2015 Active Targets and TPC for Nuclear Physics Experiments Workshop

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National Superconducting Cyclotron Laboratory

Book of Abstracts

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Workshop Introduction and Goals

Session 1 / 42

From nuclear forces to structure and astrophysics

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In this talk I will introduce the big picture of modern low-energy nuclear theory. Specifically, I will first go over the efforts toward connecting nucleon-nucleon and three-nucleon interactions with the fundamental theory of Quantum Chromodynamics, in the context of what is known as chiral Effective Field Theory (EFT). I will then discuss first-principles studies of the many-nucleon problem that use chiral EFT to assess some of the systematic uncertainties involved in theoretical predictions. This overview will include both finite nuclei and infinite matter, that is, systems that are of both terrestrial and astrophysical relevance.

Session 1 / 38

Active Target Detector types

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In this talk I will review different types of Active Target detectors and their application to various experimental situations. Although Active Target detectors have clear advantages from the points of view of luminosity and angular coverage, their optimization to particular experimental goals often require different configurations. Several of the parameters that can be considered will be covered in relation with their implications towards the fulfillment of the experimental goals. The concept of Active Target is relatively new in Nuclear Physics, but already a large number of ideas on how to use it are starting to emerge in laboratories around the world.

Session 2 / 35

Gas properties and optimization for active targets

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Active targets have been used for a wide variety of nuclear physics experiments since the eighties. These systems are somehow strange animals in the world of gas detectors. While the gas or mixture of gas usually chosen is adapted to the nuclei or particle you want to detect (gain, counting rate. . .), the gas and pressure in gaseous active targets is determined in terms of target nuclei quantity.
After a general introduction on gaseous detection processes and TPCs, the presentation will focus on active target peculiarities like the characteristics of the gases usually used and the

pressure regime. The problematic linked to high counting rates and/or high energy deposits will be discussed. Moreover, the detector quality is of primary importance and some calibrations methods will be presented. The problem of energy resolution, that is influencing the performances of the chamber, will be also treated.

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Resonance Studies with Active-Target Detectors: Examples from Prototype AT-TPC

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Resonance studies are of great importance in the study of nuclear structure and the production of elements in astrophysical scenarios. Active-target detectors are well suited to study resonances with radioactive beams due to their tracking ability and the large of amount of target material they provide. An overview of using active-target detectors to perform resonance studies will be presented with examples from experiments performed with the Prototype Active-Target Time-Projection Chamber.

Session 2 / 20

GEANT4 Simulations for Astrobox2 and the MDM-Oxford Spectrometer Detector Upgrade

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During the commissioning of the prototype AstroBox1 detector at TAMU [1], it was noticed that a gas detector with Micro Pattern Gas Amplifiers (MPGAD) [2] had two applications. First, such a detector was useful for detecting low-energy protons ($<$ 1 MeV) from beta-delayed proton decay because the energy deposit of the beta-particles in the gas was small and the signal from the proton energy loss in the gas could be amplified many times by the MPGAD. Second, it was noticed that the detector also could be used as a high-resolution gas detector for heavy-ions. These two applications were successfully modeled by GEANT4 simulations [1, 3]. With these applications in mind, the Astrobox2 detector has been designed to attempt to improve upon the results obtained with Astrobox1, and an MPGAD has been installed into the MDM-Oxford Spectrometer detector [4]. These two devices have been simulated in the GEANT4 framework as part of the design process. The simulations have been useful in the understanding of the data obtained with these devices. I plan to present a brief overview of the Astrobox2 and Oxford detector upgrade and to explain how the devices are currently being modeled in the GEANT4 framework using a few example cases. The simulations will be compared to existing experimental data, if available.

[1] E. Pollacco et al., Nucl. Instr. and Meth. A 723 (2013) 102-108. [2] Y. Giomataris et al., Nucl. Instr. and Meth. A 376 (1996) 29. [3] S. Agostinelli et al., Nucl. Instr. and Meth. A 506 (2003) 250. [4] J.S. Winfield et al., Nucl. Instr. and Meth. A 251 (1986) 297.

Session 3 / 43

Development of low pressure TPC within the FIPPS project.

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The FIPPS (Fission Product Prompt gamma-ray Spectrometer) project was presented during the Vision 2020 conference in Grenoble in 2010 and is now part of the ILL ENDURANCE program. It addresses two fundamental domains of nuclear physics: fission of heavy elements and structure of neutron rich matter. Neutron capture induced reactions provide a valuable way to investigate these domains. The present ILL instruments Lohengrin and GAMS have over the years made a valuable contribution to this field. Since these very specific instruments have limitations in solid angle, access to time scales and sample environment, a complementary instrument would overcome these limitations and complement the existing Nuclear Physics instrument suite at the ILL.
FIPPS consists of a high efficiency gamma detector array surrounding a fission target with a thick backing, coupled to a fission fragment spectrometer based on a gas filled magnetic (GFM) device. The new instrument will be positioned at an external neutron beam at the ILL. The combined spectrometer will give access to new nuclear spectroscopy information of neutron-rich nuclides by tagging the complementary fragment and new insight into the fission process via combined measurements of mass A, nuclear charge Z, kinetic energy Ek and excited states .
The final design of the magnet is ongoing. It includes the possibility to accommodate different additional instrumentation for particle tracking (positioning, TPC, dE/dx, TOF) inside the magnet itself. In particular, the TPC option would allow the individual 3D tracking of the fragments maximizing the angular acceptance of the spectrometer without compromising the mass resolution. However, the working principal of a gas-filled magnet requires for TPC to be used with light gases at low pressure (10-50 mbar). Such a possibility is under study and preliminary results of experiments with a Micromegas TPC prototype performed at the Lohengrin mass spectrometer will be discussed. A conceptual design of the new FIPPS instrument will also be presented.

Session 3 / 7

Hardware Performance of the NIFFTE fissionTPC for High Precision Measurements

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Nuclear physics and engineering communities call for new, high precision measurements to improve existing models for understanding fission and designing next generation reactors. The Neutron Induced Fission Fragment Tracking experiment (NIFFTE) has developed the fission Time Projection Chamber (fissionTPC) to measure neutron induced fission cross-sections with unrivaled

precision. The fissionTPC is annually deployed at the Weapons Neutron Research facility at Los Alamos Neutron Science Center where it operates with a neutron beam passing through the drift volume, irradiating heavy actinide targets to induce fission. At the Lawrence Livermore National Laboratory, the fissionTPC measures spontaneous fission sources to characterize the detector, develop performance, and improve upon earlier measurements. The fissionTPC uses a MICROMEGAS amplification stage and has a two-chamber, compact cylindrical drift volume (15 cm diameter, 12 cm length) resulting in 4π acceptance of fission fragments. Nearly 6000 channels are readout at 50MHz using custom electronics, built from off-the-shelf components resulting in a cost of $55 per channel. The fissionTPC is designed to handle ˜MBq activity with a dynamic range that allows identification of particles from proton recoils to fission fragments, with energies from 10 keV to hundreds of MeV. This talk will further explore the fissionTPC system performance and developments to include: gain regimes, data acquisition, track reconstruction, particle identification and more.

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Precision Nuclear Data Measurements with the NIFFTE fissionTPC

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Nuclear data play a vital role in nuclear energy and defense applications. The community heavily relies on simulations and modelling, and therefore on available data and their uncertainties. The Neutron Induced Fission Fragment Tracking Experiment (NIFFTE) collaboration employs a fission Time Projection Chamber (fissionTPC) to measure fundamental nuclear data with unprecedented precision. The novel instrument enables precise tracking of charged particles and their energy deposition providing a direct measurement of systematic uncertainties in fundamental data such as fission cross sections, fragment angular distributions or branching ratios. The NIFFTE collaboration aims to understand and minimize uncertainties in those measurements, currently focusing on particle identification and target and beam uniformities. Preliminary experimental results illustrate the physics capabilities of the fissionTPC. The talk will include neutron-induced fission data taken recently with a 239Pu/235U target at Los Alamos Neutron Science Center (providing neutrons from 200 keV to hundreds of MeV), and spontaneous fission data taken with 244Cm and 252Cf at Lawrence Livermore National Laboratory.

Session 3 / 26

Development of WeMATar (Western Michigan Active Target) - An active target time projection chamber for fast rare isotope beam experiments

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Many experiments with fast energetic beams require an open geometry allowing, in some cases, the identification of heavy residues downstream in a magnetic spectrometer or detection of particles in ancillary detectors. An optimized and portable Active Target detector is essential to accommodate a broad experimental program and the coupling to a wide range of equipment the science requires. We present a cost effective solution to these challenges by developing the WeMATar –Western

Michigan Active Target time projection chamber to be used to study reactions induced by fast rare isotope beams at the National Superconducting Cyclotron Laboratory (NSCL) and at the future Facility for Rare Isotope Beams (FRIB). The technical details of the project as well as its physics motivation will be discussed.

Session 3 / 44

Active Targets for Nuclear Structure Studies with Radioactive Beams at GSI and at FAIR

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The investigation of light-ion induced reactions using radioactive beams in inverse kinematics gives access to a wide field of nuclear structure studies in the region far off stability. The experimental concept of active targets was already proven to be a usefull tool for such investigations, in particular in the region of low momentum transfer. The world wide first experiments with radioactive beams interacting with an active target were performed at GSI Darmstadt with the IKAR setup, where the halo structure of light neutron-rich nuclei was investigated within the last 3 decades. A brief overview on recent results will be given. The experimental conditions at the future international facility FAIR will provide outstanding opportunities for nuclear structure and nuclear astrophysics studies on nuclei far off stability, and will allow to explore new regions in the chart of nuclides. Therefore two versions of active targets, dedicated for investigations at the R3B and SUPER-FRS facilities at FAIR, are presently under design and partly under construction, one allowing for coincidence measurements of recoil particles and gammas, the other with a larger range acceptance for the investigation of recoil particles allone. The experimental program for direct reactions at low momentum transfer, which includes elastic proton scattering for the investigation of nuclear matter distributions and neutron skins, inelastic alpha scattering for the investigation of giant resonances, and charge exchange reactions for the investigation of Gammow-Teller strength, will be discussed, and the complementarity to studies with stored radioactive beams, interacting with internal targets of storage rings, will be displayed. Finally the status of the design, construction and the results of feasibility studies with prototype setups will be discussed.

Session 4 / 27

Active Target and Time Projection Chamber (ACTAR TPC)

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The Active Target and Time Projection Chamber (ACTAR TPC) is the foremost European project in the development of a high-luminosity and versatile gas-filled detection system for experiments in nuclear physics. The core of the detector will consist of micro pattern gaseous detectors coupled to a highly pixelated pad plane (25 channels per cm2) with a total of more than 16k electronic channels. Physics cases include rare and exotic modes of nuclear decay, resonant elastic and inelastic scattering, and single and multi-nucleon transfer reactions that will be performed at rare isotope beam facilities worldwide including GANIL and ISOLDE. Technical challenges associated with mechanics and readout of such a high-density front end have required several parallel developments including the design and construction of a comprehensive ASIC-based electronics system within the General Electronics for TPCs (GET) collaboration. An overview of the ACTAR TPC project and first results obtained from an in-beam test with a 2048-channel prototype version of the final design will be presented.

Session 4 / 2

Measurement of the isoscalar monopole response in the neutron-rich 68Ni using Active Target MAYA

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The study of the Isoscalar Giant Monopole Resonance (ISGMR) in stable nuclei provided relevant information on both nuclear matter and nuclear structure in past decades. For instance the ISGMR centroid can be linked to the incompressibility modulus of the infinite nuclear matter. Values for exotic nuclei would help in constraining it. In unstable nuclei, only one measurement has been performed so far (56Ni) [1]. Moreover the existence of a soft mode is predicted by different theoritical models in neutron-rich isotopes but has never been observed. In order to study the evolution of the monopole response along an isotopic chain, measurements in neutron-rich Ni are called for.
To reach this goal, a dedicated experiment was performed at GANIL. A 68Ni beam at 50MeV/A and with an intensity of 4.104pps has been produced on LISE beamline. The inelastic scattering of deuteron and alpha particles on 68Ni in inverse kinematics has been studied. Due to the low energies of the recoiling particles, the use of an active target is suitable, so the experiment has been performed with the active target MAYA. It is the first attempt to measure the ISGMR in an unstable neutron-rich nucleus. Excitation energy spectra and angular distributions concerning the inelastic scattering reaction in deuterons gas and in alpha gas have been extracted and will be shown. The measurement of the ISGMR and a soft mode will be discussed, as well as the observation of the Isoscalar Giant Quadrupole Resonance (ISGQR). These results [2-3] are promising for the physics of Giant Resonances in exotic nuclei, but the resolution is limited, in this way the development of future active targets will be very helpful and will be discussed.
[1] C. Monrozeau et al., Phys. Rev. Lett. 100, 042501 (2008). [2] M. Vandebrouck et al., Phys. Rev. Lett. 113, 032504 (2014). [3] M. Vandebrouck et al., « Measurement of the Isoscalar Giant Resonances in the Neutron-rich Nucleus 68Ni » in preparation.

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Conceptual design and simulation of a Proton Detector for studying low-energy resonances relevant in thermonuclear reactions

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Classical novae and type I x-ray bursts are explosive events that occur in close binary systems where hydrogen-rich material is accreted on the surface of a compact object. This accreted material is heated and compressed until a thermonuclear runaway occurs. During this explosion heavier nuclei are produced via proton captures and beta decays. In many proton capture reactions, resonant capture dominates the reaction rate. Sometimes the measurement of these resonances cannot be done directly with radioactive ion beams. However, they can be studied indirectly via beta-delayed proton emission of proton-rich nuclei. The main challenges in the detection of these emitted protons are that the kinetic energies and the branching ratios of the protons are very low and the corresponding peaks are overcome by beta particle backgrounds using standard solid state detectors . In order to overcome this difficulty, a novel detection system has been developed by a group at Texas A&M and CEA Saclay. It consists of a gas volume where radioactive ions are implanted. Gas reduces the sensitivity to the beta-particles emitted minimizing their contribution to the background. The use of Micro Pattern Gas Detectors like MICROMEGAS assures a good resolution, efficiency and gain. A detection system based on this technique is being designed at NSCL to measure these resonances using intense NSCL beams and the SeGA array of HPGe detectors. References: [1] E. Pollacco et al. NIMA 723, 102 (2013)

Session 4 / 5

Toward Nuclear Astrophysics studies with Electronic TPC (eTPC) and gamma beams from ELI-NP

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The Extreme Light Infrastructure-Nuclear Physics (ELI-NP) – currently being built near Bucharest, Romania – will deliver monochromatic, brilliant and polarized gamma-ray beams (tunable energy from 1 to 20 MeV). We propose to use a gaseous active target detector to study (&alpha,&gamma) and (p,&gamma) nuclear reactions of current astrophysical interest by means of studying time-inverse processes induced by high energy photons. The advantage of such an approach stems from the fact that photons are not subject to the nuclear Coulomb barrier. The ultimate goal of such an active target detector is to measure cross sections and angular correlations for 16O(&gamma,&alpha)12C reaction at lower center-of-mass energies that were studied so far, and to provide input for astrophysical models of He-burning in massive stars. The charged products of photodisintegration reactions will be measured by means of a special Time Projection Chamber (eTPC) with innovative 3-coordinate (u-v-w) planar electronic readout acting as virtual pixels. The detector will be equipped with triple-GEM structure for gas amplification and will work at lower-than-atmospheric pressure. The eTPC detector is part of a broader effort of the Charged Particle Detection Working Group established at ELI-NP, and will be complemented by: an SSD detector (solid target) and a bubble chamber (liquid target). The concept of eTPC detector and preliminary results from a demonstrator detector will be presented in this talk.

Session 4 / 6

Nuclear Astrophysics With an Optical Readout TPC (O-TPC) at the HIγS Facility *

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An Optical Readout TPC (O-TPC) [1] has been used over the last four years for studies in Nuclear Astrophysics (and Nuclear Structure) with gamma-beams extracted from the HIγS facility at TUNL, Duke University [2]. The O-TPC operates with the gas mixture of CO2(80%) + N2(20%) at 100 torr [1], as well as with N2O(80%) + N2(20%) gas. Both carbon and oxygen contained in the CO2 gas were used as active targets. The O-TPC is intended primarily for measuring the photo-dissociation of 16O in the 16O(γ,α) reaction which is the time reverse of the 12C(α,γ) reaction, an essential ingredient of stellar evolution. The 12C(γ,3α) reaction was also used to study the structure of 12C [3]. We are in the process of installing an isotopically enriched gas handling system with gas recycling that will be used for example with the 13CO2 gas in order to remove the background from the 12C(γ,3α) reaction. The new isotopically enriched gas system, the optical readout with a fast CCD camera and the first significant result on the 16O(γ,α) reaction measured with N2O gas will be discussed.

- This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Award Numbers DE-FG02-94ER40870 and DE-FG02-97ER41033.

[1] M. Gai, M.W. Ahmed, S.C. Stave, W.R. Zimmerman, A. Breskin, B. Bromberger, R. Chechik, V. Dangendorf, Th. Delbar, R.H. France III, S.S. Henshaw, T.J. Kading, P.P. Martel, J.E.R. McDonald, P.-N. Seo, K. Tittelmeier, H.R. Weller and A.H. Young; JINST 5, 12004 (2010).
[2] H. R. Weller, M. W. Ahmed, H. Gao, W. Tornow, Y. K. Wu, M. Gai, and R. Miskimen, Prog. Part. Nucl. Phys. 62, 257 (2009).
[3] W.R. Zimmerman, M.W. Ahmed, B. Bromberger, S.C. Stave, A. Breskin, V. Dangendorf, Th. Delbar, M. Gai, S.S. Henshaw, J.M. Mueller, C. Sun, K. Tittelmeier, H.R. Weller, and Y.K. Wu; Phys. Rev. Lett. 110, 152502 (2013).

Session 4 / 9

Exotic decay modes studied by means of the Warsaw Optical Time Projection Chamber

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The development of an Optical Time Projection Chamber (OTPC) at the University of Warsaw about a decade ago opened the possibility to investigate a broad range of rare decay modes with very high sensitivity. The detection of one decay event is sufficient to unambiguously identify the decay mode and establish its branching ratio. The detector is a TPC with amplification stage formed by a stack of GEM foils and optical readout consisting of a CCD camera and a photomultiplier tube (PMT). The images recorded by the CCD camera together with the time distribution of light collected in the PMT allow to reconstruct the trajectory of the decay products [1,2]. Such an approach is ideally suited to study the decay by (multi-) particle emission of very exotic isotopes. It was originally designed to obtain the first unambiguous proof of the two-proton (2p) decay of 45Fe and to study the angular correlations between the protons [3]. The same methodology and detection set-up was successfully applied also to measure the 2p decay of 48Ni [2,4], to discover the beta-delayed 3 proton (β3p) emission decay branch in 45Fe [5], and 43Cr [6] at the NSCL, and in 31Ar at GSI Darmstadt [7,8],. Moreover, it was applied to measure the energy distribution of beta-delayed deuterons from the decay of 6He at ISOLDE [9] and to study the beta-delayed tritium-alpha-neutron decay of 8He at the JINR in Dubna [10]. A review of the results and an outlook on future studies will be presented.

[1] M. C´wiok et al., IEEE Trans. Nucl. Sci. 52 (2005) 1895. [2] M. Pomorski et al., Phys. Rev. C 90, 014311 (2014). [3] K. Miernik et al., Phys. Rev. Lett 99 (2007) 192501. [4] M. Pomorski et al., Phys. Rev. C 83 (2011) 061303(R). [5] K. Miernik et al., Phys. Rev. C 76 (2007) 041304(R). [6] M. Pomorski et al., Phys. Rev. C 83 (2011) 014306. [7] M. Pfützner et al., GSI-SR2012-PHN-ENNA-EXP-17, GSI Report 2013-1 (2012). [8] A. Lis et al., in preparation. [9] S. Mianowski et al., in preparation. [10] M. Pfützner et al., in preparation.

Session 5 / 33

Transfer reactions: opportunities and challenges for the modern era

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Much of what has been learned about the structure of atomic nuclei over the past several decades has been determined from studies of transfer reactions. Typically, these are reactions where one or two nucleons are exchanged between a beam and a target. The data can provide information such as the excitation energies and quantum numbers for nuclear states, as well as other more subtle properties such as spectroscopic factors which are sensitive to many aspects of the nuclear wave function. Data from transfer reactions can be used to guide theoretical calculations of nuclear structure, and are important for understanding the properties of exotic nuclei produced in modern laboratories. The latest experiments utilize radioactive beams which make studies of transfer reactions technically more difficult than those performed with stable nuclei in the past. Many new methods have been developed recently to contend with the technical challenges, and active-target experiments in particular will play an important role in future research in this area. This talk will present some background of the physics that can be studied with transfer reactions, review the technical challenges, and describe how new experimental approaches can best utilize the exotic beams produced by today's modern facilities.

Session 5 / 11

Active target developments in Japan

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Active target is a key device expanding the studies with nuclear scattering experiment, owing to its high detection efficiency, high luminosity and detection capability of the low energy recoil. In Japan, several active targets have been developed for the studies with wide-energy-range unstable nuclei beam available in RIBF and RCNP and for the studies with gamma source in NewSUBARU facility.
An active target using multi-wire amplification was developed for the measurement of photo-disintegration of 4He. MAIKo has been developed aiming at the study of the cluster structure in nuclei and used for the measurement of the photo-disintegration. GEM-MSTPC has been developed for application in studying low-energy nuclear reactions using radio-isotope beams. CAT with deuterium gas has been developed for the high-intensity intermediate-energy radio-isotope beams.
This talk will introduce these active target developments in Japan and their outlook.

Session 5 / 16

One-dimensionality in atomic nuclei: linear-chain alpha clustering in 14C

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The clustering of alpha particles in atomic nuclei results in the self-organization of various geometrical arrangements at the femtometer scale. The one-dimensional alignment of multiple alpha particles is known as linear-chain structure, evidence of which has been highly elusive since its proposal in the 1950s. We show via resonant alpha scattering of a radioactive 10Be beam that excited states in the neutron-rich nucleus 14C agree with recent predictions of linear-chain struc- ture based on an anti-symmetrized molecular dynamics model. Our results support the model's claim that the linear-chain states in 14C are stable against bending; their wavefunctions satisfy the orthogonality condition to lower-lying triaxially-deformed states that largely contain the bending 3-alpha configurations, thus stressing the importance of the fundamental quantum mechanical law of orthogonality in the one-dimensional formation of alpha clusters in atomic nuclei.

Session 6 / 34

Developments and Applications of Micro-pattern Gaseous Detectors (MPGD): a concise review

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Gaseous detectors are fundamental components at the frontier of present and planned physics experiments. Over the past decade Micro-Pattern Gas Detector (MPGD) technologies have become increasingly important; the high radiation resistance, large sensitive area, high rate capability and excellent spatial and time resolution make them an invaluable tool to confront future detector challenges at the next generation of colliders. Originally developed for the high energy physics, MPGD applications have expanded to nuclear physics, astrophysics, neutrino physics, material science, neutron detection and medical imaging. This talk provides an overview of the state-of-the-art of the MPGD technologies: it presents and discusses operation mechanisms, properties and main applications of the most popular MPGD designs, with particular focus on charge-particle tacking applications.

Session 6 / 32

Giant resonances in exotic nuclei

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Large efforts have been undertaken in the past years in order to develop the experimental tools for an investigation of giant resonances in unstable nuclei. Data are still scarce, but promising results have emerged, in particular concerning the dipole and monopole giant resonances. The interest in studying the multipole response of exotic nuclei is on one hand the nuclear structure aspect concerned with the collective response of neutron-rpoton asymmetric nuclei, where a change is expected towards a softer response, including possibly new modes of excitation related to the excess nucleons. On the other hand, the giant resonances or the multipole response of heavy nuclei in general can be related to nuclear matter properties. Measurements for neutron-proton asymmetric nuclei will be able to constrain parameters of the equation of state for asymmetric nuclear matter, as the giant monopole resonance energy for the incompressibility, and the dipole

polarizability for the density dependence of the symmetry energy. I will discuss some recent results and developments.
*supported by BMBF under contract 05P12RDFN8

Session 6 / 4

MAIKo active target for RI beam experiments

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An active target system MAIKo (Mu-PIC based Active target for Inverse Kinematics.) is under development at RCNP. This system is designed to perform missing mass spectroscopy with RI beam. Missing mass spectroscopy will be a powerful method to study high-excited states of unstable nuclei above particle decay thresholds. MAIKo is based on a time projection chamber (TPC). We utilize micro-pixel chamber (μ-PIC) for the amplification and detection of the drifted electrons. μ-PIC is a kind of micro-pattern gaseous detectors developed by the cosmic ray group at Kyoto University and has high position resolution. In 2013, the first beam test experiment was carried out to study the detector performances such as angular resolution and gas gain under high beam rate. Scattering events were also acquired to develop a tracking algorithm. The first experiment with RI beam will be proposed in this summer. In the present talk, the detailed design of MAIKo TPC will be reported. The results of the test experiment will be also discussed.

Session 6 / 8

Photodisintegration measurement using MAIKo

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The photodisintegration of 4He have been extensively studied both from the experimental and theoretical aspects. The photodisintegration is mainly caused by an electric-dipole transition to the giant dipole resonance and the subsequent decay. This process is deeply related to the nucleosynthesis in the universe, therefore, it is very important from a view of astrophysics as well as nuclear physics. However, the experimental situation for this reaction is not satisfactory. Although much effort was devoted to measure the cross section for the photodisintegration reaction in 4He over the last four decades, the experimental data contradict each other, and new reliable experimental data are desired. The active target is quite suitable to the photodisintegration measurement because it covers a large solid angle for charged particles emitted from the photonuclear reaction. Moreover, there is no limitation from the beam counting rate, which is the destined difficulty for the active target, because the active target is almost insensitive to gamma rays. Recently, the active target MAIKo, which is jointly developed by Kyoto and RCNP, was successfully employed to measure the photodisintegration cross section for 4He. In the present talk, the details of the experimental setup and results will be reported.

Session 7 / 15

Hyperon Time Projection Chamber for J-PARC experiments

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We are developing a Hyperon Time Projection Chamber (HypTPC) as the main detector of two experiments at the J-PARC Hadron Facility. The J-PARC E42 experiment proposes to search for the H-dibaryon resonance in $\Lambda\Lambda$ production from $(K^-, K+)$ reactions off nuclei and the bound H-dibayron by its weak decays in order to answer the long-standing question about the existence of the H-dibaryon, which has a "*uuddss*" quark configuration. The J-PARC E45 experiment approaches to fundamental understanding of non-perturbative QCD through high-precision data of baryon resonance spectra for $\pi N \to \pi\pi N$ and $\pi N \to KY$ channels. Both experiments demand high-intense hadron beams of 10^6 cps and detector acceptance of almost 4π solid angle around a experimental target. HypTPC is designed to have a sensitive volume of ϕ˜500\,mm˜× H˜550\,mm and a inner target holder. Since beams are directly injected into the sensitive volume, we are able to reconstruct the primary vertex by measuring the beam trajectory in addition to the trajectories for produced particles. However, it is very challenging to operate a TPC with a exposure to the high-rate beam. Our solutions are electron amplification using Gas Electron Multipliers (GEMs) and a gating method of electric filed with wires to control electron drift. A specialized frontend electronics are also essential to handle about 6000 channels of HypTPC readout pads. We collaborate with the GET (General Electronics for TPC) project led by Saclay, GANIL, MSU, IRFU and CERNBG. The project provides us the total readout system including hardware and software.
In this presentation, we will discuss physics interests of the J-PARC experiments. R\&D status of HypTPC with the GET system will also be reported.

Session 7 / 17

Integration of GET electronics on TPC for HIC program at RIBF

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A Time Projection Chamber˜(TPC) for the heavy ion collision experiments has been produced as the main detector of SAMURAI-SPiRIT project for the study of nuclear equation of state. As the readout system for the SPiRIT-TPC, we are integrating the GET system, which stands for the Genaral Electronics for Tpc and was developed mainly by France and USA collaboration. For the integration of GET electronics, development of interfaces in terms of both hardware and software are nessesary. For example, the interface of the electronics of GET to TPC depending on the each detector specifications, such as type of connector and characteristics of detector signal, has to be developed. We call such interface ZAP board, which is for adapting connector on TPC and for protection of electrical circuit. The board was designed to fit in the space on the TPC which is supposed to be installed in SAMURAI chamber, to reduce the noise to gain the dynamic range, and to reduce the distortion of gain among the different channel. The achived noise level with our ZAP is 4˜ADC under the configuration of dynamic range of 120˜fC and shaping time

of 233˜nsec. It can be reduced to be 2∼3˜ADC after the subtraction of fixed noise pattern line which is not connected to TPC pads. In addition to the report of the status of development and intergration of electronics, the benchmark test data of GET system on Brahms-TPC performed at HIMAC at 2014 Nov will be presented.
This material is based on work supported by the DOE under Grant No. DE-SC0004835, and Japanese MEXT Grant No. 24105004.

Session 7 / 14

Current Status of SπRIT Time-Projection Chamber Project

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The SAMURAI Pion-Reconstruction and Ion-Tracker (SπRIT) has recently been constructed at Michigan State University as part of an international effort to constrain the symmetry-energy term in the nuclear Equation of State (EoS). The SπRIT-TPC is designed for measurements of the density dependence of the symmetry-energy term at around twice the saturation density. This study will be performed in the SAMURAI spectrometer at the Radioactive Isotope Beam Factory (RIBF) at RIKEN by measuring yield ratios for pions and other light isospin observables from central collisions of neutron-rich ions, such as 132Sn + 124Sn. The SπRIT-TPC was designed to fit inside the SAMURAI spectrometer, and thus has an overall design height of 742 mm, with a vertical drift length of 500 mm in the detection volume. The installation of the TPC into the spectrometer has been successfully tested in the summer of 2014, and an operational test was performed using the magnetic field. Signals from cosmic rays were multiplied with a multi-wire anode and image charges from this multiplication were read out on portions of the 12096 channel pad-plane using the recently developed Generic Electronics for TPCs. Significant progress has been achieved for the SπRIT-TPC experiment, and preparations continue to move forward. The current status of the SpRIT-TPC project will be presented in this talk. This material is based on work supported by the DOE under Grant No. DE-SC0004835, NSF under Grant No. PHY-1102511 and the Japanese MEXT Grant-in-Aid for Scientific Research on Innovative Area Grant No. 24105004

Session 7 / 13

The SπRIT-TPC data acquisition system and analysis framework

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The SAMURAI-SπRIT project will aim to constrain the symmetry-energy term of the nuclear Equation of State (EoS) at supra-saturation densities [1]. For such purpose, a Time Projection Chamber (TPC) was recently constructed in order to measure π−/π+ and t/3He yield ratios in central collisions of neutron-rich heavy ions. The TPC will be installed inside the SAMURAI superconducting dipole magnet (at RIKEN, Japan) to benefit from its large magnetic rigidity. To deal with the large particle multiplicities, the pad plane is highly segmented in 12,096 pads of 12x8 mm2 of area. Signals are digitized and read out by the General Electronics for TPC system [2,3], with a maximum of 512 time buckets at 1 to 100 MHz of sampling rate. In order to process the large amount of data expected (Hundreds of MB/s) and to combine the data from auxiliary detectors, the NARVAL data acquisition system was adopted. Moreover, an advanced analysis framework is also being developed by our collaboration to reconstruct the relevant observables by using sophisticated tracking algorithms, and transport codes to simulate the underlying physics. In this contribution we report the performance and present status of the SπRIT-TPC data acquisition system and the dedicated analysis framework, called SπRITROOT.
This material is based on work supported by the DOE under Grant No. DE-SC0004835, Japanese MEXT Grant-in-Aid for Scientific Research on Innovative Area Grant No. 24105004 and the National Research Foundation of Korea under grant No. 2012M7A1A2055596.
[1] R. Shane et al., Nucl. Instrum. and Meth. A (accepted for publication). [2] T. Isobe et al., RIKEN Accel. Prog. Rep. 46, 151 (2014). [3] E. Pollaco et al., Physics Procedia 37, 1799 (2012).

Session 7 / 19

Upgrade of the TAMU MDM-Focal Plane Detector with MicroMegas Technology

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MicroMegas is a relatively new detector technology that operates as a two stage parallel plate avalanche chamber. It consists of a small amplification gap (50-300 um) and a much larger drift gap (on the order of cm) separated by a thin electroformed micromesh. It has been shown to provide gains of up to 10ˆ5. [1] We have previously used this technology at our Institute in the AstroBox [2], a detector system built specifically for low noise and used to detect very low-energy protons from beta-delayed proton emitters. During these decay experiments, we observed that this device also detected the incoming energetic heaver ions with good resolution for particle identification. This latter result was the starting point for the upgrade of the MDM-Oxford detector, which is the principle focal plane detector of the Multipole-Dipole-Multipole spectrometer at Texas A&M Cyclotron Institute. It is used to identify particles and measure their positions along the dispersive x-direction. Using raytrace reconstruction we can determine the scattering angle at the target as a function of the angle of the particle path in the detector. In the nuclear astrophysics group, this setup has been used primarily to study scattering and transfer reactions involving nuclei with A$\leq$26. However at higher masses than that, we found that we are having significant difficulties with the particle identification due to the insufficient resolution of both the dE and E signals. A detailed description of the MDM detector can be found in ref [3]. Briefly, dE is the energy lost by particles passing through an ionization gas and is measured by three Aluminum anode plates. Currently, the first two plates connected produce a

signal we call ΔE1 with energy resolution of 10-15%. This is enough for particles with A <20 but starts becoming problematic above that. The third plate, ΔE2, gives a signal that is too noisy to be of any use. For this reason, we decided to replace this anode with a MicroMegas plate of identical size. Due to technical constraints, the new plate was divided into 28 pads (4 rows x 7 columns). Therefore, instead of one ΔE2 energy loss signal, we now detect 28. We tested the new setup with three beams, 16O, 22Ne and 28Si scattered elastically off gold foil. Preliminary results indicate a definite improvement in dE detection. We operated the Micromegas without issues at isobutane pressures from 100 Torr down to 30 Torr. Energy resolution varies from 5-6% at higher pressure to 10-11% at lower pressure. For all three beams, we obtained improved Z separation and intend to continue testing with heavier beams, A>28. Given the current results we feel that we can go forward with using the upgraded system for experiments in the mass region of the tests. Specifically, we intend to continue studying nucleon capture reactions that present an interest in explosive nucleosynthesis, 27Al(n,g), as well various peripheral transfer reaction for optical potential model studies, 22Ne(n,g), 28Si(n,g). When the facility-wide upgrade is completed, the modified detector is intended to also be used in experiments with radioactive ion beams.

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Session 8 / 40

Nuclear reactions studied at small momentum transfers

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Several nuclear reactions are best investigated when the momentum transfer to the nucleus is small. Among these are the IsoScalar Giant Monopole Resonance (ISGMR) which helps determine one of the parameters of the equation of state, namely the incompressibility of nuclear matter, and proton elastic scattering from nuclei which is sensitive to parameters of nuclear density such as the matter root-mean-square radius. These have been extensively studied in the past using stable beams. However, with the advent of radioactive ion facilities around the world, it is desirable to study these reactions with unstable nuclei. The reactions, however, have to take place in inverse kinematics in which the radioactive ions impinge on a light target (hydrogen or helium). Simple kinematics calculations show that the outgoing recoil particles should be measured at extremely low energies (down to few hundred keV). Solid targets are, therefore, not suitable for these reactions. There are two methods to deal with this challenge: either do the experiments in storage rings with gas jet targets or any other thin targets, or perform the measurements with an active target which also acts as a detector. In both cases, the energy threshold will be much lower than a fixed target of a reasonable thickness.
We have performed measurements with the radioactive 56Ni using both methods. In the ring measurements, proton elastic scattering was the main goal for this nucleus while feasibility studies were done with 58Ni and a helium target to study ISGMR. With the active target, the main goal was to study ISGMR with an active target of helium. Preliminary results of both methods will be presented during the workshop and the methods will be compared to each other.

Session 8 / 3

MINOS : performance and results from the first physics experiment at the RIBF

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MINOS is a new device composed of a thick liquid hydrogen target and a Time Projection Chamber (TPC), dedicated to the in-beam spectroscopy of very exotic nuclei in inverse kinematics by proton-induced knockout reactions at the Radioactive Isotope Beam Factory (RIBF) in Japan. This TPC enables the detection of the charged particles produced by knockout reactions and the reconstruction of the reaction vertex, thus ensuring a good Doppler correction for the measured gamma rays. The TPC has been validated in beam at the HIMAC facility in Chiba in October 2013 and the MINOS device was coupled to the DALI2 scintillator array during the first experimental campaign aimed at the first gamma-spectroscopy of 66Cr, 70Fe, 72Fe and 78Ni at the RIBF in May 2014. The performance and tracking algorithm of the TPC will be presented, as well as first analysis results from the experimental campaign.

Session 8 / 18

SpecMAT: An array of gamma-ray detectors around an active gas target

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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. A rich research program including direct and resonant reactions, as well as decays, will be addressed with this new instrument. In many cases, it is highly desirable to collect gamma-ray information concurrently to the particle track information obtained with the ACTAR TPC. The project SpecMAT, funded by a second ERC grant, seeks this objective through either scintillators (LaBr3:Ce or CeBr3), or Broad Energy high-purity Germanium (BEGe) detectors, 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 SpecMAT setup, while working within certain mechanical limitations. This talk will present results of these tests, as well as simulations performed in Geant4 for the final array of detectors.

Session 8 / 23

Design of Gating grid driver for SπRIT Time Projection Chamber

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The SAMURAI Pion-Reconstruction and Ion-Tracker (SπRIT), a Time Projection Chamber (TPC) is part of an international effort to constrain the nuclear symmetry energy around twice the saturation density [1]. The field cage of the SπRIT TPC is designed to measure the momentum distribution of pions and isotopically resolved light particles emitted in heavy ion collisions. The field cage consists of a drift volume and three wire (gating grid, ground and anode) planes located just below the pad plane at the top. Positive ions produced in an electron avalanche near the anode wires can distort the electric field in the drift volume of a Time Projection Chamber. A gating grid is designed to prevent these ions from going back into the drift volume and to block electrons ionized by unreacted beam particles from entering the multiplication region. In the "open" mode, all the gating grid wires are set to have the same potentials (nominally -110 V). This condition allows drifting electrons to pass into the multiplication region consisting of the ground wire and anode wire planes. When the gating grid is "closed", alternate wires are biased up or down by about 70 V (-40 V and -180 V). The electric field created between the wires assures that no electrons pass through the gating grid wire plane to the anode plane. The gating grid has a dead region in which ionization electrons drift to the grid before it is opened. The size of this dead region is governed by the electron drift time and the time needed to open the gate. It is also related to the properties of the detector gas, pressure, and the electric field. We have investigated how to minimize the dead region by matching impedance of the driving circuit, estimate the inductance of the system and tune resistance, capacitance and inductance values so that the gating grid runs slightly underdamped. The designs, properties and operation of different gating grid drivers and the time each takes for the gating grid to open will be discussed. This material is based on work supported by the DOE under Grant No. DE-SC0004835, and Japanese MEXT Grant No. 24105004. [1] R. Shane et al., Nucl. Instrum. and Meth. A (accept for publication)

Session 8 / 25

Development of the TexAT Detector at Texas A&M University

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With the upgrade to the facilities nearing completion, the Cyclotron Institute at Texas A&M University is poised to provide a range of new high quality re-accelerated radioactive ion beams to compliment the existing rare isotope beam capabilities based on the in-flight separator MARS. To take full advantage of the opportunities available for low-energy nuclear structure and astrophysics, a general purpose active target detector, TexAT, is currently under development. The TexAT detector will be a high efficiency TPC, combining a MicroMegas plane with nearly 3pi solid angle coverage by CsI-backed silicon detectors, and will be optimized for high resolution scattering, nucleon transfer, and decay spectroscopy experiments. This talk will discuss the current status of the project, including results from detailed Monte Carlo simulations of the key reactions envisioned for study using the TexAT detector.

Session 9 / 36

Nuclear Astrophysics: the unfinished quest for the origin of the elements

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Nuclear astrophysics aims to understand the cosmic origin of the chemical elements and the energy generation in stars. It constitutes a truly multidisciplinary arena that involves researchers in theoretical astrophysics, observational astronomy, cosmochemistry and nuclear physics. New tools, developments and achievements have revolutionized our understanding of the origin of the elements: supercomputers have provided astrophysicists with the required computational capabilities to study the evolution of stars in a multidimensional framework; the emergence of high-energy astrophysics with space-borne observatories has opened new windows to observe the Universe, from a novel panchromatic perspective; cosmochemists have isolated tiny pieces of stardust embedded in primitive meteorites, giving clues on the processes operating in stars as well as on the way matter condenses to form solids (e.g., planets); and nuclear physicists have measured reactions at or near stellar energies, through combined efforts in stable and radioactive ion beam facilities. This talk will provide an overview of the nuclear history of the Universe and related topics: starting from the Big Bang, when the ashes from the primordial explosion were transformed to hydrogen, helium, and few trace elements, to the rich variety of nucleosynthesis mechanisms and sites in today's Universe. Particular emphasis will be devoted to explosive nucleosynthesis occurring in core-collapse and thermonuclear supernovae, gamma-ray bursts, classical novae, X-ray bursts, superbursts, and stellar mergers.

Session 9 / 30

Coincidence auxiliary detection devices

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Active targets are very versatile instruments. On some aspects, like the luminosity of a reaction measurement, they have a clear advantage over more traditional setups. In other areas, sometimes a compromise has to be chosen in order to obtain usable information on various parameters such as energy, channel and particle identification. The use of auxiliary detectors and techniques can help improve the performances of active targets. The dynamic range for the detection of charged particles in the gas can be extended by the use of magnetic fields and/or solid-state detectors surrounding the active volume. These devices, besides providing direct information, also give additional degrees of freedom in the choice of the optimal configuration of the whole detection setup, for example allowing more freedom in the choice of the gas parameters. The demand for energy resolution becomes especially important when dealing with medium-mass and heavier nuclei, for which a high density of states is expected. The addition of an array of gamma-ray detectors may represent a viable solution, provided that a high detection efficiency is ensured. At the same time, granularity is necessary for an effective correction of Doppler broadening. Electronic integration of the auxiliary arrays with the new-generation active target devices is also an important factor. We will review these aspects and present some results of ongoing studies and tests.

Session 9 / 28

Exotic decays and processes beyond drip lines

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The isotopes within the limiting lines of bound nuclei (or drip-lines) are goals of exploration for as many elements as possible. However the drip-line is not the end of the nuclear existence, and

nuclei beyond the proton and neutron drip-lines may live much longer than the characteristic time of an orbital motion of nucleons in nuclei. These nuclei called resonances have lifetimes determined by the centrifugal and Coulomb barriers and also are strongly affected by pair nucleon correlations. Nuclear resonances can be studied by their decays via emission of proton(s) or neutron(s), or proton or neutron radioactivity, respectively. Outside the proton drip-line, proton radioactivity prevails and some isotopes with two-proton decays have been observed. They allow studying two-proton correlations in nuclei. Four-proton decay is also expected in some very exotic proton-rich nuclei. The new experimental results on two-proton decays of 19Mg and previously unobserved 30Ar isotopes will be presented. Their decays in-flight have been studied by using tracking technique which allows for measurements of lifetime and decay energy. Also neutron radioactivity will be reviewed. Theoretical predictions of this still unobserved phenomenon, the recent experimental activity and plans will be presented. In particular, the case of two-neutron decay of 26O will be considered in detail. Prospective candidates for observation of neutron radioactivity and the related experimental methods and detectors will be discussed.

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Development of the Online Analysis Software for the CRIB Active Target

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An active target, which acts as both a reaction target and a detector, is one of the promising particle detection systems in nuclear physics experiment. It provides comprehensive physical information such as traces of injected particles and particle discrimination in atomic numbers based on energy-loss information. Our active target is basically a gas-filled time projection chamber developed by CNS in-flight radioactive ion beam separator at low energy (CRIB) in the RIKEN Nishina Center, Japan. As a part of preparatory steps for experiments at CRIB, a software dedicated to online monitoring and event reconstruction of the CRIB active target has been developed as the user-friendly graphical interface in the framework of ROOT. With modification of existing codes that can meet requirements for beta delayed alpha decay measurements, new features have been successfully implemented an evaluated with N-16 radioactive ion beams. We present a detailed description of signal processing and data analysis for the CRIB active target.

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Photogrammetry measurements of the SpiRIT TPC

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The SAMURAI Pion[U+2010]Reconstruction and Ion[U+2010]Tracker (SpiRIT), a Time Projection Chamber (TPC), is designed for measurements of the density dependence of the nuclear symmetry energy around twice the saturation density. This TPC will be used inside the large SAMURAI dipole magnet in the Rare Isotope Beam Facility (RIBF) in RIKEN Wako, Japan. To understand the relative locations of the TPC drift volume, with respect to the enclosure of the TPC, the dipole, and other auxiliary detectors, we use a calibrated camera system from Geodetic in which multiple photographs can be reconstructed into a 3-dimenstional coordinate system to make 3D measurements of the SpiRIT TPC. This measurement technique known as photogrammetry is accurate to <100 micrometers and commonly used in SAMURAI experiments [2]. In this talk, I will describe the precise measurements and the uncertainties in mapping various TPC components in the magnet chamber using the photogrammetry technique.
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[1] R. Shane et al., Nucl. Instrum. and Meth. A (accept for publication) [2] H.Otsu, et. al., RIKEN accelerator progress report vol. 46 (2013) 149.

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Garfield Simulation of the SpiRIT TPC Field Cage

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The SAMURAI Pion-Reconstruction and Ion-Tracker (SpiRIT), a Time Projection Chamber (TPC), is designed to measure the density dependence of the nuclear symmetry energy around twice the saturation density. The heart of the TPC is a field cage designed to measure the momentum distributions of pions and light particles emitted in heavy ion collisions. The interior of the field cage is 145 cm long x 97 cm wide x 52 cm high. The side and front walls are constructed of 1.6 mm thick halogen-free G10 printed circuit boards (PCBs) with 6 mm wide copper strips and 4 mm gaps between strips corresponding to a 1 cm pitch on both the interior and exterior sides of each PCB. The exterior strips are offset by 5 mm from the interior strips to expel electrons from the insulating gap. The top of the field cage is open to the wire and pad plane region and the cathode is located at the bottom. This rigid and gas tight structure has a thin (4 micrometer) PPTA upstream beam entrance window (6 cm wide x 7 cm high), and a larger (39cm x 81cm) and thicker (125 micrometer) polyamide exit window that allows passage of light charged particles and heavy ions with minimal energy loss to ancillary detectors downstream. Aluminum electrode surfaces were evaporated on the entrance and exit windows. These and the copper electrodes on the PCBs provide the electric field that drifts the ionized electrons to the wire planes.

We use GARFIELD simulations to study the uniformity of the electric field within the field cage geometry, the transmission properties through the gating grids and their dependence on the voltages set, and to investigate ExB drift effects in the avalanche wire region. Garfield is used because of its predictive power of optimizing drift properties of electrons, and ions, through the gas volume. In this talk, I will present the important simulations related to the design and operation of SpiRIT and the strengths and limitations of these calculations.
This material is based on work supported by the DOE under Grant No. DE-SC0004835, NSF under Grant No. PHY-1102511 and the Japanese MEXT Grant-in-Aid for Scientific Research on Innovative Area Grant No. 24105004.

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Preliminary Results from the Commissioning of the AT-TPC at MSU

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The Active-Target Time Projection Chamber (AT-TPC) was recently commissioned at MSU using a stable beam of 4He at 3 MeV per nucleon from ReA3 on a target of He+CO2 gas. Tracks were measured in the detector at magnetic field strengths of 0, 0.5 and 1 Tesla. Analysis of the data is underway. This talk will focus on the application of the Kalman filter method to this highly nonlinear problem, and preliminary results will be presented.

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Workshop Closing

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Workshop Closing