ALICE

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The ALICE upgrade for high-rate operation

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FSP 201 ALICE

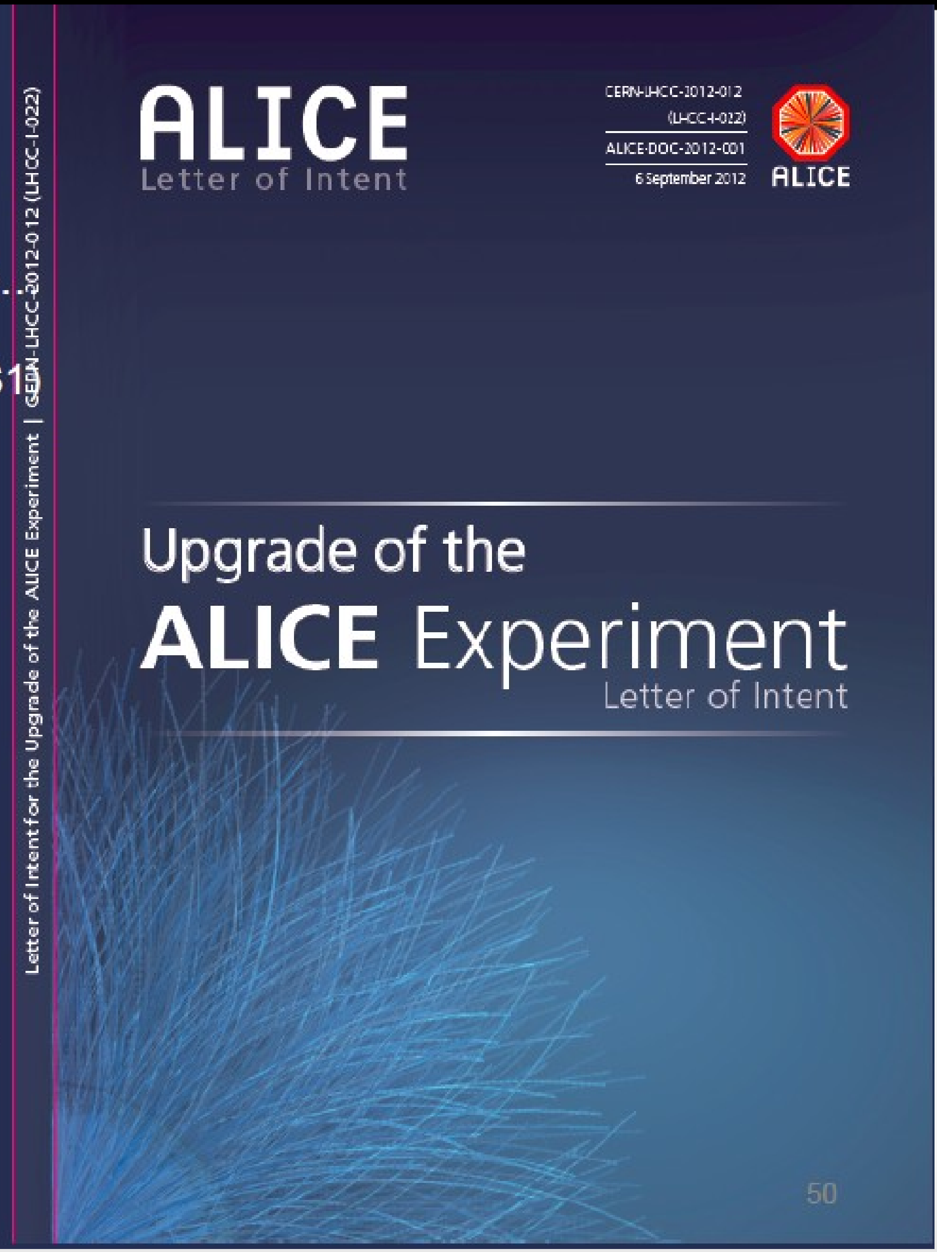
Outline

- ALICE upgrade program
- Performance with the ITS upgrade
- Implications of the TPC upgrade
- Reconstruction strategy
- Summary

ALICE upgrade

- 2013: **pPb and Pbp**
  initial state effects, shadowing…
- 2013-14: LHC Long Shutdown 1 (LS1)
- 2015-17: **FULL ENERGY !!**
  pp @ 7 TeV,
  PbPb @ √sNN = 5.5 TeV
- 2018: LHC Long Shutdown 2
- ≥ 2019: **HIGH LUMINOSITY**
  50 kHz PbPb collisions

ALICE UPGRADES
- New vertex detectors
- Faster readout, high level triggers…
- TPC with continuous readout …

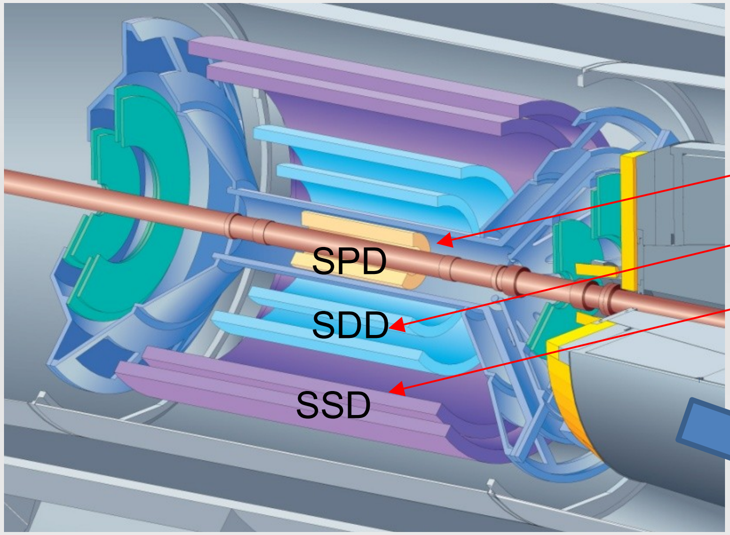


Operation at high-rate

- Operate ALICE at luminosity ($L = 6 \cdot 10^{27}$ $cm^{-2}s^{-1}$)
- Record all minimum bias events
  - 50kHz Pb–Pb collisions → 100x higher than present
  - Event pile-up in TPC → tracks from 5 interactions
- Large data rate → high compression required

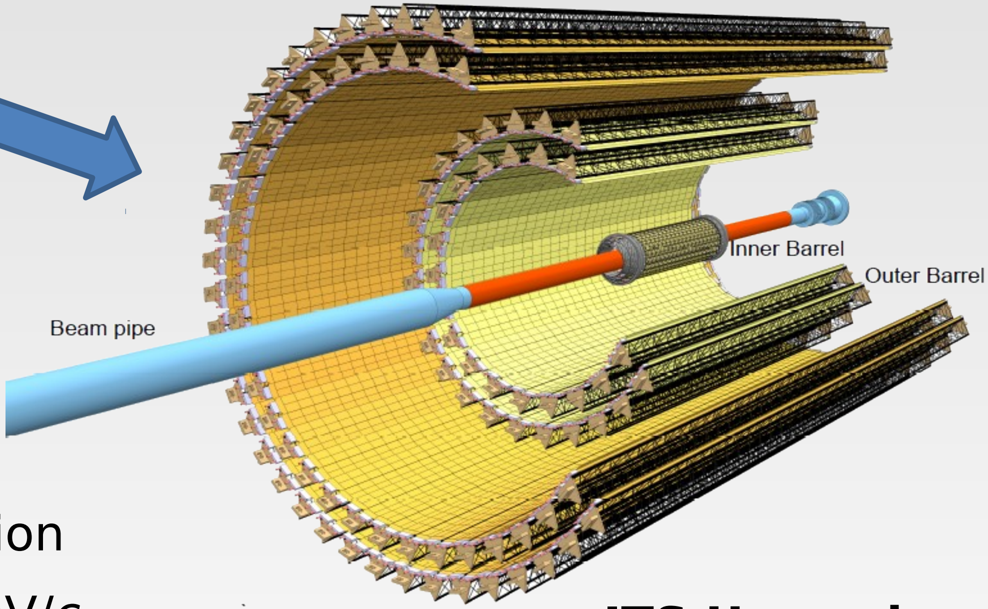
Detector	Input to Online System (GByte/s)	Peak Output to Local Data Storage (GByte/s)	Avg. Output to Computing Center (GByte/s)
TPC	1000	50.0	8.0
TRD	81.5	10.0	1.6
ITS	40	10.0	1.6
Others	25	12.5	2.0
Total	**1146.5**	**82.5**	**13.2**

ITS upgrade



Current ITS

6 layers, 3.9 < R < 43 cm
2xSPD (50x425 µm2) 1.14 % X/X0 per layer
2xSDD (202x294 µm2) 1.3 % …
2xSSD (95x40000 µm2) 0.85% …



Goal

Improved track impact resolution

Extend tracking to p_T< 100 MeV/c

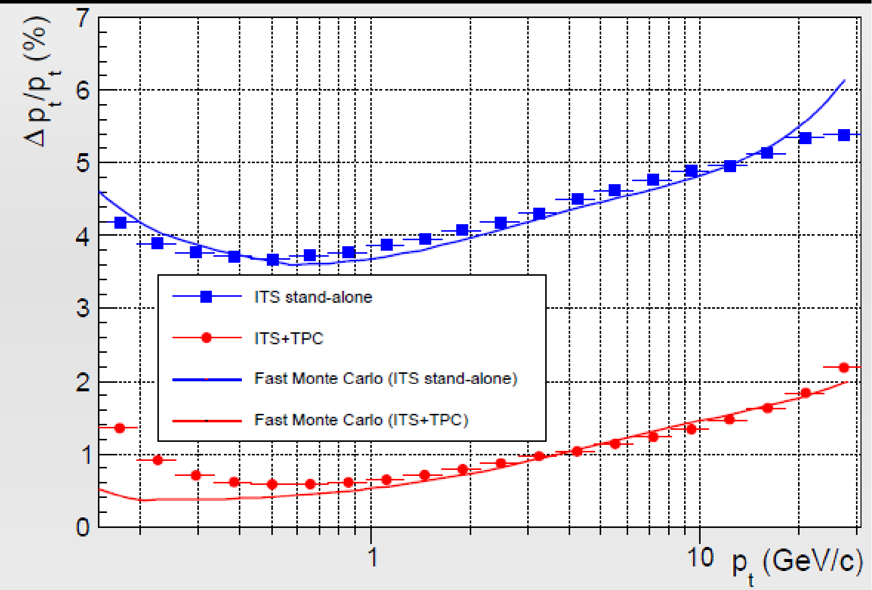
ITS Upgrade

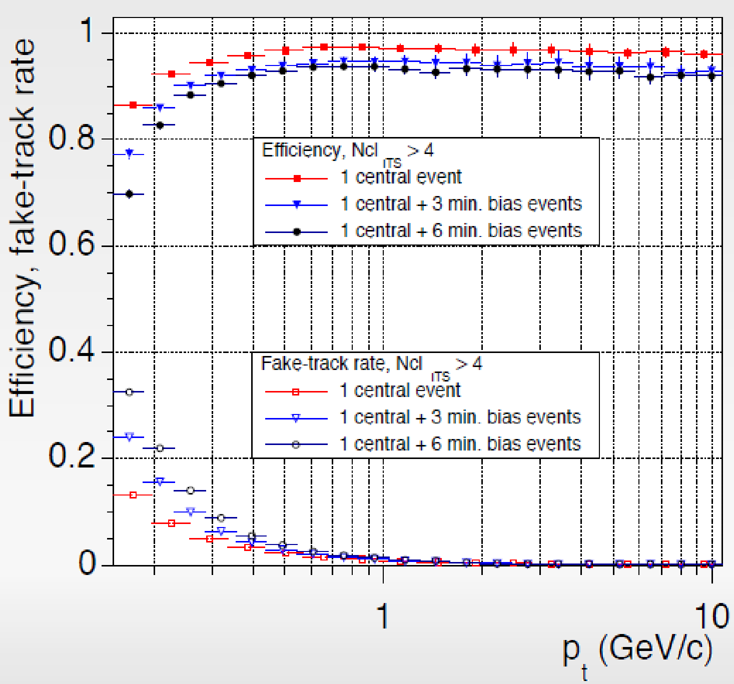
7 layers of pixels (MAPS) of 20-30 µm pitch
2.2 < R < 40 cm
Inner barrel: 0.3% X/X0 per layer
Outer barrel: 0.8% X/X0 per layer

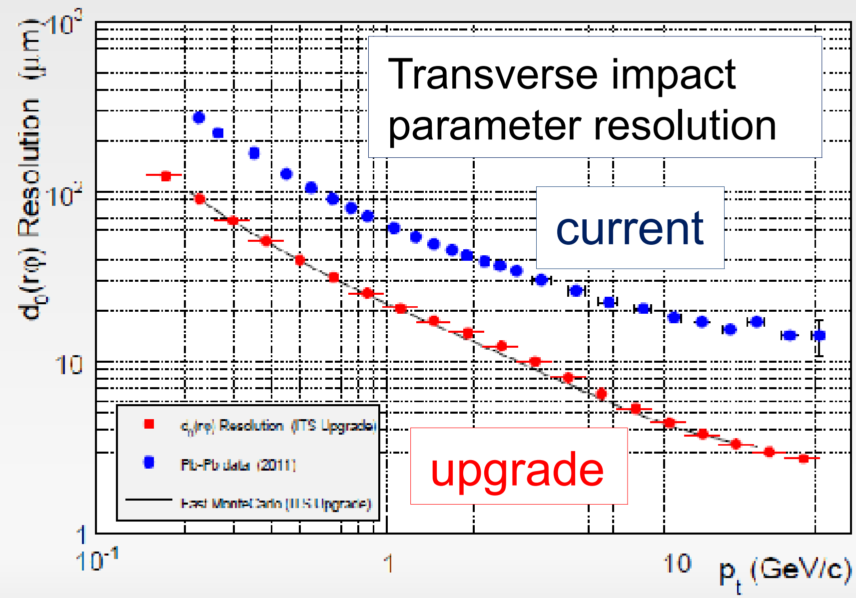
ITS upgrade

Tracking

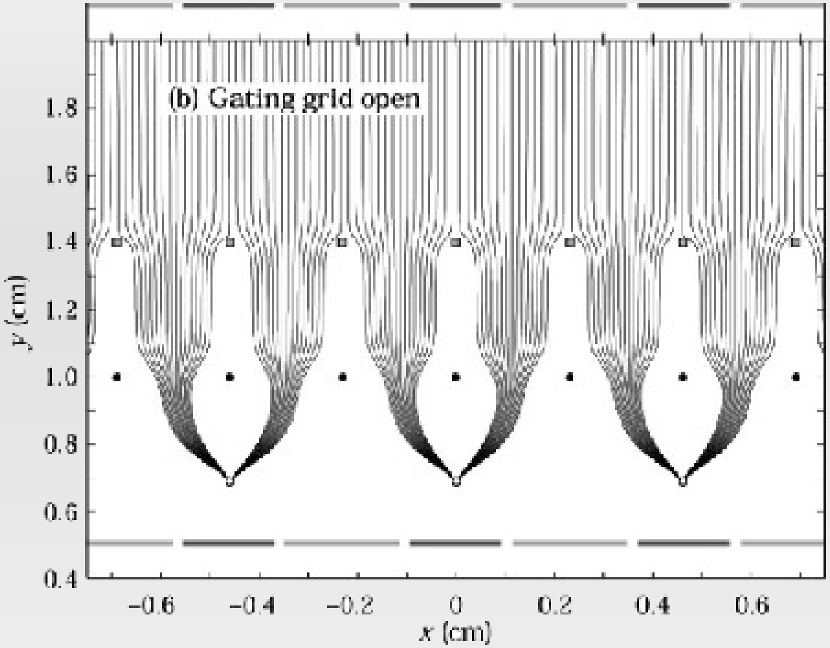
- Analytical tool for performance checks and layout optimization (prototype from STAR)
- Standalone reconstruction: in development (main candidate: CAT based on CBM code)
- Track following with seeds from TPC (used for physics performance studies)

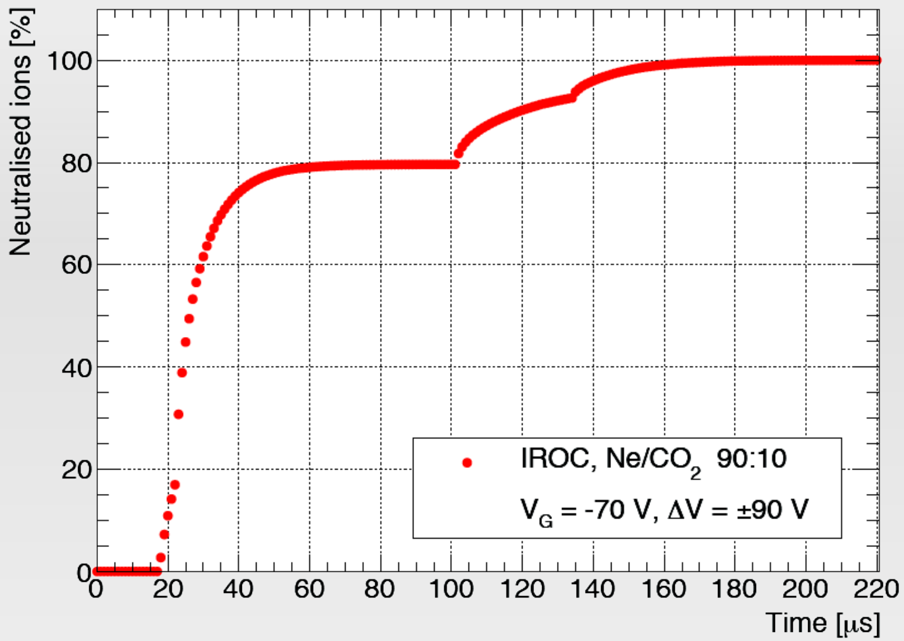






TPC upgrade
Limitations of the present system

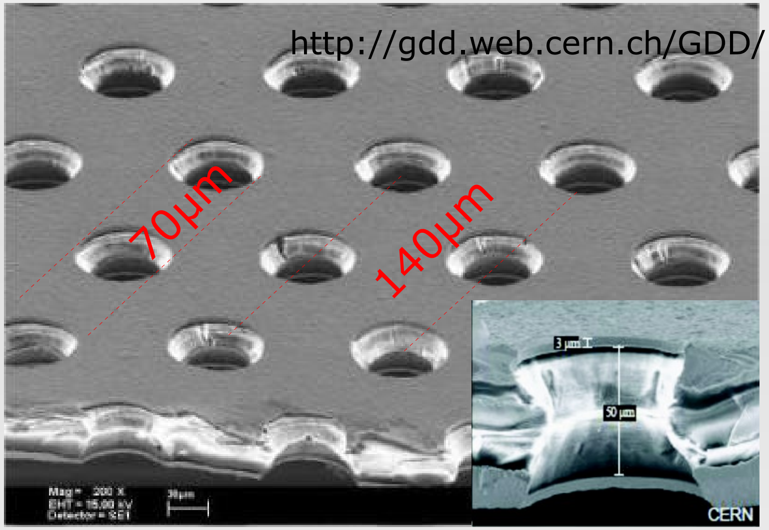


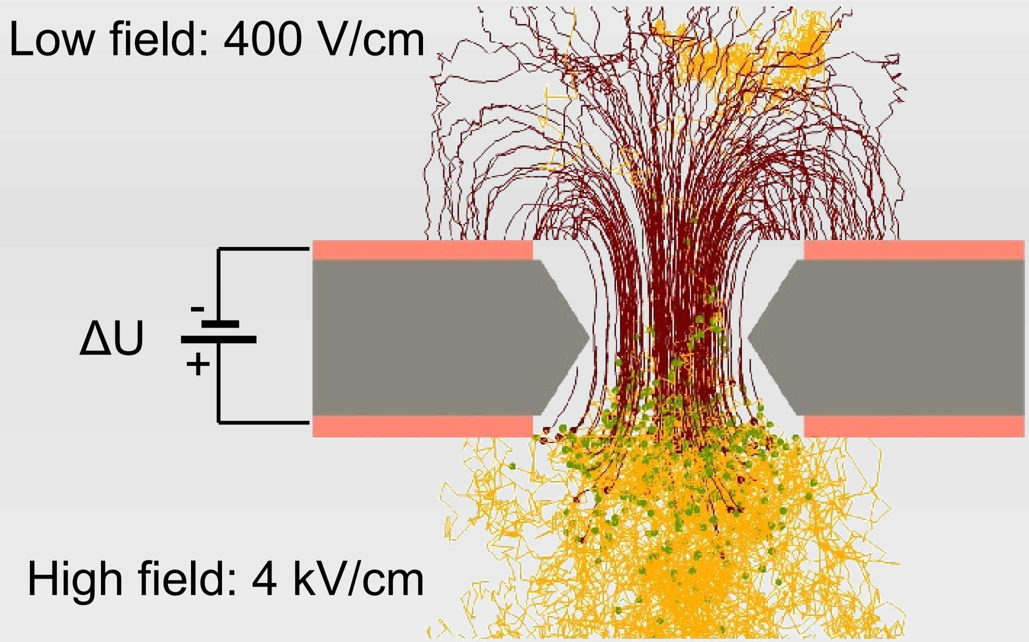


- MWPC with a gating grid (GG) limits operation to ~3.5kHz
- 100μs (electron drift) + 200μs (GG closing – full ion blocking)
  - Otherwise sizeable distortions due to space charge
- Novel technology required: Gas Electron Multipliers
  - Allows for continuous readout

GEM detectors

Working Principle

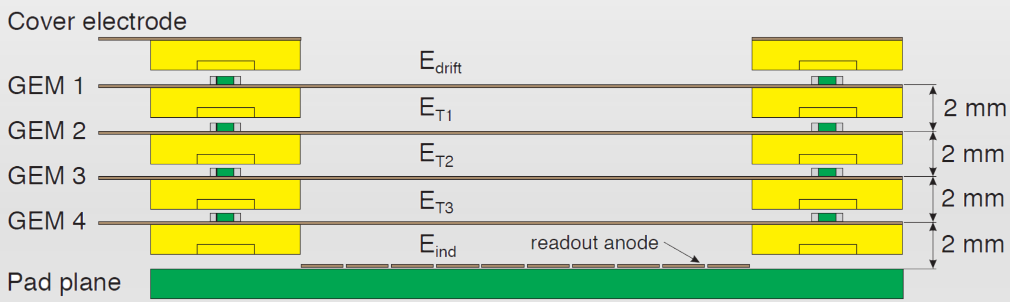




- Gas Electron Multiplier: micro-pattern gas detector
- Holes act as multiplication channels
  - Up to ΔU≈500V
  - Fields up to ~100kV/cm
- Sufficient ion blocking with multi-GEM system

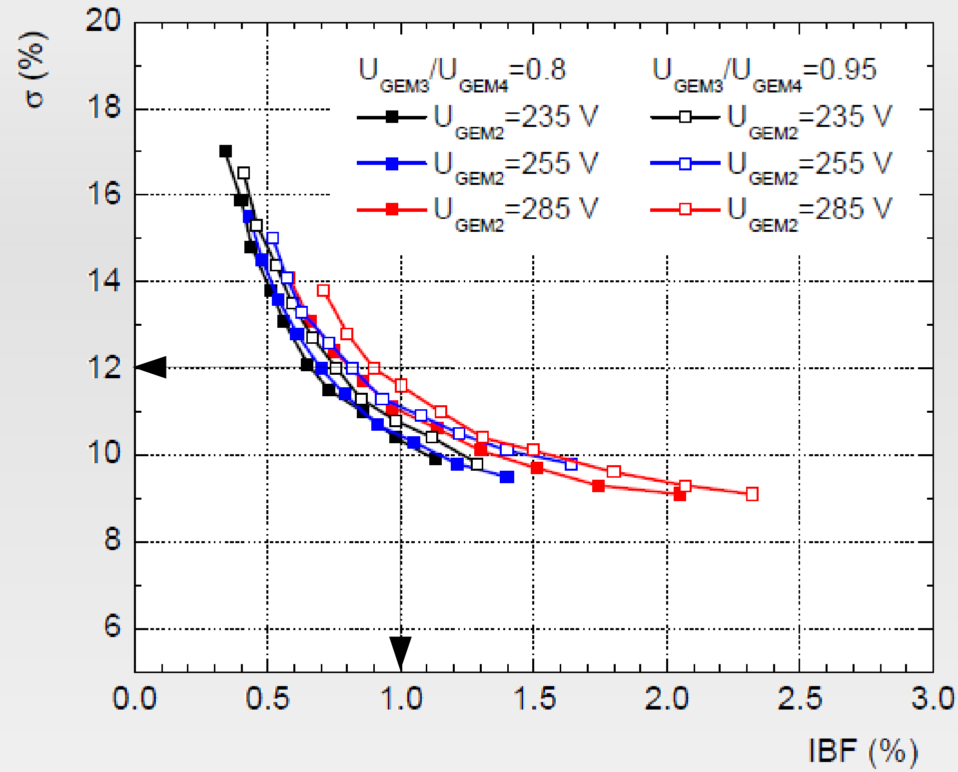
Ion Back Flow (IBF)

Baseline solution: 4-GEM setup



$$n_{tot} = n_{ion} * IBF * G_{eff}$$

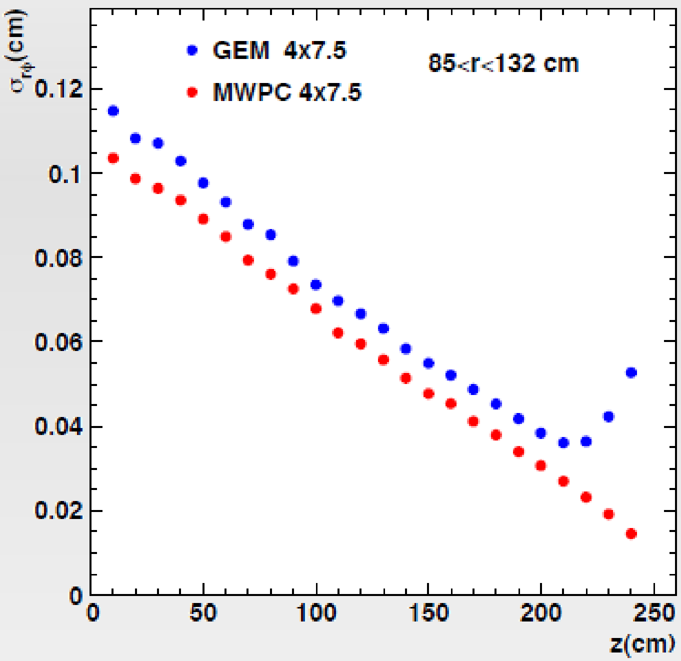
$$\varepsilon = IBF * G_{eff} - 1$$

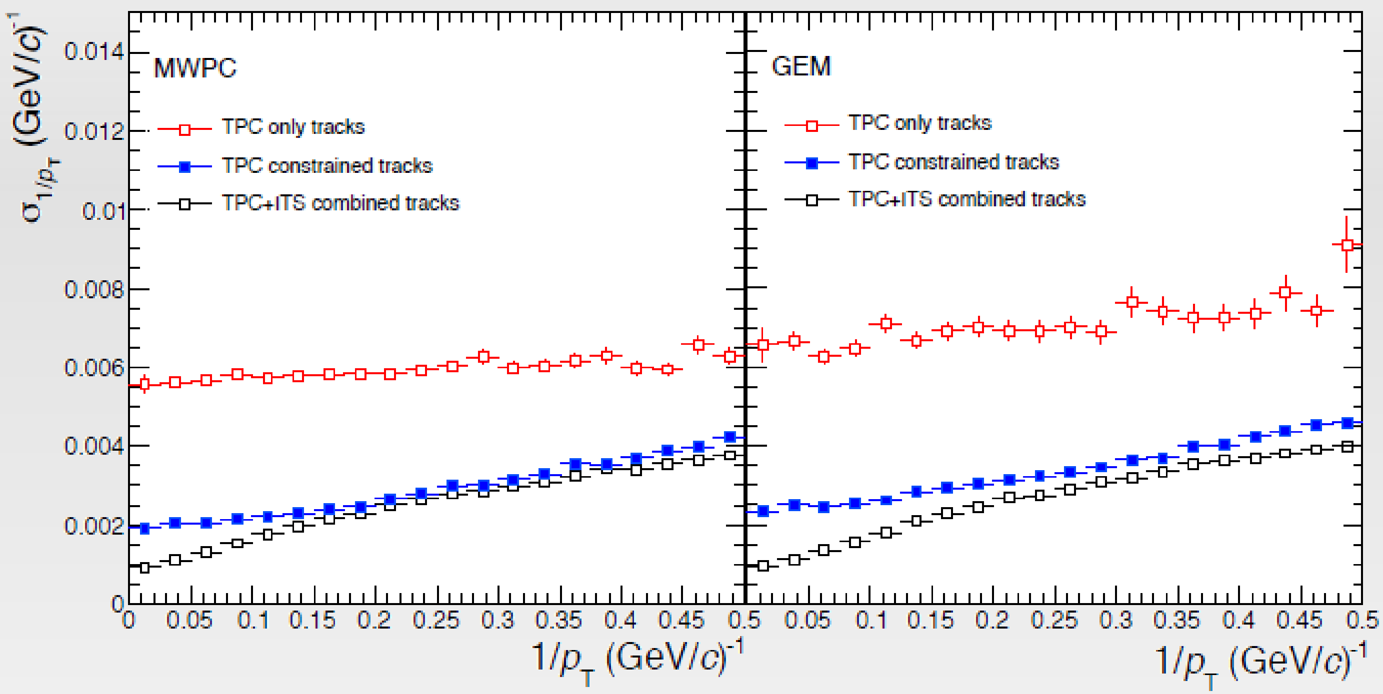


- Ion blocking not as efficient as GG
- Total ions in drift volume (n_{tot}) strongly depending on *IBF*
- Requirements: IBF < 1% & energy resolution (σ) < 12%
- Reached with a 4-GEM setup

Intrinsic performance

Cluster and momentum resolution

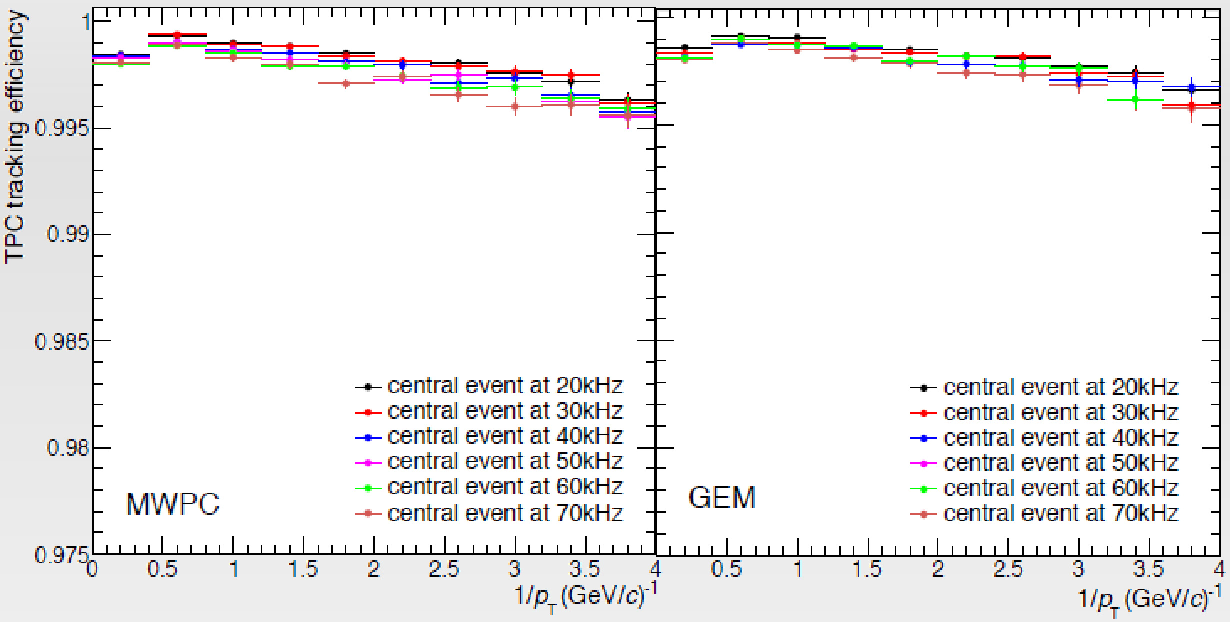


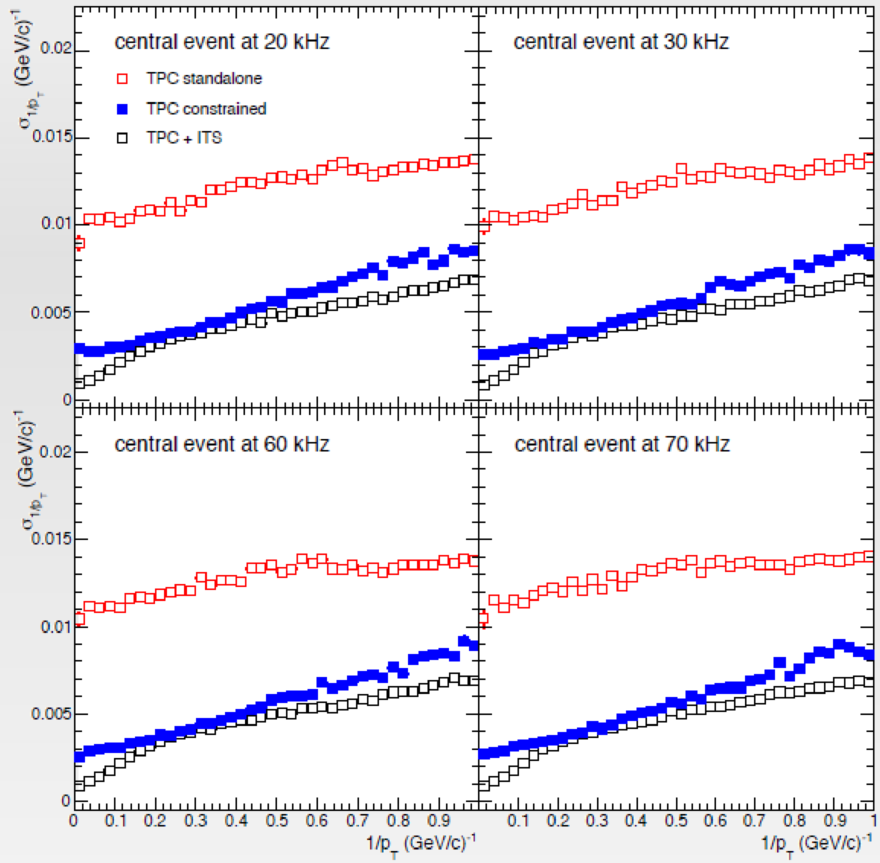


- Full detector simulation (central Pb-Pb event)
- Slightly worse resolution of TPC only tracks (space point resolution)
- Resolution restored matching tracks to the ITS

Performance with pileup

Track reconstruction efficiency and p_T resolution

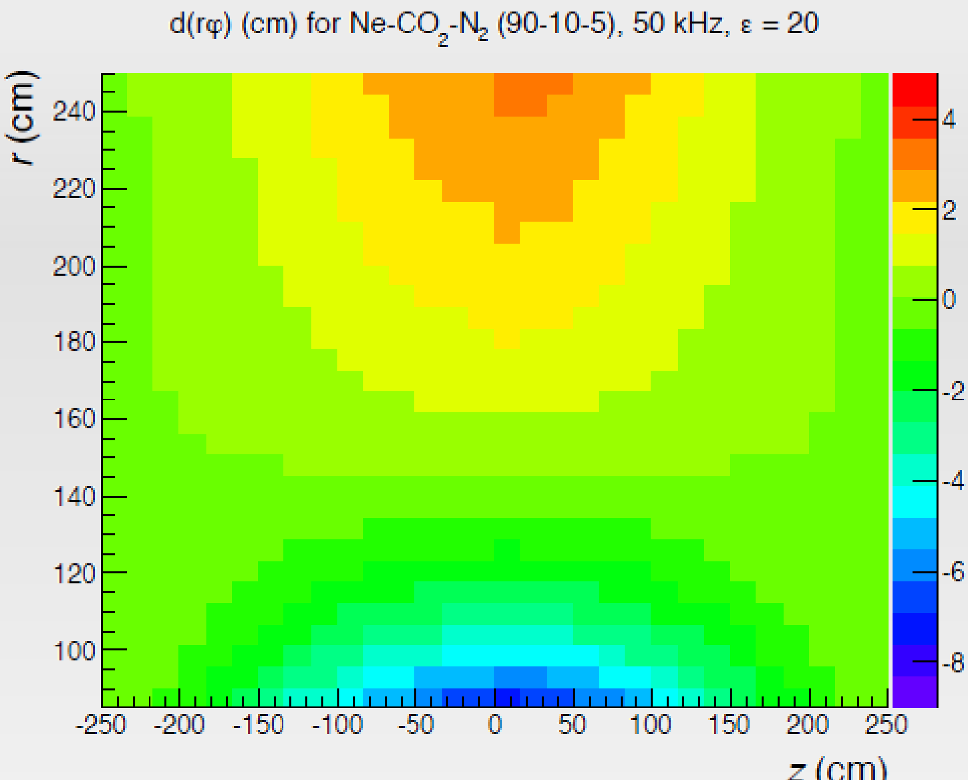


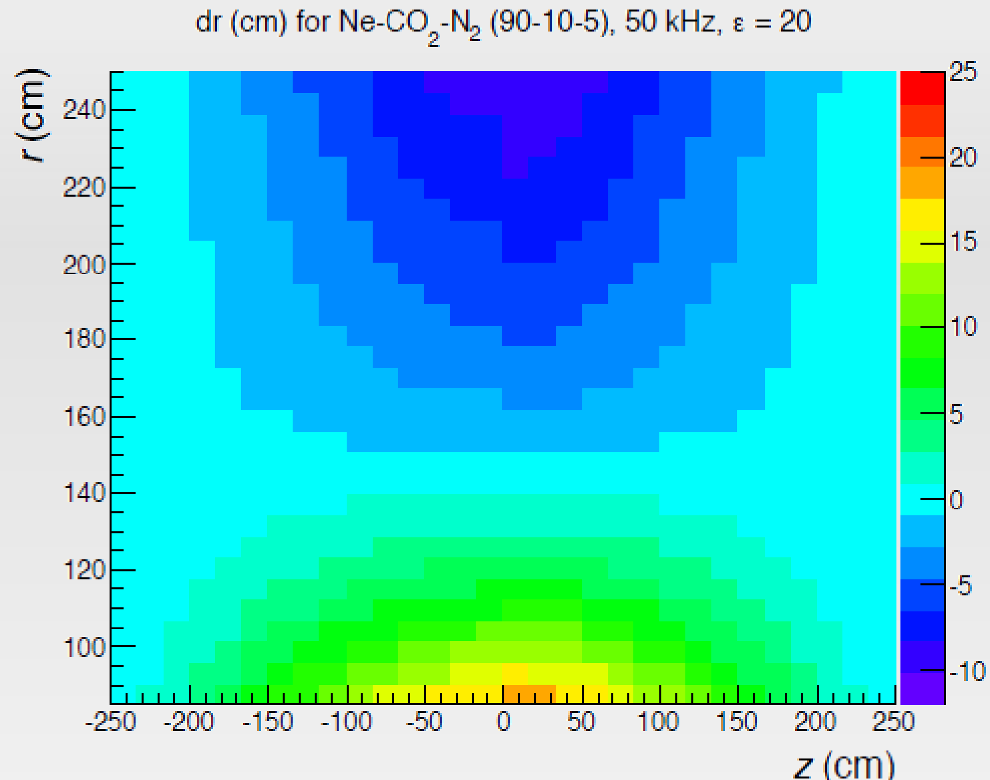


- On average 5 events overlapping @ 50kHz
- Track reconstruction efficiency not significantly affected by pileup + equal performance for MWPC and GEM
- p_T resolution unaffected

Space charge distortions

Magnitude of the distortions

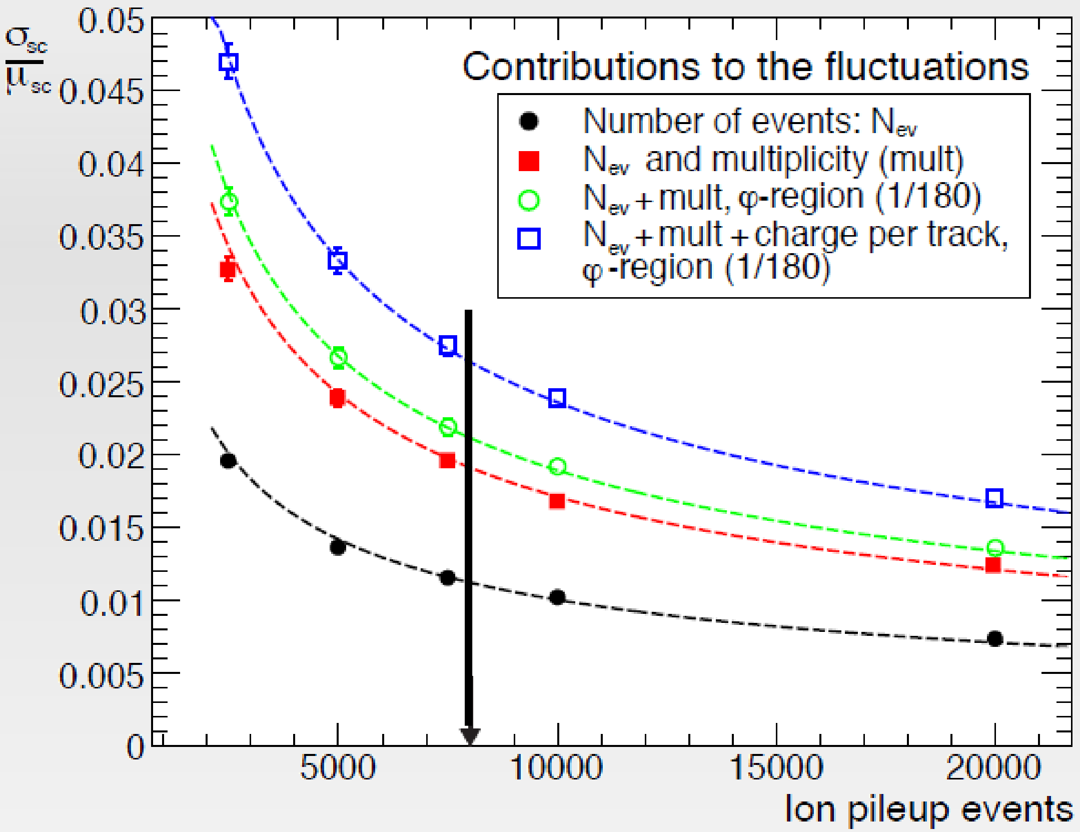




- 50kHz Pb-Pb, gain = 2000, IBF=1% (ε = 20)
  - $t_{d,ion}$ = 160ms → ion pileup from 8000 events
- Distortions up to dr ≈ 20cm d$r\varphi$ ≈ 8cm (small r and z)
  - Final calibration to ~10^{-3} required

Space charge fluctuations

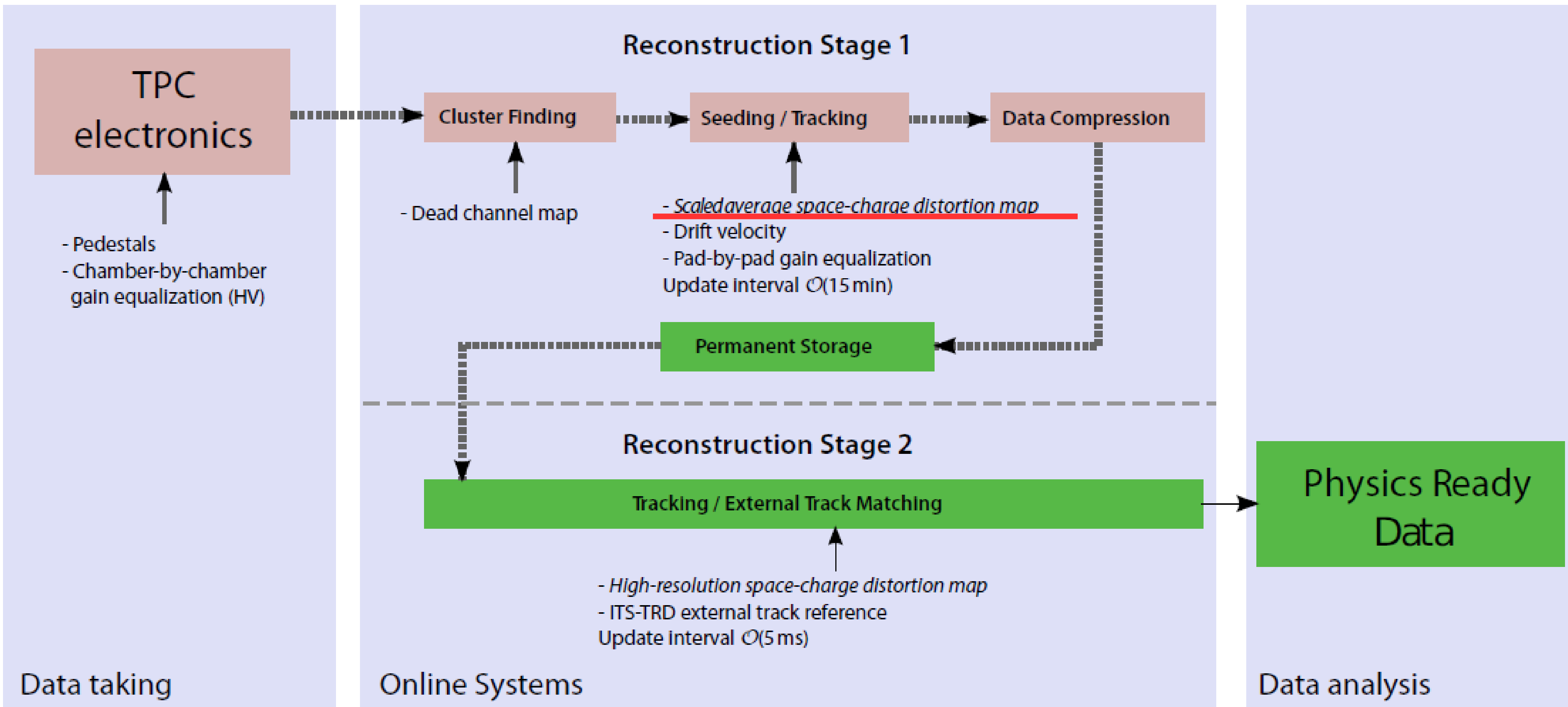
Magnitude of fluctuations



- Space-charge fluctuations at the level of 3%
- With knowledge of the average space-charge density this leads to
  - Max ± 6mm residual distortion in *r*
  - Max ± 2.5mm residual distortion in *rφ*

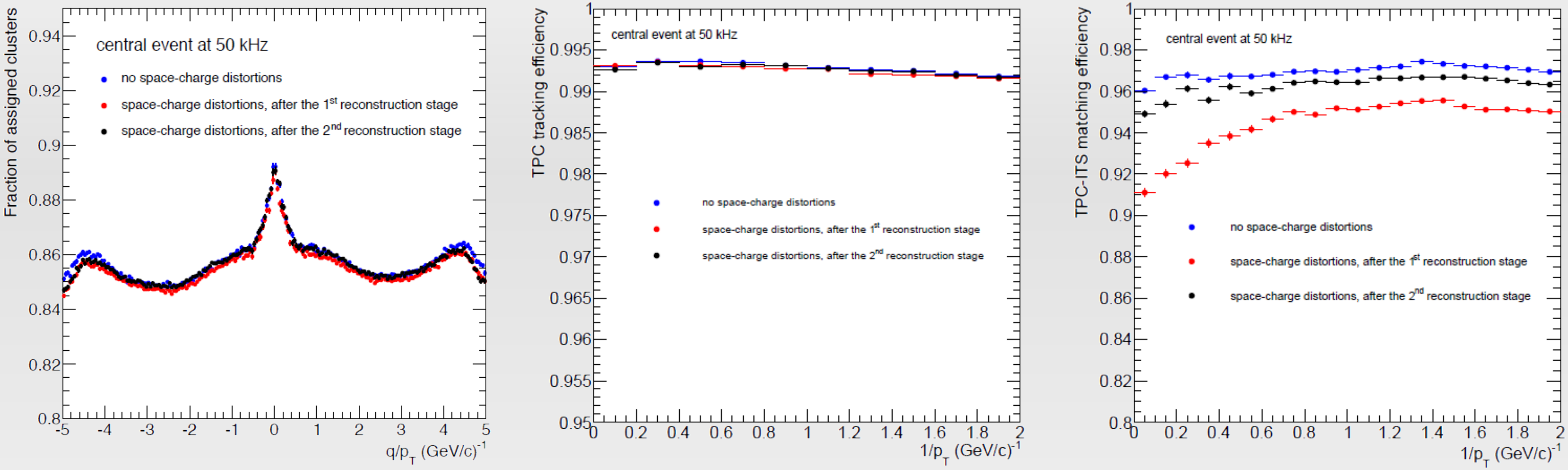
- Space-charge fluctuations are dominated by event and multiplicity fluctuations
- Sets constraints on the update interval for the final calibration: O(5ms)

Reconstruction strategy



Performance with distortions

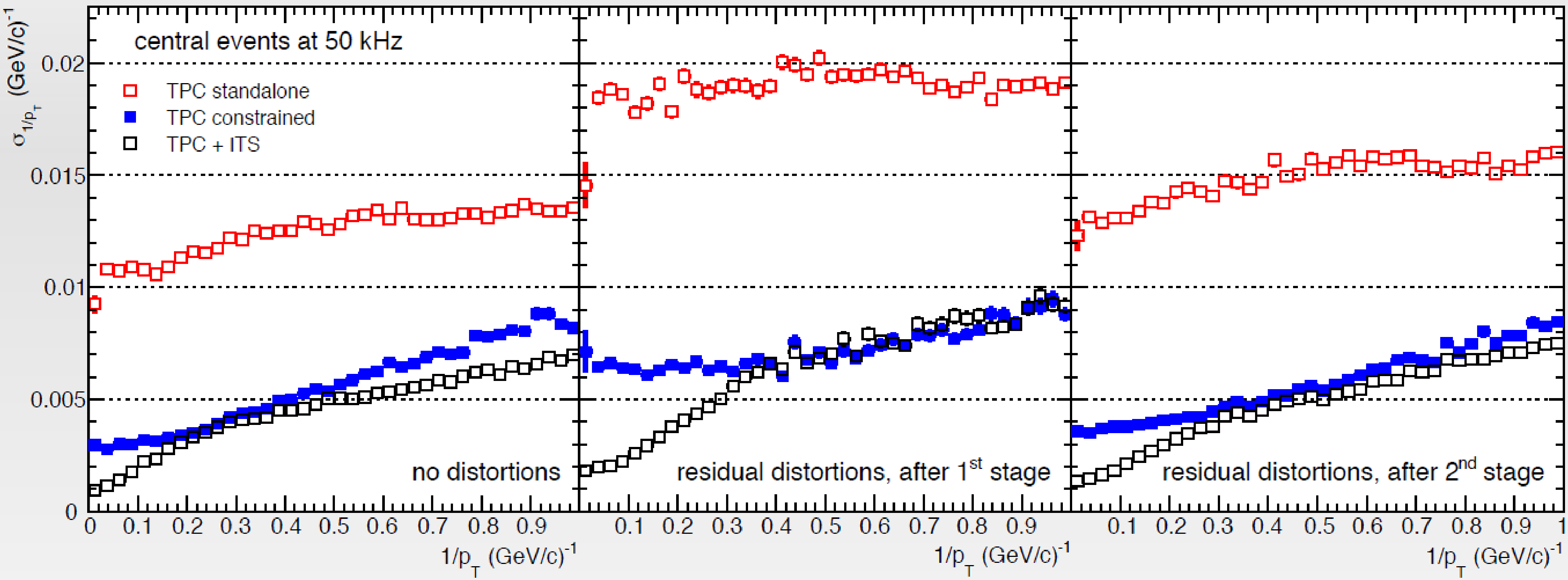
Cluster finding, tracking and matching



- Cluster finding and tracking efficiency not modified by residual SC distortions
  - Even in the 1st stage with a scaled average correction map
- Matching eff. after 2nd stage close to ideal case w/o distortions
  - Will be fully restored with a better tuning of the algorithm

Performance

Momentum resolution



- Momentum resolution for tracks matched with the ITS practically restored after 2nd reconstruction stage

Continuous readout

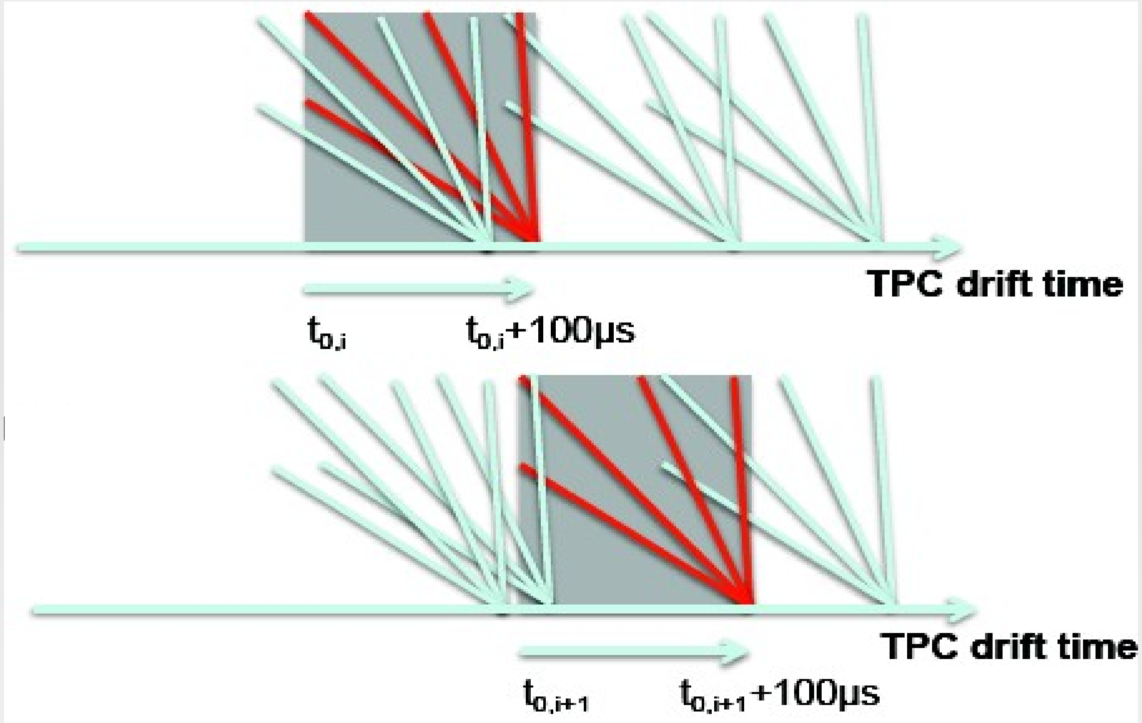
Implications and treatment of space-point corrections

$$\vec{r}_{\mathrm{cls}} = \vec{r}_{\mathrm{ro}} + \int_0^{-t_d} \vec{v}_{\mathrm{d}}(x, y, z)\,\mathrm{d}t$$

- Space-point reconstructions requires
  - Drift-velocity, $\vec{v}_{\mathrm{d}} = (0, 0, v_{\mathrm{d}})$ (ideal case – no distortions)
  - Drift-time, $t_{\mathrm{d}} = t_{\mathrm{digit}} - t_0$
- $\vec{r}_{\mathrm{cls}} = (x_{\mathrm{ro}}, y_{\mathrm{ro}}, z_{\mathrm{roc}} - v_{\mathrm{d}} t_{\mathrm{d}})$ – no distortions
- In continuous readout mode, t_0 not known a priori
- Distortions treated as effective corrections
  - $\vec{r}_{\mathrm{cls}} = (x_{\mathrm{ro}}, y_{\mathrm{ro}}, z_{\mathrm{ro}}) + \vec{\Delta}(x_{\mathrm{ro}}, y_{\mathrm{ro}}, z_{\mathrm{ro}})$ → requires t_0!

Tracking approaches

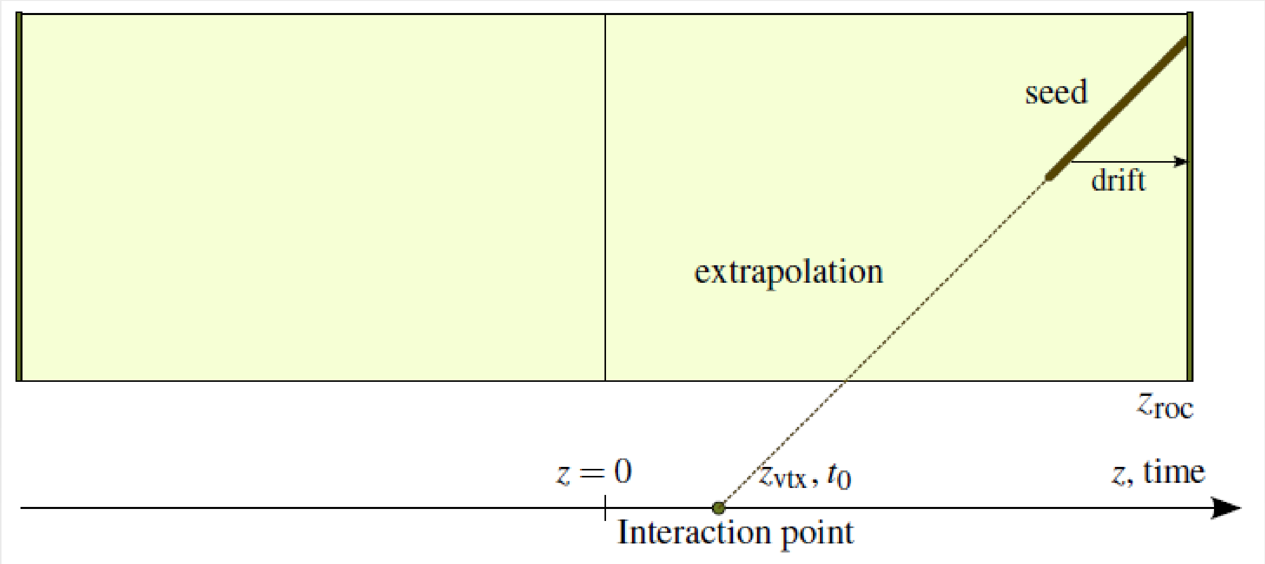
Straight forward reconstruction



- Scan all $t_{0,i}$ in current TPC drift time → external detector
- Apply SCD corrections to all clusters
  - clusters from central interaction will be corrected properly, others are background)
- SCD corr. applied multiple times → Computation issue

Tracking approaches

TPC standalone tracking



- Seeding in region with small distortions (ad-hoc SCD corr.)
- Extrapolation to x=y=0 → t_0 estimate: better SCD corr.
- Track following → Modify search road with SCD estimate
- Clusters corrected once (fast)
- TPC only information (robust)

Tracking approaches

Further ideas

- Modification of the tracking model
  - Inclusion of t_0
  - Inclusion of the the distortions
- Separate algorithms
  - Fast cluster to track association: Simple helix model
  - Best performance: refit with Kalman-Filter

Summary: ITS upgrade

ITS upgrade provides major improvements

- Lower material budget
  - better track pointing and secondary vertex resolution
  - improved low-p_T reach
- Better intrinsic resolution
  - improved double track resolution
- ITS upgrade TDR (CERN-LHCC-2013-024)

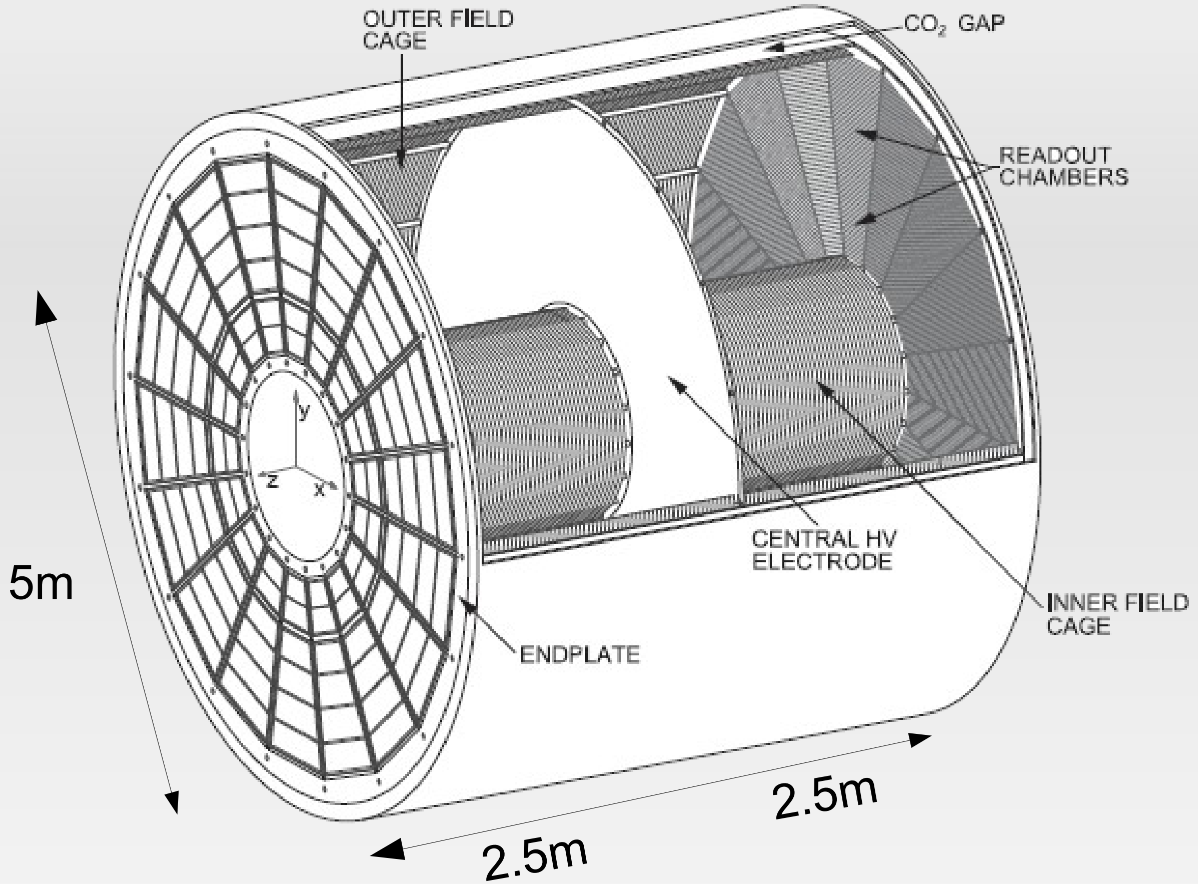
Summary: TPC upgrade

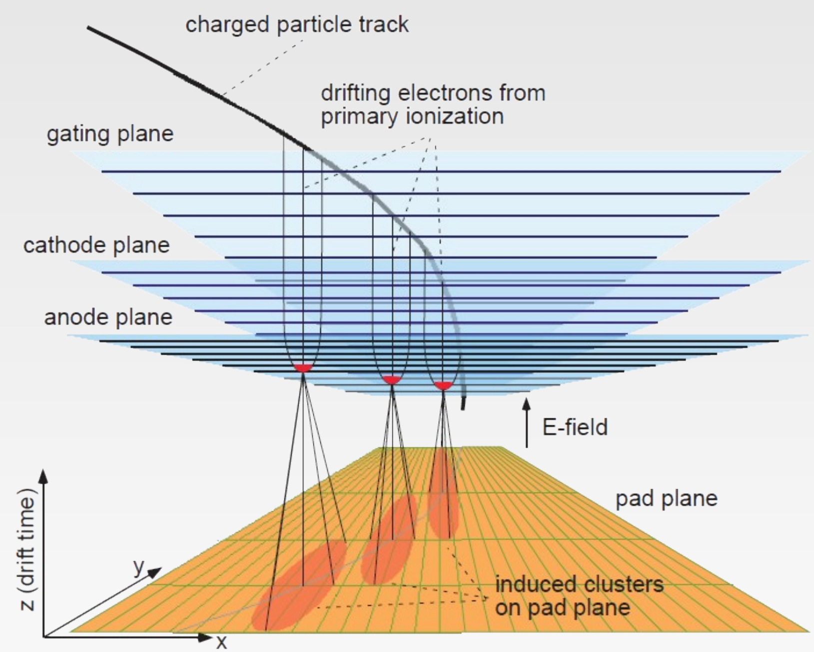
- TPC data taking at 50kHz Pb–Pb possible using a 4-GEM system
- Major challenges in calibration/reconstruction
  - Continuous readout → Interaction time estimate
  - Fast online reconstruction to perform compression
  - Large distortions due to space-charge (20cm max.)
  - Pile-up: ~5 events overlapping
  - Update of calibration for data in 5ms
- TPC upgrade TDR (CERN-LHCC-2013-020)

Backup

The ALICE detector

Time Projection Chamber



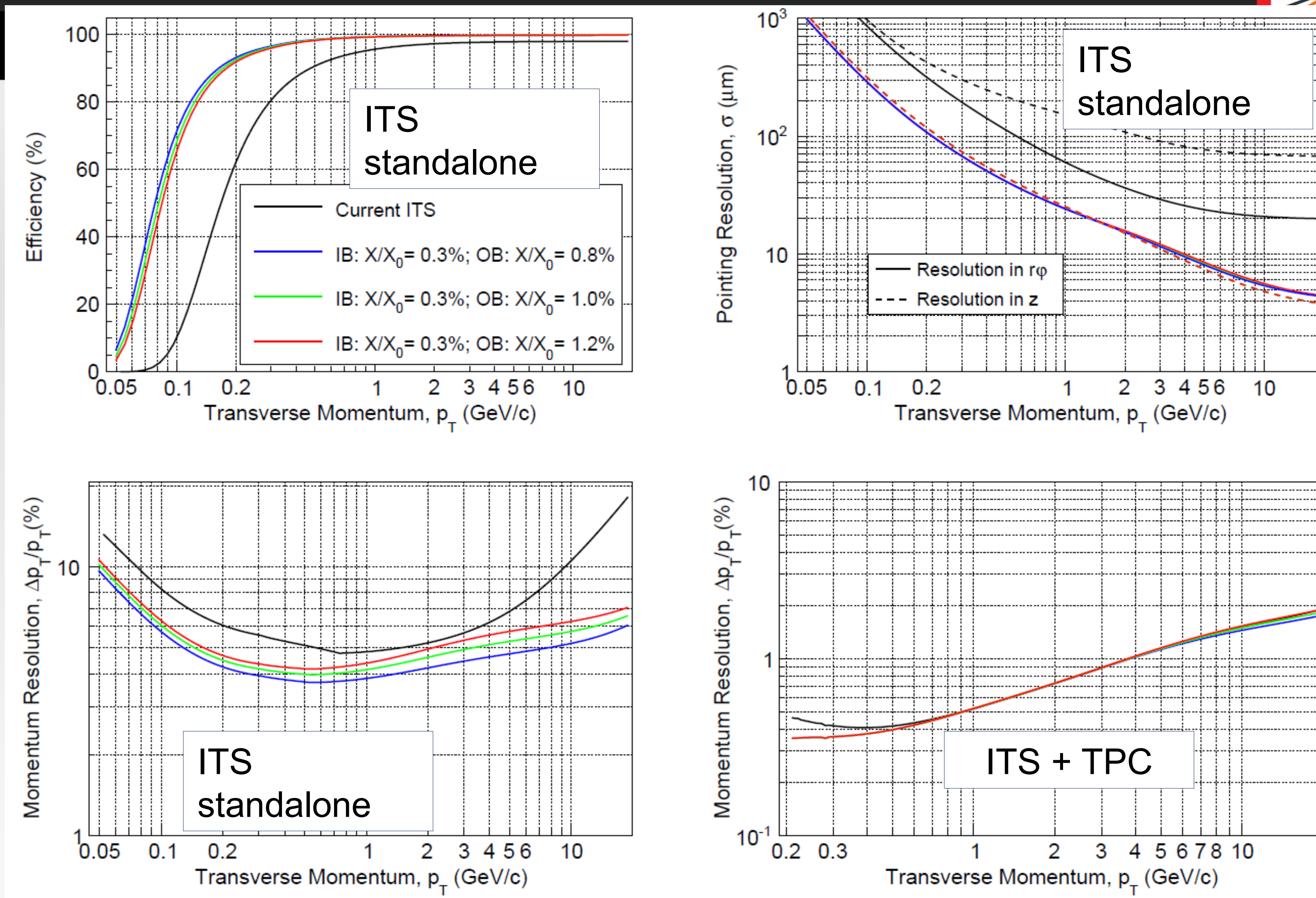


Volume: ~ $90m^3$

Gas: $Ne\text{-}CO_2\text{-}N_2$ (90-10-5)

Drift voltage: 100kV, 94µs drift time

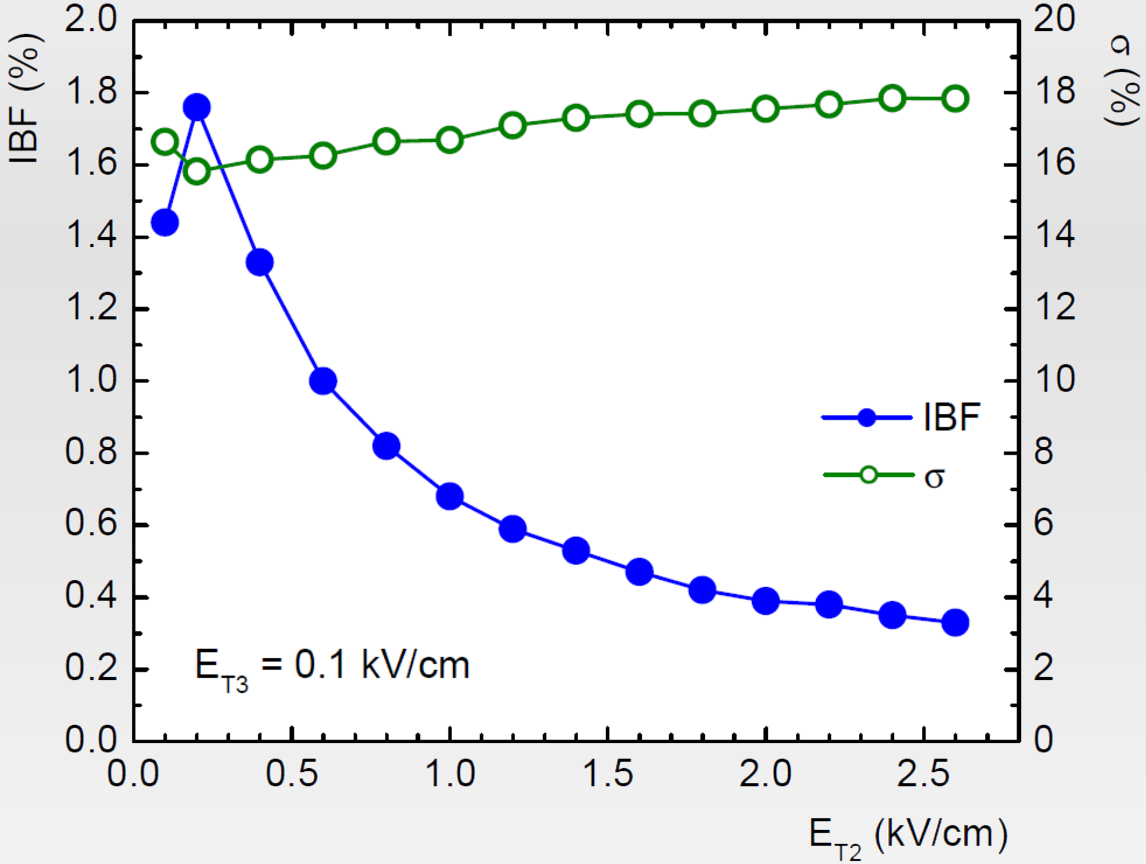
72 MWPCs with 557768 readout pads

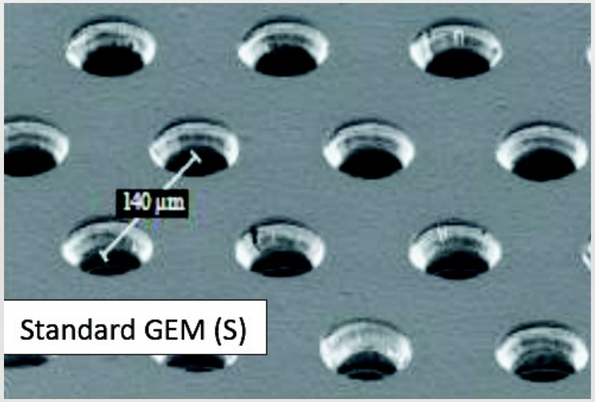


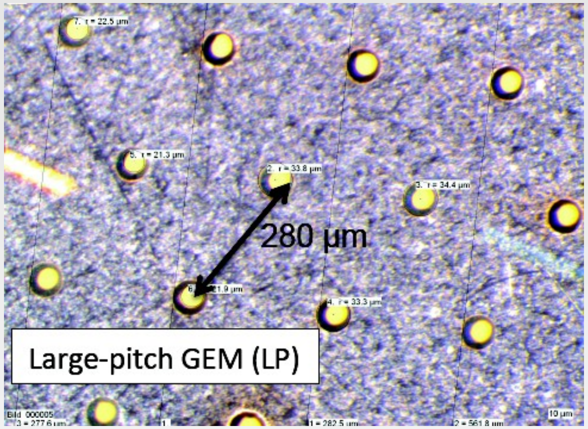
Performance for different material-budget options for the upgraded detector compared with current ITS

IBF optimisation

4 GEM system – S-LP-LP-S



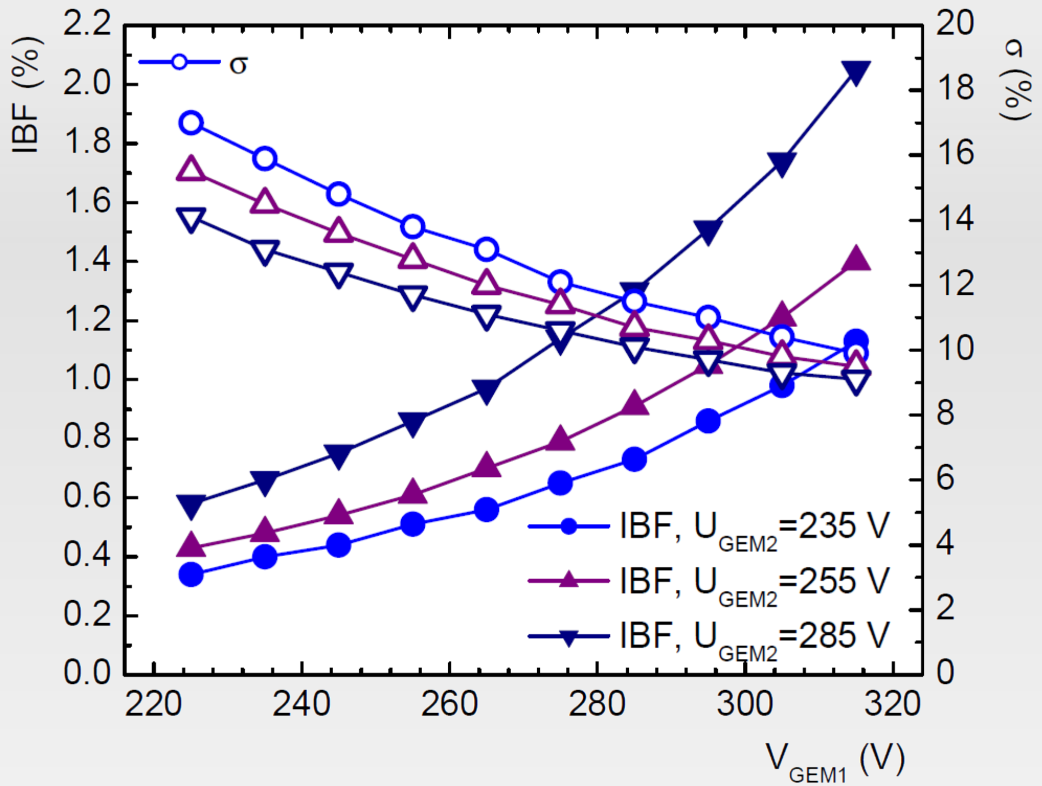


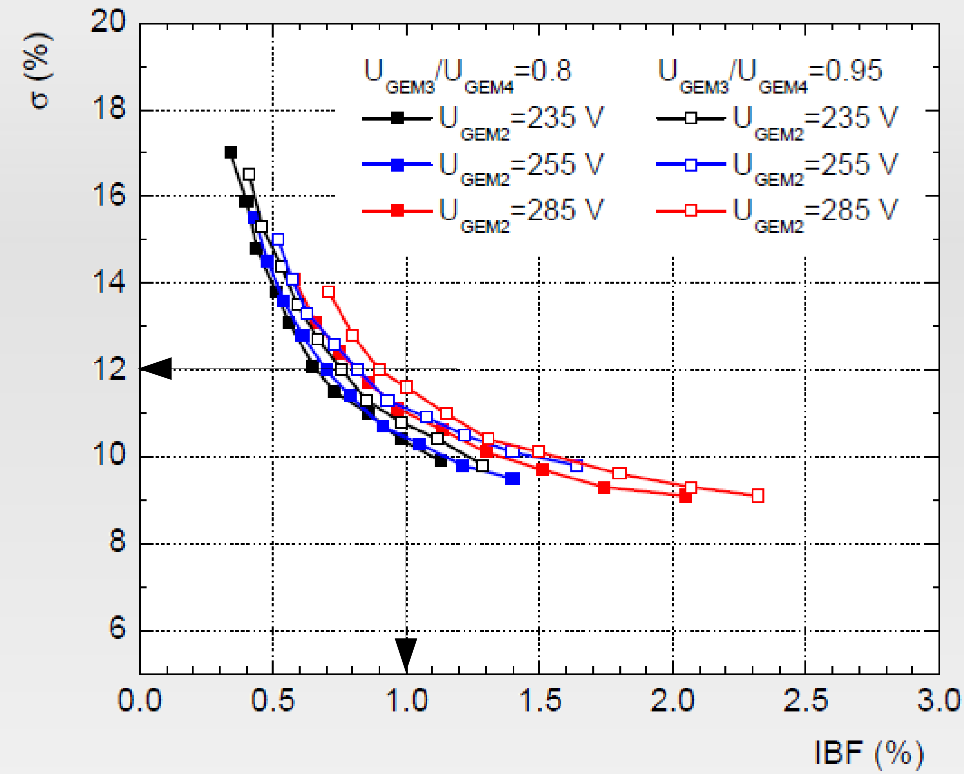


- 4 GEM S-LP-LP-S system allows for IBF < 1%
- Additional requirement: Energy resolution (σ)
  - → Small σ required for efficient PID

IBF optimisation

4 GEM system – S-LP-LP-S

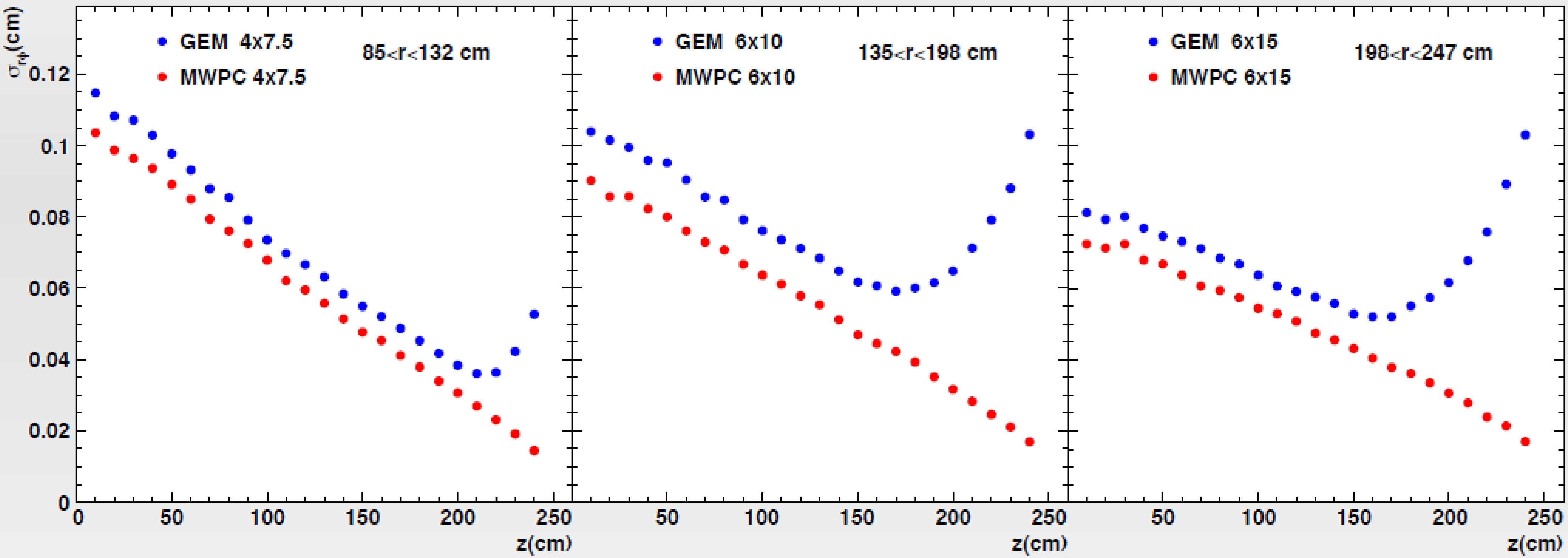


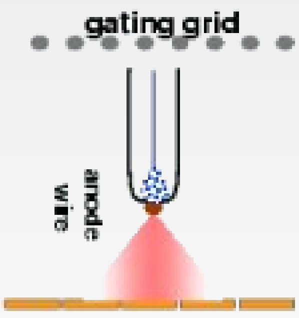


- Requirements: IBF < 1% & energy resolution (σ) < 12%
- Large parameter space available
  - → Allows for further optimisation

Intrinsic performance

Space point resolution

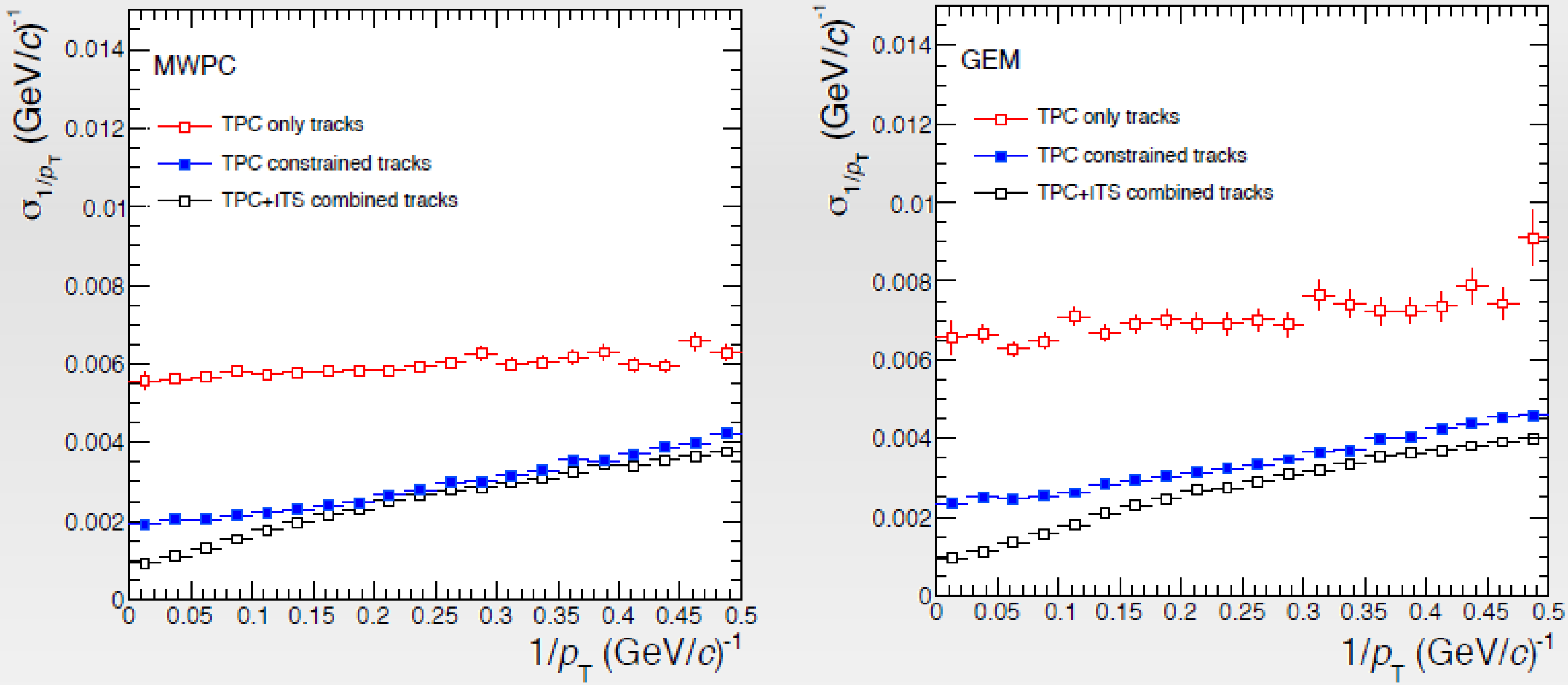




- Optmised Pad Response Function for MWPCs
- PRF of GEMs very narrow → diffusion helps to spread signal over several pads
- Slightly worse overall resolution with GEMs

Intrinsic performance

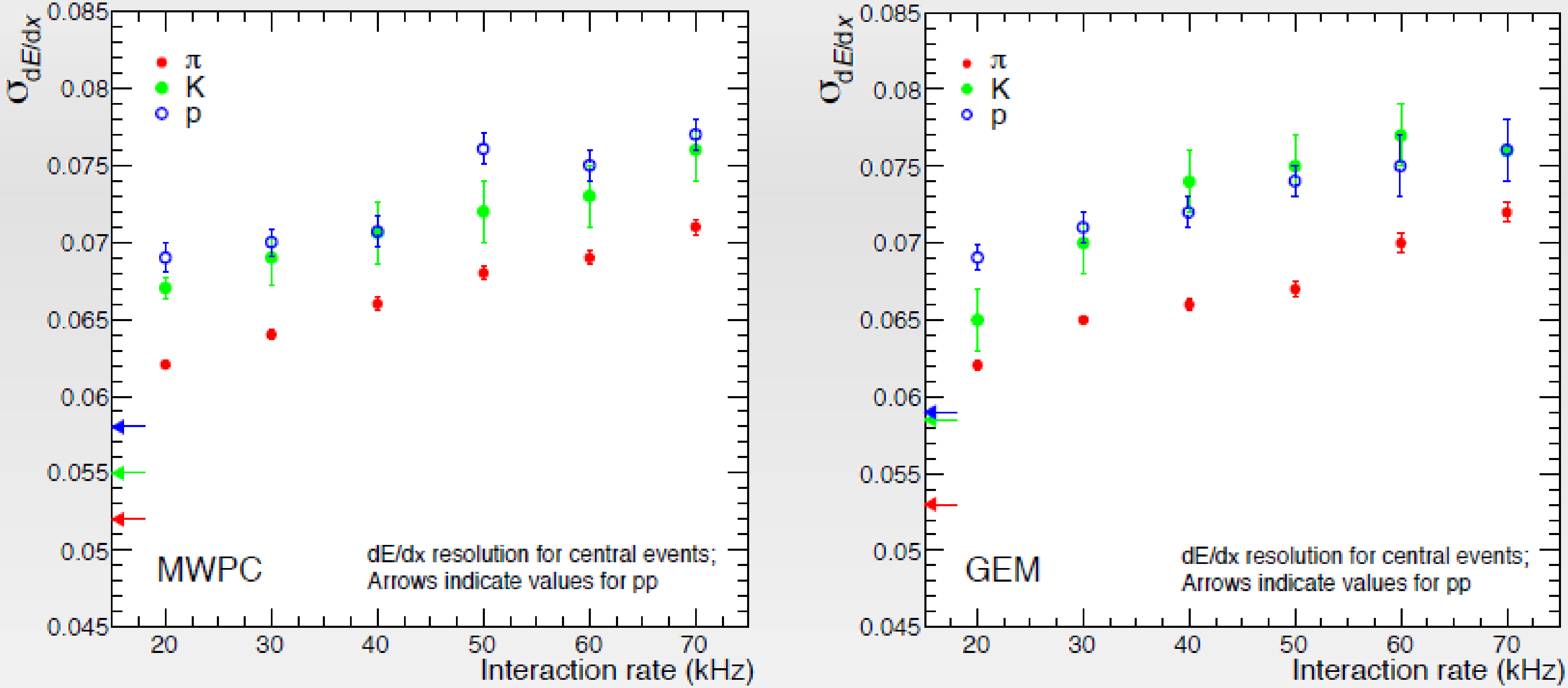
Momentum resolution



- Full detector simulation (central Pb-Pb event)
- Slightly worse resolution of TPC only tracks (space point resolution)
- Resolution restored matching tracks to the ITS

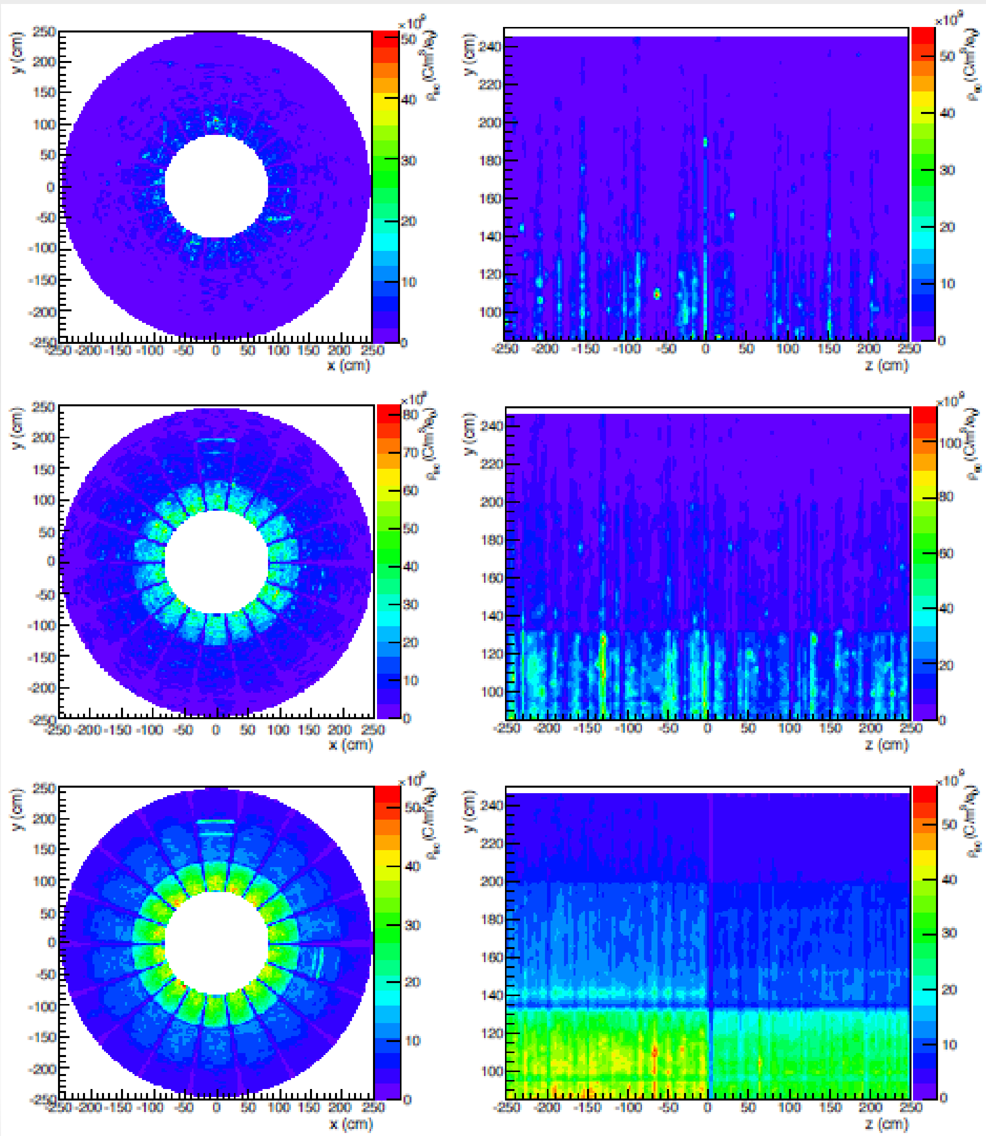
Performance with pileup

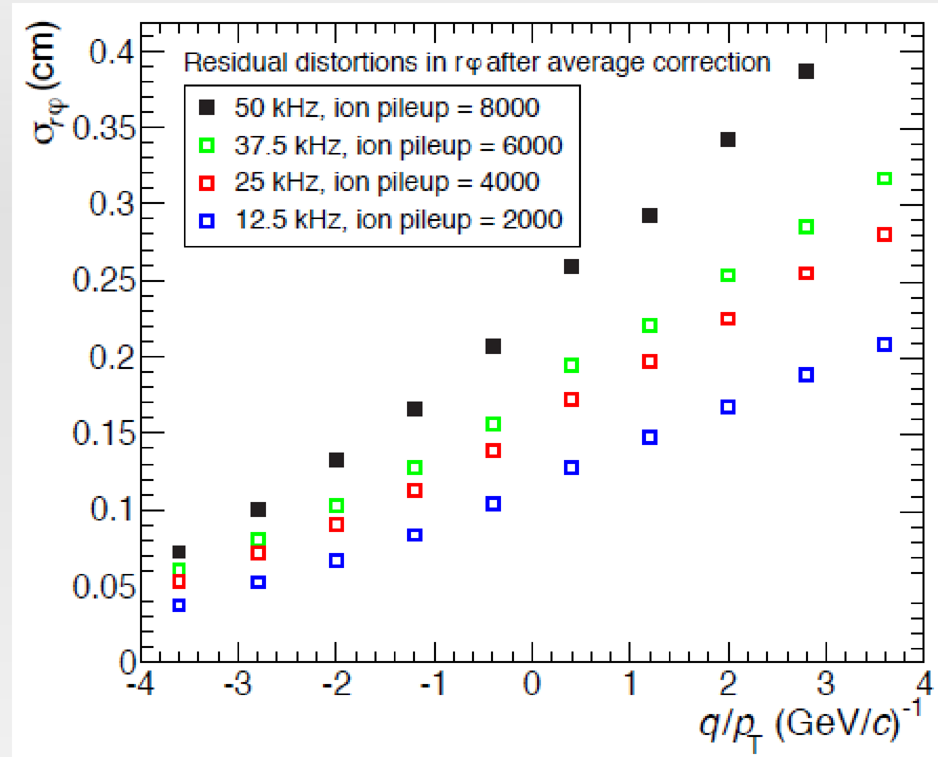
dE/dx resolution

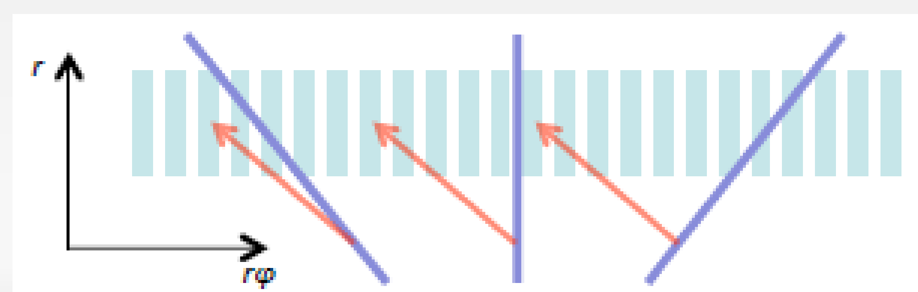


- Moderate worsening with increasing pileup (cluster merging)
- No difference between MWPC and GEM system

Space charge fluctuation

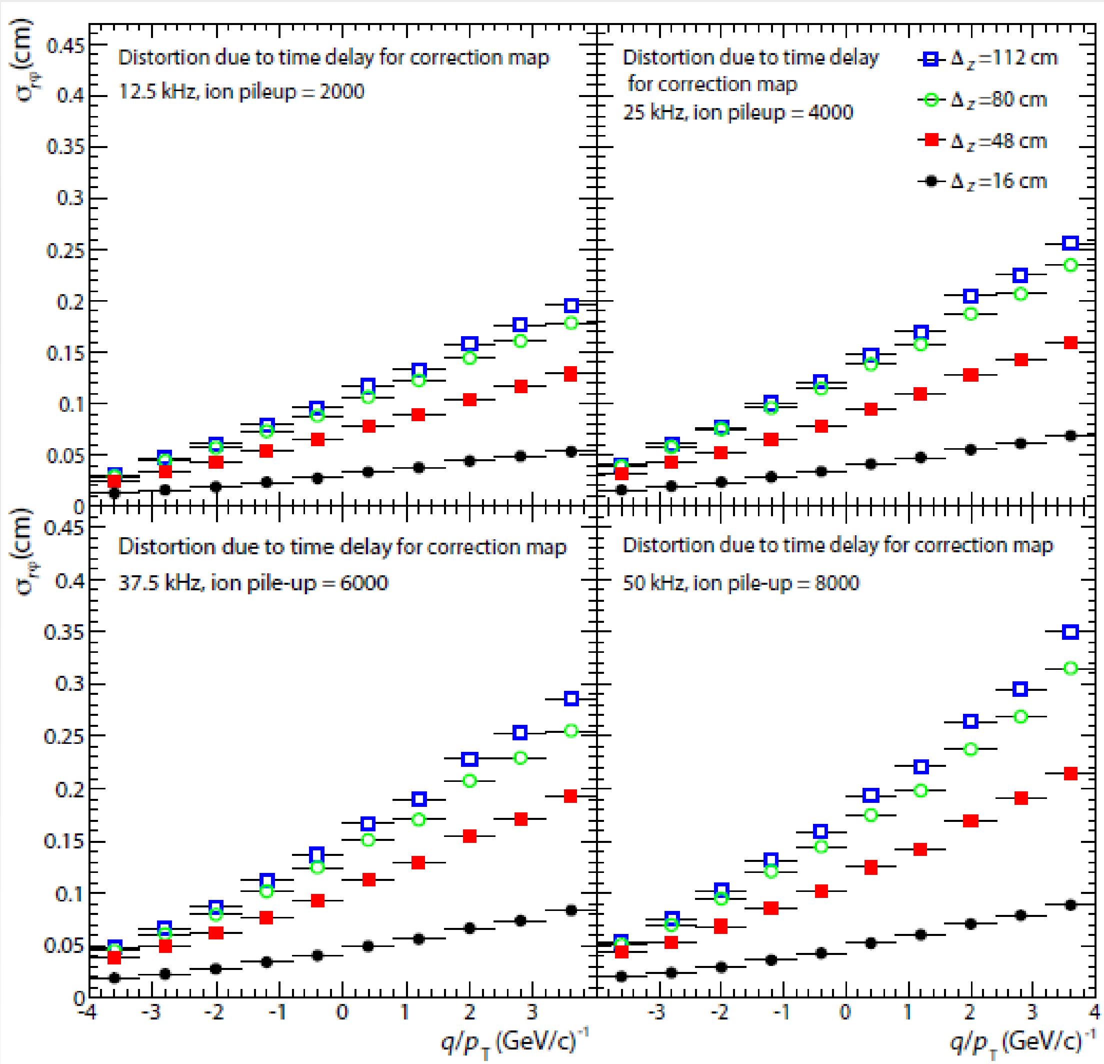






Space-charge fluctuation

Required update interval



Implications for the TPC

High rate operation

- High interaction rate: 50kHz
- New detector technology required
  - Allows for continuous readout
  - Results in space-point distortion due to space charge
- Huge data rate
  - Requires online compression
  - Sufficient suppression only feasible with online reconstruction
- Several events piling up in the TPC
  - Efficient reconstruction algorithm