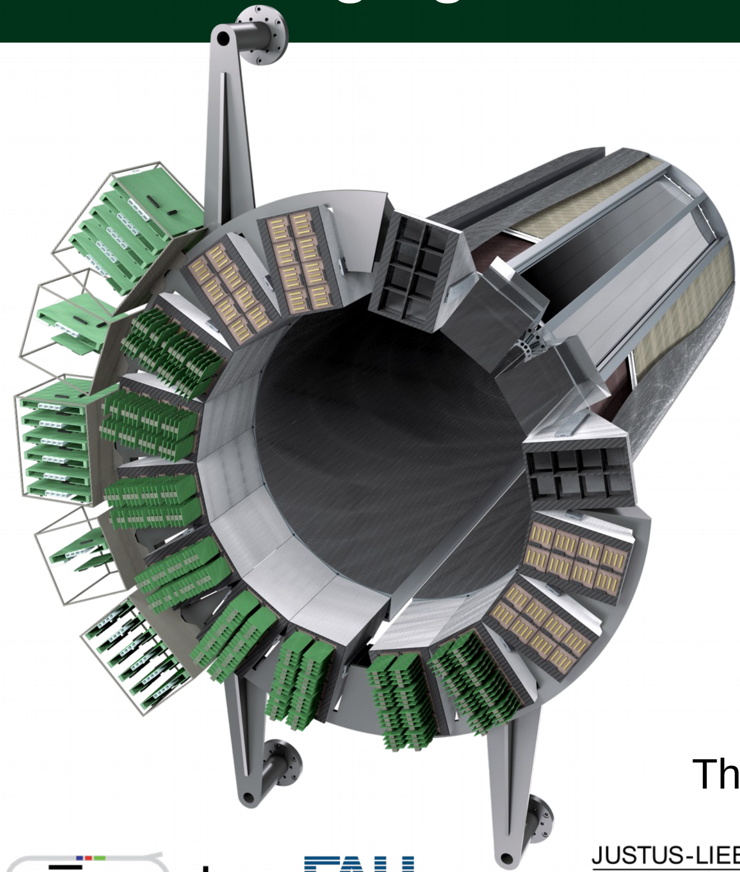
Time imaging reconstruction for the PANDA Barrel DIRC

DIRC 2019



Roman Dzhygadlo

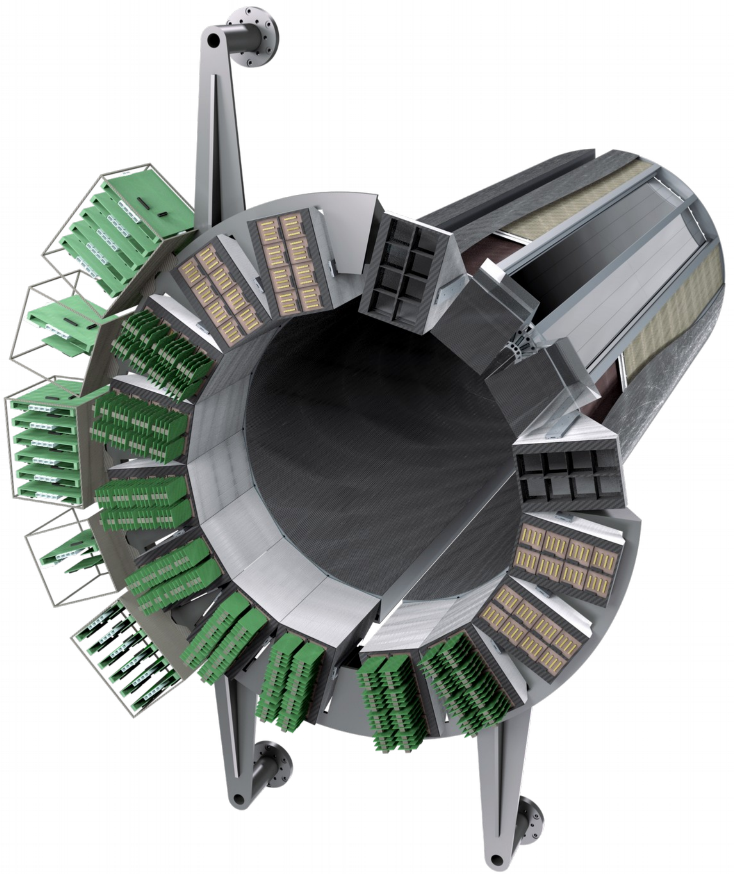
for the PANDA Cherenkov Group

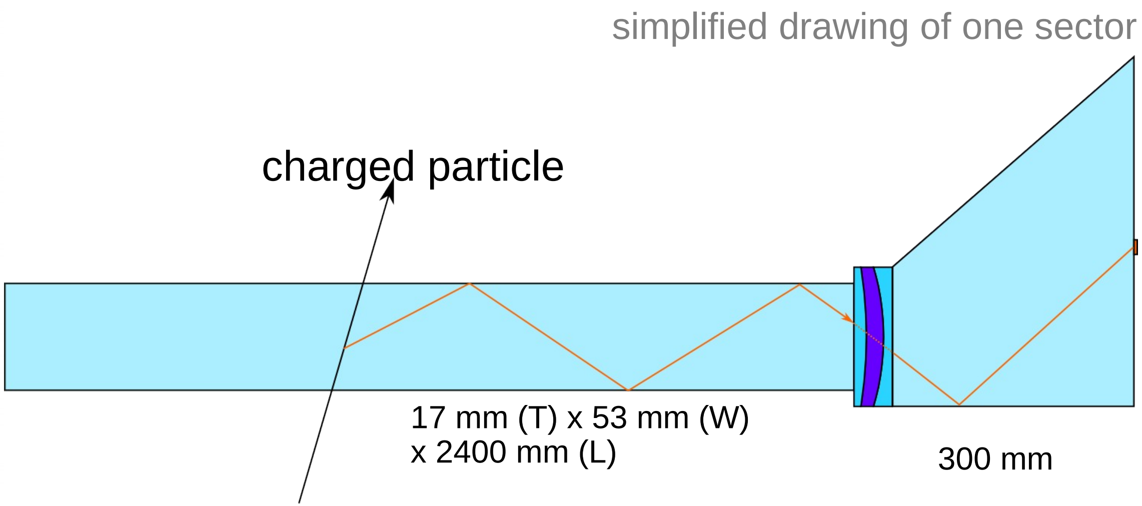
- Observables
- Reconstruction algorithms
- PDFs
- Results
- Summary

The PANDA Cherenkov Group:

panda · FAU Friedrich-Alexander Universität Erlangen-Nürnberg · Justus-Liebig-Universität Giessen · Goethe Universität Frankfurt am Main · Johannes Gutenberg Universität Mainz · GSI · FAIR

PANDA Barrel DIRC



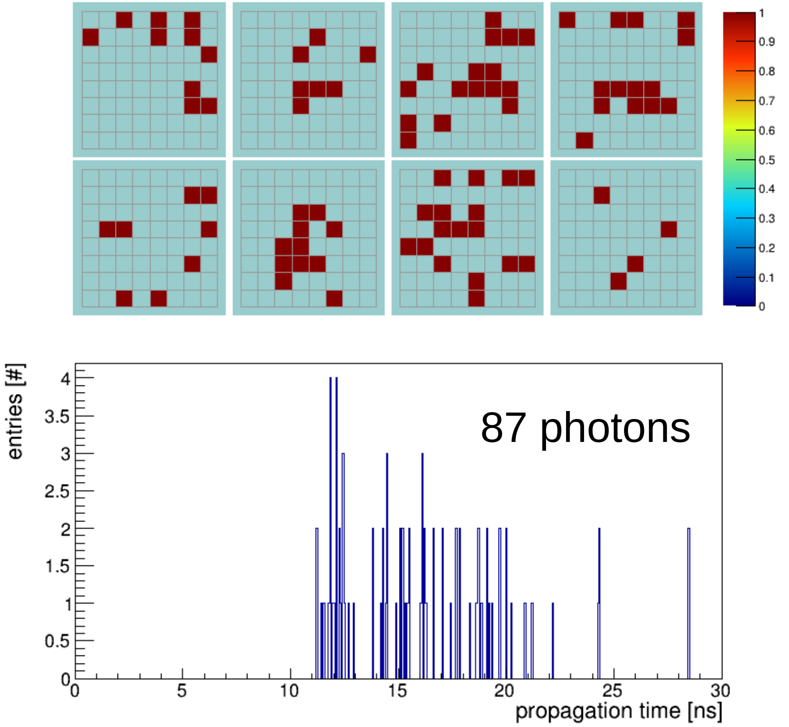


Observables:

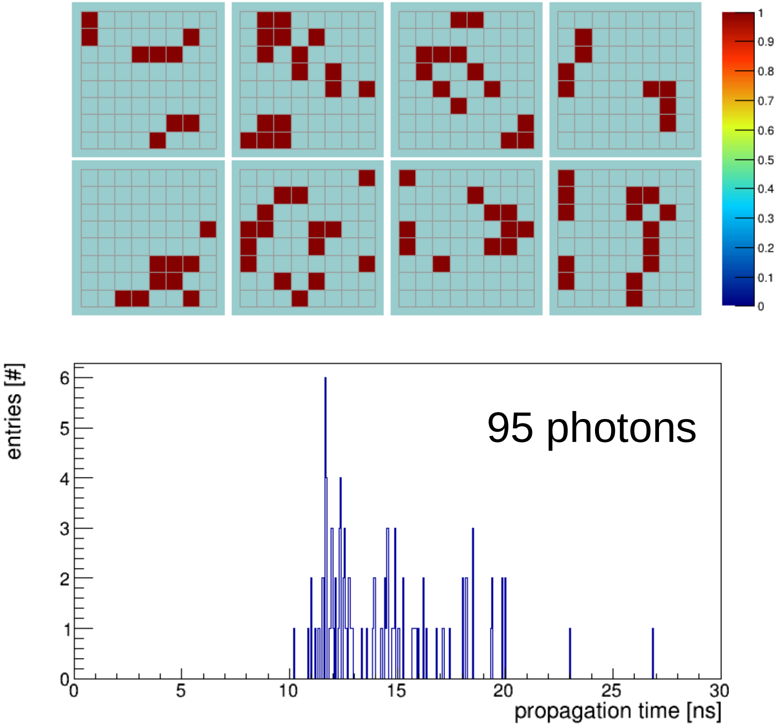
- photon yield
- photon hit position (6x6 mm^2 pixels)
- photon propagation time (~100 ps precision)

Observables

one pion



one kaon

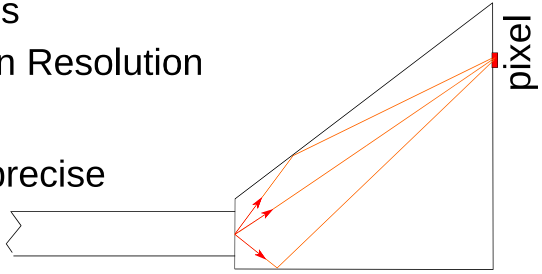


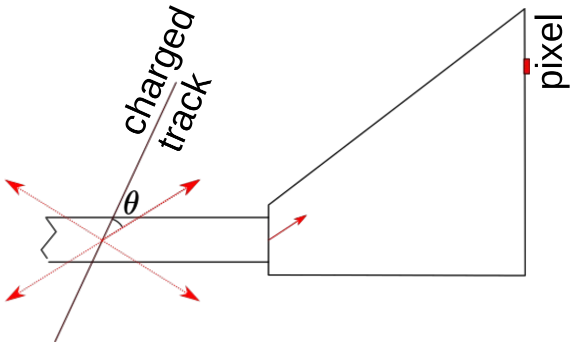
Reconstruction Methods

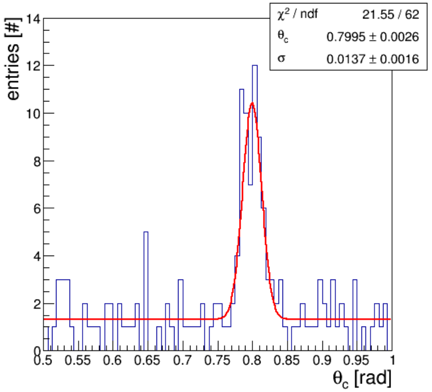
Geometrical

more info: R. Dzhygadlo, et al., Nucl. Inst. and Meth. A 766 (2014) 263-266

- BABAR-like
- Needs Look-Up Tables
- Delivers Single Photon Resolution
- Fast
- Does not depend on precise time measurement







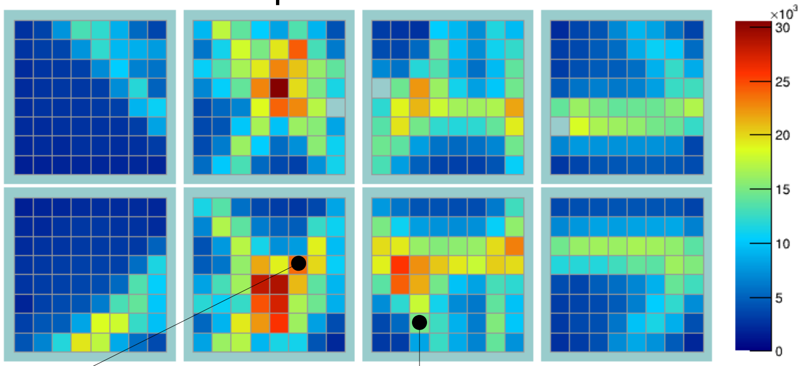
Time imaging

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

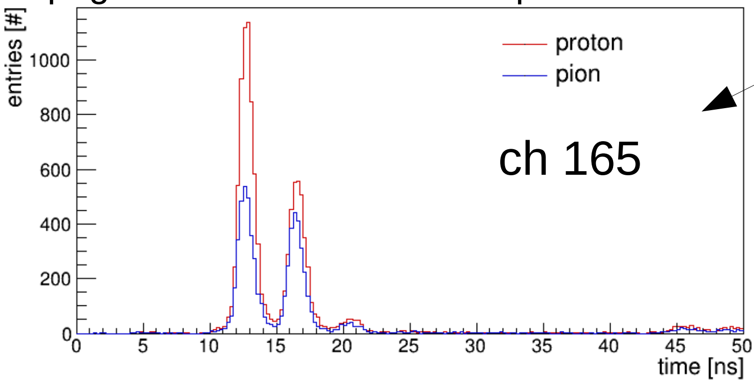
Time Imaging

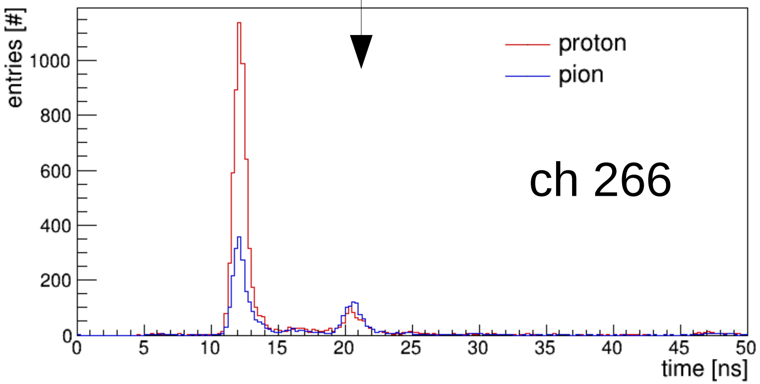
- CERN 2018 prototype test beam data
- protons/pions at 7 GeV/c (equivalent to kaons/pions at 3.5 GeV/c) at 20°

accumulated hit pattern



propagation time of Cherenkov photons:

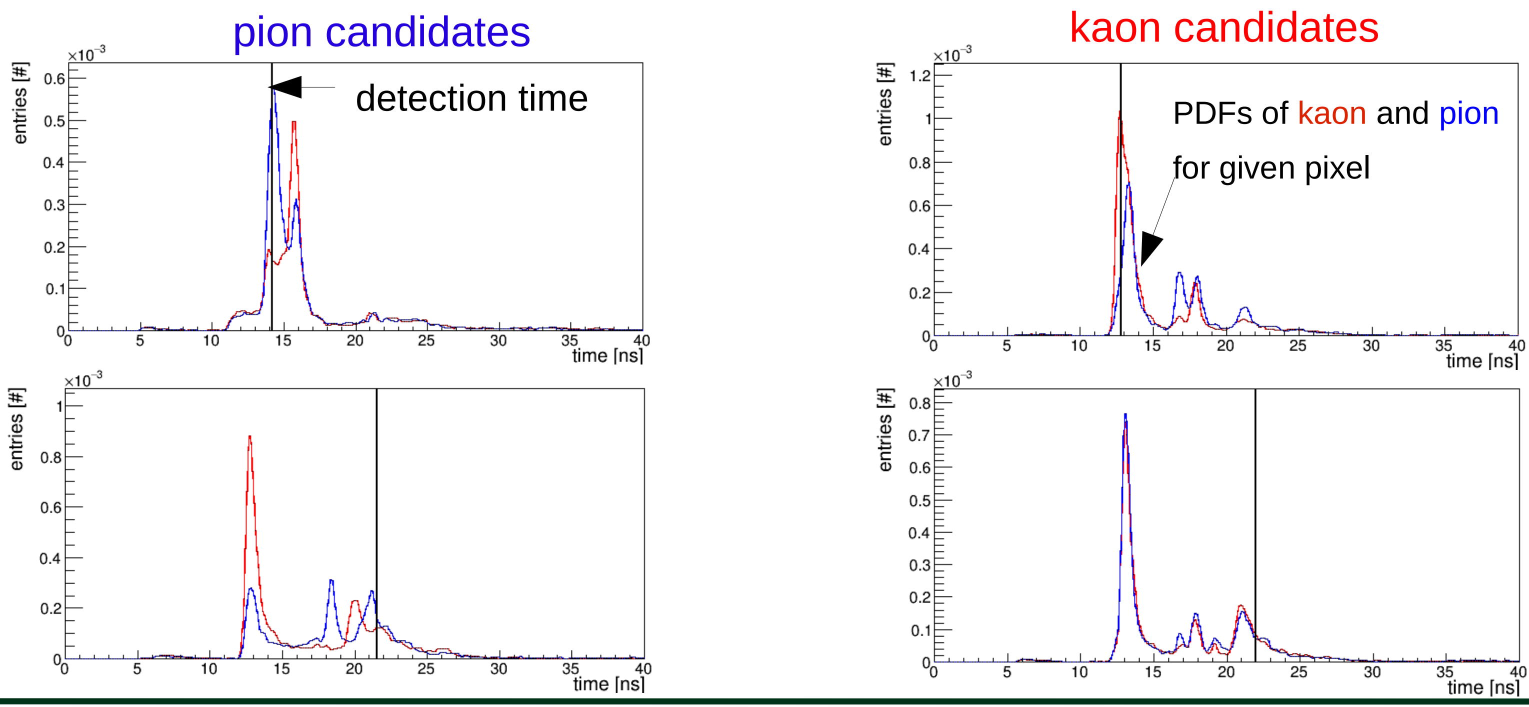




$$\log\mathcal{L}_h = \sum_{i=1}^{N} \log(S_h(c_i, t_i) + B_h(c_i, t_i)) + \log P_N(N_e)$$

Time Imaging

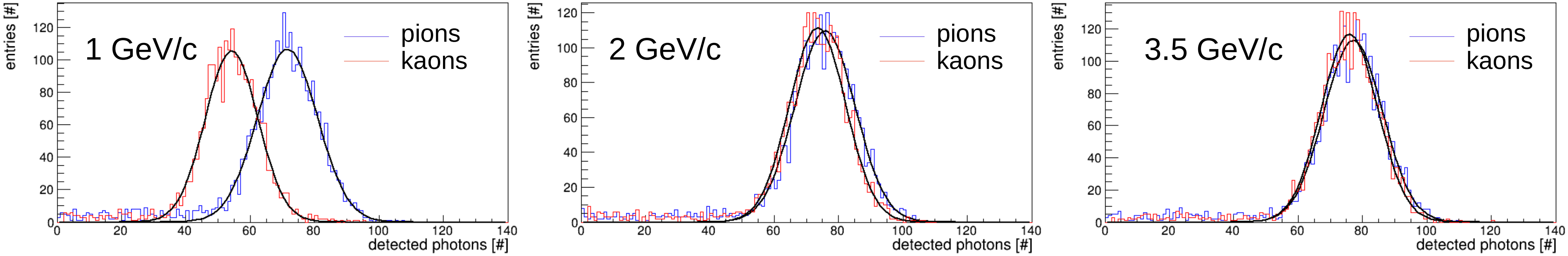
$$\log\mathcal{L}_h = \sum_{i=1}^{N} \log(S_h(c_i,t_i) + B_h(c_i,t_i)) + \log P_N(N_e)$$



Time Imaging

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

photon yield for different momenta:



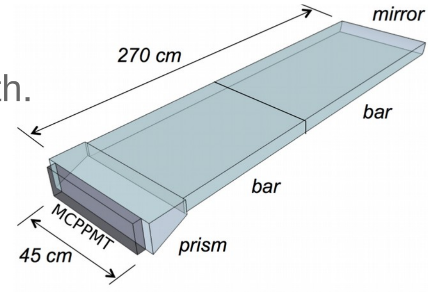
Probability Density Functions

- From data
  - best PID (does not need calibration)
  - requires a large amount of data in whole angular and momentum acceptance
  - large memory footprint
- Simulated
  - requires a large amount of simulation (slow)
- Analytical
  - fast
  - low memory footprint

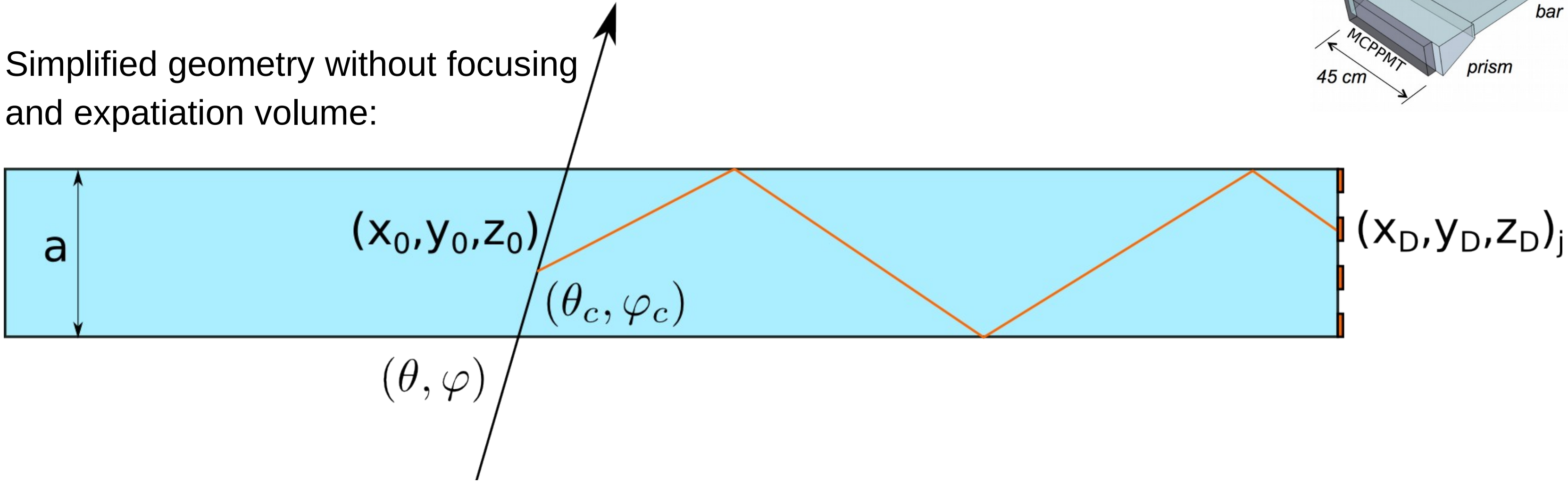
Analytical PDF

M. Staric, et al., Nucl. Inst. and Meth. A 595 (2008) 252

Belle II TOP



Simplified geometry without focusing and expatiation volume:



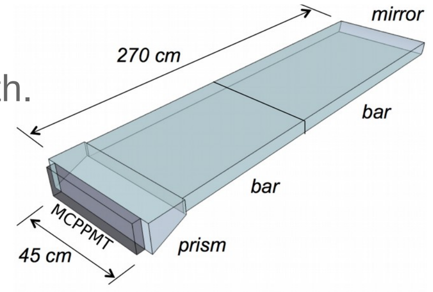
$$\log\mathcal{L}_h = \sum_{i=1}^{N} \log(S_h(c_i,t_i) + B_h(c_i,t_i)) + \log P_N(N_e)$$

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

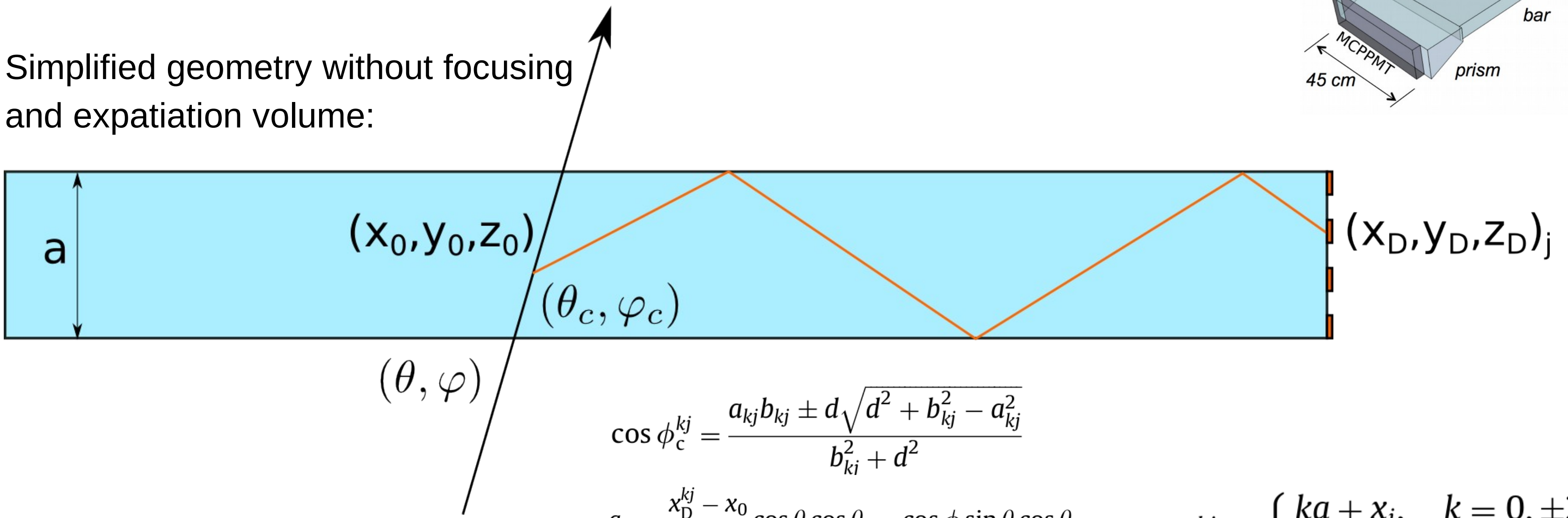
Analytical PDF

M. Staric, et al., Nucl. Inst. and Meth. A 595 (2008) 252

Belle II TOP



Simplified geometry without focusing and expatiation volume:



$$\cos\phi_c^{kj} = \frac{a_{kj}b_{kj} \pm d\sqrt{d^2 + b_{kj}^2 - a_{kj}^2}}{b_{ki}^2 + d^2}$$

$$a_{kj} = \frac{x_D^{kj} - x_0}{z_D - z_0}\cos\theta\cos\theta_c - \cos\phi\sin\theta\cos\theta_c$$

$$x_D^{kj} = \begin{cases} ka + x_j, & k = 0, \pm 2, \pm 4, \ldots \\ ka - x_j, & k = \pm 1, \pm 3, \ldots \end{cases}$$

k - number of reflections inside radiator

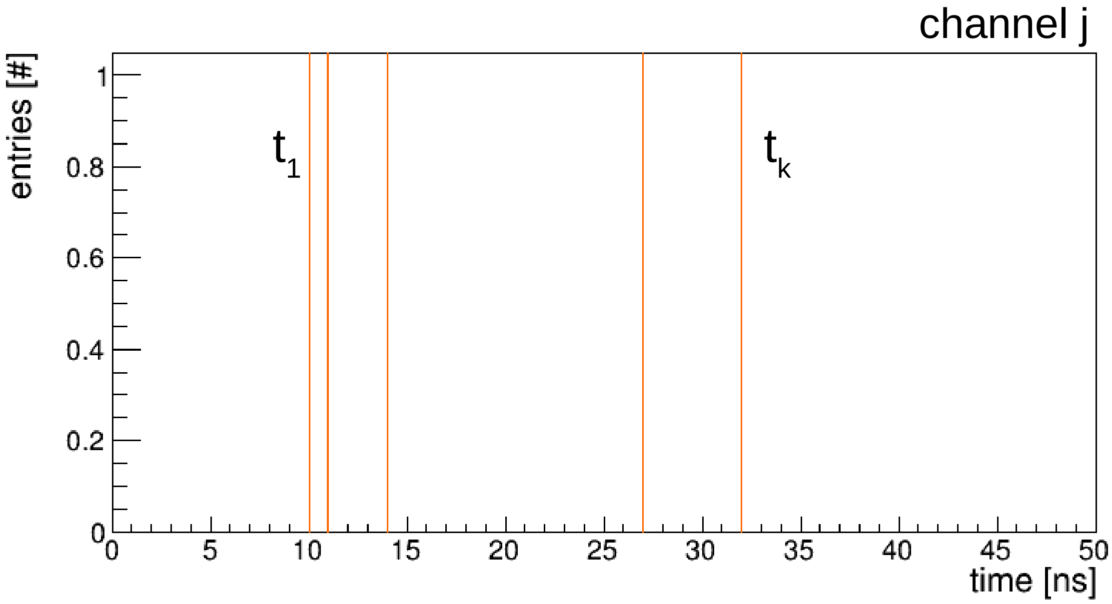
$$t_{kj} = \frac{z_D - z_0}{(\cos\theta\cos\theta_c - \sin\theta\sin\theta_c\cos\phi_c^{kj})}\frac{n_g}{c_0} + t_0$$

$$b_{kj} = \frac{x_D^{kj} - x_0}{z_D - z_0}\sin\theta\sin\theta_c + \cos\phi\cos\theta\sin\theta_c$$

$$d = \sin\phi\sin\theta_c$$

Mean Time

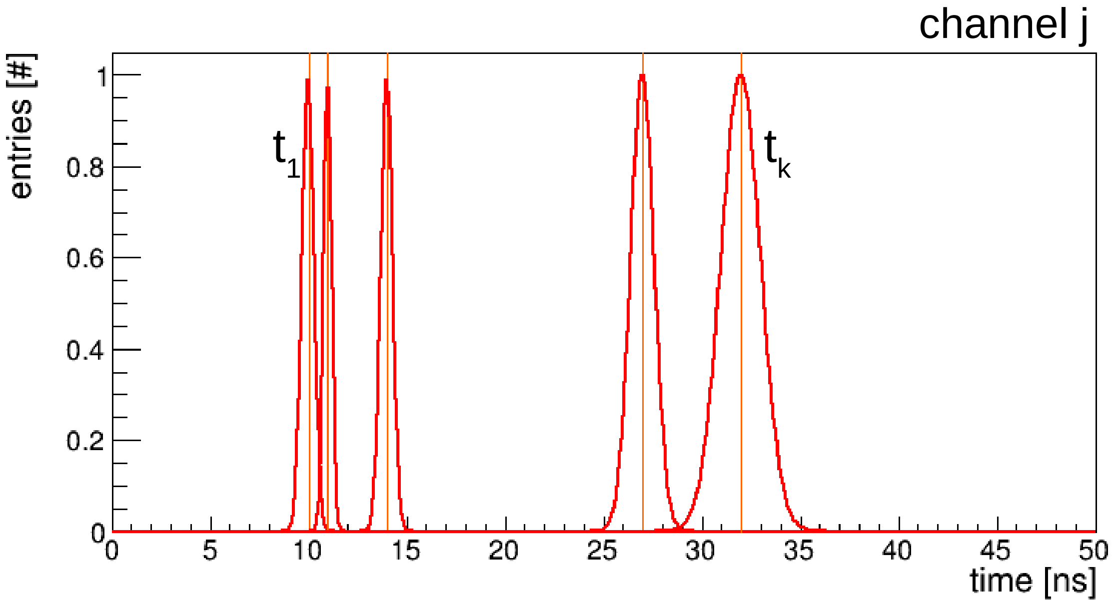
$$t_{kj} = \frac{z_D - z_0}{(\cos\theta\cos\theta_c - \sin\theta\sin\theta_c\cos\phi_c^{kj})}\frac{n_g}{c_0} + t_0$$



Sigma

Dispersion

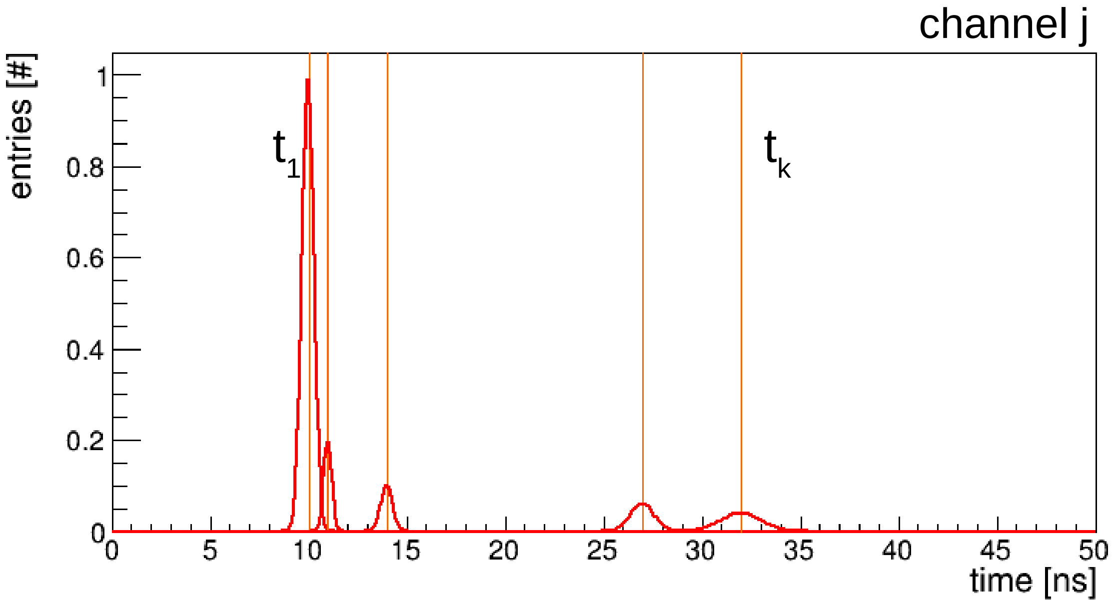
$$\sigma_{kj}^{\text{disp}} = (t_{kj} - t_0)\left| f_{kj} \frac{1}{n}\frac{\mathrm{d}n}{\mathrm{d}e} + \frac{1}{n_g}\frac{\mathrm{d}n_g}{\mathrm{d}e} \right| \sigma_e \qquad f_{kj} = \frac{(\cos\theta \sin\theta_c + \sin\theta\cos\theta_c\cos\phi_c^{kj})\cos\theta_c}{(\cos\theta\cos\theta_c - \sin\theta\sin\theta_c\cos\phi_c^{kj})\sin\theta_c}$$



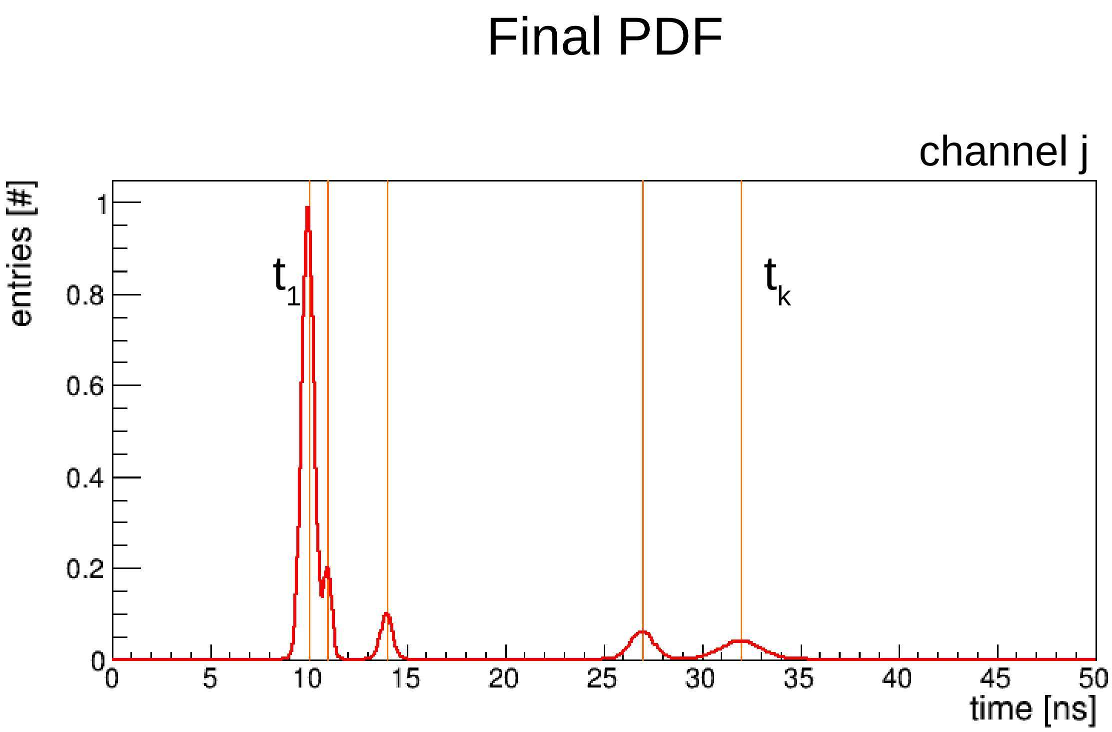
Weight

Effective size of the pixel for a given photon direction

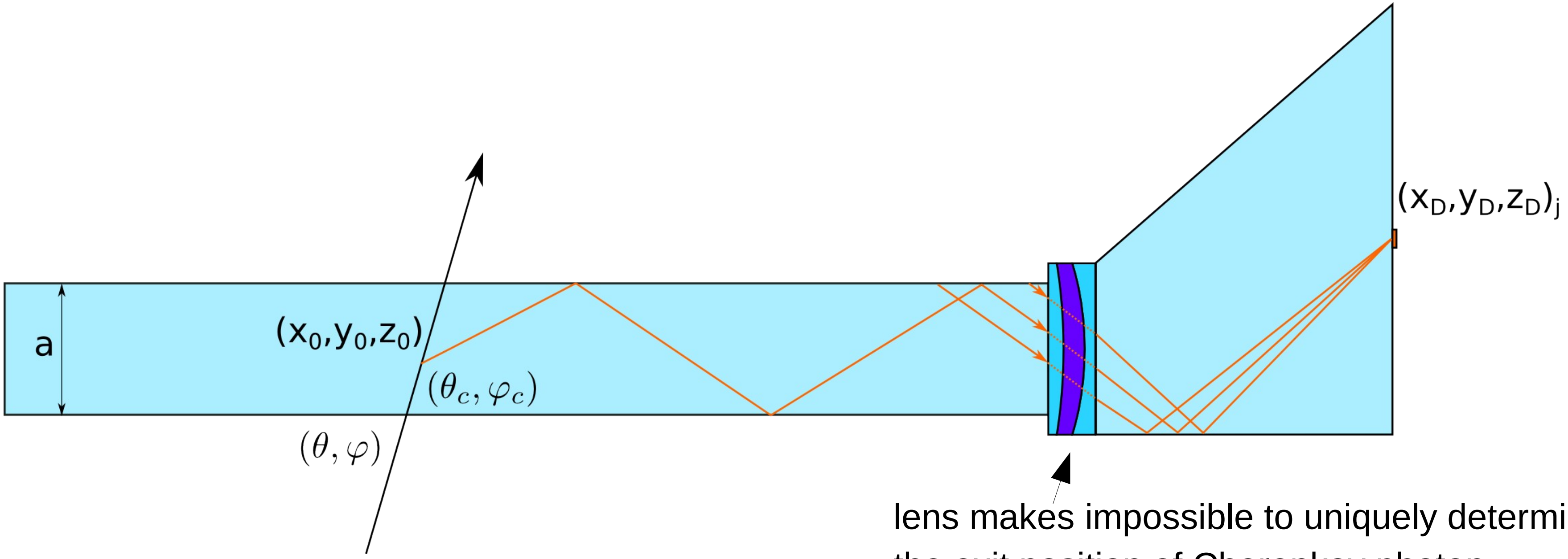
$$n_{kj} = N_0 l_{\text{track}} \sin^2 \theta_c \frac{\Delta\phi_c^{kj}}{2\pi}$$



Superposition



Analytical PDF with Focusing



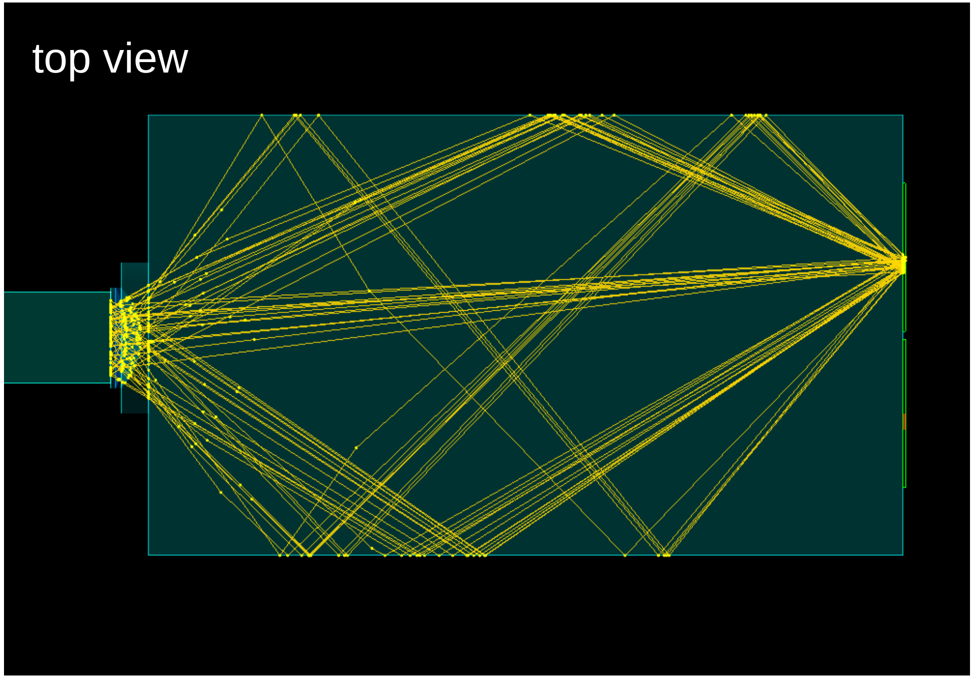
lens makes impossible to uniquely determine the exit position of Cherenkov photon

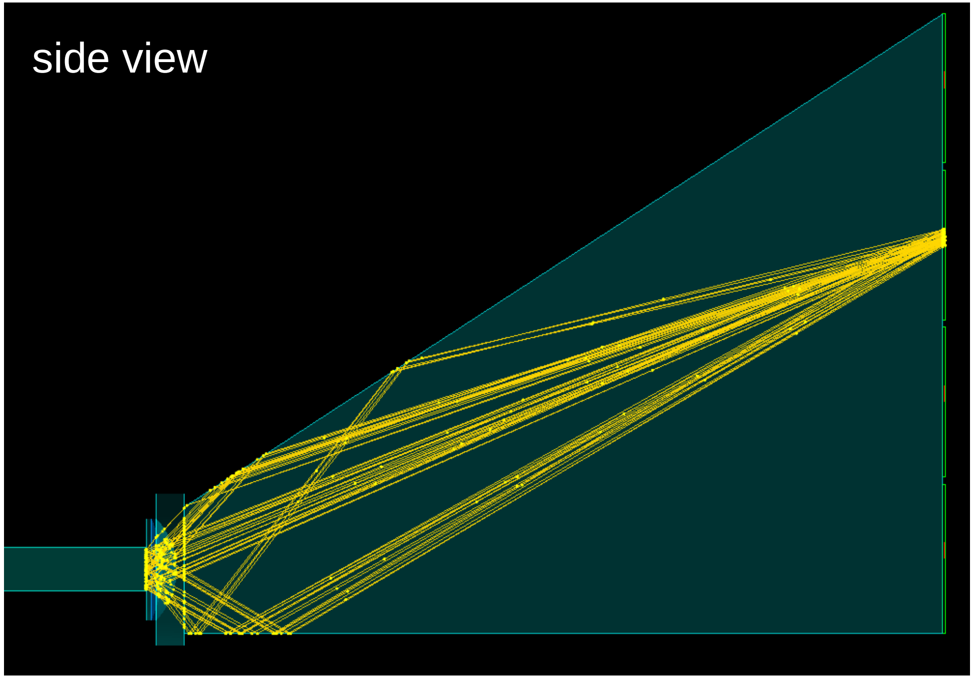
Solutions:

- Iterate through different exit position (double iteration, slow)
- Use LUT to store exit direction for each pixel (greatly simplifies t_{kj} calculation)

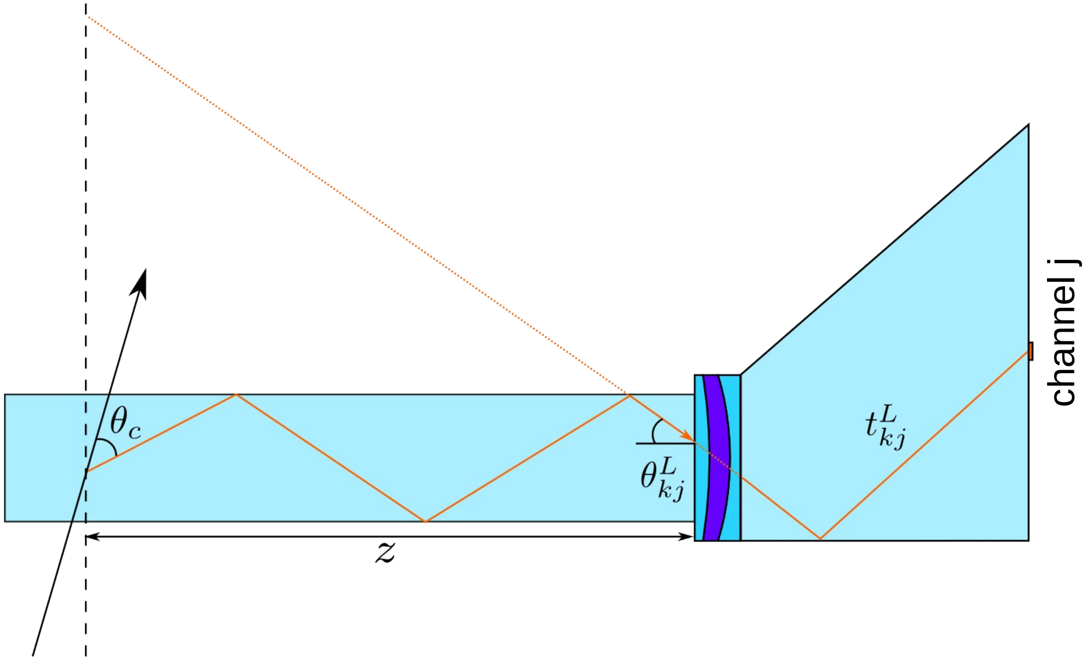
Analytical PDF using LUT

Geant4 simulation of LUT for channel 312:

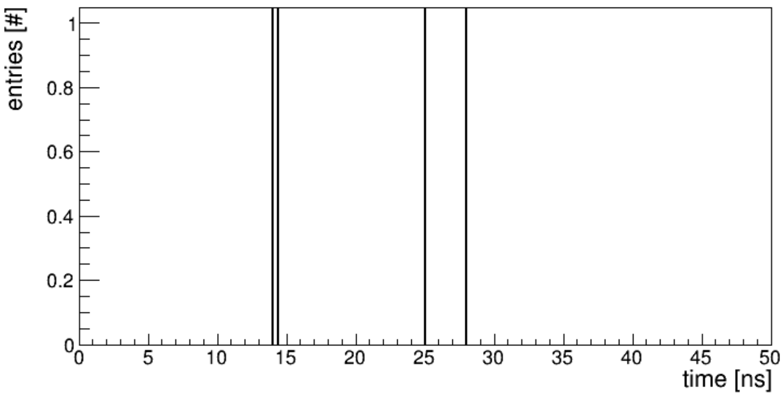




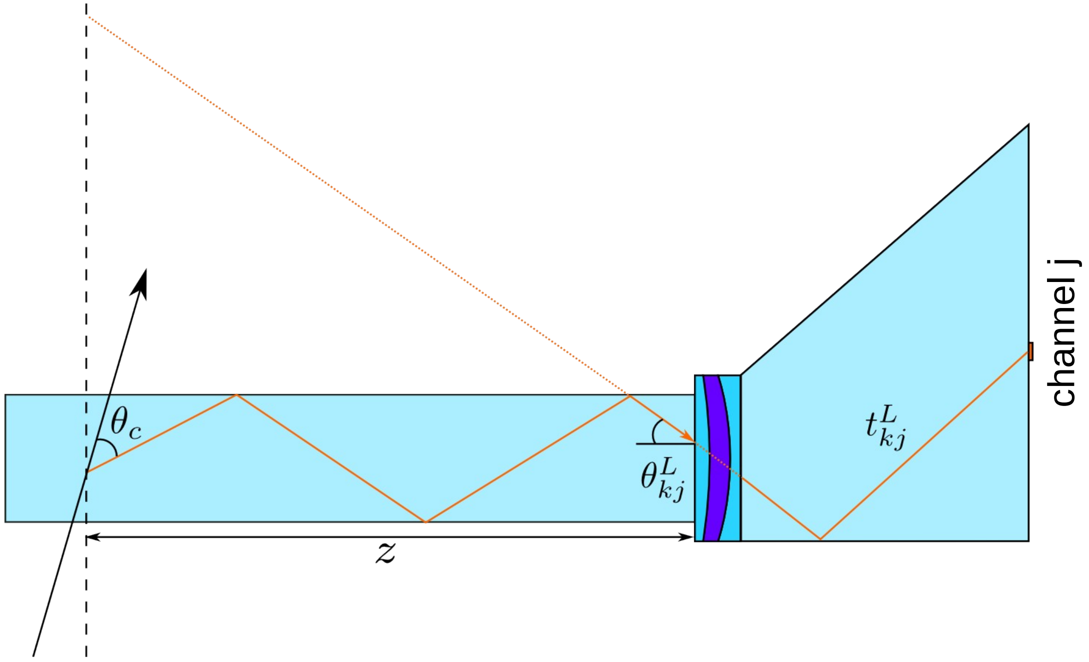
Analytical PDF using LUT



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

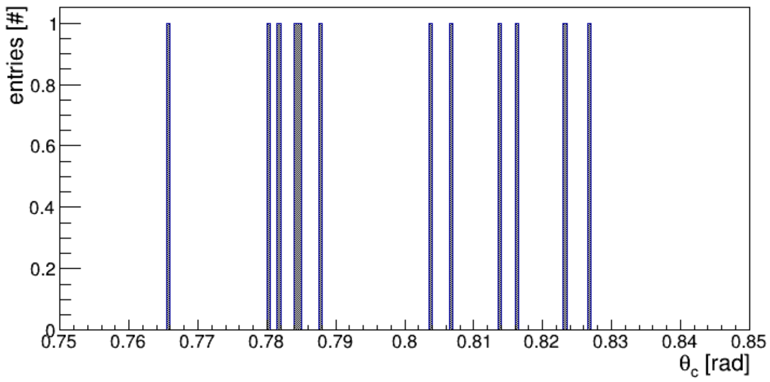


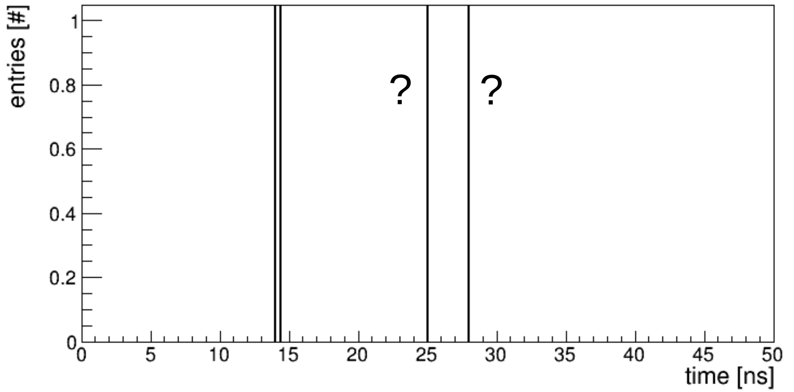
Analytical PDF using LUT



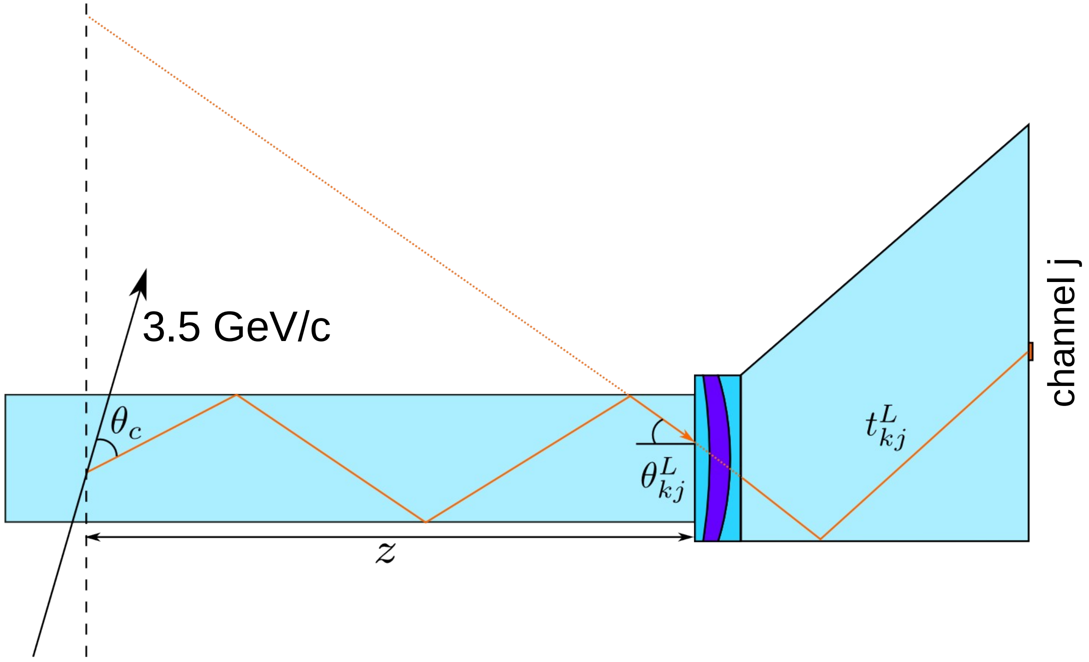
$$t_{kj} = \frac{z}{v_g \cos\theta^L_{kj}} + t^L_{kj}$$

Cherenkov angle distribution





Analytical PDF using LUT



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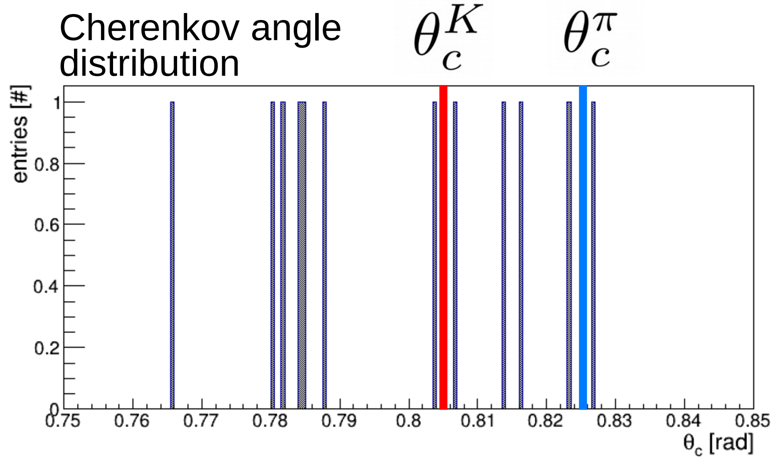
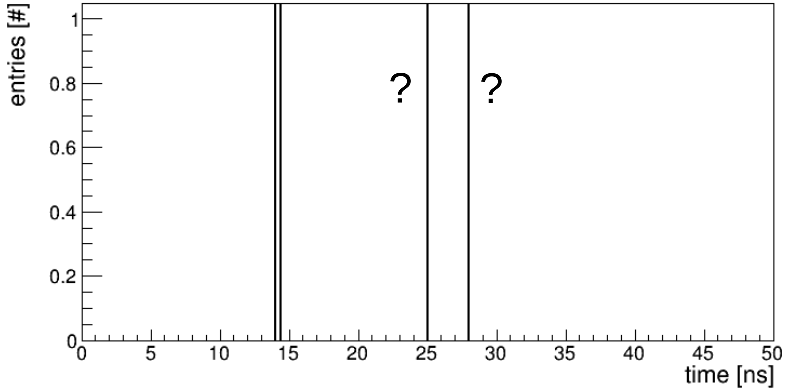
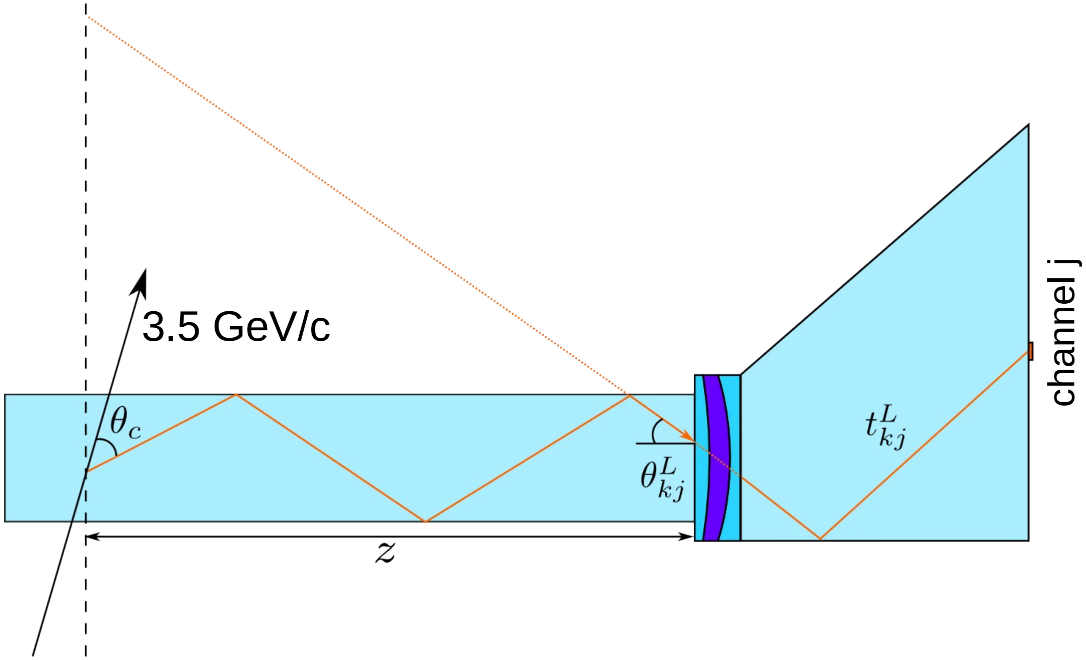




Analytical PDF using LUT



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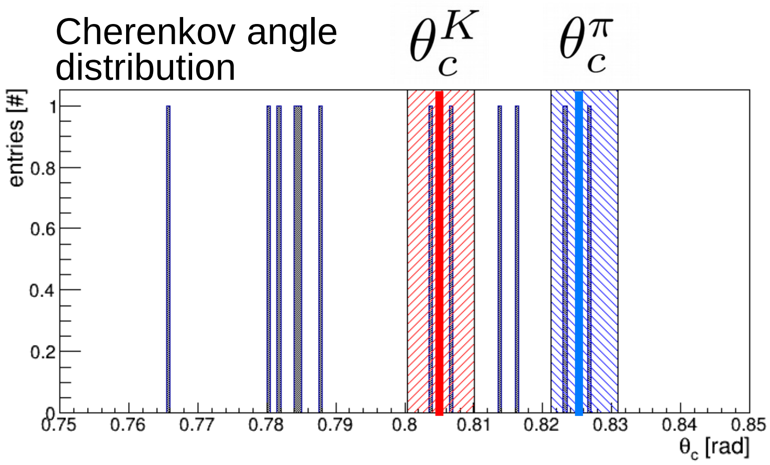
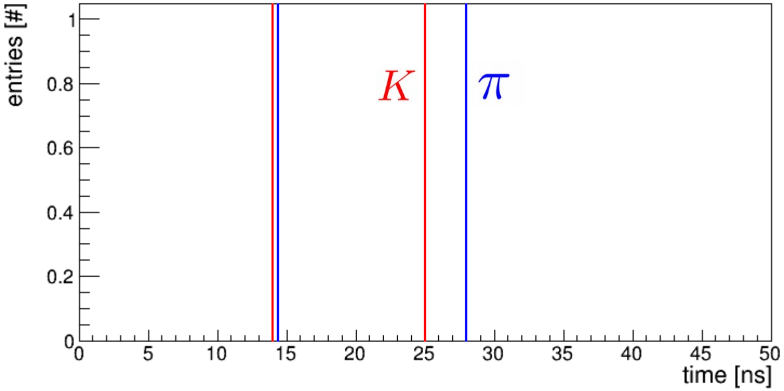
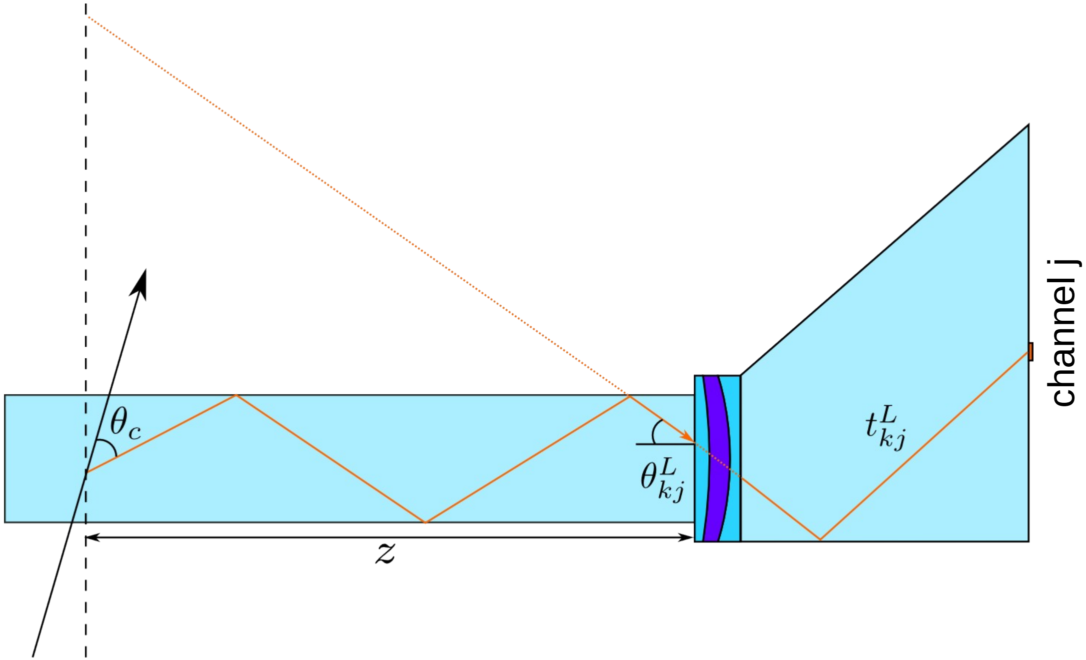
Cherenkov angle distribution





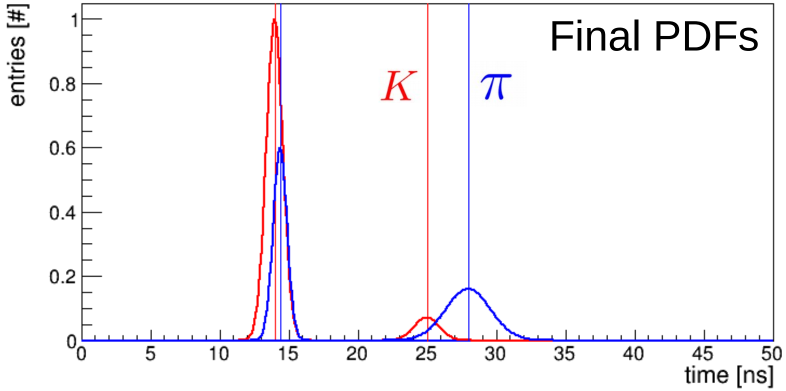
Analytical PDF using LUT



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

$$n_{kj} = N_0 l_{\mathrm{track}} \sin^2\theta_c \frac{\Delta\phi_c^{kj}}{2\pi}$$

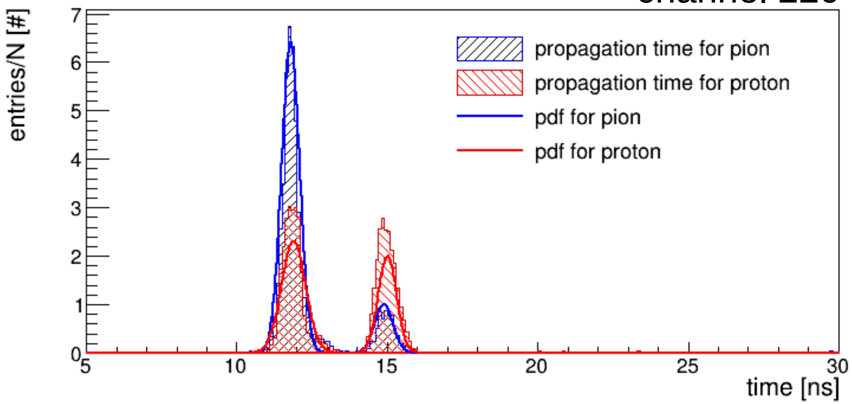
$$\sigma_{kj}^{\mathrm{disp}} = (t_{kj} - t_0)\left| f_{kj} \frac{1}{n}\frac{\mathrm{d}n}{\mathrm{d}e} + \frac{1}{n_g}\frac{\mathrm{d}n_g}{\mathrm{d}e} \right| \sigma_e$$



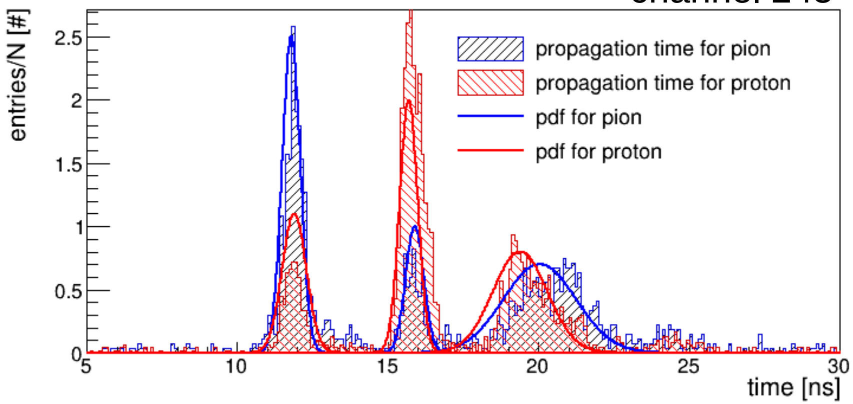
Analytical PDF: Example

- CERN 2018 prototype simulations
- protons/pions at 7 GeV/c (equivalent to kaons/pions at 3.5 GeV/c)

channel 220



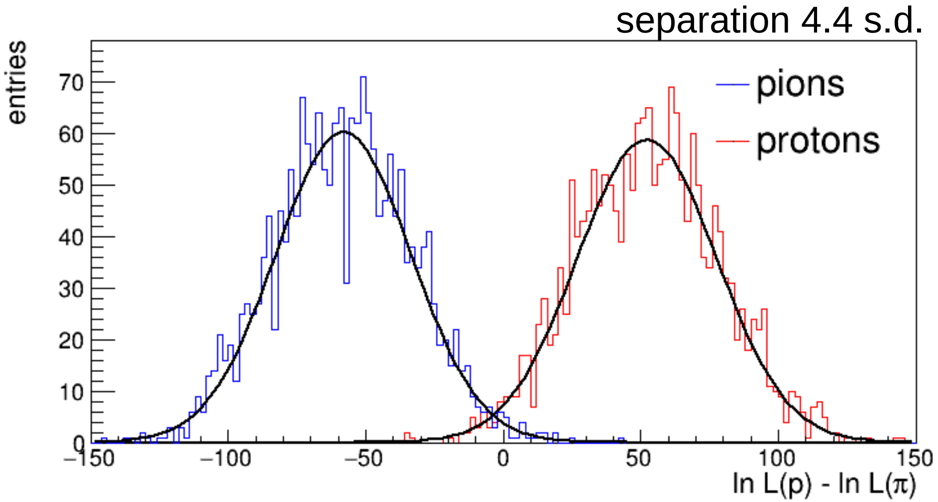
channel 245



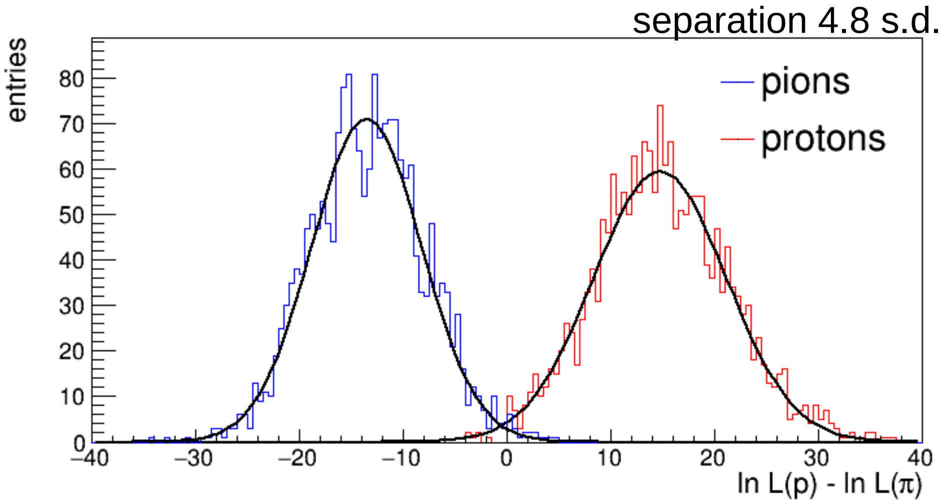
Analytical PDF: Separation

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

analytical PDF



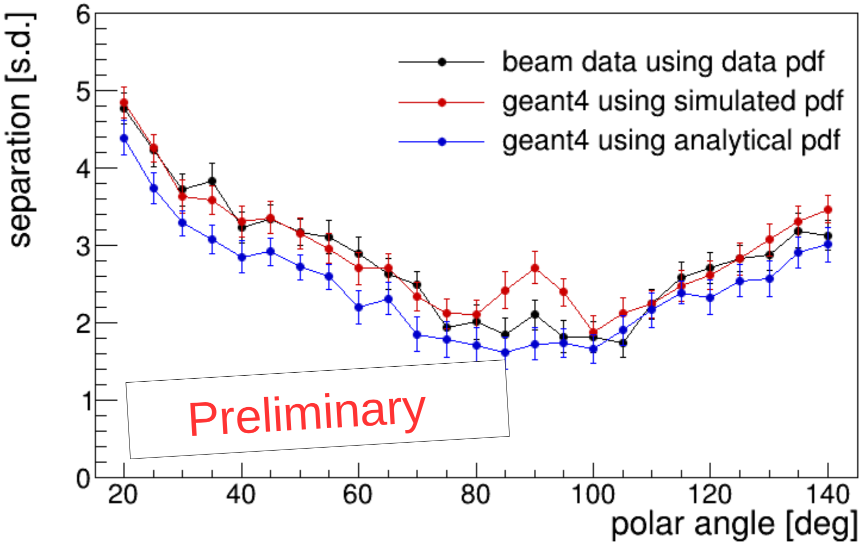
simulated PDF



For comparison: geometrical reconstruction delivers 3.5 s.d.

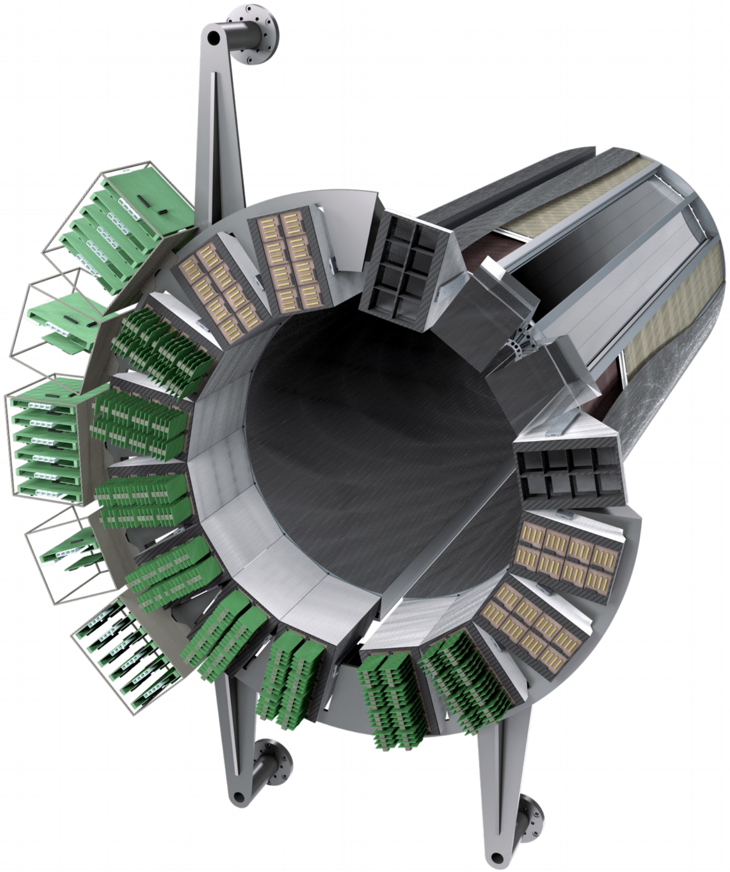
Analytical PDF: Theta Scan

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



Summary

- Time Imaging uses both position and time measurements in optimal way to deliver PID
- Combination of LUT with analytical approach gives a fast way to create Probability Density Functions for Time Imaging
- Application of the Time Imaging with analytical PDFs to the prototype geometry from CERN 2018 beam test gives PID performance close to one with simulated PDF (4.4 s.d. vs. 4.8 s.d.)



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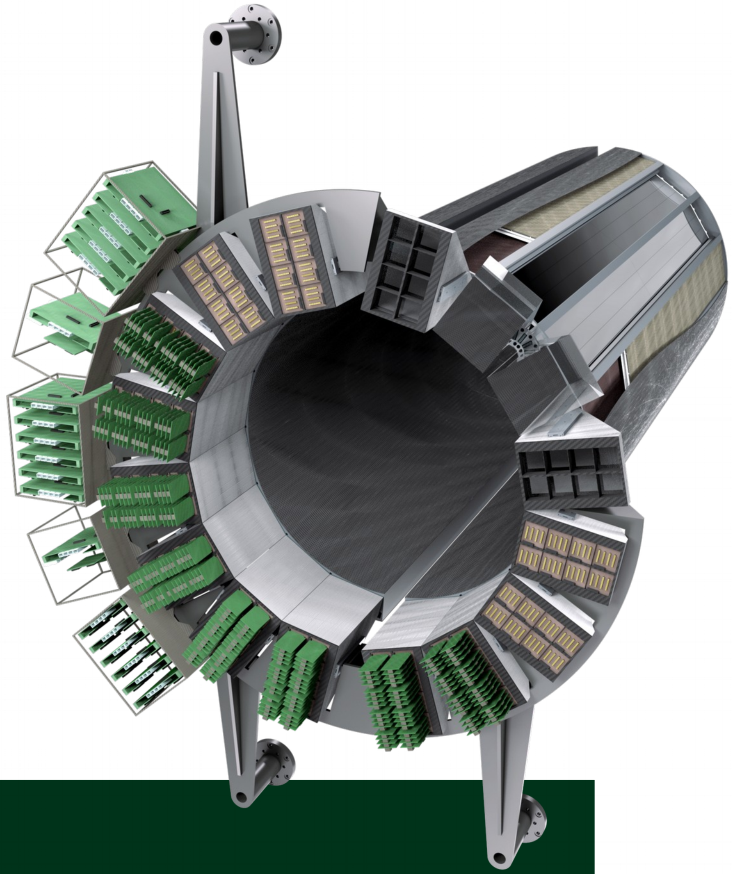

Thank you for the attention