BPS scientific meeting 2024
29th May VUB Brussels

List of Abstracts

Note: posters with a numbering (BPC#) participate to the Best Poster Contest

Session: Astro, Geo & Plasma Physics

Orals

14:30 - 15:00 Georgi Trenchev (invited speaker) : Carbon circularity through state-of-the-art atmospheric plasma: prototypes, pilots and more

15:00 - 15:20 Simon Chiche : Loss of coherence and change in emission physics for radio emission from very inclined cosmic-ray air showers

15:20 - 15:40 Jethro Stoffels : The Radio Neutrino Observatory in Greenland: status and first results.

15:40 - 16:00 Krijn D. de Vries : The Radar Echo Telescope

16:00 - 16:20 Dirk Van Eester : A mixed Fourier-variational approach to solve differential or integro-differential wave equations for magnetised plasmas

16:20 - 16:40 Viviane Pierrard : Project Biosphere: Study the Effects of the Solar and Cosmic Radiation on the Terrestrial Atmosphere

Loss of coherence and change in emission physics for radio emission from very inclined cosmic-ray air showers

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Next-generation radio experiments such as the Radio Detector of the upgraded Pierre Auger Observatory and the planned GRAND and BEACON arrays target the detection of ultra-high-energy particle air showers arriving at low elevation angles. These inclined cosmic-ray air showers develop higher in the atmosphere than vertical ones, enhancing magnetic deflections of electrons and positrons inside the cascade. In this talk, we will evidence two novel features in their radio emission: a new polarization pattern, consistent with a geo-synchrotron emission model and a coherence loss of the radio emission, both for showers with zenith angle $\theta \gtrsim 65^\circ$ and strong enough magnetic field amplitude. Our model is compared with both ZHAireS and CoREAS Monte-Carlo simulations. Our results break the canonical description of a radio signal made of Askaryan and transverse current emission only and provide guidelines for the detection and reconstruction strategies of next-generation experiments, including cosmic-ray/neutrino discrimination [1].

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The Radio Neutrino Observatory in Greenland: status and first results.

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The Radio Neutrino Observatory in Greenland (RNO-G) is a second-generation in-ice radio array aiming at the detection of comic neutrinos at energies beyond 10 PeV. Designed to be a discovery instrument, RNO-G is currently under construction at Summit Station in Greenland. The full array will comprise 35 autonomous stations along a regular grid spaced at distances of ~1.25 km, observing nearly independent volumes of ice of about 1km3 each. Due to its geographical location RNO-G is the first radio neutrino detector exploring the Northern Sky at ultra high-energies and well suited to search for neutrinos from transient sources in an energy range complementary to IceCube, but within an overlapping field of view. Currently, seven stations have been installed and collecting data. In this talk I will discuss the science motivation, design and current status of RNO-G, as well as describe the efforts in calibration and analysis of the first data.

The Radar Echo Telescope

Krijn D. de Vries[1] , for the Radar Echo Telescope collaboration

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In this talk we present the Radar Echo Telescope (RET). The radar echo method to probe high-energy particle cascades in dense media was confirmed at the SLAC T-576 experiment. These results lead to the construction of the Radar Echo Telescope for Cosmic Rays (RET-CR) that operates at Summit Station, Greenland and was installed in summer 2023. The main goal of RET-CR is to provide the in-nature proof-of-concept of the radar echo method to probe high-energy cosmic-ray or neutrino-induced particle cascades in dense media. Its installation and operation is presented, along with an outlook to the second data-taking run, which will take place during summer 2024. Finally, we discuss the Radar Echo Telescope for Neutrinos (RET-N) and its sensitivity to probe the cosmic neutrino flux above PeV energies.

A mixed Fourier-variational approach to solve differential or integro-differential wave equations for magnetised plasmas [(*)]

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The All ORders Spectral Algorithm (AORSA) wave equation solver by Jaeger [Jaeger et al (2001) *Phys. Plasmas* **8** 1573] solves the integro-differential wave equation relevant for the radio frequency (RF) domain and for fusion-relevant conditions in tokamaks or stellarators, retaining all finite Larmor radius corrections by substituting the continuous Fourier integrals by a sum over a discrete set of modes. Its strength is also its weakness: the simplicity of the method results in significant computational effort, a full matrix needing to be inverted to solve the associated linear system. Based on the notion that modes are gradually more independent if their eigenvalues differ, the present paper proposes a straightforward numerical method to partly alleviate this need, allowing to substitute the full system matrix by a banded one. Although exploited in the context of magnetic confinement fusion here, the adopted method can be applied to a wide variety of equations. A few 1D examples—of relevance for solving the wave equation in the RF domain of frequencies—are provided: the tunneling equation is used to illustrate the potential of the method, and the all-FLR wave equation (retaining all Finite Larmor Radius corrections in the dielectric response) adopted by Jaeger is solved comparing the solutions found to those based on simpler models (a cold plasma and a 'tepid plasma' - i.e. a kinetic model truncated at zero order in Larmor radius—description).

(*) [D. Van Eester & E.A. Lerche (2024) *Plasma Phys. Control. Fusion* **66** 045002]

Project Biosphere: Study the Effects of the Solar and Cosmic Radiation on the Terrestrial Atmosphere

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The EURAMET BIOSPHERE project (https://www.euramet-biosphere.eu) has for goal to study how increasing atmospheric ionization caused by extra-terrestrial radiation (cosmic rays and solar ultraviolet (UV) radiation) boosted by anthropogenic emissions can affect the Earth biosphere by depleting the ozone layer. An increase of the biologically active UV radiation flux has significant implication for ecosystems, plants and human health, like cancers and cellular dysfunctions.

At BIRA-IASB, we have determined the different sources of ionization of the atmosphere [1] and using GEANT 4 simulations AtRIS, their relative importance as a function of the altitude. While the solar UV radiation have important effects during the day at the equator, the solar particle radiation and cosmic rays are deviated to high latitudes by the terrestrial magnetic field [2]. The solar activity cycle of 11 years, with a maximum expected in 2025, modulates the UV radiation generating the ionosphere above 60 km and its extension the plasmasphere, both directly correlated to the solar activity. On the contrary, cosmic rays that penetrate at deeper altitudes due to their higher energy, are anti-correlated with the solar cycle, due to the protection of the interplanetary magnetic field. Specific events like solar energetic particle events [3], radiation belt electrons [4] or auroral particles [5] also increase the ionization of the atmosphere. The presentation will explain the main solar and space mechanisms that influence the terrestrial environment of the Earth and space weather.

Acknowledgements

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Session: Astro, Geo & Plasma Physics

Posters

BPC-1 Offline Neutrino Filtering using a Convolutional Neural Network-Based Algorithm at the Radio Neutrino Observatory in Greenland
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Latitudinal and seasonal changes in atmospheric density leads to variations in cosmic ray induced ionization and radiation dose rates
A. Winant

BPC-1

Offline Neutrino Filtering using a Convolutional Neural Network-Based Algorithm at the Radio Neutrino Observatory in Greenland

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Neutrino astronomy is currently one of the most vibrant fields of study in astrophysics, owing to both their expected production in the universe’s most energetic phenomena and their importance as messengers from various sources. Detecting these particles is a non- trivial endeavour, as the combination of a low cross section and zero electromagnetic charge make the neutrino one of the most elusive particles in the standard model. The Radio Neutrino Observatory in Greenland (RNO-G) aims to exploit sporadic neutrino in- teractions in the Greenland ice sheet to detect radio frequency electromagnetic signals. As the measured data is dominated by thermal noise fluctuations (> 99 %) , a sophisti- cated and robust filter is to be developed. In this contribution we present the current work on the development of such a filter using real RNO-G data and simulated neutrino signals to categorize measured data as noise or a neutrino-like event.

This work is under development and hence what is presented should be considered pre- liminary.

BPC-2

Event-by-Event Mass Separation of Simulated Cosmic Rays using Several Mass Sensitive Air-Shower Observables

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The origin of the highest energy cosmic rays is still a mystery. These cosmic rays, charged particles of astrophysical origin, interact with atmospheric nuclei to initiate extensive air showers of secondary particles and electromagnetic radiation. Ground-based detection methods of air showers reconstruct specific air-shower observables, such as the atmo- spheric depth of shower maximum and a measure of the air-shower muon content, within which indirect information of the primary cosmic-ray mass is encoded. For knowledge of a single observable, event-by-event mass determination is difficult due to intrinsic mass- separation limits of the observable; however, combining knowledge of multiple mass sensitive air-shower observables can alleviate this challenge. From CORSIKA air-shower simulations, exact knowledge of several air-shower observables is extracted and used to study the event-by-event mass separation between proton, helium, oxygen, and iron pri- mary cosmic rays with a Fisher linear discriminant analysis. We study the mass separation of vertical ($< 60^\circ$) showers in an energy range of 10PeV to a few EeV, containing the Galactic-to-extragalactic transition of cosmic-ray origin. Mass separation is studied us- ing simulations at the locations of both the IceCube Neutrino Observatory at the South Pole and the Pierre Auger Observatory in Malargu ̈e, Argentina, where results are found to be consistent between observatory locations. Overall, we find combined knowledge of all studied observables yields promising mass separation for proton and iron primaries across all energy and zenith ranges studied. Yet intermediate mass separation (helium- oxygen, helium-proton) proves to be difficult. The muon content and depth of shower maximum contribute most to the overall mass separation, where high-energy muons (> 500 GeV) provide promising mass separation as an individual observable. This analysis motivates the reconstruction of multiple air-shower observables for the next generation of cosmic-ray observatories, with emphasis on both muon and depth of shower maximum reconstructions. Further information can be found in [1].

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Integral dielectric kernels for Maxwellian tokamak plasmas

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Current magnetic fusion experiments and future reactors require multi-megawatt auxiliary heating systems in order to bring the plasma to relevant operating temperatures. Plasma heating by means of high-frequency electromagnetic waves is one of the main approaches and is carried out in different frequency ranges such as ion cyclotron, electron cyclotron and lower hybrid resonance frequencies. Modelling the latter two generally appeals to geometric optics and ray tracing methods, but this approximation is generally not valid in the ion cyclotron range of frequencies (ICRF), for which the relevant wavelengths are typically decimetric and comparable with the characteristic lengths of the configuration: modelling ICRF requires solving Maxwell's equations as a boundary value problem inside the plasma-filled vacuum chamber of the tokamak ("full-wave" approach).

To accurately model the radiofrequency dielectric properties of tokamak plasmas in presence of rotational transform (i.e. of a poloidal component of the equilibrium magnetic field), most of the theoretical models and codes addressing full-wave propagation and absorption are based on toroidal and poloidal Fourier expansions of the RF fields (see for instance [1-4]). A significant drawback of this field representation is its lack of flexibility, in that it does not allow local refinements of numerical discretizations on a given magnetic surface.

As a remedy to this, two generations of theoretical expressions have been obtained for the dielectric response of Maxwellian tokamak plasmas in the form of integral operators which are *(i)* in a first step, free from the poloidal mode expansion [5], and *(ii)* in a second step, free from both poloidal and toroidal mode expansions [6], i.e. fully expressed in configuration space. These results involve mildly singular integral kernels which incorporate the non-local nature of wave-particle interactions along the equilibrium magnetic field lines and the associated spatial wave dispersion. They are independent of the RF field representation inside the plasma volume and therefore amenable to three-dimensional finite element discretizations.

The poster will summarize the theoretical results. Their forthcoming application to ICRH modelling is discussed in the companion contribution [7].

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Characterization of plasma parameters and neutral particles in Microwave and Radio Frequency discharges in the TOMAS device

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The upgraded TOroidal MAgnetized System (TOMAS) is a device designed to research wall conditioning methods for superconducting devices such as W7-X and ITER [1]. The machine allows the utilization of both microwaves (MW) and radio frequency (RF) waves for plasma production. The RF discharges are generated by an Ion Cyclotron Radio Frequency (ICRF) system, using a single-strap antenna with a frequency range of 10–50 MHz, capable of coupling up to 6 kW to plasma. Additionally, Electron Cyclotron Resonance Heating (ECRH) plasmas are initiated by a continuous wave 2.45 GHz magnetron, with a maximum power output of 6 kW. TOMAS features a toroidal magnetic field with a peak intensity of 0.125 T along its axis [1].

The characterization of MW and RF plasmas requires the use of several specialized plasma diagnostics, including a Time-of-Flight Neutral Particle Analyzer (ToF-NPA) to measure neutral particle fluxes and the energy distribution of neutrals in the 10–725 eV range [2]. The experimental setup is equipped with a set of movable Langmuir probes, utilized to determine plasma parameters such as plasma potential, electron temperature and electron density at various positions within the vessel. A microwave interferometer has been installed to monitor the line integrated electron density.

Characterizing the neutral fluxes and plasma parameters in the TOMAS device is essential for accurately determining the conditions in sample exposure experiments, which are conducted using a dedicated sample load-lock system designed for exposing material samples to plasma [1]. The objective of this research is the optimization of plasma parameters to obtain fluxes that are relevant to the Electron Cyclotron Wall Conditioning (ECWC) and Ion Cyclotron Wall Conditioning (ICWC) techniques, foreseen for magnetic confinement devices like ITER [3]. The characterization using the set of plasma diagnostics in TOMAS is performed by exploring a wide range of parameters in MW discharges, RF discharges, and combined MW + RF plasmas. This is done by systematically changing the power used to generate the plasma, adjusting the frequency of the RF waves launched into the device, and manipulating the intensity of the magnetic field.

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BPC-4

The Biggest Bangs: Traces of turbulence in GRBs

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Gamma-ray bursts (GRBs) are the most energetic, transient explosions in the Universe and emit most of their energy in the form of gamma-rays [1]. They last extremely short on cosmic time scales, but show a wealth of time variability in their gamma-ray emis- sion. Properties of this variability may carry information about the processes the gamma- rays emerge from, which are still poorly understood [1, 2]. This research investigates the redshift-corrected gamma-ray light curves of 198 GRBs, observed with the Fermi Gamma-Ray Space Telescope between 2008 and 2023. We calculate the average power- density spectrum of different groups of GRBs, based on peak rate, energy, duration, red- shift, and distinguish between the different GRB phases. Almost all spectra reveal a power-law behaviour with indices distributed around a value of -5/3. This value can be related to fully developed turbulence, suggesting that the gamma-ray production in GRBs occurs in turbulent processes [3].

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ANSYS HFSS as a new numerical tool to study RF sheath the Ion Cylotron Range of Frequencies

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Abstract. This paper presents the first assessment of the expected near-field sheath potential arising on the limiters of two different WEST ICRH antenna concepts during their operation using the simulation tool Ansys HFSS. We first present the method used to compute those sheaths with several benchmark cases where sheath potentials are computed from two independent methods: a post- processing method and an equivalent dielectric method. After that, we use the equivalent dielectric method to compare the sheath potential with a more realistic WEST case for two different antennas: the west Q2 antenna and the Travelling Wave Array (TWA). We compare the sheath potential and the sputtering that can be expected for those two cases and draw first conclusions.

Keywords: ANSYS HFSS, ICRF, ICRH, WEST, ITER, plasma

BPC-5

From Cosmic Crashes to IceCube Neutrinos

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The IceCube Neutrino Observatory at the South Pole detected in 2013 for the first time a diffuse astrophysical neutrino flux [1]. Presently, the sources of these neutrinos remain largely unknown. Multimessenger observations of both neutrinos and gamma rays show, however, that the contribution of gamma-ray bright objects to the observed astrophysical neutrino flux is largely constrained [2]. As such we propose for the first time (ultra)luminous infrared galaxies (U/LIRGs) in the Great Observatories All-Sky LIRG Survey (GOALS) as candidate sources of high-energy neutrinos. These (interacting) galaxy systems are among the brightest infrared sources in the Universe, containing a tremendous energy budget combined with extreme amounts of obscuring matter. These two key features make GOALS objects excellent candidate neutrino sources, which may also be gamma-ray opaque.

We present a phenomenological framework for starburst-driven neutrino production via proton-proton collisions and apply it in a case study to the LIRG Arp 299 [3]. Furthermore, we discuss how this study shaped a parallel ongoing analysis which uses IceCube data to infer whether U/LIRGs are spatially correlated with neutrinos observed in IceCube.

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BPC-6

Advancing understanding of solar wind acceleration: A systematic approach with new Parker Solar Probe observations and kinetic modeling

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The solar wind, the continuous outflow of material from the solar surface, is mainly composed of protons and electrons that are accelerated throughout the heliosphere up to a few hundred km/s. Although many theoretical models have been developed since the first solar wind observations in the sixties, we still do not completely comprehend the mechanism behind the acceleration of the solar wind. In particular, the origin of the observed high-energy electrons is not understood. The aim of this presentation is to investigate the mechanisms responsible for this acceleration by using the new Parker Solar Probe (PSP) observations combined with kinetic models. Fits of the observed velocity distributions from PSP with Kappa distributions functions have already shown that high-energy particles are observed even below 20 solar radii [1]. Moreover, through constraining a kinetic exospheric model based on observational data and incorporating the impact of high-energy electrons, it was demonstrated that the model effectively replicated the observed average profiles of solar wind speeds relative to distance from the Sun [1]. Therefore, the kinetic exospheric model can explain at least part of the solar wind acceleration while further improvements are needed to explain the faster winds. In fact, the solar wind comprises two distinct modes: one characterized by high speed (typically exceeding 500 km/s) and another by lower speed (typically below 400 km/s) coming from specific regions of the Sun's surface. PSP reaches distances where the solar wind has a significant remaining acceleration inducing difficulties to discriminate between fast and slow winds by using only the bulk velocities. This discrimination is critical in constraining the models. Recently, a new way of differentiating the data of slow and fast winds has been found for the observations of PSP using the apparent strong correlation between bulk velocity and temperature of protons [2]. The poster that will be presented aims at describing how those results are crucial in explaining the acceleration of the solar wind.

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Integral dielectric kernel approach to modelling radiofrequency heating in toroidal plasmas

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The realistic full-wave modelling of Ion Cyclotron Resonance Heating (ICRH) in toka- maks and stellarators traditionally relies on Fourier expansions of the radiofrequency (RF) fields along two angle coordinates, the toroidal and the poloidal angle. This approach allows convenient theoretical treatment of wave dispersion effects along the curved equi- librium magnetic field and leads to mixed spectral-finite elements numerical formulations of the wave equation, in which the plasma is described by a dielectric tensor formulated in Fourier space. Recent theoretical and numerical treatments such as [1, 2, 3], have sought to express the plasma RF response as a nonlocal integral operator formulated in configuration space. This approach promises major advantages: (i) it enables the use of finite element methods (FEM) - in 2 or 3 space dimensions - to model wave propagation and absorption in hot inhomogeneous fusion plasmas; (ii) it allows for local mesh re- finements which were ruled out with spectral methods; (iii) it will allow straightforward connection of the plasma model with advanced descriptions of the peripheral RF heating antennas, themselves based on the finite element method. The present contribution reports on the ongoing implementation of this integral approach to study RF wave propagation and absorption in tokamak and stellarator plasmas. As stressed above, the approach is nonconventional and its novelty lies in the treatment of non-locality in physical space, which is not typical of FEM. The numerical treatment of the nonlocal kernels appearing in the integral operators requires due care, since these new special functions are loga- rithmically singular. Taking a gradual approach to validate our methods, we are initially implementing the theory to lowest order in the Larmor radius to study experimentally relevant ICRH minority RF heating scenarios, in which resonant wave absorption takes place via ion cyclotron damping at the fundamental cyclotron frequency and via electron Landau damping. Geometrical complexity and additional wave physics will progressively be included. We are seeking to exploit already available open-source FEM libraries and the associated meshing, solving and postprocessing tools as much as possible.

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Latitudinal and seasonal changes in atmospheric density leads to variations in cosmic ray induced ionization and radiation dose rates

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When high-energy particles originating from space penetrate the atmosphere, they may interact with atoms and molecules, initiating secondary particle air showers propagating toward the ground. They result in atmospheric ionization and contribute to the radiation dose at lower altitudes. We uses the GEANT-4 based Atmospheric Radiation Interaction Simulator (AtRIS) toolkit [2, 3] to compute those quantities in the Earth's atmosphere. We take advantage of the unique Planet Specification File (PSF) of the Atmospheric Radiation Interaction Simulator (AtRIS) to investigate the effect of the state of the atmosphere on the resulting induced ionization and absorbed dose rates from the top of the atmosphere (at 100 km) down to the surface. The atmospheric profiles (density, pressure, temperature, and composition) are computed with the NRLMSISE- 00 model at various latitudes and every month of 2014, corresponding to the last maximum of solar activity. The resulting ionization and dose rates present different profiles that vary with latitude in the atmosphere, with the relative difference between equatorial and high latitudes ionization rate reaching 68% in the Pfotzer maximum. We obtain differences up to 59% between the equator and high latitudes observed at commercial flight altitudes for the radiation dose. Both ionization and absorbed dose rates also feature anti-phased seasonal variations in the two hemispheres throughout 2014. Based on those results, we computed global maps of the ionization and dose rates at fixed altitudes in the atmosphere by using pre-computed maps of the effective vertical cutoff rigidities and the results of three AtRIS simulations to consider the effect of latitude. While sharing the same general structure as maps created with a single profile, those new maps also show a clear asymmetry in the ionization and absorbed dose rates in the polar regions.

Acknowledgements

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Session: Biological, Medical, Statistical and Mathematical Physics

Chairs: Yves Goussin (UMons) and Bart Cleuren (UHasselt)

Orals

14:30 - 15:10 Nele Vandersickel (Invited speaker) : Catalysing change in cardiac arrhythmia treatment: An interdisciplinary journey from theory to practice

15:10 - 15:30 Indrani Jayam (ULB) : Collection efficiency of large surface plane parallel ionization chamber used for dose monitoring in flash non-uniform pulsed proton beam

15:30 - 15:50 Pieter-Jan Piccard (UHasselt) : Organic solvent nanofiltration and data-driven approaches

15:50 - 16:10 Joseph Indekeu (KULeuven) : Wetting transitions in mixtures of ultracold Bose gases

COLLECTION EFFICIENCY OF LARGE-SURFACE PLANE-PARALLEL IONIZATION CHAMBER USED FOR DOSE MONITORING IN FLASH NON-UNIFORM PULSED PROTON BEAM

Indrani Jayam[1] , Gilles De Lentdecker[1] , Quentin Flandroy[2] , Nicolas Gerard[2] ,

Pierre Gerard[1] , Jarrick Nys[2]

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Background & aims

Large-surface plane-parallel ionization chambers are standard for dose monitoring in proton therapy. Boag theory is well known to explain IC recombination losses in uniform beams. At high intensities expected in UHDPP (Ultra high dose per pulse) mode with high instantaneous beam current (10μA), non-uniformities start to play a significant role. We aim to modify Boag theory for non-uniform beams and validate if the same theory still holds at an ultra-high dose rate.

Methods

In a 229.5 MeV IBA S2C2 pulsed proton beam (10μs pulse duration), we compare the collected charge from the IC to the charge measured by a Faraday cup in order to derive an experimental value of the IC collection efficiency. We tested electrode spacings of 1, 2.5, 3 and 5 mm with respective bias voltages of 500, 500, 1500 and 1500 V. The beam charge varied between 2 and 450 pC per pulse. We measured the beam intensity profile at the IC exit and entrance using Gafchromic films. The total collection efficiencies, computed as the beam-intensity weighted sum of the pixel collection efficiencies, are compared with experimental values. We also studied the effect of various systematic uncertainties on the collection efficiency.

Results

The adjusted Boag model for non-uniform beams effectively describes IC collection efficiencies at low currents but inadequately explains the recombination losses at high currents expected at UHDPP (ultra-high dose per pulse). Free electron fraction which is described by Boag as constant could be varying and depend on beam intensity. Importantly, none of the systematically examined factors could provide a satisfactory explanation for the observed discrepancy in any instances.

Conclusions

Recombination models as described by Boag can be successfully modified to explain IC recombination losses in non-uniform high-intensity beams at low currents. Checking the significance of the free electron fraction as a function of beam intensity is proposed in this work while the study of probable space-charge effects remains ongoing. Eventually, an attempt to minimize recombinations could be done by reducing the IC gap size and increasing the voltage across the IC’s is yet to be studied taking into account the onset of charge multiplication.

Wetting transitions in mixtures of ultracold Bose gases

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A concise review, as well as new unpublished results, are presented of theoretically predicted wetting phase transitions in mixtures of ultracold Bose-Einstein condensates (BEC). Previous Gross-Pitaevskii (GP) theory for wetting in *two-component* BEC relied on an optical wall boundary condition, on which the character and location of the wetting phase transitions depend sensitively [1, 2, 3]. From GP theory it is now predicted that phase-segregated *three- component* BEC in a magnetic trap without optical wall (see Fig.1), feature a wetting phase diagram that depends only on atomic masses and atomic scattering lengths [4]. This provides a new opportunity for experimental observation of first-order and/or critical wetting phase transitions in BEC mixtures.

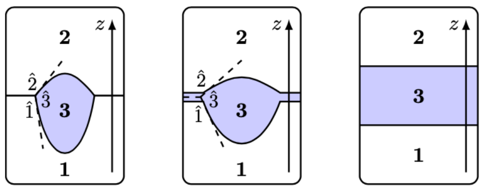

Figure 1: Nonwet and wet three-component BEC configurations. Shown are 2d sections, on a scale of typically 1 μm, of the contact zone where three coexisting phases meet. (a) Nonwet: Condensates 1, 2 and 3 meet pairwise at their mutual interfaces, displaying dihedral angles $\hat{1}$, $\hat{2}$ and $\hat{3}$ at a common line of contact. (b) Nonwet, with a microscopically thin film of 3 adsorbed at the 1-2 interface. (c) Wet: Contact angle $\hat{3}$ is zero and a wetting layer of 3 intrudes between 1 and 2.

Acknowledgement: This research is supported by NAFOSTED grant 103.01-2023.12

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Session: Biological, Medical, Statistical and Mathematical Physics

Posters

BPC-7 Monte Carlo Simulations of the T2 relaxivity induced by Cubic-Shaped Superparamagnetic Nanoparticles
Florent Fritsche (UMons)

BPC-8 Exploring membrane lipids of breast cancer cells via ToF-SIMS
Charlotte Rossi (UNamur)

BPC-7

Monte Carlo Simulations of the T2 relaxivity induced by Cubic-Shaped Superparamagnetic Nanoparticles

F.Fritsche[1] , G. Rosolen[2] , A. De Corte[2] , B. Maes[2] , Y. Gossuin[1] and Q.L. Vuong[1]

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[2] *micro- and nano- Photonic Physics Unit, UMONS, Belgium.*

Nanoscale materials have garnered immense scientific interest for the past few decades due to their wide range of applications [1] and their unique properties, such as enhanced surface reactivity and quantum effects. At this scale, composite materials of magnetite and maghemite exhibit superparamagnetic behavior at room temperature in addition to a high surface area-to- volume ratio. Those superparamagnetic iron oxide nanoparticles (SPION) are predominantly used as T2 or T2* contrast agents to detect tumors in magnetic resonance imaging (MRI) [1]. In MRI, the image quality is closely tied to the enhancement of contrast between two distinct tissue types. To artificially increase the contrast, SPION can be introduced inside the tumors via targeting methods to reduce the transversal relaxation time (T2), making the tumor appear darker on images.

In this work, the effect of the SPION shape [2] on T2 is theoretically studied in a high magnetic field at room temperature. Monte Carlo simulations of CPMG sequences using cubic nanoparticles ranging from 20 to 500nm have been simulated via a well-known methodology from reference [3]. The analytical magnetic stray field of cubic particles is implemented [4], and results are compared volume-wise to spherical particles to keep the magnetic moment constant. The diffusion of protons is modeled by a random walk and their spins as vectors rotating around the stray field of the cubic particles.

Our results indicate that the transverse relaxation time does not significantly change between a cubic particle and a spherical particle for sizes over 20 nm, corresponding to the static diffusion regime and the partial refocusing regime. For particles below the 20 nm threshold, corresponding to the motional average regime (MAR), a 10% increase in T2 is observed for the cubic nanoparticles.

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BPC-8

Exploring membrane lipids of breast cancer cells via ToF-SIMS

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Nowadays, breast cancer is a significant global health concern. Understanding the lipidomics of breast cancer is crucial to improve diagnostic and therapeutic strategies.

In the context of biological research, Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) is a performing tool widely used to detect and characterize different types of biomarkers in cancer and other diseases both on cells and tissues. This yields information about molecules such as lipids with a submicron spatial resolution and a high mass resolution [1]. In this way, ToF-SIMS is a promising method to establish the lipidomics of various cancer cell lines, with a single cell approach.

In this work we propose to investigate the composition of membrane lipids of breast cancer cells by using ToF-SIMS. Specifically, this work aims to validate a proper preparation method for ToF-SIMS analysis of MDA-MB-231 cells grown on a silicon wafer and establish the lipidome of this cell line. Ultimately, this methodology will be applied to characterize lipid biomarkers involved in radio-induced cellular death.

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Session: Condensed Matter and Nanostructure Physics

Chairs: Marc Debliquy (UMons), Frank Renner (UHasselt)

Orals

14:30 - 15:05 Tim Schwarz (invited speaker) : Introduction to (cryo)-atom probe tomography and its applications

15:05 - 15:30 A. De Corte, S. Fr. Koufidis, M. W. McCall, and B. Maes : Exceptional points in waveguides with extreme chirality

15:30 - 15:55 L. Siciliani, E. Verleysen, S. Bals, Heidi Demaegdt, Salvatore Ciano, Els Van Hoek and J. Mast : Analysis of (nano)particles in food contact materials using electron microscopy,

15:55 - 16:20 S. N. Klimin, J. Tempere, M. Houtput, C. Franchini : An analytic method for polarons with quadratic interactions,

16:20 - 16:45 E. Y. Guillaume, L. Henrard, K. Haenen, D. E. P. Vanpoucke : DFT+VTST investigations of (100)–(2×1):H diamond surfaces by means of first-principle calculations

Exceptional points in waveguides with extreme chirality

Alice De Corte[1] , Stefanos Fr. Koufidis[2] , Martin W. McCall[2] , and Bjorn Maes[1]

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Exceptional points (EPs) are critical points of a system's parameter space where eigenvalues as well as eigenvectors coalesce [1]. They can be observed in non- Hermitian systems adhering to parity-time (PT) symmetry, as the transition point between complex and real eigenvalues. In photonic waveguides, structures designed to confine and guide light using a suitable combination of refractive indices, EPs result in the convergence of multiple eigenmodes – photonic eigenvectors – into a single mode. This leads to remarkable dispersion relations near the merging point(s). Placing two waveguides in close proximity causes their modes to interact. Coupling waveguides in this manner offers two potential methods for achieving EPs, using either co-propagating modes or counter-propagating modes. The first method relies on non-Hermitian Hamiltonians, particularly to those adhering to PT-symmetry, with conventional coupling between waveguides exhibiting balanced gain and loss. By contrast, as detailed in [1], the second mechanism does not require the presence of gain or dissipation modulation, but rather a coupling of a standard waveguide with one exhibiting backward propagating modes. For a homogeneous waveguide, such a behavior can be achieved by exploiting negative refraction, i.e. opposite directions of phase and energy propagation. Although it is customary to achieve negative refraction by making the permittivity and the permeability simultaneously negative (see, e.g., [2]), here, we access it via extreme values of optical chirality [3]. As a weak parameter compared to the average refractive index, chirality causes the polarization rotation of propagating plane waves, but for extreme values leads to negative refraction. Apart from eliminating the need for meticulous manufacturing, chirality also offers an additional degree of freedom for remarkable light manipulation.

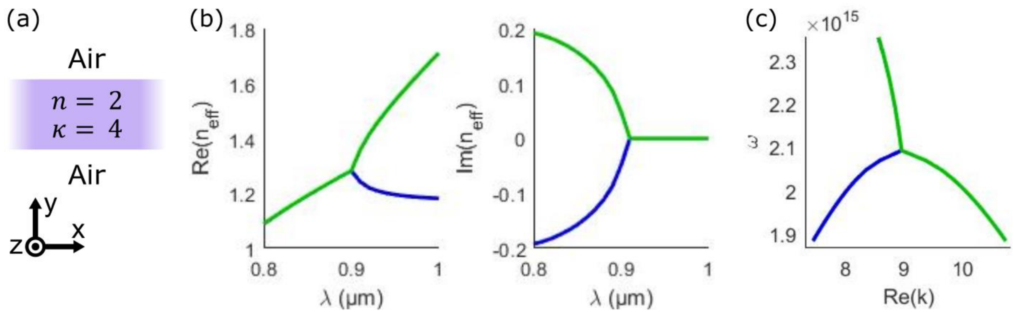

Figure 1 - (a) Schematic of a 150 nm-thick chirowaveguide, with n = 2 and κ = 2n, embedded in vacuum, (b) effective index and (c) dispersion of two modes with an EP at around 900 nm.

Using numerical simulations we first consider a single slab waveguide with giant chirality, surrounded by vacuum, as depicted in Fig. 1(a). Most modes of this waveguide exhibit backward propagation, manifested as a negative group velocity (negative slope in ω(k)) and a negative z-component of the Poynting vector. However, it appears that one mode still propagates forward in the structure, which couples with one of the backward modes to generate PT-like dispersion features: the signature "forks" of EPs are present in Figs. 1(b). An EP occurs at λ ≈ 900 nm where a forward-propagating mode (blue) and a backward-propagating mode (green) merge, as illustrated in Fig. 1(c). Such behavior is attained in a single homogeneous chirowaveguide when the chirality exceeds the refractive index.

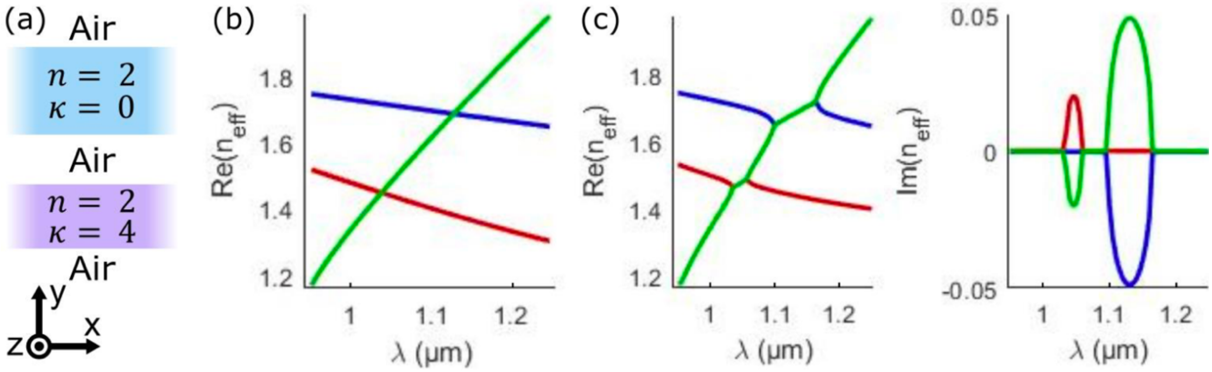

Figure 2 - (a) Schematic of a 300 nm-thick dielectric slab waveguide coupled to a 130 nm-thick chirowaveguide with giant chirality, separated and surrounded by air. (b) Effective indices of modes from the isolated achiral waveguide (blue and red) and chirowaveguide (green). (c) Effective indices of three modes from the coupled waveguides, showing four EPs.

To highlight the coupling between forward and backward eigenmodes, we examine two waveguides (Fig. 2(a)): one achiral supporting forward-propagating eigenmodes, and one chiral with giant chirality that sustains backward eigenmodes, as seen in Fig. 2(b) from their isolated dispersions. These modes interact when the waveguides are brought into proximity, by forming PT-like dispersion patterns as for the single waveguide, though more intricate. Broken PT-like zones [4] appear around each chiral-achiral crossing (around 1050 nm and 1150 nm in Fig. 2(c)), with EPs on each zone edge. The size of these zones increases with the mode coupling, controlled by varying the waveguide spacing, so that they eventually merge creating an atypical mode crossing.

Overall, we demonstrate backward propagation in waveguides with giant chirality, and achieve EPs and PT-like dispersion behaviors without resorting on gain/loss modulation or simultaneous negativity of the permittivity and permeability. Recent experimental demonstrations of meta-media with giant controllable chirality offer the necessary parameters, and thus exciting new-generation photonic devices appear within reach.

Acknowledgement

A.D.C. holds a FRIA grant from F.R.S.-FNRS; S.F.K. is a Bodossaki Foundation scholar. The SimPhotonics Matlab toolbox mode solver used in these simulations was developed at Laboratoire Charles Fabry by Mondher Besbes.

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Analysis of (nano)particles in food contact materials using electron microscopy

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The aim to reduce the use of fossil-based plastics is driving innovation in food packaging and prompting the food contact materials (FCM) industry to develop substitute materials. Such substitutes include bio-based and/or biodegradable polymers, fibrous materials and wood analogues. While these substitute materials need to be environmentally friendly, they also have to be safe for consumers. Although the use of FCM is regulated under the Framework Regulation (EU) 1935/2004, this Regulation does not take into account all the different types of materials used as FCM. Furthermore, addition of metal oxide nanoparticles into polymers has been reported to improve the characteristics of the material [1], which is especially important for biobased FCM [2]. The use of nanomaterials in the polymer nanocomposites for FCM is accompanied by safety concerns as to whether metals, nanomaterials or small-sized fractions of them may be released from FCM into food.

In this context, an approach to monitor the presence and migration of inorganic (nano)particles from FCM is presented. The properties of the (nano)particles in FCM were characterised using electron microscopy, where ultra-thin sections of FCM were prepared by embedding them in an epoxy resin, followed by sectioning using ultramicrotomy [3]. The sections were analysed by scanning transmission electron microscopy and energy dispersive X-ray spectroscopy (STEM-EDX). (Nano)particles were identified based on their elemental composition, their size, shape and agglomeration state were measured, and their location in the FCM matrix (*e.g.* inside fibres, at the surface) was assessed.

The approach was tested on 11 FCM samples including palm, bagasse, bioplastic, silicone, bamboo and textile [4]. The results from STEM-EDX allowed to identify inorganic (nano)particles in 10 of the selected FCM. It was possible to measure their size and shape properties and to demonstrate their precise localisation in the FCM. This information is useful to assess the functionality of this application of (nano)particles in FCM and is also necessary for risk assessment of this type of application.

Acknowledgment

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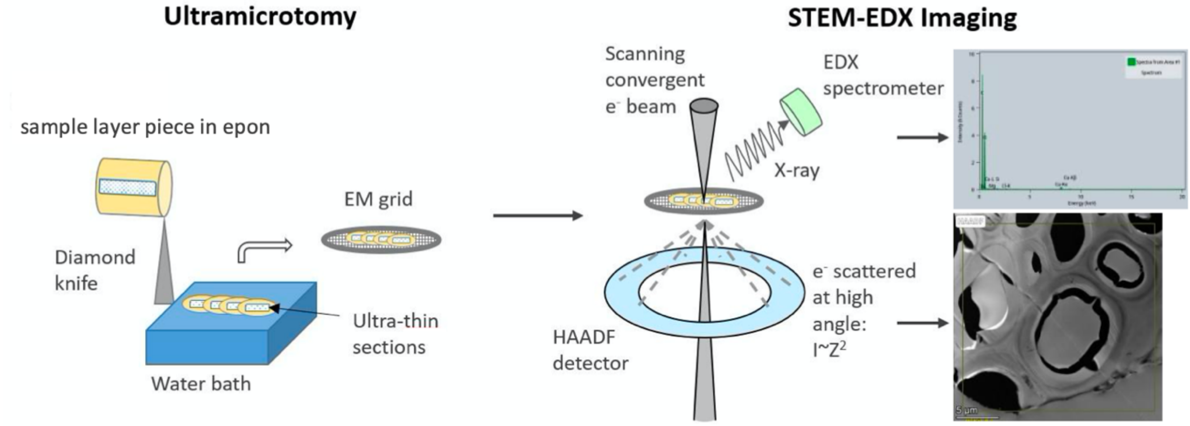

Figure 1 Schematic drawing of the protocol based on ultramicrotomy and STEM-EDX developed to analyse FCM.

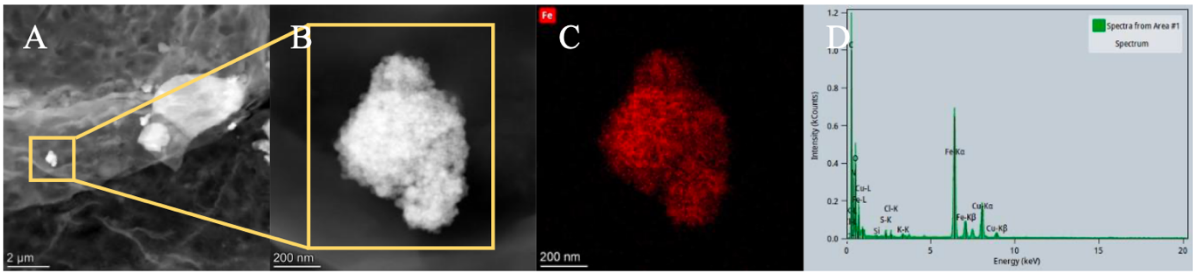

Figure 2 (A) Low magnification STEM image of a palm leaf-based sample showing the presence of particles. (B) High magnification STEM image of a particle indicated in (A). (C, D) Elemental EDX analysis of the particle indicated in (A) demonstrating that the particle consists of Fe, with (C) the spectral image of Fe and (D) the spectrum of the area indicated in (B).

An ananlytic method for polarons with quadratic interactions

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The nonlinear electron-phonon interaction has recently garnered attention due to its role as a necessary and significant component in explaining various phenomena, including superconductivity, optical response, and the temperature dependence of mobility [1 – 4].

This talk focuses on analytically treating the effects of nonlinear electron-phonon coupling on the polaron self-energy. Specifically, we incorporate a quadratic interaction into the method of squeezed phonon states [5, 6], which has proven effective for analytically calculating polaron parameters. Additionally, we extend this method to non-parabolic finite-width conduction bands while maintaining the periodic translation symmetry of the system. Our results are compared with those obtained from a recent study using the diagrammatic Monte Carlo technique [7], covering a wide range of coupling strengths for the nonlinear interaction. Remarkably, our analytic method predicts the same features as the Monte Carlo simulation.

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DFT+VTST investigations of (100)–(2×1):H diamond surfaces by means of first-principle calculations

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Radical attack and recombination are thought to play an important role in the atomic-scale mechanisms driving the growth of diamond. Unfortunately, accurate *ab-initio* calculations of the growth mechanisms are scarce[1,2]. This work presents an analysis of the reactions involving hydrogen and methyl radicals on a (100) H-passivated diamond surface.

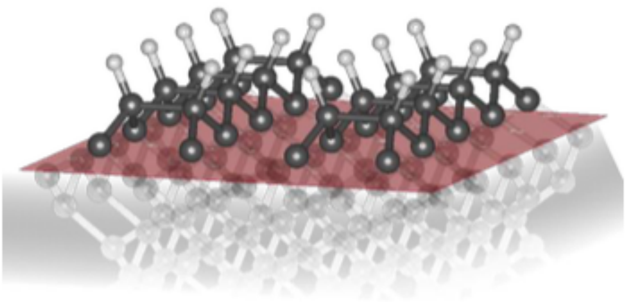

Figure 1 – Ab-initio calculations are performed on slab containing more than 200 atoms.

The reactions we investigate include migration of a lone hydrogen on a non-passivated surface[3] and of single and double vacancies on a H-passivated surface[3], along with the study of the growth steps that create a nucleation seed on the surface[4]. Calculations are carried out considering a diamond surface modelled by means of a thick slab (11 layers containing each 16 atoms, Fig. 1).
To provide an even bigger picture of the growth, we identified an ensemble of reactions that can etch the said seed (Fig 2).

One of the main features of a chemical reaction is its energy profile along the minimum energy pathway. It reveals either a tight or a loose transition state (TS), *i.e.*, the presence or absence of an energy barrier. To identify the minimum energy path (MEP) we use the nudged elastic band method for barrierless reaction (Fig 4), and the climbing nudged elastic band method otherwise (Fig 4). These methods rely on a set of intermediate configurations, also known as images, between reactants and products. Each image is assumed to be connected with the two closest ones via fictitious springs. Then a subtle combination of the forces exerted by the fictitious springs and the potential energy surface (PES) ensures that the ensemble of images converges towards the MEP.

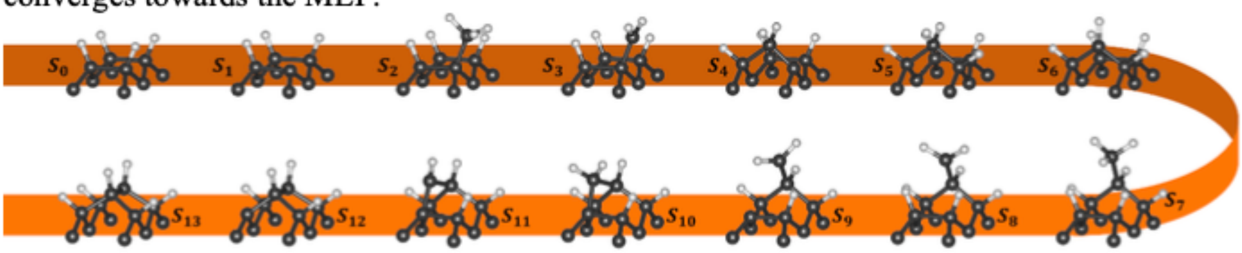

Figure 2 – Sequence of stable intermediate steps[4] between a flat surface (S_0) to a nucleation seed (S_{13}).

Calculations of the energies and forces were carried out using the VASP implementation of the density functional theory. According to the transition state theory (TST), if the energy profile reveals an energy barrier, the calculation of the reaction rate is unambiguous as it only requires the vibrational spectra of the reactants, products, and of the maximum energy image along the MEP.

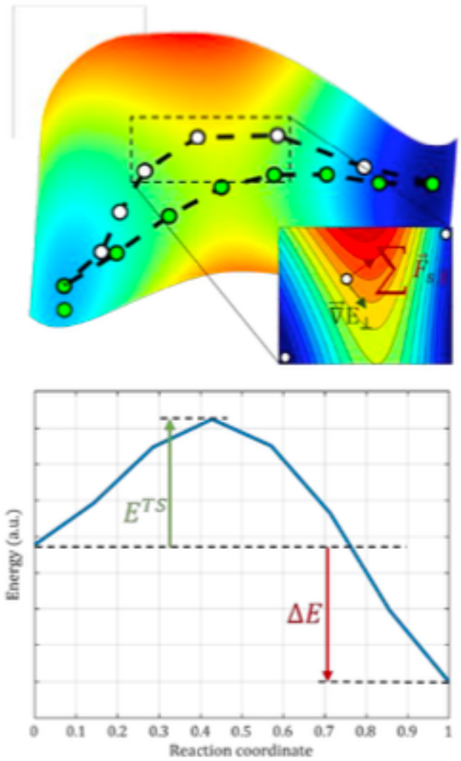

Figure 3 – Example of a tight TS on top of the MEP, whose position is only determined by the PES.

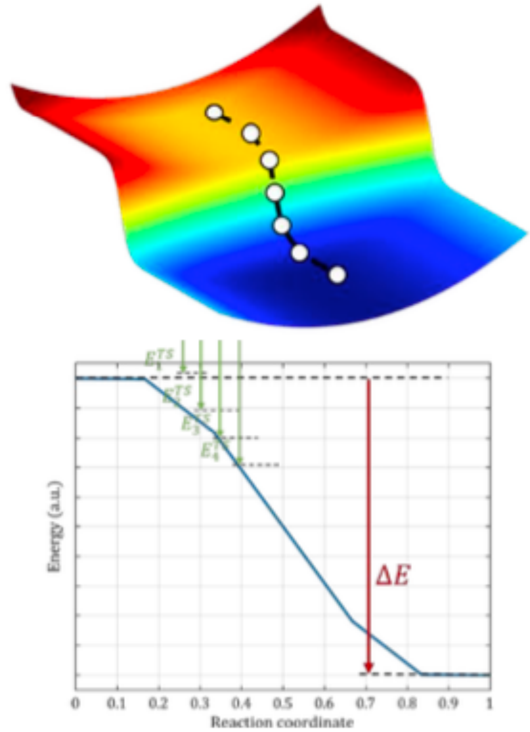

Figure 4 – Barrierless reaction containing a loose TS whose position is moving with temperature.

Then, one can compute the partition functions, zero-point energies and tunnelling coefficient to determine the exponential pre-factor for any given temperature:

$$k(T) = \kappa(\nu^{TS}, E^{TS}) \left(\frac{k_B T}{\hbar}\right) \frac{Q^{*TS}(T)}{Q^{I}(T)} \exp\left(-\frac{[E^{TS} - E^{I}]}{k_B T}\right)$$

For barrierless reactions, the approach slightly differs. We also use TST, but in its variational form. Briefly, all images along the MEP are possible transition states (TS). As such, we perform the TST calculation assuming each point to be the TS. For a specific temperature, variational TST states that the TS is the one that minimises the reaction rate:

$$k(T) = \min_{\vec{r} \in \mathrm{MEP}} \left\{ \left(\frac{k_B T}{\hbar}\right) \frac{Q^{*TS}(T)}{Q^{I}(T)} \exp\left(-\frac{[E^{TS} - E^{I}]}{k_B T}\right) \right\}$$

Using multi-scale methods (*e.g.*, kinetic Monte-Carlo), these reaction rates have great potential to provide insights into the best conditions to grow single crystal diamond: temperature, pressure, and radical densities in the reactor influence both the rate and quality of the growth. The approach used in this work can be generalised to other crystallographic orientations of diamond and even to other semi-conductor surfaces.

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Session: Condensed Matter and Nanostructure Physics

Posters

DigiLignin: modelling of sustainable lignin-based polymers
P. Castenetto

Impact of strain on GeV color centers in diamond using ab initio calculations.
T. G. I. van Wijk

BPC-9 Exploring Metal-Doped Carbon Nanomaterials for Adsorption Hydrogen Storage
B.J.B. Smeets

DigiLignin: modelling of sustainable lignin-based polymers

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The design and creation of bio-based materials is an active research area with thrilling potential applications aimed at sustainable production of renewable chemical feed-stocks. Within the context of aromatic chemical building blocks, lignin polymers (the second most abundant bio-polymer, responsible for the structural support of plants) provide an excellent replacement for traditional petroleum based sources in potential renewable source of biofuels, chemicals and value-added products. These polymers are composed of mainly three building blocks (paracoumaryl, coniferyl and sinapyl alcohols) which can form long branched chains through different linkages.

Despite the importance of lignin for industrial applications, the precise influence of the lignin polymer structure at the atomic level on their physical and chemical properties remains unknown. In this work, we aim at providing the most exhaustive description of lignin polymers. For this purpose, we plan on generating a library of molecules using molecular dynamics, to discriminate the most relevant lignin polymer, which will be investigated in depth by means of Density Functional Theory (i.e. quantum mechanical) calculations to predict their properties.

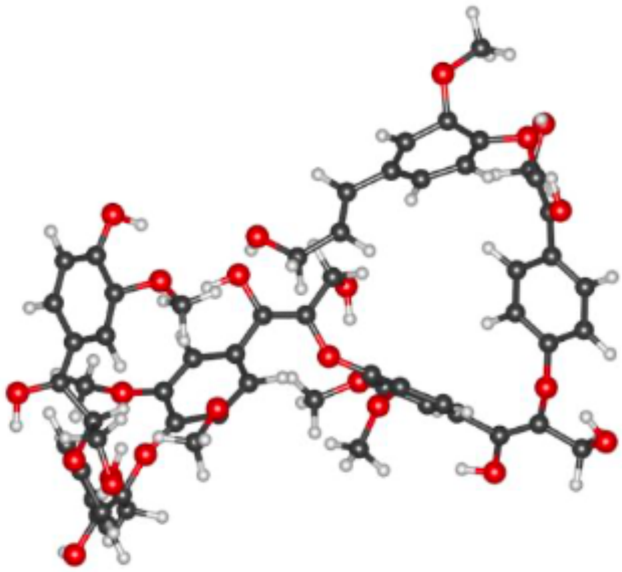

Figure 1 – Coniferyl-based polymer with β-O-4 linkage.

We believe the insights of our work will provide a more accurate description of lignin as a bio-polymer, with the potential for paving the way for sustainable production of high-quality bio-based alternative plastics for many applications.

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Impact of strain on GeV color centers in diamond using *ab initio* calculations.

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Diamond color centers are considered excellent candidates for applications in quantum information processing, biosensors, and magnetometry. The interest in the GeV center arises mainly from its intense zero-phonon line and small phonon sideband. [1, 2, 3] Further research is needed to characterize the GeV center under experimental conditions. For this purpose, *ab initio* calculations provide valuable insights into the electronic energy levels of the color center under varying conditions such as strain and color center concentration. Additionally, group theory plays a very important role in the theoretical prediction of electronic energy levels. In this work, we aim to elucidate the effect of strain on the zero-phonon line (ZPL) by combining *ab initio* calculations and group theory.

The GeV color center is modelled using Density Functional Theory (DFT). To replicate different experimental conditions, different concentrations are modelled, using different sizes of supercells, ranging from 1.5% ($2 \times 2 \times 2$ conventional supercell) down to 0.1% ($5 \times 5 \times 5$ conventional supercell), an example of such a supercell is shown in 1 a). To draw solid comparisons between our results and either as-grown or implanted color centers, the structure relaxations were performed differently. For the first scenario, we varied the cell volume and shape, while for the second, we kept a constant set of lattice vectors.

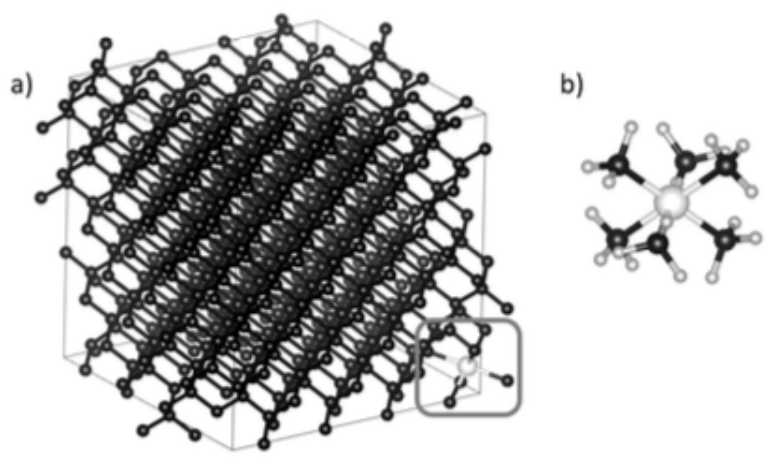

Figure 1: The GeV center depicted within (a) a $4 \times 4 \times 4$ supercell and (b) a GeC_6H_{18} cluster, with Ge atoms represented in white, C atoms in black, and H atoms in grey.

After the initial relaxation of the structure, a static calculation is performed to find the electronic structure of the defect. The effect of an experimental strain can be replicated by stretching the relaxed structure hydrostatically or along a specific crystallographic orientation, changing the geometry and symmetry of the structure. The static calculations are performed with both a standard exchange-correlation functional (PBE) and a hybrid functional (HSE).

The calculated relaxed structure shows the expected D_{3d} symmetry. This symmetry is maintained after the structure was strained hydrostatically, but changes to C_{2v} for strain along the $\langle 100 \rangle$ direction. This can also be observed in the calculated energy levels, where some of the degeneracies, observed in the unstrained calculations with D_{3d} symmetry, are broken by the change to C_{2v} symmetry. Another observation is that the ZPL changes when strain is applied, both for the hydrostatic and $\langle 100 \rangle$ strain. To elucidate the identification of the color center energy levels within the diamond host lattice, DFT calculations are performed on a GeC_6H_{18} cluster. Here, the defect atoms are placed in the same configuration as they would have in diamond, and each C atom is passivated with H atoms, as is shown in 1 b). This approach allows us to apply group theory directly to the energy levels of the GeV center and subsequently helps us to identify them in the diamond calculations.

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BPC-9

Exploring Metal-Doped Carbon Nanomaterials for Adsorption Hydrogen Storage

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Energy has been an urgent topic for years. Climate change and the recent energy crisis highlight the need for an accelerated energy transition. Significant progress is already being made, most notably in solar photovoltaics, wind energy and electric vehicles [1]. However, energy storage remains the weakest link in the energy transition. In this context, low-emission hydrogen has emerged as an important tool [2]. However, current hydrogen storage solutions impose significant risks and efficiency losses.

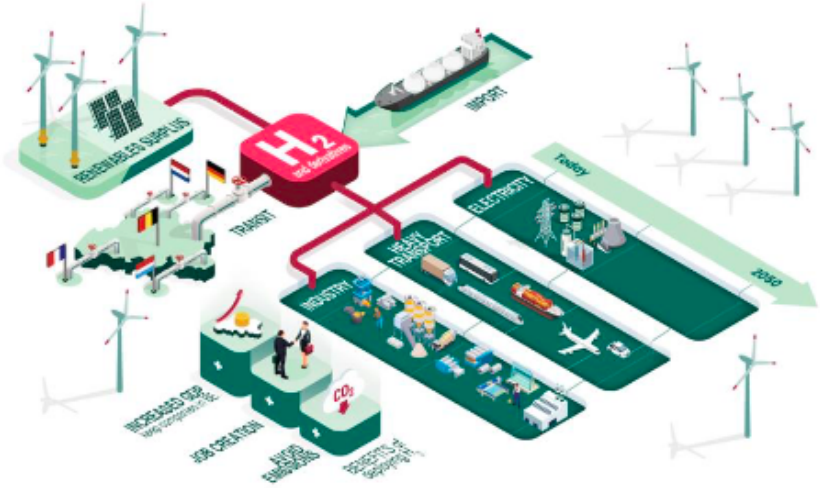

Figure 1: Visualisation of the hydrogen strategy of Belgium. Adapted from **[3]**

Adsorption Hydrogen Storage

I will present the outline of my PhD project, which will investigate adsorption hydrogen storage as an alternative storage solution, storing hydrogen in a solid material. In particular, the objective of my project is to evaluate the feasibility of transition metal-carbon porous nanostructures for adsorption hydrogen storage. Porous carbon-based materials stand out as promising candidates due to carbon's light weight, abundance, versatility, and low cost [4]. However, pure carbon surfaces typically exhibit low hydrogen binding energies, requiring cryogenic cooling to achieve a sufficient volumetric energy density [5]. This highlights the technological challenge of balancing high hydrogen density with practical demands. Studies have shown that the storage capacity of these materials can be enhanced by doping with transition metal atoms and by nanostructuring [6]. However, phenomena determining the effectiveness of hydrogen storage are not yet well understood.

The presented project will involve a three-step approach, progressively advancing to materials suited for applications. First, we will investigate isolated metal-carbon clusters under vacuum conditions to obtain insights in the preferred geometries and the chemical kinetics for hydrogen adsorption. This step aims to resolve the questions regarding the effectiveness of hydrogen storage. Based on this knowledge, we select a carbon surface system for sorption experiments across varying temperatures, still within vacuum conditions. Finally, we scale up the material to a porous system and conduct sorption experiments under pressure and temperature conditions representative for applications. This research not only contributes to the understanding of hydrogen storage mechanisms but also offers insights useful for accelerating the energy transition.

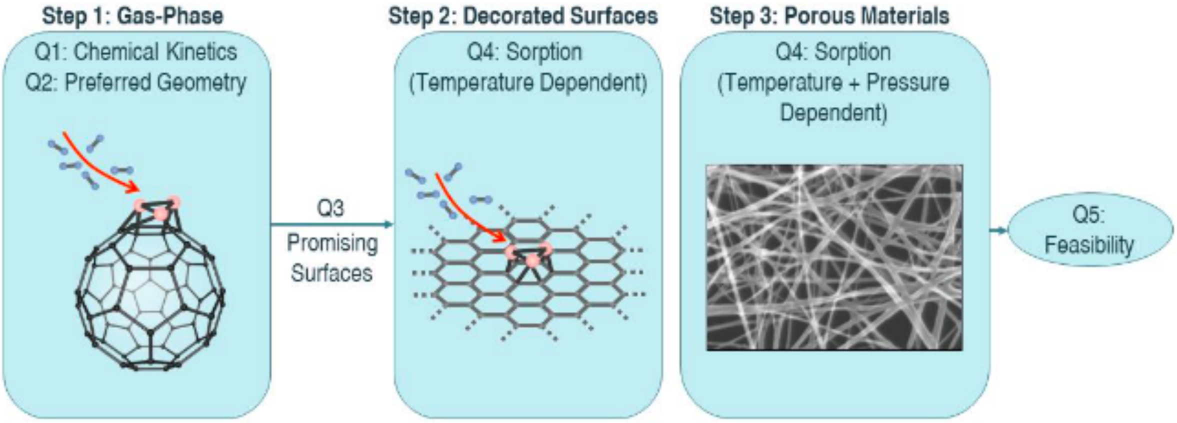

Figure 2: Schematic representation of the three-step approach. The image in step 3 is a SEM image of a carbon nanotube pellicle, adapted from **[7]**.

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Session: Fundamental Interactions, Nuclear and Particle Physics

Chairs: Barbara Clerbaux (ULB), Stijn Buitink (VUB)

Orals

14:30 - 14:50 Simon Knapen (Berkeley) : Invited talk, "Theory overview for long-lived particles at the LHC"

14:50 - 15:10 Steven Lowette (VUB) : Invited talk, "Highlights from long-lived particle searches in CMS"

15:10 - 15:30 Martin Delcourt : How Belgium is preparing the CMS Silicon Strip Tracker for high-luminosity

15:30 - 15:50 Soumya Dansana : Exclusive search for light scalars via the Higgs portal decaying to pairs of muons and hadrons at the CMS experiment

15:50 - 16:10 Nhan Chau : Indirect dark matter search in the Galactic Center with the IceCube neutrino telescope

16:10 - 16:30 Per Myhr - Low—energy astrophysical neutrino searches in IceCube

16:30 - 16:50 Xander Nagels : Criterion for ultra-fast bubble walls: the impact of hydrodynamic obstruction

How Belgium is preparing the CMS Silicon Strip Tracker for high-luminosity

M. Delcourt[1], on behalf of the CMS Tracker group

[1] Vrije Universiteit Brussel

Abstract

The CMS Silicon Strip Tracker is the largest of its kind, with an active area of 200m^2 of Silicon[1]. This detector, initially proposed in 2000 and installed in late 2007 has been operating smoothly ever since, providing excellent performance in the increasingly harsh LHC data-taking conditions[2].

In order to greatly enhance the physics reach of the Large Hadron Collider, it was decided to upgrade it through the High-Luminosity LHC program. Under the HL-LHC, the instantaneous luminosity will be increasing by a factor five with respect to the LHC design nominal intensity, and the total integrated luminosity by at least an order of magnitude[3].

These new data-taking conditions will necessitate a full overhaul of the CMS detector, with its Silicon-Strip Tracker being completely re-designed and replaced[4]. This is known as the phase-2 upgrade of the CMS Silicon-Strip Tracker, and Belgium is among the biggest contributors to this project, with over 1500 modules to be built, and a full detector end-cap to be assembled by its participating institutes.

In this talk, an introduction to the CMS Silicon Strip Tracker will be provided to give a broad overview of the performance and challenges of the current detector. Then, a general motivation and description of the Phase-2 Tracker upgrade will be laid-out. Finally, the status and plans for the detector construction, centered around activities taking place in Belgium will be shown, as well as a glimpse of the performance of detector modules in a beam-line.

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Exclusive search for light scalars via the Higgs portal decaying to pairs of muons and hadrons at the CMS experiment

Barbara Clerbaux,[1] Soumya Dansana,[1,2] Steven Lowette,[2] David Vannerom[2]

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[2] Vrije Universiteit Brussel, Physics Department, VUB Main Campus Etterbeek, Pleinlaan 2, 1050 Ixelles, Belgium

An exclusive search for BSM scalars of O(GeV) masses in final states with light hadrons and muons is presented using proton-proton collision data collected by the CMS experiment at 13 TeV, corresponding to an integrated luminosity of 138 fb^{-1}. An additional light BSM scalar particle is proposed in several Standard Model extensions in the con- text of dark matter models[1] and supersymmetric theories[2]. This search targets exotic decays of the Higgs boson to a pair of prompt or long-lived BSM scalars with decay lengths upto 100mm and masses below 2 GeV. The scalar mass leads to a unique phase space where the hadronic decay consists of only a pair of light hadrons[3, 4]. The experi- mental signature considered consists of a collimated and prompt/displaced pair of muons and charged kaons/pions arising from the decays of the scalars respectively. This search improves sensitivity to very light scalar masses and demonstrates a novel approach to probing the hadronic decay mode for light scalars.

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Indirect dark matter search in the Galactic Center with the IceCube neutrino telescope

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Multiple astrophysical observations have proven the existence of dark matter (DM), an elusive component constituting approximately 22% of the universe and 85% of the matter content [1]. Nevertheless, the nature of dark matter is still an unresolved question. One popular hypothesis is the `particle solution', where dark matter is assumed to be particles that can interact weakly with ordinary matter. These DM candidates are usually assumed to be produced in the early universe and to be stable or long-lived enough such that they can make up the current observed DM abundance whose density depends on the thermal history of the universe.

Indirect detection of DM aims to probe the anomalous flux of SM particles resulting from DM decay or annihilation [2]. These searches typically look into astrophysical objects where there is a substantial accumulation of DM. Among all targets, Galactic Center (GC) is one of the prominent sources thanks to both its large DM content and its proximity to the Earth. In this talk, I will present an indirect search for the neutrino signal from DM annihilation or decay from the Galactic Center using data from IceCube, a Cherenkov neutrino telescope located at the South Pole [3,4].

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Title: Low—energy astrophysical neutrino searches in IceCube

Abstract:
The IceCube Neutrino Observatory is sensitive from 0.5 GeV to the PeV energy range for astrophysical neutrino searches. In addition, the supernova Data Acquisition System (DAQ) allows the collaboration to be sensitive to close-by core-collapse supernovae at MeV energies. There exists, however, a gap between these covered energy ranges. This talk presents the current lowest energy transient searches and ongoing efforts to cover this gap. We will discuss various strategies to reach this goal through the use of HitSpool, a specific DAQ within IceCube, and the construction of a new event selection based on machine learning and citizen science.

Criterion for ultra-fast bubble walls: the impact of hydrodynamic obstruction

The Bodeker-Moore thermal friction is usually used to determine whether or not a bubble wall can run away. However, the friction on the wall is not necessarily a monotonous function of the wall velocity and could have a maximum before it reaches the Bodeker-Moore limit. In this talk, I compare the maximal hydrodynamic obstruction, i.e., a frictional force in local thermal equilibrium that originates from inhomogeneous temperature distribution across the wall, and the Bodeker-Moore thermal friction, where the former is studied in a fully analytical way, clarifying its physical origin and providing a simple expression for its corresponding critical phase transition strength above which the driving force cannot be balanced out by the maximal hydrodynamic obstruction. For a large parameter space, the maximal hydrodynamic obstruction is larger than the Bodeker-Moore thermal friction, indicating that the conventional criterion for the runaway behavior of the bubble wall must be modified.

Session: Fundamental Interactions, Nuclear and Particle Physics

Posters

BPC-10 The Moon Shadow using the Pierre Auger Observatory Data
Katarina Simkova

BPC-10

The Moon Shadow using the Pierre Auger Observatory Data

K. Simkova,[1,2] S. Buitink,[1] I. C. Maris ̧,[2] and V. Pelgrims[2]

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The interaction of cosmic rays with the Moon produces a shadow in the distribution of the arrival direction, the Moon acting as a negative source. This Moon shadow has been observed for example by the IceCube [1, 2] and Grapes-3 [3] experiments at energies between 10^{12} eV and 10^{15} eV, and it is a common way to test the angular resolution of astroparticle observatories. Can we observe this behavior in the surface detector data of the Pierre Auger Observatory, using cosmic rays with much larger energies above 10^{16} eV? Based on the continuous operation of the Observatory during 20 years, its very large collection area of 3000km^2 and the combination of the data from three different surface detectors, we have accumulated more than 9.5 million events. A deficit in events with an angular separation of less than 1 degree from the Moon center has been observed for the fist time at these energies, with a significance of more than 3 σ appearing between 0.5 and 1 degrees. From this deficit, the Observatory resolution was estimated to be $0.57^{+0.24}_{-0.16}$ degrees.

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[3] D.Pattanaik, S.Ahmad, M.Chakrabortyetal. (GRAPES-3Collaboration),”Validating the improved angular resolution of the GRAPES-3 air shower array by observing the Moon shadow in cosmic rays”, in *Physical Review D*, vol. 106, pp. 022009, 2022.

Session: Quantum Physics, Atoms, Molecules, and Optics

Chair: Xavier Urbain (UCL)

Orals

14:15 - 15:00 Yann MAIRESSE (CNRS & Univ. de Bordeaux) (Invited speaker) : Attosecond spectroscopy: How it started, how it's going

15:00 - 15:20 Mhamad HANTRO (UMons) : Modeling quantum emitters beyond the point-dipole approximation and assessing its validity in proximity of nanoscale structures

15:20 - 15:40 Yves CAUDANO (UNamur) : Post-selected Weak Measurements with Dissipation in the Context of Cavity Quantum Electrodynamics

15:40 - 16:00 Thomas MICHEL (ULiège) : Quasiclassical description of out-of-time-ordered correlators

16:00 - 16:45 Maximilian BEYER (Vrije Universiteit Amsterdam) (Invited speaker) : Molecular Rydberg states for ion spectroscopy and laser cooling

Modeling quantum emitters beyond the point-dipole approximation and assessing its validity in proximity of nanoscale structures

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Modeling the spontaneous emission rate of a quantum emitter can usually be carried out via a semi-classical development that remains limited to the dipolar term, where in addition, the emitter is generally approximated as a point-dipole. However, particular nanoscale structures support strongly confined fields where the point-dipole approximation (PDA) fails and can even be surpassed by higher-order transitions [1].

Recently, a first-principle framework [2] that considers both the full extension of the wavefunction, and therefore including all multipolar terms, and their interferences, was developed and applied to the case of Hydrogen. This framework is based on an eigenpermittivity mode expansion. Here, for the first time, we combine this framework with quantum chemistry to assess the validity of the point-dipole approximation for large molecular emitters.

To achieve the above-mentioned work, we use a quantum chemistry package (Gaussian in our case) to calculate the emitter's transition density matrix with Time-Dependent Density Functional Theory (TD-DFT). This can be fully incorporated within the framework and expanded over the natural transition orbitals for cost-effectiveness. This allows us to model the molecular emitter beyond the point-dipole approximation.

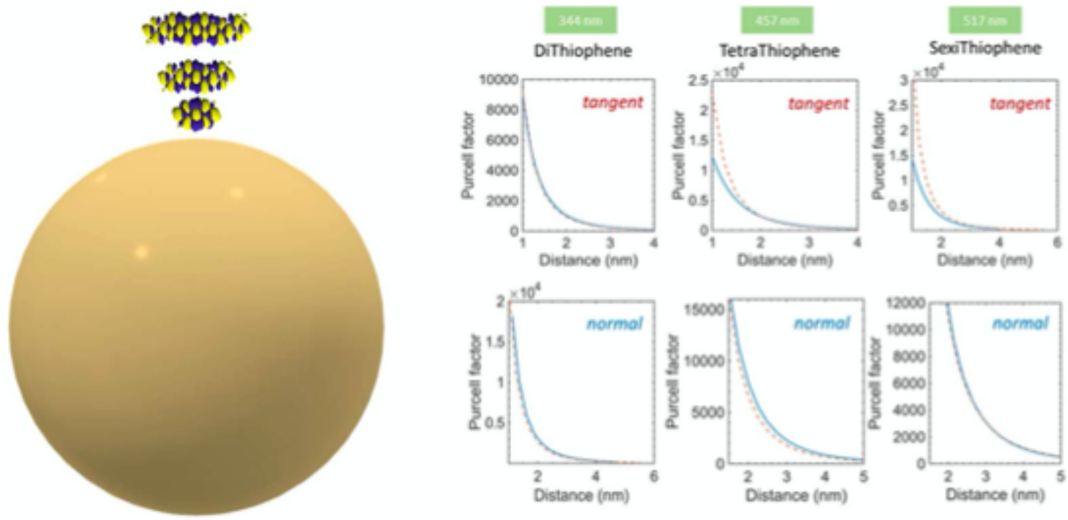

Figure 1 : (left) Representation of oligothiophene emitters placed in the vicinity of a gold nanosphere – molecule sizes are in scale with respect to the nanosphere (right) Distance dependence of the Purcell factors computed using point-dipole approximation (dashed line) and full emitter expansion (solid line), for two different molecule orientations, with their emission wavelength written on top.

We apply our new method to the system shown in Figure 1. The system consists of oligothiophene chains sitting in the proximity of a nanosphere scatterer (with a radius of 5nm). A comparison is laid down with the case of a point-dipole using the COMSOL software. The goal is to assess the validity of the PDA and to study the recovery distance at which it is valid. The thiophene chains were translated along the radial axis for two orientations. A tangent setup (as shown in Fig.1 (left)) and a normal setup where the chain becomes oriented along the radial axis. The Thiophenes showed an interesting orientation-dependent behavior. The PDA breakdown was seen in the tangent setup at 1.8 nm and 2.1 nm, for the Tetrathiophene and Sexithiophene respectively. This value correlates with their extended length approximately (2 nm and 2.4 nm, respectively). However, the same chains were described accurately by the PDA in the normal setup. To interpret these findings, a rule of thumb can be suggested: The PDA is valid when the molecule-scatterer separation is larger than the size of the molecule.

Acknowledgments

Actions de Recherche Concertées (Project ARC-21/25 UMONS2)

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Post-selected Weak Measurements with Dissipation in the Context of Cavity Quantum Electrodynamics

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Observations in quantum weak measurements depend on a complex number called a weak value. We study the impact of dissipation and dephasing on weak measurements and on anomalous weak values, i.e., weak values outside the range of eigenvalues of the probed observable. We find that the nature of the quantum system steady state affects the preservation of anomalous weak values over time, and that weak measurements can distinguish non-Markovian from Markovian dissipative dynamics.

Weak measurements

A quantum weak measurement consists of (1) a preparation of a quantum state, (2) a weak interaction of the quantum system with a meter to probe an observable without disturbing much the system state, (3) a projective measurement of the system called post-selection that sets the system final state, and (4) a meter measurement conditional on successful post-selection. When the prepared and post-selected states are nearly orthogonal, anomalous weak values enable probing small parameters with increased sensitivity, as they become very large, a phenomenon called weak-value amplification.

Results

We modeled weak measurements in the presence of dissipative dynamics of the probed quantum system [1]. We present here how the dissipation and dephasing incurred by an atom after its interaction with a cavity can be probed by measuring the cavity field in a post-selected weak measurement. We connect the weak measurement outcomes, the weak value, and the atom properties. Weak measurements with anomalous weak values can enable differentiating between Markovian and non-Markovian dynamics, either by probing coherence revivals over time through the Loschmidt echo, or by exploiting weak-value amplification at short dissipation durations. When the system reaches it steady state, the possibility of preserving anomalous weak values and amplification depends on the steady state dimensionality and structure.

Technically, our model uses Lindblad's equation to describe the dissipative dynamics in the interaction picture (Dirac's representation). The weak interaction in the cavity is described either using the usual weak measurement approximation (i.e., linearization of the time-evolution operator of the coupled particle-cavity quantum system) for very short interaction durations, or in the rotating-wave approximation for longer interac- tions. Interestingly, in the latter approximation, the weak measurement interaction can be described in terms of effectively measuring a non-Hermitian jump operator.

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Quasiclassical description of out-of-time-ordered correlators

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Out-of-time-ordered correlators (OTOCs) are quantum objects that can be used as a probe for quantum chaos. They characterise information scrambling, more specifically, how a local operator commute with another local operator that is time-evolved. We present a quasiclassical formalism of OTOCs using the semiclassical van Vleck-Gutzwiller prop- agator in combination with the diagonal approximation. For short time, we recover the same result as with the Wigner-Moyal formalism, yielding an initial exponential growth of the correlator. For long times and fully chaotic dynamics, this quasiclassical formalism yields a finite saturation value of the OTOC. However, as we verified in Bose-Hubbard systems, this quasiclassical saturation value is found to be small compared to the actual quantum OTOC saturation threshold. This finding shows the importance of effects be- yond quasiclassical physics related to trajectory pairs with small-angle crossings, as was pointed out in Ref. [1].

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Session: Quantum Physics, Atoms, Molecules, and Optics

Posters

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Deceleration of Ca atoms with a 3D-printed permanent-magnet Zeeman slower

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We report on the laser deceleration of Ca atoms from thermal velocities to a few tens of *m/s by using a custom Zeeman slower built in-house. The inhomogeneous magnetic field necessary to effectively slow down the atoms is generated by several stages of permanent magnets arranged in Halbach configuration and housed in a 3D-printed structure.*

Laser cooling can be used to bring atoms in gas phase to temperatures close to absolute zero. As a previous step to the cooling process, atoms are often slowed from thermal velocities down to a few tens of m/s, relying on the strong force exerted by a resonant laser field. However, as the atoms slow down, the Doppler shift continuously changes, taking them out of resonance and rendering their interaction with the laser field negligible. To counteract this effect, an inhomogeneous magnetic field can be employed to shift the atomic transition frequency via the Zeeman effect and compensate for the varying Doppler shift as the atoms slow down. With this so-called Zeeman slower [1], a beam of atoms with thermally-distributed forward velocities can be efficiently slowed and even stopped with laser light.

Zeeman slowers typically use solenoid-based designs, requiring an intricate coil winding, high power consumption, and active cooling. An alternative design, utilizing assemblies of permanent magnets in Halbach configuration [2], has emerged as a cost- effective, power-efficient solution. However, precise assembly is crucial due to the fixed magnetic field of the magnets.

We report on the building and characterization of a permanent-magnet Zeeman slower held by a 3D-printed structure used to decelerate Ca atoms with initial velocities of up to ~ 750 m/s. We compare the magnetic field profile generated along the Zeeman slower with our calculation and measure the velocity distribution of the atoms as they exit it. With the Zeeman slower operational, the capture of the slow atoms in a magneto- optical trap is now under way.

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Direct laser cooling of Rydberg atoms with an isolated-core transition

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Whereas ground-state atoms and small molecules have already been laser-cooled, direct laser cooling of Rydberg atoms has never been achieved. This is explained by the absence of a suitable cooling cycle for the Rydberg electron. Instead, we theoretically propose to laser cool the ion within the Rydberg electron orbit, motivated by the fact that the ion core can be, to a good approximation, isolated from the Rydberg electron [1]. We illustrate our scheme with the Ca atom, using the $4s_{1/2}$ - $4p_{1/2}$ isolated-core transition to achieve cooling and the $3d_{3/2}$ - $4p_{1/2}$ one to close the cooling cycle.

When the ion core of an atom in a Rydberg state is excited, its energy lies above the first ionization threshold, and the atom can therefore autoionize. For sufficiently high orbital-angular-momentum l values of the Rydberg electron ($l > 10$), it is however possible to suppress autoionization far below the radiative lifetime of both the ion core and the Rydberg electron. In this case, the lifetime of the states is extended to > 100 µs, which makes it possible to realize many isolated-ion-core cooling cycles.

To demonstrate the feasibility of our scheme, we first calculate the energy-level structure of the states involved in the cooling cycle. Their number is increased, and their energies split, compared to the isolated ion, by the residual Coulomb interaction between the ion-core electrons and the Rydberg one. We then examine population dynamics over the 200 states of the cooling cycle and demonstrate that an ion-core photon scattering rate of $\sim 10^7$ s^{-1} can be achieved, and, in the presence of a small magnetic field, maintained over more than 100 µs [2]. Our Rydberg-atom laser cooling scheme offers the possibility to optically cool Rydberg atoms without significantly perturbing the Rydberg electron and paves the way to explore the properties of cold Rydberg gases for a broad range of temperatures.

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The BOOSTED project :
A new infrastructure for time and frequency transfer in Belgium

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Recent developments in time and frequency transfer based on optical fibers, as an alternative to GNSS, support fast growing activities at the European scale. We will present the recent advances made in Belgium in this domain, towards the creation of a new infrastructure based on the existing internet fibered network managed by BELNET, the Belgian NREN.

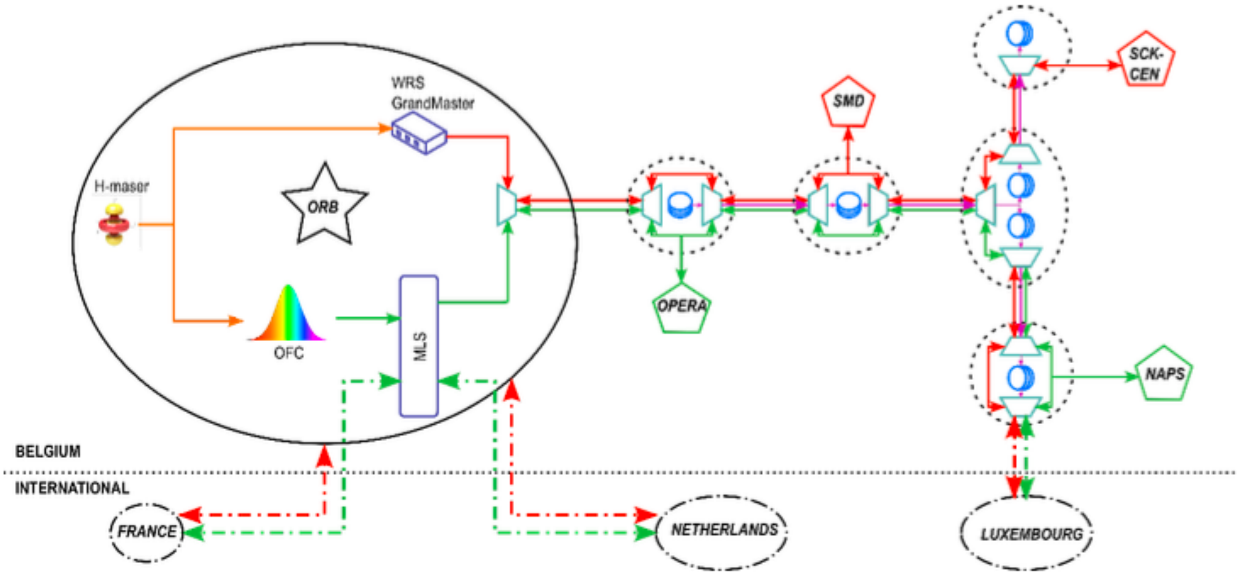

FIG 1. Simplified topology of the initial BOOSTED network (red : time ; green : frequency; violet : data)

On one side, timing services, limited for now in Belgium to NTP and PTP, will be extended to White Rabbit technology. On the other side, the project aims to make available to the whole country the frequency of UTC(ORB) based on a H-maser, thanks to the conversion from RF to optical domain using a frequency comb. This frequency services will rely on technologies compatible with the French T&F network REFIMEVE, using mainly regenerative laser station (RLS) manufactured by EXAIL. The simplified topology of the future initial BOOSTED network is illustrated in Fig. 1, with the first identified users: research centers (OPERA, NAPS, SCK-CEN) and metrology service (SMD).

Finally, the ROB also supports actively the development of the future pan-European T&F network, in close cooperation with Géant organization and others metrological institutes by the investment into larger equipment (MLS, see Fig. 1) acting as a splitter and a relay between the different countries (Belgium-France and Belgium-Netherlands) and even further (Belgium-Luxembourg) taking full advantage of the very high performances of the stabilized optical fiber links.

BPC-12

Creating NOON states with ultracold atoms via counterdiabatic driving

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We theoretically investigate quantum control protocols for the creation of NOON states using ultracold bosonic atoms on two modes, corresponding to the coherent superposition $|N,0\rangle+|0,N\rangle$, for a small number N of bosons. One possible method to create this state is to consider a third mode where all bosons are initially placed, which is symmetrically coupled to the two other modes. Tuning the energy of this third mode across the energy level of the other two modes allows the adiabatic creation of the NOON state. We demon- strate that the use of a counterdiabatic protocol to accelerate the processus is feasible and effective for a single particle, and then discuss how to extend its application to a larger number of bosons.

BPC-13

Generating Dynamical Decoupling Sequences for Qudits using Parallel Tempering

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In the last decades, great advances have been made in the field of quantum information processing, where the standard bit of information is replaced by its quantum counterpart, the quantum bit (qubit), to allow for the creation new quantum algorithms and quantum simulation schemes, which are expected to provide significant speed-up over classical computing techniques. Although qubits are the most elementary building blocks for quantum computing, some quantum hardware naturally possesses a nice multilevel structure, from which a qubit is defined by selecting a specific two- dimensional subsystem. In the recent years, scientists have considered harvesting those extra-dimensions, using both qubits and quantum dits, with d distinct levels, to perform quantum computation and simulation tasks.

However, quantum hardware of any form suffers from unwanted interaction with its environment, which leads to untrustworthy results and may even lead to a loss of the so- called “quantum advantage” provided by certain quantum algorithms. In the NISQ era, where quantum error correction codes are not yet accessible, the development of efficient error mitigation techniques is crucial to mitigate decoherence errors.

One such technique, called dynamical decoupling, aims at mitigating decoherence by the application of a carefully designed sequence of pulses, which effectively averages out the noise. Although the technique itself is pretty simple, finding relevant sequences is not a trivial process. While first order sequences can easily be found using linear programming [1], higher order, optimized sequences are generally constructed with the help of heuristic algorithms [2]. Although the field has been extensively studied for multi-qubit quantum systems, dynamical decoupling of qudit systems remains little explored.

In this work, we construct a graph on which a decoupling sequence is represented by a cyclic path and use a search algorithm to determine the optimal path to construct more efficient sequences for arbitrary Hamiltonian. We then use this technique to construct short sequences of different decoupling properties for a spin qutrit.

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BPC-14

Development of a chirped-pulse Fourier transform microwave spectrometer operating in the 6 to 18 GHz frequency range

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The chirped-pulse Fourier transform microwave (CP-FTMW) spectroscopy technique is an efficient tool for the rapid measurement of broadband rotational spectra[1] . Fast, state- of-the-art arbitrary waveform generators (AWG) and oscilloscopes are usually required for CP-FTMW spectrometers to induce and detect the free induction decay (FID) in a gas of molecules.

Alternatively, the CP-FTMW spectrometer currently developed at UCLouvain makes use of a 2.5 GSa/s direct digital synthesizer in place of an AWG, following the work of Ref. 2. It also leverages heterodyne detection to allow the acquisition of the FIDs with a 2.5 GSa/s digitizer. A quadrature demodulation technique is implemented to discriminate between the lower and upper sidebands of the probed frequency range[3] . A computer program was developed to automate the scan of the 6-18 GHz frequency range and remove the spurious features from the spectra.

Methanol spectra have been measured in the 6-18 GHz frequency range to assess the performances of the spectrometer. The methanol sample was first studied at room temperature in a waveguide cell. The frequency range was covered by concatenation of multiple 500 MHz sub-spectra, all acquired and averaged 100,000 times in about 13 minutes. In this configuration, the acquisition rate, precision, and sensitivity of the instrument were evaluated. Based on Ref. 4, we fitted the FID in the time domain and extracted the resonant frequency and the T_2 coherence time. First measurements performed in a supersonic expansion will also be presented.

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Analogy between the Goos-Hänchen Effect in Classical Optics and the Quantum Tunnelling Time Problem

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Abstract

A free quantum particle encountering a potential energy barrier can pass through it even in the case of insufficient kinetic energy, a phenomenon known as the tunnel effect. Determining the duration of the tunnel effect poses many challenges [1]. In particular, the time at which the maximum of the wave packet leaves the barrier (phase time or Wigner time) becomes independent of the barrier width for large barriers, preventing its interpretation as a physical transit time. Since time-related problems are difficult to apprehend, we considered a more convenient spatial equivalent, formulated in terms of spatial an angular shifts of laser beams reflected and transmitted at interfaces. It relies on the formal equivalence between the Helmholtz equation linked to the propagation of a paraxial Gaussian beam and the Schrödinger equation for a free particle, where the laser's direction of propagation in Helmholtz's equation plays the role of time in Schrödinger's equation.

Laser beams, which have a finite diameter, can be viewed as a superposition of plane waves with different wave vectors. As a result, geometrical optics is not an appropriate model for the description of the propagation of the main axis of beam, leading to very small deviations from the laws of geometrical optics that can manifest as a spatial jump and/or an angular deviation of the central axis of the beam upon reflection and transmission. These spatial and angular shifts can occur both in the plane of incidence and out of the plane of incidence: they are called the Goos-Hänchen and Imbert-Federov effects, respectively [2]. More specifically, in the plane of incidence, total internal reflection leads only to the Goos-Hänchen spatial shift.

We considered the case of the reflection and transmission of a paraxial Gaussian beam undergoing a frustrated total internal reflection [1]. Frustrated total internal reflection is related to the propagation of light when considering two mediums separated by a less refringent layer, with an incidence angle larger than the critical angle of total internal reflection. An evanescent wave thus exists in the second layer and produces a net transmission of the light in the third medium, in practice to the extent that the width of the less refringent layer is of the order of the wavelength (beyond a few wavelengths, the transmission becomes negligible).

We evaluated the spatial and angular Goos-Hänchen effects for reflection and transmission, which both occur in frustrated total internal reflection. Interestingly, the reflected and transmitted light undergo identical Goos-Hänchen spatial shifts because the phase of the reflection and transmission coefficients differ only by a constant (independent of the incidence angle). It appears that several aspects of the tunneling

effect of free electrons passing through a potential barrier, in the form of a wave packet with different frequencies undergoing an apparent time-related shift, can effectively be related to

similar spatial-related shifts of a paraxial Gaussian beam in reflection and transmission, although the two situations are not fully equivalent.

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BPC-15

Optical Parametric Solitons in Fiber Cavity for Optical Computing

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Embedded within the aspiration to advance towards photonics, this endeavor is centered on the fundament and the exploitation of optical Kerr solitons within a fiber cavity, parametrically driven. This rendition of the physical concept promises different future applications, ranging from random number generation to optical computing.

Kerr Cavity Soliton

A soliton is an intense and resilient wave observed notably in hydrodynamics, optics, and mechanics, maintaining stability during propagation. In the realm of nonlinear optics, the existence of such solitons is foreseen by the nonlinear Schrödinger equation under conditions of negligible material losses. It epitomizes a delicate balance between two phenomena within the medium, as in an optical fiber. Temporally, chromatic dispersion broadens the wave while the Kerr effect facilitates quadratic self-focusing of the light beam. Through modulation instability, solitons spontaneously manifest, modulated by the detuning, representing the phase difference between pump and intracavity field at the coupler. Within the OPERA laboratories, these optical solitons were initially generated by S. Coen [1] within a fiber cavity to replenish lost energy during propagation.

Parametric Soliton

By incorporating a nonlinear gain medium at the cavity entrance, losses are compensated through parametric gain, a departure from previous methodologies. The devised system resembles constructing a fiber-optic parametric oscillator (FOPO), wherein parametric solitons emerge upon reaching the pump power threshold. The particularity of these parametric solitons lies in their phase characteristics. Specifically, in the case of degenerate frequency difference generation, phase degeneracy manifests in the stationary solution, presenting two stable states with a phase difference of π. Recently, these solitons were observed within an active fiber cavity by the OPERA team [2]. In this study, I utilize periodically poled lithium niobate crystal within a free space section to realize an FOPO, improving the efficiency of the last setup. This approach facilitates easier attainment of a soliton regime within a passive cavity.

Applications

The physics underlying these solitons potentially introduces a novel tool across various photonics domains. Firstly, the dynamics of generating these singular waves are rooted in a chaotic system. Consequently, the phase accrued by the field is inherently random, owing to modulation instability gain acting upon disturbances within the ambient noise.

This presents an opportunity for implementing an optical system for generating useful random numbers, particularly valuable in cryptography. Furthermore, other possibilities exist for employing these parametric solitons in optical computing. For example, focusing on phase difference, an Ising machine could be implemented, with each soliton akin to a spin in the system's Hamiltonian. While such a method has been explored with pulses, soliton-based exploration remains nascent [3]. Furthermore, a soliton is one way for generating a frequency comb exploitable, for instance, in neuromorphic networks like [4]. In our context, phase incorporation would introduce an additional degree of freedom.

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Session Physics and Education

Chair: Mieke De Cock (KUL)

Orals

14:30 - 14:50 Riccardo Rossa : Hands-on demonstration of a virtual reality tool for measuring ionizing radiation in nuclear education and training

14:50 - 15:10 Bert Jorissen Minelabs: Physics and Chemistry in Minecraft

15:10 - 15:30: Michèle Coeck : European ENEN2 plus project: opportunities for students, pupils and their teachers

15:30 - 15:50 Alessio Rocci : Integrating the history of Ernest Solvay’s science project into educational tools

15:50 - 16:10 Sarah Doumen : Energy materials and quantum technologies for the future: the case of the Master of Materiomics

16:10 - 16:30 Yarne Beerden : Interdisciplinary Educational Projects Enabling Students to Experience Quantum Research and Space Engineering

16:30 - 16:45 Ioana Maris : An LED display of the Pierre Auger Observatory

Hands-on demonstration of a virtual reality tool for measuring ionizing radiation in nuclear education and training

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Virtual reality (VR) applications are being increasingly used in the fields of entertainment, product development, healthcare, and education and training thanks to the development of both hardware and software.
Nuclear education can also benefit from VR to enlarge the possibilities for hands-on training and practical exercises. In fact, accessibility of nuclear material and facilities is one of the bottlenecks for the wide organization of experiments during education and training. The use of VR allows to simulate exercise sessions without the need of physical availability of radiation sources and detectors. In recent years, SCK CEN has been developing VR tools for nuclear education and training [1 - 4].

The VR tool that will be demonstrated and can be tested live by the participants focusses on measuring ionizing radiation using multiple detectors. The software is developed in Unity3D as this is a frequently used game engine allowing flexibility to use the VR tool on a stand-alone PC or via a web browser (https://simmer.io/@rrossa/vipset-radiation-detection). This flexibility is required to support a broad range of users.

As shown in Figure 1 below, the available software now includes an experimental room for radiation measurements with several radiation detectors (fixed and hand-held devices), four different sources (^{252}Cf and ^{240}Pu as neutron sources ,and ^{137}Cs and ^{60}Co as gamma sources) and some shielding material (aluminum and lead) present. The design of the detectors mimics that of real detectors to perform the measurements as close to reality as possible. Simple drag-and-drop-actions can freely move the hand-held devices, sources, and shielding materials across the room allowing users to experiment.

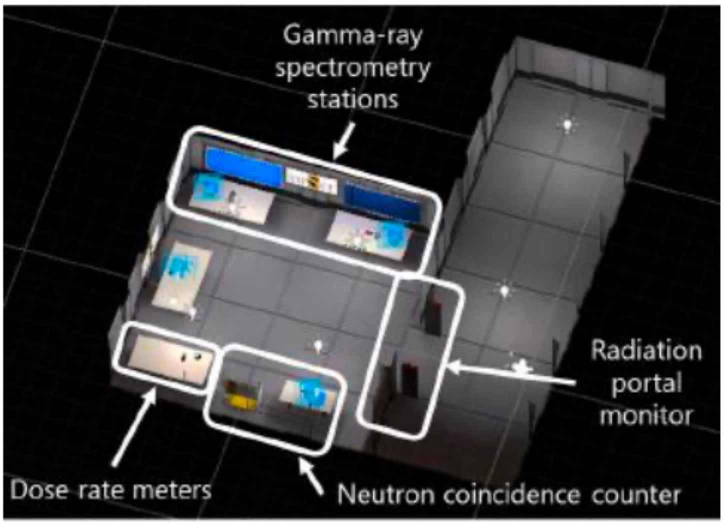

Figure 1 General overview of the VR room [4]

For both the hand-held detectors, the actual dose rate (µSv/h), averaged over five second, is constantly displayed. The calculation of the dose rate is done with point-source modelling or spectrum generator software of Nucleonica for the gamma sources and with pre-computed Monte Carlo simulations using MCNP6 for the neutron sources.

Using this VR tool, the user (e.g., pupils, students, junior professionals) can conduct measurements with the different sources using a variety of radiation detectors. The students therefore can gain experience on the use of different radiation detectors, discover the effectiveness of safety measures, learn the characteristics of various sources, and experience the impact of shielding material on measurements and spectra.

Based on the feedback from users, the current version of this VR tool can be improved. Further development can include adding more devices and sources to broaden the range measurable ionizing radiation, include more divers shielding material to illustrate better the effect of shielding, and to refine the detector responses. Additionally, teaching materials to facilitate and support the use of this tool in the classroom can be developed with the relevant stakeholders.

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Minelabs: Physics and Chemistry in Minecraft

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Game-based education is thriving, with sandbox games like Minecraft offering boundless teaching opportunities in a familiar setting. Minelabs [1] is a Minecraft Java Edition modification (mod) that adds advanced high-school physics and chemistry into the game. While Minecraft Education Edition features a basic chemistry extension, its content is limited to exploring basic chemistry on an elementary level. Minelabs offers a visual, interactive and intuitive way to learn second and third grade science concepts, including but not limited to: Bohr atomic model, Lewis structures of molecules, Coulomb force and the Standard Model of elementary particles. In this presentation we highlight one of our features (the Bohr model for atoms) and compare it with a similar concept in Minecraft Education Edition. We'll discuss how the students interact with the game, their learning gains and benefits and disadvantages of this interactive model.

Figure 1 *The Bhor blueprint for the carbon atom.*

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European ENEN2plus project: opportunities for students, pupils and their teachers

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The Belgian Nuclear Research Centre SCK CEN is one of the largest research centres in Belgium with more than 70 years of experience in nuclear science and technology. Preserving and extending nuclear knowledge and maintaining a competent workforce in industry, healthcare, research and policy organisations are key tasks. Through the SCK CEN Academy, SCK CEN provides education and training, and policy support at national and international level.

From its experience and expertise in nuclear competence building, and associated outreach activities, the SCK CEN Academy actively contributes to the ENEN2plus project (ref. nr. 101061677). Currently, this project is the largest European education and training project in the nuclear field bringing together 51 partners from 20 countries. The aims of this project are to (i) identify the human resources needs in the nuclear sector, (ii) inform new talents and attract them the nuclear field, (iii) enhance the competences of the nuclear workforce by continuous education and (vocational) training and (iv) to support a mobility program providing opportunities for cross-border and cross-disciplinary actions.

In this presentation we will focus on the ENEN2plus actions towards pupils and their teachers, as well as for students and junior researchers, to inform the Belgian target audience and to facilitate and support participation.

For secondary school pupils and their teachers, nuclear science camps are organized. The 2025 edition will include a video competition for the pupils and a STEM award for outstanding teachers. During a one-week stay in Italy, pupils and teachers will gain more insight in the basics and the main applications of radioactivity and experience theory in practice through exercises and visits to nuclear installations. In addition, junior-senior exchange meetings will be organized to give pupils a flavor of potential future careers in nuclear.

A thesis competition for BSc and MSc students in engineering and sciences brings the finalists to an advanced summer school. Based on their research in nuclear energy and reactor technology, medical applications, nuclear waste management and radiation protection, and their motivation letters, an international jury evaluates all candidates and selects 40 students to participate in the summer school. There, the students can present their work orally and the laureates are selected. Afterwards the students can participate to the summer school where experts will present state-of-the art information on several hot topics in nuclear. Students will have the opportunity to experience a unique exchange with peers and professionals at an international level.

On an annual basis, ENEN also awards the best PhD work in nuclear sciences and applications. The approach is similar as for the BSc and MSc competition: PhD students or recent graduates are invited to send in an abstract. A jury selects up to 18 candidates which are financially supported to participate in an international conference, where they present their work. Every year another nuclear conference is chosen, but all provide the added value of offering an international environment, bringing together students and professionals in an innovative and multi-disciplinary setting.

Last but not least we highlight the ENEN2plus mobility program, providing financial support for cross-border mobility to and from Europe for students and junior researchers. The program has the ambition to provide mobility actions for 100 person- years contributing to the careers of more than 1000 learners doing a cross-border mobility in nuclear domains such as nuclear engineering, medical applications, radiation protection, safeguards, waste management, etc. Individual mobility applications are possible for all students in academic education (BSc, MSc and PhD) and for junior professionals (post-docs and early career researchers) with less than 10 years of experience in the nuclear field. Group mobility applications allowing for more than one learner to attend the same event are possible within a restricted framework.

Integrating the history of Ernest Solvay's science project into educational tools

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Abstract

The talk aims at presenting a small project that has been supported by the British Society for the History of Science (BSHS) through its Outreach and Engagement Committee (OEC) Project Grant. The idea was conceived in the context of the celebrations for the centennial of the first Solvay Chemistry Council (1922-2022) as part of a postdoctoral fellowship in the history of physics and chemistry of the twentieth century at VUB. After presenting the motivations for developing the project and the historical context of the first Solvay chemistry meeting in Brussels, we discuss the educational aspects and how they have been integrated with historical details. The project's outcomes have been added to the educational tools of the Expérimentarium de Physique of the Université Libre de Bruxelles thank to the collaboration of the former director Maïte Swaelens.

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Energy materials and quantum technologies for the future: the case of the Master of Materiomics

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In 2022-2023, Hasselt University inaugurated the Master of Materiomics program. This study program targets individuals aspiring to pioneer sustainable and groundbreaking materials situated at the intersection of physics and chemistry, utilizing both theoretical/computational and empirical methodologies. The curriculum delineates four specialized domains, of which two will be highlighted in this contribution: Innovative materials for energy generation, storage and efficiency; and high-tech materials for quantum technologies. By combining diverse perspectives and fostering interdisciplinary engagement, the program cultivates students ready for interdisciplinary collaborations in the work field. Moreover, there is a continuous need for these advanced physics profiles in industry and academia (*e.g.*, Einstein telescope). Equipped as interdisciplinary scientists, students are trained to address material-related challenges pertinent to overarching societal imperatives such as climate mitigation and the transition towards sustainable energy paradigms, but also to scientific progress in *e.g.* cyber security and innovative space research.

Introduction

In the current times, society deals with a myriad of complex and interconnected challenges such as climate change, pandemics, the advancement of secure communication technologies, the transition towards sustainable energy sources, evolving industrial processes, pioneering space research, and the depletion of finite resources. In response, there is a pressing demand for scientists who are well-equipped to navigate an internationally-focused and interdisciplinary research landscape, as well as the corresponding job market. Central to addressing these challenges is the field of materials development and research, as the search for solutions often depends on innovation and breakthroughs in this domain.

Breakthrough materials for energy

The Energy specialization of the Master of Materiomics provides in-depth training in developing and characterizing innovative, high-performance materials for renewable energy generation/storage and CO_2 emissions reduction. This pillar is aimed at students interested in improving photovoltaic energy conversion, materials for thermochromic glazing that can switch between heat pass/block, designing short- and long-term battery materials, green hydrogen via water dissociation,... Here students will address questions such as "How can we increase the efficiency of the new generation of solar cells?" or "How can we convert CO_2 into usable fuels using sunlight? Reducing CO_2 emissions but certainly also capturing, converting and rendering CO_2 usable (CCU) are technological innovations in which the master can play an important role. In sum, students in the Energy specialization pillar are trained in the design, improvement and characterization of renewable materials for energy applications such as batteries, solar cells, and hydrogen cells. There is demand for such profiles by companies active in materials development specifically for these applications (*e.g.*, Umicore) as well as in research centers such as Energyville, imec, and VITO. Moreover, masters with expertise in innovative energy materials and applications can also contribute to the Einstein telescope project, *e.g.* to make it more sustainable.

High-tech materials for quantum applications

The quantum specialization pillar immerses students in state-of-the-art emerging technologies that can force breakthroughs in cybersecurity, computational power, metrology, sensitivity of sensing instruments for medical diagnostics, and much more. Students research the technology used in high-tech quantum sensors for *e.g.* NMR instruments or magnetic field sensors for space that outperform classical sensors. A well-known example in this respect is the UHasselt Oscar Qube project [1], in which ESA sent a student-built quantum magnetometer to the ISS. Another example is the recent development of promising methods by quantum physicists to reduce quantum noise in the Einstein telescope so its measurements will be 100 times more precise [2]. In addition, these materials are also of interest for future quantum computers, which are capable of solving problems unsolvable by classical computers and can play a major role in the search for new materials, encryption, security and transmission of data, among other things.

Interdisciplinary skills for the work field

In addition to this specialized knowledge, students are taught to adopt diverse viewpoints when engaging with materials and are trained to effectively communicate across disciplinary boundaries, collaborating with experts in fields such as chemistry [3]. Emphasis is placed on cultivating both academic research abilities and soft skills, thereby equipping students with the necessary tools for their future professional roles. These interdisciplinary skills have been emphasized repeatedly by employers in the field.

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Interdisciplinary Educational Projects Enabling Students to Experience Quantum Research and Space Engineering

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Understanding Earth's geodynamical processes and monitoring space weather are crucially dependent on precise magnetic field measurements in space. Conventional magnetometers face challenges in meeting requirements of modern space missions, particularly concerning size, weight, and power efficiency, without compromising sensitivity and stability. The emerging field of quantum sensing technologies based on Nitrogen-Vacancy (NV) centers in diamonds, offer a promising platform delivering a broad dynamic range, high sensitivity, and operational stability across extreme environmental conditions, while allowing for on-chip integration.

We report the development and deployment of a quantum diamond-based NV magnetometer by an interdisciplinary student team OSCAR (Optical Sensors based on CARbon materials) at UHasselt, under the framework of ESA Academy Experiments programmes - 'Orbit Your Thesis!' and ESA Space Rider. The project aims to demonstrate the sensor's viability for future Earth Observation missions and to provide hands-on quantum research and space engineering experience to students.

The OSCAR-QUBE sensor, was designed, built, and tested by the students before its installation aboard the International Space Station within the Columbus module's ICECubes Facility in September 2021. The device's compact form (1U – 10x10x10cm^3 , 420g, 5W) houses an NV center magnetometer with the capability to measure both scalar and vector components of the magnetic field with sensitivity below 300 nT/sqrt(Hz).

Data acquired during its operational period of nine months, were compared with the CHAOS-7 model of Earth's magnetic field, and long-term stability was evaluated. The NV-based magnetometer demonstrated correlation with the model and sustained its measurement accuracy and stability throughout the mission, confirming the robustness of diamond-based sensors in space. Additionally, the project contributed significantly to student education and career development, leading to 15 successful theses, employment of three team members at ESA, and the acceptance of all physics graduates into PhD programs.

The follow-up project OSCAR-QUBE+ will be tested aboard Ariane 6 inaugural flight as part of the ESA YPSAT mission. The team further miniaturized the sensor (0.4U - 6x7x8cm^3 , 315g, 3.5W) and improved the sensitivity down to 30 nT/sqrt(Hz). Recently the team was also selected for next ESA Academy Experiments programme – Space Rider – providing the team with opportunity to further develop the NV based quantum sensors.

The successful deployment and operation of OSCAR-QUBE mark a significant advancement in the use of quantum diamond-based sensors for space applications. These results shown the inclusion of NV center magnetometers in future space missions, offering a compact, resilient, and precise technology solution. Furthermore, the project exemplifies the impact of extracurricular interdisciplinary educational projects in fostering real-world experience and career readiness among students in the field of quantum technologies and space engineering.

Session Physics and Education

Posters

Energy materials and quantum technologies for the future: the case of the Master of Materiomics
S. Doumen

Energy materials and quantum technologies for the future: the case of the Master of Materiomics

S. Doumen[1] , D. Baeten[1] , P. Siyushev[1,2] , A. Ermakova[1,2] , M. Nesladek[1,2] , D.E.P. Vanpoucke[1,2] , K. Vandewal[1,2] and A. Hardy[1,2]

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