SAND2015-5205C

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SNL WORK ON COHERENT SCATTERING

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

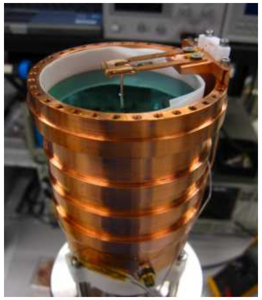
Overview

- Seven introductory slides:
  - Neutrinos for reactor monitoring
  - ULGeN project description
  - COHERENT collaboration
- Twelve slides on NSC measurements at SNS

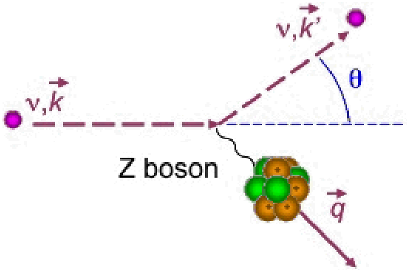
ULGeN project

- **ULGeN**: Ultra-Low noise Germanium Neutrino detection system; an NA22 collaboration between Sandia and Lawrence Berkeley.

- **Target / Detector:** Large-mass High Purity Germanium (HPGe) detector with ultra-low electronic noise threshold

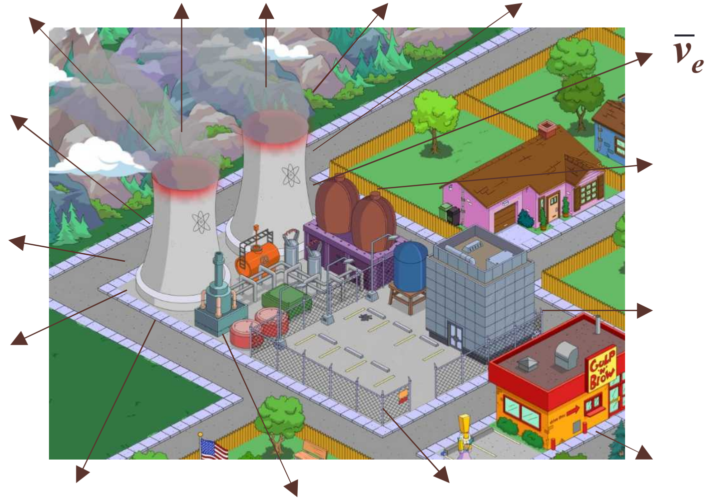


- **Antineutrino process:** Coherent Neutrino–Nucleus Scattering (CNNS) interaction.

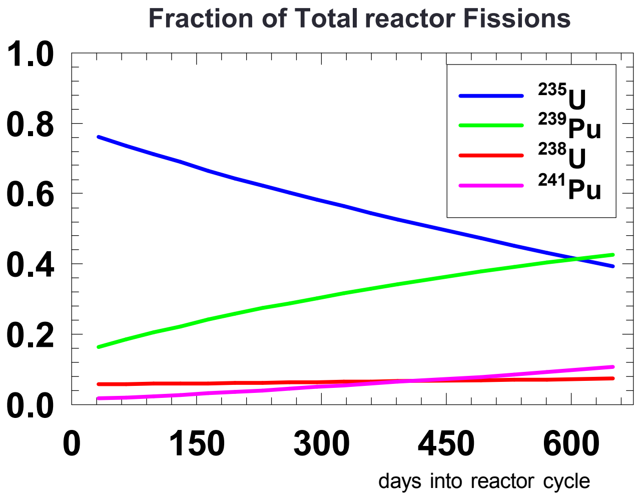


Motivation: Neutrinos for Reactor Monitoring

- 6 antineutrinos per fission from beta decay of daughters
- 10^{21} fissions per second in a 3,000-MWt reactor
- About 10^{22} antineutrinos are emitted per second from a typical reactor unattenuated and in all directions



- The isotope fuel composition changes during the reactor fuel cycle: ^{235}U is consumed and ^{239}Pu is produced
- Different antineutrino spectra from ^{235}U and ^{239}Pu
- Measured antineutrino rate is sensitive to the isotopic composition of the core



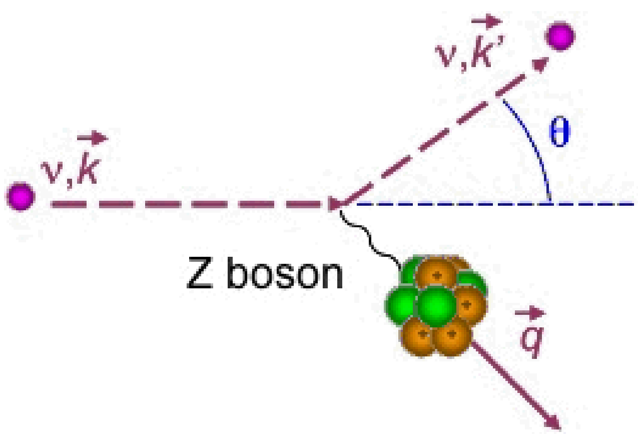
Coherent Neutrino-Nucleus Scattering (CNNS)

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

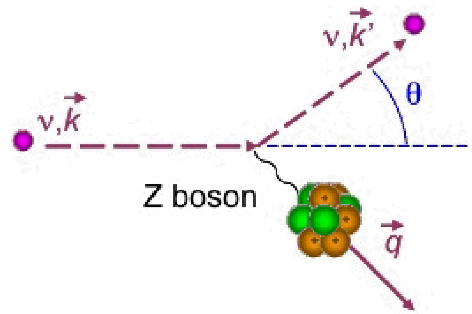


- Same for all (anti)neutrino flavors
- Cross-section is >10^2 times higher than inverse-beta decay for reactor antineutrino energies (< 9MeV)

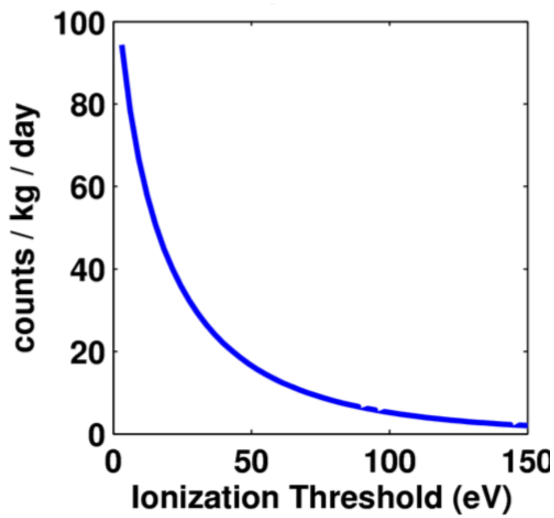
It has never been observed!

Reactor anti-ν_e signal vs. HPGe threshold

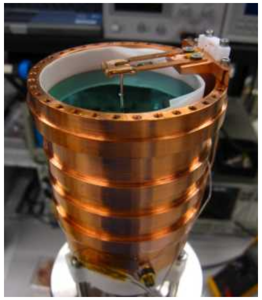
- Reactor antineutrinos cause Ge nucleus recoils with energy < 3keV. But Ge nucleus recoils can only deposit up to 0.6keV in the form of detectable ionization of electron-hole pairs
- Event rate mainly dependent on energy threshold: threshold reductions in 100eV can increase rate an order of magnitude



Ge detector Threshold (eV)	CNNS counts / kg /day at 25m from core
300	~0.08
200	~0.60
100	~5.01

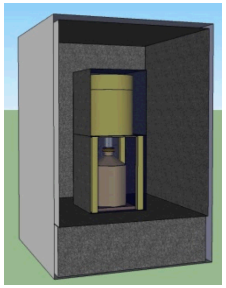


ULGeN Goals and Update



1 pF, 1pA, <100 eV
Ge Detector

LBNL: Electronic work



Active / Passive
Shielding

SNL: Background work

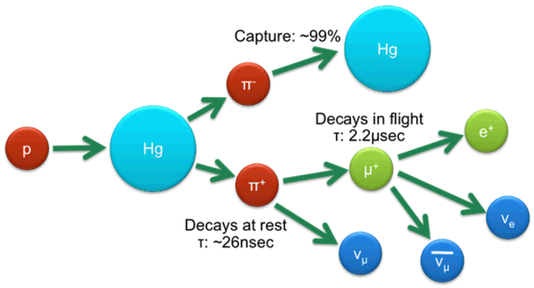
Deployment at Nuclear
Power Plant (NPP)

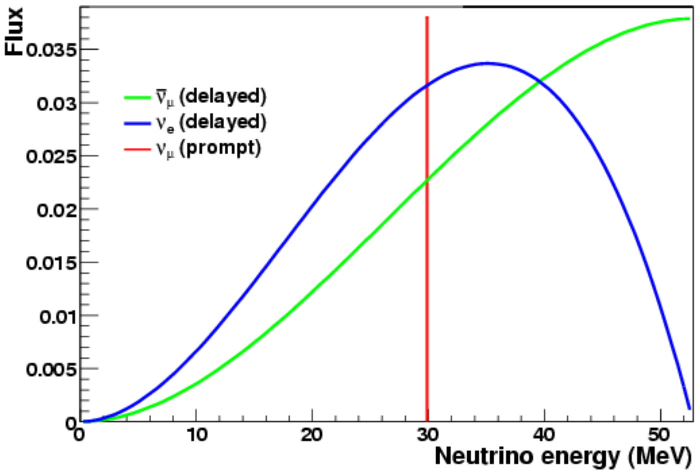
However, deployment at reactor not possible:

- Electronic work will not achieve ultra low noise technology within project timeframe for reactor deployment
- Permanent shutdown of SONGS forces us to search for other feasible reactors and neutrino sources.

✧ The Spallation Neutron Source (SNS) at ORNL produces a neutrinos of greater energies that would allow a deployment with *existing* Ge technology.

Physics of a CNNS measurement at Spallation Neutron Source

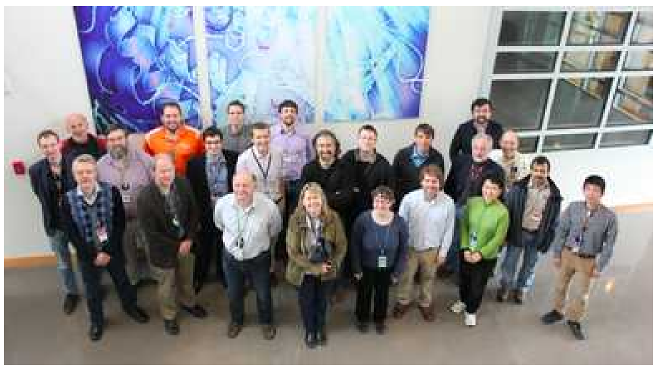




- The more energetic neutrinos from the Spallation Neutron Source (SNS) cause Ge recoils of detectable ionization energy **up to ~25keV.**
- **First-time observation of CNNS** is possible with *existing* Ge technology, the so-called p-type point contact (PPC) detectors with threshold ~ 1keV.
- Lower neutrino flux of ~10^7/cm^2/s (compared to ~10^{12}/cm^2/s from a reactor) would require larger Ge target mass, **about tens of kg**.
- Beam timing (60Hz pulsed beam) allow **to reject backgrounds** by a factor of ~10^4.

COHERENT collaboration

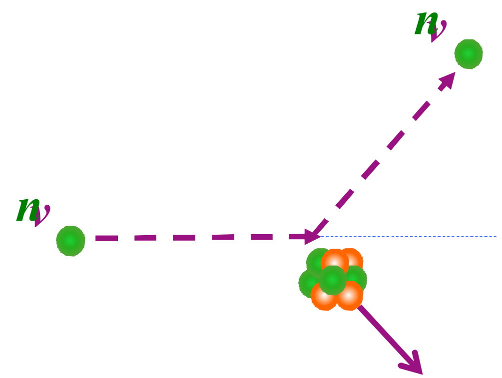
- Measure CNNS at SNS: ~50 collaborators, many institutions.
- Not only Germanium: 3 proposed targets Ge, CsI, and Xe.



Background measurements at SNS

Fast neutron background at SNS

- Neutrinos and Neutrons both create same nuclear recoils spectra.
- Neutrons of E_n = 100keV-1MeV have highest probability of creating a nuclear recoil, but these can be shielded.
- SNS creates fast neutrons at beam time (up to ~hundreds of MeV): these can create low-energy neutrons in the shield and are a concern.



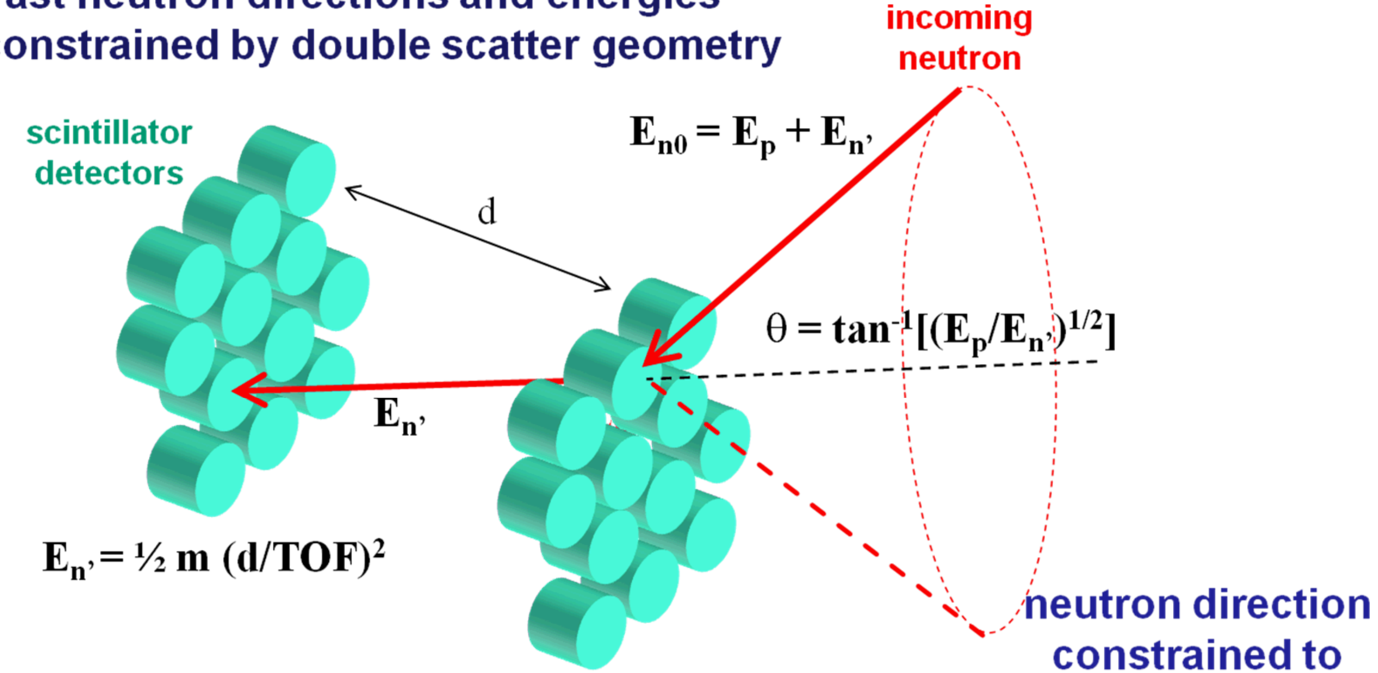
Measure neutron background at candidate SNS locations in order to determine their viability for CNNS experiment.

➡ Neutron Scatter Camera

What is a Neutron Scatter camera?

- Fast neutron imaging spectrometer
- Variable plane separation allows tradeoff of effective area, image resolution

Fast neutron directions and energies constrained by double scatter geometry



Multimode capability includes
- ***Neutron energy spectrum.***
- ***Compton imaging.***

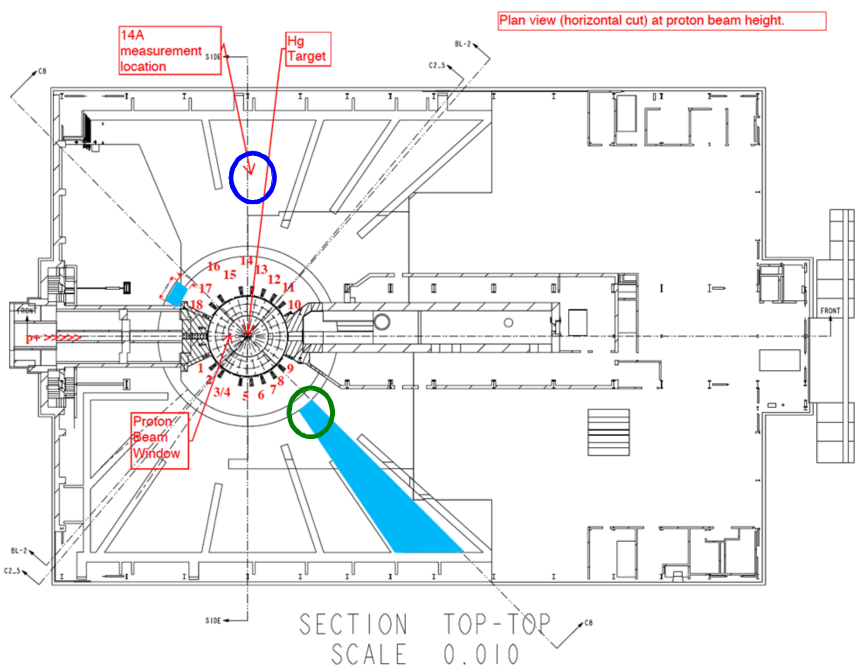
Measured SNS locations

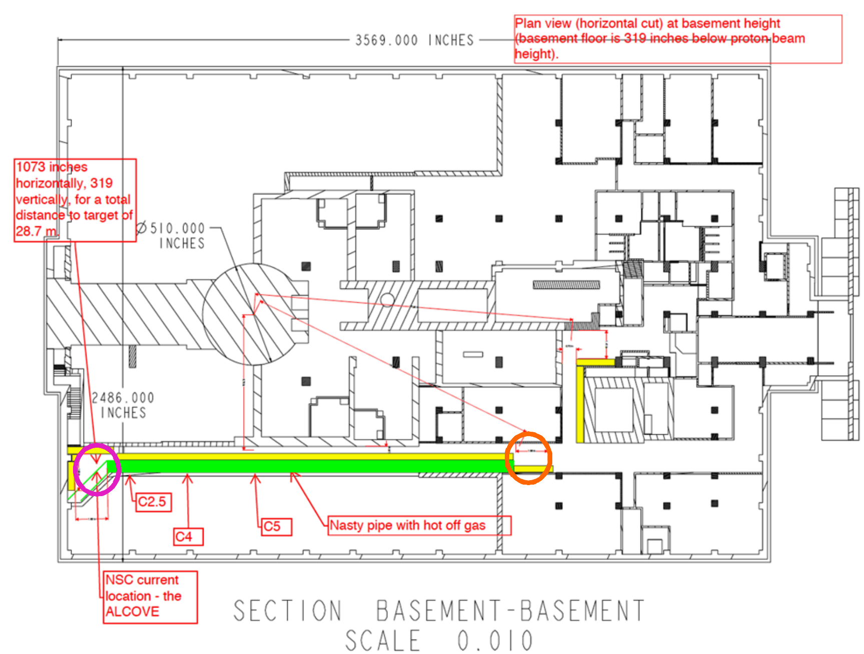
Experimental hall at ground level:

- **Location 1**: beamline 14a
- **Location 4**: beamline 8

Basement:

- **Location 2**: alcove near C2.5
- **Location 3**: C11





Summary of NSC data at SNS

Location 1: Beamline 14a:

2013

On | Off | On

Aug 15 | Sept 30 | Oct 3 | Oct 29 | Dec 6

Location 2: Basement 2.5:

Location 3: Basement 11:

2014

On | Off | On | Off | On | On

Jun 20 | Jun 25 | Sept 18 | Oct 21 | Oct 28 | Nov 19 | Dec 21

Location 3: Basement 11

Location 4: Beamline 8

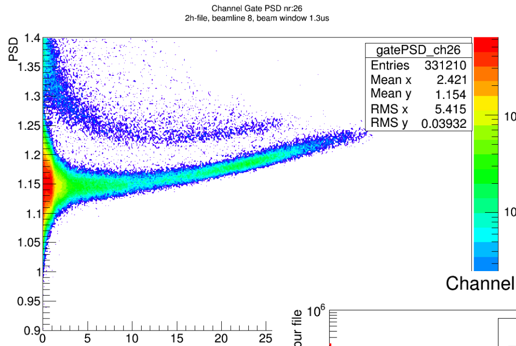
2015

Off | On | On | Off | On

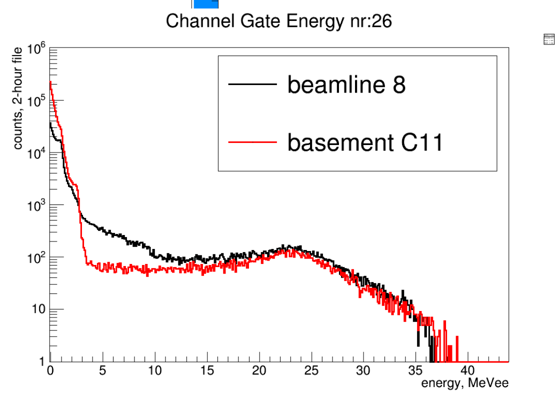
Jan 8 | Jan 17 | Feb 18 | Apr 6 | Apr 11 | Apr 21 | Present

Data analysis details

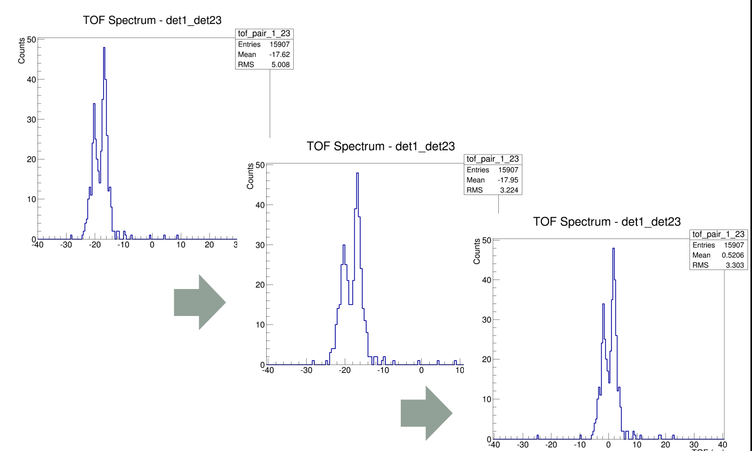
For 32 ADC channels with saved traces and ADC gates sums, and for each location:



1. Compute PSD cuts to select neutrons



2. Calibrate energy: simulation of K40, Tl208 and muon spectra in NSC cells.

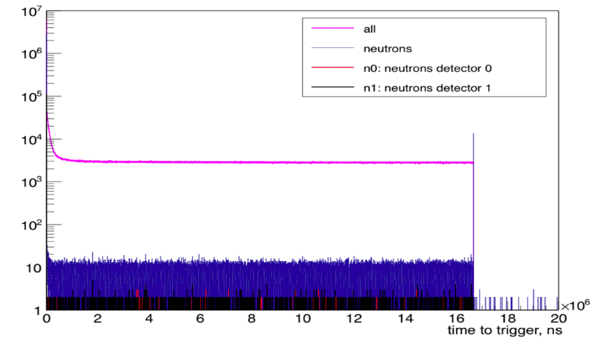


3. Compute TOF adjustments:
   - channel time offset applicable to all data
   - ADC time offset for each 2-h data file

Beam timing

- beam every 16,666,6667ns
- **beam extraction window: 1.3us**
- **post beam window: 2.2us**

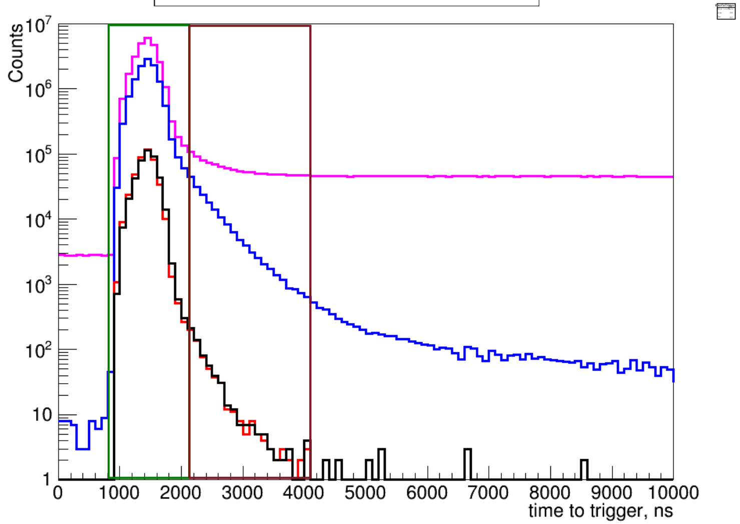
Time to trigger plot from 0-16.6ms:
See zoomed bottom plots



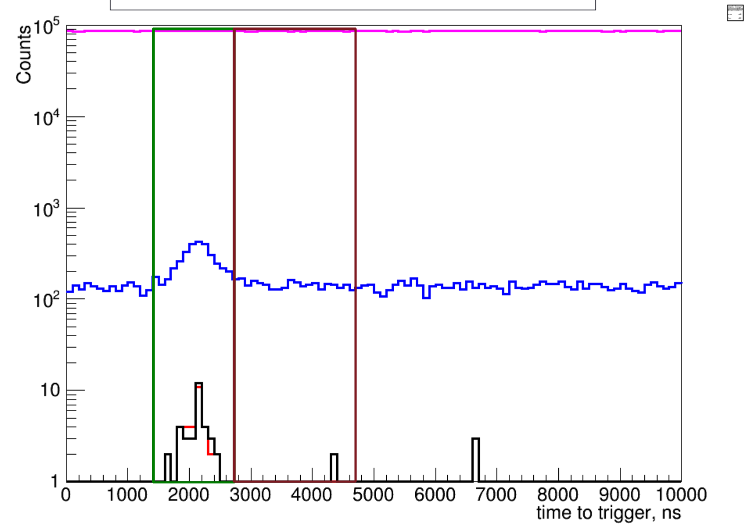
NSC events with respect to the proton beam time:

- **pink**: all events
- **blue**: PSD neutron selection
- (**red**,**black**) neutron (n_0,n_1) selected by the NSC

Beamline 8 full data set



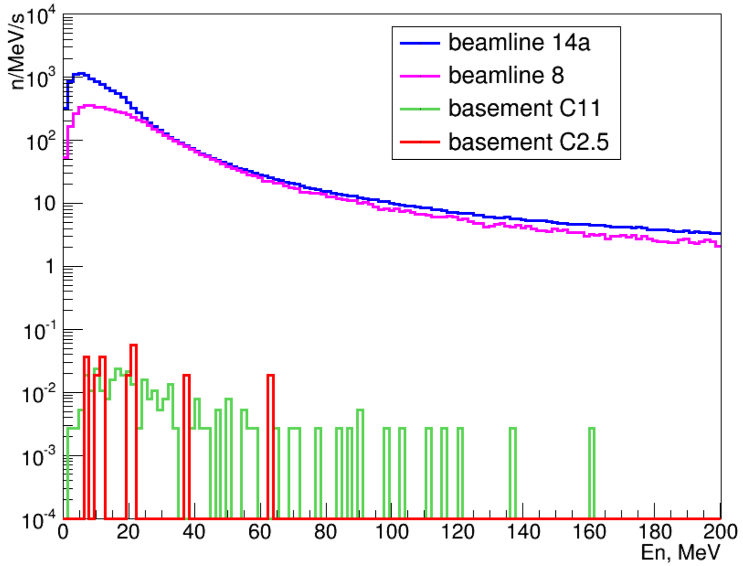
Basement C11 8 full data set



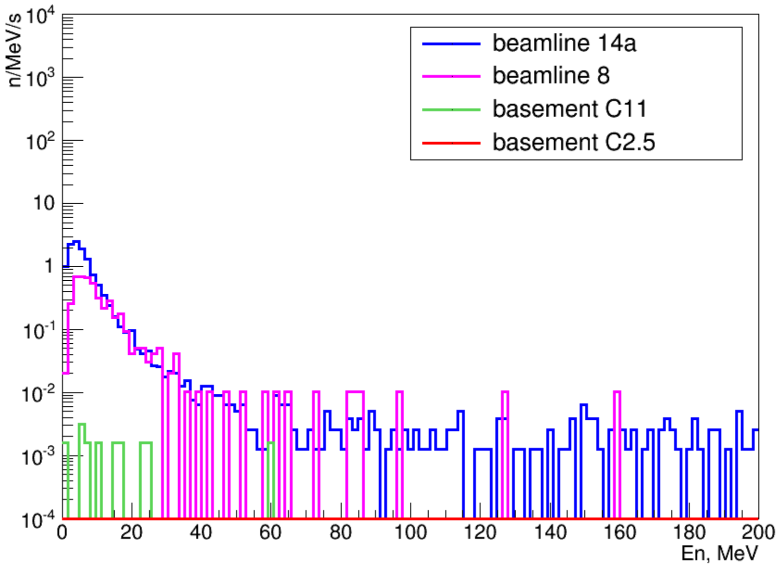
Neutron Spectra normalized by Live Time

- The following histograms are obtained from the reconstructed neutron energy histograms, restricted to the indicated time window, over each full dataset, normalized by the **total "window" live time of that dataset**, and then divided by the energy bin width (1.6MeV).

Beam window 1.3us

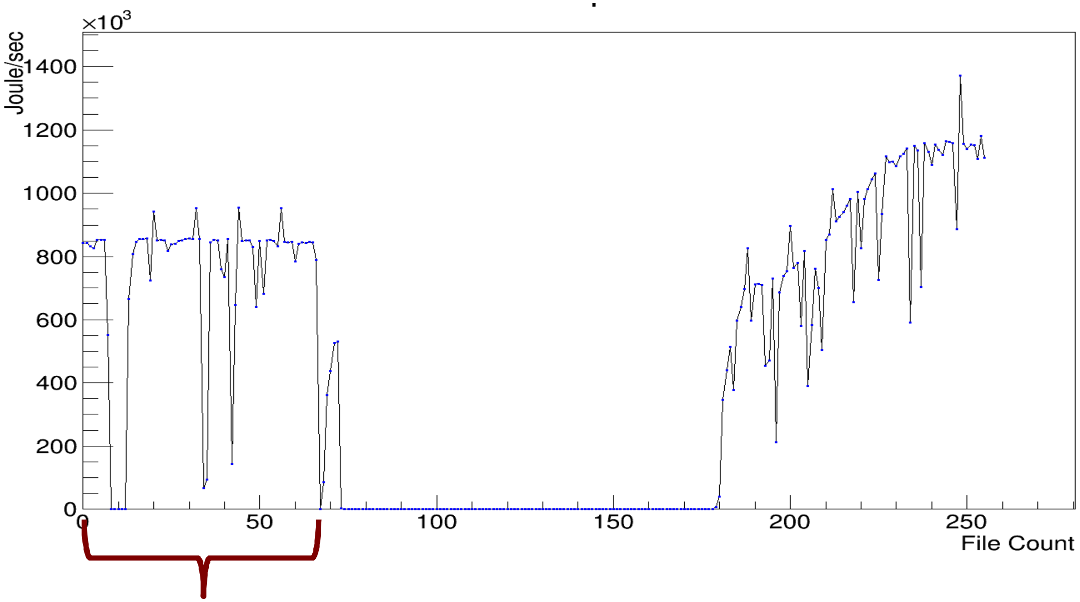


Post beam window 2.2us: larger neutron suppression in basement



Beam power varies a lot

- Since SNS beam power (in joules/sec) is not constant, neutron production will also vary
- It makes more sense to report spectra per beam power



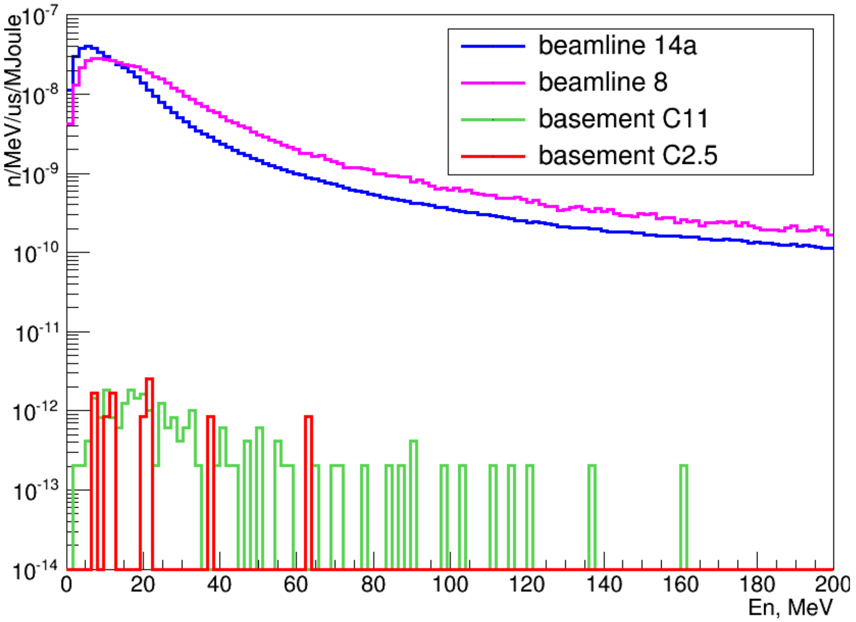
Example of beam power reported by SNS during the time of each 2h-data file

Beamline 8 data: April 6, 12:00, to April 11, 18:00, 2015

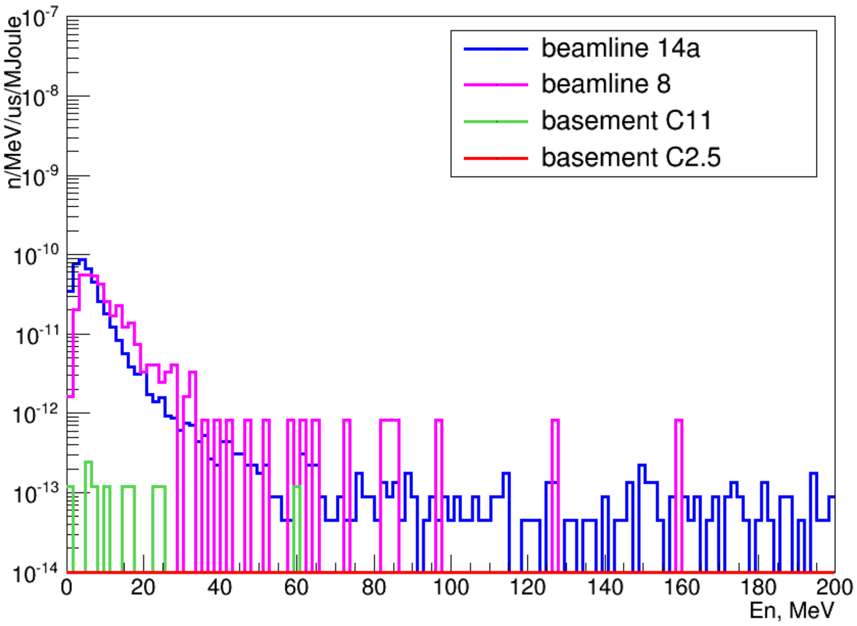
Neutron spectra normalized by Beam Power

- The following histograms are obtained from the reconstructed neutron energy histograms, restricted to the indicated time window, over each full dataset, normalized by **the total beam power of that dataset** and by **the time window duration**, and then divided by the energy bin width (1.6MeV).

Beam window 1.3us

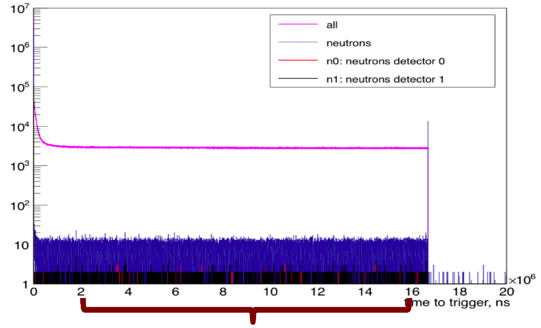


Post Beam window 2.2us

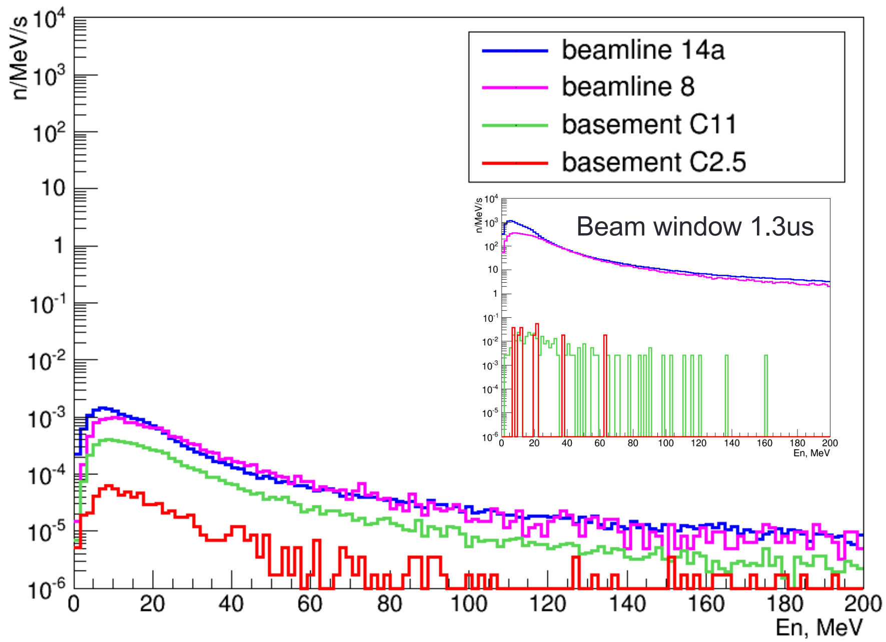


Steady Neutron Background

- The steady neutron background can be extracted from a time window that excludes beam.
- We select 14ms of out-beam window (see plot)
- For beamline 14 a, we checked that Beam-Off spectra matches the Out-Beam spectra
- Even at ground level, steady background is orders of magnitude lower than during the beam window
- Rates match the locations overburden:
  - Beamline 14a and 8 are at ground level
  - Basement C11 is just below the experimental hall, while C2.5 is under the concrete monolith



Out-beam window 14ms

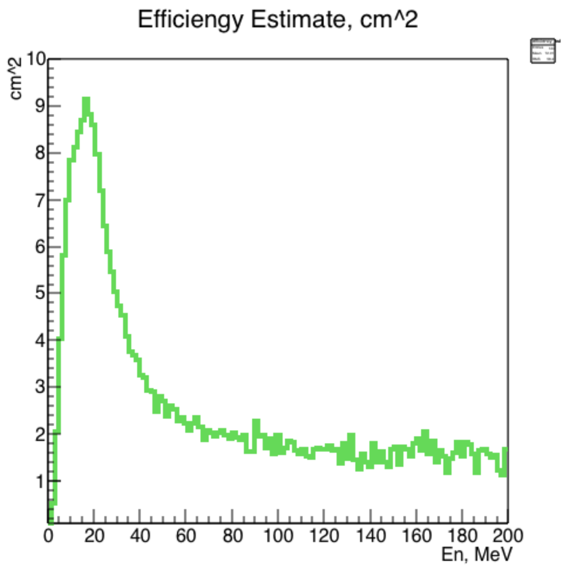


NSC Efficiency Estimate

- An absolute value of the neutron flux (in units of n/cm^2) is needed in order to calculate the background produced in each of the different detectors.
- For that, we need the NSC efficiency: hard to simulate for angular and energy dependence, but in the works.
- As a rough estimation of the NSC approximates the Ziegler spectrum:

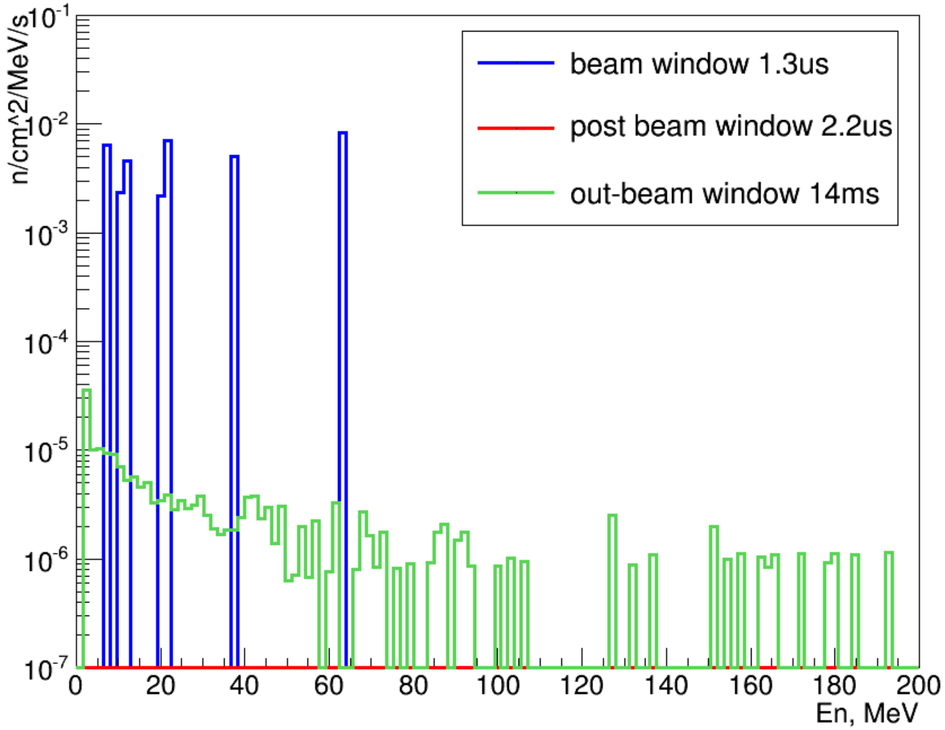
$$\text{Efficiency(cm}^2\text{)} = \frac{\text{Aboveground Steady Background(n/MeV/s)}}{\text{Ziegler Flux (n/MeV/s/cm}^2\text{)}}$$

$$\text{Absolute Flux (n/MeV/s/cm}^2\text{)} = \frac{\text{Measured rate (n/MeV/s)}}{\text{Efficiency (cm}^2\text{)}}$$



Estimated Neutron Fluxes and

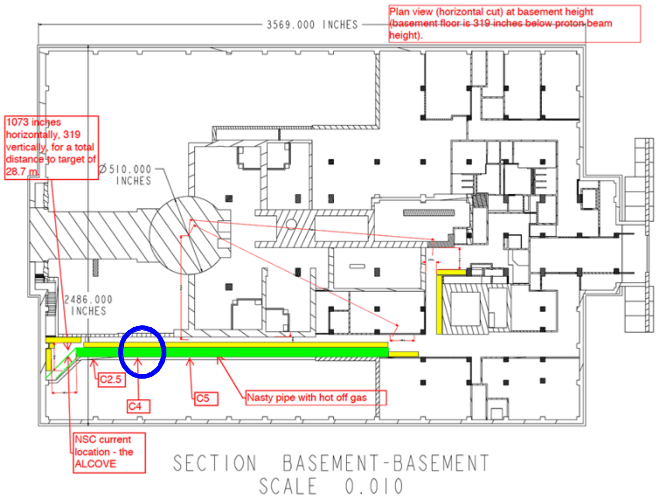
- Basement C2.5 used as an example of the neutron flux in n/cm^2/MeV/s obtained from the estimated efficiency



NSC Measurements output and future

Based on these measurements, the current collaboration is estimating that:

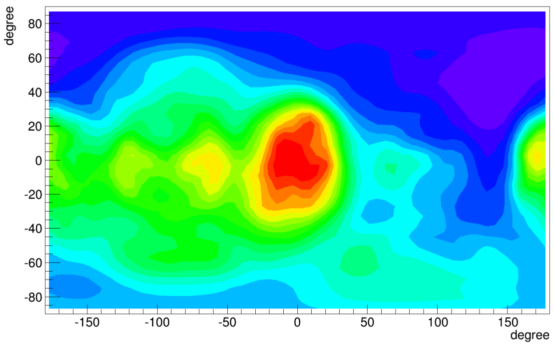
- The most likely candidate location to deploy the planned Germanium detector is a position C4 just few meters from basement C2.5 but also few meters closer to the SNS target
- The post-beam "delayed" window background shows significant reduction in hard-to-shield high-energy neutrons
- More NSC measurements planned at C4 location



Images during 1.3us beam window

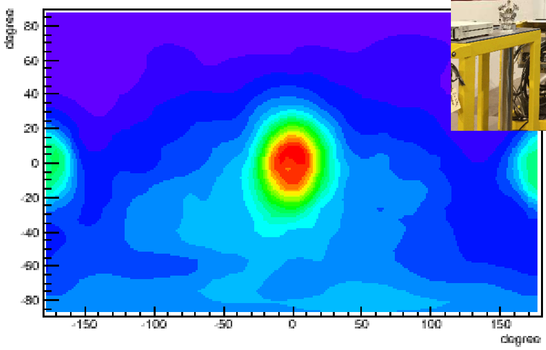
These images are created dividing by background image in order to normalize angular efficiency variations:

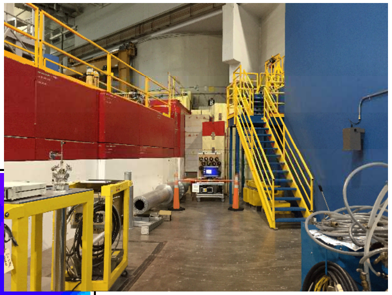
Beamline 14a



0^0 towards the SNS target

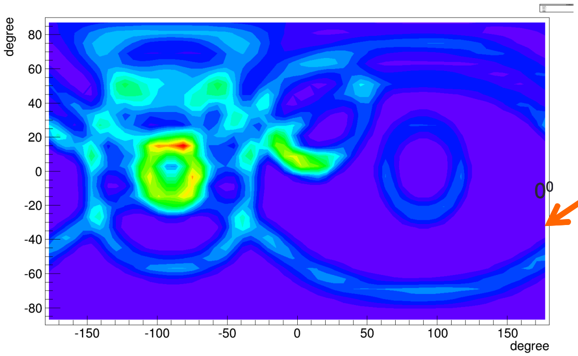
Beamline 8

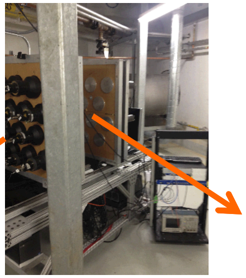




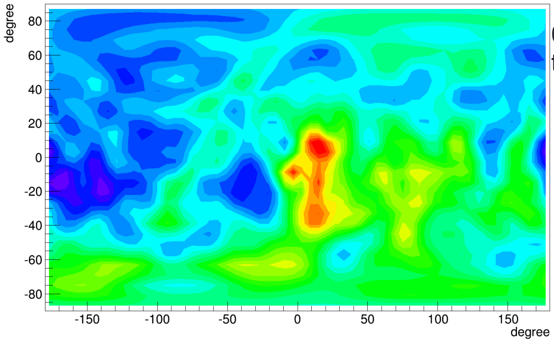
0^0 towards the SNS target

Basement 2.5

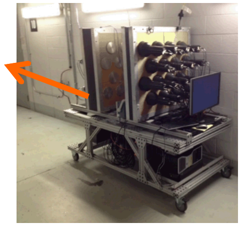




Basement 11



0^0 towards the SNS target



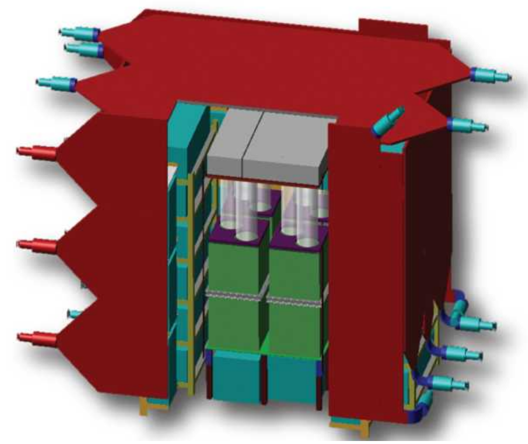
What have we learned?

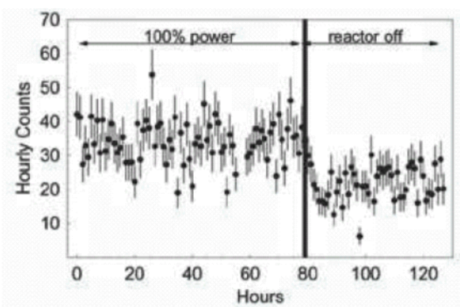
- Experimental hall locations will not work
- Basement 2.5 and 11 have comparable neutron fluxes during beam extraction window (1.3us).
- Post beam window (2.2us) show large reduction in high-energy neutron flux for both basement locations. However, neutrino flux is also reduced by factor >3.
- Images show most of neutrons coming from about the beam direction.
- Larger overburden at basement 2.5 reduces cosmic neutron background about 1 order of magnitude compared to basement 11.
- More data in candidate location basement C4 is needed

Backup slides

Antineutrino detector deployed at SONGS (San Onofre Nuclear Generating Station)

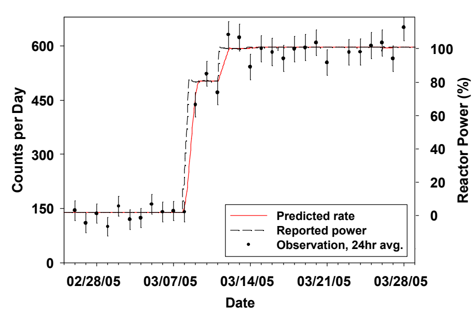
- Since 2003, SNL/LLNL have deployed several detectors at SONG demonstrating that antineutrino based reactor monitoring is possible.
- **SONGS1 Target Detector:** 0.64 tons of Gadolinium-doped liquid scintillator.
- **Antineutrino Interaction:** inverse β-decay $\bar{\nu}_e + p \rightarrow e^+ + n$

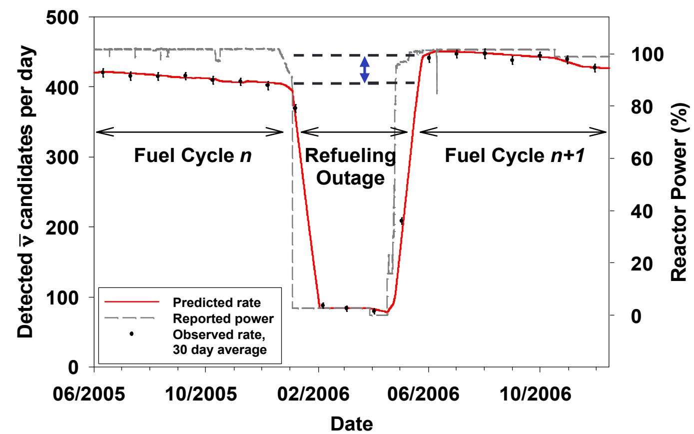




Hourly averaging of data allows for detection of a reactor “scram” within 5 hours at 99.9% confidence

Daily and weekly averaging allows relative power tracking with 8% and 3% relative uncertain, respectively

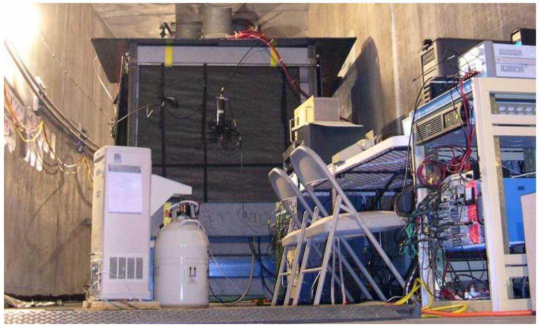


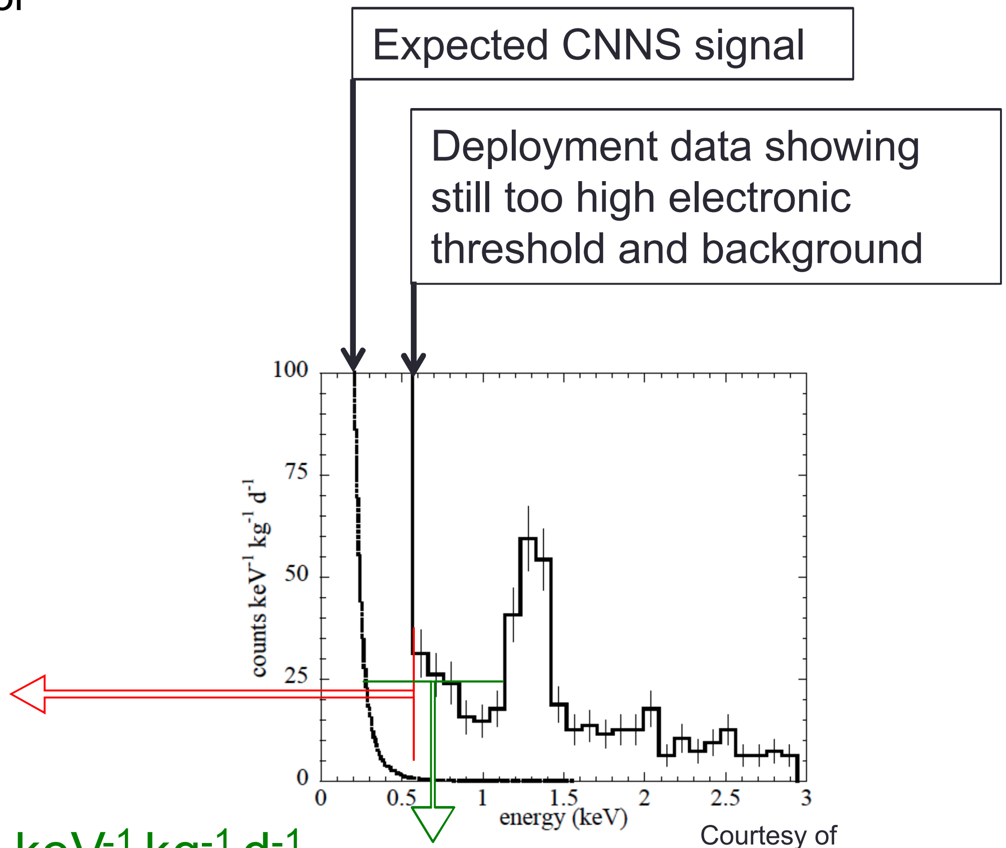


Long term monitoring-fuel composition: example of removal of 250 kg ^{239}Pu at end of cycle, and replacement with 1.5 tons of fresh ^{235}U fuel at the beginning of next cycle

Where are we now with Ge technology for Reactor Monitoring?

Best demonstrated performance so far by the 2009 deployment of a 0.4kg HPGe detector at SONGS by the CoGeNT collaboration





Courtesy of P. Barbeau

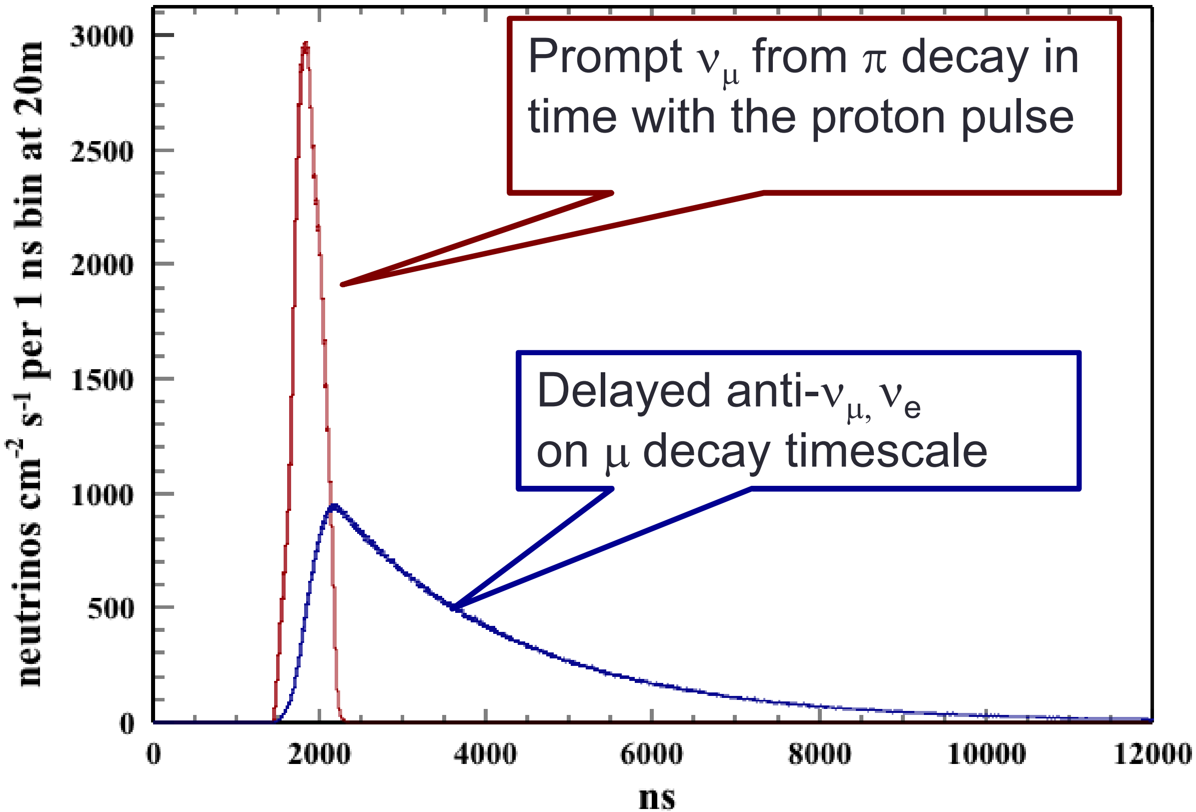
ULGeN goals:

1- Lower **electronic threshold** to 100 eV

2- Reduce **background** to ~10 c keV^{-1} kg^{-1} d^{-1}

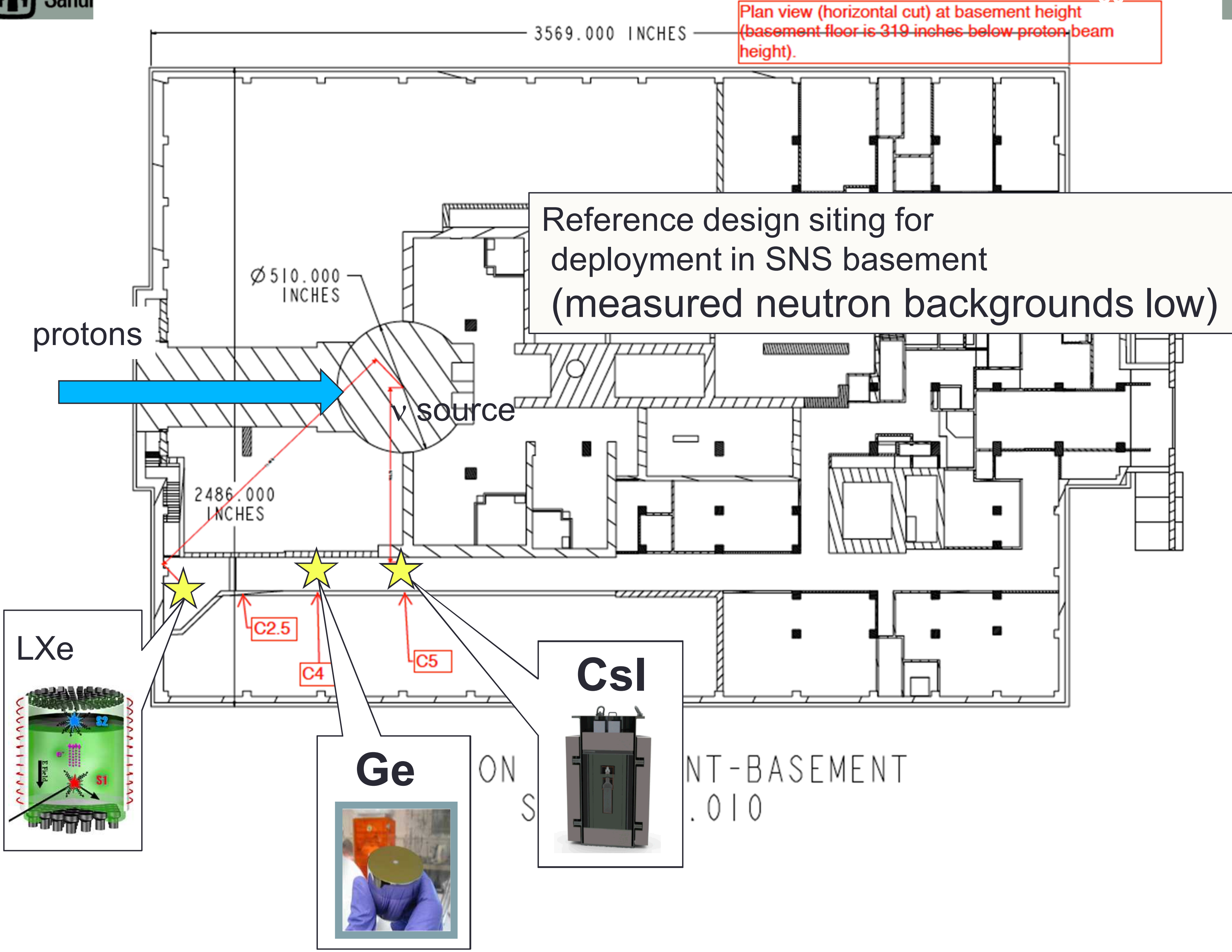
Time structure of the SNS source

60 Hz *pulsed* source



Background rejection factor ~few x 10^{-4}

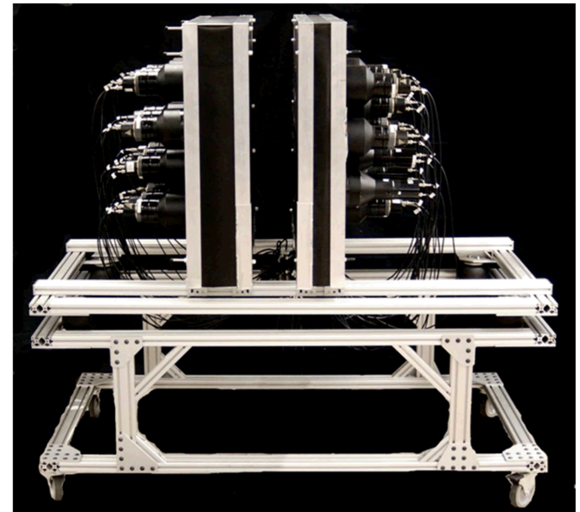
Reference design siting for deployment in SNS basement (measured neutron backgrounds low)



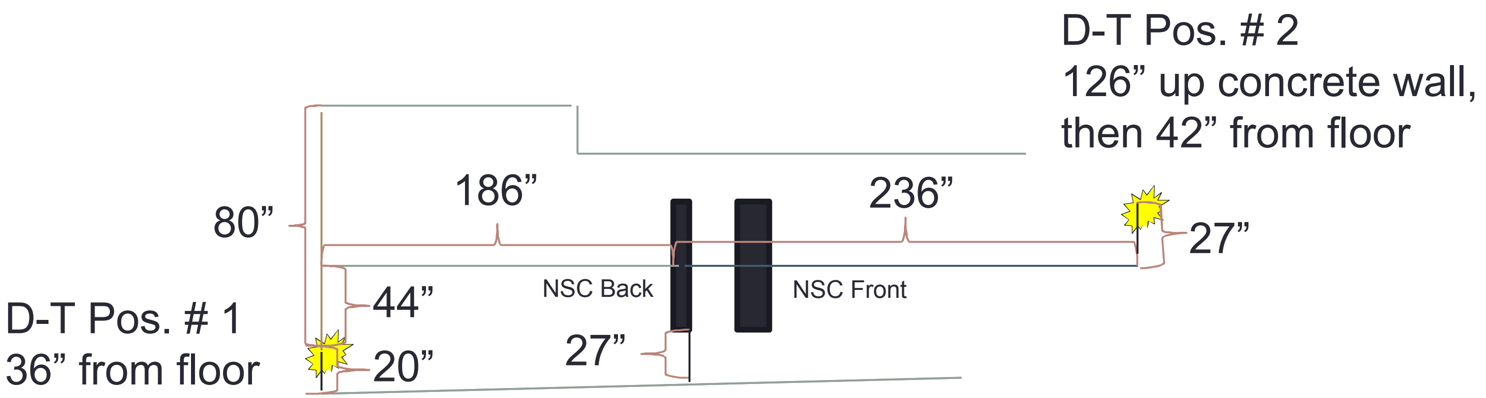
Liquid Scintillator Detectors

- Detector design refined over several generations of Neutron Scatter Camera
  - 16 - 5"D x 5"H and 16 – 5"D x 2"H liquid scintillator cells (EJ-309)
  - 5" Hamamatsu PMTs
  - 16 x 1.6L and 16 x 0.65L detectors: total active volume ~36 L

- Improvements Required to handle neutron energies > 10 MeV
  - New ADCs with larger range (Struck 3316)
  - Modified DAQ to work with new electronics and beam spill triggers



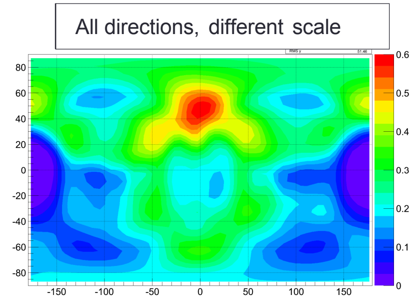
DT Generator position diagram, beamline 14a



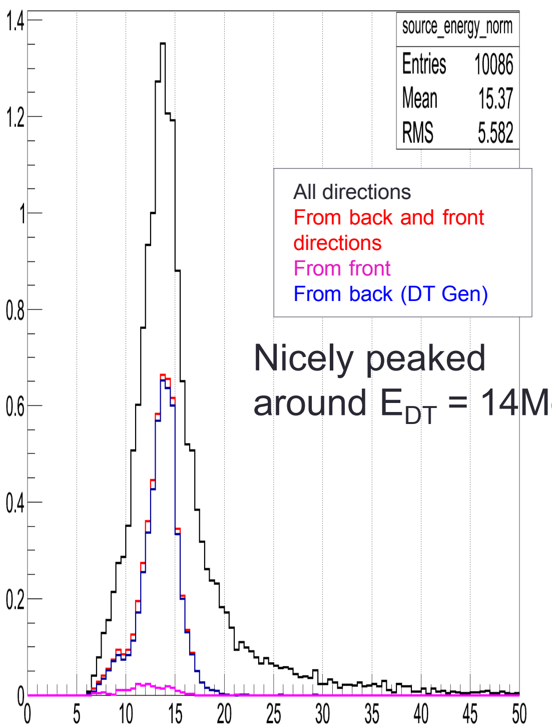
- NSC measurements to middle of 2” plane
- Wall dimensions *very* rough in this drawing.

DT generator: source spectrum and image

- NSC efficiency varies with direction, with maximum efficiency within a 60-degree cone in the forward and backward directions and dips in efficiency on the side directions



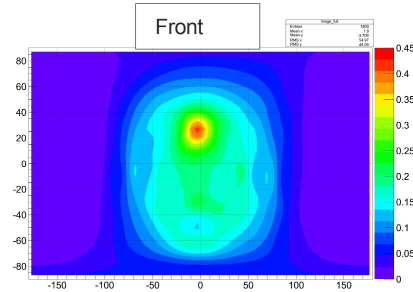
Position 2: 15 minutes

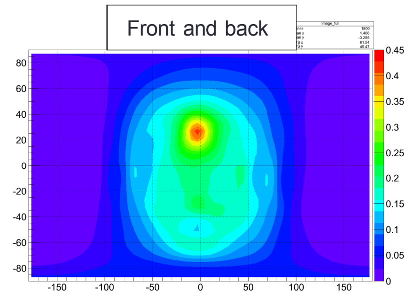


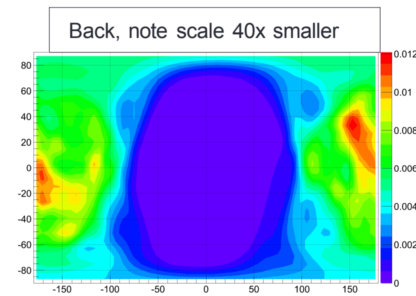
Nicely peaked around E_{DT} = 14MeV

Front of NSC: DT generator

Back of NSC: nothing

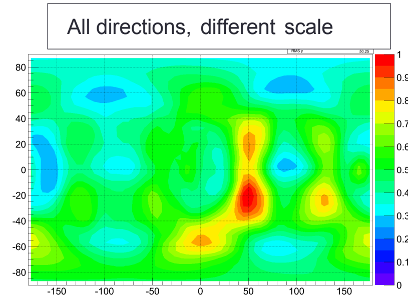




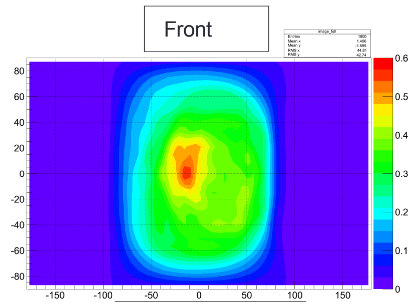


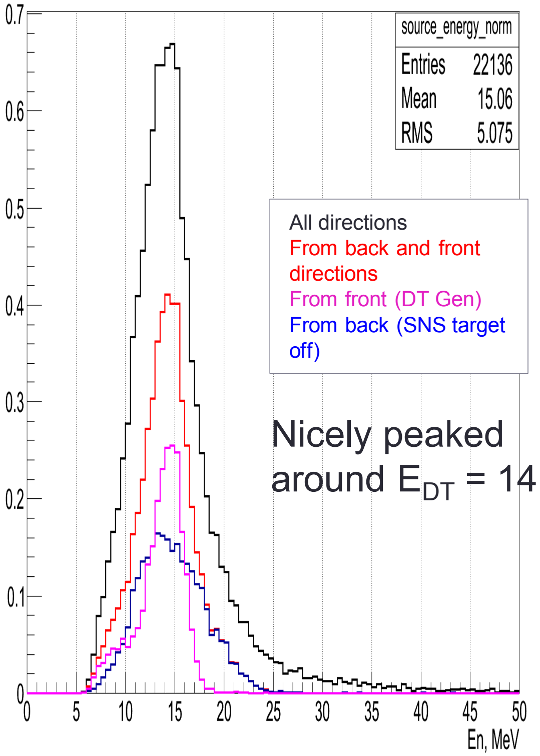
DT generator: source spectrum and image

- Observe that concrete walls create a "neutron" cave where DT neutrons backscatter



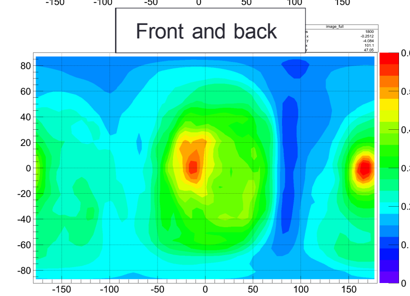
Position 1: 40 minutes

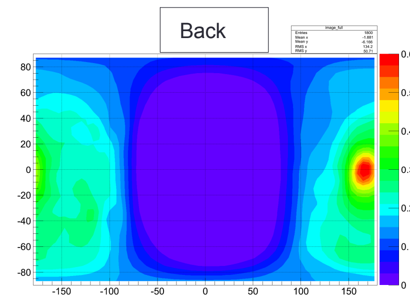




Nicely peaked around E_{DT} = 14MeV

Front of NSC: BckScttrd DT n

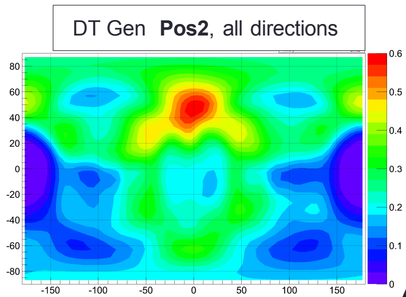




Back of NSC: DT generator

DT Generator images

- Need to understand better NSC lateral efficiency. But, preliminarily, we can normalize the efficiency variation dividing by the background:



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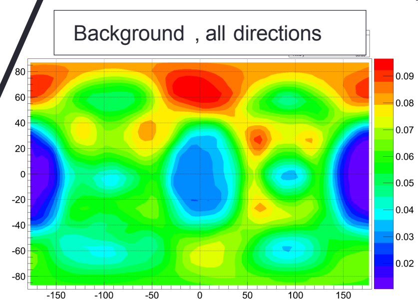

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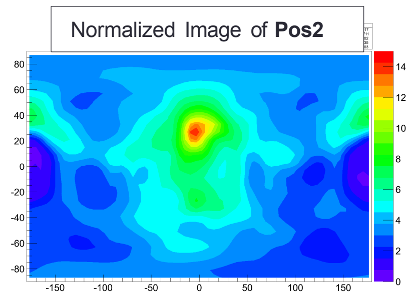

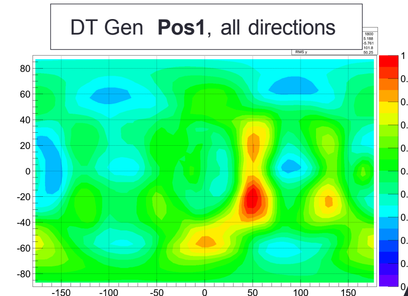

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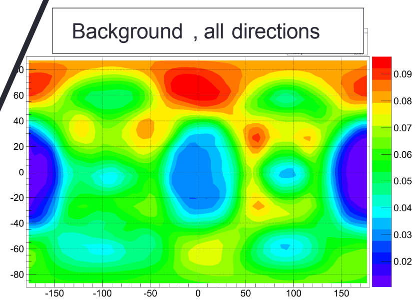

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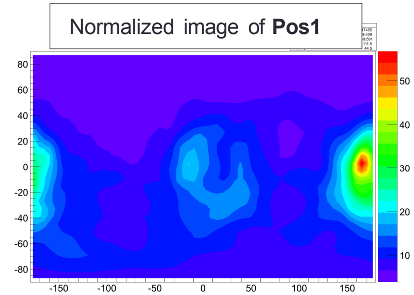

- …or applying MLEM