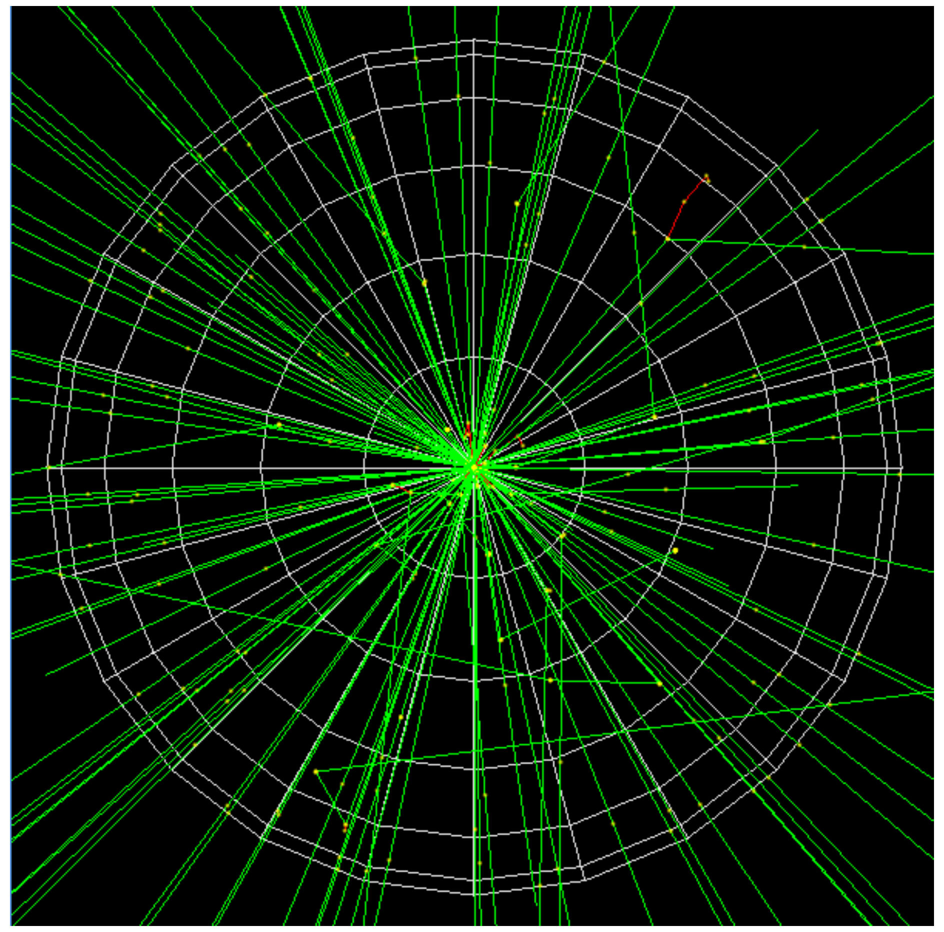

Update on radioactive sources development

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WCTE collaboration meeting July 22, 2022

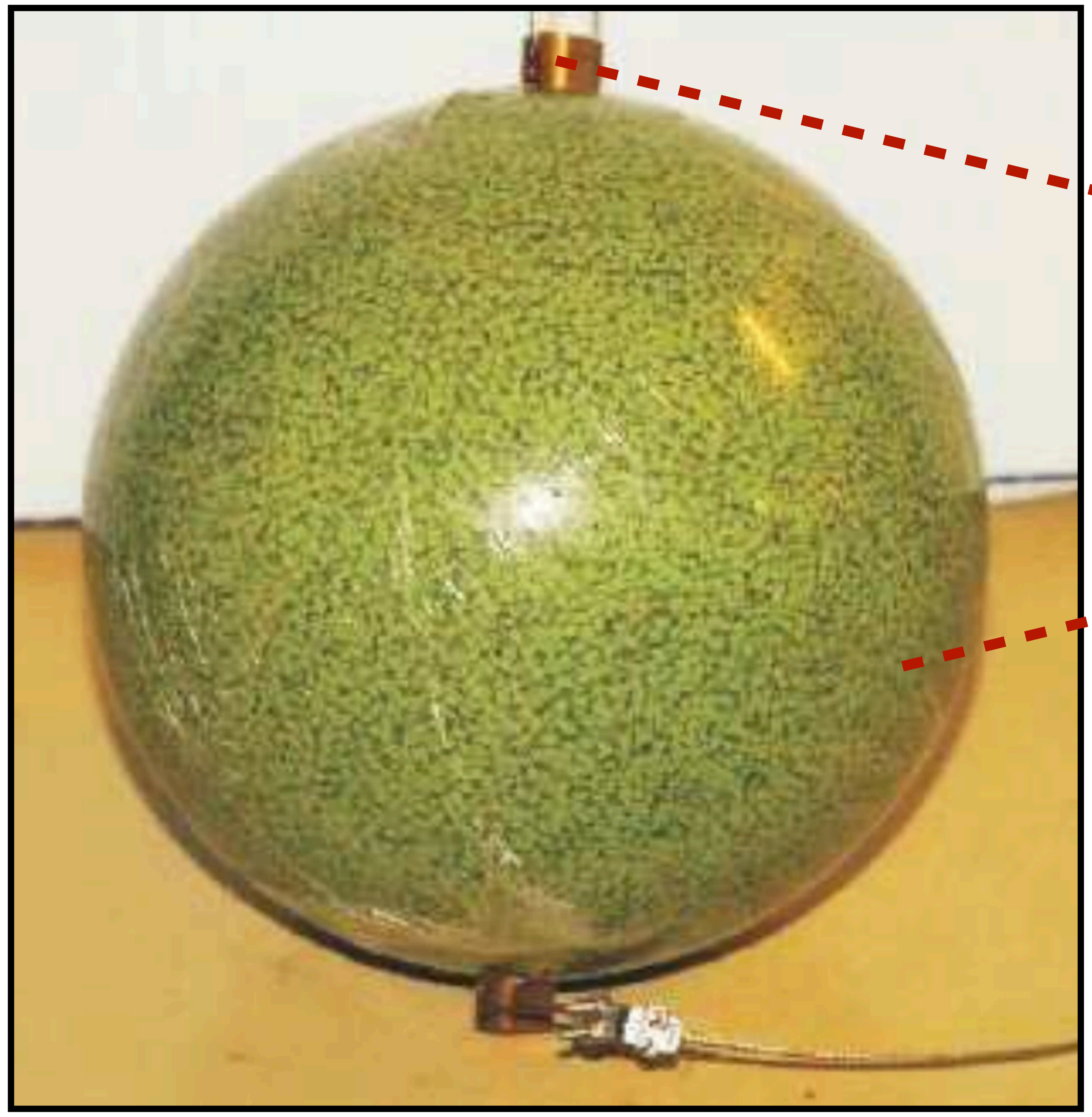
Short summary:

- **NiCf source:**
  - Initial simulations of single-photon detection rate performed
    - Gamma spectrum appears acceptable for 6.75 cm radius source size
  - Current plan is to construct the source ourselves (epoxy + NiO + polyethylene mixed in a vacuum chamber and cured) rather than contracting through a company
  - We will first attempt a “prototype” source using cheaper material to confirm construction procedure
  - Initial studies of 2 different epoxies have been carried out

- **AmBe source:**
  - Final design decisions not yet made
  - Initial simulations started

Nickel source - NiCf

- Goal is an isotropic source of gamma rays leading to single photon events for PMT calibration
- Thermal neutron capture on nickel: $^{58}Ni(n,\gamma)^{59}Ni$ (~9 MeV in gamma energy)
- ^{252}Cf decay provides neutrons
- Source is used for absolute and relative gain calibrations, as well as to study detector uniformity



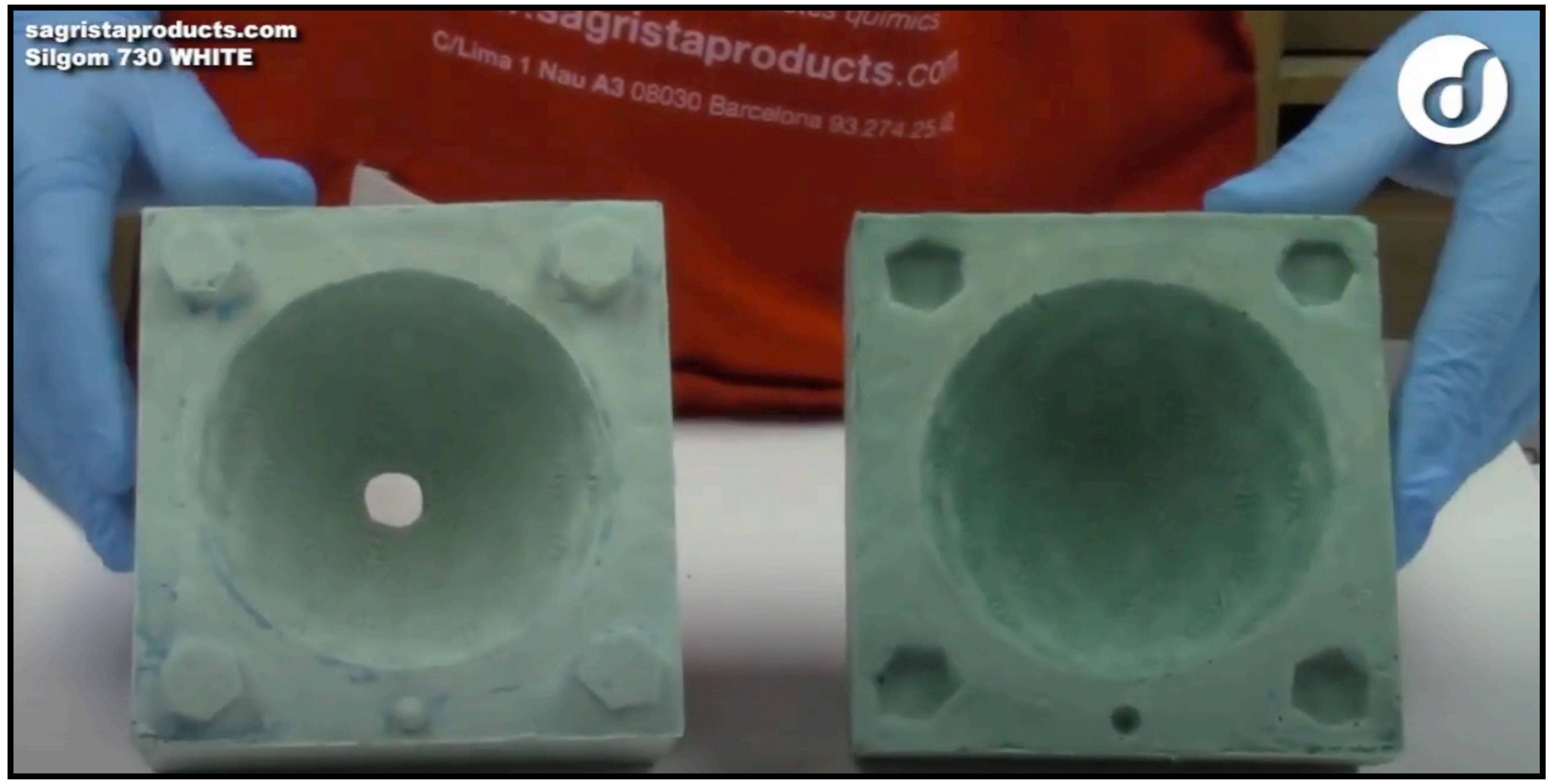
Brass rod holds ^{252}Cf source at the center of the ball

6.5 kg of NiO and 3.5 kg polyethylene

Nickel source used in SuperK (https://arxiv.org/abs/1307.0162)

Planning for source construction

1. Create a silicone spherical mould (135 mm diameter)
   - Construct in two parts around a stainless steel sphere
   - ~1 day/half curing time
2. Fill the mould with epoxy + NiO + HDPE mix
   - Mix to be performed in a vacuum chamber
   - Initial test to be done with (less costly) NiO substitute
   - Curing time of potentially several days (to be determined)



Example silicone mould
(https://www.youtube.com/watch?v=JqD3jDKLjYY)

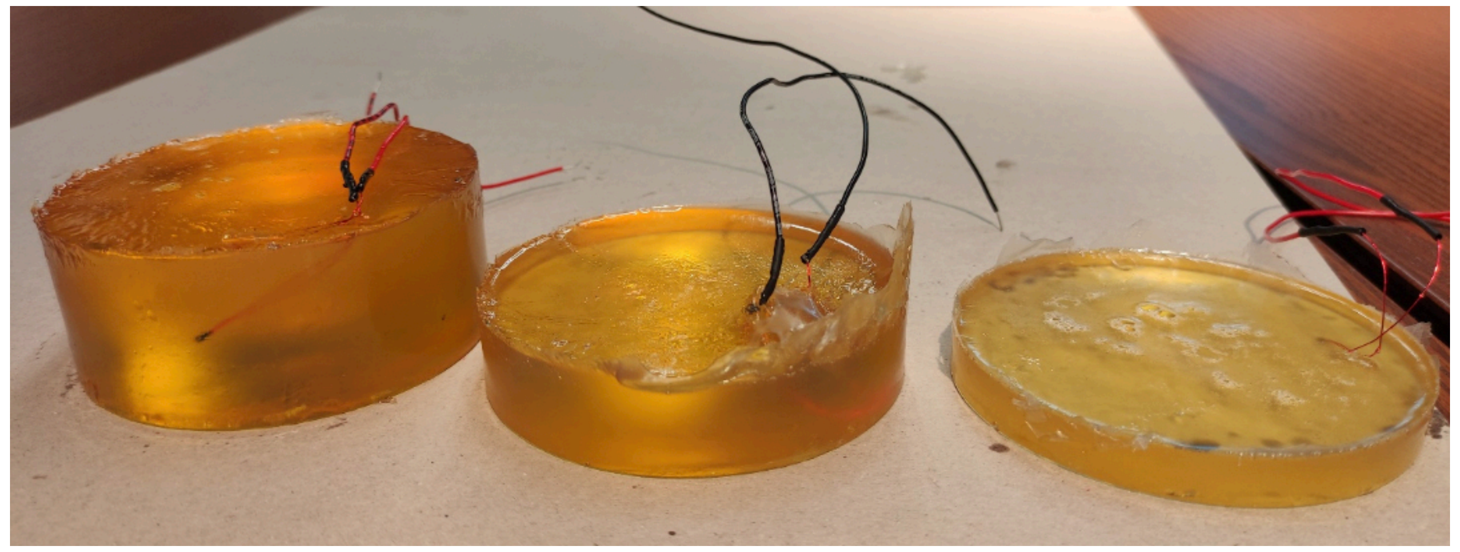
Initial sphere (with NiO substitute)

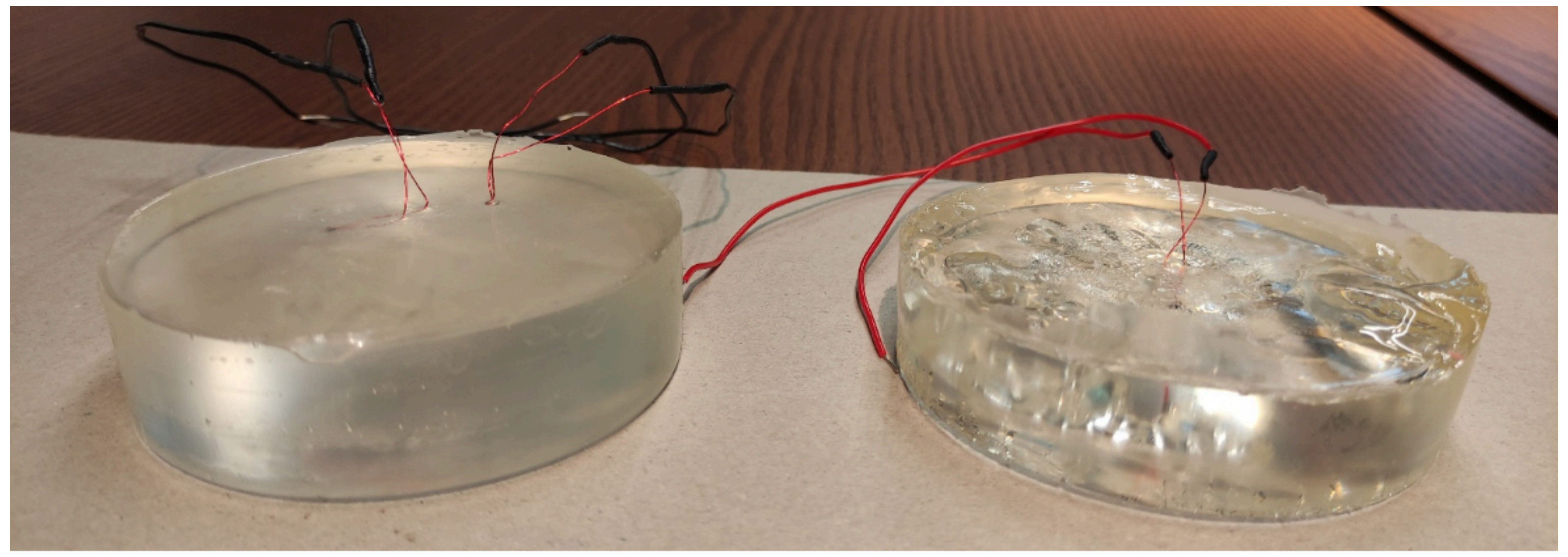
- Create an initial sphere to verify construction process
- Potential NiO substitute: iron oxide (Fe_2O_3)
- Monitor temperature with thermocouples
  - ~3 locations within the sphere
  - May require low exotherm epoxy (curation over several days) to meet temperature requirements, or curing in several parts
- Air should be removed from components (powders, epoxy) with vacuum chamber before mixture
- Final mixture filled into mould

Vacuum chamber

Epoxy test (A. Taboada, DIPC)

- **Compare two different adhesives:**

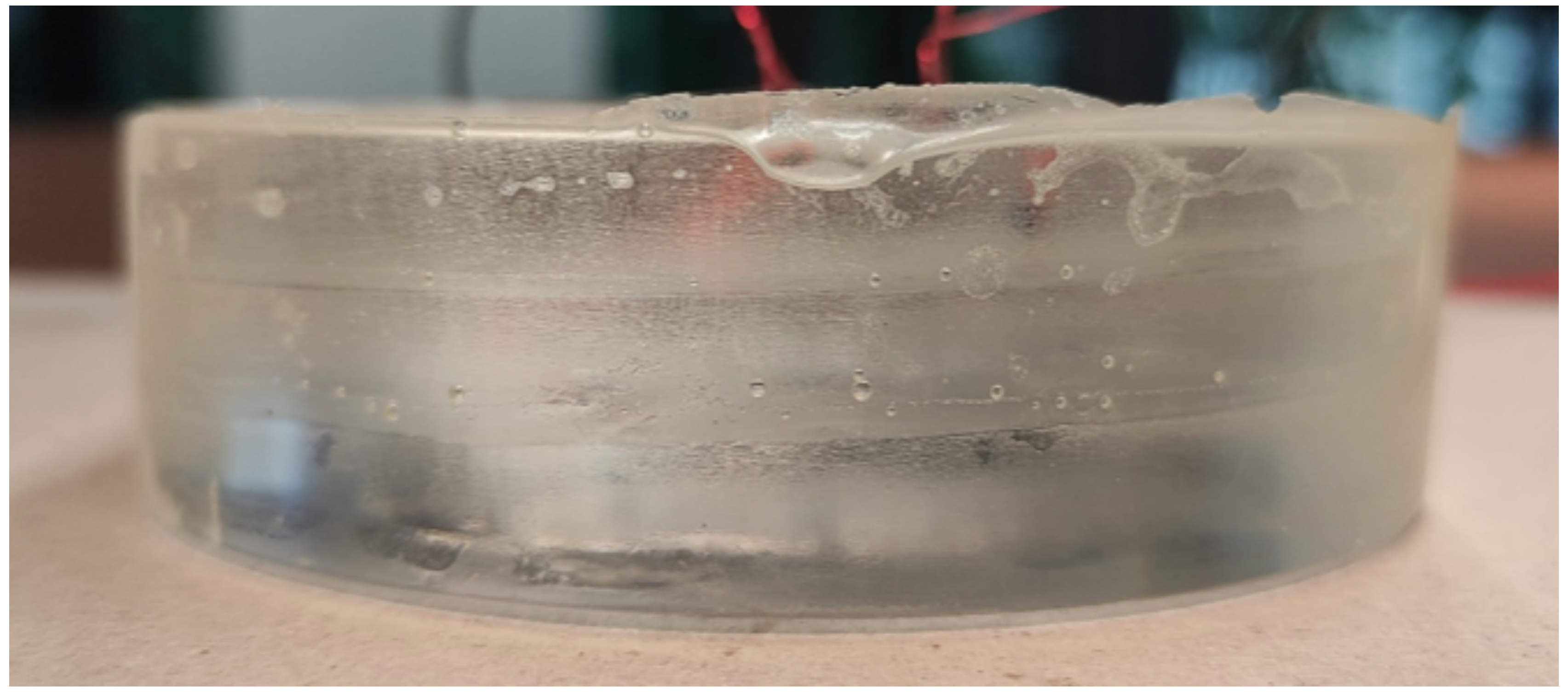




- **Temperature monitored with thermocouples and Arduino**
- **Evaluate:**
  - Union between 2 layers combined during “gel” phase of curation and after “solid” phase has been reached
  - Curing temperatures of 2 mixtures (which generates less heat)

Epoxy test (A. Taboada, DIPC)

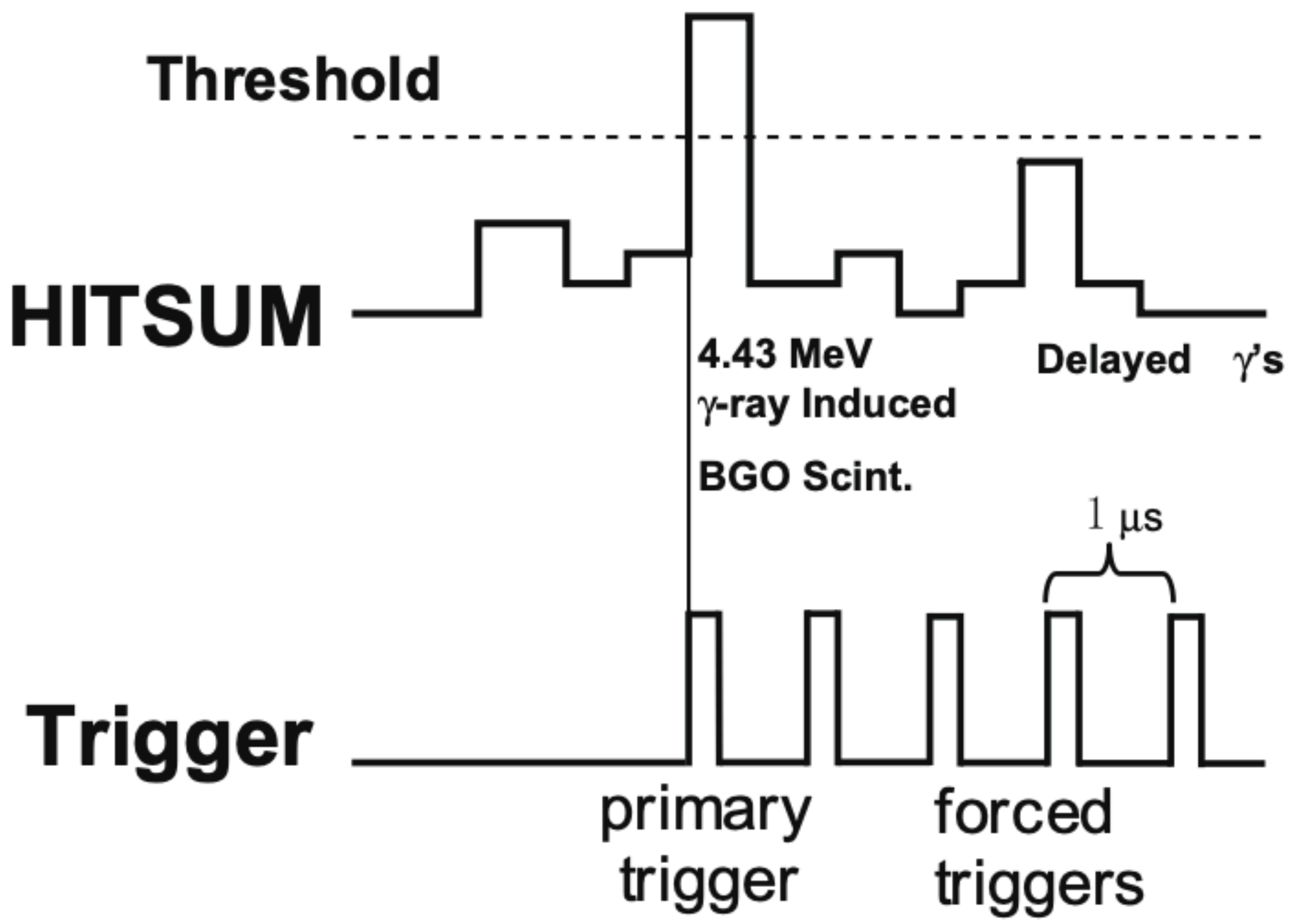
- **Key conclusions:**
  - Temperatures can rise exponentially once an activation temperature is reached
  - Epoxy is in gel phase when temperatures start to fall; requires several hours to reach solid phase
  - Interfaces between layers end up being visible (not expected to be an issue), though there is a significant time window to add epoxy in layers without noticeable difference in results
  - Mixing with a filler (e.g. sand) keeps temperature lower (but cooling also slower)



- **Next test:**
  - Clear epoxy mixed with iron oxide (substitute for nickel oxide), 4 layers

AmBe source

- Acrylic case containing BGO scintillators surrounding an AmBe neutron source
- Tagging (~4.4 MeV gamma emitted in coincidence with a large fraction of neutrons) was done by SK PMTs



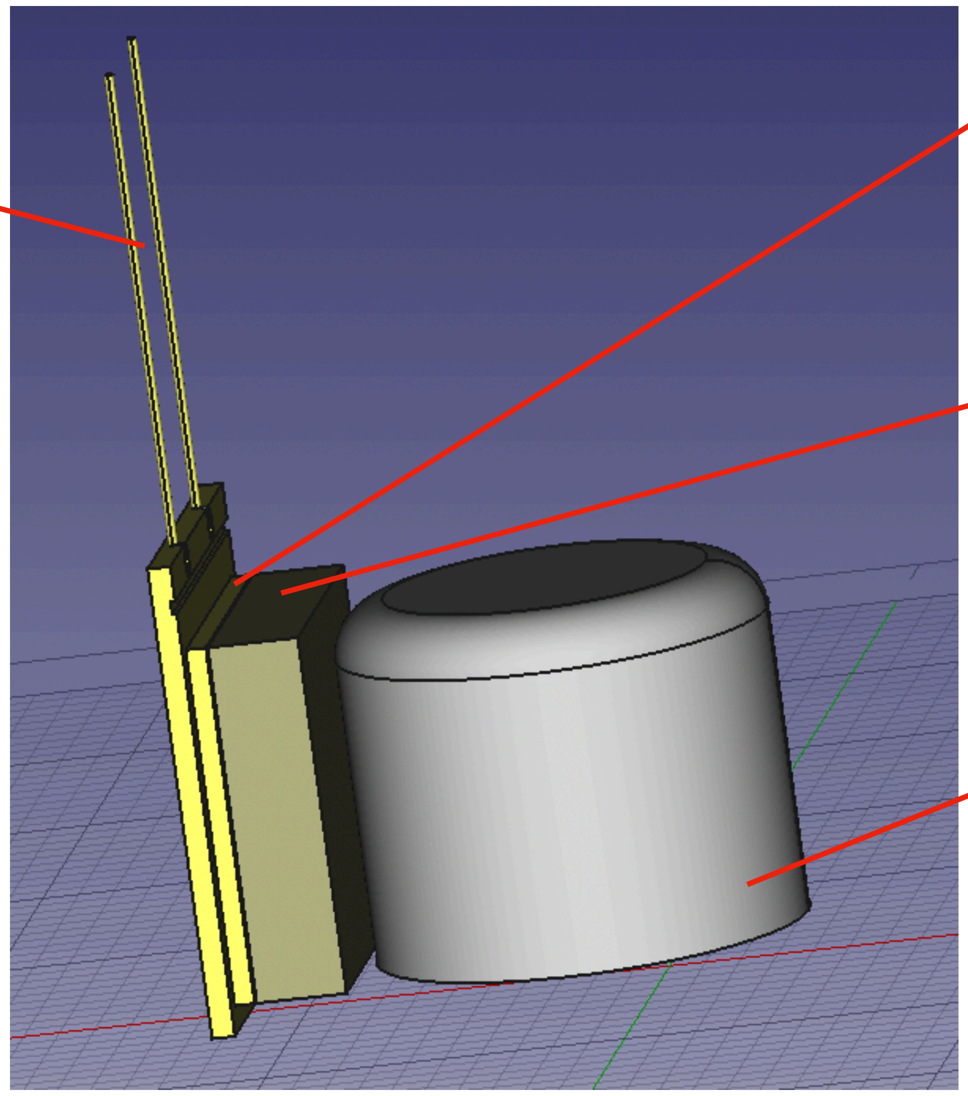
Tagging: trigger on sum of analog PMT signals within 200 ns, from [1]

[1] *H. Watanabe et al. Astropart. Phys. 31, 320 (2009)*

AmBe source

- **WCTE - tagging will require either:**
  1. Send scintillation outside the WCTE (via scintillating fibers or by operating a photodetector from within the source)?
  2. Use the PMTs of the detector?
  3. Other options?

1. ***Surround AmBe source with scintillators coupled to photodetectors***

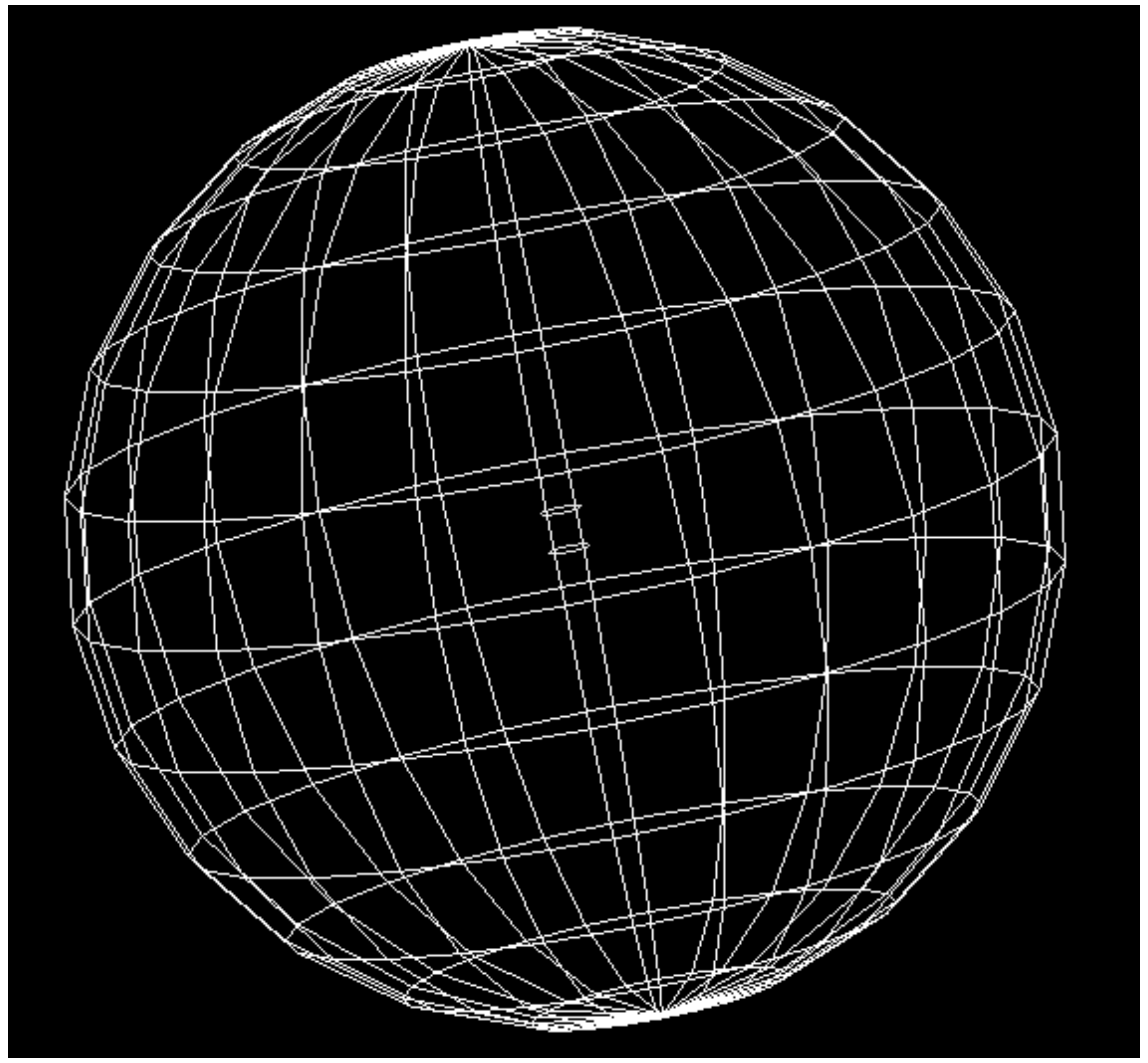


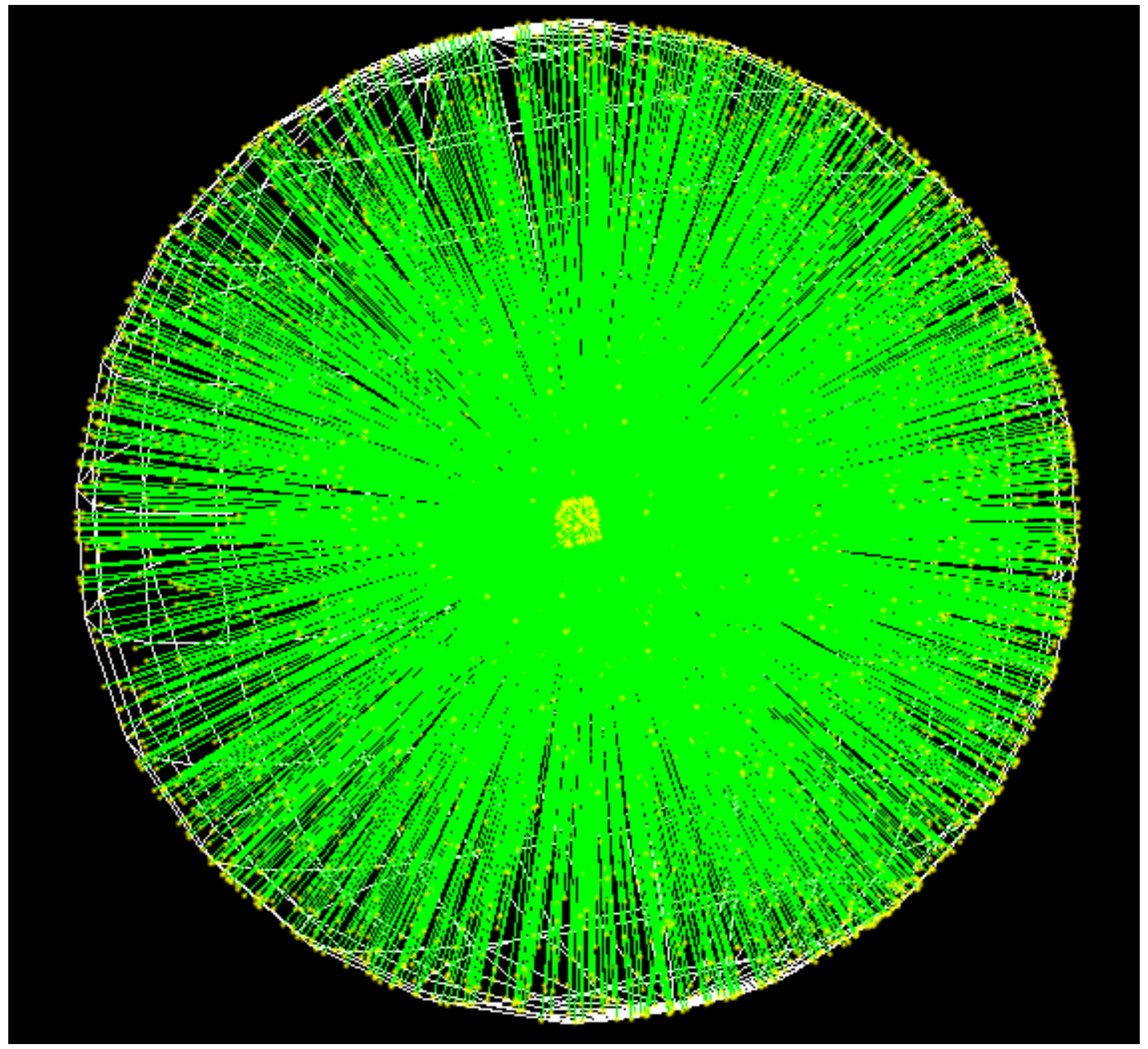
2. ***Use the PMTs of the detector***

- *BGO scintillation yield: ~8 photons / keV*
- *For 4.4 MeV, ~35200 photons*
- *40% photocoverage (HK), 20% QE —> **~2800 photons detected***
- ***Should be enough for the tag signal***

AmBe source

- **Initial Geant4 simulation**
  - BGO cylinder (4 cm diameter x 4 cm length) in sphere of water
  - Launch 4.4 MeV gamma rays and/or neutrons from center of cylinder
  - BGO scintillation distinct from Cherenkov (more photons, uniformly emitted)
  - Should be enough to identify events for which gammas from neutron capture hit the BGO: initial simulations (D. Costas) indicate this happens in ~2% of cases





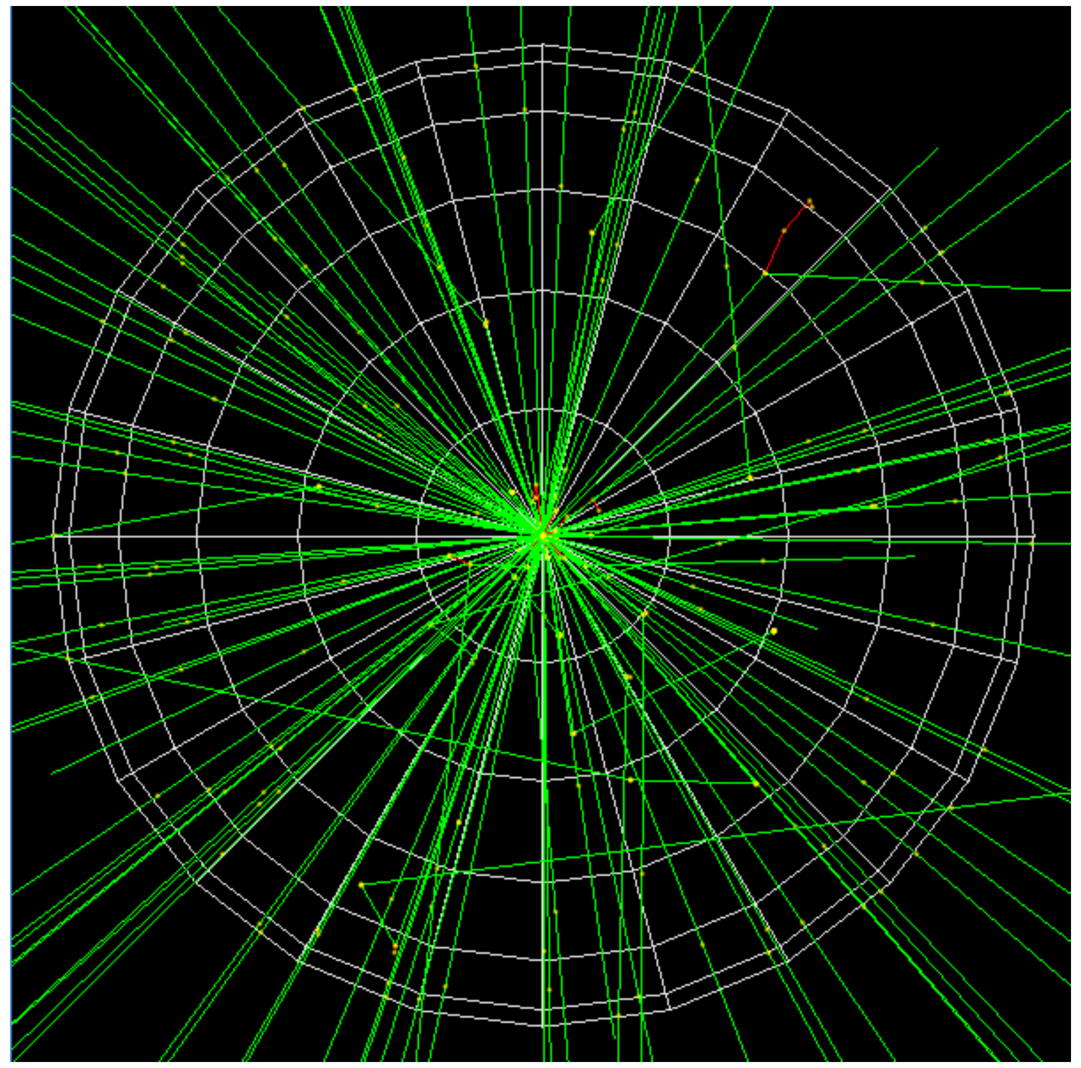
AmBe source

- **Continuing simulations studies:**
  - Determine minimum amount of BGO needed to tag the majority of gammas
    - Initial simulations (D. Costas) indicate < 50% tagging rate for a 5 cm diameter, 5 cm thick BGO cylinder
  - Determine ideal rate to avoid pileup but still produce events more frequently than the cosmic rate
  - Decide on final source geometry. Currently considering:
    - cylindrical crystal
    - placed in a cylindrical acrylic container
    - AmBe source capsule placed inside hole drilled in crystal

Backup

Simulation

Nickel source used in SuperK
(https://arxiv.org/abs/1307.0162)



Geant code:
https://github.com/nuPRISM/nicf-source

- **Geant4 simulation:**
  - Uniform sphere (NiO + polyethylene + glue)
  - Launch ^{252}Cf decays at center of sphere; observe particles escaping source volume
  - Using source composition of SuperK
  - Calculation of single-photon event rate

AmBe source

- **Neutron capture events**
    - Identified by presence of deuterium
    - Neutron capture radius and time seem reasonable