Interest in High-η Muon Upgrade from Florida Tech Muon Group

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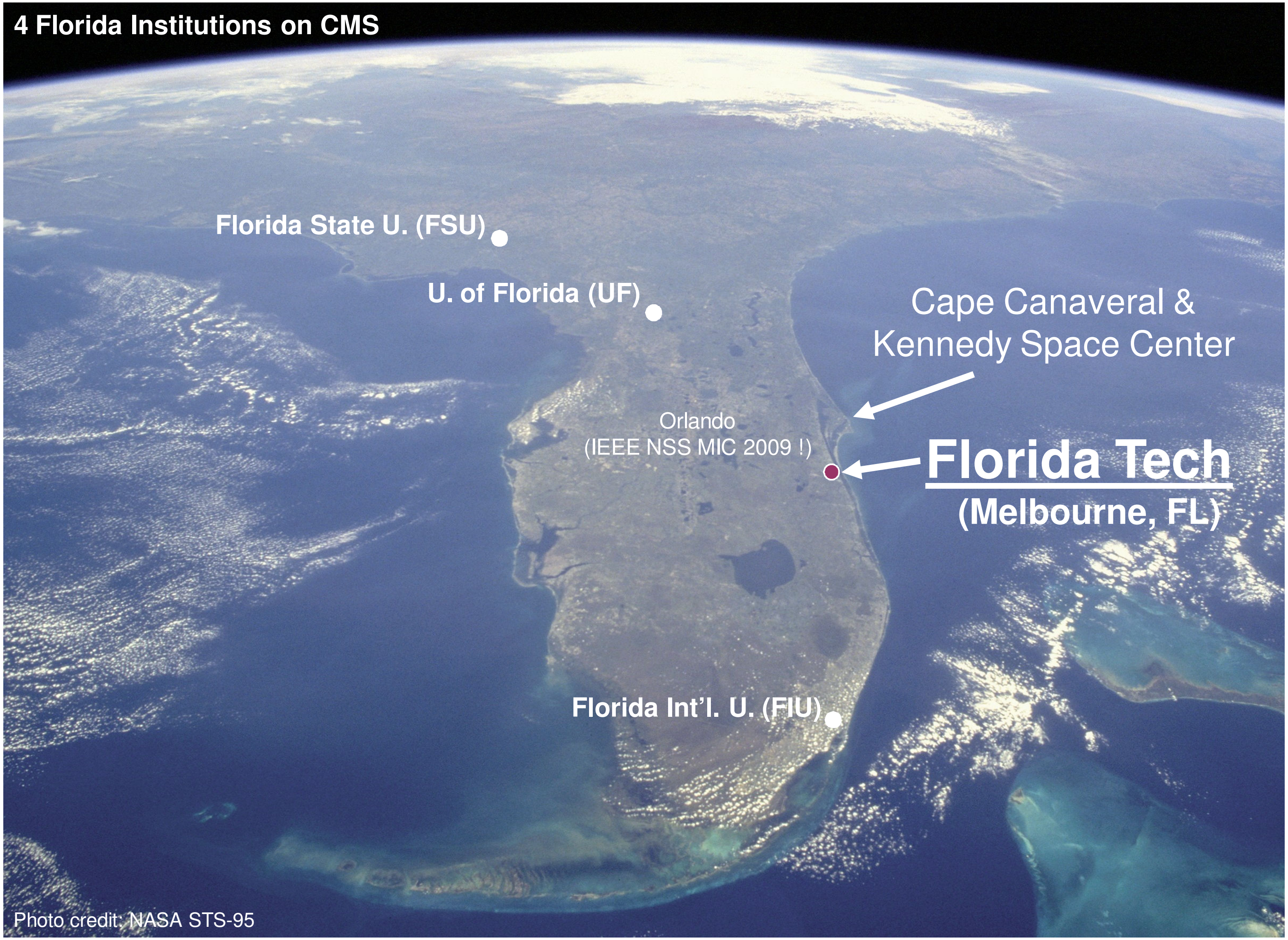
Florida Institute of Technology, Melbourne, FL, USA

2nd meeting of CMS high-η muon upgrade group - Sep 4, 2009

Outline

- Who we are
- Current detector work
  - on CMS muon detector
  - on MPGDs for Muon Tomography (with RD51)
- Interest in the high-η muon upgrade

Where's Florida Tech ?



Florida Tech Muon Group

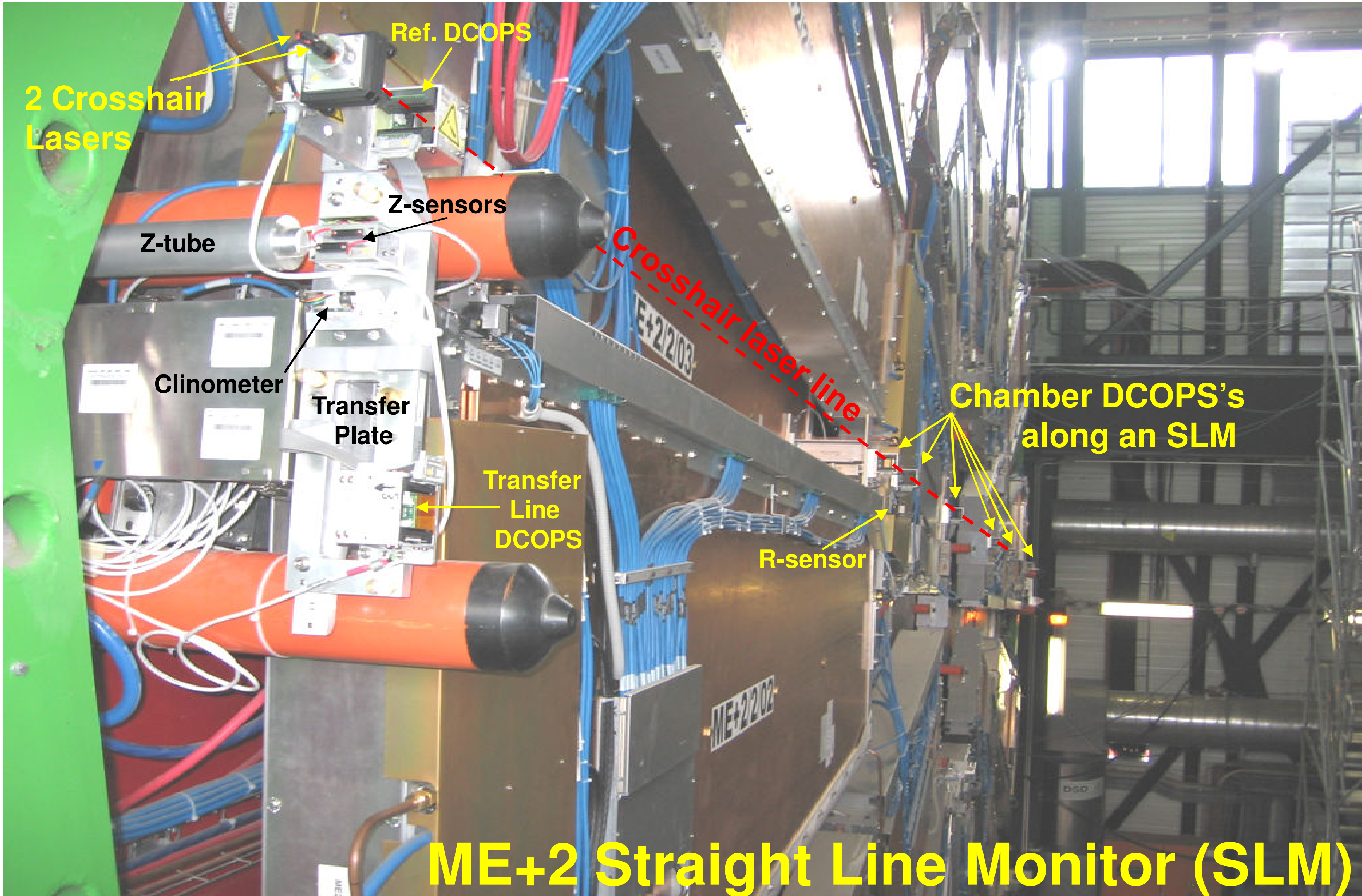
CMS members since 2002; RD51 charter member (2008)

- **Faculty:**
  - MH (CMS,RD51)
- **Research Associate (post-doc):**
  - Kondo Gnanvo (RD51, Muon Tomography)
- **Graduate Students:**
  - Samir Guragain (CMS)
  - Himali Kalakhety (CMS)
  - Amilkar Quintero (Muon Tomography, MPGD)
  - Lenny Grasso (Muon Tomography, MPGD)
- Several undergraduates (CMS Tier 3, GEANT4, Muon Tomography)

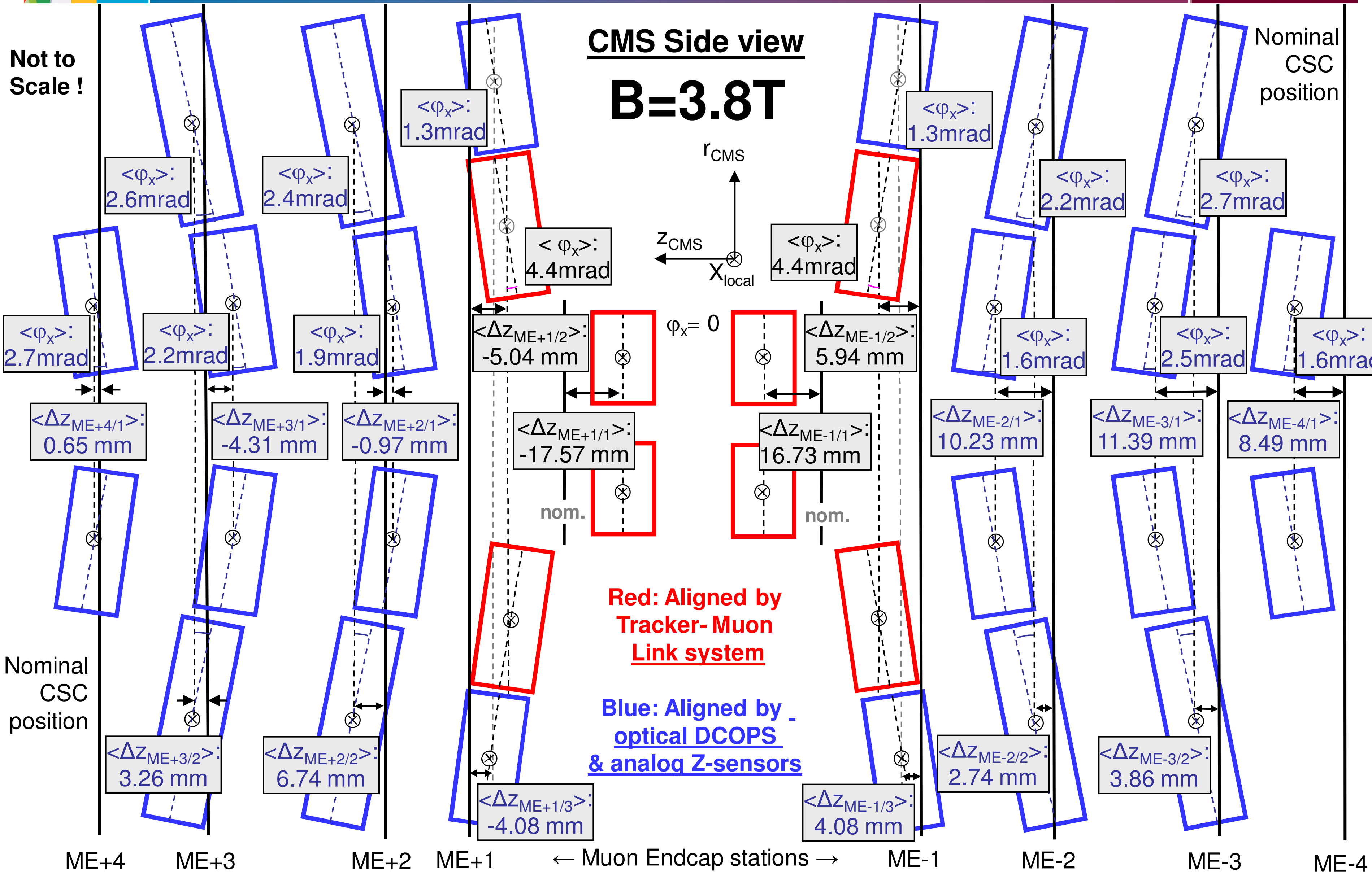
Current Fl. Tech Projects

- **CMS:**
  - Hardware alignment of CSCs in Muon Endcaps
    - Focus on reconstruction of CSC positions
    - MH co-convener of Muon Alignment group (DT, CSC, Link)
  - Physics: $Z' \rightarrow \mu^+\mu^-$ search with emphasis on endcap muons and impact from (mis)alignments
- **Muon Tomography for Cargo Inspection:**
  - Construction of prototypes of MT station with triple-GEM detectors
    - Currently constructing 10 30cm×30cm GEM detectors
    - Next prototype planned with large-area GEMs (~ 1 m^2)

CSC Alignment Hardware



CSC Alignment (CRAFT 08)



Muon Tomography
with
GEM detectors

Major Challenge in Detecting Nuclear Contraband: Shielding!

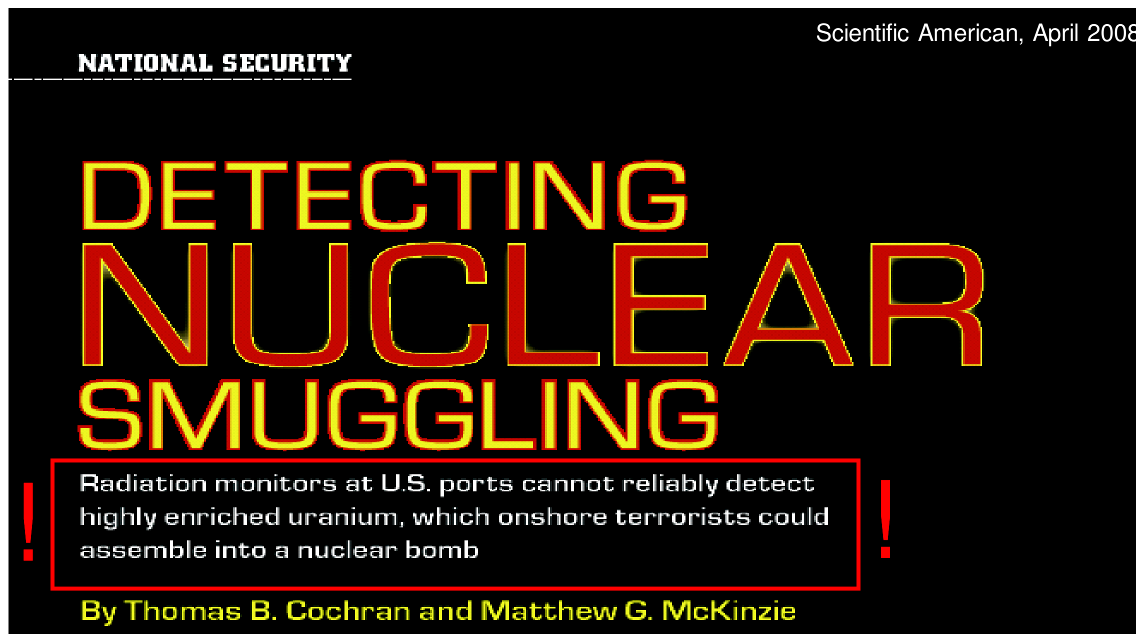
~ 800 Radiation Portal Monitors (γ,n) in U.S.

- In 2002, reporters managed to smuggle a cylinder of **depleted uranium shielded in lead** in a suitcase from Vienna to Istanbul via train and in a **cargo container through radiation monitors into NY harbor**. Cargo was even flagged for extra screening, but DU undetected.

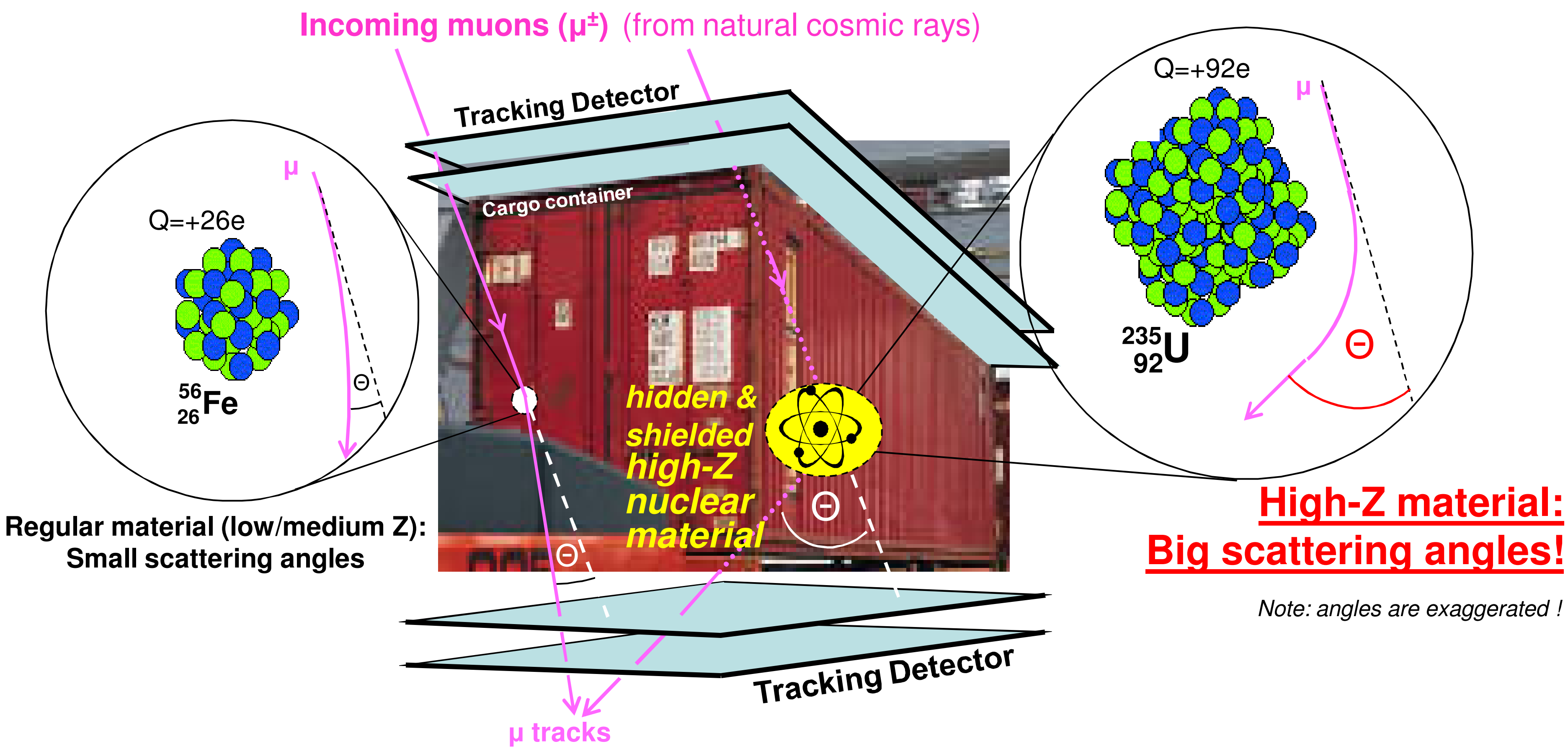
6.8 kg DU

- In 2003, took route Jakarta – LA, same result…

HEU can be **hidden** from conventional radiation monitoring because it **is easy to shield emanating radiation** within regular cargo



A Potential Solution: Muon Tomography using Cosmics

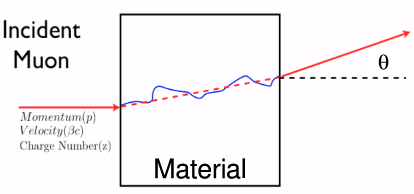


Idea: Use multiple scattering of charged particles in matter to detect high-Z material

Muon Tomography (MT): Concepts, Advantages & Challenges

Multiple Coulomb scattering:

- to 1st order produces Gaussian distribution of scattering angles θ with width $\sigma = \theta_0$:



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

Radiation length X_0

$\Rightarrow$ $\theta_0 \sim$ proportional to Z, $\sqrt{\rho}$; measuring muon scattering angles is sensitive to Z

Advantages:

- Cosmic ray muons are
  - highly penetrating since they are minimum ionizing particles (e.g. range of a 3 GeV muon is 186 cm in Pb; 242 cm in Fe) $\Rightarrow$ sensitive to high-Z nuclear material even if material is heavily shielded by cargo
  - ubiquitous & free $\Rightarrow$ passive interrogation without artificial radiation source or beam
  - come in from many directions $\Rightarrow$ allows tomographic 3D imaging

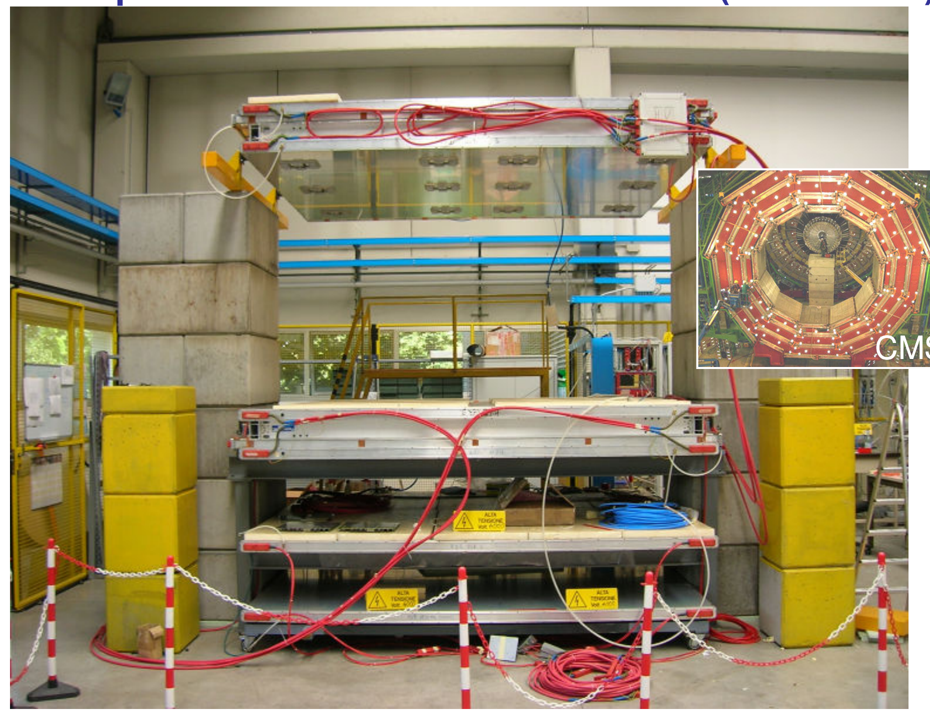
Main Challenges:

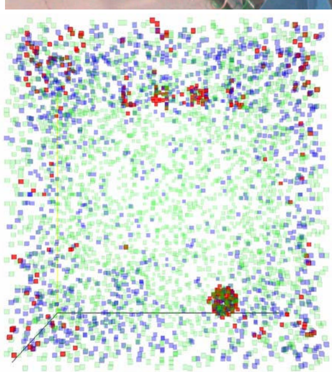
- Low cosmic ray muon rate of ~ 1 cm^{-2} min^{-1} is fixed $\Rightarrow$ integration times important
- Need to cover large volumes with muon tracking detectors

MT with Drift Tubes

Original idea from Los Alamos (2003): Muon Tomography with Drift Tubes

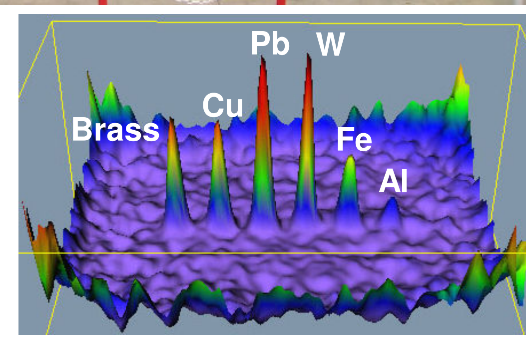
INFN Padova, Pavia & Genova: Muon Tomography with spare CMS Muon Barrel Chambers (Drift Tubes)





J.A. Green et al., “Optimizing the Tracking Efficiency for Cosmic Ray MuonTomography”, LA-UR-06-8497, IEEE NSS 2006

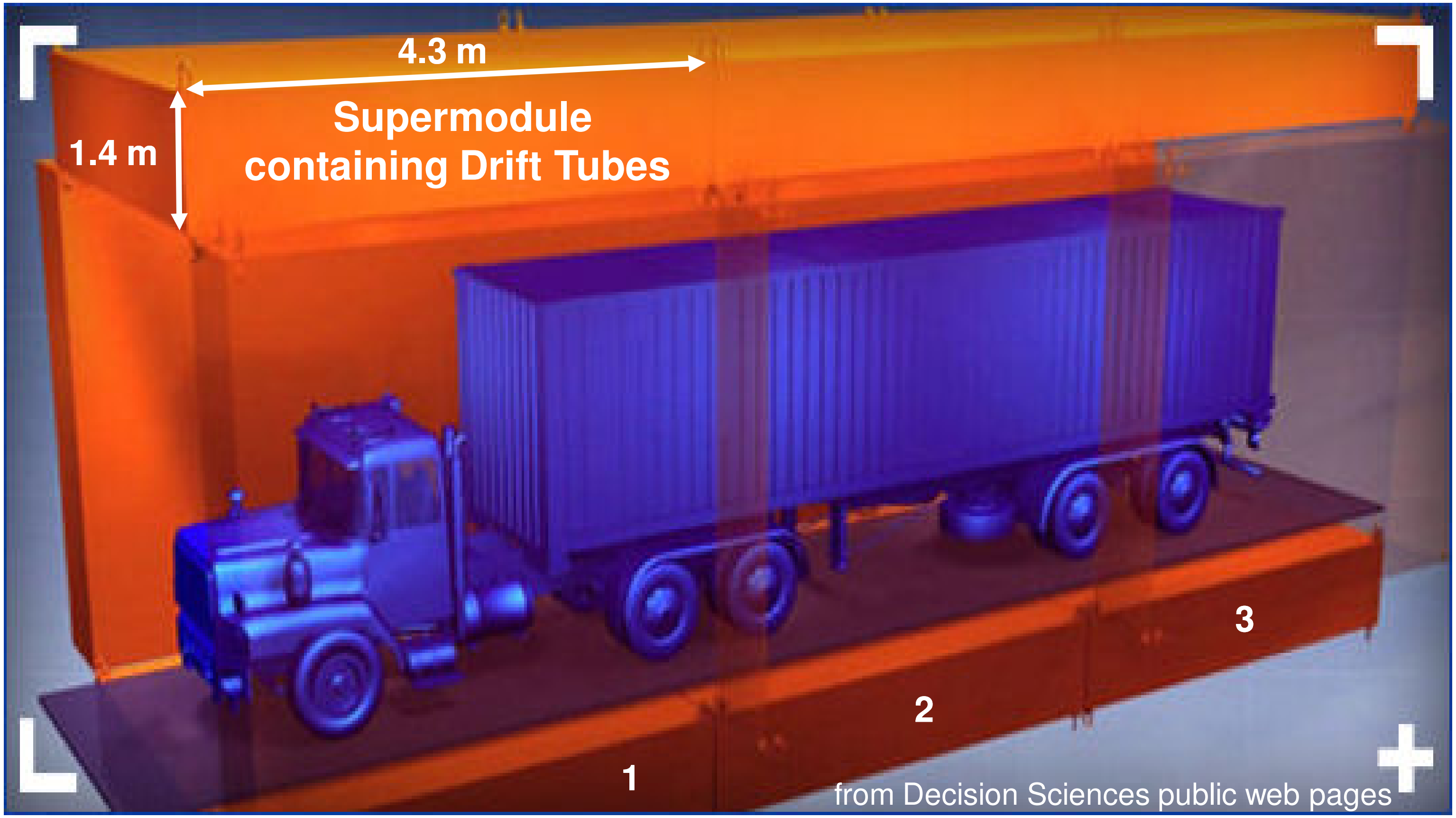
S. Pesente et al., SORMA West 2008, Berkeley, June 2008; & CRETE ’09, June 2009



Efforts also by Tsinghua U., IHEP Protvino, Decision Science (U.S. commercial), UK, Canada

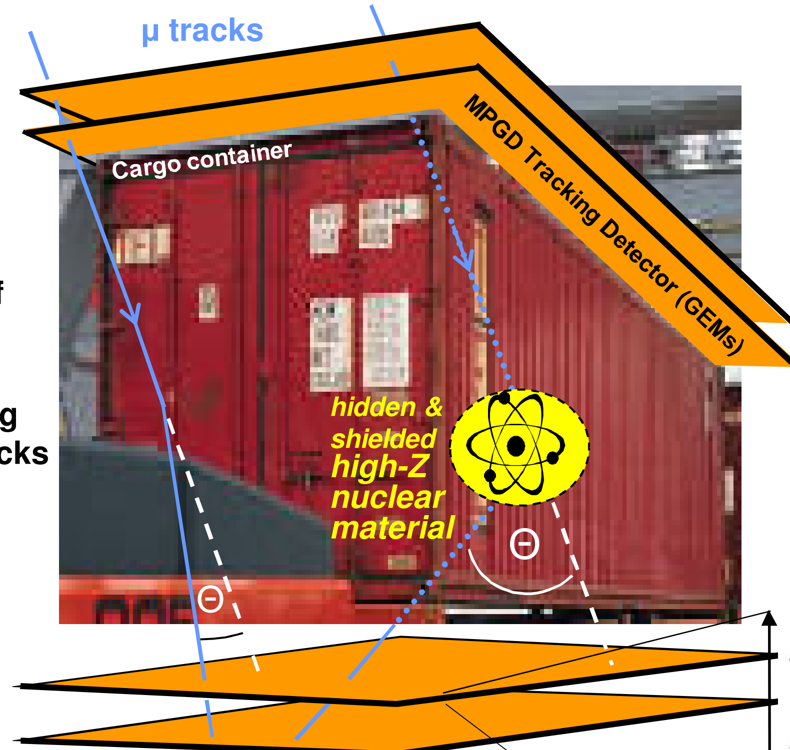
MT with Drift Tubes: A Commercial Approach

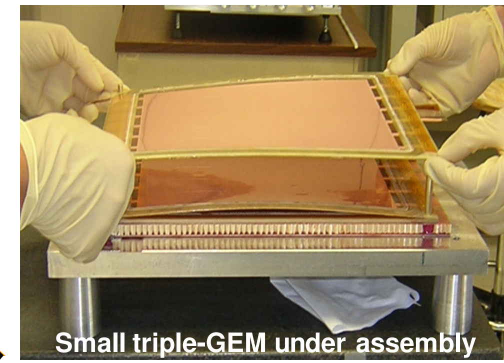
Design by Decision Sciences Corp. in cooperation with Los Alamos National Lab



from Decision Sciences public web pages

Use Micro Pattern Gaseous Detectors for tracking cosmic ray muons





ADVANTAGES:

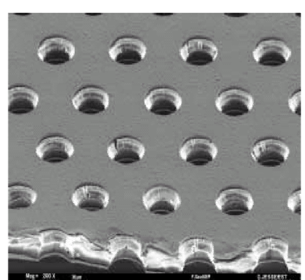
- ❑ small detector structure allows <u>compact, low-mass MT station</u>
  - thin detector layers
  - small gaps between layers
  - small scattering in detector itself
- ❑ <u>high MPGD spatial resolution</u> (~ 50 μm) provides good scattering angle measurement with short tracks
- ❑ high tracking efficiency

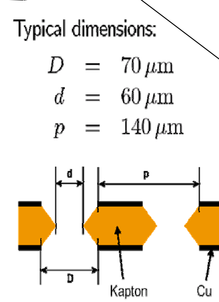
CHALLENGES:

- ❑ large-area MPGDs
- ❑ large number of electronic readout channels
- ❑ ⇒ cost

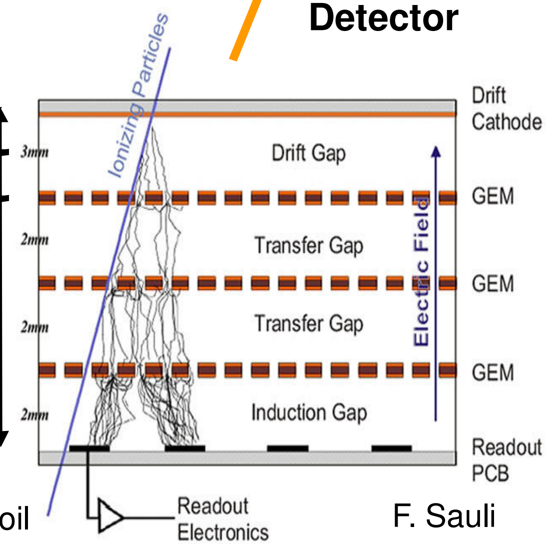
GEM Detector

~ 1 cm





Gas Electron Multiplier Foil

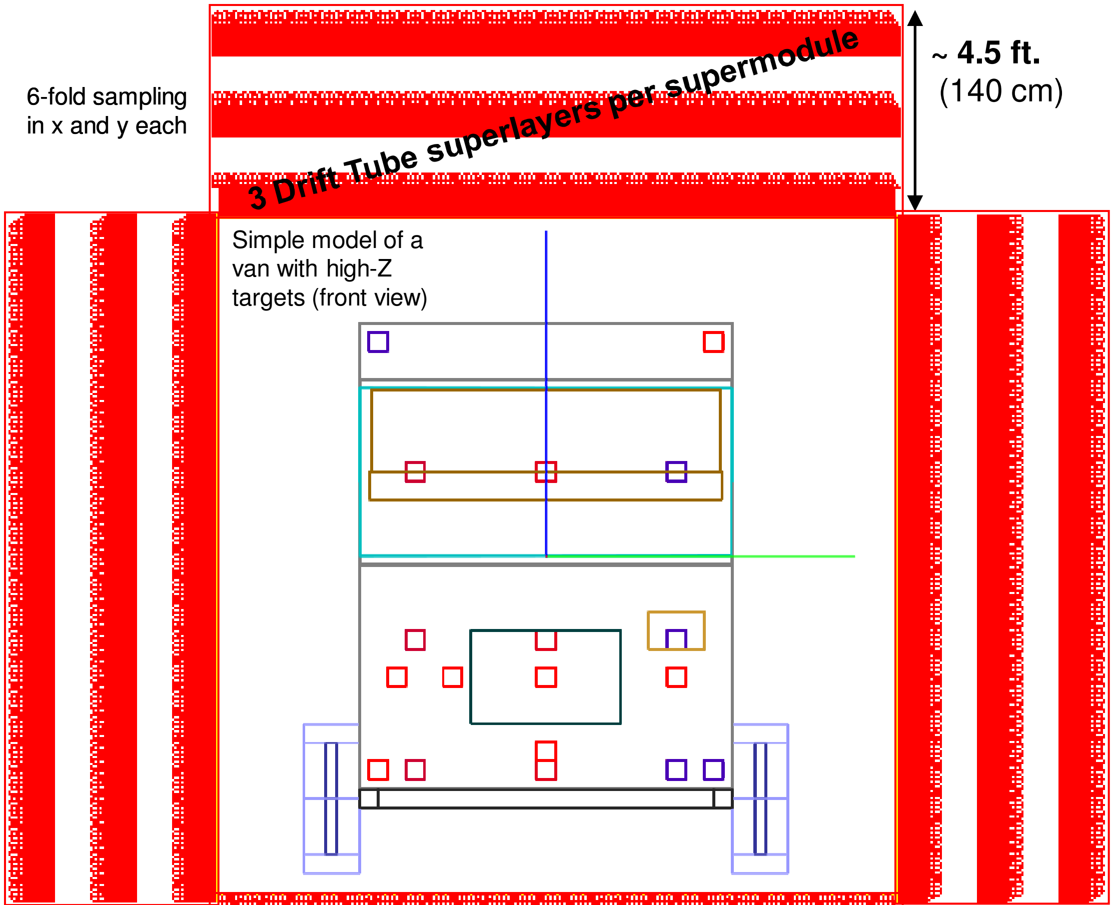


F. Sauli

MT Station Geometries

DS/LANL: Drift Tube Station

6-fold sampling in x and y each

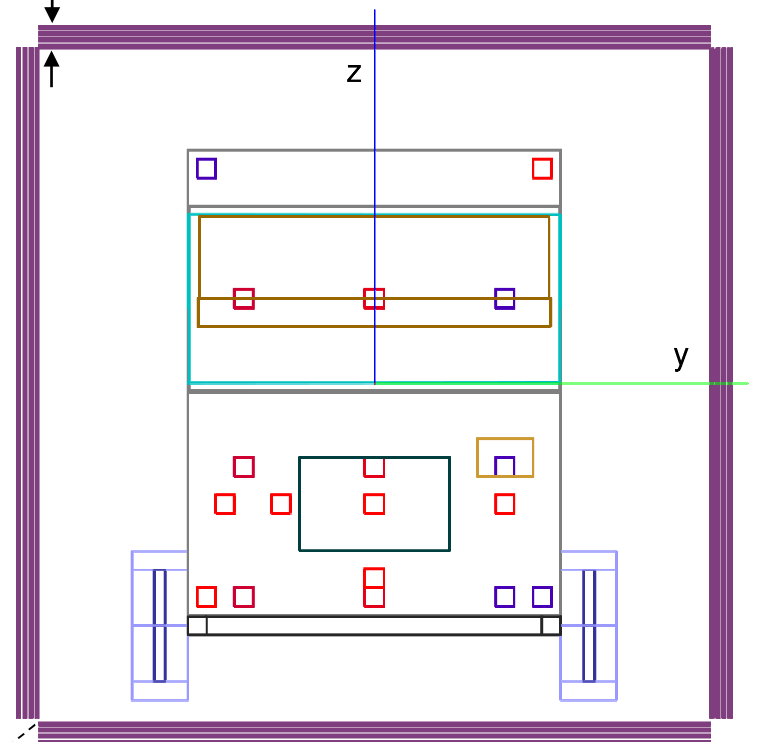


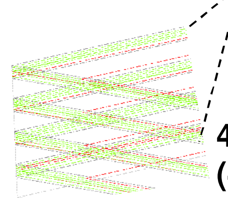
~ **4.5 ft.** (140 cm)

FIT: Compact GEM station (same detector area as DTs)

~ **4 in.** (10 cm)

GEANT 4 geometries (all dimensions to scale)

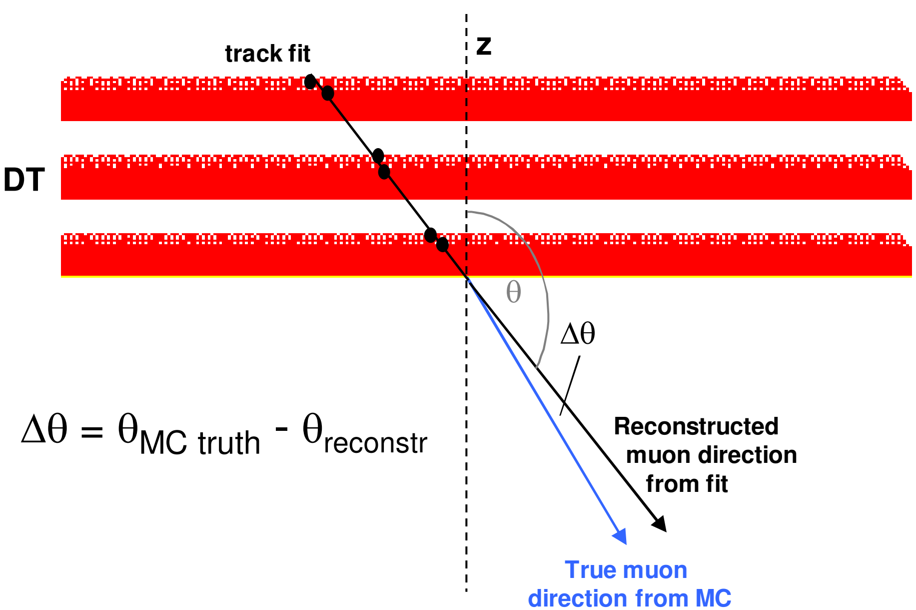




4 GEM layers with triple-GEM & x-y r/o board (4-fold track sampling in x and y each)

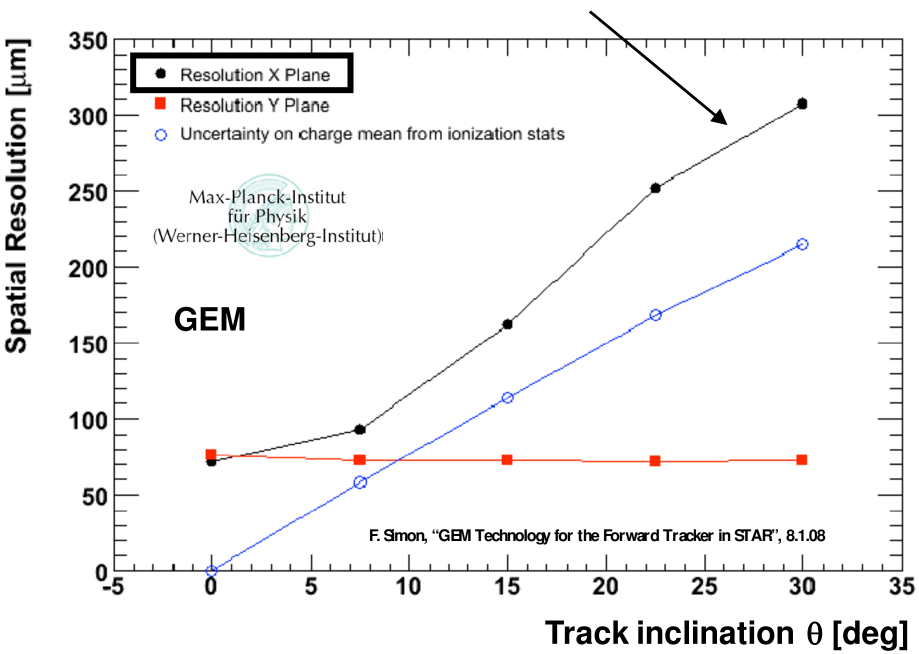
Angular Resolution I

- Finite spatial hit resolution and multiple scattering in the MT tracking station itself leads to finite angular track resolutions
- Compare polar angle θ of reconstructed muon tracks with "true" track angle from MC at exit of tracking station:



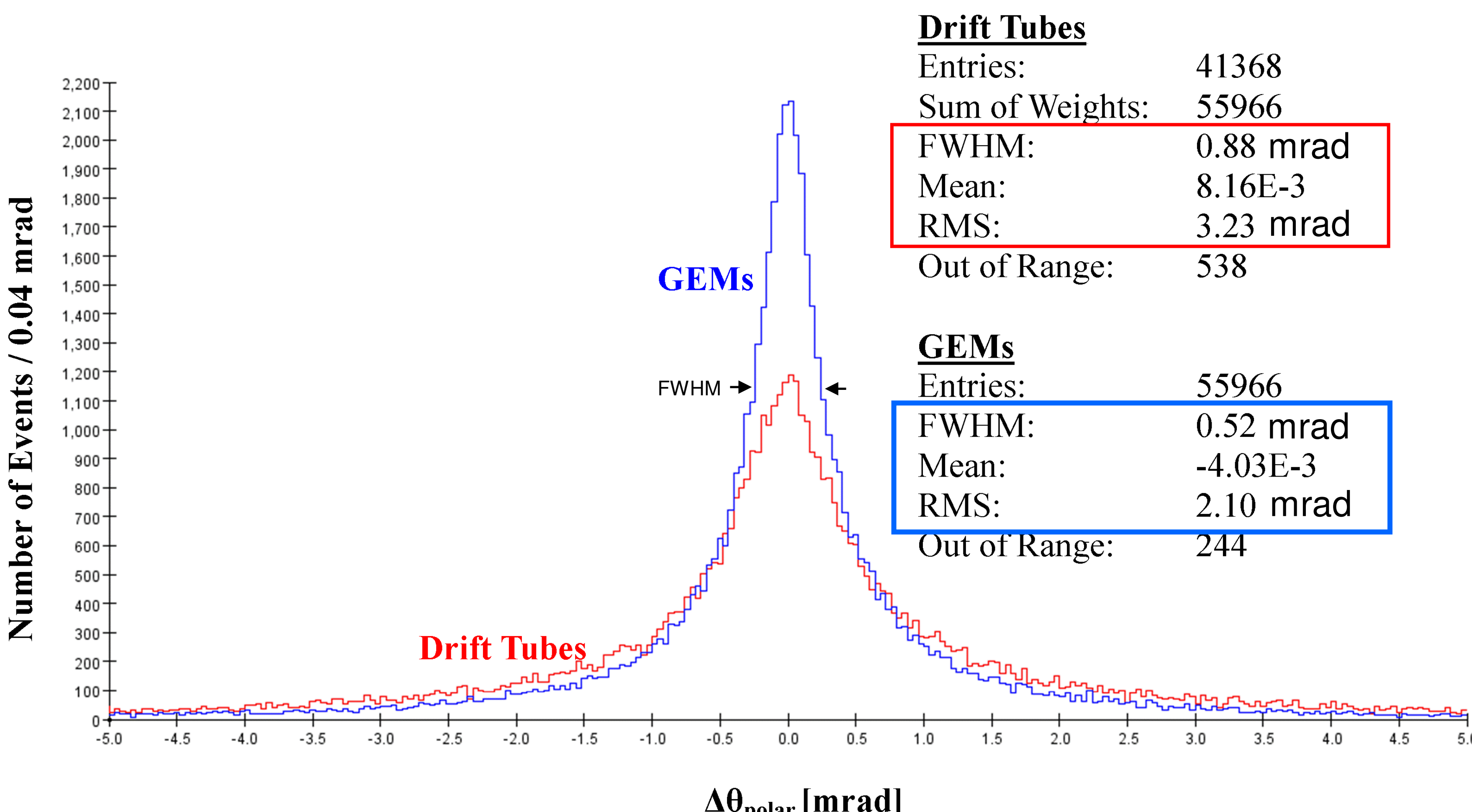
$$\Delta\theta = \theta_{\text{MC truth}} - \theta_{\text{reconstr}}$$

- Spatial hit resolution for GEMs depends on track inclination (θ)
- Parameterize measurements by MPI Munich group for MC:



Angular Resolution II

$\Delta\theta_{polar}$ for
Drift Tubes with 3 Detector Layers, 400µm Resolution, 270mm Gap
GEMs with 4 Detector Layers, 50µmResolution, 150mm Gap

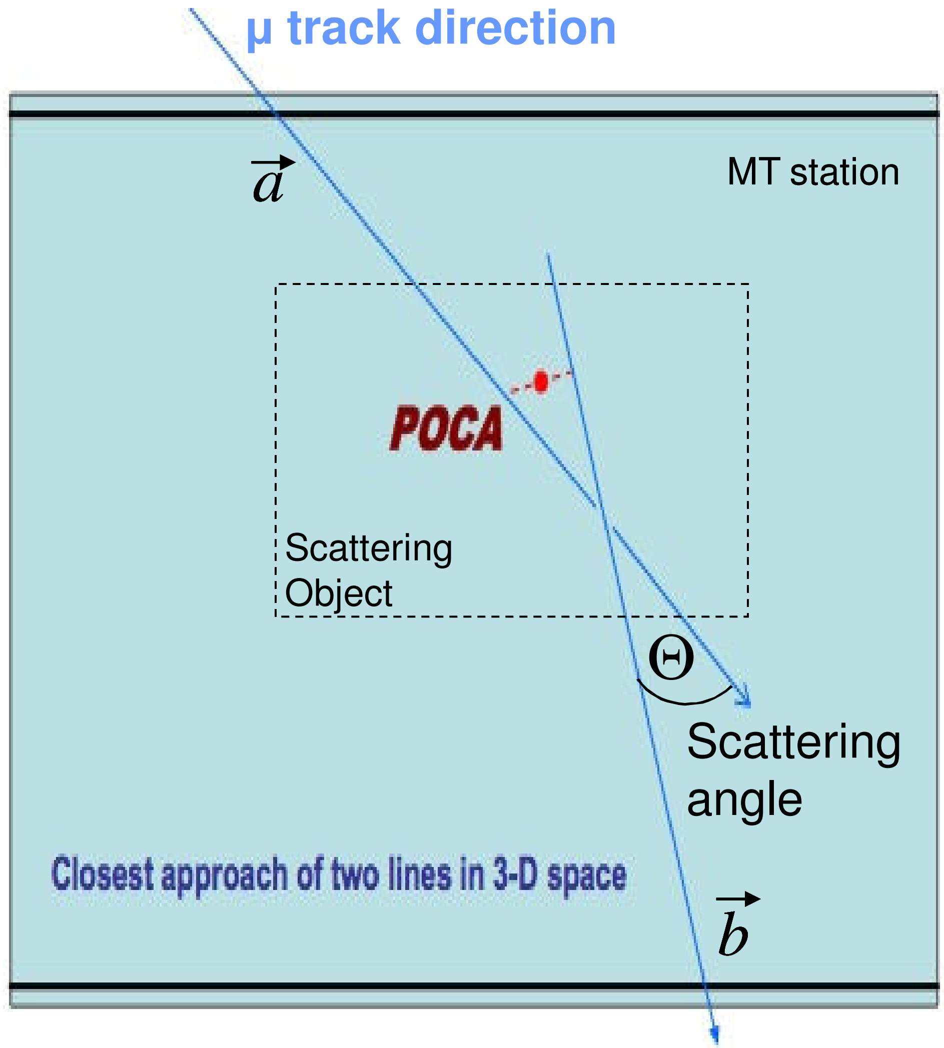


Basic Scattering Reconstruction

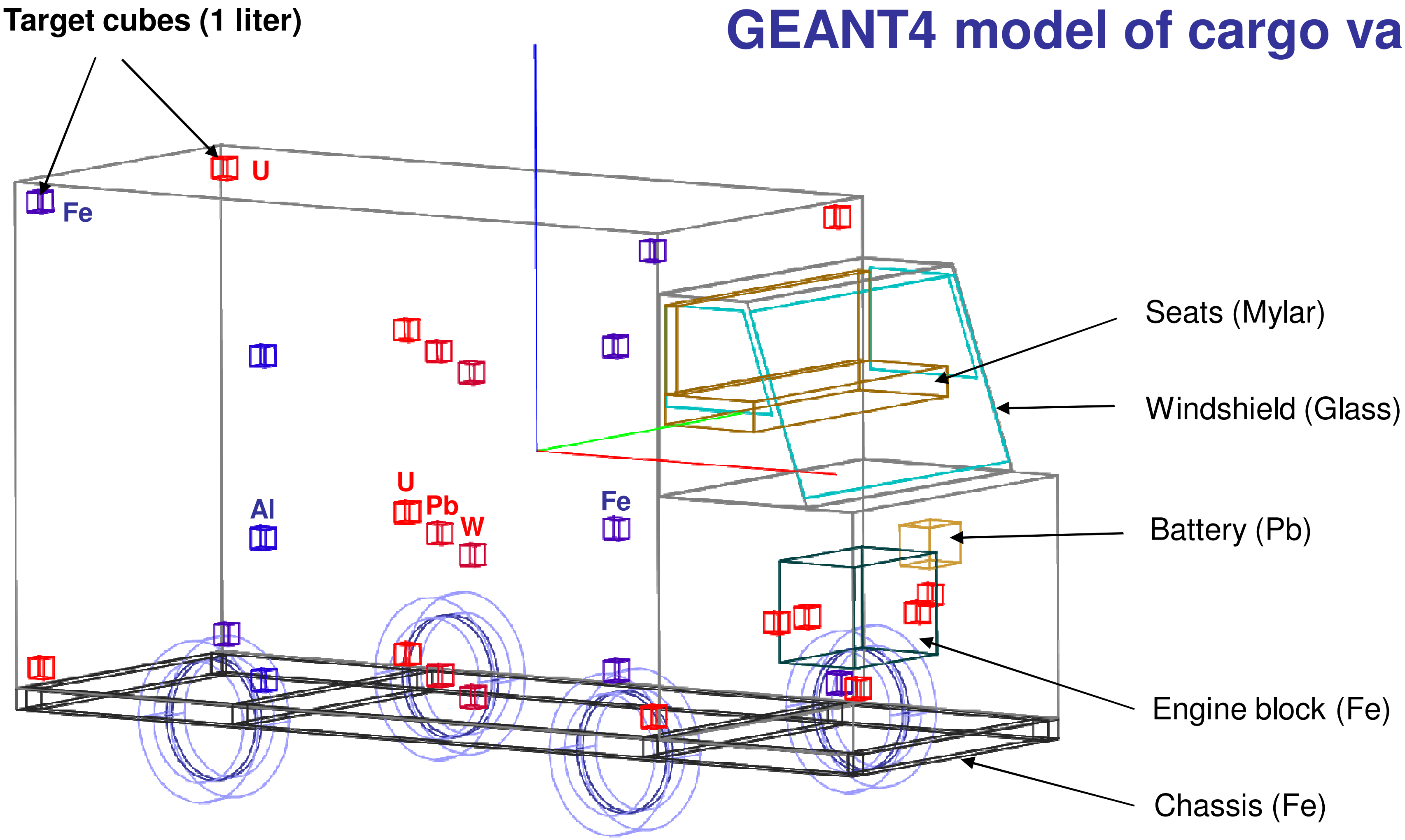
- Simple reconstruction algorithm using **Point of Closest Approach** ("POCA") of incoming and exiting 3-D tracks
- Treat as **single scatter**
- Scattering angle:

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

(with θ >0 by definition)



Threat Scenario: Van

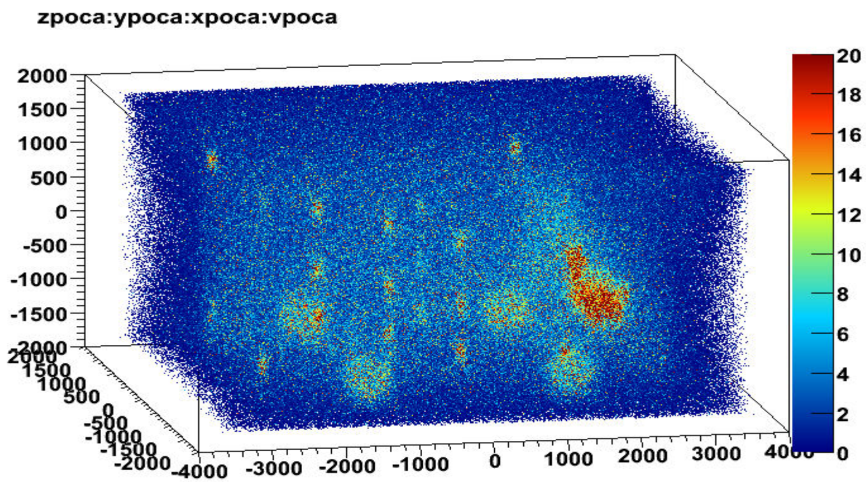


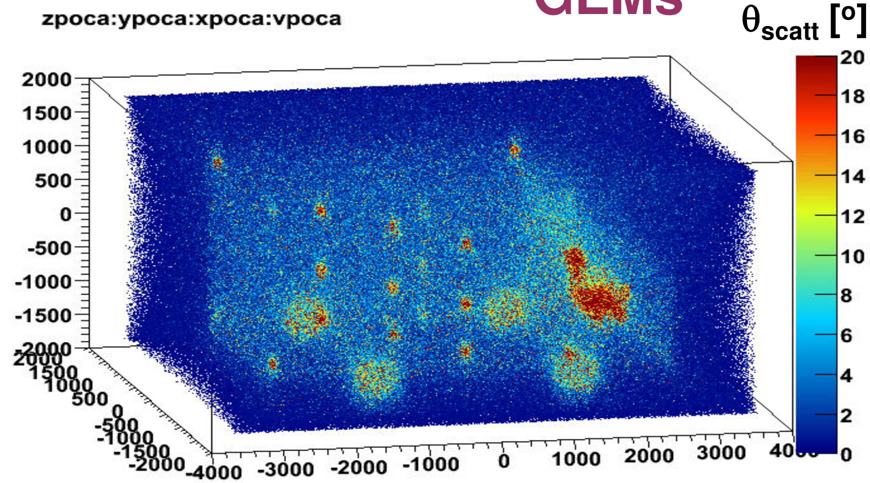
Van Reconstructions in 3D

Mean Angle (w/o momentum)

Drift Tubes | **GEMs**

θ_{scatt} [°]

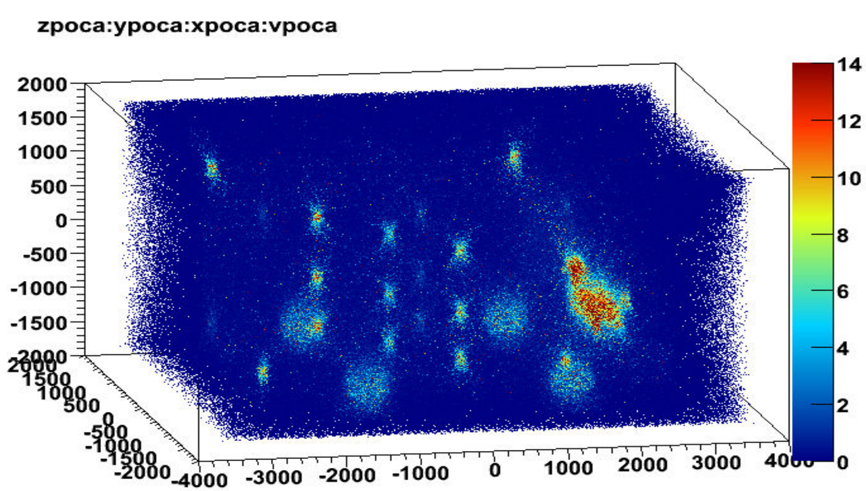


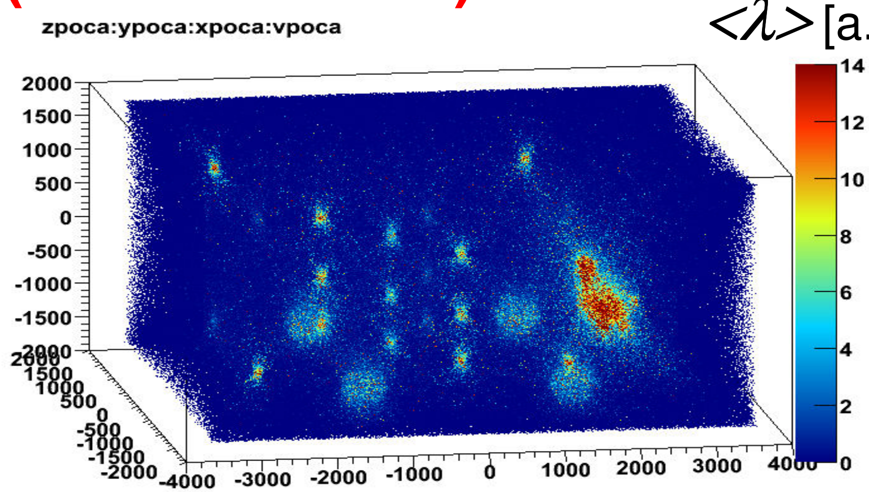


10 min. exposures

Scattering Density (w/ momentum)

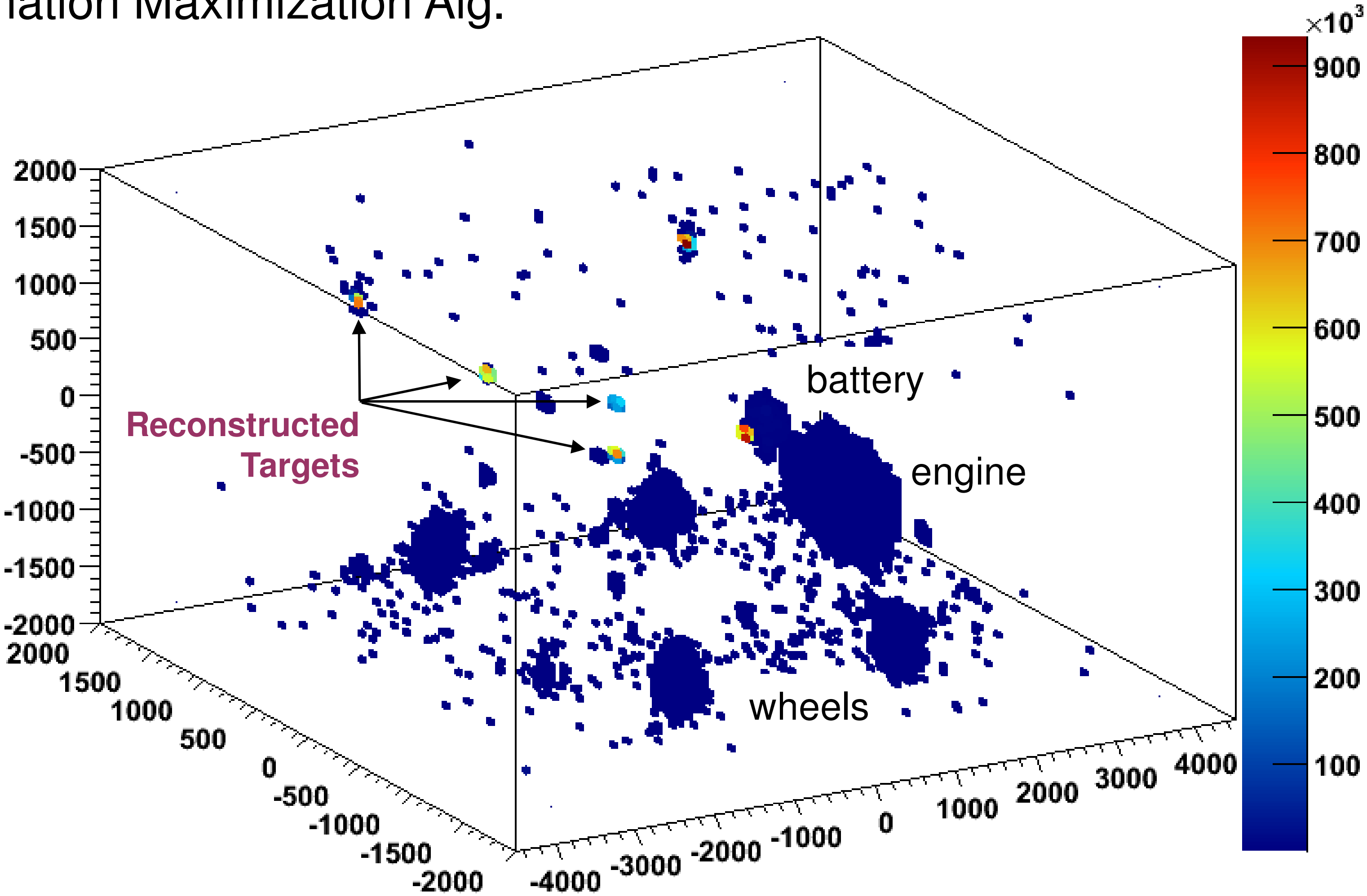
$<\lambda>$ [a.u.]





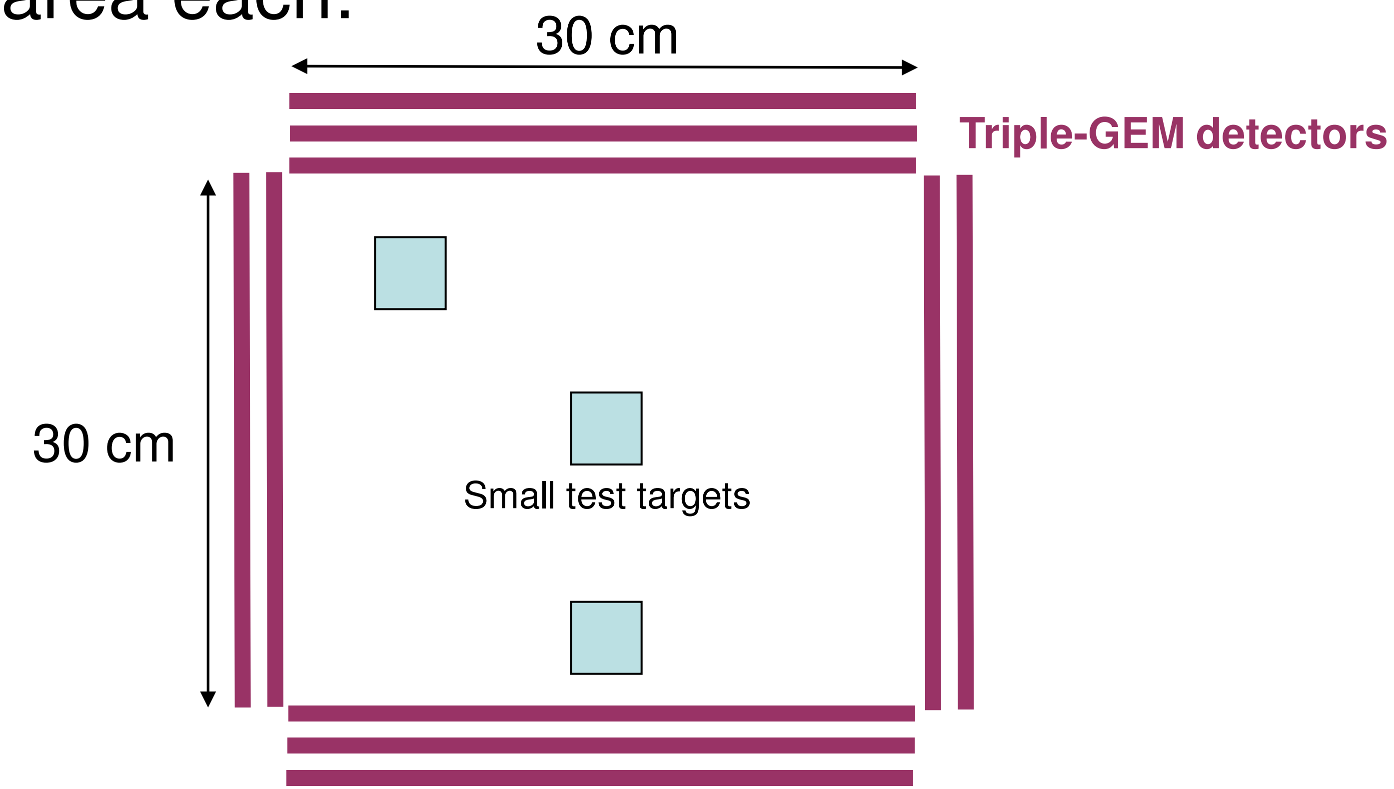
Max. Likelihood Method

Reconstruction using an
Estimation Maximization Alg.

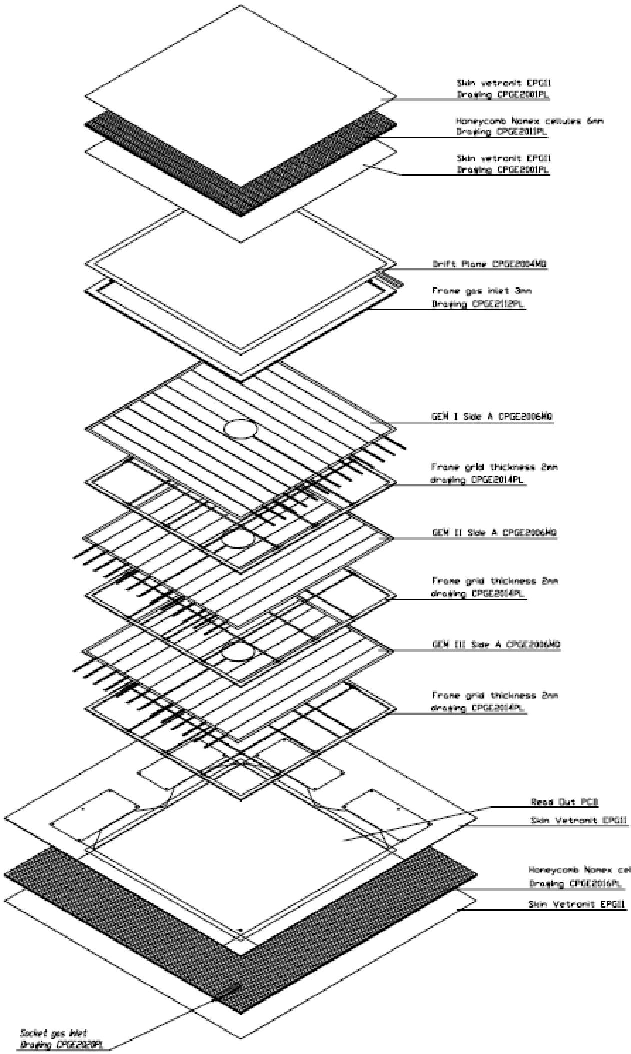


First Prototype

- Ongoing construction of first small MT prototype using 10 triple-GEM detectors with 30cm × 30cm active area each:



Triple-GEM design



Exploded Detector View

} Top honeycomb plate

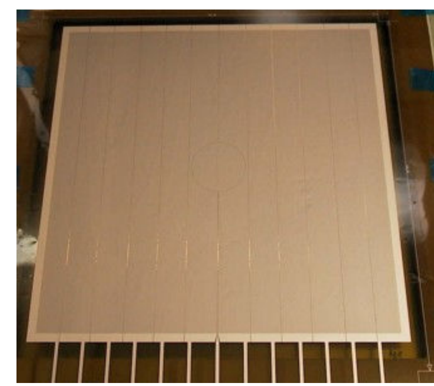
} Drift cathode and spacer

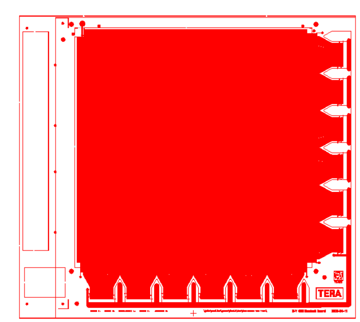
} } } 3 GEM foils stretched & glued onto frames/spacers

} 2D Readout Foil with ~1,500 strips

} Bottom honeycomb base plate

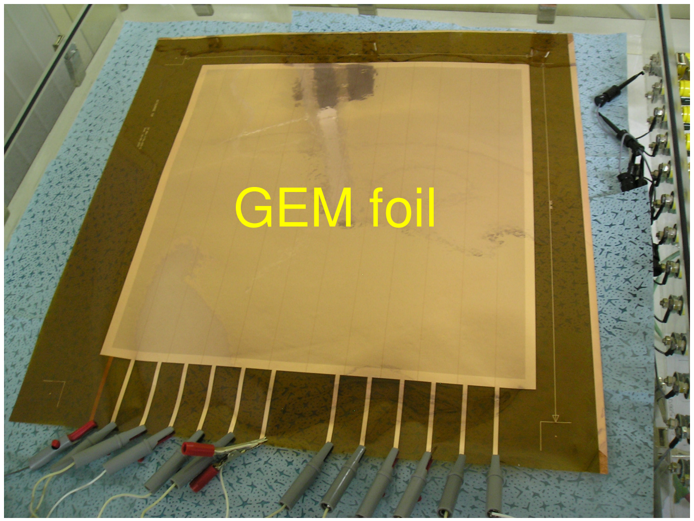
Follows original development for COMPASS exp. at CERN & further development for proton therapy application (TERA)

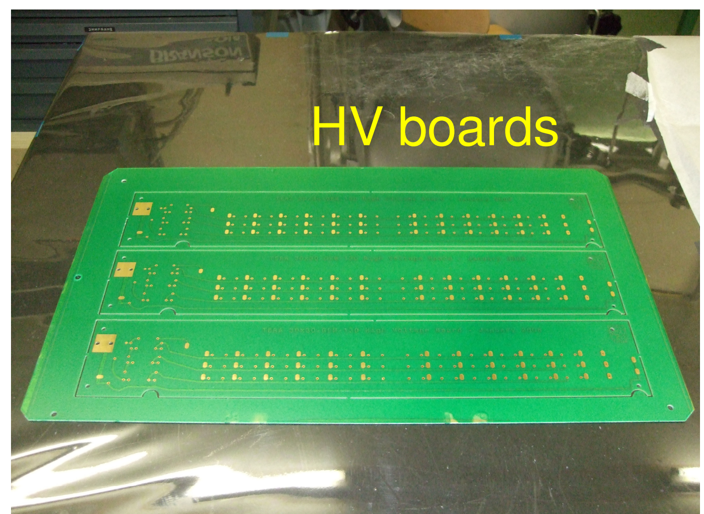




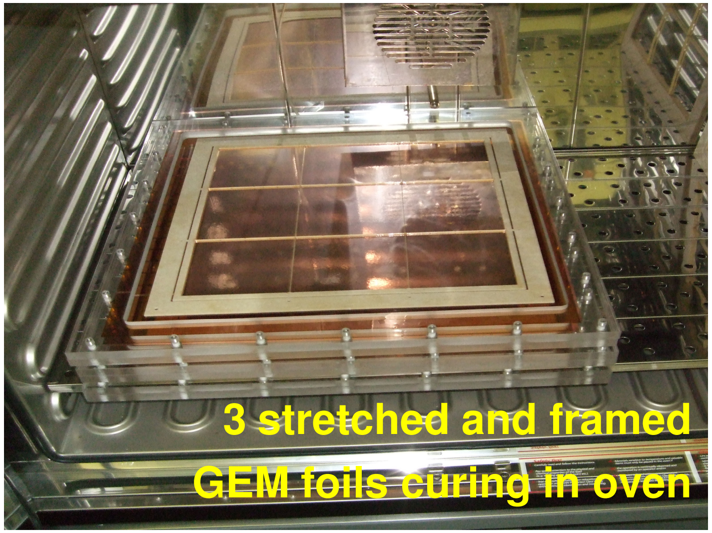
GEM Detector Production

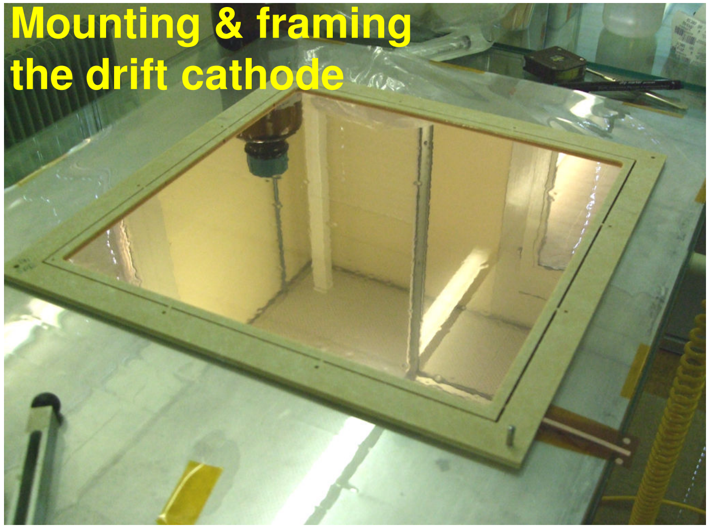
All components produced by CERN (Rui's workshop) :





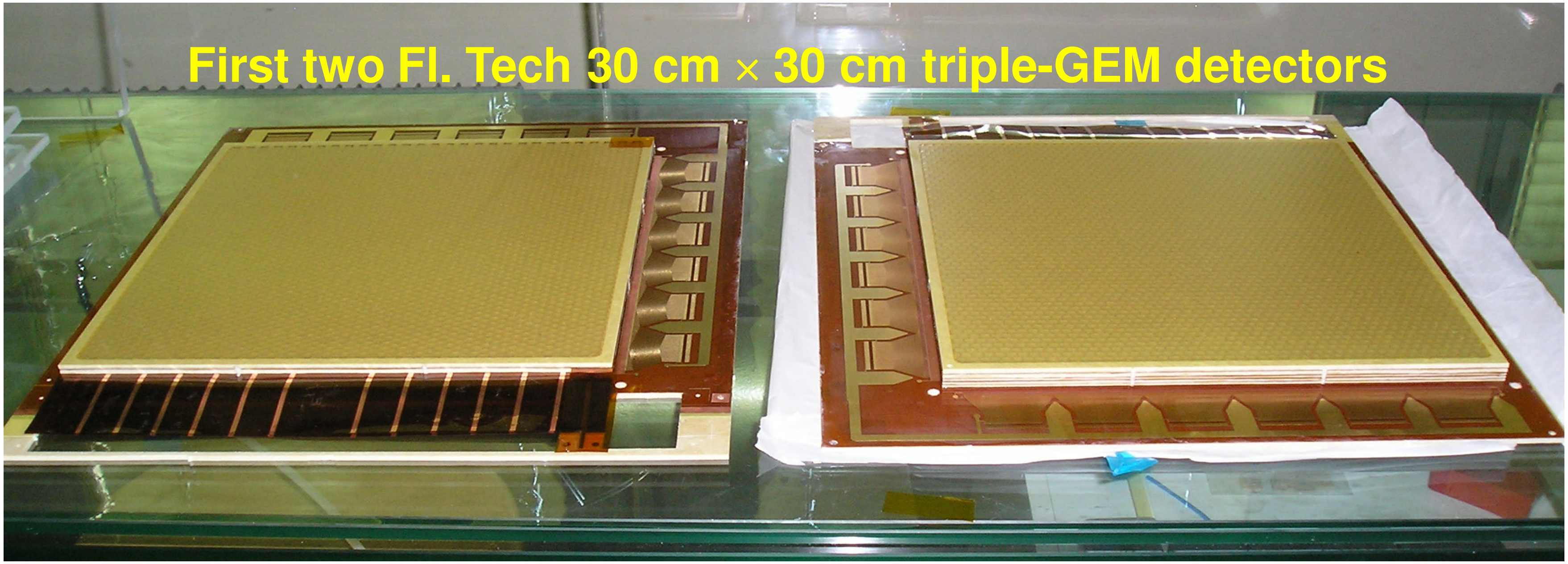
GEM Detector Assembly





CERN clean-rooms

Assembled GEM Detectors



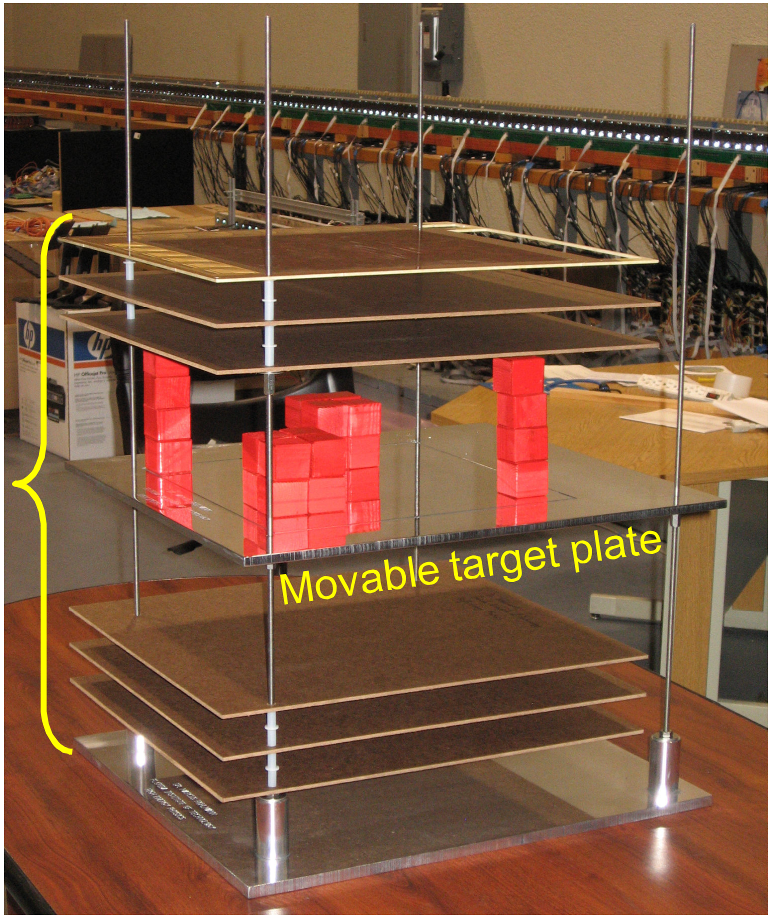
- 3 detectors assembled (still need HV board)
- 5 more to be completed at CERN late September / early October
- 2 to be assembled at Fl. Tech later ⇒ know-how transfer to home institute

Near-term Plans

Operate first small MT prototype in minimal configuration *as soon as possible*:

- start with only 2 top & 2 bottom detectors using existing GASSIPLEX front-end electronics
  - 4 GASSIPLEX cards per detector (= 4 × 96 ch. per detector) to read out central detector areas only (in both x & y)
  - 16 GASSIPLEX cards needed in total (= 4 det. × 4 cards per det. × 96 ch. per card = 1536 ch. total)
- have built a stand to accommodate 4-6 detectors in simple top & bottom configuration (L.Grasso)
- have modified CAST DAQ software (U. Athens) to accommodate 16 GASSIPLEX cards to be read out with 8 CAEN CRAMs ADC cards (K. Gnanvo); to be tested with DAQ h/w
- redesigning adaptor for Panasonic connector (on GEM detector) to SAMTEC connector (on GASSIPLEX) (K. Gnanvo)

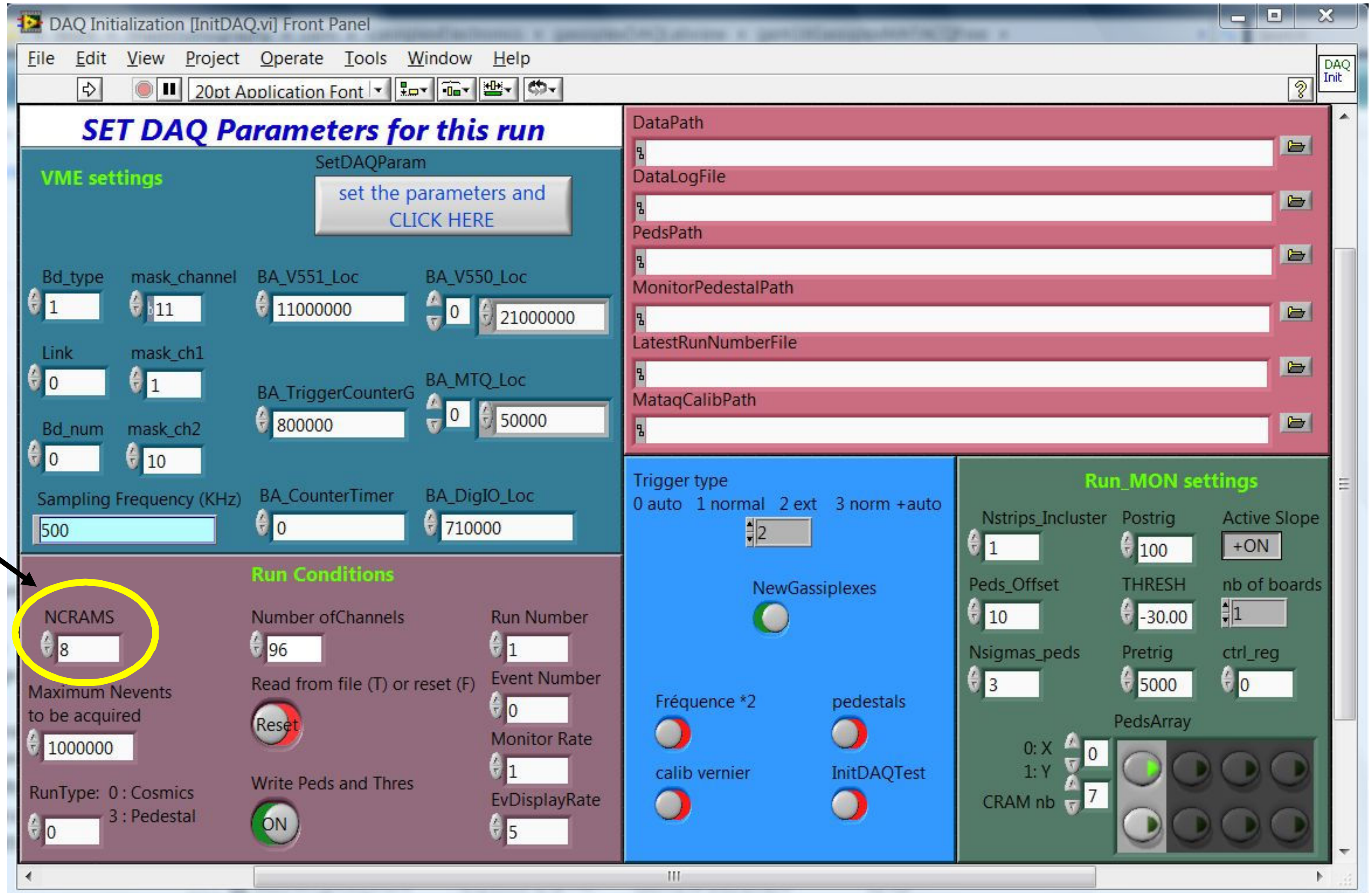
MT prototype stand with GEM mock-up



Upgraded GEM DAQ

Labview Frontpanel

- 8 CRAMS
- 16 GASSI-PLEX



Longer-term Plans

- **Medium-term: Operate first small MT prototype fully instrumented**
  - use 3 top, 3 bottom detectors, and 4 side detectors
  - adopt & test FE electronics and DAQ being developed by RD51 as soon as available (need ~15k channels)

- **Build & test increasingly large GEMs and GEM-MT prototypes**
  - Contribute to development of large-area GEM detectors (0.5 -1 m^2) within RD51
  - Build second MT prototype with ~1m^3 probed volume (= currently stated goal of the Muon Tomography project)
  - Investigate methods for reducing number of required electronic channels, e.g. charge spreading with resistive layers on readout strips; delay lines

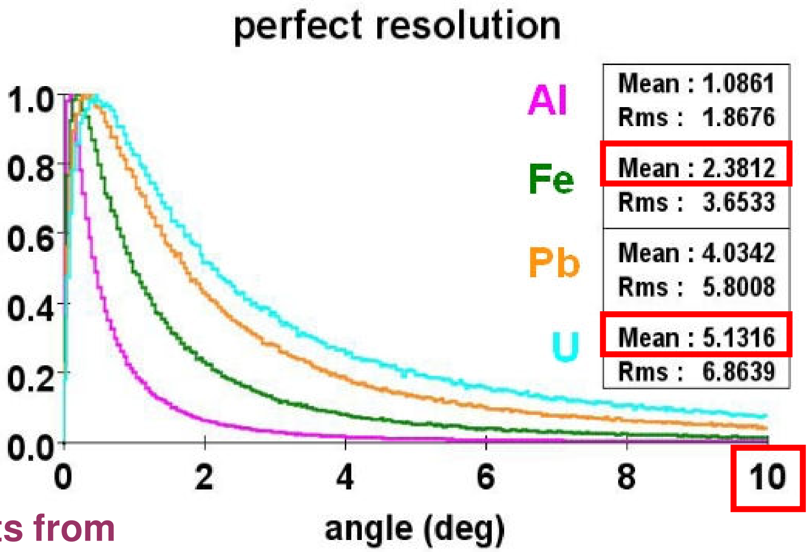
- **Interested in combining CMS & MPGD work into one project**
  - Apply know-how gained with GEM work in MT project to CMS high-η muon upgrade

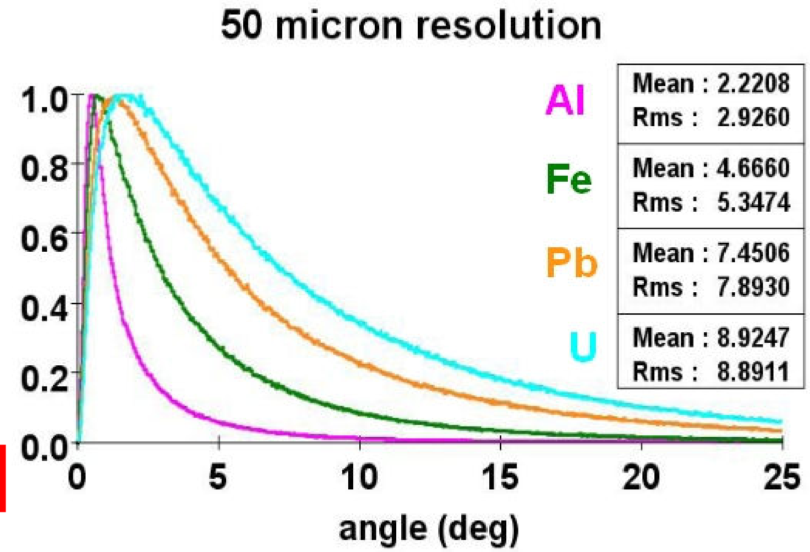
Potential contributions from Fl. Tech muon group:

- R&D on large-area GEM detectors
  - Construction techniques (stretching of large foils, alternatives !?)
  - Detector simulations (GARFIELD-style)
- MPGD Electronics issues are currently on the critical path; would be interested to help if possible
- Ten 30cm × 30cm GEM detectors could be made available for tests in CMS (with different electronics) once not needed for MT project anymore (2010?)
- Could try to approach DOE for funding through base grant or "Advanced Detector Research" program
- We are happy to discuss all possibilities within this group! Thank you…

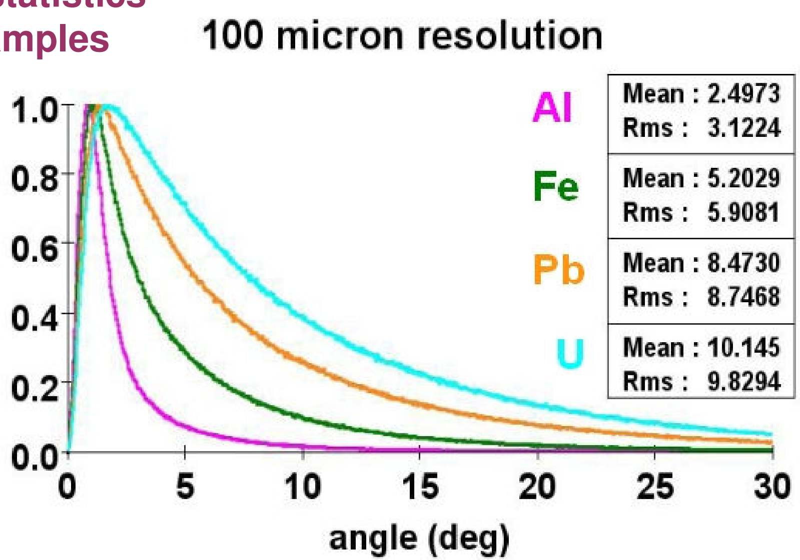
Backup Slides

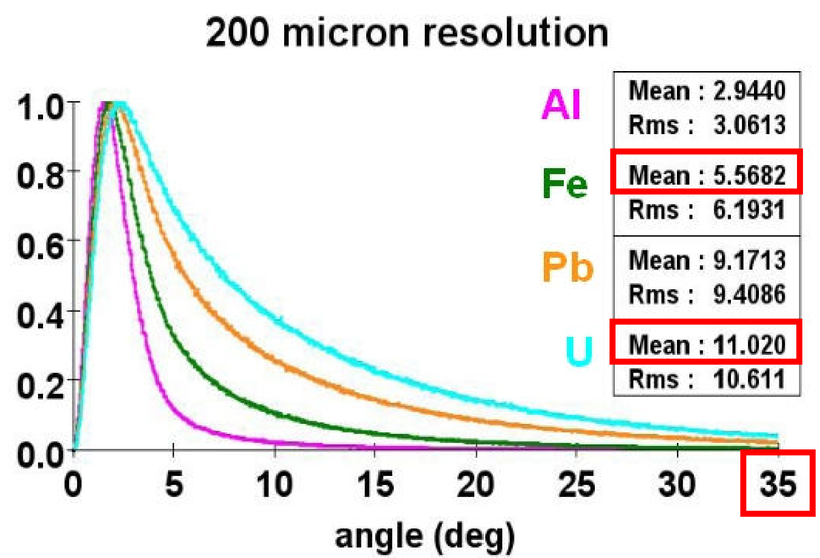
Scattering Angle Distributions





Results from high-statistics MC samples

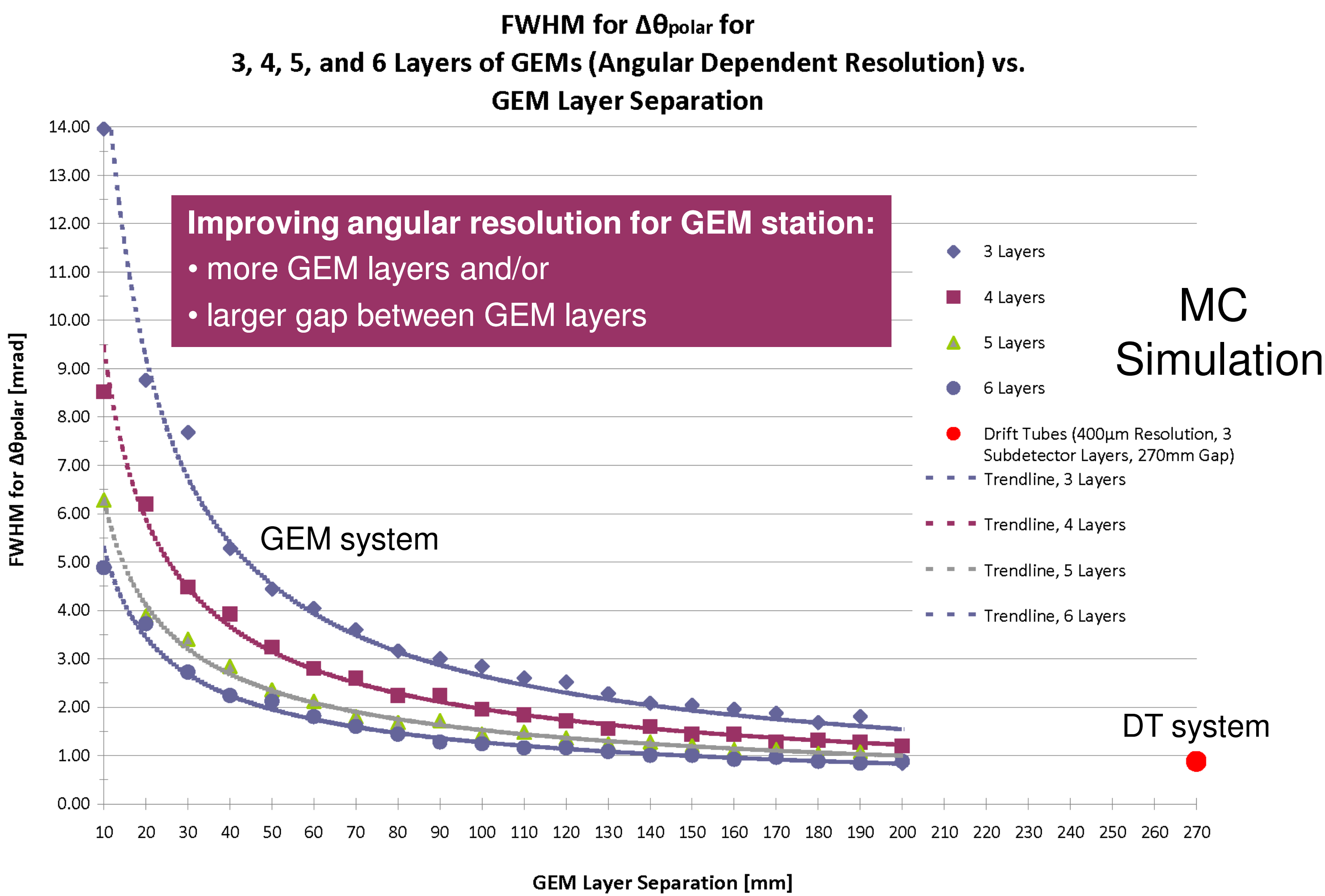




Angular Resolution III

Improving angular resolution for GEM station:

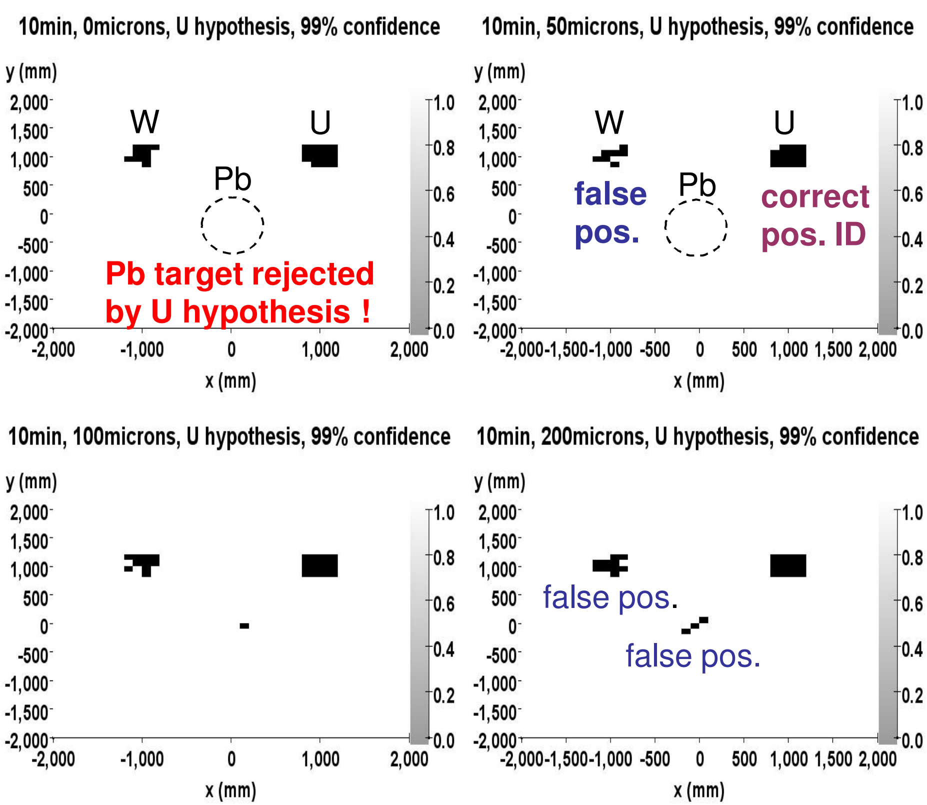
- more GEM layers and/or
- larger gap between GEM layers



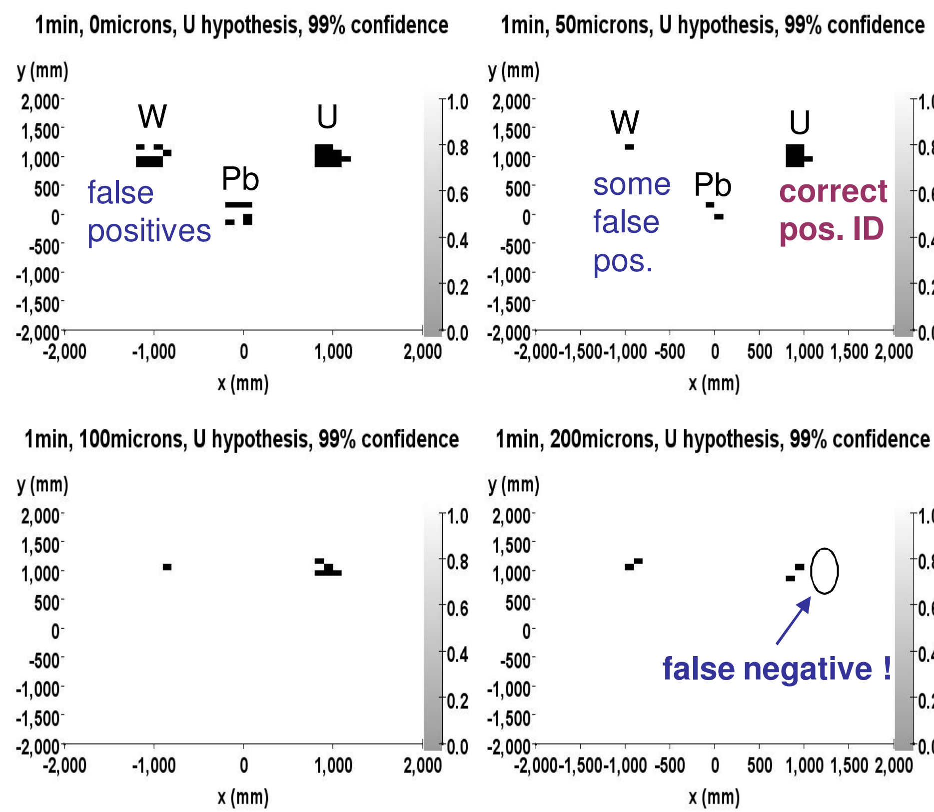
Identifying Uranium at 99% C.L.

- **Test hypothesis** that voxels with an excess over Fe actually contain U
- Flag only voxels where **mean Θ_{voxel} is within 99% confidence interval** around expected mean Θ_U for Uranium (based on high-statistics U samples)

10 min exposure



1 min exposure



Reconstruction Improvement with Momentum Information

$$\theta_{scattering} \propto \sim \mathbf{p}^{-1}$$

- Reconstruct scattering density λ of material:

$$\lambda = \frac{(\theta_{scattering})^2}{2L(1+E_p{}^2)}\left(\frac{p}{p_0}\right)^2$$

L = path length of muon within target (set to 1, a priori unknown)
E_p = momentum error (set to 0 for now)
p = momentum of cosmic ray muons
p_0 = average momentum of cosmic ray muons (3 GeV)

- Use average λ value in ith voxel as statistic:

$$<\lambda>_i = \frac{\sum_j \lambda_{ij}}{N_i}$$

λ_{ij} = λ-value for jth muon scattered in ith voxel (based on POCA)

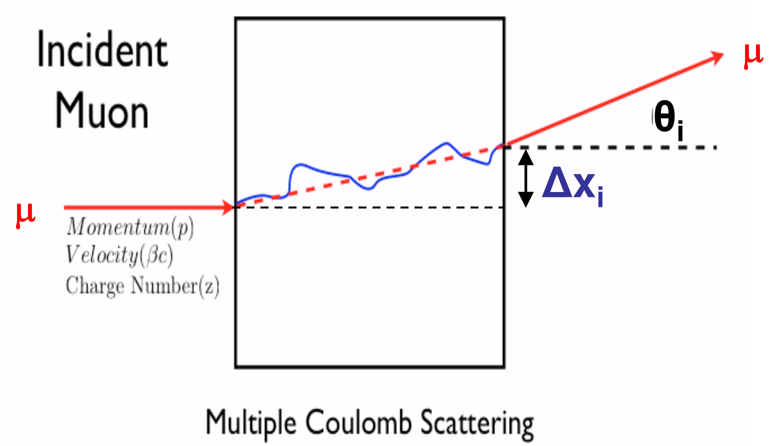
N_i = number of muons scattered in ith voxel

Caveat: As currently designed, neither detector type (DT, GEM) actually provides a momentum measurement; this would require additional instrumentation

Maximum Likelihood Method:

Reproducing Los Alamos Expectation Maximization (**EM**) algorithm

- **Input**: Use lateral shift Δx_i in multiple scattering in addition to information from scattering angle θ_i for each muon track



- **Procedure**:
  - Maximize log-likelihood for assignment of scattering densities to all voxels given all observed muon tracks
  - **Analytical derivation leads to iterative formula for incrementally updating λ_k values in each iteration**
- **Output**: Scattering density λ_i for each voxel of the probed volume