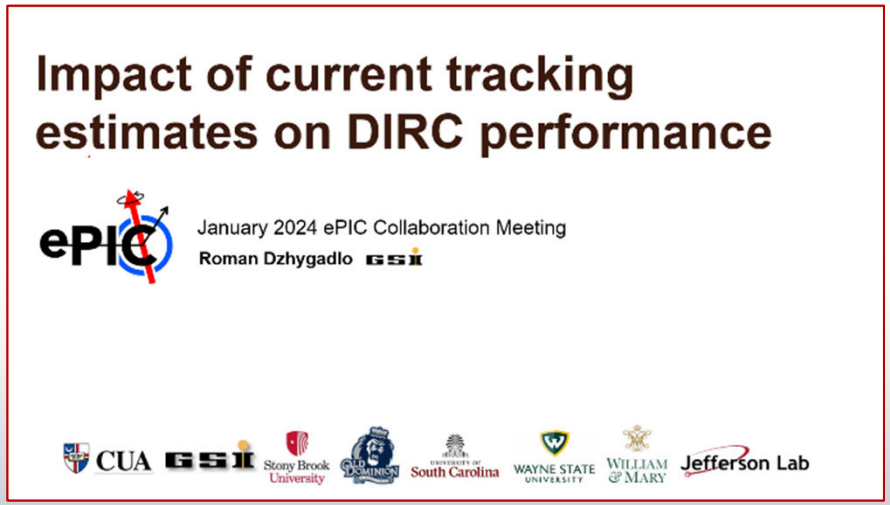
ePIC hpDIRC

TRACKING RESOLUTION REQUIREMENTS

Updated version of Roman's talk at Argonne meeting this January



Jochen SCHWIENING

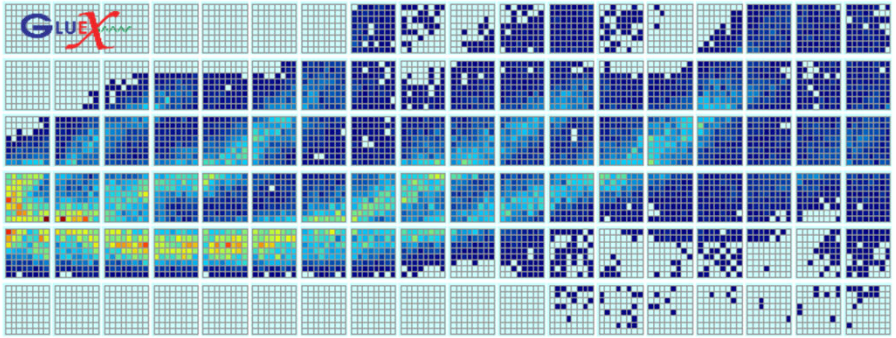
GSI

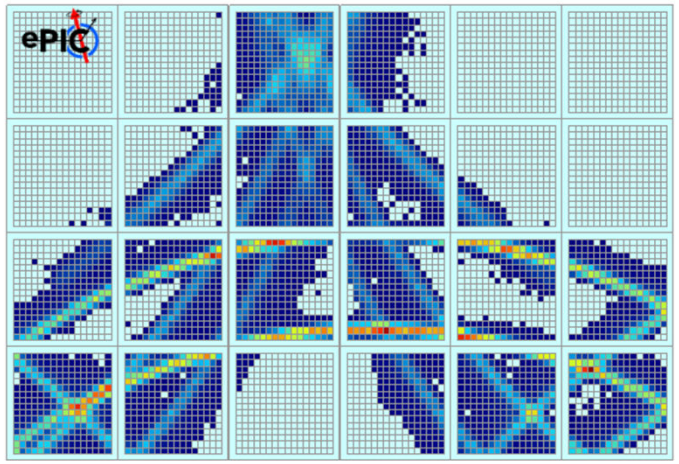
for the ePIC hpDIRC DSC

TIC meeting, Aug 19, 2024

DIRC Reconstruction/PID

Accumulated hit pattern, 3.5 GeV/c pions,
GlueX DIRC beam data





Accumulated hit pattern, 6 GeV/c pions,
ePIC hpDIRC Geant

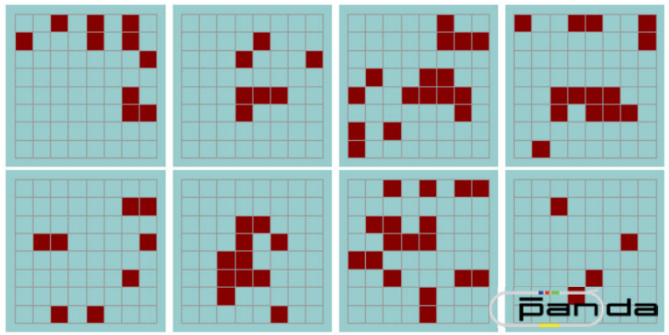
DIRC hit patterns do not look like your typical RICH "rings"

Patterns complicated by internal reflections inside bar/plate, mirror, expansion volume, shape of sensor plane

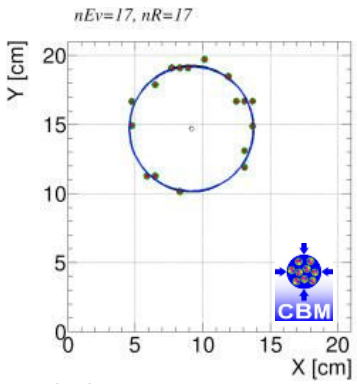
Detector space is often not the best space for DIRC reconstruction, no "simple" ring fits

Performing reconstruction and PID in Cherenkov space instead

Reconstruction/PID requires particle momentum vector and location at DIRC bar position as input



Single 3.5 GeV/c pion event,
PANDA Barrel DIRC prototype beam data



For comparison:
Single event in
CMB RICH (CO_2) prototype

DIRC Reconstruction/PID

Intuitive example: geometric reconstruction

Developed for BABAR DIRC, approximates Cherenkov photon direction

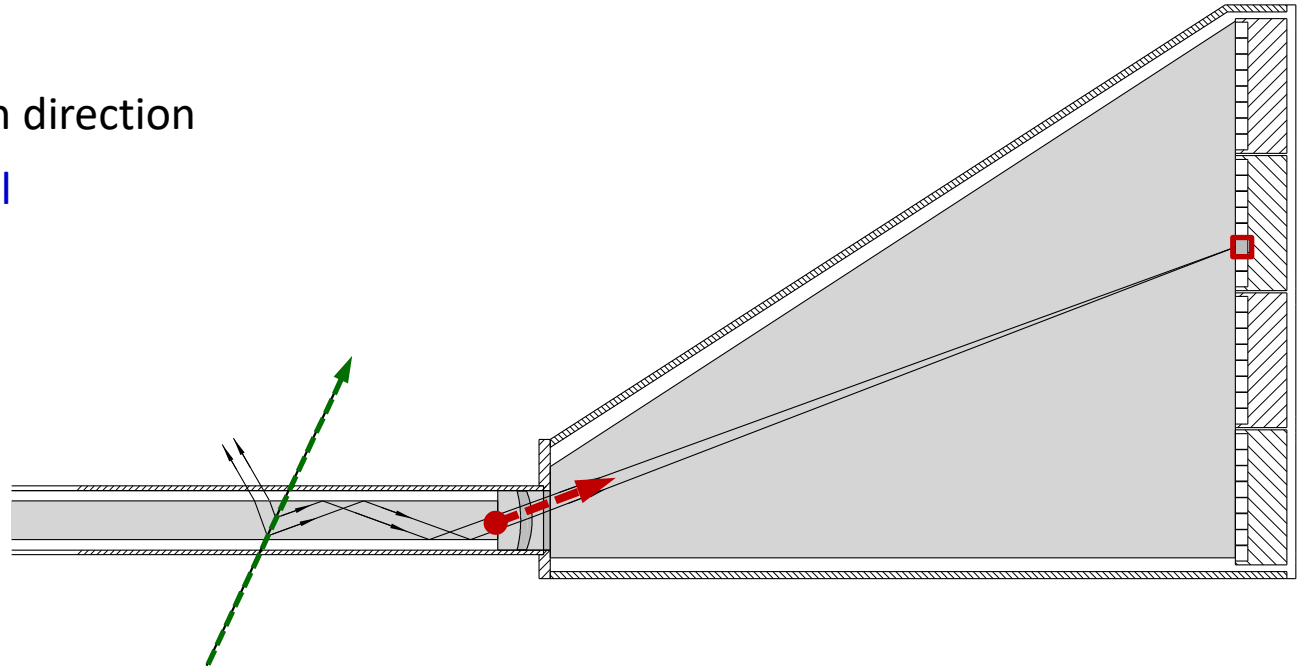
as 3D vector from center of end of bar to center of pixel

(including all possible reflections in bar/prism)

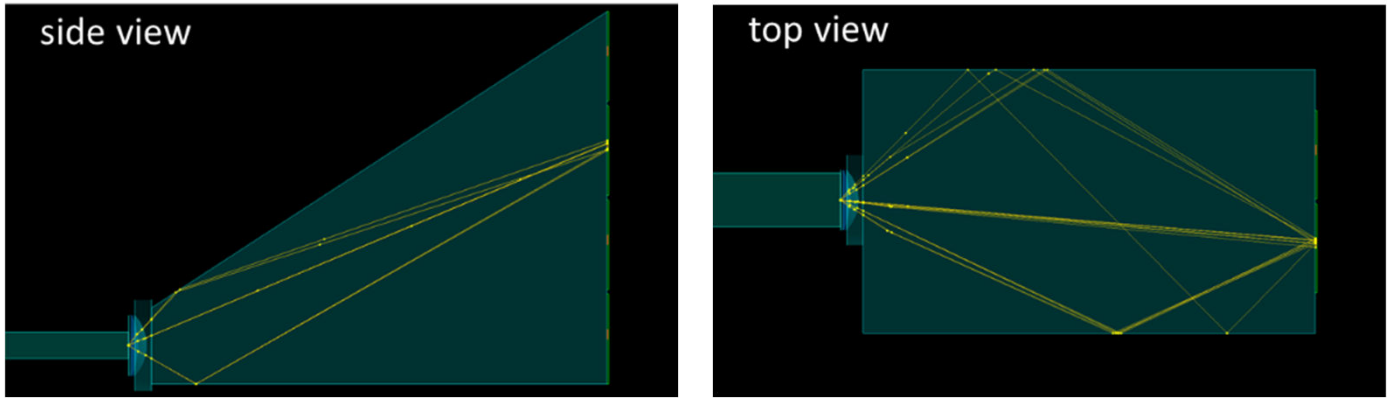
Use photon gun in simulation to create look-up tables (LUT)

of photon vectors for every pixel/bar combination

<u>Fast method, one LUT for all particle tracks</u>



Geant4 photon paths for example pixel



DIRC Reconstruction/PID

Intuitive example: geometric reconstruction

$$\log\mathcal{L}_h = \sum_{i=1}^{N} \log(S_h(c_i) + B_h(c_i)) + \log P_h(N)$$

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as 3D vector from center of end of bar to center of pixel

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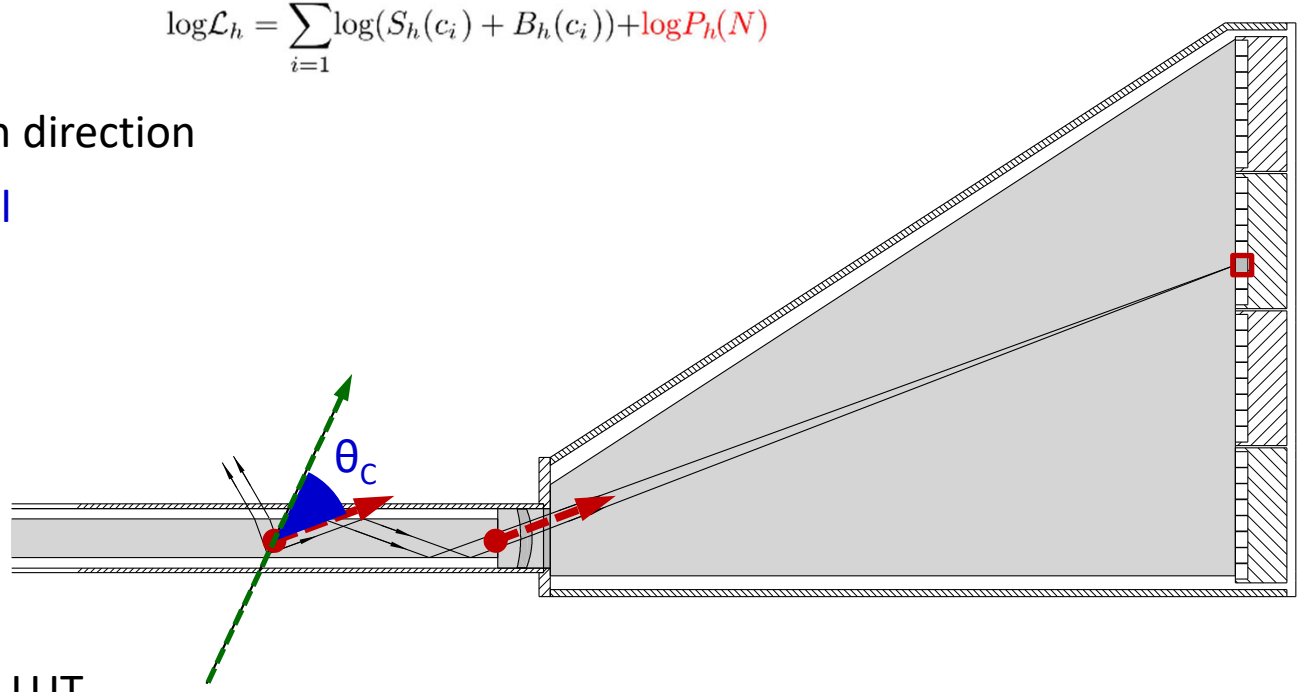


Pixel with hit → retrieve 3D direction vector collection from LUT

Combine each direction vector with particle direction vector from tracker → obtain Cherenkov angle per photon (θ_C ,φ_C)

Consider all possible reflections in bar (up/down, left/right, forward/backward) and in prism as ambiguities

Time-based reconstruction requires same info, additionally needs track position (x_{bar},z_{bar}) at DIRC with few mm precision

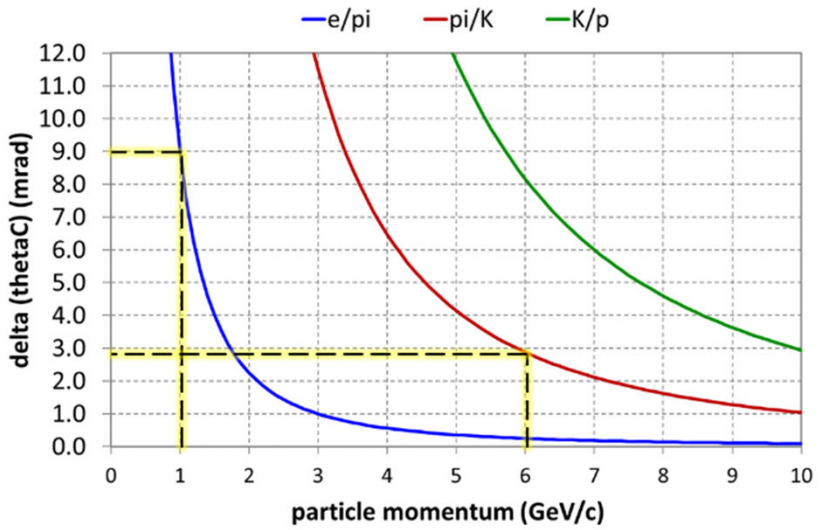
Method has better performance, separation power results shown today were obtained with this method

Cherenkov Angle Resolution

Most challenging ePIC hpDIRC PID goals:

- π/K separation up to at least 6 GeV/c → $\Delta\theta_c \approx 2.9$ mrad
  - 3 s.d. requires $\sigma_{\theta_c}(particle)$ ≤1 mrad @ 6 GeV/c
- e/π separation up to 1–1.2 GeV/c → $\Delta\theta_c \approx 6 - 9$ mrad
  - 3 s.d. requires $\sigma_{\theta_c}(particle)$ ≤3 mrad @ 1 GeV/c (2 mrad @ 1.2 GeV/c)

Cherenkov angle difference in fused silica



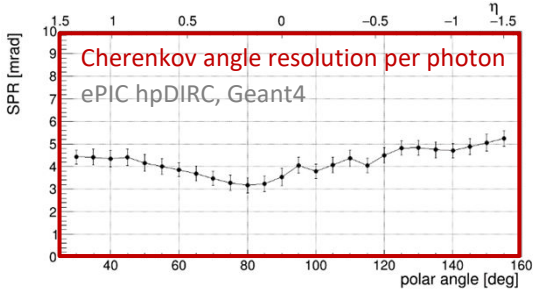
Cherenkov angle resolution per particle can be written as

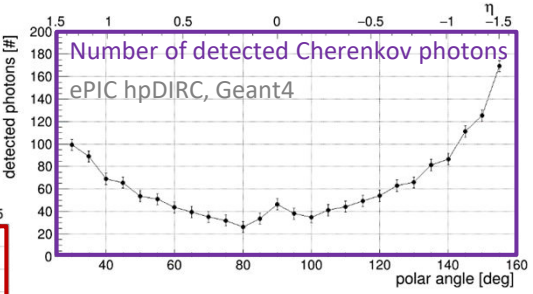
$$\sigma_{\theta_c}(particle) \approx \sqrt{\left(\frac{\sigma_{\theta_c}(photon)}{\sqrt{N_\gamma}}\right)^2 + \sigma^2_{correlated}}$$

$$\sigma_{correlated} = \sqrt{\sigma^2_{tracking} + \sigma^2_{m.s.} + \ldots}$$

Correlated term: quadr. sum of angular resolution from tracking system and multiple scattering inside DIRC bar (plus alignment, etc)

For ePIC hpDIRC: $\sigma_{\theta_c}(photon) = 3 - 5\,mrad,\ N_\gamma = 30 - 170$





Cherenkov Angle Resolution

What does this mean for the correlated term
and for the tracking angular precision requirement?

Yellow report hpDIRC requirement:

$\sigma_{tracking} \leq 0.5$ mrad at 6 GeV/c

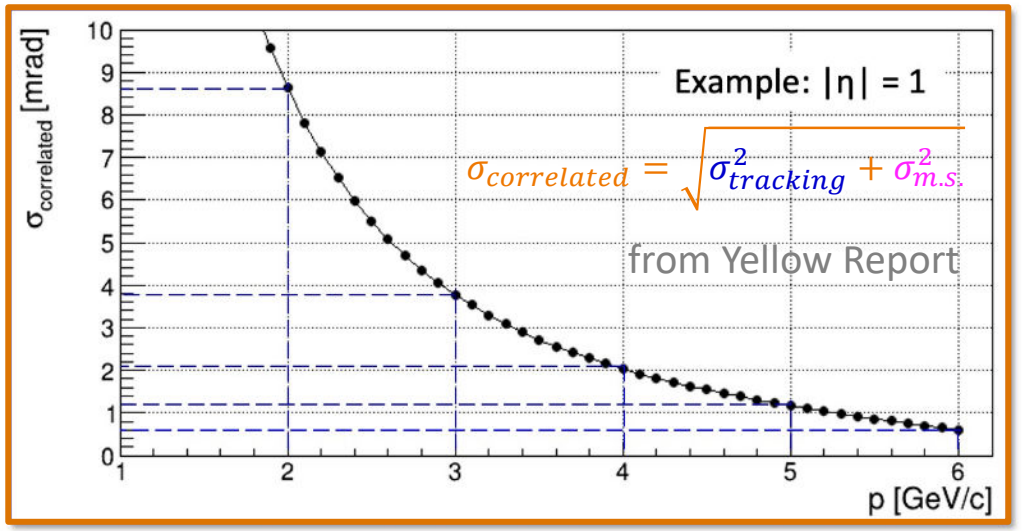
(Note that this resolution is for polar angle and azimuthal angle)

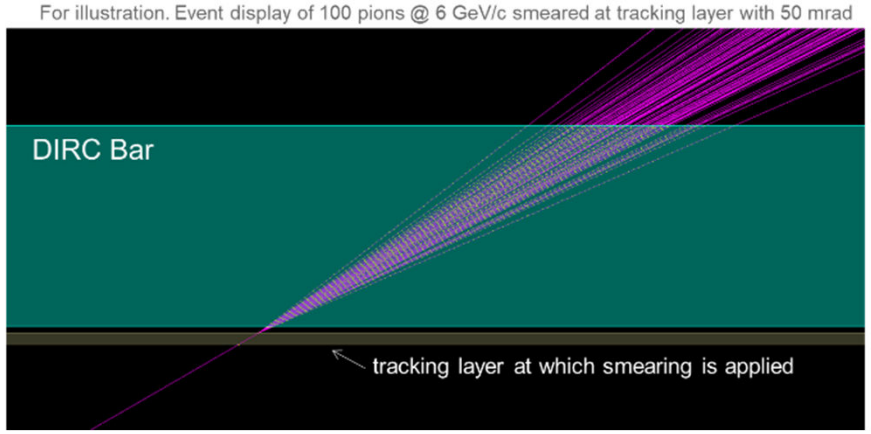
Tracking requirement less strict for lower momenta

Tracking angular precision implemented as Gaussian smearing of polar and azimuth angles of particle momentum at a special *ad hoc* "tracking layer" in standalone hpDIRC simulation

Multiple scattering inside DIRC bar depends on polar angle, momentum, particle type, included in standalone hpDIRC Geant4 simulation

Example: maximum allowed contribution from correlated term while keeping hpDIRC π/K separation power at 3 s.d.





Expected hpDIRC Performance

During YR/DPAP times, tracking experts suggested expected

tracking angular precision values of 0.5 mrad at 6 GeV/c

and 2.5 mrad at 1.2 GeV/c

Implemented these resolutions in hpDIRC standalone simulation

π/K separation at 6 GeV/c reaches 3 s.d. goal

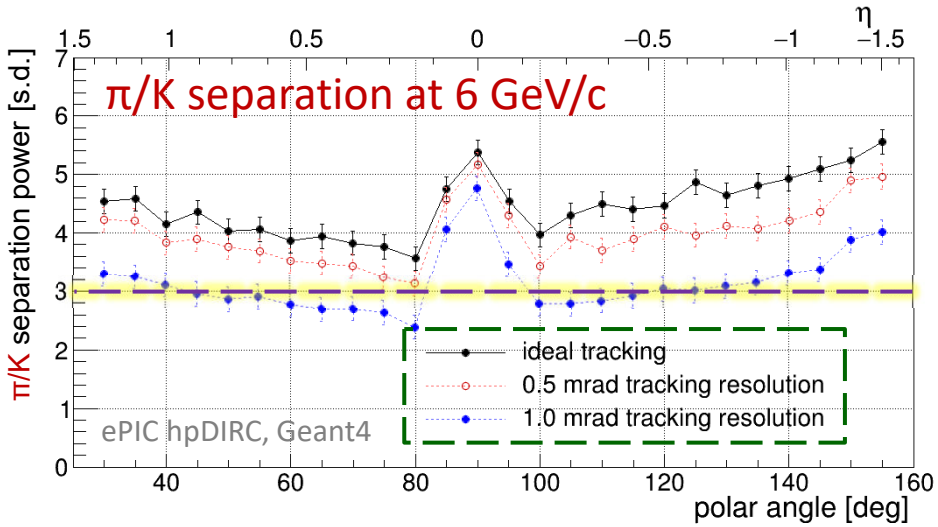
for 0.5 mrad tracking resolution

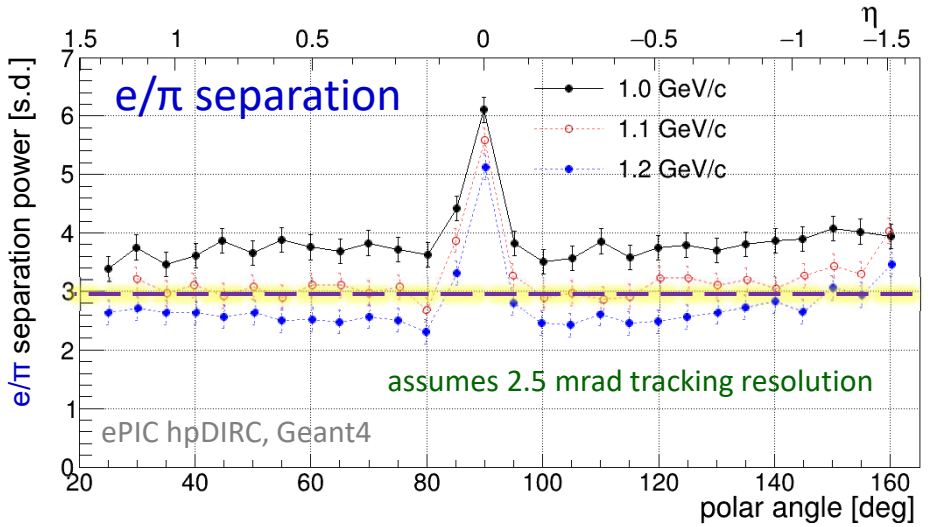
e/π separation with 3 s.d. in reach at 1.1 GeV/c

for 2.5 mrad tracking resolution

(Caveat: non-Gaussian tails from multiple scattering,

3 s.d. value for core of log-likelihood difference distribution)





Caveat for all shown results: standalone Geant4, particle gun, no magnetic field, track hits center of bar, no backgrounds, 100 ps photon timing

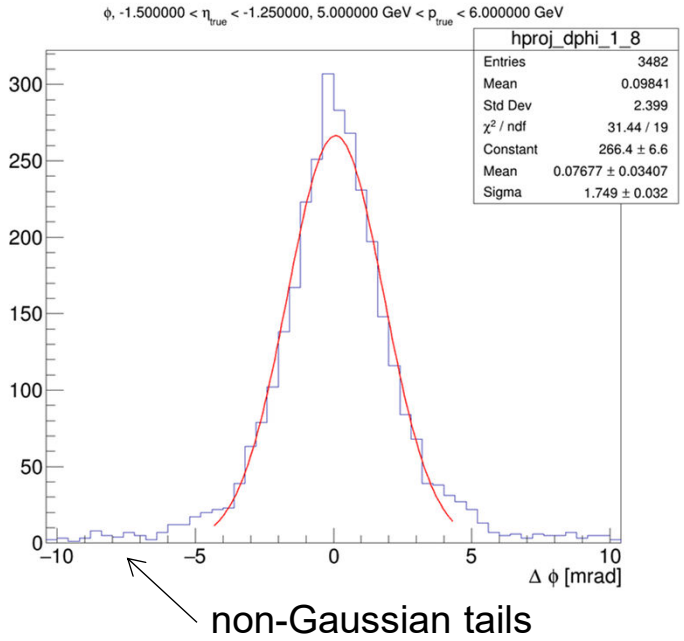
hpDIRC and Tracking Resolution

Nov 2023: Matt Posik shows study of realistic tracking resolution at hpDIRC barrel in tracking/PID meeting

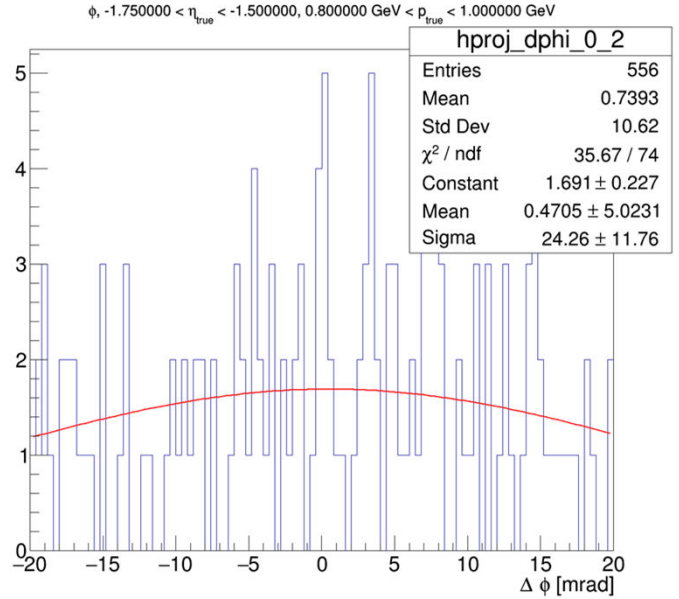
Matt shared root files with us

Examples of two bins (total of 13 bins in momentum [0.3, 10] and 14 bins in eta [-1.75, 1.75])

typical bin:



bin with low stat (@ low momentum):

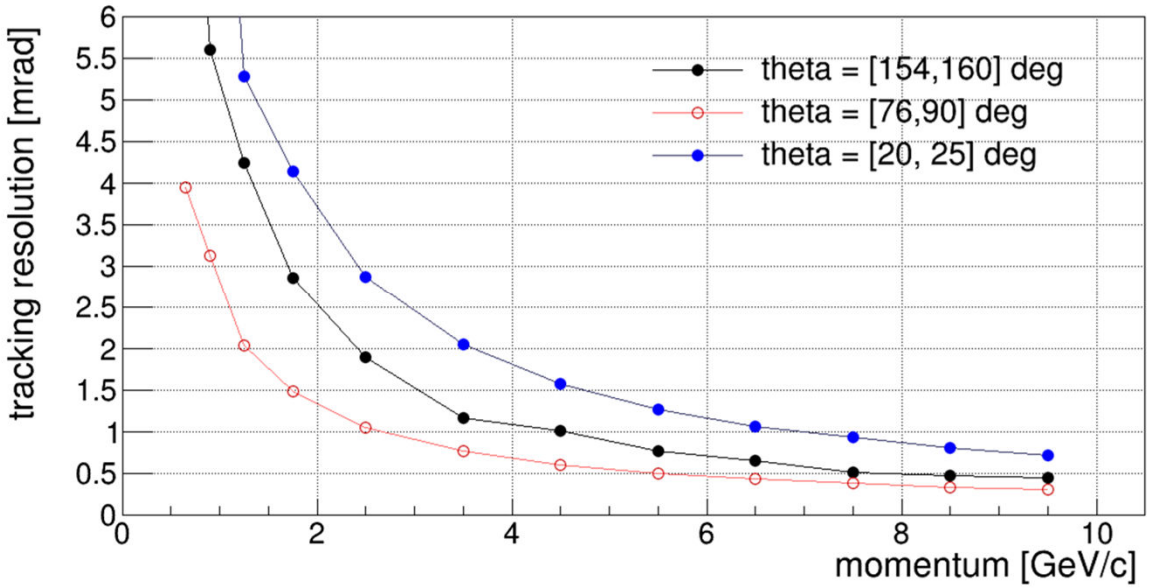


Note that use of Gaussian sigma ignores tails in residual distributions

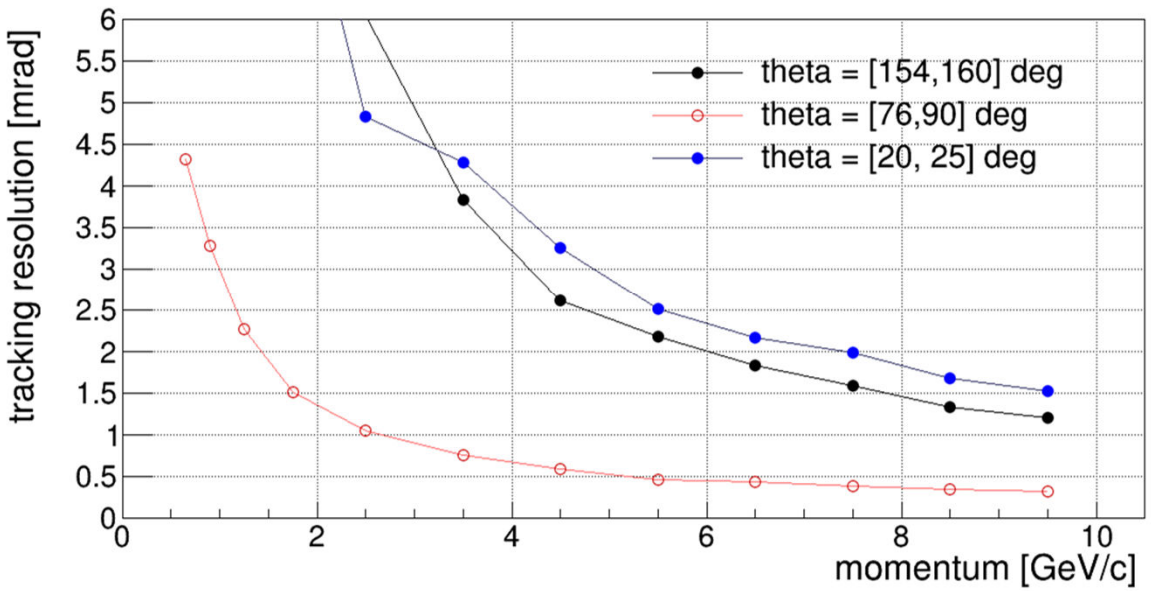
HPDIRC AND TRACKING RESOLUTION

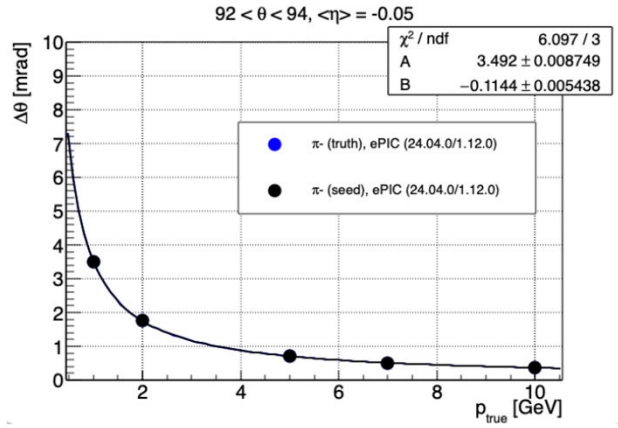
Resolution (sigma of the Gaussian fit) as a function of momentum

polar angle resolution [mrad]:



azimuthal angle resolution [mrad]:



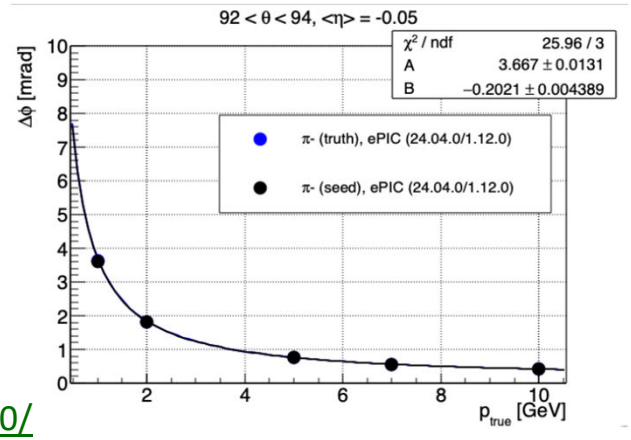


For comparison:

Matt's updated results from May 30, 2024 (σ≈0.6 mrad for η≈0)

→ consistent to 1st order

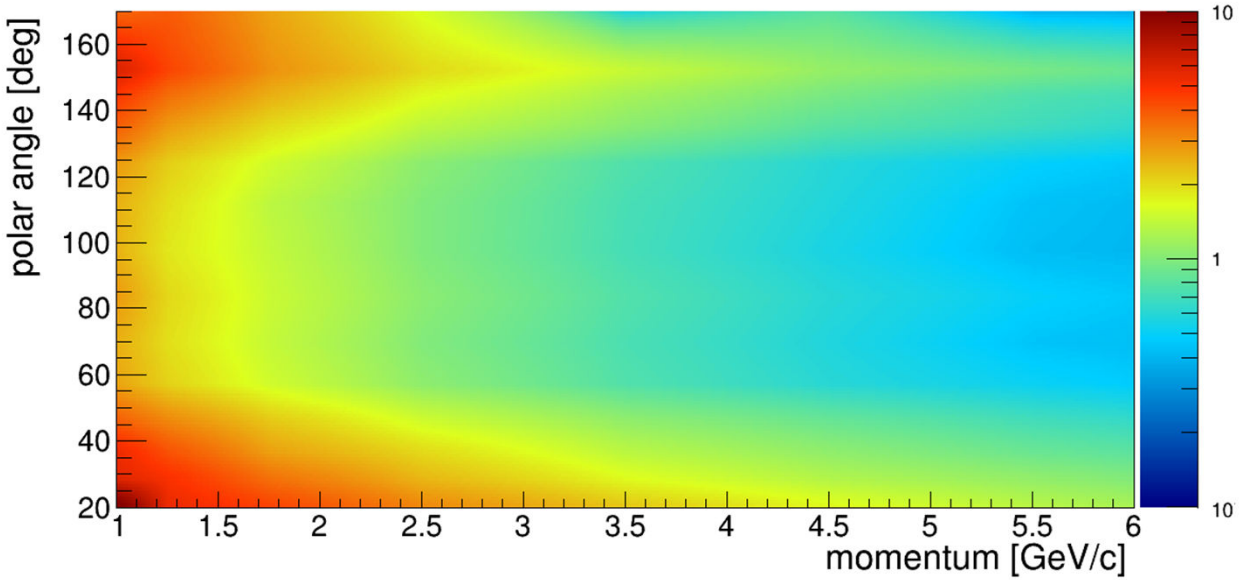
https://indico.bnl.gov/event/23630/



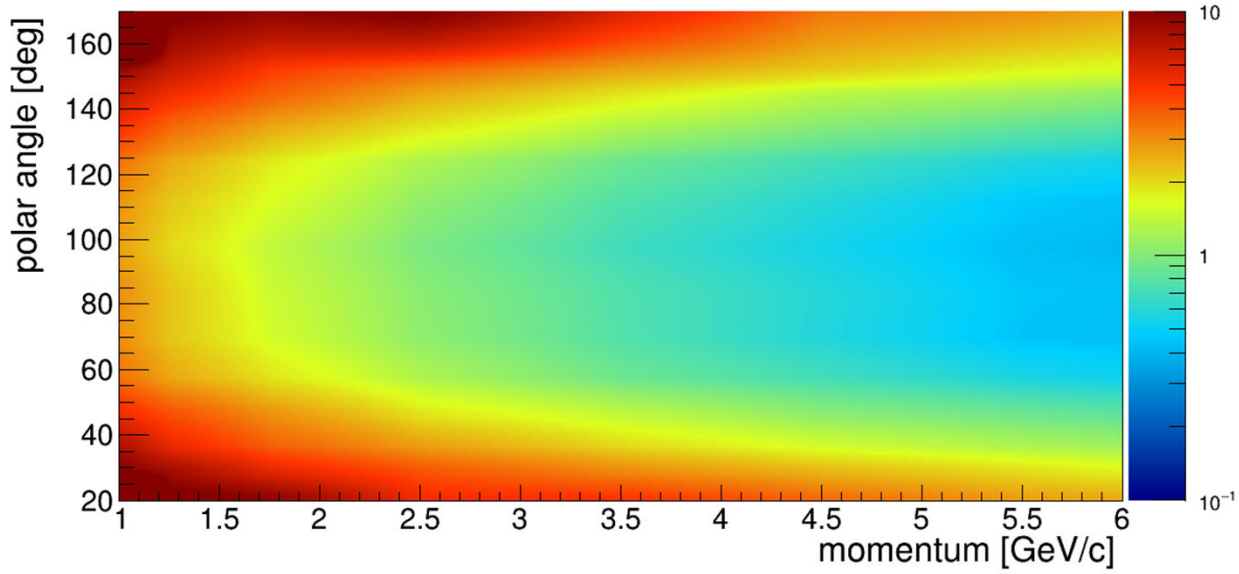
hpDIRC and Tracking Resolution

Implemented Matt's Nov 2023 resolution values in hpDIRC stand-alone simulation test
as 2D resolution maps after interpolating between bins

polar angle resolution [mrad]:



azimuthal angle resolution [mrad]:



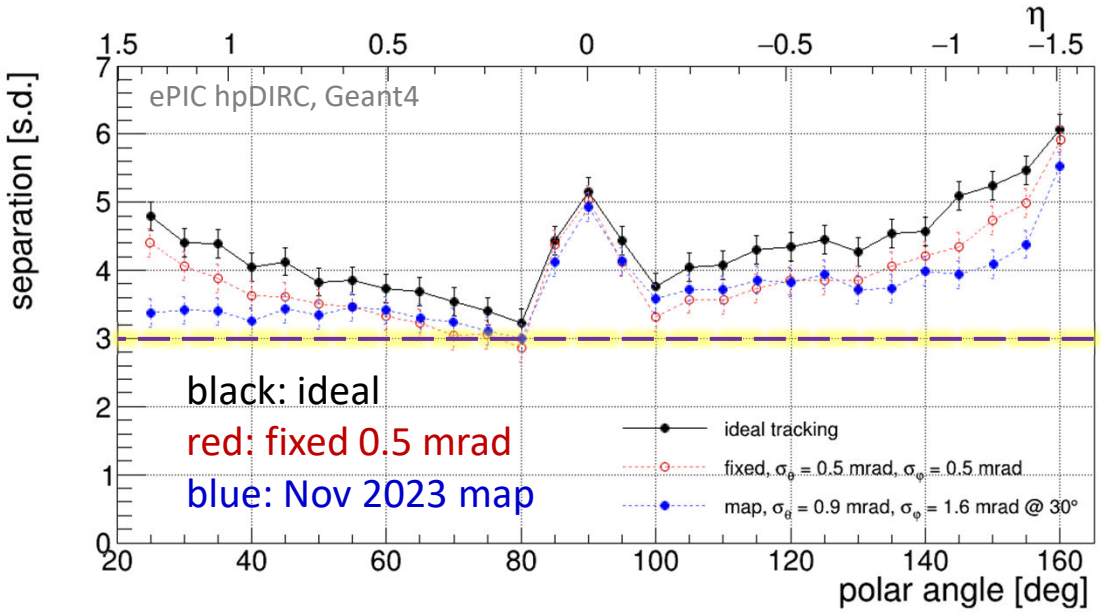
Note that flat 0.5 mrad tracking angular resolution for polar and azimuthal angle is used in PID look-up tables (decision in 2/8/24 PID meeting)

Mechanism ready for producing another hpDIRC PID LUT as soon as reliable, realistic tracking resolution maps are available

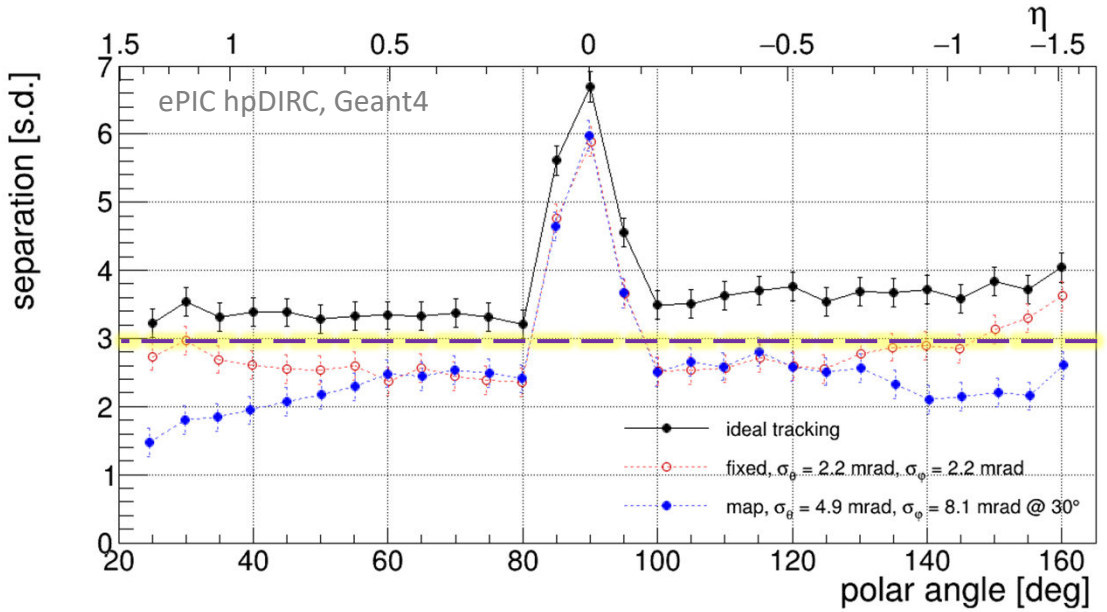
HPDIRC AND TRACKING RESOLUTION

Comparison of results for fixed tracking resolution to Nov. 2023 map resolutions

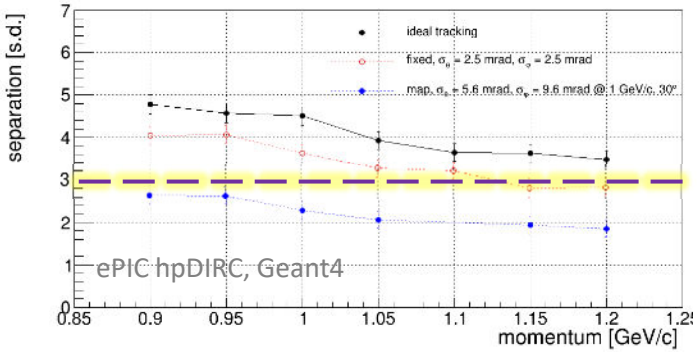
π/K separation at 6 GeV/c



e/π separation at 1.2 GeV/c



e/π separation at 30° vs momentum

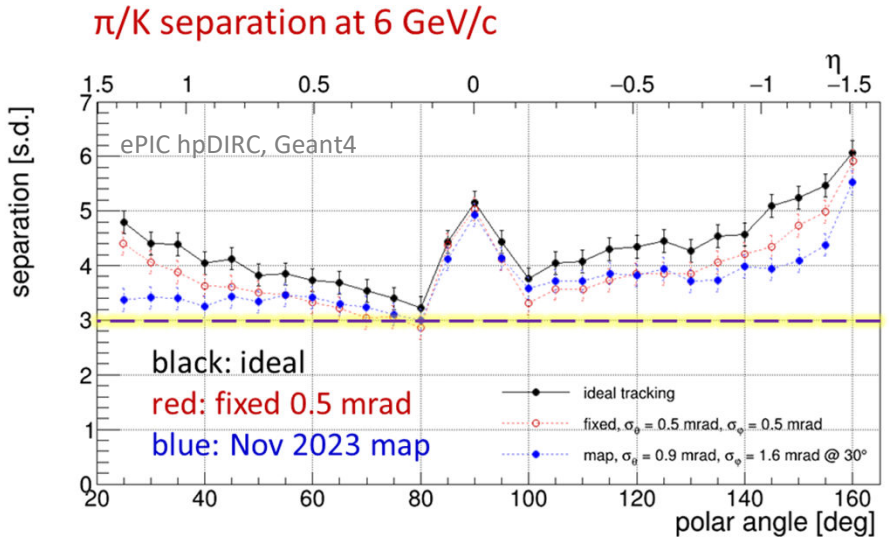


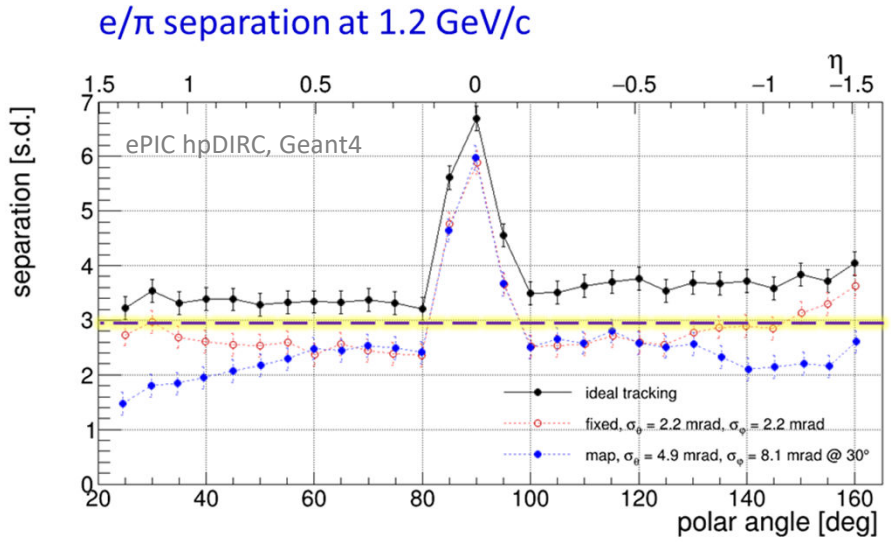
Significant performance loss when using Nov 2023 resolution map

- π/K separation drops by up to 1 s.d., still reaching 3 s.d.
- e/π separation drops below 2 s.d. for |η|>1

Summary

- hpDIRC reconstruction/PID requires momentum and position of particle at the DIRC bar as input
- Angular resolution has a direct impact on hpDIRC PID; Yellow Repost requirement: 0.5 mrad at 6 GeV/c
- PID LUT for hpDIRC use 0.5 mrad as tracking angular precision, prepared to update with new values/maps when needed
- Latest tracking angular resolution (May 2024) is worse than expected (up to ×2-2.5 in polar angle, ×3-5 in azimuthal angle)
- 3 s.d. hpDIRC PID goal for π/K @ 6 GeV/c is barely reached with latest tracking and not reached for e/π @ 1.2 GeV/c





Thank You For Your Attention