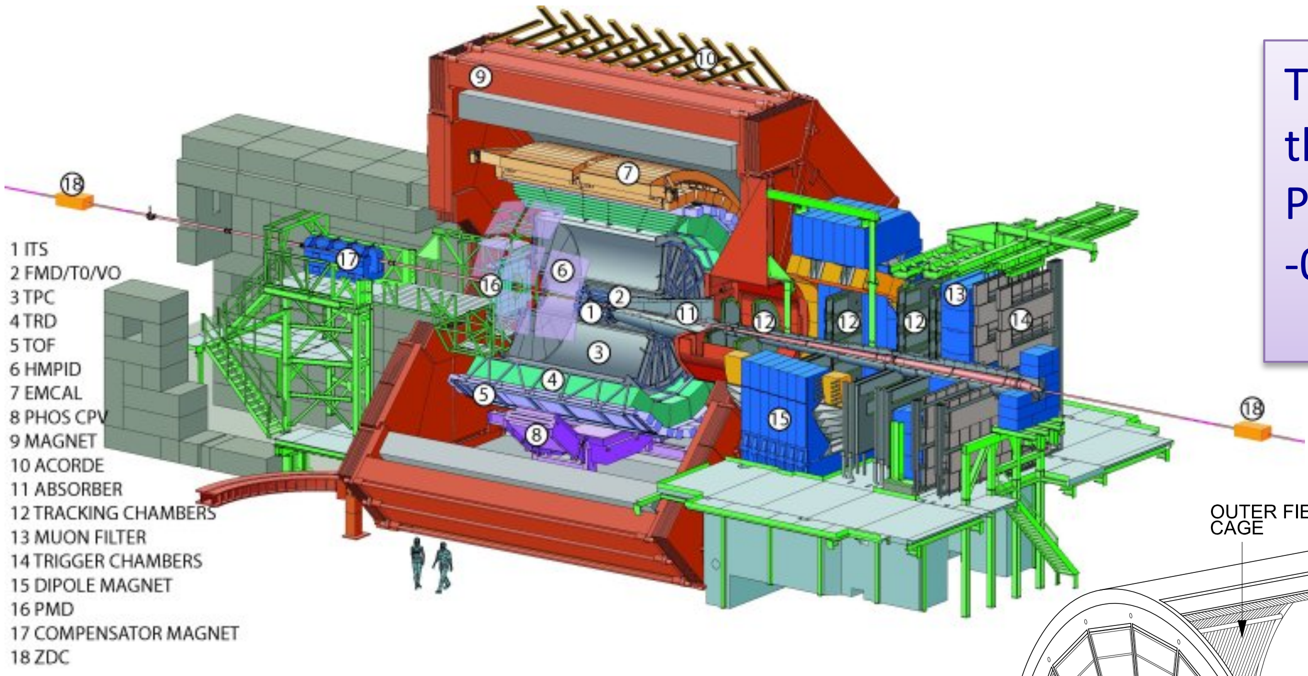
The ALICE TPC Upgrade with GEMs

C. Garabatos

The ALICE TPC

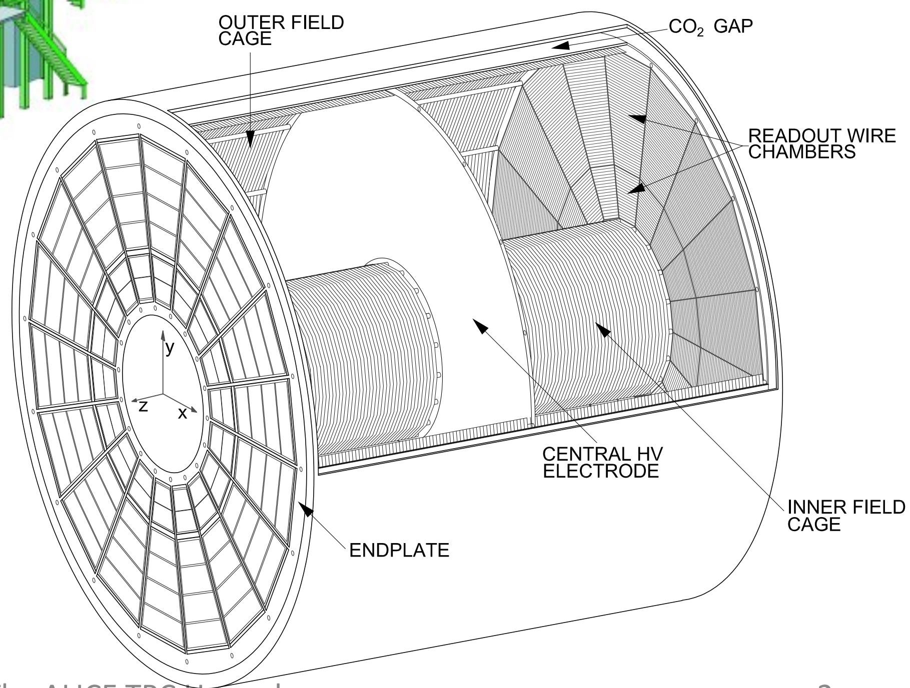


The main tracking device of the ALICE barrel
Particle ID through dE/dx
$-0.9 < \eta < 0.9$

About 90 m^3 of gas

- 2010: Ne-CO_2-N_2 (90-10-5)
- 2011-2013: Ne-CO_2 (90-10)
- 2014: Ar-CO_2 (90-10)

Drift voltage 100 kV for 94 μs drift time
72 MWPCs with 557 768 readout pads



The ALICE TPC

☞ A TPC has no redundancy
☞ Low event rate (compared to no-TPC experiments) but high hit rate

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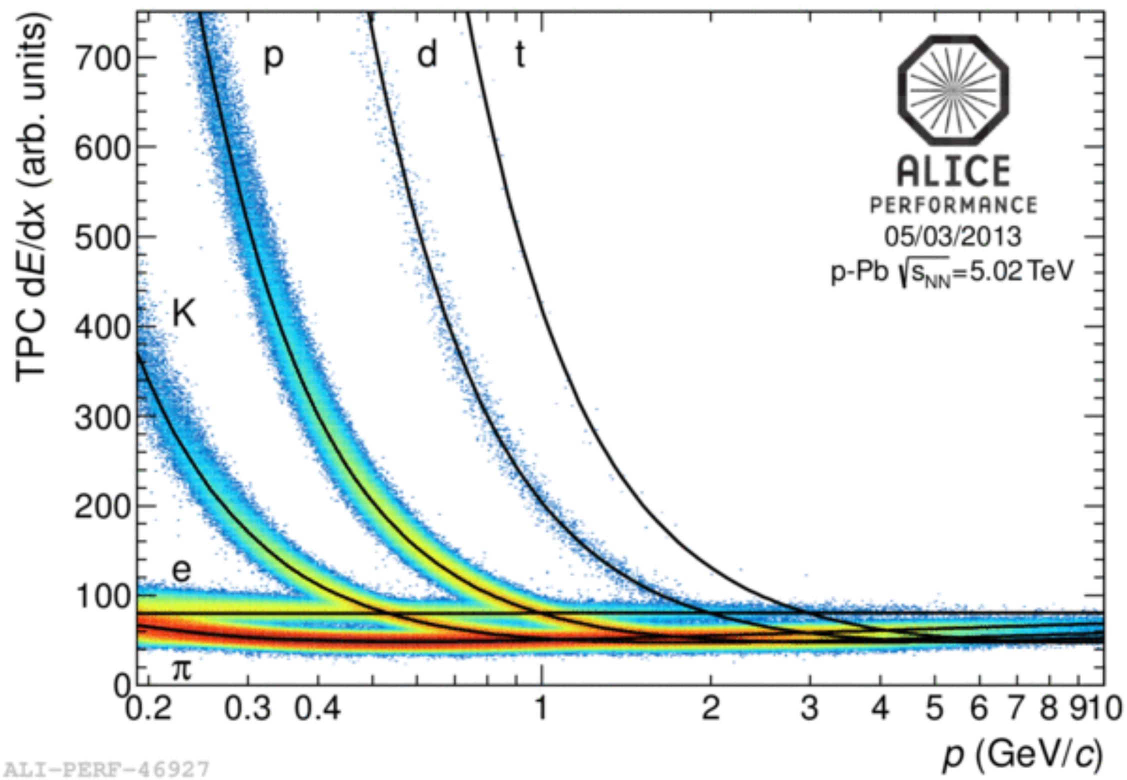
Current TPC performance

Combined TPC-ITS momentum resolution is
$\sigma(p_T)/p_T \approx 1\%$ at 1 GeV/c
(measure down to ~100 MeV/c)
Increasing to ≈ 5% at 50 GeV/c

98% tracking efficiency in pp
1-3% lower for central Pb-Pb events

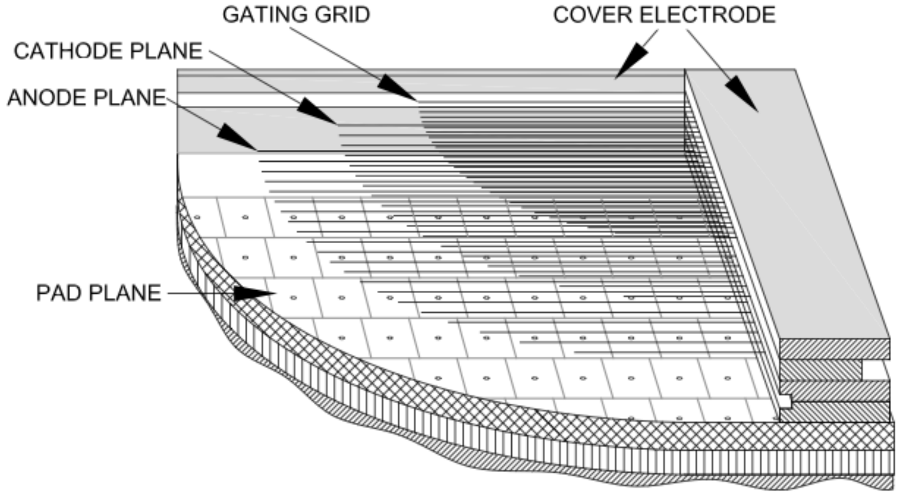
p-Pb

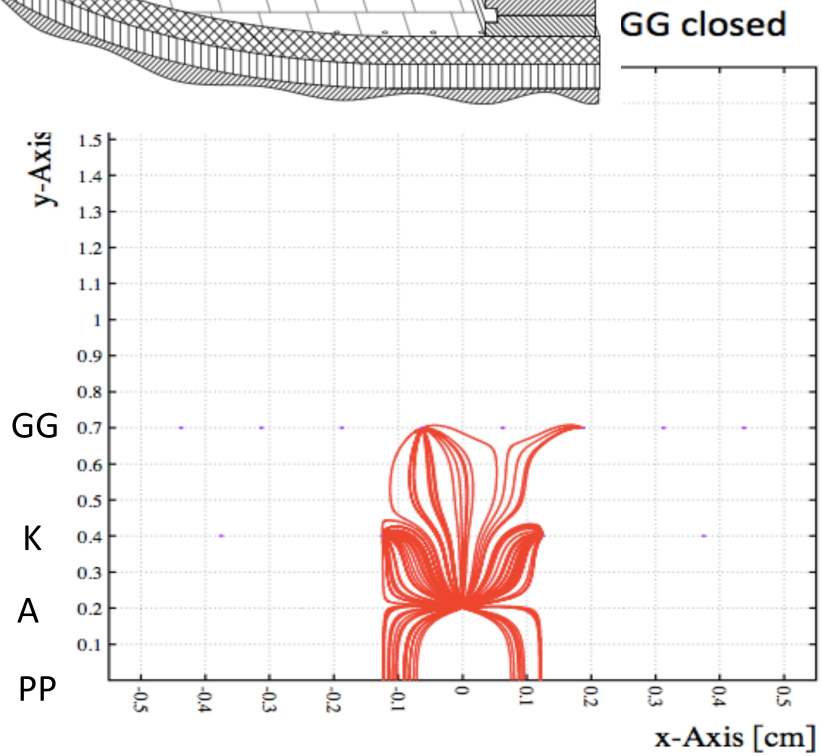


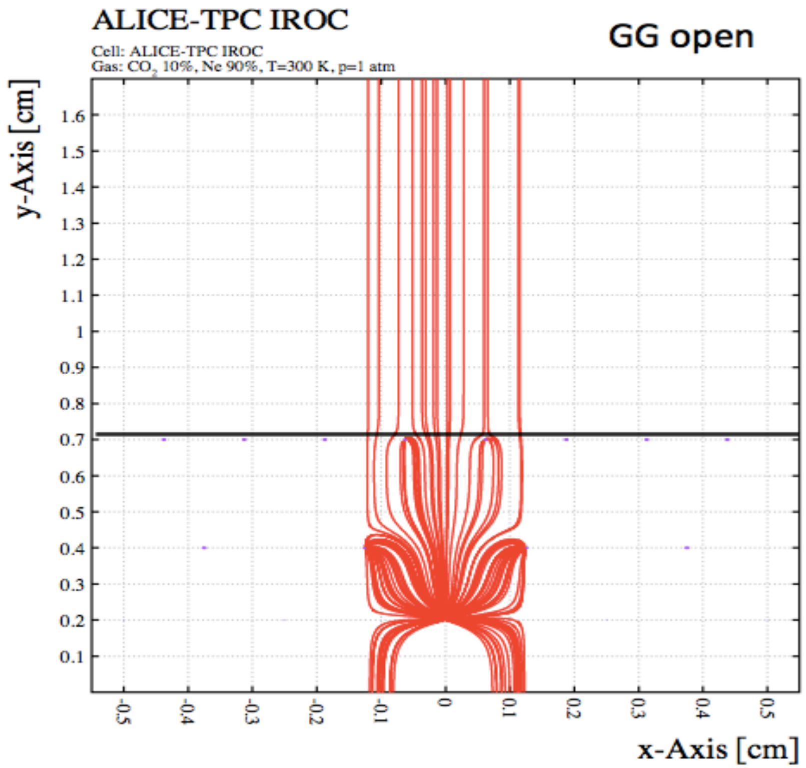
Excellent dE/dx resolution:
$\langle\sigma\rangle/\langle dE/dx\rangle \approx 0.055$ in pp
$\langle\sigma\rangle/\langle dE/dx\rangle \approx 0.07$ in Pb-Pb

The Gating Grid in MWPC

- An alternating voltage is applied to the GG 100 μs after the collision (GG closed)
- It takes 180 μs for the ions to reach the GG
- In this case IBF < 10^{-4}, but event rate limited to 3 kHz
- GG open results in IBF ~ 5-8 % at gain 8000

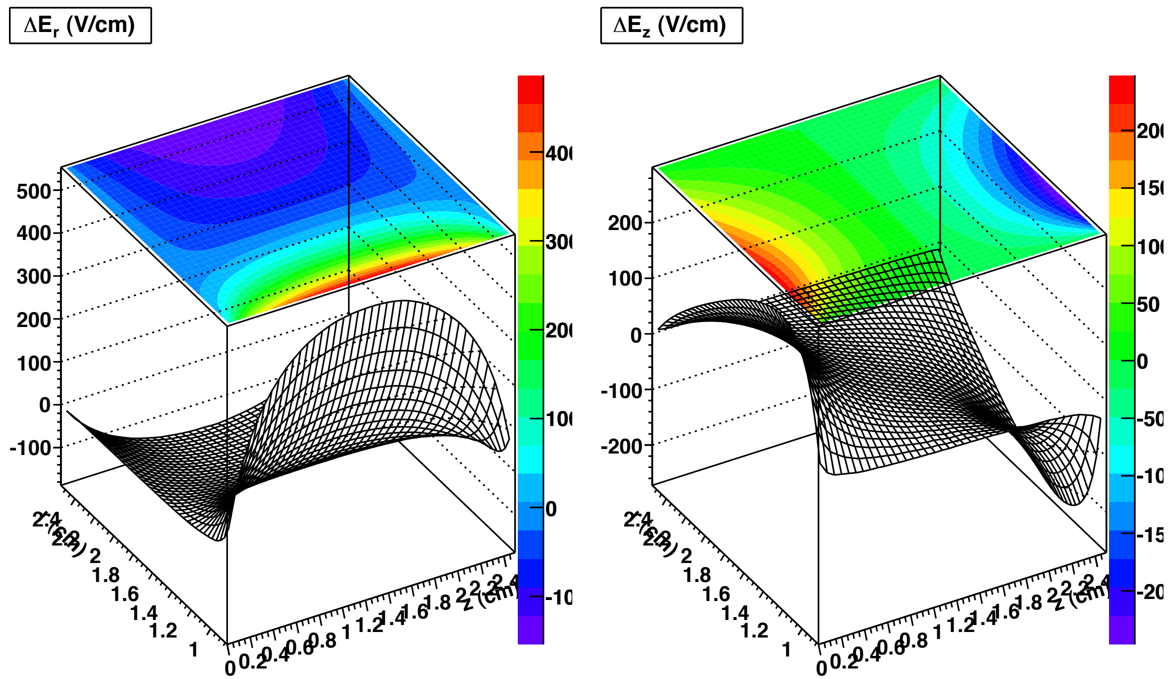






Run3: 50 kHz Pb-Pb

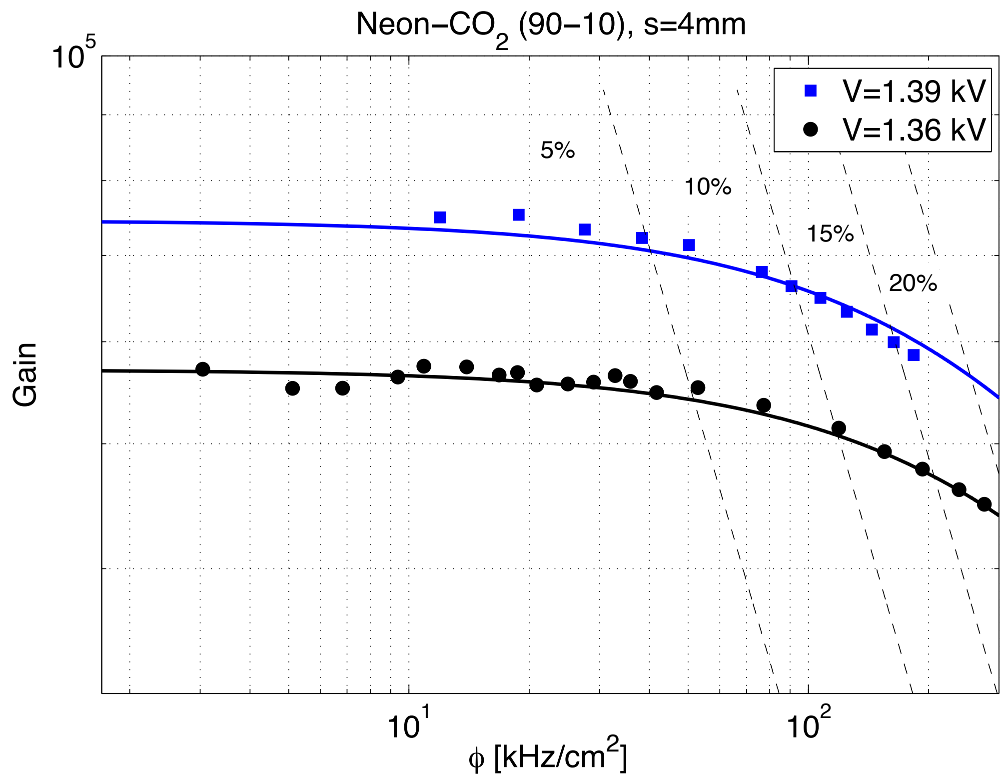
- From <1 kHz to 50 kHz (10 nb^{-1})
  - Heavy quarks, quarkonia (low p_T), dileptons, exotica
- Continuous readout: no trigger, no gating → space charge distortions of order of 1 m → not an option
- Current TPC doesn't do the job



Radial and z distortions as a function of r and z for 50 kHz Pb-Pb collisions with non-gated MWPC. Note that drift field is 400 V/cm

In addition, space-charge in the amplification region

- Maximum particle rate of 40-100 kHz/cm² → sizeable gain drop → deterioration of dE/dx



☞ Replace MWPCs with GEMs
  - intrinsic ion blocking
  - high rate capability
  - allows for a factor 3 lower gain
  - new FEE needed!
- Keep Field Cage and everything else

Enthusiastic response of the community

- ALICE TPC Upgrade Collaboration
  - Copenhagen, Helsinki, Frankfurt, Heidelberg, Munich, Munich, Tuebingen, Worms, Darmstadt, Tokyo, Mexico City, Bergen/Tonsberg, Bergen, Cracow, Bucharest, Bratislava, Lund, New Haven, Budapest
- Strong support by RD51 at CERN

Green: new in the TPC project

R&D issues with GEMs

- Most GEM detectors are triple stacks operated with a standard HV configuration with a standard gas
  - IBF is several %, OK for position resolution
- A different configuration is necessary for minimizing IBF
  - Study IBF: goal is below 1%, ε below 20, for which distortions are ~10 cm
- Therefore stability of operation has to be re-demonstrated
- dE/dx resolution has to be proven
  - maintain the current performance

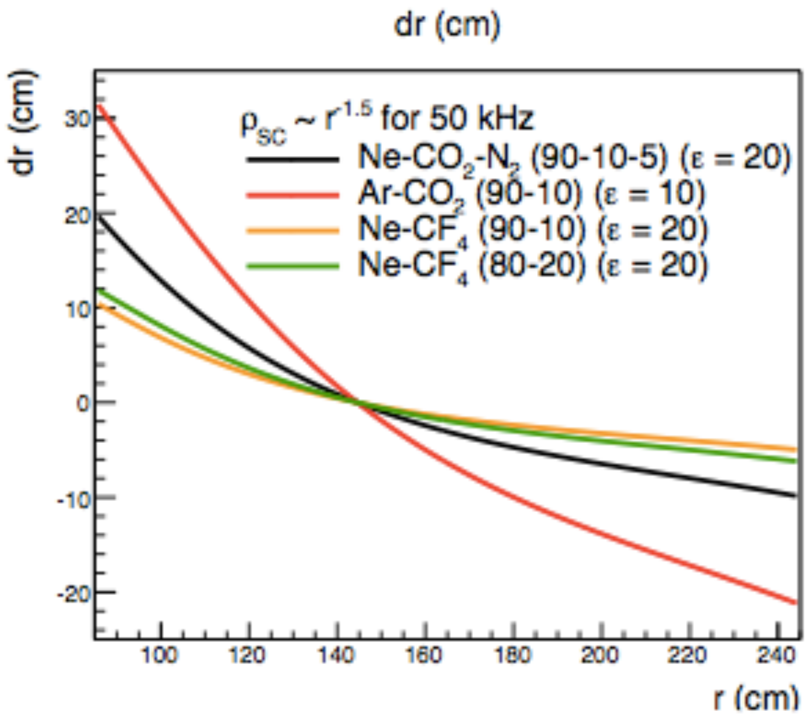
Definitions: $IBF = I_{drift}/I_{anode} = (1+\varepsilon)/gain$

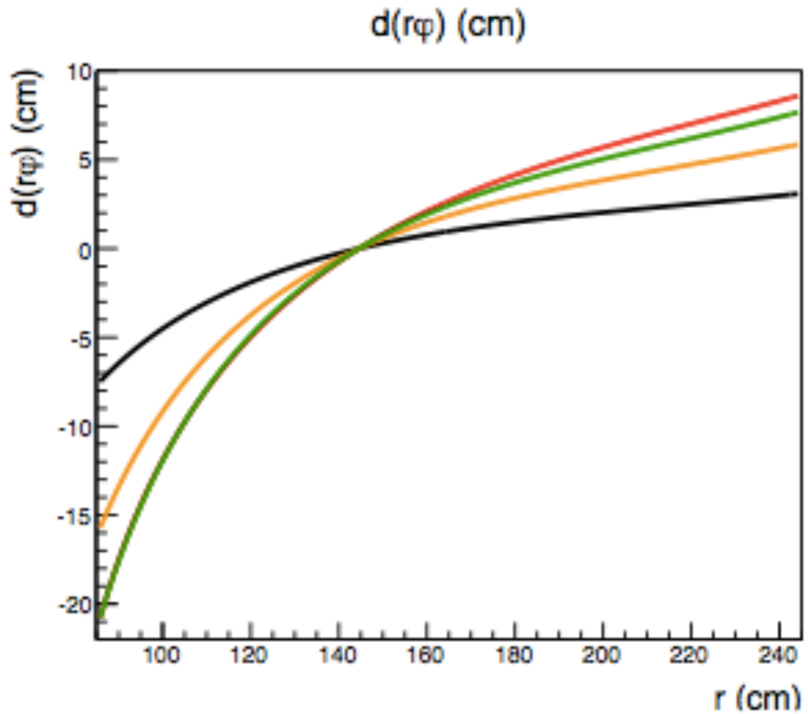
IBF

- So, if we want to use GEMs in the ALICE TPC, we have to work on the Ion Back Flow, since the current ‘intrinsic ion-blocking of GEM detectors ’ is not enough
- Gas choice closely connected to this through the ion mobility
- Preferably, do not lock all operational conditions –leave some flexibility
- We don’t have 15 years’ time to develop a new concept

IBF and gas choice

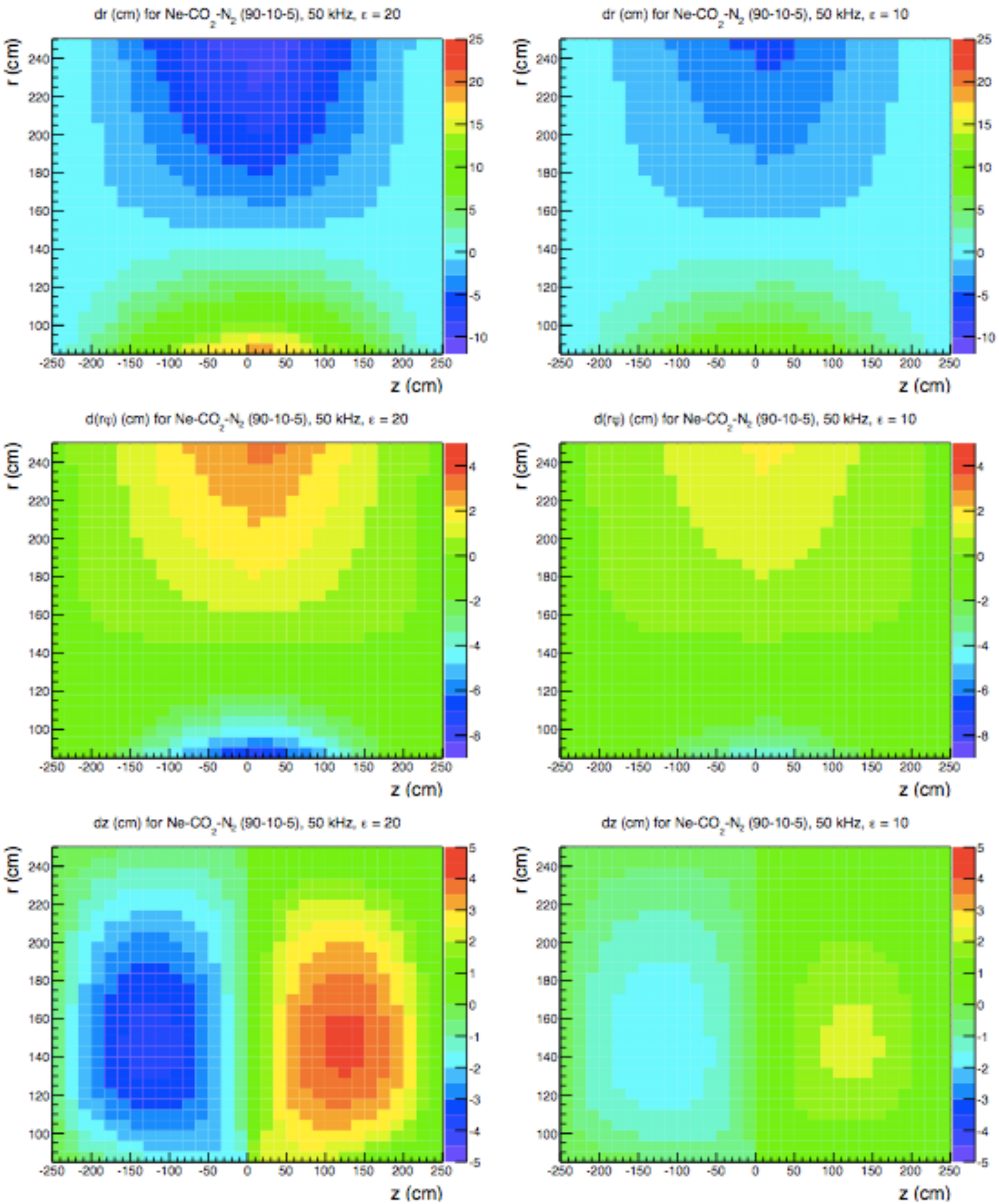
Maximum radial and azimuthal distortions for various gas mixtures at IBF = 1%





- Baseline gas mixture is Ne-CO_2-N_2 (90-10-5) for space-charge distortion, stability, and material compatibility considerations
  - Ne-CF_4 not completely discarded
  - Ar ions are just too slow

Distortions



Left: ε = 20
Right ε = 10
Top: dr
Middle: d(rϕ)
Bottom: dz

Distortions up to 20 cm (10 cm) for ε = 20 (10)

Average pile-up is 5, but fluctuations in event rte, track multiplicity, etc must be taken into account

How to minimize IBF –current intel

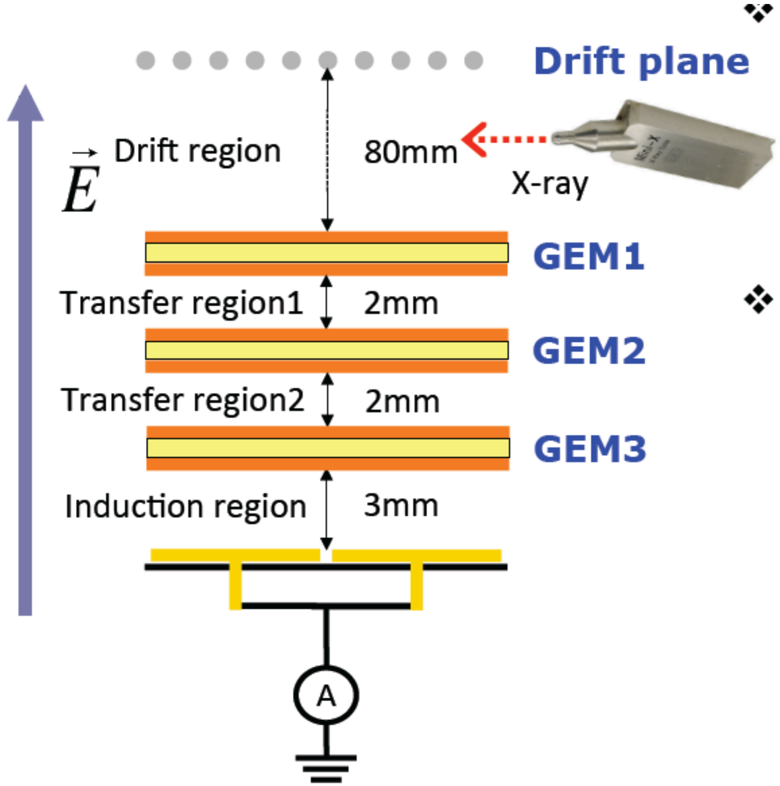
- Gain in increasing order, not decreasing
- Catch ions where they are the most
- Establish asymmetric field at the place where you want to catch them
- You may try to add a 4th GEM
- You may try to use foils with lower optical transparency

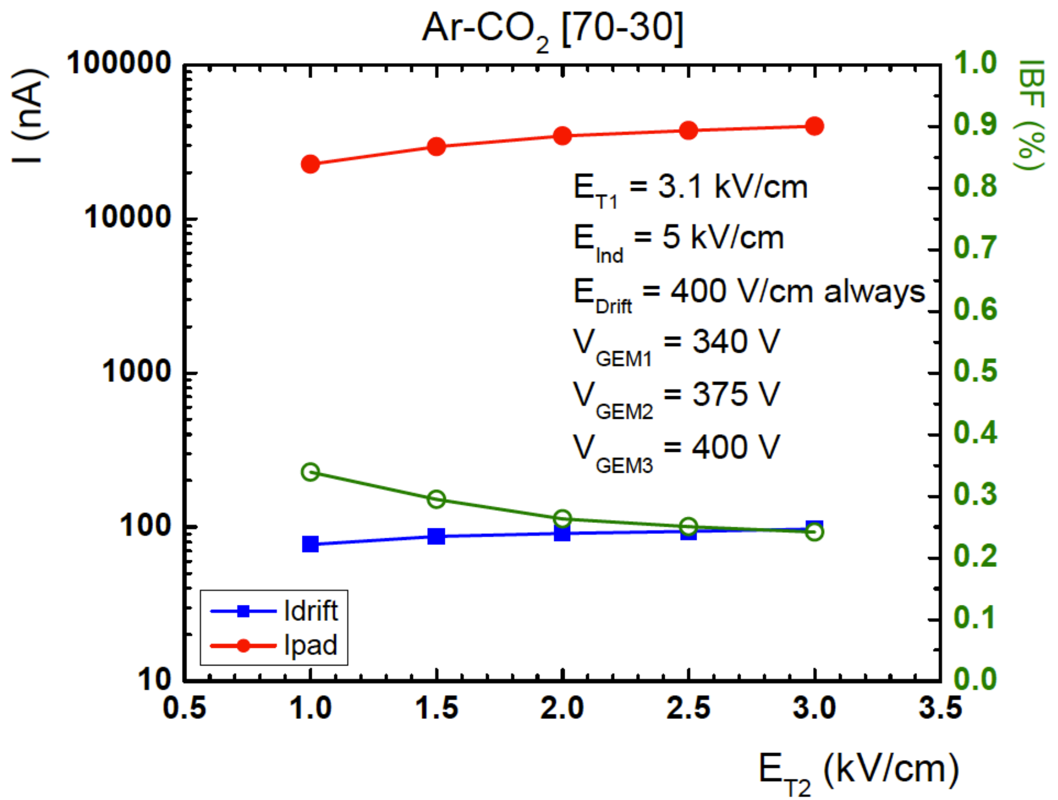
	Standard	IBF
Drift Field	0.4 kV/cm	0.4 kV/cm
ΔU_{GEM1}	400 V	225 V
Transfer Field 1	3.73 kV/cm	3.8 kV/cm
ΔU_{GEM2}	365 V	235 V
Transfer Field 2	3.73 kV/cm	0.20 kV/cm
ΔU_{GEM3}	320 V	285 V
Induction Field	3.73 kV/cm	3.8 kV/cm

☞…and if you manage, you still have to check operation stability (spark probability), gain stability (charging up, etc), energy resolution, etc

Minimising IBF: a piece of cake?

- Set up a triple GEM stack, shoot X-rays and scan all voltages and field to achieve lowest IBF
- After a few scans, reached 0.25% – fantastic!





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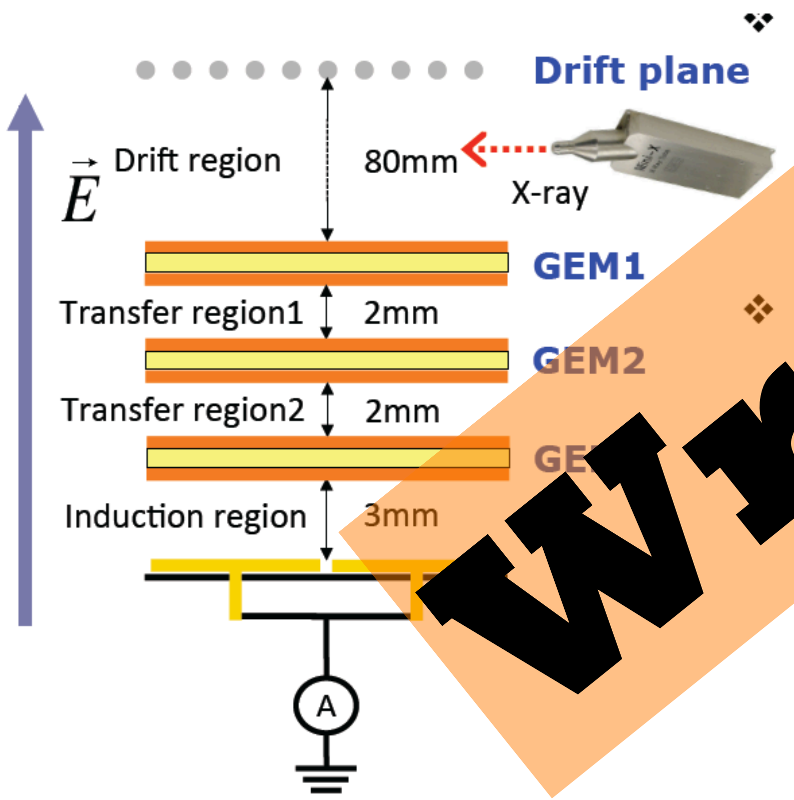
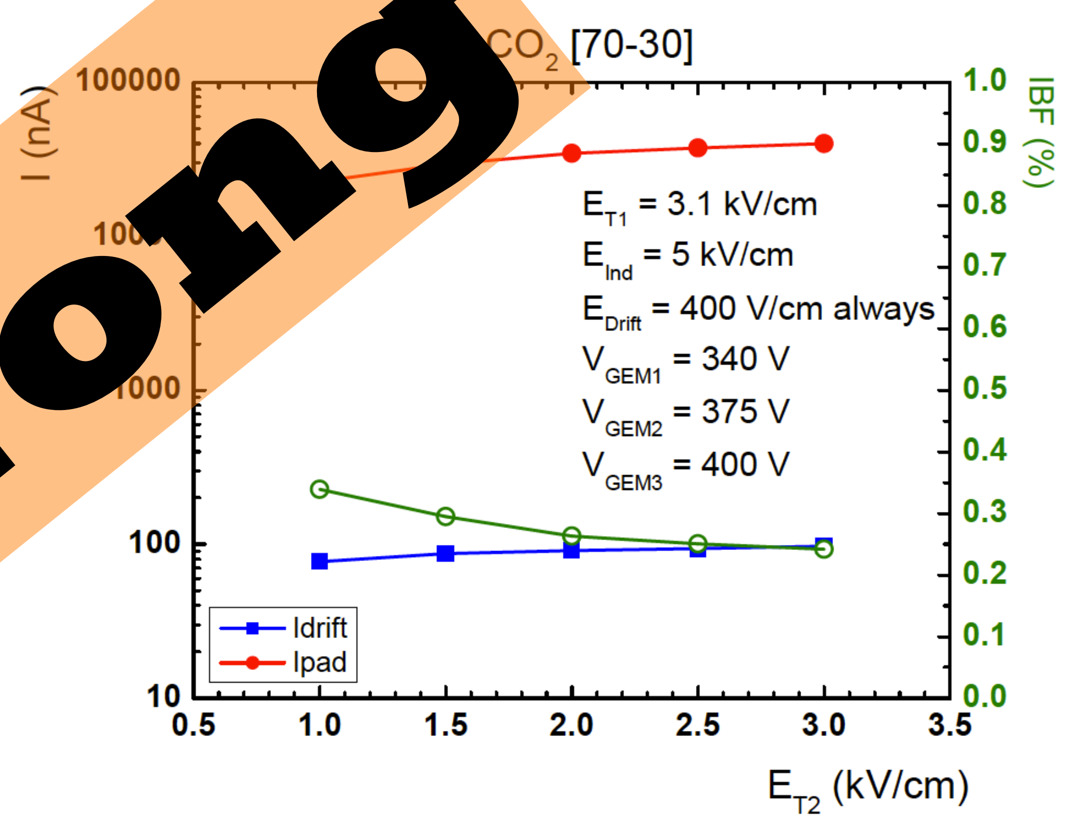
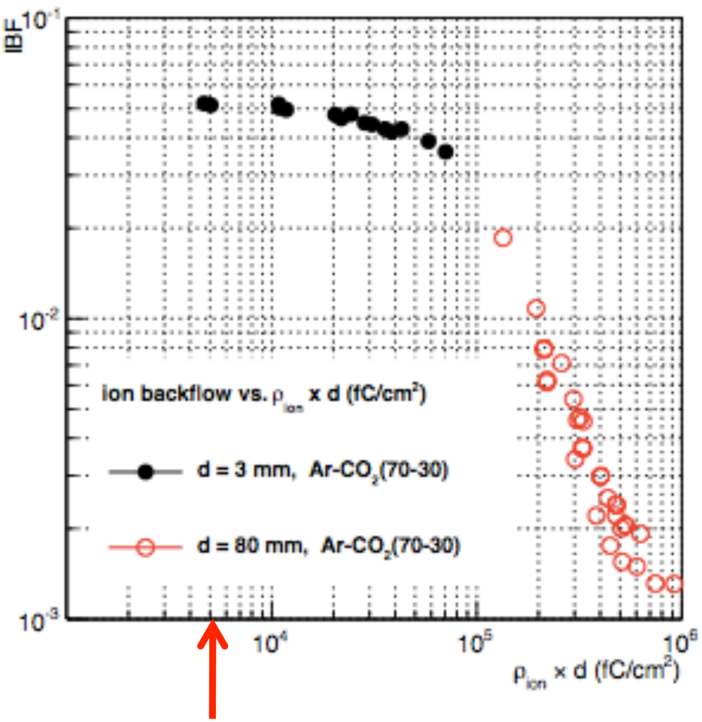
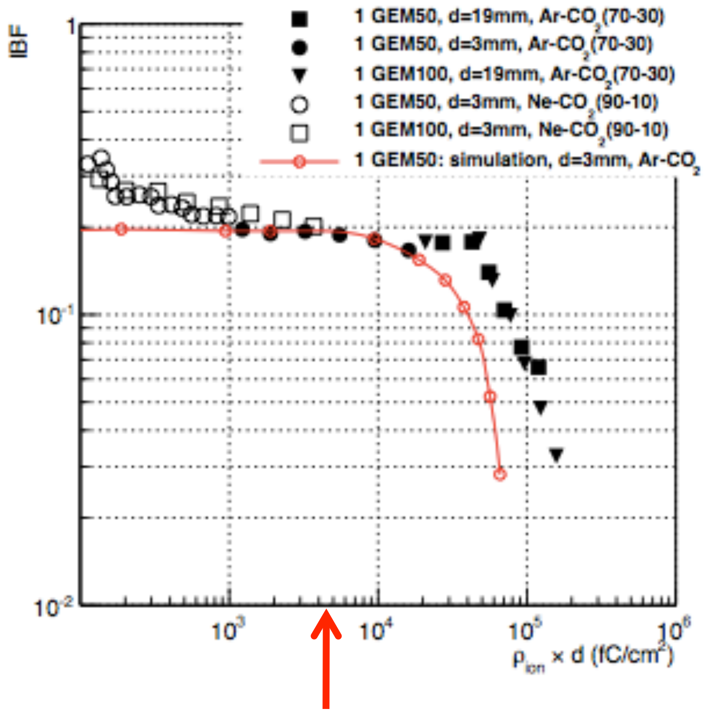




IBF dependence on rate

- Ion accumulation on top of a GEM foil produces enough space-charge to shield the electric field above from incoming ions from below, thus fakely improving IBF
- This has obviously no effect on the rate capability



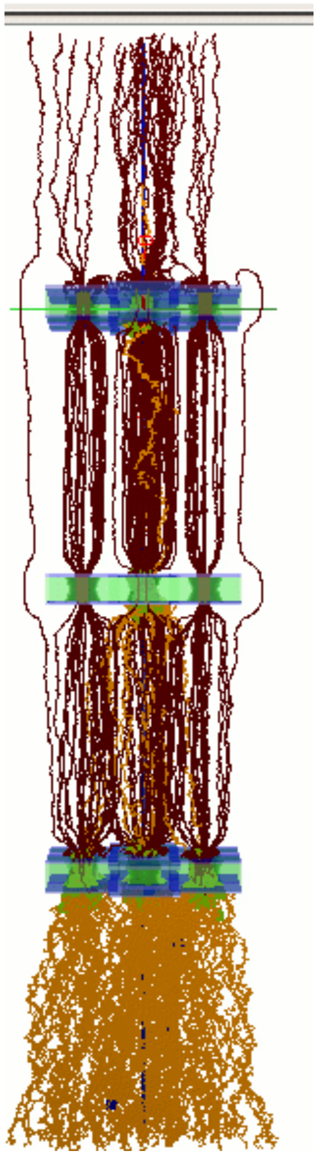


•Effect found to scale with the product of the charge density and the drift length

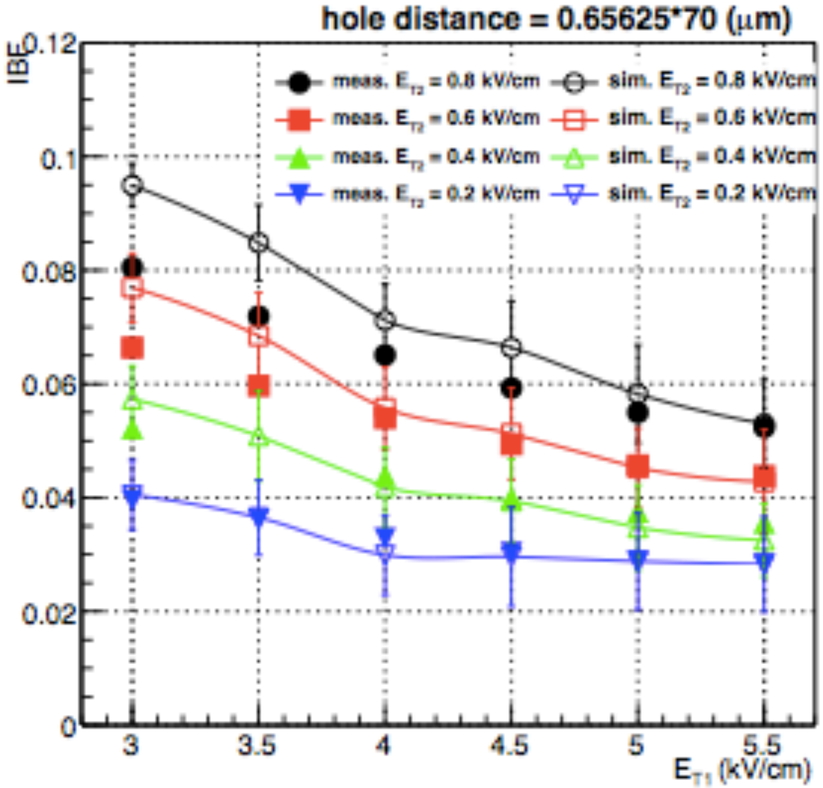
•Reasonable agreement with Garfield++ simulations

Expected in the upgrade scenario: ~ 5000 fC/cm^2

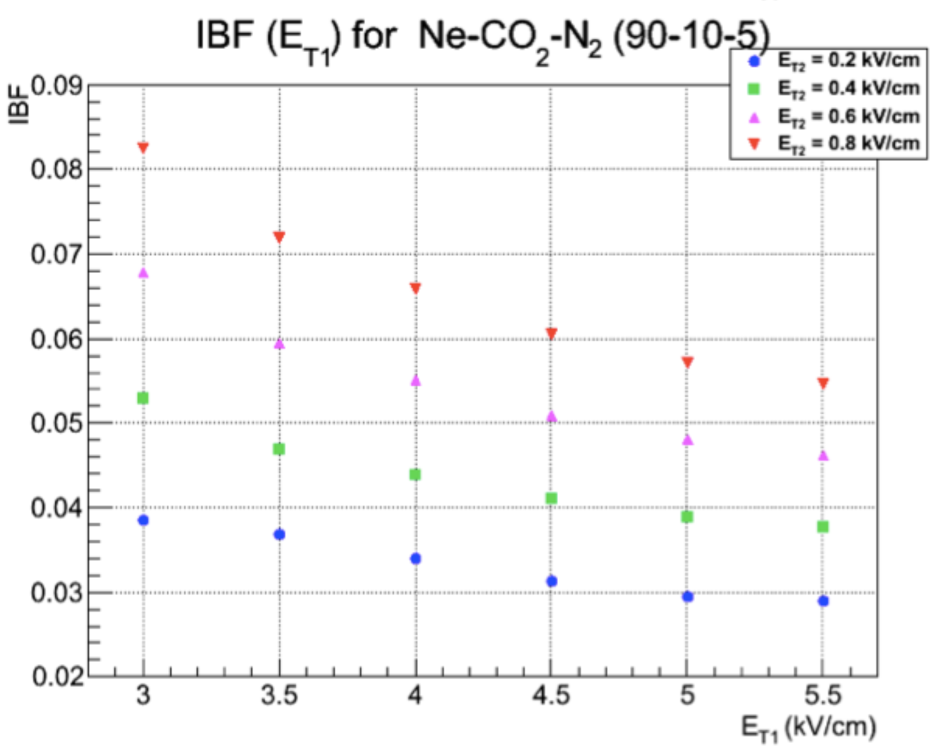
IBF dependence on hole alignment

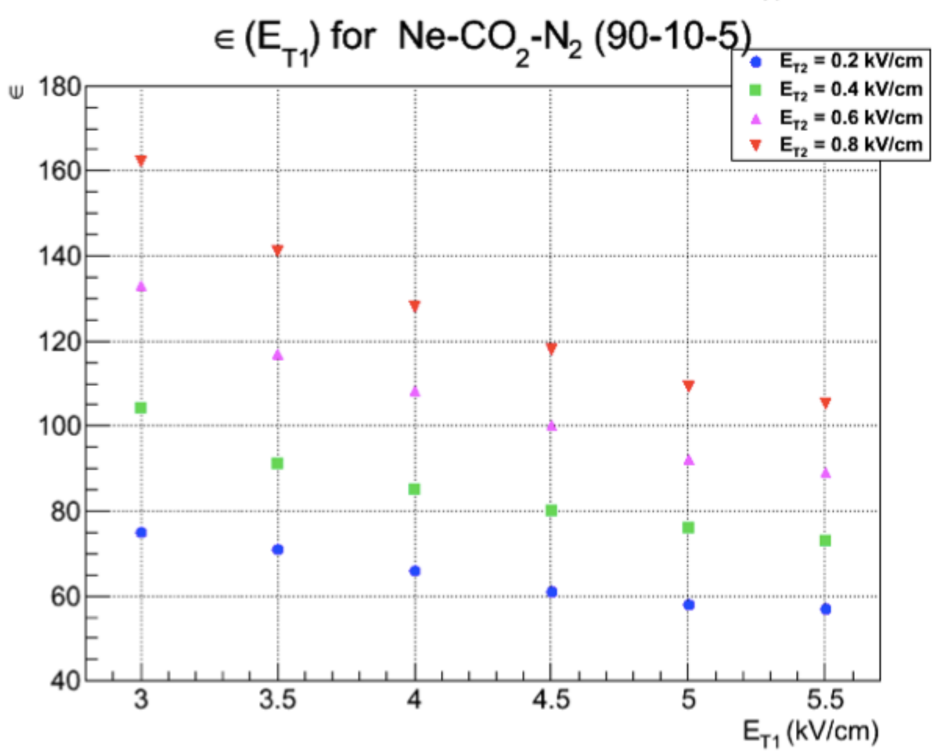


- IBF simulations reproduce measurements by ‘tuning’ the misalignment between GEM foils
- Reasonable consistency for different gases and number of GEM foils in the stack



IBF with a triple GEM





- Measurements done at gain 2000

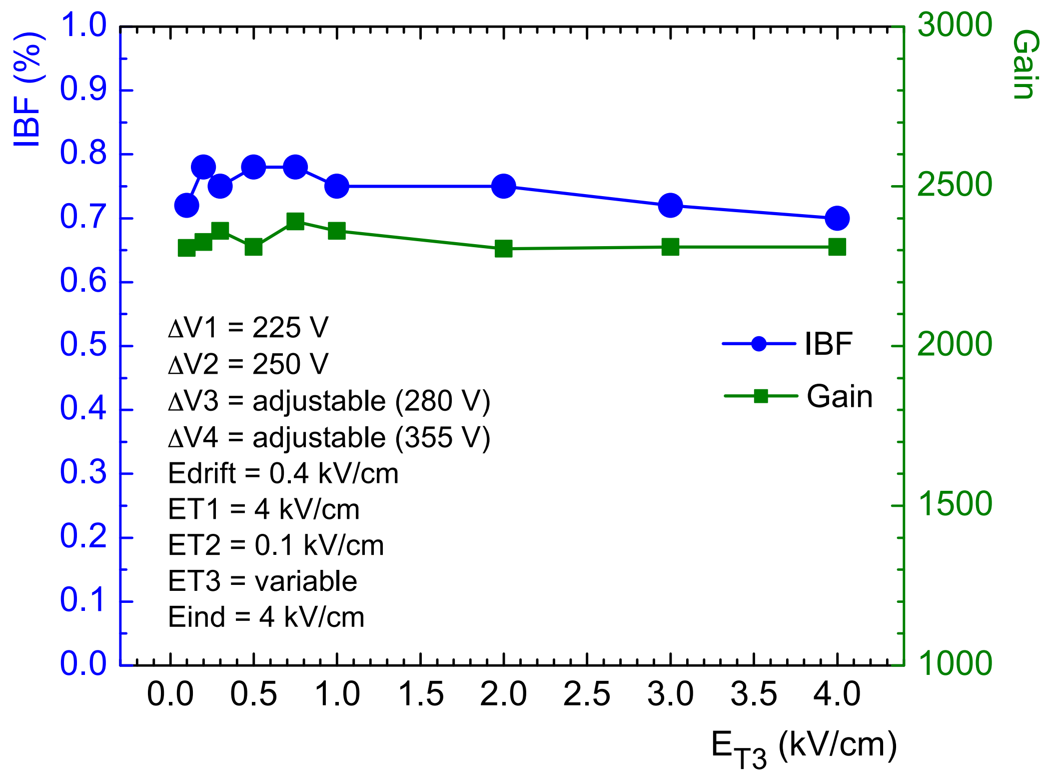
☞Not good enough

Further efforts on IBF

- Increase number of foils in the stack: 4 GEMs
- Increase the hole pitch: GEM1 and GEM3 have double the pitch (280 μm)

☞Reach 0.8% IBF, and secured some flexibility

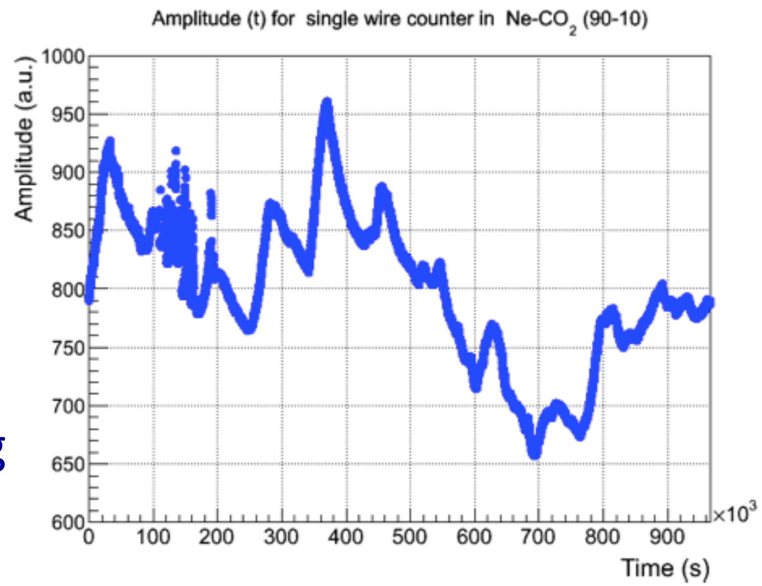
- Work in progress

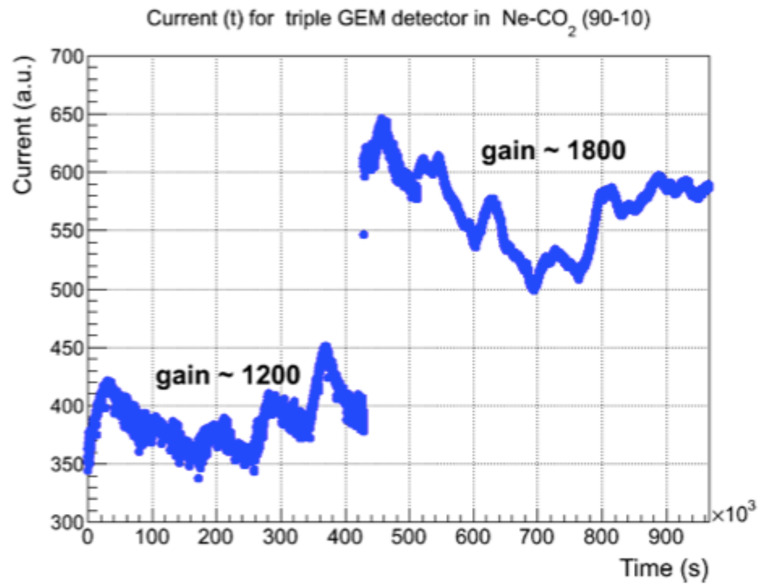


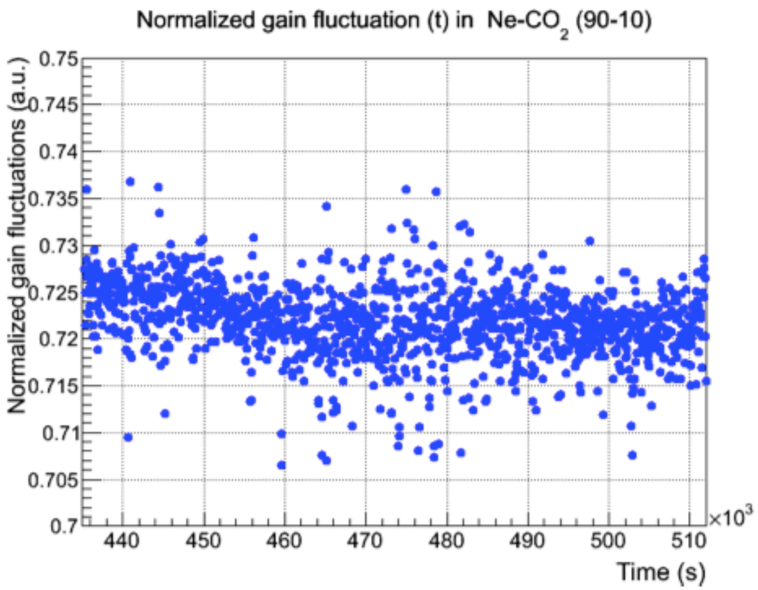
☞How about the rest of the story: energy resolution, stability

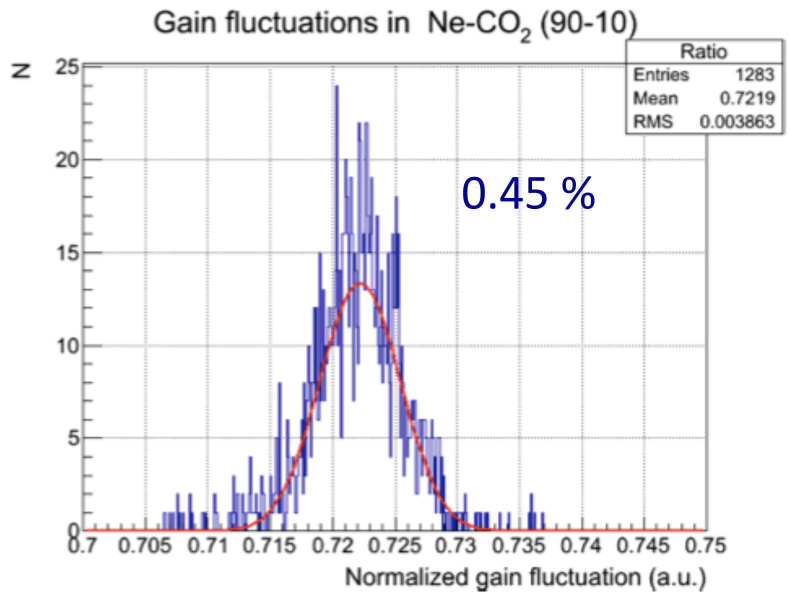
Gain stability

- In the LHC, voltages of gaseous detectors are ramped up at the beginning of each fill (on Stable Beams)
- Then there are lumi adjustments, etc





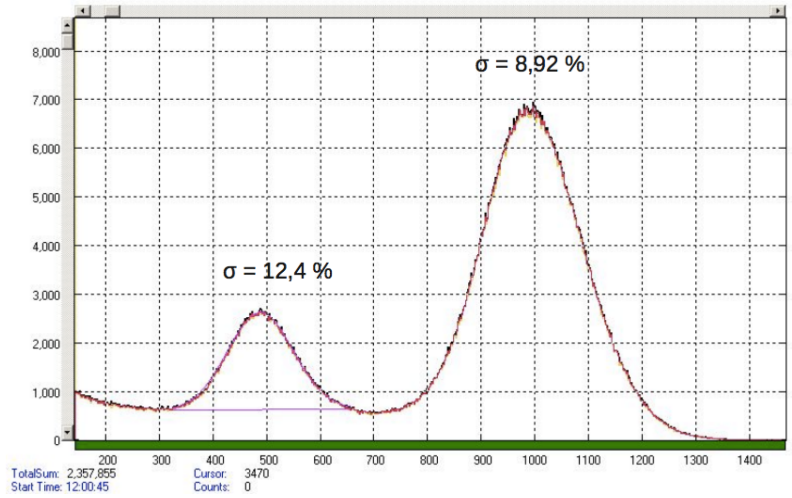




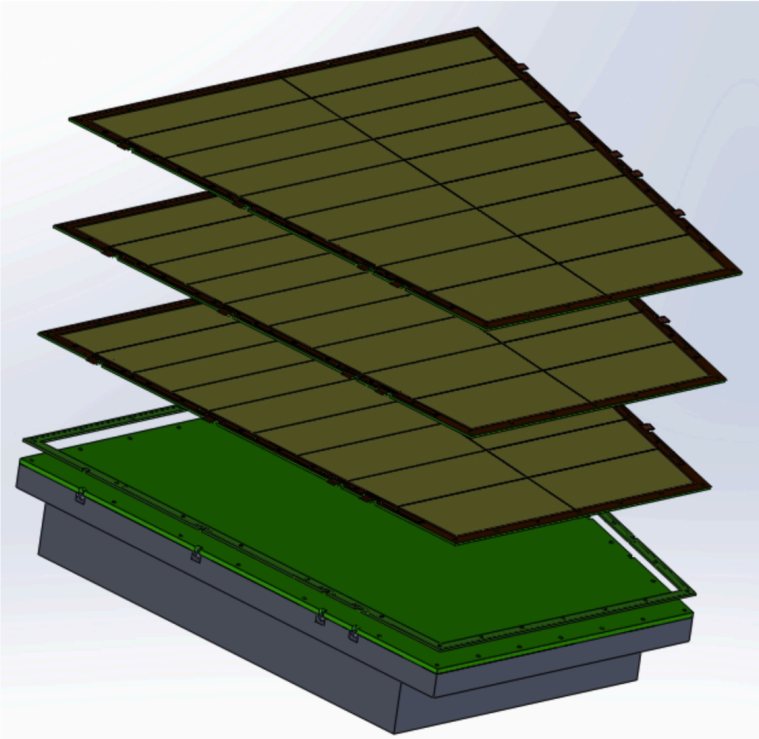
Energy resolution, spark rate

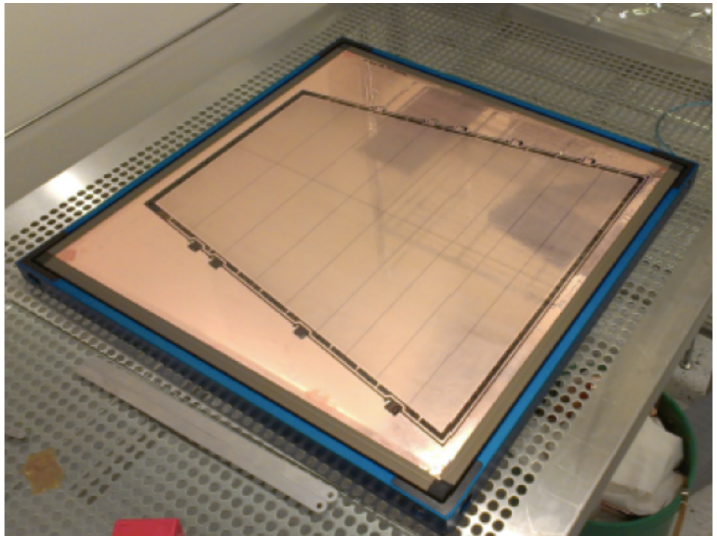
- Preliminary energy resolution measurements show no significant deterioration when going to IBF settings and quadruple stacks
  - work in progress
- Two setups for measuring spark probability with α particles in the new configuration
  - 2000 is a moderate gain

Example for triple GEM, standard settings

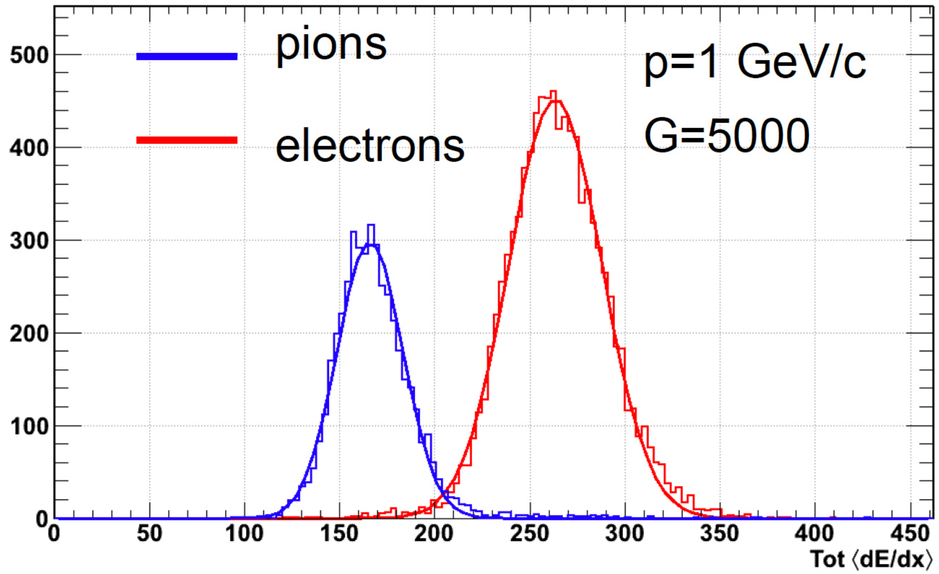


Full size prototype



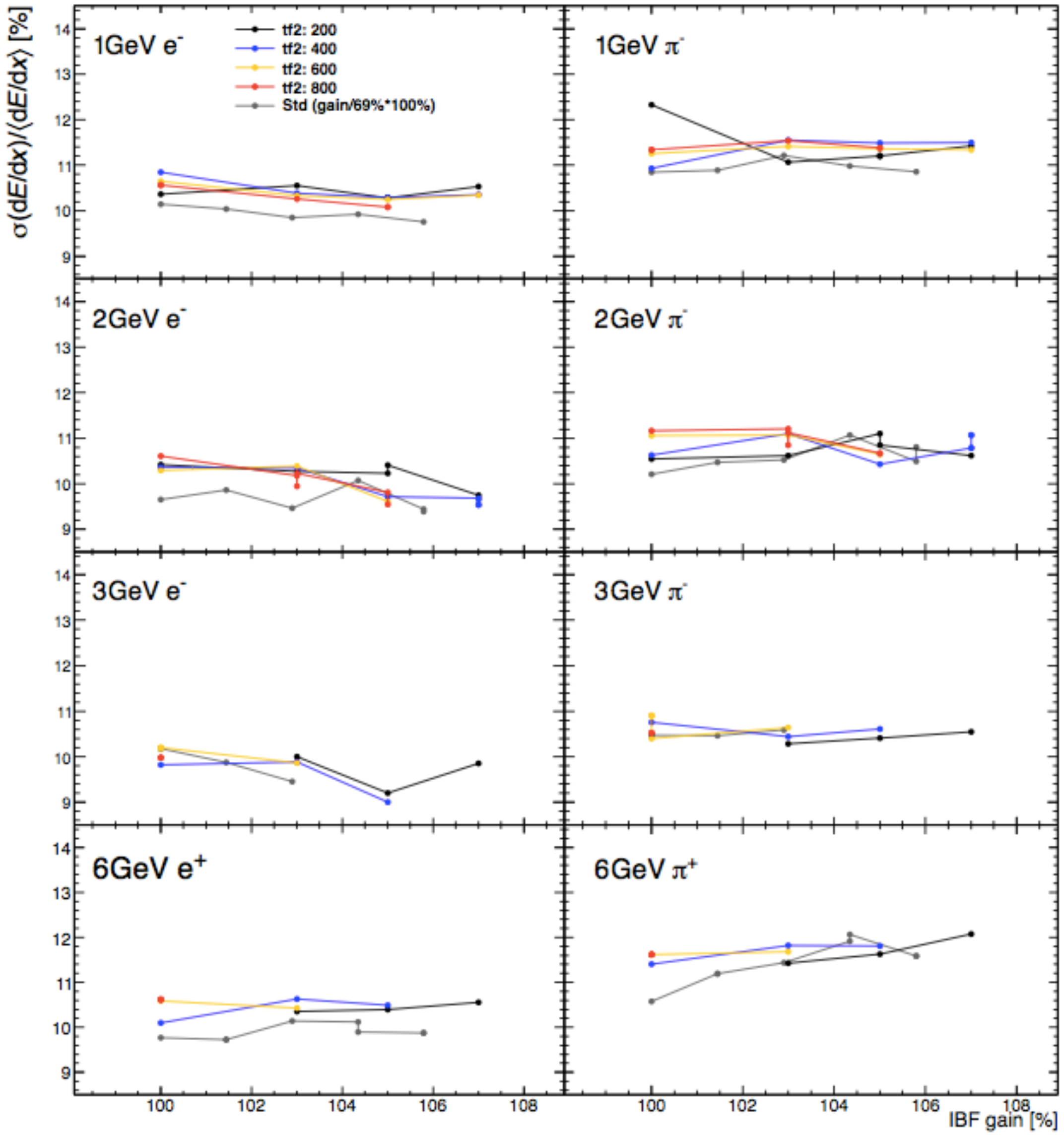


Single mask foils
For time reasons, not the best quality



- Full size triple-GEM prototype of a TPC IROC to PS test beam of electrons and pions
- Measure dE/dx resolution for various voltage configurations

dE/dx resolution

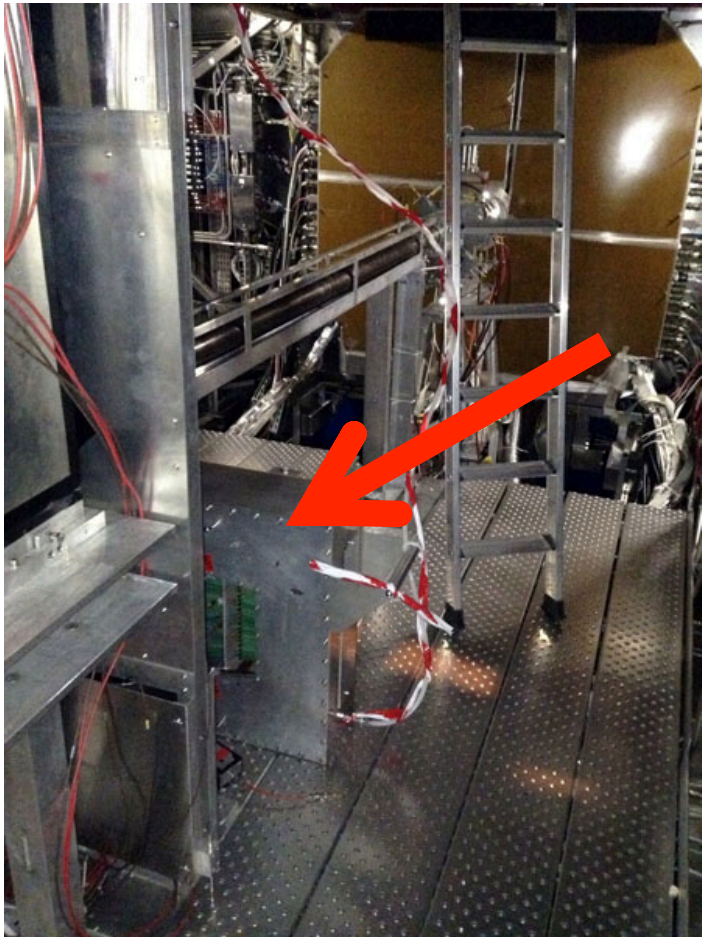


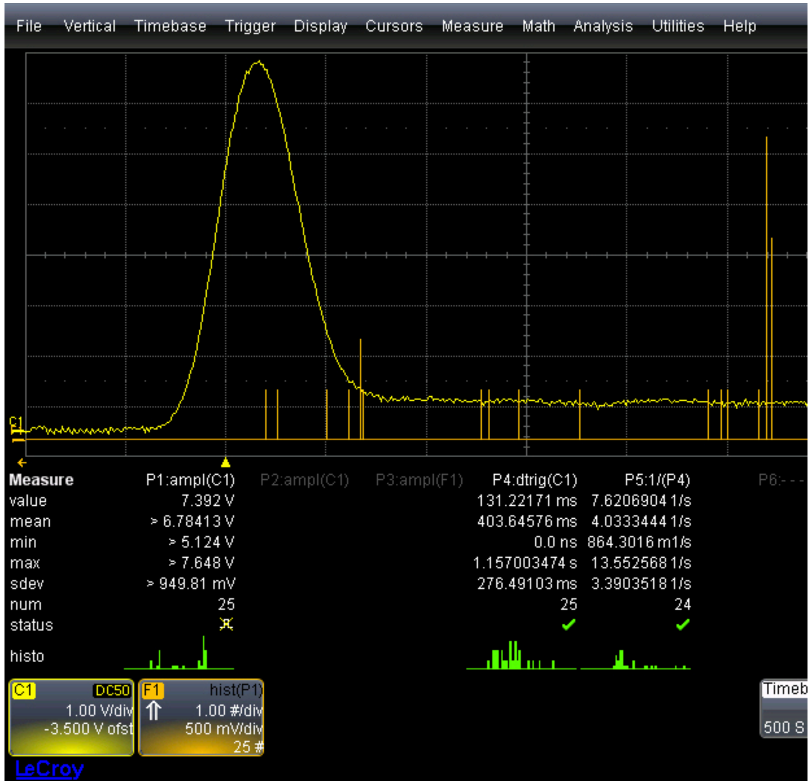
- Only 46 pad rows considered
- dE/dx resolution measured for GEMs is equal to the expected for MWPC : performance is preserved
- Expect from simulations a slightly better performance: 10.5 % for 1 GeV pions
  - density correction to gain not applied

Test in the ALICE cavern

- Prototype installed under the beam pipe during the p-Pb period in 2013
- Scan several configurations (gains) for ‘Standard’ and IBF settings

☞ See if it holds

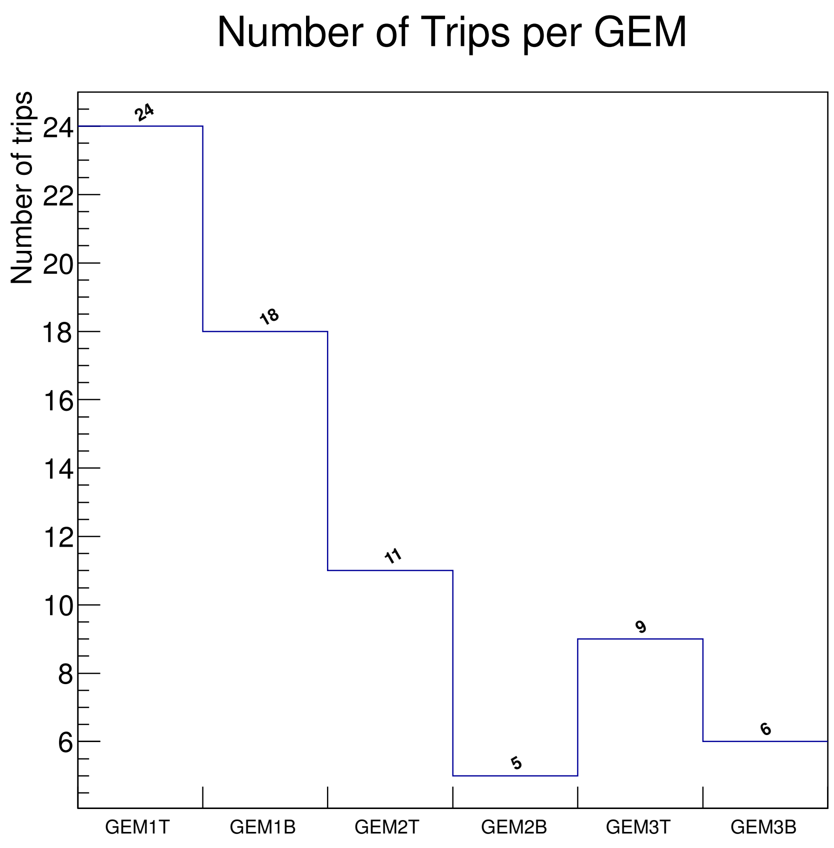




700 pads connected to spectroscopy electronics

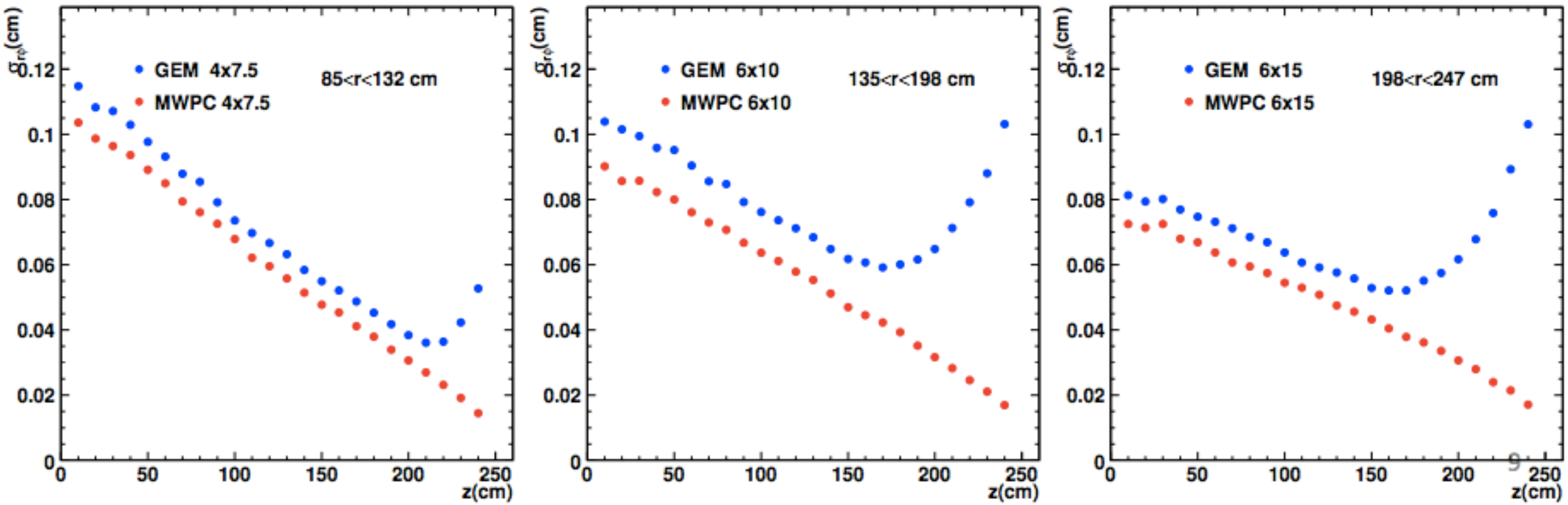
Signals recorded for various HV settings during all pA fills

Trips during the ALICE campaign



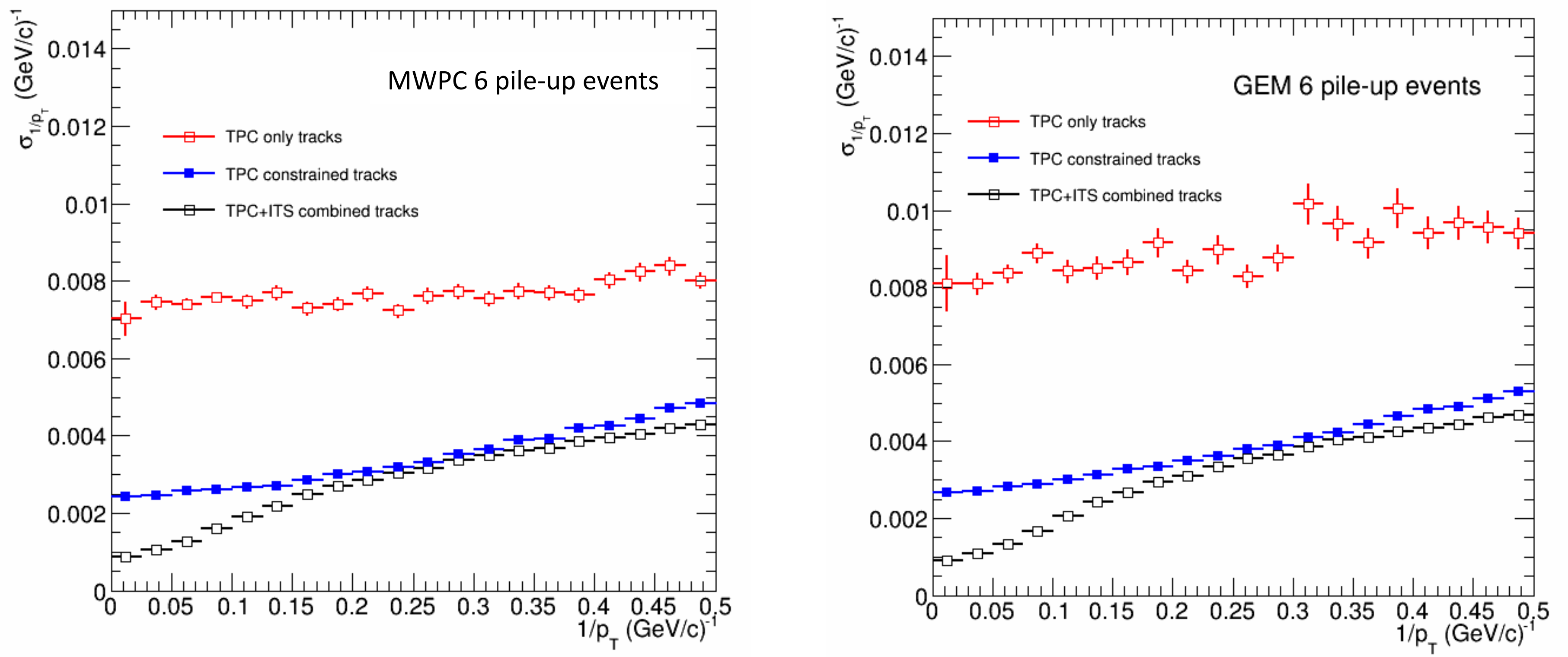
- Several trips occurred, and a few shorts developed
- No correlation found with beam conditions
- Correlation found with the maximum voltage applied (to GEM1T)
- These maximum voltages happened to be applied in IBF settings
  - The scaling of the transfer fields and the size of the induction gap (3 mm) resulted in these higher voltages in IBF configuration
- Foil quality

Performance simulations: position resolution



- Slightly worse resolution due to the lack of a Pad Response Function in GEMs
- Near the chambers worse resolution due to low diffusion
- Effect larger at larger radii, where pads are larger; η coverage relieves this effect

Momentum resolution

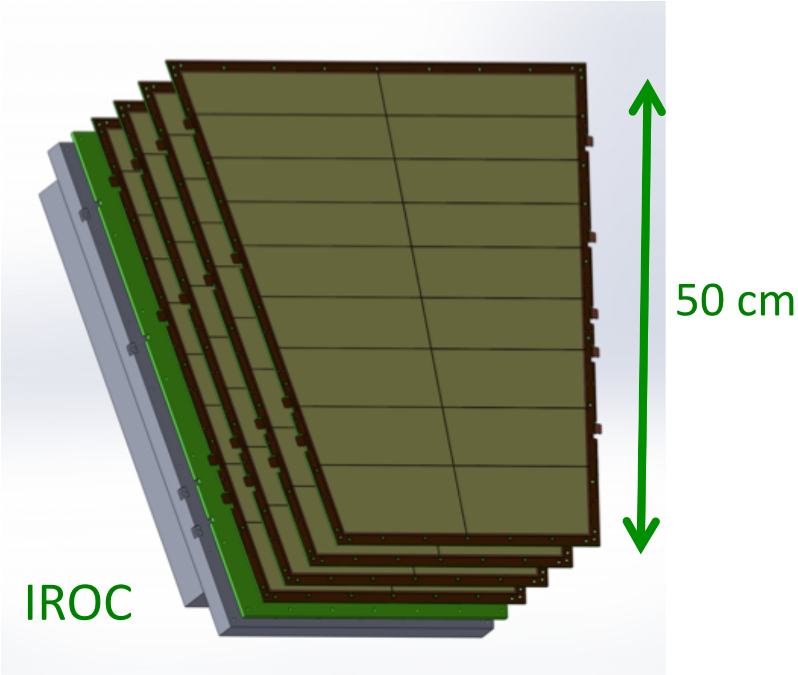


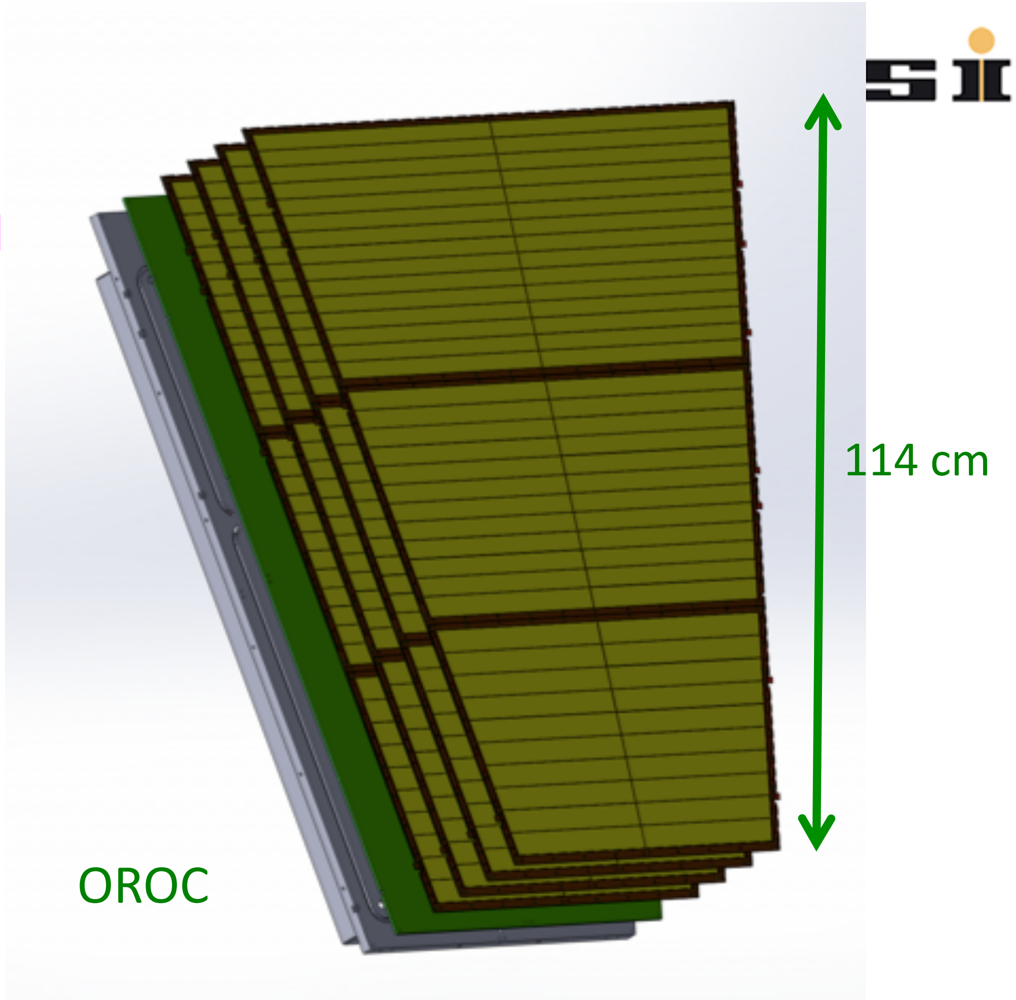
- Very little deterioration for TPC stand-alone and 6 pile-up events (expected average is 5)
  - less merged clusters in the case of GEMs: lack of PRF is an advantage
- Excellent resolution achieved with the vertex constrained and the precision of the ITS; no difference between MWPC and GEM readout

Calibration strategy

- 1st step: on-the-fly calibration to 1 mm resolution and substantial data compression
  - store clusters on tracks only (compression factor >20)
- 2nd step: use information on local, instantaneous space charge distributions, and matching to outer detectors (ITS, TRD) for ultimate resolution (200 μm)

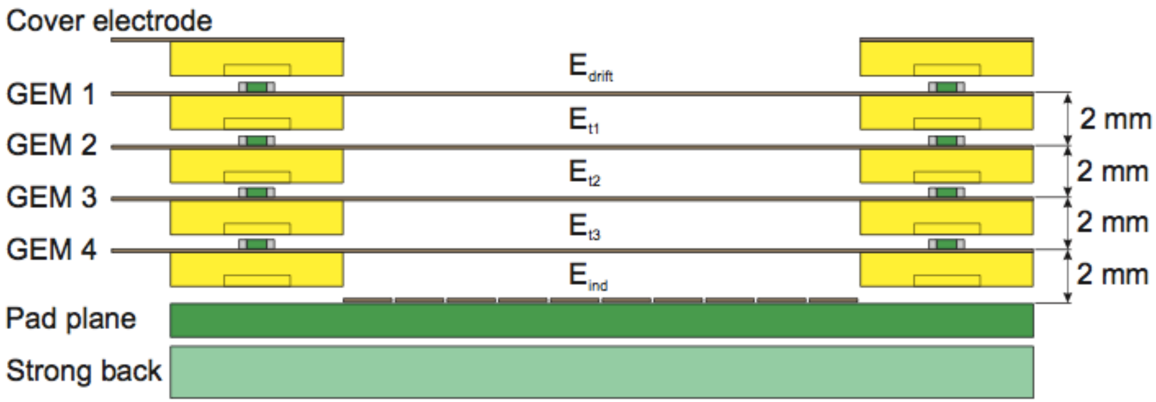
Chamber design





Single-mask technology

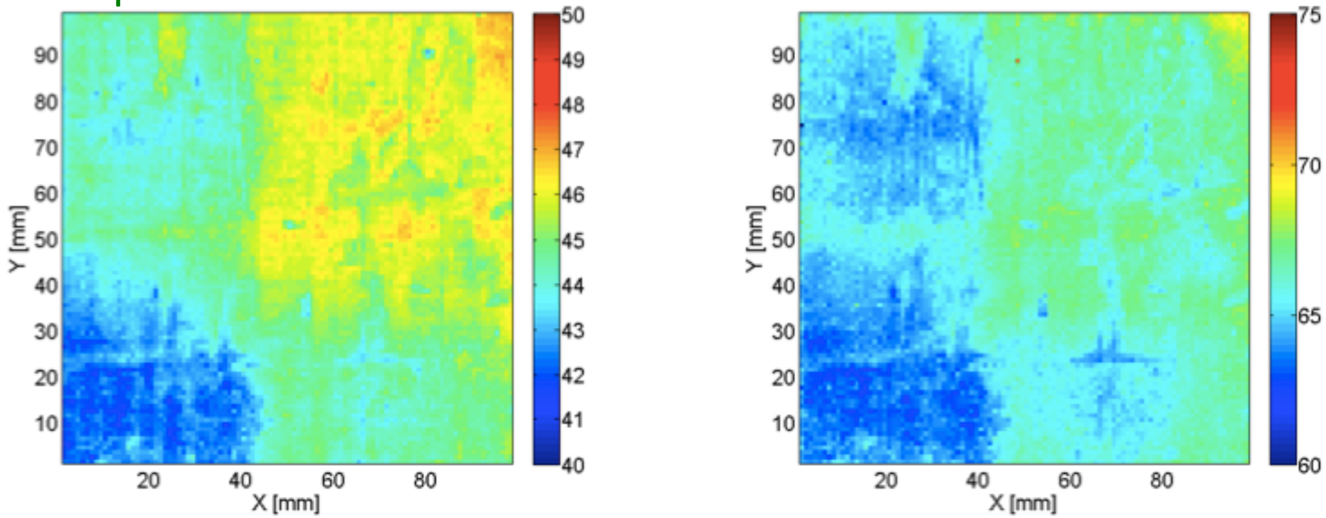
Quadruple GEM stacks, possibly with one or several large pitch foils



GEM QA

- A crucial issue as recognized by everybody
- Transport
- Optical inspection
  - Hole diameters and pitch distributions
- HV test of individual foils
- HV test of stack
  - gain scan
- HV test of chamber
  - gain scan, long-term irradiation test, gas tightness
- Final commissioning in TPC at surface and underground

Maps of inner and outer hole diameters of a 10x10 cm^2 GEM foil



Status and plans

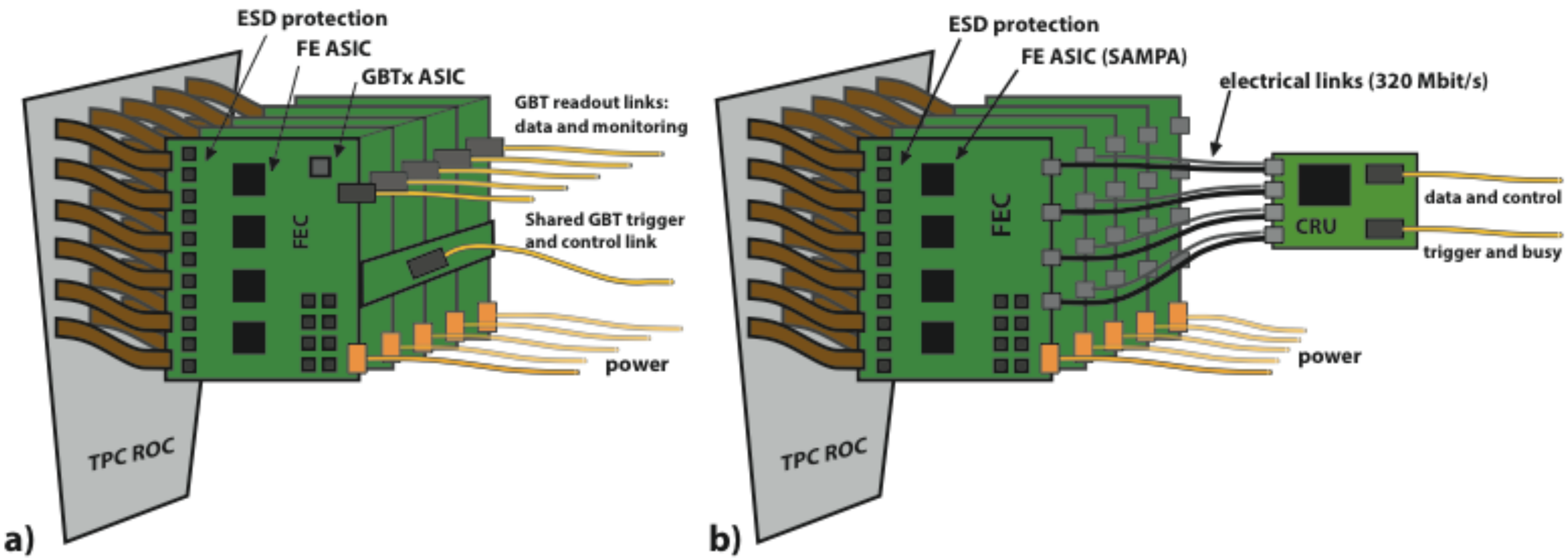
- TDR to be submitted end of October 2013
- 2013-2014: design and prototyping
- 2015-2016: production of chambers and FEE
- 2017 (or 2018): installation and commissioning
  - Depending on Shutdown scenario

Conclusions

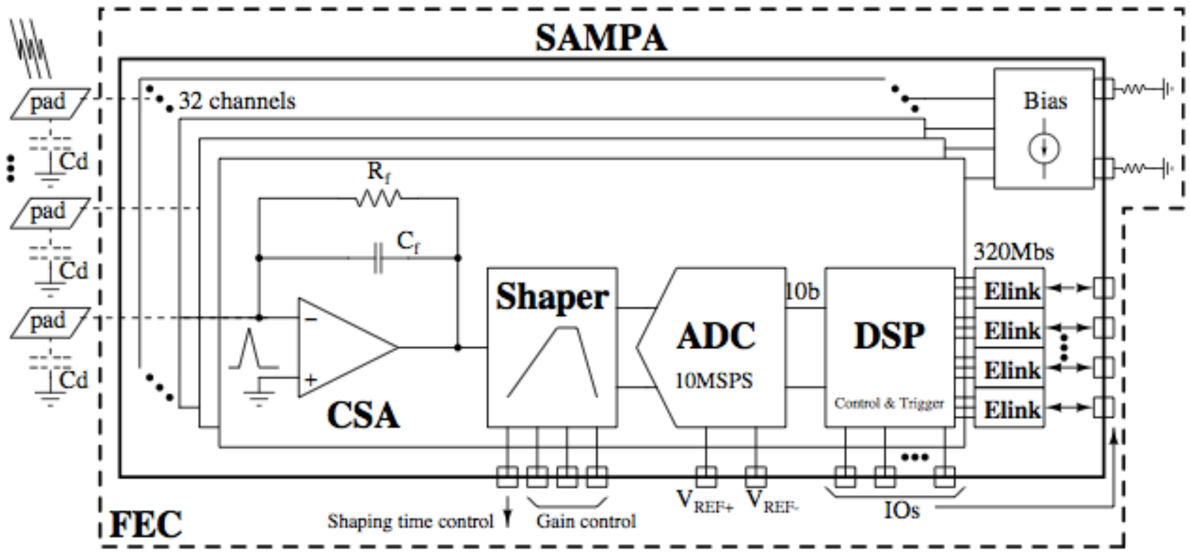
- The ALICE program for RUN3 requires an upgrade of the TPC, among other detectors
- The replacement of the TPC multi-wire proportional chambers with GEMs matches the requirements
- Extensive R&D ongoing to prove this principle, in particular low IBF (<1%) for manageable space-charge distortions
- The TPC performance shall be maintained in the 50 kHz scenario

BACKUP

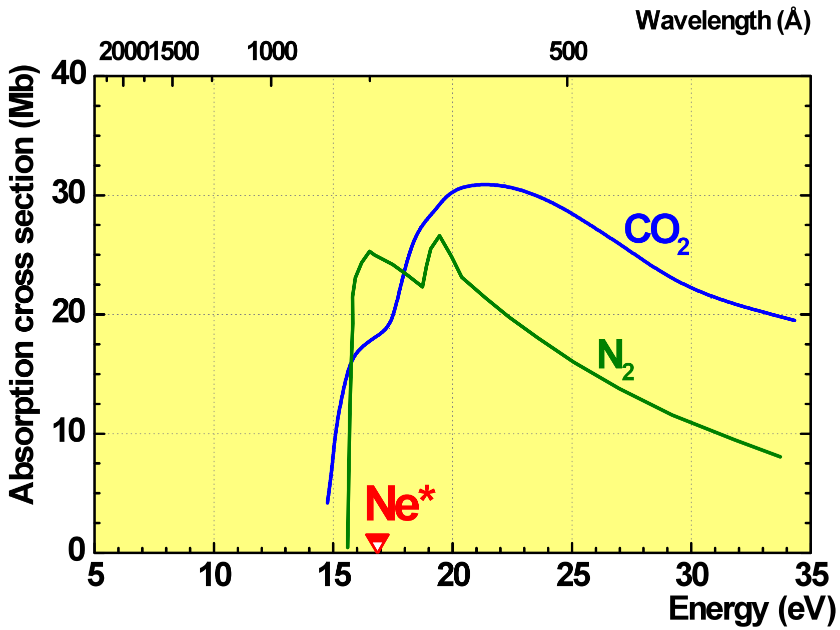
Readout system

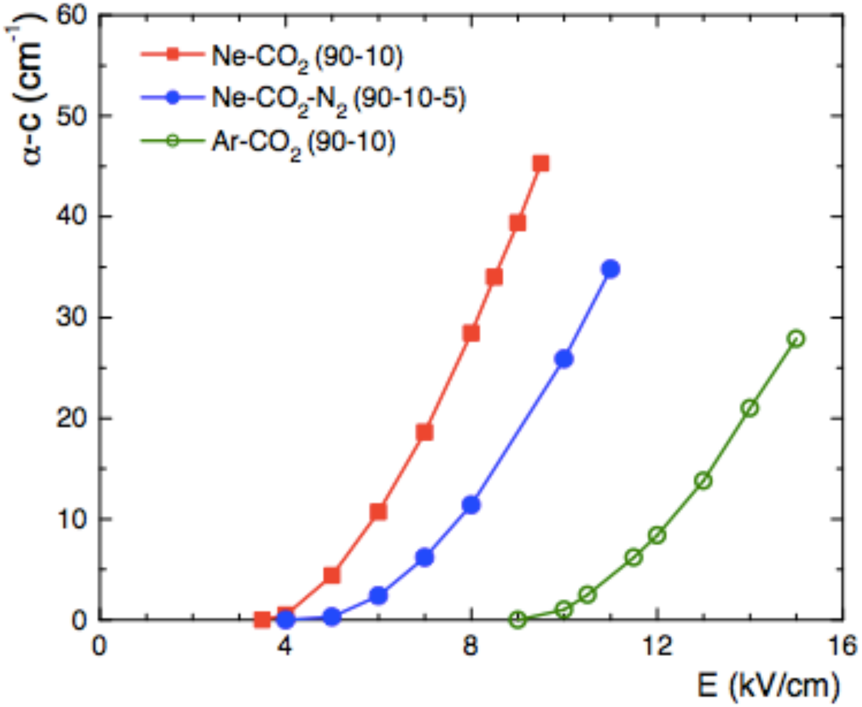


SAMPA: a common 32 channel FE ASIC for continuous readout of various ALICE subdetectors



Why N_2 in $Ne\text{-}CO_2$





- N_2 provides more and better quenching at no cost of drift time
- N_2 allows for higher transfer fields before amplification takes place, which is good for minimising IBF

Performance of IROC prototype

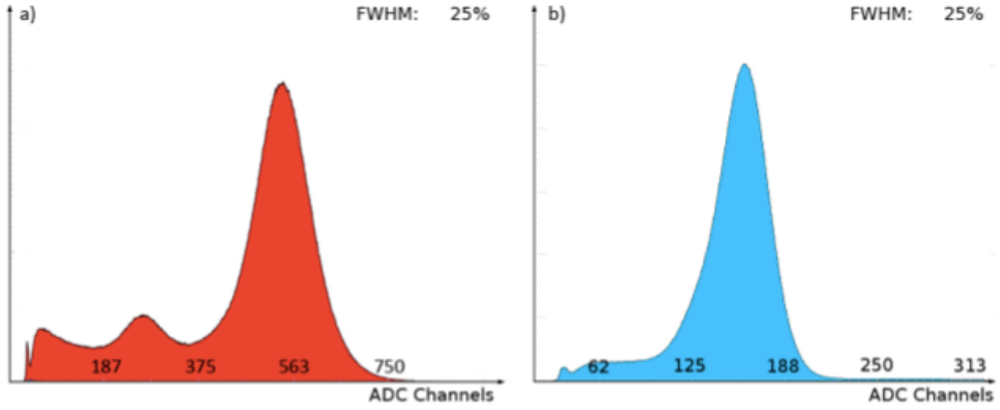
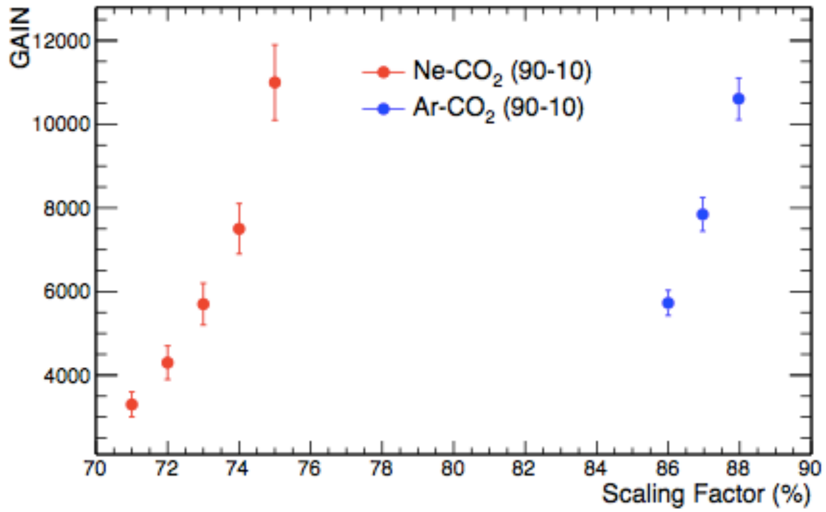
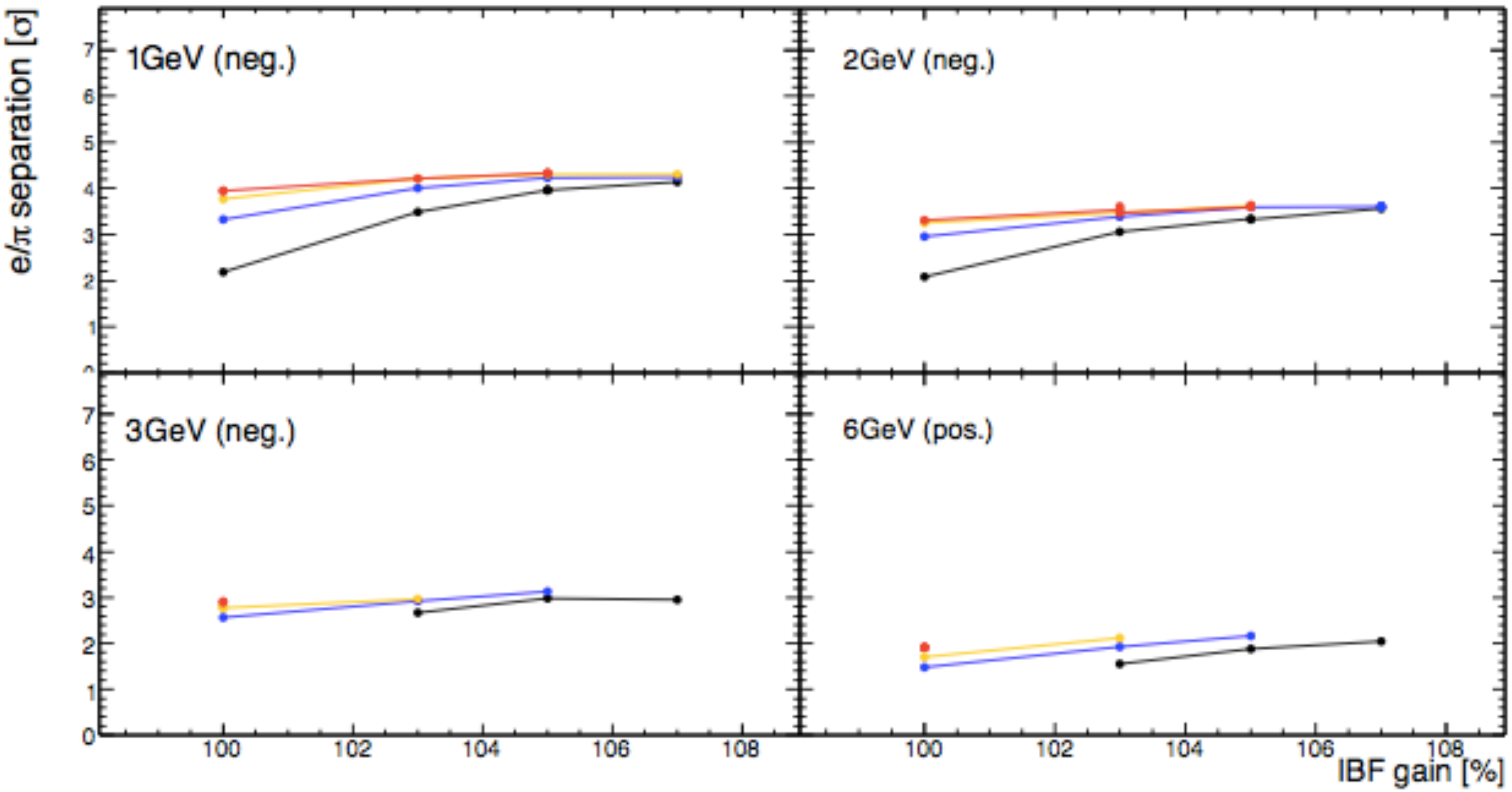


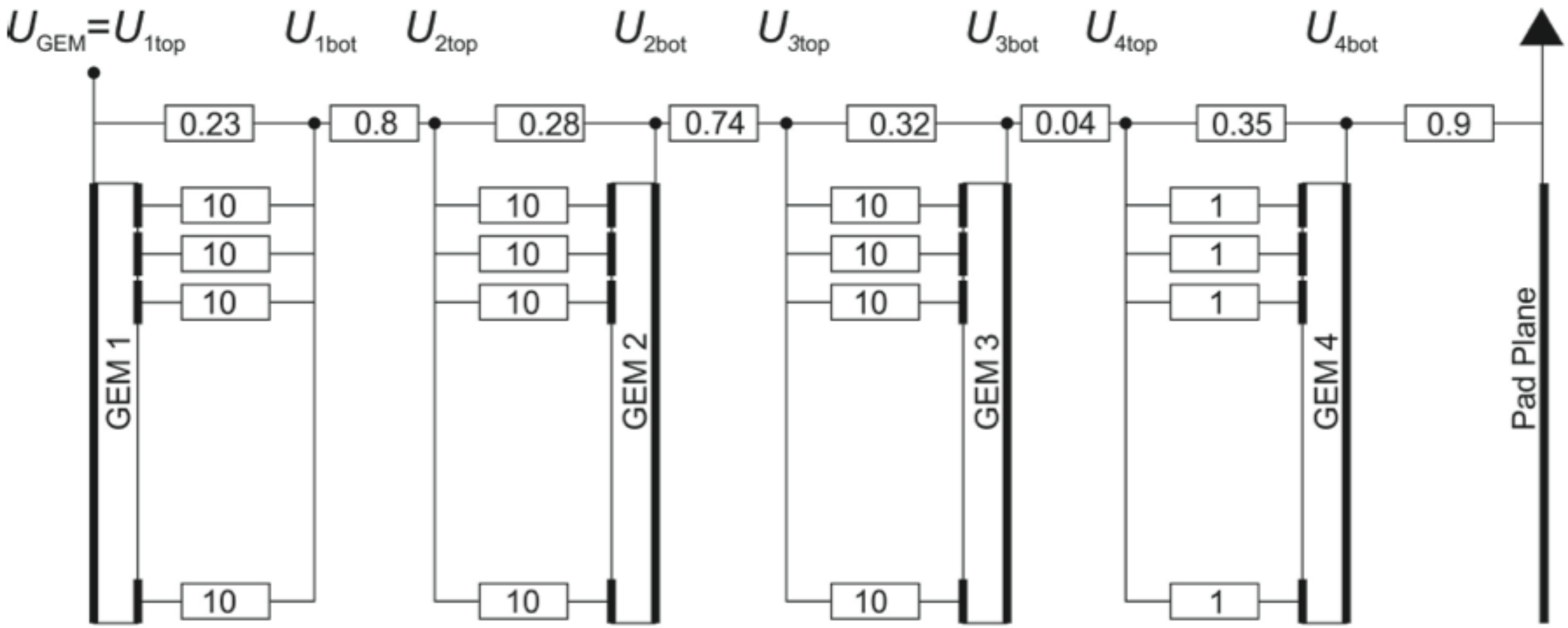
Figure 5.29.: ^{55}Fe spectra obtained in Ar-CO_2 (90-10) (left panel) and Ne-CO_2 (90-10) (right panel).



e-π separation power with IROC prototype

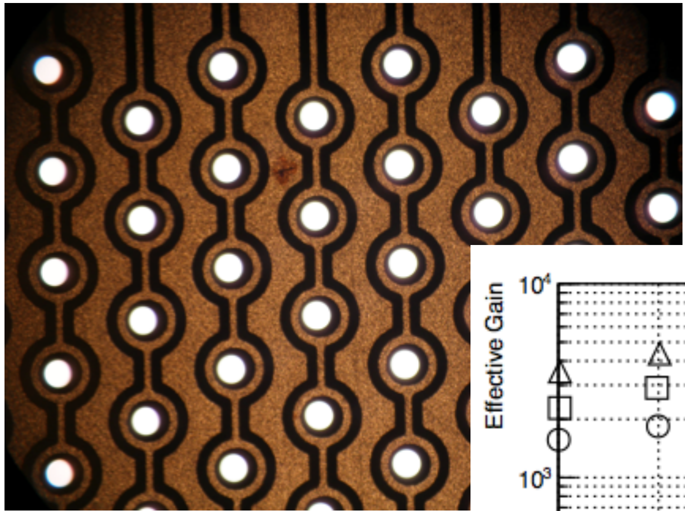


Foreseen HV distribution scheme

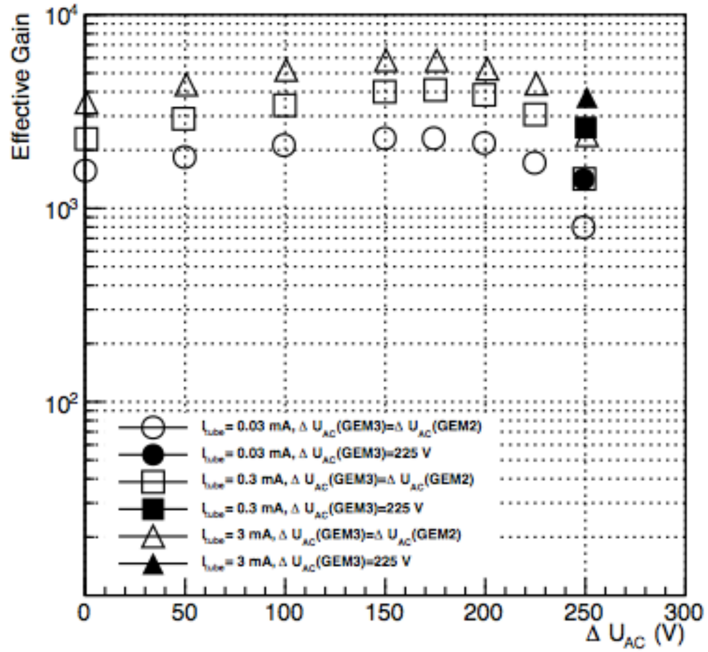


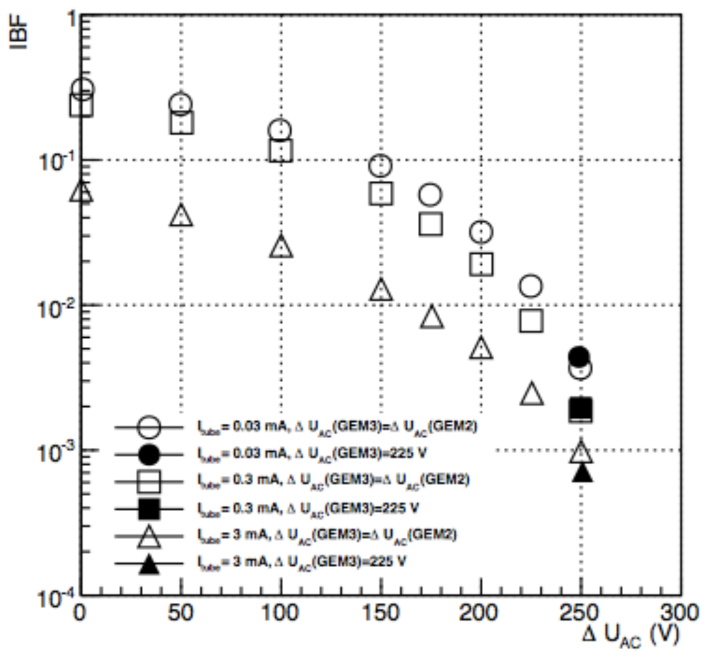
All gaps 2mm

Alternative R&D: COBRA GEM



IBF down to 0.1% with a GEM-COBRA-COBRA arrangement





☞Hybrid Micromegas+GEM is another possibility for low IBF