UNIVERSITY OF SUSSEX

DEEP UNDERGROUND NEUTRINO EXPERIMENT

From 1x2x6 to Full Detector Simulation

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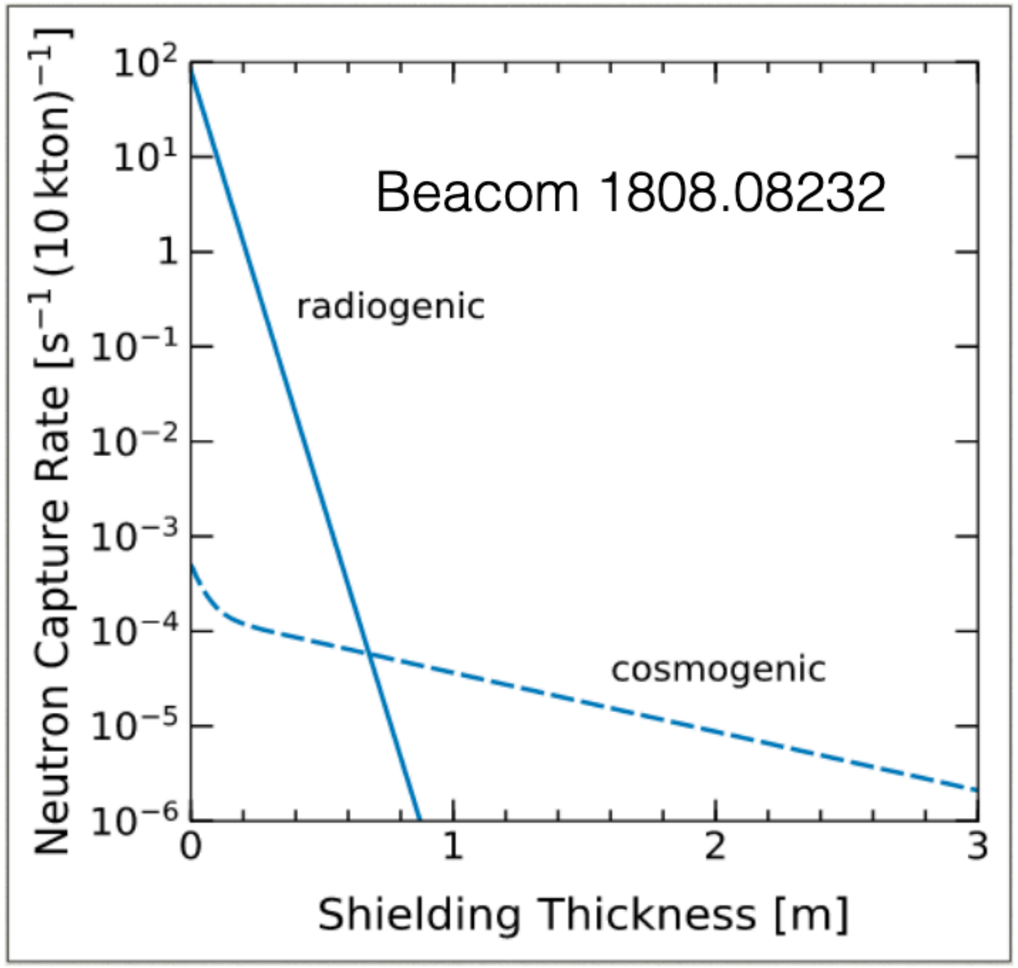
Overview

DEEP UNDERGROUND NEUTRINO EXPERIMENT

- **Radiological backgrounds in the DUNE far Detector**
  - Where do radiological backgrounds come from
  - What do we expect from the radiological backgrounds
- **Detector Geometry, past and present**
  - Legacy techniques using the 1x2x6 workspace geometry
  - Construction of a full 10 kt geometry
  - Validation tests and full geometry simulation
- **New features for simulations**
  - Generation from specified volumes
  - Additional volume addition
- **Conclusions and future work**

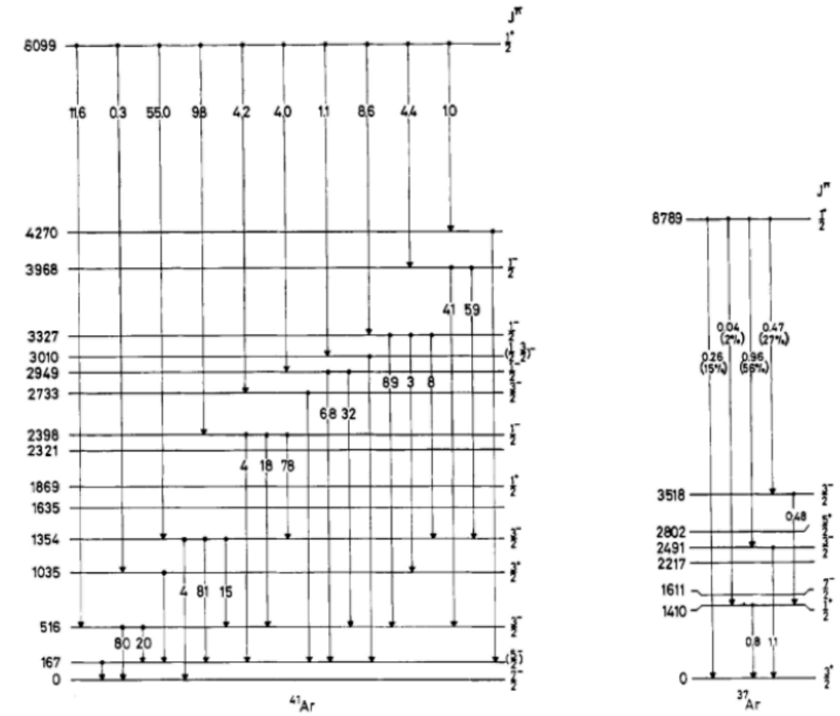
Radiological backgrounds at the DUNE Far Detector

- **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(α, n)
  - APA steel (^{238}U, ^{232}Th)
- **Cosmological neutrons**
  - Subdominant rate, however a potentially high multiplicity

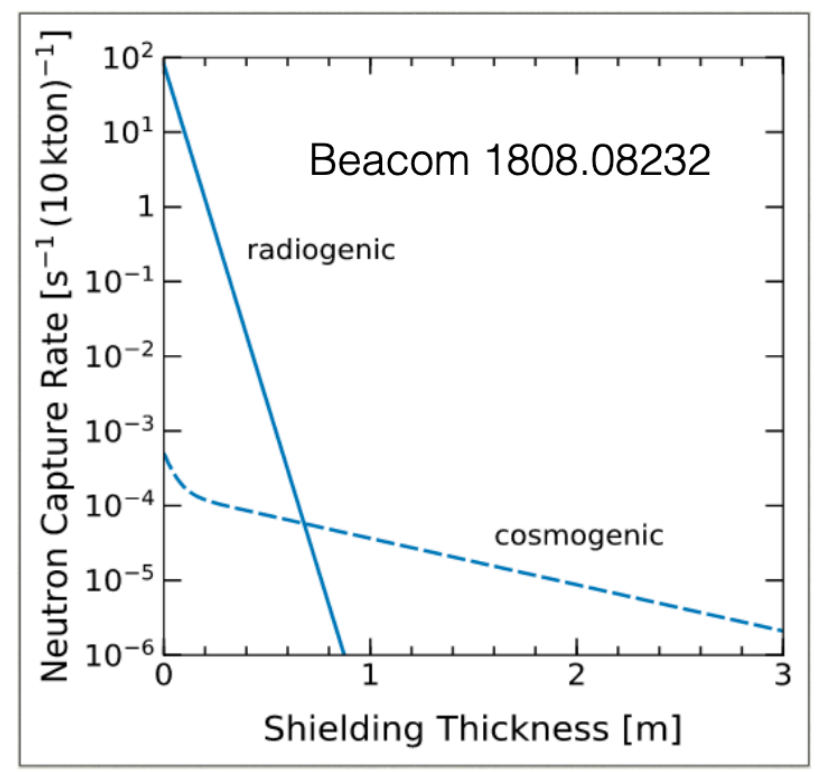


Neutron expectation at the far detector

- **Neutrons in LAr**
  - Neutron capture cross section on Ar has anti resonance at ~57 keV
  - Neutrons can travel anywhere from 30 - 100 m 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
  - Variation in input cross section to be explored in future studies



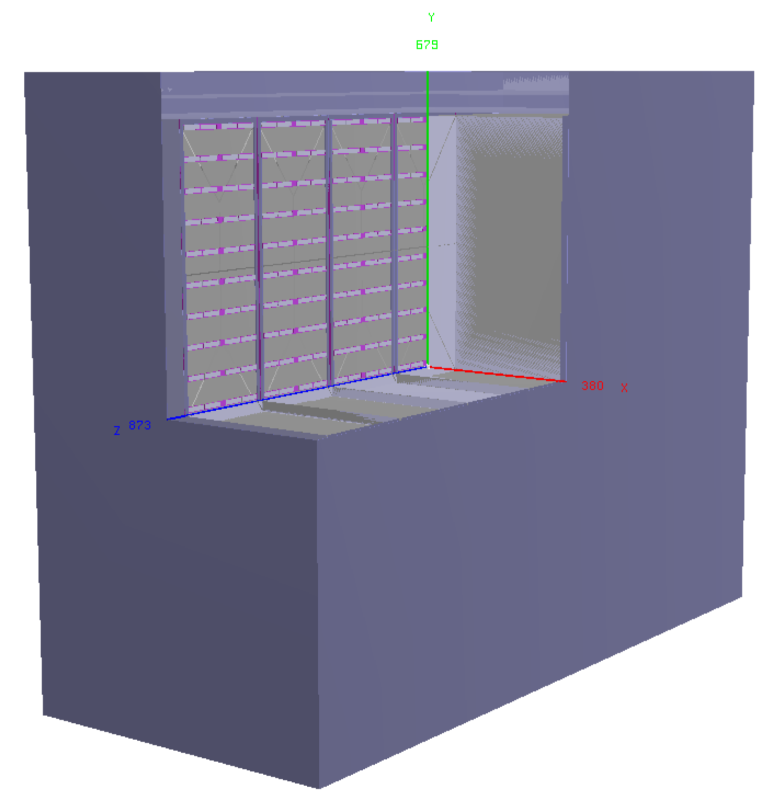
- **Neutron capture rate**
  - J. Beacom predicts a radiological neutron capture rate of 81 Hz
  - This is based on a FLUKA simulation and a simple geometry for the 10 kt module

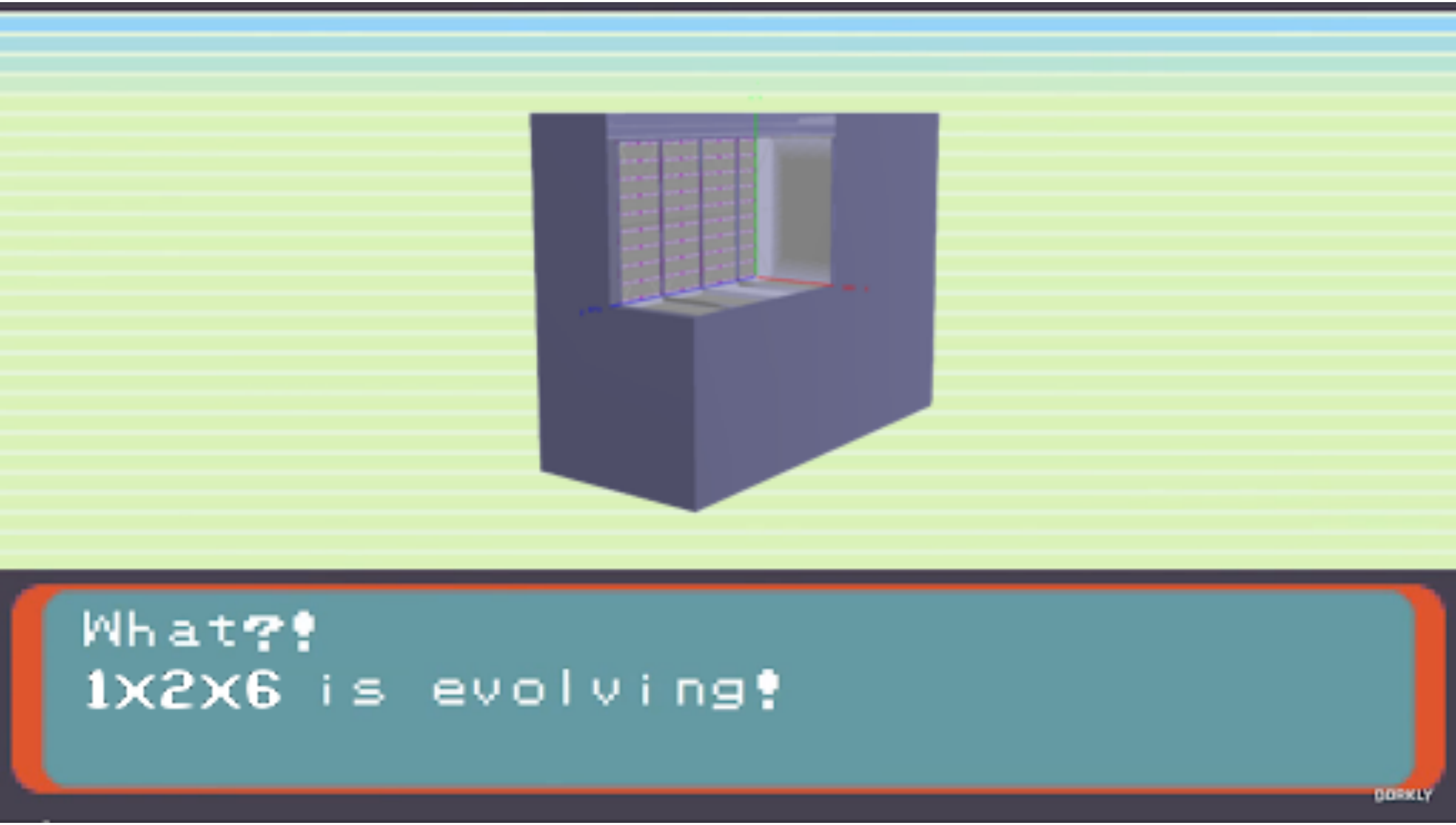


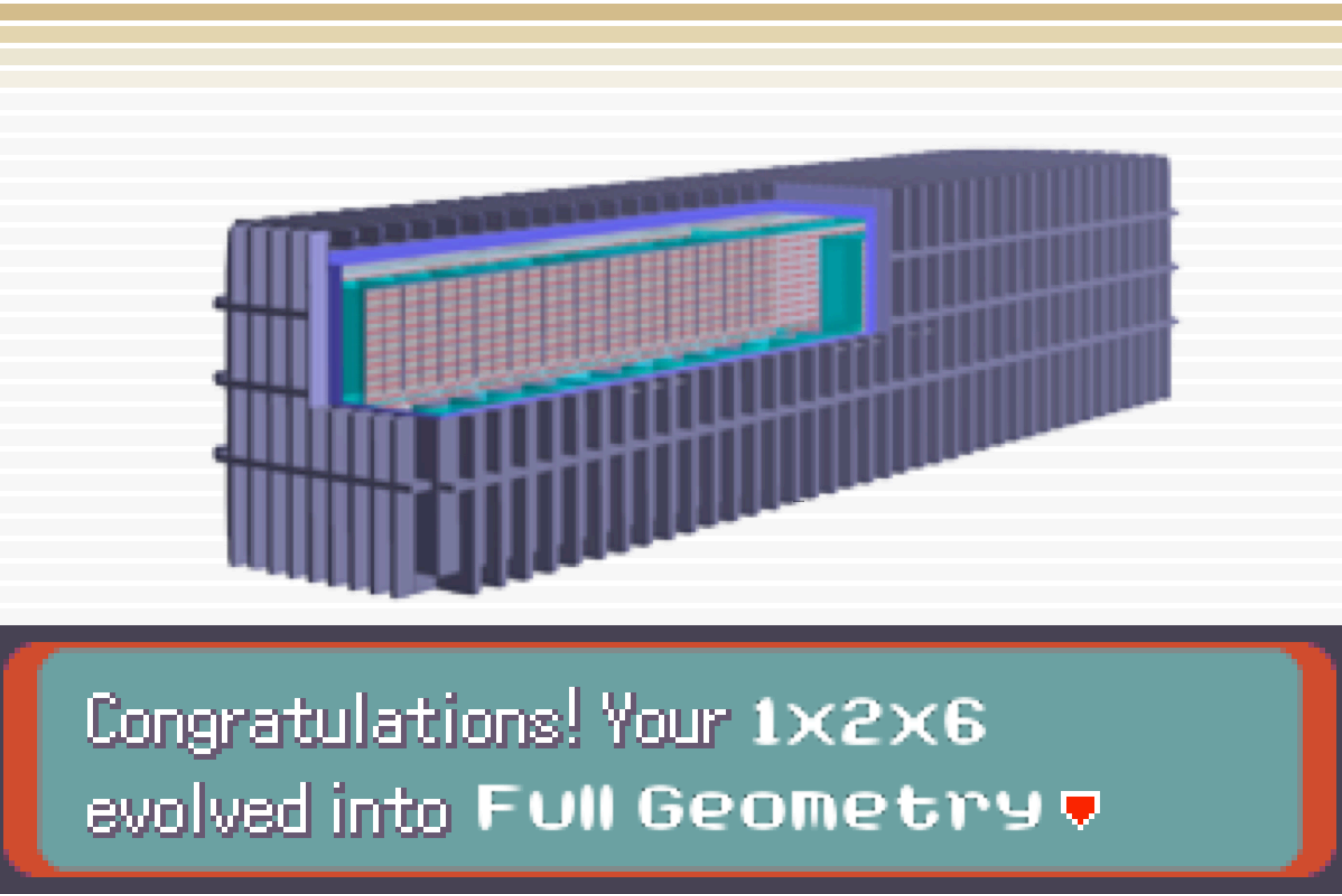
- **Neutron shielding**
  - Hydrogen rich molecules will happily eat neutrons
  - Obvious choice for shielding is then water
  - J. Beacom shows roughly and order of magnitude mitigation per 20 cm of water shielding
  - This works in an ideal case but not necessarily a physical solution

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 strange and any capture result is not trivially scalable
- **Full 10kt geometry in LArSoft**
  - The full 10 kt geometry exists in LArSoft but is very basic
  - There are some very suspicious 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




What?!
1X2X6 is evolving!
DORKLY

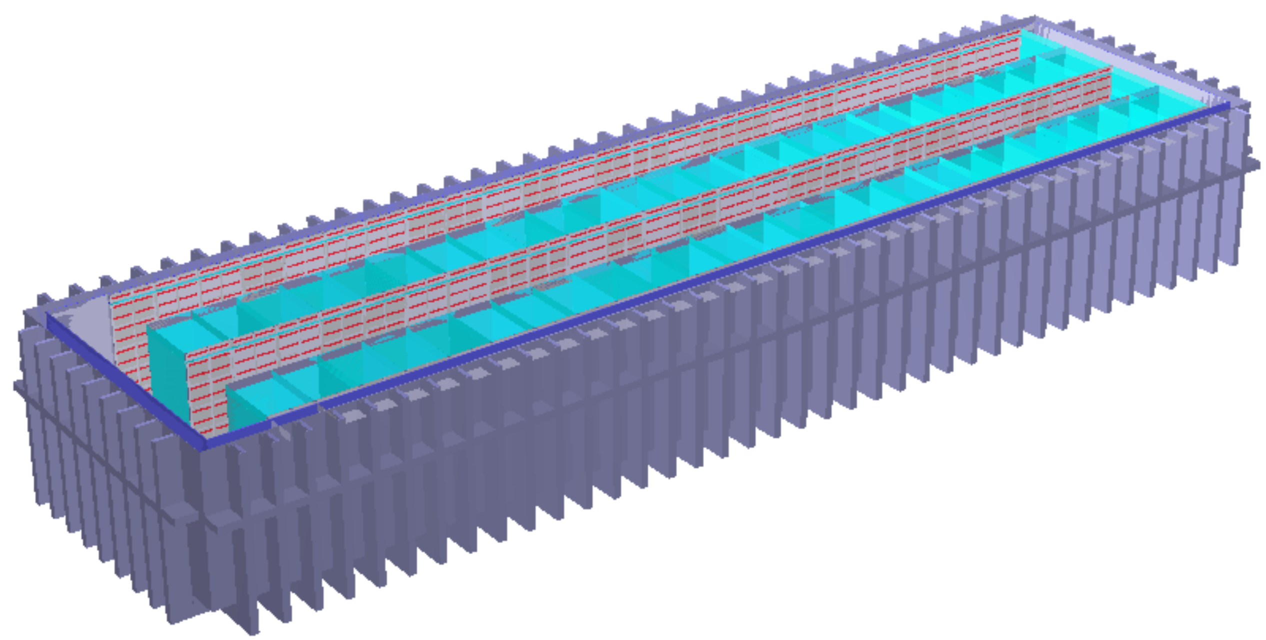

Congratulations! Your 1x2x6
evolved into Full Geometry

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
  - You could define specific active regions and ignore as much or as little of the detector as you'd like



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

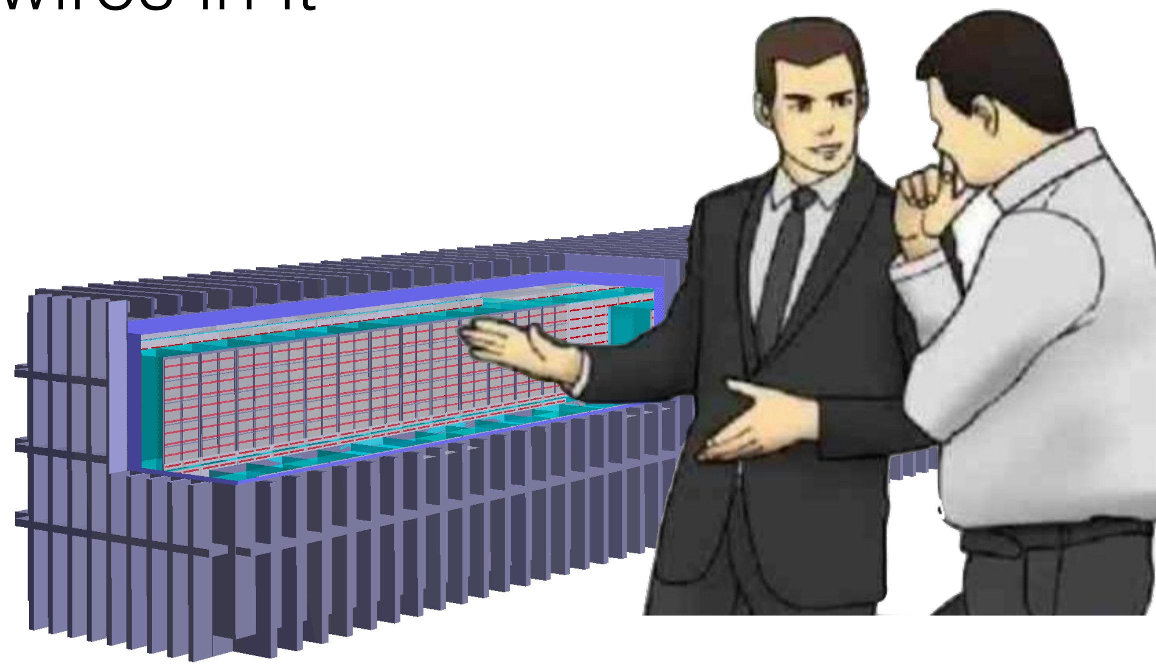
Validation new geometry

- **DuneGGD in-situ Tests**
  - — Goal: incapable of creating a geometry that breaks LArSoft
  - Wires have consistent endpoints and pitches
  - Origin in intended place
  - ROOT macro
    - checks overlaps, default draw options
- **LArSoft Tests**
  - Existing GeoObjectSorter and ChannelMap works
  - LArG4 output looks reasonable
    - IDEs where there are TPCActive, true dE/dx maps out APA Frames and other vol's
  - Check DetSim with EVD scans
  - Replaced GDML: Important standard FCLs still work
  - Go as far as checking Track/Vtx Reco?

Sanity checks in the new geometry: TPC wire planes

- **TPC plane wire placement**
  - The collection plane is very easy to build
  - Induction wire planes are very annoying to build
- **Generation of wire points**
  - Using an external module the position of the wires is calculated
  - These values are stored in a spreadsheet and read when constructing the geometry
- **Verifying correct wire placement**
  - Bottom image shows output of GeoObjectSorter
  - Number of APAs, channels, and wire pitches shown to be consistent with TDR specs when running larsoft jobs with 10 kt geometry

Scientist: *slaps roof of detector* This bad boy can fit so many wires in it



```
Initializing channel map...
%MSG
Cryostat 0:
  384000 total channels
  150 APAs
  For all identical APA:
    Number of channels per APA = 2560
    U channels per APA = 800
    V channels per APA = 800
    Z channels per APA = 960
    Pitch in U Plane = 0.4667
    Pitch in V Plane = 0.4667
    Pitch in Z Plane = 0.479
```

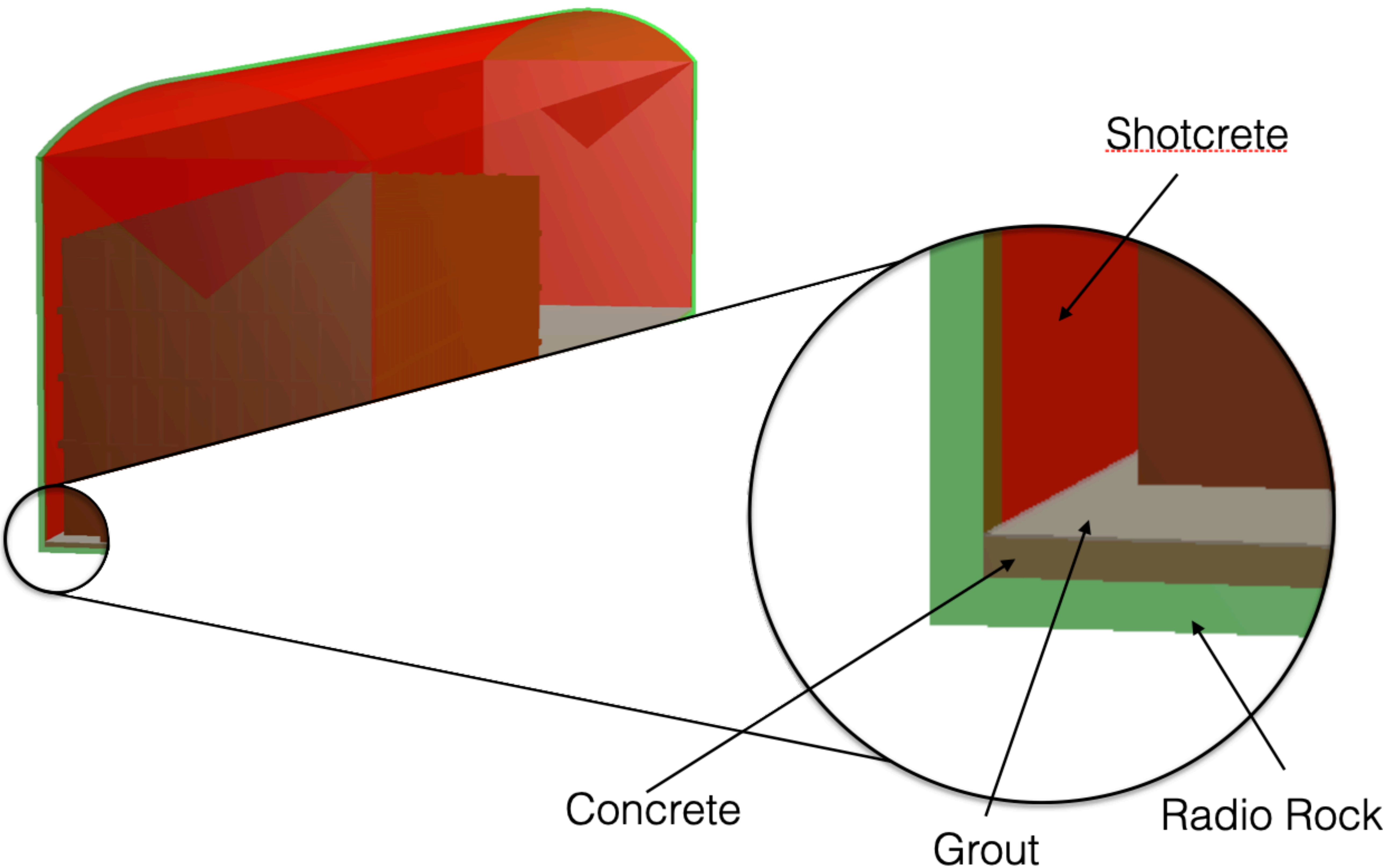
New volumes in the FD Geometry

- **Neutron production volumes**
  - Defined layer of rock on cavern walls where neutron production can be initiated
  - Thickness can be adjusted to ensure accurate simulations and results
  - Can individually define neutrons to be produced from cryostat volumes, such as the steel support structure
  - This means we can break the simulation up source by source and evaluate the contribution as such

- **Rock-ey volumes in the detector cavern**
  - The floor of the cavern as 7.5” of concrete and 1” on grout
  - The walls and ceiling have an average of 6” of shotcrete

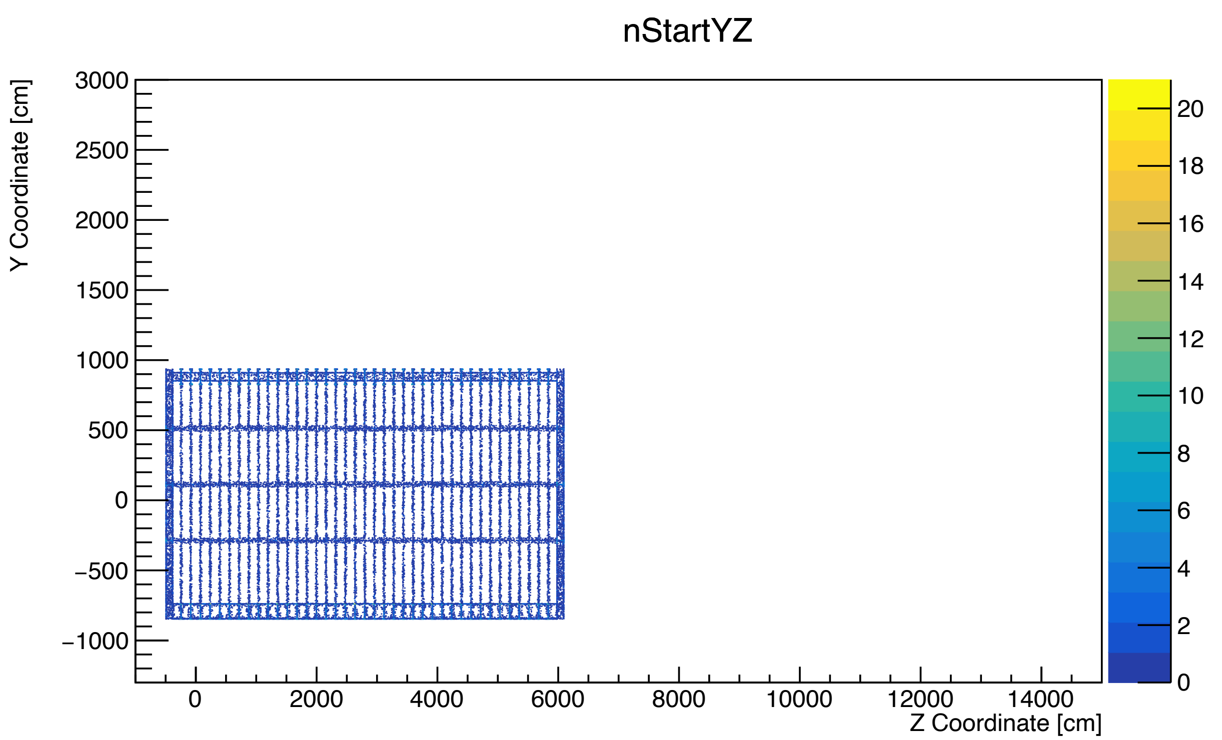
- **Material definitions and spectroscopic analysis**
  - Atomic composition of Rock, Shotcrete and Concrete are now known
  - Important because water content effects neutron propagation through the material
  - Additionally, the atomic content effects the neutron production rate within the volume

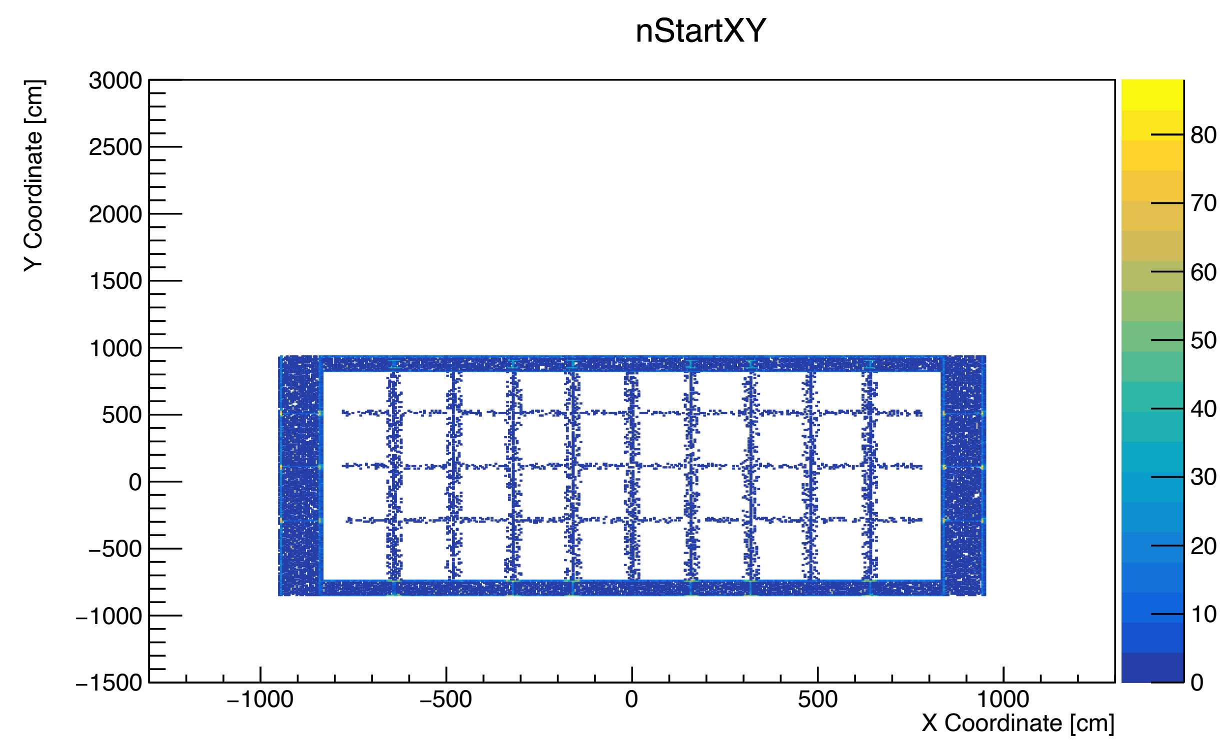
New volumes in the FD Geometry



Neutrons produced from specific volumes

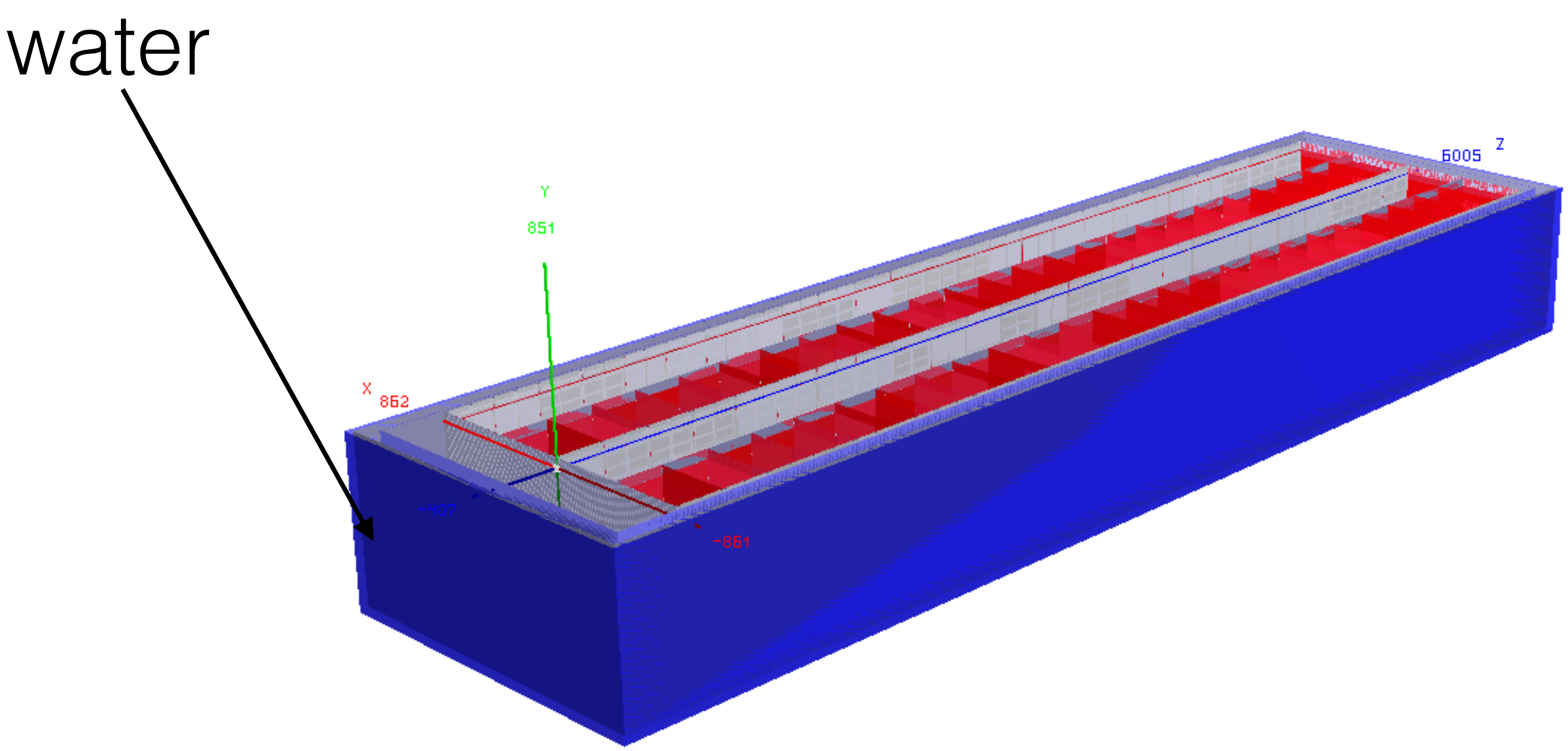
- **Example, neutrons produced from steel support structure**





Additional shielding to Cryostat

- **Can explore passive shielding**
  - Very simple to add external layers to the cryostat geometry
  - Exploring the effects of water shielding is interesting for DUNE background studies
  - This is something that would be more difficult in the previous geometry system



Conclusions and further work

- **Conclusions**
  - Full 10 kt geometry available for use in LArSoft simulations
  - Complexities defined in the TDR all included
  - Material definitions updated to reflect spectroscopic analysis of genuine samples
  - GDML scripts can be found here: https://github.com/DUNE/duneggd
- **Updates to DUNE FHiCL's**
  - Plans to update dune_radiological_model.fcl to include specified generators for neutrons coming:
    - Different sources
    - Different isotope decays
  - Will require a dedicated analyser to produce workable root files, probably to be adapted from DAQSimAna
- **Computational requirements**
  - Address issue with the photon detector to get them working in the detector simulation
  - Detector simulation required a lot of memory to run, even for zero suppressed
- **Thank you!**

Backup slides

Neutron capture gamma emissions