

# 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:  $10^\circ \dots 40^\circ$
- Momentum range:  $0.5 \dots 1.5 \text{ GeV}/c$
- Separation of  $\mu^\pm$  and  $\pi^\pm$

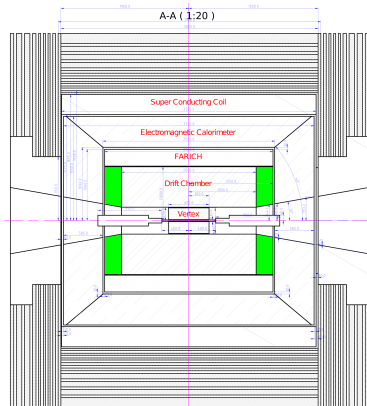


Figure: SCT Detector

# Required Resolution

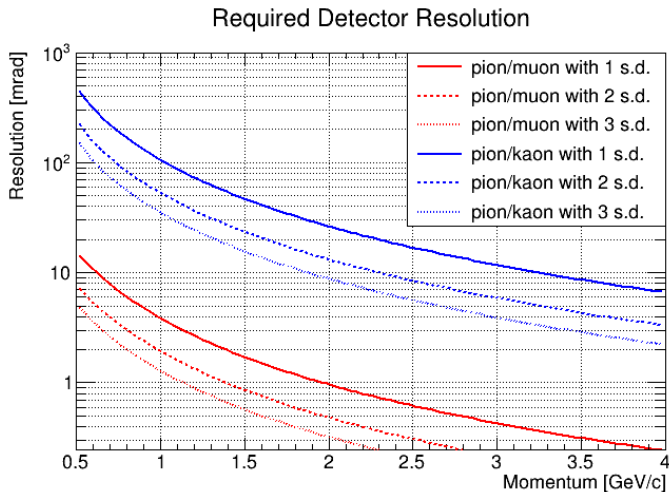
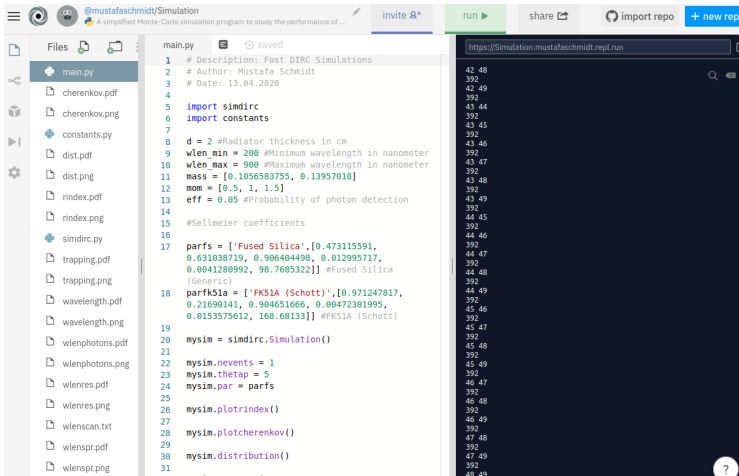


Figure: Required detector resolution



The screenshot shows a web-based Python IDE interface. At the top, the user is identified as @mustafaschmidt/Simulation. The interface includes a file explorer on the left, a code editor in the center, and a terminal on the right. The code in the editor is as follows:

```
1 # Description: Fast DIRC Simulations
2 # Author: Mustafa Schmidt
3 # Date: 13.04.2020
4
5 import simdirc
6 import constants
7
8 d = 2 #Radiator thickness in cm
9 wlen_min = 200 #Minimum wavelength in nanometer
10 wlen_max = 900 #Maximum wavelength in nanometer
11 mass = [0.1056583755, 0.13957018]
12 mom = [0.5, 1, 1.5]
13 eff = 0.05 #Probability of photon detection
14
15 #Sellmeier coefficients
16
17 parfs = ['Fused Silica',[0.473115591,
18 0.631038719, 0.906404498, 0.012995717,
19 0.0041280992, 98.7685322]] #Fused Silica
20 (Generic)
21
22 parfk51a = ['FK51A (Schott)', [0.971247817,
23 0.21690141, 0.904651666, 0.00472301995,
24 0.0153575612, 168.68133]] #FK51A (Schott)
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```

The terminal on the right shows the output of the simulation, displaying a series of numerical values such as 42.48, 392, 42.49, 392, 43.44, 392, 43.45, 392, 43.46, 392, 43.47, 392, 43.48, 392, 43.49, 392, 44.45, 392, 44.46, 392, 44.47, 392, 44.48, 44.49, 392, 45.46, 392, 45.47, 392, 45.48, 45.49, 392, 46.47, 392, 46.48, 392, 46.49, 392, 47.48, 392, 47.49, 392, 48.49.

Figure: Python code for simplified Monte-Carlo studies.

## Self-written ray-tracer for optical calculations

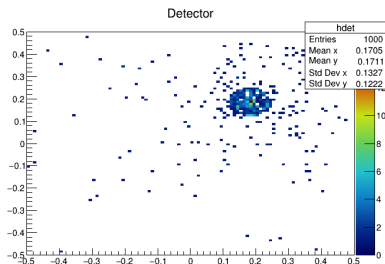
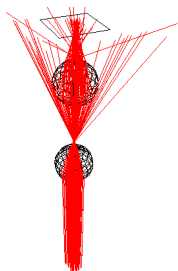


Figure: Light rays through an spherical object

- Cherenkov angle:

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

- Internal reflection:

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

- Required Condition:

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

- $\theta_p$ : Polar angle of particle
- Refractive index as function of momentum and angle

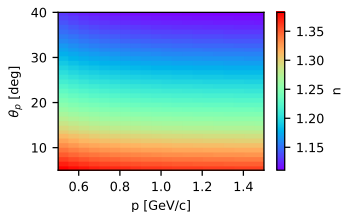


Figure: Refractive index for pions

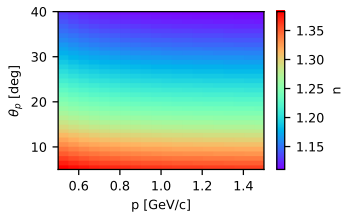


Figure: Refractive index for muons

# Time of Propagation

- Distance between intersection and FEL:

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

- Optical photon path:

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

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

- Required TOP Resolution:

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

- Not feasible!

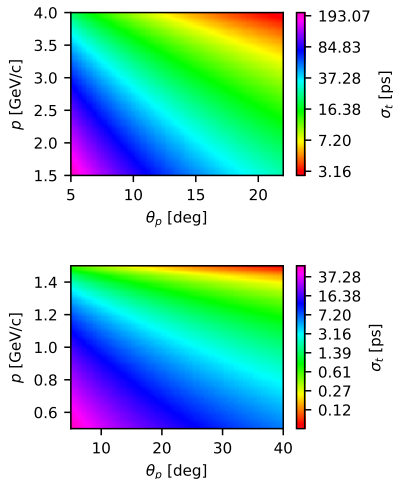


Figure: PANDA and SCTF



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

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

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

Possibilities of photon losses:

- Untrapped photons  $\varepsilon_{\text{trap}}$  (ca. 30%)
- Sensor losses  $\varepsilon_{\text{pde}}$  (ca. 90%)
- Optical losses  $\varepsilon_{\text{opt}}$  (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:

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

# Photon Trapping

- Trapping fraction depending on particle momentum and direction
- Photon direction: rotation around  $x$  axis by polar angle  $\theta_p$  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

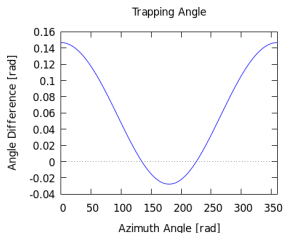


Figure: Angle distribution

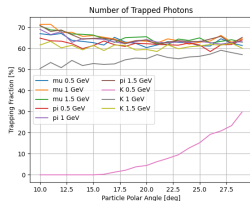


Figure: Trapping fraction

- Calculation of angular smearing

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

- Scattering after thickness  $\Delta x$

$$\Delta\sigma_{\theta} = \frac{d\sigma_{\theta}}{dx} \Delta x \quad (10)$$

- Normal distribution for every step  $\Delta x$ :

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

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

# Angle Straggling

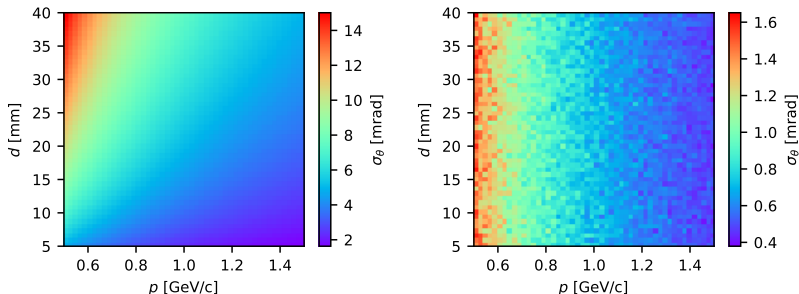


Figure: Angle straggling without and with additional tracking behind detector.

⇒ Additional tracking behind DIRC detectors required!

# Dispersion Effect

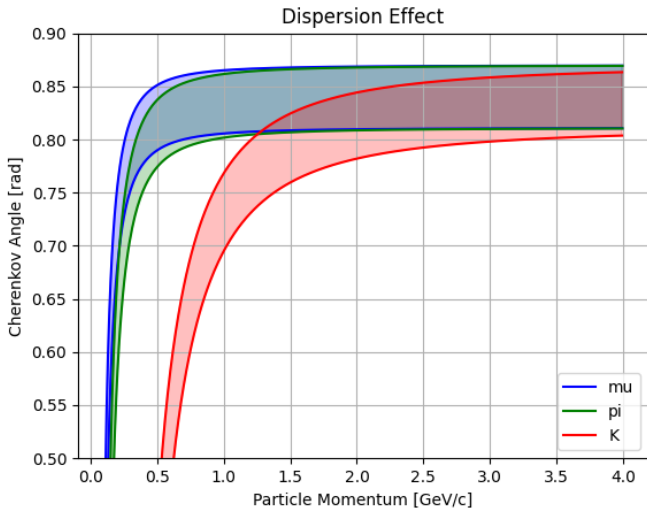


Figure: Cherenkov angle ( $200 \leq \lambda \leq 900$  nm)

# Detector Resolution (Dispersion)

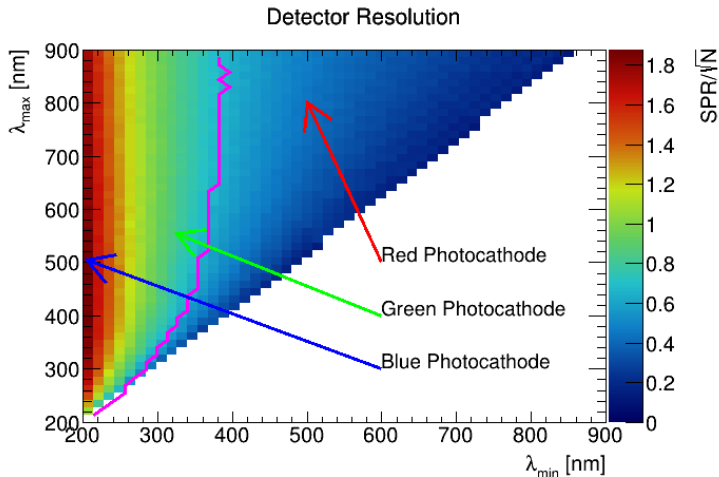
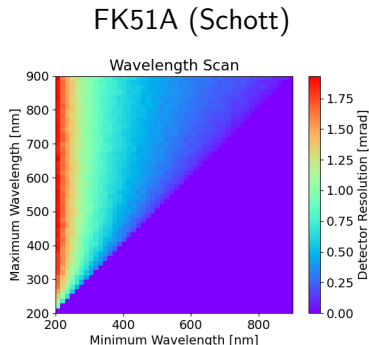
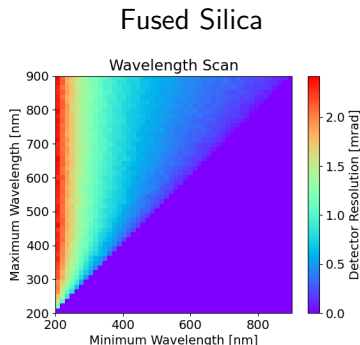


Figure: Detector Resolution for fused silica and pions.

# 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

$$n_1(\lambda) \sin \alpha = n_2(\lambda) \sin \beta \quad (12)$$

- Only 2d case taken into account

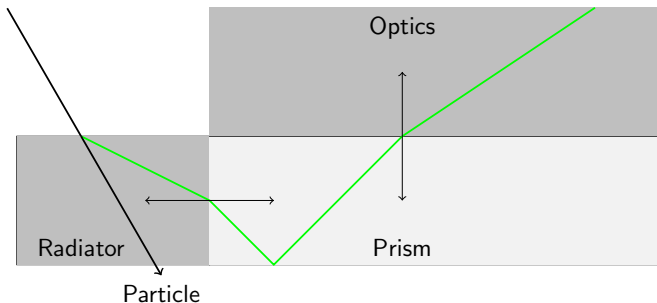


Figure: Prism for dispersion correction

# Dispersion Correction

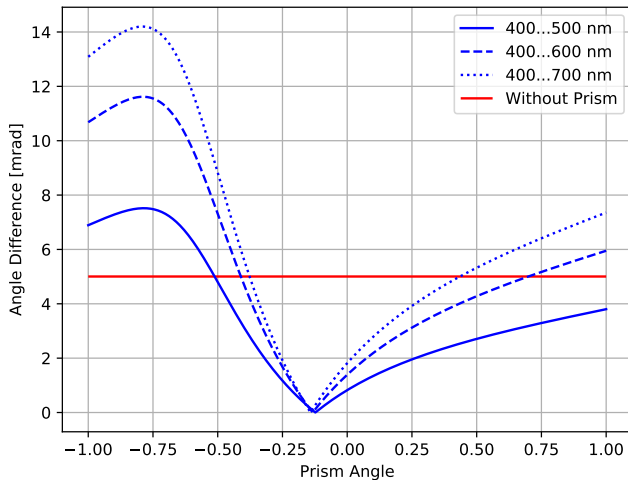


Figure: Photon angles as a function of the prism angle.

# Dispersion Correction

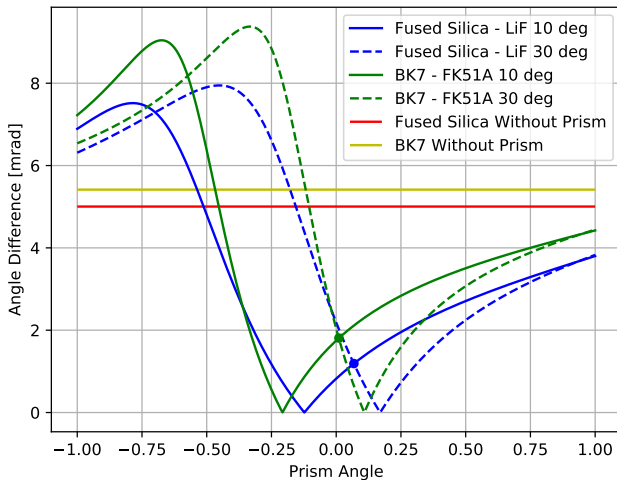


Figure: Photon angles as a function of the prism angle.

# Single Photon Resolution (Angle Scan)

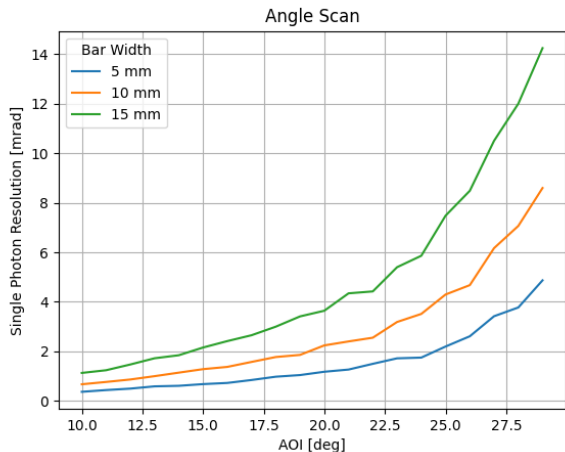


Figure: Single photon resolution as a function of the particle polar angle

# Detector Resolution (Bar Width)

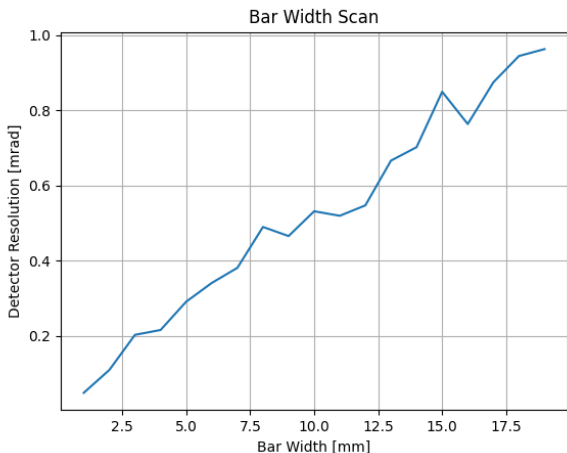


Figure: Detector Resolution resolution as a function of the bar width

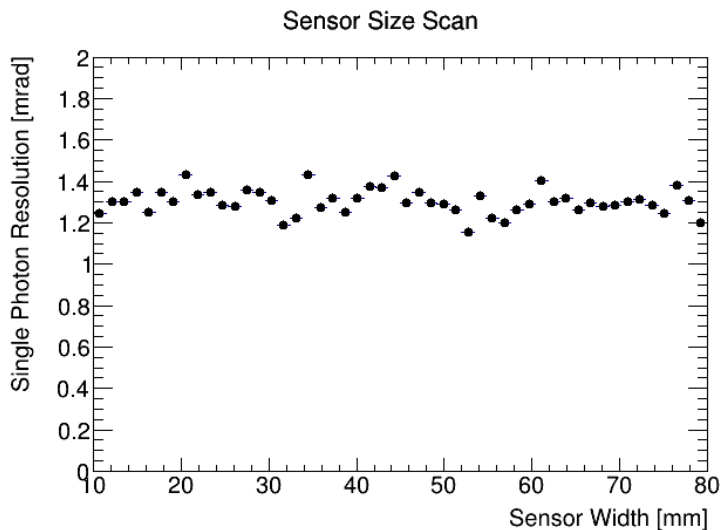


Figure: Sensor width scan with adapting mirror radius

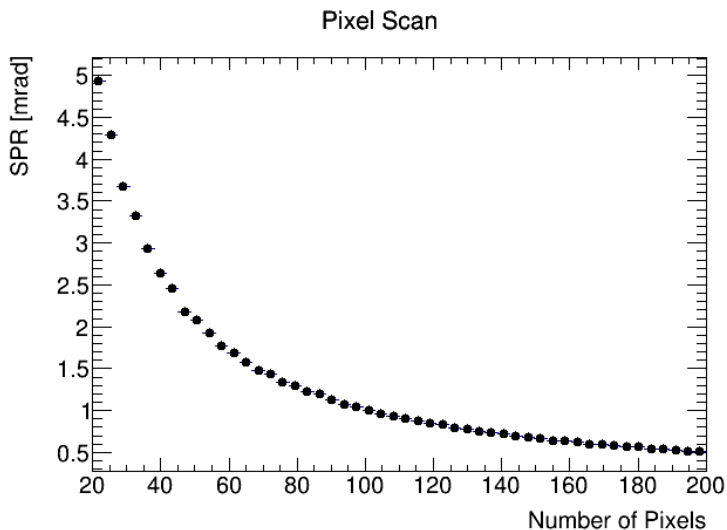


Figure: Pixel scan

# Conclusion & Outlook

- Small resolution of  $\leq 1$  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