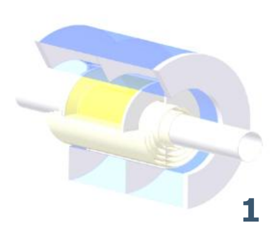
A new active target GEM-based TPC: present and future developments

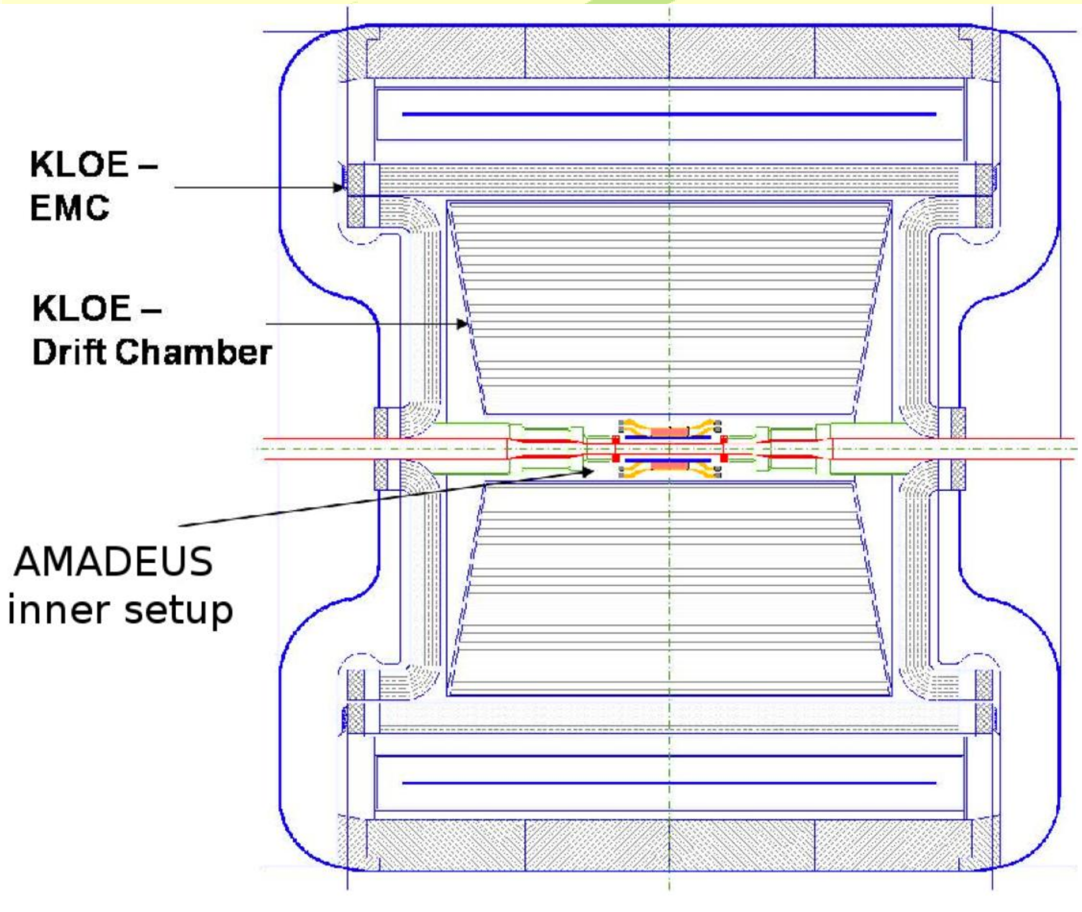
Outline:

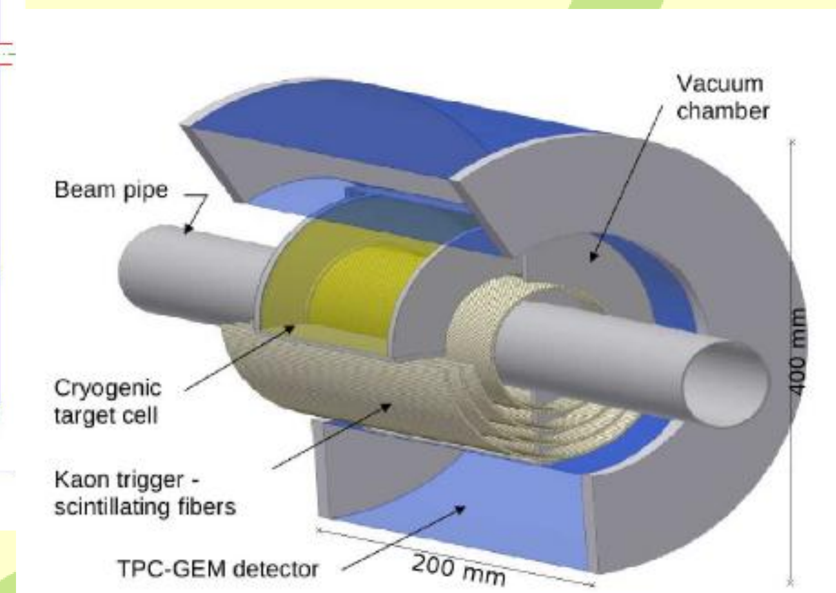
- GEM-TPC in the AMADEUS experiment;
- GEANT results of an active target detector;
- Prototype design & construction;
- GEM: principle of operation;
- Gas Mixtures choice;
- PSI beam test setup;
- Performances with Isobotune-based gas mixtures & pure Helium;
- Conclusions



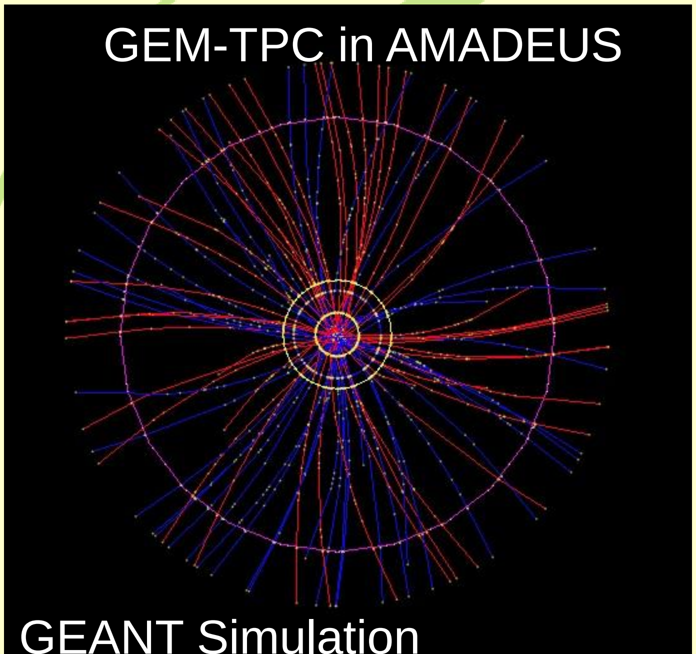
AMADEUS Experiment

A novel idea of using an active target GEM-based TPC as a low mass target & tracker/PID detector at the same time is investigated





Active target GEM-TPC requirements



Size

- Diameter: 40 cm
- Length: 20 cm
- Solid angle coverage: Up to $|\cos\theta| = 0.98$

Momentum resolution: $<1*10^{-2}$ / GeV/c

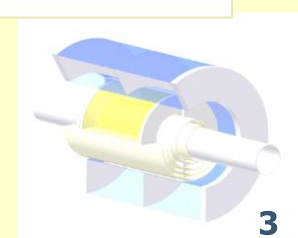
- About 120 measurement point per track
- $r\varphi$ point resolution < 200 μm

Other performance requirements

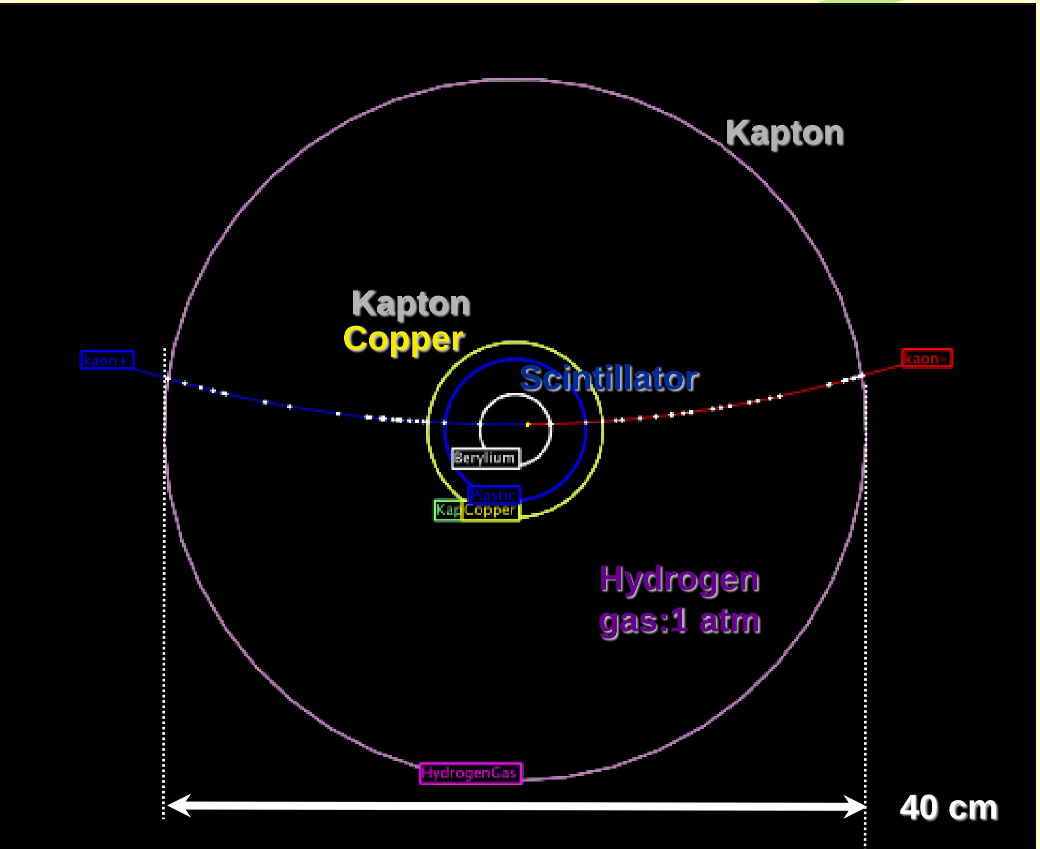
- rz point resolution < 500 μm
- dE / dx resolution < 10 %

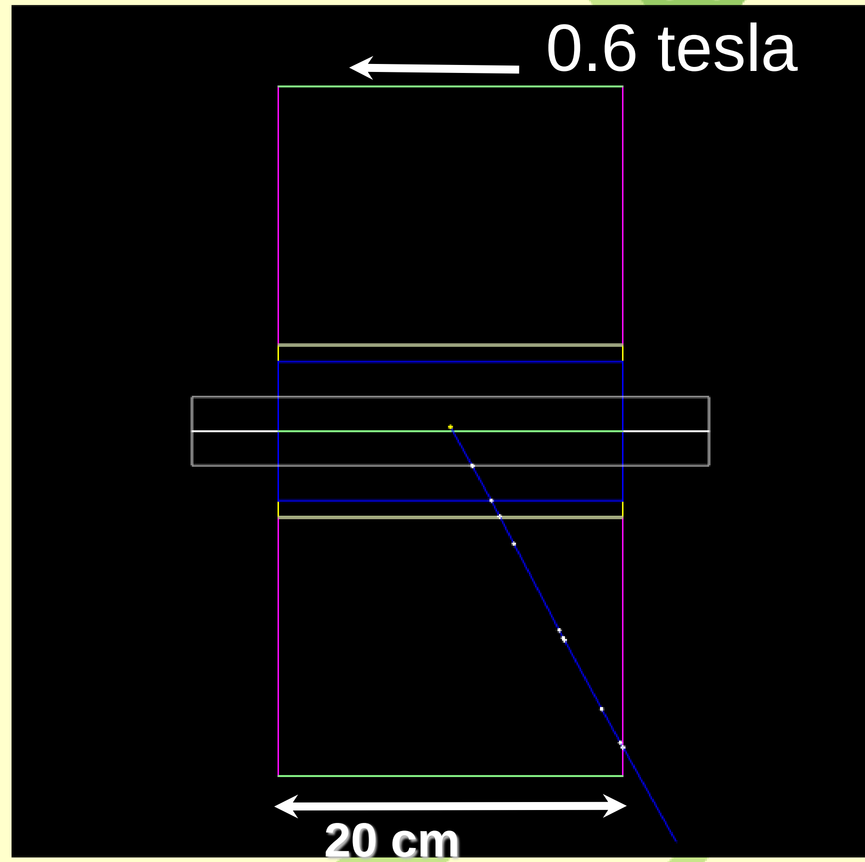
Material budget

- 0.5 X_0 in the barrel
- 1.5 X_0 in the endcaps



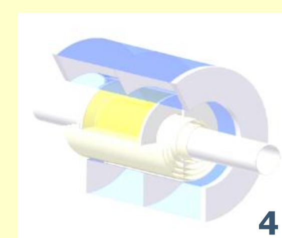
GEANT Simulation of a pure H_2 Active Target GEM-TPC



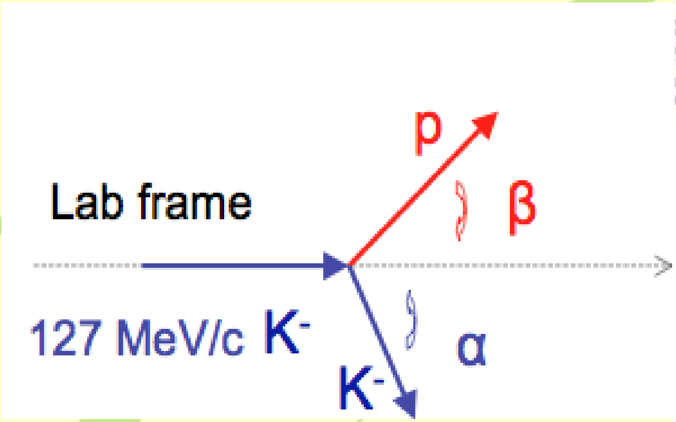


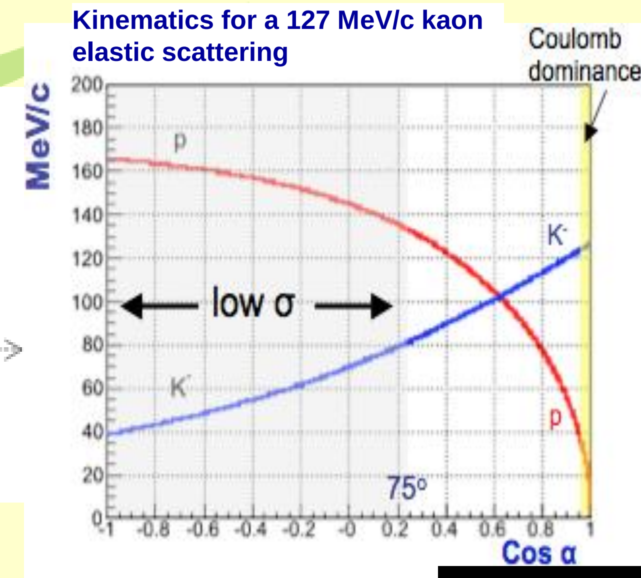
Berylium beam pipe:		20 mm - 20.5 mm
Plastic Scintillator	:	40 mm - 40.5 mm
Kapton target wall	:	49.95 mm - 50. mm
Copper Cage	:	49.94 mm - 49.95 mm
Hydrogen gas	:	50 mm - 200 mm

Performed with H. Shi

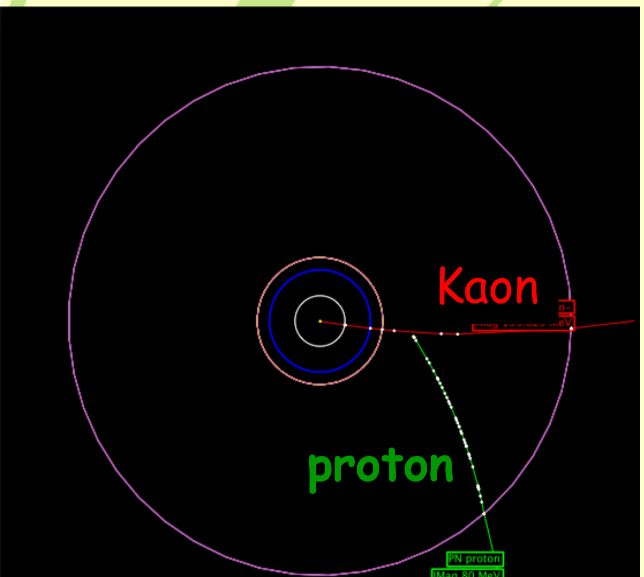


Elastic Scattering: $K^{\pm} p \rightarrow K^{\pm} p$

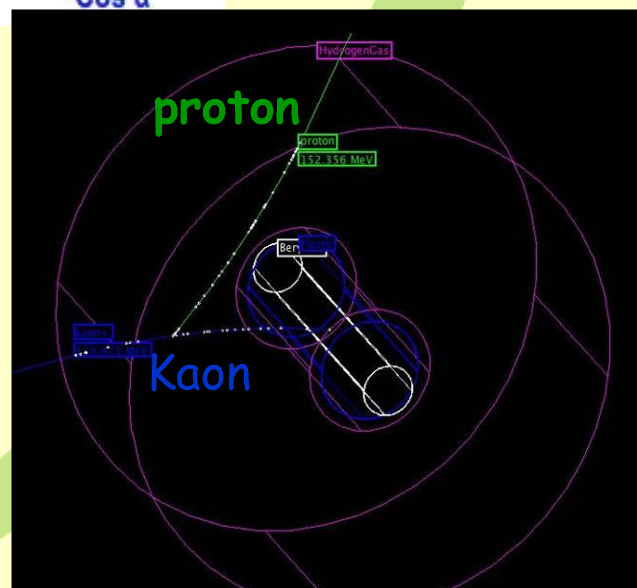




Both backward & forward scattering can be tracked in the target GEM-TPC



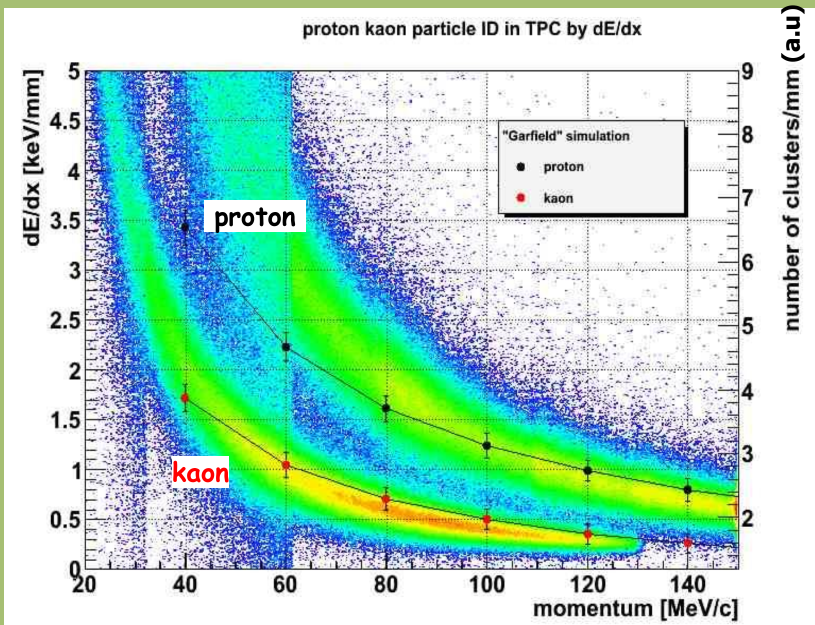
Forward Scattering



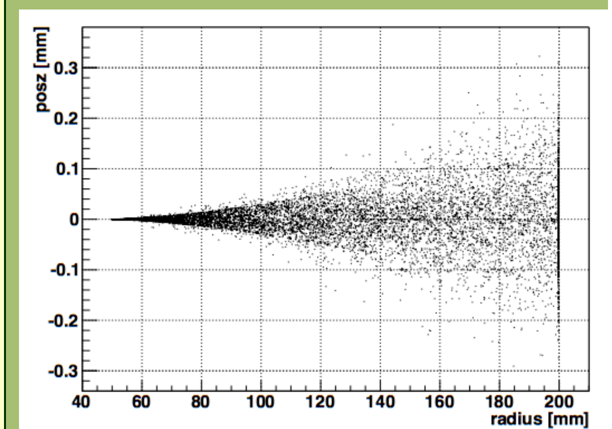
Backward Scattering

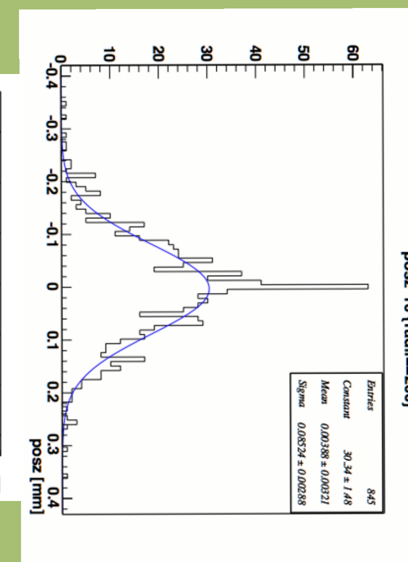
Performances in a pure H_2 Active Target GEM-TPC

Particle ID with dE/dx for Kaon & proton



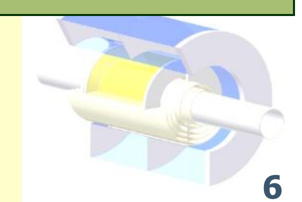
Kaon Multiple-scattering



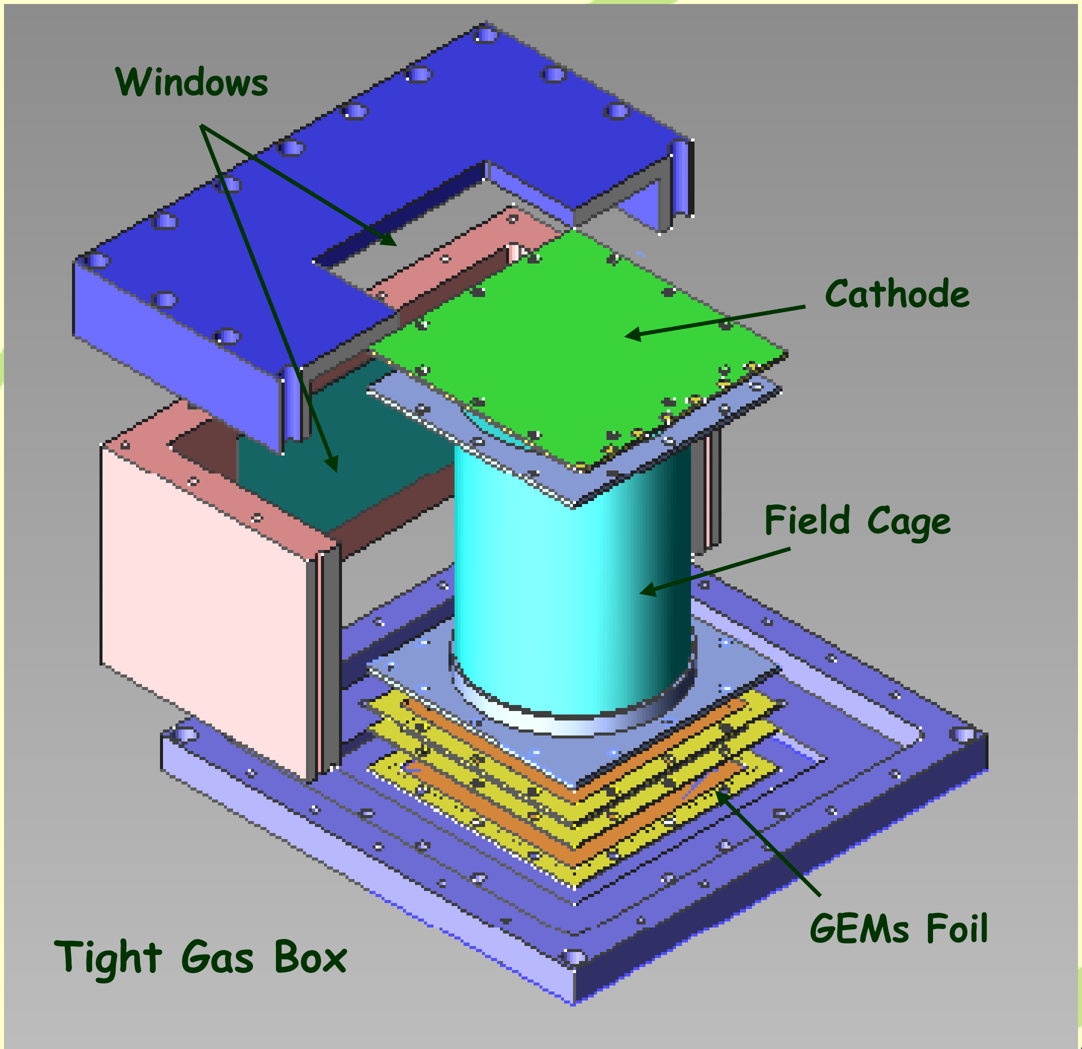


Angular distribution of diffused kaons < 1 mrad

σ_z= 0.085+-0.003 mm
@ radius = 20 cm



GEM-TPC R&D design



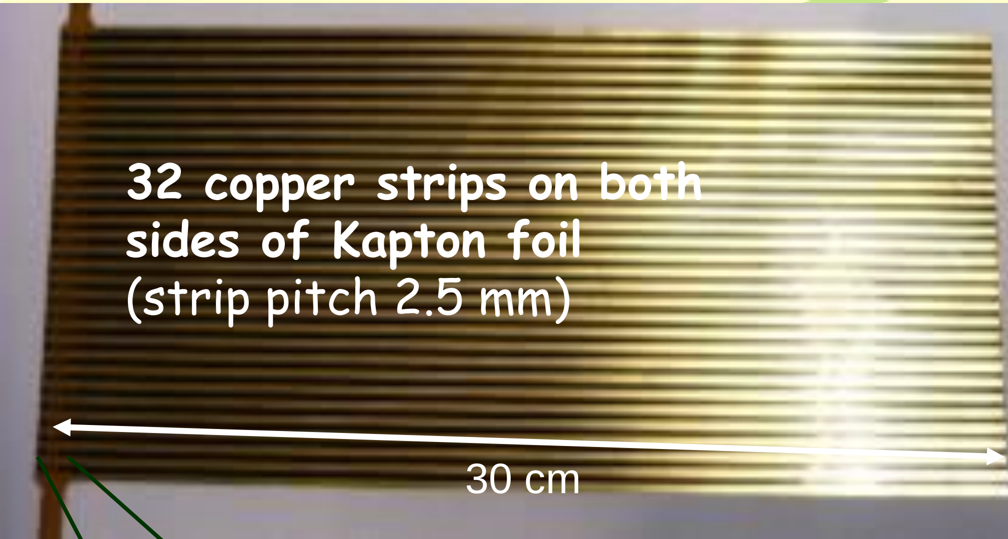
A prototype of 10x10 cm^2 active area and 15 cm drift gap has been realized in a class 100 clean room.

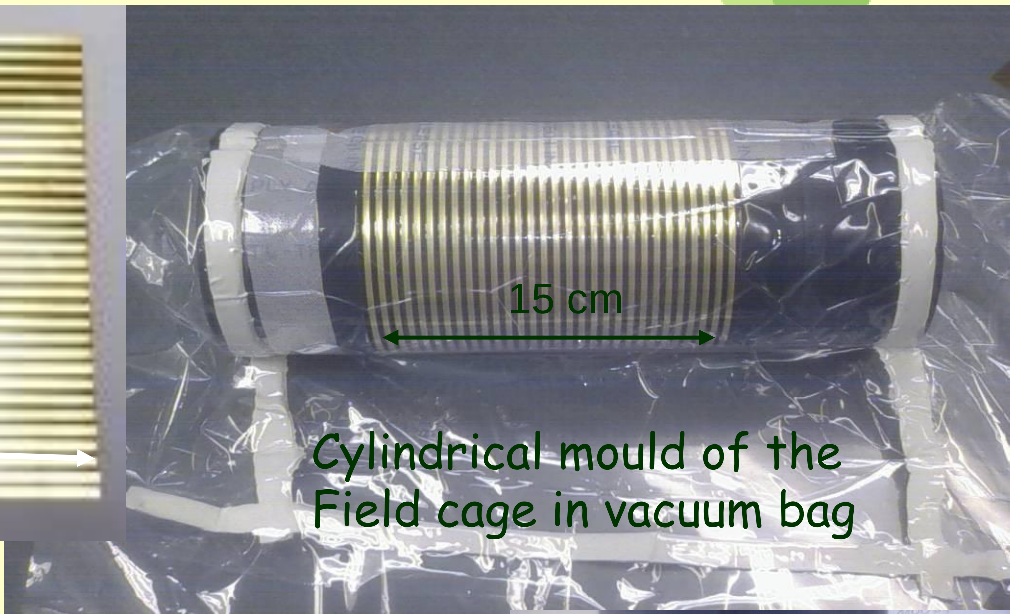
The detector is encapsulated inside a gas tight box (PERMAGLASS material) which allow to simply change the geometry and/or replace with new GEMs.

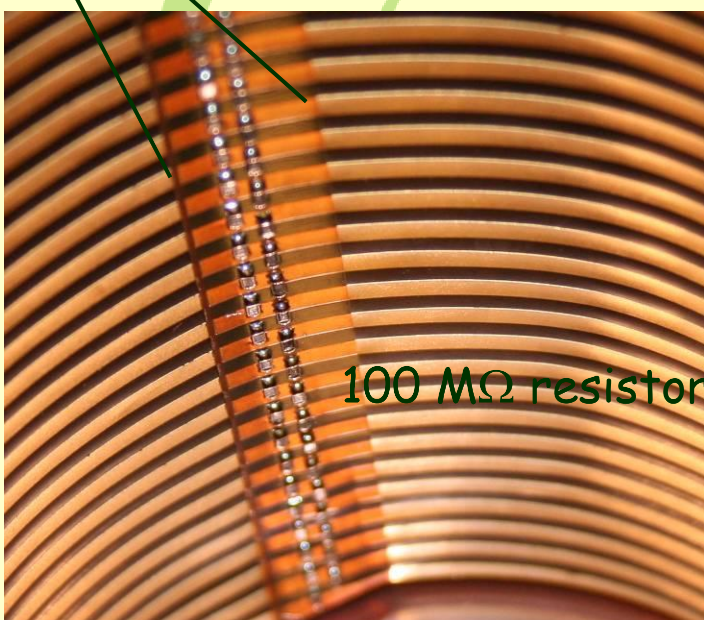
The water contamination is below 100 ppmv

No value for O_2 contamination

GEM-TPC construction: Field Cage



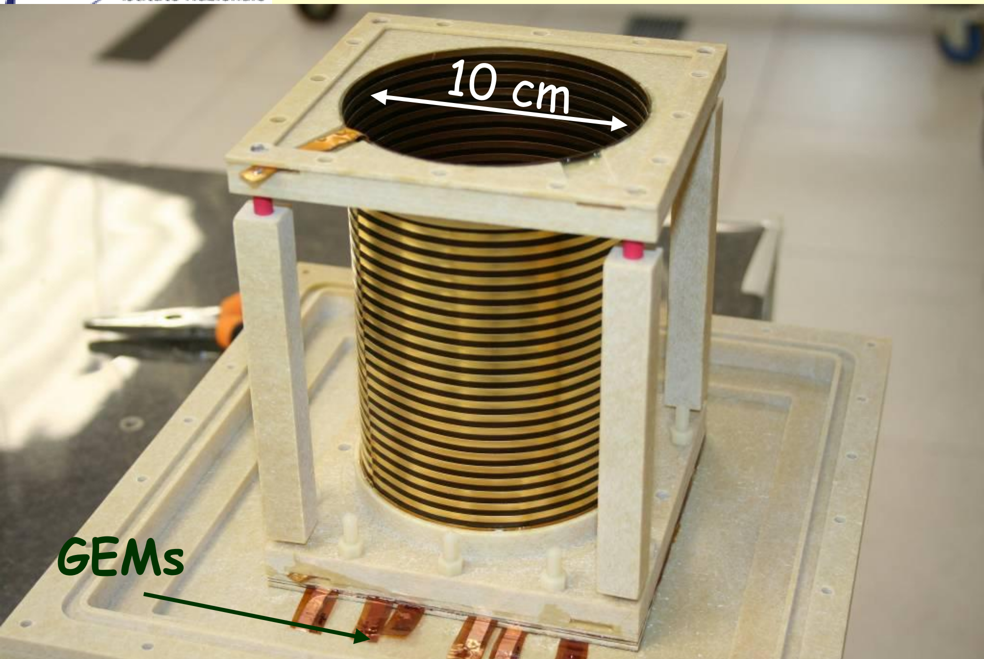


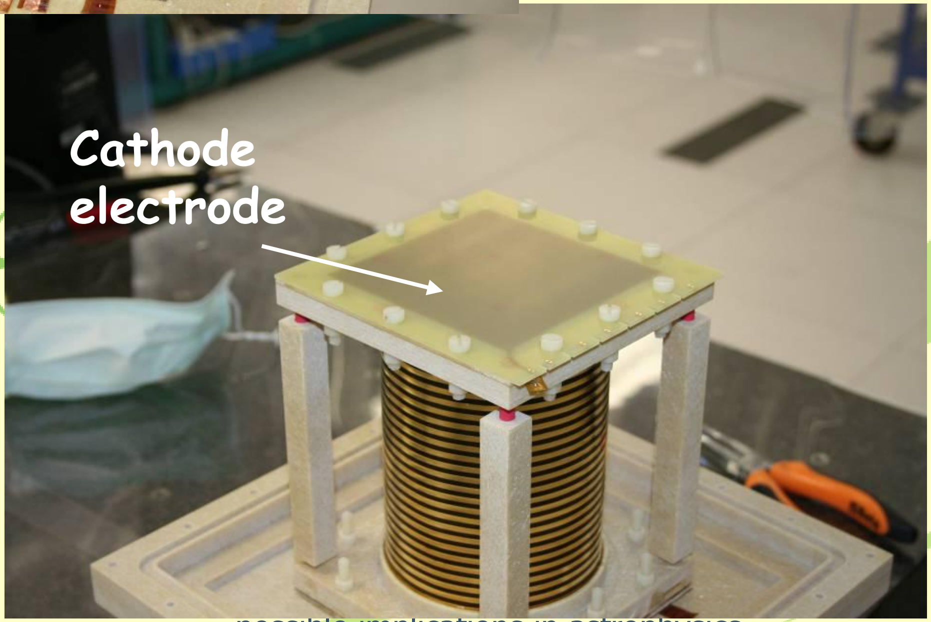


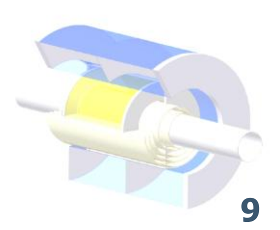
The Field Cage has been produced with the same C-GEM technique (*)

(*) G. Bencivenni et al., NIM A 572 (2007) 168

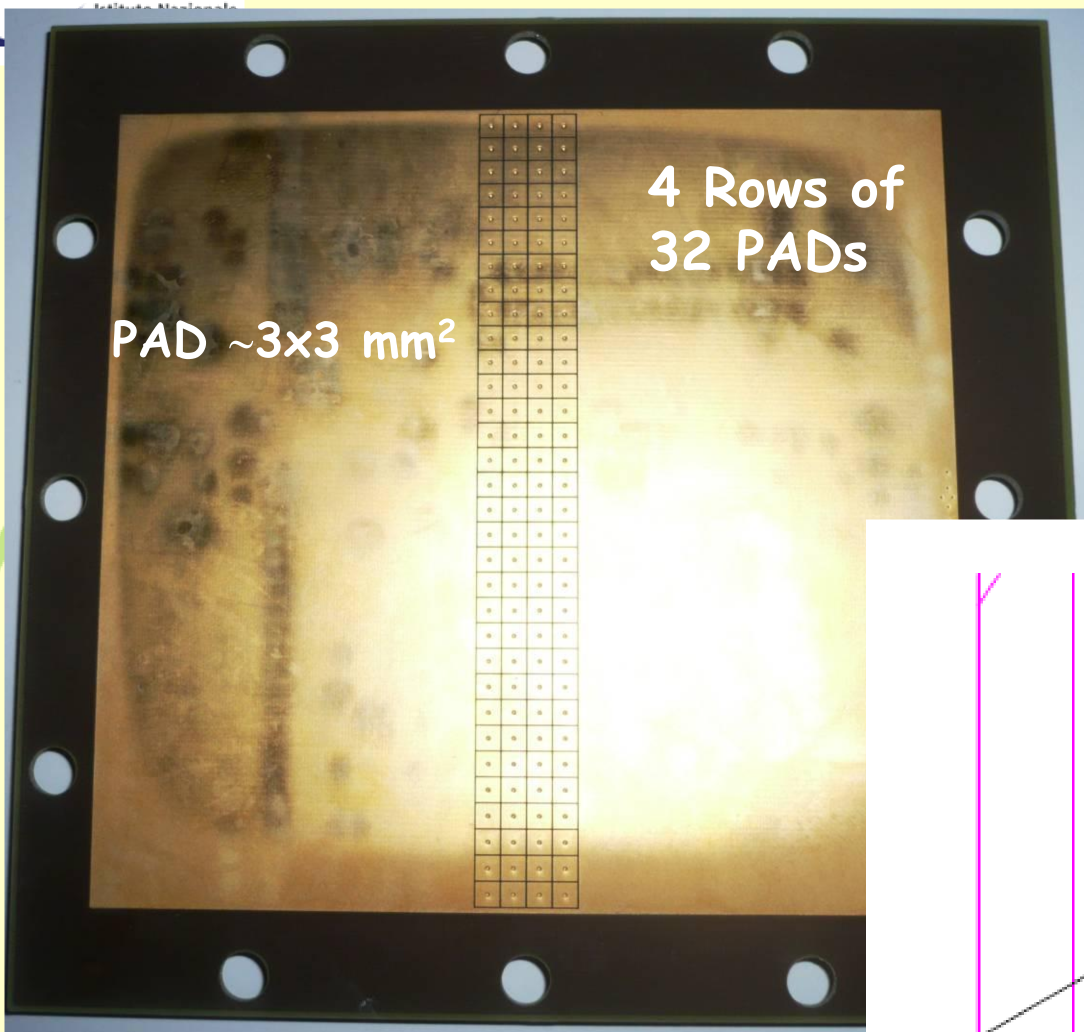
GEM-TPC construction: Assembly

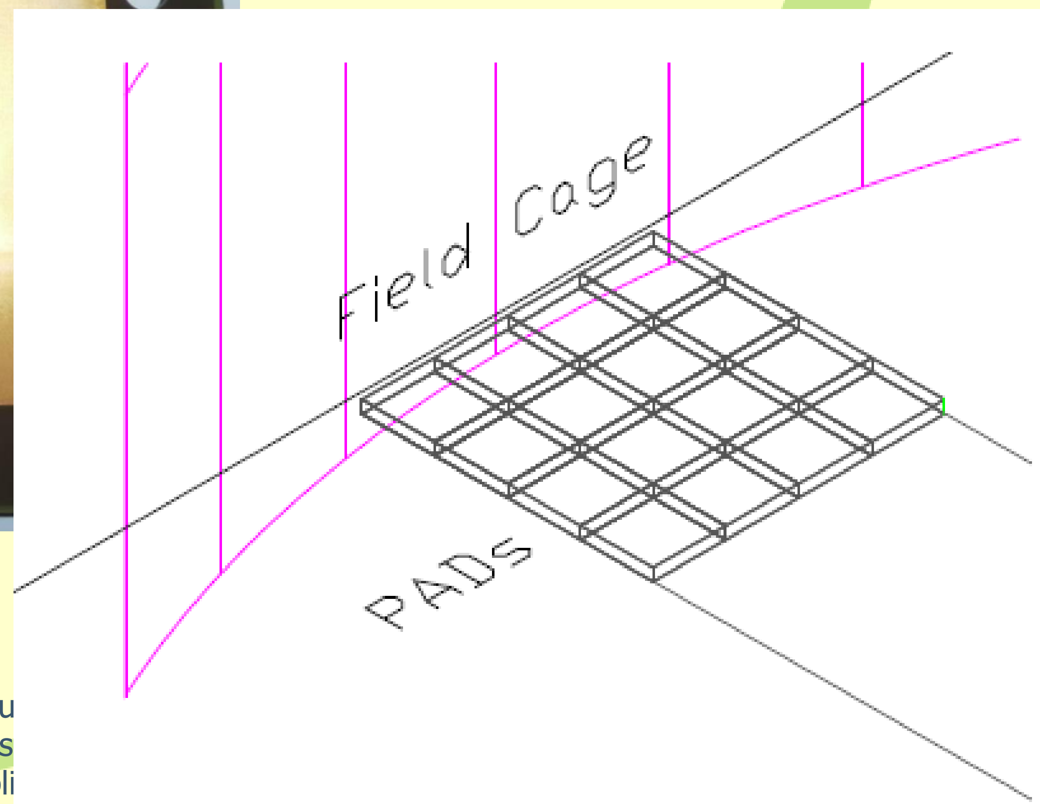




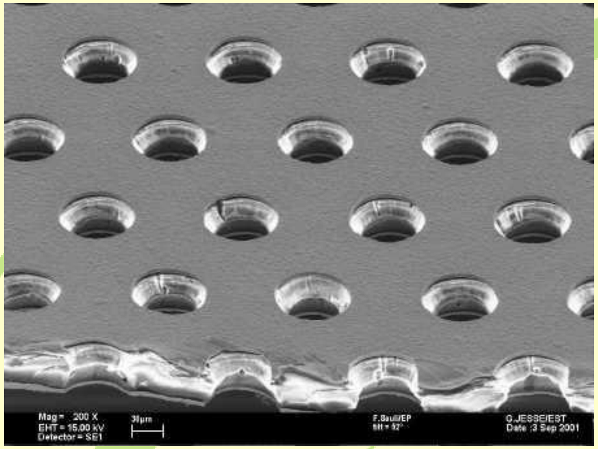


GEM-TPC construction: Readout

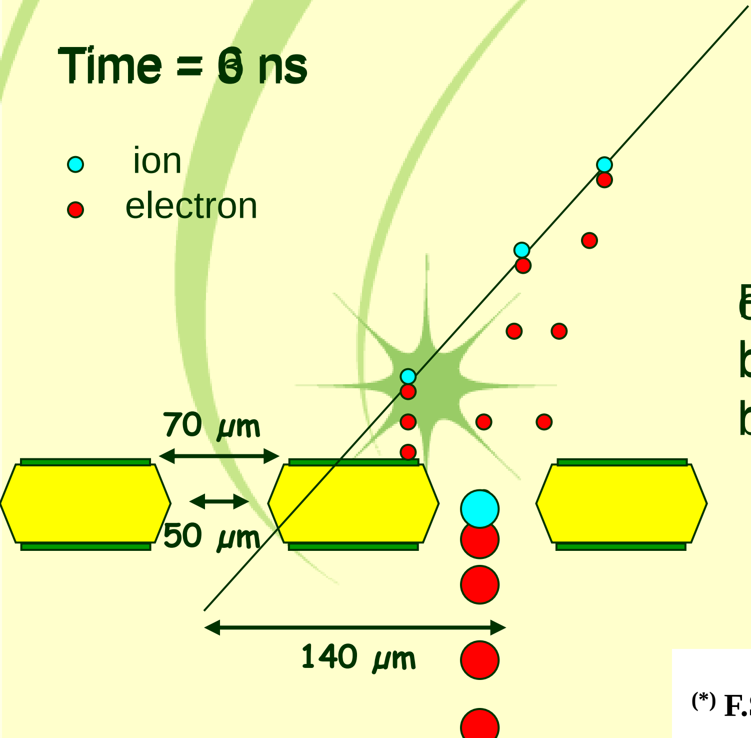




GAS ELECTRON MULTIPLIER[(*)] : principle of operation



To achieve a good gas detector response (time & space) is necessary no loss of the first(s) cluster(s) produced in the ionization gap

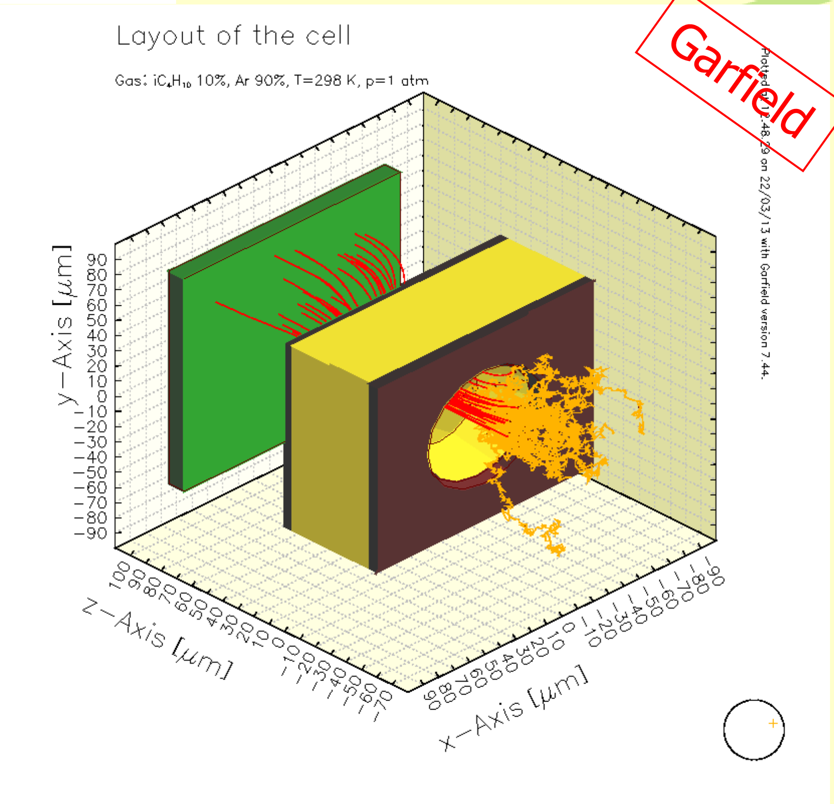


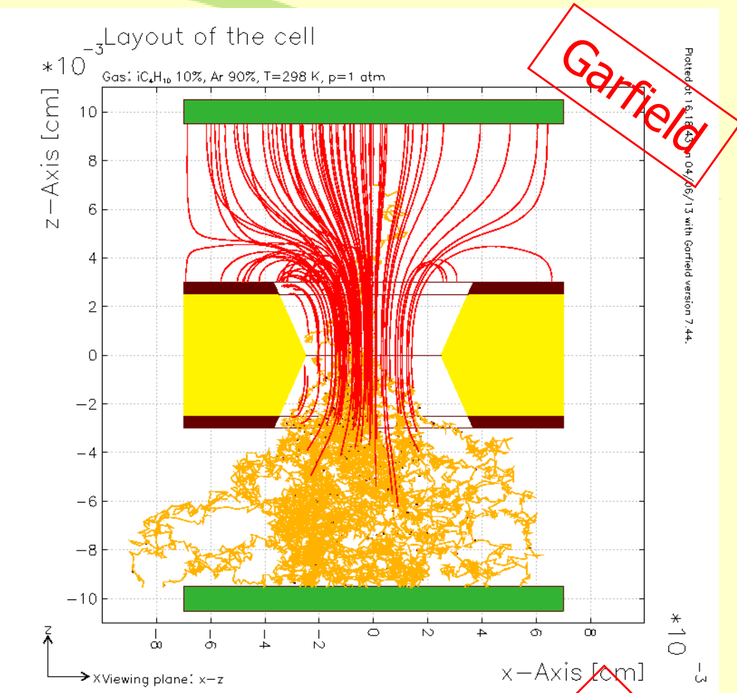
In a GEM-based TPC this means a high collection efficiency into the GEM holes, which depends on:

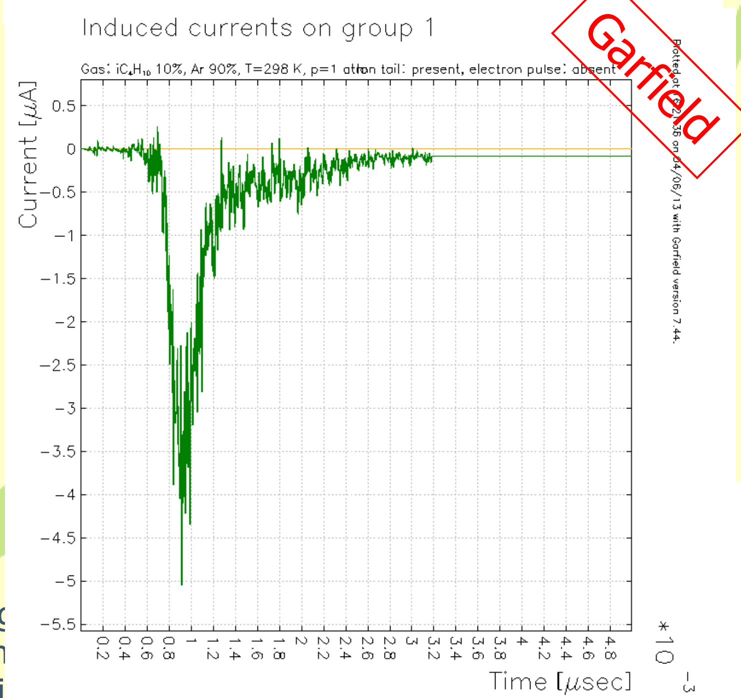
- drift field;
- field inside the GEM holes;
- primary ionization;
- front-end electronics threshold;

(*) F.Sauli, NIM A386 531 1997

GEM Detector Simulation

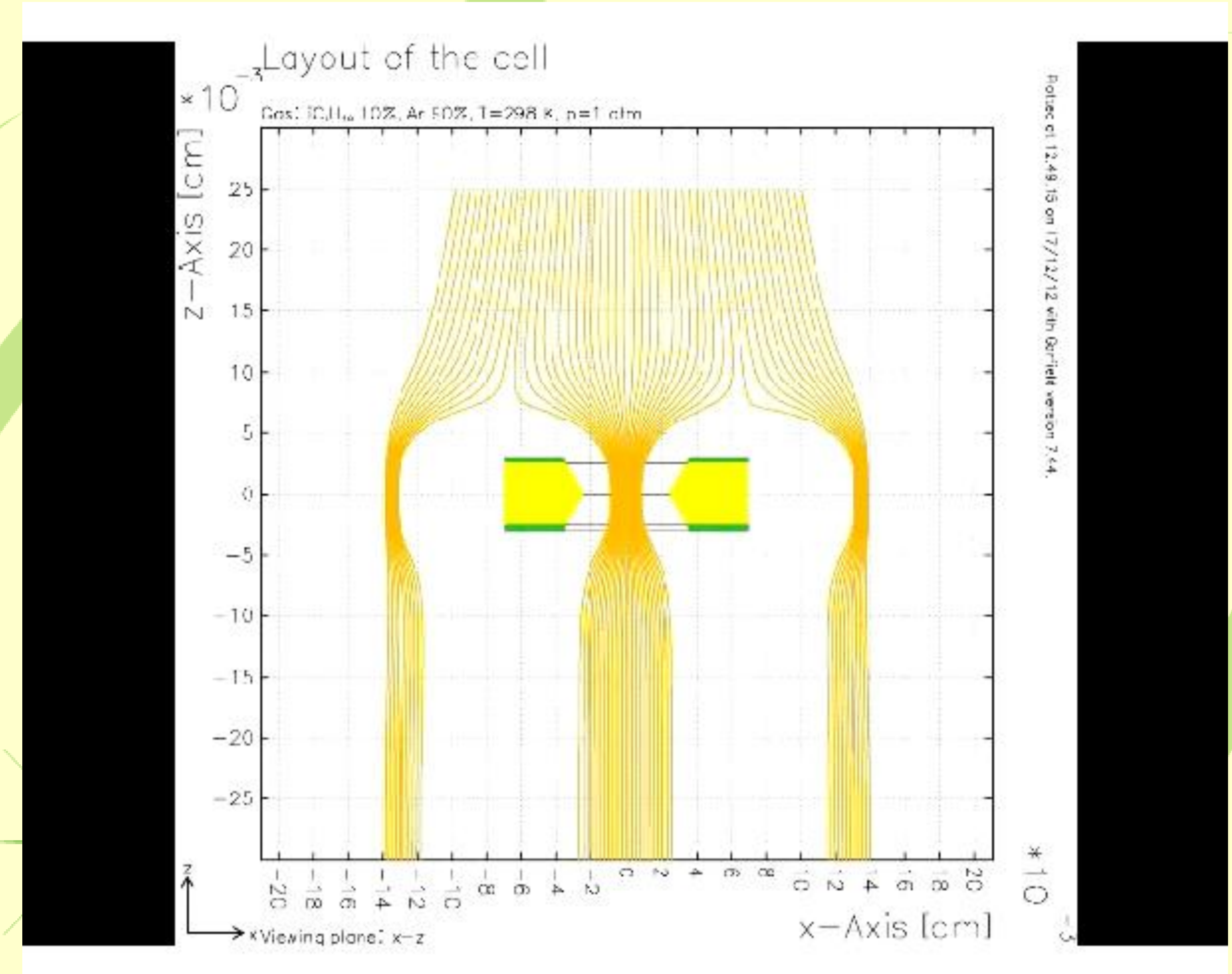




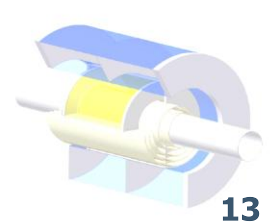


GARFIELD is a powerfull simulation tool:
primary ionization, diffusion,
attachment, multiplication,
E-/ion drift, induced & direct signal, ecc

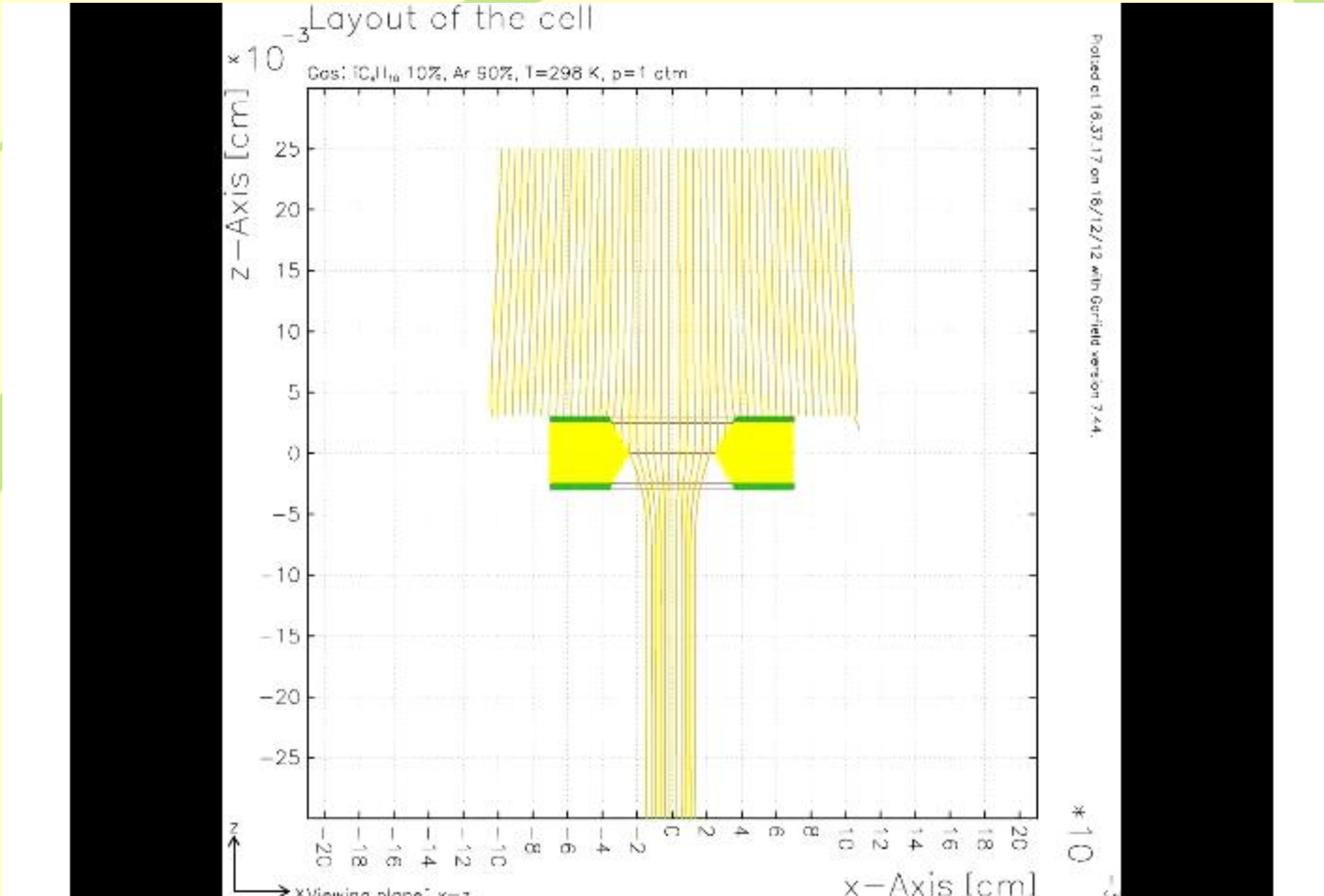
Drift Effect on the Collection Efficiency



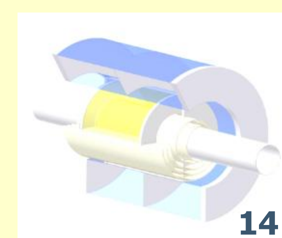
A low drift field (200-400 V/cm) is suitable for a TPC



GEM Effect on the Collection Efficiency



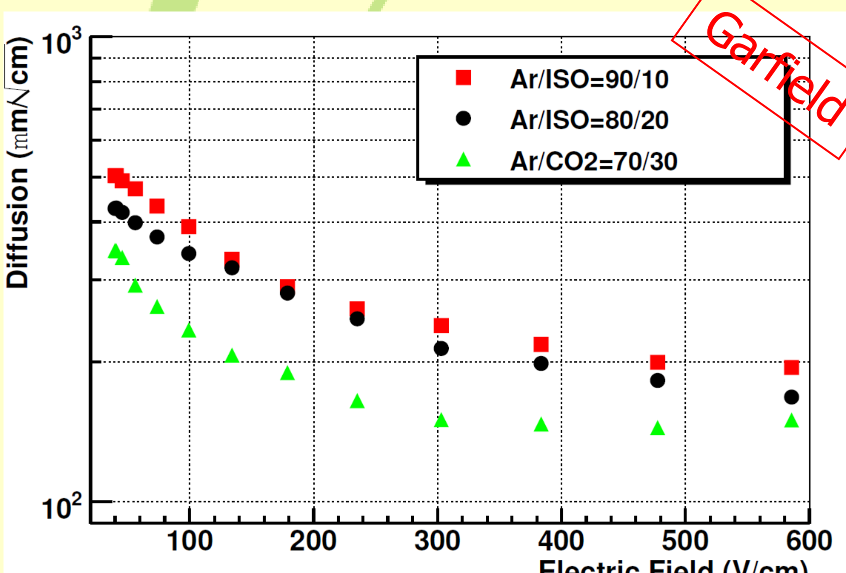
A GEM voltage of 300-400 V is suitable for a stable detector operation

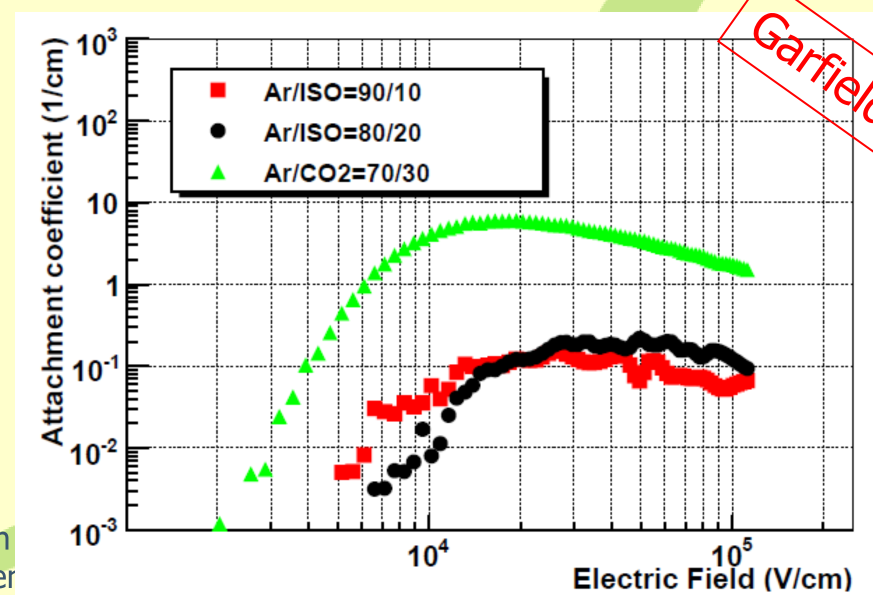


Gas Mixture Choice

The tested isobutane-based gas mixtures were chosen for the following reasons:

- high primary ionization;
- high drift velocity (~ 30 $\mu m/ns$);
- high Townsend coefficient;
- a moderate diffusion (~300 $\mu m/\sqrt{cm}$ for a drift field of 150 V);
- last but not least a very low attachment coefficient





Test beam @ PSI: Setup

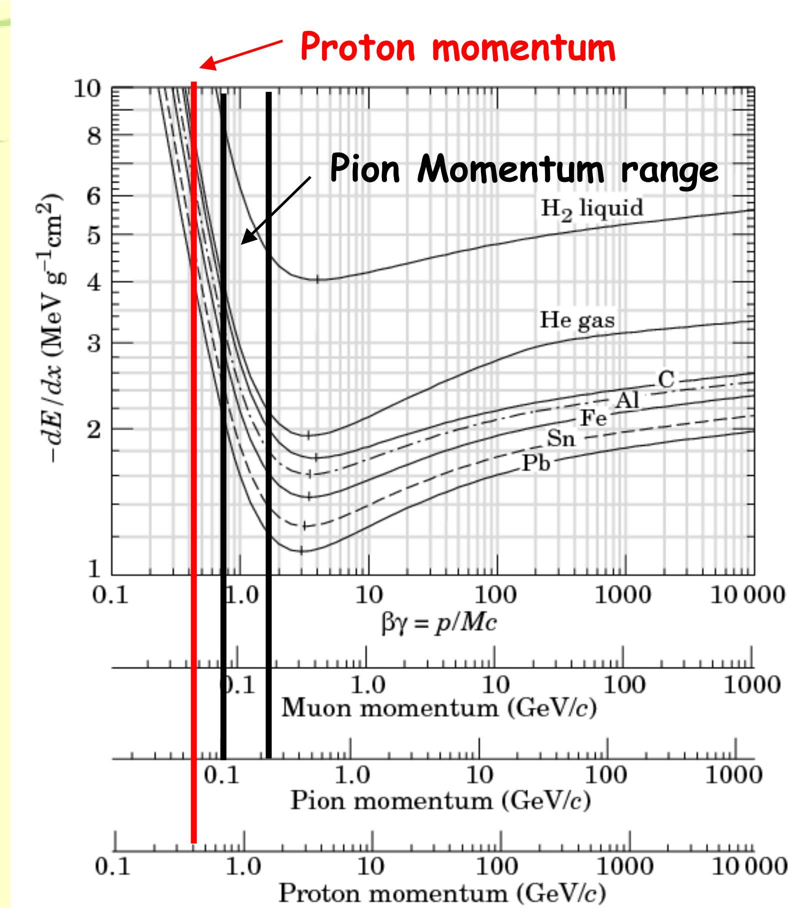
The PSI πM1 beam is a (quasi) continuous high-intensity secondary beam: Pions/proton arrive in 1 ns-wide bunches every 20 ns.

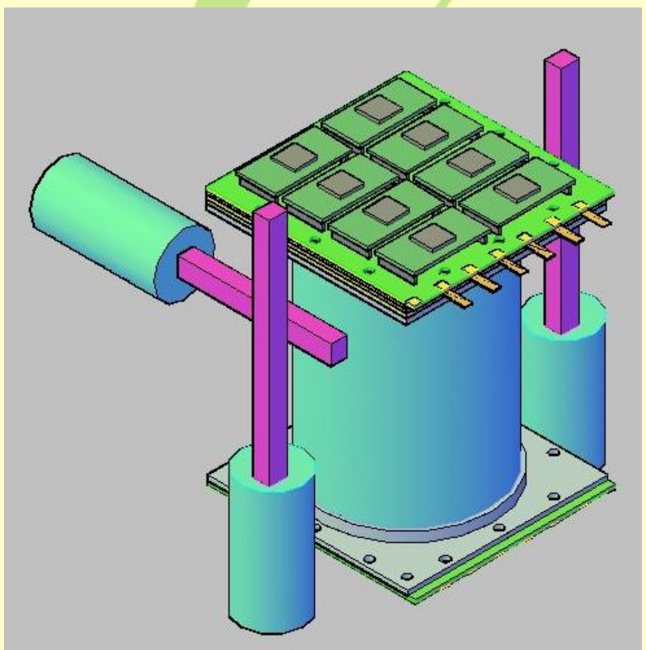
Characteristics of the piM1 beam line:

Momentum range 100-500 MeV/c

Momentum resolution 1 %

Spot size on target (FWHM): 15 mm (H)- 10 mm (V)



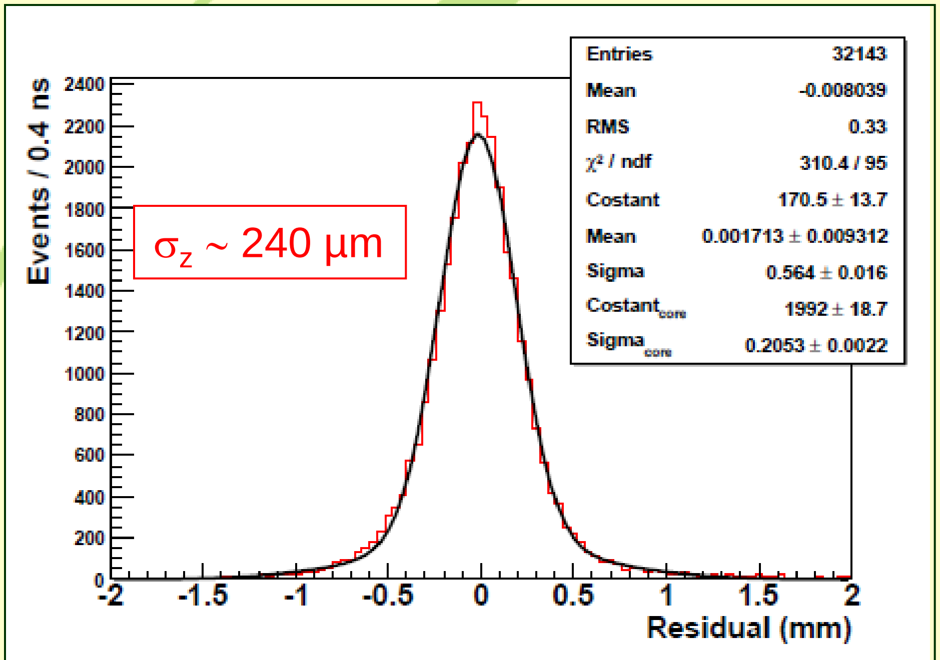


The trigger consisted of the coincidence of three scintillators placed at the edge of the detector gas tight box (~ 20 cm) and covering an area of about 12x20 mm^2.

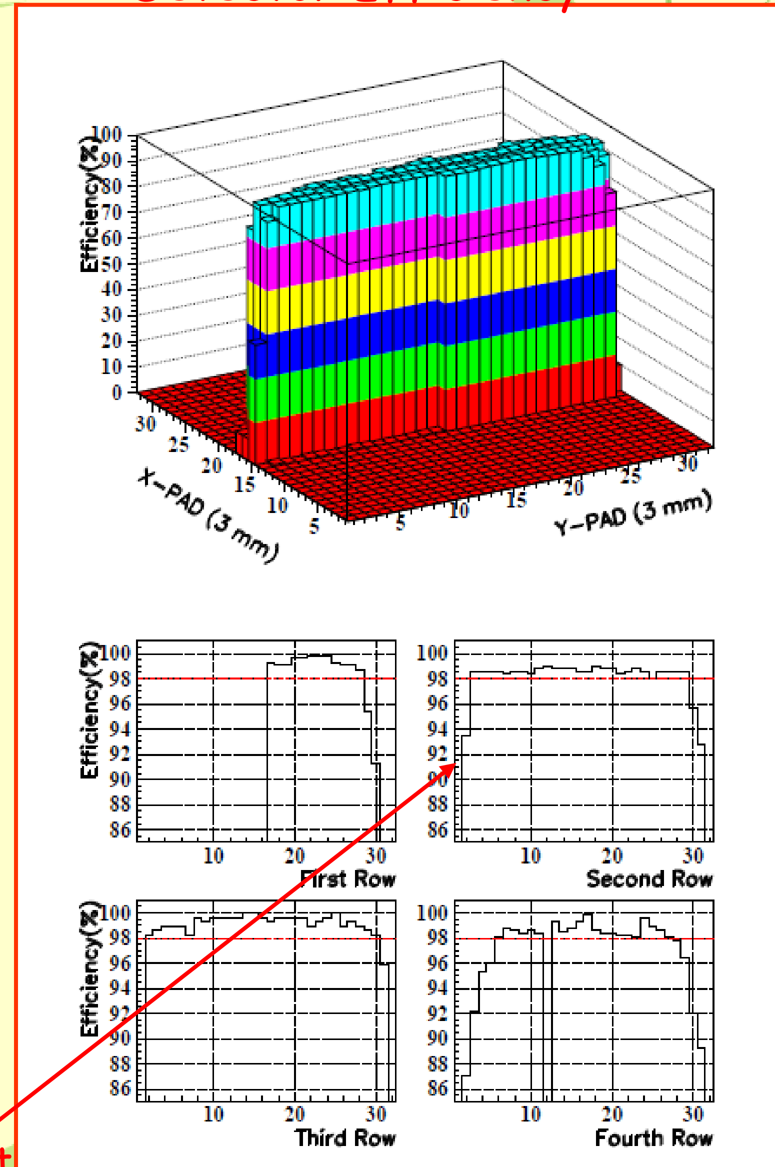
Another scintillator, 5 m far from the detector, allowed to perform the measurement of particle momentum by mean Time of Flight.

Beam Test @ PSI: results

Residual in the drift direction



Detector Efficiency

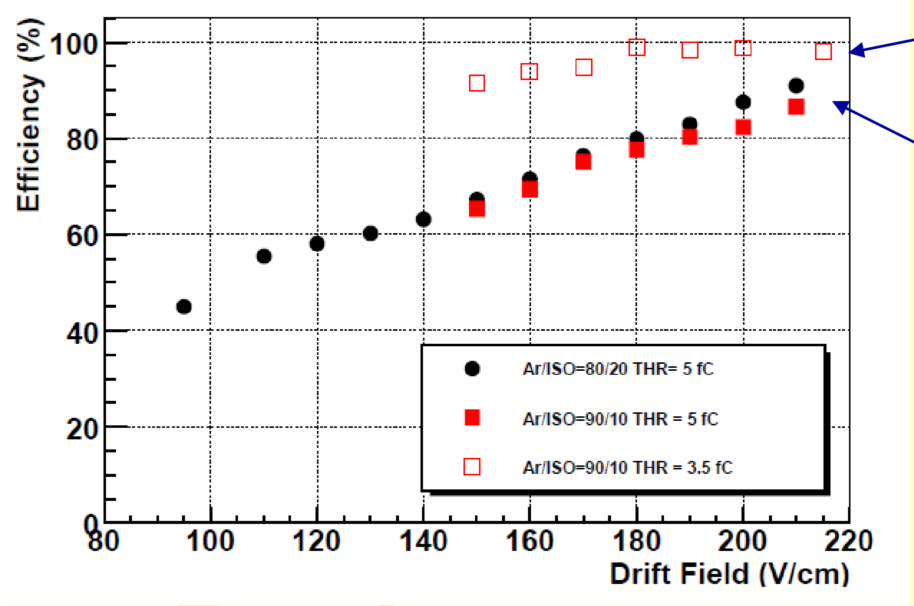


Field Cage Edge effect

Efficiency per Row

Detector efficiency with Isobutane-based gas mixtures

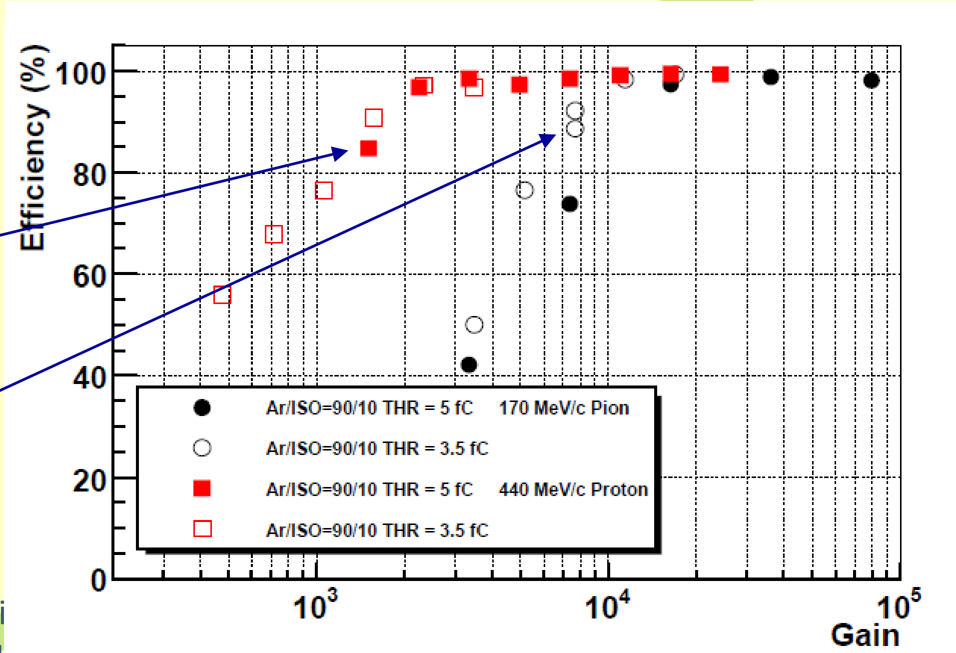
Efficiency vs drift field



Low FEE threshold

High primary ionization

Efficiency vs Gain

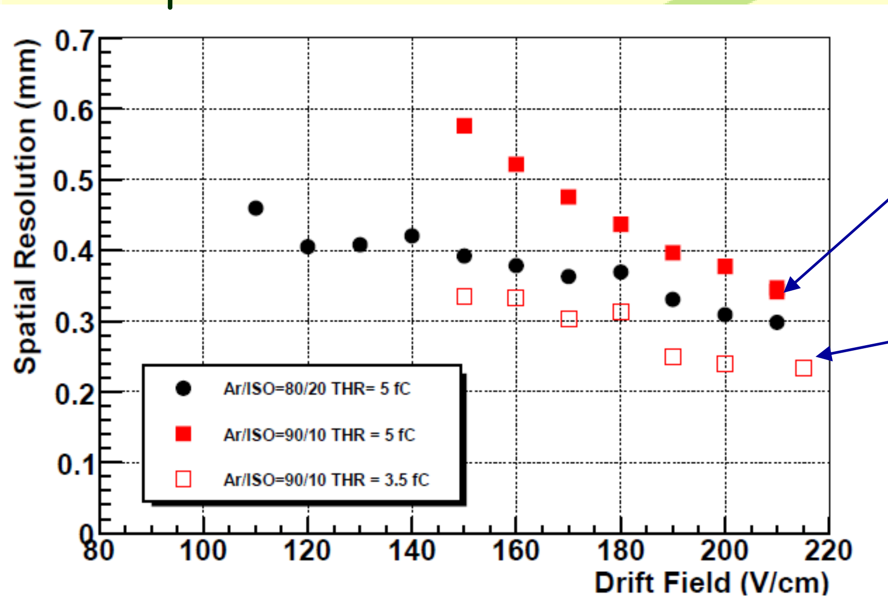


Higher ionizing particle

Low FEE threshold

Spatial resolution with Isobutane-based gas mixtures

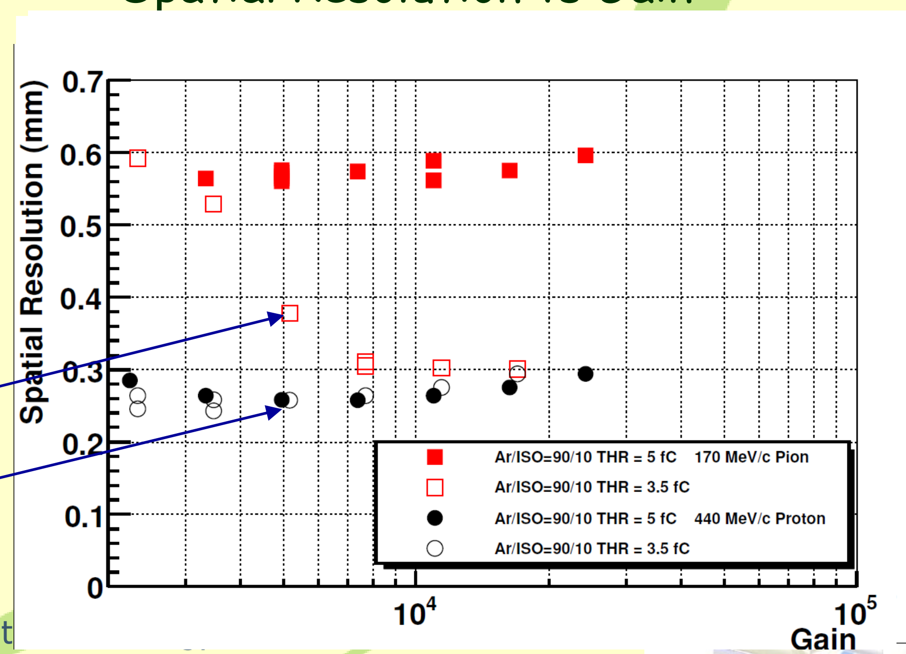
Spatial Resolution vs drift field



High primary ionization

Low FEE threshold

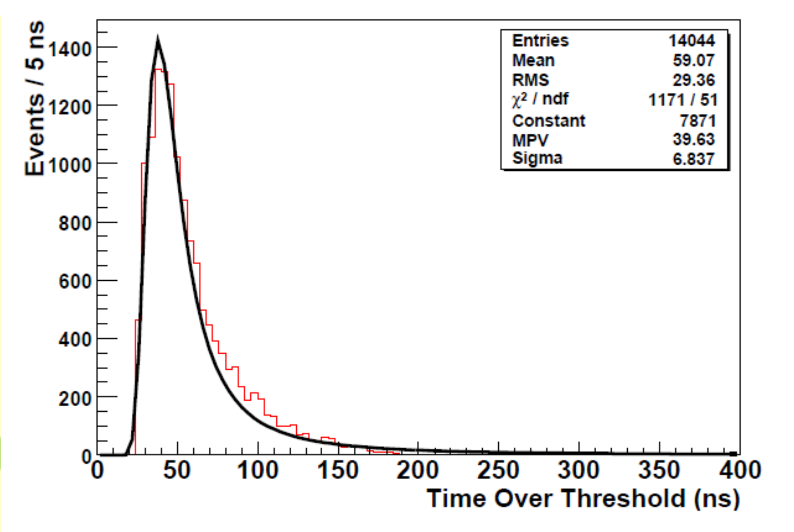
Spatial Resolution vs Gain



Low FEE threshold effect

Higher ionizing particle

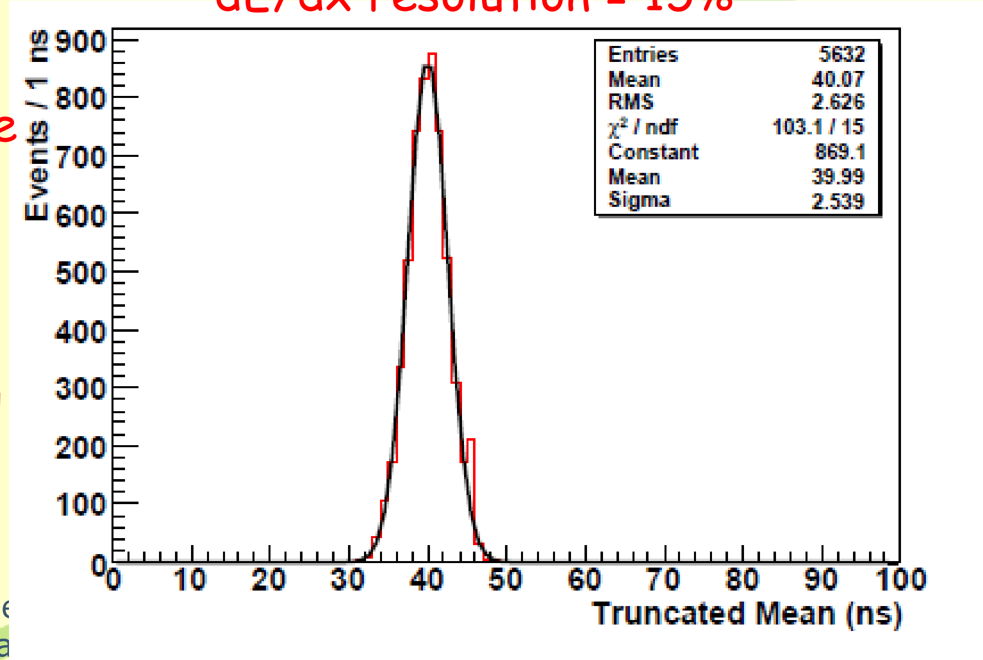
Time Over Threshold measurement



The measurement of signal pulse width above a discriminator threshold may be used as a determination of the charge

→ Landau distribution as expected

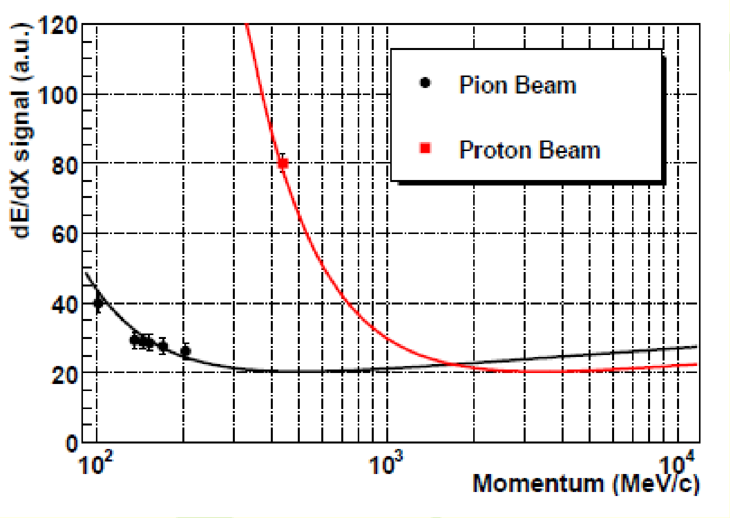
dE/dx resolution = 15%



Accepting the 40% lowest values, the most probable value of the track charge is correctly reproduce

→for higher values of the accepted fraction, the resolution gets worse due to inclusion of hits from the Landau tail
→ for smaller values, the effect is related to the loss in statistics.

PID & dE/dx measurements



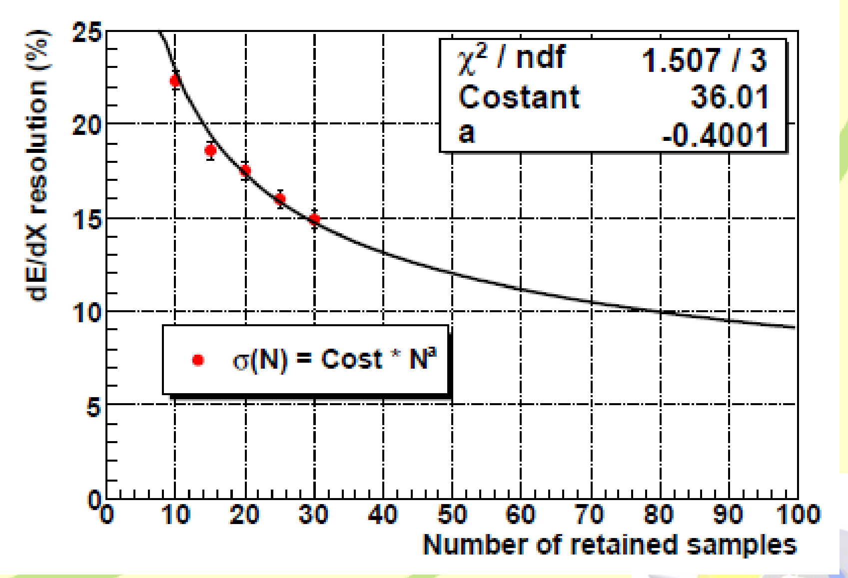
By simultaneously measuring the momentum of proton & pion (by means the time of flight) and the deposited energy (by means the mean value of the truncated distribution), an estimation of the prototype to identify the particle crossing the detector has been performed

The dE/dx resolution is usually parametrized [1] as:

$$\sigma_{dE/dx} \propto N^a * x^b$$

N=# of samples and x their length (3 mm).

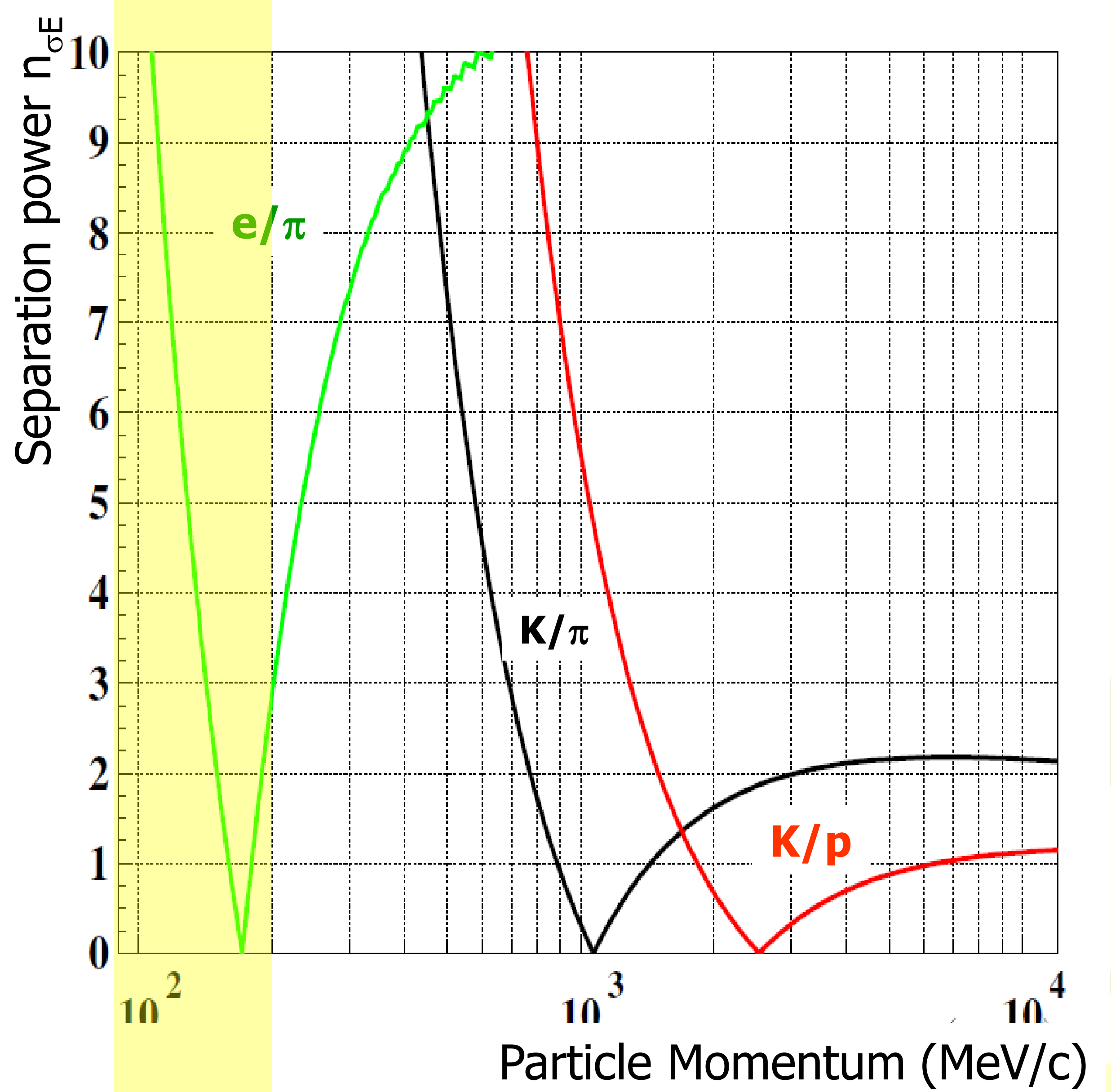
Assuming an average track length of 100 hits in AMADEUS, with 100 MeV/c pion and 40% of accepted fraction, we expect to measure a dE/dx resolution of 9%.



Advances studies in the low-energy QCD in the strangeness sector and

(*) W. Allison, J.H. Cobb., Ann. Rev. Nucl. Part. Sci 30 (1980) 253.

PID & dE/dx estimation

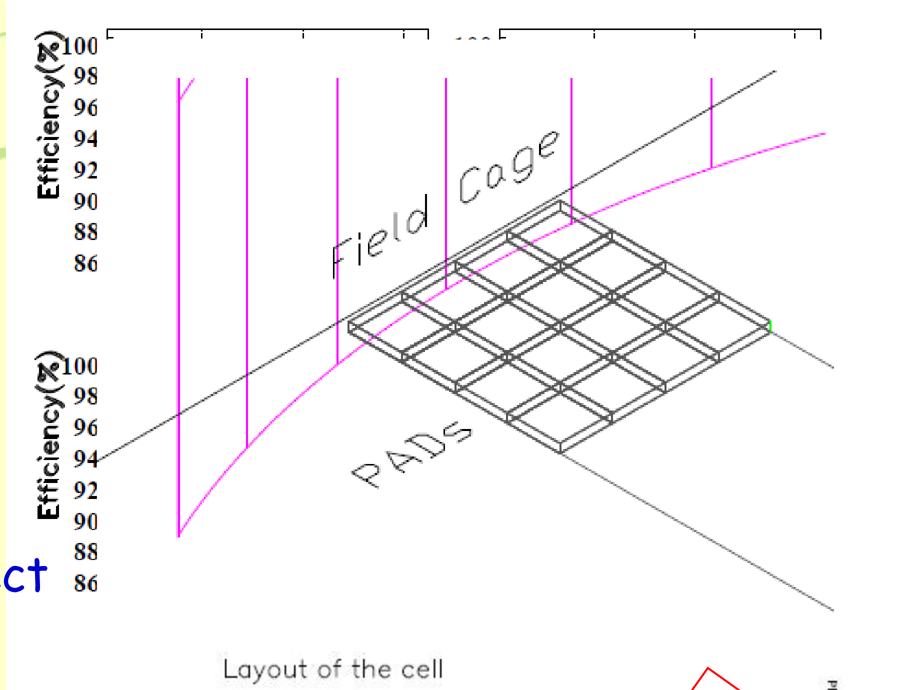


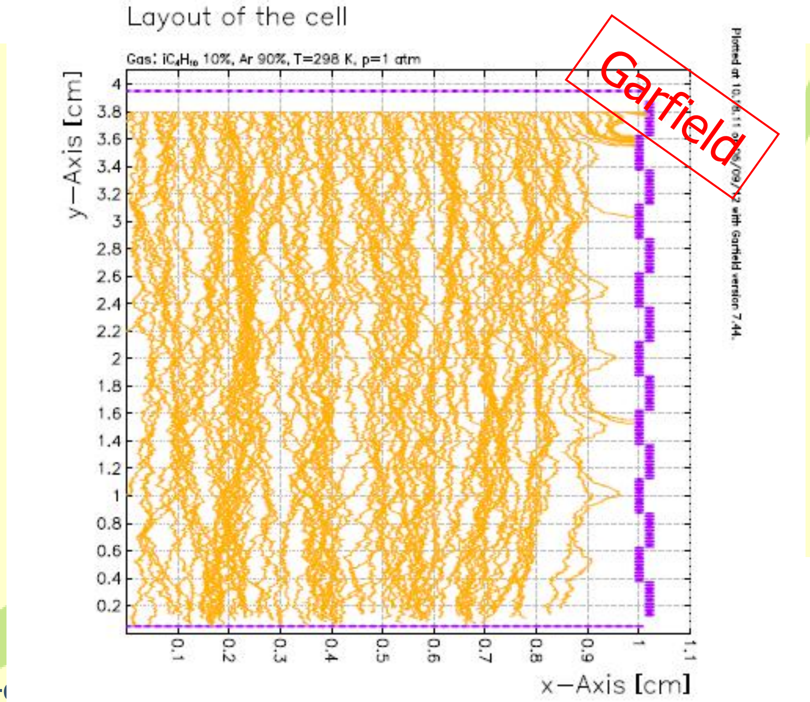
Field Cage Effects

Low and/or not full detection efficiency has been measured on the edge of each pad rows.

- the first and the last pad of each rows collect about 2/3 of the charge with respect to the other pads of the row;

- the primary electrons produced in the drift gas and drifting toward the first GEM can be collected by the internal strips of the field-cage.





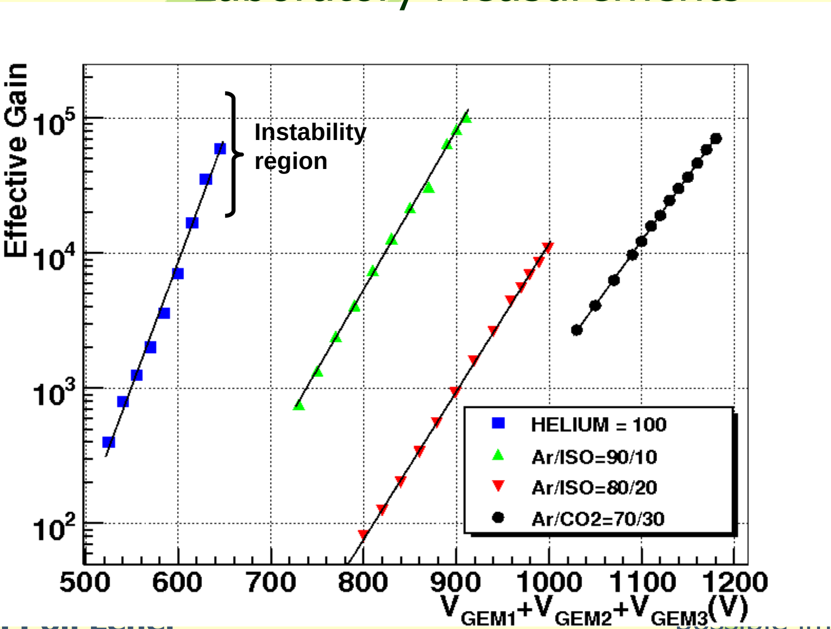
All these effects are fully reduced drifting away from the field-cage by 5 mm

Pure Helium GEM-based TPC performances

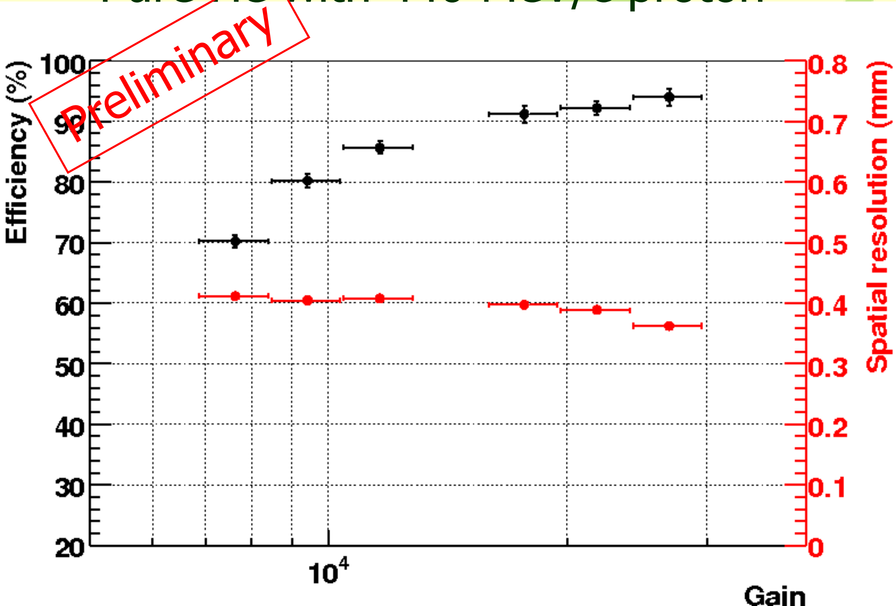
Garfield

Gas Mixture	Average Townsend Coeff. [1/V]	Drift Velocity at 200 V/cm [μm/ns]	Longitudinal & Transversal Diff. at 200 V/cm [μm/√cm]		Cluster/cm		
					170 MeV/c Pion	440 MeV/c Proton	MIPs
Ar/Iso = 80/20	(25.2±0.2)x10−3	29±2	217±16	274±12	45.2±2.1	96.6±3.5	40.0±2.0
Ar/Iso = 90/10	(27.2±0.3)×10−3	39±2	282±7	359±18	37.2±1.9	79.6±2.8	32.8±1.8
Helium = 100	(42.0±0.3)×10−3	4.4±0.5	383±15	778±5	4.5±0.9	9.5±1.1	4.0±0.9
Ar/CO2= 70/30	(22.0±0.3)×10−3	4.51±0.0 2	178±11	175±6	32.2±1.8	68.8±2.6	28.4±1.6

Laboratory Measurements



Pure He with 440 MeV/c proton



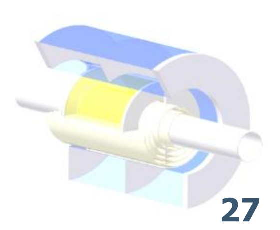
Conclusions

The GEM-TPC prototype is successfully tested at the πM1 test beam facility of PSI with isobutane-based gas mixtures and with pure Helium :

- Efficiency > 99% and Spatial Resolution along drift direction ≈ 250 μm with isobutane gas mixtures have been measured;
- With pure Helium gas a detector stability up to $3*10^4$ has been determinated
  → efficiency ~ 95% & spatial resolution ~ 350 μm;
- Estimation of Particle Identification capability;
- Measurement of the dE/dx resolution ~ 15%;
- High separation power in the AMADEUS environment

440 MeV/c Proton

	Number of cluster per cm	RMS cluster	Number of e- per cluster
Hydrogen	**19.58**	**1.4**	**1.1**
Deuterium	**-**	**-**	**-**
Helium-3	**9.69**	**0.88**	**1.97**
Helium-4	**9.68**	**0.86**	**1.85**
Ar/CO_2 = 70/30	**67.64**	**2.59**	**2.1**



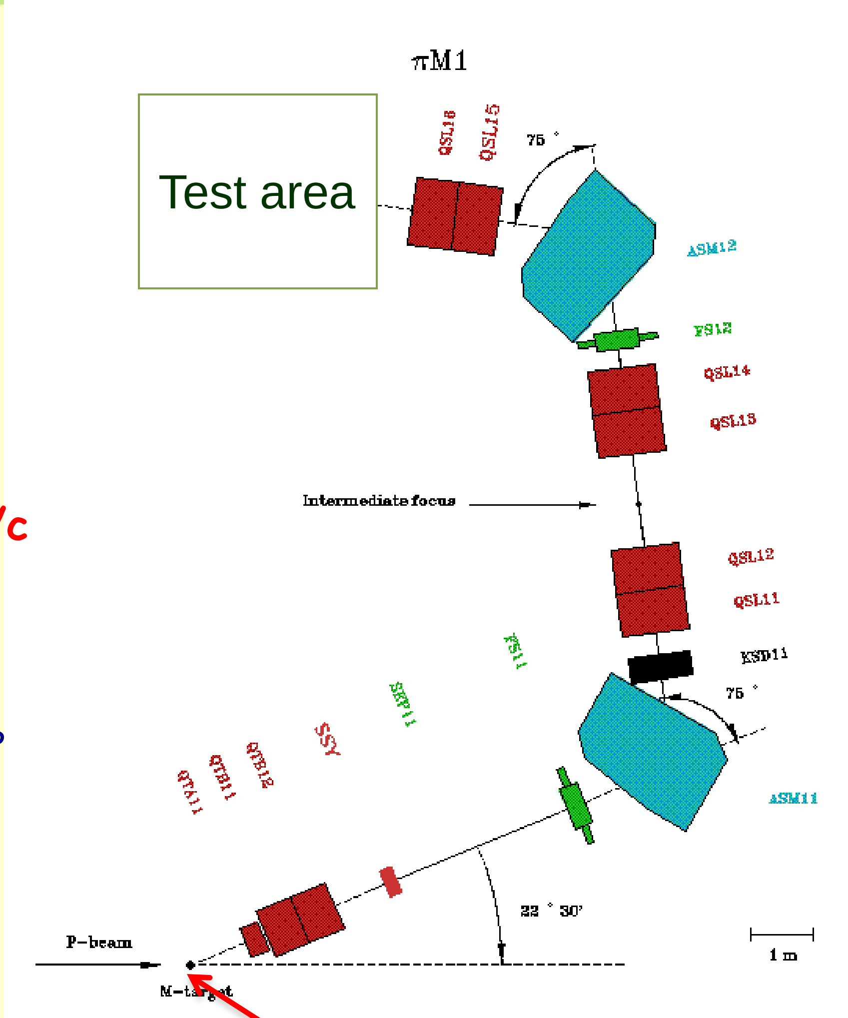
Beam Test @ PSI

The PSI πM1 beam is a (quasi) continuous high-intensity secondary beam
Pions/proton arrive in 1 ns-wide bunches every 20 ns.

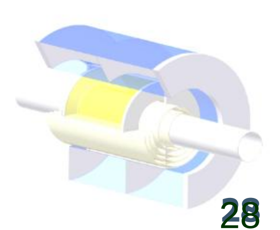
Characteristics of the piM1 beam line:

Total path length	21 m
Momentum range	**100-500 MeV/c**
Solide angle	6 msr
Momentum acceptance (FWHM)	2.9 %
Momentum resolution	**0.1 %**
Dispersion at focal plane	7 cm/%
Spot size on target (FWHM)	15 mm horizontal 10 mm vertical
Angular Divergence on target(FWHM)	35 mrad horizontal 75 mrad vertical

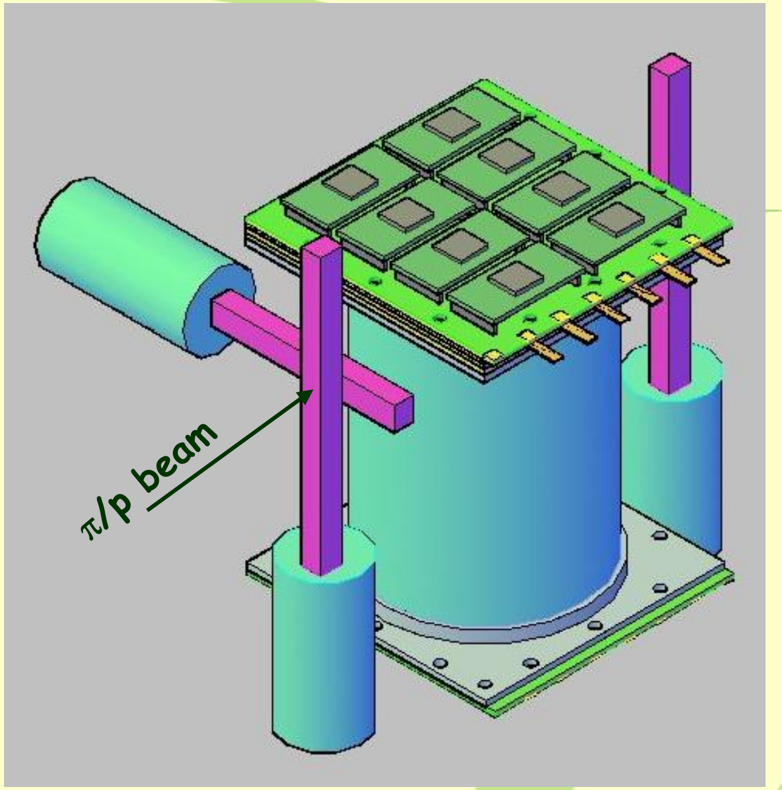
NO MAGNETIC FIELD



target

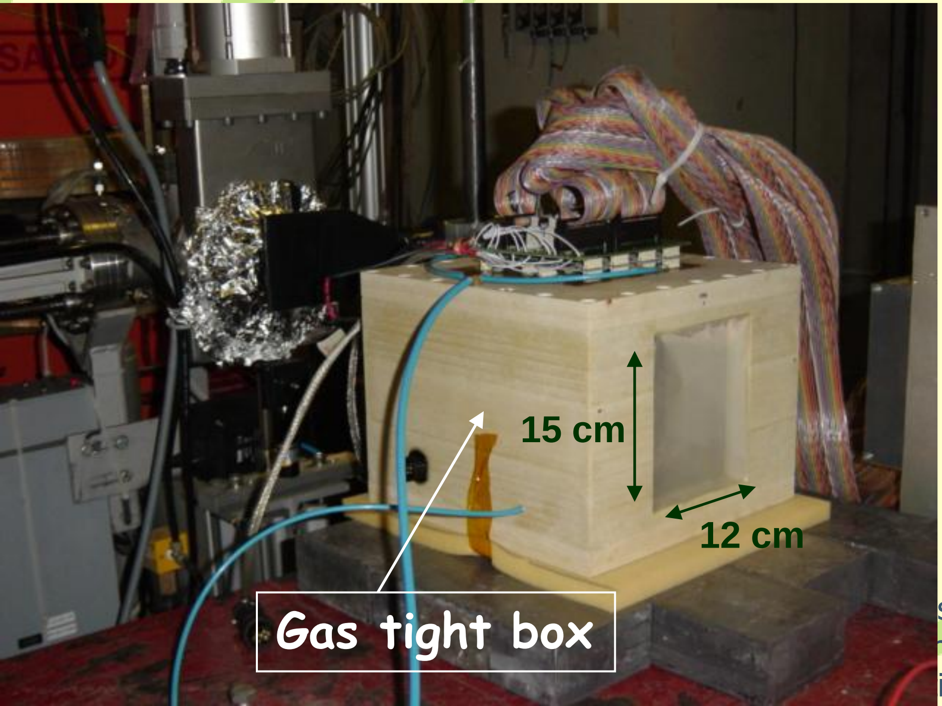


Test beam @ PSI: Setup

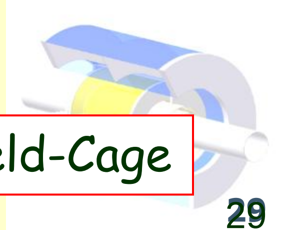


The trigger consisted of the coincidence of three scintillators placed at the edge of the detector gas tight box (~ 20 cm) and covering an area of about 12x20 mm^2.

Another scintillator, 5 m far from the detector, allowed to perform the measurement of particle momentum by mean Time of Flight.

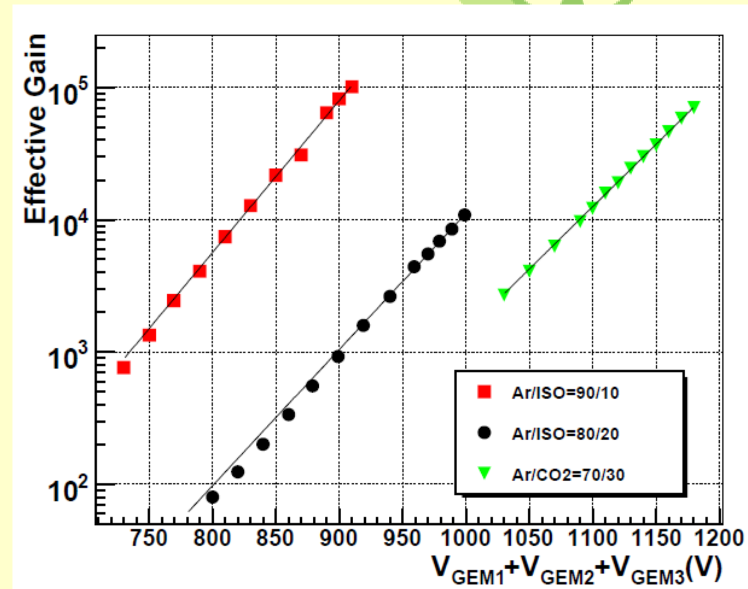


The FFE channel based on CARIOCA chip was sent to the multi-hit TDC and the leading edge (time hit) and the trailing edge, which allow to measure w.r.t leading edge the time over threshold (charge hit), were recorded.

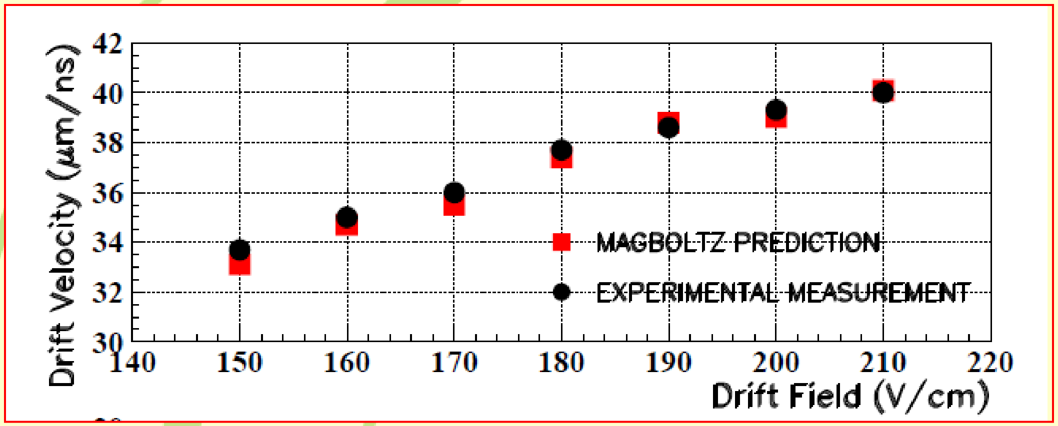


Beam orthogonal to Field-Cage

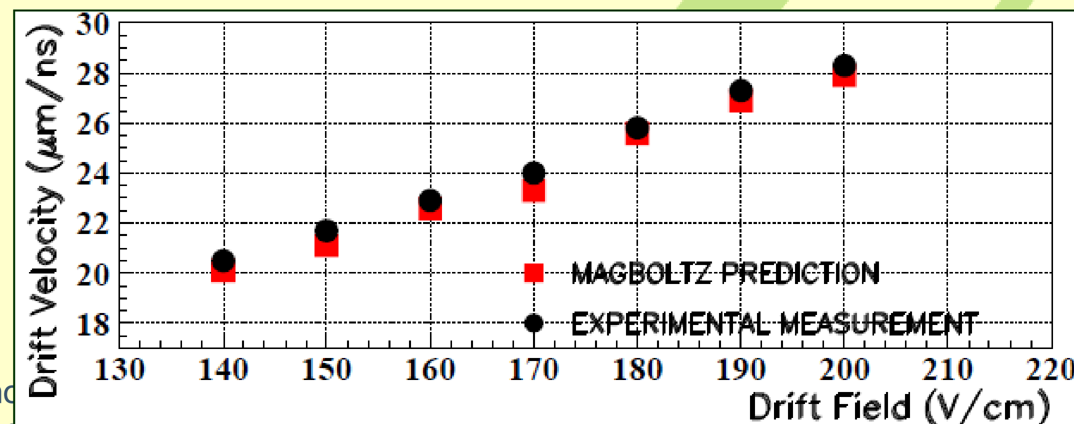
Gas Mixture characterization



Ar/Isobuthane = 90/10



Ar/Isobuthane = 80/20

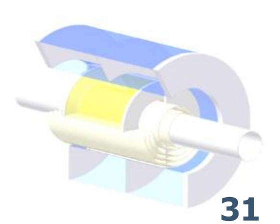


The drift velocity for the Ar/CO_2=70/30 is 3.5 μm/ns with a drift field of 150 V

Primary ionization on the Collection Efficiency

Gas Mixture		170 MeV/c Pion	440 MeV/c Proton	MIPs
Ar/C_4H_{10} 80/20	clu/cm	45.2±2.1	96.6±3.5	40.0±2.0
	e^-/clu	2.13±0.12	2.12±0.11	2.11±0.11
Ar/C_4H_{10} 90/10	clu/cm	37.2±1.9	79.6±2.8	32.8±1.8
	e^-/clu	2.14±0.12	2.12±0.11	2.12±0.10
Ar/CO_2 70/30	clu/cm	32.2±1.8	68.8±2.6	28.4±1.6
	e^-/clu	2.19±0.13	2.20±0.13	2.21±0.14

A high primary ionization reduces possible loss of the first cluster generated closer to the first GEM
(but not too high for space charge effect)



Future developments