GEMINI:
GEM Instruments for Nuclear Interactions
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1 Introduction

The main tasks of this R&D is the development of different detectors based on GEM technologies essentially for beam diagnostics. The use of GEM foils for detector construction started in Frascati on 2002 with the R&D for LHCb muon chambers M1R1. Ever since, several triple GEM chambers have been built for different applications. The results obtained in several beam tests show high performances: high rate capability (> 50 MHz/cm²), good time resolution (~ 4 ns), good space resolution O(200 μm), and good aging resistance after 2 C/cm² of integrated charge. The GEMINI R&D is devoted to the developments on detectors for neutrons and hadrons and the construction of readout electronics and power supply. The scientific activity of GEMINI for the 2010-2011 can be resumed in these five main items:

- Developments on a Compact TPC for high intensity beam;
- Characterization and installation at FTU (ENEA) of a fast neutron flux monitor;
- Characterization and installation at ToreSupra (Cadarache CEA) of a X ray monitor;
- Triple GEM monitors for fast neutrons tested at ISIS RAL;
- Design and construction of a new HV Power Supply for triple GEM detectors
- Design and construction of a new Readout Electronics FPGA based;

2 Construction and test of a Compact TPC for beam monitoring

A compact Time Projection Chamber (TPC) has been designed, built and tested, for beam monitoring. The main idea in developing this detector is to place a standard triple GEM detector parallel to the beam and to use it as a time projection chamber, by enlarging the drift gap. In this way the material crossed by the particle is particularly small (only two kapton windows) and the beam position measurement could be more precise, O(50 μm), in the coordinate along the drift, by measuring the time of arrival of the electron clusters. Moreover, a very compact detector can be realized, using standard 10 × 10 cm² GEM foils and a drift gap of 4 cm. The 128 readout channels can be organized in two configuration:

- a matrix of 8 × 16 pads 3x6mm² each
- two array of 64 pads 0.5x0.5mm² each;

obtain a good resolution O(1 mm) or better also in the other two coordinates.

The TPC, working without a magnetic field, has been operated with a gas mixture ArCO₂ (70/30) or ArCO₂CF₄ (45/15/40) at a Gain 10⁴. The high rate capability of GEM technology allows the use of this monitor not only for single tracks events but also for multiparticle beam. The electron drift velocity measured at 2KV/cm in the CF based gas mixture was 5.3 μm/ns. One similar device has been used also for the monitoring of proton and ion beam in UA9 experiment for the monitoring of channeled beam. Thanks to a small material budget crossed by the
particle (0.2%$X_0$) and the 3D reconstruction of the particles track, its use for ion beam monitor in hadrotherapy. We test this detector in June 2010 at CNAO in Pavia on a high intensity 400 MeV proton beam. The beam profile can be seen in Fig. 1. The intensity of the beam can be reconstruct with the current measurements made through the nanoammeter of our new HVGEM module described below. This results have been shown by F.Murtas at IEEE NSS Conference in Valencia in October 2011 talk.

### 3 Characterization and installation at FTU (ENEA) of a fast neutron flux monitor

In 2010, a prototype $10 \times 10 \text{cm}^2$ made of a triple GEM with a cathode of aluminum and polyethylene, has been placed in front of one port of Frascati Tokamak Upgrade. The neutron produced by the burning plasma, impinging on polyethylene, is converted in proton that releases its final energy inside the gas, producing electrons. The 128 readout pads, organized in a matrix $16 \times 8$, allow to create an intensity map of the fast neutrons. This detector was characterized in 2009 showing a good linearity up to $12 \text{MHz/cm}^2$ (the maximum flux for Frascati Neutron Generator). The detector efficiency is not high ($4 \times 10^{-4}$), but enough for this type of measurements. The active area of this monitor has been divided into two parts with the polyethylene converter optimized for the two energies (2.4 and 14 MeV from DD and DT nuclear interaction respectively).

Thanks to the strength signal released by the proton inside the gas, the low gain settings of the chamber allow to have a good rejection to photons produced by the radio activation of material around the detector.

![Figure 1: On the left the GEM TPC placed on the treatment table at CNAO; on the right the beam profile and beam angle measurement vs time.](image)

Fig. 2 shows the comparison between the GEM and neutron monitors signals in plasma dis-
charge: note that the GEM and NE213 are pretty close in the high neutron emission phase (in which the BF3 detector saturate). The tests on FTU have demonstrated that the detector can operate as a neutron diagnostic monitor in a tokamak environment. Future activity should focus on the design of a new GEM detector prototype and in particular on the optimization of the neutron converter, the use of new read-out electronics board and reducing as much as possible the distance of the GEM from the plasma for fast neutron flux maximization. The detailed results has been described on EFDA Final Report WP10-DIA-04-01-02

4 Characterization and installation at ToreSupra of a X-ray monitor;

In 2011 a triple GEM has been used as an X-ray tomography system and was installed at the tokamak Tore Supra in Cadarache (CEA) for the burning plasma diagnostic. The ultimate aim is to use this information produced by this system in real time for visualization but also potential feedback, with a particular emphasis on the optimization of the reconstruction technique.

Figure 3: Installation of GEM in Tore Supra (left). Comparison between DTOMOX and GEM time traces (right)

Various GEM acquisitions were then performed during the 2011 experimental campaign at Tore Supra. In total more than 150 shots were acquired, some of them lasting several minutes. The acquisition system and the high voltage power supply were remarkably stable during several hours of continuous functioning. As an example of such acquisition, a comparison of the time traces of each GEM pixels with the time traces of DTOMOX is shown on Fig. ?? with a good agreement between the two diagnostics.

5 Triple GEM monitors for fast neutrons tested at ISIS RAL

Fast neutron beams available at large scale facilities are becoming strategic for industrial applications, especially in relation to the assessment of radiation hardness of silicon-based nano-sized electronic chips. A stringent request for neutron beam lines dedicated to chip irradiation is the possibility to monitor and characterize the neutron beam above 1 MeV (the more concerning energy region of the spectrum) with a spatial resolution in the millimeter range or below.

A triple Gas Electron Multiplier (GEM) detector was developed as a fast neutron beam monitor for the ISIS spallation neutron source in UK. The test on beam was performed at the VESUVIO beam line, by placing the detector on the primary flight path (see Fig. 4). The spatial
distribution of the neutrons was measured in real time in the energy region between 2 and 800 MeV achieving a spatial resolution of a few millimeter thanks to the patterned readout of the detector.

Figure 4: On the left the experimental setup; on the right the online beam spot monitor

Figure 4 shows the intensity profiles along the x and y directions (the plane perpendicular to the neutron beam axis), over an integrated proton beam current of 355.4 μA*h (with an average proton current of 177.7 μA*h).

Also a time scan of the beam was performed: the start signal for time of flight recording (the ISIS clock) was delayed over 3 μs in steps of Δt = 100 ns and the count rate was measured within a time window Δt = 100 ns. The rate distribution over the whole set Δt chosen is shown in Figure 5. In this time scan it is well visible the double bunch structure of the neutrons originating by the protons hitting the spallation target. Because of the time structure of the proton beams, the arrival time onto the detector cannot be directly associated to the neutron energy. These initial tests show the high potential of the device as a fast-real time neutron beam monitor featuring a few millimeter spatial resolution. The detector has also a good photon rejection as shown in Fig 5. The performance of the device can be further extended towards spectroscopic capabilities, by characterizing its response function over a wider energy region by properly optimizing the cathode and polyethylene thicknesses. Monte Carlo simulations and new tests on beam are then envisaged to achieve this goal in the next future.

Figure 5: On the left the comparison between the neutron flux and the two proton bunches; on the right the detector efficiency vs the HV settings.
6 Development in electronics

6.1 Design and construction of a new version of HVGEM for triple GEM power supplying.

The HVGEM is a seven stage power supply specifically designed for this type of detector; it can be used also for thick GEM or Micromegas. Two type of stage power supply have been designed in a modular way: - 1400 Volt and 90\textmu am\phantom{amp} - 750 Volt and 180\textmu am. A new version has been designed in 2009, following the NIM standard (two units module): each single HV stage can be plugged on the NIM mother board, making the HVGEM more flexible and adaptable to different detectors. The module can be controlled through CANbus and USB port. A version controlled by ethernet is foreseen for 2013.

6.2 New Front End Electronics.

Up to now our GEM detectors have been readout with electronics based on Carioca GEM chip designed and realized for LHCb muon Chambers in 2007. The boards with two 8 channel chips are modular and easy to plug on the backplane of our detectors. In collaboration with Milano Bicocca University a new chip specifically thought for GEM detectors is under construction. It will be able to measure the total charge released in the active area with a good dynamics : from 20\textit{fC} up to 1\textit{pC} with a maximum rate of 2 MHz per channel. The total width of the LVDS signal will be propotional to the charge with a resolution better than 20\%. After the tests of this 8 channel chip, a new design with 32 channels is foreseen for 2012.

6.3 Design and construction of a Motherboard FPGA based.

In order to have a more flexible and portable system, a new mother board has been designed by with an FPGA, that will be able to analyze the LVDS signals coming from the FEE board. Two type of data acquisition can be implemented: 128 scalers and/or 128 multihit TDC channel with a resolution of 2 ns, sufficient to record the time drift of electrons along the 4 cm drift. The first three boards has been succesfully testes during 2010 in different sperimental setup. (see fig 6).

Figure 6: The mother board FPGA based coupled with the FEE and the GEM detector (left) and the HVGEM NIM module (right).
7 Future

Other research groups inside INFN, ENEA, CEA and CERN are interested in use of these triple GEM detectors described above and the electronics made in Frascati. Recently also two monitors for X rays have been made for burning plasma diagnostic and will be installed in Frascati Tokamak and Tore Supra at Cadarache.

Any other information can be found on the web site

http://www.lng.infn.it/esperimenti/imagem/

8 List of Conference Talks and Poster by LNF Authors in Year 2011

1. G. Croci et al.
   A New GEM Based Neutron Diagnostic Concept for High Power Deuterium Beams
   Poster, 2011 IEEE NSS and MIC, 23-29 October 2011, Valencia Spain

2. G. Corradi et al.
   High Voltage Power Supply for Triple GEM Detectors
   Poster, 2011 IEEE NSS and MIC, 23-29 October 2011, Valencia Spain

3. F. Murtas et al.
   Compact TPC GEM for High Intensity Beam Diagnostics
   Talk, 2011 IEEE NSS and MIC, 23-29 October 2011, Valencia Spain

4. F. Murtas et al.
   A Compact TPC GEM for Low and High Intensity Beam Diagnostics

5. G. Croci et al.
   nGEM fast neutron detectors for beam diagnostics
   Poster, ICFDT2 Conference Frascati December 2011

9 List of Publication in Year 2010-11

1. R. Villari, M. Angelone, B. Esposito, A. Ferrari, D. Marocco, F. Murtas, M. Pillon,
   Design of a GEM-based detector for the measurement of fast neutrons

2. F. Murtas, et al.
   Applications in beam diagnostics with triple GEM detectors