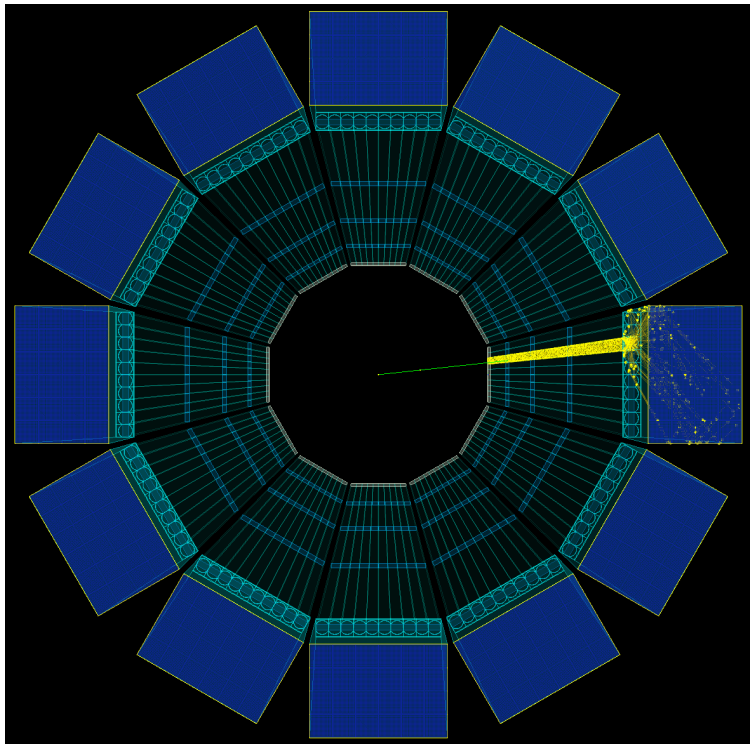
hpDIRC Simulation Status in ePIC Software

Greg Kalicy

CUA



ePIC

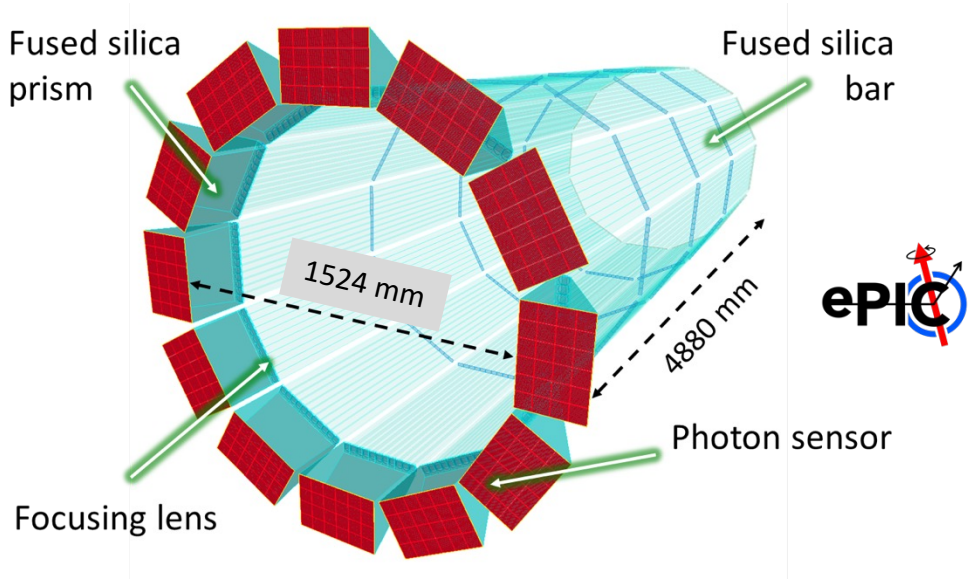
Collaboration Meeting
January 2024

CUA GSI Stony Brook University Old Dominion University of South Carolina Wayne State University William & Mary Jefferson Lab

HPDIRC PRELIMINARY BASELINE DESIGN

Radiator bars:

- Barrel radius: 762 mm, 12 sectors
- 10 long bars per sector, 4880 mm x 35 mm x 17 mm (L x W x T)
- Long bar: 4 bars, glued end-to-end,
- Short bars made from highly polished synthetic fused silica
- Flat mirror on far end



Focusing optics:

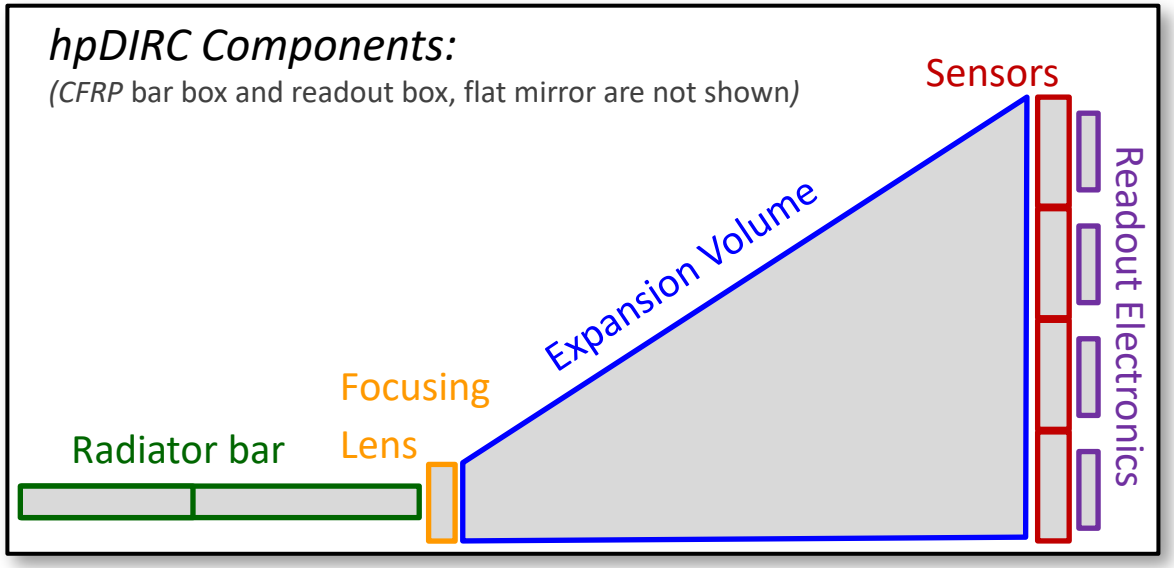
- Radiation-hard 3-layer spherical lens (sapphire)

Expansion volume:

- Solid fused silica prism: 24 x 35 x 30 cm^3 (H x W x L)

Readout system:

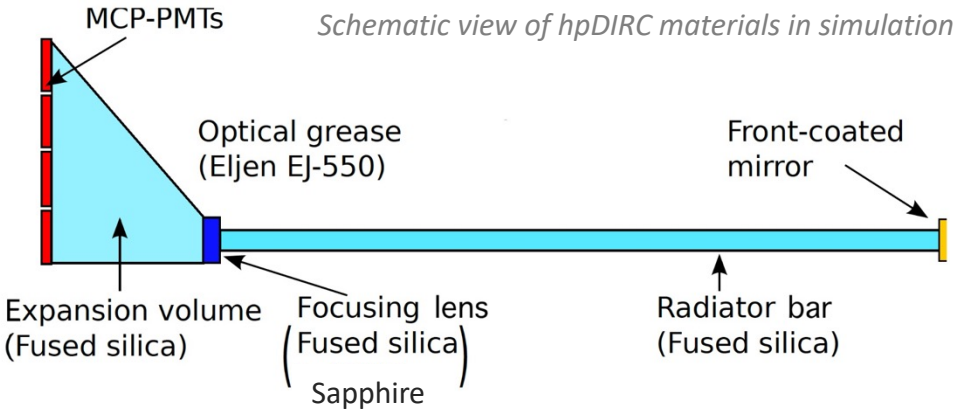
- MCP-PMT Sensors (e.g. Photek/Incom)
- ASIC-based Electronics (e.g EICROC)



HPDIRC SIMULATION

Stand-alone Geant4 Simulation

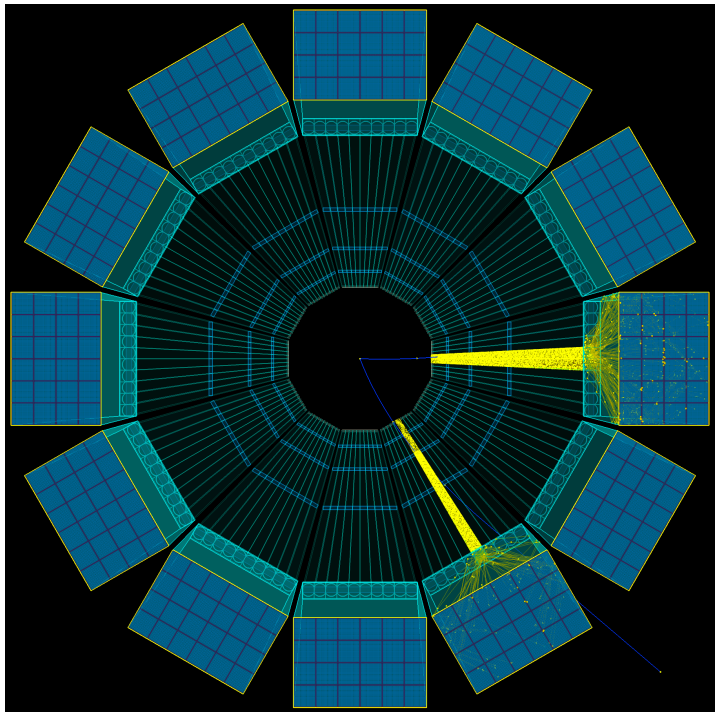
- Realistic optics, geometry, and material properties – based on prototyp and experimental data, wavelength-dependent material properties and processes
- Validated with test beam data



Schematic view of hpDIRC materials in simulation

- Design optimization studies and testing novel design options
- Impact of ePIC tracking resolution on hpDIRC performance (Roman talk in the morning)
- Performance studies with Pythia events and integrated ePIC magnetic field (Bill Llope talk)
- Plan to implement materials from other systems and support structure to improve parametrization for ultimate ePIC simulation campaigns

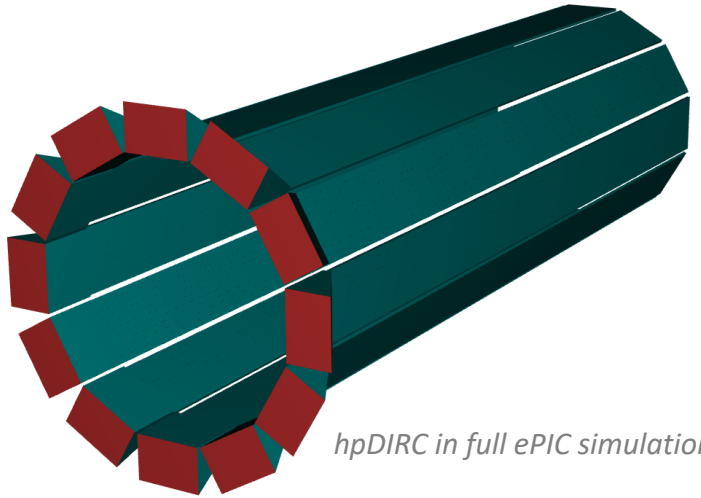
Stand-Alone hpDIRC Simulation with Pythia events



HPDIRC SIMULATION

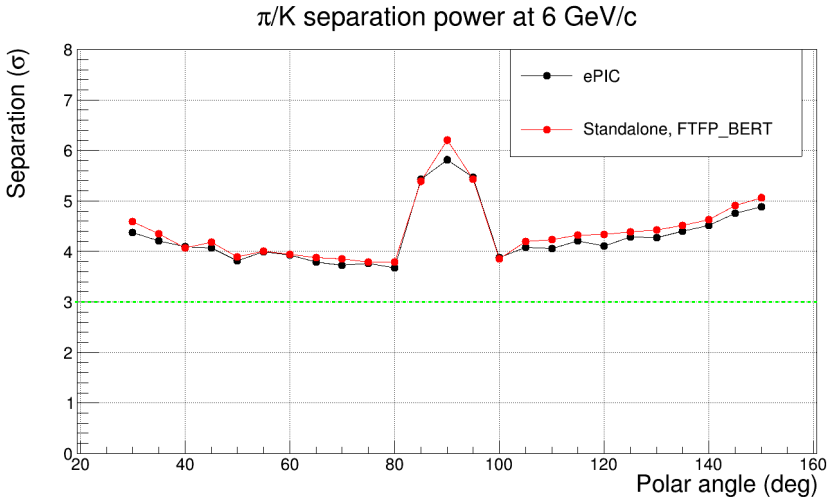
ePIC Simulation:

- Implemented geometry matches detector matrix
- Imported and integrated most of stand-alone Geant4 package, validated performance (with ideal tracking)
- Time-based reconstruction is running with only the hpDIRC module active and ideal tracking



hpDIRC in full ePIC simulation

- Efficiencies should be applied in early stage of simulation (stepping action and stacking action) to avoid tracking photons that will not get detected
- Particle momentum vector has to be saved at the entrance to DIRC bar to work on initial reconstruction implementation
- Photon paths in the prism have to be saved in a special mode of running to create Look-Up Tables



HPDIRC RECONSTRUCTION

Reconstruction and PID methods:

- Geometrical (BABAR-like), robust and fast method based on Look-Up Tables, delivers Cherenkov angle per particle and Single Photon Resolution (useful for calibration and in prototype tests), does not depend on precise time measurement
- Time Imaging (Belle II TOP-like), uses Probability Density Functions (analytical or simulation-based), makes optimum use of precision of position and time information
- Neural Network Reconstruction, directly using binned time and channel id to provide PID (synergy with PANDA)

High-precision 3D momentum vector information is crucial for reaching required hpDIRC performance

GEOMETRICAL RECONSTRUCTION

- Key features:
  - BaBar-like
  - uses Look-Up Tables
  - delivers Cherenkov angle per particle and Single Photon Resolution (useful for calibration)
  - does not depend on precise time measurement

- Pixel position + bar location define photon direction at bar end, stored in Look-Up Table (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

Look Up Table generation:

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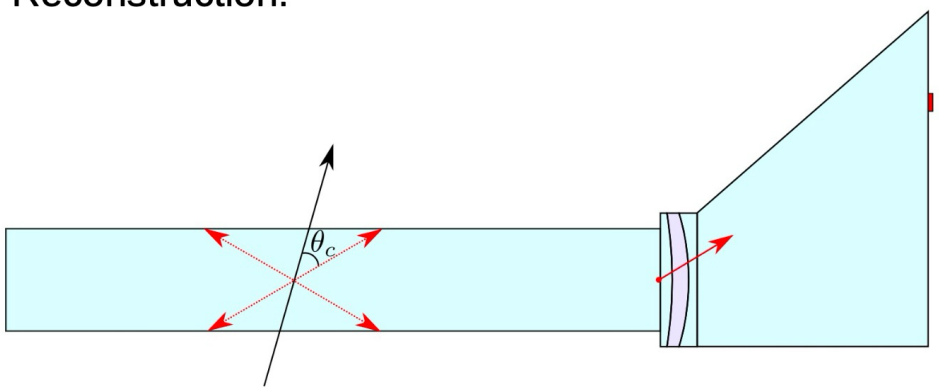
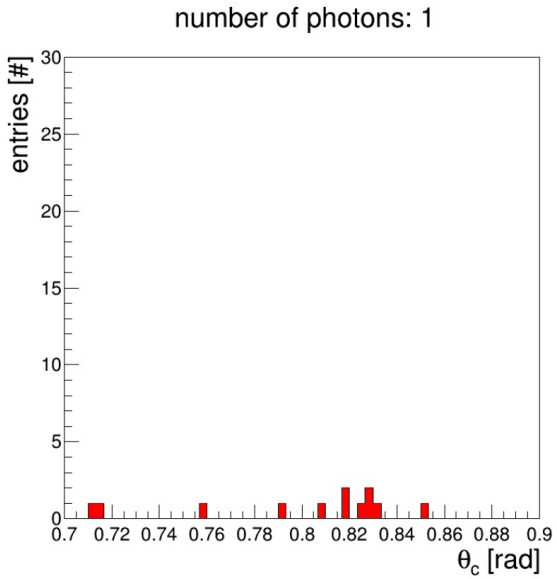
Reconstruction:





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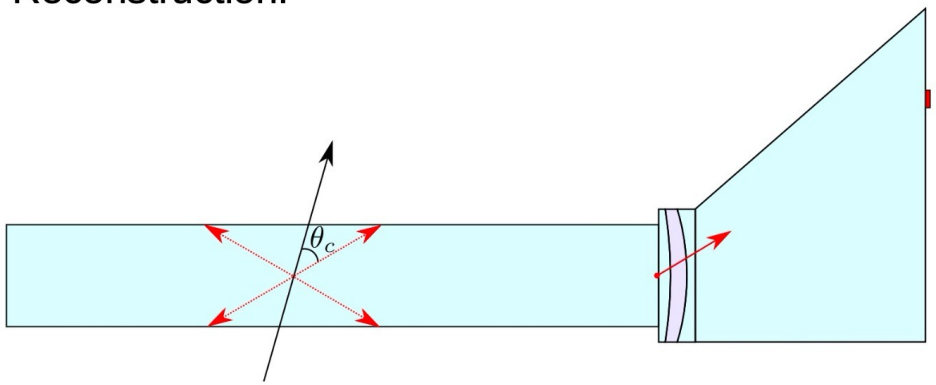

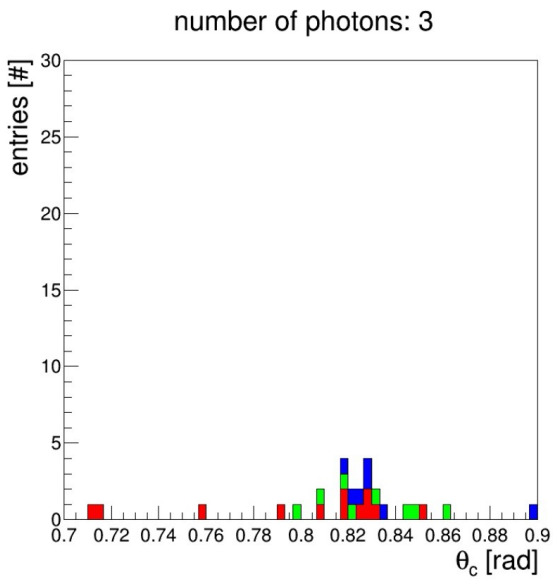

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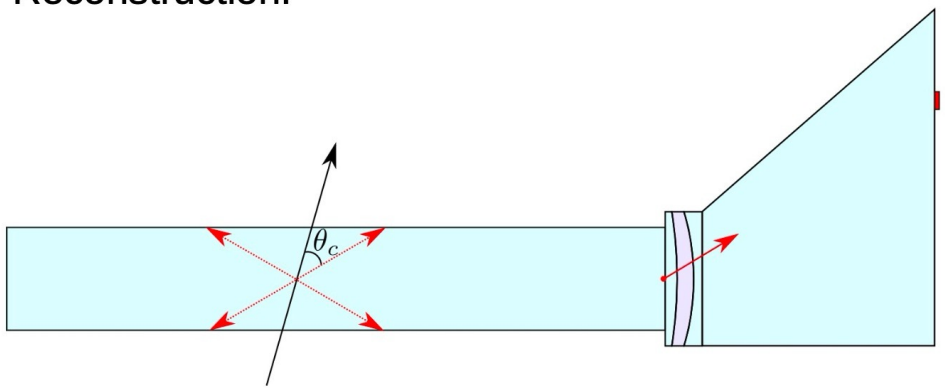

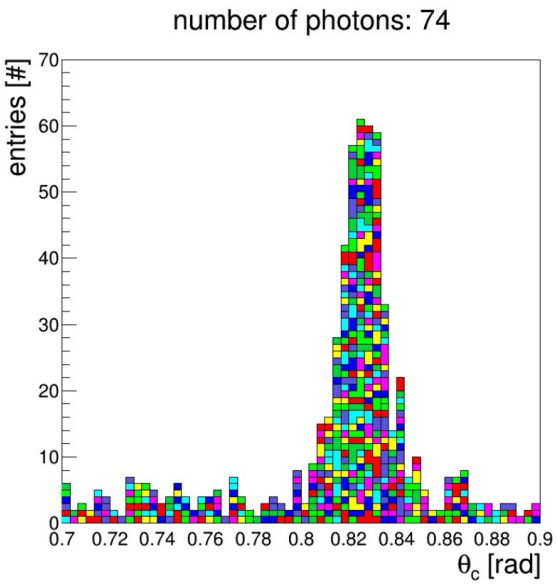

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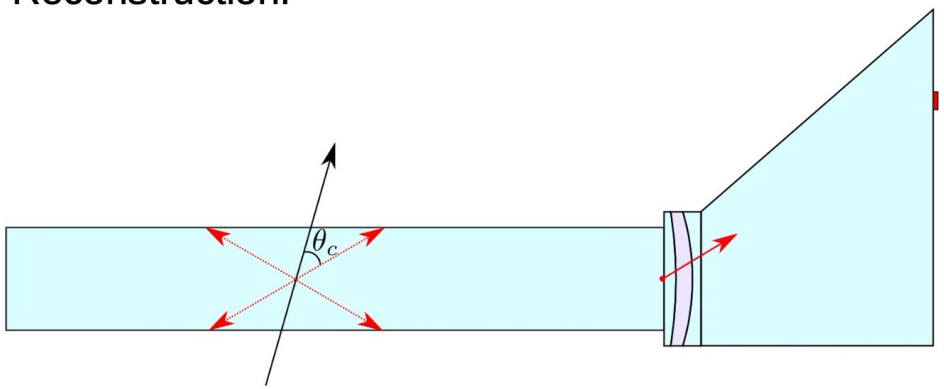

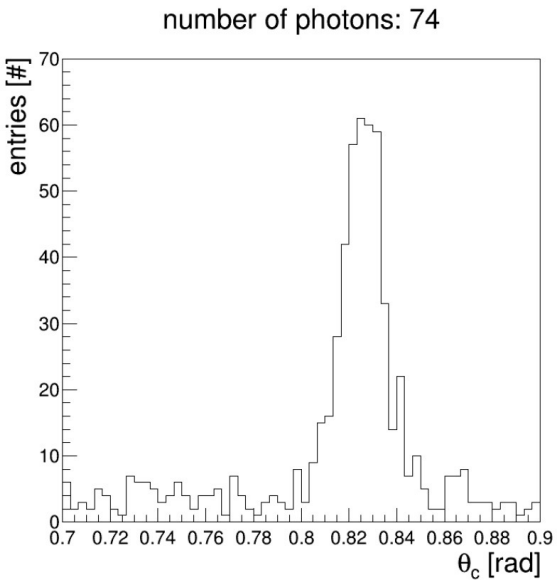

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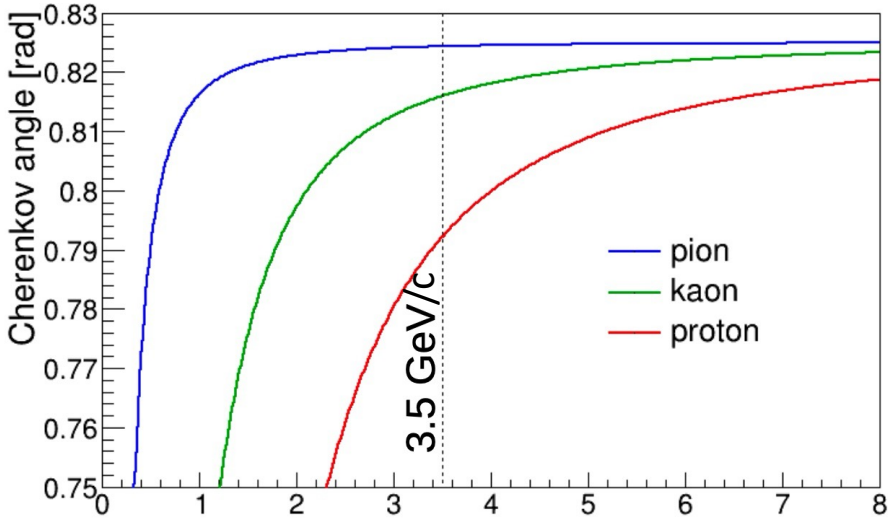
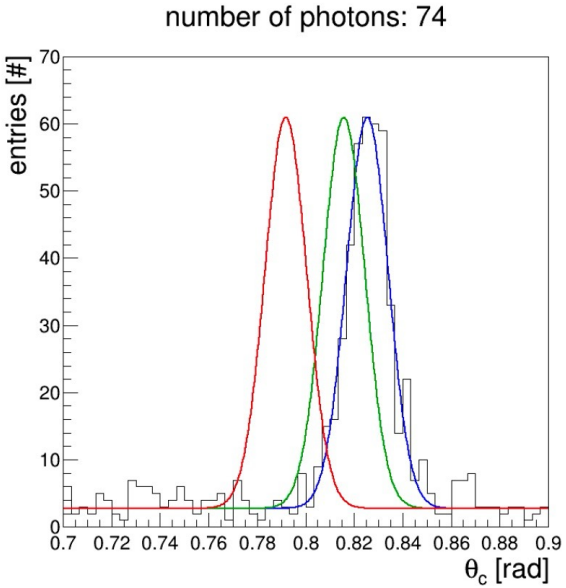
Likelihood calculation:

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

signal combinatorial background





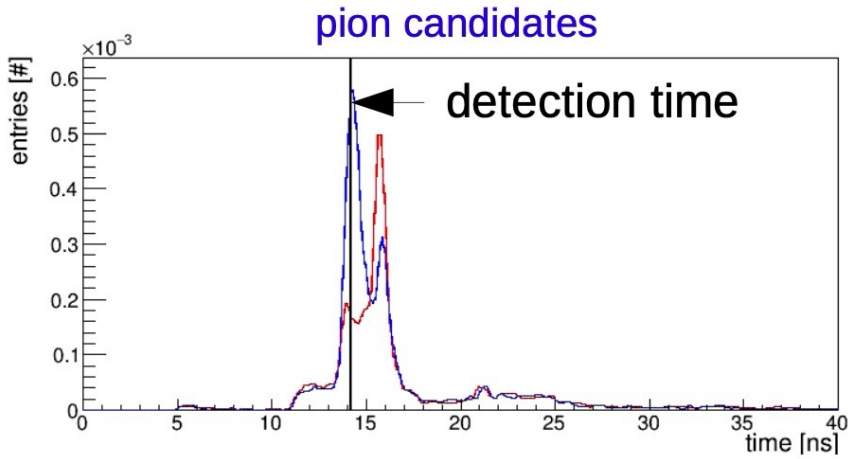
TIME-BASED RECONSTRUCTION

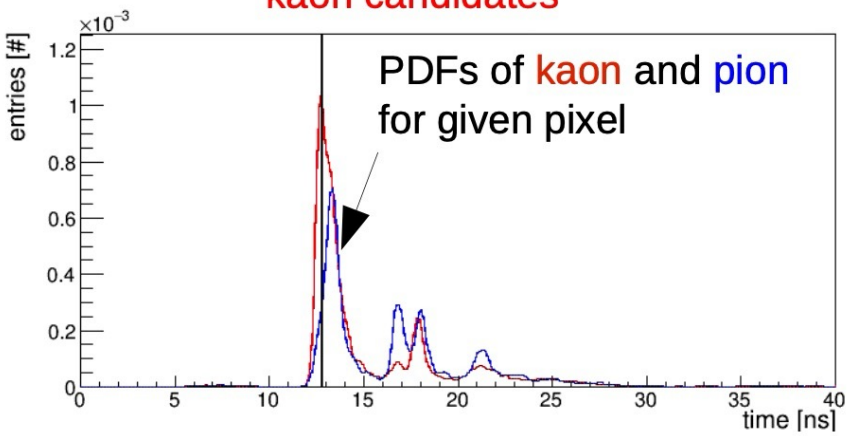
- Key Features:
  - Belle II TOP-like
  - uses Probability Density Functions
  - optimal use of position and time information

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

Probability density functions (PDFs)

- 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)





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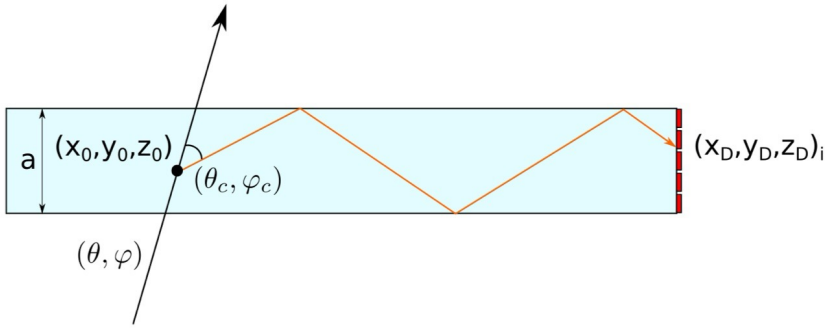

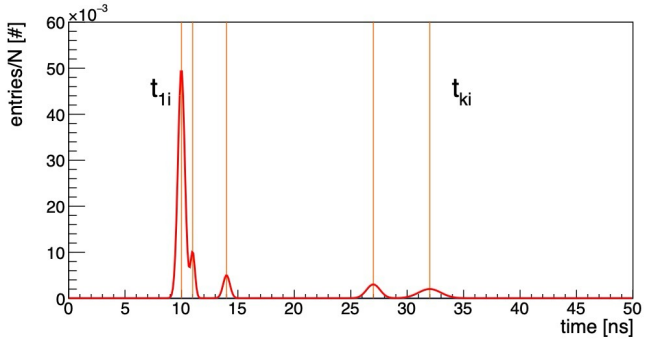

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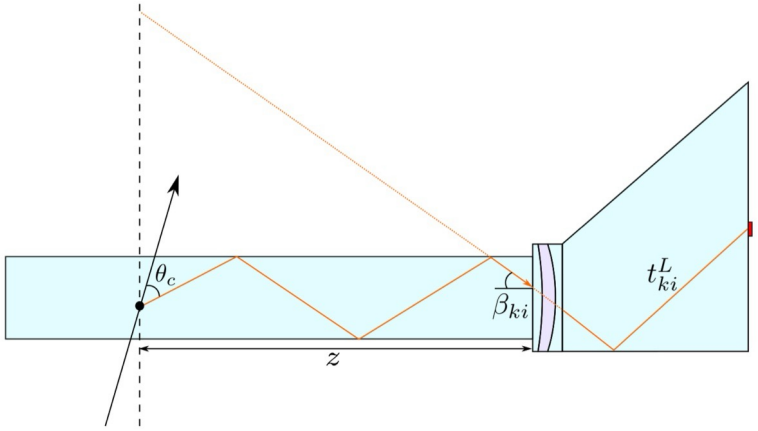

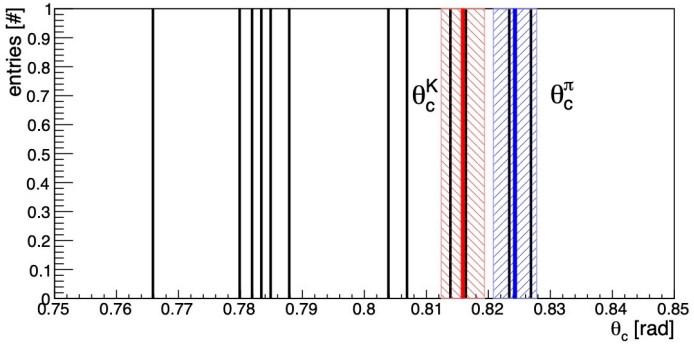

SUMMARY

- Software efforts are progressing and hpDIRC team is growing!
- Stand-alone simulation package validated with prototype in test beams, used for design optimization, performance studies, and soon for improved parametrization.
- Geometry and properties implemented in ePIC simulation, reconstruction in progress
- Two validated reconstruction/PID methods available, new ML method under development
- High-precision tracking is crucial for hpDIRC performance
- Studies of hpDIRC performance with Pythia events and magnetic field provide reassuring results!