UNIVERSITY OF SUSSEX

DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE-FD Geometry and Radiological neutrons

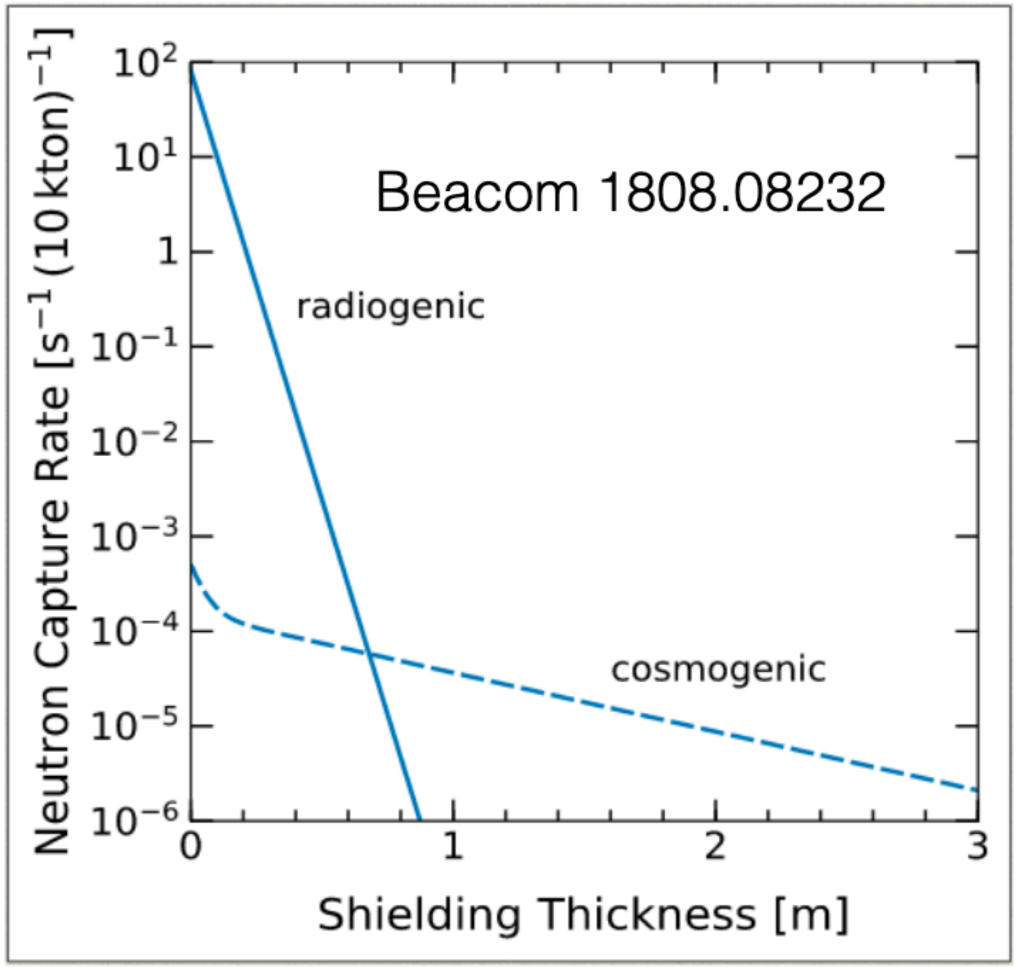
Aran Borkum

Overview

- **Radiological backgrounds in the DUNE far detector**
  - Where do they come from
  - What are the most prominent backgrounds
- **What can we expect to see in the far detector**
  - Discussion of neutron capture rates from J. Beacom and co. 1808.08232
- **Issues with the old simulation**
  - Why the 1x2x6 is just wrong
  - Issues with material definitions
- **Constructing a new accurate geometry**
  - Writing GDML with GEGEDE
- **Neutron capture rate in the new geometry**

Radiological backgrounds at the DUNE Far Detector

- **Main sources of radiological backgrounds**
  - The cavern walls, rock (^{238}U, ^{232}Th)
  - The concrete and shotcrete (^{238}U, ^{232}Th)
  - Detector support structure (^{238}U, ^{232}Th, $^{56}Fe(\alpha, n)$, $^{54}Fe(\alpha, n)$)
- **Other subdominant source**
  - ^{222}Rn produces α's, α's lead to $^{40}Ar(\alpha, n)$
  - Fibre glass insulation (^{238}U, ^{232}Th)
  - Cryostat steel (^{238}U, ^{232}Th, $^{56}Fe(\alpha, n)$, $^{54}Fe(\alpha, n)$)
  - CuBe wires $Be(\alpha, n)$
  - APA steel (^{238}U, ^{232}Th)
- **Cosmological neutrons**
  - Subdominant rate, however a potentially high multiplicity

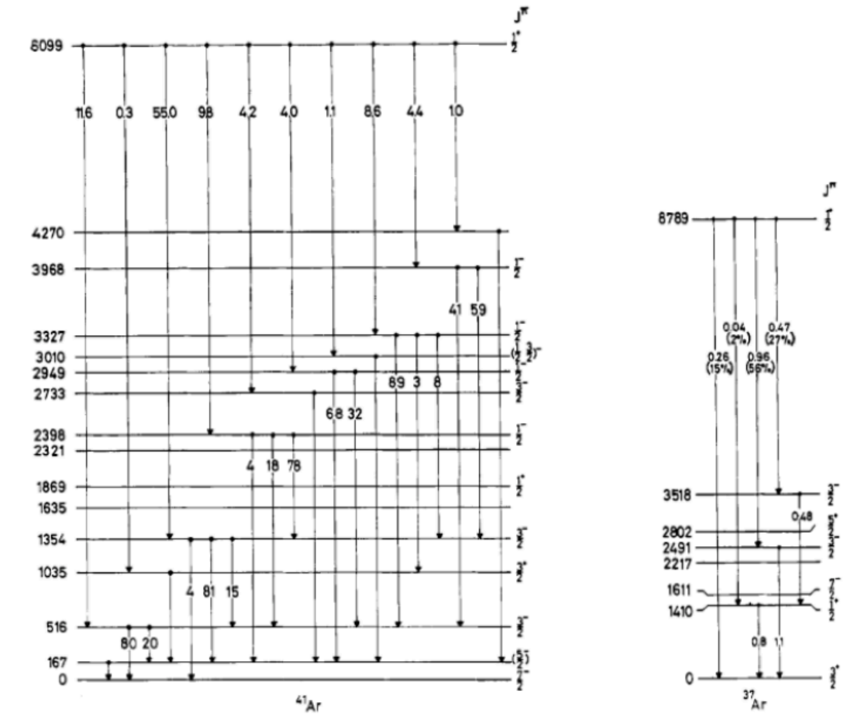


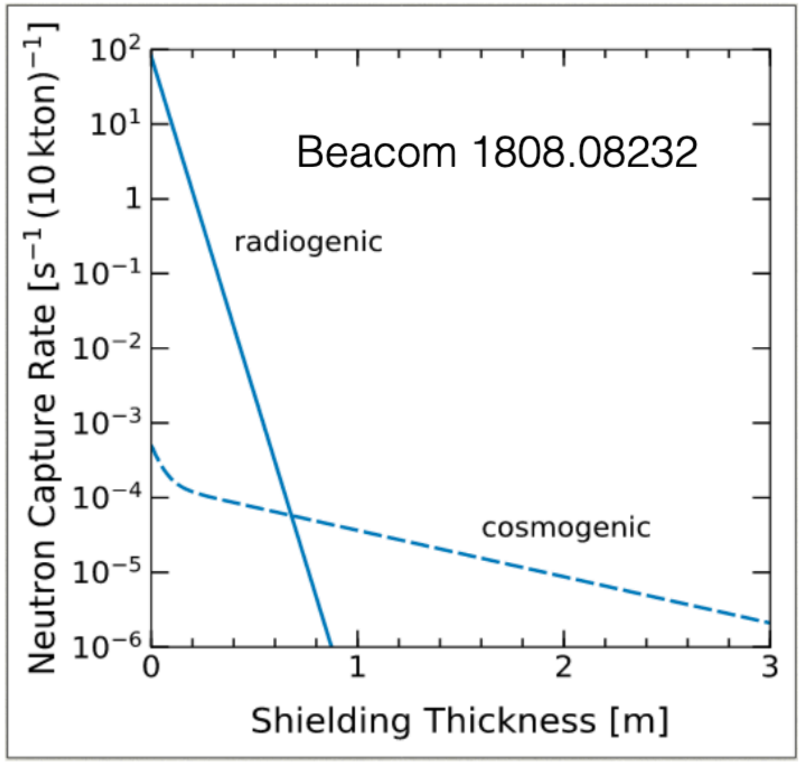
Neutron expectation at the far detector

- **Neutrons in LAr**
  - Neutrons can travel anywhere from 30-100m in LAr
  - If captured on LAr photons with a combined energy of 6.1 or 8.8 MeV are released depending on Argon isotope
  - This can look a lot like supernova neutrinos which have energies in the 10 MeV range

- **Neutron capture rate**
  - J. Beacom predicts a radiological neutron capture rate of 81 Hz
  - This is based on a FLUKA simulation and a simple geometry for the 10kt module

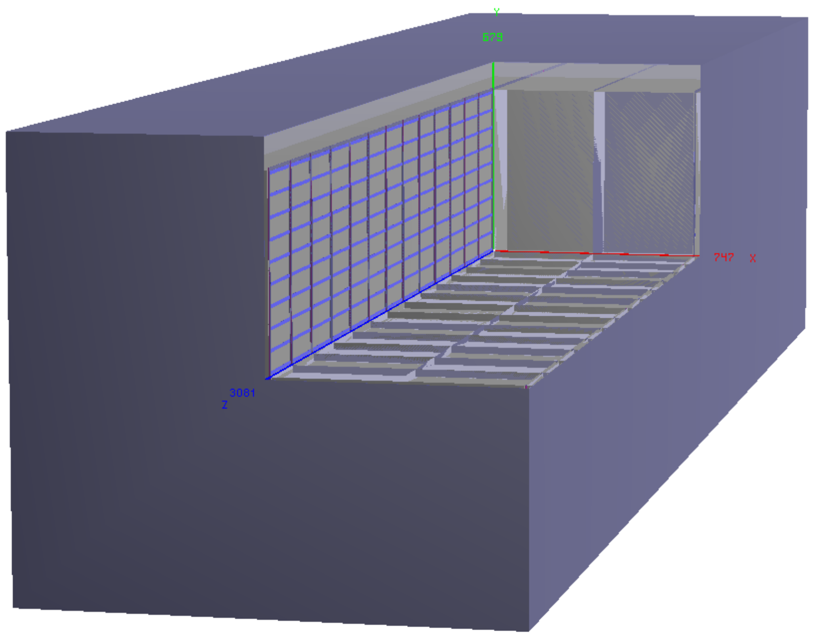
- **Neutron shielding**
  - Hydrogen rich molecules will happily eat neutrons
  - Obvious choice for shielding is then water
  - J. Beacom shows roughly and order of magnitude mitigation per 20cm of water shielding
  - This works in an ideal case but not necessarily a physical solution



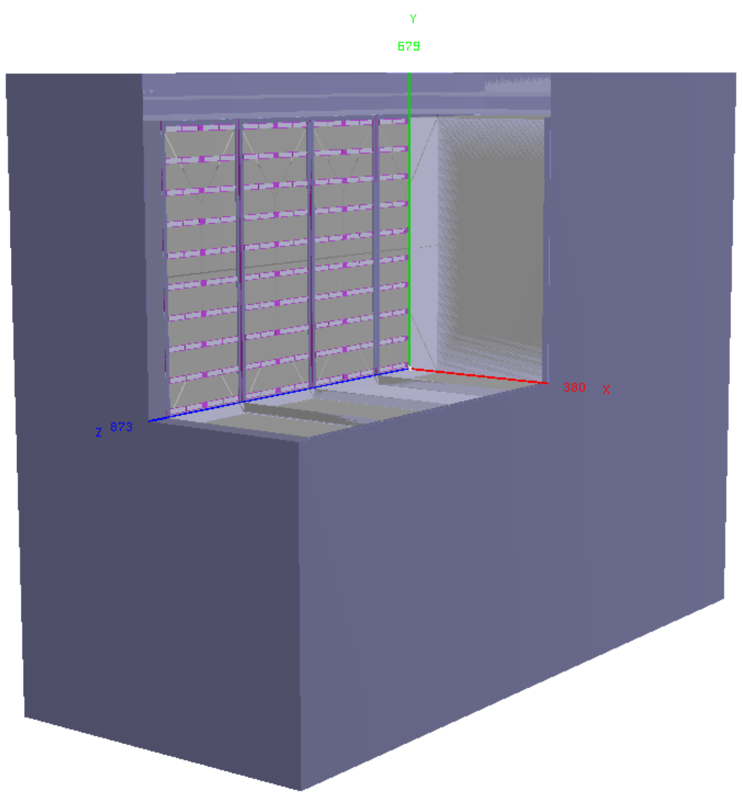


Radiological simulations in LArSoft

- **Issue with the geometry**
  - Most simulation fhicl files (and subsequently most of the MCC11 files) are based on the 1x2x6 workspace geometry
  - This is fine for most applications but not for radiological simulations
  - The production regions are very strange and any capture result is not trivially scalable



- **Full 10kt geometry in LArSoft**
  - The full 10kt geometry exists in LArSoft but is very basic
  - There are some very suspect material definitions, eg the steel support structure is defined as a uniform layer of an air steel mixture



- **Two solutions**
  - Break down the 1x2x6 simulation into separate parts and try and stitch them together to get a more accurate simulation
  - Build a new geometry that is more physically accurate and integrate that into LArSoft

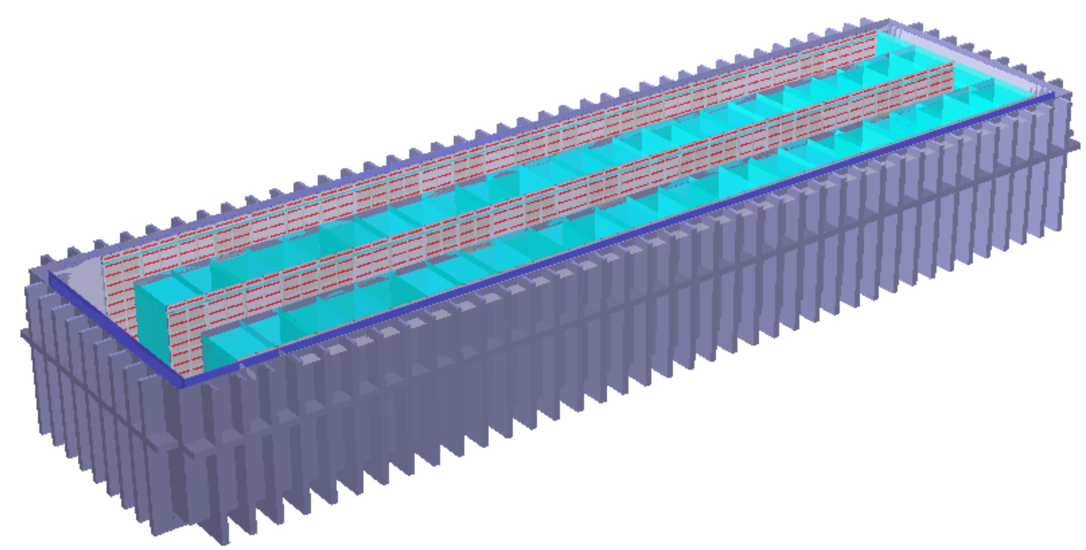
New DUNE FD Geometry

- **Development in GEGEDE**
  - Python module (way more friendly than the previous Perl scripts)
  - Build is parameterised and adjustable with config file
  - Hierarchal structure so outer elements have to fit around inner elements

```
[Cryostat]
subbuilders          = ['TPC']
class                = duneggd.larfd.Cryostat.CryostatBuilder
membraneThickness    = Q('0.5in')
cathodeThickness     = Q('0.016cm')
nAPAs                = [1, 2, 6]
# nAPAs                = [3, 2, 25]
outerAPAs            = False
#outerAPAs             = True
sideLAr              = Q('15cm')
APAToFloor           = Q('49.2cm')
APAToGAr             = Q('40.7cm')
APAToUpstreamWall    = Q('301.2cm')
APAToDownstreamWall = Q('49.2cm')
```

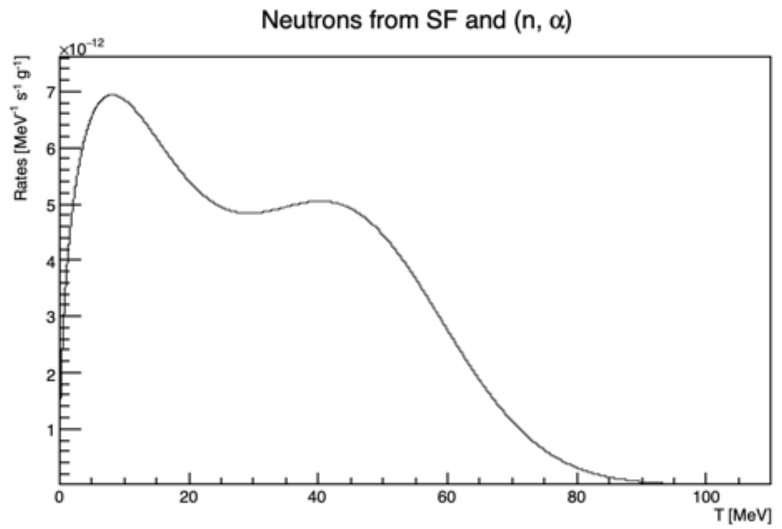
- **Possibility for exotic geometries**
  - As mentioned 1x2x6 results aren't trivially scalable
  - One could only build volTPCActives where you want them in the full 10kt if desired

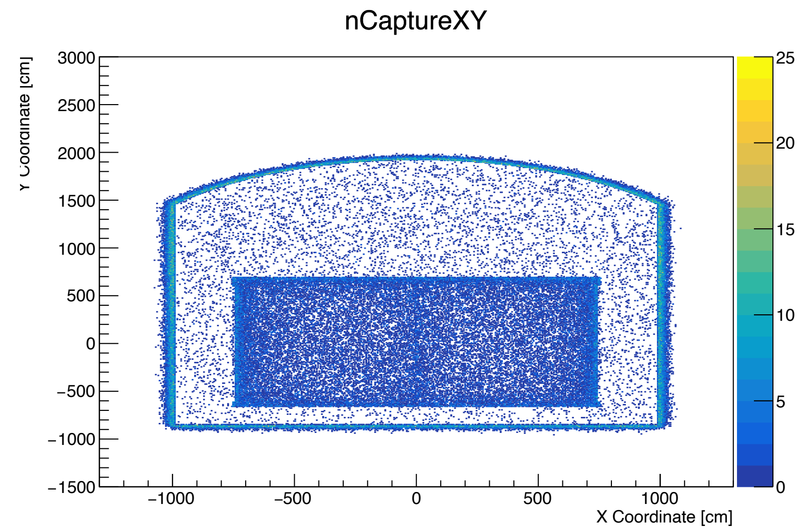
- **Addition of new volumes**
  - Theoretical shielding could be applied to the detector
  - Basic water shielding has already been explored

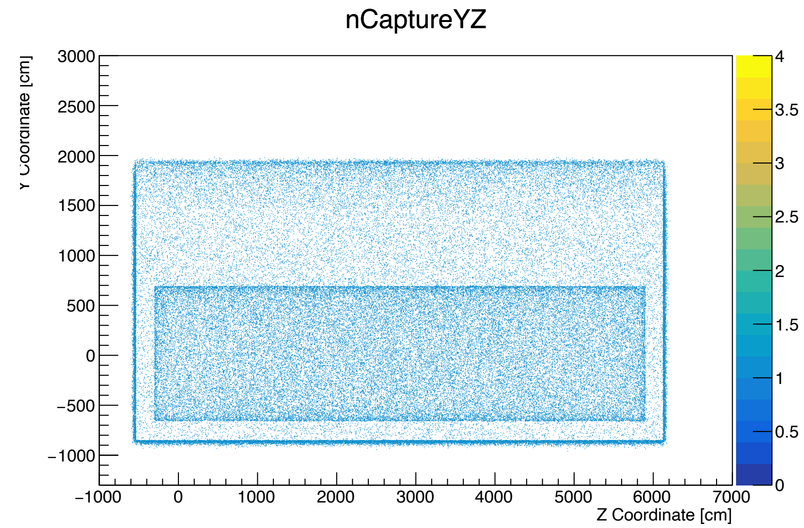


Neutron capture in new geometry Step 1: Mimic the Beacom paper

- **Simplest situation**
  - Generate neutrons on the outside the cryostat
  - Neutron rate used is 7.6×10^{-6} Bq/cc
  - Production energy spectrum shown (right)
  - Count captures on argon
  - Get capture rate
- **Simulation configuration**
  - Cryostat in subbed version of detector cavern
  - No steel support structure
  - No Insulation layers
  - Neutrons generated on the walls of the snubbed cavern

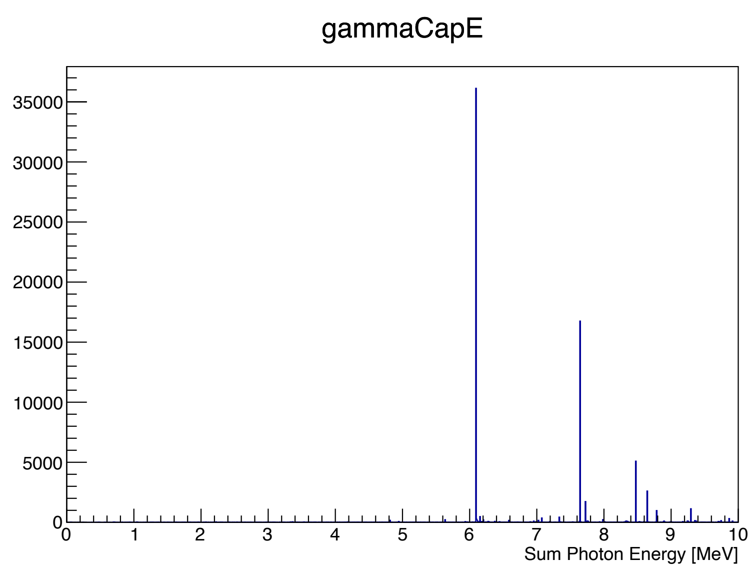


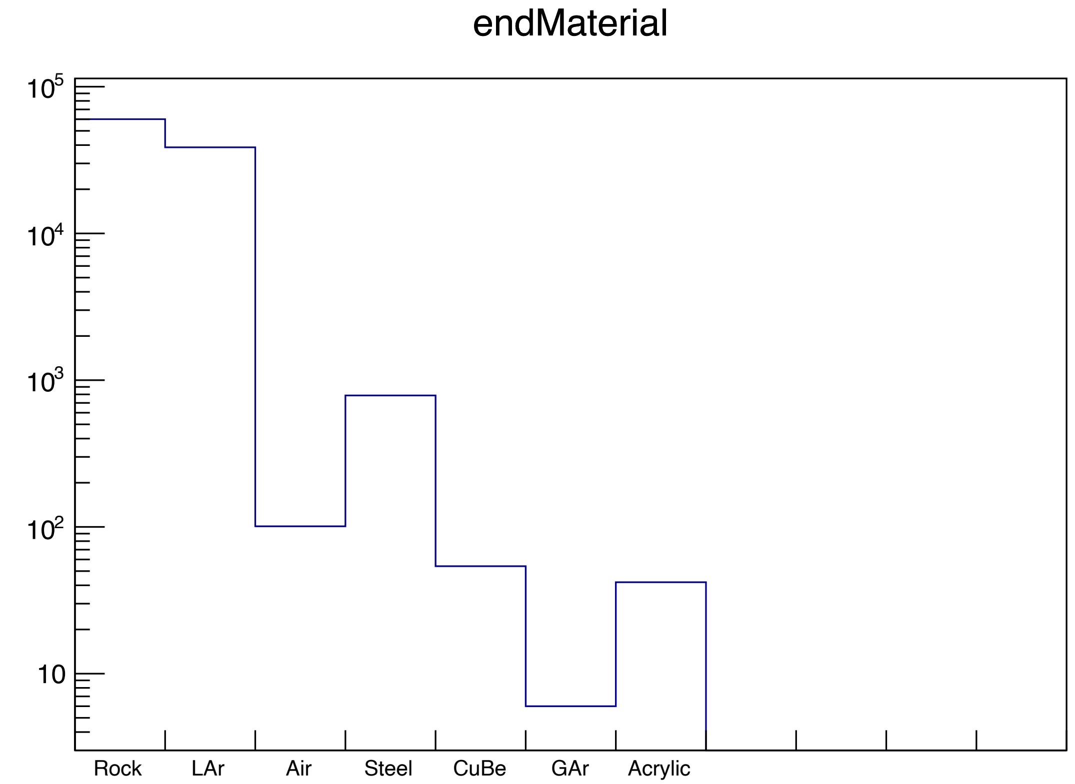


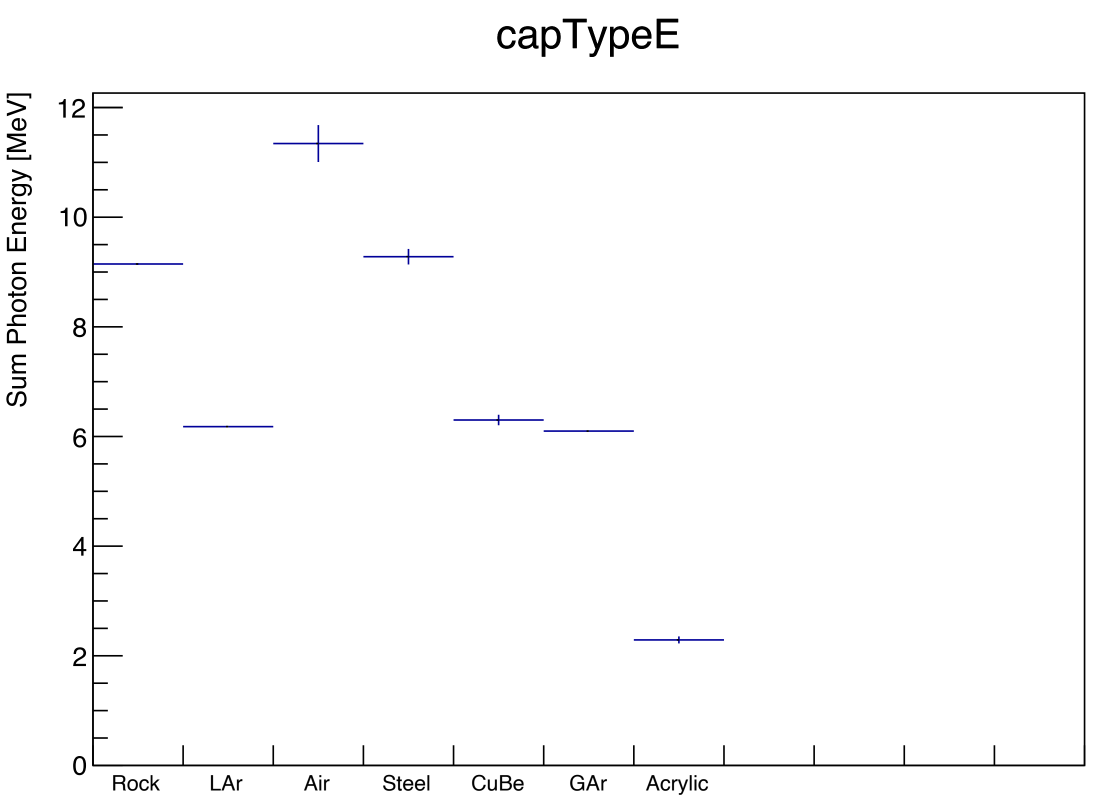


Neutron capture in new geometry
Step 1: Results

- **Capture materials**
  - Dominant capture material is rock
  - Second most dominant material is LAr
  - You can see the energy emissions post capture and the materials they correspond to
- **Capture rate in LAr**
  - Number of primary neutrons: 104564
  - Number of captures on LAr: 38627
  - Radiological neutron capture rate: 82 Hz
- **Take aways**
  - This is in very good agreement with 1808.08232
  - How will this change with using the proper cavern dimensions?
  - Now we continue to add layers of the detector



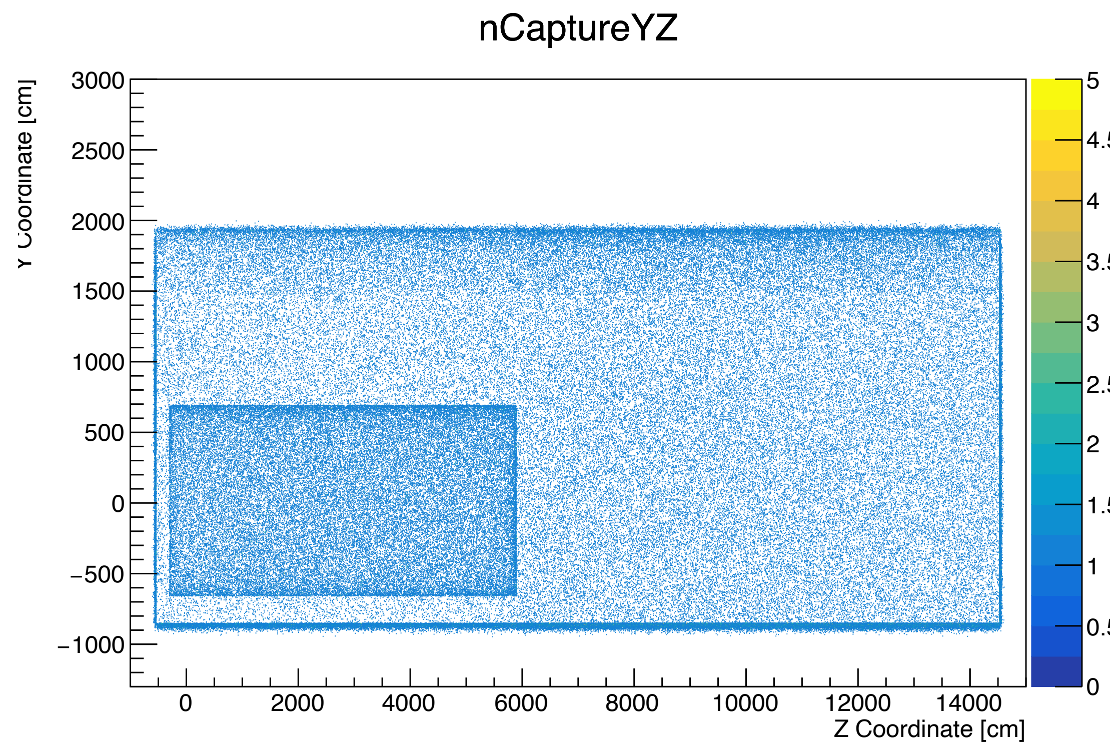


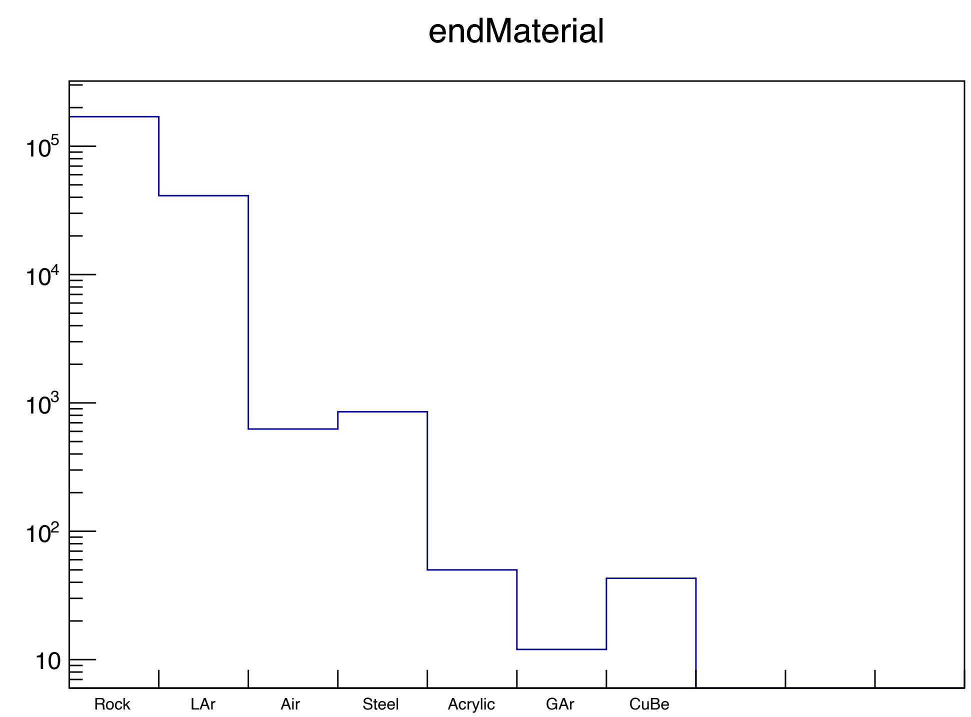


Neutron capture in new geometry
Step 2: correct cavern geometry

- **True cavern geometry**
  - The FD cavern will have ~84m of airspace when only one module is in there
  - To what extent does this effect the neutron capture rate?

- **Results**
  - Because of all the empty space considerably more neutrons die on the wall of the cavern
  - Number of primary neutrons: 236236
  - Number of captures on LAr: 41203
  - Radiological neutron capture rate: 39 Hz
  - Capture rate decreases by ~50%

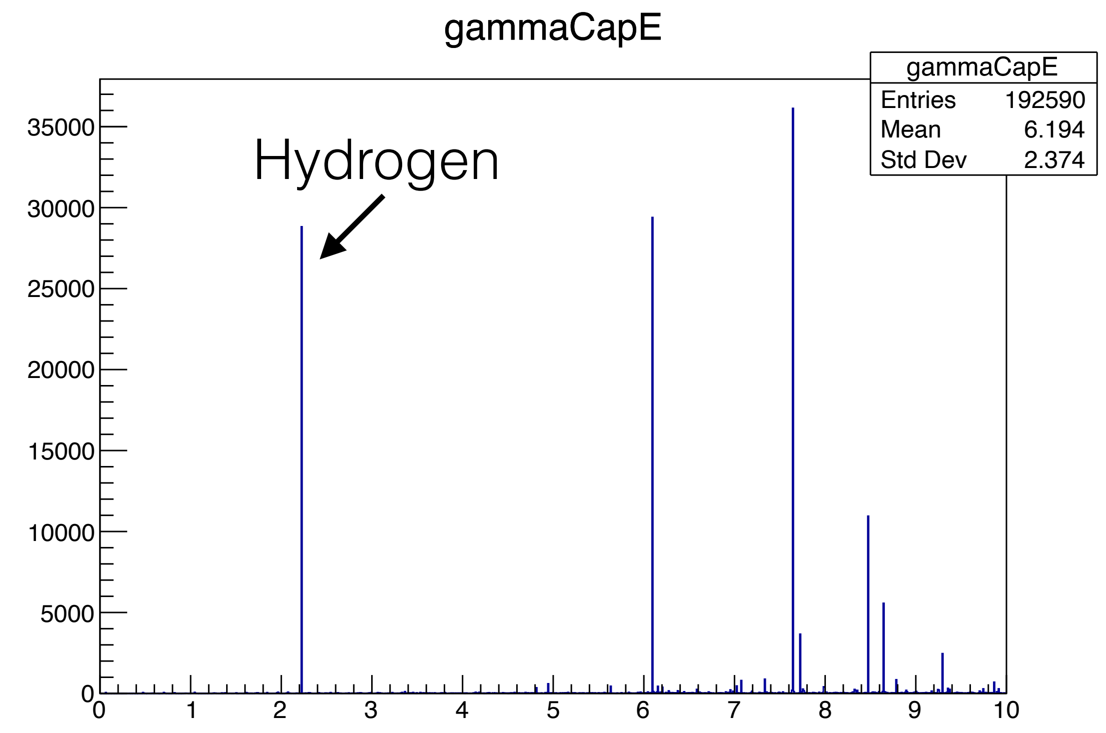


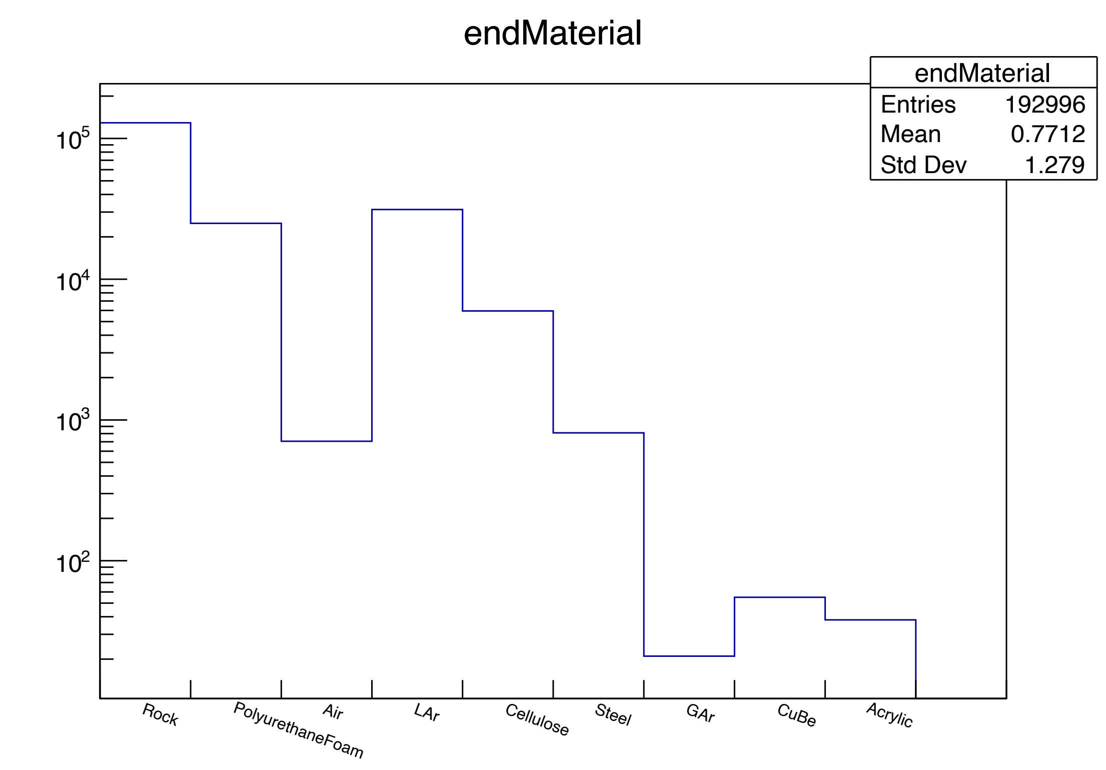


Neutron capture in new geometry
Step 3: Add the insulation layers

- **Insulation around the cryostat**
  - There are layers of ply wood and polyurethane around the cryostat
  - The ply wood is approximated as cellulose
  - Both of these materials are hydrogen rich so we can expect some neutron shielding

- **Results**
  - Besides rock the dominant capture materials are now LAr, Polyurethane and Cellulose
  - Number of primary neutrons: 233949
  - Number of captures on LAr: 31267
  - Radiological neutron capture rate: 30 Hz
  - Capture rate decreases by a further ~25%

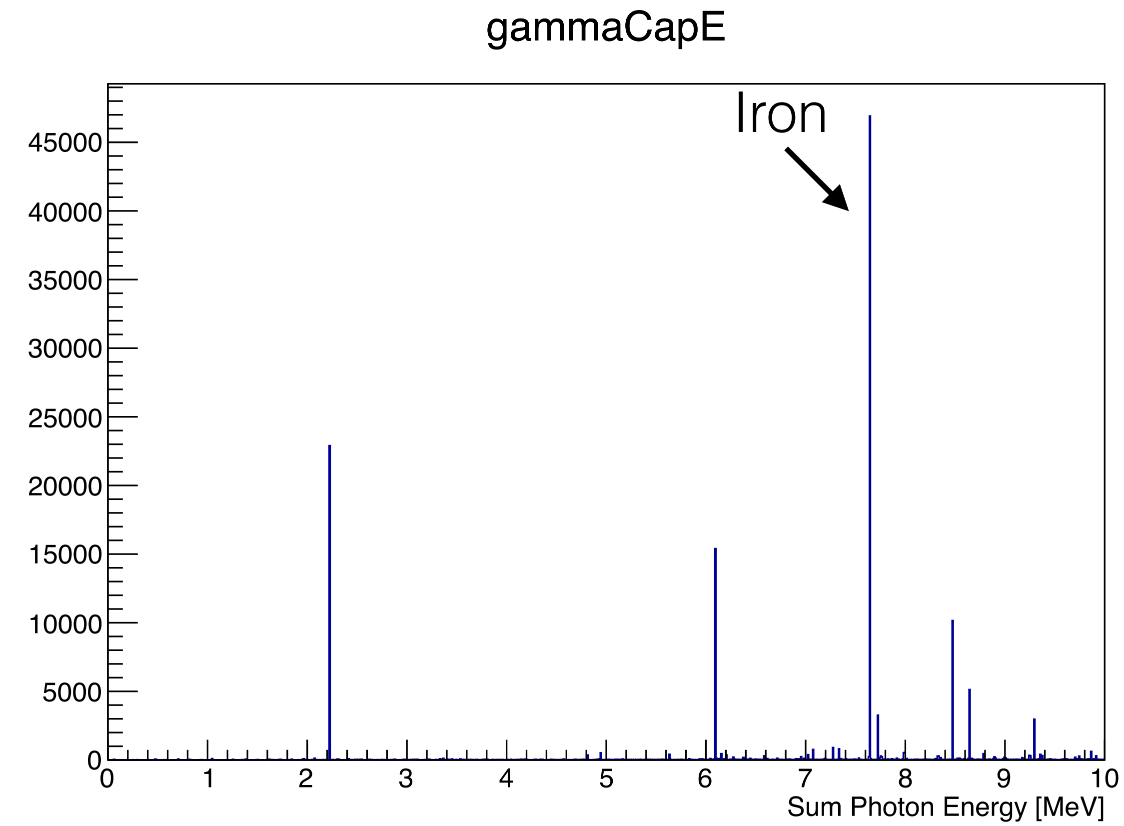


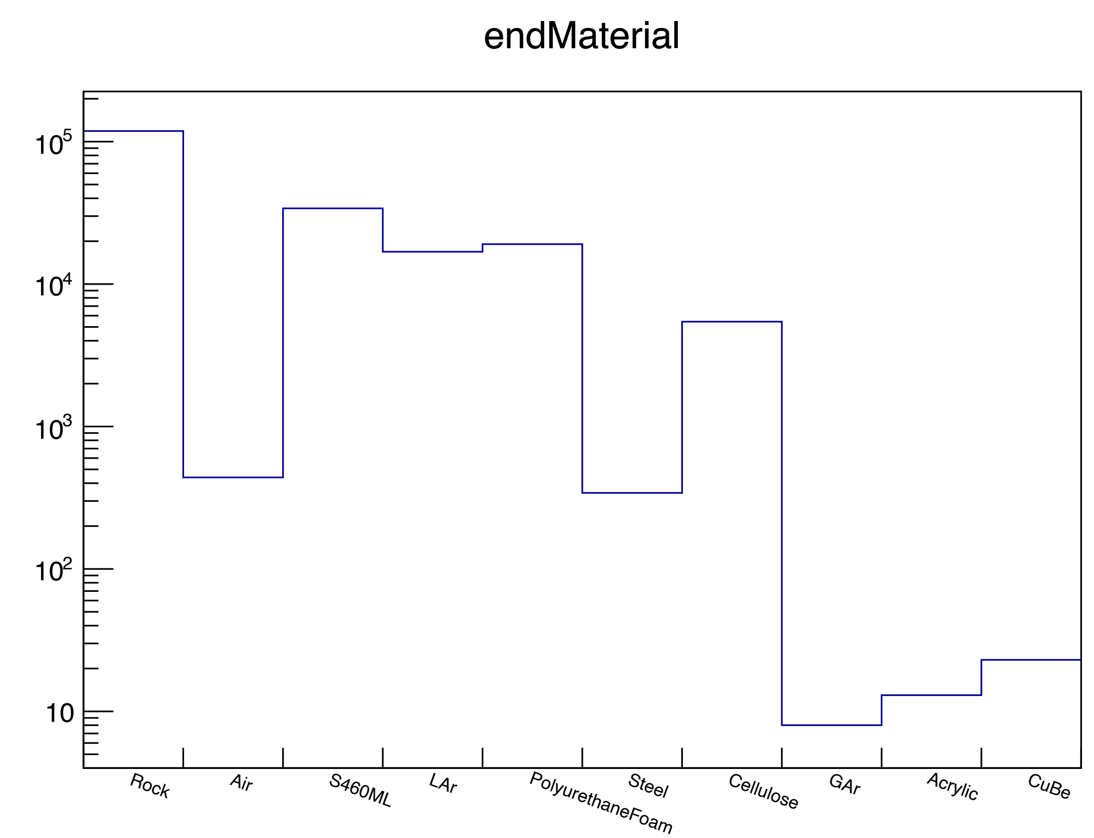


Step 4: Add the Steel Support Structure

- **The steel support structure**
  - This is a double edged sword
  - We see lots of captures on iron rich materials already but the stainless steel is a hot material so it will also produce neutrons
  - We've not considered the neutrons coming from the stainless steel in this

- **Results**
  - After rock the dominant capture material is stainless steel
  - Number of primary neutrons: 226708
  - Number of captures on LAr: 16871
  - Radiological neutron capture rate: 17 Hz



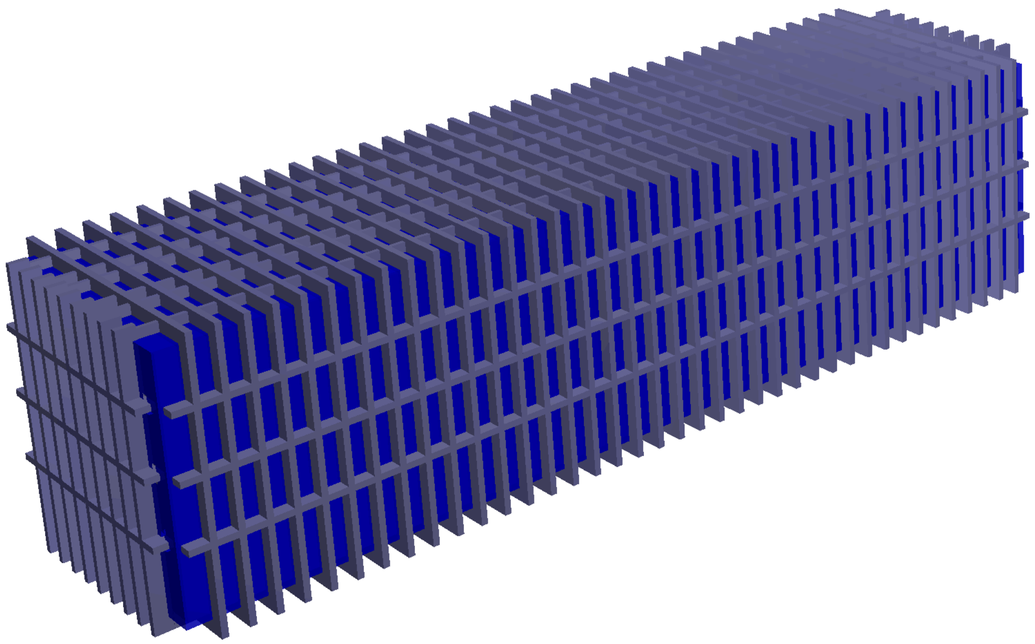


Conclusions

- **Neutron capture rate**
    - Radiological neutrons from the concrete can be expected to produce a capture rate of 16 Hz
    - This is much lower than that from J. Beacom, however this was recreated with a simplified version of the geometry
- **Issues that need attention**
    - There are sources of radiological backgrounds that are not yet accounted for in the simulations
    - If I can get the neutron production spectra from these materials I can add them to the simulation
    - These include the stainless steel support structure and fibre glass (which is not yet in the geometry)
- **Just a quick note on water shielding**

Water shielding

- **Layered water shielding**
  - Geometry from slide 11 used as the base
  - 10cm layers of water are placed on all sides of the detector (shown in blue)
  - Note: This is not perfect, there are still some overlaps that I haven't been able to fix



- **Issues?**
  - The LArSoft simulation is SO G*D D@MN F*#%JFG slow
  - Stay tuned for the results from that

Final thoughts and future work

- **Things to continue**
  - Produce our own version of the effectiveness of water shielding around the detector
  - Add in the relevant components of the detector (field cage, fibre glass)
  - Simulate the other radiologically active material (fibre glass, stainless steel)
  - Fix the detsim portion of the simulation chain and examine hit level features
- **Things to produce**
  - Cleaned up version of the GEGEDE scripts in preparation of releasing to the collaboration
  - A complete document describing the construction and usage of the GEGEDE scripts (ideally before the collaboration meeting)
- **Anything else?**


LOONEY TUNES
"That's all Folks!"

Backup slides

All capture rates

Configuration	Snubbed Geometry	Full Geometry
No Insulation No DSS	82 Hz	39 Hz
Insulation included No DSS	65 Hz	30 Hz
No Insulation DSS included	57 Hz	26 Hz
Insulation included DSS included	37 Hz	16 Hz