FATA2019:

FAst **T**iming **A**pplications for nuclear physics and medical imaging

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BOOK OF ABSTRACTS

Salleh Ahmad

Weeroc SAS, Villebon-sur-Yvette, France

Recent developments in fast timing ASICs for particle physics and medical imaging

This talk will cover recent developments and trends in ASICs designed by research institutes and companies for medical imaging and particle physics applications. Two categories of ASIC will be reviewed: picosecond resolution waveform digitizers and readout ASICs for various types of detectors (PMT, SiPM, Si diodes, LGAD,..). While ASICs for medical imaging (e.g. TOF-PET) have been designed for obtaining the lowest CTR (sub 100 ps RMS), the trends in particles physics are driven by readout of fast silicon detectors in HL-LHC upgrade program.

Nicola Belcari

University of Pisa and INFN-Pisa, Italy

UTOFPET: design of a highly scalable TOF-PET detector concept

We present the design and preliminary simulated performance of a highly scalable TOF-PET detector concept. The UTOFPET project aims at the development of a TOF-PET detector module, with beyond-state-of-the-art performance. Exploiting the scalability benefits provided by SoC-FPGAs all the detectors operate independently, without any global constraint, making UTOFPET well suited for various applications, from brain-dedicated to total-body PET. The UTOFPET detector is based on a continuous scintillator crystal read out by 256 SiPMs, arranged in a 16 × 16 matrix, whose outputs are processed by a stack of local processing and data acquisition boards based on ASICs and FPGAs. Initial simulations indicate the feasibility of on-board real time position and time estimation with a spatial resolution below 0.5 mm FWHM for the whole detector.

Giacomo Borghi

Fondazione Bruno Kessler-FBK, Trento, Italy

Photodetectors for fast timing

Giacomo Borghi, Alberto Gola (Fondazione Bruno Kessler, Trento).

Optimization of timing performance in reading out scintillator light has been one of the most important factors driving the development of Silicon Photomultipliers (SiPMs) over the last ten years, with the final purpose of enabling next-generation Time-of-Flight PET machines. Indeed, thanks to advancements in both SiPMs and scintillator materials, sub-100ps coincidence resolving time has already been demonstrated, employing SiPMs from different manufacturers coupled to small co-doped LSO and LYSO crystals (e.g, LSO:Ce:0.2%Ca and LSO:Ce:0.4%Ca). Moreover, alternative solutions are under investigation in order to obtain TOF-PET grade timing resolution. These solutions either rely on different scintillation materials, such as GGAG, LuAG, etc., or rely on exploiting Cherenkov photons emitted after photoelectric interactions in dense scintillators such as BGO. Finally, excellent overall performance of SiPMs has triggered a growing interest in their use in many next-generation big physics experiments, including those requiring advanced, sub-100 ps timing resolution. Such applications pose additional challenges and require different trade-offs in the SiPM design, such as increased radiation hardness. In the presentation, we will discuss the most important figures of merit of current-generation SiPMs developed at Fondazione Bruno Kessler (FBK), their effect on timing resolution in scintillation light readout, and the ongoing optimization of such parameters to improve timing performance, also taking into account the role of the front-end.

Ole Brandt

Desy, Hamburg, Germany

Commissioning and first image reconstruction with a new time-of-flight PET prototype

Ole Brandt[1,2] and Yonathan Munwes[2]

On behalf of the EndoToFPET-US collaboration

[1] Desy

[2] Institue for Experimental Physics University of Hamburg

[3] Kirchhoff-Institut fur Physik Universitat Heidelberg

Within the framework of the EndoTOFPET-US project an endoscopic multimodal imaging device combining Ultrasound endoscopy and Time-of-Flight Positron Emission Tomography is developed. The design foresees a miniaturized PET head installed on a commercial ultrasound endoscope and an external detector plate, which will be positioned in close proximity to the patient’s body. The prototype system described here consists of the final PET plate and an endoscopic demonstrator, which has a coincidence time resolution of 254 ps FWHM and reaches a spatial resolution of about 1.5 mm in the direction transverse to the line of sight connecting the detectors. The applications of this device are within diagnostic and surgical oncology as well as the development of new biomarkers targeted for prostate cancer. In this talk the online coincidence time optimiziation as well as first measurements and simulations of the prototype are presented.

Dominique Breton

CNRS LAL Orsay, France

Fast electronics for TOF in Nuclear Physics

Time stamping with picosecond (ps) accuracy is an emerging technique opening new fields for particle physics and medical instrumentation. It indeed permits the localization of vertices with a few mm precision, thus helping associating particles coming from a common primary interaction even in a high background. It can also be used for particle identification based on Time of Flight techniques. The progress in ultra-fast digitizing electronics (including high-end oscilloscopes) demonstrated that picosecond timing accuracy can be reached simply by directly sampling the detector signal at high rate and extracting time information by interpolation of the samples located in and around the leading edge of the signal. When one has to deal with high integration levels, large number of channels, or high counting rates, a compact solution is mandatory and the concept of WaveForm Time to Digital Converter (WTDC) permits facing all these constraints in a very compact and powerful way. The talk will summarize the requirements for high precision time measurements, explain the concept of WTDC, then focus on the SAMPIC ASIC, boards and modules based on it and present the results obtained when coupling them with fast detectors.

Pablo Cirrone

INFN-LNS, Catania, Italy

Generation, control and application of "flash" radiation beams from laser-matter interaction: the ELIMED beam line

The interaction of high-power (tens of PW) lasers with matter can bring to the production of energetic (up to hundreds of MeV) and intense (up to10E11/10E12) charged particle beams and it surely represent one of most promising approach for future new accelerator schemes. Laser-generated beams are characterised by extreme energetic and temporal features: they present, in fact, very broad spectra and extremely short pulse duration (tens of nsec): their manipulation and application represent hence, nowadays, an important and complicated scientific challenge. The main direction proposed by the community in the field of laser-driven ion acceleration is the improvement of the particle beam features in order to demonstrate reliable approaches to be used for multidisciplinary applications. The mission of the laser-driven ion target area at ELI-Beamlines (Extreme Light Infrastructure) in Czech Republic, called ELI-Multidisciplinary Applications of laser-Ion Acceleration (ELIMAIA), is to provide stable, fully characterized and tunable beams of particles accelerated by Petawatt-class lasers and to offer them to the user community for multidisciplinary applications. The focusing, selecting, measuring and irradiating parts of ELIMAIA, constitutes the so-called ELIMED (ELI-MEDical and multidisciplinary applications) portion. At ELIMED, very high-dose-rate (not less than 10^5Gy/min) controlled proton and ion beams, with energy ranging from 5 to 250 MeV, will be transported up to the in-air section where absolute dosimetry will be carried out with a maximum expected error within 5%. First radiobiological campaign for in-vitro cells irradiation is scheduled for 2020. In this work, the beamline status will be reported along with a complete description of the dosimetric systems and the first calibrations. The expected final beam characteristics, in terms of dose per-pulse, dose-rate, beam spot size, directly derived by Monte Carlo simulations, will be reported, as well.

Maurizio Conti

Siemens Healthcare Molecular Imaging, Knoxville, TN, United States

Siemens Biograph Vision and the future of TOF-PET

We will review the latest TOF PET scanner and the enabling technologies that allowed to reach 200 ps TOF resolution. We will discuss advantages and prospects of TOF PET, and challenges for the future. (Via Skype)

Franco Garibaldi

INFN-Roma, Italy

A TOF PET MRI US probe project for prostate cancer diagnosis and follow up

The TOPEMU project aims at developing a high resolution and high sensitivity multi-modality imaging system for diagnosis of the prostate cancer (PCa). The imager will have a form of an endorectal probe combining high resolution (0.03 mm) ultrasound (US) with a very high resolution positron emission tomography (PET) probe (1 mm spatial,1 mm Depth of Interaction (DOI)) with Time Of Flight (TOF) capability (100 ps FWHM TOF resolution (never achieved in this kind of detector) and an magnetic resonance imaging (MRI) coil with high Signal to Noise Ratio

(SNR). A set of MRcompatible PET panels will complete the system. The aim of this system is to precisely localize PCa lesions within the prostate enabling targeted biopsy to accurately stage local PCa lesions. With an estimated incidence of 1,111,700 cases per year and an estimated mortality of 307,000 men per year, PCa is one of the most prevalent cancers worldwide. Early and accurate diagnosis of PCa is crucial for effective and successful treatment. Multiparametric (mp) MR represents the imaging modality of choice for prostate evaluation, but diagnosis of PCa lesions will be improved significantly by the introduction of PCa-specific PET tracers targeting the prostate-specific membrane antigen (PSMA) as well as the simultaneous PET/MR imaging. The TOPEMU project integrates the break-throughs in different imaging technologies well beyond the current status of art. The device will be capable of simultaneous trimodal imaging acquisition (US, MR, PET), so of simultaneous morphological visualization combined with biological and metabolic activity with crucial improvement with respect to standard devices in spatial resolution, efficiency, signal to noise ratio (SNR), scanning time or lowering injected dose. Due to very high TOF resolution, PET images will be free from artefacts. The system will be used as a MRI-insert. An "upgrade" of any MRI device will be possible, with the best compromise performance/complexity/cost

Antonio J. Gonzalez

Institute for Instrumentation in Molecular Imaging, Valencia, Spain

MEDAMI 2019

The last MEDAMI 2019 workshop, hold last May in the city of Valencia (Spain), addressed some key questions such as Molecular Imaging Techniques for High Sensitivity Immunotherapy Guidance, Follow up, Evaluation of Mechanisms of Action, Effectiveness and Toxicity. Immunotherapy has been one of the highlights of the recent congress of the American Society of Clinical Oncology in Chicago in June 2018. The responses being seen in some patients suggest that immunotherapy can drive advanced cancer "into remission, which can be durable". This is the first time and "an extraordinary moment in human history" when the word "cure" can be seriously used in relation to cancer. During the meeting a number of Key Opinion Leaders from Biology, Medicine and Technology fields were presented. They were top class speakers especially from Imaging in Immunotherapy field, healthcare administration/funding and pharma industry associations. Among others, Israt S. Alam (Research Scientist, Sam Gambhir lab, Department of Radiology, Stanford University), Angela Krackhardt (Klinik und Poliklinik für Innerer Medizin III, Klinikum rechts der Isar TU München) or John Prior (Lausanne University Hospital, Switzerland) gave lectures on Imaging in Immunotherapy from different perspectives. This contribution will provide a summary of the most relevant findings during the MEDAMI 2019, along with current ideas from the i3M (Institute from Instrumentation in Molecular Imaging), local organizers of the last MEDAMI on the improvement of both, or either, spatial resolution and sensitivity in molecular imaging systems.

Matthias Holl

Institut für Kernphysik, Technische Universität Darmstadt, Germany

Fast timing for nuclear reaction studies at R3B

The R3B setup currently under development at GSI/FAIR is designed for experimental reaction studies with exotic nuclei far off stability, enabling a broad physics programme with emphasis on nuclear structure and dynamics. The aim is to construct a versatile reaction setup with high efficiency, acceptance, and resolution for kinematically complete measurements of reactions with fast radioactive beams. The setup is modular, and several components require timing in the ps range to achieve the precision required for mass separation (σσTOF/TOF=2·10-4) and sufficient momentum resolution (σΔp/p=10p/p=10-3) even at high rates. An overview of the setup and its physics cases will be given. Several R3B detectors using fast timing, namely the start detector LOS, the time-of-flight wall TOFD and the neutron spectrometer NeuLAND will be described in detail and examples of their performance from the recent FAIR Phase-0 experiments will be shown.

Nicolo' Jacazio

INFN-Bologna, Italy

Ten years of operation of the MRPC TOF detector of ALICE: results and perspectives

The ALICE Time Of Flight (TOF) detector consists of 1638 Multigap strip RPCs, covering a total active area of 140 m2 and accounting for more than 150000 readout channels. Thanks to its 50 ps intrinsic resolution the ALICE TOF detector provides a crucial tool for the identification of charged particles produced at intermediate momenta in high energy pp, pA and AA collisions at the LHC. This feature is fundamental in high energy nuclear physics as it allows to perform basic measurements of the identified particle production, used to characterize the Quark Gluon Plasma that is created in heavy-ion collisions. The status of the ALICE TOF detector will be presented. The running performance of the Run 1 (2009-2013) and Run 2 (2015-2018) data taking campaigns are compared. The particle identification capabilities of the detector will be presented and discussed. After ten years of operations, the detector performance remains excellent, with no observable degradation in the stability of operation or in the efficiency of particle detection. Moreover, a new calibration technique, introduced during Run 2, has brought a significant improvement in the time resolution - down to 60 ps - very close to the value observed in test-beam commissioning. This achievement guarantees a separation better than 3σ, up to a particle momentum of p ~ 2.5 GeV/c for π/K and p ~ 4 GeV/c for K/p. Few examples of PID application in the physics analysis will be described. Finally, the TOF upgrade program will also be briefly discussed: this will allow the TOF detector to become a detector with a continuous readout during the next LHC Run 3 data taking period.

Paul Lecoq

CERN, France

Ultrafast Meta-scintillators for a new generation of HEP detectors and Time-of-Flight PET

The future generation of radiation detectors is more and more demanding on timing performance for a wide range of applications, such as particle identification in nuclear physics and high energy physics detectors, high resolution hadronic calorimetry in finely segmented detectors, precise event time tagging in high luminosity accelerators, time of flight (TOF) techniques for PET cameras and a number of photonic applications based on single photon detection. There is in particular a consensus for gathering Europe's multidisciplinary academic and industrial excellence around the ambitious challenge to develop a 10ps TOF PET scanner (TOFPET). The goal is to reduce the radiation dose (currently 5-25 mSv for whole-body PET/CT), scan time (currently > 10 minutes), and costs per patient (currently > 1000 € per scan), all by an order of magnitude. To achieve this very ambitious goal it is essential to significantly improve the performance of each component of the detection chain: light production, light transport, photodetection, readout electronics. Speeding up progress in this direction is the goal of the challenge and will have an important impact on the development of a new generation of ionization radiation detectors. It will be shown that the possibility to reach 10ps time-of-flight resolution at small energies, as required in finely granulated calorimeters and PET scanners, although extremely challenging, is not limited by physical barriers and that a number of disruptive technologies, such as multifunctional heterostructures, combining the high stopping power of well know scintillators with the ultrafast photon emission resulting from the 1D, 2D or 3D quantum confinement of the excitons in nanocrystals, photonic crystals, photonic fibers, as well as new concepts of 3D digital SiPM structures, open the way to new radiation detector concepts with unprecedented performance.

Stan Majewski

University of California Davis, United States

1. Imaging is Believing -:The Future of Human Total Body Molecular Imaging Starts Now

With the construction and initial validations of the expanding family of the Explorer Total Body PET scanners, the entirely new medical era started of simultaneous dynamic imaging with kinetic modeling of the molecular processes in the whole human body, from the moment of imaging molecular agent injection to achieving the state of static distribution after sufficient uptake time. The Explorers achieve very high sensitivity that can be translated into low dose screening or very high dynamic/kinetic accuracy or very short scan times (30 seconds) among their key advantages. Measurements of the whole body biodistributions that is so important in new drug developments are becoming much easier. The accompanying development of a family of imaging agents can simultaneously assess the healthy or diseased state of different organs in cancer, dementia, inflammation, infection, blood diseases, et cetera, et cetera conditions. The whole body large (~70-80 cm diameter) Explorer PET scanners benefit largely from the constantly improving TOF performance. Due to the Signal to Noise ratio dependence on TOF, every 50 ps FWHM TOF improvement leads to substantially increased detection sensitivity. Some believe that the next generation of imagers will be a tandem combination of the Explorer (from 50 to 200 cm long) with the optimized brain PET imager.

2. The Path to the Ideal Brain PET Imager: The Race Started. The Role for TOF PET.

With the continuing successful efforts to improve spatial resolution of the Explorer family of imagers, the need to develop dedicated imagers for breast, prostate, heart, etc will slowly disappear. It is in fact happening already. With the EXCEPTION of the brain systems. The special geometry of the optimal helmet type designs for imaging of the brain still gives the opportunity to brain PET imager designers to compete for the best system. Several designs are being proposed and being built at this time in the whole world. These designs mostly fall in two categories: of the mini-Explorer type or of the helmet type with large angular coverage of the brain, assuring high sensitivity. Due to the compact sizes of the helmet type systems, to substantially benefit from the improved TOF performance, one needs to achieve better than 100 ps FWHM timing performance. In fact, 50 ps FWHM would be a very nice goal. Several groups are working on such concepts. Any new ideas from the expert instrumentation community are highly appreciated.

Michael Minot

Incom Inc. Charlton, United States

Large Area Picosecond Photodetector (LAPPD) Offers Fast Timing for HEP, NP and Medical Imaging

The availability of large-area MCP photodetectors with 10's of picosecond timing resolution and mm level spatial resolution produced economically are enabling new techniques in high energy and nuclear physics where fast timing enables benefits including: more efficient background rejection, high vertex resolution in large scale experiments, separation of Cherenkov and scintillation light, directionality information, precise track reconstruction, as well as others. Commercial application of these devices will include TOF detectors for mass spectrometers, medical imaging (PET), as well as neutron detection for scientific and homeland security (non-proliferation) applications. The LAPPD is a microchannel plate (MCP) based large area picosecond photodetector, with single-photon sensitivity at high spatial and temporal resolutions, with an active area of 350 square centimeters in an all-glass or ceramic hermetic package. Photoelectron signals are generated by a bi-alkali Na2KSb photocathode and amplified with a stacked chevron pair of MCPs produced by applying resistive and emissive atomic layer deposition (ALD) coatings to glass capillary array (GCA) substrates. Signals are collected on microstrip anodes applied to the bottom plates which exit the detector via pin-free hermetic seals under the side walls. Performance results achieved for fully functional sealed LAPPDs™ include electron gains of up to 10^7, low dark noise rates (15-30 Cts/s/cm^2), single photoelectron (PE) timing resolution of <60 picoseconds RMS (with 25pS FWHM laser pulses), and single photoelectron spatial resolution along and across strips of 2.4 mm and 0.8 mm RMS respectively. Many of these devices also had high QE bi-alkali photocathodes with about 80% uniformity over the full 195 mm X 195 mm active area (#32 QE% @ 365nm Max/Avg/Min = 22.7/20.8±1.0/19.0). We conclude with examples of how MCP-PMT sensors offering picosecond timing, in diverse applications can bring transformative change to detector technology and applications in future experiments.

Riccardo Mirabelli

"Sapienza" - Università di Roma, Italy

TOPS Project: Development of New Fast Timing Plastic Scintillators

In particle physics, charged particles are measured exploiting many different detection strategies. The plastic scintillators are cheap, versatile and show good time response, thus they are traditionally employed as timing detectors. TOPS (Time Of flight Plastic Scintillators) is an R&D project devoted on the synthesis and characterization of a novel class of plastic scintillators.

Liquid and solid samples of a tens of new scintillators have been tested and characterized. Some of them (2N, 1N, 2B, P2, T2) have shown a larger light output respect to antracene and good timing proprieties. In order to improve the matching between the scintillators emission and absorption spectra, a doping material has been added as wave-shifter. The use of POPOP as doping improved the performances of a fraction of the scintillator samples.
Based on the comparison of the light output values in measurements with cosmic rays, a selection of the most promising scintillators has been investigated also from the timing point of view.
The scintillation time characteristics of the TOPS plastic samples have been studied with minimum ionizing particles using a commercial plastic scintillator BC-412 as a reference.
The light output and timing properties have been also investigated with proton beams at different energies (70, 120, 170, 220 MeV) show promising results providing a time of flight measurements accuracy of 150 − 300 ps. In this contribution, preliminary results obtained with this new class of scintillators developed in the TOPS project will be presented.

Johan Nuyts

KU Leuven, Belgium

Using time-of-flight information for PET, PET/CT and PET/MRI reconstruction

The timing resolution of PET detectors is rapidly improving thanks to new developments in detector design. As a result, the time of flight (TOF) measurement in PET systems is becoming more accurate as well. It has been shown that the TOF measurement supplies information that is not present in non-TOF PET emission data. Because TOF reduces the uncertainty associated with each measured coincidence event, it improves the signal to noise ratio of the reconstructed images. For the same reason, the convergence of iterative reconstruction algorithms is faster and more uniform as well, which also benefits the quality of the reconstructed images. When the TOF resolution is sufficiently high, one can estimate from the TOF-PET data not only the activity distribution, but also the attenuation coefficients. This enables attenuation correction in stand-alone PET scanners and the correction of the available attenuation map in hybrid PET systems. This correction may be valuable, because the CT-based attenuation maps in PET/CT and the MR-based attenuation maps in PET/MR can be degraded by motion, metal artefacts and/or conversion errors. It is observed that for the estimation of the attenuation (or detector sensitivities) from TOF-PET emission data, accurate timing calibration and scatter correction is mandatory. When the calibration and the scatter estimates are accurate, we find that attenuation correction based on the TOF-PET data themselves produces activity images that differ only up to a few percent from the activity images obtained with reference CT-based attenuation correction. With improving TOF resolution, the power of the attenuation estimation algorithms increases, but the accuracy requirements for the timing calibration become more stringent as well.

Emanuele V. Pagano

INFN- Laboratori Nazionali del Sud, Catania, Italy

Narcos project for nuclear physics and applications

The present study has been carried out in order to investigate about the possibility of using EJ 299-33 scintillator in a multi-detector array to detect neutrons along with light charged particles.

Piotr Pawłowski

Institute of Nuclear Physics PAN, Kraków, Poland

Recent result obtained at CCB

CCB (Cyclotron Center Bronowice) is a new facility providing proton beams between 70 - 130 MeV. Several scientific applications are planned basing on the facility. Recent preliminary results for proton + gamma coincidences and the time resolution obtained with CAEN digitizers will be presented.

Maria Grazia Pellegriti

INFN - Sezione di Catania, Italy

A Time-of-Flight application for nuclear reactions at Coulomb energies

The Thick-Target Resonant Elastic Scattering Method, implemented in inverse kinematics, is an important tool for investigating resonances of the compound nucleus, spanning a wide center-of-mass energy range by using a single mono-energetic Heavy-Ion beam. The thick target can be solid (pointlike) or gaseous. Anyhow, a limit of such a technique is related to the possible energy overlap of the same ejectile produced by different reaction mechanisms. These ejectiles have different paths to the detector, allowing Time-of-Flight discrimination. Thus, in order to disentangle different reaction channels and to get, for example, a clean elastic cross-section excitation function, a Time-of-Flight event by event measurement can been performed in case of gaseous targets. In this presentation, the Time-of-Flight technique applied to Inverse Kinematic Resonant Scattering by using a thick gas target (two meter long) will be described. Results of Elastic Scattering measurements on 4He gas targets induced by light and heavy ion beams at energies around the Coulomb barrier will be shown.

Rok Pestotnik

Jozef Stefan Institute (SI), Ljubljana, Slovenia

Using Cherenkov light in TOF-PET

The image quality in positron emission tomography improves significantly when time of flight information is used. However in gamma detectors used to detect the pair of anihillation gamma rays, the time resolution is limited by the time resolution of the scintillators and of the electronics. By replacing the scintillator with a Cherenkov radiator, where Cherenkov photons are emitted promptly after the gamma conversion, the time of flight resolution can be improved significantly. In the presentation, I will show the latest results obtained with a setup consisting of PbF2 crystal as a Cherenkov radiator and SiPM as a photo sensor.

Marco Pinto

LMU Munich, Germany

Positron emission tomography in radiation therapy planning, delivery and monitoring.

Marco Pinto Ludwig-Maximilians-Universität München (LMU Munich), Munich, Germany

Julia Bauer Heidelberg University Hospital, Department of Radiation Oncology, Heidelberg, Germany National Centre for Radiation Oncology (NCRO), Heidelberg Institute for Radiation Oncology (HIRO), Heidelberg, Germany

Katia Parodi Ludwig-Maximilians-Universität München (LMU Munich), Munich, Germany

Positron emission tomography (PET) is an important tool in the context of radiation therapy. The functional and morphological information it provides supports the treatment planning process in terms of improved tumor delineation and helps assess tumor response to treatment. The development of new tracers capable of providing different insights regarding tumor function paves the way for patient-specific treatment plans, where different areas of the target volumes may require additional dosage. Furthermore, in the case of ion beam therapy, the usage of PET is not only limited to the imaging of tracers that are injected into the patient. In fact, positron emitters are also created after nuclear interactions between the impinging ions and tissues, which allows for the monitoring of the irradiation when PET is employed during or shortly after treatment. Such a monitoring is of special interest in ion beam therapy since the physical phenomena that give ions their advantageous ballistic properties with respect to photons also render it more susceptible to uncertainties, particularly to range uncertainties. Different cases in which PET is utilized in the radiation therapy workflow will be presented and discussed, as well as the different approaches for PET monitoring in ion beam therapy. The quantification of deviations based on PET monitoring outcomes is not trivial and methods to estimate such outcomes will also be shown.

Direct time-of-flight for quantitative, real-time in-beam PET

Marco Pinto Ludwig-Maximilians-Universität München (LMU Munich), Munich, Germany

Katia Parodi Ludwig-Maximilians-Universität München (LMU Munich), Munich, Germany

Paulo Crespo University of Coimbra, Coimbra, Portugal Laboratory of Instrumentation and Experimental Particle Physics (LIP), Coimbra, Portugal

External radiation therapy is one of the most important clinical tools to treat tumors. The use of ions in this context is becoming increasingly widespread and noteworthy because of the favorable ballistic properties and the lower total dose to healthy tissues when compared with photons. However, the physical phenomena that give ions their advantageous ballistic properties also render proton therapy more susceptible to uncertainties, particularly to range uncertainties. Positron emission tomography (PET) is one of several treatment monitoring techniques used to assess the actual ion range in vivo and it can be used in-beam, in-room or offline. However, for the case of the in-beam modality, a full ring PET scanner can be quite complex to install, and dual-head scanners are known to lead to image artifacts. Including time-of-flight (TOF) capabilities into the scanner decreases the background by scattered and random coincidences, hence enhancing the signal-to-noise ratio. Such an enhancement can significantly reduce the artifacts when using simpler scanner geometries. In addition, the use of a TOF-PET scanner can allow for the direct measurement of the position of the annihilation along the line-of-response connecting the two detectors involved in an event, thus bypassing the need for conventional algebraic and iterative reconstruction algorithms.

Sara Pirrone

INFN-Sezione di Catania, Italy

TOF in Heavy Ion Reaction: CHIMERA detector & ISODEC experiment

Chimera detector [1] is a powerfull array to study heavy ions collisions in a large dynamical range of energy. A summary of the characteristics and the identification methods of Chimera will be done. In particular thanks to the TOF technique and the PSD in silicon detector, it is a suitable array to study low energy nuclear reactions. Here we will present the results of the ISODEC experiment, a recent study on the neutron poor system 78Kr + 40Ca and the neutron rich 86Kr + 48Ca, at 10 A MeV. For these systems, we analyzed the fusion-evaporation and fission-like processes, [2,3,4] and their dependence from the isospin, that is expected to play a crucial role in the onset of these processes.

[1]A. Pagano et al, Nucl. Phys A 734, 504 (2004)

[2] Pirrone S. et al., Eur. Phys. J. A (2019) 55, 22

[3] Gnoffo B., Il Nuovo Cimento C, 39 (2016) 275

[4] Politi G. et al., JPS Conf. Proc., 6 (2015) 030082

John Prior

Lausanne University Hospital, Lausanne, Switzerland

Fast Timing in Medical Imaging: The medical side

Dimos Sampsonidis

Aristotle University of Thessaloniki, Greece

Precise timing with the PICOSEC-Micromegas Detector

This work presents the PICOSEC-Micromegas detector concept to achieve a time resolution bellow 30 ps. The PICOSEC consists of a “two-stage” Micromegas detector coupled to a Cherenkov radiator and equipped with a photocathode. The results from single-channel prototypes as well as the understanding of the detector in terms of detailed simulations and preliminary results from a multi-channel prototype are presented.

Paul Schotanus

SCIONIX Holland b.v., Bunnik, Netherlands

Fast Timing with scintillation detectors

An overview of industrial requirements for fast timing with scintillators is presented. The concepts of high rates and fast timing is discussed. Some new fast scintillators offer an improvement over standard materials and their properties are presented. Novel SiPm readout technologies are currently available but are these really an improvement for timing or pulse shape discrimination in industrial applications ? At attempt is made to answer this question.

Stefaan Tavernier

PETsys electronics, Brussels, Belgium

Electronics for fast timing in Medical imaging

The talk will focus on prospect for improving timing performance in readout electronics for photodetectors. We will illustrate some of this with the new TOFHIR ASIC developments for the CERN High Lumonosity-LHC upgrade. In this project we will read LYSO:Ce scintillation crystals coupled to SiPMs.

Giacomo Traini

INFN-Roma, Italy

Performance of the Time of Flight detectors in the FOOT experiment

The FOOT experiment (FragmentatiOn Of Target) of INFN (Istituto Nazionale di Fisica Nucleare, Italy) aims to determine the fragmentation cross sections of nuclei within the human body (C, O) during particle therapy treatment to improve the treatment planning quality. The apparatus is composed of several detectors that allow fragment identification in terms of charge, mass, energy and direction. The ΔE-TOF detector provides the dE/dx information and the time of flight (ToF) with respect to a start counter (ST) in order to reconstruct the fragment atomic number. A ToF resolution of 100 ps is required to achieve a sufficient resolution in the fragment atomic mass identification. The ST is composed of a thin plastic scintillator layer (4x4 cm2 area), read-out by 8 groups of 6 Silicon Photomultiplier connected in series. A scintillator thickness of 250μm has been used in order to reach the required timing performance, while keeping the beam fragmentation probability inside the detector below 1%. The ΔE-ToF detector is composed of two layers of plastic scintillator bars arranged orthogonally and wrapped with ESR specular reflector. Each bar is 3 mm thick, 2 cm wide and 44 cm long. Each layer is composed of 20 bars, corresponding to 40 x 40 cm2 active area. Each side of the bar is coupled to 4 silicon photomultipliers (MPPC by Hamamatsu) with 3 mm x 3 mm active area and 25 μm microcell pitch and each group is biased and read-out by a single channel. The 80 signals of the ΔE-ToF and the 8 channels of the ST are digitized at 4 Gsamples/s by the WaveDAQ electronics system. The performance of the ST and the ΔE-TOF in terms of energy and time resolution have been evaluated using Carbon ion beam ranging from 115 MeV/u up to 400 MeV/u at CNAO (Centro Nazionale di Adroterapia Oncologica, Pavia, Italy), and with Oxygen beams at 400 MeV/u at the GSI center. The obtained results are reviewed in this contribution.

Simone Valdrè

INFN-Firenze, Italy

Charged particle identification using time of flight with FAZIA

FAZIA is an array of three-stage Si-Si-CsI(Tl) telescopes. It was designed to operate with beams in the 20-100 MeV/u energy range and it provides charge and mass discrimination over a wide range of nuclei and energies. In order to lower the identification thresholds, the time of flight (ToF) information could be used. Our collaboration recently renewed important efforts in this direction [G. Pastore et al., submitted to Nucl. Instrum. Meth. A (2018); S. Valdre' et al., Nuovo Cimento C 41, 167 (2019)]. Traditionally, ToF measurements can be performed using two detectors placed at a certain well measured distance to obtain start and stop time marks.

Alternatively the accelerator RF signal may be used to obtain the start time mark. Since we want to exploit ToF measurement even in the absence of pulsed beam, we are studying and implementing a new approach that works for those events where at least one ejectile is properly identified in energy, charge and mass. This kind of fragments can be used to estimate the time at which the reaction occurred on an event by event basis, since their energy and mass are known. The proposed ToF extraction algorithm needs a perfect synchronization among all the ADC clock signals and a precise tuning of all the possible sampling delays. For this purpose, the collaboration developed a synchronization technique featuring fast infrared LED pulses. This contribution reports on the results obtained with this technique and it will also show an alternative synchronization algorithm which can be applied without the use of the LED device, thus allowing the precise ToF extraction in the analysis of old experiments. A comparison between the precision obtained with LED and the alternative algorithm for recent experiments will be also shown.

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New approaches to detector readout in particle physics and medical applications with efficient timing

Recent developments in particle physics and medical applications are driving the demands for new electronics equipment which is capable to perform accurate timing measurements, maintaining a reasonable cost per channel. The traditional analog chain for timing measurements has been overtaken by the current generation of Digitizers, which allows to reach a good timing resolution even without using high sampling rate. CAEN can supply Digitizers which has been experimentally proved to be suitable for self-timing and ToF measurements with fast detectors. In particular, CAEN X730 family (500 MS/s, 14-bit ADC) has shown good timing performances (res.~100 ps) even in case of pulses with a typical rising edge of 1.5 ns, where the use of extreme fast technologies may appear inevitable. Moreover CAEN recently developed some Readout Systems based on ASICs, which are competitive to Digitizers when a huge sampling rate and/or high channel density is really needed. CAEN can supply the DT5550W full-featured Readout System for SiPM, based on CITIROC or PETIROC Weeroc ASICs, and is going to put on the market the brand new FERS-5200, a distributed and scalable Front-End Readout System for large detector arrays. This latter is a platform specifically designed for experiments reading out large arrays of detector, such as SiPMs, multi-anode PMTs, Silicon Strip Detectors, Wire Chambers, Gas Tubes, etc… The system is based on a small-size Front End card (FERS unit- A52xx) that houses one or more ASICs (up to 64 channels), which can be used as stand-alone module or scaled up to 10-100k channels thanks to the collector board FERScb. The FERScb (DT5215) is a data collector board housing eight TDlink masters for the readout of FERS units (up to 128 units, that is 8192 detectors). In this way it is possible to easily build a cost-effective readout system with high channel density. There will be a complete line of FERS units (A52xx) using different ASICs or discrete Front End. We have just developed the A5202 hosting two Weeroc CITIROC chips for SiPM imaging and spectroscopy applications and we plan to implement in the same architecture other Front End ASICs.