Exercise: optical photons

Advanced course – ANL, June 2023

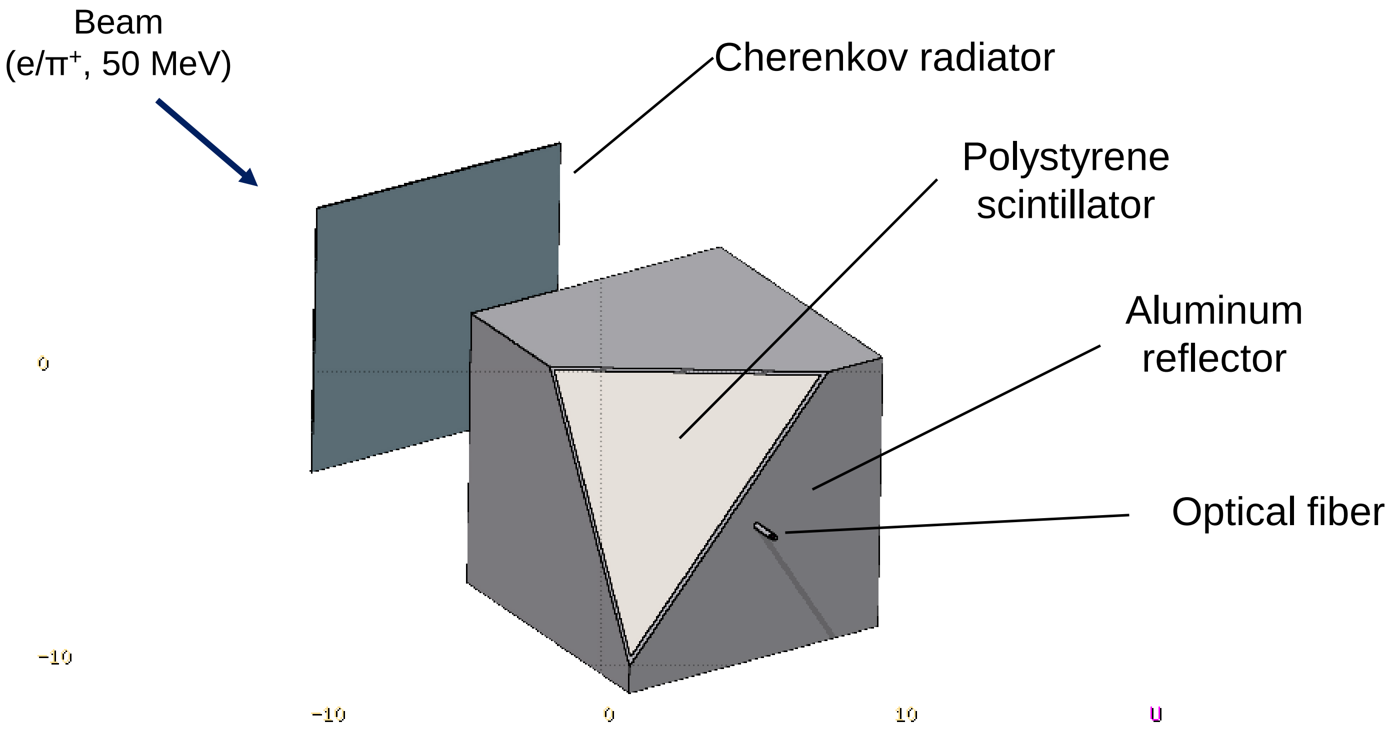
Exercise objectives

- Activate optical photon production and transport
- Tune transport properties in optical materials
- Score optical photons
- Run the simulation with a simple user routine for optical photons

e/π particle identification

- You will simulate a detector which combines a **Cherenkov tracker** and a **scintillation calorimeter**.
- You start with the provided input which only includes the geometry, materials and source.
- You will include the necessary cards for optical photon production and transport in the detector.
- You will only be instructed to score optical photons.
  - Feel free to use additional scoring to better understand your results!
  - Be wary that a very fine binning may significantly increase the runtime.
- Your goal is to compare the detector response to beams of **pions** and **electrons** and study systematic effects.

Detector geometry



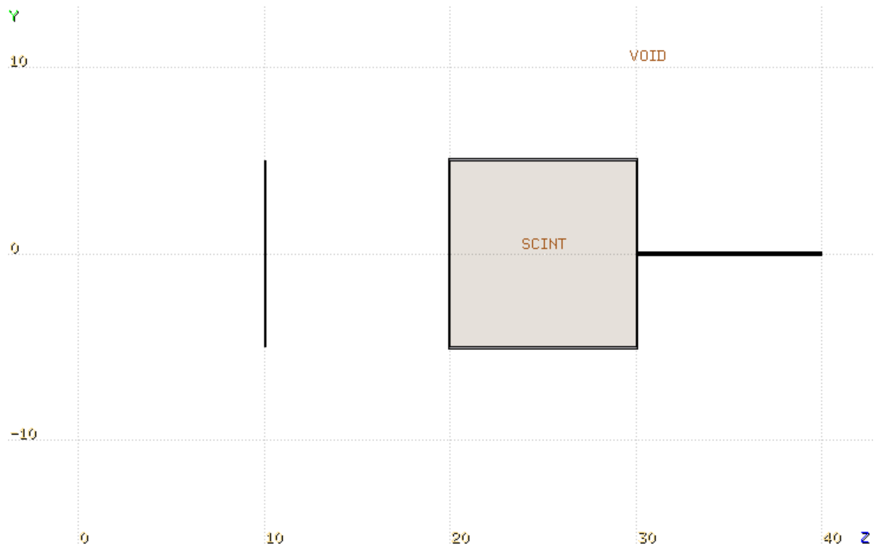
Beam
(e/π⁺, 50 MeV)

Cherenkov radiator

Polystyrene scintillator

Aluminum reflector

Optical fiber



- Poor's man water Cherenkov radiator (1 mm thick) and polystyrene scintillation calorimeter (10x10x10 cm^3) with Al reflector.
- All detector components in vacuum.
- Quartz optical fiber with Al cladding for readout.

1. Cherenkov ring

- Activate Cherenkov radiation in the radiator using an **`OPT-PROD`** card.
    - Set light production for wavelengths between 300 nm and 800 nm.
- Set the optical properties of water with an **`OPT-PROP`** card:
    - Index of refraction: 1.336
    - Absorption: 0.01 (absorption length of 100 cm)
- Create a **`USRBIN`** detector of type R-Φ-Z downstream of the radiator which scores optical photons. Use the binning:
    - 15.0 < z < 15.1 (1 bin)
    - 0.0 < R < 15.0 (60 bins)
    - 16 Φ-bins
    - x=y=0.0
- Run for least 5 cycles of 2'000 primaries with beams of electrons and pions. Use one separate run per particle type.
- Plot 2D projections in R-z and 1D projections in R. Compare the results from both runs.

2. Calorimeter

- Activate scintillation in polystyrene with an **`OPT-PROD`** card.
  - Wavelength: 550 nm
  - Energy fraction: 1.0×10^{-5} (Note: This is much smaller than typical values but should help speed up your simulation).
  - Time constant: 1 ns
- Optical properties of polystyrene:
  - n = 1.59
  - Absorption length = 100 cm
- Optical properties of quartz:
  - n = 1.55
  - Absorption length = 100 cm
- Set the reflectivity of aluminum to 95% using an **`OPT-PROP`** card with type=**`METAL`**.
- Score the optical photon fluence in the fiber using a **`USRBIN`** detector with R-Φ-Z binning. The binning should precisely cover the quartz part of the fiber. Use 100 bins in z.
- Plot a z-projection for pions and electrons.

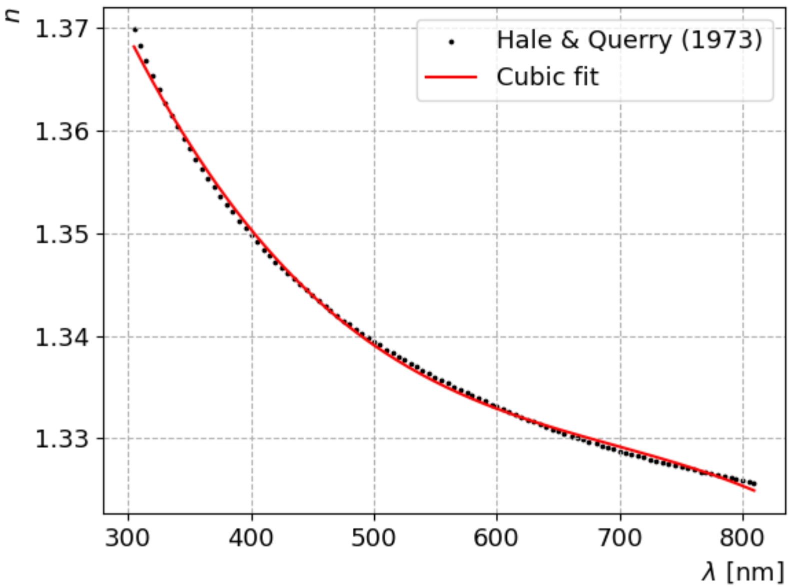
3. Light background from secondaries

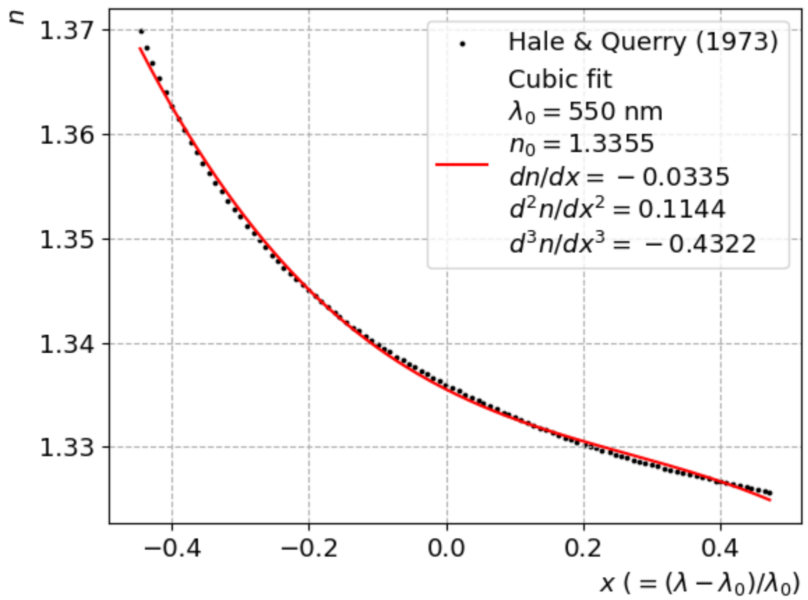
- Using an **`EMFCUT`** card, increase the production threshold for electrons and photons in water as a way to estimate the background of secondary charged particles to the Cherenkov signal.

- With a primary beam of electrons, score the Cherenkov ring using the energy cuts:
  - 10 MeV
  - 1 MeV
  - 100 keV

- Look at the contrast of the Cherenkov ring as a function of the cut. Use a logarithmic y-scale.

4. Fine-tuning the refraction index of water





- Dispersion effects can be simulated by specifying the derivatives of the refraction index as a function of wavelength.
- Using a water refraction index dataset from Hale & Querry (1973) [1].
- Change of variable **$x=(\lambda-\lambda_0)/\lambda$** assuming a central wavelength $\lambda_0 = 550$ nm.
- Cubic fit to approximate the derivatives up to the 3rd order.

[1] DOI:10.1364/AO.12.000555

4. Fine-tuning the refraction index of water

- Use an `OPT-CARD` with type `WV-LIMIT` to define the central wavelength.
  - What values should you use for λ_{min} and λ_{max}?
  - What are the default values?

- Use 3 additional `OPT-PROP` cards of types `&1/&2/&3` to specify the derivatives. Use the values already provided to you on the previous slide.

- Check the effect on the Cherenkov ring for electrons.

5. Reflector roughness

- Simulating an aluminum reflector with a ground surface finish.

- Copy the template for the roughness (`frghns.f`) user routine to your project using the database button.

- Set the roughness equal to 0.1 **only** in case `MREG` corresponds to the scintillator.
  - **Tip**: Use "`CALL GEOR2N (MREG, NAMREG, IERR)`" to match name-based to number-based regions.

- How does the roughness influence the fluence of optical photons in the fiber? Why?

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