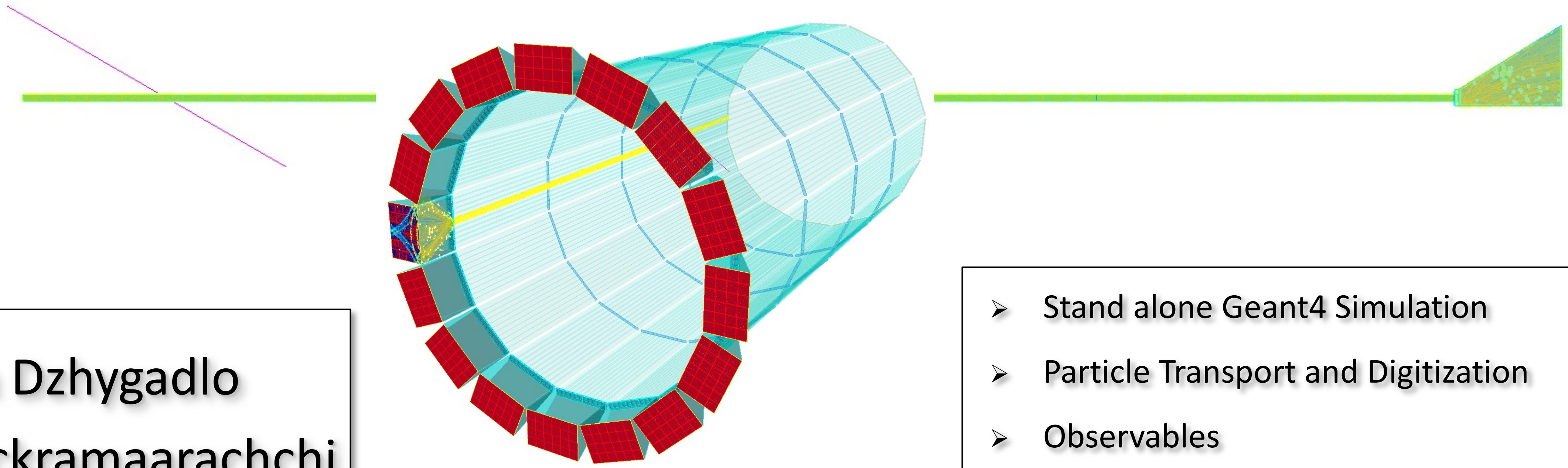
Barrel DIRC Detector Simulation for the EIC



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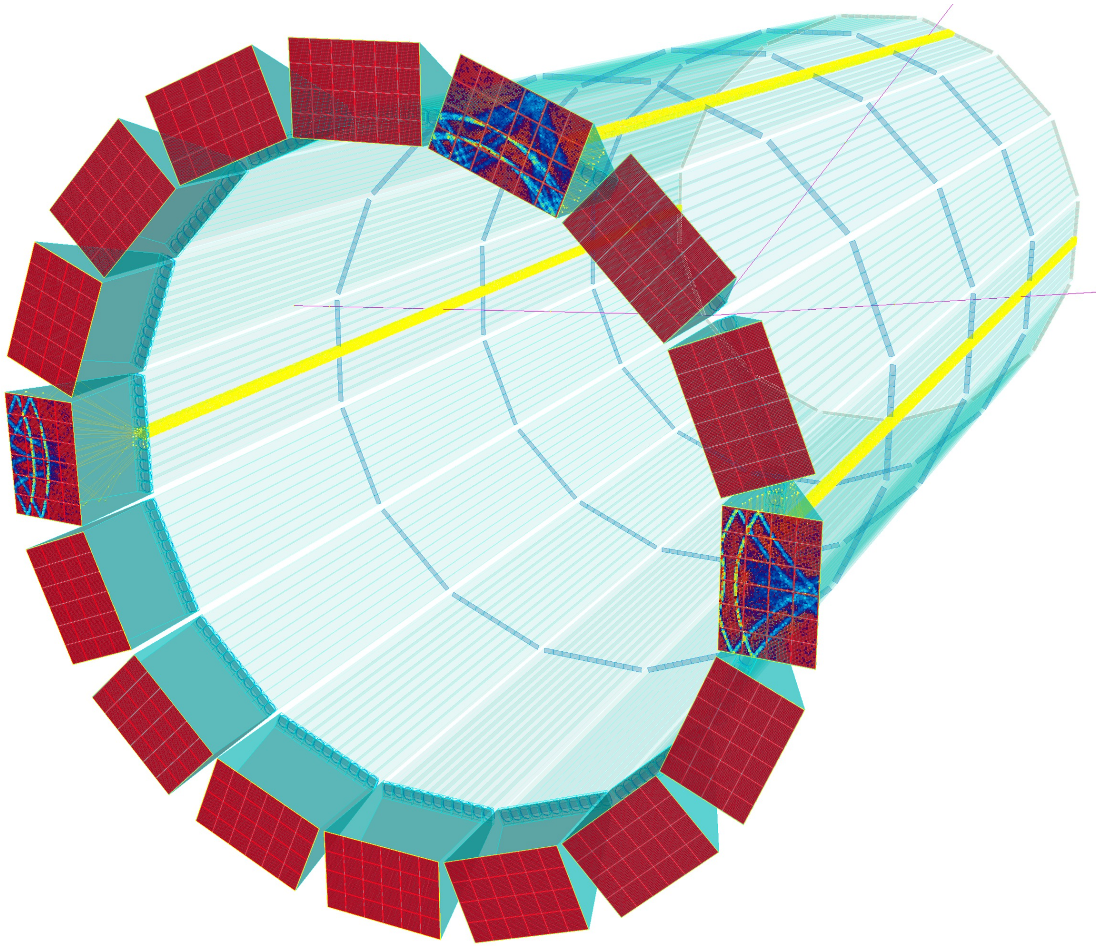
- Stand alone Geant4 Simulation
- Particle Transport and Digitization
- Observables
- Performance
- Fast Simulation Code
- Validation of Simulation

High-performance DIRC: full simulation

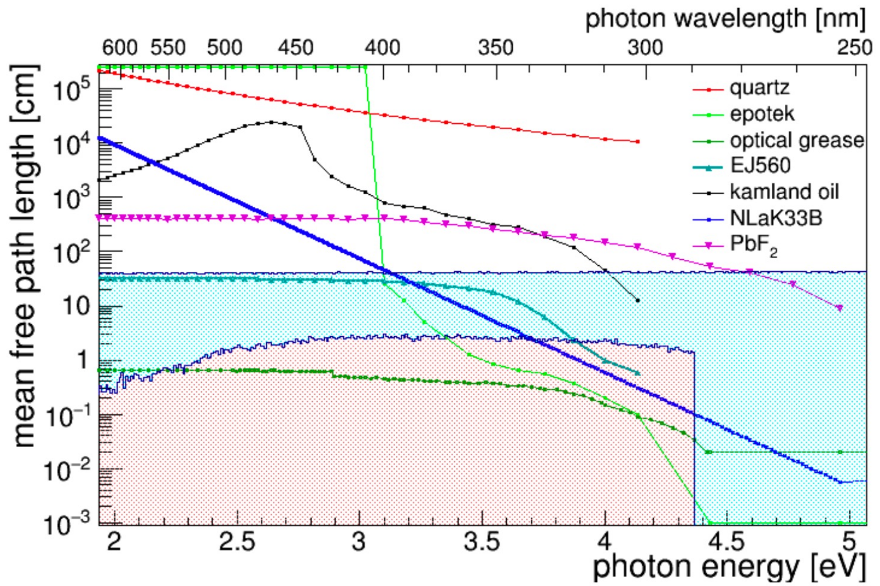
- Standalone Geant4 simulation
- Realistic geometry and material properties based on prototypes
  - Polished fused silica bars and prism, glue, optical grease
  - 3-layer spherical lens, MCP-PMT, mirror
- Wavelength-dependent material properties and processes
  - Refractive index, surface scattering, absorption, reflection
  - Photon transport and detection efficiencies
  - Chromatic dispersion in angle and time
- Includes all relevant resolution terms
  - Photon timing precision from MCP-PMT plus readout electronics
  - Tracking resolution



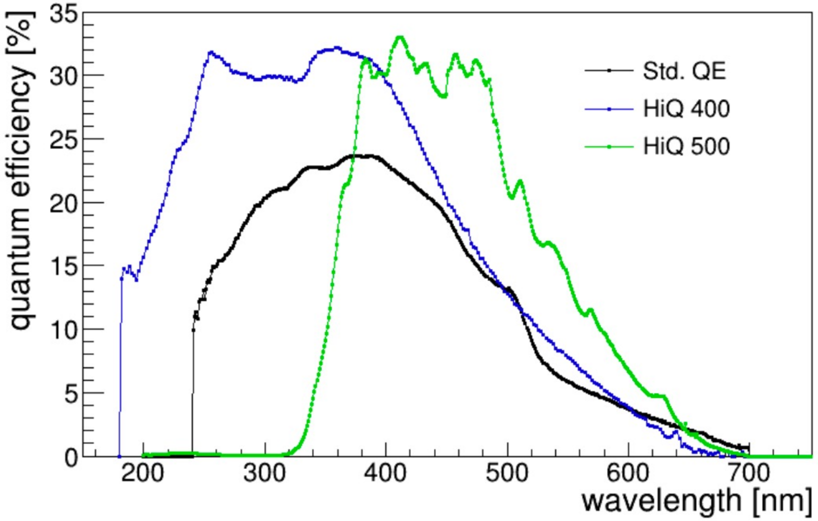
DIRC Simulation Assumptions

Bar Material	Synthetic fused silica, polished to 0.5 nm *rms* surface roughness, transmission and reflection coefficient based on PANDA DIRC bar measurements
Bar Dimension	1.7 x 3.5 cm^2 bar cross-section (the BaBar DIRC bar box reuse)
Focusing System	3-layer spherical lens (hpDIRC), optical properties based on tested prototypes
Mirror	Front-coated mirror, reflectivity based on BaBar DIRC mirror measurement
Glue	Epotek 301-2, transmission based on BaBar DIRC measurements
Optical Cookies	RTV, transmission based on GlueX DIRC measurements
Sensors	MCP-PMTs, 3 x 3 mm^2 pixel size, CE/QE/PDE based on PANDA DIRC measurements
Mechanical System	All DIRC components made from aluminum alloy or CFRP (PANDA DIRC)
Readout Electronics	Assume 100 ps timing precision per photon (sensor, electronics, synchronization) Readout boards and cables not included in Geant simulation
Background	Random dark noise background, based on PANDA DIRC measurements
Tracking	0.5 mrad polar angle resolution, no post-DIRC tracking assumed
Particle Generation	Standalone Geant4, single tracks, no magnetic field

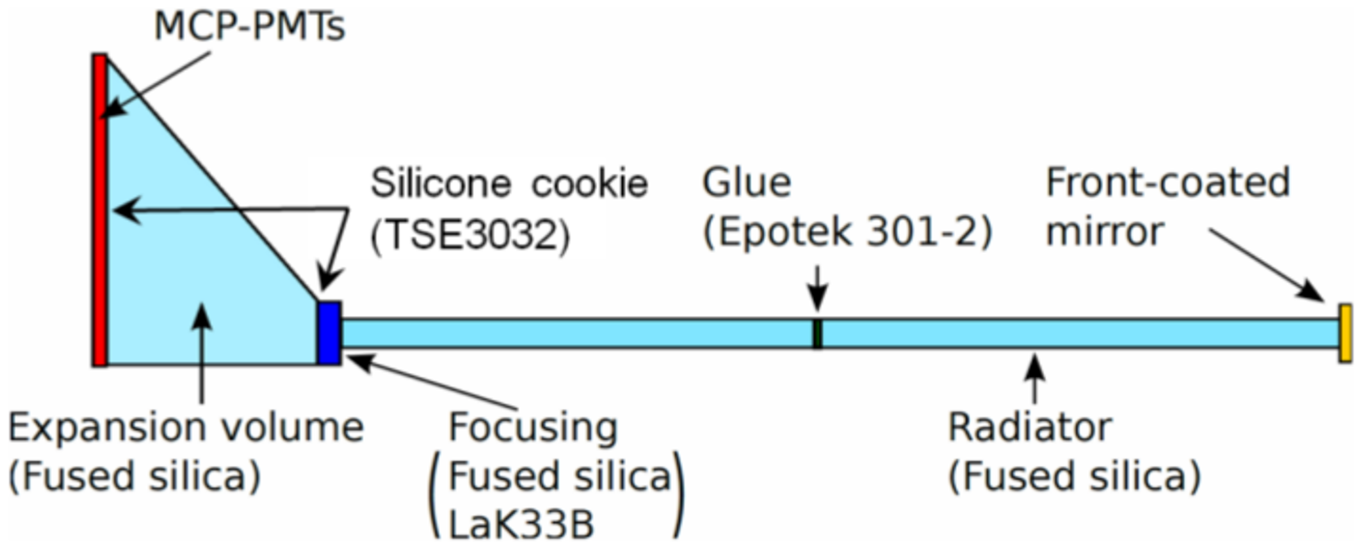
Material transmittance:



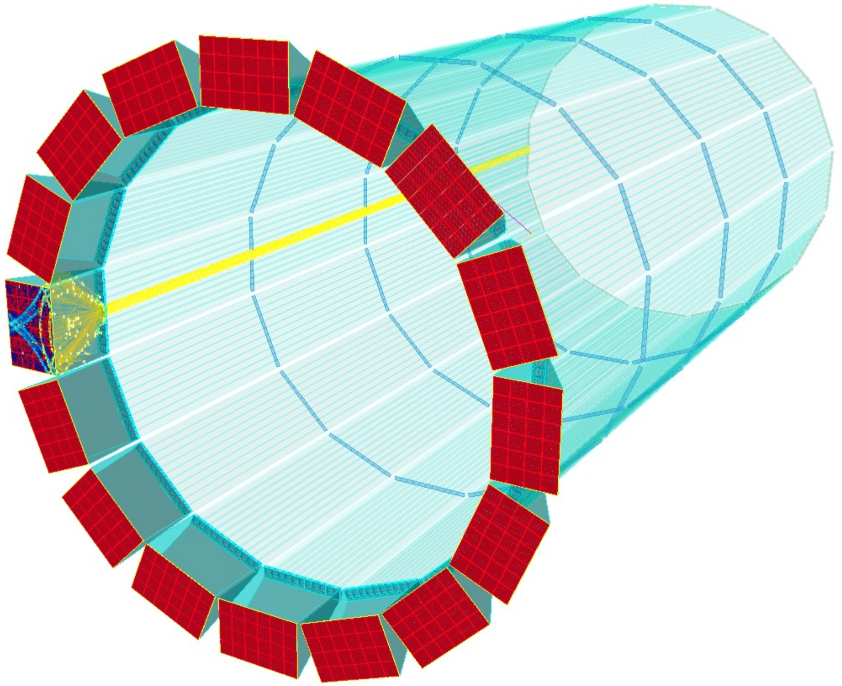
Quantum Efficiency:



Realistic material description
(from data sheets and test measurements)



$$\sigma^2_{\theta_c}(particle) = \frac{\sigma^2_{\theta_c}(photon)}{N_\gamma} + \sigma^2_{correlated}$$

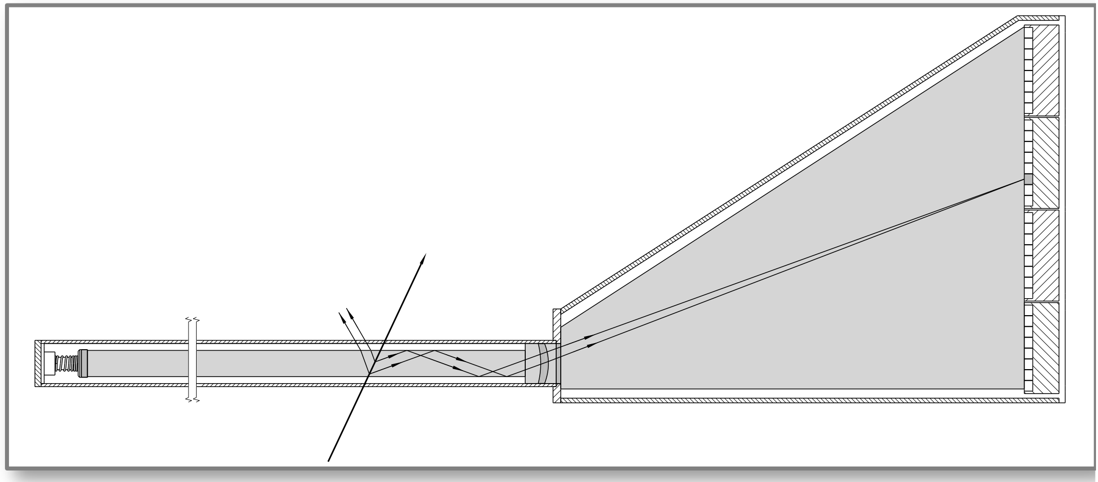


$\sigma_{\theta_c}(particle)$ Cherenkov angle resolution per particle

$\sigma_{\theta_c}(photon)$ Cherenkov angle resolution per photon
(bar size, pixel size, chromatic, bar imperfections)

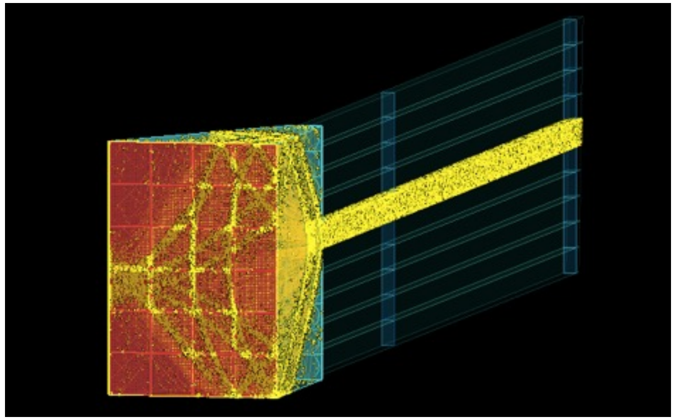
N_γ Number of detected photons per particle
(bar size, bar imperfections, Photon Detection Efficiency)

$\sigma_{correlated}$ Contribution from external sources
(tracking, multiple scattering, etc.)

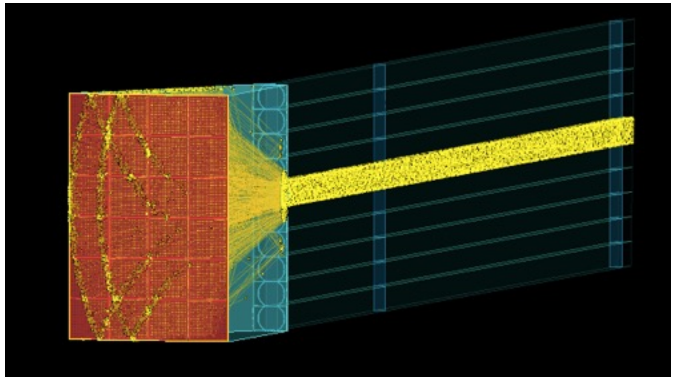


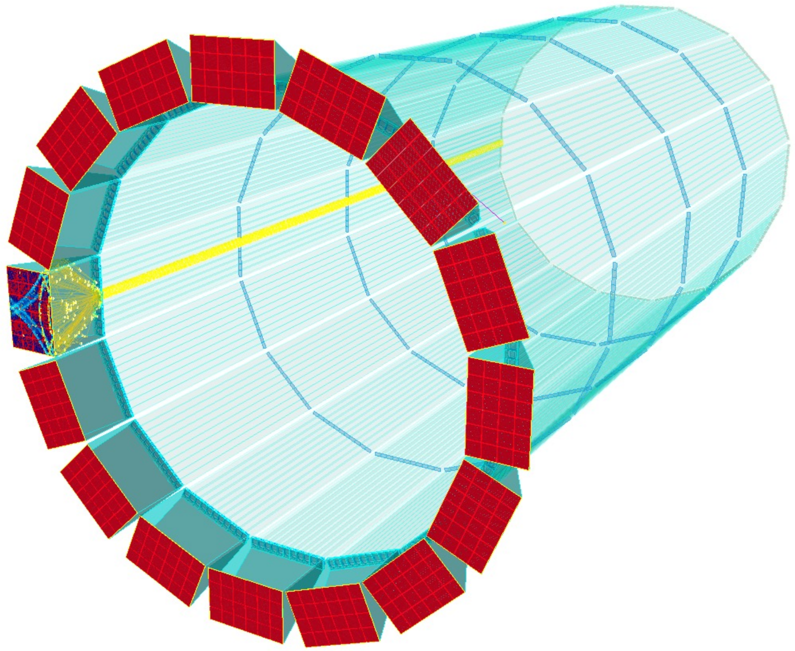
HPDIRC SIMULATION: PARTICLE GUN

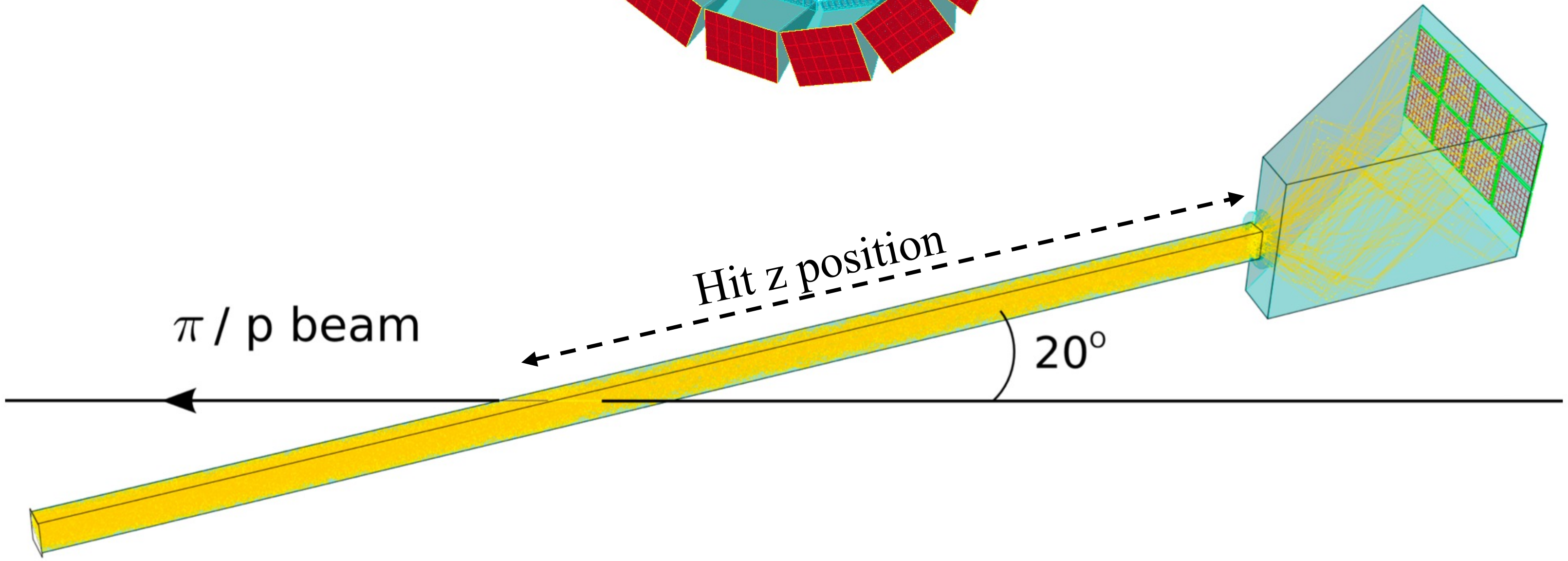
30°



90°







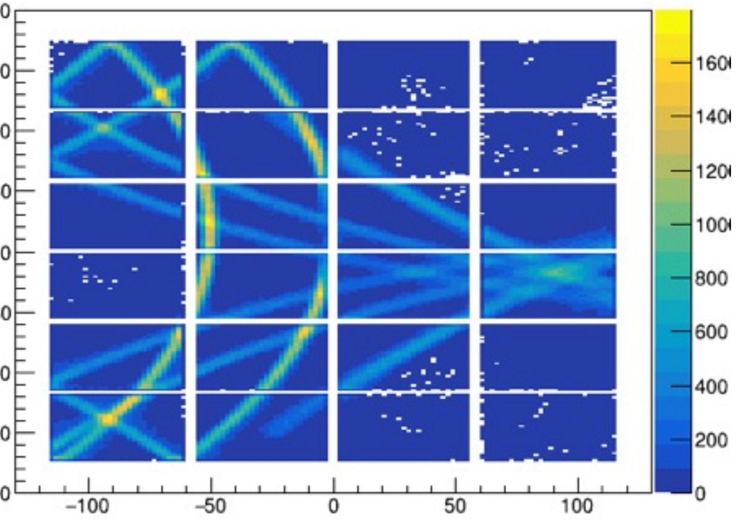
hpDIRC Simulation: Observables

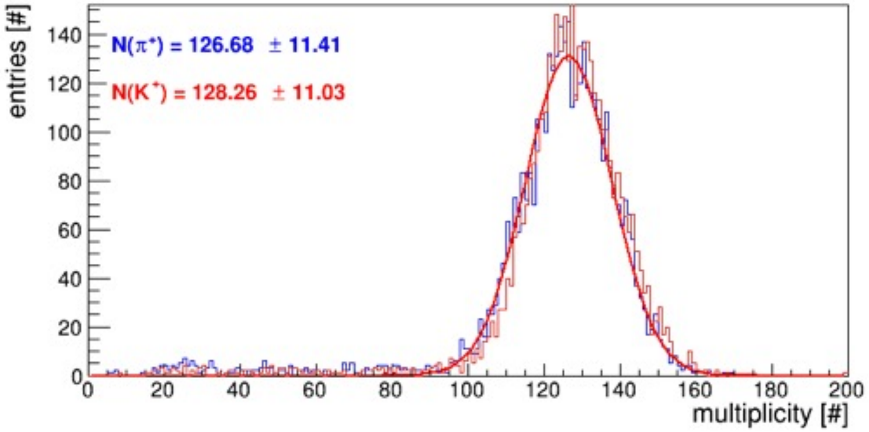
Hit pattern for accumulated pions

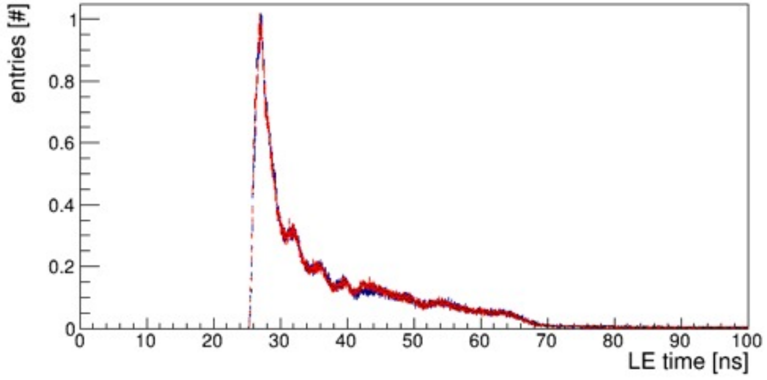
Photon yield

Photon arrival time

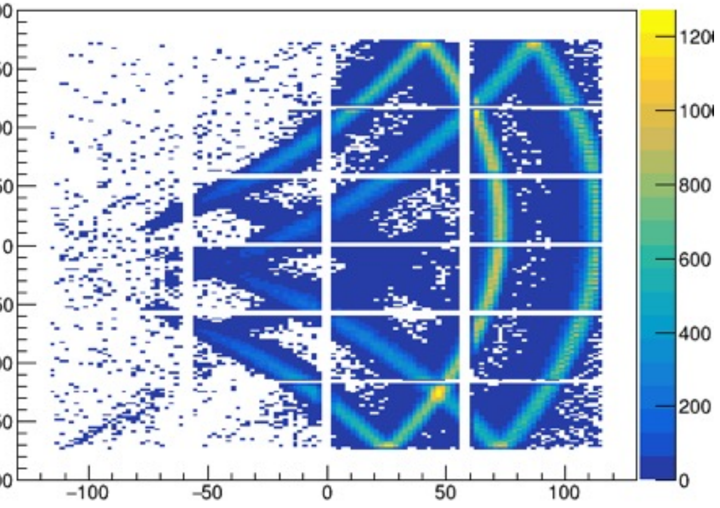
30°

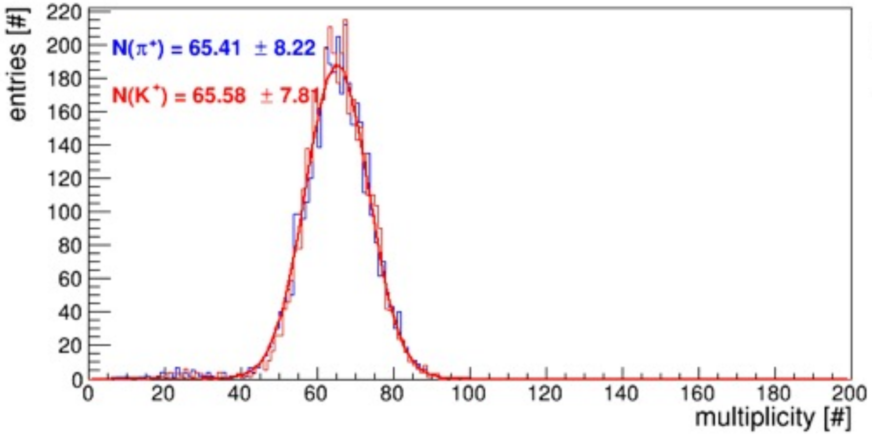


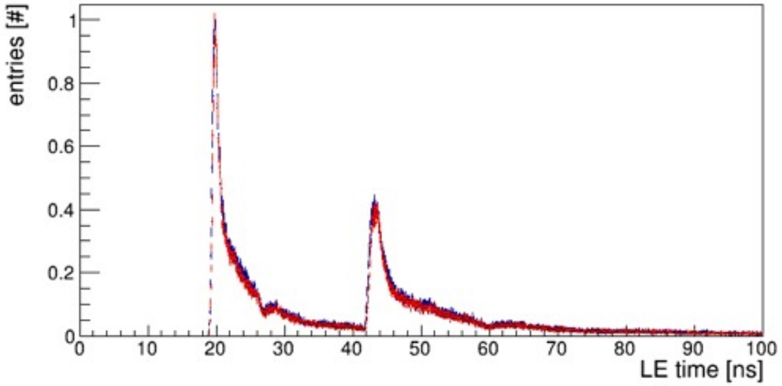




90°





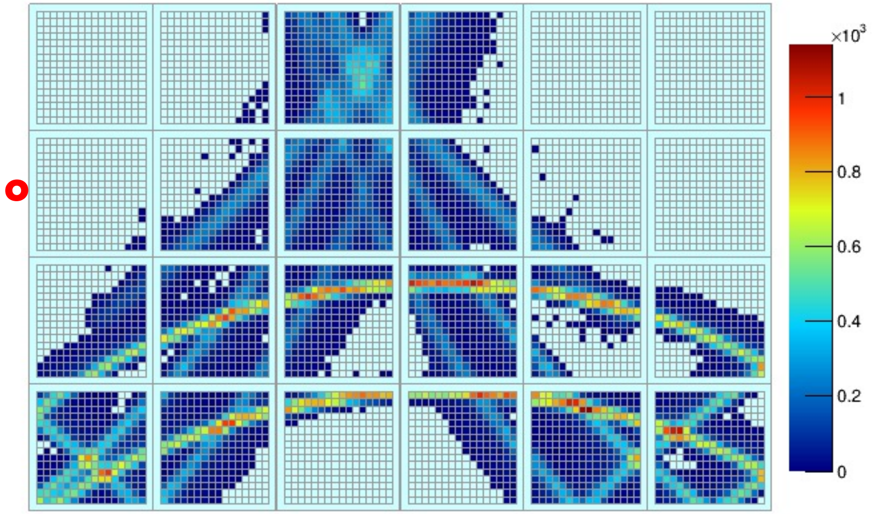


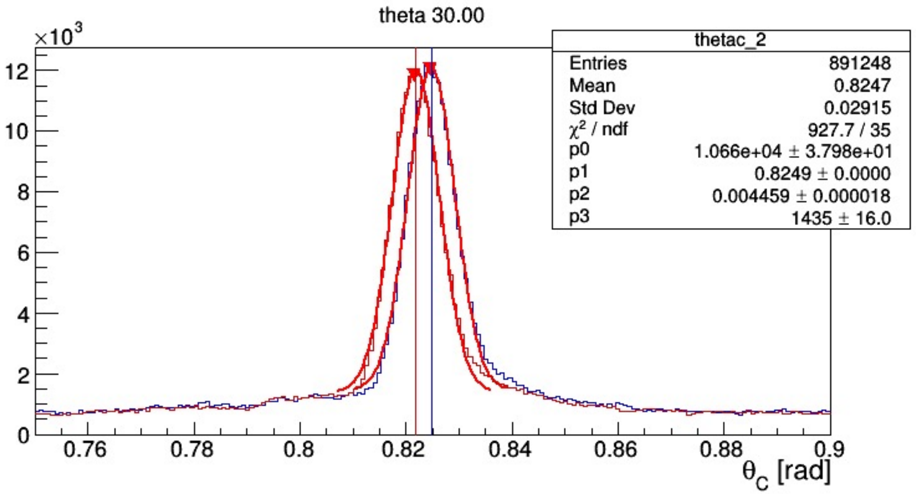
Hit pattern for accumulated pions

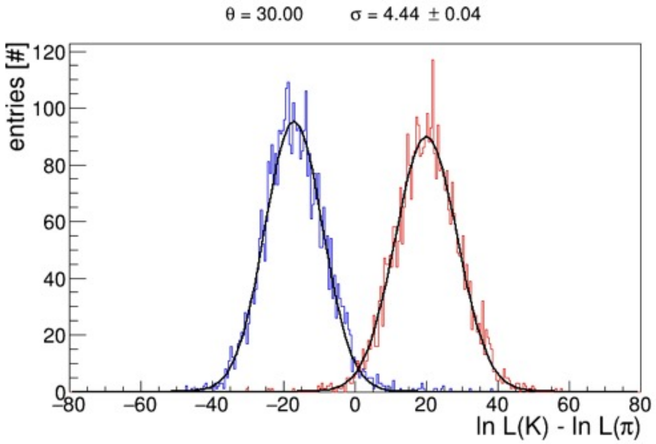
Reconstructed Cherenkov angle

Separation power

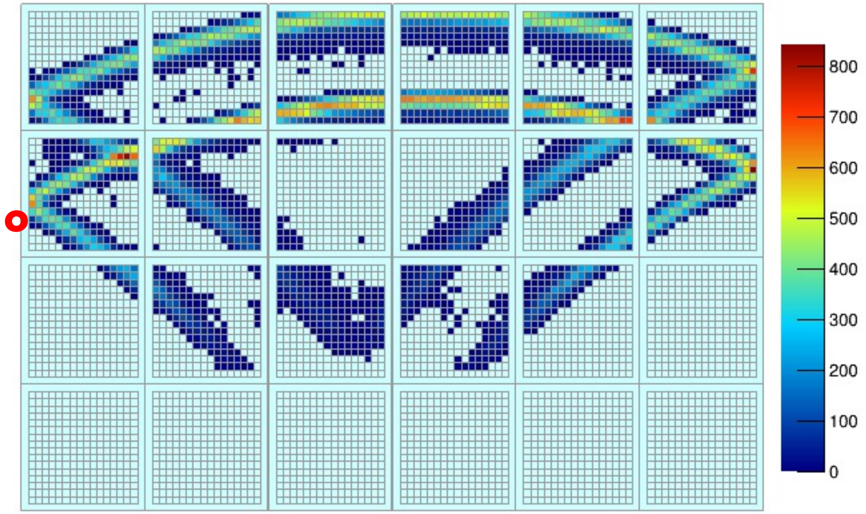
30°

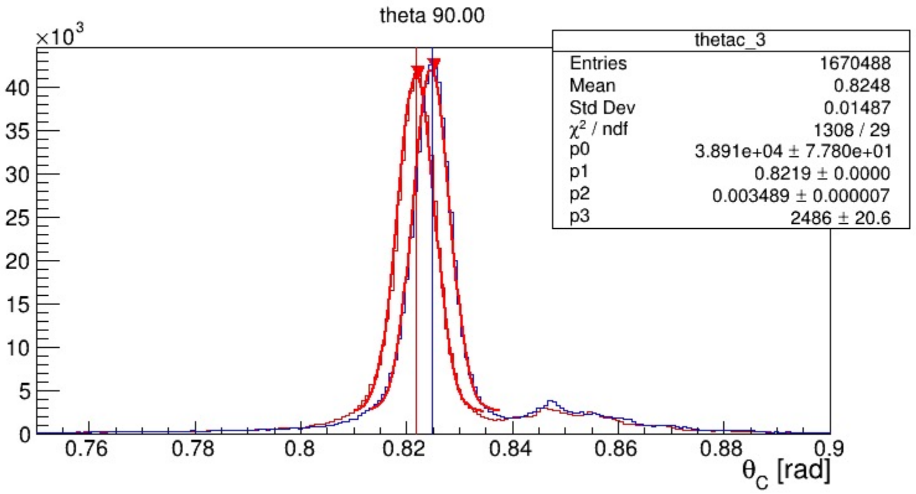


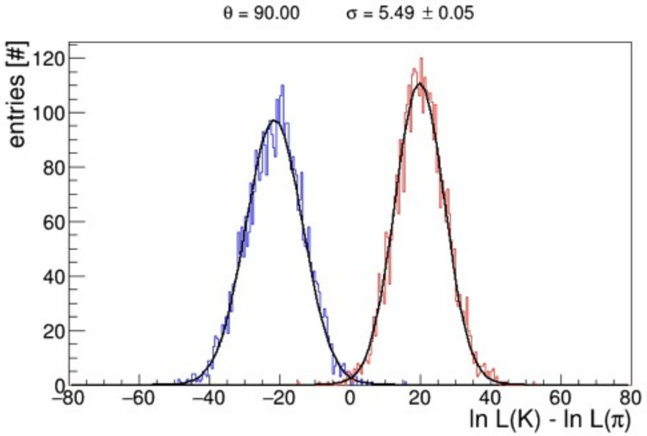




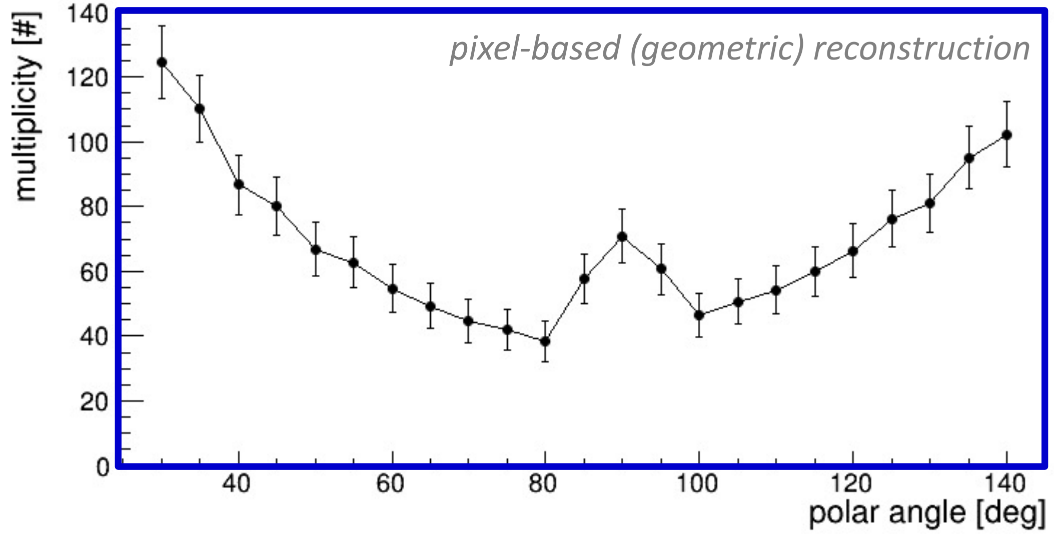
90°



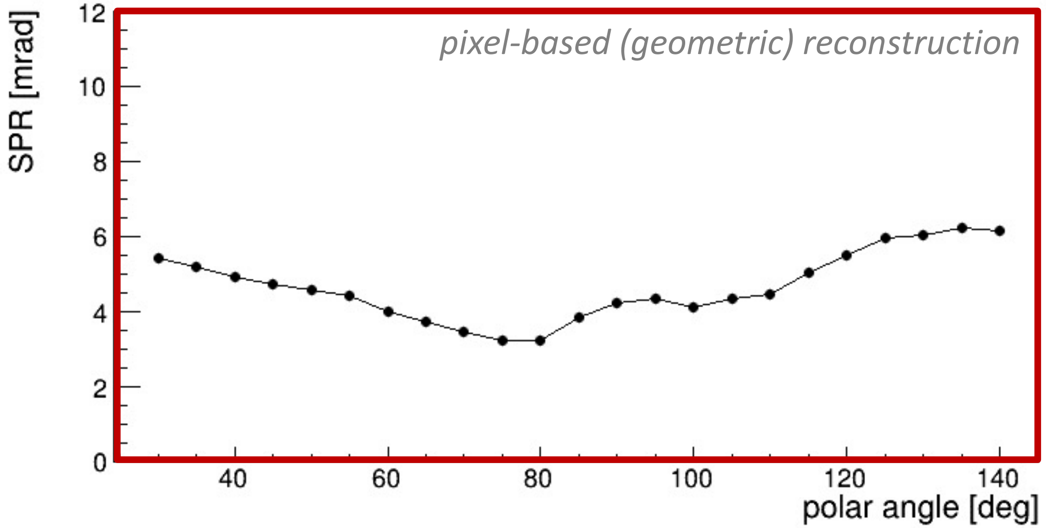




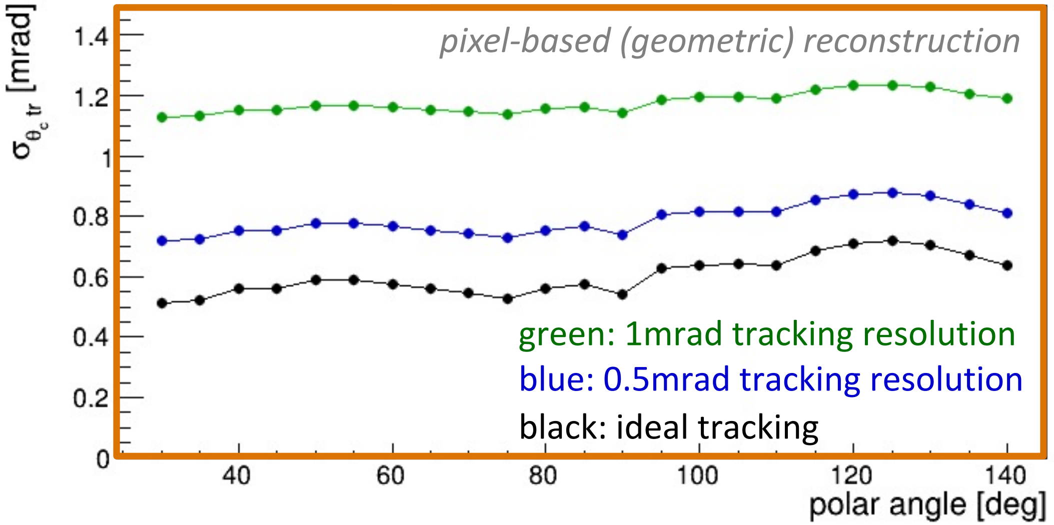
Photon yield per particle



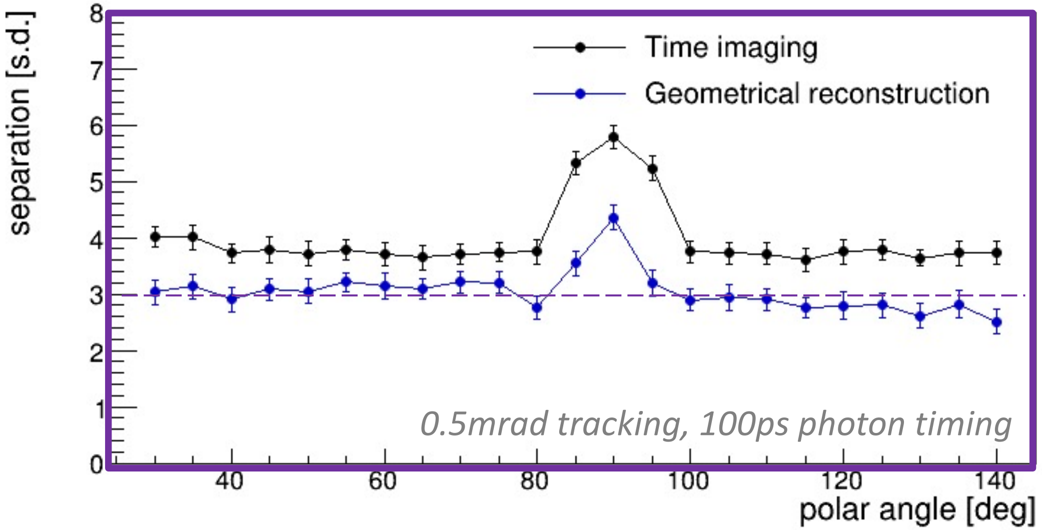
Cherenkov angle resolution per photon (SPR)



Cherenkov angle resolution angle per particle



π/K separation power at 6 GeV/c



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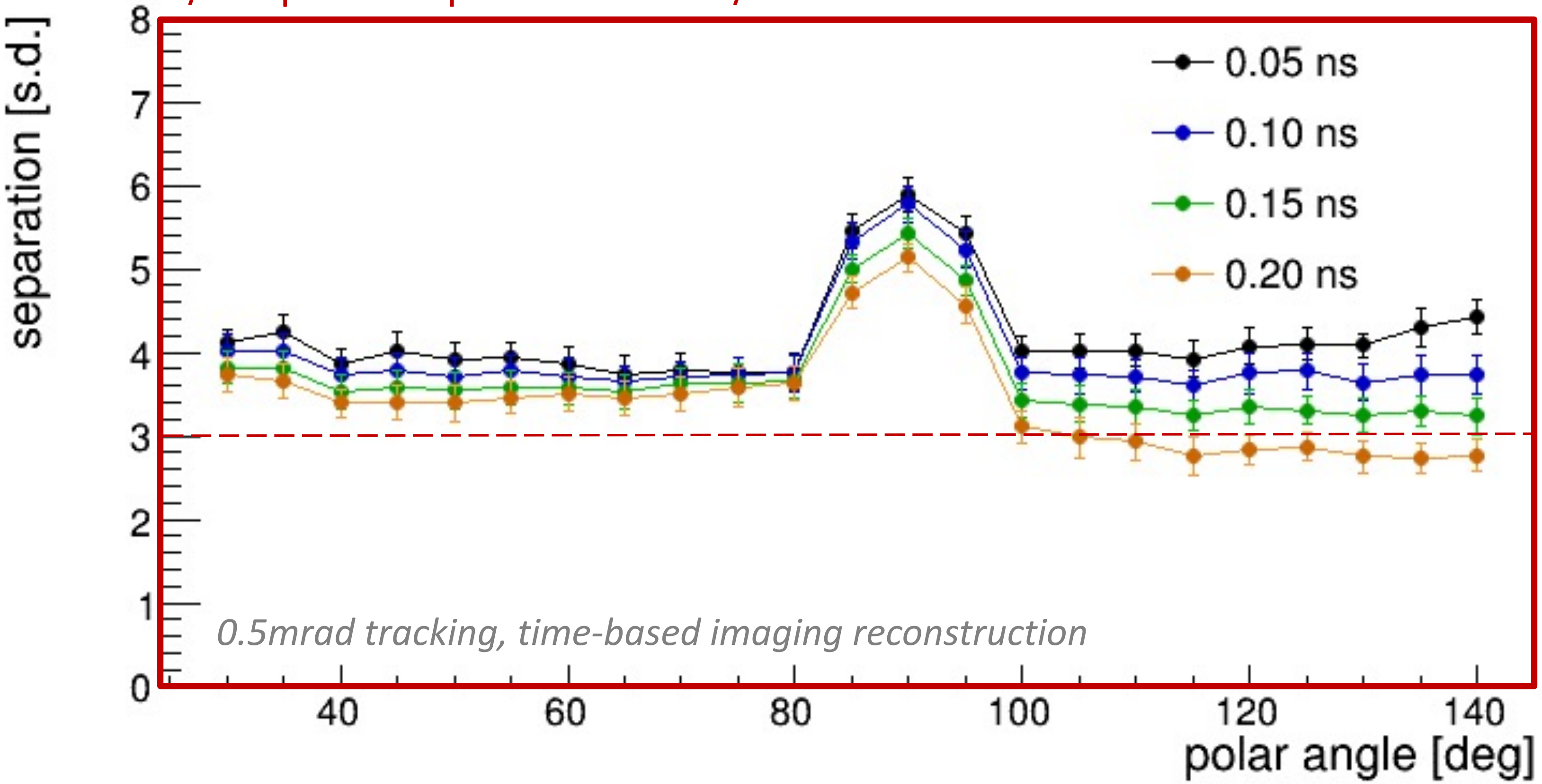
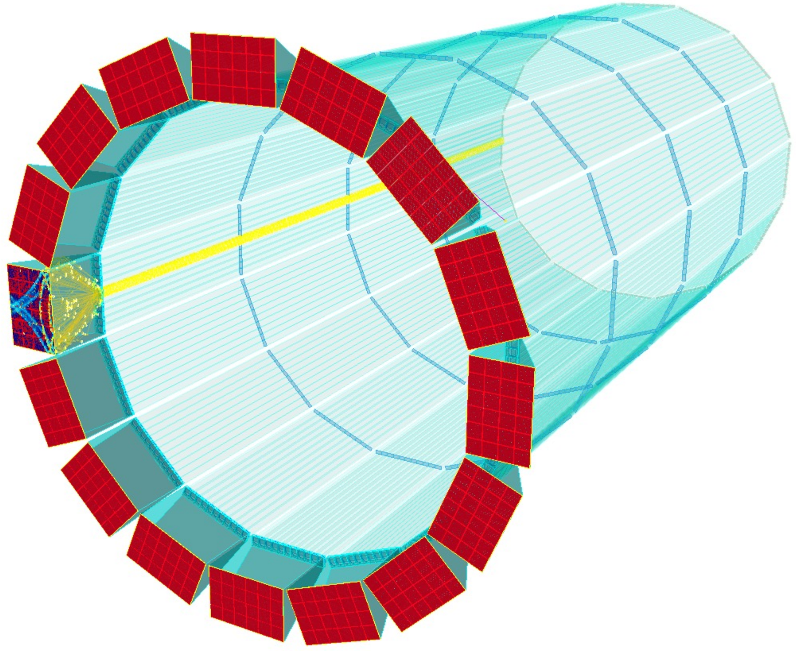


Stand alone G4 hpDIRC

- Realistic geometry and material properties based on prototypes, with wavelength-dependent material properties and processes and all relevant resolution terms
- Simulation validated with test beam data results
- Fast simulation code based on this simulations doesn't include B field and background from other systems.



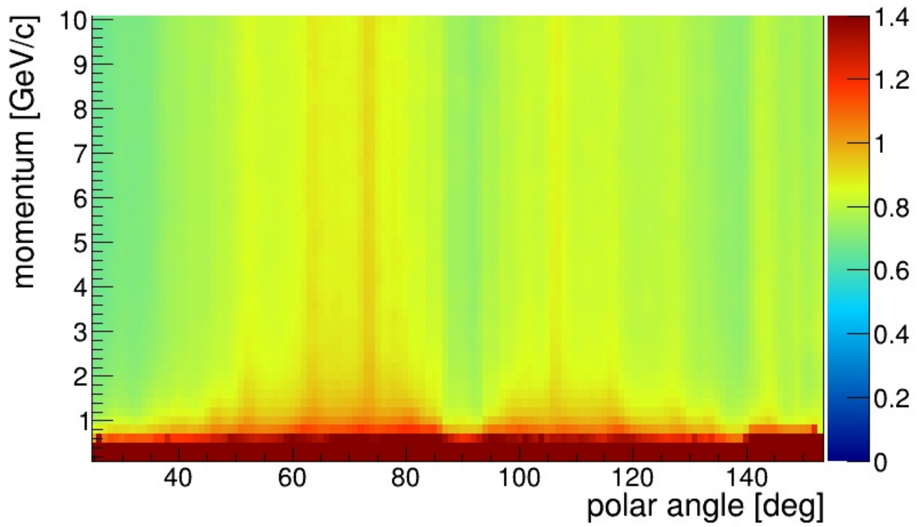
Moving forward with implementation:

- Copying all relevant code from stand alone repository
- Performing tests with particle gun and predefined particle parameters (momentum, incidence angle, hit position)
- Number of observables to look at to make sure geometry is correct, understand parameters and their definition
- Validating particle transport and digitization with performance observables

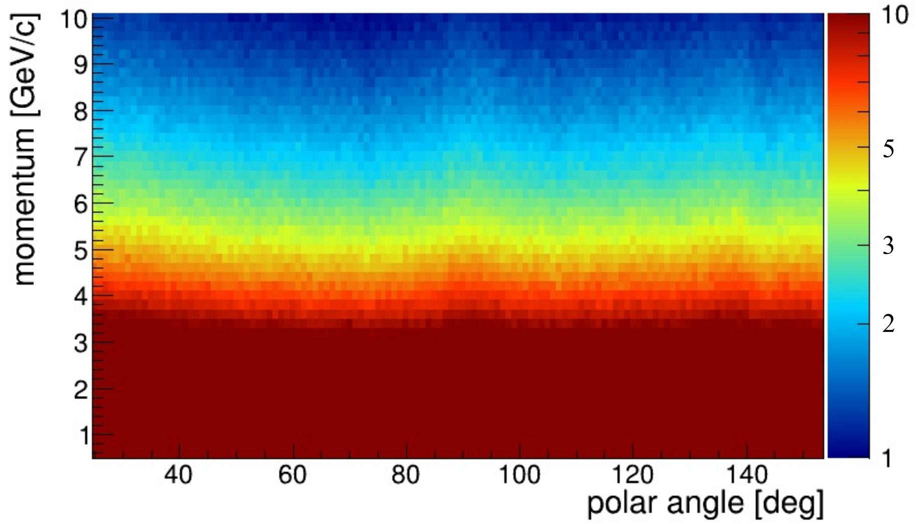
High-performance DIRC: fast simulation

- A fast simulation C++ class was designed and released to the EIC software community in 2019
- Code and documentation available in github
- Geant4 simulation of the current hpDIRC baseline design and a pixel-based reconstruction are used to determine
  - the Cherenkov angle resolution per photon
  - the number of detected Cherenkov photons per particle
- these values are used to calculate the Cherenkov angle resolution per particle and, in combination with the assumed tracking resolution, the normalized probabilities of a given track be an e, μ, π, K or p
- Normalized probabilities can also be used to obtain separation maps

Geant4 Cherenkov angle resolution per particle



Example: derived π/K separation power (tracking resolution of 0.5 mrad)



High-performance DIRC: fast simulation

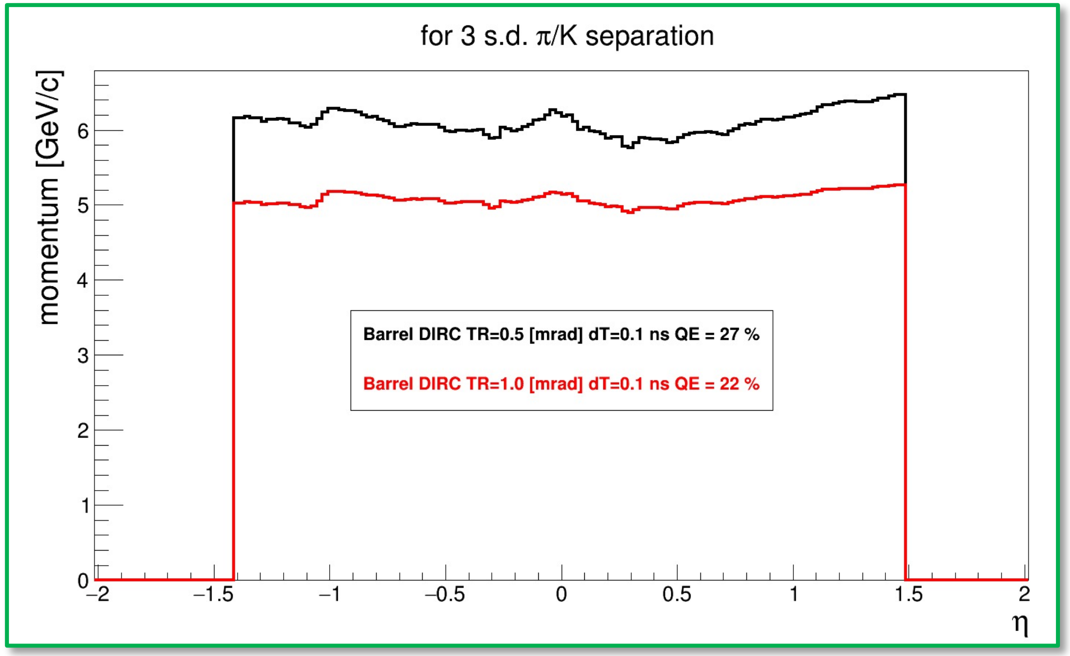
- The DrcPidFast fast simulation was adapted for the Yellow Report PID evaluation (released on March 9, 2020)
- According to the instruction given by Tom, it provides:
  - numSigma(p, PID)
  - maxP(numSigma, PID)
  - minP(numSigma, PID)

Example of usage:

```
Detectors.push_back( new barrelDirc(trackResolution,timeResolution,QE,etaLow,etaHigh) );
```

Two default scenarios implemented:

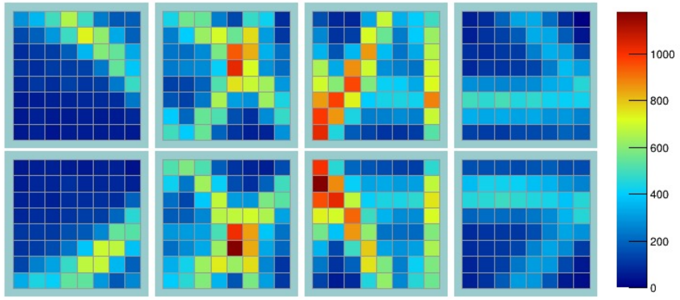
- Realistic scenario
  - 0.5 mrad tracking resolution
  - 0.1 ns rms timing precision per photon
  - 27% detective quantum efficiency of the MCP-PMT
- Pessimistic scenario
  - 1.0 mrad tracking resolution;
  - 0.1 ns rms timing precision per photon
  - 22% detective quantum efficiency of the MCP-PMT



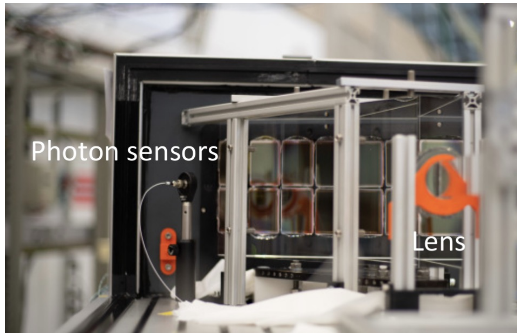
PANDA Barrel DIRC prototype at CERN PS in July/Aug 2018
(reduced number of MCP-PMTs)

- Caveat: larger sensor pixels, slower electronics than EIC DIRC → PANDA goal: 3σ π/K separation @ 3.5 GeV/c
- Optics similar to EIC DIRC design: narrow bar, fused silica prism, 3-layer spherical lens
- Measured key quantities: **photon yield, Cherenkov angle resolution per photon and per particle, and π/K separation power – all in very good agreement with simulation** (used for EIC DIRC)

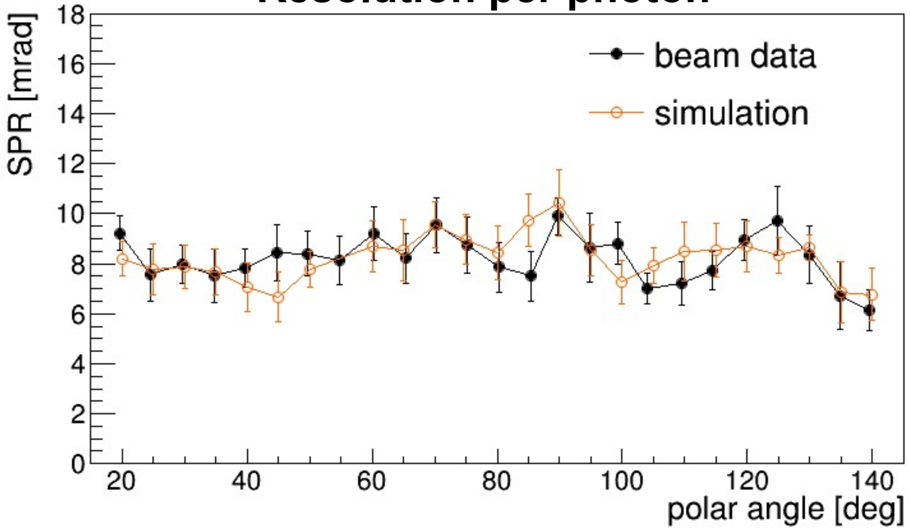
Example of hit pattern



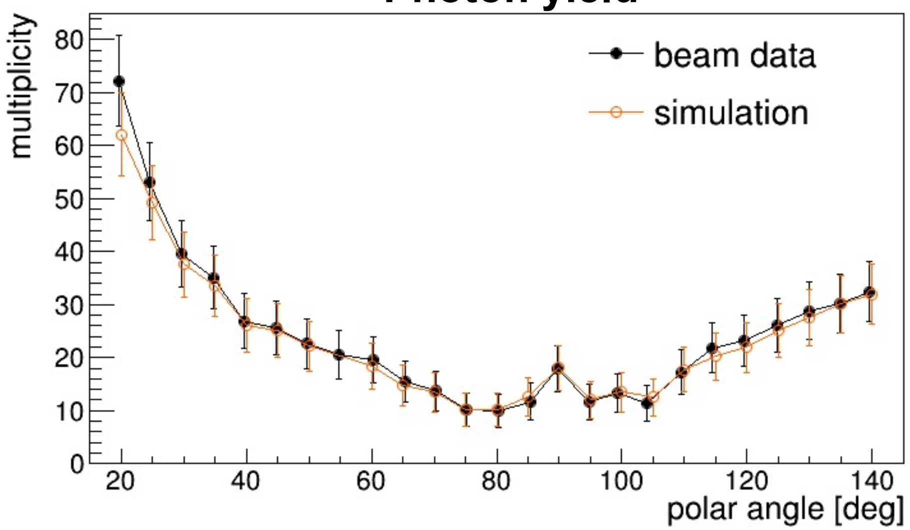
PANDA Barrel DIRC Prototype



Resolution per photon



Photon yield



Validation of hpDIRC Simulation

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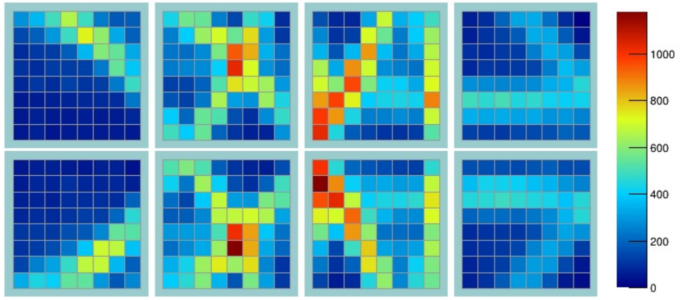
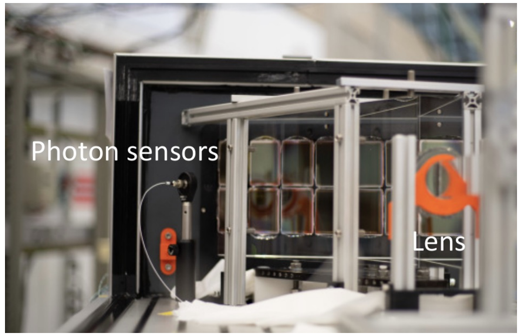


PANDA Barrel DIRC Prototype



π/p separation power at 7 GeV/c