Cosmogenic backgrounds in Plan C

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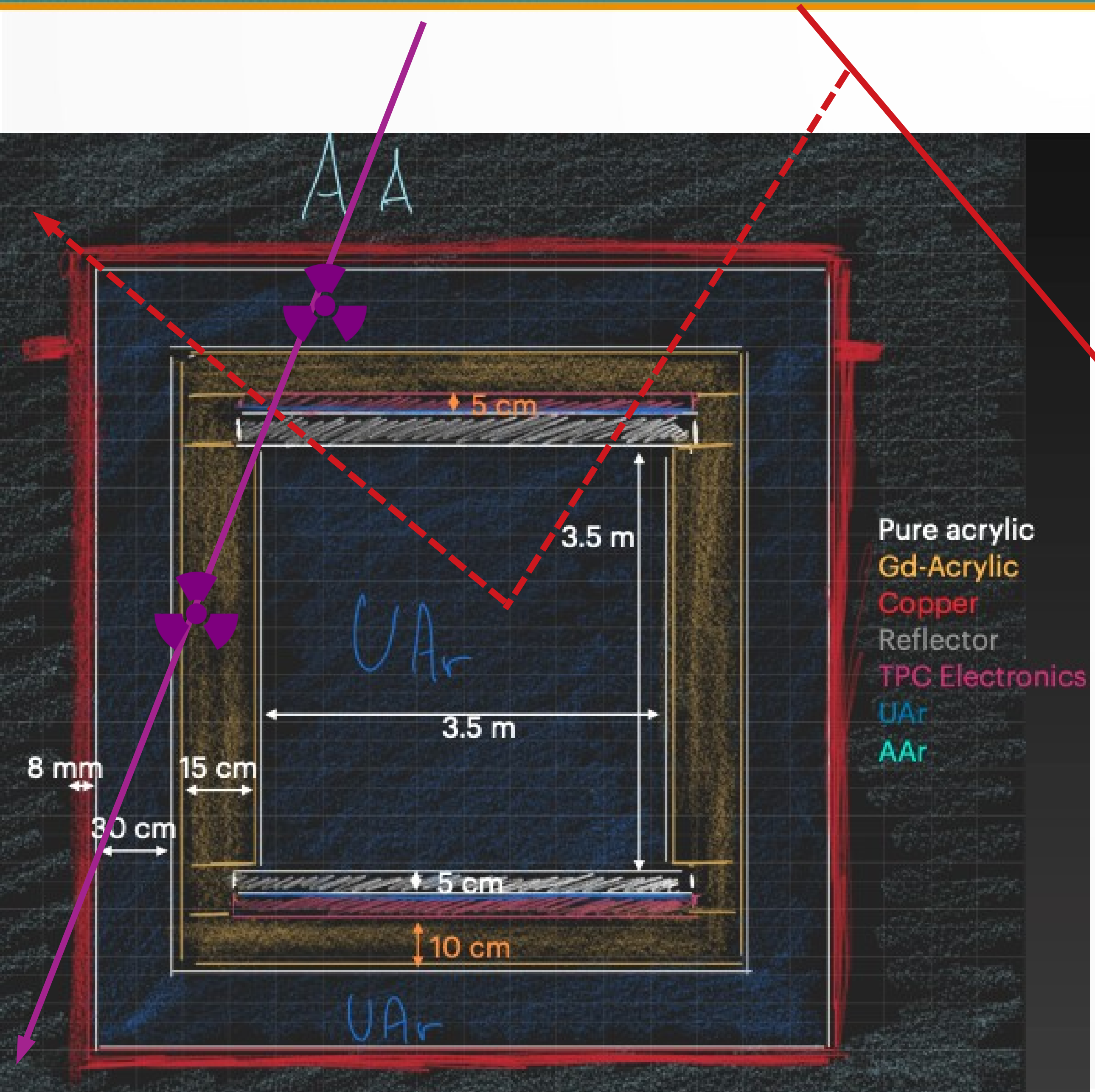
(presenting work from Zoe, Teena, Sagar, and others)

Backgrounds call
28 May 2021

Muon-induced backgrounds



Two dangerous types of background

Material activation

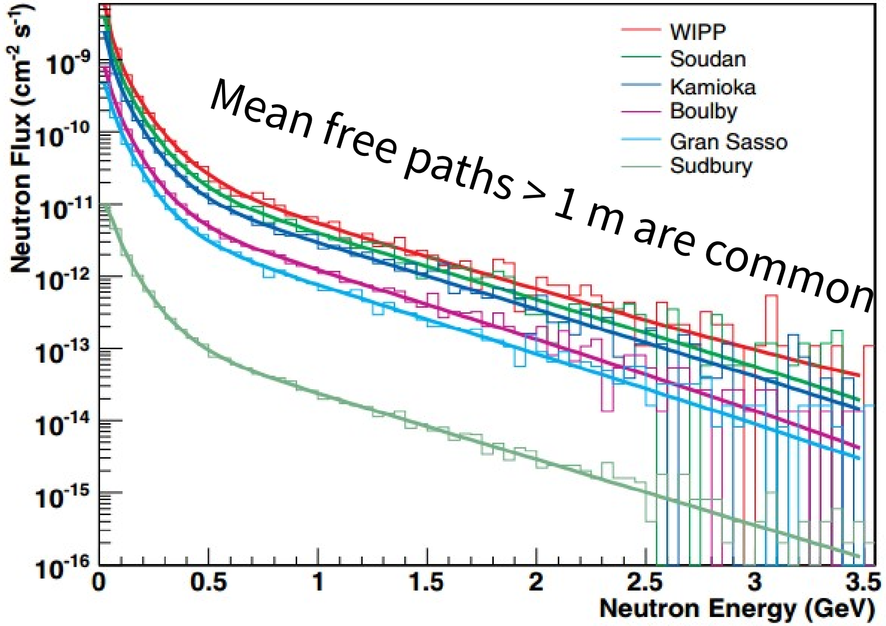
- Muon passing through detector components creates unstable isotopes with µs—hrs half-life
- Particular danger from β-delayed neutrons produced near TPC

Prompt neutrons

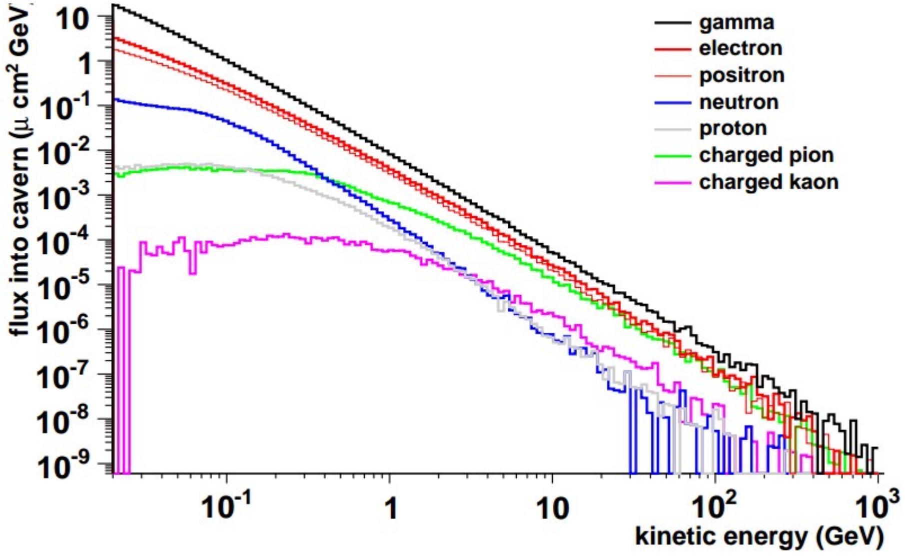
- Produce by spallation, shower, etc. induced by muon while it traverses rock, lab, and detector
- High energy, may penetrate shielding
- Muon doesn't need to come near the detector for a neutron to reach TPC
  - Neutrons may even emerge from rock with the muon

Some facts about prompt neutrons

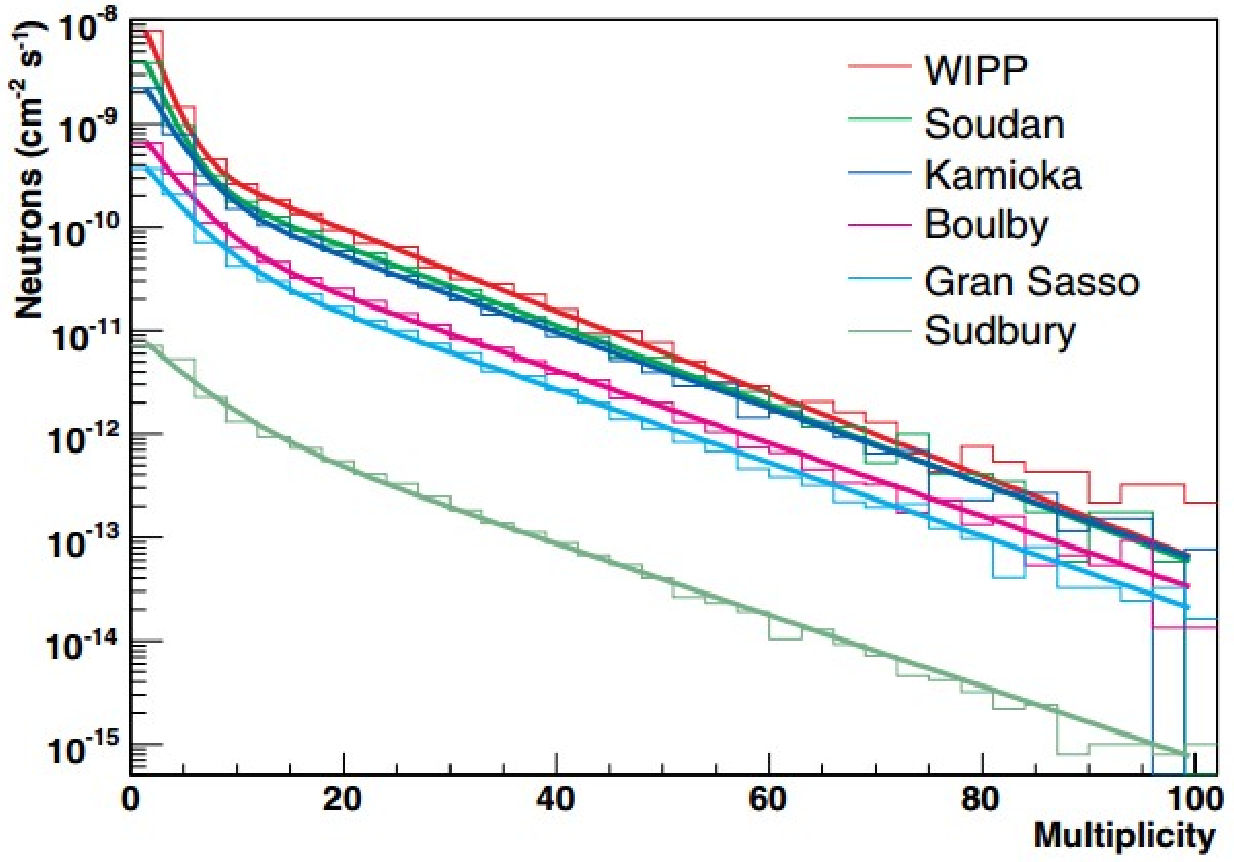
High energy neutrons → **high penetration**!



Mean free paths > 1 m are common



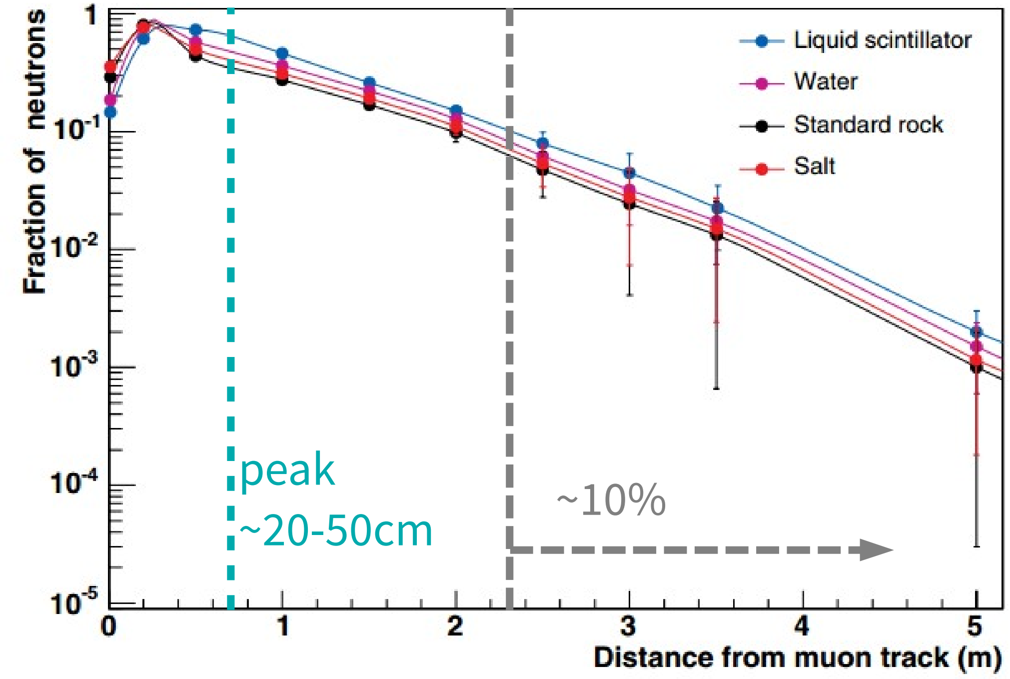
Fish can't live in a LAr tank, so we can't expect Poisson stats



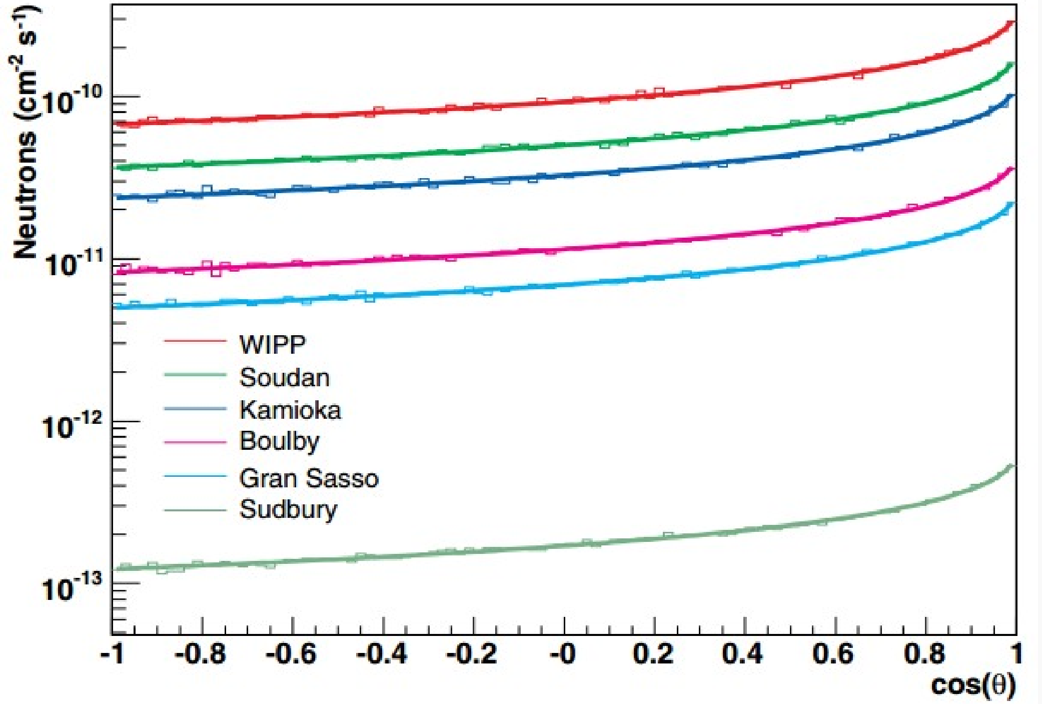
Mei and Hime. Phys Rev D 73, 053004 (2006)
A. Empl et al JCAP08(2014)064

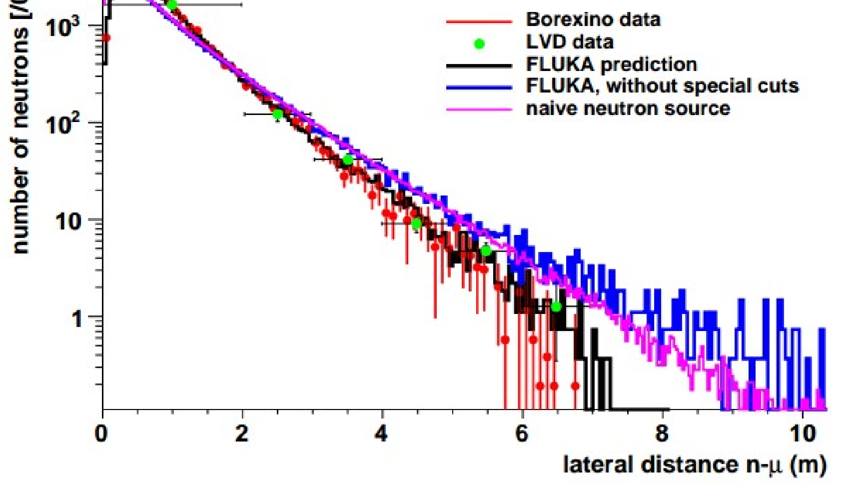
Some facts about prompt neutrons

Significant neutron production **displaced** from muon track
And the neutrons travel **far** once they are produced



Neutrons can **stray** even farther from the muon track





Mei and Hime. Phys Rev D 73, 053004 (2006)
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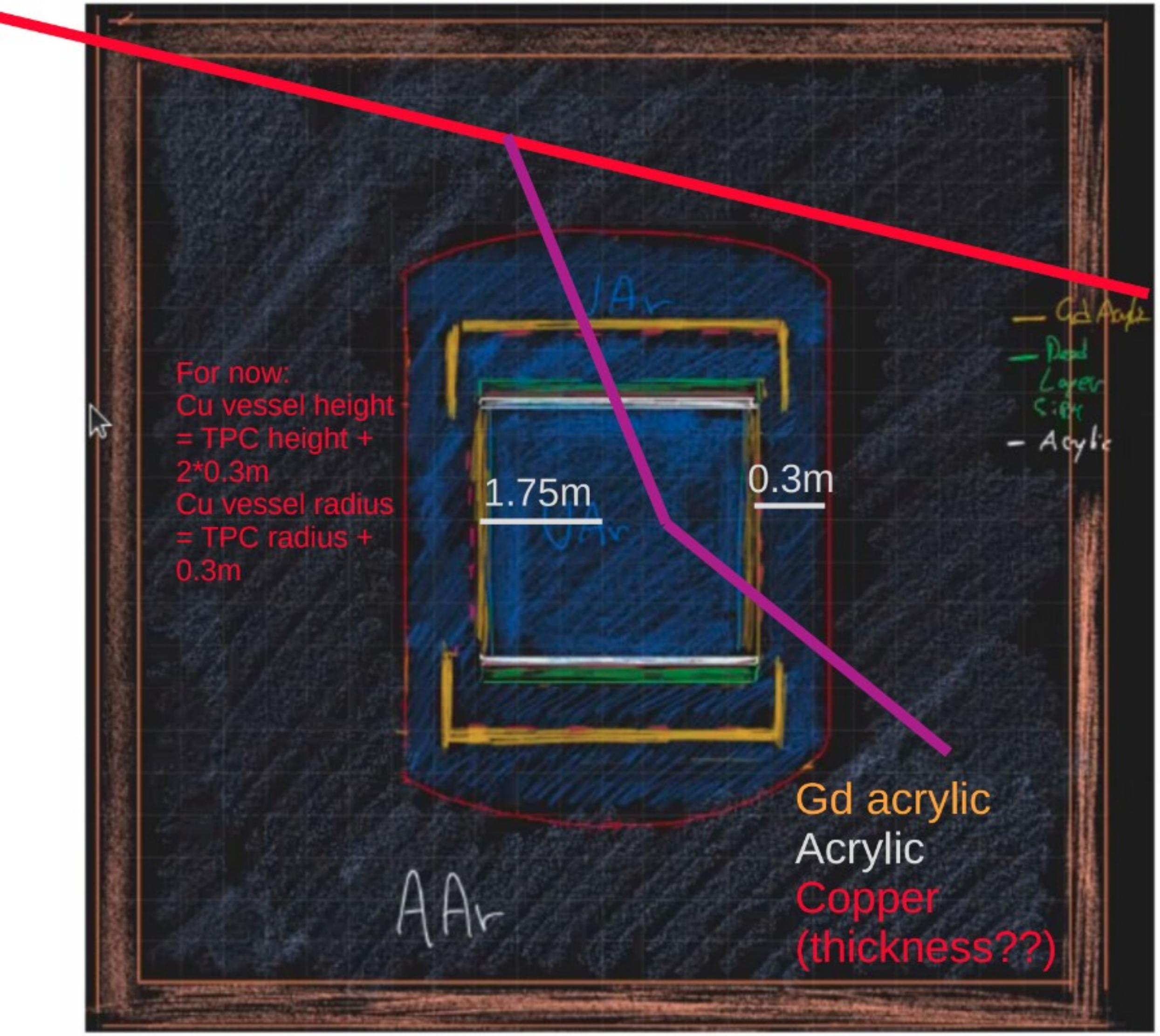
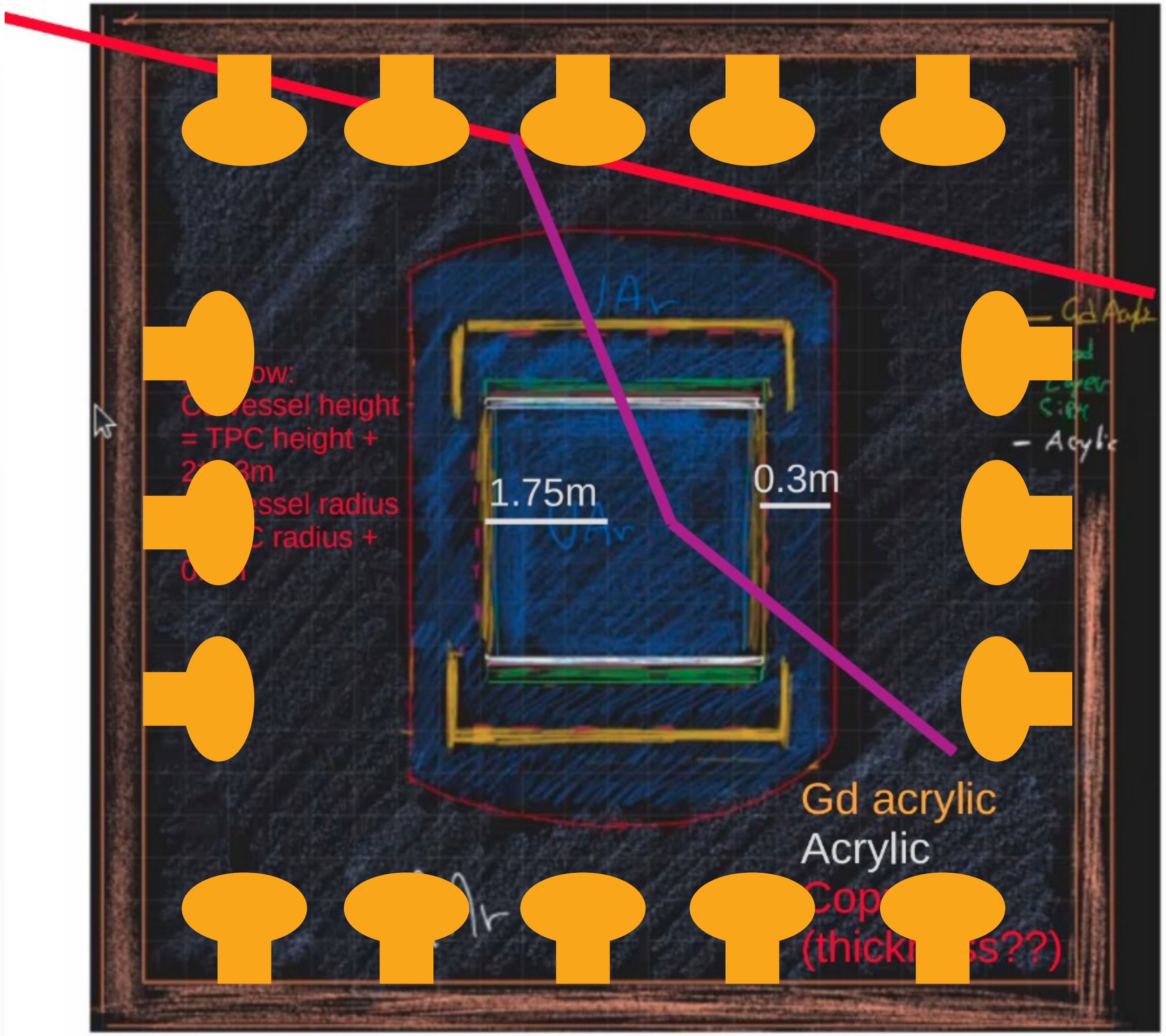
To catch a lot of muons, you need a big net



Muon missed – background!

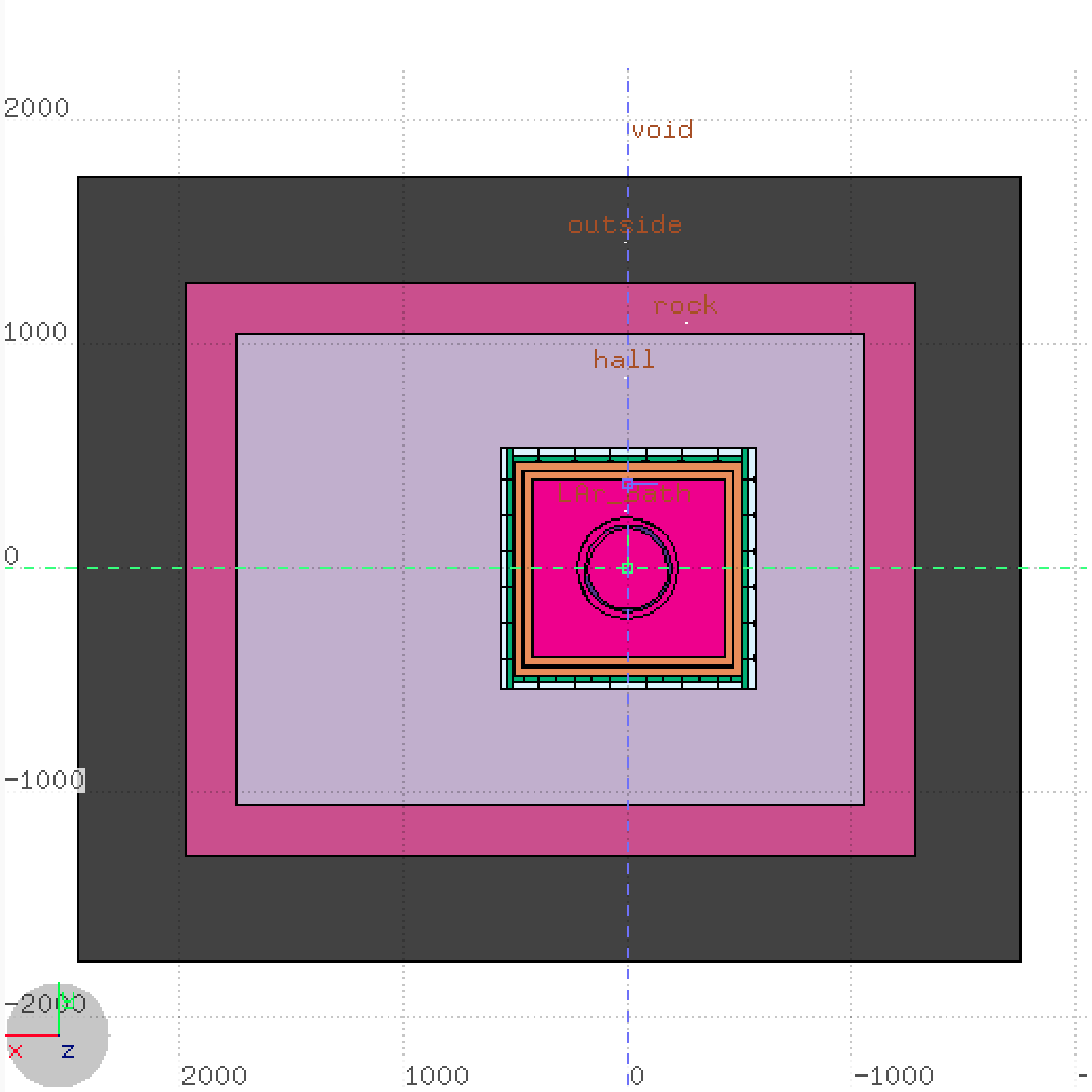


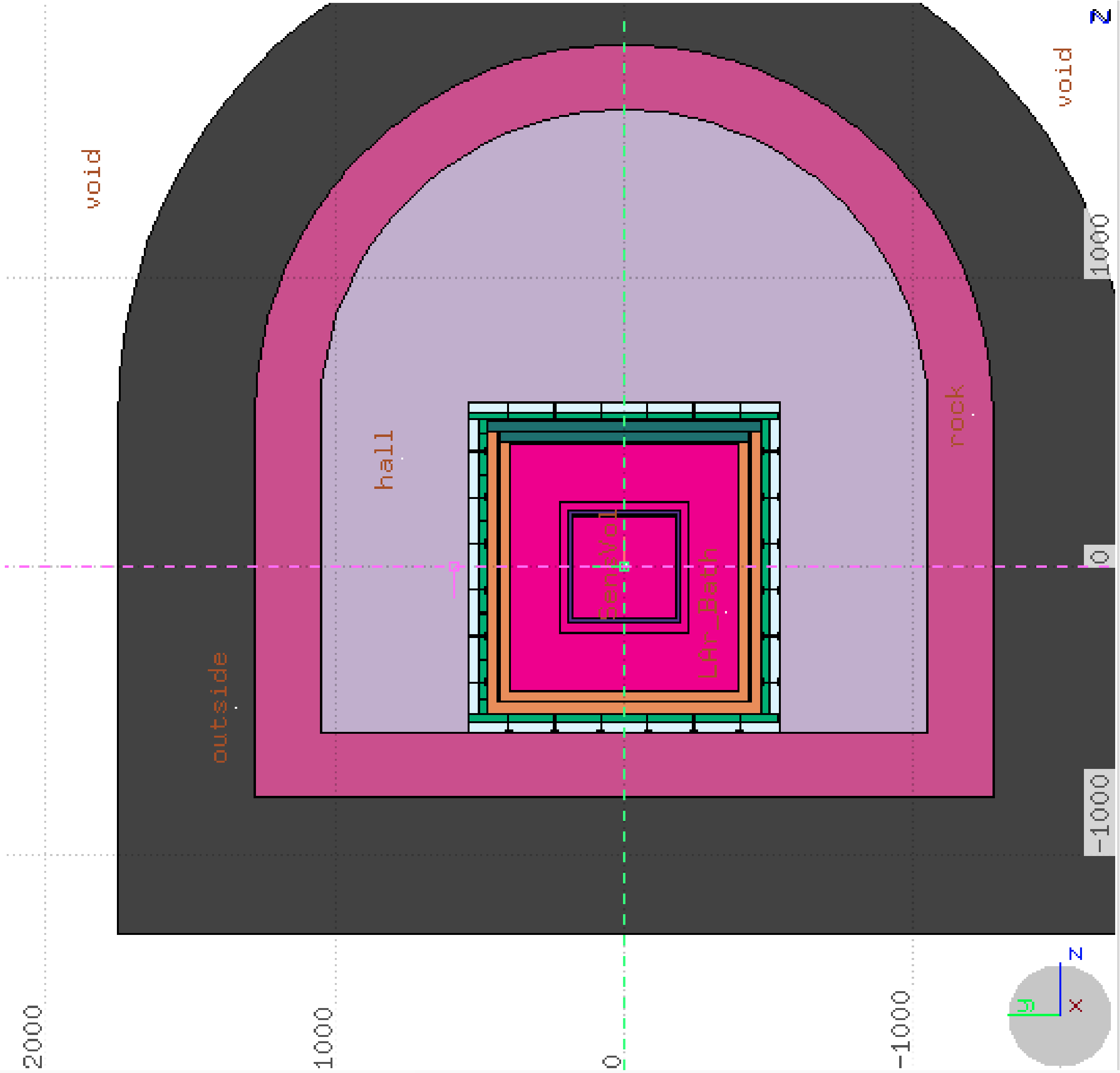
Muon caught – background vetoed :)

Plan C FLUKA simulations

- 30.6 years of muons + showers simulated in Hall C by Toni Empl
- Hall C muons propagated into Plan C geometry by Sagar, further development underway by Teena
- Disclaimers:
  - FLUKA output is cumbersome and complicated; currently existing FLUKA simulations are limited in what variables are stored for each event
  - Existing FLUKA output records
    - Total energy deposited in TPC, neutron veto, and LAr bath
    - ID of all particles entering the TPC
    - Kinetic energy of all neutrons that entered the TPC
  - Cannot apply fiducial and multiple scatter cuts with this – maybe they would improve things by a factor of ~a few
    - Some very rough approximations can be explored by cutting on what/how many particles enter TPC
  - Timescale for additional MC with higher stats and more variables stored > 1 month

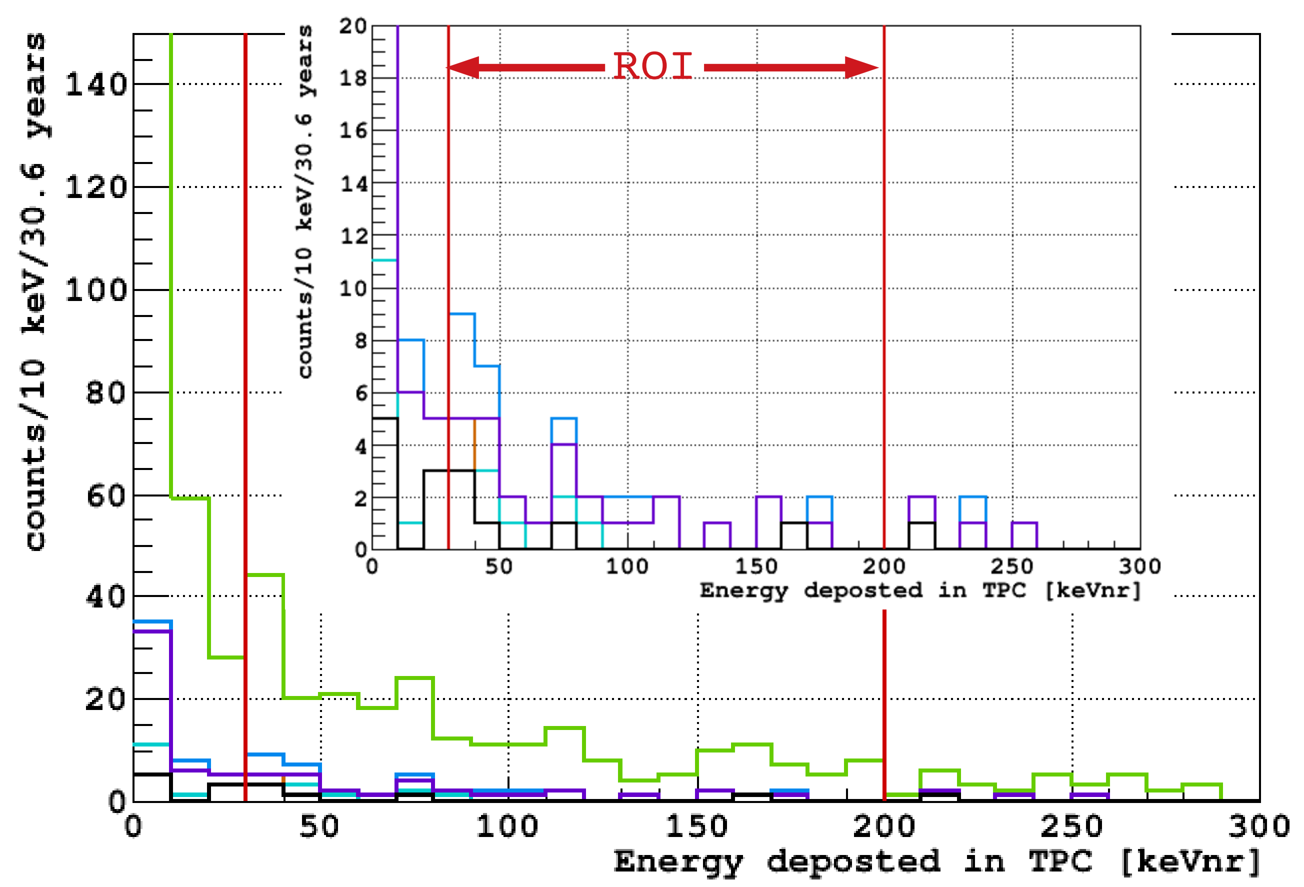
Plan C FLUKA simulations

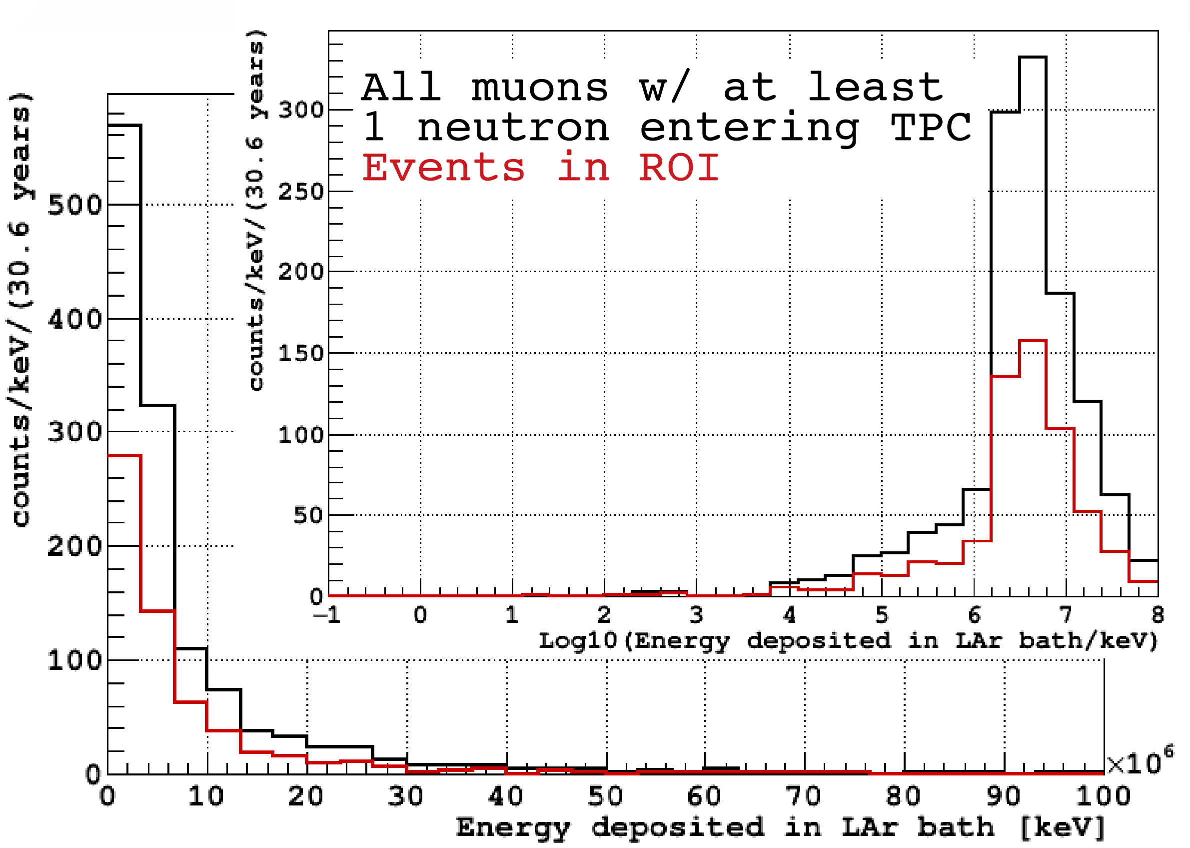




There are likely some minor differences in geometry (e.g. Cu vs. Ti barriers), but covers main elements

Plan C FLUKA simulations, 30.6 yrs: No μ veto





```
No nveto, 1 visible TPC neutron         : 234
NVeto thresh 500 keV, 1 visible TPC neut  : 38
NVeto thresh 500 keV, precisely 1 TPC neut: 28
NVeto thresh 100 keV, 1 visible TPC neut  : 15
NVeto thresh 0 keV, 1 visible TPC neut    : 9
NVeto thresh 0 keV, precisely 1 TPC neut  : 6
```

All scenarios require that no non-neutrons enter TPC

“1 visible neut” → neutrons below 1 keV don’t cause multiple scatters

Plan C FLUKA simulations, 30.6 yrs: Adding μ veto

No μ veto

```
No NVeto, 1 visible TPC neutron            : 234
NVeto thresh 500 keV, 1 visible TPC neut   : 38
NVeto thresh 500 keV, precisely 1 TPC neut: 28
NVeto thresh 100 keV, 1 visible TPC neut   : 15
NVeto thresh 0 keV, 1 visible TPC neut     : 9
NVeto thresh 0 keV, precisely 1 TPC neut   : 6
```

μ veto threshold 1 GeV

```
No NVeto, 1 visible TPC neutron            : 40
NVeto thresh 500 keV, 1 visible TPC neut   : 7
NVeto thresh 500 keV, precisely 1 TPC neut: 6
NVeto thresh 100 keV, 1 visible TPC neut   : 1
NVeto thresh 0 keV, 1 visible TPC neut     : 0
NVeto thresh 0 keV, precisely 1 TPC neut   : 0
```

μ veto threshold 100 MeV

```
No NVeto, 1 visible TPC neutron            : 12
NVeto thresh 500 keV, 1 visible TPC neut   : 4
NVeto thresh 500 keV, precisely 1 TPC neut: 3
NVeto thresh 100 keV, 1 visible TPC neut   : 0
NVeto thresh 0 keV, 1 visible TPC neut     : 0
NVeto thresh 0 keV, precisely 1 TPC neut   : 0
```

μ veto threshold 50 MeV

```
No NVeto, 1 visible TPC neutron            : 5
NVeto thresh 500 keV, 1 visible TPC neut   : 1
NVeto thresh 500 keV, precisely 1 TPC neut: 1
NVeto thresh 100 keV, 1 visible TPC neut   : 0
NVeto thresh 0 keV, 1 visible TPC neut     : 0
NVeto thresh 0 keV, precisely 1 TPC neut   : 0
```

This is ~ the nominal design, modulo fiducial+multiscatter cuts

Note: DS-50 saw 2 cosmo neutrons (vetoed)
DS-20k has a cross sectional area 136x larger

Neglecting vetoes, a simple scaling of background rate would predict 272 events
→ these simulations predict 234!

One event that's hard to kill…

- Edep TPC = 158 keV
- Edep NVeto = 459 keV
- Edep LAr Bath = 616 keV
- $n_{\text{neutrons}} = 1$, at 3.3 MeV

Can we achieve this?

- Zoe has been running g4ds simulations of Plan C geometry with PMTs added
  - Studying PE detected vs. energy deposited by muons for different configurations
- One realistic scenario: Reuse MiniCLEAN PMTs
  - Of course, not the only option (maybe we want PDMs?), but it is ~free and sets a realistically achievable baseline for argument's sake
  - 92 PMTs (80 are working perfect, they think remaining 12 are just a problem with the base and can be revived)
  - For these simulations, Zoe is using the DS-50 LSV PMTs (R5912, 8" diameter), spaced ~uniformly around the cryostat walls
- Disclaimers:
  - Muon simulations are not currently producing anything heavier than electrons. Debugging from Igor indicates that this may be fixed by upgrading to latest Geant4-10 version
  - Muon veto background model from ^{39}Ar and γ's are still being set. Realistically, this will set the achievable threshold

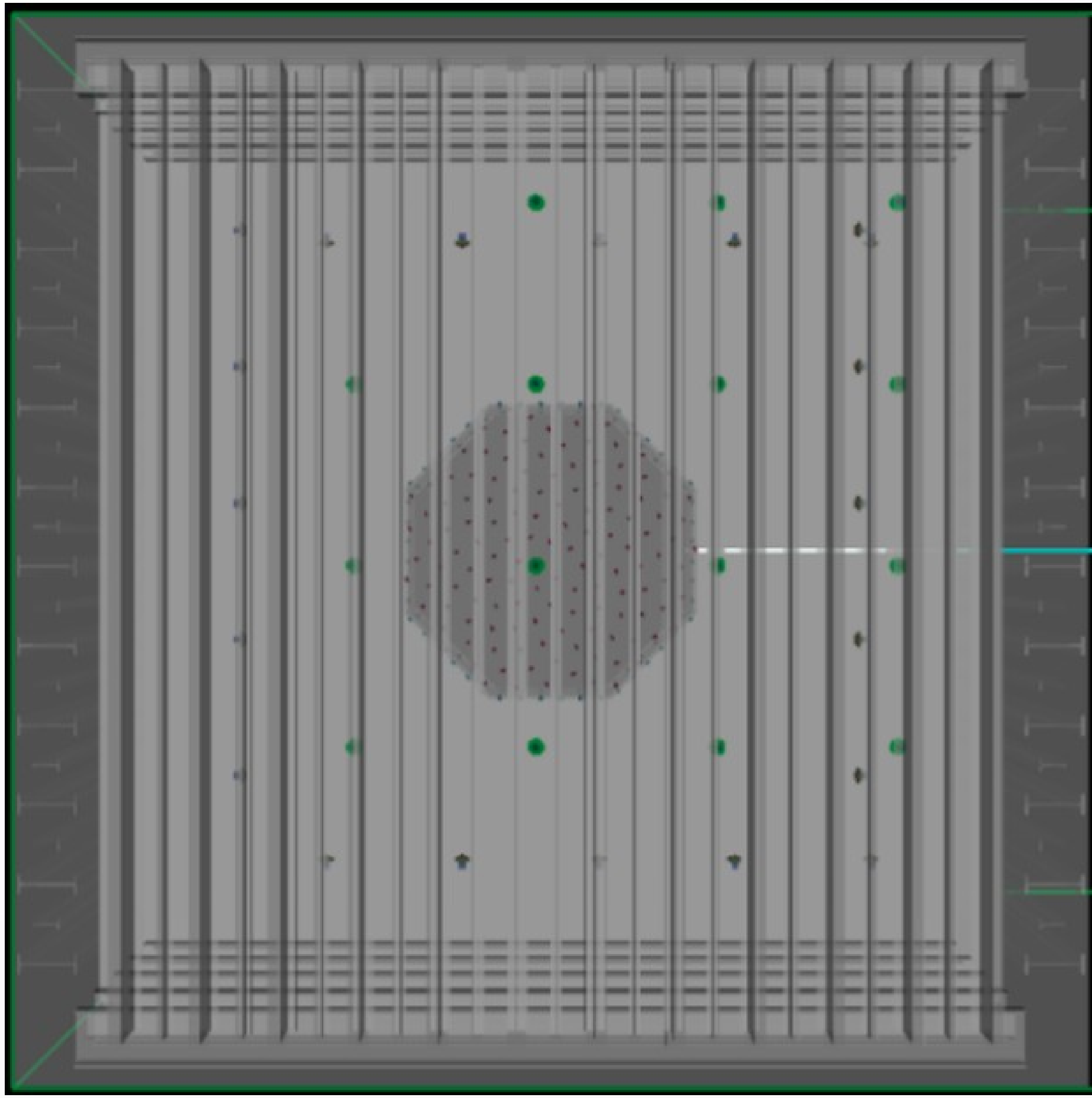
Optical muon veto simulations

Three configurations considered

- 92 PMTs, no reflector, no TPB
- 92 PMTs, Tyvek reflector, no TPB
- 92 PMTs, Tyvek reflector, TPB on PMT faces

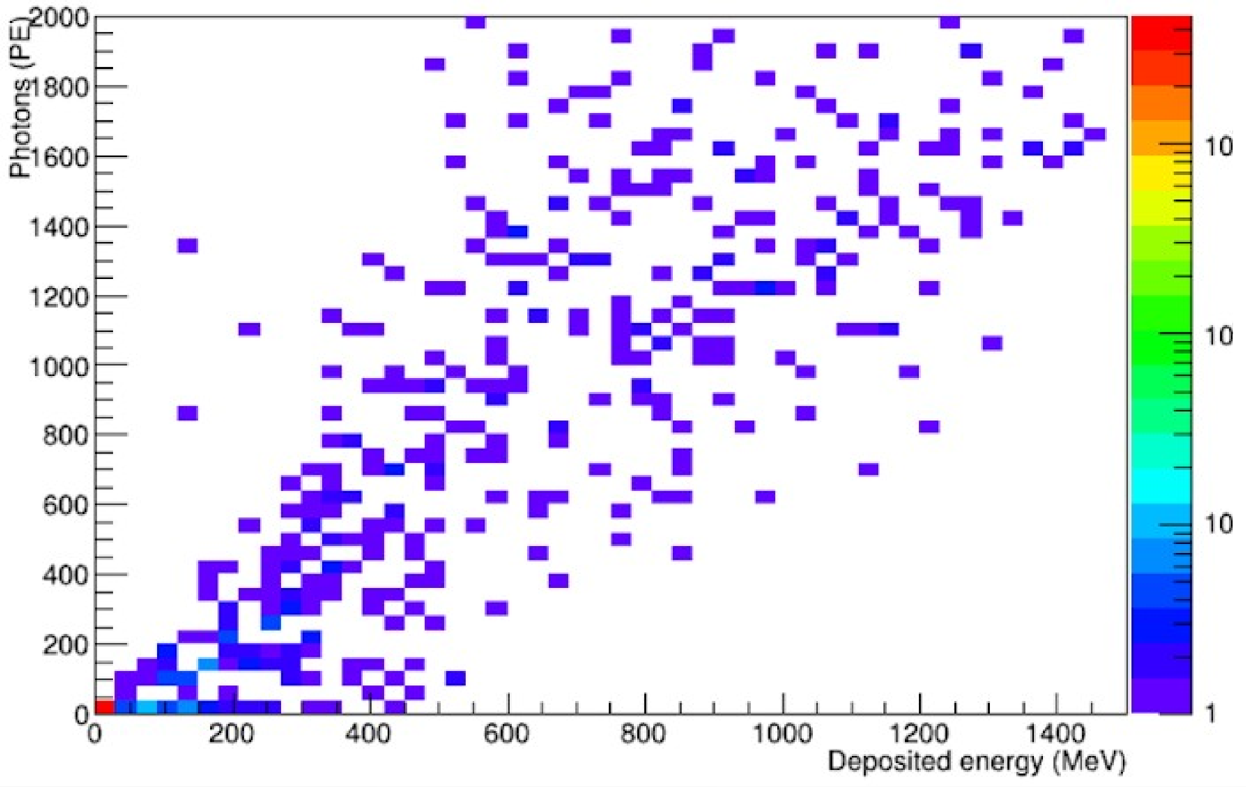
Scintillation+Cherenkov modes
^{39}Ar pileup + γ backgrounds, but significantly enhanced μ signal

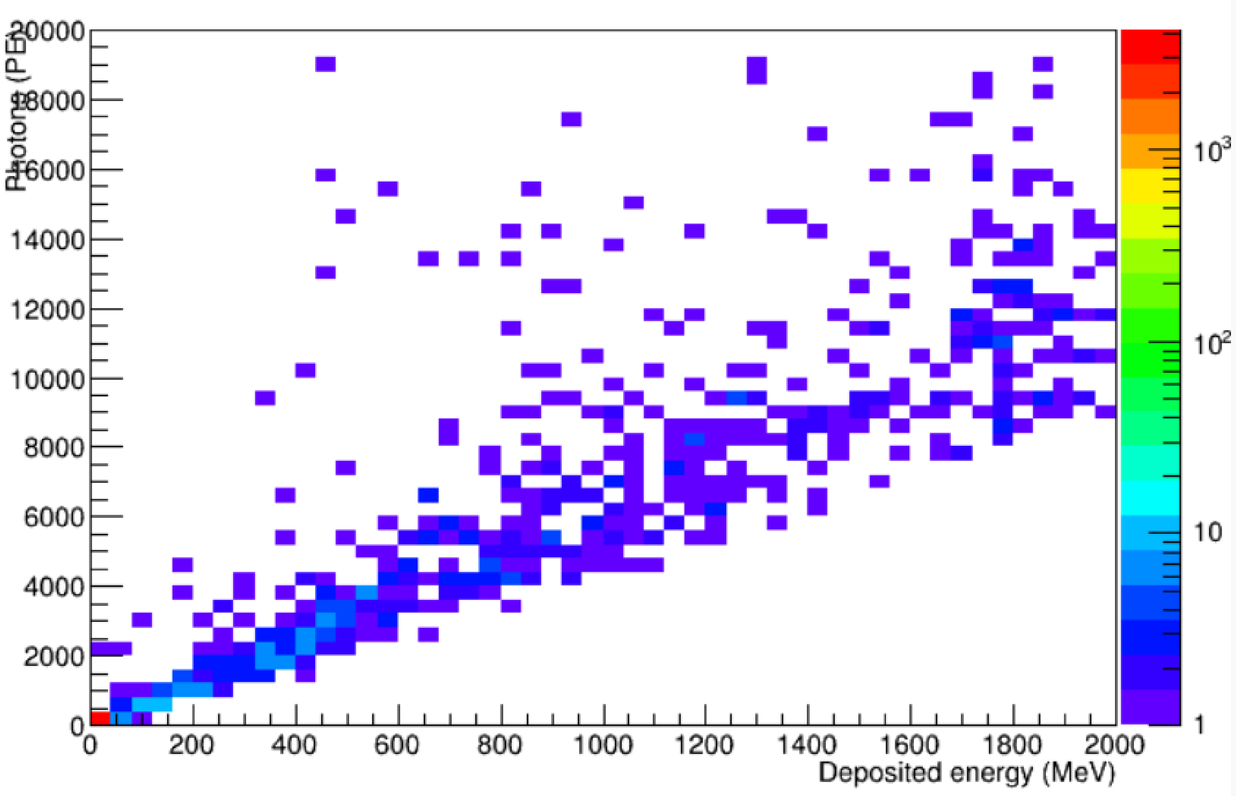
No scintillation: Cherenkov only modes
Negligible ^{39}Ar background, mostly γ's



Phototube coverage ~0.5%

Cherenkov-only modes





92 PMTs, no reflector, no TPB
LY ~ 1.3 PE/MeV ish

92 PMTs, Tyvek reflector, no TPB
LY ~ 6–7 PE/MeV

(Note the different x axes)

Scintillation + Cherenkov mode

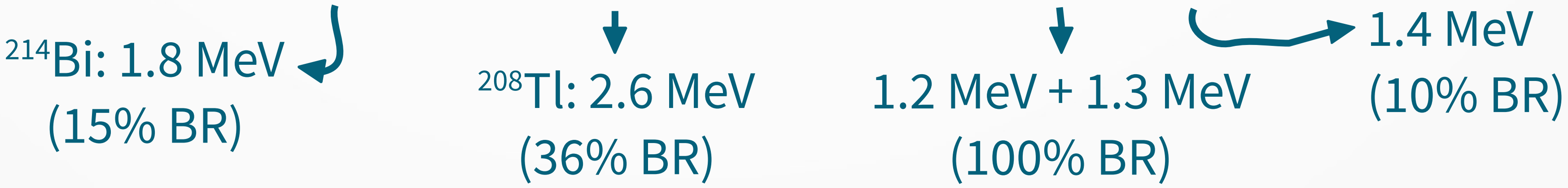
From scaling arguments we naively expect to find a LY ~ 40–400 pe/MeV

Dead time

Full simulations are being developed. For now, the following are some preliminary considerations

- ^{39}Ar: 700 tonnes → 700 kBq!
  - Negligible contribution to Chernekov (expect something like 10 PE/^{39}Ar decay at endpoint)
  - If we need a 5 (10) μs coincidence window to detect scintillation light, then we expect an average of 3.5 (7) ^{39}Ar decays to pile up
    - With a mean β energy of 219 keV, ^{39}Ar pileup will produce a wall below ~800 (1600) keV for Scintillation configuration
- γ-rays from cryostat (from Vicente's spreadsheet): Average 1.9 MeV at 77 kBq

$^{238}U_{up}$ [kBq]	$^{238}U_{mid}$ [kBq]	$^{238}U_{low}$ [kBq]	^{232}Th [kBq]	^{235}U [kBq]	^{137}Cs [kBq]	^{60}Co [kBq]	^{40}K [kBq]
64	59	57	73	2.9	12	6.6	350



^{214}Bi: 1.8 MeV (15% BR)

^{208}Tl: 2.6 MeV (36% BR)

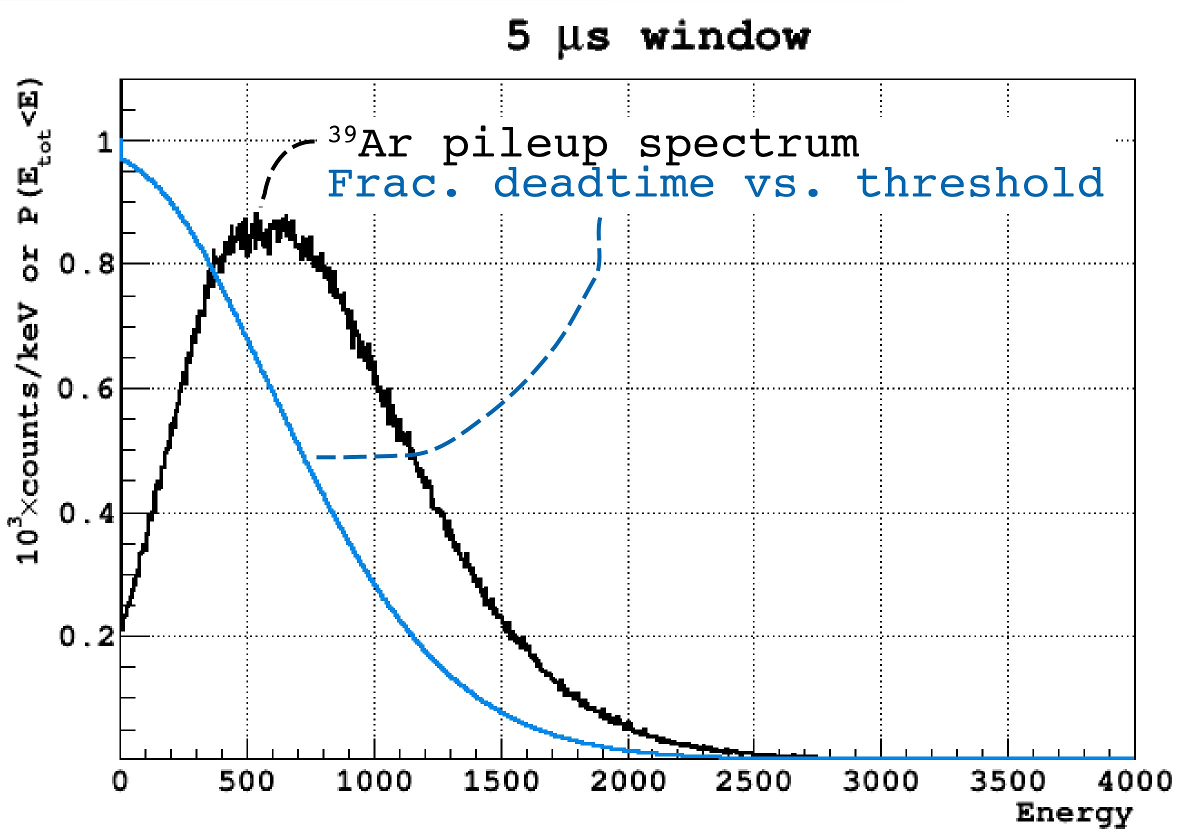
1.2 MeV + 1.3 MeV (100% BR)

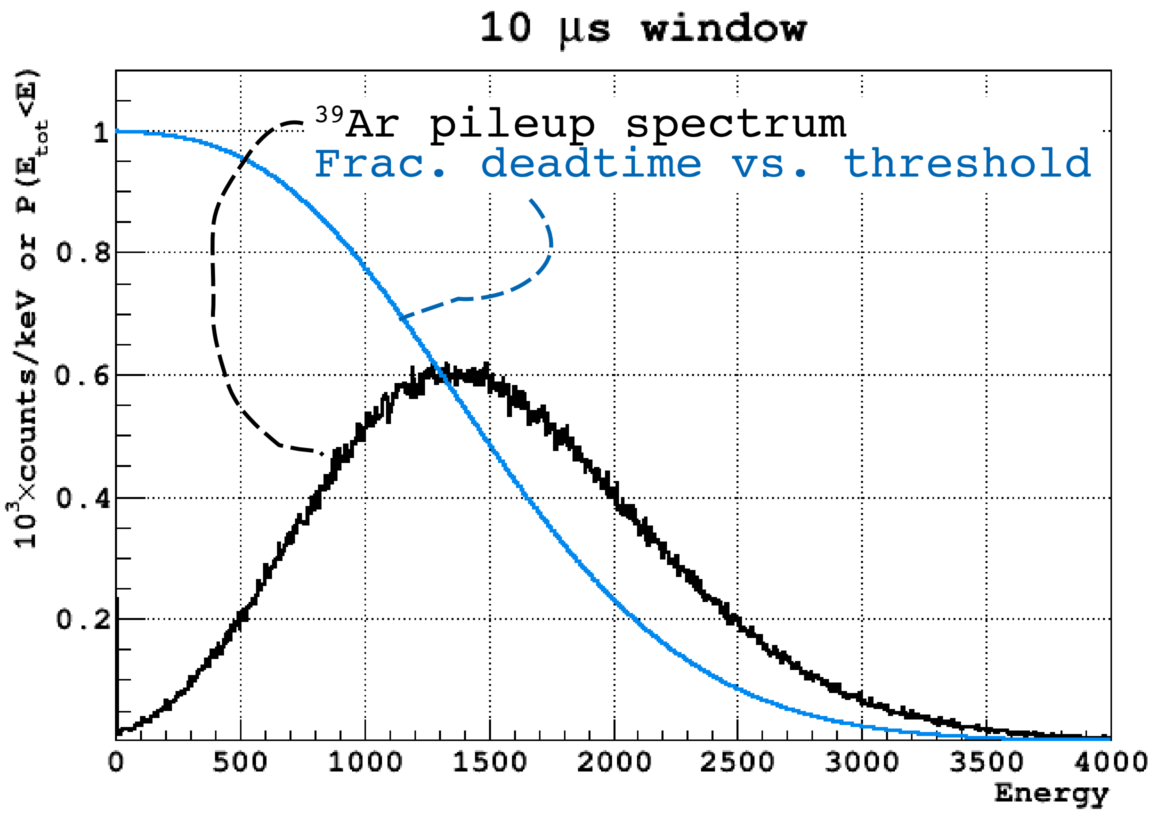
1.4 MeV (10% BR)

  - Assume half of these γ's scatter in LAr, then we have 38.5 kBq background of 1.9 MeV
  - This gives a 20 (40)% pile-up rate below 2 MeV, assuming 100% of γ energy lost in LAr
- γ-rays from rock/lab surroundings: Need reference

Dead time: ^{39}Ar toy MC and lab γ's

For the scintillation case, we will have <10% dead time from ^{39}Ar pileup above ~2.5 MeV





Lacking information of ambient lab radioactivity…

- DS-50 LSV saw ~300 kHz trigger rate prior to filling WCV.
- Assuming γ's have same energy as cryostat gammas, expect ~1.5 (3) pileup events per 5 (10) µs window, summing to 2-5 MeV total.

Veto threshold ~several MeV still seems reasonable

Conclusions

- More FLUKA statistics are needed to pin down final background expectation, along with better models of multiple scatter and fiducial cuts
- However, from the available simulations, the (unrealistically) best case scenario leaves us with two cosmogenic neutron backgrounds in 10 years – we need a muon veto
- It looks like achieving an expectation << 1 will require a muon veto threshold as low as ~50 MeV **and** decreasing neutron veto threshold below 500 keV (a 100 keV threshold works)
- Optical simulations of the muon veto are still under development, but it looks like these goals are imminently achievable with modest instrumentation
  - A 2 MeV threshold on muon tagging seems achievable given backgrounds
- Bonus note: Potentially some interesting neutrino physics through the neutrino absorption channel (ER signal at E_ν-1.5 MeV with a taggable delayed coincidence and a σ) with 700 tonnes of instrumented LAr…

END

At 1600 MeV, we get 115e6 PE. LY ~ 71.8 PE/keV