Detectors in High Energy Physics Experiments

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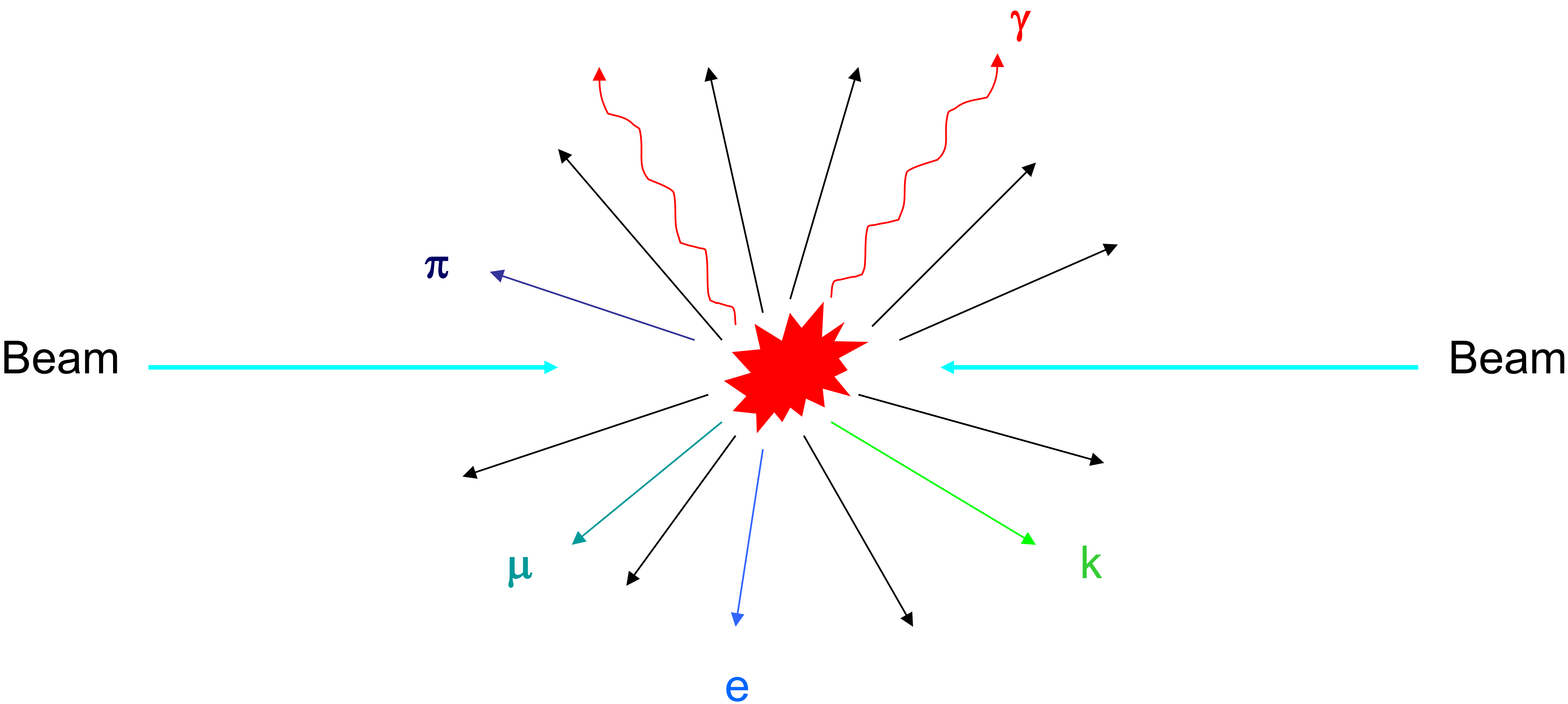
❖ Detectors

1. Collision : Yes/No?

2. Vertex

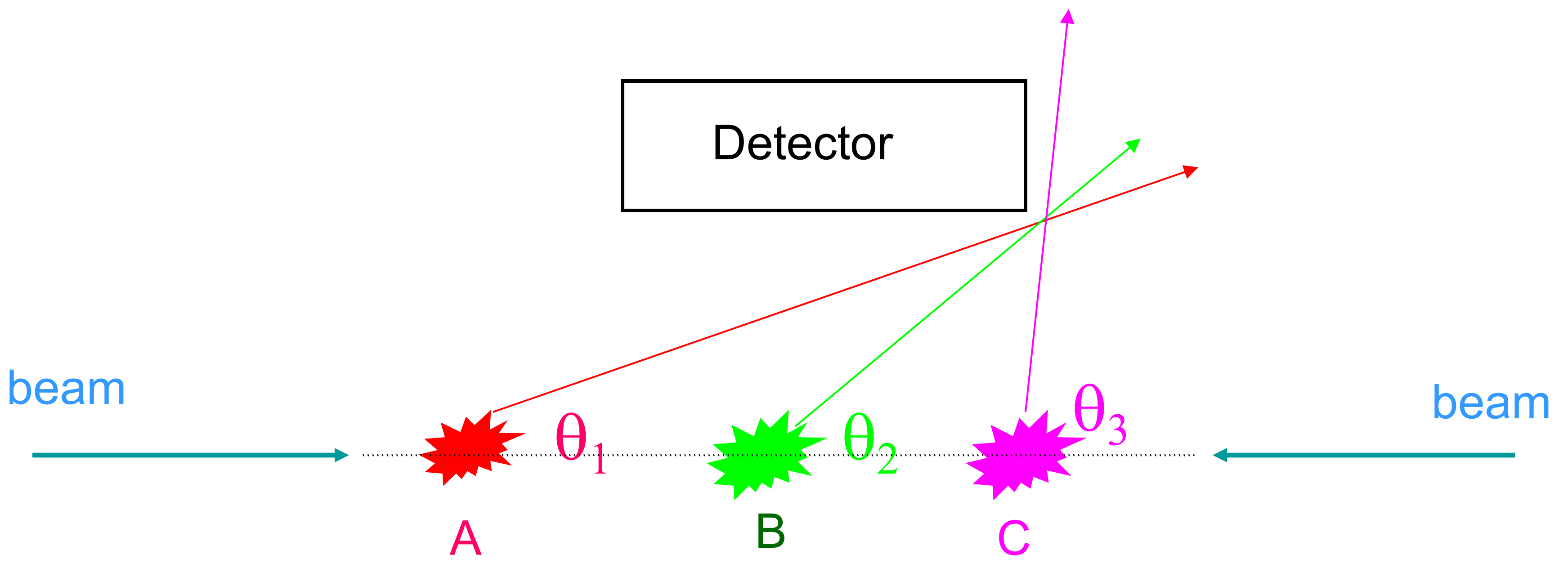


3. Luminosity

4. Centrality

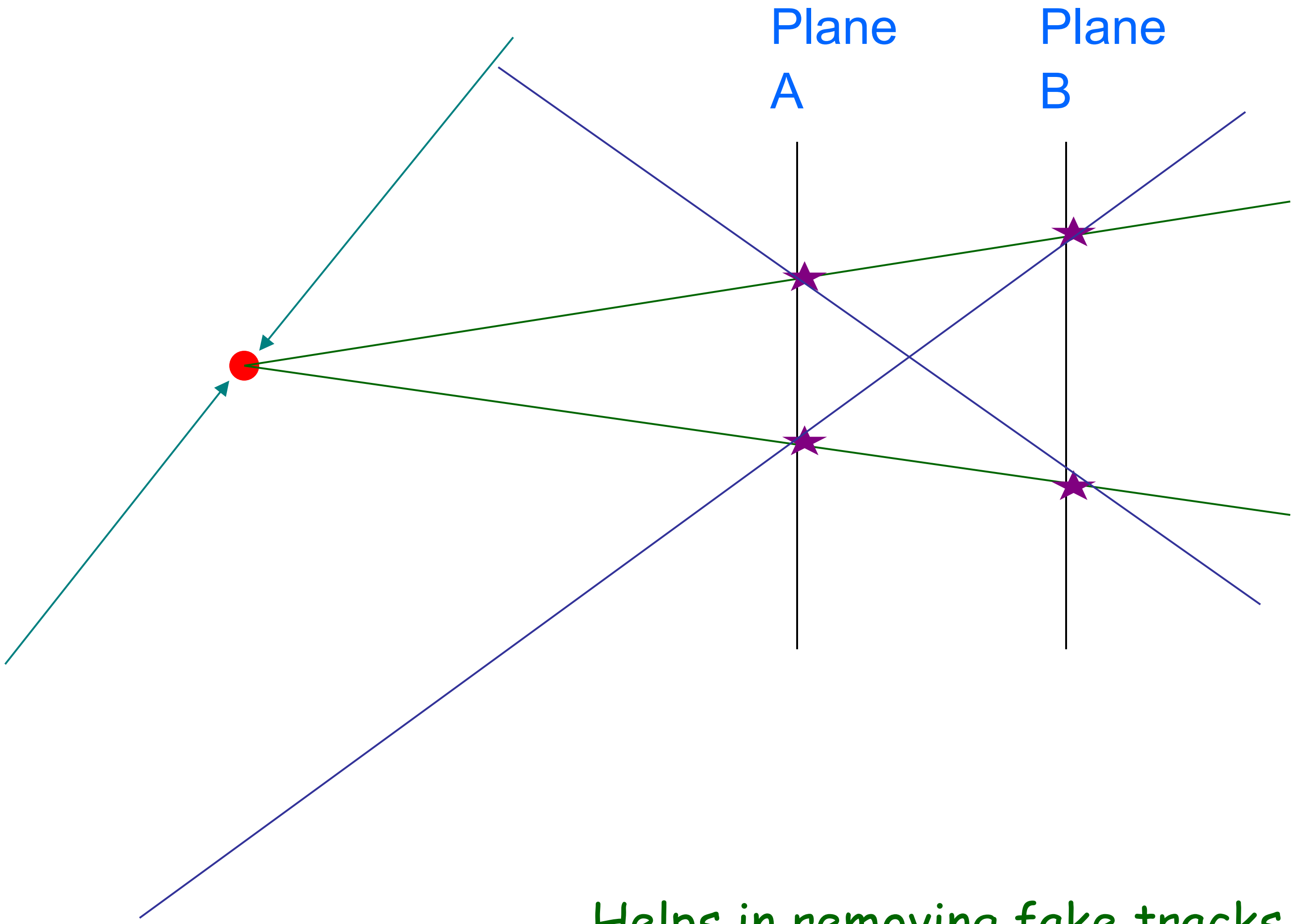
$$E\frac{d^3\sigma}{dp^3}=\frac{1}{L}\frac{1}{2\pi p_T}\frac{d^2N}{dp_T dy}$$

❖ Vertex



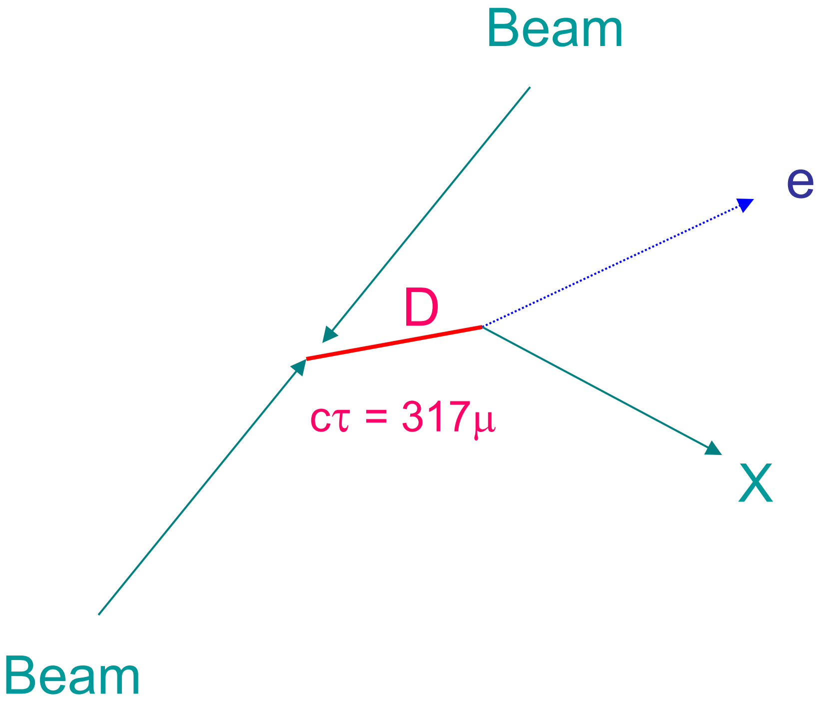
$$\eta = -\ln(\tan(\theta/2))$$

❖ Vertex



Helps in removing fake tracks

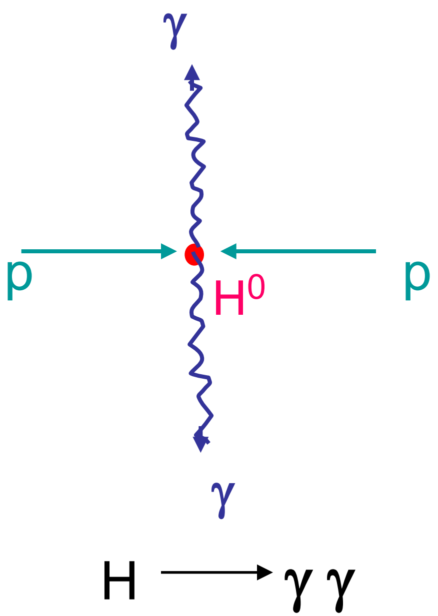
- Vertex



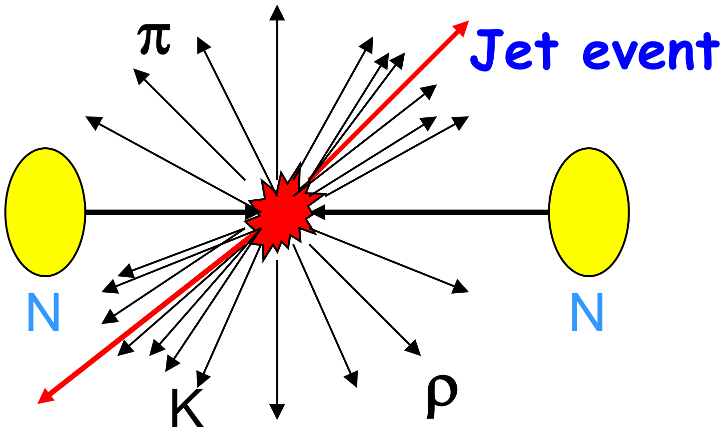
Helps in extracting weak decays

❖ Physics Objective

Particle Physics :



Heavy Ion Physics:



Need to know energy and position of both the gammas to construct the Higgs particle

Need to know both momentum and particle identification

Bottom Line

To catch all the particles (identified) with good energy, momentum and position resolution

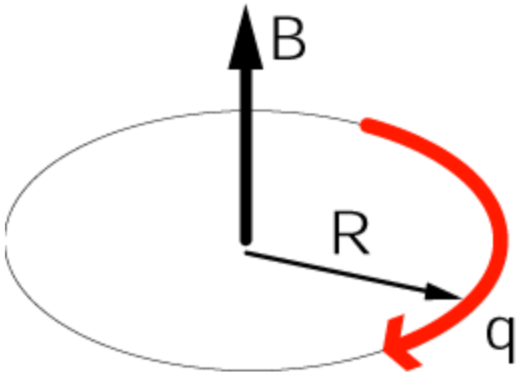
❖ Design of the experiment

❖ Catch all the particles

- 4π detector coverage

❖ Momentum of the particle

- Magnetic Field



- Tracking Chamber
  - Inner tracker : low p_T
  - Outer tracker : high p_T

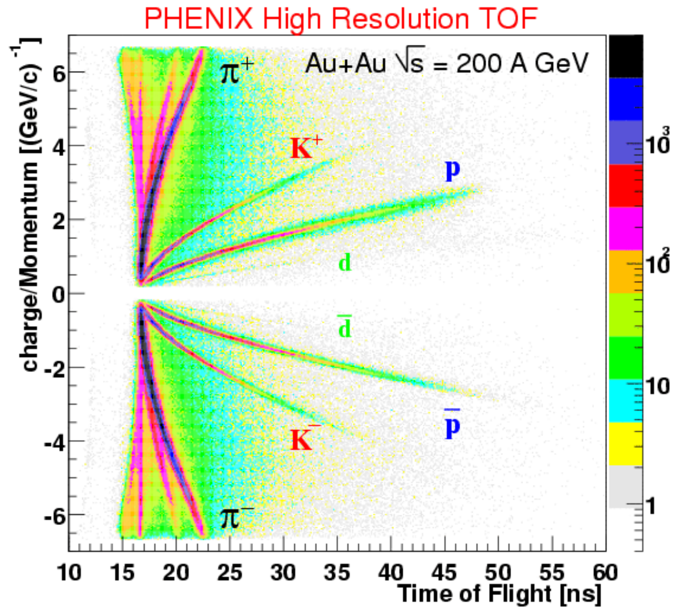
❖ Design of the experiment

Identify Hadrons

❖ Time of flight measurement

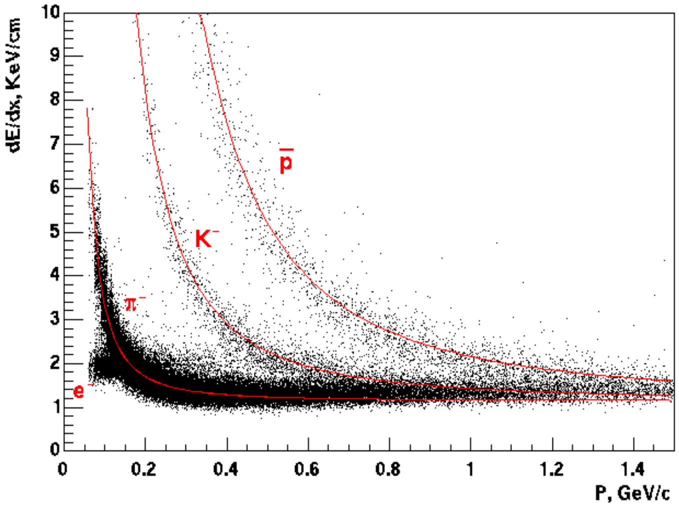
- ➢ Need a detector to detect t = 0
- ➢ Need a detector to detect t after a certain distance

(high timing resolution to go to high p_T)



❖ dE/dx measurement

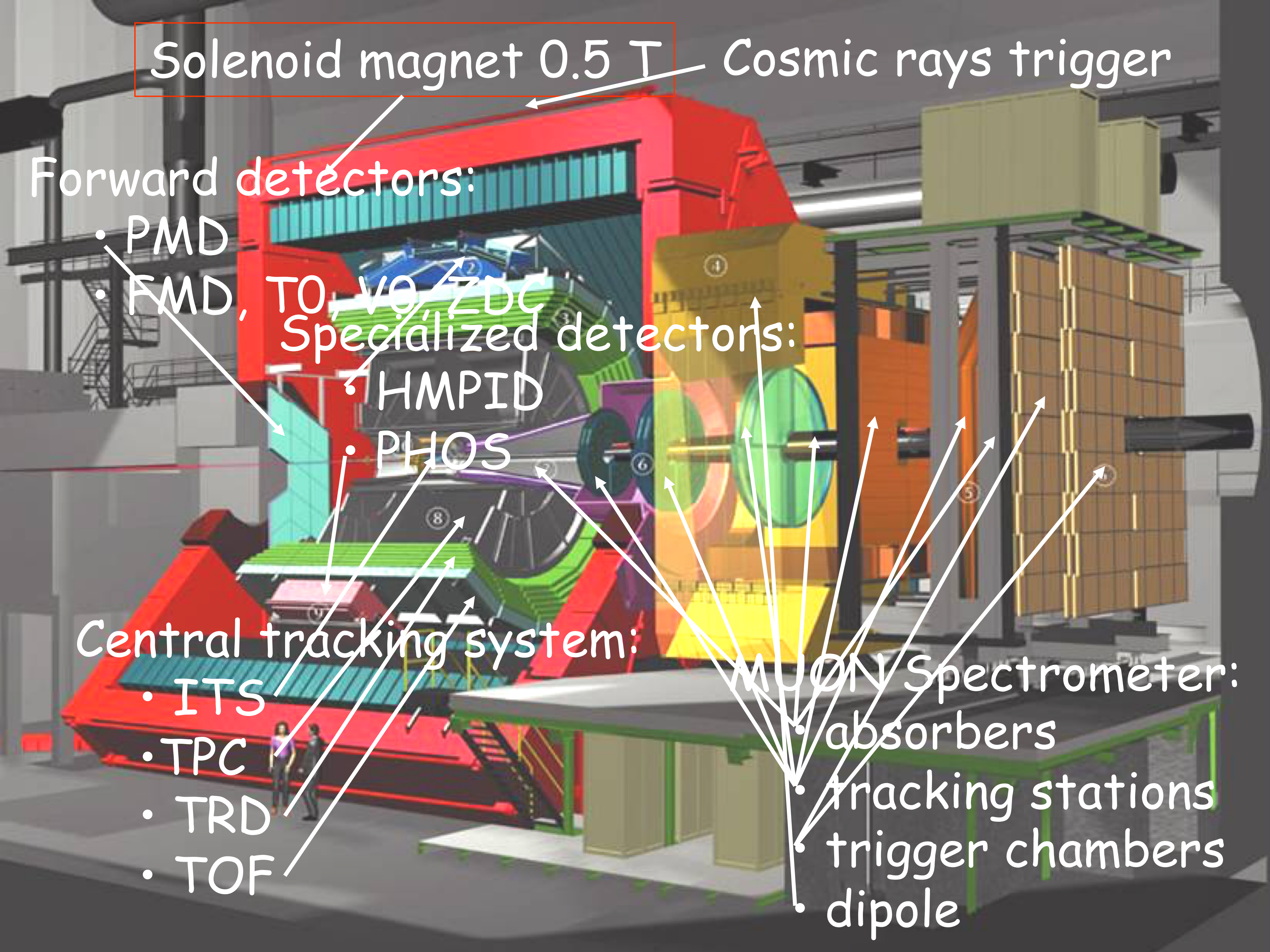
- ➢ TPC, ……….



❖ Design of the experiment

- ❖ Identify Leptons
  - ➢ e : RICH, EMCAL, TRD
  - ➢ μ : Muon spectrometer
- ❖ Photons
  - ➢ Electromagnetic Calorimeter
- ❖ Hadronic Energy
  - ➢ Hadronic Calorimeter
- ❖ Momentum measurement
  - ➢ Tracking Chamber

If you put together, the experiment becomes so complicated that you can not believe it !!!


Solenoid magnet 0.5 T
Cosmic rays trigger
Forward detectors:
• PMD
• FMD, T0, V0, ZDC
Specialized detectors:
• HMPID
• PHOS
Central tracking system:
• ITS
• TPC
• TRD
• TOF
MUON Spectrometer:
• absorbers
• tracking stations
• trigger chambers
• dipole

A MODERN HIGH ENERGY PHYSICS EXPERIMENT:

- ❖ Go to higher and higher energies
  - ➢ Large number of particles produced in a given interaction

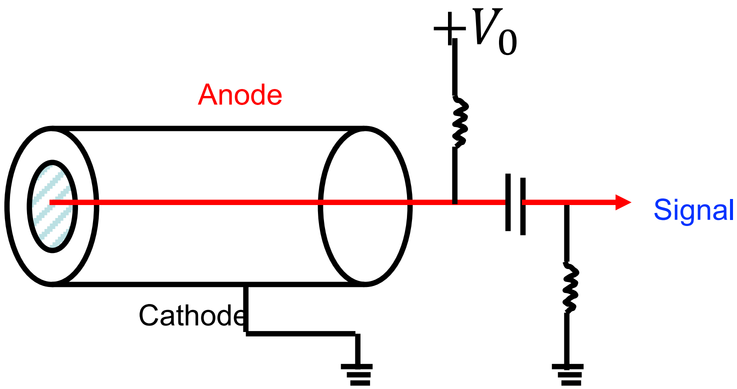
- ❖ Look for Rarer processes – work at very high luminosities
  - ➢ Multiple interactions in a single event

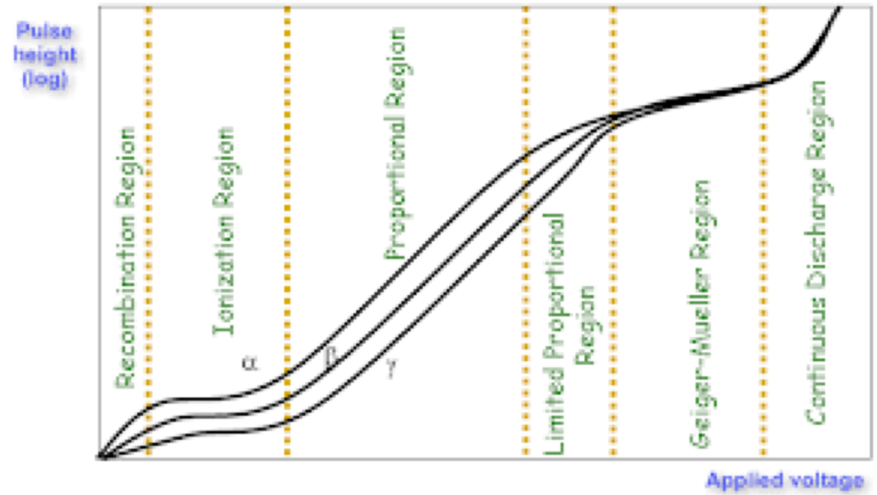
TO COPE SUCH COMPLEX REQUIREMENT:

- ❖ Use a very large and composite detector system
  - ➢ Tracking devices, Calorimeters

- ❖ To separate interactions and particles in a given Interaction – Make readout finer
  - ➢ Large number of readout channels

Ionization

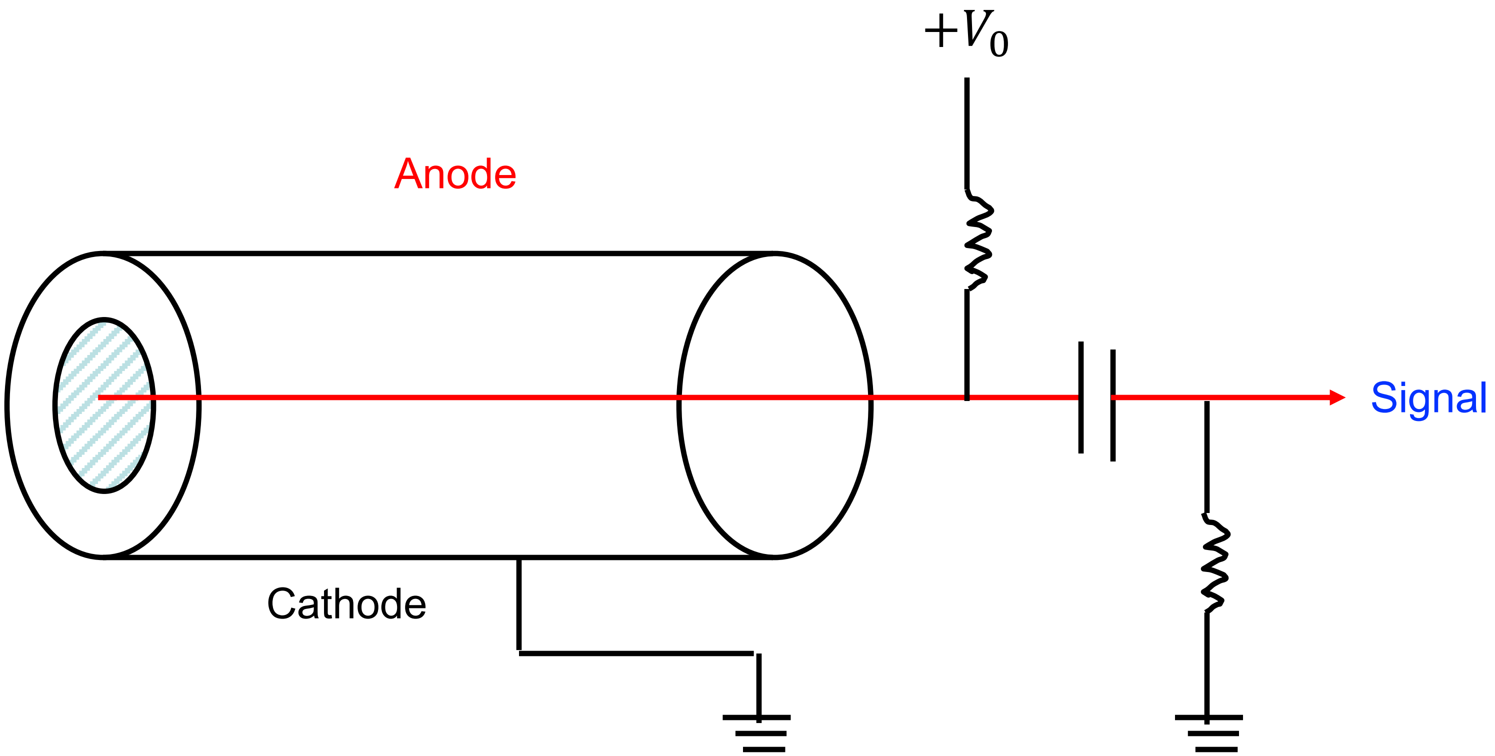




- Mean number of ion-electron pair:

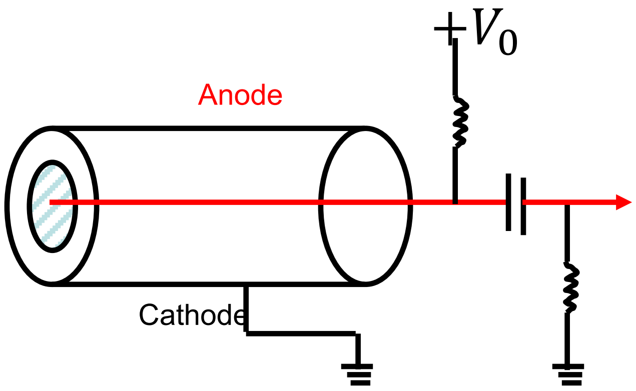
$$N \neq \frac{Energy\ loss}{Ionization\ Pot.} \qquad N = \frac{Energy\ loss}{30\ eV}$$

- For example, for a 3 keV particle, an average of $\frac{3000}{30} = 100$ ion-electron pair



- Pulse signal on the electrode is formed by induction due to the movement of the ions and electrons to respective electrodes. Not by the actual collection of charges

- For simplicity, take cylindrical proportional counter



- The electric field, and potential can be written as

$$E(r) = \frac{CV_0}{2\pi\epsilon}\frac{1}{r} \qquad C = \frac{2\pi\epsilon}{\ln(b/a)}$$

$$\varphi(r) = -\frac{CV_0}{2\pi\epsilon}\ln\left(\frac{r}{a}\right)$$

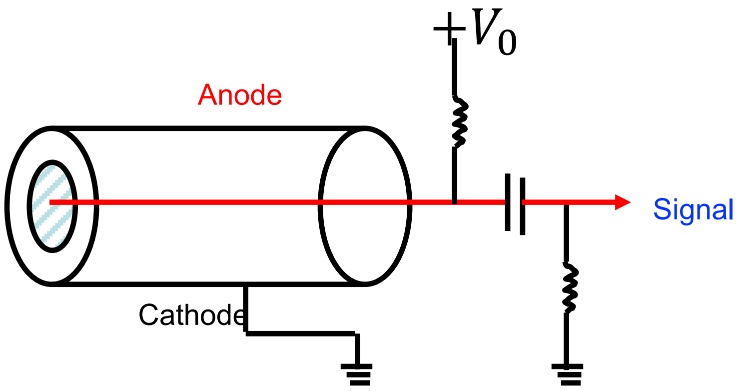
The potential energy of the charge, $W = q\varphi(r)$

If the charge moves a distance dr, then the change in potential energy is

$$dW = q\frac{d\varphi(r)}{dr}dr$$

For a cylindrical capacitor, the electrostatic energy stored $W = \frac{1}{2}lCV_0^2$

$$dW = lCV_0 dV = q\frac{d\varphi(r)}{dr}dr \qquad \Rightarrow dV = \frac{q}{lCV_0}\frac{d\varphi(r)}{dr}dr$$



- The potential can be written as

$$\varphi(r) = -\frac{CV_0}{2\pi\epsilon}\ln\left(\frac{r}{a}\right) \Rightarrow \frac{d\varphi(r)}{dr} = -\frac{CV_0}{2\pi\epsilon}\frac{a}{r}$$

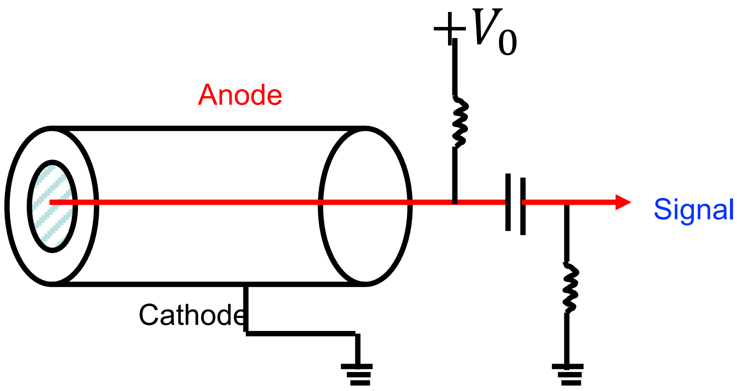
- We have $dV = \frac{q}{lCV_0}\frac{d\varphi(r)}{dr}dr$

- Assume that an ionizing event has occurred and that multiplication takes place at a distance r' from the anode. The total induced voltage from the electrons

$$V^- = \frac{-q}{lCV_0}\int_{a+r'}^{a}\frac{d\varphi(r)}{dr}dr = \frac{-q}{2\pi\epsilon}\ln\left(\frac{a+r'}{a}\right)$$

- Similarly from the positive ions

$$V^+ = \frac{q}{lCV_0}\int_{a+r'}^{b}\frac{d\varphi(r)}{dr}dr = \frac{-q}{2\pi\epsilon}\ln\left(\frac{b}{a+r'}\right)$$



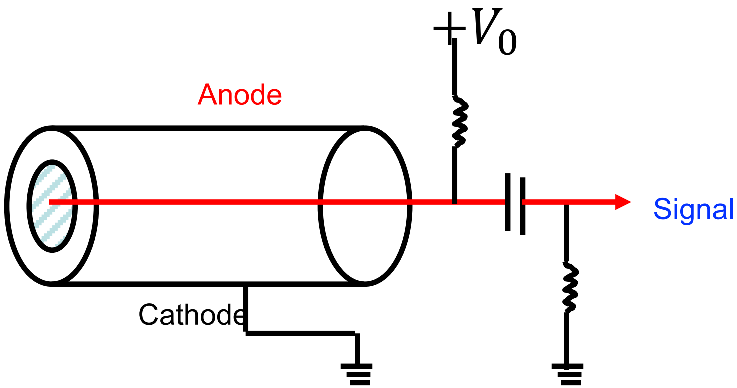
- Total potential is the sum of these two

$$V = V^- + V^+$$
$$= \frac{-q}{2\pi\epsilon l}\left[\ln\frac{a+r'}{a} + \ln\frac{b}{a+r'}\right]$$
$$= \frac{-q}{2\pi\epsilon l}\ln\frac{b}{a} = \frac{-q}{lC}$$

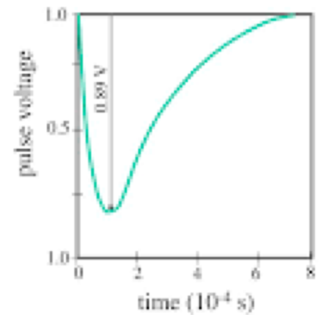
- Ratio of the contribution

$$\frac{V^-}{V^+} = \frac{\ln\left(\frac{a+r'}{a}\right)}{\ln\left(\frac{b}{a+r'}\right)}$$

- The multiplication region is limited to a distance of a few wire radii. For example, $a = 10\mu m, b = 10mm, r' = 1\mu m$, $V^- < 1\%V^+$



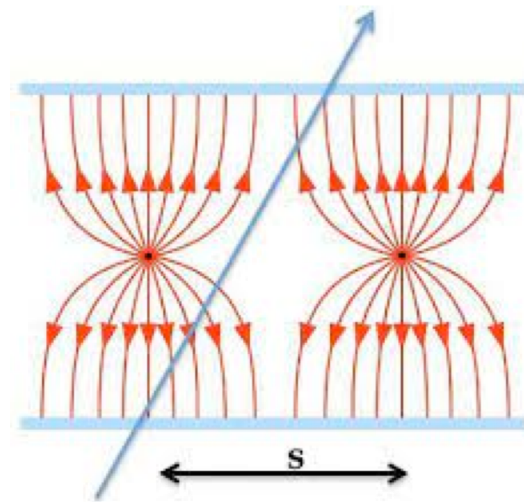
pulse shape

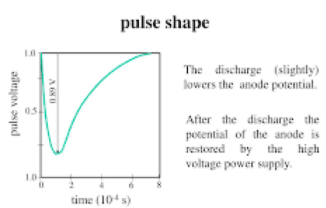


The discharge (slightly) lowers the anode potential.

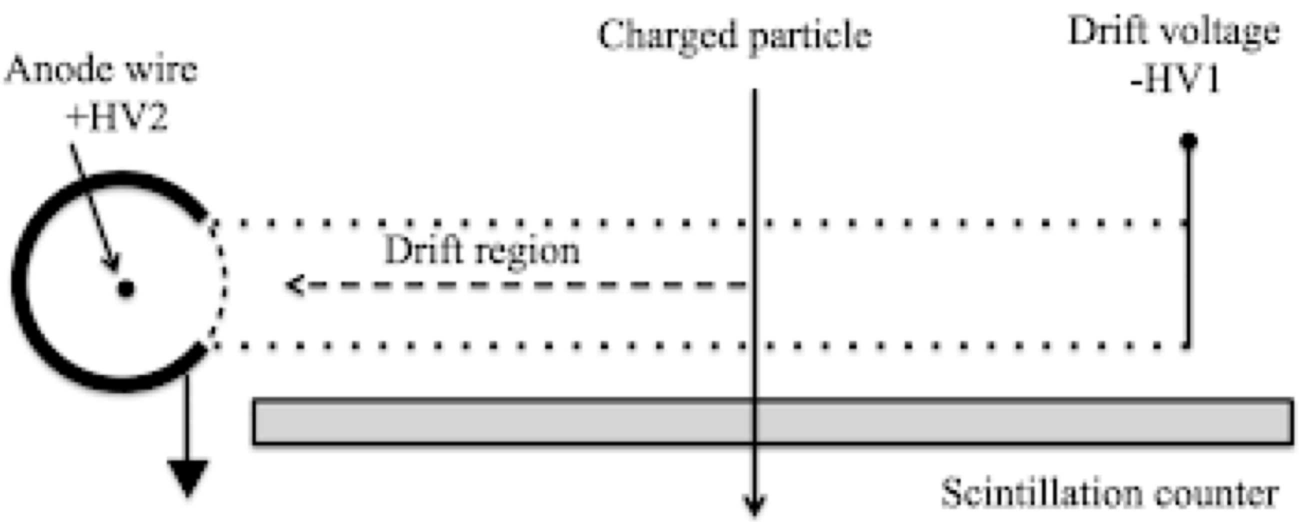
After the discharge the potential of the anode is restored by the high voltage power supply.

❖ Multi Wire Proportional Counter

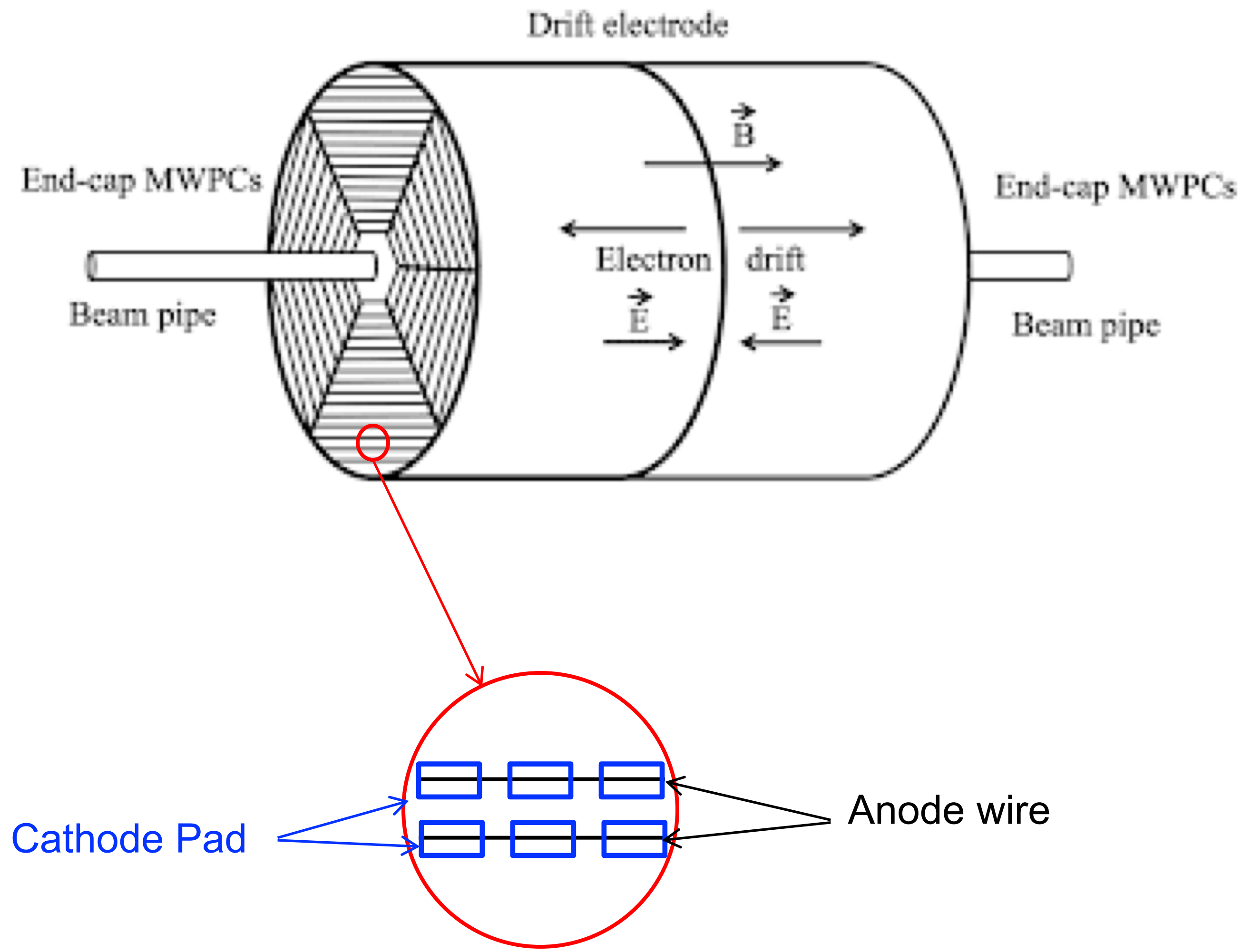




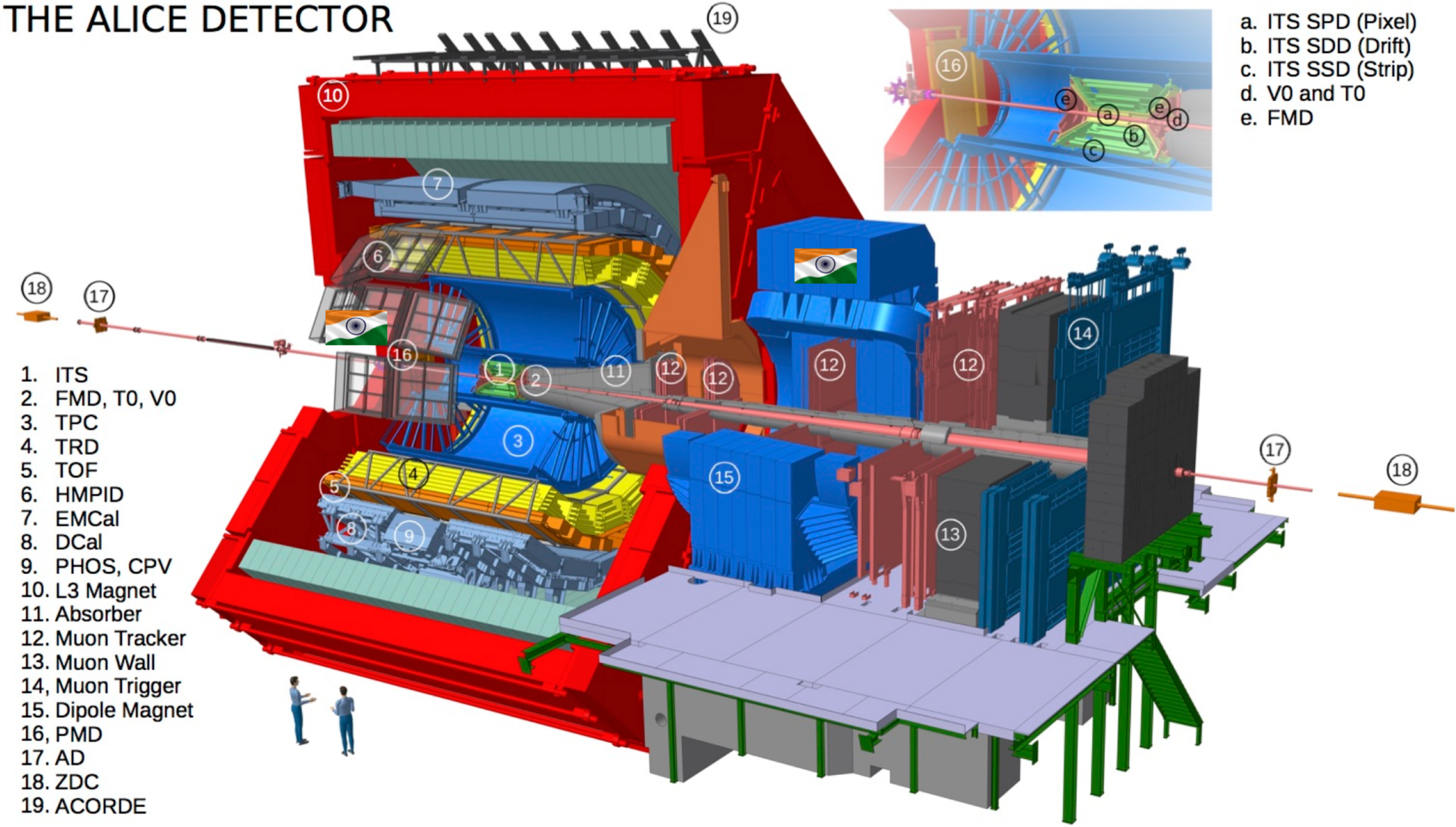
❖ Drift Chamber



❖ Time Projection Chamber

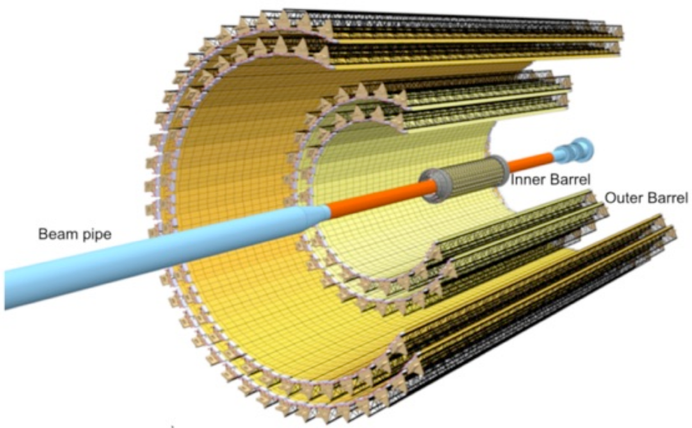


THE ALICE DETECTOR



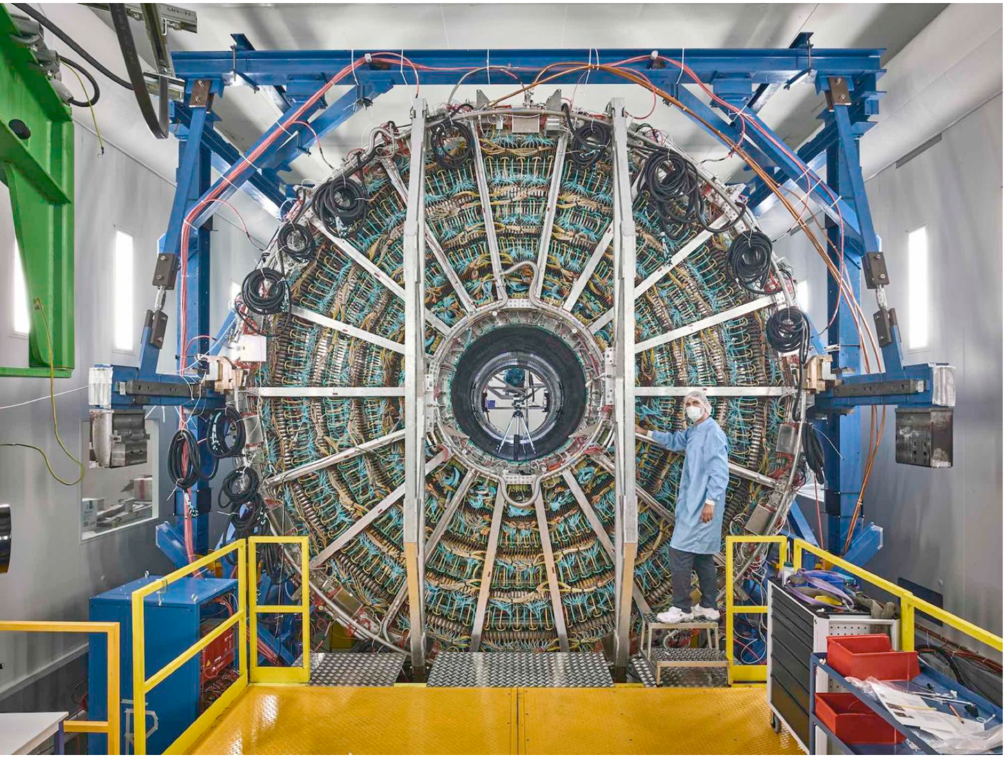
❖ Inner Tracking System

Detector	Technolog y	Purpose	Coverage	Position
ITS-SPD	Si-Pixel	Tracking Vertex	$\|\eta\| < 2$ $\|\eta\| < 1.4$	$r = 3.9cm$ $r = 7.6cm$
ITS-SDD	Si-Drift	Tracking PID	$\|\eta\| < 0.9$	$r = 15cm$ $r = 23.9cm$
ITS-SSD	Si-Pad	Tracking PID	$\|\eta\| < 1$	$r = 38cm$ $r = 43cm$



- Tracking
- Primary vertex resolution $< 100\mu m$
- Reconstruct the secondary vertex
- Particle identification below $200\ MeV/c$
- Reconstruct particles traveling through the dead region of TPC

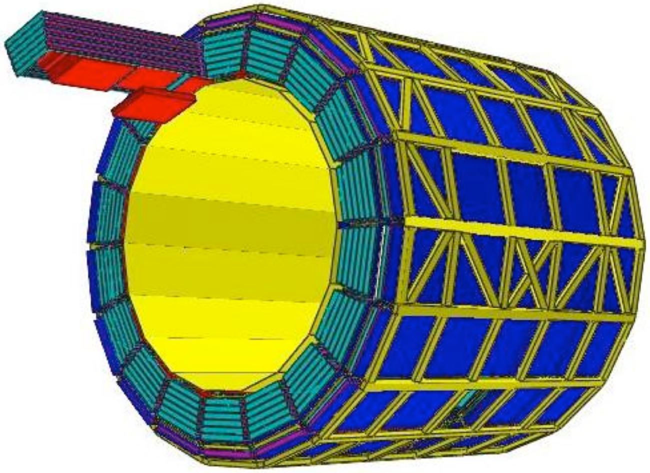
❖ Time Projection Chamber



- Main tracking detector
- Momentum measurement

  $0.1\frac{GeV}{c} < p_T < 100\frac{GeV}{c}$
- Particle identification
- Vertex measurement
- Coverage: $|\eta| < 0.9, \phi = 100\%$
- Position: 85 cm to 247 cm

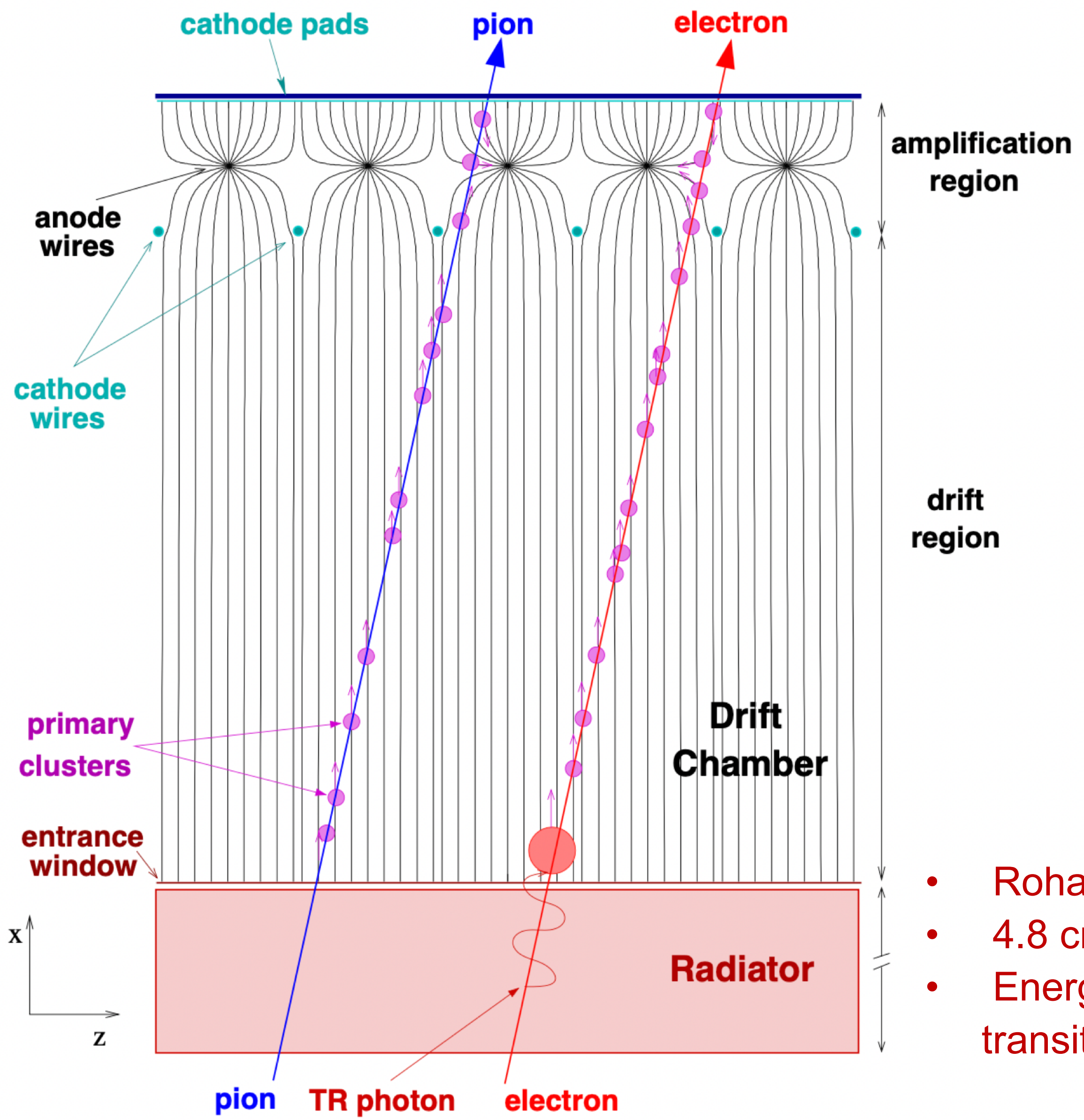
Transition Radiation Detector



- Consists of 522 detectors
- Arranged in 18 sectors in azimuth
- Each of 5 stacks in longitudinal direction
- 6 layers per stack.
- Diameter of the TRD cylinder ~ 7 m
- Length 7 m.
- Location: $r = 290\ cm\ - 368\ cm$
- Readout channels - 1.15 million
- Sampling the signal in 20 time bins.
- The active gas is a xenon-CO_2 mixture.

- Used for electron identification above 1 GeV/*c*, Tracking
- Pseudo-rapidity coverage: $|\eta| < 0.8$

Transition Radiation Detector

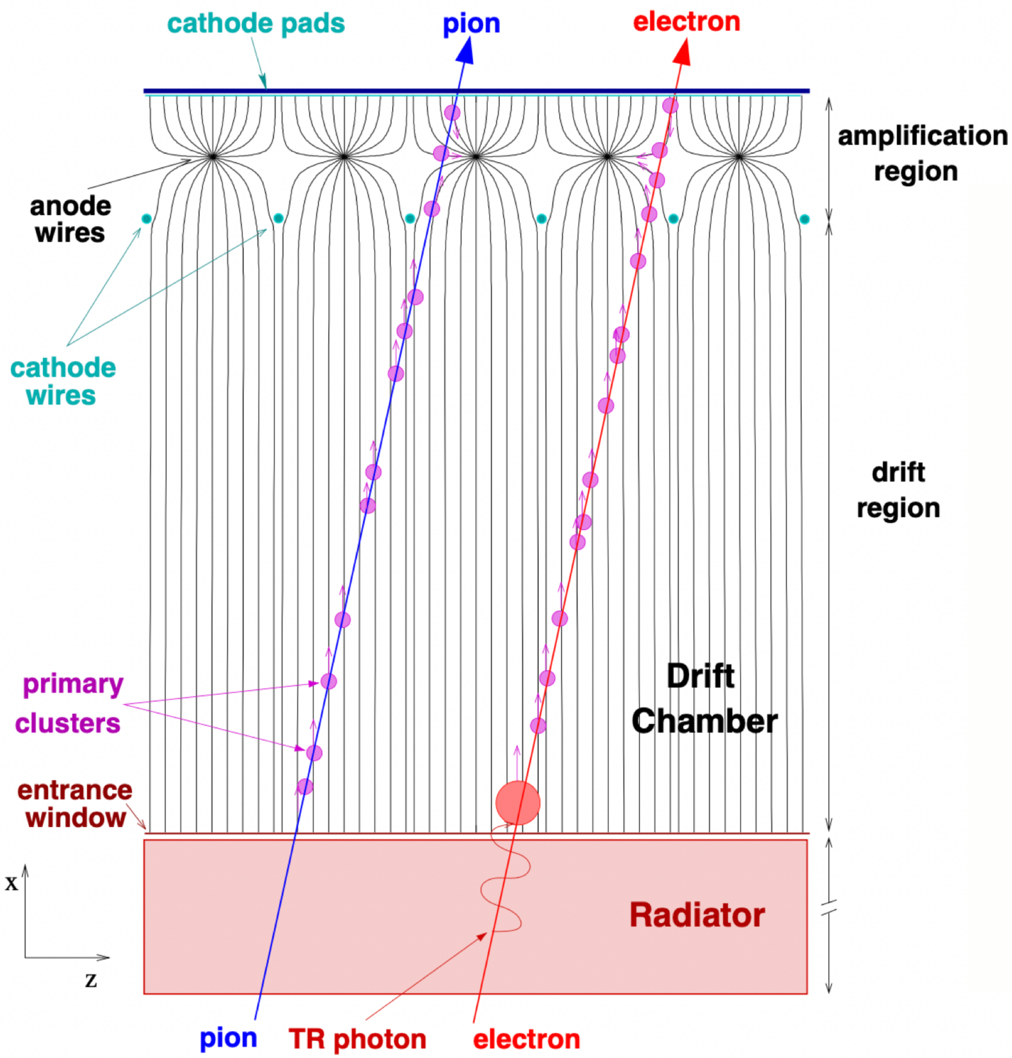


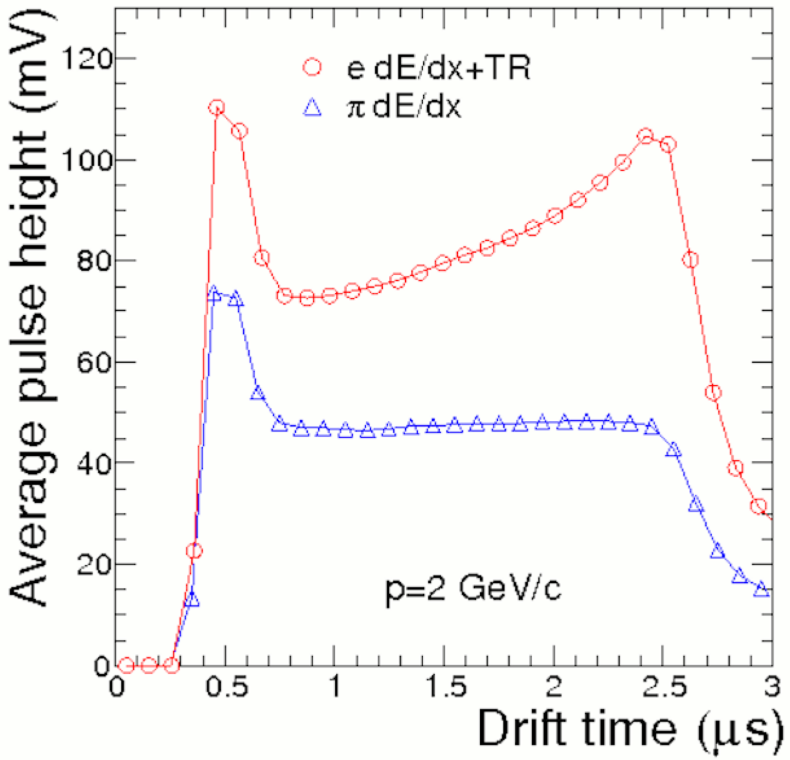
0.7 cm

3.0 cm

- Rohacell foam and fiber material
- 4.8 cm thick
- Energetic electron produces transition radiation

❖ Transition Radiation Detector



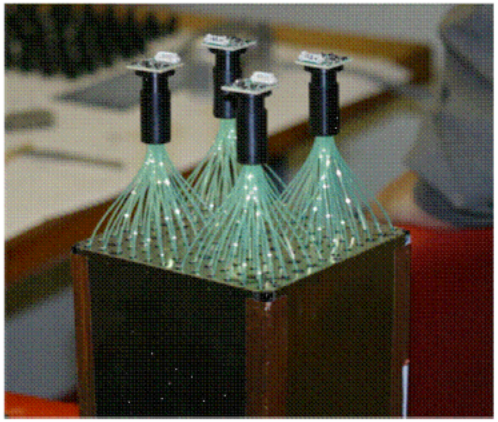


❖ Time of Flight

- Multigap Resistive Plate Chambers (MRPCs)
- double-stack design: two stacks of five gas gaps.
- Basic unit active area 120 × 7.4 cm2
- consists of 1593 MRPC strips
- subdivided into 18 azimuthal sectors.
- 152928 total readout channels.
- cylindrical array (~ 141 m^2 of active area)
- Position: $\mathrm{r} = 370\ cm\ - 399\ cm$
- Pseudorapidity: $|\eta| < 0.9$

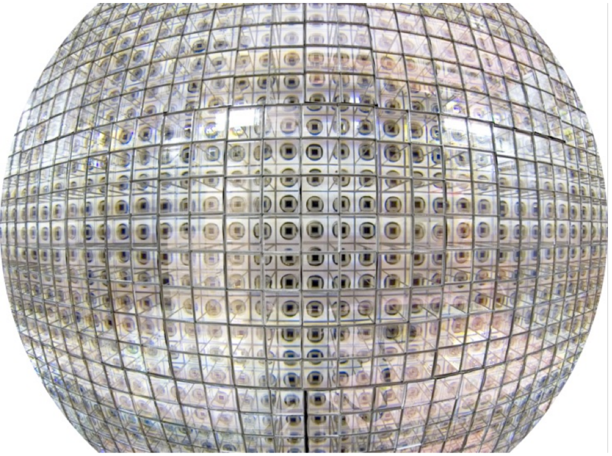
- Timing resolution was measured to be better than 50 ps.
- Provides charged-particle PID in the intermediate momentum range (below 2.5 GeV/*c* for pions and kaons, and up to 4 GeV/*c* for protons)
- Also used as trigger for cosmic ray events and ultraperipheral collisions.

❖ EMCAL



- Shashlik-type lead-scintillator sampling calorimeter
- Consists of 4416 individual modules
- Each of the modules is composed by 4 optically isolated towers
- Total number of towers -17664
- The optical readout of each tower is provided using wavelength shifting fibers coupled to an Avalanche Photo Diode (APD).
- Position: $r = 430\ cm\ - 455\ cm$
- Pseudorapidity: $|\eta| < 0.7$
- Azimuth: $80^0 < \phi < 187^0$

❖ PHOton Spectrometer (PHOS)

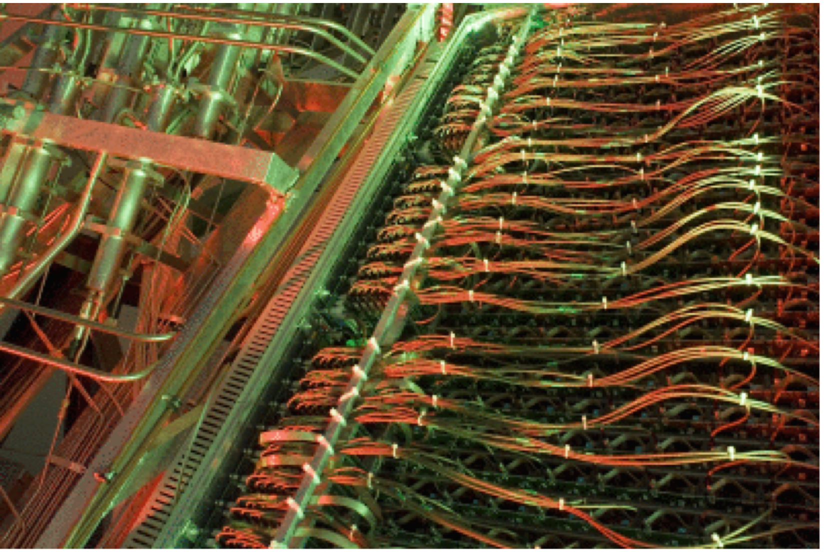


- Based on $PbWO_4$ (or PWO)
- Consists of 12544 channels
- Position: $r = 460\ cm\ - 478\ cm$
- Pseudorapidity: $|\eta| < 0.12$
- Azimuthal angle: $220^0 < \phi < 320^0$
- Provides L0 and L1 levels to CTP to select events with high-energy photons.

❖ Charged Particle Veto (CPV)

- Based on MWPC
- Placed on top of PHOS
- Material budget is less than 5% X0. Gas – Ar: 80%, CO2: 20%
- Pseudorapidity: $|\eta| < 0.12$
- Azimuthal angle: $220^0 < \phi < 320^0$
- Provides charged particles information

❖ High Momentum PID (HMPID)

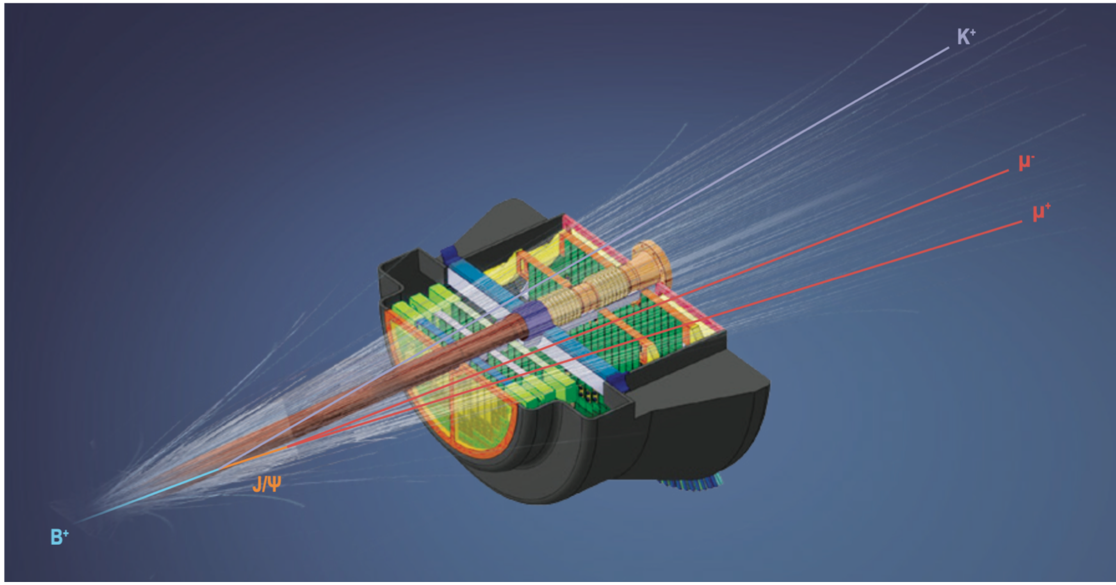


- Consists of 7 RICH counters
- Position: $r = 490\ cm$
- Pseudorapidity: $|\eta| < 0.6$
- Azimuthal angle: $1^0 < \phi < 59^0$

- Inclusive measurement of identified hadrons at $p_T > 1 GeV/c$
- Enable $\frac{\pi}{K}$ $and\ K/p$, on a track-by-track basis, up to 3 GeV/c and 5 GeV/c, respectively
- Identification of light nuclei and anti-nuclei $(d, t, 3He, \alpha)$ at high p_T

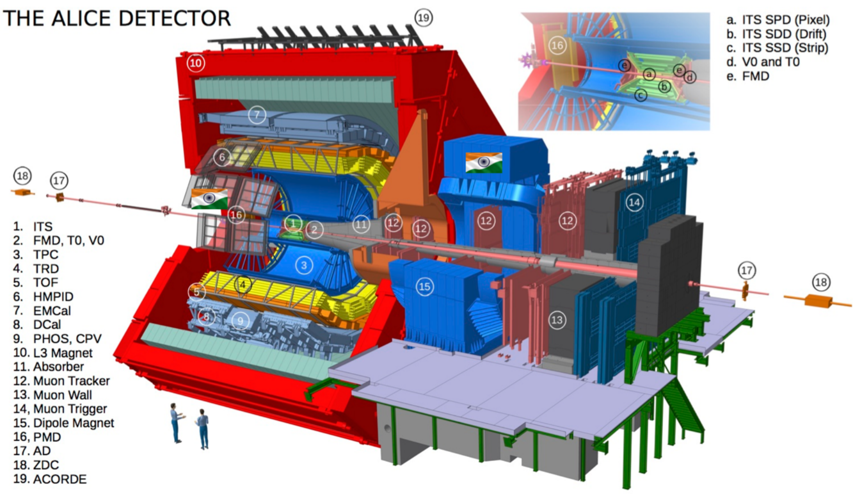
❖ Muon Forward Tracker


Muon Forward Tracker (MFT)

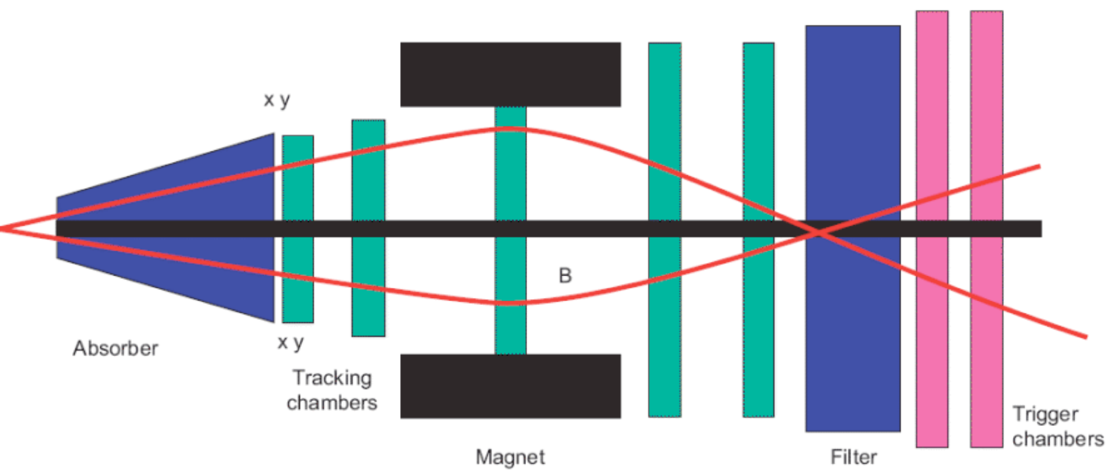


- High resolution Si-tracking detector installed in front of the Muon Spectrometer
- Consists of two half-cones containing five detection half-disks
- Placed along the beams axis between −460 mm and −768 mm away from the IP
- Covers the pseudorapidity domain $-3.6 < \eta < -2.5$

❖ Muon Spectrometer



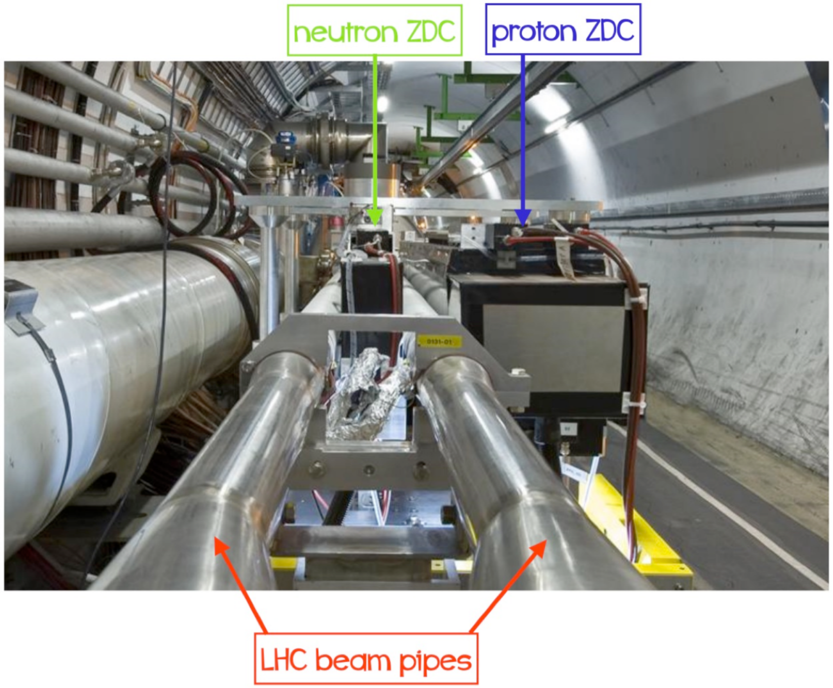
- Main Components:
  - an absorber to filter the background
  - a set of tracking chambers before, inside and after the magnet
  - a set of trigger chambers.



- Absorber: Carbon + Concrete
- Tracking Chambers:
  Cathode Pad/strip chambers
  Spatial resolution: $< 100\mu m$
- Trigger : RPC
  Spatial resolution: < 10mm
- Timing resolution ~ 2 ns
  (to identify bunch crossing)

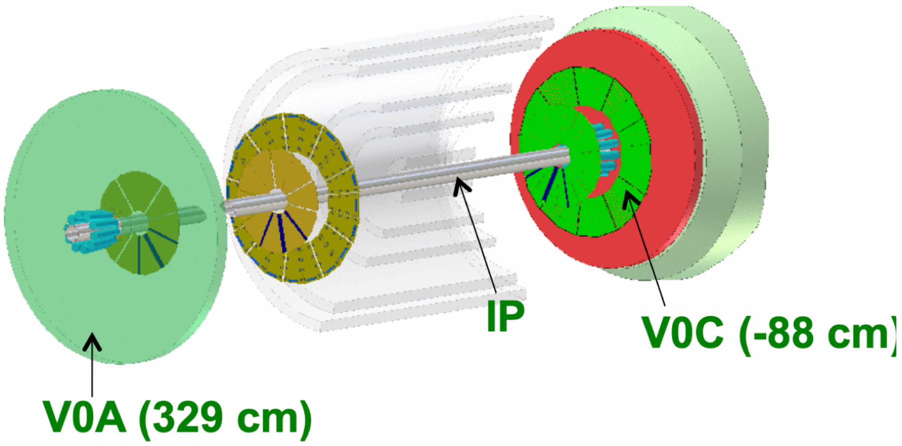
- Pseudorapidity: $2.5 \leq \eta \leq 4$

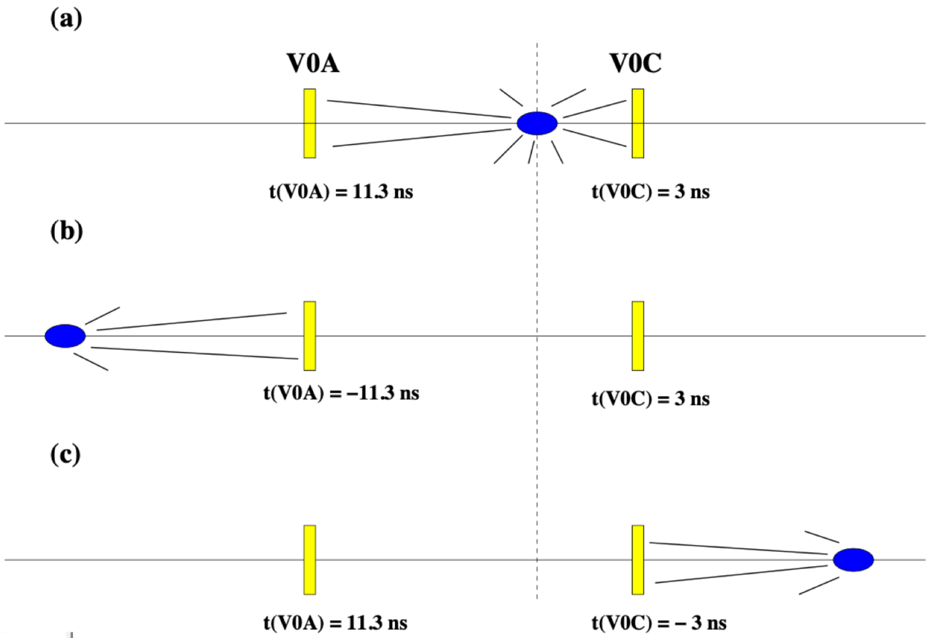
❖ Zero Degree Calorimeter

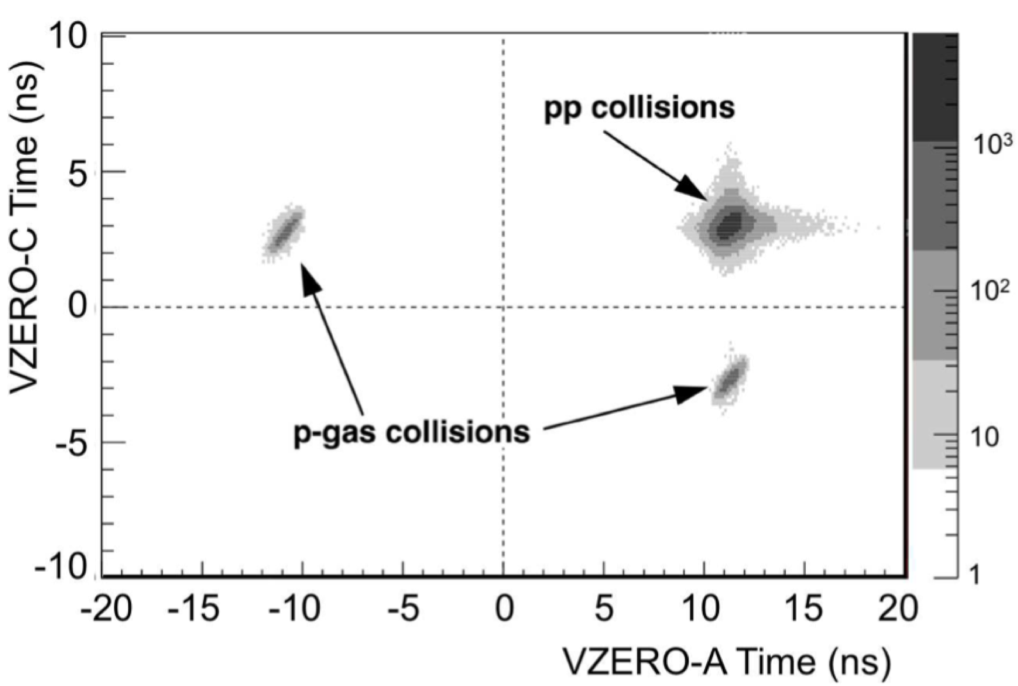


- Two identical sets of calorimeters located on both sides of IP
- Located 112.5 meters away from IP.
- Each set consists of a neutron (ZN) and a proton (ZP) calorimeter.
- The ZN is placed at zero degree with respect to the LHC axis,
- The ZP is positioned externally to the outgoing beam pipe.
- The spectator protons are separated from the ion beams by the dipole magnet

❖ V0 Detector


IP
V0C (-88 cm)
V0A (329 cm)


(a)
V0A
V0C
t(V0A) = 11.3 ns
t(V0C) = 3 ns
(b)
t(V0A) = −11.3 ns
t(V0C) = 3 ns
(c)
t(V0A) = 11.3 ns
t(V0C) = – 3 ns


pp collisions
p-gas collisions
VZERO-C Time (ns)
VZERO-A Time (ns)
10
5
0
-5
-10
-20
-15
-10
-5
0
5
10
15
20
10³
10²
10
1

❖ Central Trigger Processor

- Generates decision for ALICE based detector signals and information about LHC filing scheme

- Hardware Level Trigger (Low Level Trigger):

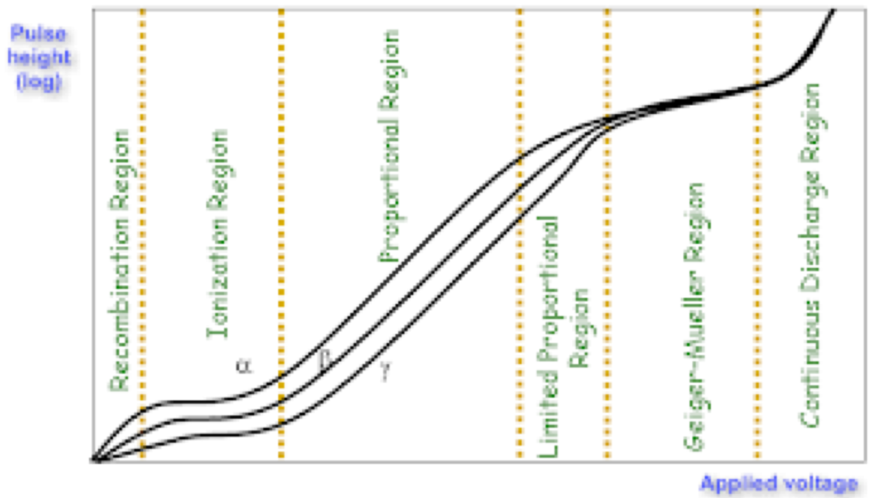
  - Level-0 (L0): $0.9\ \mu s$ after the collision using V0, T0, EMCal, PHOS
  - Level-1 (L1): $6.5\ \mu s$ after L0 evaluating L0 accepted events

  L0 and L1 trigger are sent to all detectors with a latency of $300\ ns$ enable buffering of data by detector FEE

  - Level-2 (L2): decision is made after $100\ \mu s$ and triggers sending of event data to DAQ and HLT (High Level Trigger)

- Input Information:

  - Signal from detectors: Inform the CTP that event has happened
  - LHC filling scheme: Used by CTP to suppress the background


Pulse height (log)
Recombination Region
Ionization Region
Proportional Region
Limited Proportional Region
Geiger-Mueller Region
Continuous Discharge Region
α
β
γ
Applied voltage