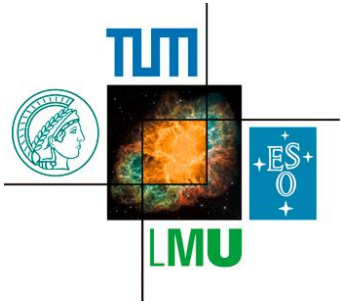


Study of the d*E*/d*x* resolution of a GEM Readout Chamber prototype for the ALICE TPC

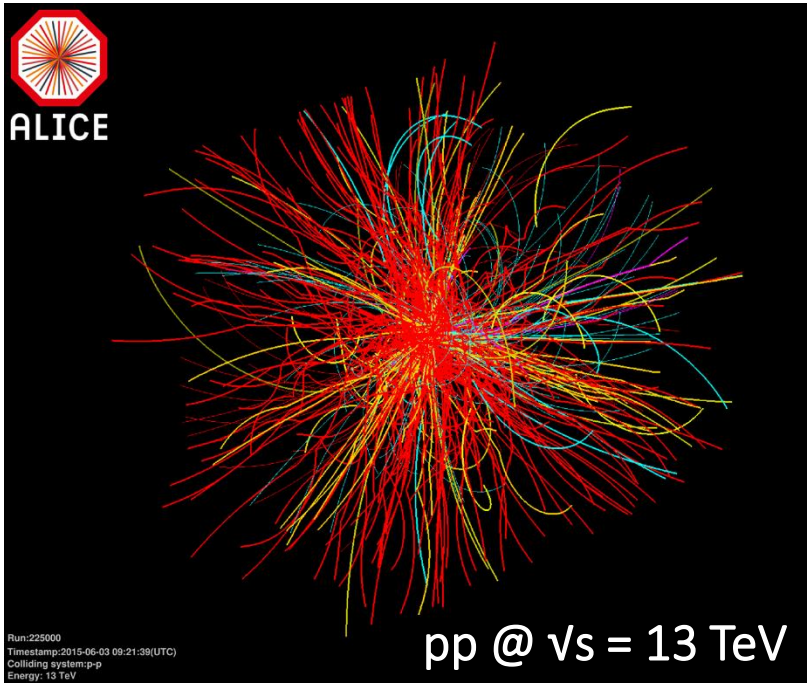
Andreas Mathis on behalf of the ALICE Collaboration

Technische Universität München

Excellence Cluster – *Origin of the Universe*

12.10.2015 – 4th Conference on Micro-Pattern Gaseous Detectors – Trieste

TPC – A VERSATILE TRACKING DETECTOR



TPC – an (almost) ideal tracking detector

- Large active volume and acceptance
- Low material budget
- 3D spatial information about hits → simple pattern recognition
- High particle densities
- Good momentum resolution
- Particle identification via measurement of the specific energy loss

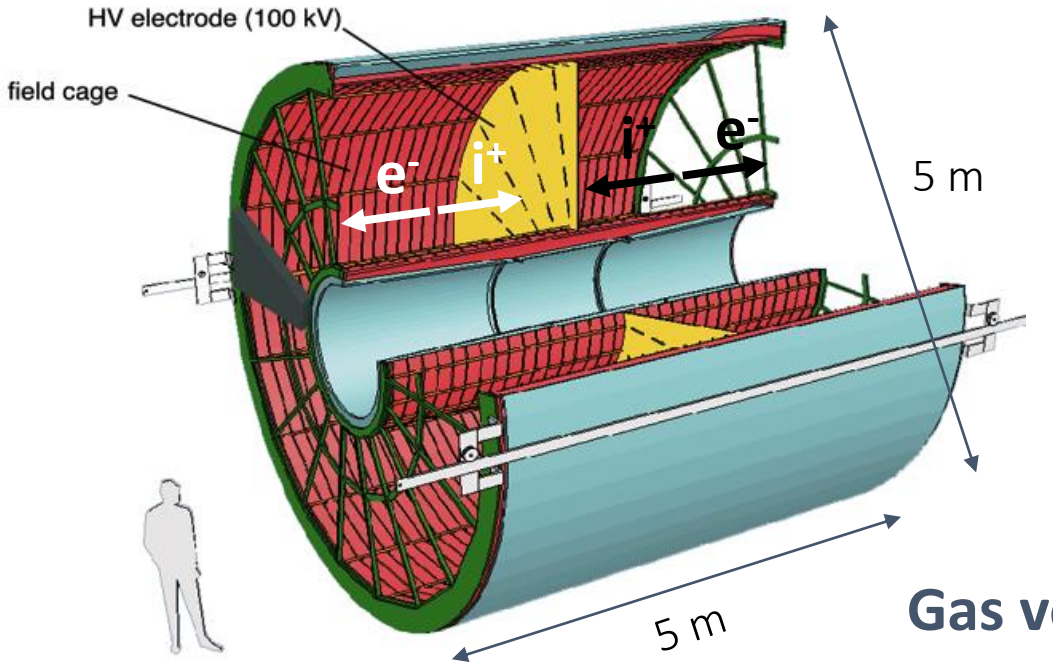
Wide range of applications

- High energy physics
- Dark matter searches
- Neutrinoless double beta decay
- … and many more

Limitations

- Huge parameter space for calibration
- Drift distortions due to backdrifting ions → gated operation
- Limited to low rate experiments

ALICE TPC

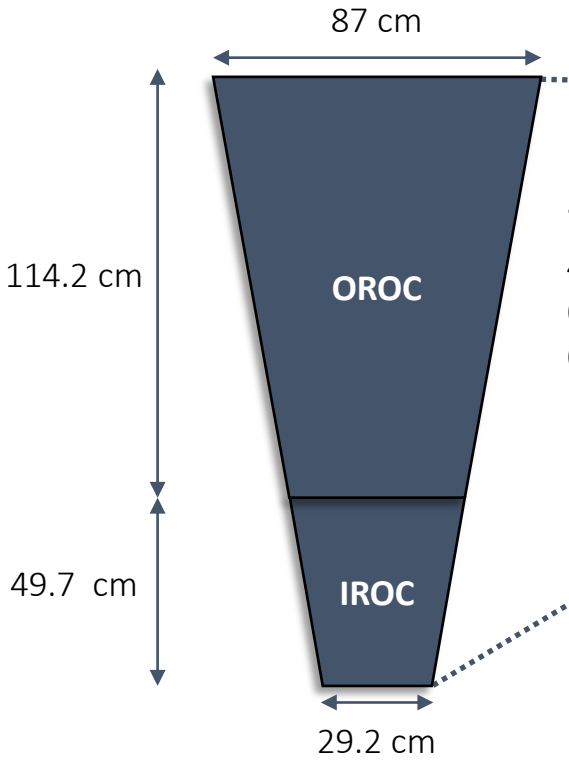


Gas volume

- ~ 90 m³ active detector medium
  - Ne-CO_2 (90-10) in RUN 1
  - Ar-CO_2 (90-10) in RUN 2
- E_d = 400 V/cm
- ~ 90 µs drift time for electrons

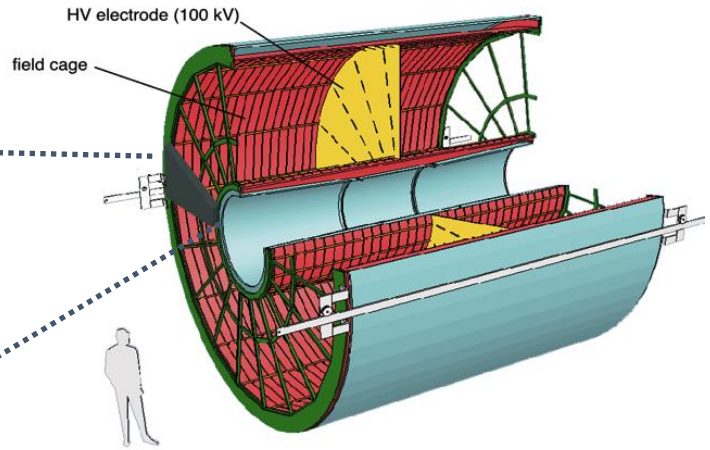
ALICE TPC

2 x 18 **O**uter **R**ead **O**ut **C**hambers



557,568 pads (159 rows)

4 x 7.5 mm^2 (IROC)
6 x 10 mm^2 (OROC)
6 x 15 mm^2 (OROC)

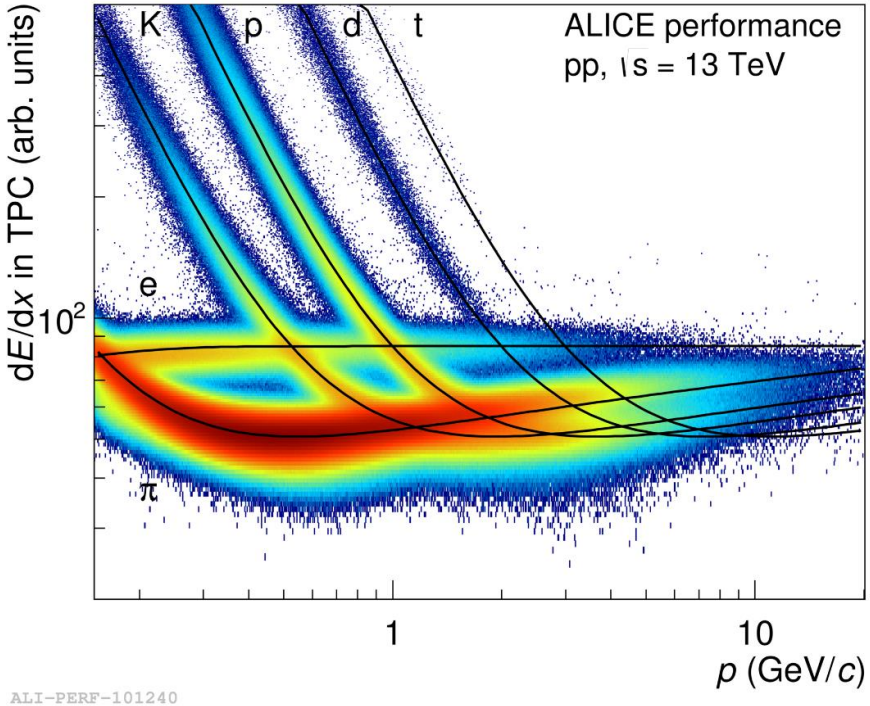


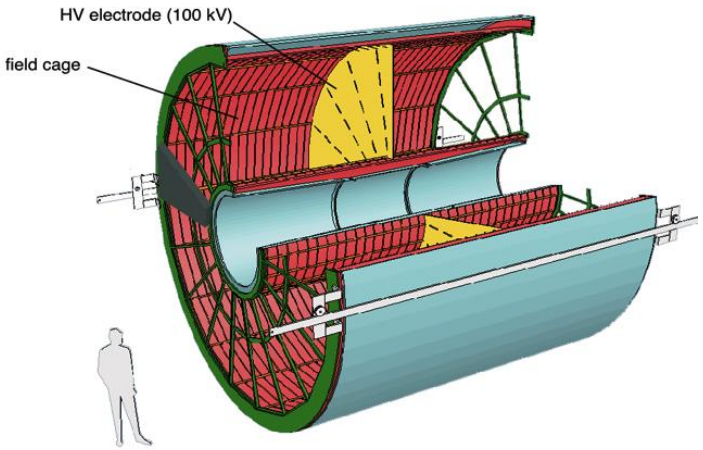
2 x 18 **I**nner **R**ead **O**ut **C**hambers

Readout chambers

- MWPCs with pad readout
- High multiplicity environment (up to 20,000 particles)
  - $\sigma_{dE/dx} \approx 5.5$ % in pp
  - $\sigma_{dE/dx} \approx 7$ % in central Pb-Pb
  - Excellent PID capabilities!

ALICE TPC





Readout chambers

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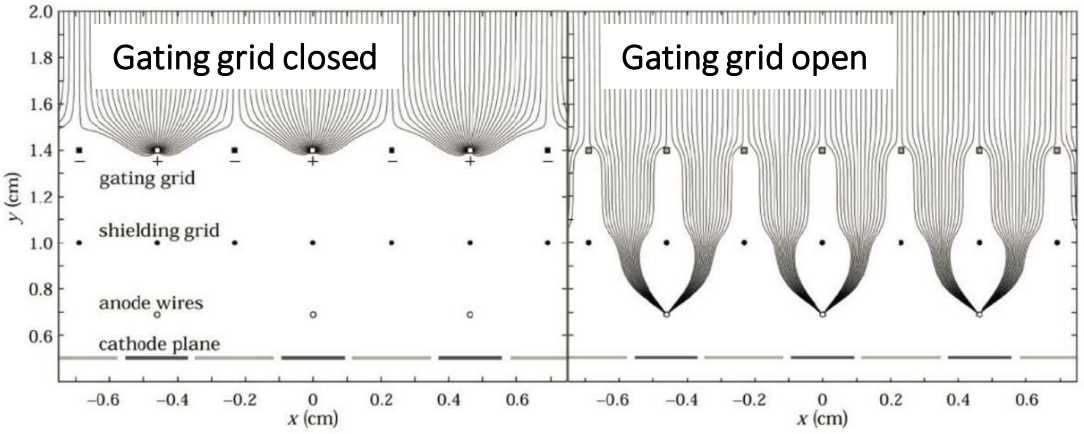
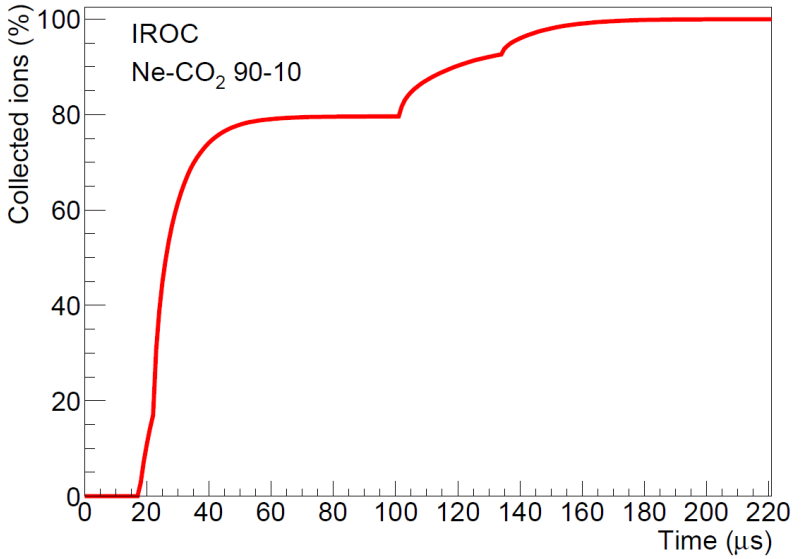
LIMITATIONS OF THE PRESENT SYSTEM





- Current MWPCs employ gating grid (GG) to neutralize ions produced in amplification process
  - Otherwise sizeable distortions due to space charge
- GG limits operation to ~ 3.5kHz
  - Electron drift (~ 90 µs) + ion blocking with GG (~ 200 µs)
- Readout rate in Pb-Pb limited to 500 Hz

➢ **Upgrade necessary to run at a higher interaction rate!**

ALICE TPC UPGRADE FOR RUN 3

Operate ALICE at high luminosity

$\mathcal{L}$ = 6 x 10^{27} cm^{-2} s^{-1} for Pb-Pb

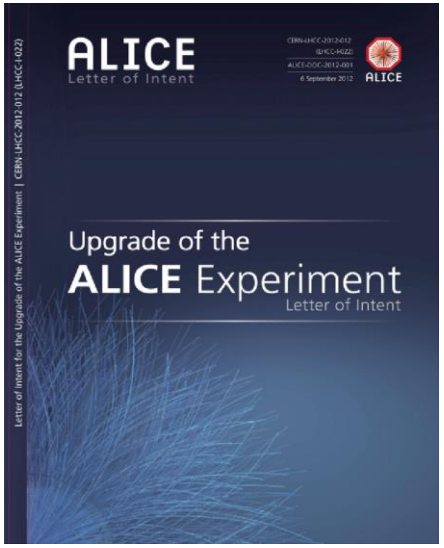
- Record all minimum bias events
  - 50 kHz Pb-Pb collisions (**100×** higher than present)
  - Average event spacing ~ 20 µs → ~ 5 events pile up in TPC
- No dedicated trigger → continuous readout
- Implies significant detector upgrades

➢ **No gating** and **continuous** readout of the TPC with GEMs

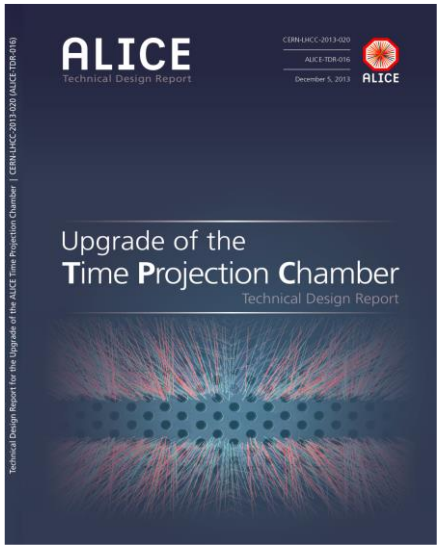
Requirements for GEM readout

- Nominal **gain = 2000** in Ne-CO_2-N_2 (90-10-5)
- **IBF < 1 %** at gain = 2000 (ε=20)
- **Maintain energy resolution**: σ_E/E < 12% for ^{55}Fe
- **Stable operation** under LHC RUN 3 conditions
- + new electronics
- + novel calibration and online reconstruction schemes

http://cds.cern.ch/record/1475243

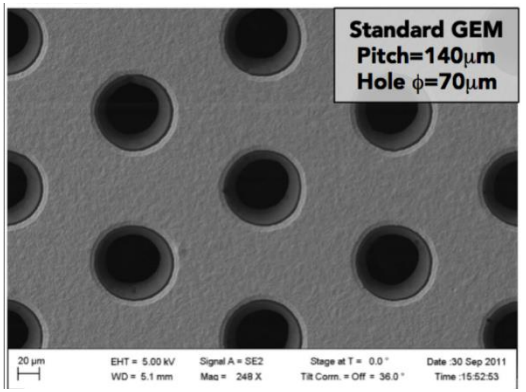


http://cds.cern.ch/record/1622286



Endorsed by LHCC

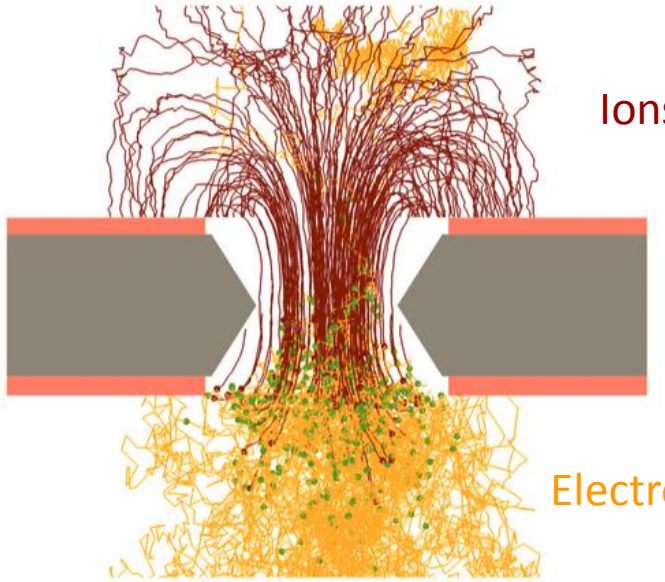
GEM – GASEOUS ELECTRON MULTIPLIER



- 50 µm polyimide foil with 5 µm cooper
- GEM foils allow for **continuous operation**
  - Intrinsic IBF suppression (*ion backflow*)

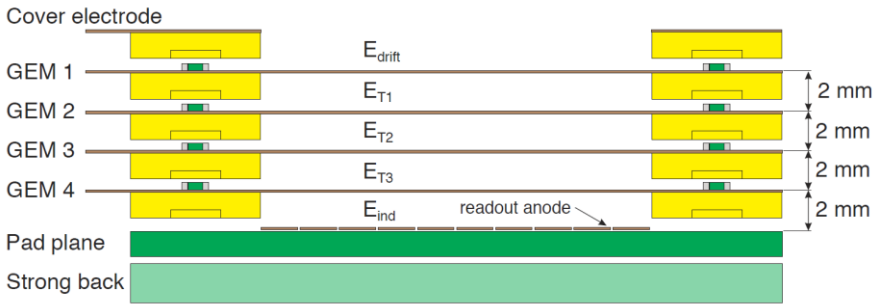
$$IBF = \frac{I_{cathode}}{I_{anode}} = \frac{1+\epsilon}{G_{eff}}$$

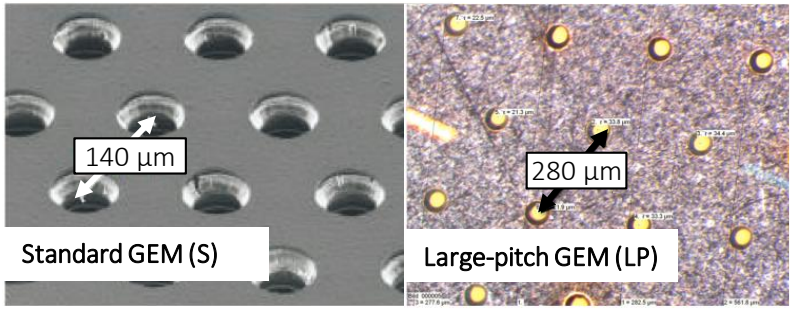
  - ε: number of backdrifting ions per incoming electron
- Operation of several GEMs in a **stack**
  - IBF of $\mathcal{O}(10^{-3})$ can be achieved
    - No gating grid required

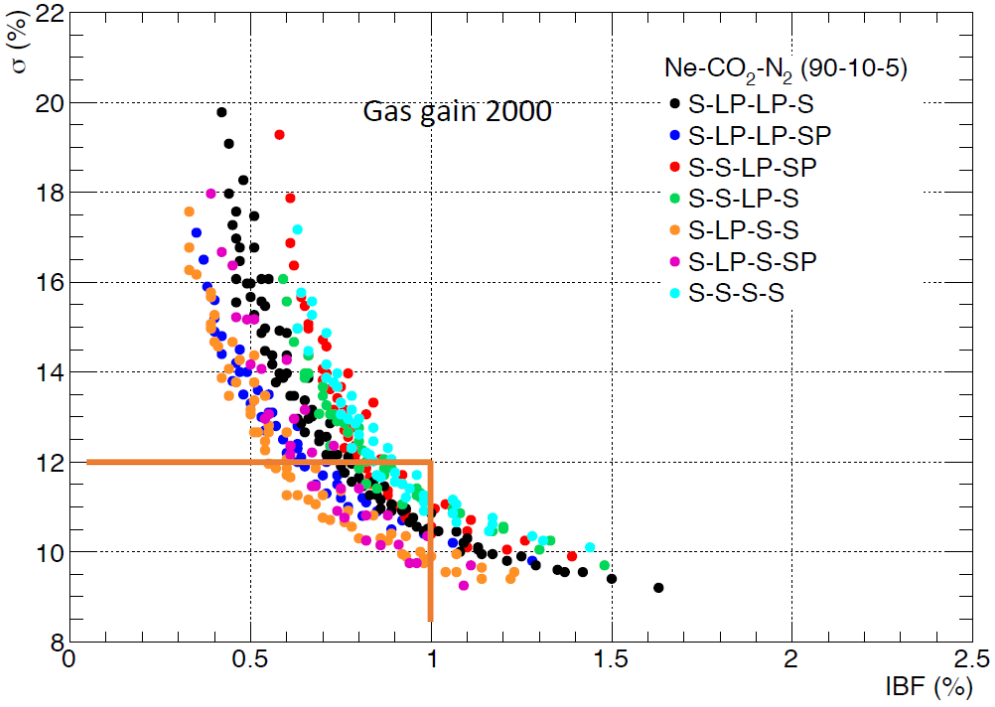


Simulated avalanche in a GEM hole
(Garfield / Magboltz simulation)

PERFORMANCE STUDIES







Talk by A. Deisting tomorrow about stability!

Baseline solution

- Result of intensive R&D phase
- S-LP-LP-S configuration

✓ IBF = 0.6 %

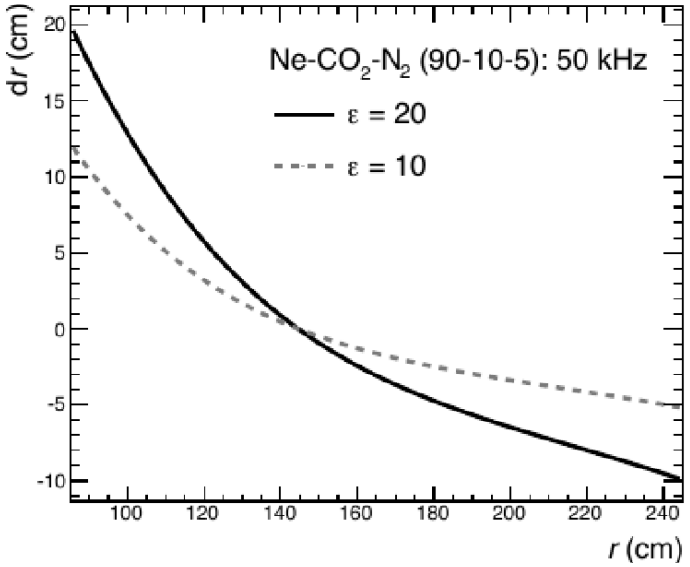
✓ $\sigma_E/E < 12$ % for ^{55}Fe

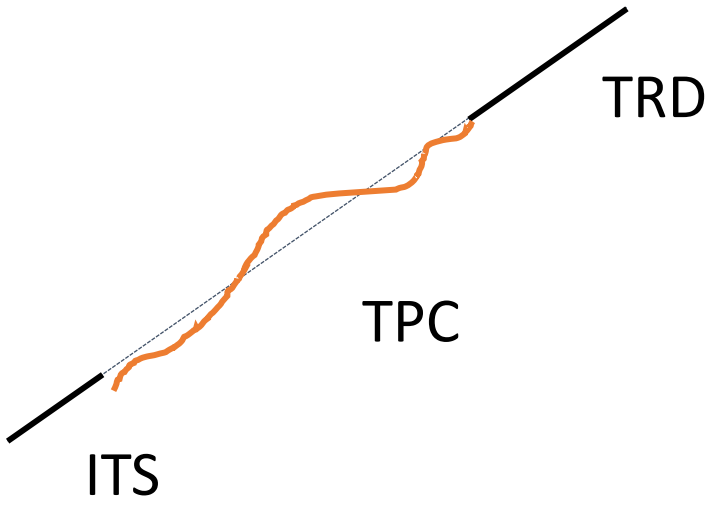
✓ Stable operation

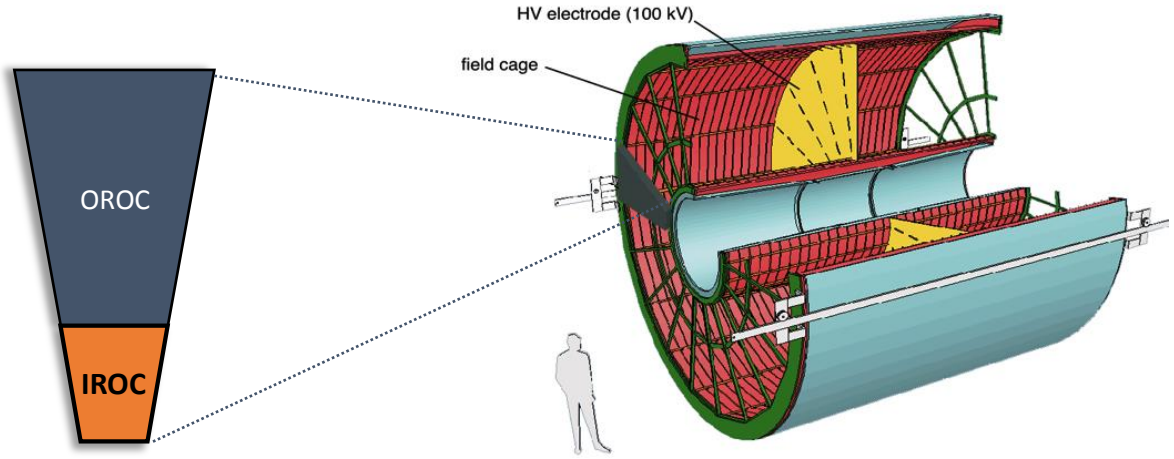
✓ Sufficient **margin for fine-tuning** of the voltages (e.g. for stability)

SPACE CHARGE DISTORTIONS & CALIBRATION

- Ions from 8000 events pile up in the drift volume at 50 kHz Pb-Pb
  - $t_{drift,\ ion}$ = 160 ms
  - Distortions up to d*r* ≈ 20 cm at ε=20
- Corrections to $\mathcal{O}(10^{-3})$ are required for final calibration
  - Space-charge distortion map
  - Track interpolation from external detectors (ITS – TPC – TRD – TOF)
- Limits of calibration procedure tested up ε= 40
  - Does not compromise the physics program





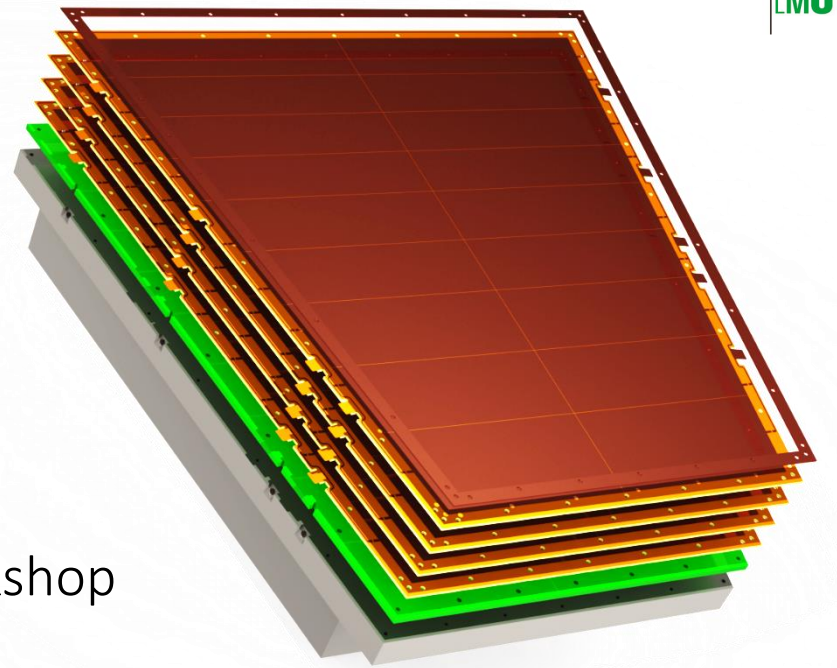


Large size prototypes

Inner Readout Chamber – IROC

d*E*/d*x* resolution studies

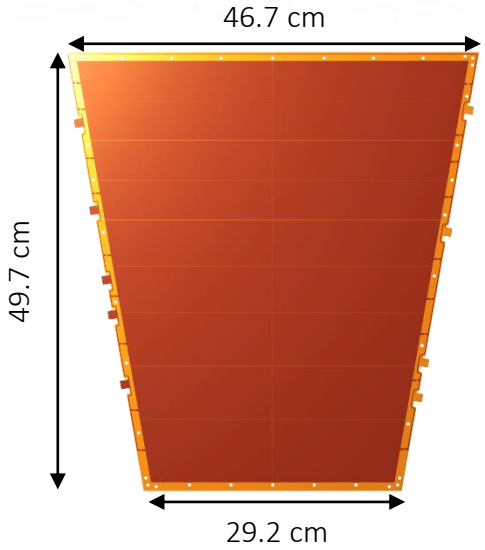
DETECTOR – 4 GEM IROC



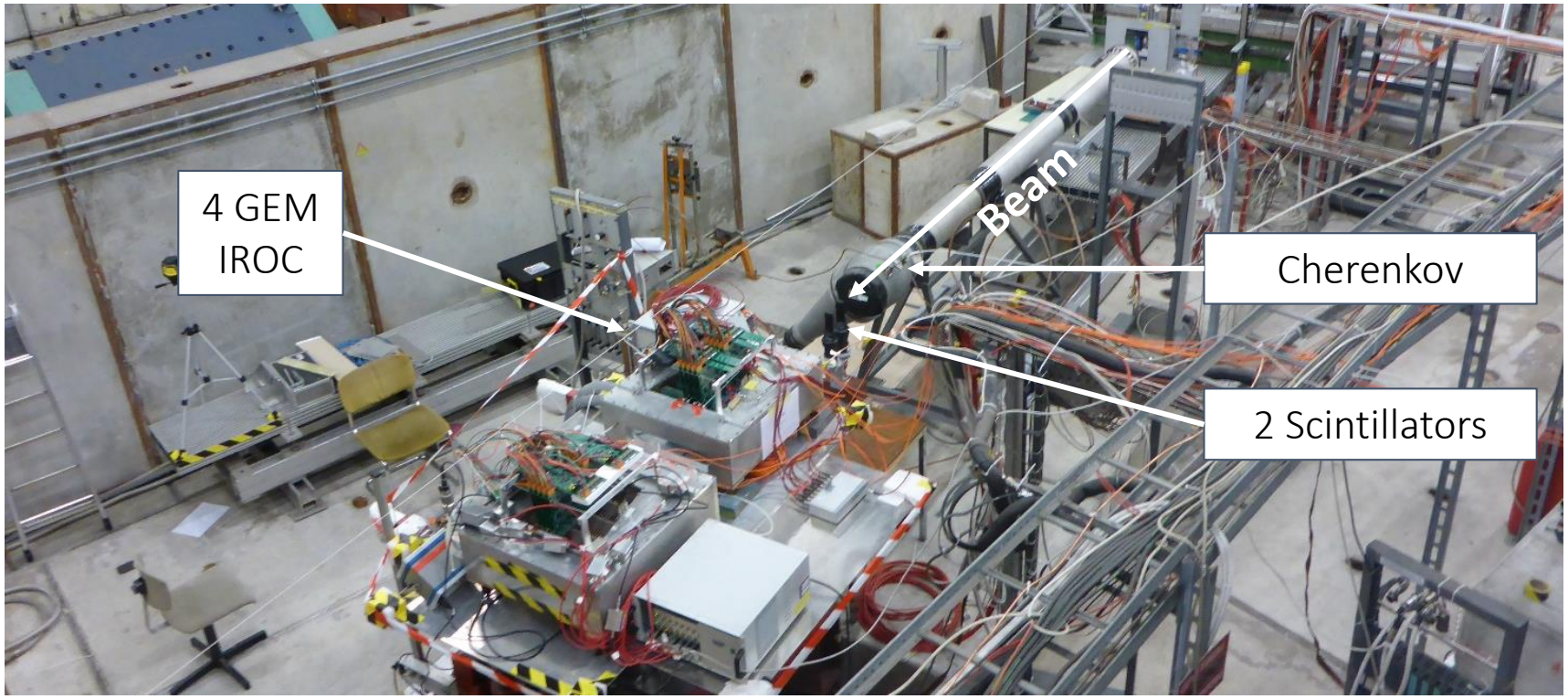
- Prototype of an Inner Read Out Chamber (IROC)
- Quadruple GEM stack
  - S-LP-LP-S configuration
  - Single-mask technology
  - Produced in CERN MPGD workshop

Mounted into field cage box

- Drift length: 11.5 cm
- Drift field: 400 V/cm
- Gas: Ne-CO_2-N_2 (90-10-5)

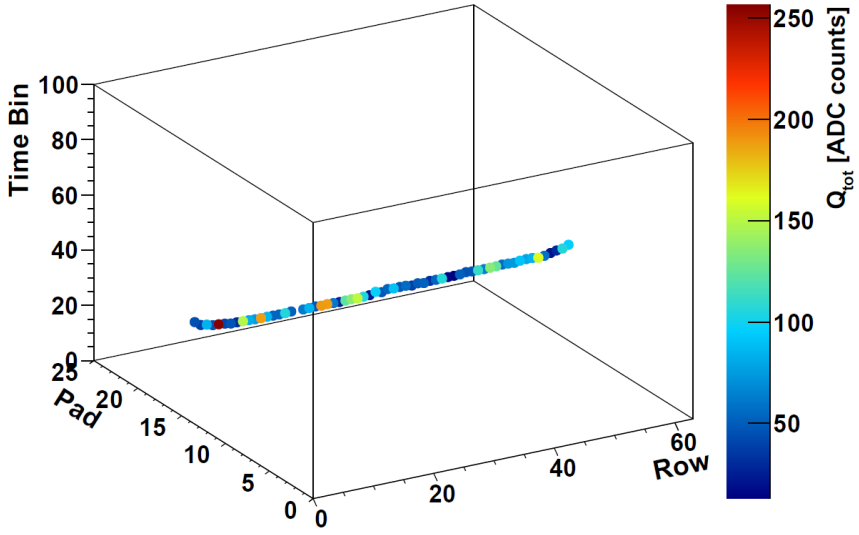


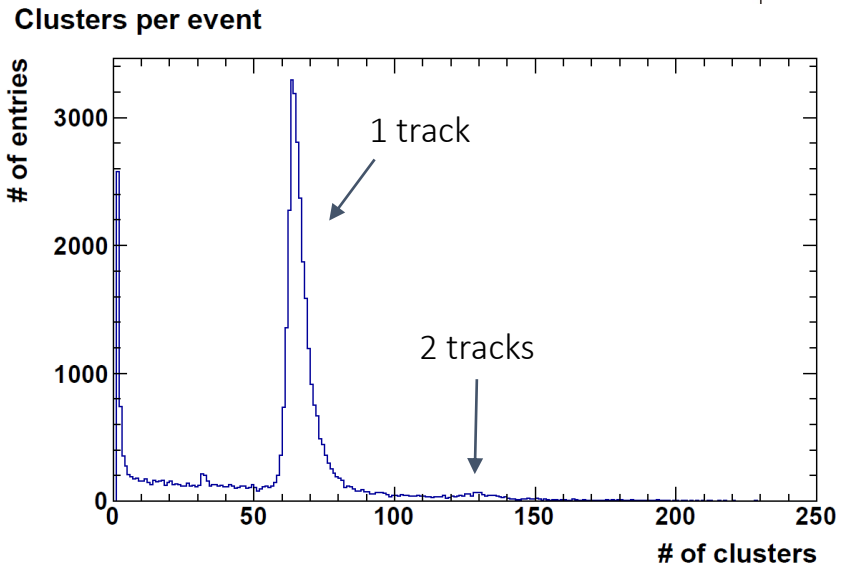
SETUP – PS EAST AREA T10



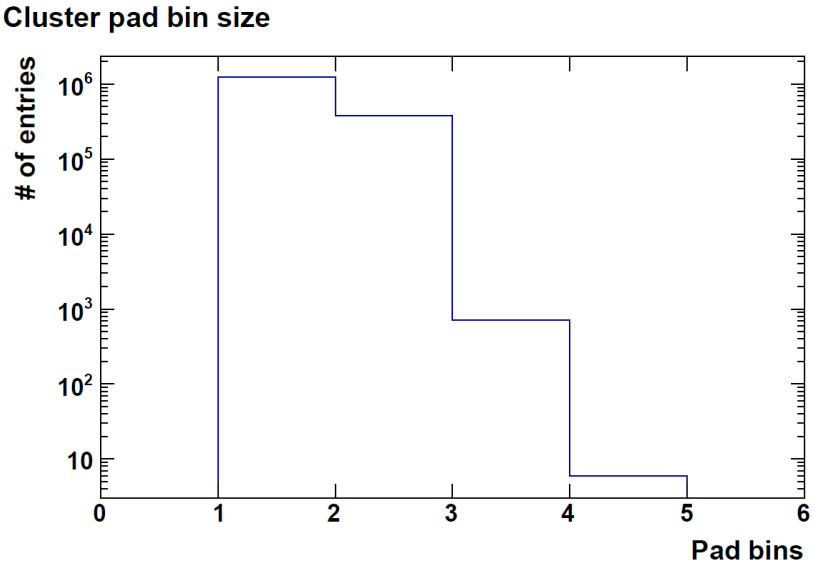
- Dedicated testbeam to study d*E*/d*x* performance of a 4 GEM IROC
  - 1 GeV/*c* secondary negative beam (e^-, π^-)
  - Average beam rate: 2000 particles/spill
  - DAQ rate: ca. 300 events/spill
  - Detector equipped with 10 *EUDET* FECs (~1200 readout channels)

CLUSTERING

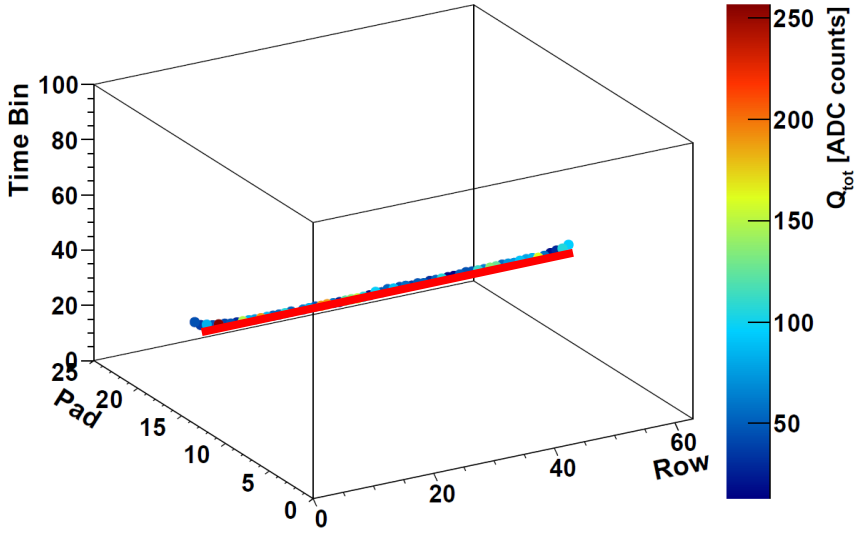


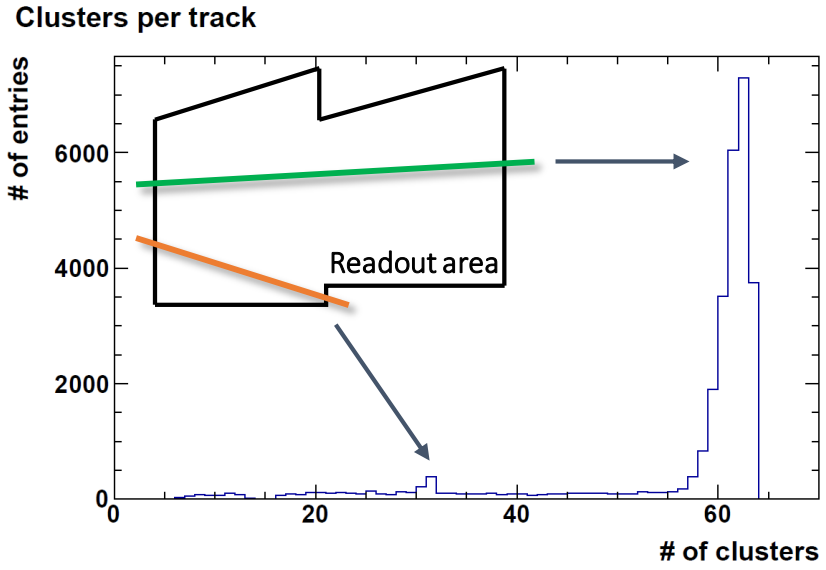


- Search for maxima in pad row – time planes
- Investigation of 5×5 bins around the central bin with maximum amplitude
- Cluster size smaller than with MWPC read out
  - Narrower PRF of GEMs



TRACKING

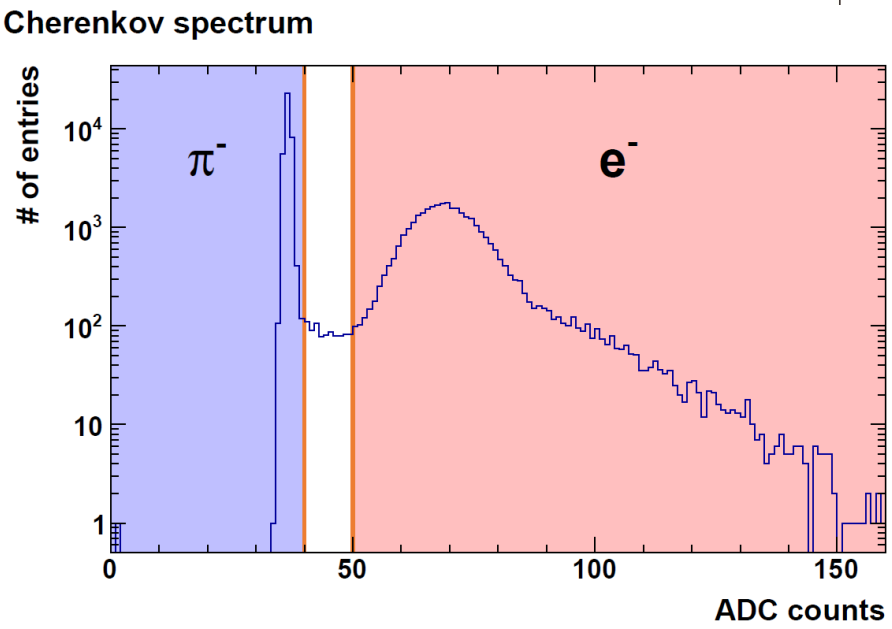


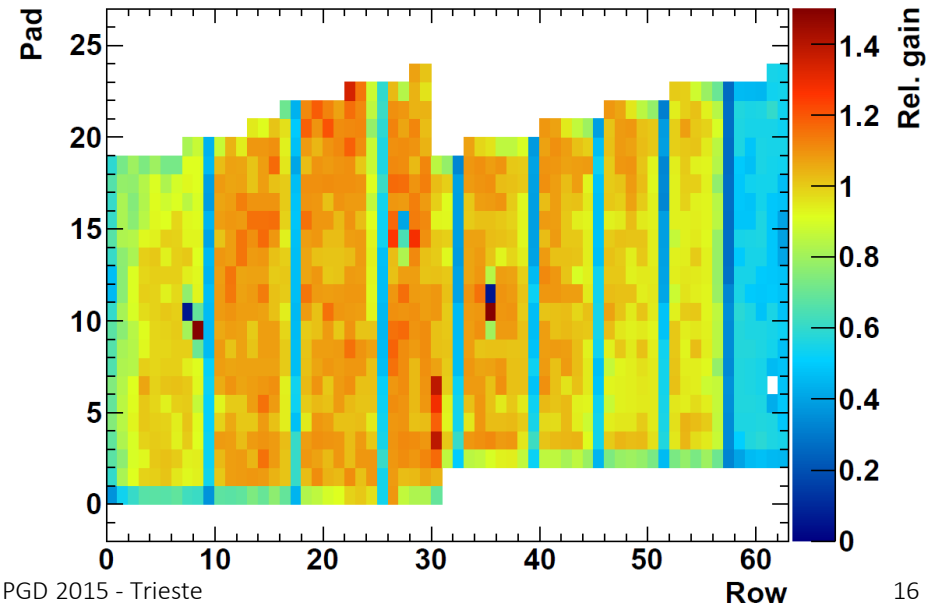


- Iterative track finding
  - Assigning clusters to a track candidate
  - Kalman filter
- Clusters assigned per track
  - ✓Matches IROC‘s 63 pad rows

d*E*/d*x* RESOLUTION – ANALYSIS STRATEGY

- PID by Cherenkov counter
  - ➢ Only one track events
- Truncated mean of the cluster charge Q_{tot}
  - Truncation: 0 – 70 %
- Corrections
  - Normalized gain map
    - Obtained with tracks from testbeam

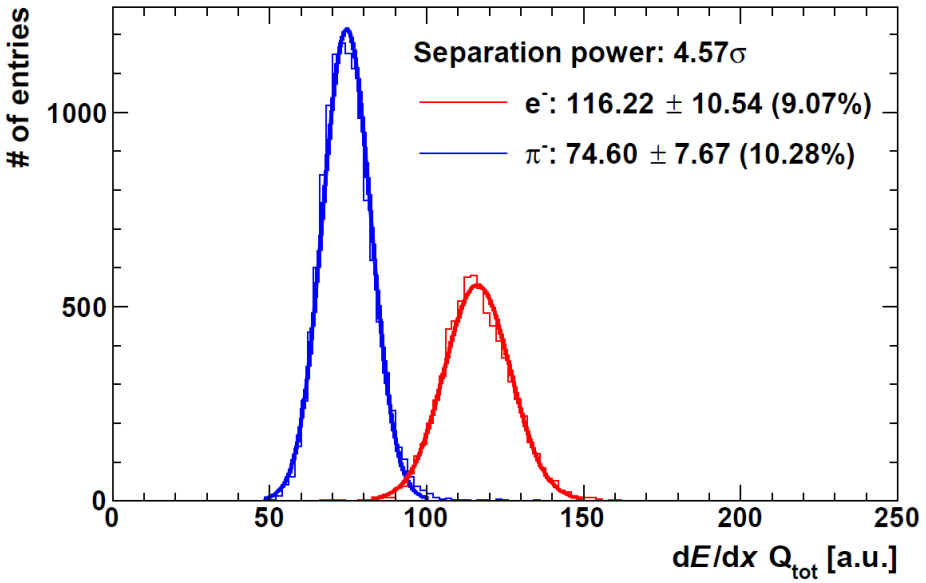


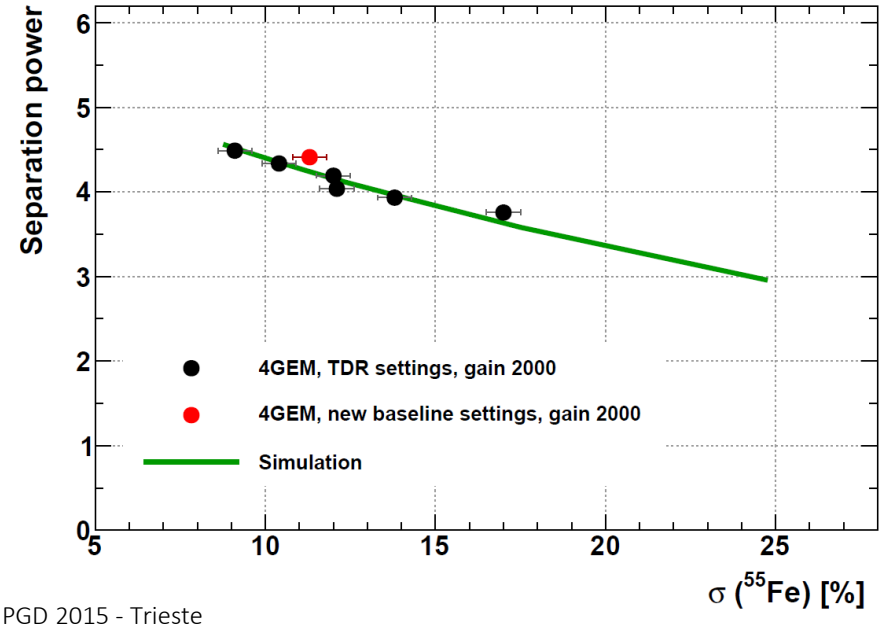


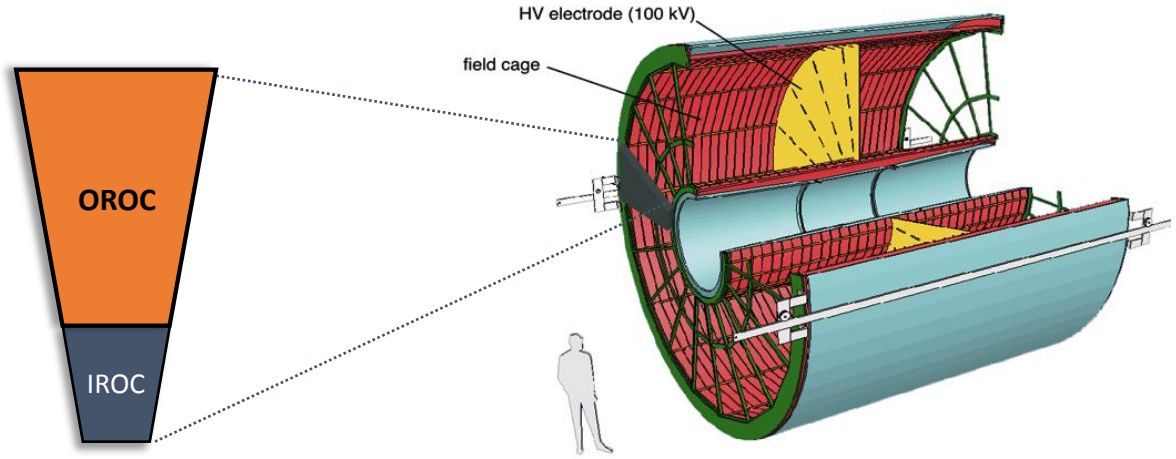
d*E*/d*x* RESOLUTION – RESULTS

Baseline settings

- ✓ Optimal detector performance
- ✓ $\sigma_E/E \approx 9.5\ \%$
- ✓ Performance compatible with current MWPCs
- ✓ Results for different HV-settings well reproduced by microscopic simulations







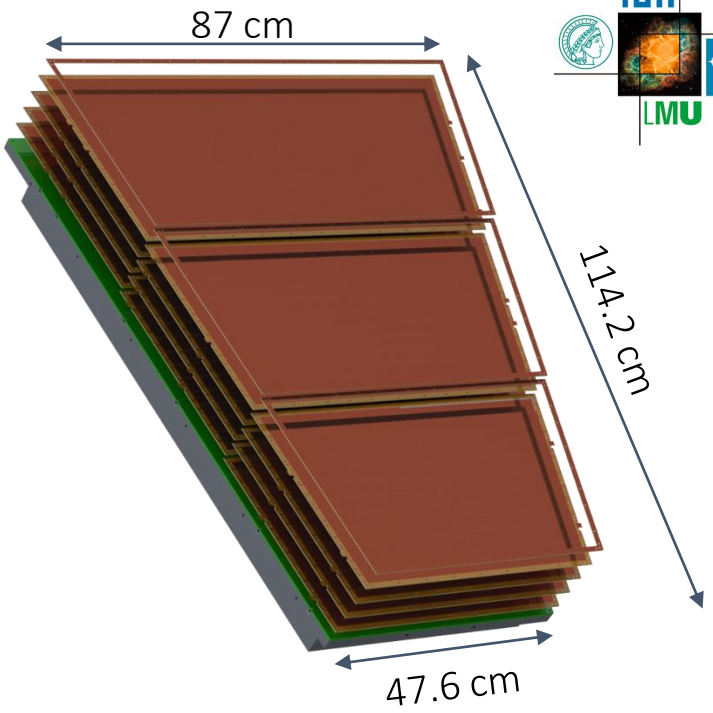
Large size prototypes

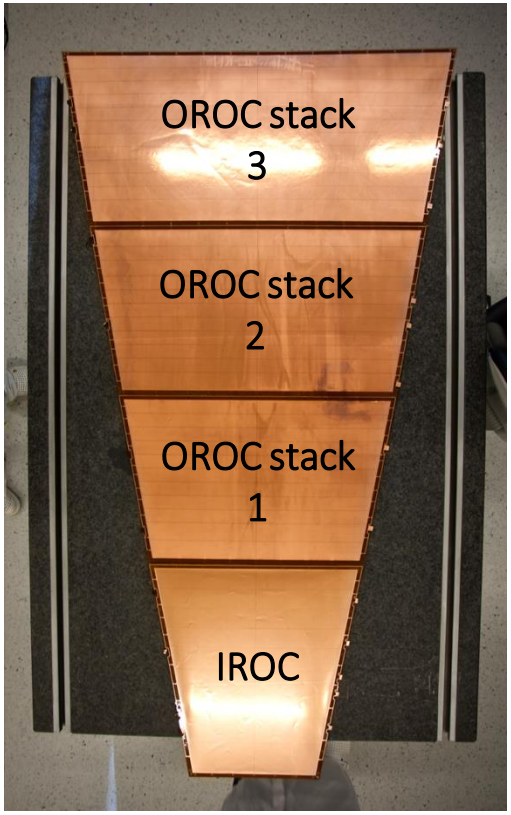
Outer Readout Chamber – OROC

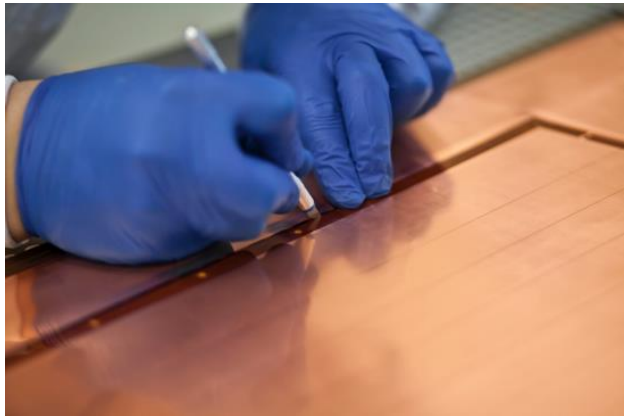
First prototype

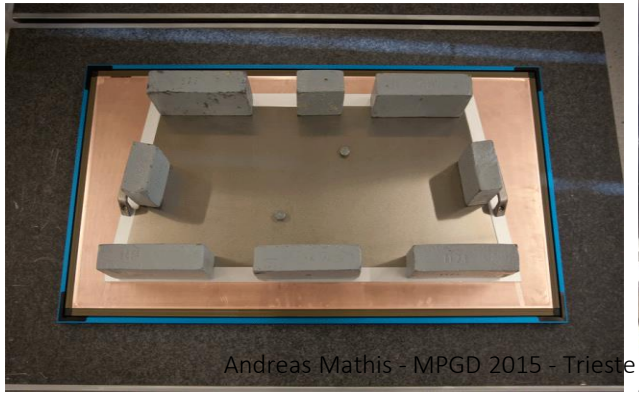
OROC PROTOTYPE

- Validate production methods with large size detector
  - Active GEM area = **0.6817 m²**
  - ✓ GEM production & framing
  - ✓ Detector assembly
  - ✓ QA protocols
- ✓ Milestone for the project









SUMMARY

- ALICE TPC will be upgraded for RUN 3 and beyond to operate at 50 kHz rate in Pb-Pb collisions
  - No gating and continuous readout with GEMs

- 4 GEM IROC prototype built and commissioned
  - Energy resolution studies carried out at the CERN PS
    - d*E*/d*x* performance compatible with requirements
      - ✓ $\sigma_E/E \approx 9.5\%$
    - ✓ Relative energy resolution not compromised after the upgrade

- 4 GEM OROC prototype build and commissioned
  - Largest GEM-based detector up to date

OUTLOOK

- ✓ R&D phase finished
  - ✓ IBF minimized while optimizing the energy resolution
  - ✓ Stability against electrical discharges enhanced
    - ✓ Discharge studies with α sources and hadrons

- Pre-production in **Q3-4 / 2015**
  - Exercise mass production
  - Close to final design

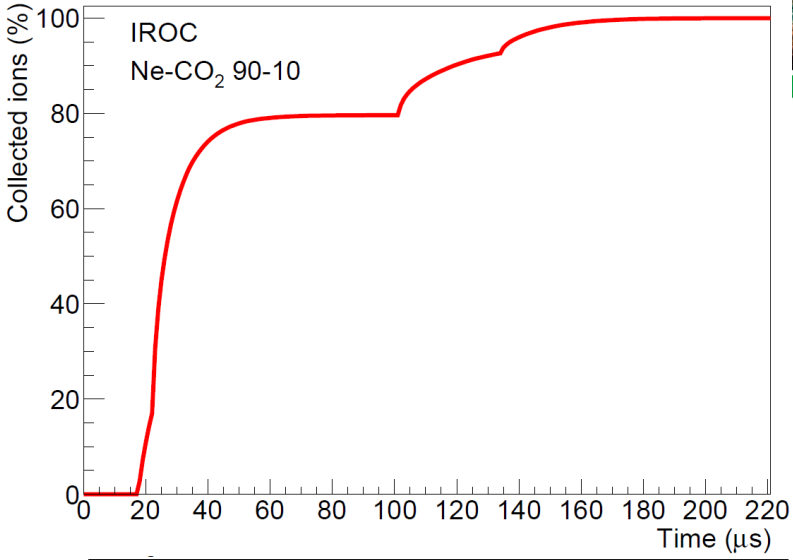
- Mass production starting in **Q1 / 2016**
  - 40 IROC and 40 OROC chambers to be built

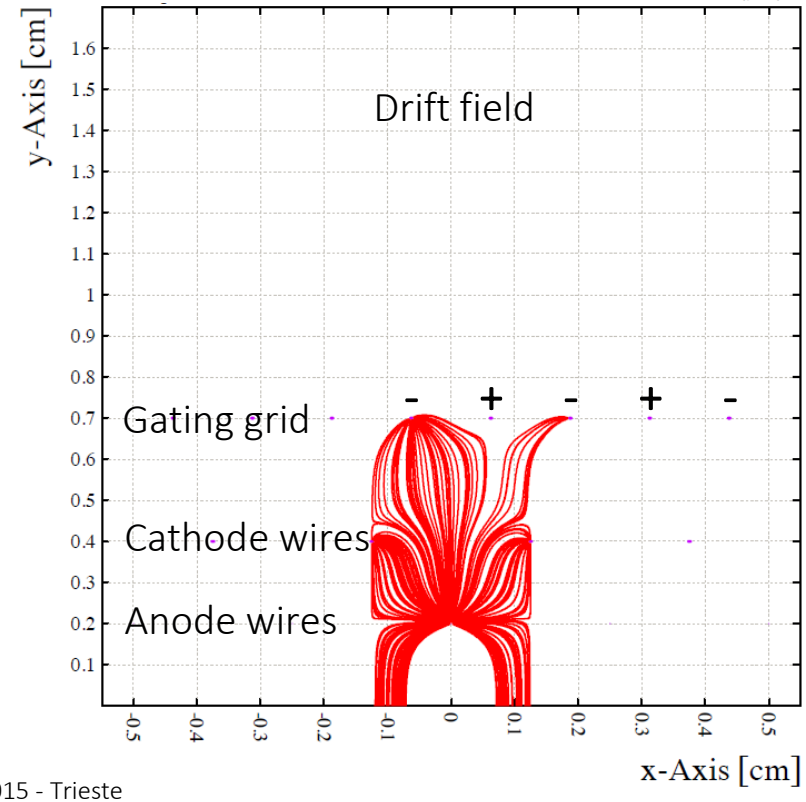
- LHC long shutdown 2 in **2019-20**
  - Replace current readout chambers and mount new electronics
  - Commissioning the TPC
  - Total number of GEM holes in ALICE TPC: **3.9×10^9** for S-LP-LP-S

Backup

GATING GRID

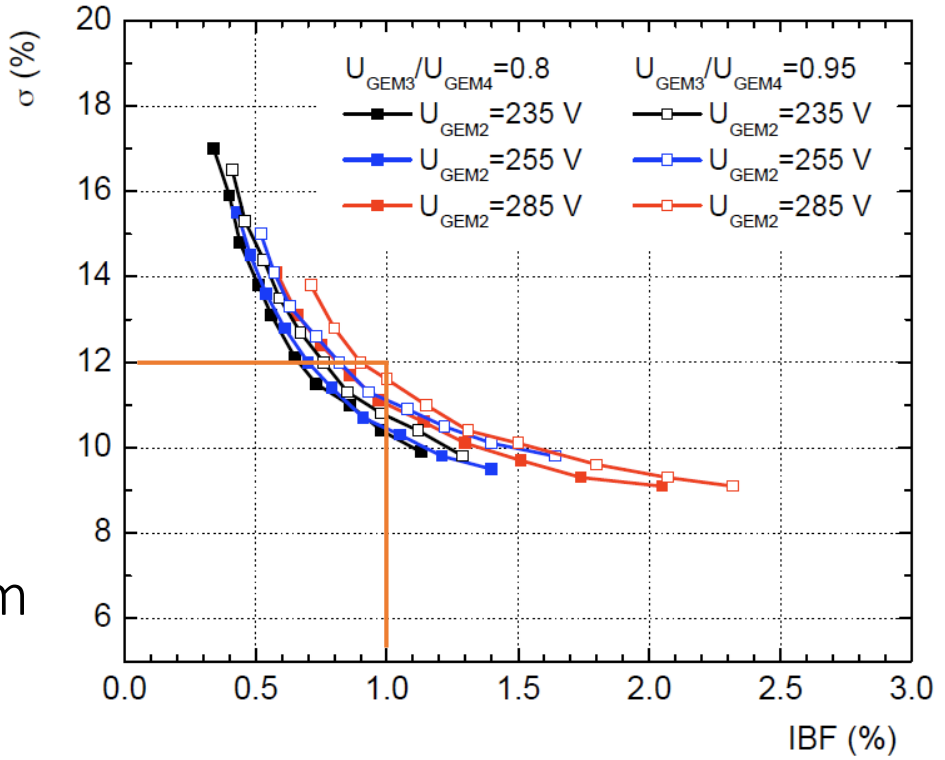
- Gating grid is supplied with $V_G \pm \Delta V$
  - + separates drift region from amplification region
  - - neutralizes the ions in the amplification region
- After 20 µs the ions are collected on the pad plane
- After 20-30 µs, the ions reach the cathode wires and are neutralized there
- After 100 or 130 µs respectively, the ions reach the two different gating grid wires





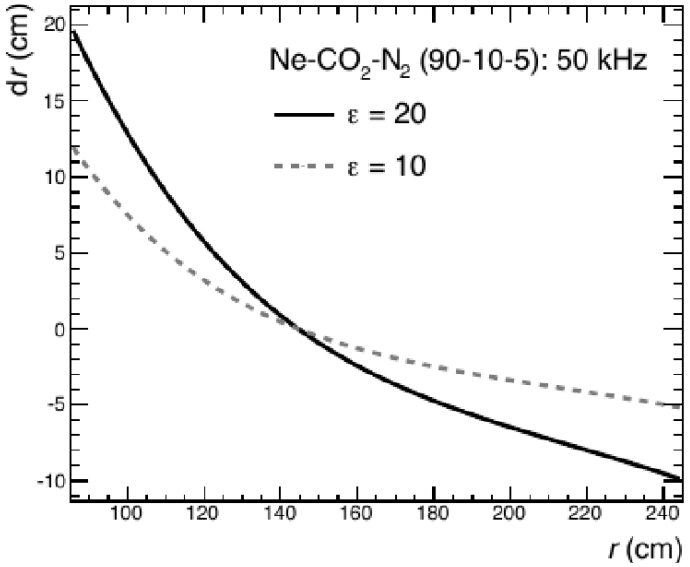
IBF STUDIES

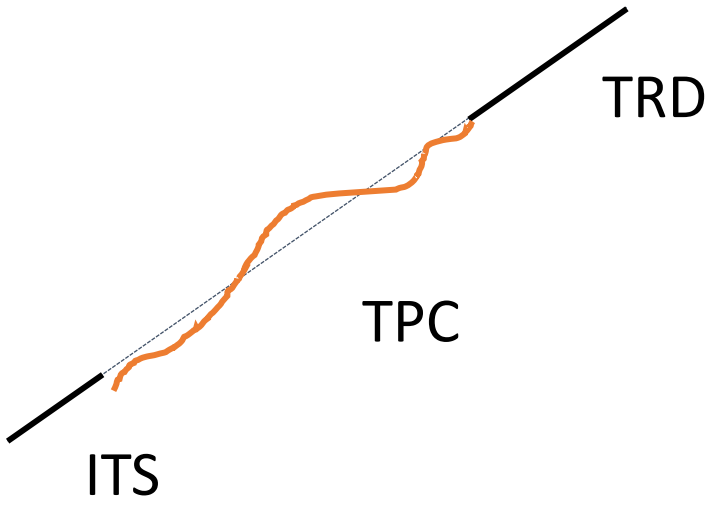
- ΔU_{GEM1} increases for a given setting from 225-315 V from left to right
- ΔU_{GEM3} and ΔU_{GEM4} are adjusted to an effective gain of 2000 with fixed ratio
- The transfer and induction fields are 4, 2, 0.1 and 4 kV/cm



SPACE CHARGE DISTORTIONS & CALIBRATION

- Ions from 8000 events pile up in the drift volume at 50 kHz Pb-Pb
  - $t_{drift,\ ion}$ = 160 ms
  - Distortions up to dr ≈ 20 cm at ε=20
- Corrections to $\mathcal{O}(10^{-3})$ are required for final calibration
  - Average space-charge distortion map – updated $\mathcal{O}$(15 mins)
  - High resolution space-charge distortion map – updated $\mathcal{O}$(5 ms)
  - Track interpolation from external detectors (ITS – TPC – TRD – TOF)
- Limits of calibration procedure tested up ε= 40
  - Slight decrease in p_t resolution at low momenta
  - Does not compromise the physics program

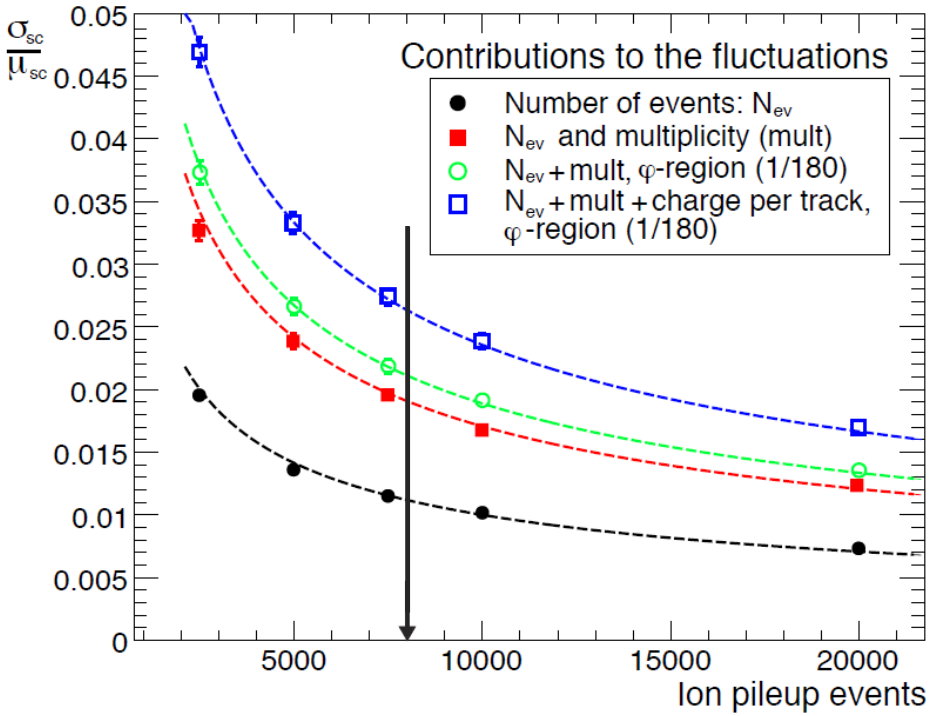




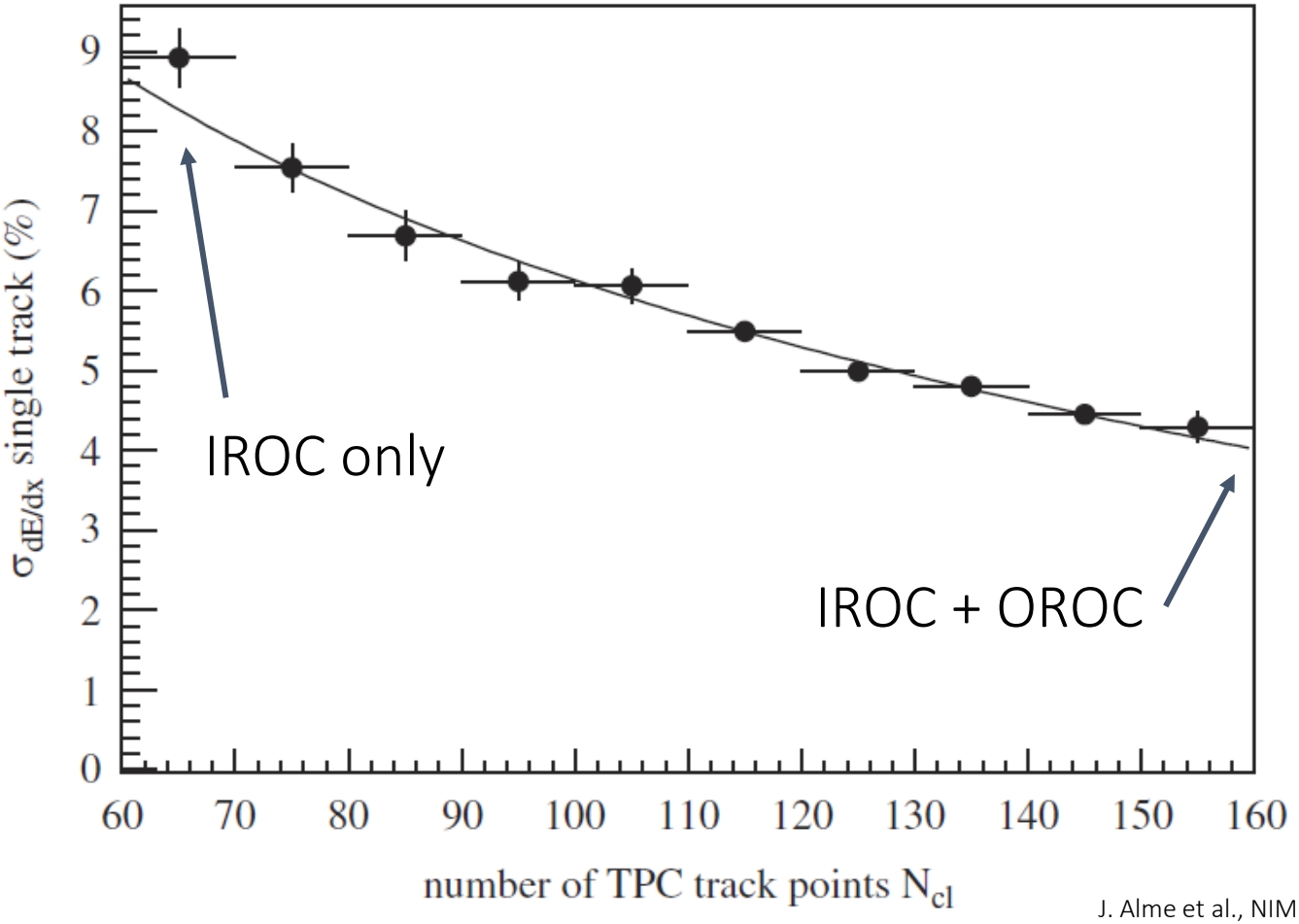
CALIBRATION – SPACE CHARGE FLUCTUATIONS

- Space-charge fluctuations at the level of 3%
- Fluctuations on top of the average distortions
  - Max ± 6mm residual distortion in r
  - Max ± 2.5mm residual distortion in rφ
  - Dominated by event and multiplicity fluctuations

➢ Constraints on the update interval for the final calibration $\mathcal{O}$(5 ms)



d*E*/d*x* RESOLUTION – EXTRAPOLATION TO FULL TPC



J. Alme et al., NIM A 622 (2010), 316–367.

$$\sigma_{\mathrm{d}E/\mathrm{d}x} \propto \frac{1}{\sqrt{n_{samples}}}$$