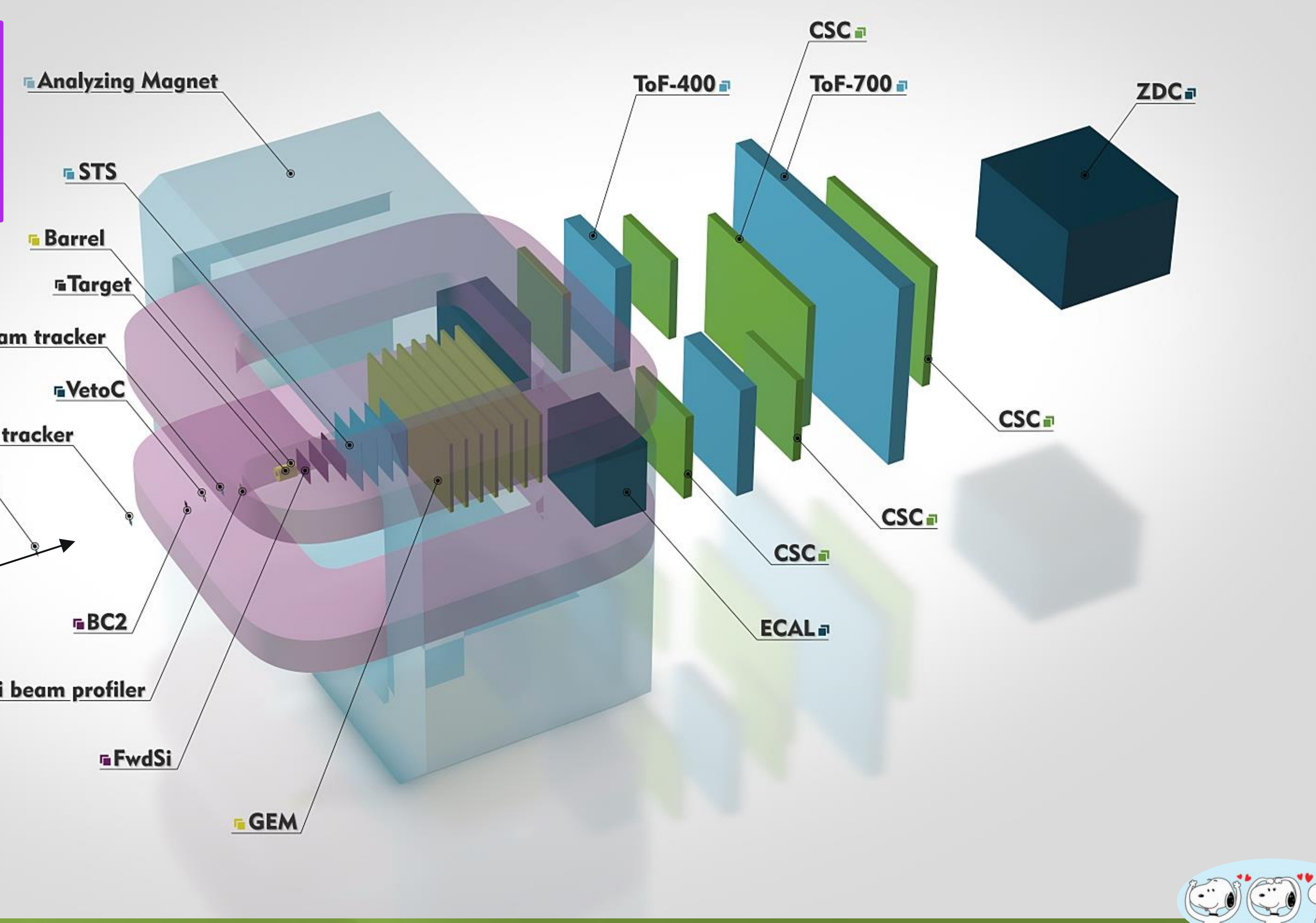
STATUS OF THE GEM/CSC TRACKING SYSTEM OF THE BM@N EXPERIMENT

Elena Kulish on behalf of BM@N Collaboration

BM@N experiment

Collisions of Nuclotron heavy ion beams with fixed targets provide a unique opportunity to study strange mesons and multi-strange hyperons close to the kinematic threshold. One of the main goals of the experiment is to measure yields of light hyper-nuclei, which are expected to be produced in coalescence of Λ-hyperons with nucleons.

Parameters of Nuclotron for BM@N experiment:
E_{beam} = 1-6 GeV/n;
beams: from **p** to **Au**;
Intensity ~10^7 c^{-1} (Au)



Basic requirements for the BM@N tracking system

BM@N advantage: large aperture magnet (~1 m gap between poles) → fill aperture with coordinate detectors, which sustain high multiplicities of particles.

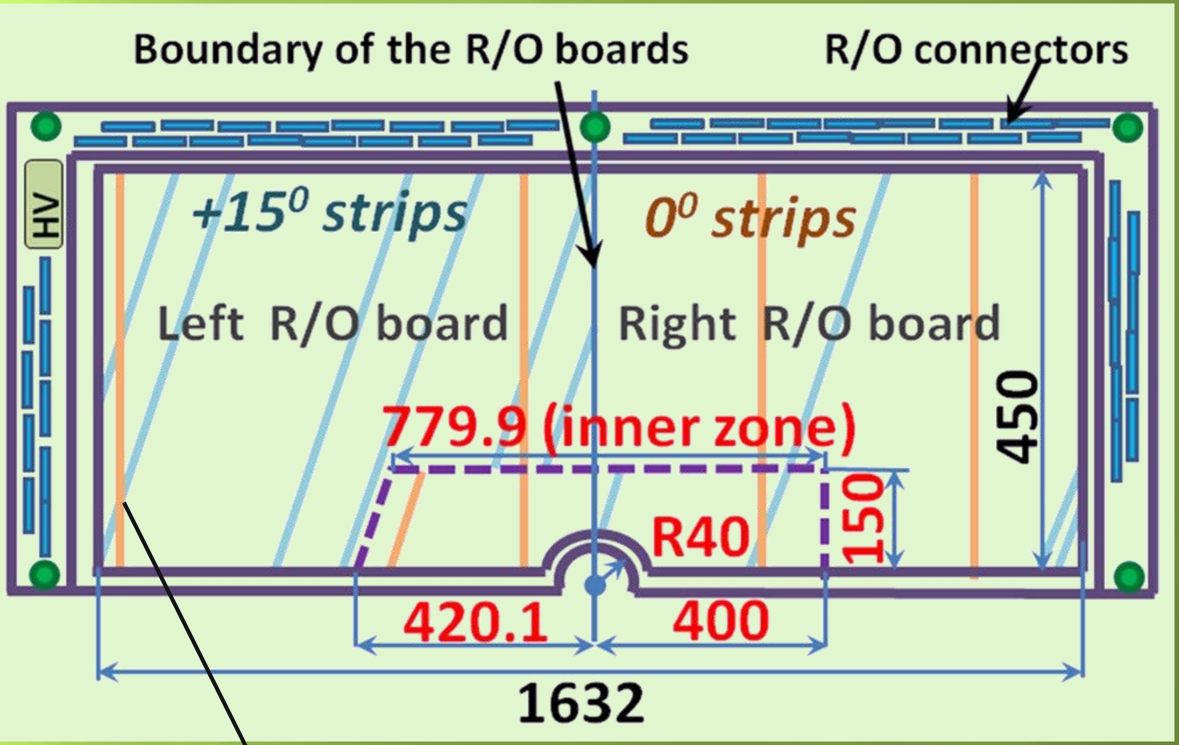
Divide detectors (downstream the magnet) for particle identification to "near to magnet" and "far from magnet" to measure particles with low as well as high momentum → fill distance b etween magnet and "far" detectors with coordinate detectors

The basic requirements for the tracking system are:
- capability of stable operation in conditions of high loadings up to 10^5Hz/cm^2;
- high spatial and momentum resolution;
- high geometrical efficiency (better than 95%);
- maximum possible geometrical acceptance within the BM@N experiment dimensions;
- capability to function in a 0.8 T magnetic field.

Central tracker inside the analyzing magnet to reconstruct AA interactions:
- **Si micro-strip sensors** for vertex reconstruction
- **GEM planes** for track momentum reconstruction

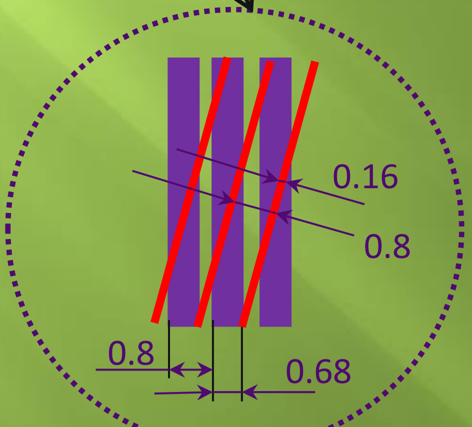
Outer tracker downstream the magnet:
- **CSC** to precise parameters of tracks, obtained in GEM's, to find corresponding hits in time-of-flight systems (ToF400 and ToF700).

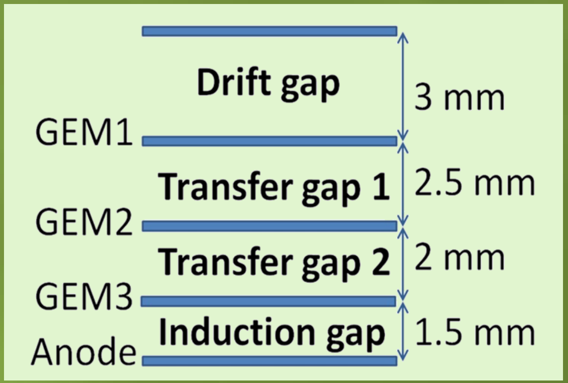
BM@N triple GEM 1632×450 mm² detectors



6365 strips

50 R/O connectors

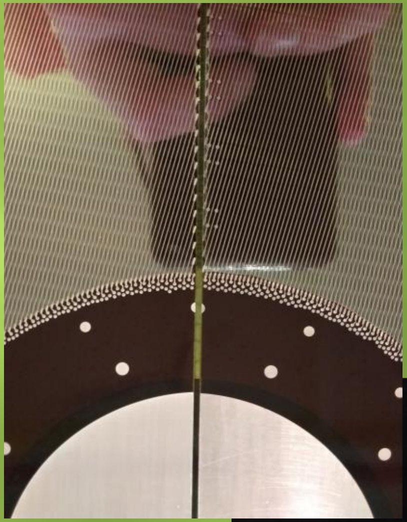




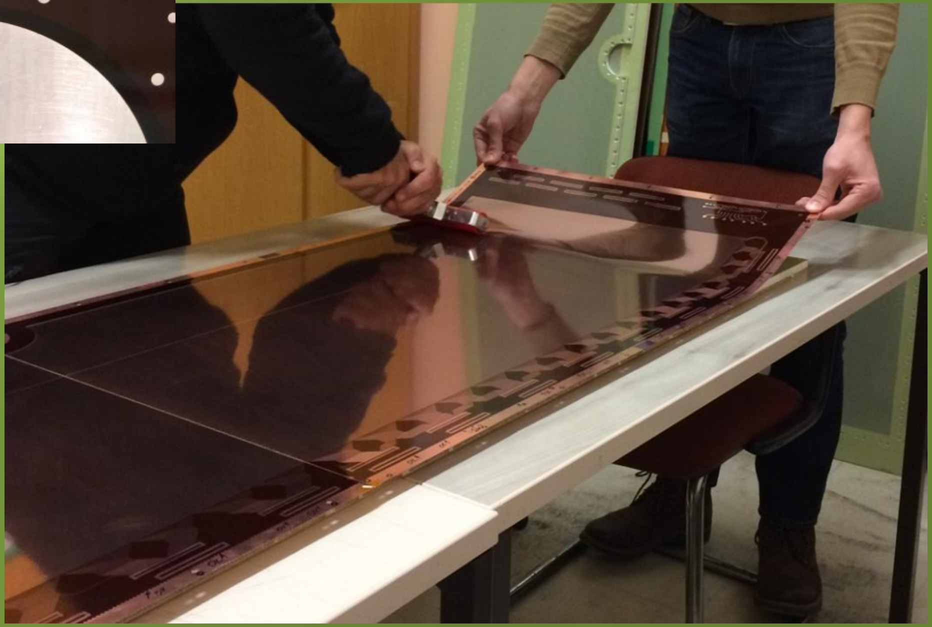
Schematic cross section of BM@N triple GEM detector

Readout board preparation at CERN Workshop

Right readout board

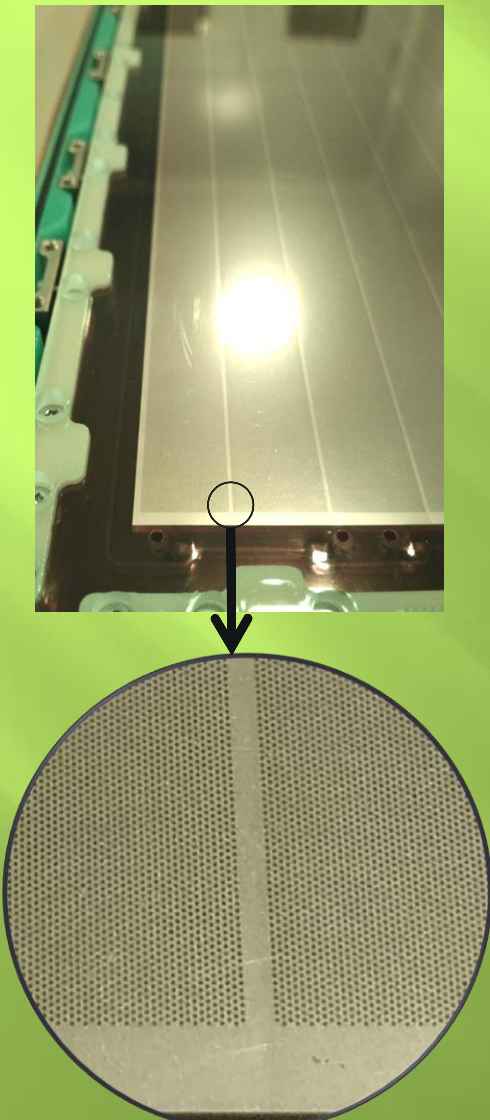


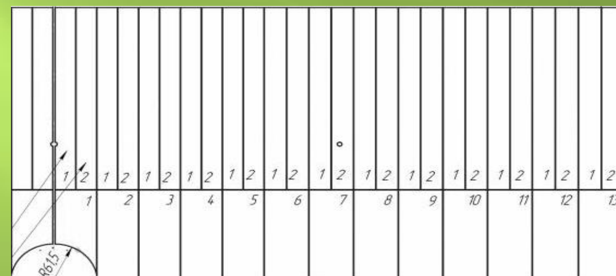
Alignment of two halves



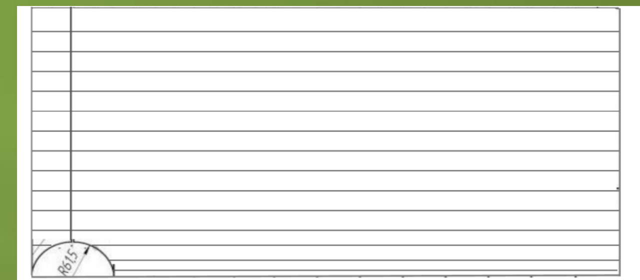
Gluing of the readout boards
on the honeycomb support plane

GEM foil sector design and occupancy

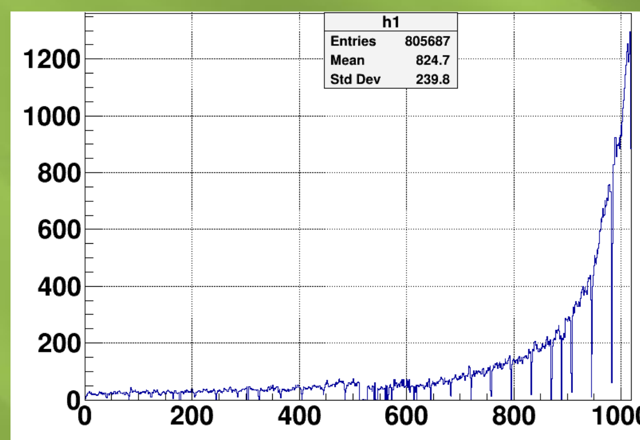




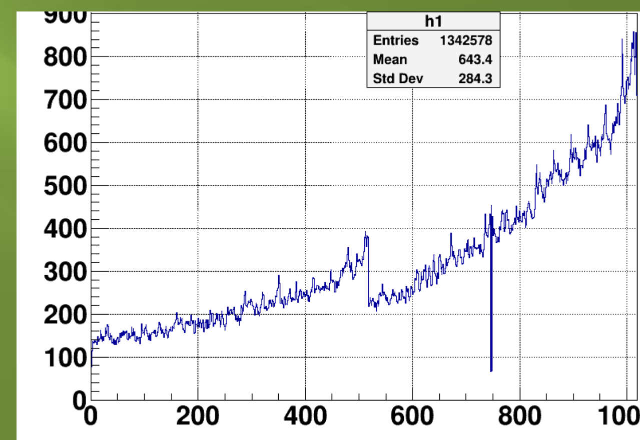
Vertical sectors



Horizontal sectors



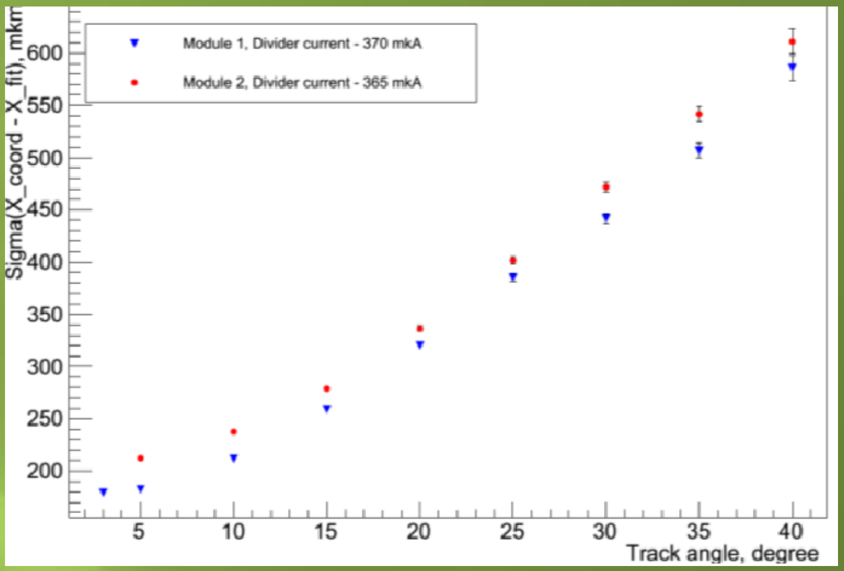
X occupancy



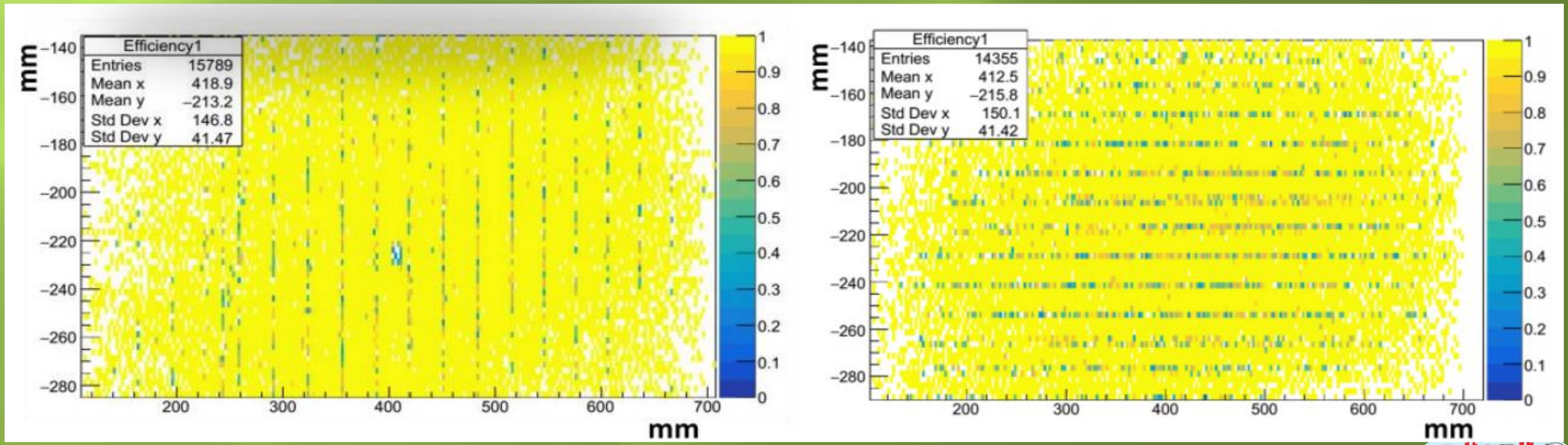
X occupancy

GEM cosmic tests

Cosmic stand

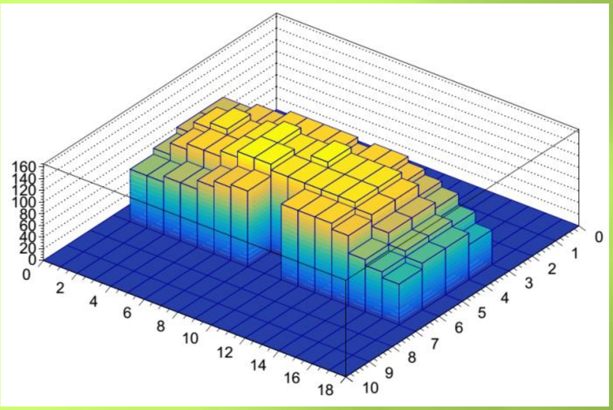
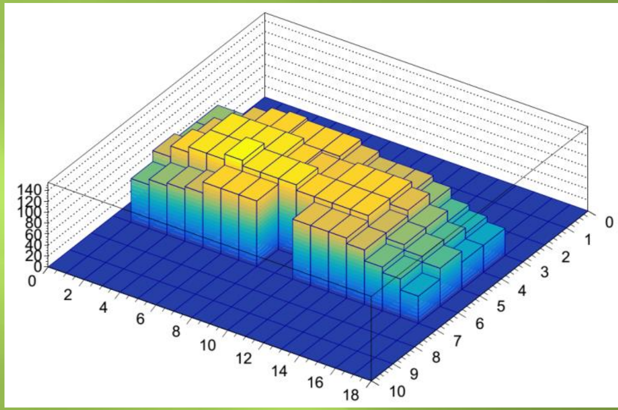
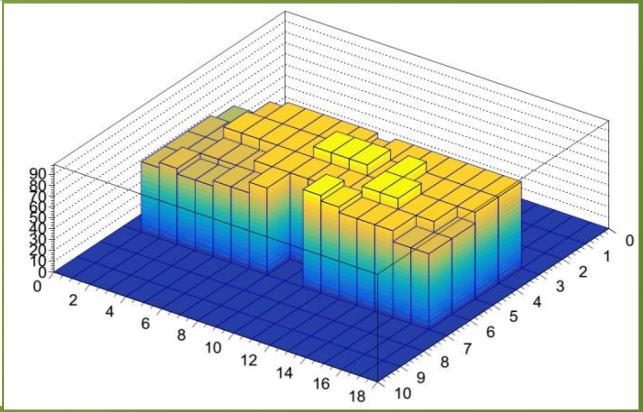


GEM residuals vs track angle

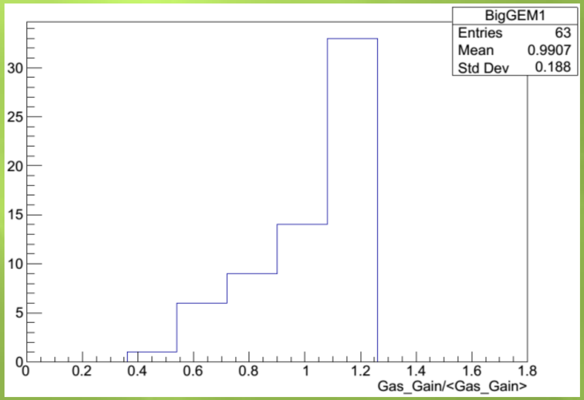


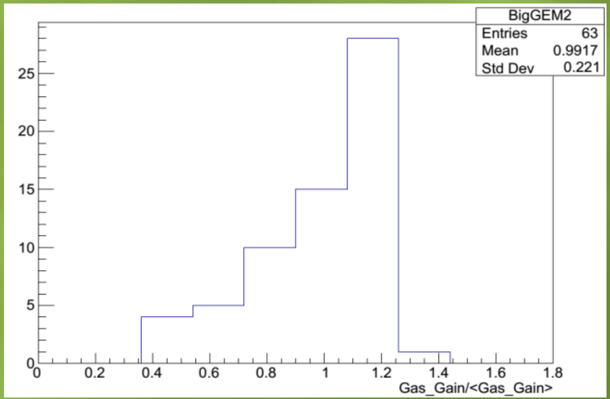
GEM geometrical efficiency

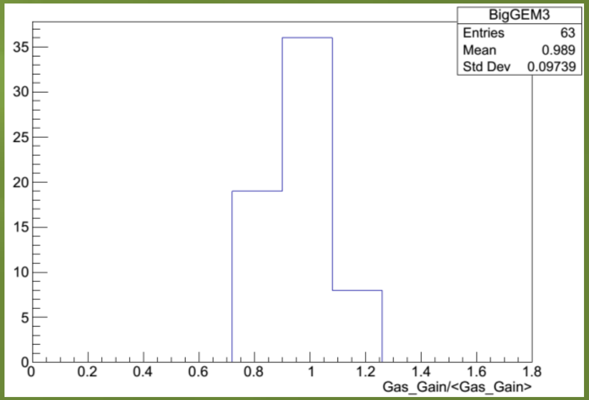
GEM 1632×450 mm^2 response uniformity

Response uniformity 3D plot of three 1632×450 mm^2 chambers, Ar(90)/Isobutane(10) gas mixture



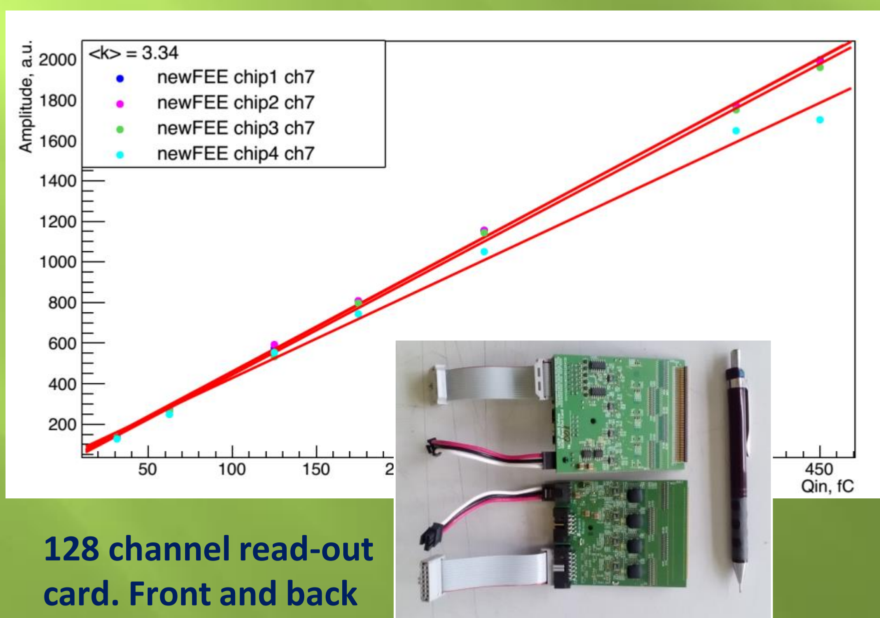




Gas gain distribution normalized on average gas gain for three 1632×450 mm^2 chambers, Ar(90)/Isobutane(10) gas mixture

GEM and CSC front-end electronics

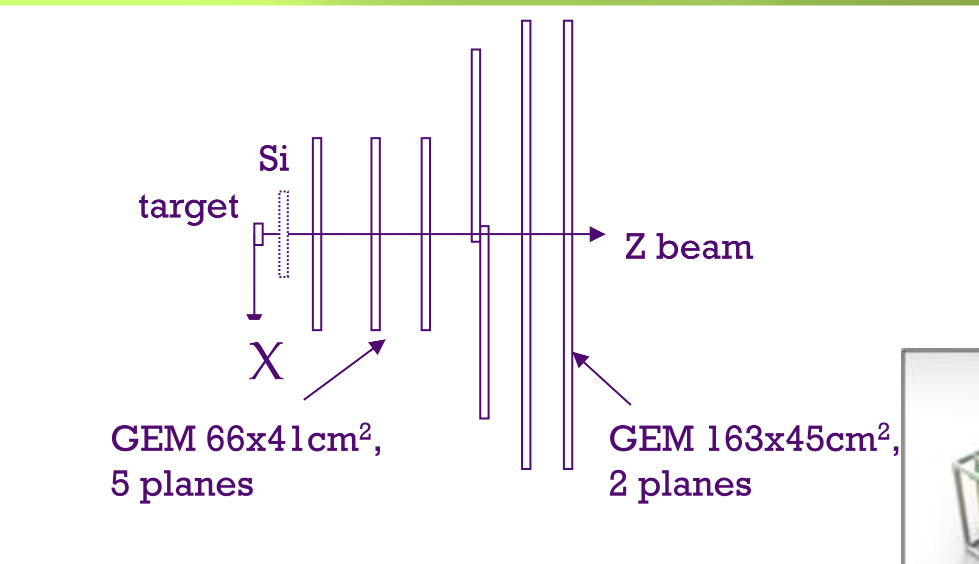
	VA162	VA163
Number of channels	32	32
Input charge	-1.5pC ÷ +1.5fC	-750fC ÷ +750fC
Shaping time	**2÷2.5µs**	**500ns**
Noise	2000e ENC at 50pF load	1797e ENC at 120pf load
Linearity positive charge	1%	0.5%
Linearity negative charge	3%	1.4%
Gain	0.5 µA/fC	0.88µA/fC
Total power max.	66mW	77mW



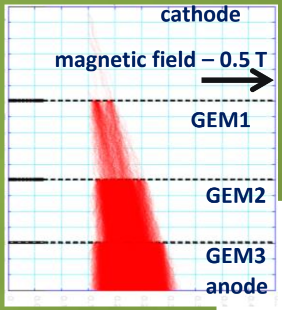
128 channel read-out card. Front and back side view

Plans: development and tests of FEE based on VMM3a/TIGER ASICs

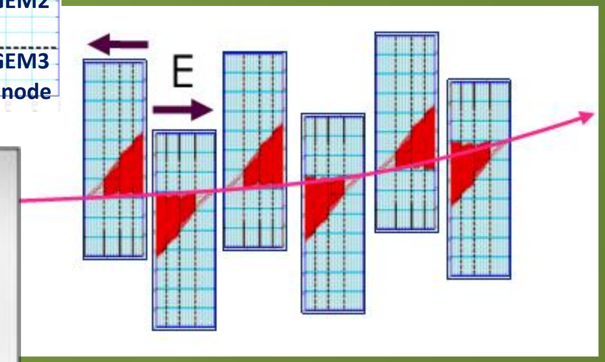
GEM tests at Nuclotron deutron beam

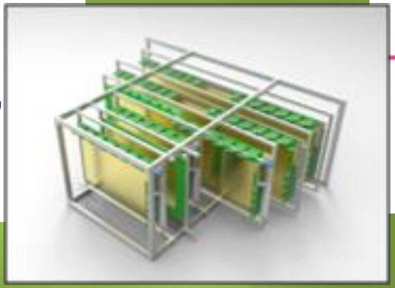


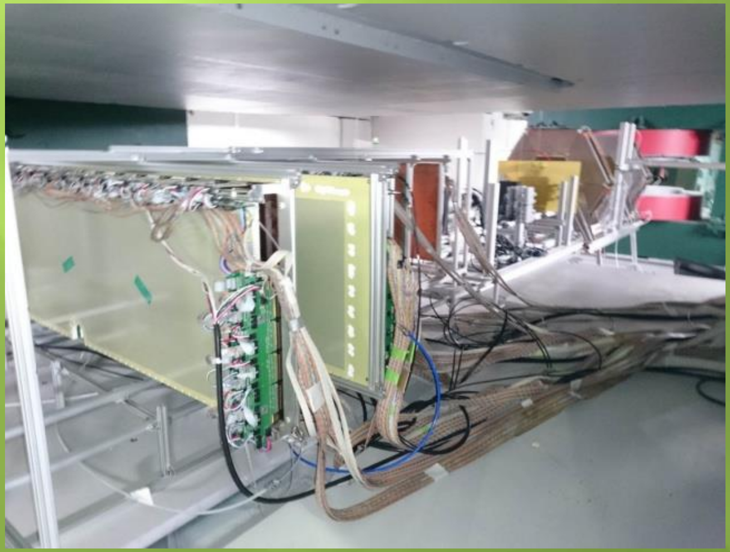
GEM configuration

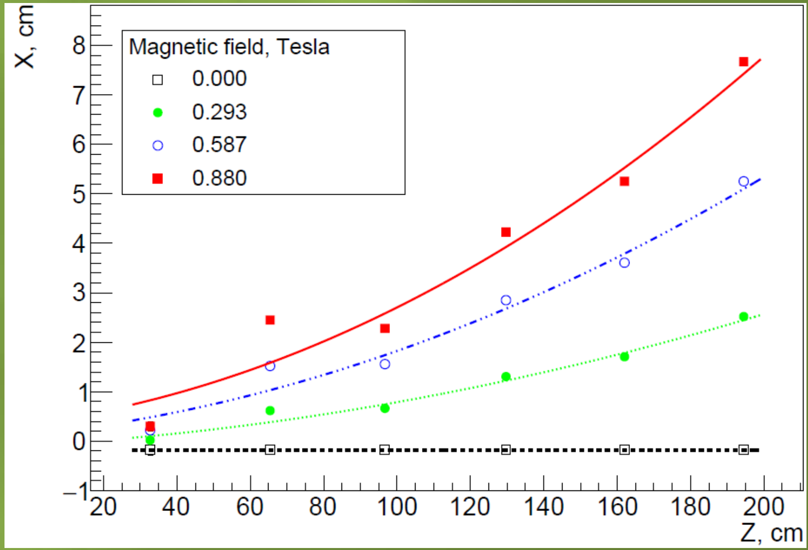


Avalanche for the triple GEM cascade in magnetic field of 0.5 T (Garfield simulation)





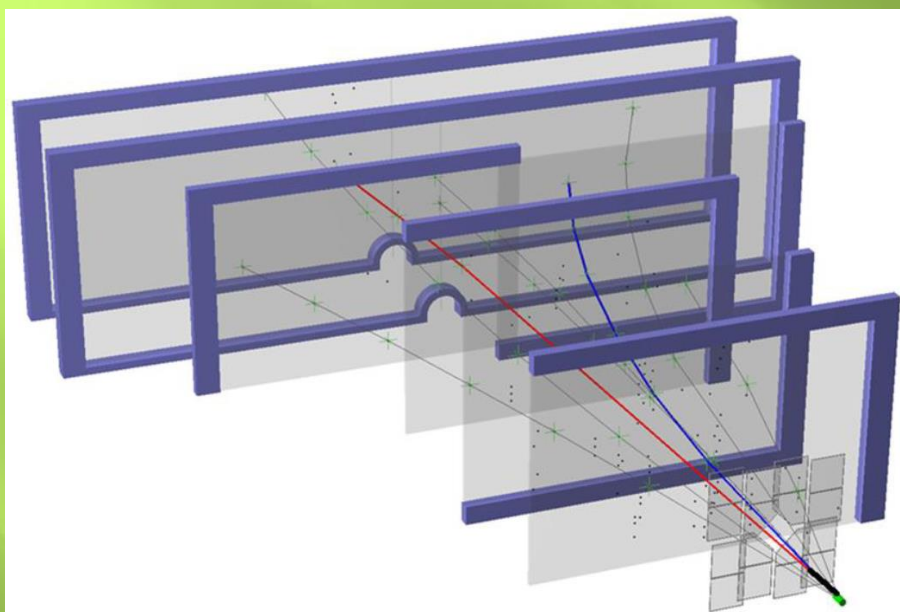


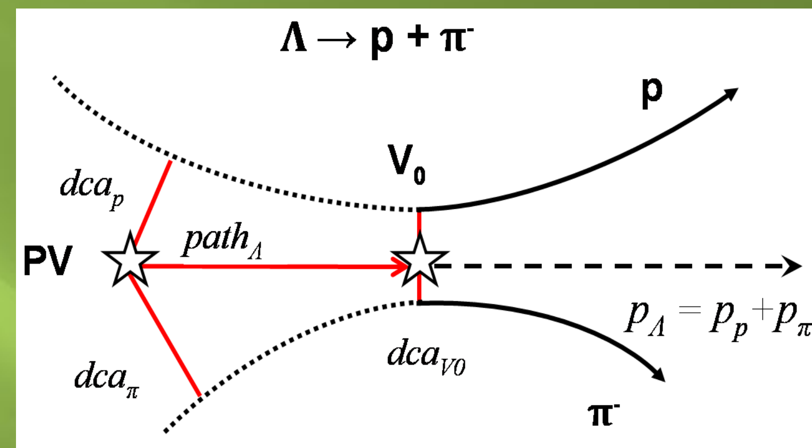


The average trajectories of the deuteron beam and the average Lorentz shifts of an electron avalanche in 6 GEM planes measured for four values of the magnetic field.

Λ hyperon production in 4 GeV/n Carbon-nucleus interactions

$\Lambda \rightarrow p\pi^-$ decay reconstruction in Si+GEM tracker in C+C interaction



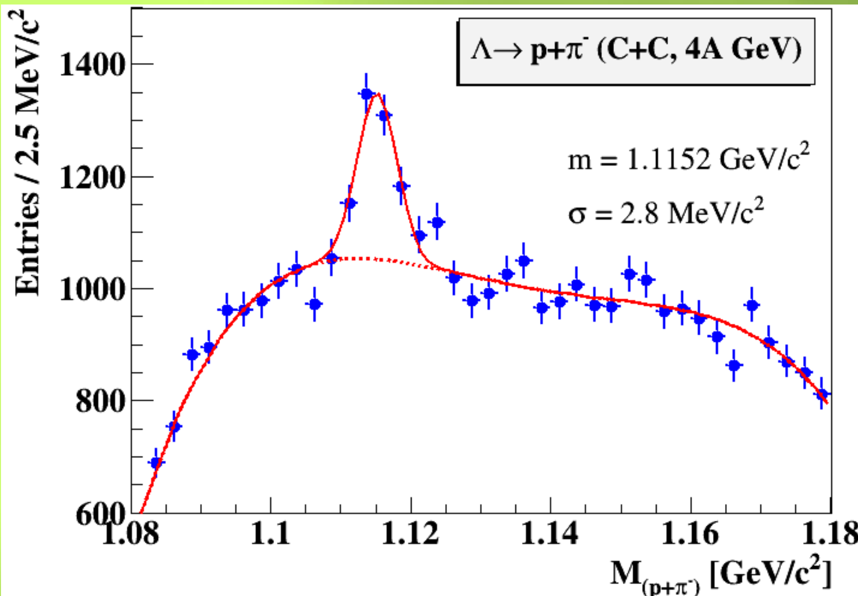


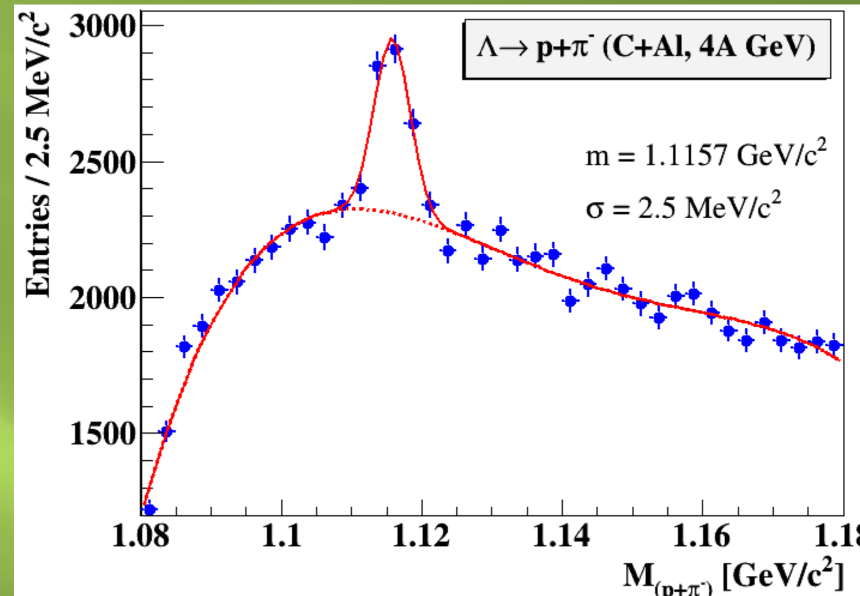
Event topology:

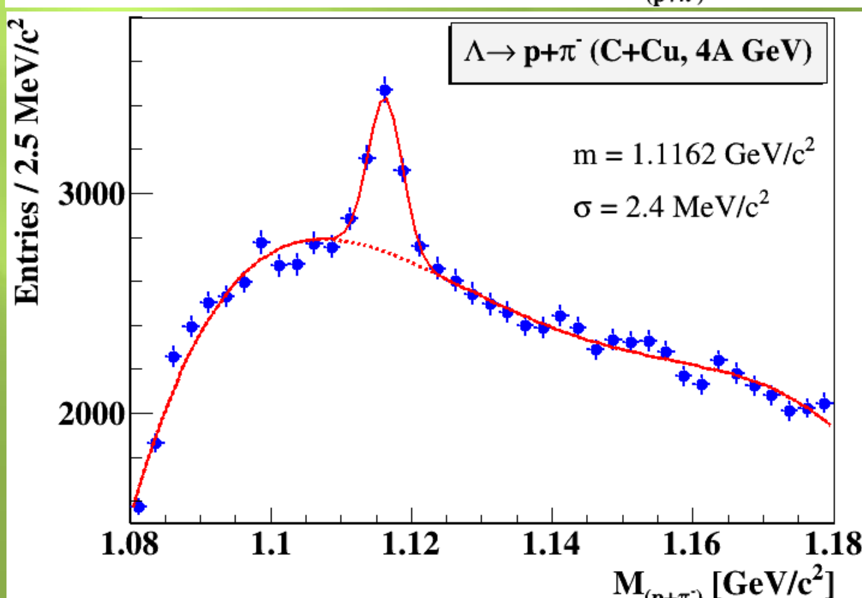
- ✓ PV – primary vertex
- ✓ V_0 – vertex of hyperon decay
- ✓ *dca* – distance of the closest approach
- ✓ *path* – decay length

Analysis without PID

Λ hyperon signals in 4 GeV/n Carbon-nucleus interactions





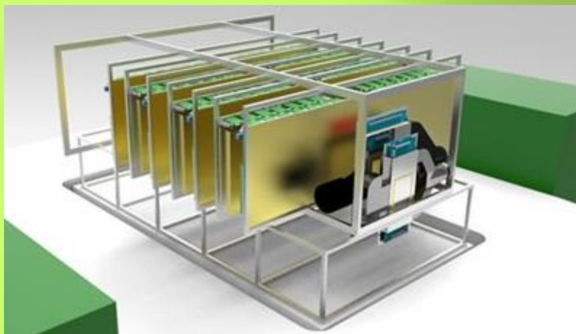


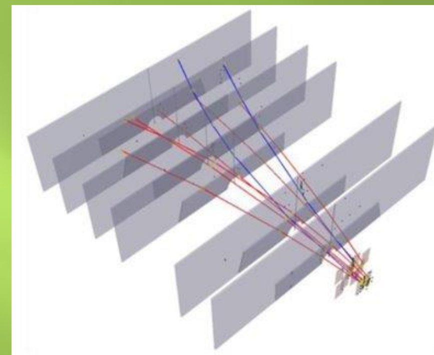
C beam 4 GeV/n
C + C, Al, Cu → Λ + X minimum bias
Λ signal width 2.4 – 3 MeV

C+C: 4.6M triggers
C+Al: 5.3M triggers
C+Cu: 5.3M triggers

2.5 days of data taking

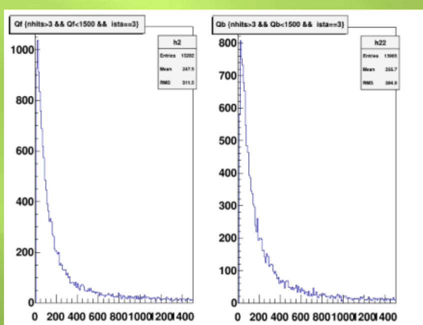
GEM central tracking system performance at Ar and Kr beams (March 2018)



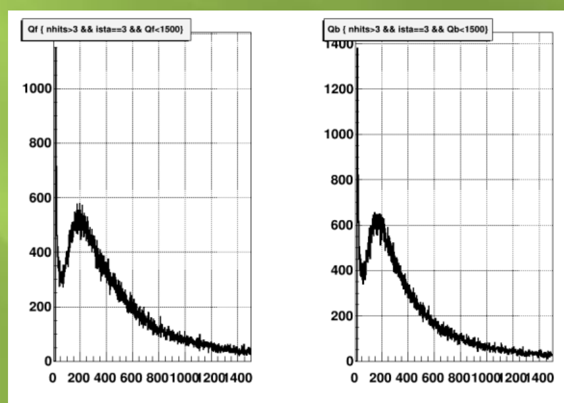


Seven GEM 1632x450 mm^2 chambers produced at CERN workshop were integrated into BM@N experimental setup.

Pile-up suppression in Ar, Kr runs: 3 µs before and 0.5 µs after trigger signal

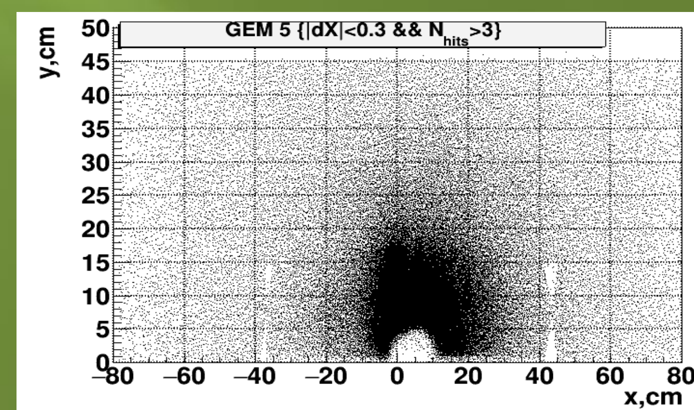


Ampl., ADC counts   Ampl., ADC counts



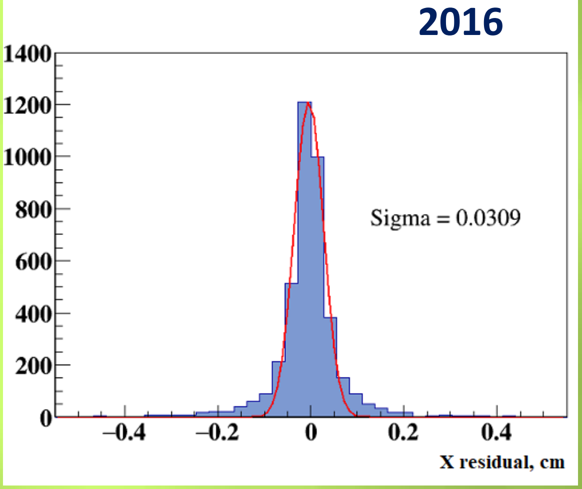
Ampl., ADC counts   Ampl., ADC counts

Fragments of Ar beam in one of the GEM chambers

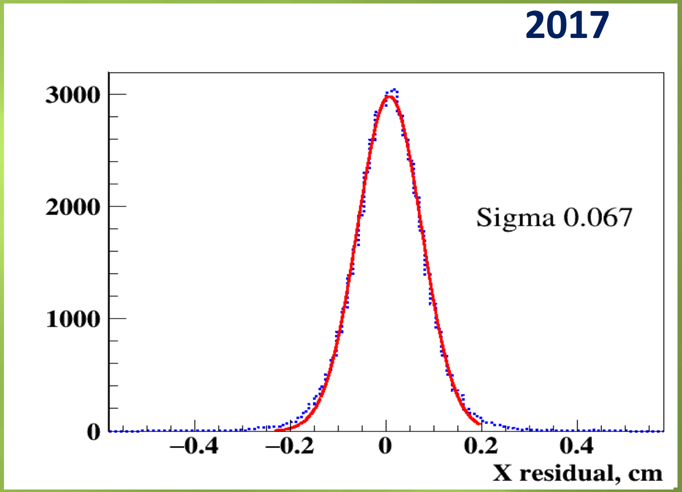


GEM X&Y track amplitude distributions for the station 3

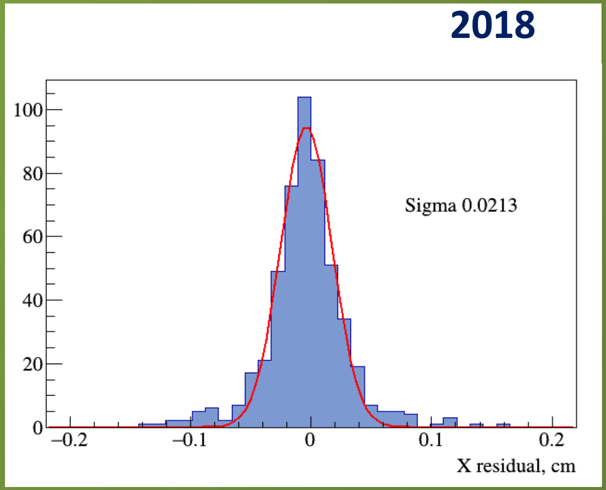
GEM hit residuals in magnetic field



Magnetic field 0.6 T,
Ar(70)/CO2(30),
C beam, E_{drift} = 1.2 kV/cm
σ = 309 μm



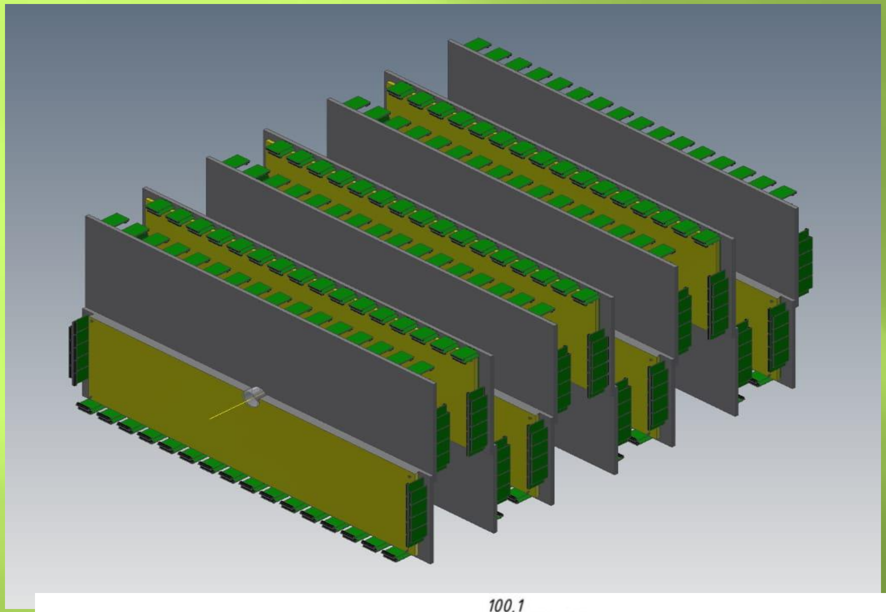
Magnetic field 0.6 T,
Ar(90)/Isobutane(10),
d beam, E_{drift} = 0.8 kV/cm
σ = 670 μm

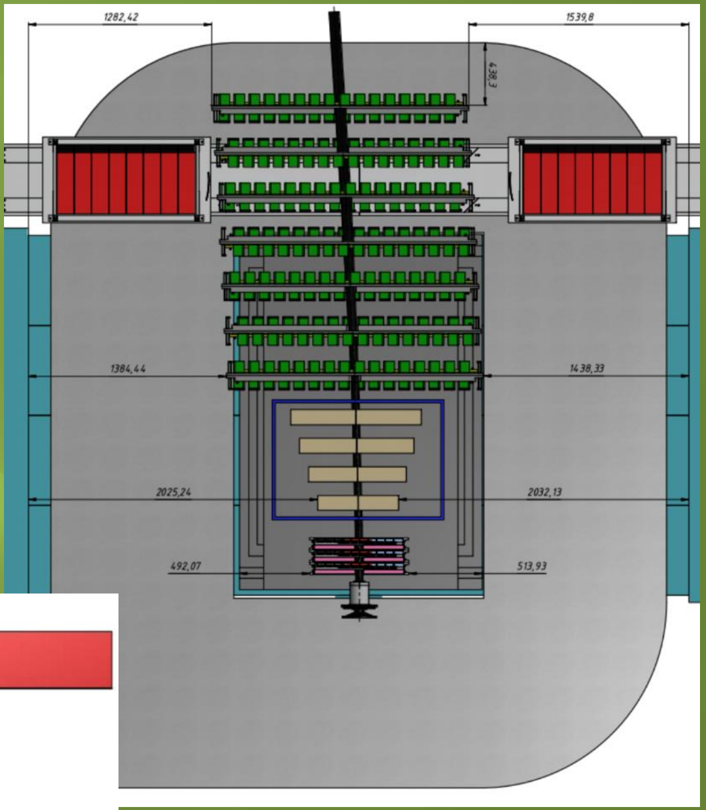


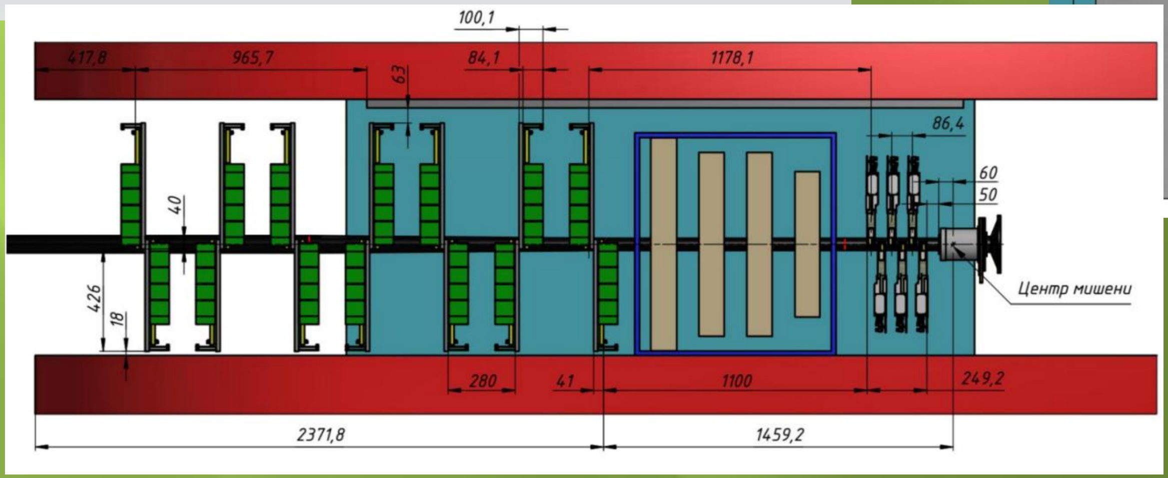
Magnetic field 0.6 T,
Ar(80)/Isobutane(20),
Ar beam, E_{drift} = 1.5 kV/cm
σ = 213 μm

In Ar and Kr runs the value of electric field in drift gaps of GEM chambers was increased. The gas mixture was changed to Ar(80)/Isobutane(20). The Lorentz shift of electrons avalanche was decreased.

Scheme of the GEM full planes configuration inside the magnet

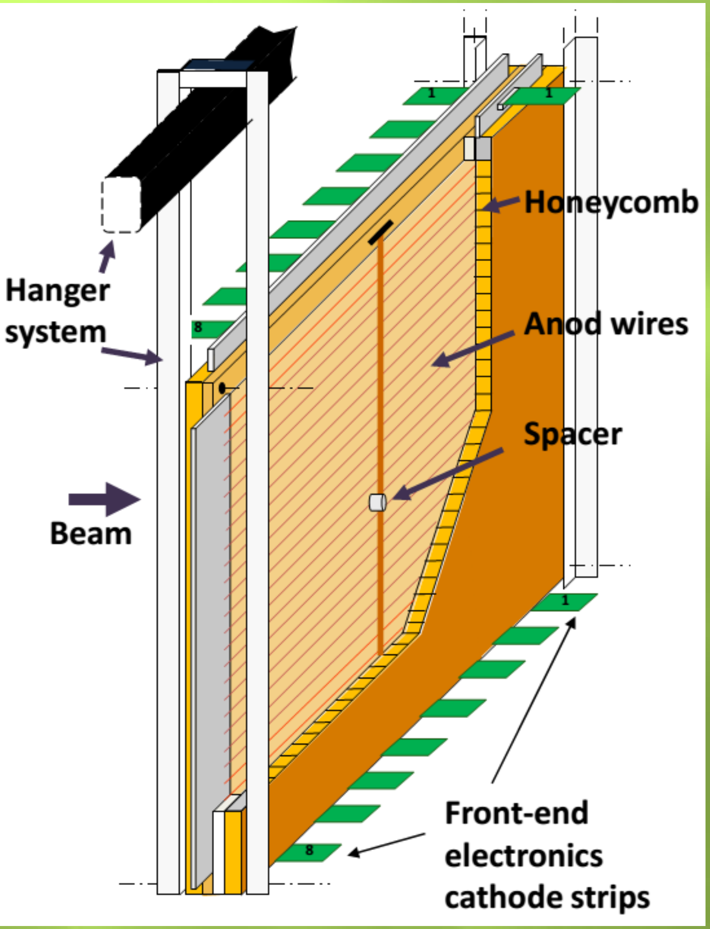


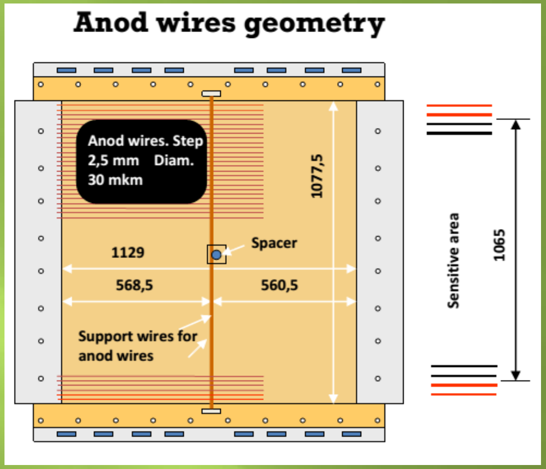


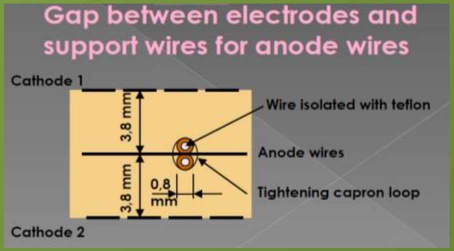


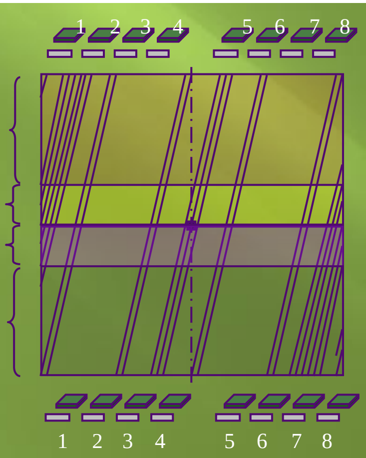
Full configuration for heavy ion beam program is planned on 2023

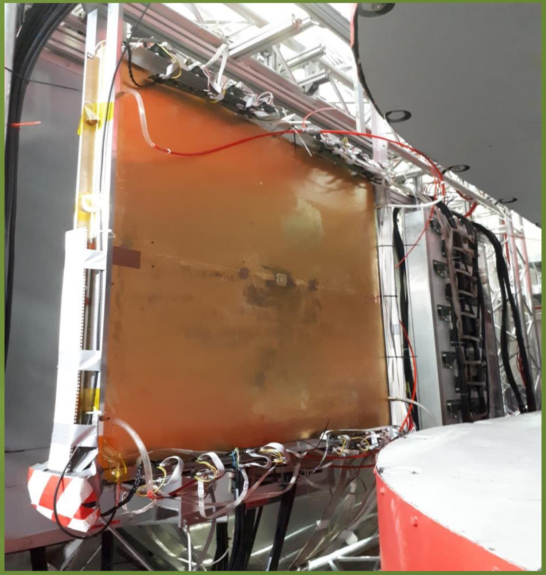
First CSC 1065×1065 mm²







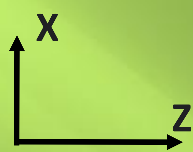




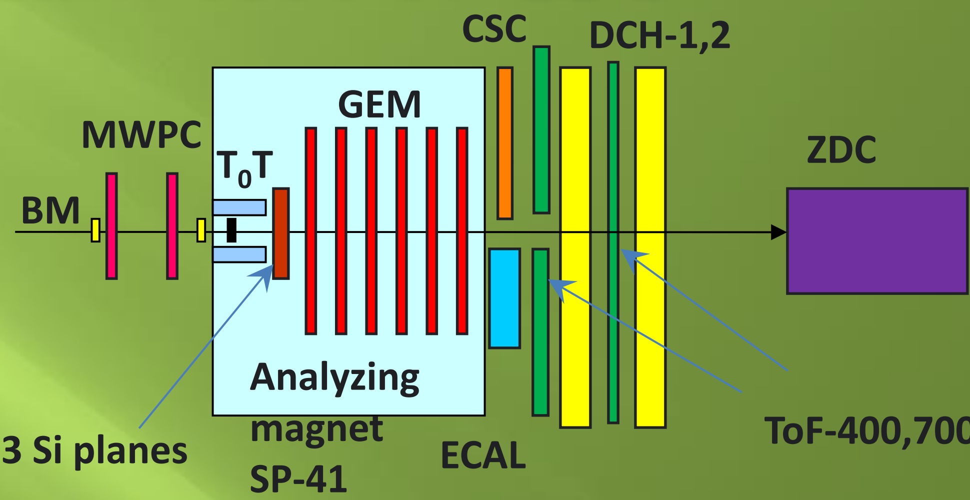
One CSC 1065×1065 mm² is produced and tested at Nuclotron beam.
Plans for 2020:
- **assembly of the three 1065×1065 mm² chambers**
- **assembled chambers are to be tested with r/a source and at cosmic stand**

First beam test of CSC

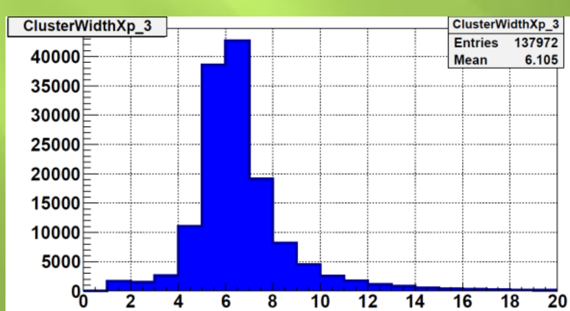
Ar beam, T_0= 3.2 GeV/n



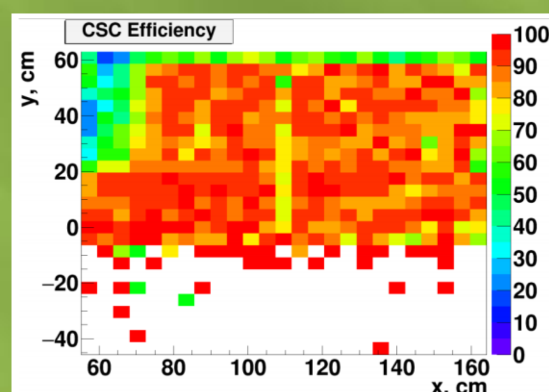
Kr beam, T_0= 2.4 (2.9) GeV/n



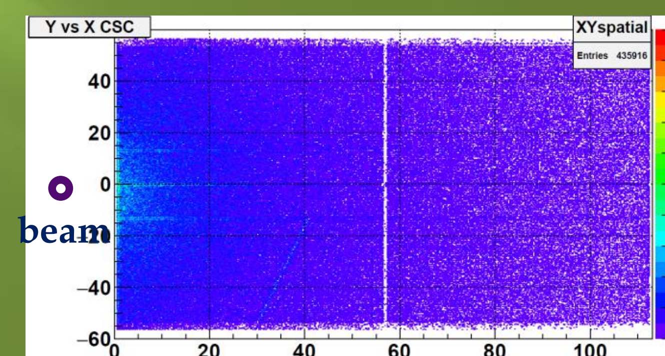
C, Ar and Kr runs in March 2018: CSC chamber is installed in front of ToF-400 to check its performance as outer tracker for heavy ions



Cluster width



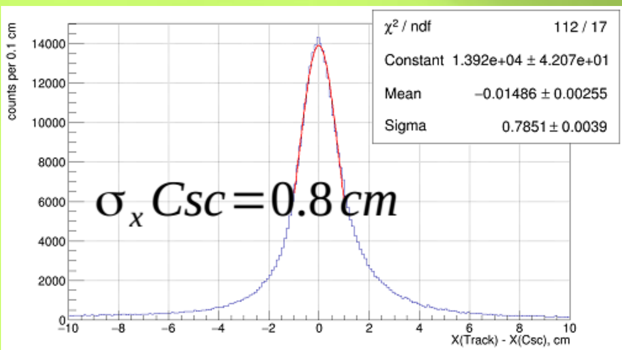
CSC efficiency in Ar run
Track extrapolated from GEM
Residual (CSC_hit – GEM) < 2cm

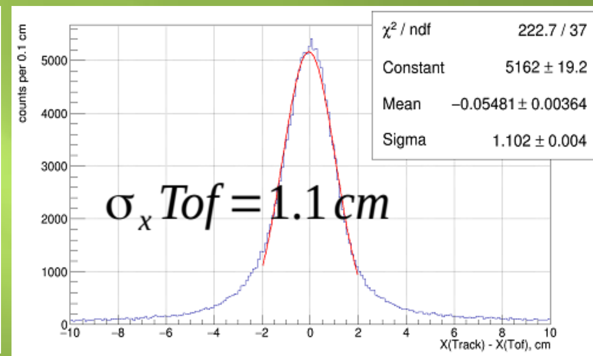


Events distribution on the chamber surface

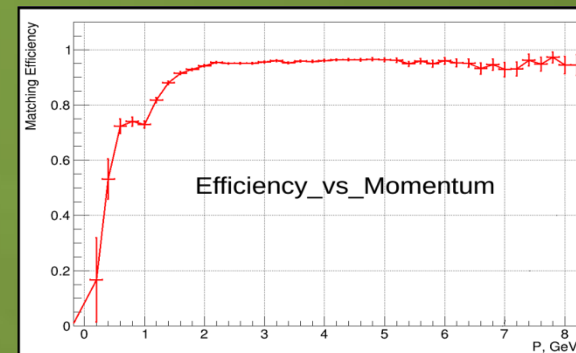
First beam test of CSC

Residuals of CSC and ToF-400

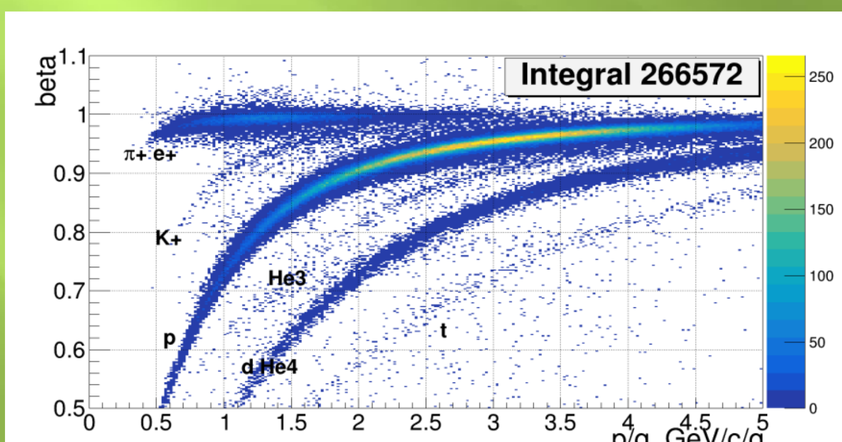


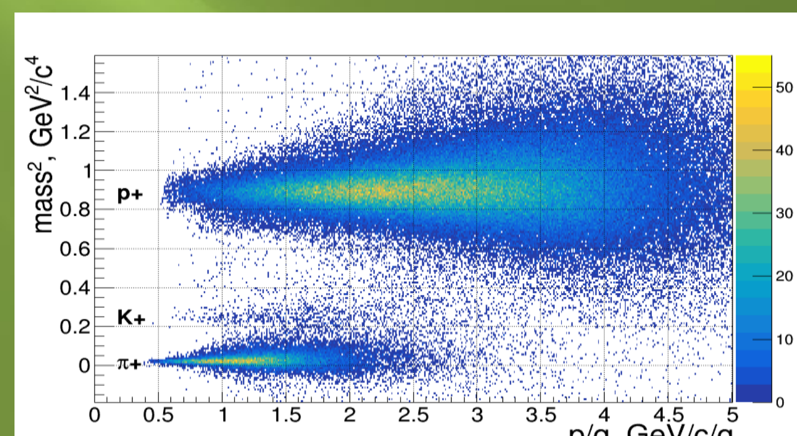


Matching efficiency of GEM+CSC track to ToF-400



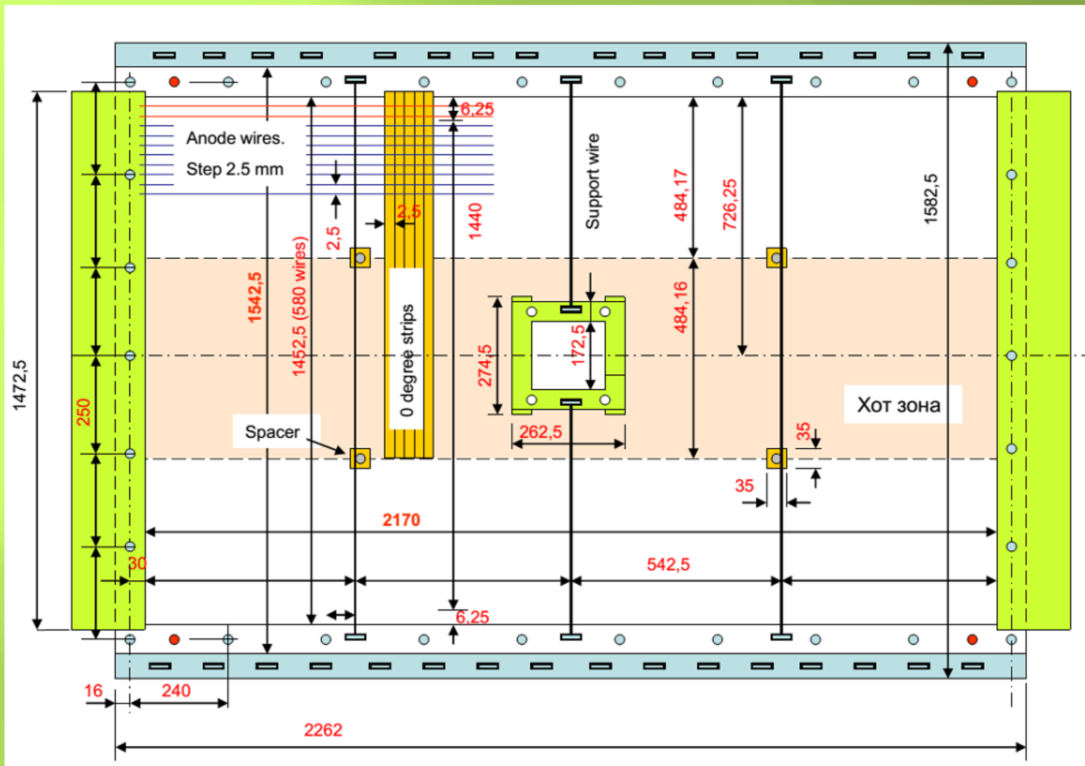
Preliminary result of identification, GEM+CSC track extrapolated to ToF-400



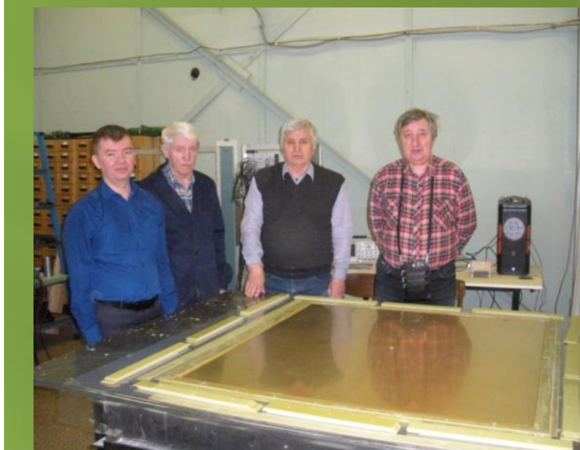


Proton Mass^2 = 0,894 ± 0,081 GeV^2/c^4, Pion Mass^2 = 0,021 ± 0,016 GeV^2/c^4

2190×1453 mm² CSC



CSC group



Design and assembly – JINR LHEP

Two cathode planes with strips inclined at 0° and 15°

Each cathode plane consists of 8 printed circuit boards.

Each pcb is divided on hot and cold zones.

Two 2190×1453 mm² CSC chambers are to be installed before and after ToF-700

Production plans:

- 2020 – design and production of the cathode planes for 2190×1453 mm² CSC chambers

- 12.2020 – Assembly of the 2190×1453 mm² CSC

- 06.2021 – All chambers are integrated into the BM@N experimental setup

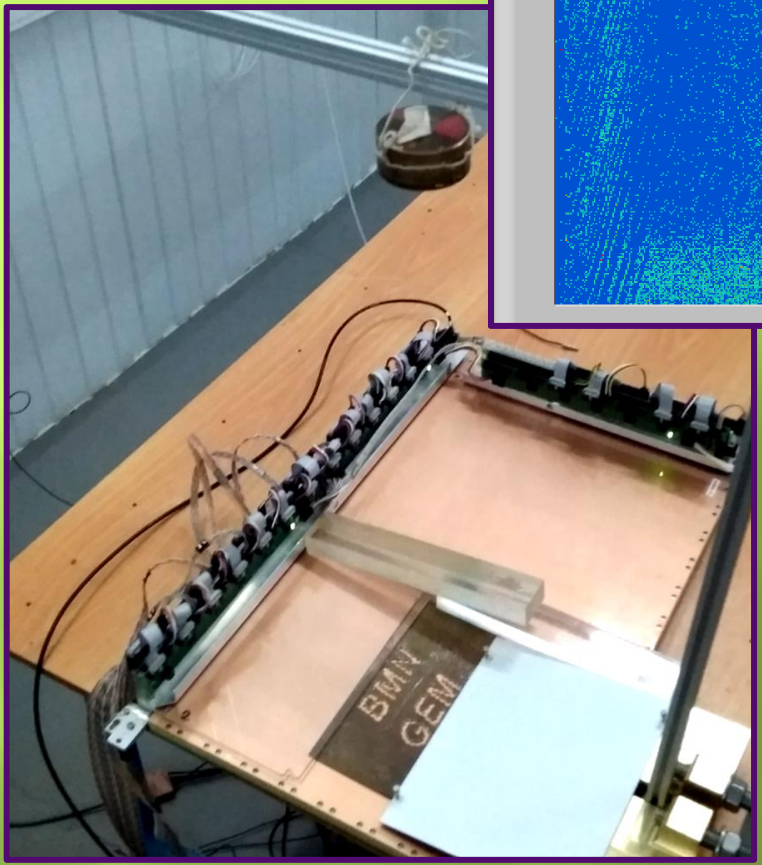
Conclusions

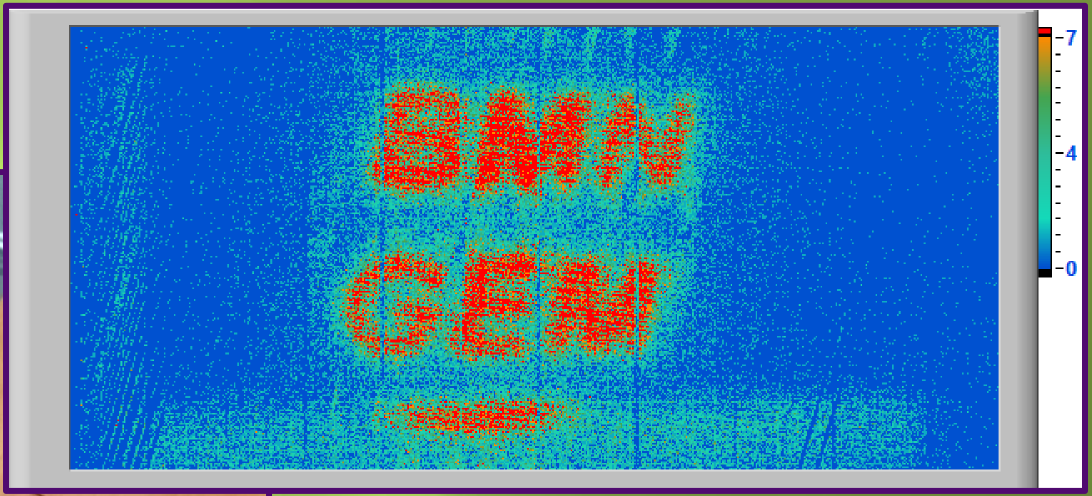
Triple GEM detectors of the BM@N tracker system have been assembled and studied in the d, C, Ar, Kr beams of the Nuclotron accelerator. The measured parameters of the GEM detectors are consistent with the design specifications. Seven GEM chambers with the size of 1632 mm × 450 mm are the biggest GEM detectors produced in the world for today.


GEM chambers integrated into BM@N experimental setup

First CSC integrated into BM@N

The first CSC was tested in technical run of BM@N in February-March 2018. First results showed that the chamber functions properly.

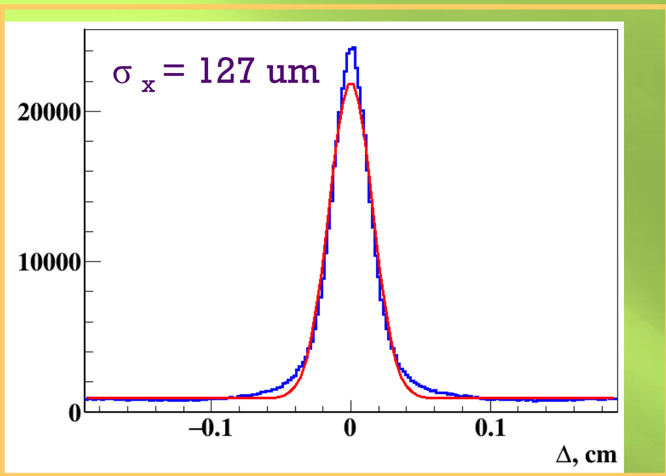




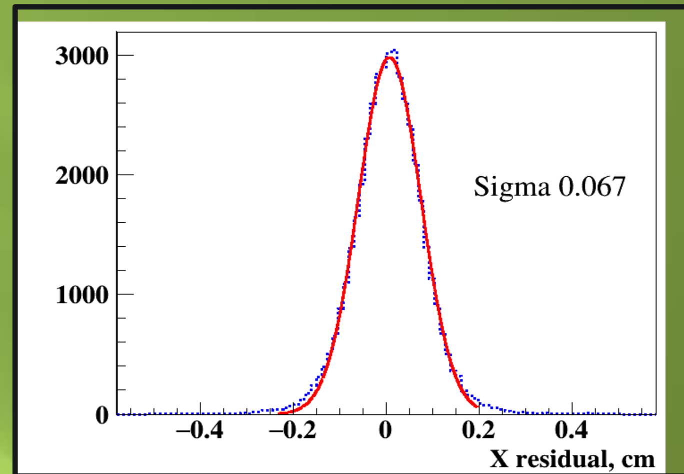
Thank you for your attention!

Back-up slides

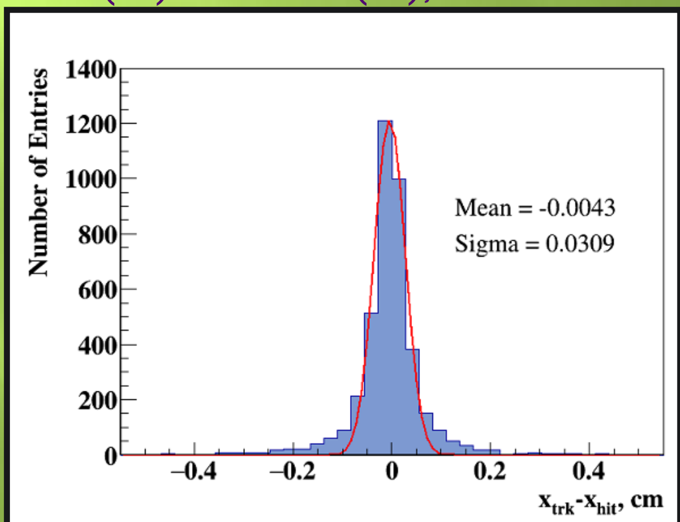
GEM tests at Nuclotron d, C, Ar beams



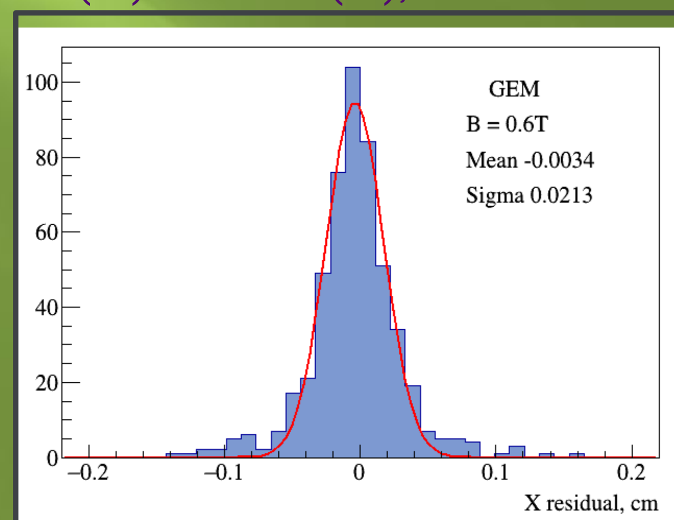
GEM hit residuals, w/o magnetic field,
Ar(90)/IsoButane(10), deuteron beam



GEM hit residuals, magnetic field 0.6 T,
Ar(90)/IsoButane(10), deuteron beam

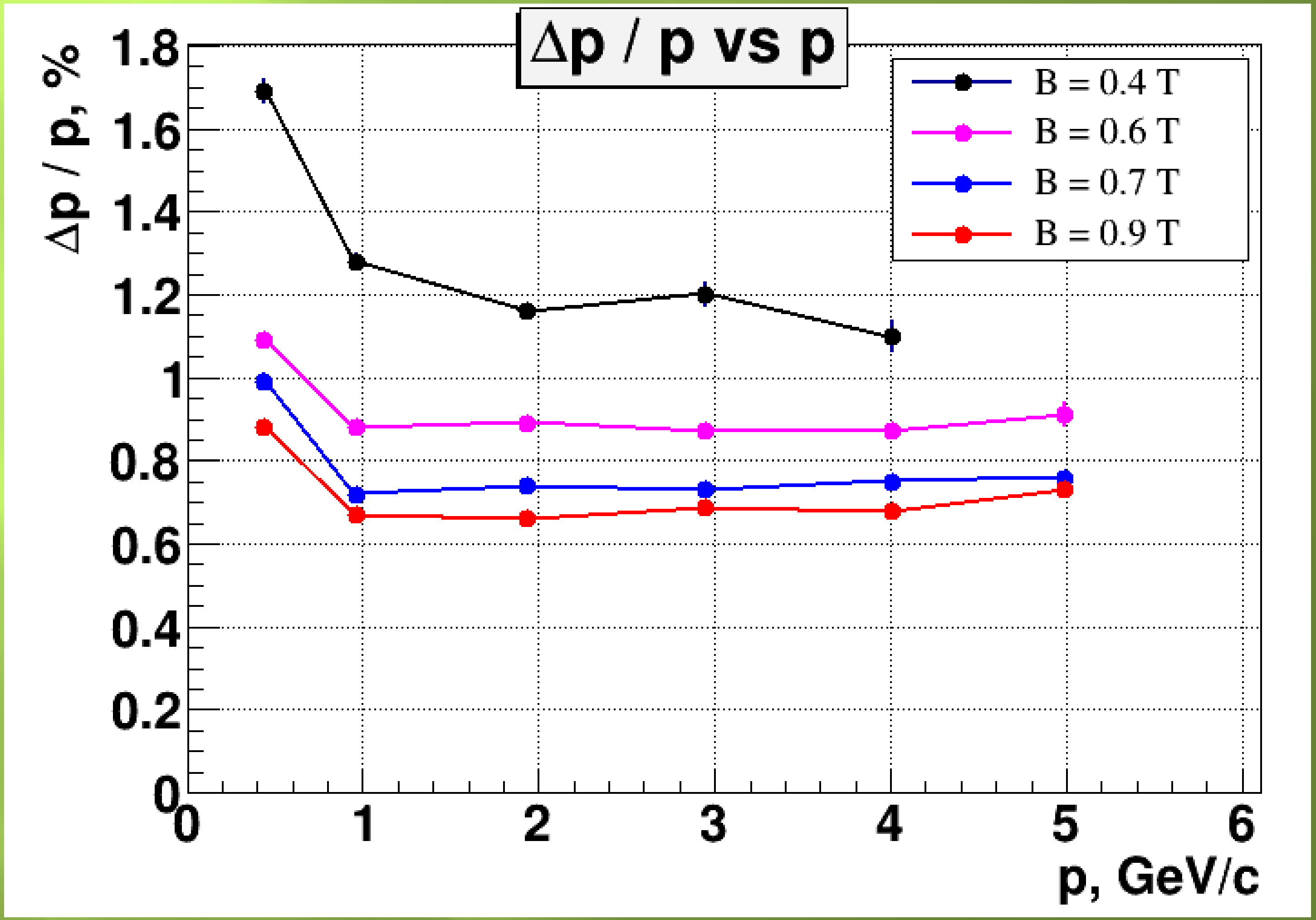


GEM hit residuals, magnetic field 0.59 T,
Ar(70)/CO2(30), carbon beam



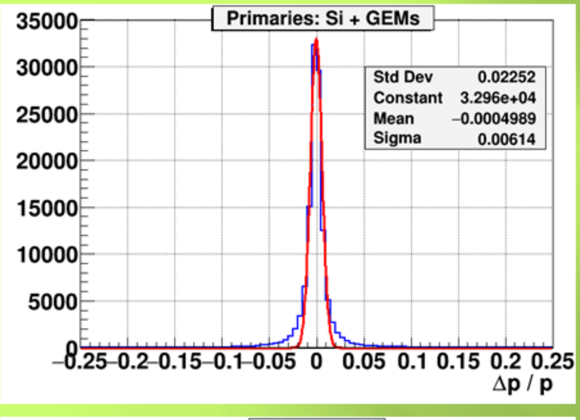
GEM hit residuals, magnetic field 0.6 T,
Ar(80)/Isobutane(20), Ar beam, Edrift = 1.5kV/cm

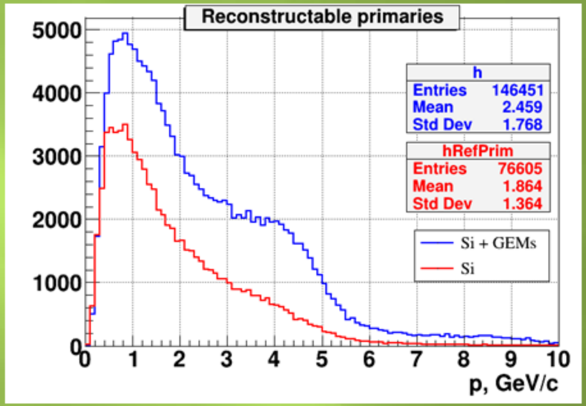
Hybrid central tracker STS+GEM momentum resolution for different magnetic field values

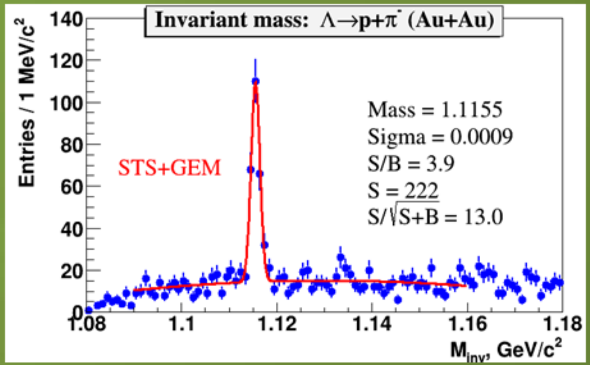


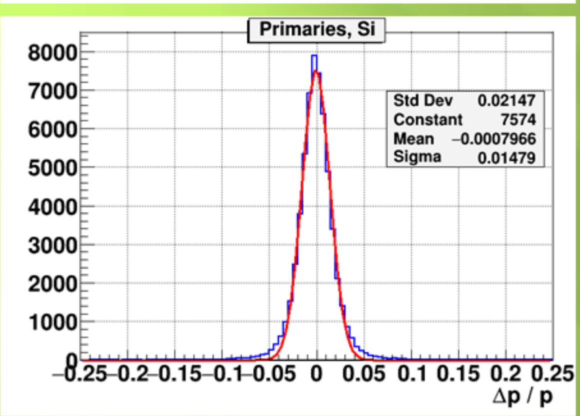
A.Zinchenko

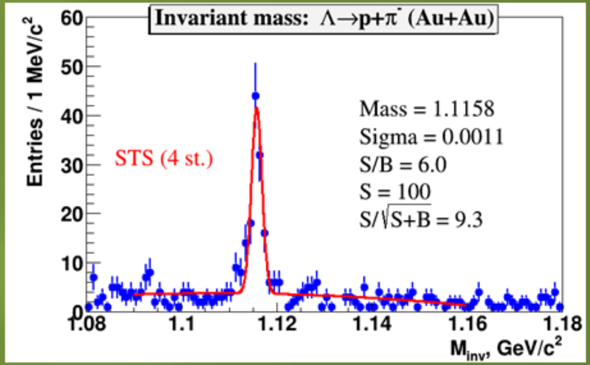
Hybrid central tracker for heavy ion runs: STS vs STS +GEM









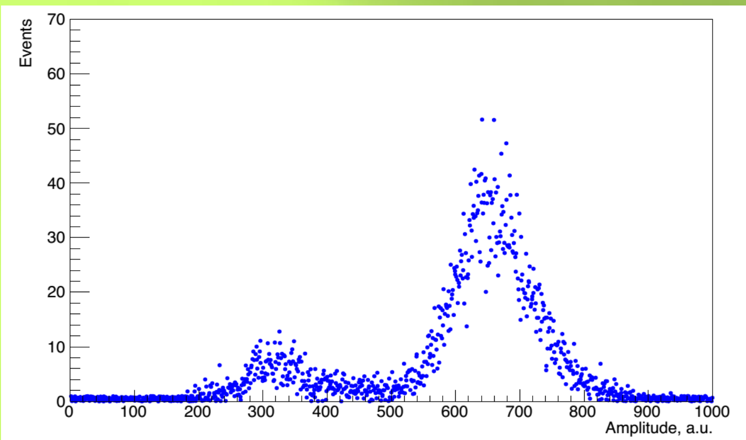


Hybrid STS + GEM tracker:

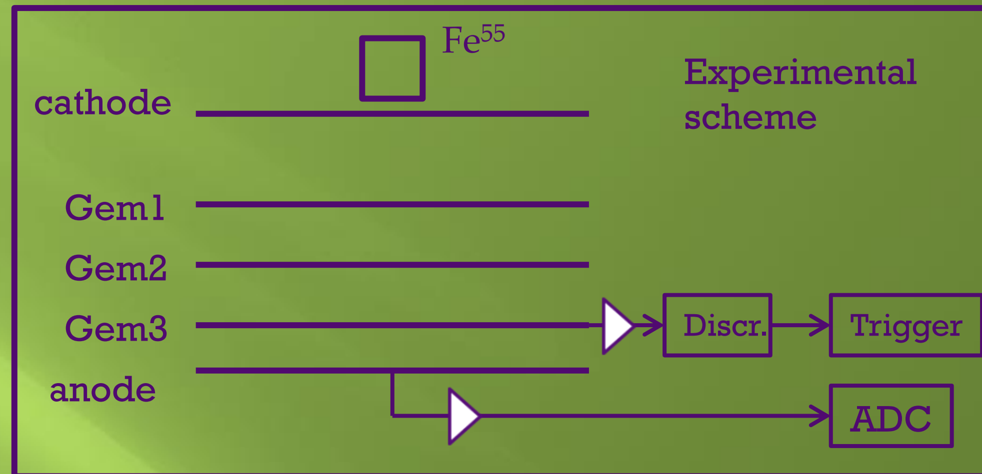
- ► 2 times increase in number of reconstructed tracks and Λ hyperons
- ► 2 times better momentum resolution

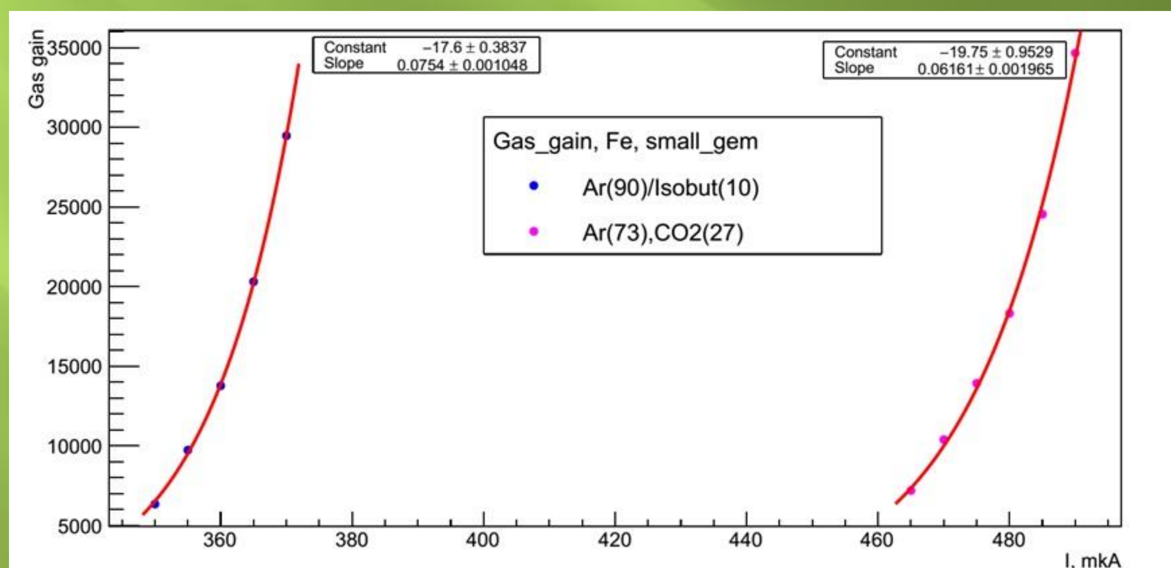
A. Zinchenko, P. Senger

GEM gas gain measurements



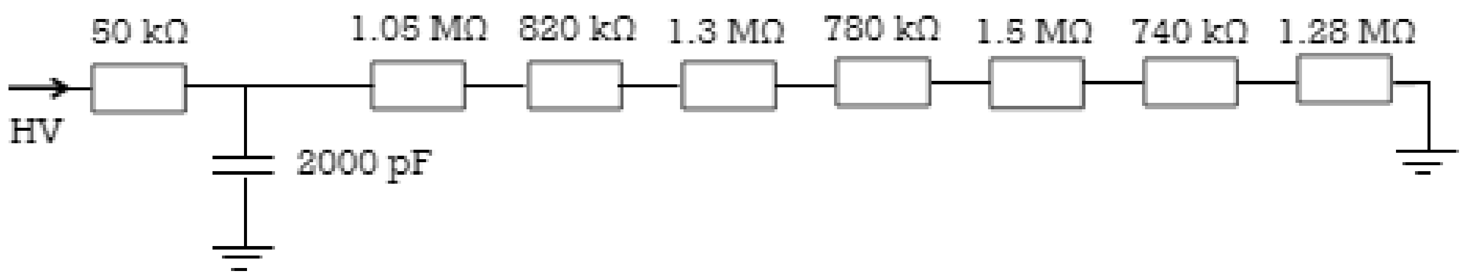
Amplitude distribution, Ar(70)/CO2(30), Fe^{55}





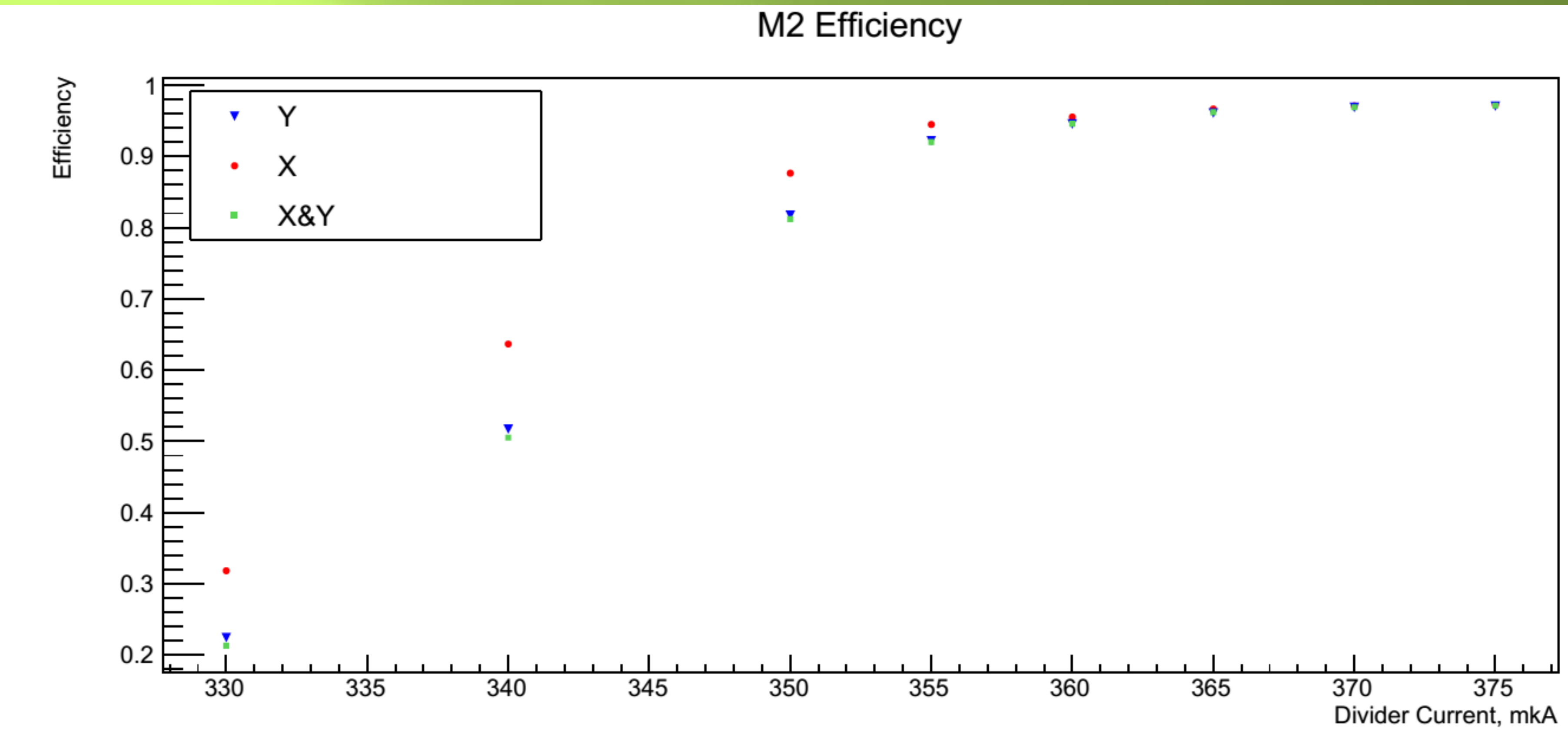
GEM gas gain for Ar(70)/CO2(30) and Ar(90)/Isobutane(10) gas mixtures

GEM HV divider scheme

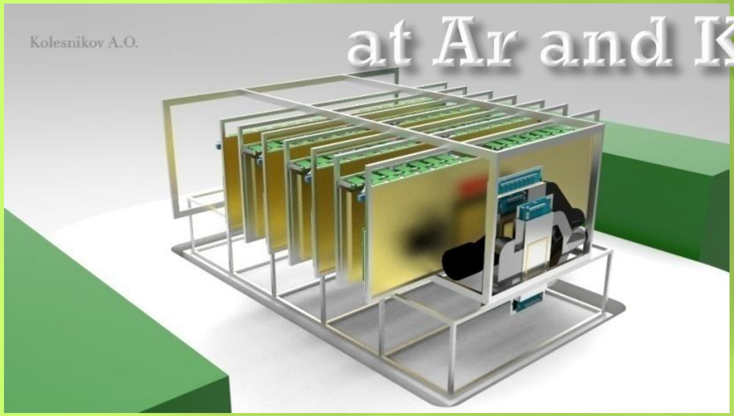


490 mkA – working point for Ar (70) + CO_2 (30) gas mixture
370 mkA – working point for Ar (90) + Isobutane (10) gas mixture
430 mkA – working point for Ar (80) + Isobutane (20) gas mixture

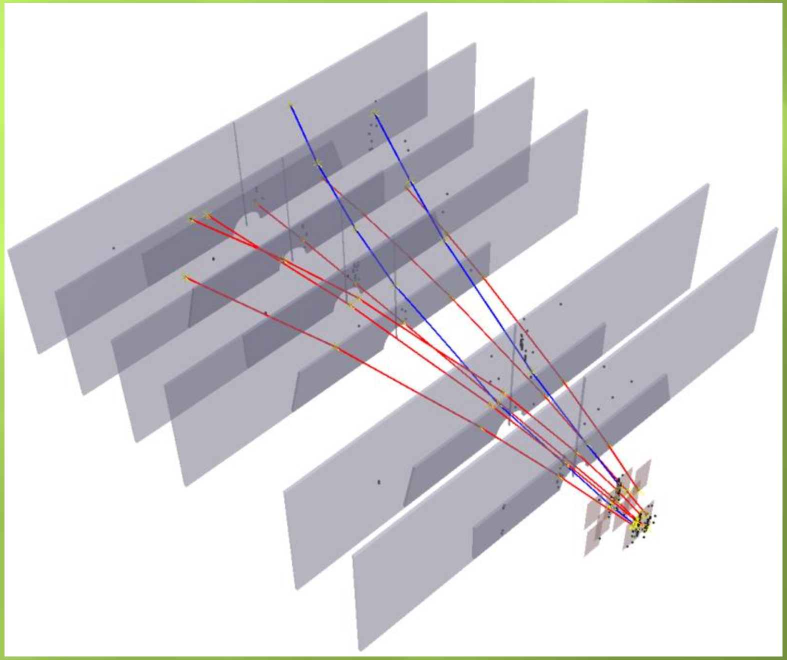
Mixture	I, mkA	DR, kV/cm	Gem 1, V	TR1, kV/cm	Gem 2, V	TR2, kV/cm	Gem 3, V	IND, kV/cm
Ar (70) + CO_2 (30)	490	1.17	402	2.58	382	3.68	363	4.18
Ar (90) + C_4H_{10} (10)	370	0.88	303.4	1.92	288.6	2.78	273.8	3.16
Ar (80) + C_4H_{10} (20)	430	1.5	352.6	2.24	335.4	3.23	318.2	3.67

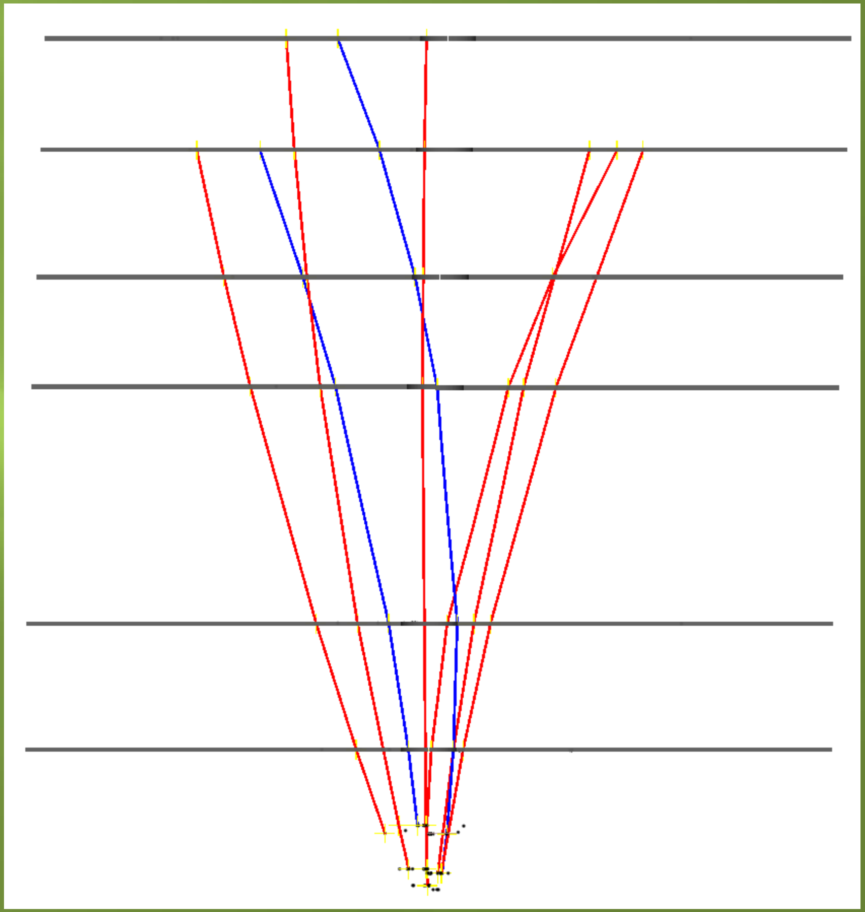

M2 Efficiency
Efficiency
Y
X
X&Y
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
330
335
340
345
350
355
360
365
370
375
Divider Current, mkA

GEM central tracking system performance at Ar and Kr beams (March 2018)



Event reconstruction

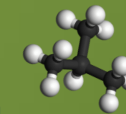




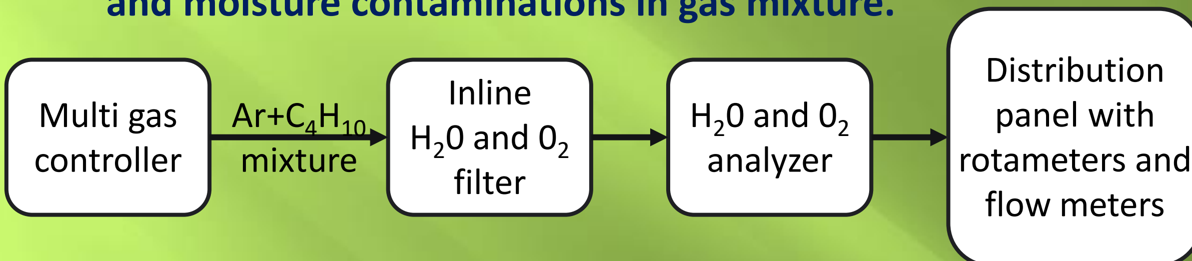
Event Display: Example of the event reconstruction in the central tracker (GEM + Si) in Ar+Al interaction.

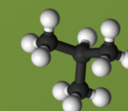
Gleb Pokatashkin

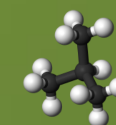
Gas system

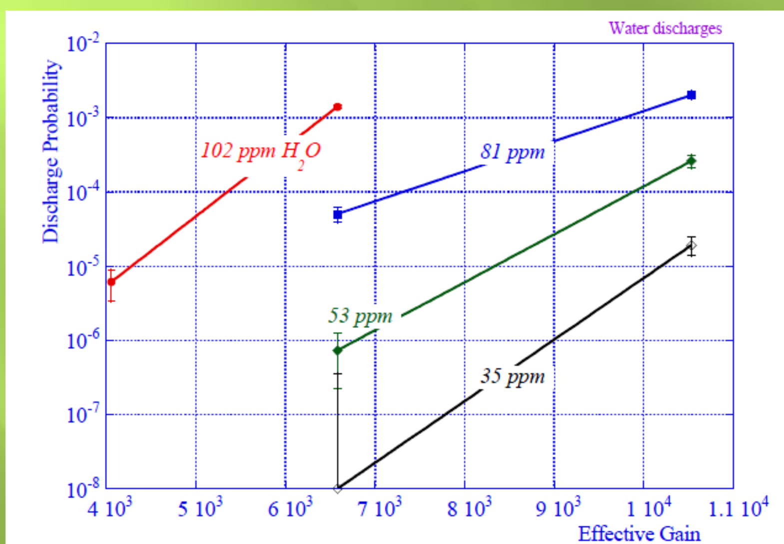


Now we have: 1 channel with Argon (80%) + Isobutane (20%) gas mixture, flow = 3 l/h through all series-connected GEM-detectors.
What we want: 7 independent channels to each GEM-plane; reduce and control oxygen and moisture contaminations in gas mixture.

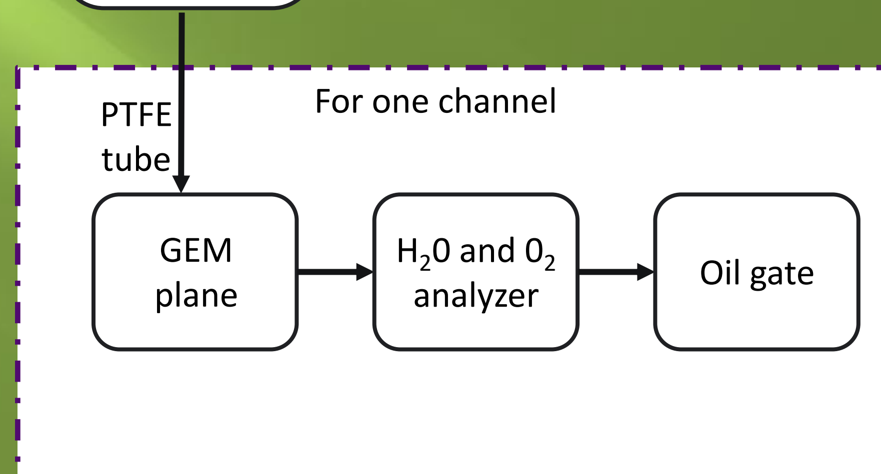






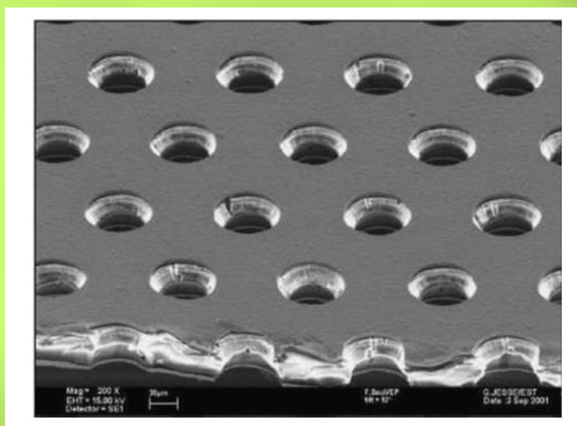


Discharge probability on alphas as a function of moisture level in the gas. COMPASS

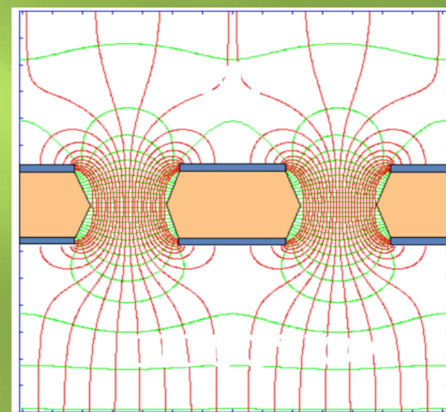


Control O2 by GE sensing oxy.IQ
Control H2O by GE sensing IQ.probe + GE sensing dew.IQ

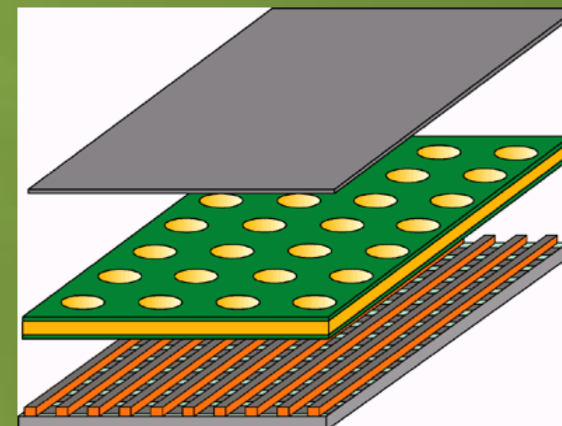
The gas electron multiplier (GEM)



Electron microscope picture of a section of typical GEM electrode, 50 μm thick. The holes pitch and diameter are 140 and 70 μm, respectively.

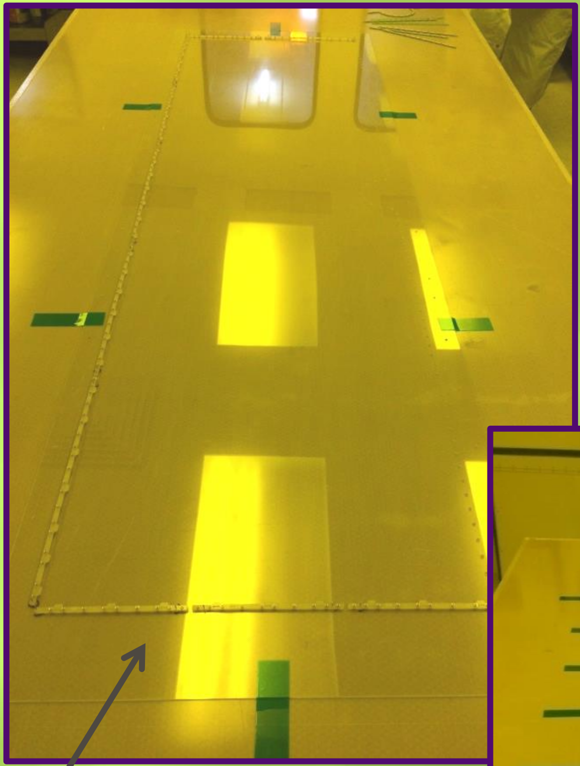


Electric field in the region of the holes of a GEM electrode

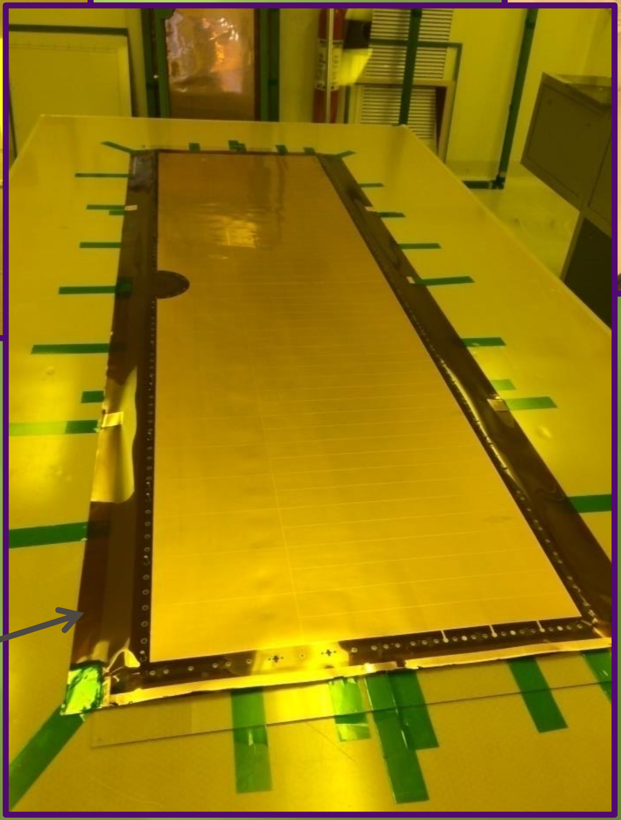


Schematics of single GEM detector with Cartesian two-dimensional strip readout.

GEM assembly at CERN Workshop



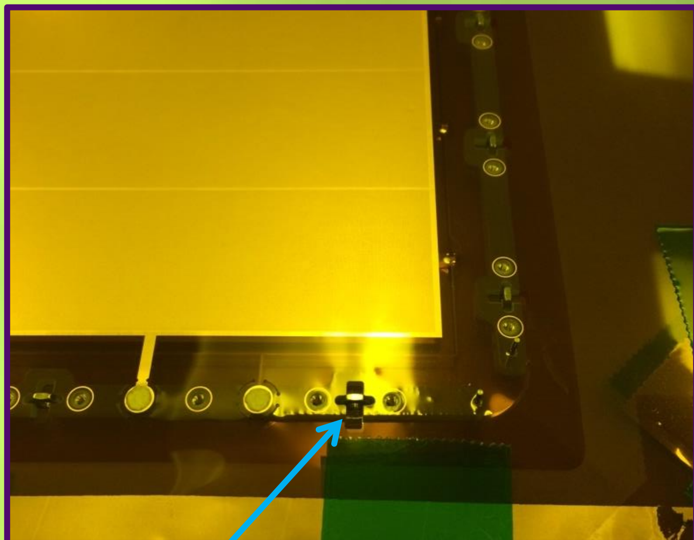
Base plastic frame



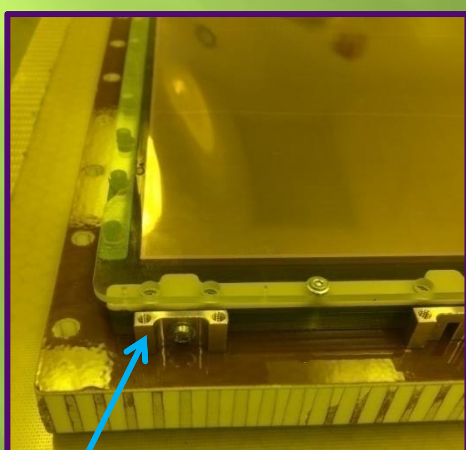
GEM foil preliminary stretching

GEM foil tests

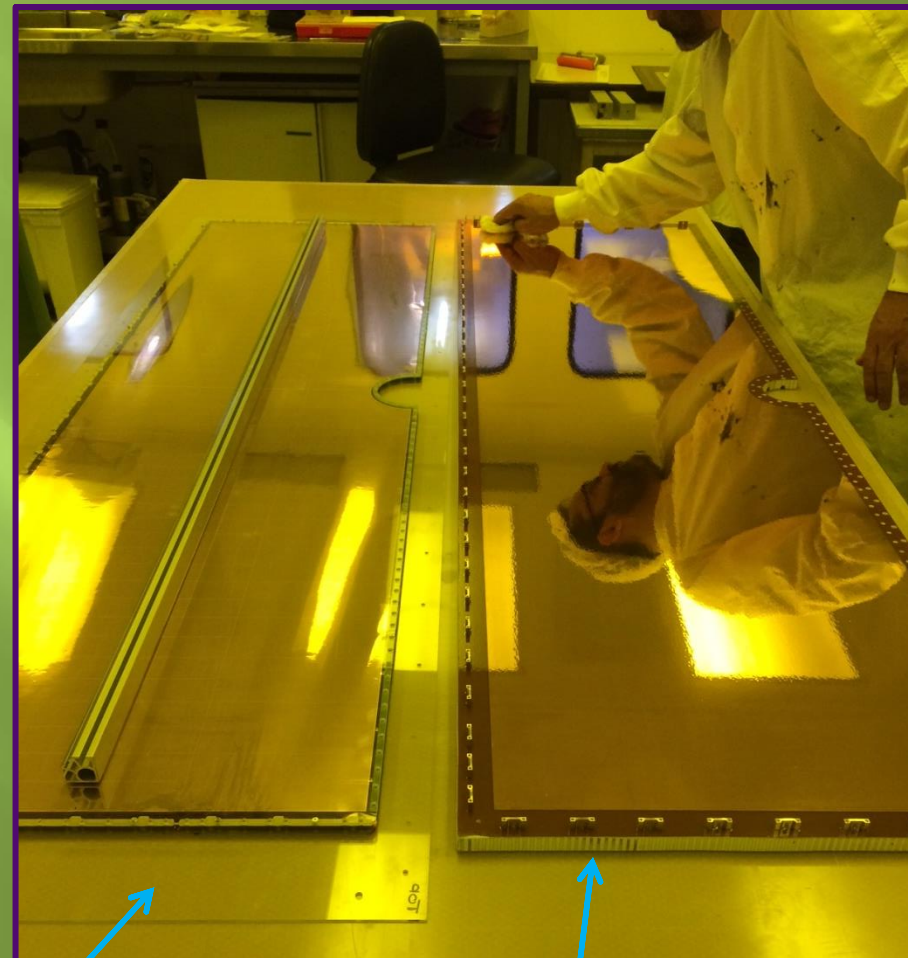
GEM assembly at CERN Workshop



Nuts in plastic frames



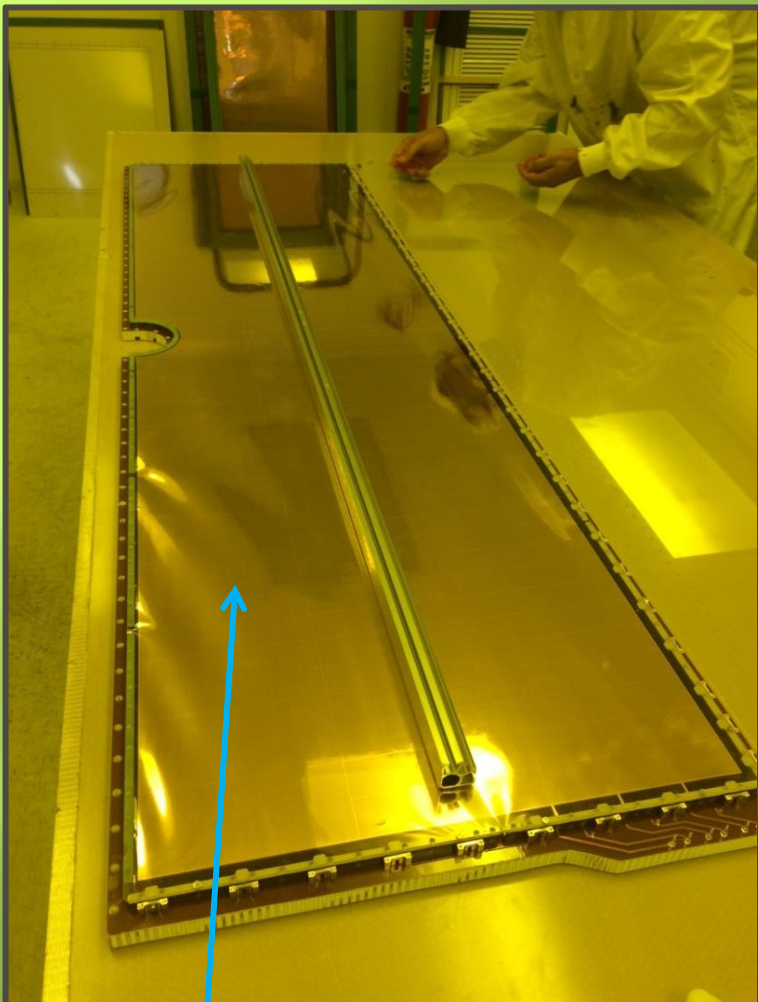
Brass fitting



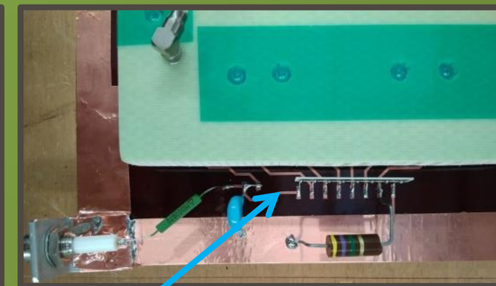
Stack of 3 GEMs

Cathode plane

GEM assembly at CERN Workshop

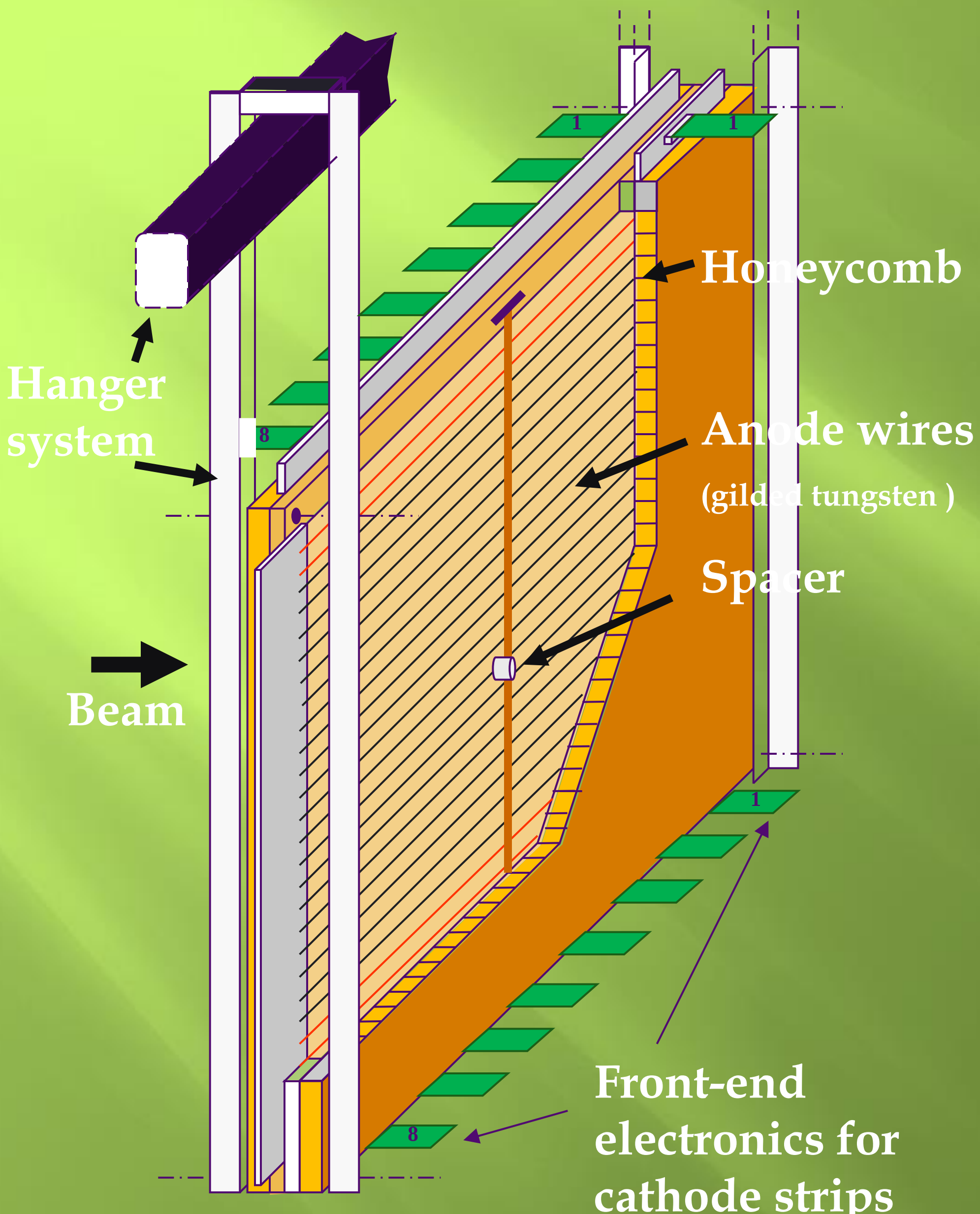


Stretching process

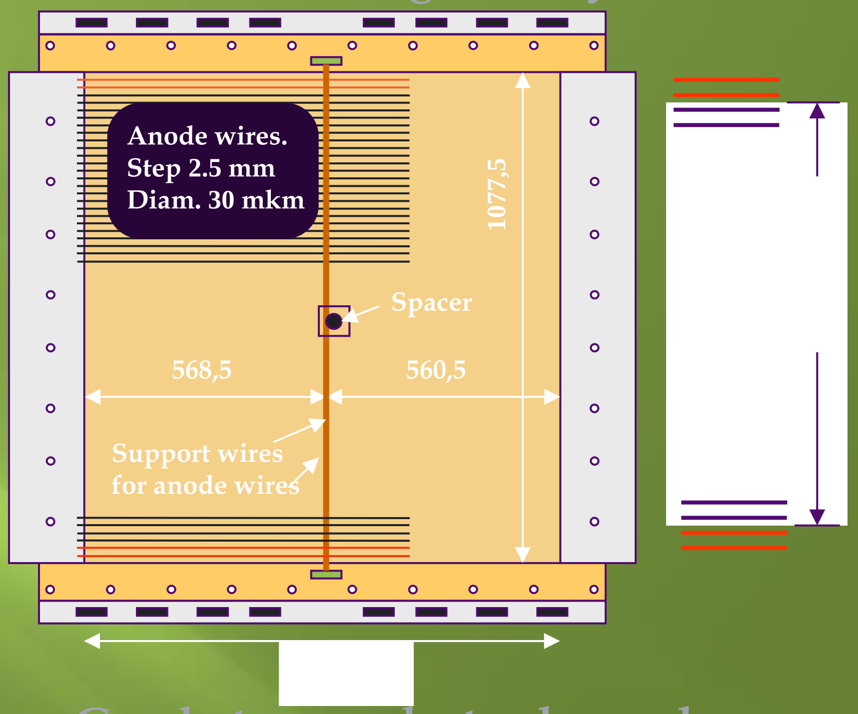


HV divider

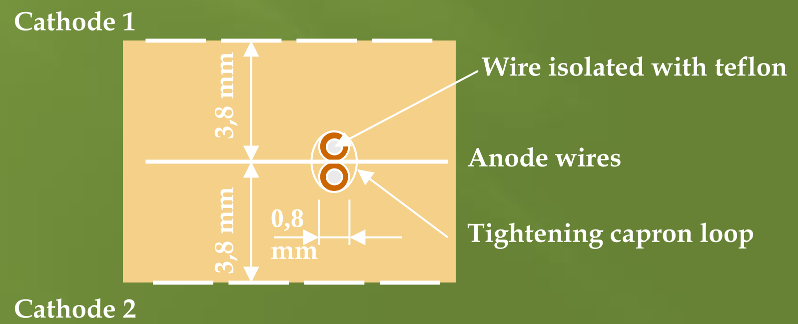
Schematic view of CSC



Anode wires geometry

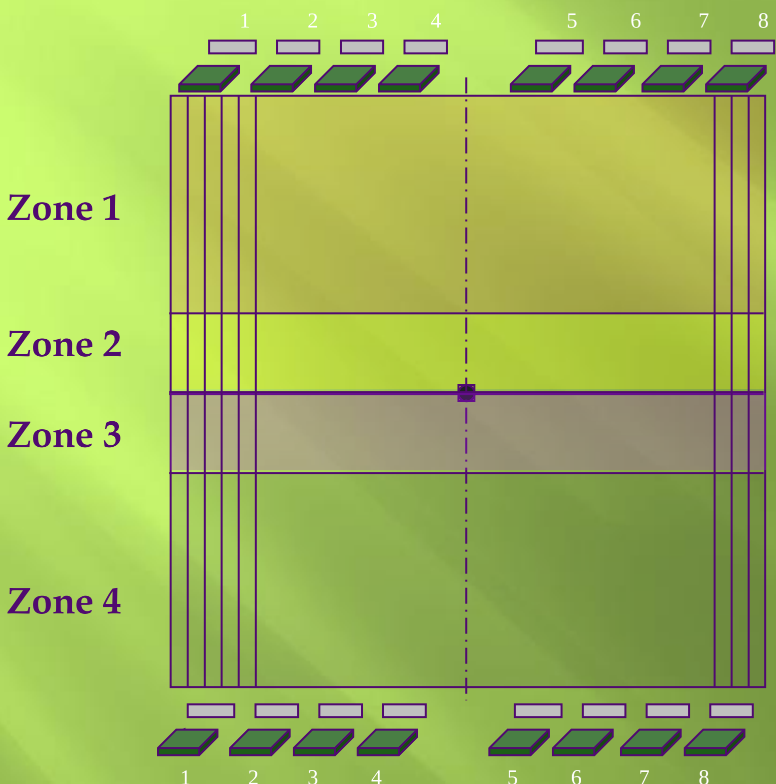


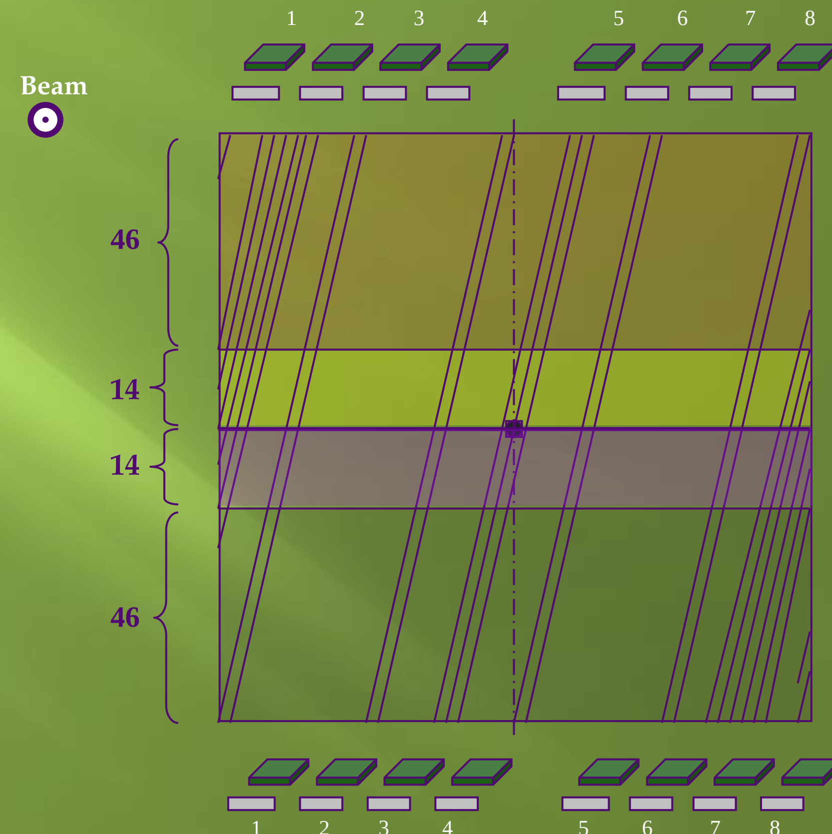
Gap between electrodes and support wires for anode wires



Readout cathode planes

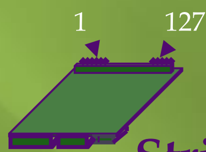
Each cathode plane consists of two printed circuit boards. Each pcb is divided on two zones.





Vertical (X) strips

1808

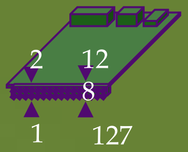


Strip width 2.5 mm

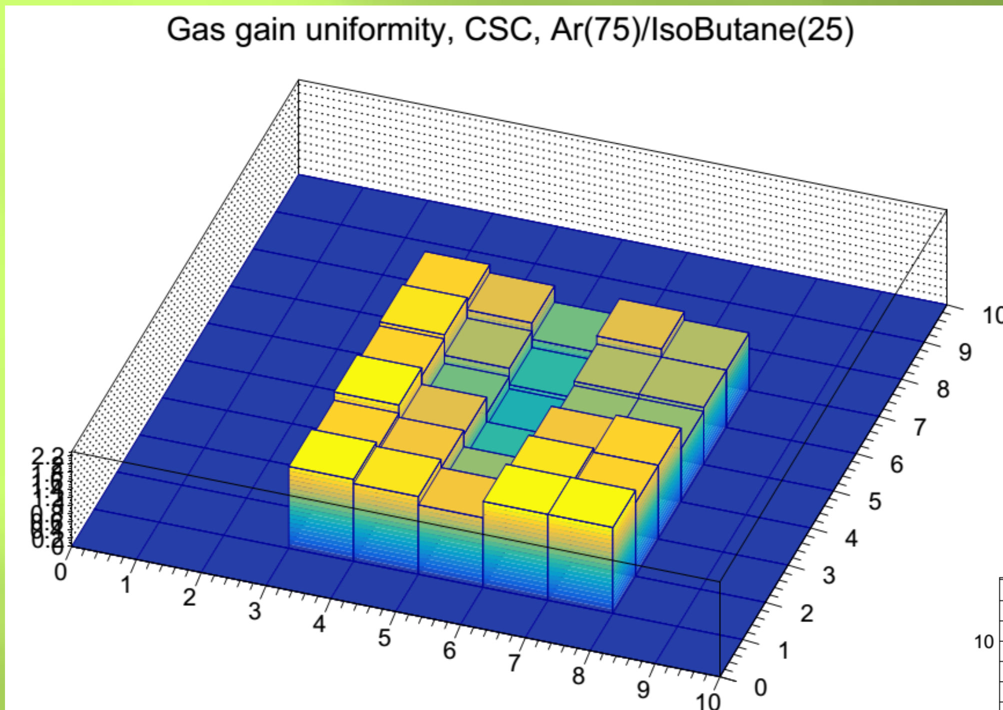
32 readout boards

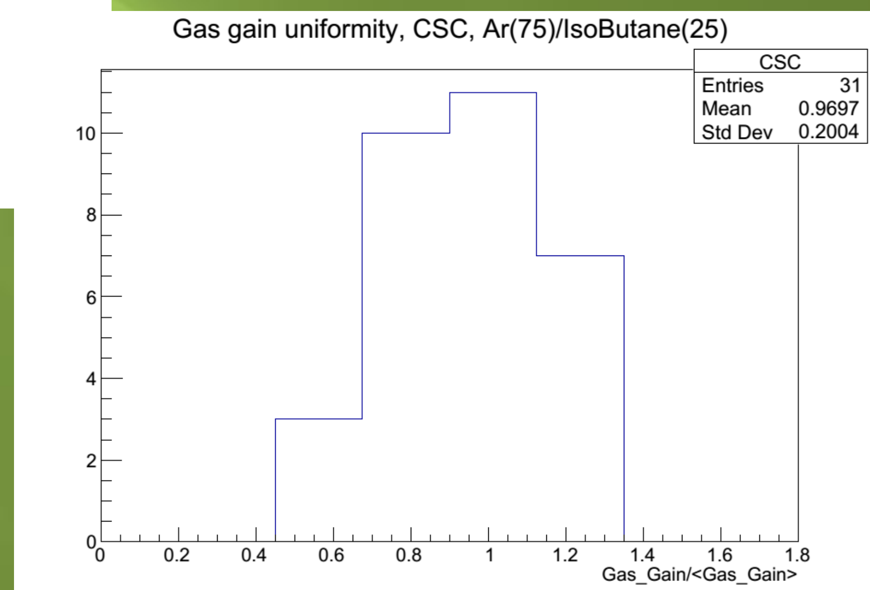
Inclined (Y) strips

1928

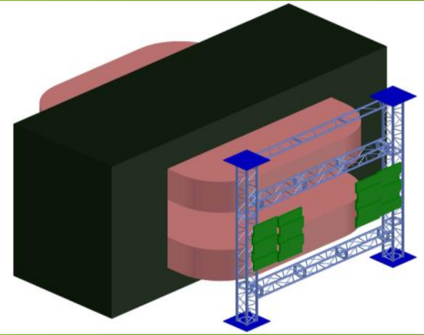


CSC response uniformity



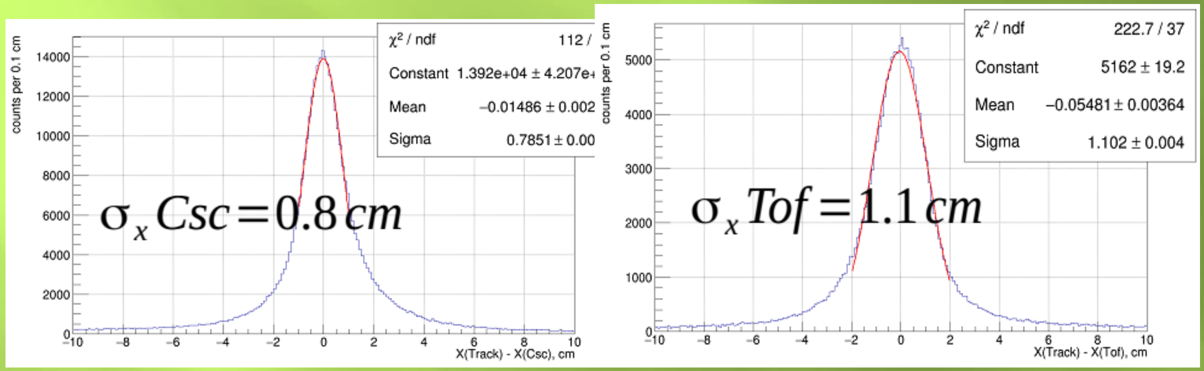


Status ToF-400

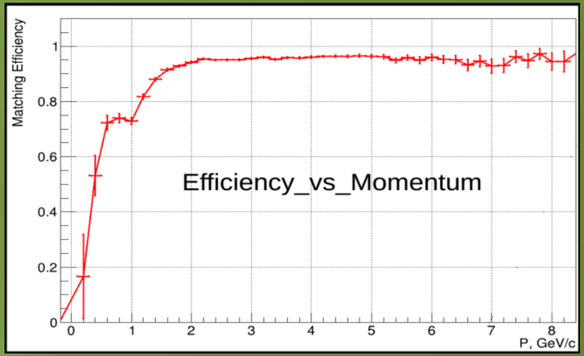


ToF-400
+ V.Plotnikov
+M.Rumyantsev

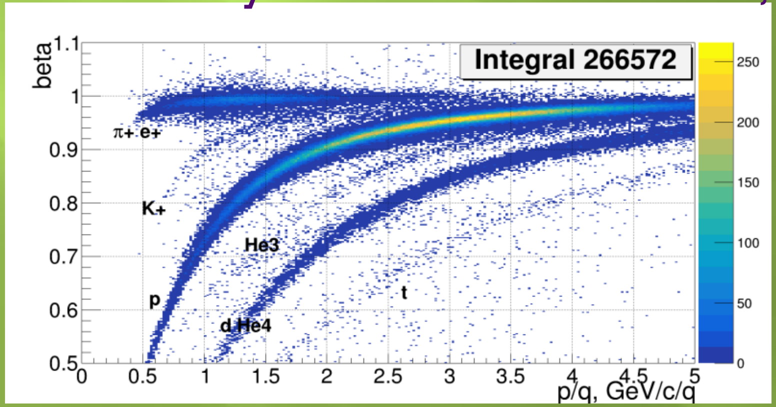
Residuals of CSC and ToF-400

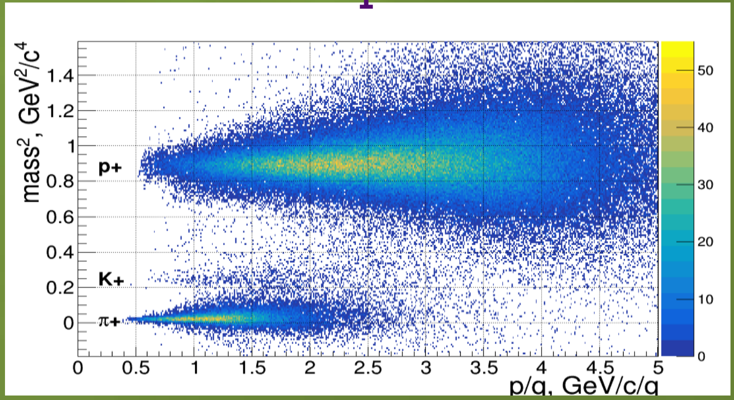


Matching efficiency of GEM+CSC track to ToF-400



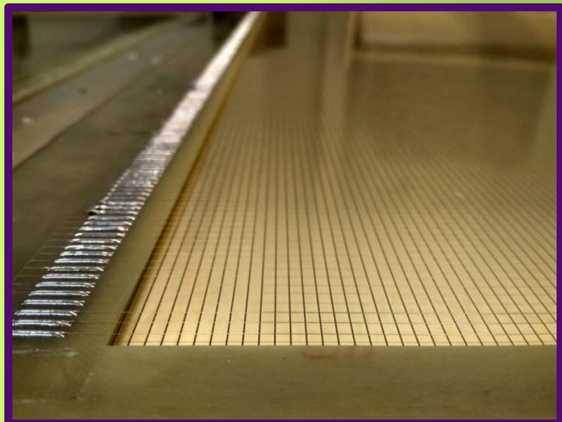
Preliminary result of identification, GEM+CSC track extrapolated to ToF-400

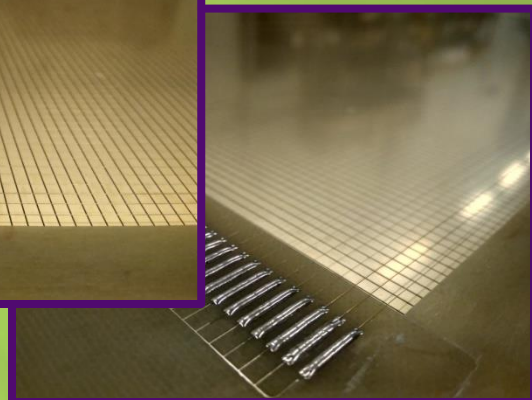


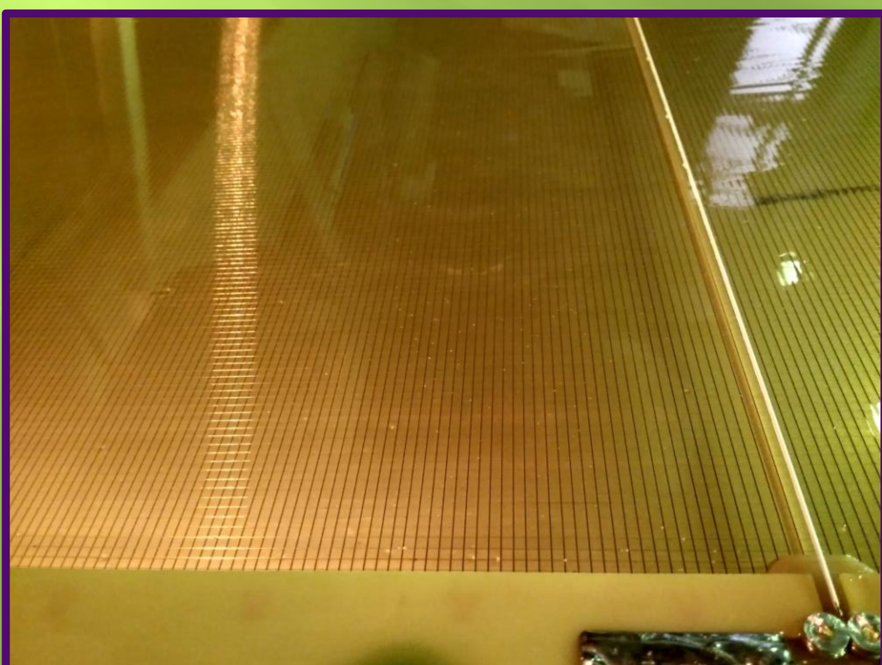


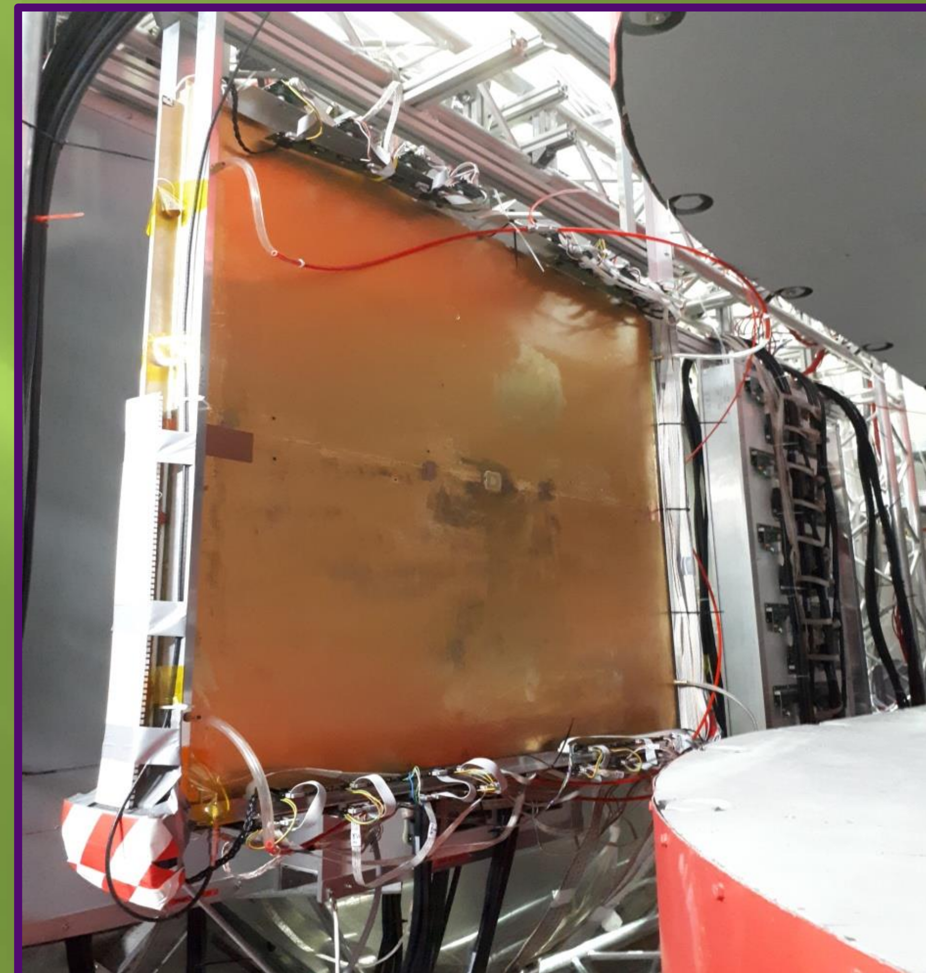
Proton Mass^2 = 0,894 +- 0,081 GeV^2/c^4, Pion Mass^2 = 0,021 +- 0,016 GeV^2/c^4

CSC prototype 1129x1065 mm^2









CSC prototype: total strips **3736**
R/O connectors (128 pins): **32**