02.06.2008, 11:30

Alessandria, Italy, Dipartimento di scienze e technologie avanzate, Universita del Piemonte Orientale and INFN sezione Torino,
D. Panzieri

Amsterdam, Netherlands. NIKHEF,
H. van der Graaf

Annecy-le-Vieux, France, Laqboratoire d'Annecy-le-Vieux de Physique des Particules (LAPP),
C. Adloff, S. Cap, M. Chefdeville, C. Drancourt, A. Espargiliere, R. Gallet, N. Geffroy, C. Girard, R. Hermel, Y. Karyotakis, J. Prast

Arlington, USA, Department of Physics, University of Texas,
A. Brandt, K. De, A. Farbin, J. Li, J.R. Smith, A. White, J. Yu

Athens, Greece, Department of Nuclear and Elementary Particle Physics, University of Athens,
D. Fassouliots, P. Ioannou, C. Kourkoumelis, K. Nikolopoulos, G. Tzanakos, G. Voulgaris,

Athens, Greece, Institute of Nuclear Physics, National Centre for Science Research "Demokritos",
G. Daskalakis, G. Fanourakis, T. Geralis, A. Kyriakis, A. Markou

Athens, Greece, Physics Department, National Technical University of Athens,
T. Alexopoulos, F. Antoniou, T. Argyropoulos, E. Dris, E. Gazis, S. Maltezos, E. Mountricha, C. Tsarouchas, G. Tsipolitis

Aveiro, Portugal, Laboratorio de Física Nuclear y Astropartículas, Universidade de Aveiro,
C. Azevedo, A. Ferreira, H. Natal de Luz. C. Oliveira, J. Veloso,

Barcelona, Spain, Institut de Fisica d'Altes Energies, Universtitat Autònoma de Barcelona,
T. Lux, F. Sanchez

Bari, Italy, Sezione di Bari, INFN,
G. Iaselli, A. Ranieri

Bonn, Germany, Physikalisches Institut, Rheinische Friedrich-Wilhelms Universität,
K. Desch, J. Kaminski, M. Killenberg

Braunschweig, Germany, Physikalisch Technische Bundesanstalt,
V. Dangendorf

Budapest, Hungary, Institute of Physics, Eötvös Loránd University,
D. Varga

Bursa, Turkey, Institute for Natural and Applied Sciences, Uludag University,
I. Tapan, E.N. Ozmutlu, O. Sahin

Cagliari, Italy, Dipartimento di Fisica dell'Universtà and sezione INFN,
W. Bonivento, A. Cardini, A. Lai, R. Oldeman,

Coimbra, Portugal, Departemento de Fisica, Universidade de Coimbra,
F. Amaro, A. Conceição, L. Fernandes, J. dos Santos, J. Maia, C. Monteiro,

Coimbra, Portugal, Laboratorio de Instrumentacao e Fisica Experimental de Particulas,
R. Ferreira Marques, P. Fonte

Columbia, USA, Department of Physics and Astronomy, University of South Carolina,
W. Park, R. Petti, M. Purohit, A. Trivedi, J. Wilson

Frascati, Italy, Laboratori Nazionale di Frascati, INFN,
G. Bencivenni, D. Domenici, G. Felici, M. Poli Lener

Freiburg, Germany, Physikalisches Institut, Albert-Ludwigs Universität,
A. Bamberger, U. Renz

Geneva, Switzerland, CERN,
M. Alfonsi, M. Capeans, G. Croci, R. De Oliveira, S. Duarte Pinto, P. Iengo, L. Ropelewski, H. Taureg,
E. van der Bij, R. Veenhof, J. Wotschack

Geneva, Switzerland, Département de Physique Nucléaire et Corpusculaire, Universite de Genève,
A. Blondel, S. Bravar, D. Ferrere, A. Ferrero, M. Ravonel

Grenoble, France, Laboratoire de Physique Subatomique et de Cosmologie (LPSC),
G. Bosson, O. Bourrion, O. Guillaudin, F. Mayet, J-P. Richer, D. Santos, A. Trichet

Hefei, China, University of Science and Technology of China,
H. Chen, C. Li, M. Shao, Y. Sun, X. Wang, Z. Xu, Z. Zhao

Helsinki, Finnland, Hesinki Institute of Physics,
F. Garcia, T. Hilden, J. Heino, M. Kalliokoski, K. Kurvinen, R. Lauhakangas, R. Orava

Kolkata, India, Saha Institute of Nuclear Physics,
S. Mukhopadhyay, N. Majumdar, S. Bhattacharya

Lanzhou, China, School of Nuclear Science and Technology, Lanzhou University,
B. Hu, D. Li, H. Yang, L. Yang, X. Zhang, Yi Zhang, Yu Zhang

Melbourne, USA, Department of Physics and Space Science, Florida Institute of Technology,
K. Gnanvo, H.Hohlmann

Mexico City, Mexico, Instituto de Ciencias Nucleares, Universidad Nacional Autonoma de Mexico,
R. Alfaro, D. Mayani, G. Paic, E. Patino, V. Peskov (also Ecole Nationale Superieure des Mines, St Etienne, France)

Montreal, Canada, Département de physique, Université de Montréal,
A. Houdayer, C. Leroy, J-P. Martin

Műnchen, Germany, Physik Department, Technische Universität,
B. Ketzer, X. Zhang

Műnchen, Germany, Max Planck Institut fűr Physik,
F.Simon

Formatted: French (France)
Formatted: French (France)
Formatted: Space After: 10 pt
Formatted: Font: Not Bold, French (France)
Formatted: French (France)
Formatted: French (France)
Formatted: Font: Bold
Formatted: Normal
Formatted: French (France)
Formatted: French (France)
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: French (France)
Formatted: Font: Not Bold, French (France)
Formatted: French (France)
Formatted: French (France)
Formatted: French (France)
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: English (U.K.)
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: French (France)
Formatted: Font: Not Bold, French (France)
Formatted: French (France)
Formatted: French (France)
Formatted: French (France)
Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Right: 0.25"

Naples, Italy, Dipartimento di Scienze Fisiche dell'Universtà and sezione INFN,
A. Aloisio, M. Alviggi, D. Della Volpe, R. Giordano

New Haven, USA, Department of Physics, Yale University,
R. Majka, N. Smirnow

Novosibirsk, Russia, Budker Institute of Nuclear Physics,
A. Bondar, A. Buzulutskov, D. Pavlyuchenko, L. Shekhtman, Yu. Tikhonov

Ottawa, Canada, Department of Physics, Carleton University,
A. Bellerive, M.S. Dixit (also at TRIUMF, Vancouver, Canada)

Pavia, Italy, TERA Foundation,
N. Malakov, J. Samarati, F. Sauli, D. Watts

Rehovot, Israel, Radiation Detection Physics Laboratory, The Weizmann Institute of Sciences,
A. Breskin, R. Chechik, M. Cortesi, A. Lyashenko, J. Miyamoto,

Rome, Italy, Sanita Group, INFN,
E. Cisbani, F. Cusanno, S. Frullani, M. Iodice, F. Garibaldi, G.M. Urciuoli

Saclay, France, Institut de recherche sur les lois fondamentales de l'Univers, CEA,
S. Andriamonje, D. Attié, S. Aune, P. Colas, A. Delbart, E. Delagnes, J. Derré, E. Ferrer, A. Giganon,
I. Giomataris, F. Jeanneau, F. Kunne, D. Neyert, J. Pancin, M. Titov

Sheffiled, Great Britain, Physics Department, University of Sheffield,
E. Daw, P. Lightfoot, S. Paganis, N. Spooner

Siena, Italy, Dipartimento di Fisica dell'Università and INFN Sezione di Pisa,
M.G. Bagliese, R. Cecchi, S. Lami, G.Latino, E.Oliveri, A.Scribano, N.Turini

St Etienne, France, Ecole Nationale Superieure des Mines,
V. Peskov

St Petersburg, Russia, Petersburg Nuclear Physics Institute,
V. Grachev, A. Khanzadeev, B. Komkov, V. Nikulin, E. Roschin

Thessaloniki, Greece, Physics Department Aristotle University of Thessaloniki,
C. Petridou, D. Sampsonidis

Trieste, Italy, Dipartimento di Fisica dell'Università and Sezione INFN,
A. Bressan, S. Dalla Torre, G. Giacomini, G. Menon, J. Polak, F. Tessarotto

Tucson, USA, Department of Physics, University of Arizona,
E. Cheu, K. Johns, V. Kaushik, M. Shupe, J. Steinberg, D. Tompkins, E. Varnes

Tunis, Tunisia, Centre Nationale des Sciences et Technologies Nucléaire ,
A. Barbouchi, N. Kahlaoui

Upton, USA, Brookhaven National Laboratory,
B. Azmoun, S. Stoll, C. Woody, B. Yu, V. Polychronakos

Valencia, Spain, Instituto de Fisica Corpuscular,
M. Ball, J.J. Gomez-Cadenas, F. Monrabal, J.M-A. Simon, N. Yahlali

Zaragoza, Spain, Laboratorio de Física Nuclear y Astropartículas, Universidad de Zaragoza ,
J.M. Carmona, S. Cebrian, T. Dafni, J. Galan, F.J. Iguaz, I.G. Irastorza, J. Morales, G. Luzon, J. Ruz,
A. Tomas

Formatted: Font: Bold
Formatted: Font: Bold
Formatted: Space After: 10 pt
Formatted: English (U.K.)

Contents

Formatted: Font: (Default) CMCSC10
Formatted: Justified
Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)
Formatted: Space After: 10 pt, Line spacing: Multiple 1.15 li, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers
Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)
Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)
Formatted: Right: 0.25"

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.S.)

Formatted: Font: 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, English (U.S.)

Formatted: Font: (Default) Calibri, English (U.S.)

Formatted: Font: 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.S.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.S.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: 11 pt, English (U.K.)

Formatted ... [1]

Formatted: Font: 11 pt, English (U.K.)

Formatted ... [2]

Formatted: Font: 11 pt, English (U.K.)

Formatted ... [3]

Formatted: Font: 11 pt, English (U.K.)

Formatted ... [4]

Formatted ... [5]

Formatted ... [6]

Formatted ... [7]

Formatted ... [8]

Formatted ... [9]

Formatted ... [10]

Formatted ... [11]

Formatted ... [12]

Formatted: English (U.K.)

Formatted: Justified

Formatted: Right: 0.25"

I. Executive Summary

The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for modern applications in basic and applied research.

Advances in particle physics have always been enabled by parallel advances in radiation-detector technology. Radiation detection and imaging with gas-avalanche detectors, capable of economically covering large detection volumes with a low material budget, has been playing an important role in many fields. Besides their massive use in particle-physics experiments, gaseous detectors are employed in many other fields; among them: astro-particle and nuclear physics, medical imaging, material science, security inspection.

While extensively employed at the LHC, RHIC, and other advanced HEP experiments, present gaseous detectors (wire-chambers, drift-tubes, resistive-plate chambers and others) have limitations which may prevent their use in future experiments. Present techniques will not be capable to cope with the expected high- flux and high-repetition rates and often will not provide the needed space point resolution. For example, point resolution in large-volume TPCs will suffer from high fluxes of back-flowing ions and from the limited granularity of the readout; particle-trackers will not withstand the high fluxes and will require large-area high-resolution localization; calorimeters will need better and faster sampling elements; Cherenkov detectors in particle and astro-particle experiments will require more efficient large-area photon detectors; rare-event cryogenic noble-liquid detectors for dark-matter, neutrino-physics double-beta decay and other searches will require large-volume detectors with adequate economic low-radioactivity readout elements. Besides resolutions - radiation hardness, rate capability and economic aspects related to production costs are of major concern.

Formatted: Justified

The possibility to produce micro-structured semi-conductor devices (with structure sizes of tens of microns) and corresponding highly integrated readout electronics led to the success of semi-conductor (in particular silicon) detectors to achieve unprecedented space-point resolution. Micro-structured gas-amplification structures now open the possibility to apply the same technology to gaseous detectors and enable a plethora of new detector concepts and applications.

Formatted: Font: (Default) Calibri

The invention of Micro-Pattern Gas Detectors (MPGD), in particular the Gas Electron Multiplier (GEM), other hole-multipliers and the Micro-Mesh Gaseous Structure (Micromegas), and more recently other micro pattern detector schemes, offers the potential to develop new gaseous detectors with unprecedented spatial resolution, high rate capability, large sensitive area, operation stability and radiation hardness. In some applications requiring very large-area coverage with moderate spatial resolutions, more crude Macro-patterned detectors, e.g. Thick-GEMs (THGEM) or patterned resistive-plate devices could offer an interesting and economic solution. Compared to past detector techniques, the new concepts can be industrially materialized. In addition, the availability of highly integrated amplification and readout electronics allows for the design of gas-detector systems with channel densities comparable to that of modern silicon detectors. Modern wafer post-processing allows for the integration of gas-amplification structures directly on top of a pixelized readout chip. Thanks to these recent developments, particle detection through the *ionization of gas* has large fields of application in future particle, nuclear and astro-particle physics experiments with and without accelerators.

Formatted: Font: (Default) Calibri

Formatted: Right: 0.25"

We propose the formation of a world-wide collaboration for R&D on MPGDs, RD51, aiming at efficient coordinated effort to advance the development of MPGDs and associated technologies. The RD51 collaboration involves 46 Universities and Research Laboratories from mm countries in Europe, America, and Asia. All partners are already actively pursuing either basic- or application-oriented R&D involving a variety of MPGD concepts. The collaboration will establish common goals, experimental and simulation tools, characterization concepts and methods, irradiation facilities at CERN, methods and infrastructures for MPGD production etc. An intensified communication between the cooperating teams will be fostered in order to better understand and solve physics and technical issues and to solve common problems connected e.g. to detector optimization, discharge protection, ageing and radiation hardness, optimal choice and characterization of gas mixtures, availability of adequate simulation tools, optimized readout electronics and readout integration with detectors, detector production aspects.

The main objective of the R&D programme is to advance technological development and application of the Micropattern Gas Detectors.

The proposed research work is organized in 7 working groups packages (WGP) each; a working group will be established for each WP, with its own work plan and a defined list of tasks. Working-group conveners will coordinate the R&D tasks of the respective working groups. They will nominate responsible persons for each individual task; they will be also responsible for proper communication between their working-group members and with other working groups.

The 7 working groups packages are shown in Figure 1. Their overall objectives and tasks are summarized and described below.

Technological Aspects and Development of New Detector Structures MPGD Technology (WPWG1): The objective of this WPWG is the optimization of fabrication methods for MPGDs and, the development of new multiplier geometries and techniques., and progress towards industrialization and cost effectiveness. The sSpecific tasks in this working group package are: (1) the development of techniques to manufacture large area modulesMPGDs with reduced material budget; (2), the optimization of MPGD fabrication procedures for bulk Micromegas, micro bulk Micromegas and single-mask GEMs; (3) further development of new geometriesin order to reduce cost and allow for larger throughput and the industrialization of these procedures. And multiplier techniquesR&D towards new, improved structures, such as Thick GEMs (THGEM), Resistive Electrode Thick GEMs (RETGEM), and Micro Hole And Strip Plates (MHSP), charge-dispersive readout and will be carried out. The recent development of integrationng of gas-amplification structures on top of a CMOS readout chip by wafer post-processing (InGrid); and (4) the development of radiation-hard detectors for the sLHC and ILC, will be further pursued and optimized.

Common Characterization and Physics Issues (WG2): In this WG, a common effort towards the development of common standards for the characterization and comparison of different technologies will be made. The collective knowledge on the physics of discharges in MPGD detectors will be bundled and solutions towards more efficient discharge protection will be made. Systematic studies on ageing and radiation hardness of MPGDs will be performed and a common database on radiation hardness and ageing properties of materials will be created in order to arrive at radiation-hard detectors beyond the limits of present devices. The tasks in the WG are: (1) Development of common test standards (comparison of different technologies in different laboratories; (2) Discharge studies and spark-protection developments for MPGDs; (3) Generic aging and material radiation-hardness studies (creation of database of "radiation-hard" materials & detectors depending on application) commercially available materials, cleanliness requirements, validation tests for final detector modules, gas system construction, working remedies); (4)

Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Default Paragraph Font, Font:
Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Default Paragraph Font, Font:
Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Strong, Font: (Default) Calibri, Not Bold, Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri
Formatted: Right: 0.25"

Charging up (gain stability issues) and rate capability; (5) Study of avalanche statistics: exponential versus Polya (saturated-avalanche mode).

-

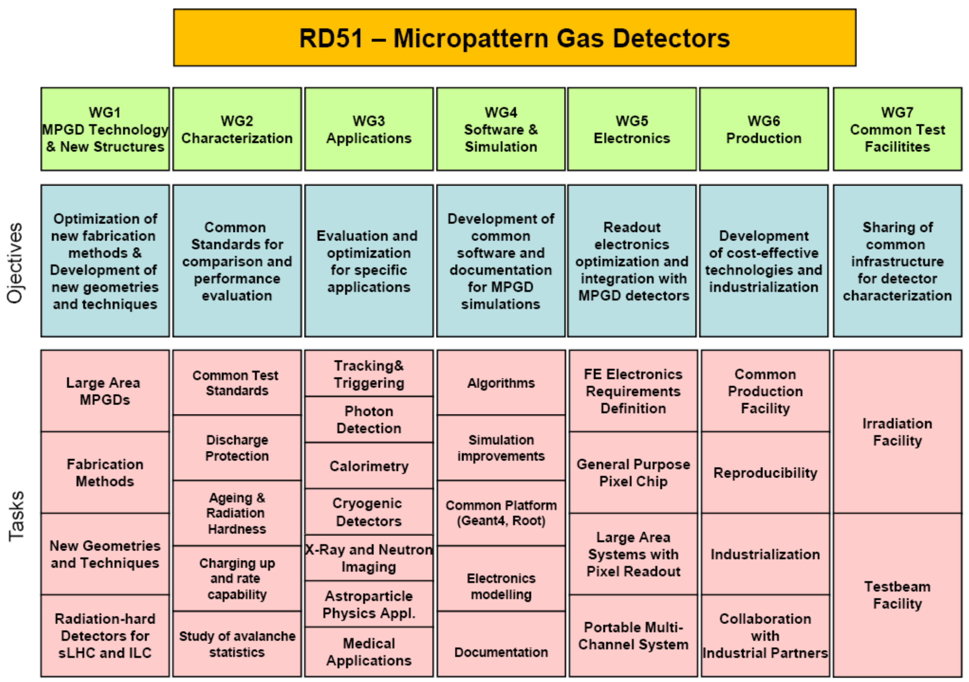


Fig.1: Working groups packages of RD51.

Characterization (WP2): In this WP, a common effort towards the evaluation of the properties and performance of different MPGD detectors shall be made. Common standards for the characterization and comparison of different technologies will be developed. The spread knowledge on the physics of discharges in MPGD detectors will be bundled and solutions towards more efficient discharge protection will be made. Systematic studies on ageing and radiation hardness of MPGDs will be performed and a common database on radiation hardness and ageing properties of materials will be created.

Novel Applications (WPWG33): Several new applications impose specific new requirements and challenges on the production and properties of MPGDs. While the development of the applications itself is carried out in the individual laboratories, the collaboration will collect the requirements coming from thesenew specific applications. The individual tasks are structured according to these applications: (1) MPGD based detectors for tracking and triggering; (2) MPGD based Photon Detectors (e.g. for RICH); (3) Applications of MPGD based detectors in Calorimetry; (4) Cryogenic Detectors for rare events; (5) X-ray and neutron imaging (6) Astroparticle physics applications; (7) Medical applications, for photon detectors, tracking detectors, calorimetry and cryogenic detectors and work towards solutions for these specific applications.

Simulations and Software Tools (WG4): In this WG, a common, open-access, maintainable software suite for the simulation of MPGD detectors will be developed. The existing tools for the simulation of primary ionization, transport and gas amplification will be extended, in particular to improve the modeling at very small scales. An effort will be made in order to integrate the tools into the GEANT4 package to make them

Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Left
Formatted: Not Highlight
Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Font: (Default) Calibri
Formatted: Font: (Default) Calibri, Not Highlight
Formatted: Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri, German (Germany), Not Highlight
Formatted: Font: (Default) Calibri
Formatted: Right: 0.25"

easier to maintain and directly applicable within arbitrary geometry and field configurations. Also the modeling of the electronics response to the detector signals has to be improved. This will also make the simulation applicable to systems with very high granularity such as CMOS pixel readout. The tasks are: (1) Development of algorithms (in particular in the domain of very small scale structures); (2) Simulation improvements; (3) Development of common platform for detector simulations (integration of gas-based detector simulation tools to Geant4, interface to ROOT); (4) Development of simplified electronics modeling tools; (5) Preparation and maintenance of user-directed documentation.

MPGD related electronics Electronics (WPWG5): The availability of highly integrated electronics systems for the charge readout of high granularity MPGD systems poses a non-trivial problem to many of the modern MPGD applications. The specifications of such systems for the different fields of application shallwill be collected. For the classical configuration of charge collecting pads or strips an easy-to-use portable readout solution will be developed. Ultimate granularity is achieved by using the inputs of a CMOS pixel readout chip directly as a charge collecting anode. The specifications of such a readout chip will be worked out and a common effort will be made towards a next-generation pixel chip for MPGD readout. The tasks are: (1) Definition of front end electronics requirements for MPGDs; (2) Development of general purpose pixel chip for active anode readout; (3) Development of large area detectors with pixel readout; (4) Development of portable multichannel systems for detector studies.

Production (WG6): In this working group cost-effective, industrial technology solutions will be developed and transferred to industry. A common “production facility” based on the MPGD workshop at CERN will be developed and maintained and procedures for industrialization will be set up. The tasks are: (1) Development and maintenance of a common production facility; (2) Issues of fabrication reproducibility; (3) MPGD production industrialization (quality control, cost-effective production, large-volume production (4) Collaboration with Industrial Partners.

Common Test FacilitiesTest Facilities (WPWG76): The development of robust and efficient MPGDs entails the understanding of their fundamental properties and performance at several stages of their development phase. This implies a significant investment for detector test beam activities to perform the R&D needed, to test prototypes and to qualify final detector system designs, including integrated system tests. The measurements in test-beam facilities cover efficiencies, noise, time, position and energy resolutions - basically all the critical performance parameters for new detector systems. Additionally, characterization of specific detector’s behaviors operated in large particle background demands some targeted aging tests in irradiation facilities. A common effort in this direction is needed because the number of groups involved in MPGD development has grown very significantly and will still do so during the comingnext years. As members of the RD-51 collaboration, research groups will get easier access to the facilities inside RD-51 collaborating institutes and at CERN, and, most important, share resources, make common requests and group experiments. The two tasks are (1) Development and maintenance of common "Irradiation Facility"; and (2) Development and maintenance of common "Test-Beam Facility".

Organizational Issues: The deciding body for all organizational and scientific matters of the RD51 collaboration is the collaboration board (CB). It will be formed of representatives of all cooperating institutions. The CB will elect its managing board (MB), its chair and deputy and the spokesperson and its deputy. The MB will nominate the working-group conveners. Details of the collaboration organization will be defined by the CB.

The conveners of the working groups will initiate frequent electronic communications and occasional meetings with their respective task-leaders, group members and other WP conveners. Common matters will be regularly discussed among conveners and members of the RD51 Managing Board (MB). General

Formatted: Font: (Default) Calibri, Not Bold, German (Germany)

Formatted: Font: (Default) Calibri

Formatted: Font: (Default) Calibri, Not Highlight

Formatted: Font: (Default) Calibri

Formatted: Font: (Default) Calibri, Not Highlight

Formatted: Not Highlight

Formatted: Font: (Default) Calibri, German (Germany), Not Highlight

Formatted: Font: (Default) Calibri, German (Germany), Not Highlight

Formatted: Font: (Default) Calibri

Formatted: Font: (Default) Calibri, Not Bold, German (Germany)

Formatted: Font: (Default) Calibri, Not Highlight

Formatted: Font: (Default) Calibri

Formatted: Font: (Default) Calibri, Not Highlight

Formatted: Font: (Default) Calibri

Formatted: Font: (Default) Calibri, Not Highlight

Formatted: Not Highlight

Formatted: Font: (Default) Calibri, German (Germany), Not Highlight

Formatted: Left, Space After: 10 pt, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Right: 0.25"

communication and discussion of the results and of future plans will be maintained through annual meetings.

A common website for collection and information of both organizational and scientific matters will be set up. The initial work plan of the collaboration is estimated to cover 5 years.

A common fund will be created by small annual contributions of the partners; it will be devoted mainly for organizational matters. Larger investments, however, will remain with the individual collaboration partners and their funding agencies.

This proposal is structured as follows: In Section 2, an overview about the state-of-the-art of MPGDs and their fields of application is provided. In Section 3, the work plan within the 7 working groups packages is outlined. Section 4 deals with organizational issues and Section 5 describes the resources and infrastructures. Collaboration with industrial partners is described in Section 6. Section 67 provides an overview about the collaboration partners and their fields of expertise and contribution to the collaborationinterest.

Formatted: Heading 1, Justified, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Right: 0.25"

II. Current Trends in Micro-Pattern Gas Detectors

II-A. Summary of MPGD Technologies and Experimental Results (introduction, design principles and outline of MPGD performances)

Modern photo-lithographic technology has enabled series of inventions of novel MPGD concepts: Micro-Strip Gas Chamber (MSGC), GEM, Micromegas and many others [1], revolutionizing cell size limits for many gas detector applications. The MSGC, a concept invented in 1988 by A. Oed [2], was the first of the microstructure gas detectors. Consisting of a set of tiny metal strips laid on a thin insulating substrate, and alternatively connected as anodes and cathodes, the MSGC turned out to be easily damaged by discharges induced by heavily ionizing particles and destroying the fragile electrode structure [3]. The more powerful GEM and Micromegas concepts fulfill the needs of high-luminosity colliders with increased reliability in harsh radiation environments. By using smaller feature size compared to classical gas counters, these detectors offer intrinsic high rate capability (fine pitch and fast collection of positive ions) [4], [5], excellent spatial resolution (~30 μm) [6], [7], and single photoelectron time resolution in the nanosecond range [8],[9].

Micromegas

Micromegas (Micromesh gaseous detector) detector was invented in 1995 by I. Giomataris et al.\cite{10}. The gas volume is split in two regions by a thin micromesh, held at a negative potential of a few hundred volts and sustained at a distance of a few tens to one or two hundred microns from a anode. To preserve a distance between the anode and the grid mesh, spacers from insulating material are used. In the region above the mesh, called the conversion or ionization region, the primary electrons are produced by the conversion of x-rays or by ionisation from a charged track. The field in this region ranges generally between 10 V/cm and one or two kV/cm, fixed by the voltage imposed on a drift cathode closing this volume. The thickness of this region ranges from a few mm for detection of normally incident tracks, to a few meters in the case of a TPC. The liberated electrons drift towards the mesh, which they pass with a high efficiency thanks to the funnel shape of the field lines. In the lower region, between the mesh and the anode, high fields of several tens of kV provide multiplication to these ionisation electrons. The electric field is homogeneous both in the drift and amplification gaps. Due to the narrow amplification region in Micromegas, locally small variations of the amplification gap are compansated by an inverse variation of the amplification coefficient and therefore do not induce gain fluctuations.

This very simple concept have many advantages. The matter budget can be kept extremely low, only two - moderate-voltages suffice to operate it, a very fast electron signal and an efficient and fast ion collection due to the small gap size, which confers high rate capabilities and low space charge build-up, an absence of balistic deficit and 1/t tails. The small amplification gap is a key element in Micromegas operation, giving rise to excellent spatial resolution: 12 μm accuracy (limited by the pitch of micromesh) is achieved for MIPs with a strip pitch of 100 μm and low diffusion CF_4/iC_4H_{10} (80:20) mixture (see Fig. 2a) [7] and very good energy resolution (~12 % FWHM at 6 keV, as shown in Fig. 2b) [11]. A time resolution of 600 ps have been achieved by the KABES beam spectrometer of the NA48 experiment.

A big step in the direction of the industrial manufacturing of large-size detectors is the development of the "Bulk" Micromegas technology [12]. The basic idea is to built the whole detector in a single process: the anode plane with copper strips, a photo-imageable polyamid film and the woven mesh are laminated together at a high temperature forming a single object. At the end, the micromesh is sandwiched between

2 layers of insulating material, which is removed after UV exposure and chemical development. Several large "Bulk" Micromegas (27*26 cm2) have been produced (see Fig. 1b) and successfully tested.

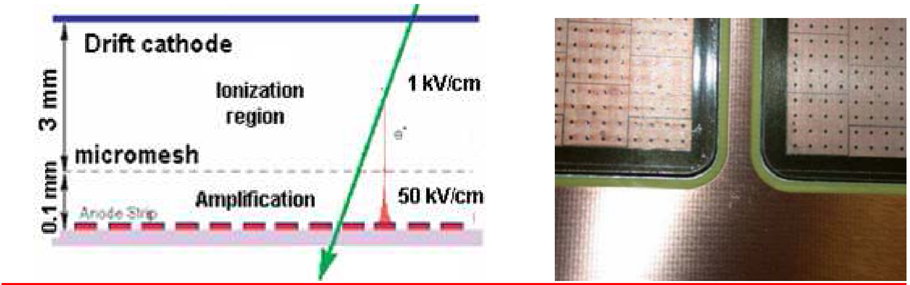


Fig. 1. a) Schematical drawing of the Micromegas detector. b) Photograph of the "Bulk" Micromegas detectors. Pillars of 400 µm diameter every 2 mm are visible.

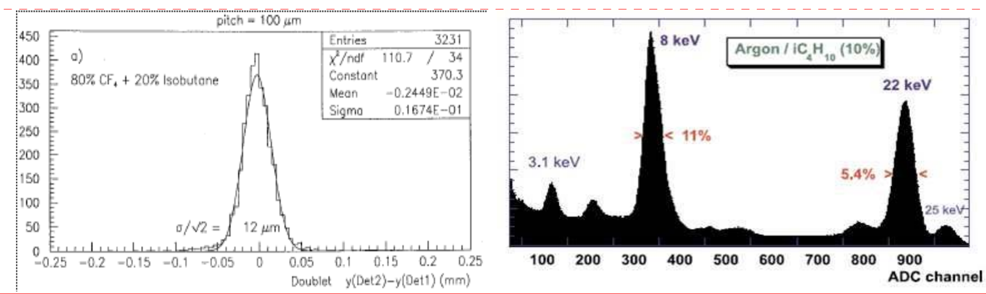


Fig. 2. a) Micromegas spatial resolution obtained with 100 µm readout strips and CF_4/iC_4H_{10} (80:20) mixture. b) CD109 source spectrum obtained with Micromegas in an Ar/iC_4H_{10} (90:10) mixture.

GEM

Introduced in 1996 by F. Sauli [13], a GEM consists of a set of holes, arranged in a hexagonal pattern (typically 70 µm diameter at 140 µm pitch), chemically etched through copper-kapton-copper thin-foil composite (see Fig. 3a). Application of a potential difference between the two sides of GEM generates the field map shown in Fig. 3b: electrons released by the ionization in the gas drift into the holes and multiply in the high electric field (50-70 kV/cm). Sharing the avalanche multiplication between several cascaded electrodes (see Fig. 3c), allows to operate triple-GEM detectors at overall gains above 10^4 in the presence of highly ionizing particles, while eliminating the risk of hazardous discharges ($< 10^{-12}$ per hadron) - the major advantage of the GEM technology [14], [15]. Fig. 4a shows the discharge probability measured as a function of total effective gain, in the single, double and triple GEM, exposed to alpha particles. The use of fast Ar/CF_4-based gas mixtures a time resolution better than 5 ns r.m.s. (see Fig. 4b). A unique property of GEM detector is a full decoupling of the amplification stage (GEM) and the readout electrode (PCB), which operate at unity gain and serves only as a charge collector. This offers a freedom in the optimization of the anode readout structure, which can be made of pads or strips of arbitrary pattern [16]. GEMs can be also easily bent to form cylindrically curved ultra-light detectors, as preferred for inner tracker applications [17], [18].

Controlled etching of GEM foils (decreasing the thickness of the copper layer from 5 to 1 µm) allows to reduce material budget in triple-GEM to 1.5×10^{-3} X_0, which is about one half of a 300-µm-thick Si-microstrip detector [19].

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Normal, Left, Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers

Formatted ... [13]

Formatted: Font: (Default) CMR8, 8 pt, English (U.K.)

Formatted ... [14]

Formatted: Font: (Default) Calibri, 11 pt, Bold, Underline, English (U.K.)

Formatted: Space After: 10 pt, Line spacing: Multiple 1.15 li, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted ... [15]

Formatted: Normal, Left

Formatted ... [16]

Formatted: Right: 0.25"

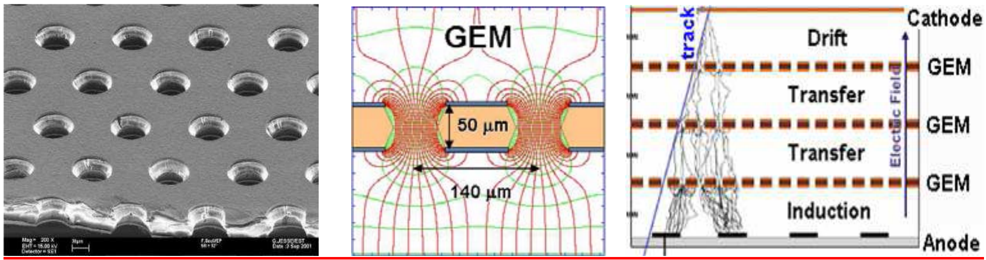


Fig. 3. a) Close view of a GEM electrode, etched on a metal-clad, 50 µm thick polymer foil. The hole's diameter and distance are 70 µm and 140 µm. b) Schematics and electric field map of the GEM amplification cell. c) Schematical drawing of the triple-GEM detector.

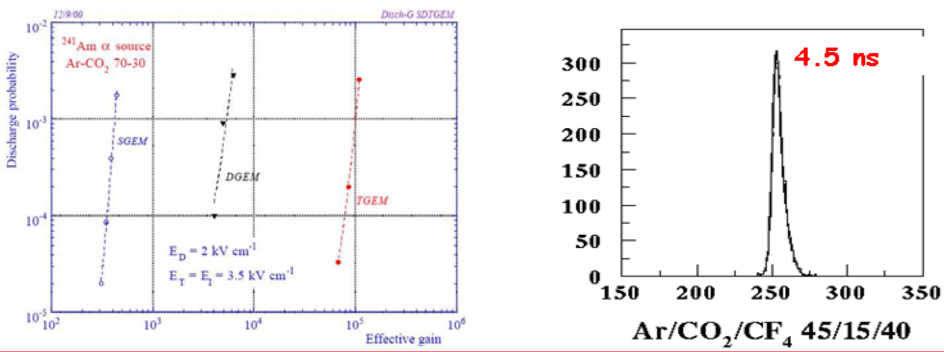


Fig. 4. a) Discharge probability as a function of total effective gain for single (SGEM), double (DGEM) and triple (TGEM) detectors. b) Time distribution in triple-GEM detector with $Ar/CO_2/CF_4$ (45:15:40). The r.m.s. of the distribution is 4.5 ns.

Thick-GEM, Hole-Type Detectors and RETGEM

The success of GEMs and glass capillary plates triggered the development of coarse and more robust structures, "optimized GEM" [20], [21] followed by think-GEM (THGEM) [22], [23] gaseous multiplier, perforated with sub-millimeter diameter holes, etched at their rims is presently subject of investigation (see Fig. 5a). Detectors formed by single and multiple THGEM foils have been studied in laboratory, also coupled to semitransparent or reflecting CsI photocathodes. Effective gas amplification factors of 10^5 and 10^7 and fast pulses of a few nanosecond rise-time were reached in single and cascaded double-THGEM elements [23]. Stable operation with high single photoelectron detection efficiency was recorded at fluxes exceeding MHz/mm^2. This technology looks pretty adequate for the needs of a new generation of photon detectors for Cherenkov imaging devices: namely good spatial and time resolution, large gains, industrial production of large surfaces, and easy construction, thanks to the intrinsic stiffness of the PCBs themselves. These characteristics make THGEMs promising also for other applications: hadron calorimetry and large surface tracking systems.

A novel spark protected version of thick GEM with electrodes made of resistive kapton (RETGEM) has been recently developed [24]. Sheets of resitive kapton 50 µm thick were glued onto both surfaces of the PCB to form resistive electrode structure; holes 0.3 mm in diameter with a pitch of 0.6 mm are drilled using a CNC machine (see Fig. 5b). At low counting rates detector operates as an conventional THGEM with metallic electrodes, while at high intensities and in case of discharges the behaviour is similar to a resistive-plate chamber. Recent studies of photosensitive RETGEMs with CsI deposited directly on the dielectric kapton (without metallic substrate) have shown a rather high quantum efficiency (34 % at 120 nm) [25]. Applications of THGEM and RETGEM concepts to the RICH technology promises to advance particle identification capabilities.

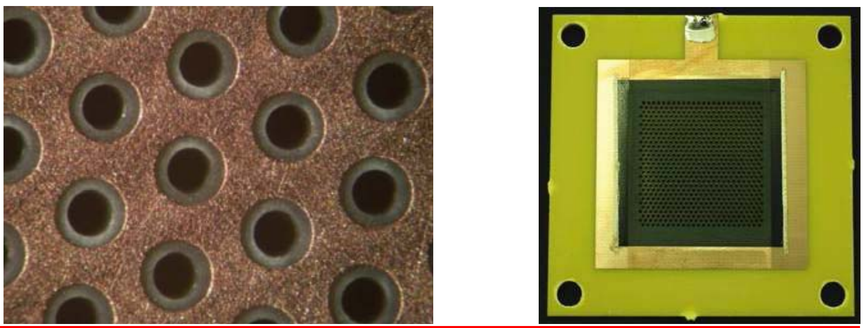


Fig. 5. a) Photo of the Thick GEM-multiplier. A rim of 0.1 mm is chemically etched around each hole to reduce discharges. b) Photo of the RETGEM detector with kapton-resistive electrodes.

MPDG with CMOS pixel ASICs

Advances in micro-electronics industry and advanced PCB technology has been very important for the development of modern gas detectors with increasingly smaller pitch size. The fine granularity and high-rate capability of micro-pattern devices can be fully exploited using high-density pixel readout with a size corresponding to the intrinsic width of the detected avalanche charge. However, for a pixel pitch of the order of 100 µm, technological constraints severely limit the maximum number of channels that can be brought to the external front-end electronics. An elegant solution is to use a CMOS pixel chip, assembled directly below the GEM or Micromegas amplification structure and serving as an integrated charge collecting anode. With this arrangement avalanche electrons are collected on the top metal layer of the CMOS ASIC; every input pixel is then directly connected to the amplification, digitization and sparcification circuits, integrated in the underlying active layers of the CMOS technology. Using this approach, gas detectors can reach the level of integration typical of solid-state pixel devices.

Particle detectors are designed to achieve sensitivity required to study physics processes of interest. The multi-pixel anode readout of micro-pattern gas detectors allows a true 2D image reconstruction and opens novel detection opportunities in:

- Astronomical X-ray polarimetry (2-10 keV energy range);
- Position sensitive single electron detection;
- Time Projection Chamber readout;
- High-rate particle tracking;
- Advanced Compton Telescope (0.4-50 MeV energy range);
- Low energy nuclear recoil reconstruction (WIMP interactions).

The advent of finely segmented MPGD with pixel read-out can lead to the appearance of a highly efficient X-ray polarimeter in the 2-10 keV energy band, which allows to measure simultaneously position and energy-resolved linear polarisation. The real breakthrough was the development of analog, low-noise and high granularity (50µm pitch) multi-pixel ASIC [26]- [29], shown in Fig. 6a, so that the initial direction and dynamics of X-Ray energy loss in the gas can be accurately tracked before it is distorted by Coulomb scattering.

A binary multi-pixel CMOS chip ("Medipix2"), originally developed for X-ray imaging [30], has been shown to work with Micromegas and GEM detectors [31]-[33]. Approximately 75 % of every pixel in the Medipix2 matrix is covered with an insulating passivation layer. Hence, the avalanche electrons are collected on the conductive bump-bonding pads, exposed to the gas (see Fig. 6b). A modification of the Medipix2 chip ("TimePix" [34]), which allows to measure the drift time information of primary electrons, has been designed, produced and already tested with GEM and Micromegas gas amplification systems for the TPC readout at future Linear Collider.

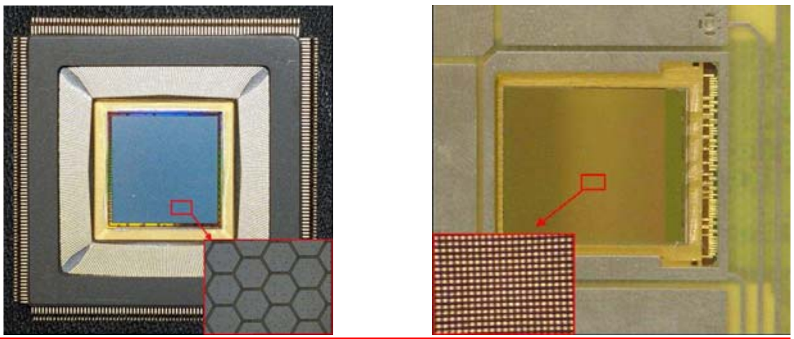


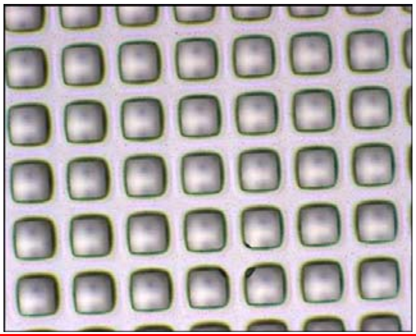
Fig. 6. a) Photo of the analog CMOS ASIC with hexagonal pixels, bonded to the ceramic package [29]. b) Photo of the Medipix2 chip [30]; a 25 μm wide conductive bump bond openings, used for electron collection, are seen as a matrix of dots [33].

Ingrid Technology

An attractive solution for the construction of MPGD with pixel anode readout is the integration of the Micromegas amplification and CMOS chip by means of 'wafer post-processing' technique [35]. With this technology, the structure of thin (1 μm) aluminum grid is fabricated on top of an array of insulating (SU-8) pillars of typically 50 μm height, which stand above the CMOS chip, forming an integrated readout of gaseous detector. This technology is called InGrid and provides an accurate control of alignment and grid geometry (see Fig. 7a). The process uses standard photolithography and wet etching techniques and is CMOS compatible. It can be used to equip both single chips and chip wafers with Micromegas grids. The sub-μm precision of the grid dimensions and avalanche gap size results in a uniform gas gain; the grid hole size, pitch and pattern can be easily adapted to match the geometry of any pixel readout chip. Ingrid detectors can also be used to measure X-ray energies with an unprecedented resolution (closed to the Fano limit). Several InGrids have been fabricated on dummy silicon substrates, showing an energy resolution of 5 % RMS at 5.9 keV (see Fig. 7b). Many basics quantities of gas physics like (Fano factors, diffusion constants, cluster size distributions) can be measured with this detector. Recently, DoubleGrid and TripleGrid structures has been developed and tested (see Fig. 8).

The protection against sparks is provided by a 10 to 20 μm thin layer of highly resistive material (hydrogenated amorphous silicon) deposited directly over the chip surface. This protection is called "SiProt" and its optimal thickness is being investigated. Several Medipix2/Timepix chips were equipped with "SiProt" and InGrids and were found to function normally after the post-processing.

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)
Formatted: Normal, Left
Formatted: Font: 11 pt, English (U.K.)
Formatted ... [100]
Formatted ... [101]
Formatted ... [102]
Formatted ... [103]
Formatted ... [104]
Formatted ... [105]
Formatted ... [106]
Formatted ... [107]
Formatted: Normal
Formatted ... [108]
Formatted: Font: 11 pt, English (U.K.)
Formatted ... [109]
Formatted ... [110]
Formatted: Font: (Default) Calibri, 11 pt
Formatted ... [111]
Formatted ... [112]
Formatted ... [113]
Formatted ... [114]
Formatted ... [115]
Formatted: Font: 11 pt, English (U.K.)
Formatted ... [116]
Formatted ... [117]
Formatted: Font: 11 pt, English (U.K.)
Formatted ... [118]
Formatted ... [119]
Formatted ... [120]
Formatted ... [121]
Formatted ... [122]
Formatted: Font: 11 pt, English (U.K.)
Formatted ... [123]
Formatted ... [124]
Formatted ... [125]
Formatted ... [126]
Formatted ... [127]
Formatted ... [128]
Formatted ... [129]
Formatted ... [130]
Formatted: Font: 11 pt, English (U.K.)
Formatted ... [131]
Formatted ... [132]
Formatted ... [133]
Formatted ... [134]
Formatted ... [135]
Formatted: Right: 0.25"

a) 

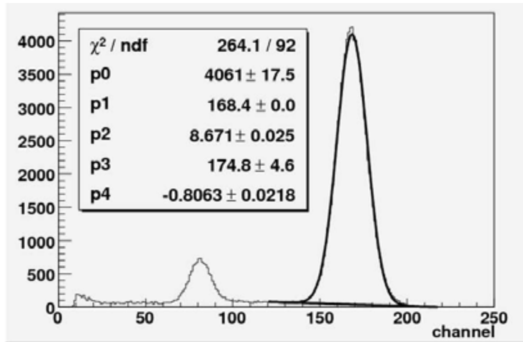
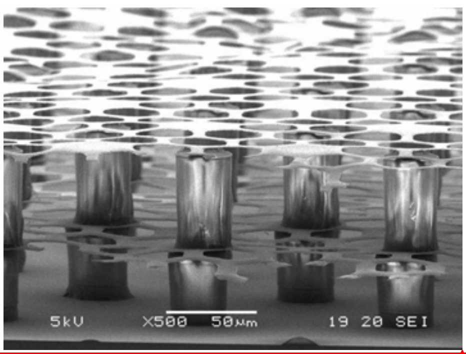
b) 

Fig. 7. a) Top view of an InGrid. Note the pillars placed in between 4 holes, minimizing dead areas. b) ^{55}Fe spectrum recorded using Ingrid detector shows 5.0 % RMS on the photo-peak. The 6.5 keV line was strongly attenuated by a Cr foil.

a) 

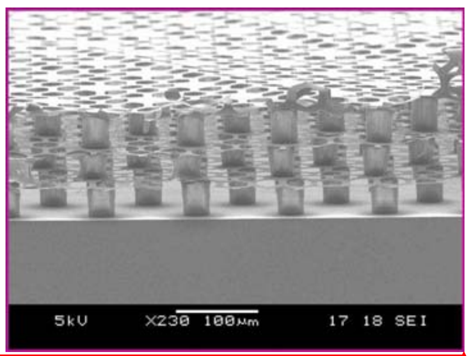
b) 

Fig. 8. a) Photo of the TwinGrid Structure. b) Photo of the TripleGrid Structure.

Formatted: Font: (Default) Calibri, 11 pt, English (U.S.)

Formatted: English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.S.)

Formatted: English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Space After: 10 pt, Line spacing: Multiple 1.15 li, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: English (U.K.)

Formatted: English (U.K.)

Formatted: English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: English (U.K.)

Formatted: Normal, Left

Formatted: Right: 0.25"

II-B. Fields of Applications (HEP, Astrophysics, Nuclear Physics, Industrial and Medical Applications)

Formatted: Normal, Left

Formatted: Right: 0.25"

III-A. Technological Aspects and Developments of New Detector Structures (WG1)

OBJECTIVE

Detector design optimization, development of new multiplier geometries and techniques.

Micropattern gaseous detectors are being developed for a wider and wider domain of applications. These applications concern various operation conditions and each of these implies different requirements. Muon chambers for SLHC detectors as well as neutrino long baseline oscillation experiments require large area detectors. For various applications, especially in nuclear physics and in vertexing for collider experiments, the material budget has to be kept as low as possible. In the forward region of sLHC detectors, radiation hardness is an issue that will require special designs. Many applications will require the development of portable detectors, sealed and with light high voltage supplies, for applications out of the laboratory. Some applications will require high rate to be sustained or on the contrary low radioactivity for low energy rare event detection. Some will require high pressure operation (dark matter search), other low pressure (low-energy Nuclear Physics). Special materials and geometries will be necessary for high magnetic field operation. Some experiments will require high granularity, others high stability. Minimization of the ion backflow is essential for a Linear Collider TPC, as well as in photo-detection. Clearly, these operation and design issues will require strong connections with Working Groups 2 and 6.

To organize the R&D in Working Group 1 in these respects, a number of tasks have been singled out and are described in this section.

TASK 1

Development of Large Area Micro-Pattern Gas Detectors (large area modules, material budget reduction)

Large Bulk Micromegas

Recent advances in Micromegas technology allowed increasing the size of detectors by a great factor. The fact that robust stainless steel mesh is used as the amplifying grid opens possibility to build detectors up to one meter long. The fabrication of bulk Micromegas consists of the following steps: 2 layers of photosensitive coverlay are laminated directly on top of the readout board, thickness of these layers is defining amplifying gap. On top of them a stretched stainless steel mesh is laid and attached to the board by lamination of another closing photosensitive coverlay. 3 layers are then exposed to UV light through the desired mask to polymerize the coverlay in places, where spacers are needed. The pitch can vary from 1 to 4 mm, while spacer diameter from 0.2 to a few millimeters. The board is then developed with a defined sprayed chemistry to remove the unwanted coverlay, followed by thermal curing and cleaning, which effectively reduces dark current between mesh and readout electrode. The limiting factors of this technology are:

• Laminator opening: 0.6m STD, 1m in some companies.

• Development machine opening: 0.6m STD, 1m in some companies.

• Readout board size: 50cm x 50cm for complex boards.

• Curing Ovens: 1m.

The stainless steel mesh is available in 1.2 m wide rolls and is not a limiting factor. 60cm x 50cm detectors can be built using this technology. CERN TS/DEM/PMT workshop is planning to build detectors of 100cm x 50cm size during the year 2008. One of the limiting factors is the readout board of this size. Possibility of merging smaller boards (easy to manufacture) is under investigation.

Single Mask GEM

Formatted: Font: Bold, Underline

Formatted: Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Justified, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

The technology of GEM foils fabrication is fully established. Only a few improvements have been implemented in the last ten years. GEM foil is produced from an adhesiveless copper polyimide clad, with typical 50 μm polyimide thickness and 5 μm thick copper layers. The copper layer on either side is patterned by photolithography and chemically etched. The images on both faces should be perfectly aligned with a precision of 10 μm. This requirement prevents to extend effective GEM foil size beyond 60 cm x 40 cm. The standard pattern is defined by 70 μm diameter holes in a hexagonal matrix of 140 μm pitch. Smaller dimensions are feasible limiting though the size of the foil due to the fabrication difficulties. After copper patterning, followed by cleaning, exposed polyimide is chemically dissolved in an anisotropic way. The foil is then cleaned and electrically tested. Two methods to overcome the size limitation given by the requirement of precise mask alignment were proposed. In the first one, laser direct imaging machines were used to pattern the copper layers on both sides of the foil. This method was abandoned due to irreproducibility and complexity. The second approach is to use single mask process, where patterning of one of the copper layers is done using polyimide previously etched as a mask. This method gave promising results and first test prototypes of large size GEM foils (60cm x 40cm) are under test; the production of the 100cm x 35 cm size foils is foreseen later in 2008.

New Materials and Material Budget Reduction

Formatted: Font: Bold, Underline, Font color: Black

Formatted: Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Font color: Black

Specific applications pose stringent requirements on the materials used in the MPGD construction. This is illustrated here below by a non-exhaustive list of different requirements to the construction materials, depending on application:

• Materials with low out-gassing properties

• Radiation hard materials

• Converters for high energy photon detection

• Materials for low detector mass application

• Materials for low cost detectors

• Materials for large size detectors.

In particular, the material budget reduction is common to several applications and some approaches have already been considered.

The simplest idea is to decrease the thickness of electrode material. Recently, GEM foils have been produced, where the electrode thickness of 5 μm Cu have been reduced to 2 μm. Correspondingly, also the read-out boards should be lightened; this is even more necessary taking into account that the electric circuits are getting more and more complex, thus requiring more layers, which result in more mass.

The second idea is to replace heavy metals by lighter ones, like Aluminum. At the present state of the art, it seems difficult to swap copper and aluminum in GEM detectors. Bulk Micromegas detectors using stainless

Formatted: Right: 0.25"

steel meshes could be lightened by using aluminum vacuum plated polyester mesh. Read-out boards can be produced using aluminum for the conductive pattern.

TASK 2

Detector design optimization including fabrication methods and new geometries (bulk micromegas, microbulk micromegas, single-mask GEM, (THGEM, RETGEM, MHSP, charge-dispersive readout, Ingrid).

The MPGD structures can be grouped in two large families: Micromesh-based detectors and hole-type structures, both groups including pretty mature detectors and novel approaches. The micromesh-based structures include: Micromegas, Bulk Micromegas, Microbulk Micromegas and Ingrid. The Hole-type structures are: GEMs, micro GEMs, thick GEMs (LEMs or THGEM), Resistive thick GEMs (RTHGEM) and MSHPs.

New Geometries of the Hole-type structures

They are derived from the GEM structure and they aim at specific applications. Within RD51 the following structures will be studied and developed:

micro GEMs, thick GEMs (LEMs or THGEM), Resistive thick GEMs (RTHGEM) and MSHPs.

In **thick GEMs**, the GEM structure is scaled to larger values of the geometrical parameters. This is obtained replacing the kapton foil with a PCB; holes are produced by standard drilling techniques; the conical shape of the GEM holes is replaced by a clearance ring around the hole, the rim, obtained by PCB etching. Typical figures for the geometrical parameters range between 0.4 and 1 mm for the thickness, between 0.3 and 1 mm for the hole diameter, between 0.6 and 1.2 mm for the pitch; the rim varies between 0 and 0.1 mm. These electron multipliers exhibit specific feature: the geometrical parameters can be scaled from GEM ones, but the microscopic behaviour of the electrons, in particular diffusion in the gas, does not scale. As a consequence specific study and parameter optimization are needed. Thick GEMs are robust, mechanically stiff and can take advantage of a production technology widely used: they are well suited to instrument large surfaces. The space resolution that can be obtained is in the mm range and the material budget in not particularly reduced. These characteristics are fully compatible with the two main applications considered: the usage of thick GEMs for the sensitive elements of digital hadron calorimetry and the design of thick GEM-based single photon detectors for Cherenkov imaging counters. In the latter application, thick GEMs are coupled to CsI photocathodes; the advantage of an architecture based on multiple layers of multipliers respect to the present used MWPCs is the possibility to limit the ion feedback bombarding and damaging the photocathode.

In order to reduce or to eliminate discharges, **resistive THGEM**-like structures have been studied, namely thick GEMs where the metal conductive electrodes are replaced by resistive materials, exhibiting surface resistivity in the range 0.1-1 MΩ/square. The main goal pursued introducing the resistive elements is to increase the electrical stability of the multipliers, making them stable at higher voltages so to obtain increased gains. Resistive structures have been produced either using resistive carbon loaded Kapton or screen printed resistive technique. Preliminary tests indicate that the Kapton resistive materials behave have better than the screen printed version: the Kapton version is more robust against discharges and showes a better stability in time. In 2008, some material samples should be available from DuPont (US) making possible studies of large size detectors, up to 500 x 500 mm^2. On the other hand, the advantage of the screen printed technology is the possibility to easily change the value of the resistivity; studies of the sparking limit in these detectors have still to be performed.

Formatted: Justified

Formatted: Justified, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Underline

Formatted: Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Justified, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Right: 0.25"

Their effectiveness of resistive thick GEMs in low rate applications has been demonstrated. More recently new geometries, where the resistive electrodes are coupled to conductive lines for fast voltage compensation have been proposed. The resistive thick GEMs share several advantages and features of the thick GEMs and the domain of applications is largely overlapping.

In the **MSHP structure**, also derived from the GEM geometry, the holes required to obtain electron multiplication are coupled to strip electrodes: the electric field configuration is modified to trap the positive ions produced in the avalanche process, in order to reduce the ion feedback flow towards the cathode. Ion feedback flows below 10^{-3} have been reported. These structures have been developed to detect single photons for Cherenkov imaging applications. The ultimate goal of this R&D program is the development of gaseous photon: the photoconverters sensible to visible light are extremely fragile and they require ion suppression in the range 10^{-4}.

In order to reduce or to eliminate discharges, THGEM-like structures have been studied, where the metal conductive electrodes are replaced by resistive materials, exhibiting surface resistivity in the range 0.1-1 MΩ/square. The main goal pursued introducing the resistive element is to increase the electrical stability of the multipliers, making them stable at higher voltages so to obtain increased gains. Resistive structures have been produced either using resistive carbon loaded Kapton or screen printed resistive technique. Preliminary tests indicate that the Kapton resistive materials behave have better than the screen printed version: the Kapton version is more robust against discharges and showes a better stability in time. In 2008, some material samples should be available from DuPont (US) making possible studies of large size detectors, up to 500 x 500 mm^2. On the other hand, the advantage of the screen printed technology is the possibility to easily change the value of the resistivity; studies of the sparking limit in these detectors have still to be performed.

Their effectiveness of resistive thick GEMs in low rate applications has been demonstrated. More recently new geometries, where the resistive electrodes are coupled to conductive lines for fast voltage compensation have been proposed. The resistive thick GEMs share several advantages and features of the thick GEMs and the domain of applications is largely overlapping.

Charge-Dispersive Readout Technique

Formatted: Underline

The main idea of the charge dispersive readout technique is to cover the read out pads with a thin dielectric layer and then cover this layer with a resistive sheet. This technology gives the possibility to increase the size of the read out pads and consequentially reduce the number of electronic channels for the same spatial resolution.

Charge dispersion readout techniques developed so far has been adequate for small 10×10 cm prototypes but they are inadequate for large detectors. The anode readout structure should have uniform RC response over its area since any non-uniformity results in systematic biases in the measured position. Although the bias can be removed by calibration, for large detectors the calibration will be cumbersome and therefore the bias errors must be minimized. This will require: a) a high quality film with homogeneous surface resistivity and uniform thickness; and also b) the quality of lamination and the intermediate insulating layer of dielectric should also be excellent to minimize the variation of spacing between the resistive layer and the readout pads. The resistive films used so far have the required uniformity of surface resistivity - within 5%. However, at present, there is no reliable supplier for high quality resistive film. Non-uniform dielectric gap is presently the major weakness as in-house lamination technique are inadequate. We have made

Formatted: Right: 0.25"

contacts with industry to investigate if spin coating or techniques used in fabricating multilayer PCBs or lamination techniques used in preparing thin silicon wafers for processing could be adapted for our needs. CERN workshop has the expertise and the resources to help here.

There are several possible areas for collaboration within the RD-51: future development of the technology and development of large area Bulk Micromegas with charge dispersion readout

Ingrid Developments

With the InGrid technology, a grid is constructed onto a CMOS chip, resulting in an integrated and monolithic readout sensor. The InGrid technology is now being transferred to industry and is expected to become widely available in the future. New R&D is required for the production of high-resistively grid material. At present, the CMOS chips are protected against gas discharges by a 20 μm thick high-resistively layer, fully covering the chip. With a high-resistively grid, this protection layer could be much thinner, or even completely removed, if circuitry in each pixel provides adequate dissipative charge drain.

Another R&D project is the development of multigrids structures. A first TwinGrid, in which a second InGrid is placed on top of the first one, has been constructed and already tested. With two grids, the gains in the two gaps can be chosen and optimized. In this mode of operation, only a modest extracting field is required in the bottom gap, avoiding discharges onto the pixel chip. Many parameters like ion feedback, energy resolution and single electron efficiency could be optimized by a variation of the geometrical parameters: the grid holes (shape and diameter), which could be different for both grids, and the gap sizes. In the next step, a third grid was added, providing new degrees of freedom, and could serve as for example a 'gating grid'. The misalignment of grid holes in this Triple-Grid may reduce or eliminate ion feedback. It should be mentioned that in order to optimize design of multigrid systems, extensive and detailed 3D simulations will be required in the future..

The 'wafer post-processing' technology can be also used if the readout CMOS matrix does not exactly match the required detector granularity. "Through-wafer vias" connections with variable re-routing lines allows to use detector elements with slightly smaller readout chips and space left over for external connections [36].

TASK 3
Development of Radiation-Hard Detectors

Radiation hardness of gaseous detectors has been a challenging and controversial topic since the beginning of their operation, and particularly for the high-energy physics experiments in view of the expected particle rates that these detectors will have to cope during their operation in the Large Hadron Collider at CERN. In the last 30 years a multitude of tests carried out in laboratory under conditions as stable and controlled as possible, have resulted in a set of good practices and recommendations that, when followed carefully, extend the lifetime of gas detectors by orders of magnitude [96], [97], [98], [99]. Among them, a careful selection of detector assembly materials, gas mixtures and operating parameters are fundamental. It has yet to be proven if those gas detectors will cope with the expected doses in the real experimental environments.

Among all available gaseous detectors technologies, the Micro-Pattern Gas Detectors have emerged

as the most robust ones. Lifetimes in excess of mC/mm^2, corresponding to a total particle flux of 10^{12} MIPs/mm^2, have been repeatedly reported with a variety of gases and obtained under different test conditions [100], [101]. The separation of gas amplification and the readout stages and a possible smaller

Formatted: Underline

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Space After: 10 pt, Line spacing: Multiple 1.15 li, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Right: 0.25"

effect of polymerization deposits on the electric field of MPGD are the main causes that would explain such immunity to aging, as compared to traditional wire chambers.

Developments underway for the following years include improvement of resistive coatings for improving the space resolution by charge spreading and protection against sparks. There, new photovoltaic techniques and screen printing are tracks to be explored. The resistive anode techniques have to be made compatible with the "bulk" technology, to combine the advantages of both. Also fine and robust meshes of larger and larger surfaces have to be developed. The possibility of segmenting the mesh has to be exploited to lower the detector capacitance and to provide an additional coordinate readout for large detectors with strips. Larger GridPix detectors have to be developped. Also "wall-paper" flexible detectors can now be envisaged. Each of these incarnations of Micromegas has applications in various fields : a large resistive bulk with segmented mesh would be a good muon detector for SLHC, a large GasPix detector would provide directionality in a dark matter search experiment, and a Micromegas TPC, either with a resistive anode or a digital readout would fulfill the requirements for the Linear Collider tracking.

Formatted: Font: (Default) Calibri, 11 pt, English (U.K.)

Formatted: Normal

Formatted: Justified

Formatted: Right: 0.25"

III-B. Common Characterization and Physics Issues (WG2)

OBJECTIVE

Development of common standards and comparison of different technologies, performance evaluation of different MPGD detectors.

OBJECTIVE

Development of radiation-hard gaseous detectors operating beyond the limits of present devices.

TASK 1

Development of common test standards (comparison of different technologies in different laboratories)

TASK 2

Discharge studies and spark-protection developments for MPGDs

TASK 3

Generic aging and material radiation-hardness studies (creation of database of "radiation-hard" materials & detectors depending on application) commercially available materials, cleanliness requirements, validation tests for final detector modules, gas system construction, working remedies)

TASK 4

Charging up (gain stability issues) and rate capability

TASK 5

Study of avalanche statistics: exponential versus Polya (saturated-avalanche mode)

III-B. Applications (WG3)

Formatted: Justified

Formatted: Normal, Left

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Justified

Formatted: Normal

Formatted: Right: 0.25"

OBJECTIVE

Evaluation and optimization of MPGD technologies for specific applications

TASK 1

MPGD based detectors for tracking and triggering

Due to their wide variety of geometry and flexible operating parameters MPGDs are a common choice for tracking and triggering detectors in nuclear and particle physics. Consequently a large variety of different projects using these devices for tracking and triggering applications are currently under way or are being studied. Common themes for future applications are low mass, large active areas, high spatial resolution, high rate capabilities and high radiation tolerance.

Classical MPGD tracking detectors use thin (*O*(mm)) gas gaps from which the primary ionization from through-going ionizing radiation is collected. This is then amplified by the amplification structure of choice. The amplified charge is collected on readout structures with a large variety of possible patterning and routed to the readout electronics.

MPGD based tracking detectors with triggering capability are being developed for the ATLAS and CMS muon systems to cope with the high particle rates of a few kHz/cm^2 expected at SHLC luminosities, replacing parts of the present muon trackers and trigger detectors. Taking into account that several detector layers are needed, areas of more then 1000 m^2 will have to be instrumented with detectors that offer a spatial resolution of ~100 µm and a time resolution of ~ 5 ns and have high radiation tolerance. The “bulk MicroMegas” technology is currently pursued to address these requirements, with involvement from INFN Naples, INP/NCSR Athens, NTU Athens, U Athens, U Thessaloniki, CERN and BNL. For LHCb, large area planar detectors based on triple GEM technology with a size of ~1000 x 250 mm^2 with a highly granular pad readout are being studied for muon tracking and triggering in the high rate environment of SLHC. Participating institutes are INFN Frascati and INFN Cagliari.

For the PANDA experiment at the future FAIR facility thin large-area planar triple GEM detectors are being developed at TU Munich, based on the experience from the triple GEM trackers with 2D strip readout and the light-weight triple GEM beam trackers with hybrid pixel/strip readout for the COMPASS experiment. For Hall A at Jefferson lab, a high resolution tracking system using triple GEM chambers with an active area of 400 x 800 mm^2 and a spatial resolution of ~ 70 µm, as well as a large area tracker with 1000 x 2000 mm^2 acceptance and a spatial resolution of better than 300 µm, both with 2D strip readout, is being planned, with involvement from INFN Rome. The STAR experiment at RHIC is currently designing and constructing a forward tracker based on 6 triple-GEM disks with a radius of ~ 400 mm and a 2D orthogonal (r-ϕ) strip readout based on GEM foils produced at Tech-Etch (supported by a US DOE SBIR grant), with an anticipated spatial resolution of better than 80 µm. In addition, the use of several small area (~ 100 x 100 mm^2) triple GEM trackers outside the main TPC of STAR is being studied as a means of improving TPC distortion corrections for high luminosity running. These projects are carried out with involvement from *MIT (still no questionaire?)* and Yale University as well as BNL, which is involved in the development of GEMs for tracking detectors and other applications at Tech-Etch. An ultra-light, fully sensitive cylindrical GEM detector has been proposed for the inner tracker of the upgraded KLOE experiment at DAFNE. The detector will provide a spatial resolution of $\sigma_{r\text{-}\phi}$ ~ 200 µm and σ_z ~500 µm, with very low material budget. This development is carried out at INFN Frascati.

Formatted: Normal

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Font: (Default) Calibri, 11 pt, Not Bold

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Normal, Justified, Tab stops: Not at 0.49" + 0.98" + 1.48" + 1.97" + 2.46" + 2.95" + 3.45" + 3.94" + 4.43" + 4.92" + 5.41" + 5.91" + 6.4"

Formatted: Right: 0.25"

In addition to their use in thin detectors, MPGDs are also widely studied for the use in time projection chambers (TPCs). They offer an improved spatial resolution, and a significant reduction of ion feed-back, relaxing the requirements on gating of the devices and, depending on the design, possibly allowing ungated operation of time projection chambers.

R&D for a high precision TPC is ongoing for the future ILC, organized in the ILC-TPC collaboration. In order to achieve the physics goals of the ILC, the main tracking TPC has to be able to reconstruct at least 200 space points on a track with a resolution of ~ 100 µm, over a maximal drift length of 250 cm in a 4 T magnetic field. Multi-track separation of 1 mm has to be reached. These requirements are in part driven by the needs of particle flow algorithms, briefly discussed in the calorimeter section. An additional requirement is low mass in the detector endplates. GEM and MicroMegas with classical pad readout are investigated. The use of a GEM foil as a gating device, or as passive device to further suppress ion feed-back into the main drift volume are also subjects of studies. In addition, the readout with GEMs or MicroMegas on top of ASICs with pixel readout that handle the charge collection as well as preamplification, digitization and sparsification of the signals, is studied. First proof of principles have been achieved with the MediPix2 and the TimePix chips, as well as with TimePix chips with an integrated MicroMegas made from Si, the InGrid. U Freiburg, U Bonn and NIKHEF participate in the ILC-TPC development efforts.

NIKHEF also investigates small TPCs to be used in directionally sensitive dark matter searches. For the planned dEDM experiment at BNL, which will study the electric dipole moment of the neutron through studies of the deuteron, a TPC with MicroMegas readout is developed by IN/NCSR Athens and NTU Athens.

A TPC based on GEM readout has been proposed by TU Munich for the inner tracker at the PANDA experiment. In order to cope with the high data rate of the experiment, this TPC will be operated without gating as a continuously sampling detector. A prototype detector, currently under construction, will be tested in the FOPI experiment at GSI and the Crystal Barrel at ELSA.

Task 2

MPGD based Photon Detectors (e.g. for RICH)

The use of gaseous detectors coupled with CsI photo-cathodes for large area Ring Imaging Cherenkov Counters (RICH) is a well-established technique in nuclear and particle physics. The present devices, based on MWPCs, suffer from limitations in the achievable gain due to aging of the photo-cathodes from ion bombardment and due to ion-induced instabilities in the MWPCs. These gain limitations also lead to the need for long integration times and consequently limits on rates and time resolution. MPGDs, in particular GEM-like devices, are a very promising technology in this field due to the intrinsic ion feedback suppression, the cascadability of the multipliers to reach high gain and the possibility to directly deposit CsI cathodes on the multiplier structures.

For the application in RICH detectors, a rather coarse spatial resolution is usually sufficient, thus ThickGEMs are currently actively studied as photo-detectors. They offer a large area that can be coated with CsI, leading to high quantum efficiency, and their stiffness facilitates detector construction. These investigations are carried out at the Weizmann Institute, INFN Trieste and U Coimbra/Aveiro. At UNA Mexico, photosensitive ThickGEMs and RETGEMs are studied for an upgrade of the ALICE RICH, the VHMPID.

The operation of MPGDs with CsI photo-cathodes in CF_4 gas opens up the possibility for windowless Cherenkov detectors, where both the radiator and the charge detectors share the same gas volume. This principle was successfully applied in the PHENIX Hadron Blind Detector using a triple-GEM system with reversed drift field, and is being further developed at BNL.

Formatted: Font: (Default) Calibri, 11 pt

TASK 3

Formatted: Font: (Default) Calibri, 11 pt, Not Bold

Applications of MPGD based detectors in Calorimetry and Muon Detectors

Formatted: Font: (Default) Calibri, 11 pt

Large area MPGD systems are being studied as potential solutions for digital hadron calorimeter and muon tracking/identification components of future Linear Colliders and SLHC upgrades respectively. Implementations in GEM, THGEM, Micromegas, MHSPs, and RPCs, have been proposed.

Physics at a future linear collider demands unprecedented jet energy and di-jet mass resolutions. The Particle Flow Algorithm (PFA) approach is a promising avenue for realizing these resolutions. PFA's require as input very detailed information on shower development. This can be provided through the use of high granularity calorimeters, with small, O(1cm^2), cells readout in digital mode (DHCAL). The challenge then is to produce several thousand square meters of detector planes having good hit efficiency, low hit multiplicity, small dead boundary regions, and robustness against discharges or sparking. High density readout will also be required for the large channel count, O(10^8).

The University of Texas at Arlington group has been developing large area GEM planes for a DHCAL with high density readout via the SLAC KPiX chip. UNAM, Mexico has similar interests in DHCAL development with GEMs.

A similar project directed at digital hadron calorimetry is being pursued at LAPP (Annecy) using micromegas. They are studying both analog and digital readout using the GASSIPLEX and HARDROC chips respectively. The University of South Carolina has also expressed interest in micromegas/readout electronics for calorimeter applications.

The use of THGEMs for large area calorimeter applications is being studied at the Weizmann Institute, MPI-Munich, and COIMBRA, Portugal. THGEMs offer the potential for low-cost large area devices that are mechanically robust and can operate at high gains.

Micromegas are being considered for the SLHC upgrades of the ATLAS and CMS muon systems. With the luminosity increase at the SLHC, the particle fluxes in ATLAS Muon Spectrometer at pseudo-rapidities > 2 will be of the order of few kHz/cm^2 at luminosity L = 10^{35}cm^{-2}s^{-1}. It is expected that forward muon tracking and trigger chambers of the ATLAS Muon Spectrometer with the highest counting rates will have to be replaced. CERN, Brookhaven and INP, Athens are participating in these SLHC upgrade developments.

Formatted: Justified, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

Formatted: Justified

TASK 4

Formatted: Font: (Default) Calibri, 11 pt, Not Bold

Cryogenic Detectors for rare events

Formatted: Font: (Default) Calibri, 11 pt

GEM, THGEM, RETGEM and MHSP systems are being developed for application in cryogenic detectors for dark matter searches, neutrino physics (neutrino beams, superbeams, and astrophysical neutrino detection), double-beta decay, axion searches, and PET.

For instance, the Budker Institute for Nuclear Physics is developing two-phase detectors, based on GEMs and THGEMs, operating in argon and xenon for coherent neutrino-nucleus scattering, dark matter searches and PET. They will detect both ionization and scintillation signals in two-phase Ar and Xe detectors using GEMs with CsI photocathodes. The final goal is to provide results that can be used for the development of a 100 l detector, large enough to be used for full-scale neutrino-nucleus and dark matter experiments.

Formatted: Right: 0.25"

Dark matter detectors are also being studied by a number of other groups: Weizmann Institute (THGEM), University of Zaragosa (Micromegas), UNAM (TGEMs and RETGEMs), University of Sheffield (THGEM), COIMBRA (MHSP, GEM, THGEM).

For applications in neutrino physics, the University of Sheffield is developing THGEM hybrid devices in combination with new generation silicon photosensors for operation in or above cryogenic liquids, notably liquid xenon. Their objective is to demonstrate robustness and reliability of MPGDs, particularly with liquids, and studies of gain issues. Neutrino physics applications are also being studied by the Weizmann Institute (THGEM for Super-Novae explosions), Budker Institute (Solar neutrinos), and the University of Zaragosa (Double-beta decay).

The University of Zaragosa is also the application of MPGDs to axion searches (CAST).

TASK 5

X-ray and neutron imaging

Gaseous detectors are used for neutron detection, usually by means of a hydrogenous converter. At PTB Braunschweig, detectors for thermal neutron as well as fast neutron (1 - 10 MeV) detection based on triple GEM readout with a neutron converter are being developed.

MPGDs are also used in X-ray detectors. A particularly interesting application is the possibility to measure X-ray polarization by tracking individual photo-electrons, emitted perpendicular to the X-ray direction, in the detector gas, whose spatial distribution is determined by the polarization of the incoming photon. This is possible with a high-resolution readout of the signals on a pad plane below a MPGD.

At Budker Institute, X-ray detectors for diffraction experiments for the use at synchrotron radiation facilities based on triple GEMs are being developed. For the CAST solar axion experiment at CERN, X-ray detectors with 2D readout using Micromegas were designed and are opperated with contributions from INP/NCSR Athens and NTU Athens. The Weizmann Institute and U Coimbra/Aveiro are active in the study of ThickGEMs and other devices for X-ray detection and polarization measurements. At U Montreal, the combination of MPGDs with Medipix2 and Timepix silicon detectors is studied for the use in X-ray and neutron detection.

TASK 6

Astroparticle physics applications

MPGDs also offer interesting possibilities for astroparticle physics applications. In many cases, this overlaps with the use of such devices in areas discussed above, since these astroparticle physics applications often demand tracking, photon or X-ray detection or cryogenic devices.

Common applications are X-ray detection, possibly with polarization measurement (INP/NCSR Athens, NTU Athens, U Zaragoza), cryogenic detectors for neutrino and dark matter detection (Budker, U Sheffield), and time projection chambers. At LPSC Grenoble, a micro-TPC (MIMAC) is being developed for direct detection of non-baryonic dark matter by accurately measuring the track of recoil nuclei in the detector gas, while U Zaragoza studies a MicroMegas TPCs for rare event detection, such as dark matter studies and the search for neutrinoless double beta decay.

TASK 7

Medical applications

Formatted: Font: (Default) Calibri, 11 pt, Not Bold

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Normal, Justified, Tab stops: Not at 0.49" + 0.98" + 1.48" + 1.97" + 2.46" + 2.95" + 3.45" + 3.94" + 4.43" + 4.92" + 5.41" + 5.91" + 6.4"

Formatted: Justified

Formatted: Not Small caps

Formatted: Font: (Default) Calibri, 11 pt, Not Bold

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Normal, Tab stops: Not at 0.49" + 0.98" + 1.48" + 1.97" + 2.46" + 2.95" + 3.45" + 3.94" + 4.43" + 4.92" + 5.41" + 5.91" + 6.4"

Formatted: Font: (Default) Calibri, 11 pt, Not Bold

Formatted: Font: (Default) Calibri, 11 pt

Formatted: Right: 0.25"

MPGDs offer a number of possibilities for high resolution medical imaging at lower radiation doses, and potentially lower cost, than traditional techniques.

Proposed medical applications for MPGDs include Positron Emission Tomography, Mini SPECT/PET, Nuclear Scattering Tomography for hadron therapy, X-ray imaging, and cancer diagnostics, and nanodosimetry.

The Weizmann Institute is studying the use of THGEMs for medical imaging, cancer diagnostics, and nanodosimetry. The imaging projects include the use of noble-liquid detectors. The Budker Institute are studying cryogenic two-phase detectors based on GEMs and THGEMs operating in xenon for PET applications. The TERA Foundation (Pavia) is developing very high rate GEM detectors for medical imaging.

The University of Sienna with INFN Pisa, and the TERA Foundation are developing GEM detectors for Nuclear Scattering Tomography/Radiography. The former group is also working on a new method for the position calibration of the outgoing proton beam of a cyclotron used to produce radioactive tracers for PET, and a mini SPECT/PET cylindrical detector based on GEM technology.

The University of Athens, the Aristotle University of Thessaloniki, and CNSTN (Tunis) are pursuing medical applications of micromegas. CNSTN is developing a small gamma camera for nuclear medicine using micromegas to obtain information about the position of interaction of the gamma rays.

TASK 8

Synchrotron Radiation, Plasma Diagnostics and Homeland Security applications

MPGDs can be used for a variety of security related applications ranging from the detection of illegal and/or dangerous cargo, through population protection from advance warning of earthquake and forest fires.

Searching for illegal nuclear material in cargo presents a major security challenge due to the vast number of containers transiting through ports on a daily basis. The main advantage of MPGD use for cargo scanning is the superior spatial resolution of GEMs to perform muon tomography on cargo to detect hidden nuclear contraband using cosmic ray muons. GEM detectors will provide precise tracking of the muons allowing measurement of the muon deflection due to multiple scattering by high-Z materials in the cargo. This will require the development of large area GEMs in combination with affordable front-end electronics.

Other applications are radon detection in the air as a early warning of earthquakes, and for UV visualization including remote forest fire detection.

SHOULD GO INTO THE TABLE: Florida Institute of Technology is developing a GEM application for cargo scanning. The Ecole Nationale Superieure des Mines is developing RETGEMs with application to radon detection in the air as a early warning of earthquakes,

III-F. Production (WG6)

OBJECTIVE

Development of cost-effective technologies and industrialization (technology transfer)

TASK 1
Development and maintenance of a common "Production Facility"

To reduce costs, it is in the interest of the collaboration to share the resources that are used to produce MPGDs. By de-facto CERN's TS-DEM-PMT workshop has played this role by providing detectors to experiments and institutes, many of which are members of the collaboration. It is at CERN where the technology to produce GEMs was created and many innovative ideas to fabricate MPGDs and read-out boards have been generated and put in practice. The PMT workshop has experienced personnel available whose full time job is to produce circuits and detectors and provide them to the collaboration members at cost. PMT is capable of producing detectors in prototype quantities and in series for small experiments (TOTEM GEM, T2K Micromegas). This mix of creating production processes, prototyping of various MPGDs and producing small series, combined with the experience of transferring production technology to industry (e.g. GEM, ATLAS TRT) suggests that CERN's workshop should be the common production facility for the collaboration.

With the current equipment in PMT it is possible to produce large detectors in small quantities but possibly not with the level of quality needed for repeatable productions of large MPGDs. Some equipment is limiting the maximum possible size of the MPGDs (e.g. laminator, exposure equipment, ovens, chemical bathes) and certain production steps can therefore not be made in the most optimal way. Current resources of CERN do not allow the level of investment needed to improve this situation without any external help.

To develop and maintain the common production facility at the required level, the following tasks have to be executed:

> 1.1 Make an inventory of production needs (MPGD type, size, volume) for the duration of the collaboration
>
> 1.2 Make an inventory of the available equipment and the limits that they impose on the capabilities (type, size, volume, quality)
>
> 1.3 Make a list of equipment and other resources needed to get the production facility up to the required level
>
> 1.4 Obtain resources
>
> 1.5 Operate the facility (maintain, produce, document procedures, risk analysis …)

→ Table of resources (FTE, skills), start/end date, deliverables

TASK 2
MPGD production industrialization (quality control, cost-effective production, large-volume production)

Quality *assurance* is needed once a development of a detector type is out of the prototyping phase. Quality *control* in the sense of all tests and controls needed during production to guarantee that the technical parameters of the circuits are within the specification, is an important factor of quality assurance. For the final products currently measurements such as leakage current, sparking voltage and certain visual controls are used.

Formatted: Justified, Indent: Left: 0.5"

Formatted: Font: Italic, English (U.K.)

Formatted: Justified

Formatted: Justified

Formatted: Right: 0.25"

To have production better under control and to be able to compare different methods of fabrication or production sites certain objective standards are needed. E.g. a standard method and tools to measure hole sizes of GEMs, with well-defined acceptability criteria may even help to improve the cost. The creation of these standards may be part of RT2, Task 1 (Development of common test standards).

A strict quality assurance system with highly detailed manufacturing procedures and quality control should be put in place for any large-volume production. It is expected that the quality control used in the common production facility can be adapted for large scale productions. Final quality assurance procedures can only be made for specific projects.

The aim of the common production facility is to develop production processes and to produce MPGDs in small to medium quantities. To be able to produce larger quantities (several hundreds per year of a single large type) the equipment and the organisation of operating the facility may need to be different. Depending on many parameters this may require investments by the common production facility or it may need the involvement of industry. Only when the different parameters of a specific project are known (e.g. type, size, volume, delivery times, available budget) it can be decided which path to take.

Tasks:

2.1 Define quality control standards for the different type of detectors

2.2 For specific large volume productions: write quality assurance procedures

2.3 For specific large volume productions: decide production method

→ Table of required resources (FTE, skills), start/end date, deliverables

TASK 3
Collaboration with Industrial Partners

There are several reasons why industrial involvement may be needed:

- The demand for MPGDs is larger than the common production facility can provide
- Allow price reductions due to large scale or industrial manufacturing methods
- Assure the availability for commercial applications

As the technology to produce most types of MPGDs is highly specific and difficult (THGEM is an exception), a transfer of technology is needed. This transfer is not easy: the technology to produce MPGDs is completely different than the products these companies normally make. If there is not a firm order for productions the companies may not be very interested or the transfer may take long; companies may be reluctant to set up technology transfer contracts as they may have difficulties seeing the market for this type of product or fear licensing issues.

CERN has experience in transferring production technology to industry and has set up several contracts with commercial companies to produce GEMs for example. The results for MPGDs are unfortunately not yet very successful as despite the transfer has taken place several years ago, even for GEMs of the small 10x10 cm size the quality is not yet up to the required level. A company producing GEMs seems to be reluctant to collaborate with CERN to solve the few remaining quality issues while another company stopped producing GEMs from one day to another.

Formatted: Font: Not Italic
Formatted: Justified, Indent: Left: 0.5"
Formatted: Font: Italic, English (U.K.)
Formatted: Justified
Formatted: Bullets and Numbering
Formatted: Right: 0.25"

There is therefore a high risk that the production of large MPGDs in industry may not immediately give the required results.

CERN's Technology Transfer unit is active in this field and has helped TS-DEM to collaborate with several companies. It is expected that the experience that is built up with the transfer of GEM technology will be invaluable for other MPGD projects. Qualification of companies before transferring technology, contractual obligations, IP licensing and other issues are a few of the subjects that may improve the chances of a successful transfer.

Industry involvement can also be useful for cost effectively making certain specific production steps (e.g. the stretching of mesh for Micromegas, exposure step for GEMs).

Tasks:

3.1 Define IP and TT policy (see VI Collaboration with industrial partners)

3.2 Understand issues of interests of industry

3.3 Understand in which cases transfer to industry is required or useful

3.4 Transfer MPGD fabrication technology to qualified companies (which detector type, define requirements, contracts …)

3.5 Understand which production steps may be subcontracted and associated IP transfer issues

→ Table of required resources (FTE, skills), start/end date, deliverables

Formatted: Font: Italic, English (U.K.)

III-G. Common Test Facilities at CERN (WG7)

OBJECTIVE

Design and maintenance of common infrastructure for detector characterization

Formatted: Justified

A common effort in this direction is needed because the number of groups involved in MPGD development has grown very significantly and will still do during the next years. As members of the RD-51 collaboration, research groups will get easier access to the facilities inside RD-51 collaborating institutes and at CERN, and

Formatted: Right: 0.25"

most important, share resources, make common requests and group experiments. An optimization of test beam plan for the whole MPGD community is of major importance also at short term, particularly during the initial LHC commissioning phase where uncertainties on beam availability could be expected.

TASK 1
Development and maintenance of a common "Test-Beam Facility"

- Construction and installation of the basic setup, including trigger and tracking devices, high precision mechanics, and services;
- Definition of a flexible DAQ system, as well as a flexible control system to set up and monitor detector's parameters;
- Definition of a common approach in data analysis and development of a common software framework for this task;
- Integration of a magnet in the system to allow measurements in magnetic field.

Formatted: Bullets and Numbering

The development of robust and efficient MPGDs entails the understanding of their fundamental properties and performance at several stages of their development phase. This implies a significant investment for detector test beam activities to perform the R&D needed, to test prototypes and to qualify final detector system designs, including integrated system tests. The measurements in test-beam facilities cover efficiencies, noise, time, position and energy resolutions - basically all the critical performance parameters for new detector systems.

Common Gas, Trigger, Tracking and DAQ Systems in the Beam Site

CERN's PS and SPS can provide a variety of particle species with a wide momentum range. A test set-up will be permanently installed in one of the CERN beam lines, that would allow quick and easy access for the different user's communities developing MPGDs. The collaboration will develop common general infrastructure (including gas systems), DAQ/controls and test beam analysis software that can easily integrate additional detector systems. It will serve as a vehicle for community building and will address individual component performance, as well as combined performance and integration issues whenever appropriate. A magnet and a high precision, fast beam telescope will be needed. Timing/trigger modules will also be needed to allow timing measurements between asynchronous beam-particles and a synchronous readout clock.

Such a test beam setup can be build up over the few years:

Stage 1: Setup of DAQ/control, gas, services, trigger and telescope - including first measurements of a few test-devices. This will also allow development of a first version of monitoring and analysis software for this basic setup. Mechanical supports for modules, also inside a magnetic field, will also require some effort.

Stage 2: Consolidation of basic infrastructures, and inclusion of a larger set of devices under test (DUTs). The readout, control and the DUTs can then be treated as extensions of the basic infrastructure and be carried out and analyzed as part of a standard hardware and software framework.

In general, it is important to identify groups that are willing to help on setting up the basic facility and maintain it, and these groups will also be central in carrying out the measurements, in collaboration with the developers of the DUTs that need to bring in specialized knowledge and efforts.

Formatted: Right: 0.25"

Two test beam periods per year is advantageous for redundancy and to allow problems to be identified and solved from the first run to the second one. It is also very important to be able to keep equipment, cables and infrastructures in one well identified place in one of the SPS beam lines, such that one can build on the existing infrastructure year by year and accumulate experience with the beam line and set-up.

TASK 2~~1~~

Development of common "Irradiation Facilities" and irradiation test programme

- Contribution to the design of the new GIF++ irradiation facility at CERN, in order to install a dedicated, permanent setup for the RD-51 collaboration;

- Develop a plan to use and contribute to the upgrade of the CERN PS-T7 proton and neutron facilities, for radiation hardness characterization of detector's components (assembly materials, electronics, etc).

~~TASK 2~~

~~Development and maintenance of a common Test-Beam Facility~~

- ~~Construction and installation of the basic setup, including trigger and tracking devices, high precision mechanics, and services;~~

- ~~Definition of a flexible DAQ system, as well as a flexible control system to set up and monitor detector's parameters;~~

- ~~Definition of a common approach in data analysis and development of a common software framework for this task;~~

- ~~Integration of a magnet in the system to allow measurements in magnetic field.~~

~~The development of robust and efficient MPGDs entails the understanding of their fundamental properties and performance at several stages of their development phase. This implies a significant investment for detector test beam activities to perform the R&D needed, to test prototypes and to qualify final detector system designs, including integrated system tests. The measurements in test-beam facilities cover efficiencies, noise, time, position and energy resolutions - basically all the critical performance parameters for new detector systems. Additionally, C~~Ccharacterization of specific detector's behaviors operated in large particle background demands some targeted aging tests in irradiation facilities. The RD-51 irradiation program will focus on using those CERN facilities to optimize the development and selection of the most suitable radiation hard technologies for the various MPGD detector components and, at a later stage, assess and monitor the radiation hardness of the qualified components during production. With the introduction of new technologies and large area detectors the study of the radiation effects on new materials, larger components, as well as room temperature glues, becomes a must.

~~A common effort in this direction is needed because the number of groups involved in MPGD development has grown very significantly and will still do during the next years. As members of the RD-51 collaboration, research groups will get easier access to the facilities inside RD-51 collaborating institutes and at CERN, and most important, share resources, make common requests and group experiments. An optimization of test beam plan for the whole MPGD community is of major importance also at short term, particularly during the initial LHC commissioning phase where uncertainties on beam availability could be expected.~~

Formatted: Normal, Justified, Tab stops: 0.25", Left

Formatted: Bullets and Numbering

Formatted: Right: 0.25"

Gamma, Charged Hadrons and Neutron irradiation facility

Formatted: Underline

Standard beam tests using secondary beams of various particle types can provide particle flux of the required rate to test performance and radiation hardness of particle detectors. However typical irradiated areas cover 10×10 cm2 at most. The CERN gamma irradiation facility (GIF), that started to operate in 1997 [105], allows testing large area detectors by exposing to an uniform high gamma flux from an intense 137 Cs source. A large flux of 660 keV γ-rays recreate the background conditions similar to those existing in the experiments during the operation of the LHC machine. Therefore GIF has been heavily used to test whether the detection efficiency and the resolution of the LHC detectors are affected by the background radiation. Until 2004, detectors placed in the GIF facility could simultaneously be tested in the SPS X5 fixed target beam. Following the dismounting of the SPS West Area beams, simultaneous beam tests are no longer possible and the present facility is scheduled to be shutdown towards the end 2009. An upgrade of the facility, called GIF++ , is under study taking into account the needs to develop detectors, especially for SLHC, with an improved layout of the test zone, higher source intensity and the simultaneous presence of a high-energy particle beam. The MPGD community, via the RD-51 collaboration, will get involved in the design of the new facility, such that specific needs for the development of these detectors, and specially of large sizes, are taken into account in the design phase. The final goal should be that the RD-51 community has a dedicated setup in GIF++ , with the relevant infrastructure for detector operation and testing, allowing efficient and careful detector characterization as needed for the RD-51 program.

Also at CERN, the PS-T7 24 GeV/c proton and neutron irradiation facilities [106] are widely used by detector communities for characterization of materials, detectors and electronics. The proton facility allows irradiation of samples with an active area up to 2×2cm2 to fluences up to 5 × 1013 protons/cm2 /hour; in the mixed field of the neutron irradiation facility samples of up to 30×30×30 cm3 and 5 kg weight can be exposed to fluences up to 1012 neq /cm2 /hour (1 MeV neutron equivalent).

~~The RD-51 irradiation program will focus on using those CERN facilities to optimize the development and selection of the most suitable radiation hard technologies for the various MPGD detector components and, at a later stage, assess and monitor the radiation hardness of the qualified components during production. With the introduction of new technologies and large area detectors the study of the radiation effects on new materials, larger components, as well as room temperature glues, becomes a must.~~

The CERN PS-T7 irradiation facilities provide a number of advantages, such as exposure to high particle flux in reasonable time, fast turnaround, the possibility to move samples into beam without entrance into irradiation area, and a well organized infrastructure that minimizes administrative and setting up procedures.

~~Common Gas, Trigger, Tracking and DAQ Systems in the Beam Site~~

~~CERN's PS and SPS can provide a variety of particle species with a wide momentum range. A test set-up will be permanently installed in one of the CERN beam lines, that would allow quick and easy access for the different user's communities developing MPGDs. The collaboration will develop common general infrastructure (including gas systems), DAQ/controls and test beam analysis software that can easily integrate additional detector systems. It will serve as a vehicle for community building and will address individual component performance, as well as combined performance and integration issues whenever~~

Formatted: Right: 0.25"

~~appropriate. A magnet and a high precision, fast beam telescope will be needed. Timing/trigger modules will also be needed to allow timing measurements between asynchronous beam-particles and a synchronous readout clock.~~

~~Such a test beam setup can be build up over the few years:~~

~~Year 1: Setup of DAQ/control, gas, services, trigger and telescope - including first measurements of a few test devices. This will also allow development of a first version of monitoring and analysis software for this basic setup. Mechanical supports for modules, also inside a magnetic field, will also require some effort.~~

~~Year 2: Consolidation of basic infrastructures, and inclusion of a larger set of devices under test (DUTs). The readout, control and the DUTs can then be treated as extensions of the basic infrastructure and be carried out and analyzed as part of a standard hardware and software framework.~~

~~In general, it is important to identify groups that are willing to help on setting up the basic facility and maintain it, and these groups will also be central in carrying out the measurements, in collaboration with the developers of the DUTs that need to bring in specialized knowledge and efforts.~~

~~Two test beam periods per year is advantageous for redundancy and to allow problems to be identified and solved from the first run to the second one. It is also very important to be able to keep equipment, cables and infrastructures in one well identified place in one of the SPS beam lines, such that one can build on the existing infrastructure year by year and accumulate experience with the beam line and set-up.~~

Description of work -- > TO BE REPLACED BY TABLES (MILESTONES AND DELIVERABLES)

Task 2~~1~~: Irradiation facilities

a) The RD51 collaboration will actively contribute in the specifications of the new irradiation facility GIF++, in order to obtain a fully-equipped, dedicated setup available for the collaboration at all times. For this reason, the collaboration must as first step gather and provide information about:

- the required source fluency, taking into account the applications of the DUTs;
- the most convenient particle beam type available in the area;
- the specifications of a permanent gas system in the area;
- the specifications of the permanent DAQ and control system that will be installed in the area;
- the other services and infrastructures required during the measurements, such as controlled environment (P, H, T), flammable gas detection systems, etc.

b) The study of the radiation-hardness properties of detectors components is one of the tasks of the RT2. For this reason, a plan to use the CERN PS-T7 irradiation facilities for the following year must be provided. The plan should propose a list of candidate assembly materials, glues and other

Formatted: Right: 0.25"

components requiring radiation hardness validation, maximum doses, in agreements with the MPGD community.
The need of an upgrade of such a facility must be evaluated.
So sub-tasks can be summarized in:

- preparation of a list of components requiring radiation hardness validation;
- definition of a use plan of the PS-T7 irradiation facility;
- evaluation of possible upgrade requests of such a facility.

Formatted: Outline numbered + Level: 2 + Numbering Style: Bullet + Aligned at: 0.5" + Tab after: 0.75" + Indent at: 0.75", Tab stops: 1.5", Left + 2.5", Left

Task 1~~2~~: Test beam facility

a) The basic setup for the test beam facility includes:
   - the design and the commissioning of the trigger devices and logic
   - the installation of tracking telescope as well as high precision support mechanics
   - the definition and the installation of the gas system
   - the definition of all the other services and infrastructures (cabling, racks, computers..)

b) The DAQ and the control system must be designed in a flexible way, to take into account, respectively, for the possible readout schemes and the possible parameters to be monitored of all the device to be tested.
A modular approach will make easier the integration of new devices.

c) A common analysis framework based on ROOT package must be developed, as a common approach in the data analysis can be crucial in the comparison of the results of different devices and technologies.

d) The introduction of a magnet entails the introduction of new services and infrastructures on the test beam facility, as well as the integration in the previous setup involving the mechanics, the DAQ and the control system, and the analysis framework.

Formatted: Right: 0.25"

6/2/2008 9:32:00 PM

6/2/2008 9:32:00 PM

6/2/2008 9:32:00 PM

6/2/2008 9:32:00 PM

6/2/2008 10:23:00 PM

6/2/2008 10:23:00 PM

6/2/2008 11:51:00 PM

6/2/2008 11:51:00 PM

6/2/2008 11:51:00 PM

6/2/2008 11:51:00 PM

6/2/2008 11:51:00 PM

6/2/2008 11:51:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:53:00 PM

6/2/2008 11:58:00 PM
6/3/2008 12:00:00 AM
6/3/2008 12:00:00 AM
6/3/2008 12:00:00 AM
6/3/2008 12:00:00 AM
6/3/2008 12:04:00 AM

6/3/2008 12:02:00 AM

6/3/2008 12:02:00 AM

6/3/2008 12:02:00 AM

6/3/2008 12:02:00 AM

6/3/2008 12:02:00 AM

6/3/2008 12:02:00 AM

6/3/2008 12:03:00 AM

6/3/2008 12:03:00 AM

5/30/2008 4:01:00 PM

6/3/2008 12:03:00 AM

6/3/2008 12:05:00 AM

6/3/2008 12:07:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:12:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:10:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 12:17:00 AM

6/3/2008 1:24:00 AM

6/3/2008 1:24:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM

6/3/2008 1:31:00 AM