NA61/SHINE detector overview

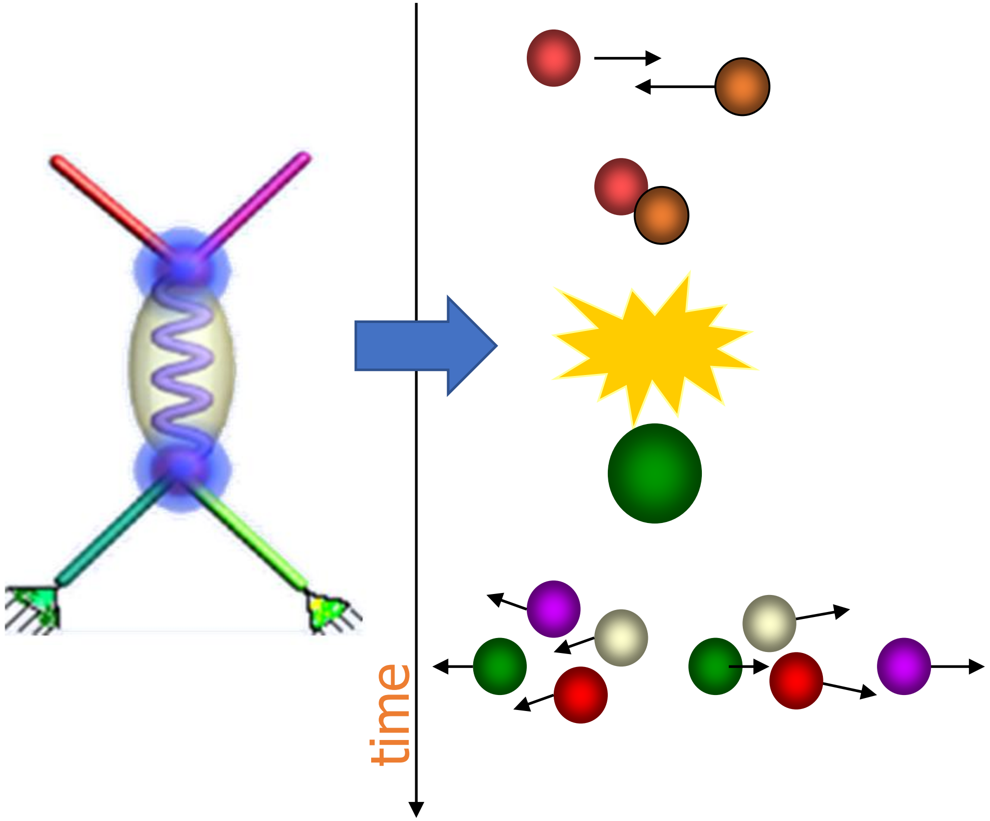
Outline

- Fixed target experiment
- NA61/SHINE detector – general overview
- Time Project Chamber
  - Tracking
  - Energy lost – particle identification
- Time of Flight
  - Particle identification
- Projectile Spectator Detector
  - Centrality of the collisions
- Vertex Detector
  - V0 particle
- Beam Detectors
- Detector Upgrade

Why we need to detect particle

Idealistic views of an elementary particle reaction

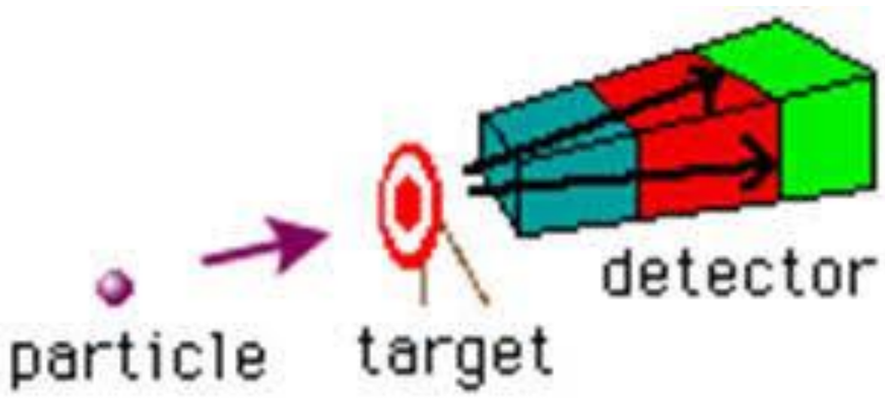
Real views of an elementary particle reaction

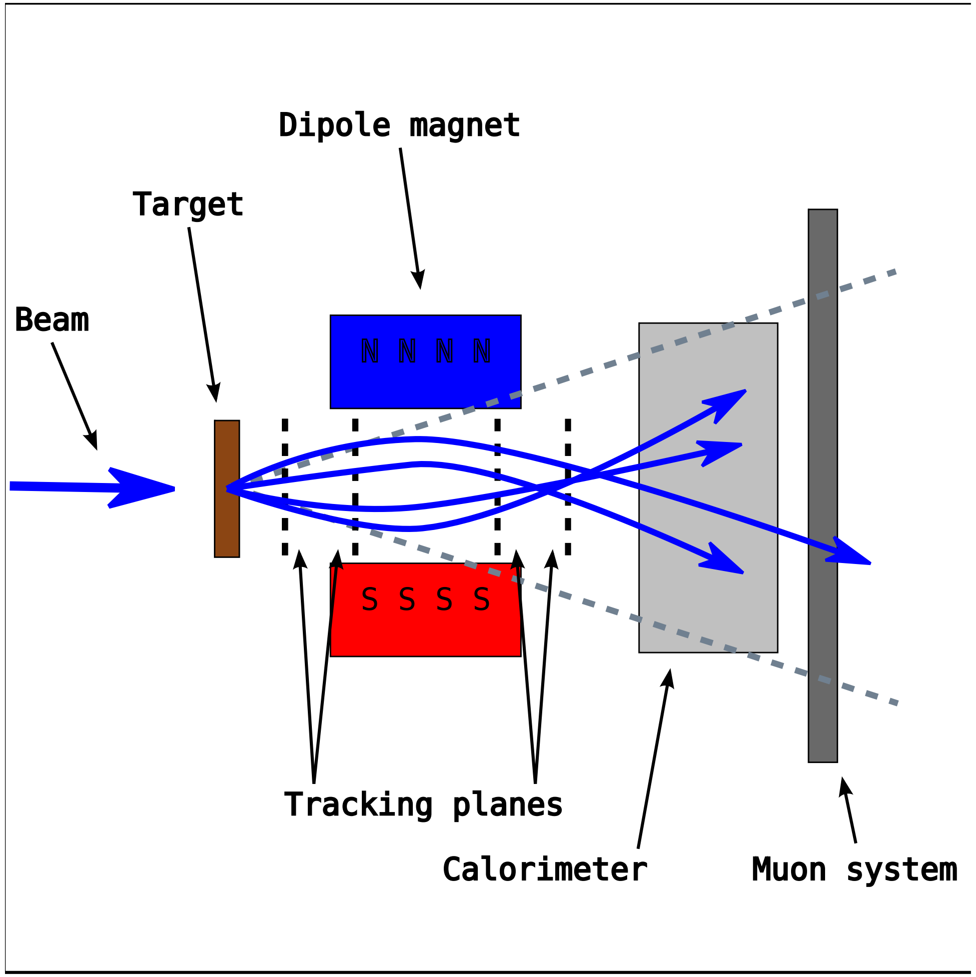


- Usually we can not ‘see’ the reaction itself, but only the end products of the reaction.
- In order to reconstruct the reaction mechanism and the properties of the involved particles, we want the maximum information about the end products
- The event - each of collisions of projectile particles

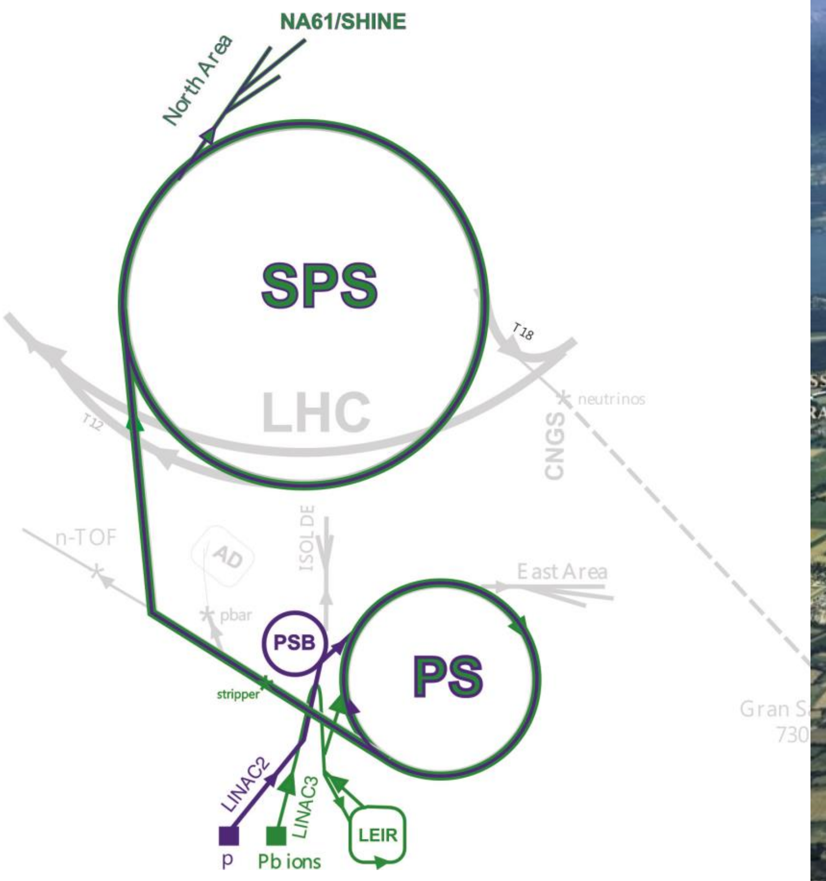
C. Schäfer / CERN

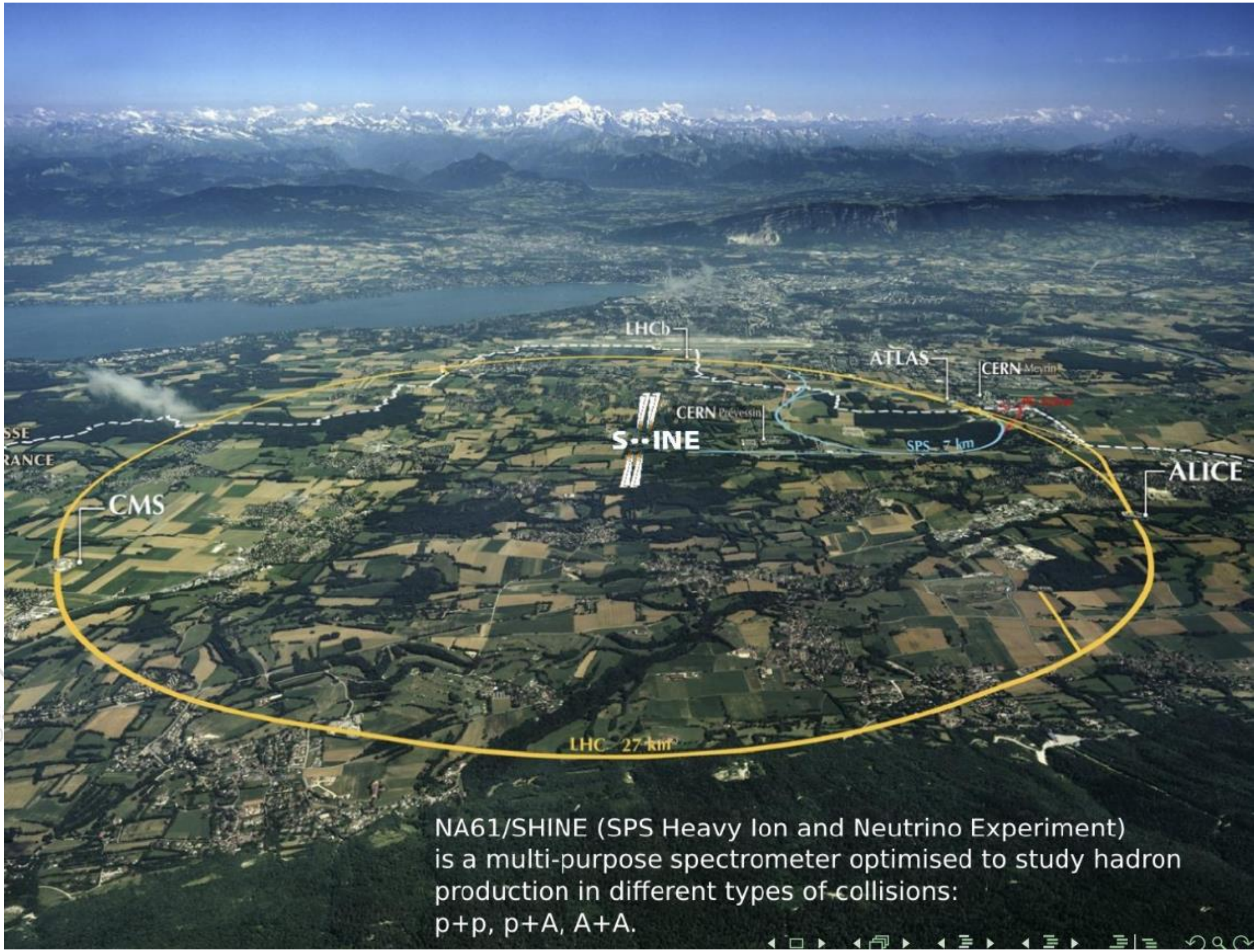
Fixed target experiment



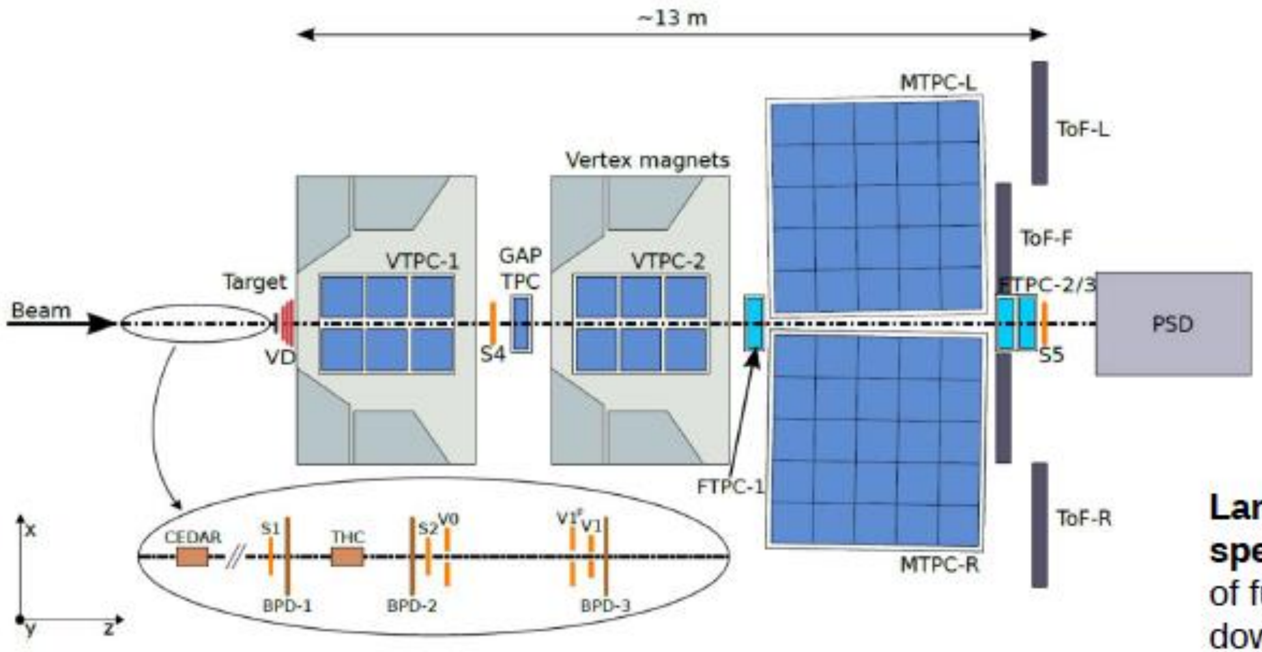


SPS


NA61/SHINE
North Area
SPS
LHC
T18
T12
neutrinos
CNGS
n-TOF
AD
ISOLDE
East Area
pbar
PSB
PS
stripper
LINAC2
LINAC3
LEIR
p
Pb ions

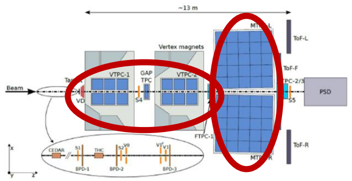

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
S··INE
SPS 7 km
ALICE
CMS
LHC 27 km
NA61/SHINE (SPS Heavy Ion and Neutrino Experiment)
is a multi-purpose spectrometer optimised to study hadron
production in different types of collisions:
p+p, p+A, A+A.

NA61/SHINE - Experimental layout



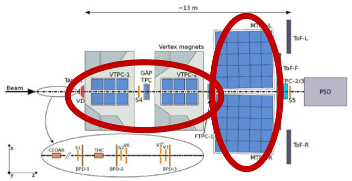
Large acceptance hadron spectrometer – coverage of full forward hemisphere, down to $p_T = 0$

- Large acceptance hadron spectrometer
- Beam particles measured in set of counters and position detectors
- Tracks of charged particles measured in set of TPCs: measurement of q, p and identification by energy loss measurement
- 3 Time of Flight Walls: identification via time of flight measurement
- Projectile Spectator Detector measures the forward energy which characterizes centrality of collision
- Vertex Detector (open charm measurements)
- Forward TPC-1/2/3

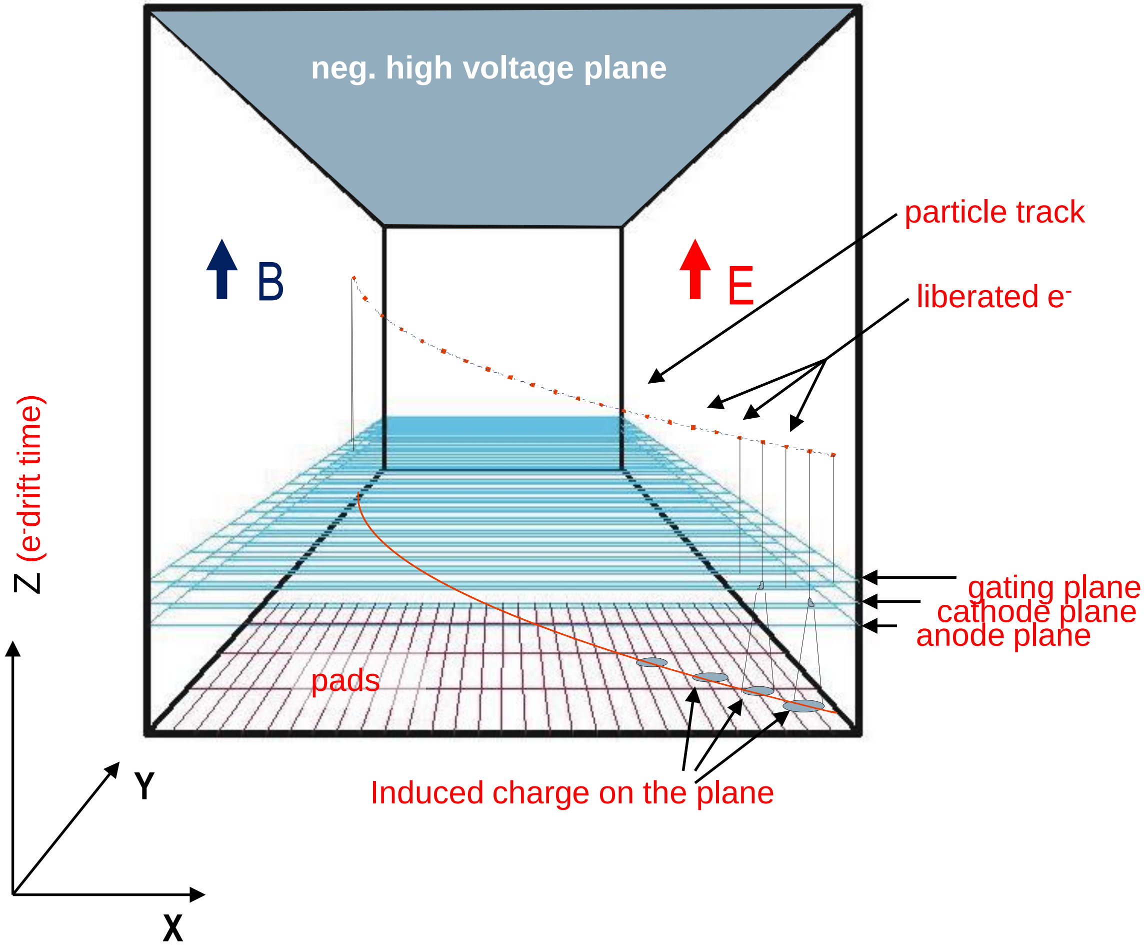


NA61/SHINE

Experimental layout



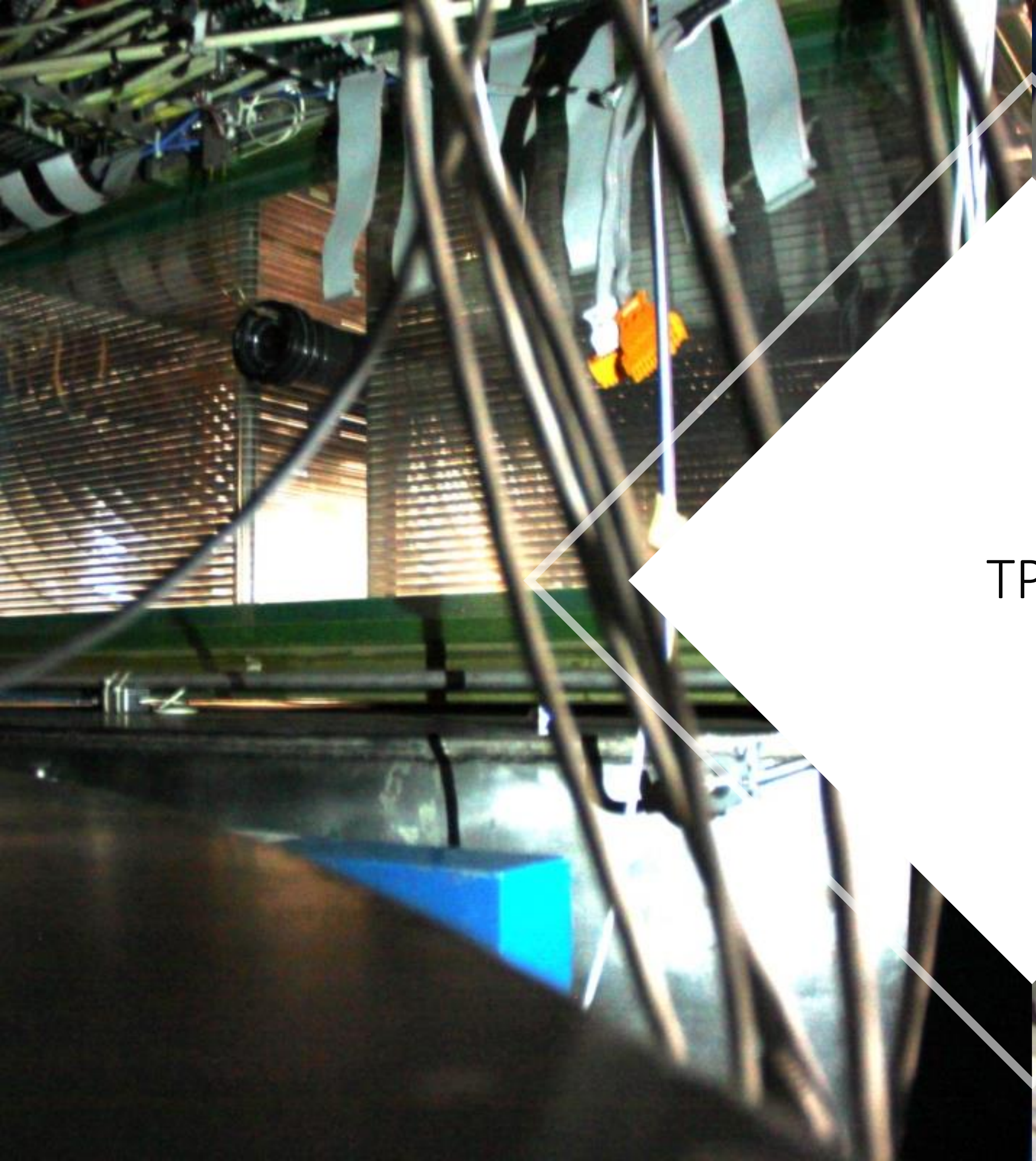
TPC - Time Projection Chamber



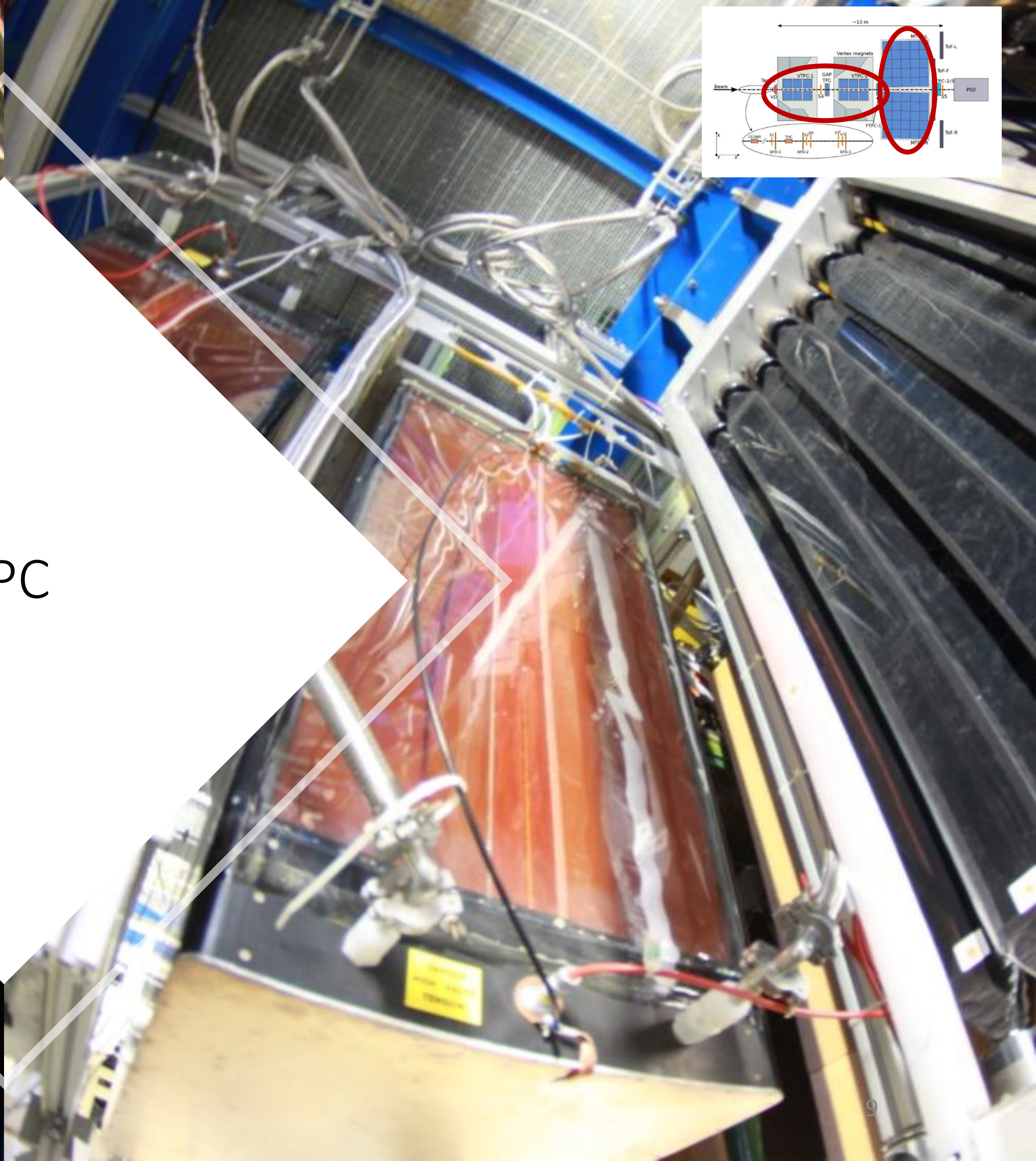
Time Projection Chamber
full 3D track reconstruction:

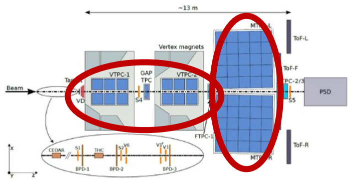
- x-y from wires and segmented cathode of MWPC
- z from drift time

- momentum resolution
  space resolution + B field
  (multiple scattering)
- energy resolution
  measure of primary ionization



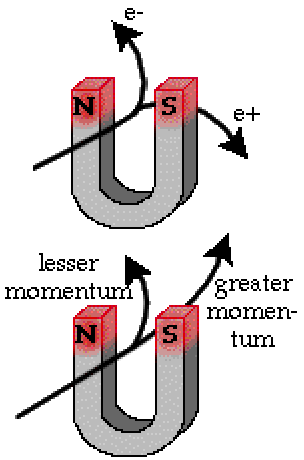
TPC

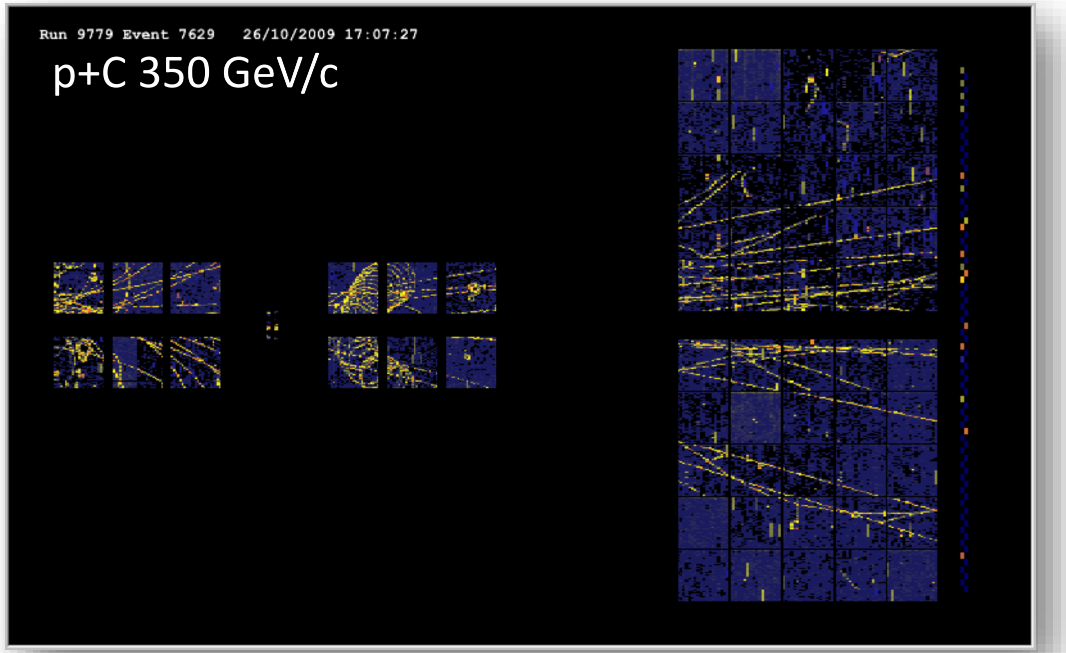

~13 m
Vertex magnets
VTPC-1
GAP
TPC
VTPC-2
Beam
VD
S4
FTPC-1
ToF-L
ToF-F
ToF-R
PSD
S5
CEDAR
S1
THC
S2
V0
V1
BPD-1
BPD-2
BPD-3
x
y
z

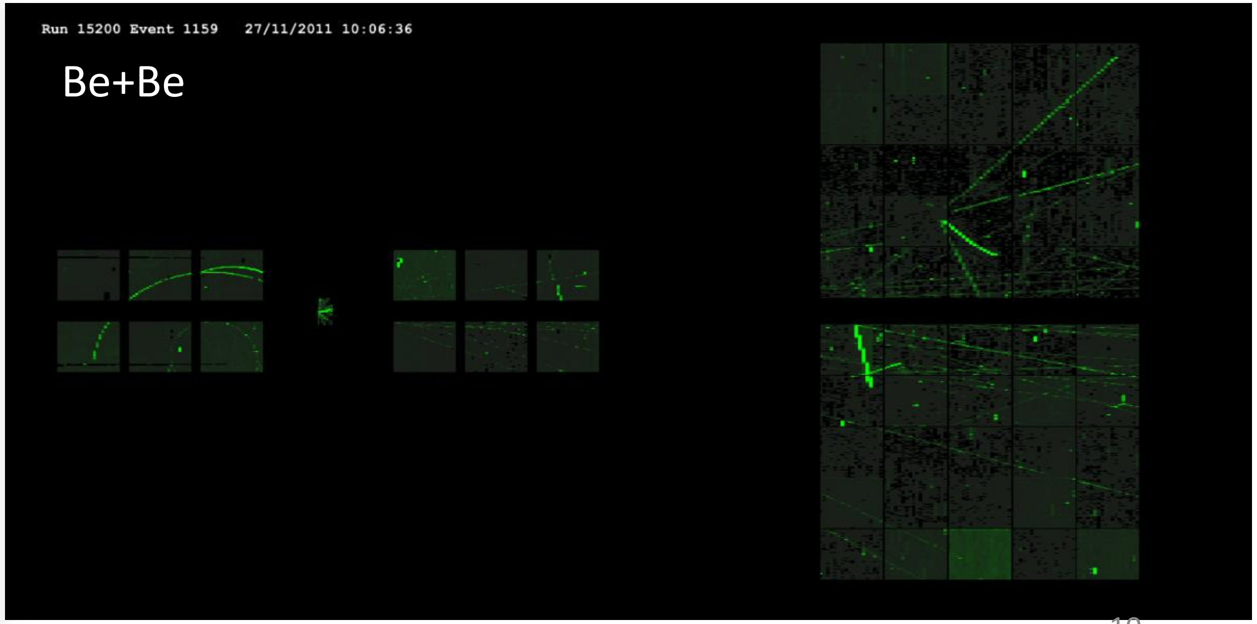


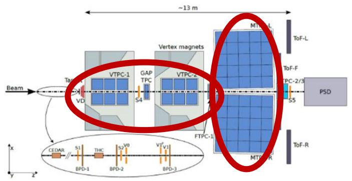
Tracking

- Measure a particle's charge and momentum
  - Tracking device, are in a strong magnetic field
  - The signs of the charged particles can easily be read from their paths
  - The momenta of particles can be calculated since the paths of particles with greater momentum bend less than those of lesser momentum.








~13 m
Vertex magnets
Beam
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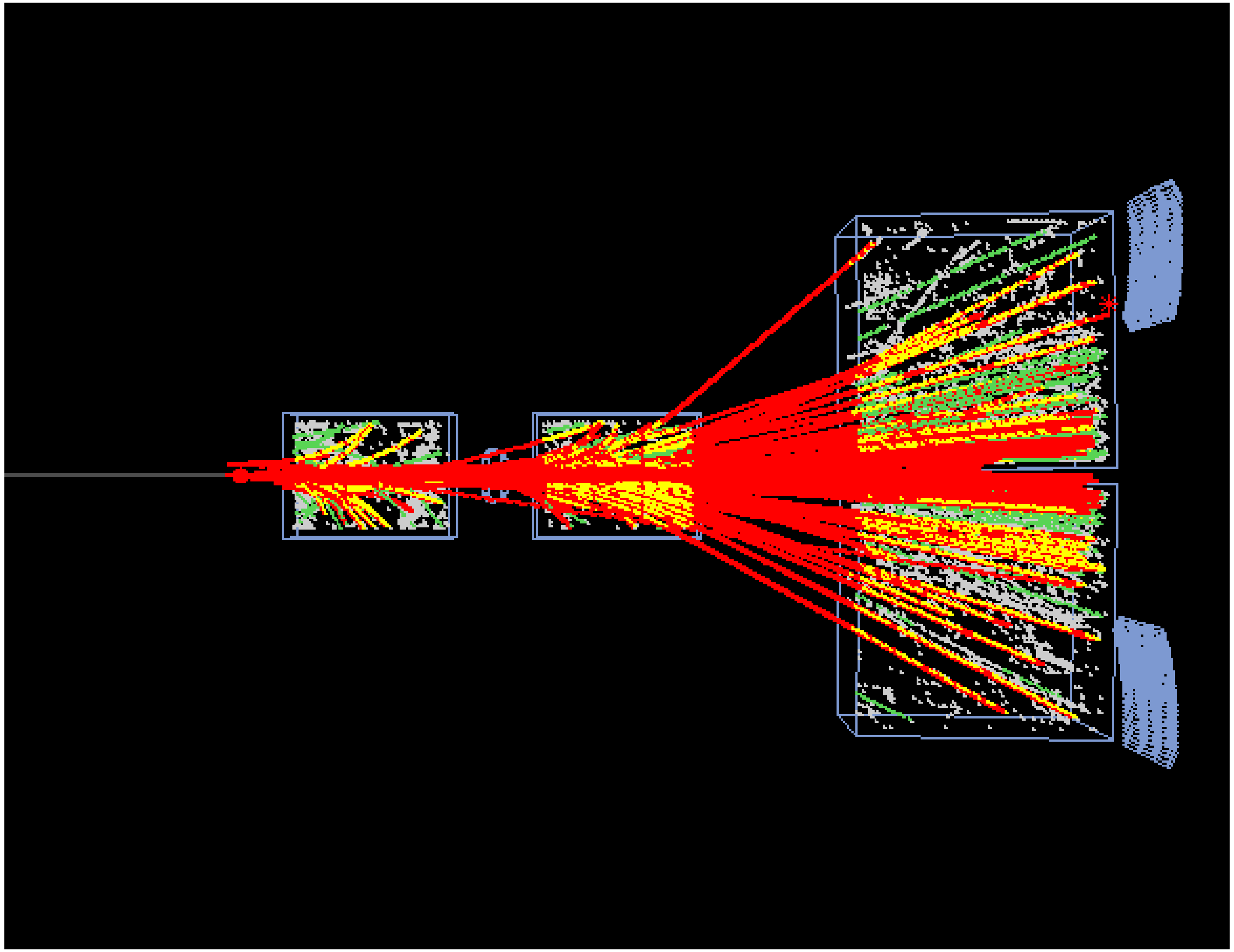
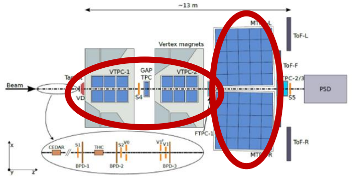
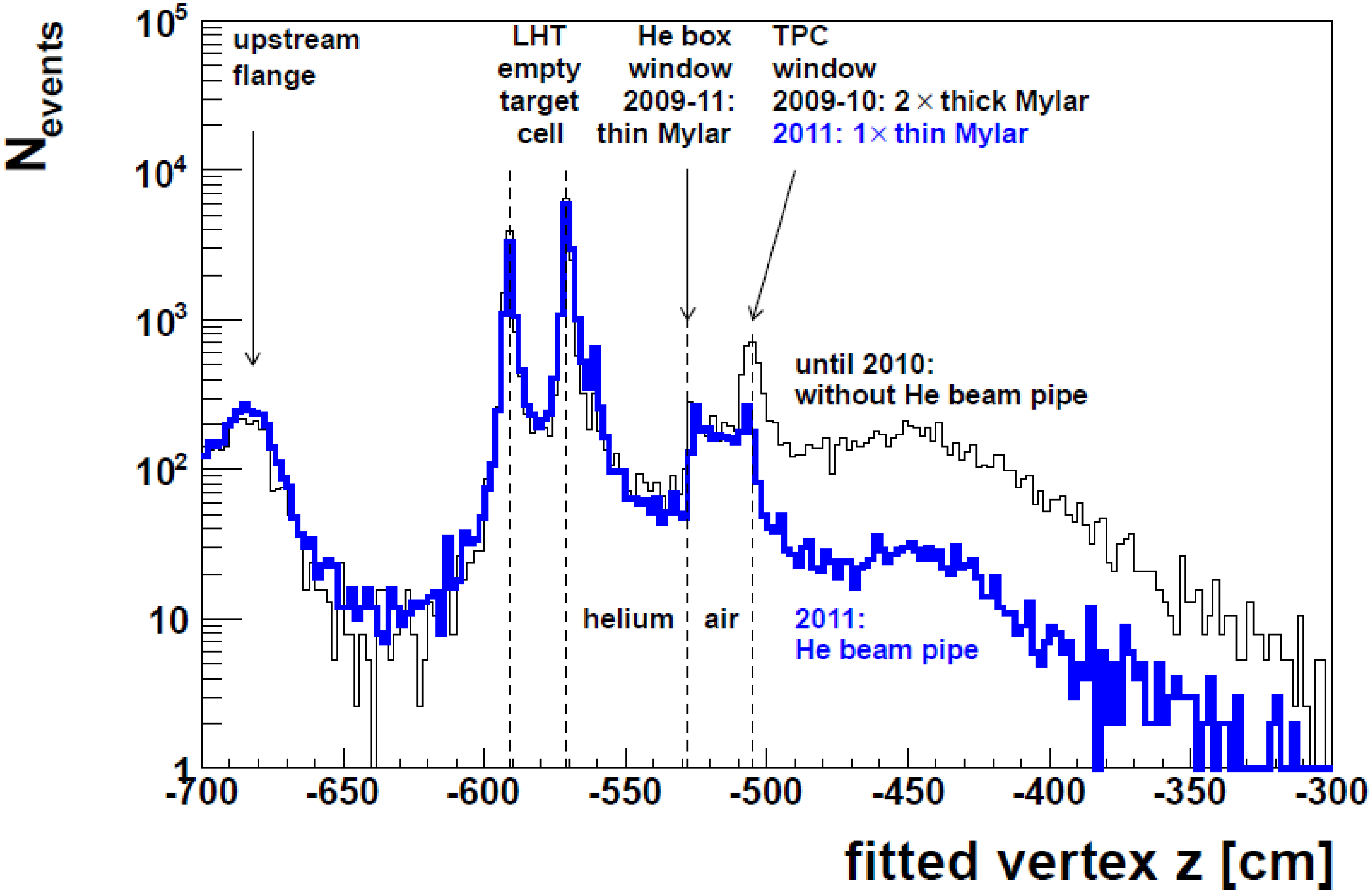
ToF-L
ToF-F
ToF-R
S5
PSD
CEDAR
S1
THC
S2
V0
V1
BPD-1
BPD-2
BPD-3
x
y
z

Pb+Pb

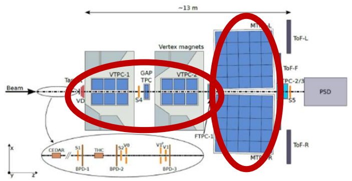


Vertex distribution along the beam axis

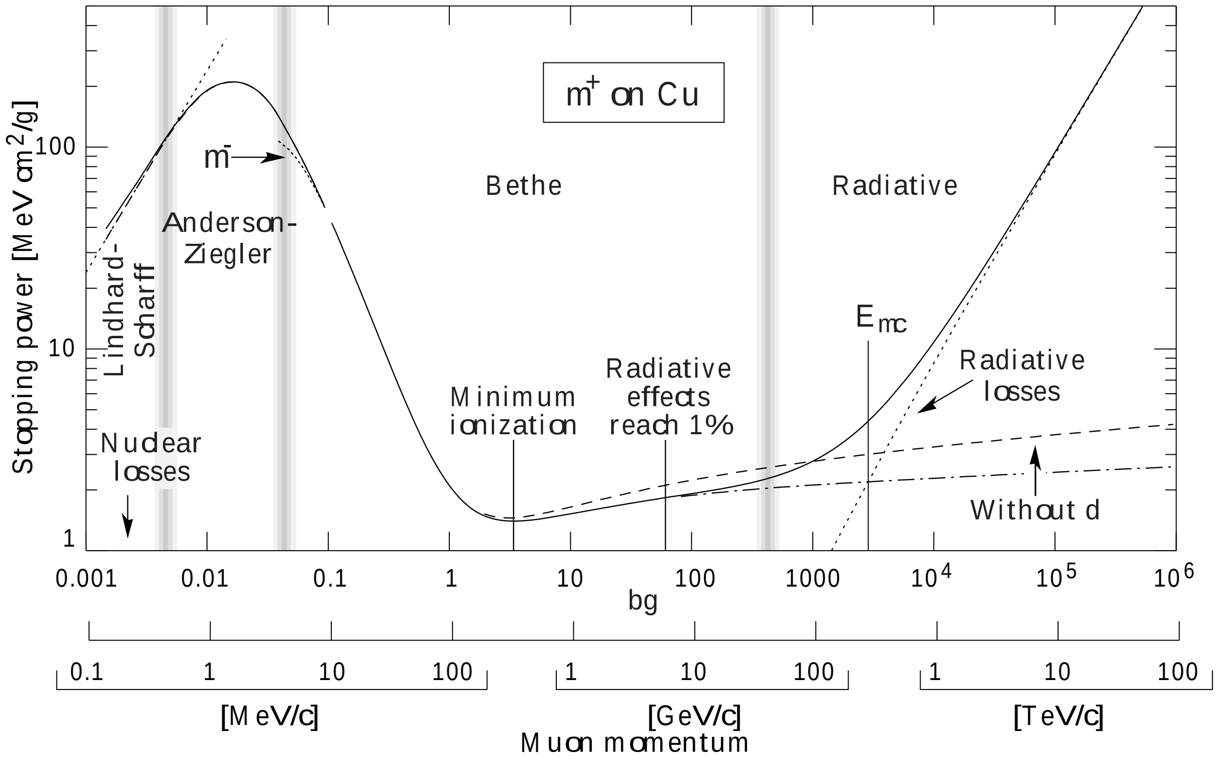


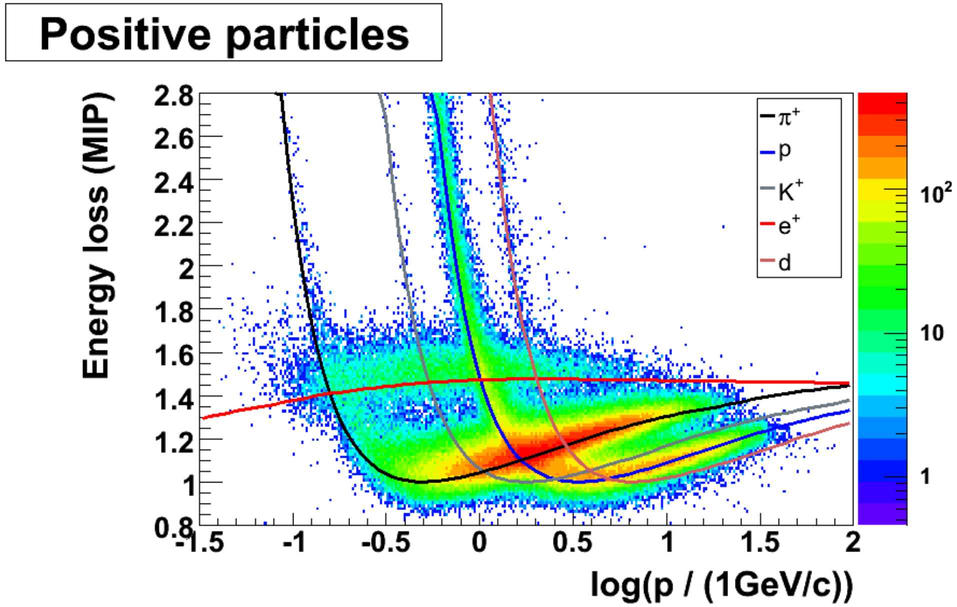


dE/dX and Momentum

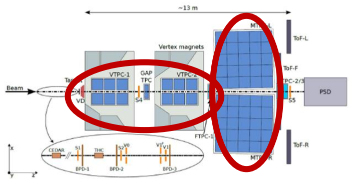


$$\frac{dE}{dX} \propto \frac{1}{\beta^2} \propto \frac{m^2}{p^2}$$

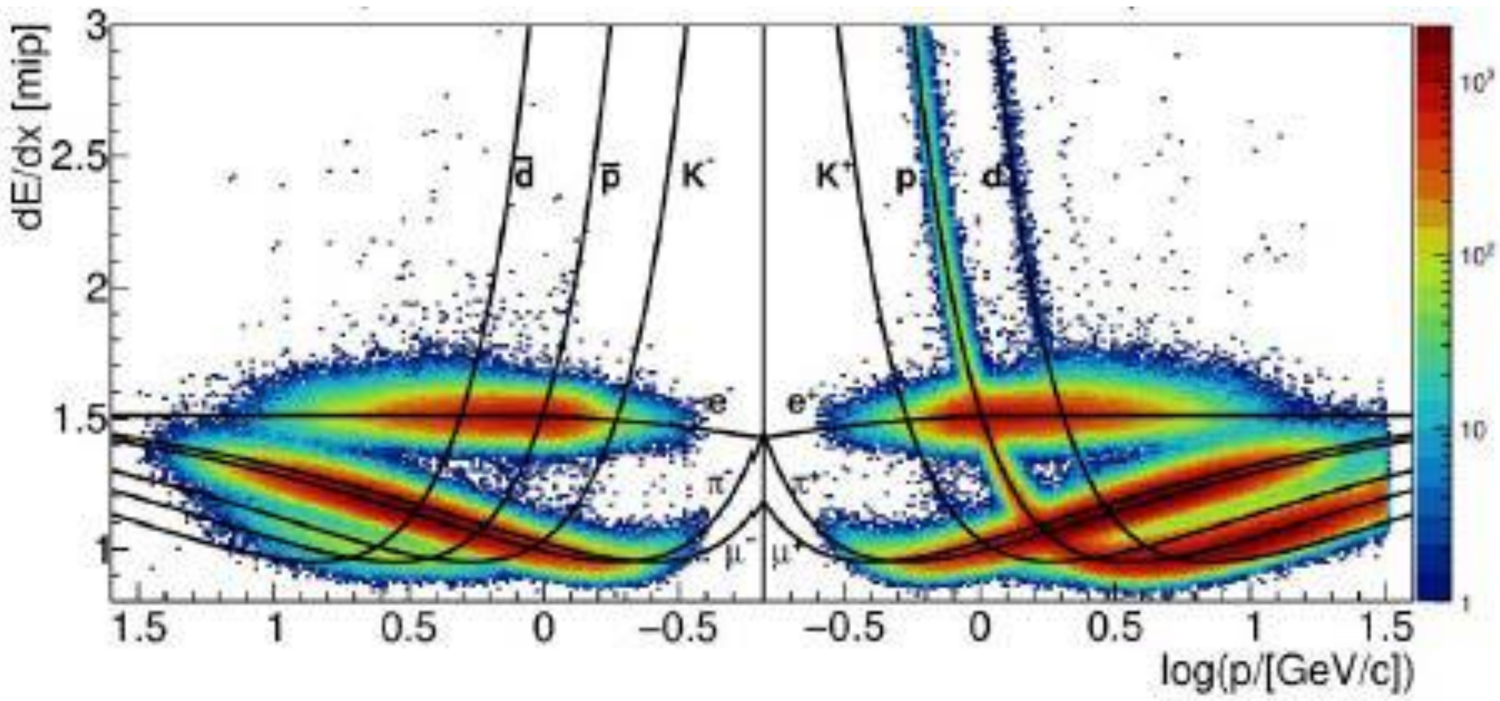




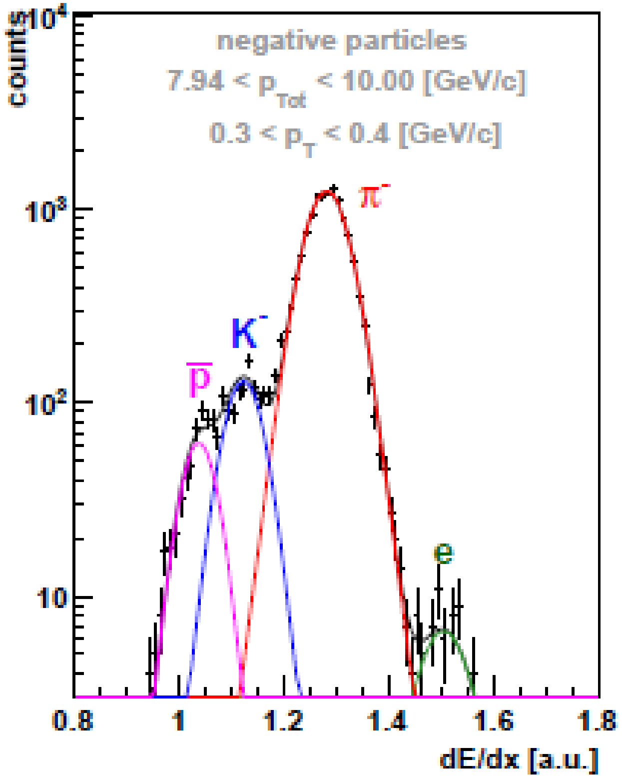
$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

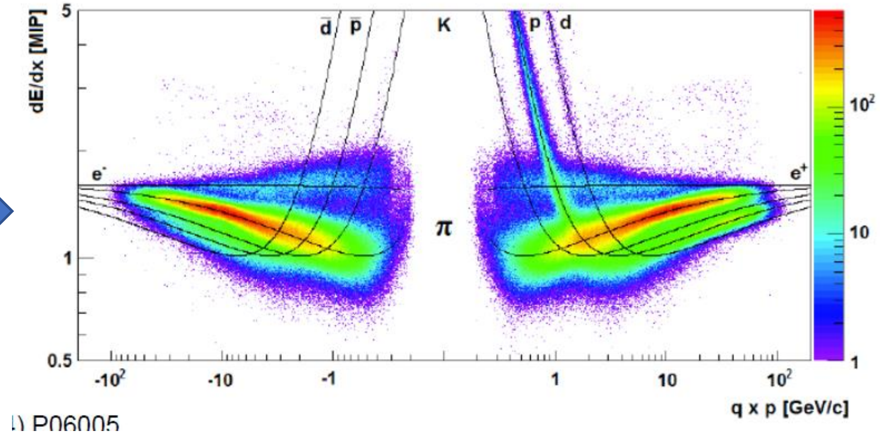


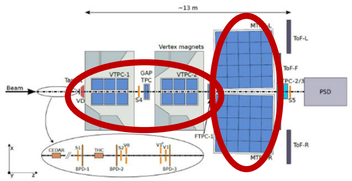
Energy lost



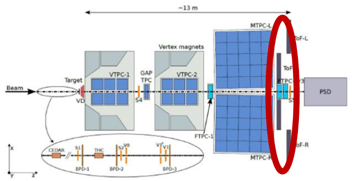
Energy loss (dE/dx) method







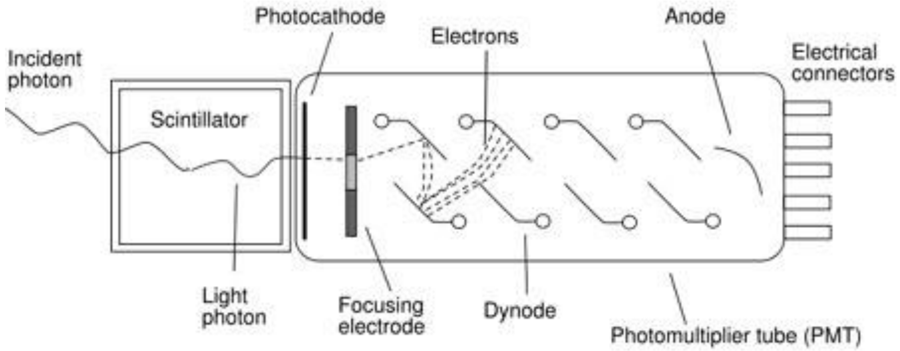
- In each p, p_T bin sum of Gauss functions is fitted to the dE/dx spectrum
- For each track the probability for being a hadron of specific type is calculated based on the fitted dE/dx distribution
- Sum of these probabilities gives the mean multiplicity of the identified hadrons

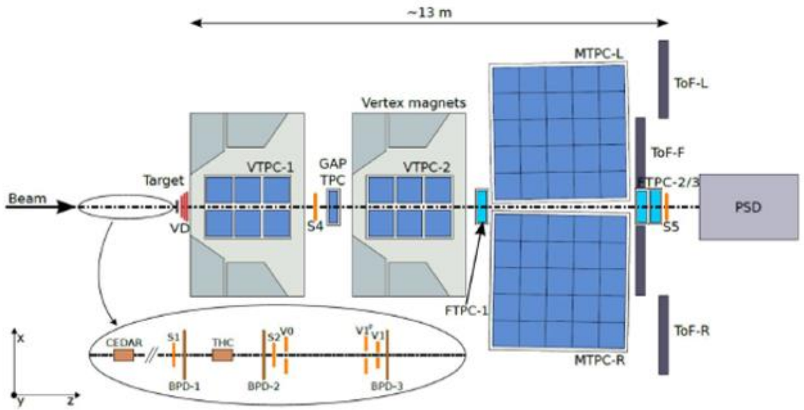


Time of Flight systems (ToF)

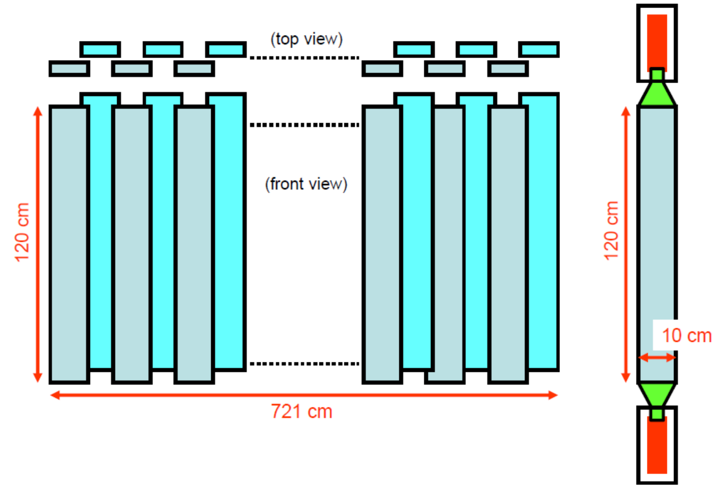
- particle identification based only on energy loss measurement can not be performer in the crossover region of the Bethe-Bloch curves
- Based on the scintillators detectors

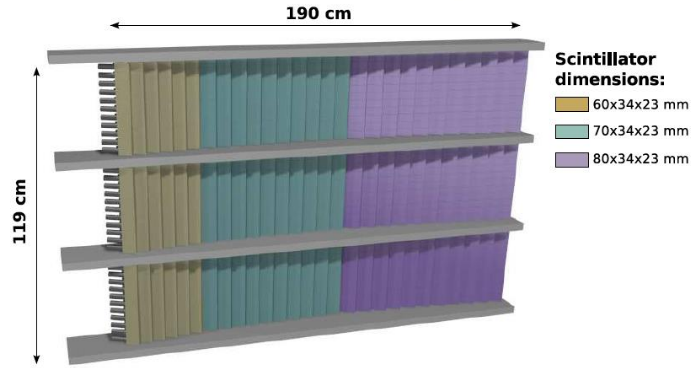
$$m^2 = p^2 \left(\frac{c^2\, tof^2}{l^2} - 1 \right)$$

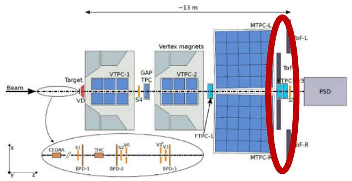


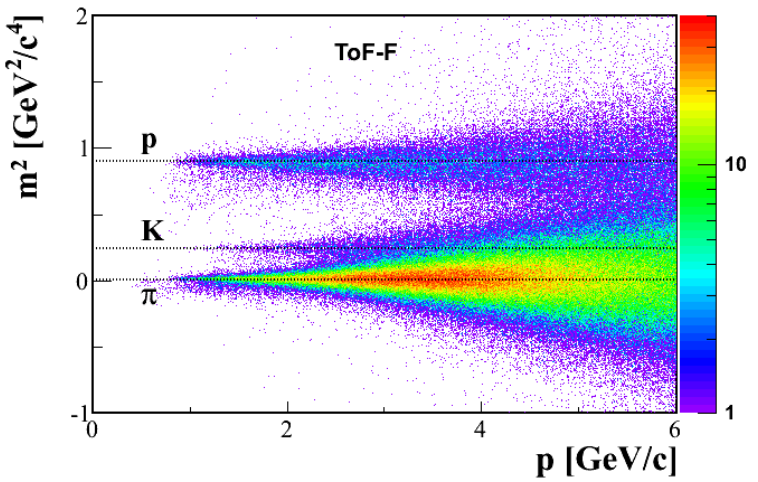


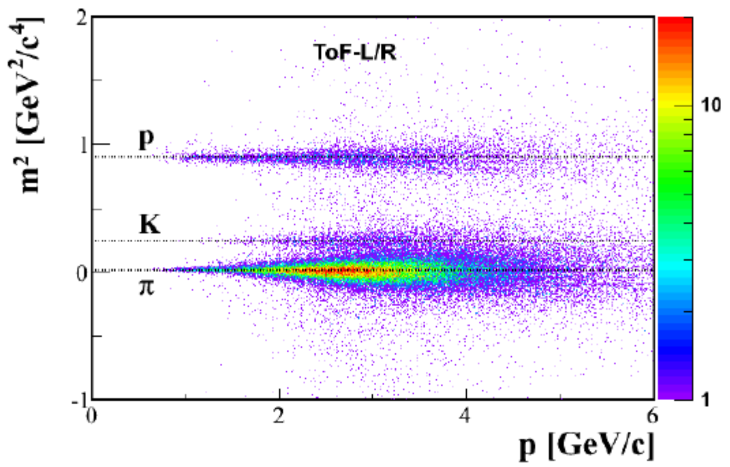
Time of Flight systems (ToF)

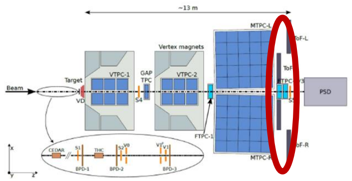






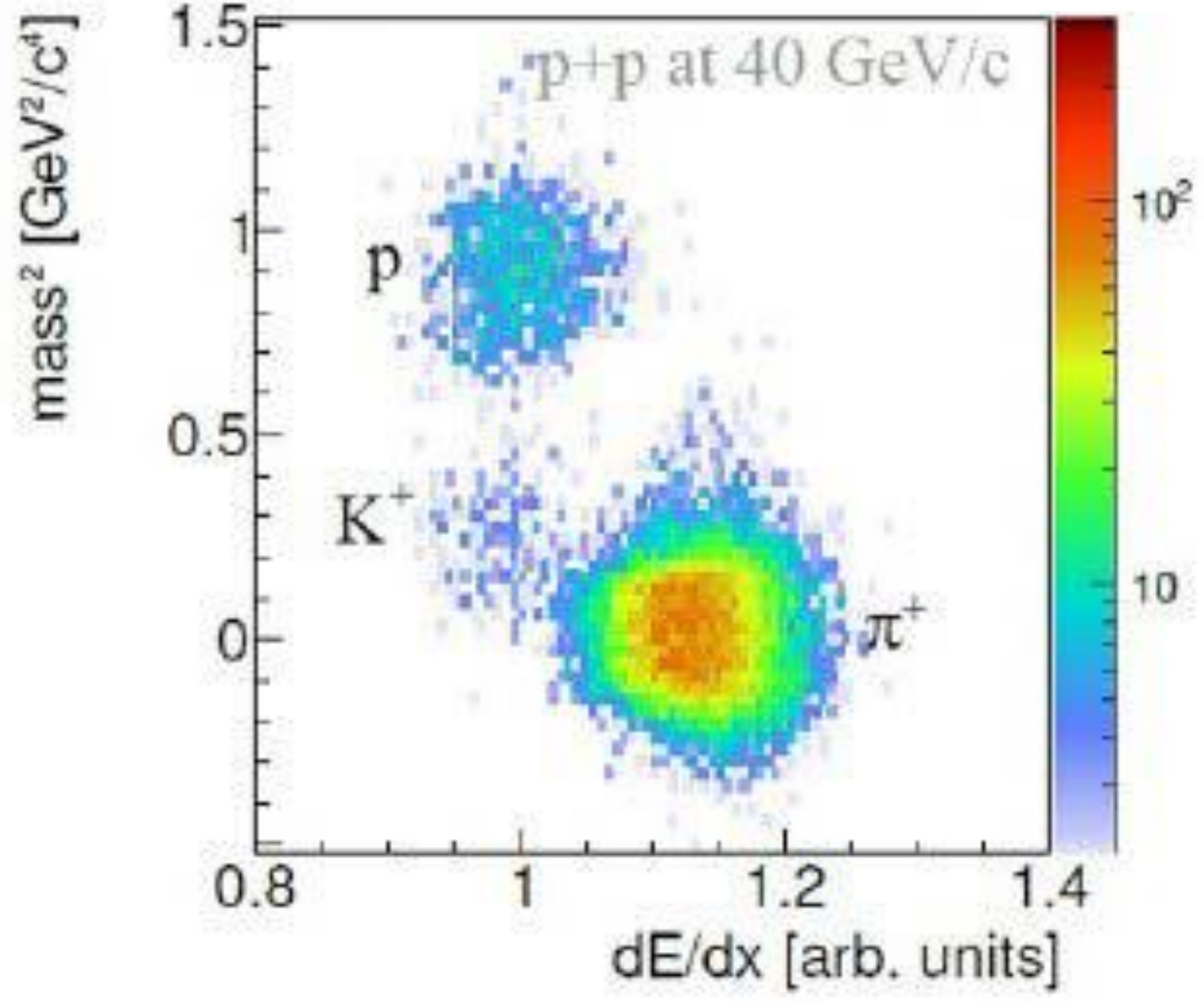


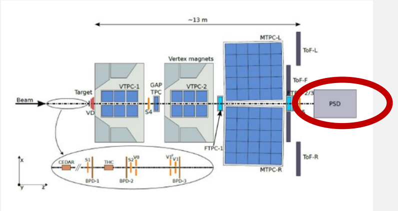




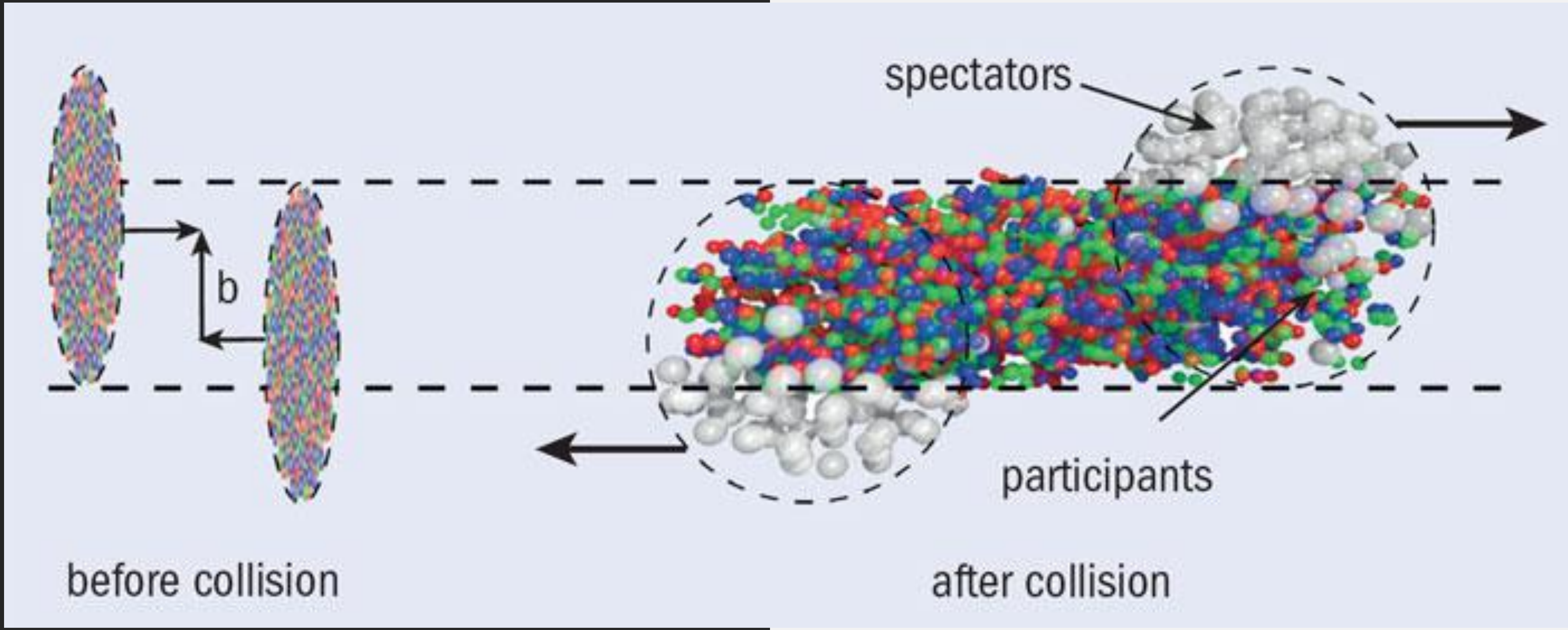
Combined PID

- *tof-dE/dx* method estimates number of p, K, π using an energy loss and a particle time of flight measurements
- *dE/dx* – form TPC
- *Tof* – from time of flight (scintillators detectors)

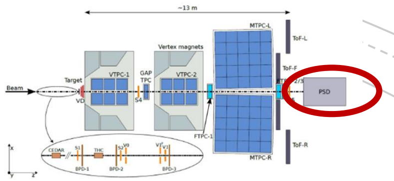


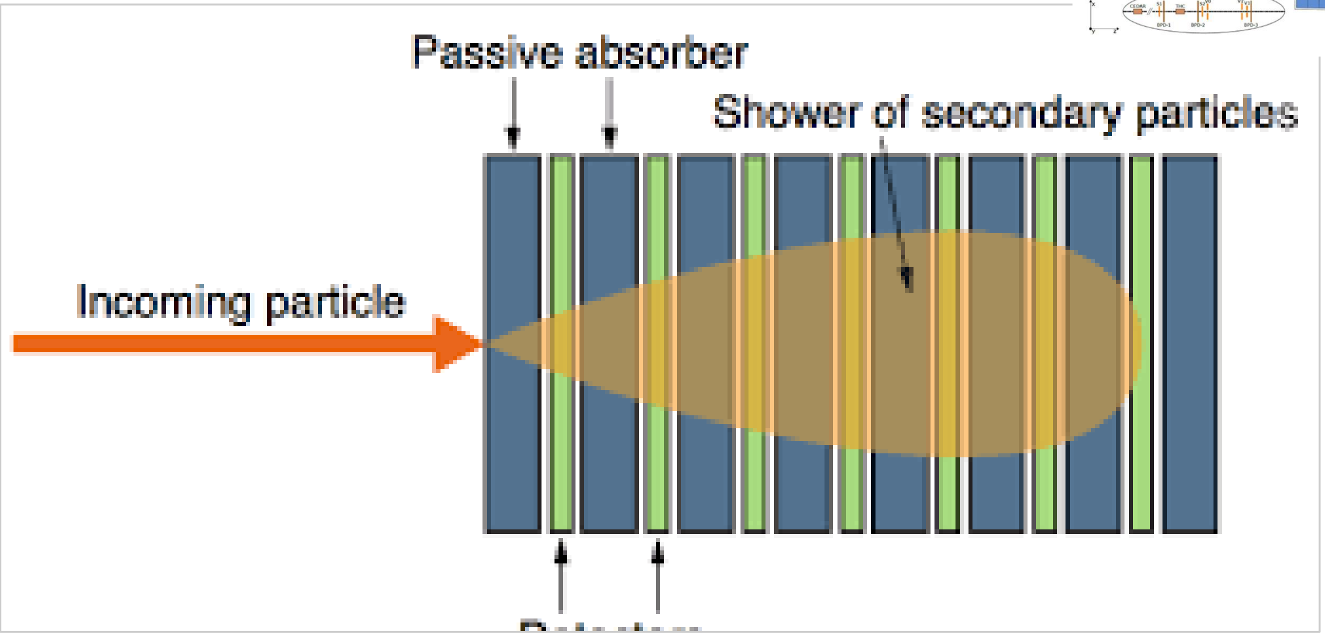


Centrality of the collision

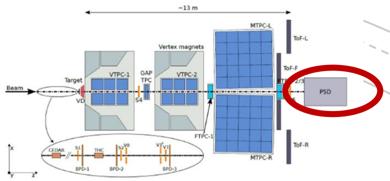


Projectile Spectator Detector



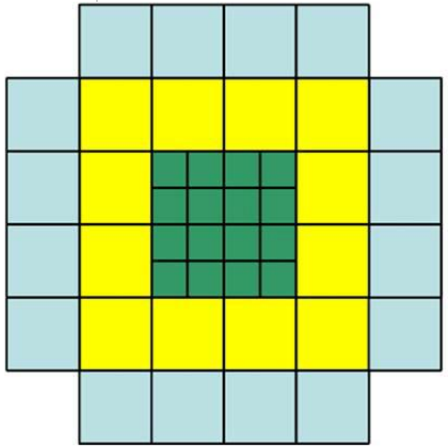


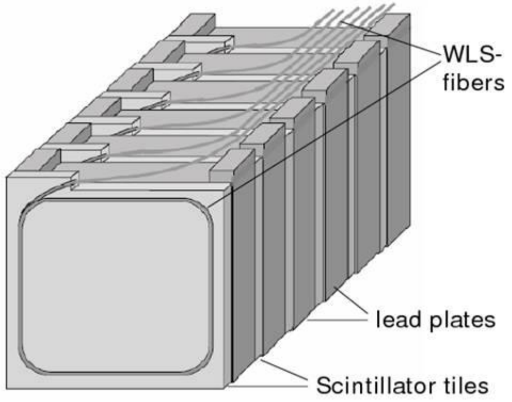
- forward hadron calorimeter
- measurement of projectile spectator energy in nucleus-nucleus collisions

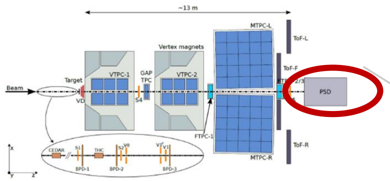


Projectile Spectator Detector

- The central part
  - 16 small modules with transverse dimension of 10x10 cm2
  - weight of 120 kg each
- The outer part
  - 28 large 20x20 cm2 modules
  - weight of 500 kg each






~13 m
Beam
Target
VD
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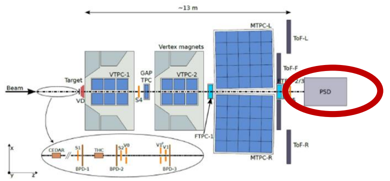
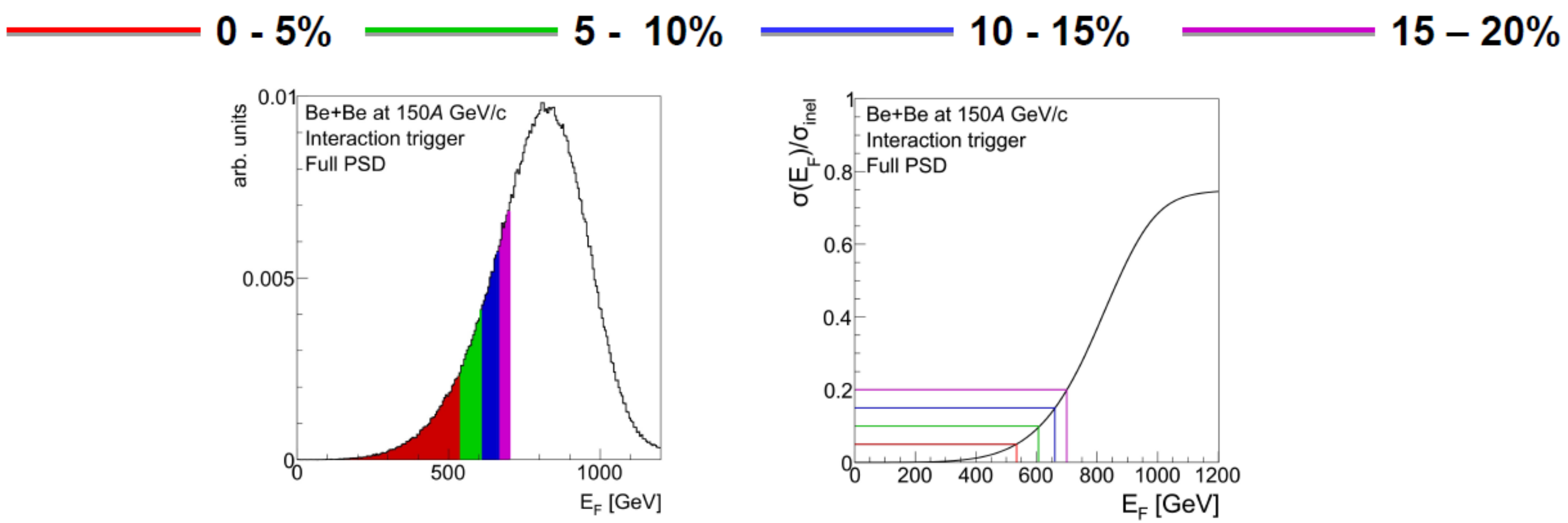
ToF-R
PSD
CEDAR
S1
THC
S2
V0
V1
BPD-1
BPD-2
BPD-3
x
y
z

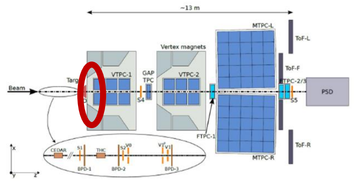
PSD



Projectile Spectator Detector

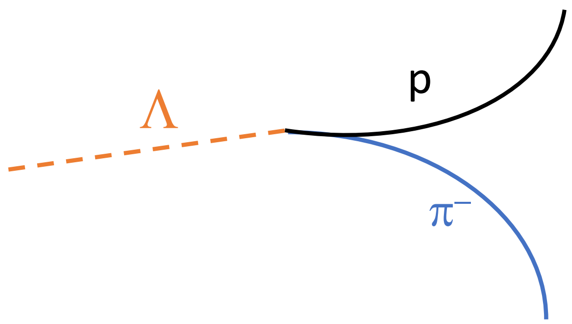
- measures the forward energy E_F related to the non-interacting nucleons of the beam nucleus
- Intervals in EF allow to select different centrality classes

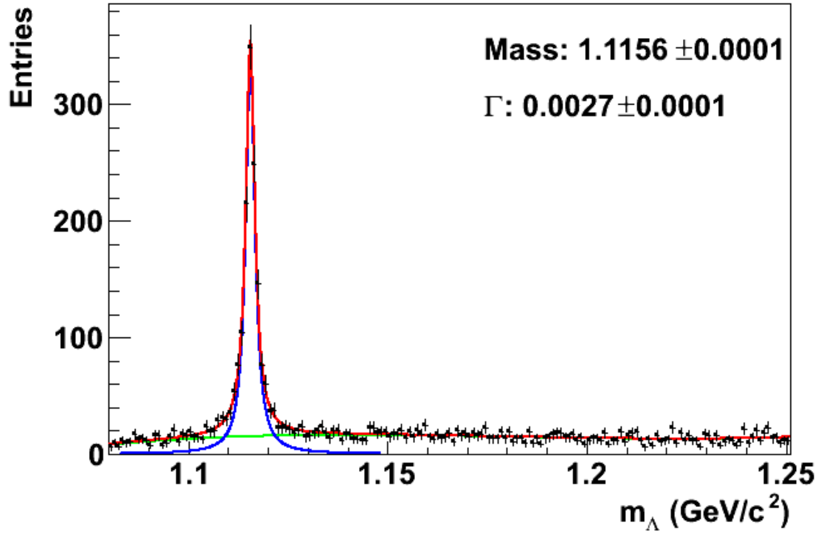




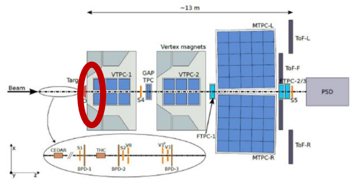
V^0 – method

- Method example
  - Decay channel: $\Lambda \rightarrow p + \pi^-$
  - Calculation of the invariant mass from products $M_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$

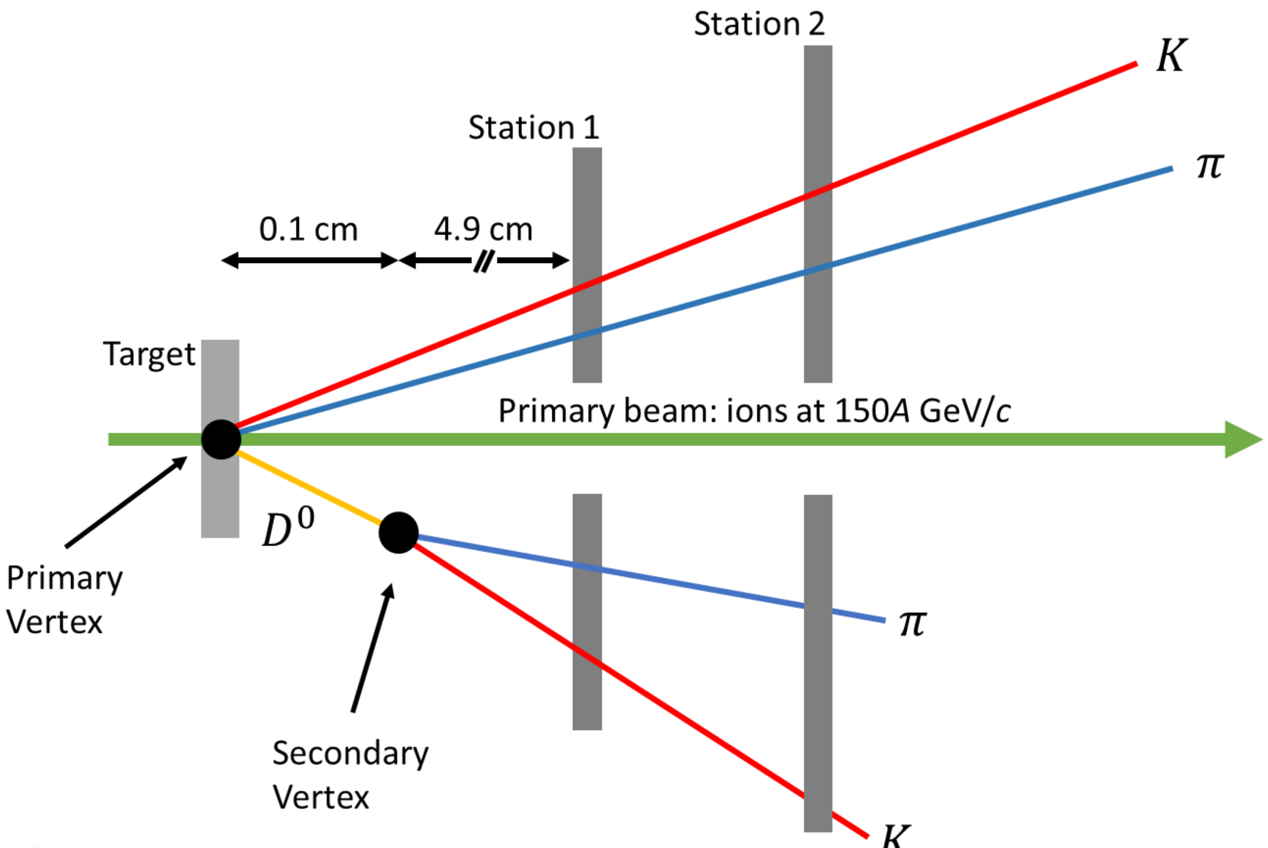




Λ mass from PDG 1115.678±0.006±0.006 GeV/c^2



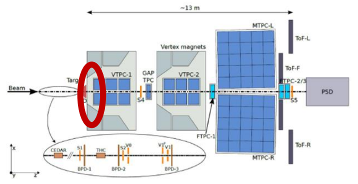
Studies of open charm measurements



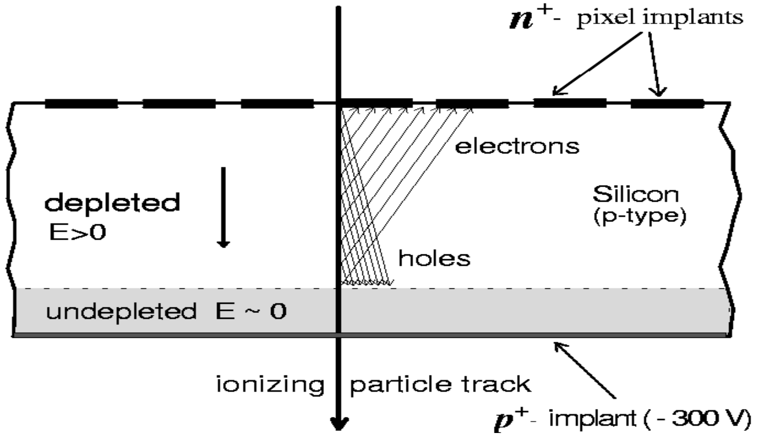
$D^0 \to \pi^+ + K^-$

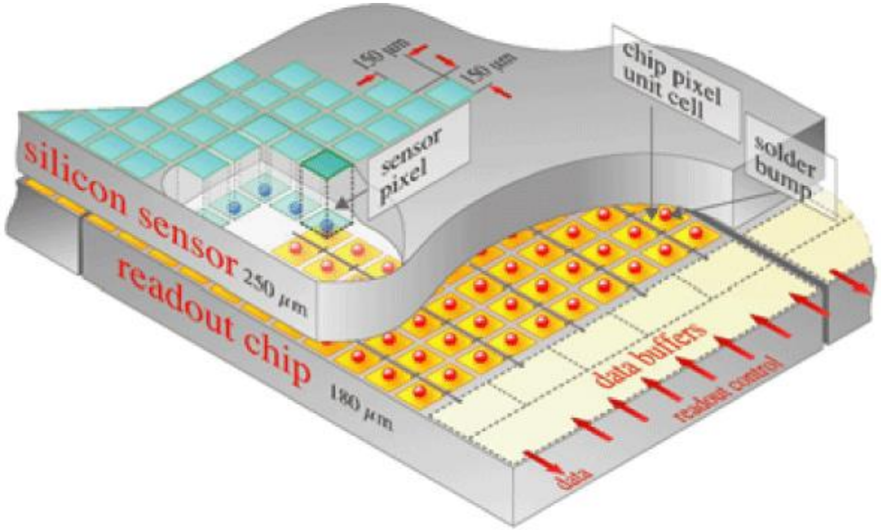
Vertex detector is needed to reconstruct primary vertex and secondary vertexes with high precision

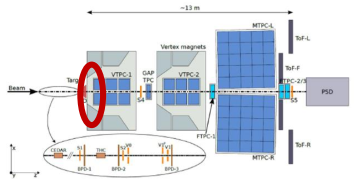
Silicon detector



- Why silicon
  - Better energy resolution and high signal
  - Thin detectors
  - Reduced range of secondary particles
  - Allows thin self supporting structures
  - fast charge collection

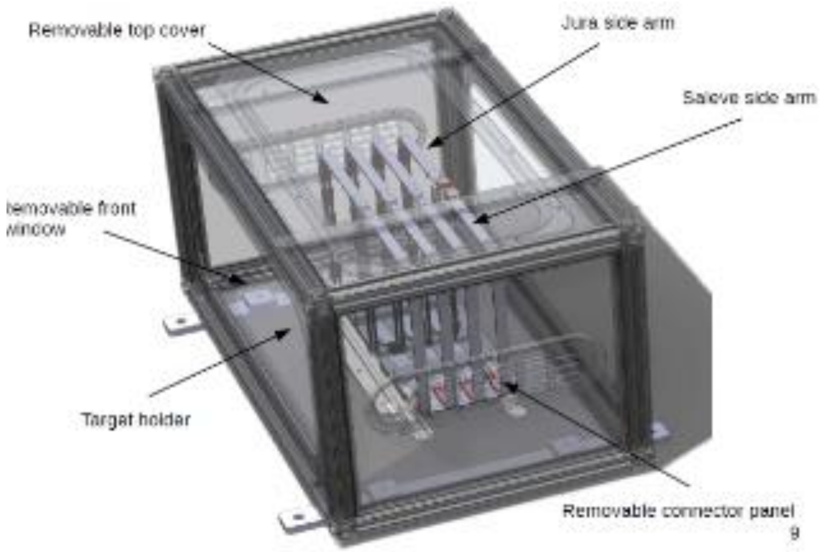


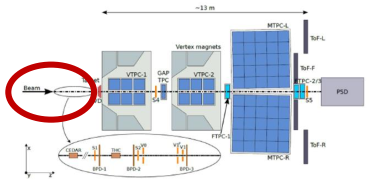




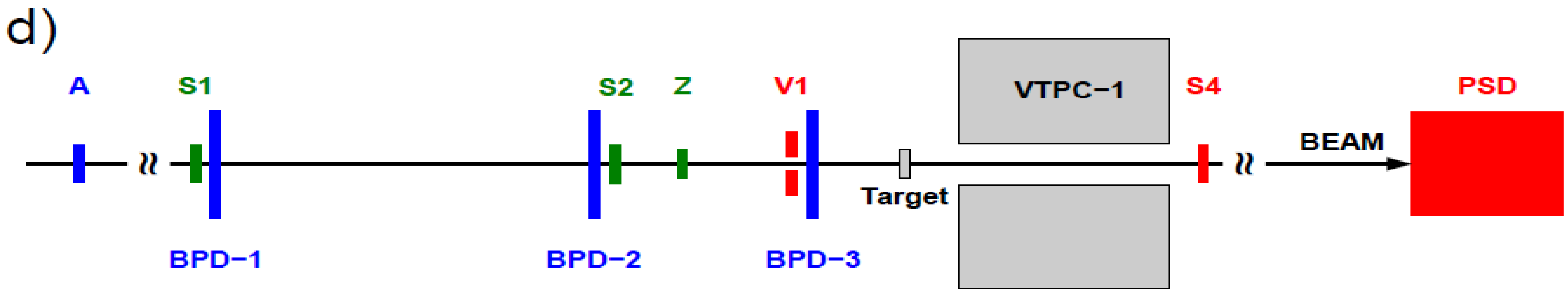
Vertex detector

- Silicon sensors located on horizontally movable arms
- Target holder integrated





Beam detectors

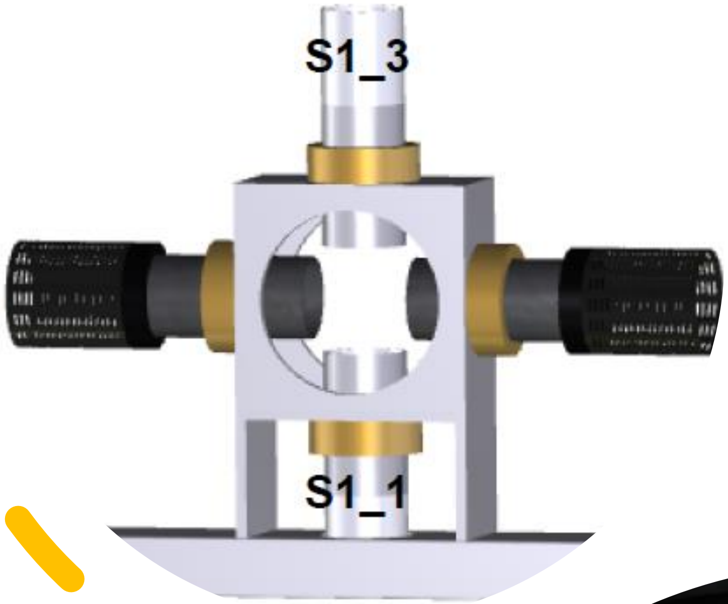


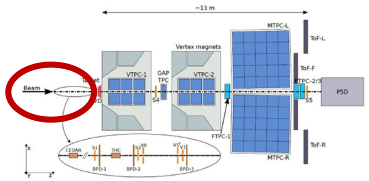
Set of scintillation and Cherenkov counters as well as the beam position detectors

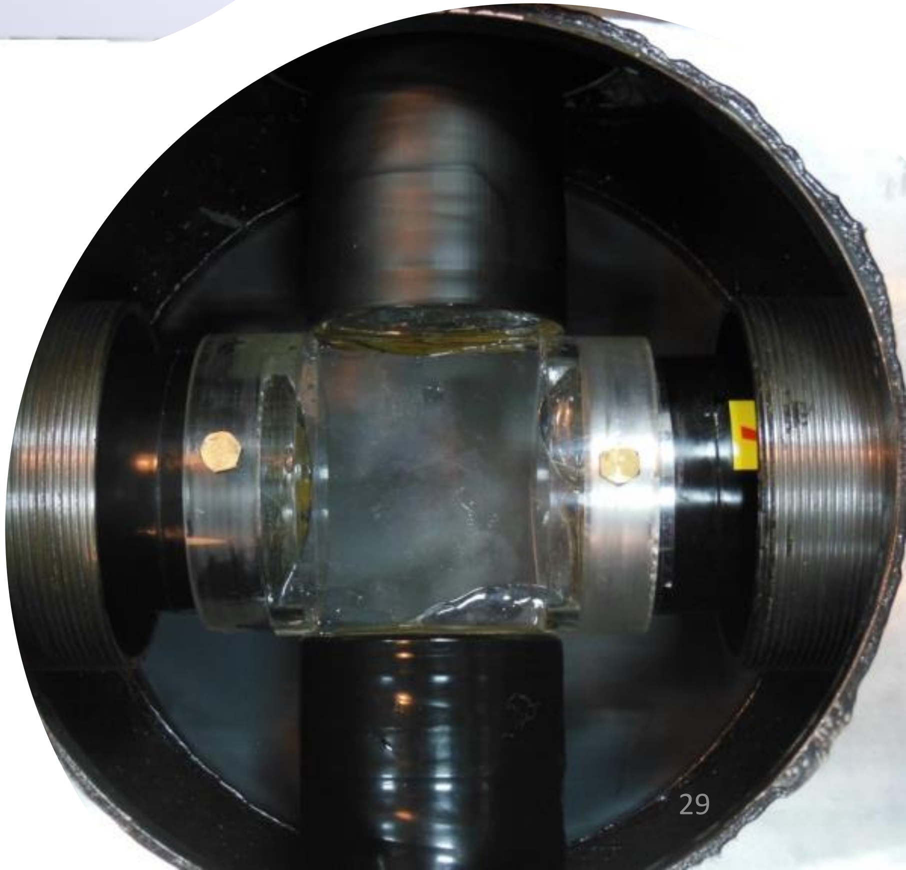
- located upstream of the target
- provide precise timing reference,
- charge and position measurement of the incoming beam particles

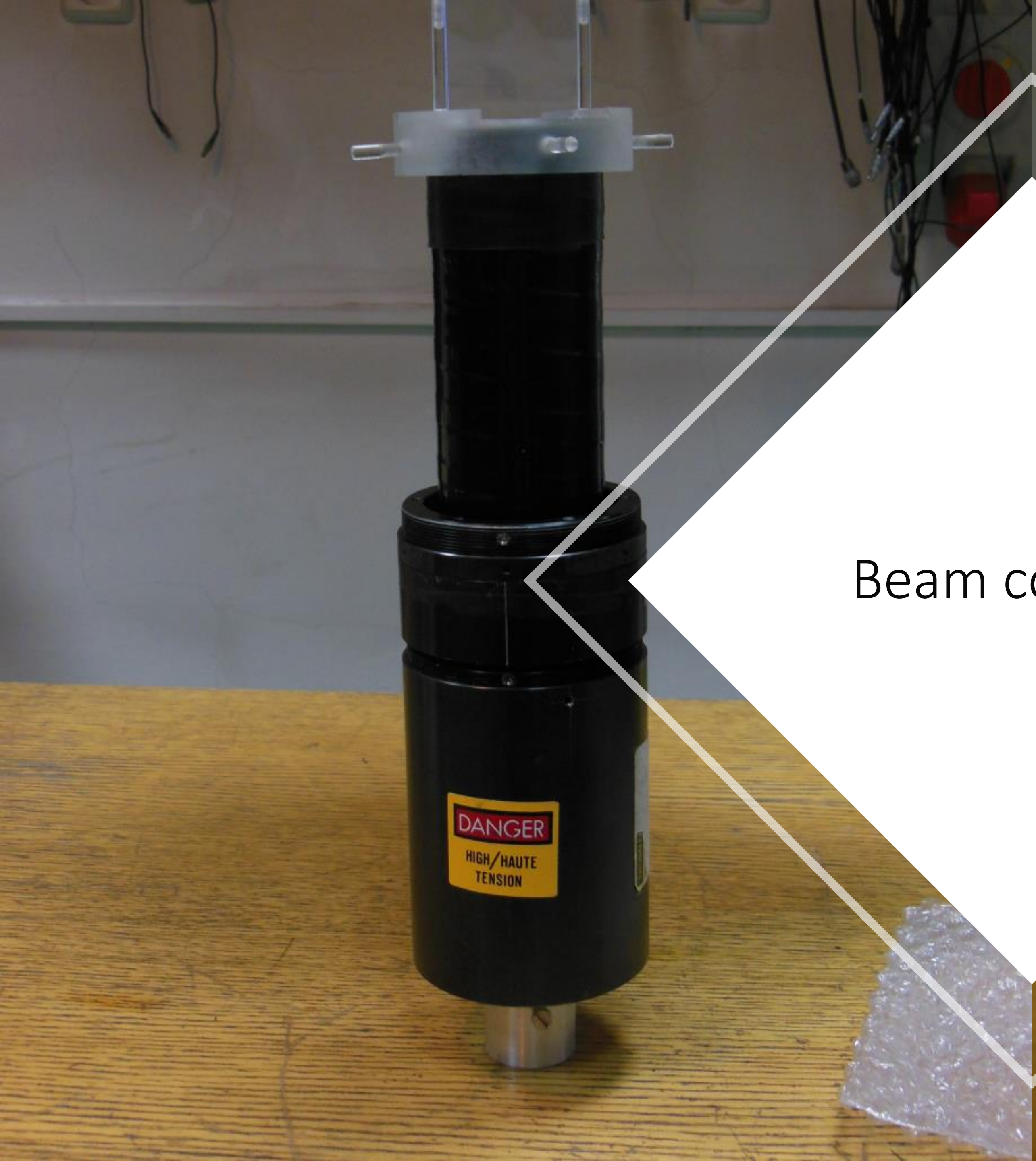
Beam counters

- plastic scintillator
- precise reference time
- counts number of beam particles

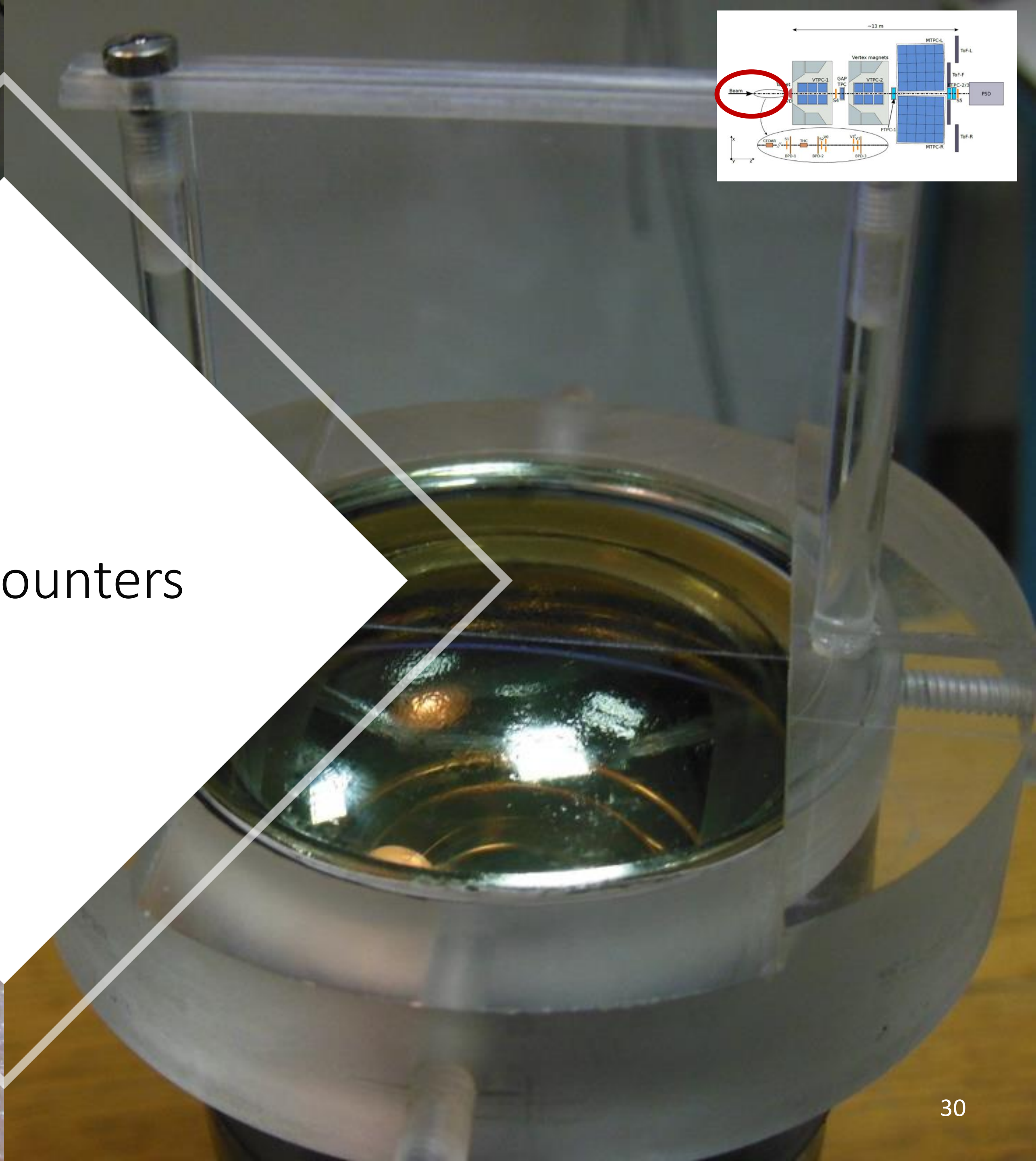




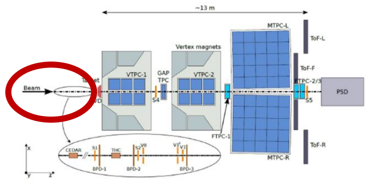


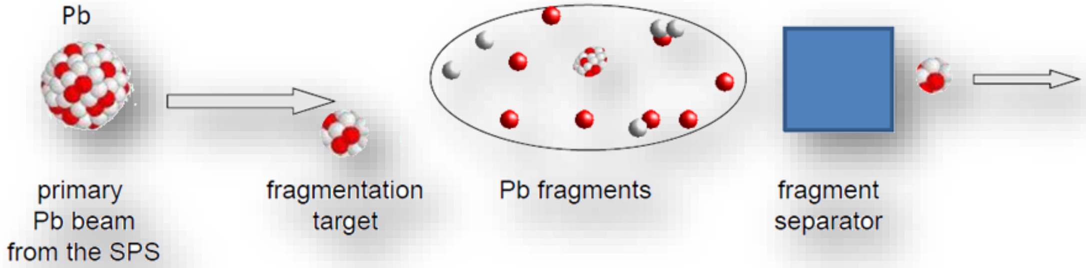


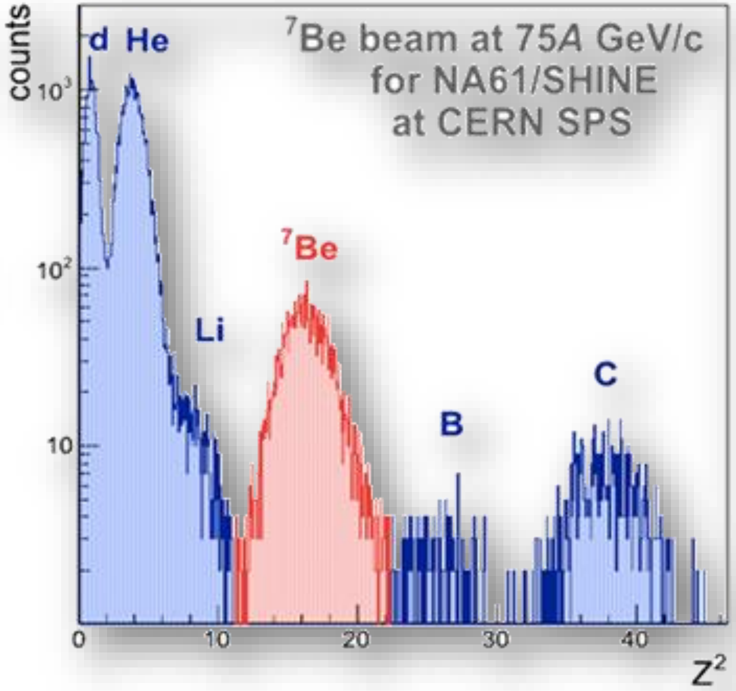
Beam counters



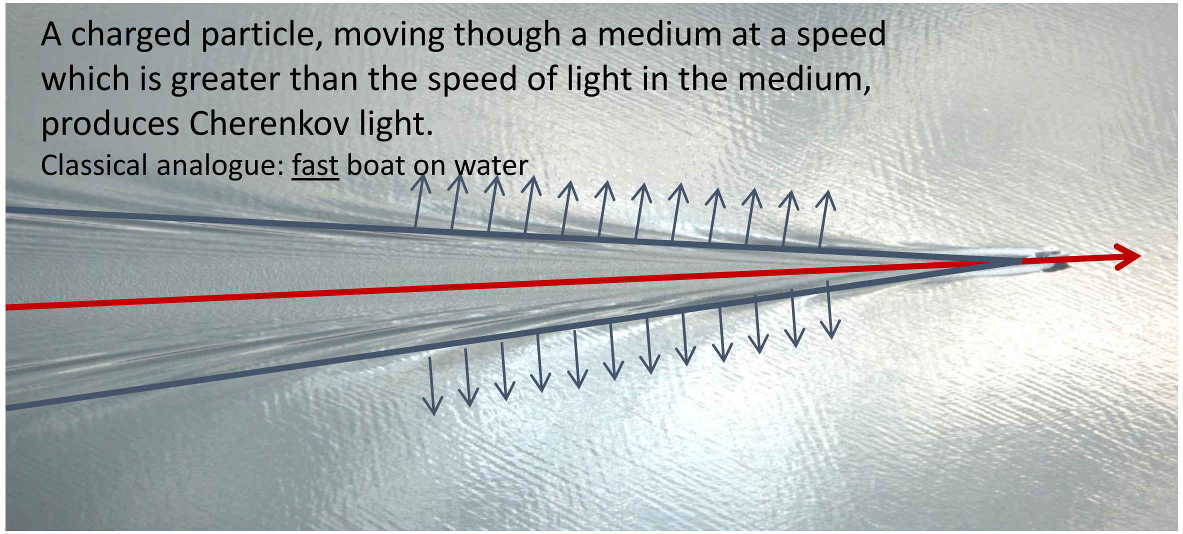
Secondary beam





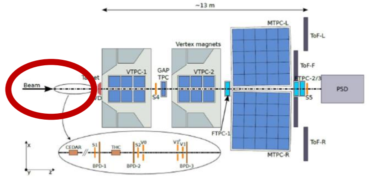


Cherenkov detector



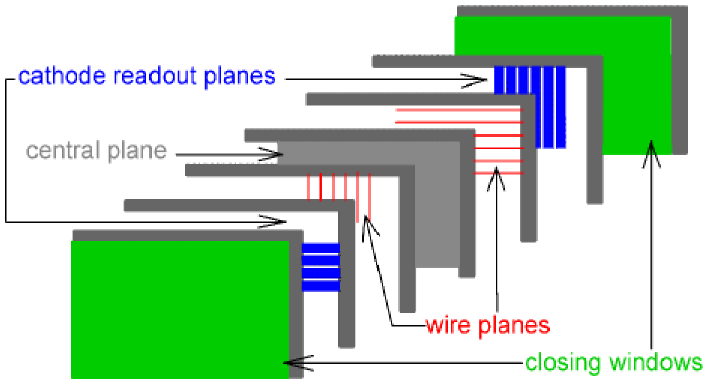
A charged particle, moving though a medium at a speed which is greater than the speed of light in the medium, produces Cherenkov light.

Classical analogue: fast boat on water

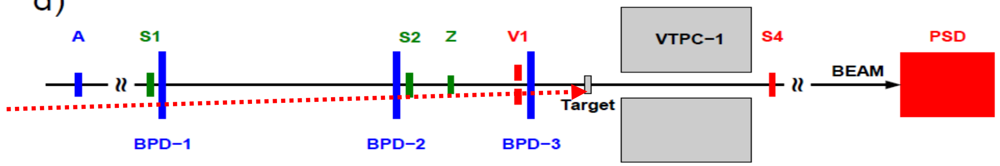


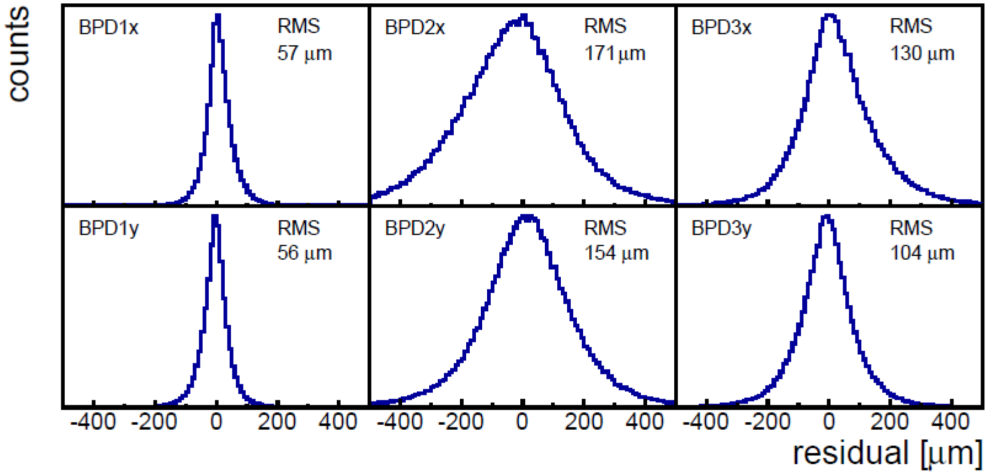
Beam Position Detectors

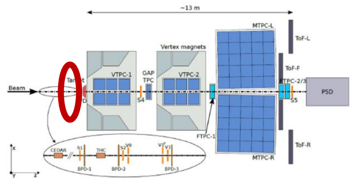
- the positions of the incoming beam particles in the transverse plane are measured by a telescope of three BPDs
- proportional chambers



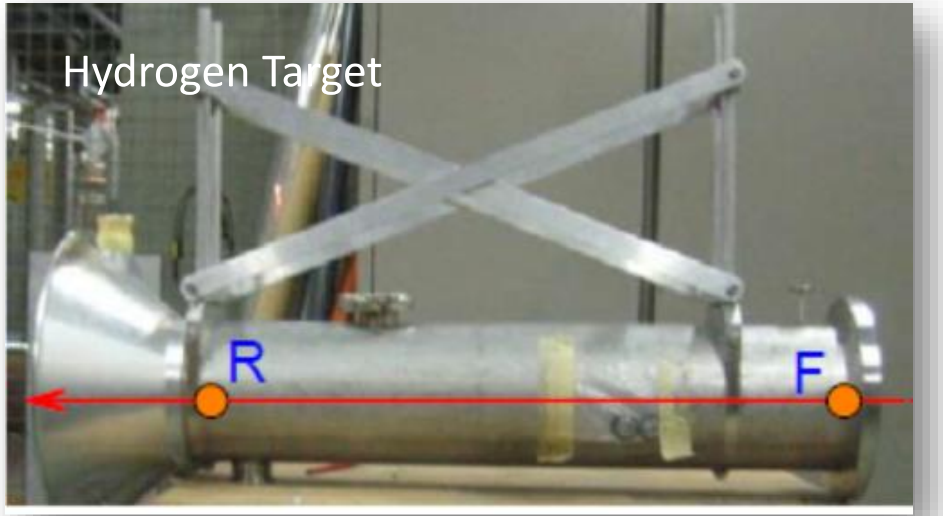
d)



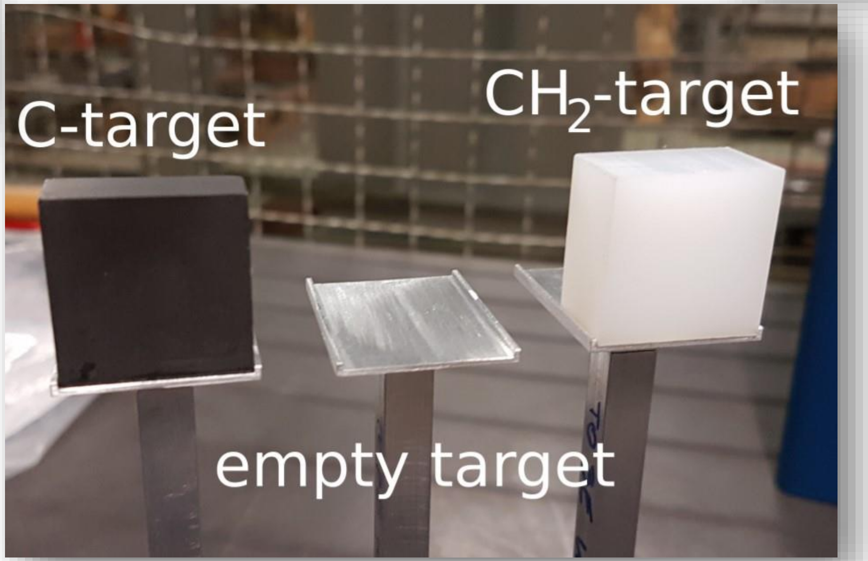


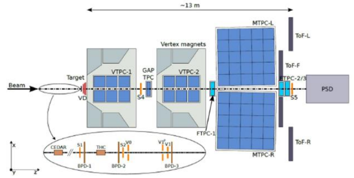


Targets


Hydrogen Target
R
F

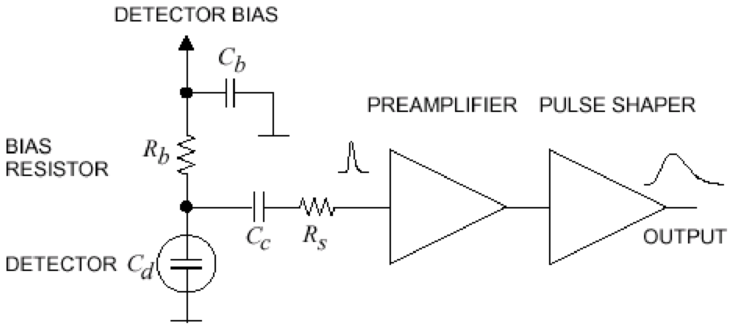

T2K replica target


C-target
CH2-target
empty target



Front End electronics

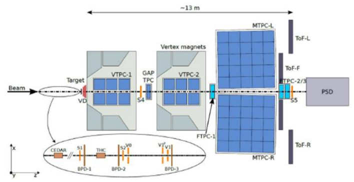
- Most detectors rely critically on low noise electronics. A typical Front End is shown below:



where the detector is represented by the capacitance C_d, bias voltage is applied through R_b, and the signal is coupled to the amplifier though a capacitance C_c. The resistance R_s represent all the resistances in the input path.

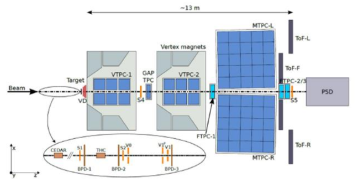
The preamplifier provides gain and feed a shaper which takes care of the frequency response and limits the duration of the signal.

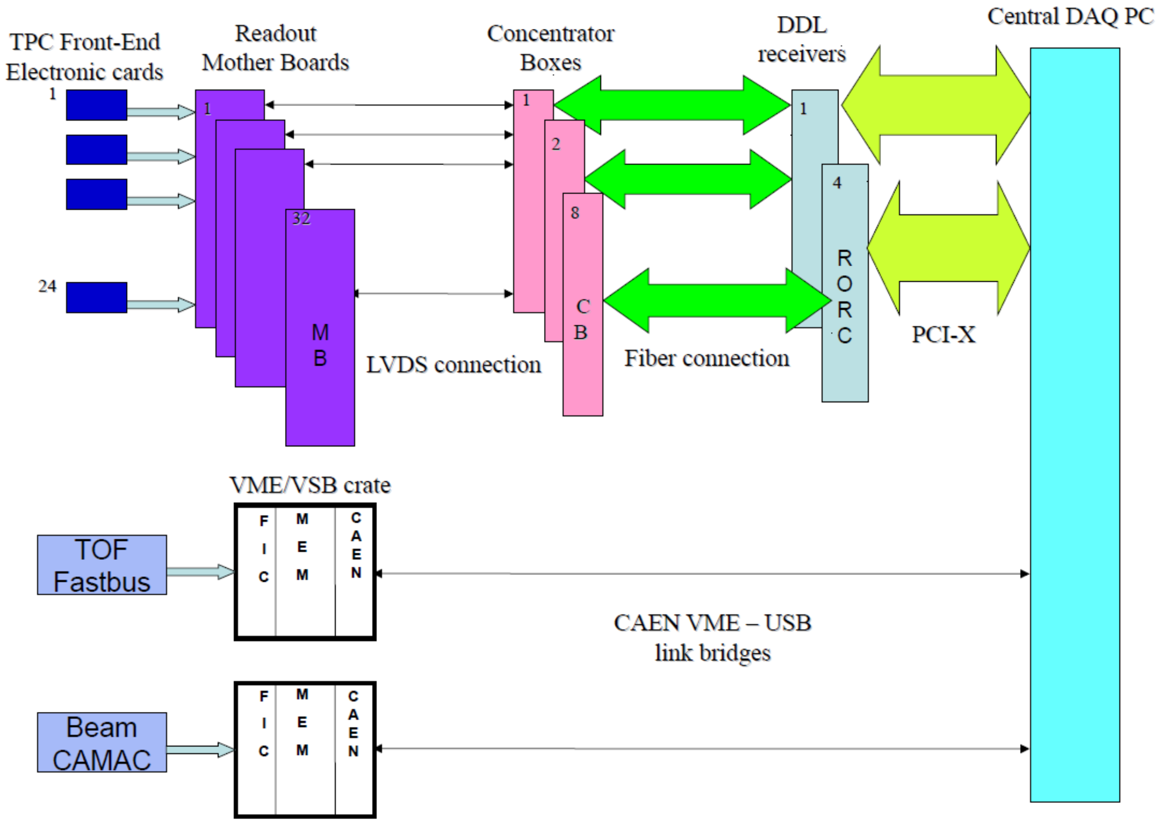
Trigger

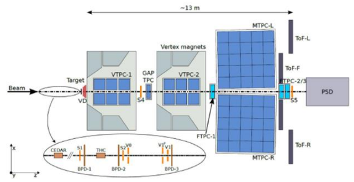


- system that uses criteria to rapidly decide which events in a particle detector to keep
- necessary due to real-world limitations in computing power, data storage capacity and rates
- NA61/SHINE
- flexible and robust system capable of handling and selecting different reactions using a variety of beams (pions, kaons, protons, ions)
- trigger is formed using:
  - beam counters
  - Cherenkov detectors
  - PSD calorimeter
- four different triggers can be run simultaneously

Readout system

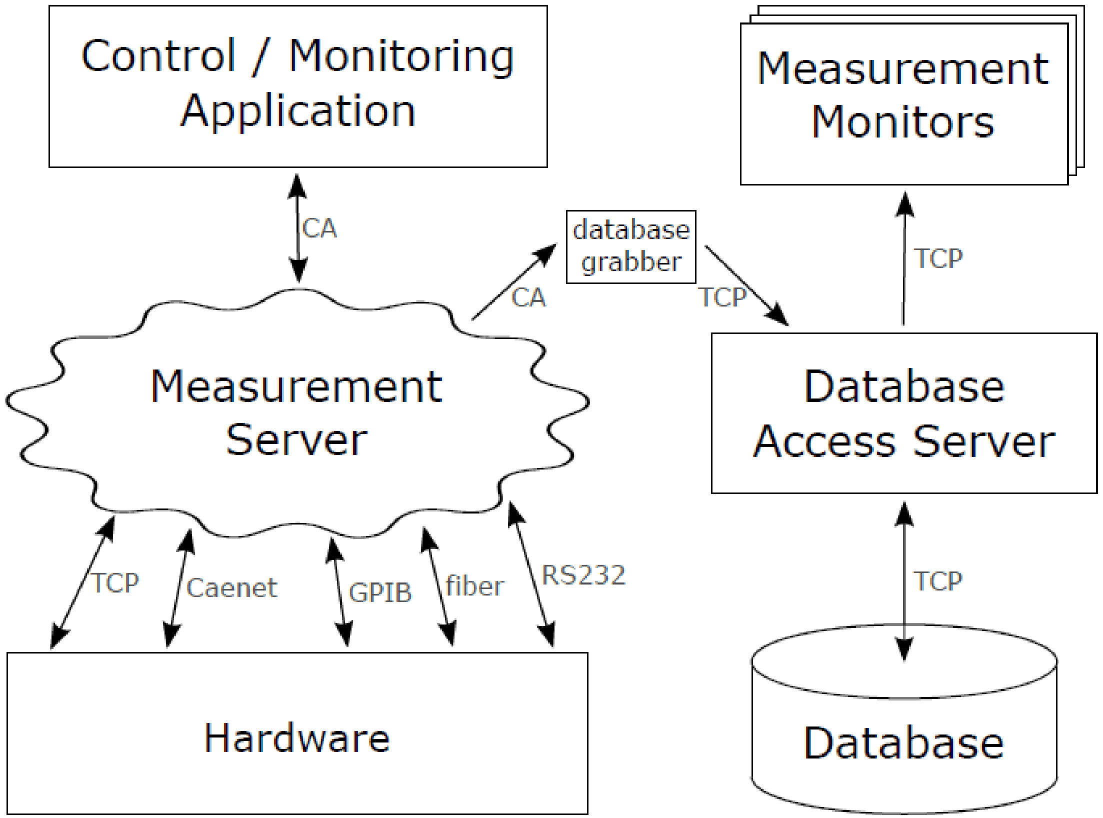




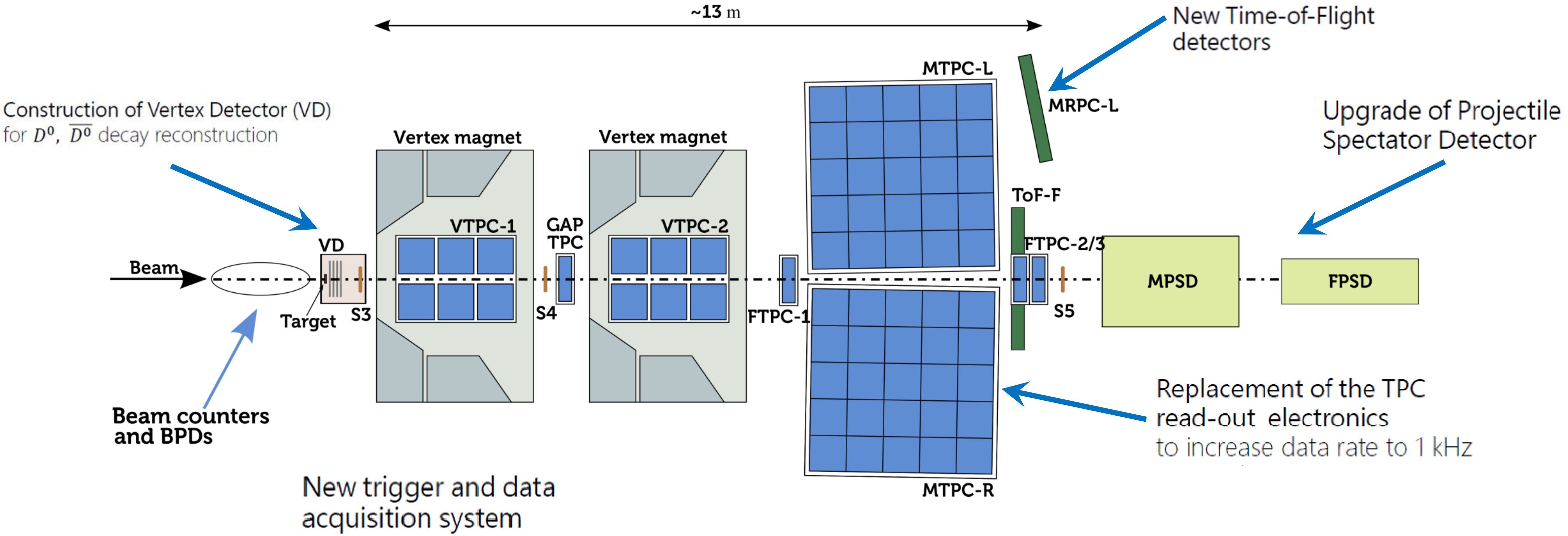


Detector Control System

- responsible for online monitoring and controlling of the working conditions of the detectors
- The system monitors parameters as:
  - gas mixture in the TPCs
  - high and low voltage



Detector upgrade during LS2



Replacement of the TPC electronics

Will increase the read-out rate by a factor of about 10 (up to 1 kHz)