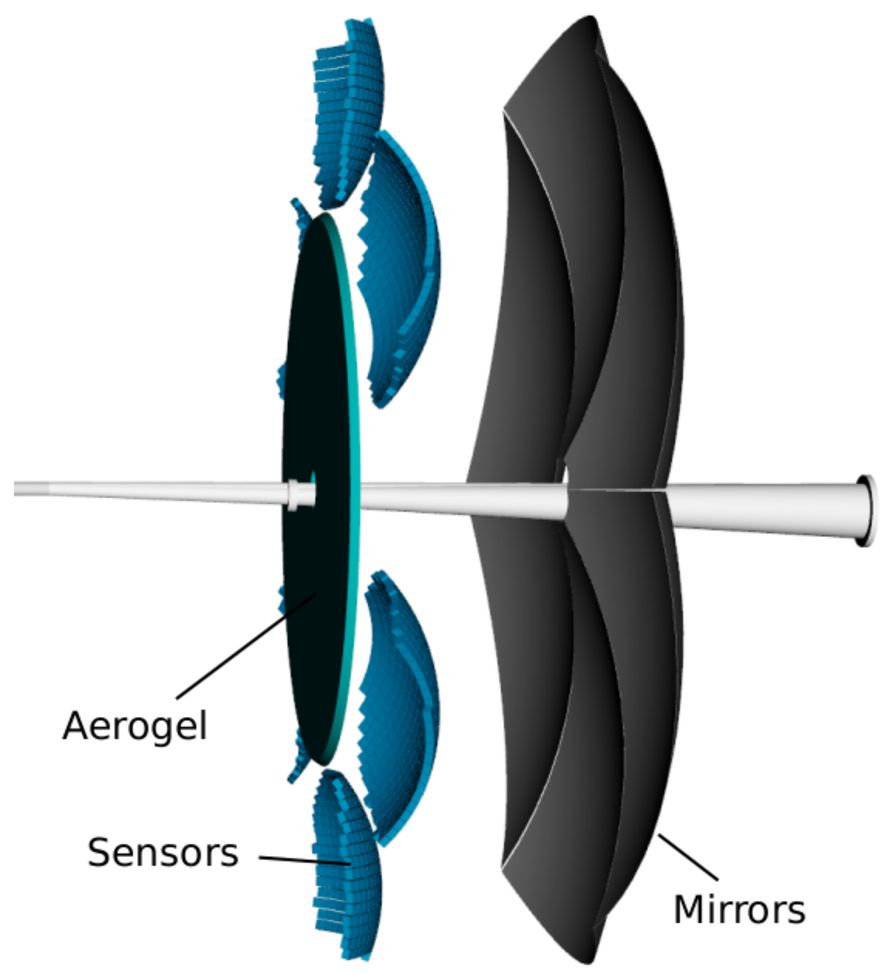
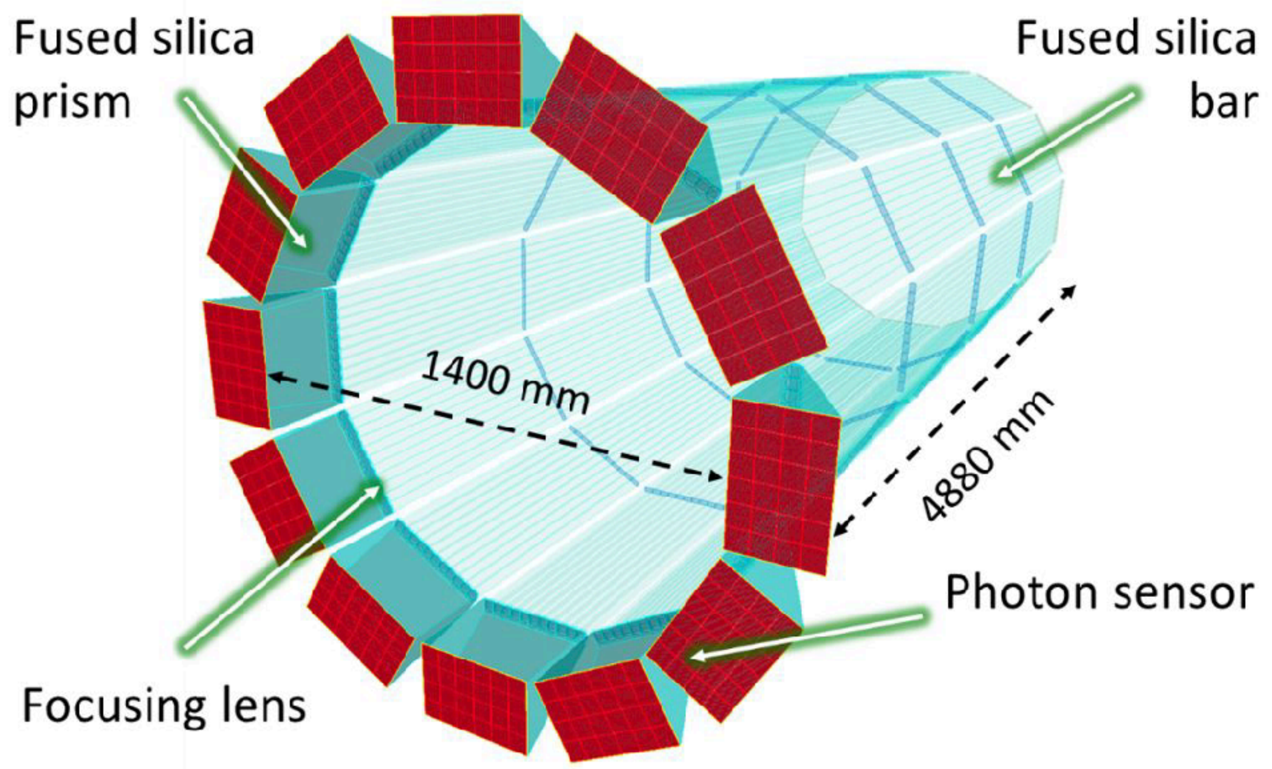
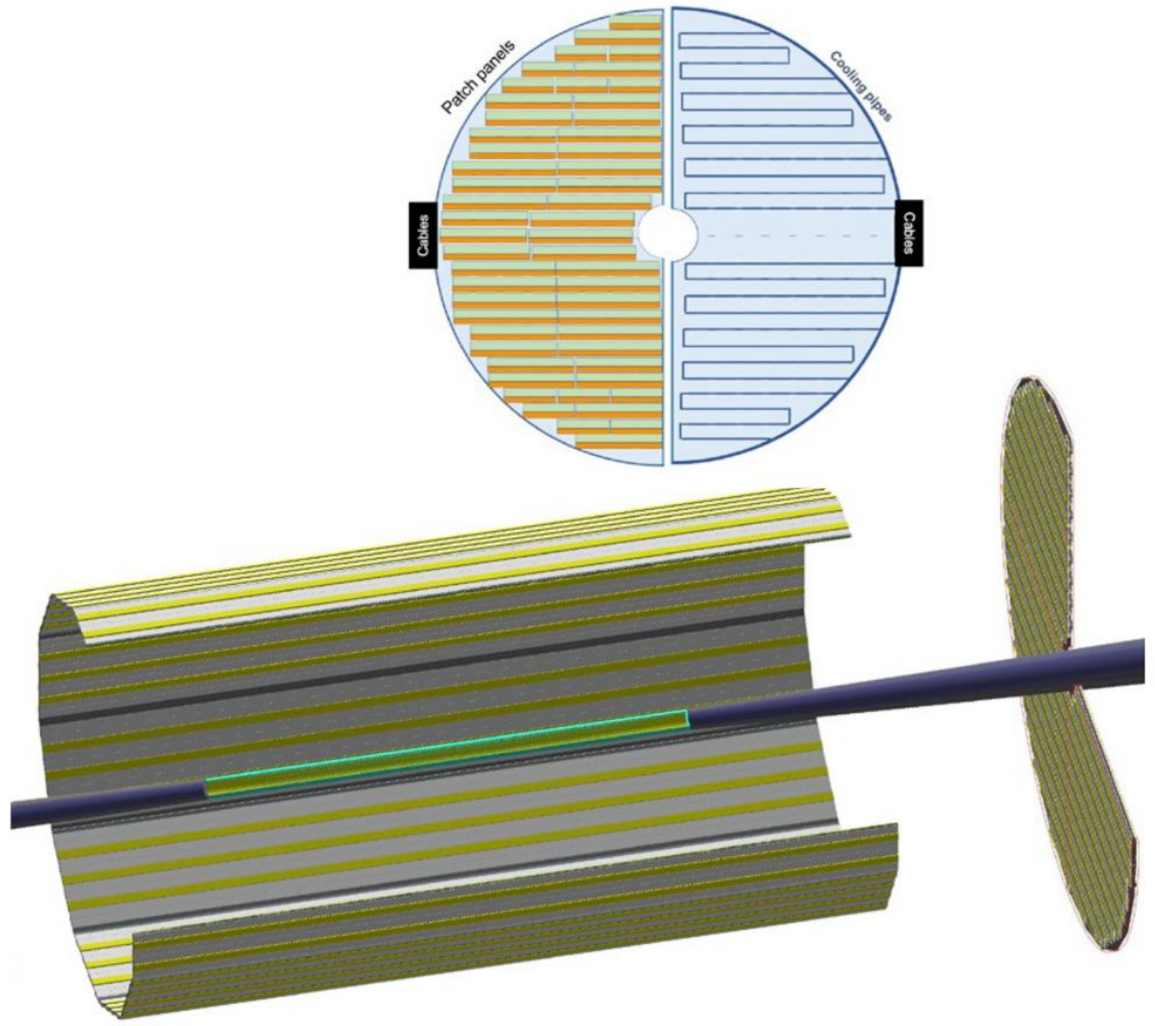
PID Workfest Report

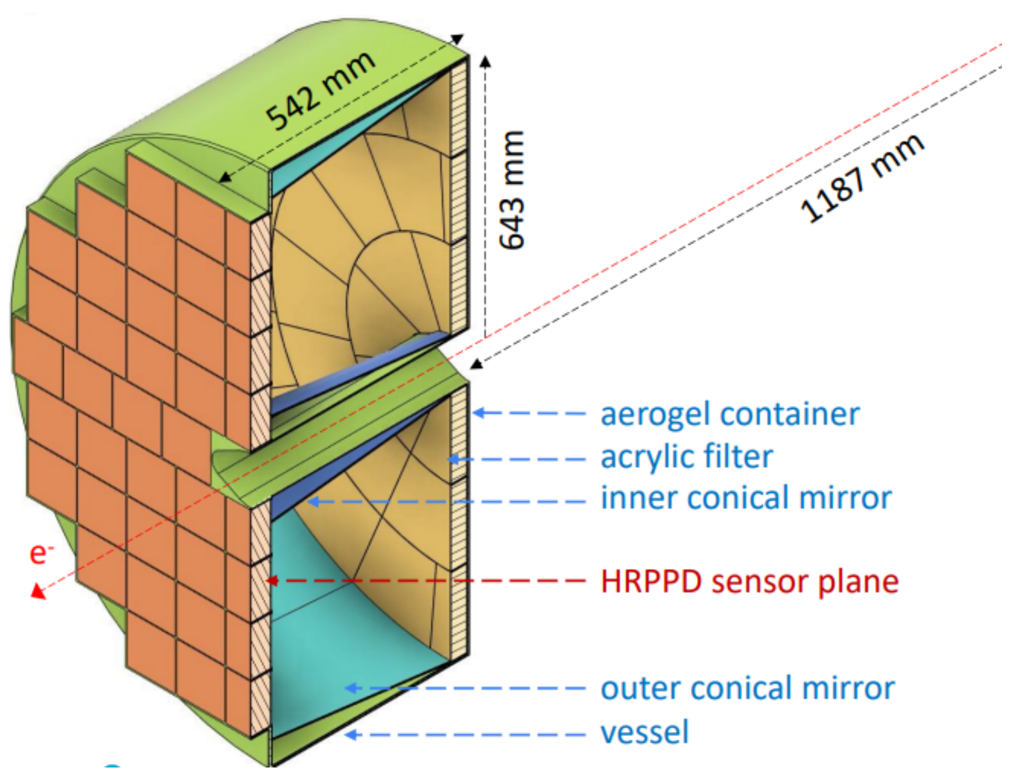
<u>Outline</u>

1. Joint PID/Tracking Workfest
2. PID Workfest









Thomas Ullrich, ePIC Collaboration Meeting, ANL, January 13, 2024

Joint PID/Tracking Workfest

8:00 AM → 9:45 AM **Joint Common PID Sim/Tracking Session**

Zoom Connection

Conveners: Ernst Sichter
Thomas Ullrich (BNL) , Os

8:00 AM **Impact o**
Speaker:
angul

8:20 AM **Status o**
Speaker:
statu

8:30 AM **pfRICH angular resolution requirements** 15m
Speaker: Alexander Kiselev (BNL)
tracking-for-pfrich.p...

8:45 AM **dRICH angular resolution requirements** 15m
Speaker: Marco Contalbrigo (INFN Ferrara)
dRICH_240111.pdf

9:00 AM **hpDIRC angular resolution requirements** 15m
Speaker: Roman Dzhygadlo (GSI)

9:15 AM **ToF angular resolution requirements** 15m
Speaker: Shirendu nanda (University of Illinois at Chicago (US))
ToF_AC-LGAD_ePIC...

10:15 AM → 12:00 PM **Joint Common PID Sim/Tracking Session**

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National Lab)

solutions at PID detectors 20m
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01-11-2024-Alternat...

10:55 AM **Using Fast simulation to understand angular resolutions** 20m
Speaker: Shyam Kumar (University and INFN Bari)
Fast_Simulation_eP... Fast_Simulation_eP...

11:15 AM **Simulated track length, which is needed by ToF for PID** 20m
Speaker: Shujie Li (Lawrence Berkeley National Laboratory)
track propagation a...

11:35 AM **Discussion** 25m

Focus of Joint Session:

Part 1: Angular Resolution Requirement

Part 2: How to measure Angular Resolution

Joint PID/Tracking Workfest

8:00 AM → 9:45 AM **Joint Common PID Sim/Tracking Session**

Zoom Connection

Conveners: Ernst Sichtermann (Lawrence Berkeley National Laboratory), Matt Posik (Temple
Thomas Ullrich (BNL) , Oskar Hartbrich (Oak Ridge National Lab)

- 8:00 AM — **Impact of current tracking estimates on DIRC performance.**
  Speaker: Roman Dzhygadlo (GSI)
  angular_resolution_...
- 8:20 AM — **Status of PID/tracking requirements** 10m
  Speaker: Thomas Ullrich (BNL)
  status_TU_ANL_ePI...
- 8:30 AM — **pfRICH angular resolution requirements** 15m
  Speaker: Alexander Kiselev (BNL)
  tracking-for-pfrich.p...
- 8:45 AM — **dRICH angular resolution requirements** 15m
  Speaker: Marco Contalbrigo (INFN Ferrara)
  dRICH_240111.pdf
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- 9:15 AM — **ToF angular resolution requirements** 15m
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  ToF_AC-LGAD_ePIC...

10:15 AM → 12:00 PM **Joint Common PID Sim/Tracking Session**

Zoom Connection

Conveners: Ernst Sichtermann (Lawrence Berkeley National Laboratory), Matt Posik (Temple University), Thomas Ullrich (BNL) , Oskar Hartbrich (Oak Ridge National Lab)

- 10:15 AM — **Current status of angular resolutions at PID detectors** 20m
  Speaker: Matt Posik (Temple University)
  01-11-2024-Angular...
- 10:35 AM — **Discussion on other potential methods** 20m
  Speaker: Matt Posik (Temple University)
  01-11-2024-Alternat...
- 10:55 AM — **Using Fast simulation to understand angular resolutions** 20m
  Speaker: Shyam Kumar (University and INFN Bari)
  Fast_Simulation_eP... Fast_Simulation_eP...
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  track propagation a...
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Tracking/PID Requirement Document

- Incremental Design and Safety Review of PID Detectors, July 20, 2023
- Committee requested a document that provides:
  - Requirement on tracking precision from PID detectors
  - Outline what the PID detectors can do for tracking
- PID & Tracking Group agreed on definitions of angular resolution
- Now working on document outlining the requirements
  - decided to use a snapshot of current know-how and modify as we make progress

Requirements on the bi-directional interface between tracking and particle identification detectors

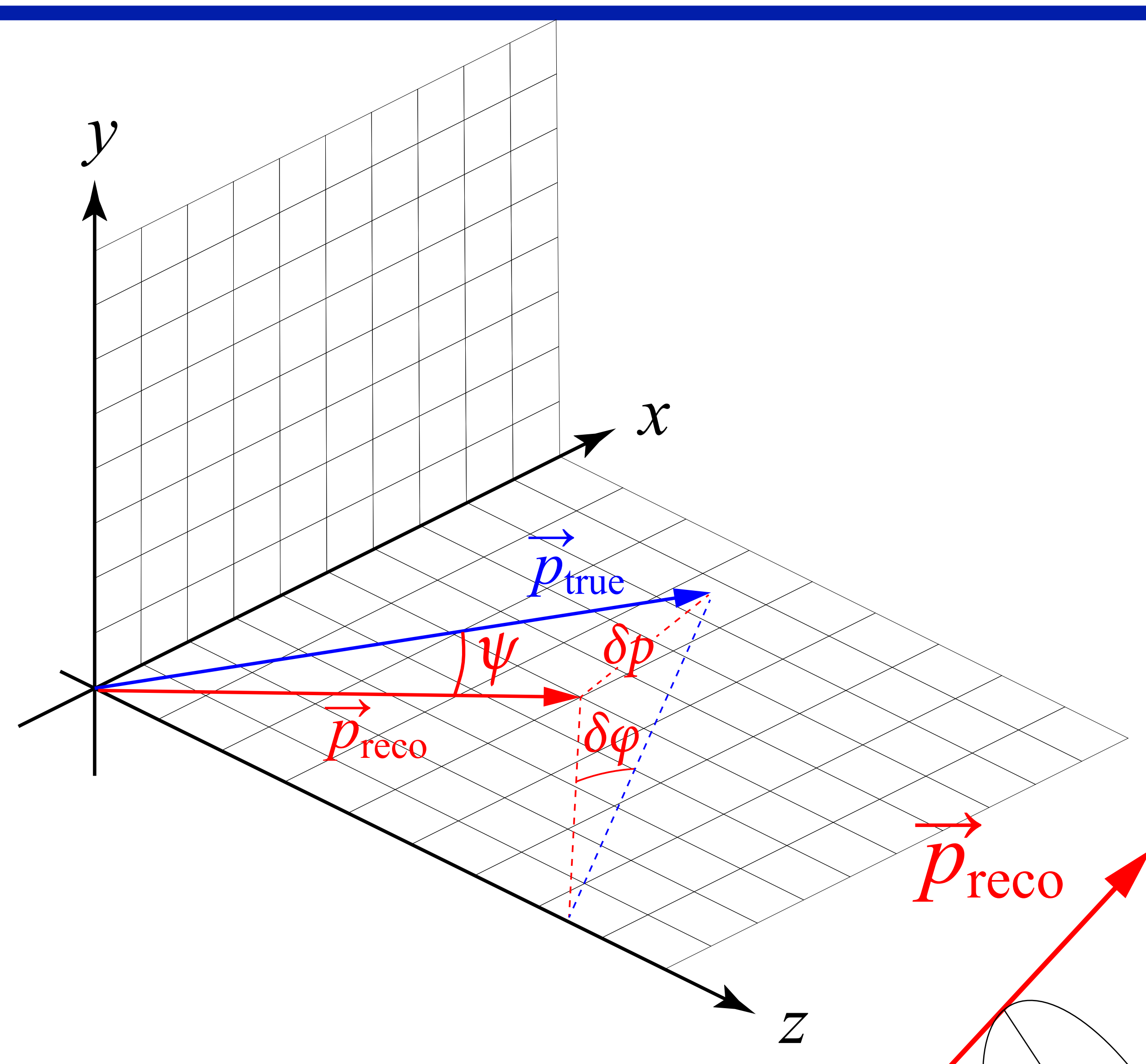
October 30, 2023

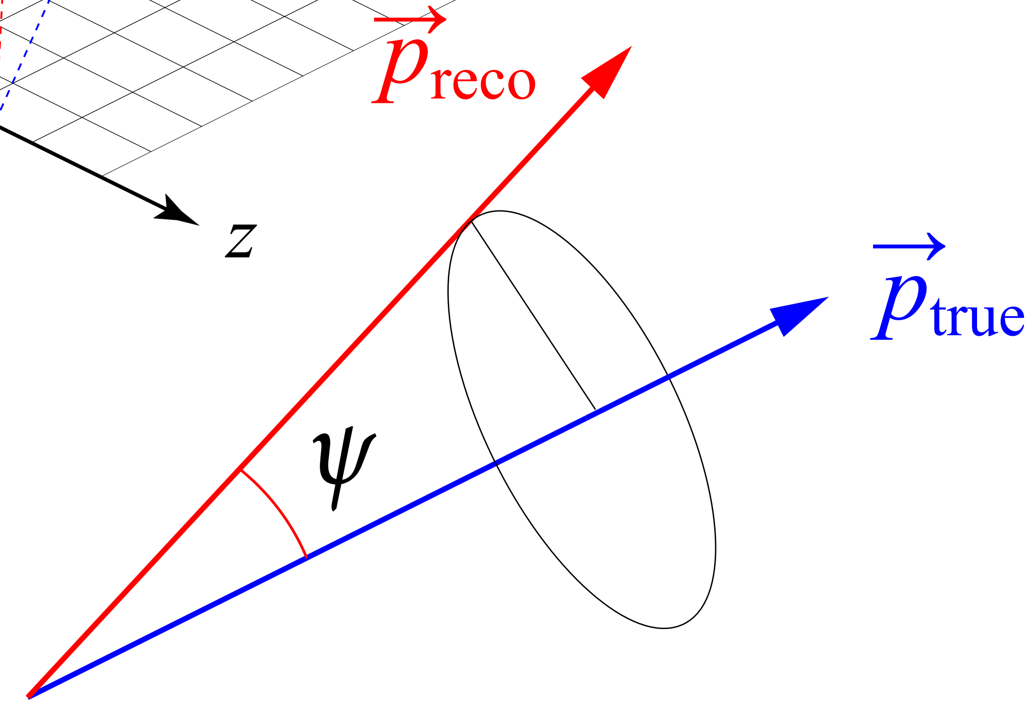
Draft 1.0

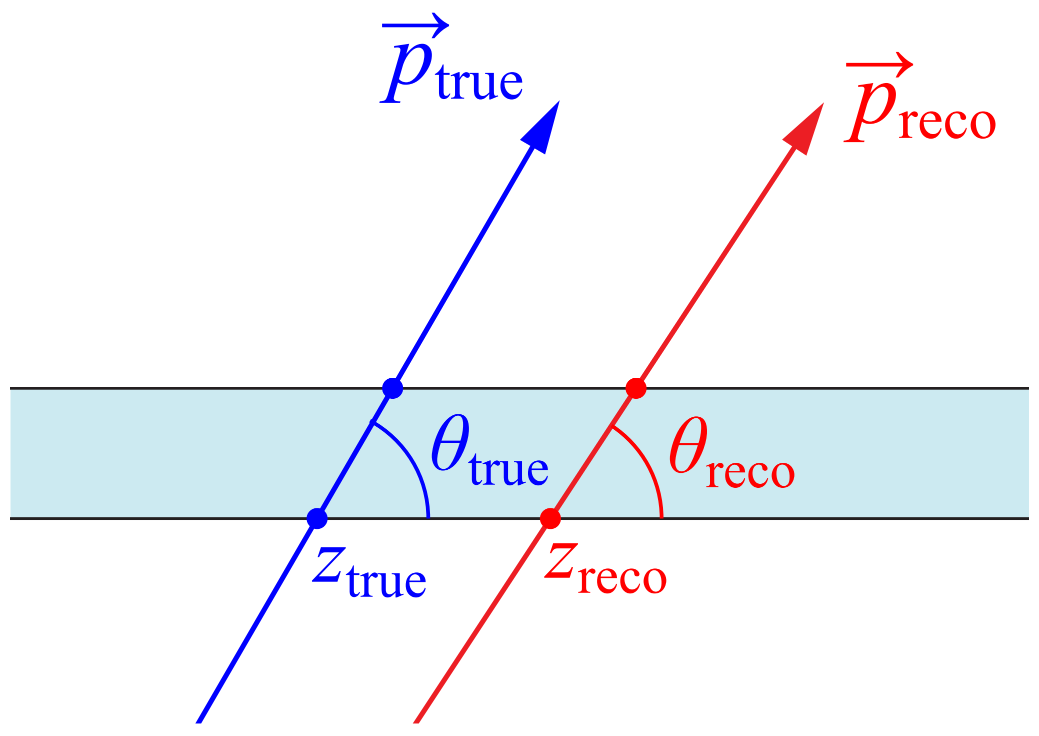
PID and Tracking Working Group

ePIC's Definitions of Angular Resolution

- **Tracking & ToF**
  - resolution reported in cylindrical coordinate system $\delta\phi, \delta\theta$
- **RICH detectors**
  - measure the angle between the Cherenkov photon and the reconstructed track $\delta\psi$
  - Tracking angular divergence, $\delta\psi \approx \delta\vec{p}/|\vec{p}|$, is different from the azimuthal angular error in the lab cylindrical coordinate system, $\delta\phi \approx \delta\vec{p}/|\vec{p_T}|$.
  - Difference is $\delta\psi \approx \delta\phi \sin\theta$, which is a factor of 10 difference at a pseudorapidity of $\eta \approx 3$ (minimal for the polar angular component)
- **hpDIRC**
  - Key variables to access matching between tracking and hpDIRC:
    $\Delta\theta = \theta_{\text{true}} - \theta_{\text{reco}},\ \Delta\phi = \phi_{\text{true}} - \phi_{\text{reco}},\ \Delta z = z_{\text{true}} - z_{\text{reco}}$
  - hpDIRC hit pattern is not a ring, making it more sensitivity to angular tracking resolution of the tracking system





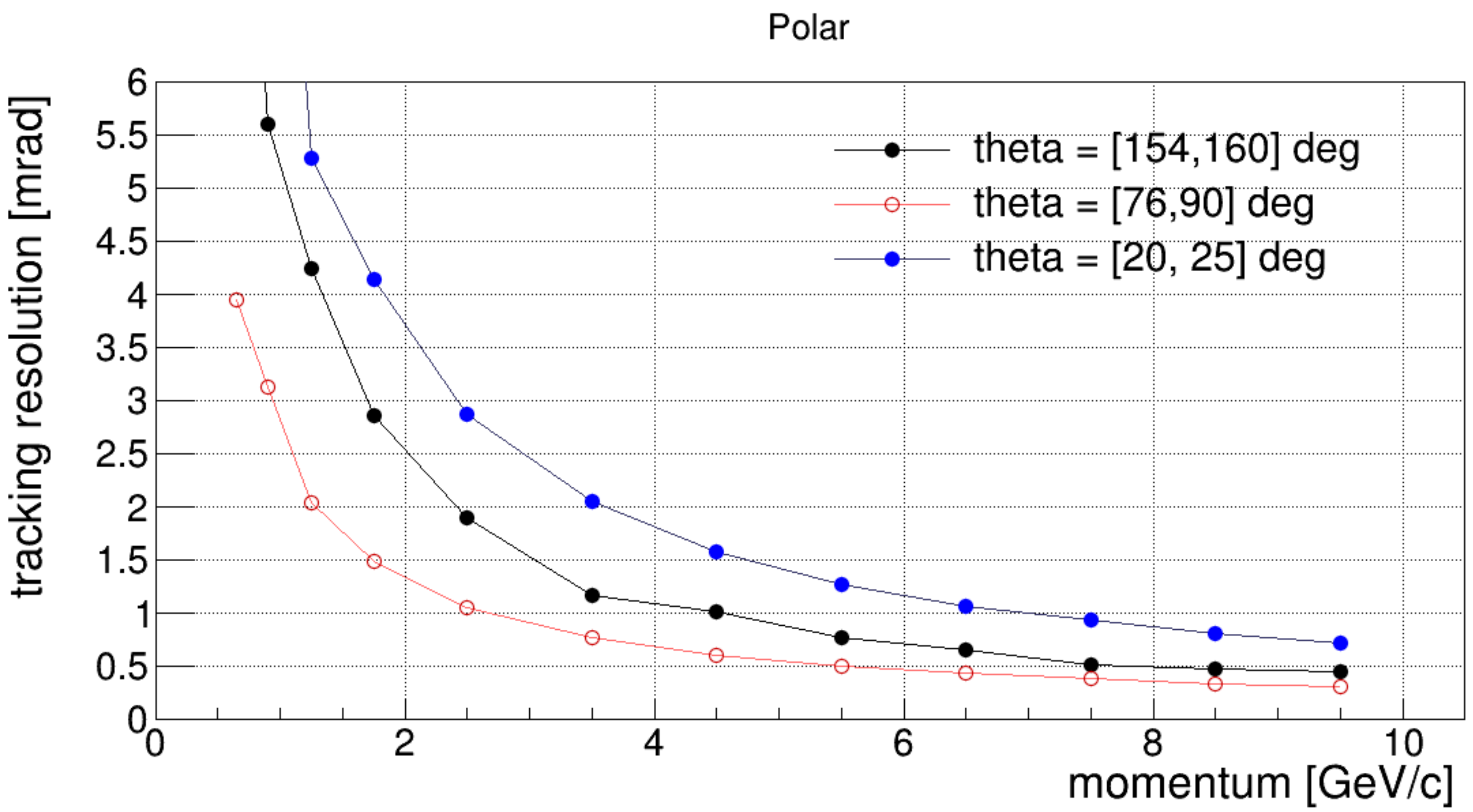


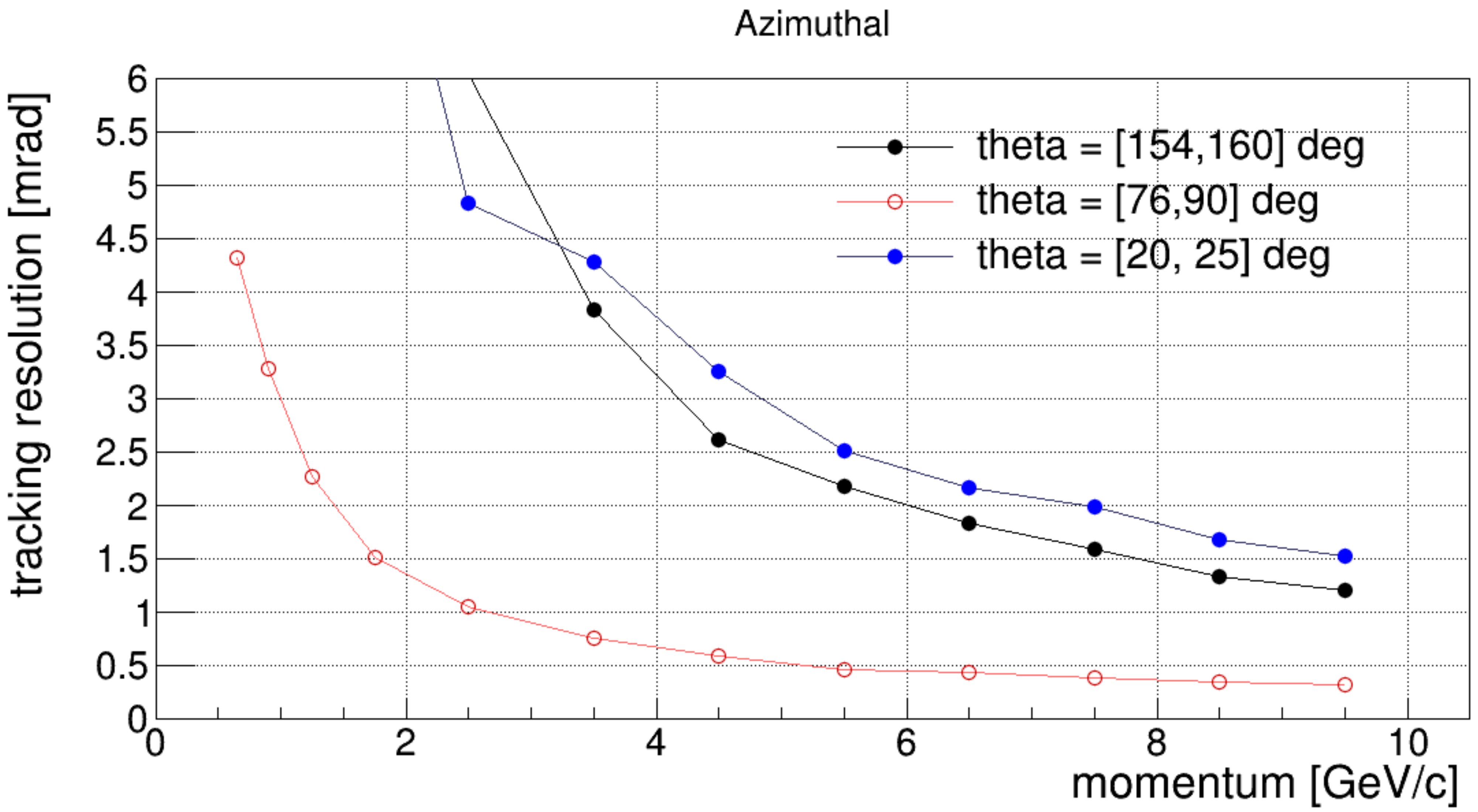
hpDIRC Requirements

Roman Dzhygadlo (GSI)

Impact of current tracking estimates on DIRC performance:

- Angular resolution has direct impact on PID
- Current angular resolution is larger then expected (up to ×2 in θ and ×3-4 in ϕ)
- DIRC PID goal for π/K @ 6 GeV/c is barely reached with current tracking and not reached for $e\pi$ @ 1.2 GeV/c
- Cherenkov ring fit is aimed to mitigate MS inside the radiator (but not to improve external tracking)





Yellow report requirement 0.5 mrad @ 6 GeV/c

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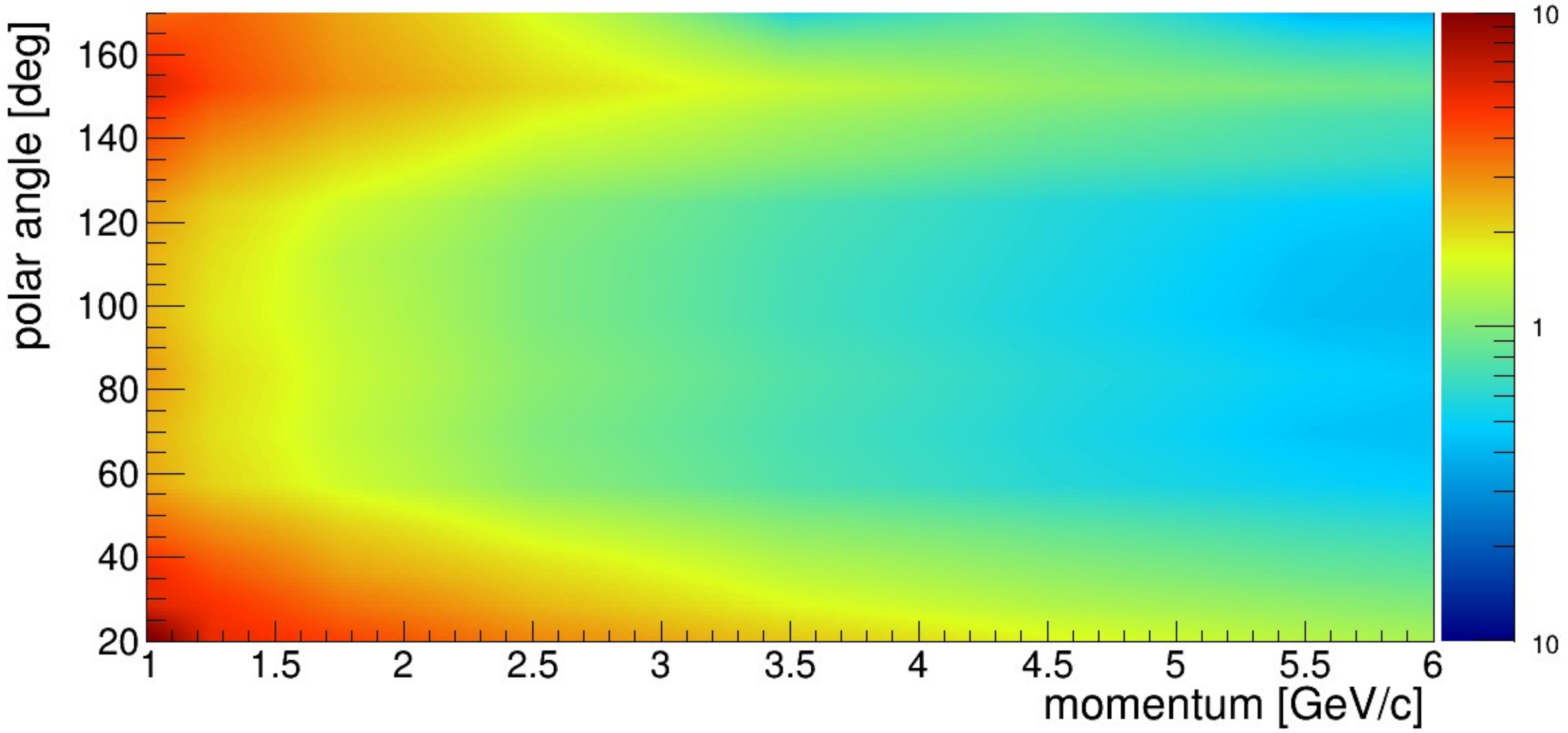
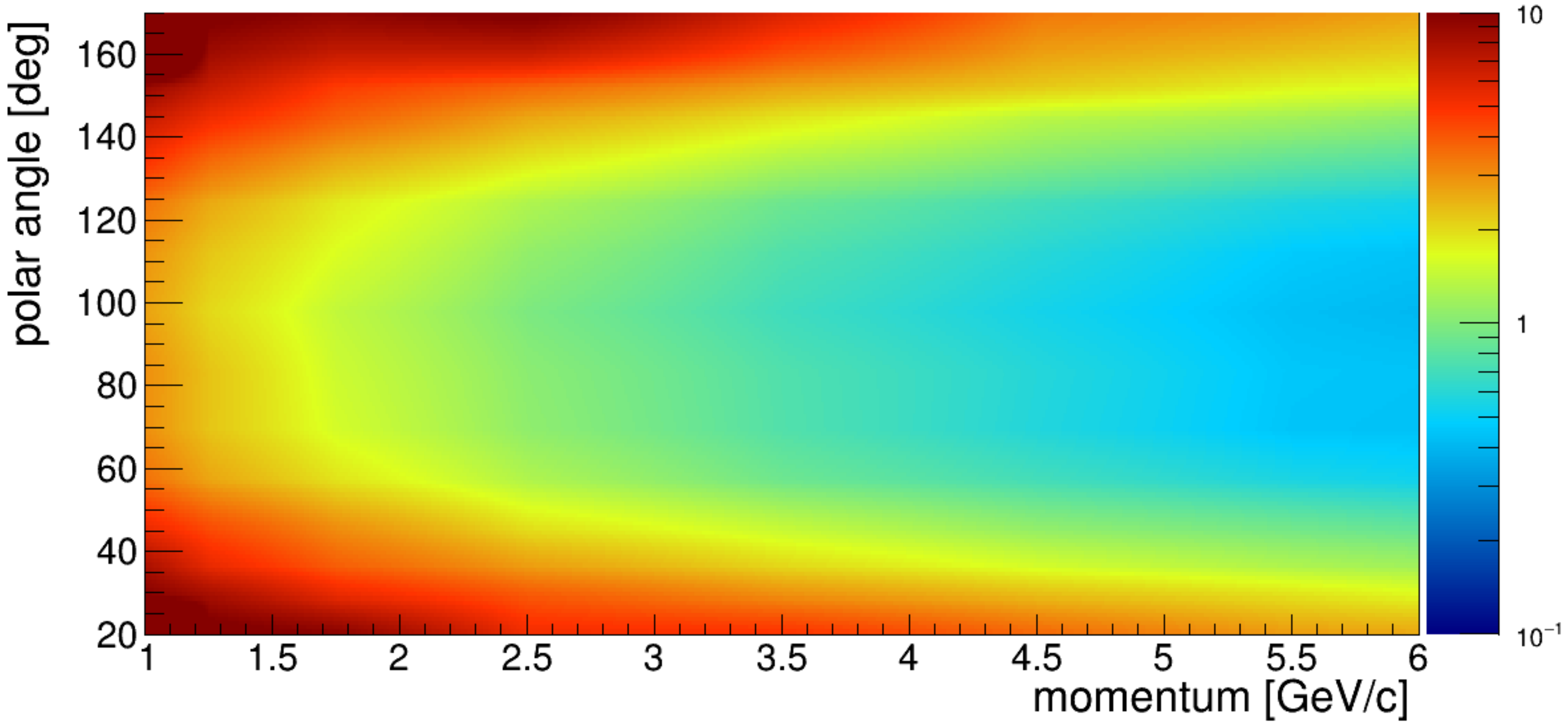
polar angle resolution [mrad]:



azimuthal angle resolution [mrad]:



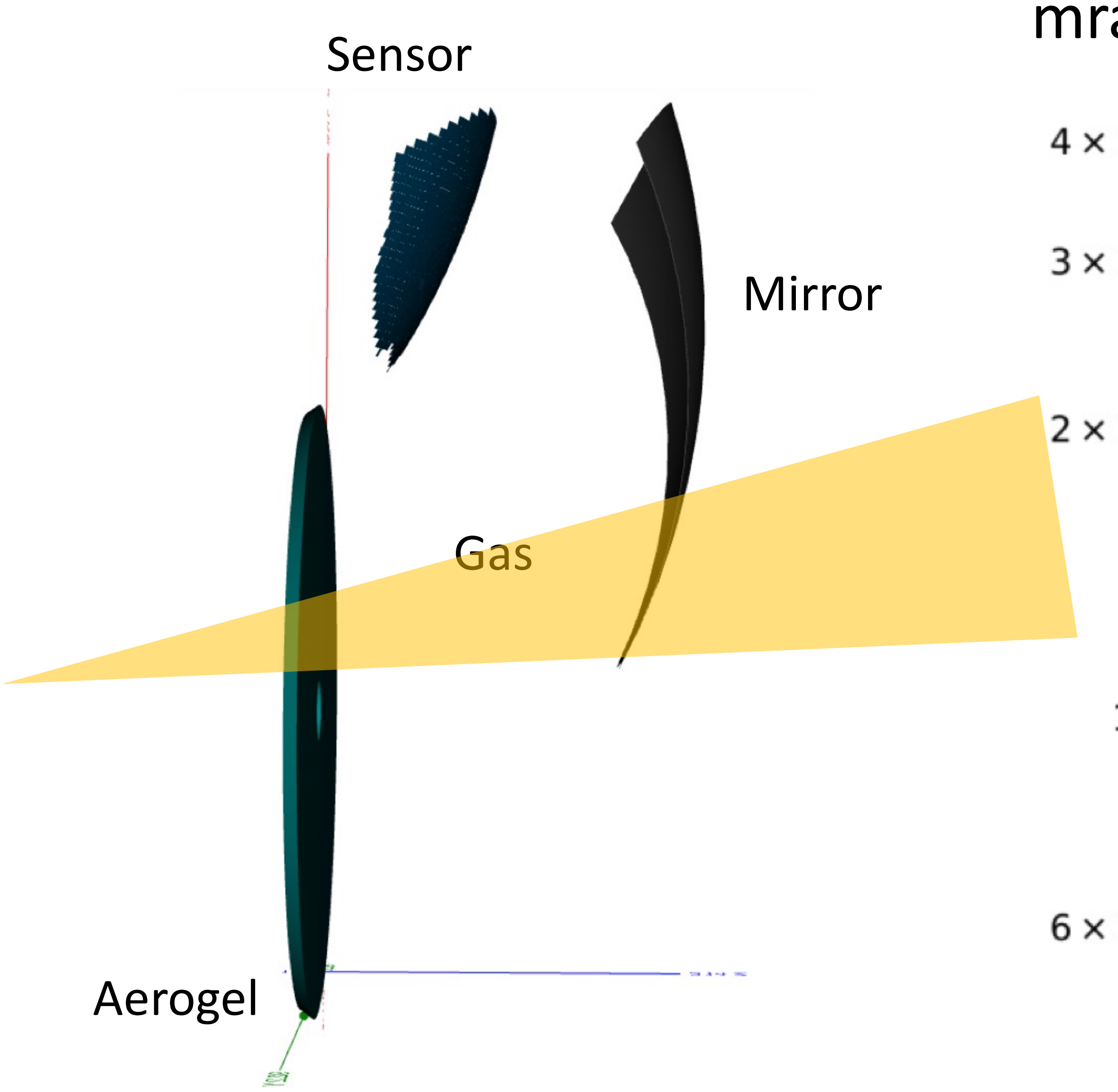
Yellow report requirement 0.5 mrad @ 6 GeV/c

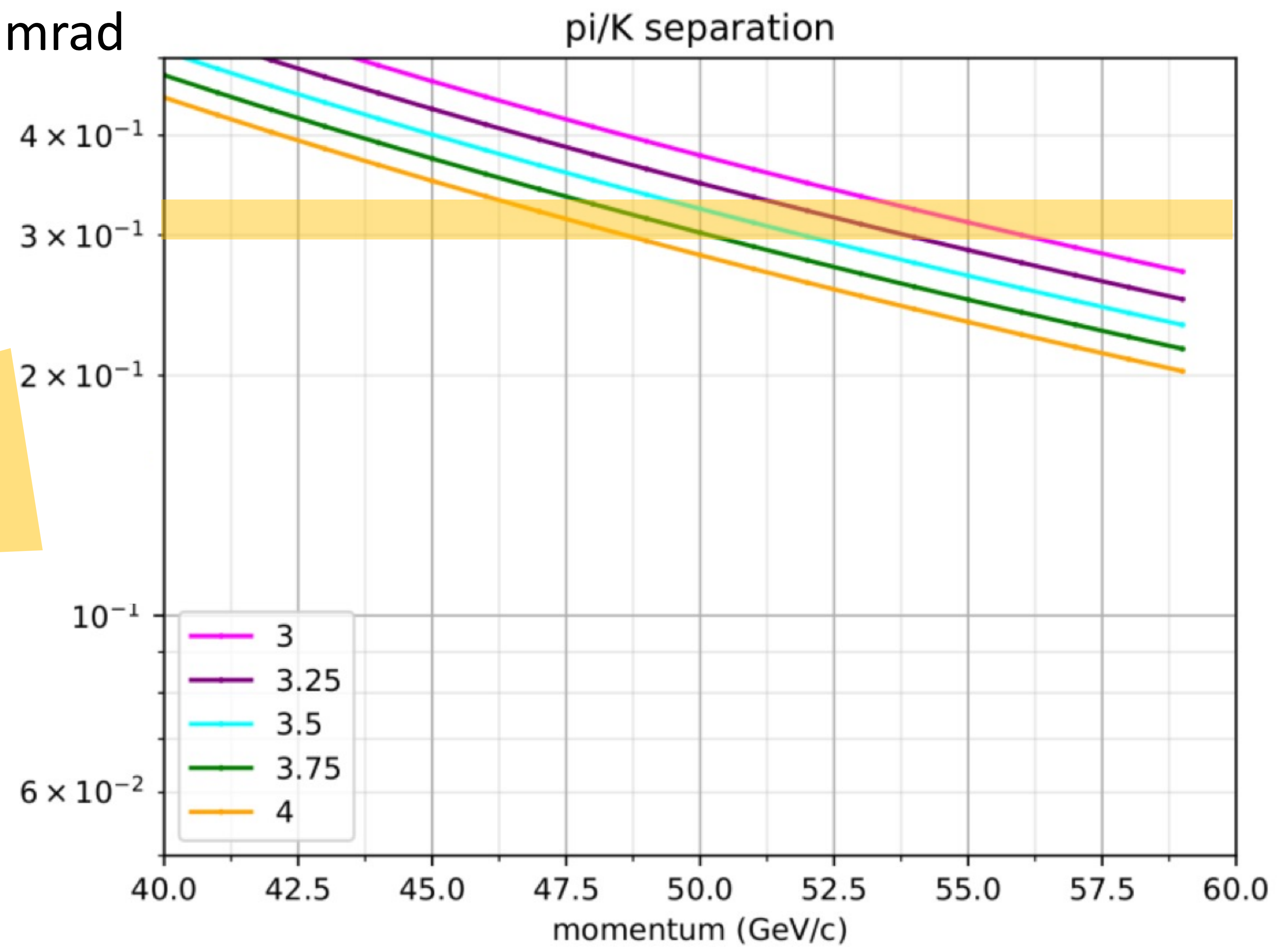
dRICH Requirements

Marco Contalbrigo (INFN Ferrara)

Focusing on the most demanding case: gas radiator at high momenta (small angles)

- Preliminary reshaping provides 0.3-0.35 mrad resolution in the 2.5-3.5 rapidity range corresponding to > 3σ separation at 50 GeV/c.





Resolution (valid for all RICHs in ePIC):

$$\sigma^2_{\theta_{C,particle}} = \sigma^2_{\theta_{C,photon}} / N_\gamma + \sigma^2_{correlated}$$

Cherenkov angle resolution per particle

Cherenkov angle resolution per photon

# of detected photons

Contributions from tracking and multiple scattering

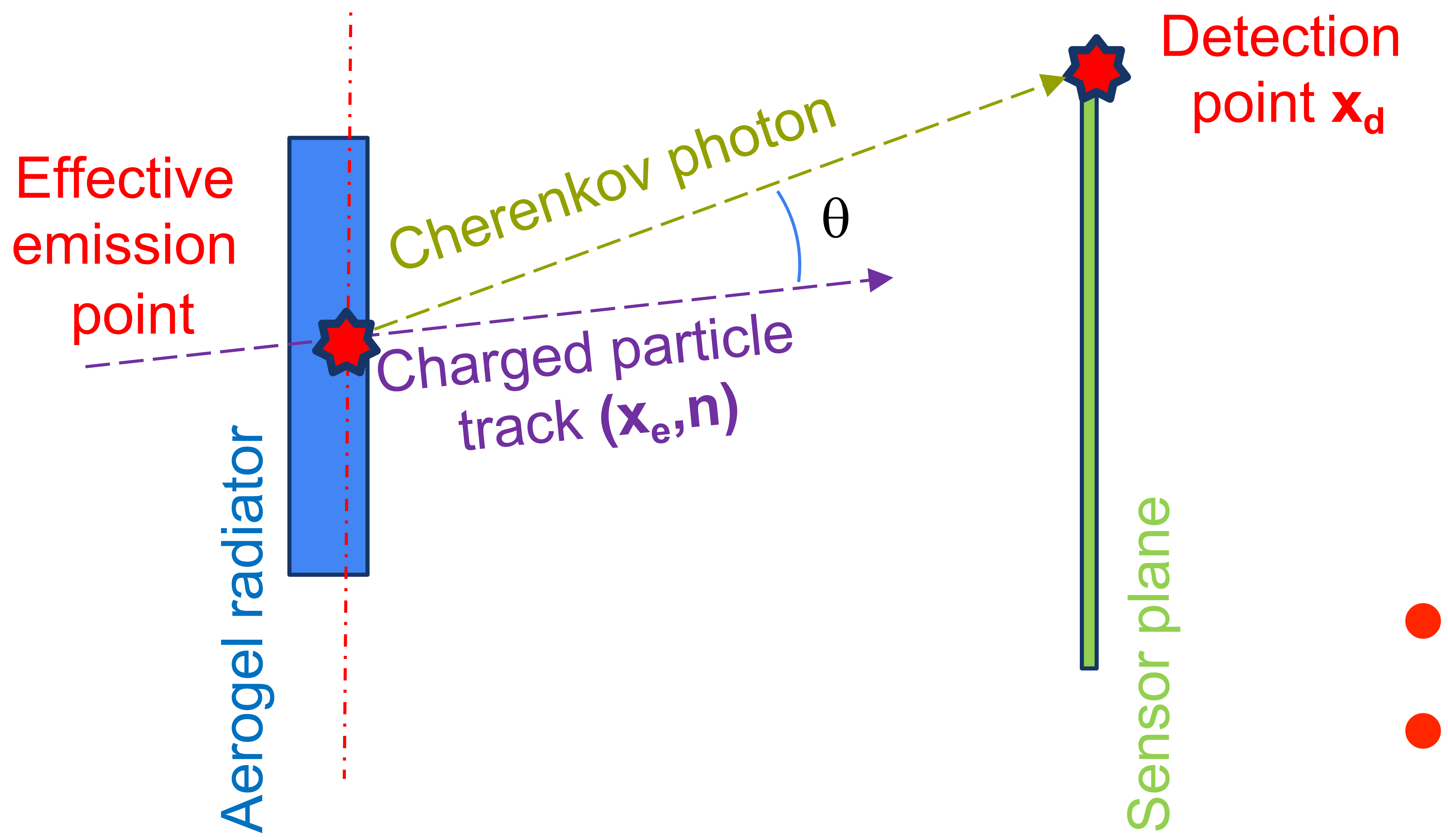
- A ~0.5 mrad track @ p_{max} resolution (mainly θ) is essential to not spoil the dRICH performance
  - there could be a limited tolerance since dRICH focalization is expected to improve
- dRICH encodes
  - a polar angular information at the level of 0.3 mrad (gas case)
  - a time information that could approach the TOF ballpark

pfRICH Requirements

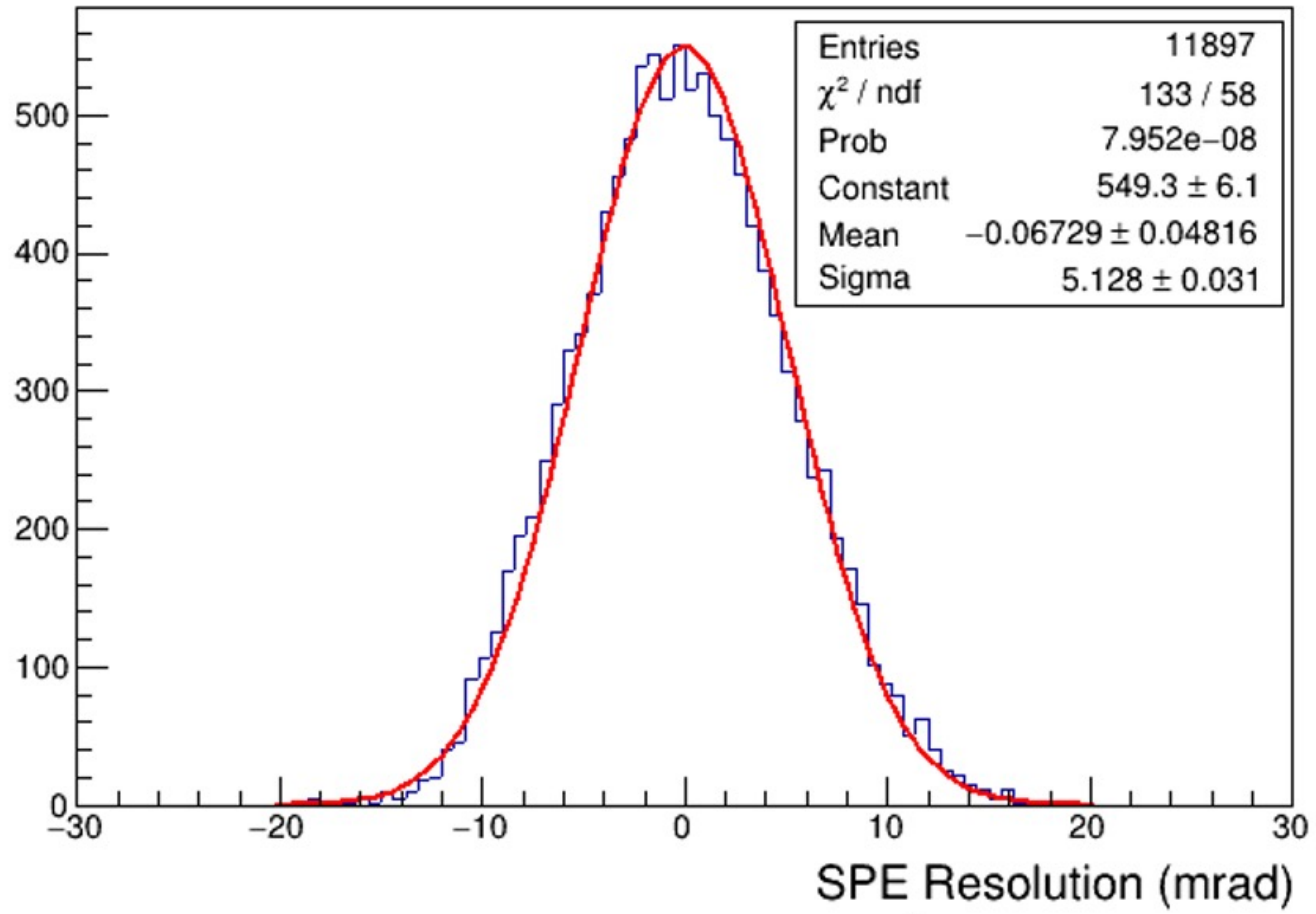
Alexander Kiselev (BNL)

What enters are:

- Emission point uncertainty
- Detection point uncertainty
- Chromatic effects



Single photon Cherenkov angle resolution ~5 mrad



σ_{SPE} ~ 5 mrad

- Expected $\langle N_{pe} \rangle$ ~ 12
- Therefore, track-level Cherenkov angle resolution is ~1.5 mrad
- To first order, require tracking resolution that is reasonably small compared to 1.5 mrad

ToF Requirements

Shirsendu Nanda (UIC)

Different than RICHs - also part of the tracking system

	Angular accept.	Channel size (mm^2)	Timing Resolution	Spatial resolution	Material budget
Barrel ToF	$-1.4 < \eta < 1.4$	0.5*10	35 ps	30 μm in φ	0.01 X0
Forward ToF	$1.5 < \eta < 3.5$	0.5*0.5	25 ps	30 μm in x and y	0.05 X0

- In pixel sensor
  - x and y resolution (along x and y direction in lab frame) of delay map for correction be achieved by the sensor itself
- In strip sensor
  - x resolution (perpendicular to the strip direction - ϕ direction in lab frame) of delay map for correction be achieved by the sensor itself
  - y resolution (along the strip direction - z direction in lab frame) of delay map, need to rely on external tracker with a reasonable resolution
    - Without delay correction, the time resolution ~ 45 – 55 ps
    - Adding the tracker-based delay corrections improves the resolution to ~ 34 ps
  - negligible change in time resolution until yBinwidth = 1.5 mm, and an increase of ~ 2.5 ps from 34.5 to 37 ps with yBinwidth = 5 mm

What can the PID detectors do for tracking?

Arguments will be a bit more general and likely w/o much support from our main simulation stream. This needs more discussion and brainstorming.

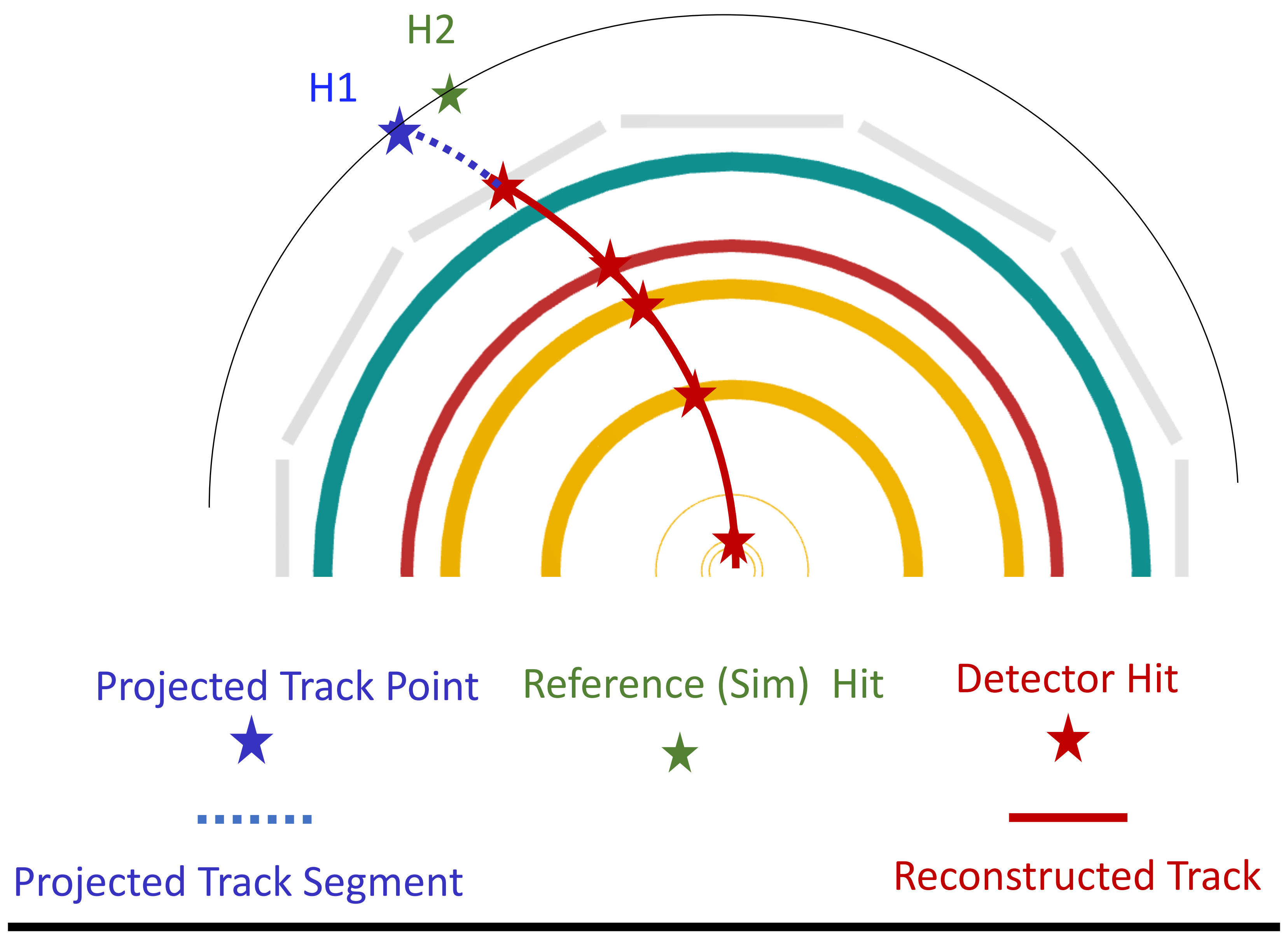
- Knowing the ID of a particle allows an improved refit of the track (Kalman filter) with better MS knowledge and possible improved p resolution.
  - PID relates *m*, *p*, and *v.* Once m is fixed could provide strong constraints in the refit
- Integration time of tracker (Si) is around 2-3 μs. That means that there is the possibility of fake/distorted tracks that can be eliminated with solid timing information from PID detectors (ToF, pfRICH/HRPPD, hpDIRC)
- Can PID info could help pattern recognition in track finding (iterative, e.g ring w/o track)

Assessing Angular Resolution (I)

Matt Posik (Temple)

Looking at 2 methods that in principle should give the same answer

Method 1



- Use projected position point vectors of projected track point (H1) and nearest Reference surface hit (H2) to obtain angles:
  - Projected Point (x,y,z) hits $\rightarrow \theta_{\mathrm{H1}}, \phi_{\mathrm{H1}}$
  - Reference Point (x,y,z) hits $\rightarrow \theta_{\mathrm{H2}}, \phi_{\mathrm{H2}}$
- Angular resolution σ_{θ}, σ_{ϕ} are extracted from width of assumed Gaussian distribution

Assessing Angular Resolution (II)

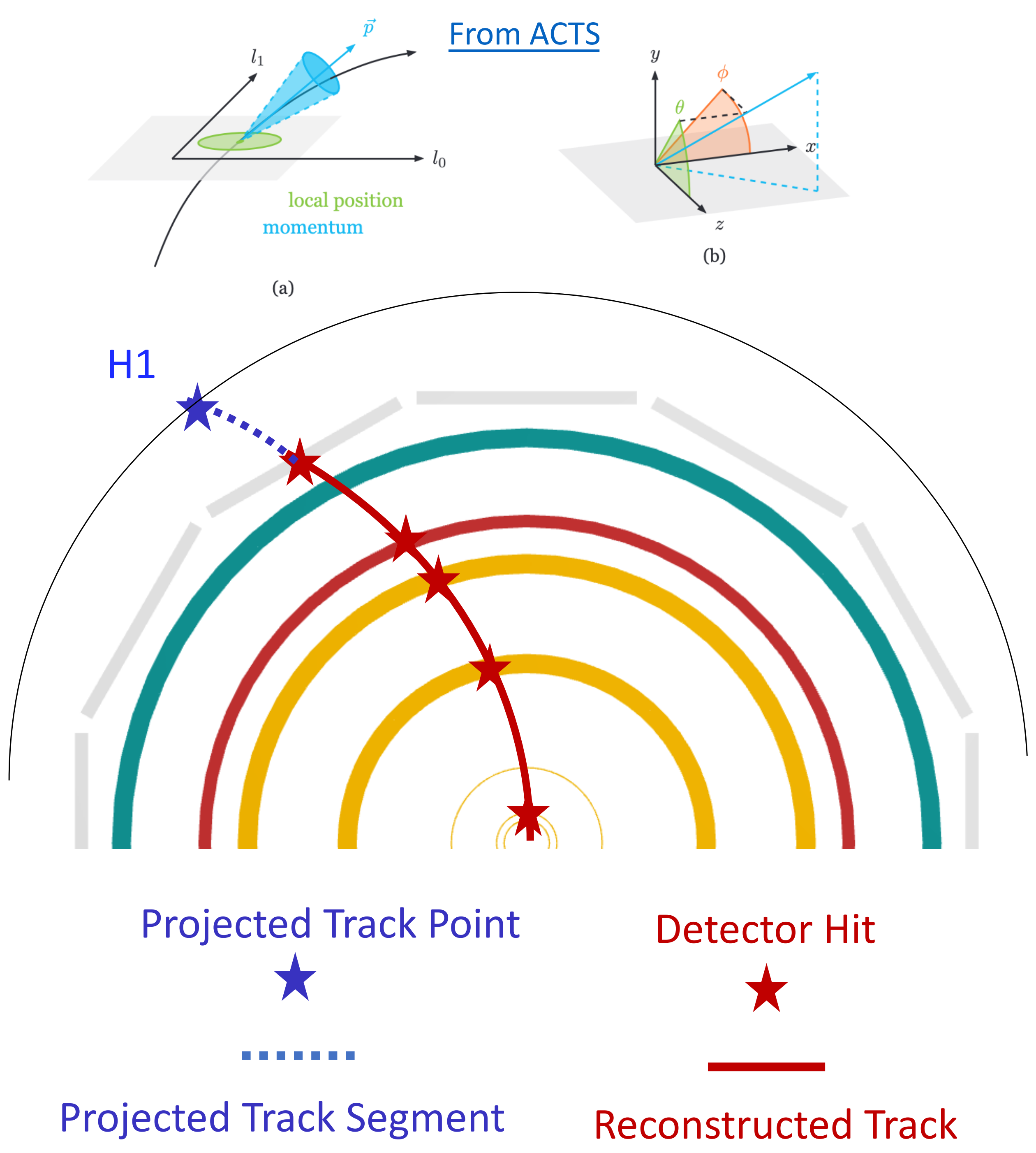
Matt Posik (Temple)

Method 2

Use propagated trajectory and track point vector to get track direction impacting PID surface: $\vec{x}_{H1} = \left(l_0, l_1, \theta, \phi, \frac{q}{p}\right)$

Obtain track direction uncertainty from covariance matrix

$$C = \begin{bmatrix} \sigma^2(l_0) & \mathrm{cov}(l_0, l_1) & \mathrm{cov}(l_0, \phi) & \mathrm{cov}(l_0, \theta) & \mathrm{cov}(l_0, q/p) \\ . & \sigma^2(l_1) & \mathrm{cov}(l_1, \phi) & \mathrm{cov}(l_1, \theta) & \mathrm{cov}(l_1, q/p) \\ . & . & \boxed{\sigma^2(\phi)} & \mathrm{cov}(\phi, \theta) & \mathrm{cov}(\phi, q/p) \\ . & . & . & \boxed{\sigma^2(\theta)} & \mathrm{cov}(\theta, q/p) \\ . & . & . & . & \sigma^2(q/p) \end{bmatrix}$$

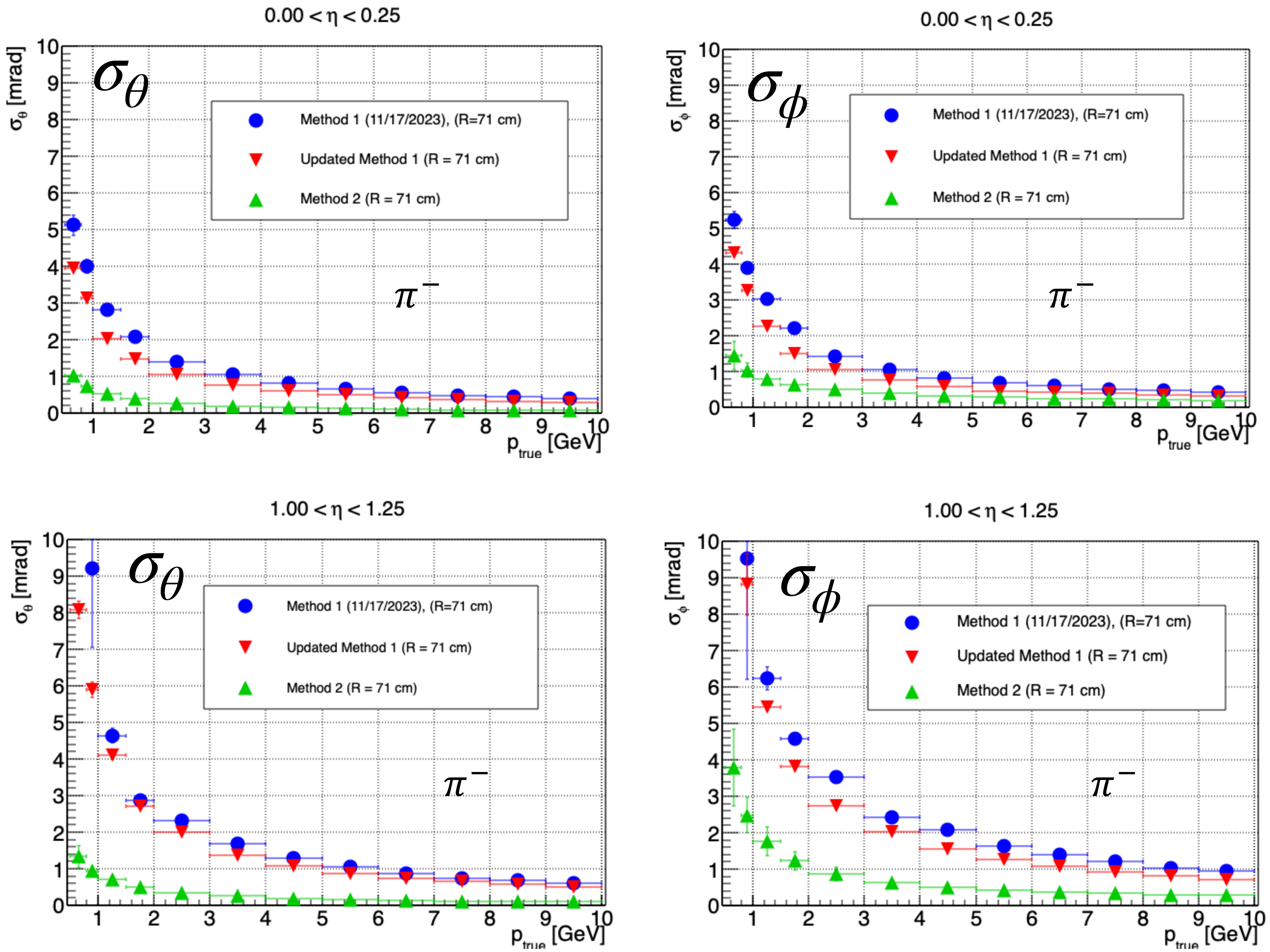


Assessing Angular Resolution (III)

Matt Posik (Temple)

Methods 1 and 2 can be used to assess angular resolutions for any detector

- Difference seen between the two methods:
  - Method 1 takes difference between propagated trajectory track point and the true hit (via Reference surface Sim hit) to extract angular resolution
  - Method 2 assigns uncertainty at each surface from Kalman Filter

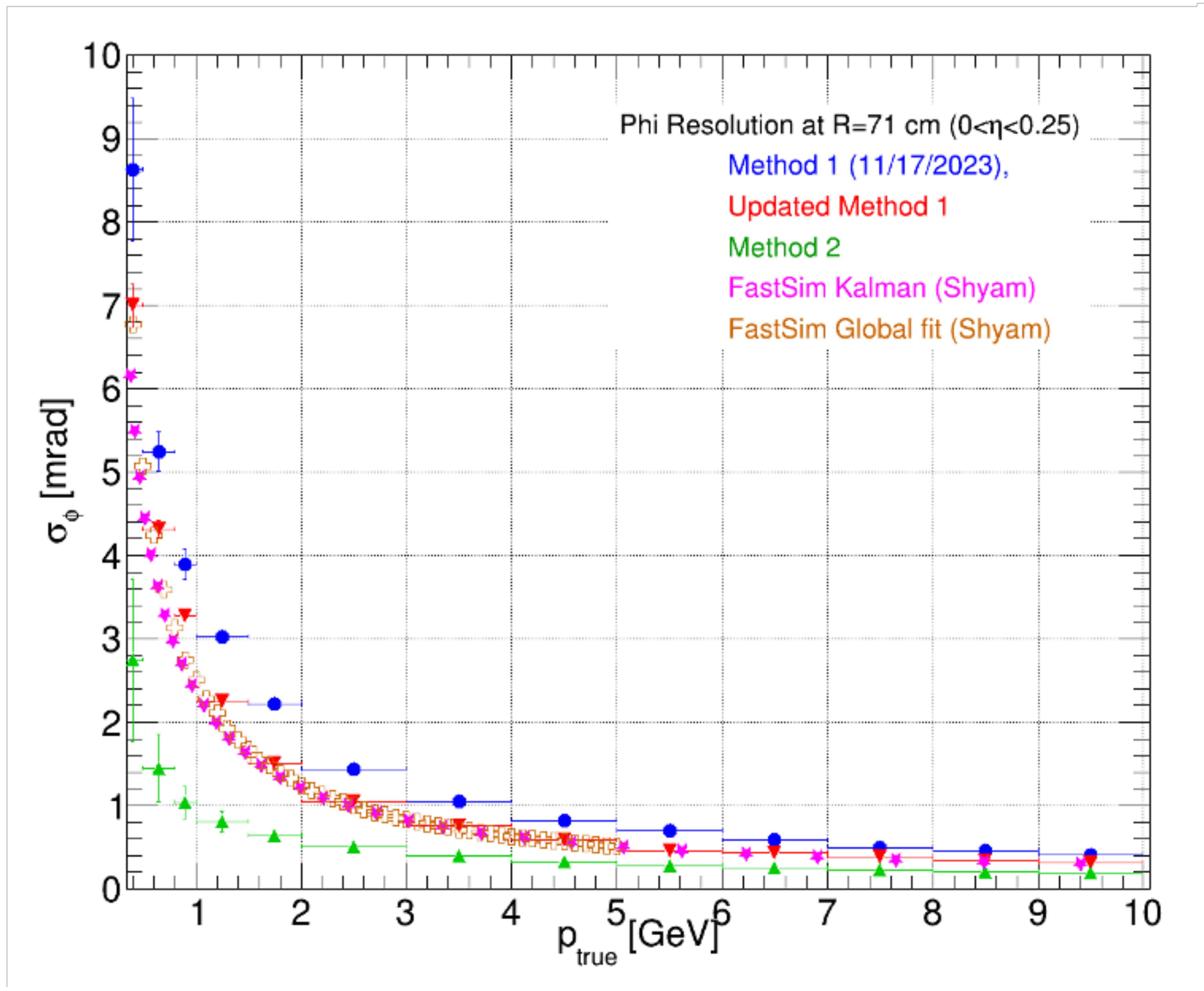


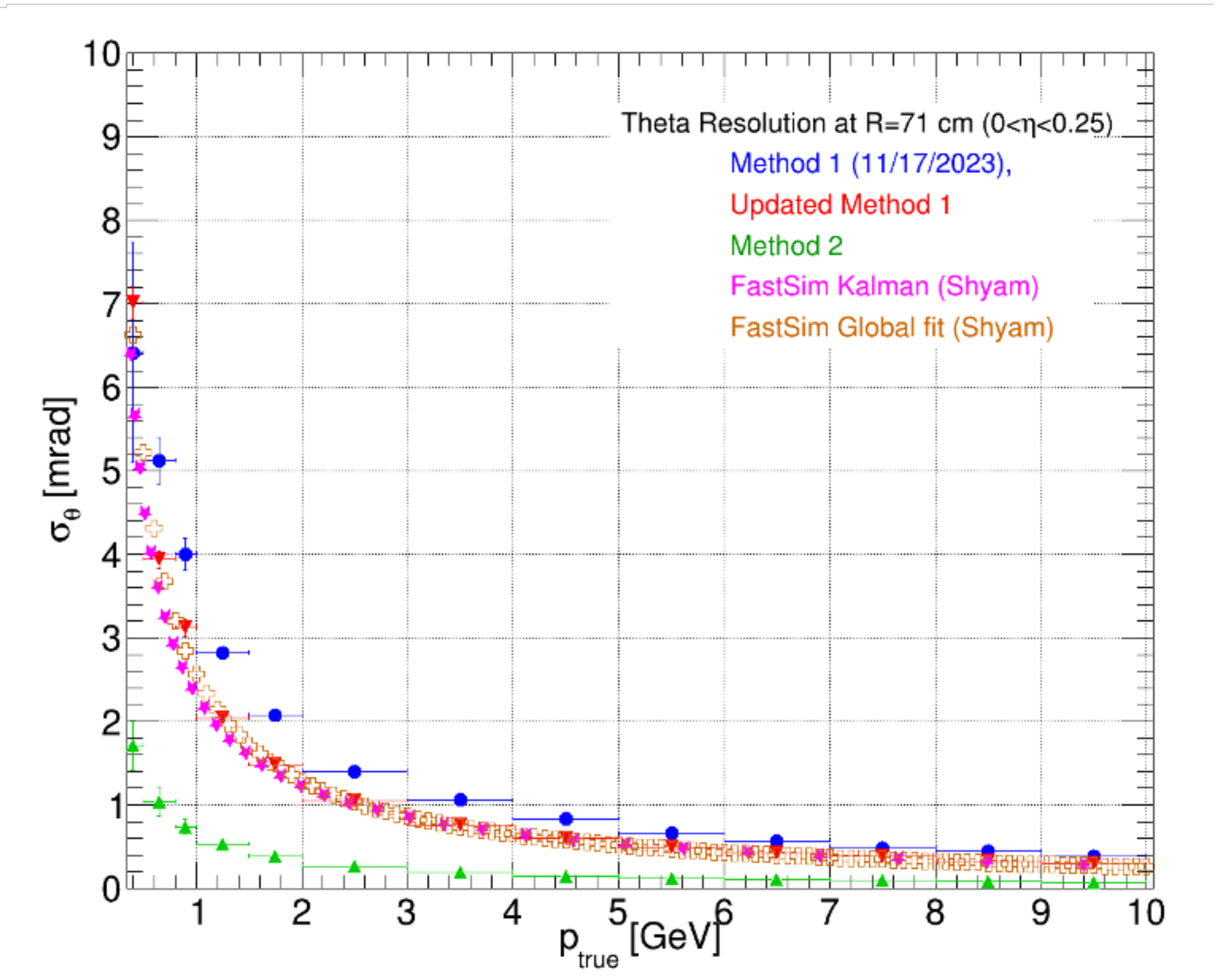
Assessing Angular Resolution - Fast Sims

Shyam Kumar (INFN)

Using fast simulation to try and understand the difference better

- fast simulation studies for the theta/phi resolutions at DIRC layer (71 cm)
- based on global fit and the Kalman filter
- use RK propagator also used in Genfit (fun4All)
- studied inward-outward fitting



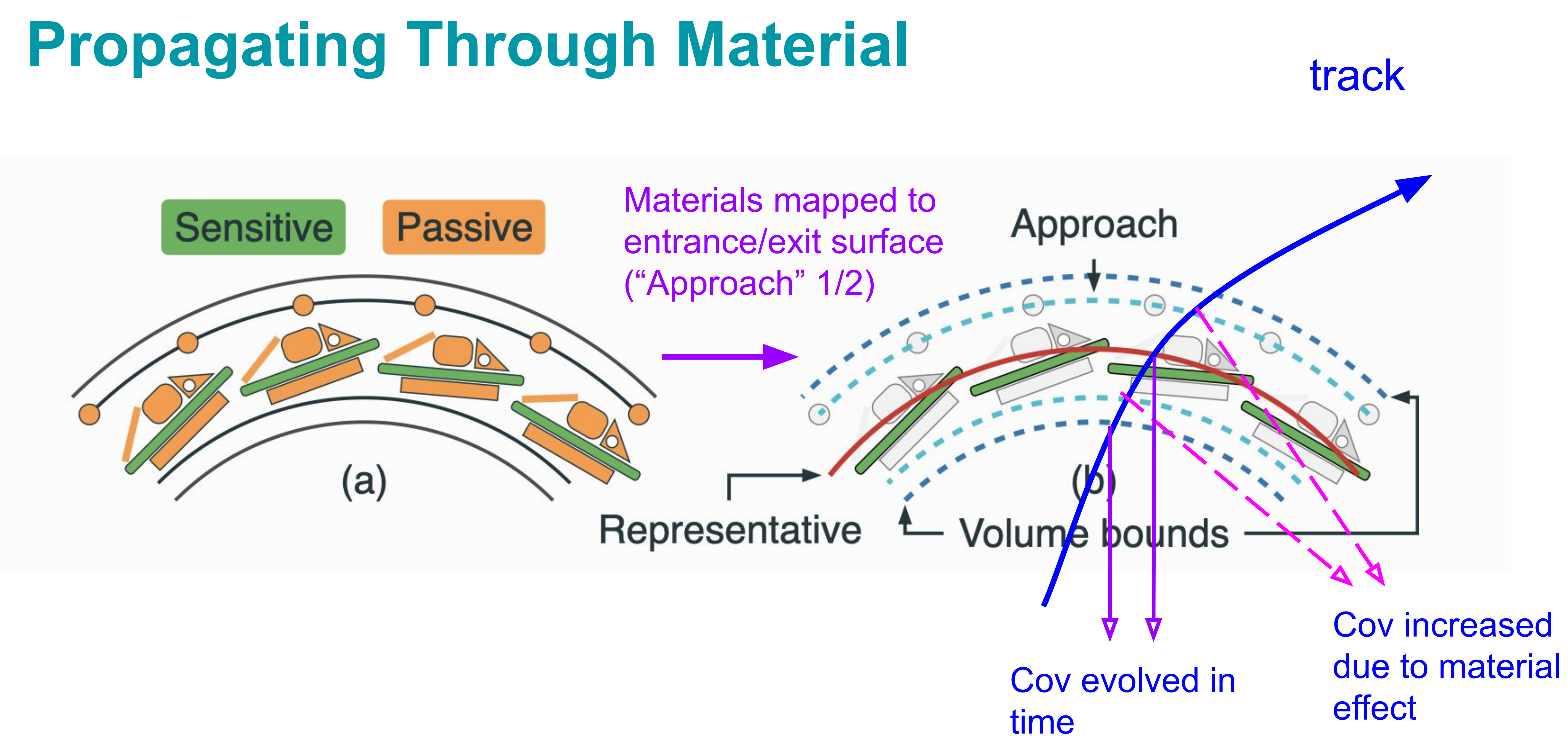


- Method 1 gives the closest results to the two independent fast simulation methods
- Global fit and Kalman can be further used to study several other cases

Track Propagation and Pathlength

Shujie Li (LBL)

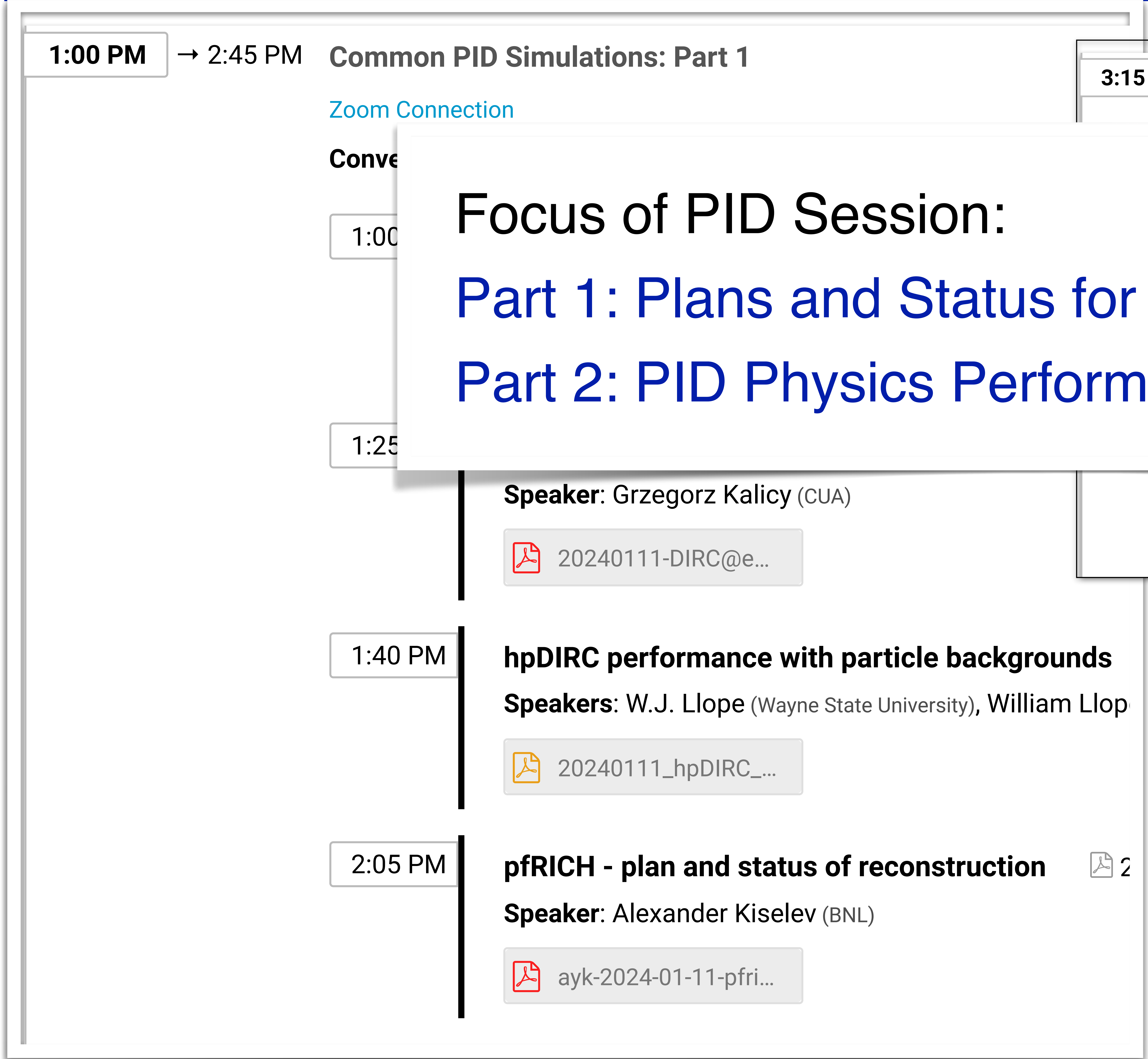
- Shoji presented an excellent tour through ACT explaining details of track propagation, propagating through material, material projections, track projection surfaces, volumes and layers in tracking envelope, and more.
- Lots of discussion about the material map generated from DD4HEP and material projections

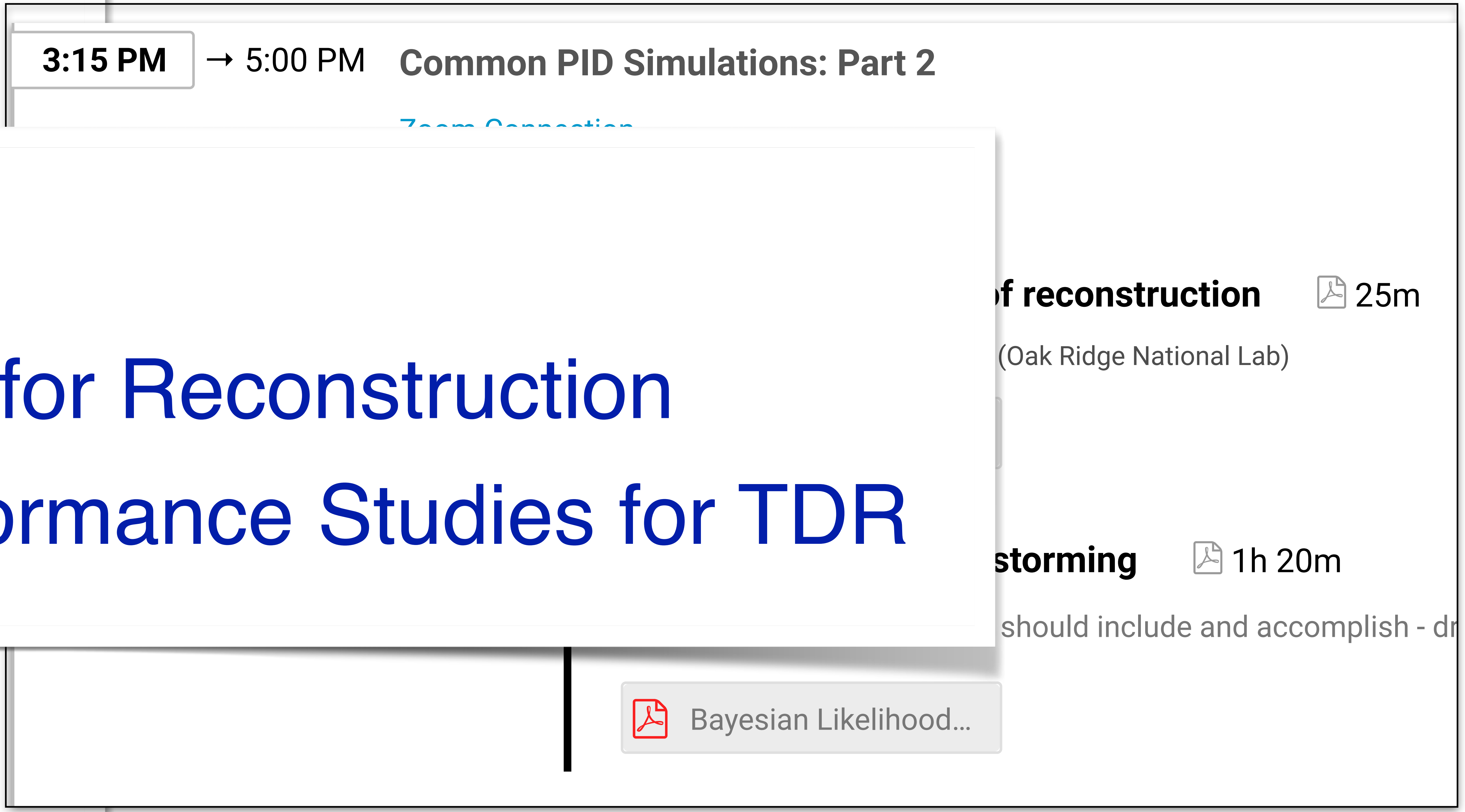


Approach taken might (?) cause an underestimation of MS and thus the covariance that might explain the discrepancies observed in the angular momentum assessment.

At a minimum it's worth a closer look/separate studies.

PID Workfest





Focus of PID Session:

Part 1: Plans and Status for Reconstruction

Part 2: PID Physics Performance Studies for TDR

PID Workfest

1:00 PM → 2:45 PM **Common PID Simulations: Part 1**

Zoom Connection

Convener: Thomas Ullrich (BNL)

1:00 PM **dRICH - plan and status of reconstruction**
Speaker: Chandradoy Chatterjee (INFN Trieste (IT))
dRICH_ePIC_CM_Si...

1:25 PM **hpDIRC - plan and status of reconstruction**
Speaker: Grzegorz Kalicy (CUA)
20240111-DIRC@e...

1:40 PM **hpDIRC performance with particle backgrounds**
Speakers: W.J. Llope (Wayne State University), William Llop
20240111_hpDIRC_...

2:05 PM **pfRICH - plan and status of reconstruction** 2
Speaker: Alexander Kiselev (BNL)
ayk-2024-01-11-pfri...

3:15 PM → 5:00 PM **Common PID Simulations: Part 2**

Zoom Connection

Convener: Thomas Ullrich (BNL)

3:15 PM **TOF - plan and status of reconstruction** 25m
Speaker: Oskar Hartbrich (Oak Ridge National Lab)
01_11_2024_EPIC_...

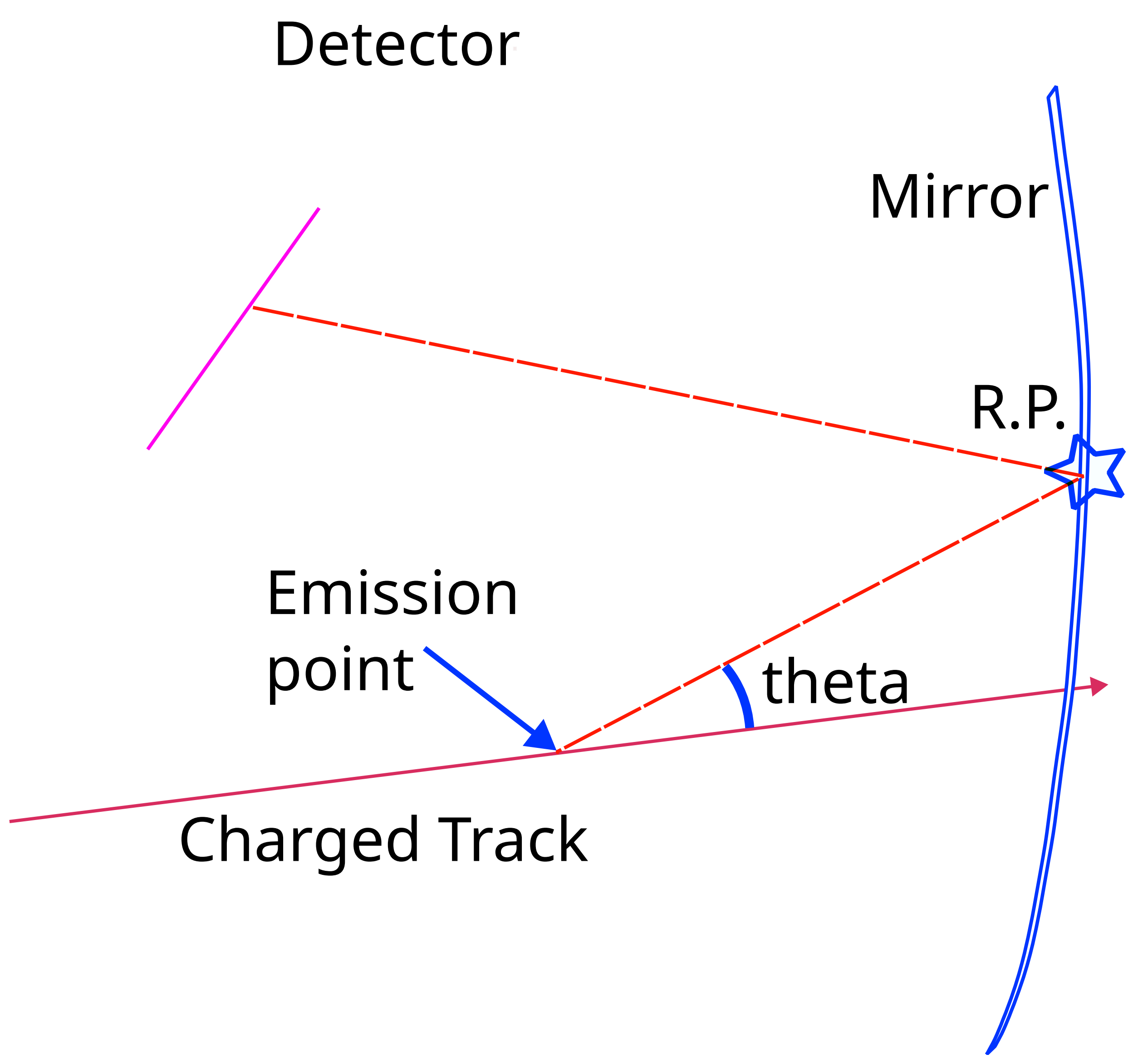
3:40 PM **Open discussion/Brainstorming** 1h 20m
What common PID software should include and accomplish - dr
Bayesian Likelihood...

dRICH Reconstruction

Chandradoy Chatterjee (INFN Trieste)

Inverse Ray Tracing (IRT):

- currently with some simplifications such as parametric surfaces
- Provides reliable values for angular resolution
- Sufficient for single particle characterization w/o noise
- capable of 3σ pi/K separation slightly above than 50 GeV/c in the forward region
- Aerogel provides 3σ separation above the K threshold in gas providing substantial overlap.
- Current version IRT v1.0 incapable to perform complicated noise handling
- Priorities: Improve and fix the reconstruction limitations, and start looking into more complicated scenarios



- Used in several RICH detectors; e.g. HERMES, COMPASS.
- Iterative solution to estimate mirror impinging point.
- W.R.T a fixed star (beam direction, mirror centre), given knowledge of detection and emission point, Cherenkov angle can be measured.

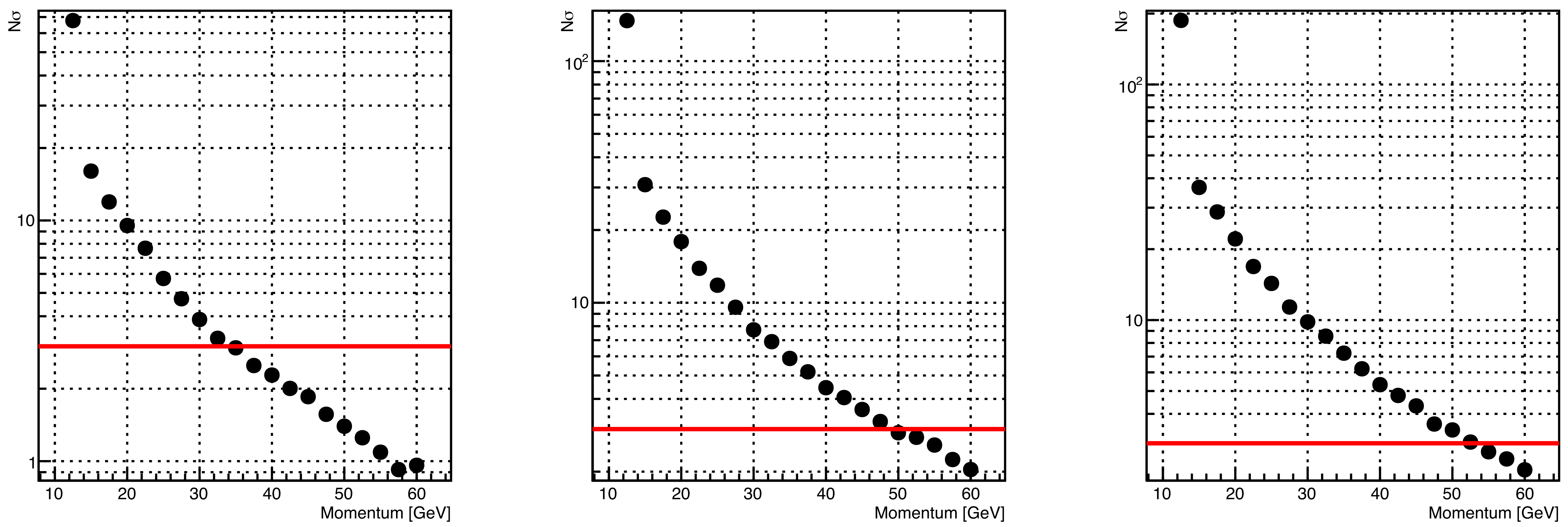


Figure: Seperation power(Aerogel to be redone); eta (1.3-2.0); (2.0-2.5);(2.5-3.5)

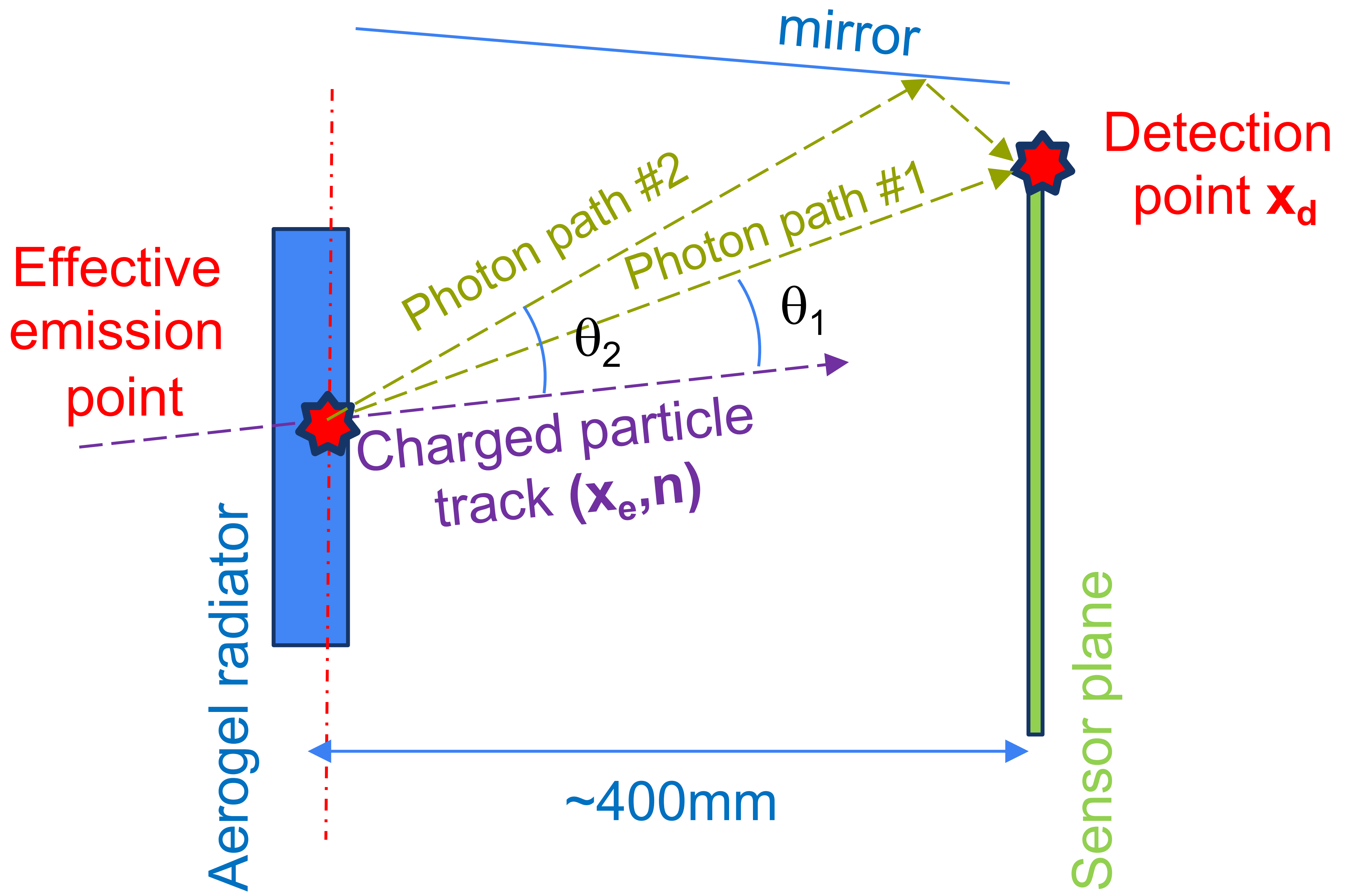
Full chain working in DD4Hep and EICRecon

pfRICH Reconstruction

Alexander Kiselev (BNL)

- Existing codes are algorithmic, χ^2 based
- Developed in a standalone GEANT4 environment
- Porting to dd4hep is in the geometry description stage
- Start with ideal case then add reality
  - Emission point uncertainty (aerogel thickness)
  - Detection point uncertainty (sensors have finite resolution)
  - Chromatic effects ($n(\lambda)$)
  - Refraction on optical media boundaries
- IRT Algorithm
- Noise and overlapping rings studied
- pfRICH + HRPPD (ToF δt ~ 50 ps)
  - Timing is used in both hit-to-track association for a given mass hypothesis, and in the χ^2 ansatz

$$\chi^2_H = \frac{[\theta_H(p,n) - \theta_c]^2}{\sigma^2_\theta}$$ for a given PID hypothesis

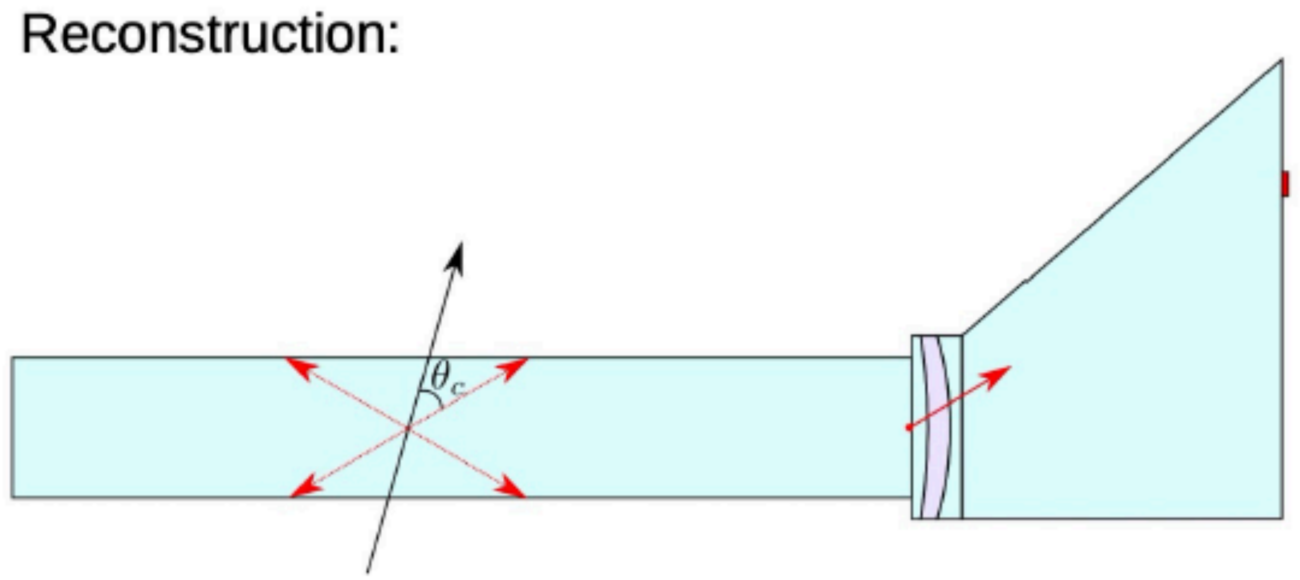


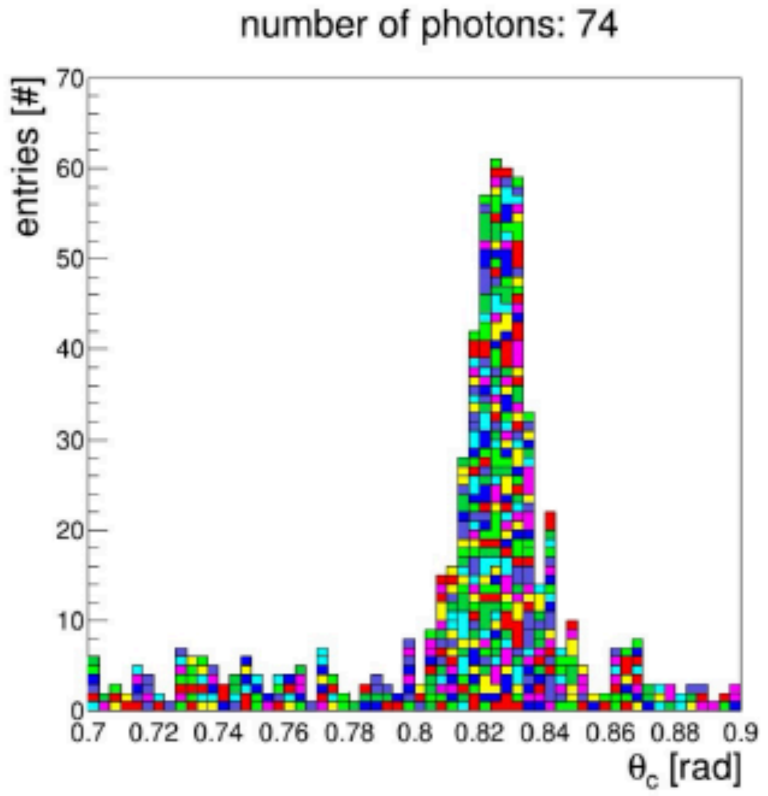
$$\chi^2_H = \sum_{k=1}^{nhits} \frac{[\theta_H(p,n) - \theta^k_c]^2}{\sigma^2_\theta} + \sum_{k=1}^{nhits} \frac{[t_H(p) - (t^k_c - t_0)]^2}{\sigma^2_t}$$

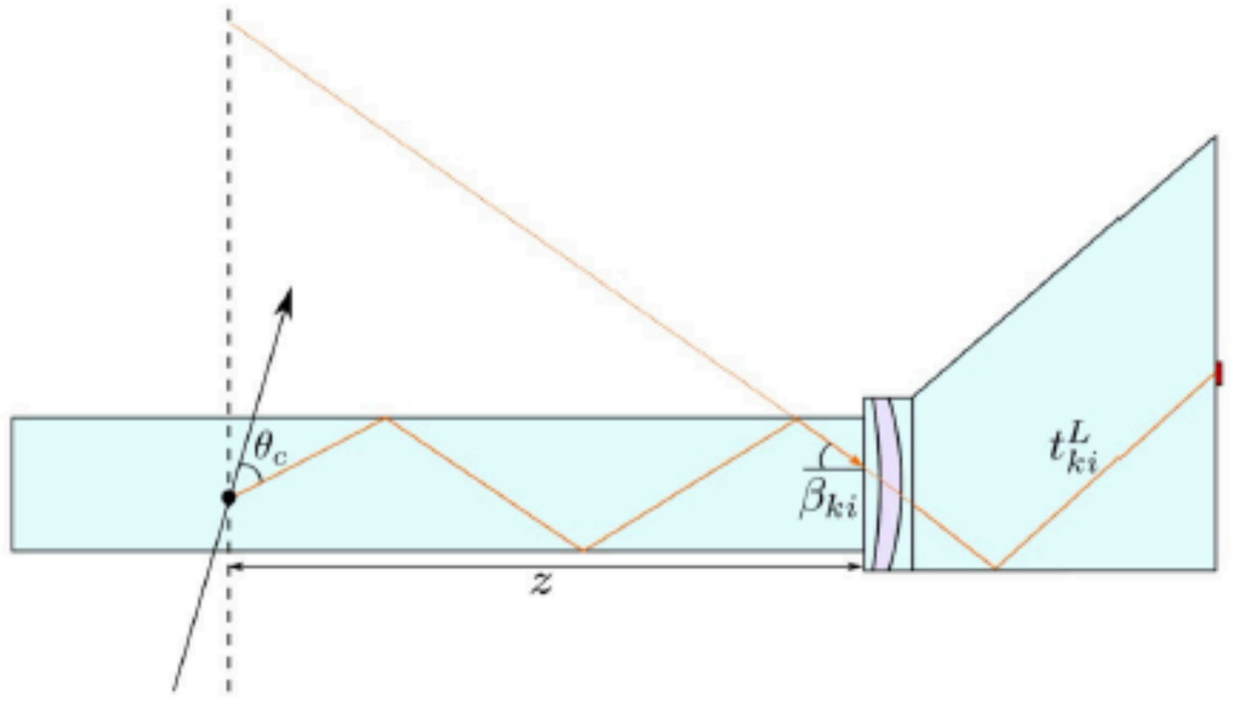
hpDIRC Reconstruction

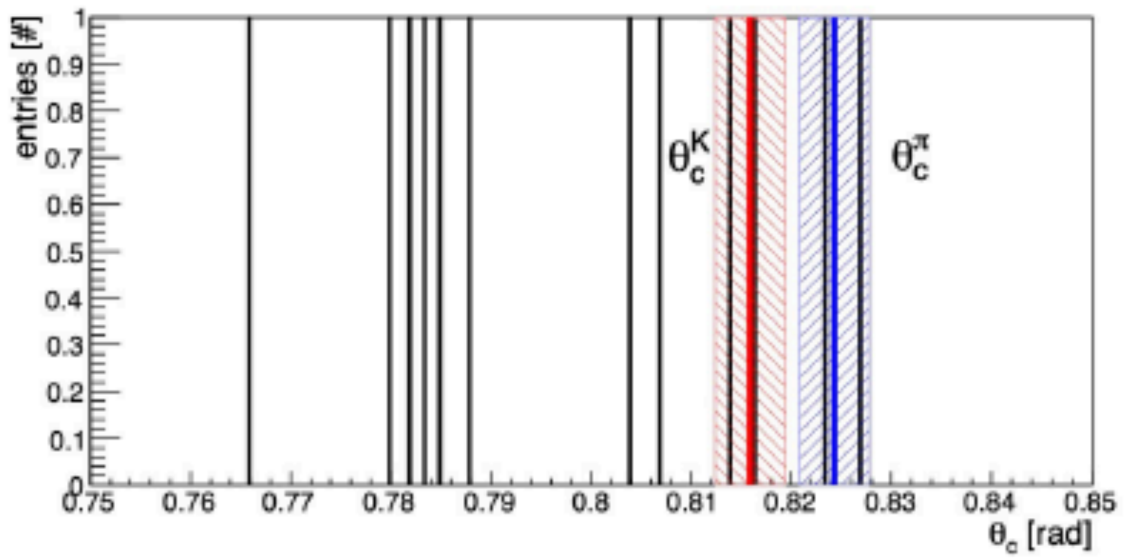
Greg Kalicy (CUA)

- Reconstruction and PID methods:
  - Geometrical (BABAR-like), robust and fast method based on LUT, delivers Cherenkov angle per particle and Single Photon Resolution (useful for calibration and in prototype tests), does not depend on precise time measurement
    - Pixel position + bar location define photon direction at bar end, stored in LUT, combined with particle track to calculate Θ_C.
    - Path pixel – bar not unique, combinatorial background in Θ_C requires careful treatment.
    - Arrival time information is used to resolve ambiguities
  - Time Imaging (Belle II TOP-like), uses Probability Density Functions (analytical or simulation-based), makes optimum use of precision of position and time information
    - from data: best PID, requires a large amount of data in whole angular and momentum acceptance
    - simulated: full Geant4 simulation of every possible particle type direction and momentum





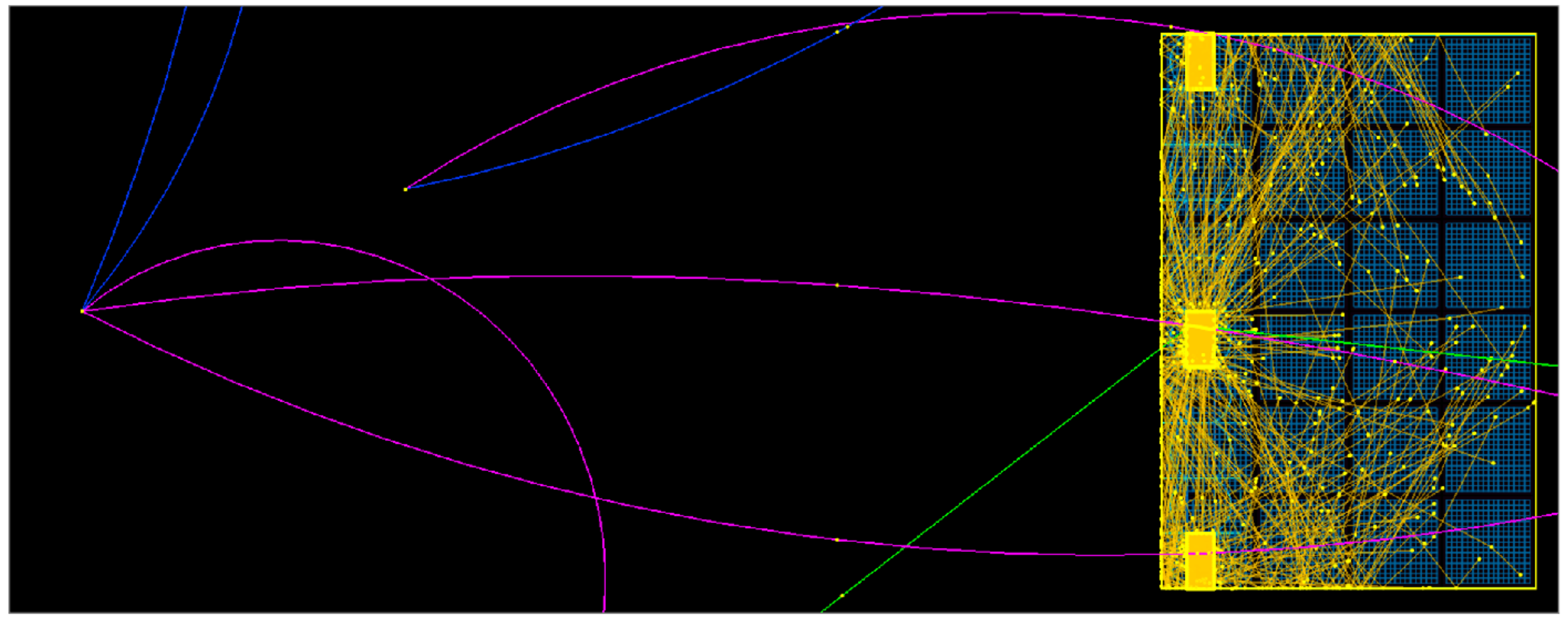


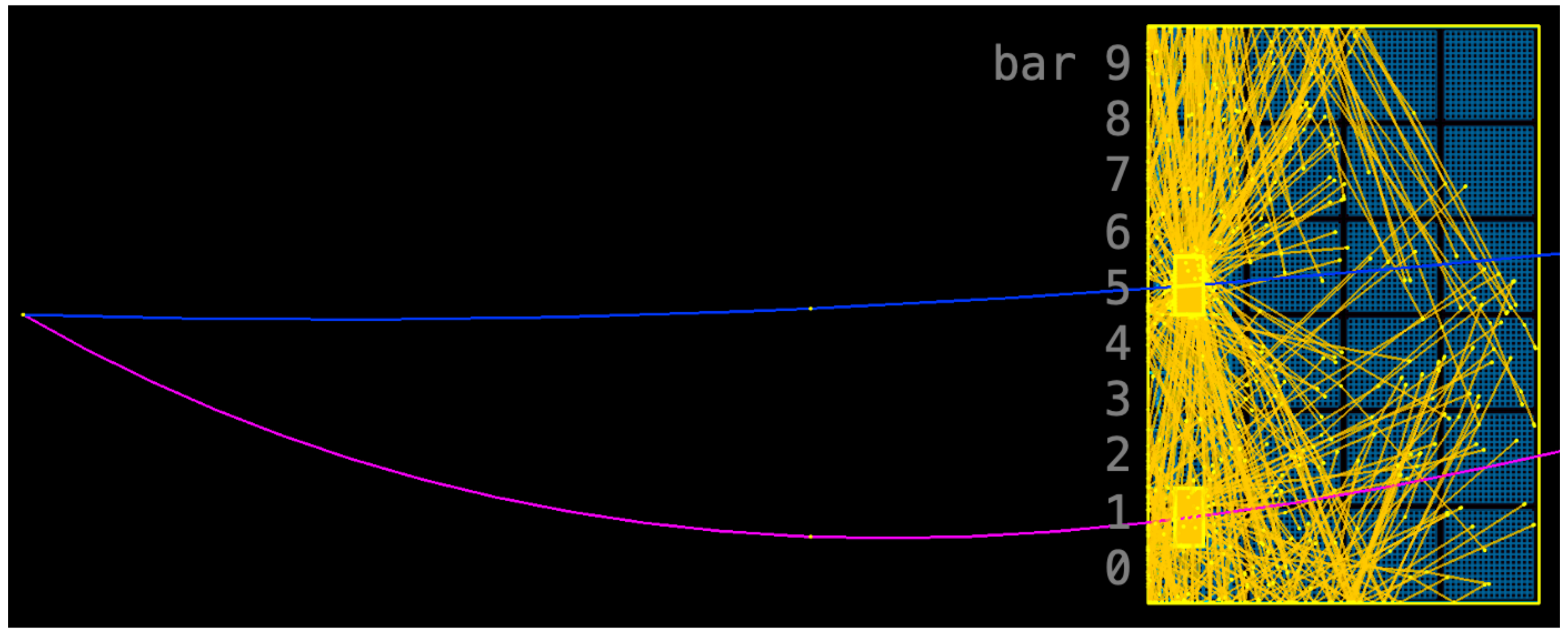


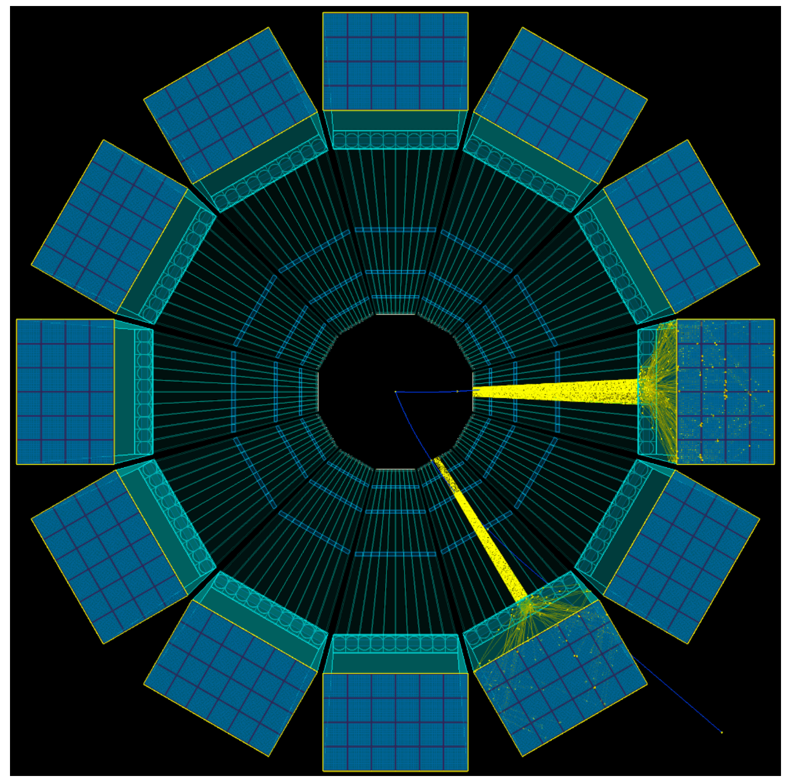
hpDIRC Performance with Backgrounds

Bill Llope (Wayne State)

- Using Time Imaging Algorithm studied various background scenarios using Pythia8
  - Pythia8 events, as an untracked background to DIRC single-particle PID:
    - PID performance (N_σ) unaffected on average.
    - "hottest" sector in each event has ~2 CP hitting same bar box
      - PID performance (N_σ) degrades by ~5% in these boxes
- More direct information on the PID degradation: throw "shadow" primary tracks.
  - These hit the same bar (or box), putting "extra" OPs on pixels, degrading N_σ
    - 6 GeV/c π/K/p in Bar 5 at q = 30, 90, 150 deg
    - PID performance (N_σ) is, at worst, 70% of the value for clean PID (two tracks hitting same bar with same p and η)
    - If two tracks hit the same bar with $|\Delta\eta| \geq 0.3$, or if the 2nd particle has low momentum, then the PID performance is essentially unaffected.
- DIRCs appear to be remarkably robust detectors!







hpDIRC Performance with Backgrounds

Bill Llope (Wayne State)

- Using Time Imaging Algorithm studied various background scenarios using Pythia8
  - Pythia8 events, as an untracked background to DIRC single-particle PID:
    - PID performance (N_σ) unaffected on average.
    - "hottest" sector in each event has ~2 CP hitting same bar box
      - PID performance (N_σ) degrades by ~5% in these boxes
- More direct information on the PID degradation: throw "shadow" primary tracks.
  - These hit the same bar (or box), putting "extra" OPs on pixels, degrading N_σ
    - 6 GeV/c π/K/p in Bar 5 at q = 30, 90, 150 deg
    - PID performance (N_σ) is, at worst, 70% of the value for clean PID (two tracks hitting same bar with same p and η)
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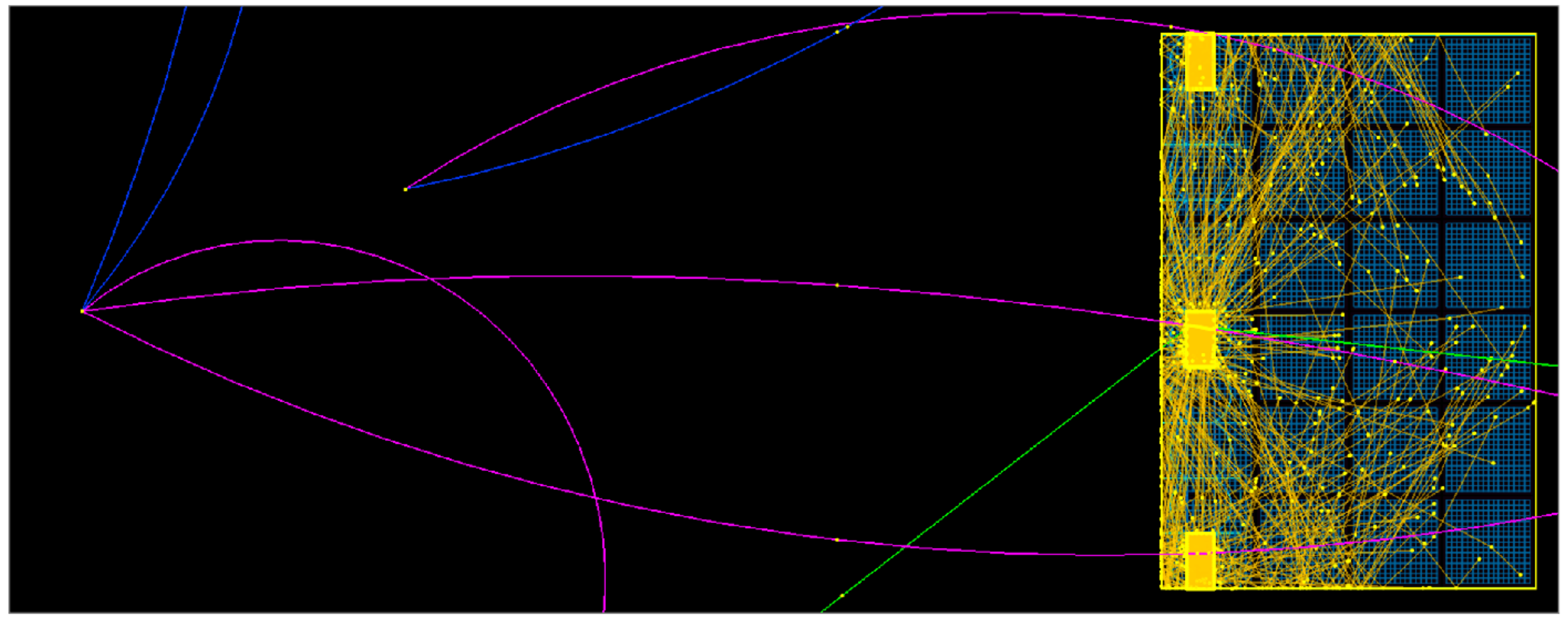
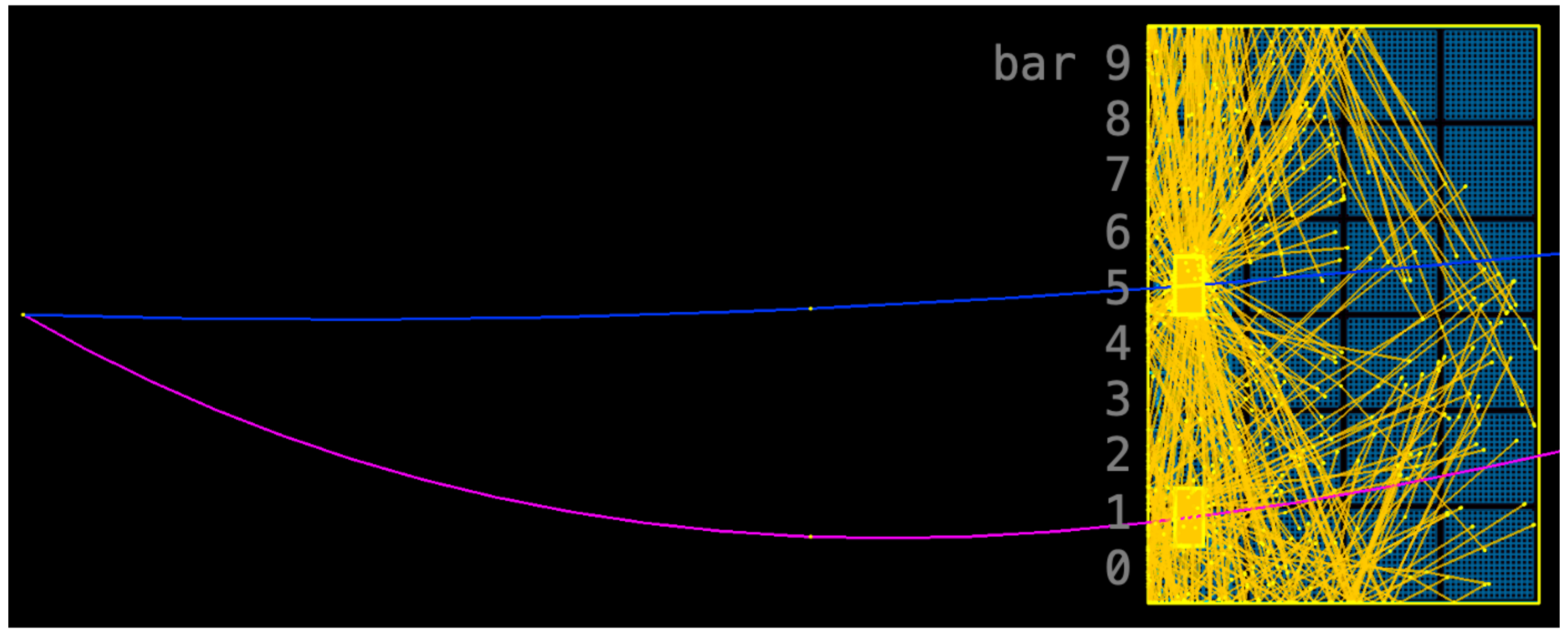
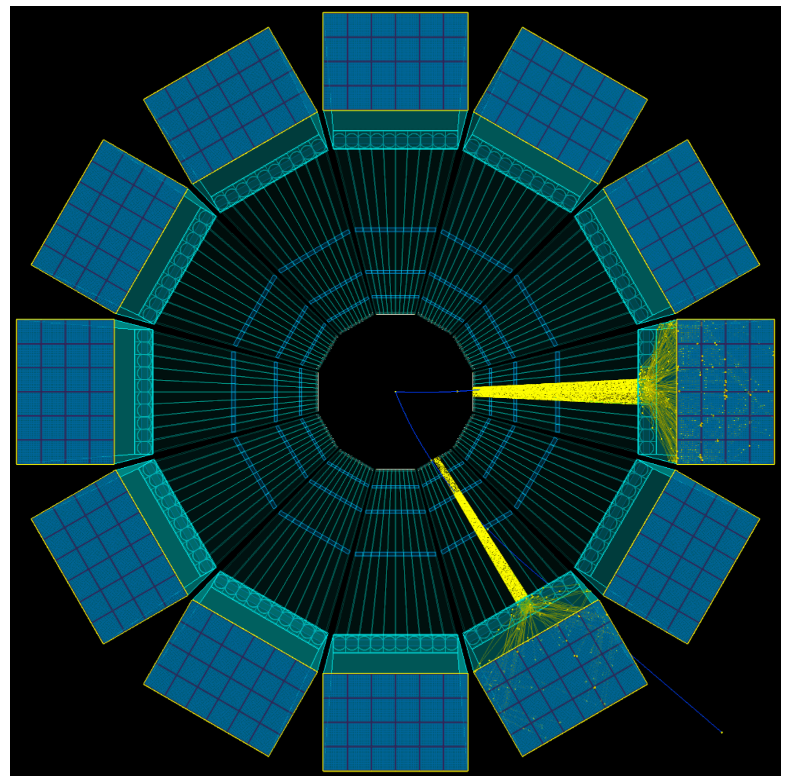




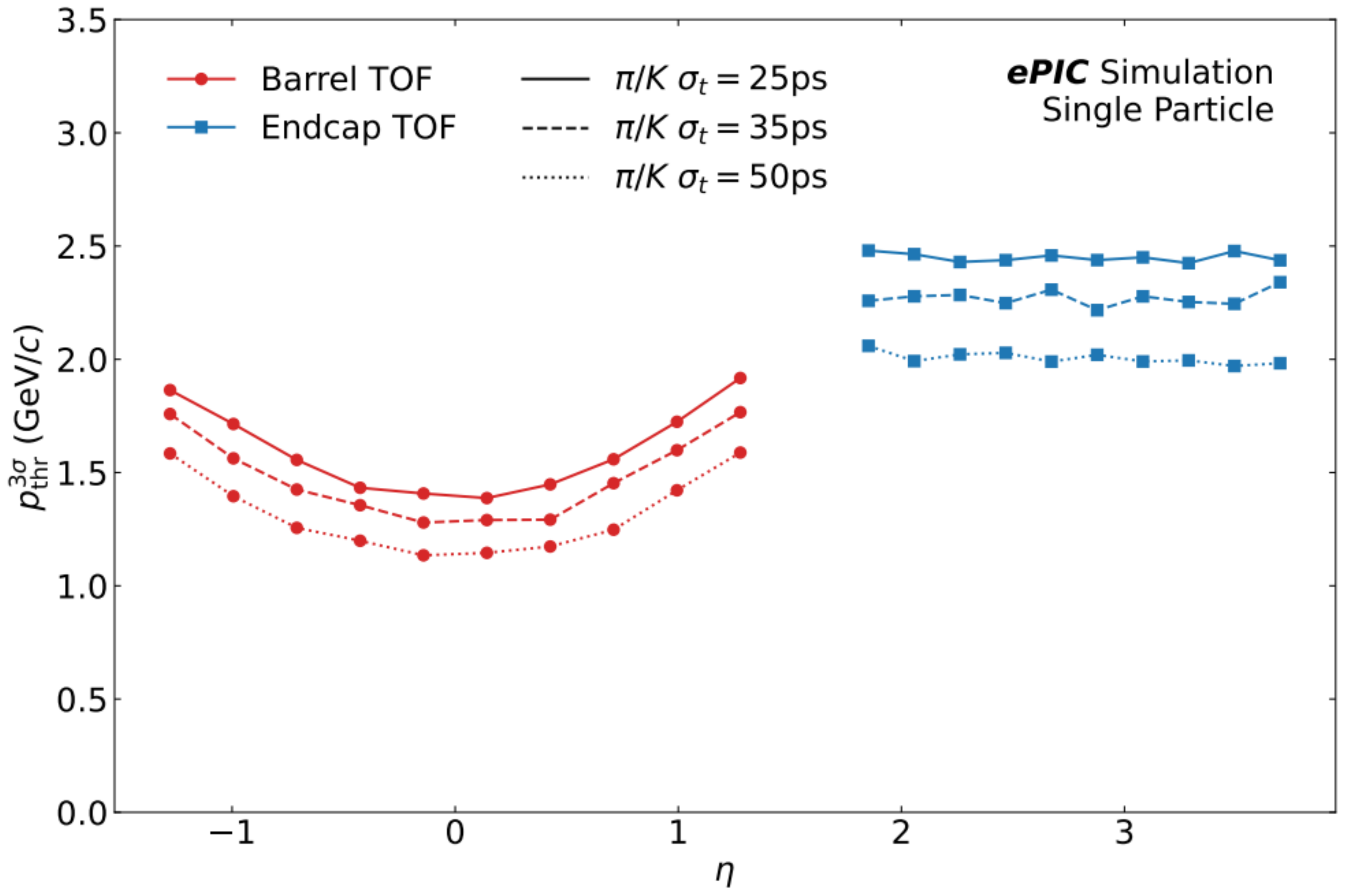
Very promising first results.
See Bill's talk for many informative animations



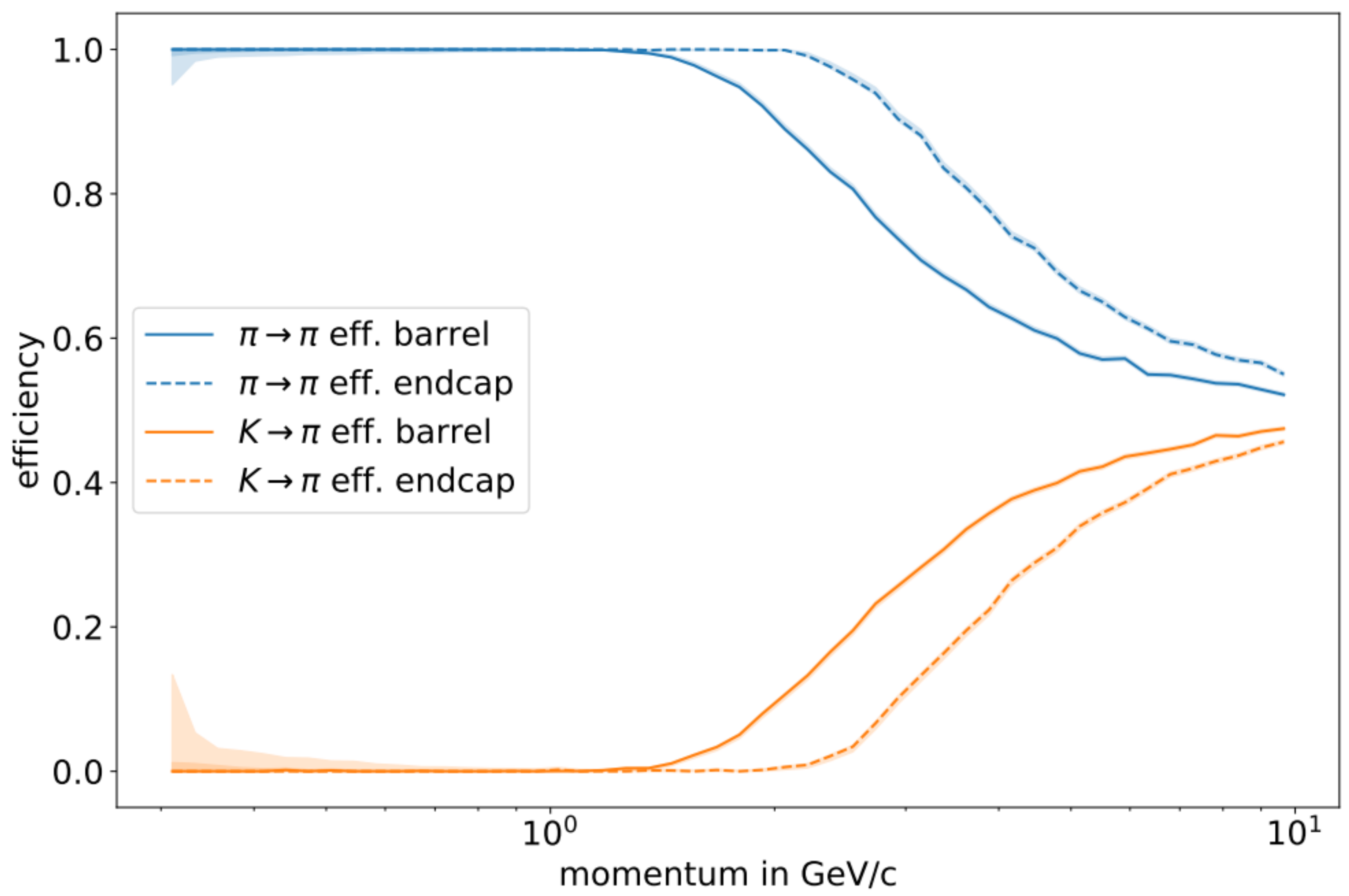
ToF Reconstruction

Oskar Hartbrich (ORNL)

- Overall simple
  - Need reconstructed momentum, track length and hit time
  - From momentum and track length calculate expected hit times of various particle species
  - Comparison of expected hit time to measured hit time yields weights/likelihoods for each hypothesis
- Devil in the Details:
  - No showstoppers but iterative improvements to be made
  - Need correctly modeled time distributions in simulation (digitization)
  - Need correctly modeled time distributions in reconstruction
  - Need correct assignment of TOF hits to track
- Currently using full eicsoft simulation software + custom plugin to write out relevant TOF hits, then do external reconstruction in python



TOF pion efficiency/mis-iD at p_π>0.5



Results of Discussion: Listen Up Y'All

- There is no fully worked out PID information in ePIC reconstruction software
- We need physics performance plot for TDR on a few month time scale including PID
- Consensus in PID groups that validated, debugged, realistic implementation in EICrecon not happening in this time scale

- **Solution:**
  - PID groups will generate LUT for efficiency and purity for K, π, p, e for kinematic bins (e.g. $p, \eta/\theta, \phi$).
  - These tables will be generated with existing tested and verified stand-alone simulations
  - PWG need to use these table to mock up PID efficiencies and purity

Instead of a Summary of the Summary

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- There were more of the informal meeting type
- They were nevertheless extremely useful and productive
- It was good seeing everyone in person and discussing
- I think everyone learned a bit from the other and we made progress
- **Thank you to all who participated**

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Thank you ePIC 2024 Argonne NATIONAL LABORATORY for your attention