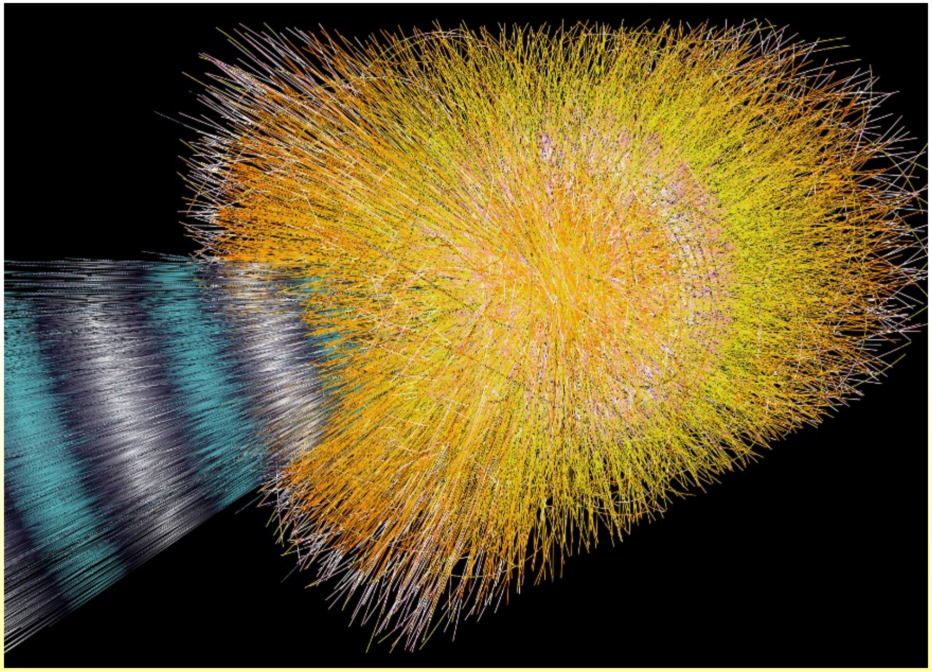
The ALICE Time Projection Chamber

(thanks to J. Wiechula for most of the slides)

Goal of these slides

- Give you a feeling for all the layers of complexity involved in a real detector
- Focus on one detector rather than many

ALICE Design Considerations



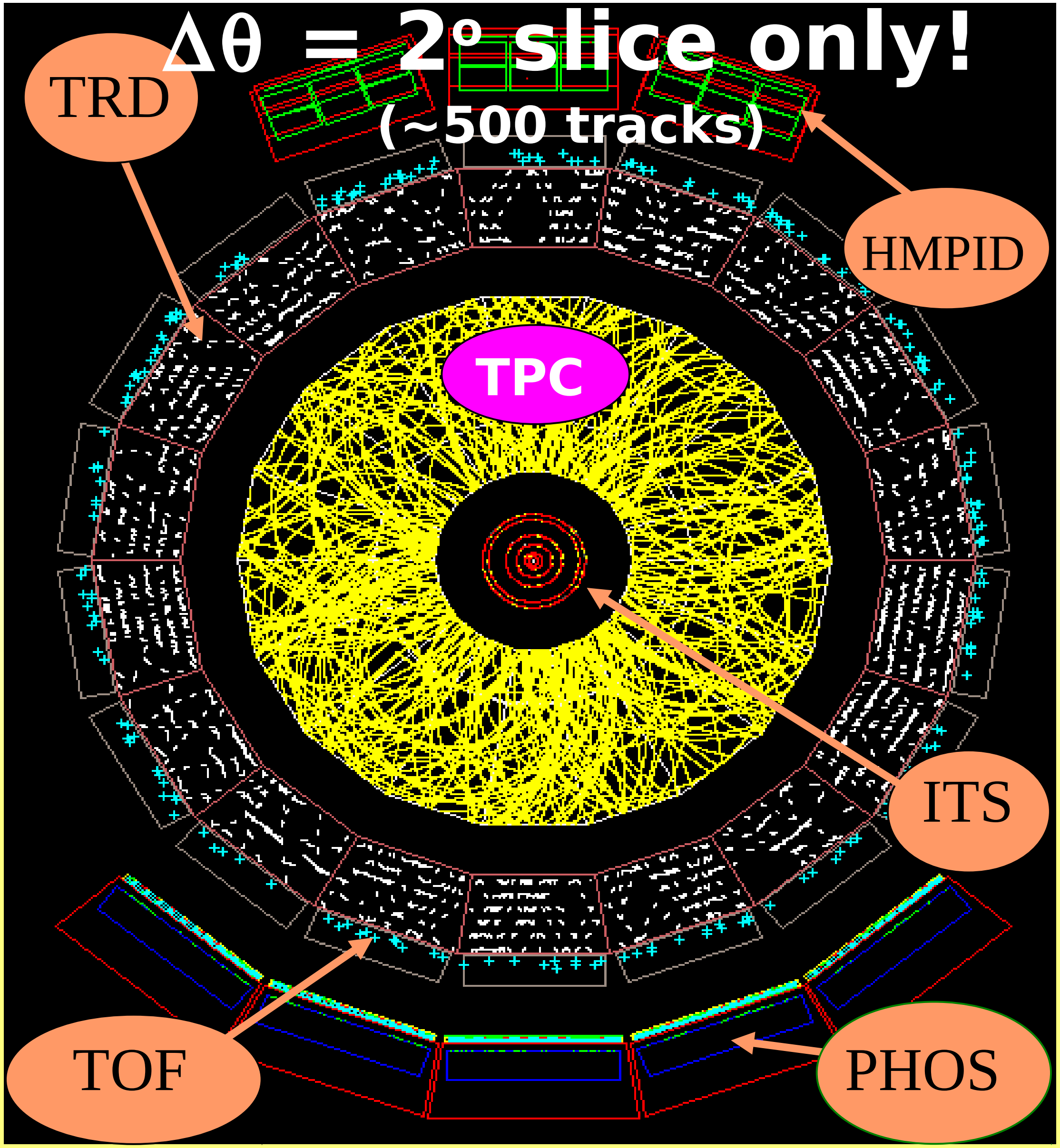
Pb+Pb simulated event

dN/dy design = 8000

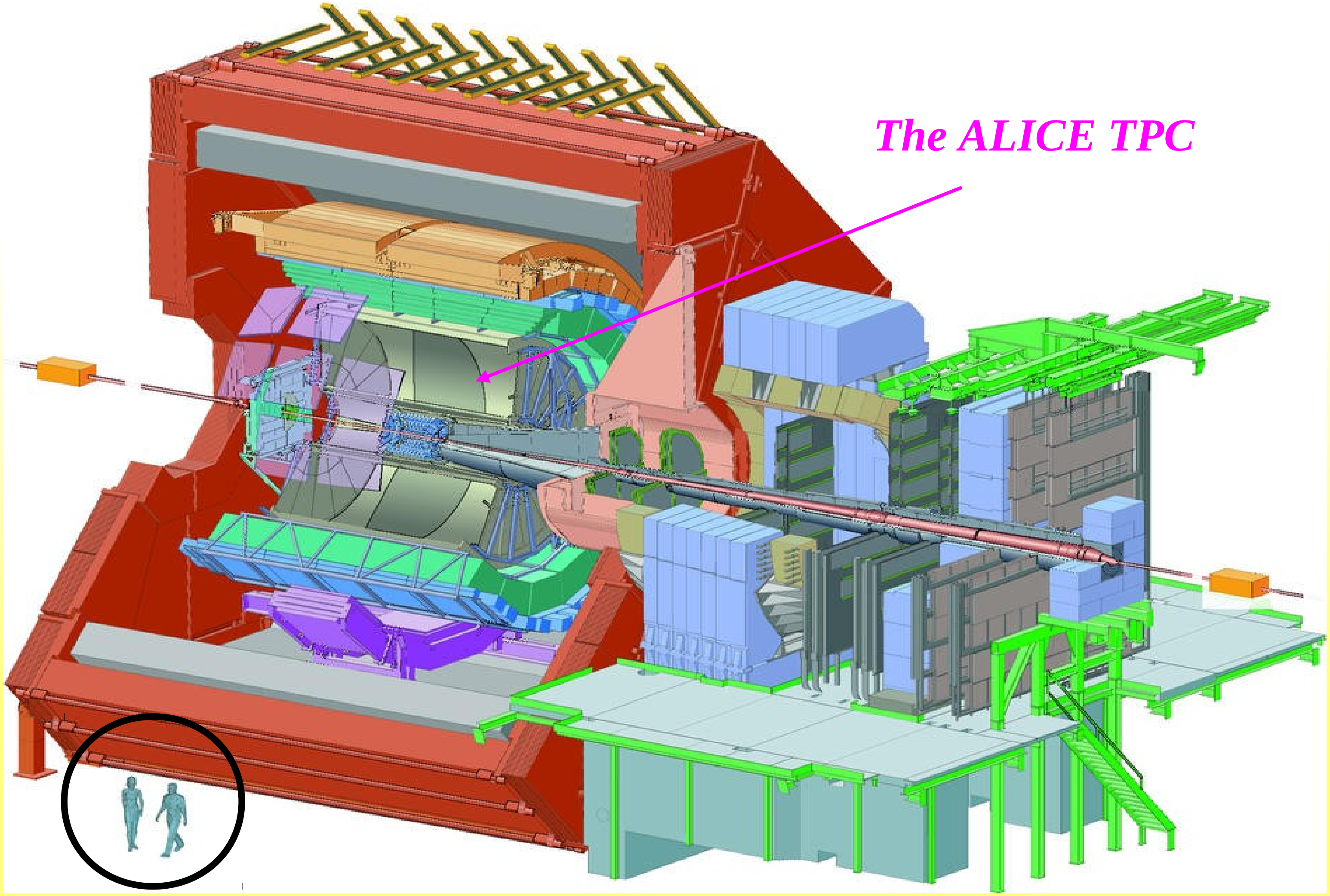
(pre-RHIC, now measured to be factor 4 smaller)

Pb+Pb:1kHz vs pp:40MHz

→ **Design is different from ATLAS and CMS**



The ALICE experiment

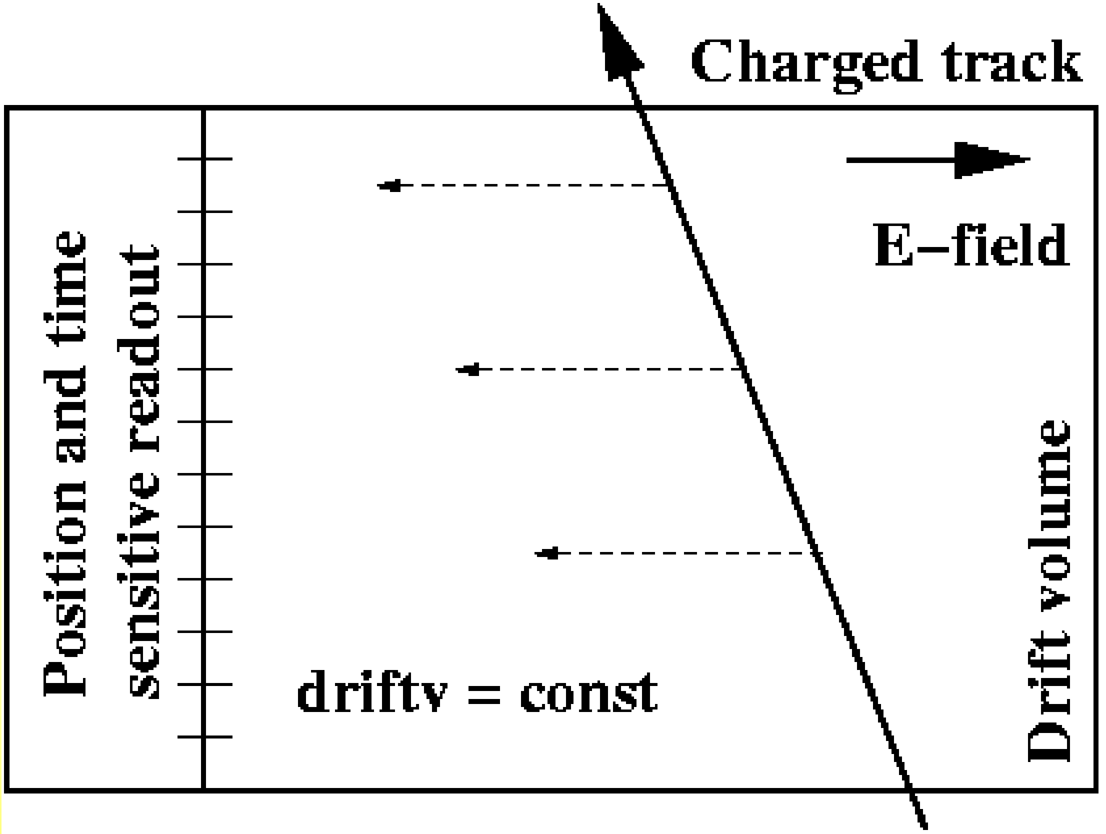


The ALICE TPC during installation

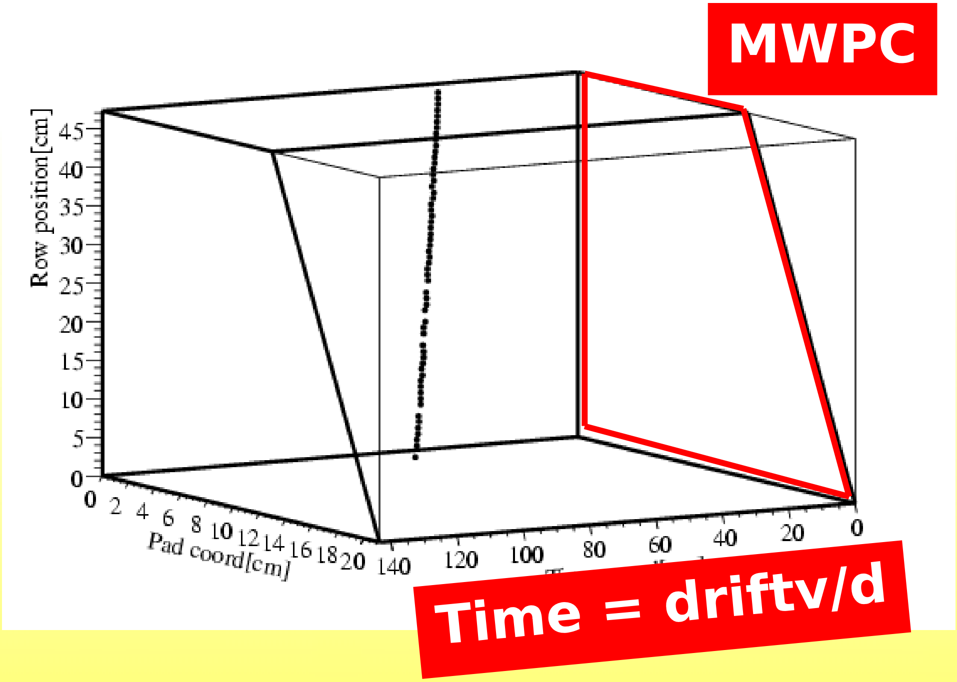
Outline

- Working principle of a Time Projection Chamber
- TPC basics
- Structure of the ALICE TPC + Auxiliary Systems
- Reconstruction & Calibration
- Performance

TPC Working Principle



Test data showing 3d tracking

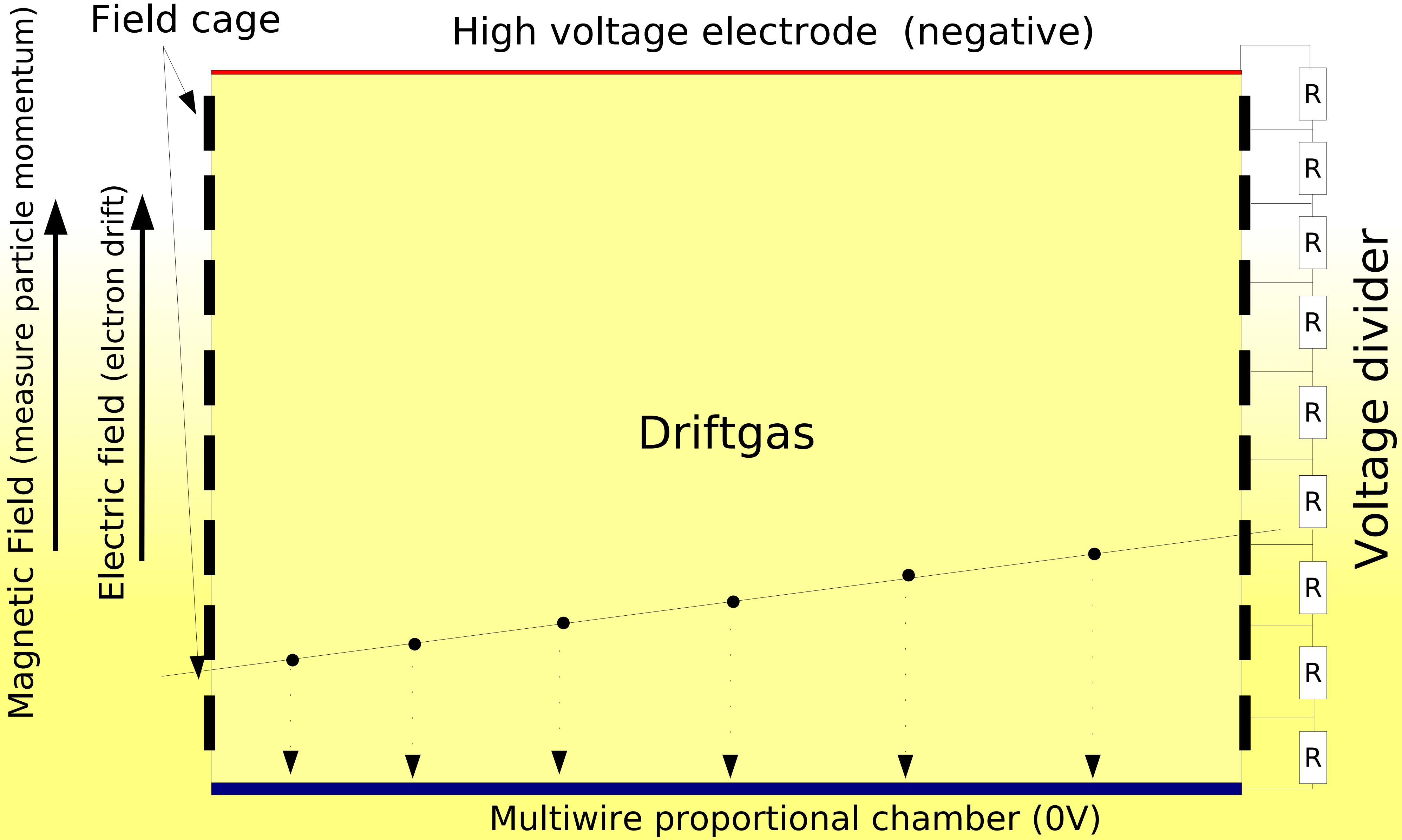


MWPC

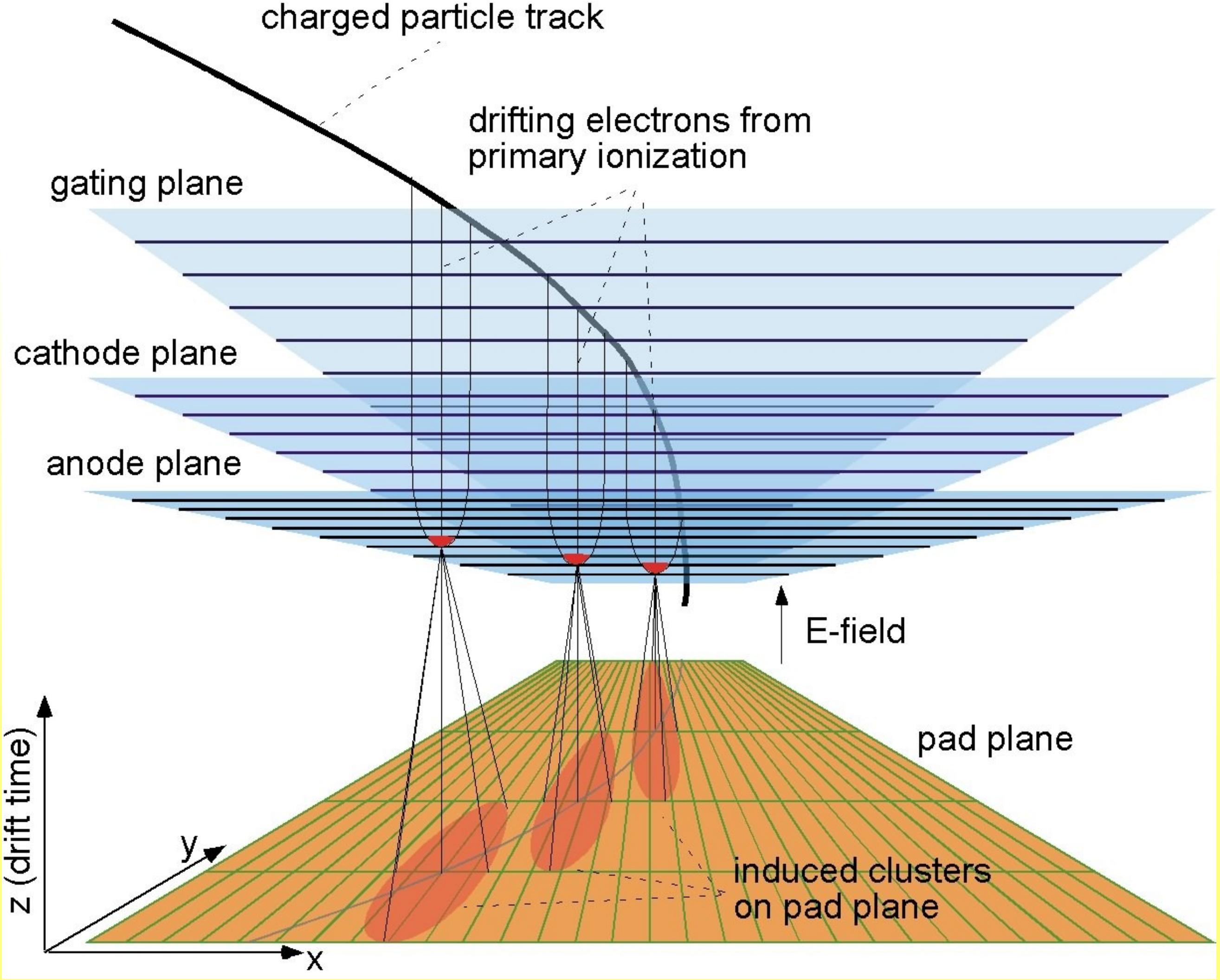
Time = driftv/d

- Charged track ionizes gas molecules
- Ionized electrons drift (because of E-field) to readout
- Read out measures the 2d position (x,y) as a function of time (z = time*drift velocity) => 3d tracking

Structure of a TPC



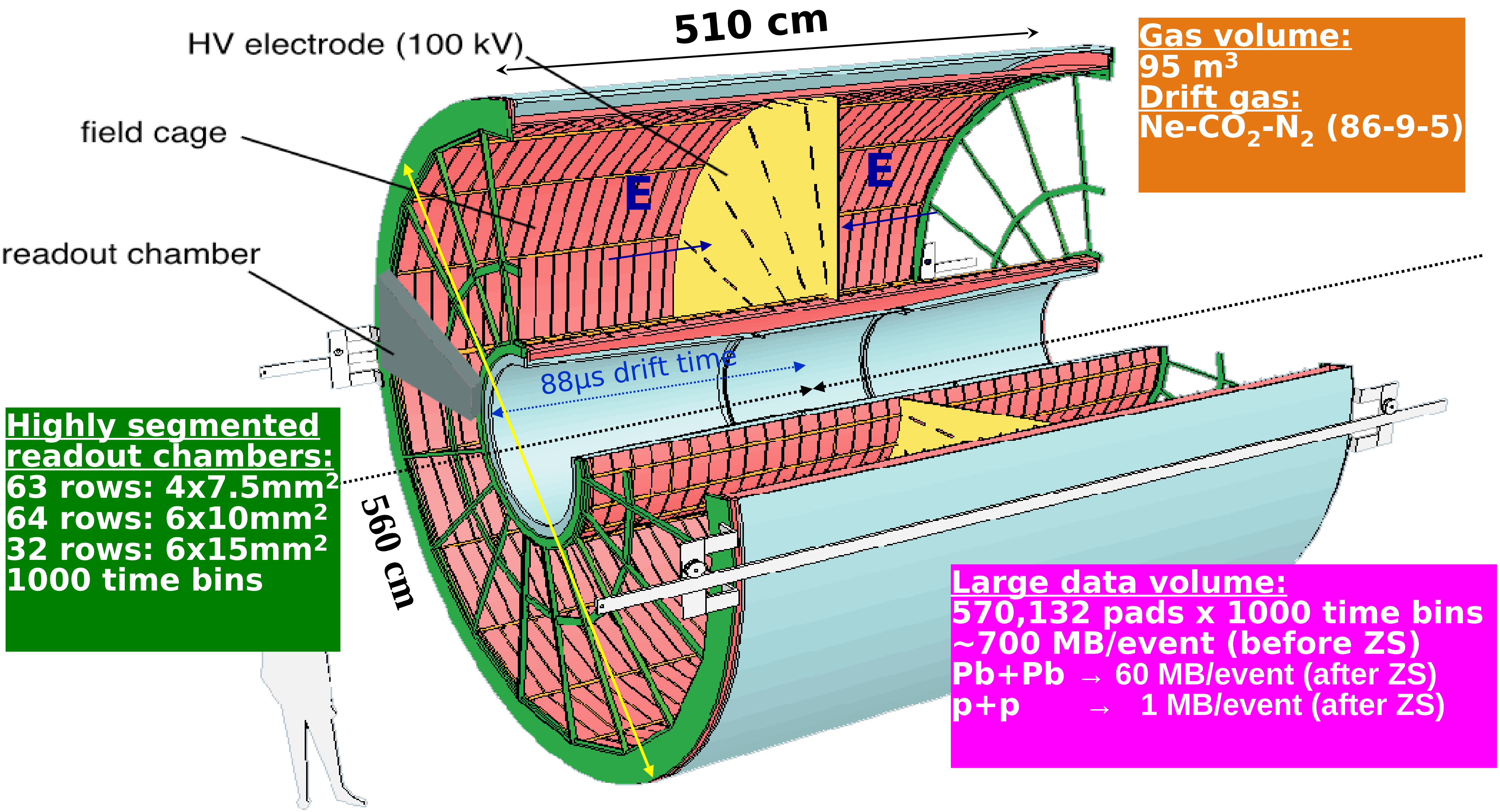
Amplification in the TPC



- Two coordinates (x,y) given by the projection on the pad plane
- Third coordinate (z) given by the drift time and drift velocity ($z = v_{Drift} \times t_{Drift}$)
- Anode: 1400 - 1650 V
- Cathode: 0 V
- Gating: -100 ± 90 V
  open closed

- Gas gain ≈ $2 \cdot 10^4$

ALICE TPC Layout:
The worlds largest TPC



Gas volume:
95 m^3
Drift gas:
Ne-CO$_2$-N$_2$ (86-9-5)

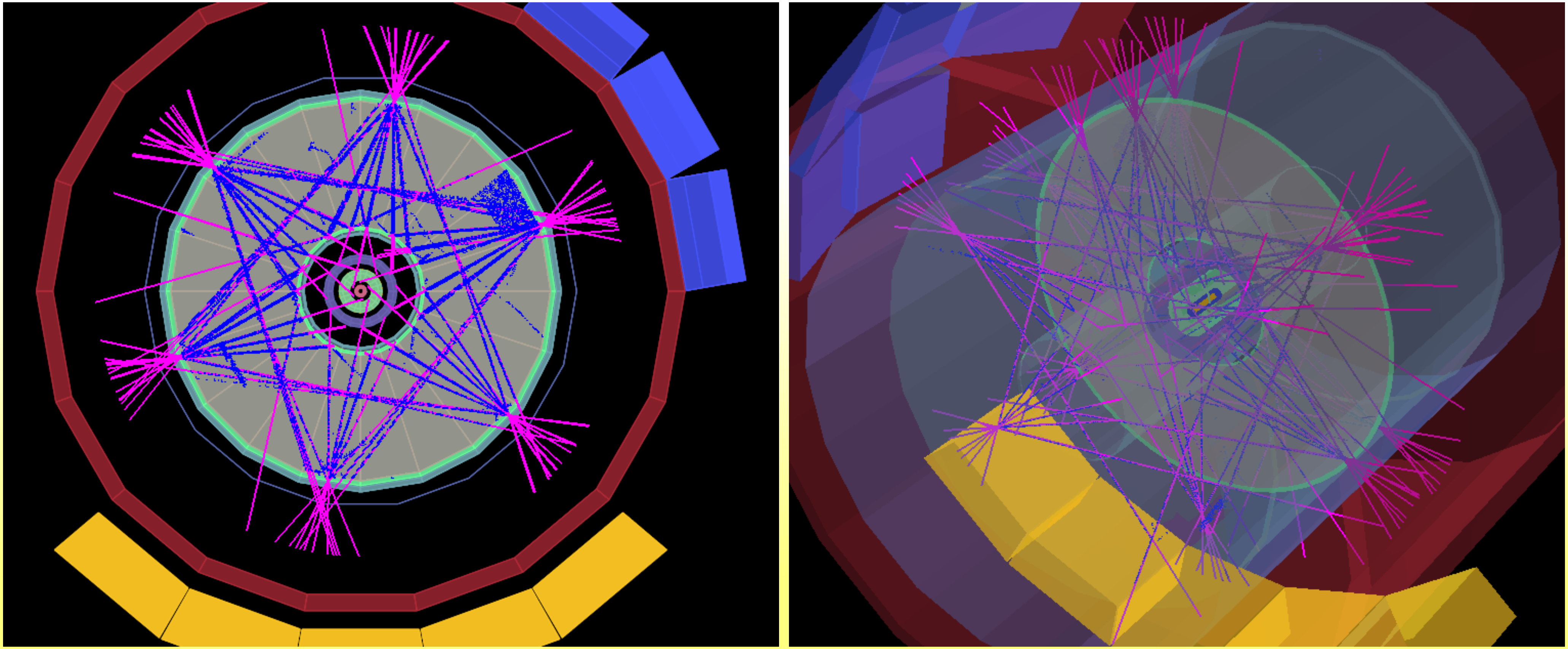
Highly segmented readout chambers:
63 rows: 4x7.5mm^2
64 rows: 6x10mm^2
32 rows: 6x15mm^2
1000 time bins

Large data volume:
570,132 pads x 1000 time bins
~700 MB/event (before ZS)
Pb+Pb → 60 MB/event (after ZS)
p+p → 1 MB/event (after ZS)

Movies

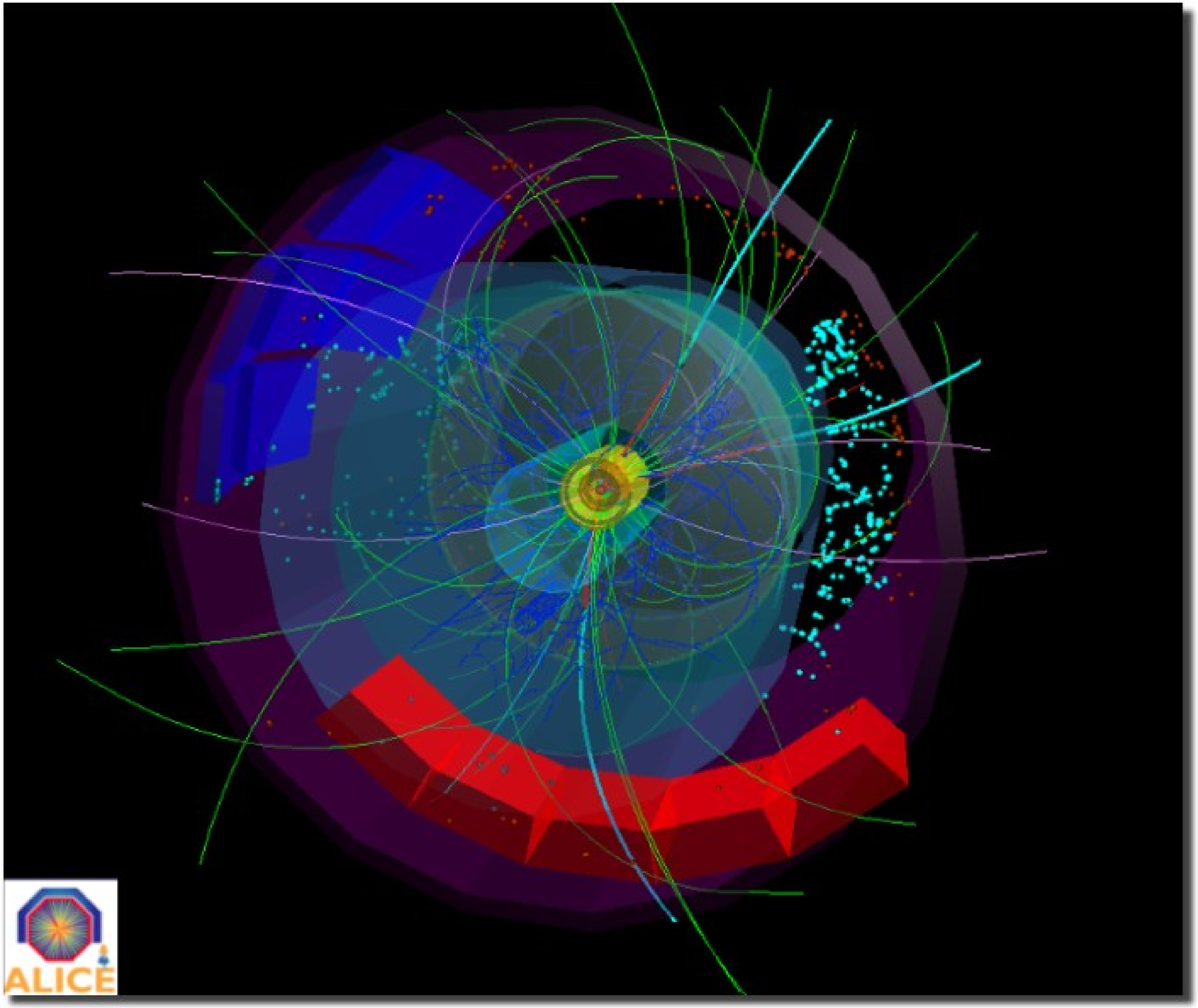
TPC Calibration Laser

2d display **3d display**

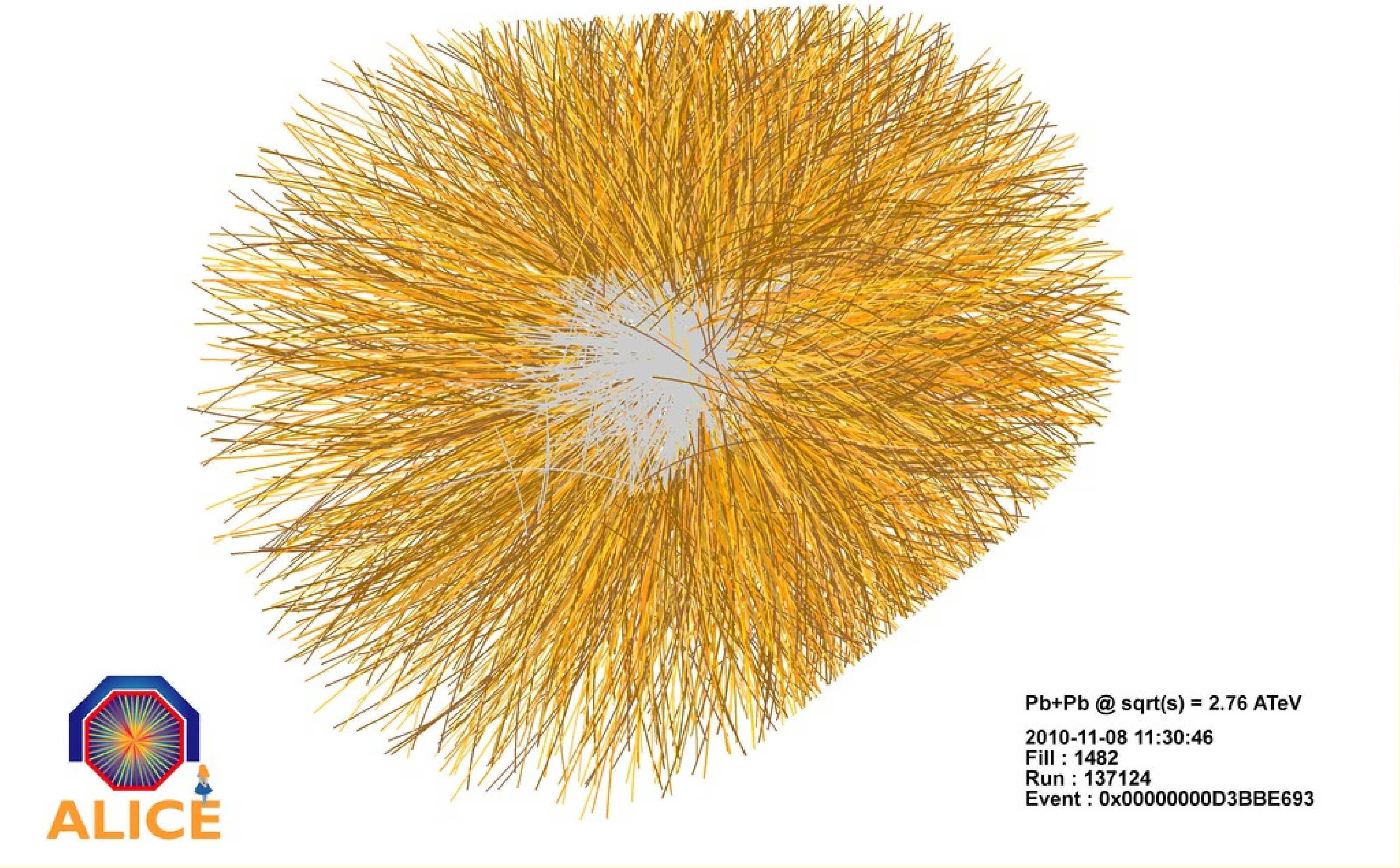


- The Calibration laser system is used to monitor drift velocity and study space point distortions

TPC p+p event



TPC Pb+Pb event



Why use a TPC

A TPC is the perfect detector for HI collisions …

- almost the whole volume is active
- minimal radiation length (field cage, gas)
- easy pattern recognition (continuous tracks)
- PID information from ionization measurements

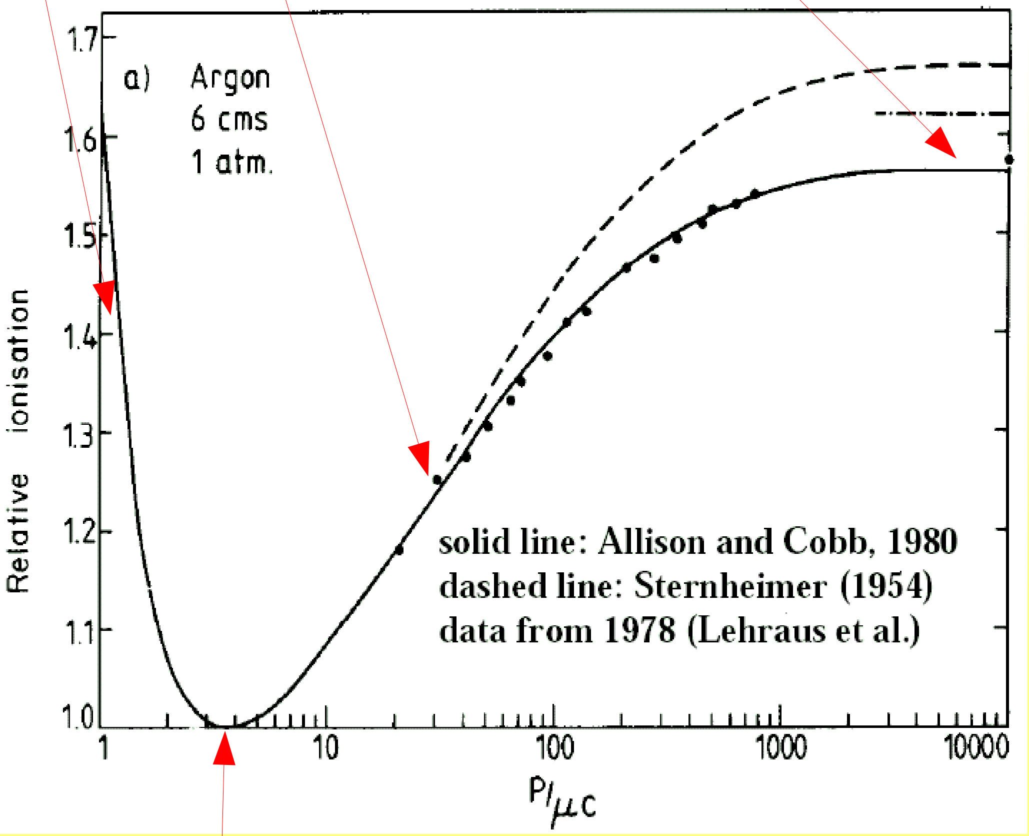
TPC basics

- Energy loss of charged particles
- Ionisation
- Gas amplification
- Drift velocity
- Diffusion

The Bethe-Bloch-Formula

$$\left\langle \frac{dE}{dx} \right\rangle = -4\pi N_A \rho m_e c^2 z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\ln \frac{2m_e c^2 \beta^2 \gamma^2}{I_0} - \beta^2 - \frac{\delta(\beta)}{2} \right]$$

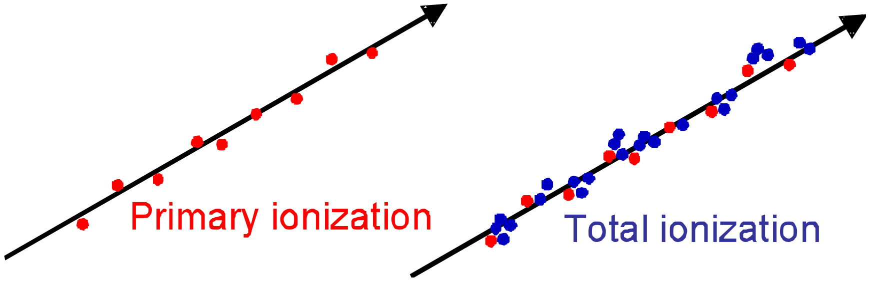
- dE/dx first falls ∝ $1/\beta^2$ (kinematic factor)
- a minimum is reached at $\beta\gamma \approx 4$ (Minimum Ionising Particle - MIP)
- then again rising due to the ln $\gamma 2$ term (relativistic rise: contributions of more distant particles due to the relativistic expansion of the transverse E-Field)
- at high γ the relativistic rise is cancelled by the “density effect” (fermi plateau: polarisation of medium screens more distant atoms; described by the δ parameter)



Minimum Ionising Particle (MIP)

Ionisation

Distinguish between primary and secondary ionisation:
Atoms become excited or suffer primary ionisation , electrons with energies above 100 eV can make secondary ionisation.



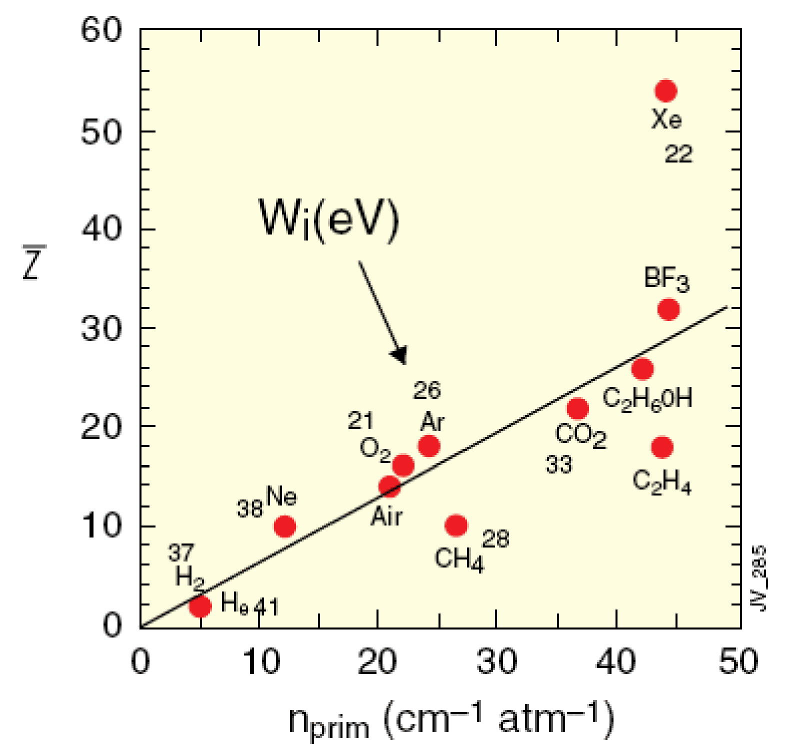
Lohse and Witzeling, Instrumentation In High Energy Physics, World Scientific,1992

$$n_{total}=n_{primary}+n_{secundary}=\frac{\Delta E}{W_i}=\frac{\frac{dE}{dx}\Delta x}{W_i}$$

$$n_{total}\approx 3\ldots 4\cdot n_{primary}$$

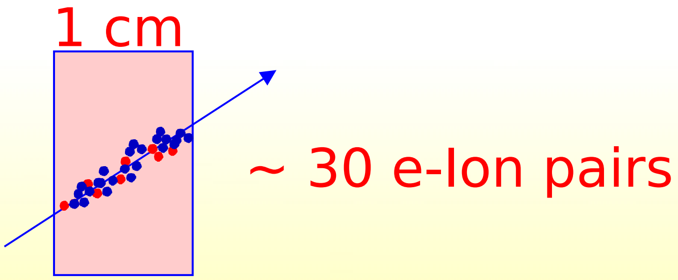
W_i = mean energy loss per produced ion pair ($W_i > I_0$) ≈ 30 eV

ΔE = total energy loss



Measurement of ionisation

Example: 1 cm gas counter, filled with Neon;
$n_{prim} \approx 10$ /(cm atm), $n_{total} \approx 30$



≈ 30 Electron-ion-pairs are hard to detect!

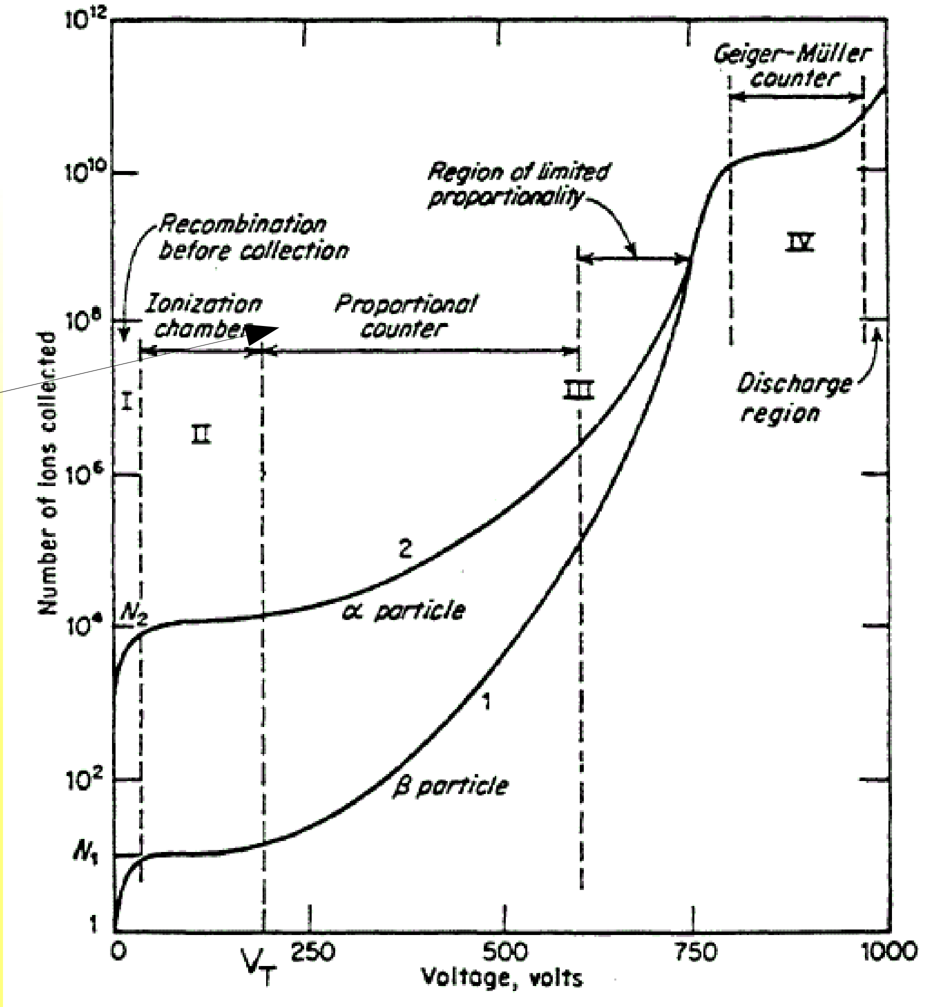
Amplifier noise is typically ≈1000 e^- (ENC) !

⇒ Number of electrons has to be increased noiselessly!

⇒ Gas amplification

Gas amplification

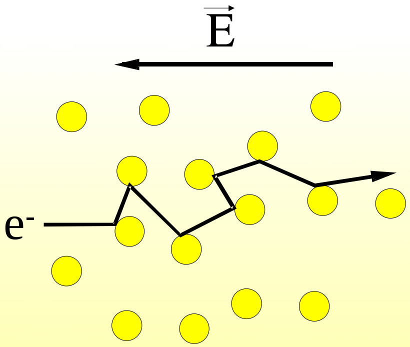
Proportional mode:
Detected signal is proportional to the original total ionisation ‚ measurement of dE/dx! Gain ≈ 10^4 - 10^5



Drift of electrons an electric field

Electrons in a gas drift with a constant drift velocity u_{Drift} in an external electric field:

Mechanism:
Due to its small mass the electron scatters isotropically at the (heavy) gas molecules and looses its initial direction. In between the collisions (mean time between collisions τ) the electrons are accelerated to the velocity u_{Drift} in the electric Field:



$$u_{Drift} = a \cdot \tau = \frac{F}{m} \cdot \tau = \frac{e \cdot E}{m} \cdot \tau$$

In the next collisions this additional energy is lost, so that there is an equilibrium between the gained energy and the scattering loss; therefore a constant macroscopic drift velocity u_{Drift} is observed.

Drift velocity

In the approximation that the energy from the electric field $\varepsilon_E >> \varepsilon_{therm}$ the thermal energy the drift velocity v_D can be written as

$$u_D = \frac{e}{\sqrt{2m}} \cdot \frac{E}{N} \frac{1}{\sigma(\epsilon)\sqrt{\epsilon}}$$

With e, m the electron charge and mass, E the electric field, N the density of the drift gas, σ(ε) the collision cross-section as a function of the electron energy.
Due to the trivial dependence on the gas density N=1/k·P/T the drift velocity is often plotted as a function of the reduced electric field E/P or E/N

Life gets more complicated with a B field ...

$$\vec{u} = \frac{\mu|\vec{E}|}{(1+\omega^2\tau^2)} \left[\hat{E} + \omega\tau\left(\hat{E} \times \hat{B}\right) + \omega^2\tau^2\left(\hat{E} \cdot \hat{B}\right)\hat{B} \right]$$

Drift velocity measurements

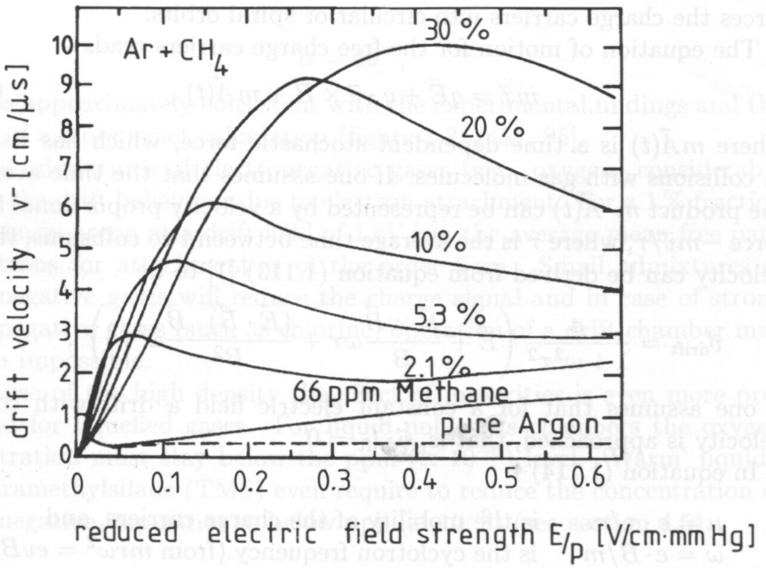
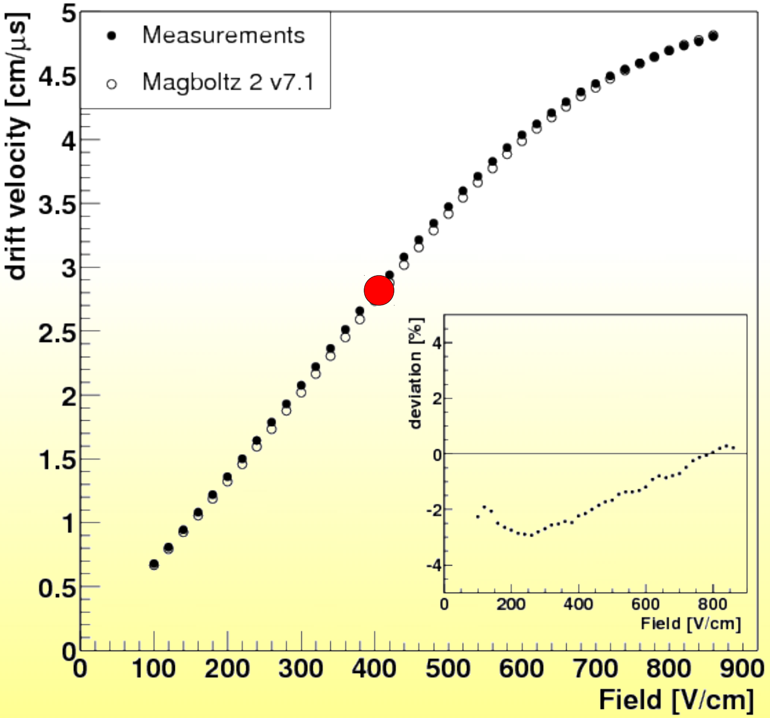


Fig. 1.19. Drift velocities for electrons in argon-methane mixtures [51, 92, 93, 94].

ALICE gas mixture: NeCO$_2$

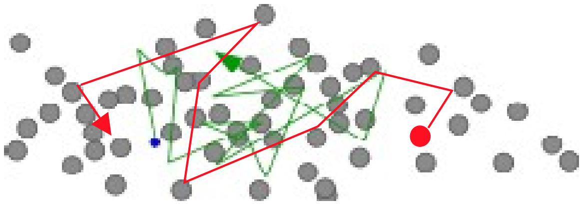


Non saturated drift velocity in ALICE
Challenging condition:
- sensitive to small variations in the gas density

Diffusion

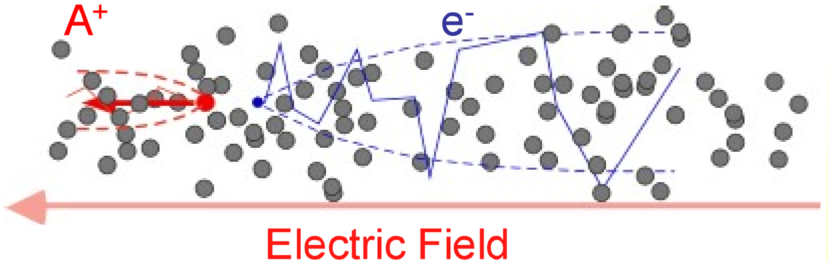
E=0 thermal diffusion

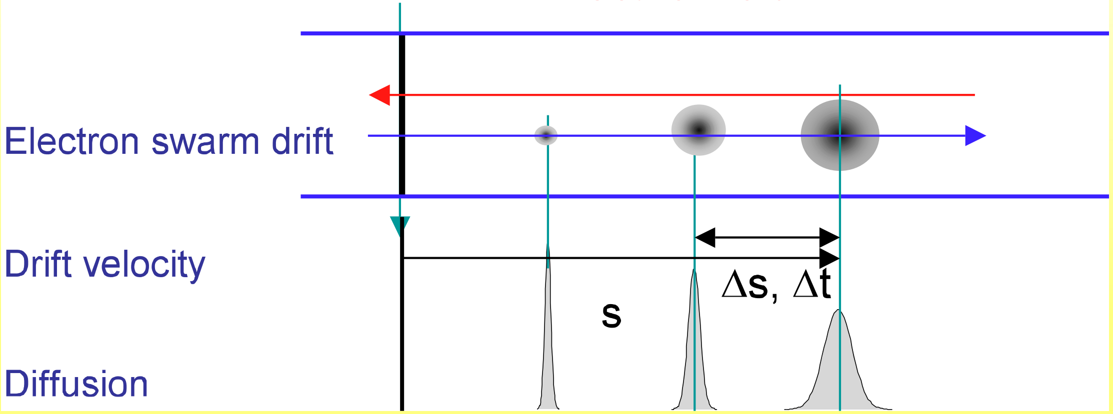
$\langle v \rangle_t = 0$



E>0 transport and diffusion

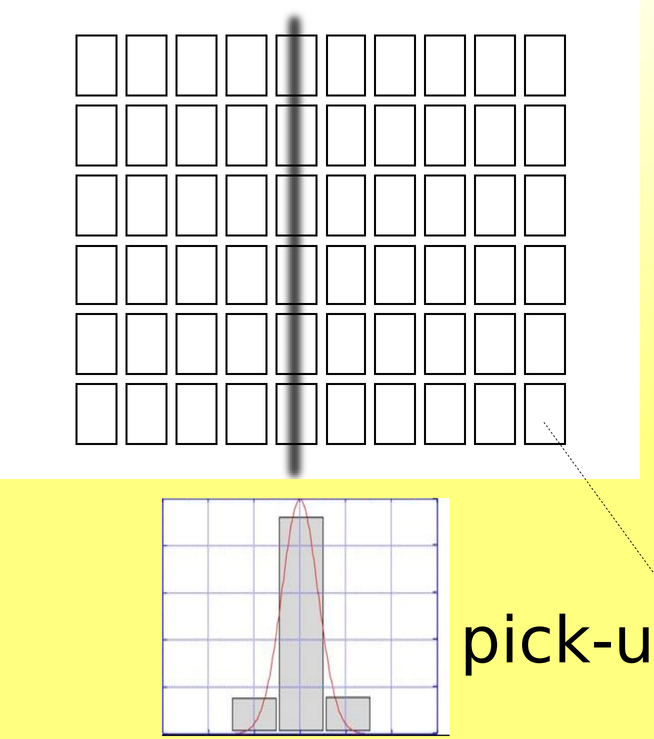
$\langle v \rangle_t = v_D$





Diffusion

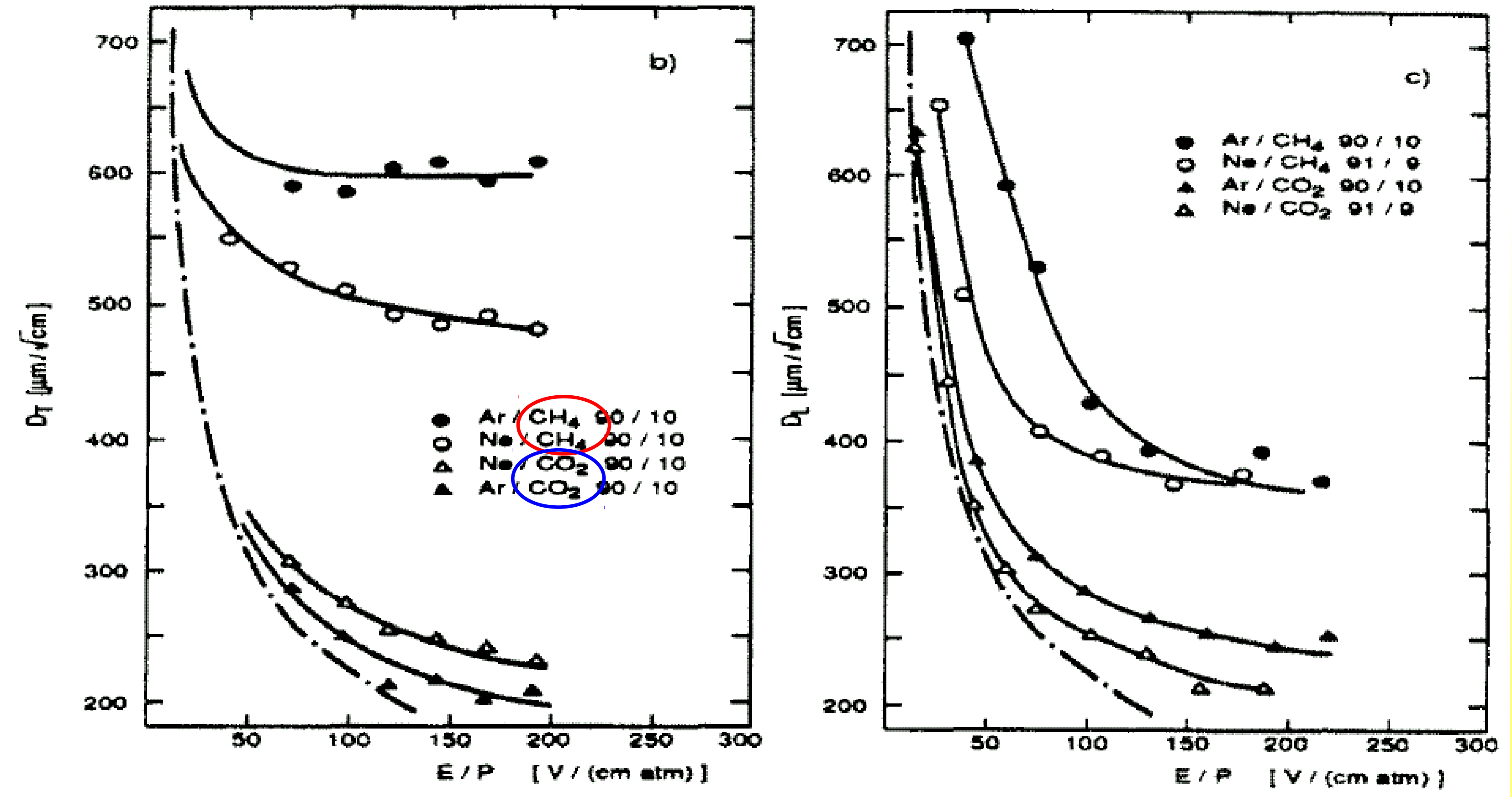
The diffusion constant is one of the essential parameters for choosing the gas mixture. To get the desired two track separation and position resolution the diffusion constant has to be chosen very carefully.



pick-up pads

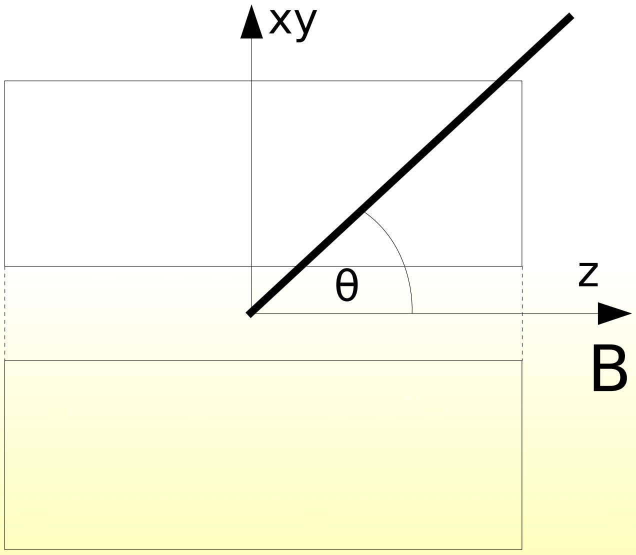
Diffusion measurements

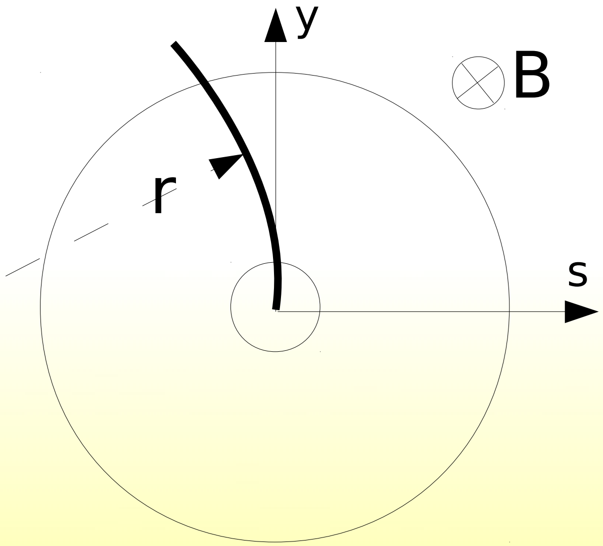
A. Kühmichel / Nucl. Instr. and Meth. in Phys. Res. A 360 (1995) 52–56



In rare gases the diffusion is high due to a small number of degrees of freedom for exitation. Molecular gases with a large number of excitation states have a small diffusion constant. Distinguish “hot” and “cold” gases.

Momentum measurement





equation of motion:

$$\vec{F}=q\cdot\vec{v}\times\vec{B} \quad (\vec{B}=B\cdot\vec{e}_z)$$

$$\vec{F}=m\cdot\dot{\vec{v}} \quad \rightarrow \quad \text{Helix}$$

longitudinal

$$\tan\theta=\frac{p_T}{p_z}$$

transverse

$$\omega=q\cdot B/m; \quad v_T=\omega\cdot r\rightarrow$$

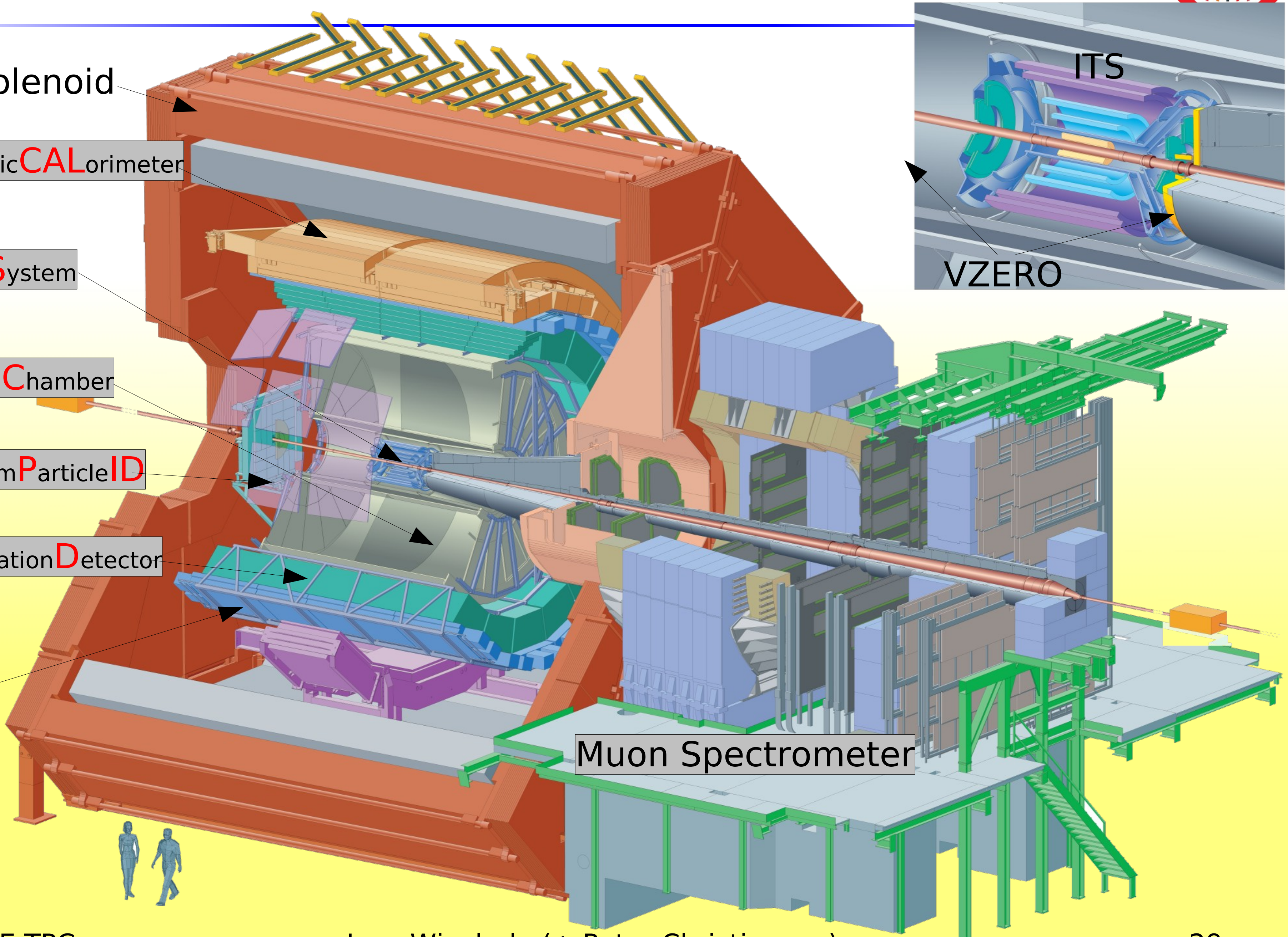
$$p_T=mv_T=qBr$$

$$p_T[\mathrm{GeV}]=0.3Br[\mathrm{T}\cdot\mathrm{m}]$$

Structure of the ALICE TPC

- The TPC in ALICE
- Gas volumes
- Central Electrode (CE), fiel cage, Endplates
- Voltage Divider, Resistor rod
- ReadOut Chambers (ROCs)
- Servie Support Wheel (SSW)
- FrontEnd Elektronics (FEE)

The ALICE detector



0.5T solenoid

ElectroMagneticCALorimeter

InnerTrackingSystem

TimeProjectionChamber

HighMomentumParticleID

TransitionRadiationDetector

TimeOfFlight

Muon Spectrometer

ITS

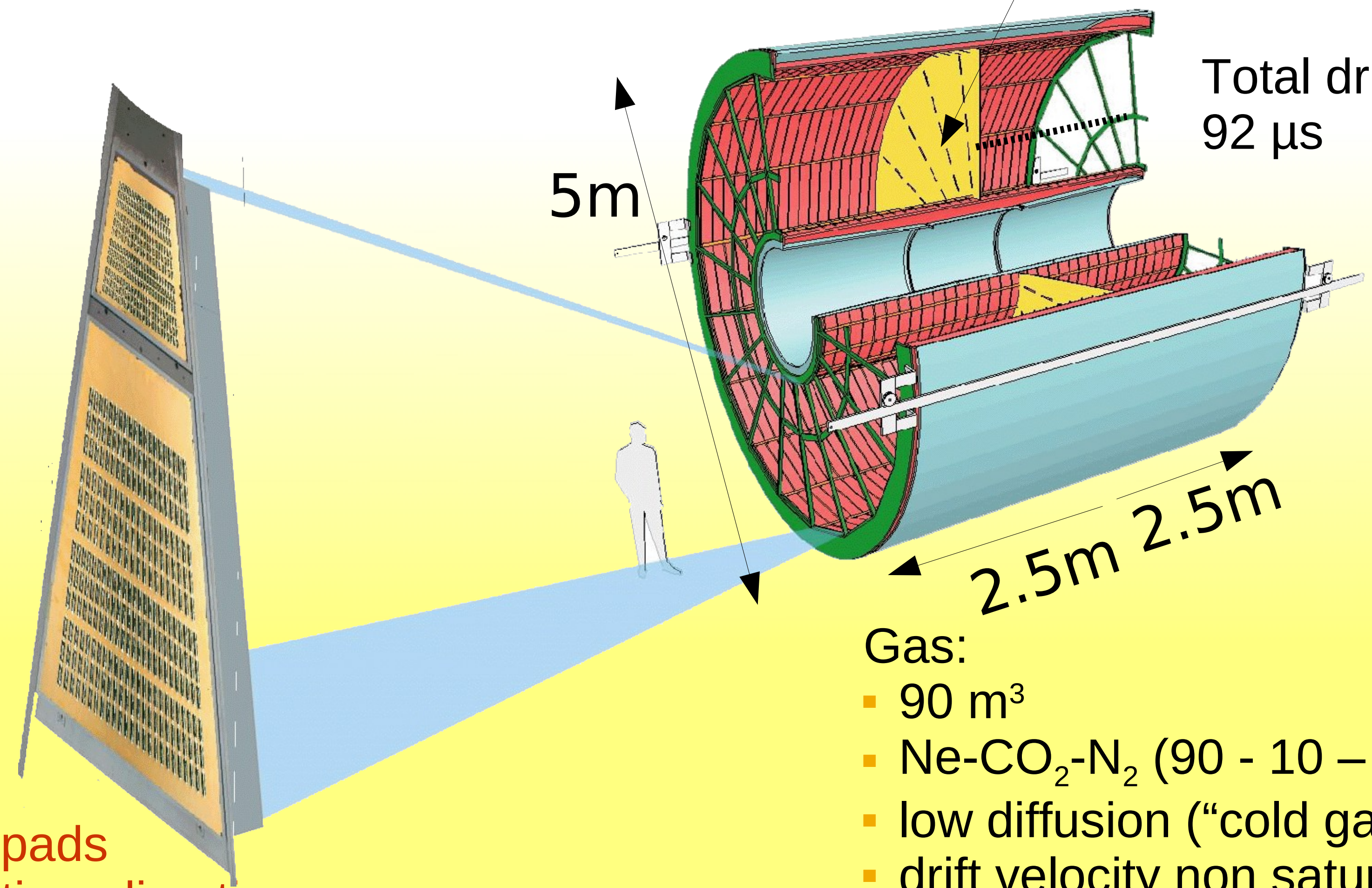
VZERO

Overview

Most challenging TPC ever built

2x18 Inner Readout Chambers

2x18 Outer Readout Chambers

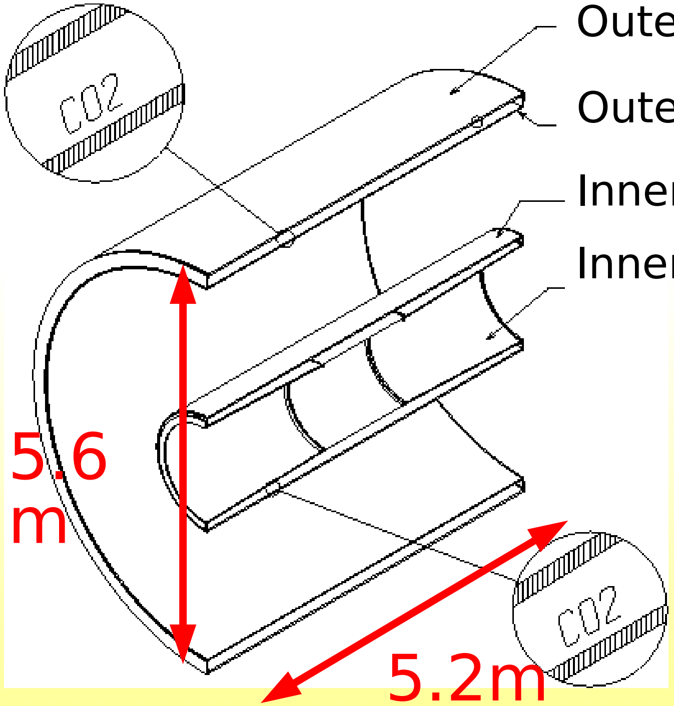


557568 readout pads
1000 samples in time direction

Gas:

- 90 m^3
- $Ne-CO_2-N_2$ (90 - 10 – 5)
- low diffusion (“cold gas”)
- drift velocity non saturated
  - temp. homogeneity and stability 0.1 K required

Gas Volumes

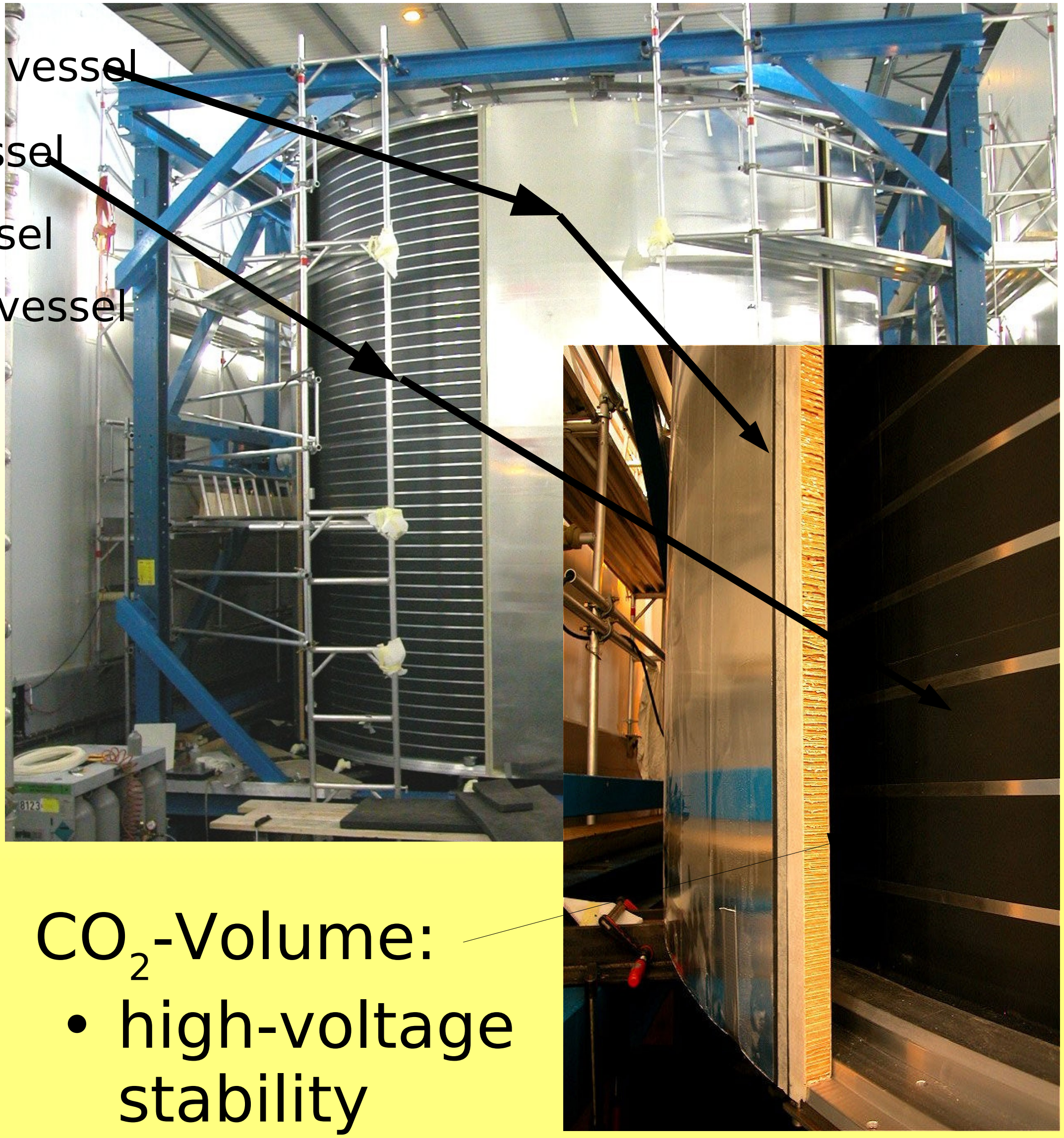


Outer containment vessel

Outer fieldcage vessel

Inner fieldcage vessel

Inner containment vessel



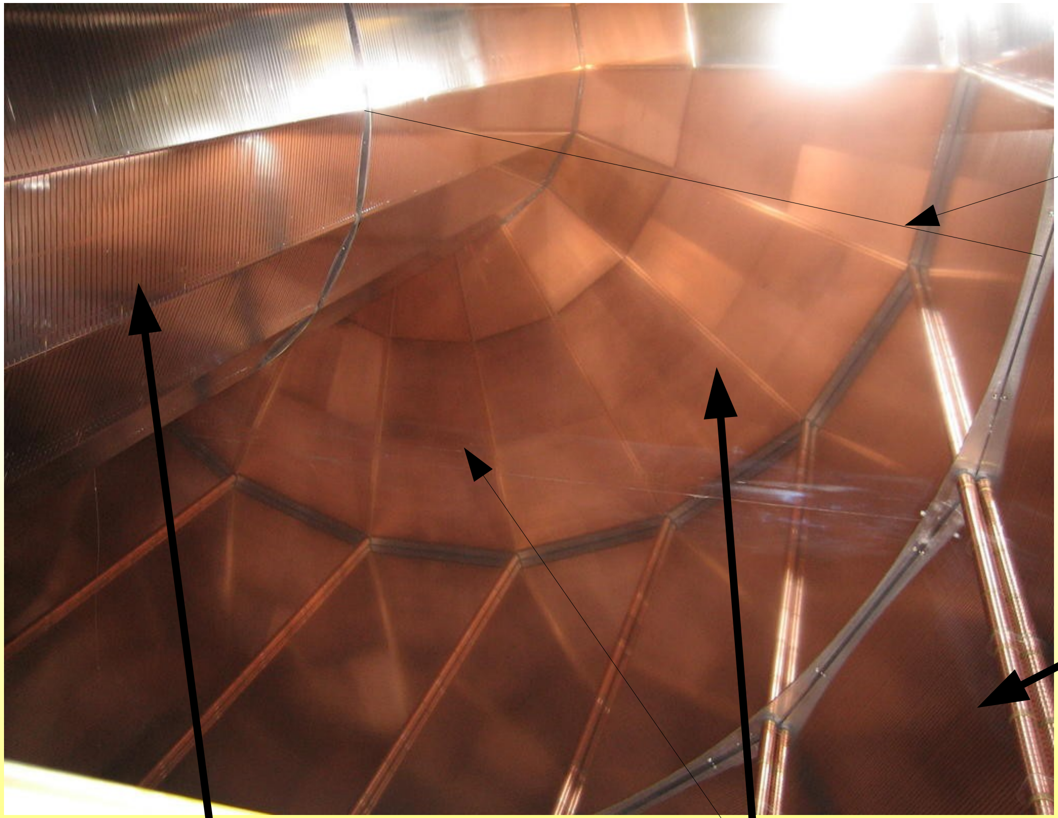
Drift gas Ne-CO_2(-N_2) [90-10(-5)]

- ≈ 90m^3
- Ionisation
- Drift
- Gas amplification

CO_2-Volume:

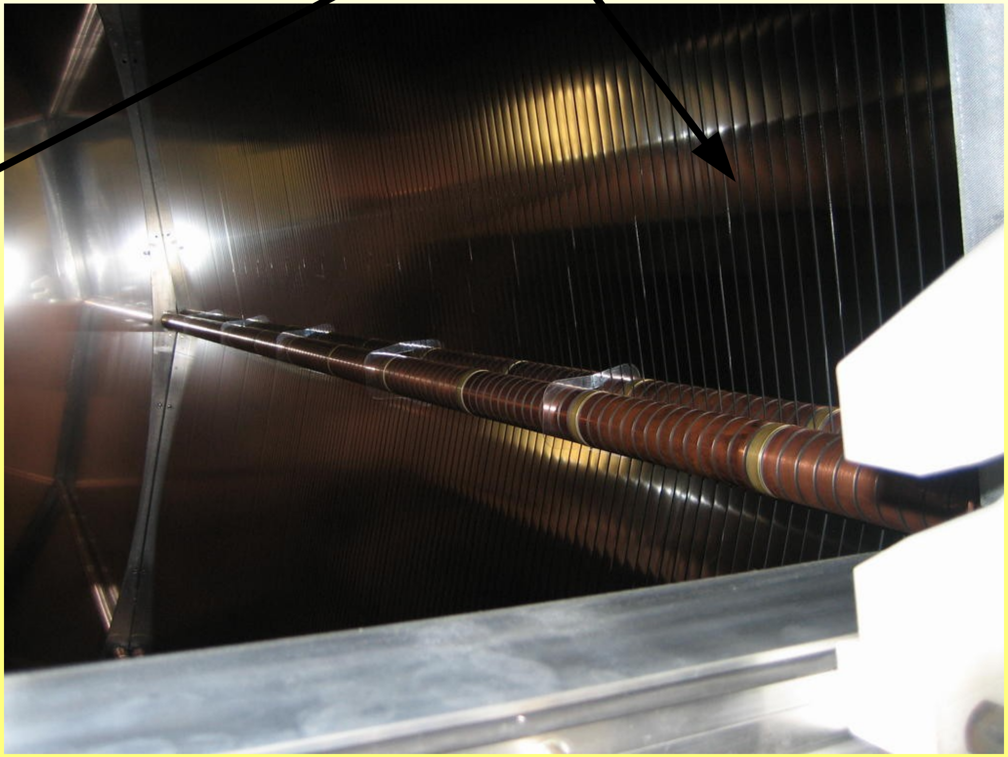
- high-voltage stability
- Gas tightness

Central Electrode and field cage



Central electrode

Outer part of the field cage

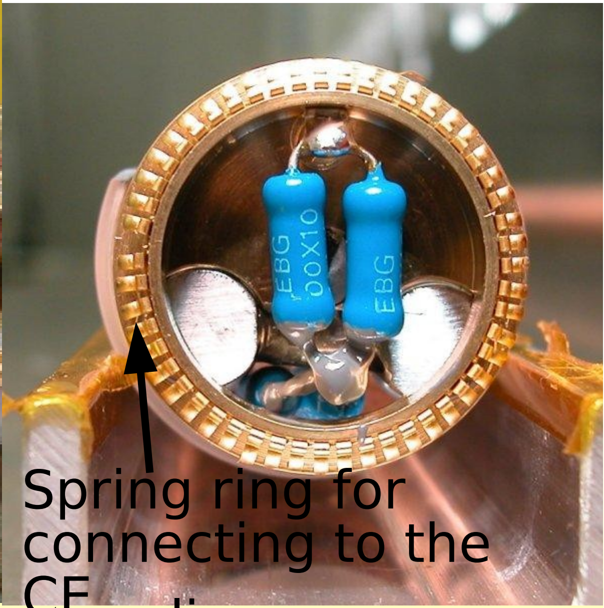


Inner part of the field cage

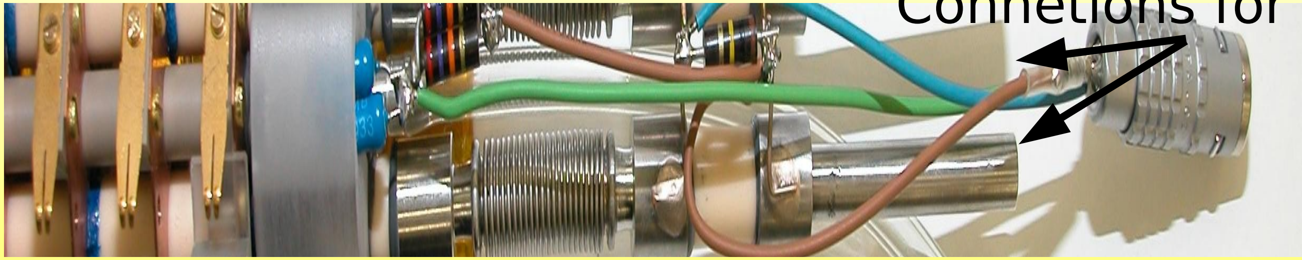
Refexion of the padplane. mirrord on the CE

Voltage divider (resistor rods)

Resistor rods



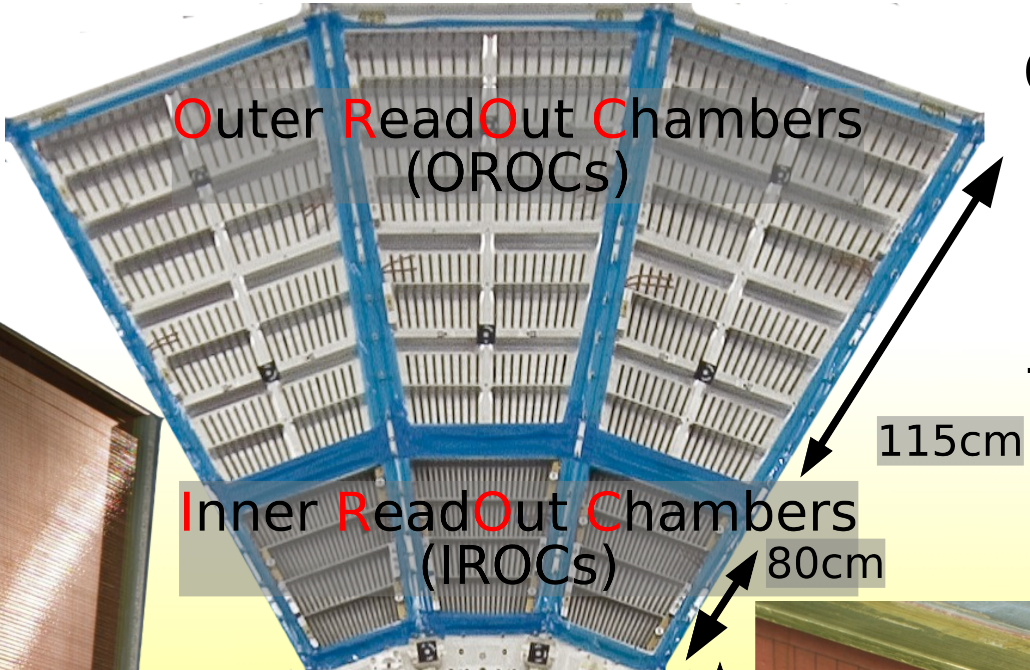
Spring ring for connecting to the CE



Connetions for the water cooling

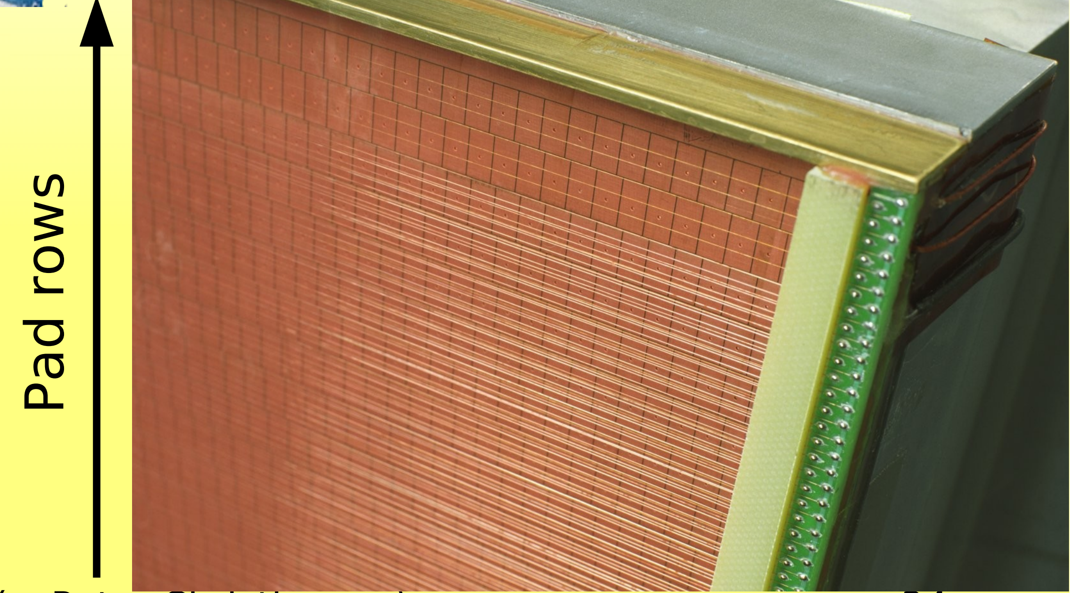
- Water cooled voltage divider
- 2 on each side (1 inner, 1 outer)
- Power dissipation ≈ 4*8W (≈ 40min to heat the gas by 1K, planned T stability 0.1K)

Readout chambers

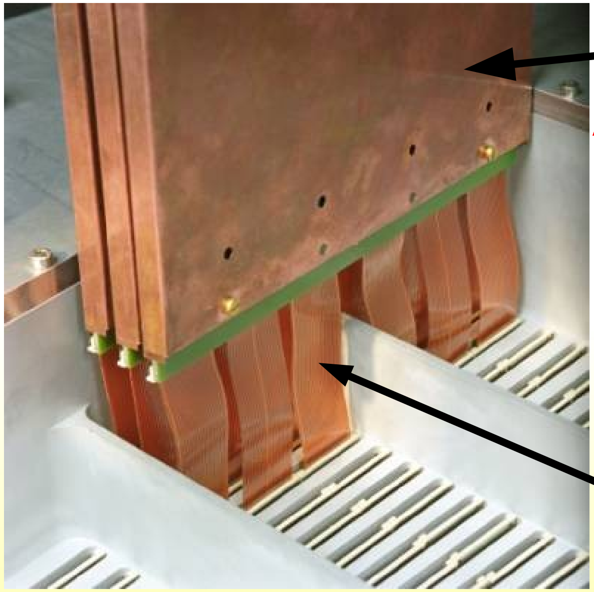


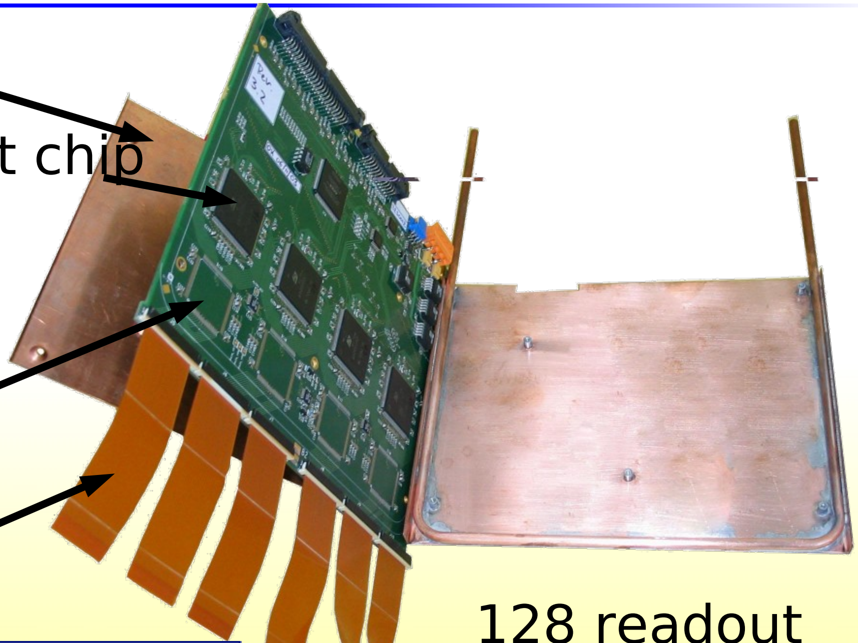
On each side:
- 18 IROCs
- 18 OROCs

72 ROCs in total



FrontEnd Cards





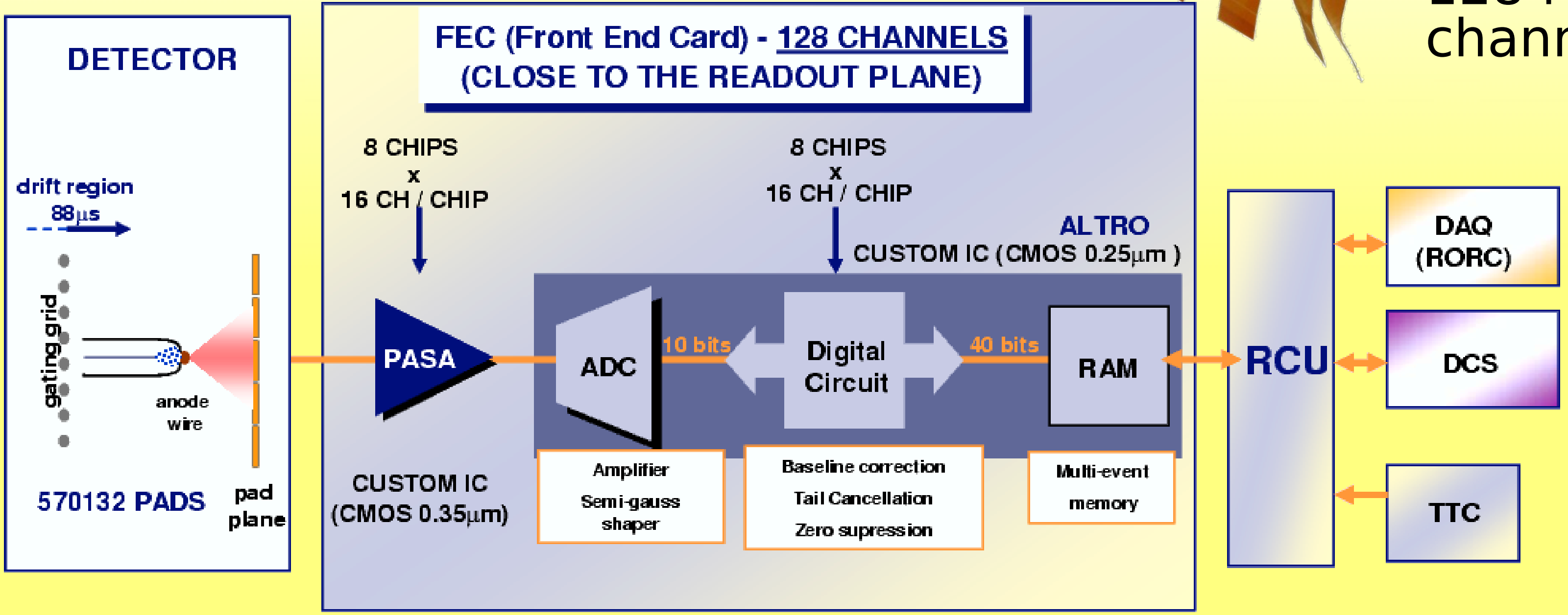
cooling plate

ALice TPC ReadOut chip

PreAmplifire-
ShAper

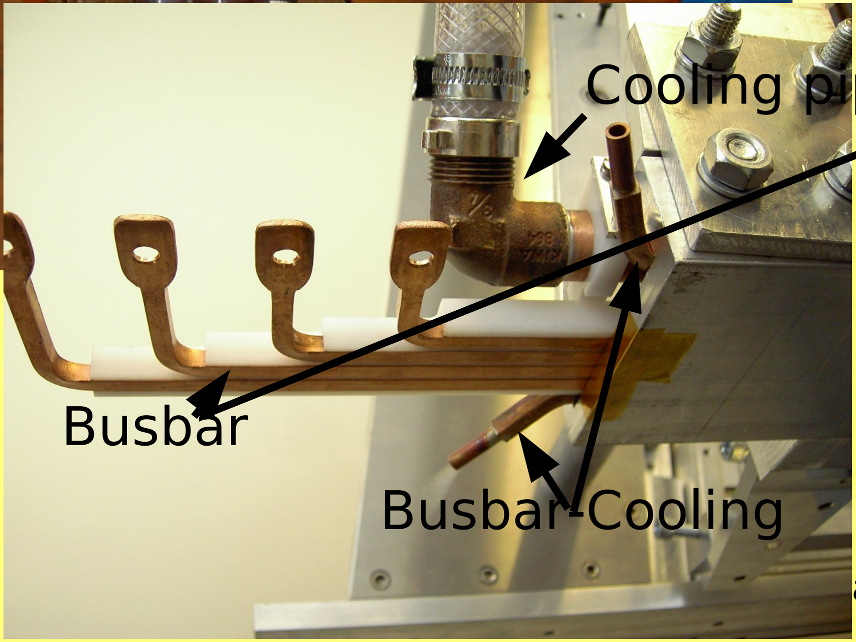
capton cables

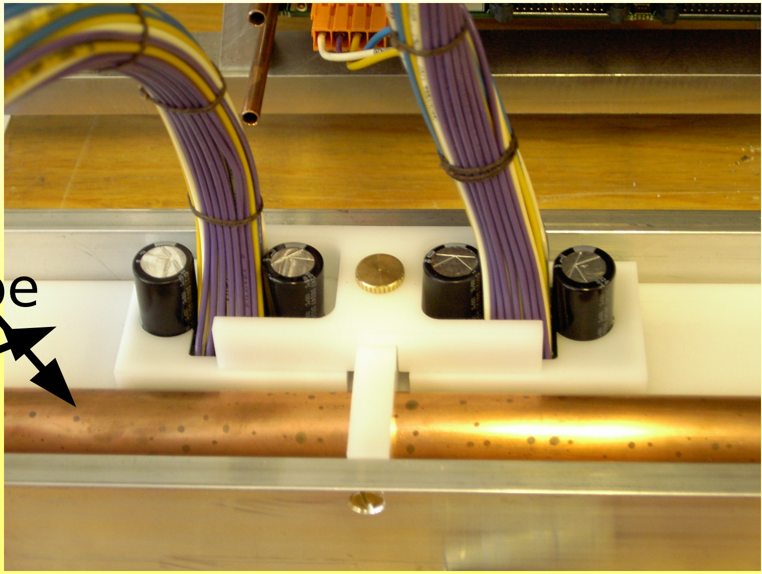
128 readout channels



Service Support Wheel

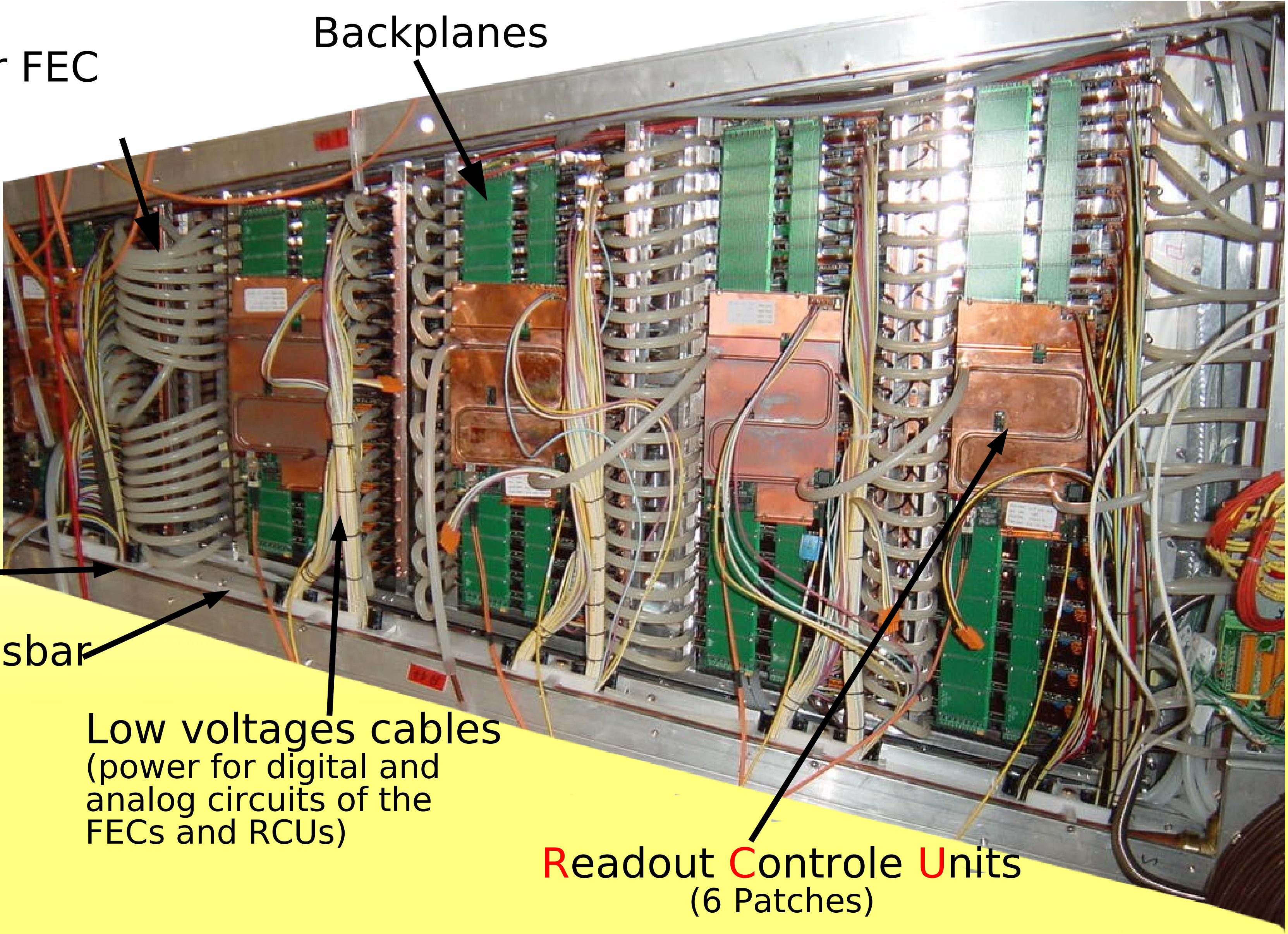
FEC mounting frames





Low voltages cables

Fully assembled sector



Backplanes

hoses for FEC
and RCU
cooling

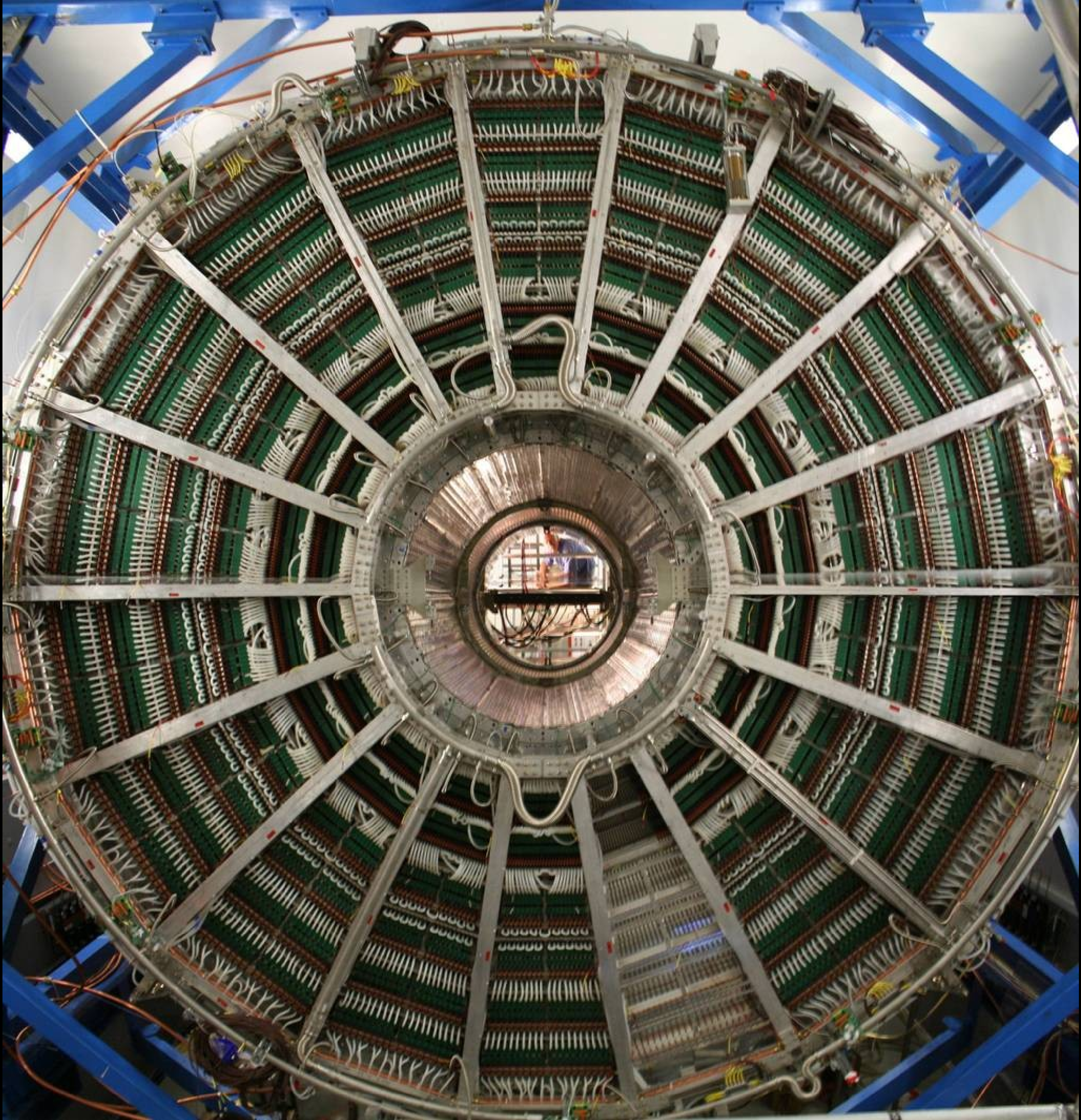
Service
support
wheel

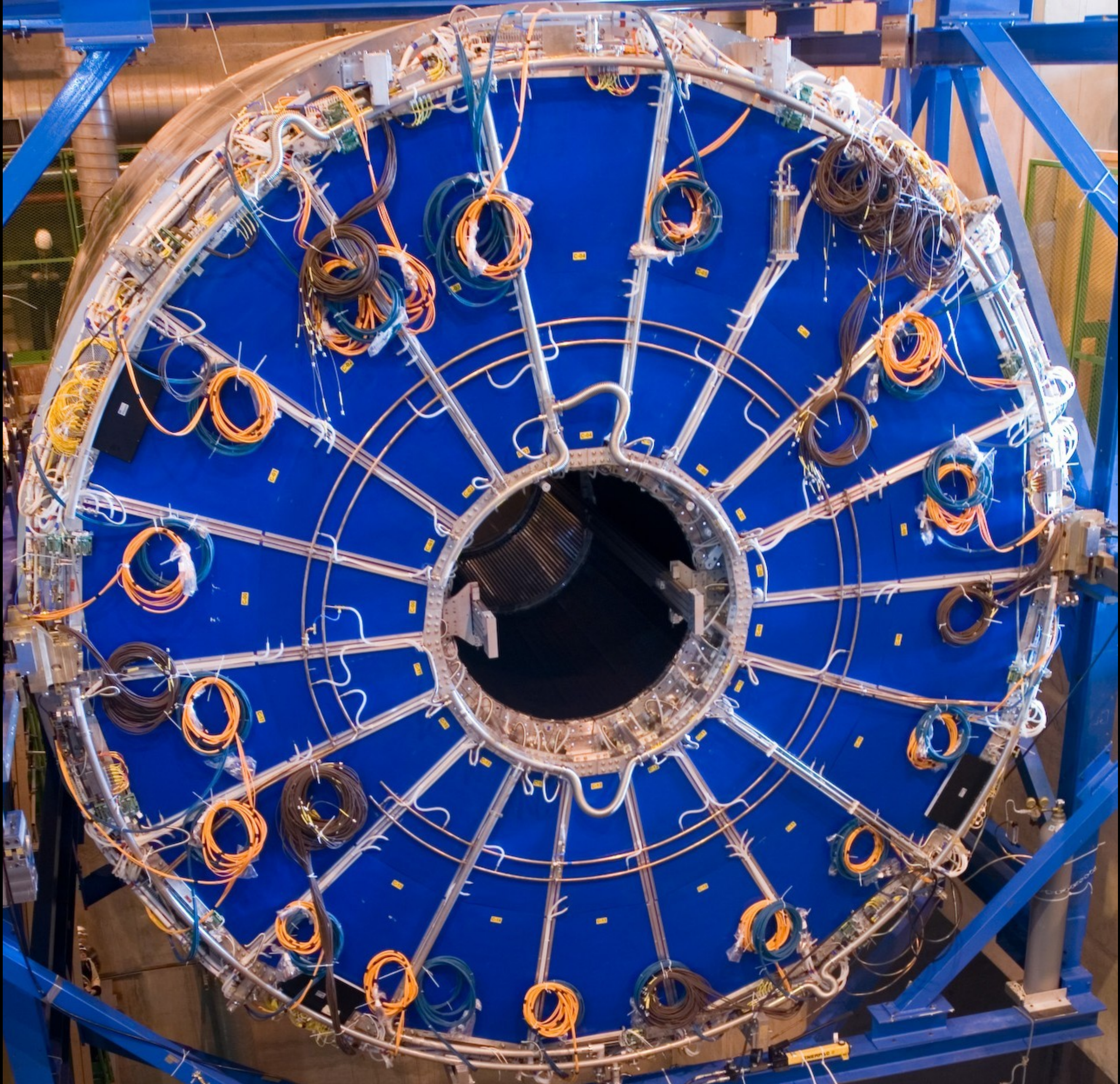
Cooling pipe

Busbar

Low voltages cables
(power for digital and
analog circuits of the
FECs and RCUs)

Readout Controle Units
(6 Patches)





Auxiliary systems

- Gas system
- Cooling system
- Temperature monitoring system
- Laser system

Gas system

Control Backup Mixer Purifier CO2 Distr Analys Pump

TPC Gas System at SLXL2

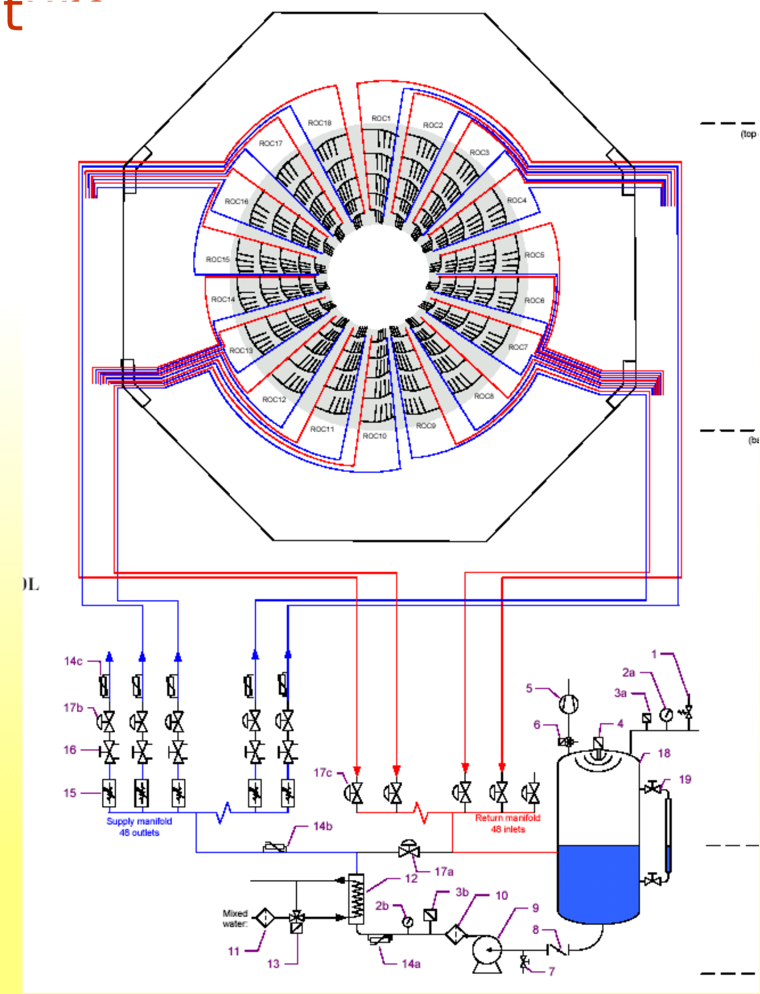
- Recirulating gas system -> recover Ne
- Purifier (removal of H_2O and O_2)

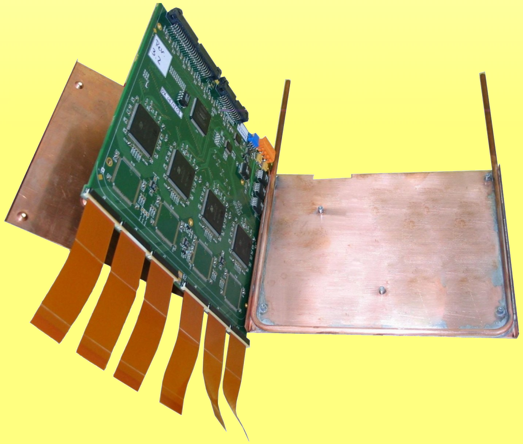
Cooling system

Complex cooling system to equalise TPC temperat

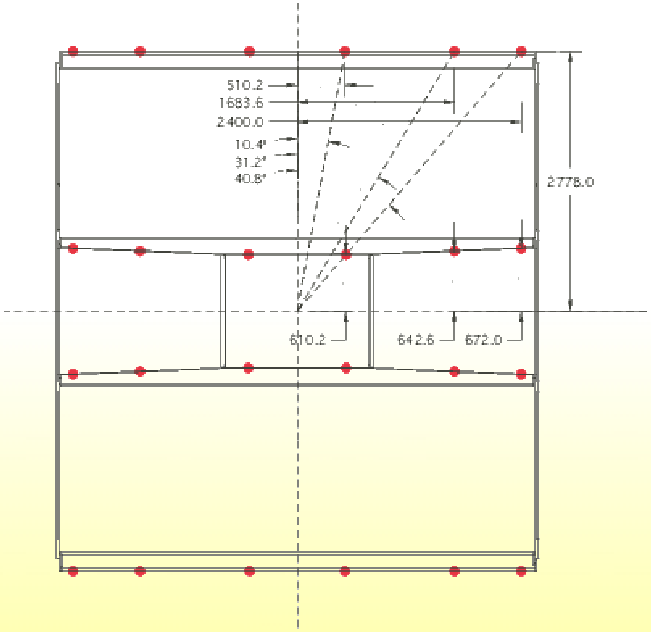
About 60 adjustable cooling circuits:

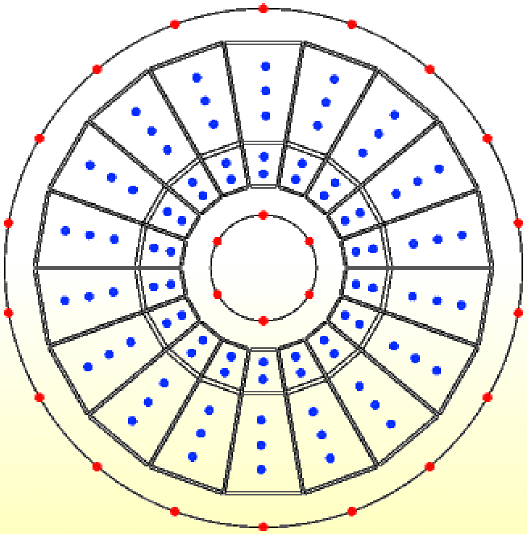
- leakless underpressure system
- cooling of ROC bodies
- FEE enveloped in copper plates (≈ 27kW)
- thermal screens towards ITS and TRD
- service Support Wheel closed with copper shields

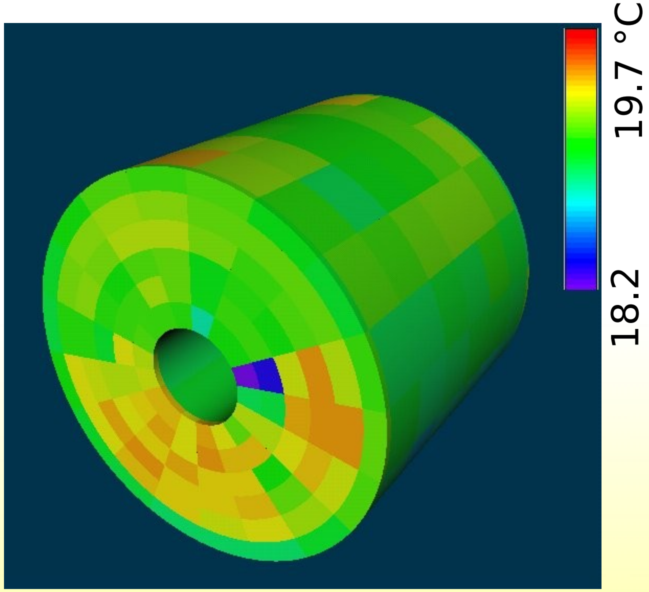




Temperature monitoring system

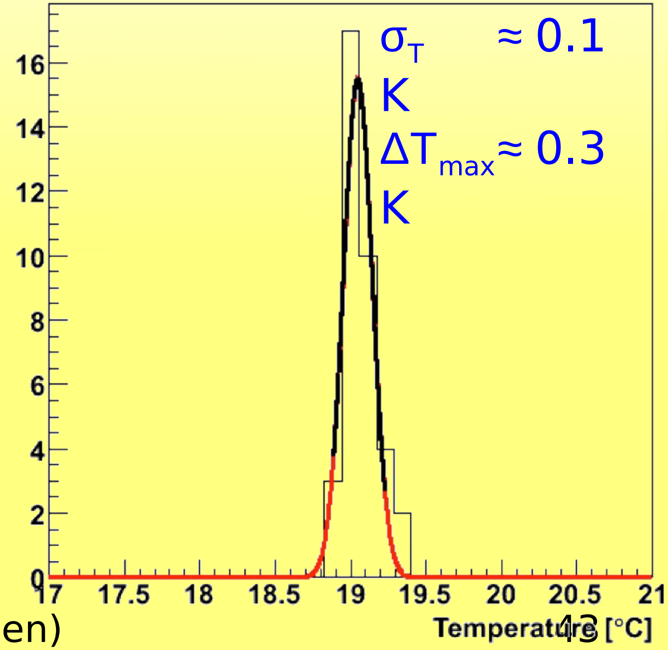






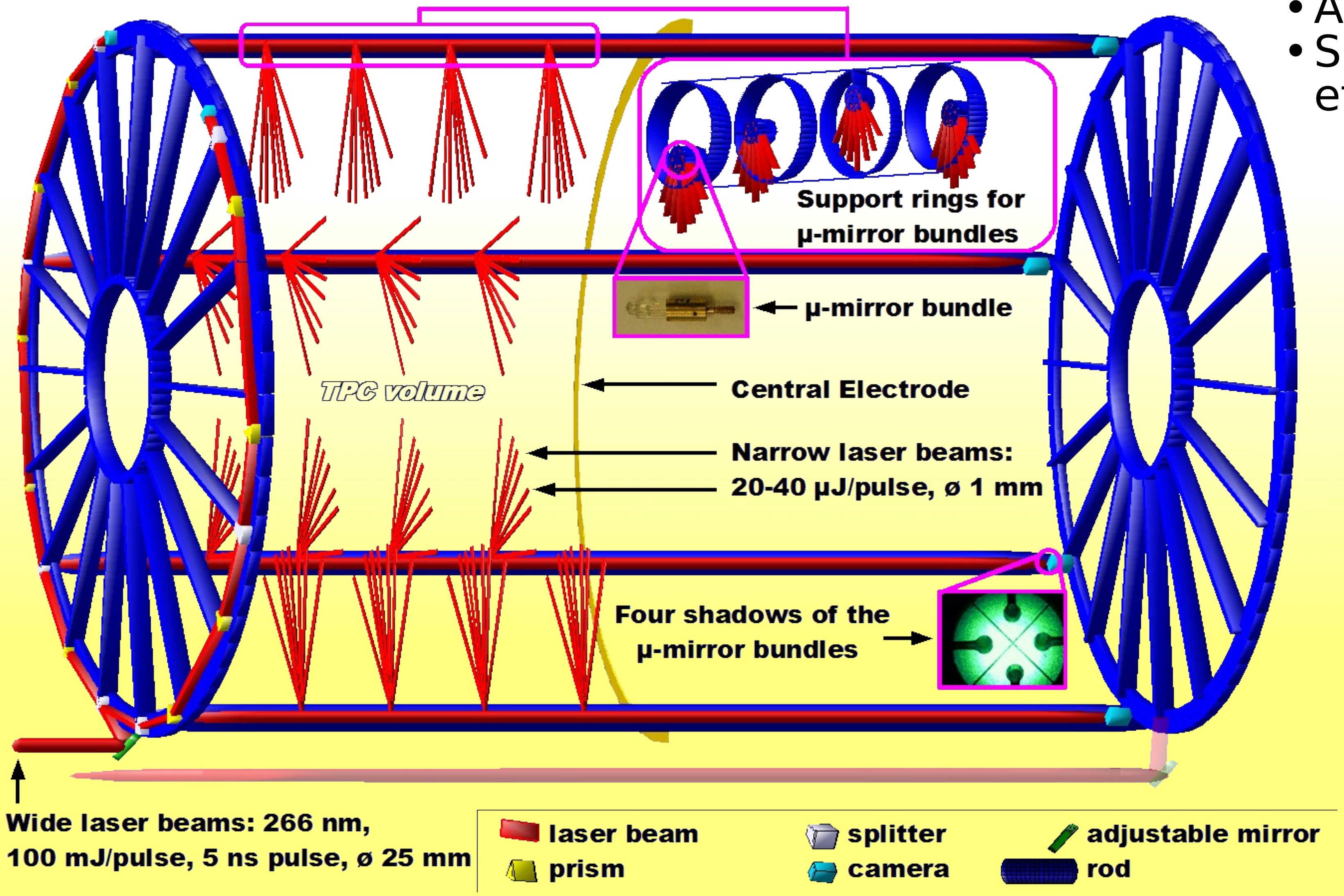
- About 500 sensors distributed all over the TPC
- calibrated within ~ 100mK

Successful calibration of the cooling system to design specifications



Laser calibration system

The principle of the laser system for the TPC



Support rings for µ-mirror bundles

µ-mirror bundle

TPC volume

Central Electrode

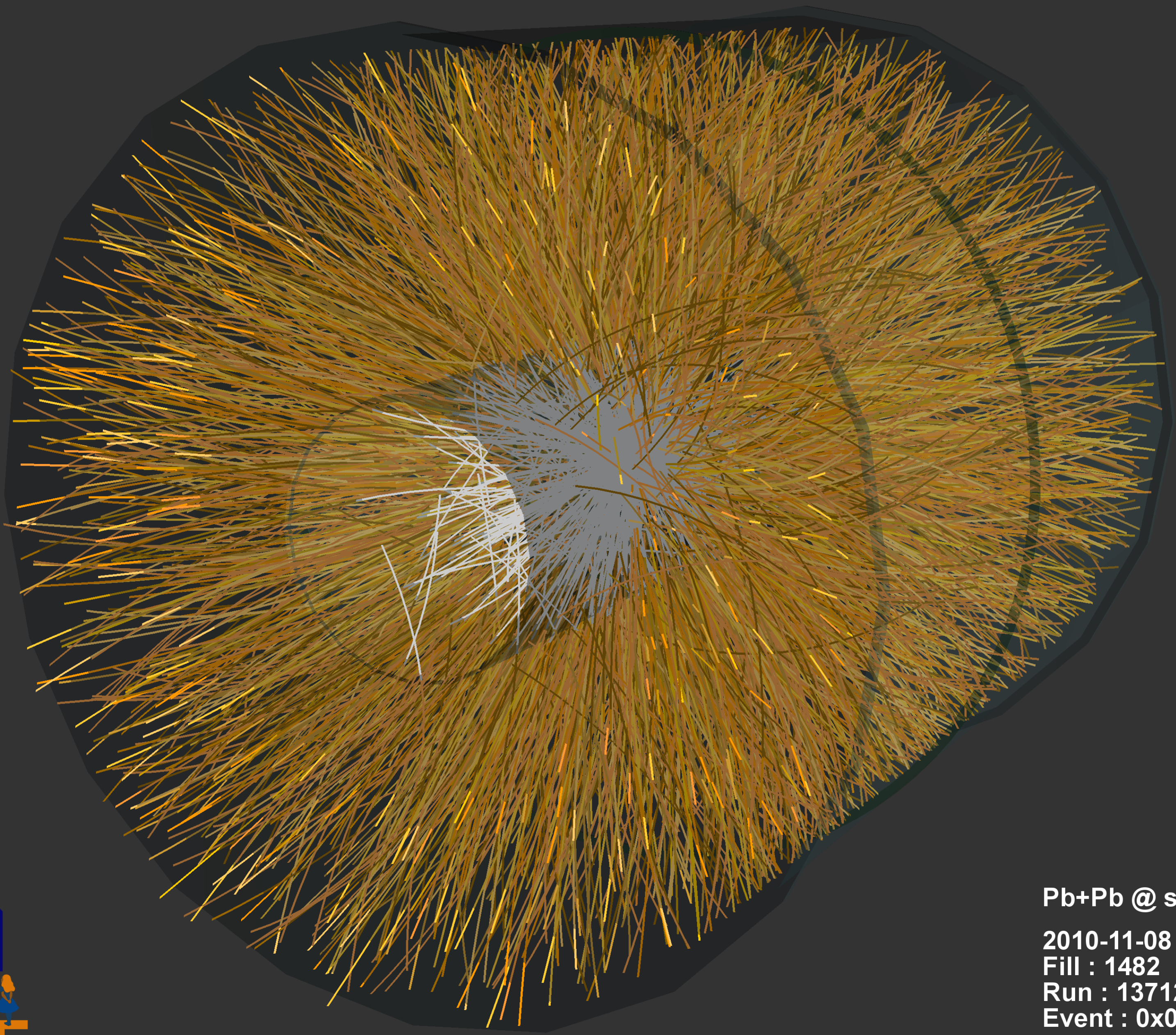
Narrow laser beams:
20-40 µJ/pulse, ø 1 mm

Four shadows of the µ-mirror bundles

Wide laser beams: 266 nm,
100 mJ/pulse, 5 ns pulse, ø 25 mm

🟥 **laser beam**	**splitter**	**adjustable mirror**
prism	**camera**	**rod**

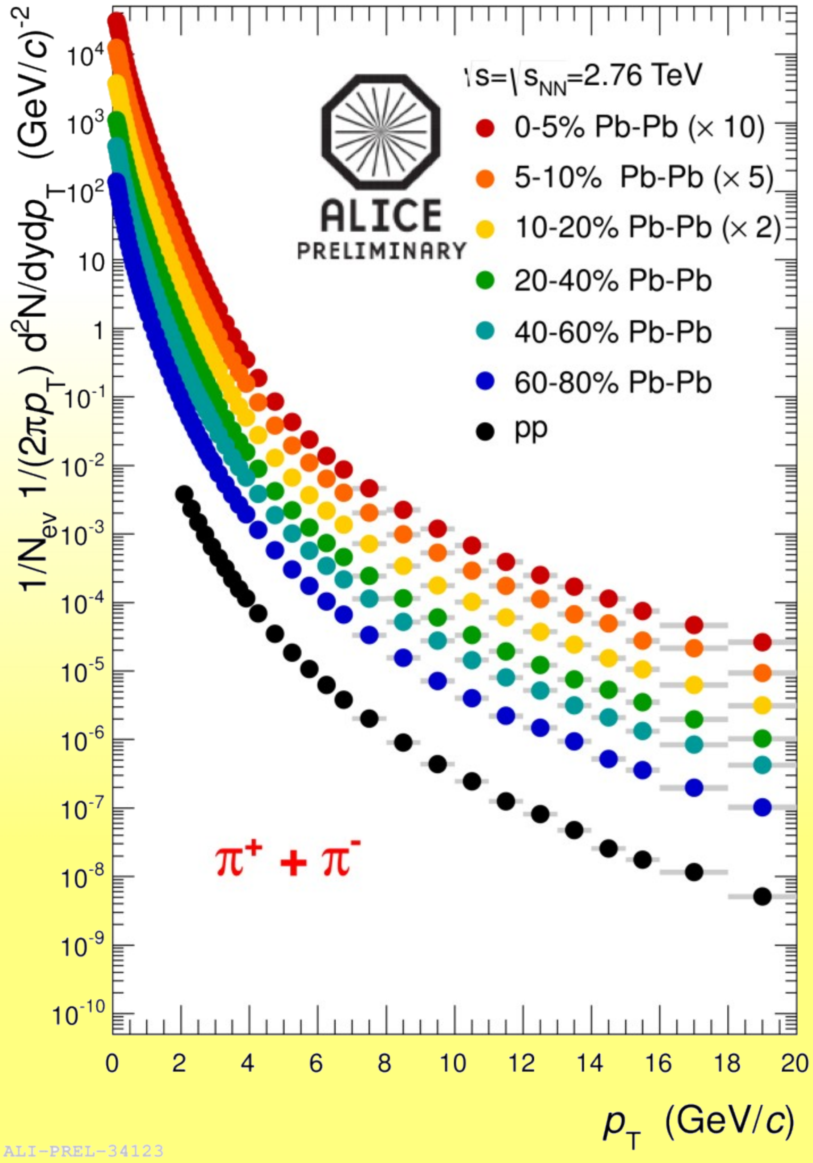
- Drift velocity
- Alignment
- Space charge effects



Pb+Pb @ sqrt(s) = 2.76 ATeV

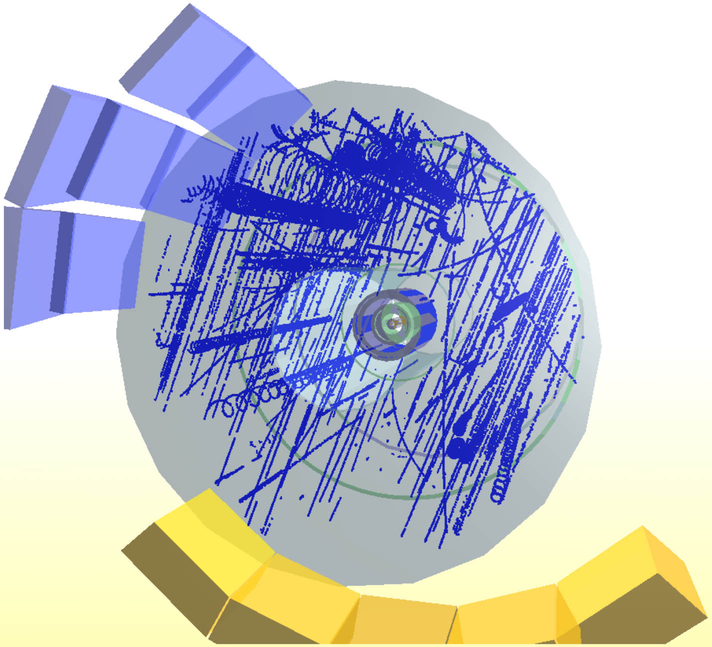
2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

PHYSICS results and performance



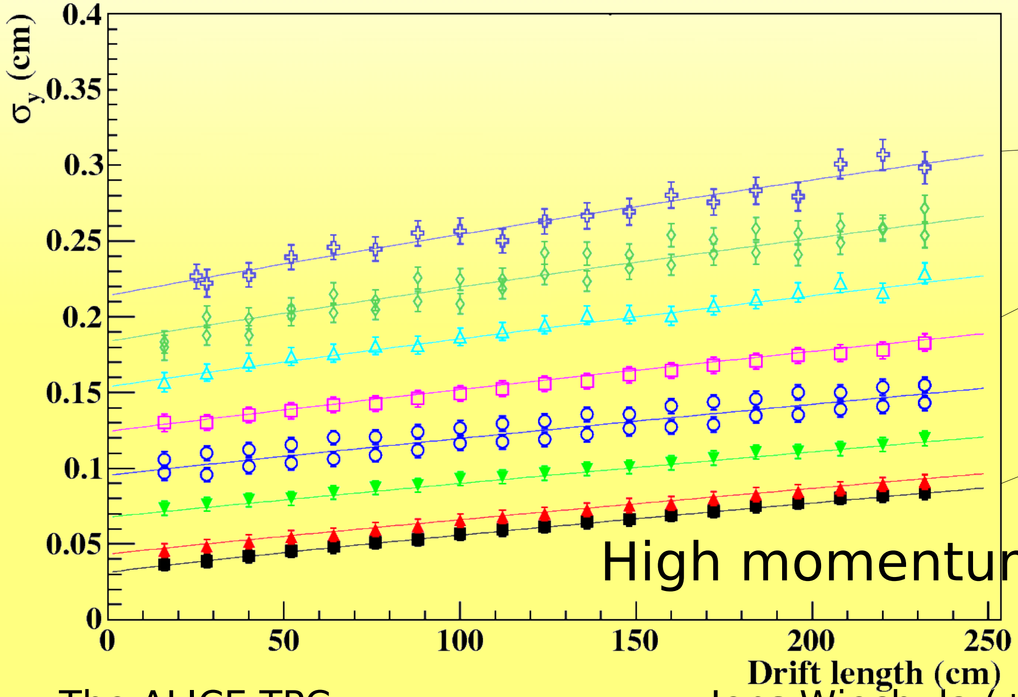
Space point resolution

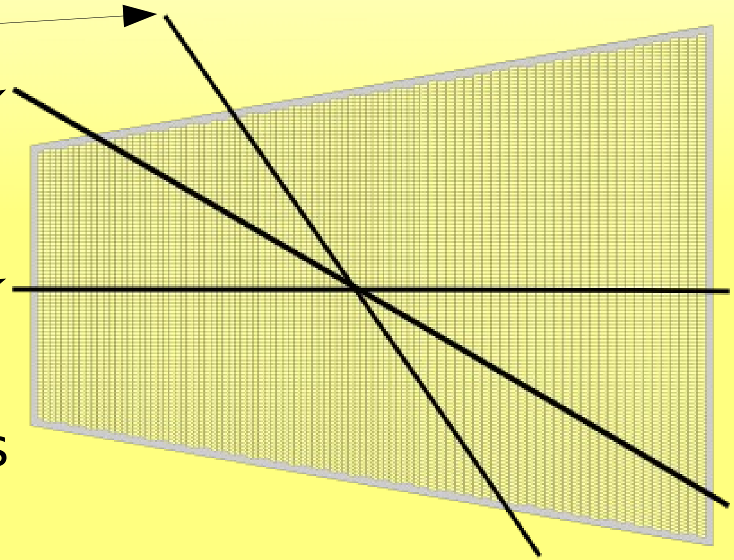
Space point resolution depending on
- drift length (diffusion)
- pad inclination angle (ideally close to zero)



Measurements in agreement with simulations:

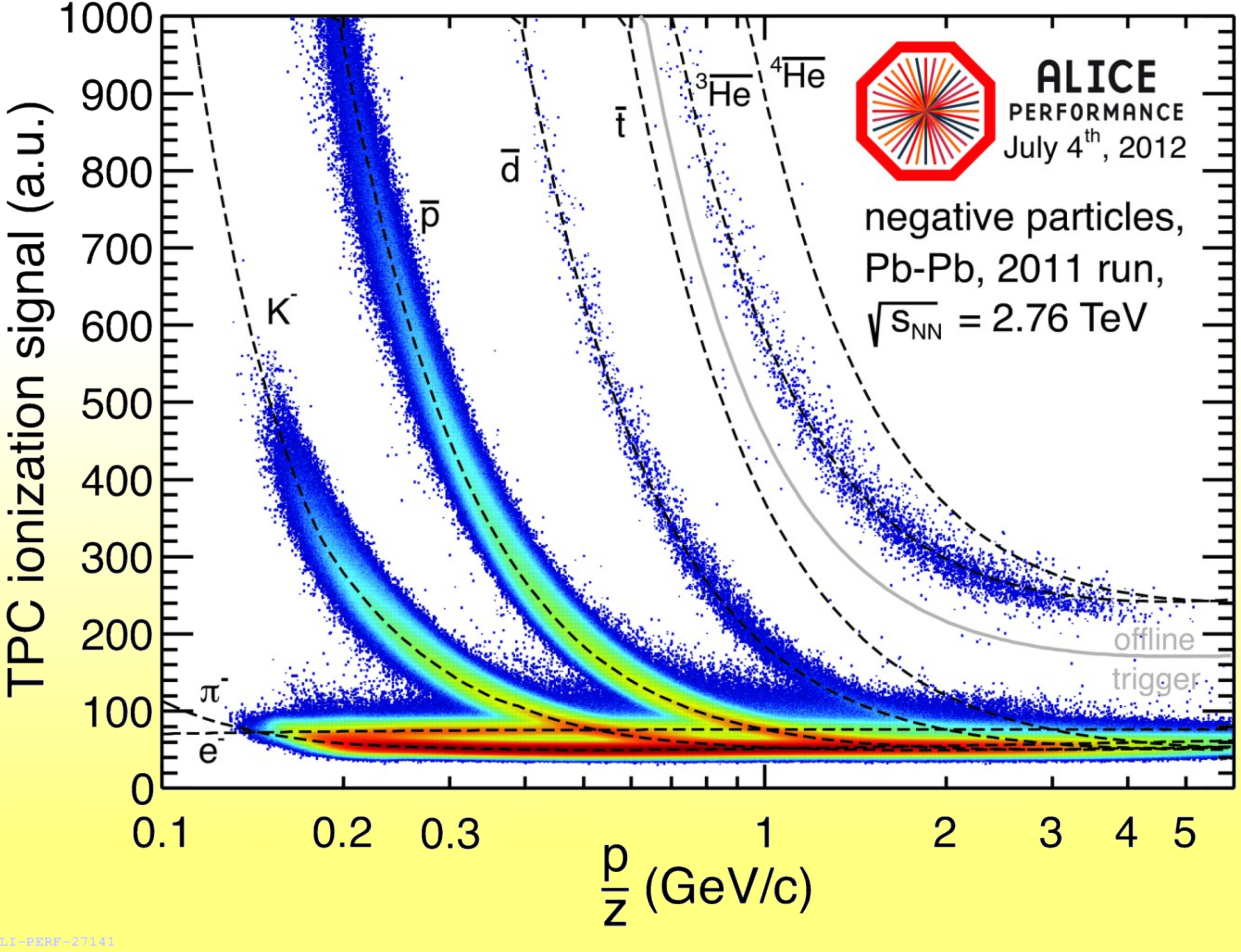
space point resolution in rφ 300 – 800 µm
for small inclination angles
(high momentum tracks)





High momentum tracks

Particle identification with the TPC



- Nicely calibrated TPC
- But how to identify particles → expected energy loss & resolution

Fitting of the Bethe Bloch function