GridPix TPC as a Compact tracking and PID device

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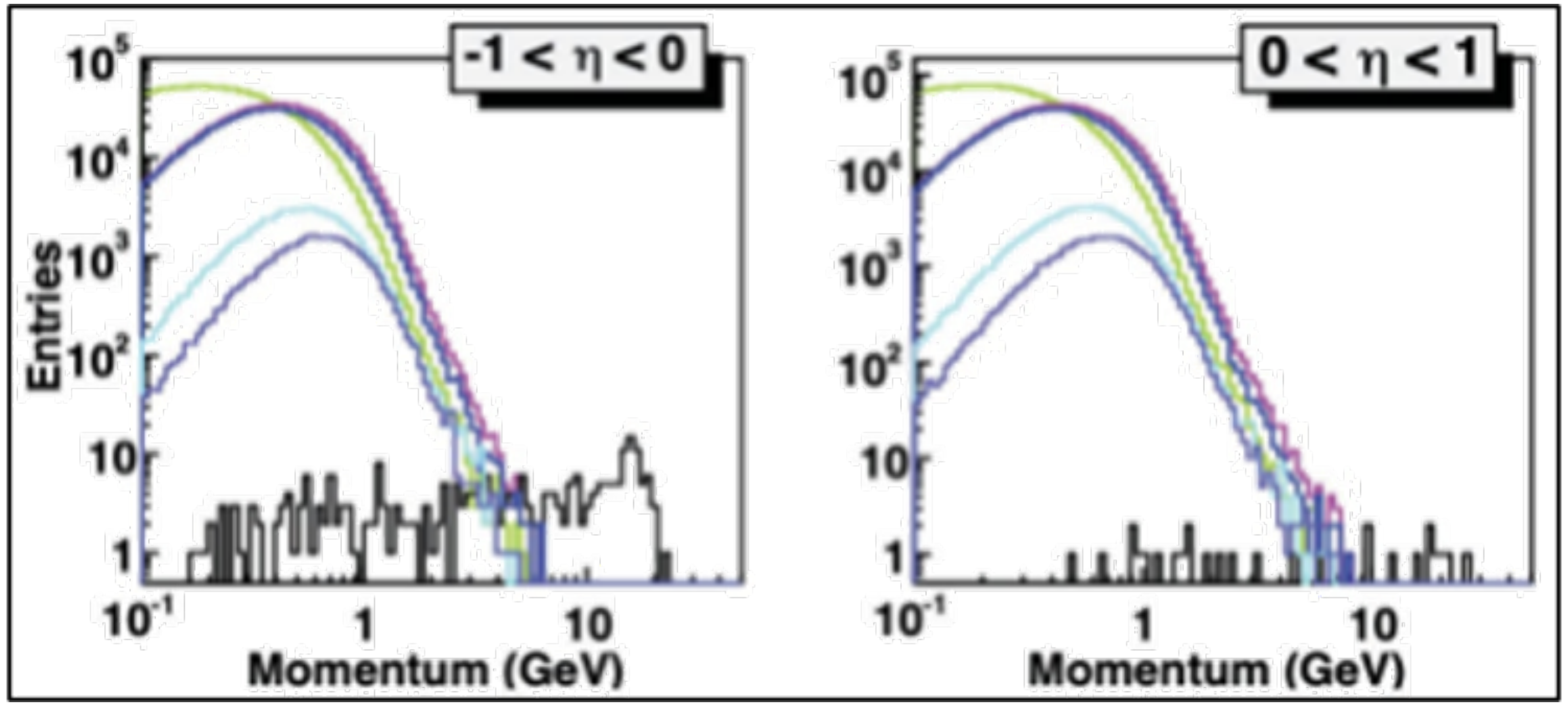
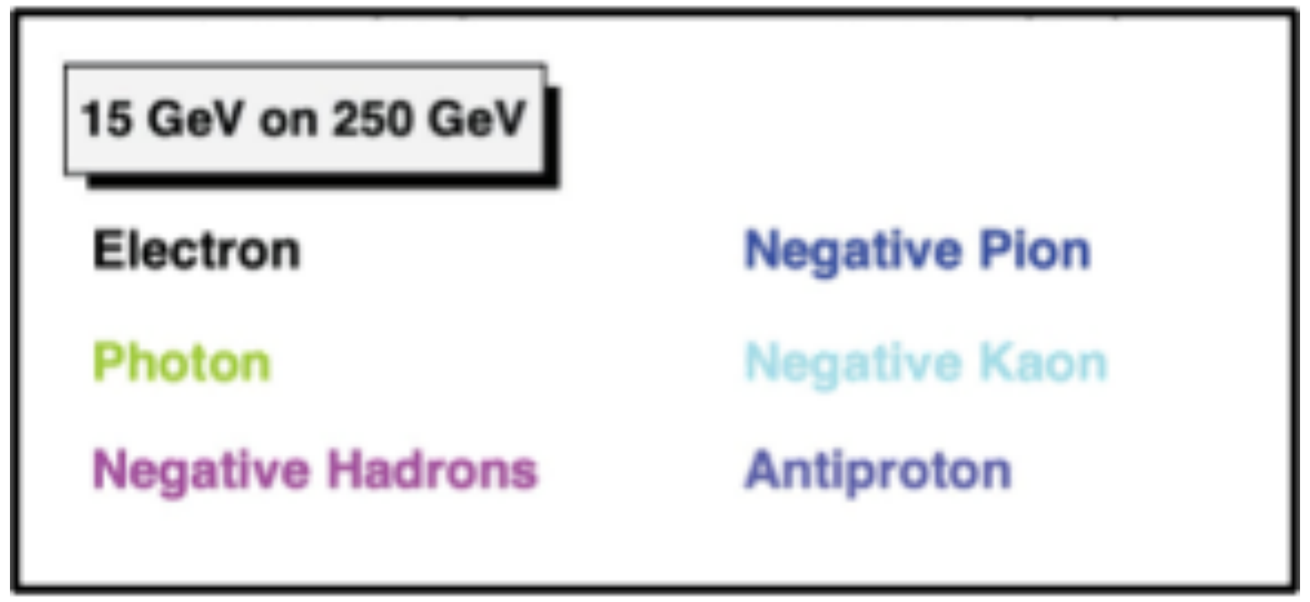
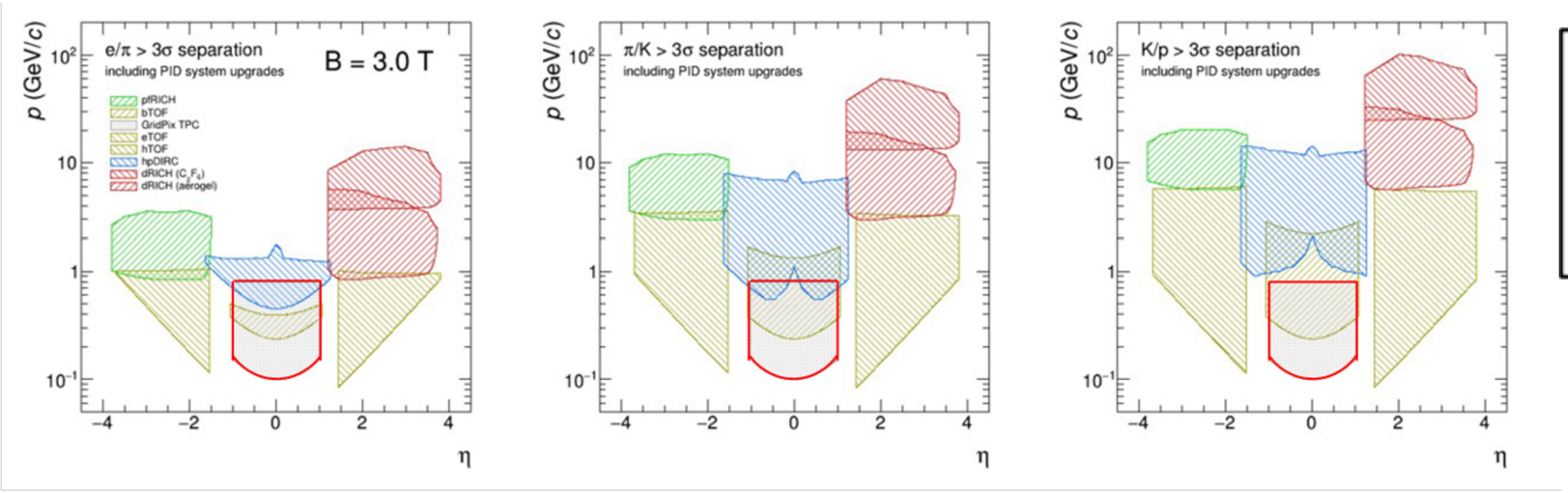
GridPix Momentum Coverage & EIC Kinematics

At the lowest momenta particle identification by dE/dx is advantageous.

Promising technology for EIC detector 2







How GridPix is different from Conventional TPC?

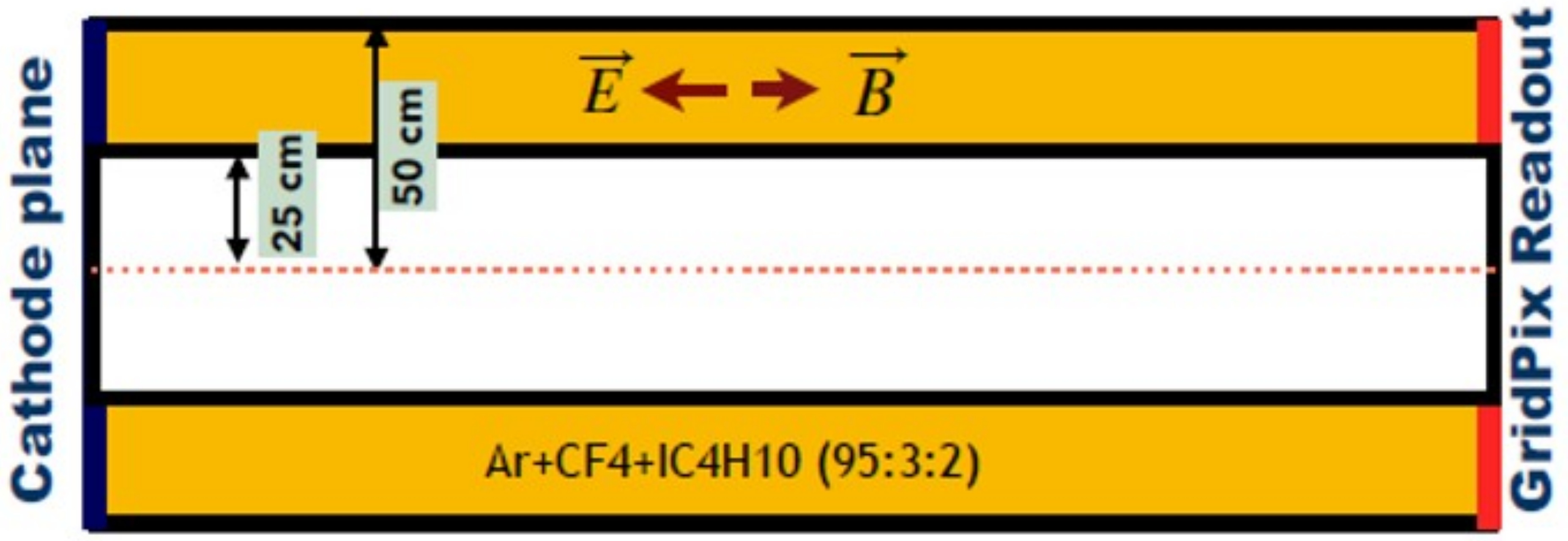
1. Truncated mean

- ◉ Split the ionization trail into many small samples along the length.
- ◉ Reject all measurements whose yield is a factor f higher than the mean of the others.
- ◉ Average the remaining samples.

2. Distribution Fit

- ◉ Split the ionization trail into many small samples along the length.
- ◉ Fit the probability distribution of all the samples to a Landau curve.
- ◉ Use the most probable value from the fitted Landau function as $^{\text{dE/dx}}$

Divide the tail as much as possible -> Easy with GridPix



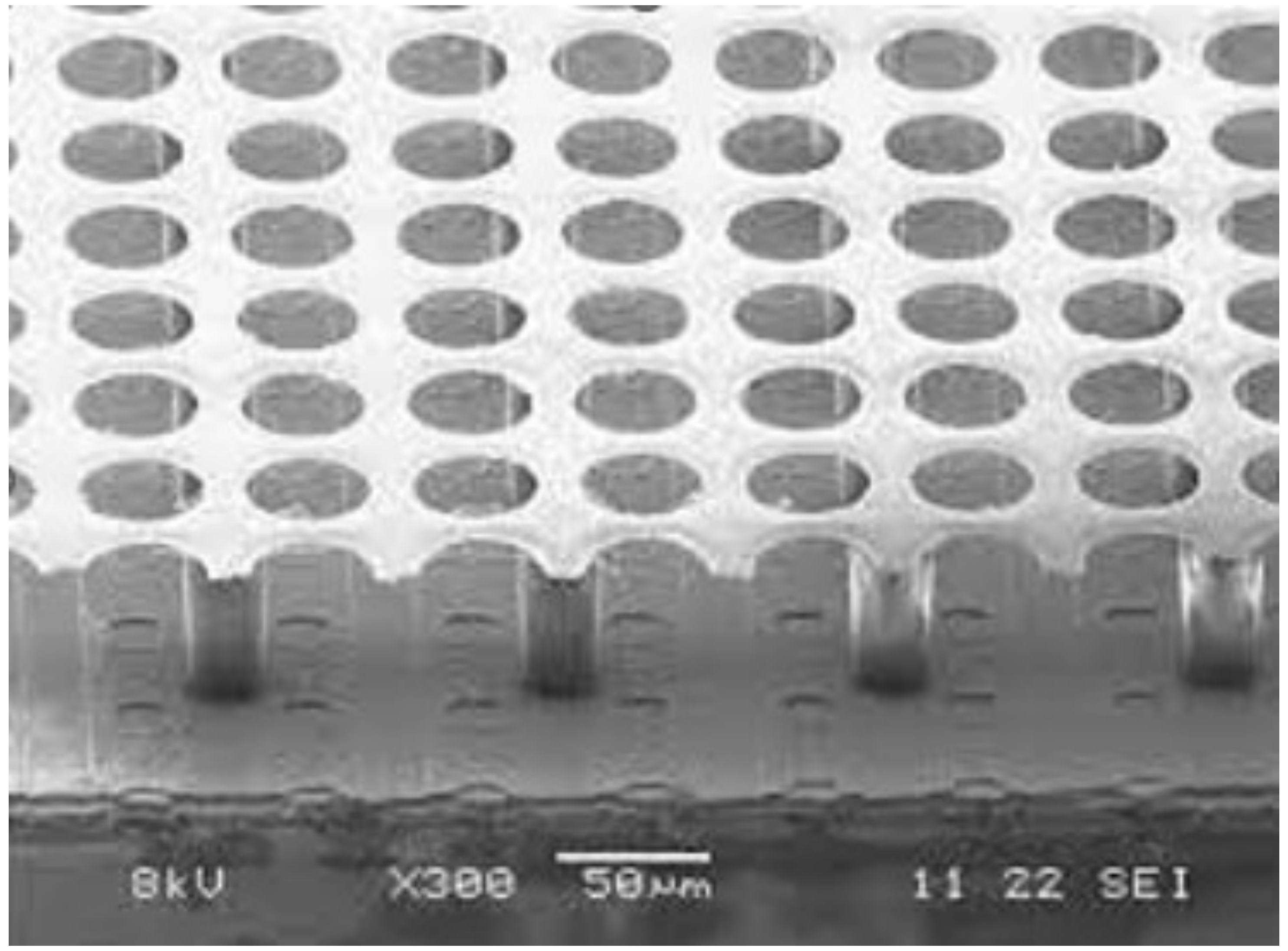


Figure 5: A magnified image of the GridPIX shows the basic operating principle of the chip. An avalanche mesh, similar conceptually to a μMEGAS, amplifies the electron signal across a small gap. Charge in then collected onto 55x55 μm^2 silicon pixels.

Few Words about GridPix

Known and Proven Technology for GridPix

- GridPix is a 55 µm × 55 µm pixel readout for a gaseous TPC
- First Timepix3 based GridPix test beam (2017)
- Quad module performance from test beam (2018)
- Investigations of the 8 quad detector (2020)

Ultimate dE/dx Device

- Avalanche grid in front of 55 x 55 µm2 pixels.
- Greater than 90% efficiency for single electrons.

Goal:

  - Enough diffusion to get every electron into a different hole
  - Count electrons one-by-one.

- Three generations of development and continuing.
- Large area is VERY expensive, but this proposal is small area.

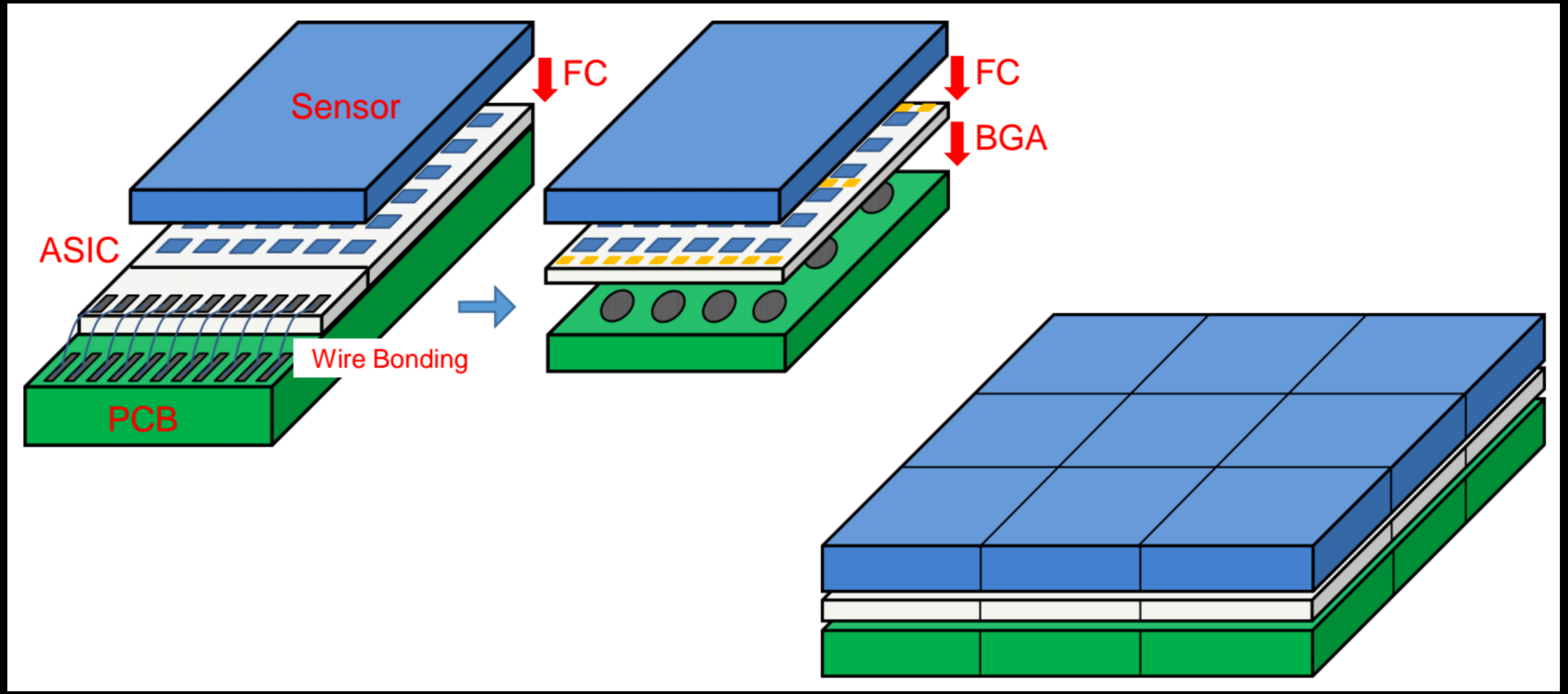
Some References:

- Talk on GridPix for future experiments in Topical workshop on New Horizons in Time Projection Chambers,
- Talk on Timepix4 detectors by X. Llopart in 2nd MUonE Collaboration Meeting at CERN
- PhD thesis on The Pixel-TPC: A feasibility study, by Michael Lupberger

4-sided buttable pixel arrangement

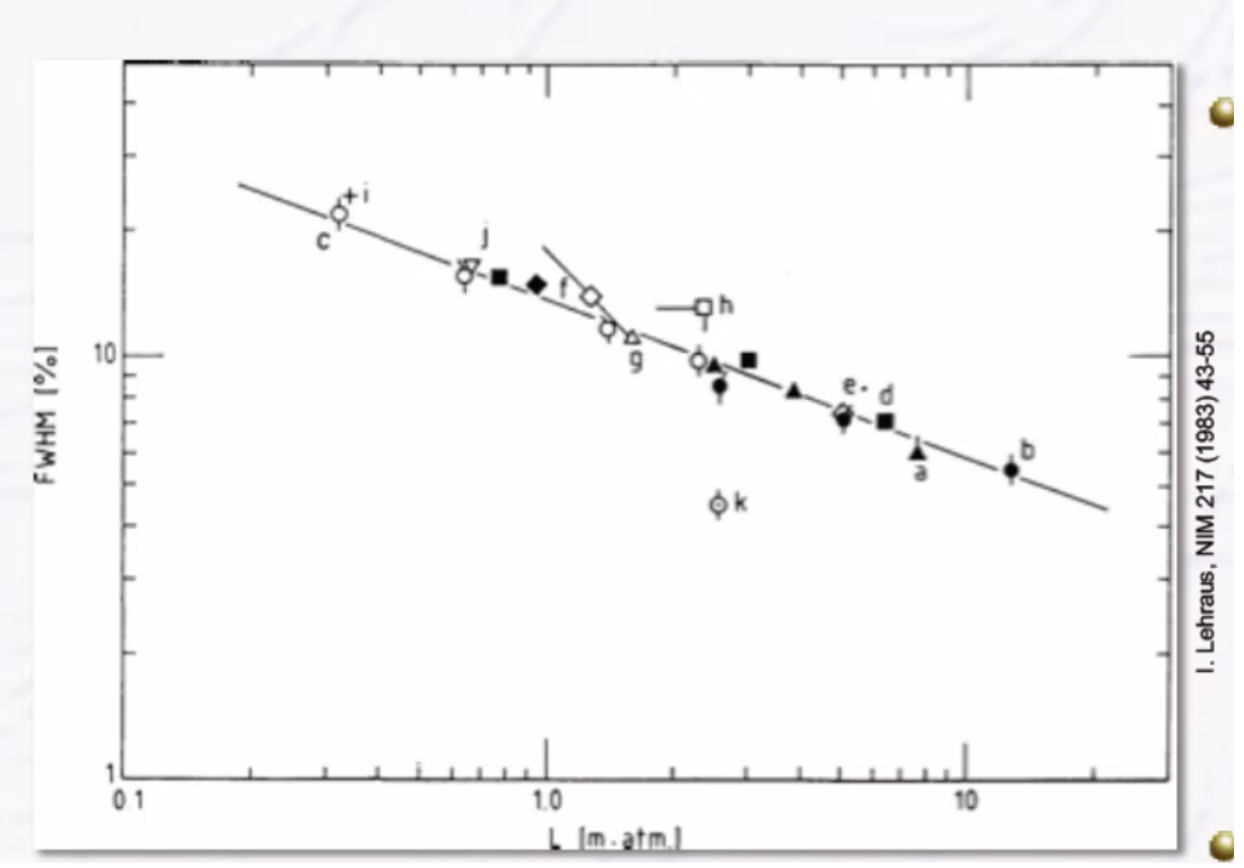
- Model 4 replaces wires bond with bump bond (improves active area) (93.7% -> 99.5% active area)

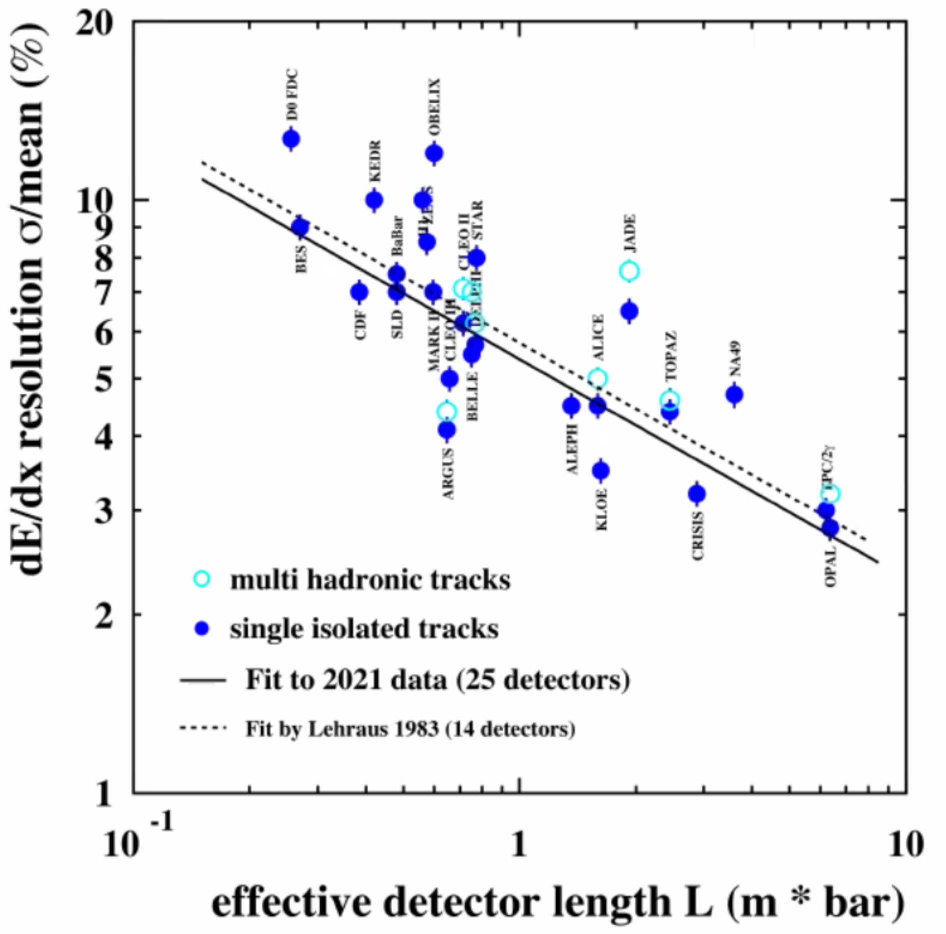
- DAQ interface by Through-Silicon-Vias (TSV).

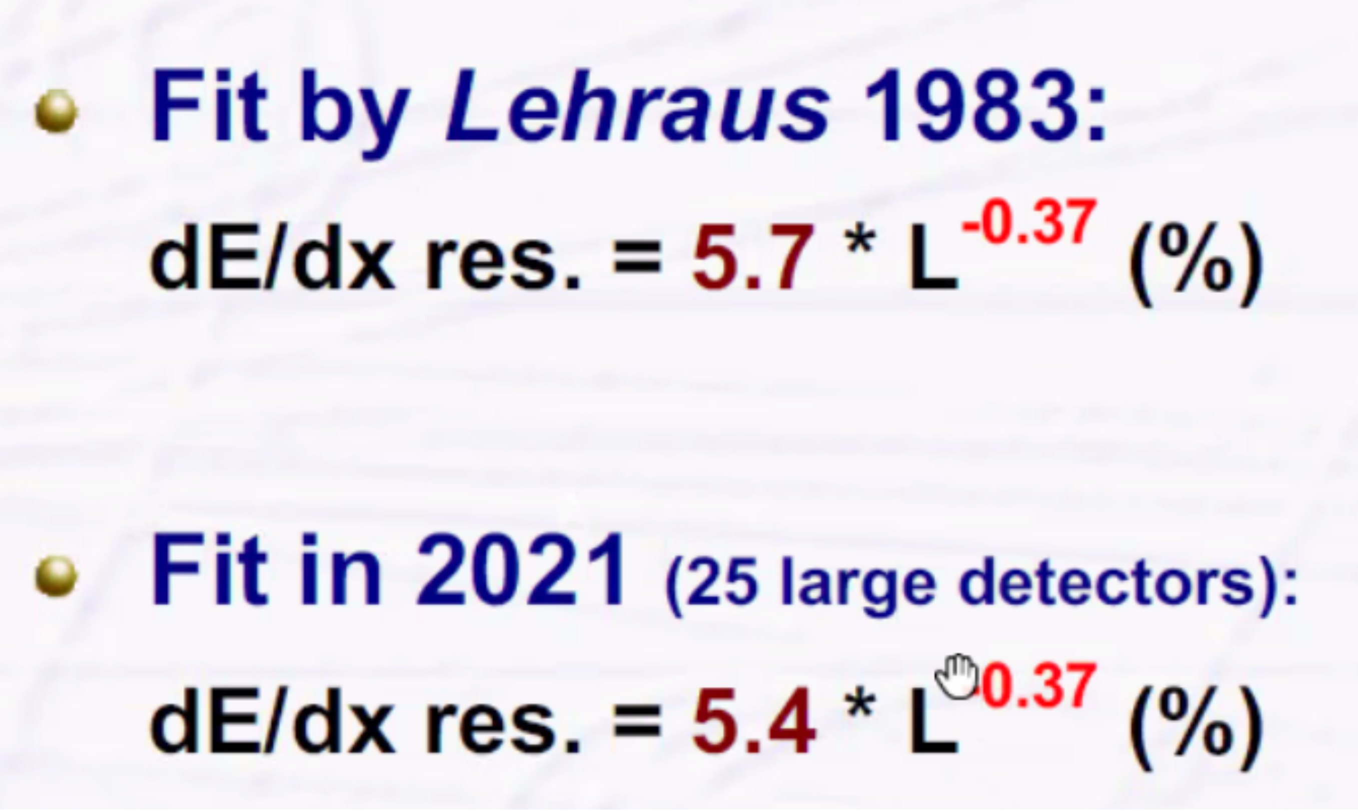


We are in close contact with Jochen Kaminski et. al. from Bonn and having weekly meeting

Anticipated Performance for PID:





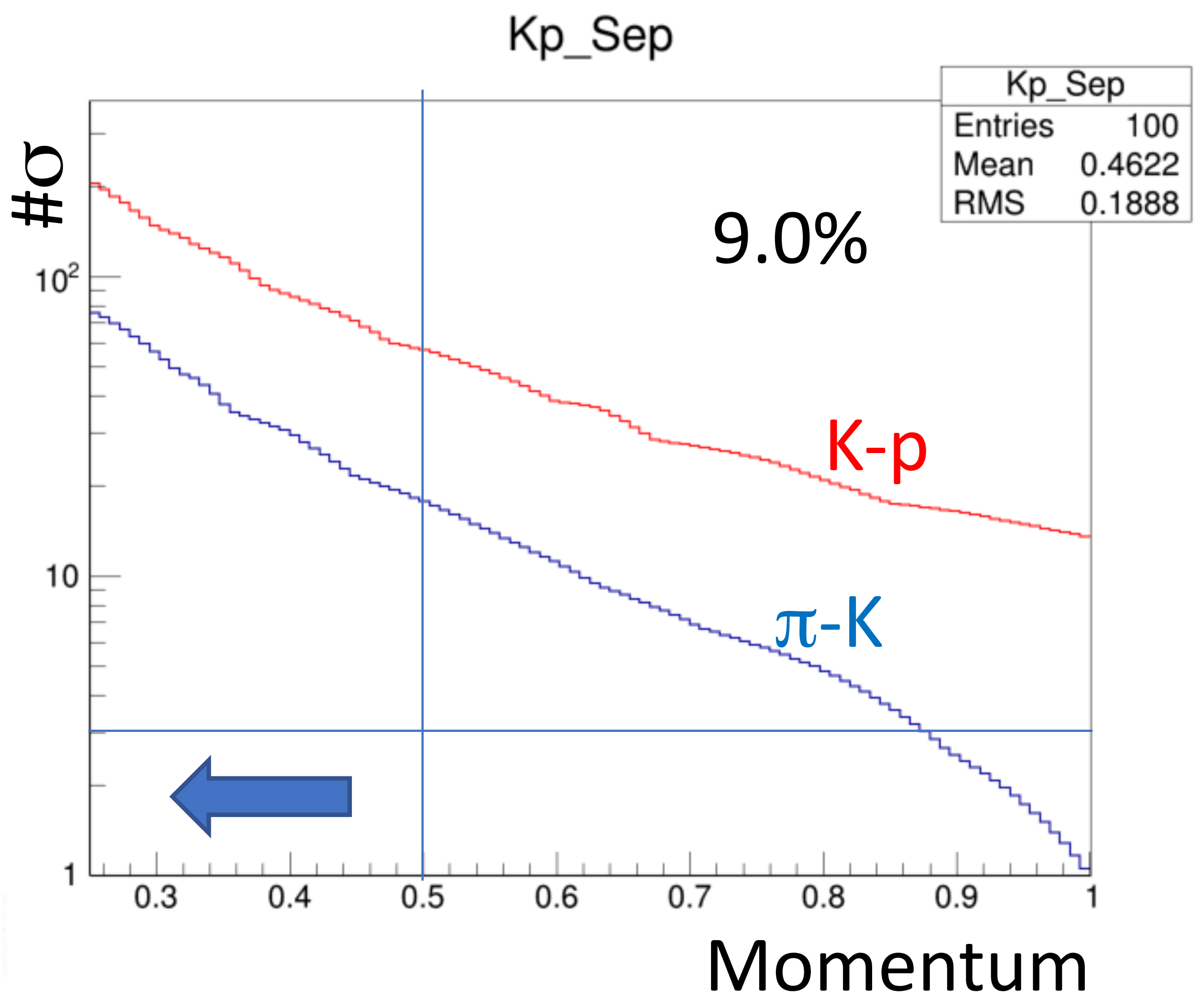


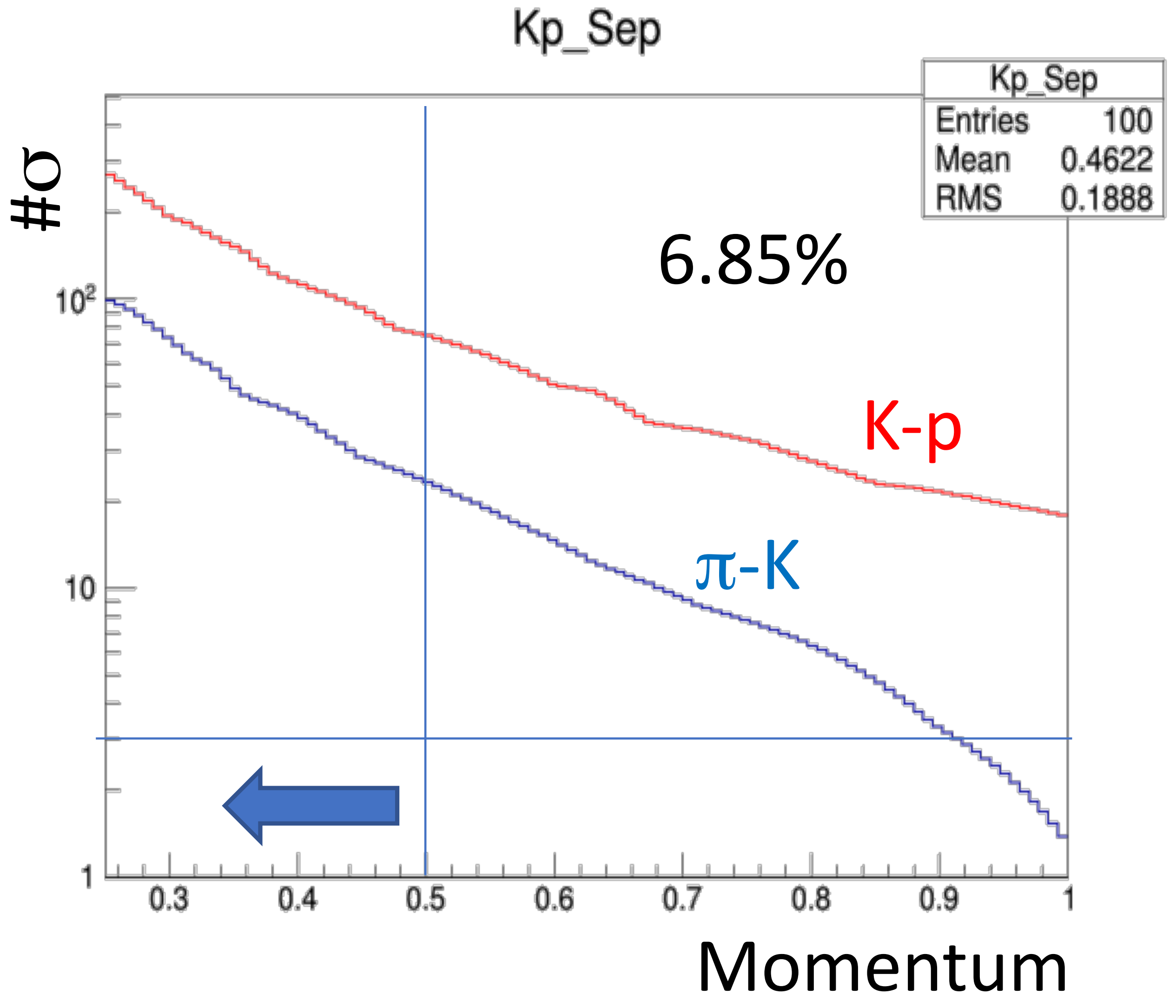
- **Fit by *Lehraus* 1983:**

  dE/dx res. = 5.7 * $L^{-0.37}$ (%)

- **Fit in 2021** (25 large detectors):

  dE/dx res. = 5.4 * $L^{-0.37}$ (%)



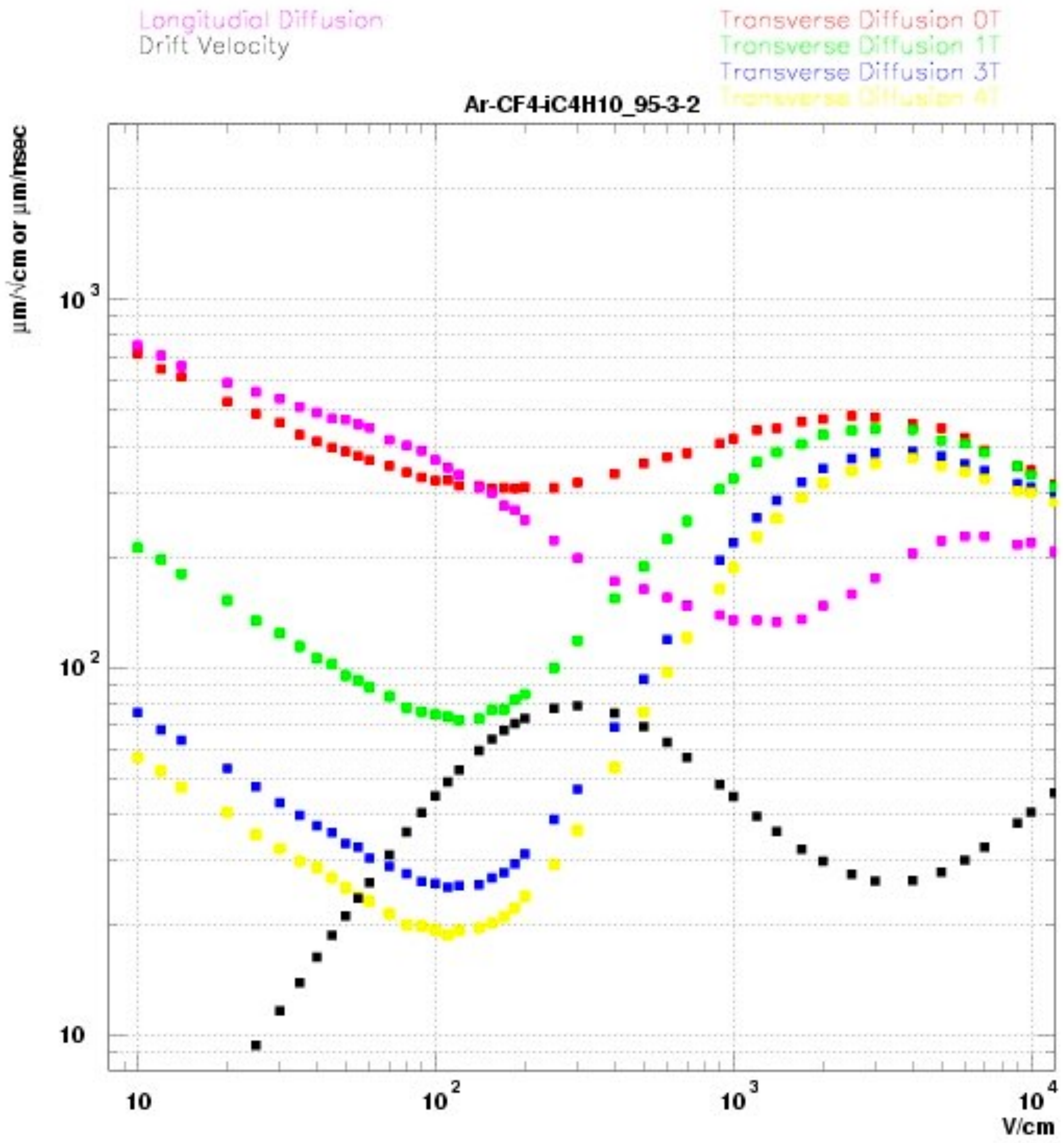


Lehraus Plot

- Using 5.4 as a standard TPC
  - $5.4*(0.25)^{-0.37} = 9.0$
- Measured for GridPIX (truncated Mean)
  - 4.1% at 1 meter
  - $4.1*(0.25)^{-0.37} = 6.85$
    - This was the prior assumption quoted by us.
- Roughly 20 sigma at 0.5 GeV/c
- Useful range overlaps with DIRC

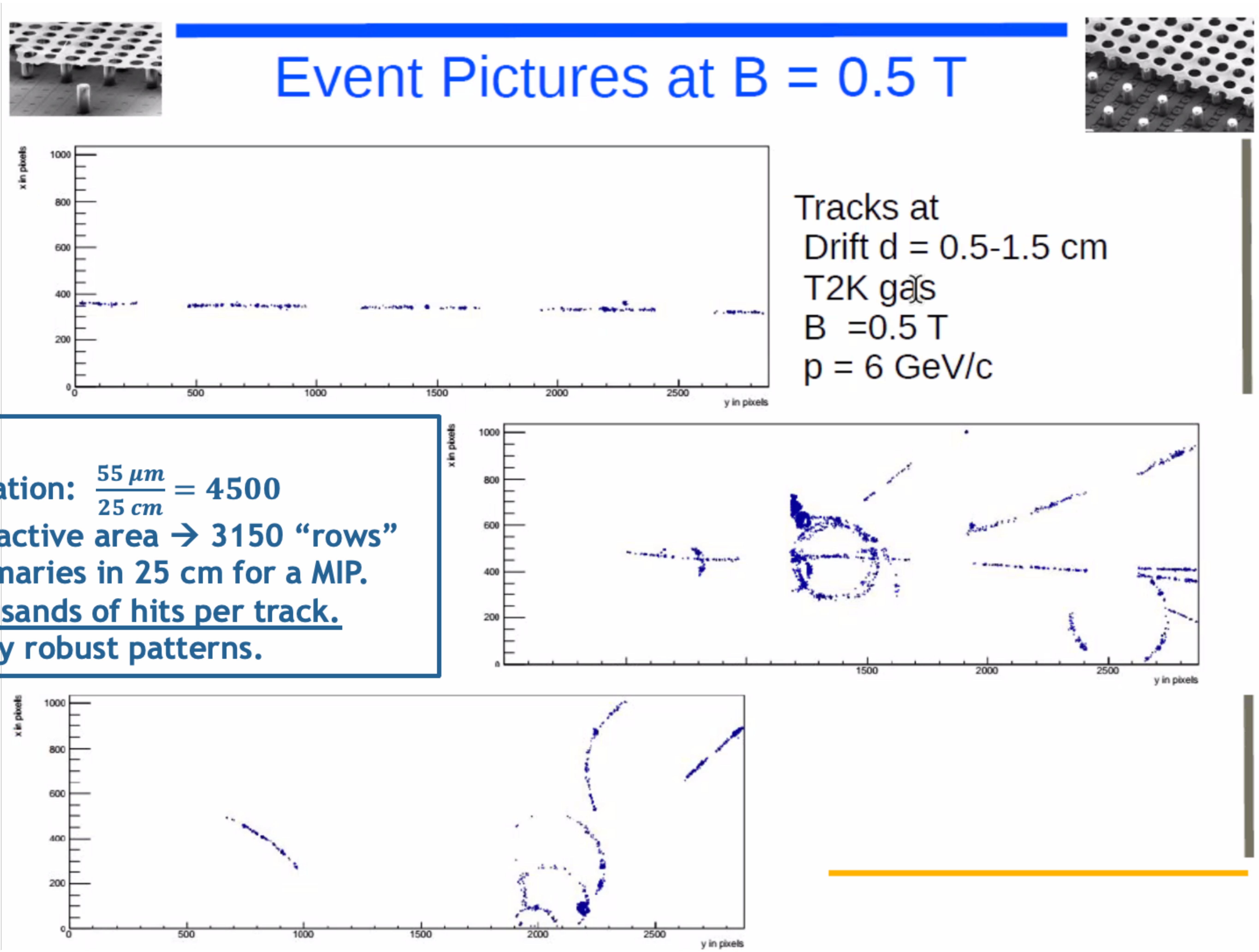
Overly Simplified Momentum Resolution

- Figure of Merit:
  - $\sigma_p \propto \frac{\sigma_{hit}}{\sqrt{N_{meas}}} \equiv Figure\ of\ Merit$
- Can be compared to Silicon with detailed Monte Carlo
- Here is simple-minded estimate
  - $Figure\ of\ Merit(Si) = \frac{\frac{20\ \mu m}{\sqrt{12}}}{\sqrt{4}} = 2.9\ \mu m$
  - Gas:
    - Including efficiency ~3000 electrons (minimum!) per track
    - Each suffers digitization (σ = 55 μm/sqrt(12) = 16 μm)
    - Diffusion(Length) = $25 \frac{\mu m}{\sqrt{cm}} \sqrt{L}$
      - D(2cm) = 35 μm → FOM = 0.70 μm
      - D(25cm) = 125 μm → FOM = 2.3 μm
      - D(50cm) = 176 μm → FOM = 3.2 μm
      - D(100cm) = 250 μm → FOM = 4.6 μm
  - Although ignoring many significant effects,
    initial result is on the order of the layers of silicon.



Event Topology and Synchrotron Radiation:

June 2021



Event Pictures at B = 0.5 T

Tracks at
Drift d = 0.5-1.5 cm
T2K gas
B =0.5 T
p = 6 GeV/c

Overview:

- Segmentation: $\frac{55\ \mu m}{25\ cm} = 4500$
  - 70% active area → 3150 “rows”
- 2400 primaries in 25 cm for a MIP.
  - Thousands of hits per track.
- Extremely robust patterns.

Particle Identification via velocity measurement

(Velocity dependent interaction with the detector via. specific ionization)

Traditional charge counting vs cluster counting

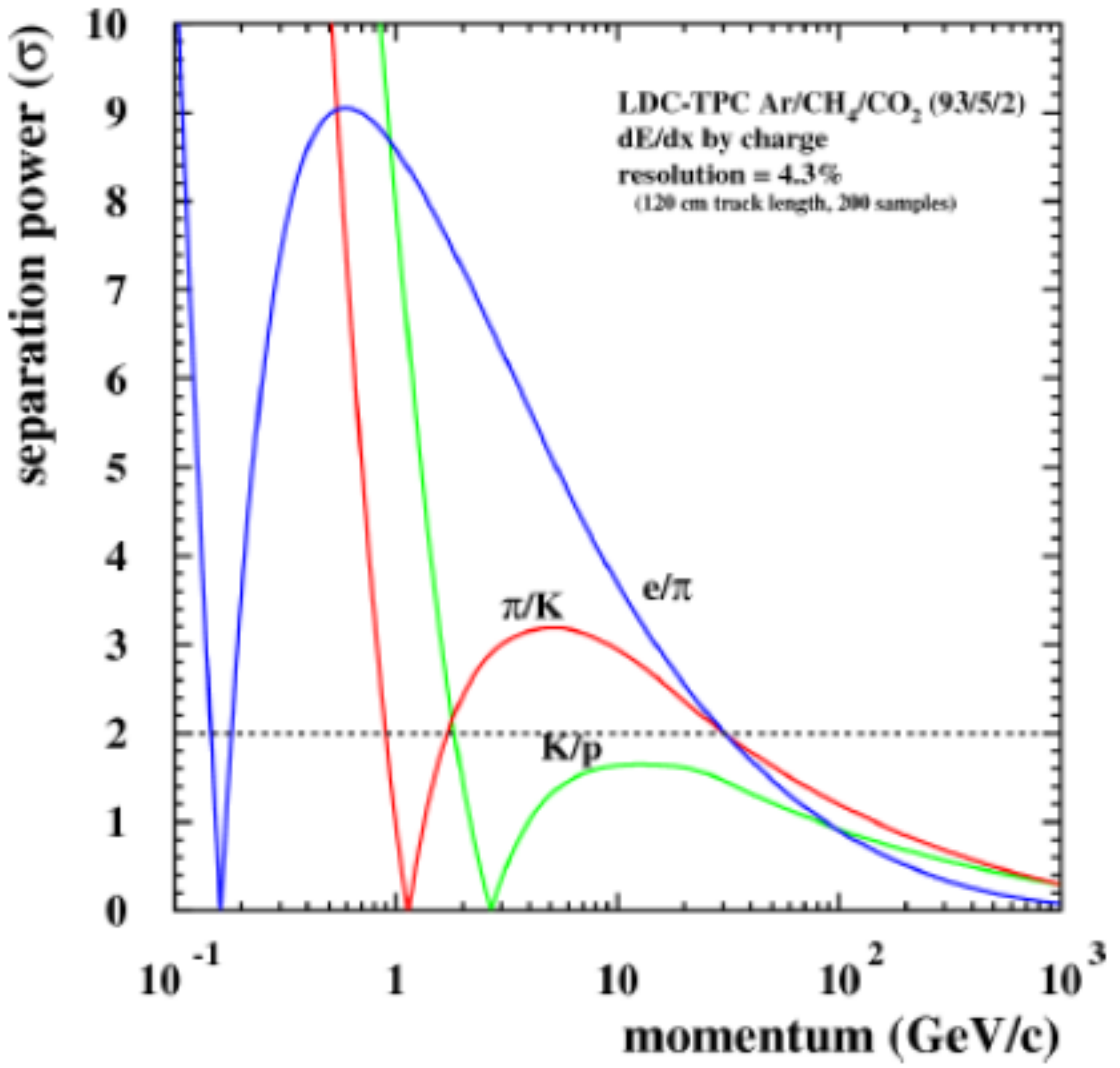


Figure 5: Separation power for charge counting, with energy resolution of 4.5% and track lengths of 120 cm and 200 samples along the track.

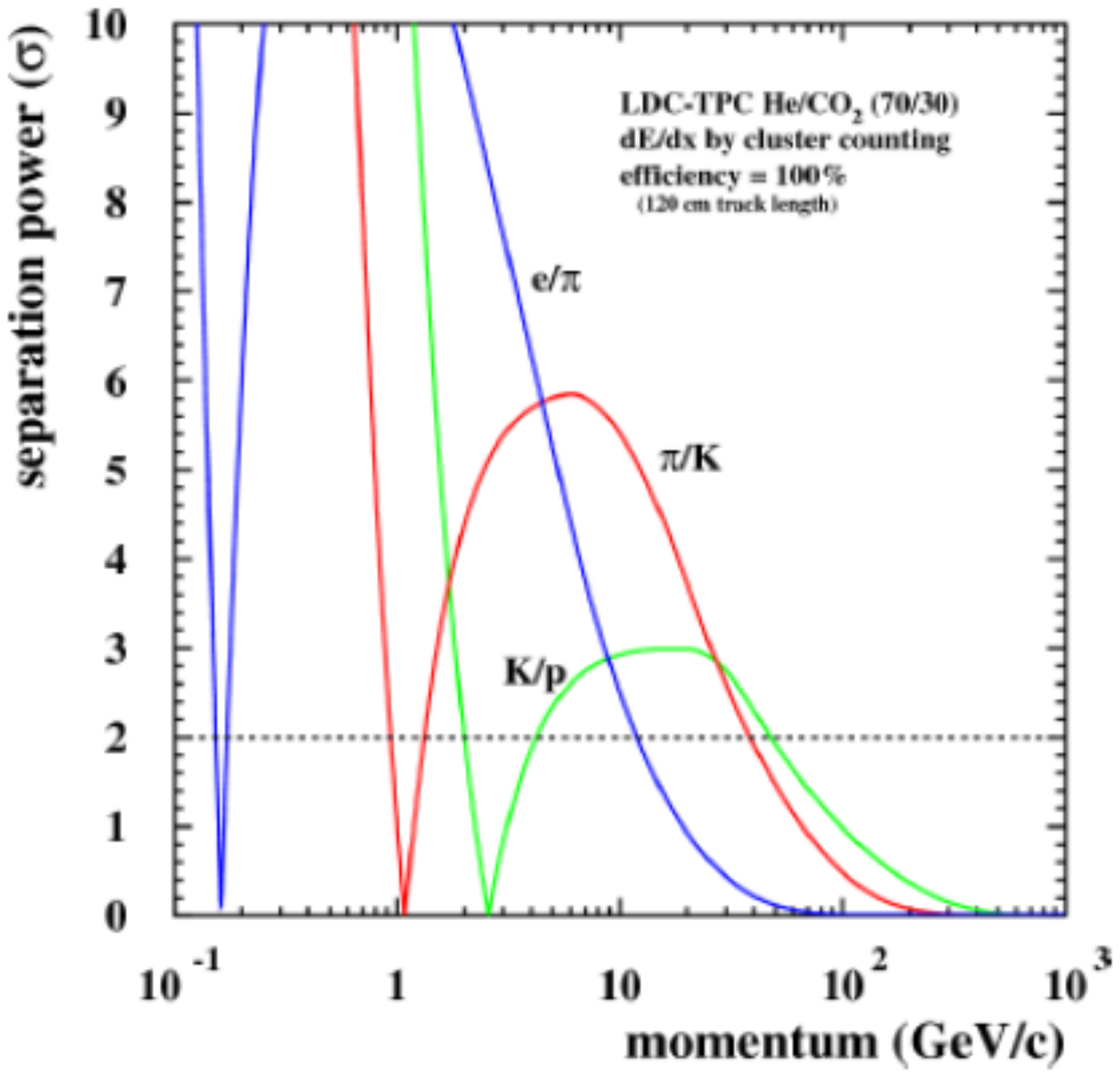
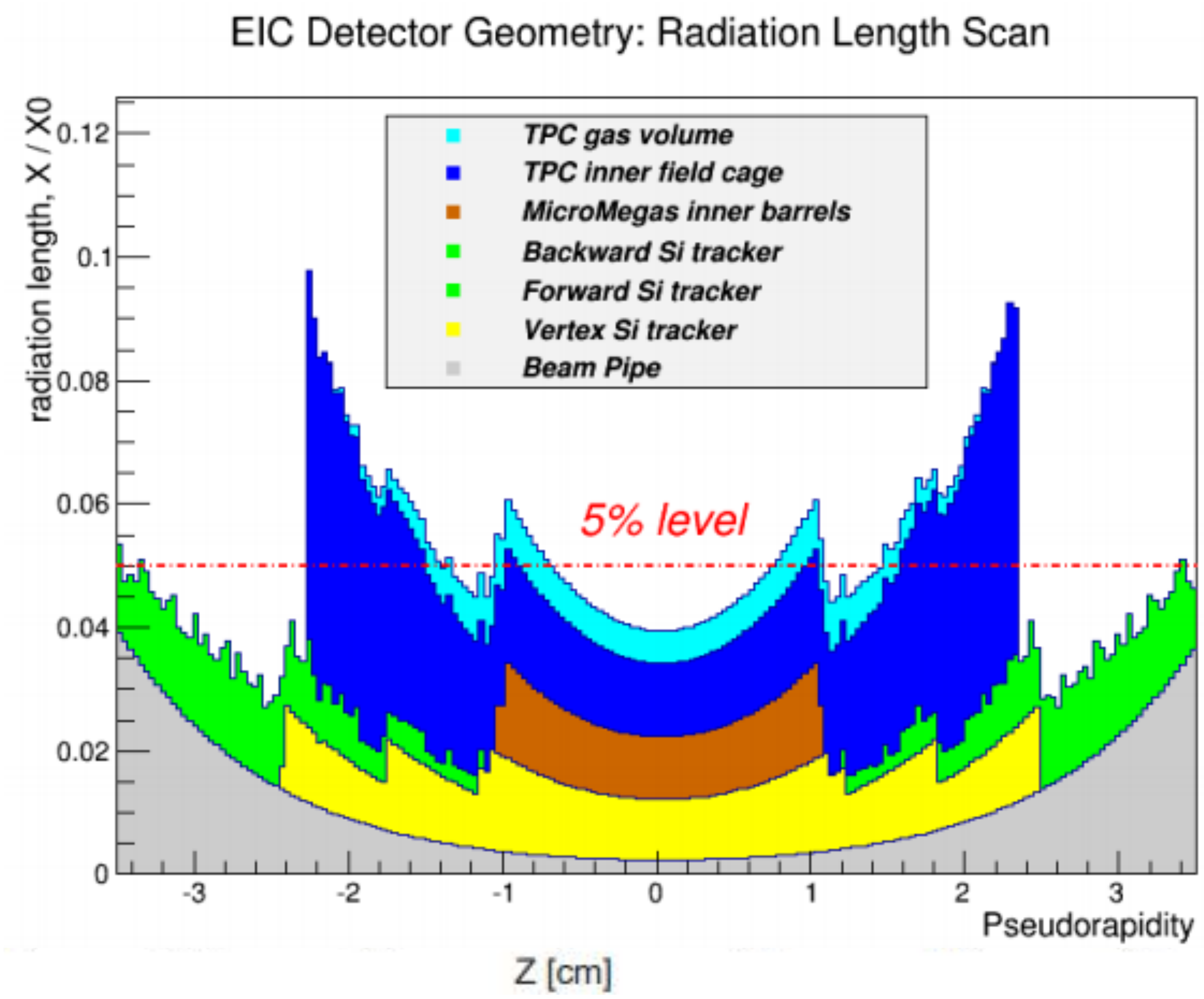
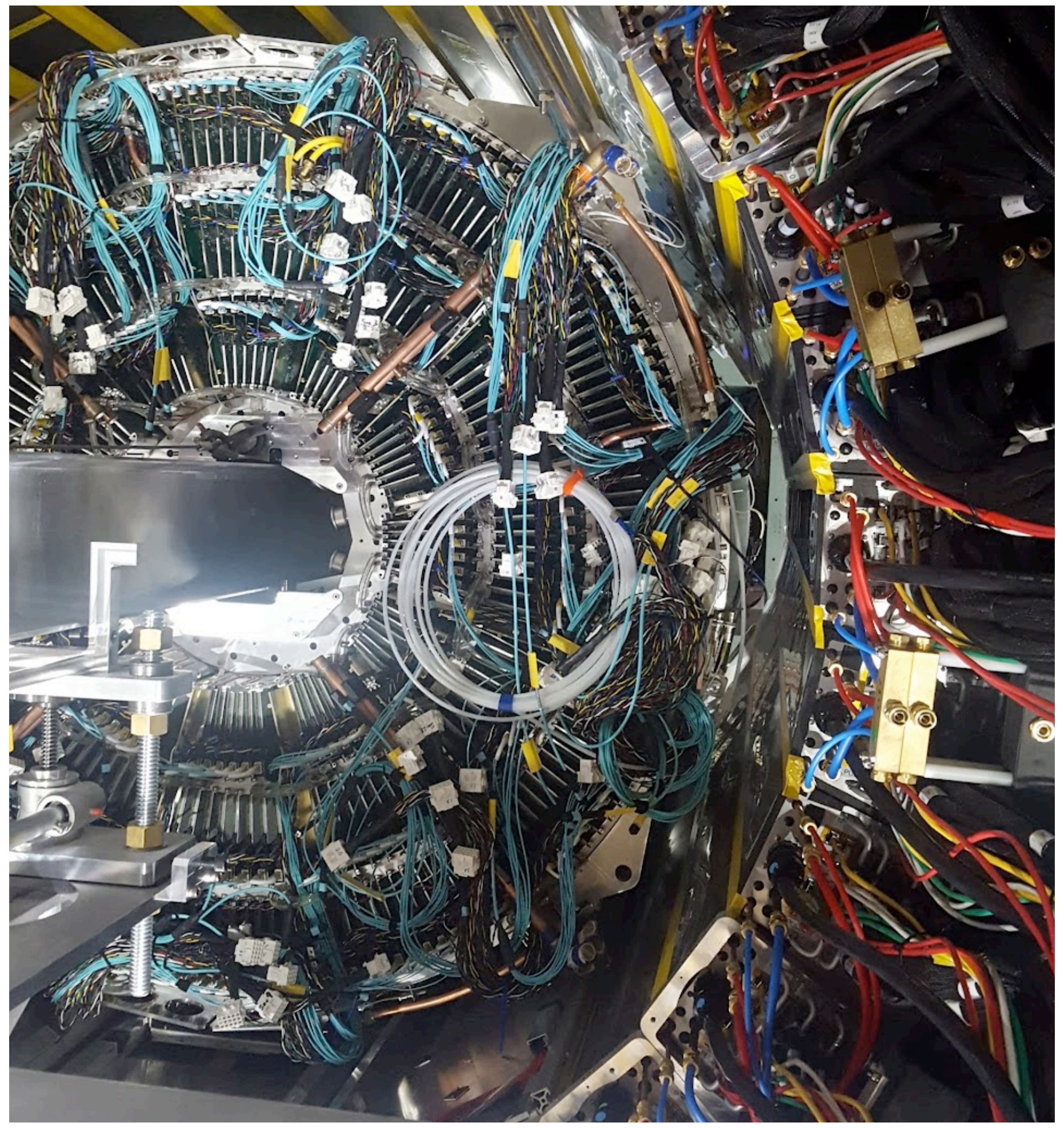


Figure 6: Separation power for cluster counting, for the same gas and track length as in Figure 5. A 100% counting efficiency is assumed.

Typical Radiation Length Scan





STAR TPC as an example:

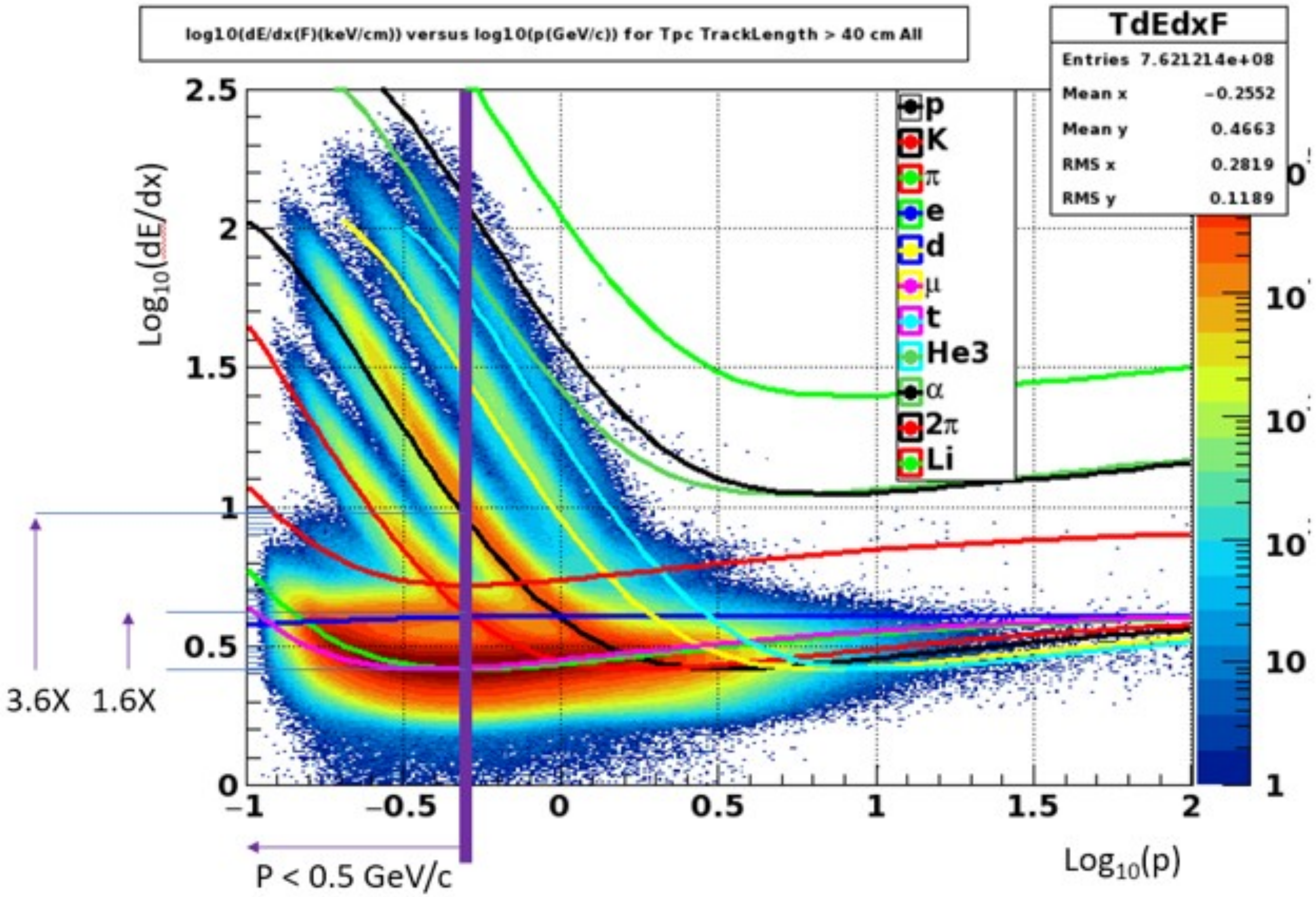


Figure 7: $\frac{dE}{dx}$ measured in the STAR TPC. The figure illustrates that the although $\frac{dE}{dx}$ measurements can be challenging in the region of the relativistic rise, the low momentum regime is comparatively simpler.

Large Space & Material Budget of end cap makes TPC less attractive e.g. for EIC

Smaller Space, single ended readout & less Material Budget of end cap can make GridPix more attractive for EIC

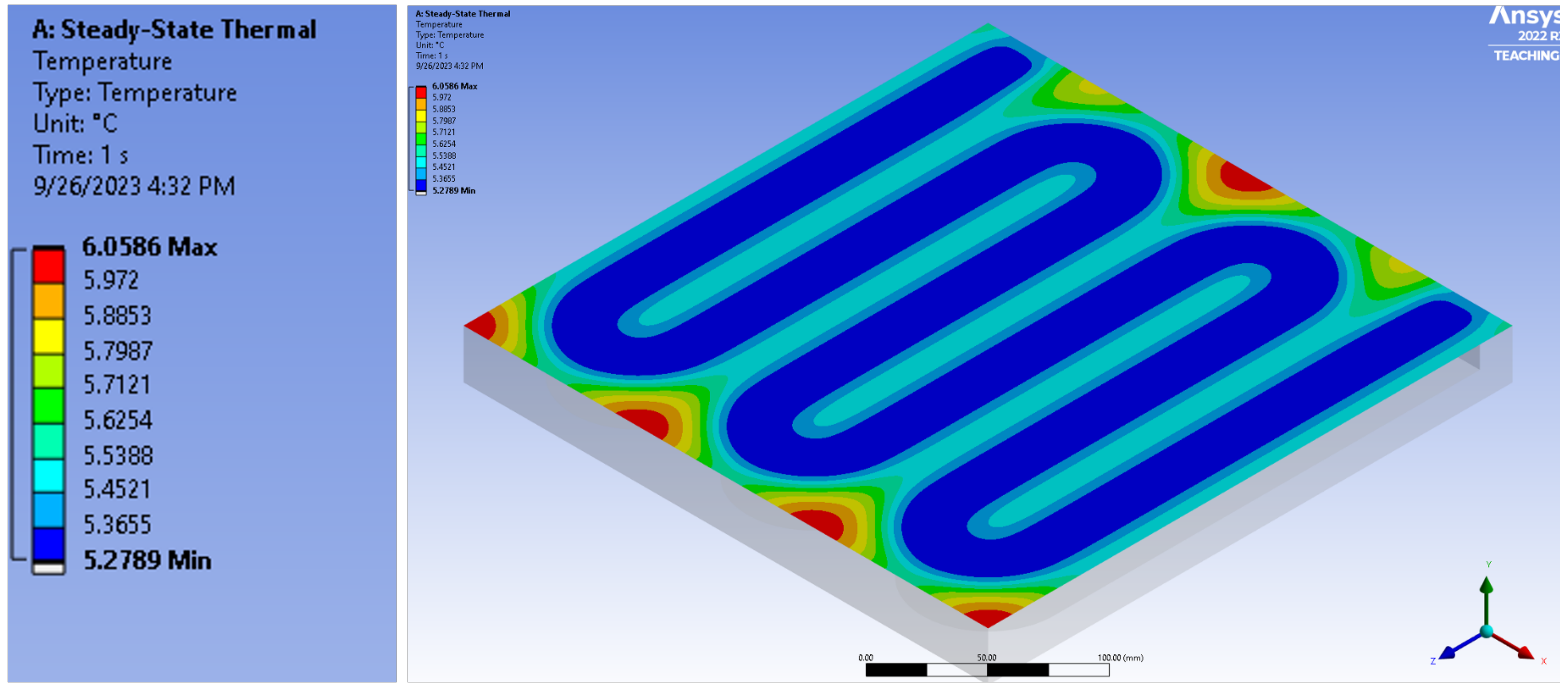
Motivation to CO2 cooling

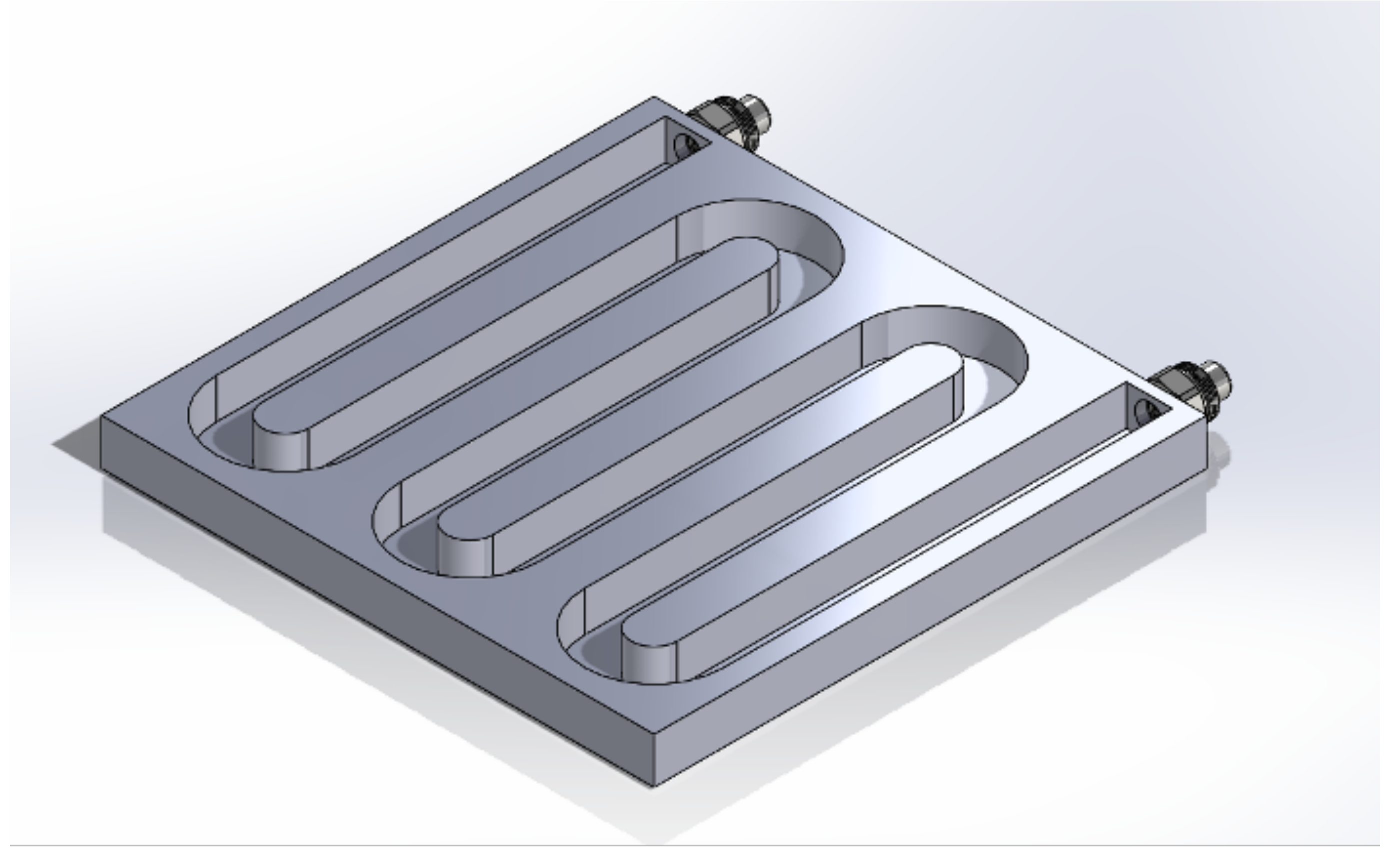
- **Careful: 1.2 - 5.4 kW of power (occupancy dependent)**
- **Conventional water cooling is bulky**
- **Water cooling is not uniform (Important for single electron counting)**

➡ **In general it would be of interest for other detector systems at EIC**
➡ **Plan Is to build a portable CO2 cooling system which can be used by others**

Pros:
- Known/Proven Technology
- Active further development (Bonn)
- Best $\frac{dE}{dx}$ possible (~count each electron)
- Affordable for a small area
- High resolution tracking
- Low mass in electron arm
- Continuous (aka streaming) readout

Cons:
- ~3 kW of power:
- Must find a low mass way to handle.
- Services “bulky” (compared to just Si)
  - Gas
  - HV membrane
  - Cooling
  - DC power lines (3kV goes in too)





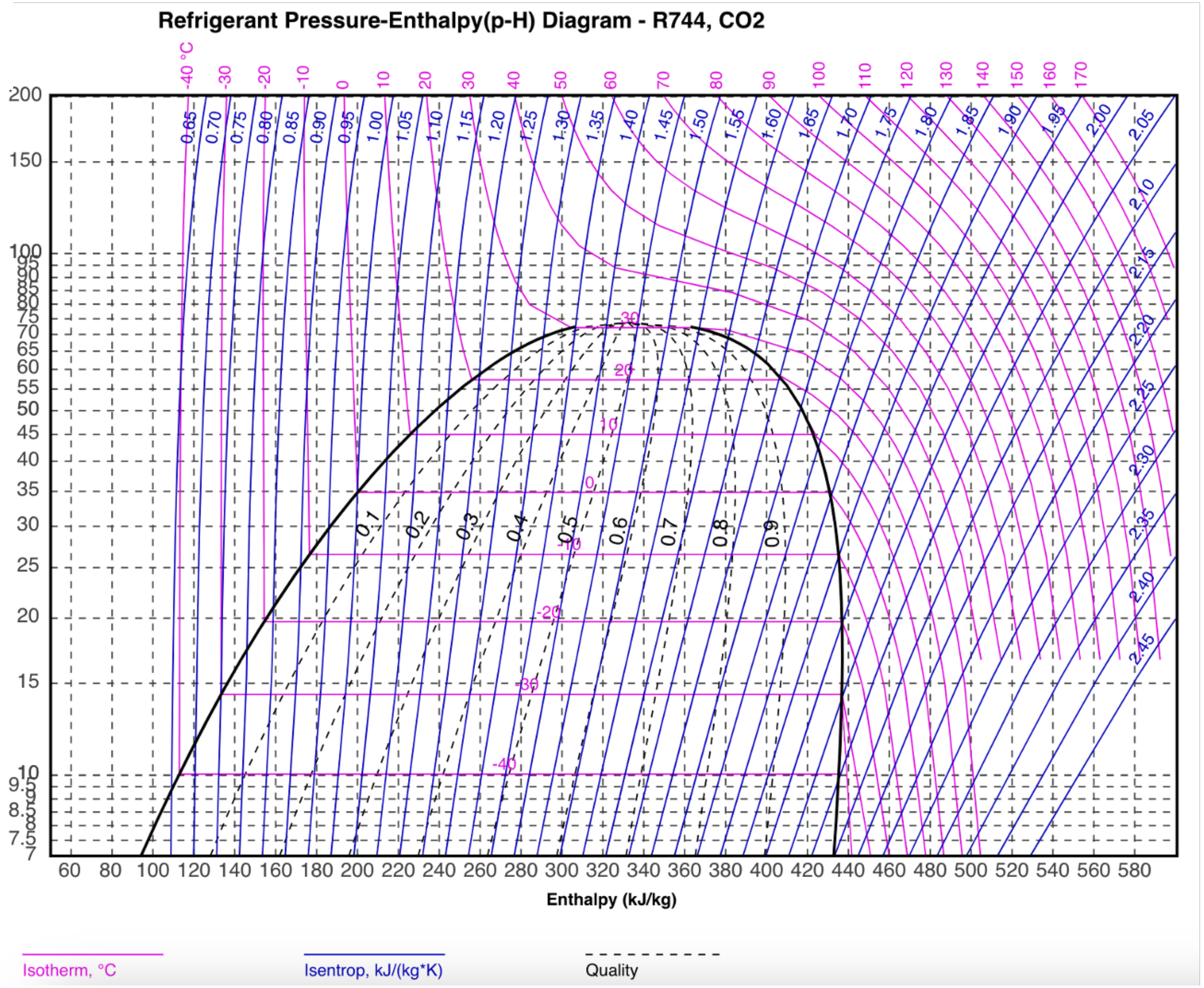
The TPC with two phase CO2 cooling

The thermo-physical properties of CO2 make it an attractive gas for cooling in particle detectors:

- CO2 has a high volumetric cooling capacity, because of its large latent heat.
- Does not require a high flow rate or corresponding tubing
- Low viscosity facilitating a uniform flow
- Non-toxic
- Radiation hard
- The pressure controls the evaporation temperature, and at 65 bar it can take out heat at room temperature.
- A CO2 cooling system is expected to be able to extract the generated ~kW of heat per end plate.

P-H Chart

Point on graph	Description	Pressure (bar)	Temperature (°C)
1	CO_2 bottle	59	20
2	Entry to HX annulus	55	18.3
3	Exit from HX annulus	55	15.4
4	Entry to Environment chamber	50.9	15
5	Exit from Environment chamber	50.9	15
5a	Entry to HX shell	50.9	15
6	Exit from HX shell	50.9	15



Summary

- ◉ **Large Material budget -> A significantly reduced material budget with GridPIX**
- ◉ **Large Volume -> Relatively smaller Volume, take advantage of cluster counting**

➡**Recently got approved for generic R&D @EIC**

https://www.jlab.org/research/eic_rd_prgm/receivedproposals

➡**More Test Beam results will be exciting to check the performance**