Title of the project:

CLAS-MED

Intervention area:

PHYSICAL SCIENCE AND ENGINEERING (PE)
Subject related to Excellent Science of HORIZON2020, ERC project

HEALTH, DEMOGRAPHIC TRENDS AND WELLNESS

Course of intervention (art. 3):

Course of intervention 1

Institution of reference:

INFN

Coordinator of the project:

Contalbrigo Marco

Short description of the project:

The project is part of the ongoing international research activity aiming to study the three-dimensional (3D) structure of the nucleon and, more in general, strong interactions and confinement of quarks in stable hadronic states. The project foresees the upgrade of the large acceptance spectrometer Clas12 in Hall-B at the Thomas Jefferson National Accelerator Facility (JLab), Newport News VA, USA, with the realization of a Ring Imaging CHerenkov (RICH) detector to improve the hadron identification capabilities and to allow for measurements sensitive to the quark flavors. The research and development activity needed for the realization of a large area detector at affordable costs has potential spillovers both on fundamental research (Nuclear and Particle Physics) and on applied research (Medical Physics).

Fundamental Physics

The study of partonic dynamics in 3D is an innovative research field where the contribution of Italian physicists covers a relevant position. It is part of the more general problem of describing the ordinary matter from first principles in terms of quarks, gluons and QCD, the gauge theory describing their interactions. Since the earliest measurements in the 70s, hadronic Physics deals with surprising phenomena that cannot be explained in the framework of perturbative QCD. Examples are the small contribution of the spin of quarks to the overall spin of the nucleon (proton and neutron), the single-spin asymmetries (that do not scale with energy) and the azimuthal asymmetries in unpolarized reactions. The recent experiments in various Laboratories in the world (DESY, CERN, JLab, BNL, SLAC, KEK, etc.) and the parallel theoretical developments opened the way to new fields of investigation and showed the importance of the 3D study of parton dynamics, and in particular of the correlations between transverse momentum and spin of partons, related to partonic orbital momenta and spin-orbit effects. Furthermore, inconsistencies are observed in present data concerning the standard parton distributions relative to the strangeness content of the nucleon: there are experimental evidences that its effect can be relevant, in contrast to theoretical expectations.

The precise knowledge of parton distribution functions is not only interesting on its own, but can also have an important impact on fields that are not strictly related to the structure of nucleons, such as the precise determination of the W boson mass or the studies of the distribution of transverse momentum in collisions at LHC (CERN).

Jefferson Lab aims to become the most complete facility in this field in the medium term and is the only existing Laboratory of particle Physics in the United States with a funded development program in the long term with a relevant presence of Italian physicists. The proposed experiments are based on deep-inelastic scattering of a high-intensity and high-polarization 12 GeV electron beam off light polarized targets, and are expected to work at very high luminosities (ranging from 10^{34} to 10^{38} $cm^{-2}s^{-1}$.) The completion of the 12 GeV JLab upgrade was recently recommended by NSAC to DOE as the first priority for the Nuclear Physics program in the United States.

Large Area Cherenkov light Detectors

The CLAS12 large acceptance spectrometer in Hall-B of JLab has unique features (luminosity and resolution) to allow for a substantial progress in this field in the medium term. The approved physics program requires a RICH detector able to improve the identification among the produced hadrons, and thus to distinguish the flavor of the involved quarks. The instrument has to match with the rest of the spectrometer already under construction. In particular, it has to cover a large area in order to extend the measurements in the most interesting kinematic regions and to allow multi-dimensional analyses, a key element for such kind of research. Further details are provided in *Probing Strangeness in Hard Processes: the science case for a RICH detector for CLAS12*, H. Avakian et al., arXiv:1202.1910.

The project foresees the realization of the CLAS12 RICH detector in its basic configuration (two azimuthal sectors out of six, each covering an area of about 4 squared meters) in time for the beginning of the dedicated experiments with the 12 GeV beam. The first sector allows to start the physics program with unpolarized and longitudinally polarized targets. The second sector extends the kinematical coverage into the most interesting regions and allows for the symmetric arrangement needed to control systematic effects in precision measurements with transversely polarized targets. These measurements are crucial for the study of partonic dynamics related to angular momentum and spin-orbit effects.

The proposed solution foresees a RICH detector in a hybrid proximity and mirror-focusing configuration, that uses aerogel as radiator material and multi-anode photomultipliers. In order to reduce the instrumented area of the detector to about 1 m^2 per sector and limit the costs, focalizing mirrors will be used to direct the light produced from particles at large angles into the light-detection region. Further details are given in *The CLAS12 large area RICH detector*, M. Contalbrigo et al., NIMA 639 (2011) 302 (see Attachment 3).

In order to extend the detector to the remaining sectors and to obtain precision data in kinematic regions otherwise inaccessible, innovative techniques are needed to reduce the cost per surface unit. The project thus foresees a R&D activity based on new photon-detectors. In particular, the silicon based photo-detectors (SiPM) are expected, in the next years, to replace the traditional photomultiplier tubes, yet providing similar gains and equivalent, if not better, detection efficiency and time response. In addition, SiPMs are not sensitive to magnetic fields, are very compact and solid, work at low voltages, and can reach a higher spatial resolutions than the traditional tubes. The developments in the production technique has recently shown, and is expected to continue in the next years, fast progresses in the suppression of background dark-counts (per surface unit) and a cost reduction towards values significantly lower than for standard photomultipliers.

Very promising are also the Large-Area Pico-second Photo Detectors (LAPPD), based on the Micro-Channel Plate photomultipliers. Combining integrated advances in material sciences and electronics, this innovative technology aims at the production of large scale photodetectors with high spatial and time resolutions at low costs.

A third line of R&D will examine the possibility of use GEM detectors as optical photon position detectors; the GEM technology is very chip respect to the PMTs, flexible enough to be adapted and optimized to specific needs and single elements can cover pretty large areas of the order of 1 m^2 keeping the spatial resolution significantly below 1 mm. The detection of optical photons can be performed with a thin deposition of photosensitive material (e.g. CsI) in the active region of the GEM. Matching of the sensible wavelength region with the aerogel emission and absorption spectra, as well as photon-conversion efficiency are two of the main issues that we plan to investigate within the project.

Medical Applications

The development of innovative photo-detection techniques, that allow to cover large areas at affordable costs, finds application also in Nuclear Medicine.

Thanks to their characteristics, SiPMs are of great interest for all those applications that make use of photomultipliers, especially for those which require high spatial and time resolution, compactness and insensitivity to magnetic fields. One of these applications is molecular imaging with radionuclides (Single Photon Emission-SPE, Positron Emission -PE and their tomographic versions SPECT and PET) today in use for early diagnosis of tumors (breast, prostate) as well as for studies in-vivo on animal models of human diseases (cardiovascular, brain,...) and for their care (i.e. with stem cells and their tracking in the animal model).

The good time (a few hundreds of ps) and spatial (a few mm) resolutions allow for the development of new TOF-PET solutions, also competitive in price. The Micro Channel LAPP is expected to provide few tens of ps time resolution; this would represents the detector of election in TOF-PET.

The insensitivity to magnetic fields of the SiPM can allow the realization of innovative multi-modal medical devices based on the integration of PET-SPECT techniques and MRI systems, e.g. an endorectal system effective for the prostate diagnosis, where the application of SiPM can result in a substantial reduction of the scanning duration, a wider angular coverage and a consequent effectiveness in photo attenuation corrections (crucial for quantitative analysis).

The compactness and the wide configuration flexibility of SiPM (and thus better integration with the collimation and scintillation components) can lead to, e.g., solutions for scintimammography ”wearable”, not allowed by the actual photomultiplier tubes, and thus a closer proximity to the hypothetical tumor lesion and consequent smaller dose to be administered to the patient.

GEM detector most likely represents the cheapest solutions among the considered options; however its effective use as optical photon detector must be demonstrated. Tumor therapy portal imaging (where good spatial resolution must combine to large active area, to tolerance of high particle fluence and to rather flexible readout configuration) is probably one of the possible medical applications of such kind of detector.

All these applications can, to various degrees, benefit of the developments that are planned for the RICH, especially concerning noise suppression, reduction of dead areas between sensitive pixels, enhancement of uniformity in the detector response, reduction of costs and development of integrated electronics, with independent control and readout channels.

Goals of the Project:

The project aims to preserve the Italian groups in a leading position in a research frontier field (the 3D study of the nucleon), which they contributed to launch in recent years. The project will contribute significantly to the construction of the most complete facility for the 3D study of the nucleon in the medium term, with the construction of a RICH detector for the identification of hadrons that allows measurements sensitive to the quark flavors.

The project aims to study innovative techniques for detection of photons over large areas, based on the development of integrated electronics dedicated to cutting-edge detectors (multianode photomultipliers, SiPM, GEM chambers or derived from micro-channel plate with appropriate photo-conversion layers).

The problems associated with the detection of photons over large areas are of great interest in various fields, ranging from High-Energy Physics (Cherenkov light detectors) to Medicine (SPECT and PET tomography). Examples of the fruitful connections are the MBI project between ISS, INFN e Metaltronica company for scintimammograpy and the patent RM2008A000451 registered by members of the project.

Skills development

1. Knowledge of the structure of the nucleon in 3D, the strong force and QCD.
2. Reconstruction techniques (pattern-recognition) and data analysis.
3. Innovative techniques of position sensitive photo-detection at low cost.
4. Integrated electronics for new types of photodetectors.
5. New instruments for diagnostics and medical research.

National and International framework:

The project is part of the international collaboration Clas12 for the realization of a large acceptance spectrometer for the study of the 3D structure of nucleon in the medium term. The project is linked to a number of national initiatives for medical diagnostics.

Involvement of public and private institutions

INFN, along with associated personnel from different Italian Universities, has the lead role in the project, including several public Institutions at international level.

1. INFN Section of Ferrara and University of Ferrara (contact M. Contalbrigo): it is among the initial promoters of the 3D study of the nucleon structure, holding various responsibilities (Analysis Coordinator, Convener of Transverse Physics) in the precursor HERMES experiment. It promotes an extensive physics program at JLab, his members being co-author (as co-spokesperson) of several proposals approved by JLab PAC. It offers a broad competence in the field of SiPM, originally developed for the IFR muon detector of SuperB: it has developed a dedicated front-end electronics and verified the response of SiPMs to single photon and to radiation-damage in a number of test-beam experiments. It has set up a laboratory for characterization and maintenance of the aerogel radiator.

2. Laboratori Nazionali di Frascati (contact M. Mirazita): it collaborates with the JLab since the early years of activity, contributing to build some Hall-B detectors and covering responsibility positions within the Collaborations CLAS and CLAS12; researchers of LNF were and are responsible for the various analyses of experimental data on the study of the 3D nucleon structure, and are among the proponents of further experiments with the 12 GeV beam of JLab. The LNF also offers a high-stability laser test-station for photodetector characterization, a clean room for delicate detector assembling, and a cutting-edge machine workshop where a prototype of the RICH, used in two test-beams at CERN, were realized.

3. INFN Section of Genova (contact P. Musico): since years develops electronic systems for acquisition of photo-detectors (PMT and SiPM) and charged particles (GEM) for applications in Nuclear Physics, Astrophysics and Medical Physics.

4. Istituto Superiore di Sanità - ISS (contact E. Cisbani): collaborates since years at Nuclear Physics experiments on the structure of the nucleon (at DESY and JLab) in particular by contributing to the Cherenkov detectors, RICH. Is involved in the construction of GEM tracking detectors and offers a evaporation chamber that can be used for depositing photo-conversion layers. It is involved in various research activities and R&D for Medical Physics.

5. INFN Section of Bari and University of Bari (contact R. De Leo): has been working for years in the construction of Cherenkov detectors and is collaborating to the realization of GEM tracking devices.

6. University of Roma I (contact G. Urciuoli): collaborates since years with the JLab and has developed reconstruction algorithms for Cherenkov light detectors. It contributes to several R&D programs based on SiPM detectors in Medical Physics (i.e. AXPET-CERN and TOPEM-INFN) and Astrophysics.

Other Institutions involved

1. Thomas Jefferson National Accelerator Facility (contact Valery Kubarovsky) of US Department of Energy: is the host laboratory for the facility foreseen in the project. Provides expertise in mechanics and electronics and advanced laboratories, in particular for the production of elliptical mirrors.

2. Budker Institute of Nuclear Physics (contact Evgeniy Kravchenko) and Institute of Catalysis (contact Alexander Danilyuk) of the Siberian Branch of the Russian Academy of Science: collaborate in the development of innovative techniques for production of large thickness and large area aerogel tiles with superior optical properties (high transparency).

3. Universidad Tecnica Federico Santa Maria de Valparaiso, Chile (contact William Brooks): contributes to the development of dedicated electronics for photo-detectors.

4. University of Glasgow, UK (contact Ken Livingston): works on data analysis and characterization of aerogel radiators and photomultipliers.

5. Argonne National Laboratory (contact Kawtar Hafidi) of US Department of Energy: works on simulations of the detector performance. It is developing large area and low cost photon detectors based on micro-channel plates, which are the faster and allow, in principle, higher spatial resolutions than photomultipliers.

6. Institut für Kernphysik of Mainz, Germany (contact Matthias Hoek): is involved in data acquisition programs and characterization of photomultipliers and aerogel radiators.

The project foresees collaborations with various public and private Italian subjects at the forefront of the detectors and electronics, as the FBK foundation of Trento for SiPM developement and electronic companies like CAEN, as well as with producers of printed circuit boards. The project is linked to activity in Medical Physics, in collaboration with medical diagnostics companies. Examples are the TOPEM experiment and the MBI (Molecular Breast Imaging) project, which brings together ISS, INFN and Metaltronica (a company that produces mammographies) funded by Regione Lazio (through its agency Filas) for the development of a scintimammograph, where solutions with SiPM are being considered.

Team and governance:

The project coordinates an international effort under the Italian leadership. The Italian team (24 people, of which 5 women researchers and 7 young researchers under 35 years old, corresponding to 15 FTE, whose 7 FTE are from staff members) brings together several experts in the field and presents a balanced mix of employees of the Universities and Italian EPR together with young researchers with fixed-term contracts.

The governance is made up of scientists who are actively involved in the areas of the project, who have extensive and complementary experience in related research fields and held positions of responsibility (see Attachment 1).

Responsible of the project: *Marco Contalbrigo, researcher at INFN Section of Ferrara, has covered several roles of responsibility in the study of the nucleon structure (Analysis Coordinator e Convenor of Transverse Physics at the HERMES experiment) and is co-spokesperson of two approved experiments at JLab, which will require the use of the RICH detector.*
Coordinates the work of the various units and the management of funds and personnel.

Scientific Responsible: *Marco Mirazita, researcher at Frascati National Laboratories, has participated to the construction of JLab detectors, he has been working for years in the study of the structure of the nucleon within the CLAS collaboration, is co-spokesperson of two approved experiments at JLab that require the construction of the RICH.*
He supervises the scientific activity, is responsible for the detector performance simulations and coordinates the collaboration with theoretical and experimental groups interested in the project.

Technical Assistant: *Sandro Tomassini, technologist at National Laboratories of Frascati, is an aeronautical engineer involved for many years in the mechanical and cryogenics designs for nuclear and particle physics experiments.*
Supervises the technological activities, is responsible for the installation of the detector and for the security.

Administrative Responsible: *Paola Fabbri, fifth level official administrative at the INFN - Sezione of Ferrara, deals with accounting, payments and personnel management and is Head of the Management Board and of the Fondo Economale of the INFN - Ferrara.*
Supervises the administrative activity and takes care of the financial book-keeping and final balance, and of the personnel contracts.

Technical Secretariat: *Donatella Pierluigi, fifth level administrative assistant of the Frascati National Laboratories, she worked in Management Secretariat and is currently a member of the Secretariat of the Research Division of the LNF.*
It deals with tenders and purchase orders.

Module 1 - Design and construction: *the responsible, Dario Orecchini, fourth level Technical Collaborator of Research Institutes (CTER) of Frascati National Laboratories, has a long*

experience of mechanical design and installation of detectors in experiments.
The module includes the activity related to the mechanics of the detector, in particular of design and mechanical construction (Frascati and JLab), mirror alignment (Ferrara) assembly and installation (JLab). The tasks of the module are the design and construction of the support structure and the gas container of the RICH, the support and alignment of the various optical elements and the positioning of the photo-detectors, adaptation of the apparatus and its services to the geometry of CLAS12.

Module 2 - Electronics: *the responsible Paolo Musico, first technologist at INFN section of Genova and head of the electronic workshop, is an expert in the design of electronics and FPGAs programming, has developed systems of acquisition of detectors for fundamental physics and applications in Nuclear Medicine.*
The module includes the activities linked to the development of the electronics for the readout of the photo-detectors, coordinating the current activities in integrated electronics for photon and tracking detectors (Genova), electronics for SiPM (Ferrara), electronics for silicon detectors (Rome I) and data-acquisition (JLab and Valparaiso). The tasks of the module are the production of the front-end electronics for the multi-anode photo-multipliers readout compatible with the DAQ of CLAS12 and the development of integrated electronics for innovative large-area low-cost photon detectors.

Module 3 - Optical Elements: *the responsible Raffaele De Leo, Full Professor at the University of Bari, has extensive experience in the development of photon detectors for fundamental physics.*
The module includes the activities linked to the production and collection of Cherenkov light, in particular the development of highly transparent aerogel radiator (collaboration between the Russian Institutions and Ferrara) and light mirrors of large area (collaboration between JLab and Frascati). The tasks of the module are obtaining highly transparent aerogel, which allows to separate pions and kaons with momenta up to 8 GeV/c and the multiple passage of the reflected light, and the realization of mirrors with minimum material budget to avoid degrading the performance of the CLAS12 detectors downstream of the RICH (time-of-flight and calorimeter).

Module 4 - Quality Control of Components: *the responsible Vincenzo Lucherini, research director of the National Laboratories of Frascati, was technical coordinator and spokesperson of the FINUDA experiment, has participated in the construction of the Cherenkov detector for the identification of kaons for the DIRAC experiment at CERN.*
The module includes the activities related to the component quality control, in particular characterization of the photomultipliers (Frascati, Glasgow and Mainz), aerogel (Ferrara and Bari) and mirrors (Frascati and JLab). The tasks of the module are the definition and organization of quality control procedures to be repeated on thousands of components and the construction of an on-line monitor (active during the data taking) of the stability and performance of the various elements.

Module 5 - Innovative Technologies: *the responsible Evaristo Cisbani, researcher at the Istituto Superiore di Sanità with role of research in the related group Sanità of INFN Rome, Head of the Unit of Physics and Nuclear Technology for Health, since years is involved in the development of detectors for (sub) nuclear physics and applications to human health.*
The module includes the activities linked to the use of innovative technologies of photodetection of large area and low cost, optimizing the use of new generation detectors (SiPM in Ferrara, GEM chambers at ISS and Bari and micro-channel plate at Argonne) with dedicated readout electronics. The task of the module is to evaluate the impact of new techniques for detecting photons in High-Energy Physics and for applications in Medical Physics (possibly involving companies working in the Italian Health System)

Status of the project:

The project is part of an ongoing activity which has already concluded the preparatory phase.

The first phase of prototyping, just ended, identified a solution capable of ensuring the required performance in time for the experiments on the 3D structure of the nucleon in the experimental Hall-B of JLab (see Attachment 2). The proposed solution involves a hybrid proximity and mirror-focusing RICH detector that uses aerogel as radiator and multi-anode photomultipliers. The Hamamatsu photomultipliers H8500 with readout electronics developed in Genova and based on MAROC3 chips have been successfully tested on the bench and with hadron beams.

The project foresees a second phase of prototyping dedicated to the development of integrated electronics, which allows on one hand to maximize the performance of the basic configuration, on the other hand the use of innovative photon detectors (SiPM, last generation micro-channel plate or GEM chambers with appropriate photoconverter) at affordable costs for the extension of the detector up to six sectors and/or at larger angular intervals. This would allow to obtain experimental data of great statistical accuracy in a kinematic region otherwise inaccessible and has potential spillovers in medical applications.

Structure of the project and realization times:

The project spans three years and includes the construction of the detector in time for the beginning of the data taking of dedicated experiments in Hall-B of JLab and a R&D activity on innovative techniques for large-area and low-cost photodetection with potential spillovers on fundamental and applied research.

First year: completion of Technical Design Report based on the results of the already performed tests on the prototype with hadron beams; procurement of major components that require long production times and large quantities to reduce costs, such as aerogel and photomultipliers; selection of the front-end chip (MAROC3, NINO, CLARO) for the readout of the RICH photomultipliers and of innovative detectors.

Second year: development of front-end electronics dedicated to the RICH and R&D with innovative detectors (SiPM, last generation micro-channel plate or GEM chambers with appropriate photoconverter); quality test of RICH detector components; mechanical structure and mirror construction; test with innovative detectors.

Third year: RICH detector assembly and installation completed with services; integration of front-end electronics in the Clas12 data-acquisition system; commissioning of the detector; evaluation and study of the impact of novel techniques on the detectors for Medical Physics.

Economic value, attraction of investments, socio-economic impact and economic and financial sustainability :

The costs of the project are summarized in Table S2.

Costs for the development and investment attraction

The estimated cost of the project is 5.79 million Euros, including the cost of staff (salaries) for the part of correlated activities that accounts for about 1 Meuro. Four annual research grants in each year of activity are foreseen, at a total cost of 276 kEuro.

The bulk of costs (3.65 million euro) covers the materials for the construction of the RICH in the basic configuration and for the R&D on innovative photodetection systems. The major fraction (2.44 million euro) is related to the components (aerogel and photomultipliers for the RICH and chips for the readout electronics) that has to be ordered during the first year of project, in order to ensure the production time and the subsequent quality control and assembly. The costs for material in the second and third year (about 0.6 million euro each) focus on the completion of the RICH redout and other RICH components like mirrors, mechanics and services, and the continuation of the research and development of innovative methodologies.

The project, under Italian leadership, has already attracted funding from foreign Institutions which cover part of the costs. The funds FOE7% (2.19 million euro) contribute to the costs in the first year of activity which includes the largest investments on the RICH and the starting phase of the R&D activities.

Various institutions involved have already received or budgeted for funds covering a part of the initial investment and the exposed costs of the second and third year of the project, both for personnel and material.

1. JLab: 2 M$ budgeted for building the RICH (material and general expenses)
2. Valparaiso: 400 k$ budgeted for building the RICH (electronics)
3. INFN: 190 keuro from the project I3HP funded by the UE for personnel (144 keuro) and R&D on SiPM (46 keuro on innovative methodologies)
4. JLab: 25 k$ obtained for R&D on SiPM (innovative methodologies)
5. Argonne: 360 k$ obtained for foreign personnel
6. Glasgow: 24 keuro from the project I3HP funded by the UE for foreign personnel

The budget of the three years of the project is presented in the following table:

Macro-category of expenses (keuro)	Year 1	Year 2	Year 3	Total	FOE %7	Co-funding (so far budgeted)	
Personnel in Italy (staff)	333	333	334	1000	-	1000	(1000)
Personnel in Italy (to he hired)	92	92	92	276	92	184	(144)
Aerogel	594	-	-	594	594	-	
Photomultipliers	1475	-	-	1475	633	842	(842)
RICH electronics	298	298	100	696	298	398	(298)
RICH mechanical Structure	-	90	-	90	-	90	(90)
Other RICH components	-	243	417	660	-	660	(563)
Innovative Methodologies	70	30	30	130	65	65	(65)
General Expenses (15%)	505	192	172	869	505	364	
Total	3367	1278	1145	5790	2187	3603	(3002)

The project foresees applications for financial coverage to the various involved Institutions, National Agencies, DOE and European funds to cover the uninsured costs of the second and third years of activity, for a total of 601 kEuro (10 % of the project cost). The capability to draw investment is demonstrated by the funding received so far.

The project foresees the use of already acquired components and existing infrastructures, partially build during the preparatory phase of the project and funded in Italy by INFN for a total amount of about 300 kEuro. Example is a laboratory for the characterization and maintenance of the aerogel radiator in Ferrara, and a test-bench for the characterization of multianode photomultipliers and a mobile structure for large prototypes, made in Laboratories of Frascati, together with the mentioned clean rooms and evaporation chamber.

Future costs of operation and maintenance for the life of the program/project

The costs of management and maintenance (both for personnel and material) are foreseen to be under the availability of ordinary funds of the involved Institutions.

Socio-economic impact

The project aims to contribute to the initial investment in the RICH detector components, designed in Italy, and to launch the development activity of the front-end electronics and R&D for innovative photodetection methods to be developed mainly in Italy.

The expected outcomes for Italy are

- to lead the construction of a state-of-the-art Cherenkov detector and significantly contribute to the most complete facility for the 3D study of the nucleon structure in the medium term maintaining a prominent role in this field;
- to perform research and developement of novel techniques for large-area and low-cost photodetection, interesting for both fundamental and applied research, and to assess the potential impact for medical diagnostics in collaboration with national companies: examples are the already funded MBI project with Metaltronica and the registered patent RM2008A000451.

Key words:

3D Structure of the Nucleon, QCD, Cherenkov Detectors, Large-area Photodetectors, Nuclear Medicine.

Elements and criteria proposed for the verification of the results:

Publications in international journals and talks at the conferences will report the intermediate achievements following the milestones of the project.

First year: Technical Design Report; choice of the RICH front-end electronic chip; conclusion of the tenders for the main components.

Second year: front-end electronic design; mechanical structure and mirror production; definition of procedures and first quality controls of the components; first test with innovative detectors.

Third year: front-end electronics integrated within Clas12 data-acquisition system; detector assembling and commissioning; conclusion of the tests on innovative photodetectors and impact assessment.

The final goals of the project are the construction and installation of the Clas12 RICH detector on time for the beginning of the physics data taking with expected significant outcomes in Hadronic Physics; and the impact assessment of innovative photodetection technologies with potential spillovers on fundamental (High-Energy Physics and Astrophysics) and applied science (Nuclear Medicine).

Attachment 1 – Curriculum Vitae of the Proponents:

Responsible of the Project:

Marco Contalbrigo is Researcher of INFN - Sezione di Ferrara since 01/02/2005.

After having contributed to Electro-Weak Physics topics of cosmological interest (neutrino oscillations and CP-violation in the kaon sector), he has been concentrating his activity in Hadronic and Spin Physics, a field nowadays in rapid evolution, aiming to the explanation of long-standing questions on the nucleon structure (spin puzzle, single-spin asymmetries, proton form-factors).

As gr. III Coordinator of INFN - Sezione di Ferrara, he has promoted the extension of the group activity, initially concentrated on HERMES experiment, to other experiments: PAX, PANDA and JLab12. He promotes high-quality laboratories in Ferrara (polarized targets, superconductive magnets and cryogenics, silicon detectors, aerogel radiators and characterization).

He has led with several responsible positions the activity of HERMES, a precursor experiment which has published several first-observations and has contributed to open a new branch of research in QCD with a current intense experimental and theoretical activity: the three-dimensional study of non-collinear parton dynamics and of novel parton distributions related to spin-orbit effects.

He has contributed to the PAX program about the use of polarized antiproton beams for unique measurements of nucleon transversity and time-like form factor phases and participates to the preparatory experiments on polarizing spin-filtering technique.

He is promoting the Spin Physics program for the 12 GeV upgrade which will make JLab the largest facility for deep-inelastic-scattering measurements starting from 2015. He has contributes to several approved experimental proposals for precise measurements of the spin effects and novel parton distributions with high luminosity and large acceptance spectrometers. He is leading the project of a large-area ring-imaging Cherenkov detector for hadron identification to access parton flavor decomposition.

Recent Professional Records:

2013-	**Project Leader** of the CLAS12 RICH detector
2011-	**Co-spokesperson** of the C12-11-111 experiment at JLab (conditionally approved)
2010-	**Analysis Coordinator** of the HERMES experiment at DESY
2009-	**Co-spokesperson** of the E-09-008 experiment at JLab
2009-	**INFN Local Responsible** of the JLab12 experiment
2008-	**Editorial Board Member** of the HERMES experiment
2008-2012	**Convenor** of physics with transverse polarization (HERMES)
2008-2009	**INFN Local Responsible** of the HERMES experiment
2006-2012	**Coordinator gr. III** of INFN - Sezione di Ferrara
2006-2010	**Vice-responsible** of the PAX detector
2006 (June)	**Period Coordinator** of the HERMES data-taking
2003-2006	**Convenor** of the inclusive physics (HERMES)
2002-2005	**Target Coordinator** of the HERMES experiment (selected periods)

10 Most Relevant Publications:

1. A. Airapetian et al. (Hermes), *Azimuthal distributions of charged hadrons, pions, and kaons produced in deep-inelastic scattering off unpolarized protons and deuterons*, **Phys. Rev. D 87**, 012010 (2013).
2. W. Augustyniak et al., *Polarization of a stored beam by spin-filtering* **Phys. Lett. B 718**, 64 (2012).
3. A. Airapetian et al. (Hermes), *Effects of transversity in deep-inelastic scattering by polarized protons*, **Phys. Lett. B 693**, 11 (2010).

4. A. Airapetian et al. (Hermes), *Observation of the Naive-T-odd Sivers Effect in Deep-Inelastic Scattering*, **Phys. Rev. Lett. 103**, 152002 (2009).
5. A. Airapetian et al. (Hermes), *Measurement of Parton Distributions of Strange Quarks in the Nucleon from Charged-Kaon Production in Deep-Inelastic Scattering on the Deuteron*, **Phys. Lett. B 666**, 446 (2008).
6. A. Airapetian et al. (Hermes), *Precise determination of the spin structure function g(1) of the proton, deuteron and neutron*, **Phys. Rev. D 75**, 012007 (2007).
7. A. Airapetian et al. (Hermes), *Single-spin asymmetries in semi-inclusive deep-inelastic scattering on a transversely polarized hydrogen target*, **Phys. Rev. Lett. 94**, 012002 (2005).
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Scientific Responsible:

Marco Mirazita is Researcher at the INFN Frascati National Laboratories.

He had research experiences at LNF (graduation thesis on nuclear photoabsorption), Bonn (PhD thesis on nuclear photoabsorption measurements) and JLab, where he is involved in hadronic physics experiments and in the study of the nucleon structure, using both real photon (deuteron photo-disintegration, search for exotic multi-quark states, photoproduction of strangeness) as well as virtual photons in Semi-Inclusive Deep Inelastic Scattering experiments (to access the transverse momentum dependent parton distribution functions).

Within the CLAS Collaboration of JLab, he has been responsible for various data analysis, member of analysis review committees and co-spokesperson of a Letter of Intent and of three new Proposals for measurements that will be performed after the 12 GeV upgrade of the JLab accelerator. He his one of the proponent of the construction of a RICH detector to be installed in the new CLAS12 spectrometer for the Hall-B of the JLab, for identification of kaons up to 8 GeV/c of momentum. He participated in the construction of a RICH prototype and in the beam test performed at CERN and at the Frascati Beam Test Facility.

He is author of about 140 publications on international reviews with referee (with about 40 citation on average and index h=39 on InSpires), he made about 15 oral presentations in International Conferences and 4 in National Conferences and he has been member of the local organizing committee of 4 International Conferences.

Professional Records:

1992-2005 - Research activity at the INFN for graduation, PhD and post-Doc.

December 2004 Term position at the INFN Frascati National Laboratories.

March 2009 Co-spokesperson of the two proposals E12-09-007a (Study of partonic distributions in SIDIS with H and D targets, approved) and E12-09-007b (Study of partonic distributions using K SIDIS, approved) for the Hall B at JLab.

May 2009 - Permanent position at the INFN Frascati National Laboratories.

January 2011 - Co-spokesperson of the proposal PR-11-003 (DVCS on the neutron with CLAS12 at 11 GeV, approved) for the Hall B at JLab.

May 2012 Local coordinator of the Italian JLAB12 Collaboration at the Frascati National Laboratories.

February 2013 - Nominated in the Board of Editors of the MIUR for the Nuclear and Particle Physics.

March 2013 - Distinguished Visitor at the Glasgow University.

Technical Assistant:

Sandro Tomassini is Technologist at the INFN Frascati National Laboratory.

He is senior Dr. aeronautical engineer with a long expertise in the field of mechanical design and large mechanical and civil installation plants for nuclear physics research. He has skills in the design of ultra high vacuum system, high precision mechanics, survey and alignment, Finite Element Analysis software, planning of large installation activity and coordination of large team work.

He has been deputy of Frascati Accelerator Division (technical field only). Recently he has been in charge of MEchanical Design, ALignment and Survey service (MEDALS) of the technical department for the INFN flagship project aiming at the construction of a super flavor factory in the Frascati area.

Main Professional Activities:

The SuperB Conceptual Design Report, site selection and cost analysis

The SPARX Technical Design Report, mechanical design and engineering of the facility, general layout of the civil infrastructures and coordination of the mechanical design

Mechanical design, engineering and alignment of the DAFNE upgrade at Frascati in order to implement the large Piwinsky angle and crab waist scheme

Mechanical design, engineering, mechanical installation and alignment of the SPARC project LINAC

FINUDA experiment: mechanical design of the vertex detector, mechanical design and coordination of the technical collaboration with the Japanese group at KEK for the manufacturing of the new time-of-flight system (TOF), coordination of the experimental setup assembly in DAFNE.

Module 1 Responsible - Design and Construction:

Dario Orecchini is Technical Collaborator of Research Institutions (CTER) of fourth INFN level at the Frascati National Laboratories

Hired on February 1987 at the Frascati National Laboratories of INFN at the Mechanical Design Service. He has been involved in the activity of design of detectors for the experimental physics, using software for 3D modelization and for structural analysis (FEM). He had responsibilities for market research for the detector components, assignment, test and supervision of the manufactures. He also had responsibilities for coordinating the installation of the equipments in many experimental collaborations. He completed several refresh courses in mechanical design and manufacturing and in cryogenic gases.

Professional Records:

1987, ALEPH experiment (CERN), collaboration to the muon chamber design.

1988, LVD experiment (LNGS), collaboration to the design of the Iarocci Tube chambers and of the support structure for the LST tests

1990, OBELIX experiment (CERN), participation to the design of the four supermodules HARGD for gamma detection and at the assembly phase coordination;

1991, Jet-Target experiment (Frascati), design and installation of a beam collimator

1992, winner of a CTER position at the INFN Frascati National Laboratories

1992, ROG experiment (Frascati), collaboration to the design, construction and installation of the rotating platform for the Nautilus gravitational antenna

1993, KLOE experiment (Frascati), collaboration to the definition of the detector, in particular for the electromagnetic calorimeter;

1995, FINUDA experiment (Frascati), general definition of the detector, of the straw-tube system, of the construction and assembly of the Clessidra central detector and of his cabling system and installation inside the detector;

1997, DEAR experiment (Frascati), definition of the support platform, supervision of the project, construction, assembly and alignment;

1998, DIRAC experiment (CERN), collaboration to the definition of the geometry of the mirrors for the Cerenkov detector, design and construction of the supporting structure of the detector and assembly.

2000, OPERA experiment (LNGS), design of the magnetic spectrometers, in particular the supporting structures, coordinating the construction and installation till 2007;

2008, PANDA experiment (GSI), design of the supporting structure for the Straw Tube detectors, definition of the systems for the gas and the electronics, design of the central tracking and vertex systems, supervision of the construction and assembly of the prototypes and of the various components;

2010, BESIII experiment (ISR), development of the design and construction of the small angle calorimeter;

2012, CLAS12 experiment (JLab), design, construction and installation at the CERN T9 beam line of the RICH prototype;

Module 2 Responsible - Electronics:

Paolo Musico is First Technologist at the Genova INFN unit.

Expert in electronic systems design and FPGA programming, he realized Data Acquisition Systems for detectors used in fundamental physics as well as for nuclear medical science applications. He developed high professional expertise in: - development of multichannel front-end, readout and trigger system for high energy physics experiments; - HDL languages used for FPGA and digital ASIC development; - high level programming languages C, C++; - standard buses as VME (VME64x), USB (2.0), PCI and other lower speed communication interfaces (I2C, SPI, 1-Wire,); - electronic CAD software for electrical schematic drawing, PCB design, analog and digital simulation, ASIC development.

His recent activity includes: - development of readout system for silicon detector of E835 experiment at Ferimilab; - partial development of digital ASIC for pixel detector control in the ATLAS experiment at CERN; - development of the trigger system for Borexino experiment at Gran Sasso laboratory; - development of mixed signal ASIC dedicated to multianodic photomultipiers (PMT) front-end and laboratory test setup; - development of electronic system to handle scintillating fibers timing counter of the MEG experiment at PSI; - development of front-end and High Voltage power supply for the directional optical module of the NEMO experiment; - development of the electronic system for a gamma camera used for both small animal SPECT and scintimammograpy. - development of electronic system to readout GEM chambers at JLAB in the framework of the 12 GeV upgrade: design of the front end card housing a dedicated 128 channel ASIC and of the readout module VME64x compliant which handles 2048 channels; - Development of electronic system to readout a SiPM matrix in the framework of a PET-SPECT detector for prostate multimodal imaging.

Professional Records:

September 1989 - December 1991 Worked at Marconi Italiana S.p.A.

January 1992 Hired as Technologist at I.N.F.N. Genova Unit

September 1994 Responsible of Electronic Department; direct responsible of 12 electronic technicians.

December 2005 First Technologist at the I.N.F.N Genova Unit

Module 3 Responsible - Optical elements:

Raffaele De Leo is Professor of Applied Physics at the Faculty of Biotechnology, University of Bari

Experimental Nuclear Physicist. Has taken experiments in this field in many Italian (Bari, 14 MeV neutrons; Catania, 2.5 MeV tandem; Milano, 40 MeV proton cyclotron) and International (Groningen, Kernfysisch

Versneller Instituut, 120 MeV cyclotron and 100 MeV/amu superconducting cyclotron; Munich, 20 MeV tandem; Osaka, Research Center for Nuclear Physics, 200 MeV cyclotron; Amburgo, Deutsche Elektronen Syncrotron, 27 Gev electron; Newport News (USA), Jefferson Lab., 6 GeV electrons) Laboratories. Has got experience in the following fields of Nuclear Physics: -spectroscopy of light-medium nuclei with many Nuclear Models: (roto-vibrationals, Interacting boson model, Random phase approximation, shell model, and others) - phenomenological nucleon-nucleus interaction, particularly related to the isospin dependent terms - static properties of nuclei(charge distributions, transition form factors, etc, etc,), Giant Resonances - nucleon spin constituents (constituent longitudinal and transverse quarks, sea quarks, gluons, ..).

He is an expert in development of detectors and photodetectors for TOF, threshold and Ring Imaging (RICH) Cherenkov with gas and aerogel radiators, single photon detection with PMT, MAMPT, HPD, CPM, organic, inorganic, wave length shifter scintillators for charged particles, neutrons and gamma rays. In 1995, he participated in the CERN experiments that demonstrated the feasibility of a RICH detector using aerogel radiator and in the construction of the world first RICH prototype able to identify pions and kaons up to 3 GeV/c momenta. A bigger RICH detector was successfully used in the HERMES experiment at DESY. He was also involved in the installation of a RICH detector in the Hall-A of JLab. Since 2000, he participates in the construction of tomographic emission tomography (PET) equipment for medical-imaging. As part of an International Collaboration, he developed an innovative concept of PET to allow the 3D reconstruction of the source of positrons with high efficiency while maintaining a high spatial and energy.

Co-author of over 200 scientific publications in international scientific journals of Nuclear Physics with "peer-reviewing", Supervisor of several master thesis and PhD in Physics and external reviewer of the PhD thesis in many Italian and foreign universities.

Recent Professional records:

1974-1987 Lecturer in General and Nuclear Physics at the Faculty of Science of the University of Bari

1987-1991 - Full Professor in General Physics at the Faculty of Sciences, University of Lecce

1989- "Qualified expert 3-degree" by the Italian Labour Inspectorate, for the control and measurement of ionizing radiation doses employed by workers in medical laboratories, research laboratories and nuclear facilities

1991 - Full Professor in Physics at the University of Bari

1995 - appointed "Professor of Excellence" by the Ministry of Scientific Research of Japan and called to lead an international group for experiments at the center of RCNP of Osaka.

2011 - appointed of the Italian National Commission for the prediction and prevention of major risks

Module 4 Responsible - Quality Control of Components:

Vincenzo Lucherini is Research Director of INFN at Frascati National Laboratories.

From 1978 to 1992 he worked in experiments in fundamental Nuclear Physics done at the Laboratori Nazionali di Frascati of INFN, using real photons with energies spanning from 120 MeV to 1300 MeV. Employing a gas Jet Target on the ADONE $e^+ - e^-$ collider, he performed also experiments of scattering of electrons of 1.0-1.5 GeV on ^{16}O nuclei. The aim of this research was to uncover the transition from a description of the nucleus as a system of bound nucleons, to a description in which also mesonic and subnucleonic degree of freedoms start to play a role.

In 1993 he joined the OBELIX experiment at CERN devoted to the study of the multi particles final states produced by low energy anti-protons (and anti-neutrons) from the LEAR accelerator annihilating on nuclei. Subsequently, after the completion of the OBELIX experiment, he joined the DIRAC experiment at the CERN PS from 1997 to 2001. The DIRAC experiment was devoted to the production of $\pi^+\pi^-$ atoms (and later on of π^+K^- atoms) in order to check the understanding of the Chiral Symmetry Breaking in QCD in a model independent way by measuring their lifetimes.

In 1994, he contributed at the elaboration of the two relevant proposals for the new DAΦNE collider at LNF, FINUDA and DEAR/SIDDHARTA and to the subsequent building of the corresponding experimental set up and measurements in the period 1995-2009. FINUDA was devoted to the study of the interactions of stopped K^- on several target nuclei, ranging from light to medium-light, resulting in the production of Hypernuclei. DEAR/SIDDHARTA experiments used the slow K^- produced at DAFNE to produce exotic-atoms, in which an e- is substituted by a K^-. By measuring with high precision the energy of the X-rays emitted in the radiative transition to the atom fundamental level, a direct test of Chiral Symmetry Breaking in systems with strangeness can be performed.

In 2007 he joined the PANDA collaboration. In PANDA he is member of the tracking group, and is involved in the construction and tests of the straw tube detector. In 2009 he joined the CLAS Collaboration of JLab, in which he is involved in the study, test and construction of the RICH detector proposed to enhance the particle identification of the CLAS12 spectrometer, to allow the discrimination of charged π and K up to 8 GeV/c.

Positions held and Responsibilities:

1984 to 1988. National Responsible of the MENFI experiment: mechanisms of nuclear excitation leading to fission;

1989 to 1991. National Responsible of the ASSO experiment: total photonuclear absorption of real photons in nuclei from the Delta resonance to 1.3 GeV;

1999-2007. Technical and Run Coordinator of the FINUDA experiment;

1999-2009. Responsible of the Kaon Detector in the DEAR/SIDDHARTA experiments;

2005-2010. Spokesman of the FINUDA experiment.

Module 5 Responsible - New Technologies:

Evaristo Cisbani is Head of the Nuclear Physics and Technology for Health unit of the Department Technology for Health.

His experimental research activities are devoted mainly to the study of the structure of the nucleons at JLab and DESY.

The challenging technologies and experience developed in the experimental subnuclear physics are exploited in the development of innovative instrumentation for human health: early tumour diagnosis (current project on molecular breast imaging with Metaltronica/SMI and INFN) and study of human diseases by small animal models (detectors for single photon emission); cancer radiotherapy (ionization chamber with micro pattern technology, current project on a proton-therapy linear accelerator facility with ENEA, IFO) and environmental radiological monitoring (compact ionizing radiation detectors on aerial platform). Main specific technological areas of interest are: development of radiation detectors, data acquisition and control system design, Montecarlo implementation.

Co-author of more than 150 publications in refereed journals. Co-inventor of the patent RM2008A000451 (11 August 2008) on a novel device for early diagnosis of small breast tumours by molecular imaging with radionuclides.

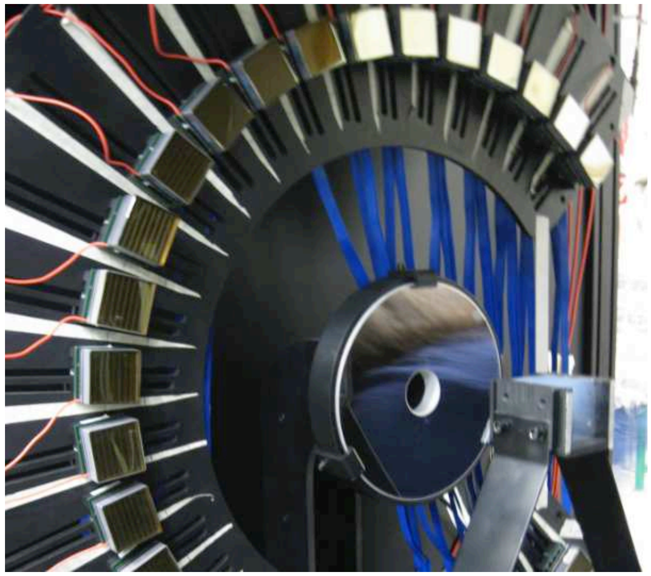
Recent Professional records:

15/01/2008 to now - ISS, Head of the Nuclear Physics and Technology for Health unit of the Department Technology for Health. Coordination of researches in the field of experimental Nuclear Physics, development of innovative instrumentation for Nuclear Medicine, Radiotherapy and Radiation Protection. Member of the III (Nuclear Physics) National Scientific Commission of the Italian National Institute of Nuclear Physics (INFN) since 24/06/2011. Member of the INFN/DAFNE Beam Test Facility Committee at Frascati National Laboratory (since Oct. 2012), Member of the Committee on Radiation Protection and Public Health of the OECD/NEA (since May 2011). Member of the National Commission for the Radioprotection Expert selection (from Sept.2009 to June/2012). Coordinator of the JLab12 Italian collaboration of INFN (from July/2008 to June/2012).

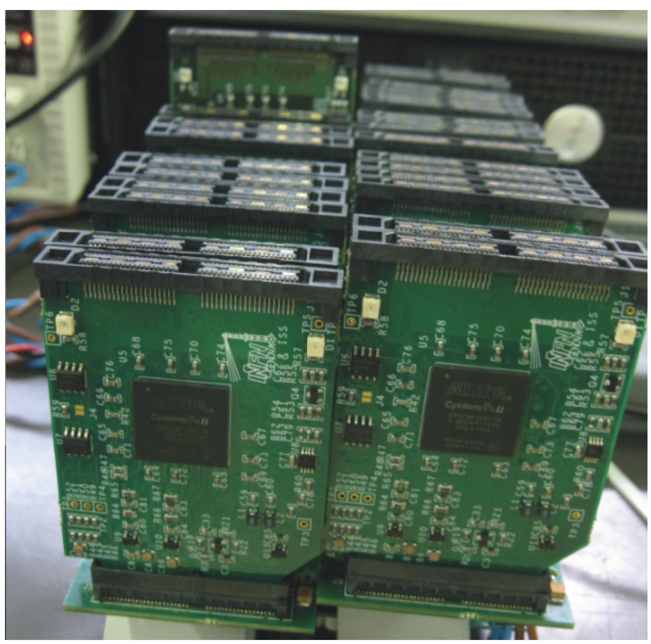
21/12/2004 - 14/01/2008 ISS, Senior Scientist (Nuclear Physicist, staff member). Development of instrumentation for application in molecular imaging with radionuclide, therapeutic proton beam diagnostic, radiological and atmospheric pollution monitoring, tracking system based on GEM (Gas Electron Multiplier) chambers for nuclear physics experiments. Co-spokesperson of 4 experiments on the nucleon structure running at the Thomas Jefferson National Laboratory (JLab) in USA. Member of the Italian working group on Quality Assurance in Nuclear Medicine (since 19/01/2007).

01/04/2001 - 20/12/2004 Telespazio, Senior Software Engineer, Earth Observation Department (staff member). Responsible of the development of algorithms for image enhancement and image quality control within the CosmoSkyMed space mission ground segment - project. Local coordinator of the ESA projects on the development of algorithms for early fire detection from MODIS and Meteosat-8 satellites images.

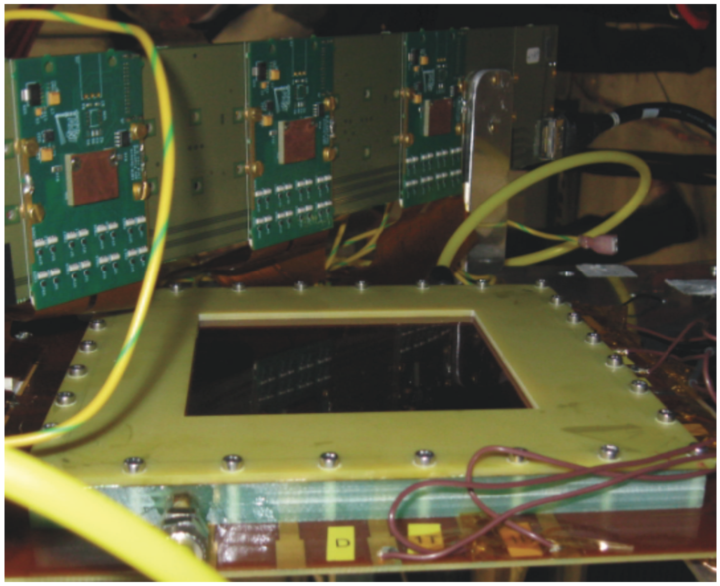
Attachment 2 – Technological Highlights of the Prototyping Phase:



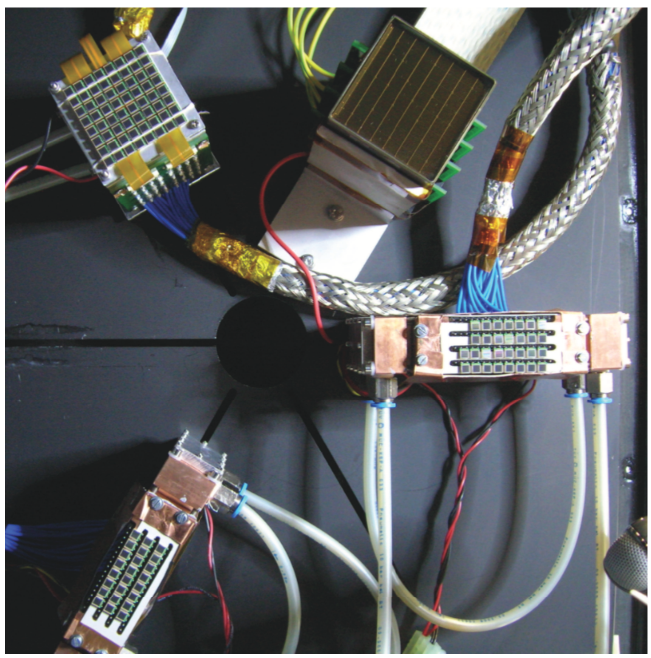
The RICH prototype based on 5x5 cm^2 large-area cost-effective Hamamatsu H8500 multi-anode photomultipliers aligned on a circle intercepting the Cherenkov cone. Although these photomultipliers are not designed for single-photon detection, the tests have demonstrated that they can work for Cherenkov detectors if used in conjunction with a dedicated electronics.



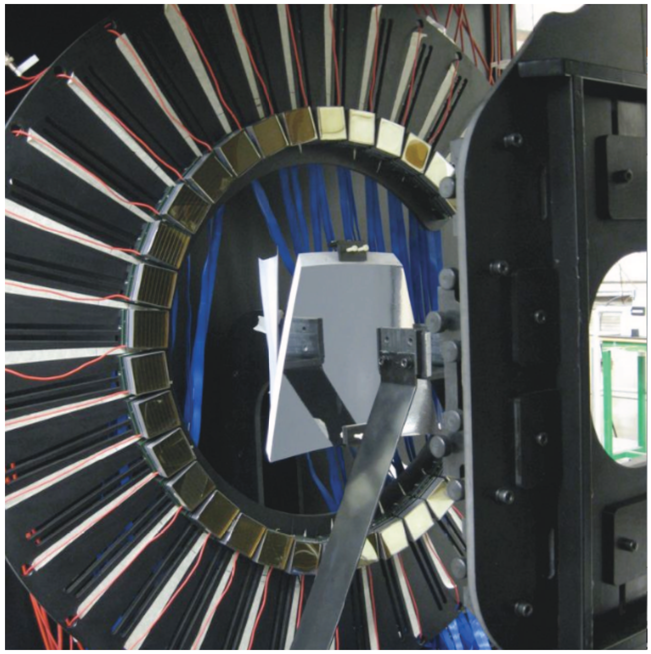
The prototype Front-End cards based on the MAROC3 chip and initially developed for medical applications (SPECT and scintimammography). Each 5x5 cm^2 card serves a 64 channel multi-anode PMT. The controller board can host up to 64 Front-End cards allowing to concentrate thousands of readout channels in a very compact layout.



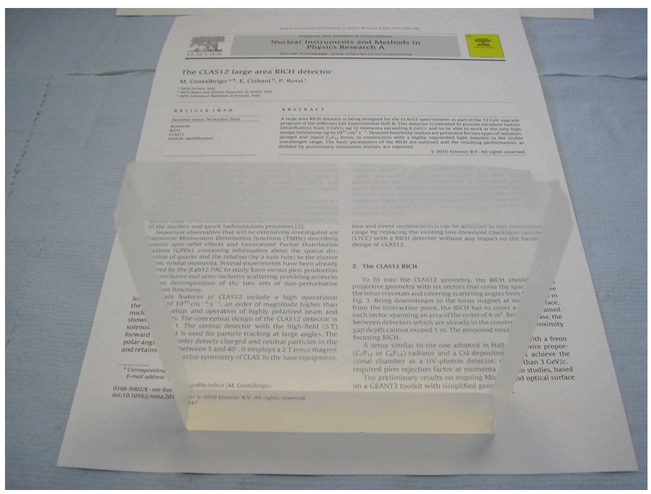
The 10x10 cm^2 GEM chamber with 2D strip readout (400 μm pitch) with high density (128 channel Front-End card) dedicated electronics used to track the beam charged particles. The very same electronics can be used to readout GEM detectors treated with a photo-conversion deposit to detect optical-photon.



The prototype comparing a commercial and two custom matrices of 3x3 mm^2 SiPM, all laying on a circle intercepting the Cherenkov cone. The SiPM signals are sent via coaxial cables to VME-like amplification and discrimination boards developed for the SuperB muon detector IFR. The matrices are controlled in temperature and can be cooled down to -25 degree via the use of water-cooled Peltier cells. Their achieved performances are comparable with the Hamamatsu H8500 multianode PMT.



The elliptical mirror produced at JLab with test-beam performances comparable to a glass mirror of high-optical quality but much lower density.



The 2 cm thick aerogel tile with n=1.05 refractive index. Thanks to the collaboration with the Russian Institutes a transmission length value larger than 5 cm was achieved at 400 nm wavelength, approaching the goal value of the project.

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The CLAS12 large area RICH detector

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ABSTRACT

A large area RICH detector is being designed for the CLAS12 spectrometer as part of the 12 GeV upgrade program of the Jefferson Lab Experimental Hall-B. This detector is intended to provide excellent hadron identification from 3 GeV/*c* up to momenta exceeding 8 GeV/*c* and to be able to work at the very high design luminosity-up to 10^{35} cm^2 s^{-1}. Detailed feasibility studies are presented for two types of radiators, aerogel and liquid C_6F_{14} freon, in conjunction with a highly segmented light detector in the visible wavelength range. The basic parameters of the RICH are outlined and the resulting performances, as defined by preliminary simulation studies, are reported.

1. Introduction

At the Thomas Jefferson National Accelerator Facility (Newport News, VA) Hall-B currently houses the CLAS detector [1], which will be modified and upgraded to CLAS12 to meet the basic requirements for the study of the structure of nucleons and nuclei with the CEBAF 12 GeV upgraded electron beam. The major focus of the Hall-B physics program at 12 GeV, starting in 2014, will be the study of the internal dynamics and 3-dimensional imaging of the nucleon and quark hadronization processes [2].

Important observables that will be extensively investigated are Transverse Momentum Distribution functions (TMDs) describing partonic spin–orbit effects and Generalized Parton Distribution functions (GPDs), containing information about the spatial distribution of quarks and the relation (by a sum rule) to the elusive partonic orbital momenta. Several experiments have been already approved by the JLab12 PAC to study kaon versus pion production in hard exclusive and semi-inclusive scattering, providing access to the flavor decomposition of the two sets of non-perturbative distribution functions.

The main features of CLAS12 include a high operational luminosity of 10^{35} cm^{-2} s^{-1}, an order of magnitude higher than the present setup, and operation of highly polarized beam and nucleon targets. The conceptual design of the CLAS12 detector is shown in Fig. 1. The central detector with the high-field (5 T) solenoid magnet is used for particle tracking at large angles. The forward spectrometer detects charged and neutral particles in the polar angle range between 5 and 40°. It employs a 2 T torus magnet and retains the six sector symmetry of CLAS. In the base equipment, hadron identification is achieved by Cherenkov and time-of-flight counters. Such detectors do not provide an as efficient kaon identification at large momenta, from 3 to 8 GeV/*c*, as a RICH detector. There the semi-inclusive kaon yield is one order of magnitude smaller than the pion yield, see Fig. 2, thus the required rejection factor for pions is around 1:1000 (corresponding to 4.7 sigma pion–kaon separation). Moreover the base equipment detectors do not allow the separation of kaons from protons in the 5–8 GeV/*c* momentum interval. Improved particle identification and event reconstruction can be achieved in this momentum range by replacing the existing low-threshold Cherenkov counter (LTCC) with a RICH detector without any impact on the baseline design of CLAS12.

2. The CLAS12 RICH

To fit into the CLAS12 geometry, the RICH should have a projective geometry with six sectors that cover the space between the torus cryostats and covering scattering angles from 5 to 40°, see Fig. 3. Being downstream to the torus magnet at more than 5 m from the interaction point, the RICH has to cover a large surface, each sector spanning an area of the order of 4 m^2. Being constrained between detectors which are already in the construction phase, the gap depth cannot exceed 1 m. The proposed solution is a proximity focusing RICH.

A setup similar to the one adopted in Hall-A [3], with a freon (C_5F_{12} or C_6F_{14}) radiator and a CsI-deposited multi-wire proportional chamber as a UV-photon detector, does not achieve the required pion rejection factor at momenta greater than 3 GeV/*c*.

The preliminary results on ongoing Monte Carlo studies, based on a GEANT3 toolkit with simplified geometry and optical surface

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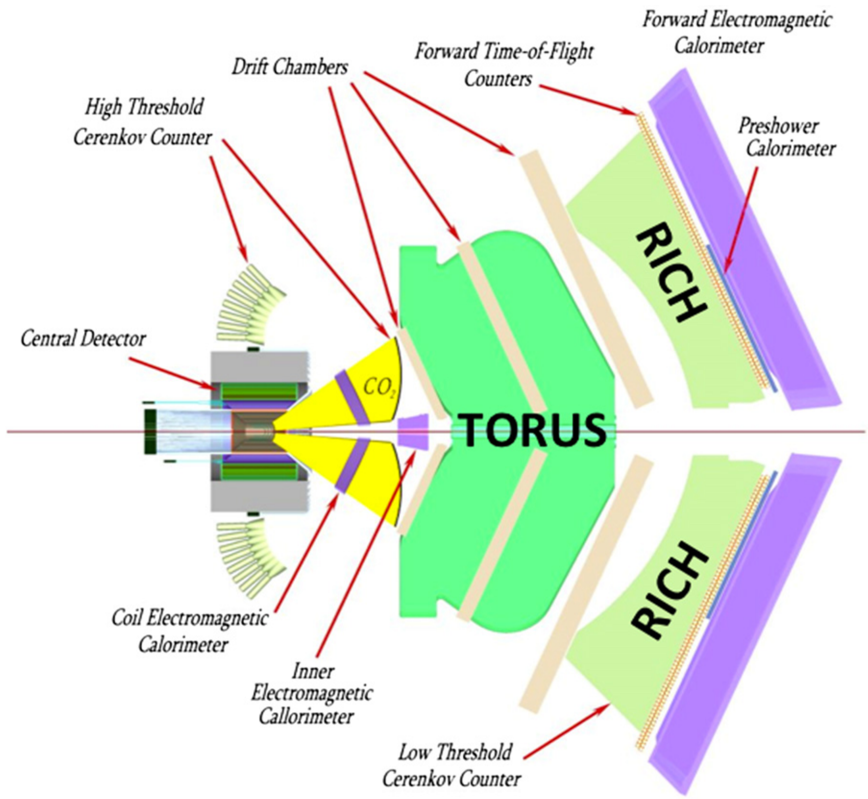

Fig. 1. Schematic of the CLAS12 detector. Improved particle identification can be achieved by replacing the existing low-threshold Cherenkov counter with a RICH detector.

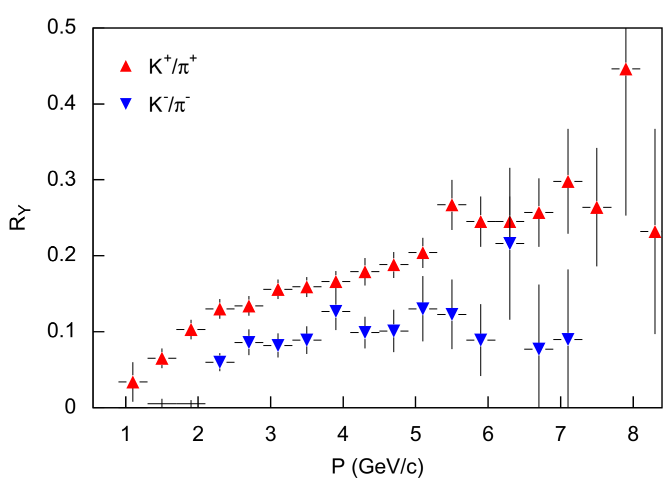

Fig. 2. Semi-inclusive kaon versus pion yield ratio R_Y.

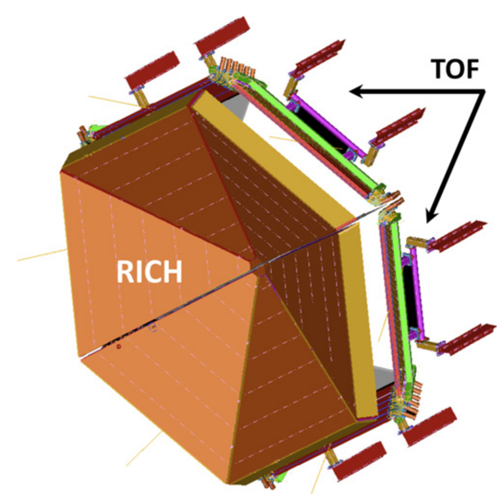

Fig. 3. Sketch of the six-sectors RICH layout, downstream of the CLAS12 torus and in front of the time-of-flight counter wall.

description, show that RICH requirements can be met by using aerogel as radiator and detecting light in the visible wavelength range. With respect to the use of freon in the UV region, such a solution offers a suitable refractive index, a lower chromatic error and a higher quantum efficiency in photon detection. The RICH performance has been studied as a function of the aerogel refractive index and thickness, as well as the photon detector pad size (minimum spatial resolution) for several geometrical configurations compatible with CLAS12. For aerogel, a now standard 40 mm transmission length (at a refractive index of 1.03 and 400 nm wavelength) has been assumed.

The study shows that, using a 3 cm thick aerogel with a refractive index of 1.03, a pion–kaon separation greater than 4 sigma up to 8 GeV/c momentum can be achieved if the detector pad size is less than 1×1 cm^2, see Fig. 4. The corresponding average number of detected photo-electrons is expected to be around 10, see Fig. 5. Although for larger aerogel thickness the number of photo-electrons increases, the also increased uncertainty on the photon emission point dominates the Cherenkov angle resolution and reduces the performance in pion–kaon separation. An increased number of photo-electrons could also be obtained with an increased aerogel refractive index, however, the RICH performance does not improve in the high-momentum range of interest, since at large refractive indexes the aerogel transparency is reduced (limiting the gain in photo-electrons) and the Cherenkov

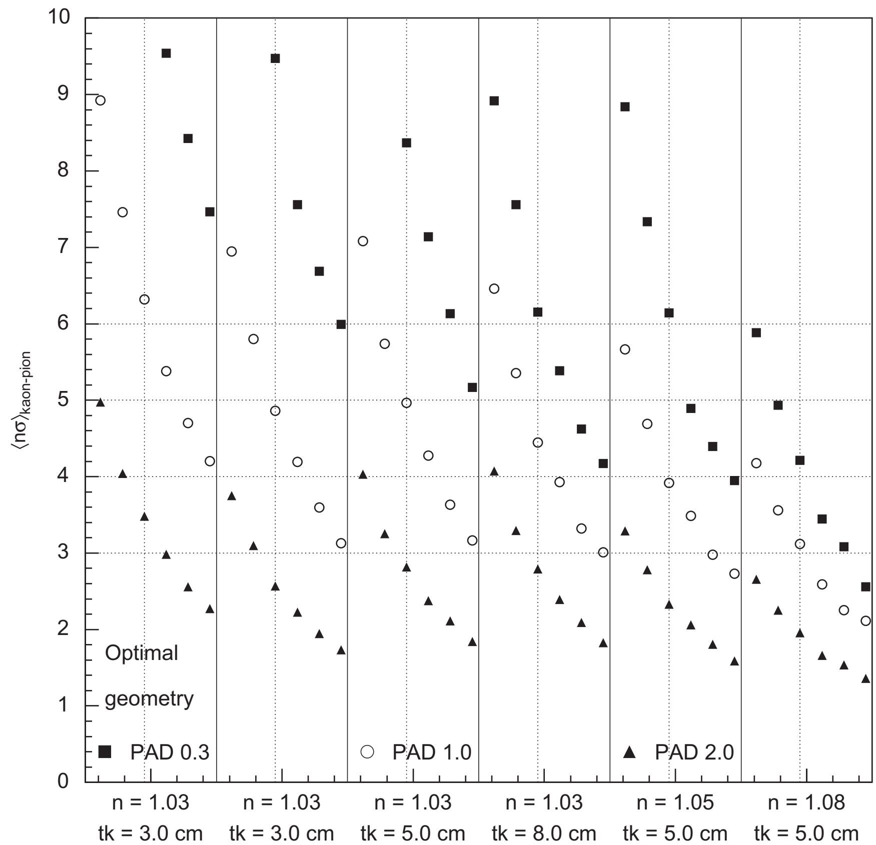

Fig. 4. Preliminary results of MC simulations of the CLAS12 RICH performance for different detector configurations. The study is performed for various refractive indexes (from 1.03 up to 1.08) and thicknesses (from 3 up to 8 cm) of the aerogel radiator, indicated on the horizontal axis. The optimal geometry corresponds to a photon detector extended to a region close to the beam-pipe not covered in the standard design. For each configuration, the average number of sigmas in pion–kaon separation is plotted in the 5–8 GeV/*c* momentum range, at intervals of 0.5 GeV/*c*. Three photon detector pad sizes are considered (2×2, 1×1 and 0.3×0.3 cm^2), indicated by the different symbols.

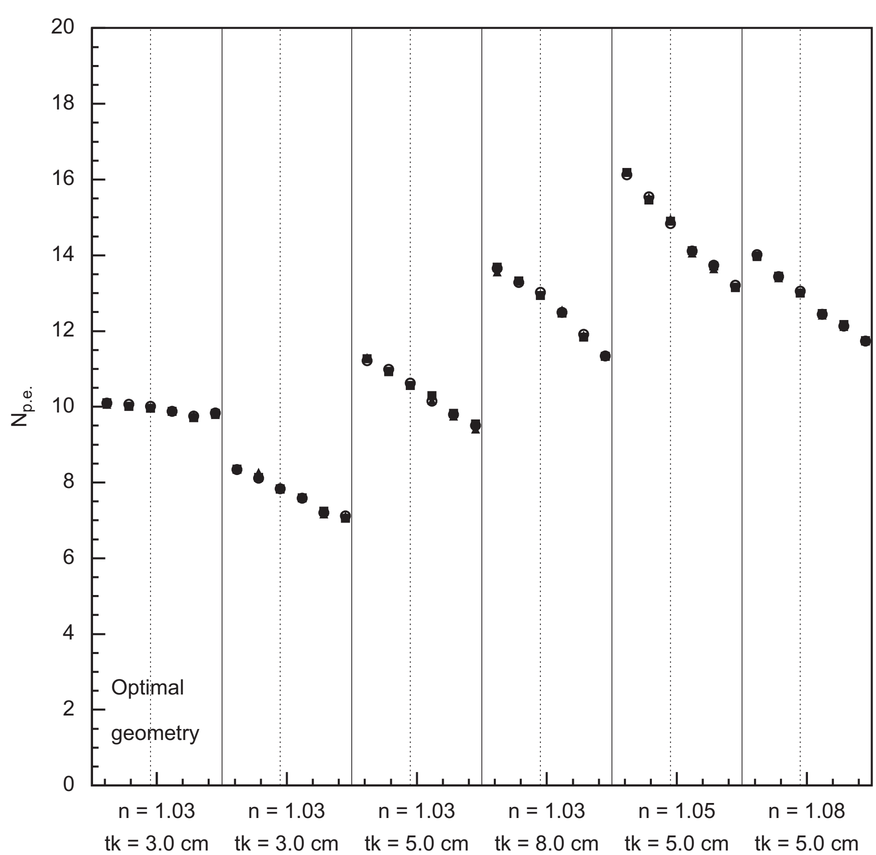

Fig. 5. The average number of photo-electrons is plotted in the 5–8 GeV/*c* momentum range, at intervals of 0.5 GeV/*c*, for different detector configurations. See Fig. 4 for detailed explanations.

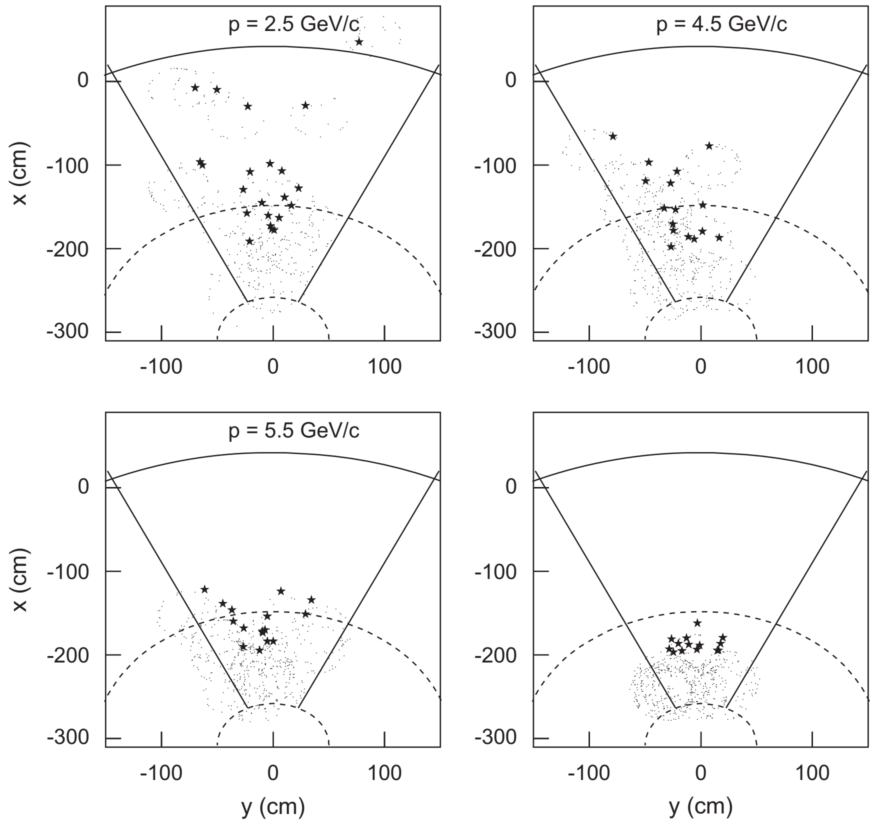

Fig. 6. Spatial distributions of the particle impact point at the RICH entrance (stars) and gamma impact point at the detector surface (dots) for few overlapping events. The plots distinguish among particles of increasing average momentum, from 2.5 up to 7.5 GeV/*c*, from top to bottom and left to right. High-momentum particles concentrate in a limited forward region close to the beam line, arbitrarily delimited by the two dashed arcs just for illustration.

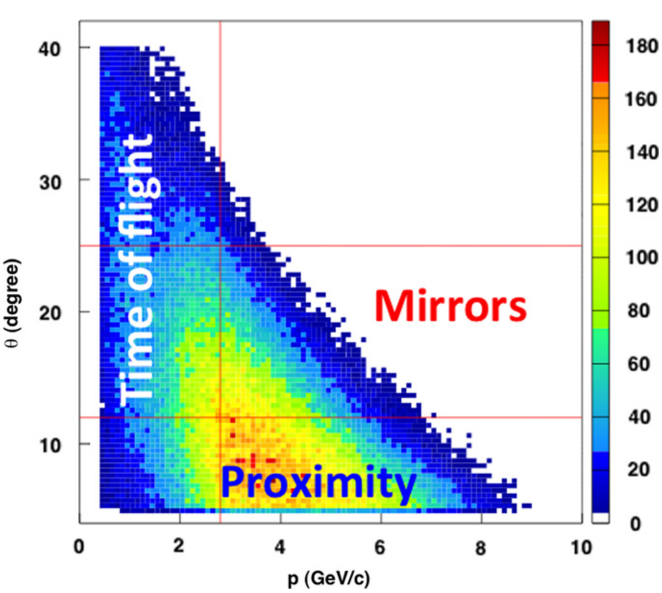

Fig. 7. Scattering angle versus momentum of the hadrons in the CLAS12 forward spectrometer. The TOF counters cover the low momentum region, a proximity focusing RICH is suitable for the high-momentum region at forward scattering angles, while at intermediate momenta and large scattering angles a mirror system could be the most effective option. The boundaries in scattering angle are arbitrarily defined by the two horizontal lines just for illustration.

angles of pion and kaon become closer. A larger aerogel thickness can be effective in the case of separated radiator layers or radiators with variable refractive index, and aerogels with increased transparency at large refractive indexes start to be available. The study of these options is ongoing.

The study shows the importance of extending the photon detector to a region close to the beam-pipe not covered in the standard design, in order to catch the full Cherenkov ring of high-momentum particles. In this way the average number of photo-electrons versus the momentum of the particle is stable, and one gets the best performance up to 8 GeV/*c* momentum.

3. Photon detection options

In order to match a (less than) $1 \times 1\ cm^2$ photon detector resolution, multi-anode photomultipliers (MA-PMTs) or silicon photomultipliers (SiPM) have been considered, although the recent development of hybrid photomultipliers for the BELLE upgrade [4] is being followed with interest.

Among MA-PMTs, the R7600 by Hamamatsu is optimized for single-photon detection and has been already in use with success [5]. However, light concentrators have to be developed to compensate the large dead area (around 51%) of this photomultiplier. It is not clear if the use of lens telescopes, as the ones used in the COMPASS RICH [5], can cope with the relatively large Cherenkov angles obtained with aerogels and the broad range of particle impact angles at the RICH surface due to the bending in the CLAS12 toroidal field. Although H8500 MA-PMT by Hamamatsu is not optimized for single-photon detection, it is being considered as a suitable option thanks to its excellent packing factor (89%). Several tests are ongoing on H8500 by various collaborations with promising results (see e.g. Refs. [6,7]).

The SiPM option can better cope with the fringe fields of the torus magnet, which are estimated to be of the order of 50 Gauss in the photon detector region. SiPMs are compact and robust devices, insensitive to external magnetic fields, and have high spatial resolution and quantum efficiency. However, to suppress the high dark-current counting rate, the DAQ system should be designed with tight (of the order of few nanoseconds) coincidence time-windows and a sub-nanosecond time resolution. In addition, SiPMs require light concentrators since the actual cost per unit of surface is higher than for MA-PMTs and cannot be used in all environments since they are highly sensitive to radiation damage [8].

Various types of photomultipliers are being tested, and a prototype is being realized to compare the photon detector options under the experimental conditions foreseen for CLAS12.

The use of aerogel as radiator and the detection of light at visible wavelengths is an expensive solution. Work is in progress to limit the area of photon detection to about 1 m^2 per sector. The approach is to instrument a limited area around the beam line to have direct detection in the forward region at high momenta, see Fig. 6. At large angles and lower momenta, where the requirements on RICH performance can be loosened, a system of focusing mirrors catch the light and reflect it toward the photon detector. Such a solution would better decouple the RICH from the downstream time-of-flight system (TOF), since the mirrors minimize the amount of material and the effect on TOF resolution, while the photon detector only covers a spatial region where a large fraction of particle momenta is above the TOF working range, see Fig. 7. The challenging task is to avoid multiple passages of the reflected Cherenkov photons through the radiator, which will cause a dramatic loss in light intensity due to the limited aerogel transparency.

4. Conclusions

In summary, unambiguous kaon identification is needed for a complete study of exclusive and semi-inclusive reactions in Hall-B with the CLAS12 detector. A significant improvement in the particle identification in the 3 to 8 GeV/c momentum range can be obtained by replacing the low-threshold Cherenkov counter with a proximity focusing RICH. Preliminary studies show that the use of an aerogel radiator (with $n=1.03$ and 3 cm thickness) and a photon detector for visible light with pixel sizes smaller than 1×1 cm^2 matches the requirement of greater than 4 sigma separation between pions and kaons (about 1:1000 pion rejection factor). Work is in progress to obtain a more realistic simulation based on GEANT4 toolkit with refined geometry and optical properties of the surfaces. A prototype is being built to verify the expected performances and test the most promising options for the photon detection and geometry configurations in order to minimize the total instrumented surface (and therefore the cost).

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