# GEM-based neutron beam monitors for spallation sources

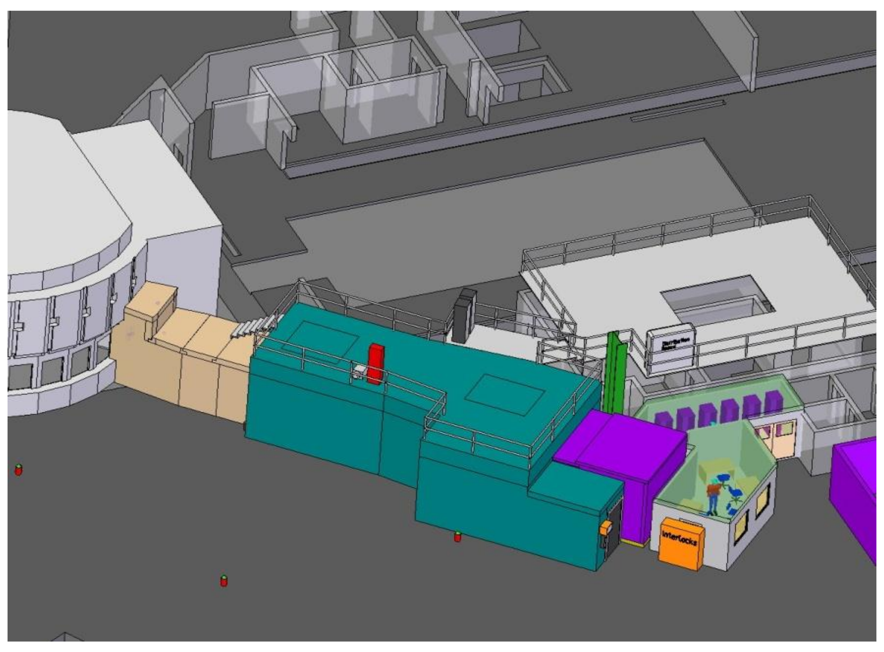

G.Croci[1,3], R. Caniello[1], C. Cazzaniga[2], G.Gervasini[1], G.Grosso[1], F.Murtas[5], G. Claps[5], R.Pasqualotto[4], E.Perelli Cippo[2,3], , M.Rebai[2,3], M.Tardocchi[1,3], E. Vassallo[1], M. Cavenago[6] and G.Gorini[1,2]

[1]IFP-CNR, Milano - [2]Università di Milano-Bicocca - [3]INFN–Milano-Bicocca - [4]Consorzio RFX Euratom-ENEA Association, Padova - [5]LNF-INFN, Frascati - [6]LNL-INFN, Legnaro


Due to $^3$He worldwide shortage, new high efficiency thermal neutron detectors shall be developed in order to replace $^3$He detectors in the future spallation sources. Large area fast neutron detectors are also needed in order to equip new fast neutrons lines and to characterize the neutron beams in an energy range form 2 MeV to 800 MeV

New high flux neutron monitors based on **GEM** as fast/thermal neutrons beam monitors for the **ChipIr** line at ISIS (RAL-UK) and for **ESS** (European Spallation Source).

ISIS (RAL, Didcot, U.K.):spallation neutron source (800 MeV).



ChipIr CAD model at ISIS-TS2

ESS model

Fast neutron detectors (**nGEM**) consist of **Triple GEM** (Gas Electron Multipliers) detectors, equipped with a properly designed **cathode** made of two layers of Al + $CH_2$that also serves as **neutron-proton converter** foil.

Thermal neutron detectors (**bGEM**) consist of **Triple GEMs** equipped with a **cathode** made of Al coated by a thin layer of Boron (1 µm) that is used to detect thermal neutrons using the **$^{10}$B(n,α)$^7$Li** nuclear reaction.

## Detectors Components

### nGEM Converter Cathode

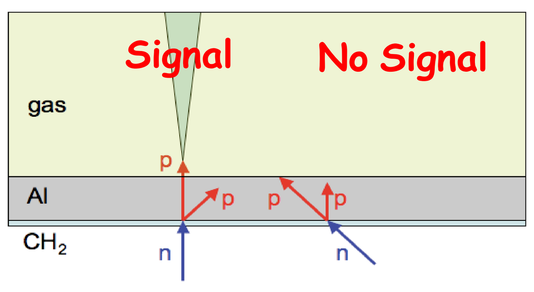
One Layer of Polyethylene
+ One Layer of Aluminium

2.5 MeV Neutrons interact with $CH_2$, and, due to elastic scattering processes, protons are emitted.

Protons entering the gas volume generate a detectable signal.

Al thickness ensures the directionality capability, stopping protons that are emitted at a too wide angle

Optimized $CH_2$-Al thicknesses (50 µm-50 µm) determined by simulations (MCNPX-GEANT4)



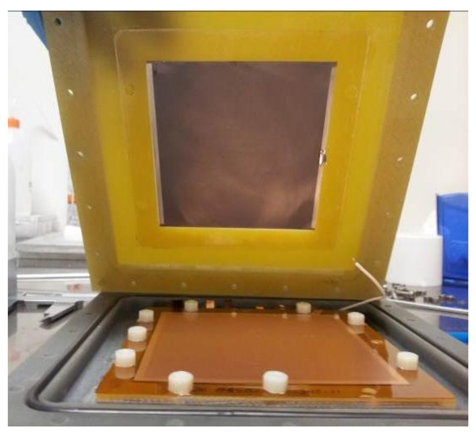

### bGEM Converter Cathode

400 µm thick aluminium foil (10X10 cm$^2$ area) coated by a 1 µm thick natural boron carbide film deposited by plasma sputtering or evaporationtechniques

1.47 MeV alpha particles and 0.84 MeV $^7$Li ion emitted back to back [ σ(25 meV) = 3980b]

Alphas/ $^7$Li ions entering the gas volume generate a detectable signal.

Boron carbide thickness ensures an efficiency of around 1% (sufficient for high flux beam monitors)



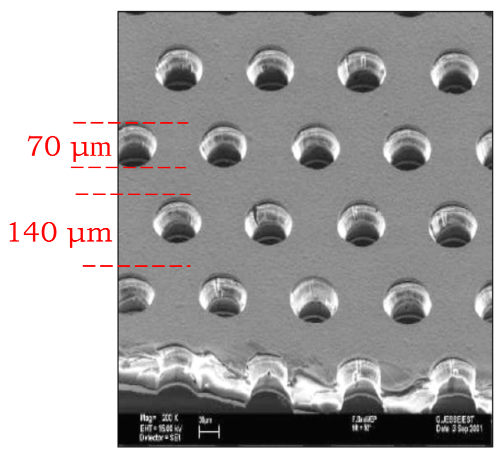
### GEM Foils

Thin Kapton insulating foil copper-clad on both sides and perforated by a high density, regular matrix of holes

Charge amplification structure.

Localization performed recording the charge reaching a suitably padded readout board.

Multi-GEM based detectors provide a gain of about $10^2$ (in this case), with a negligible discharge probability.




### Electronics & Read Out

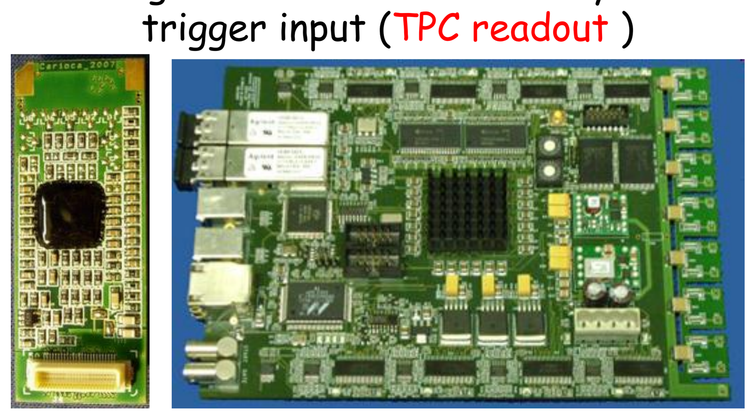
Padded readout Anode:
active area 10 x 10 cm$^2$
128 Pads
Pad Area 12 x 6 mm$^2$

### CARIOCA-GEM Digital Chips

8 channels (sensitivity of 2-3 fC)
Outputs: time over threshold LVDS signals (width 50-100 ns)
Radiation tolerant
Channel density of 1 ch/cm$^2$

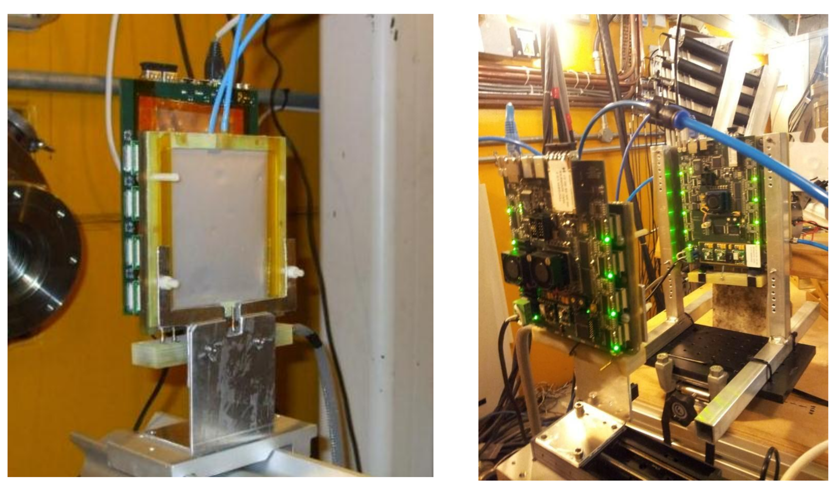
### FPGA Mother Board

Acquisition of 128 LVDS signals and measurement of:
- Rate measured by each pad within different gates (Scaler readout);
-Signal arrival time relatively to a trigger input (TPC readout )

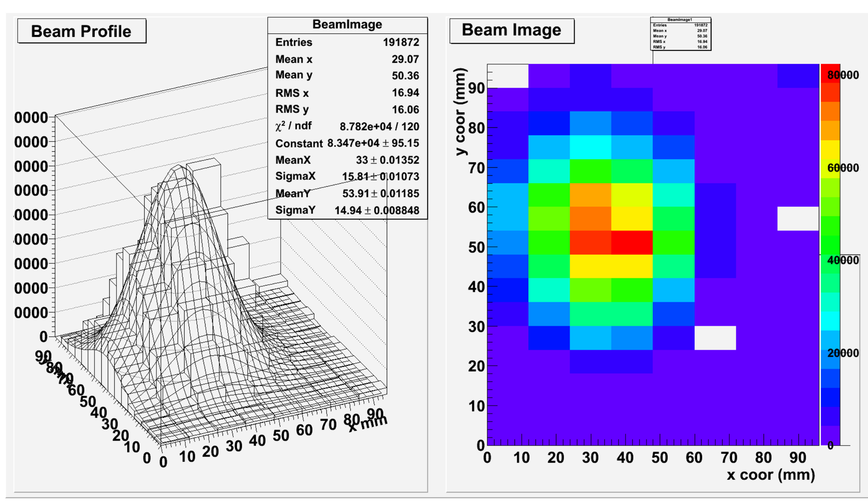


## Test of nGEM and bGEM Detector Prototypes at ISIS-RAL Facility

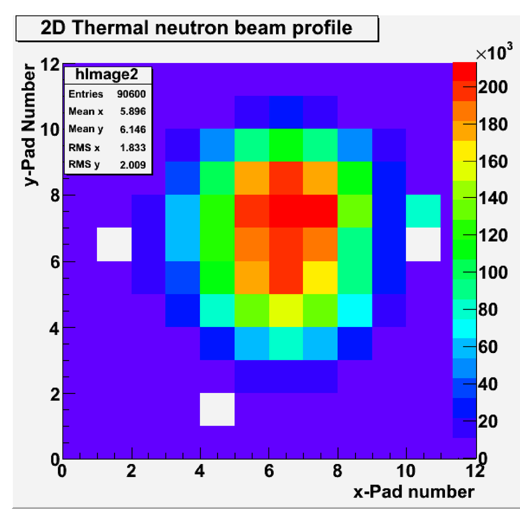
Test of the prototypes as a beam monitor for the neutron beam of the VESUVIO facility at RAL-ISIS.
This is a thermal/fast neutron beam with energies ranging from a few meV to 800 MeV. The functional shape of the flux intensity of this beam is described by a 1/E function.



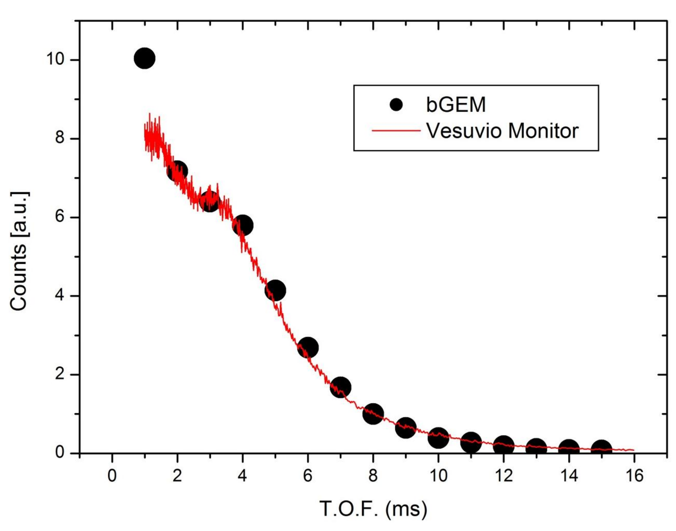
Pictures of the detectors installed in the Vesuvio beam line (left: front view of **nGEM**, right: rear view of **nGEM** and **bGEM**)



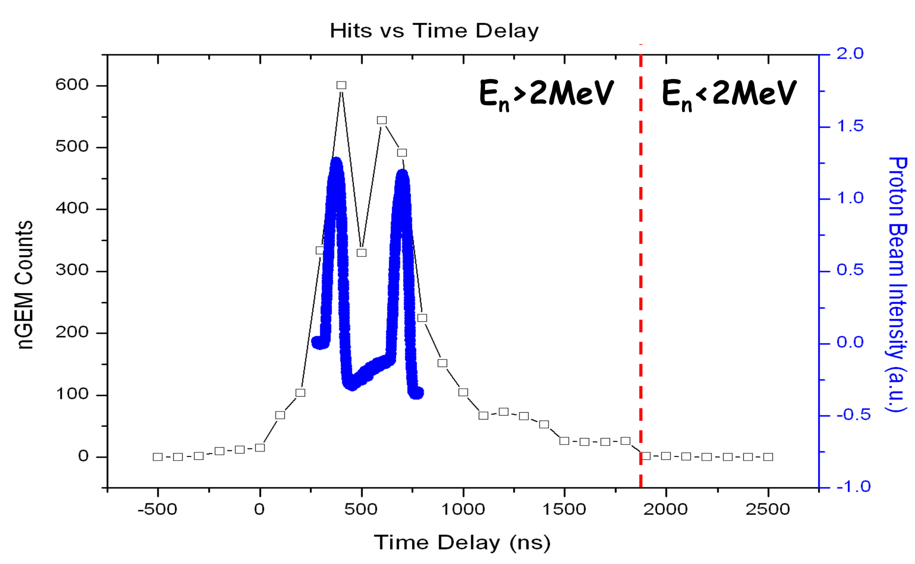

**nGEM** Fast neutron Beam Profile Intensity Measurement ($\Sigma\Delta V_{GEM}$ = 870 V)



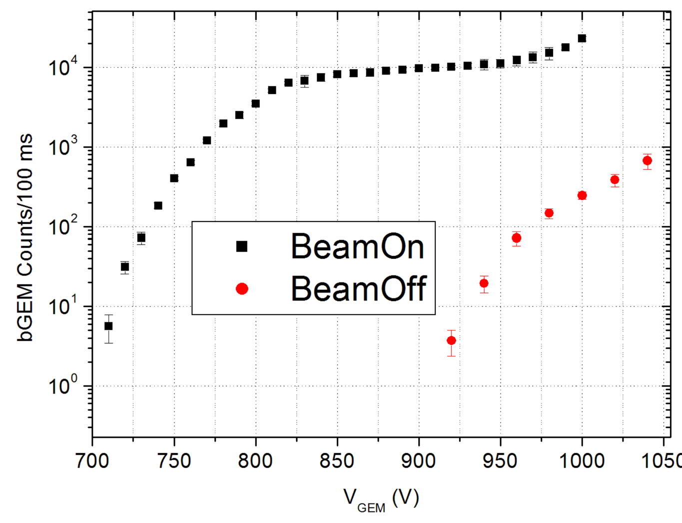

**bGEM** Thermal neutron Beam Profile Intensity Measurement ($\Sigma\Delta V_{GEM}$ = 870 V)




Measurement of the TOF spectrum of thermal neutrons of the Vesuvio beam line using the **bGEM** prototype and comparison with standars Vesuvio beam monitor




Measurement (@ $\Sigma\Delta V_{GEM}$ = 870 V) of the difference between the arrival time of bunch i and the T0 of bunch (i-1) using **nGEM** counts during a 100 ns wide gate and comparison with proton beam profile intensity




**bGEM** Counting rate Vs chamber gain: up to 890 V the chamber is senitive to thermal neutrons but not to gamma rays

**ISIS tests confirm that nGEM and bGEM detectors are both insensitive to γ rays and can be used as high rate, real-time fast and thermal neutron beam monitors.**

**bGEM detectors represent the first step towards the realization of high efficiency thermal neutron detectors as alternative to $^3$He**


Corresponding Author croci@ifp.cnr.it



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