The ALICE TPC: Tracking and Particle ID for Relativistic Nuclear Collisions at the Terascale

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Workshop on QCD Thermodynamics
in High-Energy Collisions
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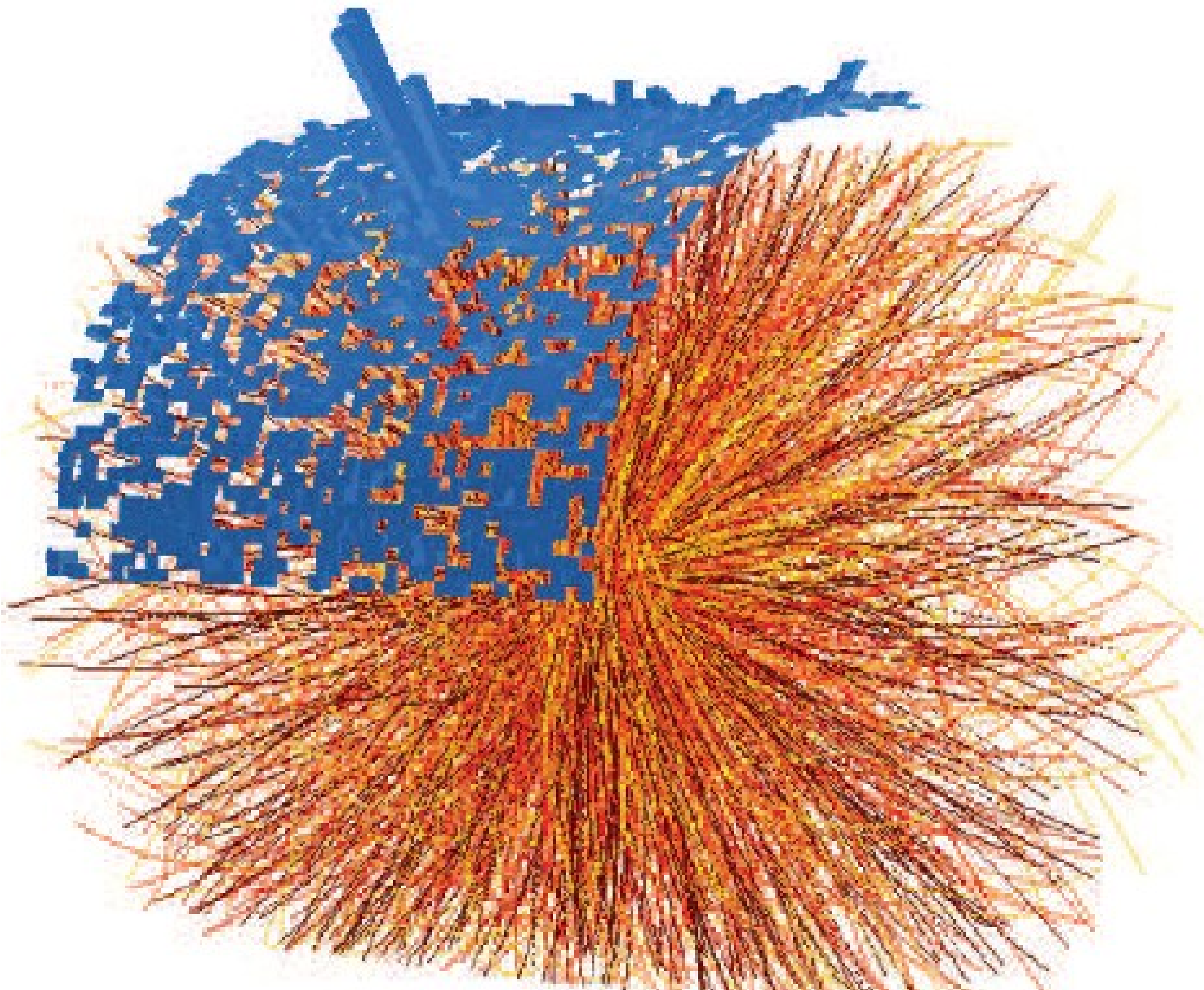
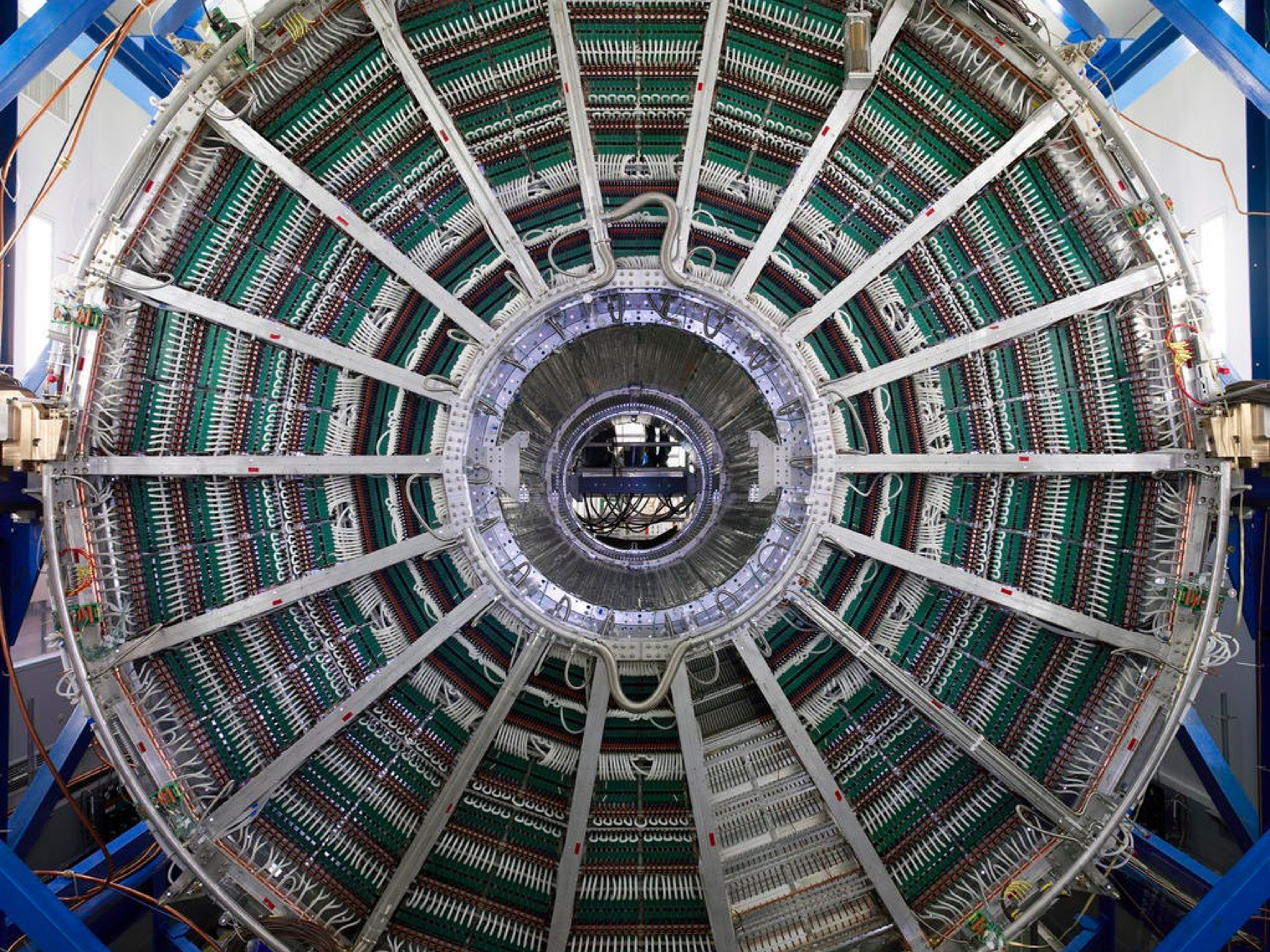
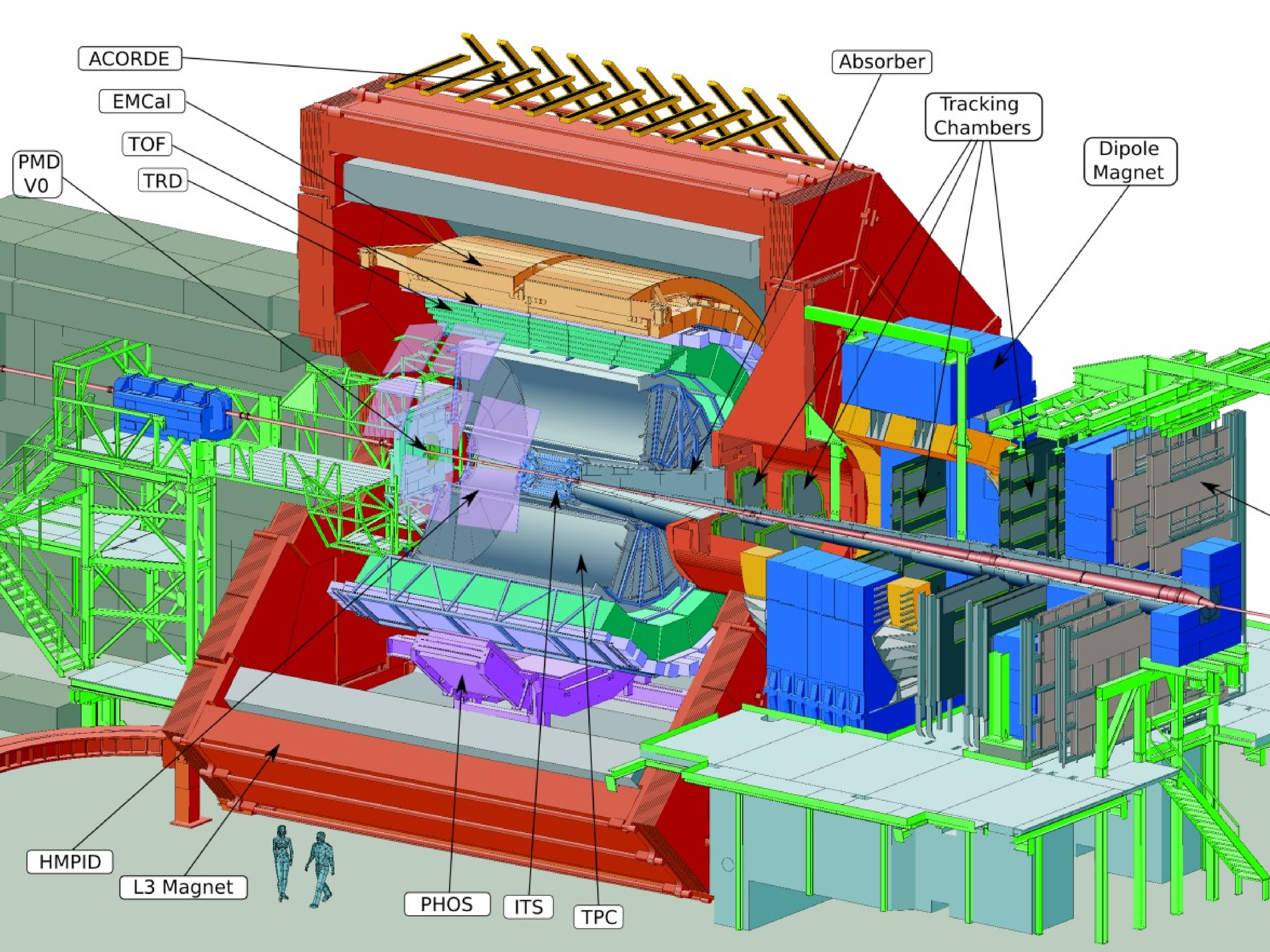
College of Physical Science and Technology
Central China Normal University, Wuhan, China






ACORDE
EMCal
TOF
PMD
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Absorber
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Chambers
Dipole
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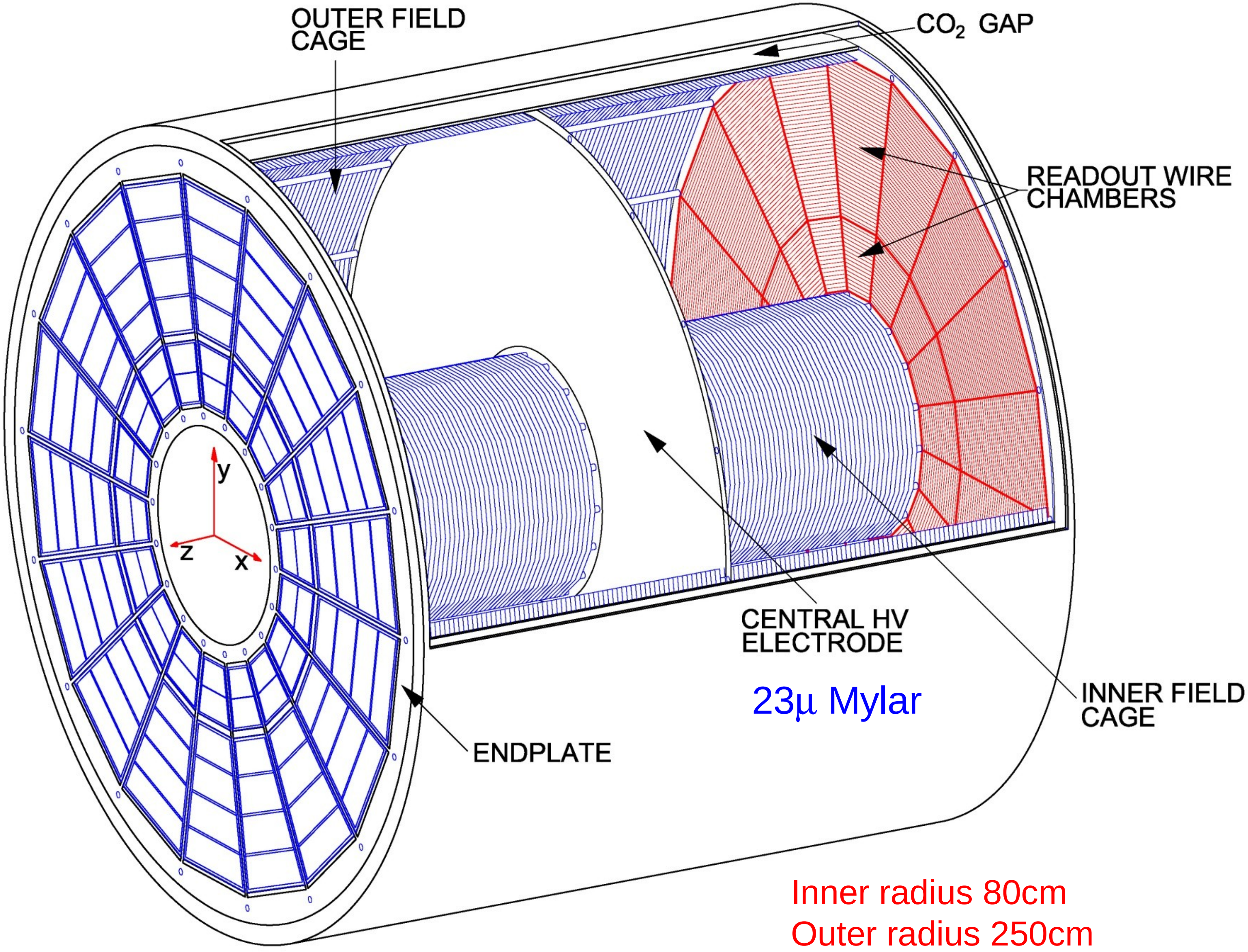
L3 Magnet
PHOS
ITS
TPC

ALICE TPC



23µ Mylar

Inner radius 80cm
Outer radius 250cm
Length 2x250cm

ALICE TPC is a large volume Time Projection Chamber with overall ‘conventional’ lay-out but designed for extremely high track density expected in Pb-Pb collisions at LHC energy.

GAS CHOICE Run1

Ne because:
less material, faster ion mobility (less space charge effect), low diffusion
Quencher: **CO_2** (minimized aging)+ N_2.

Active volume: 90 m^3
Final gas mixture: Ne-CO_2-N_2: 85.7% - 9.5% - 4.8%
(N_2 added to improve quenching at high gain)
Cool gas - low diffusion
Non-saturated drift velocity: temperature stability and homogeneity $\leq$ 0.1 K
Gain ~ 10^4

With this gas mixture we need 400V/cm in the field cage!

GAS CHOICE Run2

Ar-CO_2 because:

goal to achieve ultimate dE/dx performance, at improved stability for 10 kHz Pb-Pb running

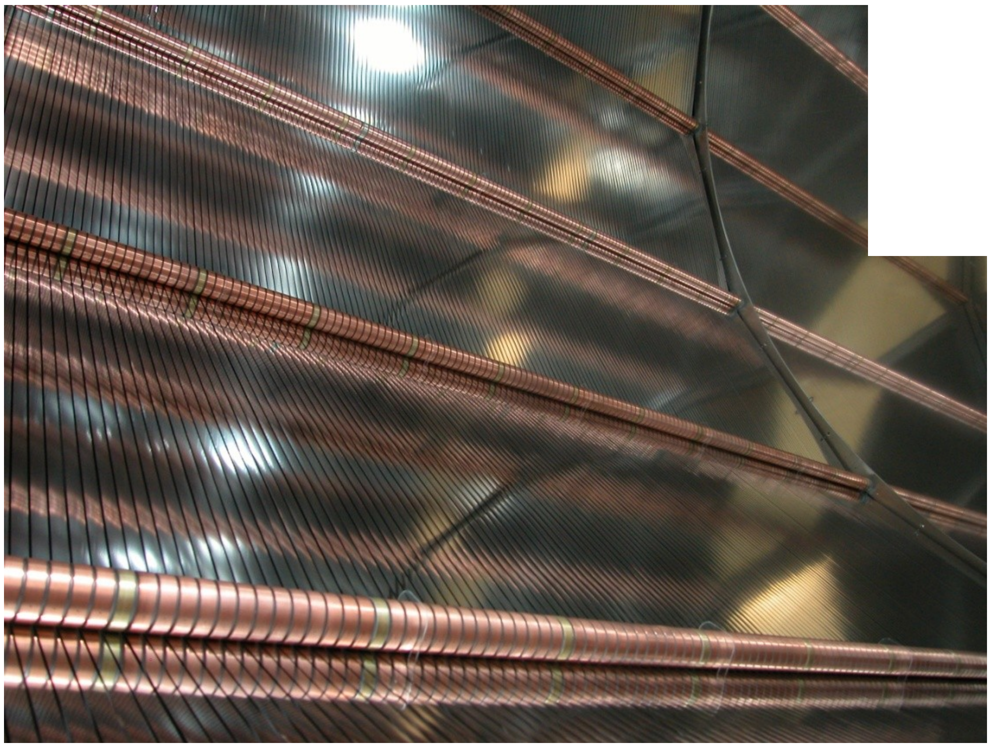
Quencher: **CO_2** (minimized aging)

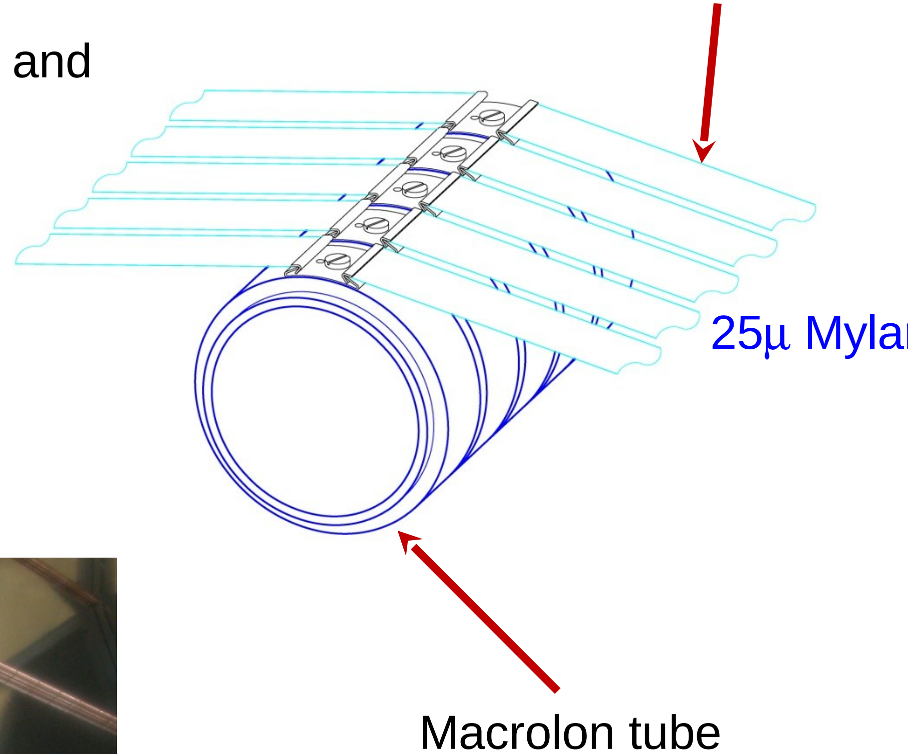
- Active volume: 90 m^3
- Final gas mixture: Ar-CO_2: 90%-10%
- Cool gas - low diffusion
- Non-saturated drift velocity: temperature stability and homogeneity $\leq$ 0.06 K
- Gain ~ 1.3 x 10^4

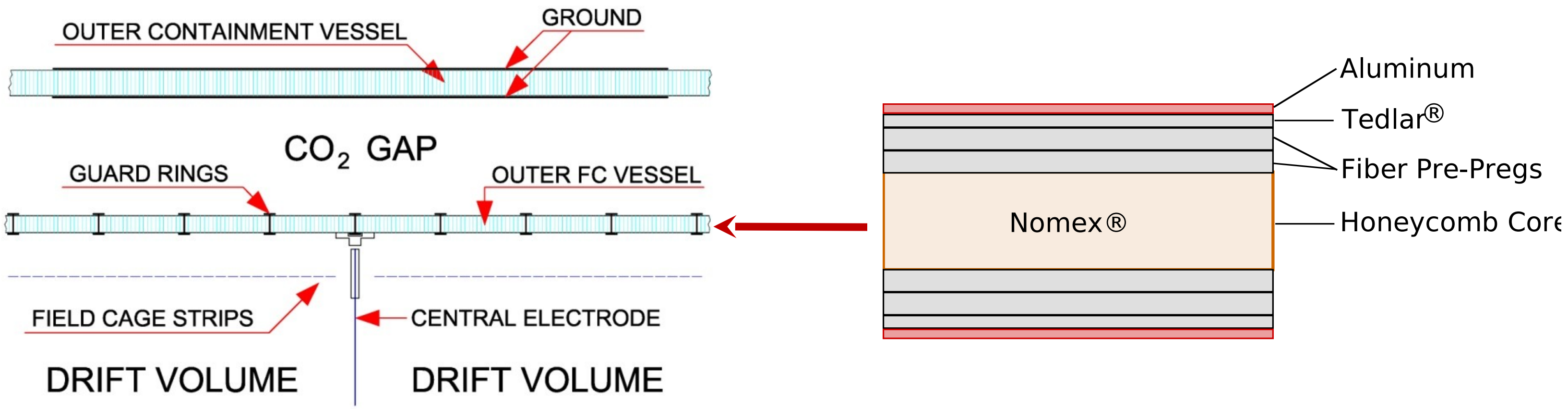
With this gas mixture we need 400V/cm in the field cage!

ALICE TPC Field cage is made of free standing aluminized Mylar strips

More complicate system but very stable and reliable for high drift voltages.



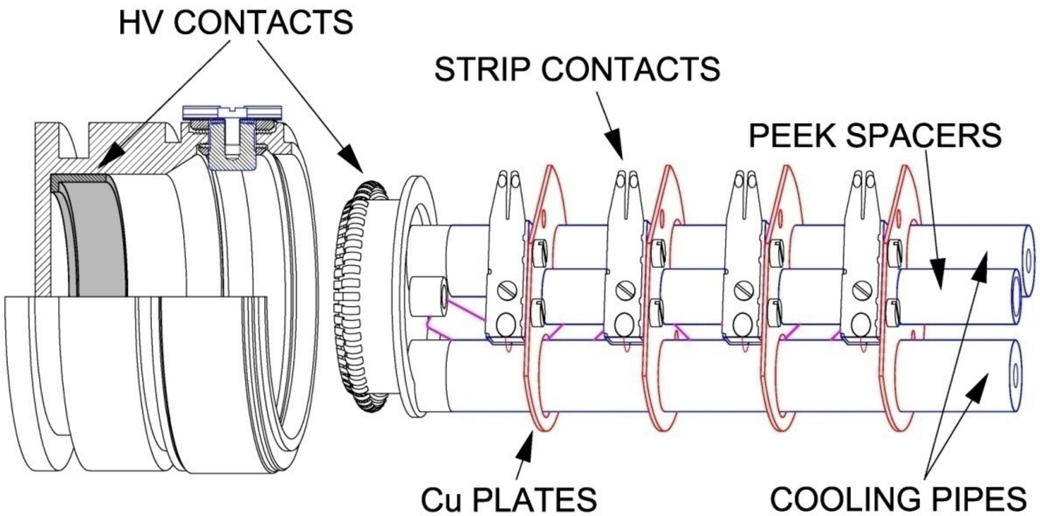




The ALICE field cage consists of two parts; a field cage vessel with a set of coarsely segmented guard rings and finely segmented field cage which is located inside the field cage vessel.

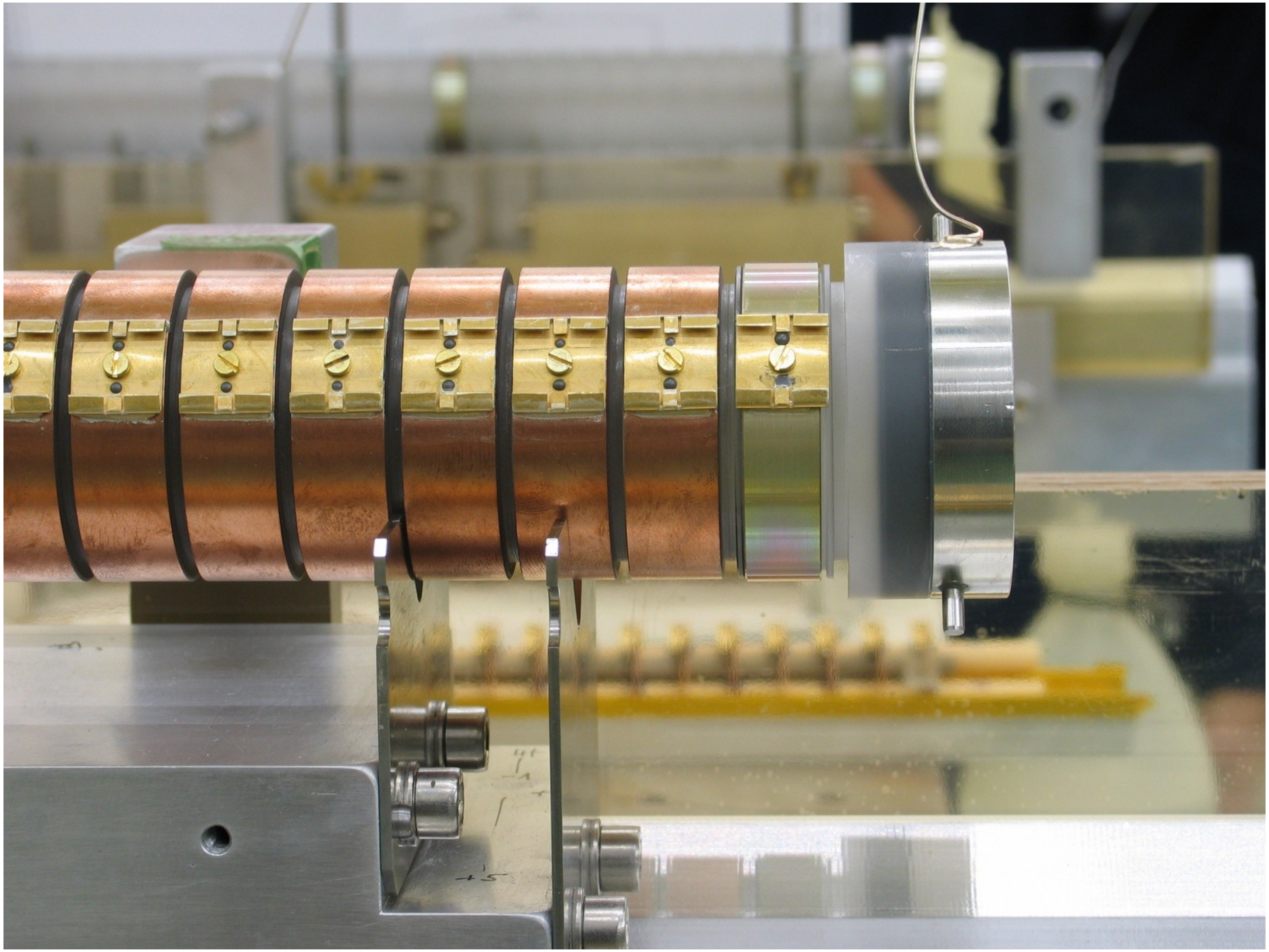
For temperature stability and homogeneity ≤ 0.1 K

Leakless cooling system including FC Resistor rod

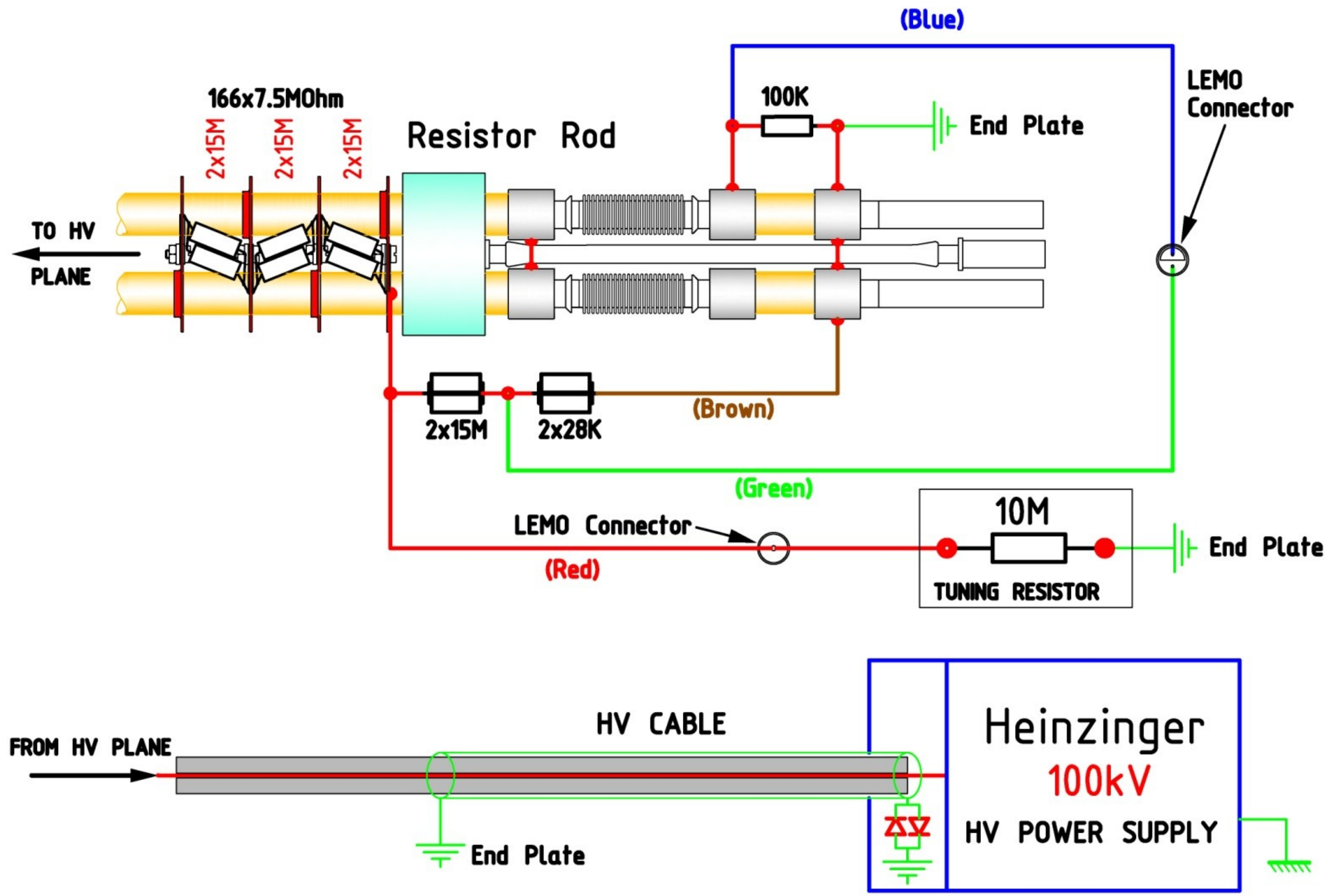


To monitor the temperature distribution
~500 PT1000 sensors are mounted both inside and outside of the gas volume

RESISTOR ROD WITH WATER COOLING – OUTER PART



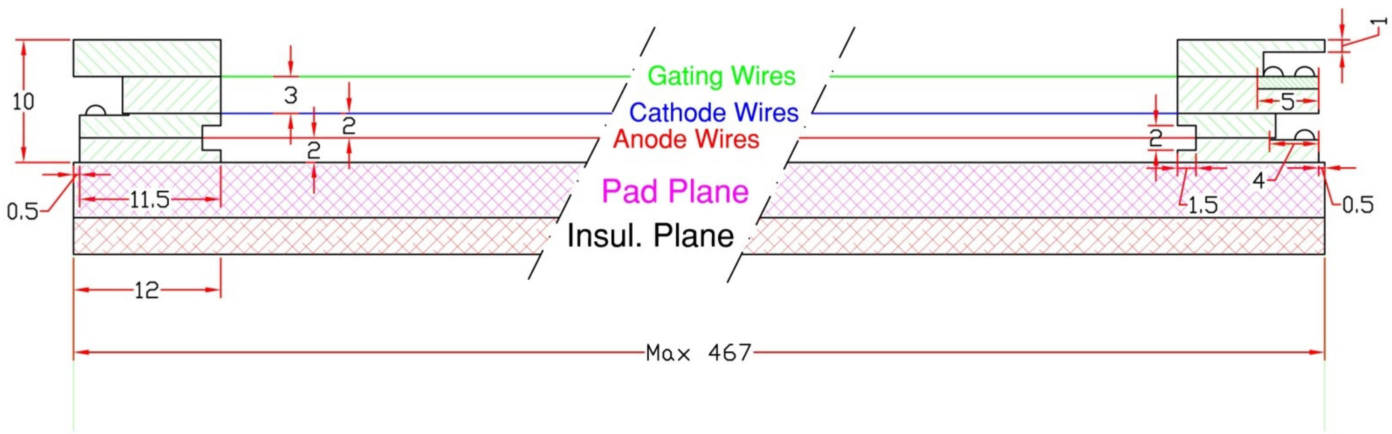
RESISTOR ROD - MECHANICAL AND ELECTRICAL ARRANGEMENT



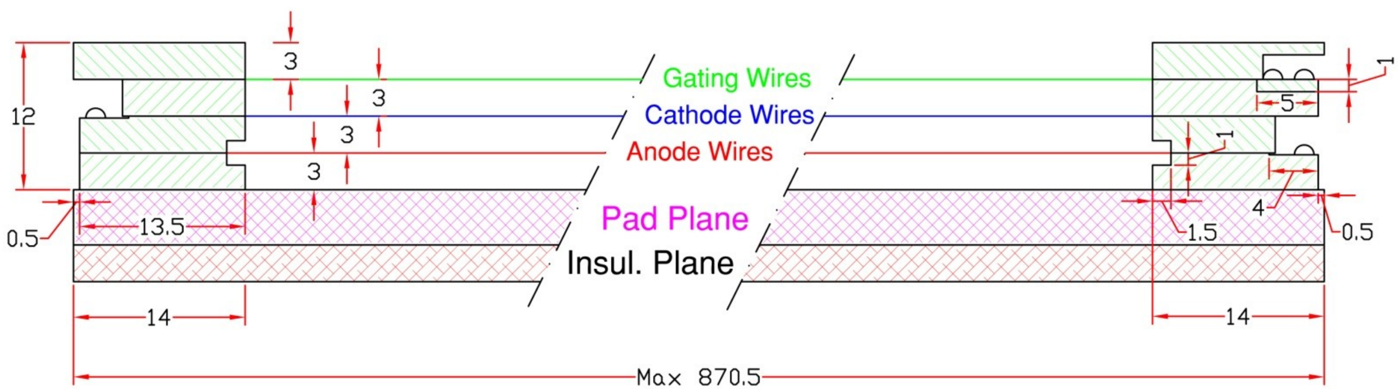
READ-OUT CHAMBER DESIGN

MWPCs with pad-readout with extra optimization for high rate and high track density.

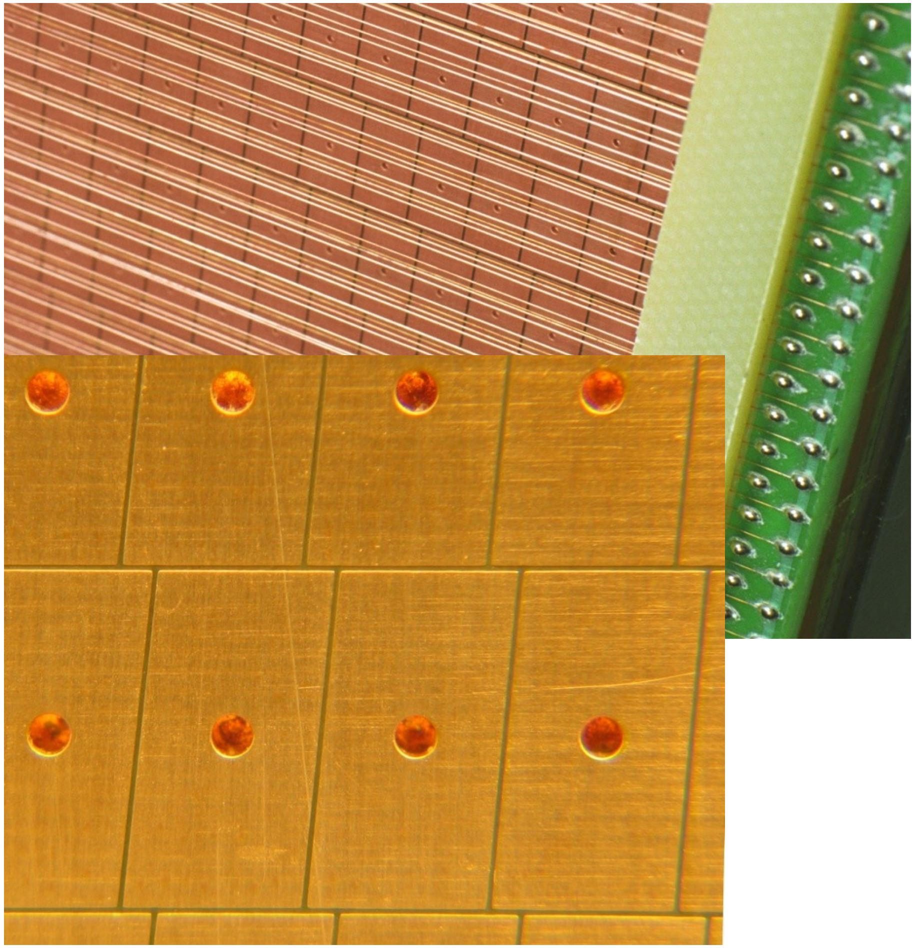
Inner Chamber



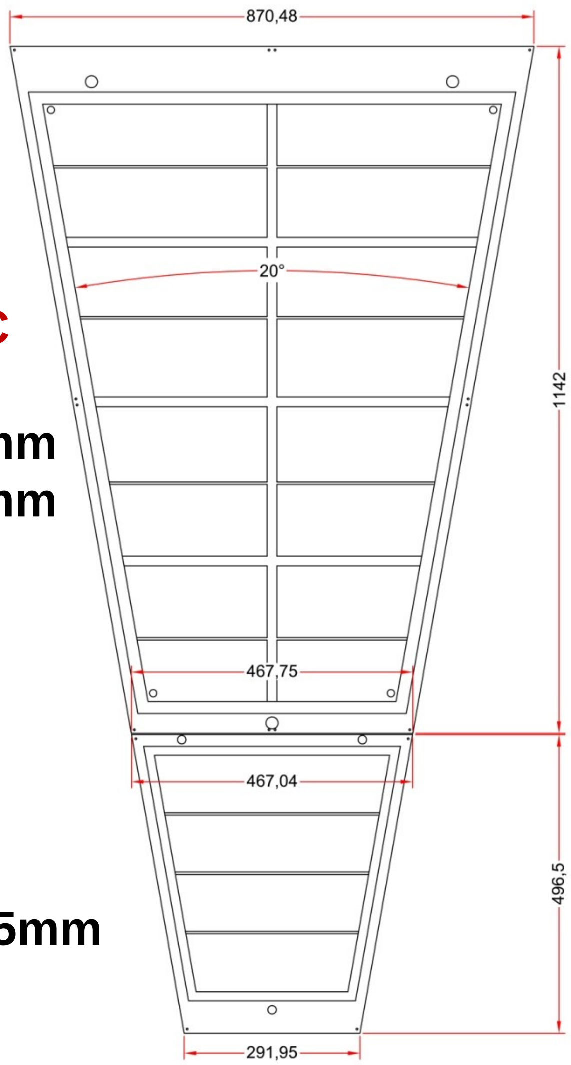
Outer Chamber



READOUT CHAMBERS



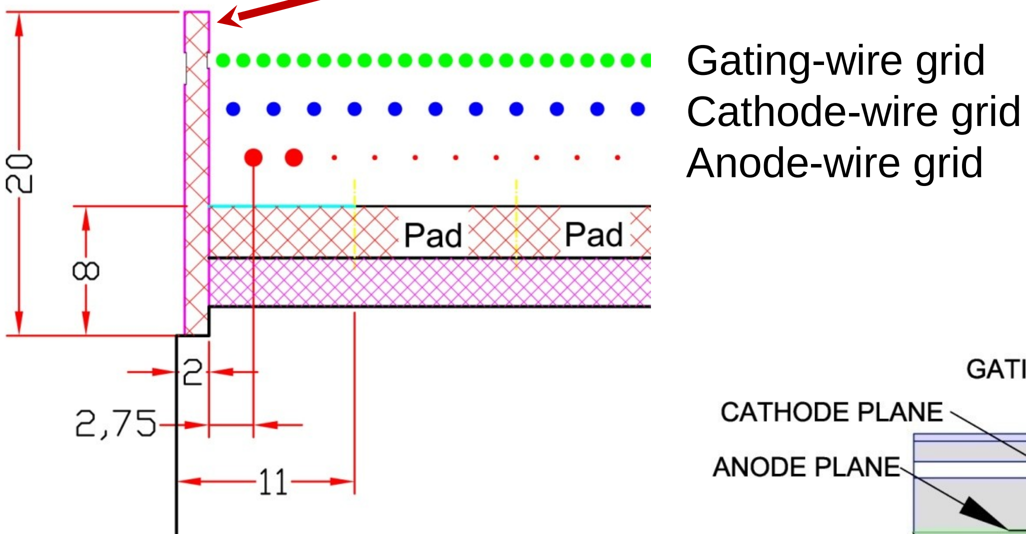
ONE OF THE 36 SECTORS

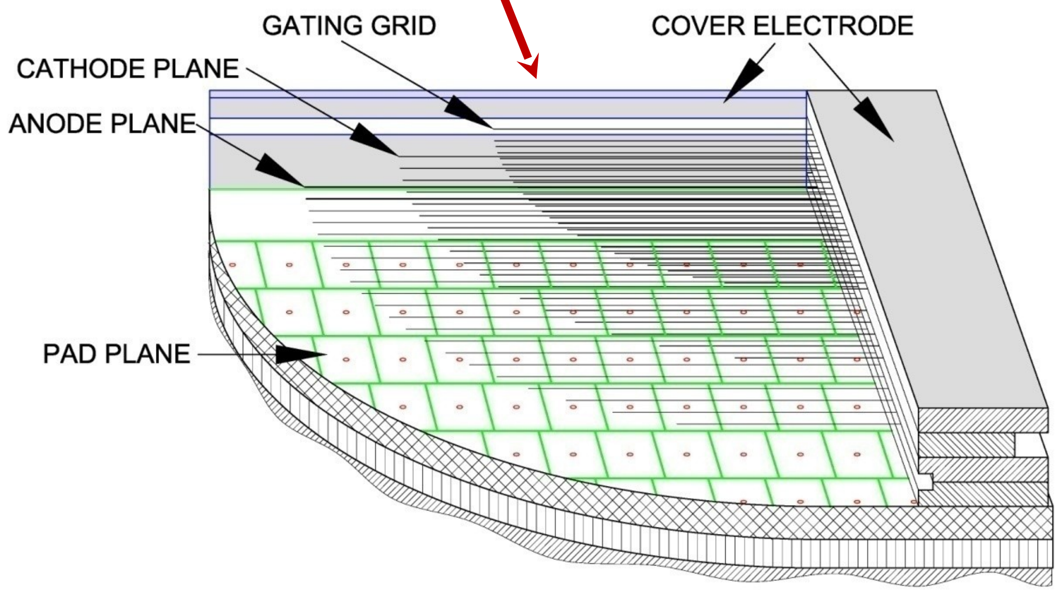


OROC
pads
6x10mm
6x15mm

IROC
pads 4x7.5mm

Positive ion leakage protection ('cover electrode')

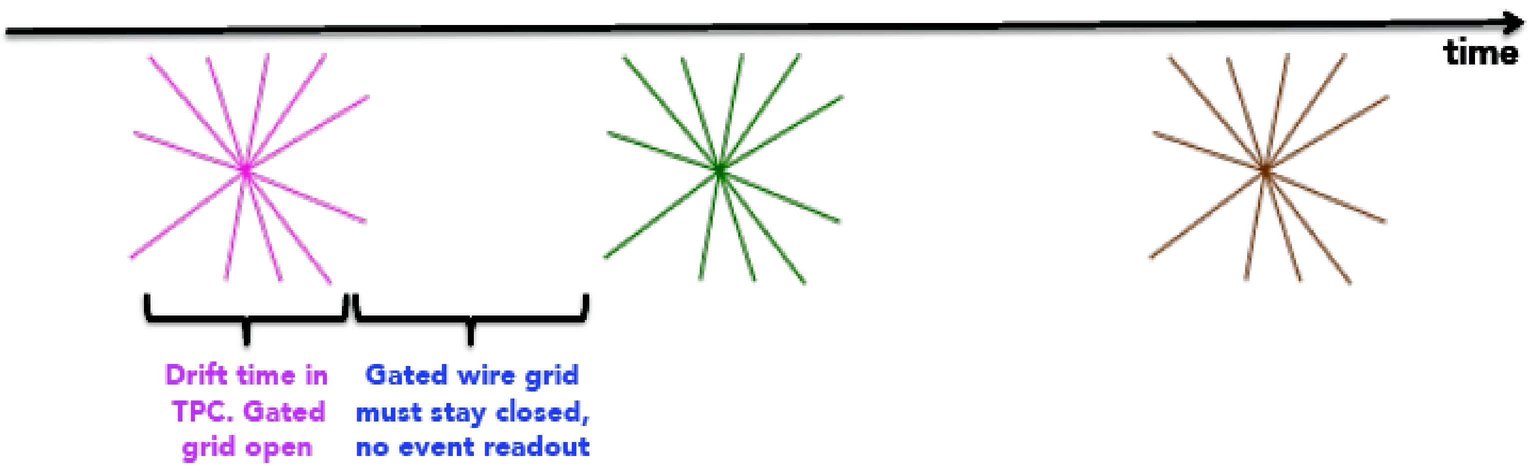




Very important to minimize ion leakage into drift volume

Gated operation in RUN1

Typical data taking with TPC in RUN1: Low luminosity Pb-Pb collisions

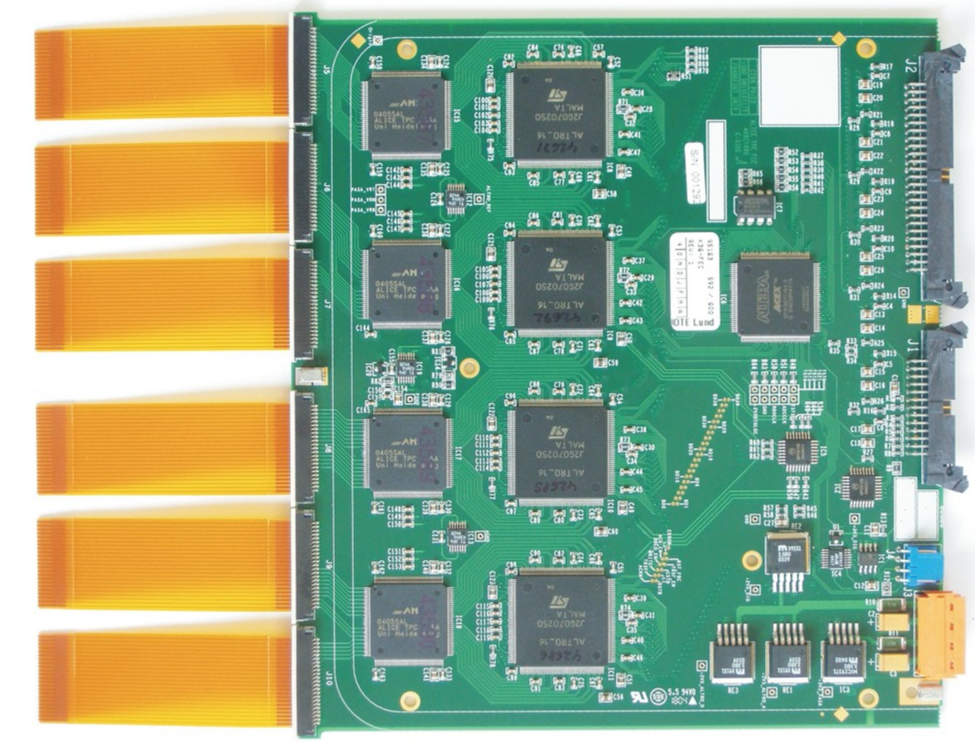


- Triggered operation with gated grid (max rate: few kHz)
- Maximum drift time of electrons in TPC: ~ 100us
- Additional gated grid closure time: 180us (to minimize ion backflow and drift distortions)

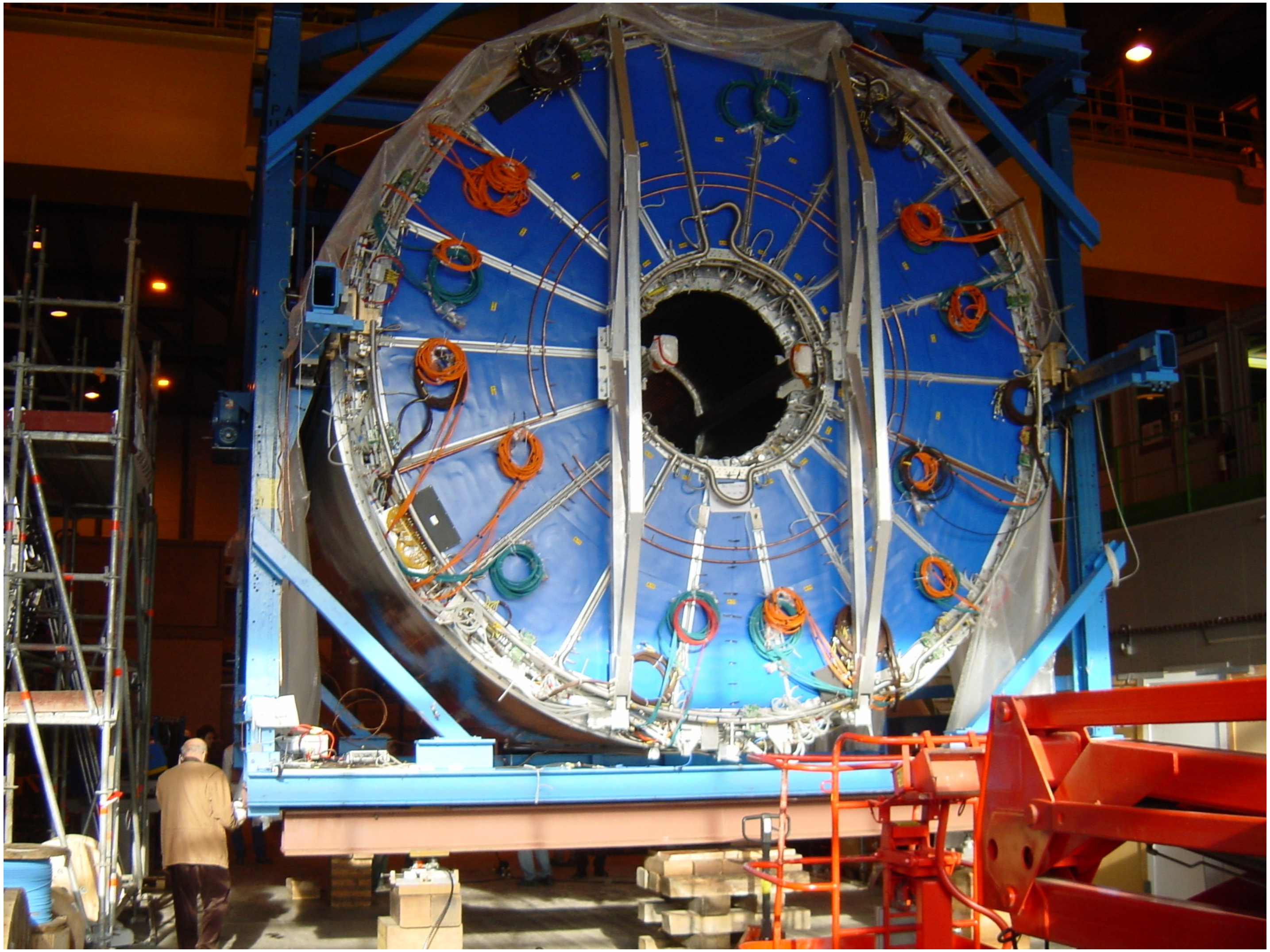
FRONT END ELECTRONICS AND READOUT

The signals from 557 568 pads are passed to Front-End Cards (FEC) via 7cm long flexible Kapton cables.
FEE is designed to cope with a signal occupancy as high as 50%. Furthermore the extremely large raw data volume (750MB/event) requires the zero suppression already in the FEE in order to fit events at the foreseen event rate into the DAQ bandwidth (216 links at 160 MB/s)

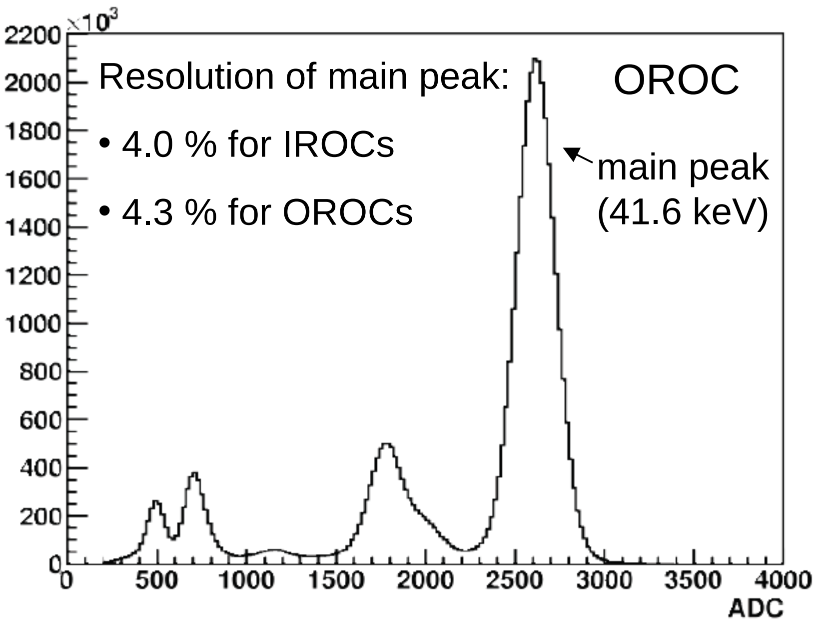
FEC with Kapton cables for 128 inputs.



Ready to move into the experiment



Gain calibration using Kr



Determine gain for each pad

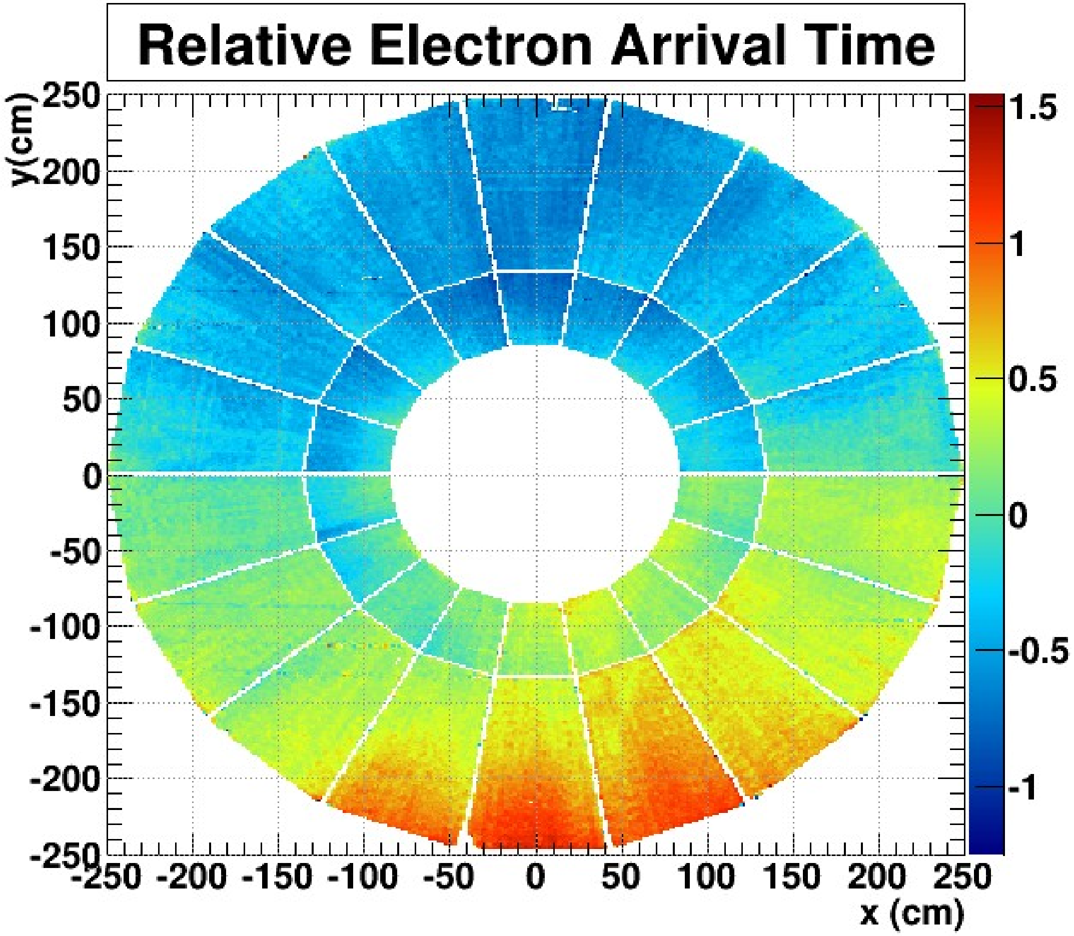
- 3 different HV settings (gains)
- High statistics: several 10^8 Kr events
- Accuracy of peak position: << 1% (design: 1.5%)

-> recent development:

Equalization on the sector-voltage level

Drift velocity calibration

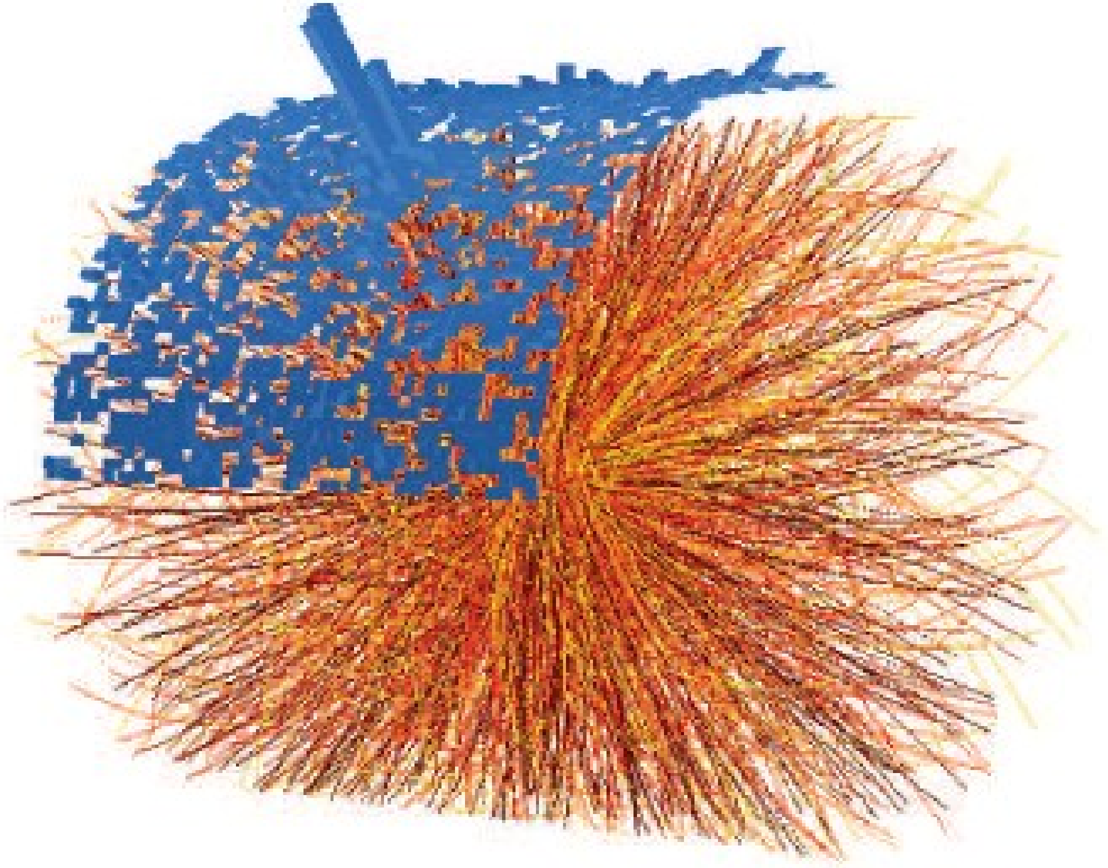
achieved temperature stability: < 50 mK
drift velocity precision: < 10^{-4}



Ne-CO2 mixtures are very sensitive to gas density
The drift velocity is measured with precision via the signal produced by stray laser light on the aluminized central electrode (by photoelectric effect)
The drift time gradient due to the pressure gradient is observed
(1 time bin = 100 ns)

ΔVd ~ 0.35 % per K
Δgain ~ 1 % per K

ALICE TPC performance in beam



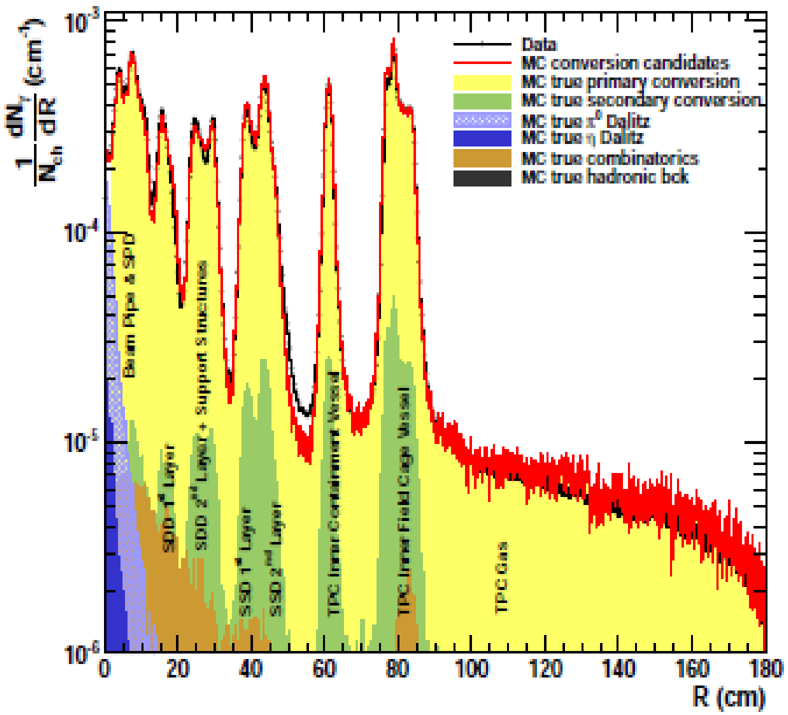
a central Pb—Pb event with a jet
charged particle multiplicity > 3500

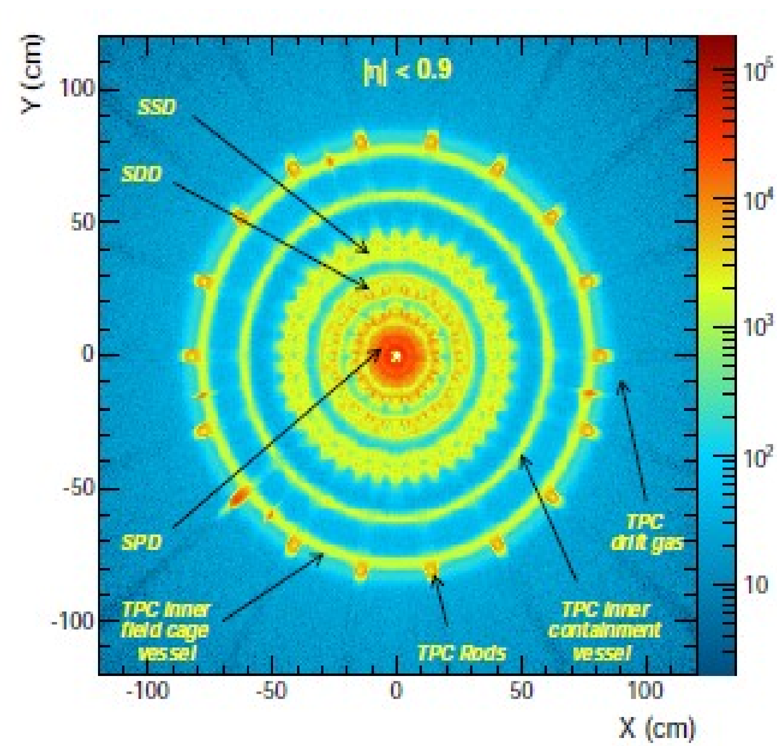
Material budget through photon conversion measurements

Inner FC 1.367% X/Xo

Outer FC 2.153% X/Xo

Radial distribution

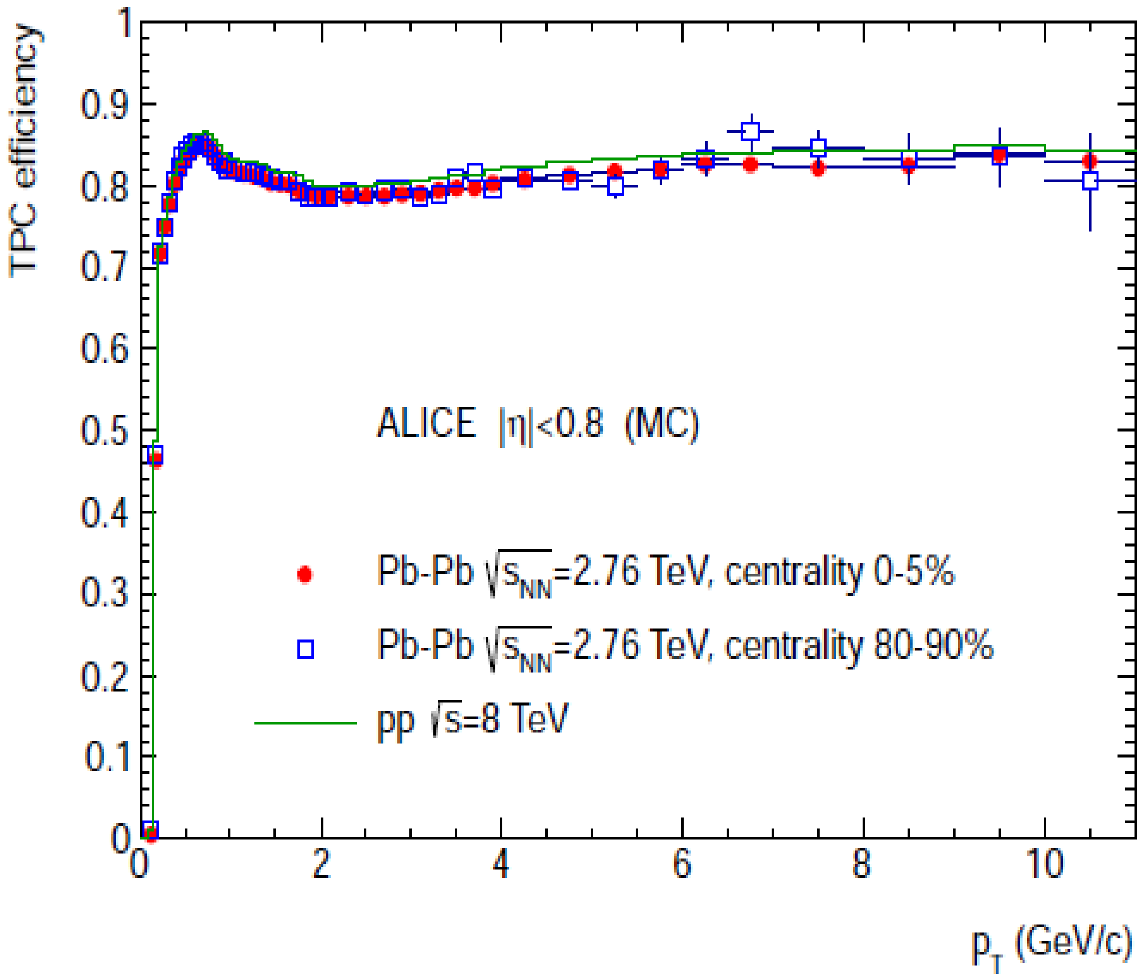




TPC begins here

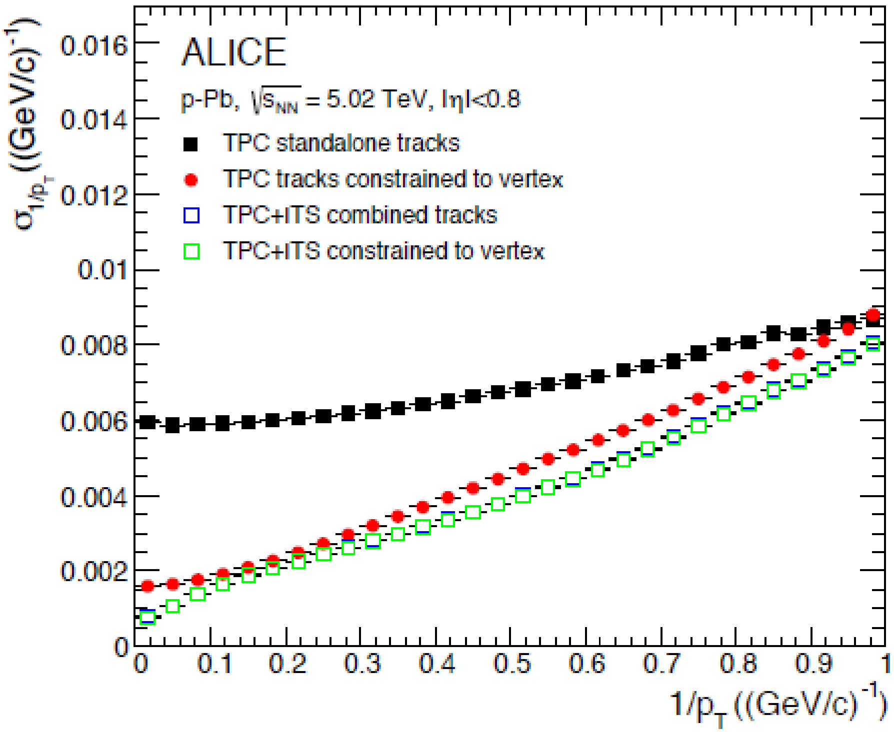
Agreement between MC and DATA: 5.5% in $|\eta|<0.9$

Tracking efficiency



Tracking accuracy

$$\frac{\sigma_{p_T}}{p_T} = p_T \, \sigma_{1/p_T}$$

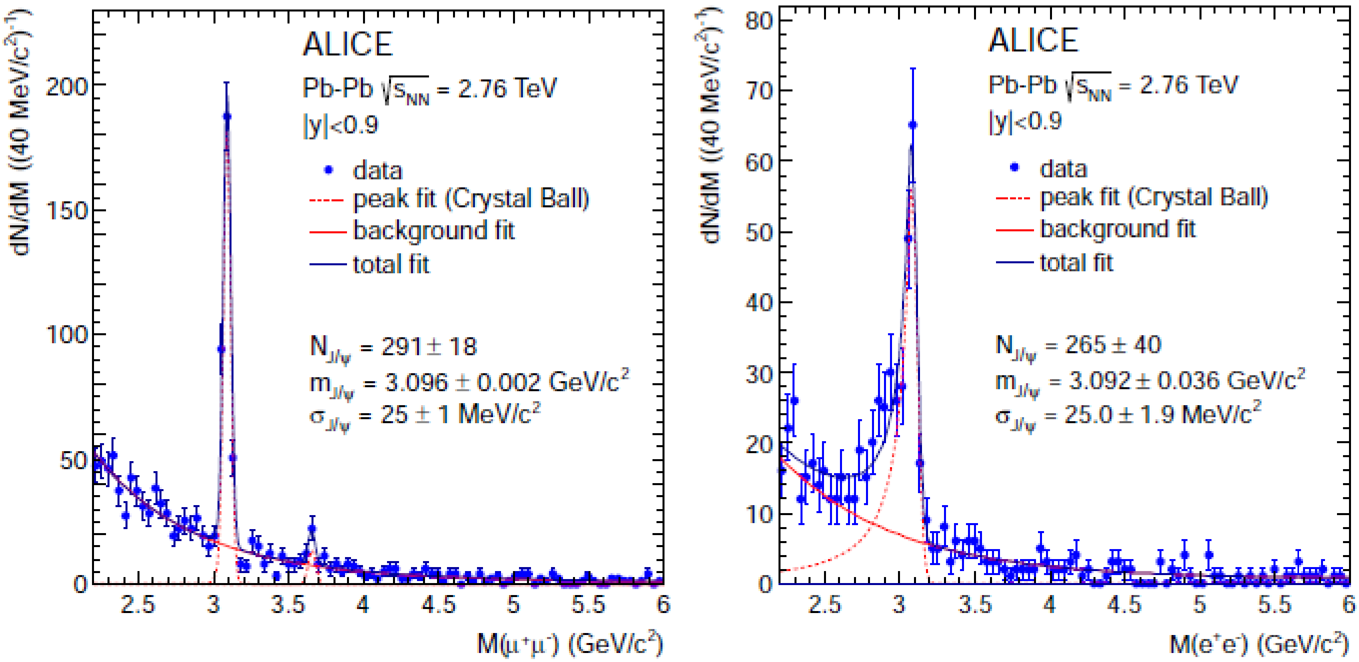


This implies

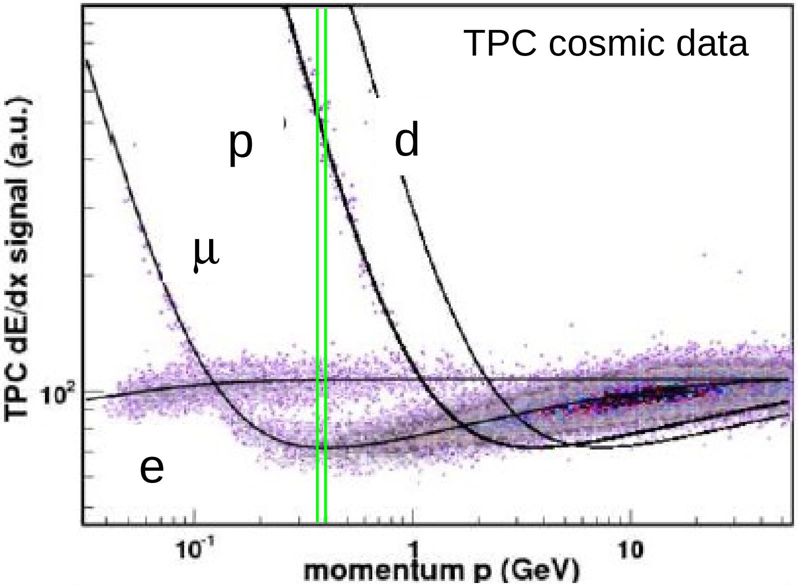
- σpT/pT ≲ 3.5 % at 50 GeV/c
- σpT/pT ≲ 1 % at 1 GeV/c
- Matching to external detectors significantly improves resolution at high pT

Despite increased multiple scattering the values for the Ar mixture are nearly unchanged because of global tracking including the ALICE ITS detector.

Tracking accuracy
J/psi measurement in ultra-peripheral Pb-Pb collisions

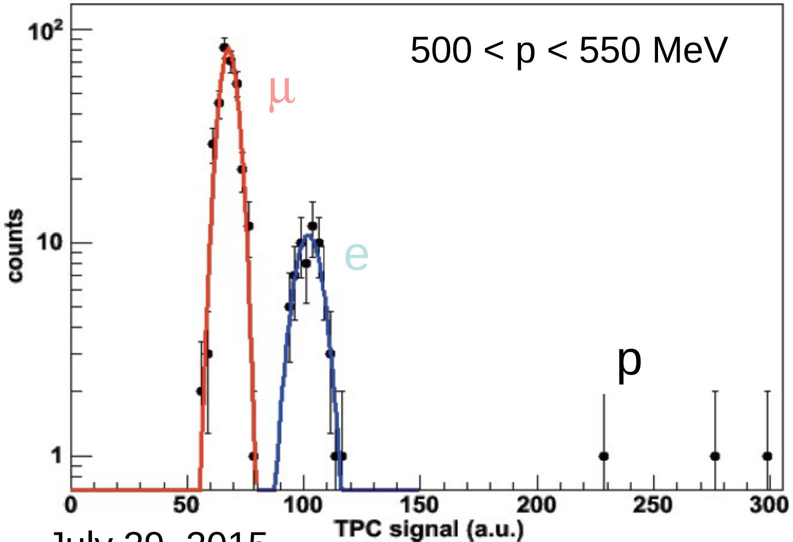


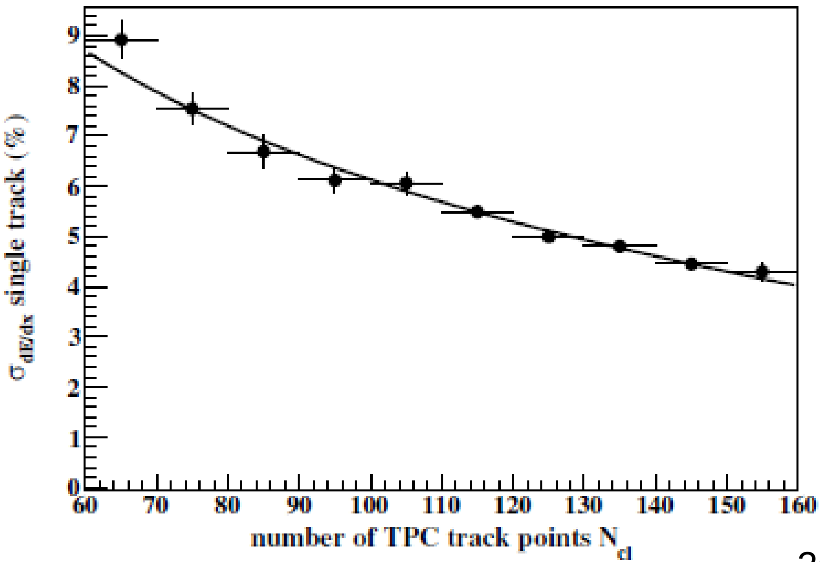
dE/dx resolution - cosmics



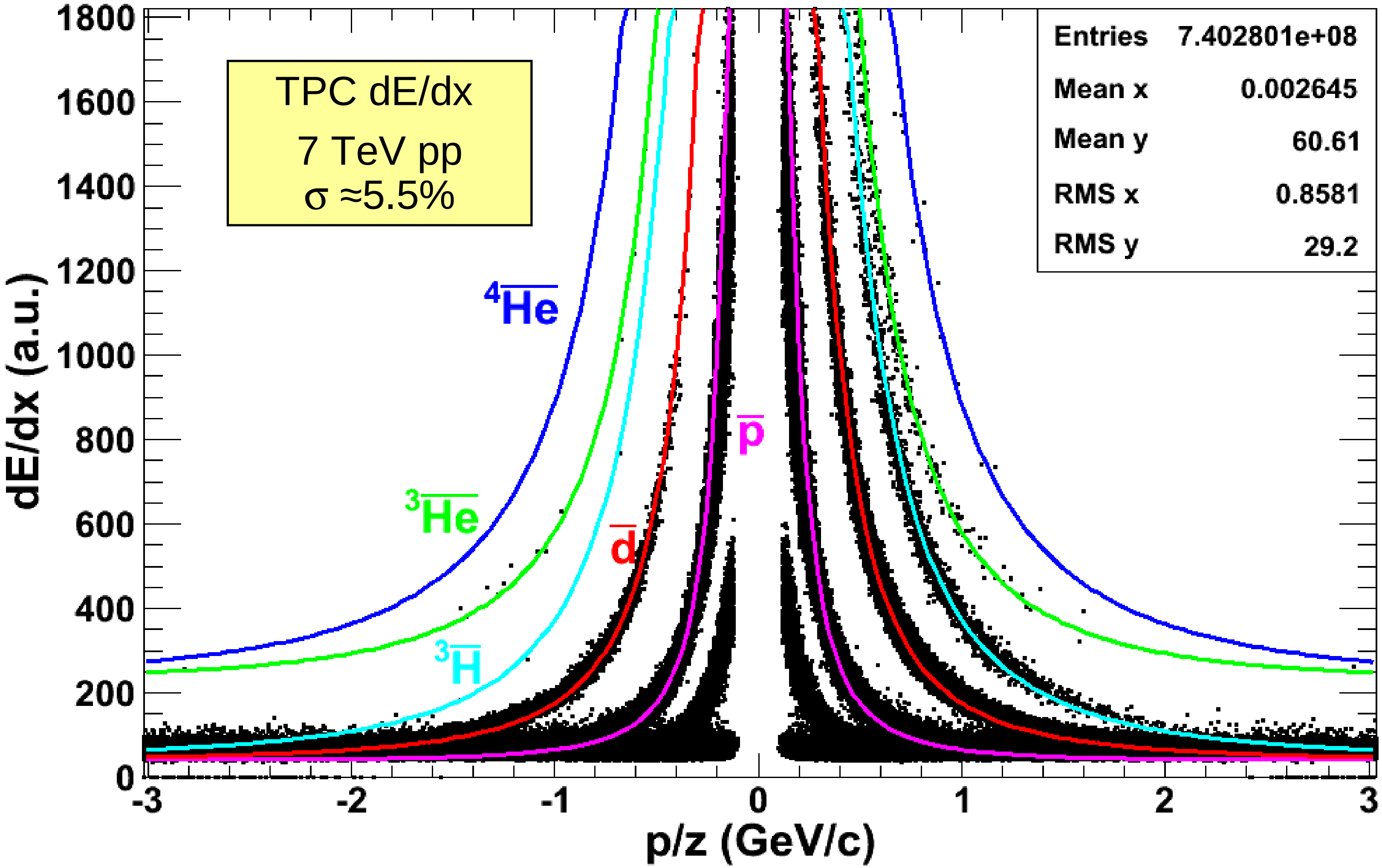
Allows particle identification up to 50 GeV/c

- Statistics: 8.3×10^6 cosmic tracks in 2008
- Design goal: 5.5 %
- Measured: < 5 %

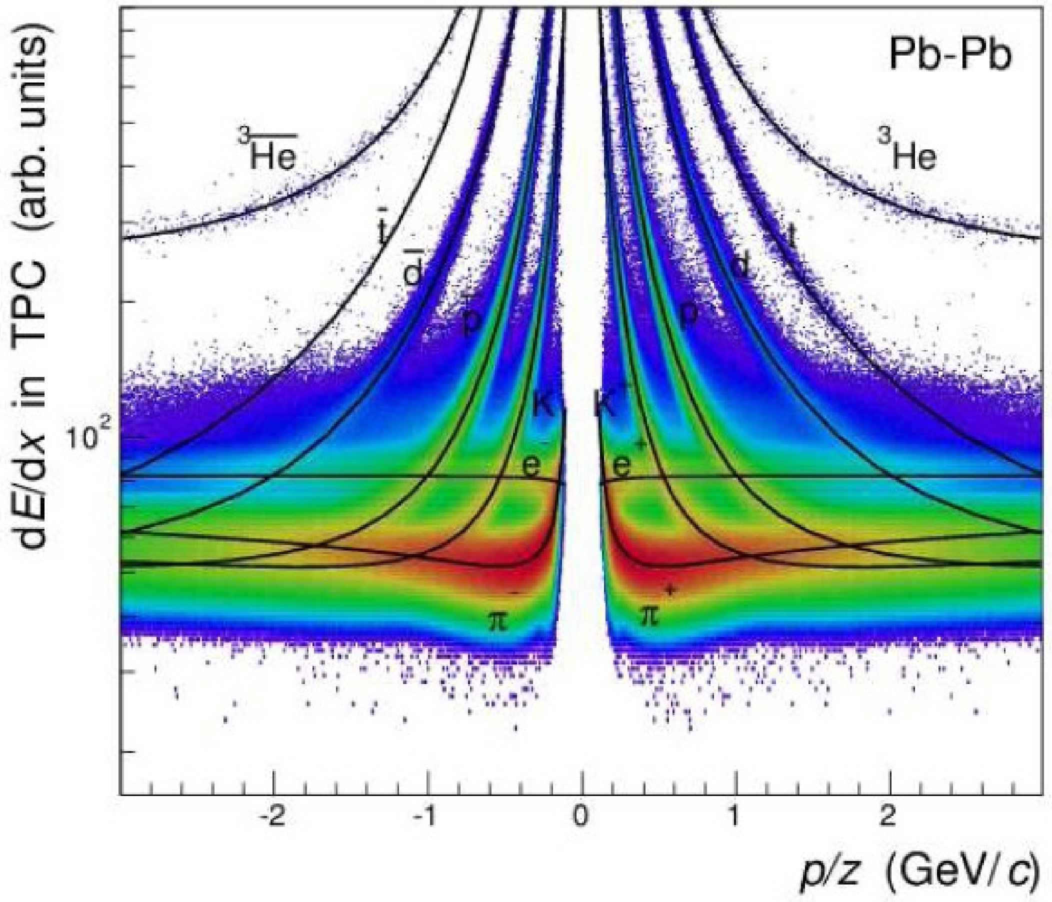




dE/dx resolution – pp Run1

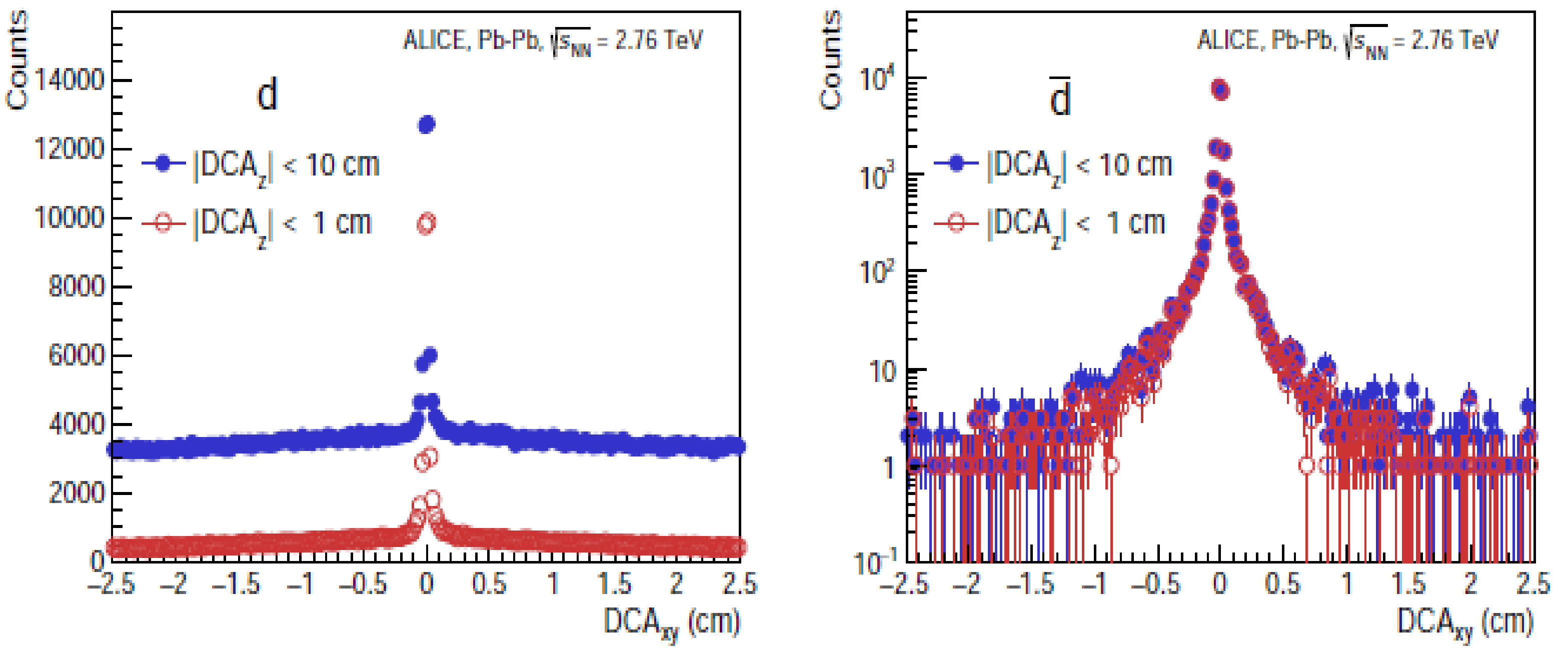


Particle identification via dE/dx measurements - Pb-Pb



arXiv:1506:08951   loose vertex cuts   centrality: 0-80%
apparent asymmetry between t and anti-t is caused by large spallation background at low momentum for tritons
anti-t/t yield is consistent with 1 after final cuts

Separation of primaries from secondaries



separation of primaries from secondaries through vertex cut -

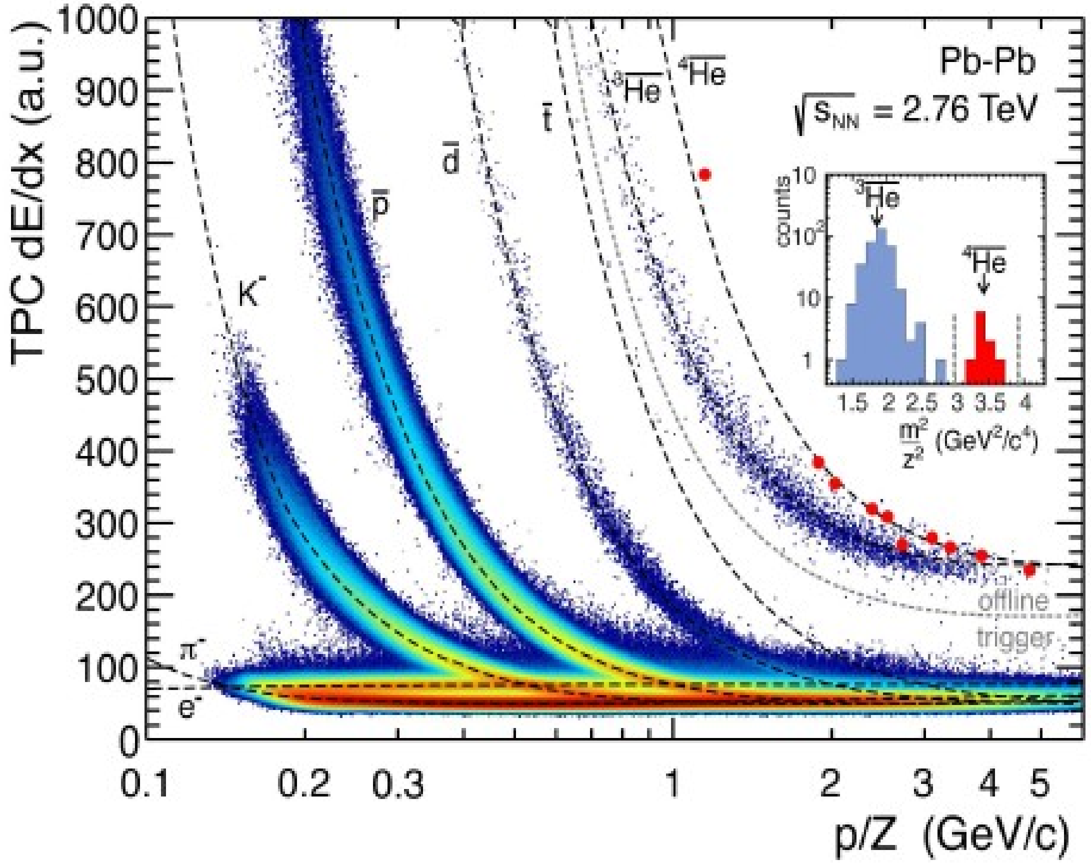
important for particles, not anti-particles

dE/dx resolution – Pb—Pb using TPC and TOF

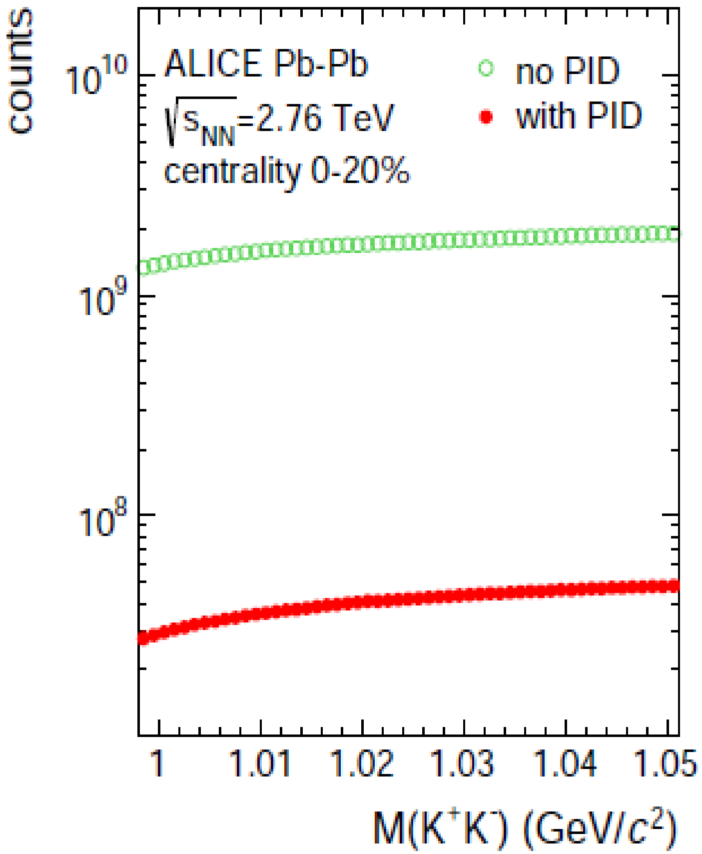
TPC dE/dx

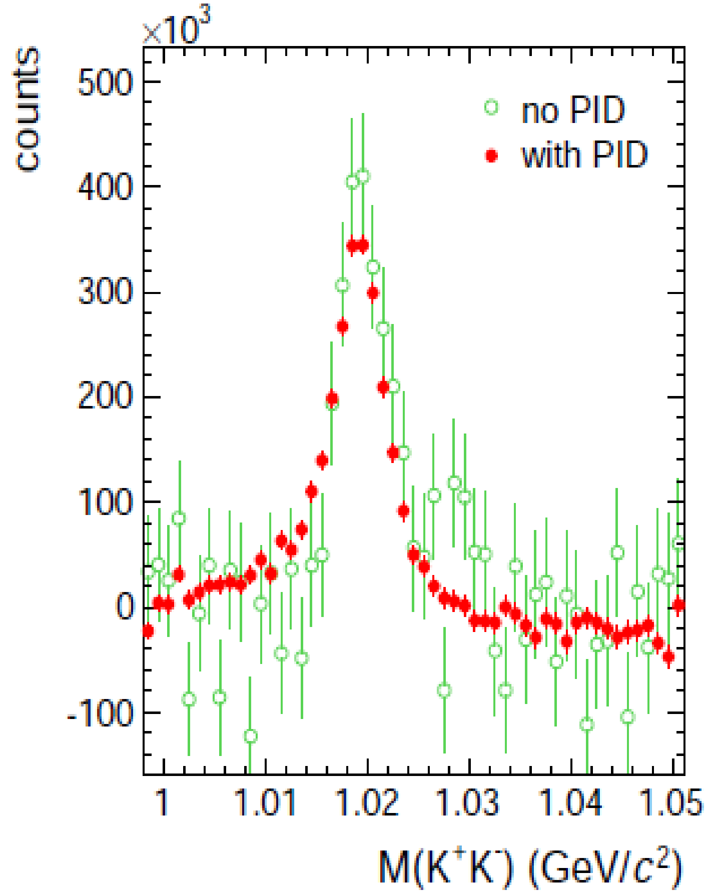
Pb--Pb
σ ≈7%

hope to achieve 5.5% with Ar in Run2



The power of PID: strongly improved signal/background





dE/dx resolution - Pb--Pb

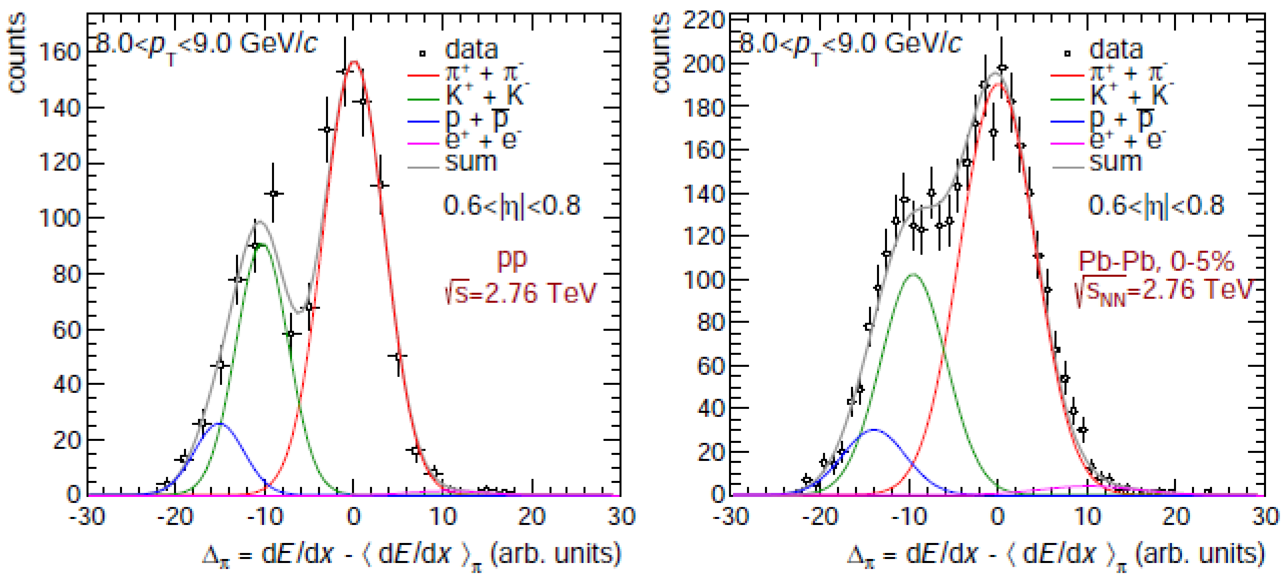
TPC dE/dx

Pb--Pb

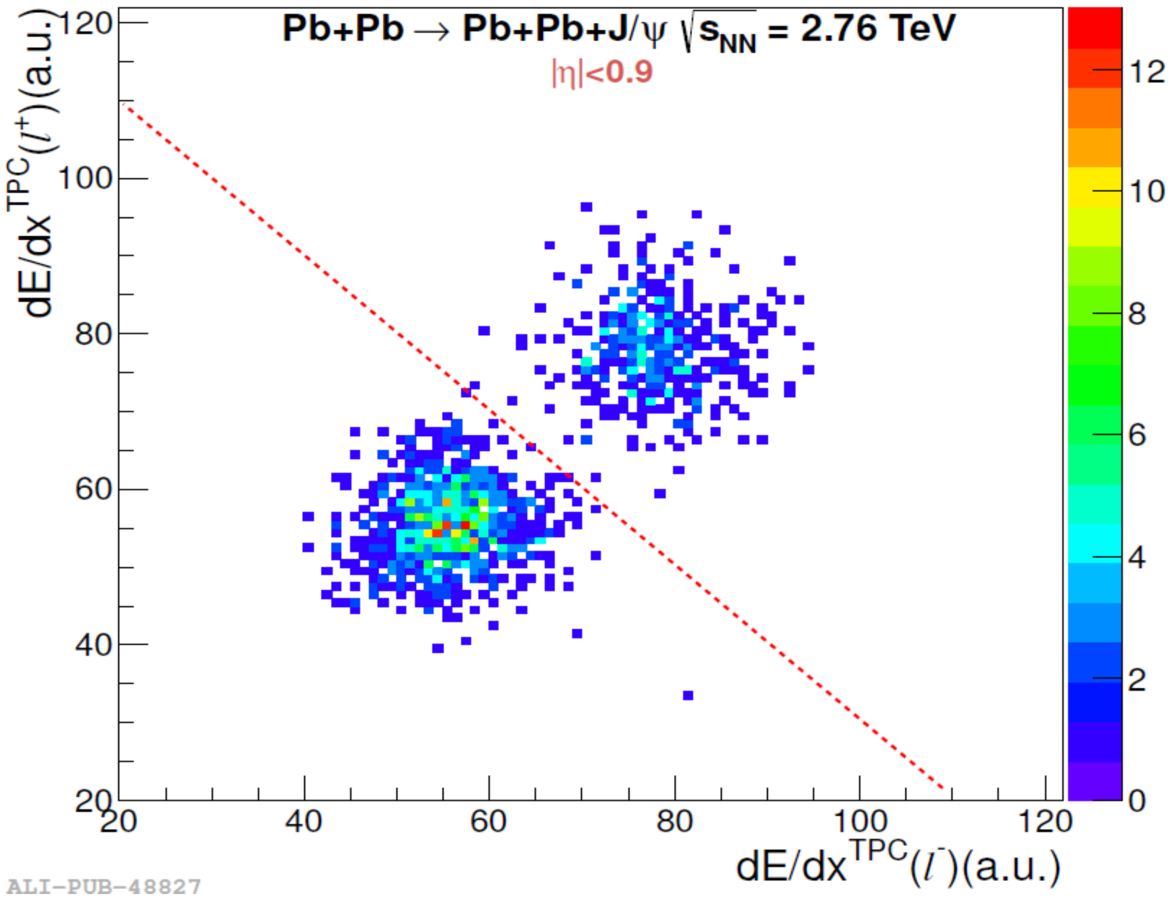
σ ≈7%

Particle identification in the relativistic rise:

pi/K/p separation possible up to 30 GeV

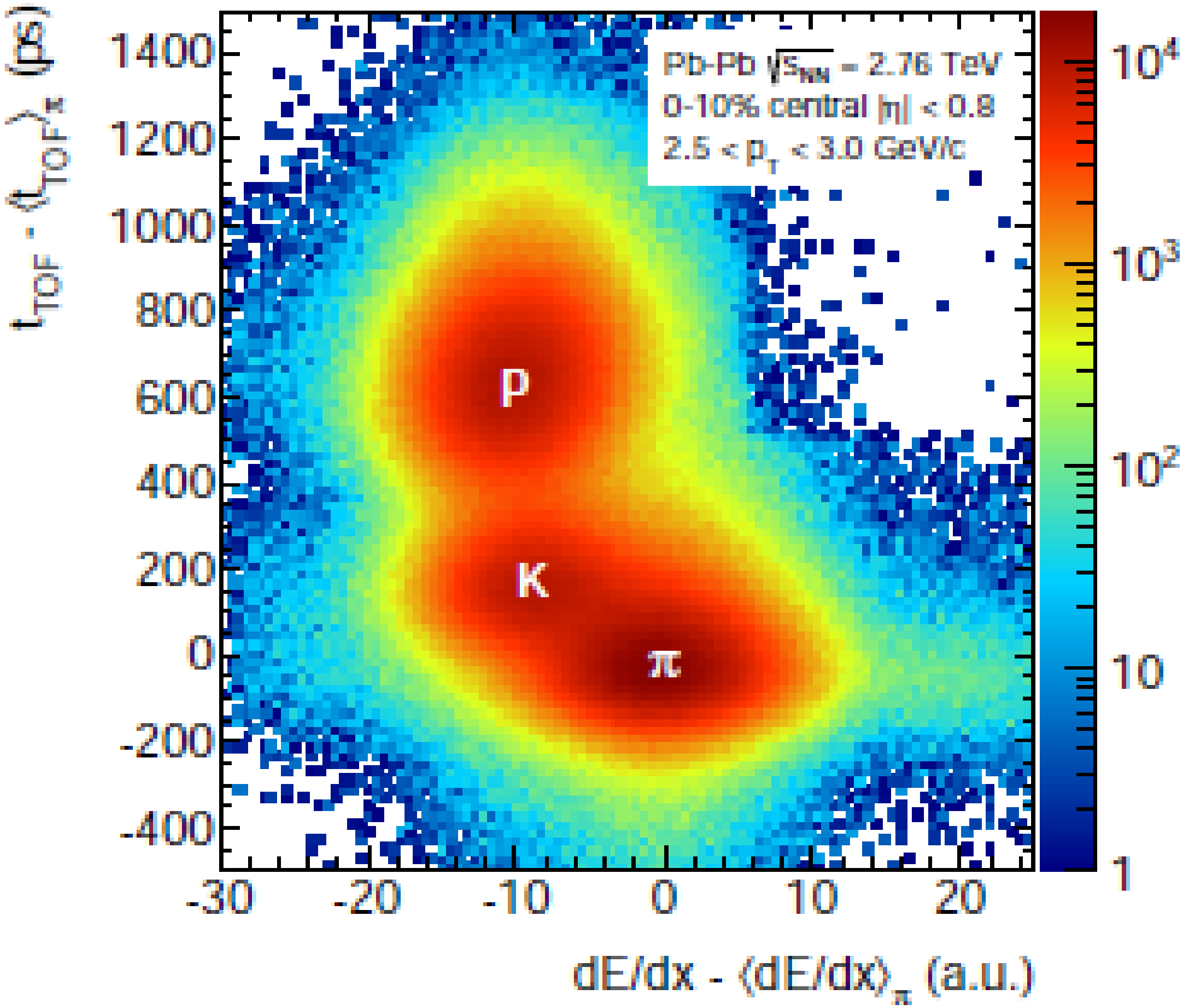


electron-muon separation in the ALICE TPC



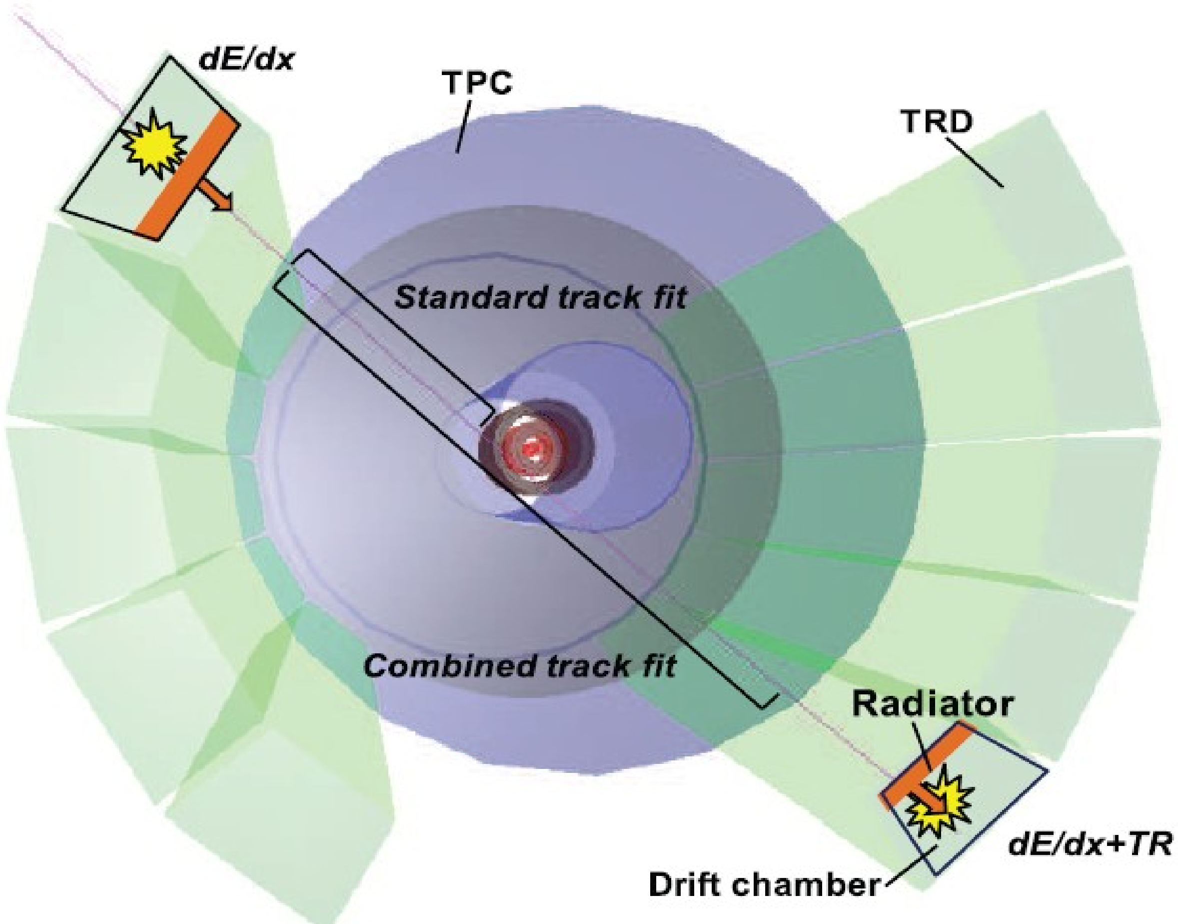
dE/dx of the positive lepton as a function of the negative one, as measured in the TPC for J/ψ candidates

muons and electrons are clearly separated, with the latter showing an higher dE/dx



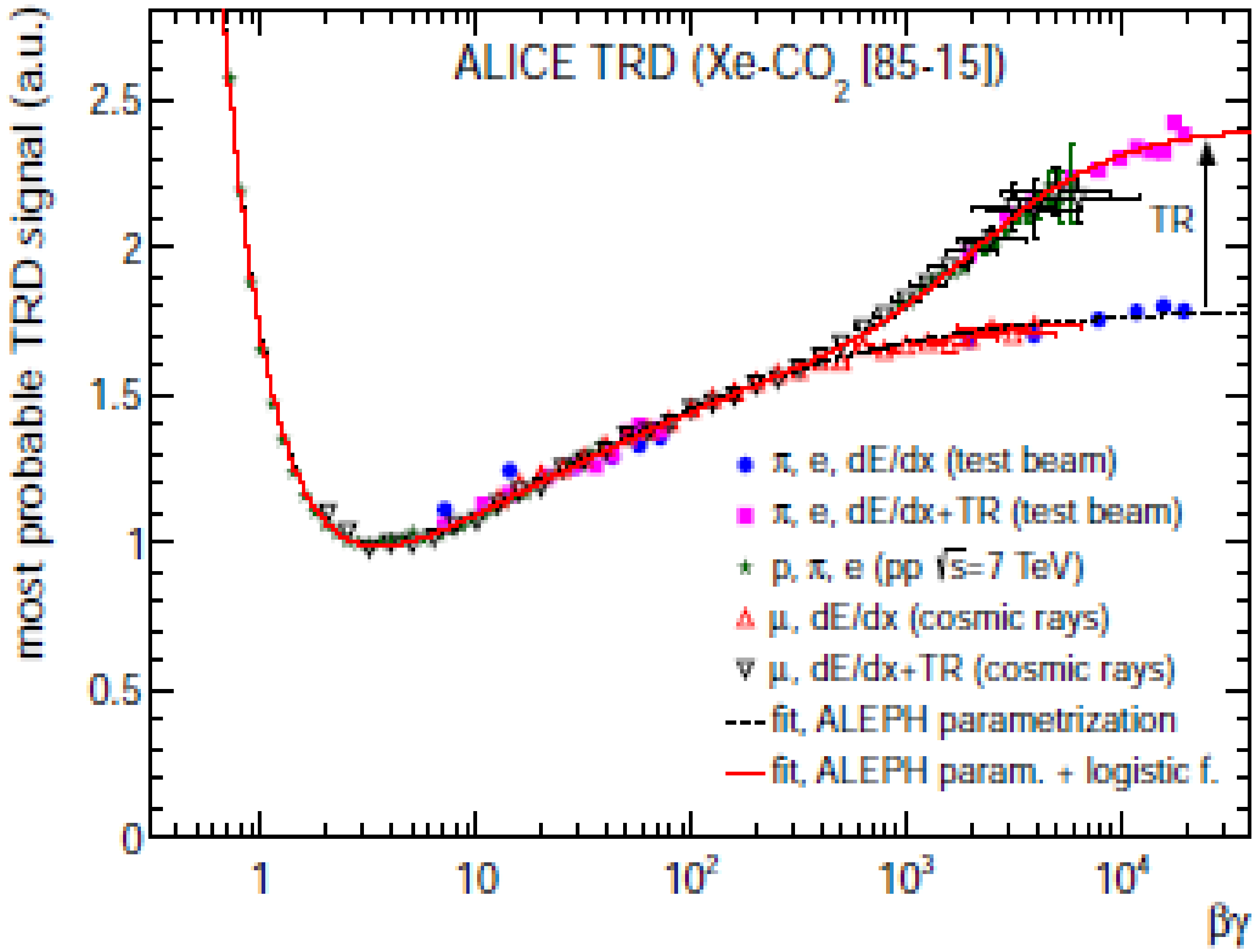
Combined pion identification with TOF and with dE/dx in the TPC.

TRD performance with TPC-TRD combination and cosmics

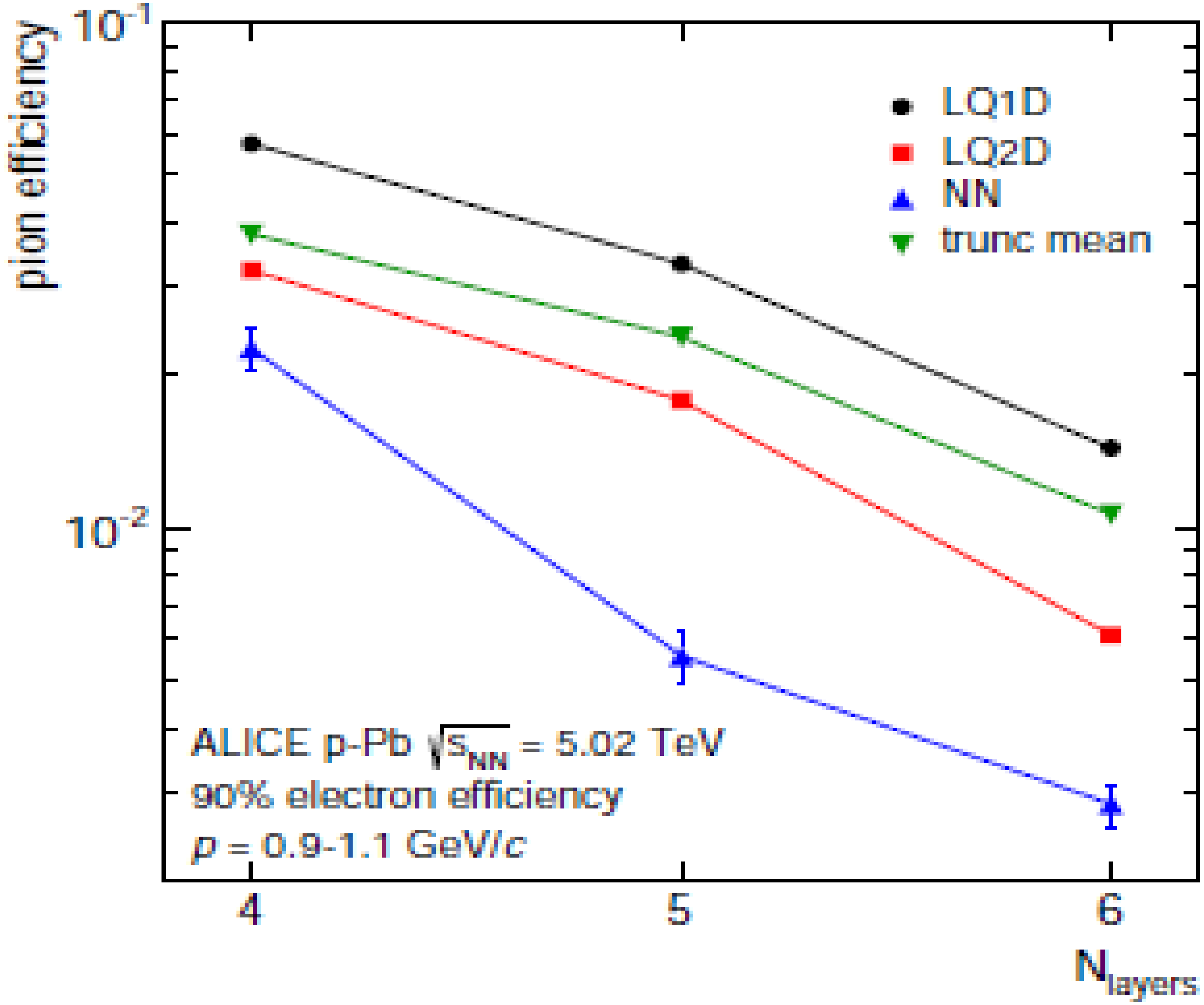


Separation of energy deposit from dE/dx and from transition radiation via measurement of cosmics through the TPC and the TRD

TRD performance with TPC-TRD combination and cosmics



TRD performance – pion rejection



Plans for Run 2   2015 - 2017

- Pb—Pb interaction rate > 10 kHz with luminosity levelling
- Ar/CO_2 gas mixture
- Double read-out rate to about 500 Hz for central collisions by new read-out control unit (RCU2) and increased fiber-optics band width
- Partial on-line calibration and full on-line cluster finding

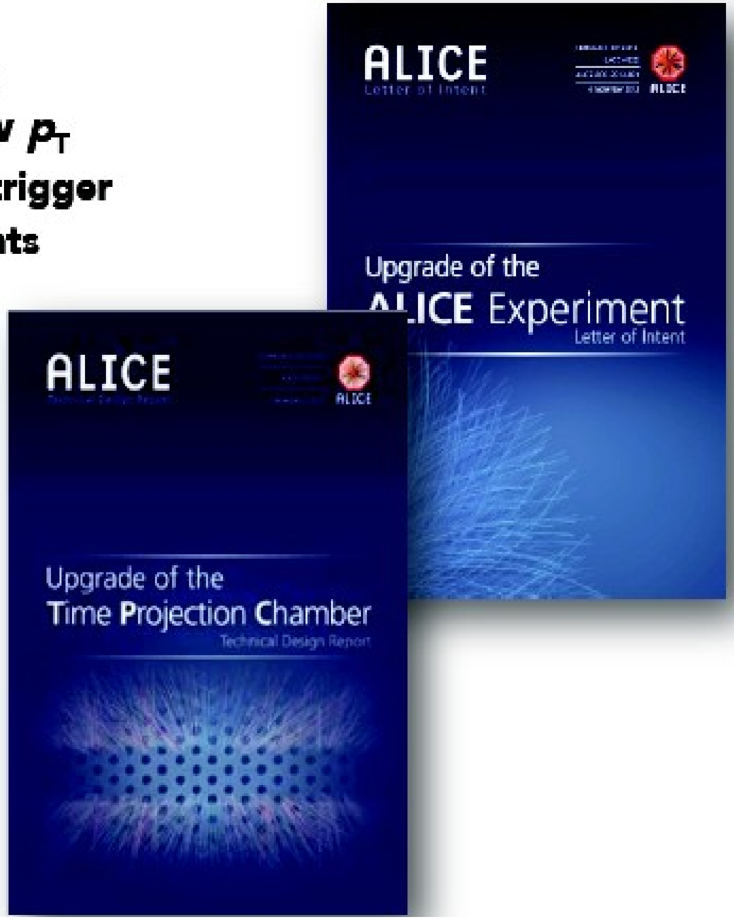
Run 3-4 plans – 2020 - 2027

- Replace current MWPC read-out chambers with GEM based chambers
- Provide continuous read-out for 50 kHz Pb—Pb collisions
- Complete on-line calibration and partial on-line tracking to correct for space charge distortions on a 1-2 ms basis and to reduce data volume
- Upgrade to take place in 2018-2019 (LS2)
- Fully approved by all CERN committees

Slides of ALICE TPC upgrade: courtesy of Christian Lippmann

ALICE upgrade strategy (1)

- **Motivation:** Focus on high-precision measurements of rare probes at low p_T
  - can not be selected with hardware trigger
  - need to record large sample of events
- **Strategy:** Read out all Pb–Pb interactions at maximum interaction rate of 50 kHz
- **When:** 2nd LHC Long Shutdown (LS2): 2018/19



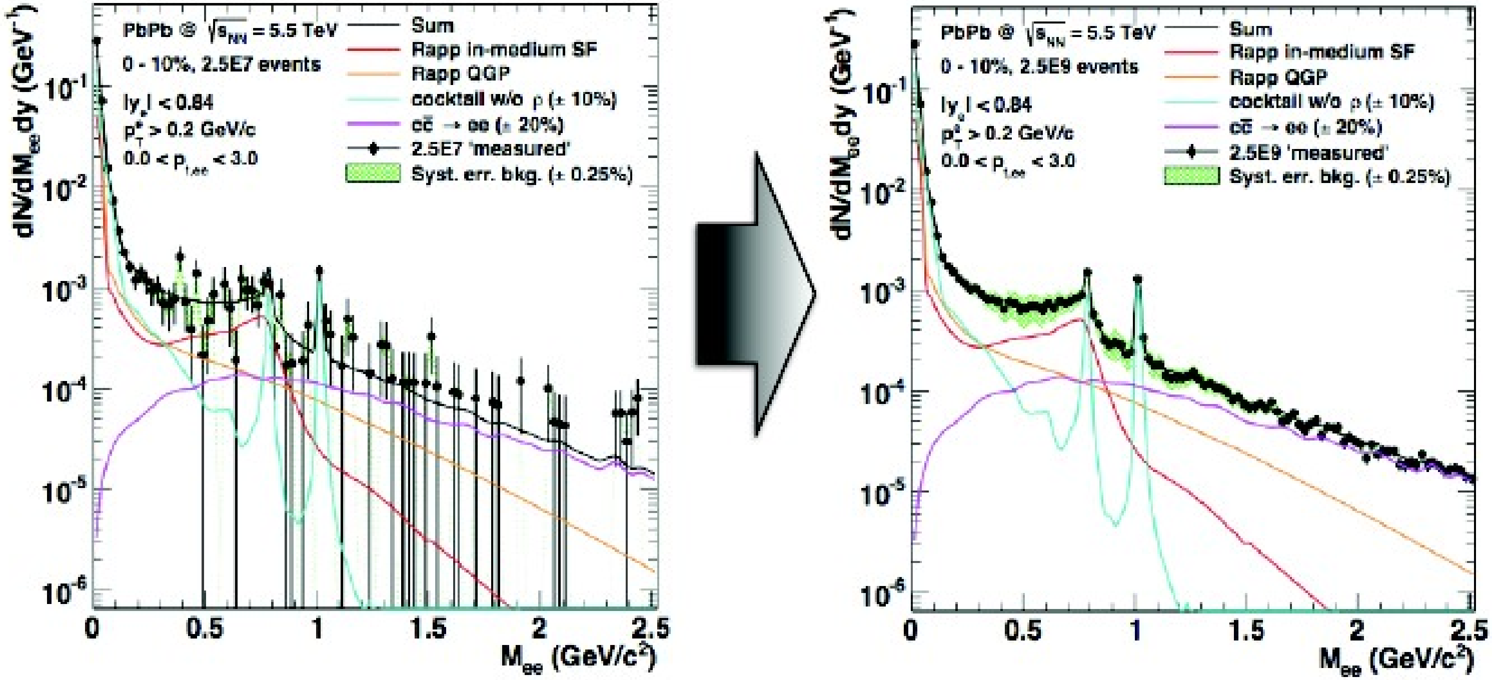
- ALICE Upgrade LOI: https://cds.cern.ch/record/1475243
- ALICE TPC Upgrade TDR: https://cds.cern.ch/record/1622286
- Addendum to the TPC TDR: https://cds.cern.ch/record/1984329

ALICE upgrade strategy (2)

- Example: Low mass di-leptons

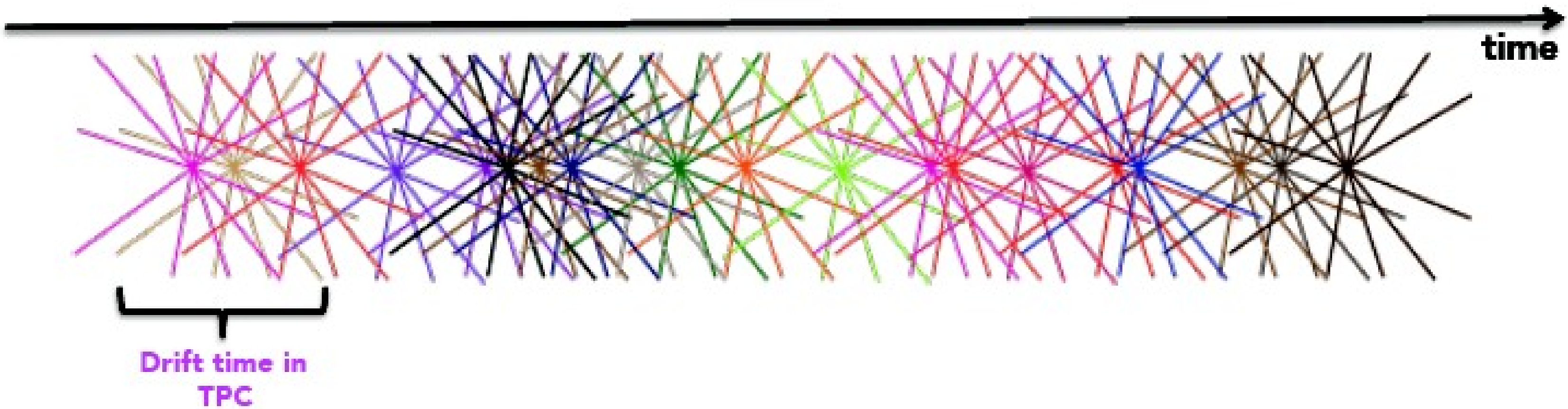
Simulation: Current data rate

Simulation: Upgrade scenario



Continuous operation in RUN3

Typical data taking with TPC in RUN3: High luminosity Pb-Pb collisions



- **Maximum drift time of electrons in TPC: ~ 100us**
- **Average event spacing: ~20us**

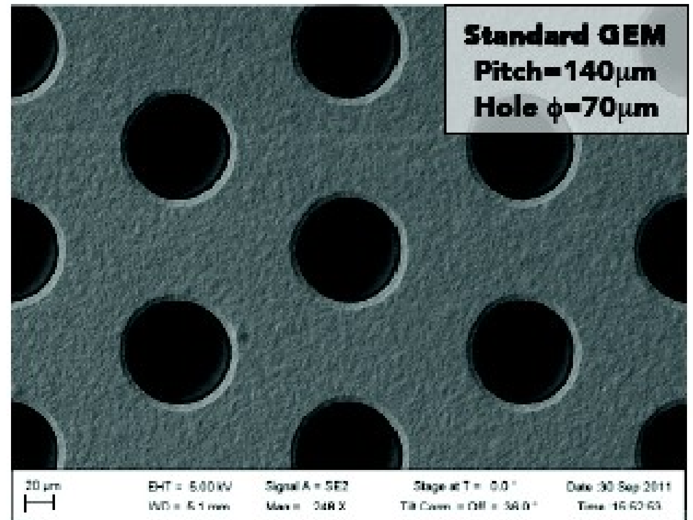
- **Event pileup**
- **Triggered operation does not make sense**
- **Minimize ion backflow (IBF) in different way**

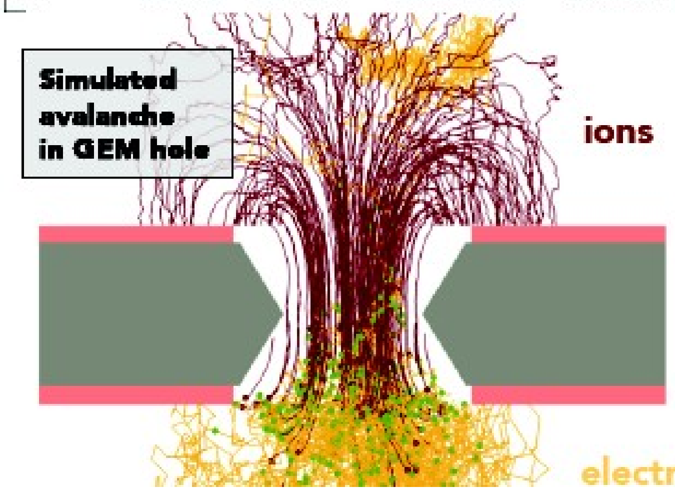
→ **Continuous read-out**
Micro Pattern Gas Detectors

GEM read-out

- Requirements for read-out system:
  - IBF < 1% at effective gas gain 2000
  - Local energy resolution <12% (σ) for ^{55}Fe
  - Stable operation under LHC condition

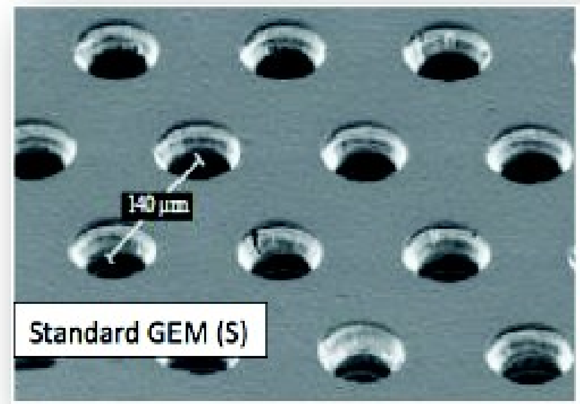
- Implementation:
  - Replace MWPC read- out system with GEMs
    - low ion backflow (IBF)
    - high rate capability
    - no ion tail
    - continuous read-out possible
  - Gas with fast ion drift: $Ne\text{-}CO_2$
  - New read-out electronics

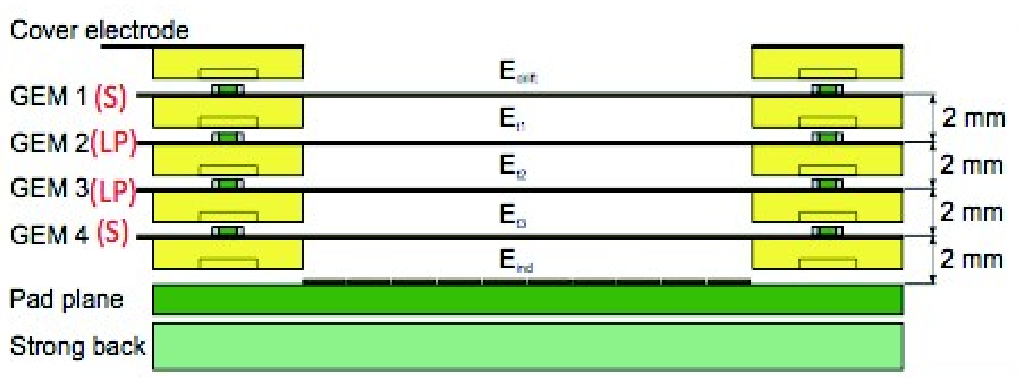


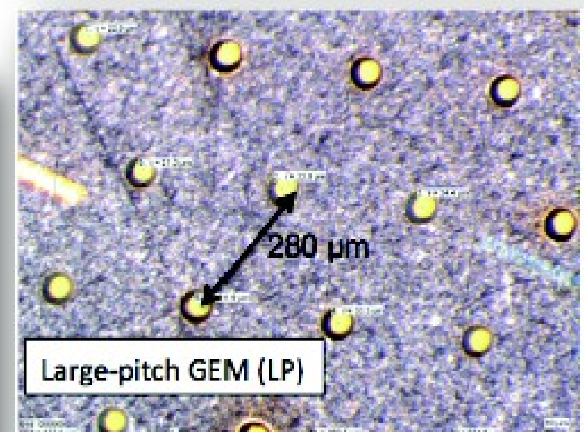


IBF optimized configuration

- **Satisfactory performance could not be achieved with 3 GEM stack**
- **Best results in terms of IBF and energy resolution:**
  - 4 GEM stack
  - S-LP-LP-S configuration
  - S: standard GEM foils
  - LP: large hole pitch foils
  - Optimized V settings: V_{GEM}, E_T (transfer fields)



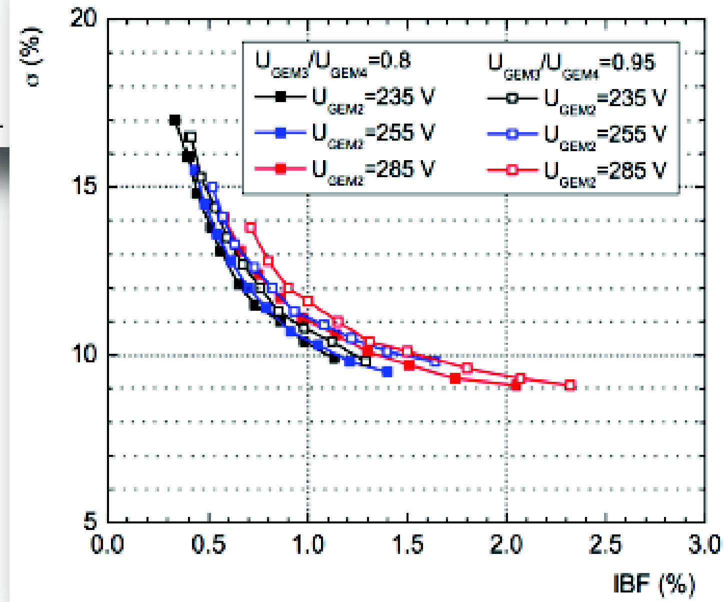




IBF optimized configuration

Drift Field				$= 0.4\,\mathrm{kV/cm}$
Potential at top of GEM 1			$= 3150\,\mathrm{V}$	
ΔU_{GEM1}	$= U_{1\mathrm{top}} - U_{1\mathrm{bot}}$	$= 270\,\mathrm{V}$		
Transfer Field 1 (E_{T1})	$= (U_{1\mathrm{bot}} - U_{2\mathrm{top}})/0.2\,\mathrm{cm}$			$= 4.0\,\mathrm{kV/cm}$
Potential at top of GEM 2			$= 2080\,\mathrm{V}$	
ΔU_{GEM2}	$= U_{2\mathrm{top}} - U_{2\mathrm{bot}}$	$= 250\,\mathrm{V}$		
Transfer Field 2 (E_{T2})	$= (U_{2\mathrm{bot}} - U_{3\mathrm{top}})/0.2\,\mathrm{cm}$			$= 2.0\,\mathrm{kV/cm}$
Potential at top of GEM 3			$= 1430\,\mathrm{V}$	
ΔU_{GEM3}	$= U_{3\mathrm{top}} - U_{3\mathrm{bot}}$	$= 270\,\mathrm{V}$		
Transfer Field 3 (E_{T3})	$= (U_{3\mathrm{bot}} - U_{4\mathrm{top}})/0.2\,\mathrm{cm}$			$= 0.1\,\mathrm{kV/cm}$
Potential at top of GEM 4			$= 1140\,\mathrm{V}$	
ΔU_{GEM4}	$= U_{4\mathrm{top}} - U_{4\mathrm{bot}}$	$= 340\,\mathrm{V}$		
Collection/Induction Field (E_{ind})	$= U_{4\mathrm{bot}}/0.2\,\mathrm{cm}$			$= 4.0\,\mathrm{kV/cm}$

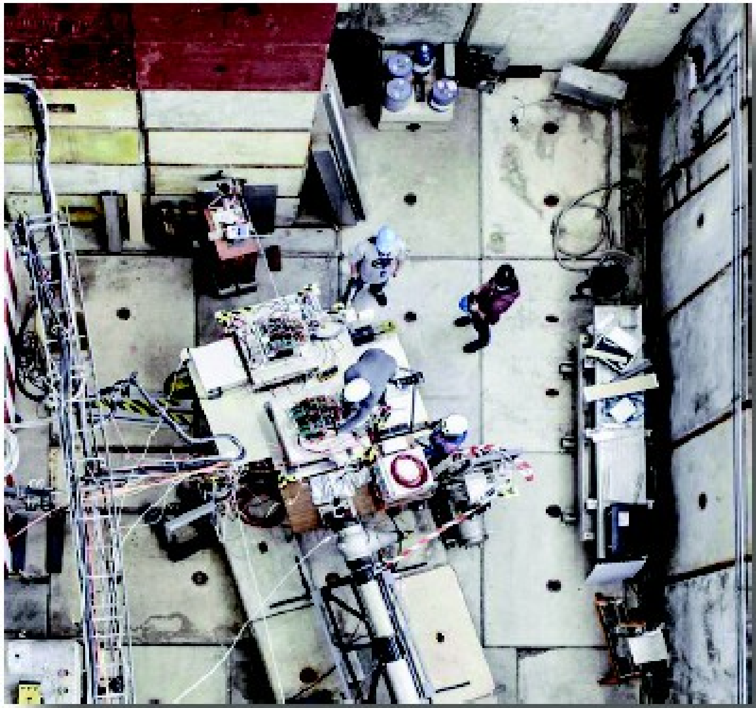
- **IBF optimized settings:**
  - **high E_{T1} & E_{T2}**
  - **low E_{T3}**
  - **$V_{GEM1} \approx V_{GEM2} \approx V_{GEM3} < V_{GEM4}$**

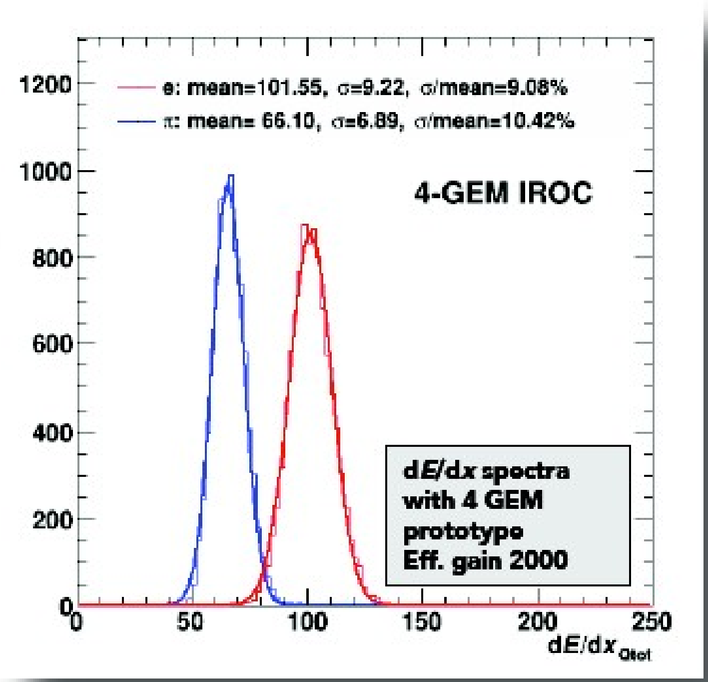


- **Achieved performance:**
  - **0.63 % IBF at σ(5.9 keV) ≈ 11.3 %**
- **Typical voltage settings are shown above (eff. gas gain is always 2000)**

Prototype beam tests: PID

- 4GEM IROC prototype tests: d*E*/dx resolution measurements at CERN PS





– Excellent d*E*/dx resolution: ~10% (IROC only)
– Performance equal to existing MWPC IROCs

TPC upgrade for Run3

Summary and outlook

- Major upgrade of the ALICE experiment for installation in 2018/19
- Continuous TPC read-out to inspect 50 kHz Pb-Pb collisions
- New read-out chambers based on 4 GEM stacks
- Required ion backflow, energy resolution and stability achieved
- New electronics for continuous read-out
- 2-stage reconstruction scheme able to retain physics performance
- Technical Design Report endorsed
- Successfully tested ROC prototypes
- GEM foil production starts in August
- ROC assembly starts next year

summary

- The ALICE TPC is the key detector for particle ID and tracking in the central barrel

- Resolutions in momentum and dE/dx exceeding the original specifications have been achieved at track densities corresponding to dN/dy = 2000 and at interaction rates of 5 kHz for Pb—Pb collisions

- For the upcoming Run 2 at full LHC energy the TPC read-out will be significantly upgraded to record 500 Hz central Pb—Pb collisions

- On-line calibration and data reduction is key to the success of this run

- For Run 3 in 2020+ 50 kHz operation is planned. This implies new end-plate read-out technology (GEMS) and continuous read-out along with on-line calibration and tracking

The anticipated physics output is well worth
the major effort to realize these ambitious plans

We owe much of this success to the original ideas and insights of David Nygren, first realized for the PEP4 TPC

Thank you!