15th RD51 collaboration Meeting - March 20th, 2015

Proton range radiography

Martina Bucciantonio, Mattia Fontana, Fabio Sauli, Ugo Amaldi

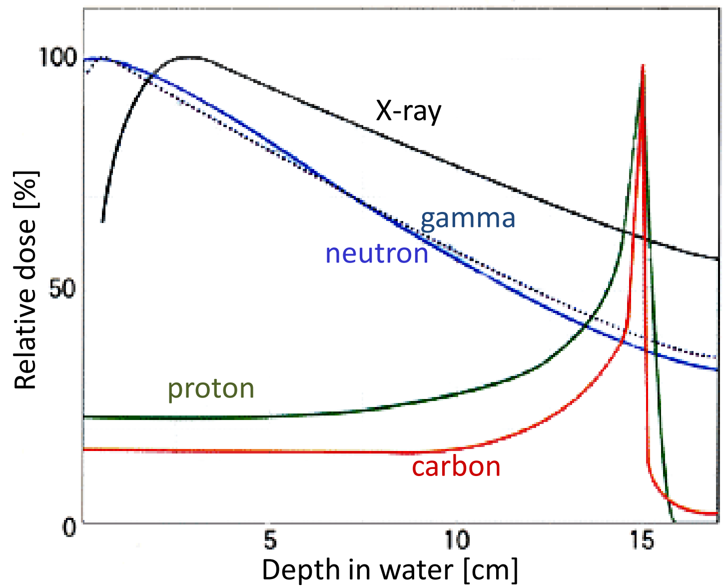
martina.bucciantonio@cern.ch

Hadrontherapy

18% of all cancers are not treatable either by surgery or radiotherapy

⇓

More targeted and effective cancer treatments with protons and Carbon ions



Advantages

- lower tissue damage
- biological effect ~10% > Xray
- less energy deposited in healthy tissues
- better conformity in dose distribution

Issues

- CT scans with uncertainty of ~ 3% ⇒ Conservative TPS (reduced effectiveness)
- Not common CT scans between sessions to verify changes of the tumor (high dose and cost)
- No ways of checking the interaction point during the treatment

Higher tumour control probability

but

Higher precision of the treatment delivery ⇒ Improvements in QA

Our solution

Proton Range Radiography

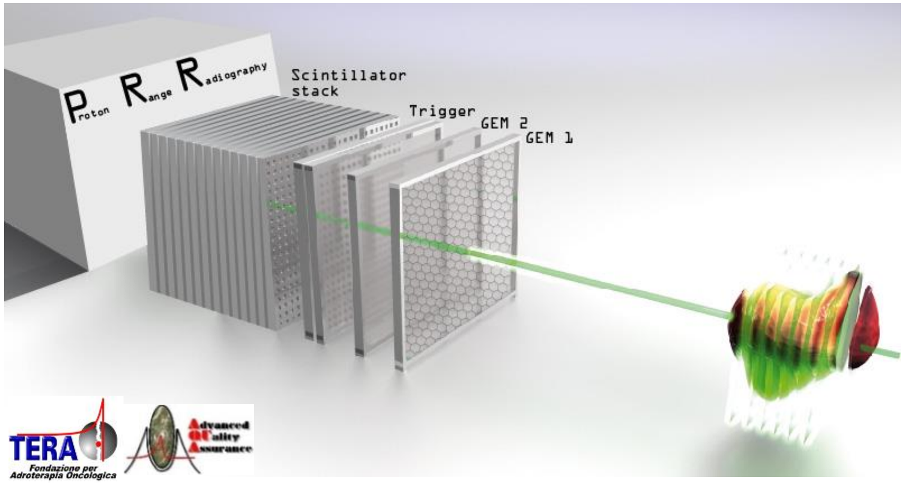
novel portable detector for integrated diagnostic with **increased accuracy** in :

- Direct tissues density measurements
- Patient positioning
- Tumor size verification between sessions with **lower dose** and **no need of repositioning**

using the **same proton beam** [70 : 230] MeV (up to 300 MeV where possible)
but at lower intensity (from 10^9 down to $10^{5 \div 6}$ p/sec)

Correlated measurement of **track position** and **residual range** by density measurement

⇨ 2D integrated density image
with range uncertainty of $\sim 1.6\%$



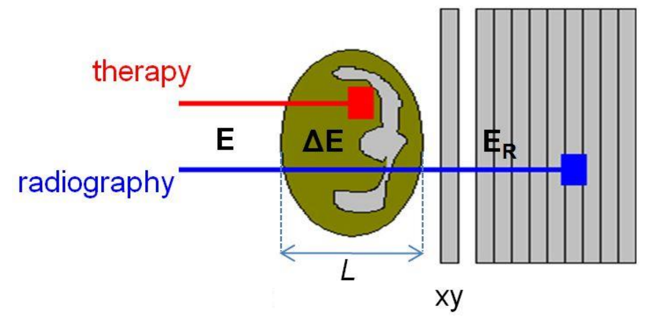
Proton Range Radiography (i)

Energy loss is proportional to the integrated relative electron density ρ of the target

$$\Delta E = E - E_R = \int_0^L \left(\frac{dE}{dl}\right)_l dl = \int_0^L \rho(l) S(l, E_l) dl$$

$$R(E) \cong \alpha E^p$$

$p \sim$ 1.8 for protons in the therapeutic range



For 150 Mev proton beam ($L \cong$ 15 cm w.e.)

$$\sigma_R = \sqrt{(\sigma_{Straggling})^2 + (\sigma_{Momentum})^2 + (\sigma_{Detector})^2} \Rightarrow \approx 1.6\%$$

~1.1% ~1% ~0.6%

for 3 mm thick organic scintillator

With 200 recorded events in 1 mm^2 pixel (*suitable for a good medical imaging system*)

$$\frac{\sigma_\rho}{\rho} = \frac{\sigma_R}{L\sqrt{N}} \Rightarrow \approx 0.11\%$$ across the full 15 cm w.e.

$\approx 0.34\%$ for an object within the target of 5 cm w.e.

For an image size of 20x20 cm^2 acquired in 10 sec = $8 \cdot 10^6$ proton tracks

$\Rightarrow \sim$ 1 MHz readout is needed

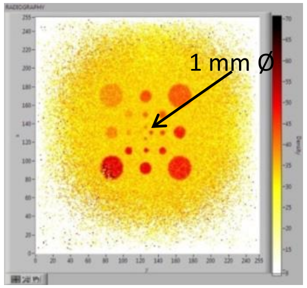
Proton Range Radiography (ii)

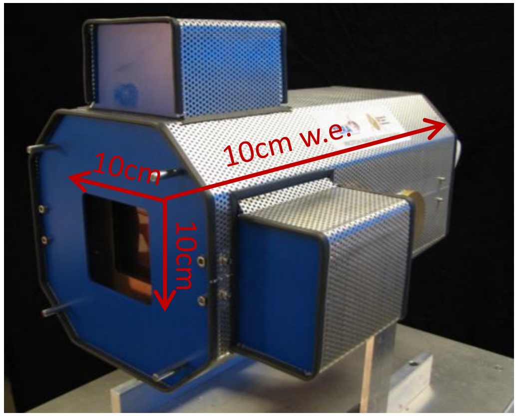
First Proton Range Radiograpy prototype – PRR10 (2010)

- Range resolution: 0.44 scintillator units = 1.6 mm WEPL

but

- Limitation 10 kHz data throughput





U. Amaldi et al, NIM. A 629 (2011) 337

New Proton Range Radiograpy telescope – **PRR30**

- Scintillator stack

- 48 Plastic scintillators 30x30 cm^2
  3 mm each (15 cm water equivalent)
- WLS fiber to SiPM

30MeV to 190MeV Residual Energy

- Tracker

- Two 30x30 cm^2 triple-GEM detectors (Compass style)
- 2D XY strip readout (800 um pitch)
- Readout electronics capable of 1M events/sec

⇨ New electronic development

GEM readout requirements

- Required spatial resolution < 1 mm

  ⇨ Strips connected in pairs (800 μm pitch)

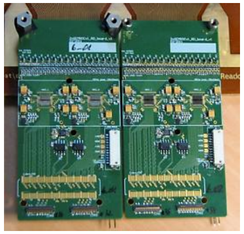
  (total strip capacitance of ~ 90 fC)

- Expected flux on GEM 30x30cm^2 10^6 s^{-1} (10^5 pulses/s per readout channel appearing randomly in time)
- Input charge 0 - 500 fC (50 fC most probable)
- Short current pulses with 40 ns duration time
- Time resolution < 100 ns p-p (The maximum rate is limited by the time resolution of signals recorded from X and Y strips)
- Discrimination threshold 6 fC input equivalent

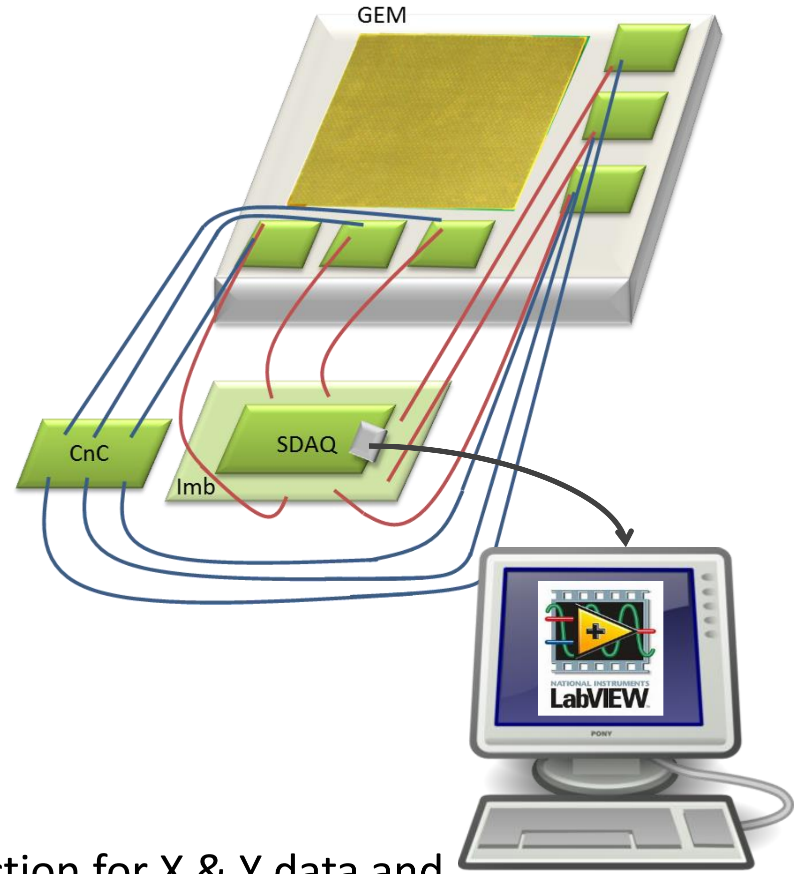
⇨ Novel dedicated **ASIC** for GEM **GEMROC**
Hybrid Front End board developed by AGH Cracow University
in collaboration with TERA

GEM readout electronics

- 12 GEMROC front-end boards



Asic: 32 self-triggering channels
Each channel splits into
a slow (energy) at 31.25 MHz and
a fast (timing) at 125 MHz sub-channel
Switchable gain



- 6 GR_DAQ

to process 4 Asics in parallel, collecting digital data, digitizing the analog ones and combine them together to create a 48 bit word

- 1 Master unit Imb-SDAQ

to generate clock, slow controls, master/slave connection for X & Y data and to send data through a Quick USB module (nominal Max. 48Mbytes/s)

- 1 Clock and Control

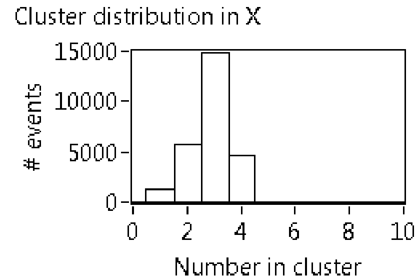
to send clock, reset, re-synch, test-pulse to all the GR-DAQs and to propagate the trigger coming from the scintillator DAQ

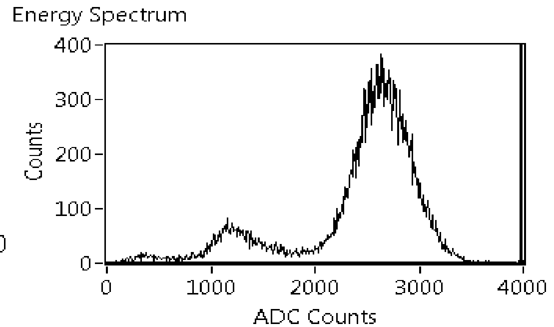
GEM performance (i)

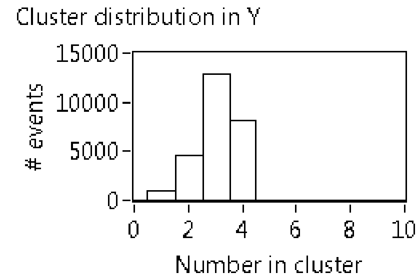
Analog response:

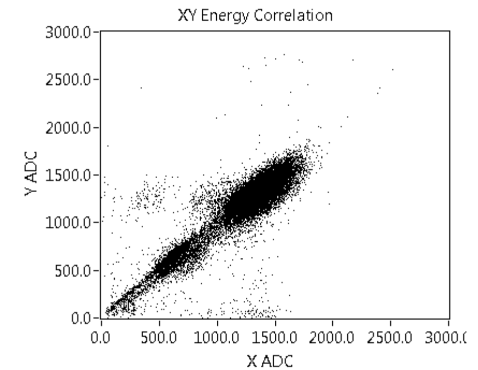
Map with X-ray generator and ^{55}Fe source:

- Correlation of cluster amplitudes between Top (X axis) and Bottom (Y axis) strips
- Amplitude Gaussian fit: resolution 25% FWHM



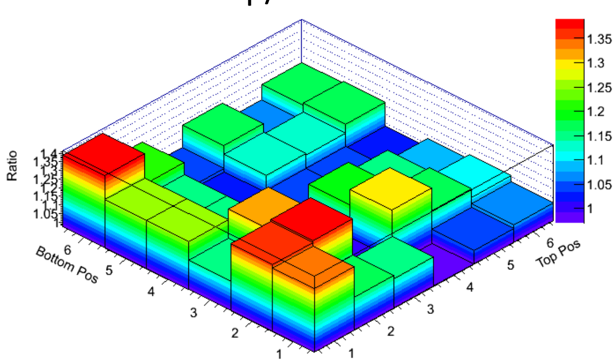




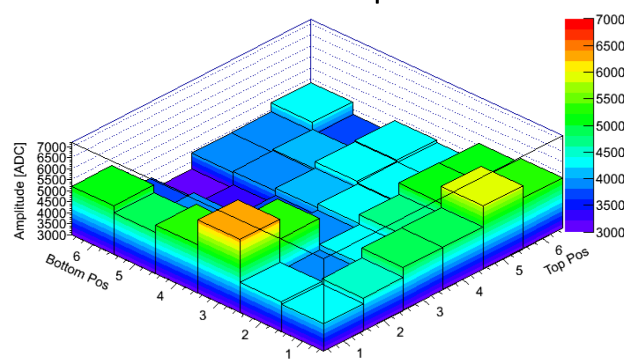


Homogeneity:

Top/Bottom



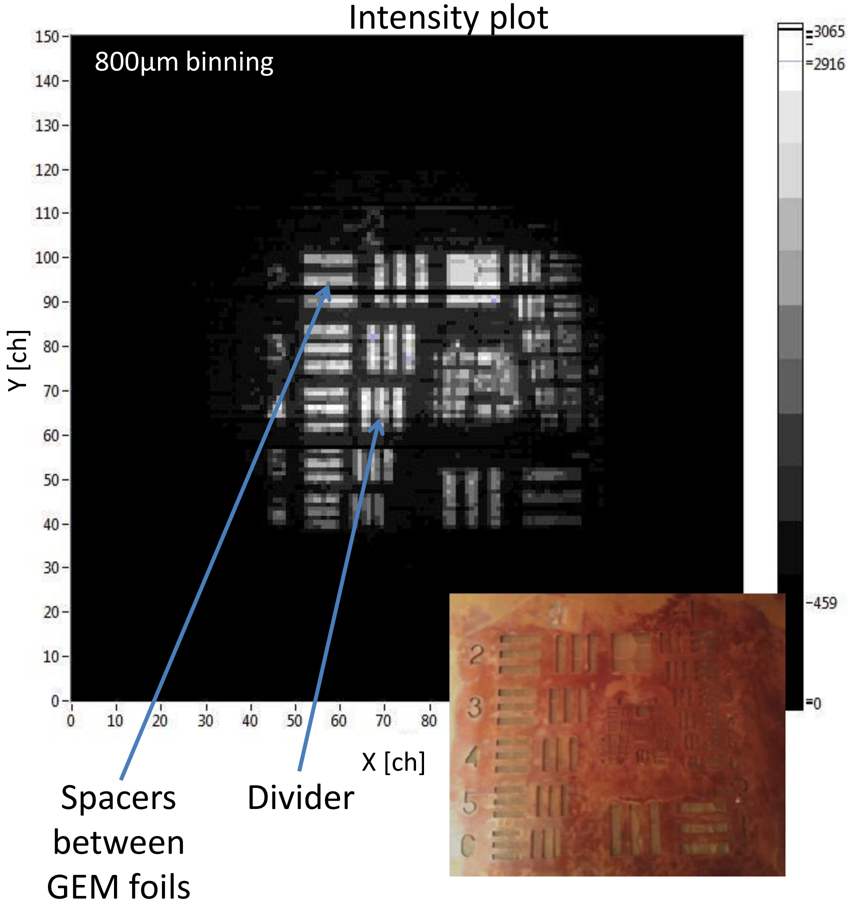
Cumulative amplitude

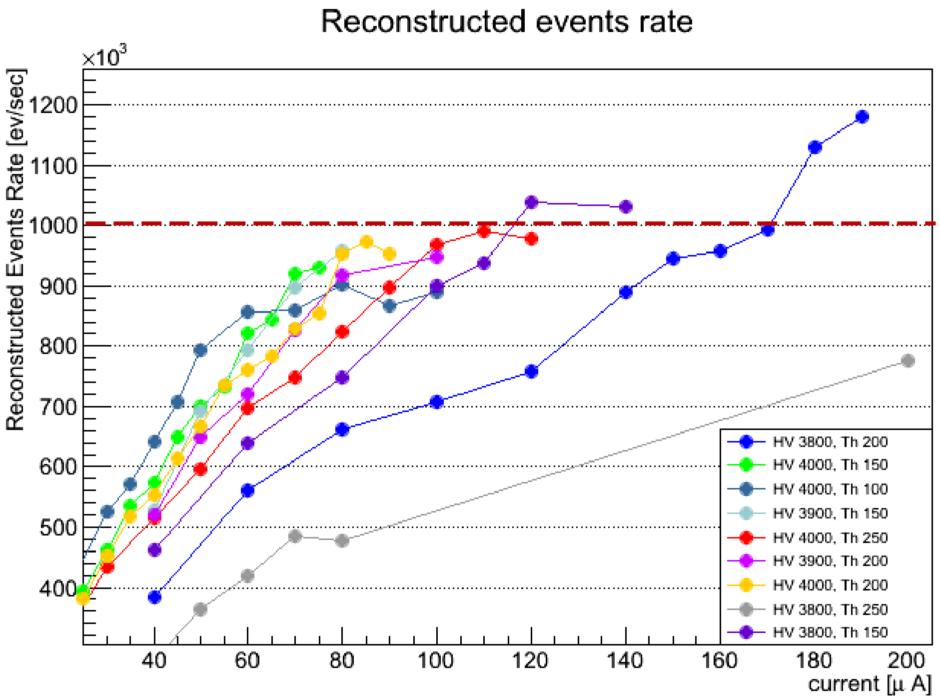


GEM performance (ii)

GEM (4000 V): X-ray radiography- mask

Portable X-ray tube (miniX Au target from RD51)
10kV 5uA
8.000.000 reconstructed events in XY
at ~ 400 kHz



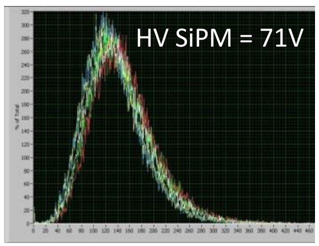


⇒ *Firmware and DAQ software optimization*

Scintillators stack

- 50 organic plastic scintillators (polyvinyltoluene), 3 mm thickness
  - faster but less light yield than inorganic $\Rightarrow$ good candidates charged particle detection
- 1 mm diameter wavelength shifting fiber to MPPC

- Response of each scintillator to minimum ionizing electrons from $^{106}Ru \sim 16\ \gamma e^{-}$/MIP

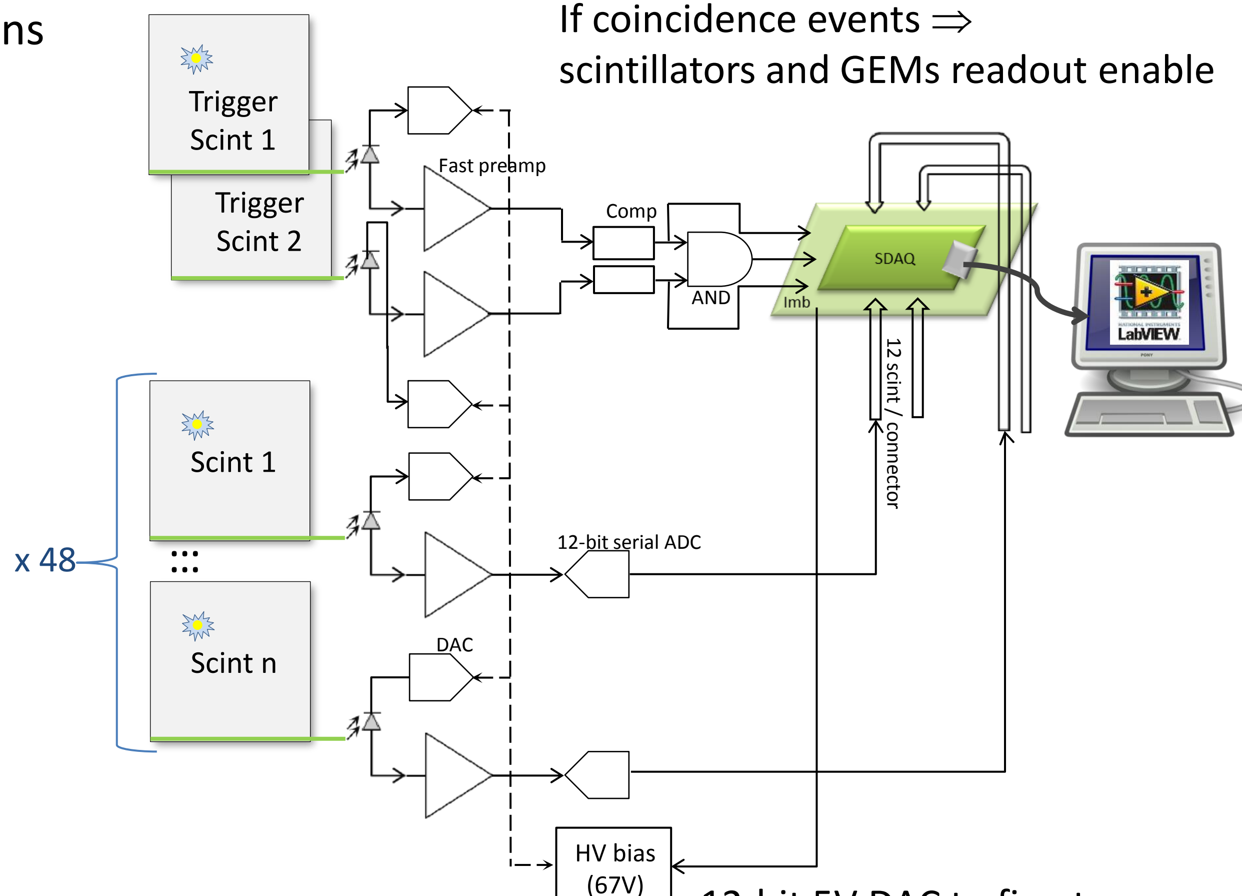


Since protons are 3-20 MIPs, the response of the scintillators is satisfactory

- Calibration with cosmic rays ongoing

- LV DAQ control and DAQ optimization ongoing

If coincidence events $\Rightarrow$ scintillators and GEMs readout enable



12-bit 5V DAC to fine tune each MPPC response

DAQ

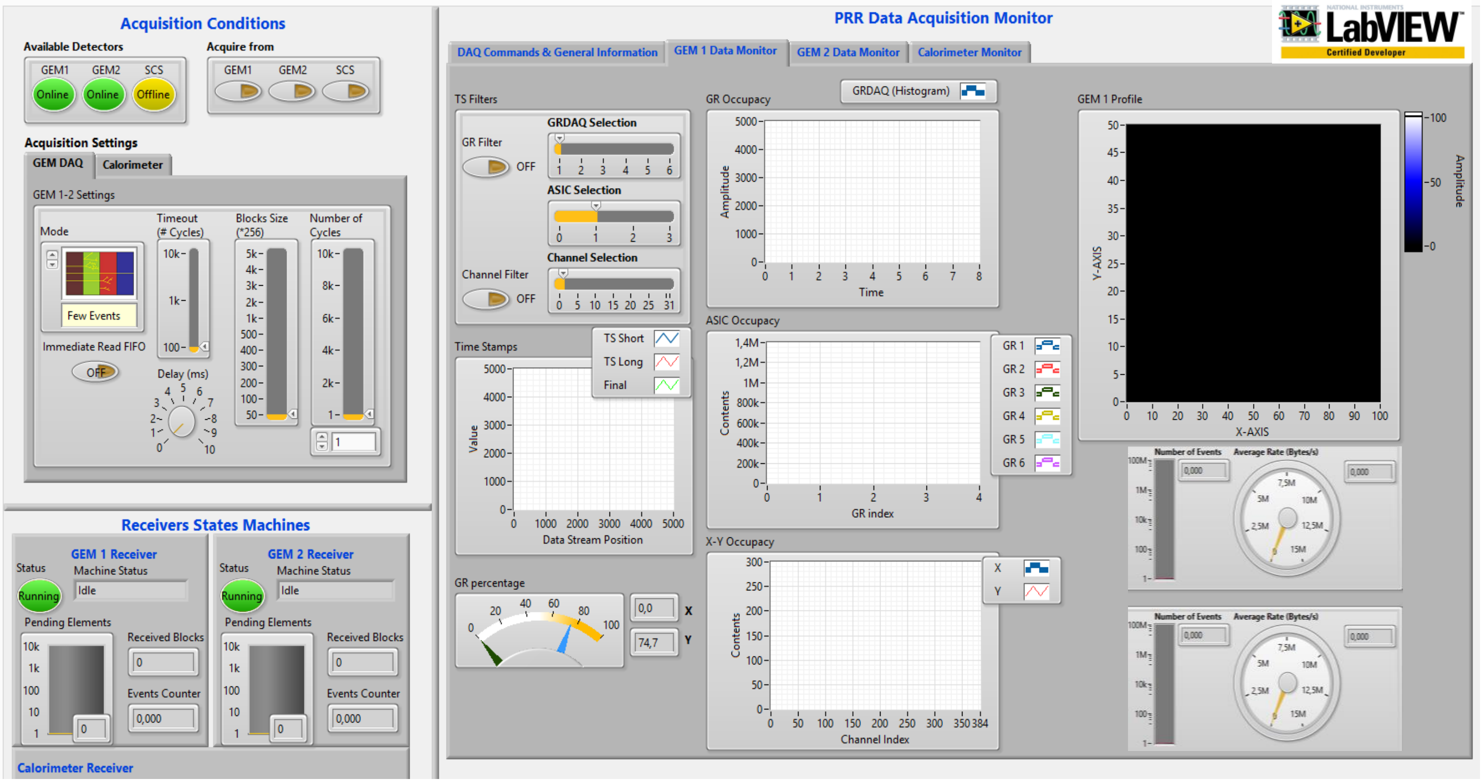
Final software by Riccardo de Asmundis (INFN Naples)

Instruments

- DAQ mode
- Block size and number of blocks to be taken
- Consumers (receivers) Status Monitor
- Data transmission rate

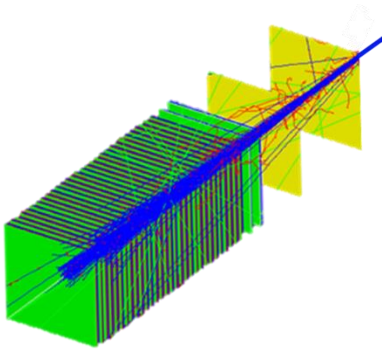
Data Monitor

- Time stamps response with filters
- Occupancy statistics
- Geometrical profile



Thanks Hans and Givi for your support!

PRR30 test beam (i)



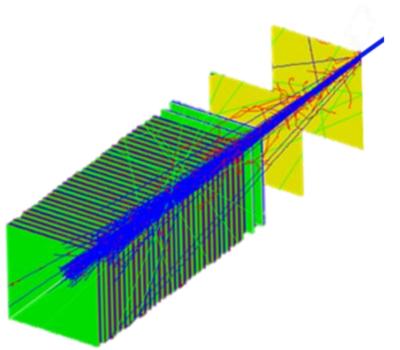
CERN test beam objectives

- Validate the new GEM acquisition electronics and software
- Validate the PRR30 data acquisition
- Calibrate the calorimeter (SNR, energy loss spectra vs position)
- GEM localization accuracy analysis

Beam types and planned measurements

- pions and muons: intensities up to 10^5 - 10^6 particles/(sec · mm^2)
    - Acquisition rate check
- spot size: > 1 cm^2 (defocused beam up to 10 cm^2)
    - Scintillators: calibration, efficiency
    - GEM DAQ response when multiple ASICs/GRs are simultaneously involved
- beam with small divergence (~ μrad)
    - GEMs position reconstruction accuracy (cluster size, centre of gravity …)

PRR30 test beam (ii)



Period of interest

- Weeks 22-25 (May 28th – June 17th)

Beam types requested

- pions and muons: intensities up to 10^5 - 10^6 particles/(sec · mm^2)
- spot size: > 1 cm (defocused beam up to 10 cm)
- beam with small divergence (~ μrad)

PRR30 characteristics for the installation

The detector lies over a trolley housing low voltage power supplies and PC
Detector dimensions (L x P x H): 54 x 71.5 x 83.5 cm, 65 Kg
Centre of detector height (trolley included): 125.5 cm
Budget material

- 2 GEMs: 14.4 ‰ of X_0
- 50 Scintillators: 40 % of X_0 (18 cm water equivalent)

Hardware needed at NA T2-H4

- Gas: $ArC0_2$ 70:30 (2 L/h)
- GEMs HV supply: [3.8 - 4.2] kV up to 80 μA, 2 channels
- Ethernet connection for remote control

Summary

Thanks to the test beam at CERN we aim to validate the PRR30 acquisition system in order to move toward the proton radiography test beam

Next steps

- Improvements on detector angular resolution (larger distance between the two GEMs) and position resolution (better than 400μm)
- Angular cuts to cope with multiple Coulomb scattering
- Radiography program
- Test beam with protons (90 up to 230 MeV at PSI-proton therapy) for calibrations, proton stopping power and range measurements

Looking forward for
a successful
test beam together!