Directional Beta Source Development for the Eos Experiment

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Workshop on Hybrid Cherenkov/Scintillation Detection Technologies

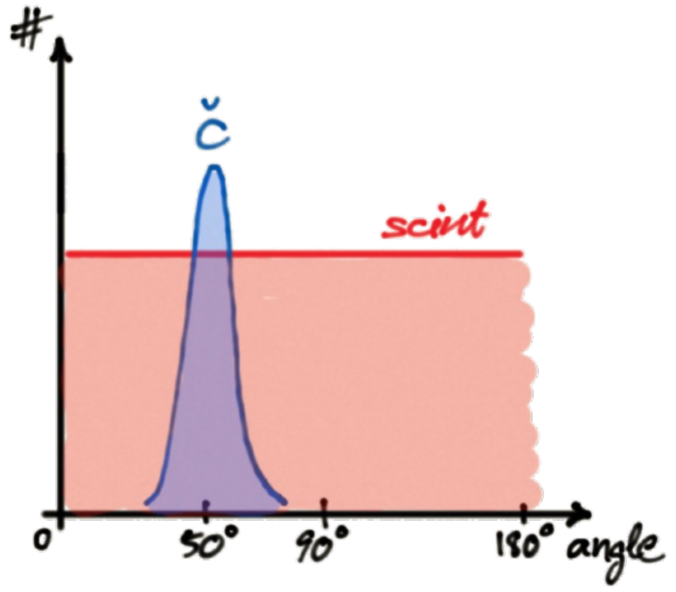
University of Pennsylvania, June 5th, 2025

National Nuclear Security Administration

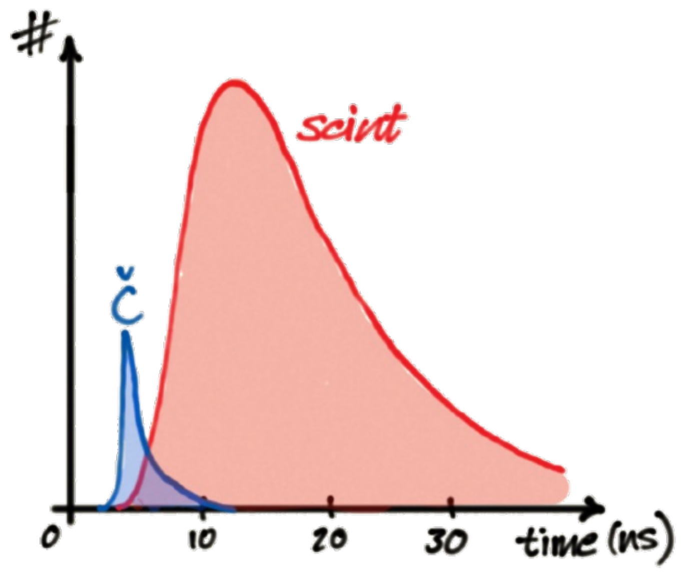
BOSTON UNIVERSITY

The Motivation

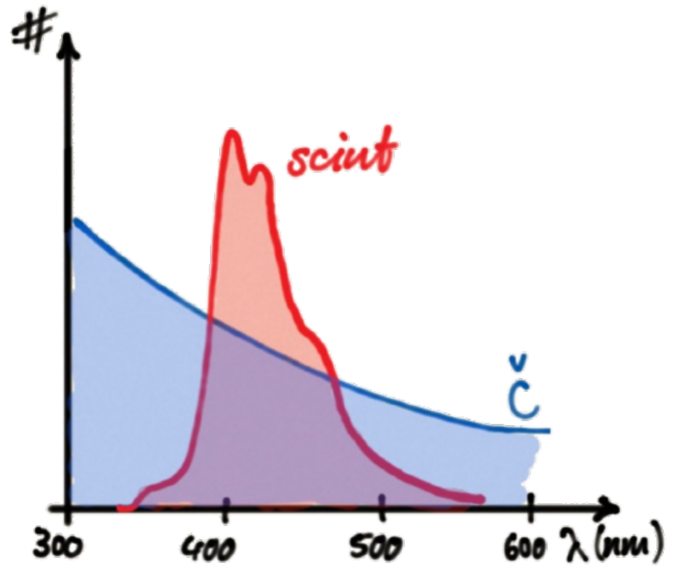
Cherenkov / Scintillation separation is a crucial part of hybrid detection...



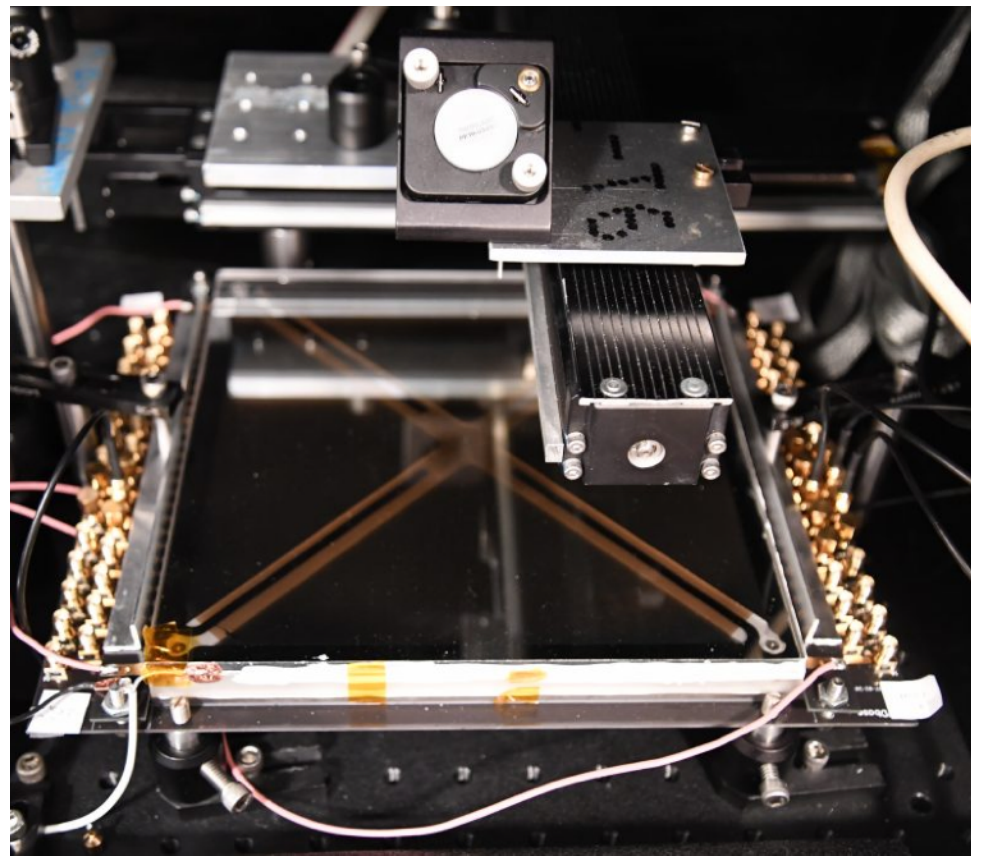
Angular distribution

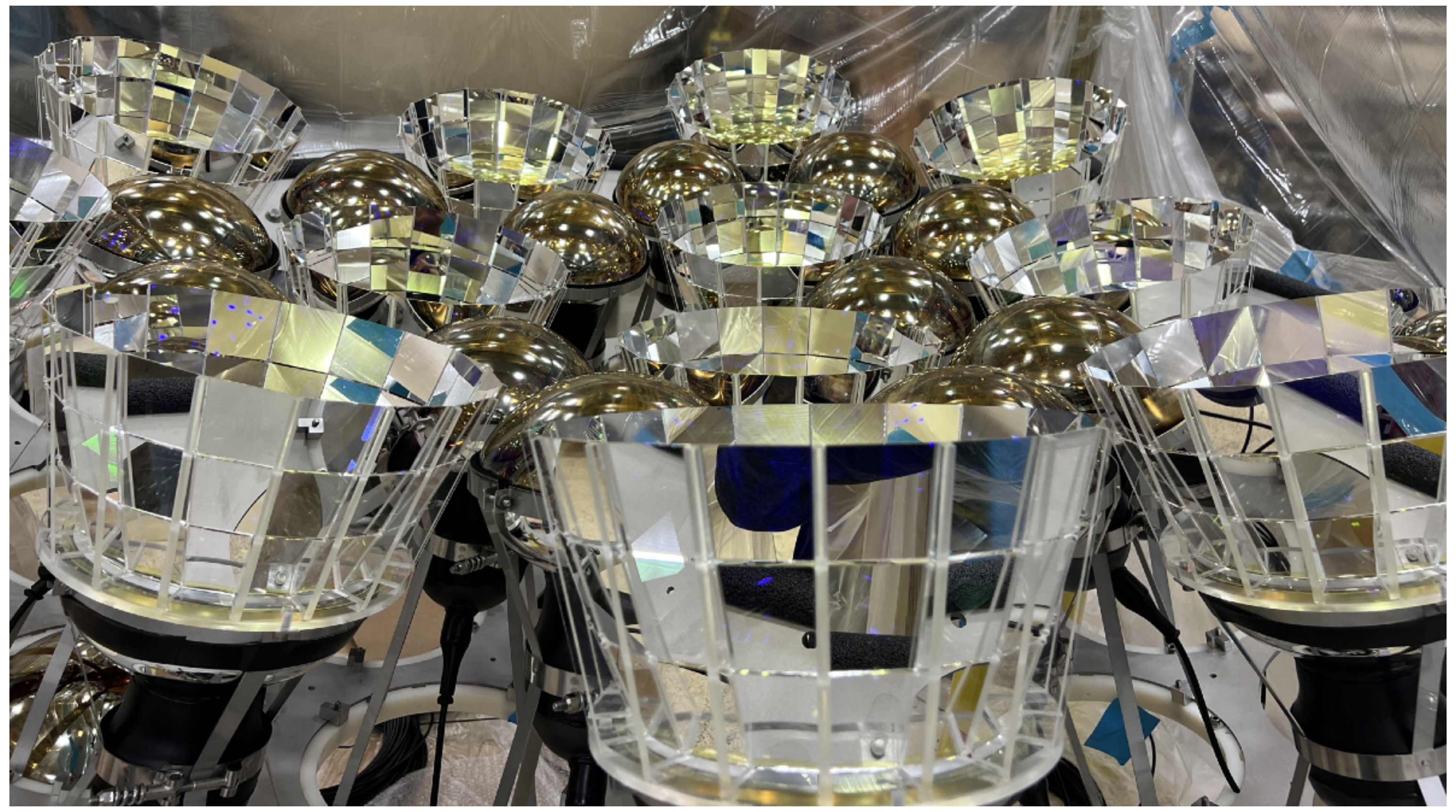


Time



Wavelength





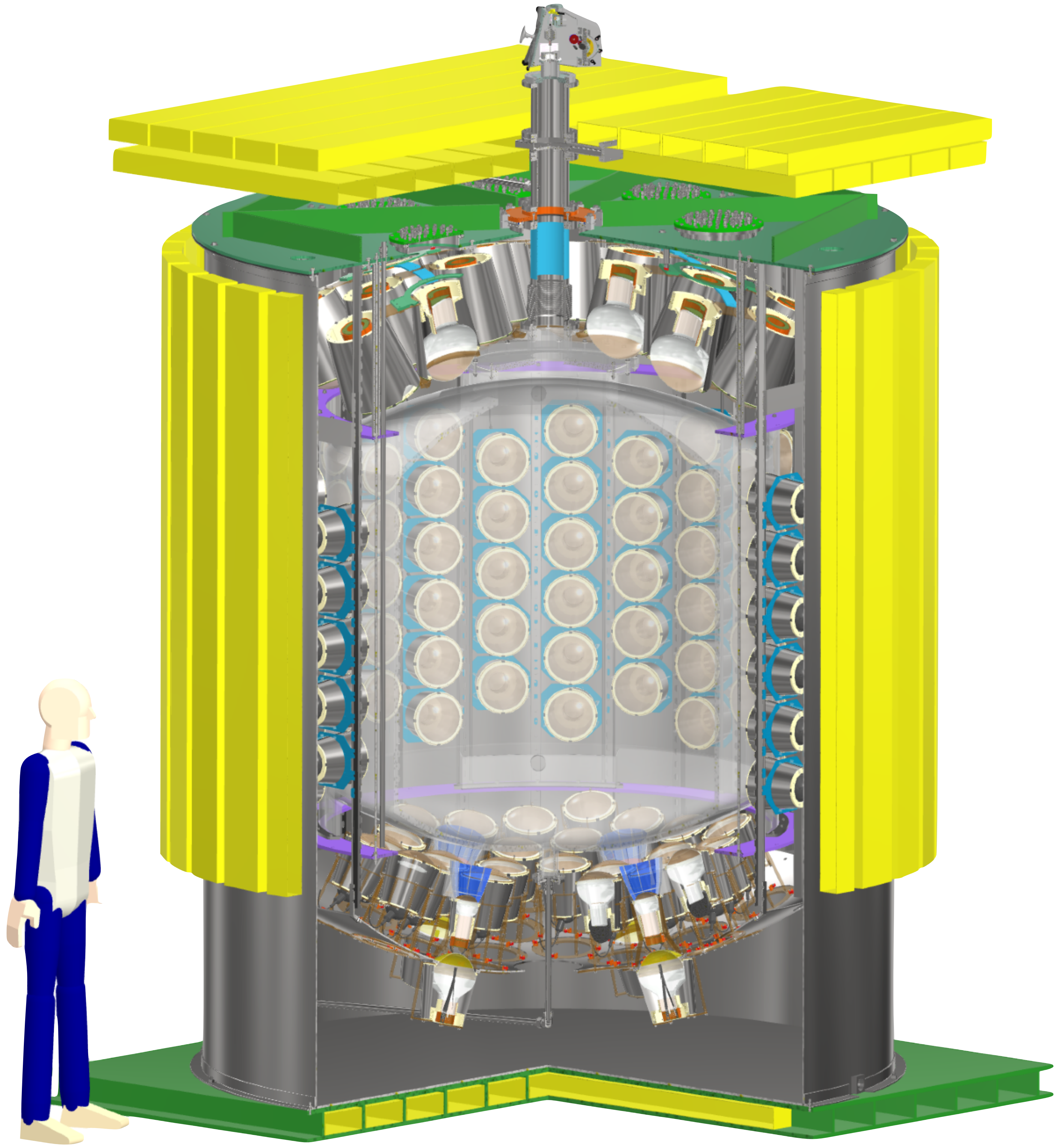
...how well have we separated them, and how does it affect event reconstruction?

In particular, how can we test our *direction* reconstruction performance?

It would be great to have a calibration source where we know the **direction** of our events...

A Directional Source

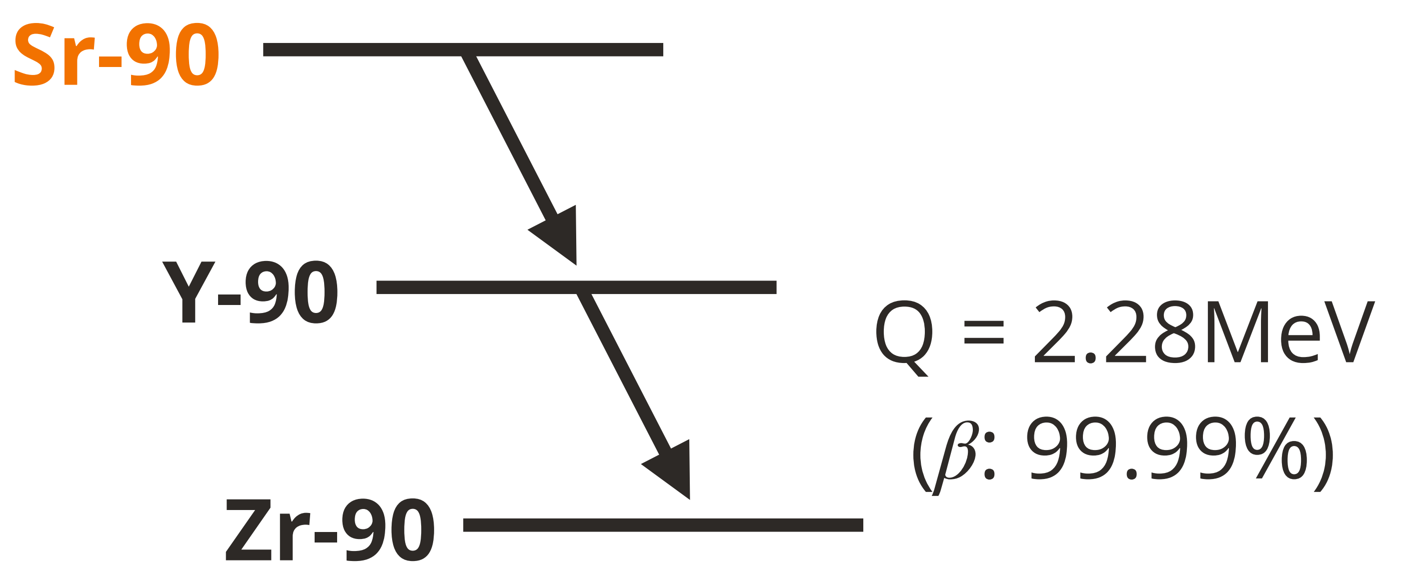
- Designed to demonstrate **direction reconstruction** capabilities of **Eos**

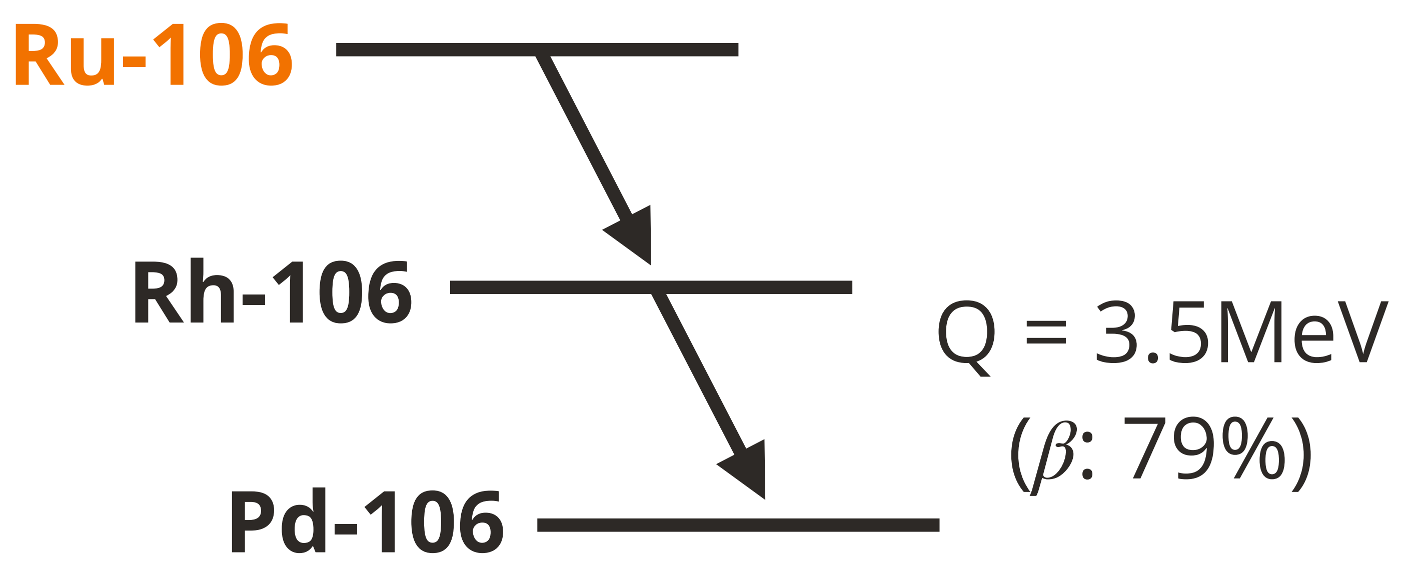


- Hybrid neutrino detector at UC Berkeley
- 20-tonne detector, 4-tonne target material
- Low E event reconstruction, MC model validation
- 204 8" fast timing PMTs, Dichroicons deployed at bottom of detector

A Directional Source

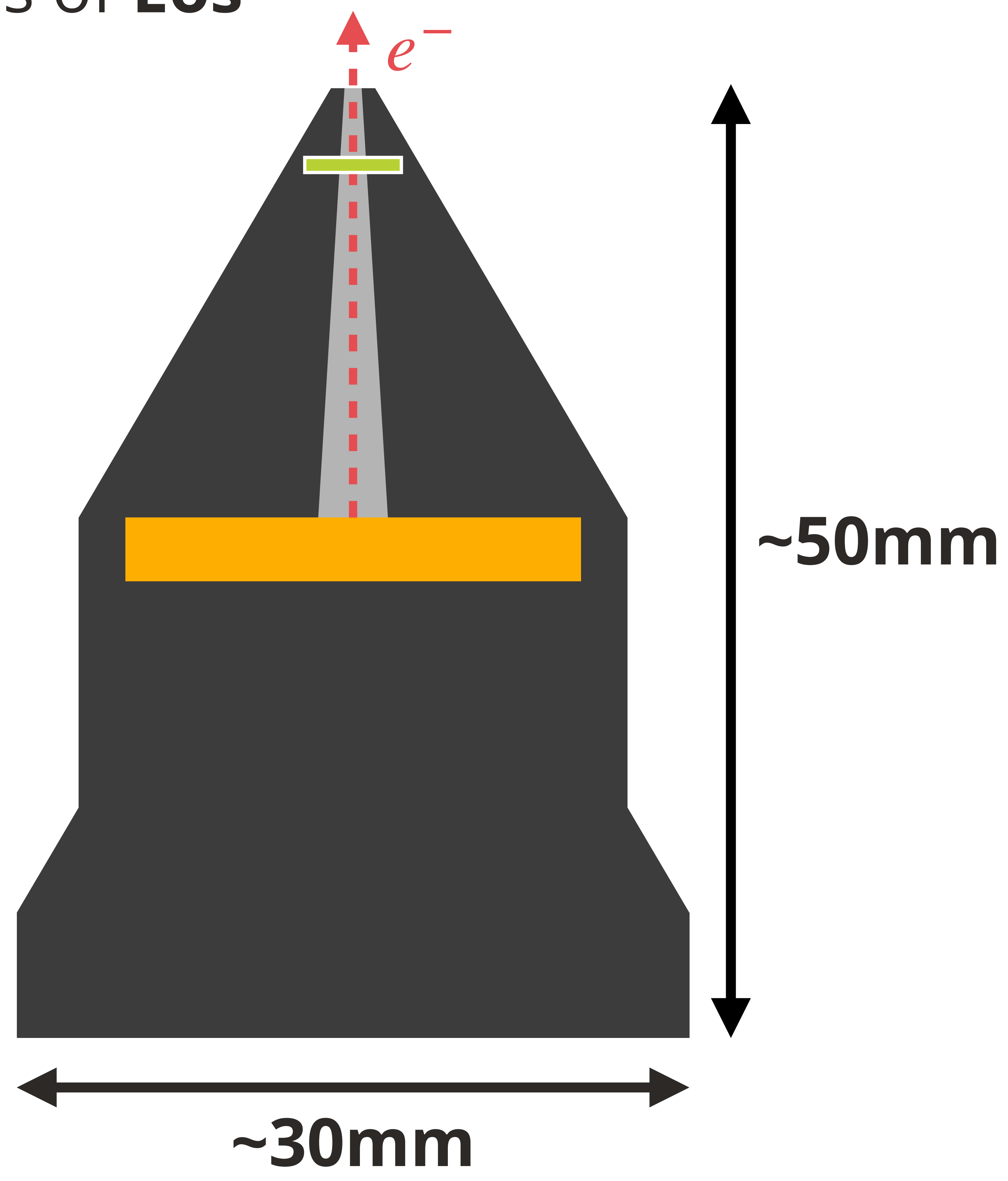
- Designed to demonstrate **direction reconstruction** capabilities of **Eos**
- Small capsule containing **radioactive isotopes**





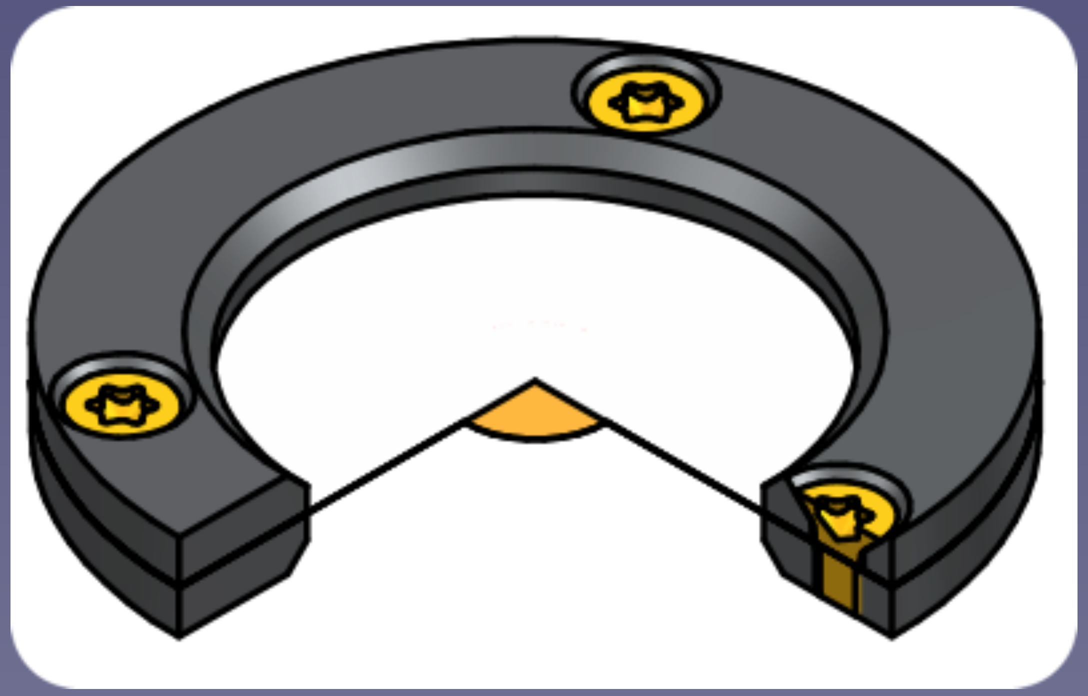
(Higher E endpoint, but with gamma contamination)

- Creates a collimated beam of electrons, ~Hz
- **Self Triggering system** to tag exiting electrons

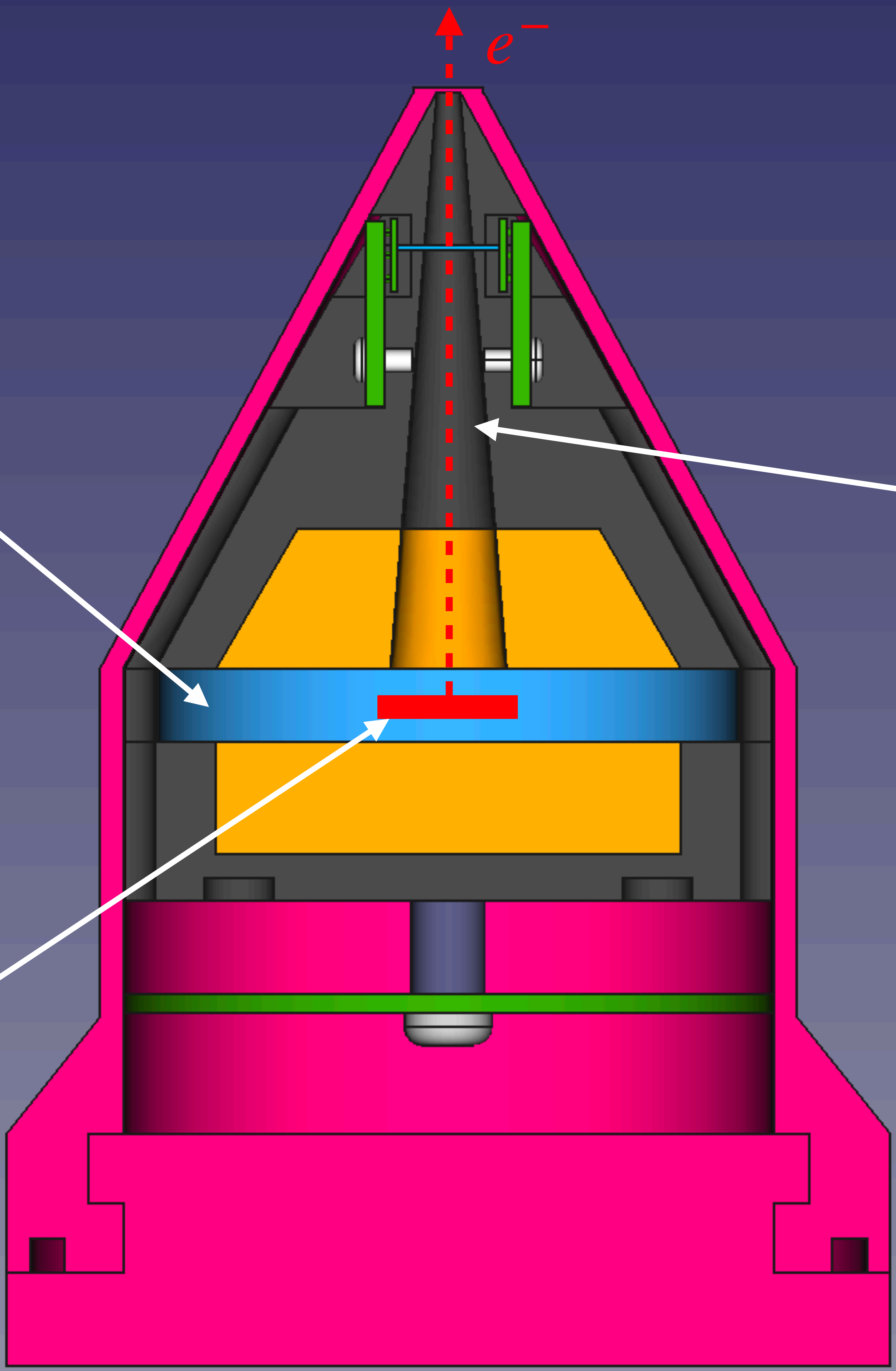


Design

Radioactive Source
(Sr-90 or Ru-106)



Active area of radioactive source is 5mm wide.

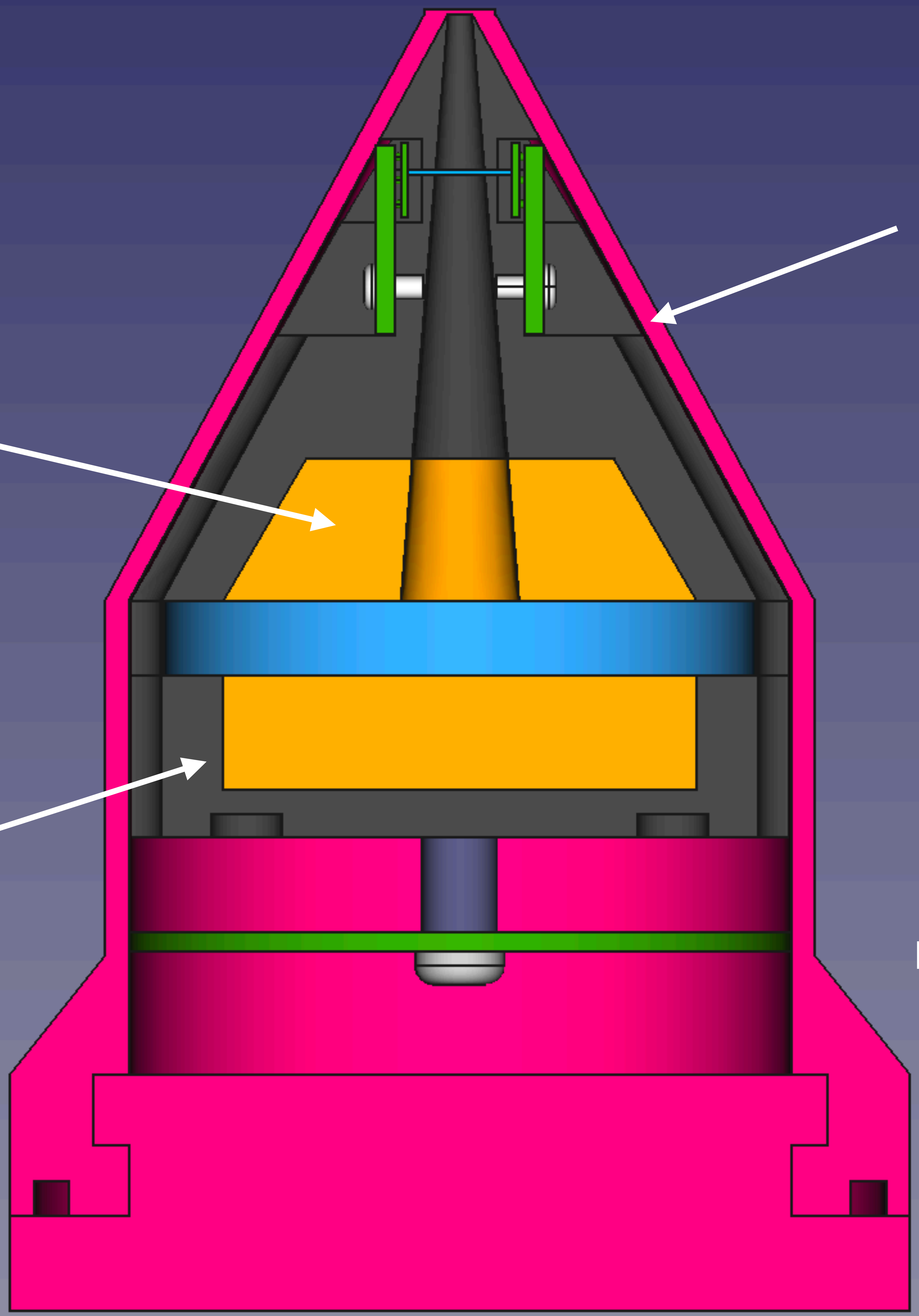


Betas escape through a **conical borehole** that collimates the particles.

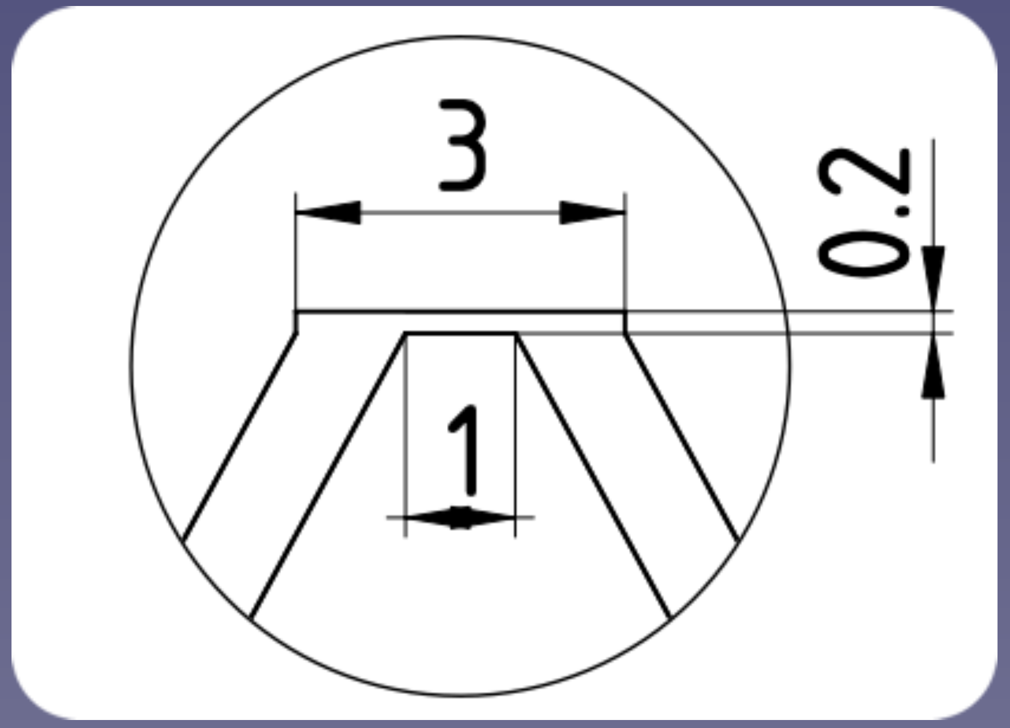
Design

Plastic inner shielding near radioactive source to slow down betas and prevent Bremsstrahlung radiation

Metal shielding to shield betas from escaping in other directions

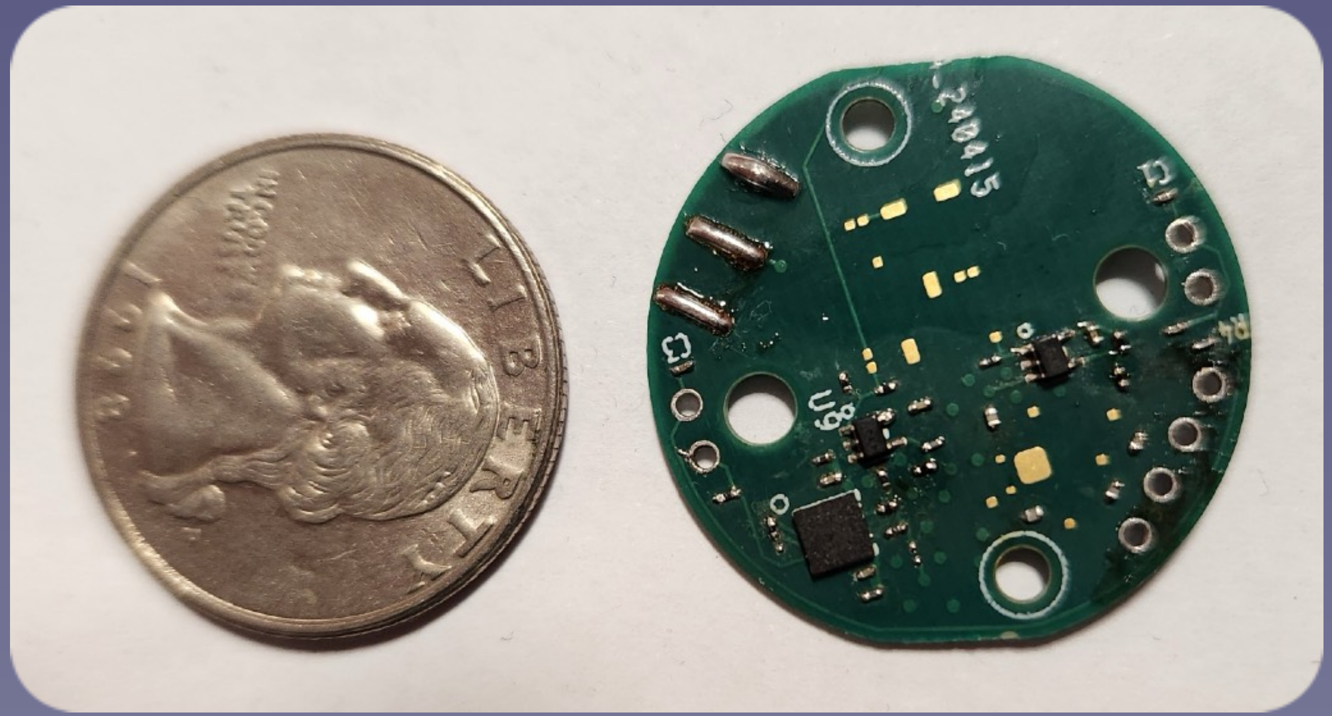


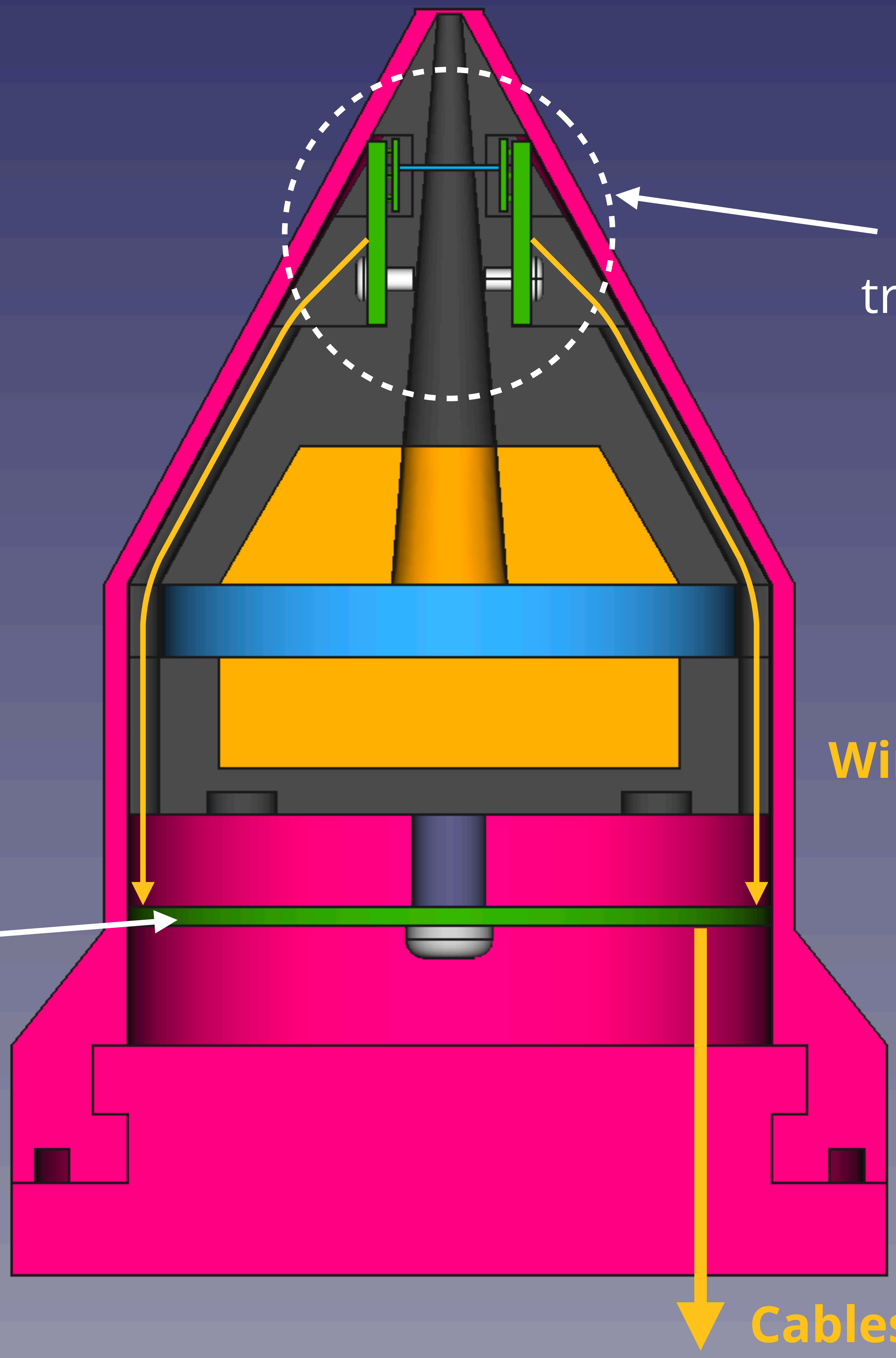
Plastic outer shielding encapsulates everything and keeps source watertight

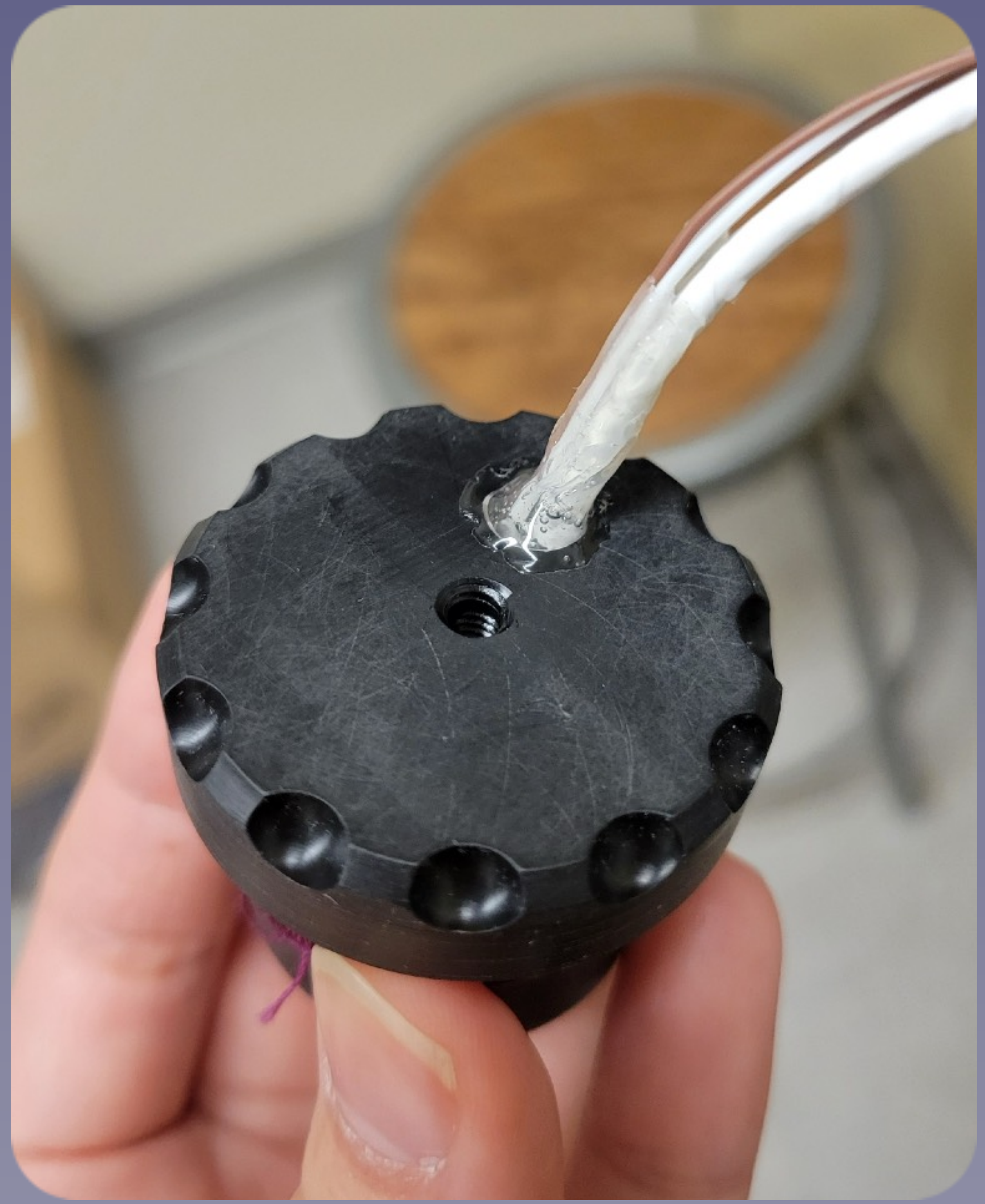


Front tip of the outer shielding near exit is made thin (~0.2mm) to minimize energy loss

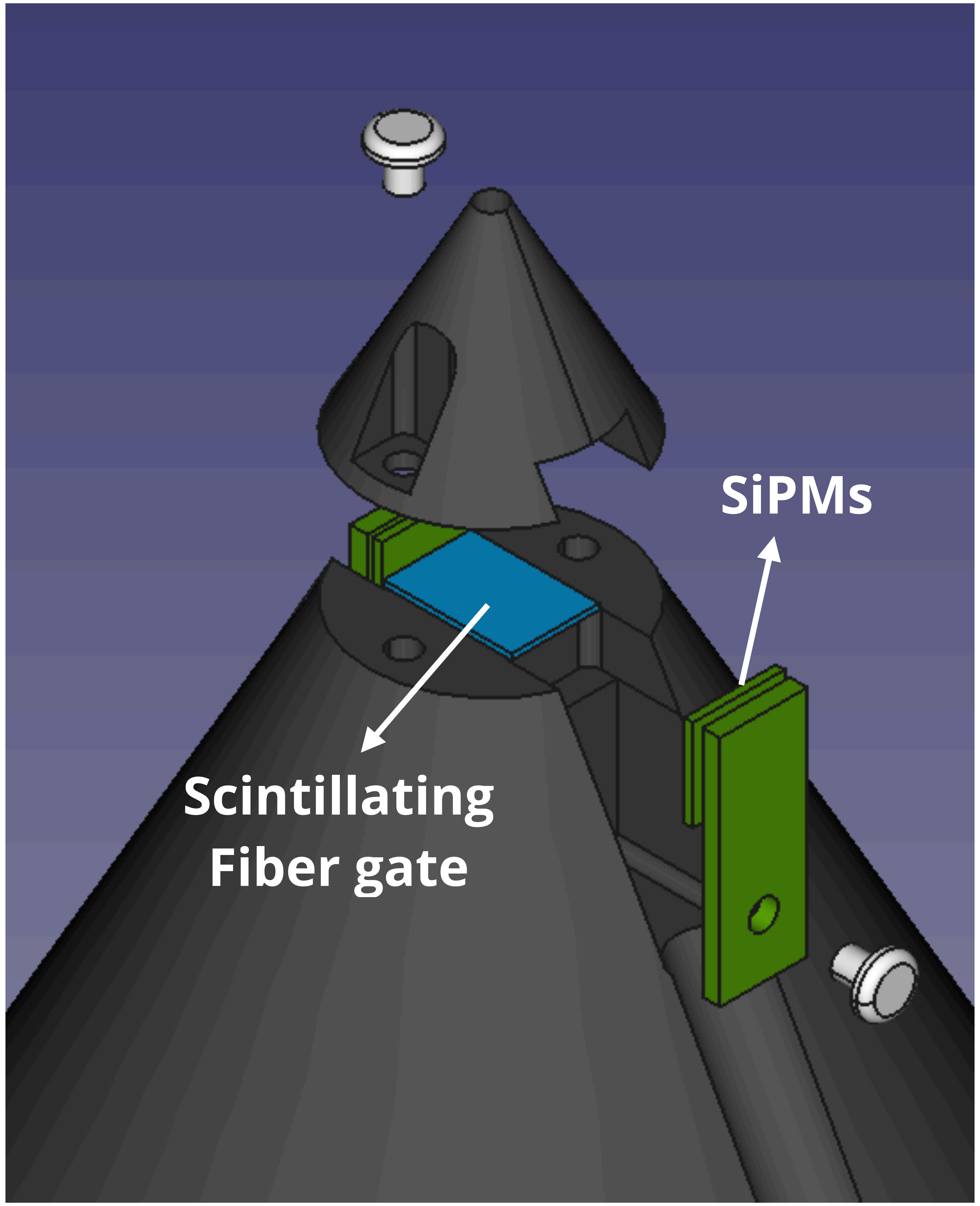
Design




Self Triggering System to trigger on betas as they escape the source capsule.
Wires
Trigger board electronics
Cables for signal & power

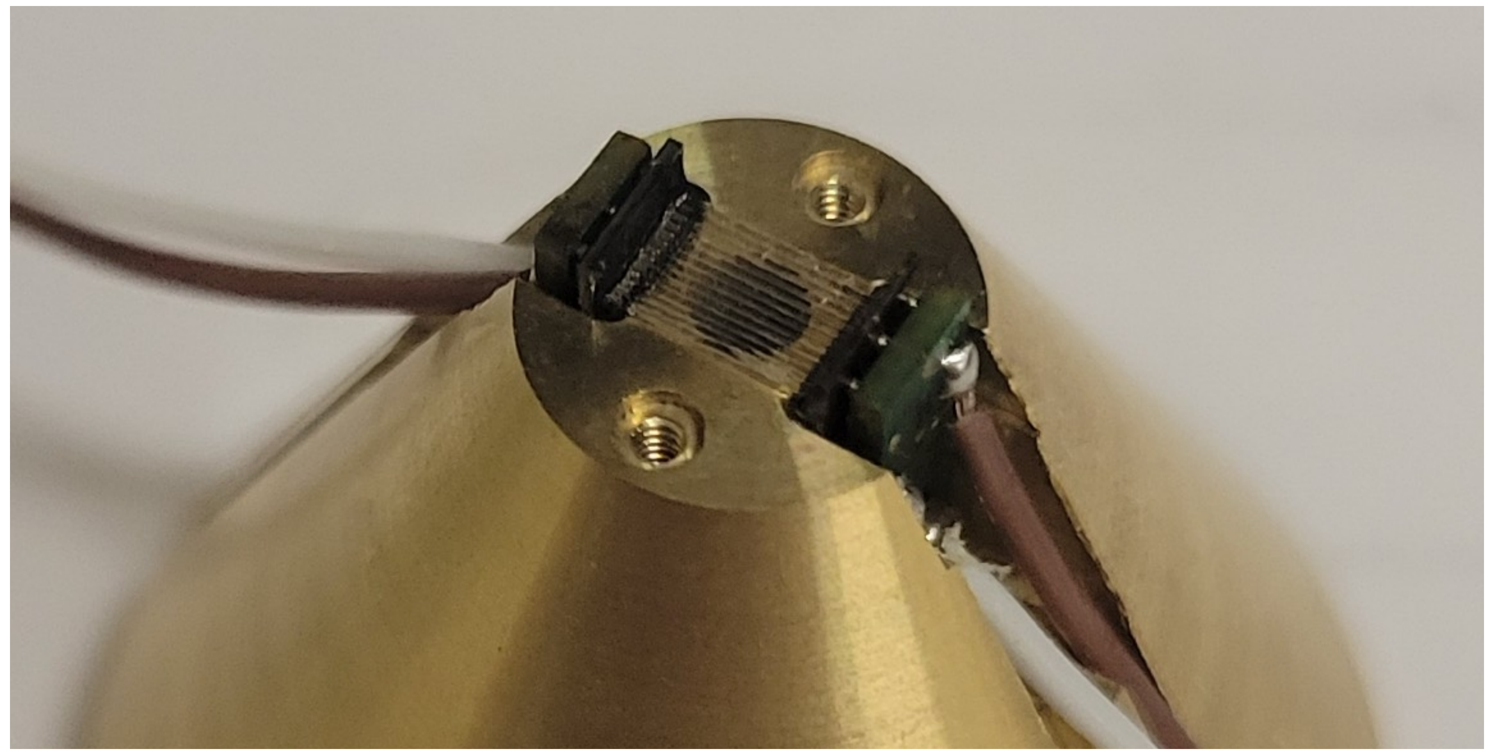


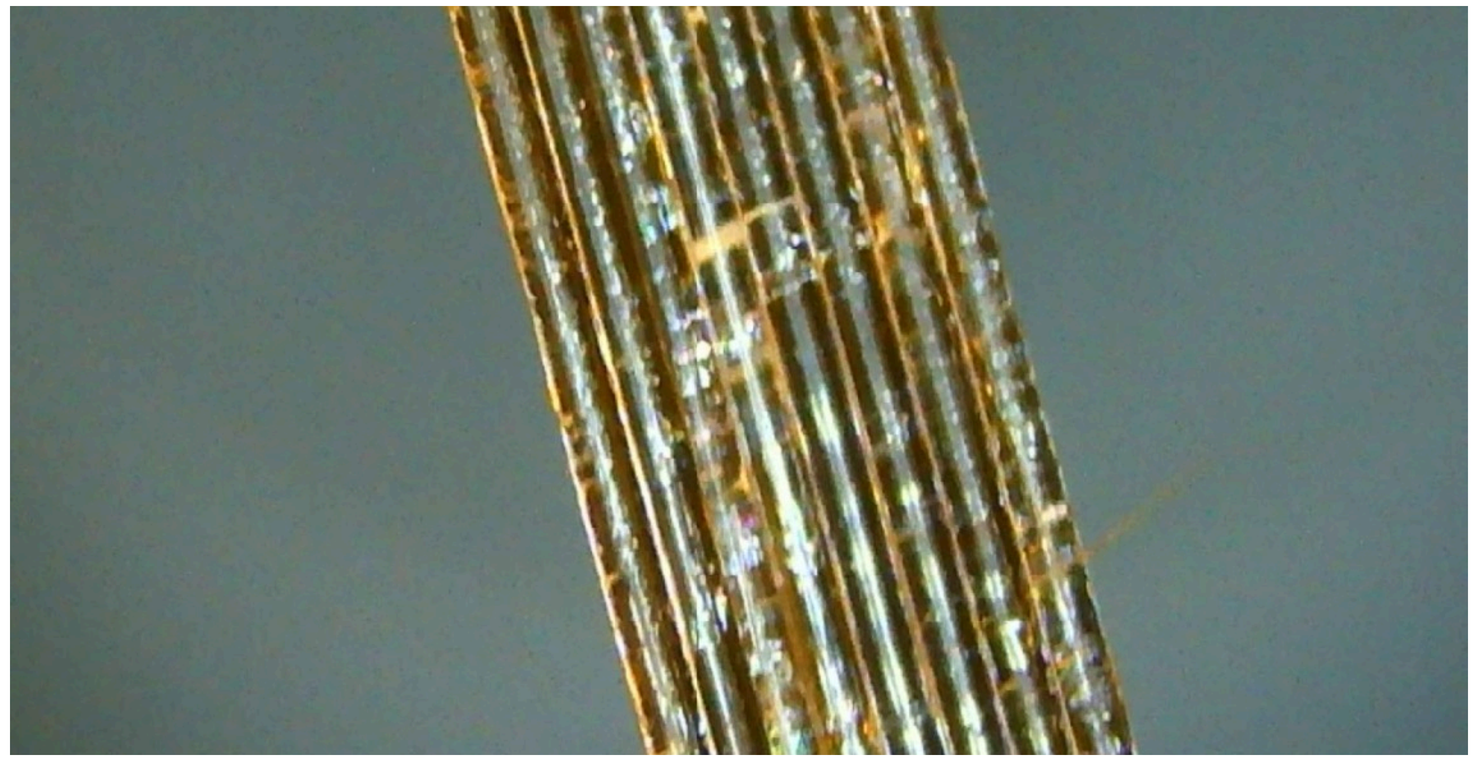
Self Triggering System



Triggering system consists of:

- a **scintillating fiber gate** that covers the borehole, made from 0.2mm scintillating optical fibers
- two **Silicon Photomultipliers** (SiPMs) detecting light from the scintillating fiber gate
  - Triggering on coincident pulses of both SiPMs significantly reduces dark pulse rate
- Triggering efficiency estimated to be ~50%

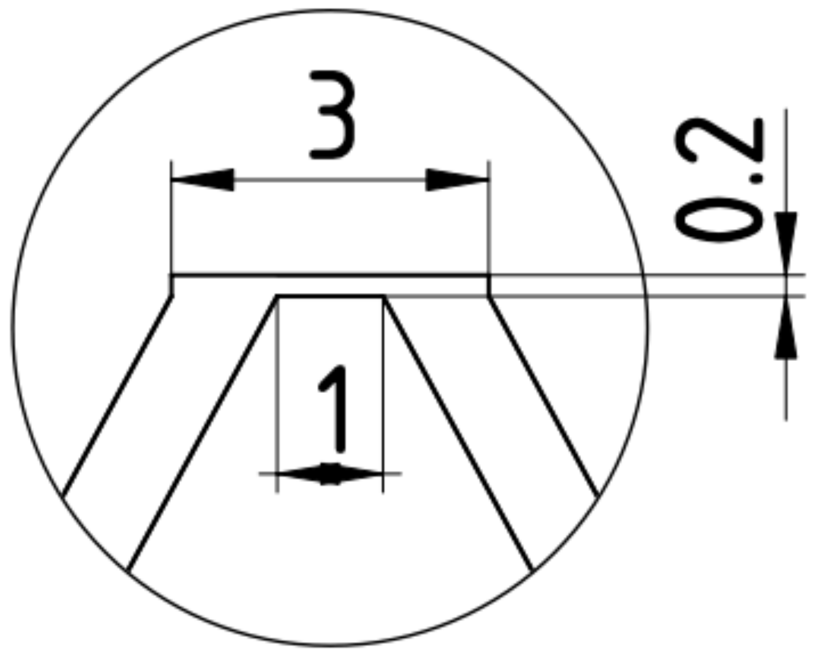




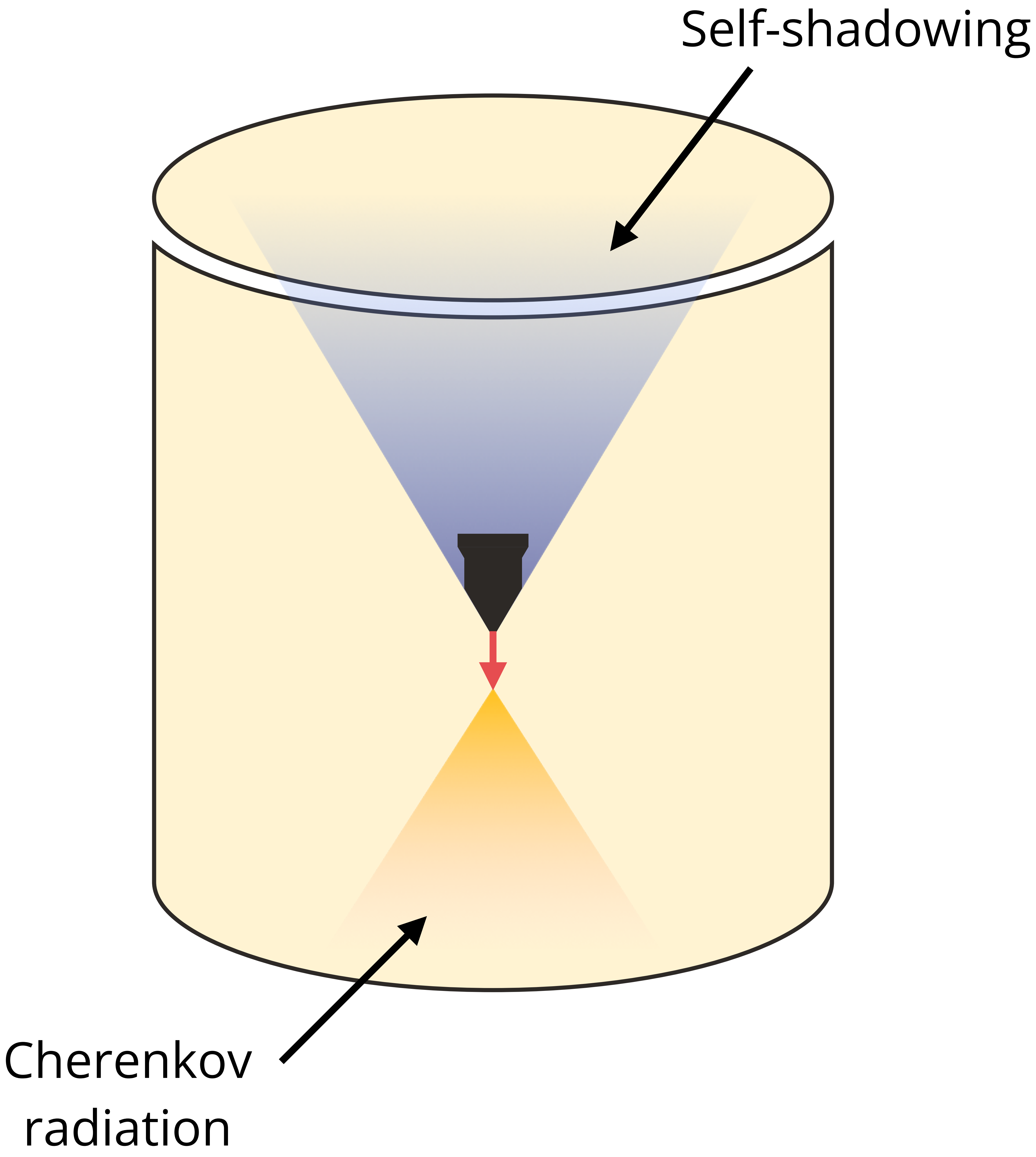
Self Shadowing Effect

- Because betas only travel ~1cm in WbLS, a shadow is cast behind source capsule from the scintillation light ("**self-shadowing**")
- Self-shadowing introduces a bias in direction reconstruction
- We can...

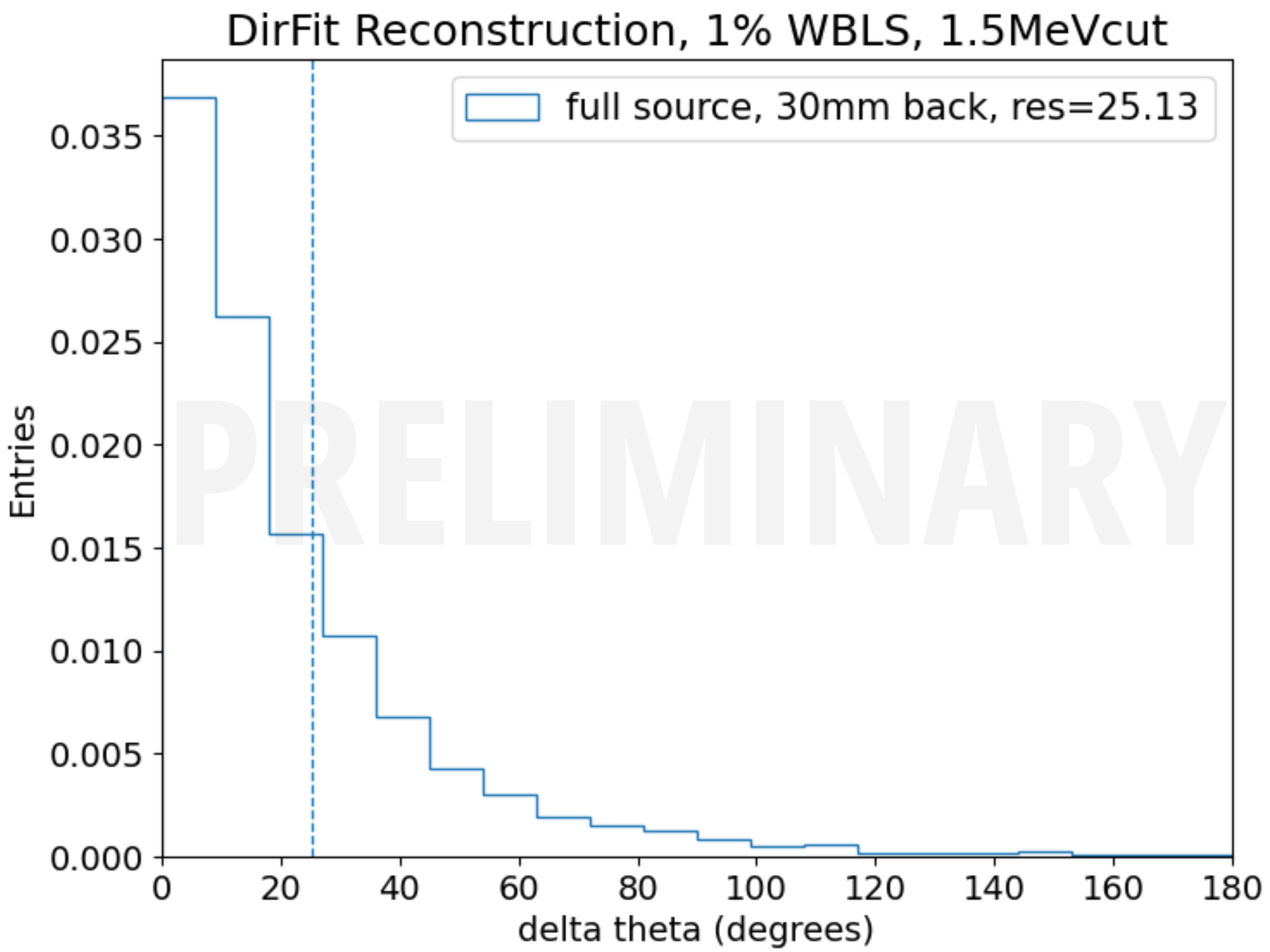
Minimize the size of the shadow



Demonstrate that we understand the effects of self-shadowing

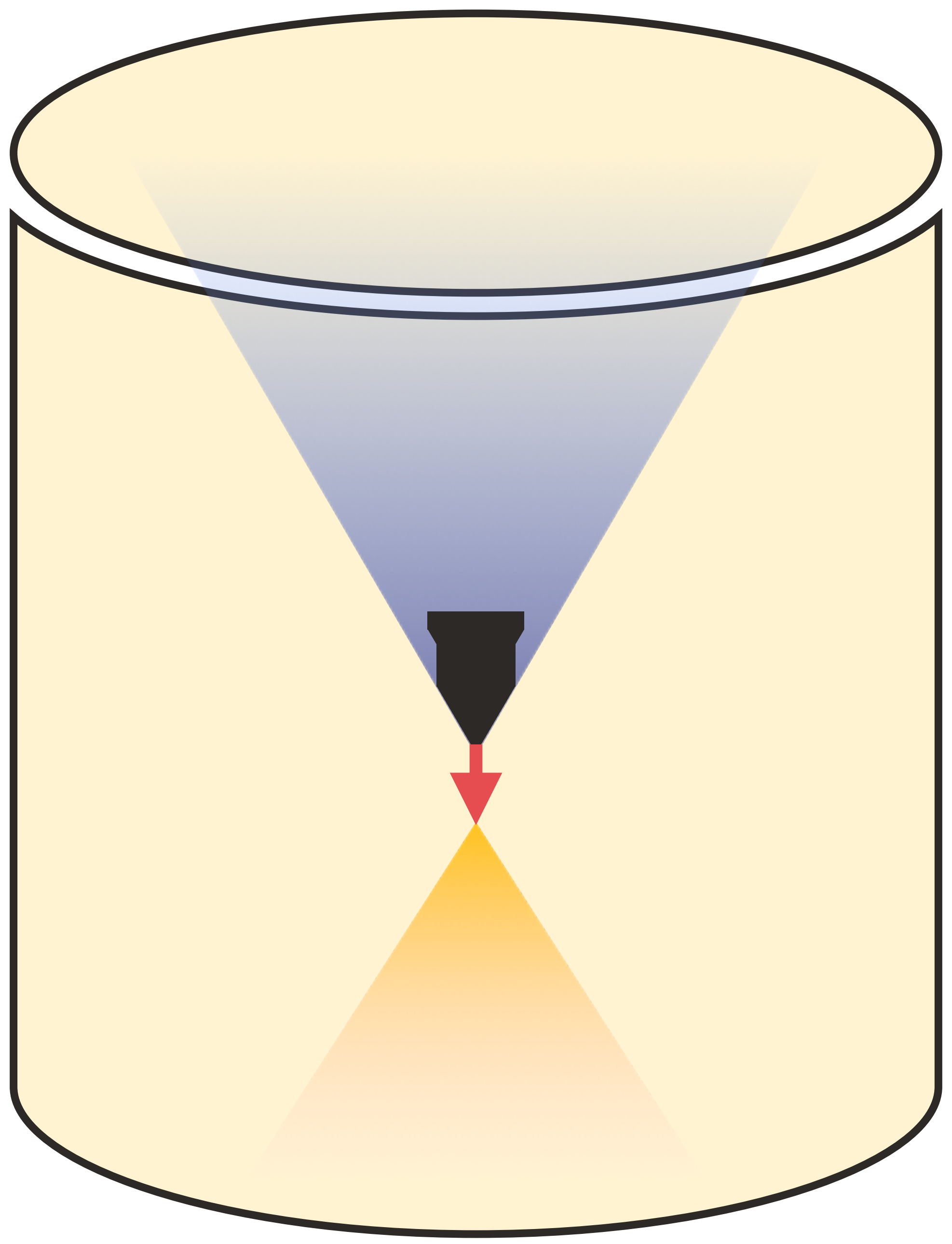


Self Shadowing Effect

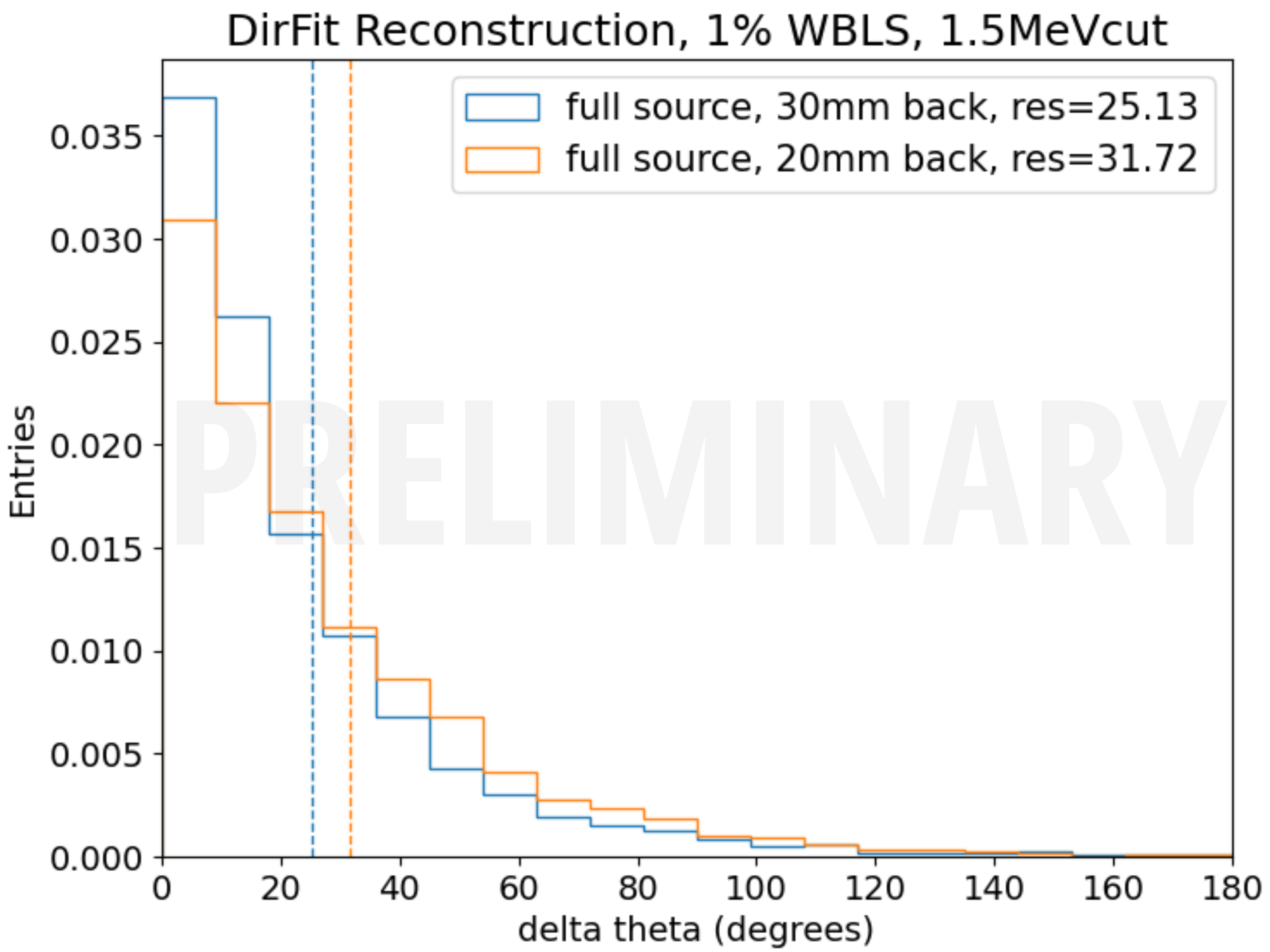


Direction reconstruction using likelihood fit on MC

A directional source, in Eos

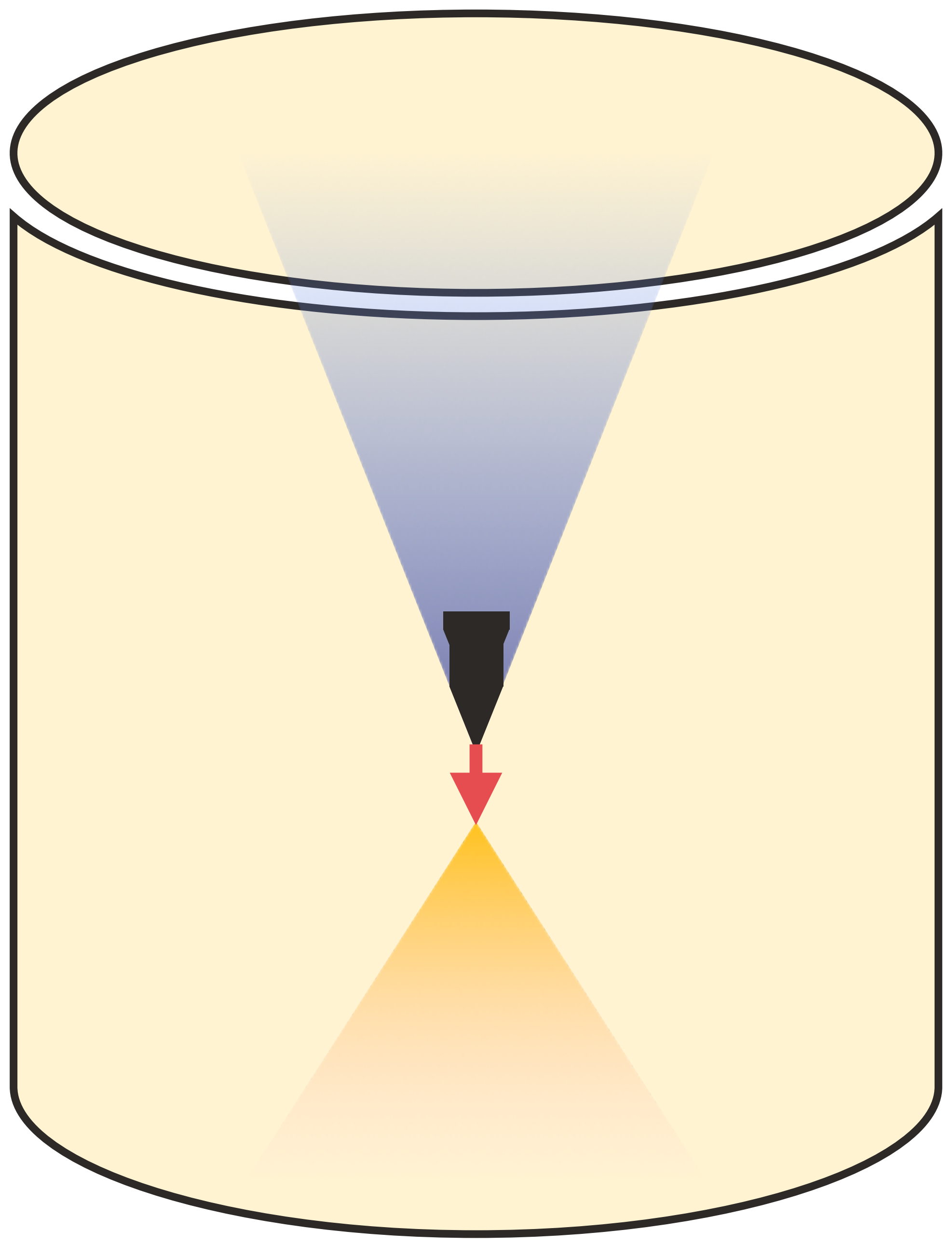


Self Shadowing Effect

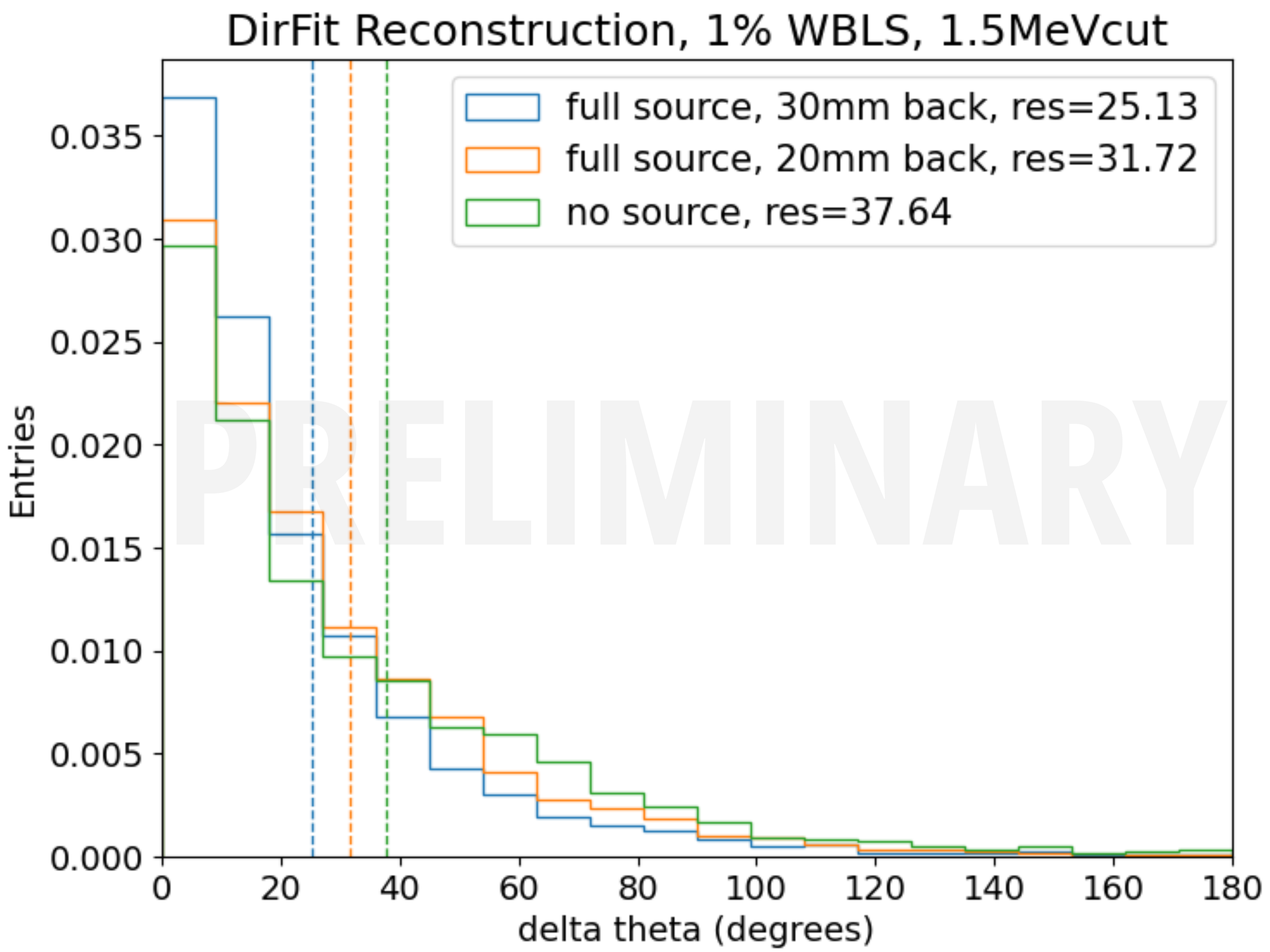


Direction reconstruction using likelihood fit on MC

…a smaller directional source, in Eos



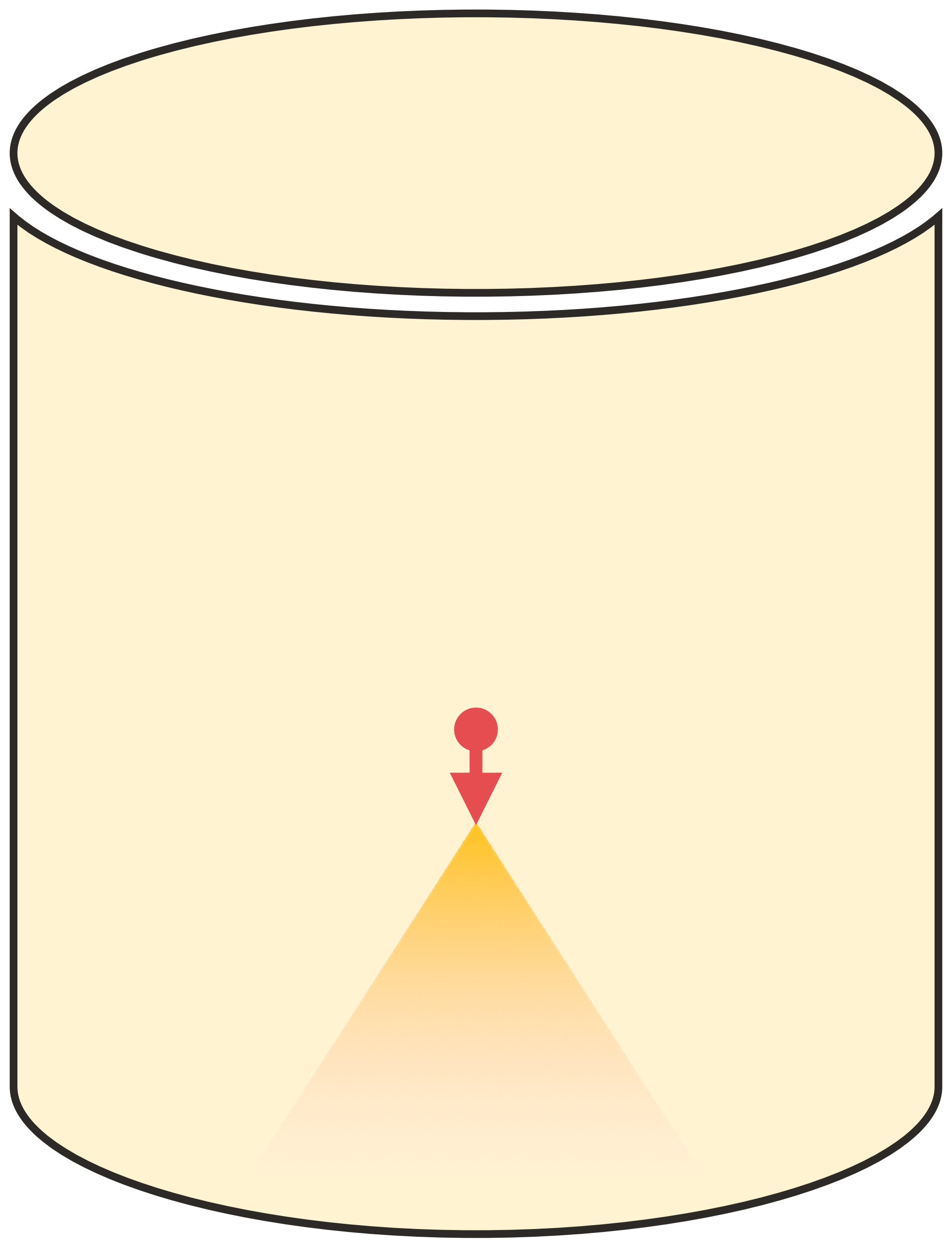
Self Shadowing Effect



Direction reconstruction using likelihood fit on MC

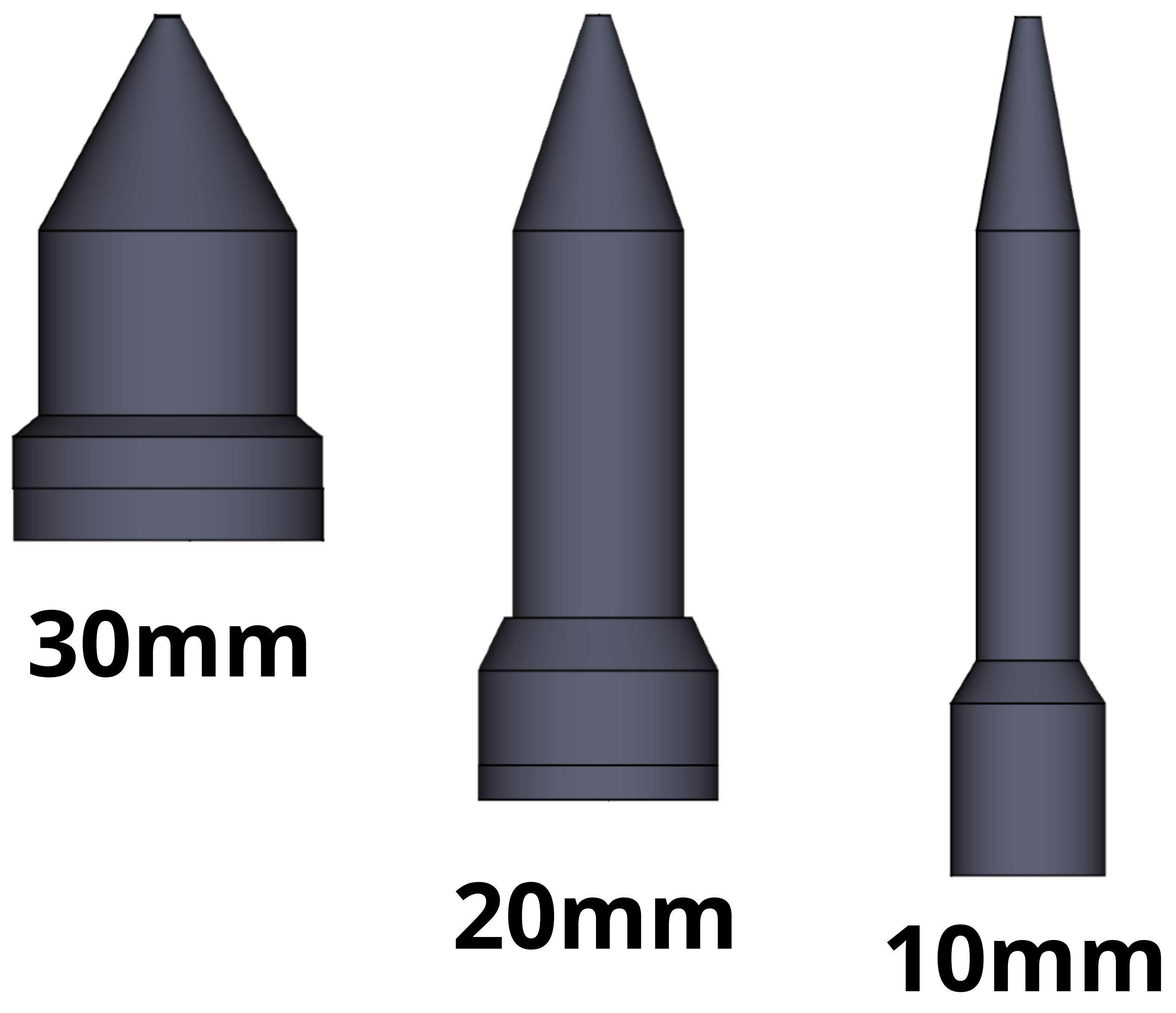
“No shadow” scenario

→ Expected reconstruction performance for real physics events

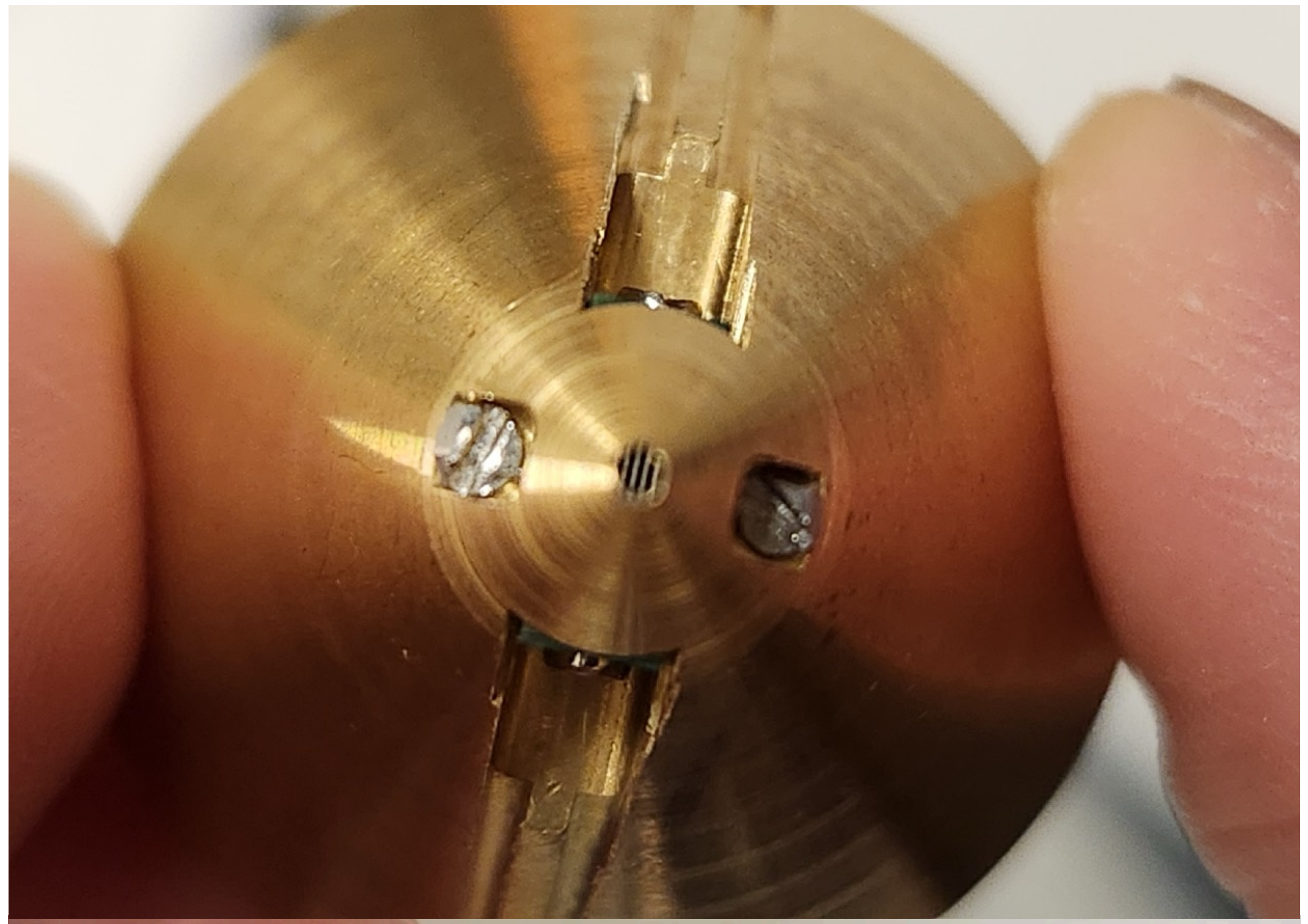


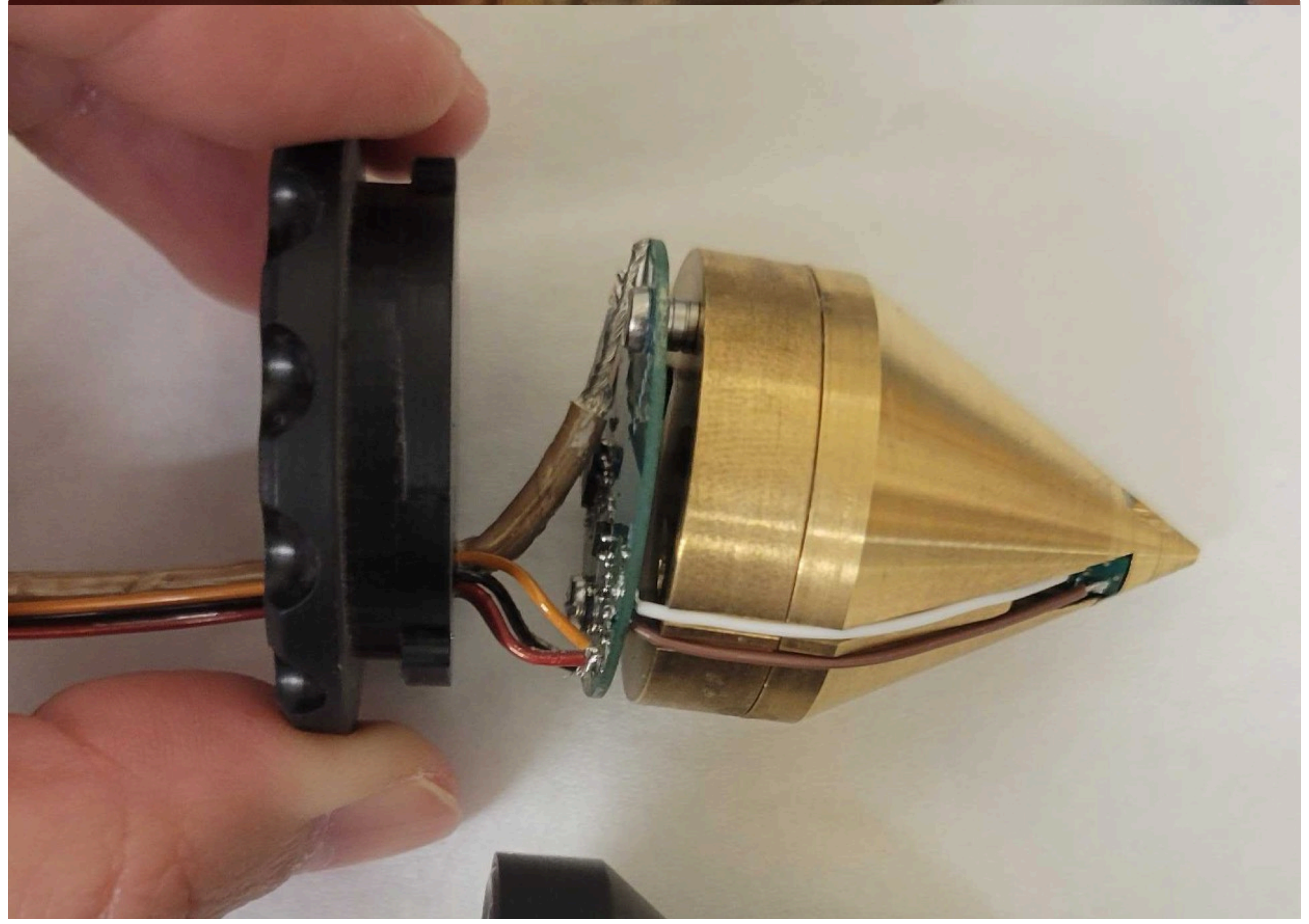
Construction of Directional Source(s)

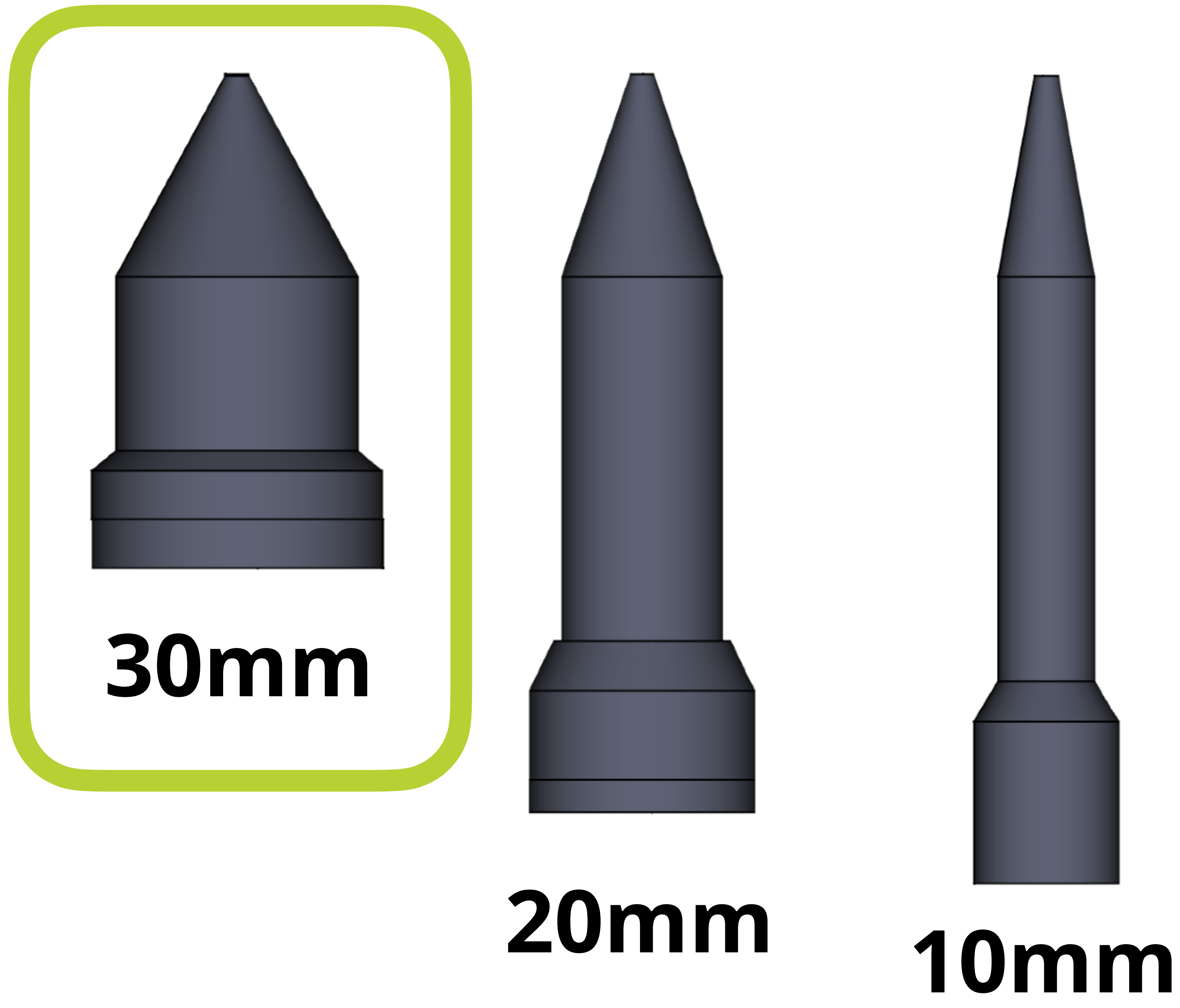
3 source sizes to thoroughly test
the affects of self shadowing

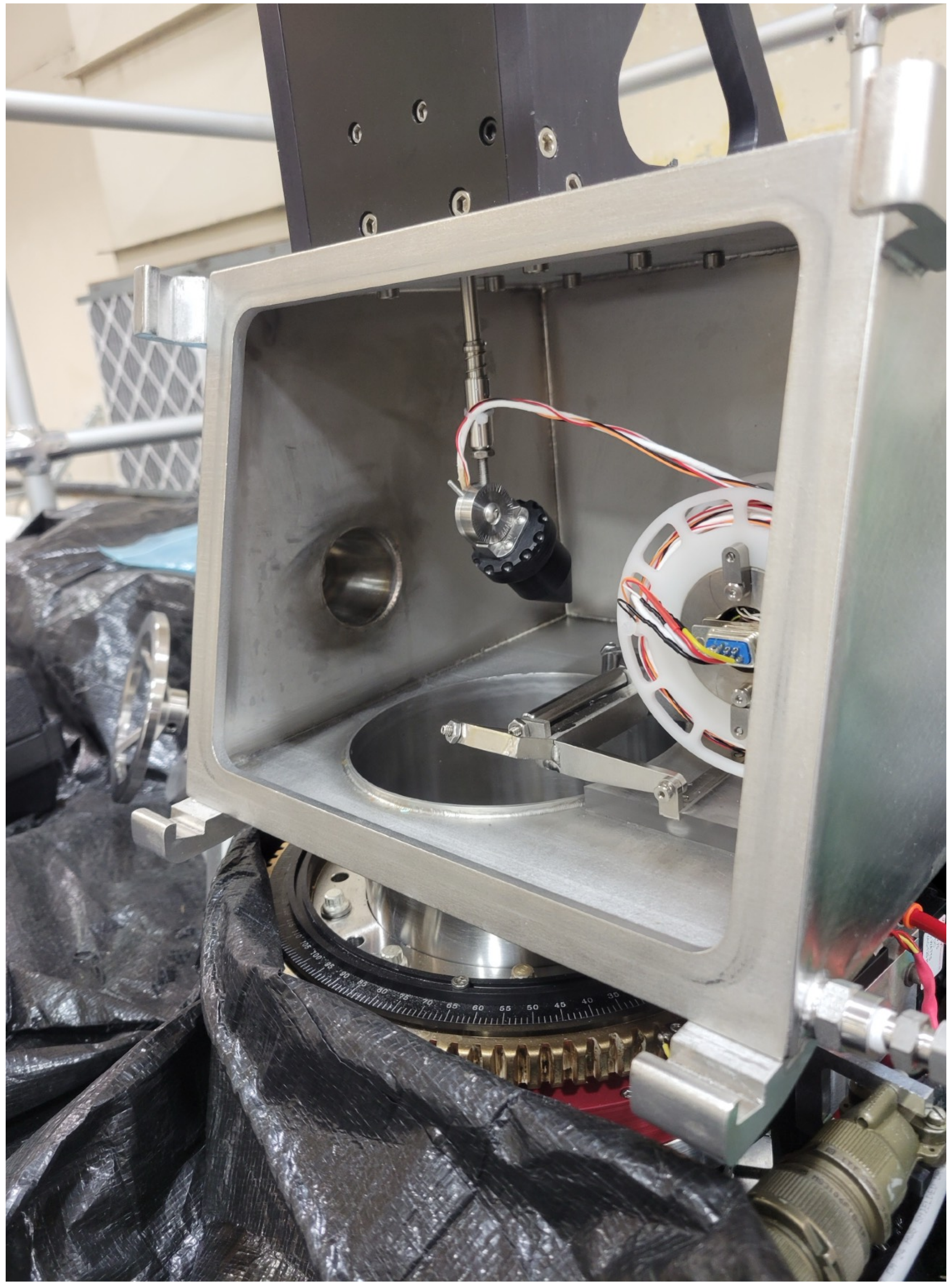


Construction of Directional Source(s)

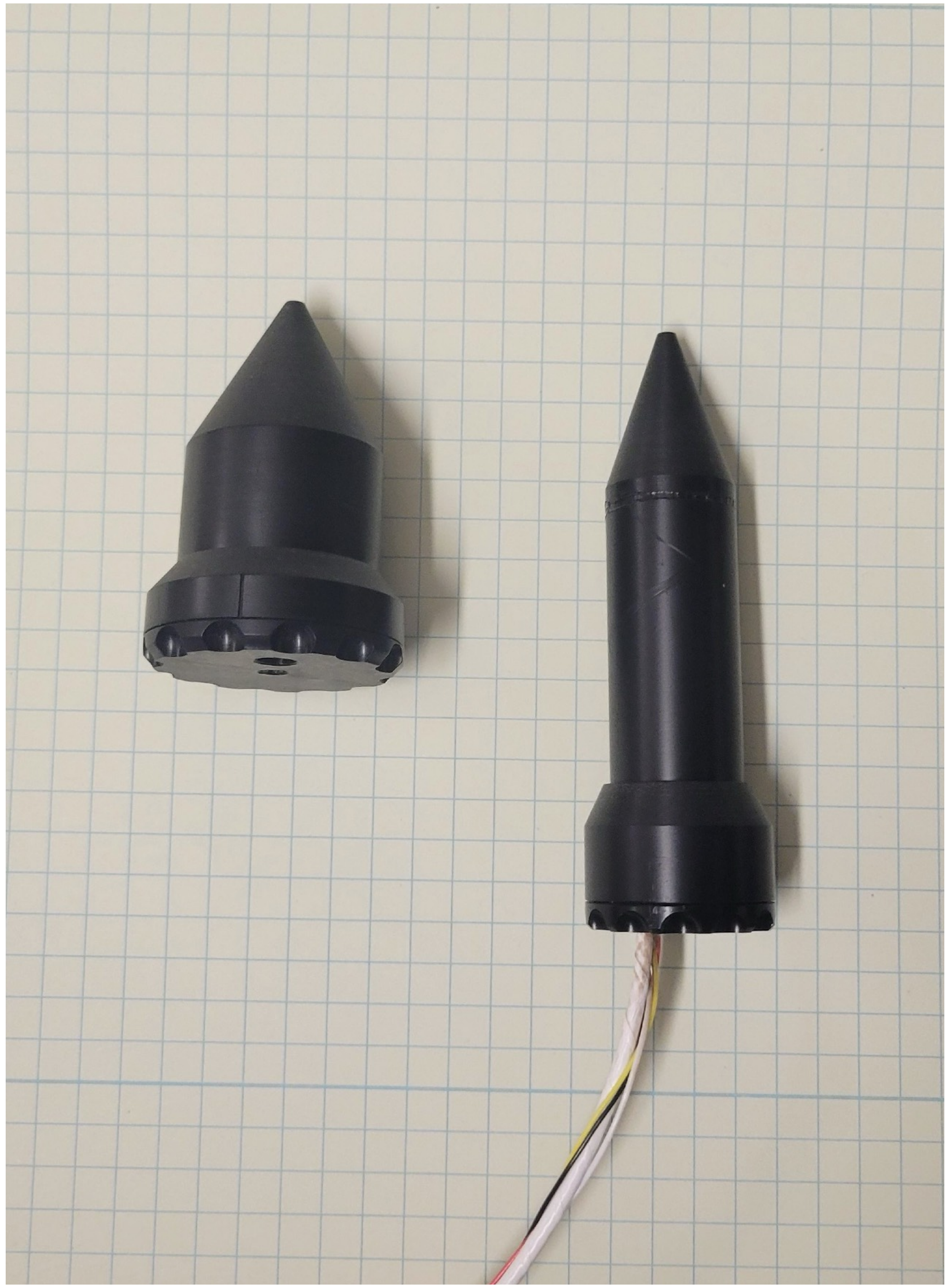


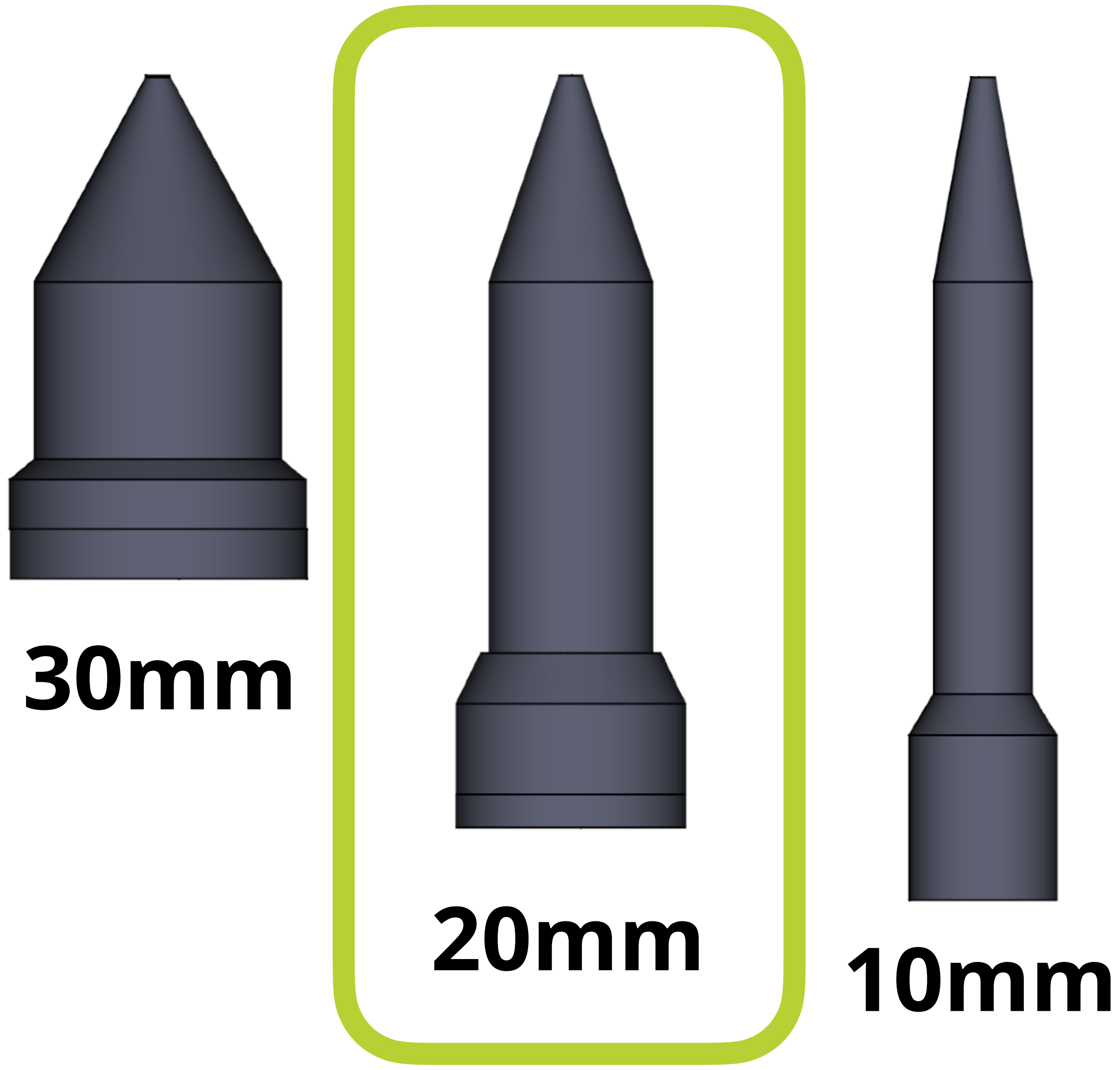




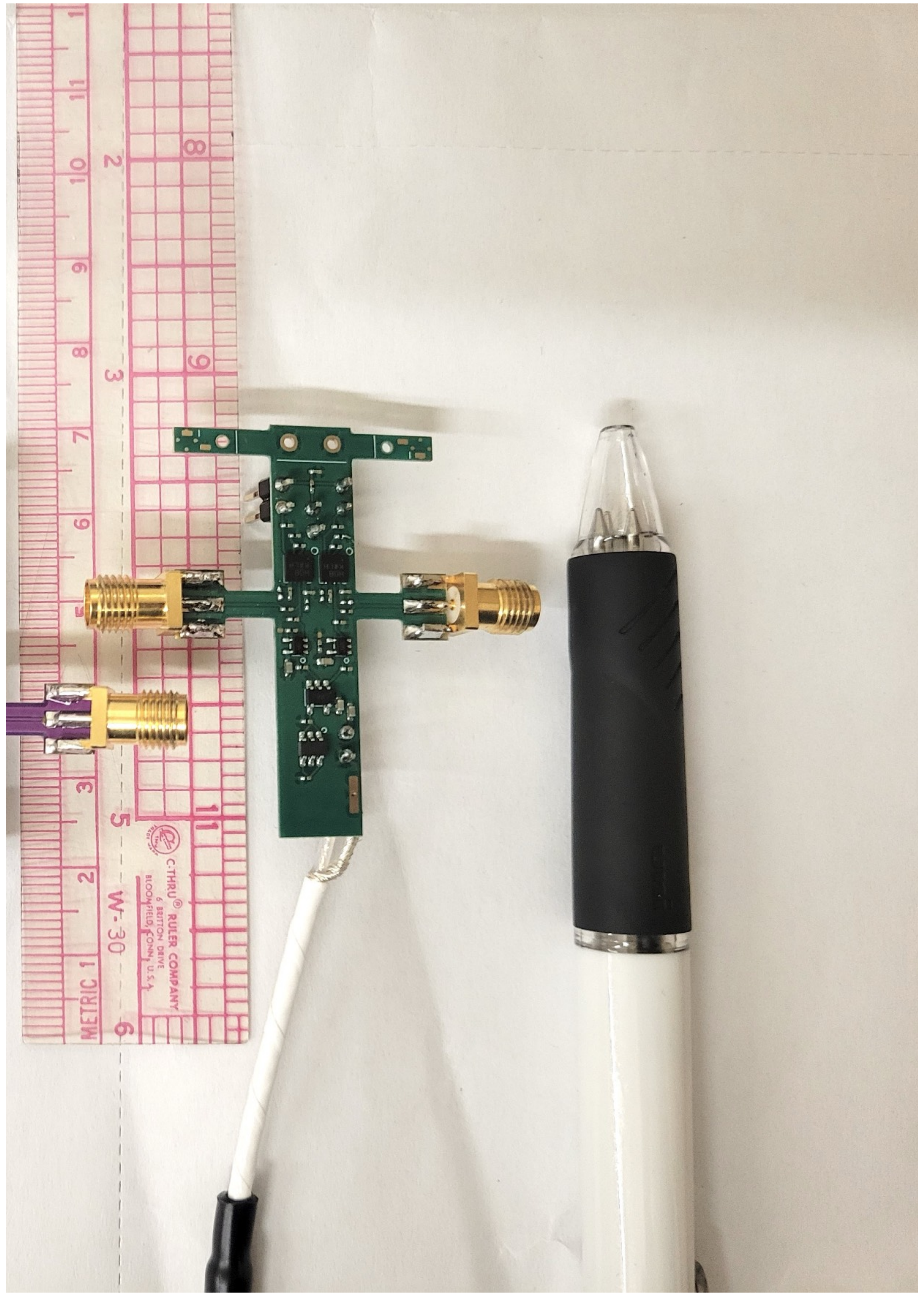


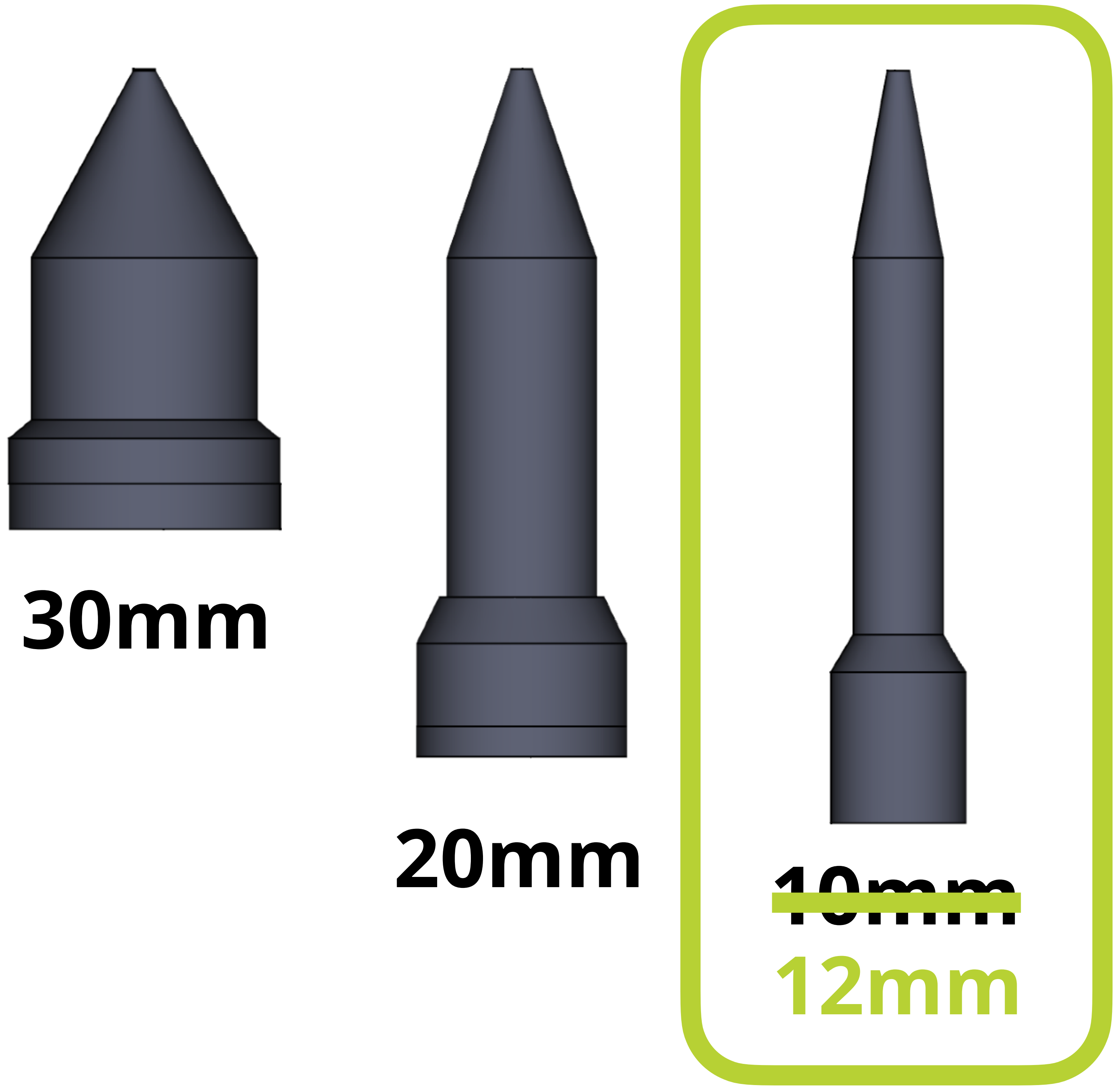
Construction of Directional Source(s)



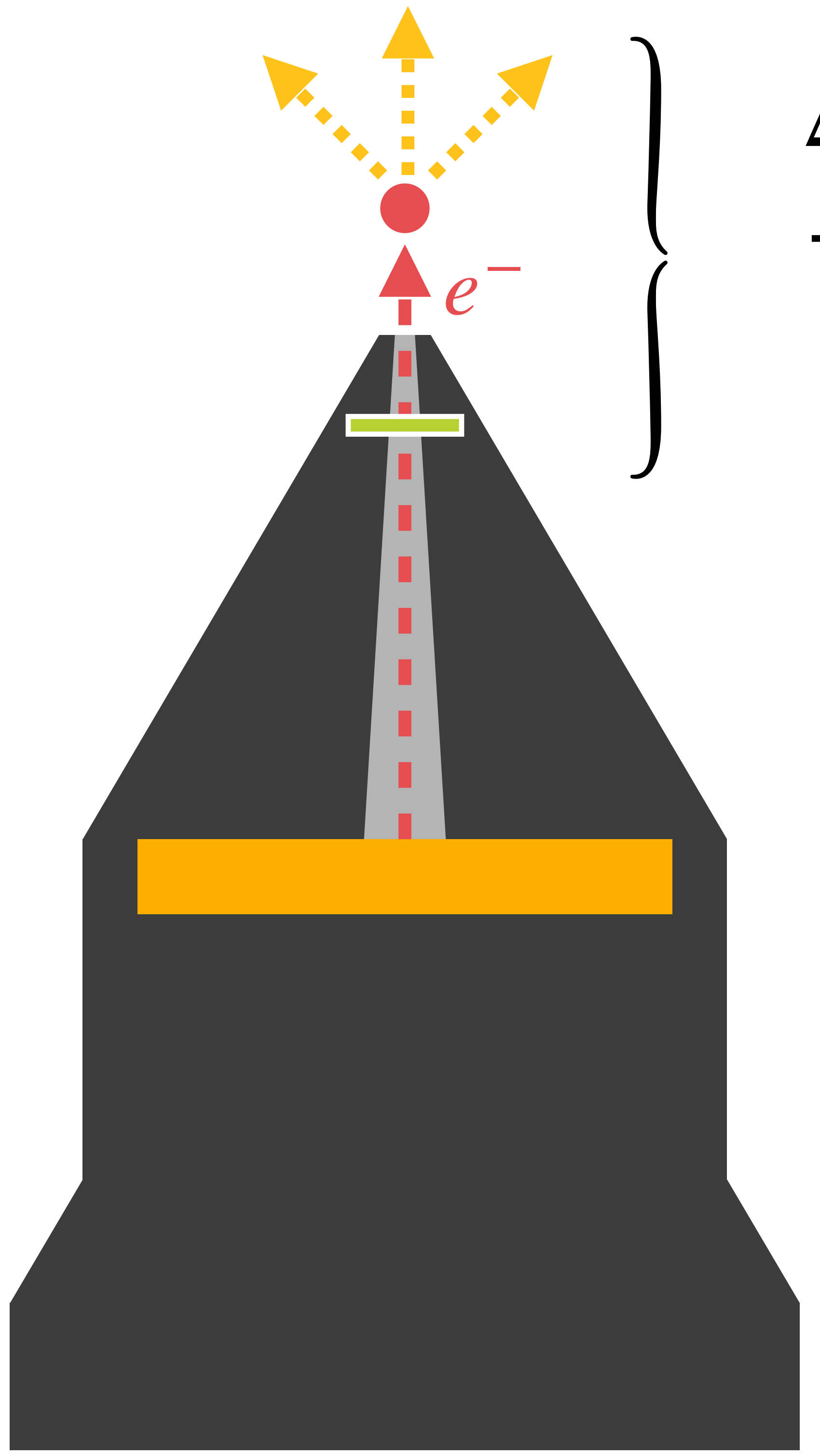


Construction of Directional Source(s)

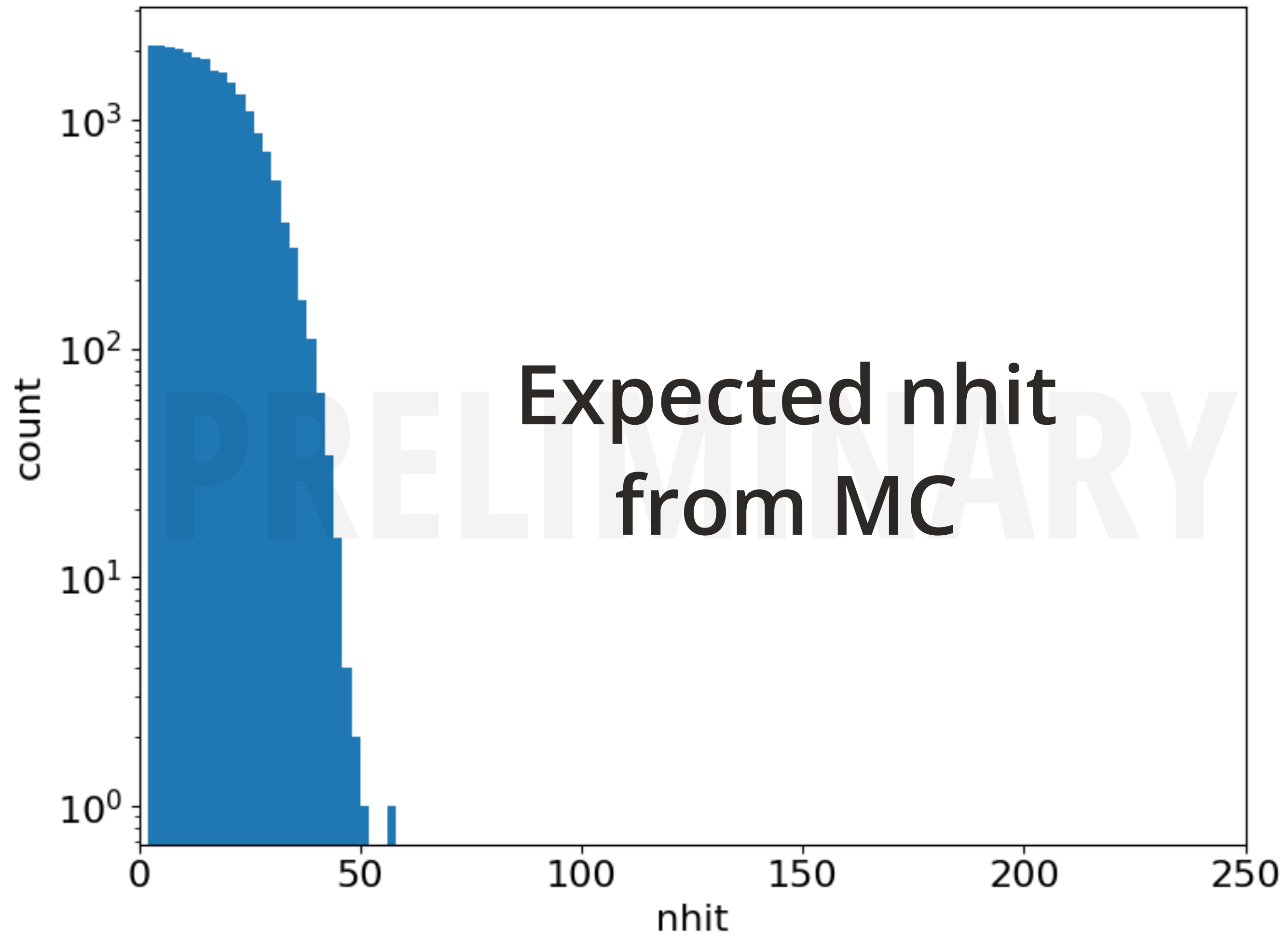


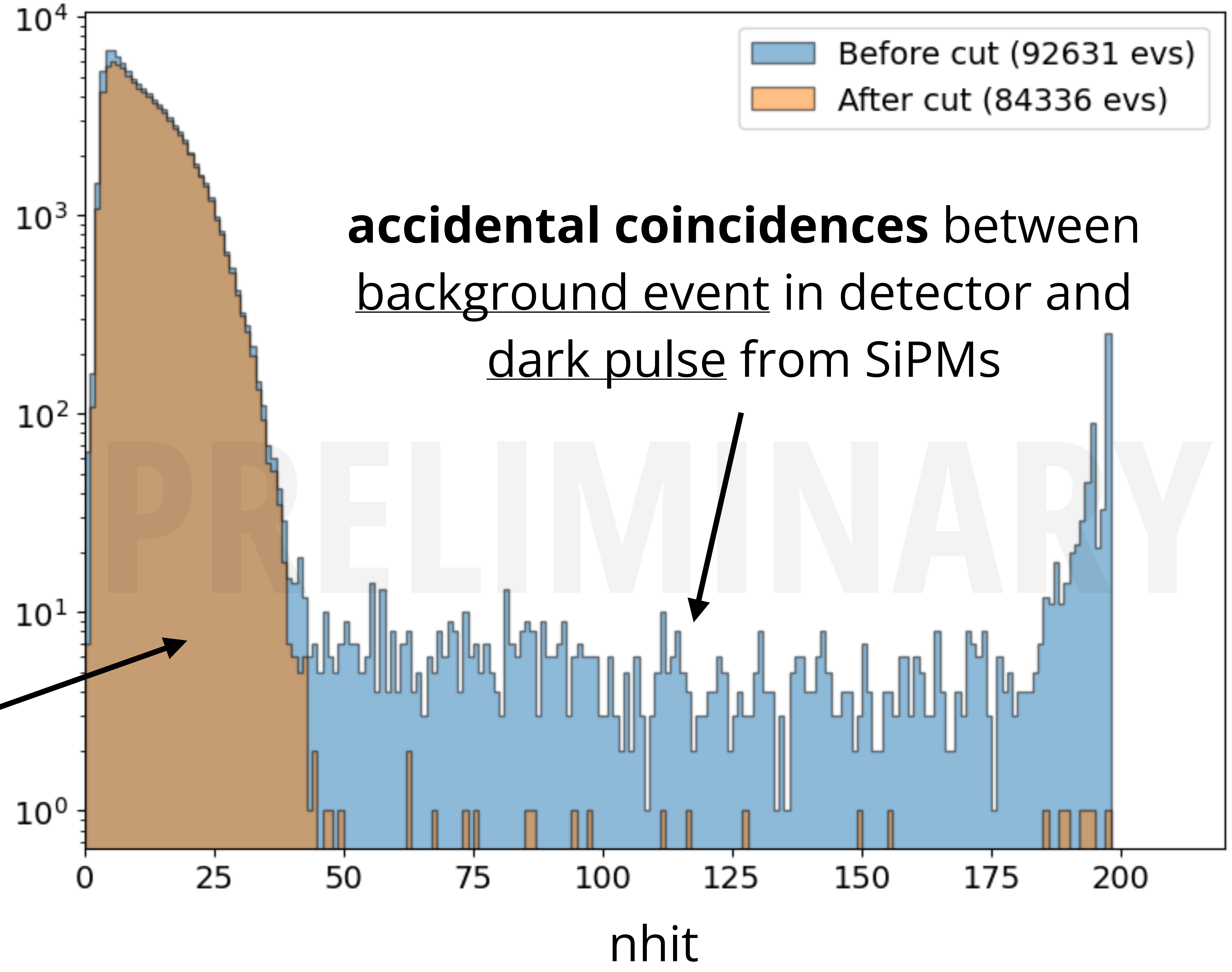


Deployment in Water



Δt is very consistent
→ impose tight timing selection



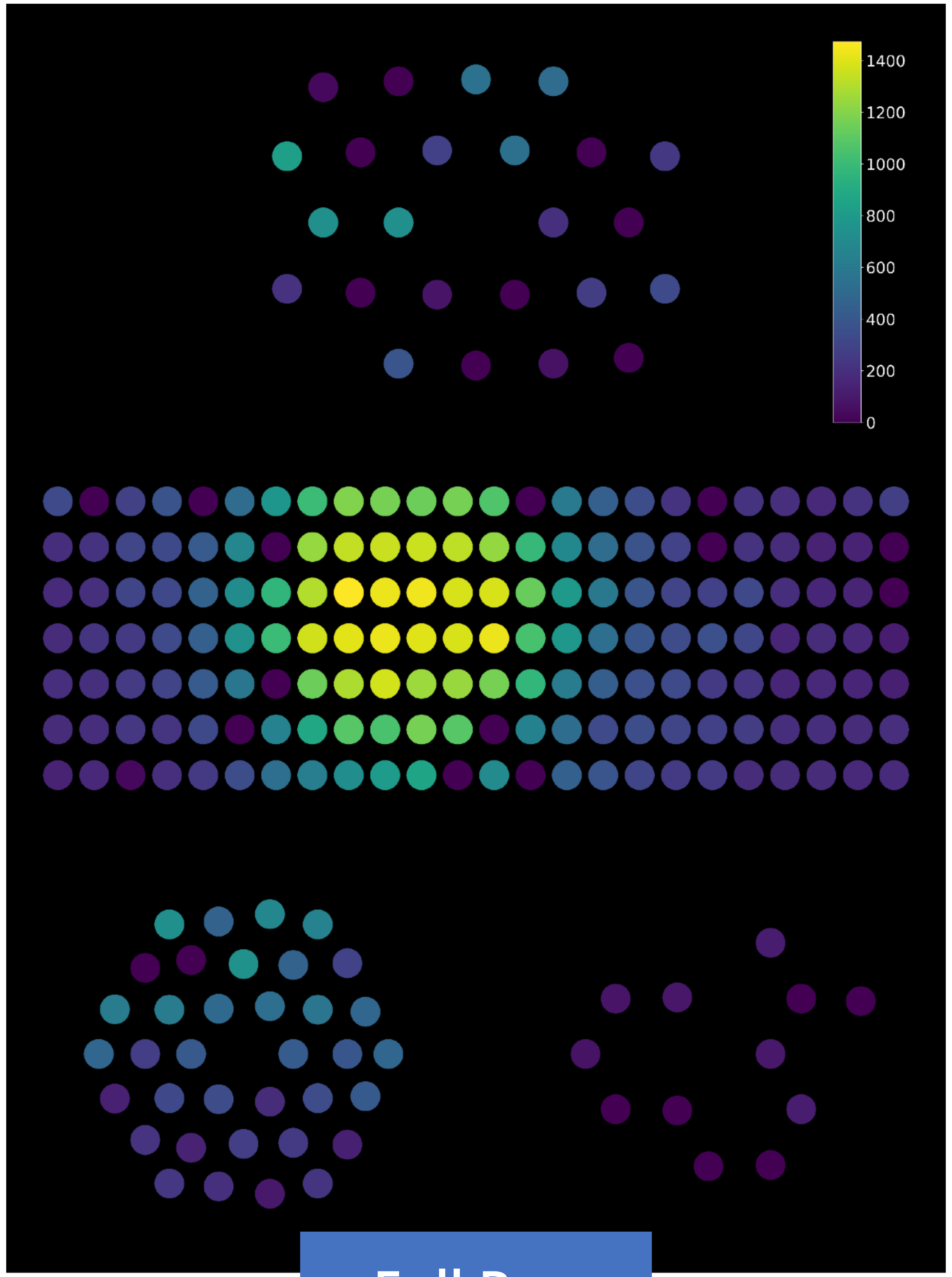


accidental coincidences between background event in detector and dark pulse from SiPMs

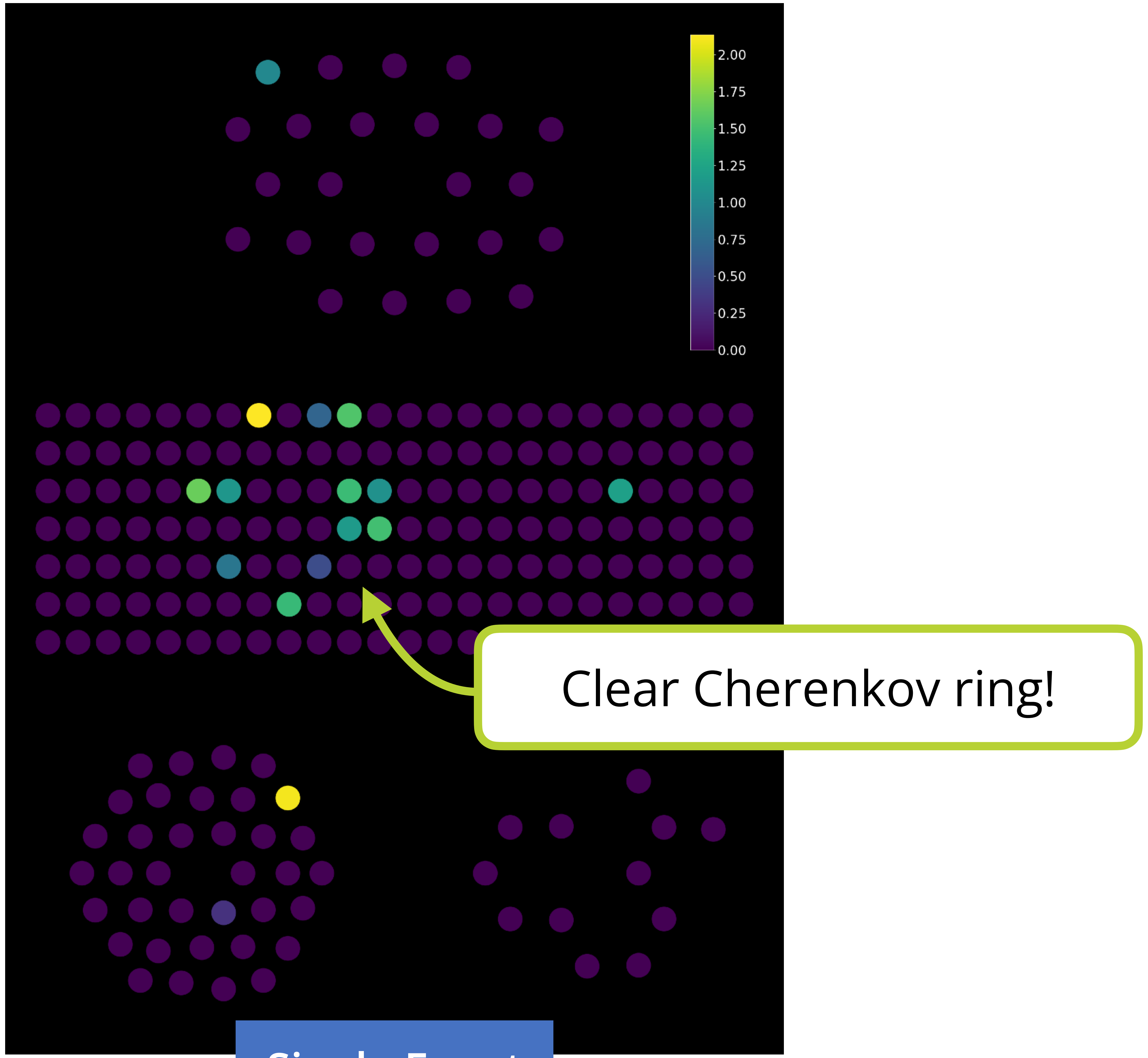
Self-triggering system allows us to achieve clean signal after relatively simple cuts.

Background reduced to ~0.1% for Ru-106 runs
~1% for Sr-90 runs

Deployment in Water

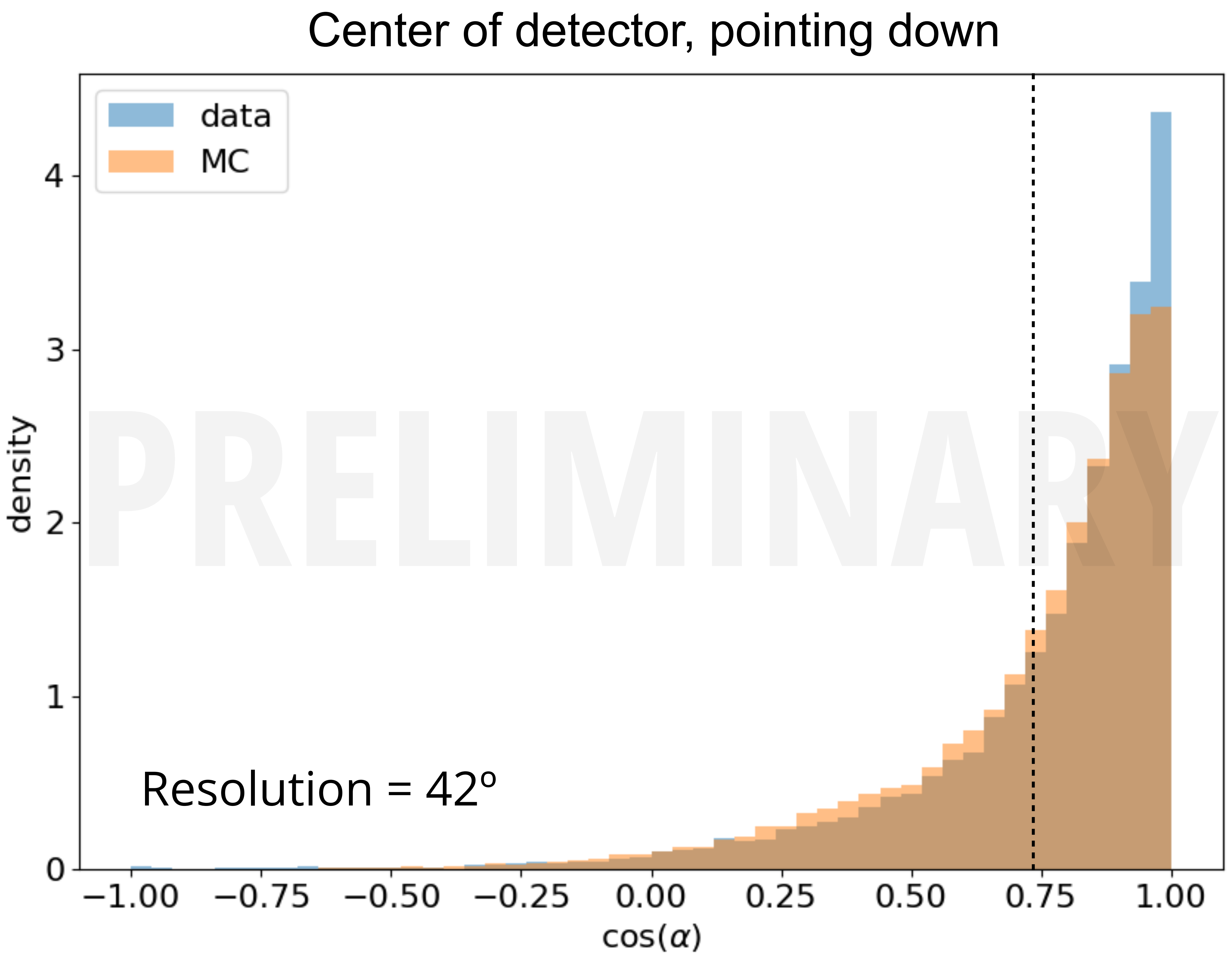


Full Run



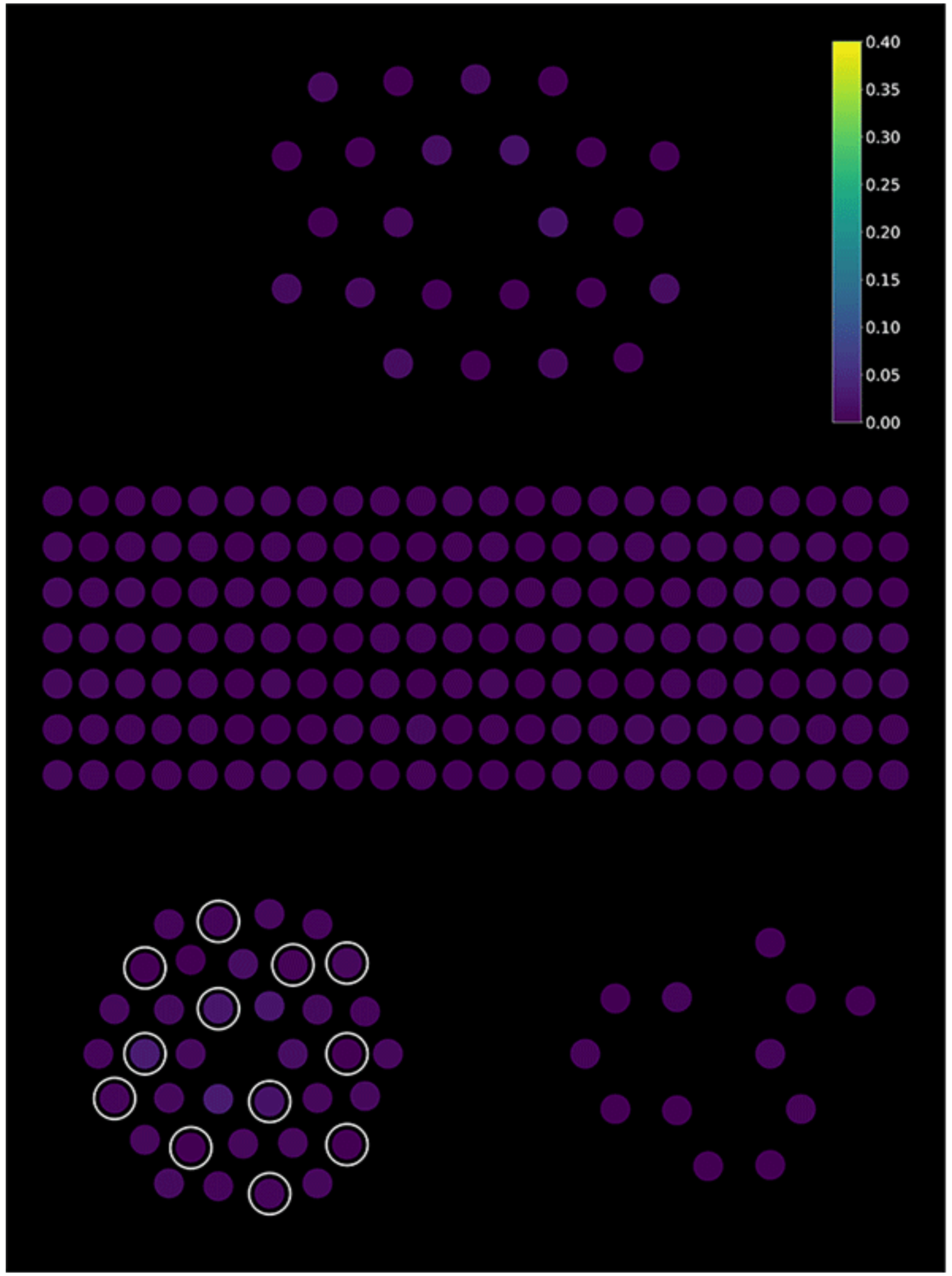
Single Event

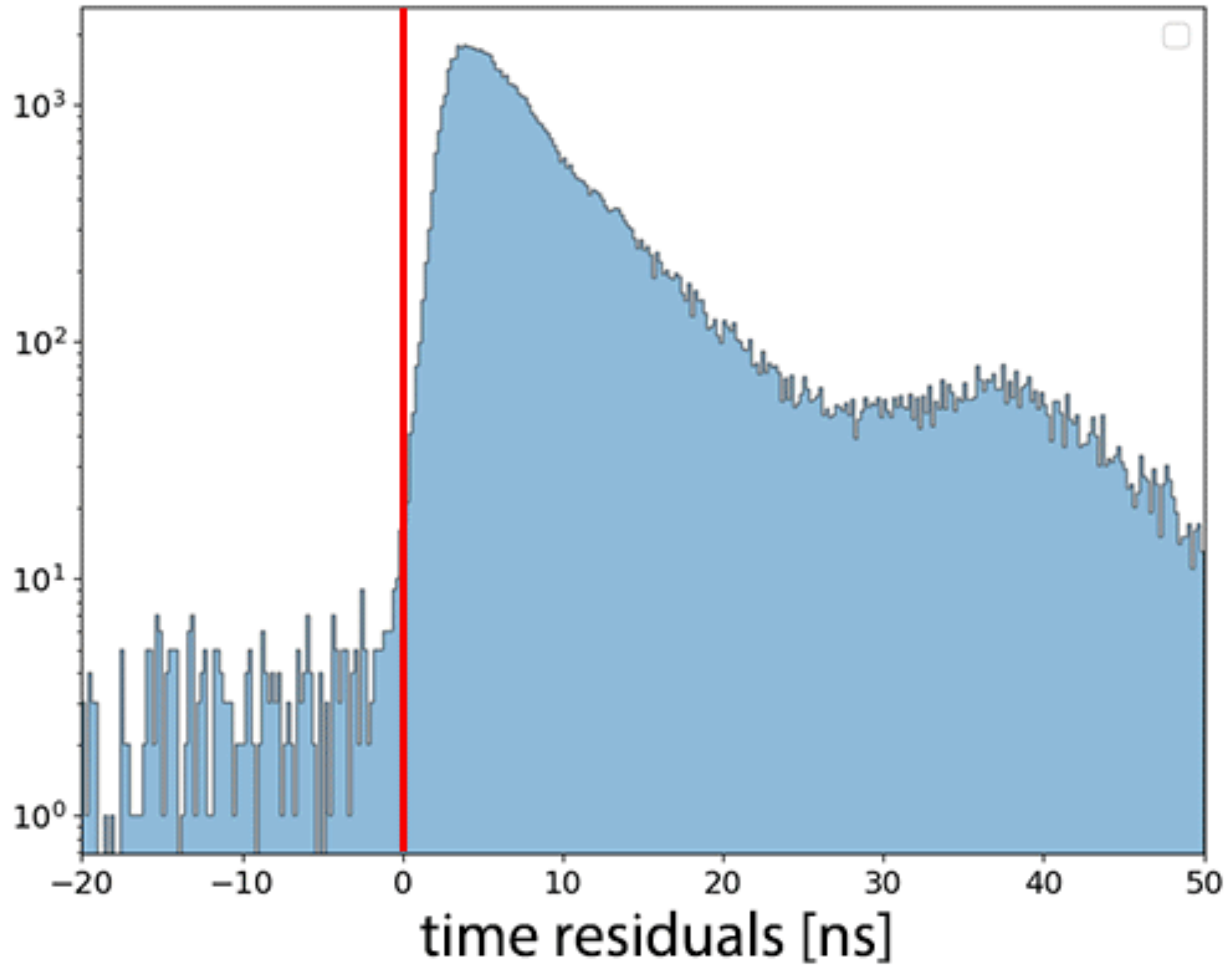
Direction Reconstruction



- Likelihood-based direction reconstruction shows resolution (68th%) of 35~58º, depending on direction and position of source
  - PDF made using PMT hitmap
- Other direction reconstruction algorithms are being tested, such as ML-based approaches or BONSAI

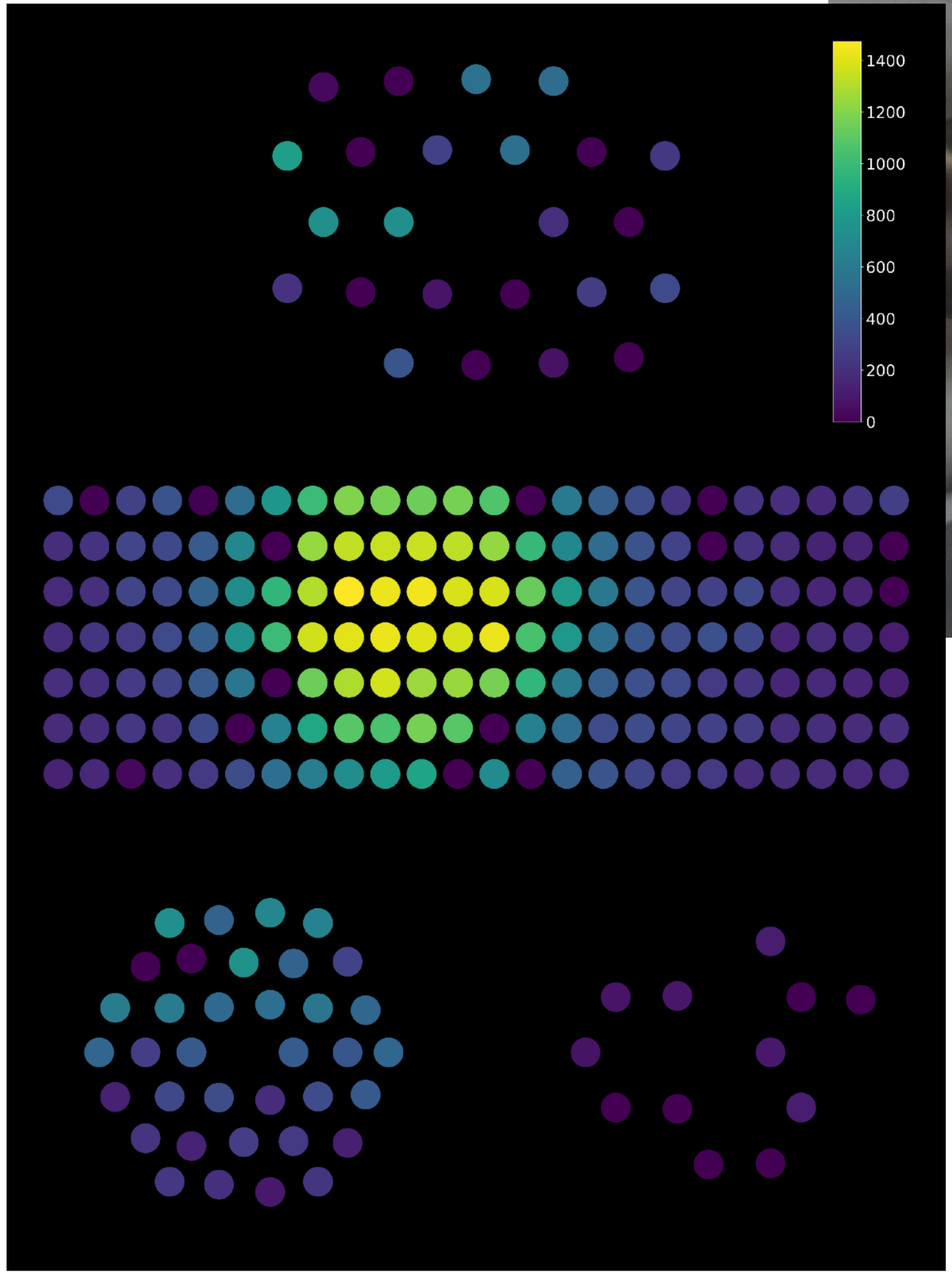
Deployment in WbLS





Summary

- Direction reconstruction is a great way to demonstrate our ability to separate Cherenkov and scintillation light.
- A novel **Directional Beta Source** has been designed to demonstrate direction reconstruction capabilities of Eos.
- 3 different source sizes are being built to thoroughly evaluate our understanding of the self-shadowing effect.
- Deployment in water shows that the we are able to get clean data with expected direction reconstruction performance.



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