DIRC Reconstruction Algorithms

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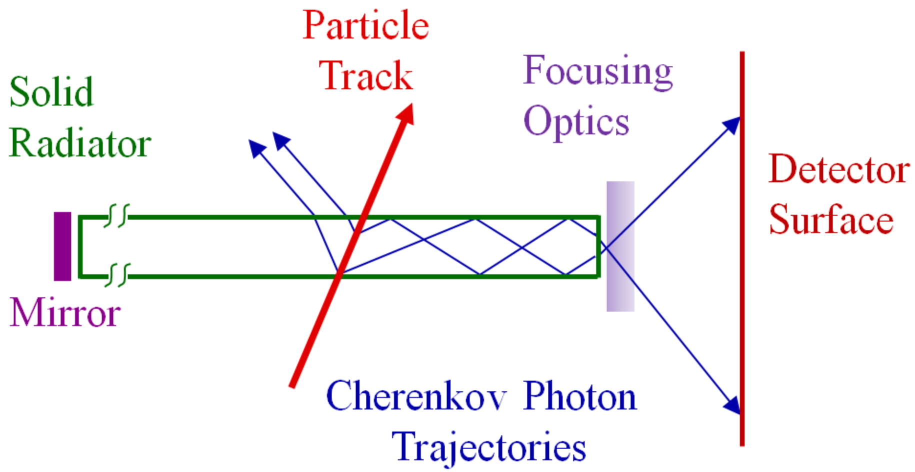
Hadron Physics Monthly Meeting

Outline

- Introduction
- Geometrical Reconstruction
- Time-Based Imaging
- Alternative Methods
- Summary

DIRC Concept

Detection of Internally Reflected Cherenkov Light



- Charged particle traversing radiator with refraction index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/n\beta(\lambda)$.

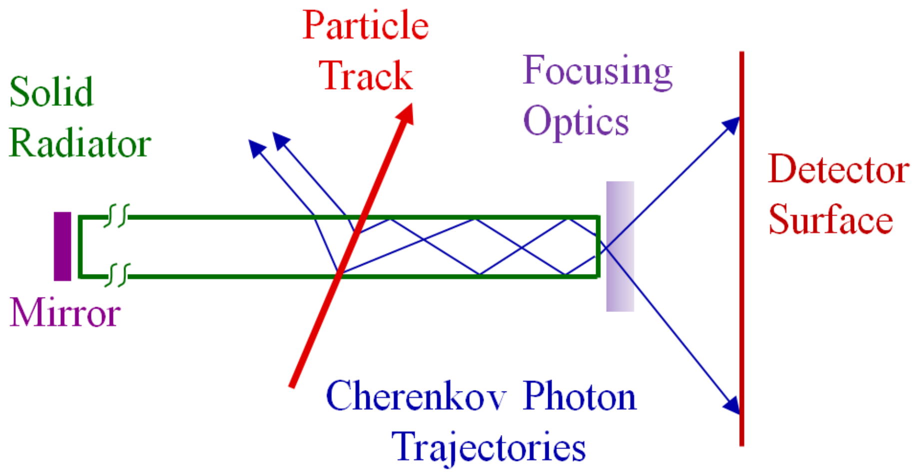
- For $n > \sqrt{2}$ some photons are always totally internally reflected for $\beta \approx 1$ tracks.

- Radiator and light guide: bar, plate, or disk made from Synthetic Fused Silica ("Quartz") or fused quartz or acrylic glass, etc.

- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished).

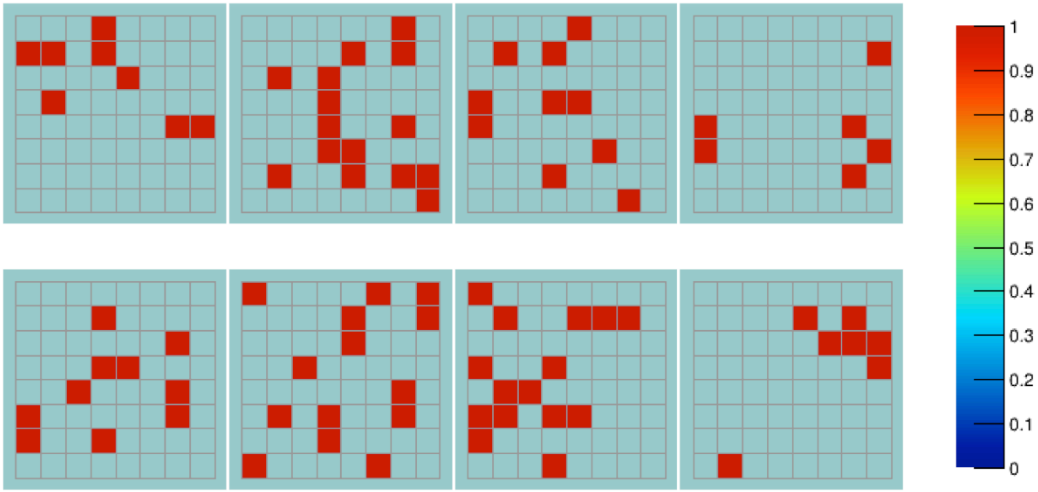
DIRC Concept

Detection of Internally Reflected Cherenkov Light

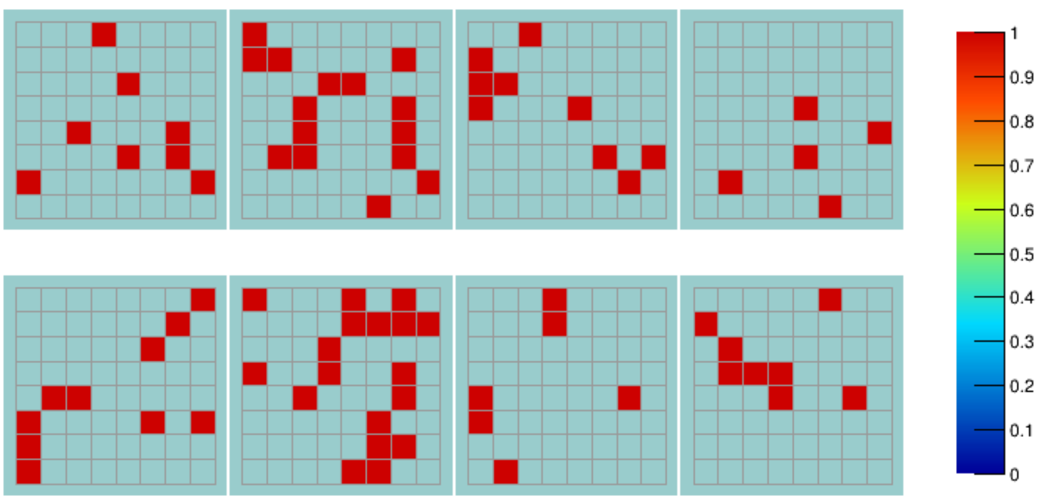


- Mirror attached to one bar end, reflects photon back to readout end.
- Photons exit radiator via optional focusing optics into expansion region, detected on photon detector array.
- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining: θ_c, ϕ_c and $t_{propagation}$.
- Ultimate deliverable for DIRC: PID likelihoods.

Single Event Hit Pattern



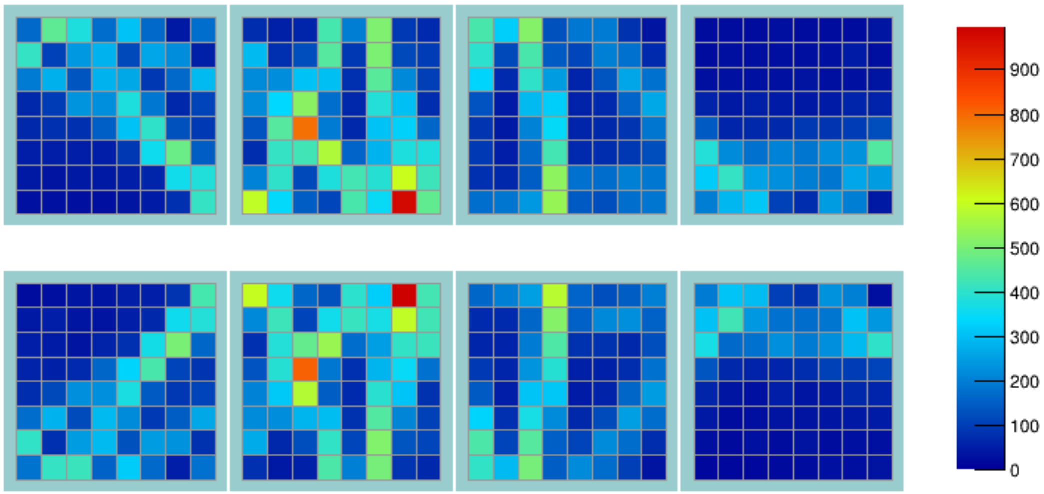
Pion hit pattern at 3.5 GeV/c and 25 degree polar angle



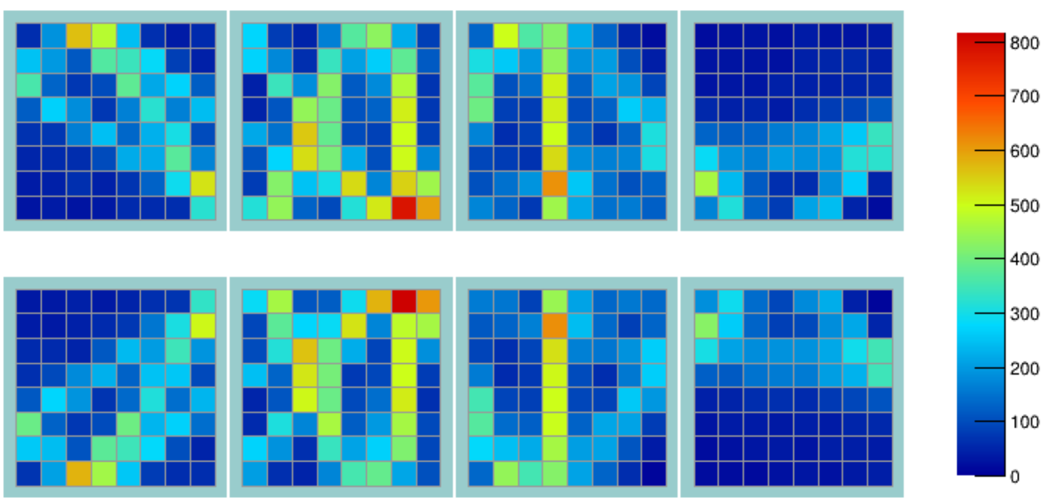
Kaon hit pattern at 3.5 GeV/c and 25 degree polar angle

latest beam test MCP-PMT layout

Accumulated Event Hit Pattern

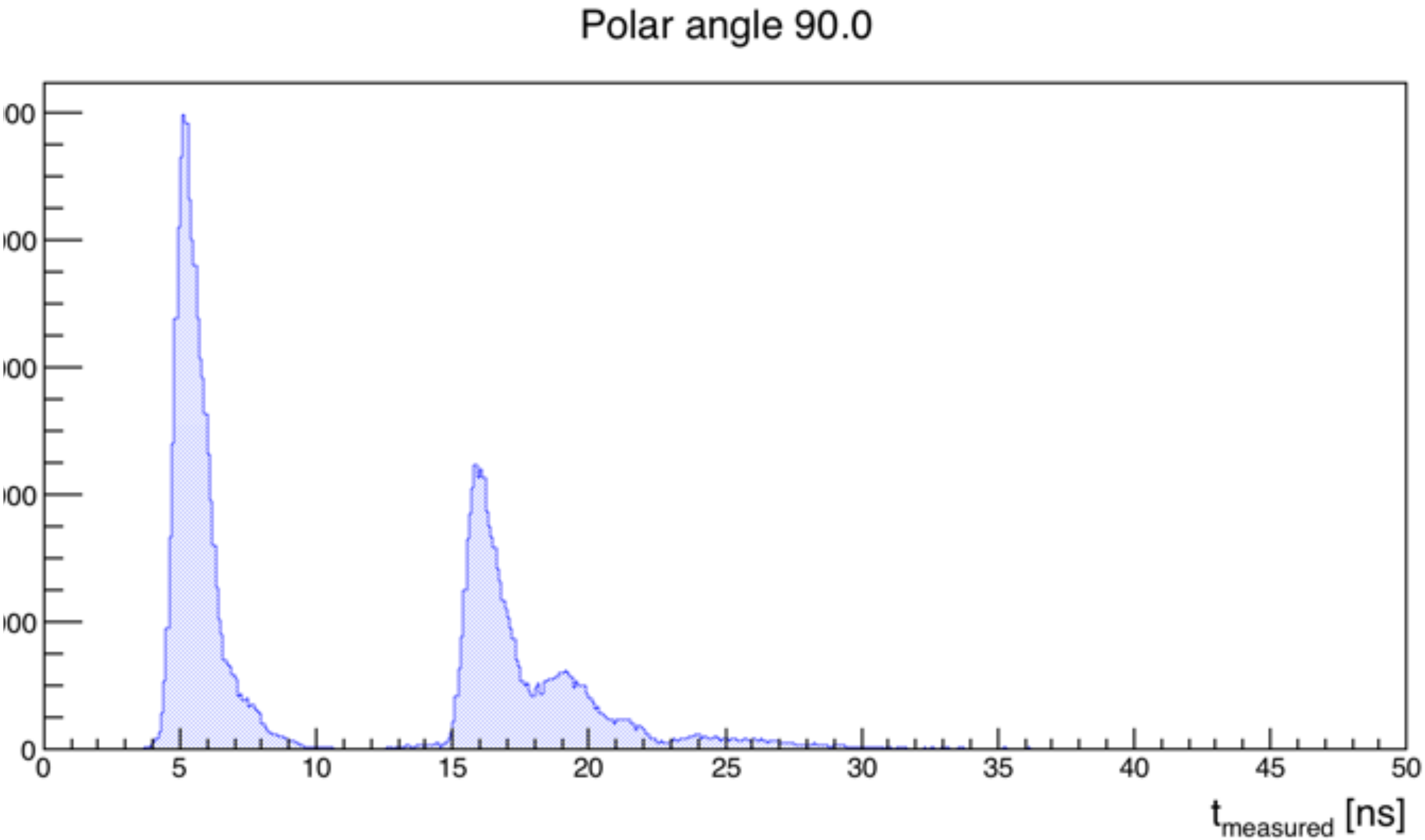


Pion 1k accumulated hit pattern at 3.5 GeV/c and 25 degree polar angle



Kaon 1k accumulated hit pattern at 3.5 GeV/c and 25 degree polar angle

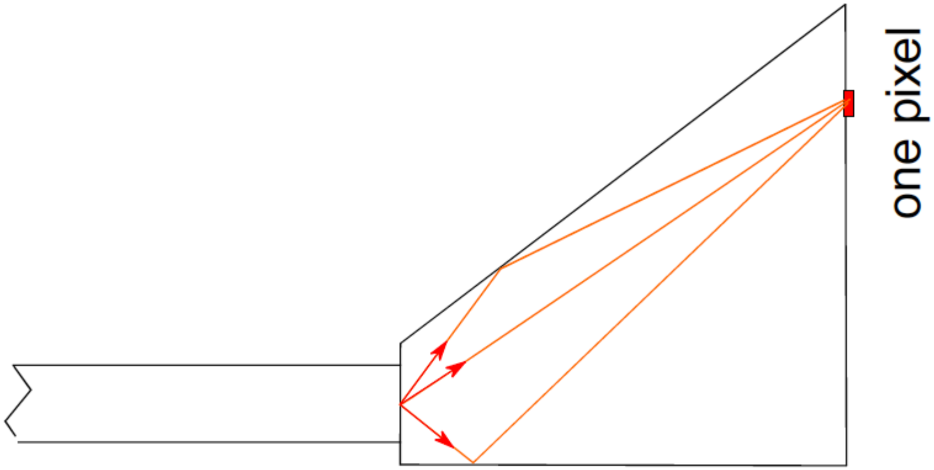
Photon Arrival Time

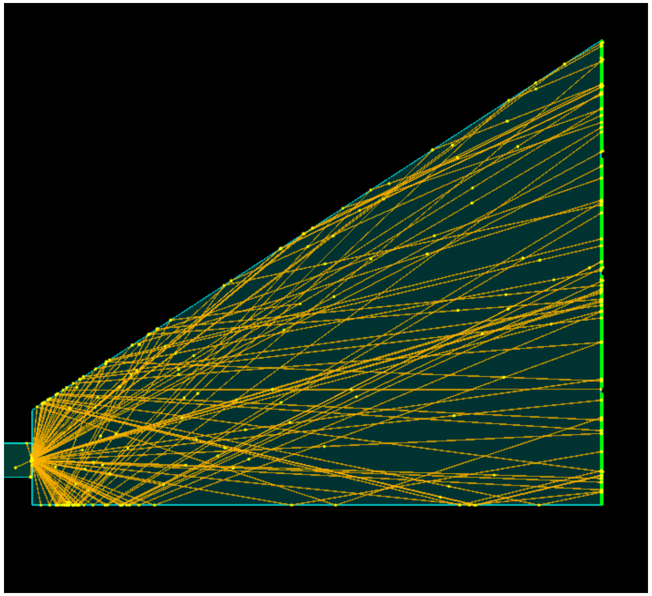


Detected Cherenkov photons time at 90 degree polar angle

Geometrical Reconstruction

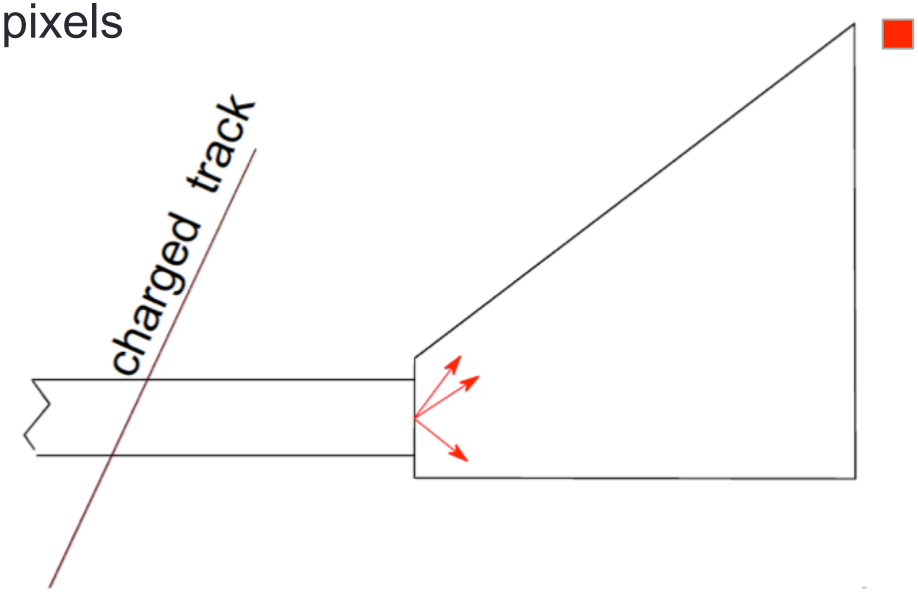
- BABAR-like reconstruction
- Look-Up Table creation: store direction at the end of the radiator for each hit pixel
- Provides Cherenkov angle distribution, SPR, photon yield and likelihoods





Geometrical Reconstruction

- Reconstruction: direction from LUT for hit pixels are combined with charged track direction



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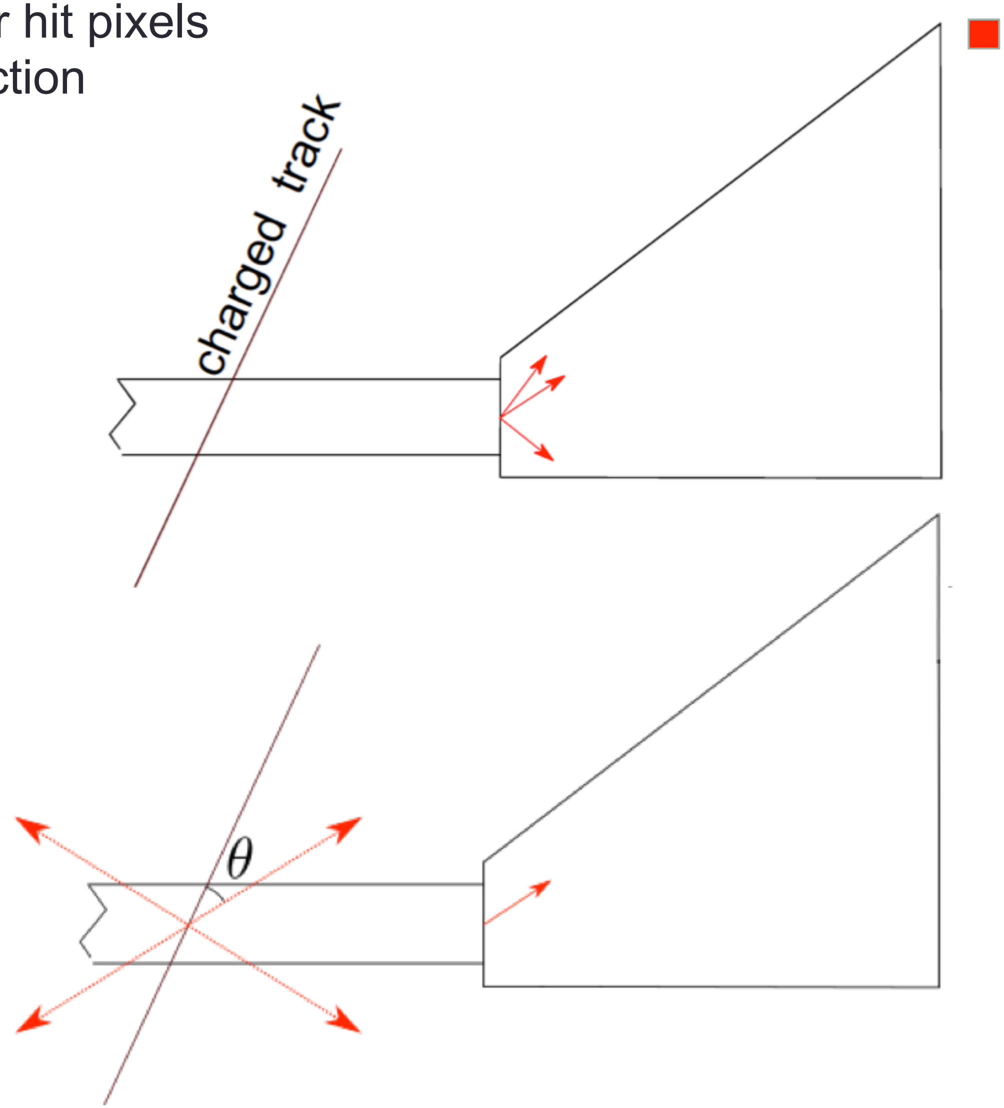
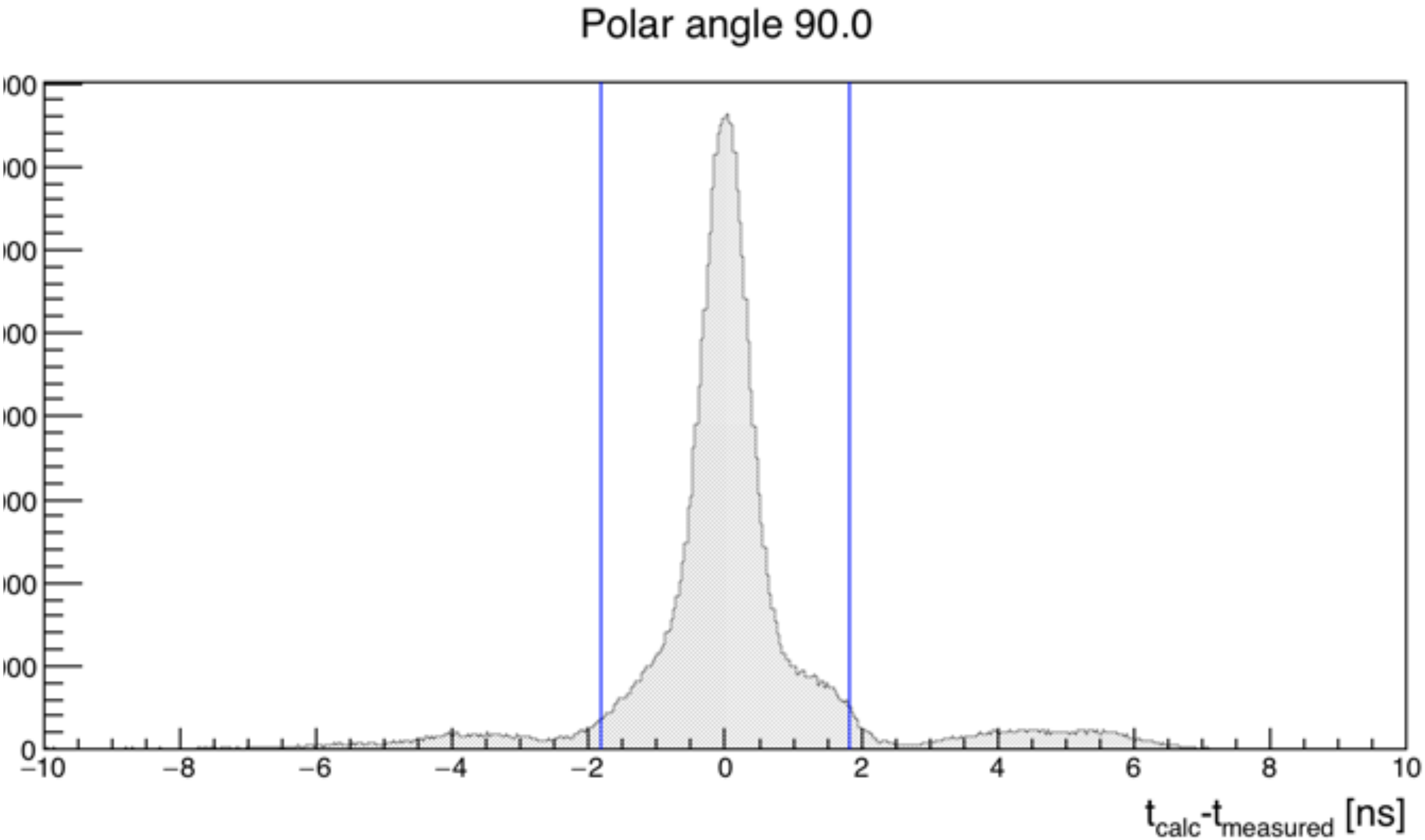


Time Difference



Photon time difference at 90 degree polar angle

Geometrical Reconstruction

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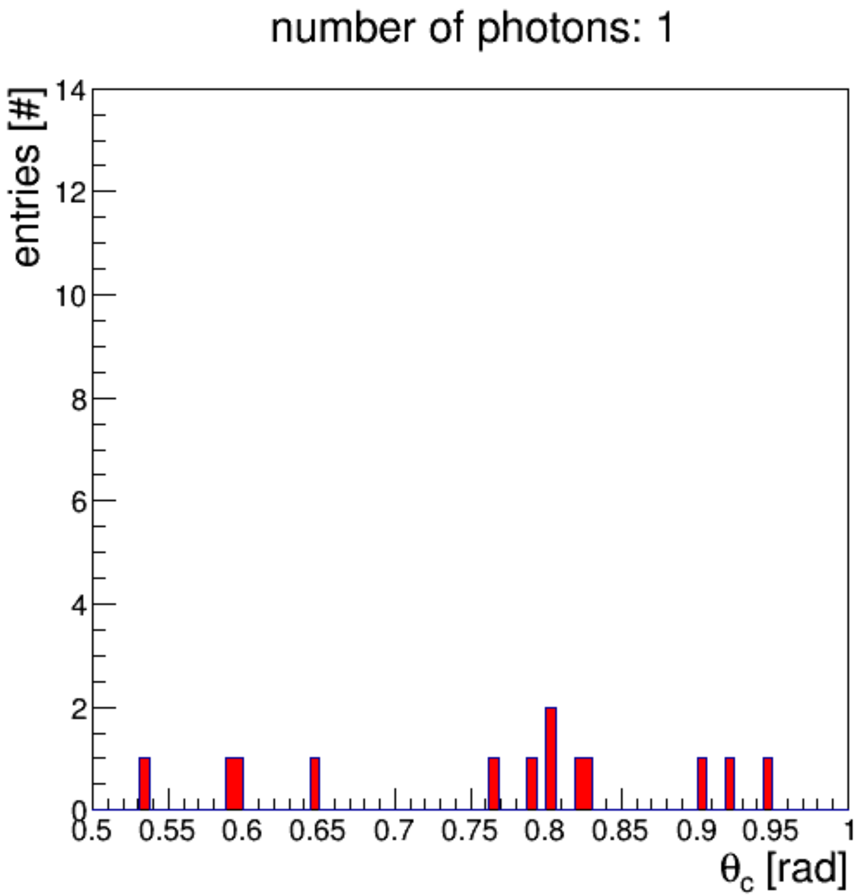

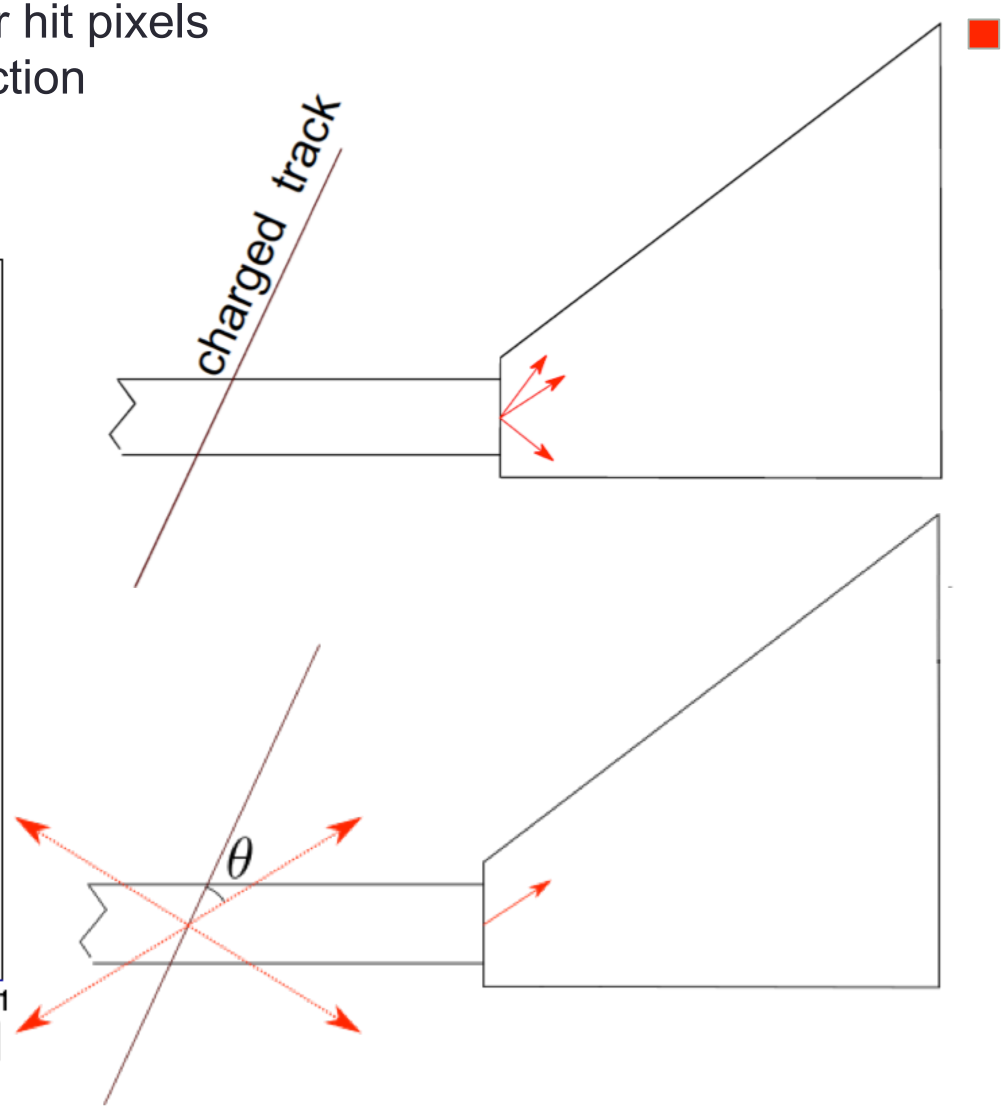

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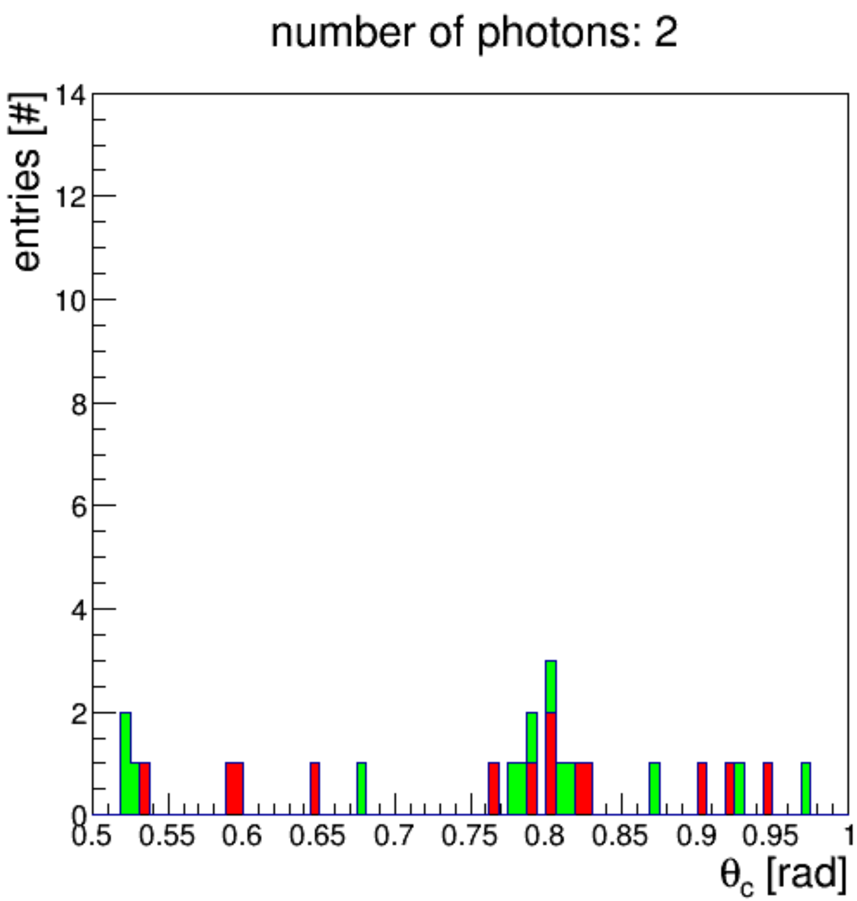

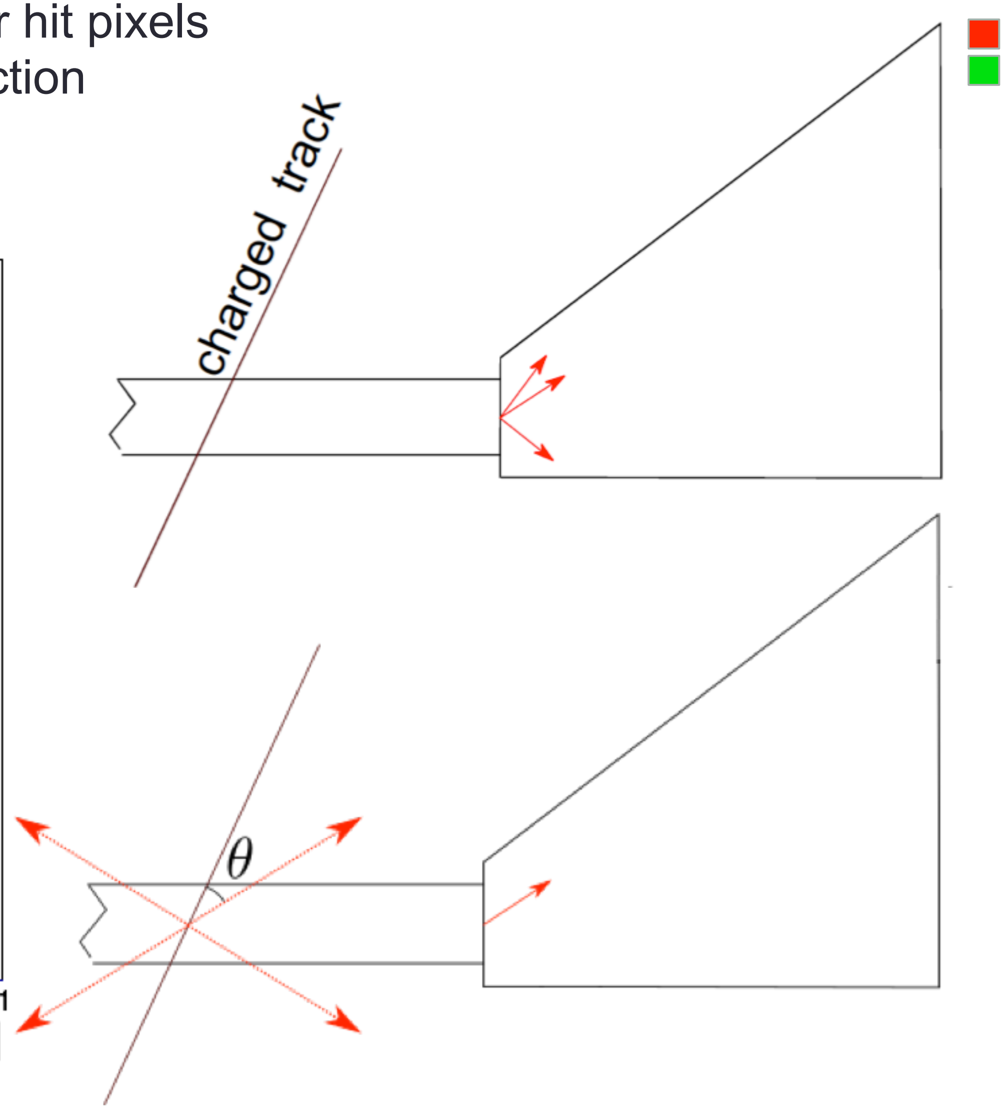

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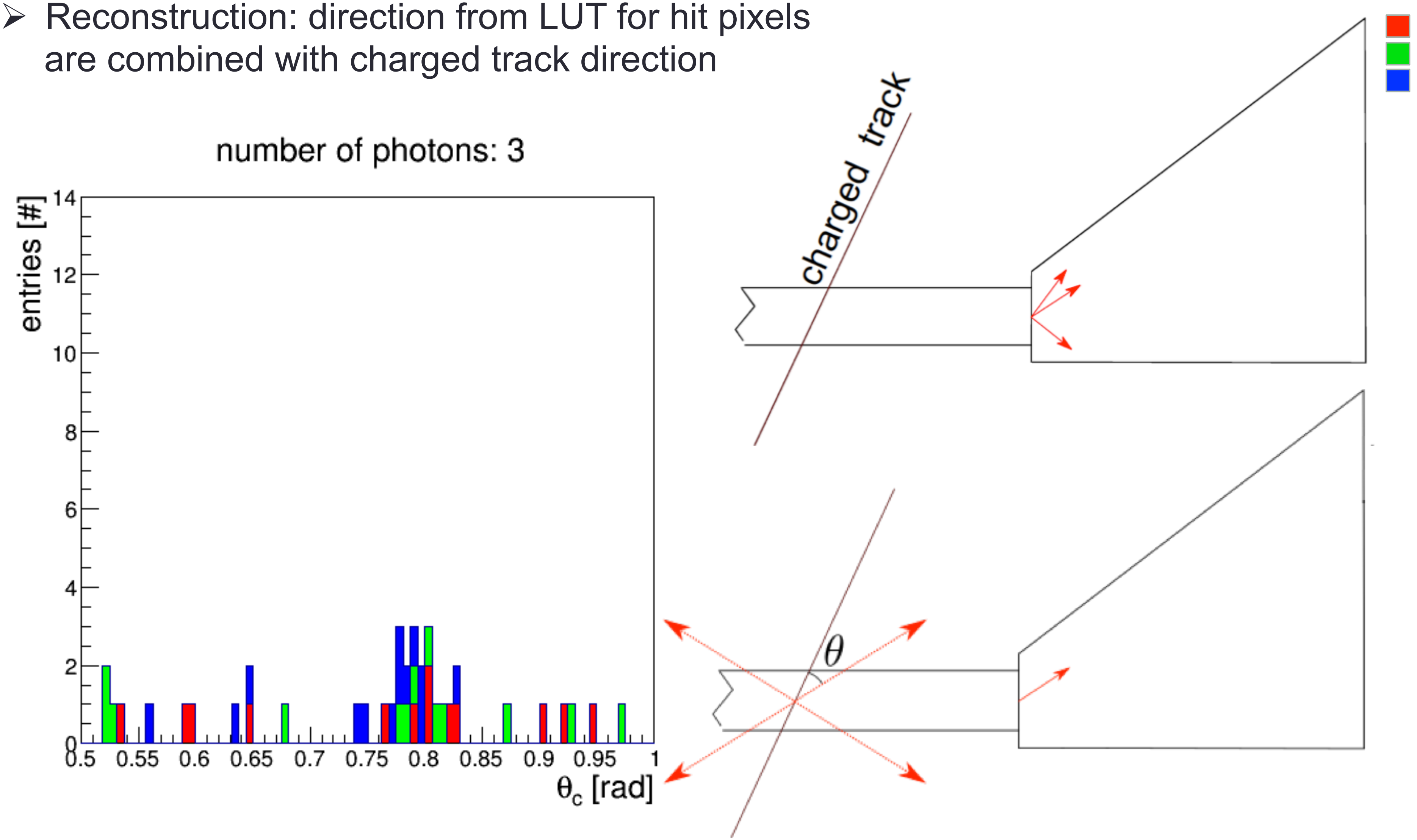

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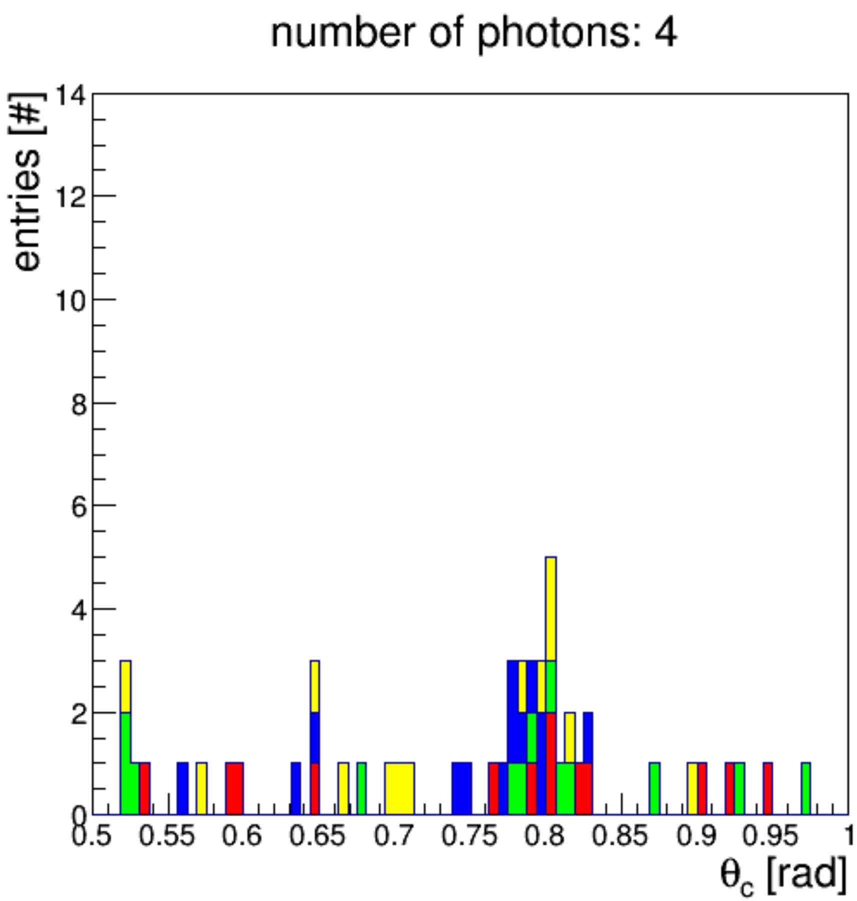

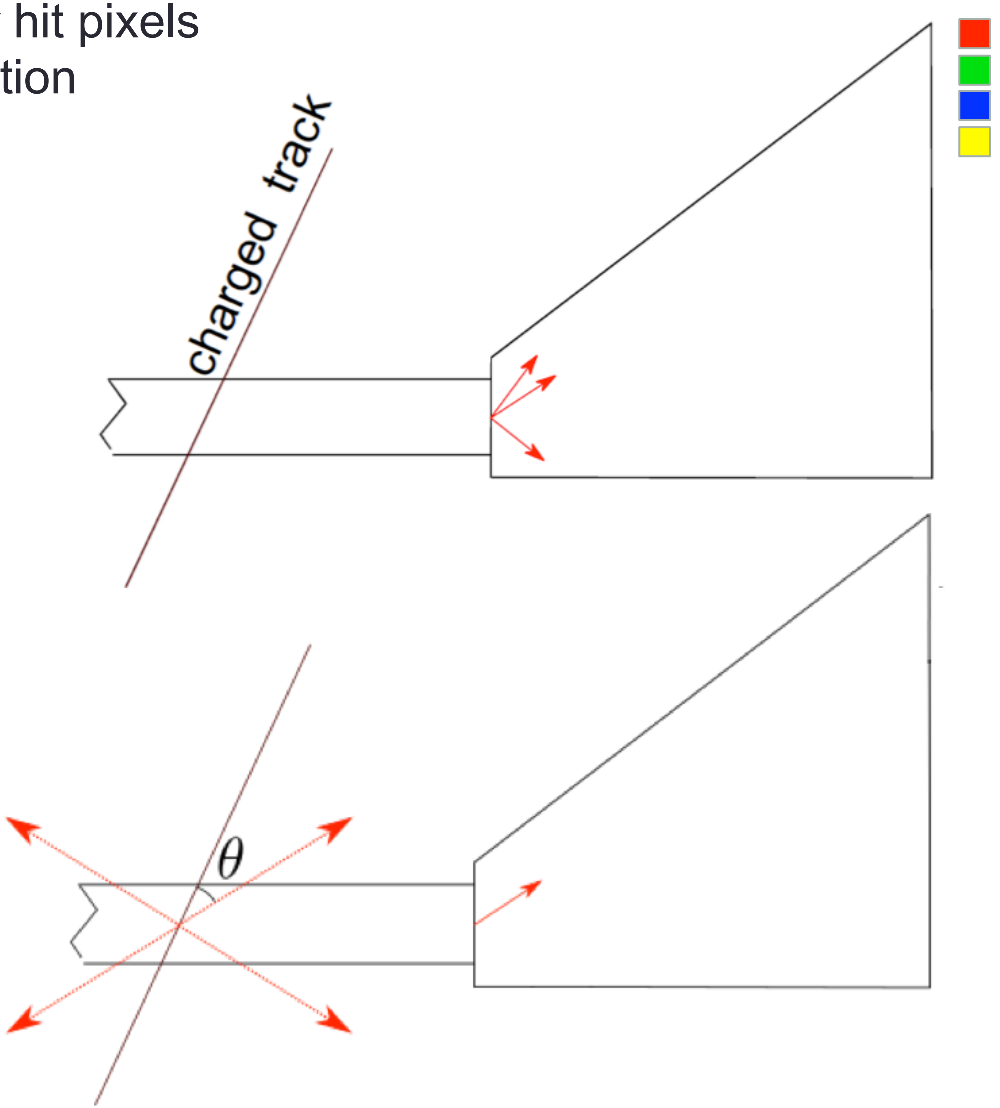

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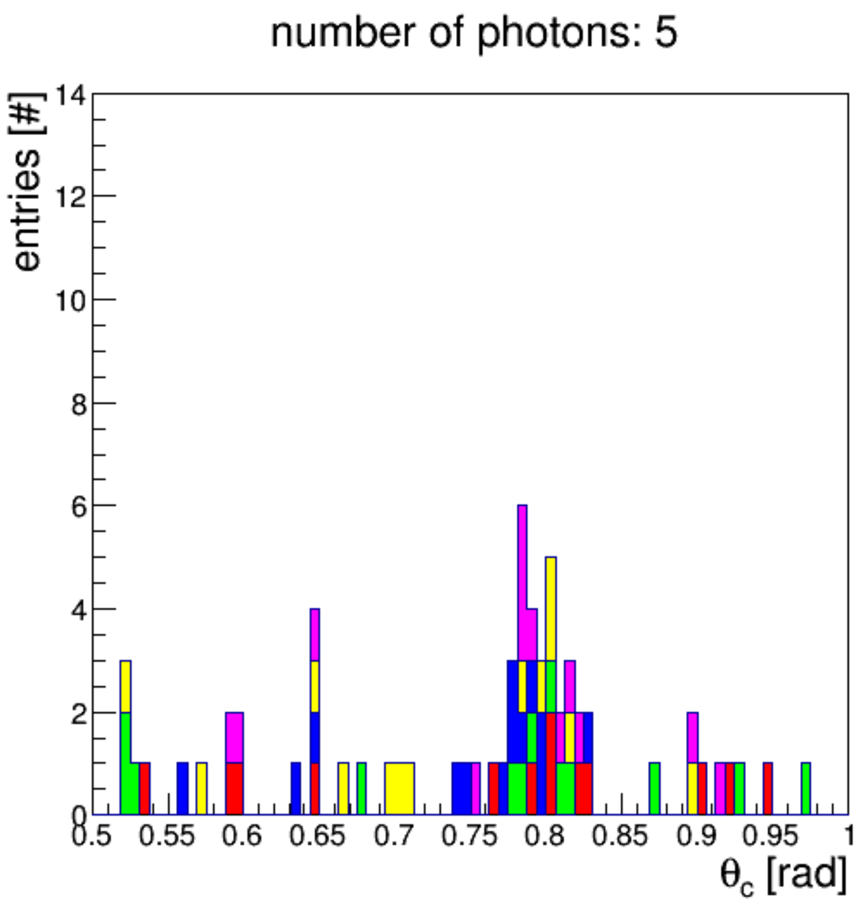

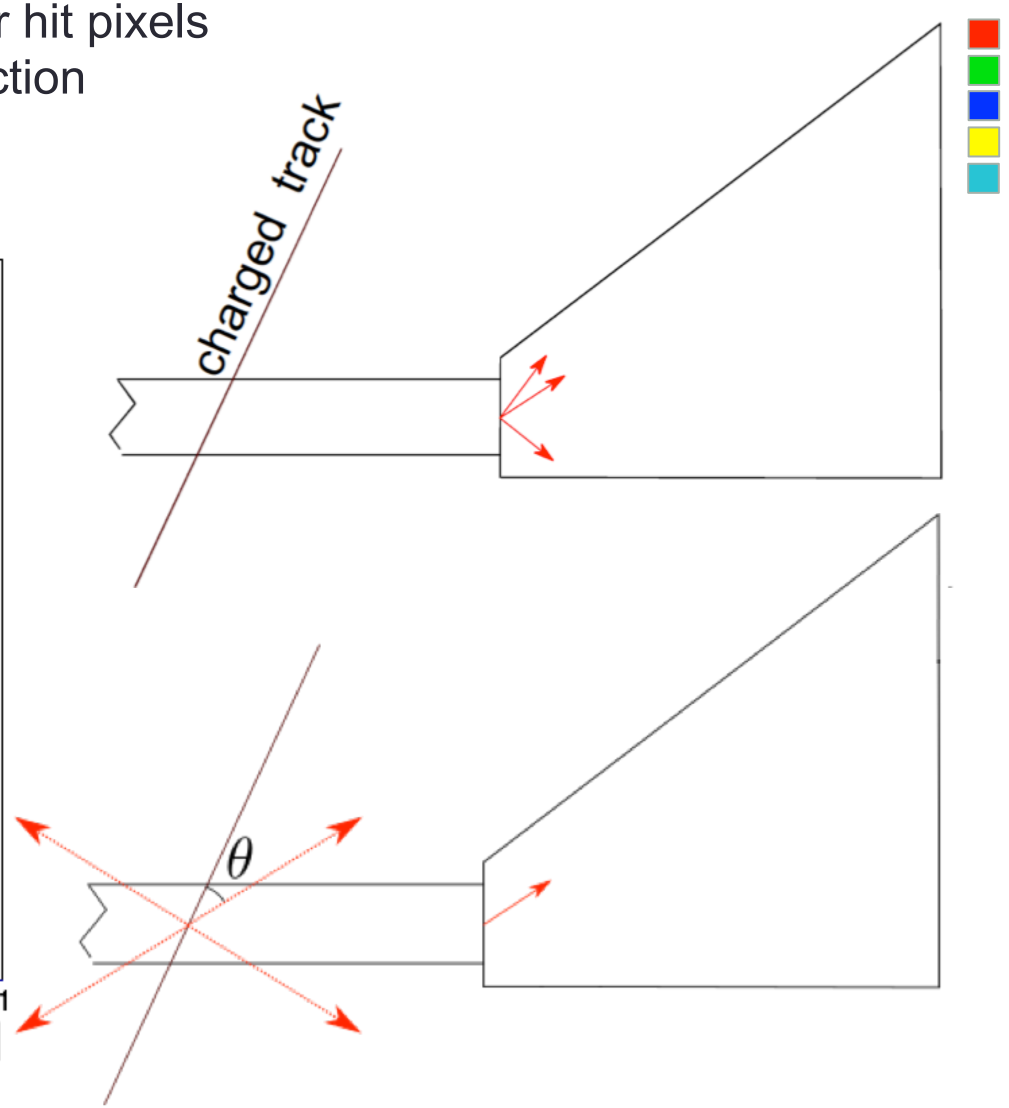

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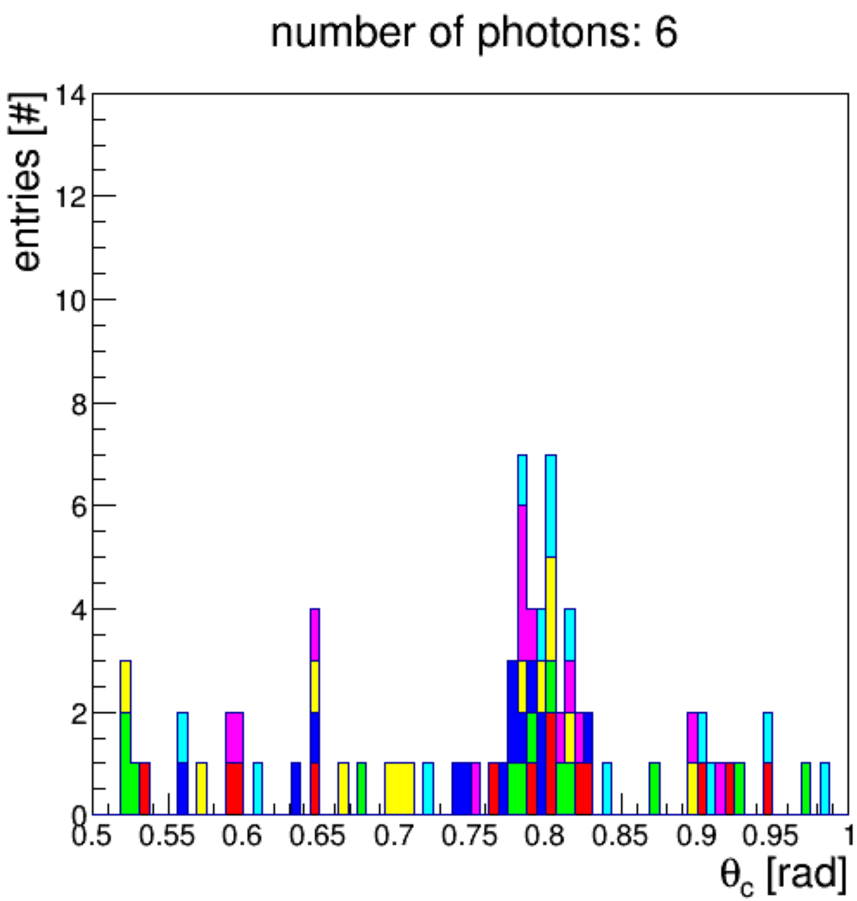

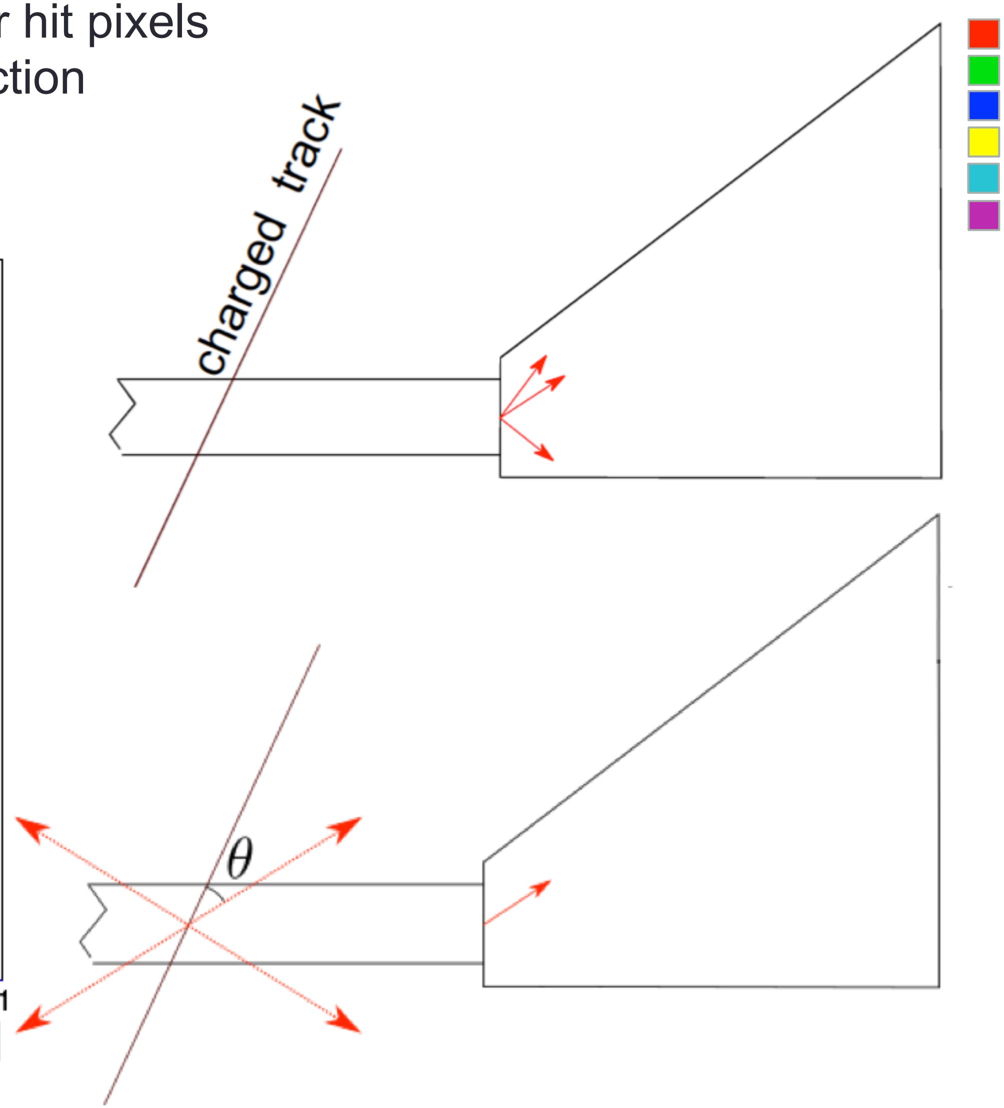

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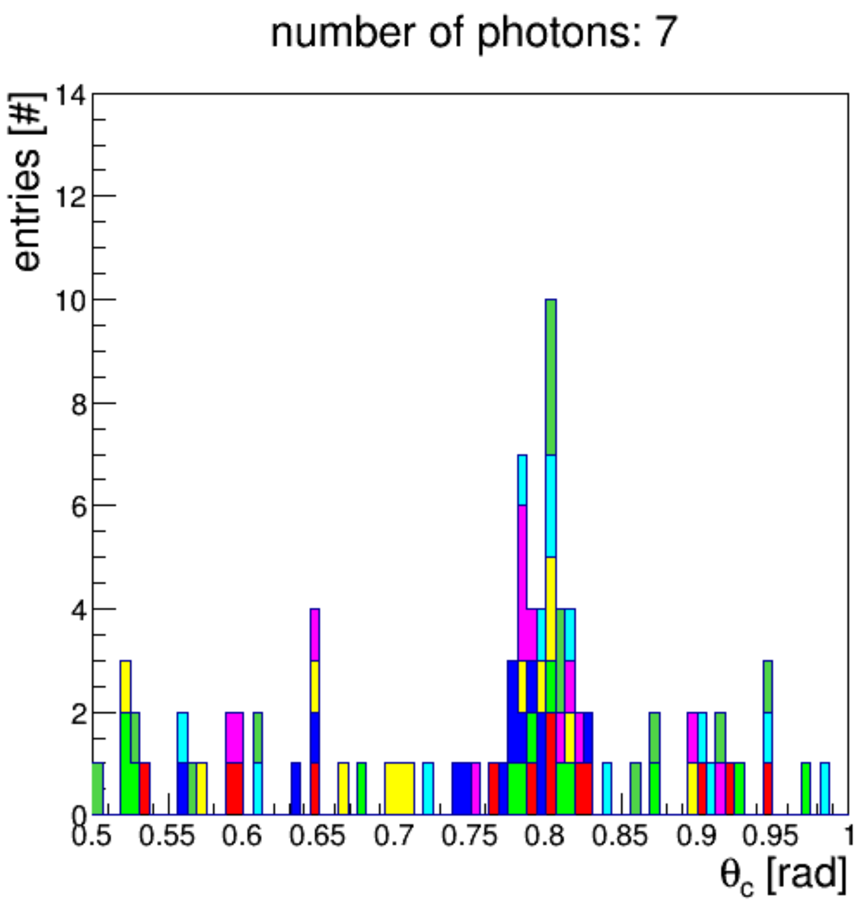

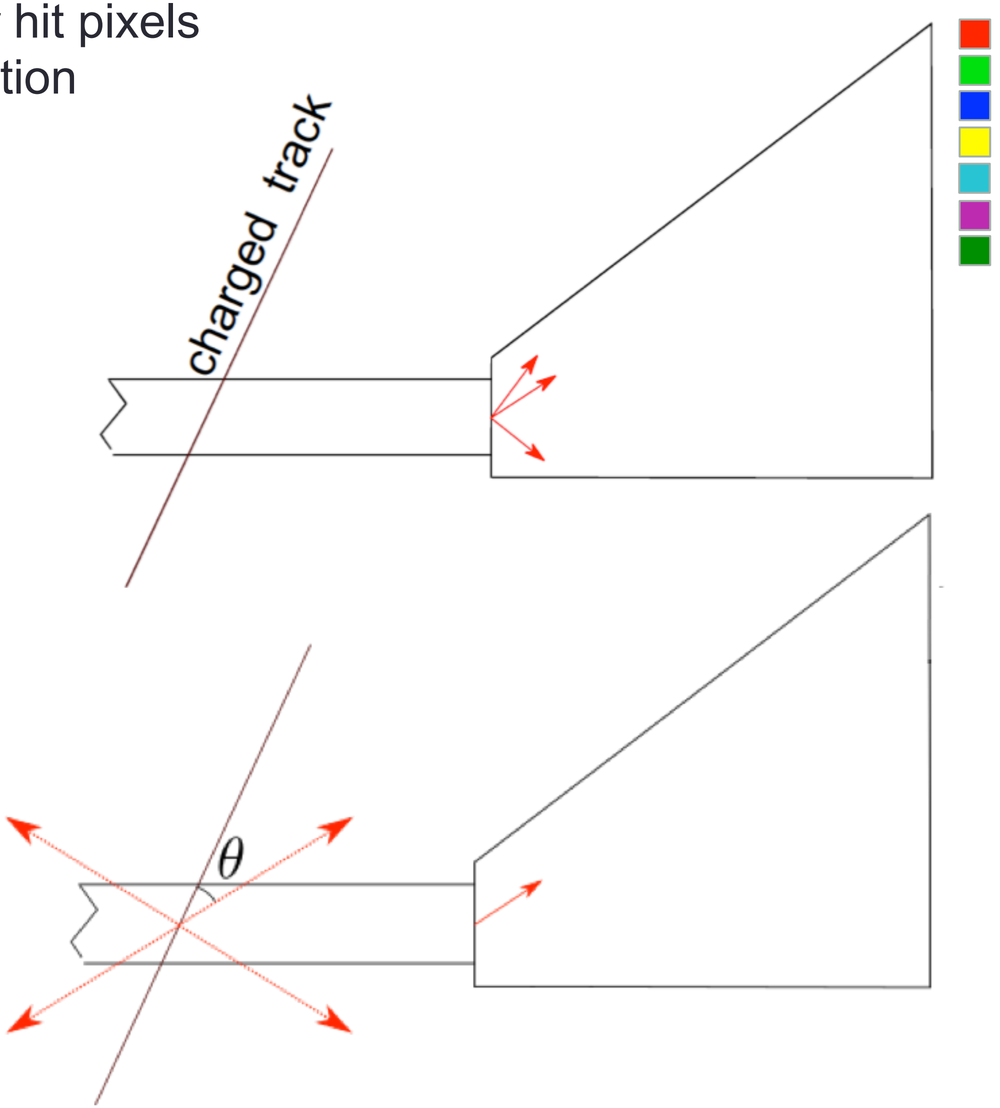

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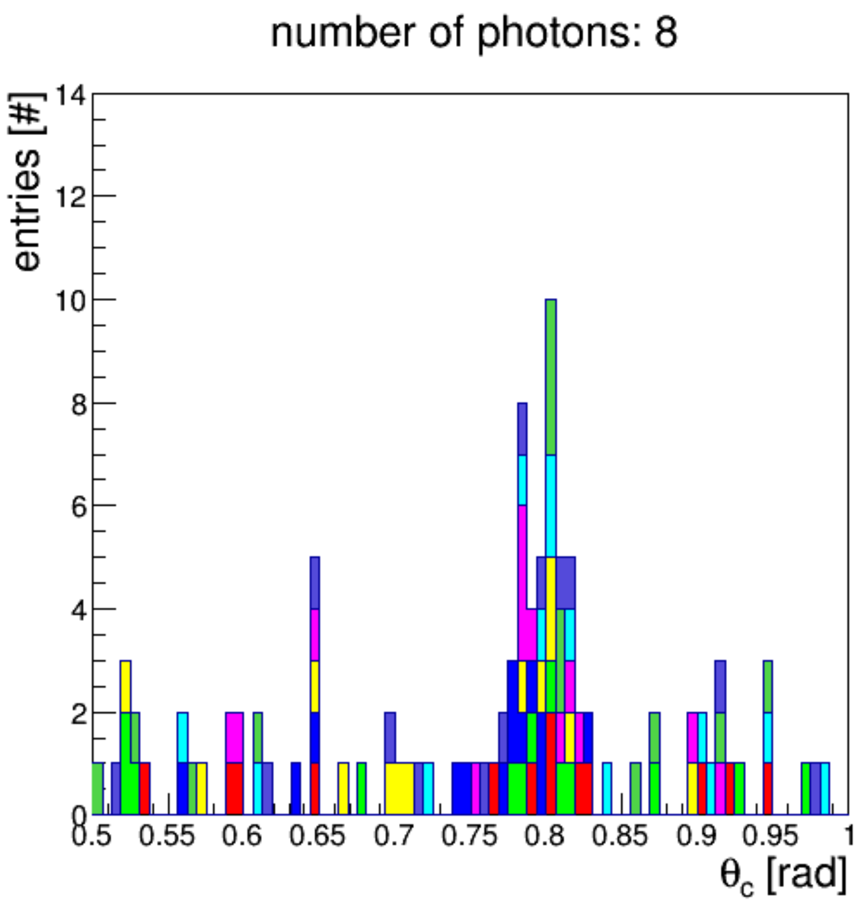

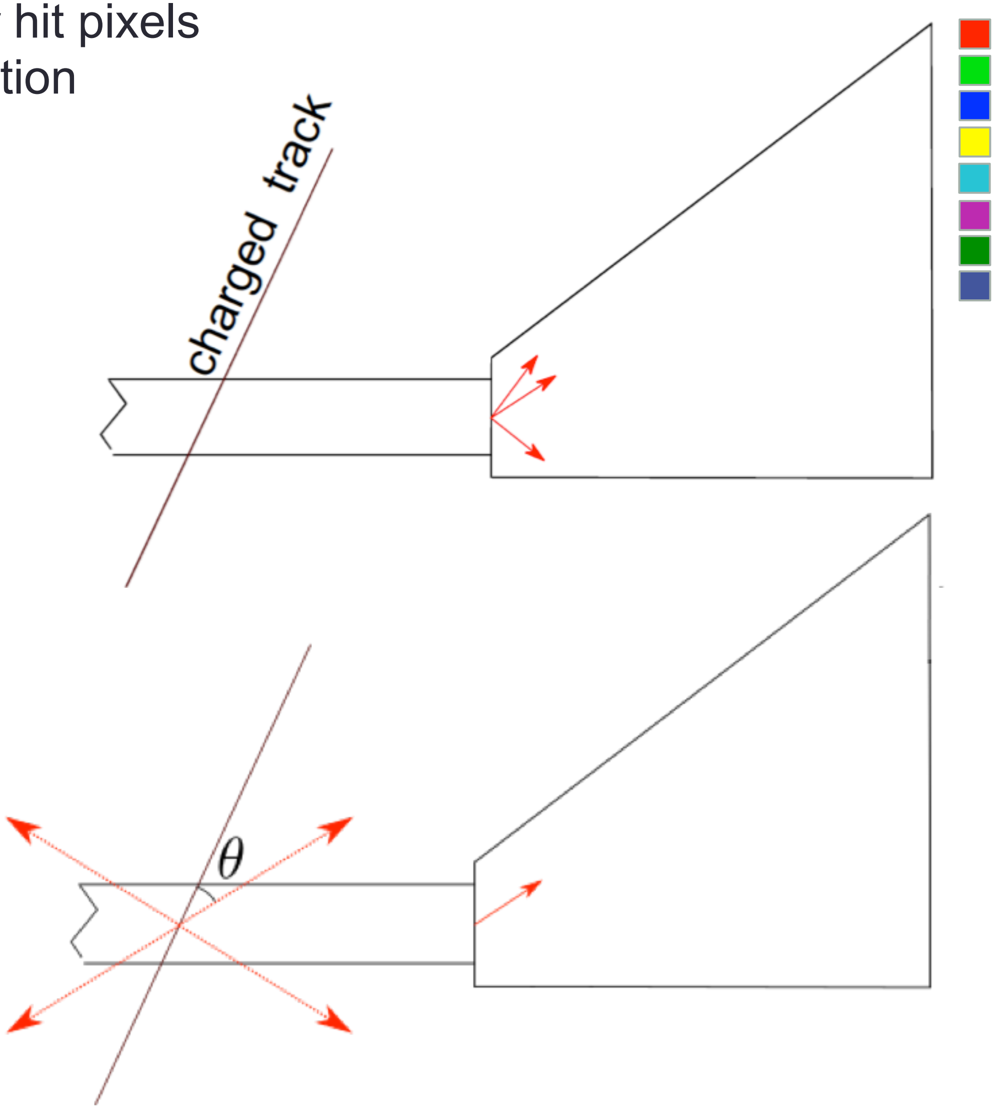

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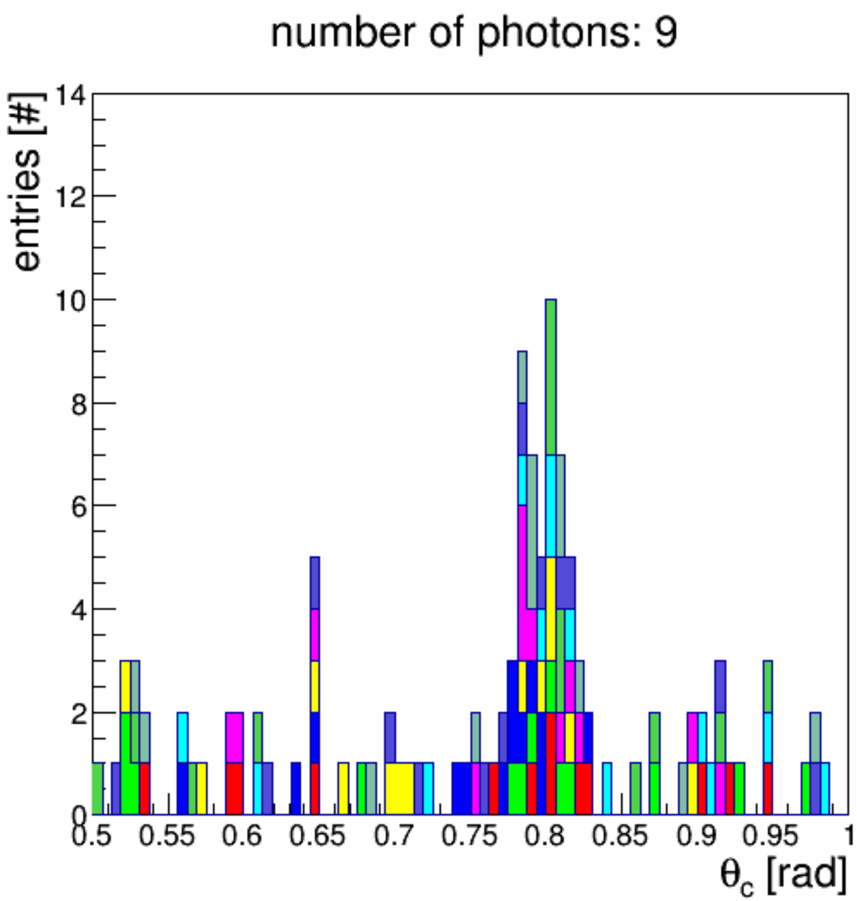

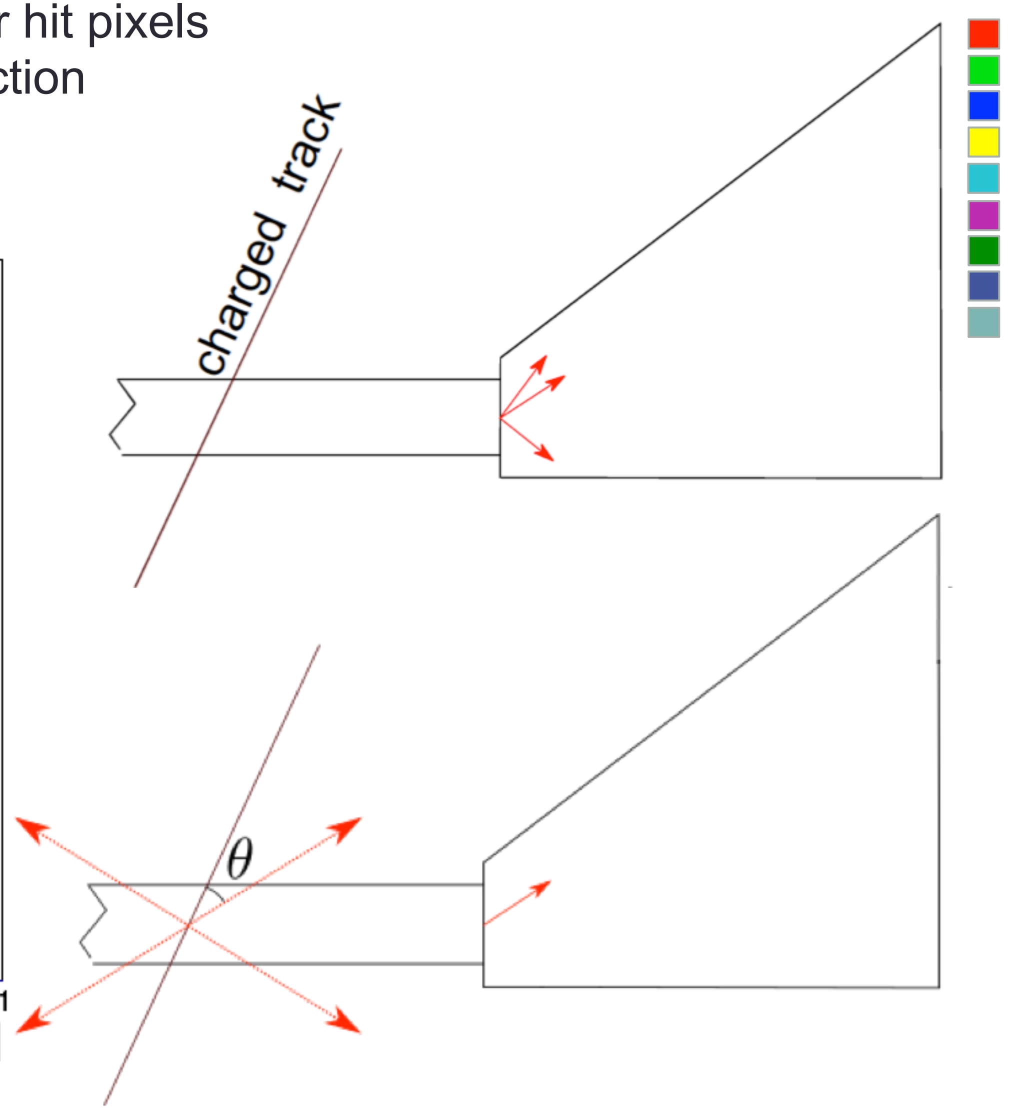

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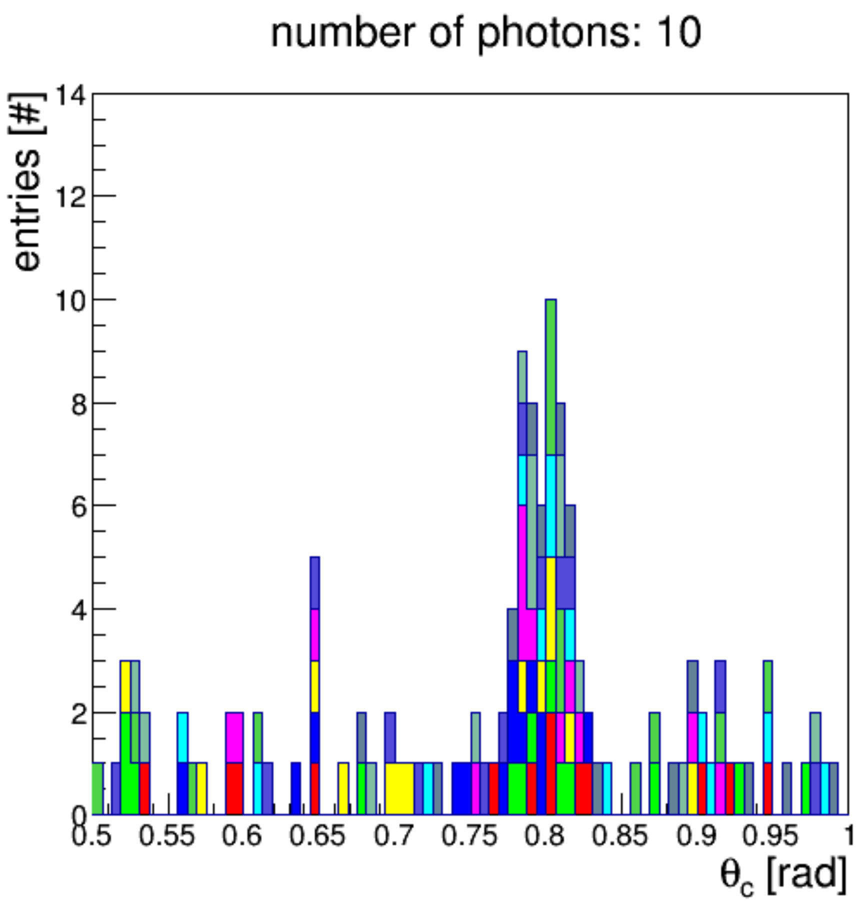

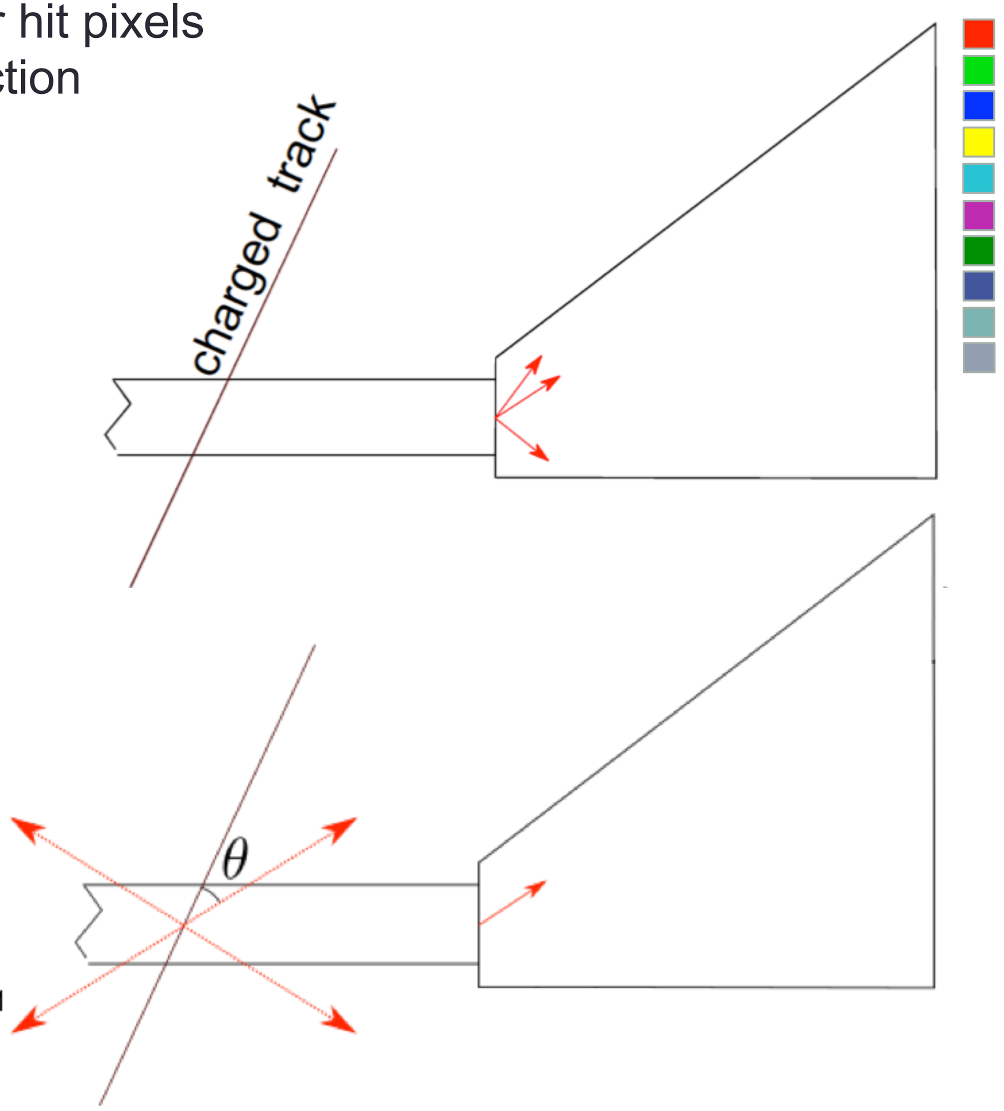

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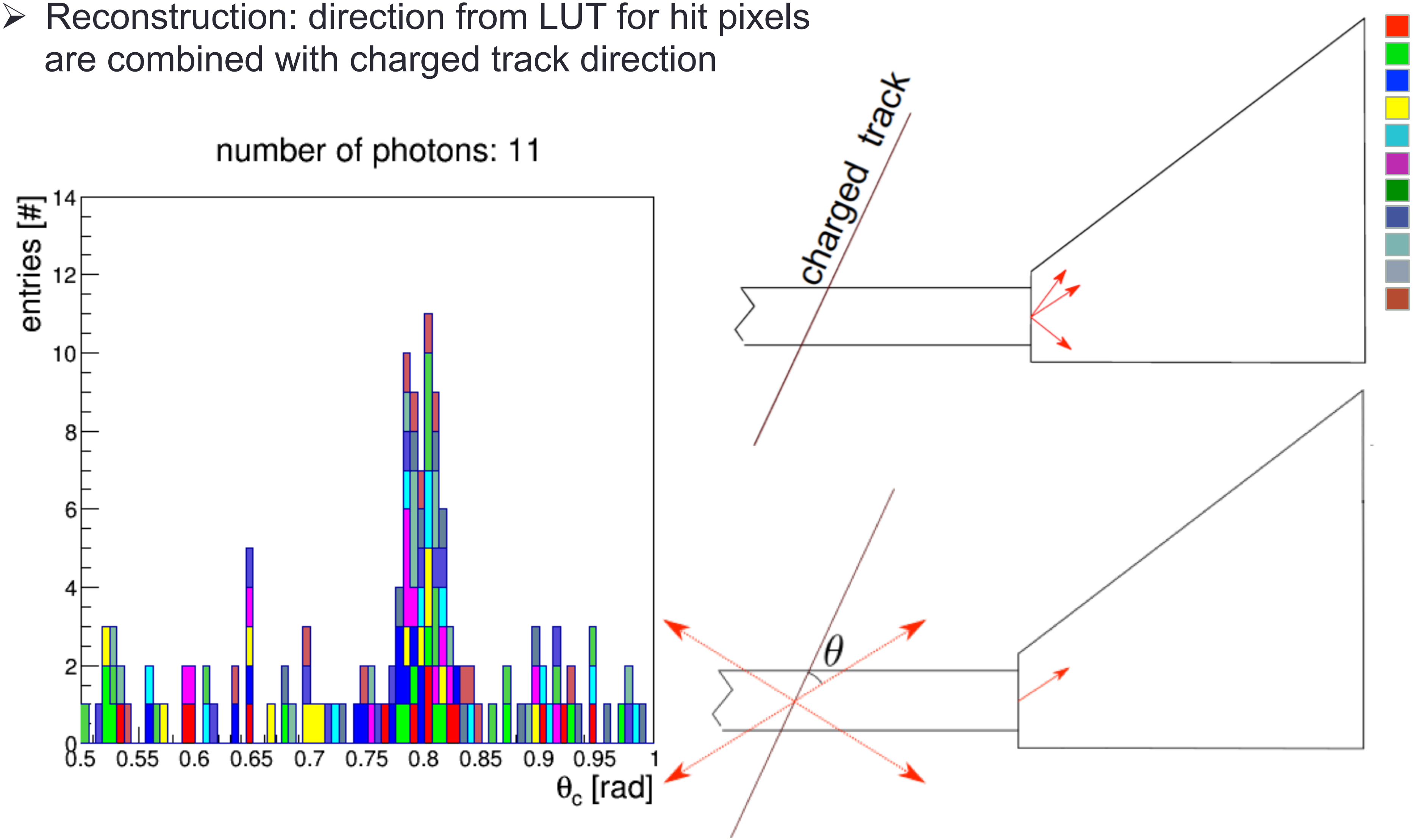

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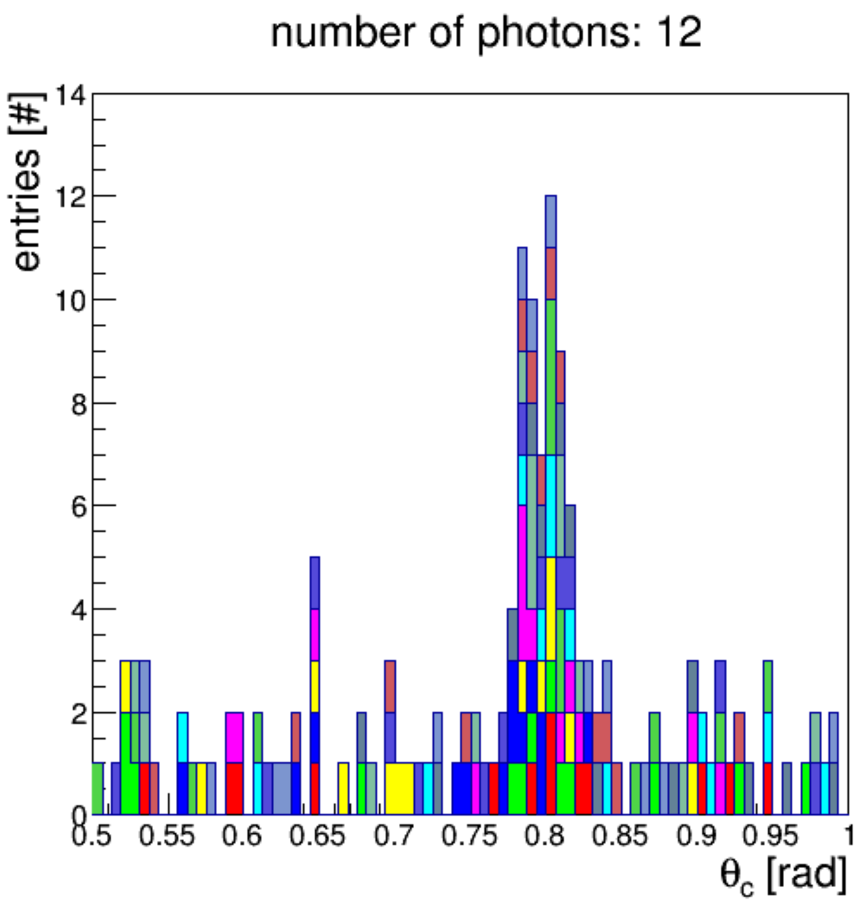

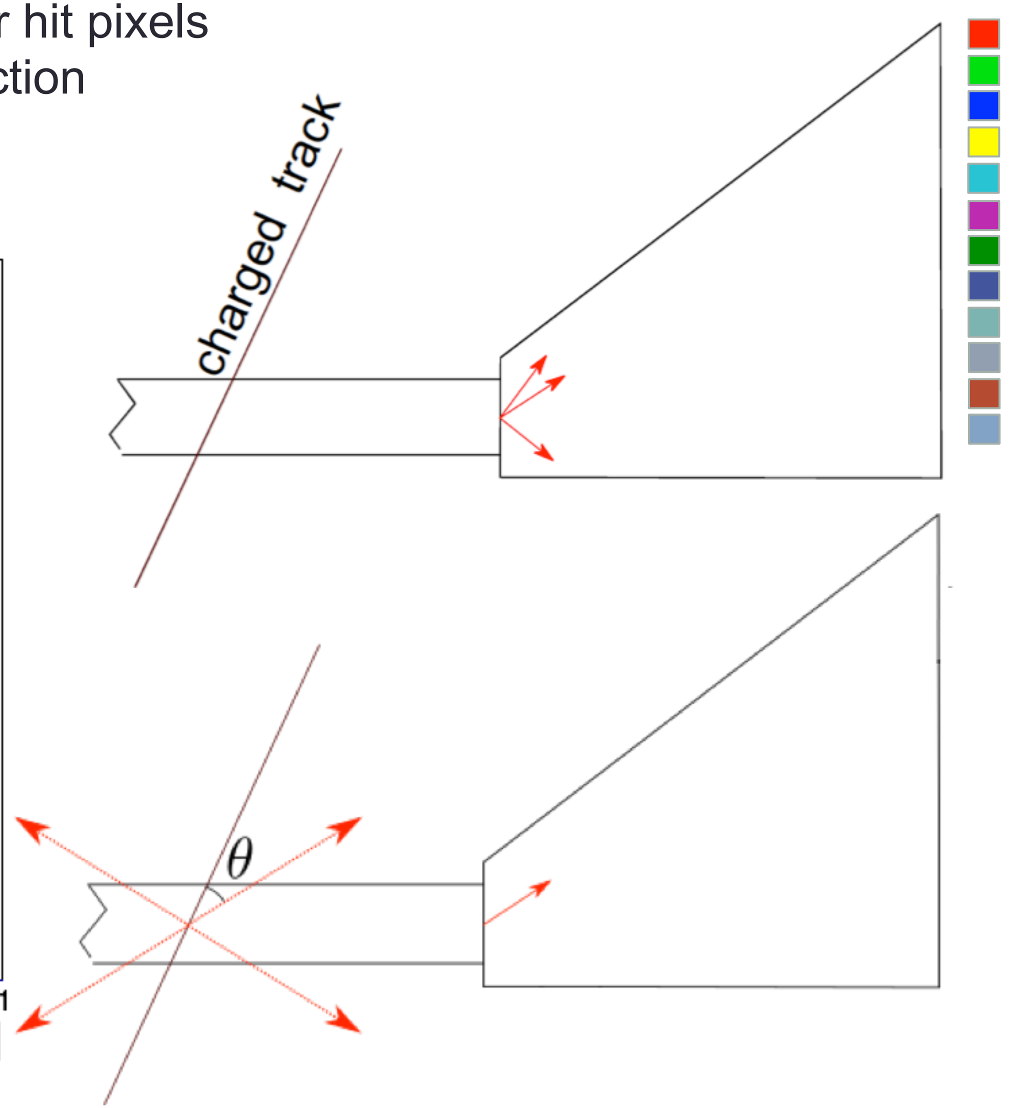

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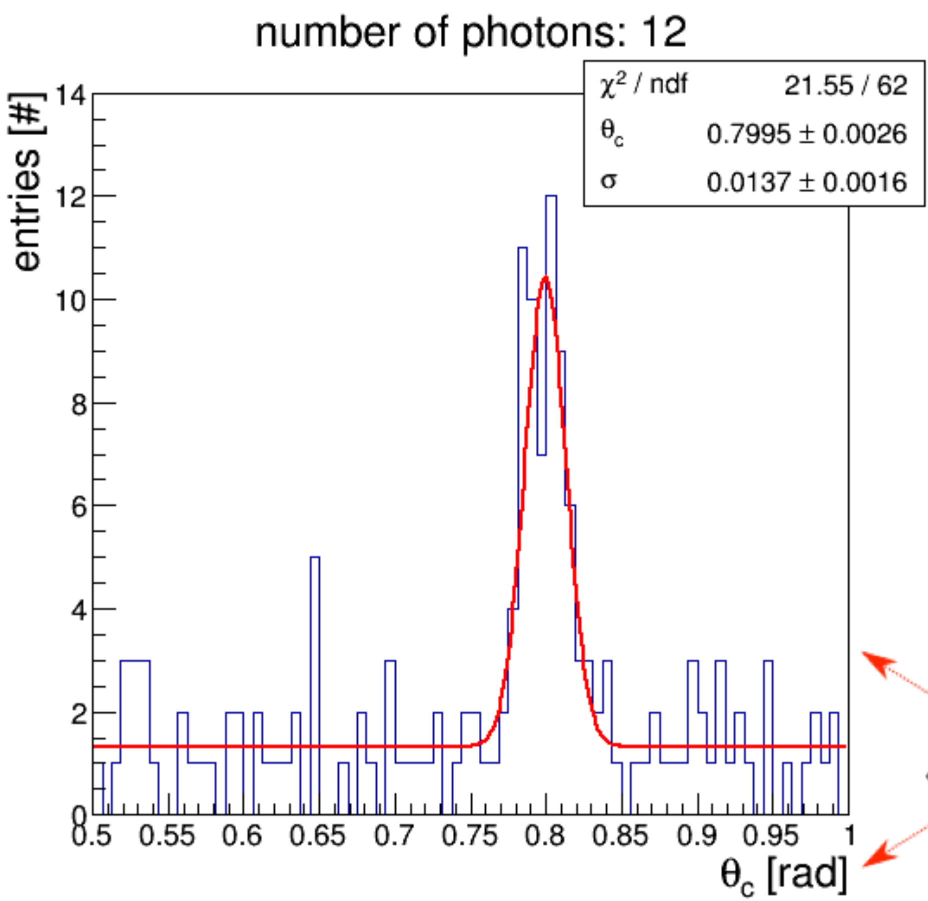
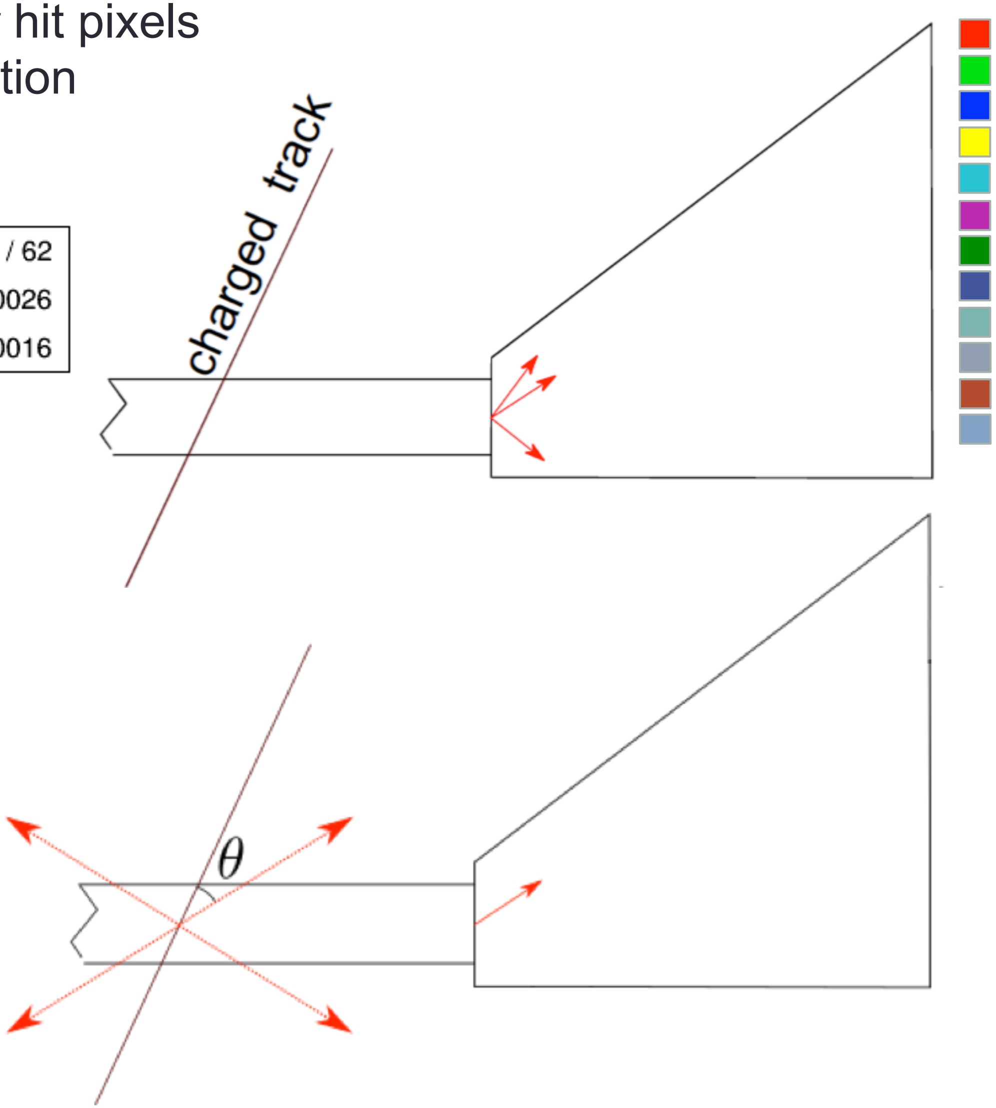
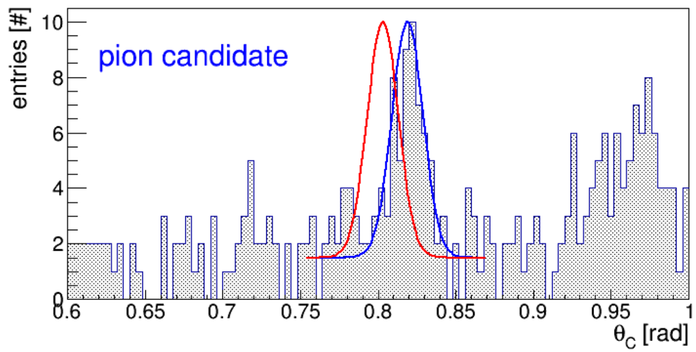


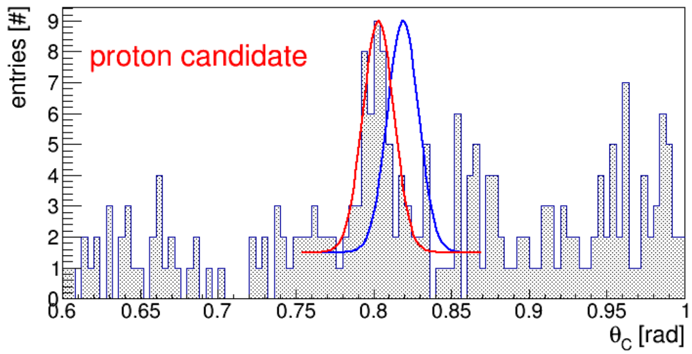


Geometrical Reconstruction

PID evaluation

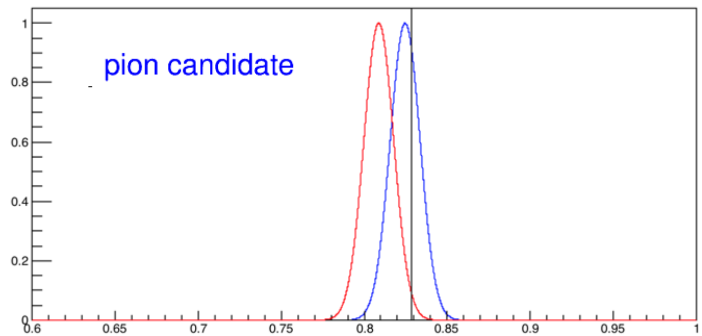
- Track-by-track Cherenkov angle fit likelihood hypotheses test

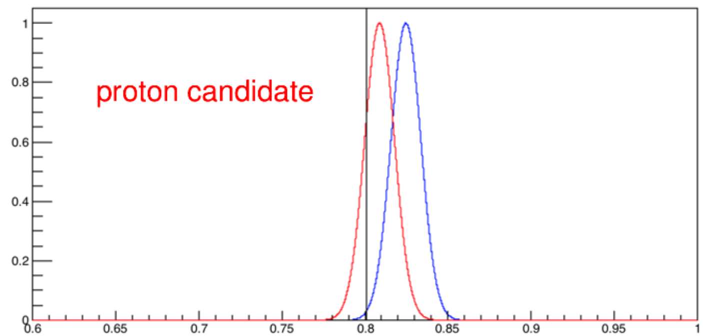




Red and blue lines indicate the expected distribution for the hypotheses.

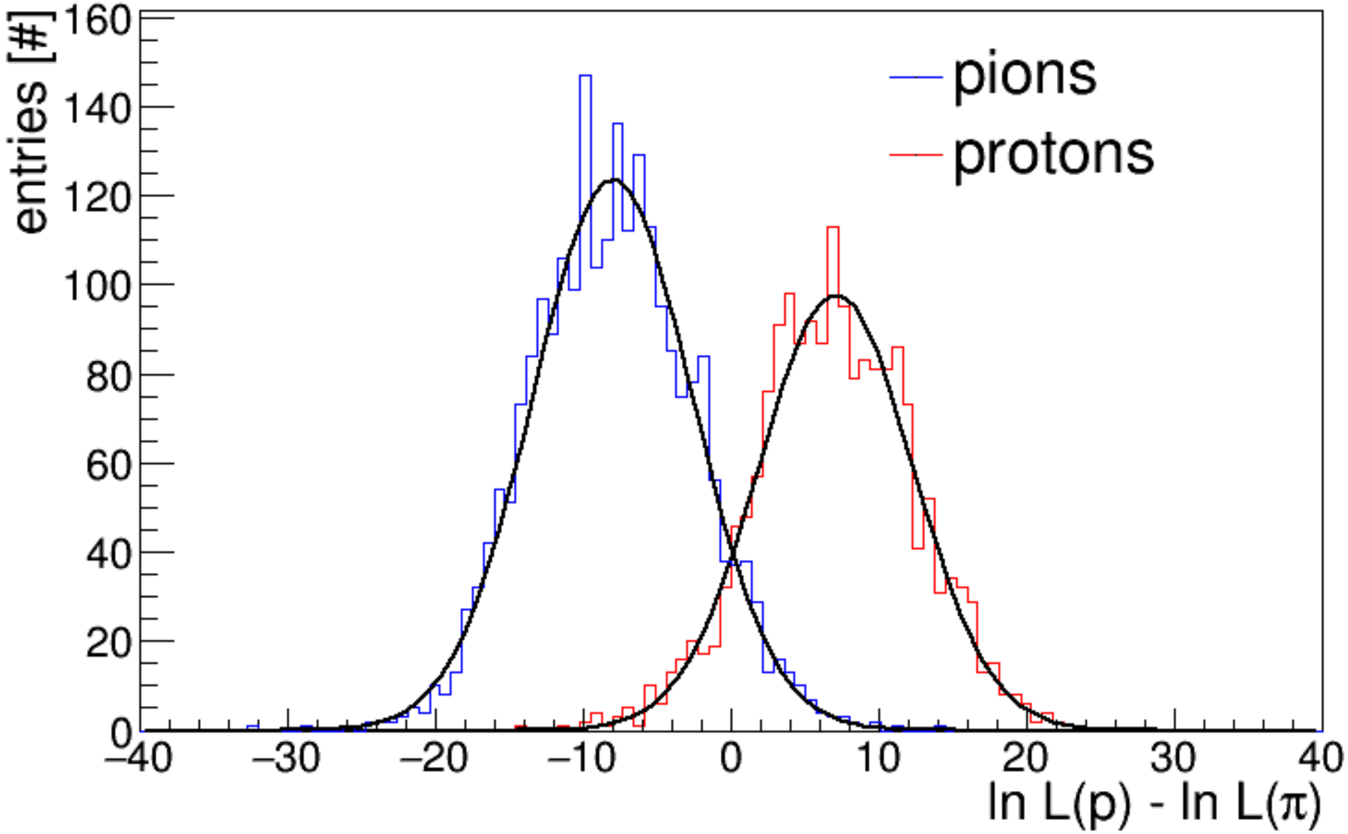
- Track-by-track unbinned likelihood hypotheses test





Expected distribution for the hypotheses at 5 Gev/c

Geometrical Reconstruction



Proton-Pion log-likelihood difference distributions using geometrical reconstruction

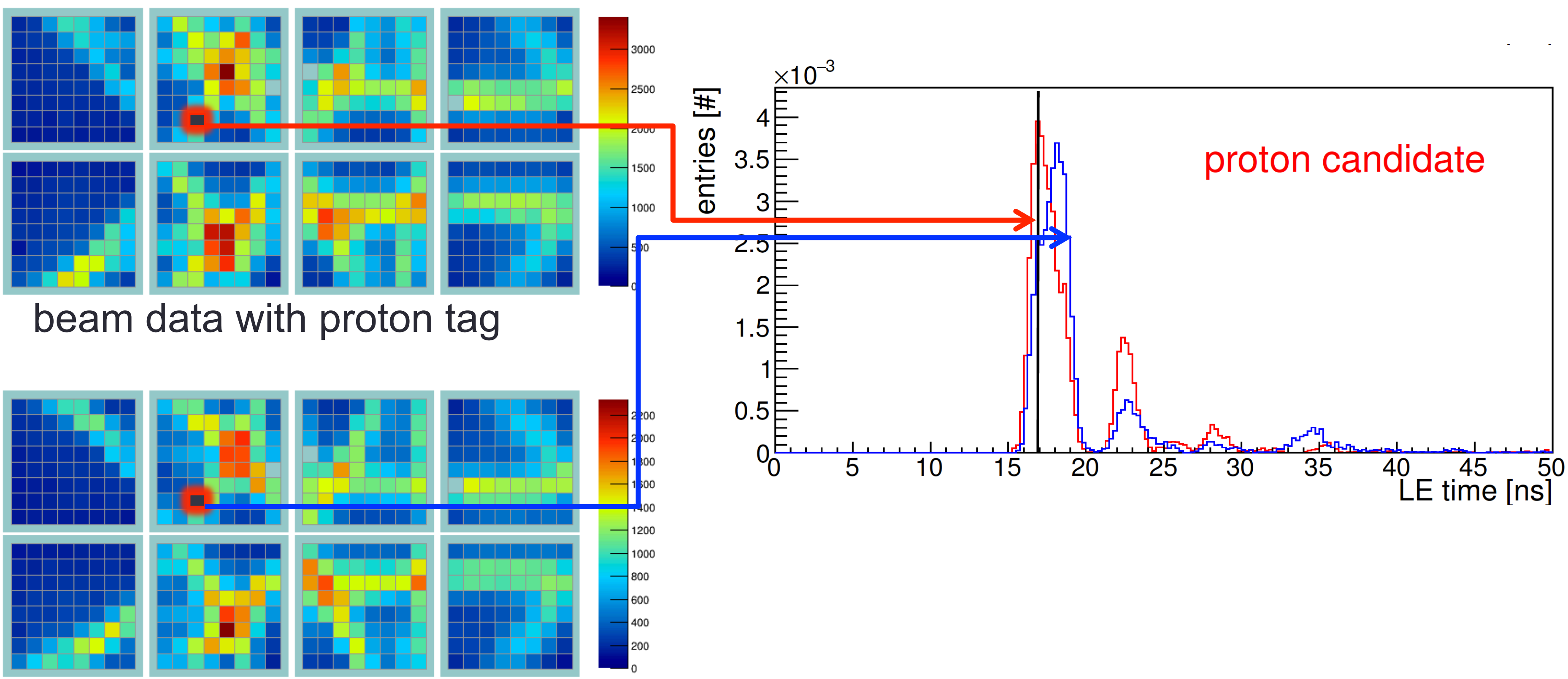
$$\log \mathcal{L}_h = \sum_{i=1}^{N} \sum_{j=1}^{N_i^{amb}} \log\left(S_h^{ij} + B_h^{ij}\right) + \log P_N(N_e),$$

Geometrical Reconstruction

- Day one reco. algorithm for PANDA barrel DIRC
- Less sensitive to time resolution
- Provides likelihoods, Cherenkov angle distribution, SPR, and photon yield.
- Applied to narrow bars
- Depend only on the detector geometry and not on the particle properties
- LUT can be created prior to event reconstruction

Time-based Imaging

- Based on Belle II time-of-propagation (TOP) counter.
- Create PDFs for every pixel and for every particle hypothesis

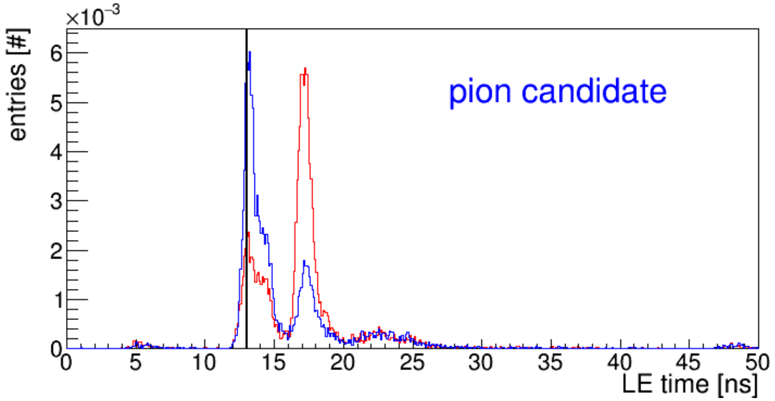


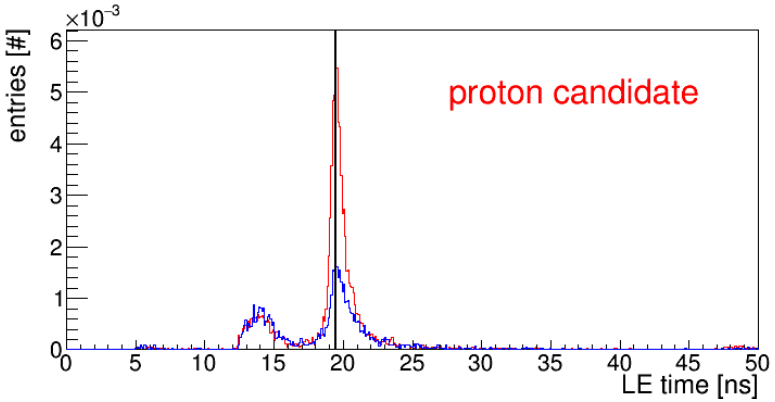
beam data with proton tag

beam data with pion tag

Time-based Imaging

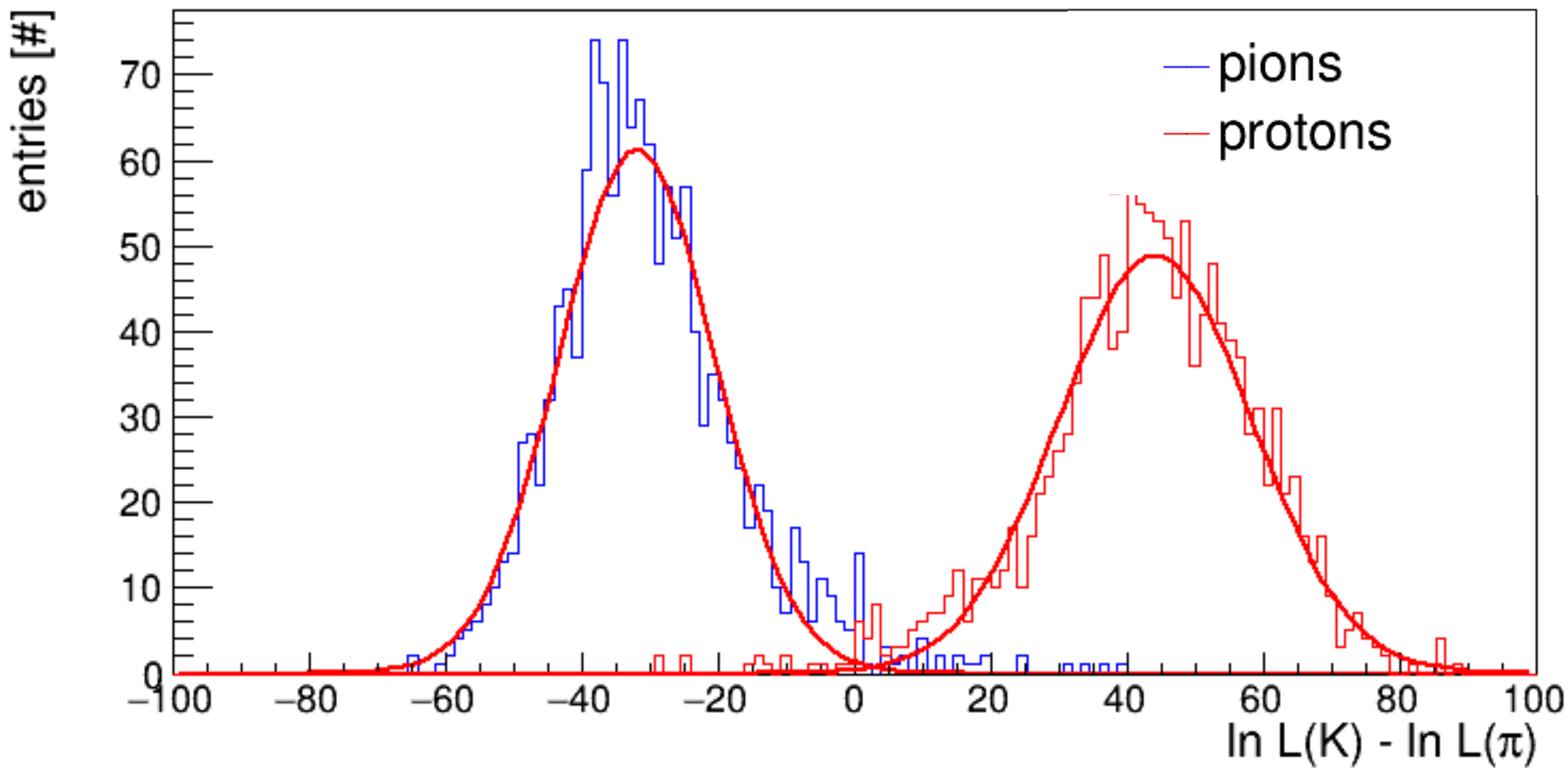
- Measure arrival time of Cherenkov photons in each single event
- Compare to the expected photon arrival time for every pixel and for every particle hypothesis
- Yielding the PID likelihoods.





Expected photon arrival time for a given pixel

Time-based Imaging



Proton-Pion log-likelihood difference distributions using time-based imaging

$$\log \mathcal{L}_h = \sum_{i=1}^{N} \log \Big(S_h(x_i, y_i, t_i) + B_h(x_i, y_i, t_i) \Big) + \log P_N(N_e),$$

Time-based Imaging

PDFs generation challenges:

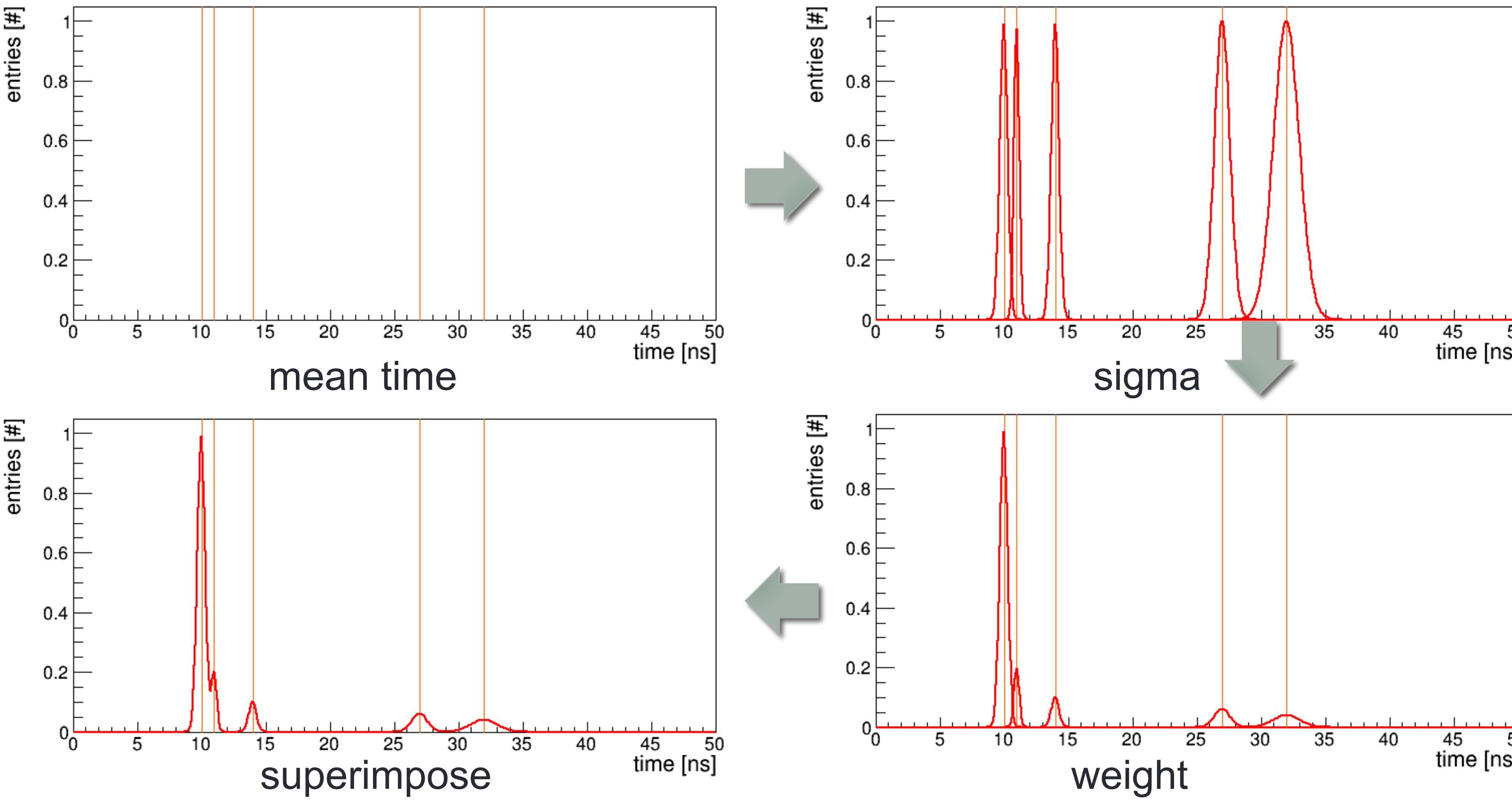
- PDFs creation using either beam data or simulations require large storage capacities

- Require generate a large number of simulated events for every possible:
  - particle direction
  - momentum
  - particle type

- The Belle II TOP group has shown that the timing PDFs can be calculated analytically instead

Time-based Imaging

Example of the analytical PDF



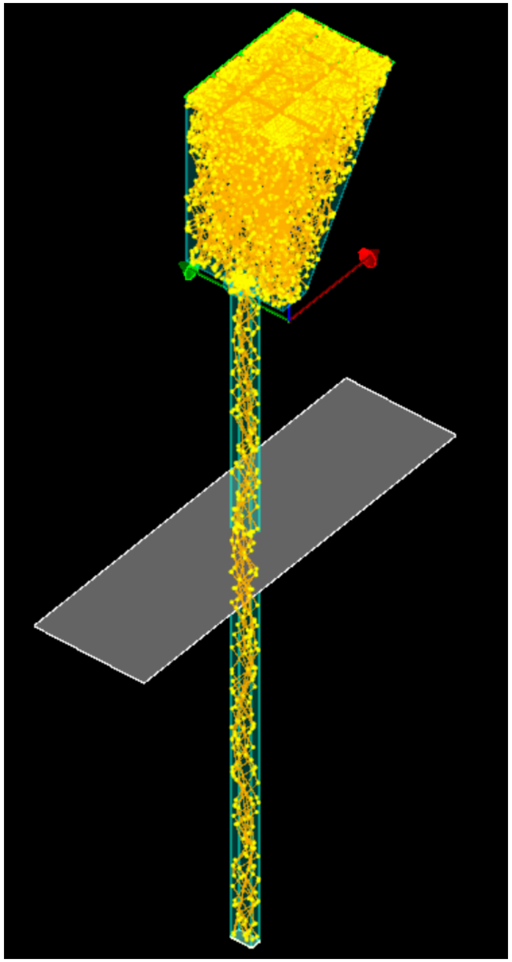
Time-based Imaging

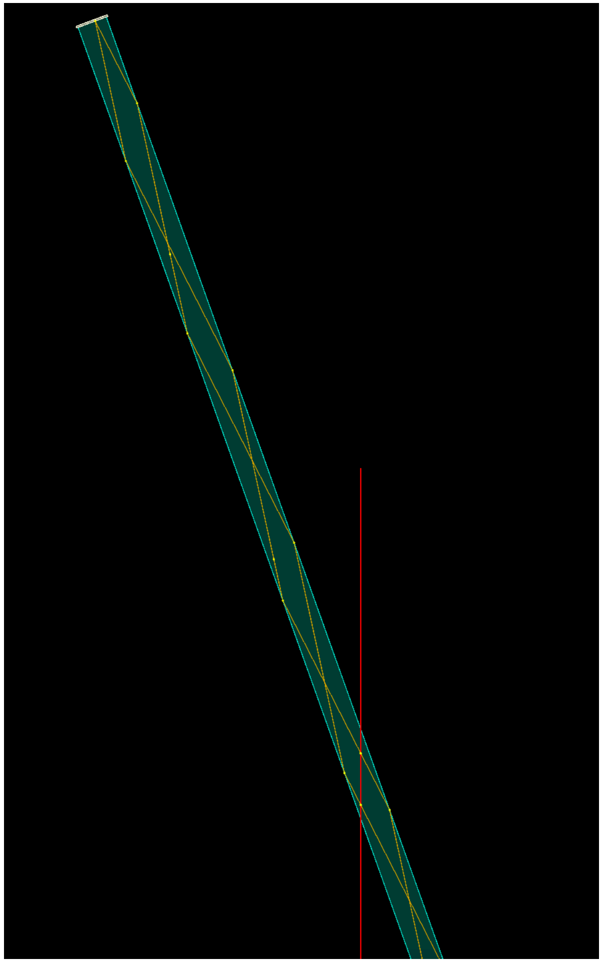
- Performance superior to geometric reconstruction results.
- Require large storage capacities (for PDFs generated by beam data and simulations)
- PDFs can be generated analytically

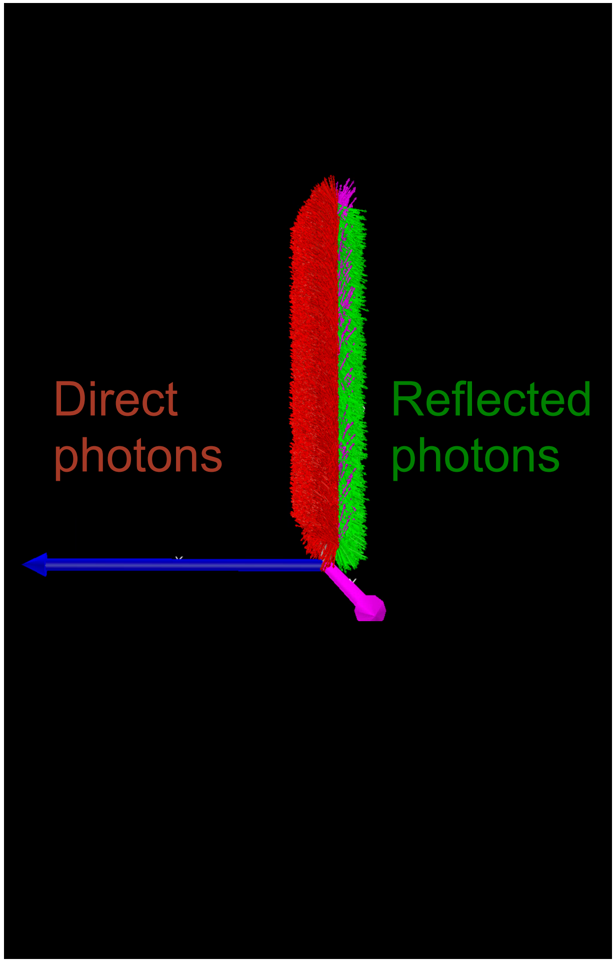
Alternative Methods

Backward Lookup Table

Simulation setup & visualization







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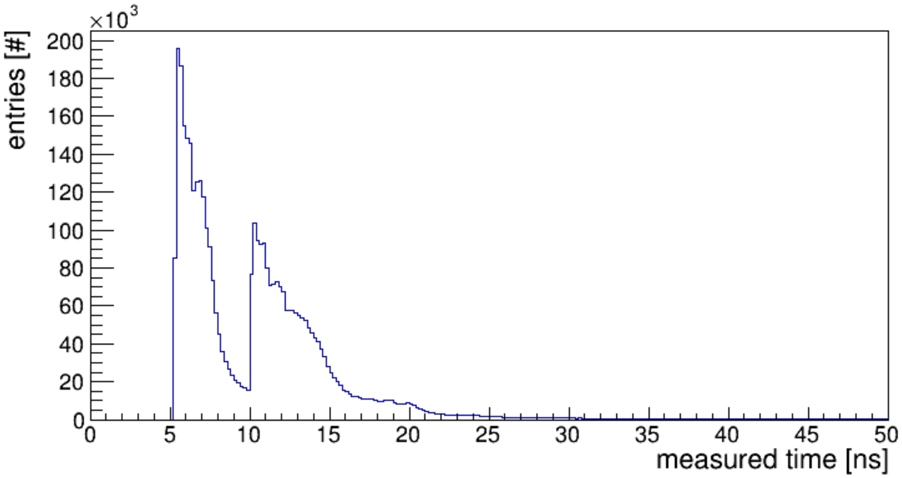
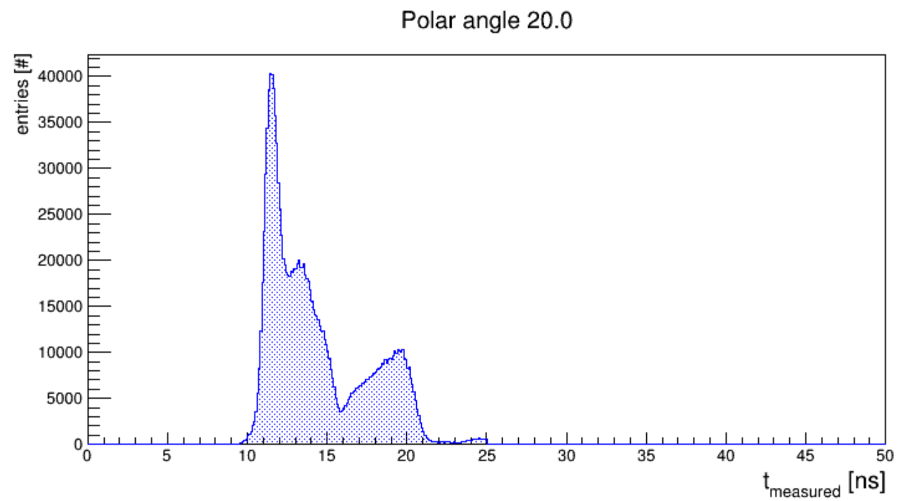
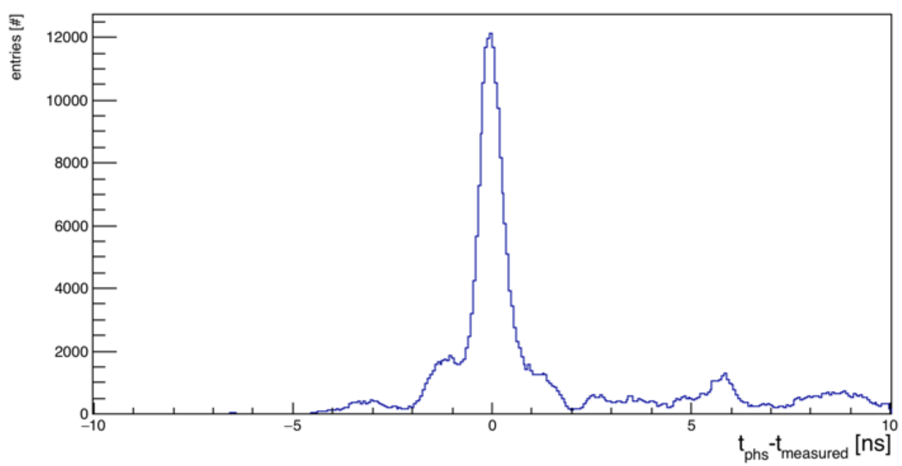


Phase space time distribution



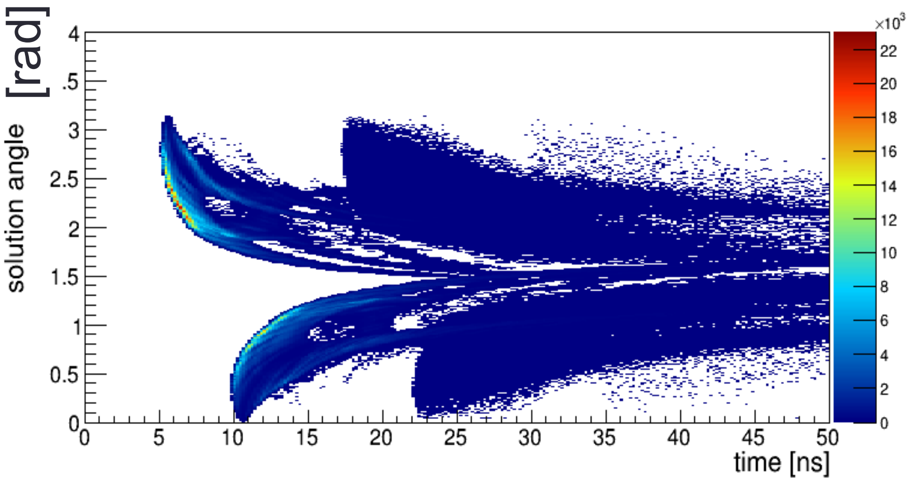
Detected Cherenkov photons time



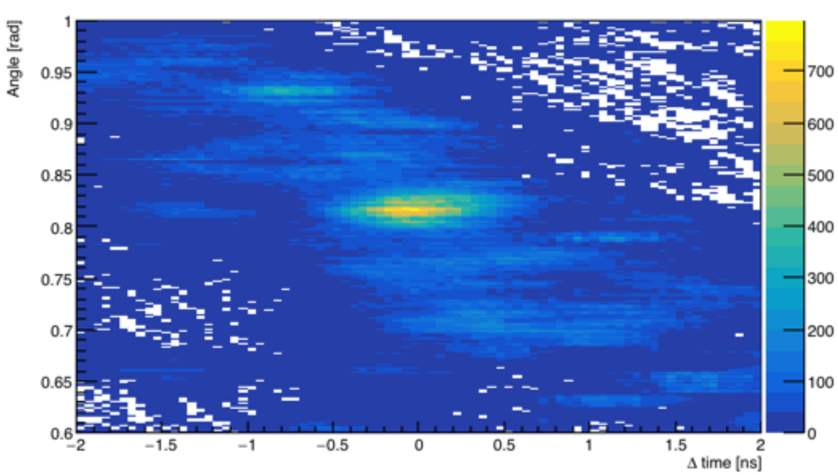
Time difference

Backward Lookup Table

- ➢Matching between Cherenkov photons and Phase Space (PhS) solutions



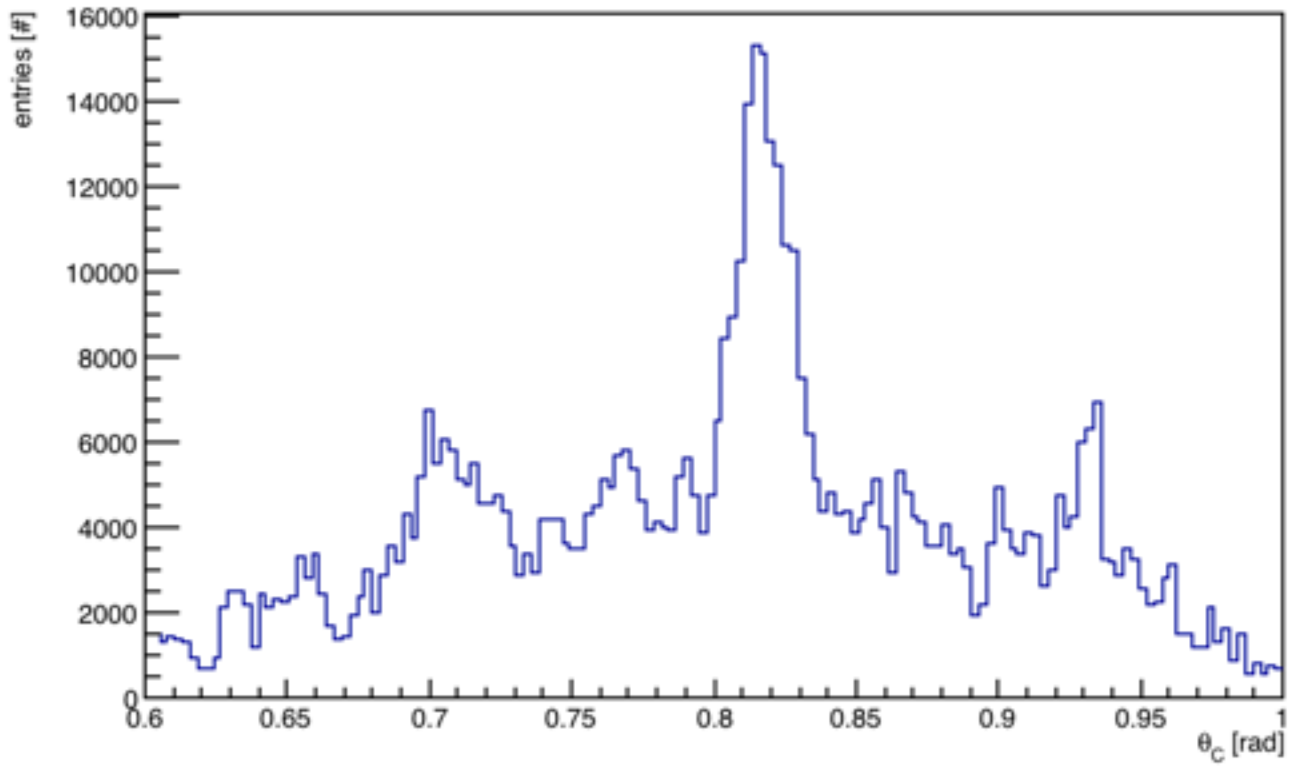
solutions time-angle space



Time difference vs reconstructed angle

Backward Lookup Table

- ➢Reconstructed Cherenkov angle per photon



Reconstructed Cherenkov angle per photon backward lookup table

Backward Lookup Table

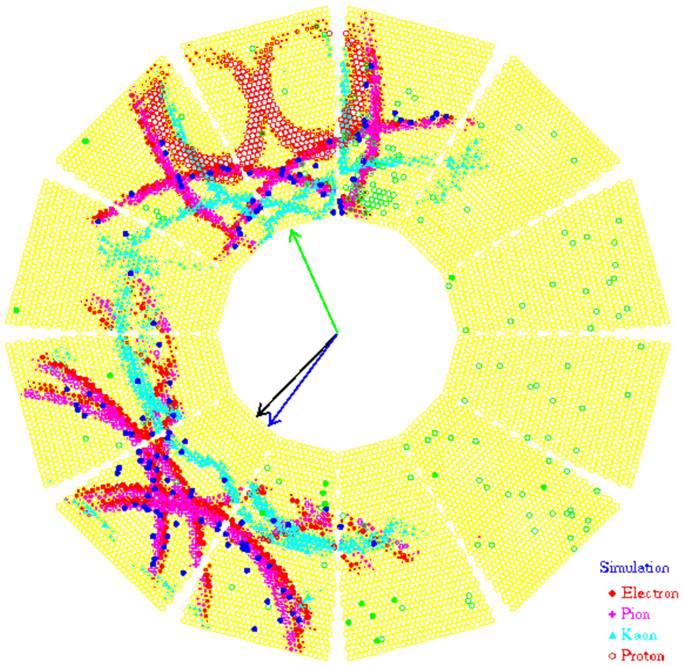
- Geometrical reconstruction method
- Photons generated from each pixel to create backward LUT
- Registered photons information stored in PhS file
- Matching between Cherenkov photons and PhS solutions
- Reconstructed Cherenkov angle is the angle between charged track direction and selected solutions
- Performance close to standard geometrical reconstruction

Alternative method from BaBar

- Calculate unbiased likelihood for observed PMT signals to originate from e/μ/π/K/p track or from background.

  (Likelihood: $\mathbf{Pdf}(\theta_c) \otimes \mathbf{Pdf}(\Delta t) \otimes \mathbf{Pdf}(N_\gamma)$)

- Particle ID is based on log likelihood differences of the five hypotheses.



Example: Comparison of real event to simulated response of DIRC to e/π/K/p.

Summary

Geometrical Reconstruction

- Delivers a measurement of the SPR and the Cherenkov angle of the track and photon yield, important variables for the detector performance studies
- Fast algorithm since the LUTs depend only on the detector geometry and not on the particle properties
- Less sensitive to time resolution
- LUT can be created prior to event reconstruction

Time based imaging

- Performance superior to geometric reconstruction results
- Require large storage capacities
- PDFs can be analytically generated

Alternative method

- Backward LUT introduced
- Provides performance close to the standard LUT method

Thanks For Your Attention