F-DIRC for SCT

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Motivation

- Short status update for DIRC development at Giessen
- Introduction: Self-written software for ray-tracing and simplified Monte-Carlo simulations
- Results of systematic resolution studies: angle straggling, dispersion, geometrical errors etc

Detector

- Onion shell: Vertex detector, Drift chamber, RICH/DIRC, Calorimeter, Solenoid
- PID including barrel and endcap part (green)
- Distance to IP: 1,100 mm
- Inner radius: 200 mm
- Outer radius: 800 mm
- Polar angle range: $10^\circ \ldots 40^\circ$
- Momentum range: $0.5 \ldots 1.5$ GeV/c
- Separation of $\mu^\pm$ and $\pi^\pm$

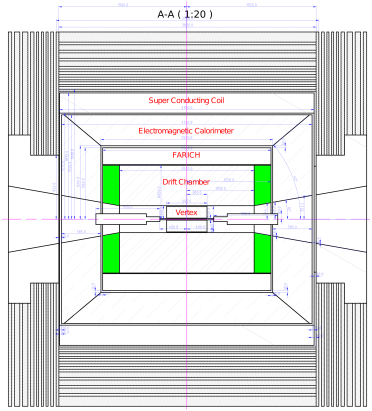

Figure: SCT Detector

Required Resolution

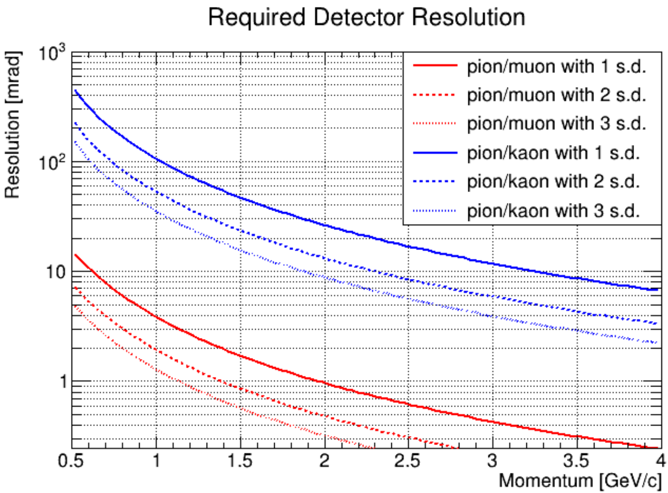

Figure: Required detector resolution

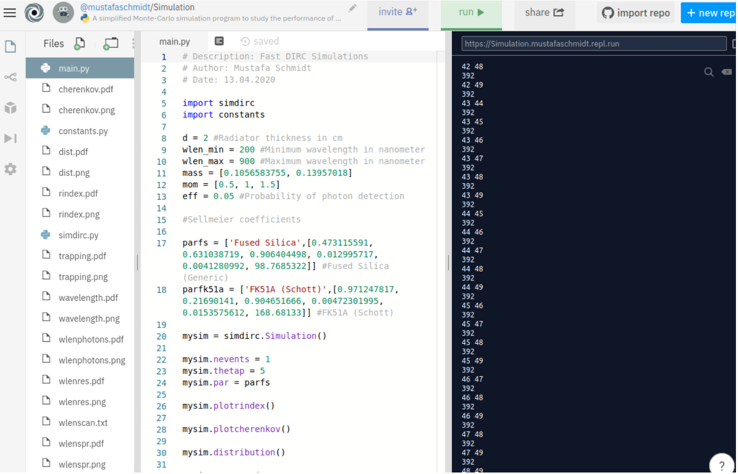

Figure: Python code for simplified Monte-Carlo studies.

Raytracer

Self-written ray-tracer for optical calculations

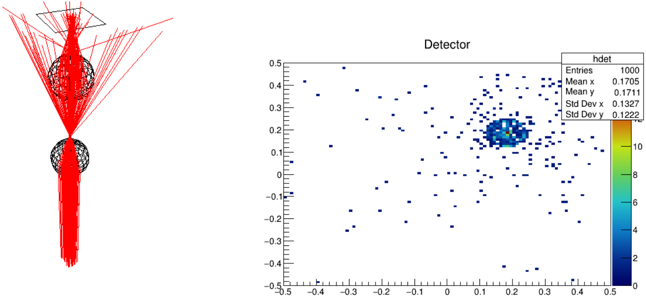

Figure: Light rays through an spherical object

Refractive Index

- Cherenkov angle:

$$\theta_c = \arccos\left(\frac{1}{n\beta}\right) \qquad (1)$$

- Internal reflection:

$$\theta_r = \arcsin\left(\frac{1}{n}\right) \qquad (2)$$

- Required Condition:

$$\theta_c + \theta_p > \theta_r \qquad (3)$$

- θ_p: Polar angle of particle
- Refractive index as function of momentum and angle

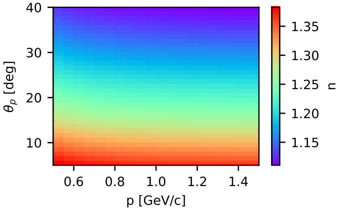

Figure: Refractive index for pions

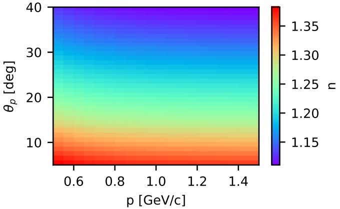

Figure: Refractive index for muons

- Distance between intersection and FEL:

$$s_0 = R - d \tan\theta_p \qquad (4)$$

- Optical photon path:

$$s = \frac{s_0}{\cos\varphi} \qquad (5)$$

with $\varphi = \pi/2 - (\theta_p + \theta_c)$

- Required TOP Resolution:

$$t = \frac{1}{n}\left|\frac{s_{\mu,\pi}}{v} - \frac{s_{\pi,K}}{v}\right| \qquad (6)$$

- Not feasible!

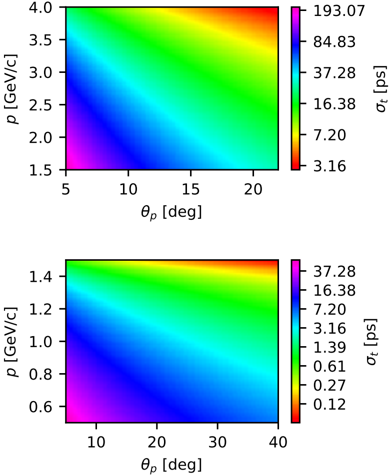

Figure: PANDA and SCTF

Square sum of all individual errors equals the overall detector resolution:

$$\sigma_{\theta_c}^2 = \frac{\sigma_{\text{geom}}^2 + \sigma_{\text{sens}}^2 + \sigma_{\text{opt}}^2 + \sigma_{\text{disp}}^2}{N} + \sigma_{\text{track}}^2 + \sigma_{\text{strag}}^2 \quad (7)$$

- σ_{geom}: Error resulting from width of FELs
- σ_{sens}: Error from finite pixel width
- σ_{opt}: Optical errors from mirror
- σ_{disp}: Error from chromatic dispersion
- σ_{track}: Tracking resolution of charged particle
- σ_{strag}: Angle straggling of charged particle in radiator

Photon Losses

Possibilities of photon losses:

- Untrapped photons $\varepsilon_{\text{trap}}$ (ca. 30%)
- Sensor losses ε_{pde} (ca. 90%)
- Optical losses ε_{opt} (ca. 10%)
- Ineffective area between bars $\varepsilon_{\text{geom}}$ (ca. 20%)
- Propagation losses such as diffraction, scattering, and absorption $\varepsilon_{\text{prop}}$ (ca. 5%)

Photon loss studies:

- Created photons: $N_{\text{tot}} \approx 1000$ per event
- Remaining photons:

$$N = \varepsilon_{\text{trap}} \cdot \varepsilon_{\text{pde}} \cdot \varepsilon_{\text{geom}} \cdot \varepsilon_{\text{prop}} \cdot \varepsilon_{\text{opt}} \cdot N_{\text{tot}} \approx 20 \ldots 60 \quad (8)$$

Photon Trapping

- Trapping fraction depending on particle momentum and direction
- Photon direction: rotation around x axis by polar angle θ_p of particle

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_p & -\sin\theta_p \\ 0 & \sin\theta_p & \cos\theta_p \end{pmatrix} \cdot \begin{pmatrix} \sin\theta_c \cos\phi \\ \sin\theta_c \sin\phi \\ \cos\theta_c \end{pmatrix}$$

- Calculating intersection with horizontal plane and fraction of two areas

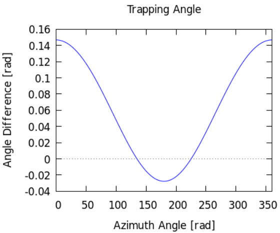

Figure: Angle distribution

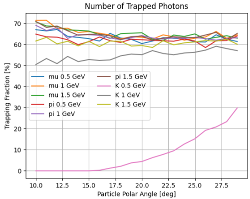

Figure: Trapping fraction

Angle Straggling

- Calculation of angular smearing

$$\sigma_\theta = \frac{13.6\,\mathrm{MeV}}{\beta c p} z \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right) \tag{9}$$

- Scattering after thickness Δx

$$\Delta\sigma_\theta = \frac{d\sigma_\theta}{dx} \Delta x \tag{10}$$

- Normal distribution for every step Δx:

$$\theta' = \frac{1}{\sqrt{2\pi\sigma_\theta^2}} \exp\left(-\frac{\theta^2}{\sigma_\theta^2}\right) \tag{11}$$

- Averaging start and end point (before and after DIRC)
- Difference between angle at each scattering step
- Calculating RMS for all data points

Angle Straggling

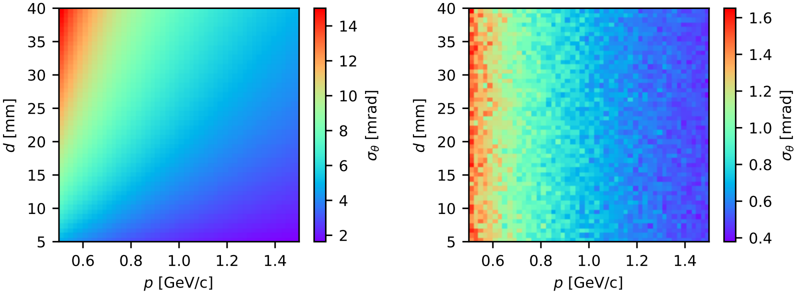

Figure: Angle straggling without and with additional tracking behind detector.

$\Rightarrow$ Additional tracking behind DIRC detectors required!

Dispersion Effect

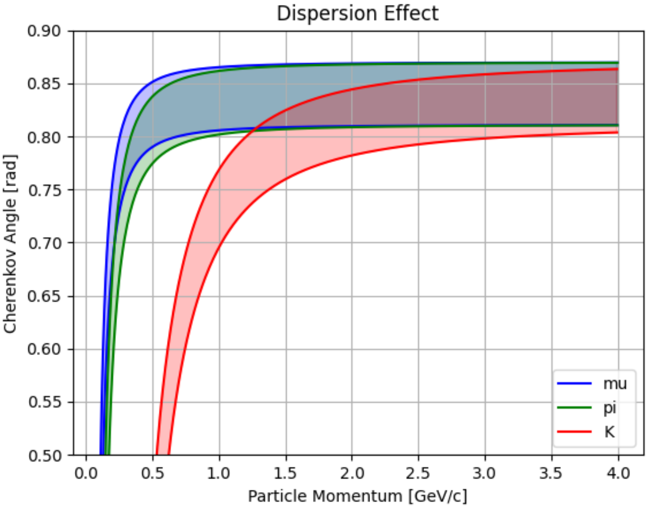

Figure: Cherenkov angle ($200 \leq \lambda \leq 900\,\mathrm{nm}$)

Detector Resolution (Dispersion)

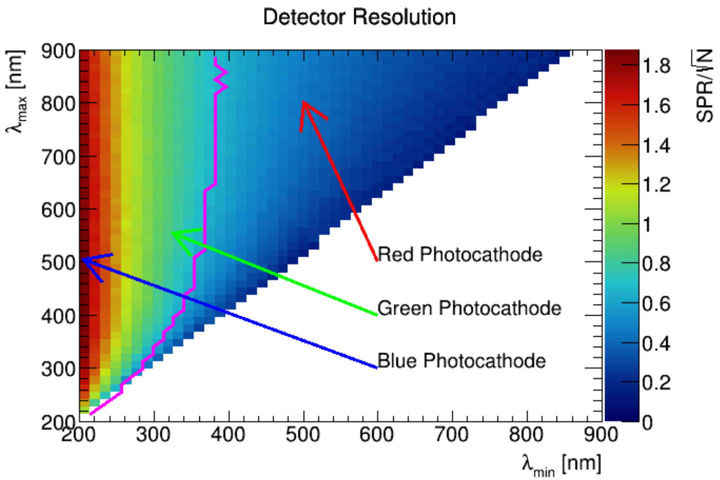

Figure: Detector Resolution for fused silica and pions.

Detector Resolution (Dispersion)

Simulated detector resolution for different materials:

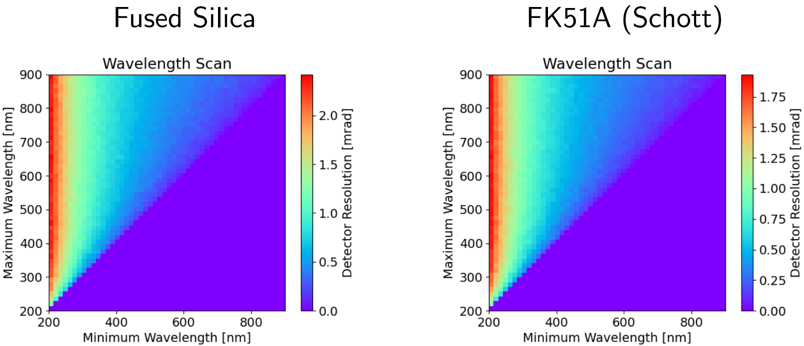

Table: Dispersion for fused silica (Abbe 67.82) and FK51A (Abbe 84.47).

Dispersion Correction

- Using Snell's law for calculating incoming and outgoing photon

$$n_1(\lambda)\sin\alpha = n_2(\lambda)\sin\beta \tag{12}$$

- Only 2d case taken into account

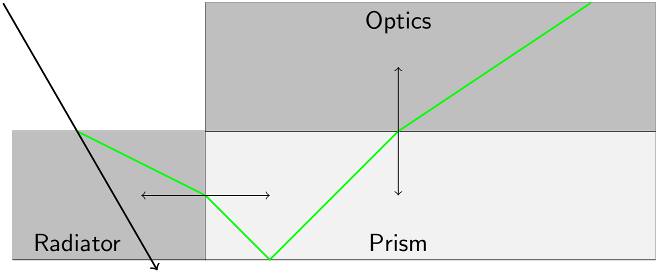

Figure: Prism for dispersion correction

Dispersion Correction

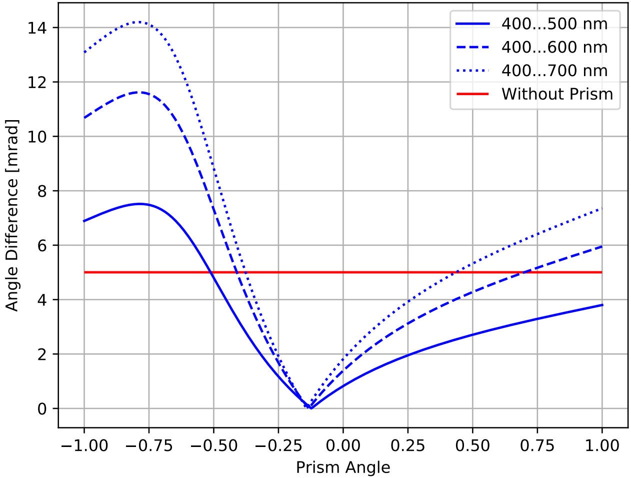

Figure: Photon angles as a function of the prism angle.

Dispersion Correction

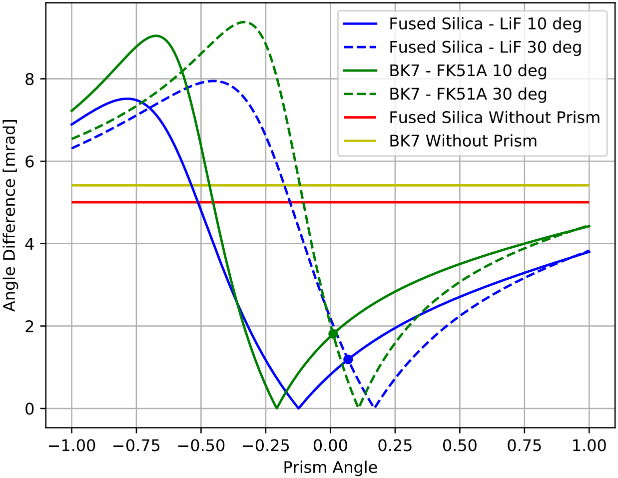

Figure: Photon angles as a function of the prism angle.

Single Photon Resolution (Angle Scan)

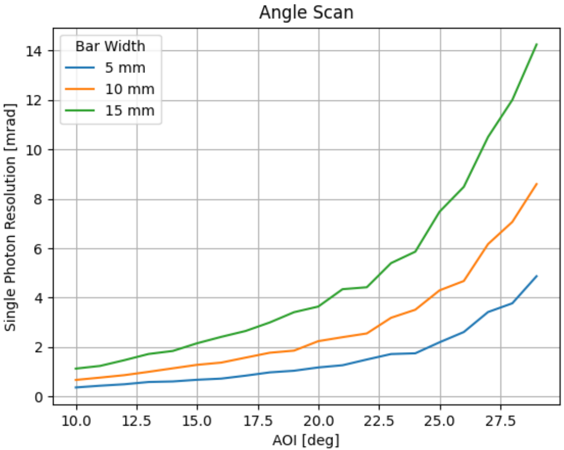

Figure: Single photon resolution as a function of the particle polar angle

Detector Resolution (Bar Width)

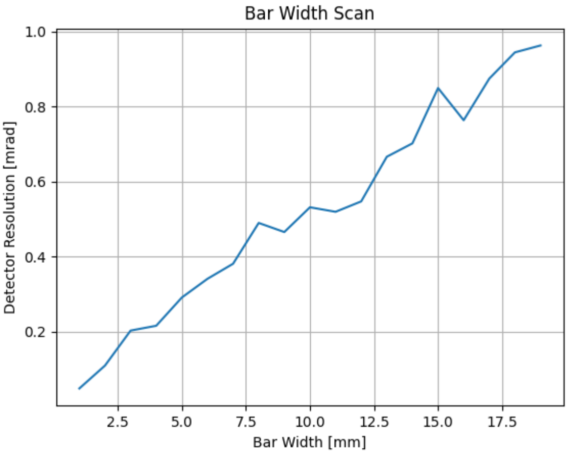

Figure: Detector Resolution resolution as a function of the bar width

Sensor Width

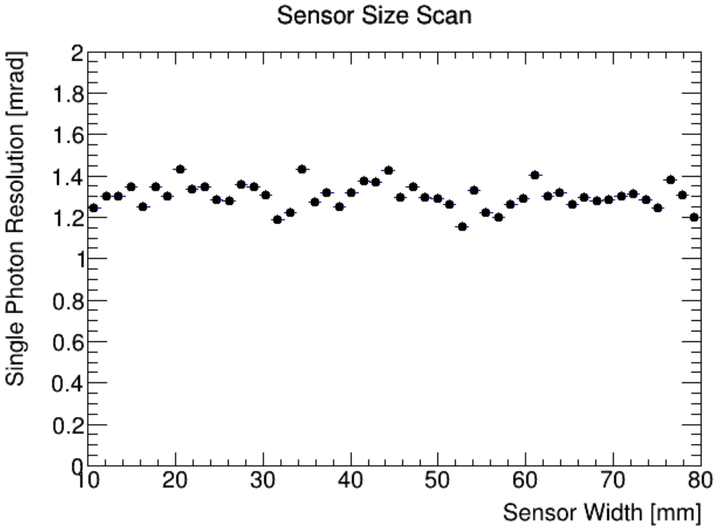

Figure: Sensor width scan with adapting mirror radius

Pixel Scan

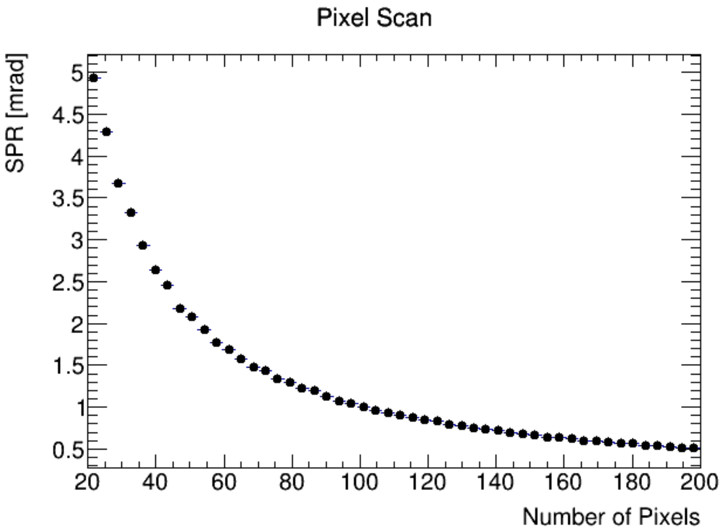

Figure: Pixel scan

Conclusion & Outlook

- Small resolution of $\leq 1\,\text{mrad}$ challenging but not impossible
- Dispersion: major influence on resolution $\Rightarrow$ correction or optimization in sensor required
- Systematic error dominated by angle straggling: additional tracking with high resolution behind DIRC compulsory
- Optical resolutions in right order of magnitude
- Next step: Inserting all results in Geant4 and optimizing parameters