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Cherenkov angle reconstruction on Xilinx Virtex

Workshop // on // Fast Realtime Systems // and // Realtime Machine Learning

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April 09, 2024

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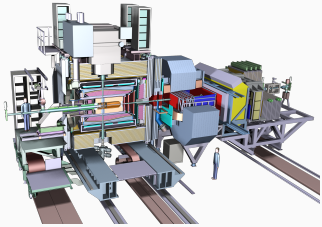
FAIR

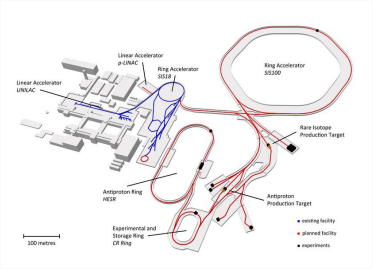
- Antiprotons $\bar{p}$ from HESR
- High luminosity mode:

$$\mathcal{L} = 2 \cdot 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

- Average interaction rate:

$$\dot{N} = 2 \cdot 10^{7}\,\mathrm{s}^{-1}$$





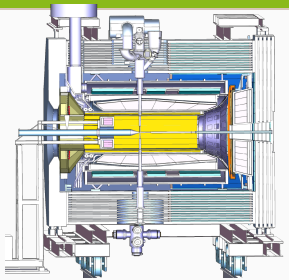
PANDA

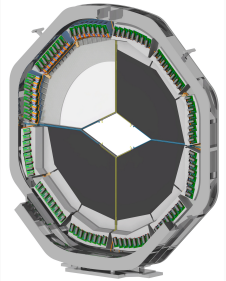
- $p\bar{p}$ collisions with hydrogen target
- Created particles with forward boost in z-direction
- Excellent PID necessary to fulfill physics program goals

Detector Concept

Particle Identification

- Two Cherenkov PID detectors in target spectrometer: Barrel & Disc DIRC
- Large area of kaon phase space covered with both detectors





Disc DIRC

- Only 2 cm thickness in z-direction
- Polar angles: $5^\circ \leq \theta \leq 22^\circ$
- 3-σ separation of $\pi^\pm/K^\pm$ up to momentum $p = 4\,\mathrm{GeV/c}$
- Radiator plate consisting of 4 independent fused silica quadrants

Detector Overview

Opening angle of Cherenkov Cone:

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

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

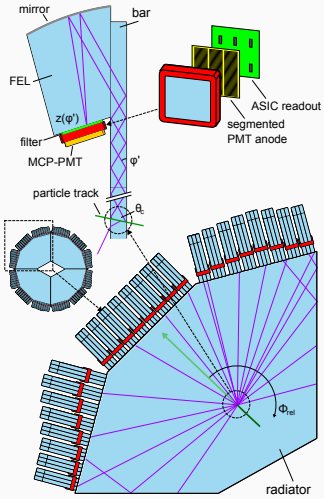
Number of photons per track length according to Frank-Tamm-Formula:

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

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

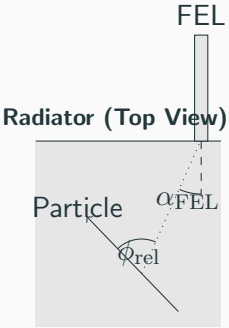
Only 21 photon hits/event measured

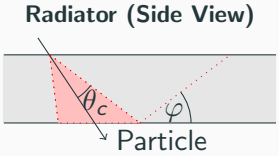
New detector geometry with 8 ROMs per side:



Geometrical Model

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

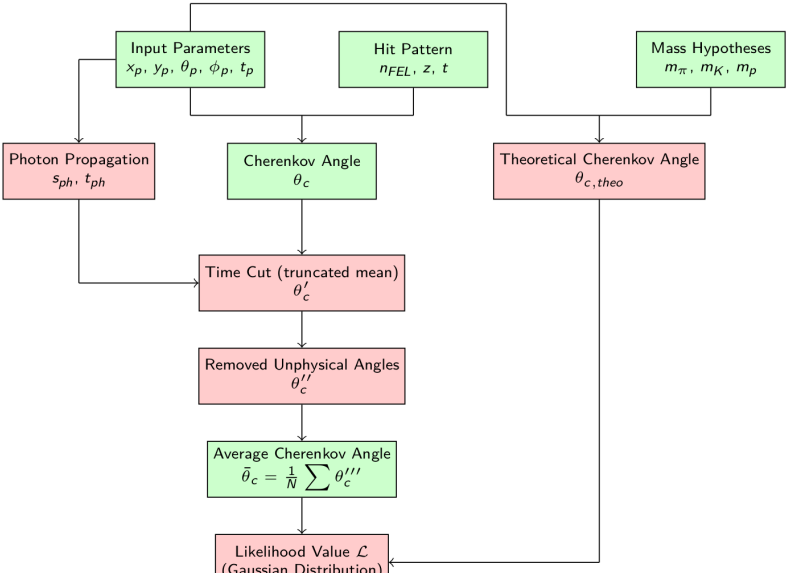




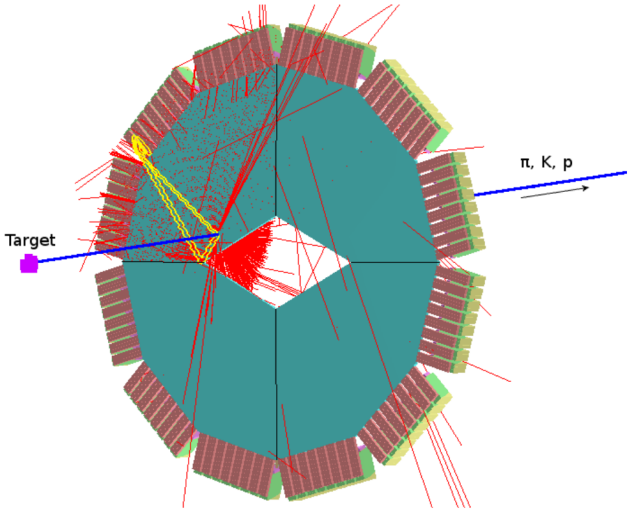
$$\tan\varphi' = \frac{\tan\varphi}{\tan\alpha_{FEL}}$$

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

Backward Reconstruction Algorithm

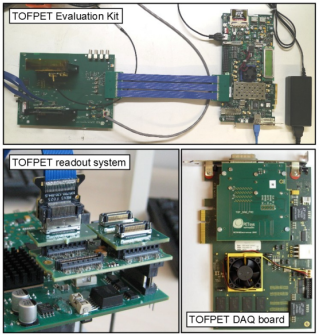


Implementation of Disc DIRC in PandaRoot Framework



Endcap Disc DIRC (EDD)

- Fast digitization of MCP-PMT signals will be done with TOFPET ASICs by PETsys
  - Successful tests with an evaluation kit as well as a full system with several hundred channels have been done
  - Will also be used by the SciTil, new TOFPET2 ASIC with improved specs



TOFPET2 ASIC specifications:

- Signal amplification and discriminiation for each of 64 independent channels
- Dynamic range: 1500 pC
- RDC time binning: 30 ps
- Max channel hit rate: 480 kHz
- Max output data rate: 2.6 Gb/s
- Clock frequency: 200 MHz

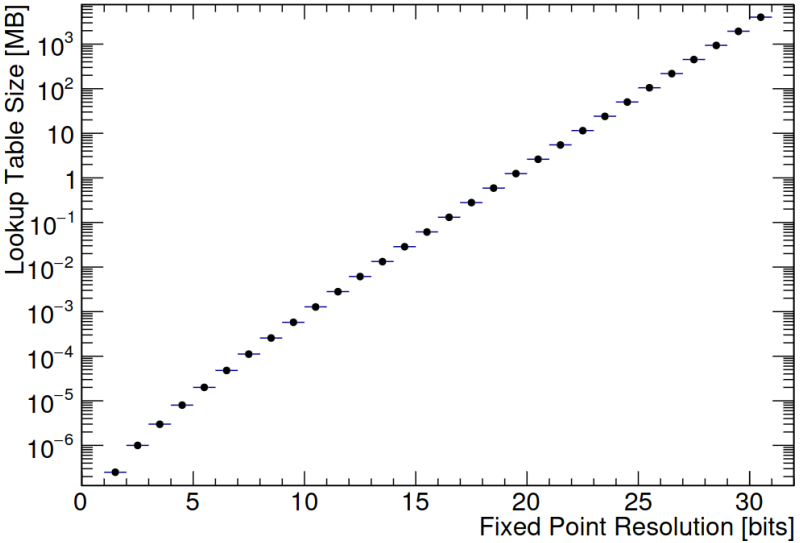
Online Reconstruction

- Requirement: Should be usable with 20 MHz interaction frequency (50 ns time window)
- Prototype: SiTCP package developed at KEK for gigabit ethernet communication
- Prototype working with ML403 board and Xilinx Virtex 4 chip
- Available block RAM: 648 kB
- Clock frequency: 130 MHz $\rightarrow$ 7.7 ns per clock cycle
- Sending data in 8 bit blocks per clock cycle into FIFO buffer
- Small self-written C++ client sending simulation data to FPGA card

Transfer Application

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>

int main()
{
        short number = 1423;

        uint8_t num1 = number1 &0xFF;
        uint8_t num2 = number1 >> 8;

        int conn_sock;
        struct sockaddr_in server_addr;
        conn_sock=socket(AF_INET,SOCK_STREAM,0);

        server_addr.sin_family=AF_INET;
        server_addr.sin_port=htons(24);
        server_addr.sin_addr.s_addr=inet_addr("192.168.10.16");

        connect(conn_sock, (struct sockaddr *)&server_addr,
                sizeof (server_addr));

        send(conn_sock, &num1, sizeof(num1), 0);
        send(conn_sock, &num2, sizeof(num2), 0);

        uint8_t num3[8];
        int result = recv(conn_sock, &receive,
                sizeof(receive), 0);
}
```

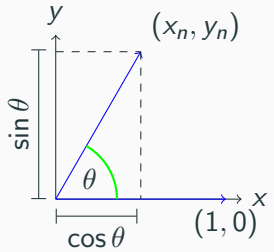
Lookup Tables



CORDIC Algorithm

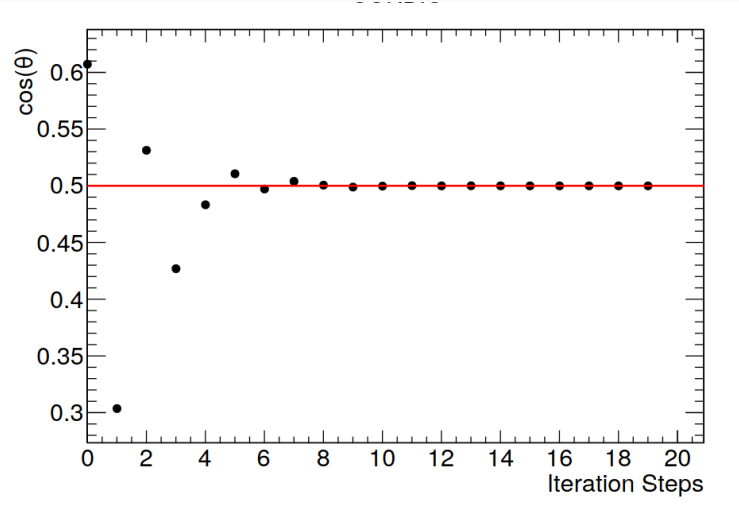
- Coordinate Rotation Digital Compouter (CORDIC) for computation of trigonometric functions
- Motivation: Calculate $\sin\theta$ and $\cos\theta$ with rotation of vector $\vec{x_0} = (0, 1)$ to $\vec{x_1} = (\cos\theta, \sin\theta)$
- Using linear combination $\theta = \sum \sigma_i \alpha_i$ and setting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

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



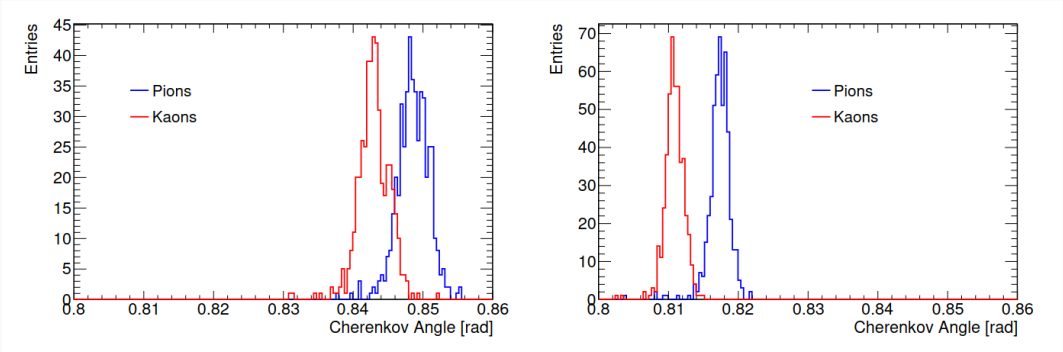
Convergance

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

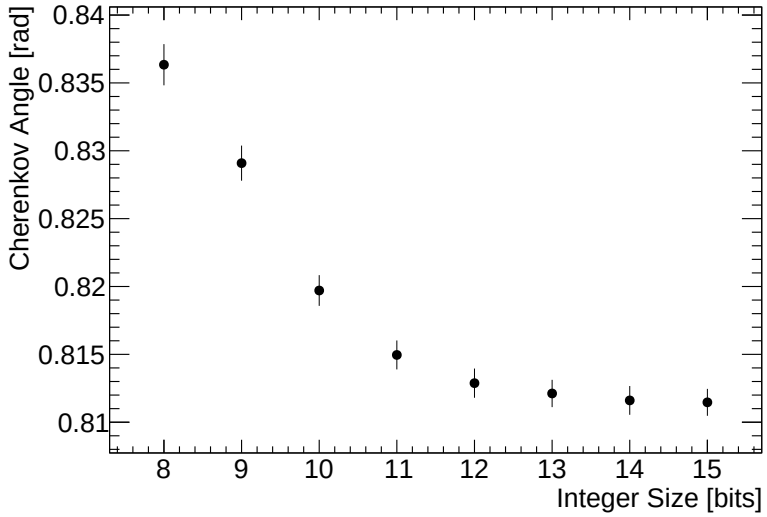


Online Reconstruction Results

Results with 8 bit and 16 bit resolution:



Reconstructed Cherenkov Angle



Conclusion & Outlook

- First Cherenkov angle reconstruction on FPGA for PANDA
- Much more work to be done for online reconstruction prototype but maybe initial step
- Changes to be adapted according to FPGA, memory, possibility for parallelization etc
- To be tested with DAQ at testbeam or cosmic test stand

Thank you very much for your attention!