Everything you wanted to know about the TPC but were afraid to ask
Everything you were afraid to know about the TPC and never wanted to ask.
Outline

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

Field cage

High voltage electrode (negative)

Magnetic Field (measure particle momentum)

Electric field (electron drift)

Driftgas

Multiwire proportional chamber (0V)

Voltage divider
Working principle of a TPC

- Two coordinates \((x, y)\) given by the projection on the pad plane
- Third coordinate \((z)\) given by the drift time and drift velocity \((z = v_{\text{Drift}} \times t_{\text{Drift}})\)
- Anode: 1400 - 1650 V
- Cathode: 0 V
- Gating: -100 ± 90 V open closed
- Gas gain \(\approx 2 \cdot 10^4\)
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

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

- \( \frac{dE}{dx} \) first falls \( \propto 1/\beta^2 \) (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 \( \gamma \) the relativistic rise is cancelled by the “density effect” (fermi plateau: polarisation of medium screens more distant atoms; described by the \( \delta \) parameter)
Ionisation

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

\[ W_i = \text{mean energy loss per produced ion pair} \ (W_i > I_0) \approx 30 \text{ eV} \]

\[ \Delta E = \text{total energy loss} \]

\[ n_{\text{total}} = n_{\text{primary}} + n_{\text{secondary}} = \frac{\Delta E}{W_i} = \frac{dE}{dx} \Delta x \]

\[ n_{\text{total}} \approx 3 \ldots 4 \cdot n_{\text{primary}} \]
Measurement of ionisation

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

\[ 1 \text{ cm gas counter, filled with Neon;} \]
\[ n_{\text{prim}} \approx 10 / (\text{cm atm}), n_{\text{total}} \approx 30 \]

\[ \sim 30 \text{ e-Ion pairs} \]

\[ \approx 30 \text{ Electron-ion-pairs are hard to detect!} \]

Amplifier noise is typically $\approx 1000 \text{ e}^- (\text{ENC})$!

⇒ Number of electrons has to be increased noiselessly!

⇒ Gas amplification
Gas amplification

Proportional mode: Detected signal is proportional to the original total ionisation $\rightarrow$ measurement of $dE/dx$. Gain $\approx 10^4 - 10^5$
**Drift of electrons an electric field**

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

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

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

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 $u_{\text{Drift}}$ is observed.
Drift velocity

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

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

With $e$, $m$ the electron charge and mass, $E$ the electric field, $N$ the density of the drift gas, $\sigma(\varepsilon)$ the collision cross-section as a function of the electron energy. Due to the trivial dependence on the gas density $N=1/k \cdot P/T$ 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 ...

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

ALICE gas mixture: NeCO₂

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

$E=0$ thermal diffusion \hspace{1cm} \langle \mathbf{v} \rangle_t = 0$

$E>0$ transport and diffusion

$\langle \mathbf{v} \rangle_t = \mathbf{v}_d$

Electric Field

Electron swarm drift

Drift velocity

Diffusion

$s, \Delta s, \Delta t$
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.
Diffusion measurements

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

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Momentum measurement

equation of motion:
\[ \vec{F} = q \cdot \vec{v} \times \vec{B} \quad (\vec{B} = \vec{B} \cdot \vec{e}_z) \]
\[ \vec{F} = m \cdot \vec{v} \rightarrow \text{Helix} \]

longitudinal
\[ \tan \theta = \frac{p_T}{p_z} \]

transverse
\[ \omega = \frac{q \cdot B}{m} ; \quad v_T = \omega \cdot r \rightarrow \]
\[ p_T = m v_T = q Br \]
\[ p_T \text{[GeV]} = 0.3 Br \text{[T} \cdot \text{m]} \]
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

ElectroMagnetic CALorimeter

Inner Tracking System

Time Projection Chamber

High Momentum Particle ID

Transition Radiation Detector

Time Of Flight

Muon Spectrometer

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Overview

Most challenging TPC ever built

- 557,568 readout pads
- 1000 samples in time direction
- 2x18 Inner Readout Chambers
- 2x18 Outer Readout Chambers

Gas:
- 90 m³
- Ne-CO₂-N₂ (90 - 10 – 5)
- low diffusion (“cold gas”)
- drift velocity non saturated
  - temp. homogeneity and stability 0.1 K required

Central HV electrode 100kV
Total drift time 92 µs
Gas Volumes

Drift gas Ne-CO$_2$(N$_2$) [90-10(-5)]
- $\approx$ 90m$^3$
- Ionisation
- Drift
- Gas amplification

CO$_2$-Volume:
- high-voltage stability
- Gas tightness
Central Electrode and field cage

Inner part of the field cage

Refexion of the padplane. mirrored on the CE

Central electrode

Outer part of the field cage
Voltage divider (resistor rods)

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

On each side:
• 18 IROCs
• 18 OROCs

72 ROCs in total

Pads

Inner ReadOut Chambers (IROCs)
80 cm

Outer ReadOut Chambers (OROCs)
115 cm
## Readout chambers

<table>
<thead>
<tr>
<th>Pad Size [mm²]</th>
<th>Number of pad rows</th>
<th>Number of pad</th>
</tr>
</thead>
<tbody>
<tr>
<td>IROC (81.1 - 132.1 cm)</td>
<td>4 x 7.5</td>
<td>63</td>
</tr>
<tr>
<td>OROC (134.6 - 198.6 cm)</td>
<td>6 x 10</td>
<td>64</td>
</tr>
<tr>
<td>OROC (198.6 - 246.6 cm)</td>
<td>6 x 15</td>
<td>32</td>
</tr>
<tr>
<td>TPC total</td>
<td>159</td>
<td>557 568</td>
</tr>
</tbody>
</table>

**Gating-Grid**

### OROC
- 1.25mm

### IROC
- 1.25mm

**Kathode wires**

**Anode wires**

(Sense wires)

**Pad plane**

Pad size changes with track density
FrontEnd Cards

- Cooling plate
- ALice TPC ReadOut chip
- PreAmplifier-Shaper
- Capton cables

128 readout channels

FEC (Front End Card) - 128 CHANNELS (CLOSE TO THE READOUT PLANE)

- 8 CHIPS x 16 CH / CHIP
- Custom IC (CMOS 0.35μm)
- PASA
- ADC
- Digital Circuit
- RAM
- RCU

DAQ (RORC)
DCS
TTC

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Service Support Wheel

FEC mounting frames

chilled water distribution pipes

Cooling pipe

Busbar

Busbar-Cooling

Low voltages cables
Fully assembled sector

- Hoses for FEC and RCU cooling
- Backplanes
- Service support wheel
- Cooling pipe
- Busbar
- Low voltages cables (power for digital and analog circuits of the FECs and RCUs)
- Readout Control Units (6 Patches)
Auxiliary systems

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

- Recirulating gas system -> recover Ne
- Purifier (removal of H₂O and O₂)
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 ($\approx 27$ kW)
- 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 $\approx 100\text{mK}$

Successful calibration of the cooling system to design specifications
Laser calibration system

• Drift velocity
• Alignment
• Space charge effects
Lets breath for a moment, then the fun starts!
AliAnalysisTaskGiveMeMyPiSpectraForAllMultiplicities

But ...

• How do I get those tracks out of my detector
• How do I know it's a pion
Reconstruction & Calibration

- Space points
- Track finding
- $dE/dx$ calculation
Space point reconstruction

- Extract space point for each pad row
- Determine centre of gravity in time direction
- Determine centre of gravity in pad direction
Space point calibration I

- z coordinate depends on the measured electron drift time and drift velocity
- Drift velocity changes over time
  - Variations in the gas density (P/T)
  - Changes in the gas composition
- Calibration
  - Use laser system for initial measurement (online)
  - User matching of TPC tracks with ITS

~ ± 5cm for longest drift
Space point calibration II

- Drifting electrons are deflected from ideal drift path
- Imperfections in the field cage
- Maximum (very local):
  - $\delta r = 10$ mm (shown here);
  - $\delta r\phi = 0.8$ mm
Space point calibration III

- Drifting electrons are deflected from ideal drift path
- B field shape (homogeneity) and alignment with E field
- Maximum
  - $\delta r = 4 \text{ mm};$
  - $\delta r\phi = 8 \text{ mm (shown here)}$

Example: A side, $z=1\text{cm}$
Space point calibration – even more

- Readout chamber alignment
- ...

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Track fitting

- Fit reconstructed space points with a helix parametrisation

Procedure
- Fit from larger to smaller radii
- Start 'seeding' from outer most clusters (low occupancy)
- Extrapolate to next row
- Look for cluster close to extrapolation
- Associate cluster to track & update parameters

Kalman filter
- Track parameters improve with added points
- Provides error parametrisation of parameters & fit quality (e.g. $X^2$/cluster)
<dE/dx> measurement

Truncated mean (<dE/dx>) cutting upper 40% of the charge distribution used as PID signal
<dE/dx> calibration I

• Gain variations expected due to manufacturing tolerances (readout chips, chambers)

• Calibration
  - Release radioactive $^{83}$Kr into the TPC gas
  - Record decay spectrum for each single pad
  - Create gain map on single pad level
  - Repeat ~ yearly
<dE/dx> calibration II

- Gain changes over time
  - Gas density (P/T)
  - Gas composition
  - HV on chambers
- Calibration
  - Monitor gain for each chamber

- Gain changes with drift distance
  - Electron attachment
  - Diffusion (cluster lost below threshold)
- Calibration
  - Monitor gain vs. drift time
<dE/dx> calibration – even more

- dx dependence on local inclination angles
- Correct for lost clusters (below electronics threshold)
- Ion tail corrections
- ...
Performance

- Space point resolution
- Momentum resolution
- dE/dx 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 $r\phi$ 300 – 800 $\mu$m
  for small inclination angles
  (high momentum tracks)
Momentum resolution

Combined tracking TPC-ITS momentum resolution $\sim 10\%$ at 50 GeV/$c$
(Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV from 2010)

For new productions, the momentum resolution improved to $\sim 5\%$ at 50 GeV/$c$, as a result of improved TPC-ITS matching.
dE/dx resolution

- <dE/dx> resolution close to design values
  - 5.5% at low multiplicity
  - 6.8% at high multiplicity
- Depends on several parameters
  - <dE/dx> itself
  - # of used clusters
  - eta

\[ p_{\text{TPC}} \sim 1.5 \text{ GeV/c} \]

\[ \tan(\Theta) \sim 0.3 \]
Particle identification with the TPC

- Nicely calibrated TPC
- But how to identify particles → expected energy loss & resolution
Fitting of the Bethe Bloch function

\[ \Lambda \rightarrow p\pi \]
\[ K^0_s \rightarrow \pi^+\pi^- \]

\[ \gamma \rightarrow e^+e^- \]

Actually used points
Residual calibration at low momentum

Small deviations at low momentum
The Bethe Bloch parametrisation, corrected for the low momentum effect is called spline
Residual calibration on eta

Momentum dependence of eta dependence ($\Delta'_{\text{Species}}$) of V0pr

Scale for eta dependence is $O(10\%)$!!!
Residual variation after correction

Momentum dependence of eta dependence (\(\text{Delta}' \) of \(V_{0pr}^{\text{Species}}\))

Residual eta dependence \(O(1\%)\)

\(\Rightarrow 1\) order of magnitude smaller than without correction!
What is most commonly used - $n\sigma$

Number of sigmas: “deviation of the measured energy loss to the expected energy loss of a certain particle expressed in terms of the detector resolution”

$$n_{\sigma}^{\text{particle}} = \frac{\langle dE/dx \rangle_{\text{measured}} - \langle dE/dx \rangle_{\text{spline, particle}}}{\sigma(\langle dE/dx \rangle)(\text{PID clusters, } dE/dx, \eta)}$$

---

**Pull vs. $P_{\text{TPC}}$ for $0.00 <= |\tan(\Theta)| < 0.10$**

Plot for protons!
Ok, let's breath again!
What you see from that

```c
void AliAnalysisTaskGiveMeMyPiSpectraForAllMultiplicities::UserExec(Option_t *)
{
    AliVEvent *event=InputEvent();
    AliAnalysisManager *man=AliAnalysisManager::GetAnalysisManager();
    AliInputEventHandler* iH = (AliInputEventHandler*) (man->GetInputEventHandler());
    AliPIDResponse *pid=iH->GetPIDResponse();

    for (Int_t itrack=0; itrack<event->GetNumberOfTracks(); ++itrack) {
        AliVTrack track=(AliVTrack*)event->GetTrack(itrack);
        if (!passesMyCuts(track)) continue;
        Double_t nsigma=pid->NumberOfSigmasTPC(track,AliPID::kPion);
        if (abs(nsigma)>2) continue;
        myPionHist->Fill(track->Pt());
    }
}
```

... ok, also analysis is not THAT simple ;-)
Produce results

What's left?
- sweat lot
- work hard
- do some more magic
- get nice physics results

\[ \frac{1}{N_N} \frac{1}{1/(2 \pi p_T)} \frac{d^2 N}{dy dp_T^2} \ (\text{GeV}/c)^2 \]

\[ s = s_{\text{NN}} = 2.76 \text{ TeV} \]

ALICE PRELIMINARY

\[ \pi^+ + \pi^- \]

\[ \rho \ (\text{GeV}/c) \]

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Summary

• The TPC is a very complex device
  - Most challenging TPC ever built
• It needs very sophisticated calibration in order to reach the desired physics performance
• Most of the time you don't see anything of this :-)

• Be patient if something doesn't work out of the box or may take some time
Summary

• The TPC is a very complex device
  - Most challenging TPC ever built
• It needs very sophisticated calibration in order to reach the desired physics performance
• Most of the time you don't see anything of this :-)

• Be patient if something doesn't work out of the box or may take some time

(Everything) you wanted to know about the TPC but were afraid to ask  Everything you were afraid to know about the TPC and never wanted to ask
Many people involved
Thanks to the TPC team

- Planning
- Design
- Construction
- Testing
- Calibration
- Operation
- ....

and a few more
Literatur

- ALICE Technical design report of the Time Projection Chamber, CERN/LHCC 2000-001

- The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events, arXiv:1001.1950 [physics.ins-det]

- W. Blum, W. Riegler, L. Rolandi: Particle Detection with Drift Chambers

- F. Sauli: Principles of operation of multiwire proportional and drift chambers
Backup
## TPC related Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTRO</td>
<td>ALice TPC ReadOut chip</td>
</tr>
<tr>
<td>DAQ</td>
<td>Data AcQuisition</td>
</tr>
<tr>
<td>DCS</td>
<td>Detectro Control System</td>
</tr>
<tr>
<td>DDL</td>
<td>Detector Data Link</td>
</tr>
<tr>
<td>FEC</td>
<td>FrontEnd Card</td>
</tr>
<tr>
<td>FEE</td>
<td>FrontEnd Electronics</td>
</tr>
<tr>
<td>HLT</td>
<td>High Level Trigger</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>IROC</td>
<td>Inner ReadOut Chamber</td>
</tr>
<tr>
<td>LV</td>
<td>Low Voltage</td>
</tr>
<tr>
<td>MIP</td>
<td>Minimum Ionising Particle</td>
</tr>
<tr>
<td>OROC</td>
<td>Outer ReadOut Chamber</td>
</tr>
<tr>
<td>PASA</td>
<td>PreAmplifier ShAper</td>
</tr>
<tr>
<td>PID</td>
<td>Particle Identification</td>
</tr>
<tr>
<td>RCU</td>
<td>Readout Control Unit</td>
</tr>
<tr>
<td>RORC</td>
<td>ReadOut Receiver Card</td>
</tr>
<tr>
<td>SSW</td>
<td>Service Support Wheel</td>
</tr>
<tr>
<td>TPC</td>
<td>Time Projection Chamber</td>
</tr>
<tr>
<td>VHV</td>
<td>Very High Voltage</td>
</tr>
</tbody>
</table>
Energy loss of charged particles

The energy loss of “heavy” \((M \gg m_e)\) particles is described by the Bethe-Bloch-Formula and results in Ionisation

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

Absorber properties \((Z, A, \rho, \text{Ionisation potential } I_0, \text{Screening and density correction term } \delta)\)
Particle properties \((\beta, z)\)

• remarks:
  • \(dE/dx\) only depends on \(\beta\), it is independent of \(m\)
  • often \(dE/dx\) means \(1/\rho \cdot dE/dx\); one defines \(dx := \rho dx\)
    \(\Rightarrow dE/dx\) in \([\text{MeV g}^{-1} \text{ cm}^2]\)
  • Electrons and positrons need special treatment \((m_{\text{proj}} = m_{\text{target}})\)
    \(\Rightarrow \left\langle \frac{dE}{dx} \right\rangle_{\text{tot}} = \left\langle \frac{dE}{dx} \right\rangle_{\text{col}} + \left\langle \frac{dE}{dx} \right\rangle_{\text{rad}}\) (energy loss because of bremsstrahlung)
Ionisation and energy loss of charged particles

The distribution of the energy loss $\Delta E$ passing through a layer of thickness $D$ is described by the Landau-Distribution:

$$\langle \Delta E \rangle \sim \langle dE/dx \rangle D$$

$$L(\lambda) = \frac{1}{\sqrt{2\pi}} e^{-1/2(\lambda+e^{-\lambda})}$$

$$\lambda \equiv \frac{\langle \Delta E - \langle \Delta E \rangle \rangle}{\langle \Delta E \rangle}$$
Diffusion in a zero field environment

In the case of no external field the diffusion is isotropically and the densities follow a Gaussian distribution:

\[
\frac{dN}{dx} = N \frac{1}{\sqrt{4\pi D_x t}} e^{-\frac{x^2}{4D_x t}}
\]

It is assumed that all charge is located in (0,0,0) at \( t=0 \).
The equation describes which fraction \( \frac{dN}{N} \) of the charge is left in \( dx \) after the time \( t \).

D is called the diffusion constant and is given by:

\[
\sigma_x = \sqrt{2D_x t} \quad \sigma_{vol} = \sqrt{3\sigma_x} = \sqrt{6D_x t}
\]
In an electric field the charge is transported over the distance \( L = v_D \cdot t \) in the time \( t \).

If we introduce the electron mobility \( \mu \) ( \( v_D = \mu E \) ) we get \( L = \mu Et \) and therefore:

\[
\sigma_x = \sqrt{2D_{xt}} = \sqrt{\frac{2D_x L}{\mu E}}
\]

In literature the diffusion constant is often given by

\[
D_x = \frac{\sigma_x}{\sqrt{L}} = \sqrt{\frac{2D_x}{\mu E}}
\]

The minimum energy an electron can adopt is the mean thermal energy in of the gas. Therefore the diffusion must have a lower limit, which is described by the Nernst-Townsend-Formula:

\[
\frac{D}{\mu} = \frac{kT}{e} \quad D_x = \sqrt{\frac{2kT}{eE}}
\]
Central Electrode, field cage, Endplates

- TPC divided in two sides (A (Shaft), C (Muon))
- Field strength: 400V/cm, drift length 250cm -> 100kV
- ≈ 170 Field stripes on both sides
- End plates are segmented into 18 Sectors in phi
- Sectors are divided into an inner and outer part
Two photon ionisation (laser)

The typical lasers used have a wavelength of 266nm (≈ 4.7 eV). Ionisation energy of e.g. Ne ≈ 20eV.

What is ionized are impurities in the gas (long-chain hydrocarbons). A two photon process is needed to obtain a high enough energy.

From the system of equations of the transition rates one obtains.

\[ P_2 \sim P_0 \Phi^2 \]
Gain curve

Gas gain

Working point $2 \cdot 10^4$

Anode voltage (V)

Gain

Module 03
19.02.02
FrontEnd Electronics

- 18 – 25 FECs (patch) per RCU
- 6 RCUs per sector (6patches)
- 6 x 36 = 216 RCUs in total
Readout of the TPC

FEC (Front End Card) - 128 CHANNELS (CLOSE TO THE READOUT PLANE)

- 8 CHIPS $\times$ 16 CH / CHIP
- ALTRO
- CUSTOM IC (CMOS 0.25 $\mu$m)

RCU

- DAQ (RORC)
- DCS
- TTC

- PASA
- ADC
- Digital Circuit
- RAM

- CUSTOM IC (CMOS 0.35 $\mu$m)
- Amplifier
- Semi-gauss shaper
- Baseline correction
- Tail Cancellation
- Zero suppression
- Multi-event memory

- 570132 PADS
- Scintillation
- Pad plane
- Drift region
- 88 $\mu$s
ALTRO signal correction

Event 251, Channel 150

After ALTRO Correction
Readout chain

Overall TPC: 4356 Front End Card
216 Readout Control Unit

ON DETECTOR

COUNTING ROOM

RCU

Detector Data Link (200 MB/s)
Etherent (1 MB/s)
TTC optical Link (Clock, L1 and L2)

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Data AcQuesition

Event Building Network (Ethernet Switch)

Storage Network

File

Event

Load Bal.

Sub-event

Event Fragment

Rare/All

CTP Central Trigger Processor
DSS DAQ Service Servers
FERO Frontend Readout
GDC Global Data Collector
LDC Local Data Concentrator
LTU Local Trigger Unit
PDS Permanet Data Storage (Tapes)
TDS Transien Data Storage
TTC Time & Trigger Control

CTP

L0, L1a, L2

CTP

BUSY

LTU

L0, L1a, L2

LTU

BUSY

TTC

TTC

FERO

FERO

FERO

FERO

LDC

LDC

LDC

LDC

123 DDLs

262 DDLs

329 D-RORC

175 Detector LDC

175 Detector LDC

EDM

GDC

GDC

GDC

GDC

50 GDC 25 TDS

50 GDC 25 TDS

PDS

TDS

TDS

DSS

DSS

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Gas quality monitor (Goofie)

- measure drift velocity
- measure gas gain
  ✔ calibrate curves for changes of N₂ and CO₂ in Ne
  → monitor N₂
  → monitor CO₂ change

HV ≈ 10kV

≈ 20 cm

α-Source
Start counter

drifting electrons

Voltage divider
Pick-up counter (0V)
Laser calibration system
Pre-comissioning 2006

- Only 2 sectors operated simultaneously
- Cosmic and laser events taken
Status in 2007

- TPC is fully equipped and operational (not yet with all final systems)
- Two commissioning phases successfully accomplished (no major problems occurred)