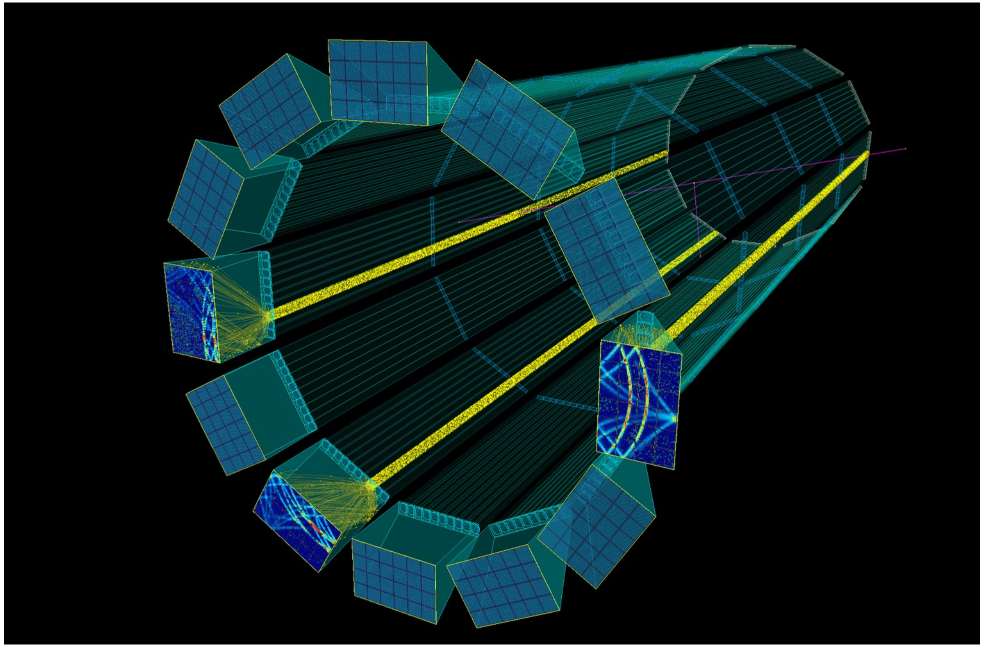
hpDIRC - Status on Simulation and Reconstruction Software



January 2025 ePIC Collaboration Meeting

Roman Dzhygadlo GSI

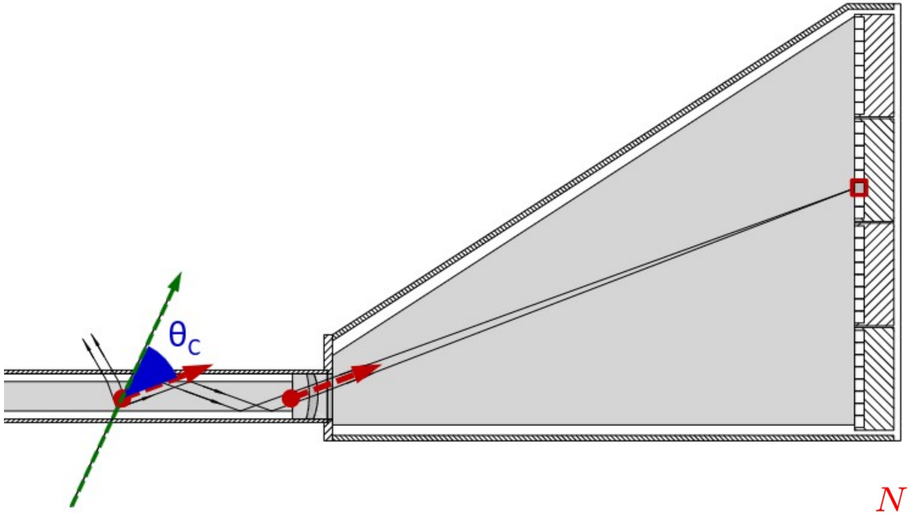
Sim/Reco Status in ePIC and EICrecon

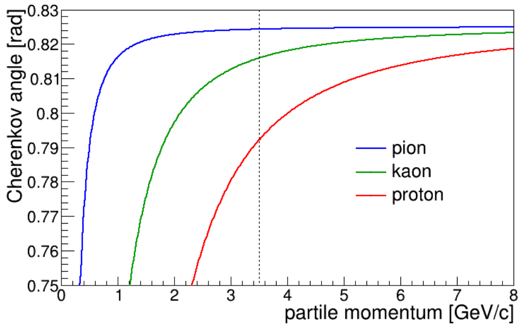
- all optical components of the geometry are implemented (radiator, focusing system, EV, mirror)
- wave-length dependent material properties
- quantum and collection efficiencies of PMTs are implemented (stacking action class)
- digitization: DIRCRawHit (RawTrackerHit) → celd Id → position → PMT Id, pixel Id → DIRC tree
- reconstruction is done using DIRC tree
- documentation for reconstruction is here: https://github.com/eic/snippets/tree/main/PID/hpDIRC
- realistic PID LUT is provided for a fast sim/reco

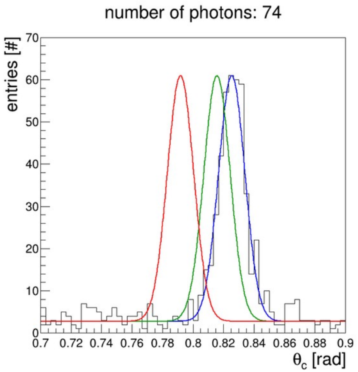
- Nilanga switched to another position
- Bill Llope is a new maintainer of hpDIRC code in ePIC sim/reco stack Yay!

Geometrical Reconstruction

- uses Look-Up Tables
- delivers Cherenkov angle per particle and Single Photon Resolution (useful for calibration)
- does not depend on precise time measurement
- LUT currently created using standalone Geant4 simulation







Likelihood calculation:

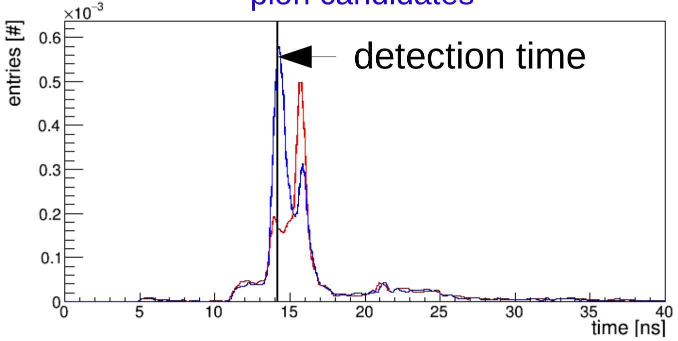
$$\log\mathcal{L}_h = \sum_{i=1}^{N} \log(S_h(c_i) + B_h(c_i)) + \log P_h(N)$$

signal — combinatorial background

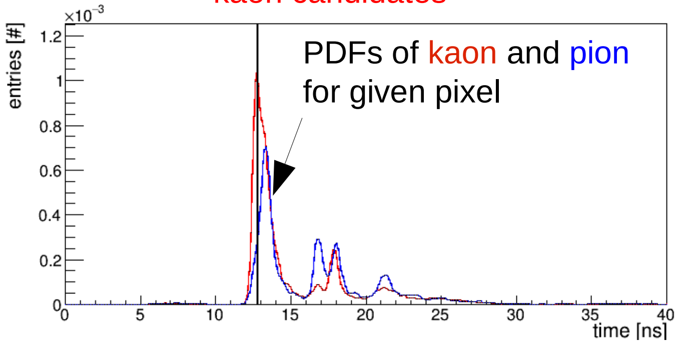
Time Imaging

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

pion candidates



kaon candidates



Probability density functions

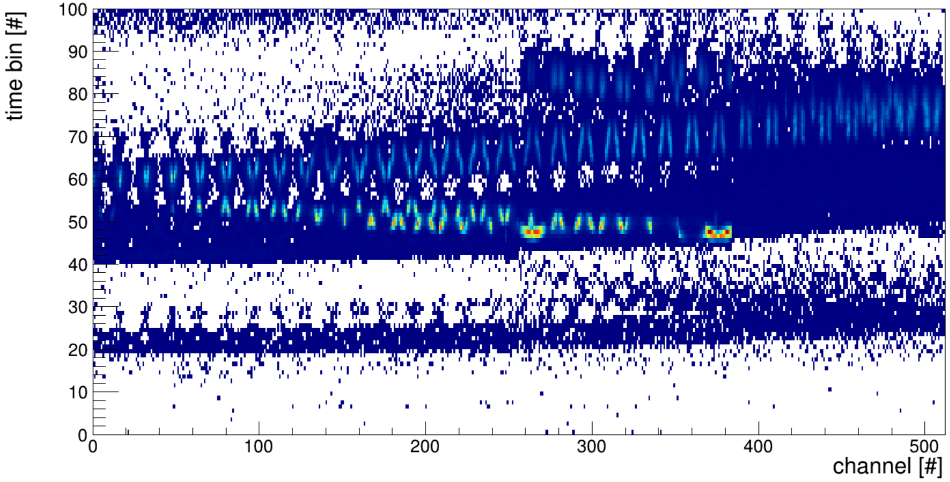
- from data: best PID, requires a large amount of data in whole angular and momentum acceptance
- simulated: full Geant4 simulation of every possible particle type direction and momentum
- analytical: fast, low memory footprint
  - initially developed for Belle II TOP (M. Staric, et al., Nucl. Inst. and Meth. A 595 (2008) 252)
  - modified to account for spherical lens focusing (PDFs using LUT)

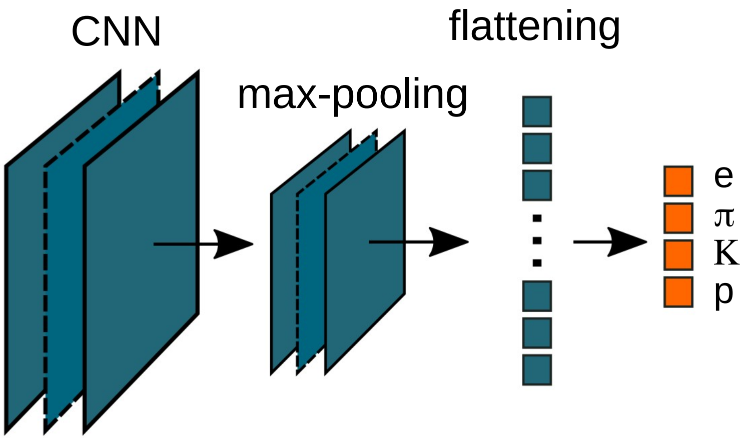
(R. Dzhygadlo et al. 2020 JINST 15 C09050, arXiv:2009.09927)

Neural Network Reconstruction

- directly using binned time and channel id to provide PID
- training relatively fast (for specific angles)
- performance comparable with Time Imaging (for specific angles)

input to the neural network

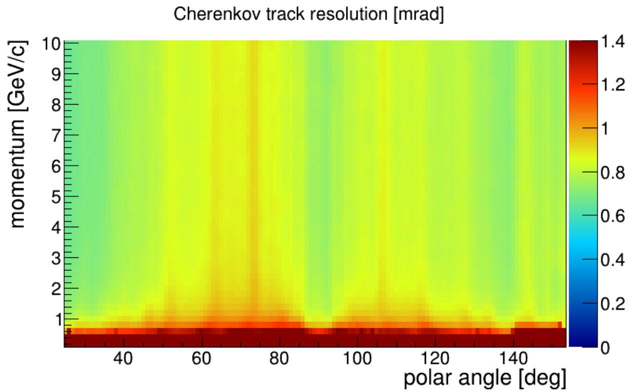




Additionally: Deep RICH for hpDIRC by Cristiano Fanelli, James Giroux

PID LUT for Fast Simulation and Reco

Based on Cherenkov track resolution map obtained by using the full standalone Geant4 simulation and reconstruction



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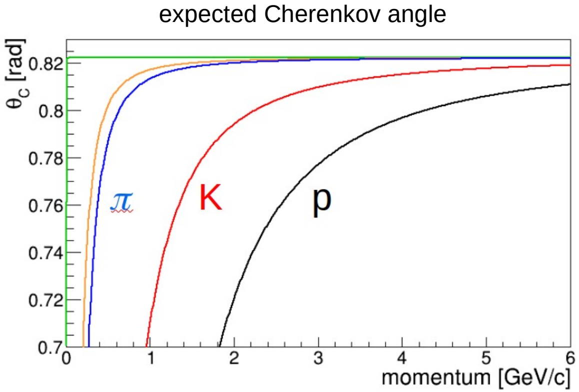
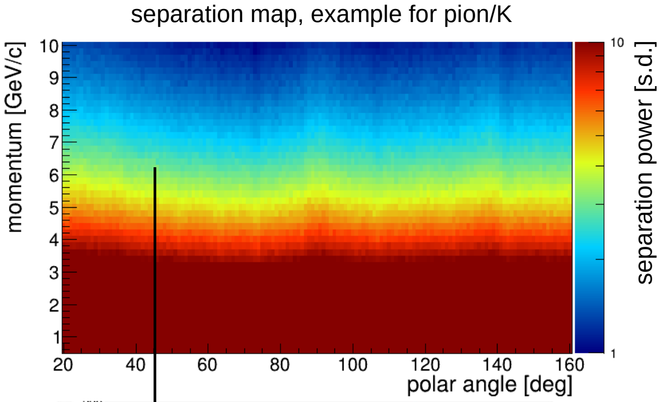
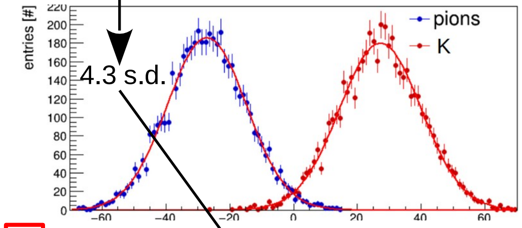
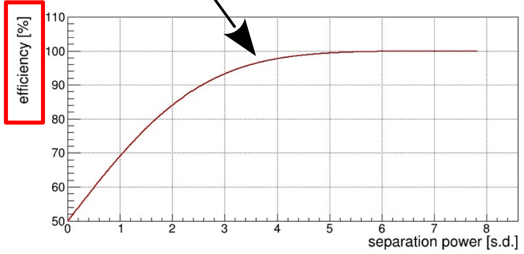


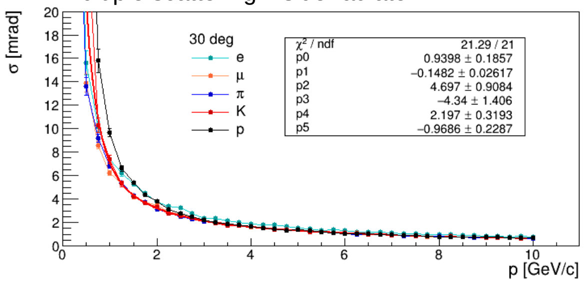




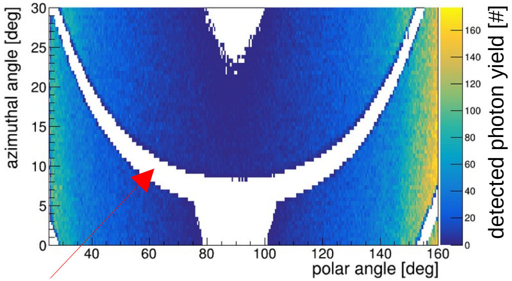


- uses 0.5 mrad tracking resolution combined with multiple scattering inside radiator
- accounts for azimuthal acceptance gaps
- includes threshold mode PID

multiple scattering inside radiator



example of phi acceptance for K^- @ 0.55 GeV/c



azimuthal acceptance gaps between bar boxes

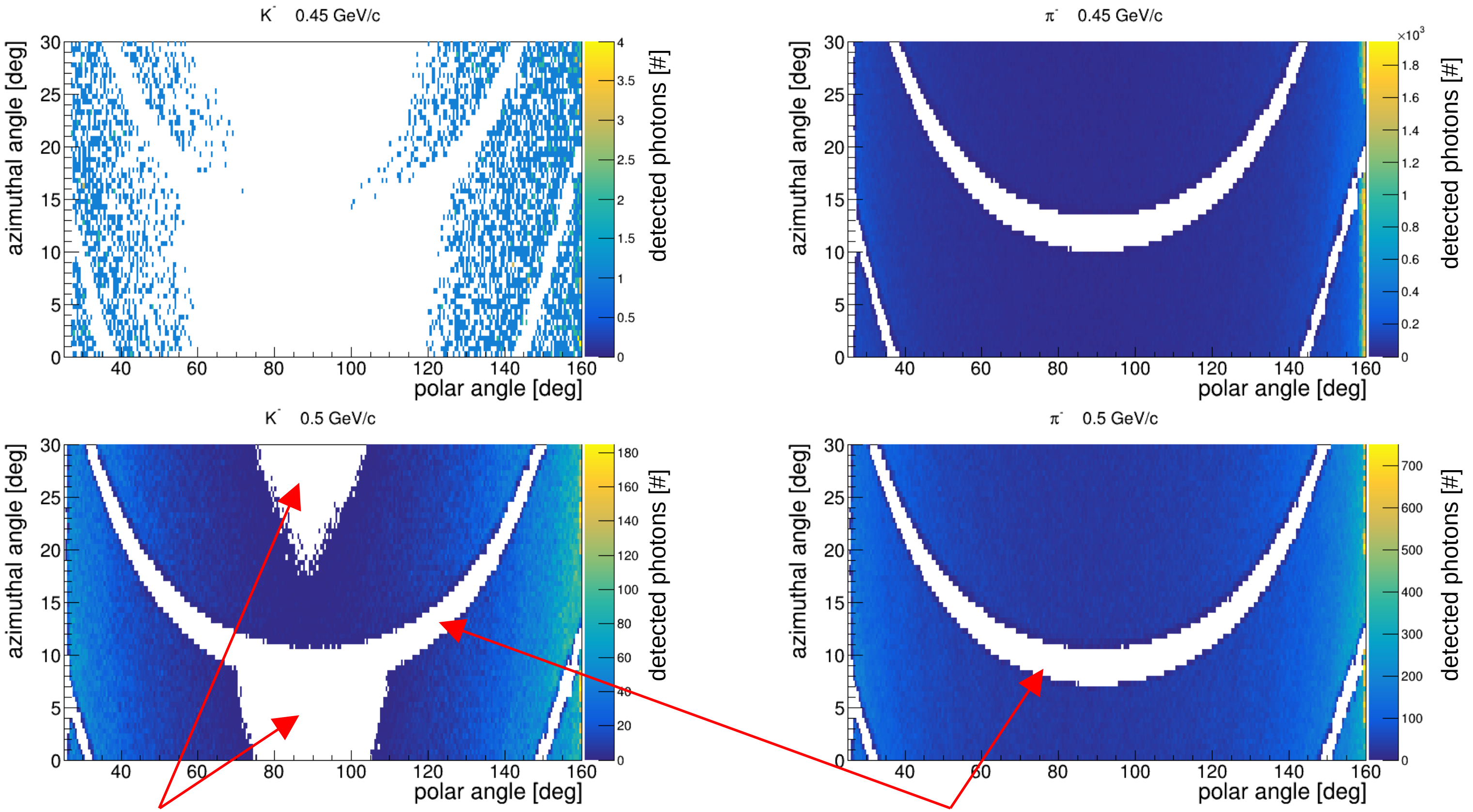
PID LUT for Fast Simulation and Reco

Example of threshold mode

Require more than 5 detected photons for robust PID

positive ID for pions over whole phase space @ 0.45 GeV/c

positive ID for pions over large part of phase space @ 0.5 GeV/c



acceptance gap due to total internal reflection

acceptance gap due to space between bar boxes

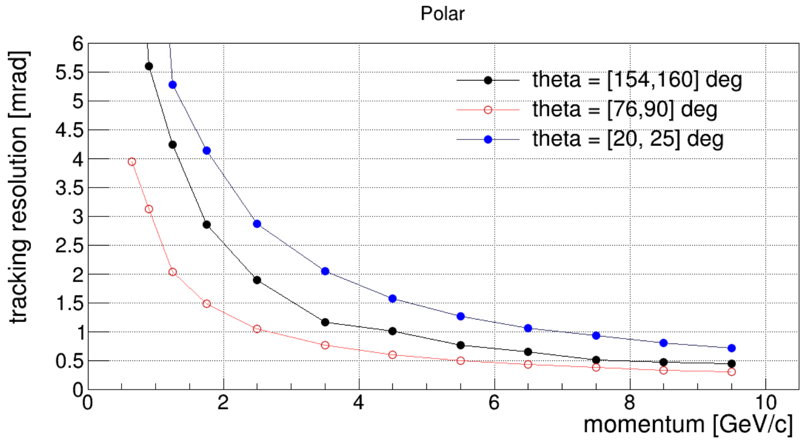
Fine binning in angle and momentum needed to deal with rapid changes in photon yield

Standalone Geant4 Sim/Reco

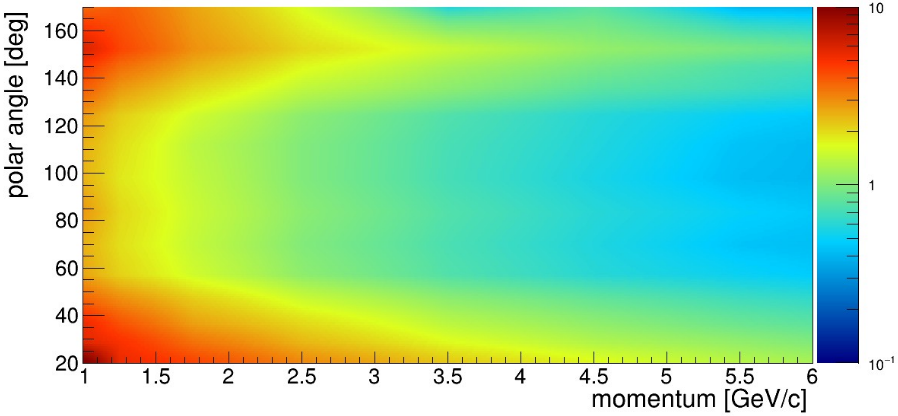
- flexible, full featured
- for testing alternative / cost saving design options, corrections, and reconstructions
- tuned to the test beam data of prototype tests
- B-field
- realistic angular resolution

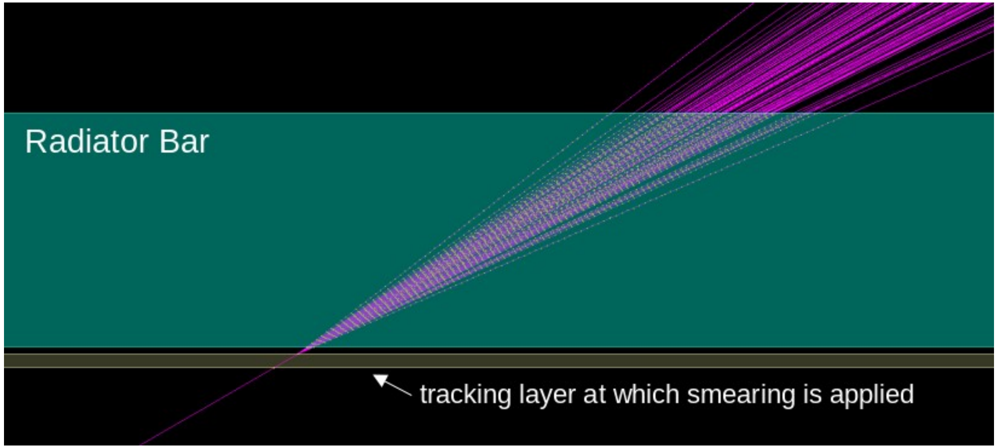
Realistic Angular Resolution Map

- track resolution evaluated using “residual method” at hpDIRC radius (latest version from Matt)
  see “Tracking Projections/Resolution @ hpDIRC” WG on Jan 21
- interpolated in polar angle – momentum space
- track smearing applied before the radiator



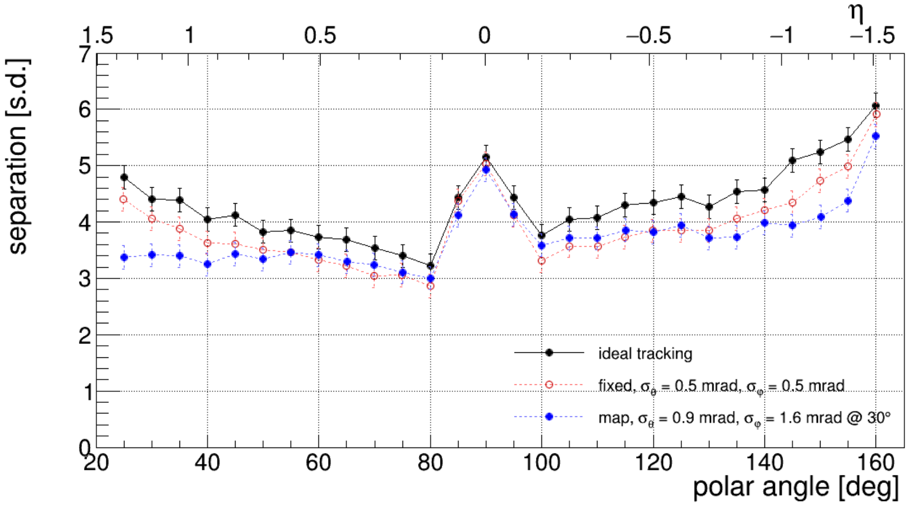
polar angle resolution [mrad]:



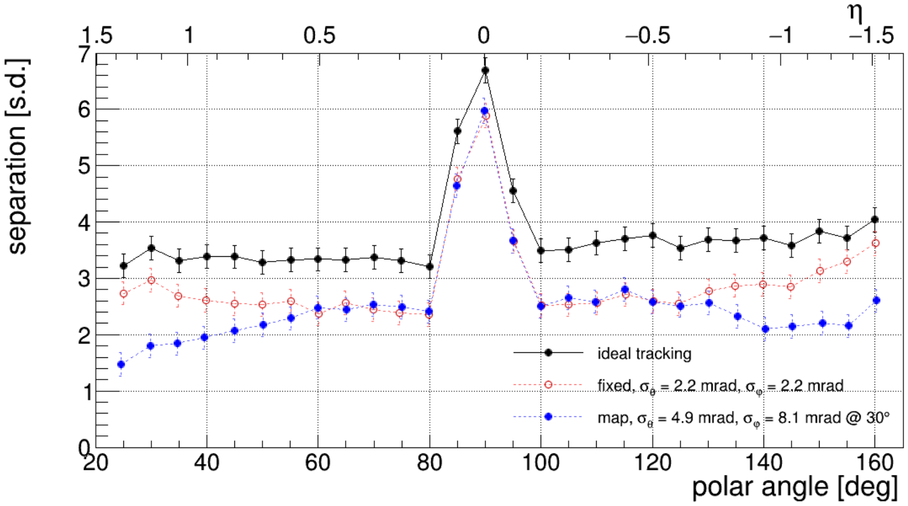


DIRC Performance

π/K @ 6 GeV/c



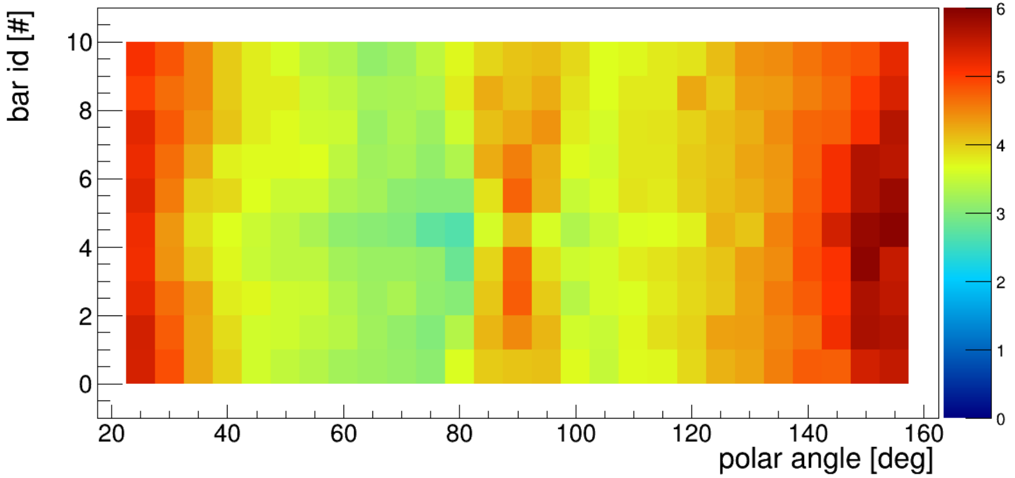
e/π @ 1.2 GeV/c

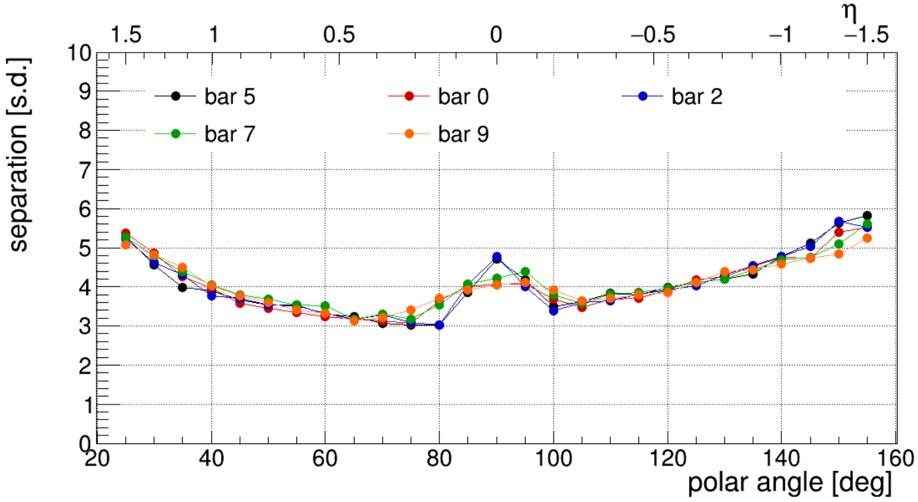


- standalone geant4 sim/reco without magnetic field
- central radiator bar
- no background events

DIRC Performance

- evaluated for full phase space (across all radiator bars)
- with B-field
- Time Imaging for pi/K @ 6 GeV/c





Alternative Designs for the Expansion Volume

Baseline design

3 x 1225 mm (bars) + 893 mm (bars)

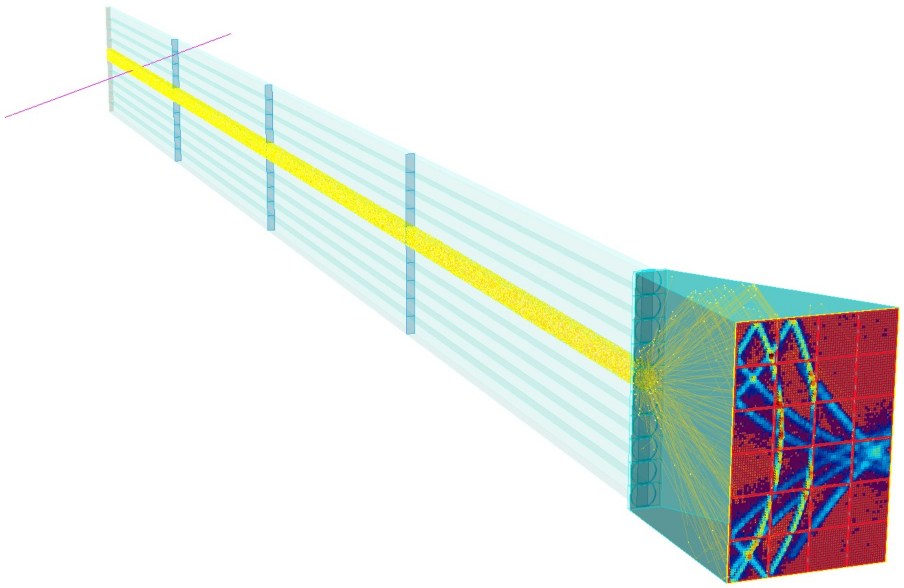
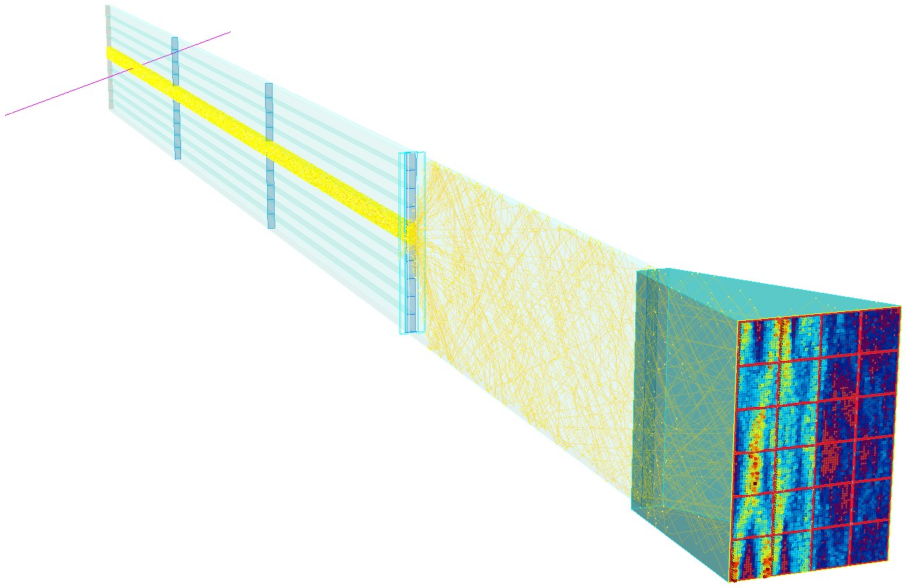


Plate as optical guide:

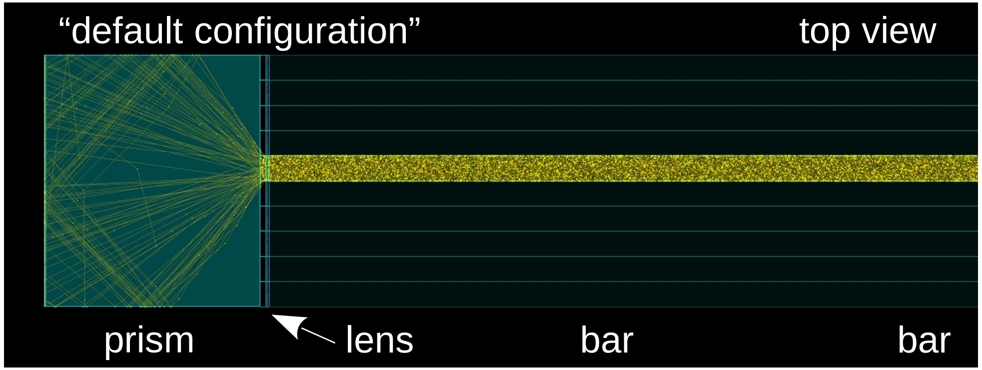
3 x 1225 mm (bars) + 893 mm (plate)

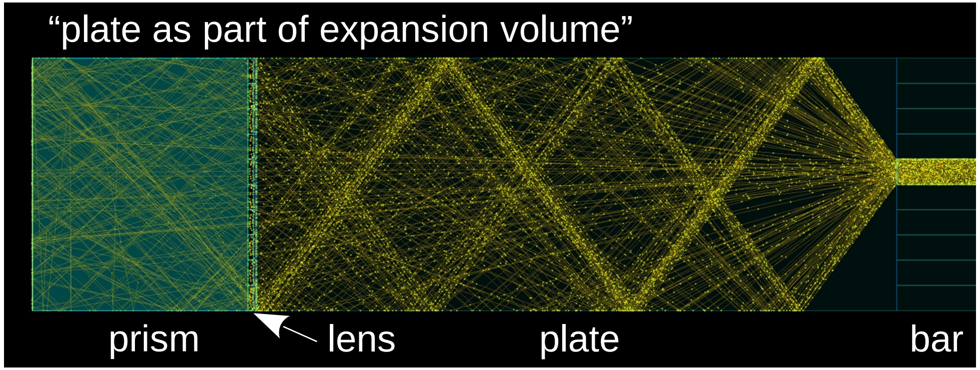


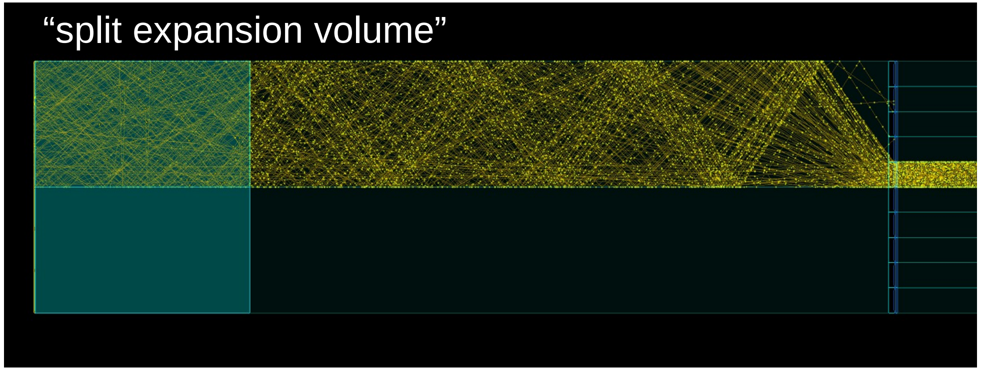
see “hpDIRC - R&D for future upgrades” by Jaydeep Datta

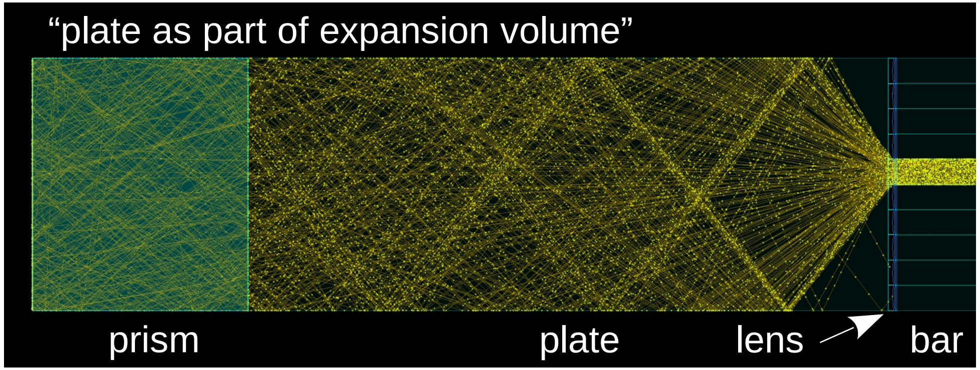
Alternative Designs for the Expansion Volume

event display witch Cherenkov photons from 1 pion @ 6 GeV/c



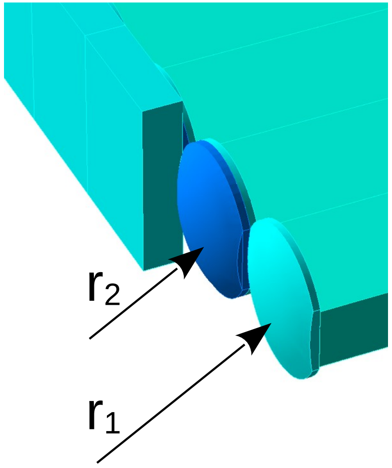




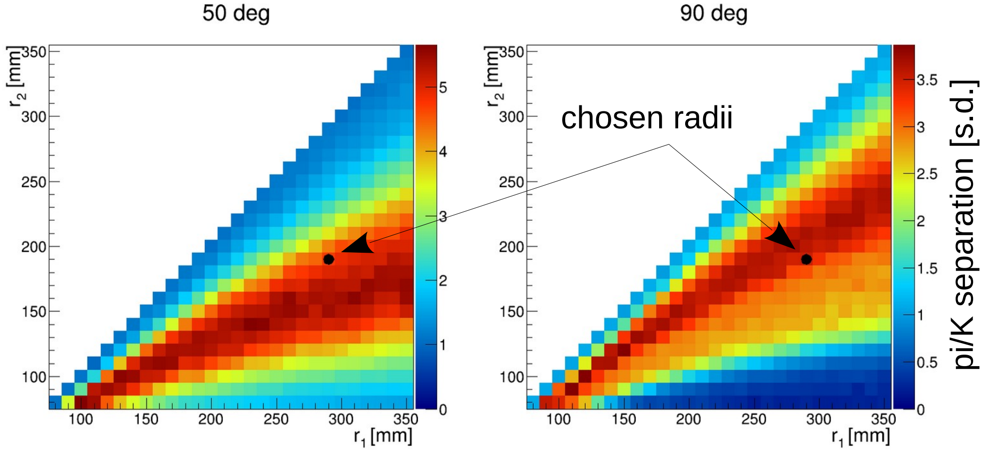


Focusing System

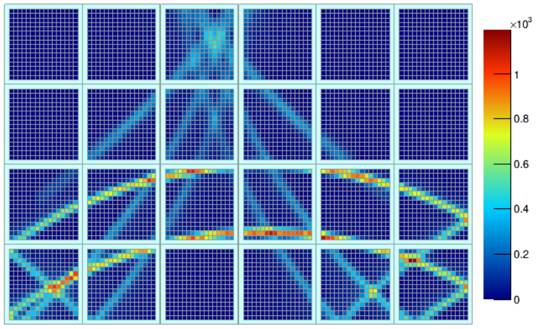
- 3-layer spherical lens
- optimized using radii scan with time imaging reconstruction
- Hit pattern is more complicated
  - kaleidoscopically effect
  - chromatic dispersion



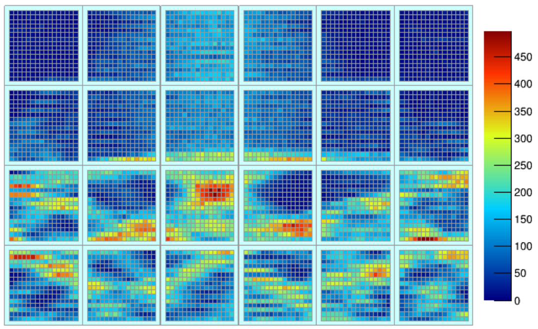
example of radii scan



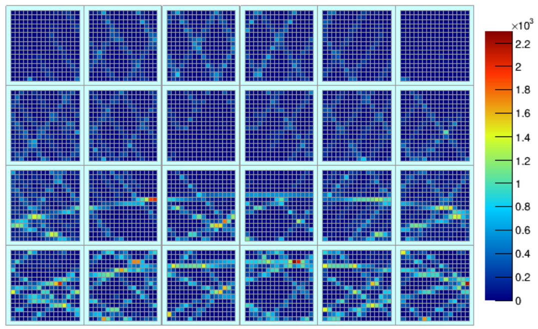
EV-SL-bars-bars



EV-plate-SL-bars

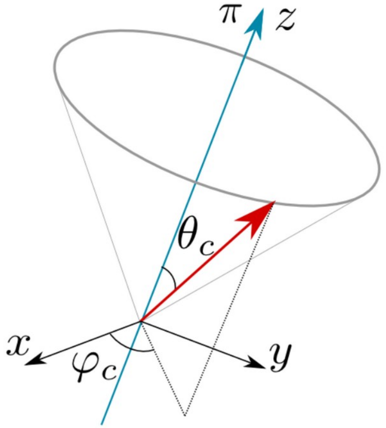


EV-plate-SL-bars with monochromatic Cherenkov light



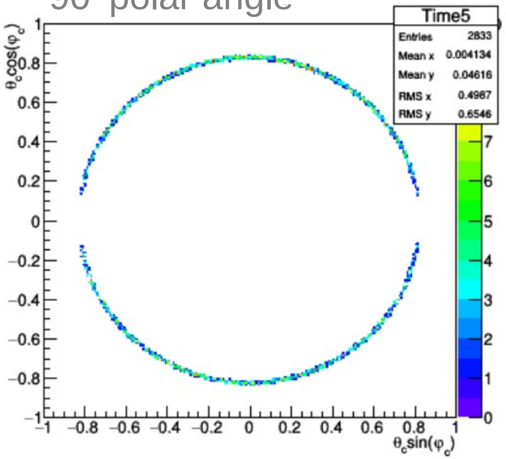
Other Activities

- chromatic correction
- per-PMT Cherenkov angle correction
- alignment calibration (Afaf A. Wasly)
- layout optimization of PMTs (Md. Imran Hossain)
- simulation / reconstruction with high amount of dark noise from SiPM (Md. Imran Hossain)
- Cherenkov ring fit (corrects the direction of the charged track)

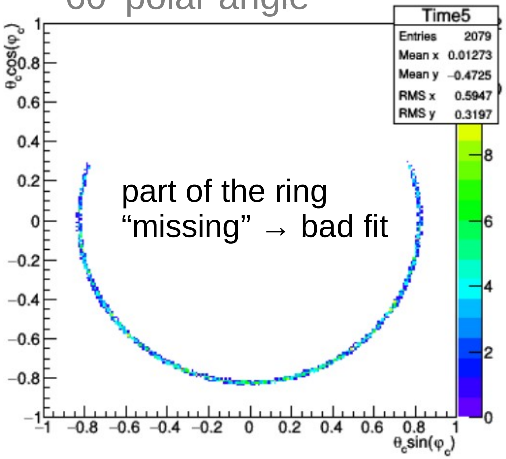


Accumulated pattern for 100 pions @ 6 GeV/c:

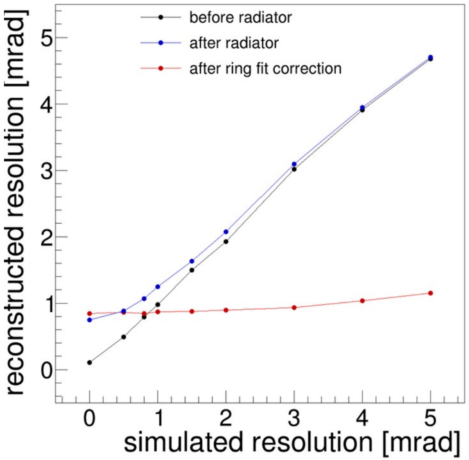
90° polar angle



60° polar angle



90° polar angle



Summary

- hpDIRC geometry is implemented in the ePIC simulation (all optical components)
- 2 main reconstruction methods are implemented, NN reconstruction is in development
- realistic PID LUT is provided for a fast sim/reco
- standalone Geant4 sim/reco is used for testing alternative/cost saving design options
- different correction / calibration methods are in development

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Thank you for your attention!