Detectors for Particle Radiation

- Ionization chamber
- Proportional and Geiger counter
- MWPC's
- TPC   as an example of a state-of-the-art detector
- Scintillation counters
- Solid state (Si, Ge) detectors
- Calorimeters
- Cerenkov and transition radiation detectors

Layout of a Geiger and Proportional Counter

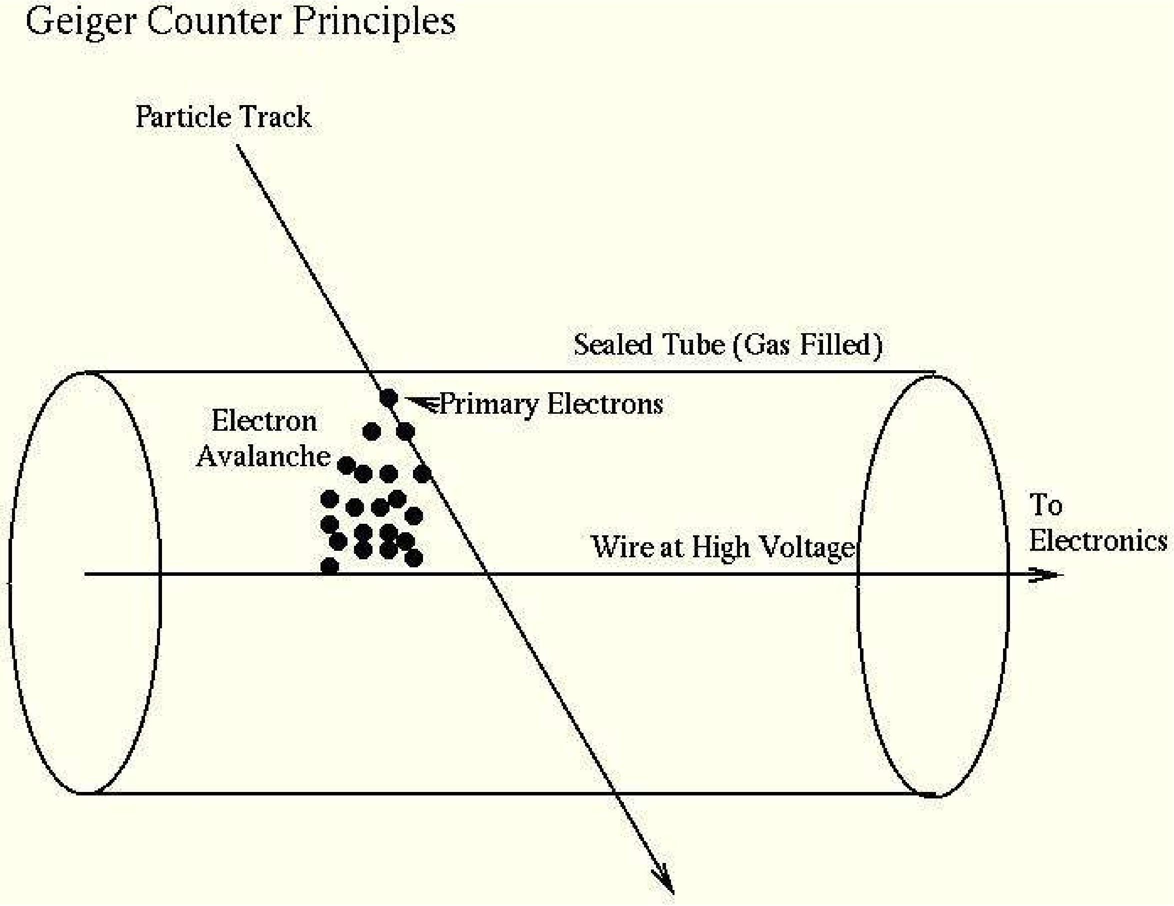
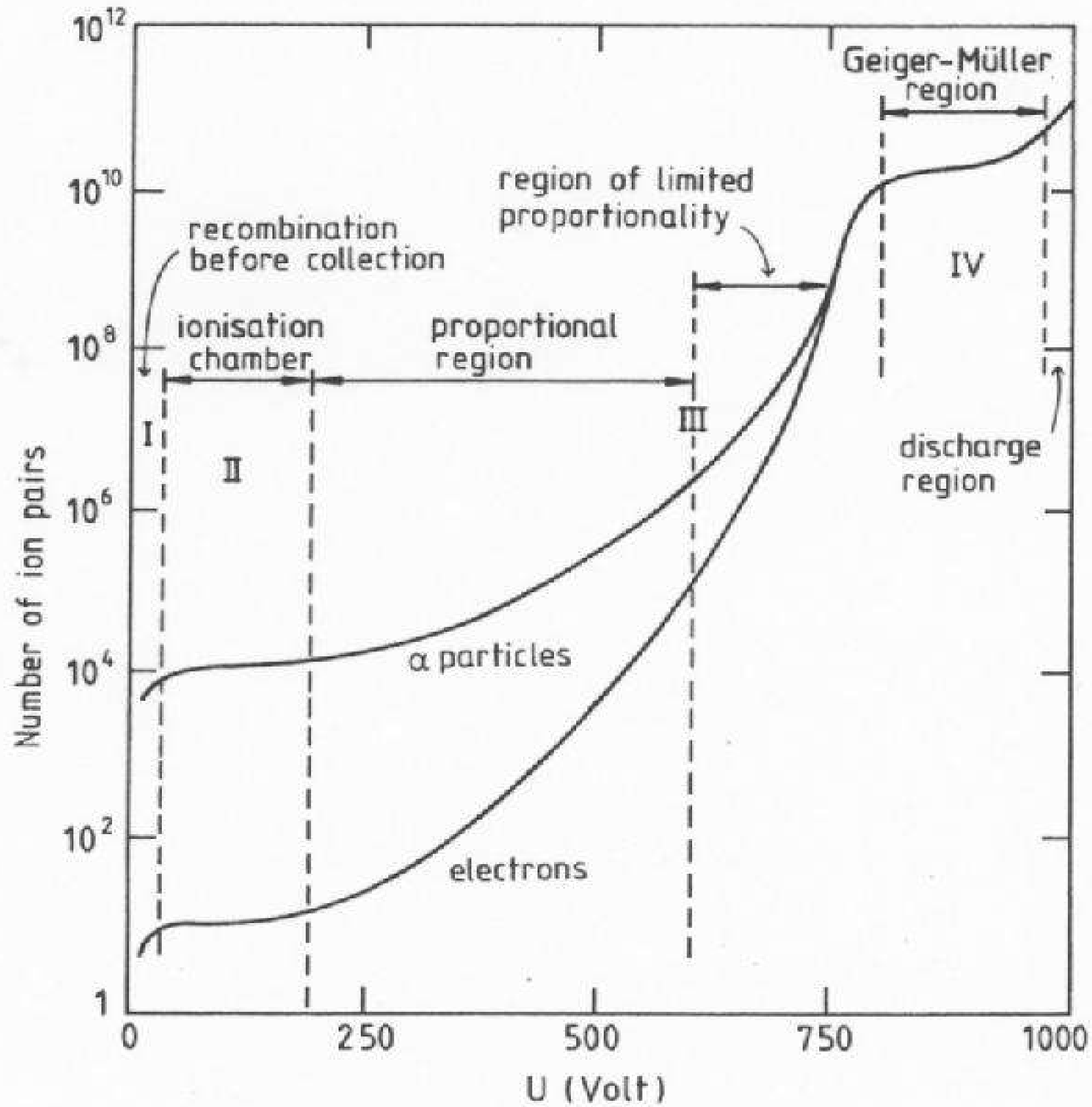


Fig. 2.8. Gas amplification factor as a function of voltage applied in a proportional counter for ionizing α-particles and electrons (after [PR 58]).



The MWPC counter

multi-wire proportional counter

Fig. 3.1. Principle of multiwire proportional chamber. Upper part, schematic diagram of the geometry; lower part, equipotential surfaces (broken curves) and electric field lines (full curves) in the neighbourhood of two anode wires in the plane perpendicular to the wire direction [ER 72].

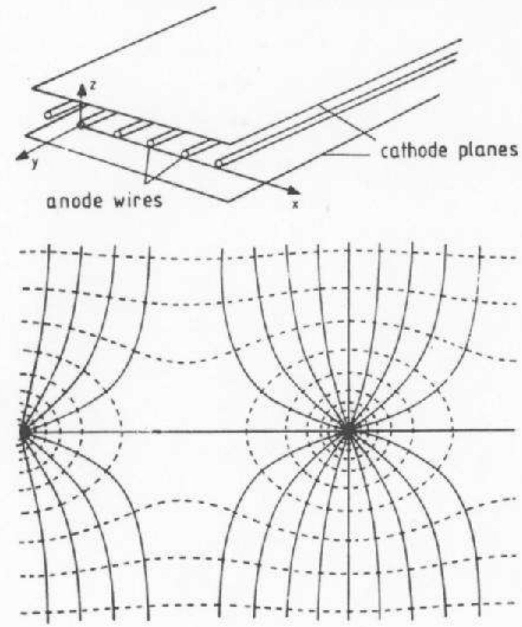
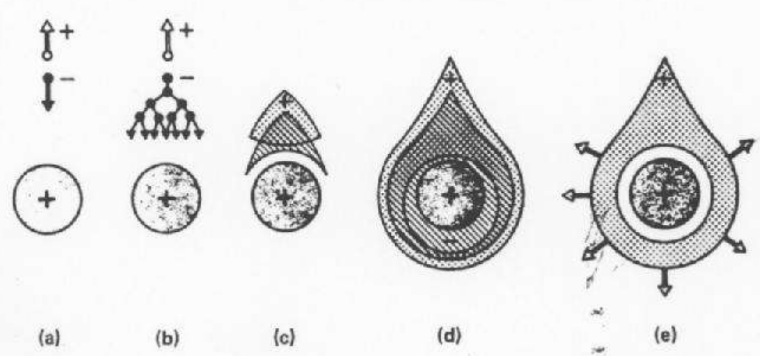
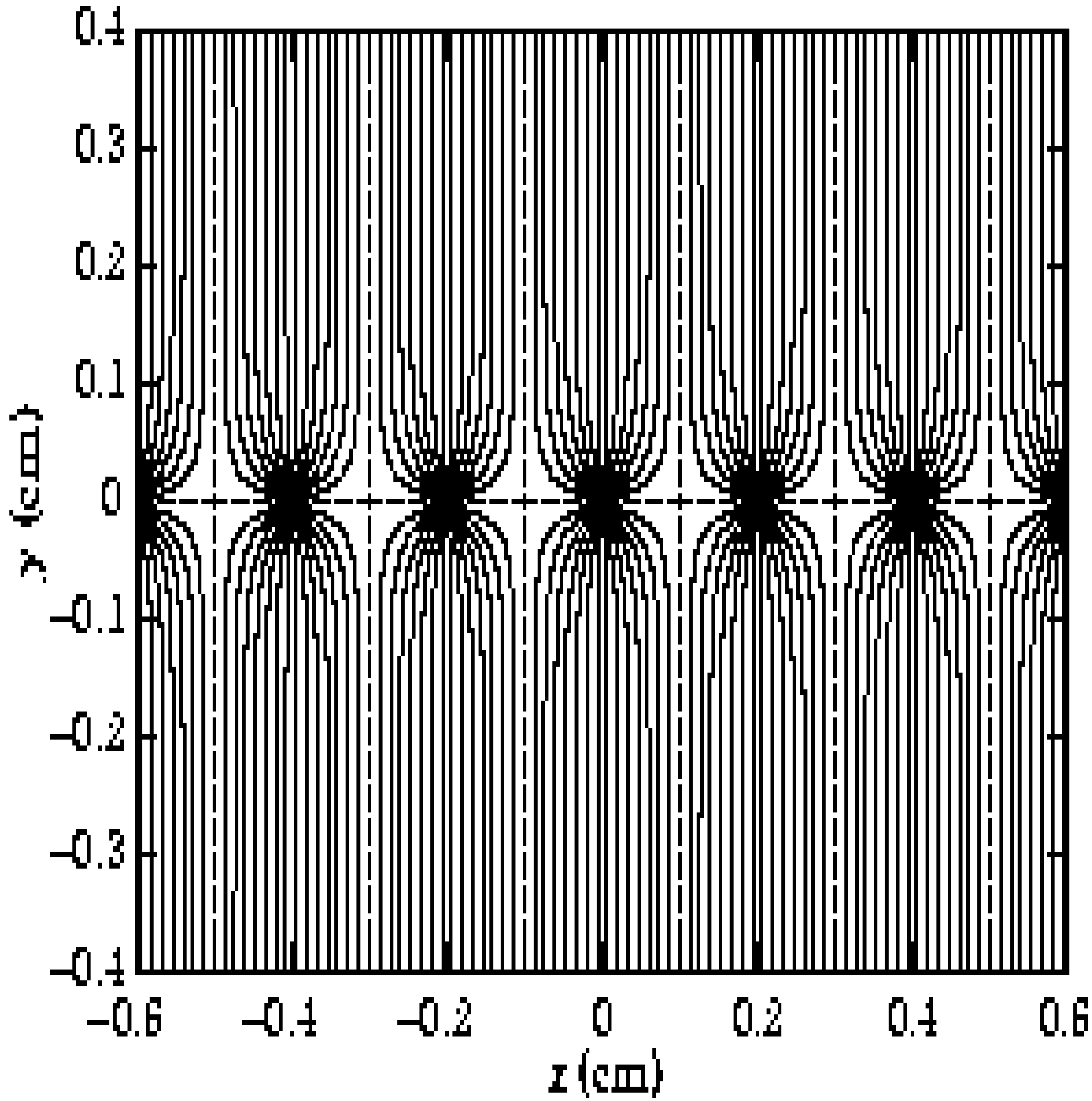


Fig. 3.2. Time development of an avalanche near to an anode wire in a proportional chamber. (a) Primary electron moving towards anode. (b) The electron gains kinetic energy in the electric field and ionizes further atoms; multiplication starts. (c) The electron and ion clouds drift apart. (d), (e) The electron cloud drifts towards the wire and surrounds it; the ion cloud withdraws radially from the wire [CH 72].




0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
y (cm)
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
z (cm)

Cathode read-out for multi-dimensional information

Fig. 3.4. Detection efficiency of a proportional chamber, with 6 mm gap, as a function of a high voltage, for different lengths of the electronic gate for accepting pulses [SC 71].

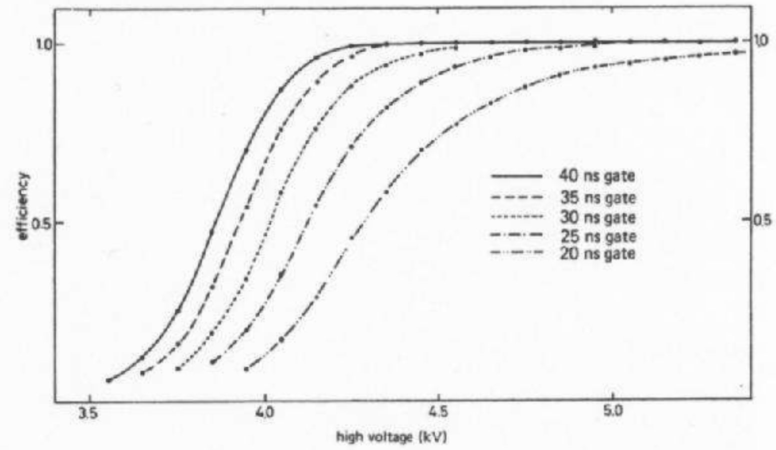
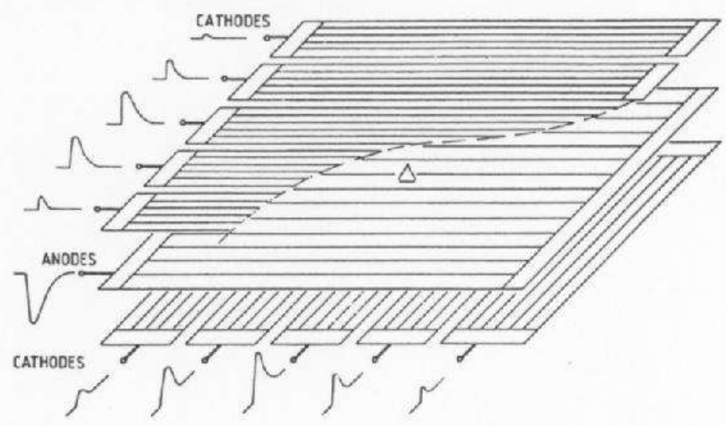


Fig. 3.5. Principle of cathode readout in proportional chambers. The centre of gravity of the charges induced on the cathode strips running orthogonal to the anode wires determines the position of the avalanche, shown here as a triangle [CH 78*a*].



TPC Characteristics

– Only gas in active volume

  Little material

– Very long drift (> 2 m)

  slow detector (~40 µs)

  no impurities in gas

  uniform E-field

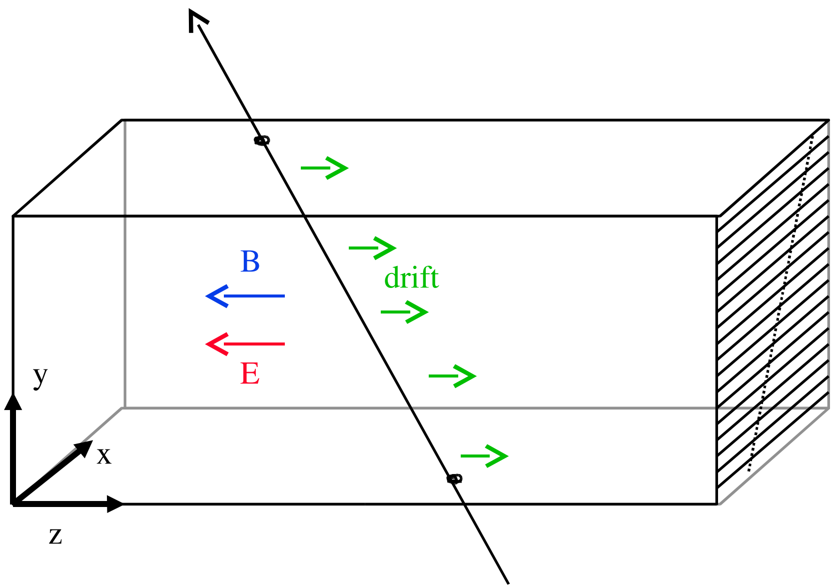
  strong & uniform B-field

  $\vec{E} \times \vec{B} = 0$

– **Track points recorded in 3-D (x, y, z)**

– **Particle Identification by dE/dx**

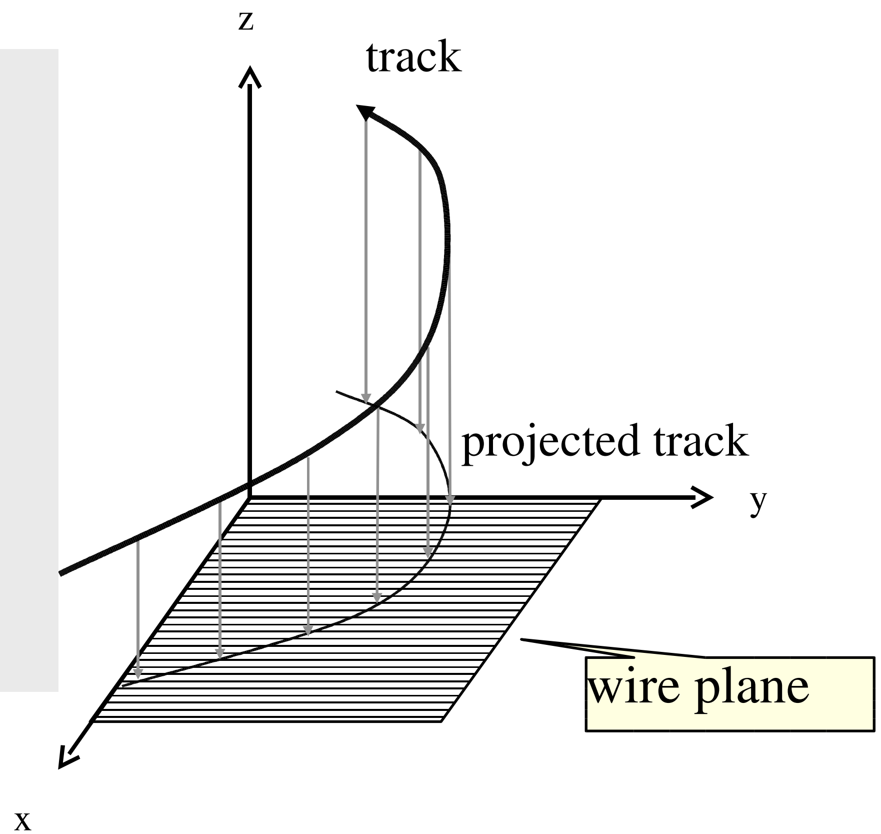
– **Large track densities possible**

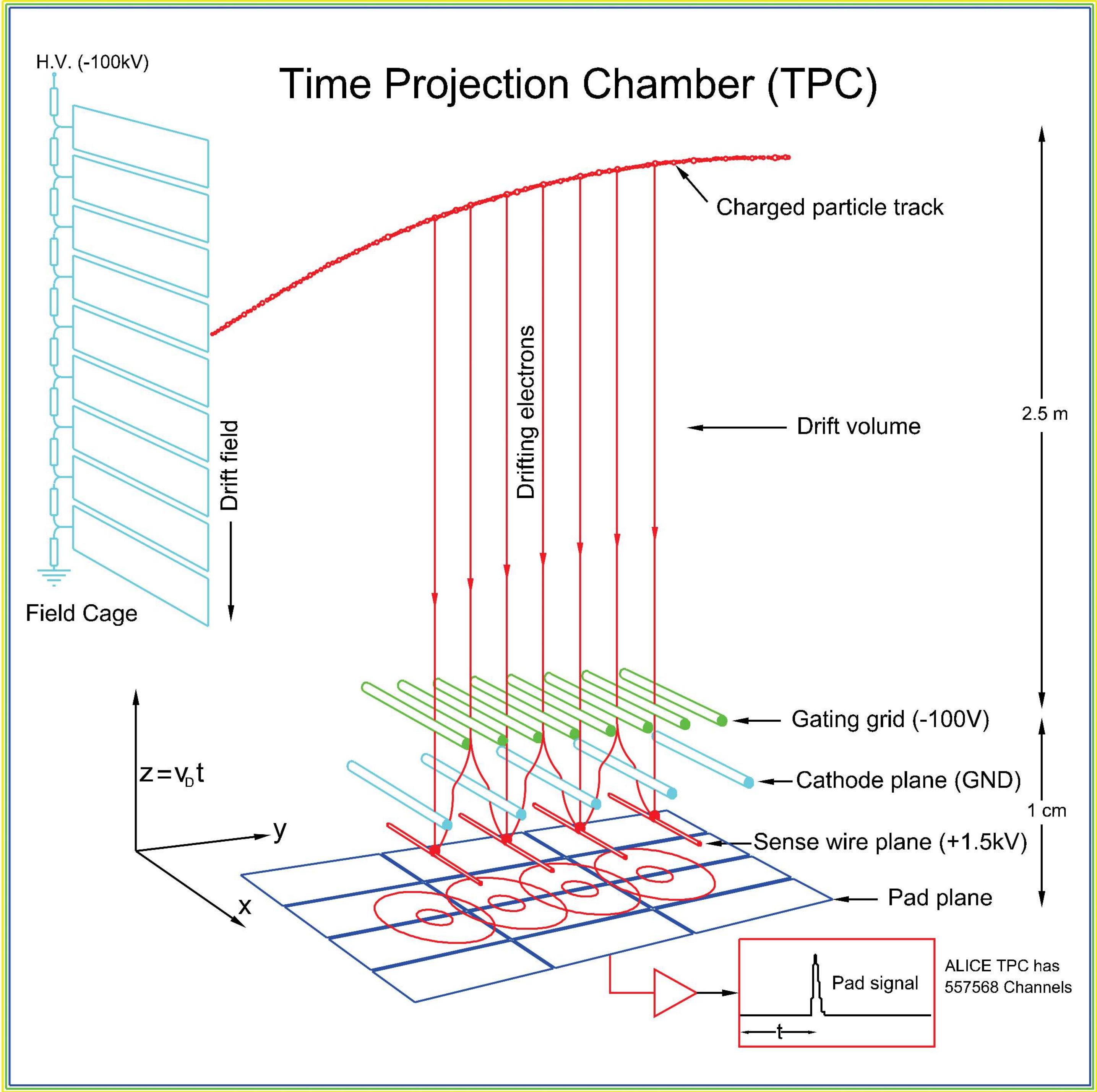


charged particle track

3-D coordinates

- Z coordinate from drift time
- X coordinate from wire number
- Y coordinate?
  - along wire direction
  - need **cathode pads**

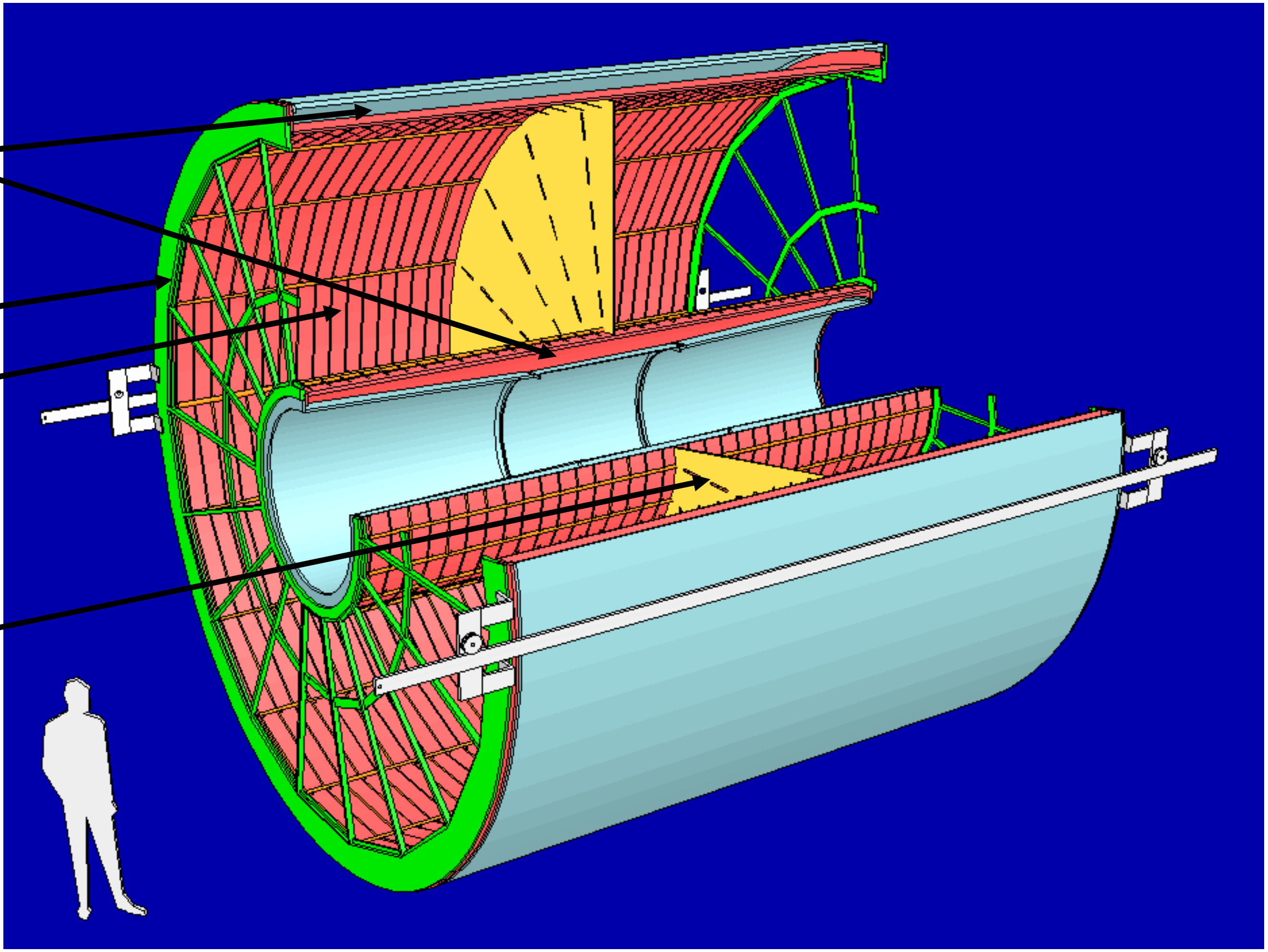




Time Projection Chamber (TPC)
H.V. (-100kV)
Field Cage
Drift field
Charged particle track
Drifting electrons
Drift volume
2.5 m
Gating grid (-100V)
Cathode plane (GND)
1 cm
Sense wire plane (+1.5kV)
Pad plane
z=v_D t
y
x
Pad signal
t
ALICE TPC has
557568 Channels

TPC Field Cage Overview

- Inner and outer isolation vessels flushed with CO_2
- End plates housing 2x2x18 ROC's
- Field defining system: aluminized mylar strips (166) supported by rods
- Central membrane 100 kV
- 5 x 5.6 m diameter, 88 m^3 volume



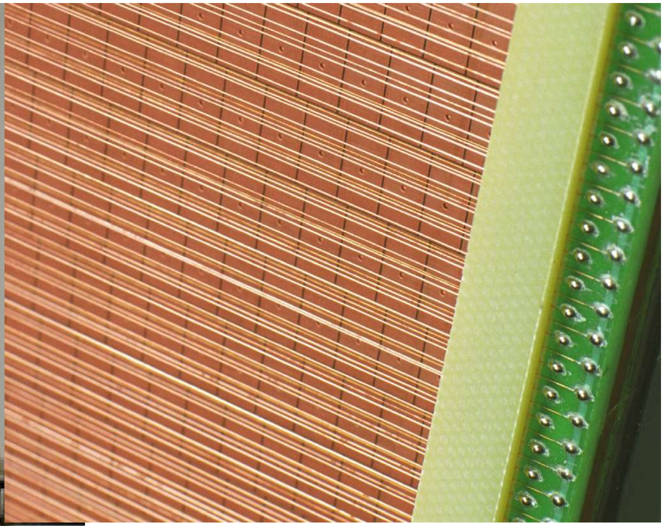
Field Cage Assembly

Field Cage Assembly

A fisheye's view

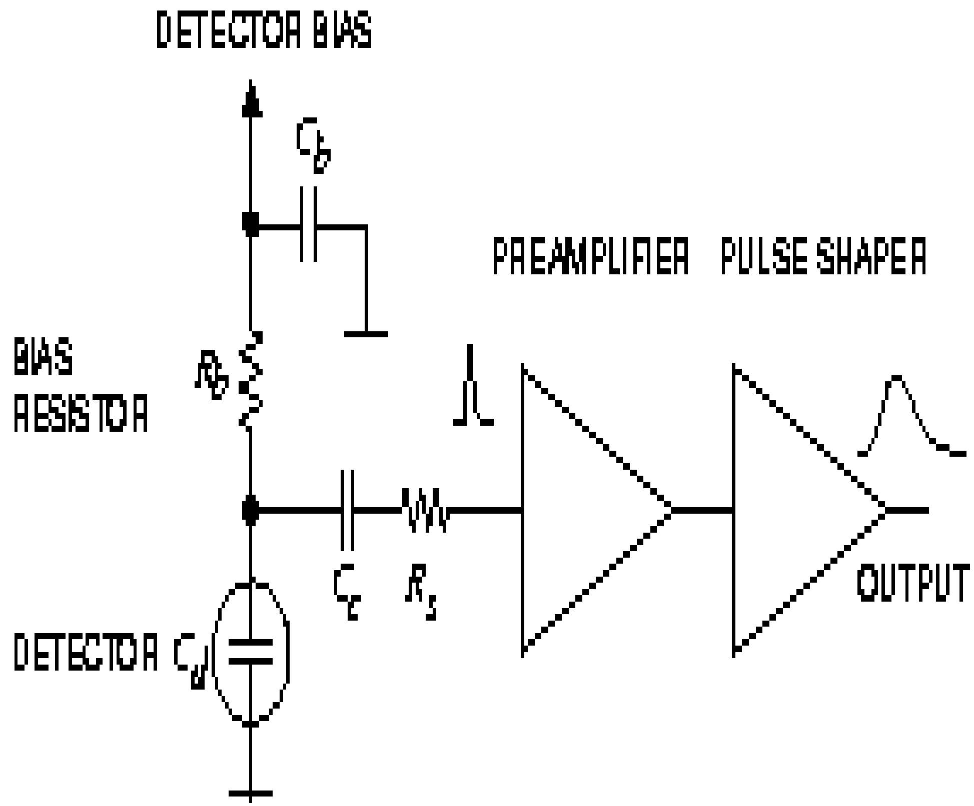
bmb+f - Förderschwerpunkt
ALICE
Großgeräte der physikalischen Grundlagenforschung

Readout Chamber Production Heidelberg/GSI

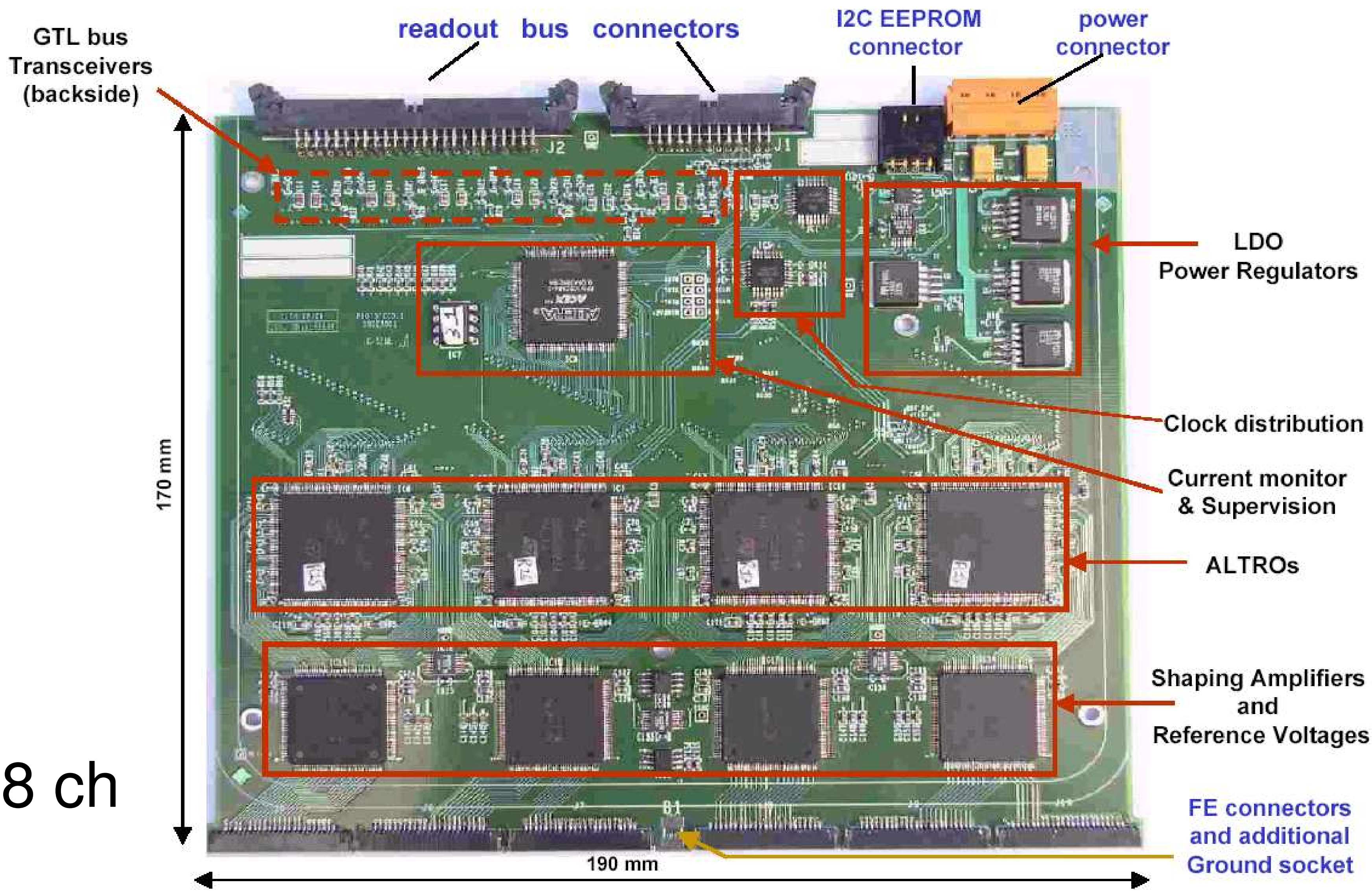


Pads and wires

Adjusting a wire plane before glueing, small chamber type


DETECTOR BIAS
C_b
PREAMPLIFIER
PULSE SHAPER
BIAS
RESISTOR
R_b
C_c
R_s
OUTPUT
DETECTOR
C_d

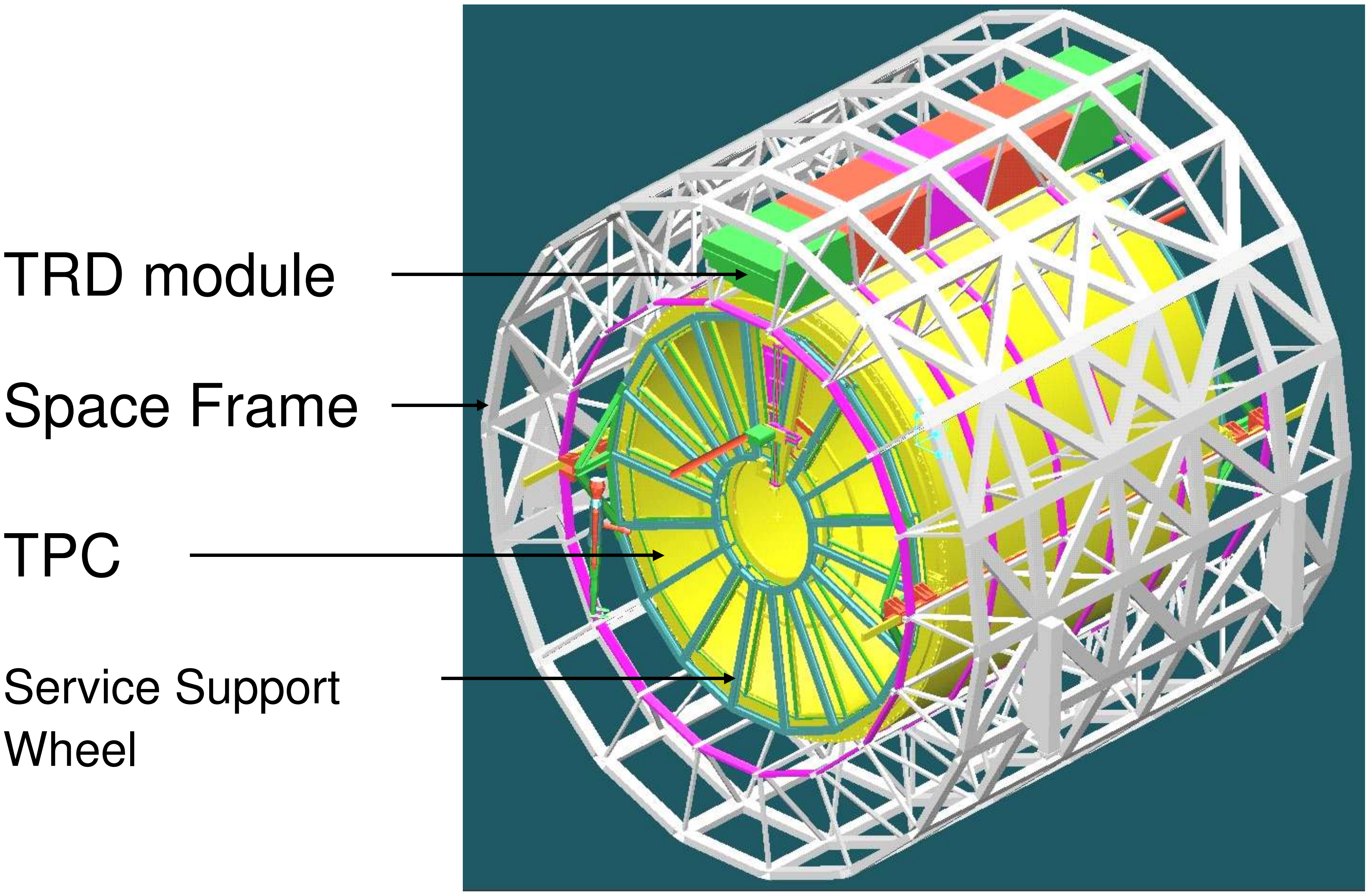
Front-end Card



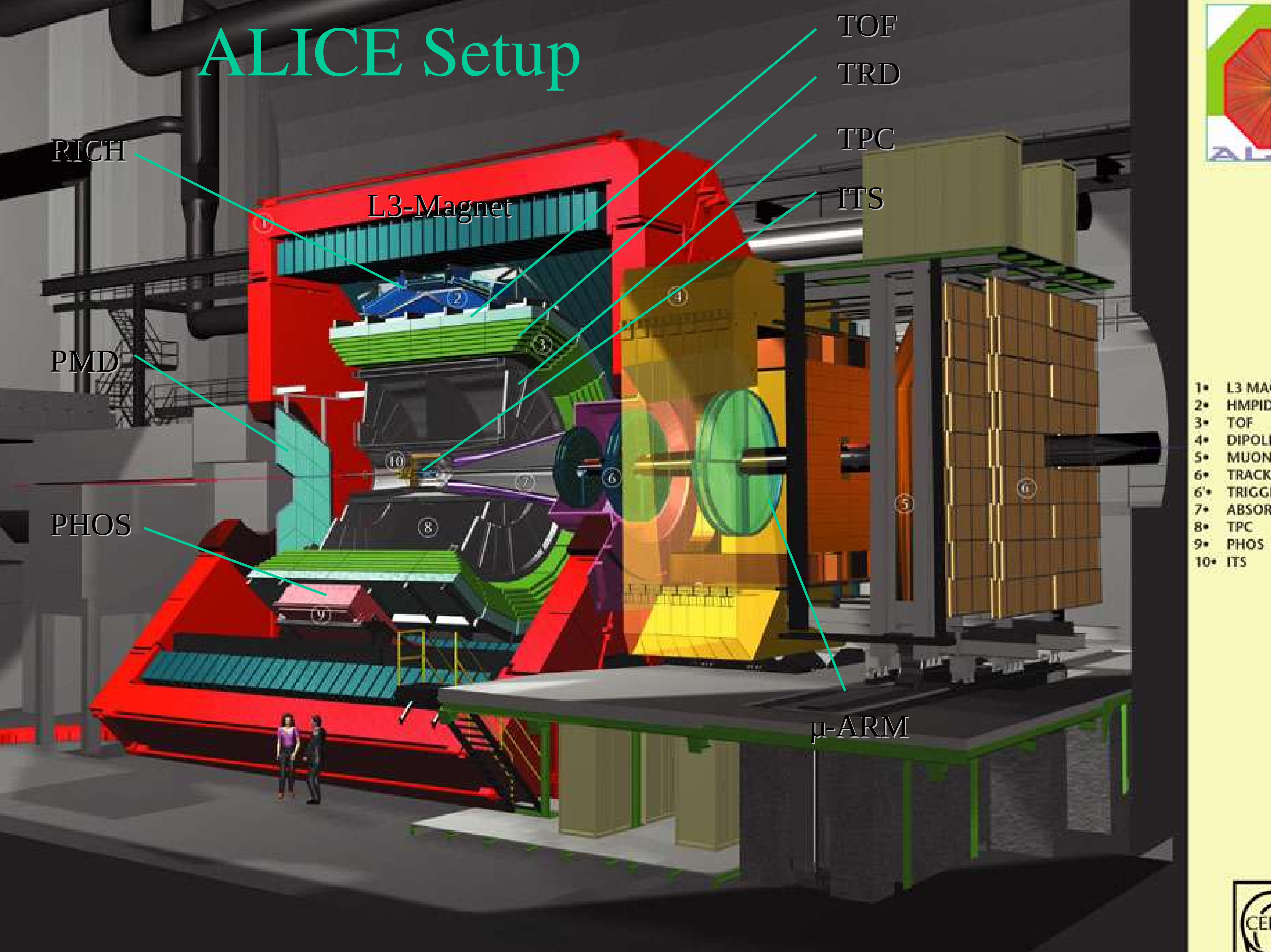
128 ch

all electronics designed and built by TPC team

The Environment of the TPC

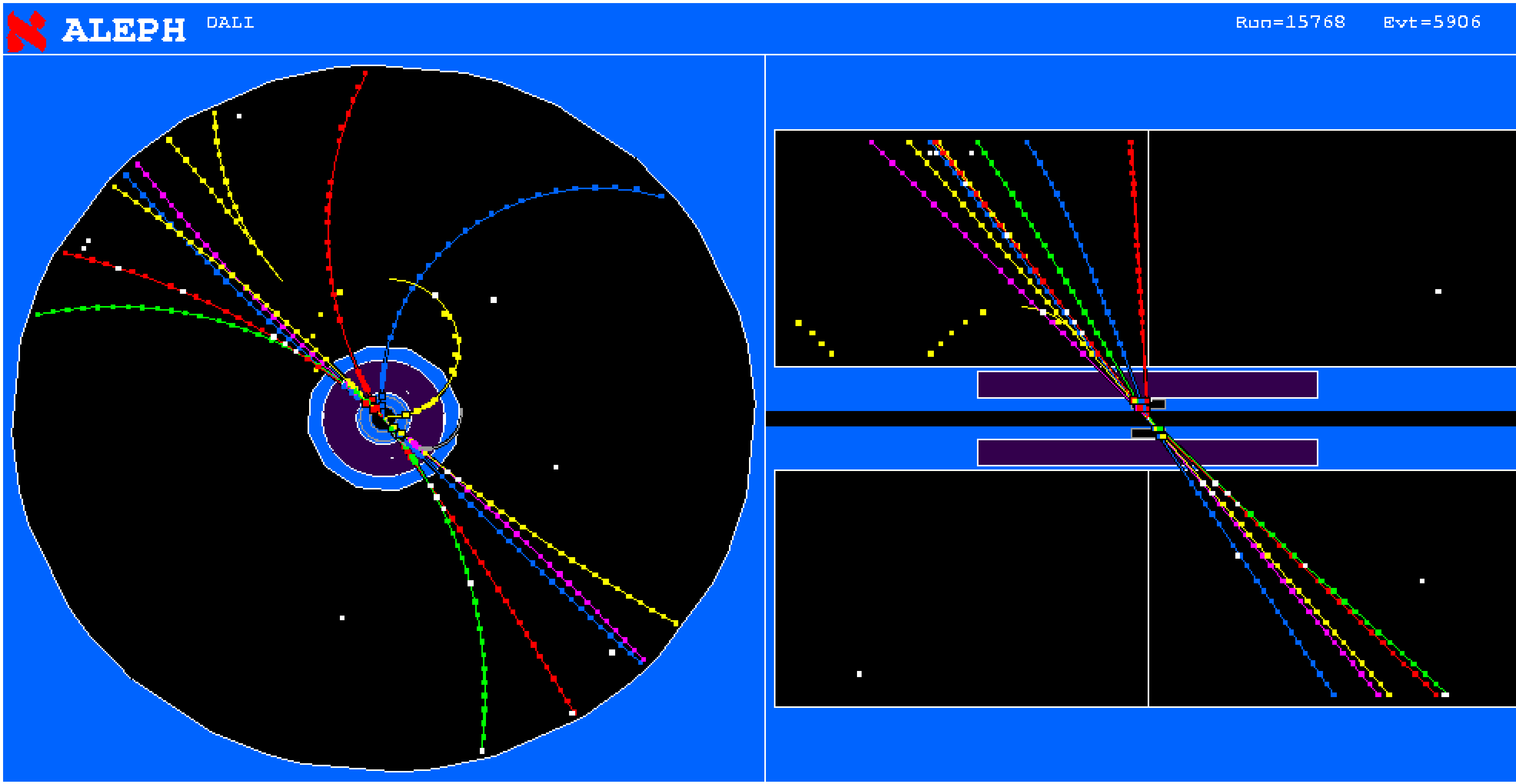


ALICE Setup



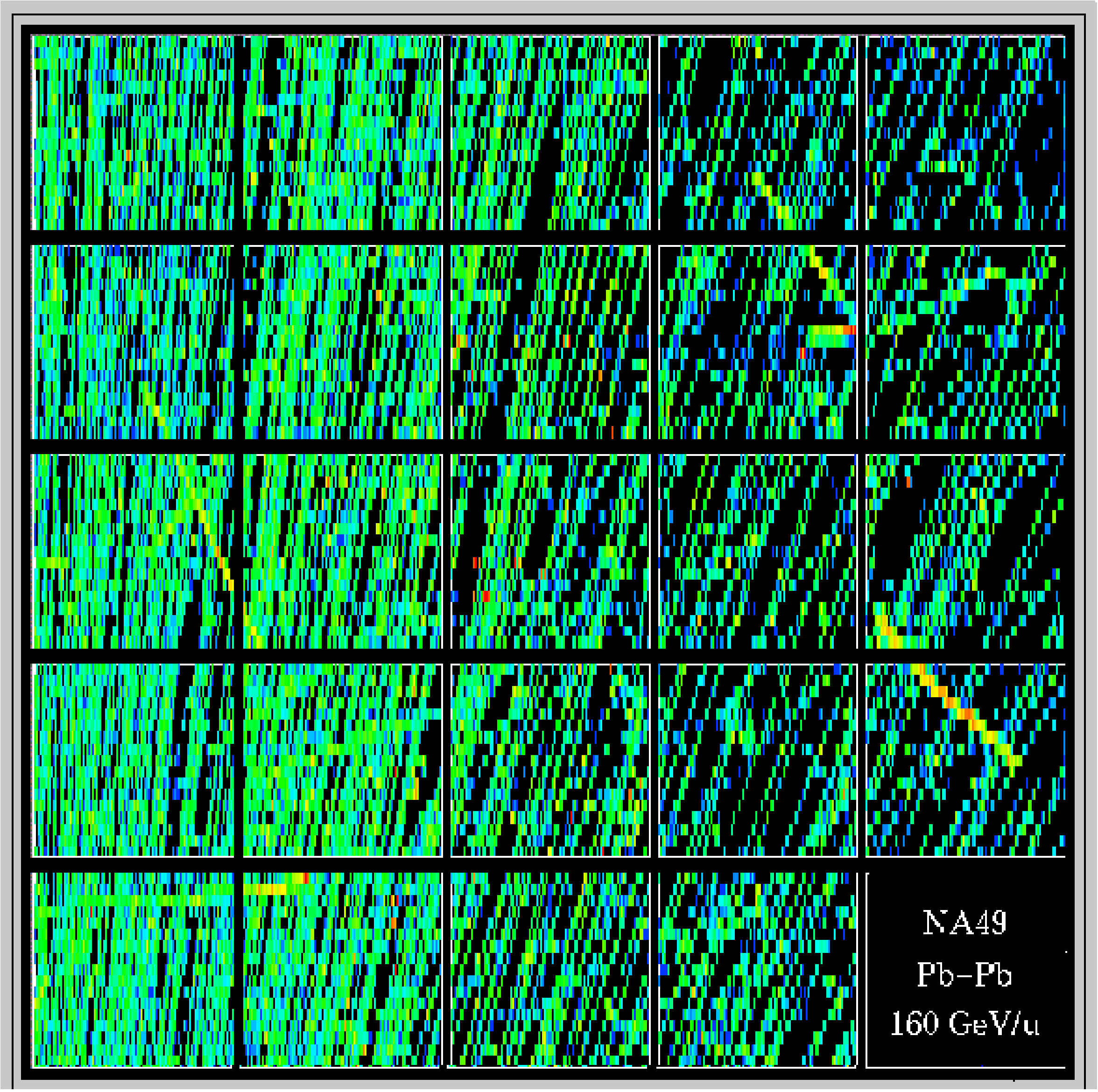
TOF
TRD
TPC
ITS
RICH
L3-Magnet
PMD
PHOS
μ-ARM
1• L3 MA
2• HMPID
3• TOF
4• DIPOL
5• MUON
6• TRACK
6'• TRIGG
7• ABSOR
8• TPC
9• PHOS
10• ITS

ALEPH Event



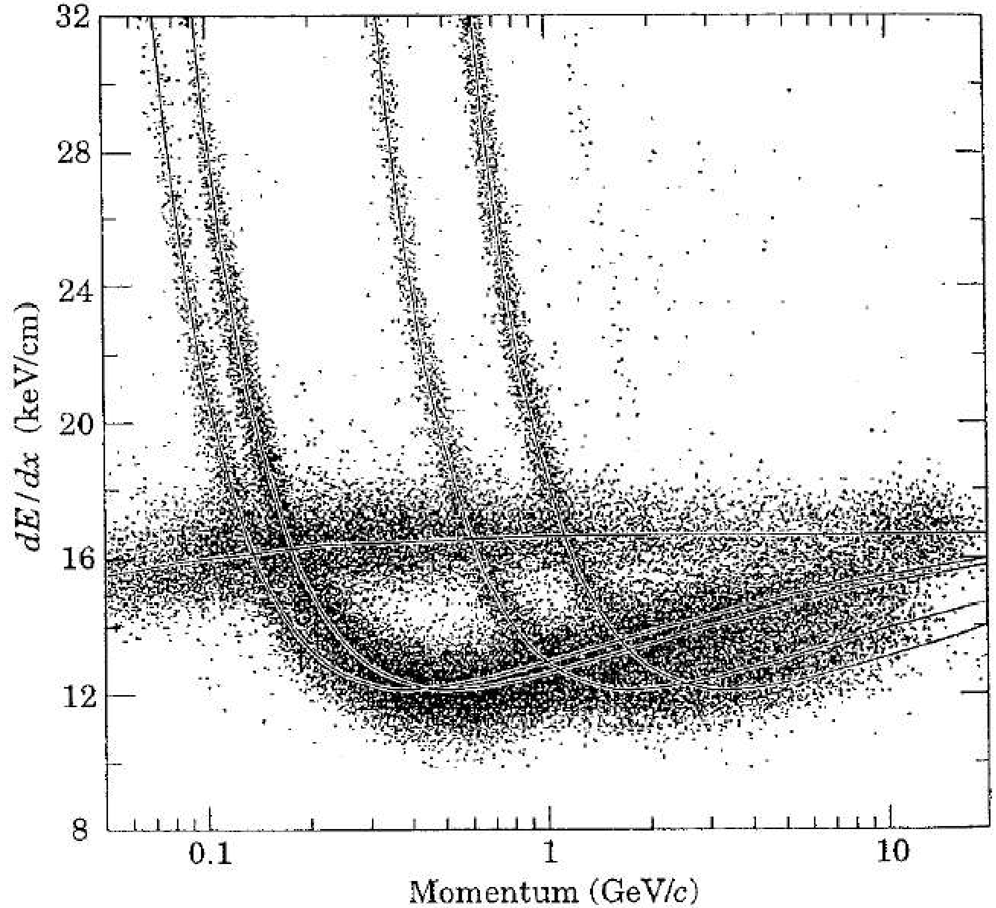
NA49 Event

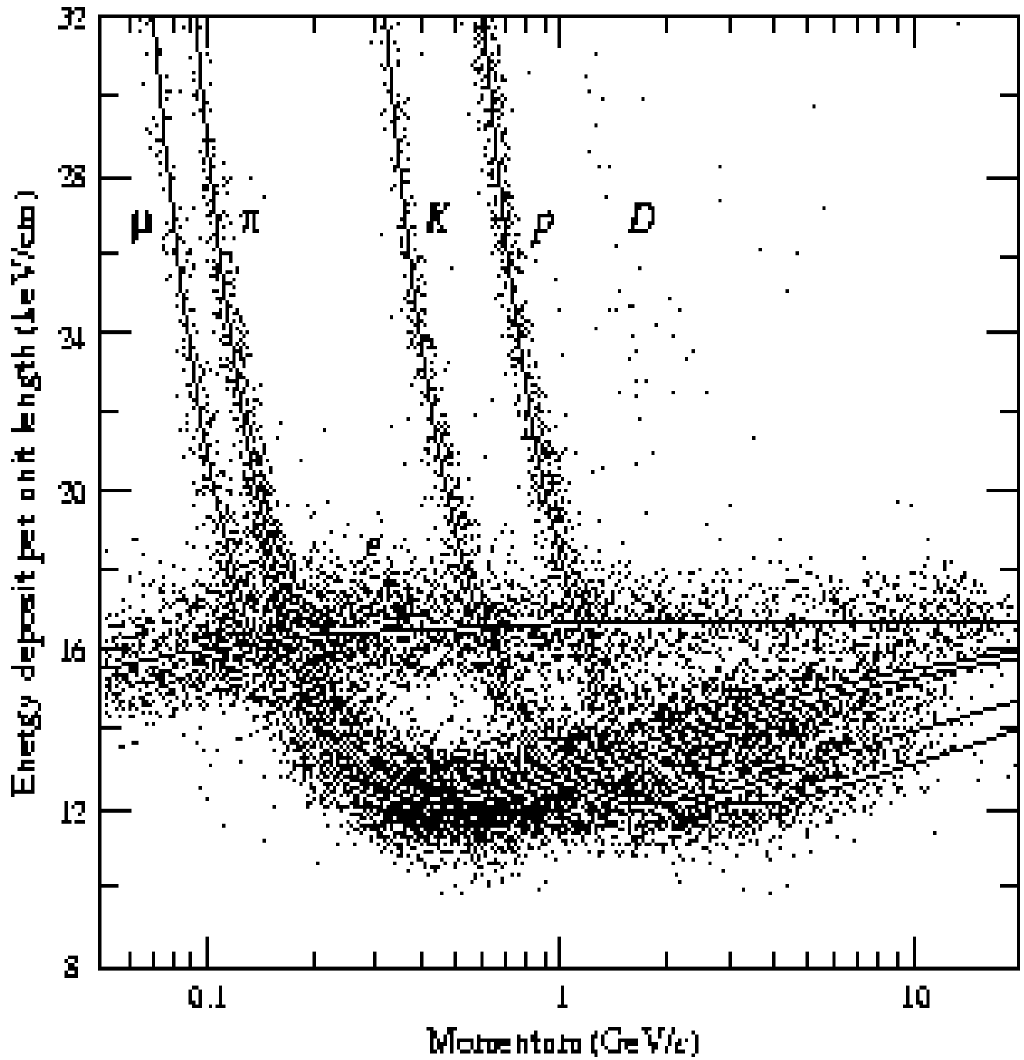
Particle tracks in one of the main TPCs for a Pb-Pb collision



Application in Particle ID

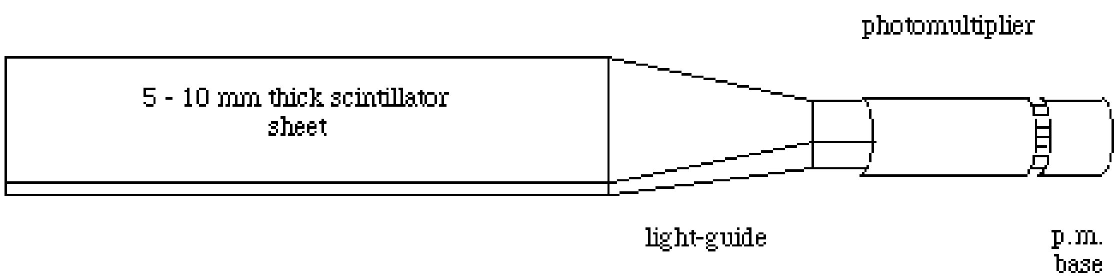
- Energy loss as measured in a TPC
- at a given momentum different particles have differing dE/dx

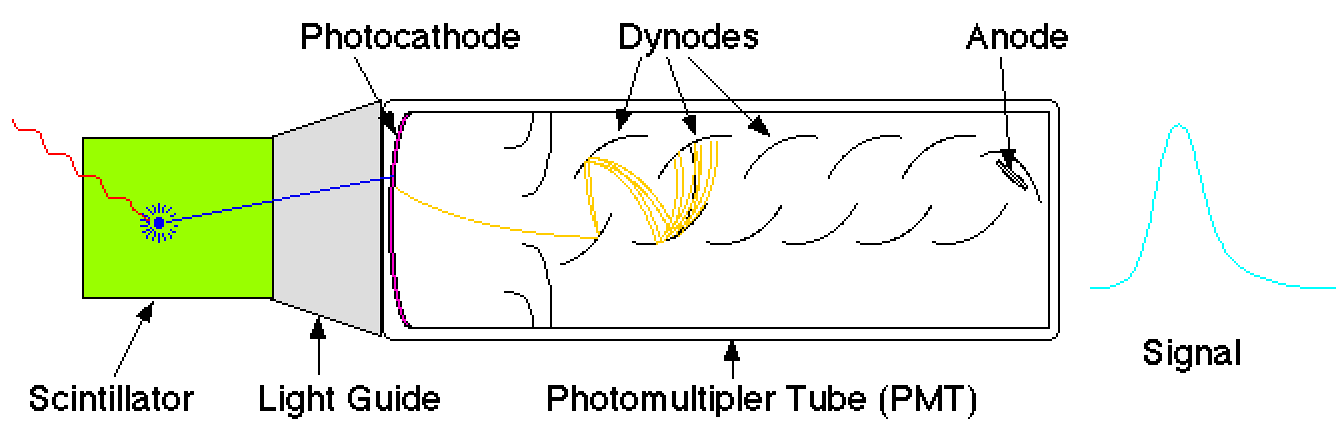




Energy deposit per unit length (keV/cm)
Momentum (GeV/c)
μ
π
K
p
D
e
8
12
16
20
24
28
32
0.1
1
10

- Scintillation counter:
  - energy liberated in de-excitation and capture of ionization electrons emitted as light - "scintillation light"
  - light channeled to photomultiplier in light guide (e.g. piece of lucite or optical fibers);
  - scintillating materials: certain crystals (e.g. NaI), transparent plastics with doping (fluors and wavelength shifters)

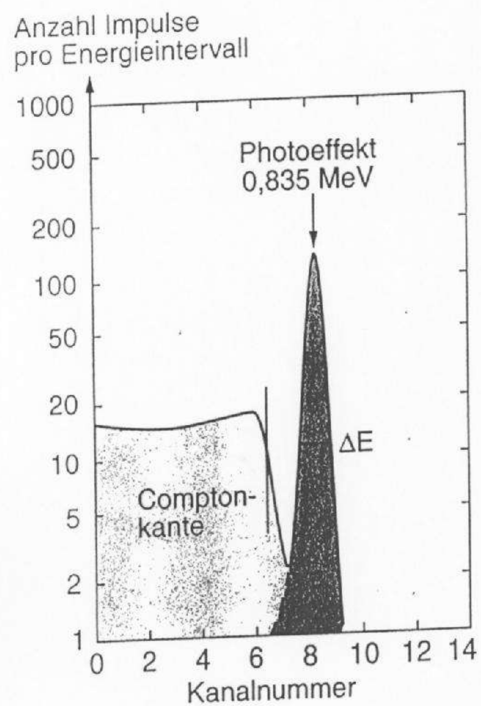




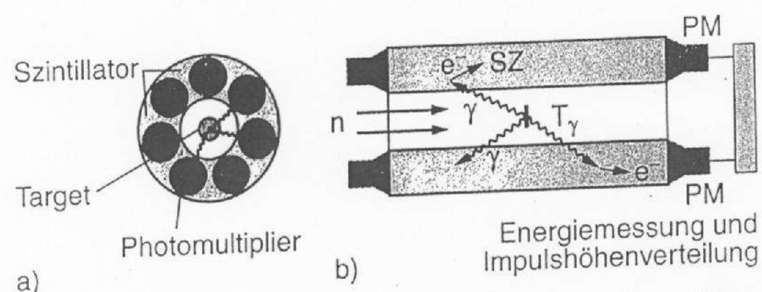
Calorimeters -- principle of operation

- Principle:
  - Put enough material into particle path to force development of electromagnetic or hadronic shower (or mixture of the two).
- Total absorption calorimeter:
  - depth of calorimeter sufficient to "contain" showers originating from particle of energy lower than design energy
  - depth measured in "radiation lengths" for e.m. and "nuclear absorption lengths" for hadronic showers
  - most modern calorimeters are "sampling calorimeters" – separate layers of high density material ("absorber") to force shower development, and "sensitive" layer to detect charged particles in the shower.
  - total visible path length of shower particles is proportional to total energy deposited in calorimeter
  - segmentation allows measurement of positions of energy deposit
  - lateral and longitudinal energy distribution different for hadronic and e.m. showers – used for identification
  - absorber materials: U, W, Pb, Fe, Cu,..
  - sensitive medium: scintillator, silicon, liquid argon,..

NaI: an example of a 'calorimeter'



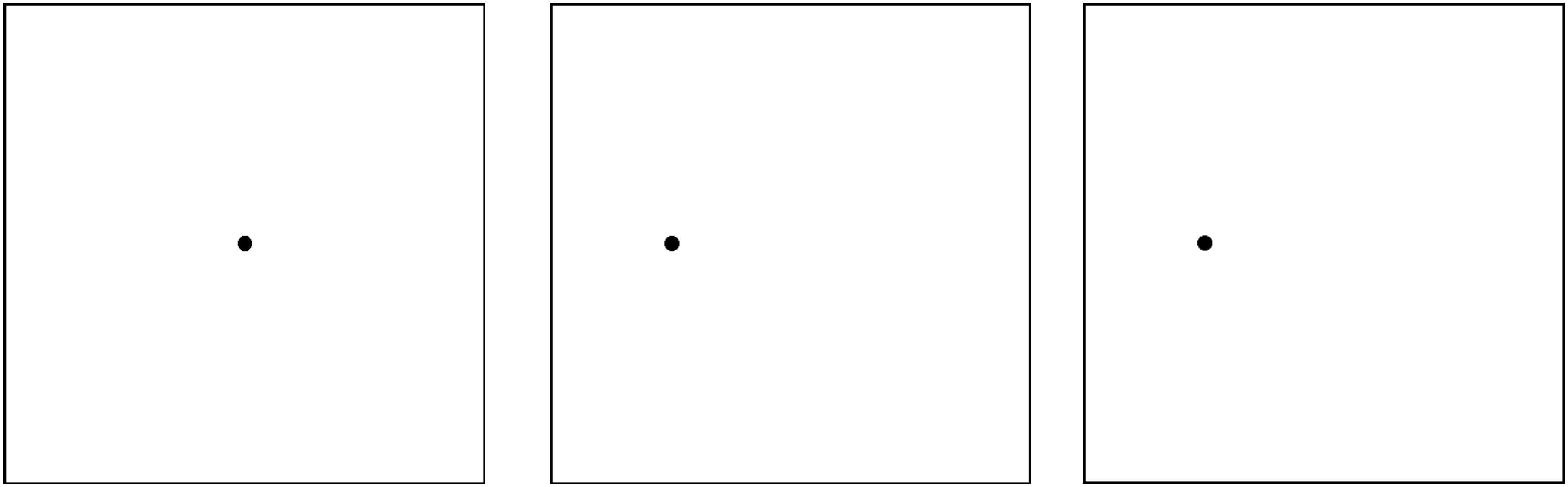
Energiespektrum von monoenergetischen γ-Quanten der Energie $E = 0{,}835$ MeV, gemessen mit einem zylindrischen NaI(Tl)-Kristall (Höhe 7,6 cm, $\varnothing = 7{,}6$ cm). Das vom Detektor noch auflösbare Energieintervall ΔE ist hier etwa 125 keV



Szintillationsdetektor zum Nachweis von Neutronen und zur Messung ihrer Energie. (**a**) Frontansicht, (**b**) Seitenansicht

Cherenkov Radiation

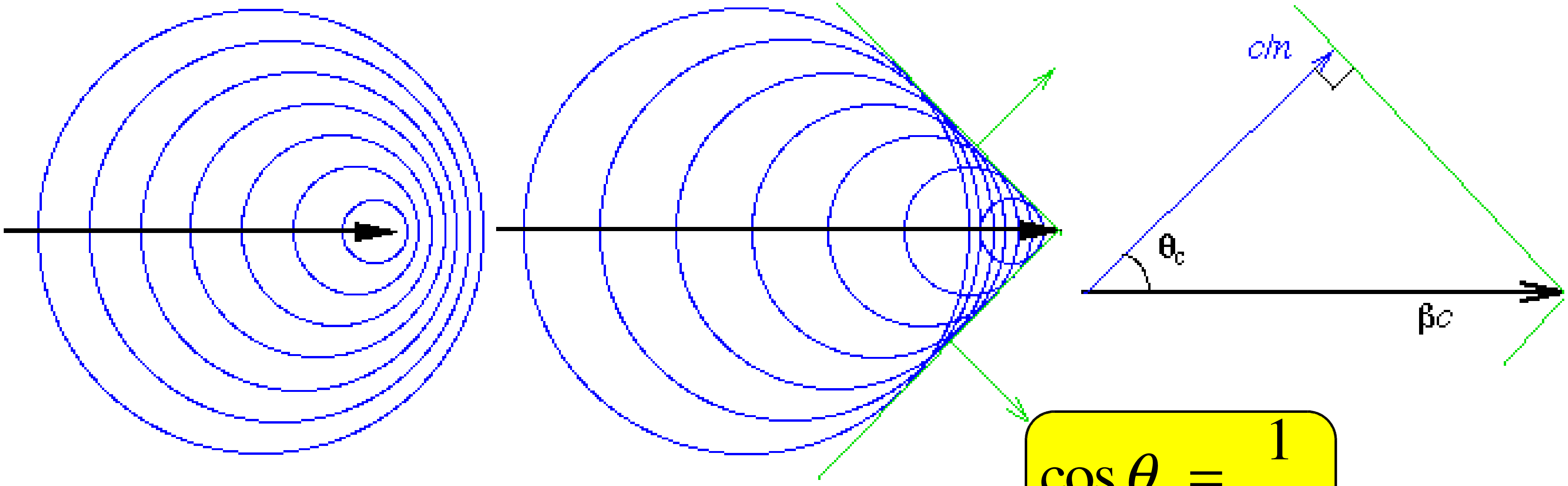
- Moving charge in matter



at rest slow fast

Cherenkov Radiation – mostly UV photons

- Wave front comes out at an angle



$$\cos\theta_c = \frac{1}{\beta n}$$

- determined by index of refraction of the material
- emitted photons detected, e.g., by photomultiplier

Transition Radiation

- Transition radiation is produced when a relativistic particle traverses an inhomogeneous medium
  - Boundary between different materials with different n.
- Depends on relativistic γ factor of particle
  - generated by accelerated charges
  - can be used to identify high energy electrons

Historical sketch of a transition radiation detector