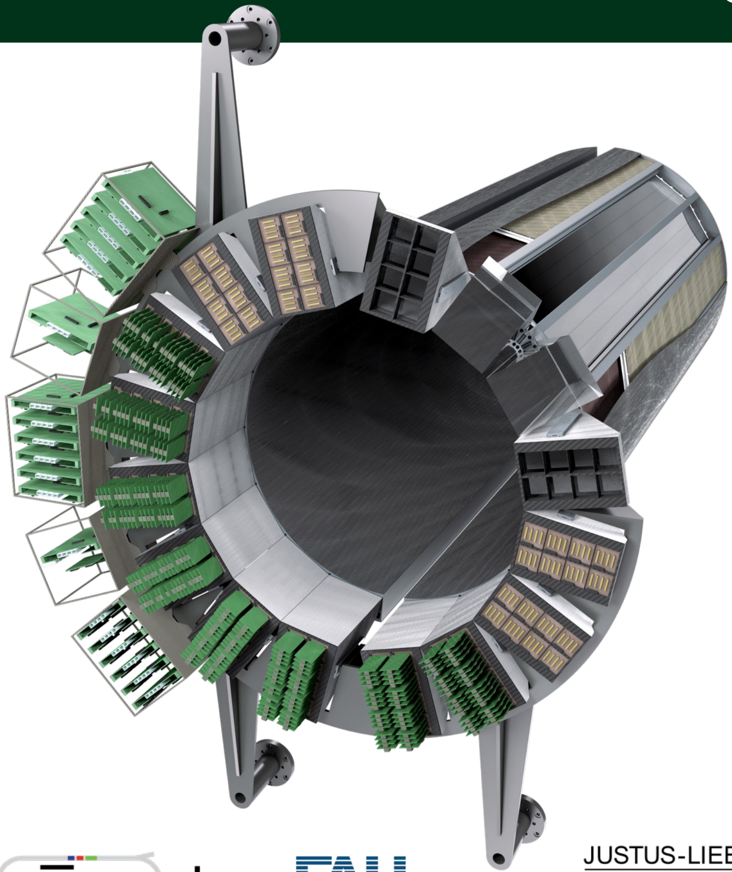
Particle Identification Algorithms for the PANDA Barrel DIRC



CHEP
4-8 Nov 2019,
Adelaide, Australia

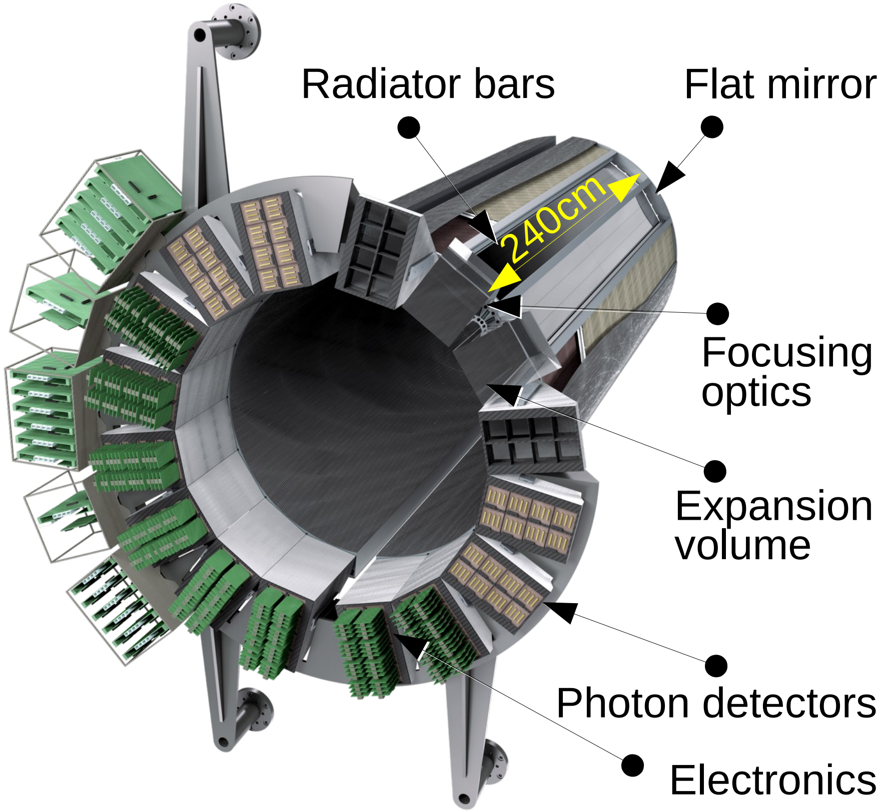
Roman Dzhygadlo
for the PANDA Cherenkov Group

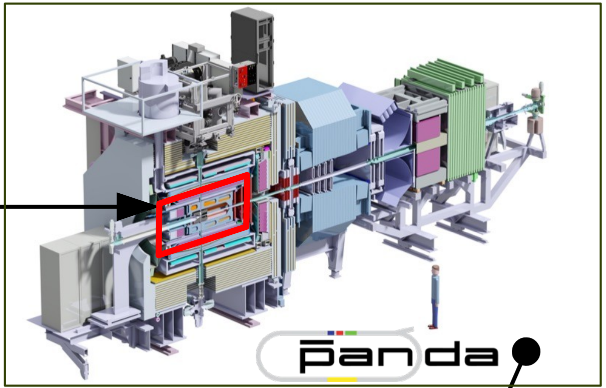
- PANDA Barrel DIRC
- Reconstruction algorithms
- Performance results
- Summary

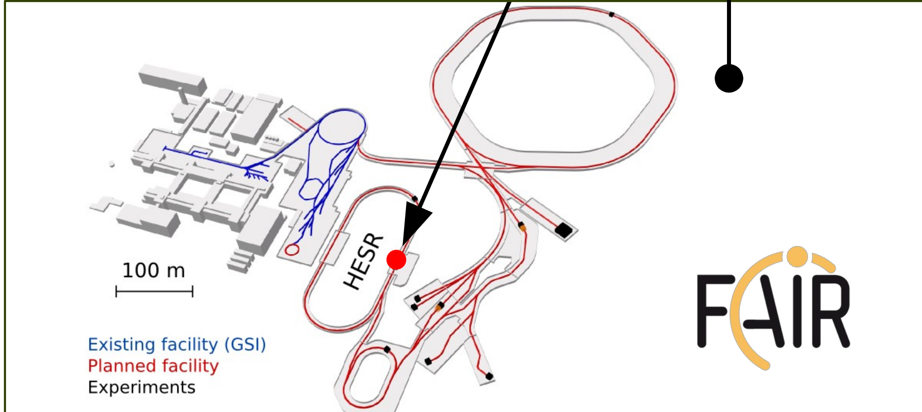
The PANDA Cherenkov Group:

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
GOETHE UNIVERSITÄT FRANKFURT AM MAIN
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
GSI
FAIR

PANDA Barrel DIRC at FAIR



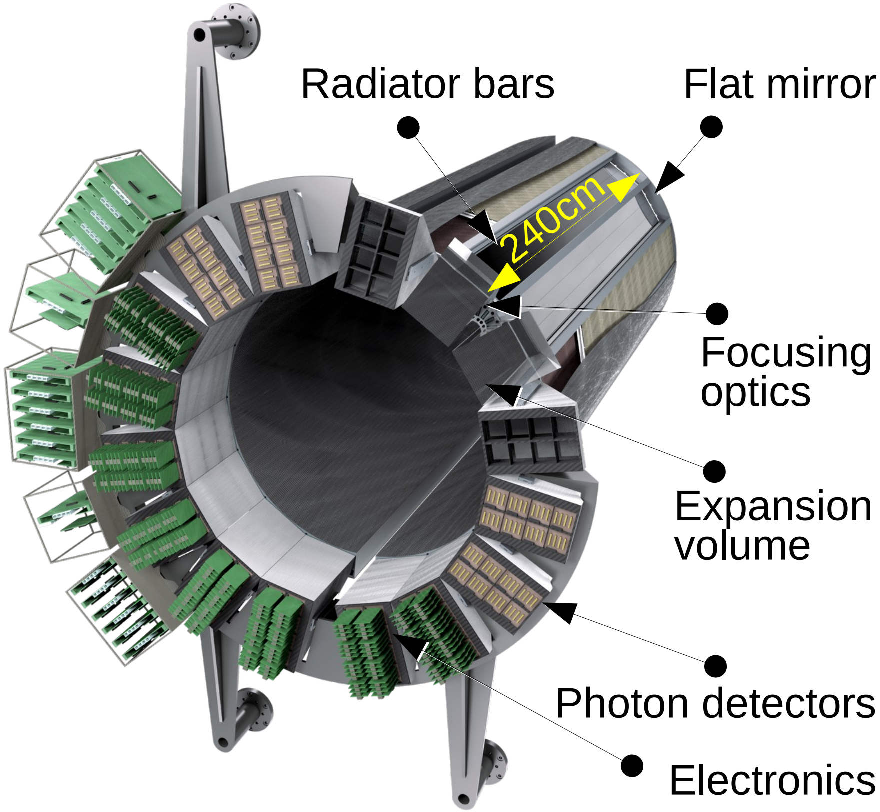




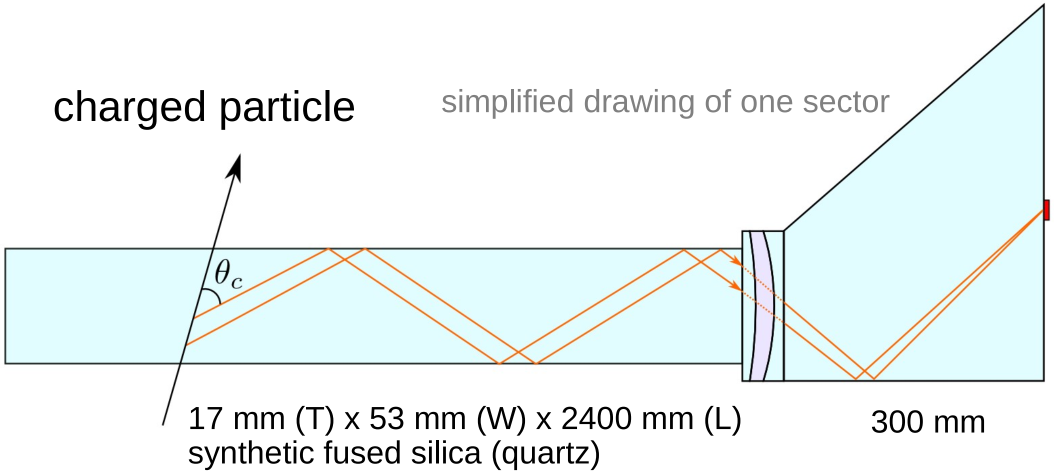
Goal: 3 s.d. π/K separation up to 3.5 GeV/c, 22^{o} - 140^{o}

Facility for Antiproton and Ion Research

PANDA Barrel DIRC



Detection of Internally Reflected Cherenkov Light

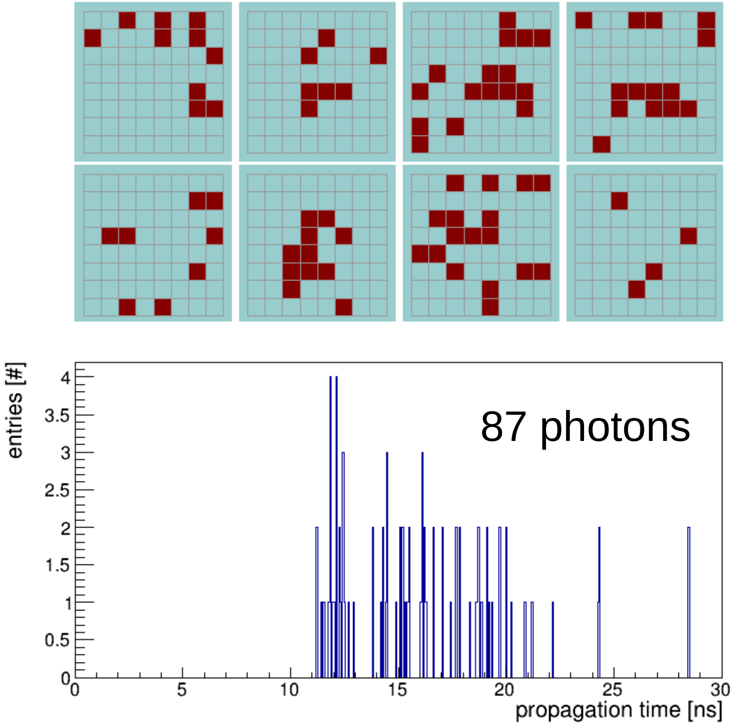


Observables:

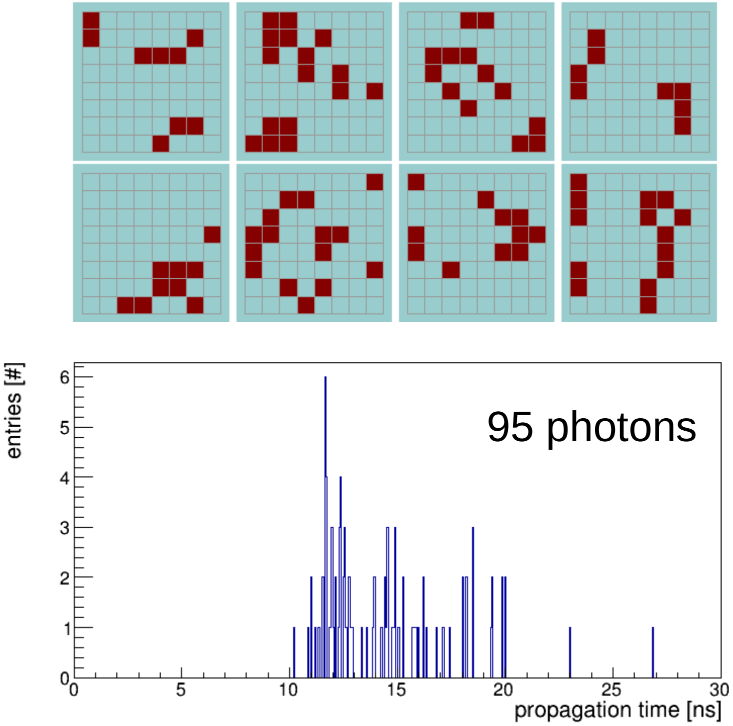
- photon yield
- photon hit position (6x6 mm^2 pixels)
- photon propagation time (~100 ps precision)

Observables

one pion



one kaon



Reconstruction Methods

Geometrical

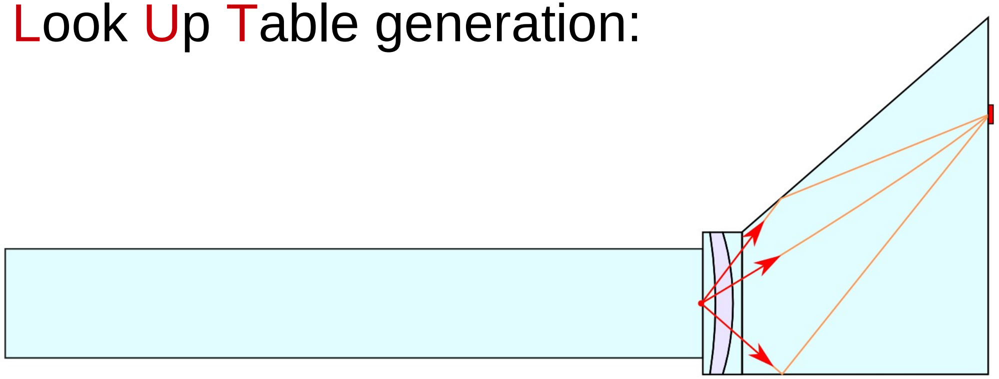
- BABAR-like
- Uses Look-Up Tables
- Delivers Cherenkov angle per particle and Single Photon Resolution (useful for calibration)
- Does not depend on precise time measurement

Time Imaging

- Belle II TOP-like
- Uses Probability Density Functions
- Most optimal use of position and time information

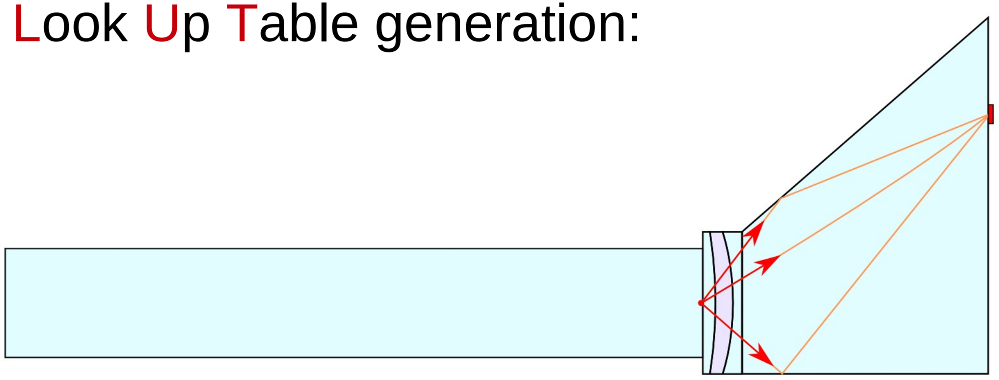
Geometrical Reconstruction

Look Up Table generation:

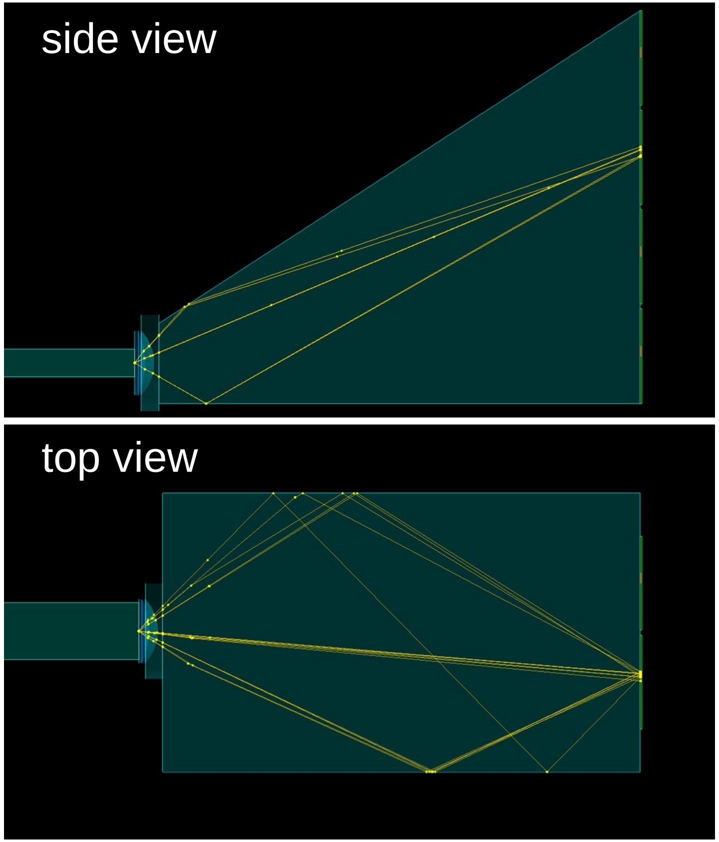


Geometrical Reconstruction

Look Up Table generation:

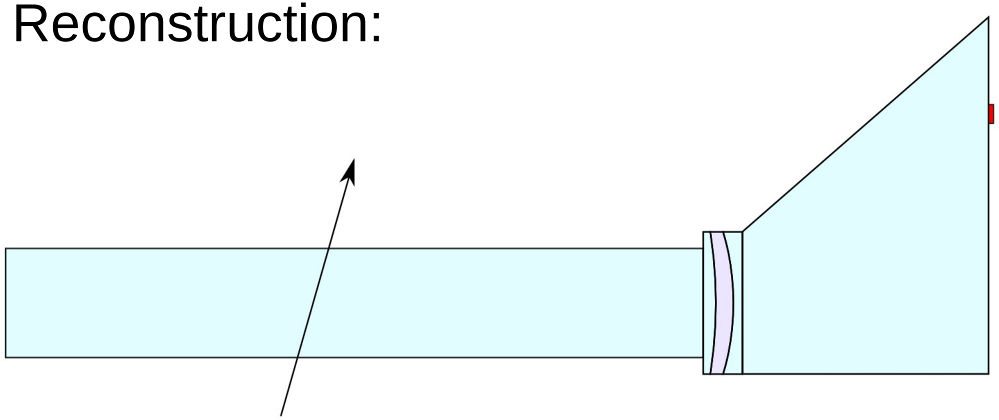


Geant4 simulation of LUT for channel 312:



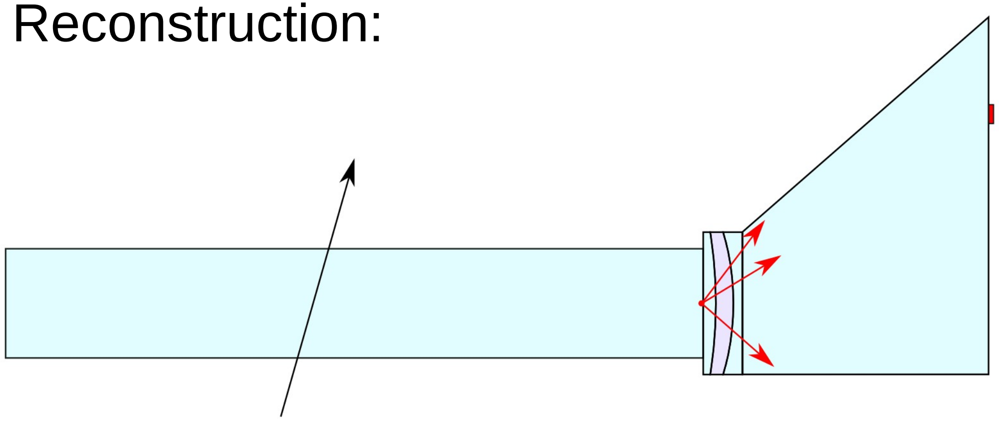
Geometrical Reconstruction

Reconstruction:



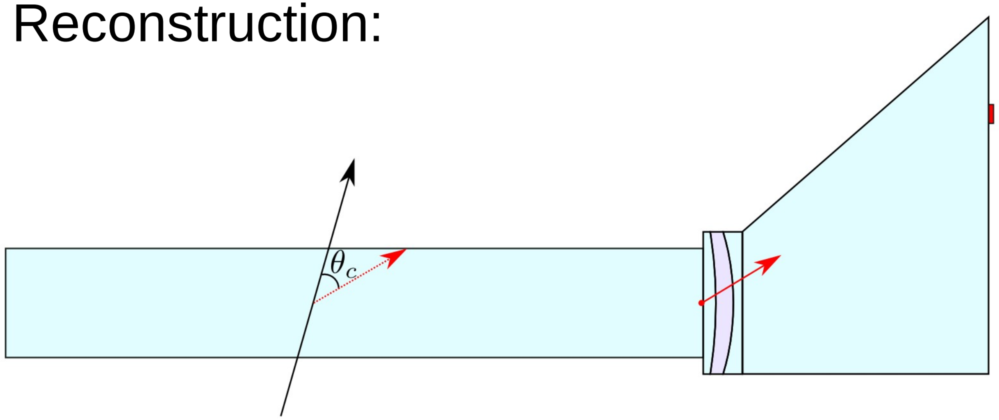
Geometrical Reconstruction

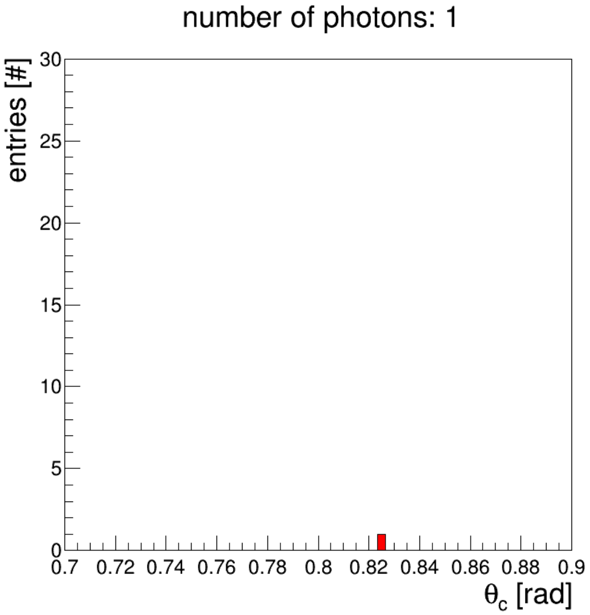
Reconstruction:



Geometrical Reconstruction

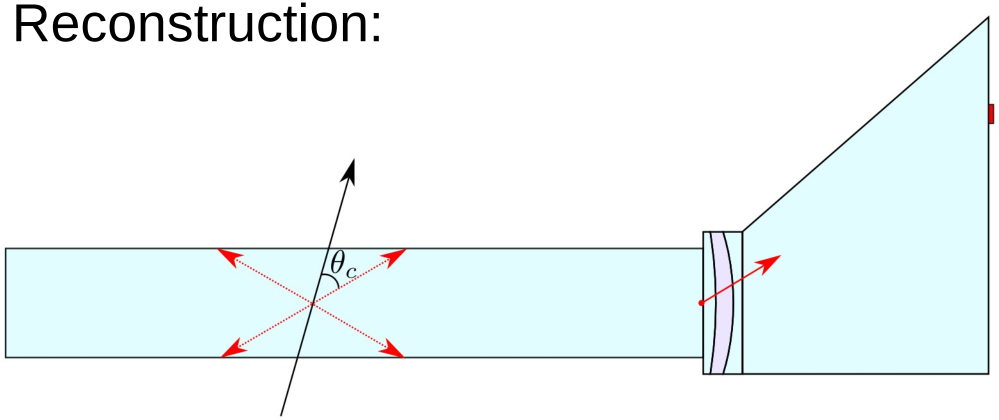
Reconstruction:

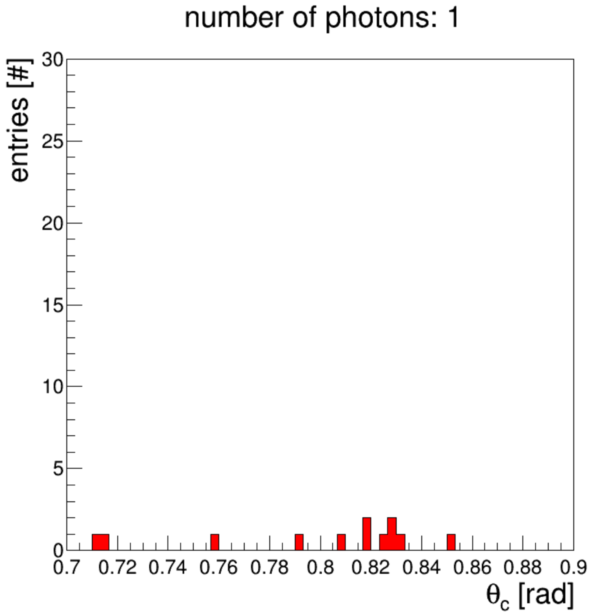




Geometrical Reconstruction

Reconstruction:





Geometrical Reconstruction

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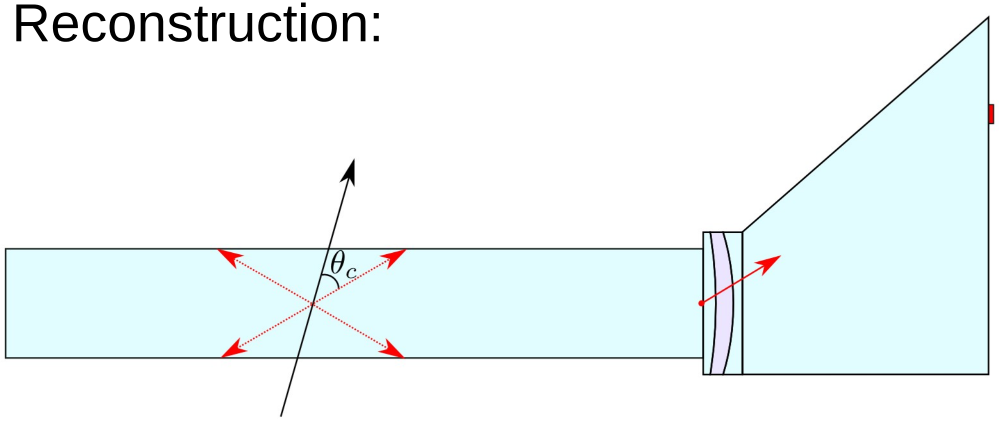

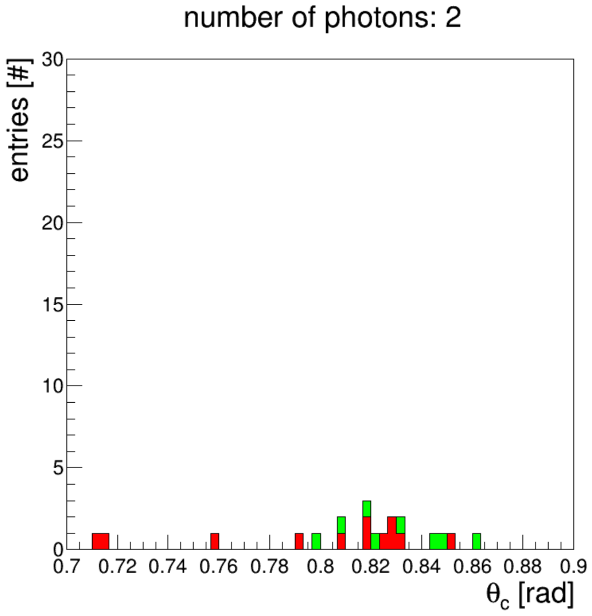

Geometrical Reconstruction

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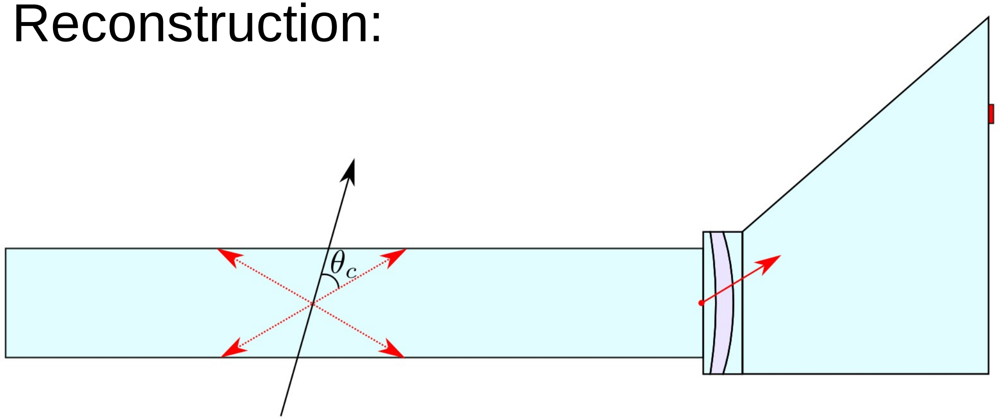

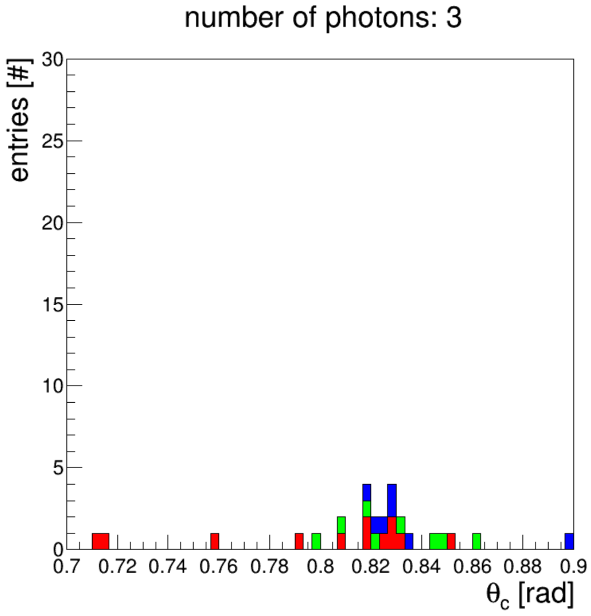

Geometrical Reconstruction

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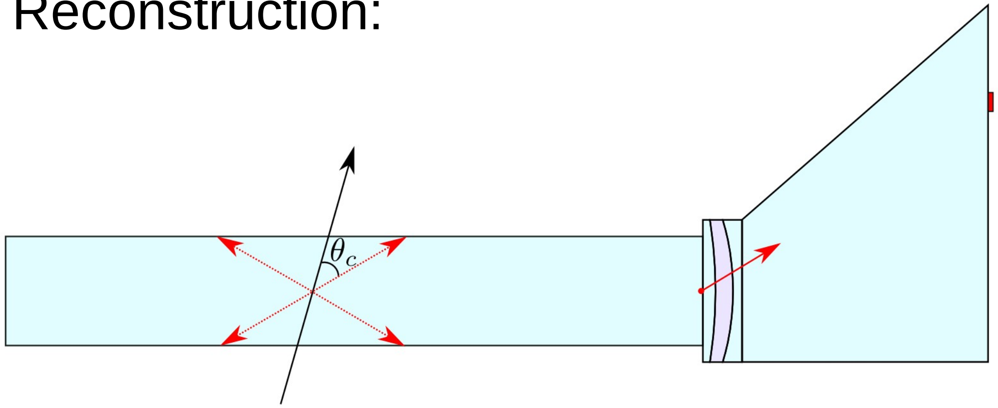
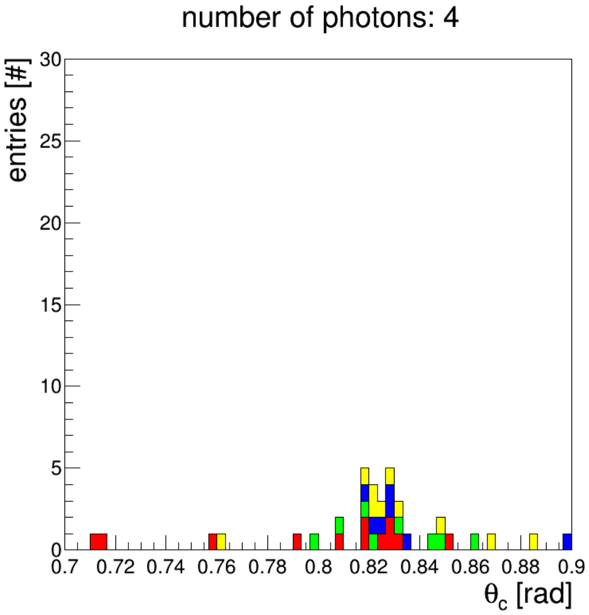
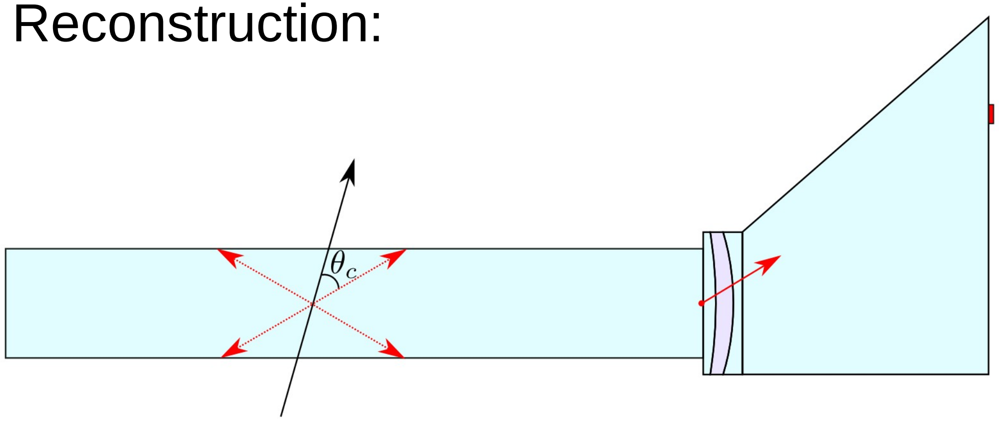
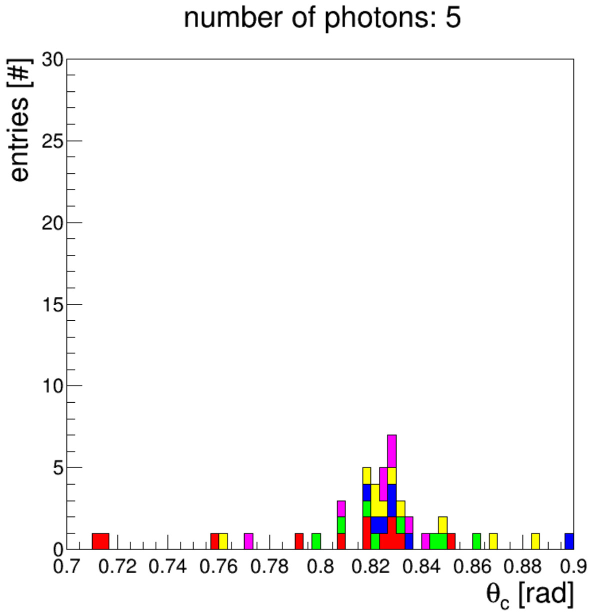




Geometrical Reconstruction

Reconstruction:





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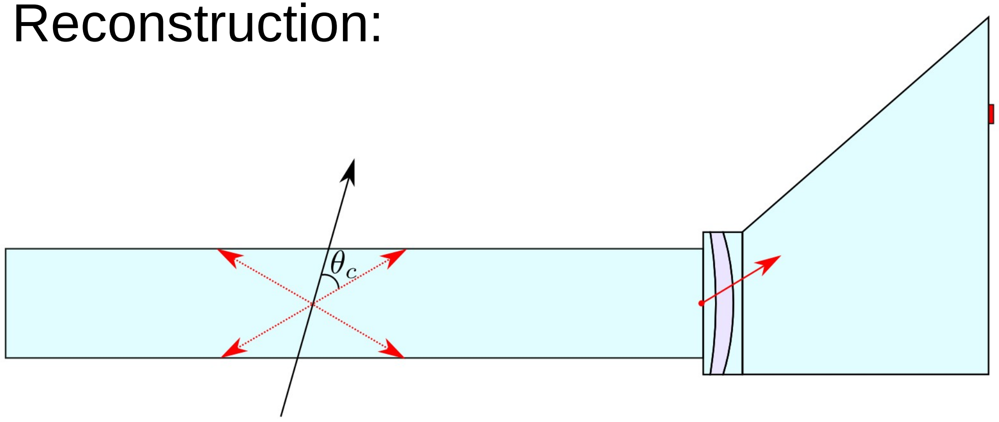
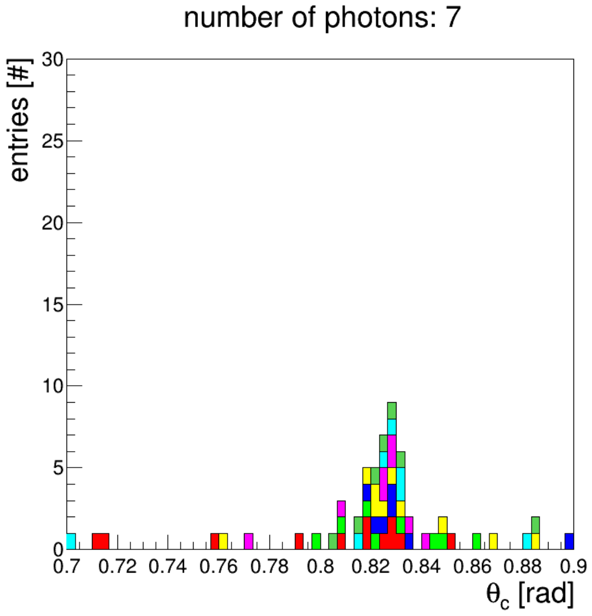
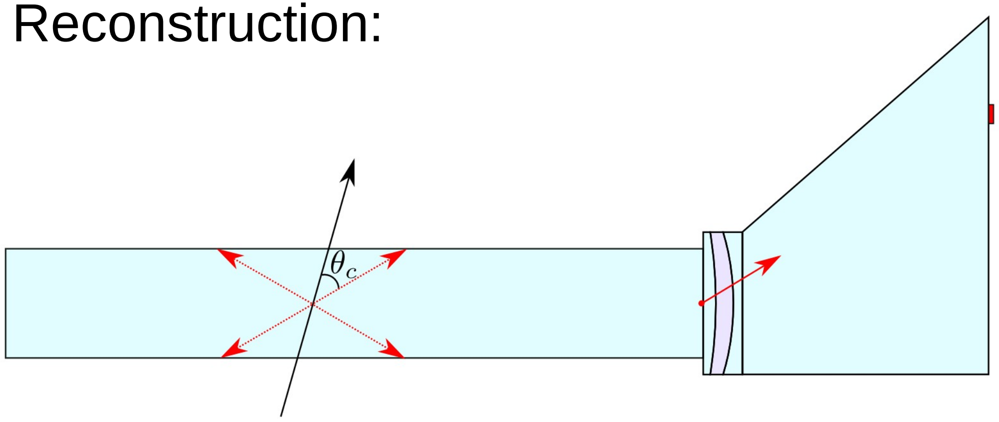
Reconstruction:

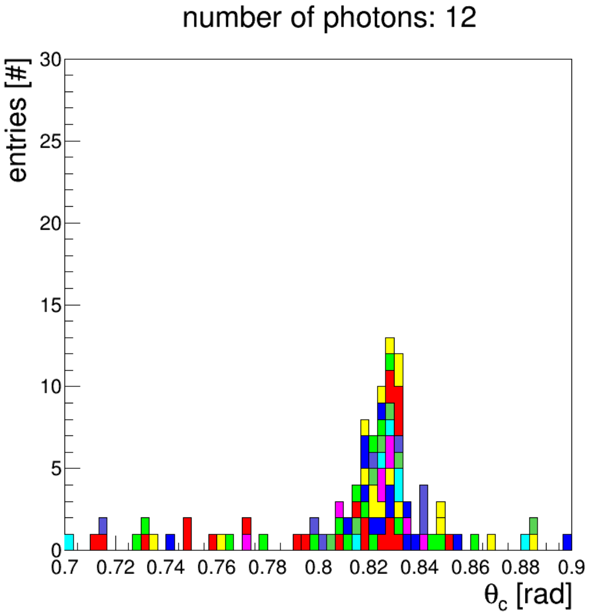




Geometrical Reconstruction

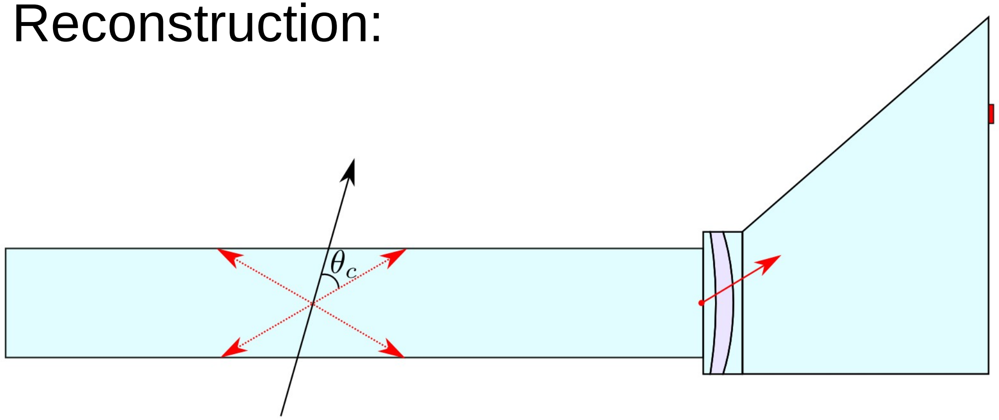
Reconstruction:

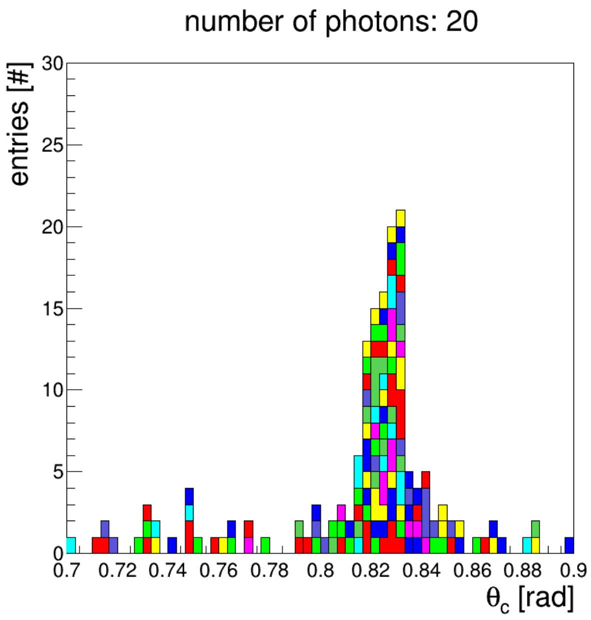




Geometrical Reconstruction

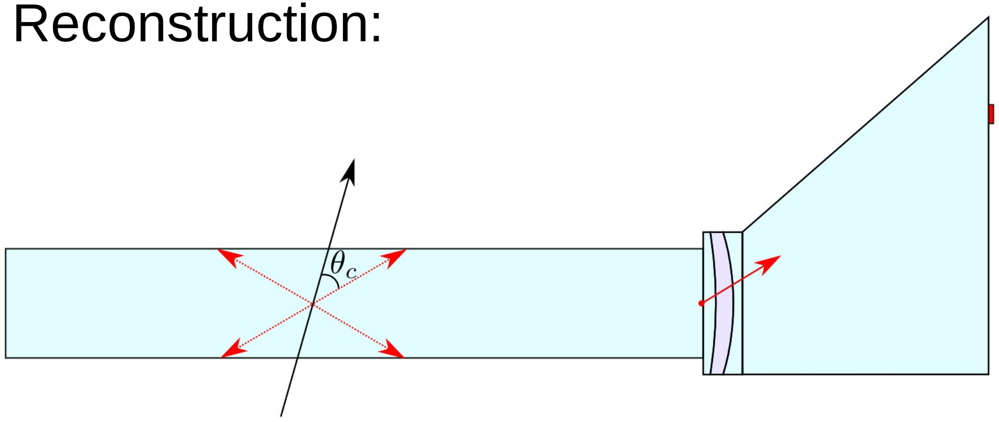
Reconstruction:

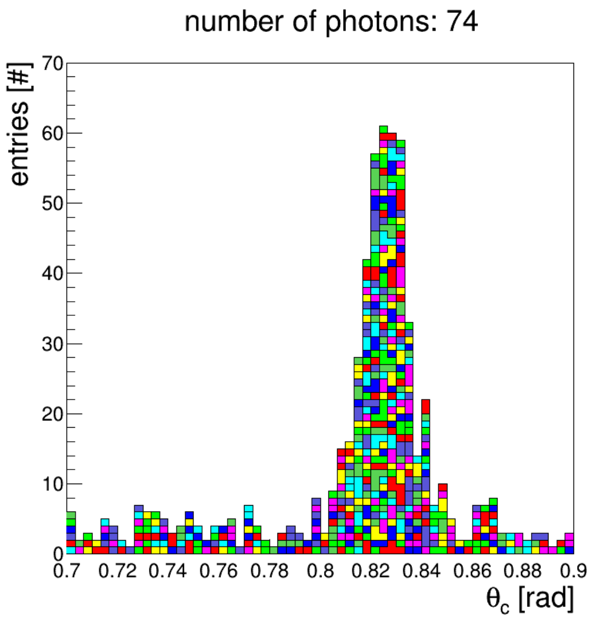




Geometrical Reconstruction

Reconstruction:





Geometrical Reconstruction

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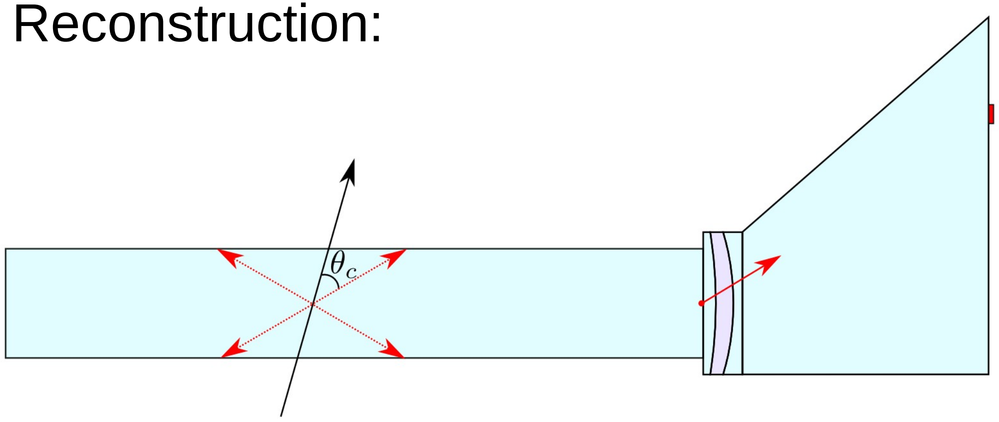
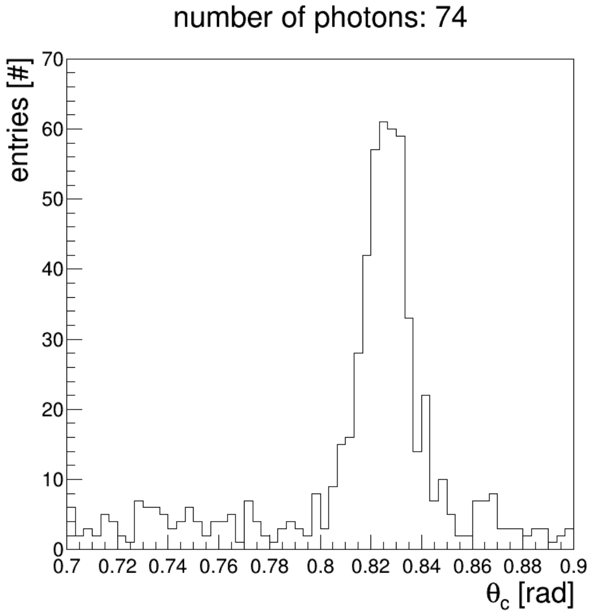
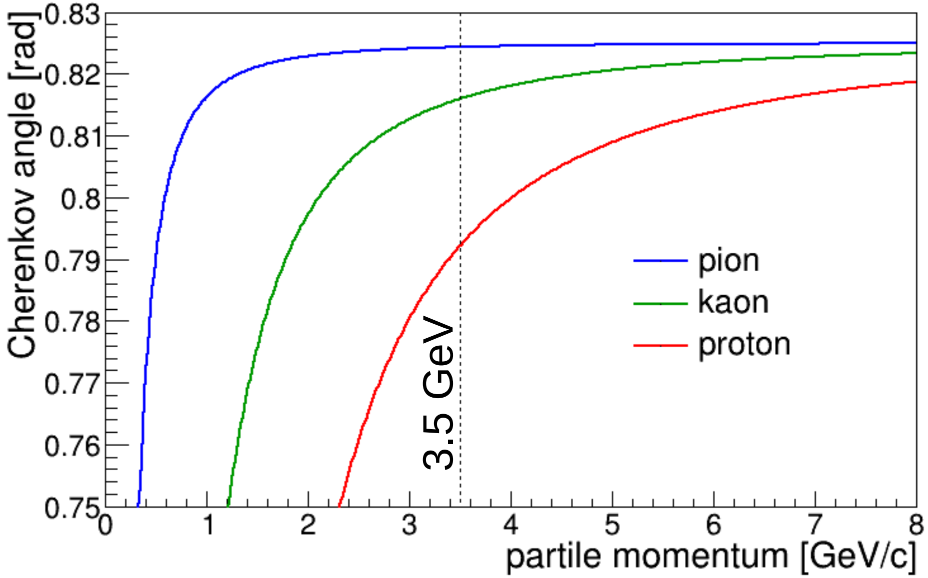
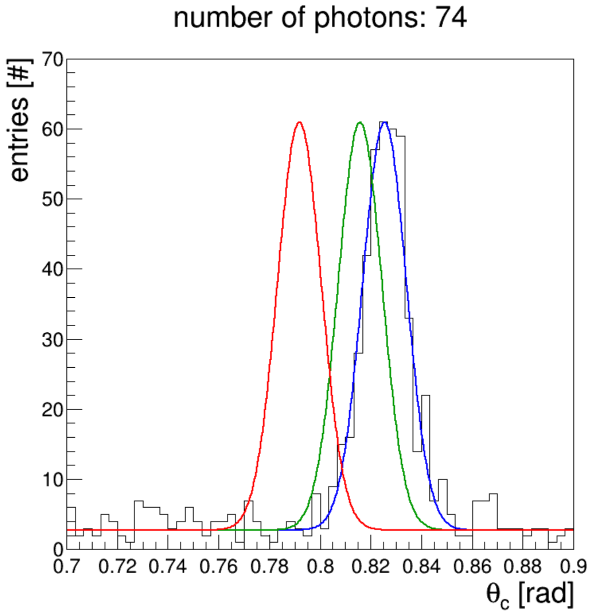




Geometrical Reconstruction





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

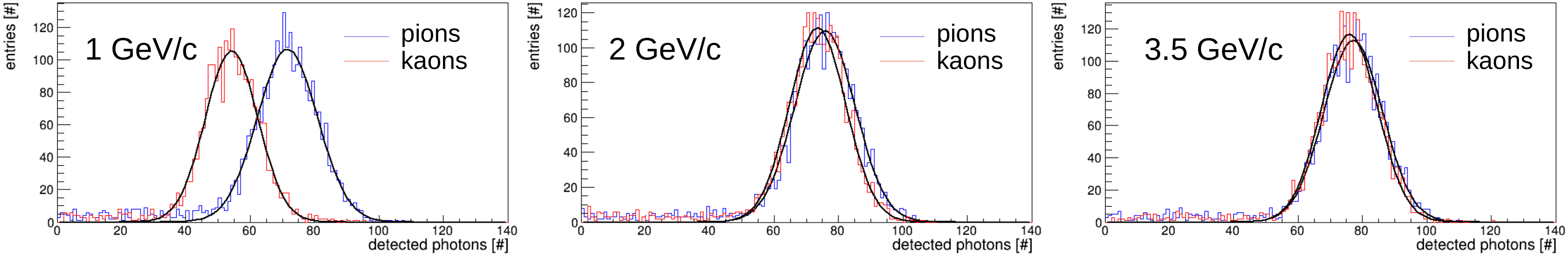
signal   combinatorial background

Geometrical Reconstruction

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

photon yield contribution

photon yield for different momenta at 20° polar angle:

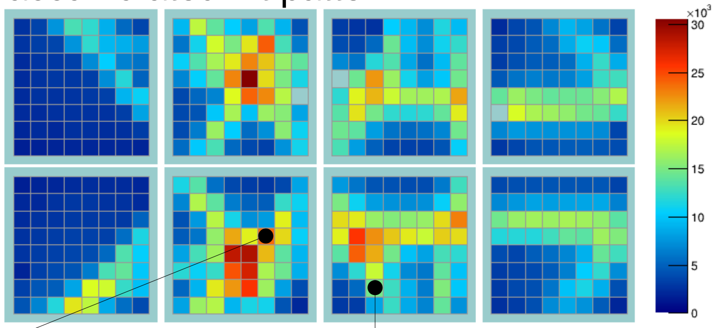


Time Imaging

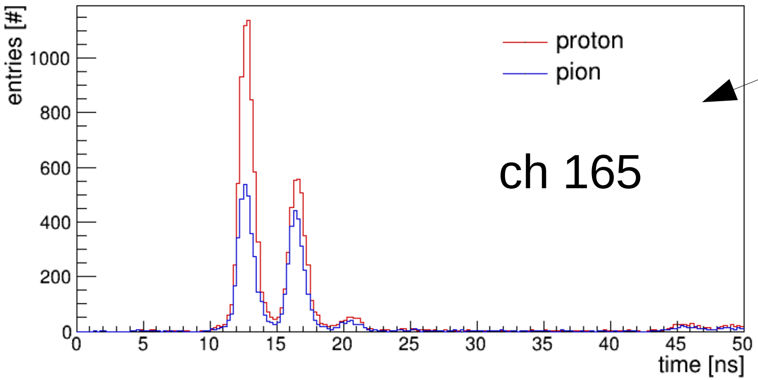
$$\log\mathcal{L}_h = \sum_{i=1}^{N} \log(S_h(c_i,t_i) + B_h(c_i,t_i)) + \log P_h(N)$$

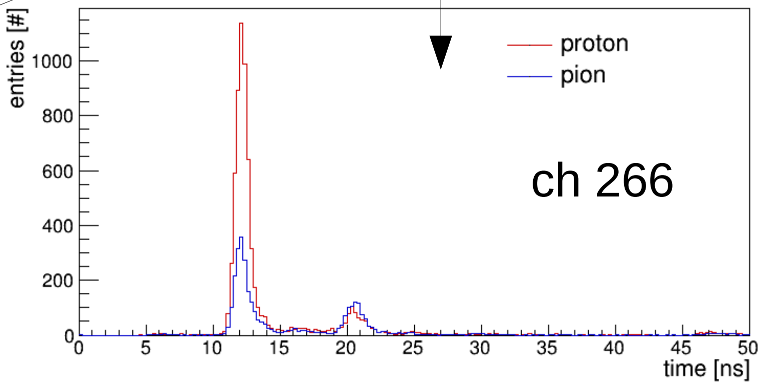
- CERN 2018 prototype test beam data
- protons/pions at 7 GeV/c (equivalent to kaons/pions at 3.5 GeV/c) at 20°

accumulated hit pattern



propagation time of Cherenkov photons:

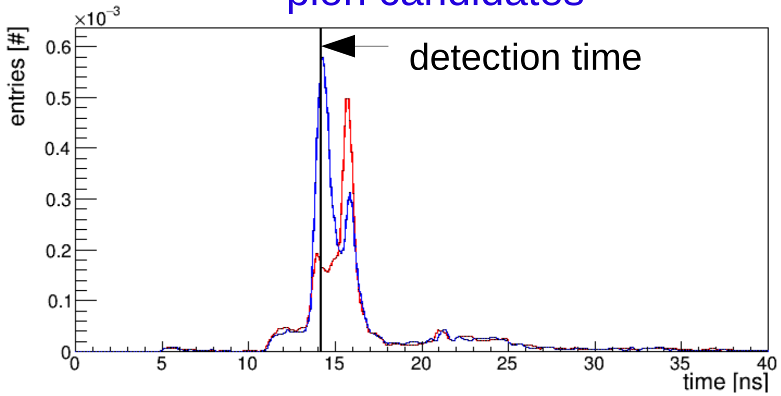




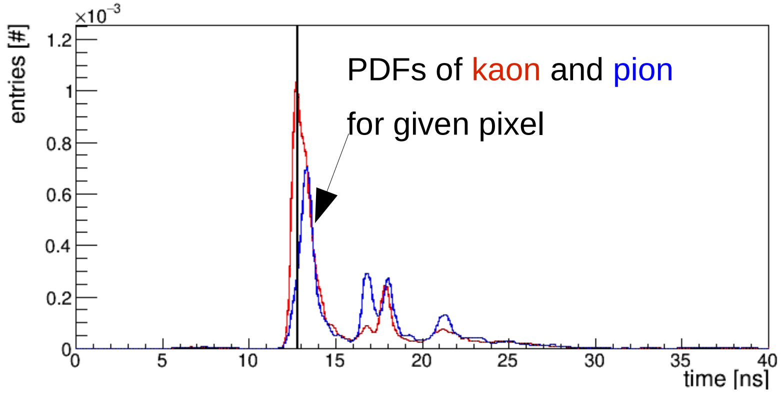
Time Imaging

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

pion candidates



kaon candidates



Probability Density Functions

- From data
  - best PID (does not need calibration)
  - requires a large amount of data in whole angular and momentum acceptance
  - large memory footprint
- Simulated
  - full Geant4 simulation of every possible particle type direction and momentum
  - requires a large amount of simulation (slow/unusable)
- Analytical
  - fast
  - low memory footprint
  - initially developed for Belle II TOP (M. Staric, et al., Nucl. Inst. and Meth. A 595 (2008) 252)
  - modified for PANDA Barrel DIRC to account for spherical lens focusing (PDFs using LUT)

Analytical PDF using LUT

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

$$\sum_{k=1}^{m_j} n_{kj}\, g(t_{kj}, \sigma_{kj})$$ = sum of Gaussians

n_{kj} ~ effective pixel size

σ_{kj} ~ chromatic dispersion, optical aberrations

Analytical PDF using LUT

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

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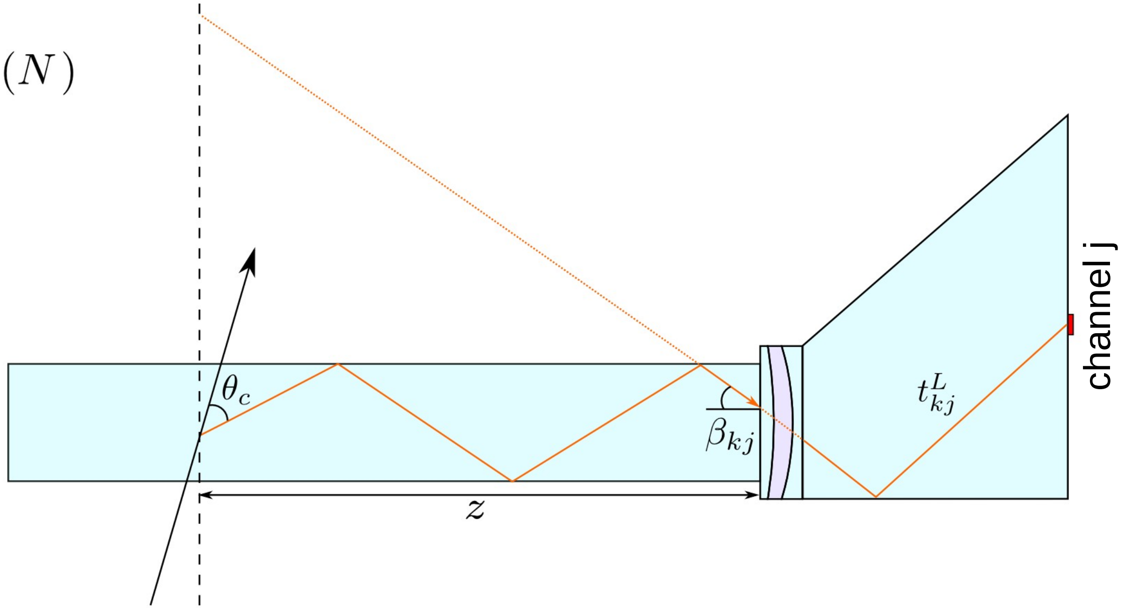

$$t_{kj} = \frac{z}{\cos\beta_{kj}} + t^L_{kj}$$

Analytical PDF using LUT

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

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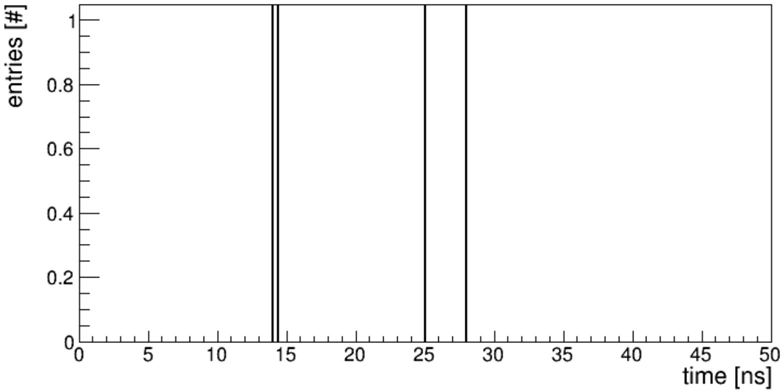
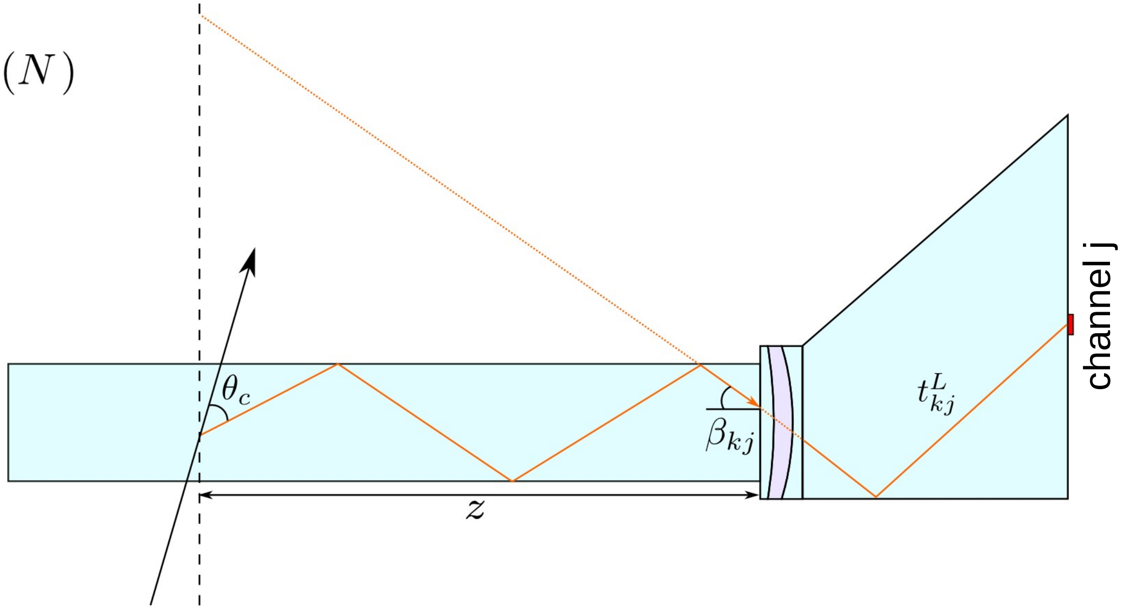
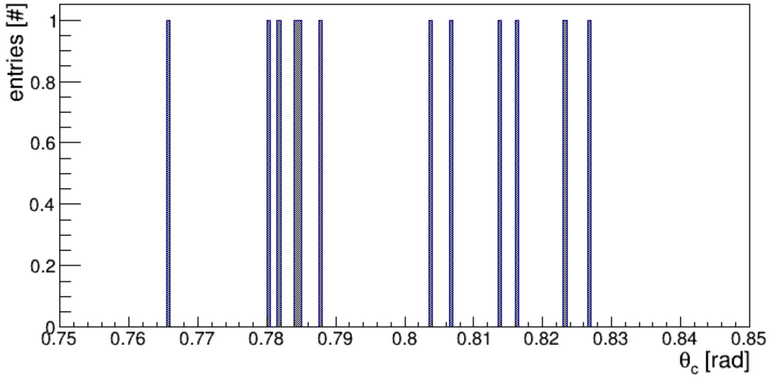


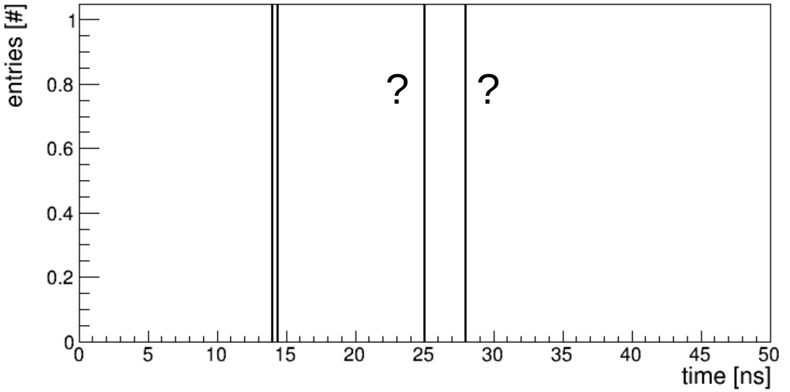


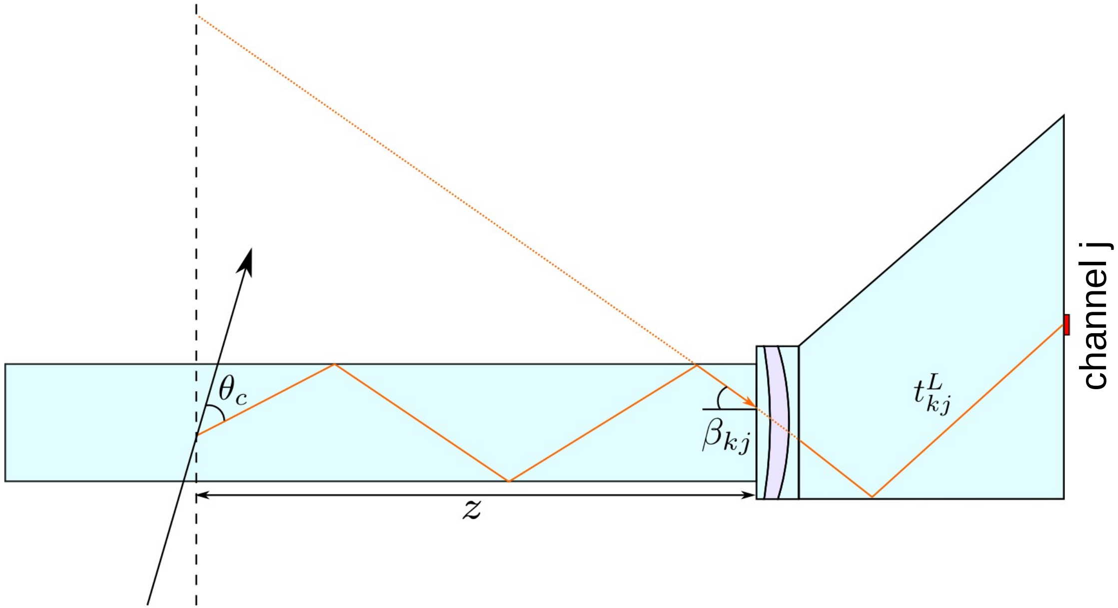
$$t_{kj} = \frac{z}{\cos\beta_{kj}} + t^L_{kj}$$

Analytical PDF using LUT

Cherenkov angle distribution

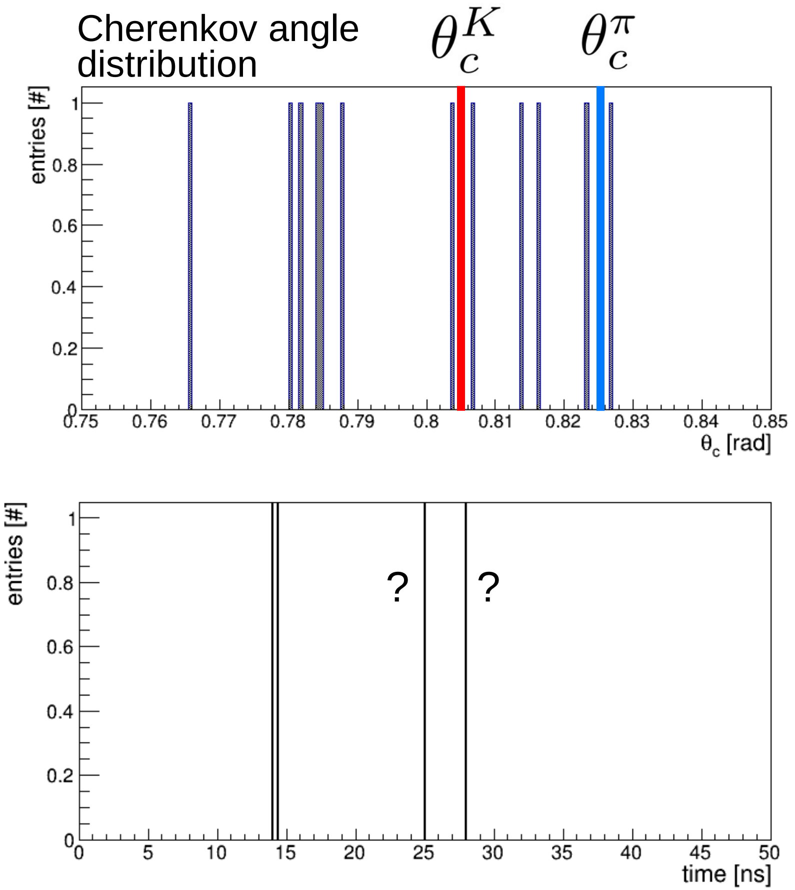


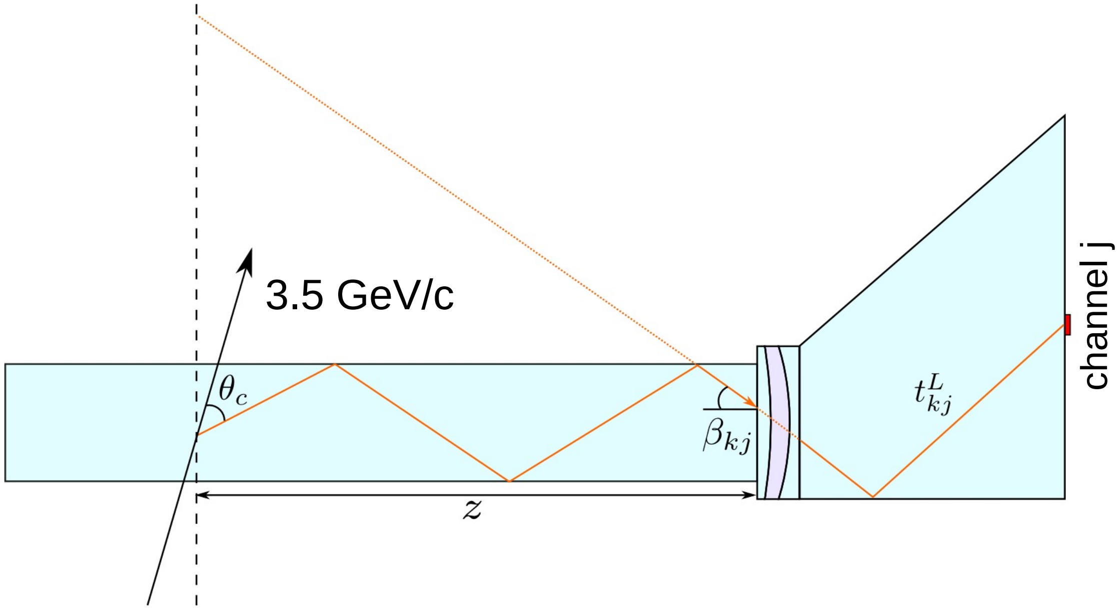




$$t_{kj} = \frac{z}{\cos\beta_{kj}} + t^L_{kj}$$

Analytical PDF using LUT

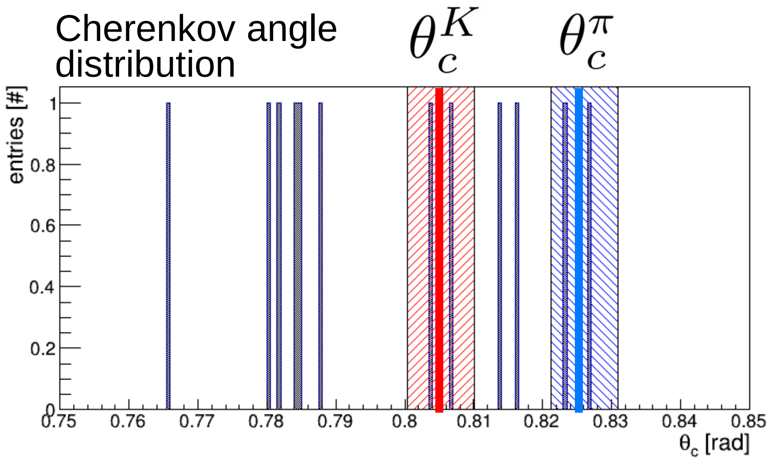


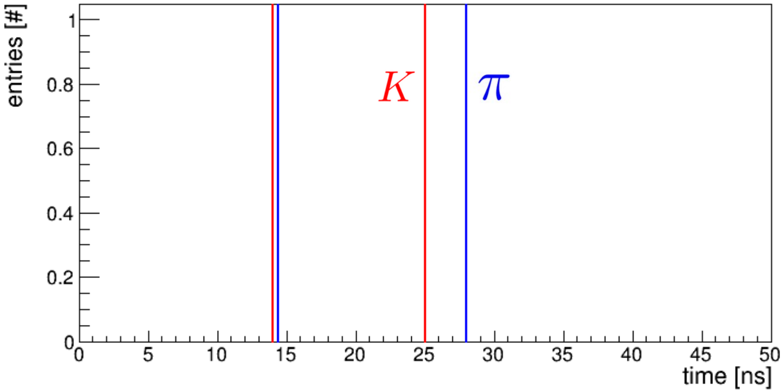


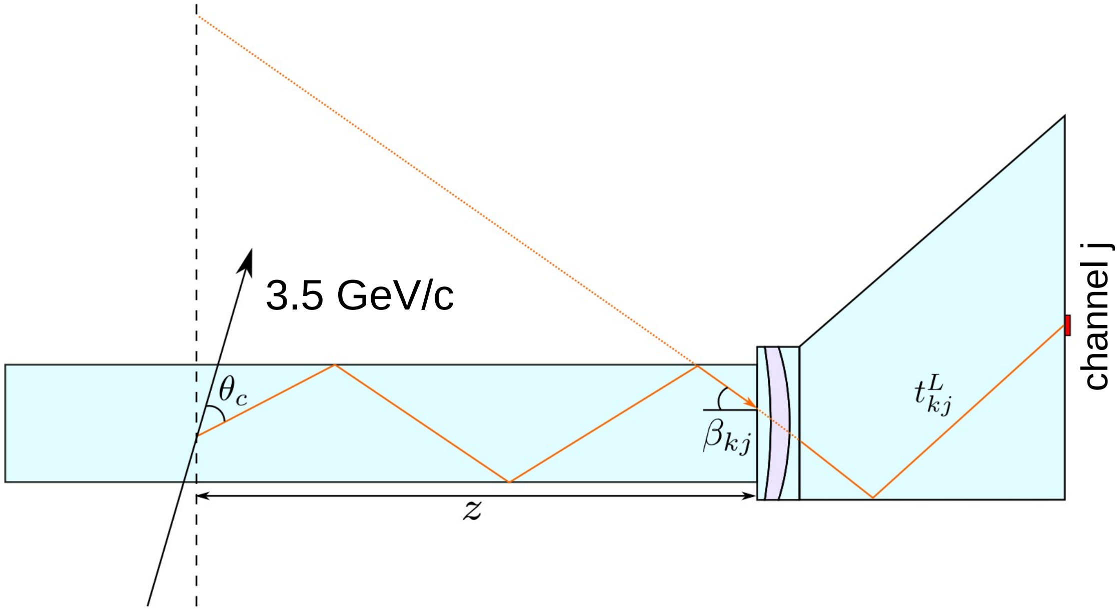
$$t_{kj} = \frac{z}{\cos \beta_{kj}} + t_{kj}^L$$

Analytical PDF using LUT

Cherenkov angle distribution







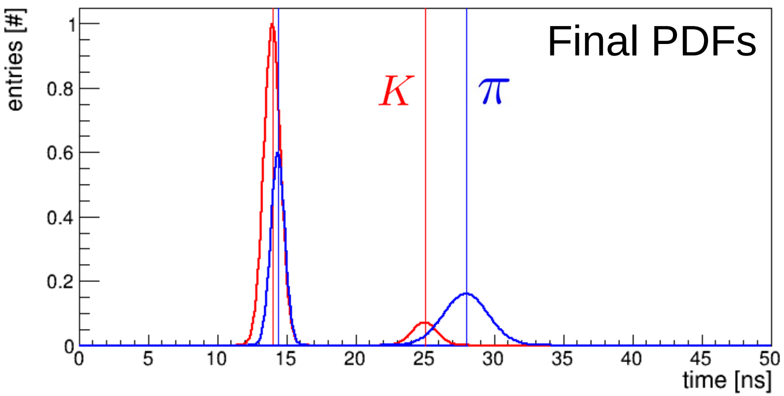
$$t_{kj} = \frac{z}{\cos\beta_{kj}} + t^L_{kj}$$

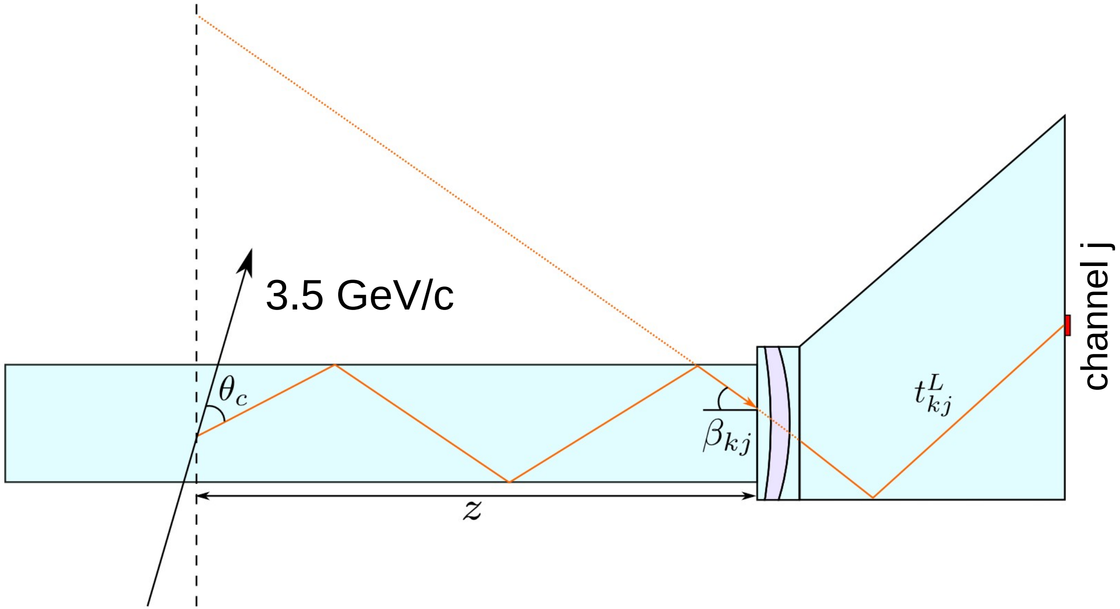
Analytical PDF using LUT

$$\sum_{k=1}^{m_j} n_{kj} g(t_{kj}, \sigma_{kj})$$ = sum of Gaussians

n_{kj} ~ effective pixel size

σ_{kj} ~ chromatic dispersion, optical aberrations

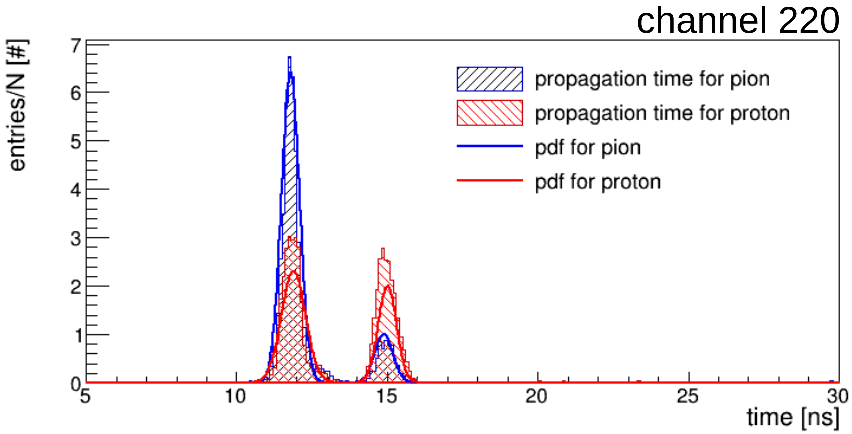


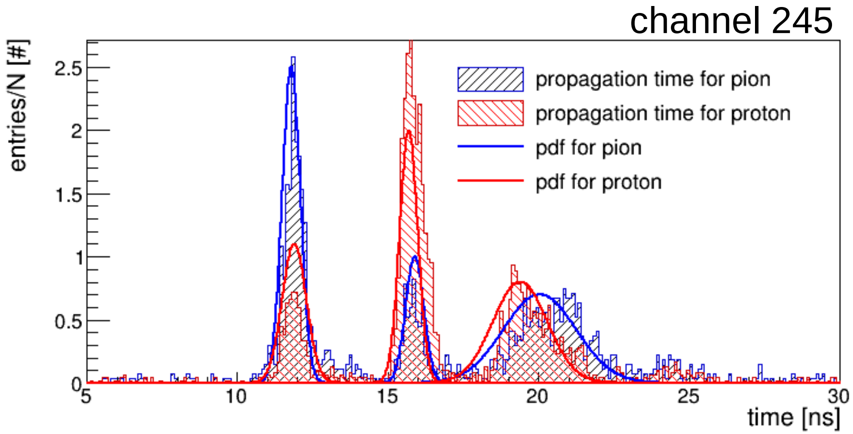


$$t_{kj} = \frac{z}{\cos\beta_{kj}} + t_{kj}^{L}$$

Analytical PDF: Example

- CERN 2018 prototype simulations (~200 ps time precision)
- protons/pions at 7 GeV/c (equivalent to kaons/pions at 3.5 GeV/c)

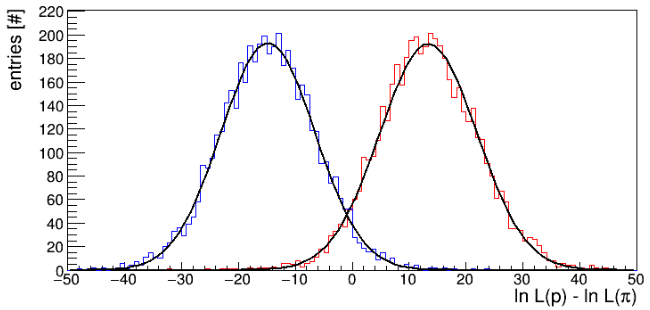




PID Performance Results

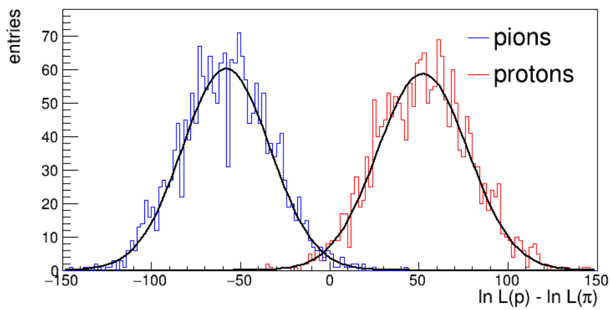
- CERN 2018 prototype simulations (~200 ps time precision)
- protons/pions at 7 GeV/c (equivalent to kaons/pions at 3.5 GeV/c)

geometrical reconstruction



separation 3.5 s.d.

time imaging with analytical PDF

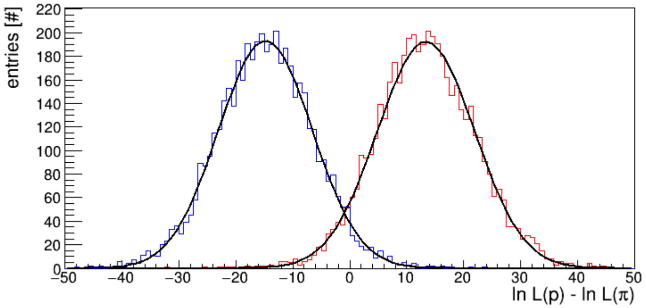


separation 4.4 s.d.

PID Performance Results

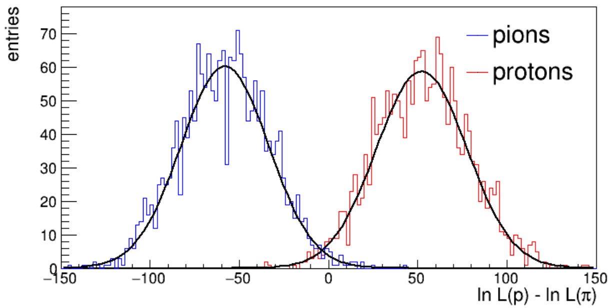
- CERN 2018 prototype simulations (~200 ps time precision)
- protons/pions at 7 GeV/c (equivalent to kaons/pions at 3.5 GeV/c)

geometrical reconstruction



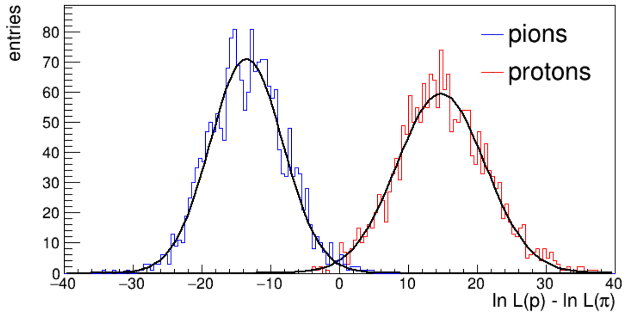
separation 3.5 s.d.

time imaging with analytical PDF



separation 4.4 s.d.

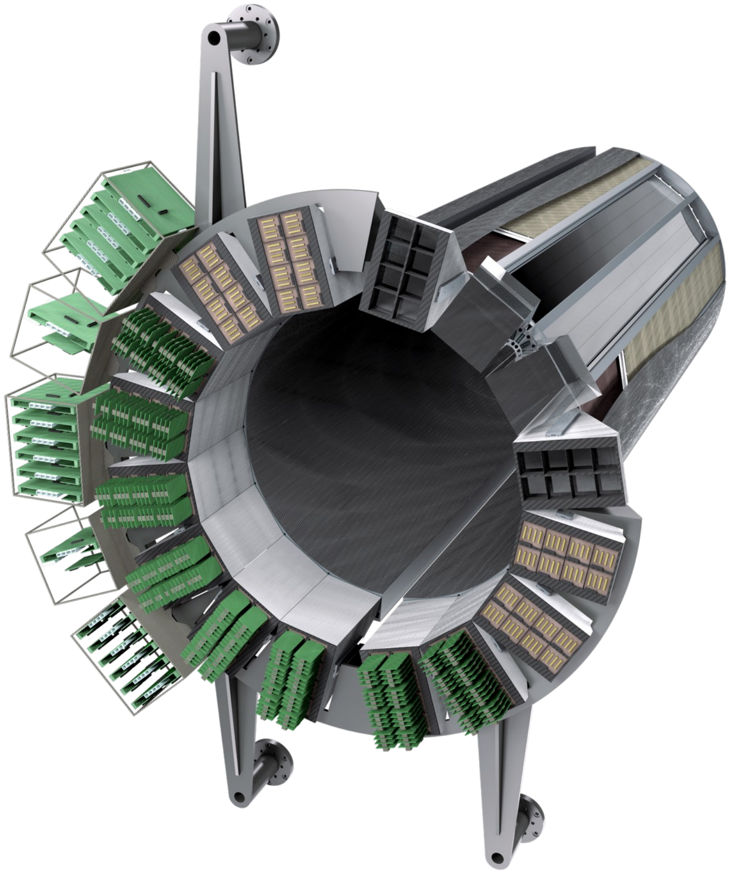
time imaging with simulated PDF



separation 4.8 s.d.

Summary

- Two reconstruction methods for the PANDA Barrel DIRC were developed and validated with data from prototypes in particle beam
- Geometrical approach delivers robust PID which doesn't depend on precise time measurements
- Time Imaging provides best PID by combining position and time measurements in optimal way
- Probability Density Functions for time imaging can be created by modified analytical approach using LUTs



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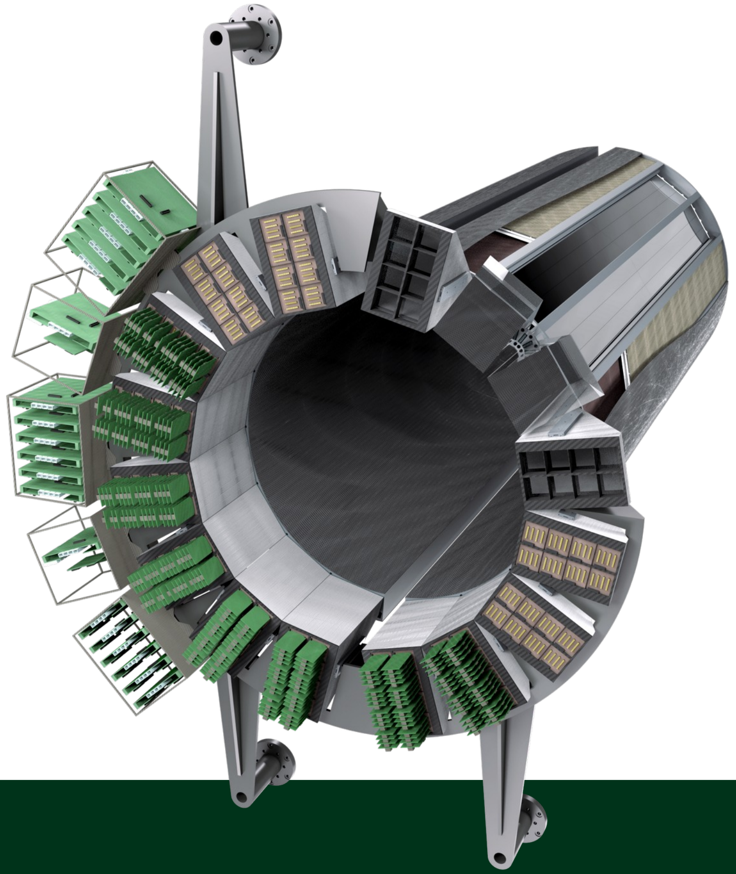

Thank you for the attention