# Dimuon Measurement in CBM Experiment at FAIR

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**VECC, Kolkata**

# Outline

- Dilepton measurements
- CBM experiment at FAIR
- Schematic of dimuon measurements in different expt.
- Muon Chamber (MUCH) system of CBM
  - -- Simulation results
  - -- Detailed R&D
- Summary

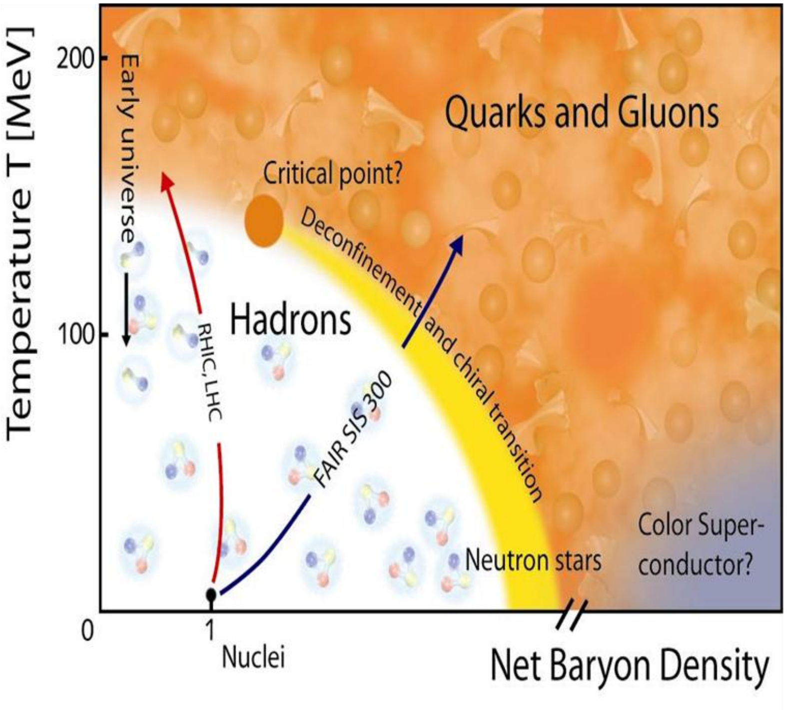
# The Compressed Baryonic Matter Experiment (CBM)@FAIR

- **Fixed target heavy ion expt.**
- **Energy range 2-45 GeV/u**
- **Expected to begin** 2021

**CBM physics program:**
- Equation-of-state at high $\rho_B$
- Deconfinement phase transition
- QCD critical endpoint
- Chiral symmetry restoration

**Diagnostic probes of the high-density phase:**
- open charm, charmonia
- low-mass vector mesons
- multistrange hyperons
- flow, fluctuations, correlations

**Exploring the QCD Phase Diagram**




Rare Probes
→ high interaction rates
→ selective triggers

# The Dileptons

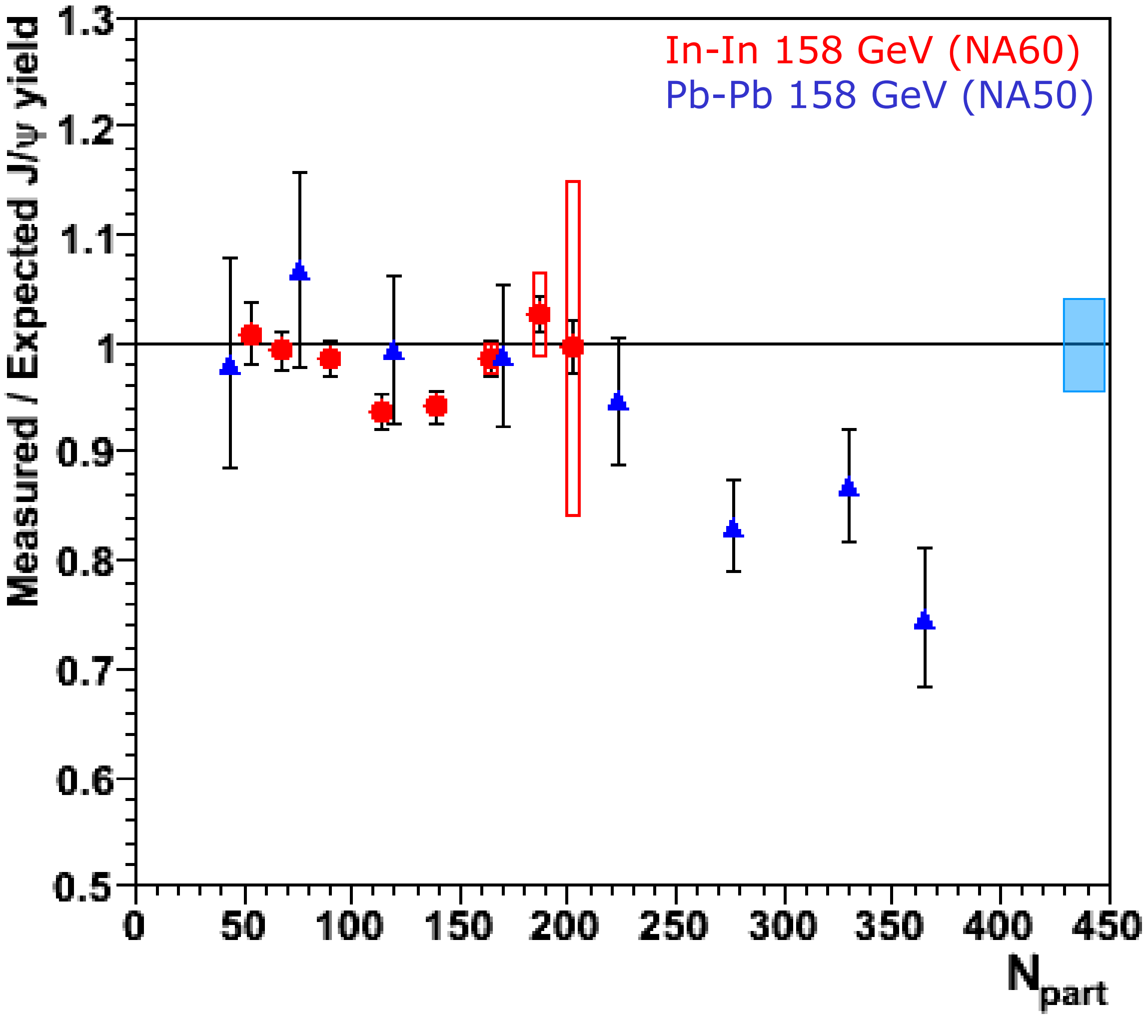
- Dilepton pairs emitted in energetic heavy-ion collisions provide valuable information on the evolution and on the properties of the hot and dense fireball.

- Comparison of charmonium yields measured in proton-nucleus and nucleus-nucleus collisions has led to the observation of an anomalous dissociation of charmonium in central collisions of heavy nuclei which was explained by color screening in the quark-gluon phase.

- Till today, this observation still has remained one of the most convincing experimental facts hinting towards the existence of partonic degrees of freedom in the fireball at top SPS energies.

- The dilepton measurements at the CERN-SPS have been performed mainly at 158 A GeV, except for one spectrum taken in Pb+ Au at 40 A GeV by the CERES collaboration where even an increased excess yield has been observed

# Anomalous suppression




Using the previously defined reference:

Central Pb-Pb:
→ still anomalously suppressed

In-In:
almost no anomalous suppression


B. Alessandro et al., EPJC39 (2005) 335
R. Arnaldi et al., Nucl. Phys. A830 (2009) 345
R.Arnaldi, P. Cortese, E. Scomparin Phys. Rev. C 81 (2009), 014903

- A systematic beam energy scan in order to search for the onset of in-medium mass modifications of vector mesons or for partonic contributions to the dilepton yield has not been performed yet.

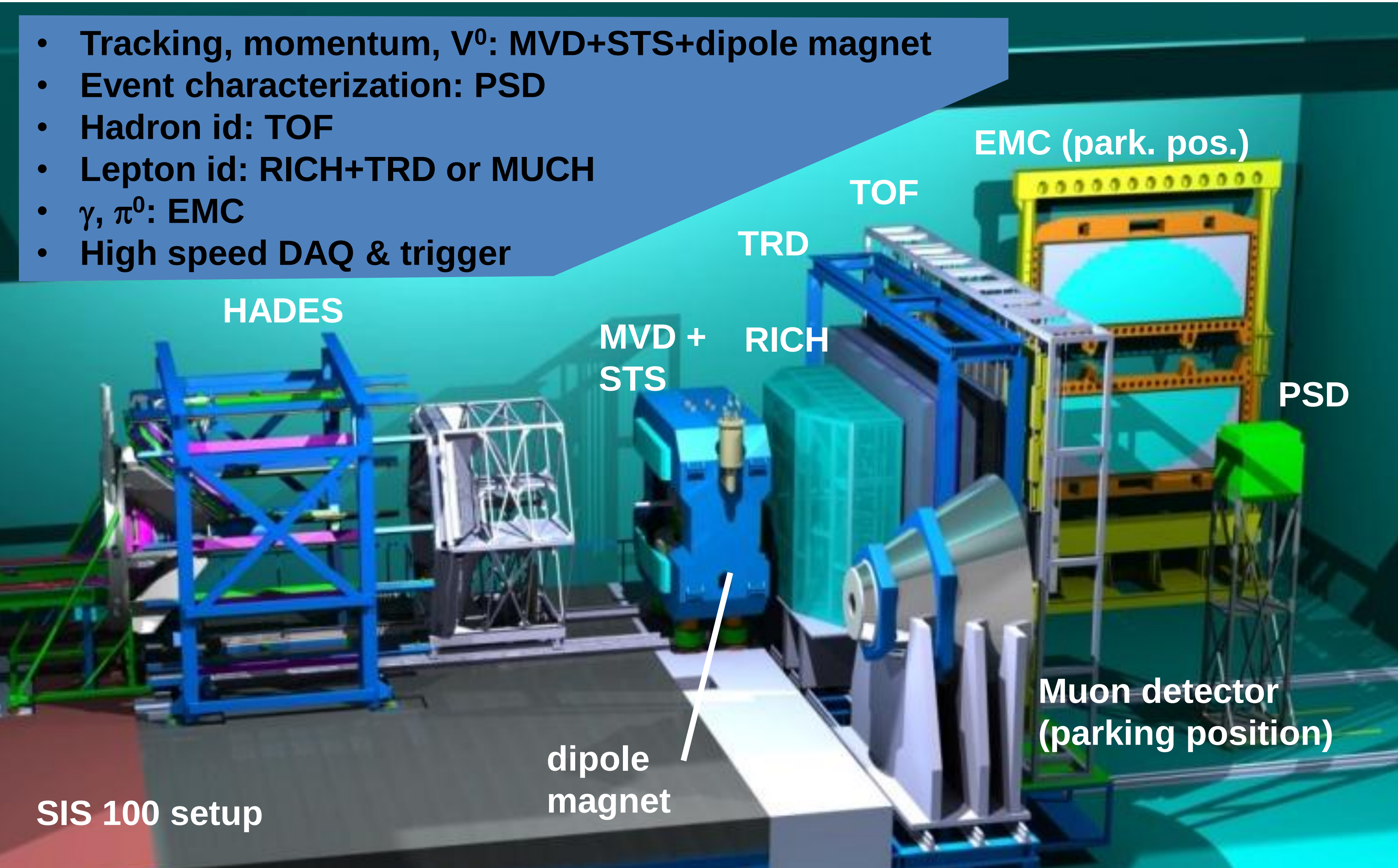
- **With the dilepton measurements in heavy-ion collisions at FAIR energies the CBM collaboration will open a new era of dilepton experiments in the energy range between 2 and 40 A GeV where the highest net- baryon densities can be created in the laboratory,**

- **no dileptons have been measured in heavy ion collisions at these energies.**
-
- The CBM collaboration will systematically measure both dielectrons and dimuons in p+p, p+A and A+A collisions as function of beam energy and size of the collision system.

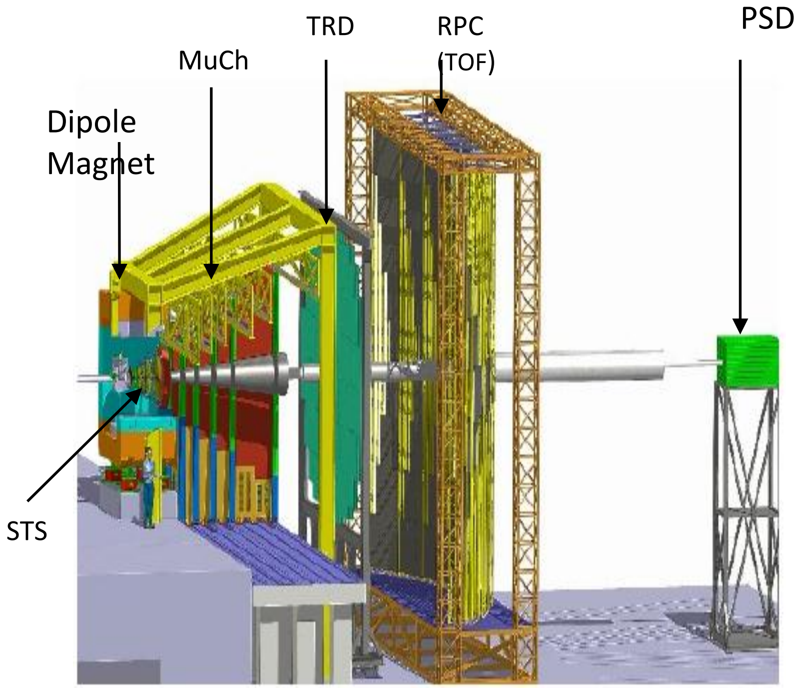
- **The dielectron and dimuon high-precision data will complement each other, and will provide a complete picture on dilepton radiation off dense baryonic matter. Also gamma conversion contamination is largely suppressed in case of dimuons.**
-

# The CBM experiment

- Tracking, momentum, $V^0$: MVD+STS+dipole magnet
- Event characterization: PSD
- Hadron id: TOF
- Lepton id: RICH+TRD or MUCH
- $\gamma$, $\pi^0$: EMC
- High speed DAQ & trigger

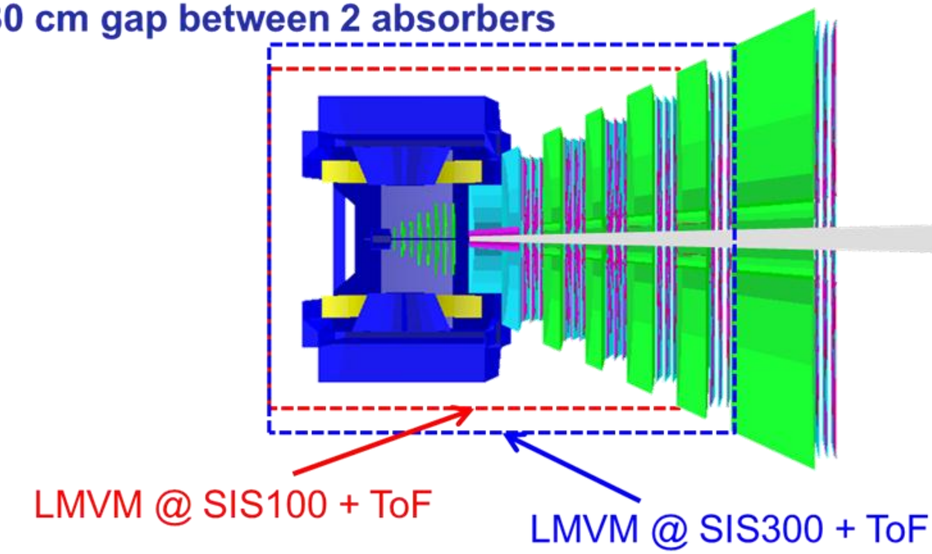


# CBM Experiment @ FAIR




## Muon Chamber (MUCH) system

60 (C) + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
30 cm gap between 2 absorbers



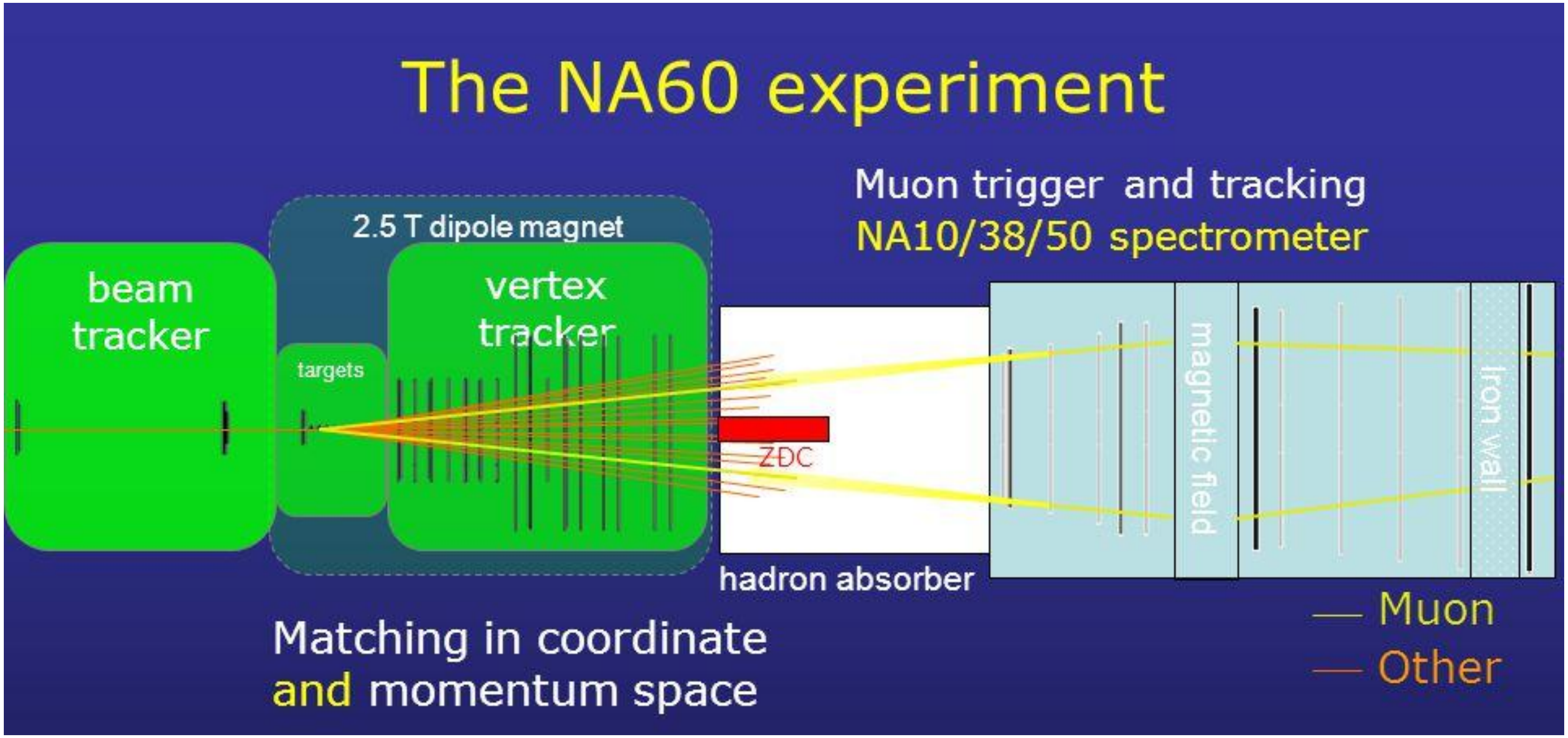

(13.5 $\lambda_I$)

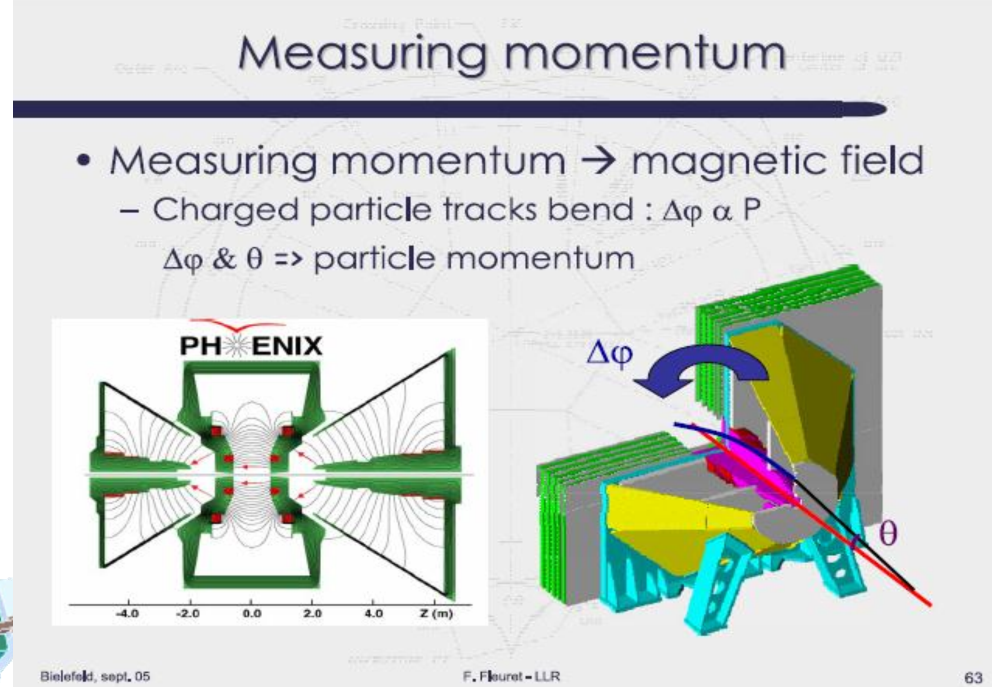
**Aim: to detect dimuon signals from low mass vector mesons and J/ψ**

Novel subsystem of segmented absorbers
-- design goal being to simultaneously identify low and high momentum muons over full phase space

SIS100 : 2-4 GeV/u → 4 chambers + 4 absorbers
SIS300 : upto 45 GeV/u →5 det.stations + 6 absorbers

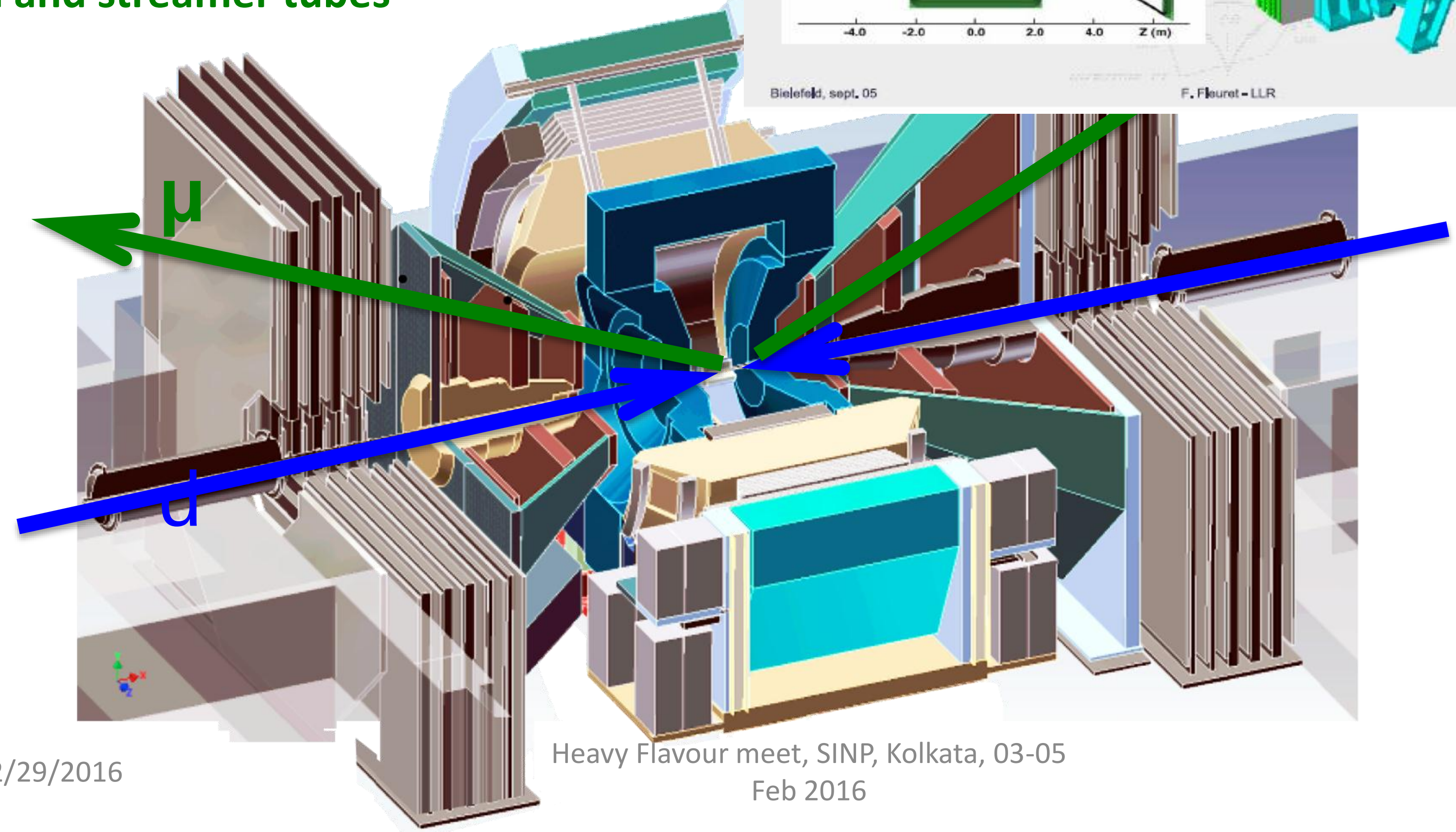
## What is the typical configuration for dimuon detection in particle physics ?


The NA60 experiment
Muon trigger and tracking
NA10/38/50 spectrometer
2.5 T dipole magnet
beam tracker
vertex tracker
targets
ZDC
magnetic field
iron wall
hadron absorber
Matching in coordinate and momentum space
Muon
Other




**Semi-leptonic decays of HF hadrons:**

Muons: 1.2 < |y| < 2.2
~10λ hadron absorbers
-Tracked with wire chambers
-Further muon ID with layers of steel and streamer tubes

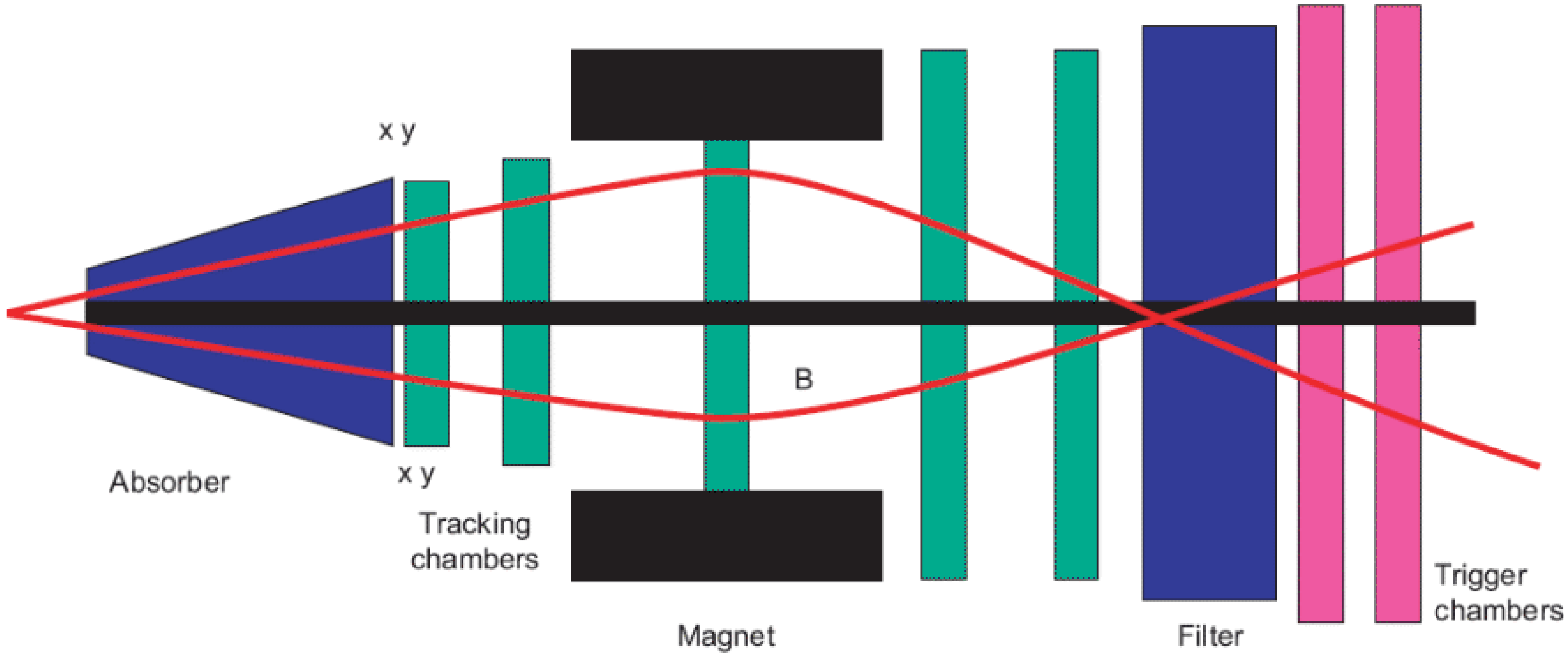


# ALICE Detector

**(Muon Arm)**

# ALICE MUON ARM

The ALICE forward muon spectrometer will study the complete spectrum of heavy quarkonia (J/Ψ, Ψ′, ϒ, ϒ′, ϒ′′) via their decay in the μ+μ– channel.



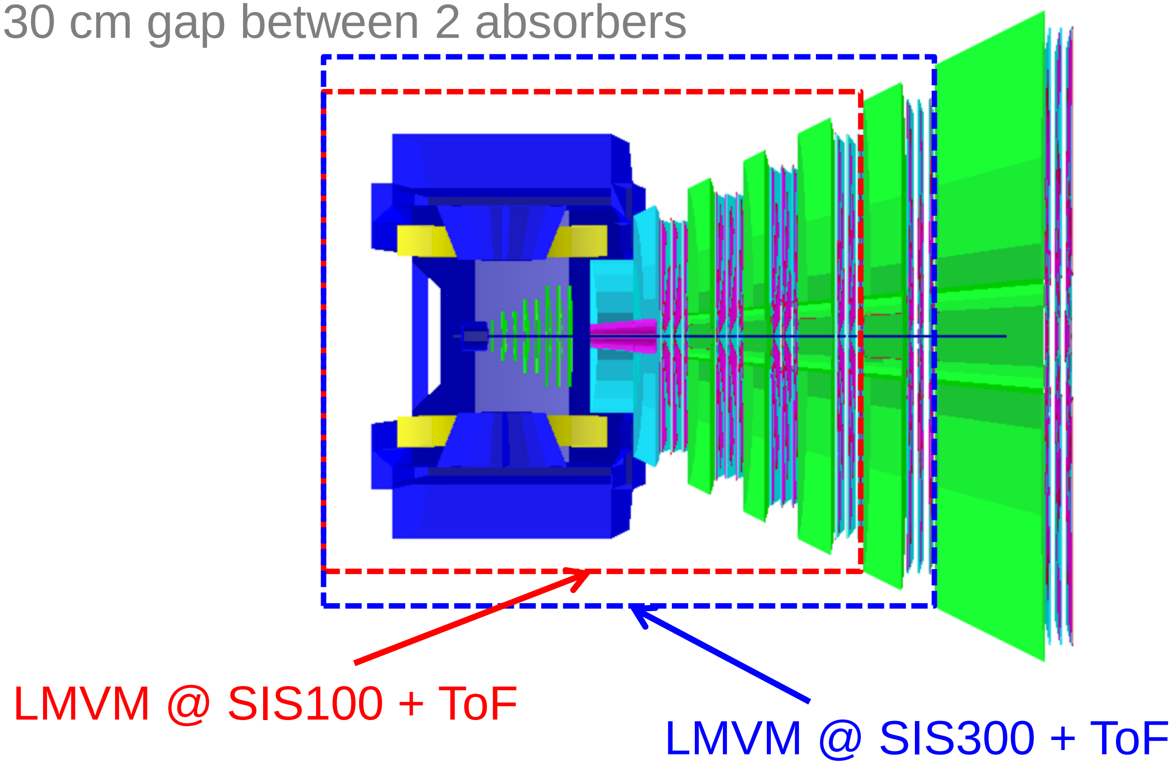

The optimized design provides
--- a good shielding capability and
--- a limited multiple scattering (…mass resolution).
→ Using low-Z material in the absorber layers close to the vertex, and a high-Z shielding materials at the other end. => Pb + Boronated polyethylene & Pb + tungsten

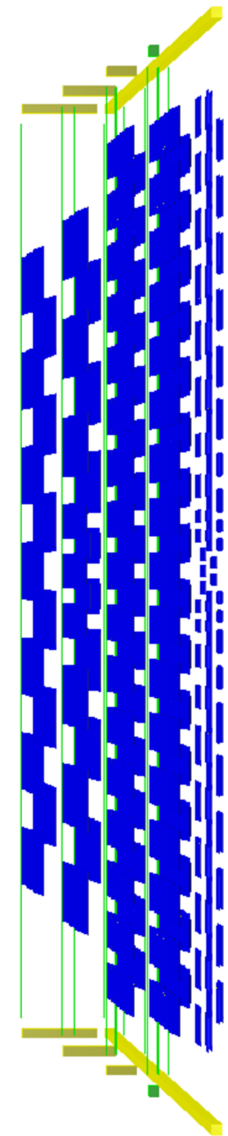
# Muon detection system: MUCH

- ID after hadron absorber with intermediate tracking layers
- **major combinatorical background from $\pi$,K decays into $\mu\nu$, punch through of hadrons and track mismatches**

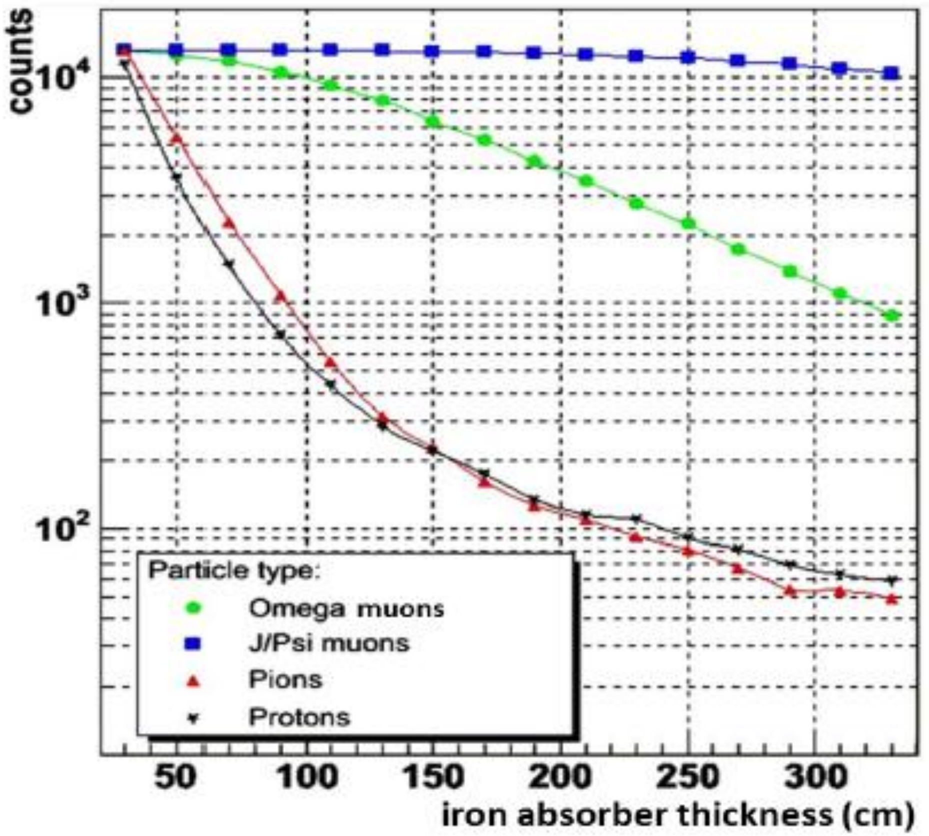
$\rightarrow$ use excellent tracking to reject $\pi$,K decays in the STS

60 C + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
30 cm gap between 2 absorbers



# Optimizing Absorber thicknesses

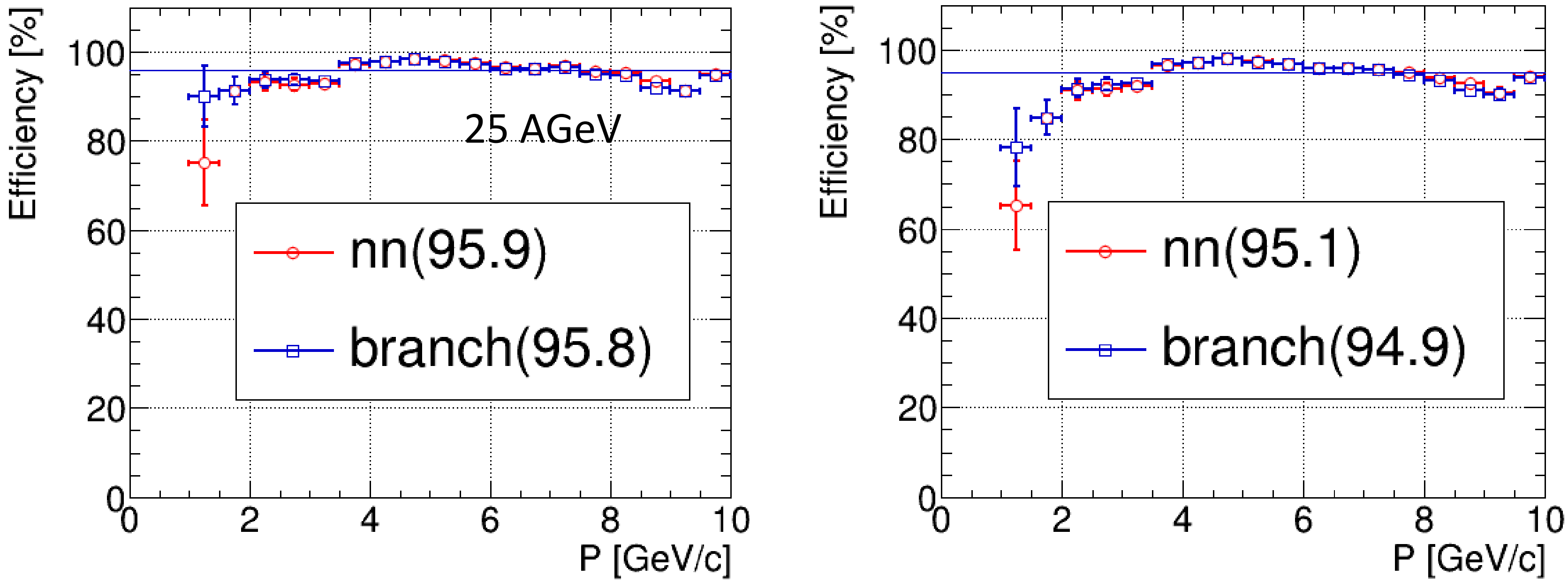



## Inputs for Detector Optimization

**URQMD background :**
**central Au+Au @8, 10 and 25 AGeV**
**p+Au @ 30 GeV**

**Pluto : signal distributions**
**LMVM @ 8 and 25 AGeV**
**J/ψ @10 AGeV and 30 GeV**

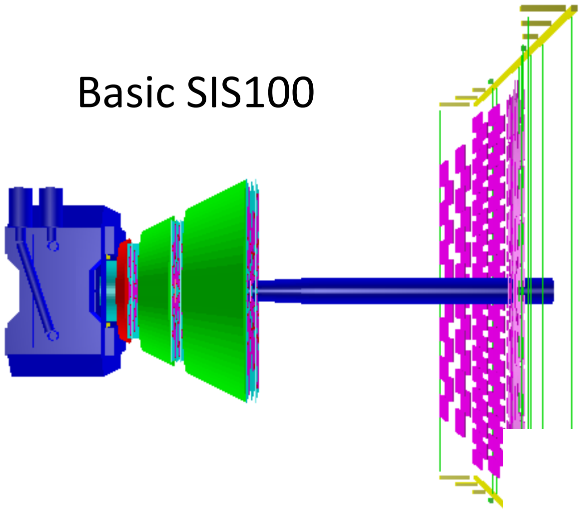
Total number of particles as a function of the traversed length in iron. The particle momenta have been taken from the simulation of central Au+Au collisions at 25 A GeV, their numbers have been normalized.



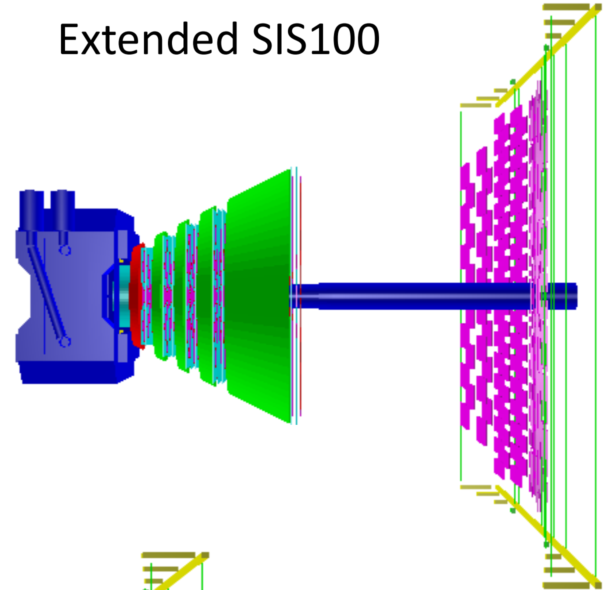

**Track reconstruction efficiency for primary muon tracks from J/psi  as a function of momentum for two tracking algorithms: nearest neighbor (red) and branching (blue). Left plot shows MUCH tracking efficiency, right plot shows STS-MUCH tracking efficiency. Horizontal lines represent numbers integrated over momentum.**

# 3 layout options for SIS100 and SIS300

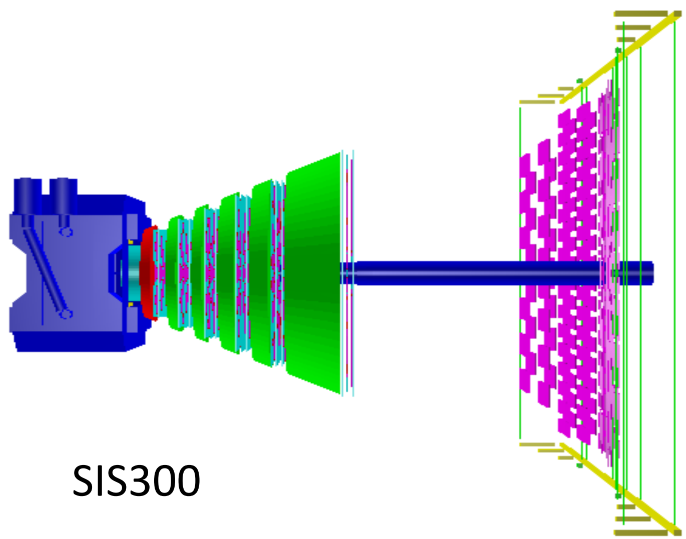
Basic SIS100



Extended SIS100

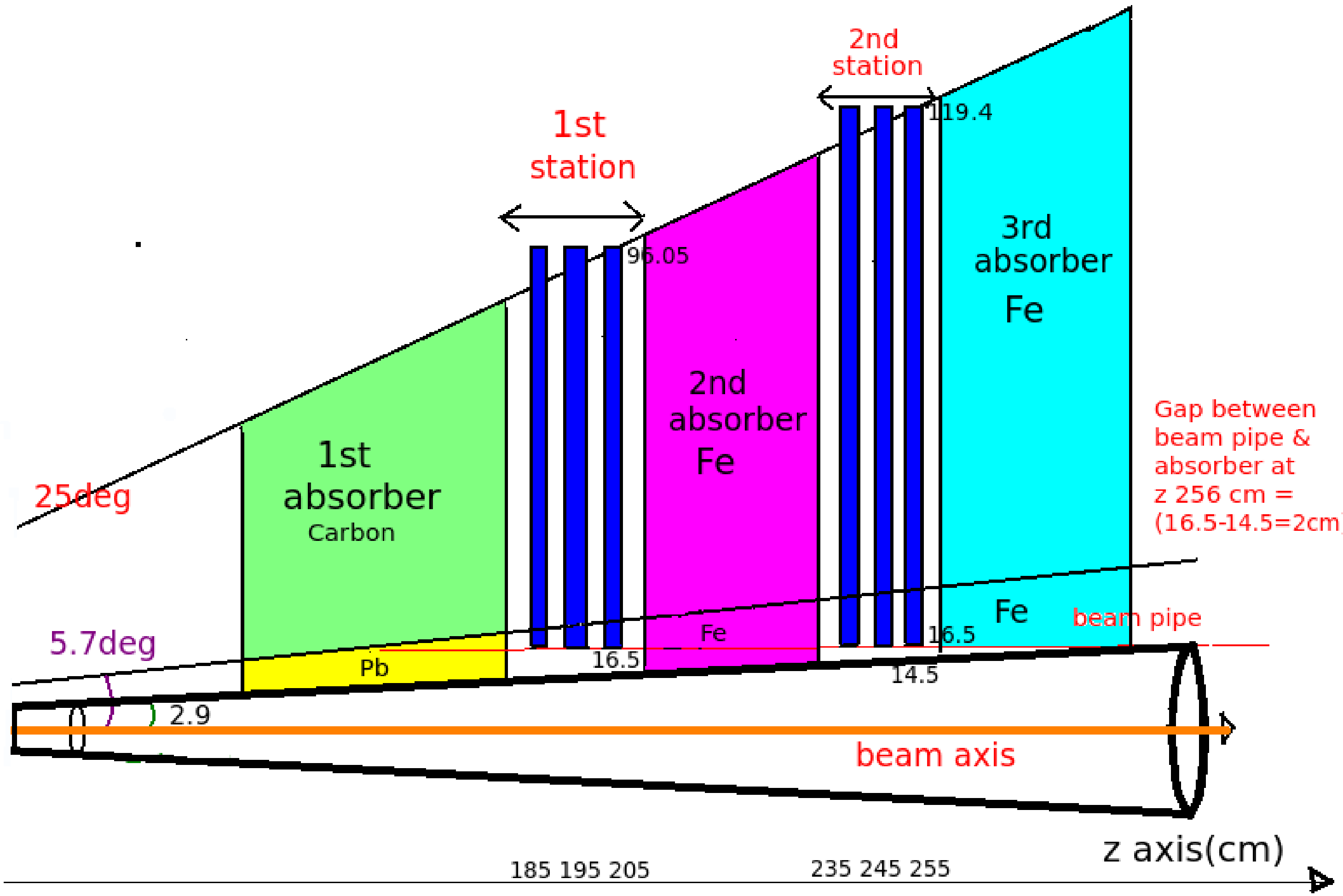


**Lengths:**
**6.4m (SIS100)**
**7.3m (SIS300)**



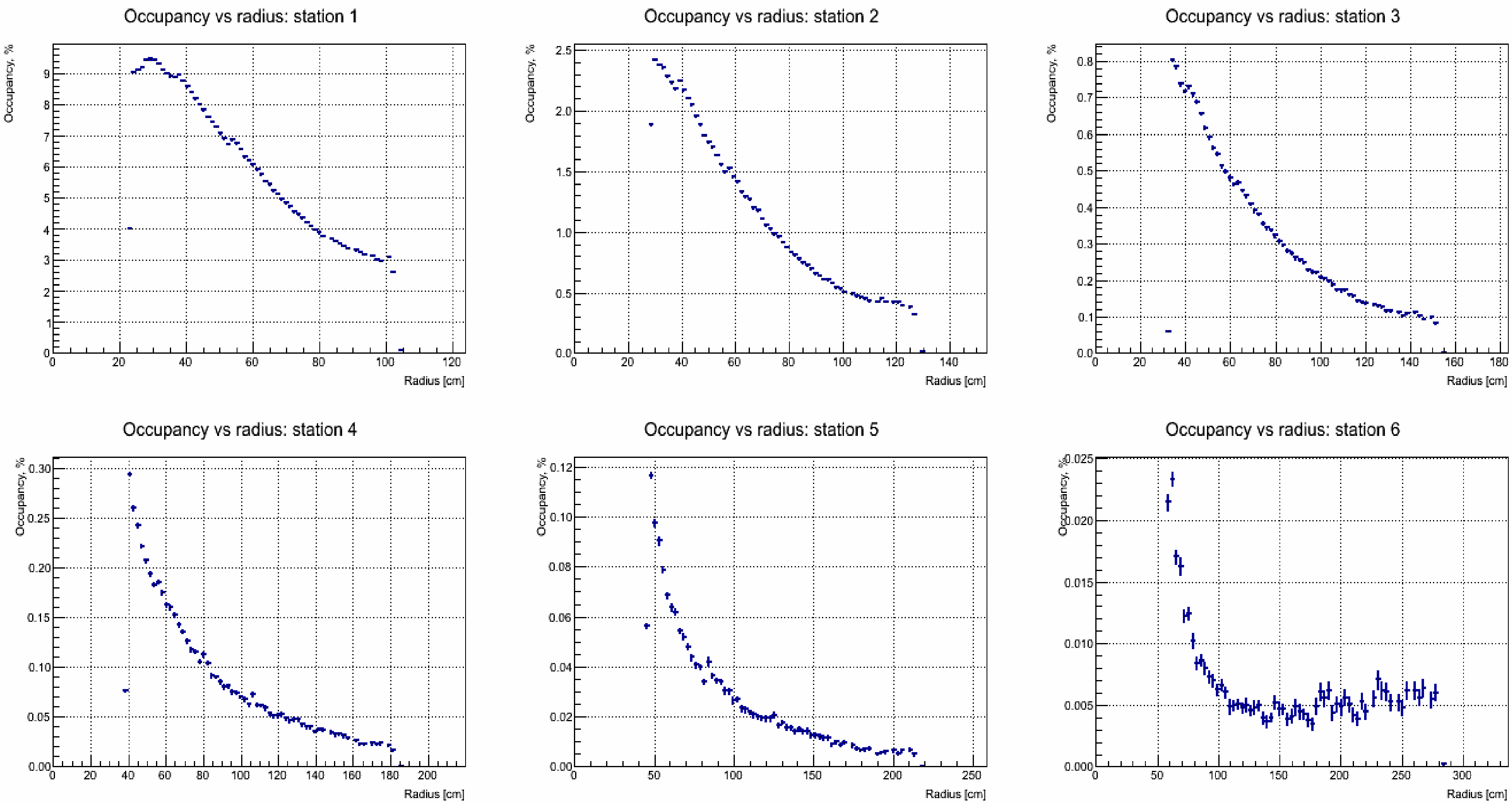
TOF wall

SIS300



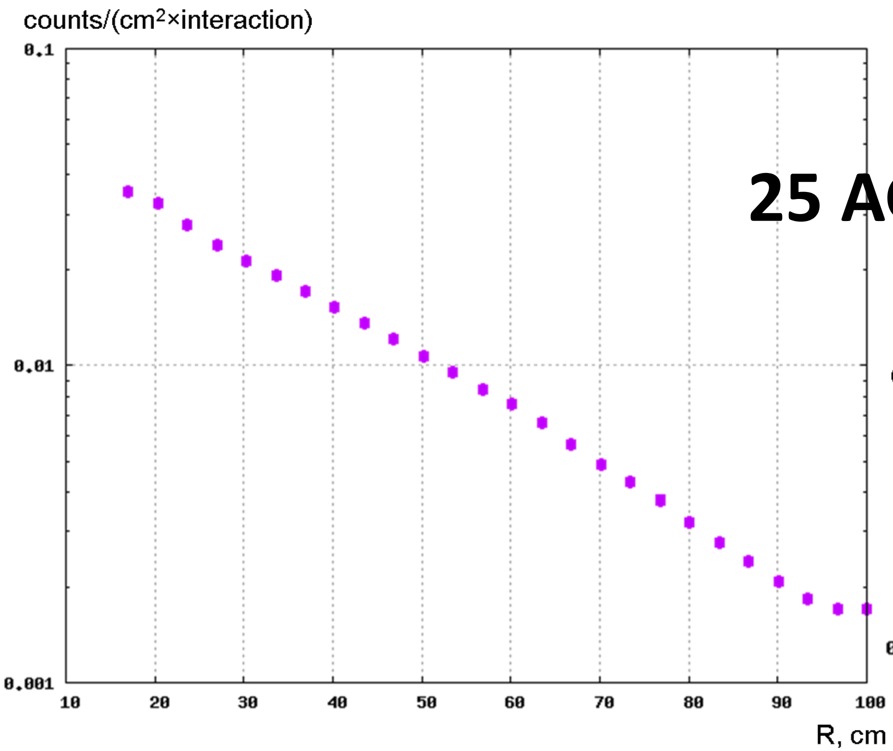

**Ekata Nandy, VECC**

# Occupancy (25 AGeV central collisions)




***Geant3 + segmentation + GEM profile implemented***

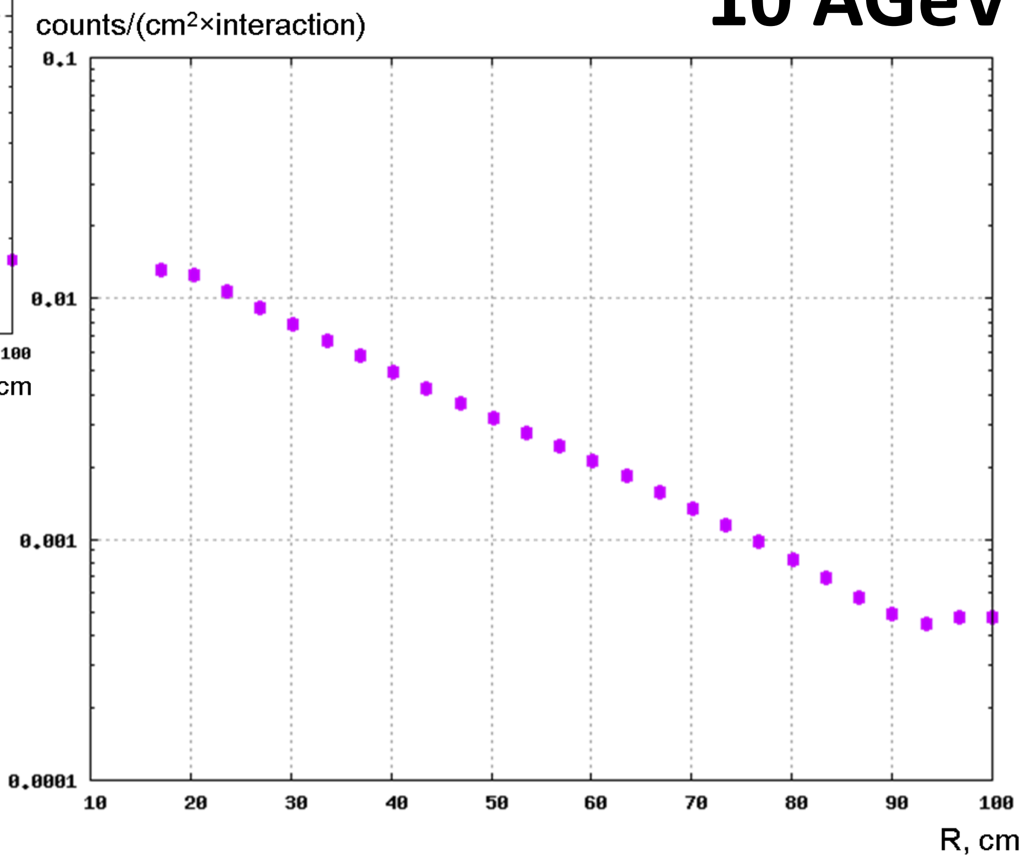
# Hit density on 1st station (Carbon as first absorber)




400 KHz/cm^2

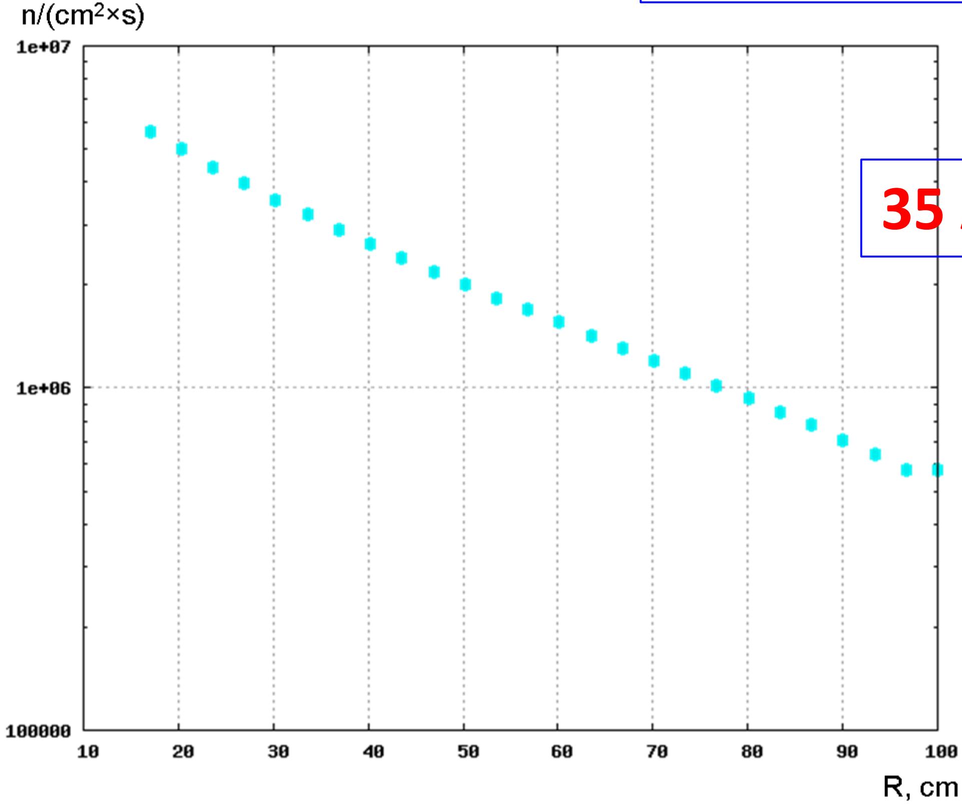
**25 AGeV**

**10 AGeV**



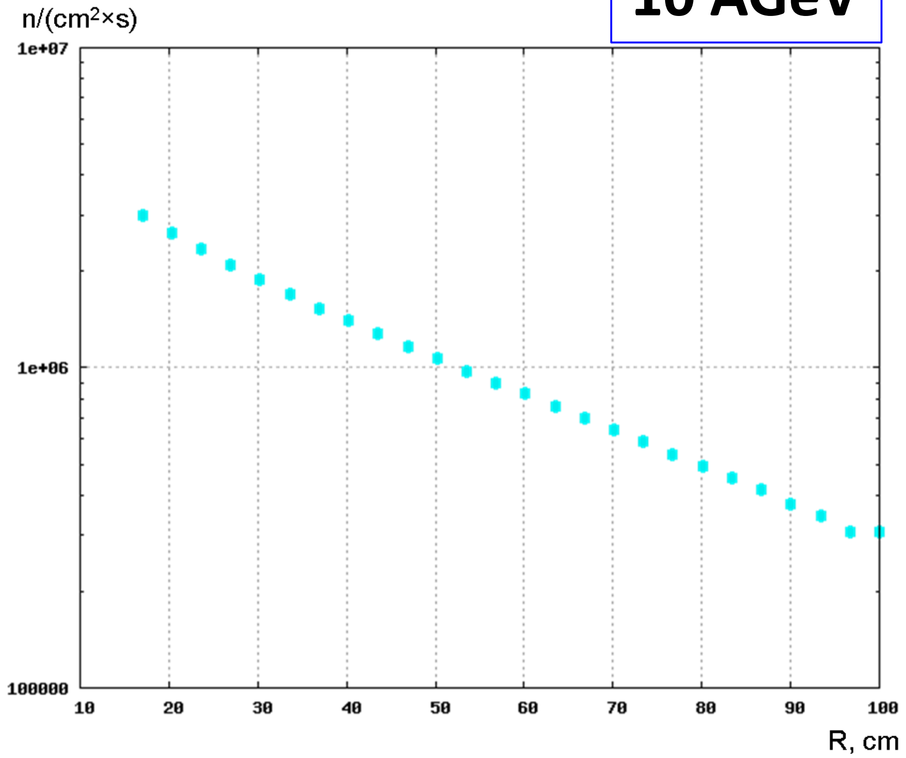

FLUKA calculations (min-bias collisions)

# Neutron Flux on 1st station




**35 AGeV**

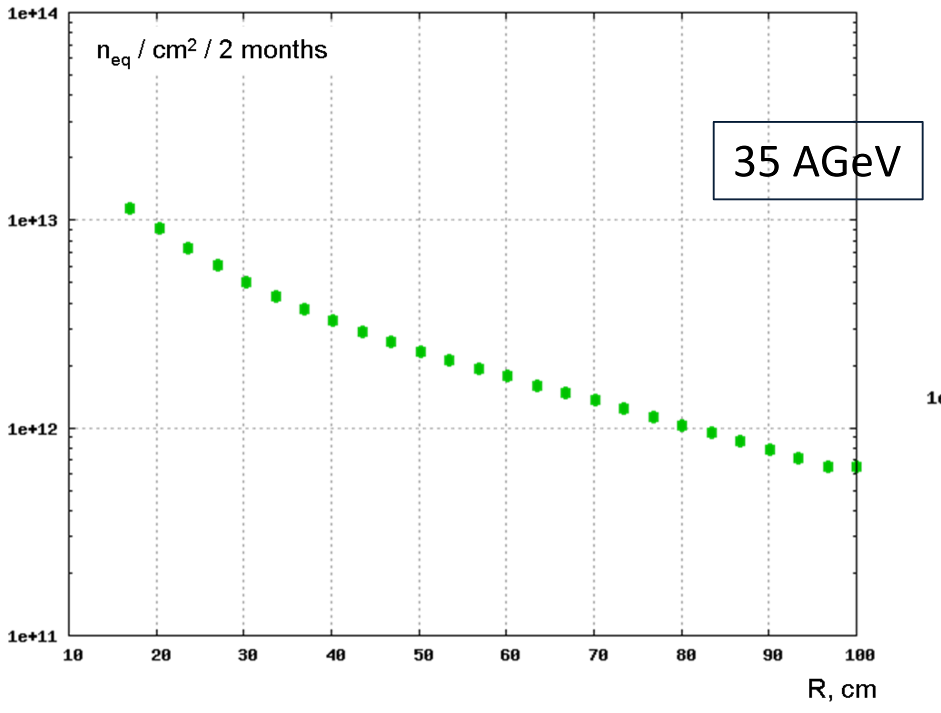
**10 AGeV**

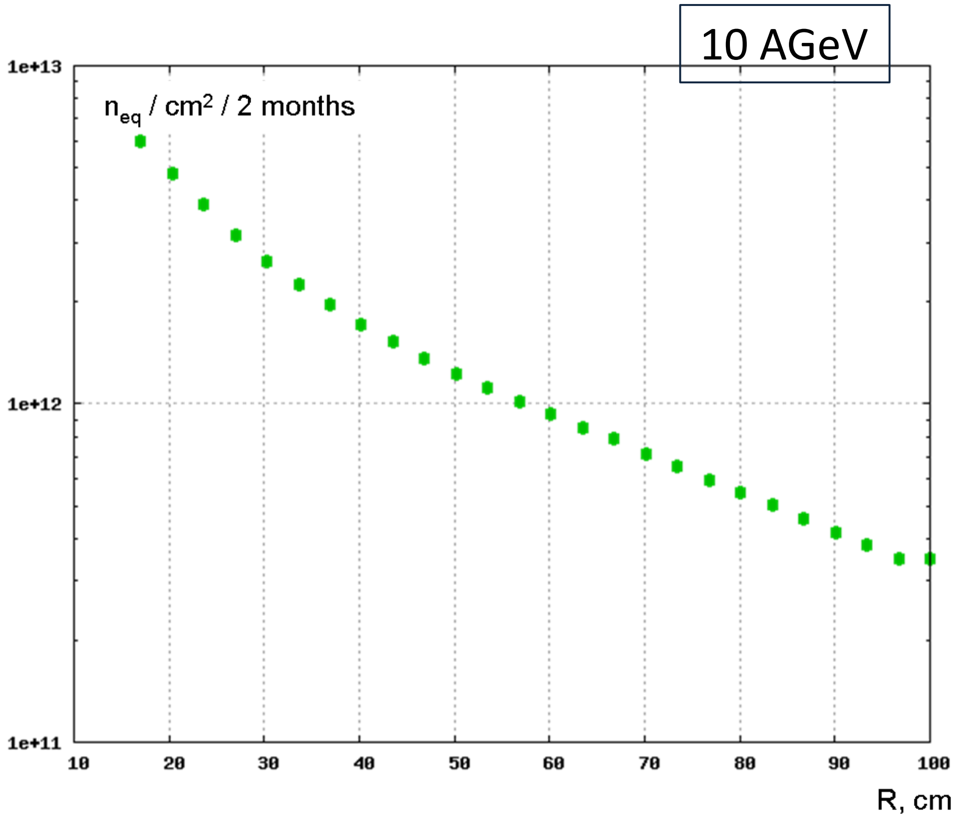



*FLUKA calculations*

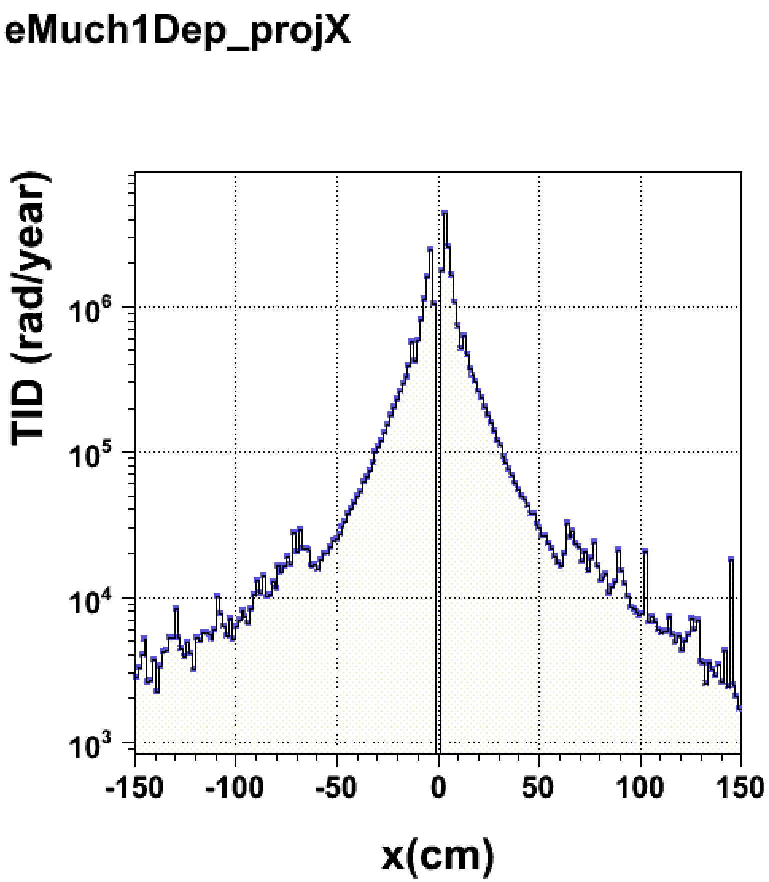
A. Senger, GSI

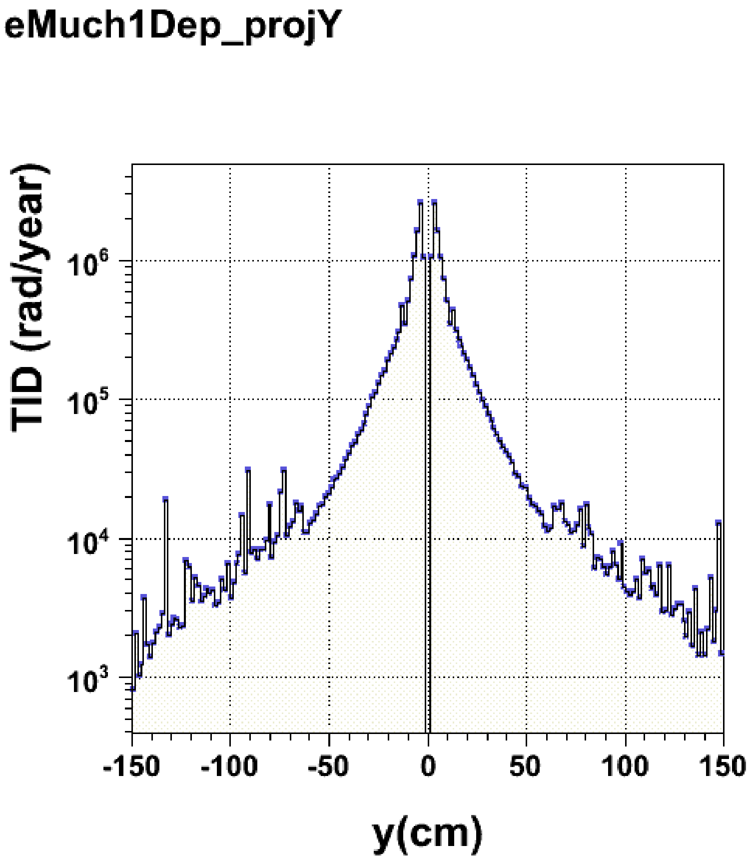
# Neutron-equivalent dose



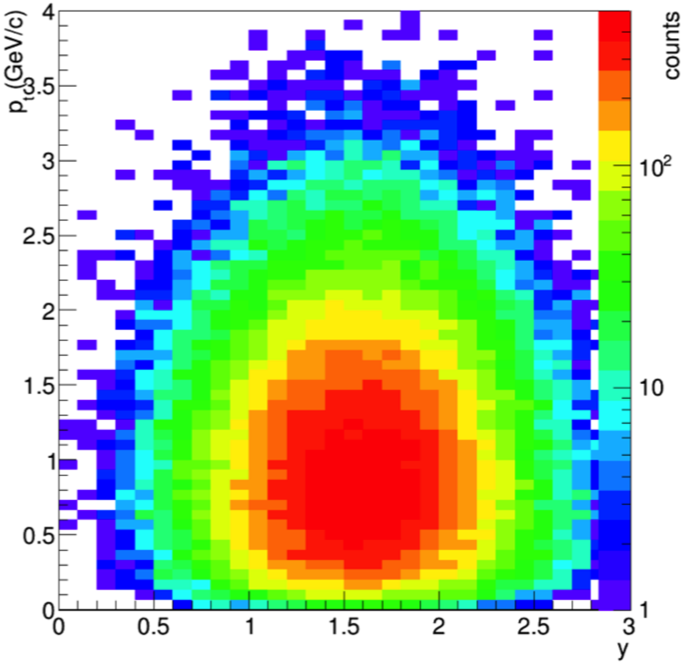
**TID: Total Ionizing Dose at the outer edge of the detector is around 10krad**

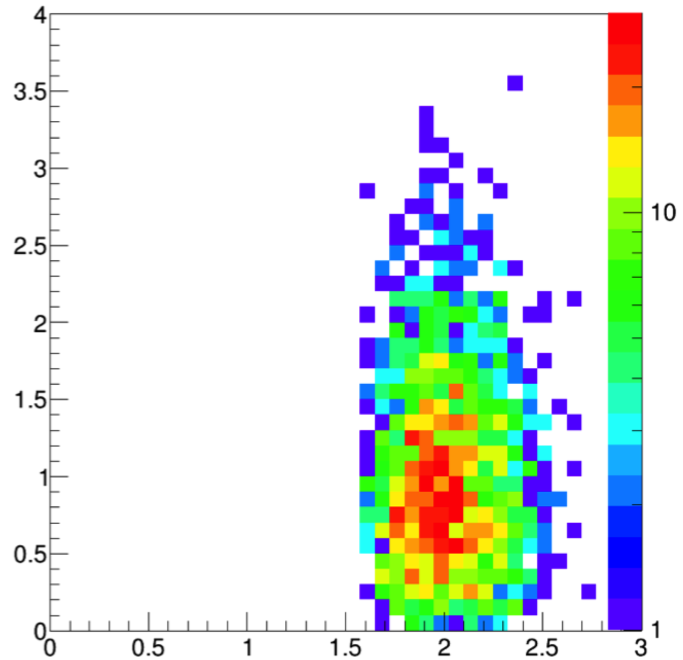



Ref : http://cbm-wiki.gsi.de/cgi-bin/viewauth/Radiationstudies/WebHome?CGISESSID=2bce338388a71f099de8d3ca43e0f2b7

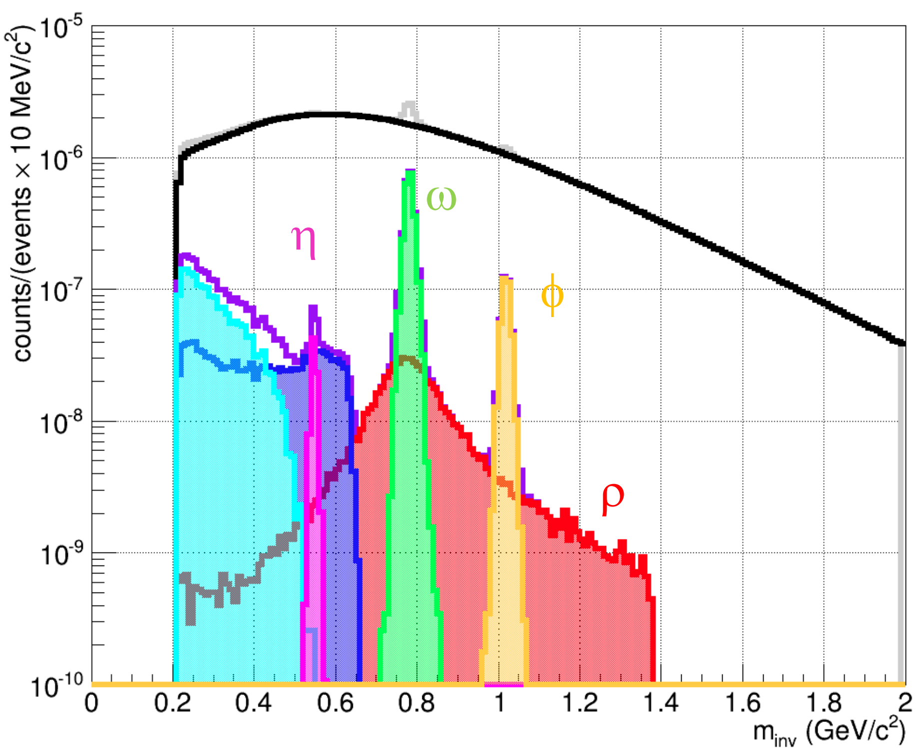
## Acceptance plots for J/psi mesons simulated for Au + Au collisions at 10 A GeV for the PLUTO input (left) and after reconstruction (right).

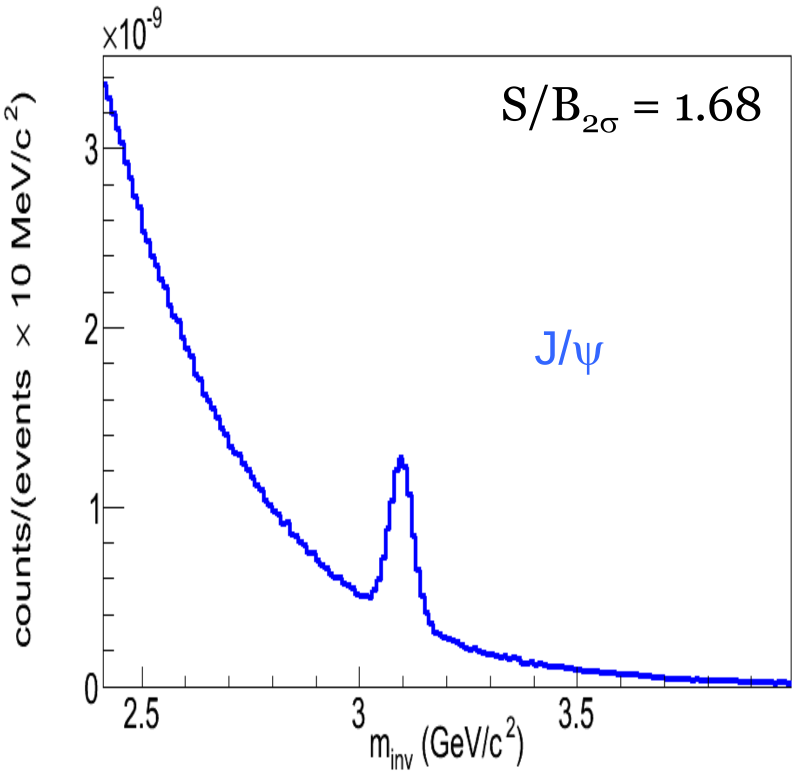


# Invariant mass spectra – muons

- Shown: central (b=0fm) Au+Au collisions at 25 AGeV
- Mass resolution: 12 MeV (ω) and 29 MeV (J/ψ) only due to momentum determination in STS
- LMVM spectra for SIS100 show similar quality
- J/ψ in central pAu at 30GeV with superb S/B ratio



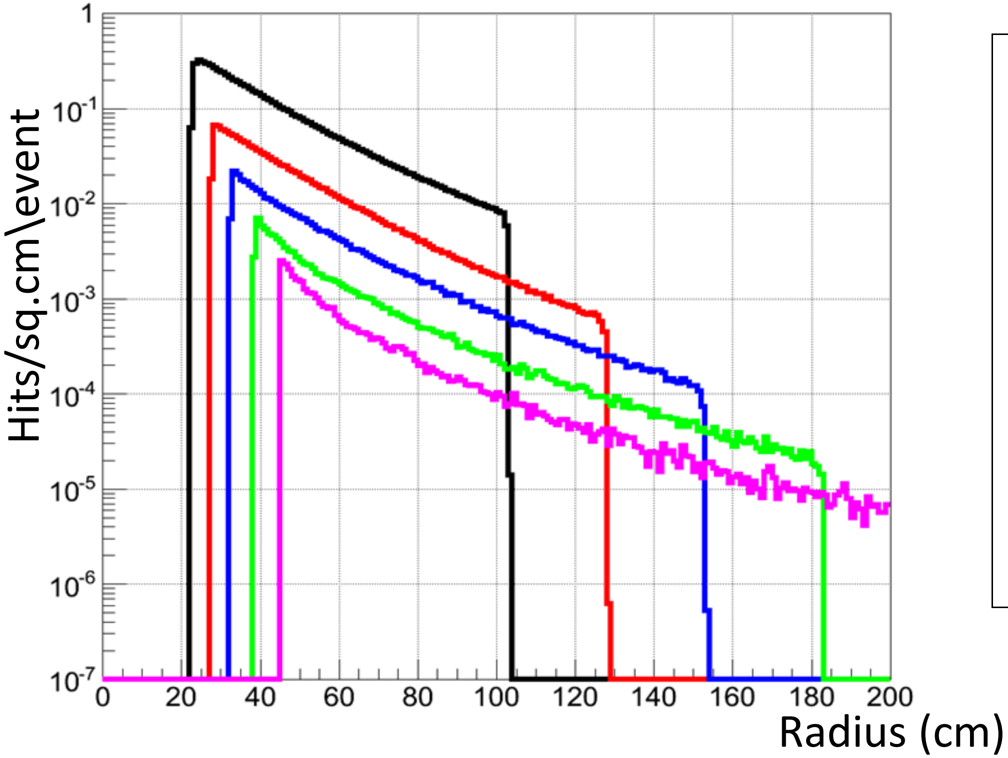



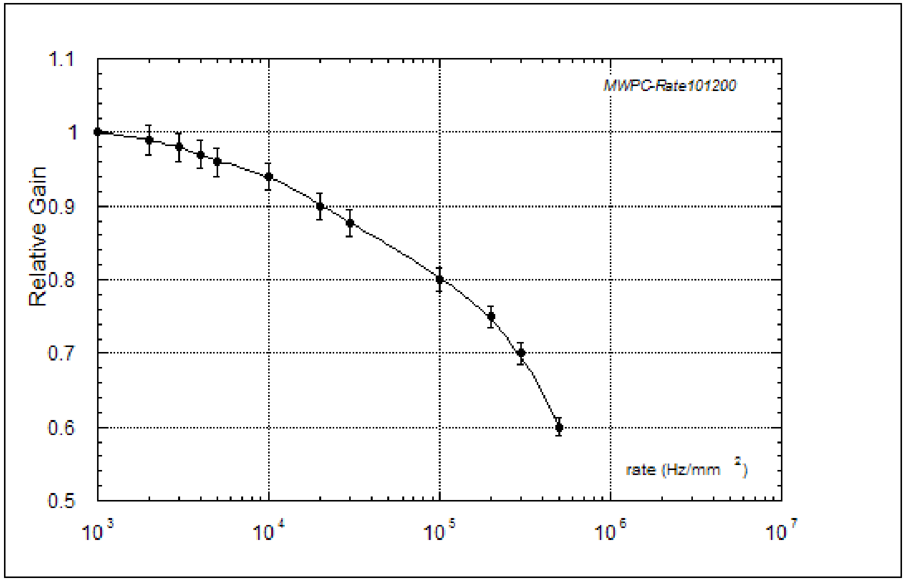
# Challenges in Muon detection

## Main issues:

- High collision rates ~ 10 MHz
- The first plane(s) have a high density of tracks
  High granularity ~ average hit rate is about 0.4 hit/$cm^2$
- Should be radiation resistant –
  high neutron dose → ~$10^{13}$ n.eq./sq.cm/year
- Large area detector – with modular arrangement
- Data to be readout in a self triggered mode
  -- a must for all CBM detectors.
  -- and event reconstructed offline by grouping the timestamps of the detector hits.

# Particle Density at Different MUCH stations



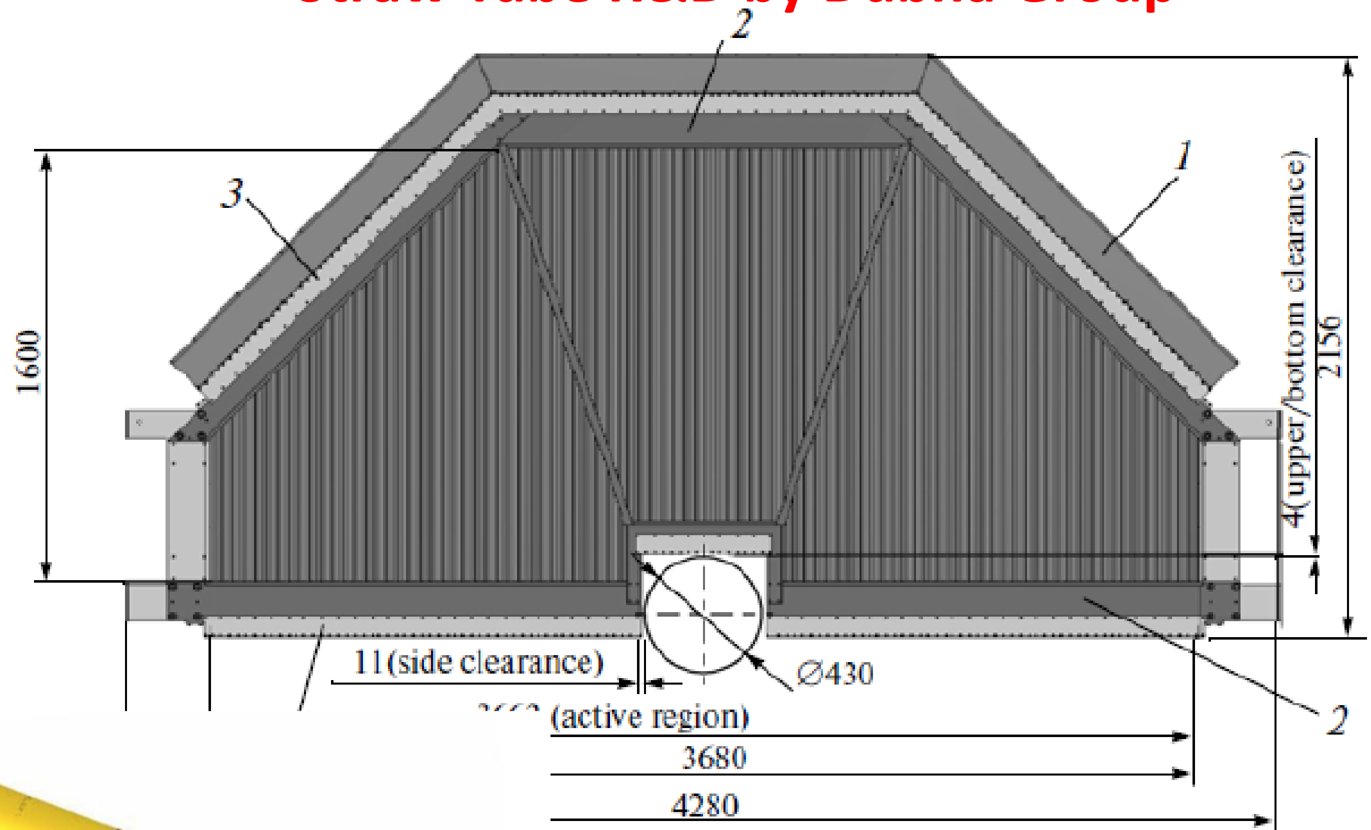



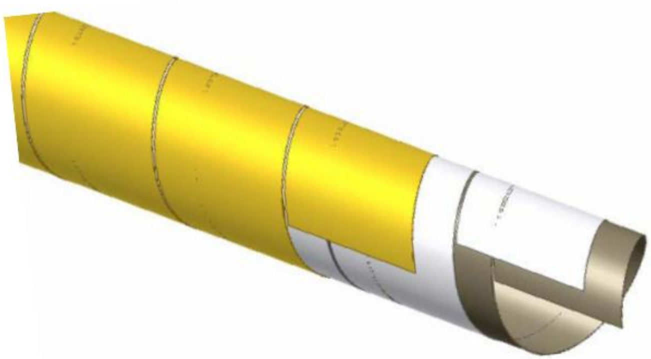

Different detector technologies for different stations

**-- For the first two stations, which demand a high rate capability, Gas Electron Multiplier technology (GEM) would be used.**

**-- Straw tube and TRD for the other layers.**

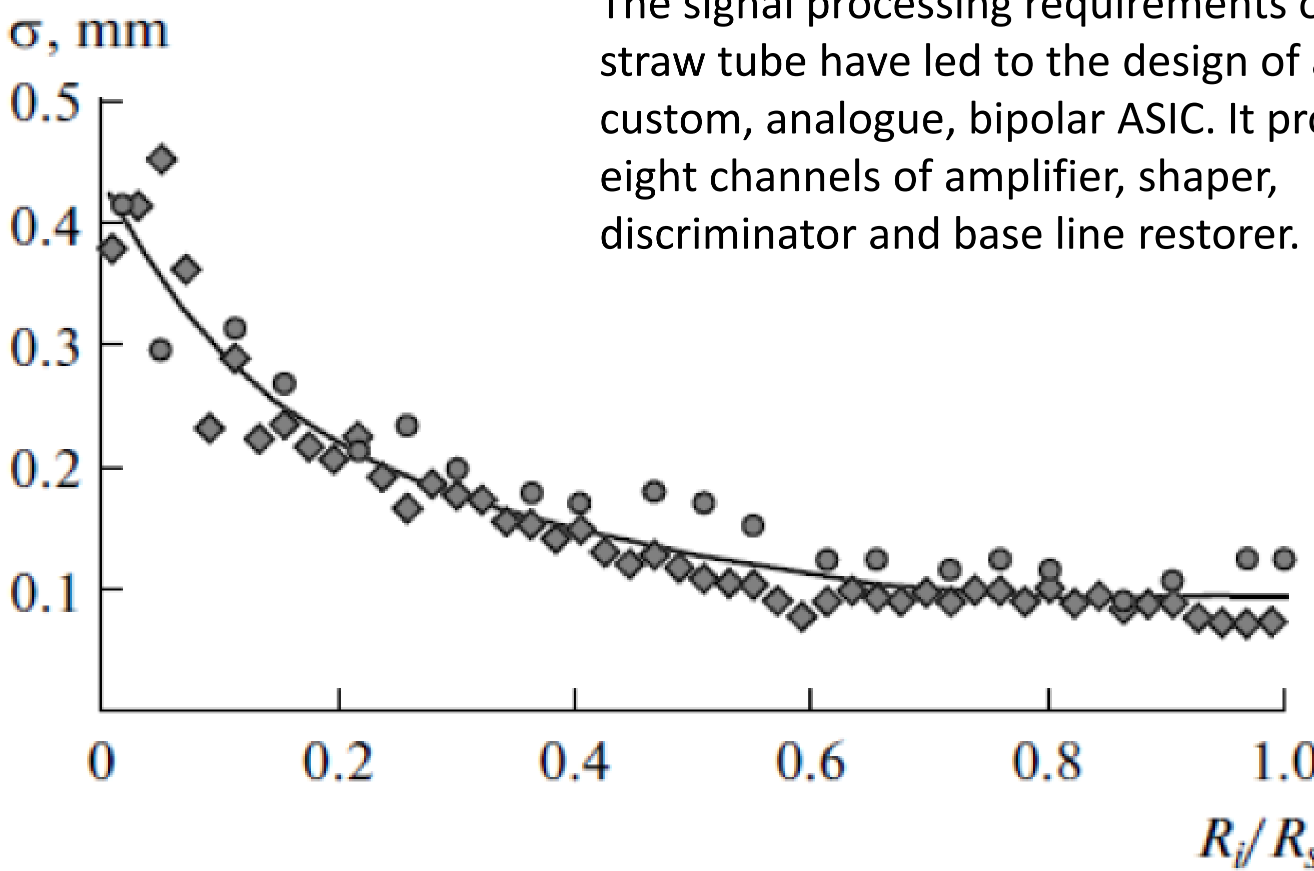
# Straw Tube R&D by Dubna Group



The straws with inner diameters of 4 and 9.53 mm have been tested in the SPS test beam at CERN, with the same gas mixture of Ar/CO2 (80/20) and the gas gain 7 104 in both cases. **The efficiency was about 98% and 99% for the 4 mm and 9.53 mm straws, respectively**.

| Gas mixture | Percentage | $t_{max}$, ns | dE/E, % |
|---|---|---|---|
| $Ar/CO_2$ | 70/30 | 68.4 | 180.8 |
| $Ar/CO_2/CF_4$ | 63/32/5 | 66.7 | 22.5 |
| $Ar/CO_2/CF_4$ | 63/27/10 | 60 | 26.4 |
| $Ar/CO_2/CF_4$ | 63/17/20 | 45 | 33.5 |
| $Ar/CO_2O_2$ | (70/30)/0.8 | 64.1 | 18.8 |
| $Ar/CO_2/O_2$ | (70/30)/1 | 63.2 | 19 |
| $Ar/CO_2/O_2$ | (70/30)/1.5 | 59.5 | 28 |
| $Ar/CO_2/O_2$ | (70/30)/3 | 56.2 | - |

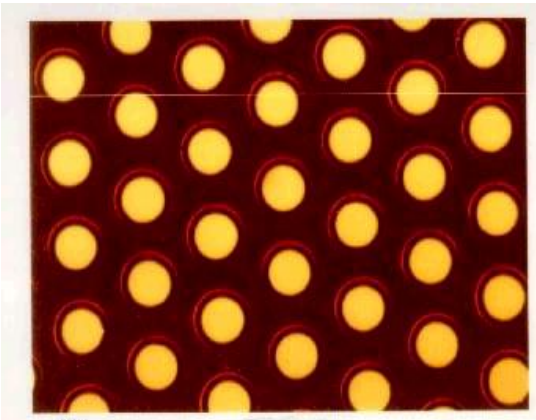


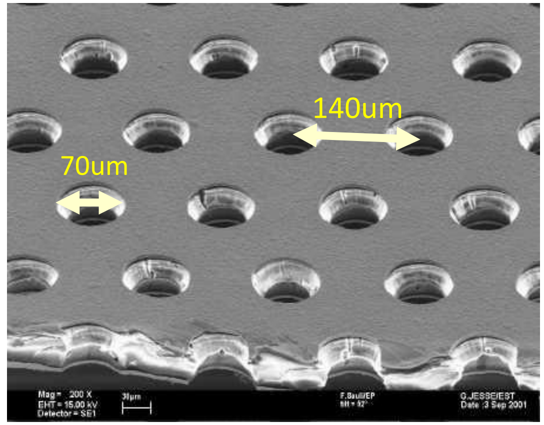

The signal processing requirements of the straw tube have led to the design of a full-custom, analogue, bipolar ASIC. It provides eight channels of amplifier, shaper, discriminator and base line restorer.

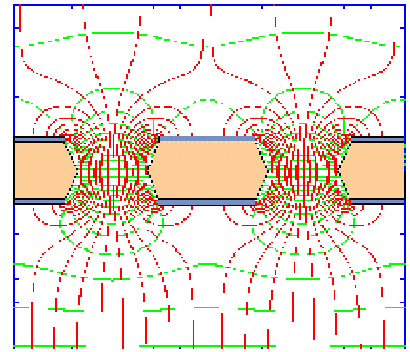
Spatial resolution as a function of the scaled distance to the anode for the straws with 4 mm (circles) and 9.53 mm (diamonds) inner diameter.
gas mixture Ar/CO2 (80/20), and the gas gain was about 70K in both cases.

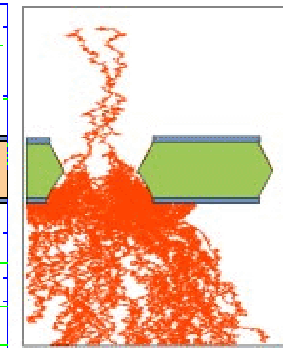
# Triple GEM module for the first Two stations

# Gas Electron Multiplier (GEM) and its working principle



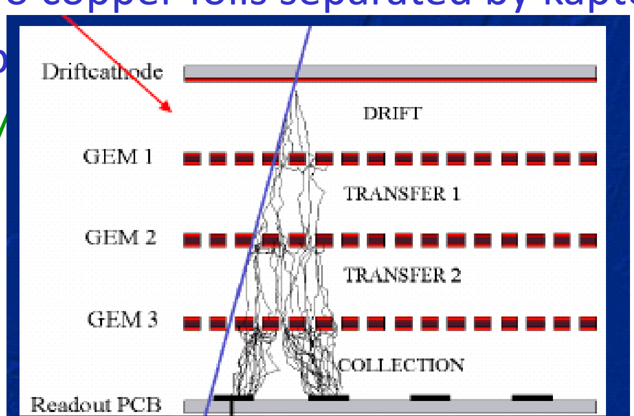




**a 50 micron polyimide foil with a 5 micron Cu layer deposited on both sides of polyimide**

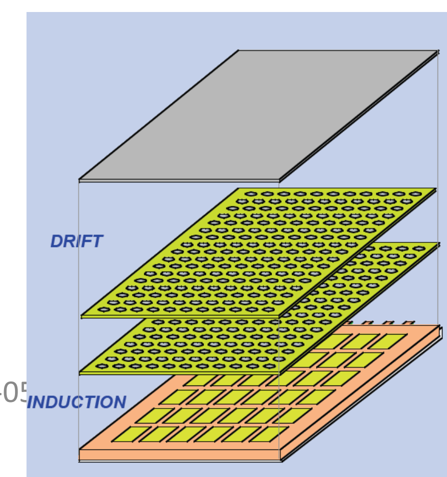
- Active medium is a gas mixture.
- electron multiplication takes place in holes of two copper foils separated by kapton
- Amp
  - M



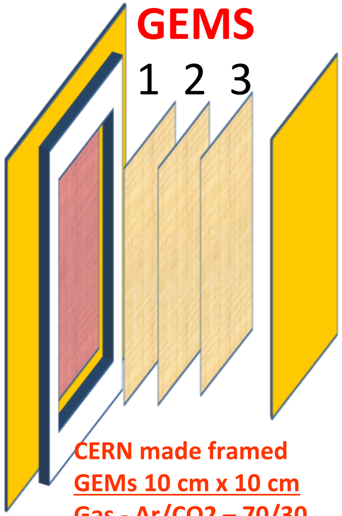

**Basic elements of a GEM chamber:**

1. **Drift plane**
2. **Amplifying element – GEM**
3. **Readout Plane**

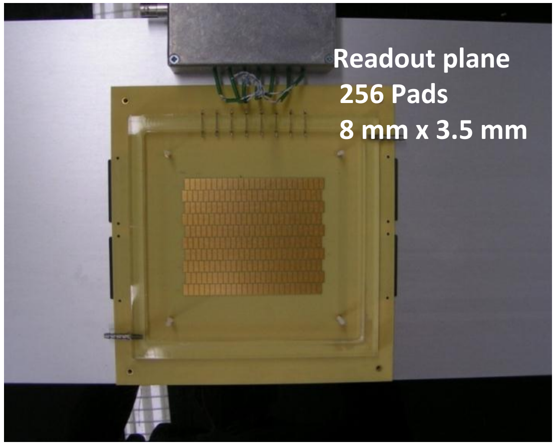
**Cascaded GEMs can give higher gains and have lesser spark proability**

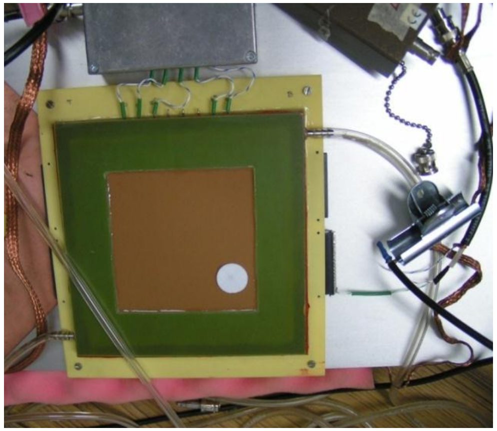


# Prototype fabrication at VECC

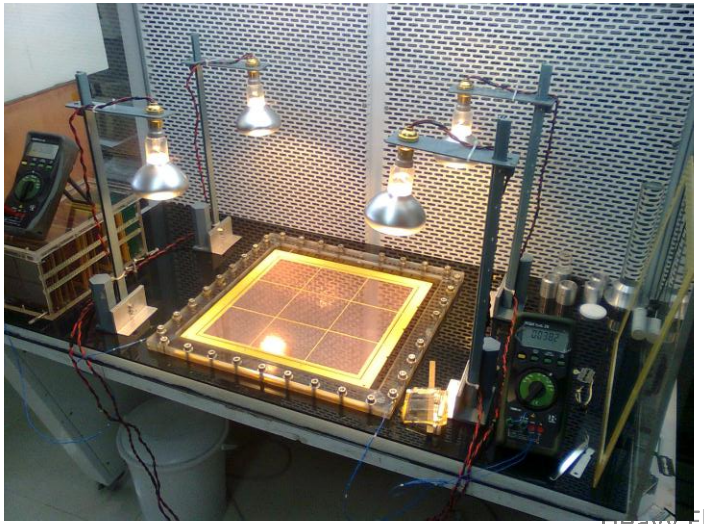


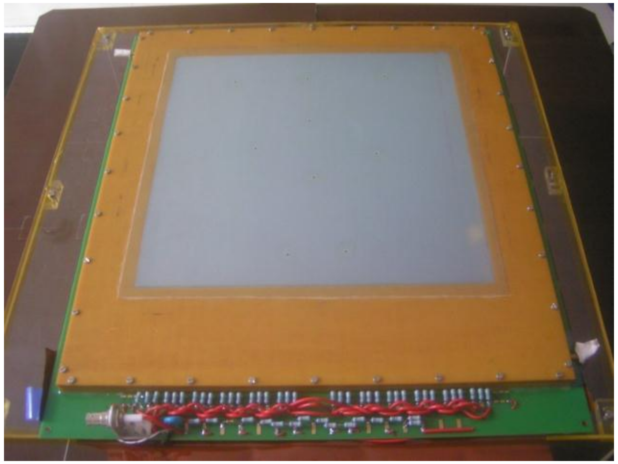

CERN made framed
GEMs 10 cm x 10 cm
Gas - Ar/CO2 – 70/30



## Thermal stretching and framing of 31 cm x 31 cm large size GEMs at VECC





# Beam test of GEM prototype chambers

**Aim :**

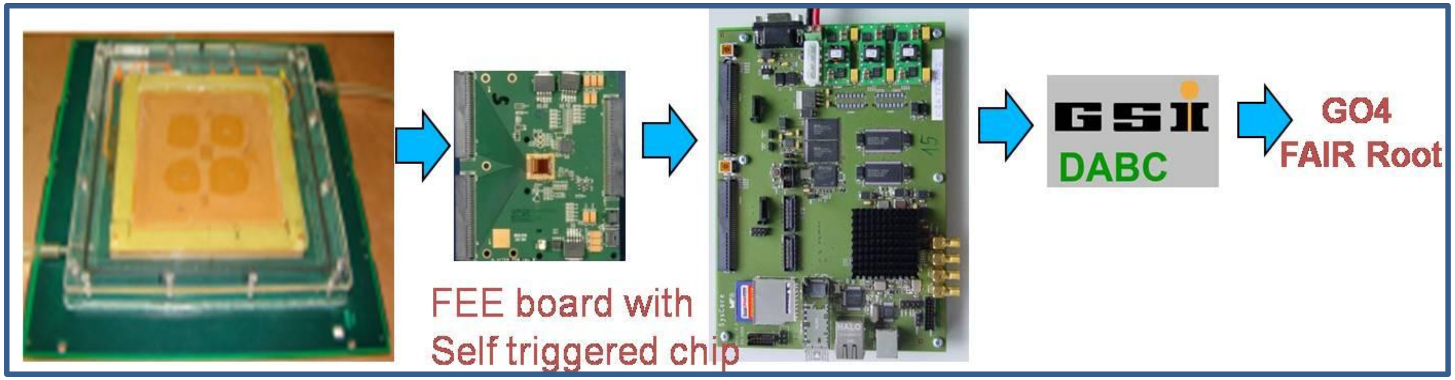
-- to test the response of the detector to charged particles. mainly in terms of efficiency, cluster size, gain uniformity, rate handling capability

-- testing with actual electronics for CBM : nXYTER

nXYTER is a 32 MHz, 128 channel self triggered ASIC first developed by DETNEE collaboration for neutron measurements.

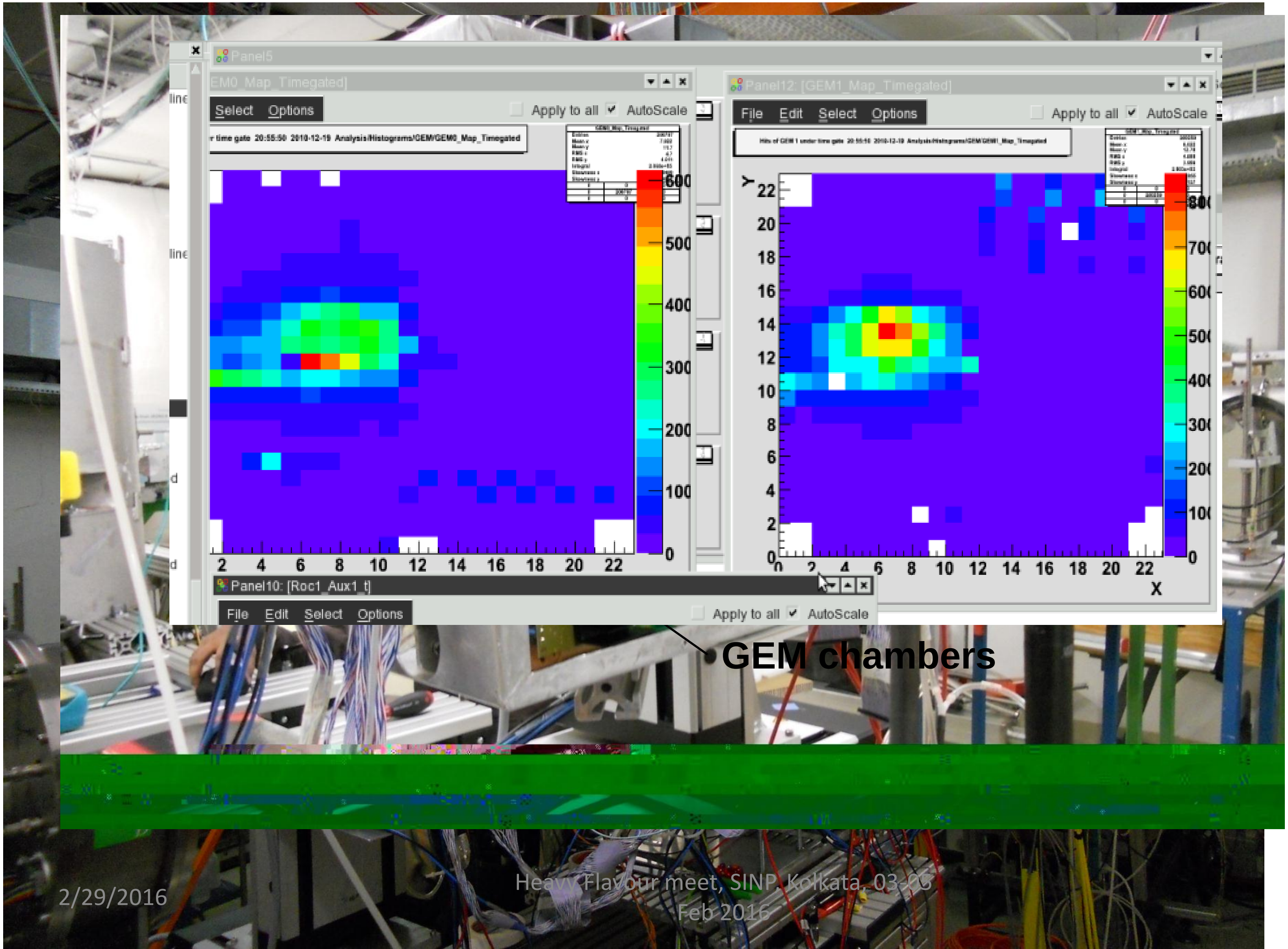
– coupled to ROC(ReadOut Controller) and then fed to the DAQ.

-- testing with the actual CBM DAQ

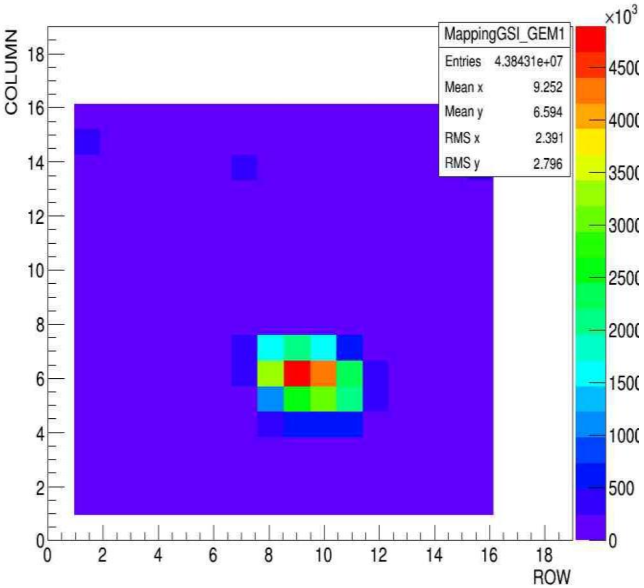



The nXYTER ADC spectra is inverted as compared to conventional picture, this has to be subtracted from a baseline value channel by channel

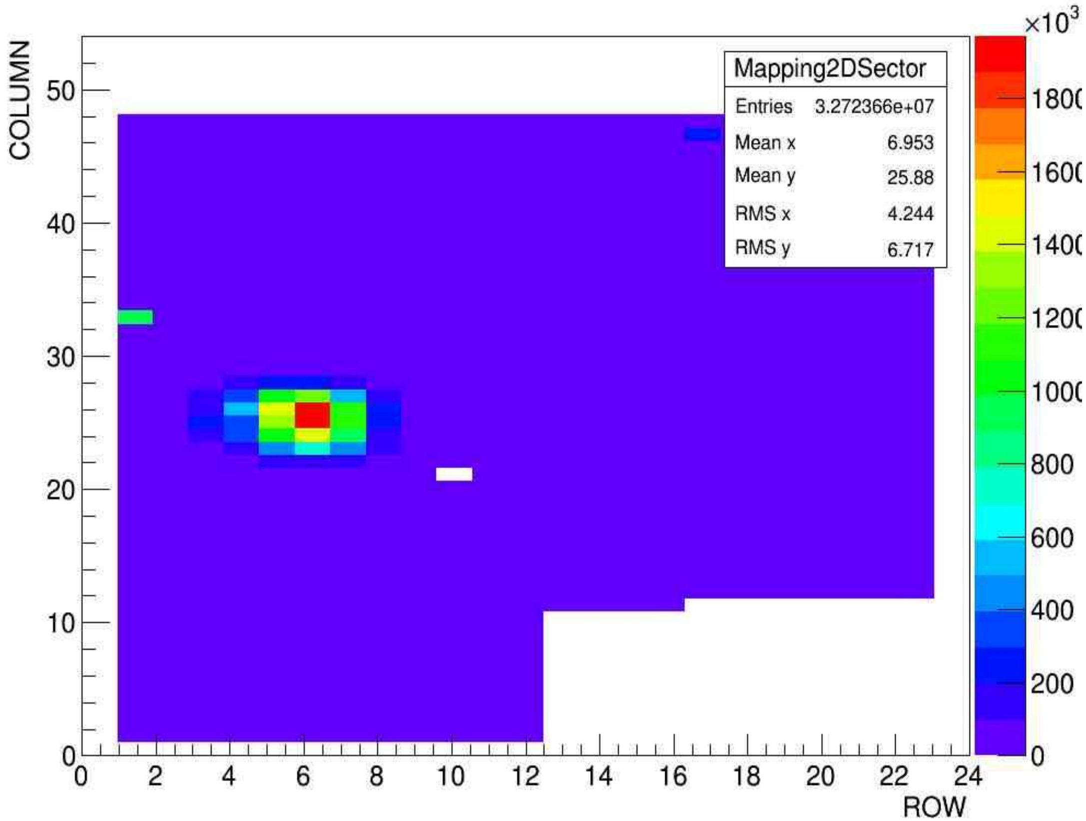
# Test setup at Jessica beamline at COSY (Julich)



# Beam spot (for high intensity runs), 2.3 GeV/c protons




GEM 2(10 cm x 10 cm)

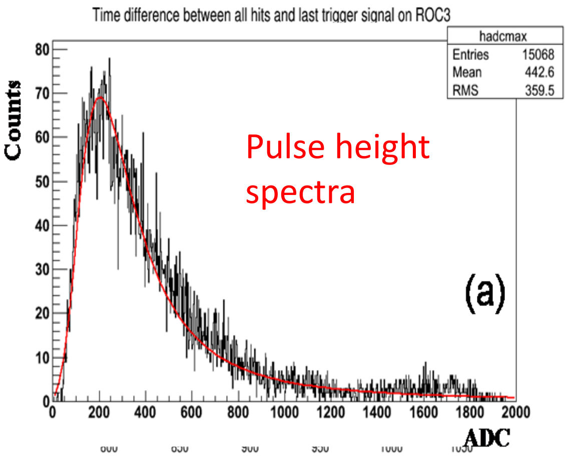


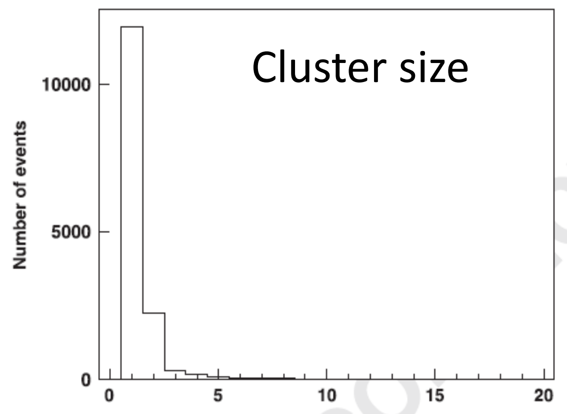

GEM 3 (31cm x 31 cm)

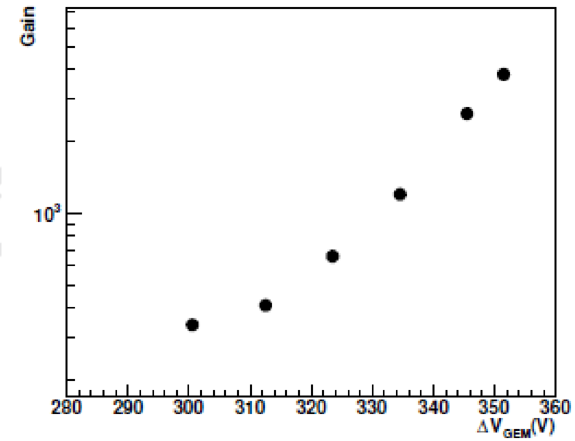
Beam profiles as seen by 10 cm x 10 cm prototype and 31 cm x 31 cm prototype (right)

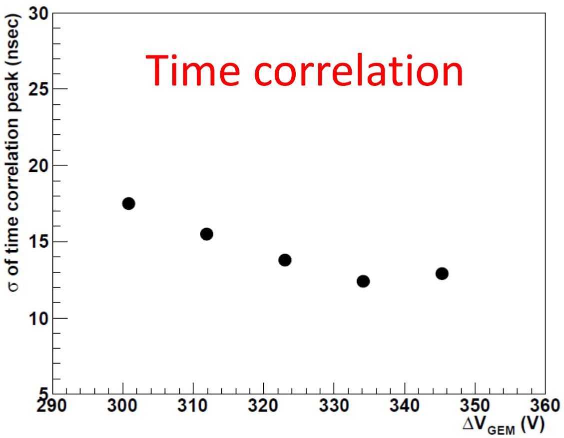
# Test Results

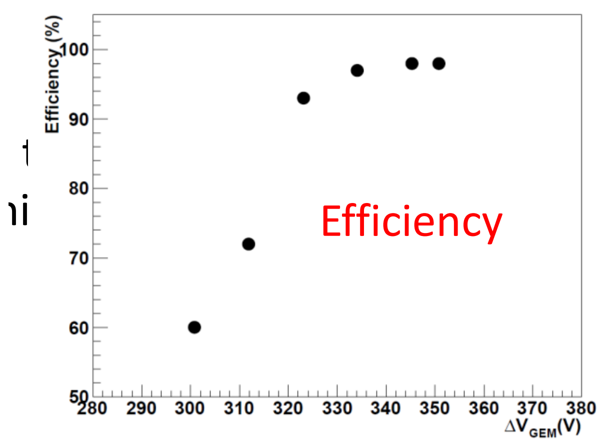
## self triggered mode

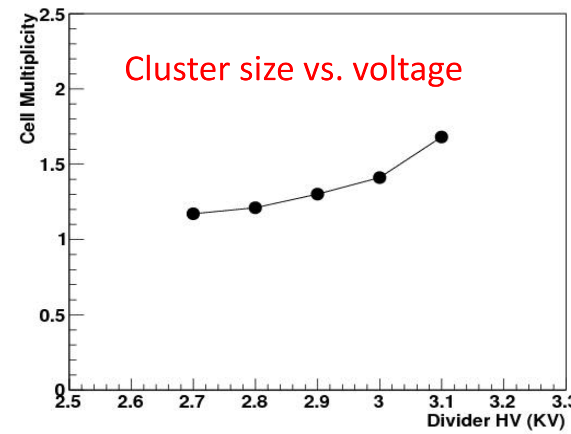


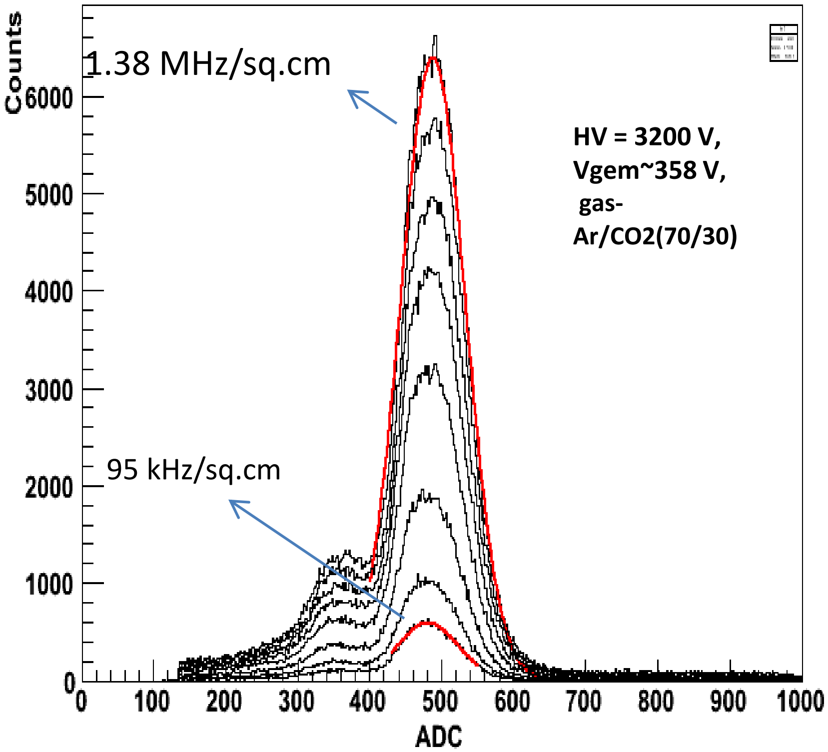




*Published in NIMA*

# Rate test

## using high intensity Cu X-ray source in RD51 lab at CERN, <u>with conventional electronics</u>

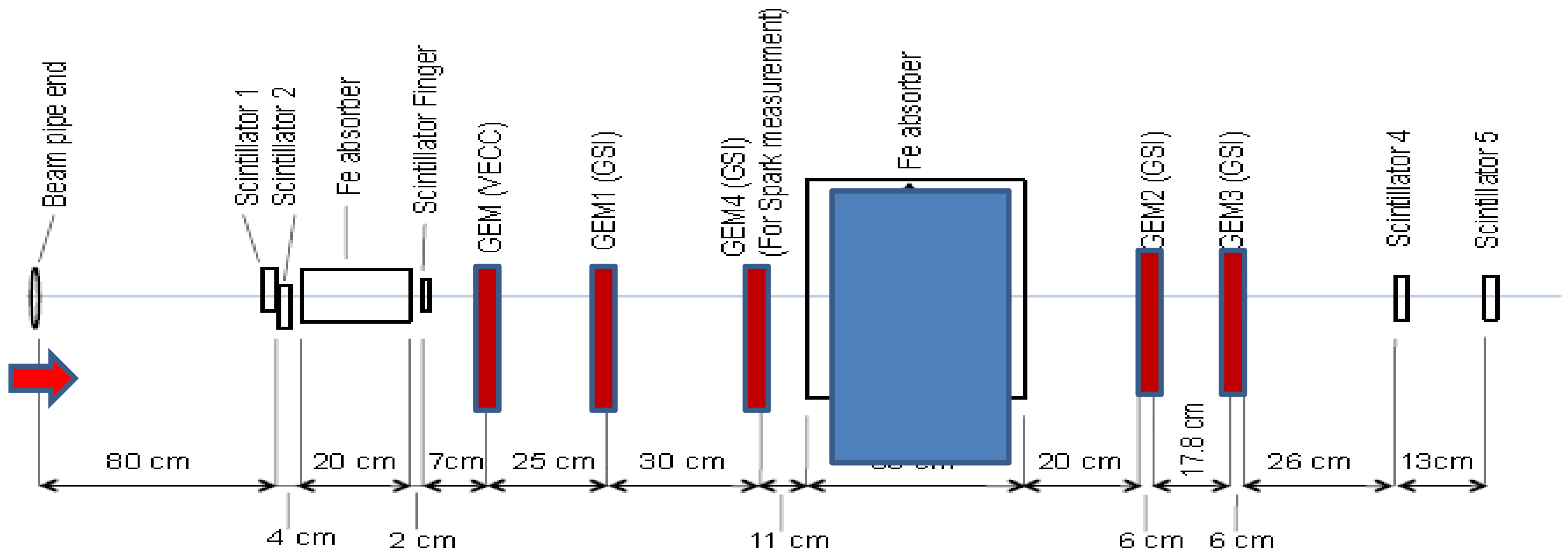



Gain remains almost stable with rate

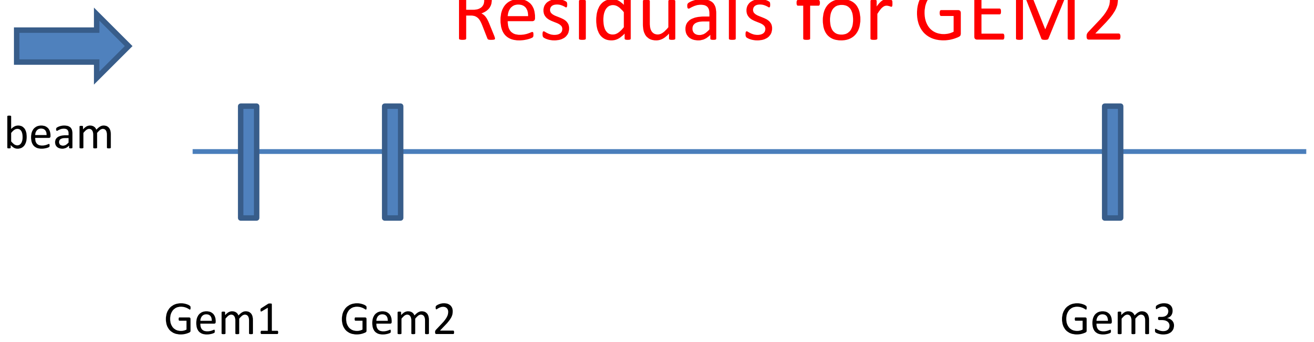
Highest Rate in this picture ~ 1.4 MHz/$cm^2$

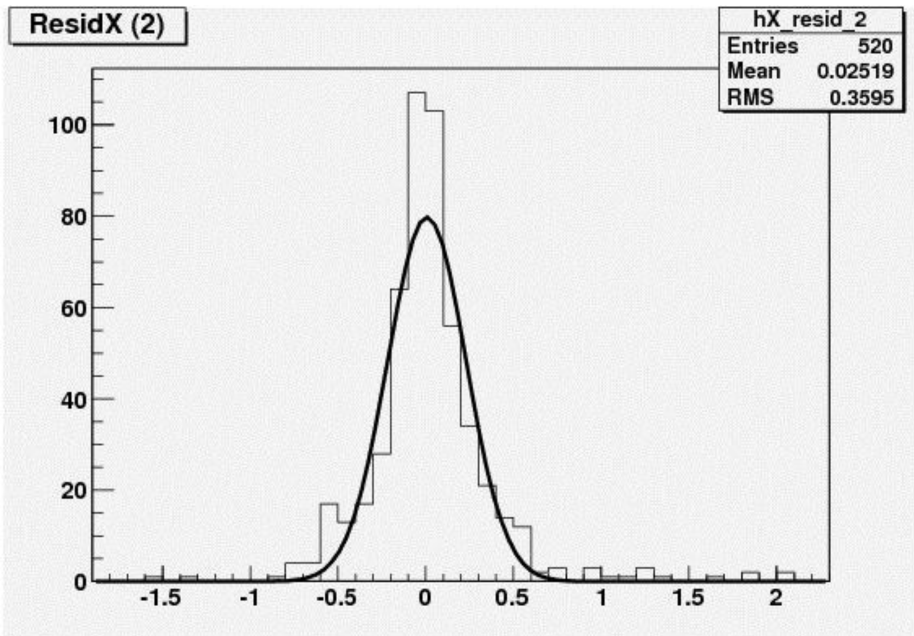
*Published in JINST-2014*

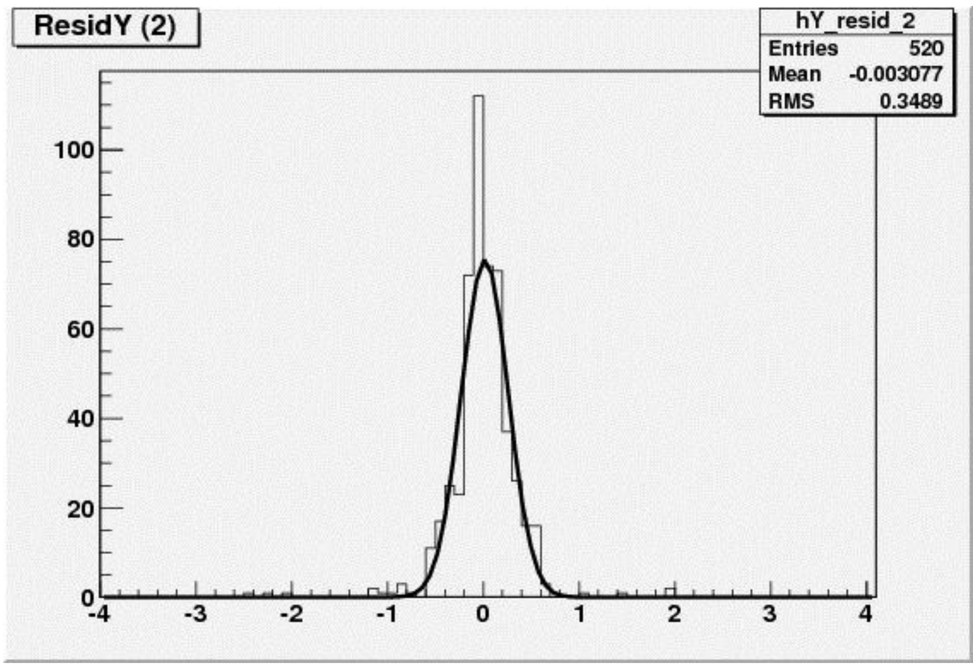
# Test with absorbers – MiniMUCH at CERN SPS, H4 beamline. Pion beams of GeV/c(with some muons and electrons)



# Residuals for GEM2



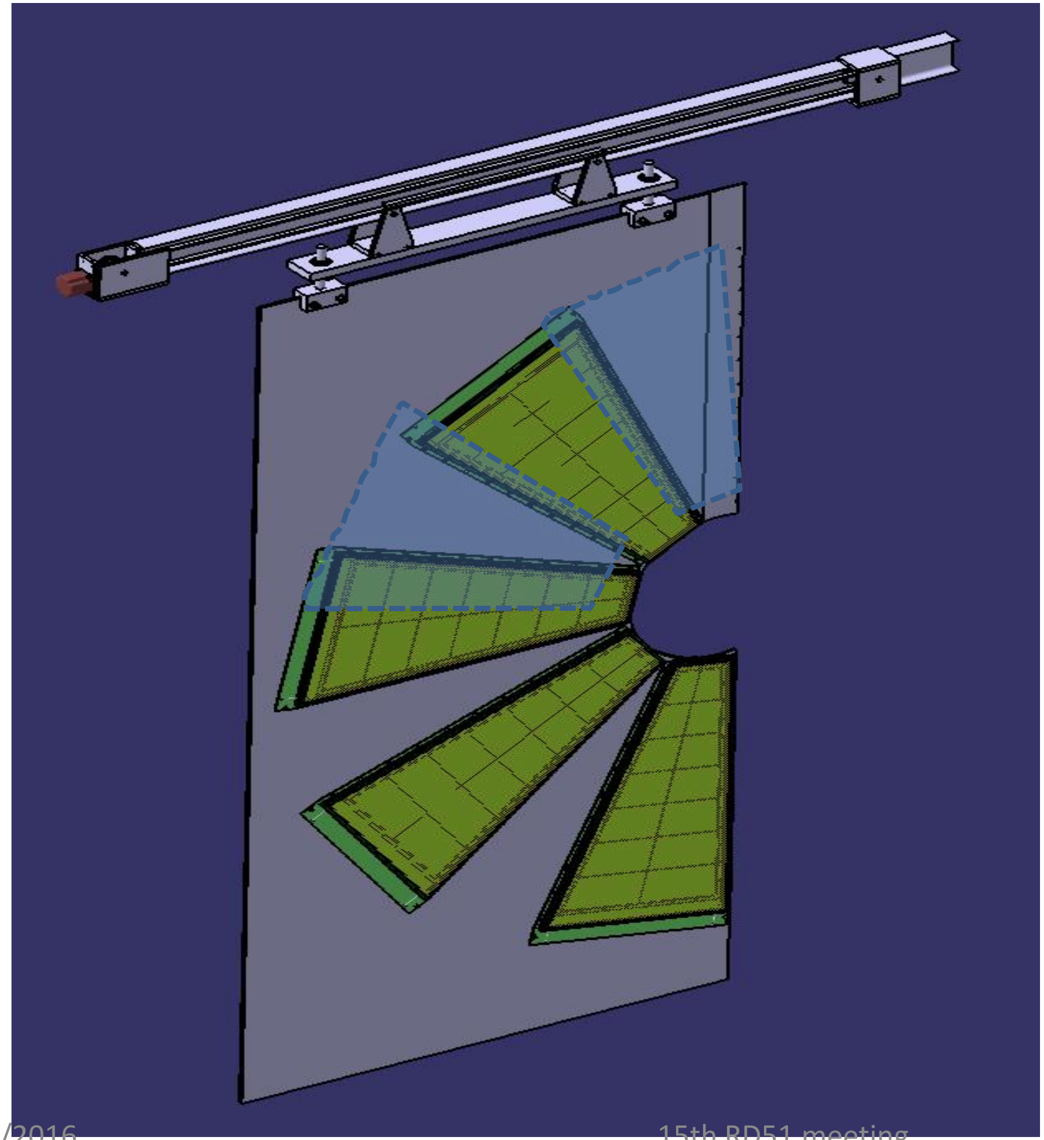



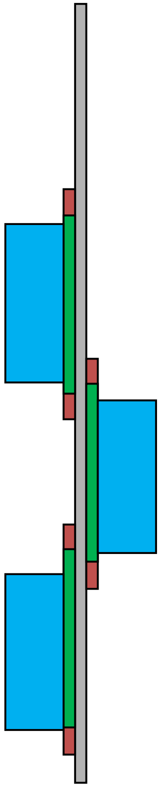




**Reconstructing the track using GEM1 and GEM3 and Projecting the hits at plane_GEM2 and finding the distribution of residuals**

# Building a Real size MUCH sector prototype

# Layout --one layer of MUCH on a Drive

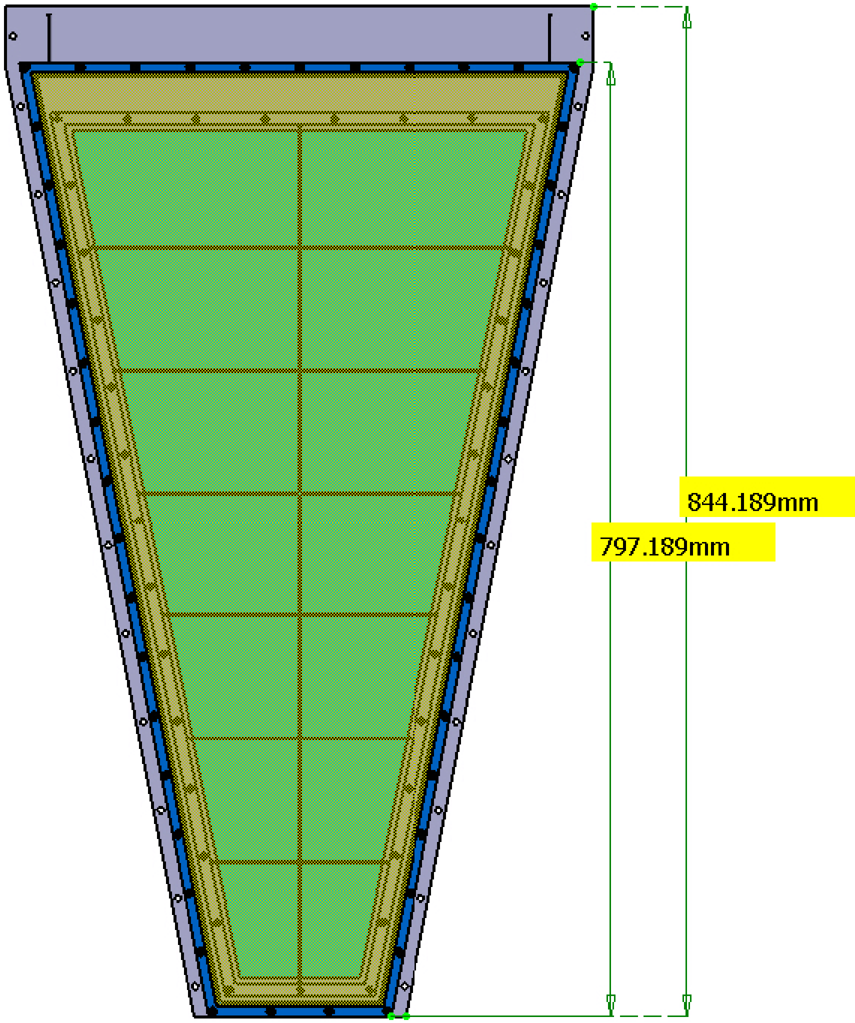


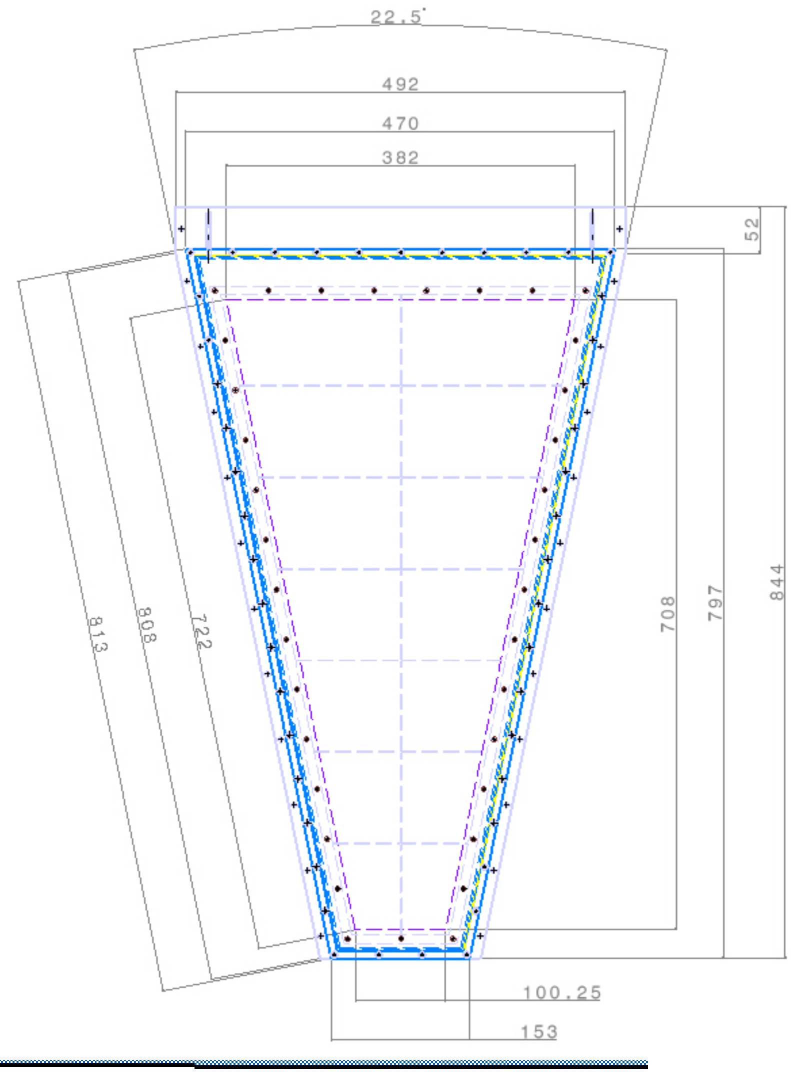


# # of sectors, FEB, area, etc.

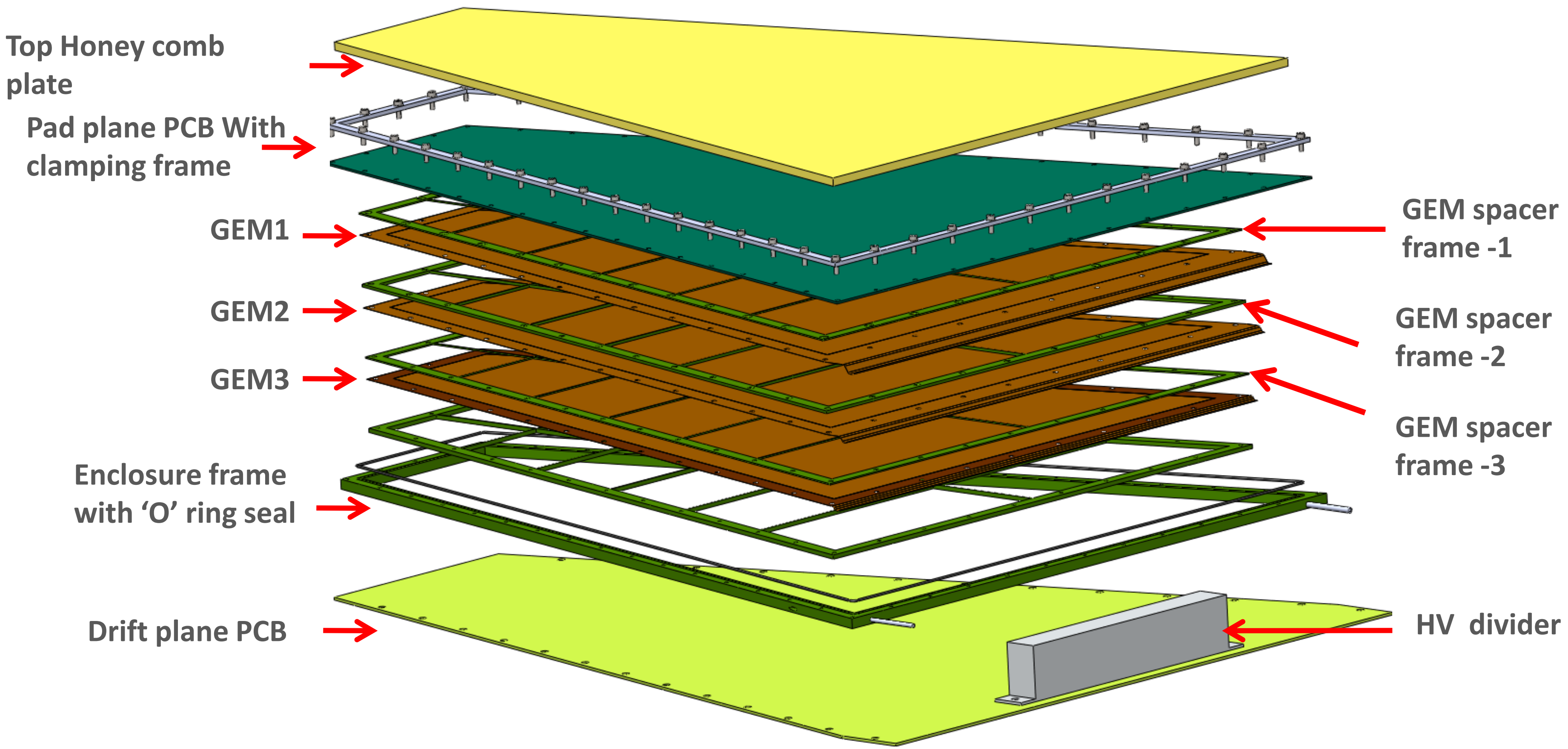
| Station # for SIS100 | Layer # | Total no of pads | **R1 (cm)** | Pad size (min) | **R2 (cm)** | Pad size (max) | **Area (sq.mt)** | No of 128 channel FEB/layer (round off) | No of Sector per layer |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 28800 | **25** | 4.36mm | **100.25** | 17.48mm | **2.95** | 240 | 16 |
| | 2 | 28800 | **25** | 4.36mm | **100.25** | 17.48mm | **2.95** | 240 | 16 |
| | 3 | 28800 | **25** | 4.36mm | **100.25** | 17.48mm | **2.95** | 240 | 16 |
| 2 | 1 | 30600 | **34.5** | 5.9mm | **146.9** | 25.4mm | **6.4** | 240 | 24 |
| | 2 | 30600 | **34.5** | 5.9mm | **146.9** | 25.4mm | **6.4** | 240 | 24 |
| | 3 | 30600 | **34.5** | 5.9mm | **146.9** | 25.4mm | **6.4** | 240 | 24 |

| Station # for SIS300 | Layer # | Total no of pads | R1 (cm) | Pad size (min) | R2 (cm) | Pad size (max) | Area (sq.mt) | No of 128 channel FEB/layer (round off) | No of Sector per layer |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 28800 | 25 | 4.36mm | 100.25 | 17.48mm | 2.95 | 240 | 16 |
| | 2 | 28800 | 25 | 4.36mm | 100.25 | 17.48mm | 2.95 | 240 | 16 |
| | 3 | 28800 | 25 | 4.36mm | 100.25 | 17.48mm | 2.95 | 240 | 16 |
| 2 | 1 | 30240 | 29.5 | 5mm | 123.5 | 21.3mm | 4.5 | 240 | 20 |
| | 2 | 30240 | 29.5 | 5mm | 123.5 | 21.3mm | 4.5 | 240 | 20 |
| | 3 | 30240 | 29.5 | 5mm | 123.5 | 21.3mm | 4.5 | 240 | 20 |

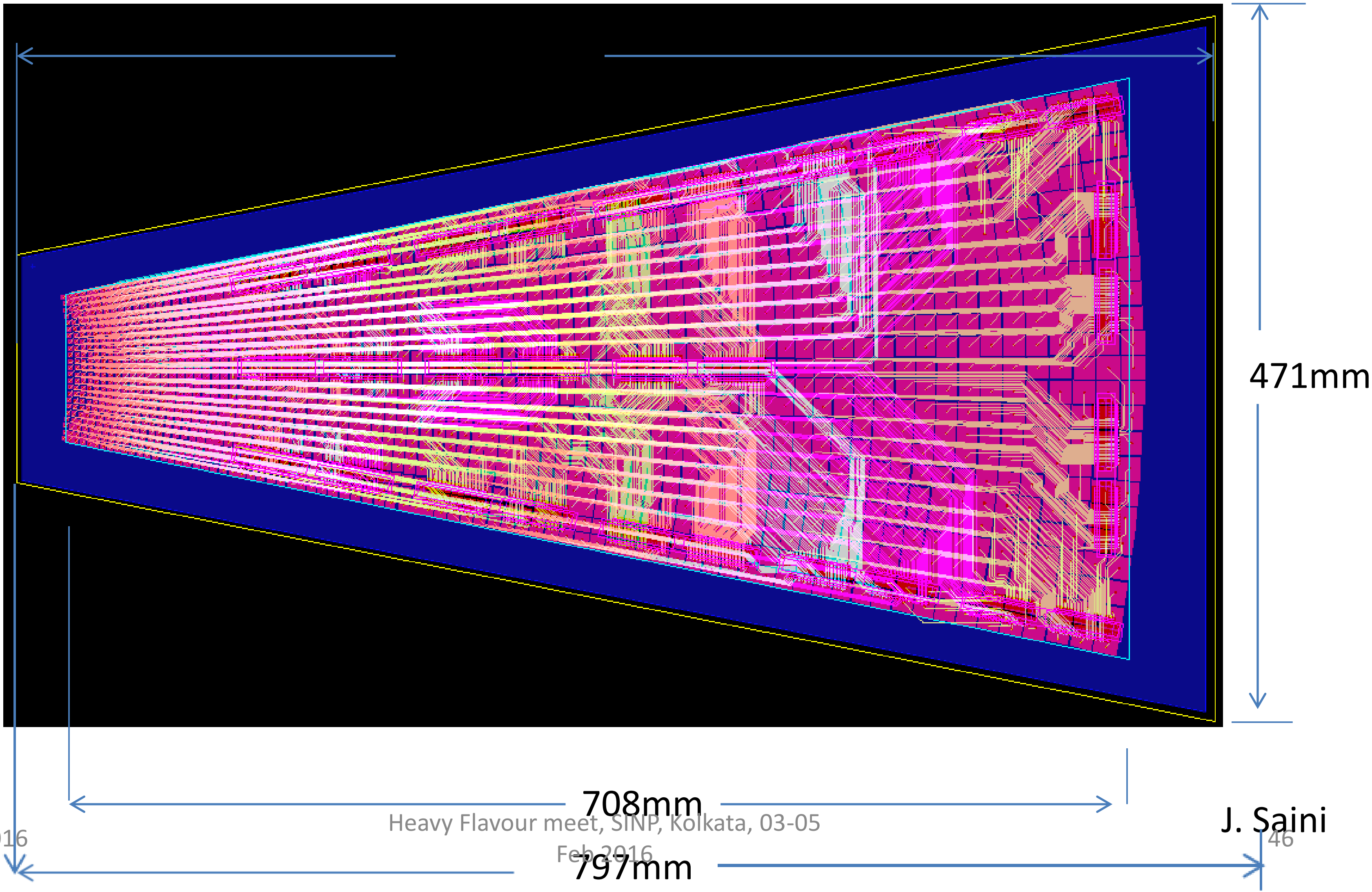

844.189mm
797.189mm


22.5°
492
470
382
52
813
808
722
708
797
844
100.25
153

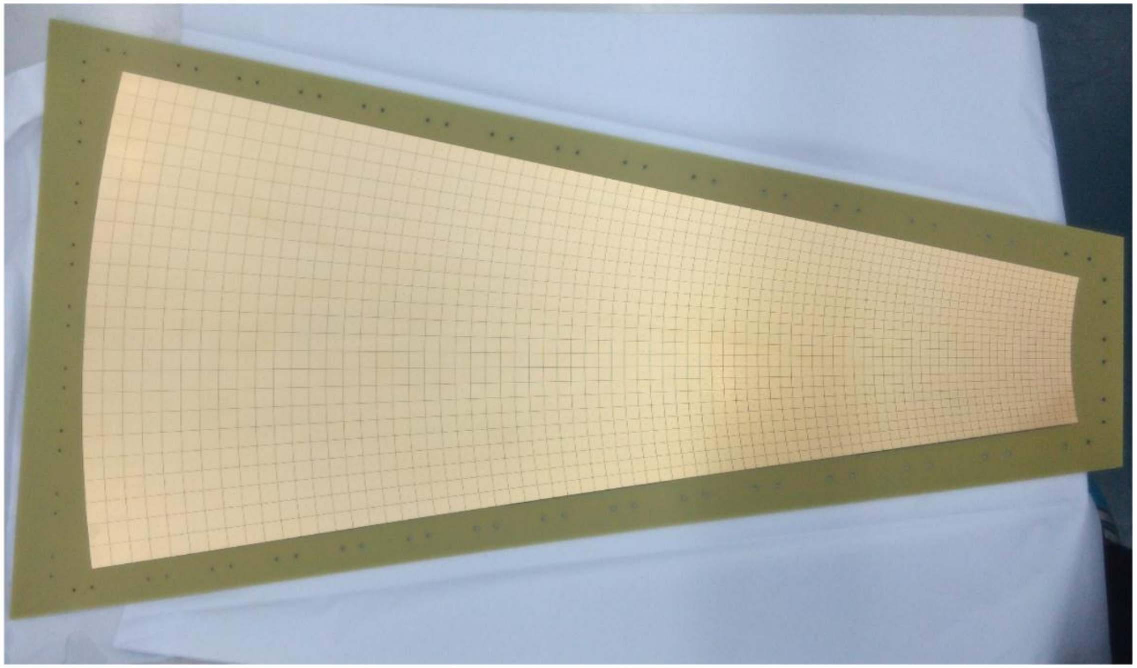
# *Sector Chamber elements – (old design)*



# Real size readout PCB designed at VECC



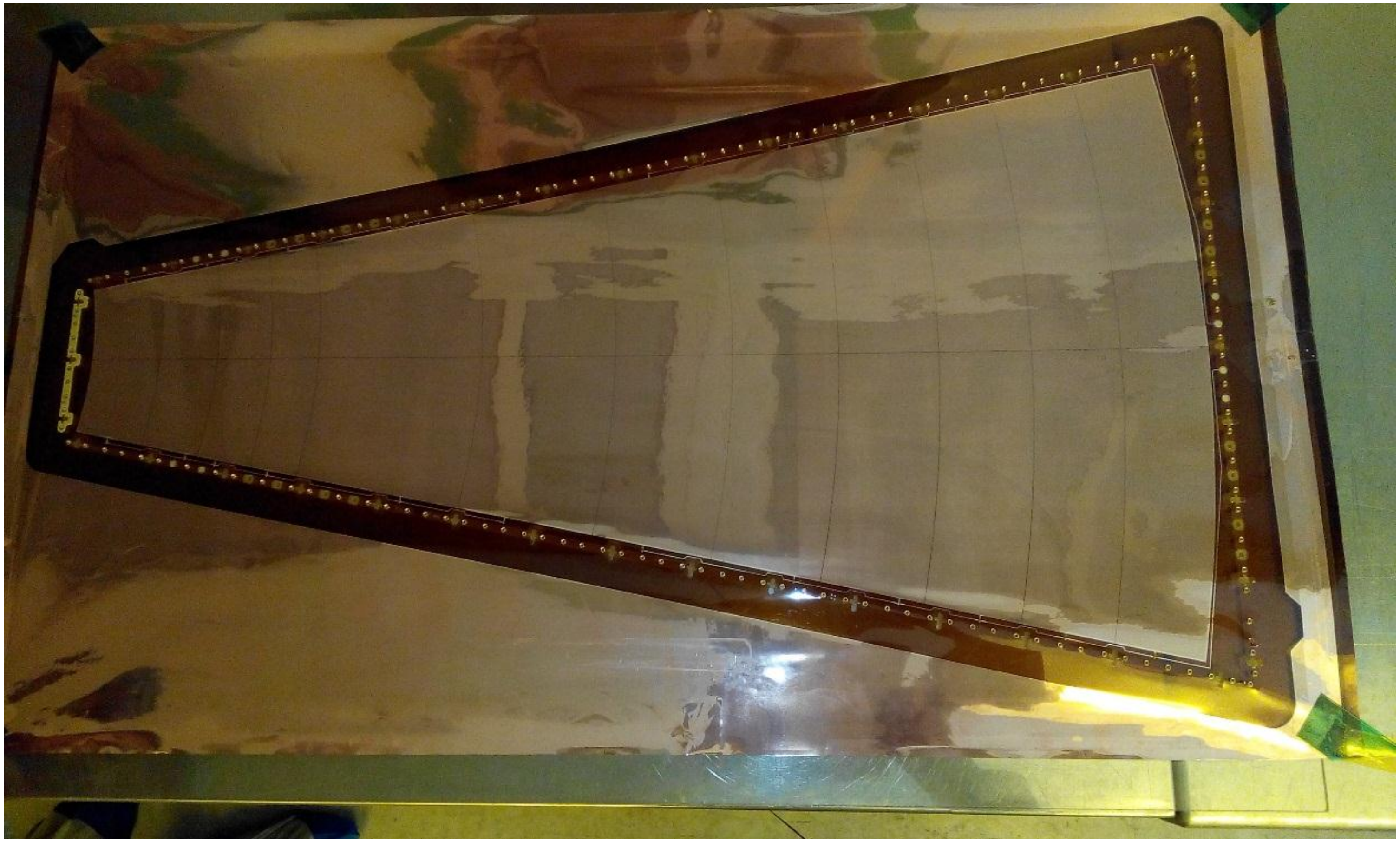

J. Saini



Readout PCB inner side

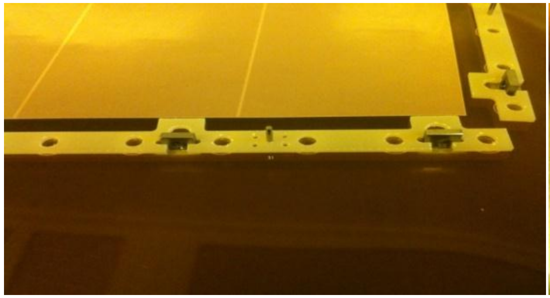
Readout PCB outer side with FEB connectors

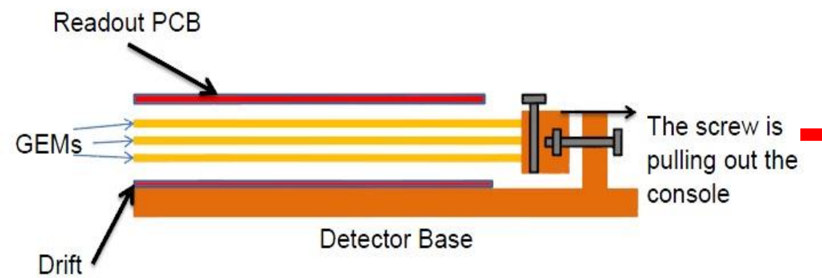
# Real size GEM foil

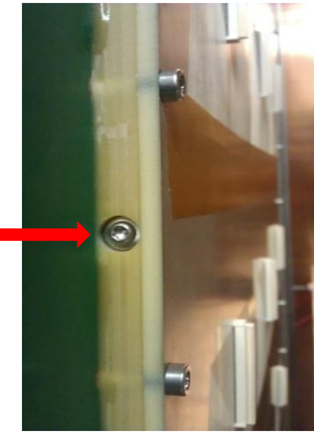


For CBM MUCH -- GEM foils having 24 HV Segmentation.

# Stretching of GEM foils – glue-less approach – "ns2"





•Now all the three layers of each clamp segment are fastened together with screws at select places. While designing the layout of the GEM foil some circular copper patterns are generated at the edges to enhance the grip of the edge clamp segments.

•The clamp segments are provided with an internal groove to accommodate a stainless steel nut. Thus after assembly of the segment a screw can be inserted sideways through the segment which mates with the embedded nut Fig.xx

•The outer chamber frame has provision to insert screws from side walls through a small gas tight O-ring seal and the screw can be coupled to the embedded nut in the corresponding clamp segment.

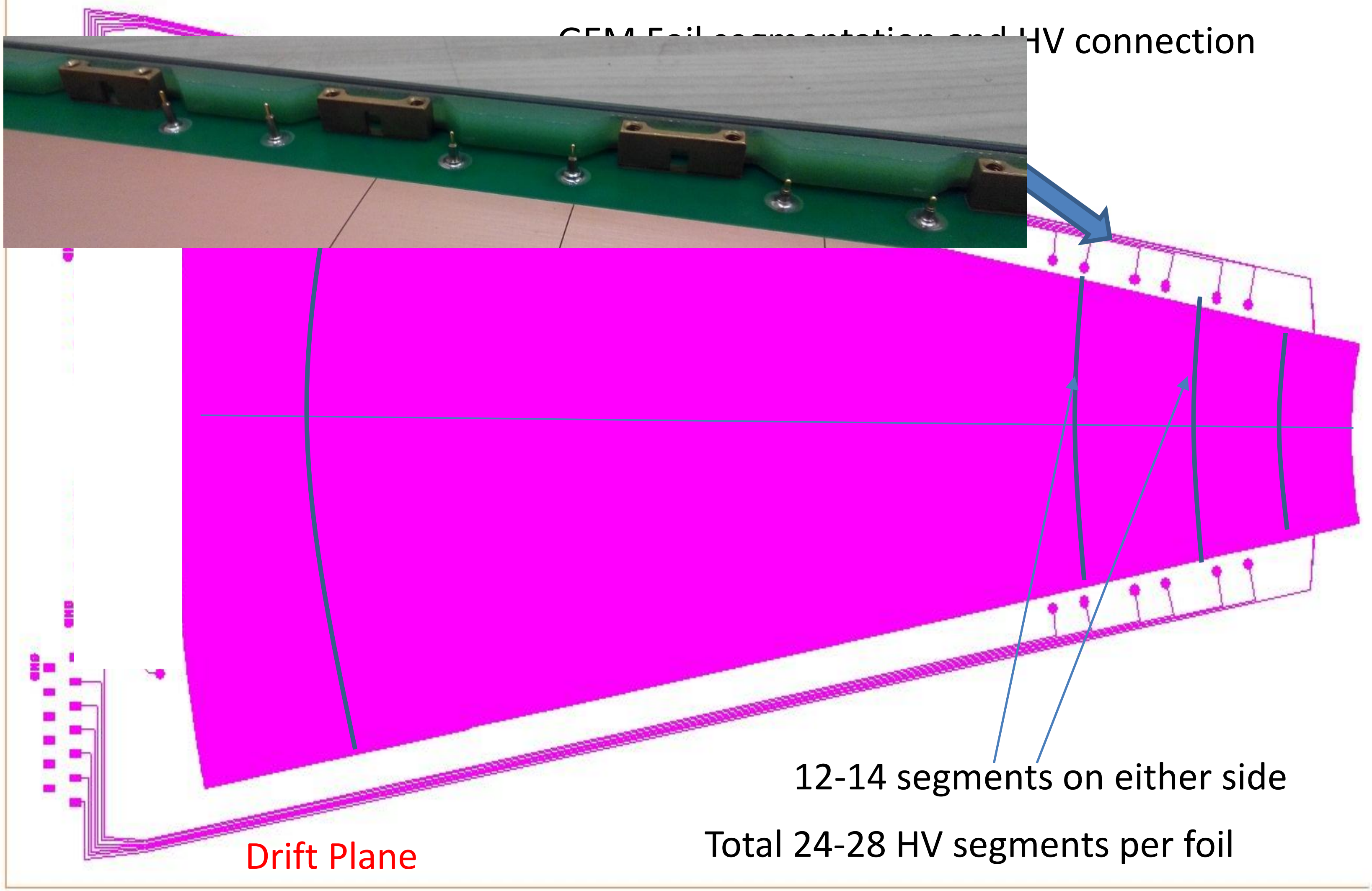
•After clamping all the foils the screws on the sides of the chamber frame can be tightened to stretch the foils in-situ .The screws are tightened until optimum tension is reached in all the three GEM foils.

•HV contacts are brought out of the foils through spring contacts. This needs further improvement.

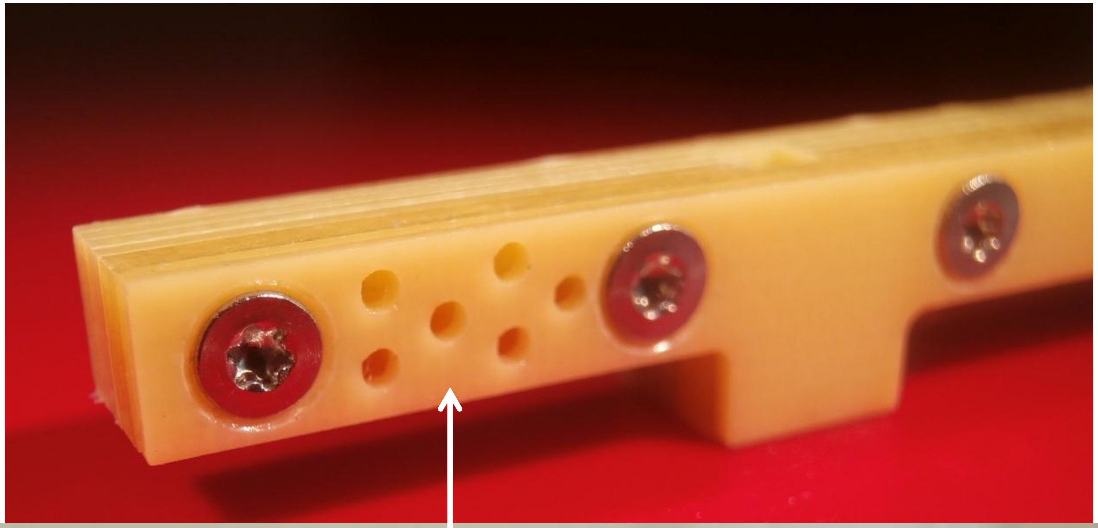
•For large scale production it may be possible to mould the clamp segments with some engineering plastic like PEEK.

This method completely eliminates the slow gluing procedure and suitable for large volume production of chambers. Also since the grid-spacers are absent in the active zone, sparking probability due to glass filaments on the grid edges is eliminated. The chamber is opened for GEM replacement.

# GEM Foil segmentation and HV connection



GE 1/1 for CMS



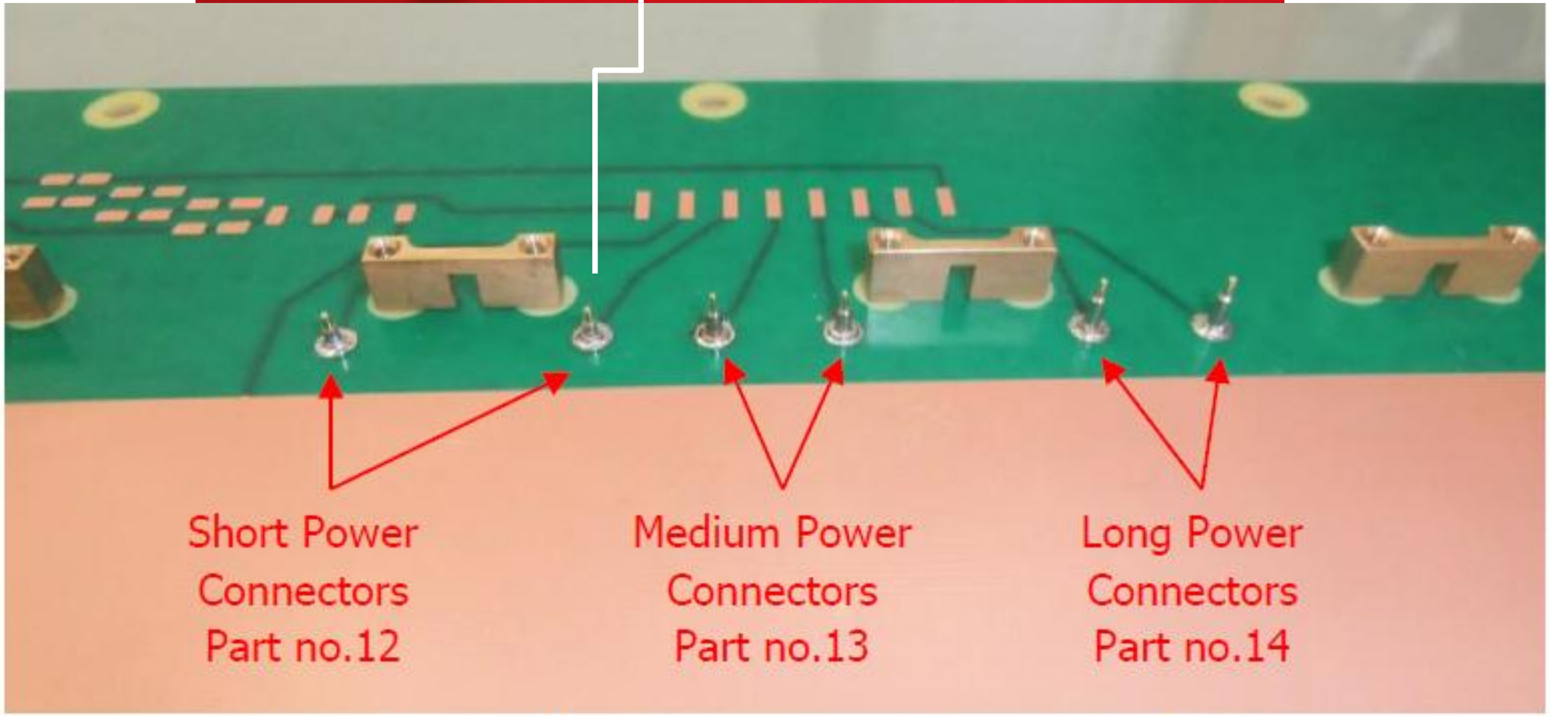
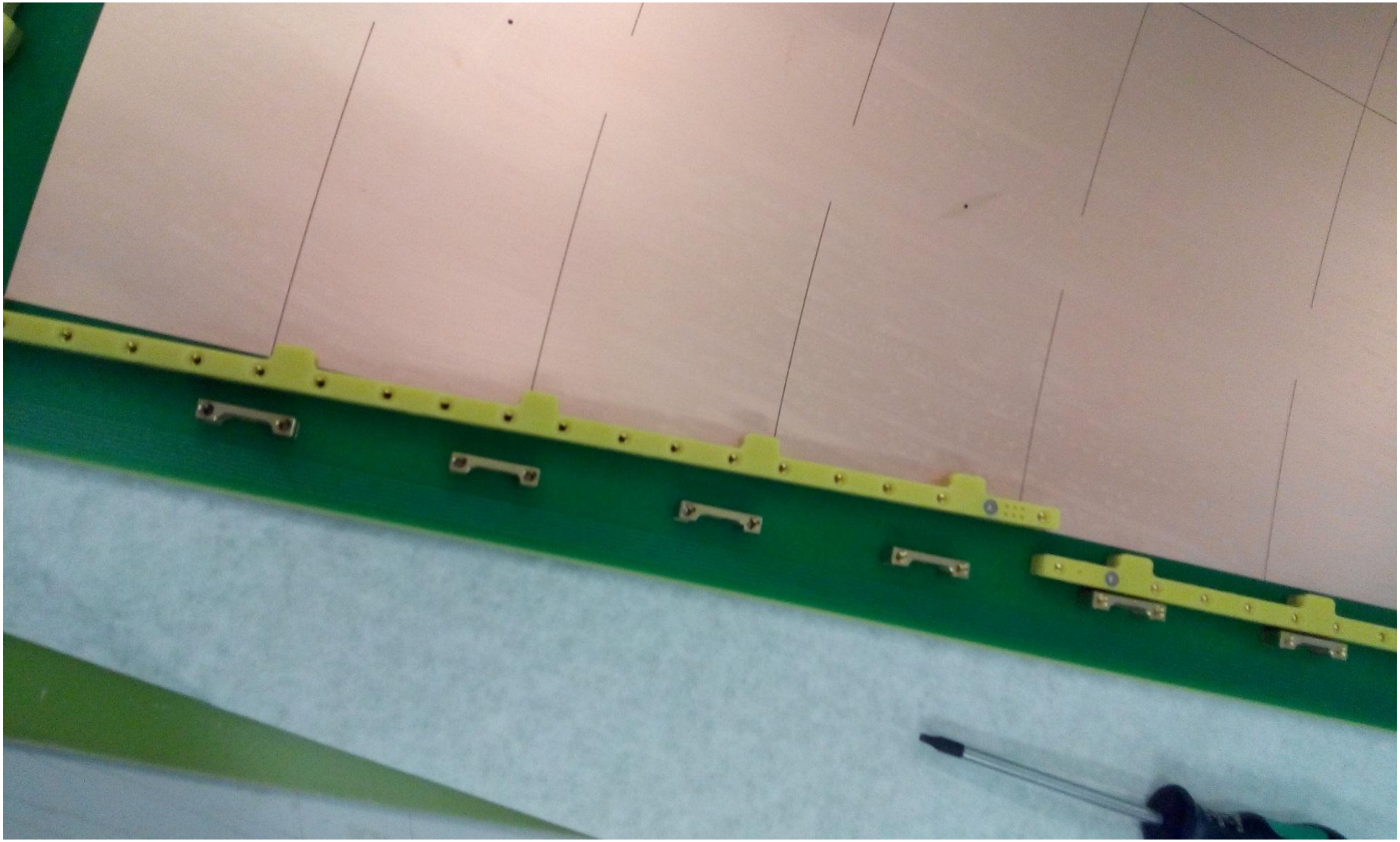
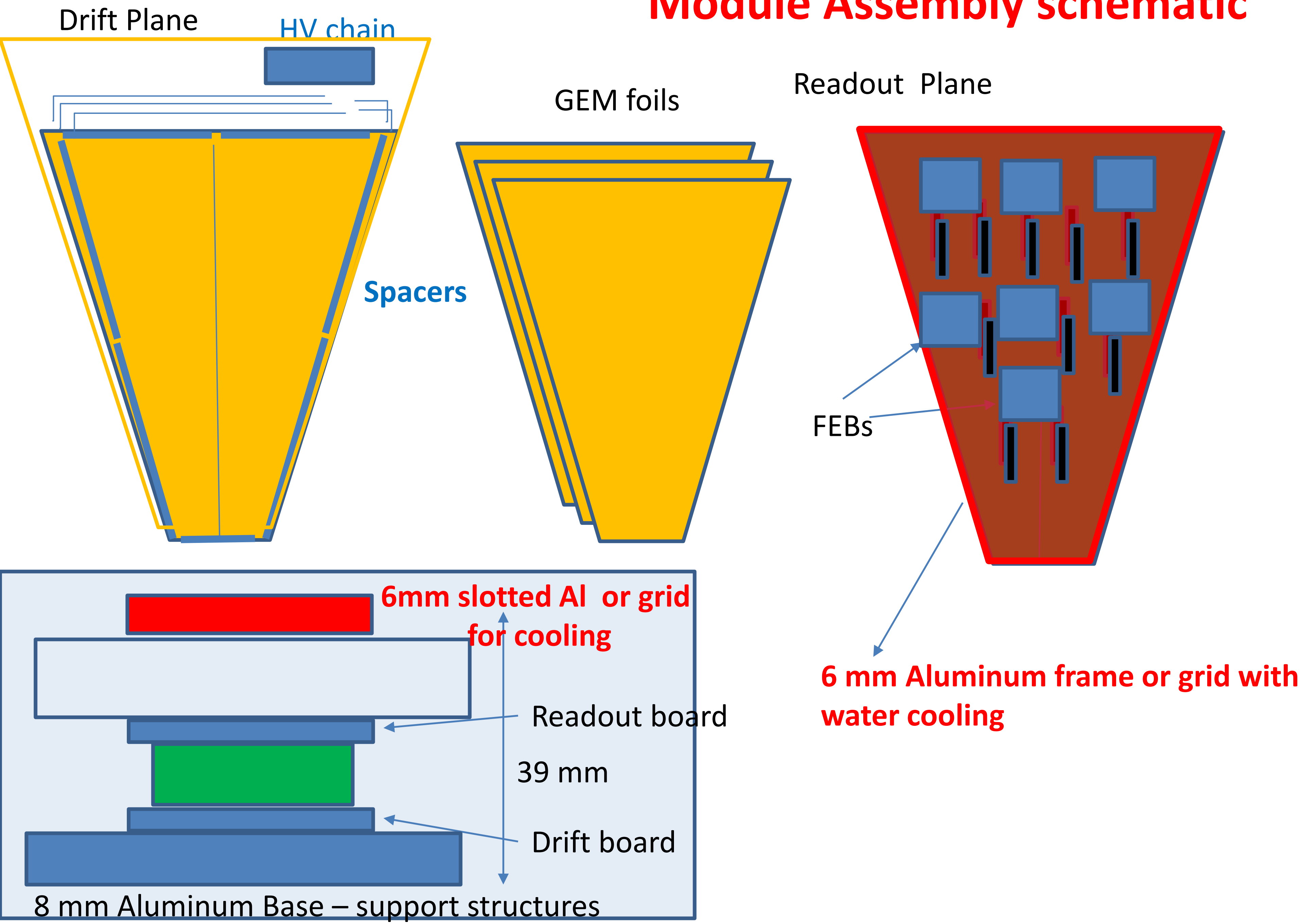



**Figure 8:** Position of power connectors for GEM foils.

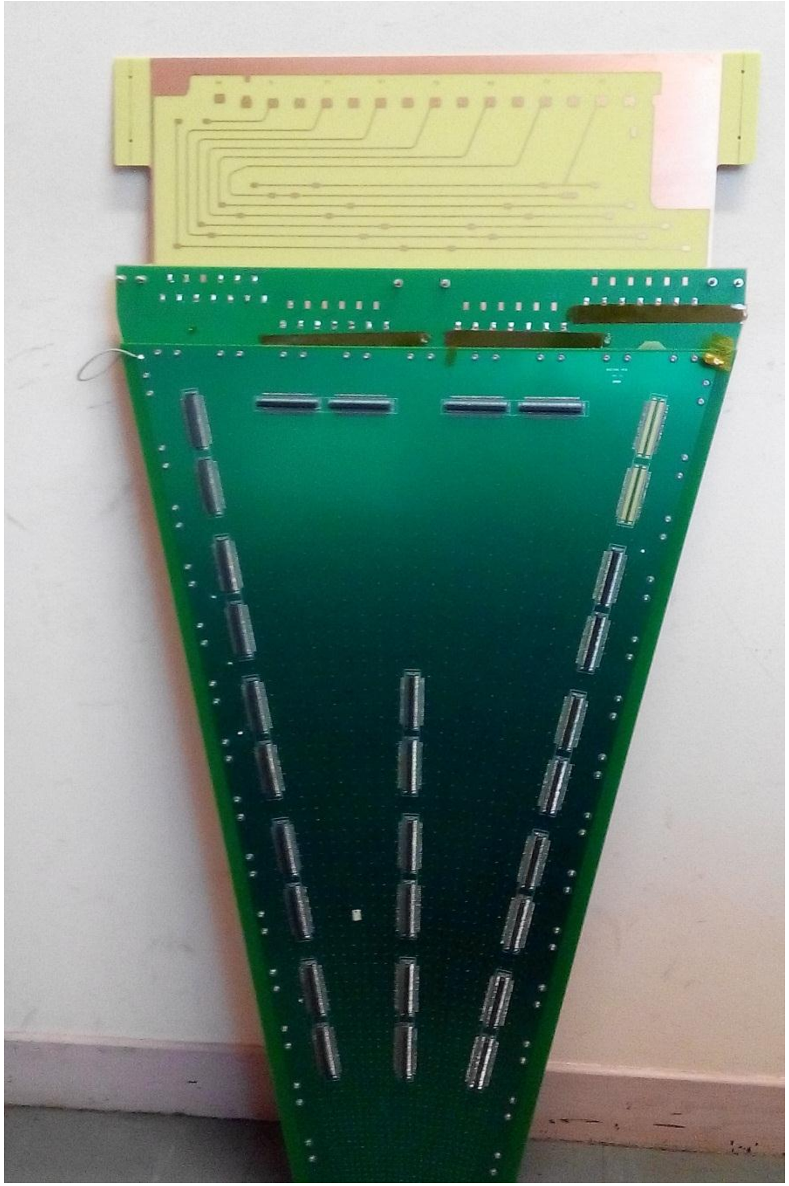


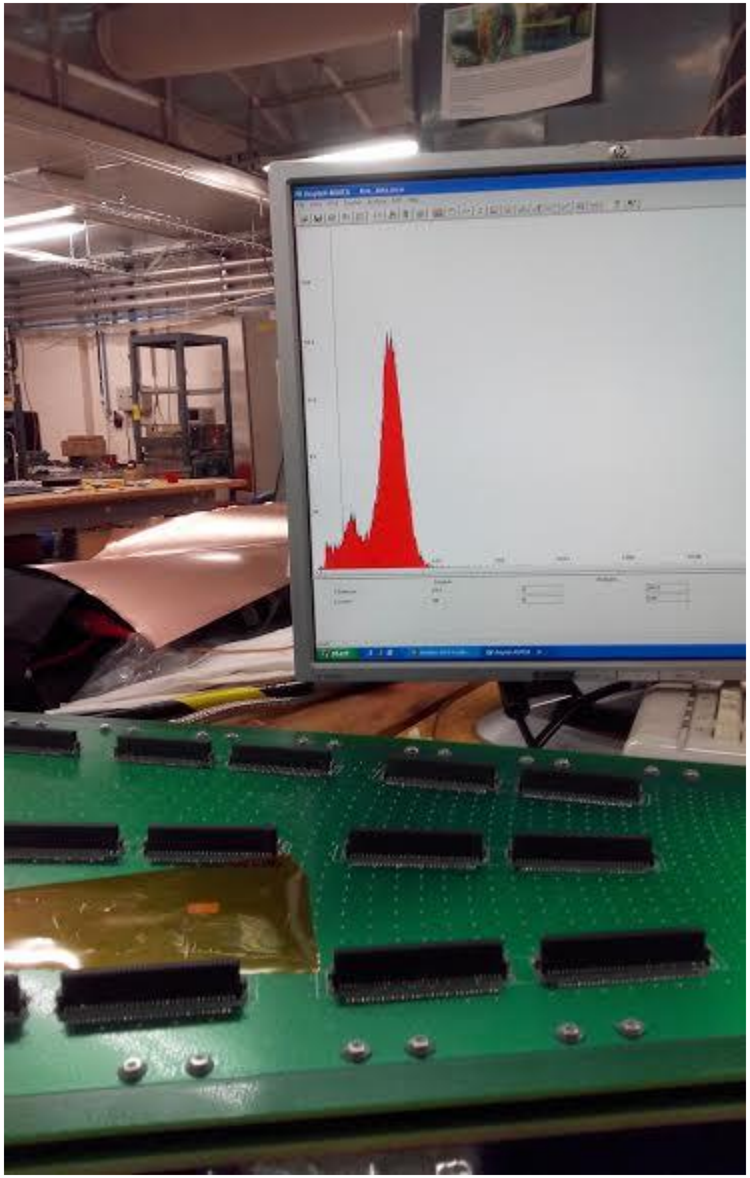
# Module Assembly schematic



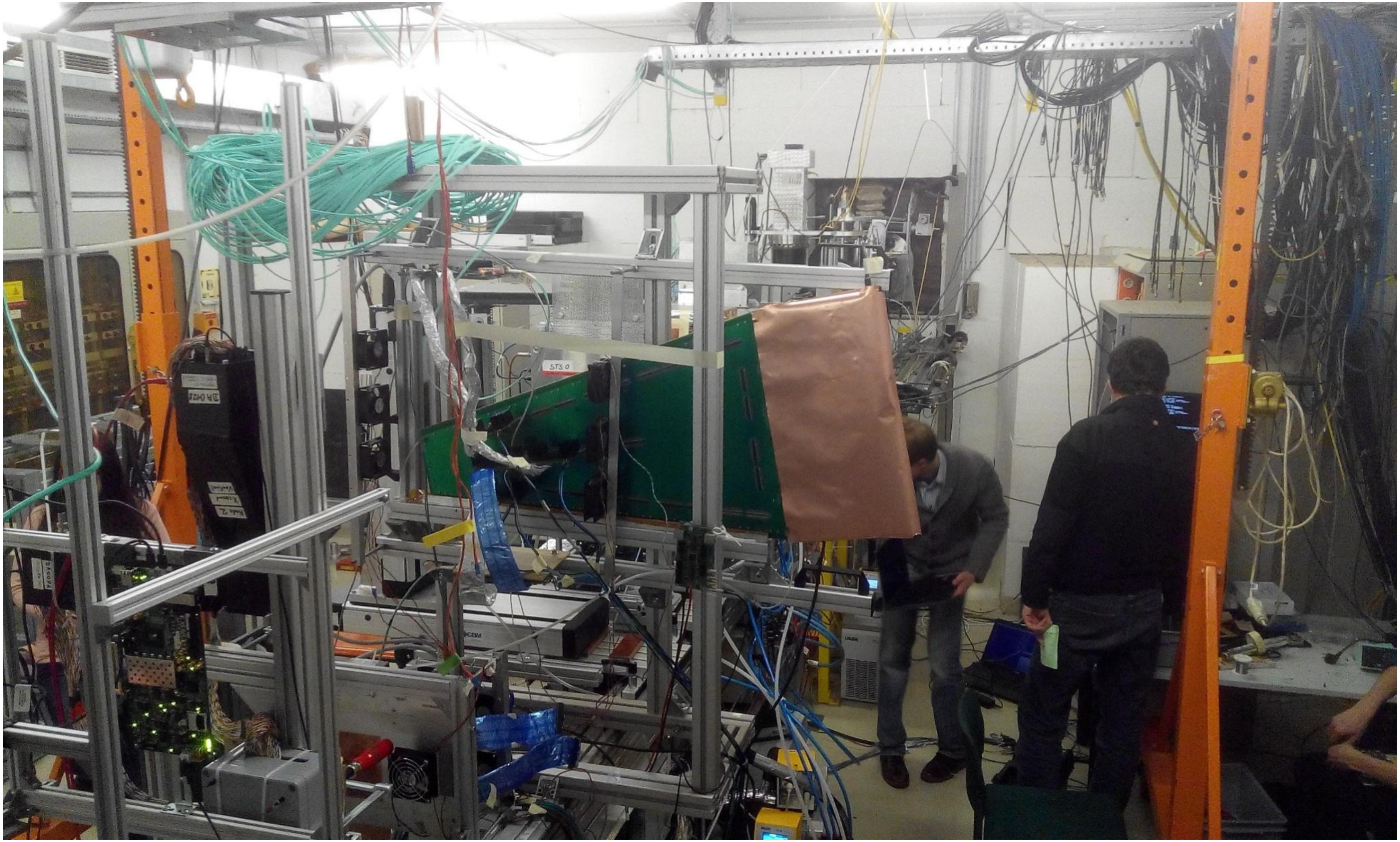
# GEM foils for Real-size prototype

# Response of the real size prototype to Fe55 X-rays

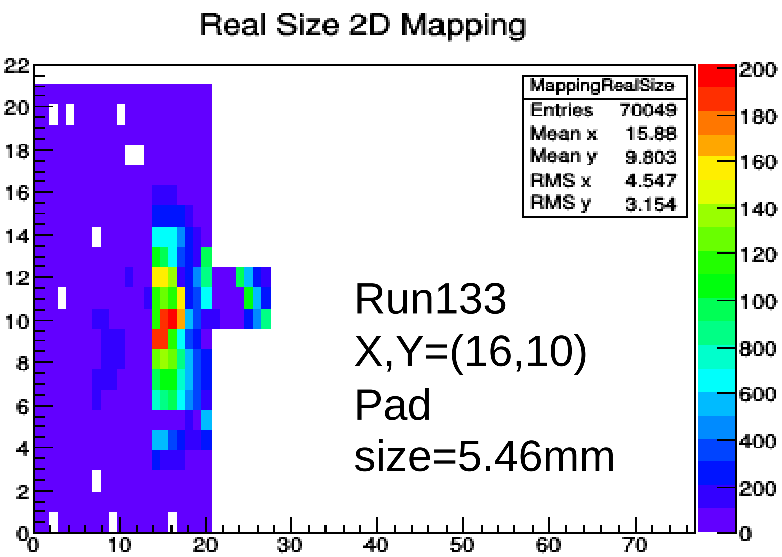


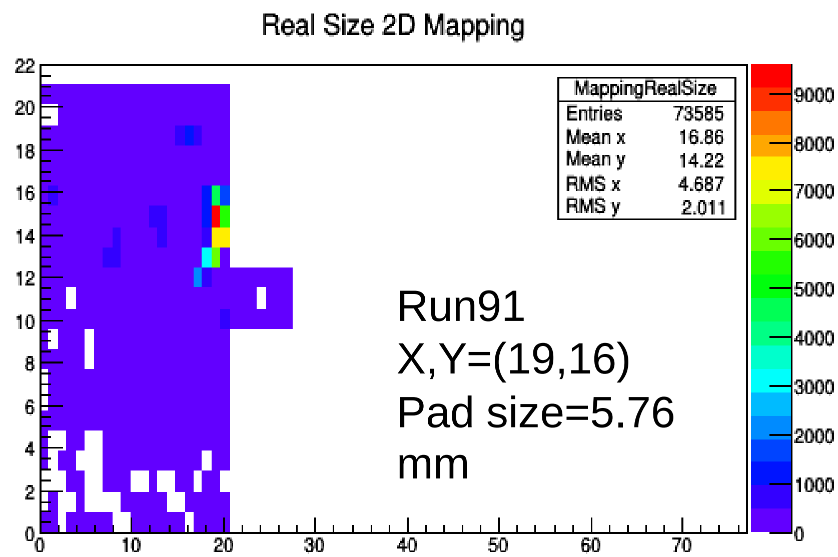


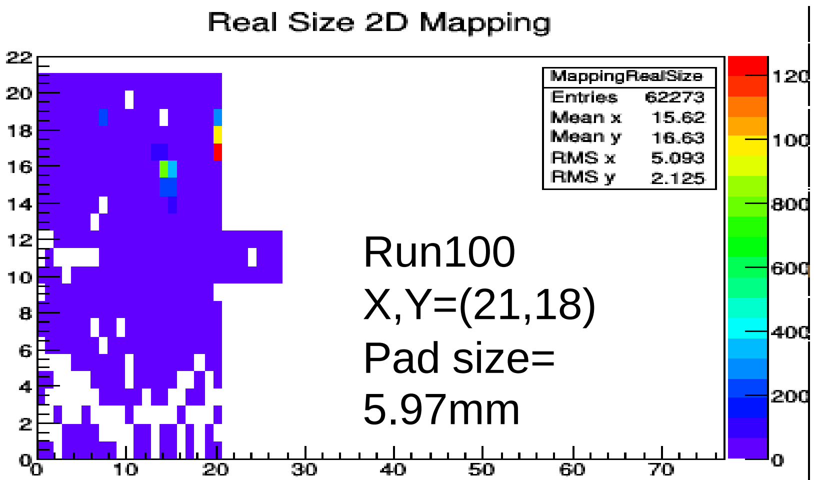
# Beamtest of real size prototype at JESSICA@COSY, Juelich

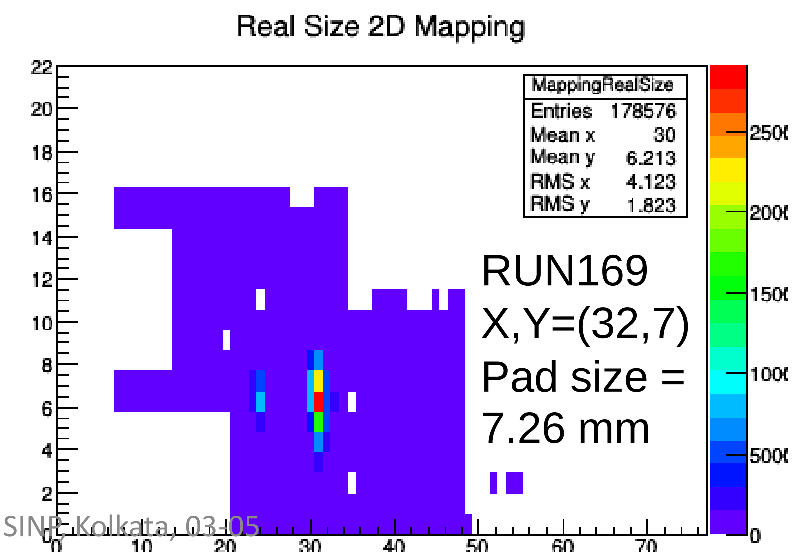


# Beam spots at different positions of the prototype

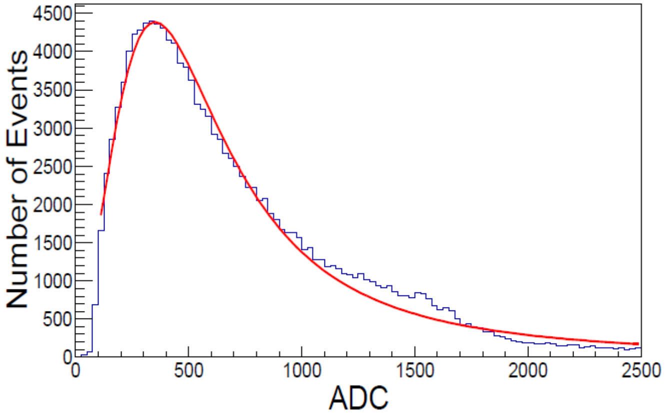


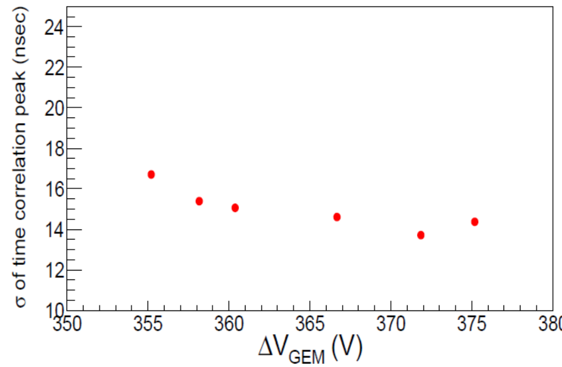



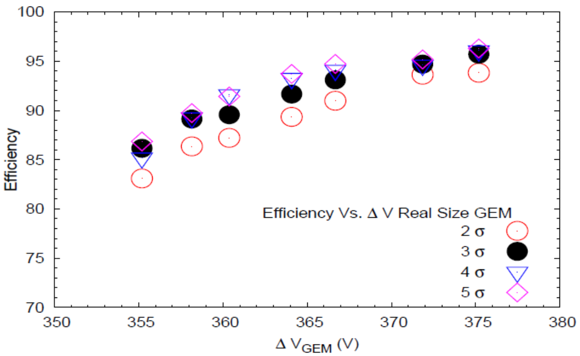



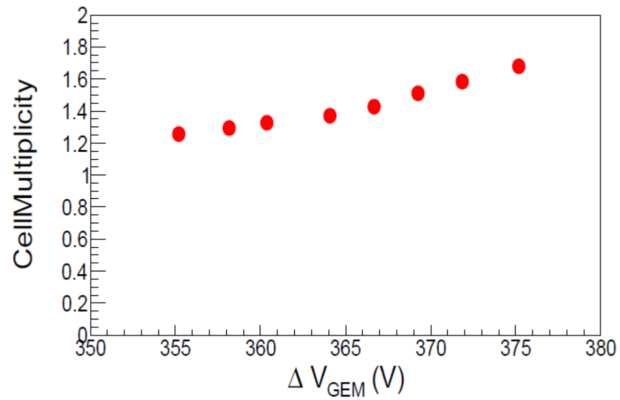



# Test Results of Real Size Prototype

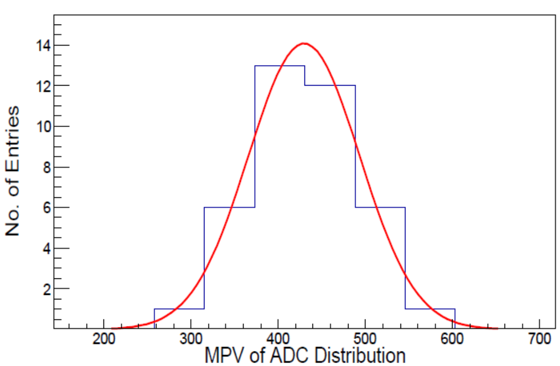


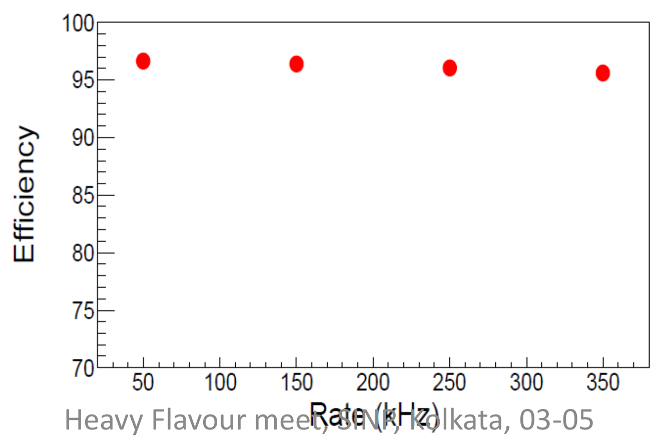




**-- a gain uniformity of < 15 % observed**





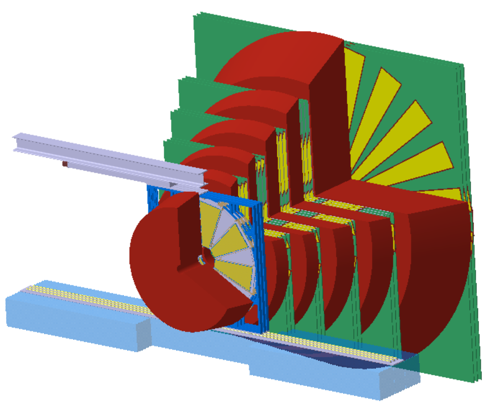

R. Adak, Bose Institute, Kolkata

Compressed Baryonic Matter Experiment

# Technical Design Report for the CBM

## Muon Chamber (MUCH)

The CBM Collaboration



December 2013

**Technical Design Report**
**Submission for internal review: 21/10/13**
**Review: 7-8 Nov 2013**

**Submitted to FAIR: December 2013**

**Approved – December 2014**

( VECC + 12 Indian Institutes, GSI Darmstadt, PNPI Gatchina, JINR Dubna )

# Summary

- Dimuon measurement is at the core of the CBM physics program
- Feasibility studies performed for a layout with
  segmented absorber and detector triplets
- Different detector technologies will be implemented at different stations
- SIS100 layout R&D completed, can be extended to SIS300 chambers
- First Real size Prototype using "ns2" stretching assembled and tested successfully with proton beams and using self triggered nXYTER electronics. New radiation hard chip for actual experiment would be available soon.
- Mechanical design underway for superstructure and detector chambers.
- GEM module production may start early next year.

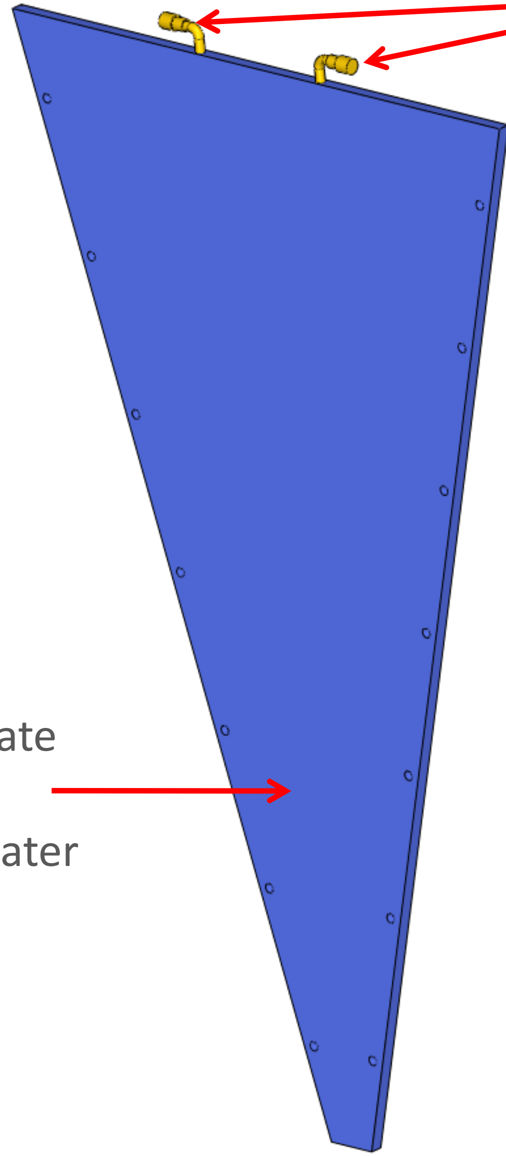
# Thank You

- 
- BACKUPS

# Experiments exploring dense nuclear matter

| Experiment | Energy $\sqrt{s_{NN}}$ (Au/Pb beams) | Observables | Reaction rates Hz |
|---|---|---|---|
| STAR@RHIC BNL | 7 – 200 GeV | hadrons, electrons, muons | 1 – 800 (limitation by luminosity) |
| NA61@SPS CERN | 6.4 – 17.4 GeV | hadrons | 80 (limitation by detector) |
| HADES@SIS18 GSI | < 2.4 GeV | electrons, hadrons | $2 \cdot 10^4$ (limitation by detector) |
| Future/planned Experiments: | | | |
| CBM@SIS FAIR | 2.7 – 4.9 GeV<br>2.7 – 8.3 GeV | hadrons, electrons, muons | $10^5 – 10^7$ (limitation by detector) |
| MPD@NICA Dubna | 4.0 – 11.0 GeV | hadrons | 100 - 1000 (limitation by luminosity) |

# Cooled plate for FEB cooling



Chilled water In/Out connections

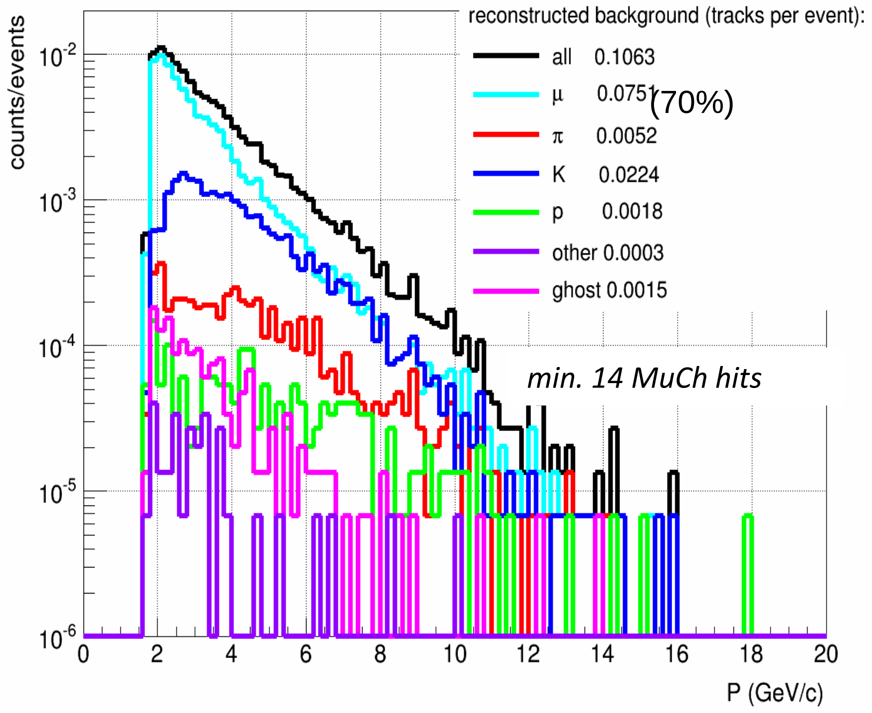
8mm thick Alluminum plate with internal channel for water flow

# Background - muons

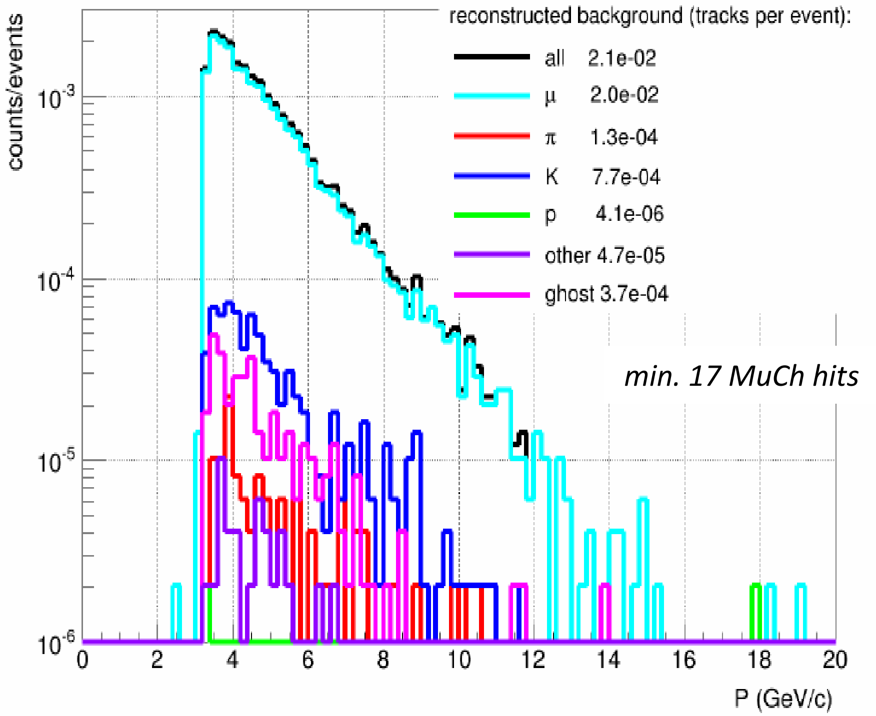
Particles identified as muons = reconstructed after MUCH (25 AGeV central Au+Au)

- Total number allows for a trigger also for LMVM

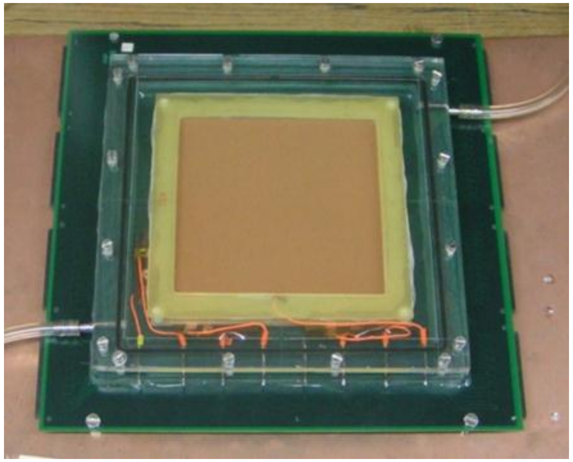
LMVM setup (no TOF)



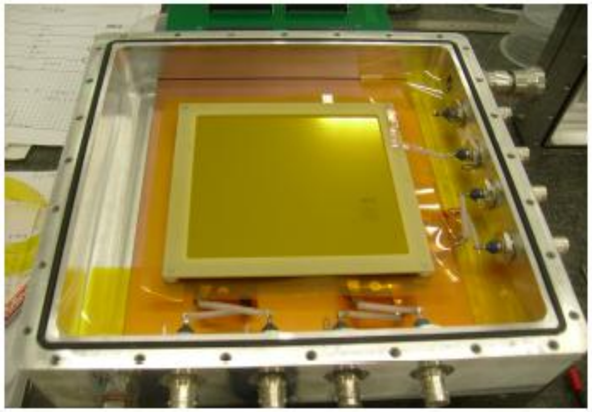

J/ψ setup (no TOF)



# Picture of the triple GEM prototype chambers



built at VECC



built by GSI Colleagues

(GEMS stretched and framed at GSI)

| Parameter | GEM chamber (VECC) | GEM chamber (GSI) |
|---|---|---|
| Drift gap | 3 mm | 3 mm |
| Transfer gap-1 | 1 mm | 2 mm |
| Transfer gap-2 | 1 mm | 2 mm |
| Induction gap | 1.5 mm | 2 mm |
| Segmentation | 3 mm x 3 mm | 6 mm x 6 mm |
| Number of pads | 512 | 256 |

# CBM @ SIS-100 & SIS-300

**The first years of CBM operation will be at SIS-100 with a start setup**

| Beam | $p_{lab, max}$ | $\sqrt{s_{NN, max}}$ |
|---|---|---|
| heavy ions (Au) | 11A GeV | 4.7 GeV |
| light ions (Z/A = 0.5) | 14A GeV | 5.3 GeV |
| protons | 29 GeV | 7.5 GeV |

**CBM at SIS-300**

| Beam | $p_{lab, max}$ | $\sqrt{s_{NN, max}}$ |
|---|---|---|
| heavy ions (Au) | 35A GeV | 8.2 GeV |
| medium ions (In)<br>(Cu) | 38A GeV<br>41A GeV | 8.5 GeV<br>8.9 GeV |
| light ions (Z/A = 0.5) | 45A GeV | 9.3 GeV |
| protons | 90 GeV | 13 GeV |

**…. at interaction rates up to 10 MHz (J/ψ)**