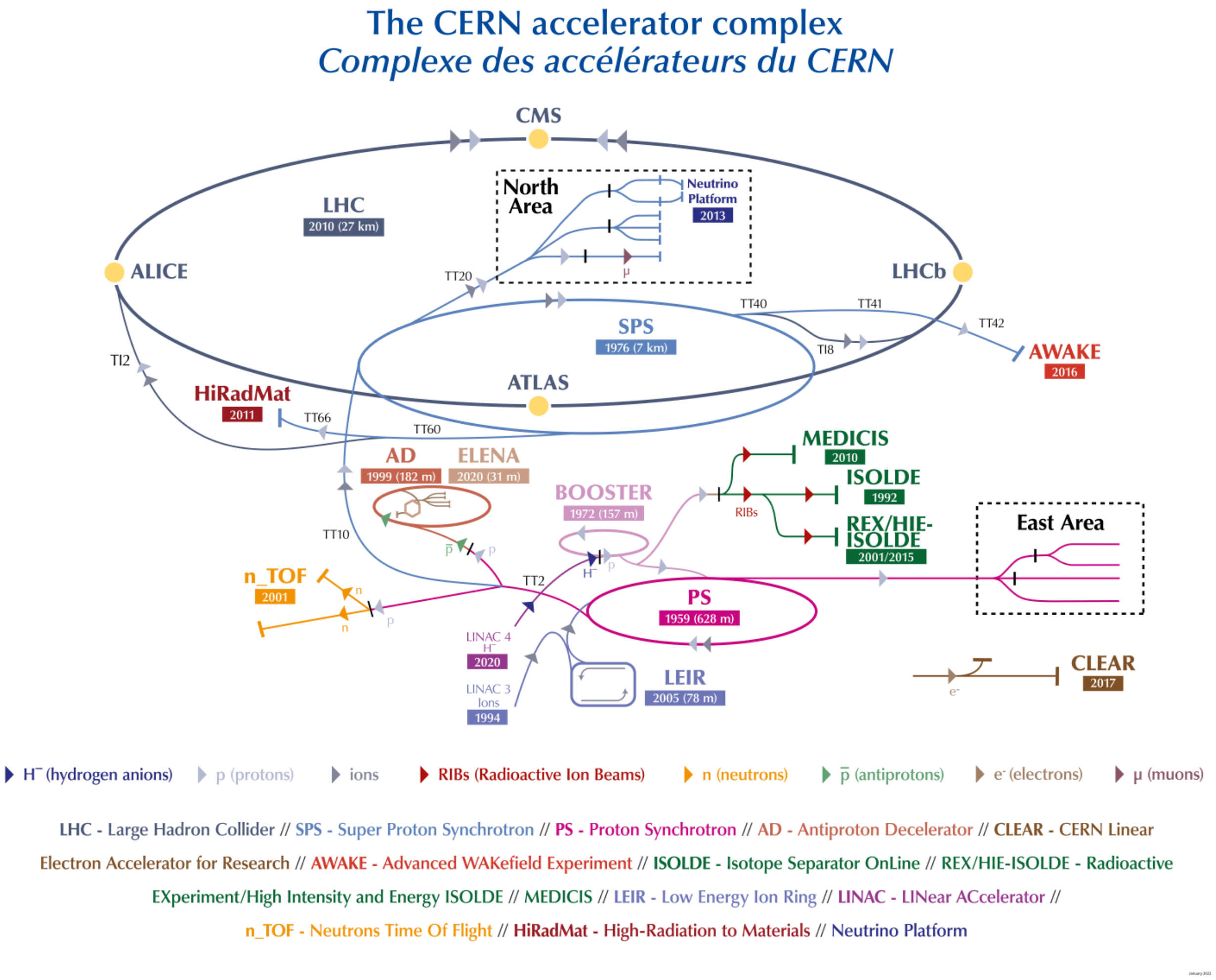
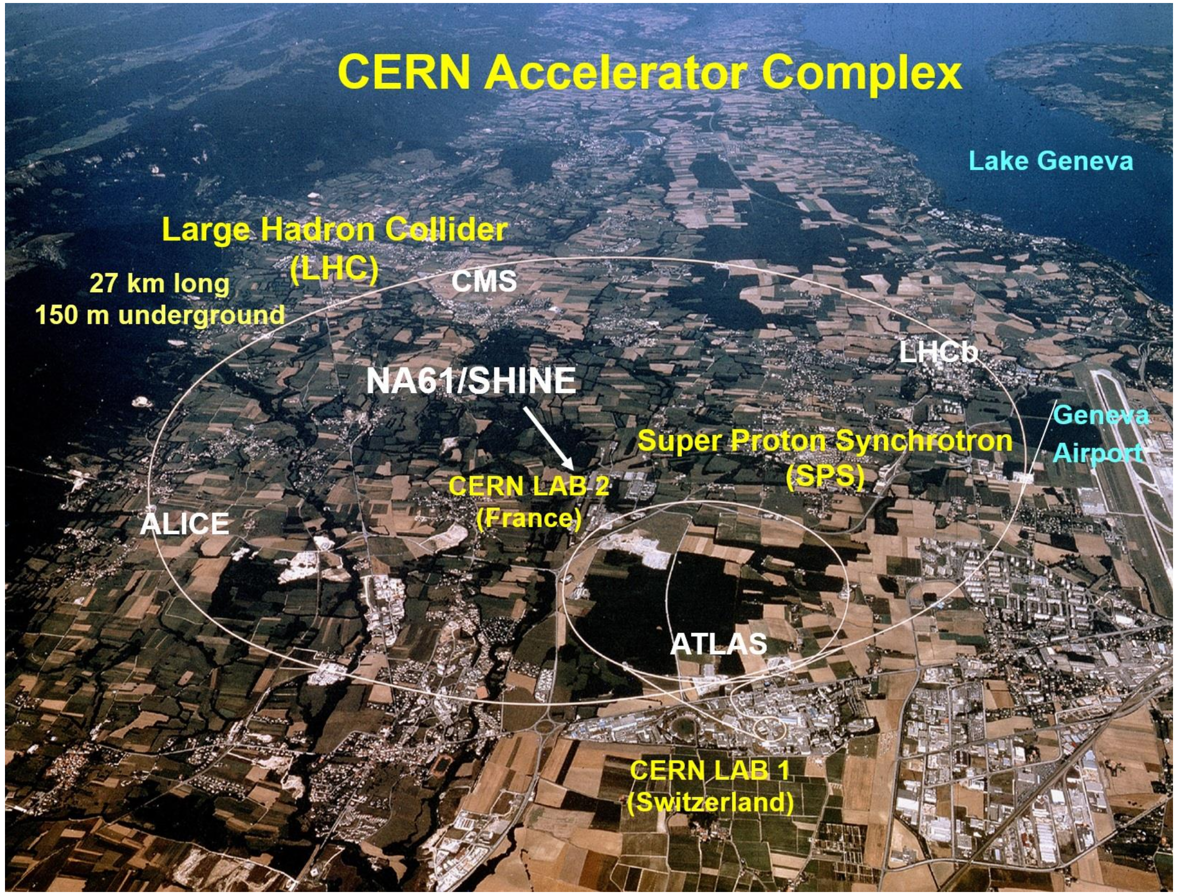
NA61/SHINE detector overview

Outline

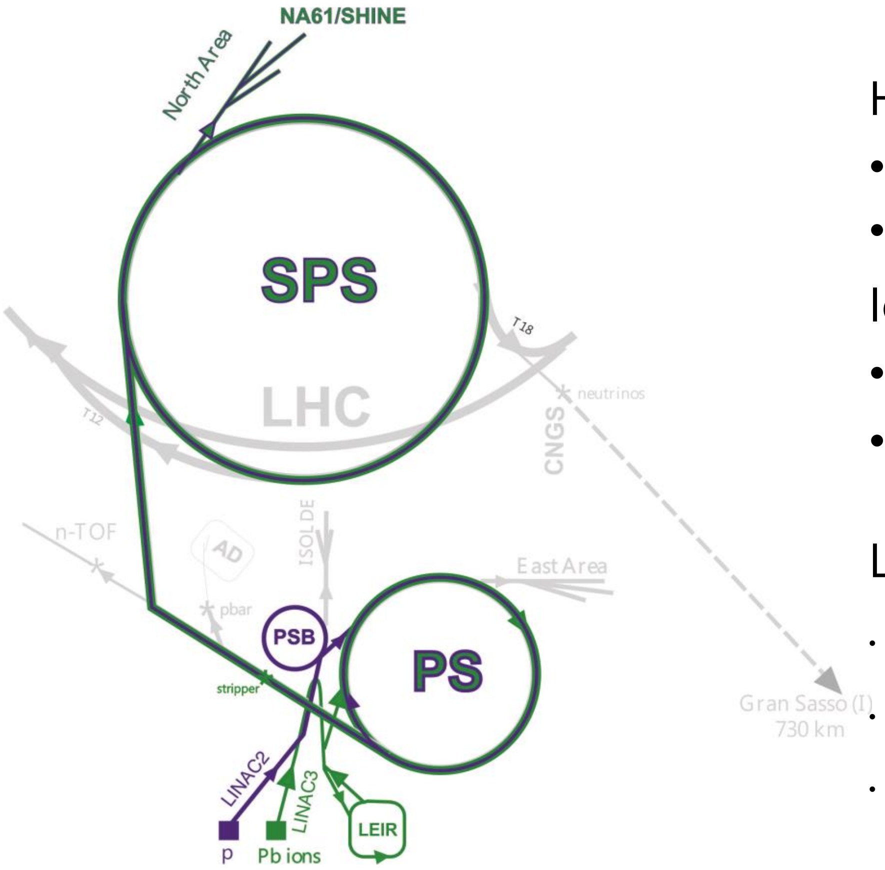
- Fixed target experiment
- NA61/SHINE detector – general overview
- Time Project Chamber
  - Tracking
  - Energy lost – particle identification
- Time of Flight
  - Particle identification
- Projectile Spectator Detector
  - Centrality of the collisions
- Vertex Detector
  - V0 particle
- Beam Detectors

CERN accelerator complex





SPS



Hadron beams:

- p (400 GeV/c)
- Secondary π, K, p (13−350 GeV/c)

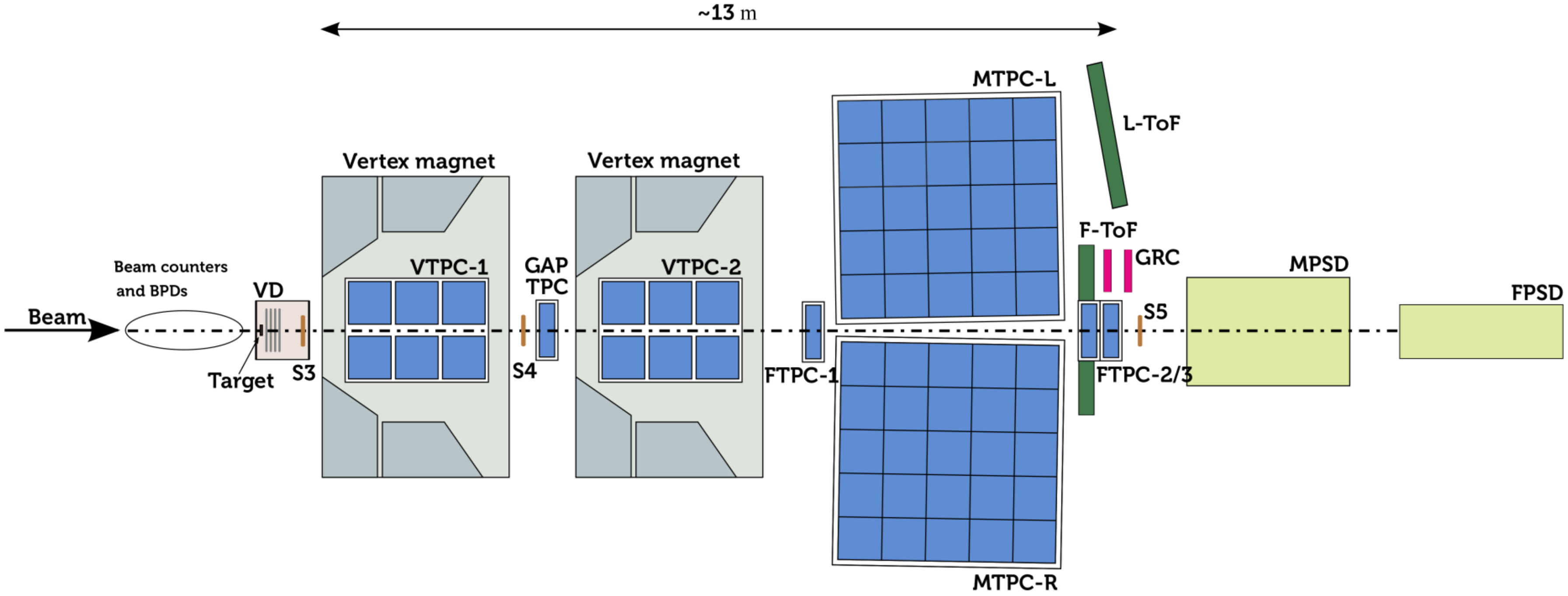
Ion beams:

- Ar, Xe, Pb (13−150A GeV/c)
- Secondary Be (13−150A GeV/c) (from Pb fragmentation)

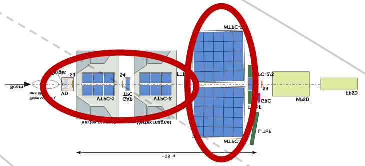
Large acceptance:

- Full forward hemisphere coverage (down to pT = 0)
- Tracking efficiency: > 95%
- Event rate: ~ 1k events/s

NA61/SHINE - Experimental layout



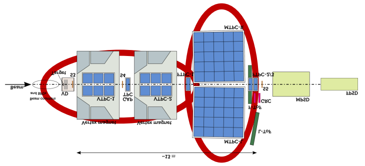
- Large acceptance hadron spectrometer
- Beam particles measured in set of counters and position detectors
- Tracks of charged particles measured in set of TPCs: measurement of q, p and identification by energy loss measurement
- Two Time of Flight Walls: identification via time of flight measurement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

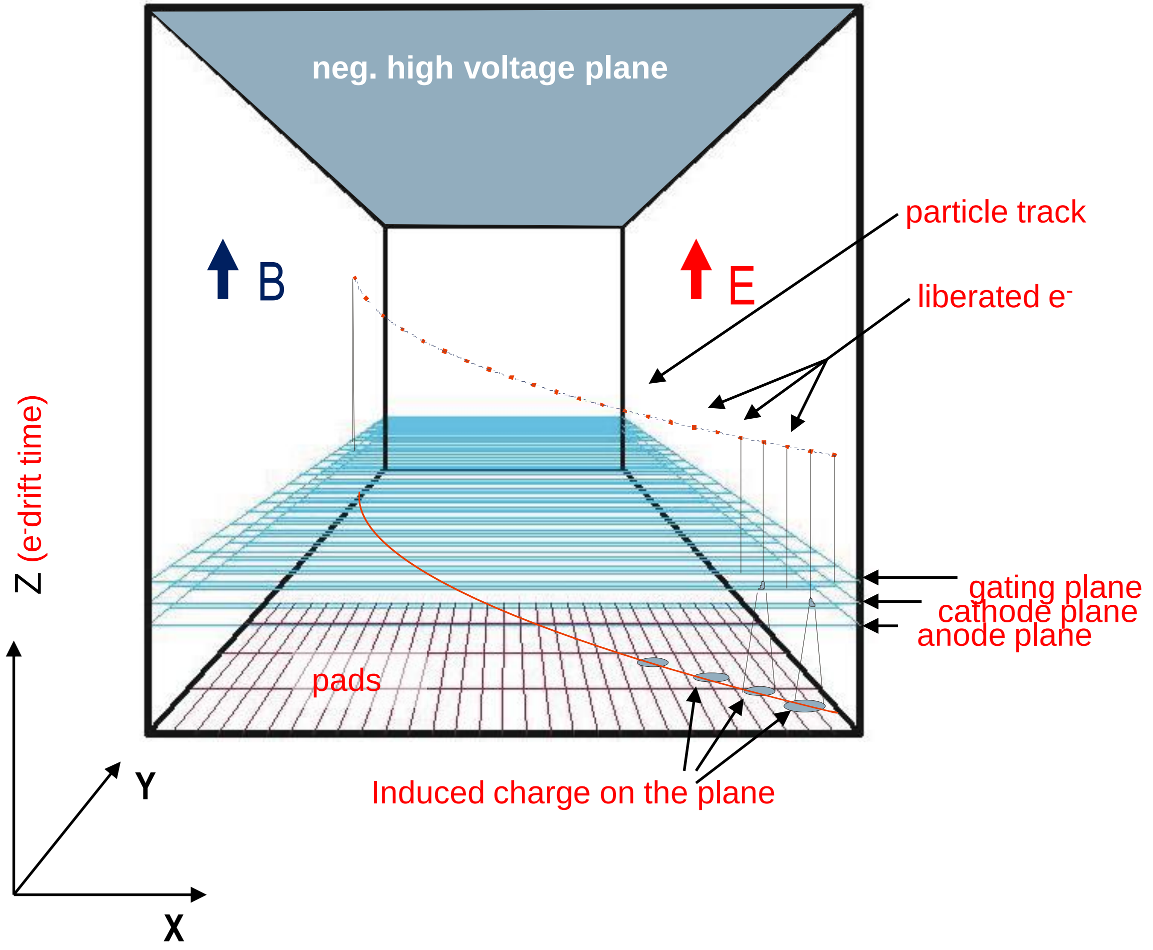


NA61/SHINE

Experimental layout

TPC - Time Projection Chamber



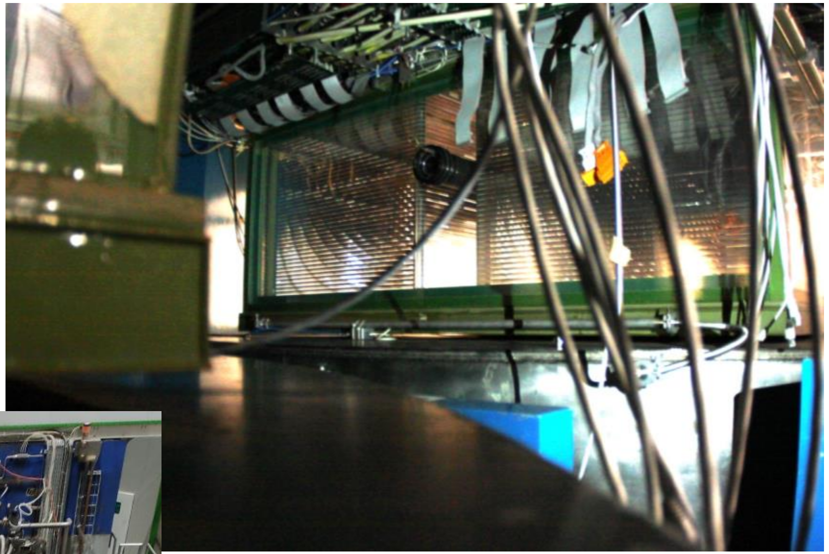


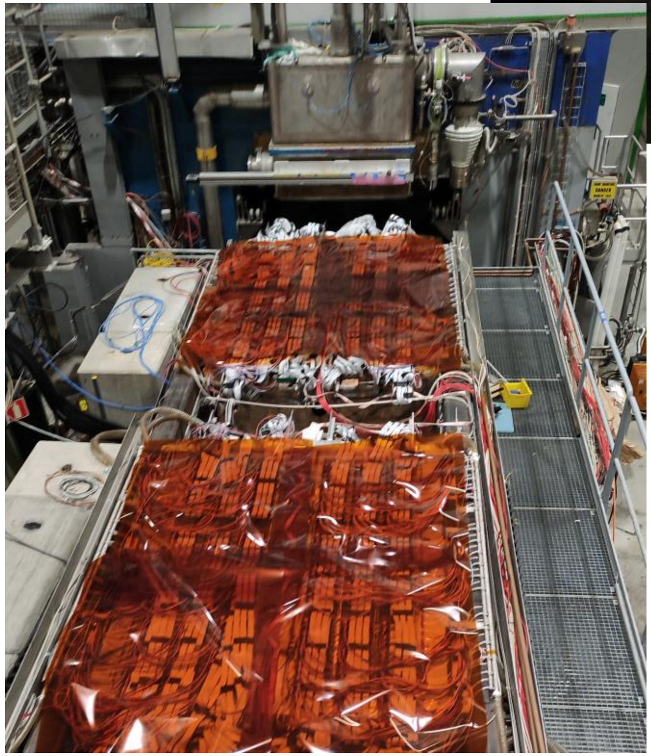
Time Projection Chamber
full 3D track reconstruction:

- 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

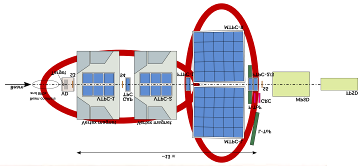
TPC

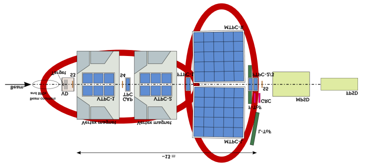




VTPC

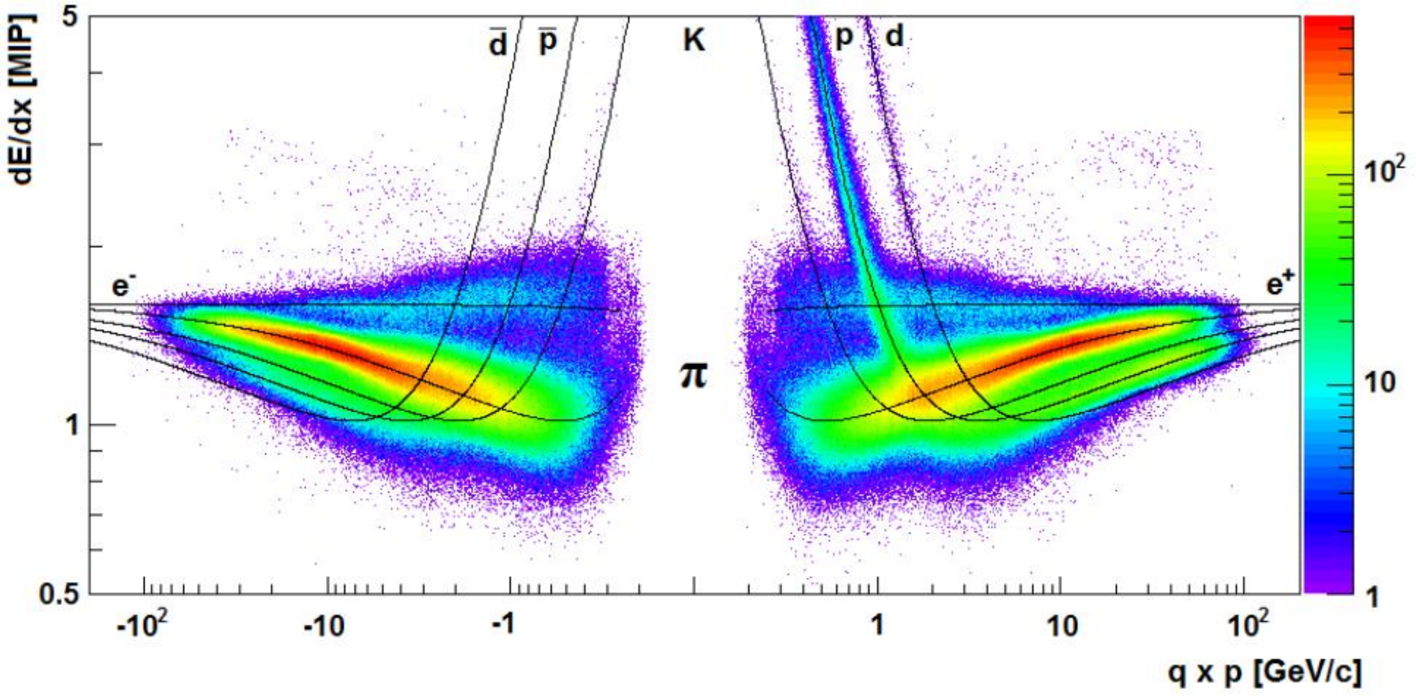
Inside the MTPC



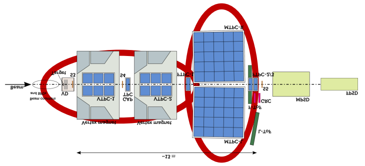


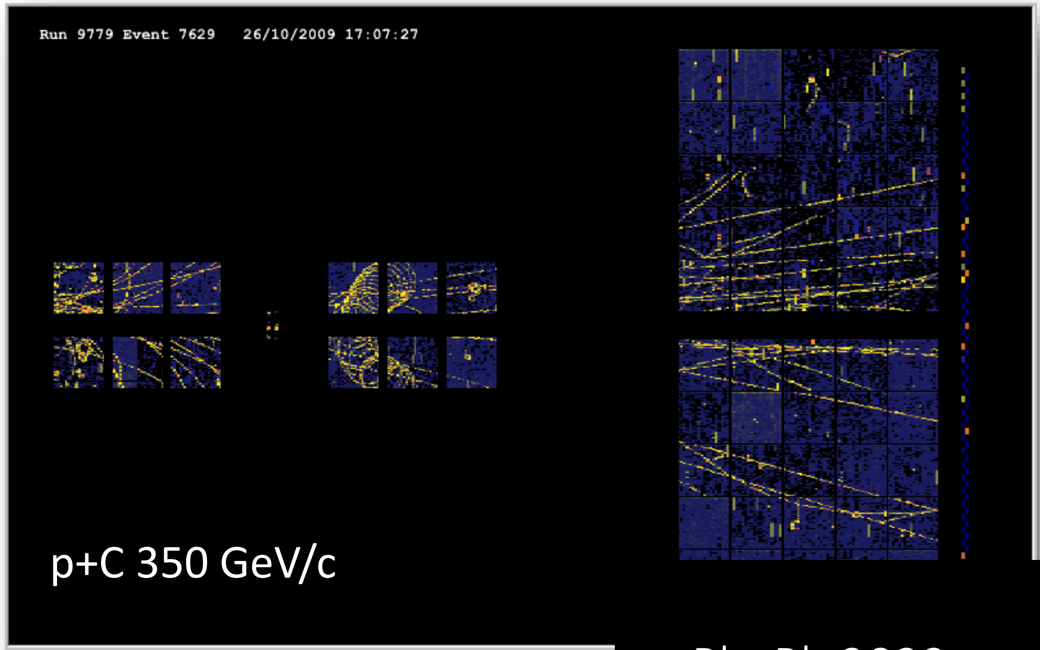
TPC performance

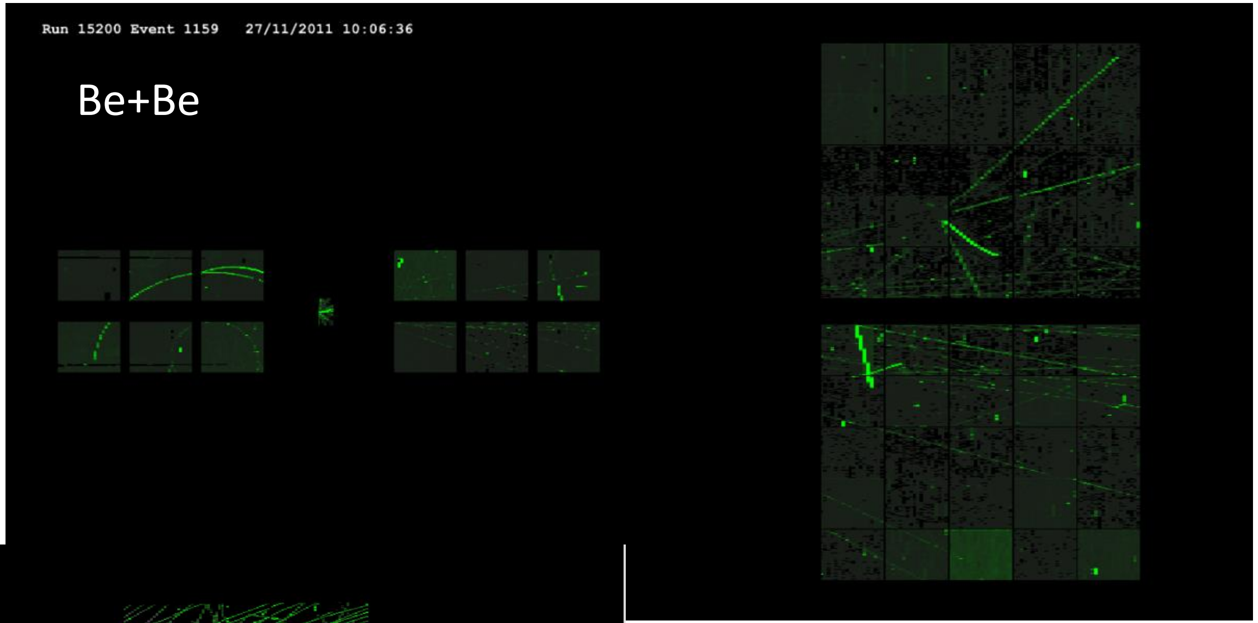
- Bending power of the 2 vertex magnets: 9 Tm at 1.5 T magnetic field (setting for 150 GeV/n)
- Field is scaled with the beam momentum
- Momentum resolution: $\sigma(p)/p^2 = 10^{-4}$ $(GeV/c)^{-1}$
- Particle identification via dE/dx: $\sigma(dE/dx)/dE/dx$ = 3 - 4% (p-p … Pb-Pb)
- Gas mixture Ar/CO2

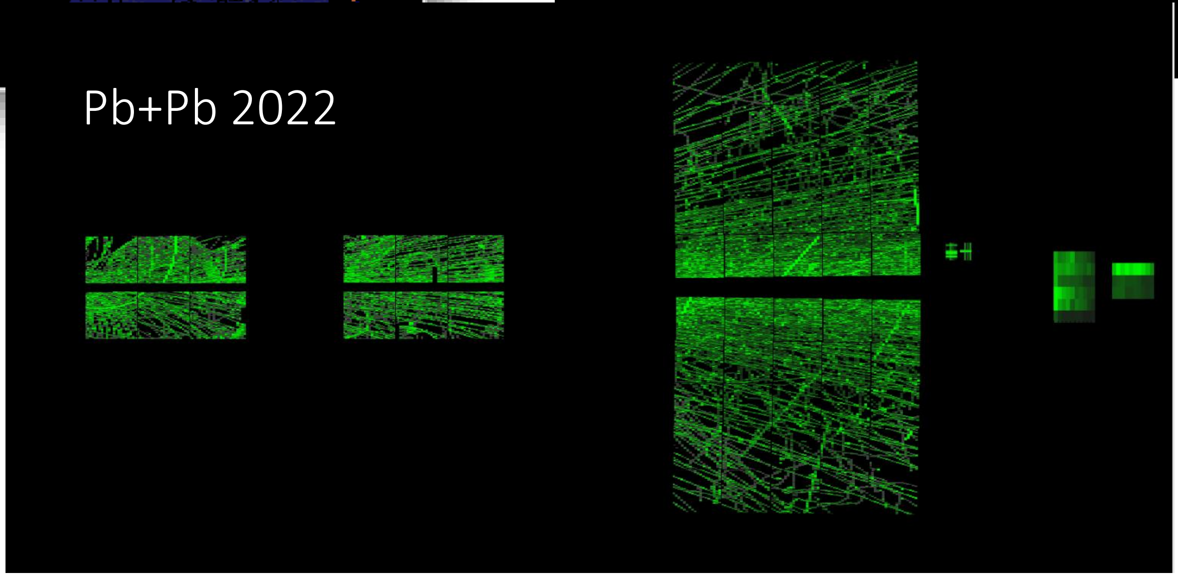


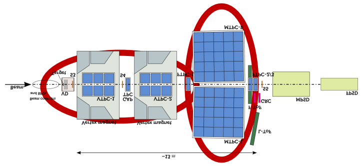
TPC - Tracking





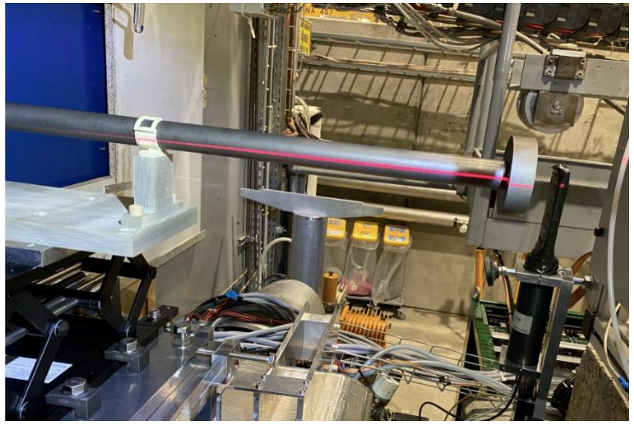


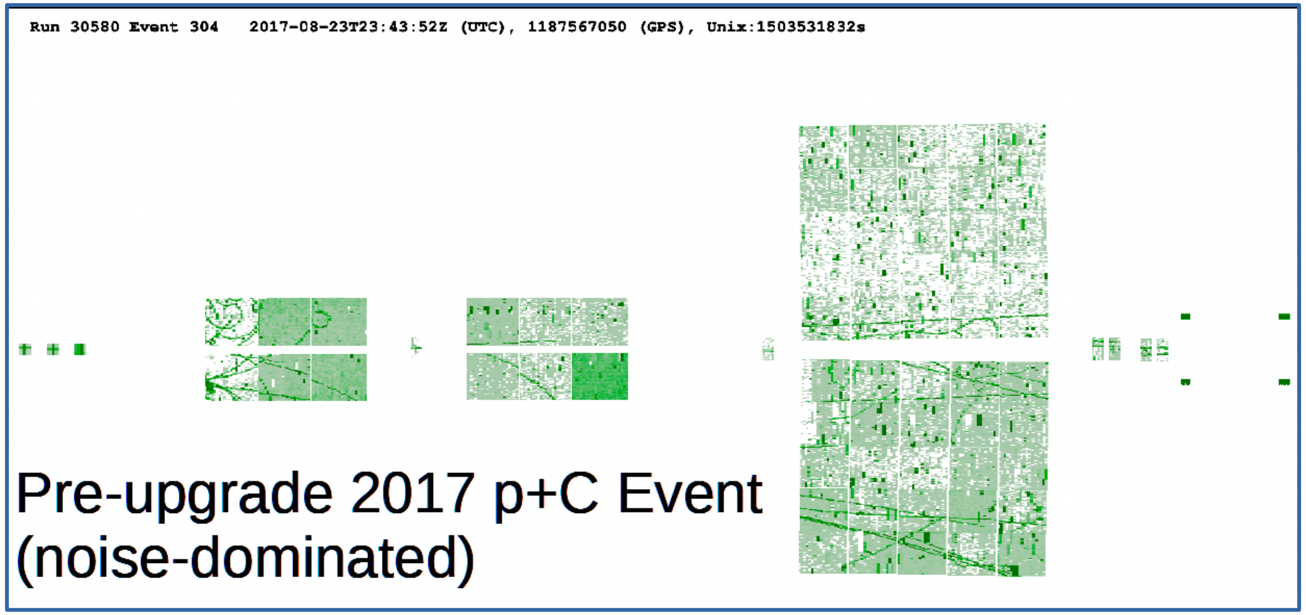




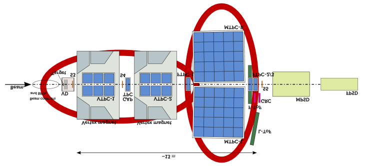
TPC performance

- First data after upgrade:
  - Summer 2022 data: 31 GeV/*c* protons on T2K replica target
- Very low noise observed
- Stable operation at 1.6 kHz
- Over 180 million events collected in 3 weeks (compared to 10 million in 5 weeks in previous T2K target running)

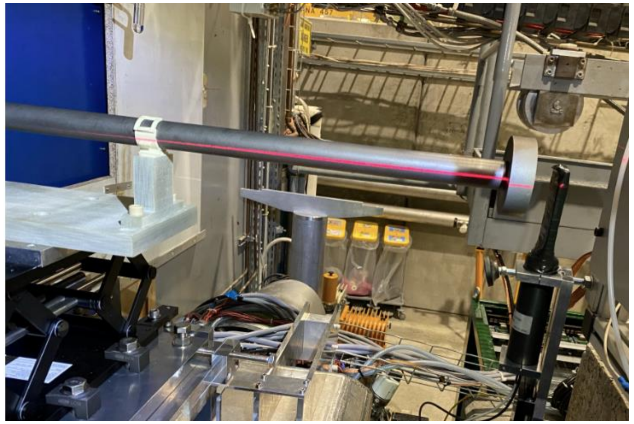




Pre-upgrade 2017 p+C Event (noise-dominated)



TPC performance



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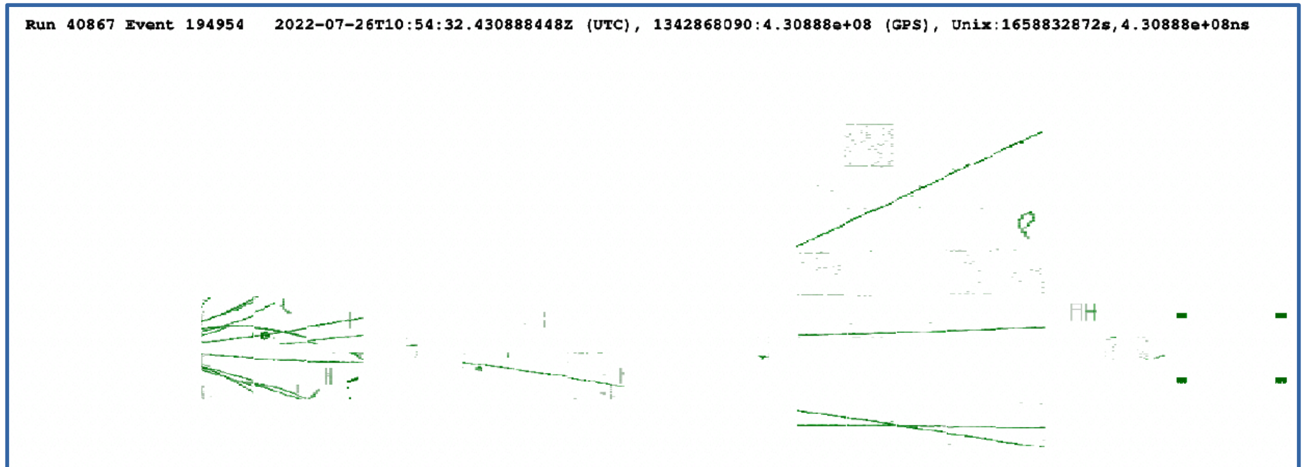
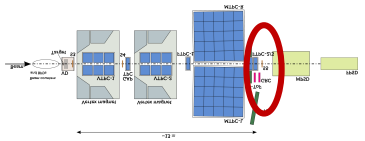
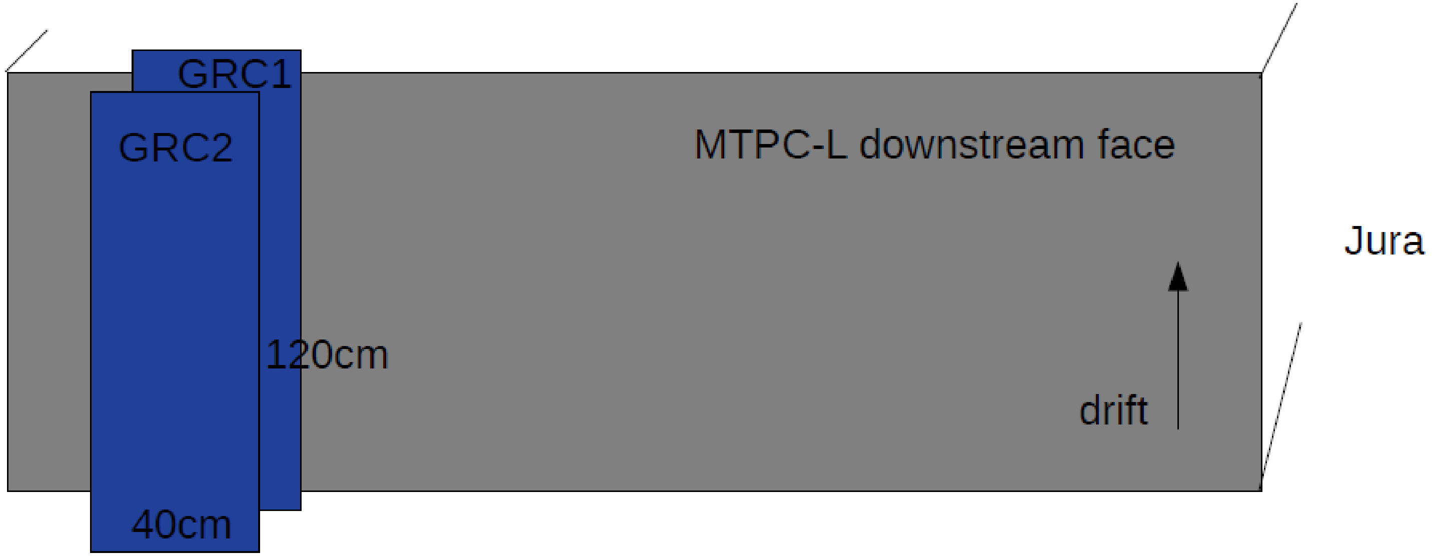


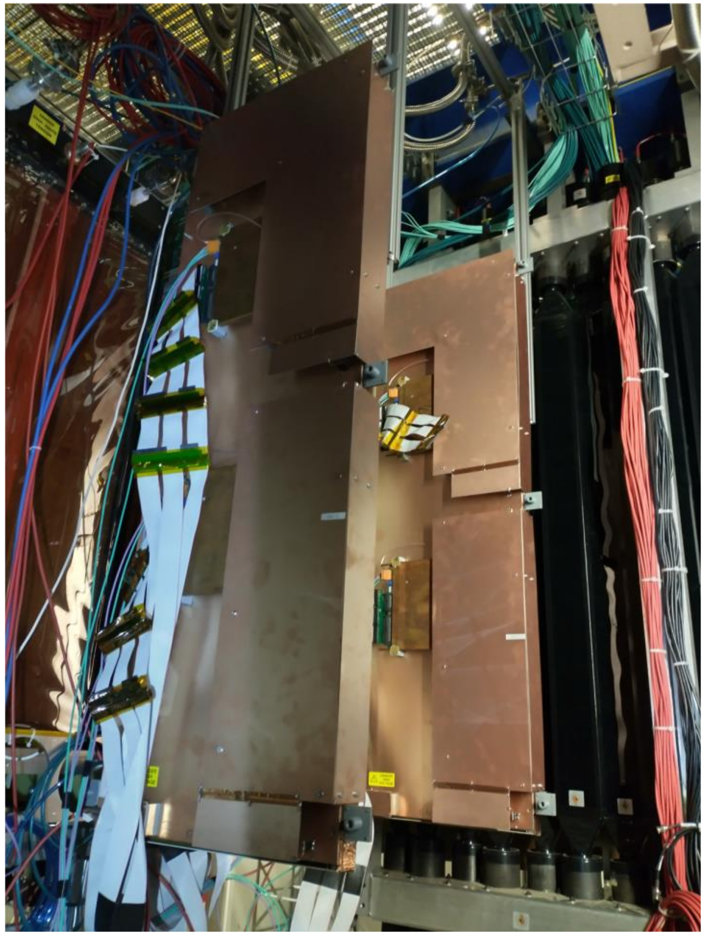
Post-upgrade 2022 p+T2K Event (track-dominated)

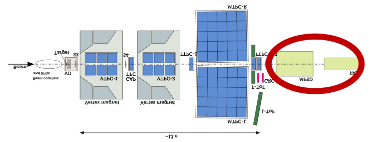


GRC - Geometry Reference Chamber

- Calibrate TPC y-drift coordinate
- Two GRCs chambers are installed
  - (40 x 120 cm MWPC)





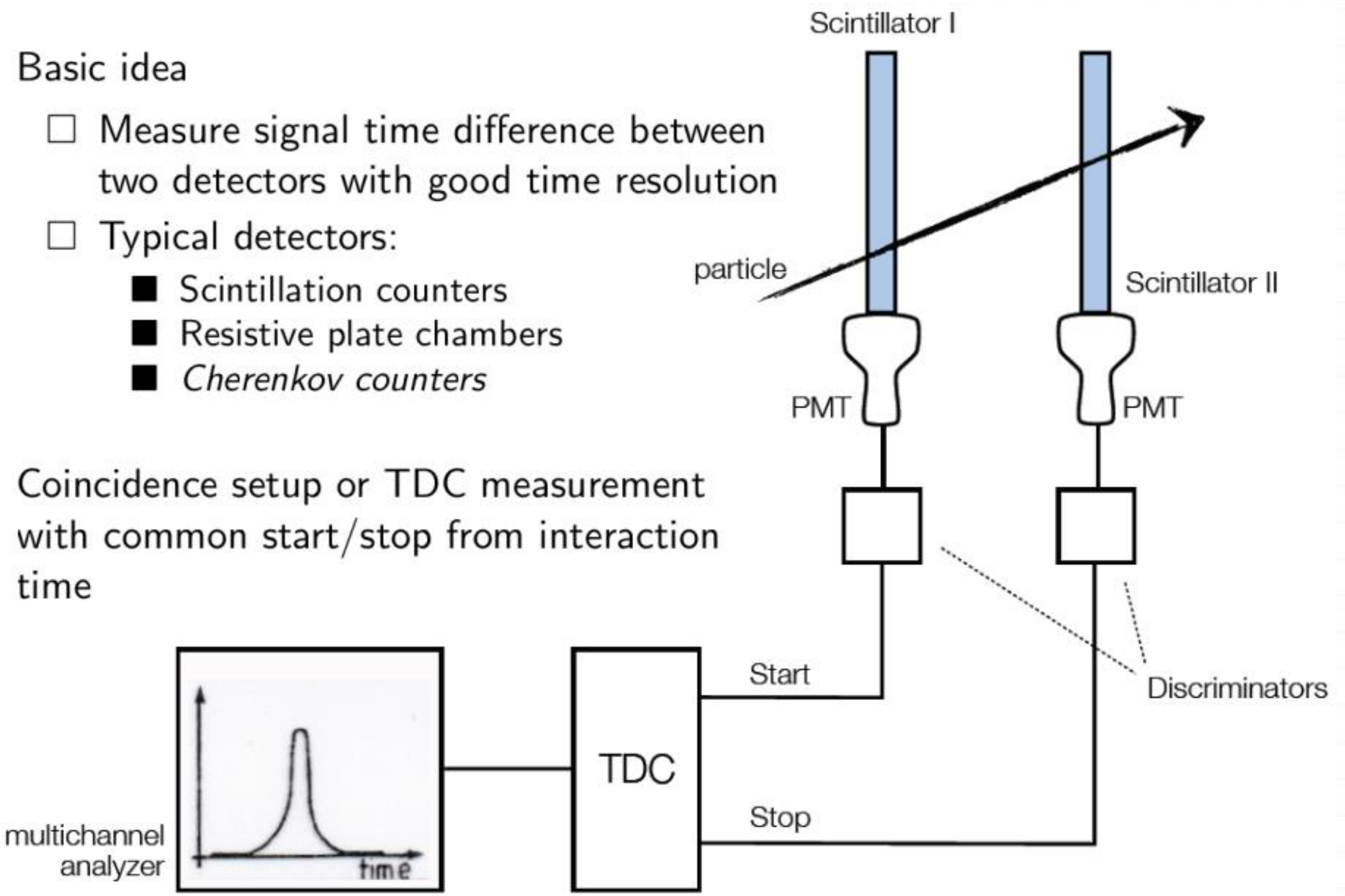


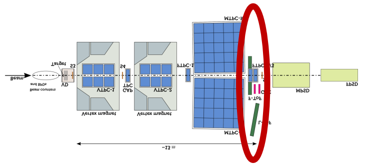
Time of Flight systems (ToF)

Basic idea

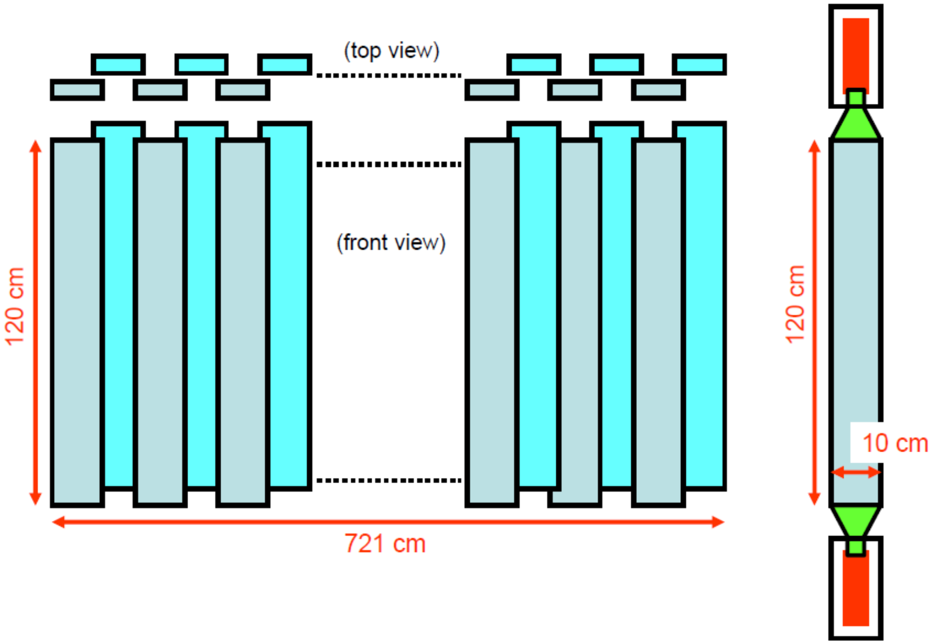
- ☐ Measure signal time difference between two detectors with good time resolution
- ☐ Typical detectors:
  - ■ Scintillation counters
  - ■ Resistive plate chambers
  - ■ *Cherenkov counters*

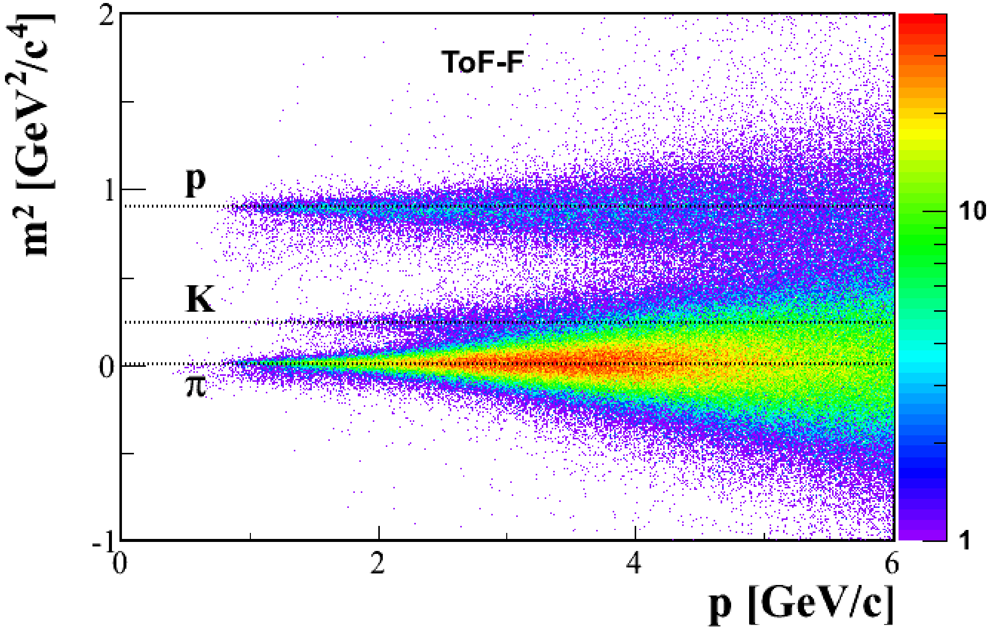
Coincidence setup or TDC measurement with common start/stop from interaction time





Forward Time of Flight systems (F-ToF)

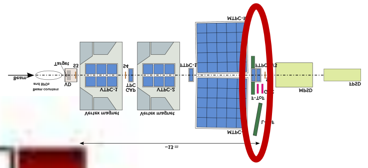


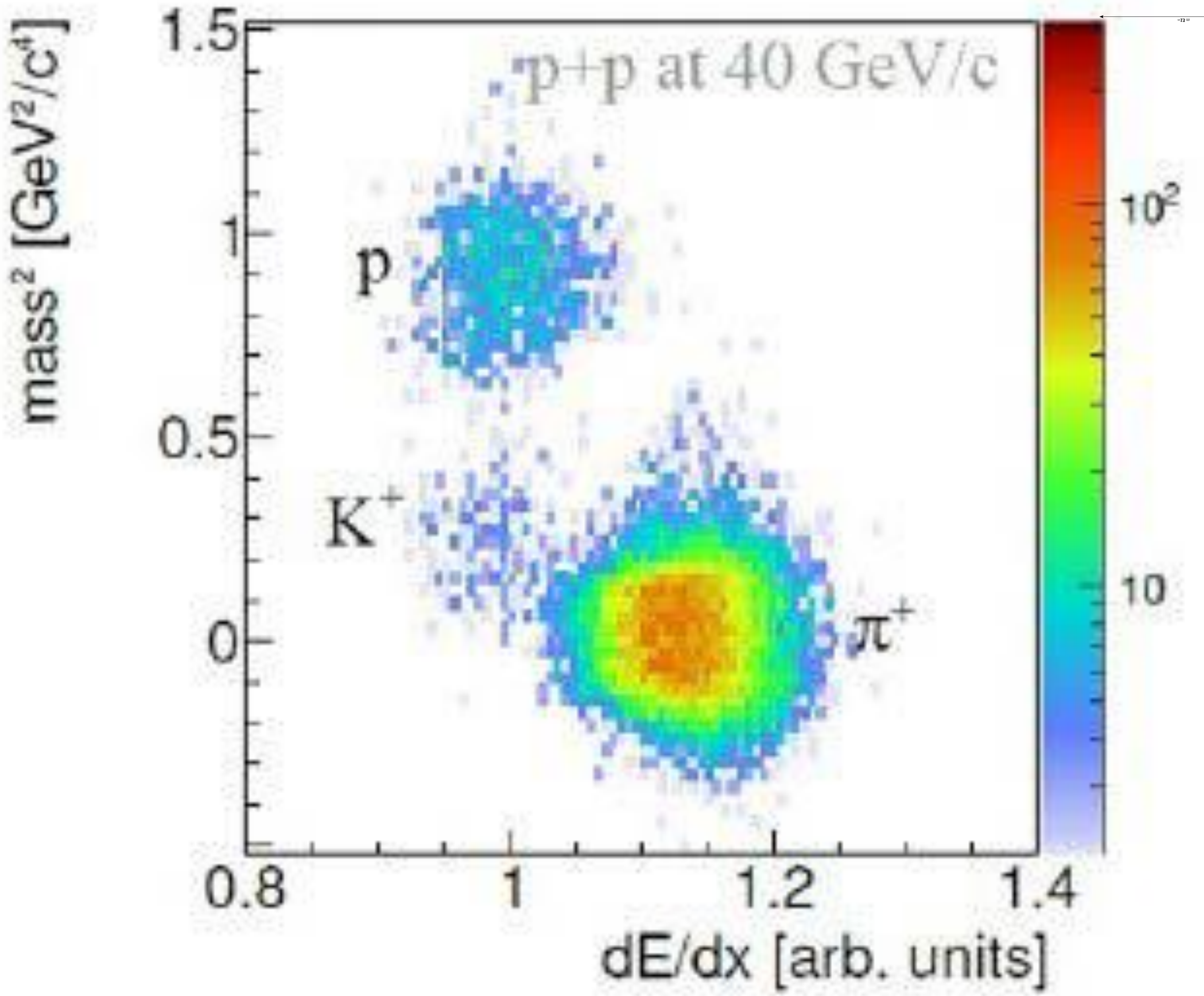


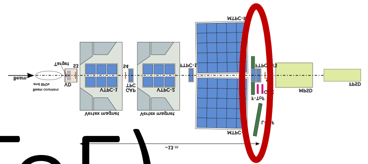
Good particle identification: $\sigma(TOF) \approx$ 80 ps (for old TOF walls)

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)



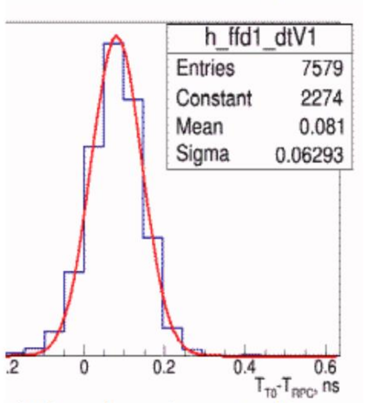




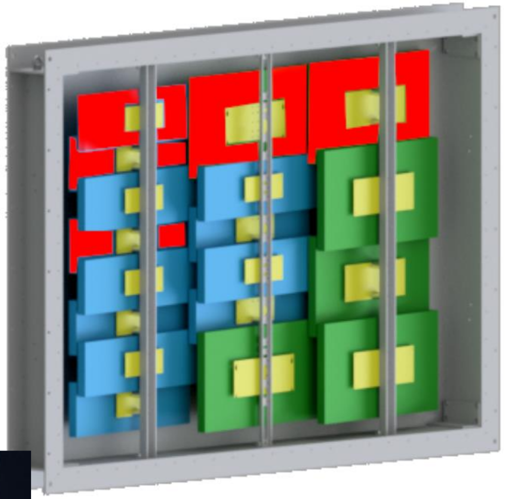
Multigap Resistive Plate Chamber (MRPC ToF)

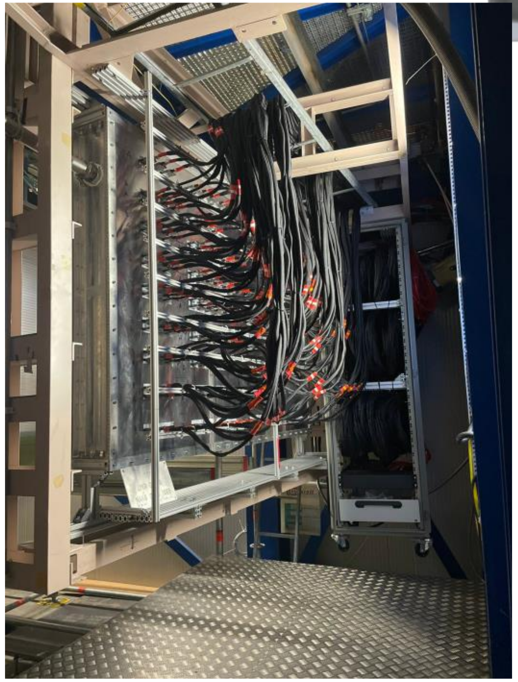
- high efciency (> 95%);
- intrinsic time resolution < 75 ps;
- high granularity in order to keep the overall system occupancy below 10%;
- good position resolution to provide effective matching of the TOF hits with the tracks;
- MRPC-L – operational
- MRPC-R – in production (ready 2023)

$$\sqrt{63^2 - 48^2} \approx 41\,\text{ps}$$



The best result

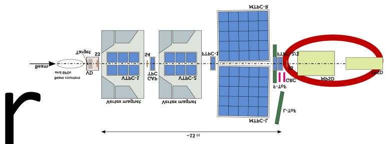


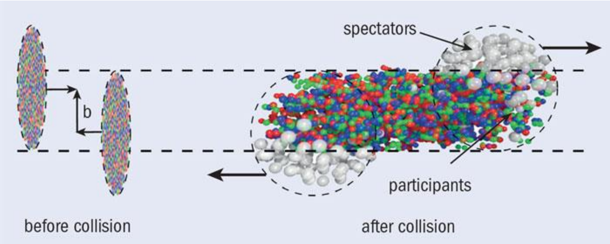


	Number of detectors	Number of readout strips	Sensitive area, m^2	Number of FEE cards	Number of FEE channels
MRPC	1	48	0.090/0.180	6	96
Columns	4/6/8	192/288/384	1.23	24/36/48	384/576/768
MRPC-L	**18**	**864**	**1.896**	**108**	**1728**
MRPC-L+R	40	1920	3.792	240	3840

ult

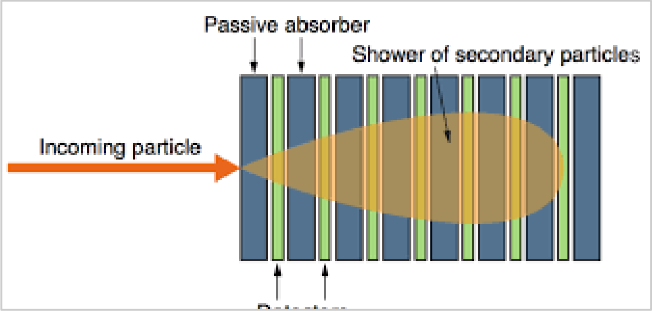
PSD - Projectile Spectator Detector

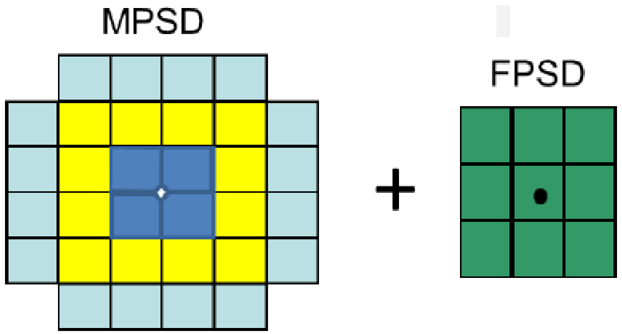




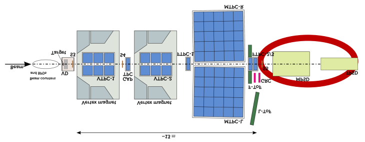
- forward hadron calorimeter
- measurement of projectile spectator energy in nucleus-nucleus collisions
- Measure centrality of the collision

Main PSD: 32 modules.
Forward PSD: 9 modules



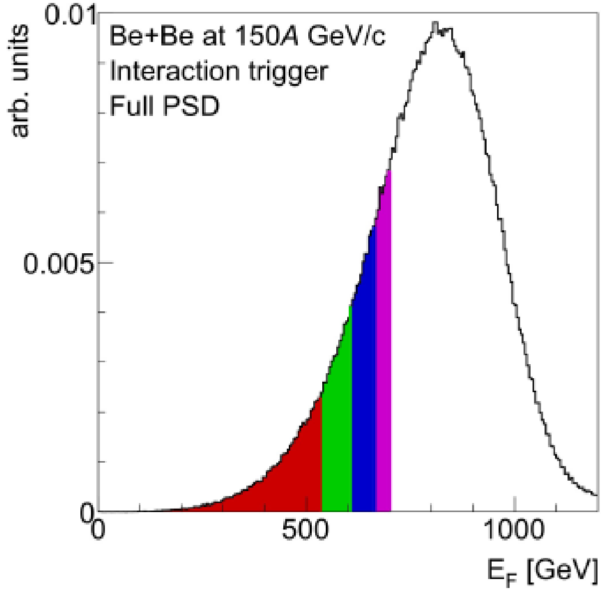


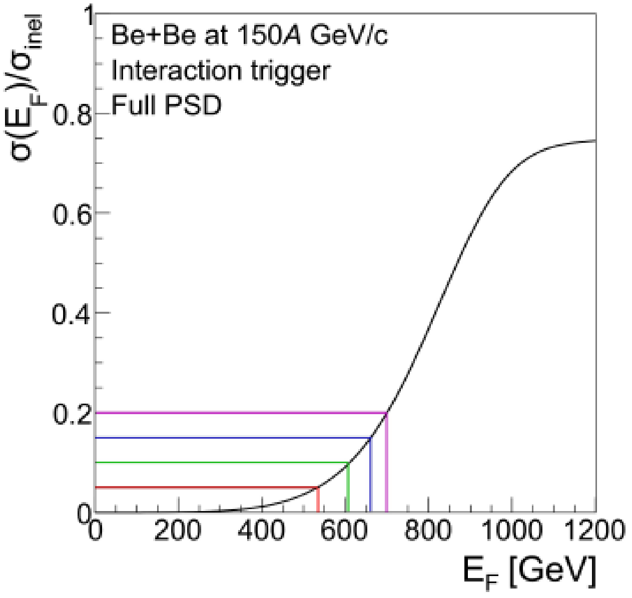
Projectile Spectator Detector

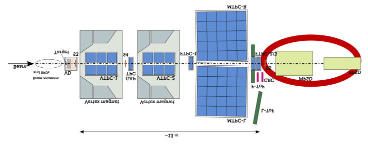


- measures the forward energy E_F related to the non-interacting nucleons of the beam nucleus
  - Intervals in EF allow to select different centrality classes

0 - 5% **5 - 10%** **10 - 15%** **15 – 20%**



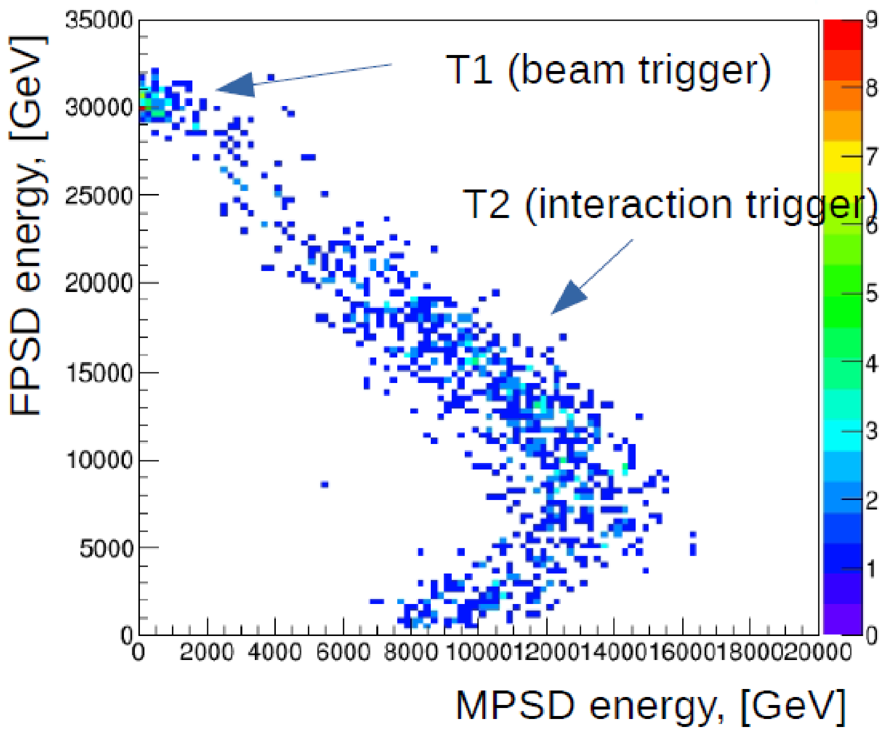




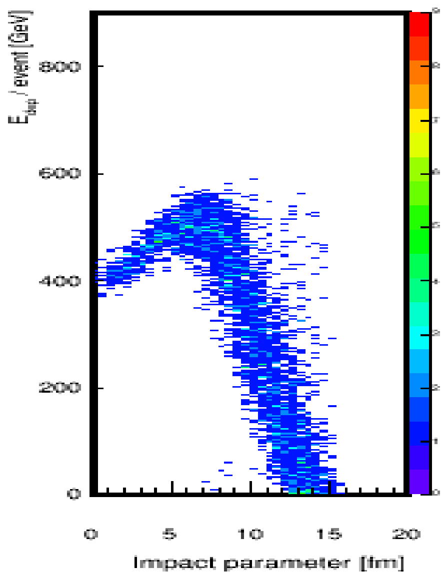
PSD

- Main PSD: 32 modules.
- Forward PSD: 9 modules

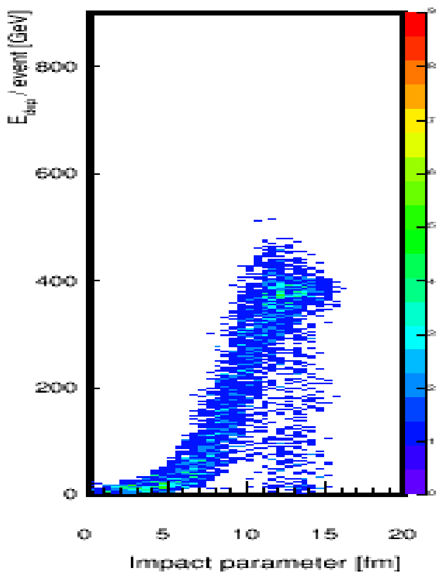
First data from FPSD + MPSD on beam of Pb+Pb 150 AGeV, November 2022



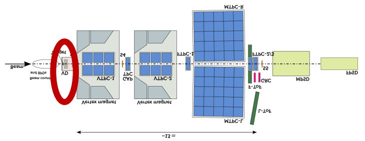
Energy in MPSD



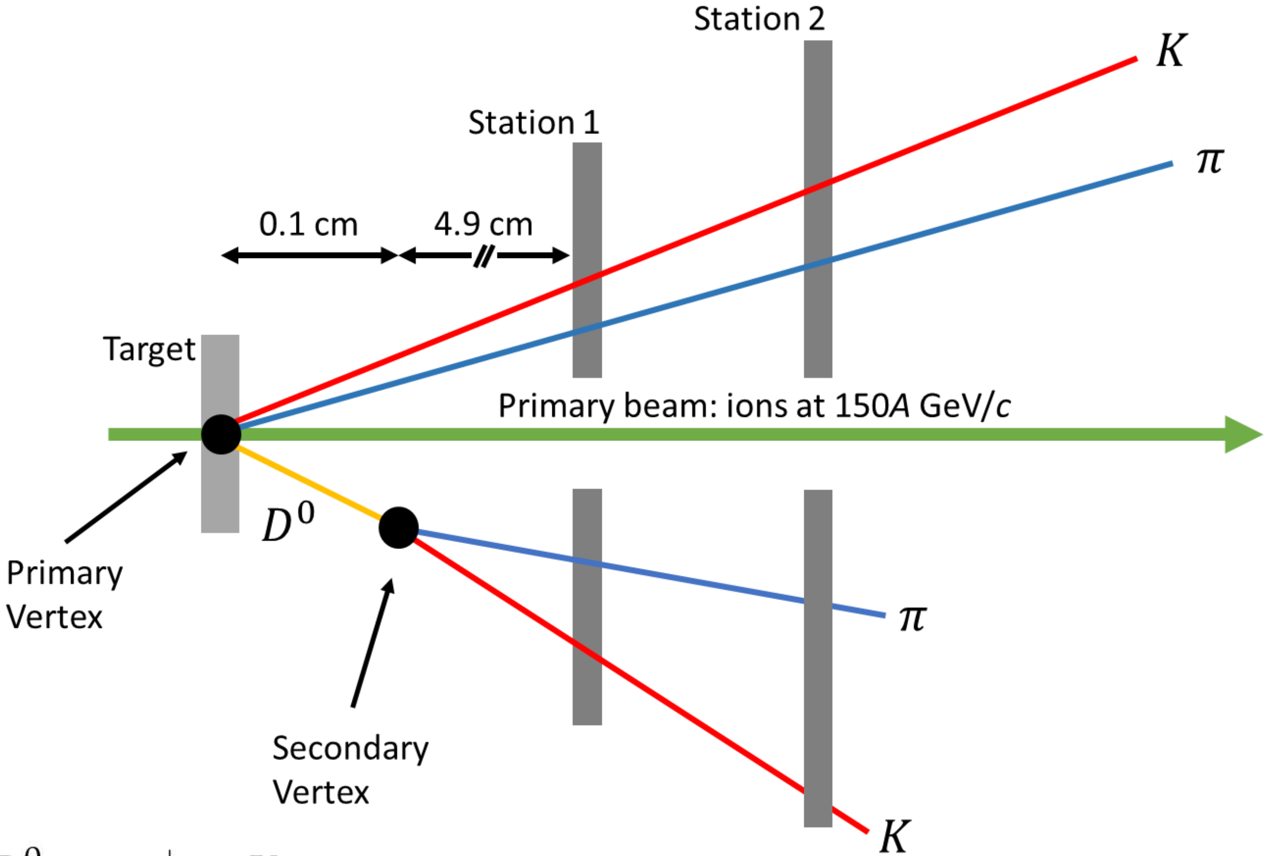
Energy in FPSD



Simulation of Pb+Pb@150 AGeVwith QGSM model

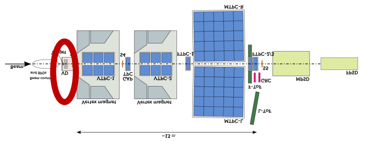


Studies of open charm measurements



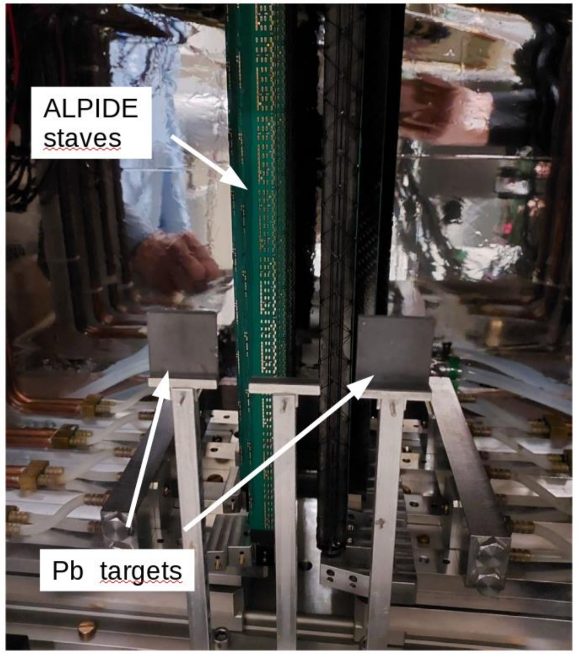
$$D^0 \rightarrow \pi^+ + K^-$$

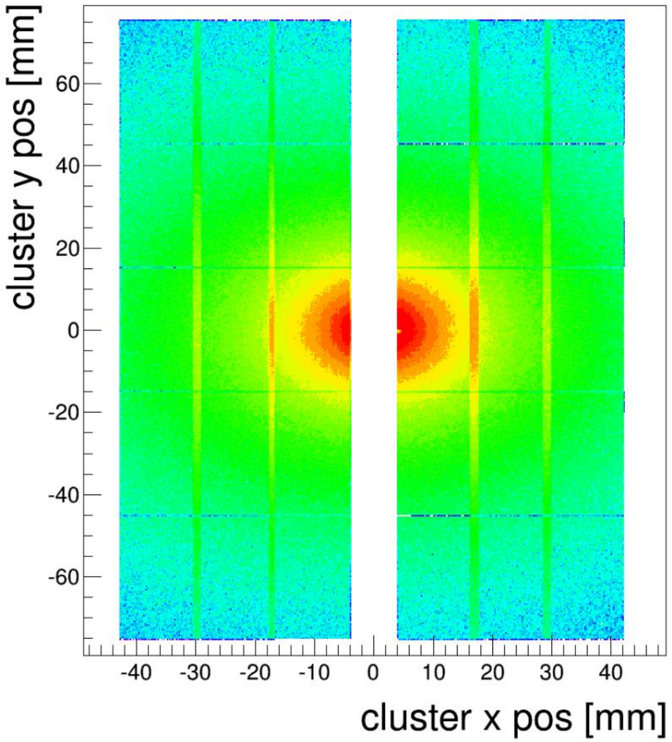
Vertex detector is needed to reconstruct primary vertex and secondary vertexes with high precision

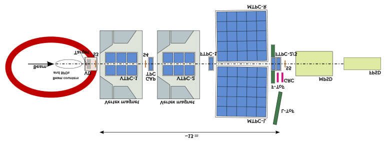


Vertex detector

- Silicon sensors (ALPIDE) located on horizontally movable arms
- Target holder integrated





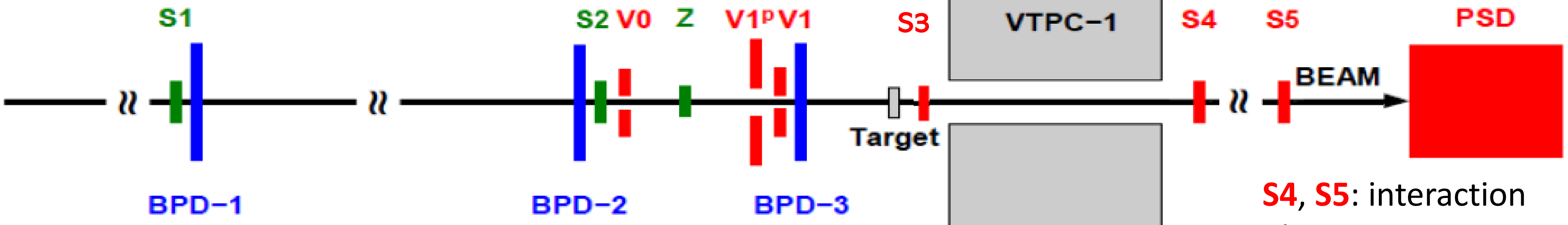


Beam detectors

V0, **V1**, **V2**: veto to limit beam diameter

S1, **S2:** trigger detectors: timing

Z: dE/dx charge of beam

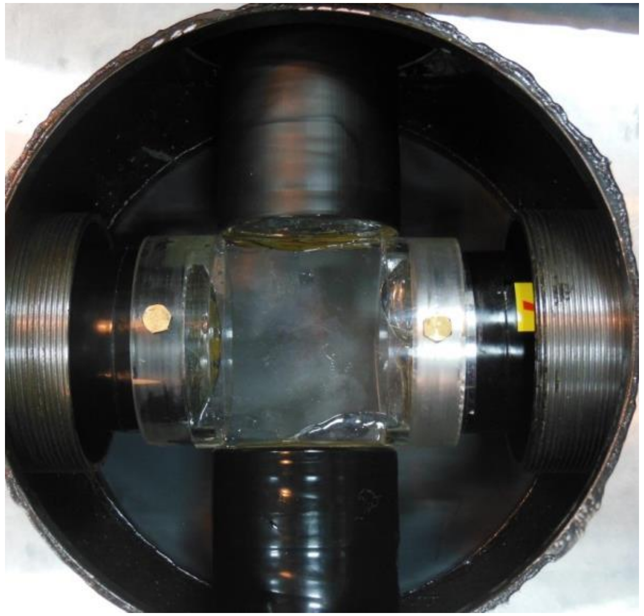


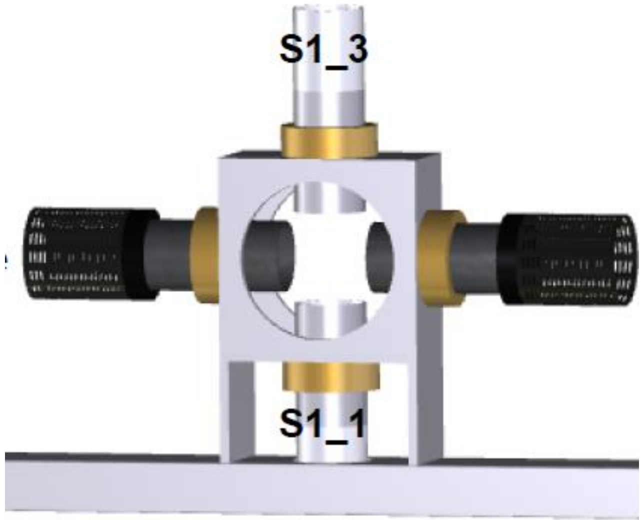
S4, **S5**: interaction detectors

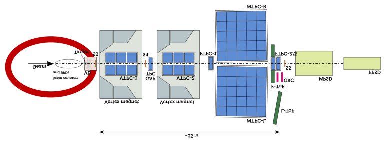
Beam **P**osition **D**etectors (x,y coordinates)

Set of scintillation (plastic) and Cherenkov counters (quartz) 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

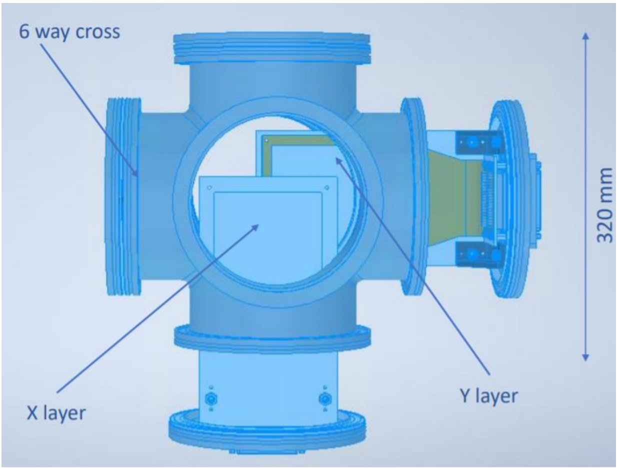


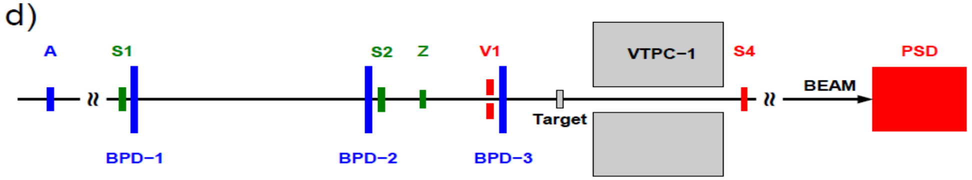


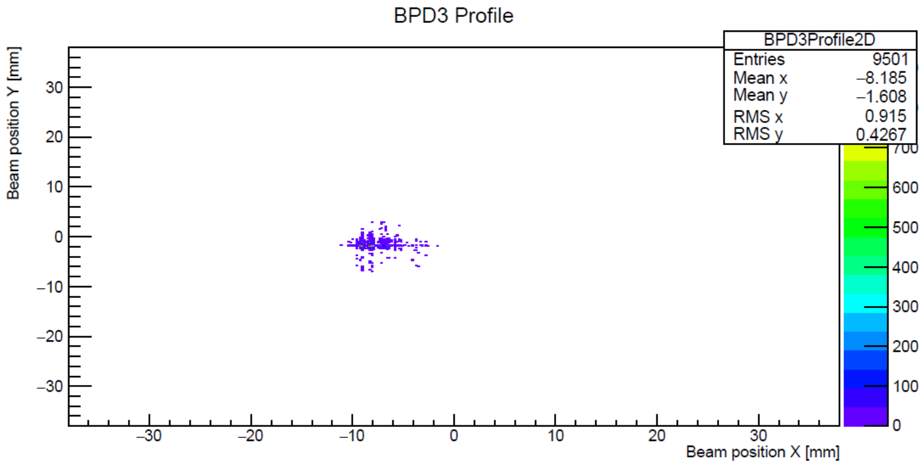


Beam Position Detectors

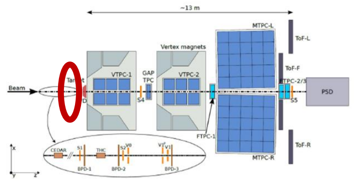
- The positions of the incoming beam particles in the transverse plane are measured by a telescope of three BPDs
- Single Sided Silicon strip detector
- 200 channels



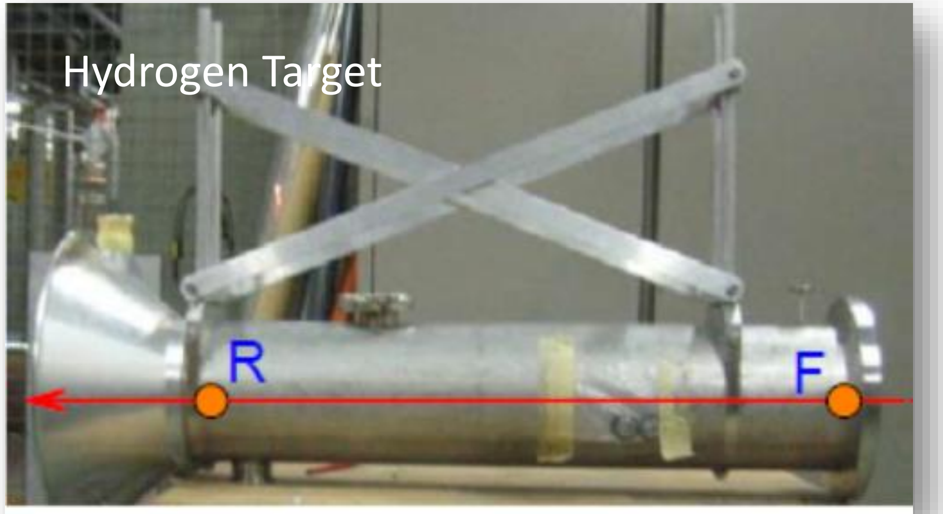


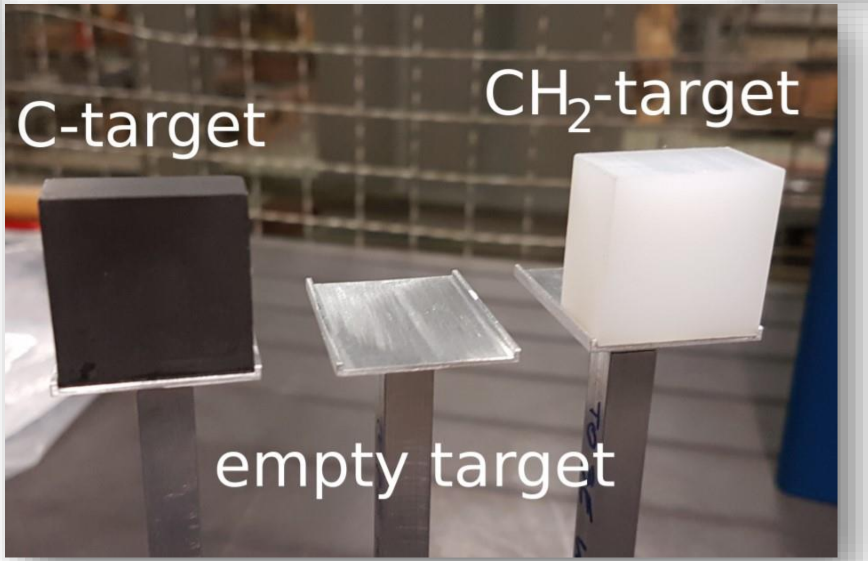


Targets



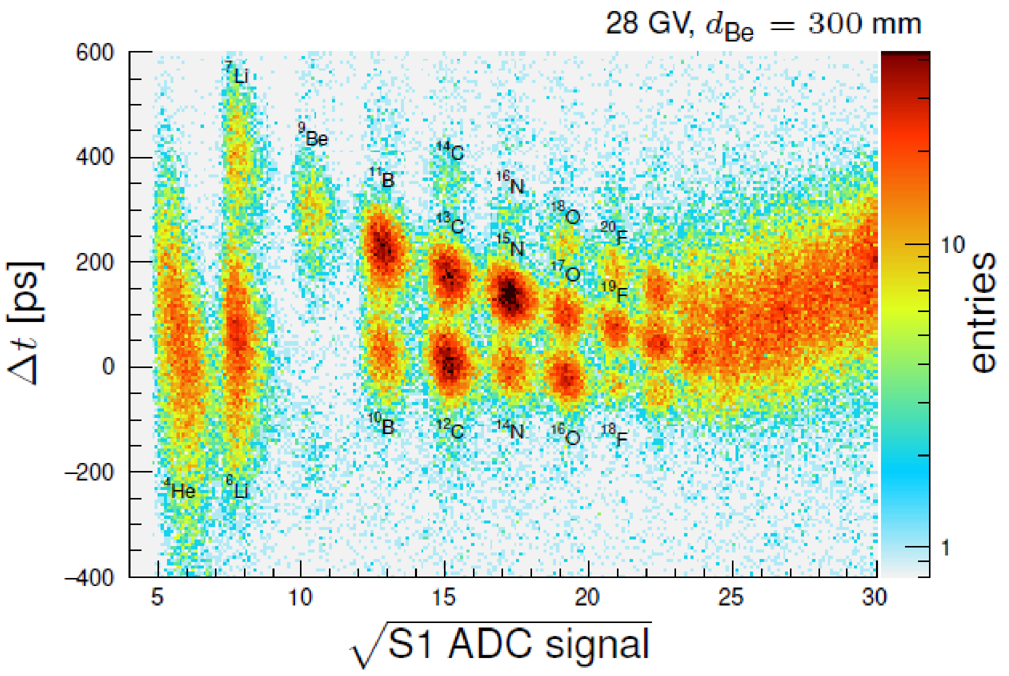

T2K replica target


Hydrogen Target
R
F

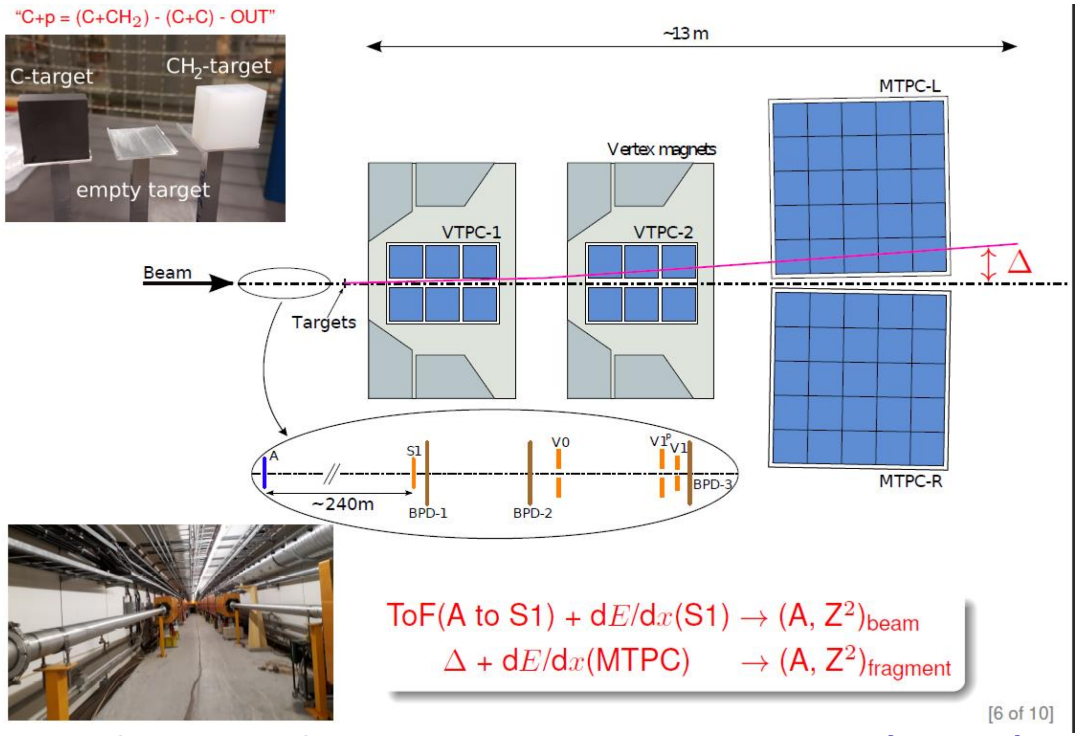

C-target
CH2-target
empty target

Flexibility of the detector

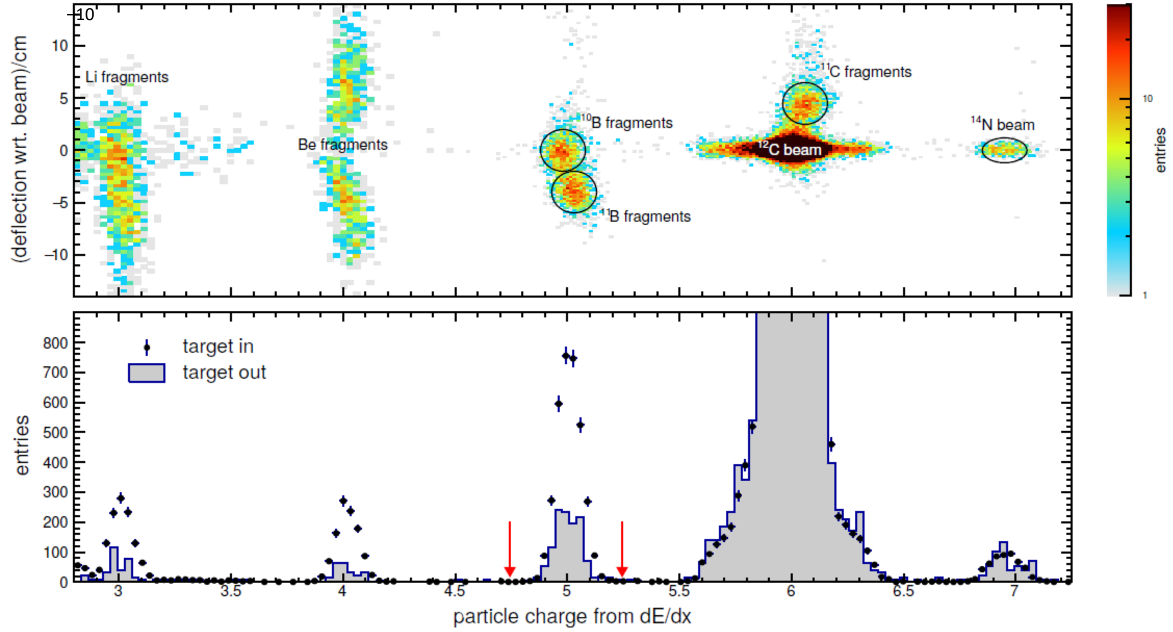
Nuclear Fragmentation run



composition of secondary ion beam

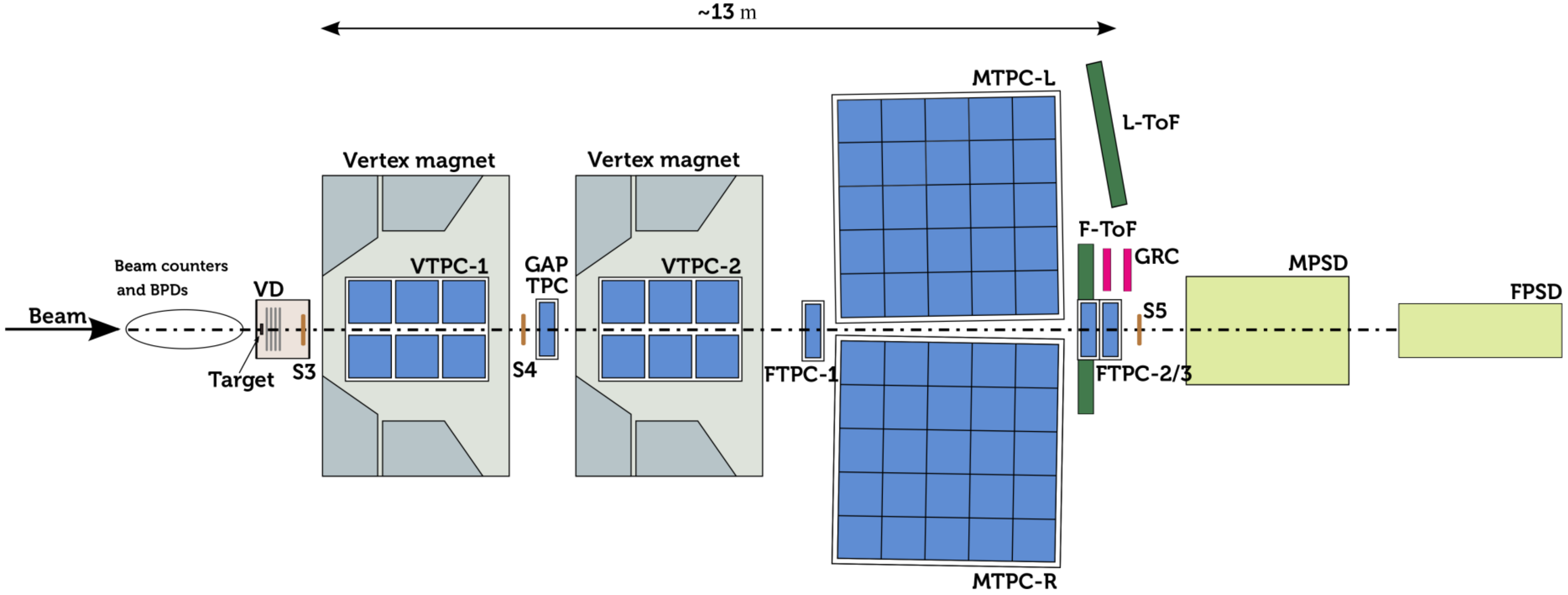


Identification of Isotopes Produced in Target (MTPC)



Summary

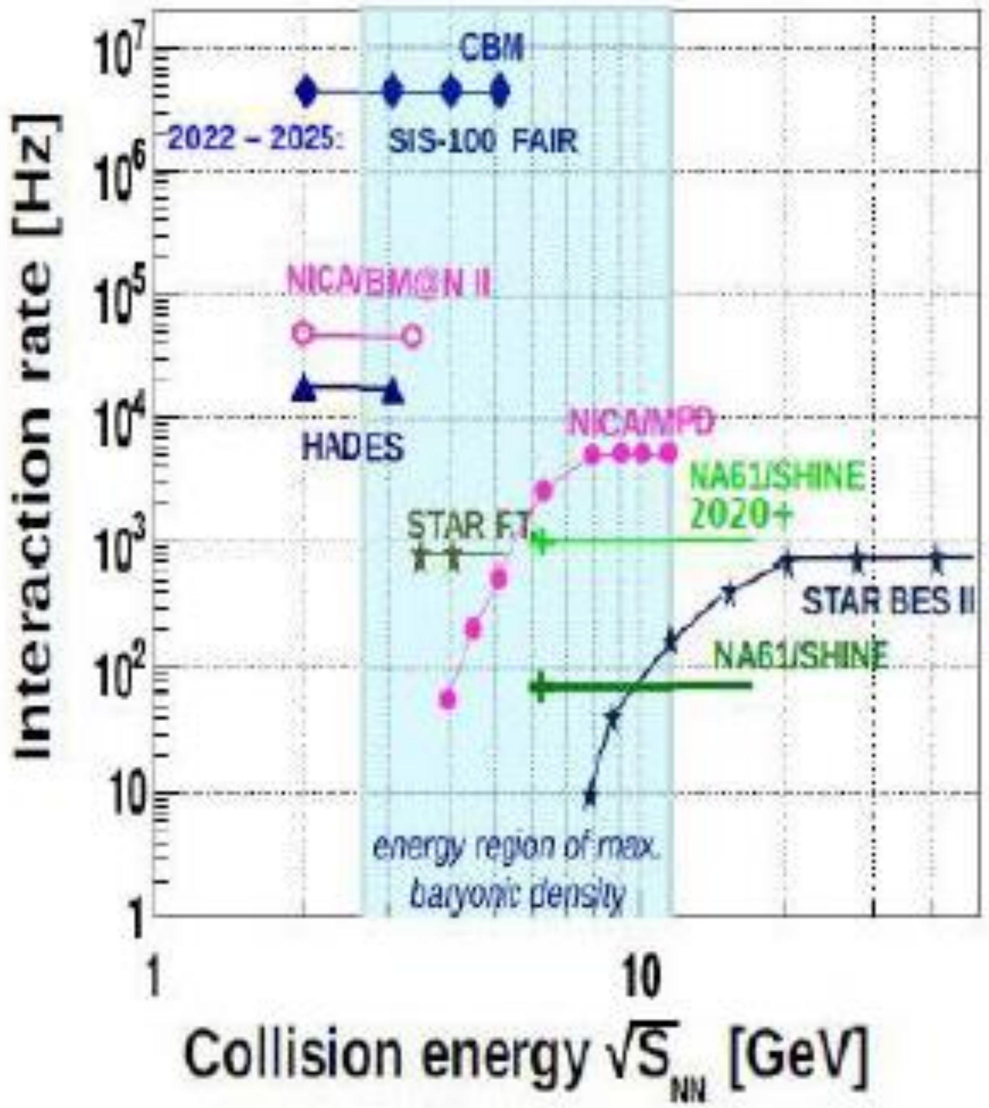
- Large acceptance hadron spectrometer
- Flexible detector set with possibilities for upgrades
- Use various types of beams (ions to pions)

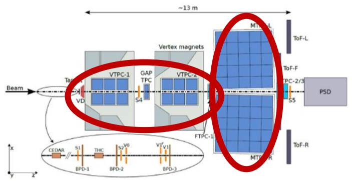


Thank you

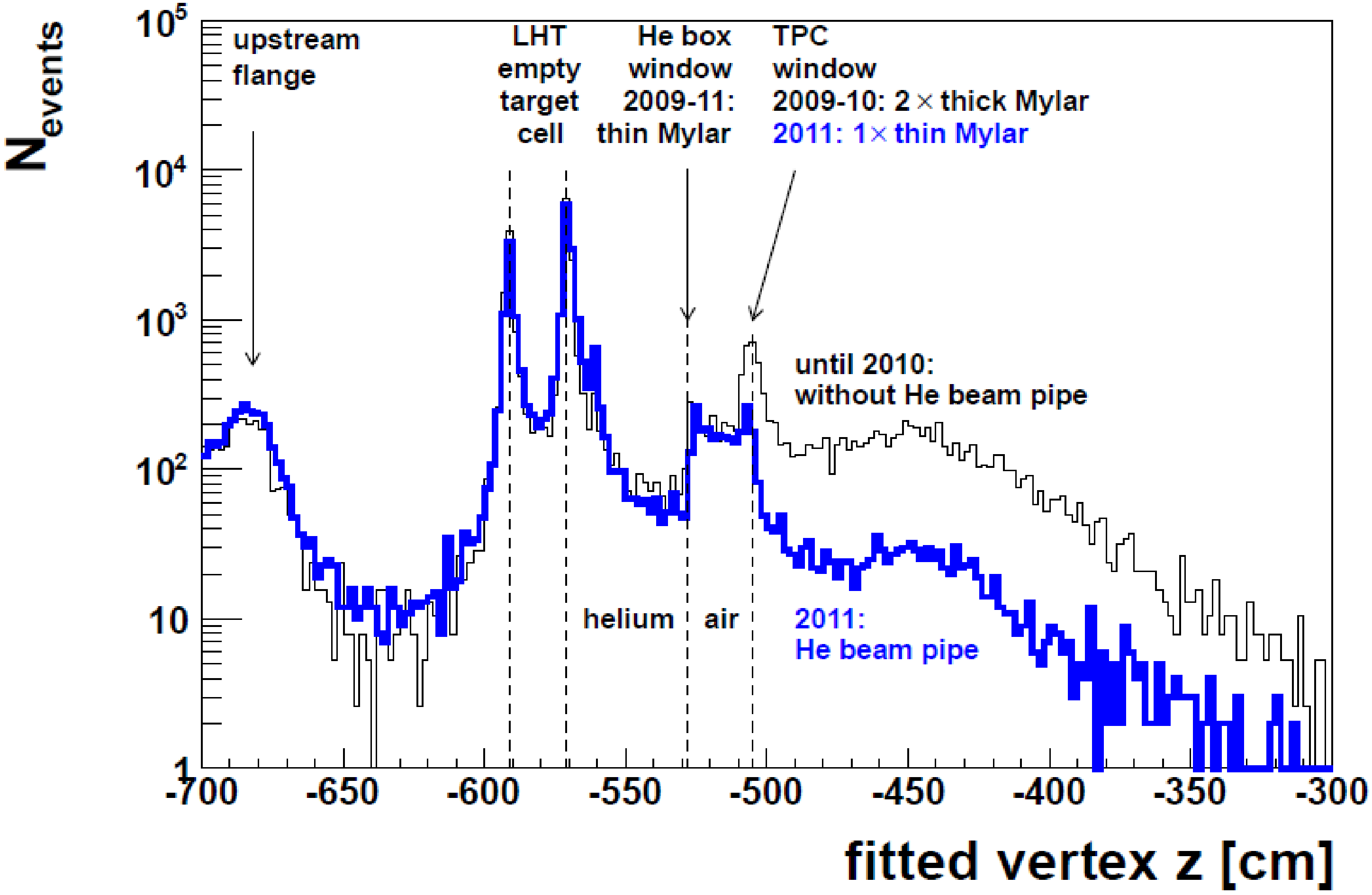
Replacement of the TPC electronics

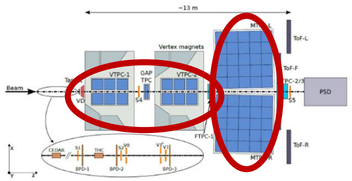
Will increase the read-out rate by a factor of about 10 (up to 1 kHz)





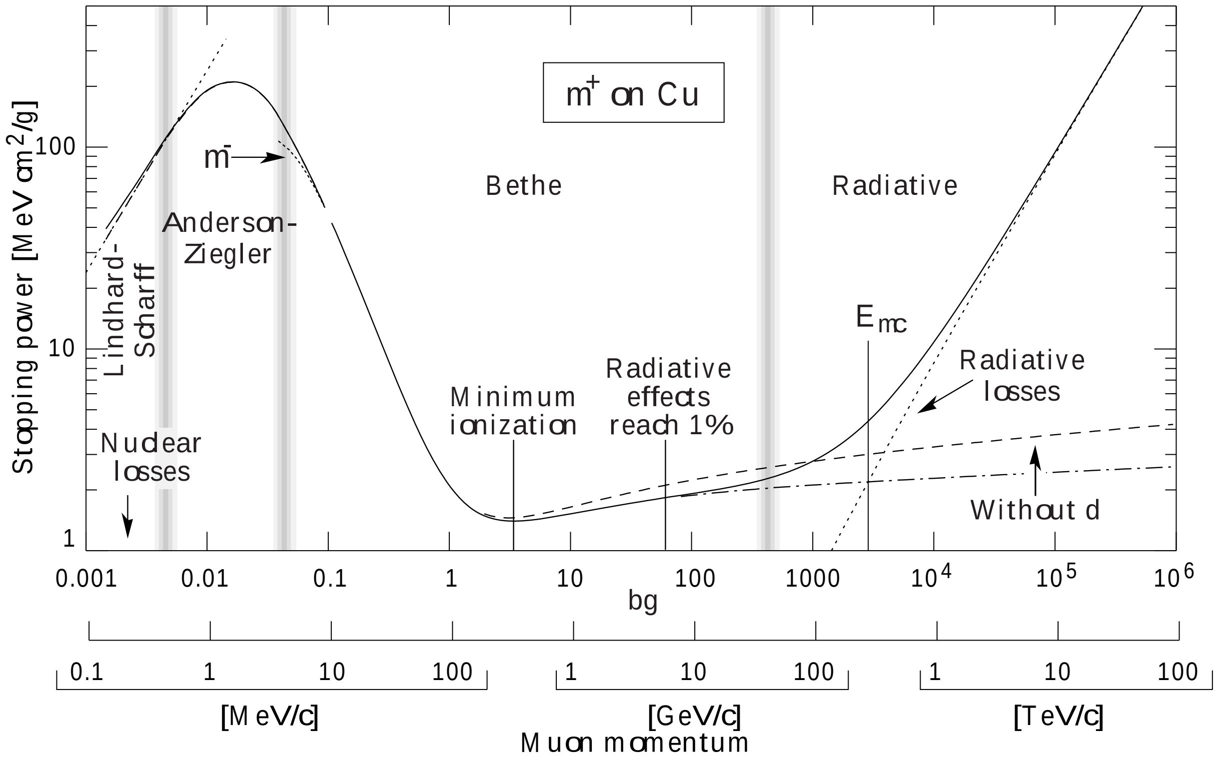
Vertex distribution along the beam axis

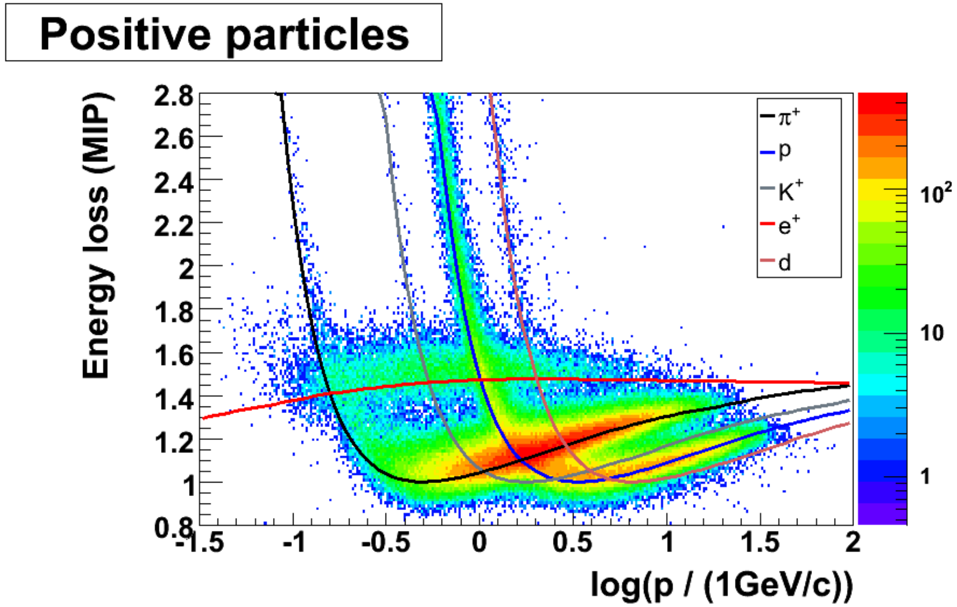




dE/dX and Momentum

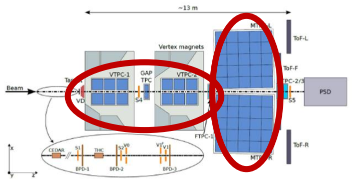
$$\frac{dE}{dX} \propto \frac{1}{\beta^2} \propto \frac{m^2}{p^2}$$

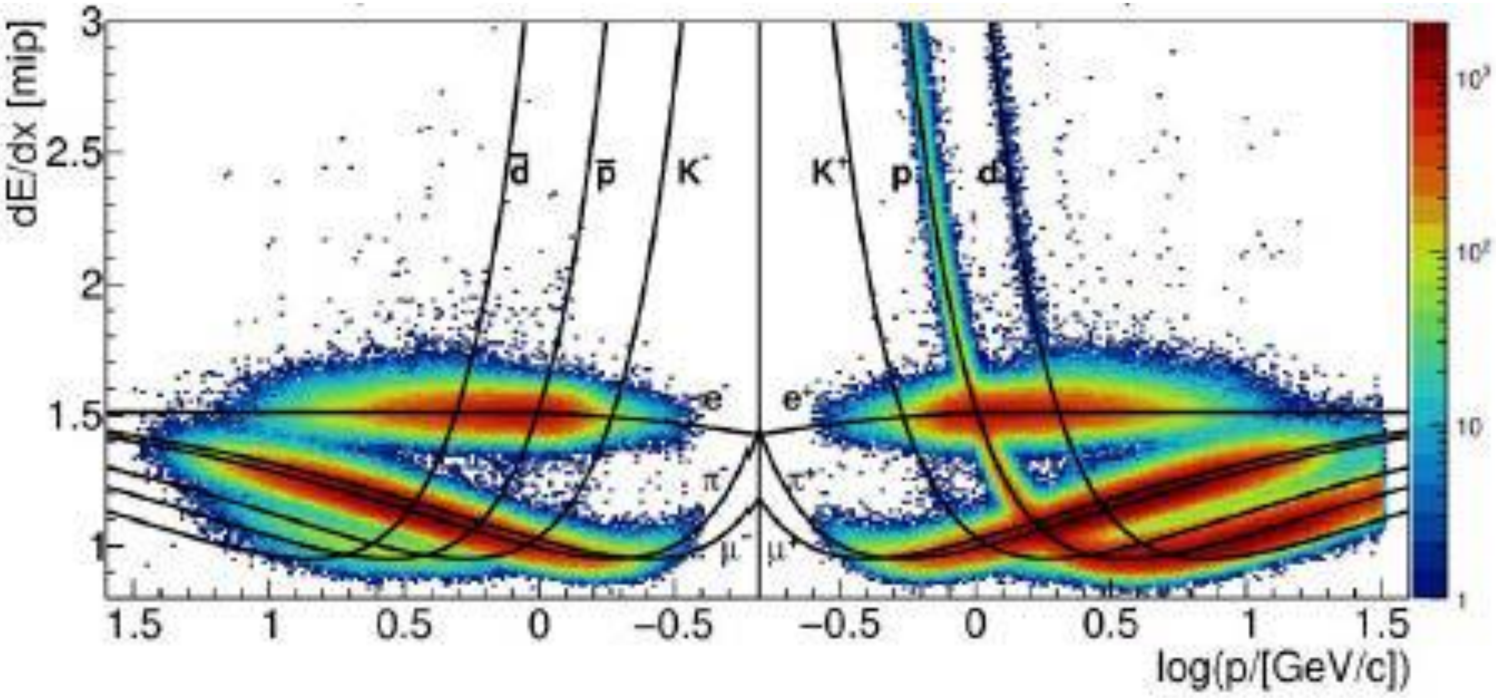




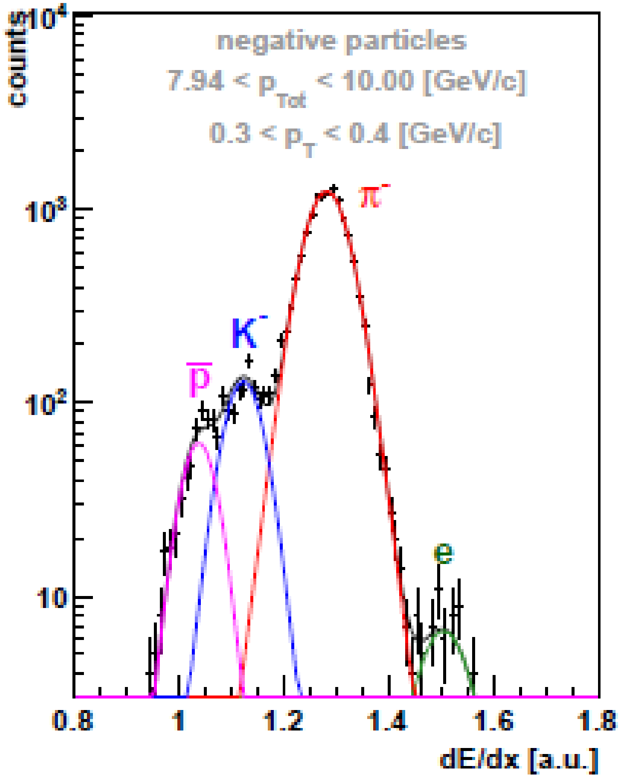
$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

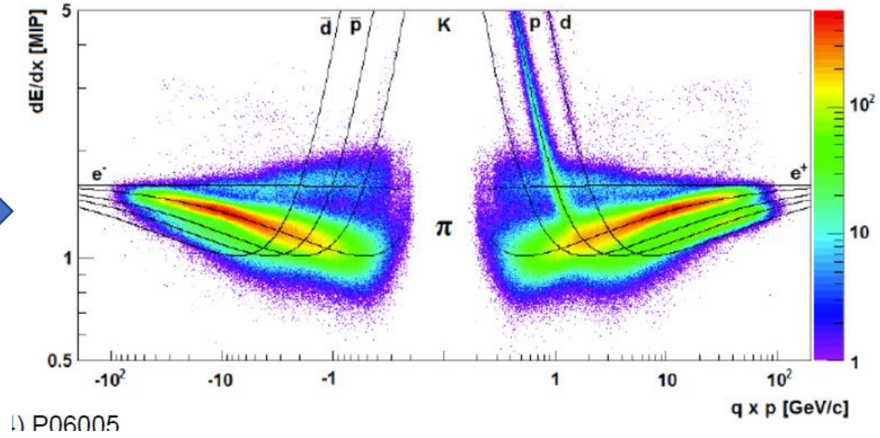
Energy lost

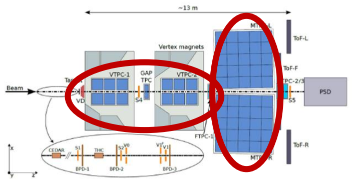




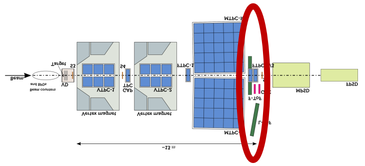
Energy loss (dE/dx) method







- 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

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