A POSSIBLE TPC TRACKER FOR DET-II@IP8

- Klaus Dehmelt

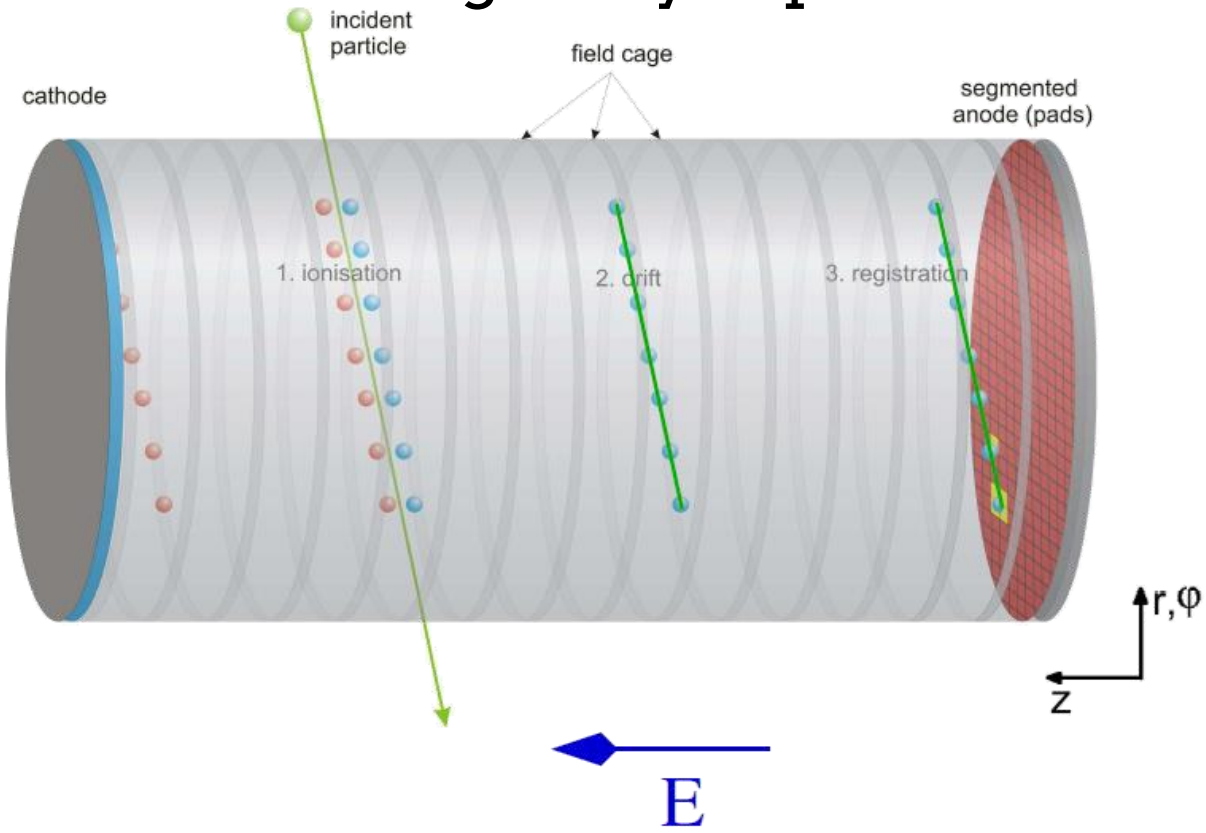
- Open Detector-II Meeting & Discussions
- April 09, 2024

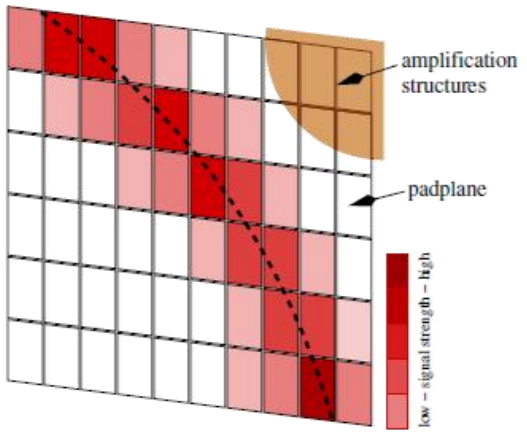
TIME PROJECTION CHAMBER

- A Time Projection Chamber for DET-II@IP8
  - TPC can serve multi purposes
    - Tracking
    - Pattern recognition
    - Momentum determination
    - Particle identification

TIME PROJECTION CHAMBER

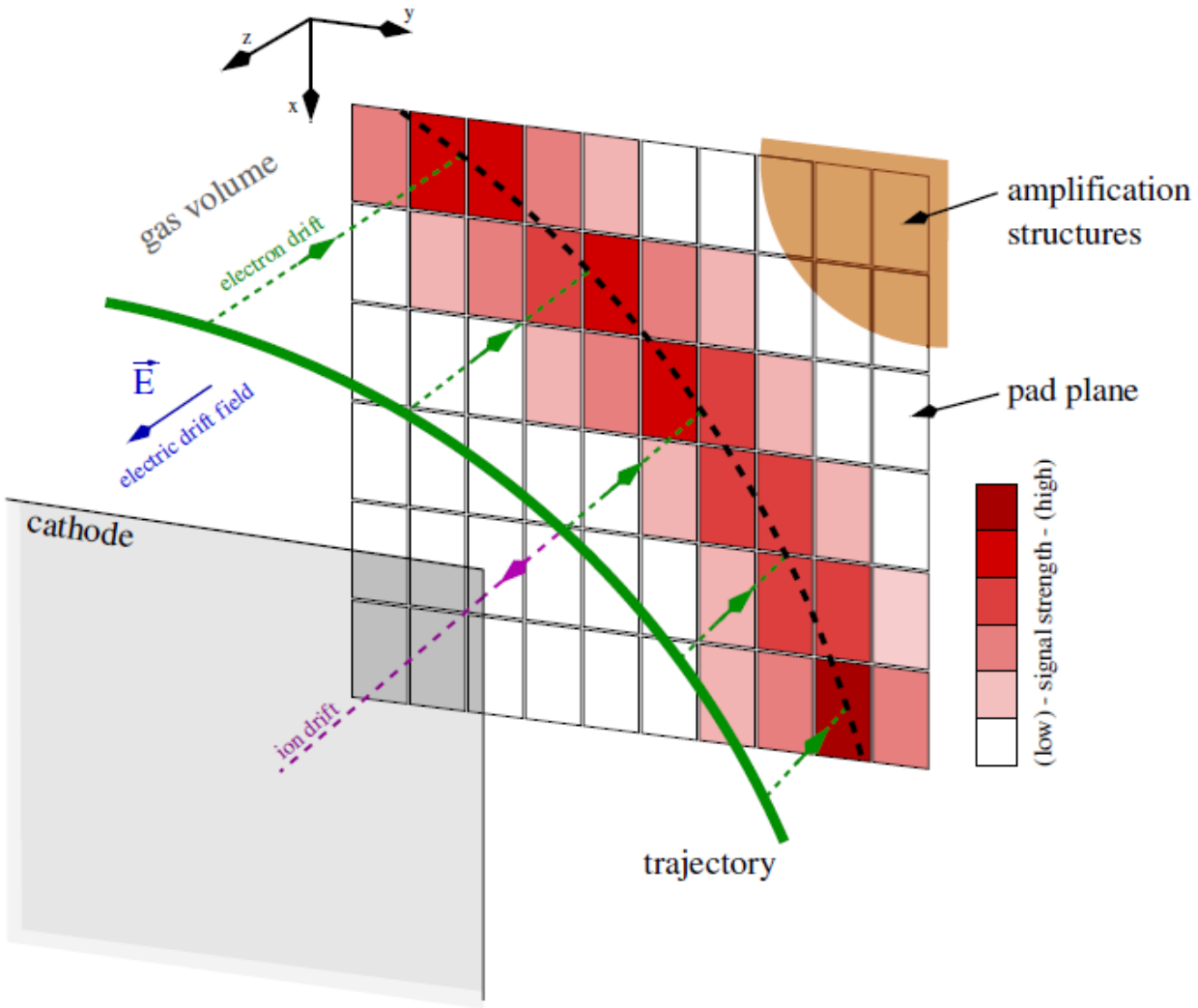
- A Time Projection Chamber for DET-II@IP8
  - Gas ionization → drift → amplification → sampling on pads
  - Reconstruction of z-coordinates from drift time
  - Electric field homogeneity important for undisturbed projection





TIME PROJECTION CHAMBER

- A Time Projection Chamber for DET-II@IP8



TIME PROJECTION CHAMBER

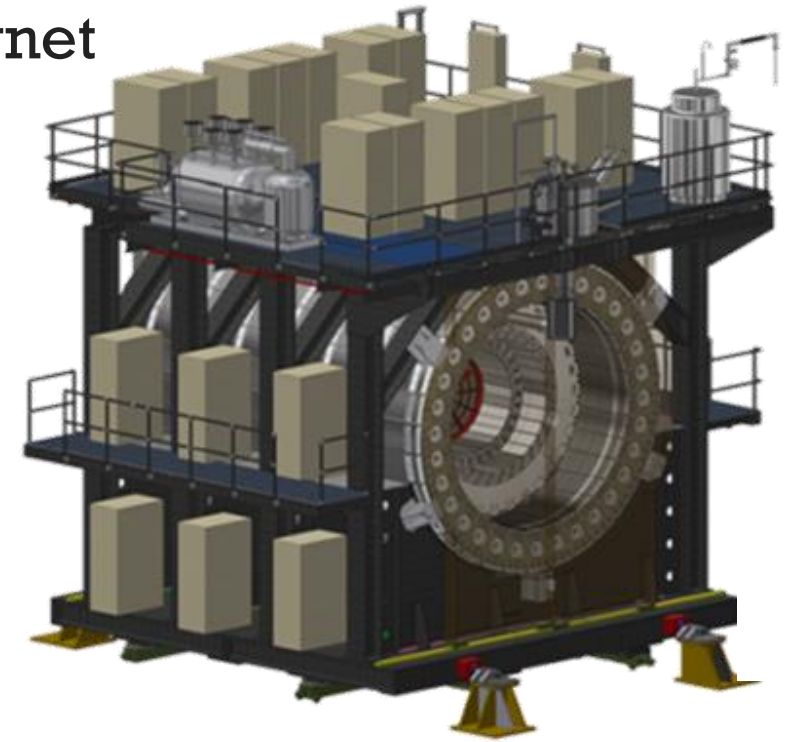
- A TPC for DET-II@IP8
  - What are the constraints on length and outer radius?
  - What field uniformity is required?
  - What are the limitations on angular resolution
    - At the vertex?
    - At r_{max}?
  - What PID capabilities are possible?
  - What are the material budgets?
  - Integration issues with other detectors?

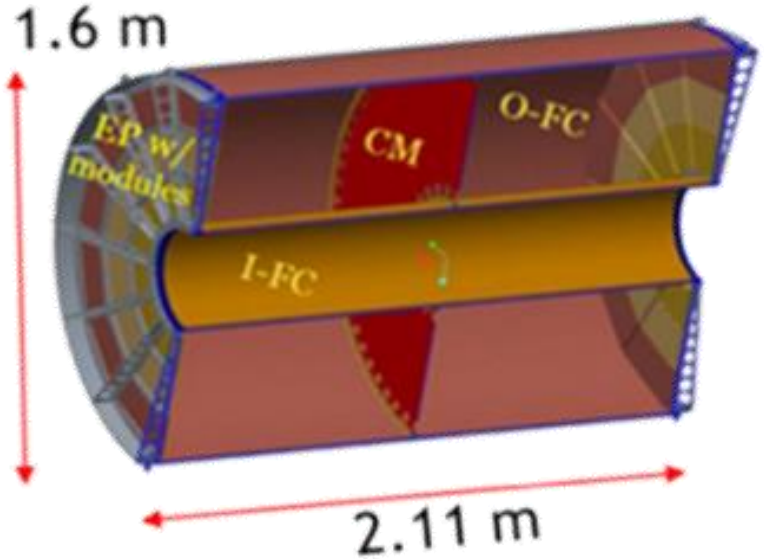
TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8
  - What are the constraints on length and outer radius?

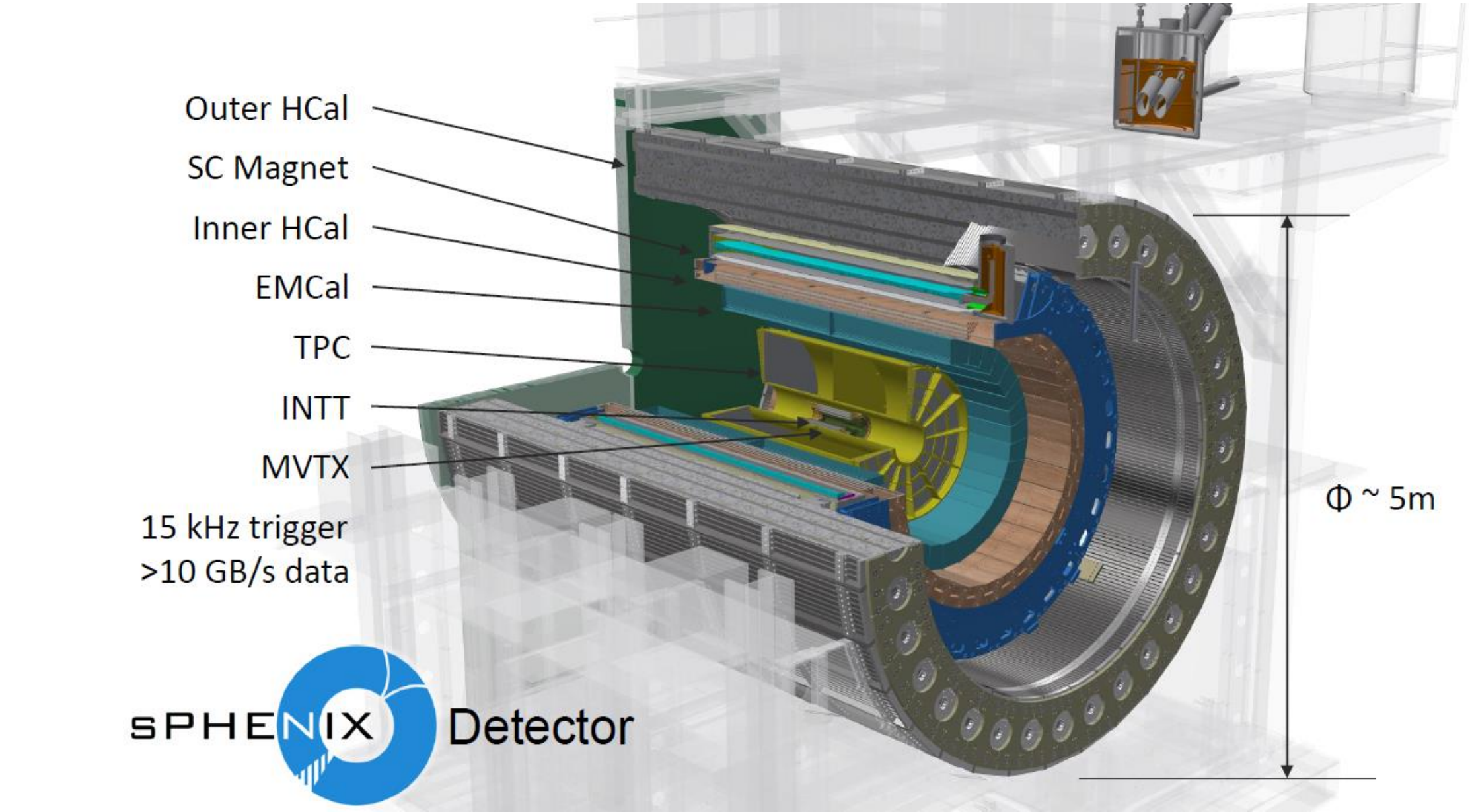
Typically, one wants to cover central rapidity $\eta \approx \pm 1 \rightarrow$ diameter ≈ length – constraint is magnet

sPHENIX within Babar magnet





TIME PROJECTION CHAMBER



TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8
  - What field uniformity is required?

TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8

  - What field uniformity is required?
    - Two field configurations to be considered
      - Magnetic field
      - Electric field

$$\vec{v}_{\text{drift}} = \frac{\mu E}{1+(\omega\tau)^2}\left[\hat{E} + \omega\tau\hat{E}\times\hat{B} + (\omega\tau)^2(\hat{B}\cdot\hat{E})\cdot\hat{B}\right]$$

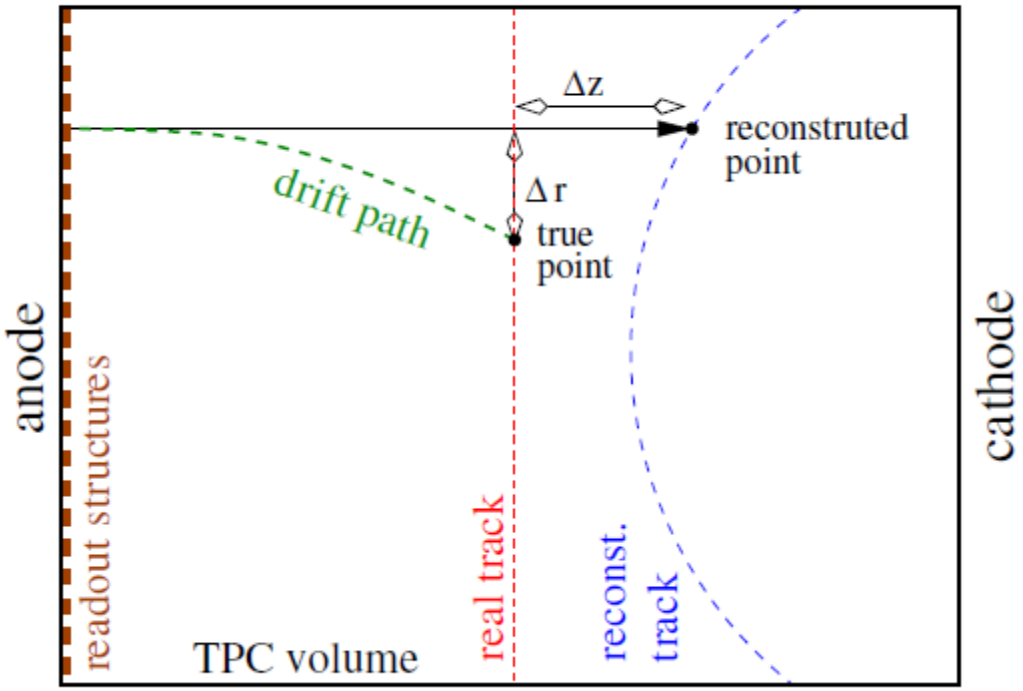
$\hat{B}, \hat{E}$: unit vectors along B/E-field

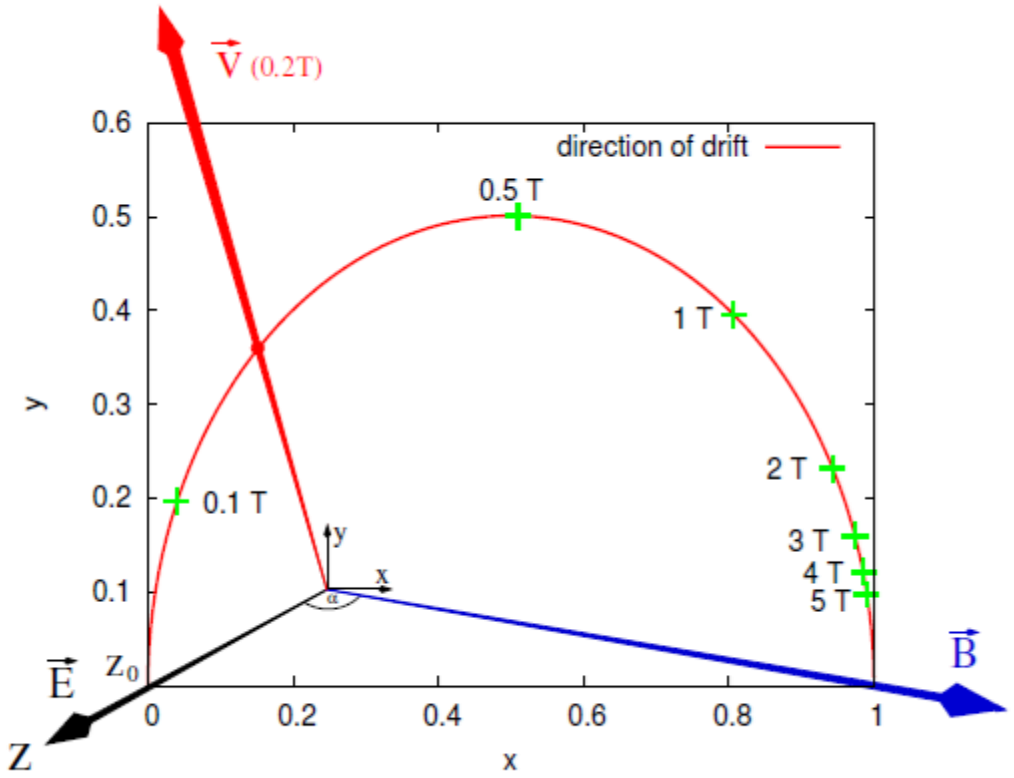
$$v_{\text{drift}} = \mu E \qquad \text{if} \qquad \vec{E}\times\vec{B} = \vec{0}$$

TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8

  Effect of non-parallel alignment of E- and B-field





TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8
  - Momentum resolution dictates space point resolution
  - Space point resolution (in a TPC) dictates field homogeneity

$$\frac{\sigma_p}{p} \propto \sigma_x * \frac{p_T}{BL^2\sqrt{N_{Pad\ Rows}}}$$

Fixed

  - Typically, modern experiments require σ_x of 100 μm or better
  - Resolution degradation of at most 5% require

$$\Delta E/E \lesssim 10^{-4} \qquad \int_0^z \frac{B_r}{B} dz \lesssim 3\,\mathrm{mm}$$

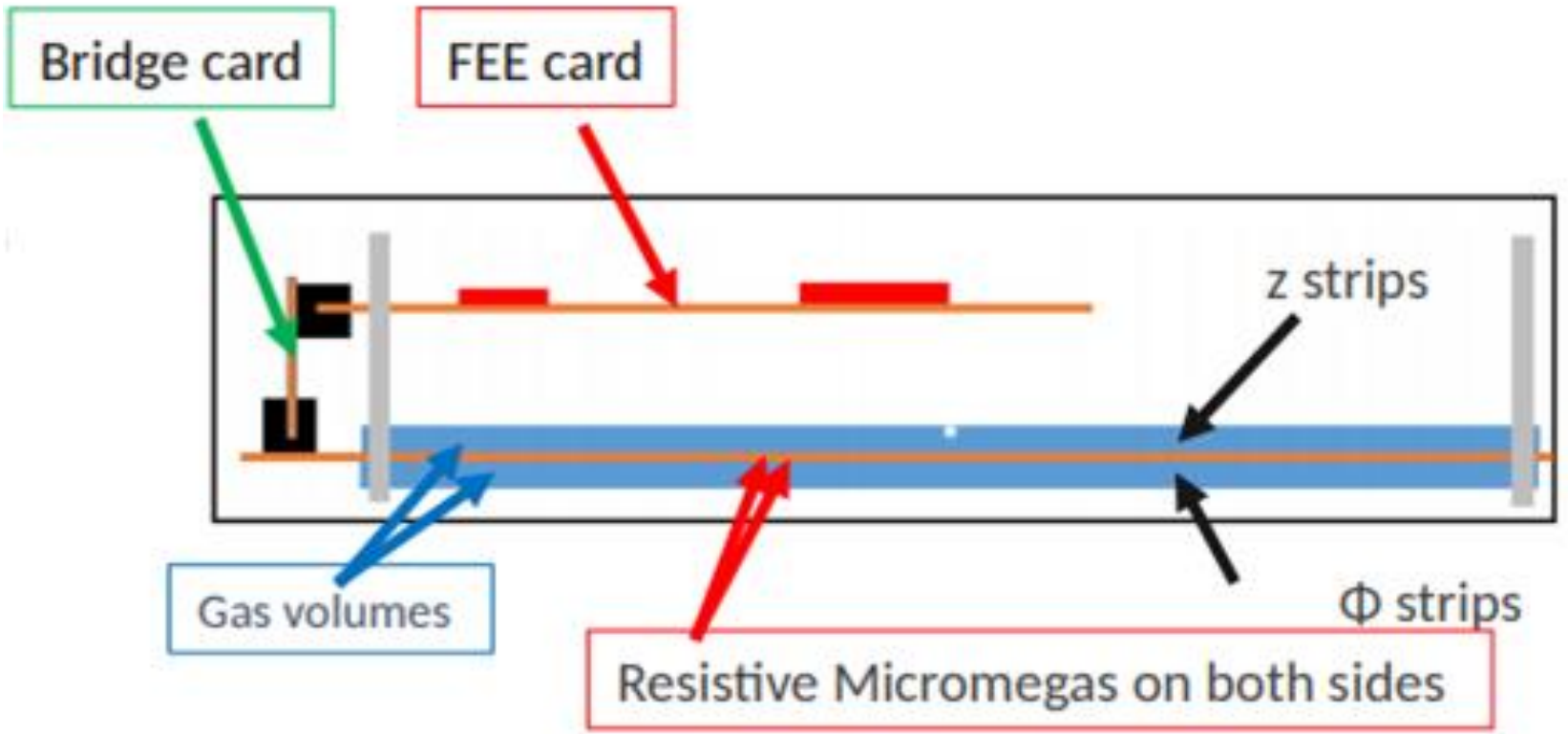
TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8
  - What are the limitations on angular resolution
    - At the vertex?
    - At r_{max}?

TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8
  - A TPC has a multitude of point measurements
    - ~50 in the sPHENIX TPC
    - $\mathcal{O}(200)$ in the ALICE TPC
  - A TPC measures space points with a ten-fold worse resolution as compared to Si-detectors
  - A TPC is a slow readout device
    - Distortion of z-position
    - Can have impact on entrance/exit point determination in the TPC
    - Can be circumvented with the introduction of "fast" entrance/exit point measurement

TIME PROJECTION CHAMBER



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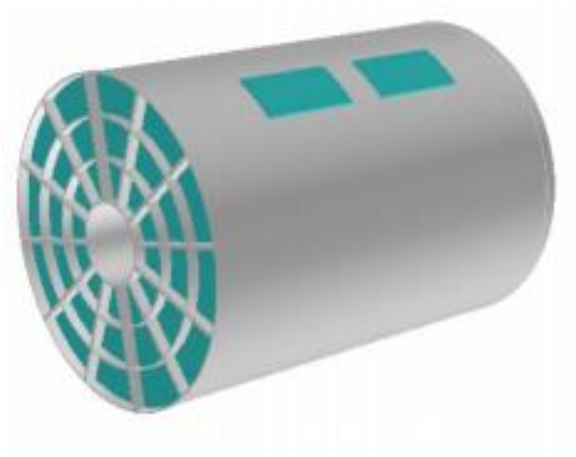
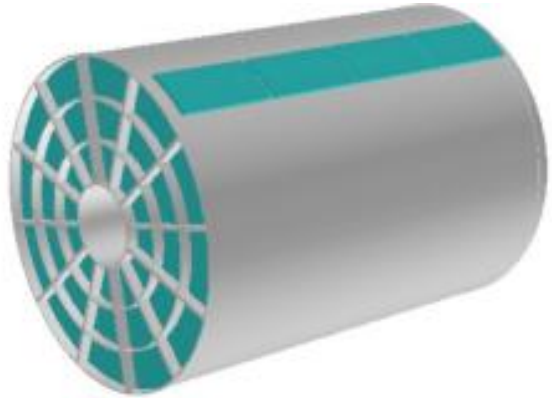


Two tiles

One on each side of the central membrane

In front of one GEM sector

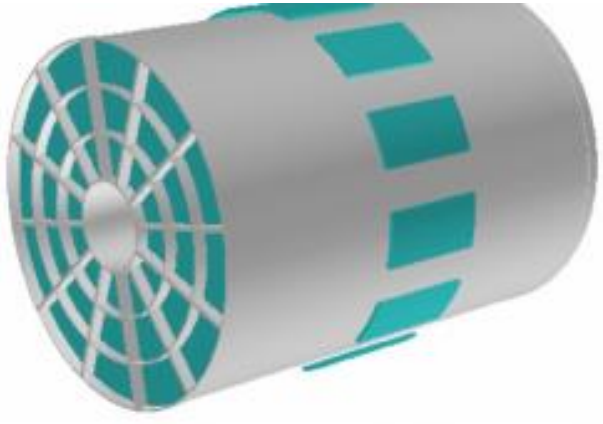


Four tiles

Covering full z acceptance

In front of one GEM sector

Allows to monitor the full z extend of the distortions



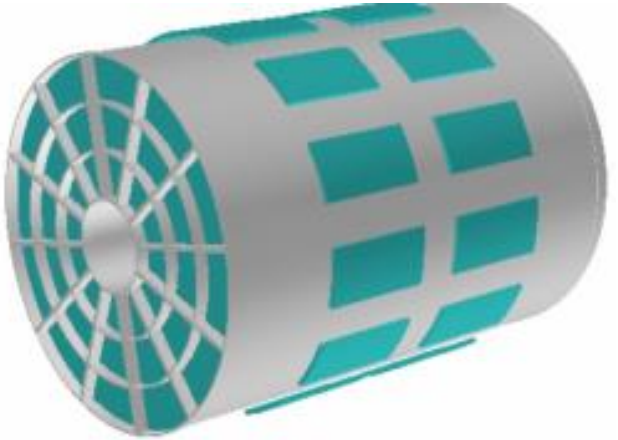
12 tiles at mid-rapidity

In front of each GEM sector

Monitor Gain/IBF fluctuations

Enables some physics at mid rapidity

Suffers from dead area due to central membrane



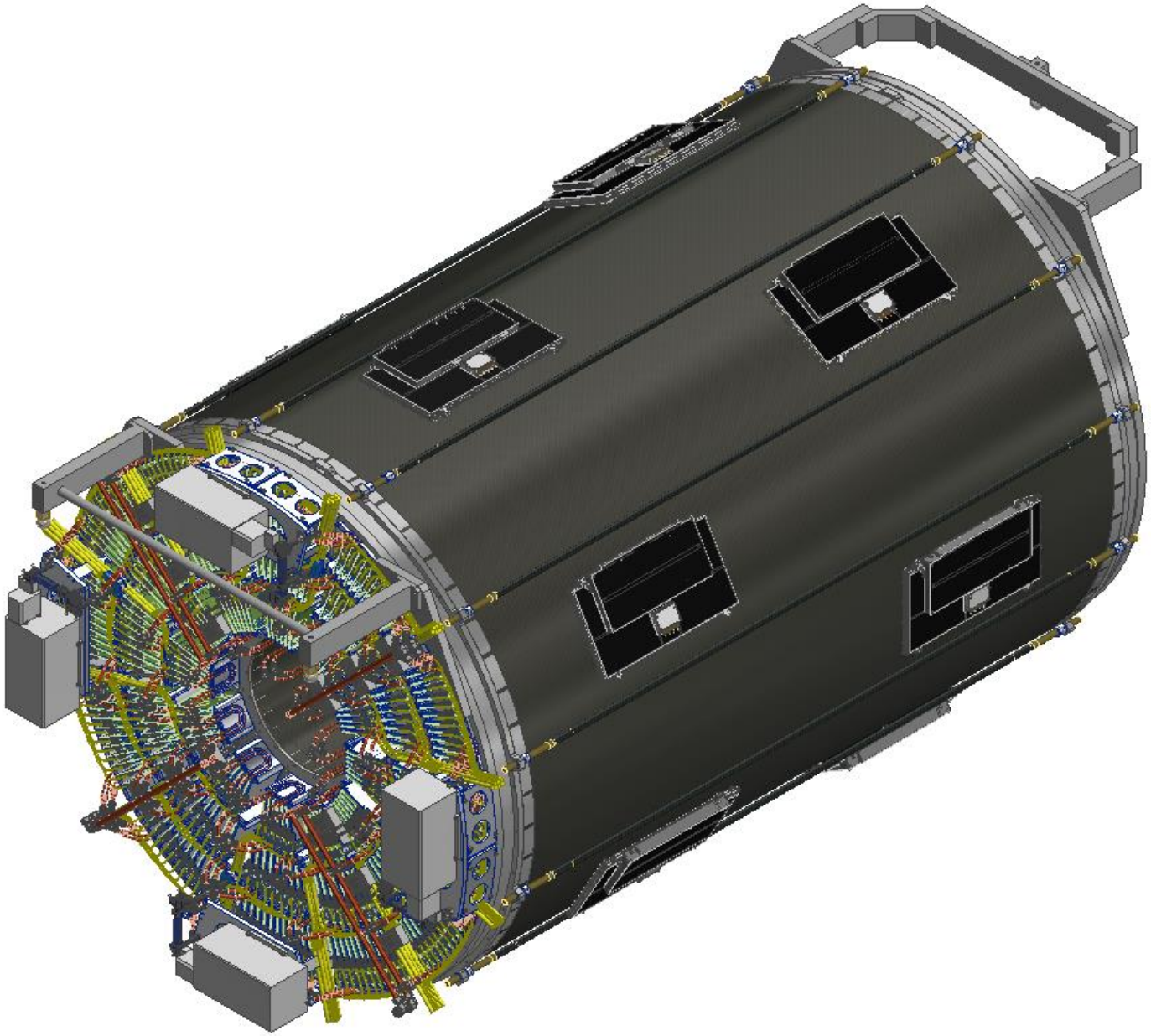
24 tiles

12 on each side of the central membrane

One tile in front of each GEM sector

Same as 12 Tiles but no dead area from CM

TIME PROJECTION CHAMBER



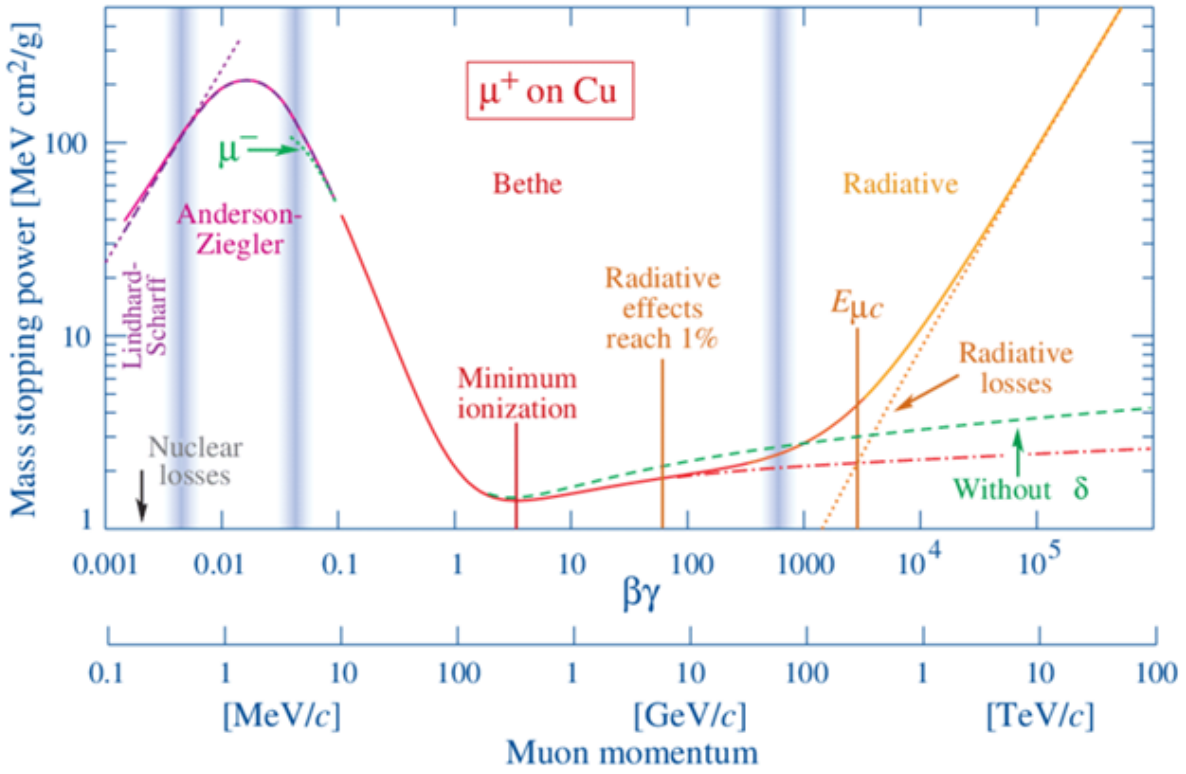
TIME PROJECTION CHAMBER

- A TPC for DET-II@IP8
  - What PID capabilities are possible?

TPC – PID CAPABILITIES

- Particle Identification via velocity measurement
  - Velocity dependent interaction with the detector → specific ionization

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = 4\pi\, N_\mathrm{A}\, r_\mathrm{e}^2\, m_\mathrm{e}\, c^2\, z^2\, \frac{Z}{A}\, \frac{1}{\beta^2} \left[\ln\left(\frac{2 m_\mathrm{e}\, c^2\, \gamma^2\, \beta^2}{I} \right) - \beta^2 - \frac{\delta}{2} \right]$$



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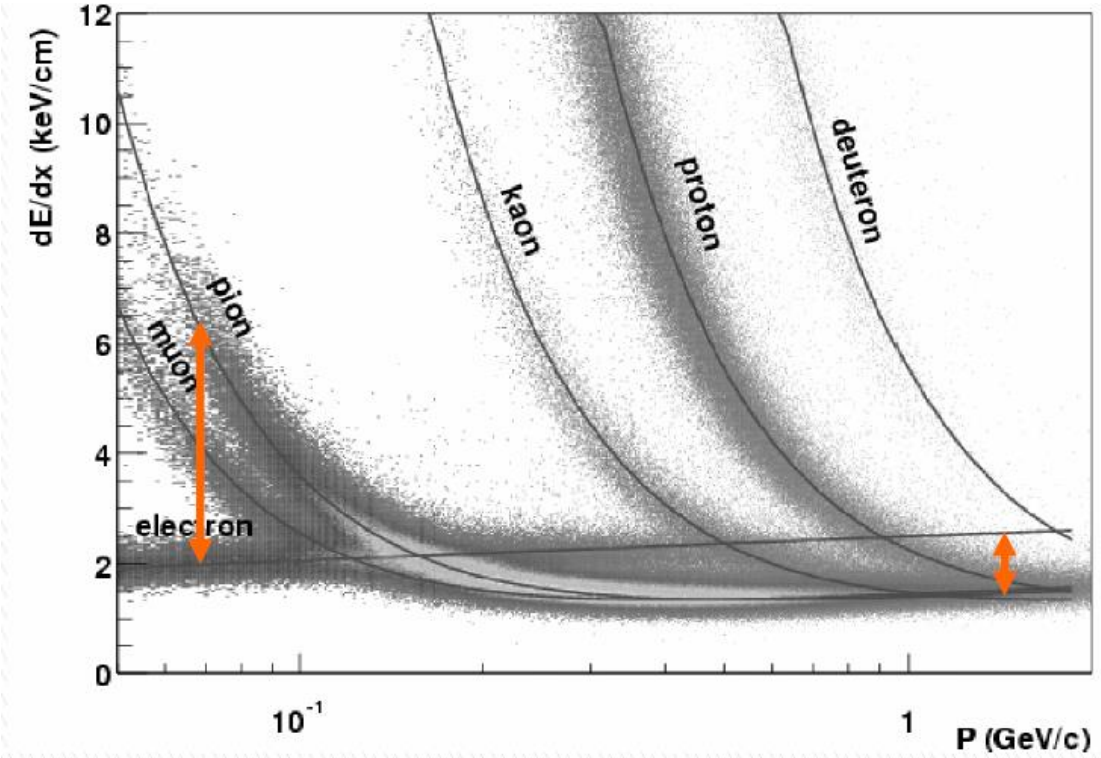
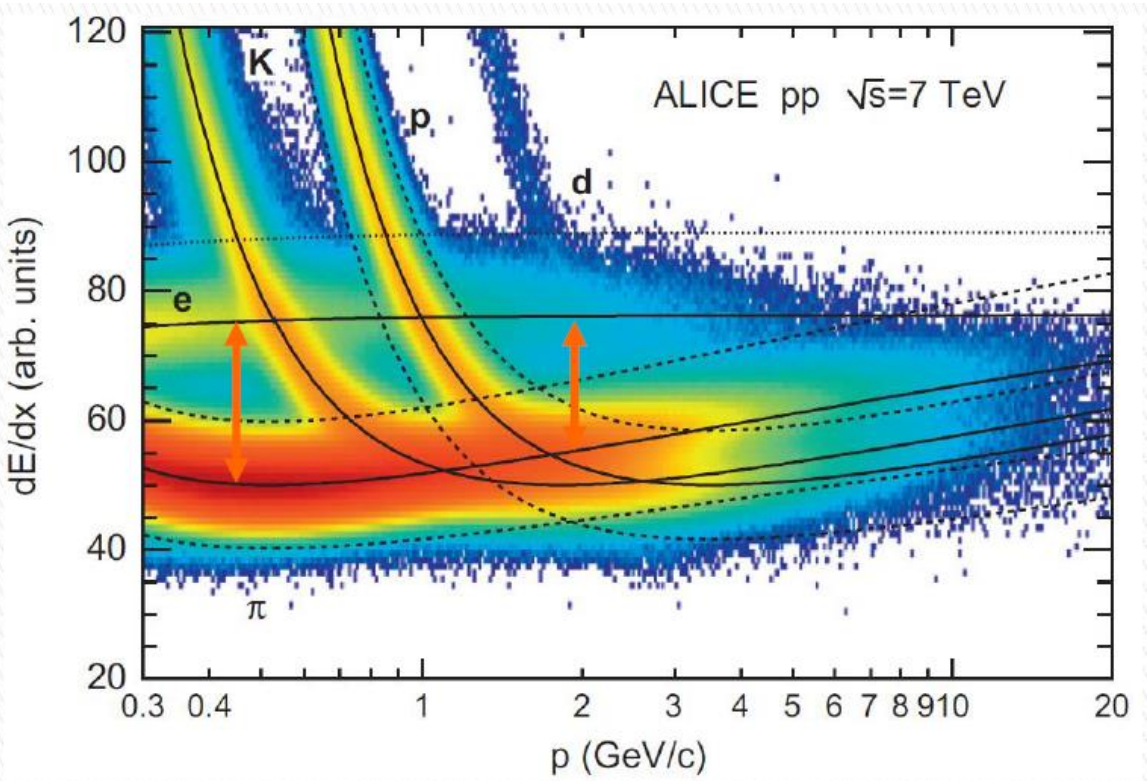


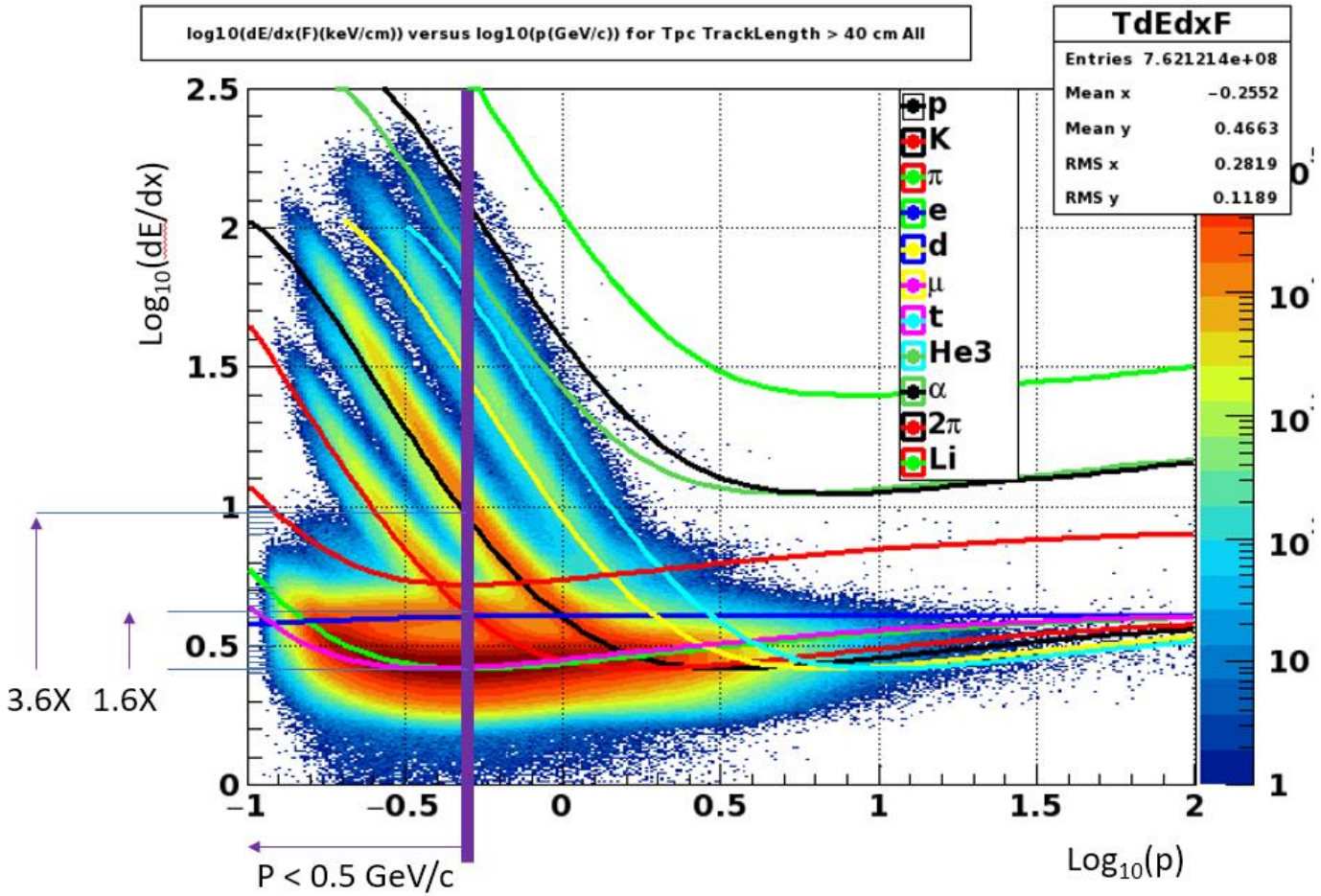


STAR (2003 NIMA):
DOI: 10.1016/S0168-9002(02)01964-2

ALICE (2013 NIMA)
DOI: 10.1016/j.nima.2012.05.022

TPC – PID CAPABILITIES

- Particle Identification via velocity measurement
  - Velocity dependent interaction with the detector → specific ionization



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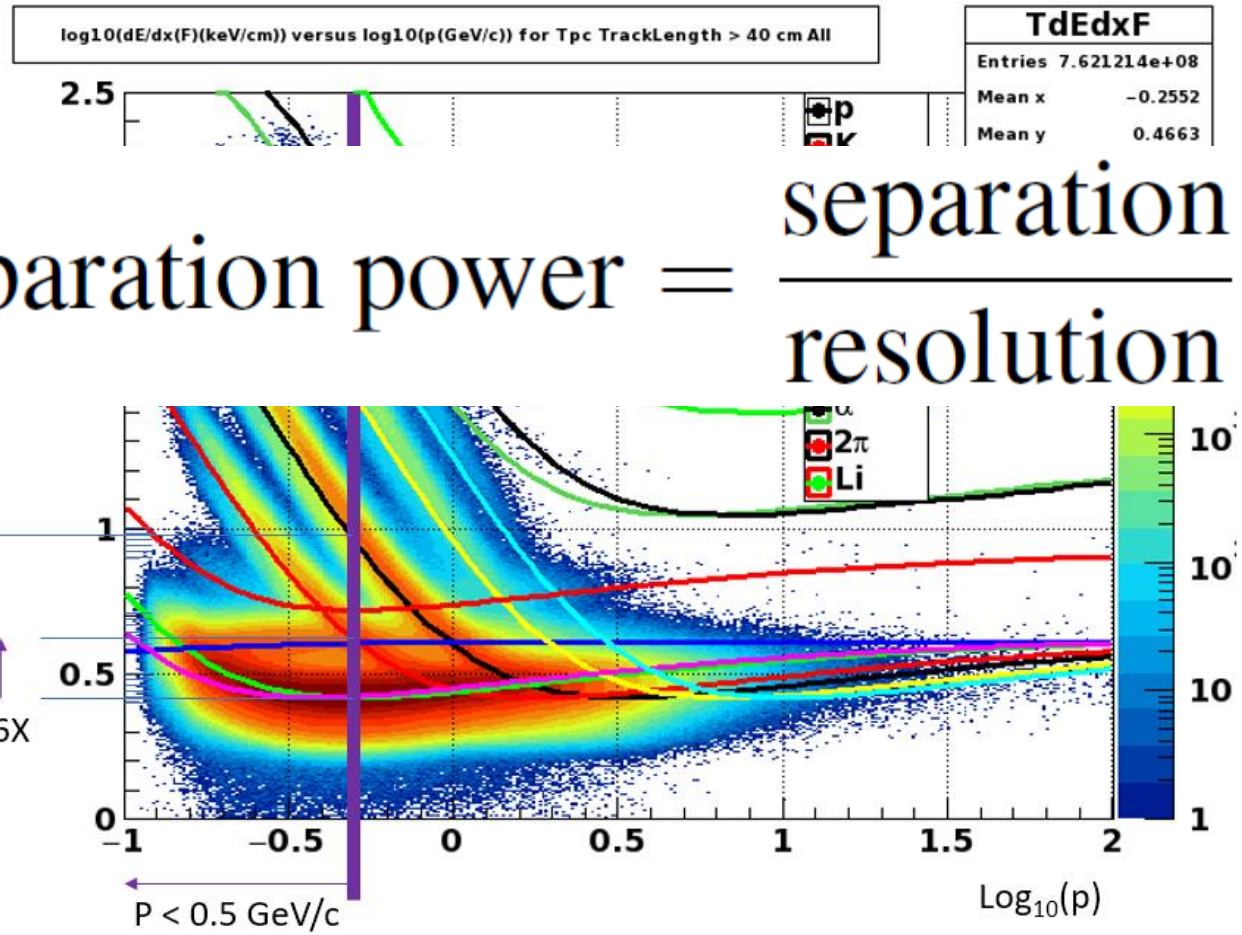


TPC – PID CAPABILITIES

- Particle Identification via velocity measurement
  - Traditional charge counting vs cluster counting

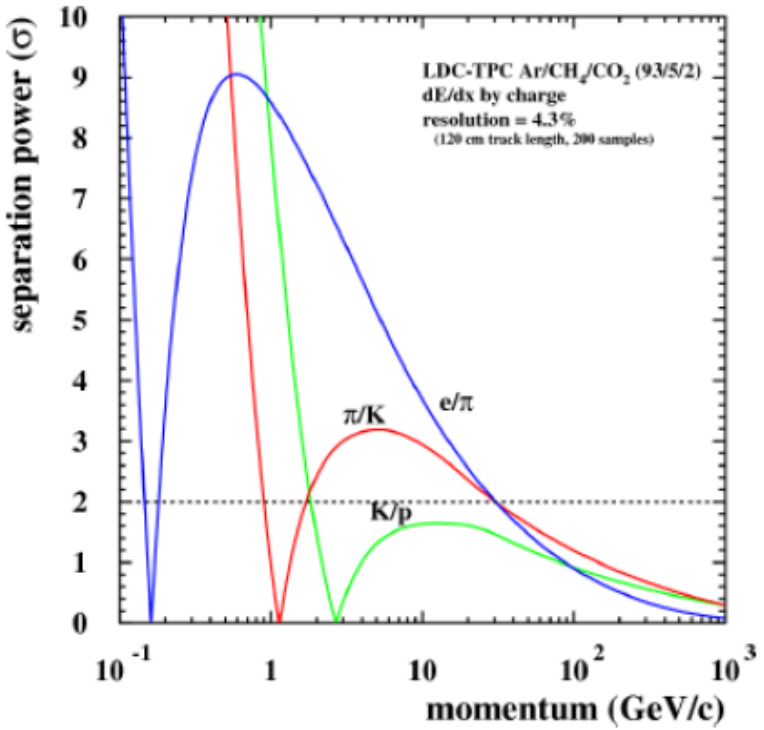


Figure 5: Separation power for charge counting, with energy resolution of 4.5% and track lengths of 120 cm and 200 samples along the track.

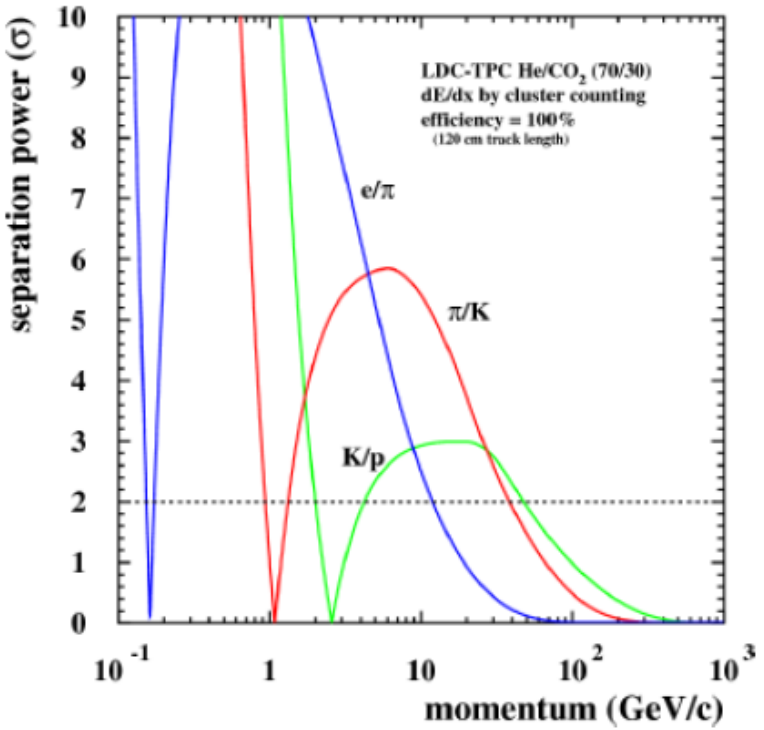


Figure 6: Separation power for cluster counting, for the same gas and track length as in Figure 5. A 100% counting efficiency is assumed.

TPC – PID CAPABILITIES

- Particle Identification via velocity measurement
  - Traditional charge counting vs cluster counting

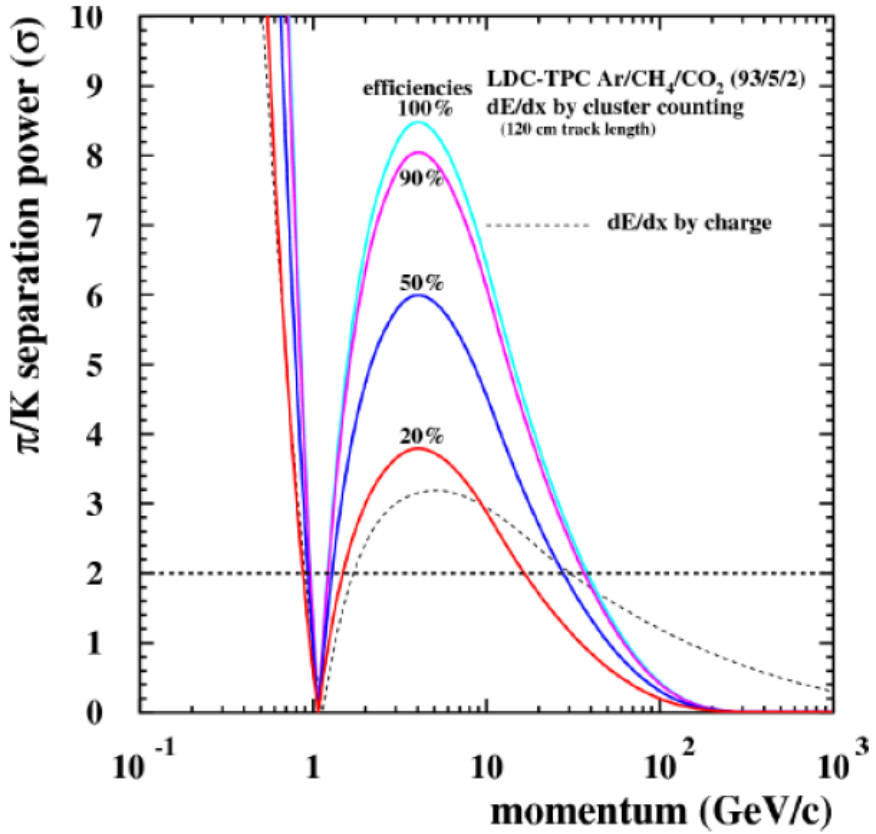
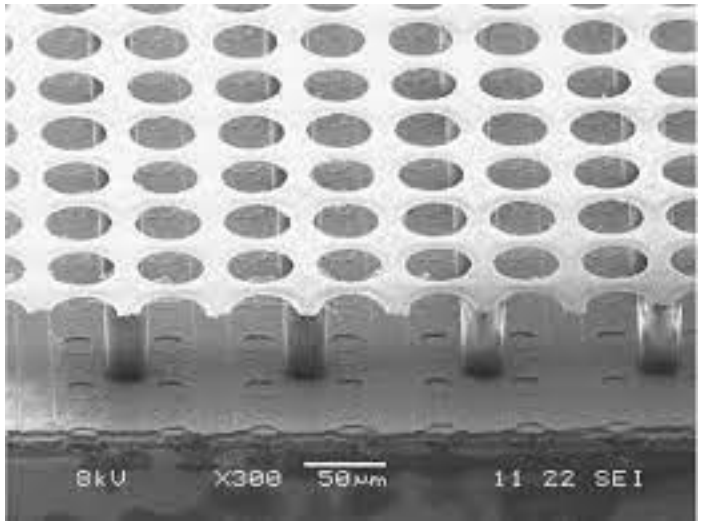
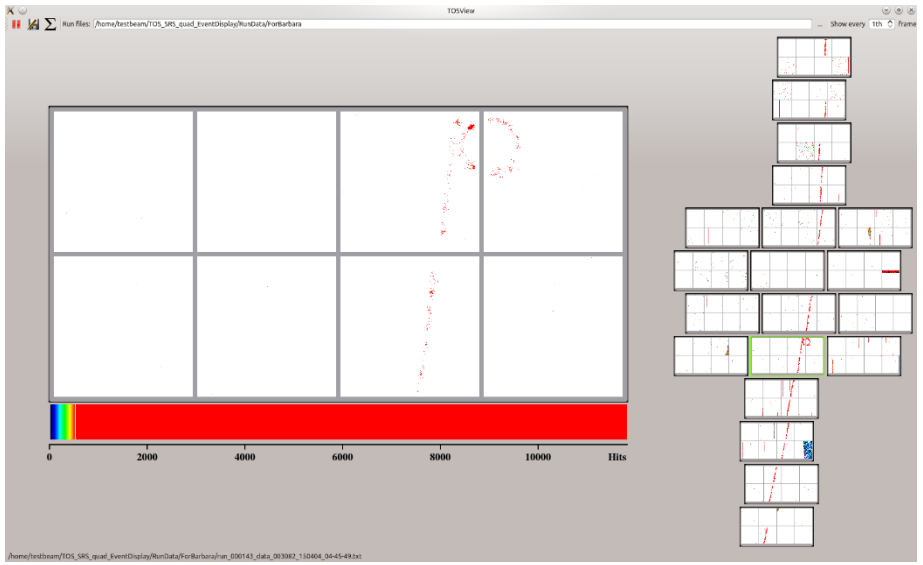


Figure 7: Separation power for π/K with cluster counting, based on different counting efficiencies (solid lines), compared to the separation power with charge counting.

TPC – PID CAPABILITIES

- Particle Identification via velocity measurement
  - Count each electron → GridPix

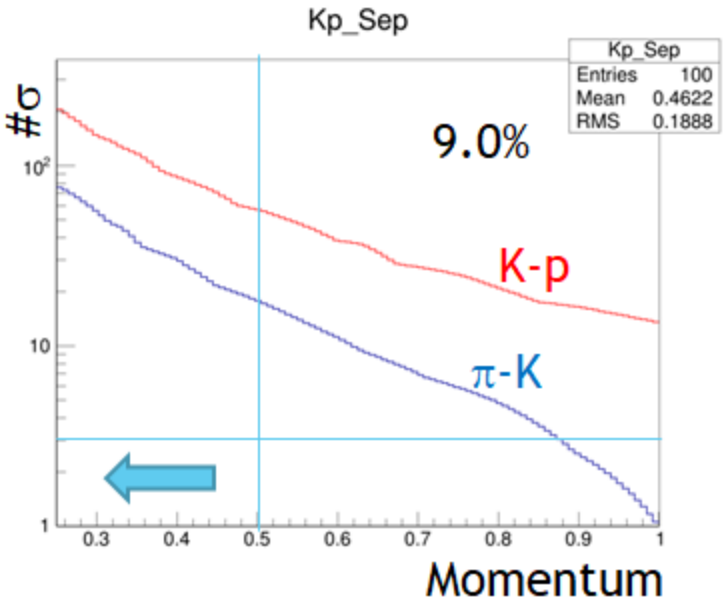


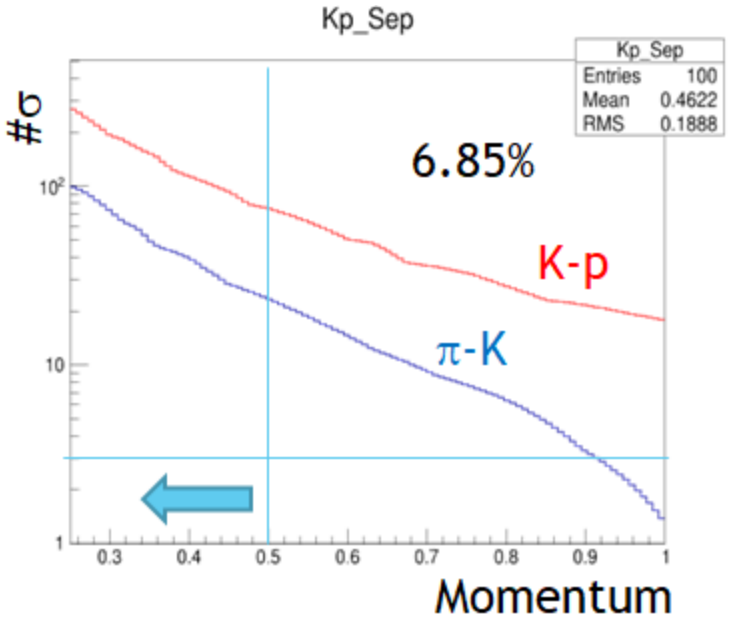


- Ultimate dE/dx device.
  - Avalanche grid in front of 55 x 55 μm^2 pixels.
  - >90% efficiency for single electrons.
  - Goals:
    - Enough diffusion to get every electron into a different hole.
    - Count electrons one-by-one.
  - Three generations of development and continuing.
- Small area is not particularly expensive.
  - 1800 chips (order/produce/test 3600) = $716k
  - Careful: 1.2-5.4 kW of power (occupancy dependent).

TPC – PID CAPABILITIES

- Particle Identification via velocity measurement
  - Count each electron → GridPix
  - Anticipated dE/dx resolution



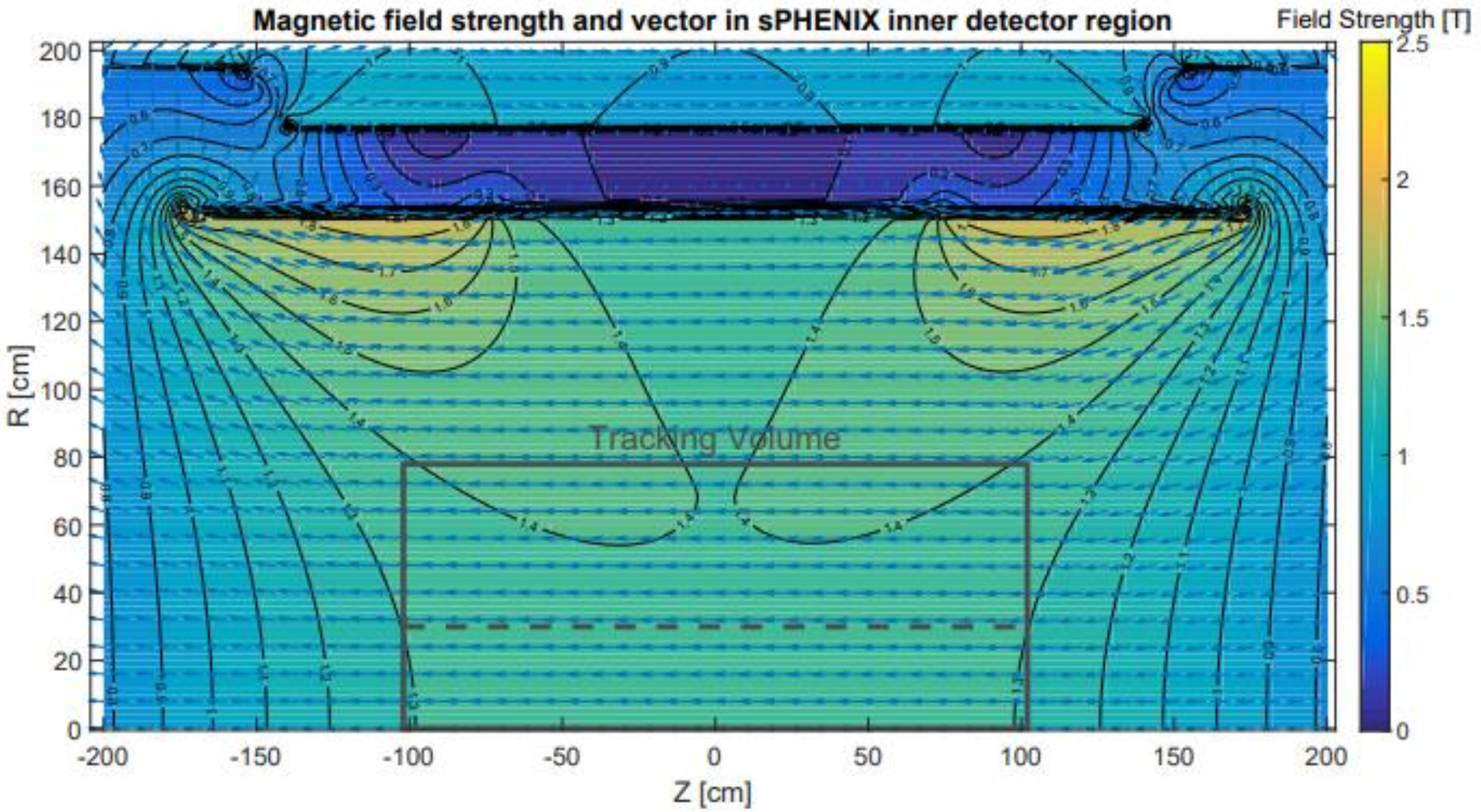


Lehraus Plot
- Using 5.4 as a standard TPC
  - $5.4*(0.25)^{-0.37} = 9.0$
- Measured for GridPIX (truncated Mean)
  - 4.1% at 1 meter
  - $4.1*(0.25)^{-0.37} = 6.85$
- Roughly 20 sigma at 0.5 GeV/c
- Useful range overlaps with DIRC

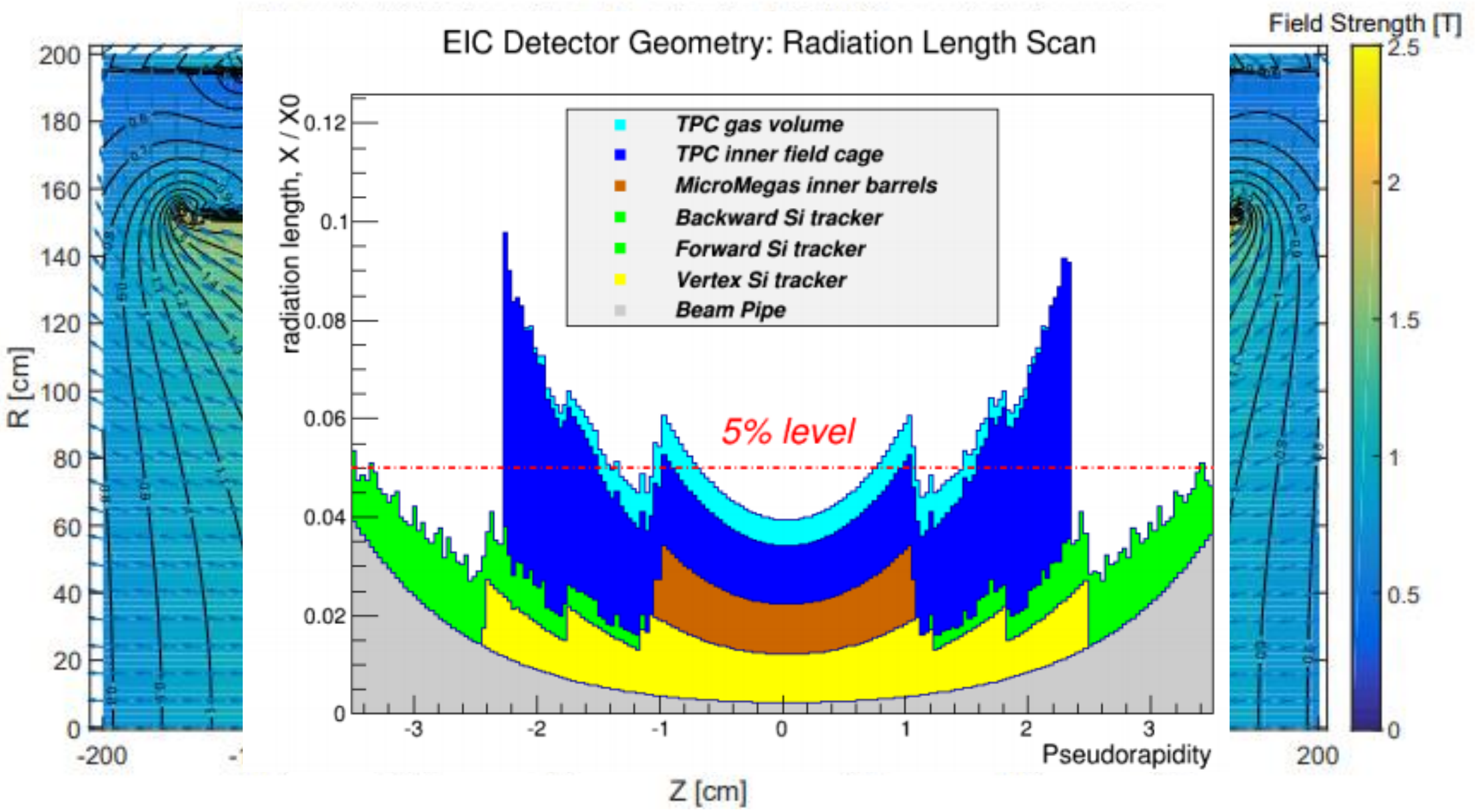
A TPC FOR DET-II@IP8

- What are the material budgets?
  - Keep material budgets at minimum to avoid multiple scattering, secondary particle production, …

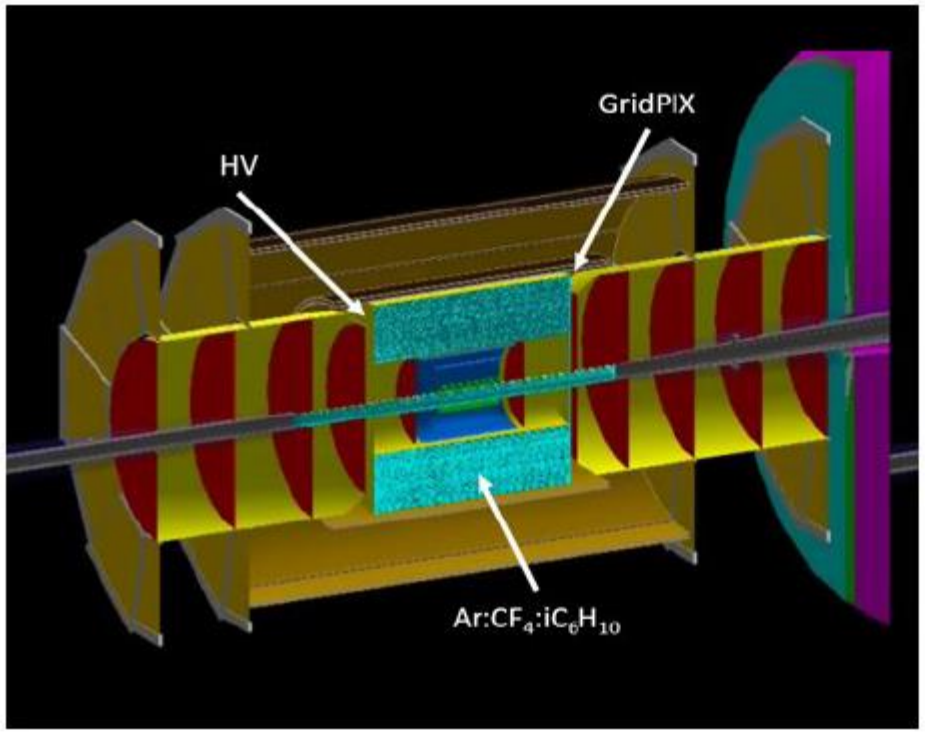
BABAR MAGNET AND TPC - MATERIAL BUDGET

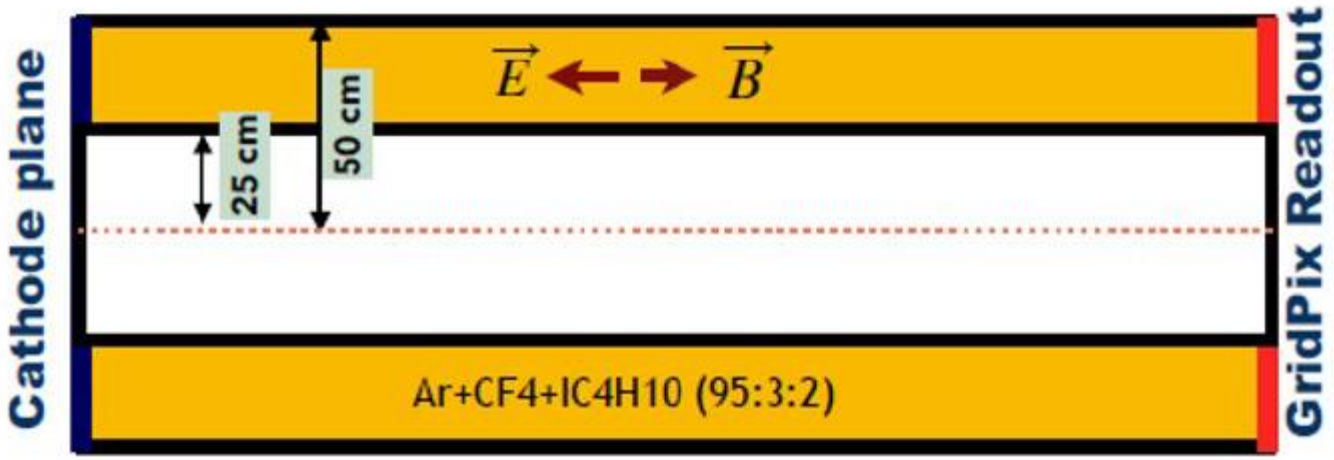


BABAR MAGNET AND TPC - MATERIAL BUDGET



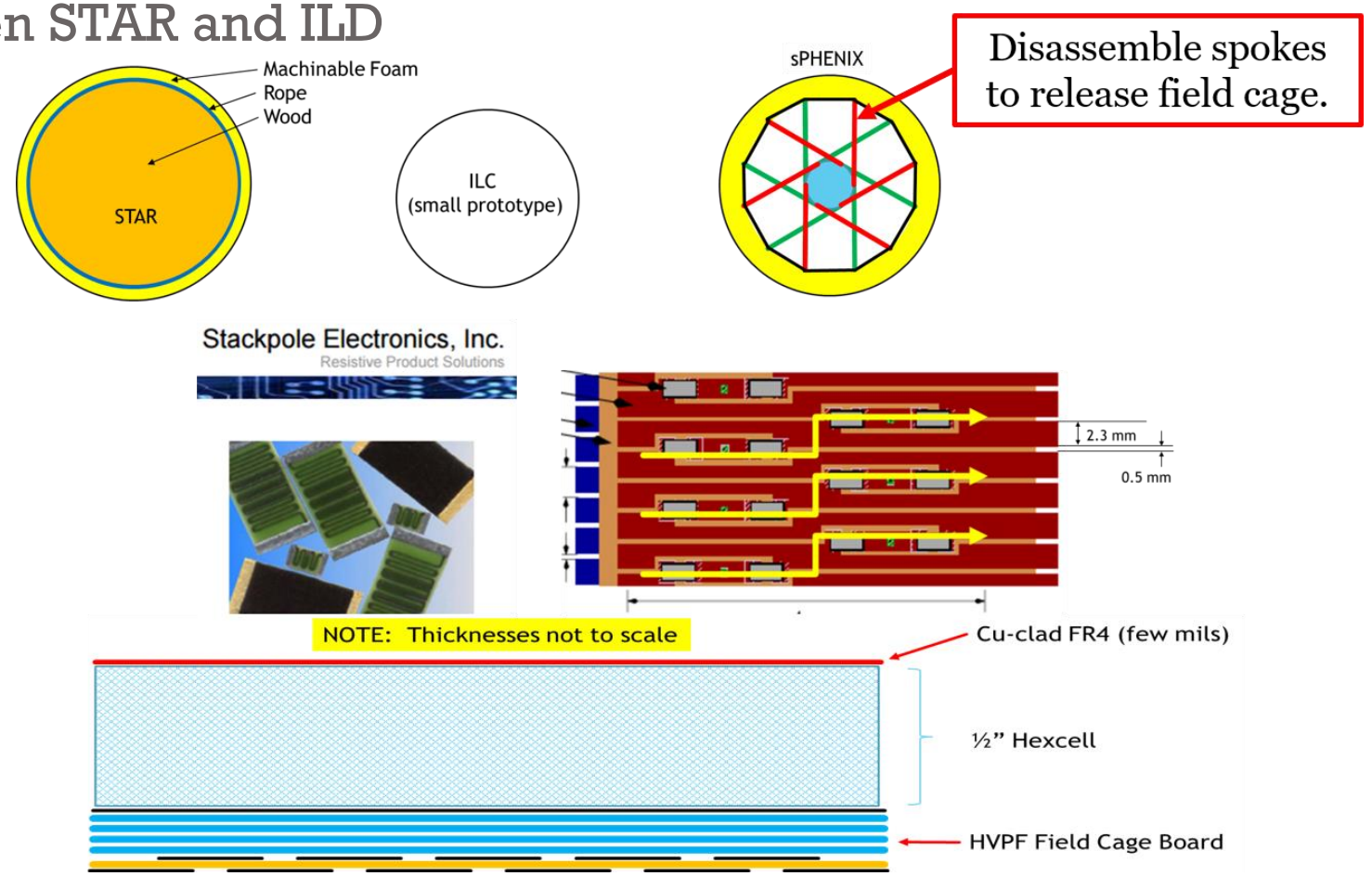
A TPC FOR DET-II@IP8





TPC - MATERIAL BUDGET

- Field Cage → Inner/Outer for sPHENIX
  - Hybrid between STAR and ILD



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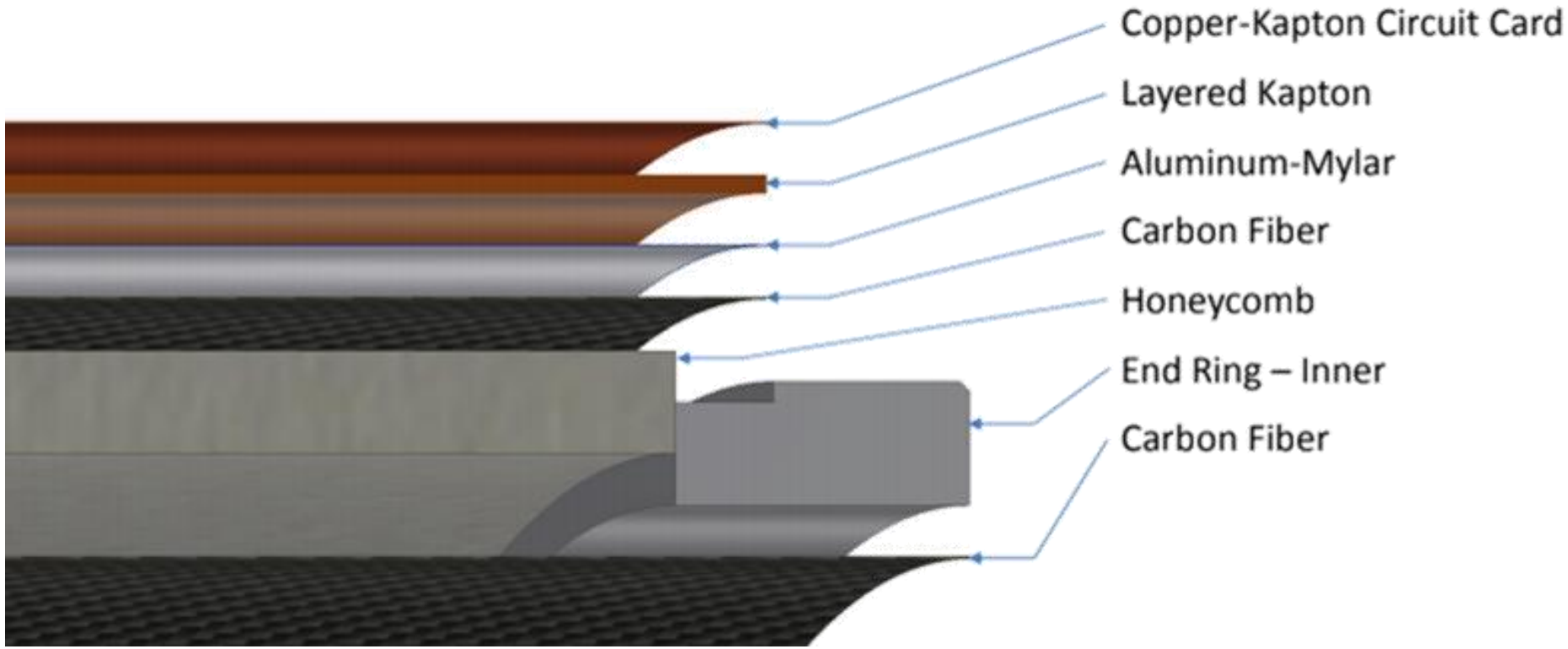
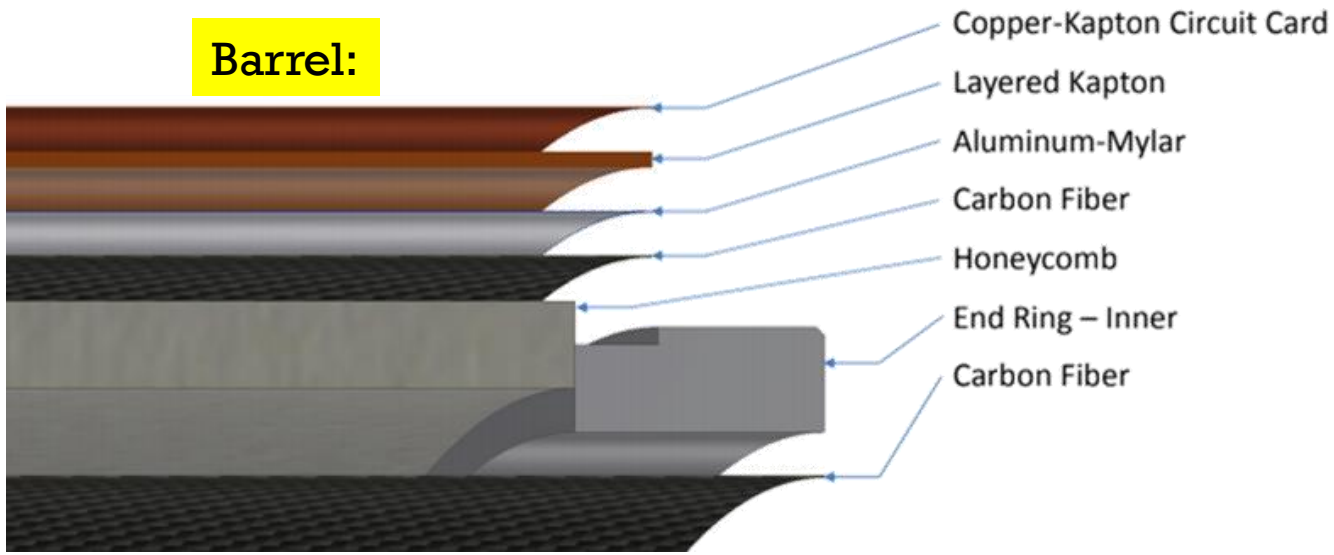
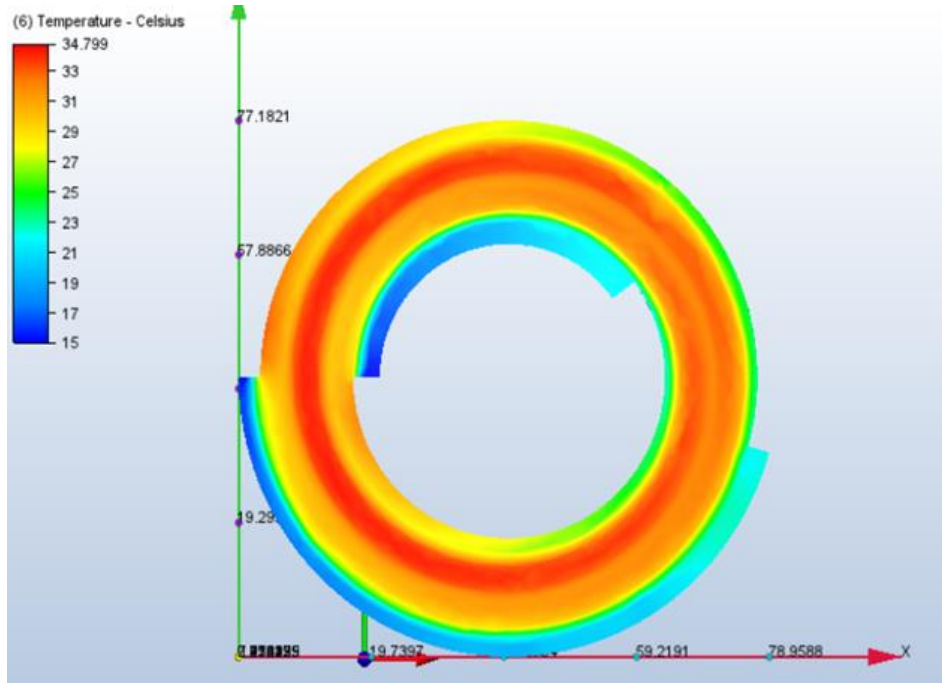


GRIDPIX TPC - MATERIAL BUDGET

Barrel:



End Cap:



sPHENIX:

- 45 kV & 18 layers kapton.

Inner field cage	X_0 [cm]	cm	%X_0
1/2 Oz Copper	1.4	0.0017	0.12
kapton	28.6	0.0051	0.02
1/2 Oz Copper	1.4	0.0017	0.12
Kapton (coverlay)	28.6	0.0076	0.03
Epoxy	35.7	0.0127	0.04
Kapton (insulating)	**28.6**	**0.2286**	**0.80**
Carbon Fiber	23.4	0.0254	0.11
Epoxy	35.7	0.0127	0.04
Honeycomb	845.4	1.2700	0.15
Epoxy	35.7	0.0127	0.04
Carbon Fiber	23.4	0.0254	0.11
TOTAL		**0**	**1.56**

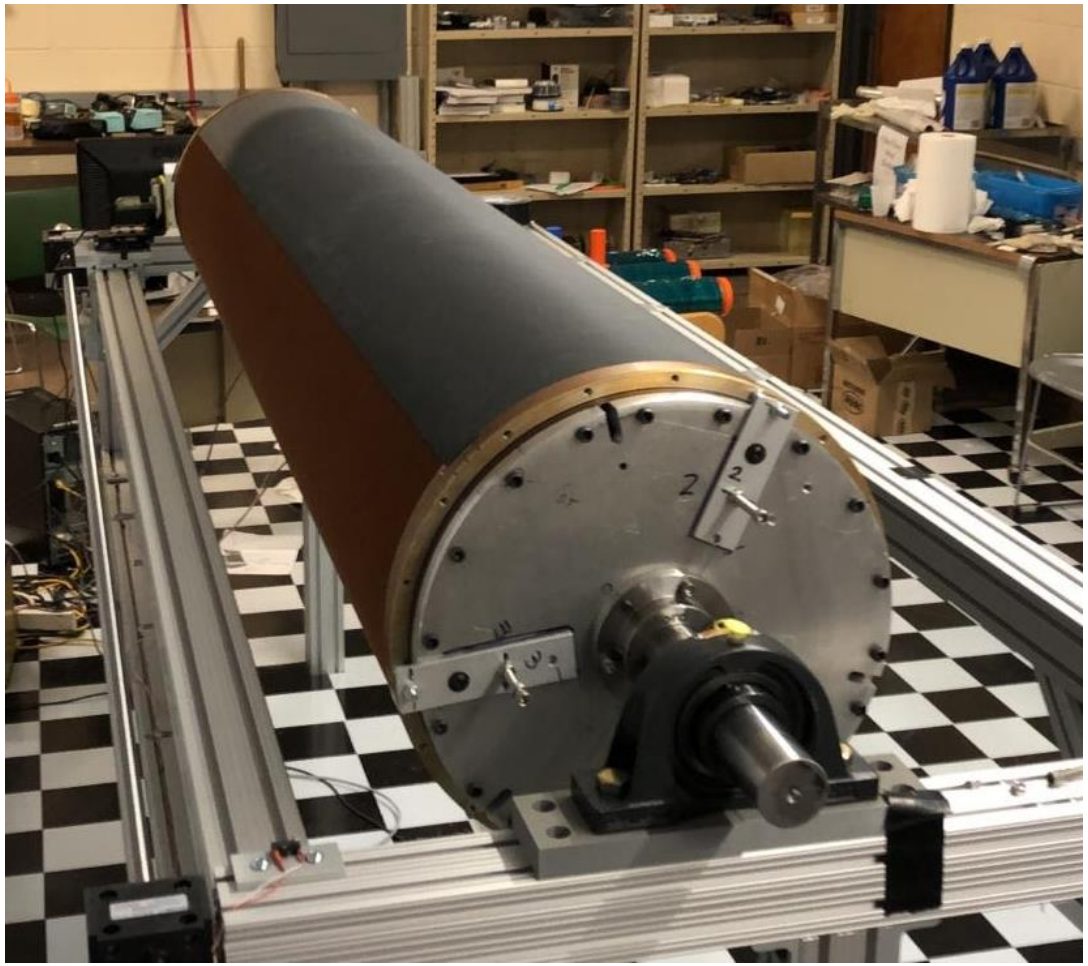
EIC:

- 10 kV & 5 layers kapton.

Inner field cage	X_0 [cm]	cm	%X_0
1/2 Oz Copper	1.4	0.0017	0.12
kapton	28.6	0.0051	0.02
1/2 Oz Copper	1.4	0.0017	0.12
Kapton (coverlay)	28.6	0.0076	0.03
Epoxy	35.7	0.0127	0.04
Kapton (insulating)	**28.6**	**0.0635**	**0.22**
Carbon Fiber	23.4	0.0254	0.11
Epoxy	35.7	0.0127	0.04
Honeycomb	845.4	1.2700	0.15
Epoxy	35.7	0.0127	0.04
Carbon Fiber	23.4	0.0254	0.11
TOTAL		**0**	**0.98**

- Temperature Profiles: 3 kW
- Coolant above the dew point
  - Conventional Cooling OK at 4%
  - CO_2 cooling promises ~2% ?

sPHENIX TPC CONSTRUCTION



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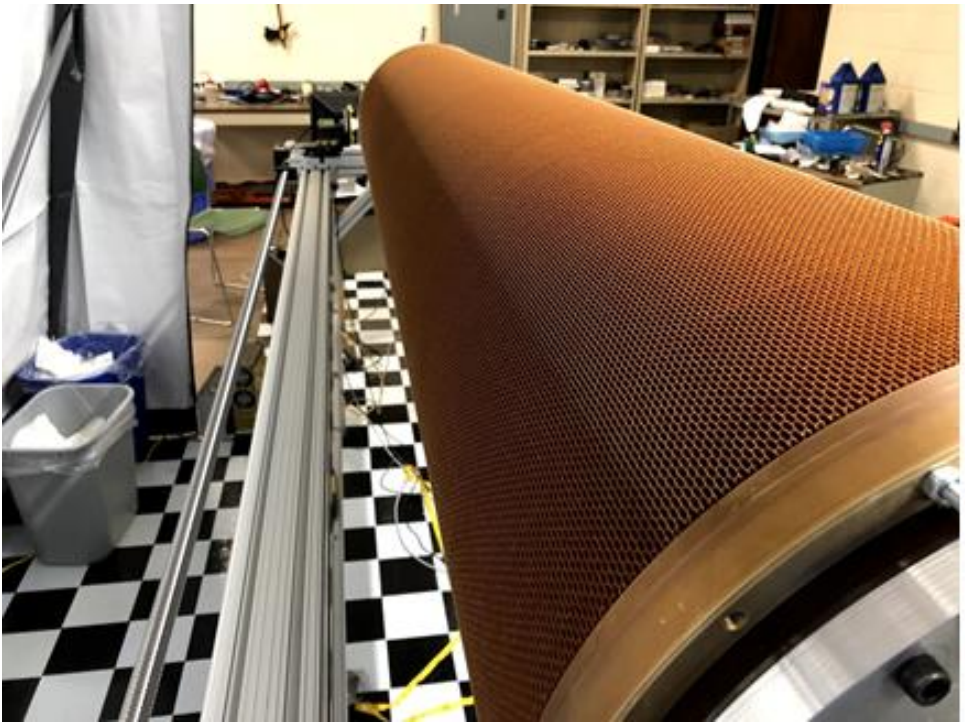

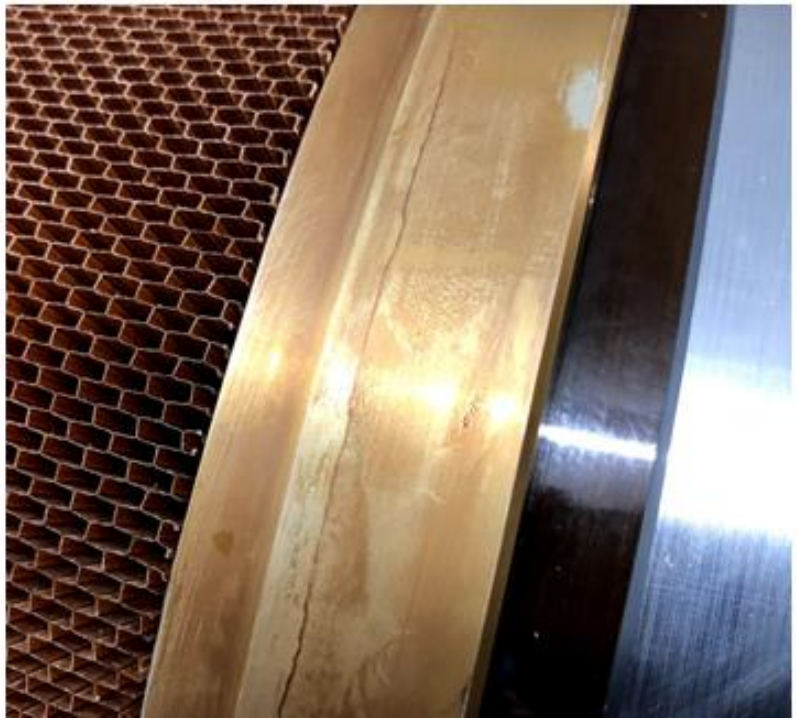

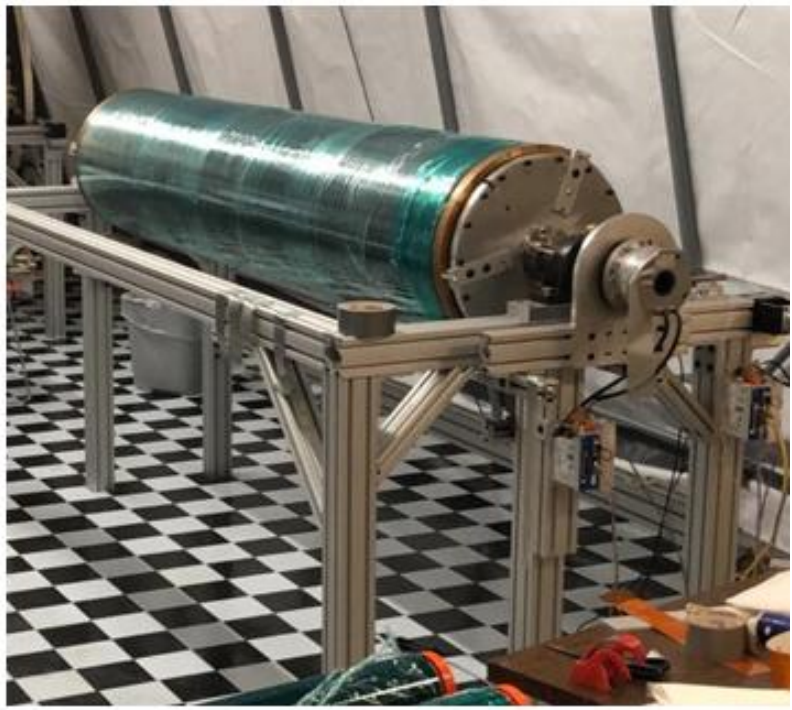

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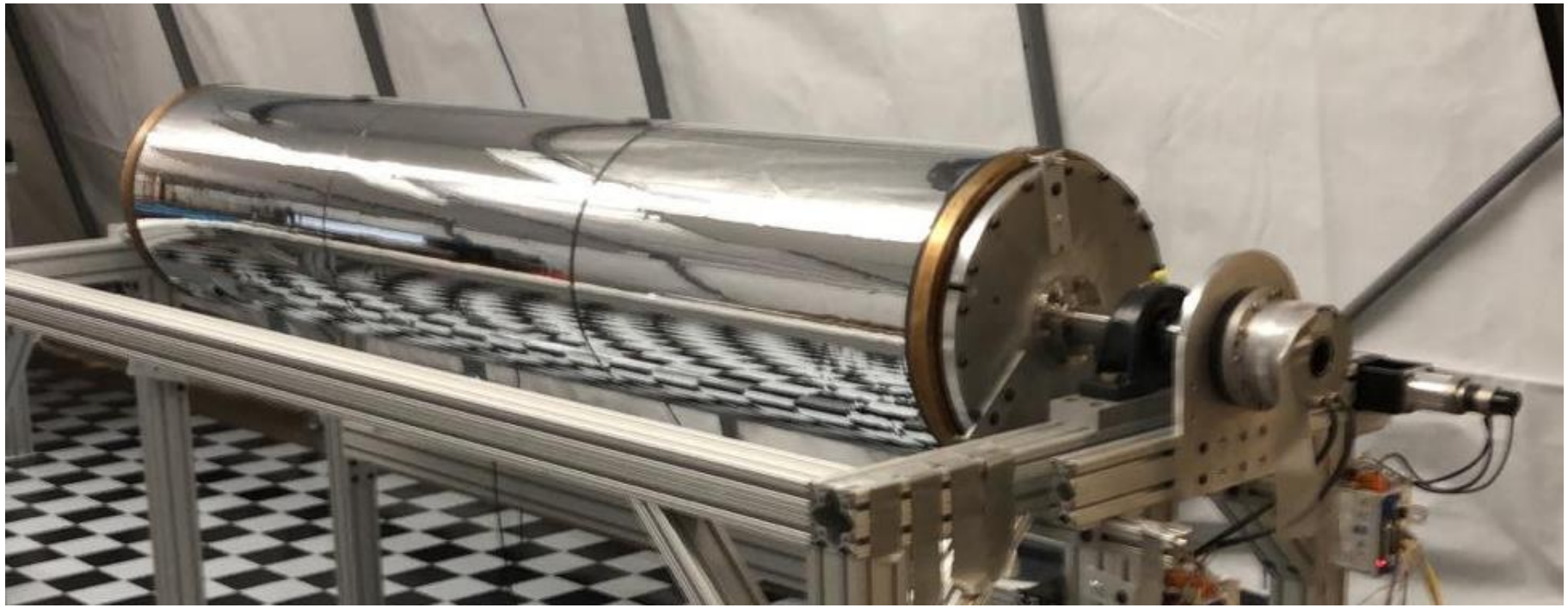

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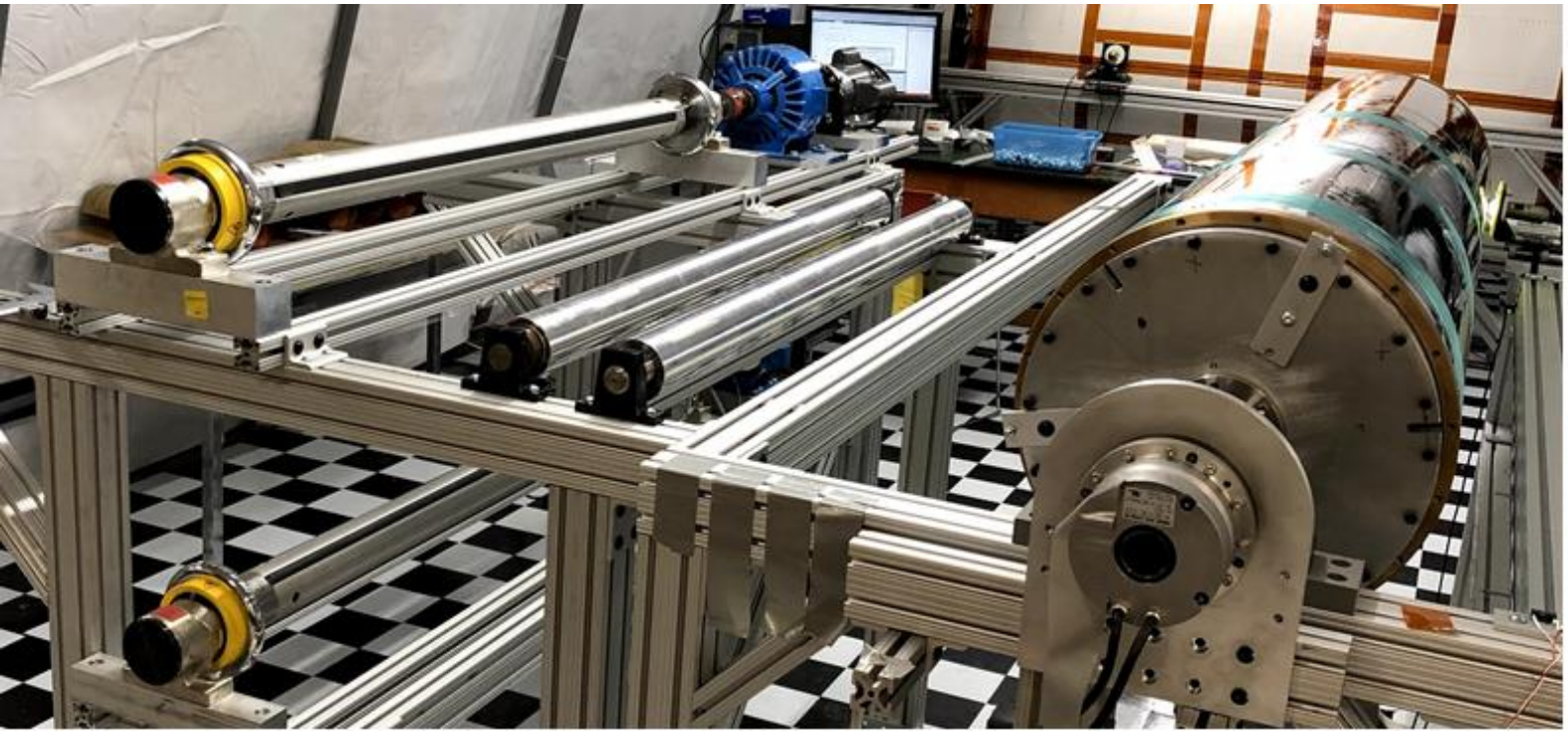

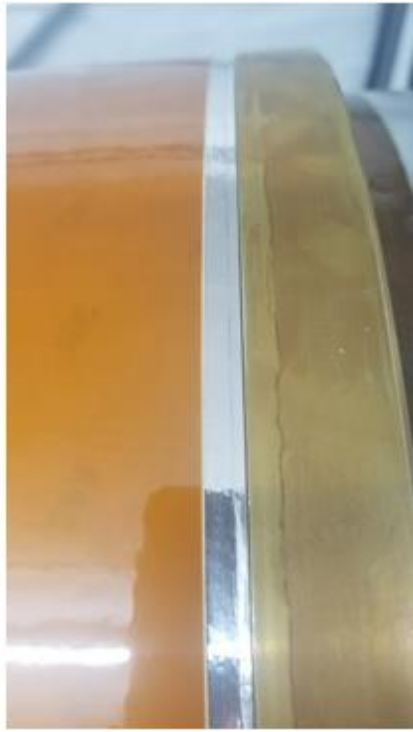

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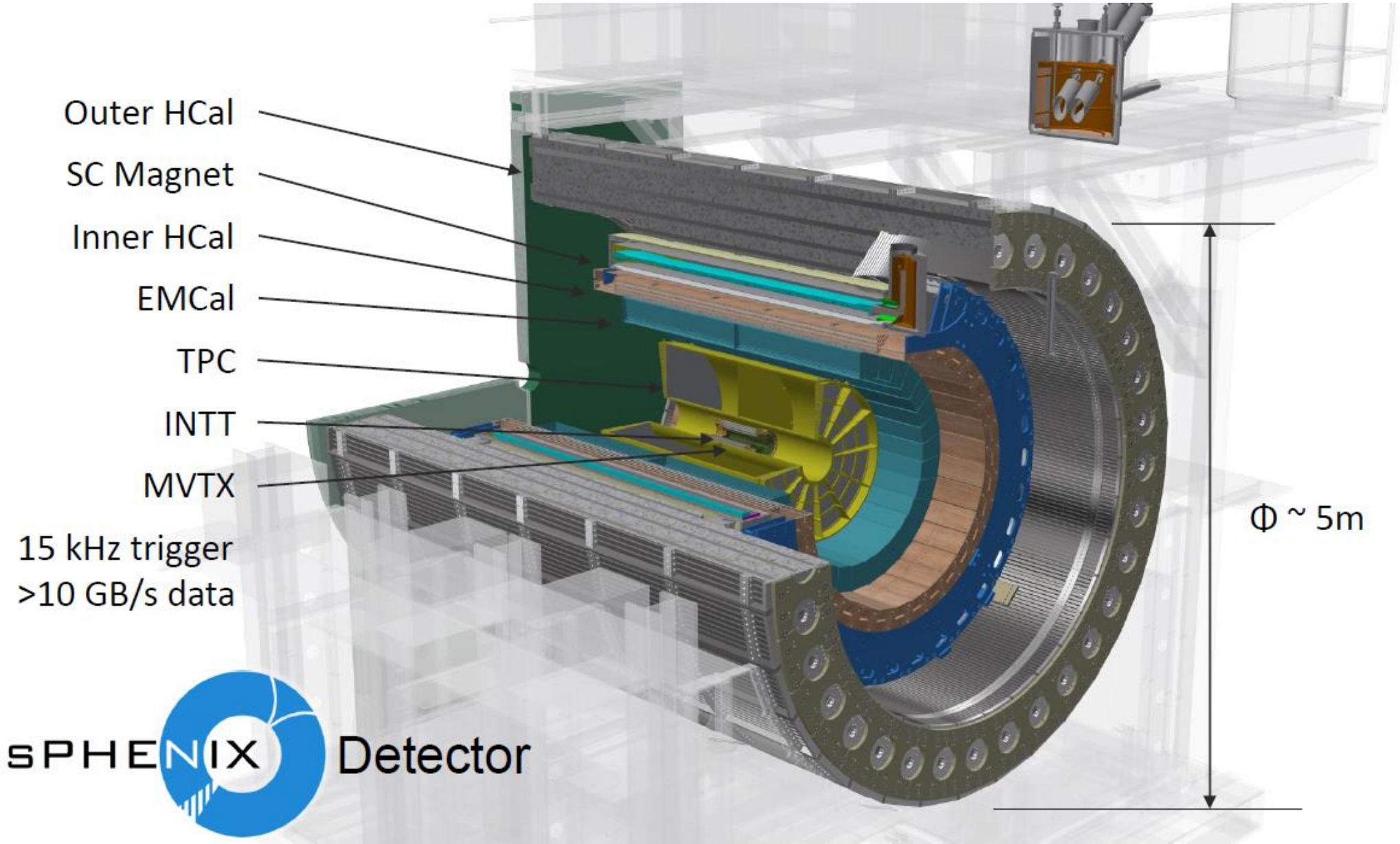
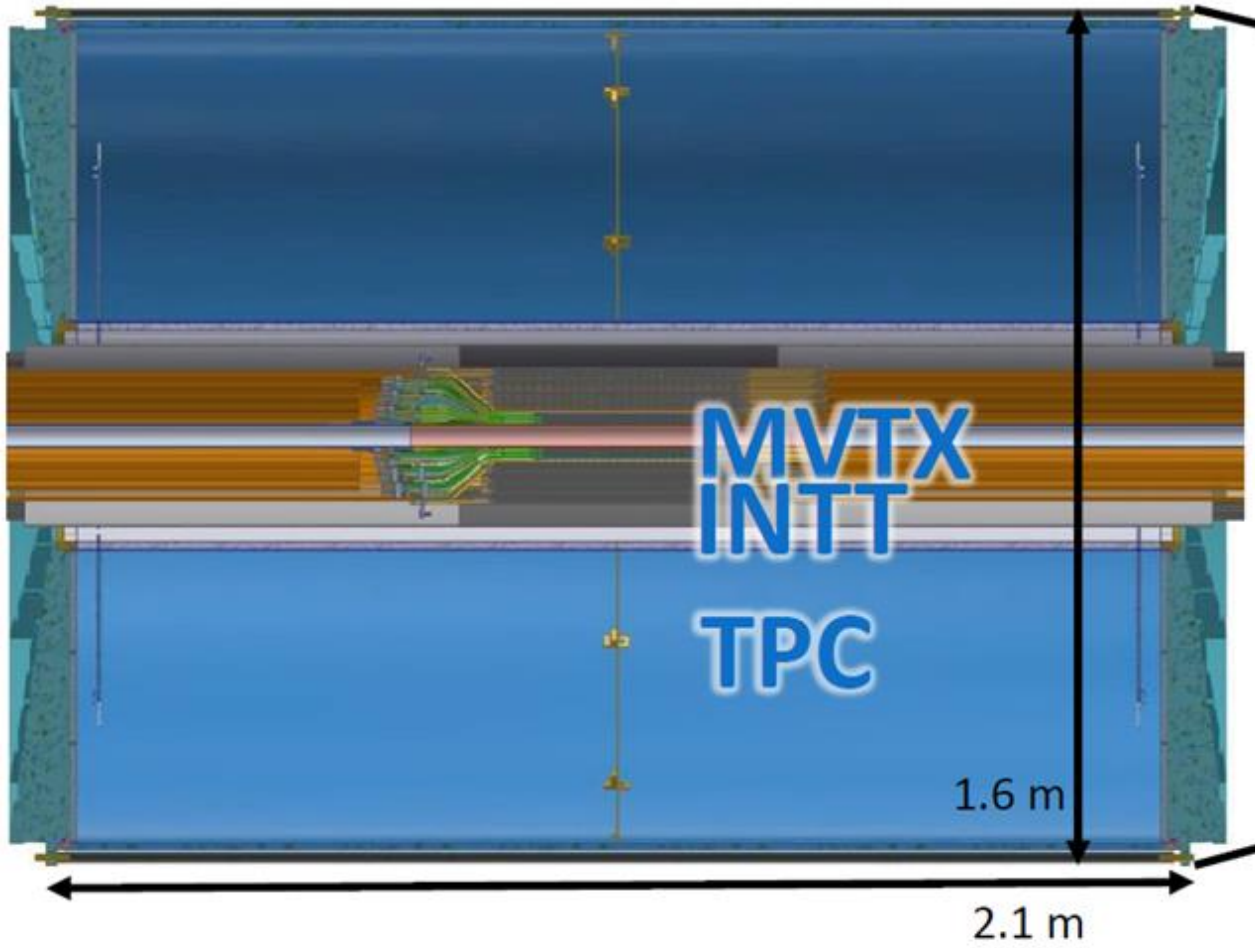
TIME PROJECTION CHAMBER

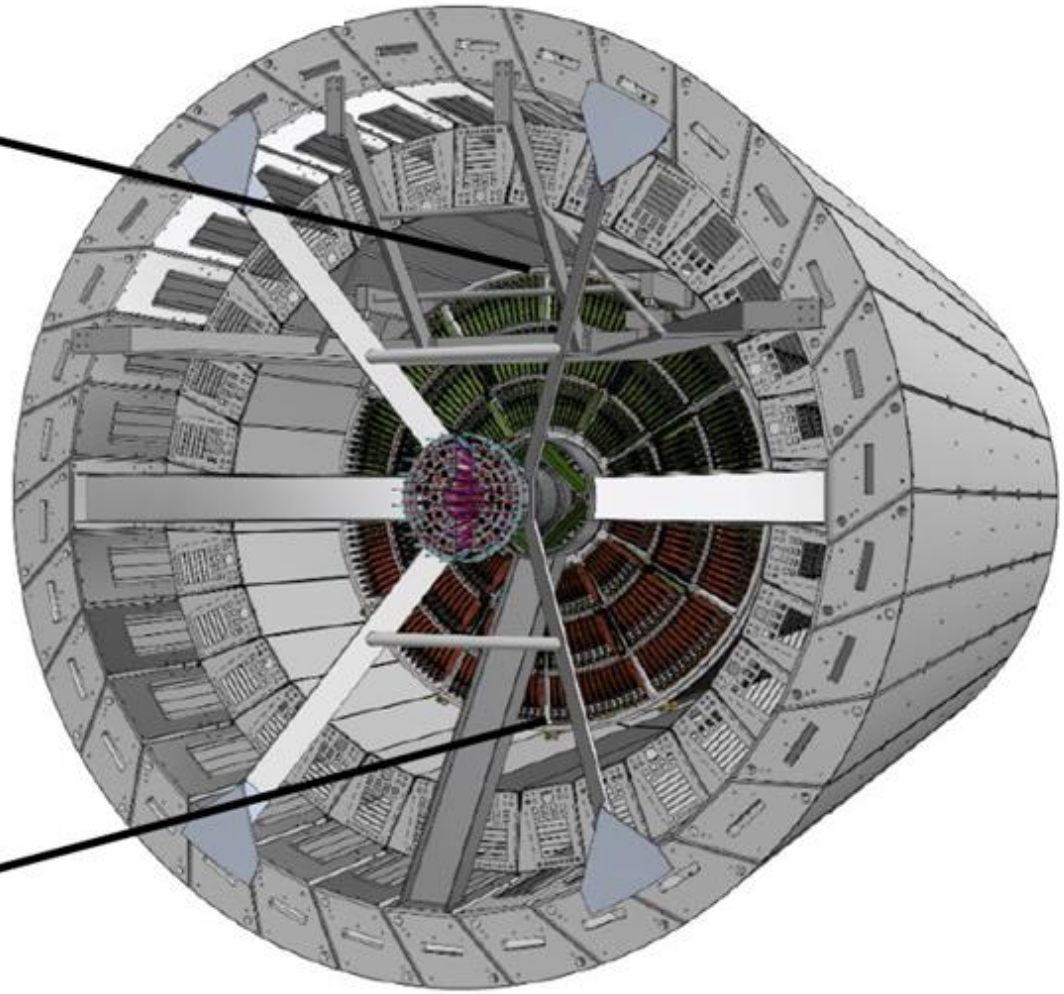
- A TPC for DET-II@IP8
  - Integration issues with other detectors?

INTEGRATION ISSUES FOR A TIME PROJECTION CHAMBER



INTEGRATION ISSUES FOR A TIME PROJECTION CHAMBER





Detectors inside the magnet


BACK UP