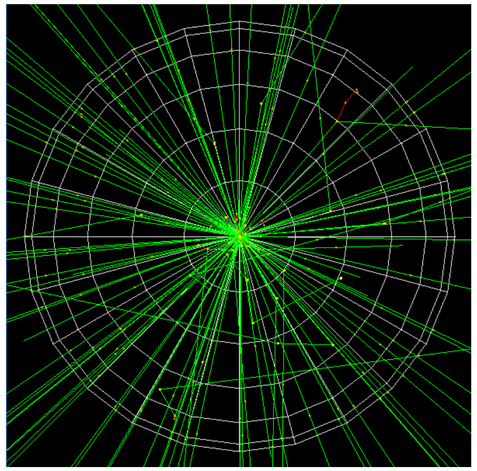


Ni calibration source development

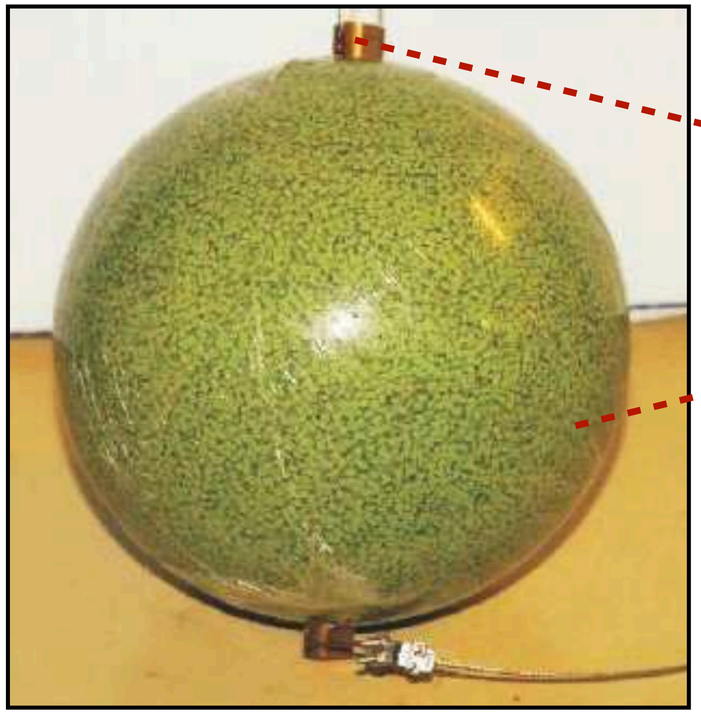
D. Costas[1], P. Fernández[2], F. López[2], F. Monrabal[2], **J. Renner[1]**, J. A. Hernando-Morata[1], J.J. Gómez-Cadenas[2]

[1] IGFAE/Universidade de Santiago de Compostela
[2] Donostia International Physics Center (DIPC)

WCTE collaboration meeting Dec. 1, 2021

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



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

Summary of recent developments

- **Simulation:** Initial calculations of single-photon rate / PMT under way
  - WCTE source (6.75 cm radius) must be smaller than SK sources (8-9 cm radii) to fit in CDS
  - Similar gamma spectrum from the source, but with fewer high-energy (> ~4 MeV) gammas per ^{252}Cf decay

- **Construction:** Discussions with a company in Spain to manufacture Ni ball
  - Funding expected to arrive in first quarter of next year
  - **Recent offer: ~12k€ (for Ni ball + rod)**

Current offer:

- **Quote (135 mm diameter sphere):**
  - NiO 7 μm powder, HDPE 90 μm powder
  - Mold for fabrication of sphere in 1 piece
  - Precision mixture of NiO/HDPE masses (better than 2%)
  - Mixture of Araldite adhesive AY103 (80%) + hardener HY956 (20%)
  - Drilling of hole through the diameter
  - Construction of cylindrical rod (10 mm diameter, 140 mm length)
  - Packaging and shipping within peninsular Spain
- **Total:** 12,336.37€

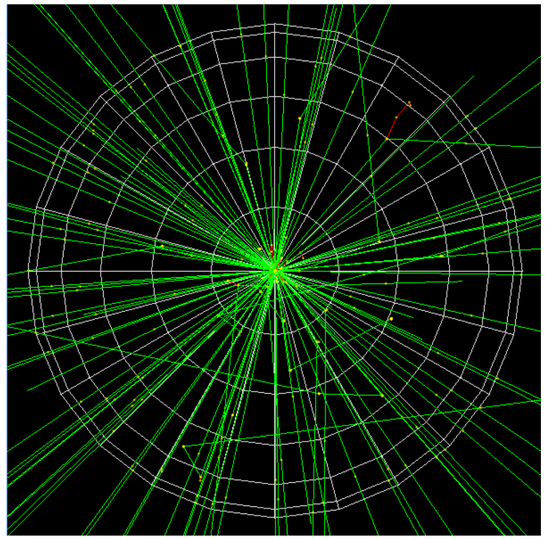
- *It is noted that the budget is highly dependent on the sizes of the NiO and HDPE powders*

Source construction

- Mainly following process for SK source construction
- Several points of discussion:
  - Tolerances in mixture and radius (~1-2%?)
  - Size of the grains of powdered materials?
    - **NiO**: 7-1700 μm
    - **HDPE**: 90-150 μm
  - Radiopurity? (currently aiming for 99.99%)

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 provided by T. Yano (now including Araldite glue and using measured final density)
  - Calculations of single-photon event rate in progress

Simulation: initial source rate calculation

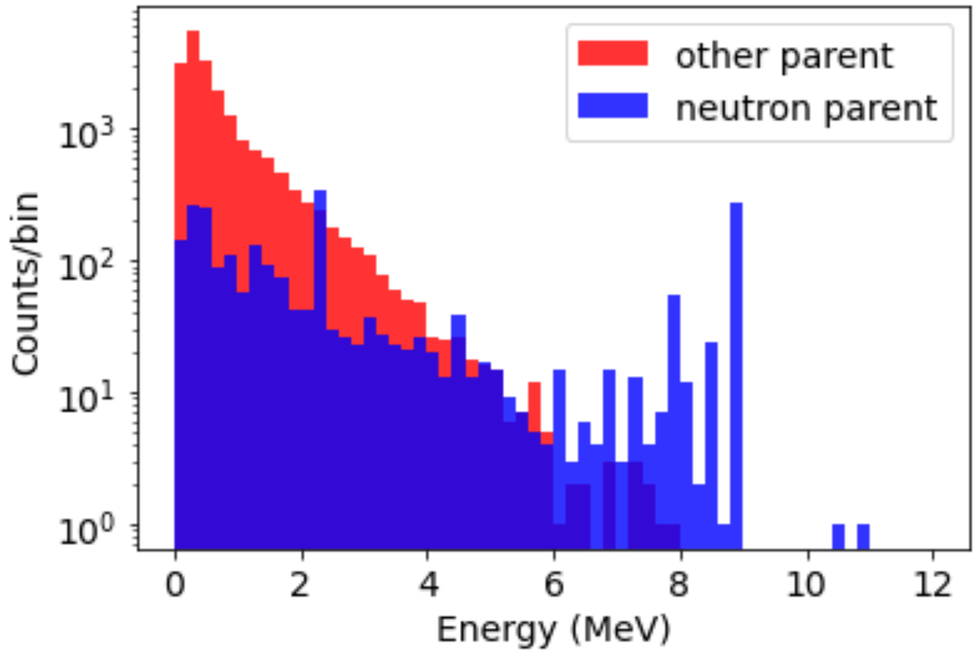
- **Geant4 simulation:**
  1. Simulate ^{252}Cf decays in standalone Geant4 simulation of the source geometry: record spectrum of gammas leaving the source volume
  2. Launch gammas over the relevant range of energies in the WCTE geometry and record the number of photons observed in each PMT
  3. Reconstruct the gamma events in step 2 with BONSAI to characterize reconstruction efficiency
  4. Compute the number of photons recorded in each PMT per ^{252}Cf decay

- *Note that here we perform the rate computation assuming gammas are emitted one at a time, which will not always be the case.*

Simulation: Gammas escaping the source

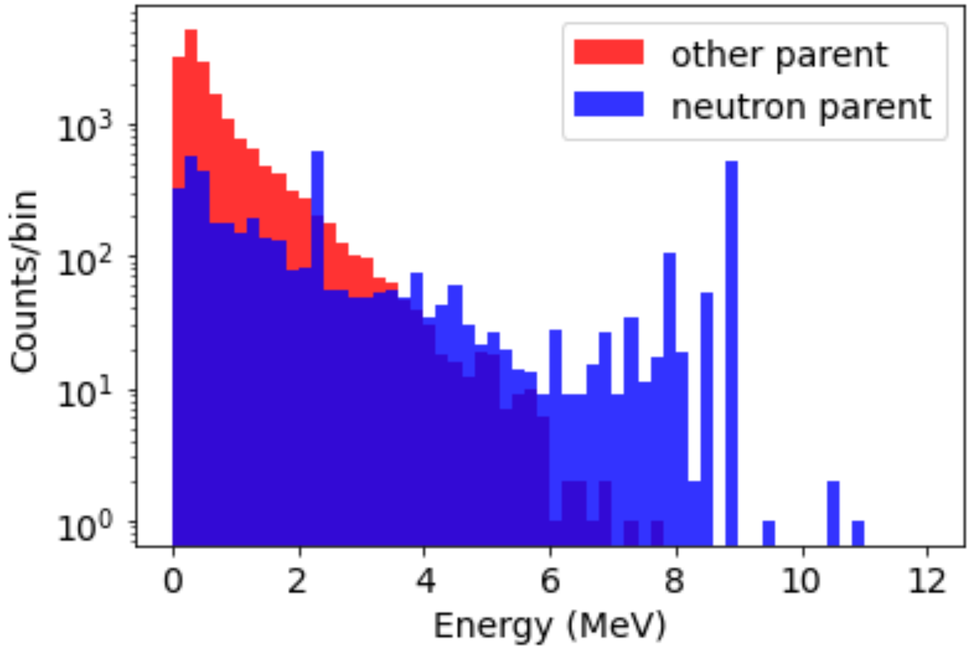
- **R = 7 cm**

```
Other parent events: 19570
Neutron parent events: 2448
```



- **R = 9 cm**

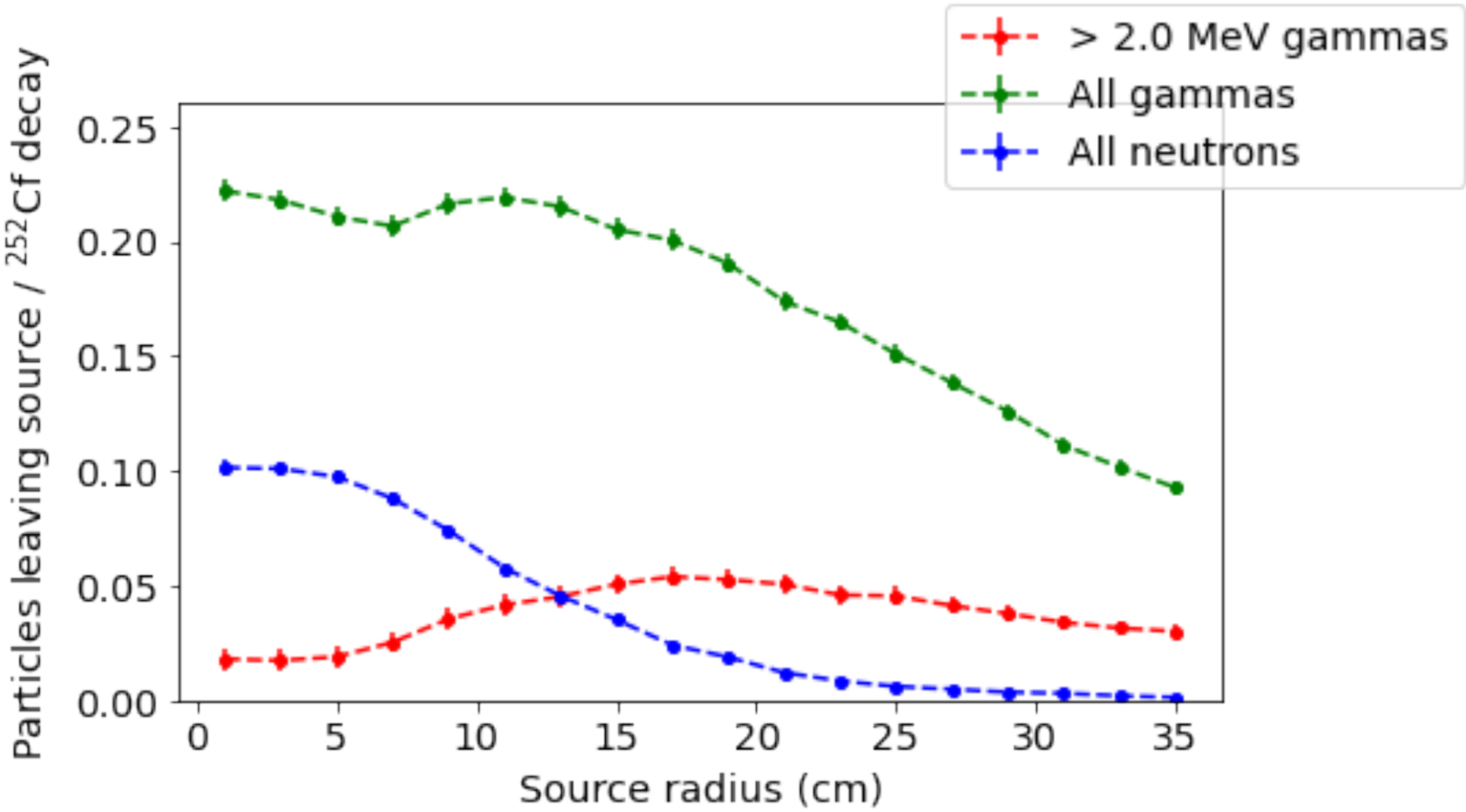
```
Other parent events: 17878
Neutron parent events: 4641
```



- **Fewer gammas at r = 7 cm, but still a considerable amount**

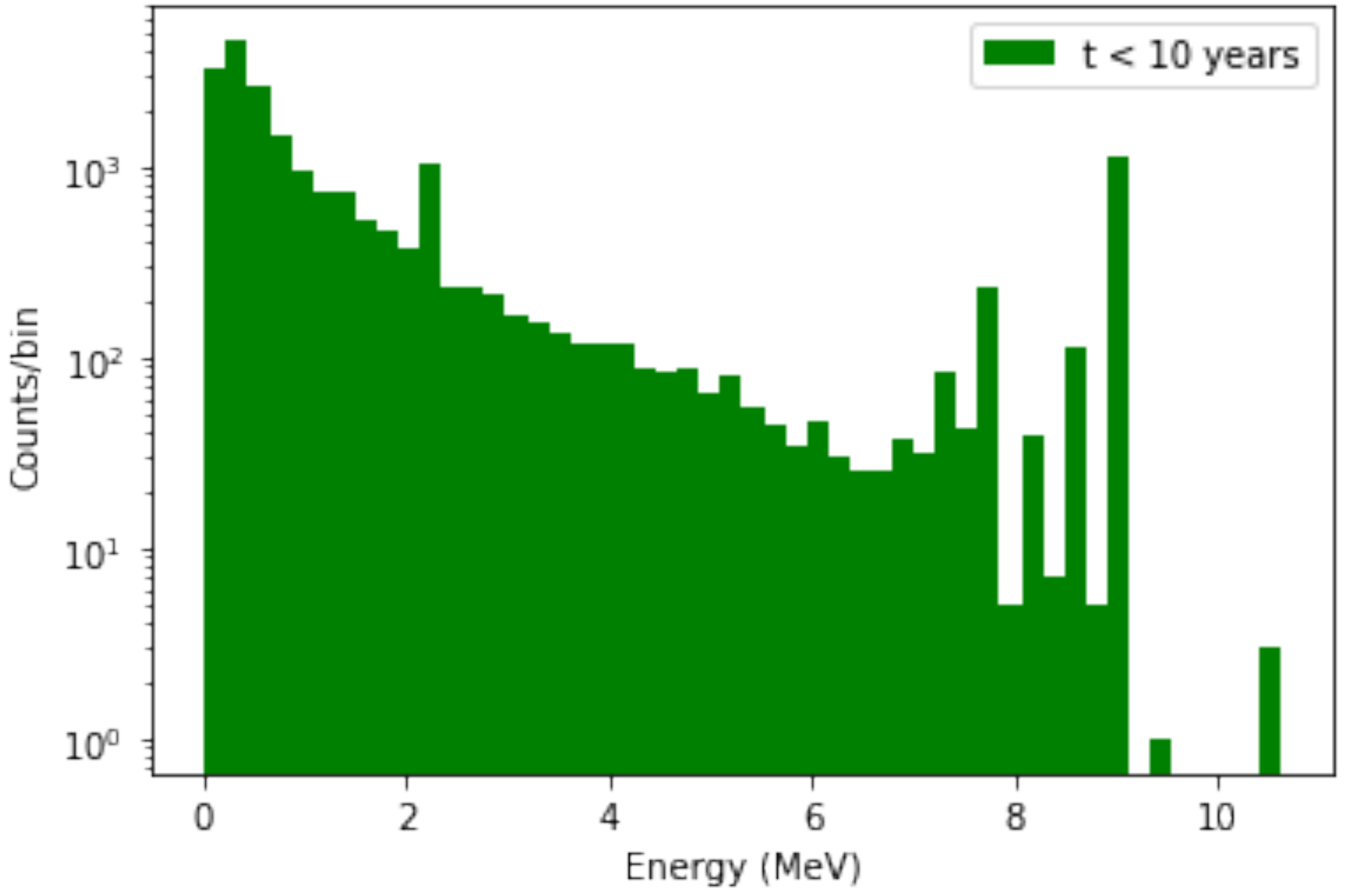
Simulation: Gammas/neutrons escaping the Ni ball

- 10k ^{252}Cf decays launched per radius
- Most gammas are low-energy; nearly 10% of decays give neutrons at source radius of 7 cm



Simulation: Gamma spectrum for r = 6.75 cm

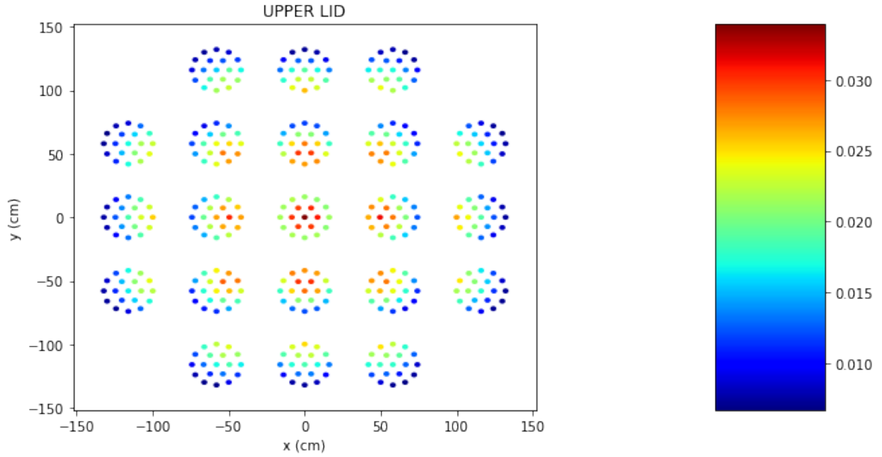
- Spectrum of gammas leaving the source (time cut: decay must have occurred within 10 years)
- 100k total ^{252}Cf decays

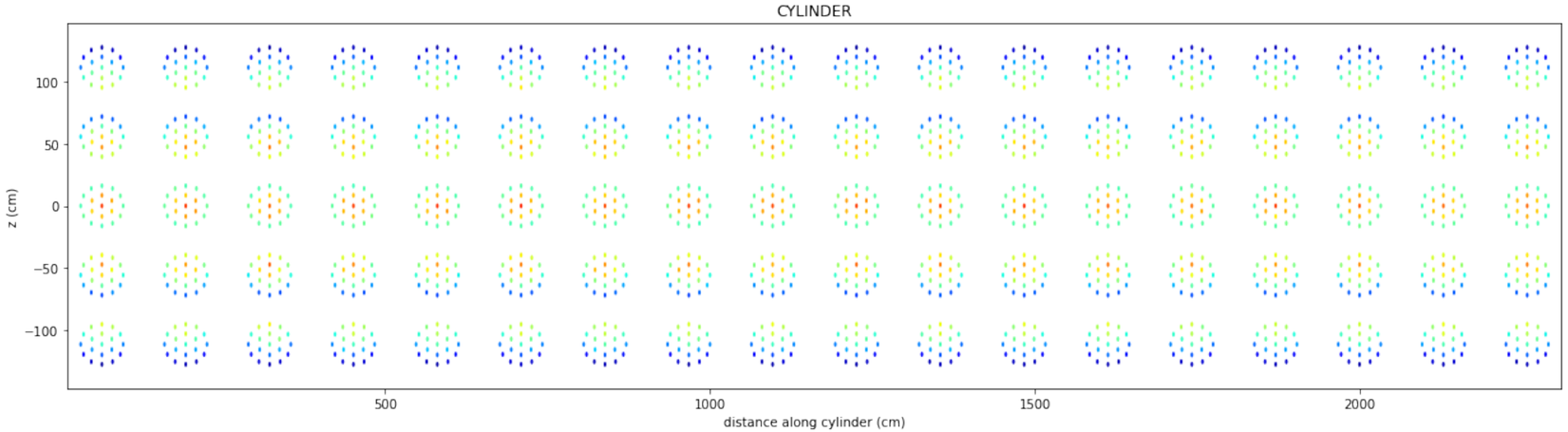


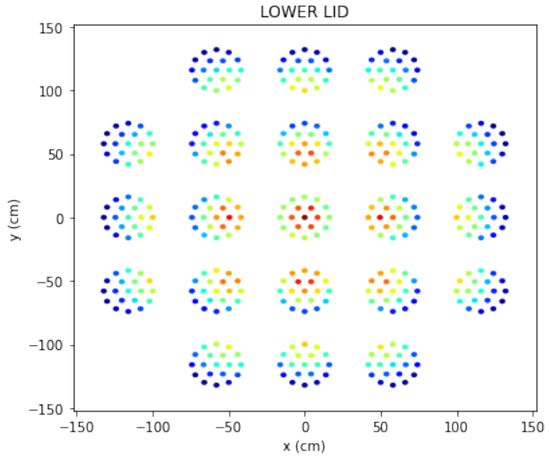
- *Will need to compute the spectrum with higher statistics, as the higher-energy gammas of interest occur much less frequently than the lower-energy gammas, and there seems to be large fluctuations.*

Simulation: Detected photons in WCSim

- Gammas launched with a uniform distribution in energy (0.5-10 MeV) from center of WCTE geometry
- Average number of photons detected per event

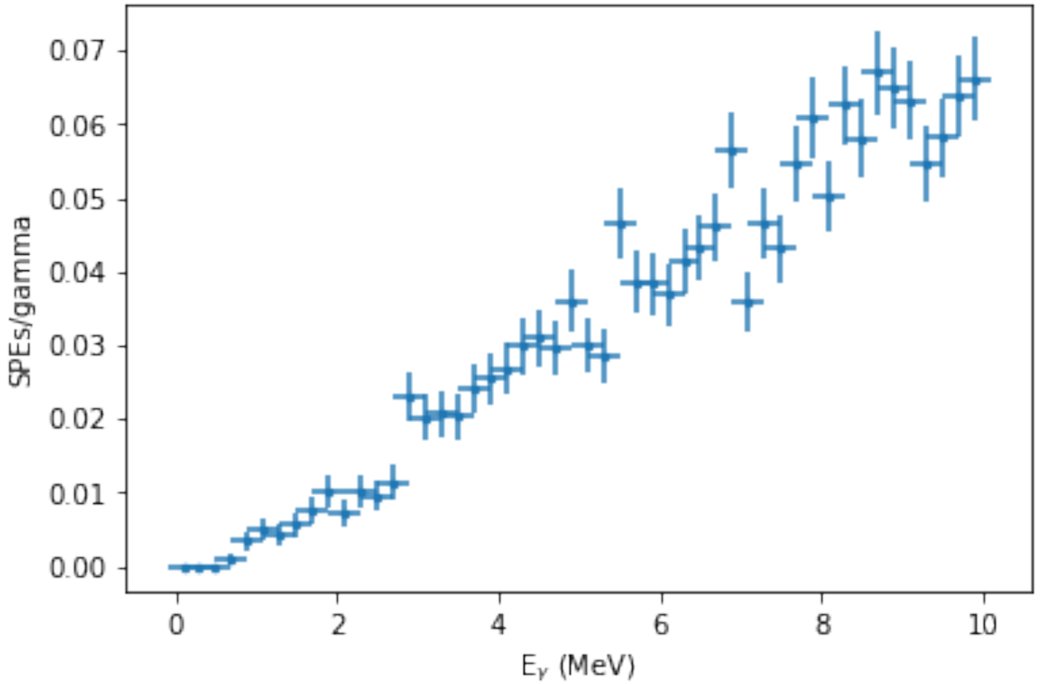






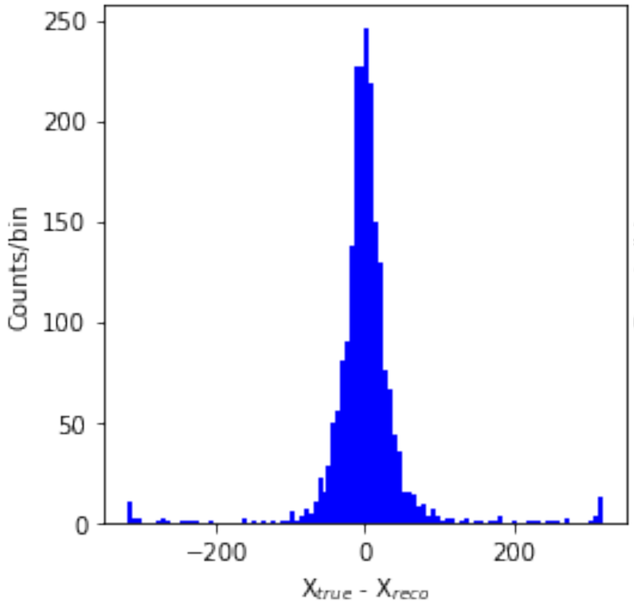
Simulation: Single photon events in WCSim

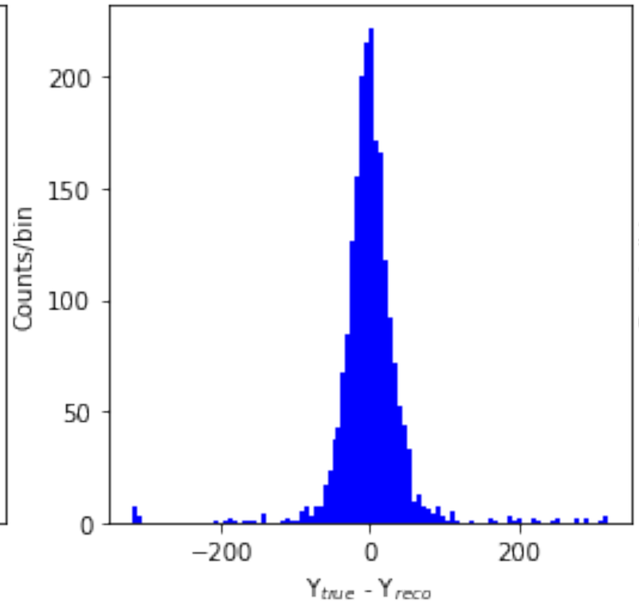
- Gammas launched with a uniform distribution in energy (0-10 MeV) from center of WCTE geometry
- Average number of photons recorded per gamma vs. gamma energy (for a given PMT)

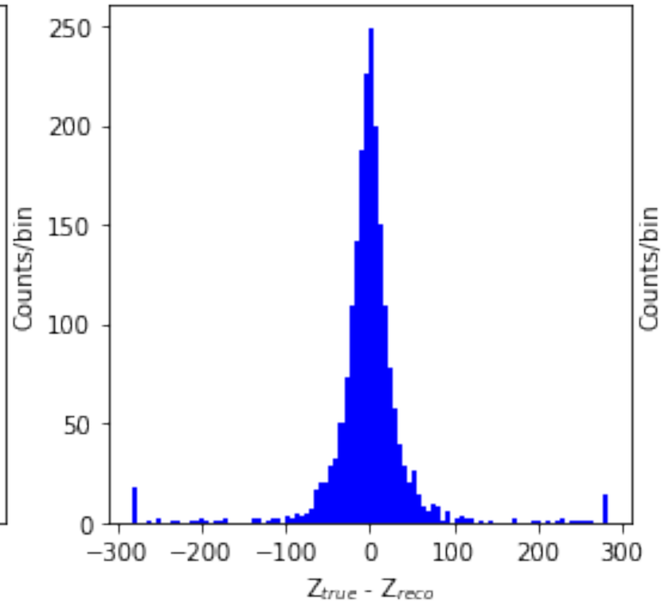


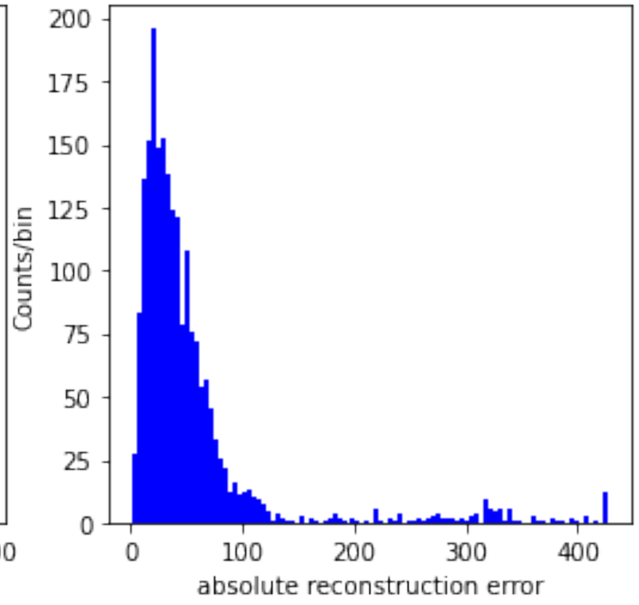
Simulation: reconstruction with BONSAI

- **BONSAI reconstruction**
  - Gammas shot from (0,0,0) with energies between 0 -10 MeV
  - Reconstructed times near ~945 ns?
  - Example below: reconstruction errors (in x, y, z, r) for gammas with energies from 8-8.2 MeV



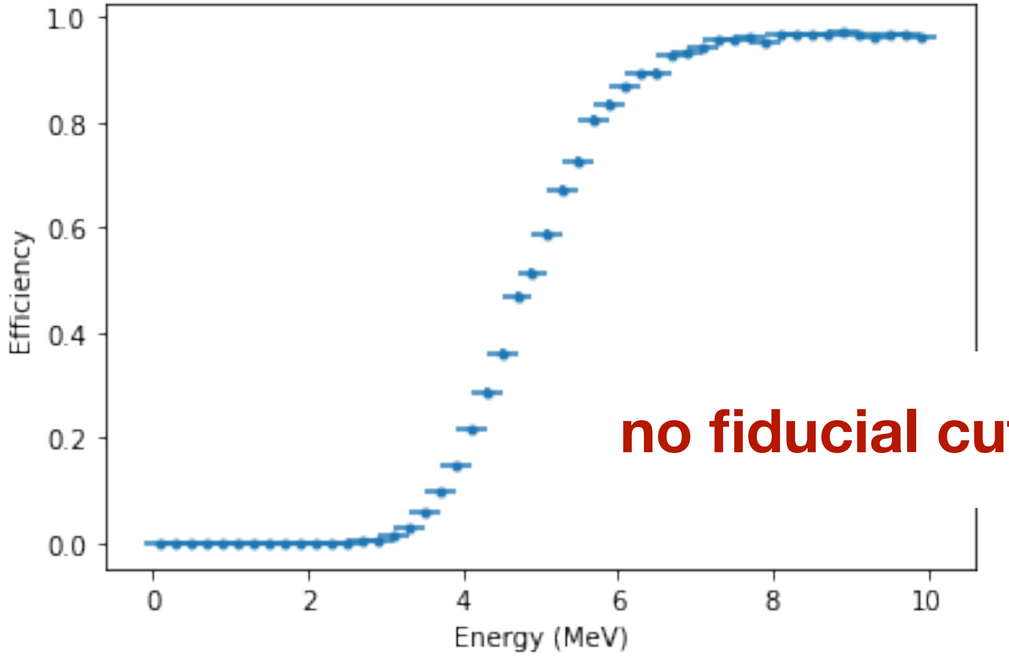




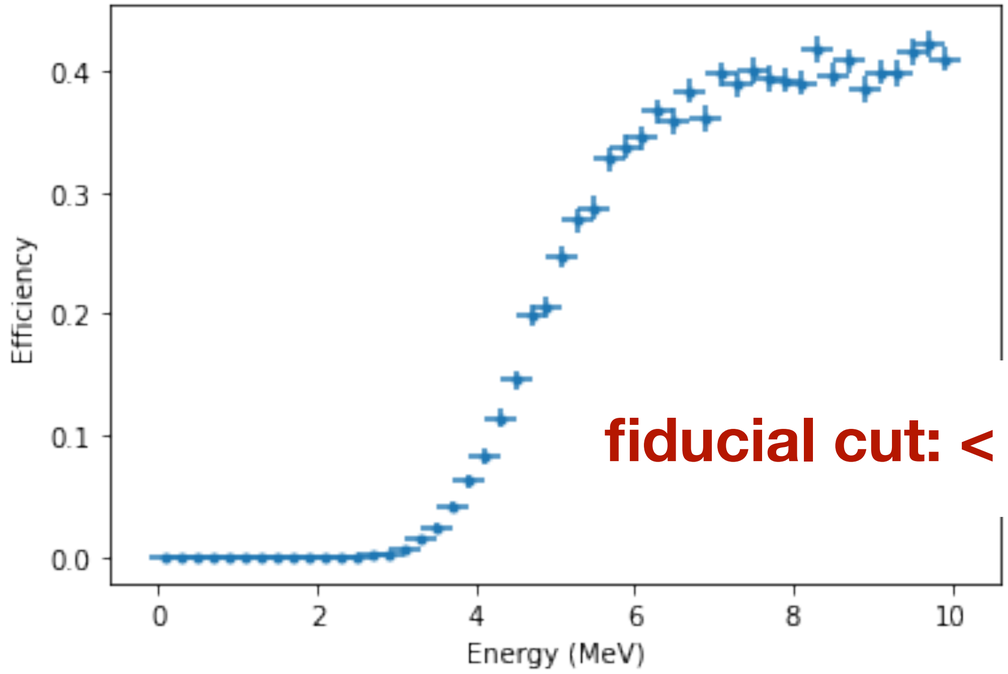


Simulation: reconstruction with BONSAI

- **BONSAI reconstruction efficiency**
  - For each bin:
    (# events “successfully” reconstructed) / (total # of events)
  - Higher energy gammas will be most relevant

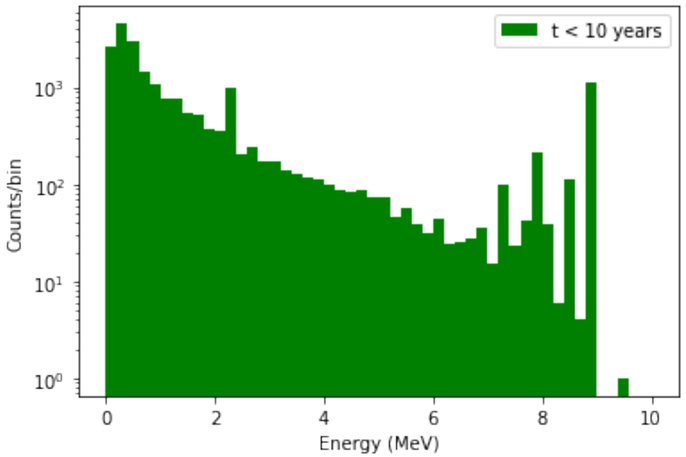


no fiducial cut



fiducial cut: < 30 cm

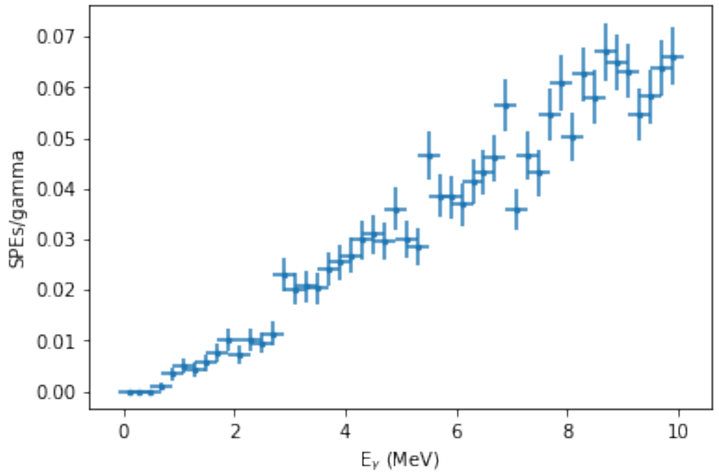
Preliminary photon rate calculation (WCTE)



[source spectrum, 0-10 MeV]

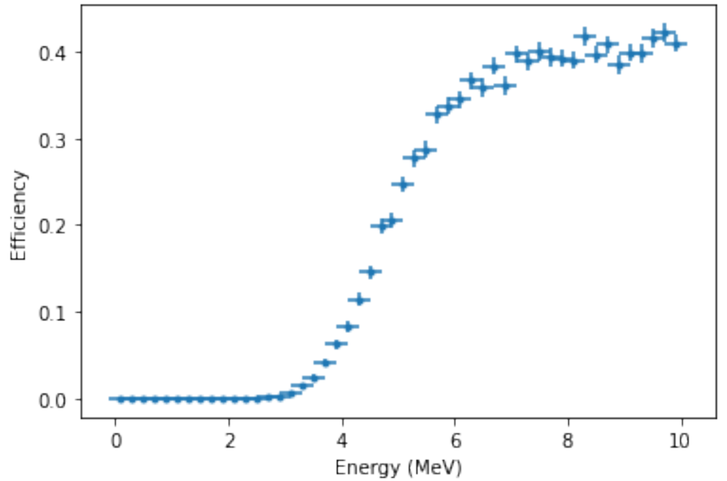
*** divide by 10^5 simulated decays**

X



[photon spectrum]

X

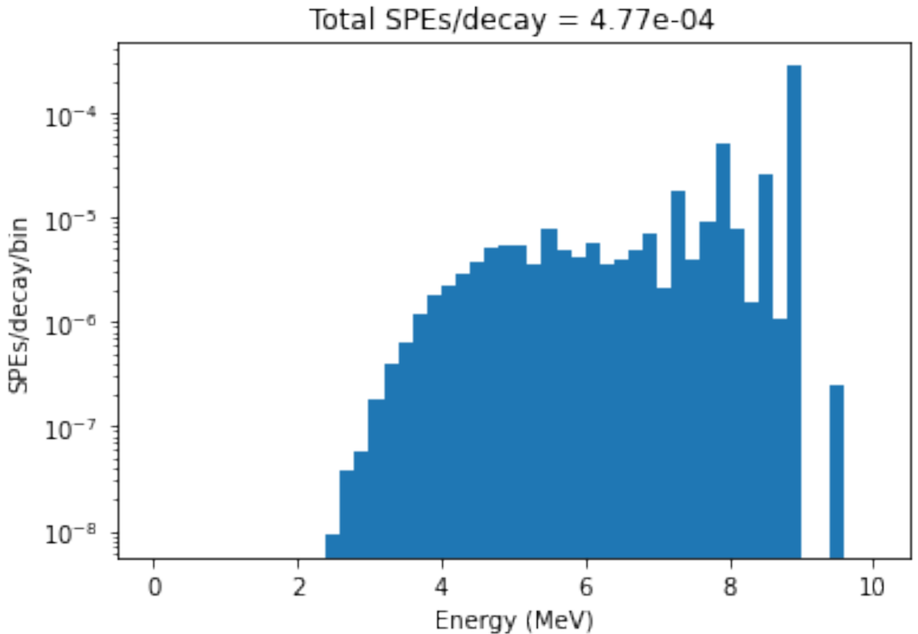


[BONSAI reconstruction efficiency + 30 cm fiducial cut]

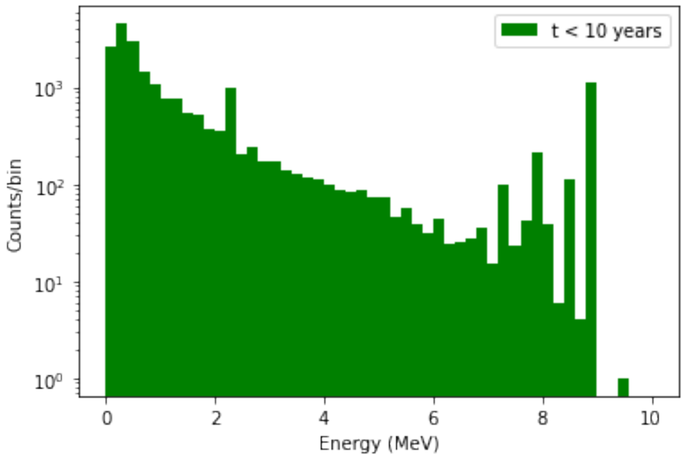
- For PMT with ***maximum*** average photon rate

~5 x 10^{-4} photons/ ^{252}Cf decay

=



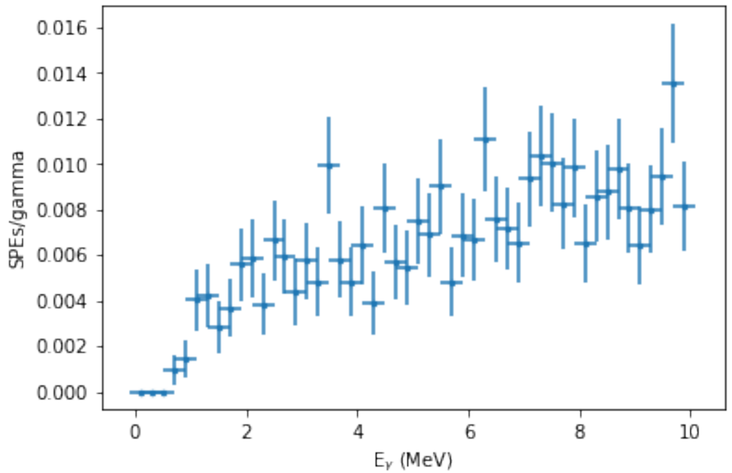
Preliminary photon rate calculation (WCTE)



[source spectrum, 0-10 MeV]

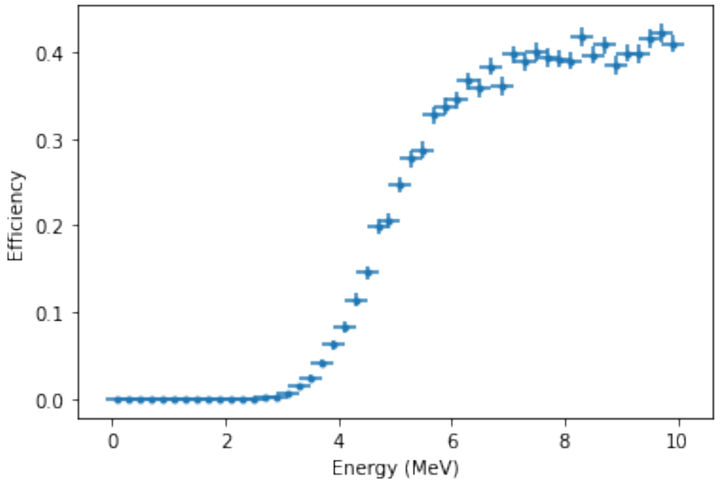
*** divide by 10^5 simulated decays**

X



[photon spectrum]

X

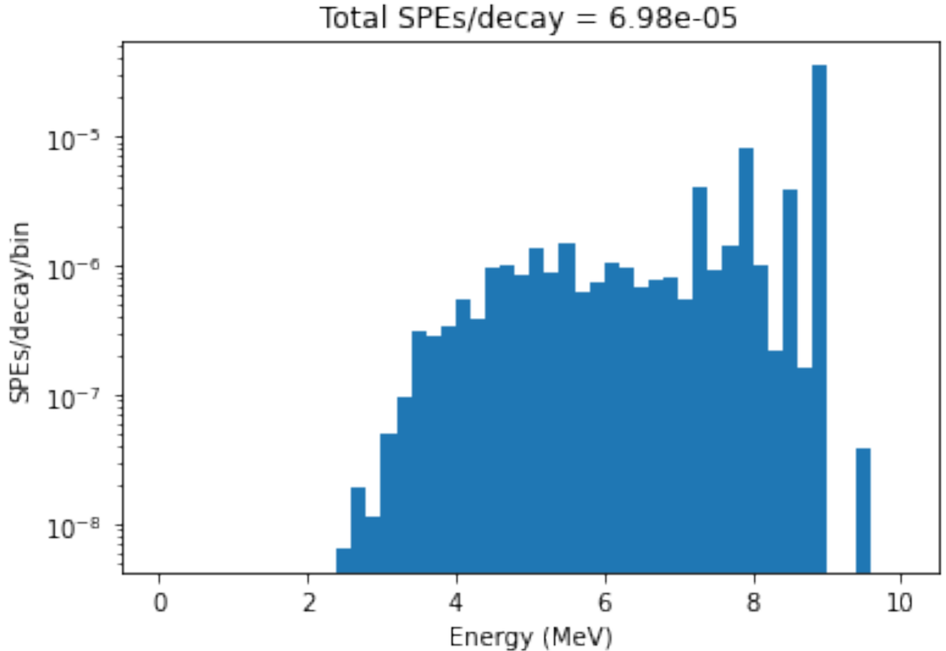


[BONSAI reconstruction efficiency + 30 cm fiducial cut]

- For PMT with ***minimum*** average photon rate

~7 x 10^{-5} photons/ ^{252}Cf decay

=



Preliminary photon rate calculation (WCTE)

- ^{252}Cf source rate —> single photon events

$$\left(\begin{array}{c}\textbf{~[0.5-7] x } 10^{-4} \\ \text{photons/decay}\end{array}\right)\left(\begin{array}{c}\textbf{~3.7 x } 10^{4} \\ \text{decays/(s-μCi)}\end{array}\right)$$

$$= \quad \textbf{~[1.8-26]}\ \text{photons/s}$$

(per μCi of ^{252}Cf activity)

* for SK activity of 8 μCi, approx. **14-208 photons/s,** depending on PMT

Summary

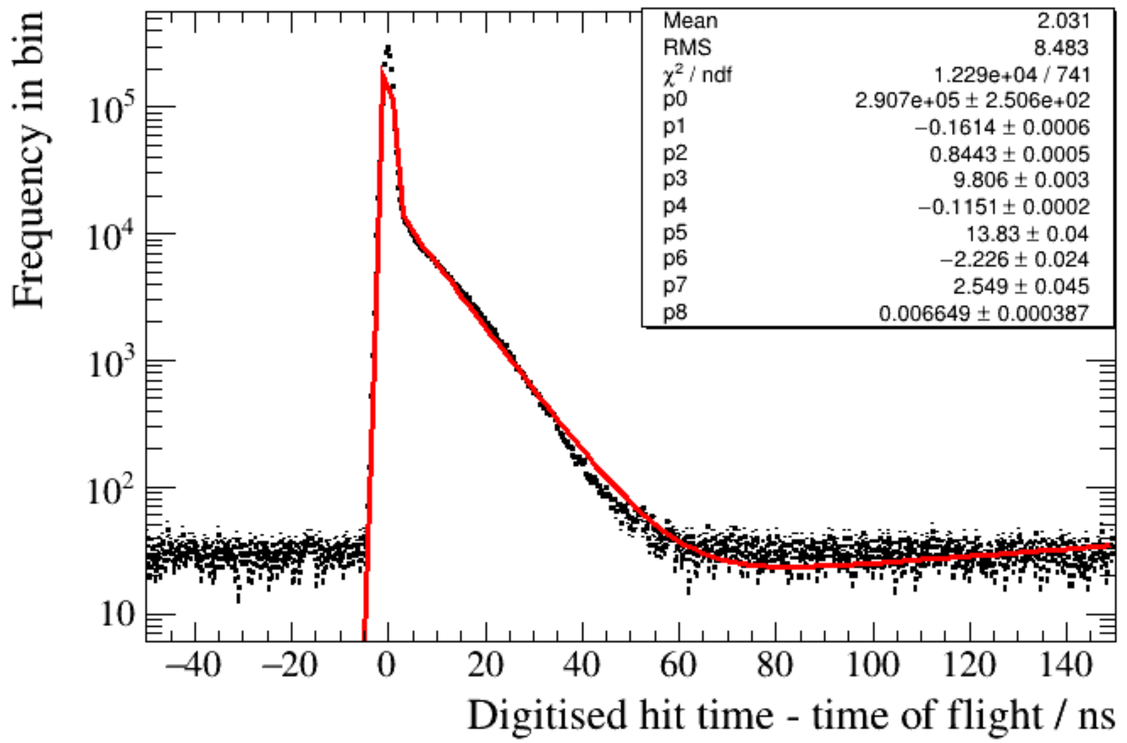
- Calculations based on a Geant4-based NiCf source simulation + WCSim
  - Should expect a spectrum similar to the SK source
  - Source will emit a significant number of neutrons
  - Calculations require more statistics, and consideration of multi-gamma events
- Initial offer on source construction obtained

- Considering also an AmBe neutron source
  - Similar to SK neutron source (AmBe + BGO scintillators) but with active tagging
  - Will require significant study to design readout of tagger signal (fibers carrying scintillation photons to be transported out through the CDS?)

Backup

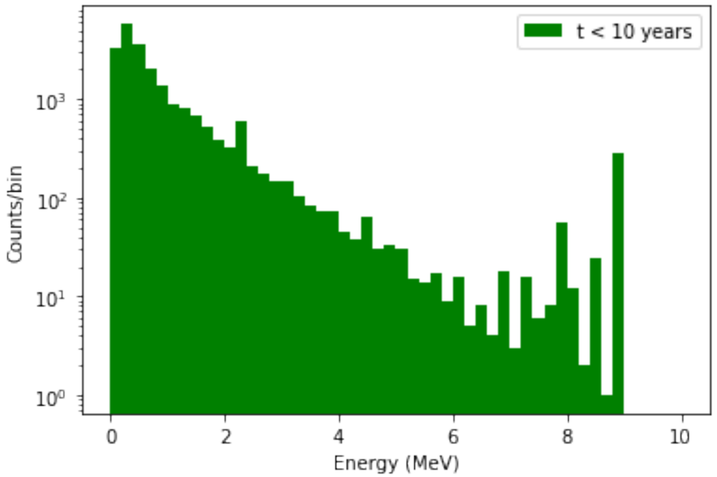
Source studies: reconstruction with BONSAI

- **BONSAI tuning**
  - WCTE geometry
  - “NoTrigger” option not available in WCTE/WCSim (though appears to be present in WCSim/WCSim repository)
  - Adjusted digit time by hand to get peak near zero (correct?)



Preliminary photon rate calculation (WCTE): r = 7 cm

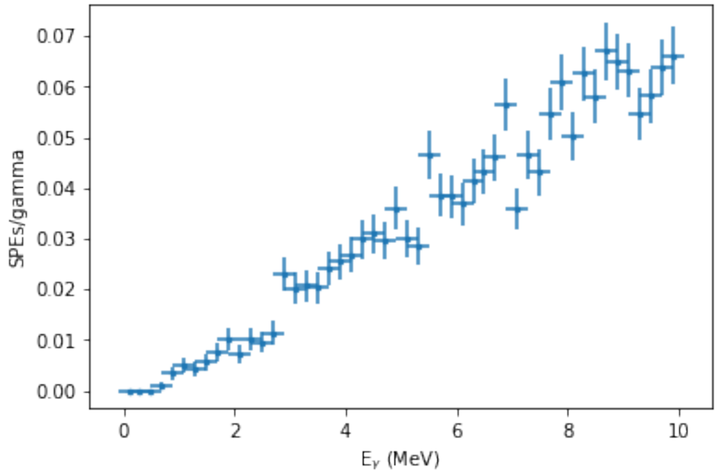
- For PMT with ***maximum*** average photon rate



[source spectrum, 0-10 MeV]

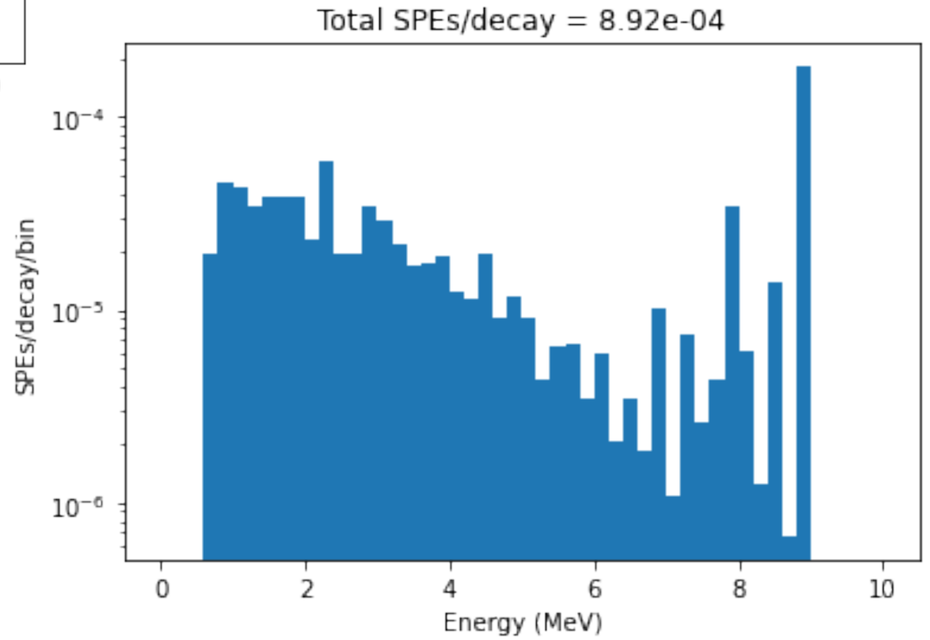
*** divide by 10^5 simulated decays**

X



[photon spectrum]

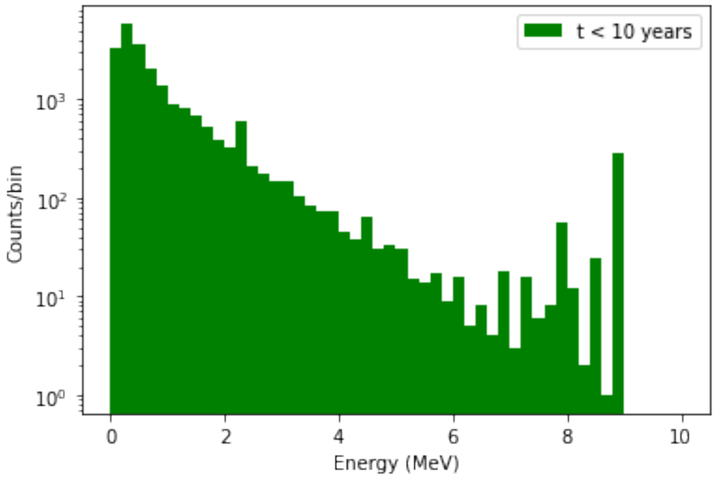
=



~9 x 10^{-4} photons/ ^{252}Cf decay

Preliminary photon rate calculation (WCTE): r = 7 cm

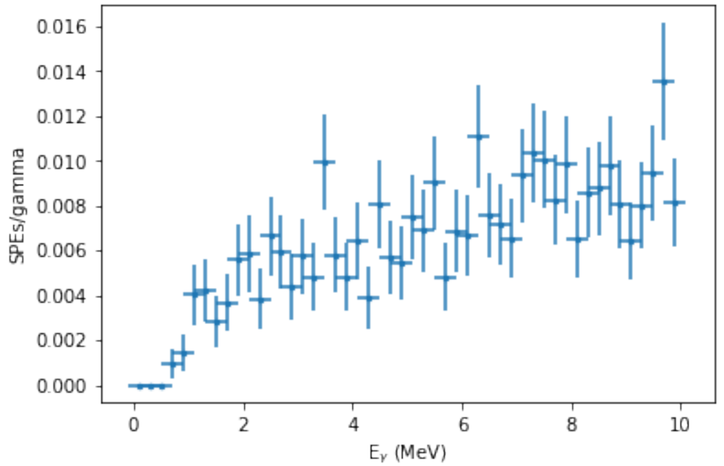
- For PMT with ***minimum*** average photon rate



[source spectrum, 0-10 MeV]

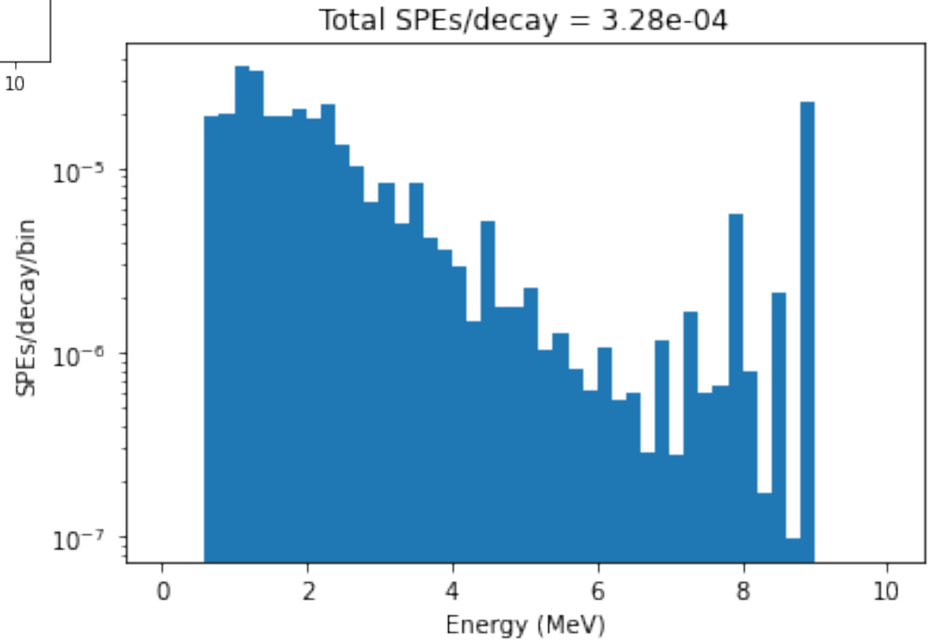
*** divide by 10^5 simulated decays**

X



[photon spectrum]

=



~3 x 10^{-4} photons/ ^{252}Cf decay