Comments in red
Major modifications in blue

==

III. Research Topics and Workplan

A. Technological Aspects and Developments of New Detector Structures

Remove : List of participating institutes: ???
Remove: Conveners: P. Colas, S. Dalla Torre, A. Bondar

Objective: Optimization of fabrication methods, development of new multiplier geometries and techniques.
Task 1: Development of Large Area Micro-Pattern Gas Detectors (large area modules, material budget reduction)
Task 2: Optimization of fabrication methods (bulk micromegas, microbulk micromegas, single-mask GEM)
Task 3: Further developments of new geometries and multiplier techniques (THGEM, RETGEM, MHSP, charge-dispersive readout, Ingrid)
Task 4: Development of radiation-hard detectors for the sLHC and ILC

New proposal about objective and tasks, option 1
Objective: Detector design optimization and related development of fabrication methods, development of new multiplier geometries and techniques.
Task 1: Development of Large Area Micro-Pattern Gas Detectors (large area modules, material budget reduction)
Task 2: Detector design optimization and related development of fabrication methods (bulk micromegas, microbulk micromegas, single-mask GEM)
Task 3: Further developments of new geometries and multiplier techniques (THGEM, RETGEM, MHSP, charge-dispersive readout, Ingrid)
Task 4: Development of radiation-hard detectors
New proposal about objective and tasks, option 2
Objective: Detector design optimization, development of new multiplier geometries and techniques.
Task 1: Development of Large Area Micro-Pattern Gas Detectors (large area modules, material budget reduction)
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)
Task 3: Development of radiation-hard detectors

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.

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 1.2m 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

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 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.

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 programme 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 structure 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 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.

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

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
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 (mis) alignment of grid holes in this TripleGrid 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].

New Materials and Material Budget Reduction

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 status of the art, it seems difficult to swap copper and aluminum in GEM detectors. Bulk Micromegas detectors using stainless steel meshes could be lightened by using aluminum vacuum plated polyester mesh. Read-out boards can be produced using aluminum for the conductive pattern.

Comment: mentioning THGEM with Al electrodes or THGEM with resistive electrodes is not pertinent to illustrate examples of low mass detectors: fiberglass by itself is not a low mass material → It has been removed.

Remove : **Quality Control**

Remove : **Industrialization and System Integration Aspects**