Possible implementation and collaboration of PHITS at ESS

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European Spallation Source

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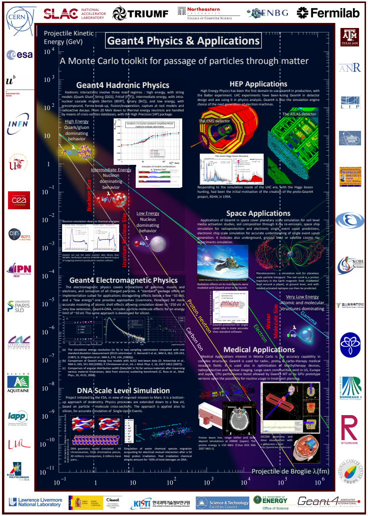
Code Comparisons

- GEANT4 is a C++ framework *for physics*
- GEANT4 has an advanced geometry management system
- Object-oriented, inheritance-based
- Easy to code, nightmare to safety validate (but that's not what it's for)



Code Comparisons

- PHITS and MCNP are monolithic programs
- Program can be validated with standard inputs
- Easy to validate, nightmare to code

Simulation Strategy

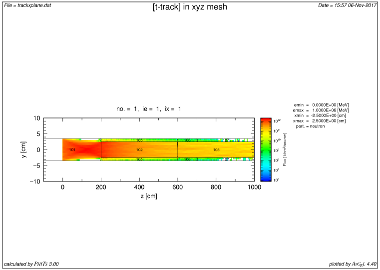
- Use GEANT4 for physics and backgrounds
- Use PHITS/MCNP when necessary for safety

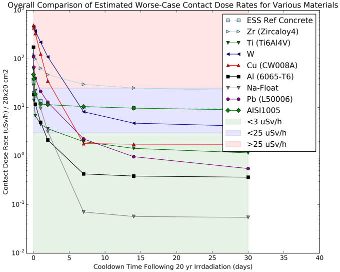
Simulation Strategy Part 2

- PHITS and DCHAIN are actually VERY fast
- Can explore material activation several m away from target in a few minutes on a laptop

Material Activation

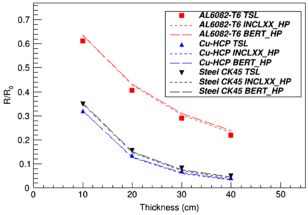
- Good understanding of materials in bunker
- Possible to optimise for human access
- No show-stoppers
- Several “forbidden” materials
- Good convergence with regular communication with Radiation Protection group

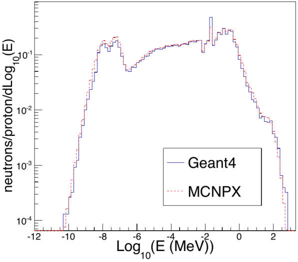




GEANT4 vs Other Tools

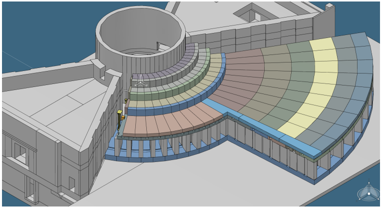
- G4 is free, from CERN, but now worldwide collaboration
- Extremely well benchmarked physics
- Convenient C++ geometry management
- Important for us: Detector group makes highly detailed detector models in GEANT4
- We have spent lots of time benchmarking (see Doug's talk)

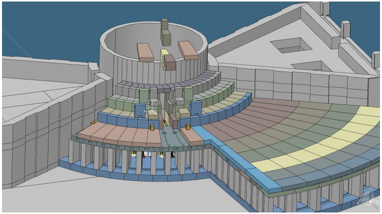




Bunker Model Comparisons

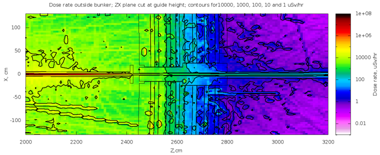
- The bunker is a common shielding area near the target
- (Picture on the right is an older version)
- It is quite large, bigger than the JPARC bunker, but a similar idea



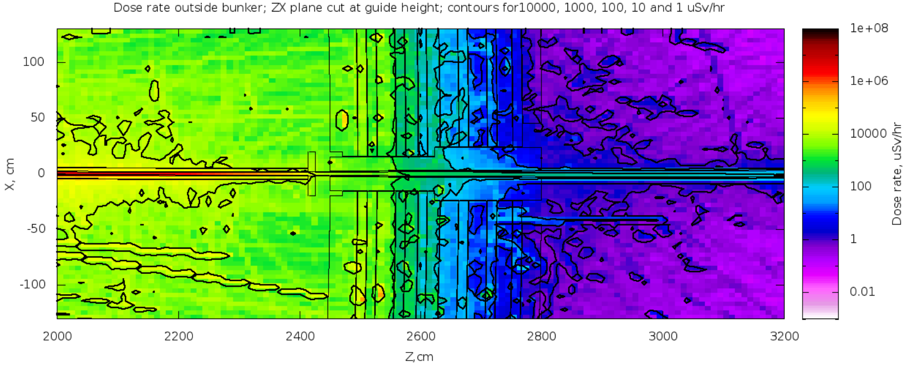


Bunker Model - IFE

- FLUKA work by Rodion Kolevatov (IFE, Norway)
- The dose rate is dominated by neutrons
- Streaming of intermediate energy neutrons through the bunker wall plug affects the dose, leading to a suggestion to add polyethylene near the wall penetration.

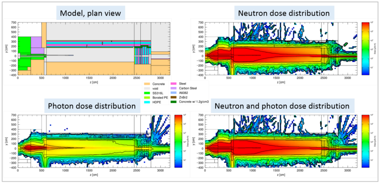


Bunker Model - IFE

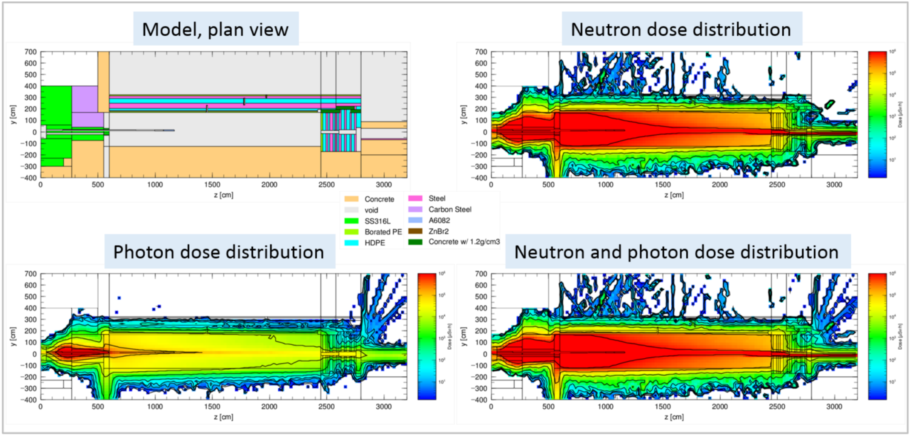


Bunker Model - JPARC

- PHITS work by Kazuo Takeda (RIST, Japan)
- The roof and wall appear to meet the dose rate objectives for neutron dose, but there is no obvious opportunity to remove shielding
- Wall: need for additional *gamma* shielding

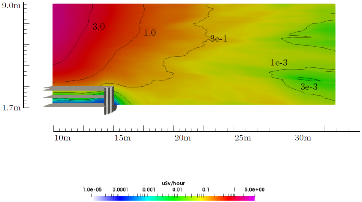


Bunker Model - JPARC

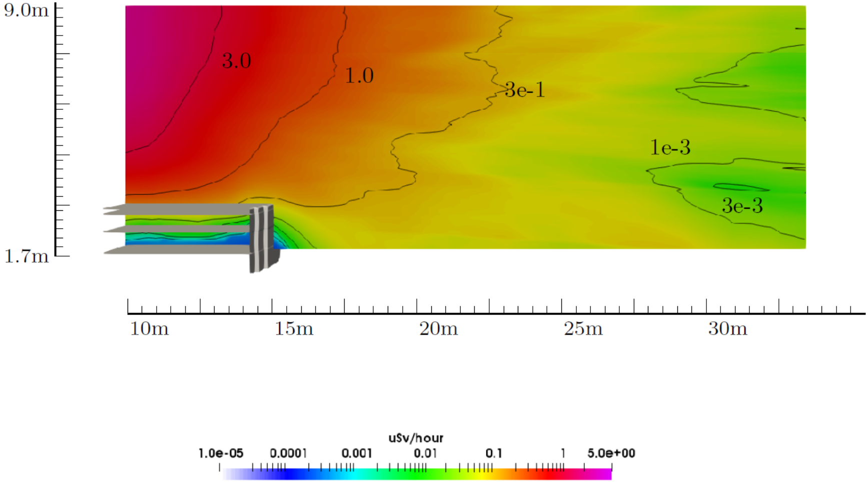


Bunker Model - ESS - Roof

- CombLayer/MCNP work by Stuart Ansell
- In agreement with previous two results

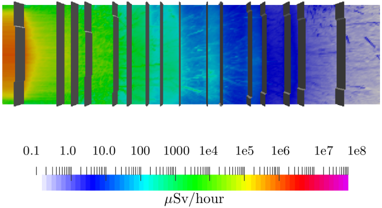


Bunker Model - ESS - Roof

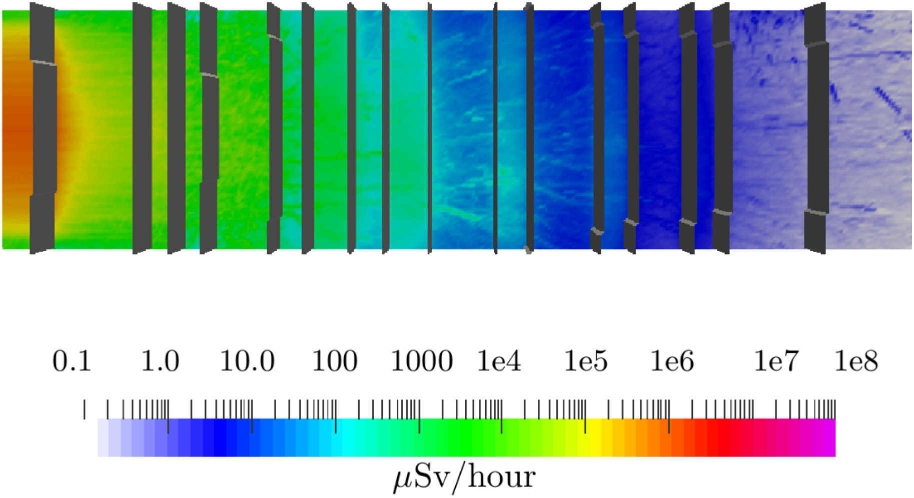


Bunker Model - ESS - Wall

- CombLayer/MCNP work by Stuart Ansell
- In agreement with previous two results
- No guide penetration, additional integration needed for real instrument



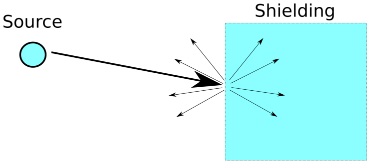
Bunker Model - ESS - Wall

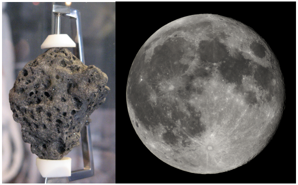


Core Physics

Fast Neutron Albedo

- Albedo refers to scattered rays
- Moon rock is actually black, but appears white in the sky





M Ames; Luc Viatour / www.Lucnix.be

Fast Neutron Albedo

- Between 30% and 70% of fast neutrons are scattered back towards the source
- Easy fact to remember:
  - *roughly half of fast neutrons hitting shielding will come back out again*

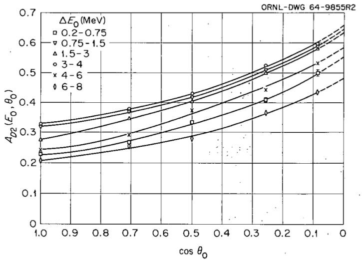
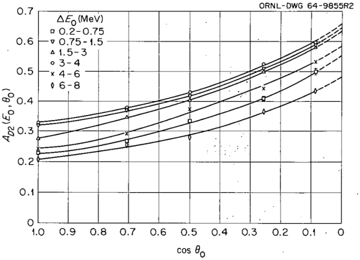


Fig. 4.3. Total Single-Collision Dose Albedo as a Function of cos θ_0 and ΔE_0 for Fast Neutrons (>0.2 MeV) Reflected from Concrete. (From Maerker and Muckenthaler, ref. 1.)

W. E. Selph, ORNL-RSIC-21 (DASA-1892-2)

Fast Neutron Albedo

- Between 30% and 70% of fast neutrons are scattered back towards the source
- Easy simplification to remember:
  - *roughly half of fast neutrons hitting shielding will come back out again*
- Compare that with supermirrors!
- Of course, supermirrors only work at very small grazing angles...



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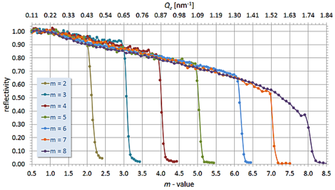
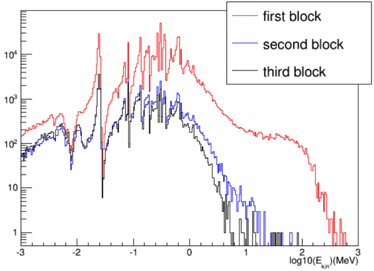


Multiple Line of Sight

- Losing line of sight if possible saves cost
- Certainly helps with background
- Diminishing returns after $2\times$ LOS
- Twice line of sight is recommended strategy for cost and background
- Instrument project should look at at least one option



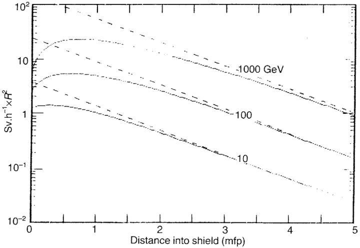
V. Santoro *et al*

Secondary Particles

- Pion production begins at energies of order 100s MeV
- Hadrons (neutrons, protons) of this energy are readily scattered
- Each pion can also scatter
- Any interaction can free neutrons
- This *is* spallation

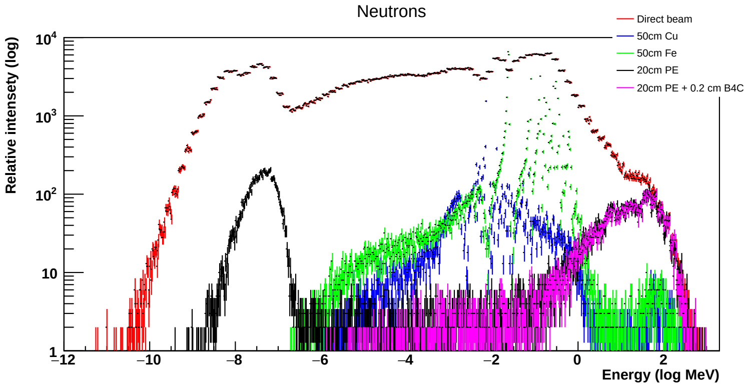
Secondary Particle Equilibrium

- Secondary neutrons are important
- Simplification:
  - Logarithmic behaviour only begins below pion production
- Usually this is 3 MFP
- Adding shielding might make a problem worse!
- Empty spaces can be good
- Guessing can be difficult, we need to simulate



A. H. Sullivan, ISBN 1 870965 183 (1992), p. 39

Hadronic Shielding Materials

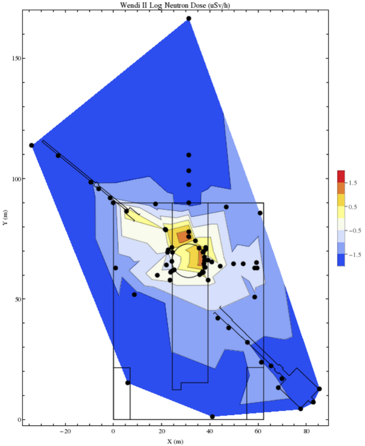


C. Cooper-Jensen *et al*, in preparation

Survey of SNS

Three brightest *n* sources:

- Harp / A2T source — mitigated by interface with Tom Shea (Accelerator)
- Monolith interfaces — earthquake gap between target & bunker!
- Basis shielding — mitigated by margin of error on the LOS.



DiJulio *et al*, Journal of Physics: Conference Series 746 (2016) 012033

Survey of SNS

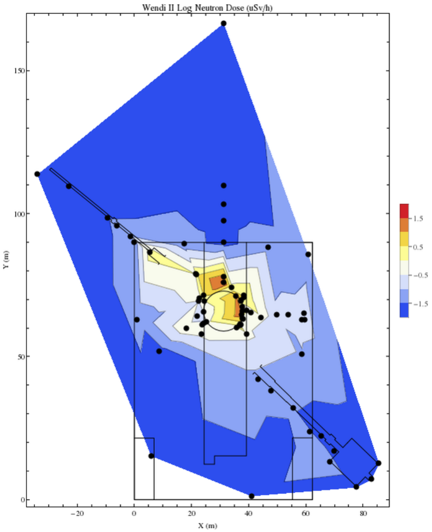
- Earthquake gap is a problem at any facility
- Conflicting requirements!

Survey of SNS

Other interesting facts:

- The accelerator is quiet
- POWGEN straight beamline is OK
- BASIS thin shielding is OK out of line of sight

We thought we might see a safe but significant number of fast neutrons there, but we didn't.



Background Requirements

Requirements

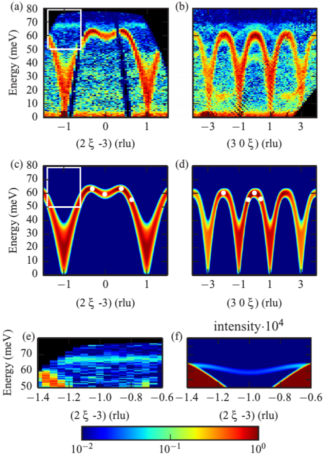
- "The world's leading neutron source"
- Interpreted by almost all instruments as exceeding current world leading signal-to-noise by factor of 10 [1]
- Typical numbers:
  - $10^{-6} - 10^{-7}$ elastic line to background on inelastic spectrometers
  - 6-8 decades on log-log plot for SANS & Reflectometry
  - 10^{4} Bragg-peak to background on diffraction

[1] NOSG Handbook, ESS-0039408

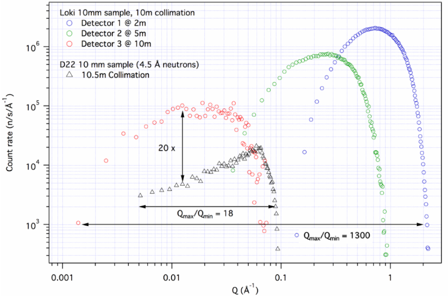
The Problem

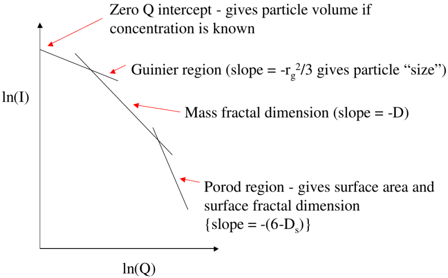
- Background limited science is frequently on a log scale.
- Weak scattering
- Small samples
- “New horizons in science”...
- The instruments are still radiologically safe

Spectroscopy

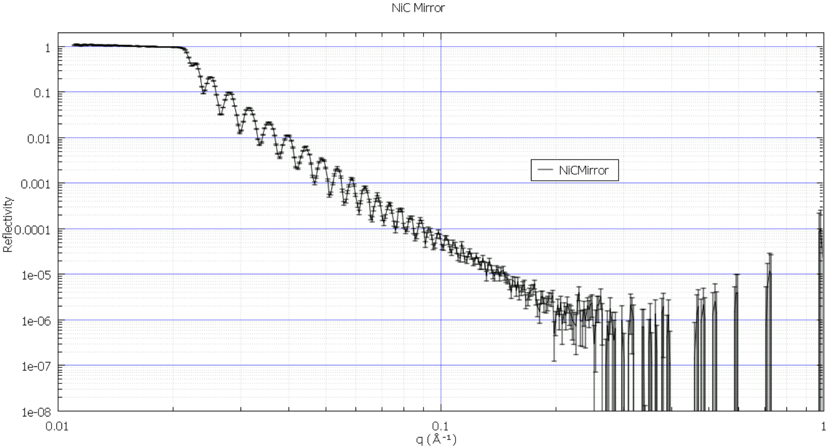


SANS

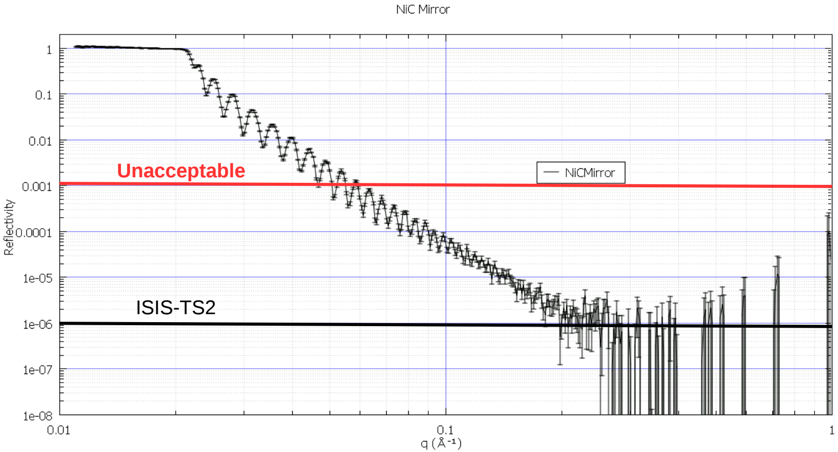

Loki 10mm sample, 10m collimation
Detector 1 @ 2m
Detector 2 @ 5m
Detector 3 @ 10m
D22 10 mm sample (4.5 Å neutrons)
10.5m Collimation
20 x
Q_{max}/Q_{min} = 18
Q_{max}/Q_{min} = 1300
Count rate (n/s/Å^{-1})
10^3
10^4
10^5
10^6
0.001
0.01
0.1
1
Q (Å^{-1})


Zero Q intercept - gives particle volume if concentration is known
Guinier region (slope = $-r_g^2/3$ gives particle “size”)
Mass fractal dimension (slope = -D)
Porod region - gives surface area and surface fractal dimension {slope = $-(6-D_s)$}
ln(I)
ln(Q)

Reflectometry — 10^{-6} is Possible

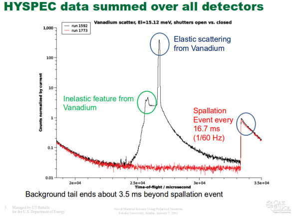


Reflectometry — 10^{-3} Doesn't Cut It

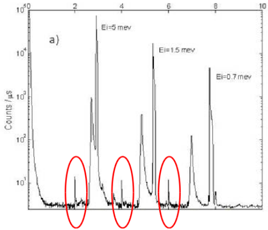


Background Requirements

- SNS CNCS and HYSPEC: BG$\approx$ 11-30 n s^{-1} whole detector).
- BG:S $\approx 10^{-3}$
- $\sim 100\times$ too high
- Instrument proposals: 10^{-6}–10^{-8} n m^{-2} s^{-1}
- TS2 and LET internal backgrounds are so low you even see TS1 background



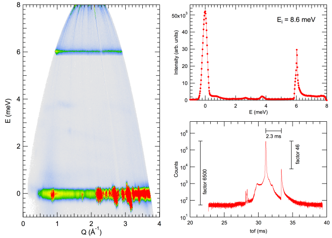
HYSPEC (SNS), 100$\times$ too high

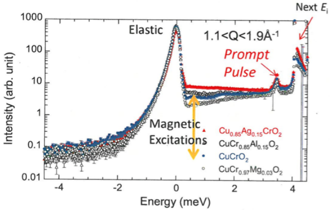


LET (ISIS) Acceptable

Background Requirements

- Similar problems on CNCS
- Similar problems at JPARC

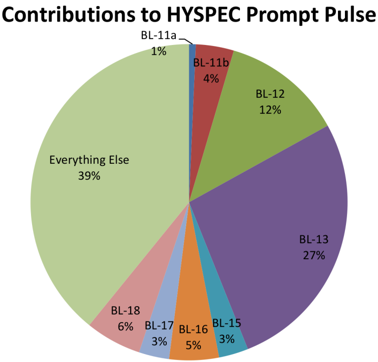




Amateras (JPARC)

HYSPEC Background Sources

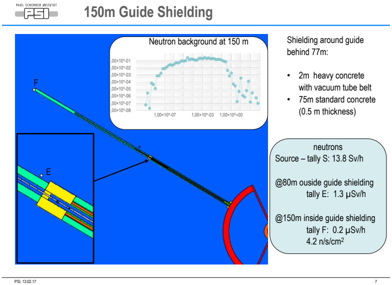
- Not trivial to debug backgrounds
- Even if you find sources, fixing them can be expensive
- Need to fix as much as possible during early design



M. Smith *et al*, ORNL/TM-2015/238

Cave Echo Estimate at 150 m

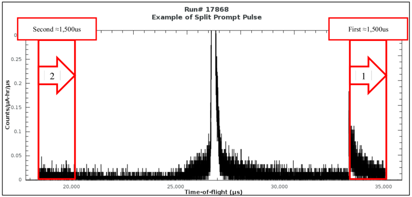
- MAGIC source (Uwe Filges) 4 neutrons /cm2 /s
- Fairly flat spectrum from keV to 1 MeV



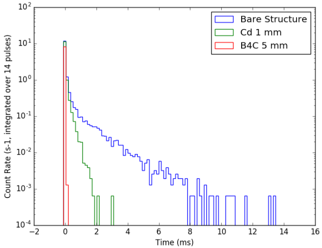
U. Filges (PSI)

ns Pulse — Compare Model to Other Spallation Sources

- $5 \times 5 \times 5\ m^3$ cave
- "Bare structure" tail matches time structure very well
- *No skyshine, A2T, target, bunker, crosstalk*
- Illustrates the fast suppression of boron, compared to cadmium



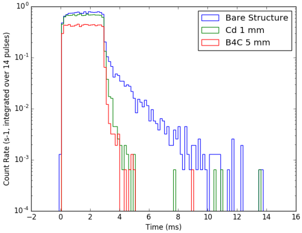
M. Smith et al, ORNL/TM-2015/238



Simple model (MCNP+GEANT4+python script)

ESS Pulse (CSPEC,TREX)

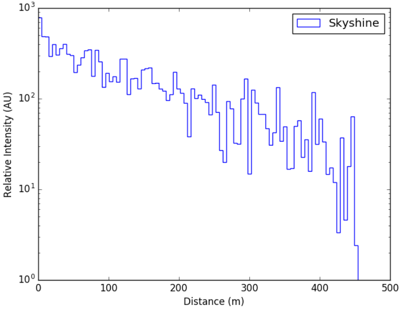
- $5 \times 5 \times 5\ m^3$ cave
- $\sim 5\ \text{m}^2$ detector area
- $+$ TOF broadening (150 m flight)
- 1 n/s fast neutron count rate
- TREX has $\sim 5{\times}10^4$ n/s signal
- These numbers are consistent with 10^{-4}



Simple model (MCNP+GEANT4+python script)

Preliminary Skyshine Results

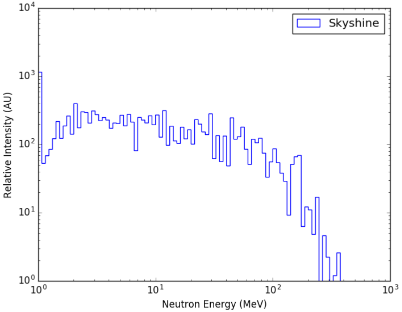
- The ESS accelerator is very powerful
- Skyshine covers the whole site



VERY PRELIMINARY results :)

Preliminary Skyshine Results

- Broad distribution of energies $\sim$ 100s MeV
- Skyshine signal is *large*: 10s n /m^2 /s



VERY PRELIMINARY results :)

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- Rob Dalgliesh (ISIS)
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- Franz Gallmeier (SNS)
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Thank You

Thank you for your attention