Disc DIRC PID Algortihms

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DIRC 2017 Workshop

August 08, 2017

Outline

1. Reconstruction & PID Algorithms
2. Detector Performance
3. Online Reconstruction

Introduction to FAIR/PANDA:

- Jochen Schwiening: The PANDA Barrel DIRC
- Albert Lehmann: MCP Lifetime and other Performance Studies

Introduction to Disc DIRC Detector:

- Klaus Föhl: The PANDA Endcap Disc DIRC

Opening angle of Cherenkov Cone:

$$\theta_C = \arccos\left(\frac{1}{n(\lambda)\beta}\right)$$

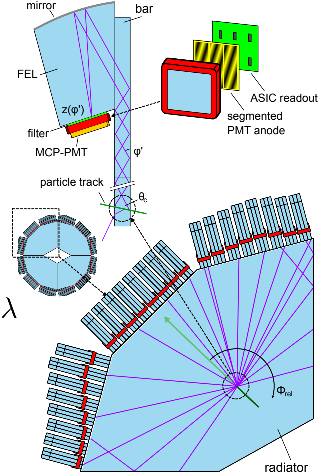
with $\beta = p/(m_0^2 + p^2)$.

Number of photons per track length according to Frank-Tamm-Formula:

$$\frac{dN}{dx} = 2\pi\alpha z^2 \int_{\lambda_1}^{\lambda_2} \left(\frac{1}{\lambda^2} - \frac{1}{n^2(\lambda)\beta^2\lambda^2}\right) d\lambda$$

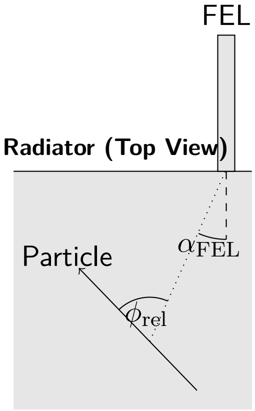
$$\approx 1000\,\text{photons/particle for } \pi^{\pm} \text{ with } 4\,\text{GeV/c momentum}$$

New detector geometry with 8 ROMs per side:

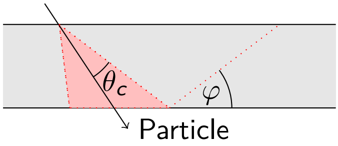


Geometrical Model

Reconstruction of Cherenkov angle θ_C and hitpattern prediction with geometrical model of detector:

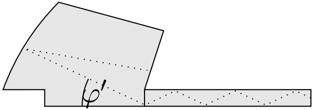


Radiator (Side View)



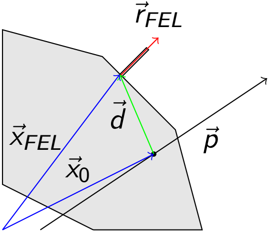
$$\tan\varphi' = \frac{\tan\varphi}{\tan\alpha_{FEL}}$$

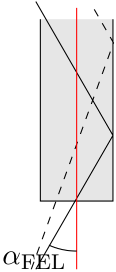
FEL and Bar



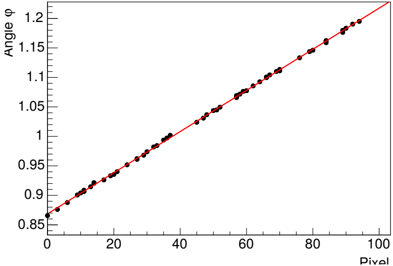
Cherenkov Angle: $\theta_C = \arccos(\sin\theta_p \cos\phi_{rel} \cos\varphi + \cos\theta_p \sin\varphi)$

Analytical Reconstruction



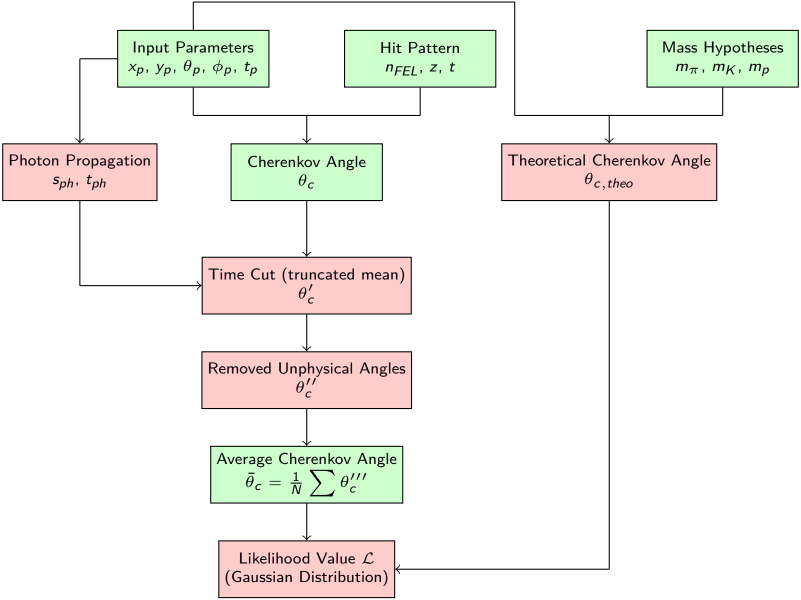


- Calculation of relevant angles geometrically with dot products
- Linear correlation between z position and φ'



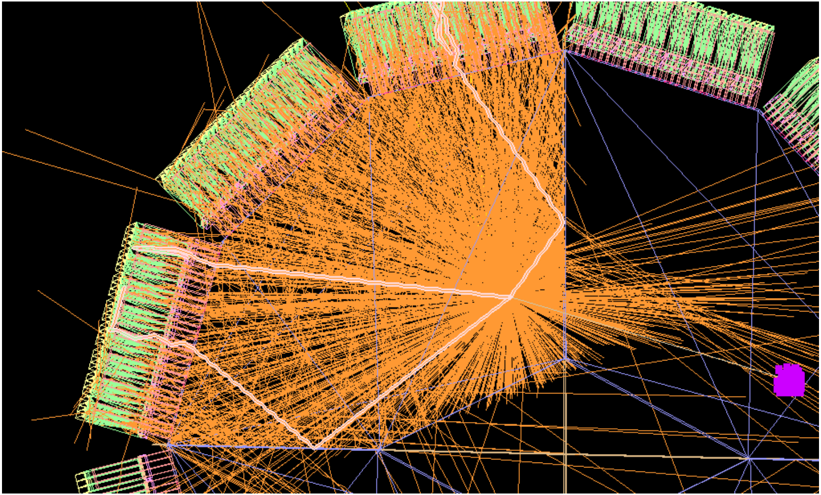
- Geometrical error depending on distance between particle position and FEL
- Computing resolution σ of predicted hit with error propagation for likelihood avalue

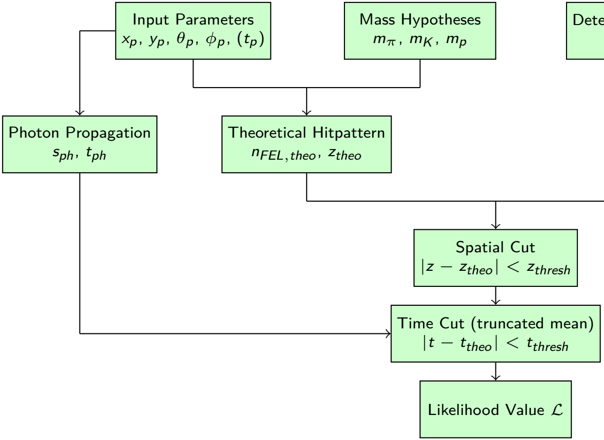
Backward Reconstruction Algorithm



Event Displays

Event display of Monte-Carlo simulations with additional reflections taken into account:



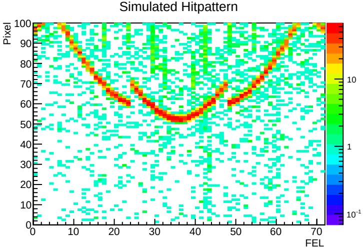


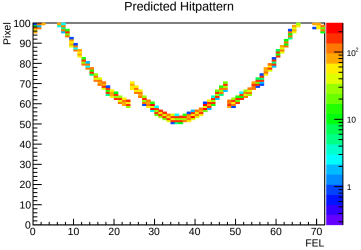
Pseudo likelihood function for accepted hits:

$$\ln \mathcal{L} = \sum_{i=0}^{N} \left(\ln \mathcal{G}(z_i | z_{pred,i}; \sigma_z) + \ln \mathcal{G}(t_i | t_{pred,i}; \sigma_t) \right)$$

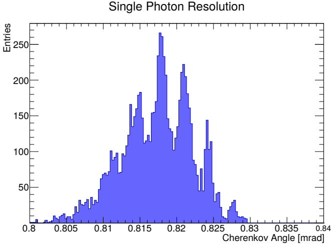
Cherenkov Angle Resolution

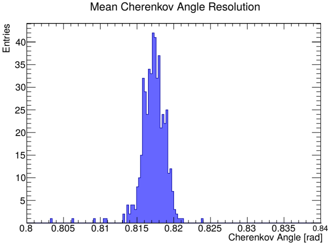
Hit pattern with new geometry (8 ROMs per side):

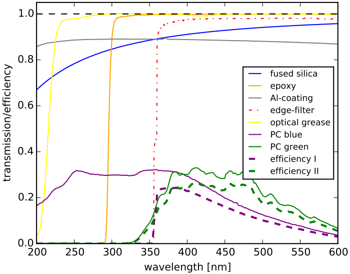




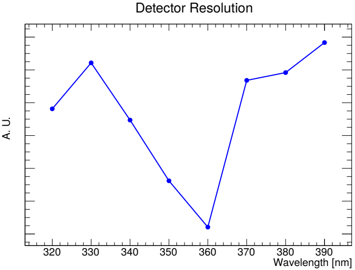
Single photon resolution and detector resolution:







- Mirror reflectivity of focusing elements
- MCP detection efficiency
- Transmission coefficiencies, refractive indices and absorption lengths of used materials
- Using bandpass filter with minimum wavelength cut off



- Detector resolution::

$$\sigma_\theta^2 = \frac{\sigma_{ph}^2}{N} + \sigma_{track}^2$$

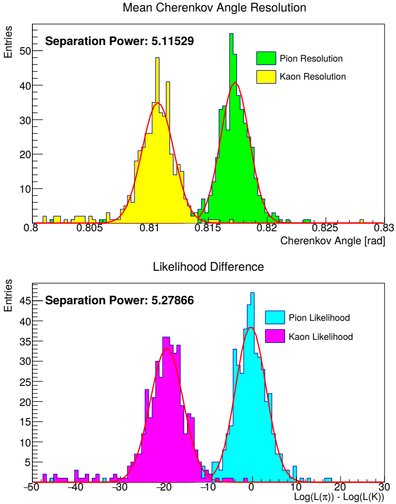
- σ_{ph} containing chromatic error

Separation Power

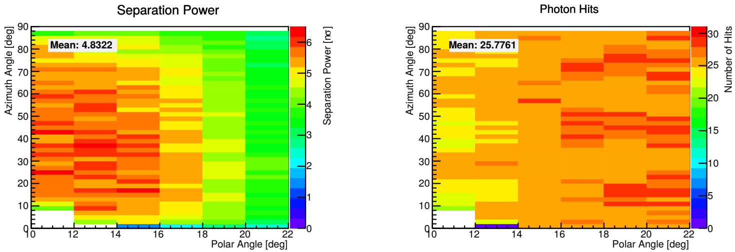
- Comparison between Cherenkov angle and likelihood reconstruction
- 1000 events π^+ and K^+
- Momentum: 4 GeV/c
- Polar Angle: 12°
- Azimuth Angle: 45°
- Separation power:

$$n_\sigma = \frac{\mu_K - \mu_\pi}{\frac{1}{2}(\sigma_K + \sigma_\pi)}$$

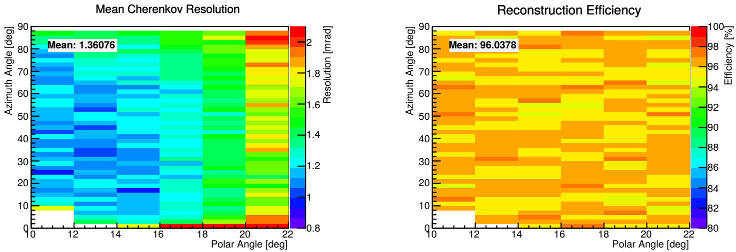
- Both results almost identical



Separation Power & Photon Yield:

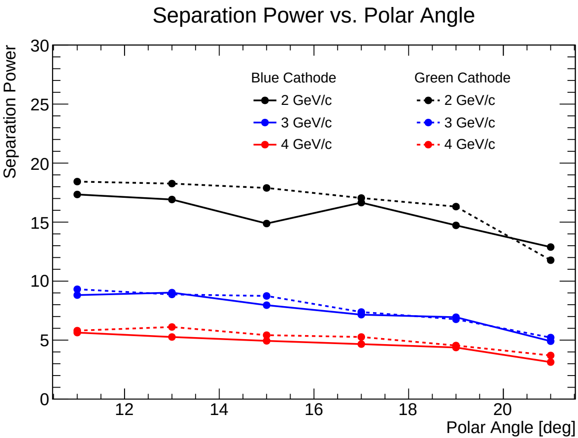


Detector Resolution & Reconstruction Efficiency:



Polar Angle Projection

Separation Power for different momenta as function of polar angle:



Important Results:

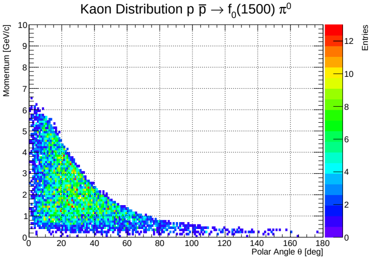
- Small difference between photo cathodes
- Worse resolution for larger polar angles

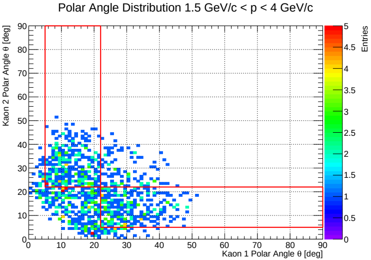
Benchmark Channel Analysis

Glueball candidate $f_0(1500)$ decay analysis with $J^{PC} = 0^{--}$ using all subdetectors of PANDA:

$$
\begin{aligned}
p\bar{p} \rightarrow f_0\pi^0 \quad &\rightarrow \quad K^+K^-\pi^0 \ (\approx 4.2\%) \\
&\hookrightarrow \quad \pi^+\pi^-\pi^0 \ (\approx 82.5\%) \\
&\qquad \text{(Possible background channel)}
\end{aligned}
$$

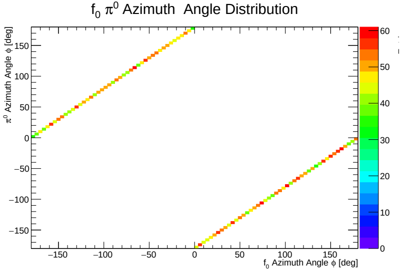
Kaon polar angle distribution:



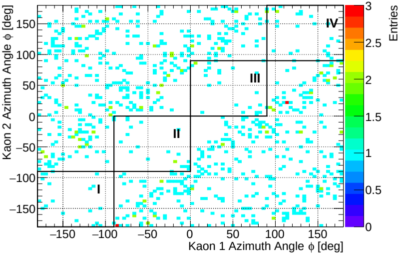


Benchmark Channel Analysis

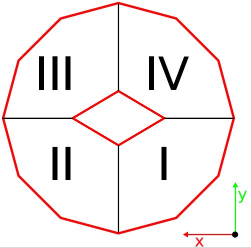
Azimuth angles f_0/π^0 decay:



Azimuth angles K^+/K^-:



- Most kaons enter different quadrants (small effect of pileup events)
- Angle distance of K^+/K^- smaller than 180° due to relativistic effects



Particle Identification

- Bayesian Approach:

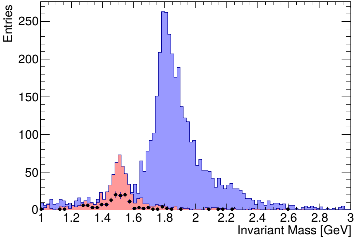
$$p(\theta|x) = \frac{\mathcal{L}(\theta|x)\pi(\theta)}{\int \mathcal{L}(\theta'|x)\pi(\theta')d\theta'}$$

- Probability for N subdetectors and $j = \pi, K$ particle hypotheses:

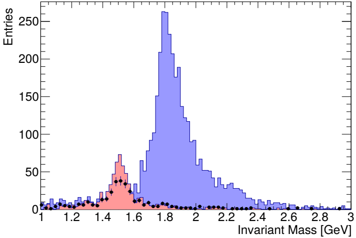
$$p(k) = \frac{\prod_i \mathcal{L}_i(k)}{\sum_j \prod_i \mathcal{L}_i(j)}$$

- PID cut at 90% for every particle
- PID results:
  Increase of signal to background ratio: 53 %

PID without Disc DIRC



PID with Disc DIRC



Online Reconstruction

- Still many questions open
- Requirement: Usable with 20 MHz reaction frequency
- SiTCP package developed at KEK for gigabit ethernet communication
- Prototype working with ML403 board and Xilinx Virtex 4 chip
- Available RAM: 648 kB
- Clock frequency: 130 MHz
- Sending data in 8 bit blocks per clock cycle into FIFO buffer
- Small self-written C++ client sending simulation data to FPGA card

Cherenkov Angle Reconstruction

1. Calculation of Cherenkov angle:

$$\theta_c = \arccos(\sin\theta_p \cos\phi_{rel} \cos\varphi + \cos\theta_p \sin\varphi)$$

2. Cherenkov angle reconstruction using sums, products, squareroots and trigonometrical functions:

$$\cos\theta_p = \frac{p_z}{\sqrt{p_x^2 + p_y^2 + p_z^2}} \Rightarrow \sin\theta_p = \sqrt{1 - \cos^2\theta_p}$$

$$\cos\alpha_{FEL} = \frac{\vec{p}\cdot\vec{r}}{\sqrt{\vec{p}^2\cdot\vec{r}^2}}, \quad \tan\varphi = \tan\varphi' \cdot \cos\alpha_{FEL}, \quad \phi_{rel} = \frac{\vec{p}\cdot\vec{r}}{\sqrt{\vec{p}^2\cdot\vec{r}^2}}$$

3. Division n bit integer by m bit integer $\rightarrow$ resolution decreases to $n - m$ bits

Numerical Calculations

- Lookup tables for $\sqrt{\cdot}$, $\sin(\cdot)$ etc.

$$(0,1)^n \rightarrow (0,1)^m$$

- Required RAM: $m \cdot 2^n$ bits
- Disadvantage: Huge memory consumption for large arrays:

Array Size	**Memory Requirement**
8 bit	256 B
16 bit	128 kB
32 bit	16 GB

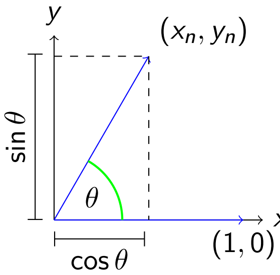
- Solution: Numerical sequential or parallel algorithms instead of lookup tables
- Disadvantages:
  - Sequential implementation → Long processing time
  - Parallel implementation: High resource consumptions (LUTs etc.) and no pipelining

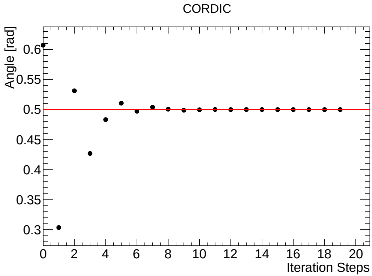
CORDIC Algorithm

- Coordinate Rotation Digital Compouter (CORDIC) for computation of trigonometric functions
- Motivation: Calculate $\sin\theta$ and $\cos\theta$ with rotation of vector $\vec{x_0} = (0,1)$ to $\vec{x_1} = (\cos\theta, \sin\theta)$
- Using linear combination $\theta = \sum \sigma_i \alpha_i$ and setting $\tan\alpha_i = 2^{-i}$:

$$\begin{pmatrix} x_n \\ y_n \end{pmatrix} = \prod_{i=0}^{n} \frac{1}{\sqrt{1+2^{-2i}}} \begin{pmatrix} 1 & -\sigma_i \cdot 2^{-i} \\ \sigma_i \cdot 2^{-i} & 1 \end{pmatrix} \cdot \begin{pmatrix} x_i \\ y_i \end{pmatrix}$$

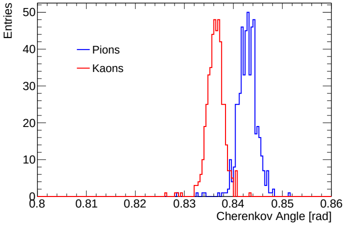
- Longer processing time ($\approx$ 6 clock cycles per photon hit)

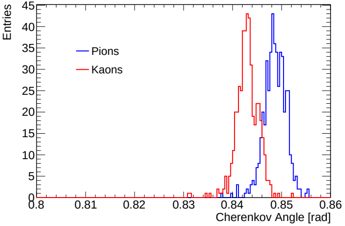




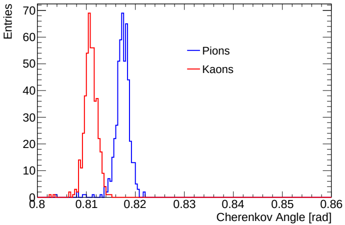
Online Reconstruction Results

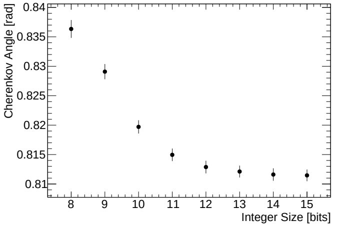
Results with 8 bit resolution (for $\theta = 12^\circ$ and $\theta = 16^\circ$):





Results with 16 bit resolution::





Summary & Outlook

Summary:

- New detector design with updated geometry
- Fully implemented and tested reconstruction algorithms
- Validated detector performance with Monte-Carlo studies
- Successfull testbeam in October 2016 (talk from Klaus)

Outlook:

- Precise measurement of photon yield in cosmics test stand (2017)
- Testbeam with magnetic field and filter in near future
- Work on full scale quadrant in progress (2018)
- Finalizing online reconstruction according to PANDA specifications

Thank you very much for your attention!