2023 international workshop on the high-energy Circular Electron Positron Collider （CEPC）

The upgraded TPC for ALICE in LHC Run 3

Xiaozhi Bai

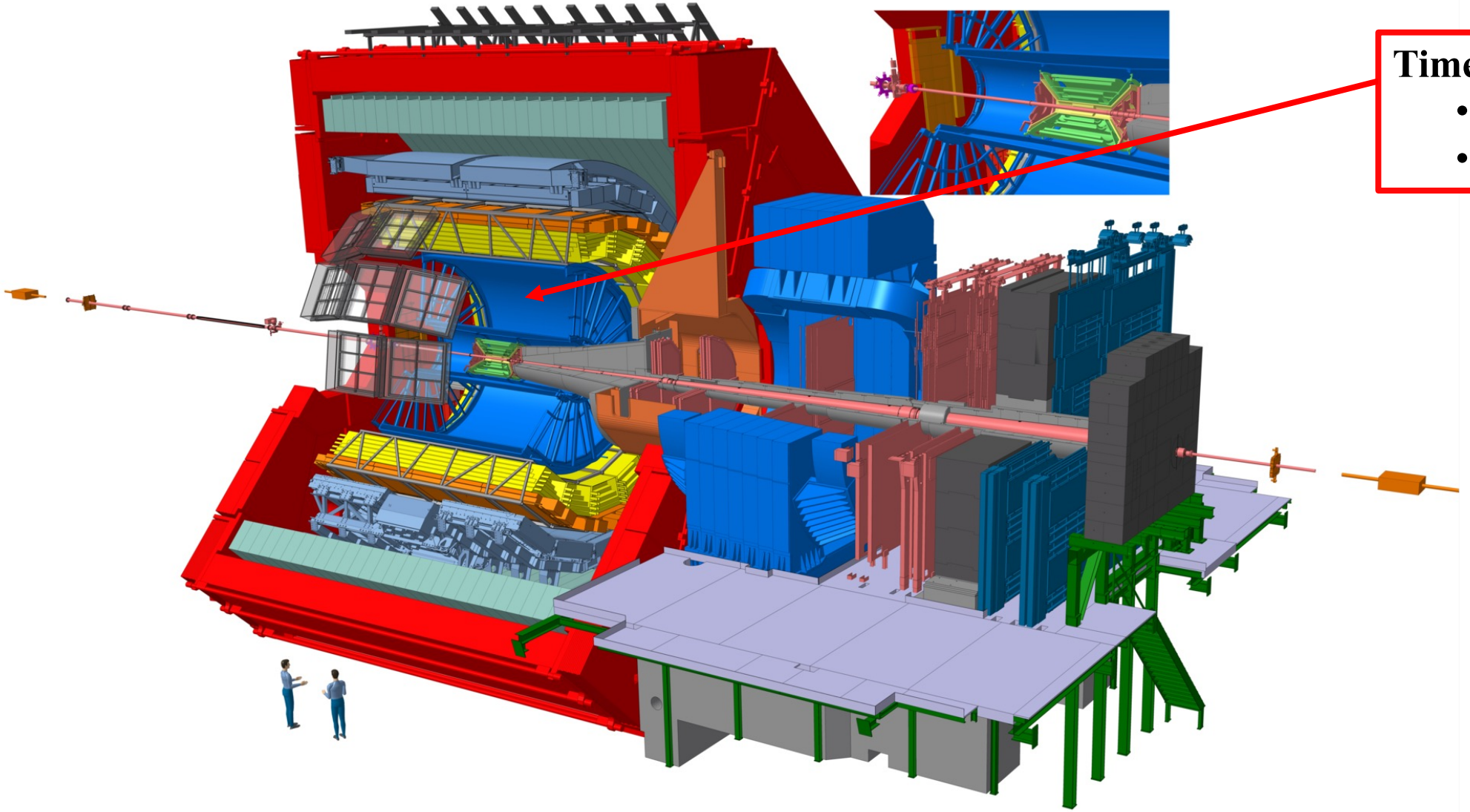
University of Science and Technology of China

Nanjing, 10.25.2023

ALICE@LHC

ALICE is optimized to study the collisions of nuclei at the ultra-relativistic energies provided by the LHC. The aim is to study the physics of strongly interacting matter, called the quark-gluon plasma.

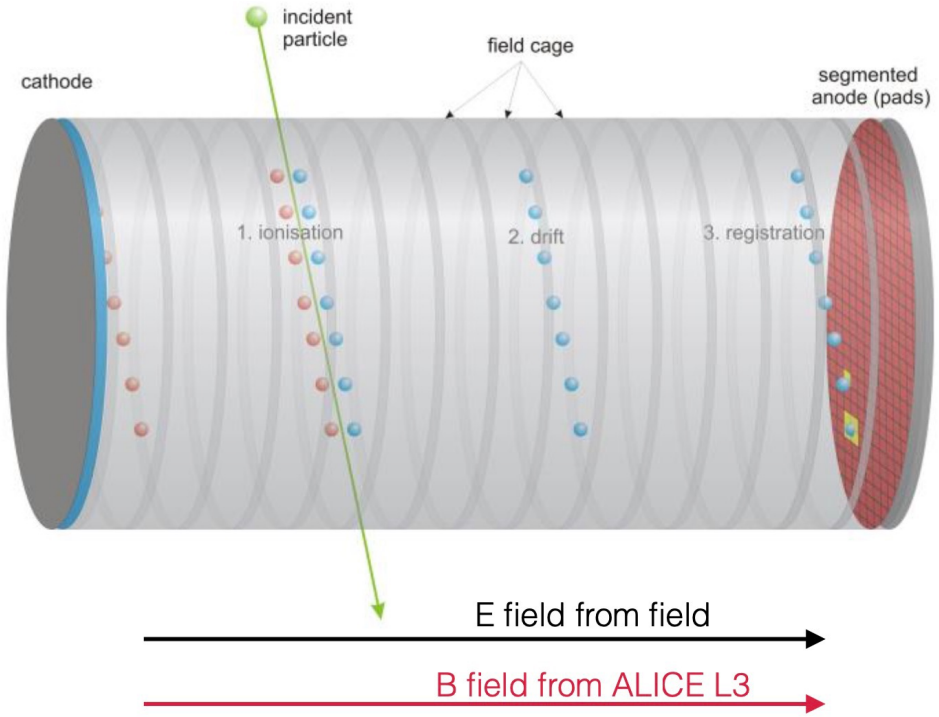
ALICE Detector Schematic



Time Projection Chamber

- Tracking,
- Particle identification

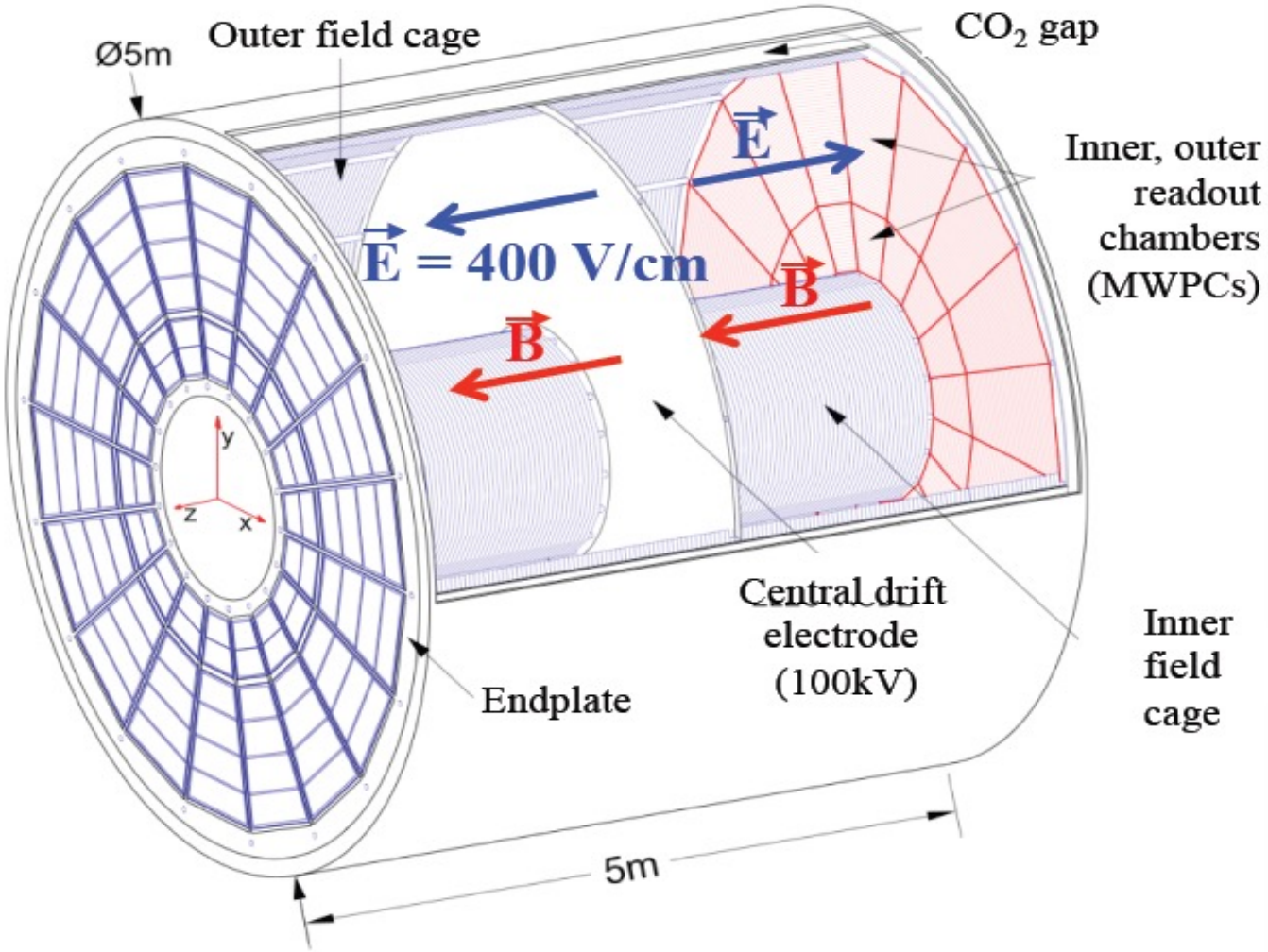
Basic principle of the TPC



- Incident particles traversing the gas volume can ionize the gas along their trajectory
- Electrons created in the ionization drift in the E-Field towards the end-plates
- The pad-planes collect the signals created in the end-plates.
- Pad signals are further amplified and shaped by the Front-End- Electronics
- X/Y position given by pad location, Z position given by drift time

Various factors impact the operation of a TPC, like changing properties of the **gas volume (T,p),** distortions created by **the charge inside the volume**, **gain variations** in the amplification region.

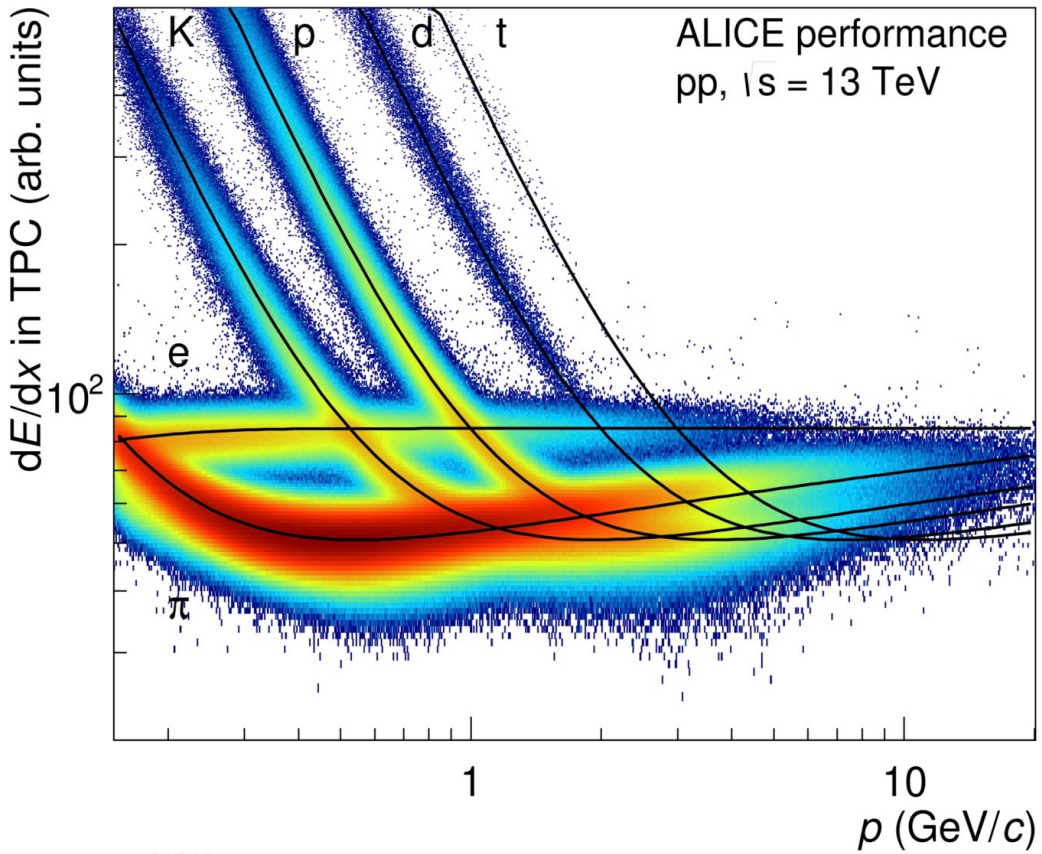
The ALICE TPC

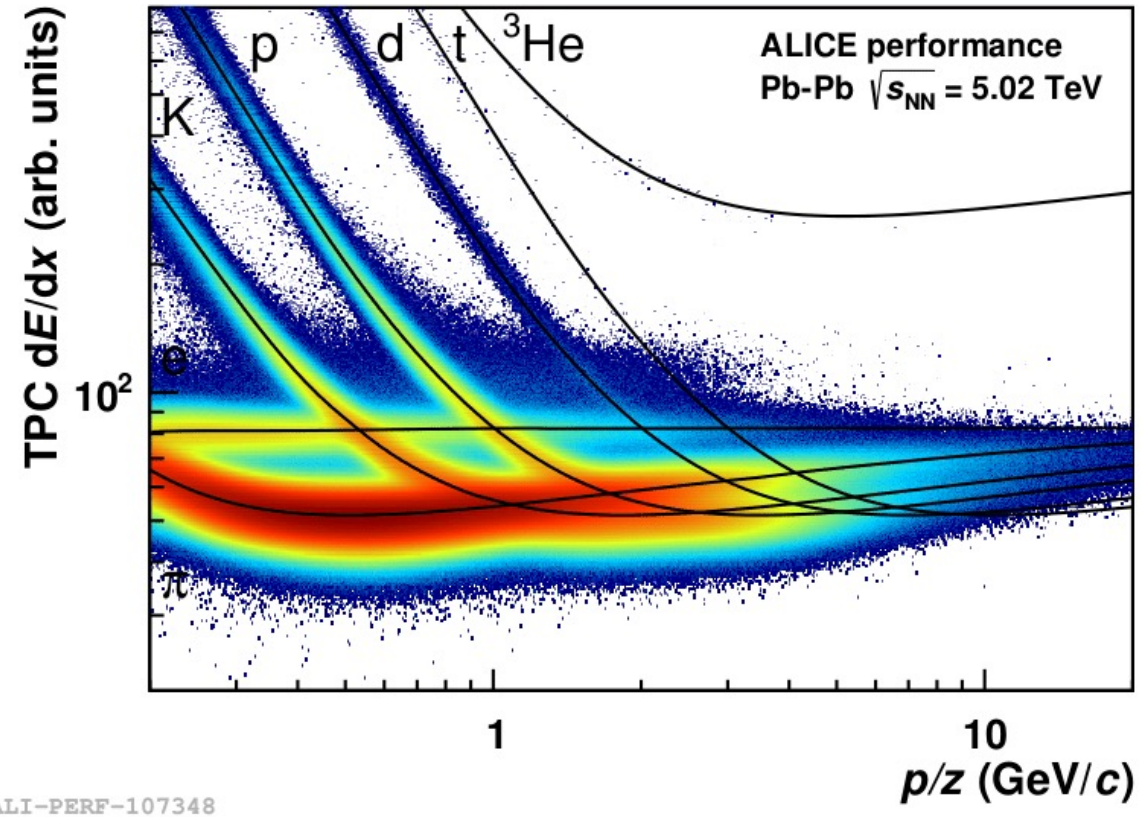


TPC main features:

- ~92 m^3 active volume with gas mixture: Ne-CO_2 (90-10)
- Low drift diffusion
- 72 (=18x2x2) MWPCs with pad readout
- Excellent performance on momentum reconstruction and dE/dx

TPC PID via dE/dx with Run 2



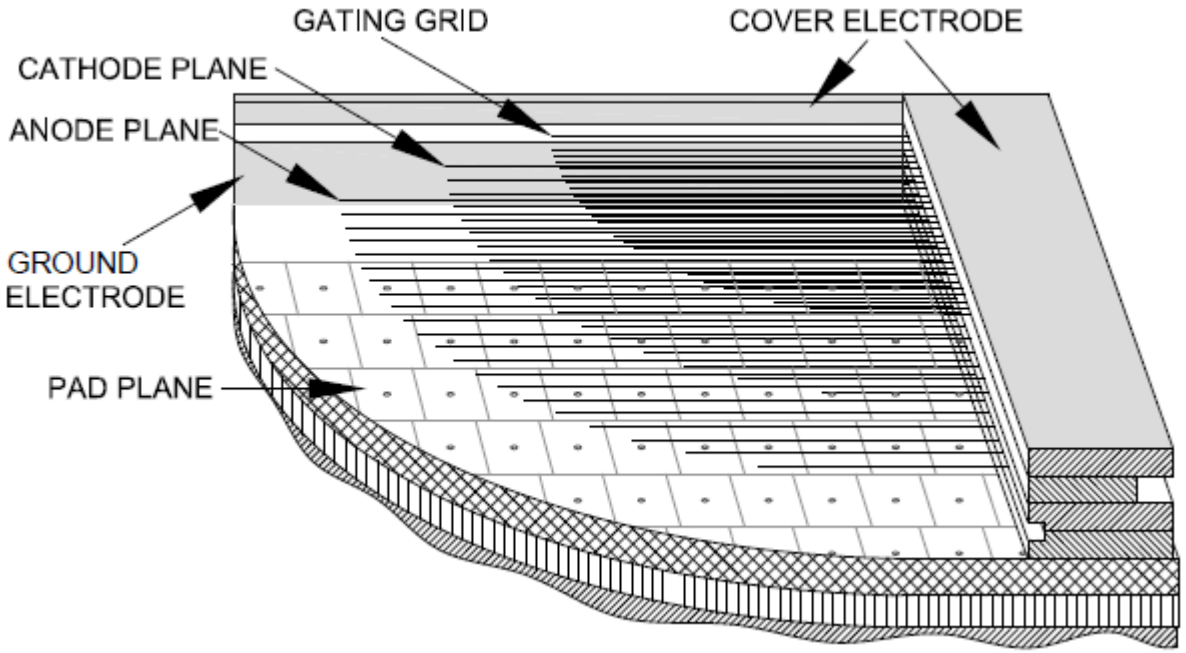


ALI-PERF-107348

Energy loss per unit path length is described by the Bethe-Bloch formula

$$\langle \frac{dE}{dx} \rangle = \frac{4\pi N e^4}{mc^2} \frac{z^2}{\beta^2} \left(\frac{1}{2} \ln \frac{2mc^2 E_{max} \beta^2 \gamma^2}{I^2} - \frac{\beta^2}{2} - \frac{\delta(\beta)}{2} \right)$$

TPC Readout Chamber (Run 2)



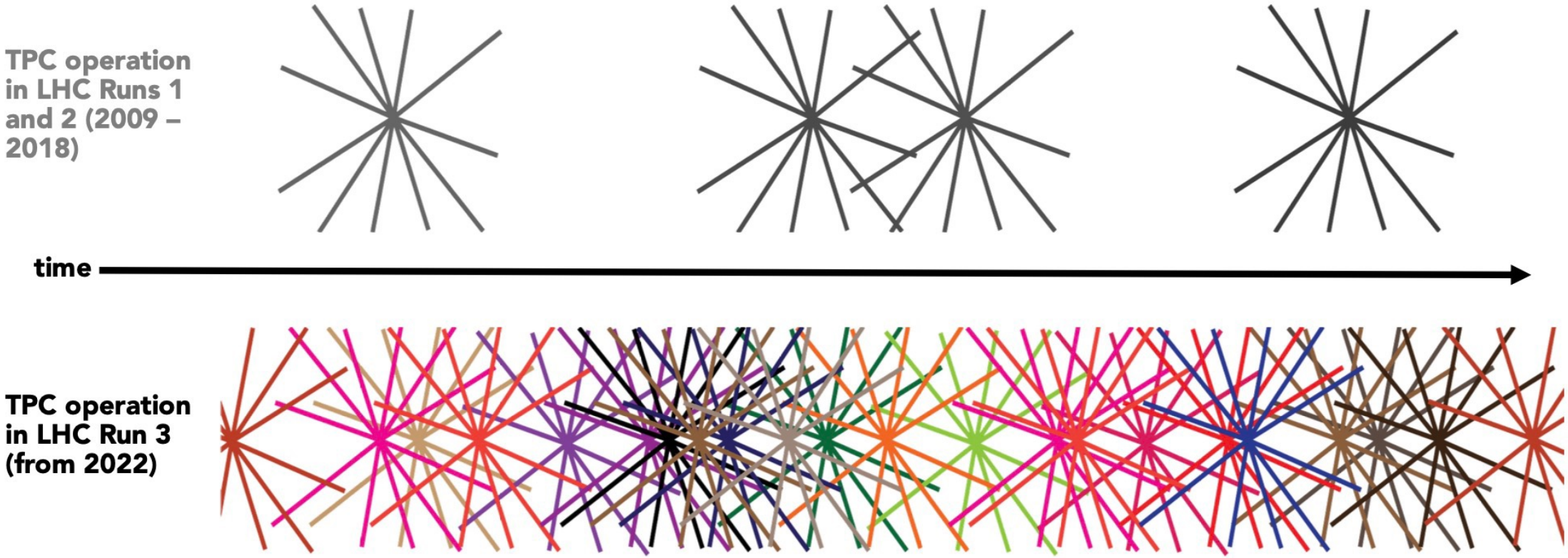
3 different pad segments:

- 63 rows with 4 x 7.5 mm^2 (IROCs)
- 64 rows with 6 x 10 mm^2 (inner OROCs)
- 32 rows with 6 x 15 mm^2 (outer OROCs)

Multi-wire proportional chambers (MWPC) + gating grid

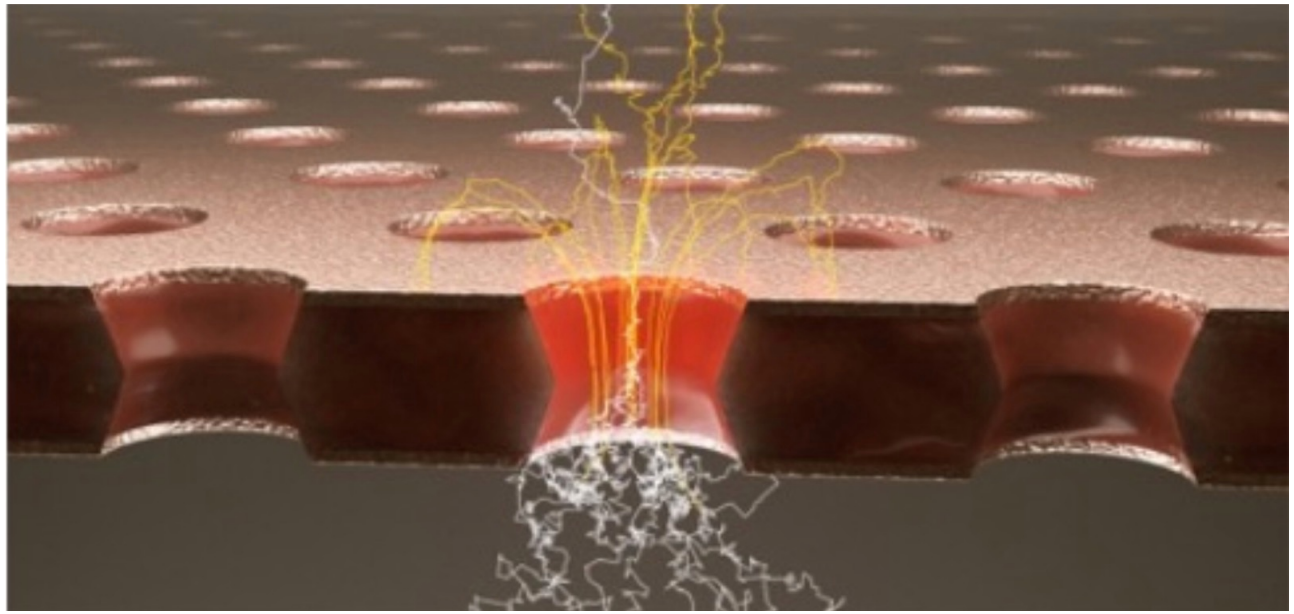
- Dead time: ~92μs (drift) + ~280μs (gating)
- Readout: 3 kHz max

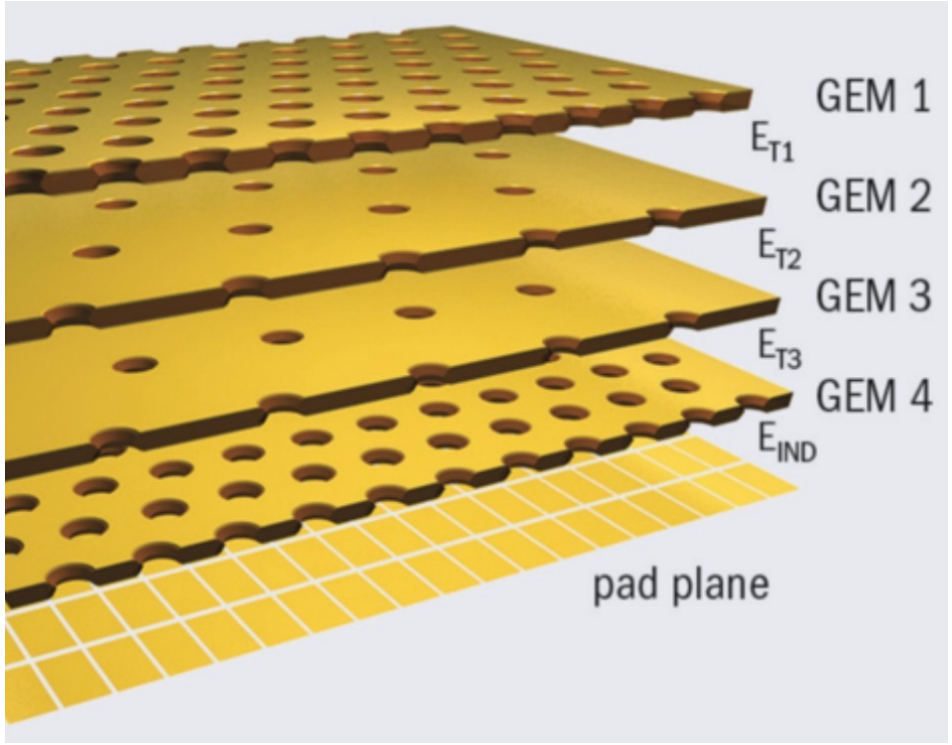
The ALICE TPC upgrades from Run 2 to Run 3



From triggered readout (Run 1&2) to continuous readout with GEMs (Run3)

The upgrade of the ALICE TPC for Run 3

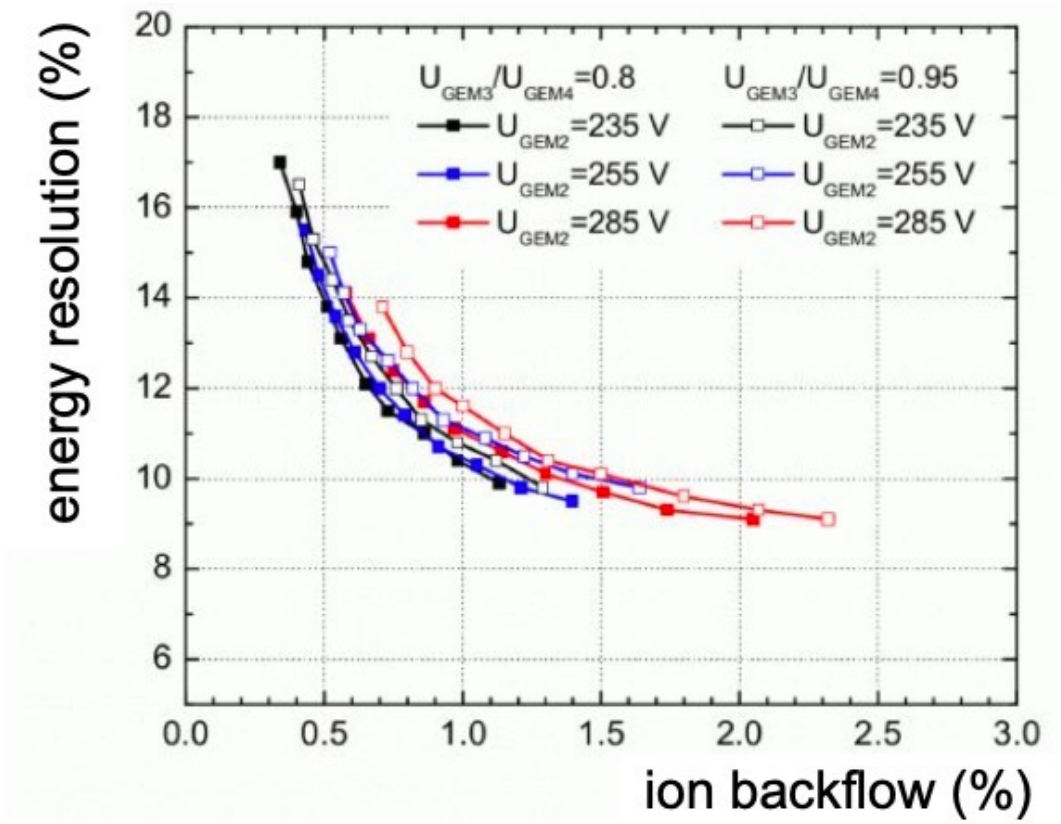




Upgrade front end electronics by Gaseous Electron Multiplier (GEM) foils

- Maintains current TPC performance
- Reduced ion backflow + high rate capability
- 4 Layers, varying GEM pitch

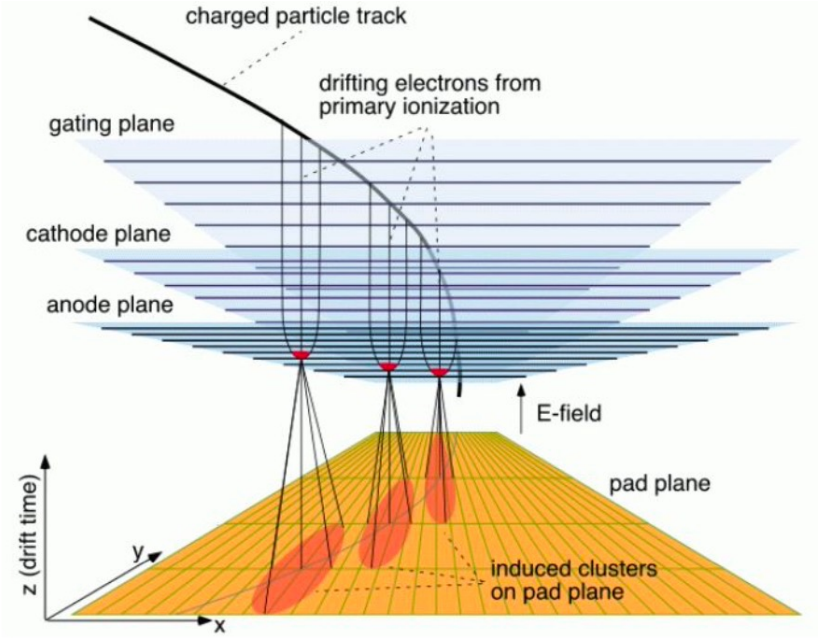
The simulation and testing of the GEM readout

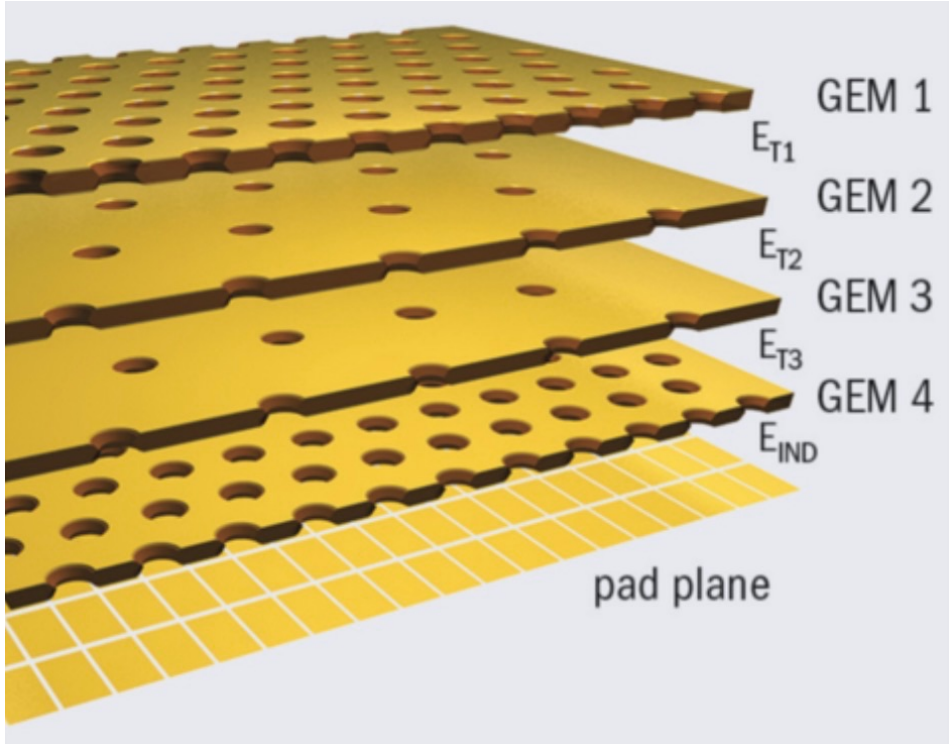



xbai@GSI clean room

- Highly optimized high voltage configuration
- Gain 2000 in Ne-CO2-N2 (90-10-5)
- Energy resolution < 12% for ^{55}Fe
- Ion backflow < 1 %

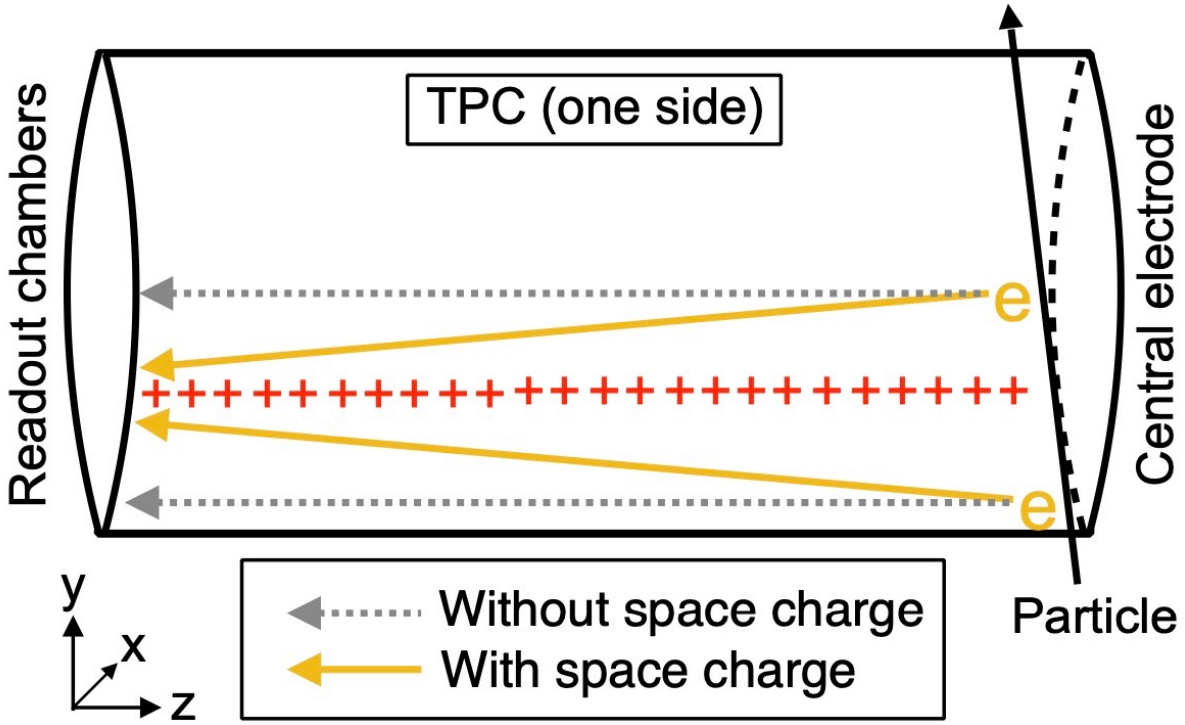
Comparison between wire and GEM chambers





	wire chamber		GEM chamber
	grid open	grid closed	
gain	8000	0	2000
ion backflow	0.13	<0.0001	<0.01

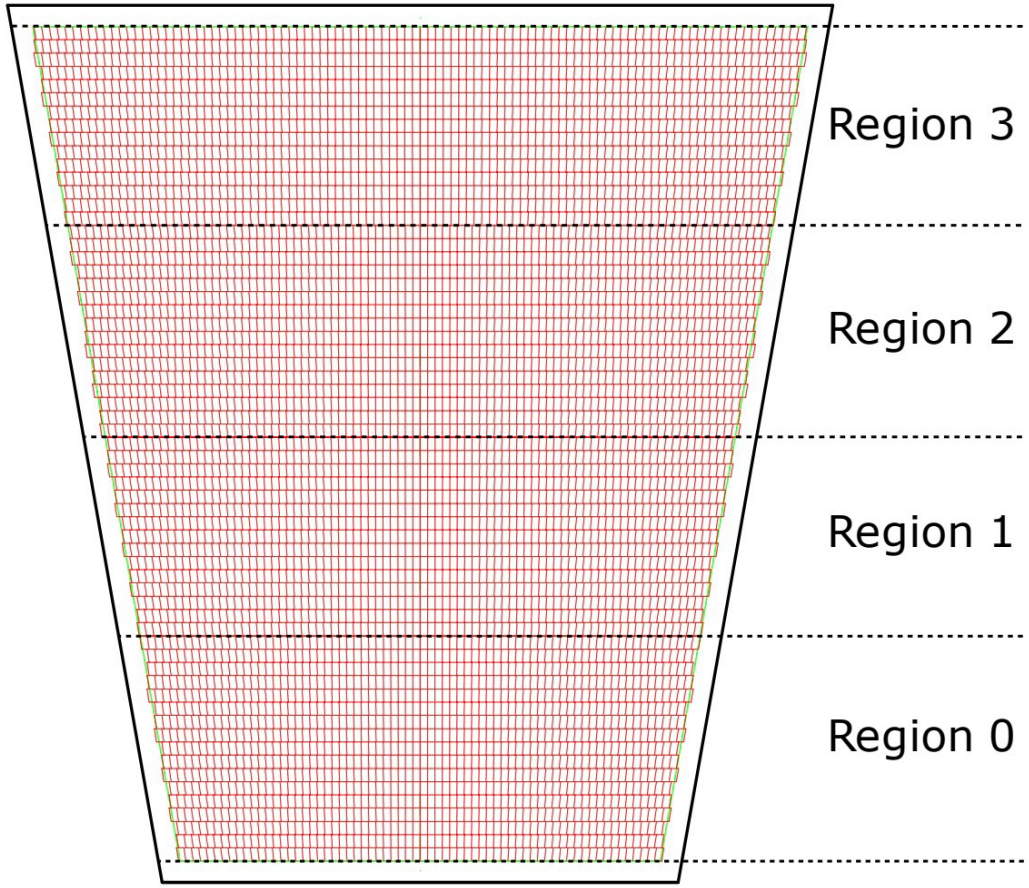
Space-charge distortion with Run3



- **Large distortions** of the drift field in specific regions of the TPC observed in Run 3 data
- **Positive ions** created inside the TPC drift volume
- Deflection of ionization electrons in radial (*dr*), azimuthal (*drφ*) and drift (*dz*) direction
- Dependence on the **drift length and interaction rate (IR)**

The momentum resolution is worse than that of the Run 1 and Run 2, offline calibrations are critical

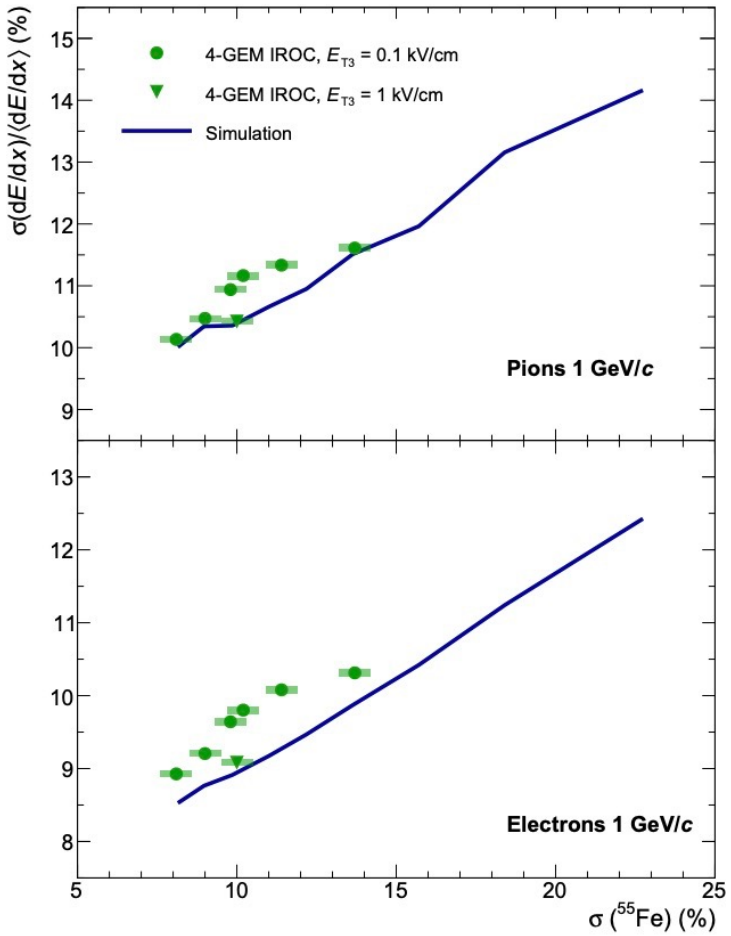
Dimensions and parameters of readout planes and pads

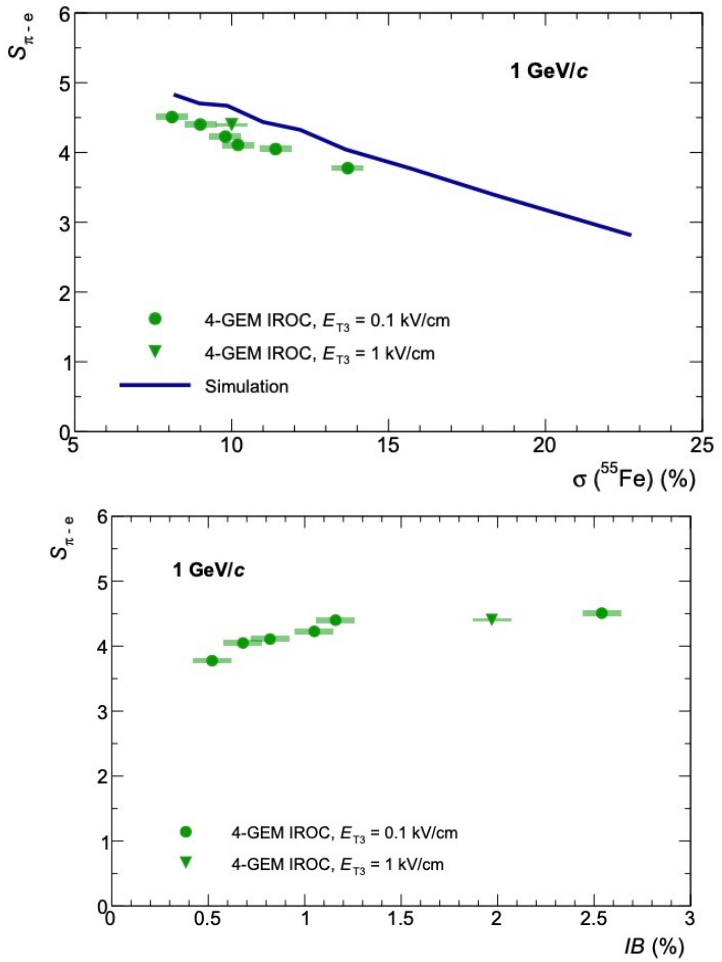


region	active range from (mm)	active range to (mm)	pad size width (mm)	pad size length (mm)	nr of rows	nr of pads
IROC						
0	848.5	976	4.16	7.5	17	1200
1	976	1088.5	4.2	7.5	15	1200
2	1088.5	1208.5	4.2	7.5	16	1440
3	1208.5	1321	4.36	7.5	15	1440
OROC 1						
4	1347	1527	6	10	18	1440
5	1527	1687	6	10	16	1440
OROC 2						
6	1708	1900	6.08	12	16	1600
7	1900	2068	5.88	12	14	1600
OROC 3						
8	2089	2284	6.04	15	13	1600
9	2284	2464	6.07	15	12	1600

The momentum resolution is worse than that of the Run 1 and Run 2, offline calibrations are critical

dE/dx resolution and PID performance



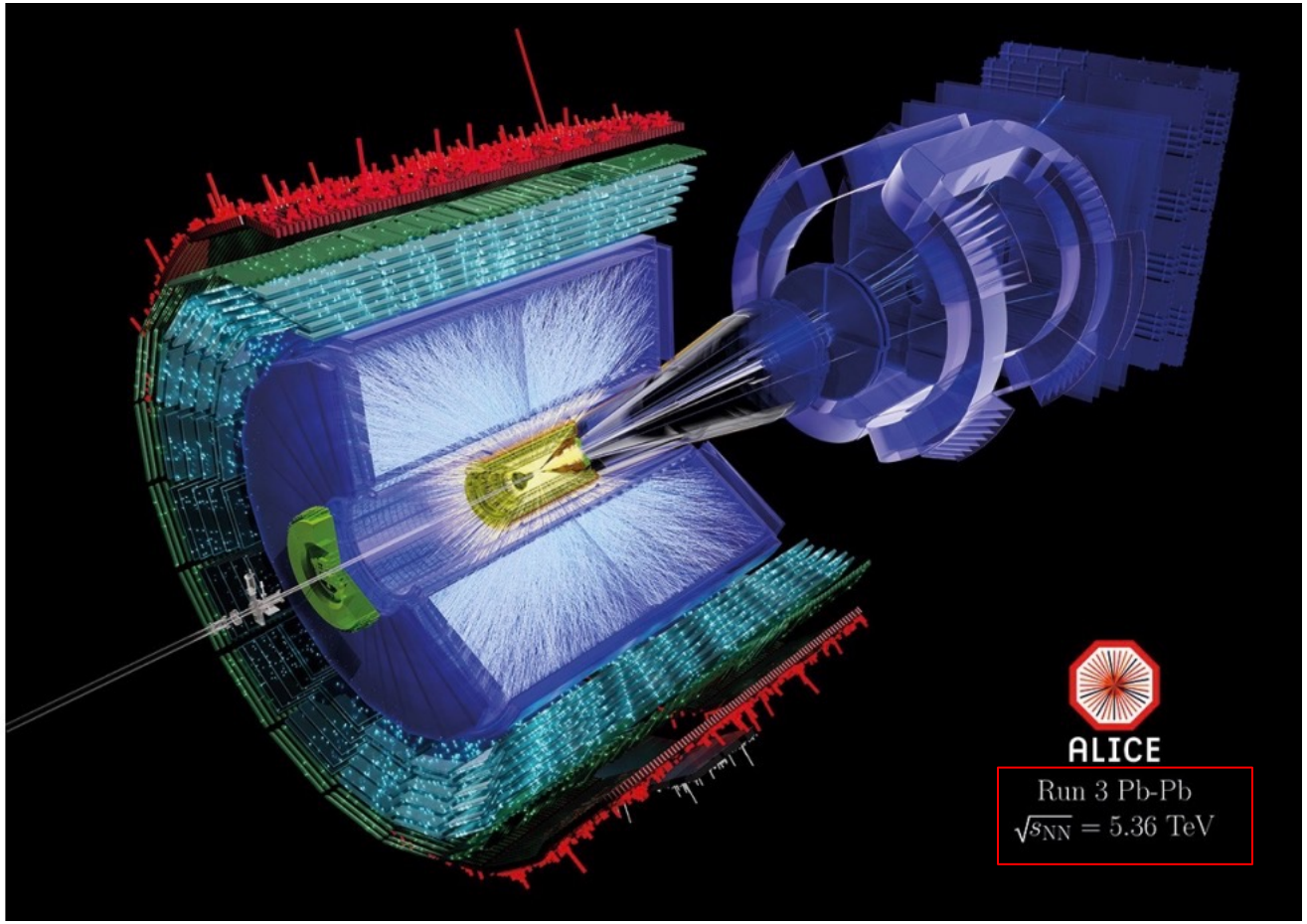


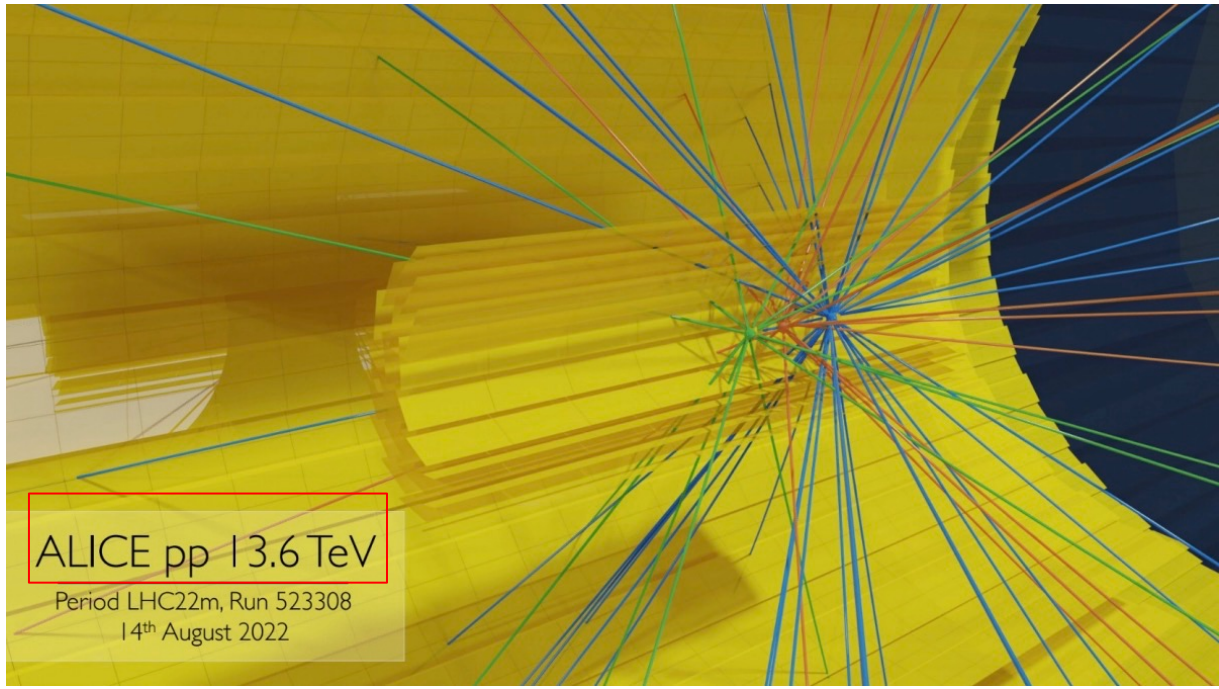
$$\mathrm{d}E/\mathrm{d}x \text{ resolution} = \frac{\sigma_{\langle \mathrm{d}E/\mathrm{d}x \rangle_{\mathrm{tr}}}}{\mu_{\langle \mathrm{d}E/\mathrm{d}x \rangle_{\mathrm{tr}}}}$$

$$S_{\pi-e} = \frac{\left| \mu_{\langle \mathrm{d}E/\mathrm{d}x \rangle_{\mathrm{tr},e^-}} - \mu_{\langle \mathrm{d}E/\mathrm{d}x \rangle_{\mathrm{tr},\pi^-}} \right|}{0.5 \cdot \left(\sigma_{\langle \mathrm{d}E/\mathrm{d}x \rangle_{\mathrm{t},e^-}} + \sigma_{\langle \mathrm{d}E/\mathrm{d}x \rangle_{\mathrm{tr},\pi^-}} \right)}$$

Extensive studies demonstrated that the dE/dx resolution **slightly worsens with increasing occupancy from 5.5% in isolated pp events without pileup to about 7.5% in central Pb–Pb at 50 kHz**

ALICE data taking in Run 3

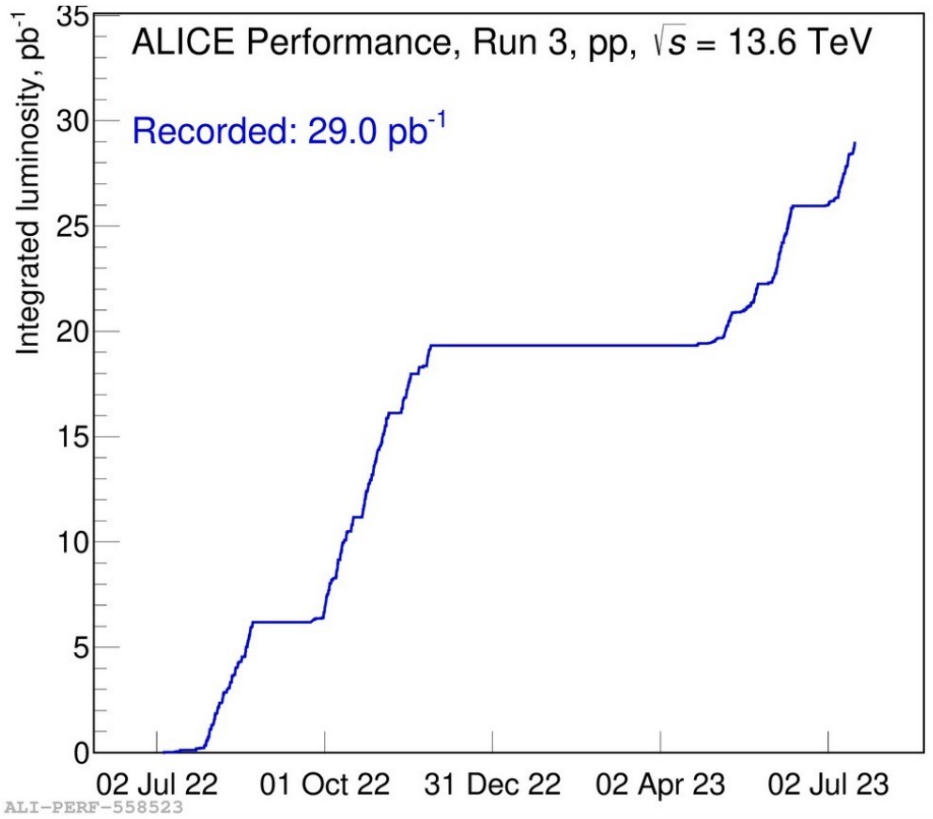




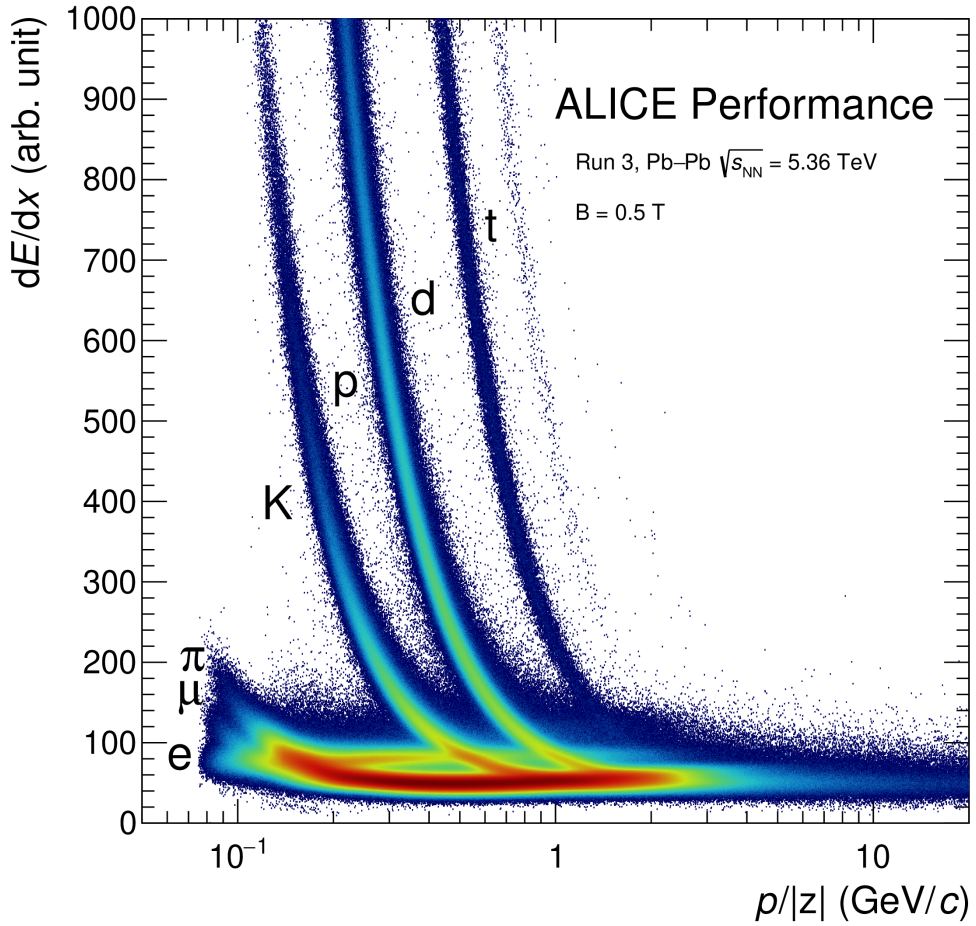
The updated TPC with GEM readout allows to take the data at the IR at 50KHz for Pb-Pb at 5.35 TeV and 500k for pp at 13.6 TeV collisions

ALICE data taking in Run 3

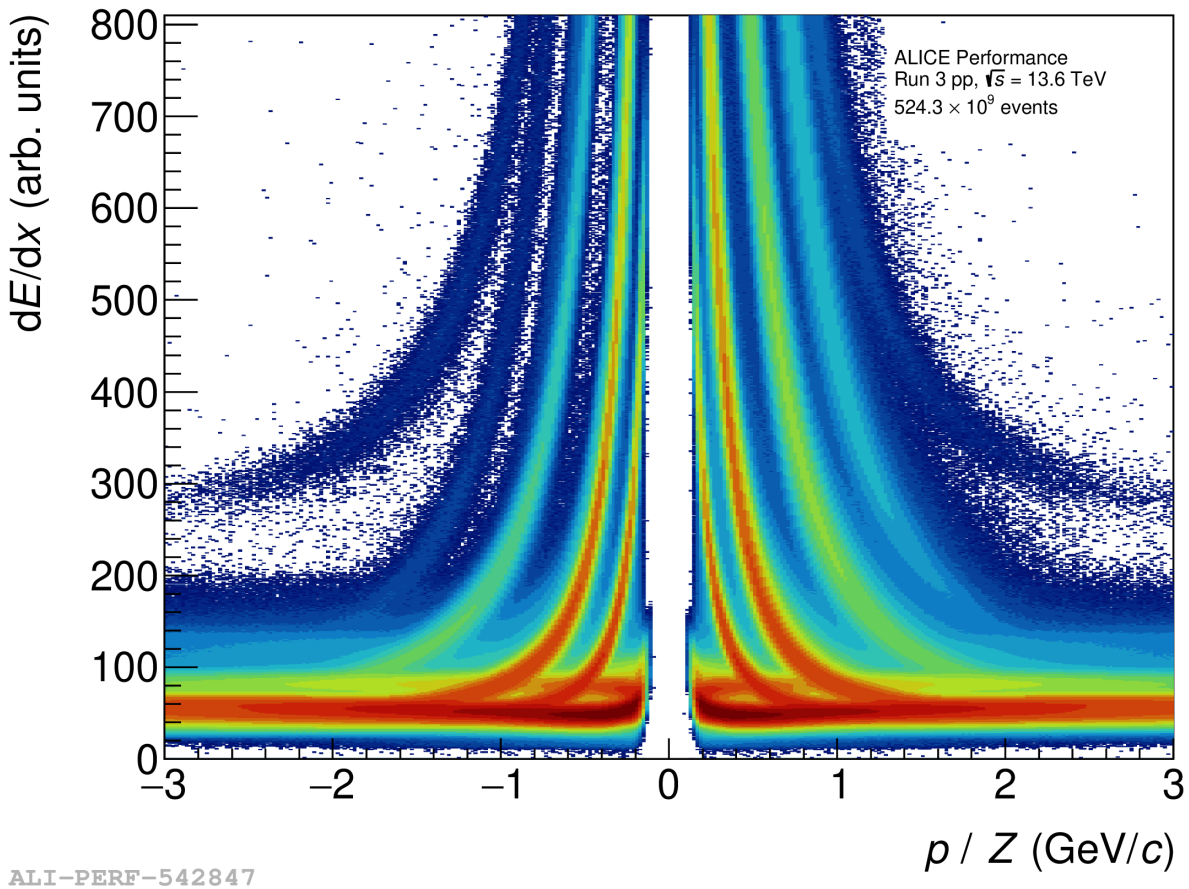
- Huge improvement in integrated luminosity wrt Run 1 and 2
  - – Pb-Pb: x100 – pp, p-Pb: x1000
- Already recorded (2022-2023):
  - – pp collisions at √s = 0.9 and 13.6 TeV (~30 pb-1)
  - – Pb-Pb at √sNN = 5.36 TeV (ongoing)
- Continuous readout with routine data taking at 500 kHz in pp collisions
- First Run 3 physics results already available



The performace of the dE/dx for PID with the Run 3



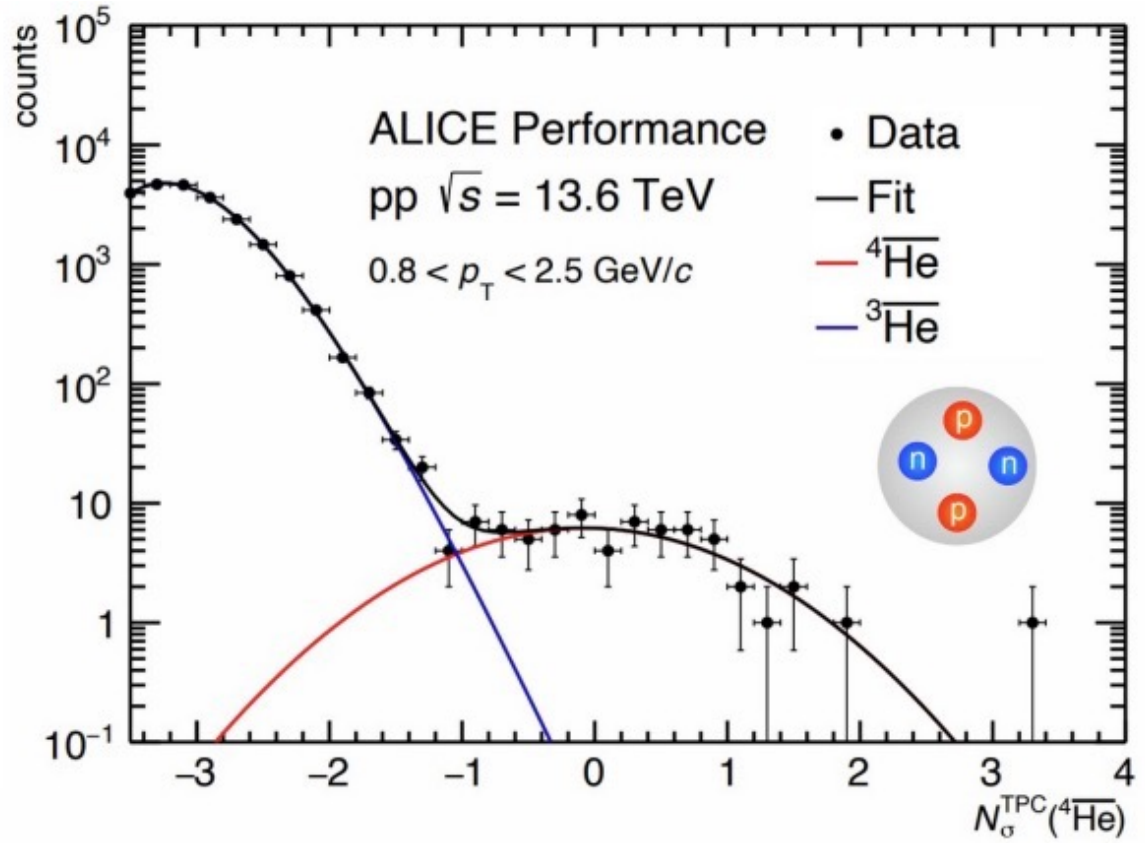
ALI-PERF-529714



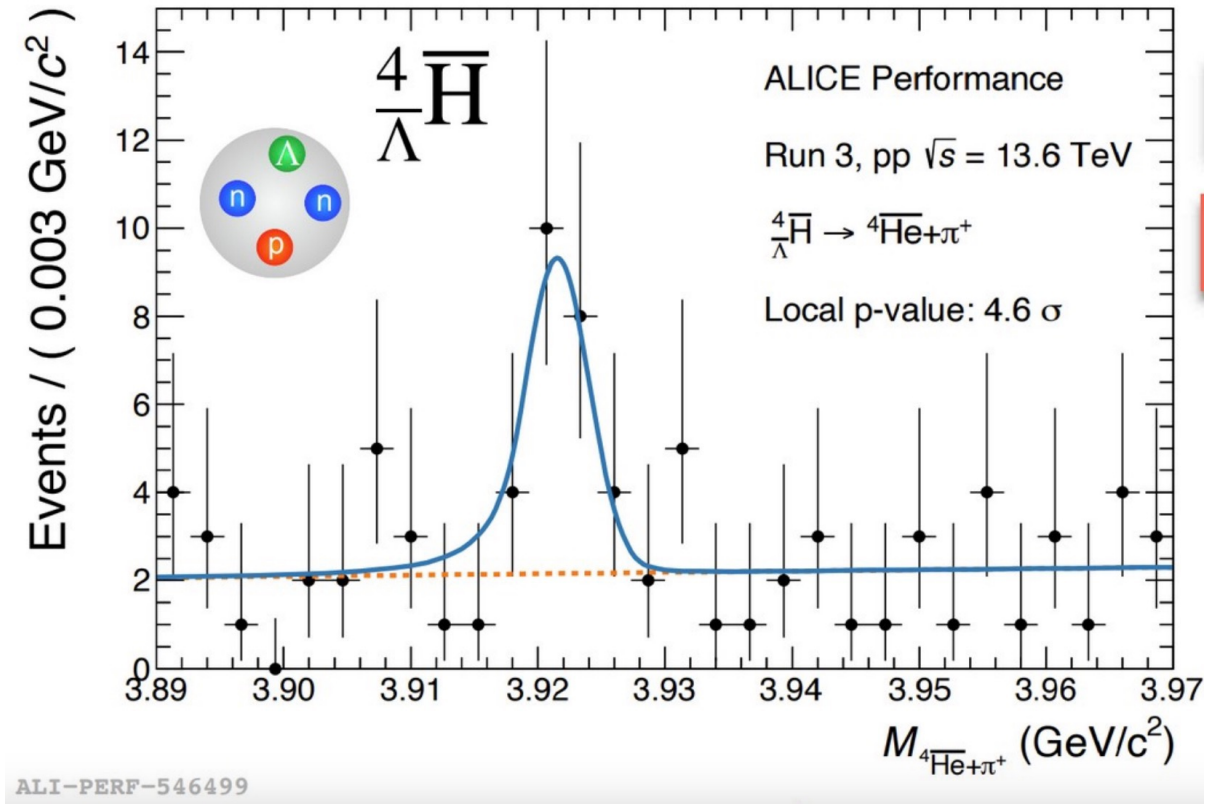
ALI-PERF-542847

Different particle species can be well discriminated by the TPC dE/dx. The resolution is slightly worse than Run 2, but it should be recovered via the new calibrations.

(Anti-)(hyper-)nuclei measurements



ALI-PERF-547176

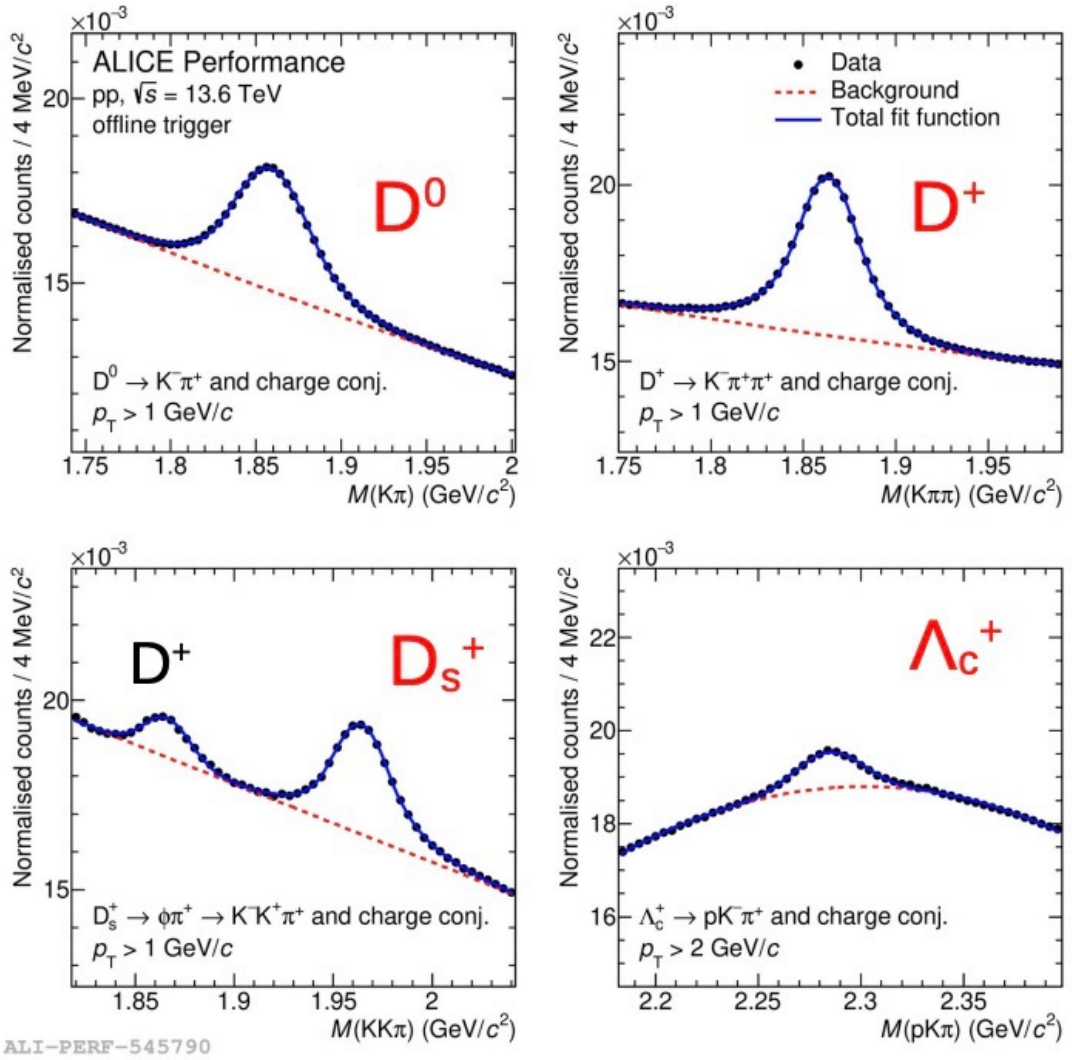


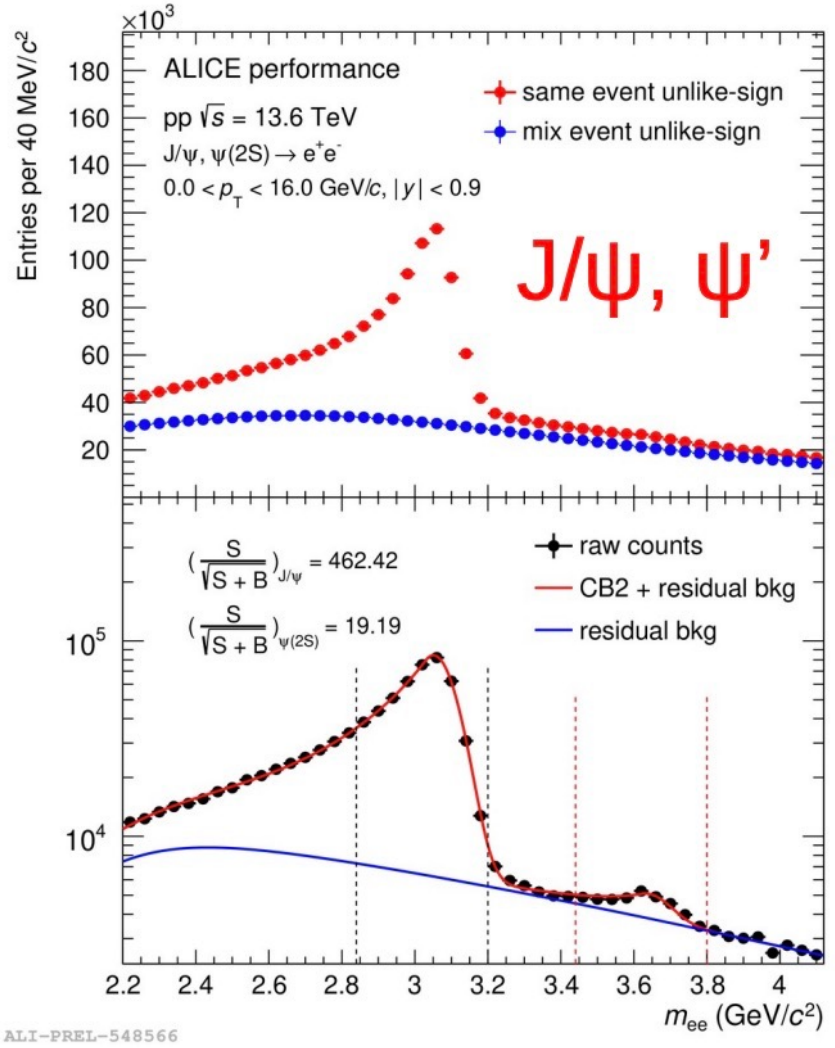
ALI-PERF-546499

Hyper-nuclear states with 4 baryons yields consistent with the thermal model

- Yields are very sensitive to feed-down from excited states
- First signals of anti-(hyper) nuclear states in Run 3 pp thanks to the upgraded TPC

Open heavy flavor and quarkonium signal in pp@13.6 TeV



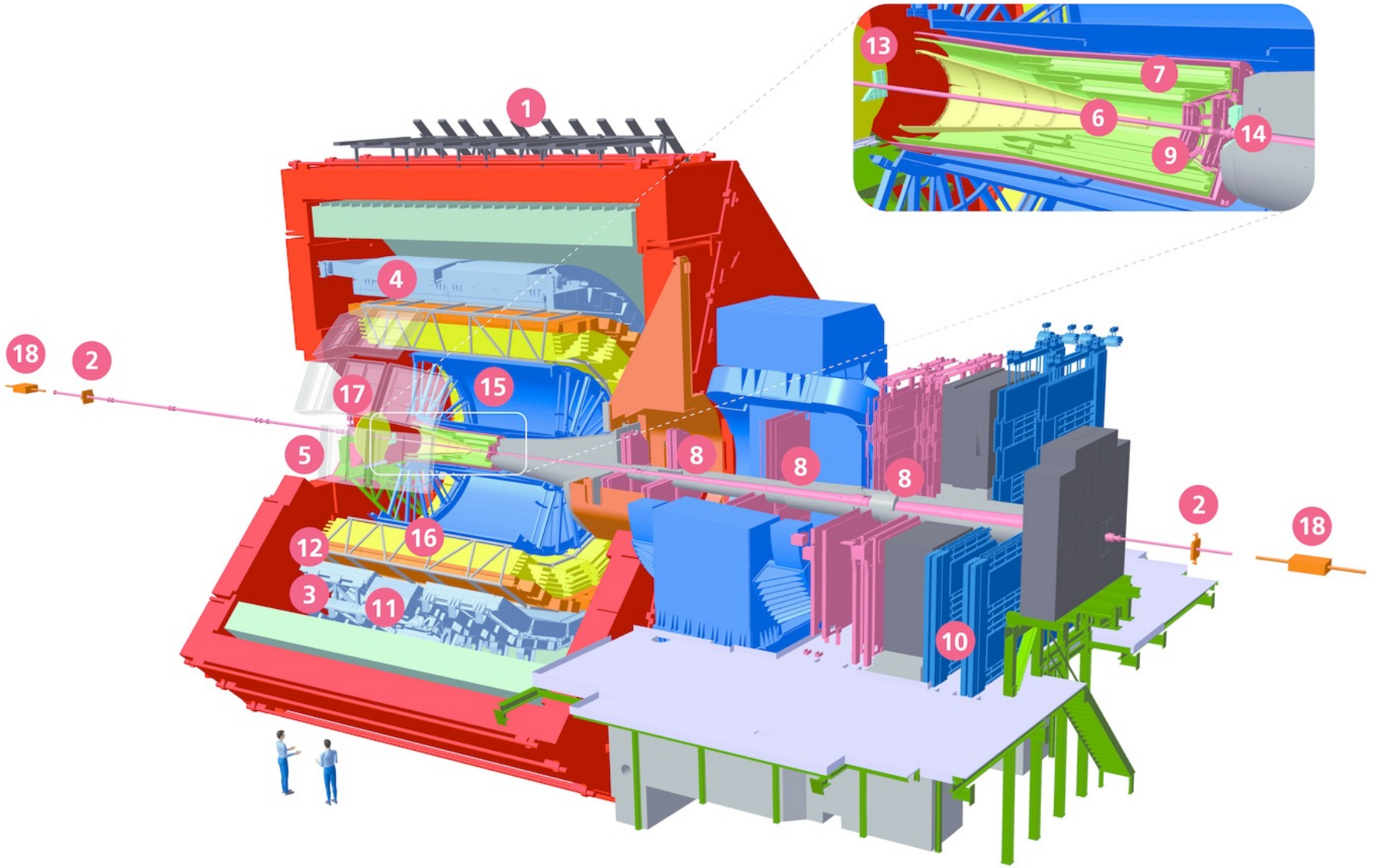


Summary

- ALICE TPC upgraded for Run 3 to operate at 50 kHz rate in Pb-Pb collisions
- No gating, continuous readout with GEMs
- Improve statistics of minimum bias for pp and Pb-Pb collisions by a factor of 10^4 and 10^2, respectively.
- Run 3 data taking ongoing with a huge boost in recorded luminosity
  - Stay tuned!

Thanks

ALICE Detector Schematic (Run 3)



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter