Workshop on the Application of Novel Scintillators
In Research and Industry

12\textsuperscript{th}-14\textsuperscript{th} of January, 2015
University College Dublin, Ireland

Programme
### Monday 12th of January

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00 – 10:00</td>
<td>Registration/Coffee</td>
</tr>
<tr>
<td>10:00 – 10:05</td>
<td>Welcome</td>
</tr>
</tbody>
</table>

#### Session 1: Development of Novel Scintillators (Chair: Sheila McBreen – UCD)

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
</table>
| 10:05 – 10:55 | Development and application of novel scintillators on an Industrial scale  
  *Paul Schotanus – Scionix, The Netherlands* |
| 10:55 – 11:45 | Nanocomposite Based Scintillators  
  *Brent Wagner – Georgia Tech, USA* |
| 11:45 – 12:05 | Scintillator research at RMD  
  *Jarek Glado – Radiation Monitoring Devices, USA* |

**Lunch** 12:05 – 13:05

#### Session 2: Characterisation of Novel Scintillators (Chair: Julie McEnery – NASA [TBC])

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
</table>
  *Nerine Cherepy – Lawrence Livermore National Laboratory, USA* |
| 13:55 – 14:15 | Characterization of new scintillators: GYGAG, SrI₂, CeBr₃ and CLYC  
  *Agnese Giaz – INFN-Milano, Italy* |
| 14:15 – 14:35 | ⁶LiF nano-particles in siloxane scintillators for thermal neutron detection  
  *Sara Carturan – INFN-Laboratori Nazionali di Legnaro, Italy* |

**Coffee** 14:35 – 15:05

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
</table>
| 15:05 – 15:55 | Influence of slow components on energy resolution of scintillators  
  *Marek Moszynski – National Centre for Nuclear Research, Poland* |
| 15:55 – 16:15 | 3”x3” LaBr₃:Ce position sensitivity  
  *Nives Blasi – INFN-Milano, Italy* |
| 16:15 – 16:35 | Phototube non-linearity correction technique  
  *Stefano Riboldi – Universita degli Studi Milano / INFN* |
| 16:35 – 16:55 | Technology Preparation for ESA’s Cosmic Vision Programme  
  *Brian Shortt – European Space Agency, The Netherlands* |

**Public Talk:** "The Hot and Energetic Universe with the X-ray Observatory Athena" by Prof. Luigi Piro. **6 pm** in the Moore Auditorium. All welcome.
Tuesday 13th of January

Session 4: Novel Scintillators in Medical Applications (Chair: Marek Moszynski – NCBJ, Poland)

09:30 – 10:20 Improving PET time-of-flight performance with prompt photons in scintillators
Paul Lecoq – CERN, Switzerland

Kevin O’Neill – SensL, Ireland

10:40 – 11:00 Para-terphenyl based polycrystalline scintillator adopted in a beta- detecting probe for radio-guided surgery
Elena Solfaroli Camillocci – CLNS-Sapienza Istituto Italiano di Tecnologia, Italy

Coffee 11:00 – 11:30

11:30 – 11:50 Picosecond timing for scintillators in particle physics and medical applications
Christophe Royon – IRFU-SPP, CEA Saclay, France

11:50 – 12:10 Need for novel detectors in Radiotherapy
Laura Shields – University College Dublin, Ireland

Session 5: Theoretical development of Materials (Chair: [TBC])

12:10 – 13:00 The high-throughput highway to computational materials design
Stefano Sanvito – Trinity College Dublin, Ireland

Group Photo/Lunch 13:00 – 14:30

Session 6: Applications of Novel Scintillators in Astrophysics (Chair: Brian Shortt – ESA)

14:30 – 15:20 Development of scintillators for gamma-ray spectroscopy of planets
Francesco Quarati – Praesepe BV & TU Delft, The Netherlands

15:20 – 15:40 Characterization of a 3D Imaging Scintillation Module for Gamma-Ray Astronomy
Aleksandar Gostojic – CSNSM, Orsay, France

15:40 – 16:00 Gamma-ray detection with LaBr3 and silicon photomultipliers
Alexey Uliyanov – University College Dublin, Ireland

16:00 – 16:20 Development of glass ceramic scintillators for gamma-ray astronomy
Daithi de Faoite – University College Dublin, Ireland
Coffee  
16:20 – 17:00

Informal Meetings/Poster Session 16:20-

Posters:

The fabrication of wavelength shifting lightguides from clear acrylic sheet by disperse dying  
John McMillan – University of Sheffield, UK

Characterisation of neutron/gamma discrimination in EJ299 plastic scintillators  
Christopher Payne – University of Surrey, UK

BurstCube: A Gamma-ray Burst Detecting Swarm of CubeSats  
Jeremy S. Perkins – NASA Goddard Space Flight Center, USA

Modelling of Scintillation Light in High Aspect Ratio Scintillator Arrays  
Sion A. Richards – University of Surrey & STFC Rutherford Appleton Laboratory, UK

18:00 – 19:00

Meet-up in Arthur Mayne’s Pub in Donnybrook (48 Donnybrook Rd)  
Buses: 46A, 145, 39A from UCD/City Centre

19:00 -

Conference Dinner in O’Connells restaurant (apx. €45/person).  
135 Morehampton Road,  
Donnybrook,  
Dublin 4

Buses: 46A, 145, 39A from UCD/City Centre
Wednesday 14th of January

Session 7: Applications of Novel Scintillators in Nuclear Physics (Chair: Oliver Roberts – UCD)

10:00 – 10:50
Novel scintillators in nuclear physics
David Jenkins – University of York, UK

10:50 – 11:10
Development of a LaBr₃ Coincidence Gamma-ray Array for Radioactive Source Characterisation and Absolute Activity Measurements at the UK National Physical Laboratory
Patrick H. Regan – University of Surrey & National Physical Laboratory, UK

11:10 – 11:30
The SpecMAT project: an array of gamma ray detectors around an active gas target
Jacobus A. Swartz – IKS KU Leuven, Belgium

Coffee
11:30 – 12:00

12:00 – 12:20
Lifetime measurements of nuclear excited states using a mixed array of HPGe and LaBr₃(Ce) detectors
Cristina R. Nita – University of Brighton, UK & IFIN-HH, Romania

12:20 – 12:40
The PARIS cluster coupled to the BaFPro electronic module: data analysis from the NRF experiment at the ELBE facility
Barbara Wasilewska – IFJ PAN, Poland

12:40 – 13:00
Scintillators in Low Energy Nuclear Physics
Alfredo Galindo-Uribarri – Oak Ridge National Laboratory, USA.

Lunch
13:00 – 14:30

Session 8: Applications of Scintillators in Defence & Security (Chair: Nerine Cherepy – LLNL, USA)

14:30 – 14:50
A review of emerging gamma detector technologies for airborne radiation monitoring
Steven Bell – National Physical Laboratory, UK

14:50 – 15:10
A Large Area Scintillator Trigger Detector for Cosmic Ray Muon Scattering Tomography
Chris Steer – AWE, UK

15:10 – 15:30
Thermal neutron scintillators using unenriched boron nitride and zinc sulphide
John McMillan – University of Sheffield, UK

Closing
ESA has recently selected The Hot and Energetic Universe as the scientific theme to be addressed by its next L2 (Large) mission. In this talk I will present the science theme and the mission implementation that the Athena consortium has proposed. Much like present and future missions, such as Planck or Euclid, have been designed to unveil the nature of the Dark Universe, a dedicated study of the Hot and Energetic Universe is mandatory to understand how ordinary matter emerge from the cosmic dawn and form the complex network of large scale structures that we see today, and how do black holes grow and shape the Universe. The majority of ordinary matter in the Universe consists of hot gas embedded in and delineating the large scale structure of dark matter. While the framework of the Universe is set by the cosmological parameters, the assembly and evolution of baryonic structures are strongly affected by processes of astrophysical origin, particularly those occurring or originating around accreting black holes. These objects have a profound effect on the evolution of galaxies and larger scale structures, as we have just started to appreciate. The challenge is to push the frontier of these studies to the highest redshift, at the epoch of the formation black holes in the Universe and their popIII stars progenitors. These two fundamental questions can only be revealed and fully understood via space-based observations at X-ray energies, with a large X-ray mission offering breakthrough capabilities, Athena, that combines unprecedented throughput with state-of-the-art instrumentation for spatially-resolved high resolution spectroscopy and wide field imaging.
Abstracts

Development and application of novel scintillators on an Industrial scale

Paul Schotanus (INVITED TALK), E. Bodewits

Last years a growing number of new scintillators have been developed for application in science and industry (LaBr₃, CeBr₃, Sr₂(Eu), CLYC etc. In this presentation we describe the difficulties and hurdles before new materials are actually used at a larger scale in instruments and “real size” scientific experiments. Differences in performance parameters as defined in scintillator research versus what is needed in actual applications are addressed. Some recent examples of the actual use of novel scintillators in industry are presented.

Nanocomposite Based Scintillators

Brent Wagner (INVITED TALK), Z. Kang, B. Beckert, J. Nadler, B. Kahn, R. Rosson

Scintillators have been long utilized in nuclear detection and radiation imaging and have been realized in many forms including particulates, single crystals, glasses and plastics. However, a relatively new form of scintillator technology has been based upon the combination of nanoparticle scintillating materials embedded in a matrix composed of a dissimilar material, or nanocomposites. The nanocomposite matrices can include a wide range of materials such as polymers, liquids and glasses while the embedded scintillating materials tend to be inorganic particles with dimensions of less than 100nm. A potential advantage of the nanocomposite approach compared to standard single crystal inorganic scintillators include the flexibility to utilize a wide range of scintillators that may, for example, provide better interaction cross-sections or emit light whose wavelength is optimized for a particular photodetector technology. Other potential advantages include cost and the ability to scale size of production. This talk will discuss these issues as well as report on the development and characterization of a range of nanocomposite scintillators based upon polymer and glass matrices.
Scintillator research at RMD


Scintillator based detectors are the most prevalent detectors of energetic radiation. They are used in numerous applications ranging from science, medical imaging to homeland security (defense). For the last 15 years RMD has been at the forefront of scintillator development efforts, improving, discovering and developing new materials. One of the first scintillating materials that we have worked with was LaBr₃, originally discovered at Delft University. This work led us to improvements of this composition in terms of its timing properties (TOF-PET) based on the observation that high Ce concentration provides better timing properties. It also opened us to the whole tri-halide family yielding CeBr₃ (commercially sold by Hellma Materials), and very promising tri-iodides (Gd, Lu, Y) compositions. Materials that RMD is most known for comes from the elpasolite crystal family. Cs₂LiYCl₆ (CLYC) became a commercial product of RMD sometime in 2012. It took considerable effort to develop this composition to sizes as large as 2 inches. Again work with CLYC opened us to the while elpasolite family slowly yielding new commercial compositions - CLLBC (Cs₂LiLa(Br,Cl)₆). Just few years ago, along with a number of national labs and universities, RMD embarked on the journey to develop SrI₂:Eu. This work again yielded a very good scintillator and a commercial product. It also opened research (shared by a number of entities) into alkaline earth halide crystal family. In this talk we will overview development of scintillation material, old and new, at RMD.

New Scintillators, Instrumentation and Applications

Nerine Cherepy (INVITED TALK)

Growth and scintillation properties of several new scintillators will be discussed, including the design of detectors and their performance in applications including gamma spectroscopy and radiographic imaging. For gamma spectroscopy, I will discuss single crystal Strontium Iodide, transparent ceramic garnets and Bismuth-loaded plastics. For imaging applications, Lutetium-based ceramics and Lithium-loaded plastics will be described.
Characterization of new scintillators: GYGAG, SrI$_2$, CeBr$_3$ and CLYC

Agnese Giaz, N. Blasi, S. Brambilla, F. Camera, S. Ceruti, V. Fossati, G. Hull, B. Million, L. Pellegrin, S. Riboldi

In this work we measured the performances of a 2"x2" tapered SrI$_2$:Eu sample, of a 2"x 3" CeBr$_3$ sample, and of a 2"x 0.3" GYGAG:Ce sample. The crystals were provided by the Lawrence Livermore National Laboratory and by the Institut de Physique Nuclaire d'Orsay. The gamma-rays energy resolution was measured up to 9 MeV. A scan along the three axes was performed by using a collimated source of 137Cs. The signals of the detectors were additionally digitized. The scintillator Cs$_2$LiYCl$_6$:Ce (CLYC) becomes an important material for radiation detection because of its ability to measure gamma rays and neutrons simultaneously. CLYC scintillators are suitable for thermal neutrons detection, owing to $^6$Li ions and they can also be used as a fast neutron spectrometers, owing to $^{35}$Cl ions. The gamma rays and neutron can be discriminated by the pulse shape discrimination. We measured the properties of two CLYC crystals: a 1"x 1" sample of a CLYC scintillator enriched by $^6$Li at 95%, and 1"x 1" CLYC that contains only $^7$Li. The response to fast neutrons was measured at 2.5 MeV and at 14.1 MeV at ENEA Laboratories of Frascati, Italy, for both detectors and at 3.2 MeV and a 2.3 MeV at LNL (Italy), for the $^7$Li enriched sample.

$^6$LiF nano-particles in siloxane scintillators for thermal neutrons detection

Sara Carturan, T. Marchi, M. Dalla Palma, M. Degerlier, F. Gramegna, G. Maggioni, M. Cinausero, A. Quaranta

The exceedingly high price of $^3$He-based detectors for the measurement of low-energy neutron fluxes has triggered a widespread and intensive research work aimed at the development of cheaper and more versatile instruments. Siloxane-based scintillators are in principle very simple and economic particle detectors. Moreover, their usefulness in thermal neutron detection through ortho-carborane loading has been demonstrated, although the limited solubility of the organo-boron compound hampered their further development.

Herein, we report on the production of a siloxane scintillator, added with a suitable combination of primary dye and wavelength-shifter, where $^6$LiF nanocrystals have been embedded. The entrapment of nanoparticles, which are known to minimize light scattering effects, has been exploited for the first time to circumvent the critical issue of light loss induced by opacity. The synthesis of the nanodiamonds of $^6$LiF has been pursued in two different ways: the co-precipitation method and the surfactant-controlled thermolysis of Li trifluoroacetate (LiTFA). Highly monodisperse LiF nanocubes have been collected with good yield in both cases, as shown by High Resolution Scanning Electron Microscopy and X-Ray Diffraction. They were later dispersed by mechanical shear blender or by dissolution directly into the siloxane matrix. Samples with different thickness and $^6$LiF content have been tested with a moderated Am-Be neutron source and promising results have been obtained.
Influence of slow components on energy resolution of scintillators

Marek Moszynski (INVITED TALK), A. Syntfeld – Kazuch, L. Swiderski

According to the present knowledge, the non-proportionality of the light yield of scintillators appears to be the fundamental limitation of energy resolution. However, several observations collected in the last 15 years on the influence of slow components of the light pulses on energy resolution suggest more complex processes in the scintillators. This was observed with CsI(Tl), CsI(Na), ZnSe(Te), undoped NaI at liquid nitrogen temperature and finally for NaI(Tl) at temperatures reduced below 0°C. A common conclusion of these observations is the fact that the highest energy resolution, and particularly the intrinsic resolution measured with scintillators, characterized by two components of the light pulse decay, is obtainable when the spectrometry equipment integrates the whole light of both components. In the recent studies separate measurements of non-proportional response of different components of the light pulse seems to show the origin of the effect. In contrast, slow components observed in many other crystals deteriorate the intrinsic resolution. In the limiting case, the afterglow could be considered also as a very slow component that spoils the energy resolution. The aim of this work is to summarize all above observations looking for their origin.

3”x3” LaBr3:Ce position sensitivity

Nives Blasi, A.Giaz, F.Camera, C. Boiano, S.Brambilla, B. Million, S.Riboldi

The position sensitivity of a thick, cylindrical and continuous 3”x 3” (7.62 cm x 7.62 cm) LaBr3:Ce crystal with diffusive surfaces was investigated. Nuclear physics basic research uses thick LaBr3:Ce crystals (>3 cm) to measure medium or high energy gamma rays (0.5 MeV < Eγ < 20 MeV). In the first measurement the PMT photocathode entrance window was covered by black absorber except for a small window 1 cm x 1cm wide. A complete scan of the detector over a 0.5 cm step grid was performed. The data show that even in a 3” thick LaBr3:Ce crystal with diffusive surfaces the position of the full energy peak centroid depends on the source position. The position of the full energy peak centroids are sufficient to identify the collimated gamma source position. The crystal was then coupled to four Position Sensitive Photomultipliers (PSPMT). We performed a scan of the crystal moving the collimated source and we acquired the signals from the 256 segments of the four PSPMTs grouping them into 64 or 16 elements. The centroid position, FWHM and area of the full energy peak were extracted from the measured spectra. The data show a regular behavior which depends on the position of the incident gamma beam. The behavior was parameterized to extract, from the measured pattern, the position of the incident gamma rays.
Phototube non-linearity correction technique

Stefano Riboldi, F. Camera, A. Giaz, B. Million

Scintillation light is often detected by photo-multiplier tube (PMT) technology; however, PMTs are intrinsically non linear devices, especially when operated with high light yield scintillators and high input photon flux. Many physical effects (e.g. inter-dynode field variation, photocathode resistivity etc.) can spoil the ideal PMT behavior in terms of gain, ending up in what is addressed as under-linearity or over-linearity effect. Established techniques implemented in the PMT base (e.g. increased bleeding current, active voltage divider, etc.) can mitigate these effects. However, it turns out that given the unavoidable spread in manufacturing and materials, every PMT sample, with respect to linearity at the percent level, is a story of its own. Residual non linearity, is usually accounted for with polynomial correction of the spectrum energy scale, starting from the known position of a few energy peaks of calibration sources, but uncertainly still remains in between of far-away peaks. With this in mind, we propose to retrieve the calibration information from the entire energy spectrum and not only the position of full energy peaks (FEP). The final calibration function CAL(E), so that $E_{\text{true}} = E_{\text{meas}} \times \text{CAL}(E_{\text{meas}})$, is derived following intermediate steps: 1) rescaling $E_{\text{meas}}$ to $E'_{\text{meas}} = \sqrt{E_{\text{meas}}}$, so that FEP widths are substantially equalized; 2) deriving a smoother, continuous spectrum by Fourier techniques; 3) comparing the result with a reference, rescaled and supposedly linear reference spectrum, acquired within the very same experimental set-up with low enough PMT voltage and 4) using LMS techniques to retrieve the CAL(E) function, taking into account the reliability (signal/noise ratio) of the information from the various spectrum regions.
The Cosmic Vision (CV) programme is the European Space Agency's (ESA) long term space science plan responsible for the identification, definition and execution of cutting-edge space missions addressing the four key questions: What are the conditions for planet formation and the emergence of life? How does the Solar System work? What are the fundamental physical laws of the Universe? How did the Universe originate and what is it made of? With the science programme being a mandatory element of ESA, twenty member states contribute to the Cosmic Vision programmes funding and implementation. This is done either through the member state subscription to ESA or at a national agency level via the provision of payload hardware elements and contributions to science data exploitation. New missions enter the Cosmic Vision plan in cycles, and are prepared over several years prior to submission to the Science Programme Committee (SPC) for formal adoption and implementation. The process follows a bottom-up approach and collectively involves the science community, the European space industry and ESA member states. For each cycle, ESA issues an Announcement of Opportunity to the science community, defining in particular the programmatic constraints such as the cost to ESA and launch date. Mission candidates are then selected from the proposals received in response to the AO, with involvement of the ESA science advisory structure. A critical aspect within the selection process is the readiness of the technology upon which the proposed missions rely. The selected candidates are critically assessed and the mission scenarios and preliminary designs elaborated by ESA through a phase 0 Concurrent Design Facility (CDF) study, supported by the proposers. Thereafter assessment (phase A) and definition (phase B1) studies are conducted whereby the mission concept is matured through competitive industrial system studies of the space segment, and in parallel payload studies are conducted, focused on the elements provided by the member states. Parallel to and in close interaction with the mission studies, the technology readiness for spacecraft and payload is evaluated in dedicated reviews and associated Technology Development Plans are defined and implemented, in order to achieve the required Technology Readiness Level (TRL5/6) prior to the mission adoption. Reaching this level of technical maturity is considered mandatory for minimising the risk to cost and schedule which increase greatly once a mission enters the implementation phase (phase B2CD). This paper gives an overview of the missions within the programme, the critical enabling technologies being developed and provides an insight into some of the long term technology developments being implemented.
Improving PET time-of-flight performance with prompt photons in scintillators

Paul Lecog

The future generation of PET scanners is more and more demanding on timing performance because of the potential of time of flight (TOF) techniques to significantly improve the image signal-to-noise ratio (S/N). The time resolution of a scintillator-based detector is directly driven by the density of photoelectrons generated in the photodetector at the leading edge of the signal. In most of the scintillators this is limited by the scintillation rise time resulting from fluctuations in the thermalization and relaxation time of hot electrons and holes generated by the interaction of ionization radiation with the crystal. These processes last for up to a few tens of ps and are followed by a complex trapping-detrapping process, Poole-Frenkel effect, Auger ionization of traps and electron-hole recombination, which can last for a few ns with very large fluctuations. However, prompt photons are also generated in scintillators. The best known are Cerenkov photons created by the recoil electrons from a photoelectric or Compton events. Even in high density/high refractive index materials used in PET scanners their yield does not exceed 20 to 30 photons/event in a useful spectral range above 300nm. Cross-luminescent materials, with a typical sub-ns decay time and light yield of about 500 photons can be considered. Unfortunately, cross-luminescence takes place in the UV or VUV region where the spectral sensitivity of fast photo-receivers like APD and SiPM becomes dramatically low. We will discuss in this talk hot intra-band luminescence, another ultrafast emission mechanism, characterized by a wide emission spectrum covering the whole visible range in a picosecond and even faster emission time. The rise time of intra-band emission is limited by electron-phonon interaction time and can be even shorter than 1ps. This kind of emission is controlled by the competition of radiative relaxation of secondary electrons and holes with electron-phonon relaxation in materials, where the density of states in the conduction and/or the valence bands is non-uniform. A detailed explanation of this mechanism will be presented, with some estimation of the yield, spectral and timing characteristics of this emission. Some considerations will also be given on the possibility to exploit quantum confinement for the production of ultrafast spontaneous or stimulated emission in semi-conductors.

Coincidence Resolving Time with Silicon Photomultipliers for Time-of-Flight Positron Emission Tomography

Kevin O’Neill, C. Jackson

In this paper we discuss how the Coincidence Resolving Time (CRT) of 511keV gamma pairs from a positron emitting source depends on the scintillating crystal, orientation, and characteristics of the Silicon Photomultiplier sensor. These characteristics include the Photon Detection Efficiency (PDE), cross-talk probability, after-pulse probability, and Single Photon Timing Response (SPTR). In particular, the dependence of the CRT on the leading edge threshold is discussed, and how the SIPM characteristics affect this.
Para-terphenyl based polycrystalline scintillator adopted in a beta- detecting probe for radio-guided surgery

Elena Solfaroli Camillocci, V. Bocci, F. Collamati, L. Recchia, A. Russomando, R. Faccini, S. Morganti

The innovation of the radio-guided surgery exploiting beta- emitters is the higher tumor-to-non-tumor ratio (TNR) allowing both a smaller radiopharmaceutical absorbed dose to detect cancerous remnants and the possibility of extending the technique also to cases with a large uptake of surrounding healthy organs. Our first study cases are meningioma brain tumors since an appropriate beta- emitting tracer is already available but the goal is to apply the technique to glioma brain tumors. Given the short range of electrons and essentially no gamma contamination, para-terphenyl was adopted as main component of a polycrystalline scintillator for the intraoperative probe detecting beta- radiation due to its high light yield, non-hygroscopic property and low density. We have developed and tested three prototypes. The best candidate has a cylindrical core of 5mm diameter and 3mm height. The device is encapsulated inside an easy-to-handle aluminum body with the size of a pen and has a blinding 10 micron-thick aluminum front-end cap. The scintillation light is guided to a photo-multiplier tube by optical fibers. A prototype with a silicon photo-multiplier is also under development. The readout electronics is portable and customized to match the surgeon needs. A wireless data transfer to the PC is envisioned. Preclinical tests with dedicated phantoms showed that with a radiotracer activity on the meningioma tumor of 5kBq/ml and a TNR of 10 a 0.1ml cancerous residual can be detected in 1s. That corresponds to administer to the patient 1MBq/kg of radiopharmaceutical, which is a dose comparable to those administered for diagnostic purposes.

Picosecond timing for scintillators in particle physics and medical applications

Christophe Royon

We will describe a new time to digital converter chip called sampic that was developed in Saclay for picosecond timing measurements. We will describe the chip performance from the pure electronics point of view and using Si or diamond detectors. Possible applications in time-of-flight measurements in particle and medical physics will be outlined.
Need for novel detectors in Radiotherapy

Laura Shields, D. O'Brien, L. Vintro, P. McCavana, B. McClean

In radiotherapy there is a need to validate calculated energy spectra of radiation beams at various locations outside the primary megavoltage treatment beam. There is also a requirement to use detectors for dosimetric validation of new techniques in challenging geometries such as intra-operative and stereotactic radiotherapy. Current research being conducted at St. Luke’s Hospital is examining the modelling, measurement and impact of radiation on normal healthy tissue positioned outside the primary treatment beam. Two independent models of the linac have been created using the Monte Carlo systems BEAMnrc and GEANT4. It is very difficult to validate these models outside the primary radiation beam. A form of validation can be performed by comparing dose measurements acquired inside the primary radiation beam to those calculated by the model. An assumption is then made that the model is sufficient for out-of-field applications if it passes the in-field validation tests. A preferred approach would be to use a detector to directly measure the out-of-field energy spectra. Such a detector would need to be capable of discriminating energies between 10keV-6MeV and withstand photon fluence rates of approximately $10^{13}$/MeV/cm$^2$/s. The ideal detector would be energy independent, instantaneous dose-rate independent, reproducible, linear in response, temperature independent, angular independent and water/tissue equivalent. The detector would enable us to validate our model directly out-of-field which has not been done to date. There is interest in scintillator detectors in radiotherapy and these detectors may provide the properties required for out of field measurements as well.

The high-throughput highway to computational materials design

Stefano Sanvito (INVITED TALK)

Every technology is intimately related to a particular materials set. The steam engines that powered the industrial revolution in the eighteenth century were made of steel and, information and communication technologies are underpinned by silicon. Once a material is chosen for a given technology, it gets locked with it because of the investments associated with establishing large-scale production lines. This means that changing the materials set in an established technology is a rare event and must be considered as a revolution. High-throughput computational materials design is an emerging new concept in materials science with the potential of making real some of such revolutions. By combining advanced thermo-dynamic and electronic-structure methods with intelligent data mining and database construction, and exploiting the power of current supercomputer architectures, scientists generate, manage and analyse enormous data repositories for the discovery of novel materials. Here I will review such concept of high-throughput computational materials design by considering the specific case of designing new high-performance magnets. We have constructed a massive electronic structures library for Heusler alloys containing 236,856 materials. We have then extracted those magnetic compounds with specific electronic properties, such as half-metallicity and large magnetization density, and finally established whether these can be fabricated at thermodynamical equilibrium. Based on our analysis we have identified 249 stable new intermetallic Heuslers, including 21 new magnets. Our work paves the way for large scale design of novel magnetic materials at unprecedented speed.
Global mapping and in-situ measurements of nuclear gamma-ray emissions can provide an extensive knowledge of the composition of soil-constituting elements over the surfaces of planets and celestial bodies such as the Moon, Mars, asteroids and Mercury. Specifically for the Mercury Gamma-ray and Neutron Spectrometer (MGNS) on board the BepiColombo (BC) mission, the European Space Agency (ESA) has promoted and supported the development of a new generation of gamma-ray spectrometers in order to make them compliant with mission requirements and the scientific goals. In this context, the development and assessment of LaCl$_3$:Ce and LaBr$_3$:Ce took place and more recently that of CeBr$_3$. CeBr$_3$ presents over LaBr$_3$:Ce the advantage in that it is part of the same rare-earth family of lanthanum halides and thus has similar properties, including the same level of radiation tolerance, but contains no naturally occurring radioisotopes interfering with the detection of $^{40}$K line at 1.46 MeV. This line together with the line at 2.6 MeV of $^{232}$Th($^{208}$Tl) are amongst the most scientifically relevant to study the relative distribution of volatile and refractory elements within a planet and then the origin of the soil on the surface. A CeBr$_3$ based flight model of MGNS has been manufactured and qualified in collaboration with MGNS instrument team of the Space Research Institute in Moscow, Russia, and it is currently under assessment for possible integration in BC. Next effort will include studies and possible development of scintillators with neutron detection capabilities for the next generation of instruments with active neutron probes.

Characterization of a 3D Imaging Scintillation Module for Gamma-Ray Astronomy

Aleksandar Gostojic

Gamma-ray astronomy in the energy range from 0.1 up to 100 MeV holds many understudied questions connected with e.g. stellar nucleosynthesis, the active Sun, neutron stars and black holes. To access the physics behind, a significant improvement in detection sensitivity is needed when compared to previous missions, e.g. CGRO and INTEGRAL. One of the promising concepts for a future gamma-ray mission is an Advanced Compton Telescope. Under the project of creating a prototype of such instrument, we study the perspectives of using a novel inorganic scintillator as a calorimeter part. Modern inorganic crystal or ceramics scintillators are constantly improving on qualities such as energy resolution and radiation hardness, and this makes them a smart choice for a new space-borne telescope. At CSNSM Orsay, we have assembled a detection module from a 5 cm by 5 cm and 1 cm thick, cerium-doped lanthanum(III)bromide (LaBr$_3$:Ce) inorganic scintillator coupled to a 64 channel multianode photomultiplier. The readout of the PMT signals is carried out with the ASIC MAROC, used previously for the luminometer of the ATLAS detector (CERN). We have carried a detailed characterization of both energy and resolution on 1st gamma-ray interaction position reconstruction. Finally, we present the results of GEANT4 simulation of our module and artificial neural network algorithm, used for 3D reconstruction.
Gamma-ray detection with LaBr$_3$ and silicon photomultipliers

Alexey Uliyanov, O. Morris, L. Hanlon, S. McBreen

Among the top priorities for high-energy astronomy are sensitive all-sky surveys in a gamma-ray energy band of 0.2-100 MeV, which require a space-borne gamma-ray telescope with a large collecting area and a large detector volume. For gamma-ray detection in this energy range, the telescope would typically include a scintillator based calorimeter. The sensitivity of the telescope can be potentially improved using a high energy resolution scintillator, such as LaBr$_3$. Silicon photomultipliers (SiPMs) are solid-state optical detectors that combine high photoelectron gain with low voltage operation, compact design and low mass required in space applications. To study the suitability of using silicon photomultipliers for readout of LaBr$_3$ crystals, a detector module was built in UCD using a single 28x28x20 mm LaBr$_3$ crystal from Saint-Gobain Crystals and a 4x4 array of SiPMs from SensL. The detector was tested using gamma-rays with energies ranging from 30 keV to 9 MeV. The detector signals required corrections for the SiPM non-linearity. With these corrections applied, the detector response to gamma-rays was found to be linear above 100 keV. The energy resolution was measured to be 4% at 662 keV. A positional resolution of 8 mm at 356 keV was measured using a collimated $^{133}$Ba source.

Development of Glass Ceramic Scintillators for Gamma-ray Astronomy

Daithi de Faoite, L. Hanlon, S. McBreen, O.J. Roberts, K. Stanton, A. Uliyanov

Glass-ceramics incorporating nano-sized scintillating crystallites are a promising new class of inorganic scintillator for gamma-ray astronomy. Families of inorganic compounds widely used for scintillator applications include the alkali, alkaline earth, and rare earth halides, and these are often doped with rare earth elements. These families of materials, which include the most widely used inorganic scintillator NaI(Tl), contain compounds that exhibit high light yield and good timing and energy resolution. However, they are very hygroscopic, and must therefore be hermetically encapsulated. Additionally, growth of these monocrystals can be challenging. Scintillators synthesised as glass-ceramics have several potential benefits compared to the currently-used halide scintillators, including non-hygrosopicity, mechanical ruggedness, ease of producing customisable shapes, and the potential for low-cost synthesis. An overview is presented of the fabrication of glass-ceramics, and the status of glass-ceramic scintillator research. Suitable candidate inorganic scintillator compounds for incorporation into glass-ceramics, and suitable glass families for use as host materials are also identified.
Novel scintillators in nuclear physics

David Jenkins (INVITED TALK)

Nuclear physics experiments frequently encompass gamma-ray detection. Until comparatively recently, this was achieved either using conventional scintillator materials which have relatively poor energy resolution but good efficiency or with high-purity germanium detectors which have excellent energy resolution but much lower efficiency. Novel scintillators are starting to offer a new paradigm for nuclear physics enhancing existing techniques such as fast-timing measurements through good timing resolution as well as opening up new experimental opportunities profiting from good energy resolution for medium energy gamma rays. This talk will review some of these initiatives and opportunities. It will also look into how some of the relevant research and development from nuclear physics is being translated into the field of industrial applications.

Development of a LaBr3 Coincidence Gamma-ray Array for Radioactive Source Characterisation and Absolute Activity Measurements at the UK National Physical Laboratory


A novel multi-detector, modular, coincidence gamma-ray spectrometer array is currently being designed and constructed for use at the UK’s National Physical Laboratory (NPL), with the aims of being used for direct measurement and metrological standardisation of specific nuclear decay activities. The NPL-based National Gamma Array (NAGA) will consist of up to 12 LaBr$_3$(Ce) (and possibly CeBr$_3$) detector modules placed in a close, high-efficiency geometry around a well-defined source position. Additional detection systems, which can provide primary standards for radioactive measurements are also like to be used in parallel with the proposed array to allow the most accurate efficiency measurements for the proposed array to be made. It is anticipated that the NAGA array will be used to provide standardised measurements for complex radioactive decays, with likely applications in medical isotope activity standardisations, such as the decay of $^{177}$Lu; characterisation of fission decay products in waste nuclear fuel reference materials; and also in fundamental nuclear physics studies for searches of rare, long-lived decays in nuclear experiment targets. This presentation will provide details on the proposed array geometry and GEANT4 simulations of its potential full-energy peak efficiency and energy resolution characteristics and discuss the detector testing and time-stamped digital data acquisition system being developed for use with the array.
The SpecMAT project: an array of gamma ray detectors around an active gas target

Jacobus A. Swartz, R. Raabe, H. De Witte

The ACTAR TPC active target project, which is based at GANIL and supported by an ERC grant, is being developed to investigate exotic nuclei at various laboratories in Europe. Nuclear reactions are to be employed in inverse kinematics with heavy, unstable nuclei incident on light gas nuclei. In the volume of active gas, an electric field will cause electrons to drift towards a position sensitive segmented detector at the bottom of the chamber, thus providing a two-dimensional charge projection for each event. Information on the third positional dimension may be inferred by looking at the relative times of charge collection. Concurrently, collection of gamma ray information is highly desirable for these events. The project SpecMAT, funded by a second ERC grant, seeks this objective by employing an array of scintillation detectors, of either LaBr₃:Ce or CeBr₃ crystals, around the active gas target. Tests are to be performed with prototype detectors to determine the optimum combination of materials, dimensions and electronics to be used in the final setup for SpecMAT, while working within certain mechanical limitations. This talk will outline the goals of the project and the options which are to be investigated for the SpecMAT gamma ray detector array.
Lifetime measurements of nuclear excited states using a mixed array of HPGe and LaBr$_3$(Ce) detectors

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This contribution will discuss the recent advances in measuring the lifetimes of excited nuclear states using scintillator detectors. The importance of measuring these lifetimes lies in their sensitivity to the structure of nuclear states and they provide a link between the experiment and a theoretical model used as an attempt to understand the nuclear structure. Lifetimes of nuclear states lower than 1 nanosecond can be measured using the electronic timing technique between gamma-rays observed in two scintillation detectors [1,2]. Until recently BaF$_2$ detectors were used for this purpose. The relatively recent discovery of LaBr$_3$(Ce) scintillation detectors which have better energy resolution than BaF$_2$ has extended the scope of this method to cases where the transitions of interest are masked in the gamma-ray spectrum. A fast-timing method has been developed at IFIN-HH which uses a triple-gamma coincidence technique between one HPGe detector and two LaBr$_3$(Ce) detectors to measure level lifetimes of nuclei produced in reactions with many final channels [3]. Two examples will be presented: $^{67}$Cu nucleus is a challenging case being close to Z~28 and N=40 where single-particle and collective degrees of freedom coexist and $^{209}$Bi is one proton away from a double-closed shell configuration. In both cases level lifetimes of about 100 ps have been measured.

References:
The PARIS cluster coupled to the BaFPro electronic module: data analysis from the NRF experiment at the ELBE facility

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In December 2013 the first cluster of the upcoming Photon Array for studies with Radioactive Ion and Stable beams (PARIS) has been assembled and tested at the γELBE facility at HZDR, Dresden, Germany. This 4π calorimeter will be made of more than 200 phoswich detectors, consisting of 2” x 2” x 2” crystals of a novel material of LaBr₃(Ce) backed by 2” x 2” x 6” crystal of standard scintillator of NaI(Tl) with common PMT, arranged in clusters of nine. The experiment mentioned above was held to test the performance of each detector separately, as well as, the whole cluster. The γELBE facility enables experiments of a Nuclear Resonance Fluorescence (NRF). In this case the target of choice was ¹¹B + C (natural) which was irradiated with Bremsstrahlung of energies up to 16 MeV from the converted electron beam. The reaction should have made possible detecting discrete gammas of energies 2125, 4444, 5020, 7285, 8917 and 15100 keV. Data were taken using BaFPro collecting the information about amplitude, charge and time for each event. Notably, the matrices of amplitude vs charge make separating signals of LaBr₃(Ce) from NaI(Tl) possible. Two possible algorithms of decomposing LaBr₃(Ce) and NaI(Tl) signals for proper internal add-back will be discussed in detail. Moreover, the algorithm of external add-back of scattered γ-ray, detected in other detector, will be presented. Conclusive spectra for the whole cluster will be shown.

Scintillators in Low Energy Nuclear Physics

Alfredo Galindo-Uribarri

Scintillation detectors based on inorganic materials represent one of the most widely applied instrumentation techniques in the fields of nuclear and high-energy physics. I will give examples of some current uses of scintillator arrays in nuclear physics and in particular will discuss the use charge particle detector arrays in conjunction with gamma-ray spectrometers. I will discuss some general characteristics of scintillator based detectors such as temperature dependence, heavy-ion response, dynamic range, pulse shape discrimination, purity of materials, and signal processing using fast digitizers.
A review of emerging gamma detector technologies for airborne radiation monitoring

**Steven Bell**, H. Philips, S. Judge, P.H. Regan

Across Europe there are many gamma detectors routinely measuring gamma dose in air and gamma emitting airborne particulates collected on filters. Many of these detectors are operated within national early warning networks. In the event of a radiological incident such as Fukushima or Chernobyl, the measurements made by these networks must be rapidly collected, analysed and assessed. The results are then forwarded to national governments where decisions with far reaching consequences may have to be made. For this reason it is critical that the gamma measurements are as accurate and complete as possible. Many of the gamma detectors currently used represent tried and tested but dated technology, such as Geiger Muller tubes and NaI(Tl). New and emerging gamma detector technologies offer the potential to improve isotope identification and quantification with improvements in energy resolution, intrinsic efficiency, background reduction and detection limits. Presented is a review of the new and emerging scintillator based gamma detection technologies that have the potential to improve the ability of national networks to monitor airborne radiation. Particular interest will be paid to coincidence measurements made with fast LaBr$_3$ detectors that have been used to identify particular radioisotopes based on their “fingerprint” gamma cascades. This approach is an example of where fundamental nuclear data can be used to reduce the detection limits for key radioisotopes likely to be released during a radiological incident. This work is part of the European MetroERM project, which aims to harmonise the measurement and analysis of airborne radiation following a radiological event.

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A Large Area Scintillator Trigger Detector for Cosmic Ray Muon Scattering Tomography

**Chris Steer**, L. Thompson, J. Burns, J. Boakes, S. Quillin, M. Stapleton

Special nuclear materials (SNM) weakly emit radiation which is easily shielded and challenging for passive radiation detection. As a partial solution to this issue, we have studied cosmic ray muon scattering tomography (MST) which measures the three-dimensional localised scattering at all points within an inspection volume. In contrast to conventional radiation detection, the MST signal increases with the presence of high density shielding materials and, due to cosmic ray energies in the GeV region, the MST technique is highly penetrating. MST is also passive with no radiation risk to operator or scanned contents. We have developed a 2m by 2m demonstration module based on gaseous drift chambers, and triggered by an array of large area injection molded scintillator tiles, readout by wavelength shifting fibres and a single PMT. We discuss the scintillator trigger system design, construction, characterisation, performance and operational challenges.
Thermal neutron scintillators using unenriched boron nitride and zinc sulphide

John McMillan, E. Marsden, A. Cole, A. Kirby

Thermal neutron detectors based on powdered zinc sulfide intimately mixed with a neutron capture compound have a history as long as scintillation technique itself. We show that using unenriched boron nitride powder, rather than the more commonly used enriched lithium fluoride, results in detection screens which produce less light but which are very considerably cheaper. Methods of fabricating large areas of this material are presented. The screens are intended for the production of large area low cost neutron detectors as a replacement for helium-3 proportional tubes.
Poster Abstracts

The fabrication of wavelength shifting lightguides from clear acrylic sheet by disperse dyeing

John McMillan, A. Cole, A. Kirby

Wavelength shifting lightguides have found extensive use as a means of collecting scintillation or cherenkov light from large areas onto a smaller area photodetector and for matching the emitted spectrum to the spectral response of the photodetector. Conventionally, such lightguides are fabricated by casting acrylic glass with the fluorescent dye incorporated in the bulk. A technique has been developed in which plain cast acrylic sheet is disperse dyed in an aqueous bath. The resulting lightguide has the fluorescent dye held in a thin layer at the surface of the material. A number of different fluorescent dyes are demonstrated and preliminary spectroscopic measurements on samples are presented.

Characterisation of neutron/gamma discrimination in EJ299 plastic scintillator

Christopher Payne, P. Sellin, M. Ellis, K. Duroe

We report the development of a detector system capable of n/gamma discrimination in a high flux neutron/gamma environment, based on the latest neutron/gamma discriminating plastic scintillator EJ299 which is now commercially available from Eljen. We investigate the effects of scintillator geometry on the observed quality of pulse shape discrimination (PSD) in EJ299, through the use of a digital data acquisition system and a digital charge integration PSD algorithm. Detector characterization measurements were carried out using an AmBe radioisotope source to produce a mixed fast neutron and gamma field. Figure of merit data (FOM) shows that as the geometry moves away from a cube geometry towards flatter slab-like shapes, the PSD performance deteriorates. Using an open test bed setup we have measured the PSD performance of a wide variety of EJ-299 scintillator sizes and investigated the performance of different PMT-scintillator coupling methods, including the use of Perspex light guides. We will present FOM data as a function of photon and fast neutron energy, in the range 100 keVee to several MeVee, and describe the various factors that tend to improve or degrade the PSD performance. Full waveform digitization of the outputs pulses from the PMT was carried out using a number of high speed CAEN waveform digitizers. These pulse files were analysed to investigate how the different sampling rates and resolution of the different digitisers affects the PSD performance. Different neutron/gamma discrimination algorithms are discussed which can be used to obtain optimal neutron/gamma event discrimination. ©British Crown Owned Copyright 2014/AWE
A group of small GRB detecting CubeSats could detect, localize, and study short GRBs. Current technology is at a mature level such that this system could perform as well or better than the current generation. The study of gamma-ray bursts (GRBs) has seen major advances in the past decade based on the results of several highly successful missions like Swift and Fermi. These prolific GRB detectors have enabled multi-wavelength follow-up of hundreds of GRBs and have allowed us to answer some of the outstanding questions in this field as well as prompted research in many new directions. It is critical to continue GRB detection, especially with gravitational wave detectors coming online in the next few years, e.g. advanced LIGO/Virgo, and the continued operation of multi-messenger observatories such as IceCube. Without the detection and study of counterparts to these future non-photon detections, the full characterization of a GRB would be difficult. The current GRB detection technology is at a mature level such that small, inexpensive detectors on CubeSats could perform as well or better than the current generation of GRB scintillator detectors. This paper will detail the design parameters and performance of small, GRB detecting CubeSats operating in a swarm that can detect, localize, and characterize GRBs via the high energy photon signatures.

The STFC Rutherford Appleton Laboratory in partnership with the University of Surrey has developed a laser ablation technique for the fabrication of segmented scintillator arrays. This technique was successfully applied to create a cadmium tungstate scintillator array 4.35 mm thick consisting of 25x24 pixels each 0.33 mm x 0.42 mm. The Geant4 based GATE Monte-Carlo simulation package was used to understand key aspects of the array geometry. The primary aims of the simulations were to understand how the segment pitch and thickness influenced the light collection efficiency of segmented scintillator arrays. The study also addressed the optical coupling method, the differences in light collection against interaction depth, the surface roughness and the reflector material. The code analyses absorption as well as specular, diffuse and total internal reflection. It was found that the mean free path of scintillation photons was a function of the pitch of the segments which in turn significantly increased the number of internal reflections in smaller pitch segments. The total number of internal reflections was found to be a function of the pitch, thickness and optical coupling method. The mean total distance travelled by a scintillation photon was found to be primarily determined by the optical coupling method and the thickness of the segment. These findings highlight the importance in the surface finish required for these arrays and that large light loss is expected at smaller pitches even with highly reflective materials due to the large number of internal reflections experienced by the scintillation photons.