A First Application for the Scalable Readout System: *Muon Tomography with GEM Detectors*

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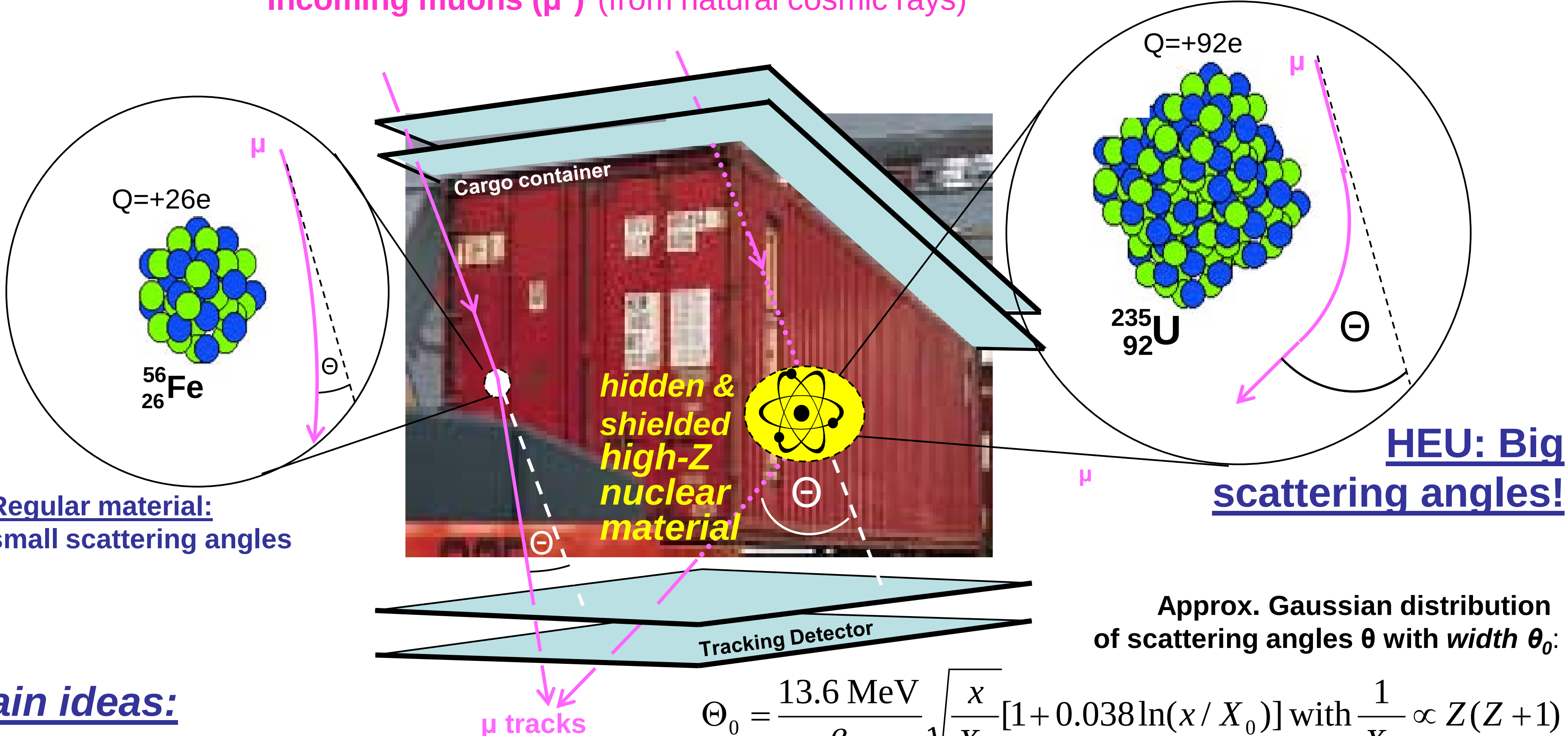
Muon Tomography Principle

Note: angles are exaggerated !

Incoming muons (μ) (from natural cosmic rays)



Approx. Gaussian distribution of scattering angles θ with *width* θ_0:

$$\Theta_0 = \frac{13.6\ \text{MeV}}{\beta c p}\sqrt{\frac{x}{X_0}}[1+0.038\ln(x/X_0)]\ \text{with}\ \frac{1}{X_0} \propto Z(Z+1)$$

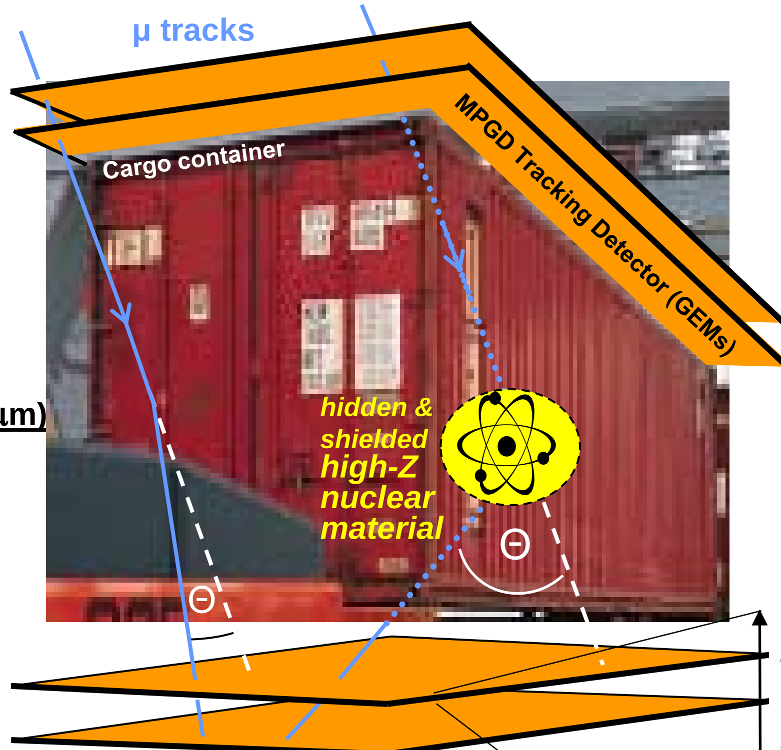
Main ideas:

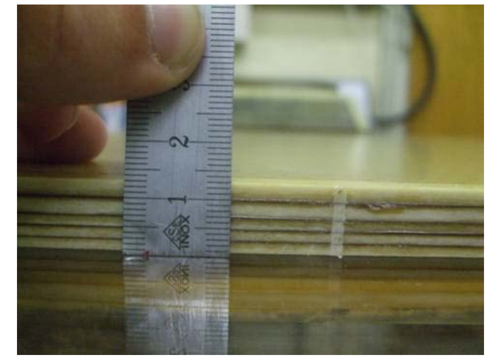
- Multiple Coulomb scattering is ~ prop. to Z and could discriminate materials by Z
- Cosmic ray muons are ubiquitous; no artificial radiation source or beam needed
- Muons are highly penetrating; potential for sensing shielded high-Z nuclear contraband
- Cosmic Ray Muons come in from many directions allowing for tomographic 3D imaging

Use Micro Pattern Gaseous Detectors for tracking muons

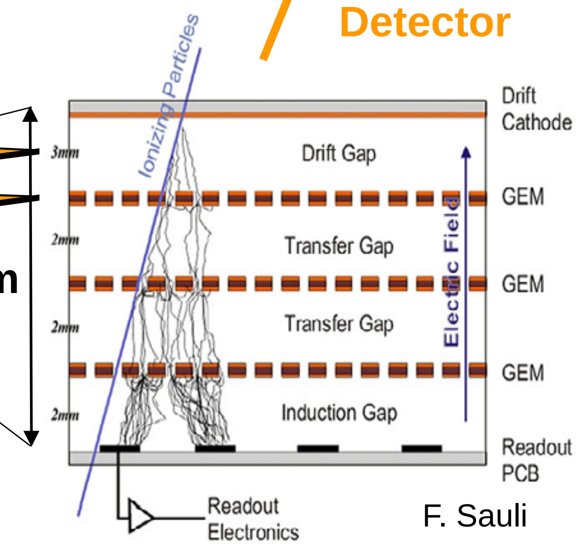
ADVANTAGES:

- small detector structure allows compact, low-mass MT station
  - thin detector layers
  - small gaps between layers
  - low multiple scattering in detector itself
- high MPGD spatial resolution (~ 50 μm) provides good scattering angle measurement with short tracks
- high tracking efficiency





GEM Detector



F. Sauli

Gas Electron Multiplier Detector

CHALLENGES:

- need to develop large-area MPGDs
- large number of electronic readout channels needed (→ SRS)

General Strategy

- Build **first prototype** of GEM-based Muon Tomography station & evaluate performance (using ten 30cm × 30cm GEM det.)
  - Detectors
  - Mechanics
  - Readout Electronics → SRS !
  - HV & Gas supply
  - Data Acquisition & Analysis
- Help develop **large-area (1m × 0.5m) Triple-GEMs and SRS electronics** within RD51
- Build **final 1m×1m×1m GEM-based** Muon Tomography prototype station
- Measure **performance** on shielded targets and “vertical clutter” with both prototypes

2009/10 Strategy

Two-pronged approach:

1. **Build and operate minimal** first GEM-based Muon Tomography station:

   – only four Triple-GEM detectors (two at top and two at bottom)
   – temporary GASSIPLEX electronics (~800 ch., borrowed from Saclay – THANKS !!!)
   – minimal coverage (read out only 5cm × 5cm area in each detector)
   – preliminary data acquisition system (LabView; modified from MAMMA – THANKS !!!)

   – **Objectives:**
     - **take real data as soon as possible and analyze**
     - demonstrate that GEM detectors work as anticipated for cosmic ray muons
     - → produce **very first experimental proof-of-concept for GEM MT**

2. **Simultaneously prepare for** 30cm × 30cm × 30cm Muon Tomography Station:

   – Top, bottom, and side detectors (10 detectors)
   – Mechanical stand with flexible geometry, e.g. variable gaps b/w detectors
   – Final SRS front-end electronics (15,000 ch.) with RD51
   – Final data acquisition with RD51 & analysis

Hardware Progress

- **Detector Assembly:**
  - **7** 30cm × 30cm Triple-GEM detectors assembled in CERN clean rooms
  - **1** 30cm × 30cm Double-GEM detector assembled in CERN clean rooms (b/c one foil was lost)
  - **2** 30cm × 30cm Triple-GEM detectors awaiting assembly at Fl. Tech
  - **2** 10cm × 10cm Triple-GEM detectors assembled at Fl. Tech (for R&D purposes)

- **Basic performance parameters** of triple-GEM detectors tested with X-rays and mips**:**
  - HV stability, sparks
  - Gas gain
  - HV plateau
  - Rate capability
  - ^{55}Fe and mip (cosmics) pulse height spectra

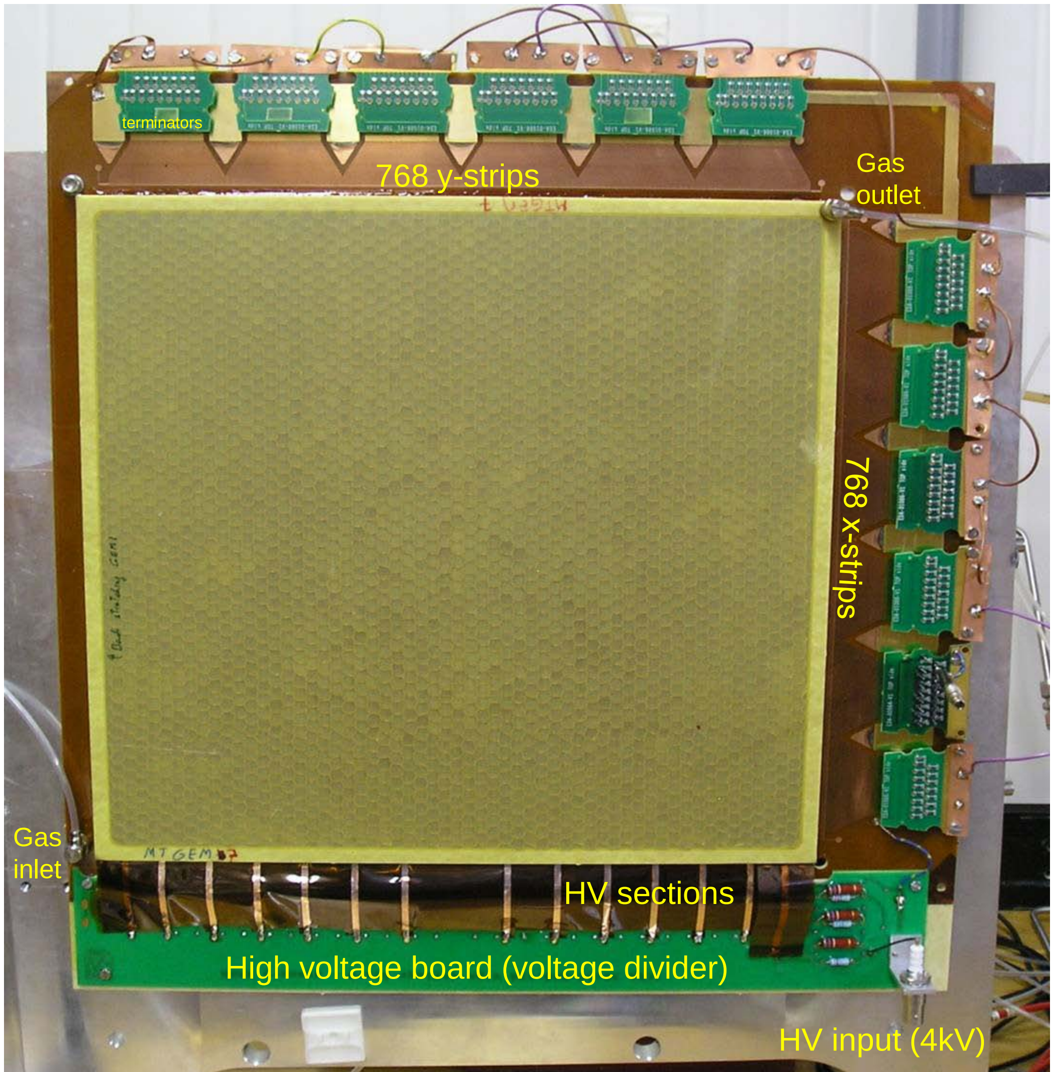
- **=> Six Triple-GEM detectors at CERN show good and stable performance**

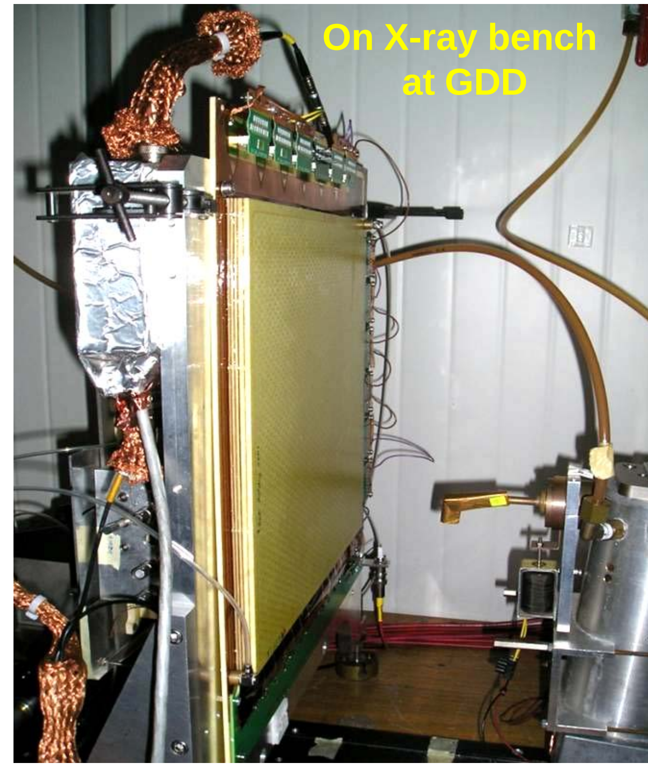
  One Triple-GEM detector has bad HV section; to be fixed

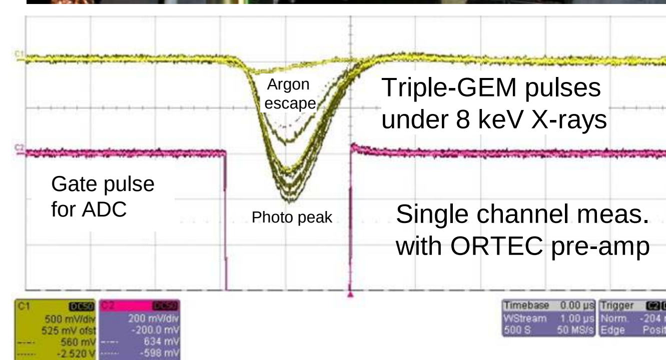
- **Built minimal prototype station** for Muon Tomography; **operated 2 weeks at CERN**
  - Designed and produced adapter board for interfacing detector r/o board with Panasonic connectors to preliminary "GASSIPLEX" frontend electronics with SAMTEC connectors (Kondo Gnanvo)
  - Used 8 GASSIPLEX frontend r/o cards electronics with ~800 readout channels for two tests (Dec '09 - Jan '10 and April '10, Kondo Gnanvo)
  - Developed LabView DAQ system for first prototype tests – lots of debugging work (Kondo Gnanvo)

- Developed GEANT4 simulation for minimal MT prototype station

Triple-GEM Detector

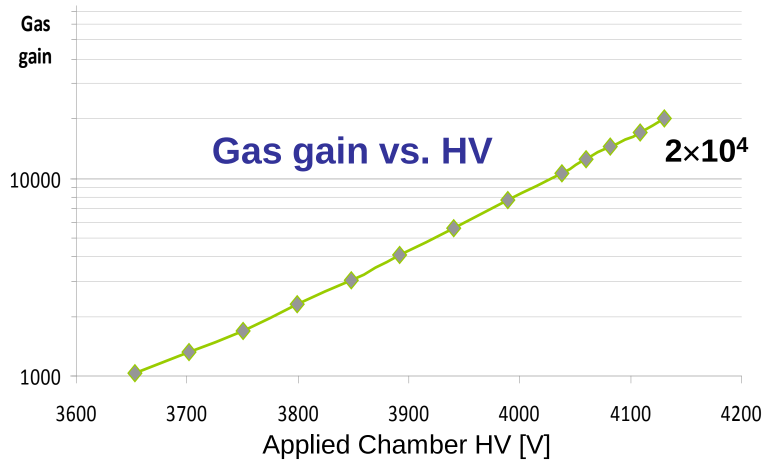


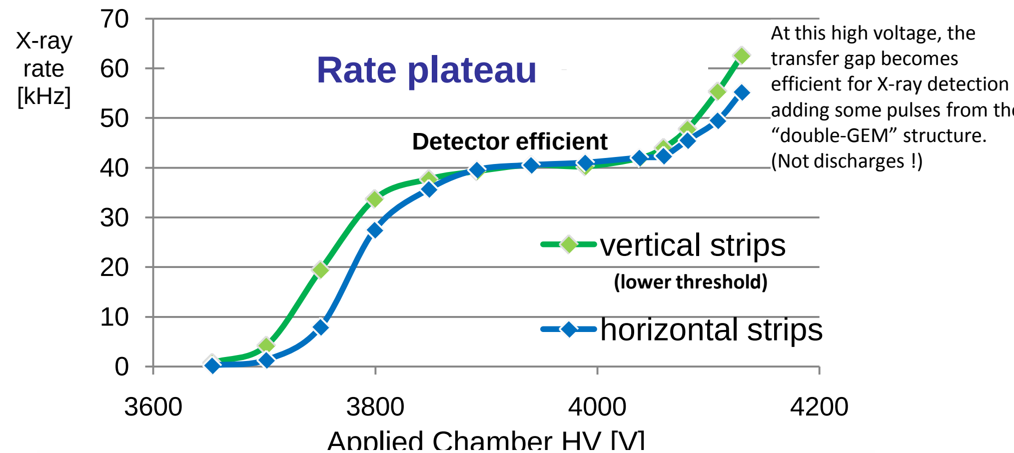


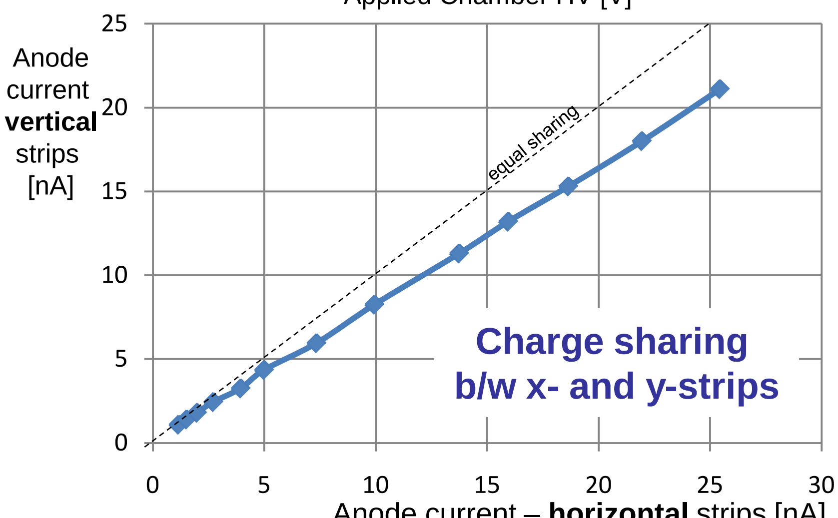


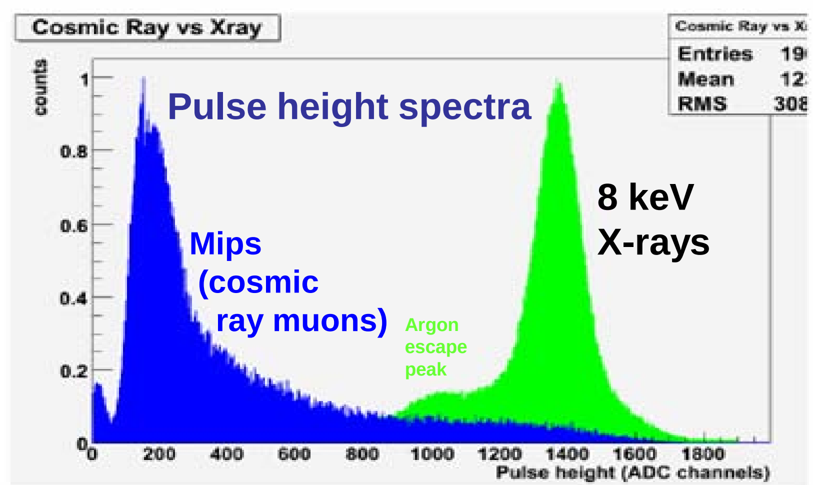
Basic Detector Performance

Results from commissioning test of Triple-GEM detectors using single-channel amp. & 8 kV Cu X-ray source at GDD

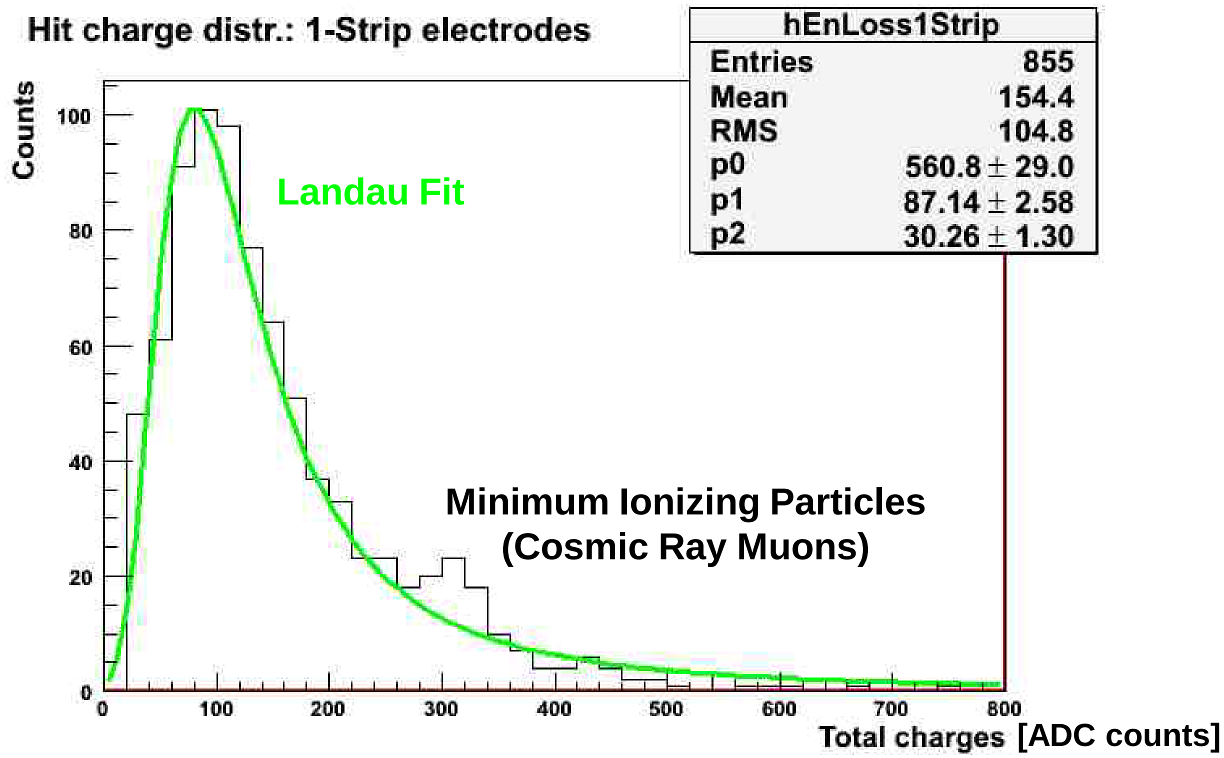








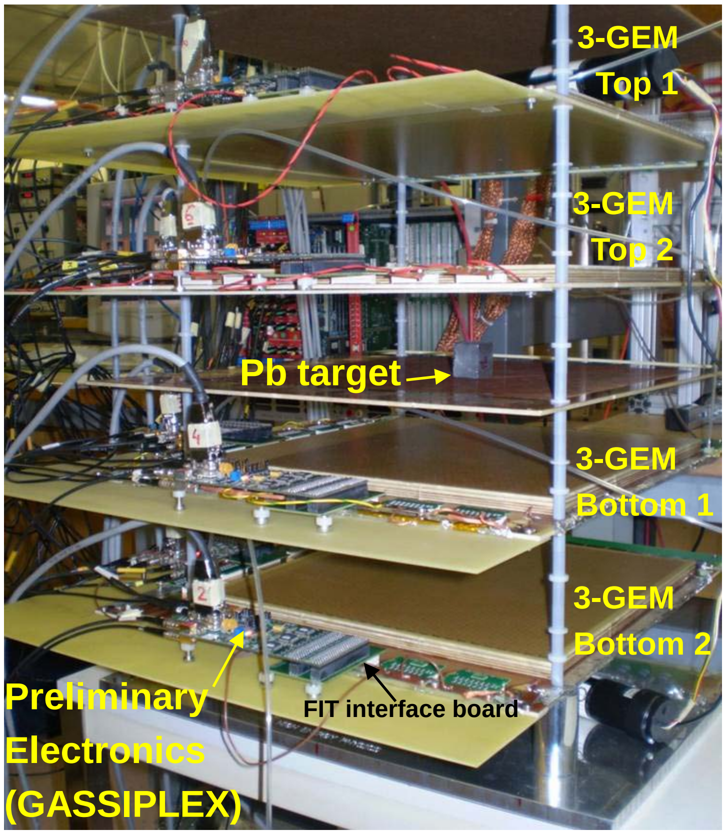
Pulse height distribution



Distribution of total strip cluster charge follows Landau distribution as expected

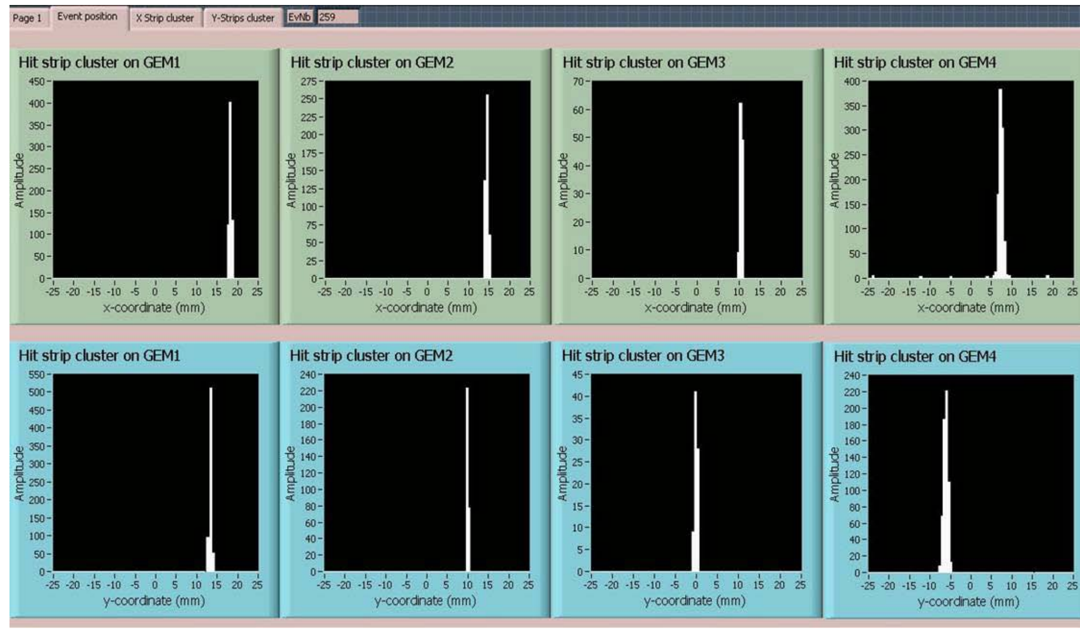
Minimal MT Station

Setup of first cosmic ray muon run at CERN with four Triple-GEM detectors



Event Display: Tracking of a cosmic ray muon traversing minimal GEM MT station

Top 1 **Top 2** **Bottom 1** **Bottom 2**



x

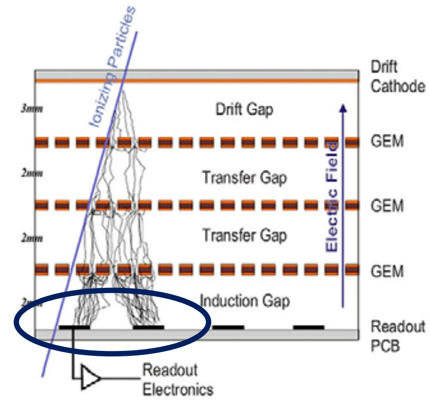
y

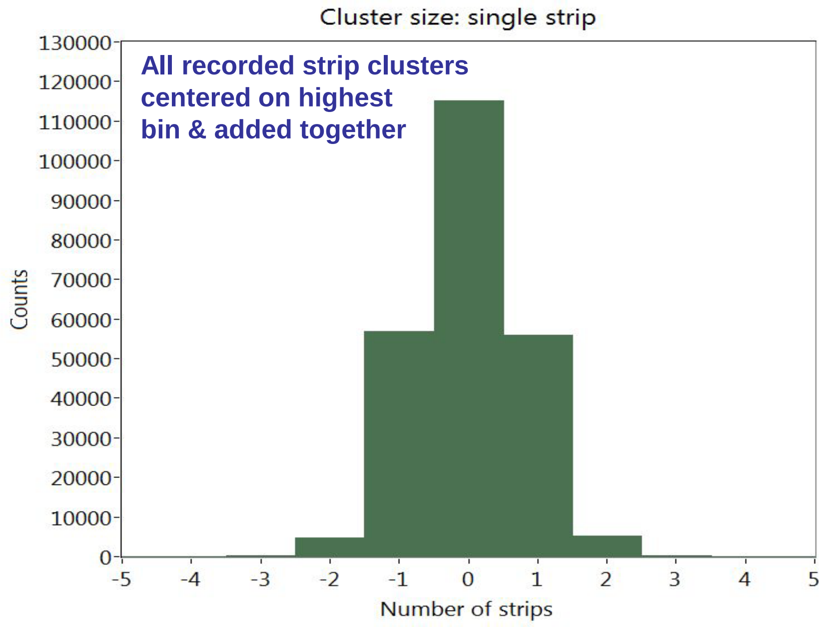
Strip Position [mm]

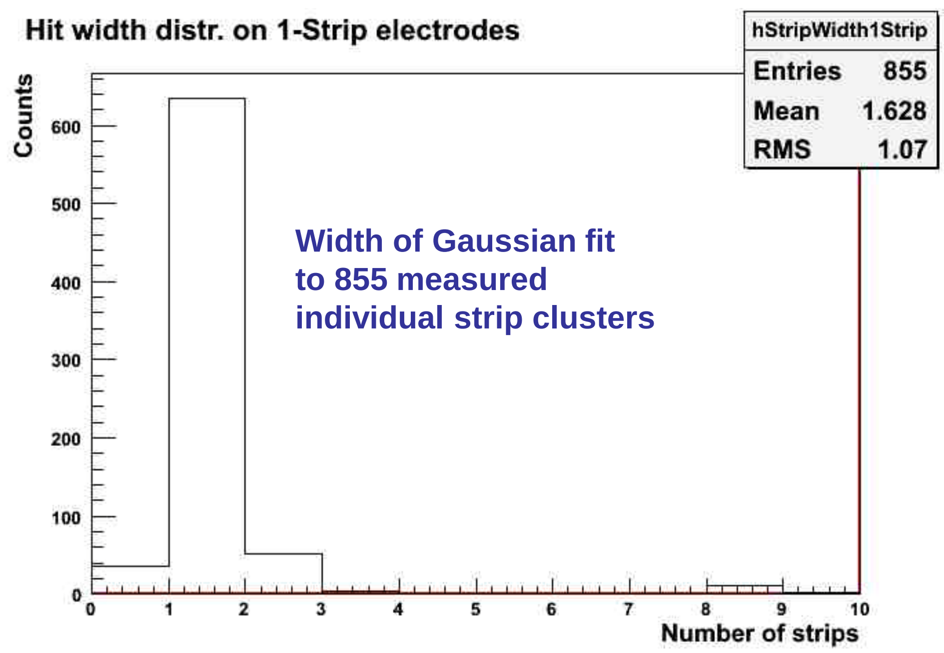
- **Pulse heights on x-strips and y-strips recorded by all 4 GEM detectors using preliminary electronics and DAQ**
- **Pedestals are subtracted**
- **No target present; Data taken 4/13/2010**

First Data: Strip Clusters

Sharing of deposited charge among adjacent strips is important for high spatial resolution by using the center-of-gravity of charge deposition when calculating the hit position:



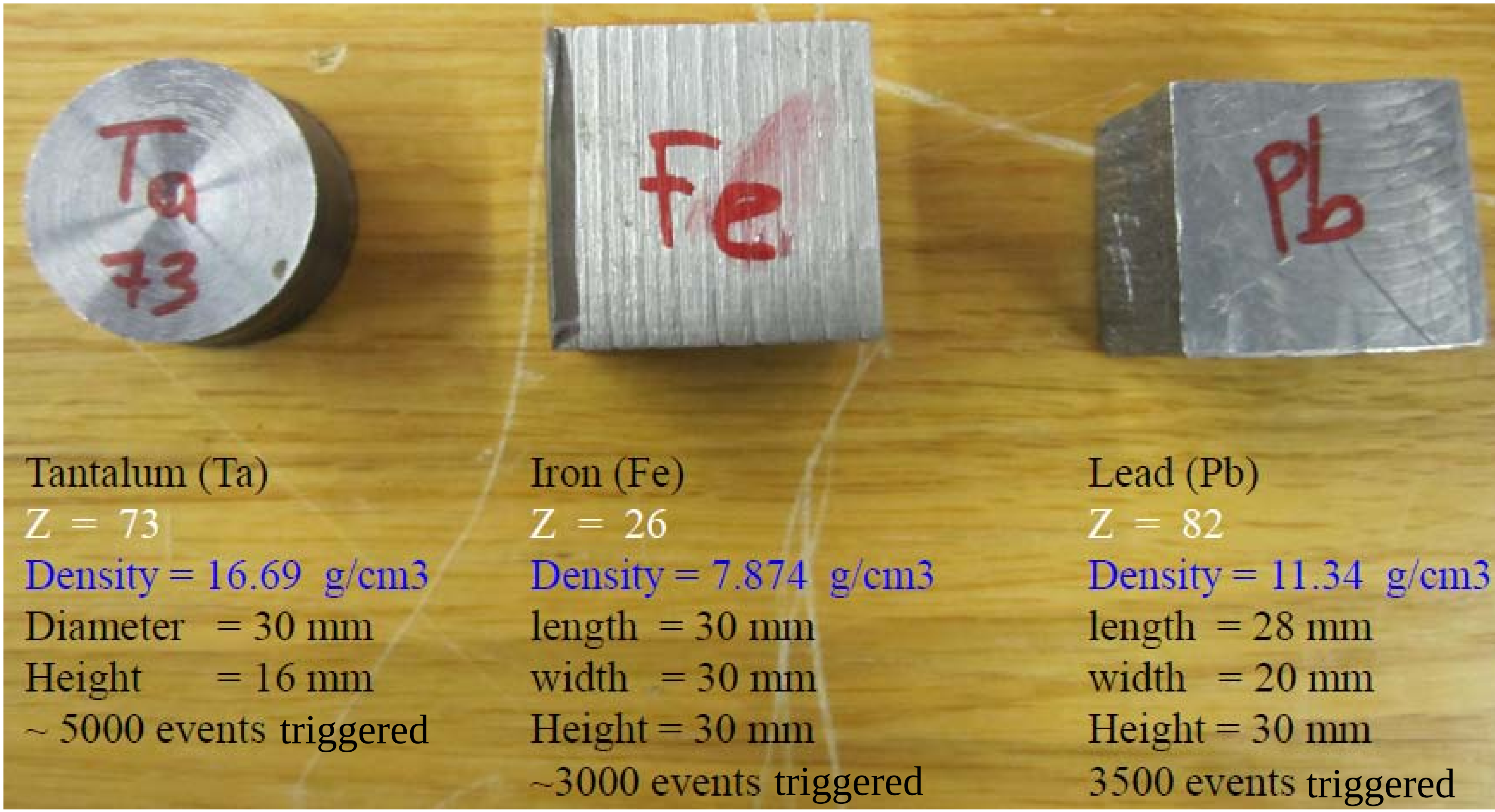




=> Charge is shared between up to 5 strips

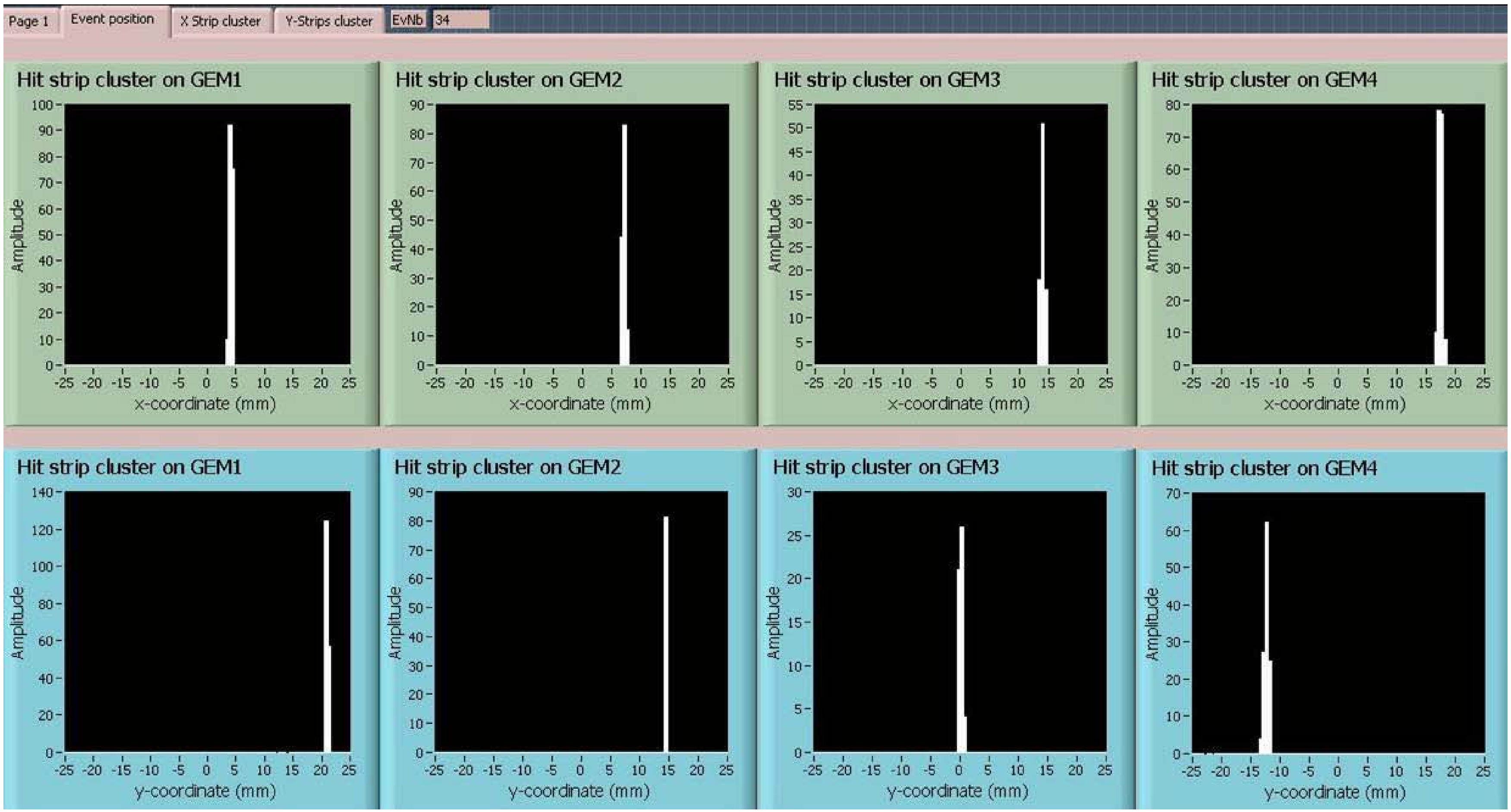
=> On the average, strip cluster is 3.2 strips wide (±1σ)

MT Targets

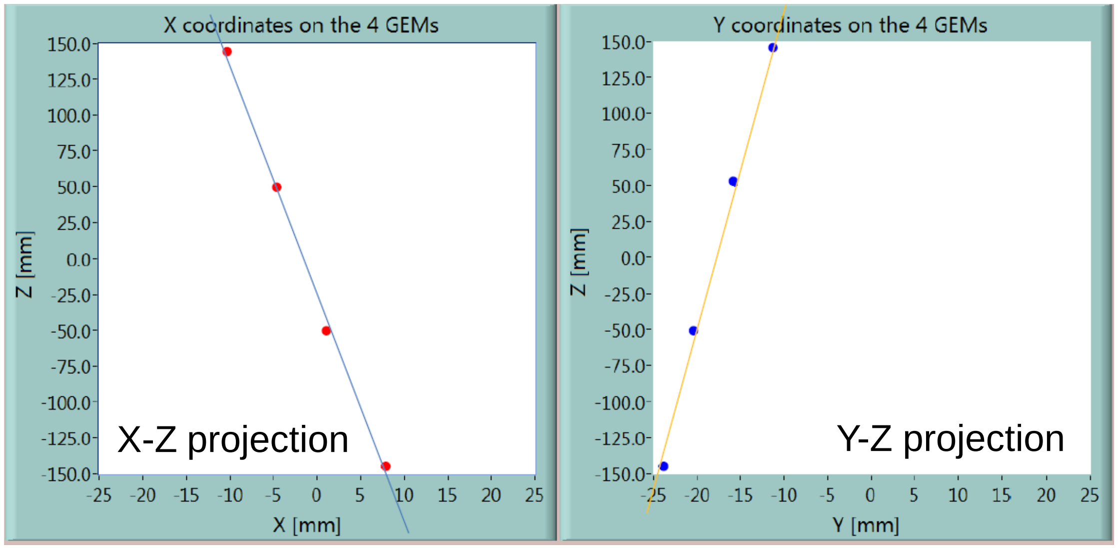

Ta
73
Fe
Pb
Tantalum (Ta)
Z = 73
Density = 16.69 g/cm3
Diameter = 30 mm
Height = 16 mm
~ 5000 events triggered
Iron (Fe)
Z = 26
Density = 7.874 g/cm3
length = 30 mm
width = 30 mm
Height = 30 mm
~3000 events triggered
Lead (Pb)
Z = 82
Density = 11.34 g/cm3
length = 28 mm
width = 20 mm
Height = 30 mm
3500 events triggered

Minimal MTS with Pb target

Event recorded with Pb target present in center of minimal MTS:



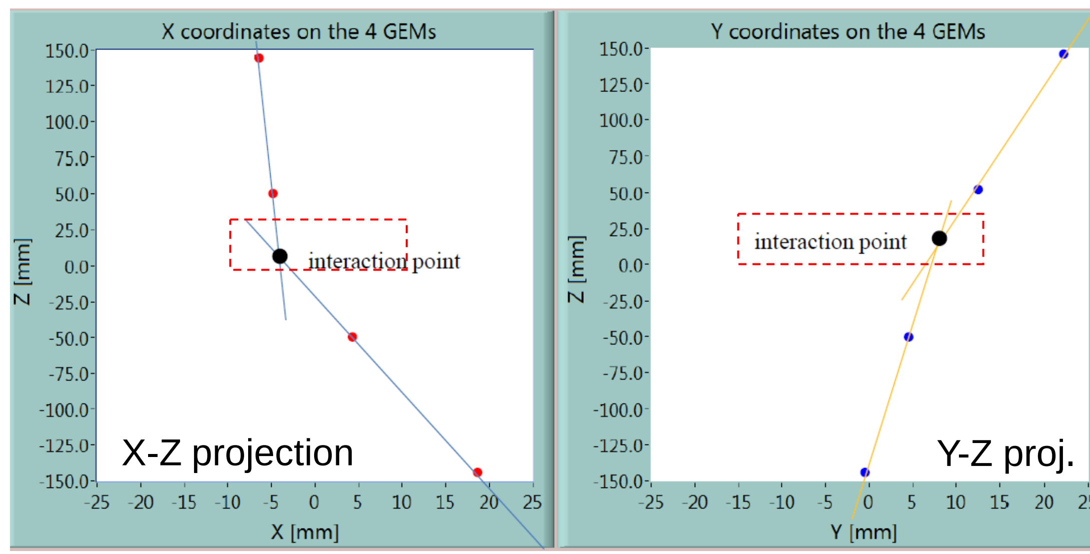
Hits & Tracking



Empty Station

Real Data

Station with Pb target

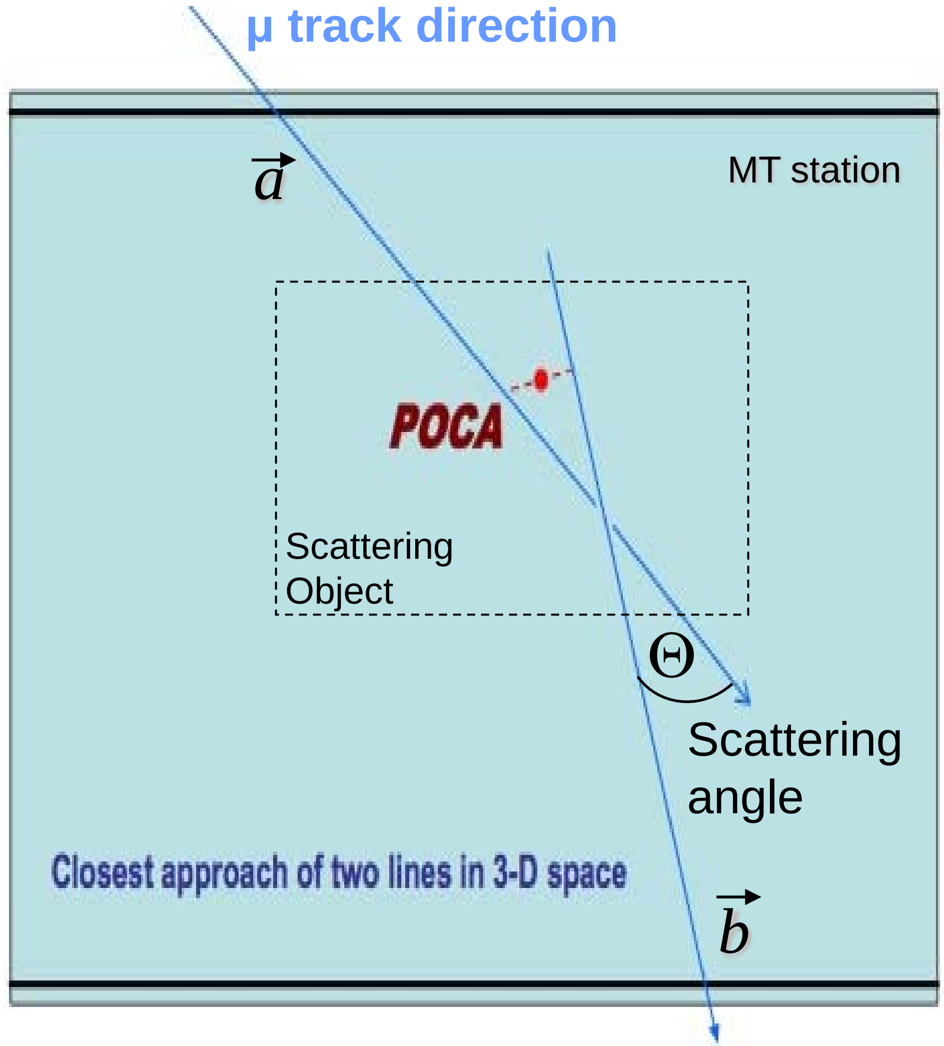


Basic Scattering Reconstruction

- Simple 3D reconstruction algorithm using **Point of Closest Approach** (POCA) of incoming and exiting 3-D tracks
- Treat as **single scatter**
- Scattering angle:

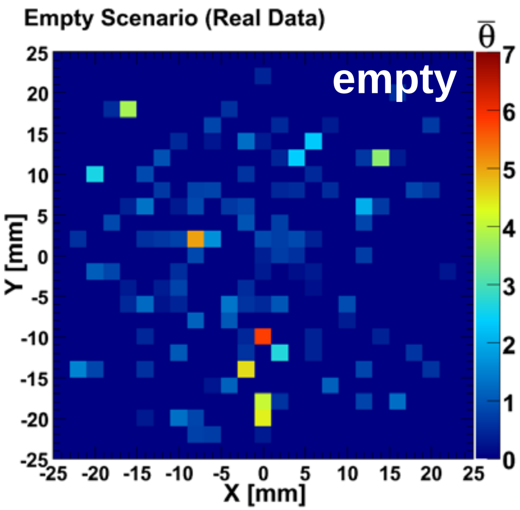
$$\theta = \cos^{-1}\left(\frac{\vec{a}\cdot\vec{b}}{|a||b|}\right)$$

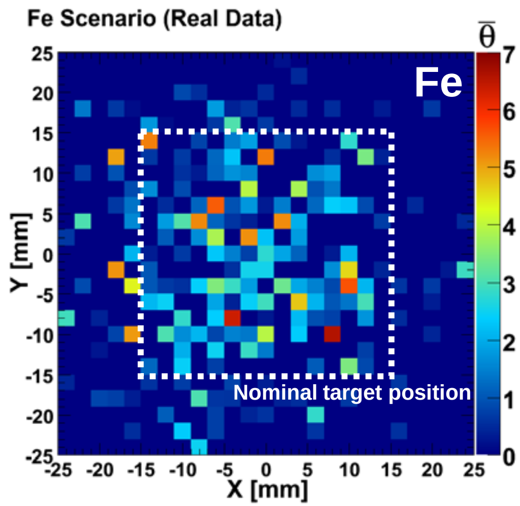
(with θ >0 by definition)

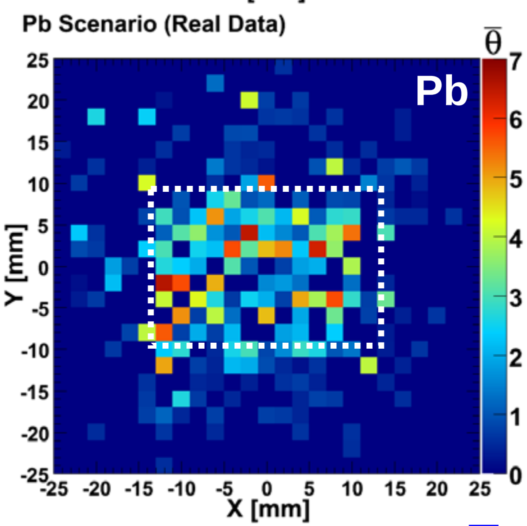


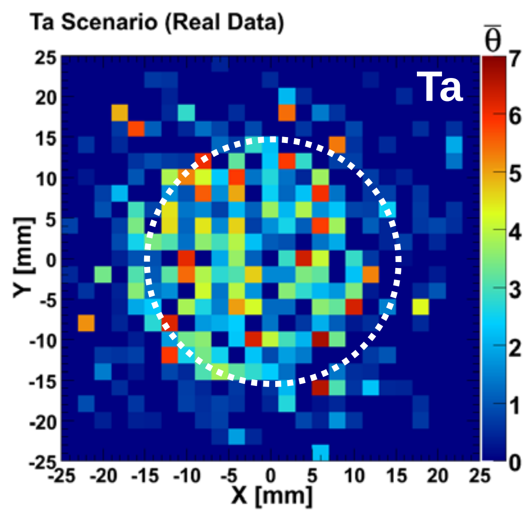
Muon Tomography with GEMs !

First-ever experimental GEM-MT Data









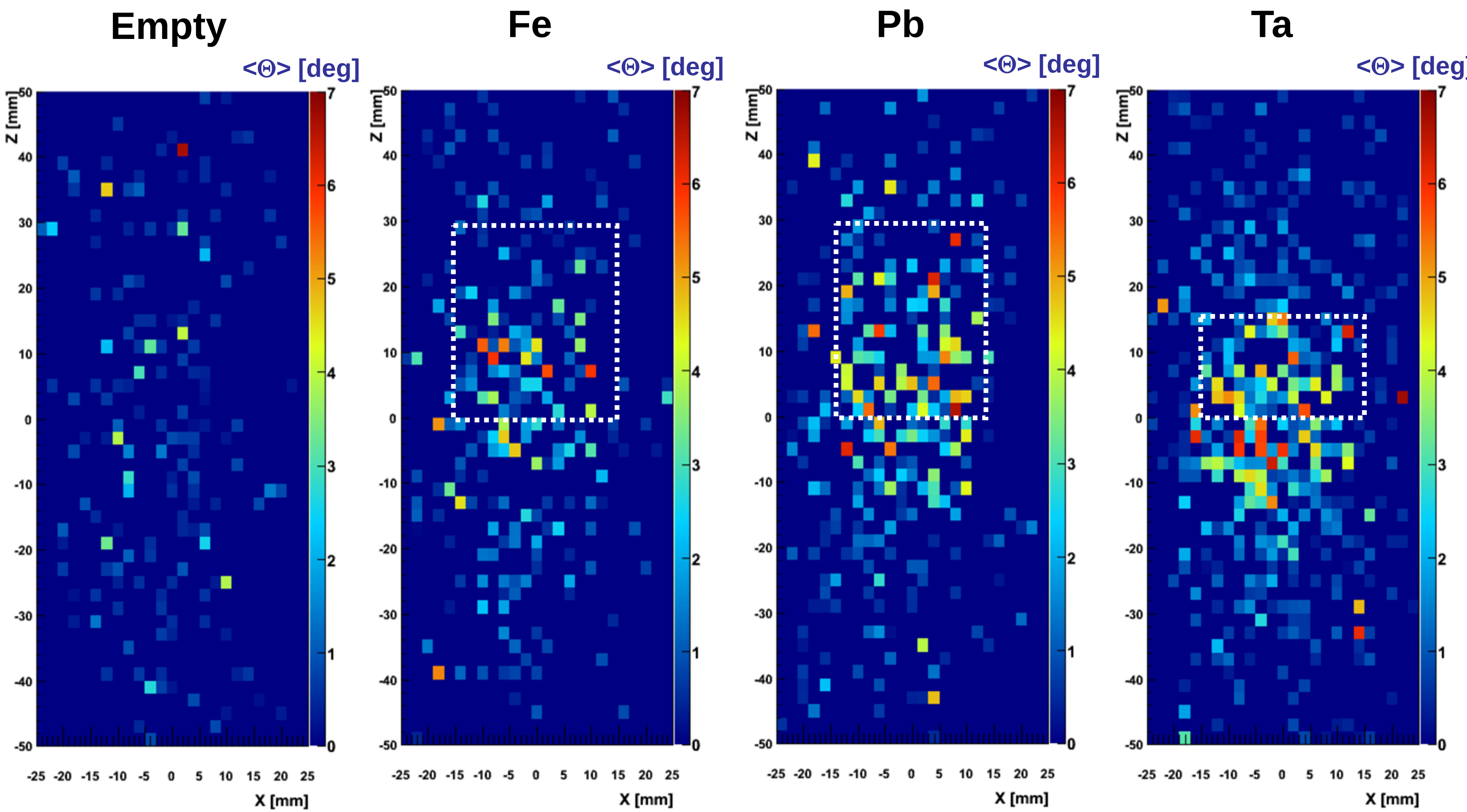
Muons reconstructed:

Empty	558
Fe	809
Pb	1091
Ta	1617

It works !!!

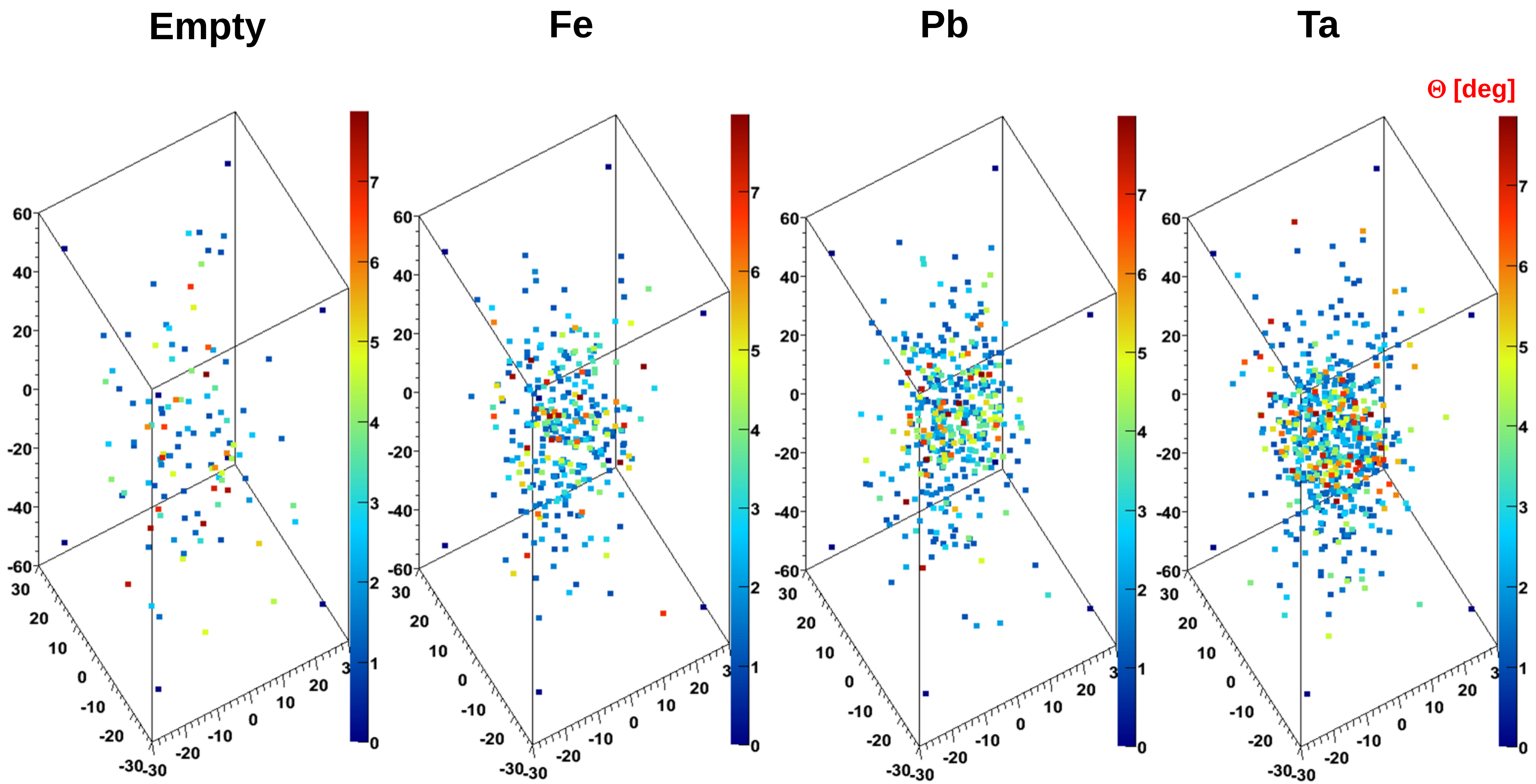
Mean scattering angles $\overline{\Theta}$ in x × y × z = 2mm × 2mm × 20mm voxels (x-y slices taken at z = 0mm)

MT Front View (x-z)



Imaging in the vertical not as good as imaging in x-y because triggered muons are close to vertical

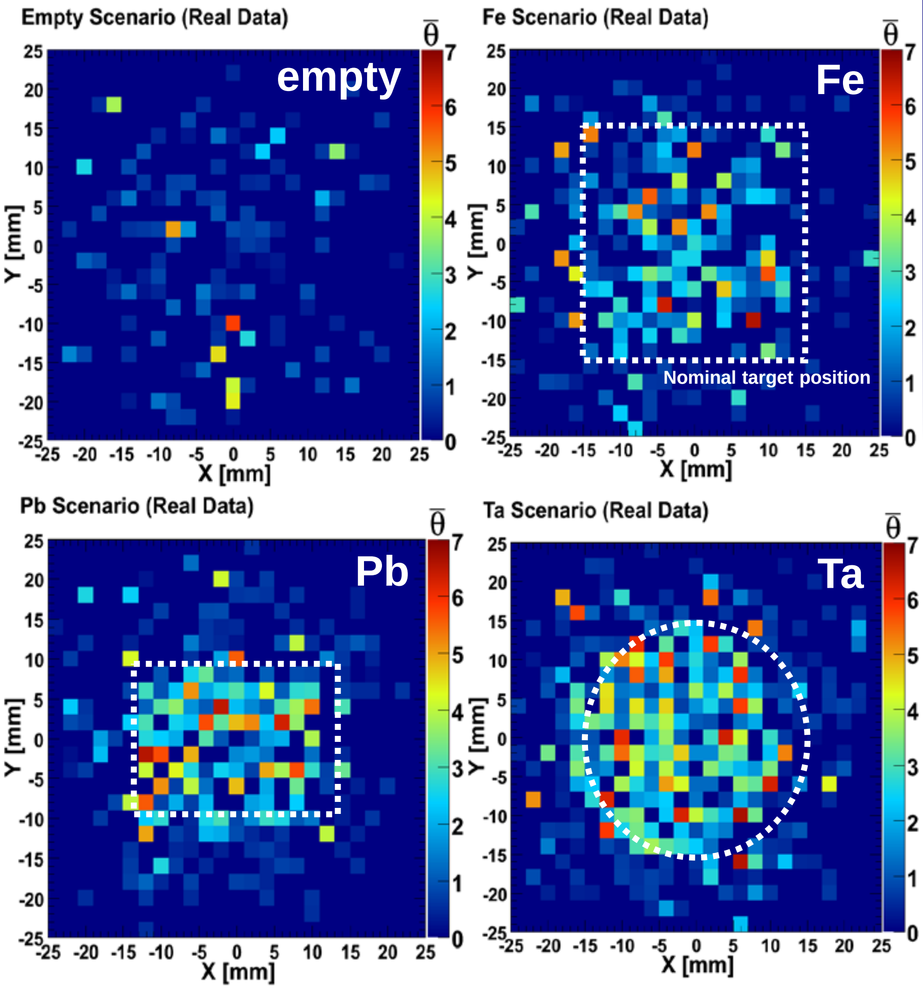
3D Target Imaging



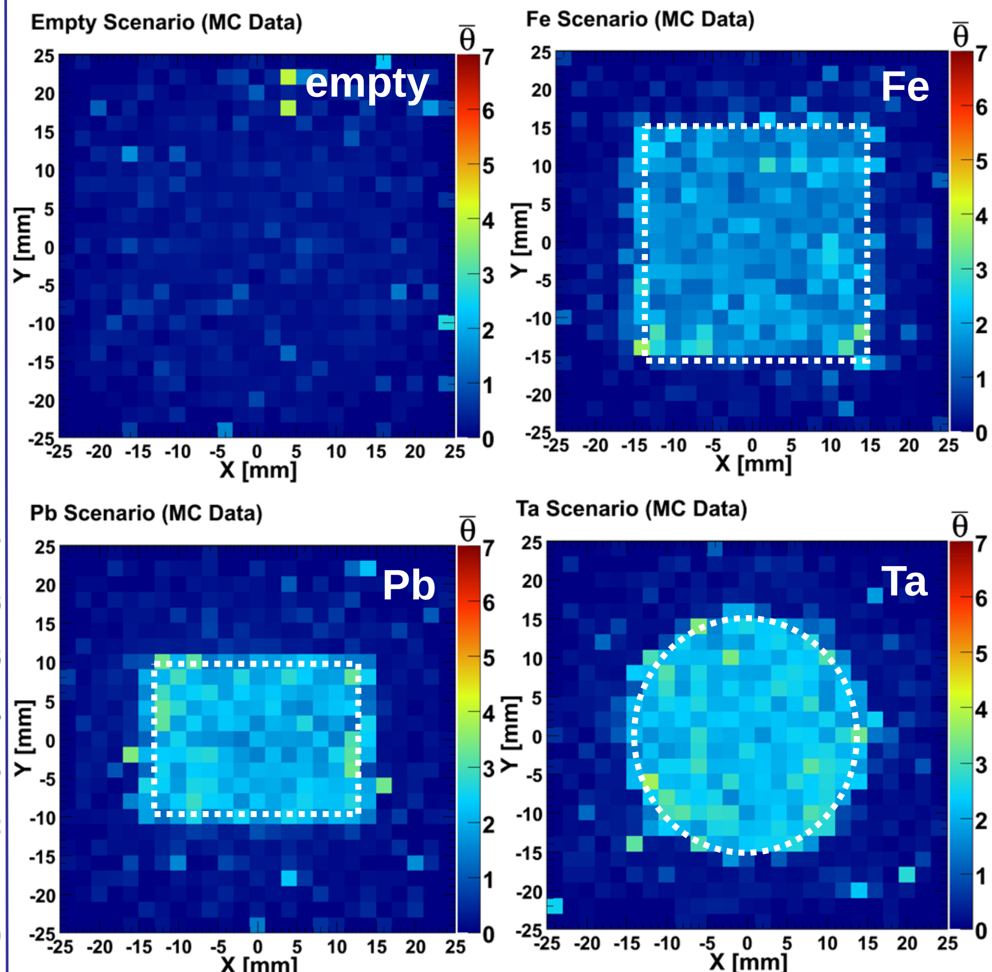
Scattering points (POCA) colored according to measured scattering angle
(Points with $\Theta < 1^{o}$ are suppressed for clarity)

Comparison Data vs. MC

Data

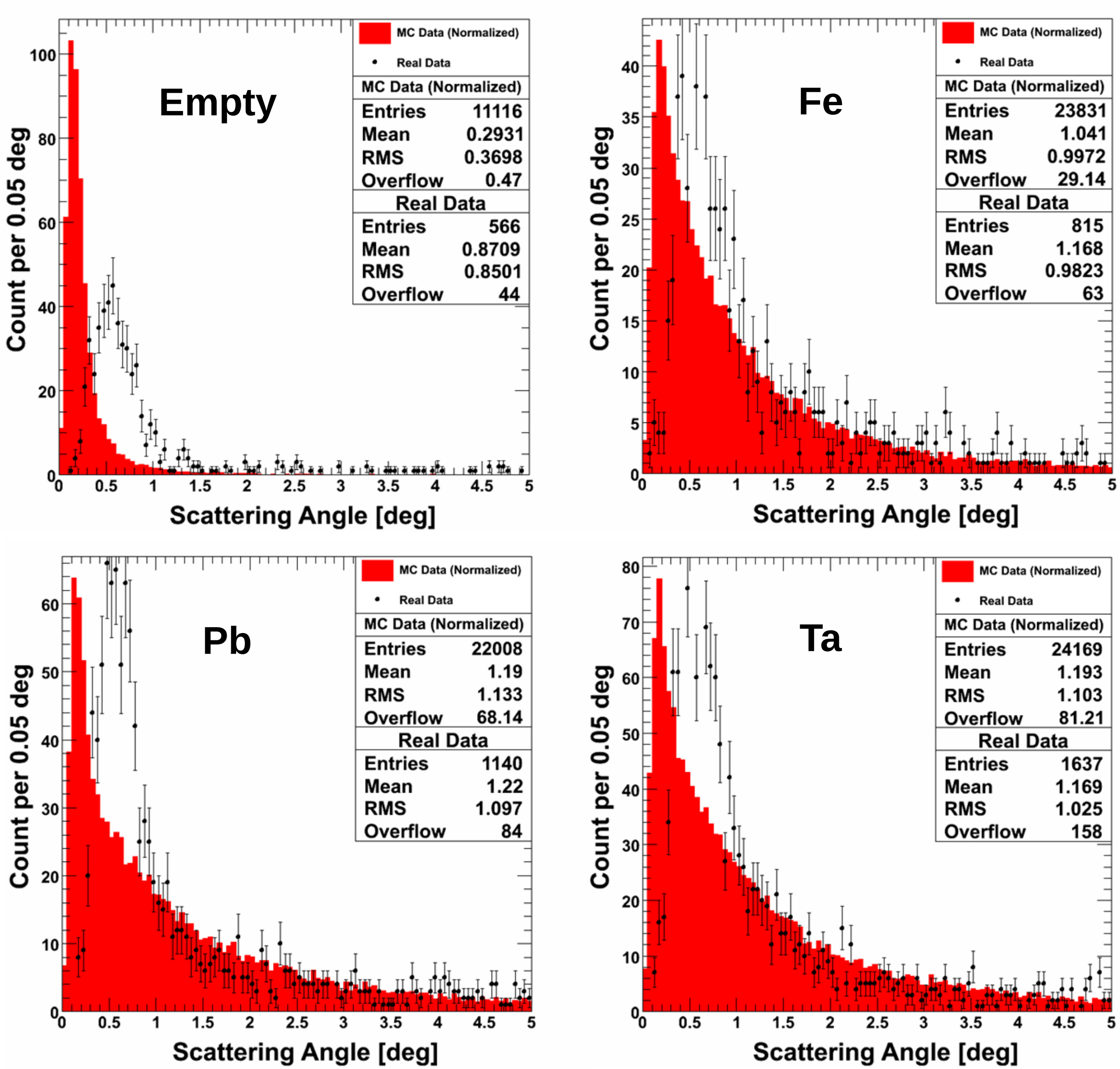


Monte Carlo (~ 20 times data)



Mean scattering angles $\bar{\Theta}$ in x × y × z = 2mm × 2mm × 20mm voxels (x-y slices taken at z = 0mm)

Comparison Data vs. MC cont'd



Only data for which the POCA is reconstructed **within** the MTS volume are used for comparison.

For measurements at small angles ($\Theta < 1^o$), MC and data do not agree that well, yet.

This is presumably due to:

- the fact that the GEM detectors in the MTS have not yet been aligned with tracks. For now, we are solely relying on mechanical alignment.

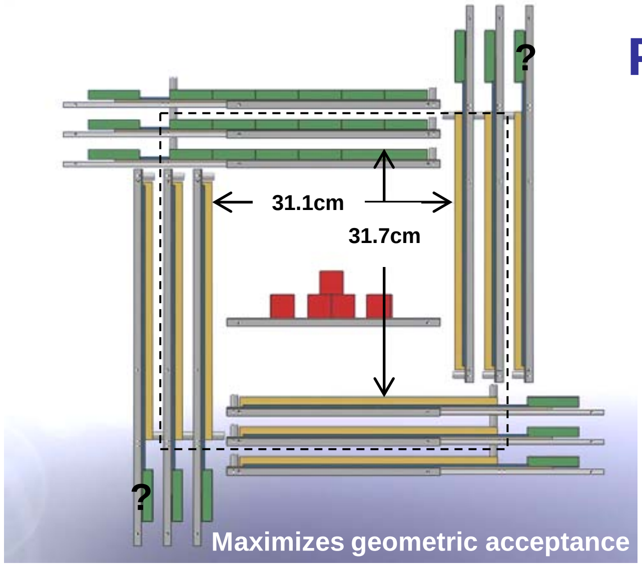
  Any **mis**alignment **increases** the angle measurement because the scattering angle is by definition positive.

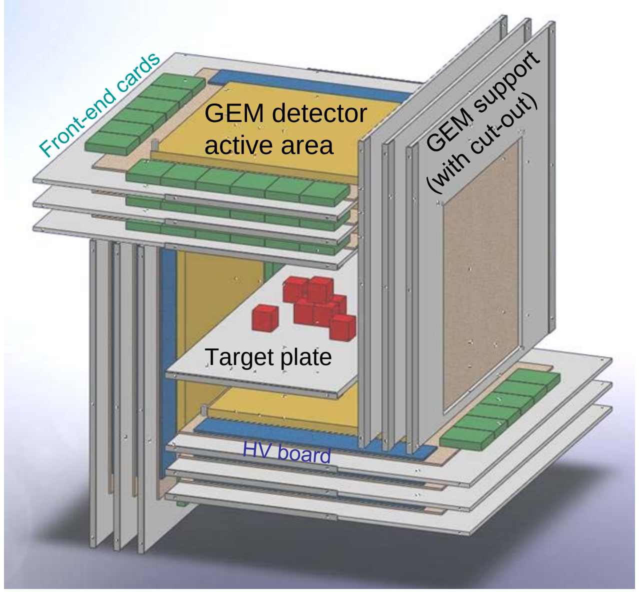
- the fact that the GEANT4 description of the materials used in the station itself is not yet perfect

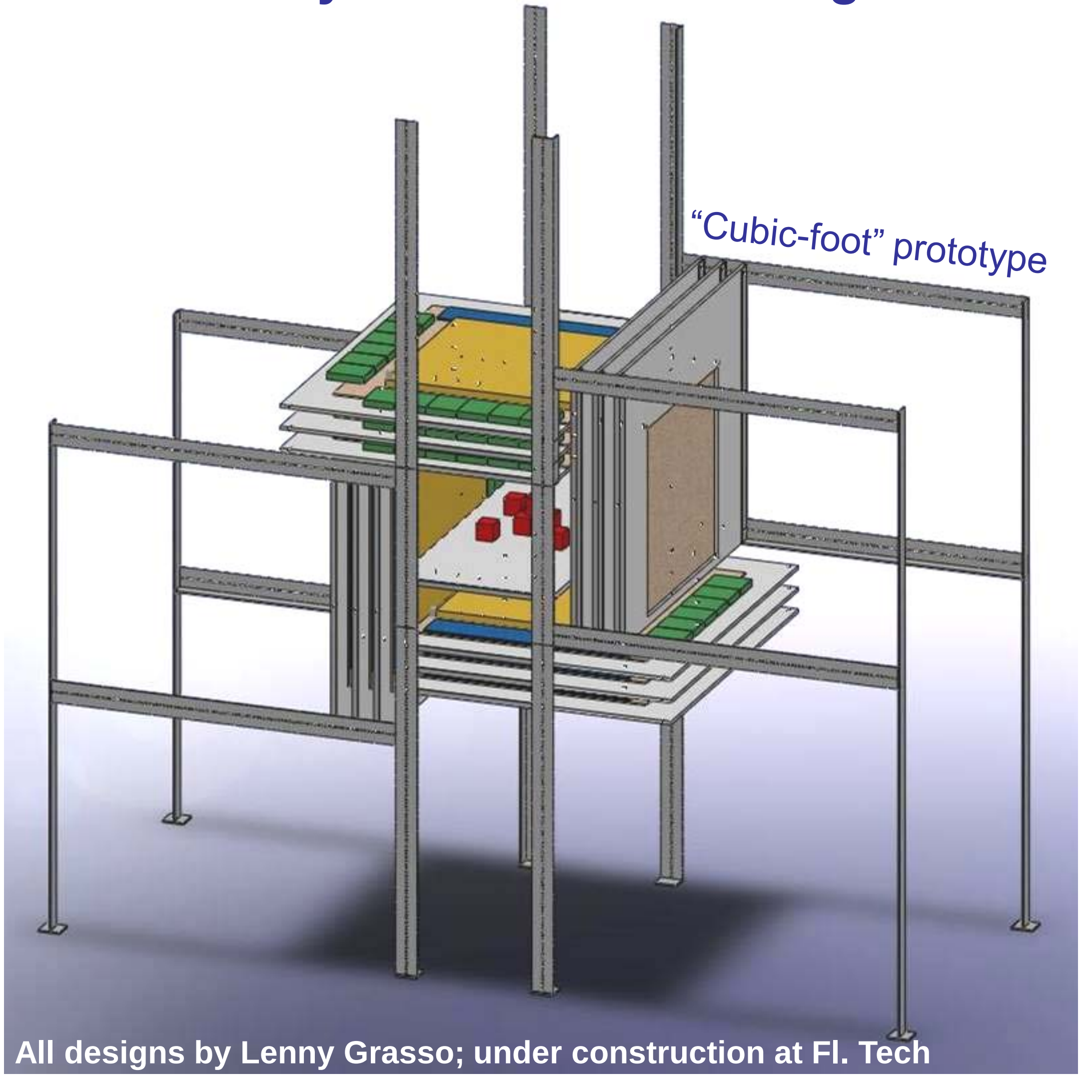
Next steps…

30cm×30cm×30cm Prototype

Planned Geometry & Mechanical Design:





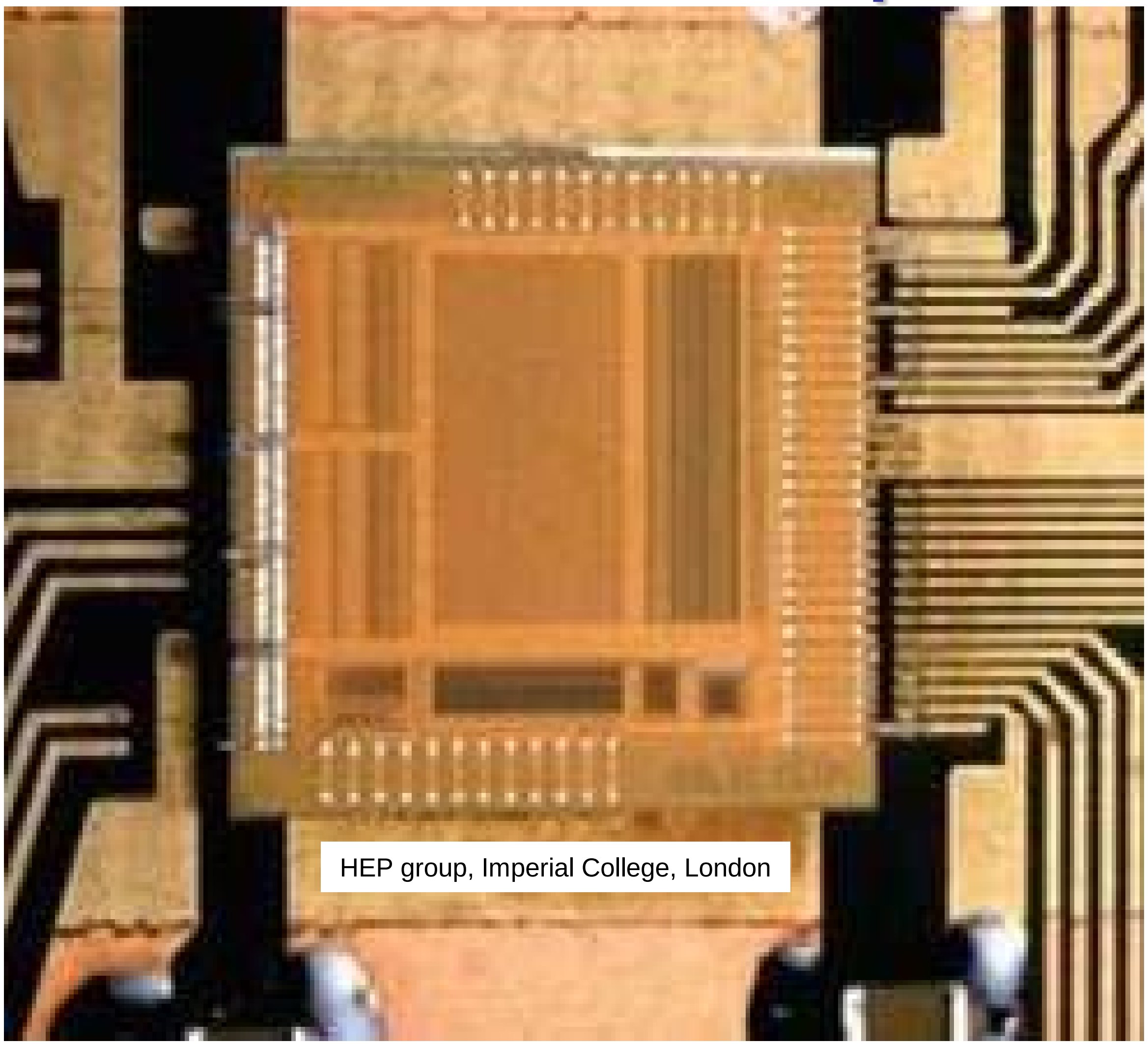


Homeland Security

30cm×30cm×30cm Prototype

Florida Tech

APV25 readout chip



HEP group, Imperial College, London

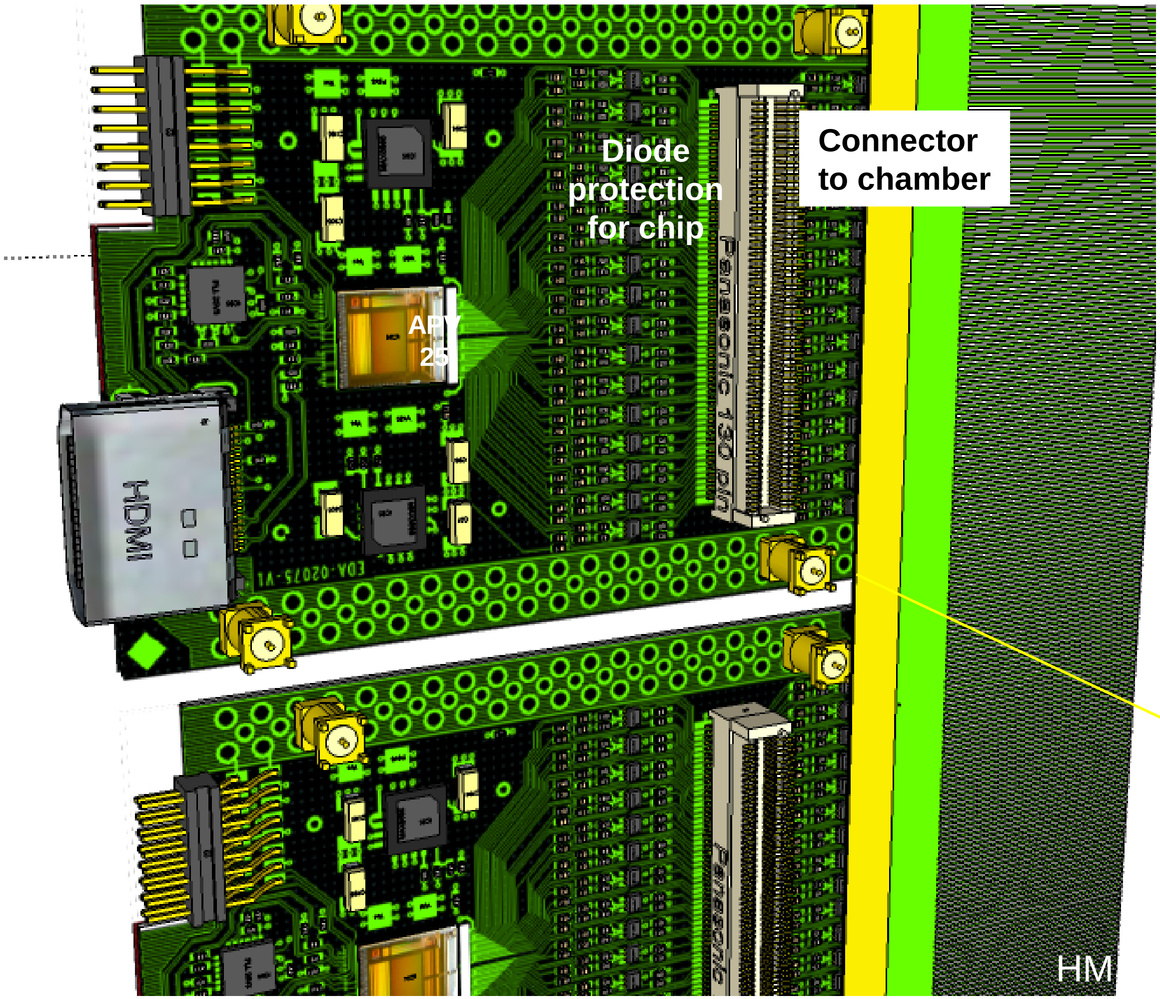
- originally developed for CMS Si-strip detector by ICL
- production in 2003/04
- yield of 120,000 good chip dies
- **128 channels/chip**
- preamplifier/shaper with 50ns peaking time
- 192-slot buffer memory for each channel
- multiplexed analog output
- integrated test pulse system
- runs at 40 MHz
- used e.g. by CMS, COMPASS, ZEUS, STAR, Belle experiments

MOST IMPORTANT:

- Chip is still available
- “Cheap” ! (CHF28/chip)

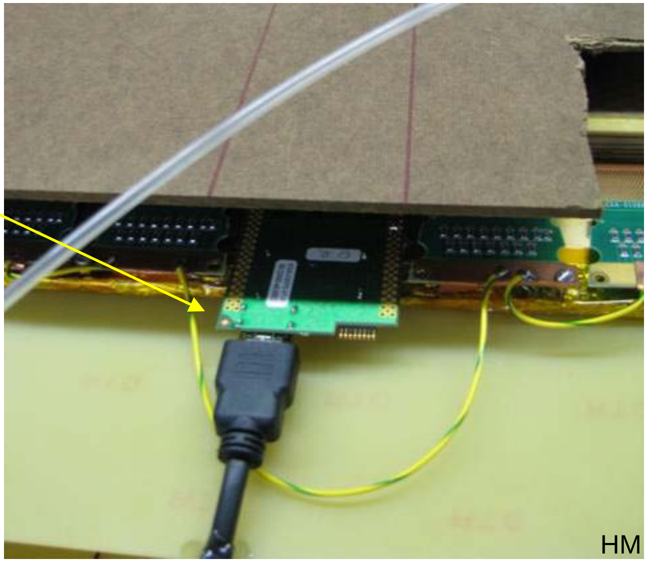
We have procured 160 chips for our ten 30cm 30cm detectors (min. 120 needed)

Front-end hybrid card



- **128 channels/hybrid**
- Integrated diode protection against sparks in GEM detector
- Estimated cost: EUR55/card
- Plan to get 160 cards for MT
- 8 Prototype boards made at CERN

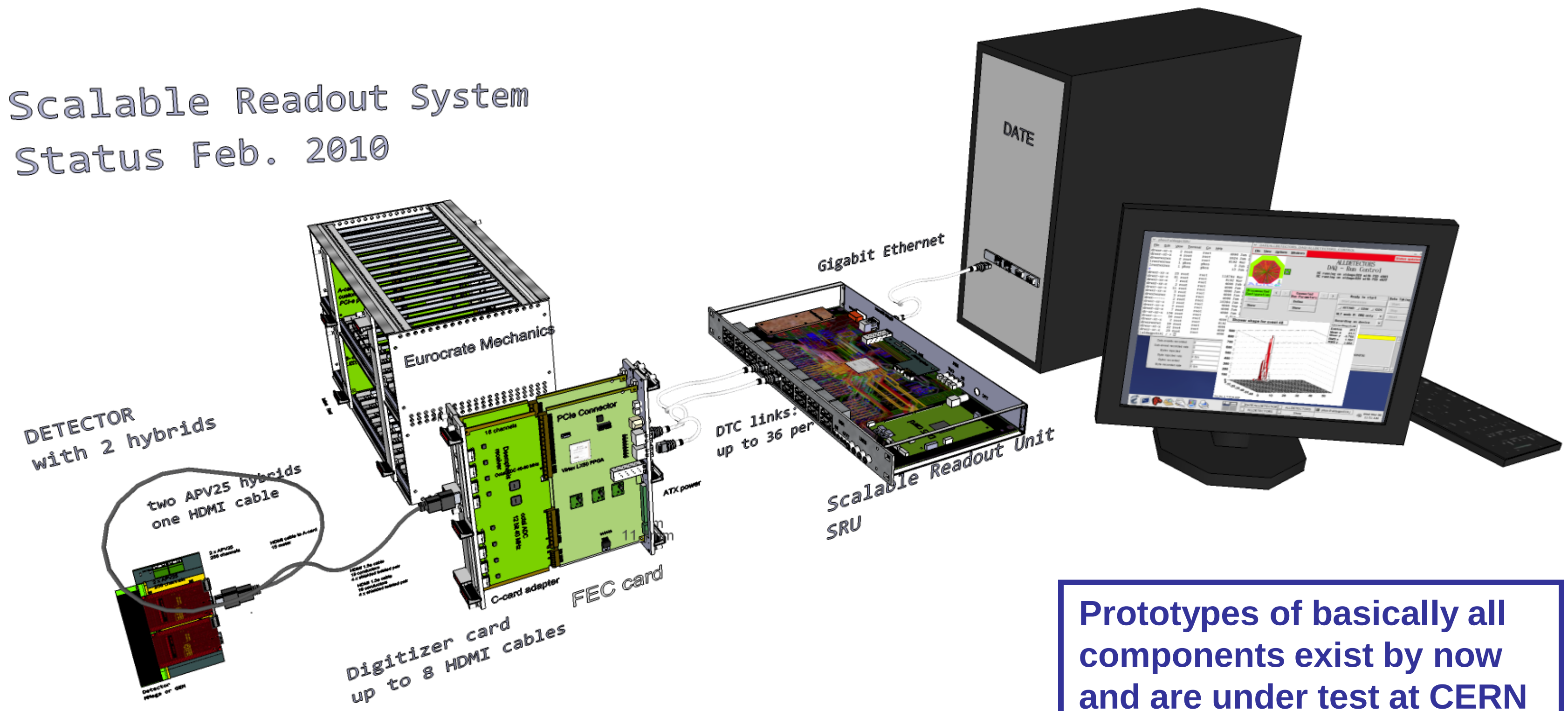
- **First on-detector tests** performed with MT-GEMs at CERN by Sorin, Hans, Kondo (→ Sorin's next talk):



30cm×30cm×30cm Prototype

Electronics & DAQ under development

Est. cost per electronics channel: $1-2



Prototypes of basically all components exist by now and are under test at CERN by RD51 electronics group

Plans for 2nd half of 2010

1. **Analyze data for minimal station**
   - Measure performance: resolution, efficiency, muon tomography
   - Test other reconstruction methods (EM, Clustering) besides POCA on real data
   - Publish results

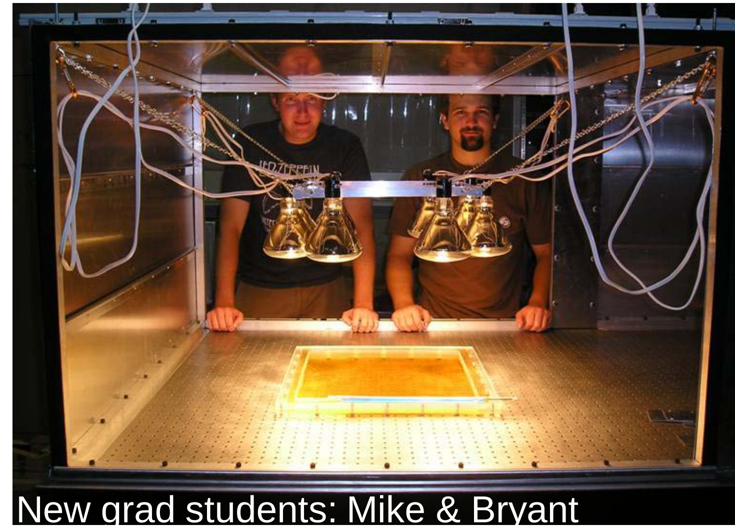
2. **Build & operate 30cm × 30cm × 30cm MT prototype with SRS**
   - Help develop DAQ for SRS (→ software!)
   - Commission all GEM detectors with final SRS electronics & DAQ at CERN
   - Develop offline reconstruction
   - Get experimental performance results on muon tracking
   - Take and analyze lots of Muon Tomography data at CERN
   - Test performance with shielded targets in various configurations
   - Ship prototype to Florida and install in our lab; continue MT tests there

3. **Development of final 1m × 1m × 1m MT station**
   - Prepare for using large-area GEM foils (~100cm × 50cm):
     Adapt thermal stretching technique to large foils
   - Try to simplify construction technique:
     Build small Triple-GEM detectors without stretching GEM foils
     (using our standard CERN 10cm × 10cm detectors, going on now)

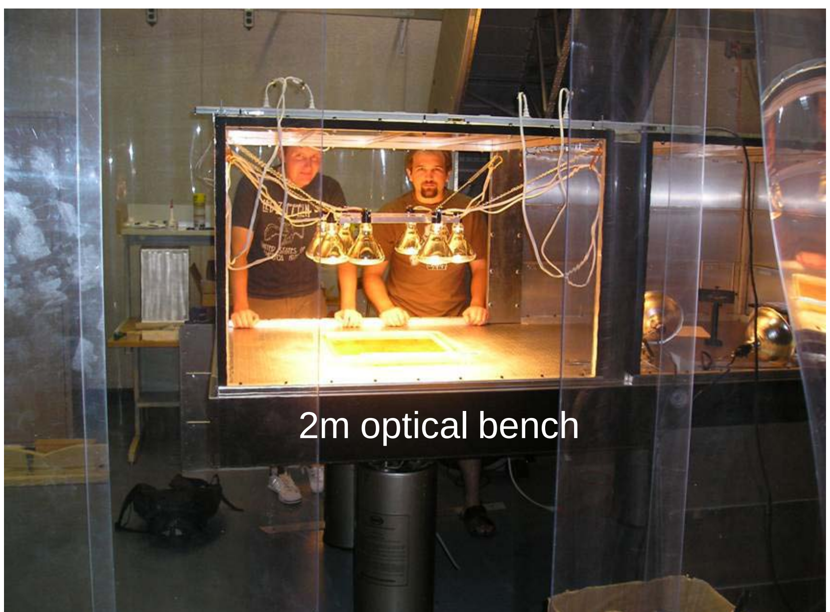
Towards 1m × 1m × 1m MT station

New infrastructure for stretching GEM foils:

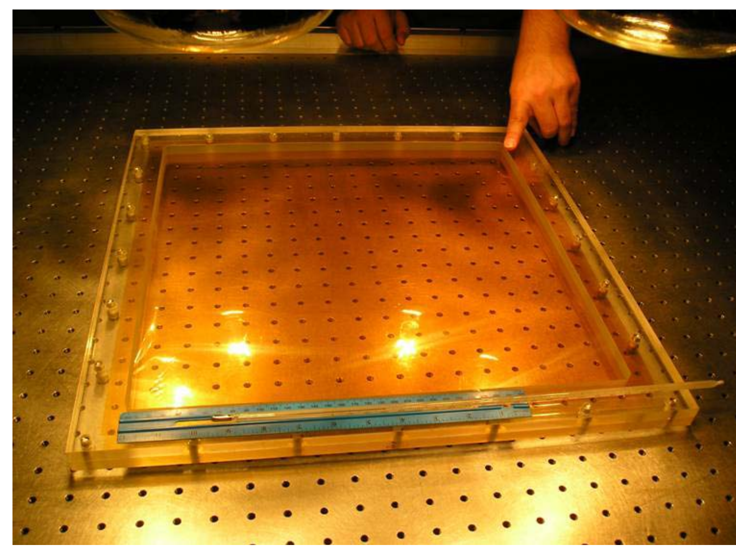
- Thermal stretching method (plexiglas frame)
- Heating with infrared lamps (40-80^{o}C)
- On flat metallic optical bench (= heat bath)
- Everything inside large mobile clean room
- Potentially scalable to 1-2 m for large GEMs



New grad students: Mike & Bryant



2m optical bench



Funding situation

- **Good news:**
  - Substantial progress with hardware in 2009/10 and **strong support from RD51** have convinced Dept. of Homeland Security to continue project for one more year
  - Funding action for June ’10 – May ’11 in progress
  - Funds for full SRS readout system (15k ch.) for “cubic-foot” station expected to be available in ‘10
  - Continuing to fund post-doc (Kondo) and one grad student (Mike) to work on project

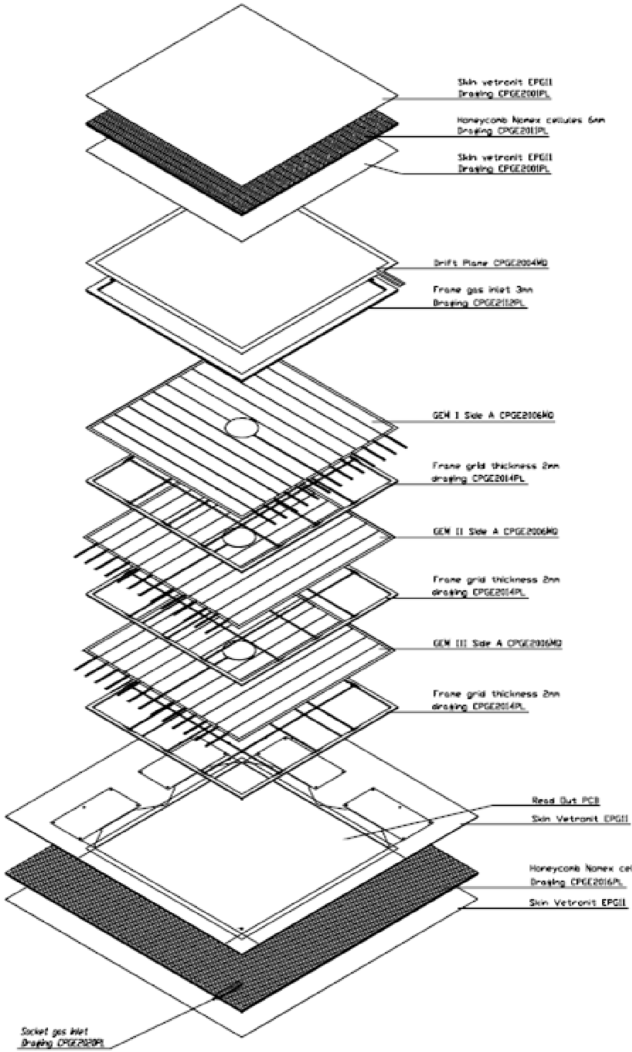
Acknowledgments

A big THANK YOU to RD51:

- Rui, Miranda for support w/ building the detectors
- Esther, Fabien, Maxim, (Saclay) for lending us the GASSIPLEX cards – *twice…*
- Theodoros (Demokritos) & MAMMA for getting us started on the LabView DAQ system
- Leszek, Serge, Gabriele, Marco & Matteo (GDD) for all the help w/ setting up tests in the GDD lab
- Hans & Sorin for all the design, development, and testing work on the SRS

Backup Slides

Triple-GEM design

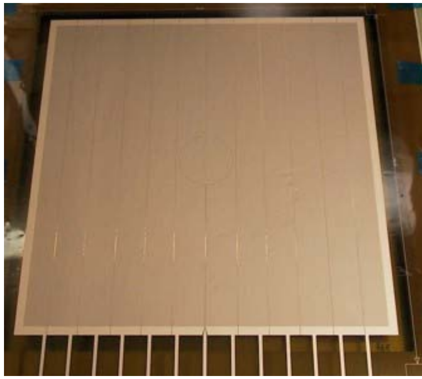


} Top honeycomb plate

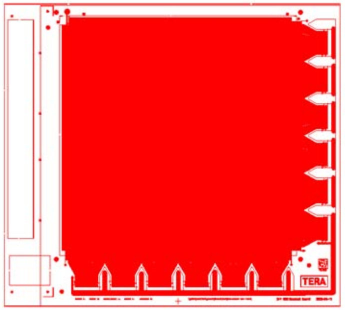
} Drift cathode and spacer

}
}
}

3 GEM foils stretched & glued onto frames/spacers



} 2D Readout Foil with ~1,500 strips



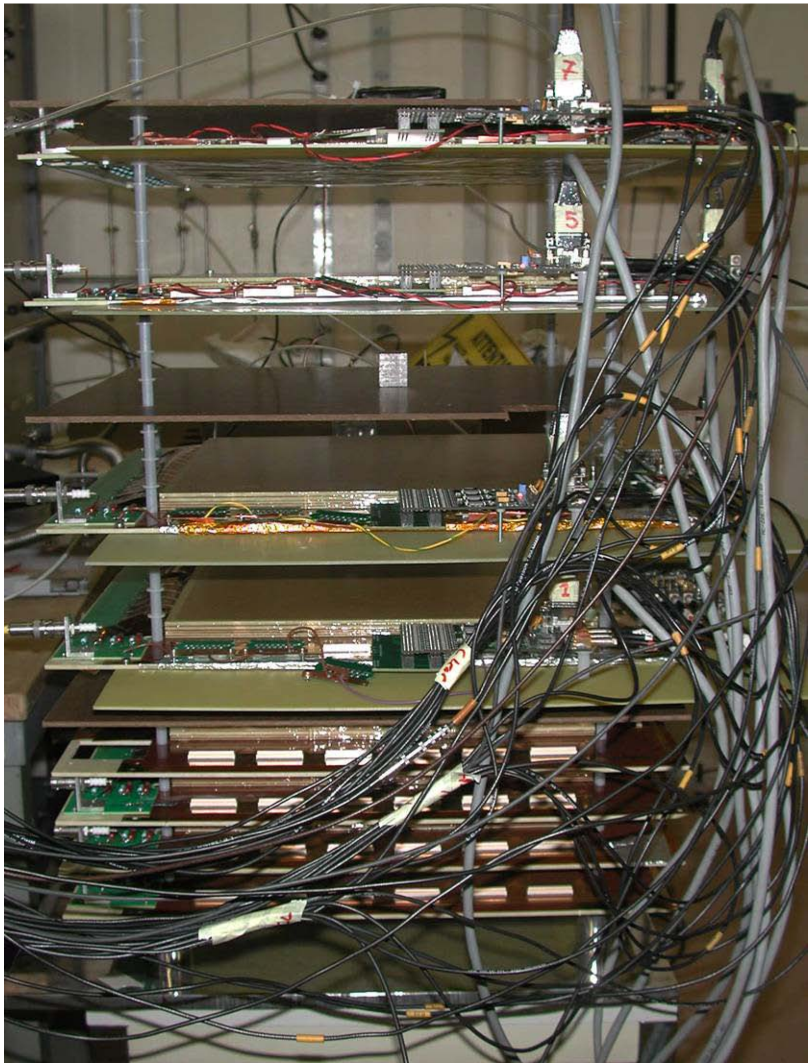
} Bottom honeycomb base plate

Follows original development for COMPASS exp. & further development for TERA

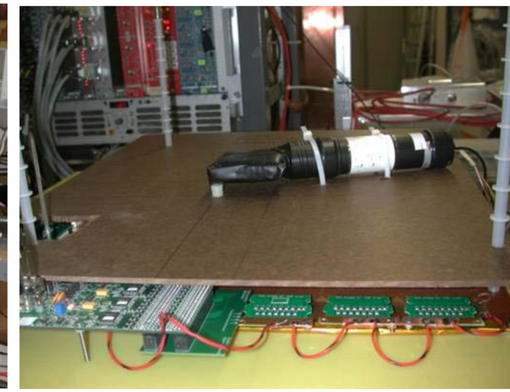
Homeland Security

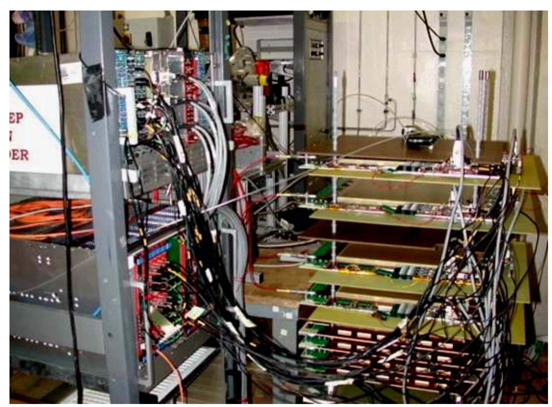
Minimal MT station

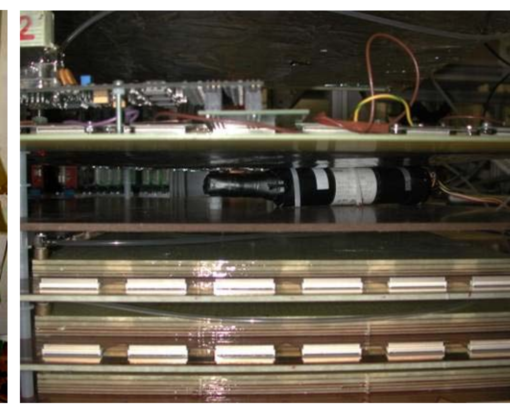
Florida Tech



Setup at GDD in April 2010

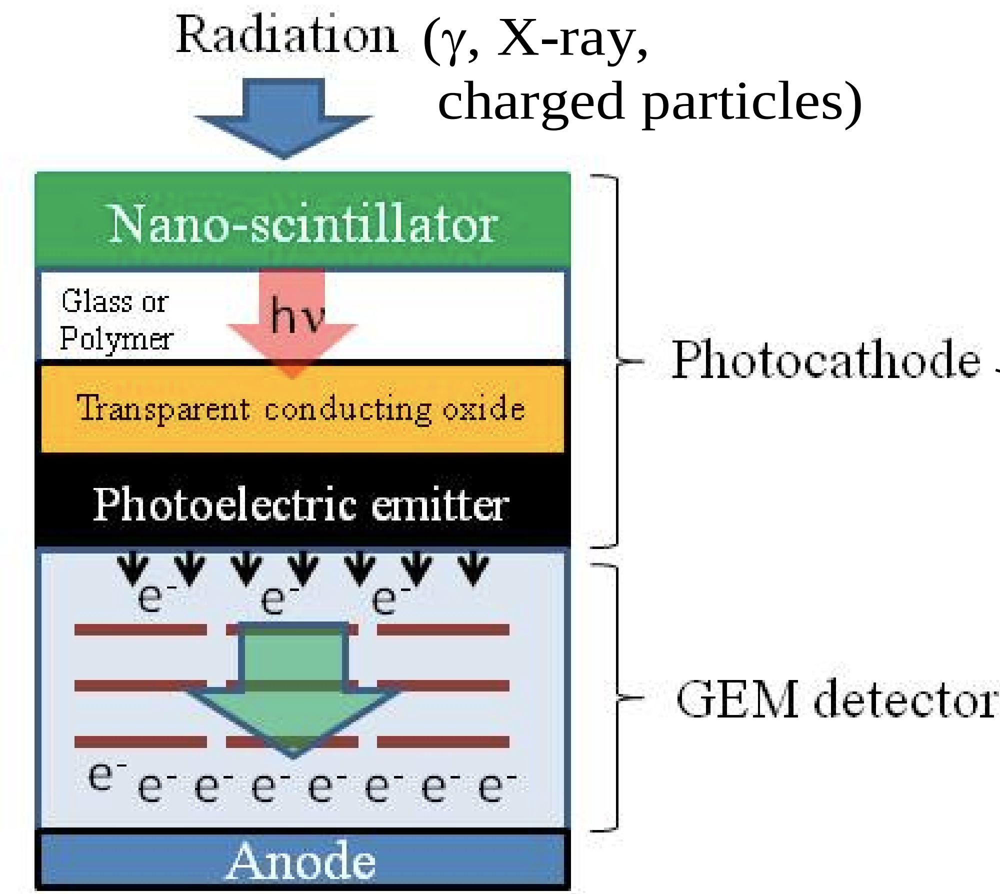




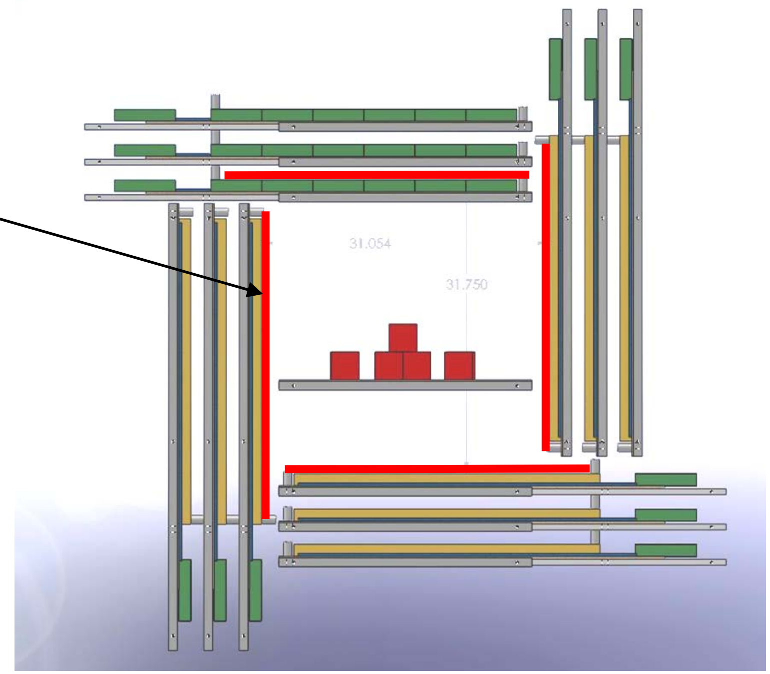


Beyond FY10…

Large photosensitive GEM Detector (100-200 keV γ's) ?



Muon Tomography with integrated γ-detection ?



Fl. Tech – U. Texas, Arlington planned joint effort (Physics & Material Science Departments)

5/26/2010 M. Hohlmann, Florida Institute of Technology – RD51 Coll. Meeting, Freiburg, Germany