Particle Identification Algorithms for the PANDA Barrel DIRC

Roman Dzhygadlo
for the PANDA Cherenkov Group

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

The PANDA Cherenkov Group:
PANDA Barrel DIRC at FAIR

Goal: 3 s.d. $\pi$/K separation up to 3.5 GeV/c, $22^\circ$ - $140^\circ$

Facility for Antiproton and Ion Research
PANDA Barrel DIRC

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

one pion

87 photons

one kaon

95 photons
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
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:

\[ \theta_c \]

number of photons: 1

entries [#]
Geometrical Reconstruction

Reconstruction:
Geometrical Reconstruction

Reconstruction:

\[ \theta_c \]
Geometrical Reconstruction

Reconstruction:

number of photons: 4

entries [#]

$\theta_c$ [rad]
Geometrical Reconstruction

Reconstruction:
Geometrical Reconstruction

Reconstruction:

(number of photons: 7)

\[ \theta_c \]
Geometrical Reconstruction

Reconstruction:

[Diagram showing geometrical reconstruction with angles and photon distribution]

number of photons: 12

 entries [#]

θc [rad]

0.7 0.72 0.74 0.76 0.78 0.8 0.82 0.84 0.86 0.88 0.9

30 25 20 15 10 5 0
Geometrical Reconstruction

Reconstruction:

\[ \theta_c \]

- Number of photons: 20
- Entries: [0, 30]

\[ \theta_c \text{ [rad]} \]

- Values: 0.7 to 0.9
Geometrical Reconstruction

Reconstruction:

number of photons: 74

\( \theta_c \) [rad]
Geometrical Reconstruction

Reconstruction:
Geometrical Reconstruction

Likelihood calculation:

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

number of photons: 74

Che Tet angle [rad]

partile momentum [GeV/c]

0 1 2 3 4 5 6 7 8

pion kaon proton

0.75 0.76 0.77 0.78 0.79 0.8 0.81 0.82 0.83

entries [#]

0.7 0.72 0.74 0.76 0.78 0.8 0.82 0.84 0.86 0.88 0.9

0 10 20 30 40 50 60 70
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 for different momenta at 20° polar angle:

- 1 GeV/c
- 2 GeV/c
- 3.5 GeV/c
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°

propagation time of Cherenkov photons:

![accumulated hit pattern](image)

![Histograms](image)
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**

PDFs of kaon and pion for given pixel
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

\[
\log L_h = \sum_{i=1}^{N} \log(S_h(c_i, t_i) + B_h(c_i, t_i)) + \log P_h(N)
\]

\[
\sum_{m_j} n_{k,j} g(t_{k,j}, \sigma_{k,j}) = \text{sum of Gaussians}
\]

\[n_{k,j} \sim \text{effective pixel size}\]

\[\sigma_{k,j} \sim \text{chromatic dispersion, optical aberrations}\]
Analytical PDF using LUT

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

\[
\sum_{k=1}^{m_j} n_{k,j} g(t_{k,j}, \sigma_{k,j}) = \text{sum of Gaussians}
\]

\(n_{k,j}\) ~ effective pixel size
\(\sigma_{k,j}\) ~ chromatic dispersion, optical aberrations

\[
t_{k,j} = \frac{z}{\cos \beta_{k,j}} + t_{k,j}^L
\]
Analytical PDF using LUT

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

\[
\sum_{k=1}^{m_j} n_{k,j} g(t_{k,j}, \sigma_{k,j}) = \text{sum of Gaussians}
\]

\[n_{k,j} \sim \text{effective pixel size}\]

\[\sigma_{k,j} \sim \text{chromatic dispersion, optical aberrations}\]

\[t_{k,j} = \frac{z}{\cos \beta_{k,j}} + t^L_{k,j}\]
Analytical PDF using LUT

Cherenkov angle distribution

\[ t_{k,j} = \frac{z}{\cos(\beta_{k,j})} + t_{k,j} \]
Analytical PDF using LUT

Cherenkov angle distribution

\( \theta^K_c \) \( \theta^\pi_c \)

entries [#]

0.75 0.76 0.77 0.78 0.79 0.8 0.81 0.82 0.83 0.84 0.85

\( \theta_c \) [rad]

3.5 GeV/c

\( t_{kj} = \frac{z}{\cos(\beta_{kj})} + t^L_{kj} \)
Analytical PDF using LUT

Cherenkov angle distribution

\[ \theta^K_c \quad \theta^\pi_c \]

entries [#]

\[ \text{time [ns]} \]

3.5 GeV/c

\[ t_{k,j} = \frac{z}{\cos(\beta_{k,j})} + t^L_{k,j} \]
Analytical PDF using LUT

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

\( n_{kj} \sim \text{effective pixel size} \)

\( \sigma_{kj} \sim \text{chromatic dispersion, optical aberrations} \)

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

Final PDFs

3.5 GeV/c
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)

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**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.
Summary

- Two reconstruction methods for the PANDA Barrel DIRC were developed and validated with data from prototypes in particle beam
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Thank you for the attention