Compact TPC with GridPix Readout
(PID and tracking option for the ATHENA Detector at EIC)
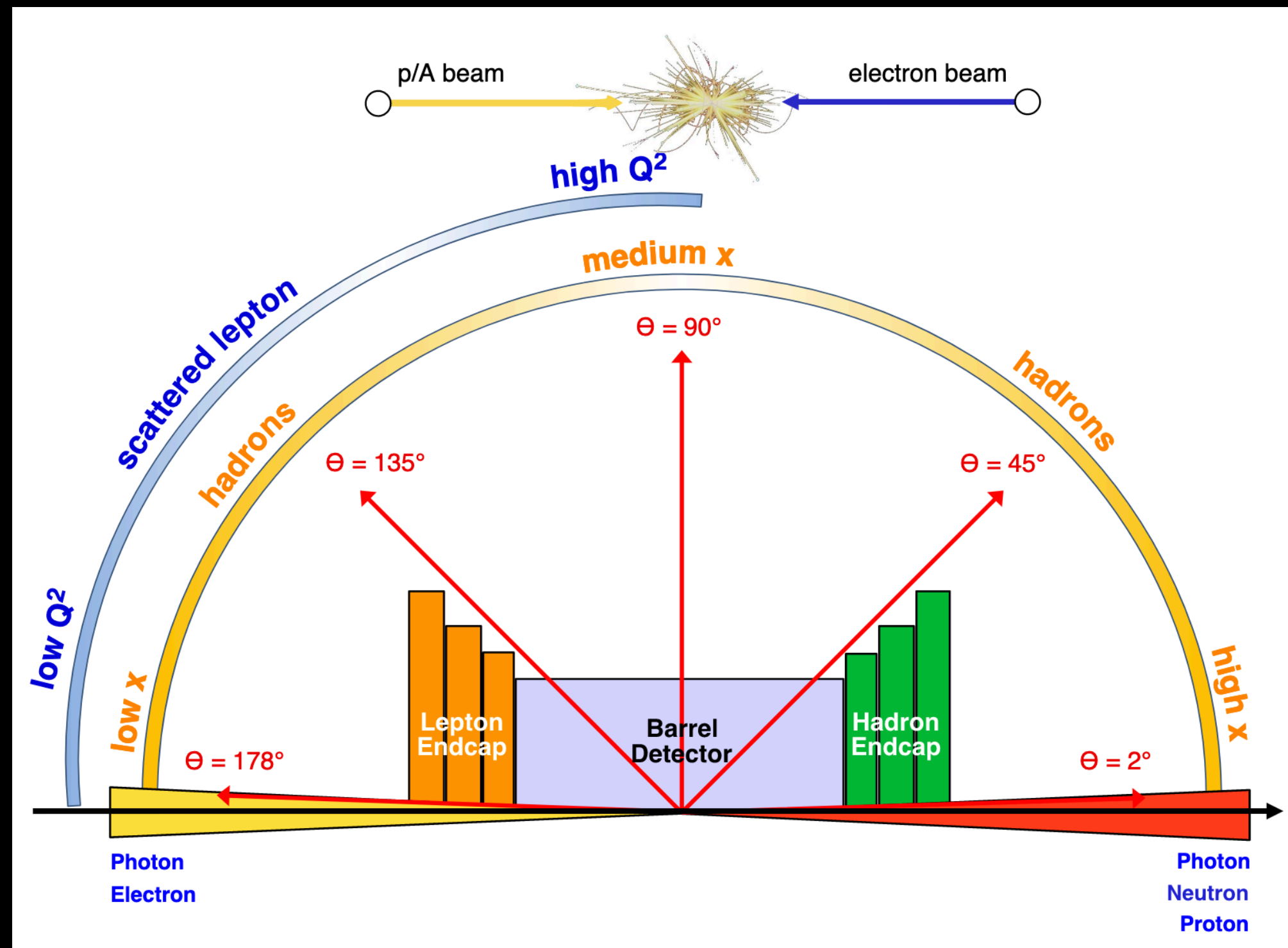

Storage Ring

Detector

Electrons

Electron Accelerator

Ions

Electrons

Ion Collider Ring
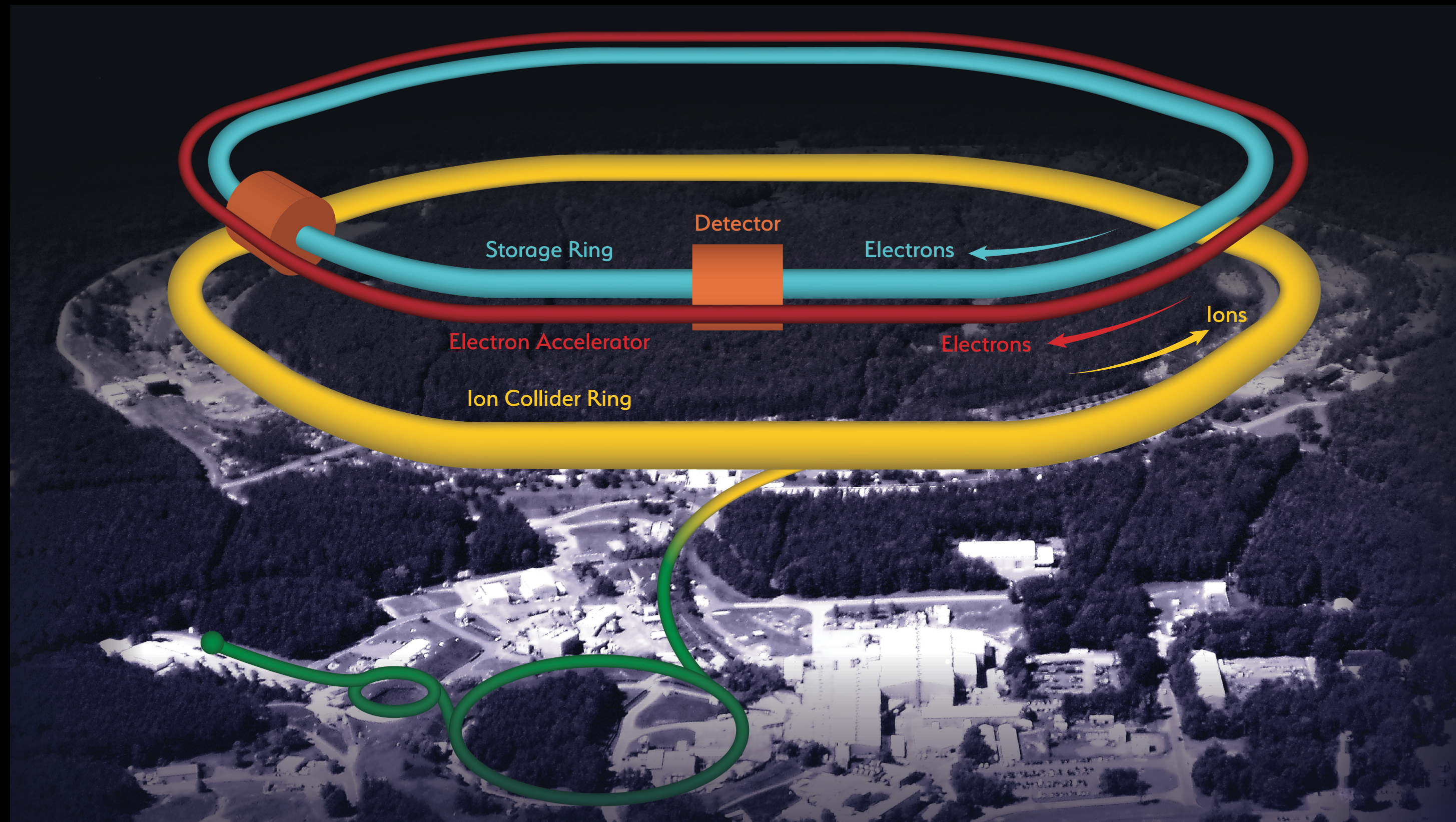
Prakhar Garg
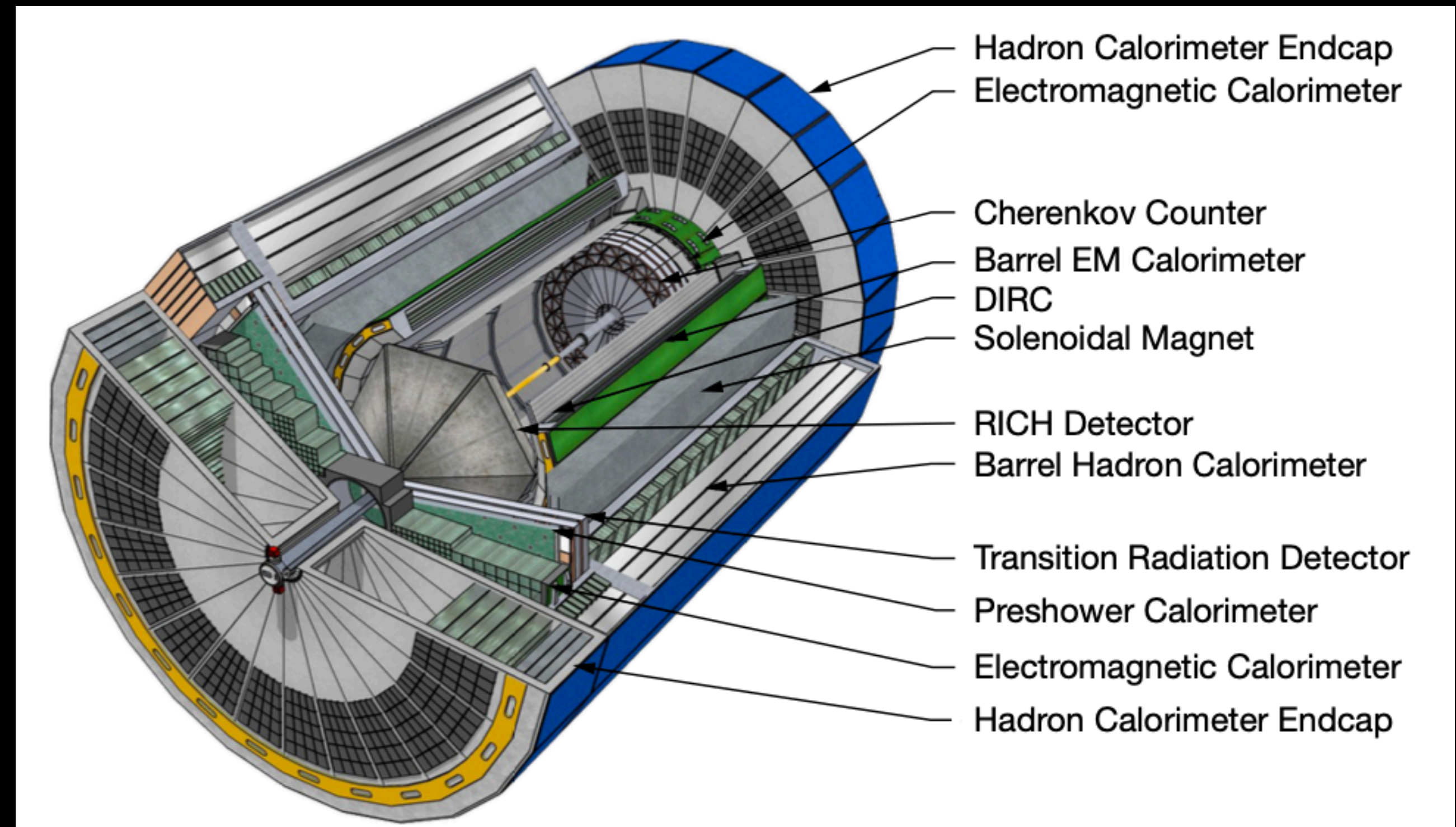**StonyBrook University**

Current Group:

T K Hemmick, K Dehmelt, S Park, P Garg (SBU)

N Smirnov, (Yale)

J Kaminski (Bonn)

Kinematics for EIC physics

A schematic showing how hadrons and the scattered lepton for different $x - Q^2$ are distributed over the detector rapidity coverage.


A cutaway illustration of a generic EIC concept detector

ATHENA: A Totally Hermetic Electron-Nucleus Apparatus

◉ Will be designed to fit in at IP6 in EIC Accelerator Complex

◉ Inspired by the Yellow Report detector concept based on a new central detector magnet up to 3T

◉ Collaboration formation is in progress

◉ ATHENA Logo Voting is still ongoing

A Call for EIC Detector Proposals has been issued by DOE & BNL/JLab on March 6, 2021, with an expected proposal submission deadline on December 1st, 2021.
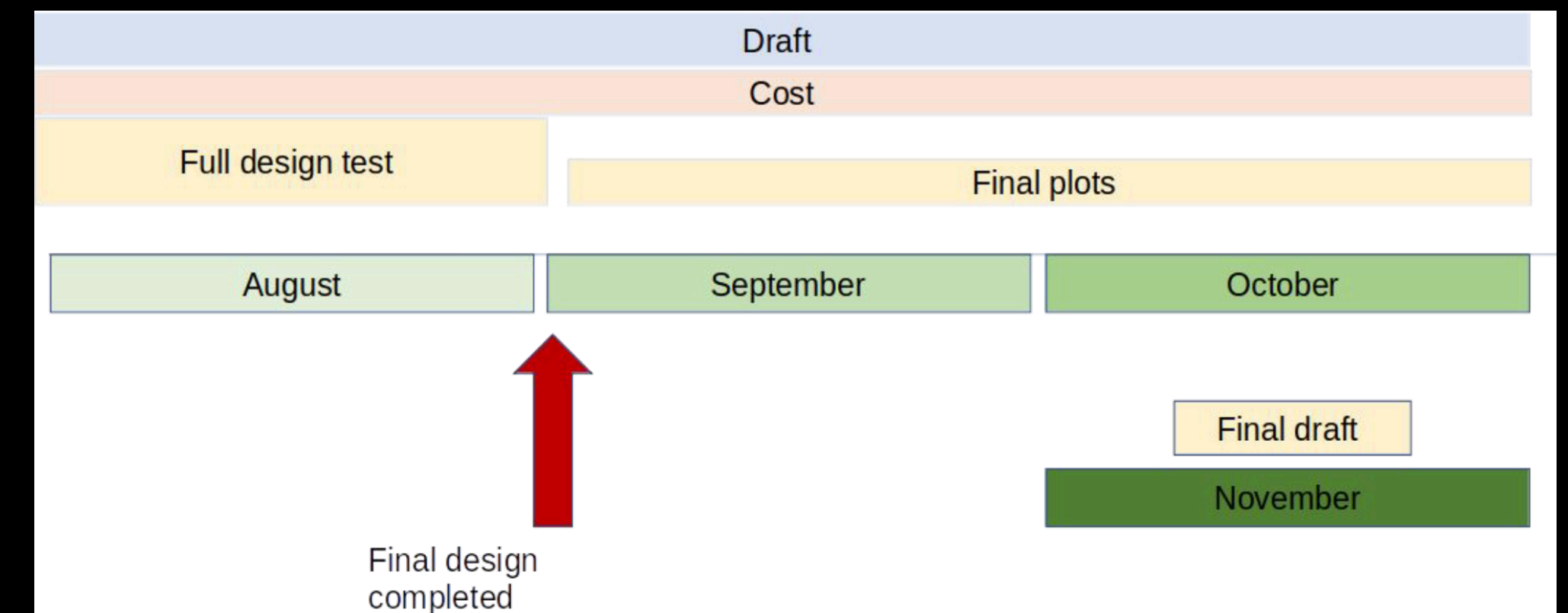
Many PID options are under consideration

Update since last meeting

➢ **PID Working Group has met weekly (May 17 - 31)**

Identified main detector proponents & gathering regular updates

B field impact on forward RICH performance	Chandradoy Chatterjee (INFN)	Estimate how the field lines of the IP6 proposed magnet affect PID performance in the forward RICH
Low-p TOF	Wenqing Fan (LBNL)	
Low momentum PID at High B-field (GridPix)	Prakhar Garg (SBU)	
mRICH	Murad Sarsour (GSU)	Simulation & performance studies
dRICh	Christopher Dilks (Duke)	Simulation & performance studies
DIRC	Joe Schwiening (GSI) Greg Kalicy (CUA)	Advice on design, simulation, performance issues
DAQ	Alexandre Camsonne (JLab)	Gathering DAQ requirements from PID WG
LGADs for TOF-PID	Wei Li (Rice)	simulation & performance studies, design, cost estimate etc.
SiPM for RICH optical readout	Roberto Preghenella (INFN)	R&D on SiPM as an option for the readout of the forward RICH
Pressurized argon for the gaseous RICH	Francesco Noto (INFN)	mechanical studies and simulations for a pressurized argon vessel for the forward gas RICH

Kick-off Meeting

PID detector updates		
DIRC	mRICH	dRICH
GridPIX	TOF	LGAD

technology/implementation updates		
B Field maps	B-field impact on RICH	SiPM for RICH readout
Pressurized Ar	LAPPD	
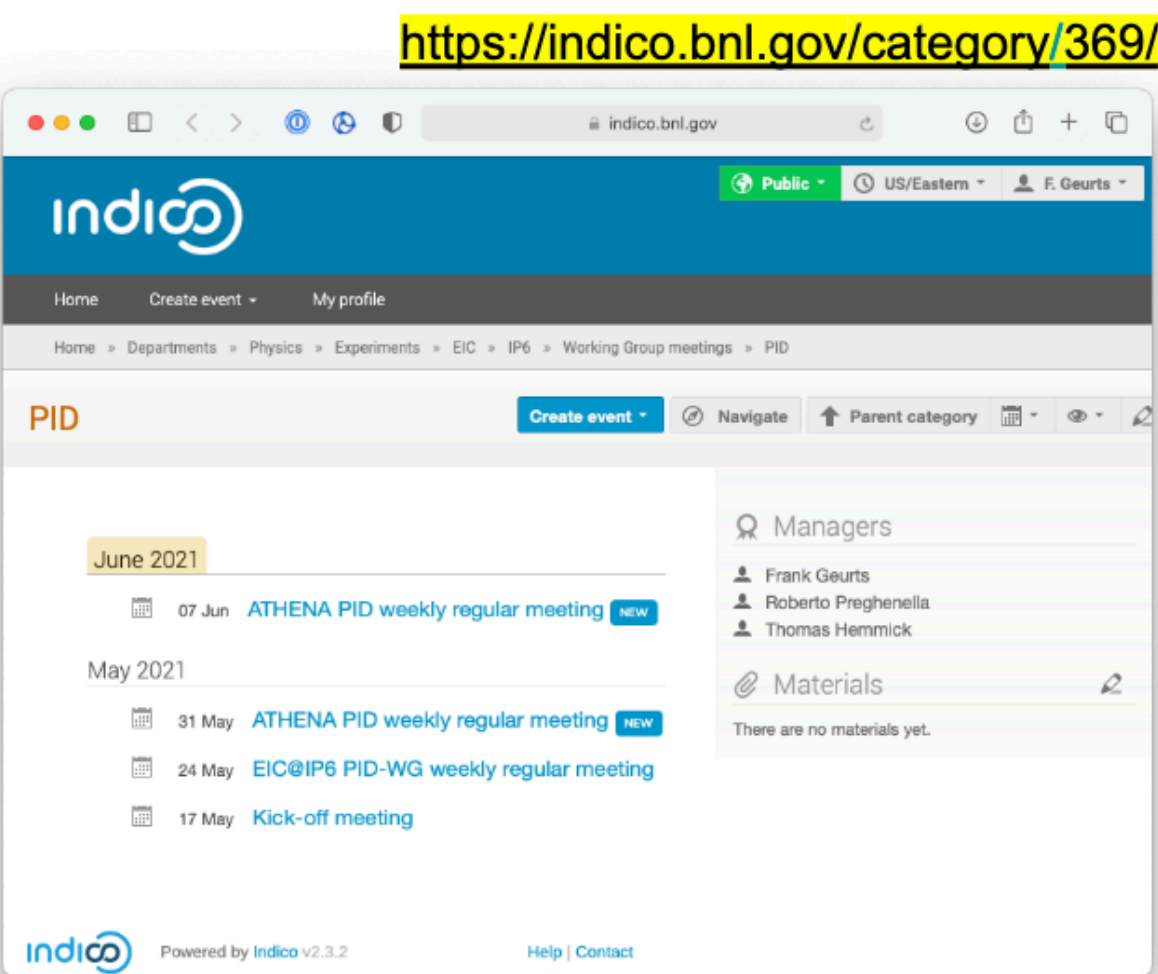
PID Performance Requirements

Reminder: PID requirements

3σ π/K/p separation

- forward (p/A going): up to 50 GeV/c
- backward (e- going): up to 7 GeV/c
- central region: up to 10 GeV/c

Challenges

- radiation hardness, B field, timing resolution
- material, integration, services, gaps
- simulation, performance
  - CAD & GEANT

Detector techniques/technologies

- low p_T
  - dE/dx (GridPix TPC)
  - TOF (LGAD)
- mid p_T
  - quartz Cherenkov (DIRC)
  - areogel Cherenkov (dRICH, mRICH)
- high p_T
  - gas Cherenkov (dRICH)

- photodetectors
  - SiPM
  - LAPDD
  - MCP-PMT

Vertex/tracking performance and requirements:

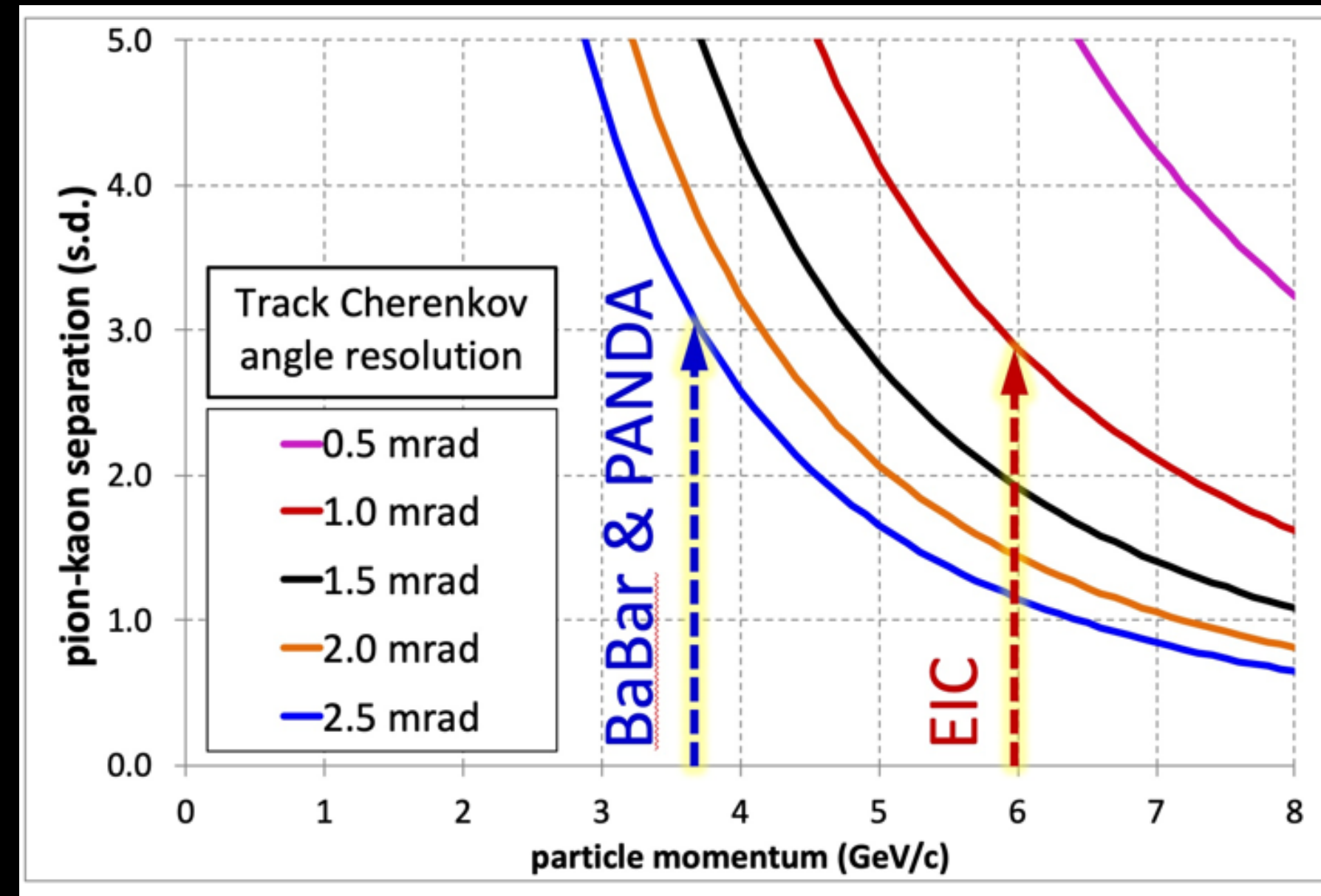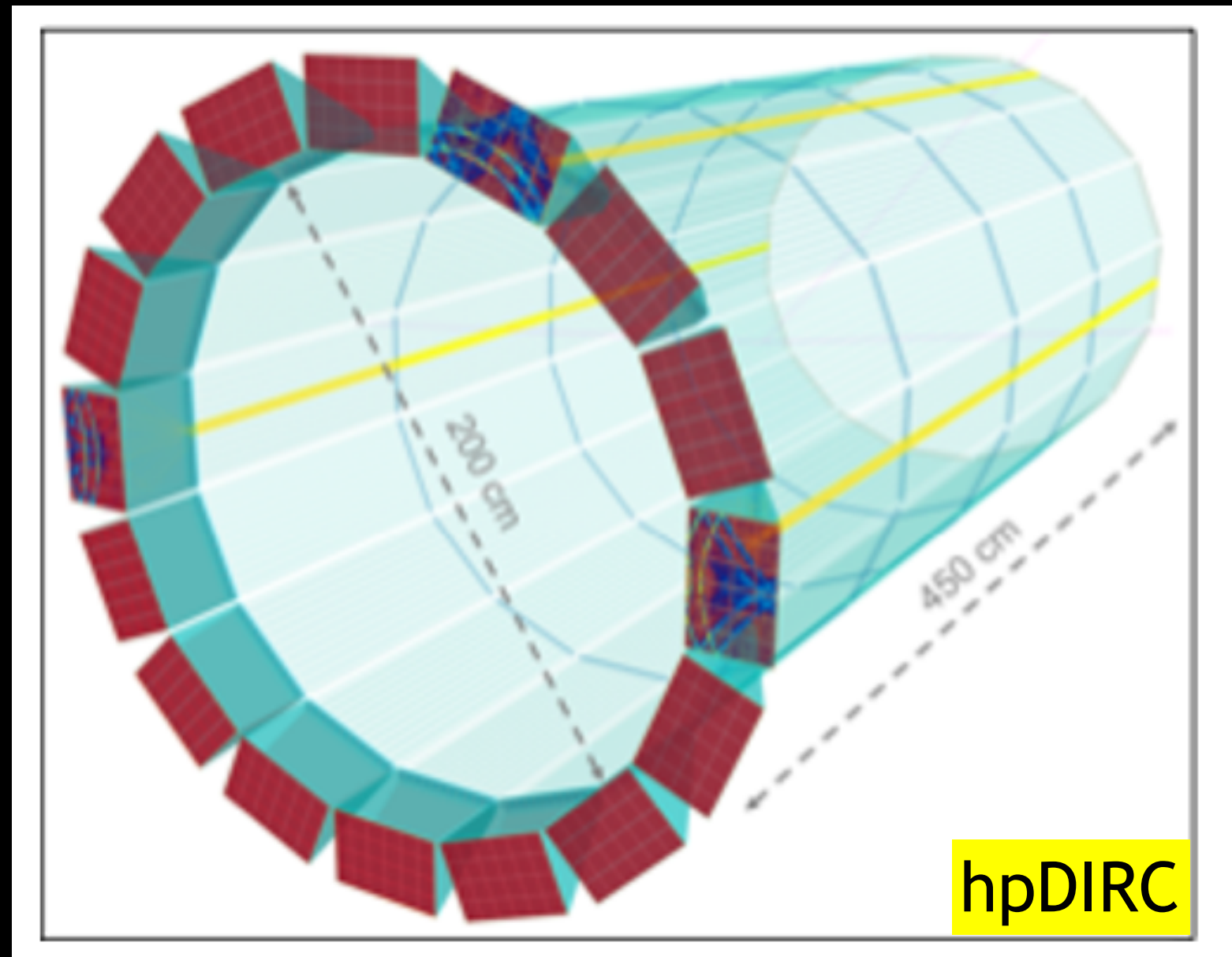Results from the YR studies compared with PWG performance summary:

all-silicon

			Tracking performance (All-silicon concept, B = 3 T)			
			Momentum res.		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	$\sigma p/p \sim 0.1\% \times p \oplus 2\%$	$\sigma p/p \sim 0.1\% \times p \oplus 0.5\%$	dca(xy) ~ 60/pT μm $\oplus$ 20 μm	dca(xy) ~ 30/pT μm $\oplus$ 40 μm
-3.0 to -2.5						
-2.5 to -2.0			$\sigma p/p \sim 0.02\% \times p \oplus 1\%$	$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$	dca(xy) ~ 40/pT μm $\oplus$ 10 μm	dca(xy) ~ 30/pT μm $\oplus$ 20 μm
-2.0 to -1.5						
-1.5 to -1.0						
-1.0 to -0.5		Barrel	$\sigma p/p \sim 0.02\% \times p \oplus 0.5\%$	$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$	dca(xy) ~ 30/pT μm $\oplus$ 5 μm	dca(xy) ~ 20/pT μm $\oplus$ 5 μm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	$\sigma p/p \sim 0.02\% \times p \oplus 1\%$	$\sigma p/p \sim 0.05\% \times p \oplus 1\%$	dca(xy) ~ 40/pT μm $\oplus$ 10 μm	dca(xy) ~ 30/pT μm $\oplus$ 20 μm
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0			$\sigma p/p \sim 0.1\% \times p \oplus 2\%$	$\sigma p/p \sim 0.1\% \times p \oplus 2\%$	dca(xy) ~ 60/pT μm $\oplus$ 20 μm	dca(xy) ~ 30/pT μm $\oplus$ 40 μm
3.0 to 3.5						dca(xy) ~ 30/pT μm $\oplus$ 60 μm

Hybrid (Si+TPC)

			Tracking performance (Hybrid concept, B = 3 T)					
			Momentum res.		Minimum pT		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	$\sigma p/p \sim 0.05\% \times p \oplus 2\%$	$\sigma p/p \sim 0.1\% \times p \oplus 0.5\%$		100-150 MeV/c	dca(xy) ~ 50/pT μm $\oplus$ 10 μm	
-3.0 to -2.5						100-150 MeV/c		dca(xy) ~ 30/pT μm $\oplus$ 40 μm
-2.5 to -2.0					160-220 MeV/c	100-150 MeV/c		
-2.0 to -1.5			$\sigma p/p \sim 0.11\% \times p \oplus 0.4\%$ (0-8 GeV/c) $\sigma p/p \sim 0.04\% \times p \oplus 1\%$ (8-30 GeV/c)	$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$		100-150 MeV/c	dca(xy) ~ 25/pT μm $\oplus$ 3 μm	dca(xy) ~ 30/pT μm $\oplus$ 20 μm
-1.5 to -1.0					300 MeV/c	100-150 MeV/c		
-1.0 to -0.5		Barrel	$\sigma p/p \sim 0.11\% \times p \oplus 0.2\%$ (0-5 GeV/c) $\sigma p/p \sim 0.03\% \times p \oplus 0.5\%$ (5-30 GeV/c)	$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$	400 MeV/c (90% acceptance)	100-150 MeV/c	dca(xy) ~ 15/pT μm $\oplus$ 2 μm	dca(xy) ~ 20/pT μm $\oplus$ 5 μm
-0.5 to 0								
0 to 0.5								
0.5 to 1.0								
1.0 to 1.5		Forward Detector	$\sigma p/p \sim 0.11\% \times p \oplus 0.4\%$ (0-8 GeV/c) $\sigma p/p \sim 0.04\% \times p \oplus 1\%$ (8-30 GeV/c)	$\sigma p/p \sim 0.05\% \times p \oplus 1\%$	300 MeV/c	100-150 MeV/c	dca(xy) ~ 25/pT μm $\oplus$ 3 μm	dca(xy) ~ 30/pT μm $\oplus$ 20 μm
1.5 to 2.0					160-220 MeV/c	100-150 MeV/c		
2.0 to 2.5						100-150 MeV/c		
2.5 to 3.0			$\sigma p/p \sim 0.05\% \times p \oplus 2\%$	$\sigma p/p \sim 0.1\% \times p \oplus 2\%$		100-150 MeV/c	dca(xy) ~ 50/pT μm $\oplus$ 10 μm	dca(xy) ~ 30/pT μm $\oplus$ 40 μm
3.0 to 3.5						100-150 MeV/c		dca(xy) ~ 30/pT μm $\oplus$ 60 μm

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PID in Central Region:

Currently Central Arm Principal Technology is DIRC but:

Kaon threshold = 0.47 GeV/c

Curling Limit p_T = 0.45 GeV/c

Lower momentum?

Motivation

log10(dE/dx(F)(keV/cm)) versus log10(p(GeV/c)) for Tpc TrackLength > 40 cm All

TdEdxF

Entries	7.621214e+08
Mean x	−0.2552
Mean y	0.4663
RMS x	0.2819
RMS y	0.1189

- p
- K
- π
- e
- d
- μ
- t
- He3
- α
- 2π
- Li

3.6X

1.6X
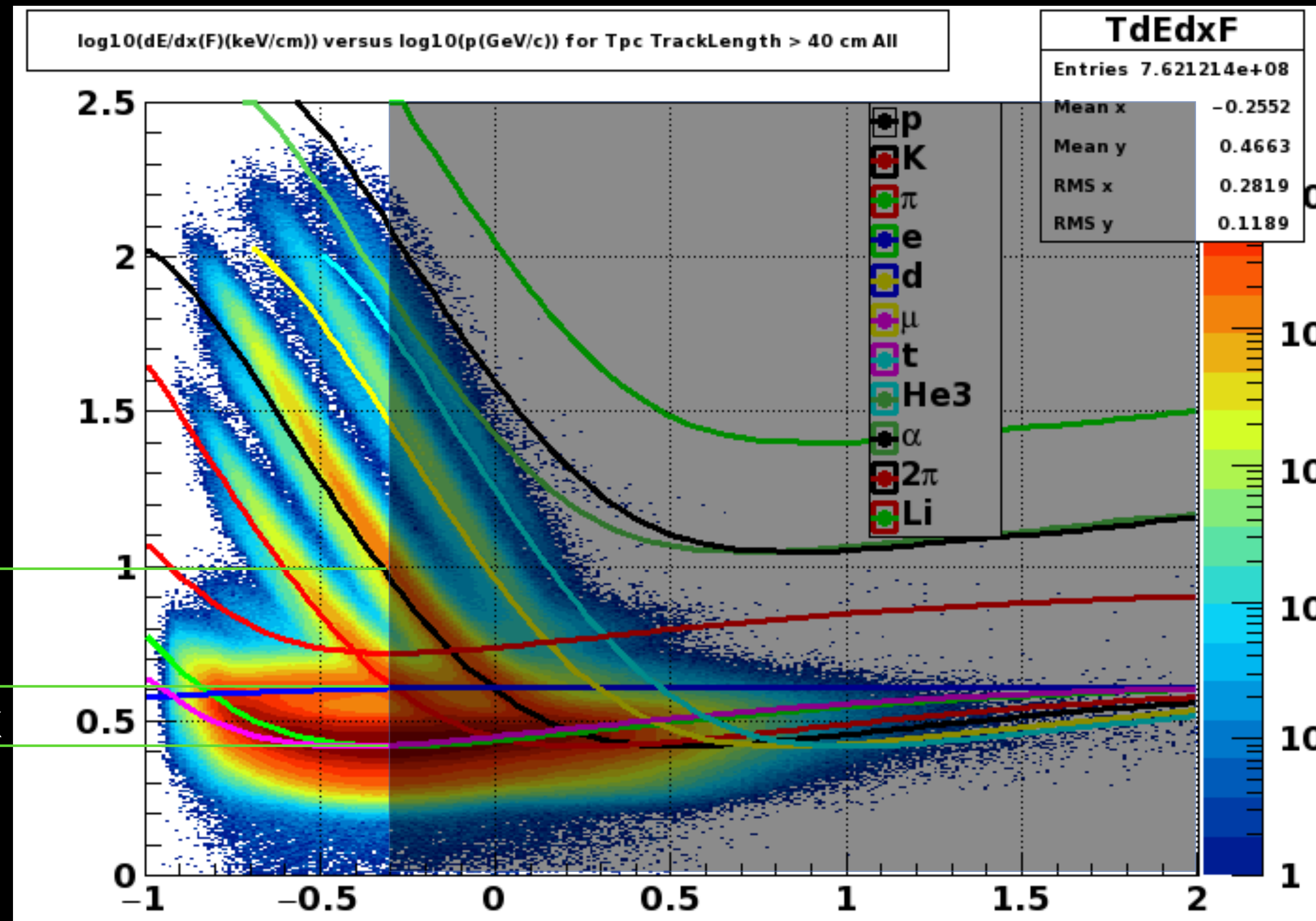
P < 0.5 GeV/c

Dual Approach:
- Standalone Garfield (optimize detector)
- GEANT (integrate into full simulation)

Restating the issue
- DIRC has low-p limitations:
    - Curl Up (0.45 GeV/c)
    - Kaon threshold (0.47 GeV/c)

- Rather than lower the field:
    - PID at low radius.
    - dE/dx separations huge!
        - 1.6X pi-K
        - 2.25X K-p

    - GridPIX
        - Established
        - Robust
        - Excellent tracking
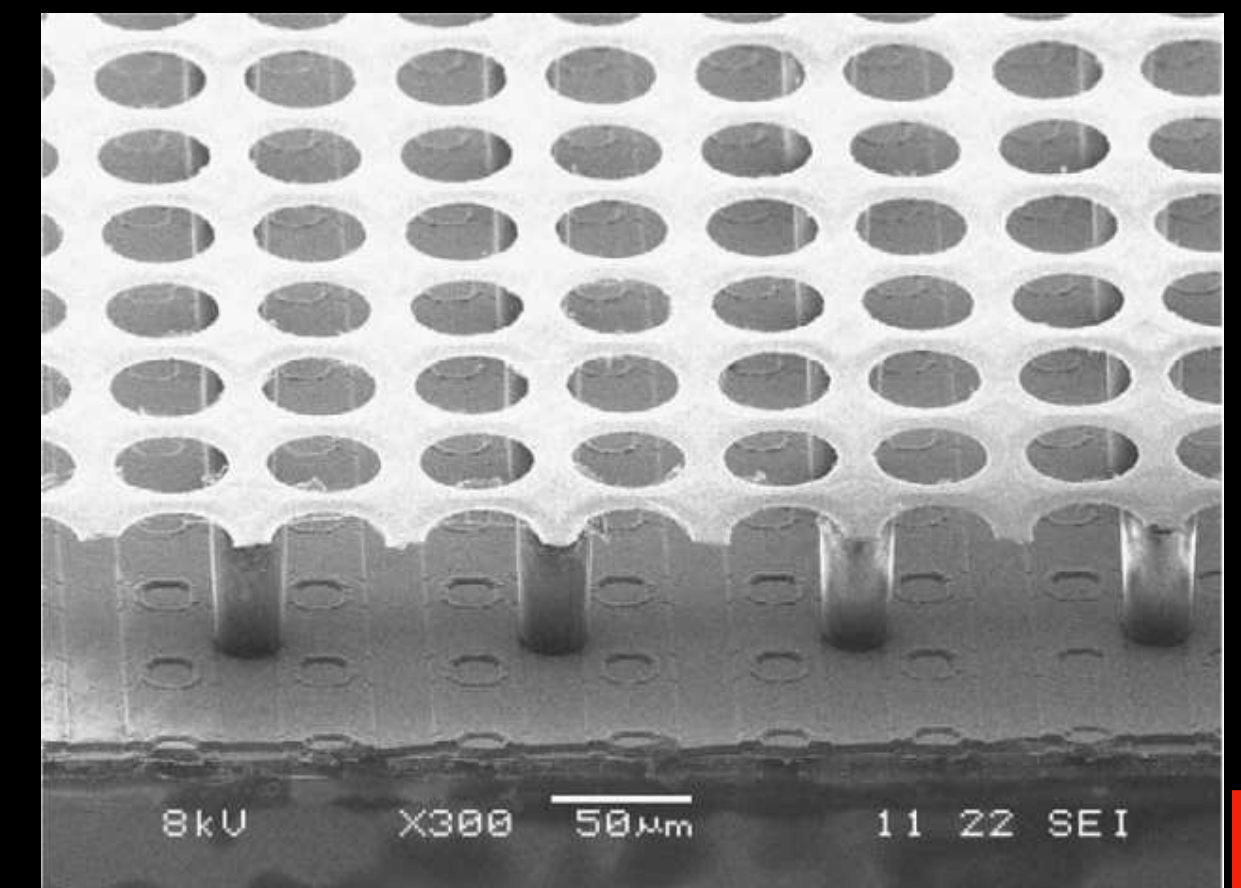
Few Words about GridPix

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).
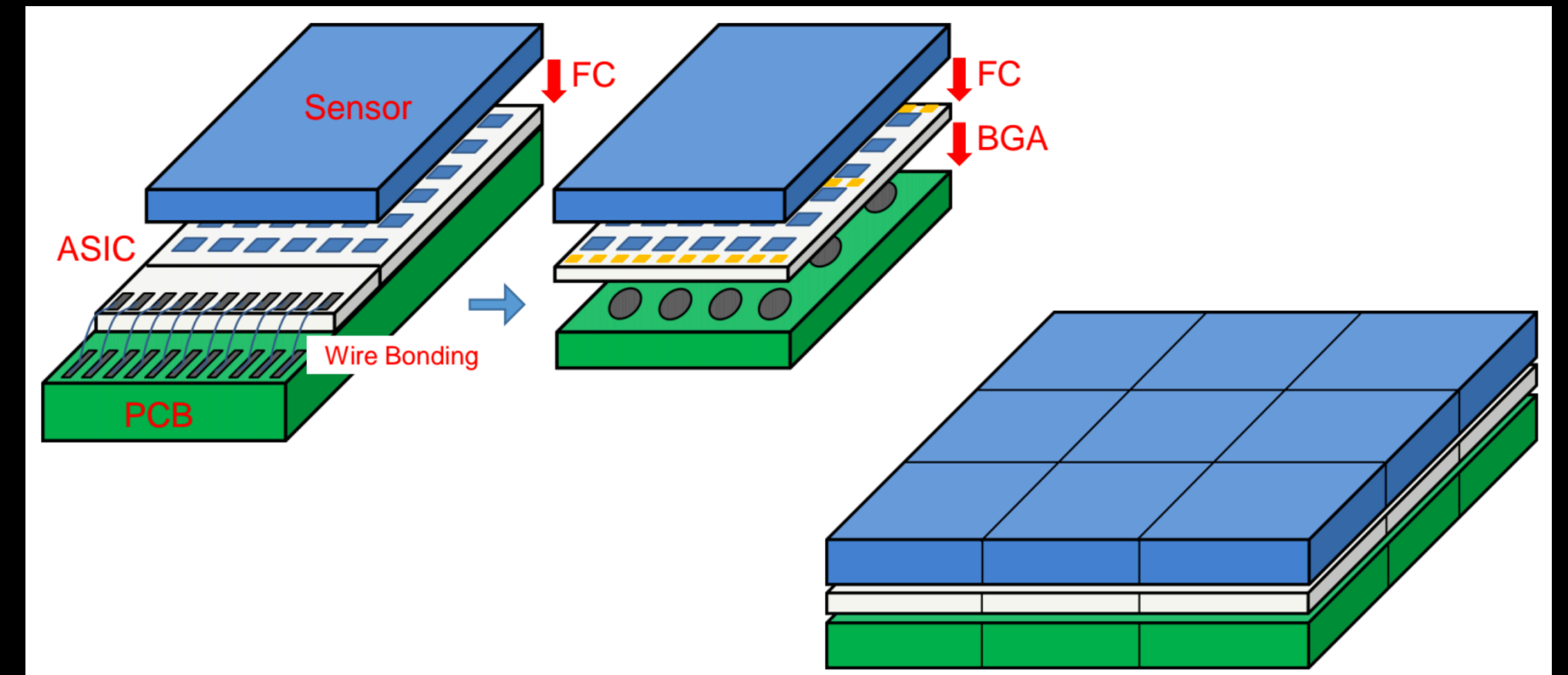

We are in close contact with Jochen Kaminski et. al. from Bonn and having weekly meeting since recently !!
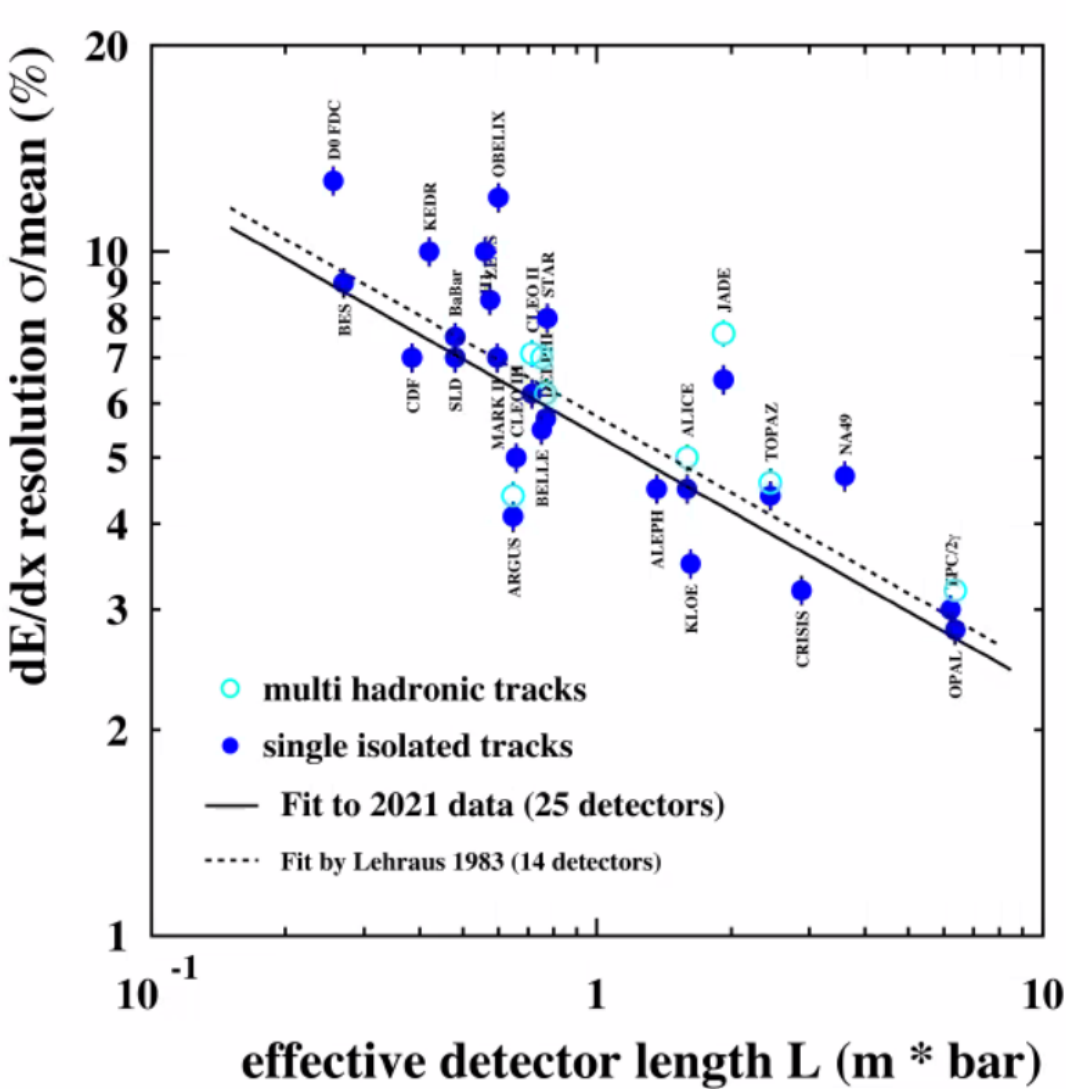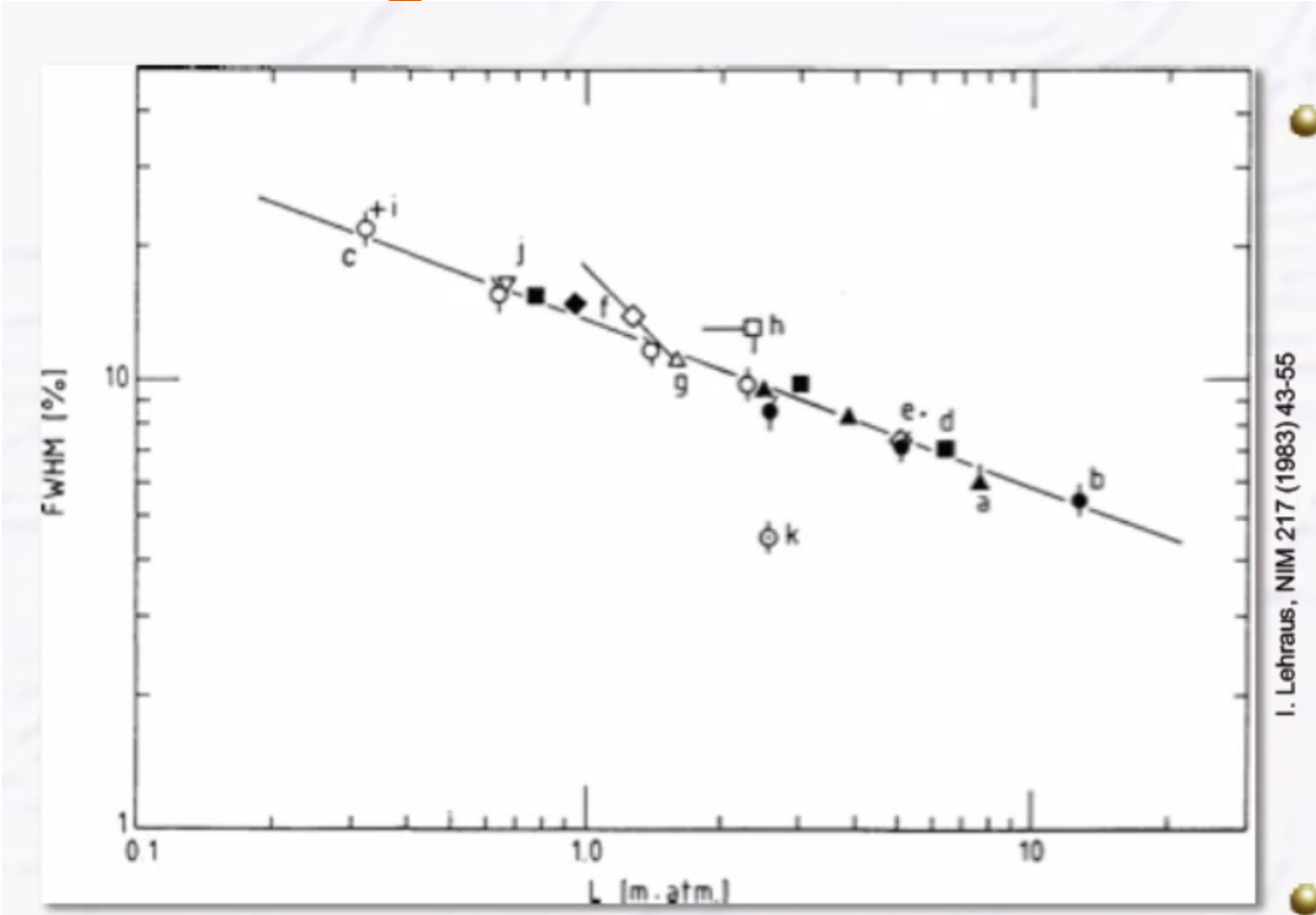
Low Momentum PID

- High magnetic field curls low(er) momentum particles.
  - Option #1: We don't care about them. (bad option)
  - Option #2: Lower the B-field for "special runs". (poor option)
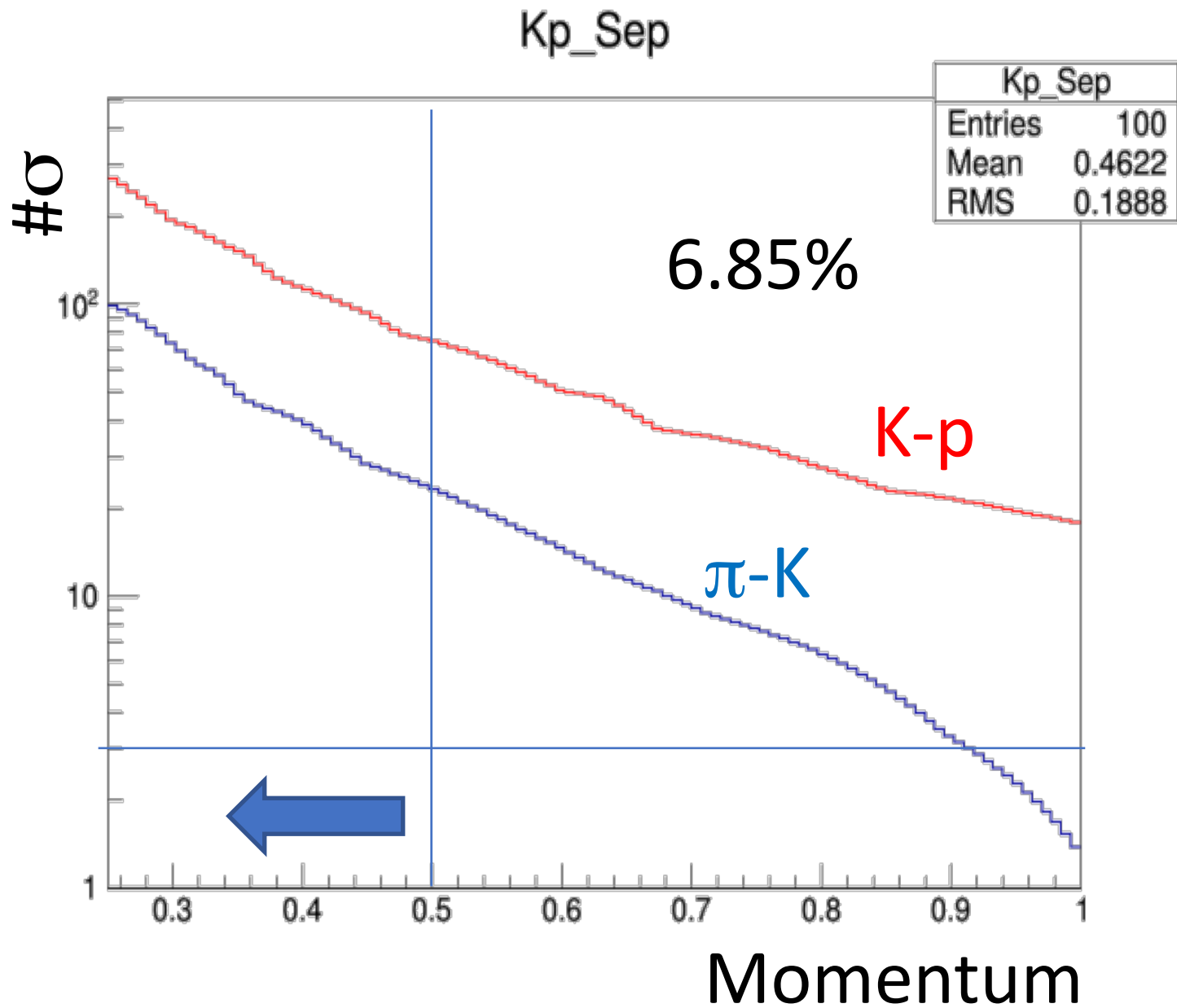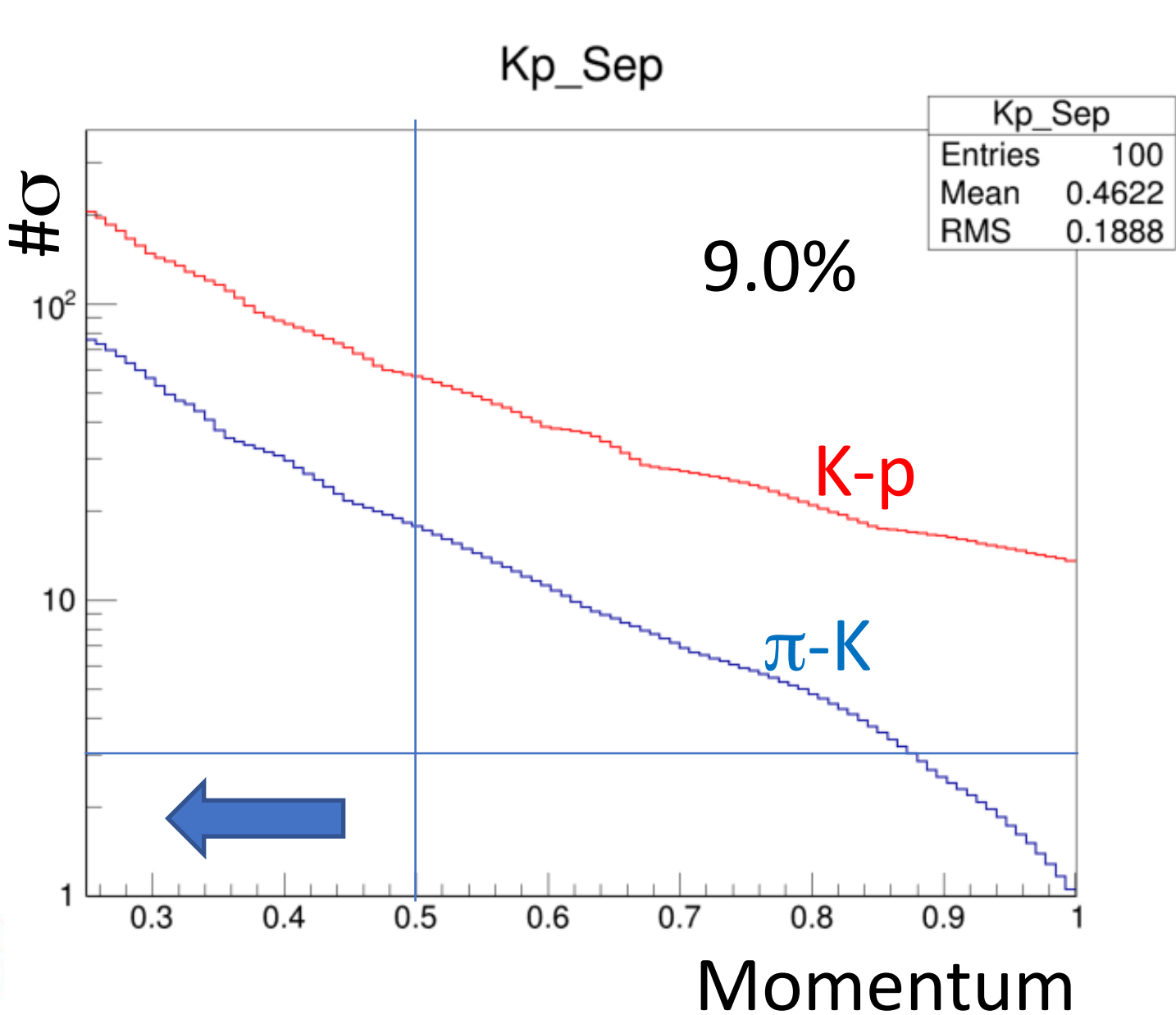 - Option #3: PID on these particles BEFORE they curl up.

Membrane

GridPix

Mostly ~~All-Si Tracker~~

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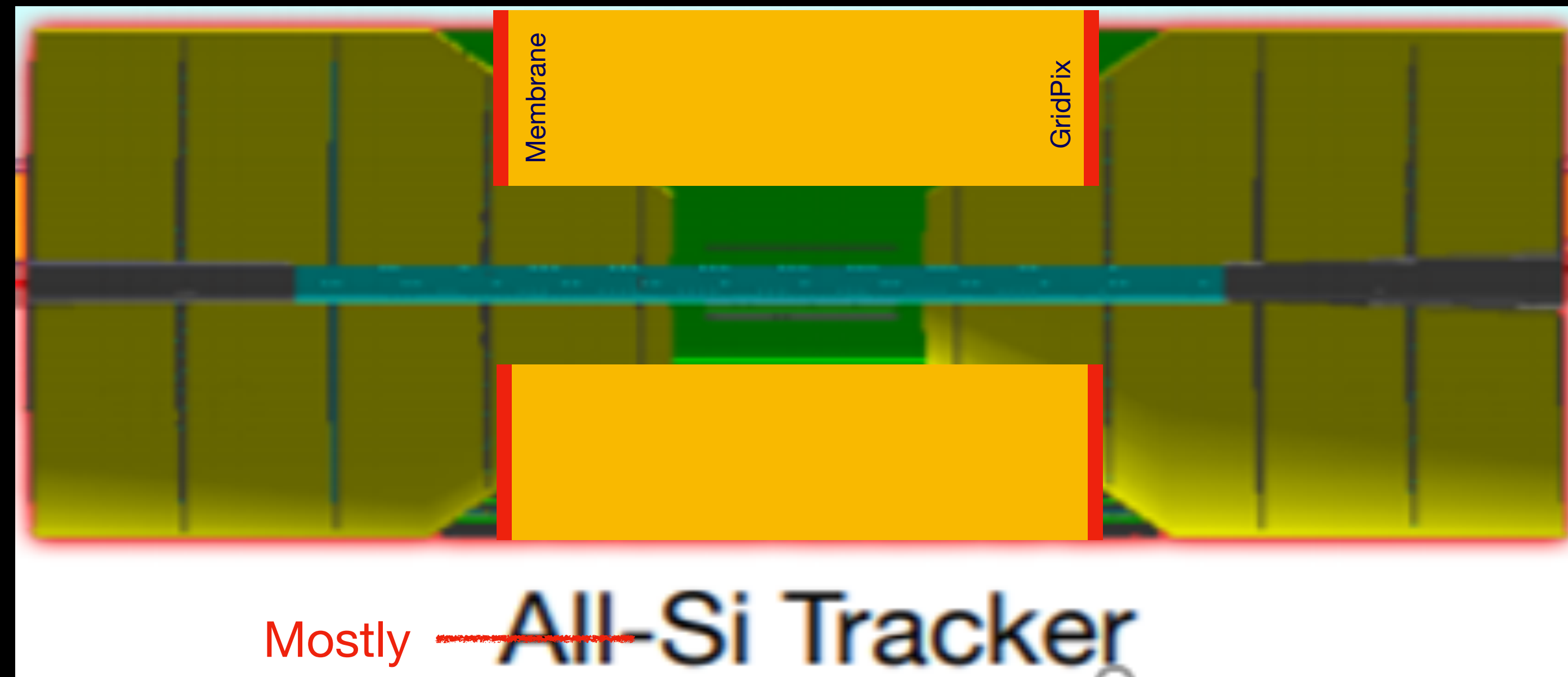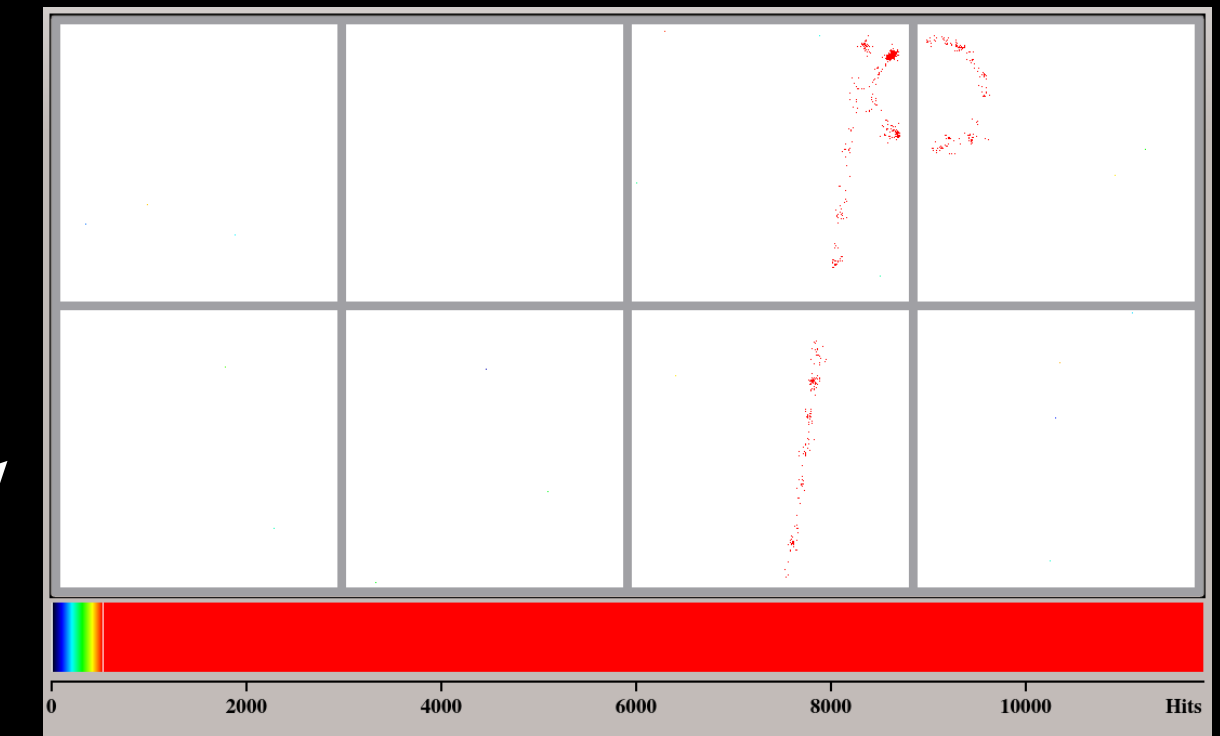
For high Momentum PID?
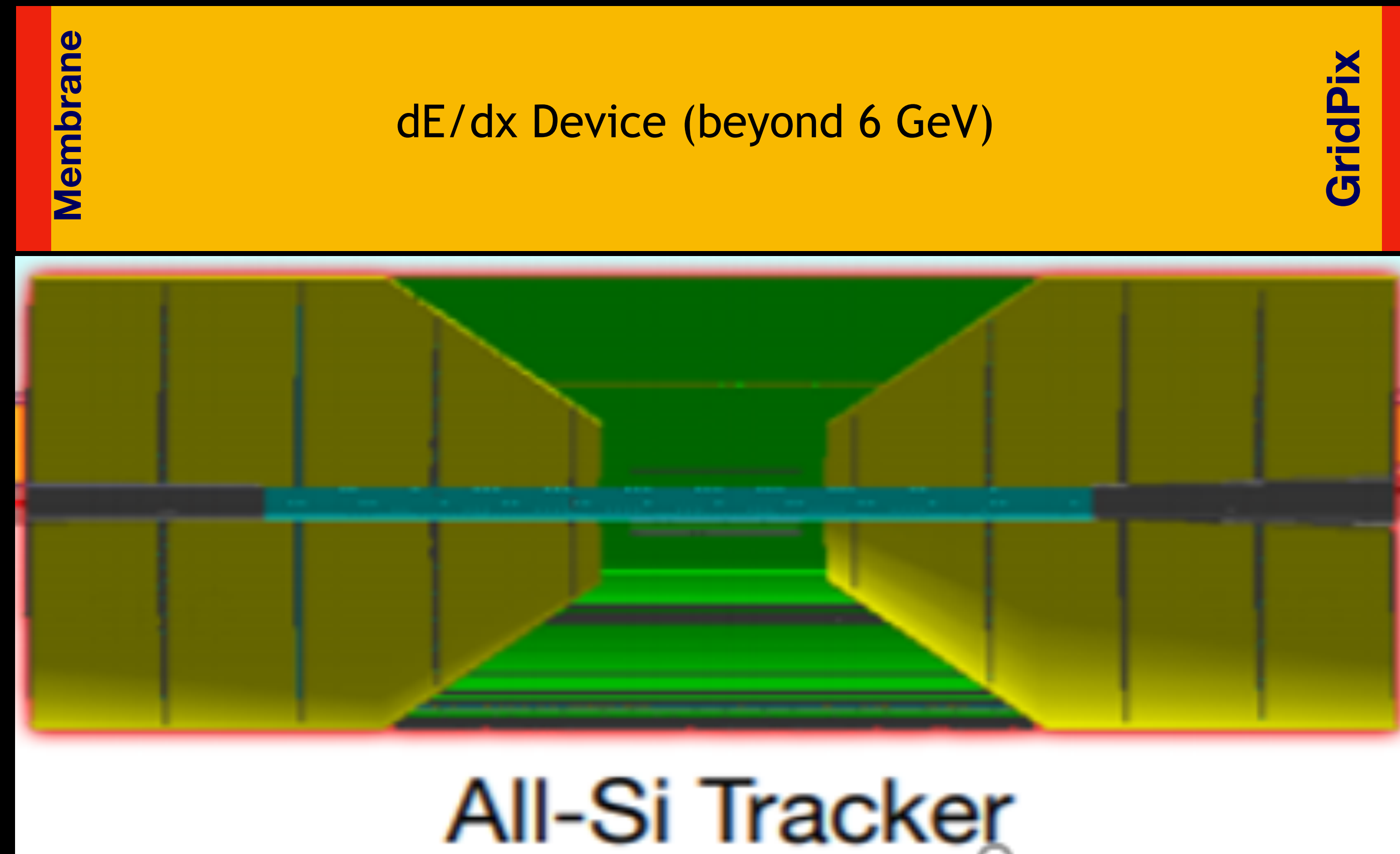
Anticipated Performance for PID:

Fit by *Lehraus* 1983:

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

Fit in 2021 (25 large detectors):

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

9.0%

6.85%

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

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Overly Simplified Momentum Resolution

- Figure of Merit:

  - $\sigma_p \propto \dfrac{\sigma_{hit}}{\sqrt{N_{meas}}} \equiv Figure\ of\ Merit$

- Can be compared to Silicon with detailed Monte Carlo

- Here is simple-minded estimate

  - $Figure\ of\ Merit(Si) = \dfrac{\frac{20\ \mu m}{\sqrt{12}}}{\sqrt{4}} = 2.9\ \mu m$

- Gas:

  - Including efficiency ~3000 electrons (minimum!) per track

  - Each suffers digitization (σ = 55 μm/sqrt(12) = 16 μm)

  - Diffusion(Length) = $25\dfrac{\mu m}{\sqrt{cm}}\sqrt{L}$

    - 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.
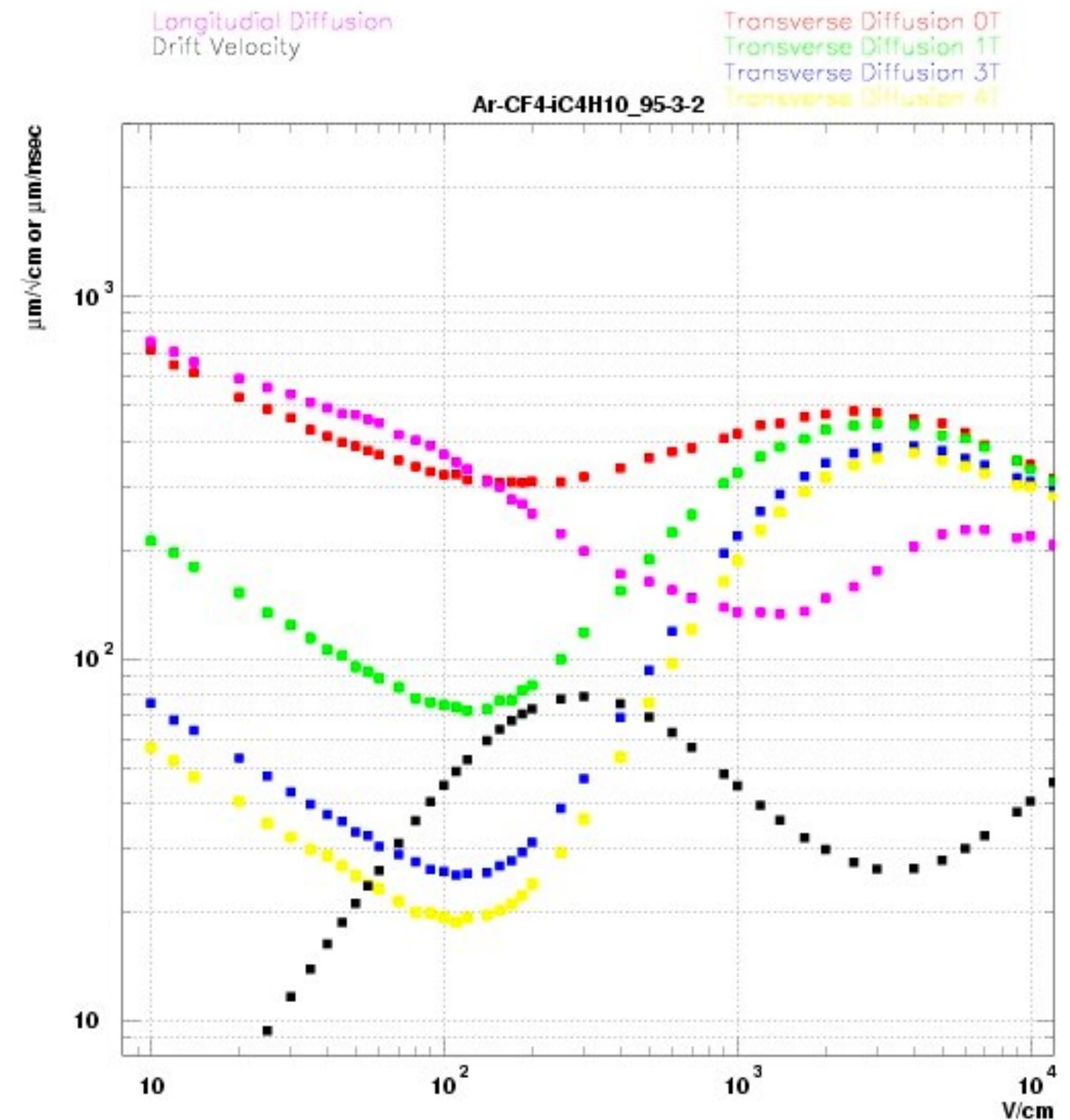
Summary:
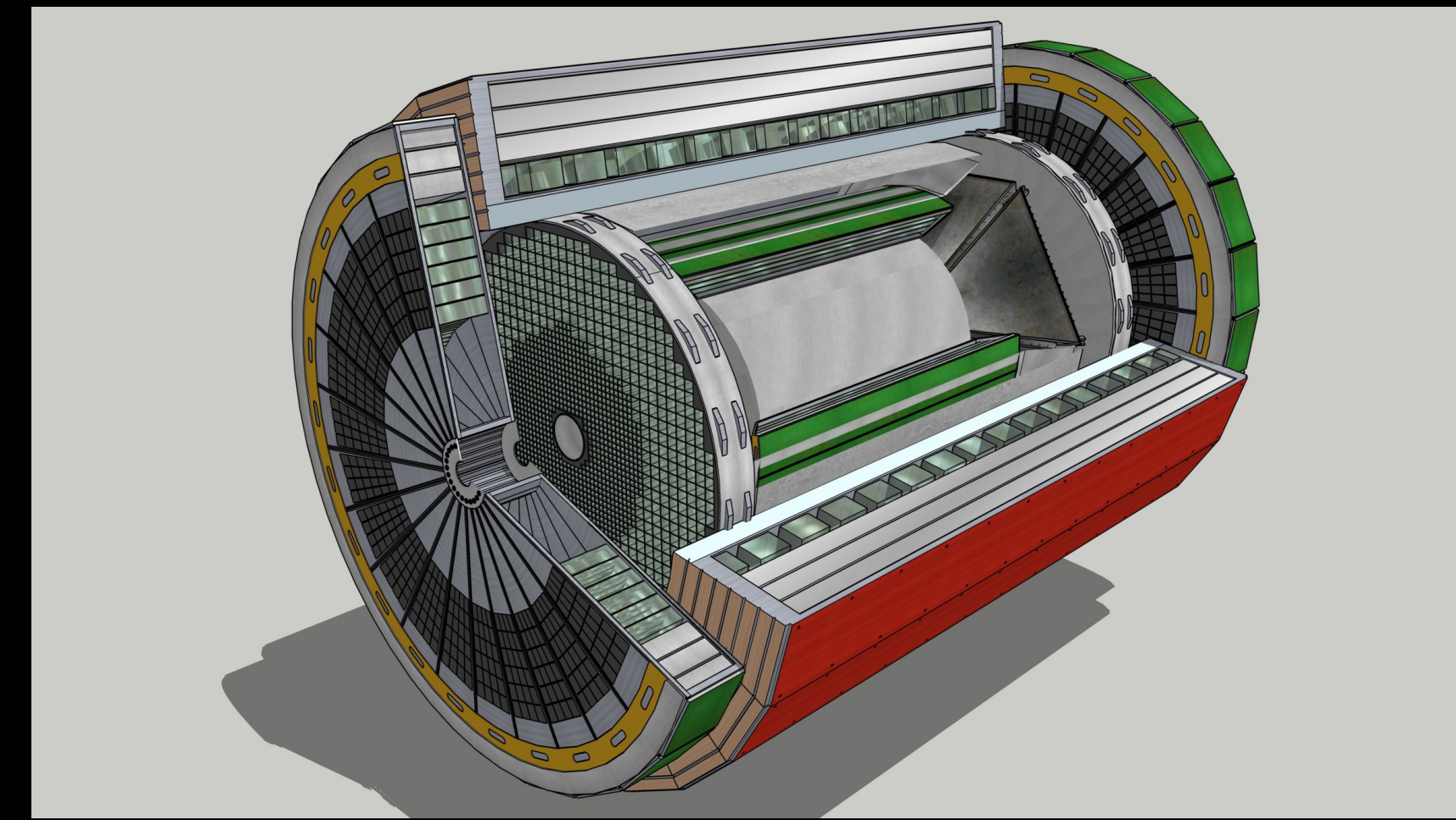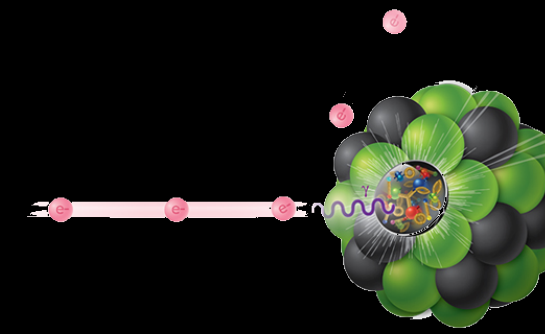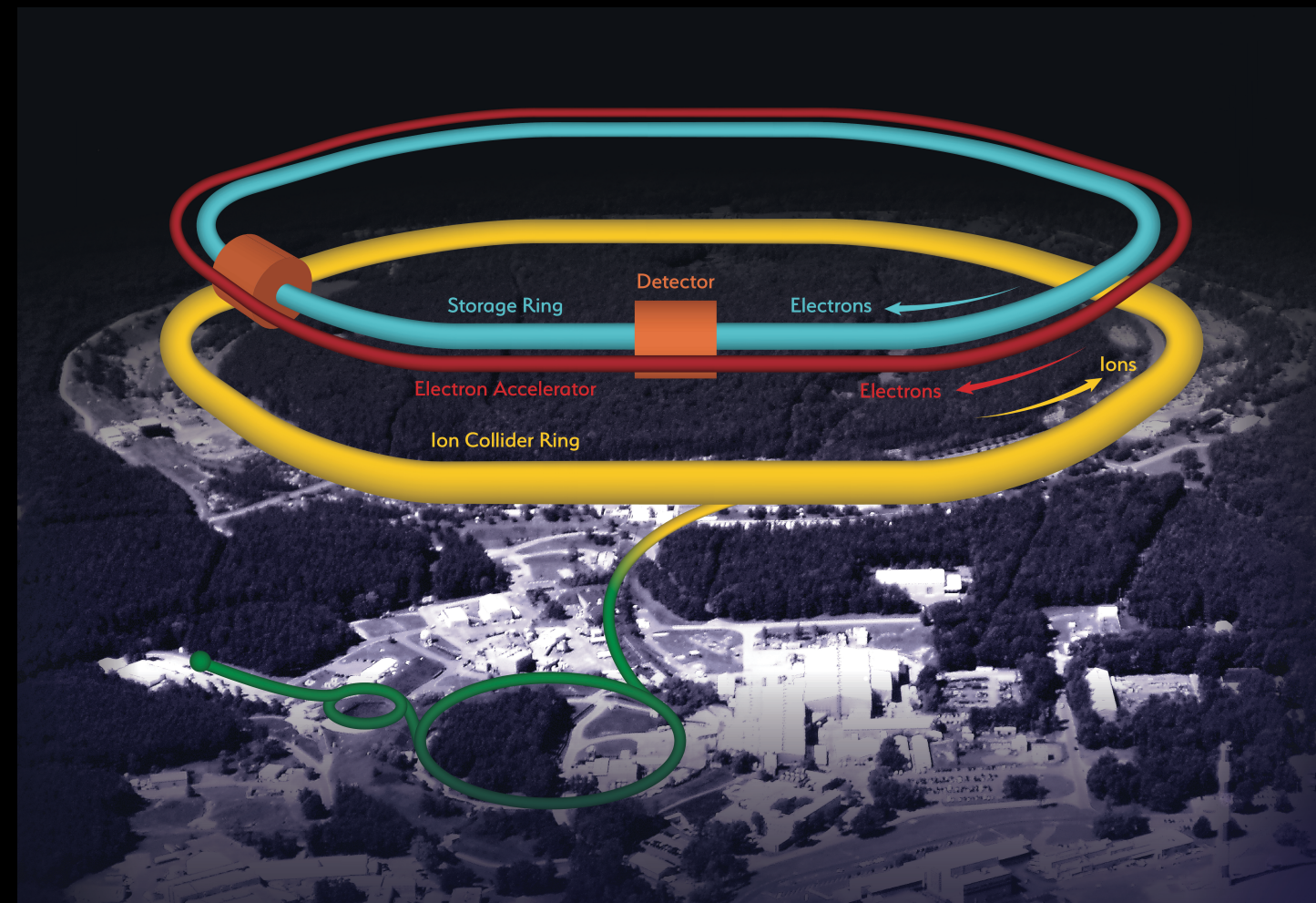
- All PID technologies have a "dynamic range"
- Most of the locations require multiple/complementary solutions.
- Its a Complex phase space.

- GridPix based Readout opens new possibilities for both PID and Tracking options
- Detailed studies are underway for GridPix based option, stay tuned.