Comparison of Radiogenic Neutron Background Calculations

Kimberly Palladino
with
J. Cooley, D.-M. Mei, S. Scorza, M. Selvi, H. Qiu, C. Zhang

LRT 2015 University of Washington

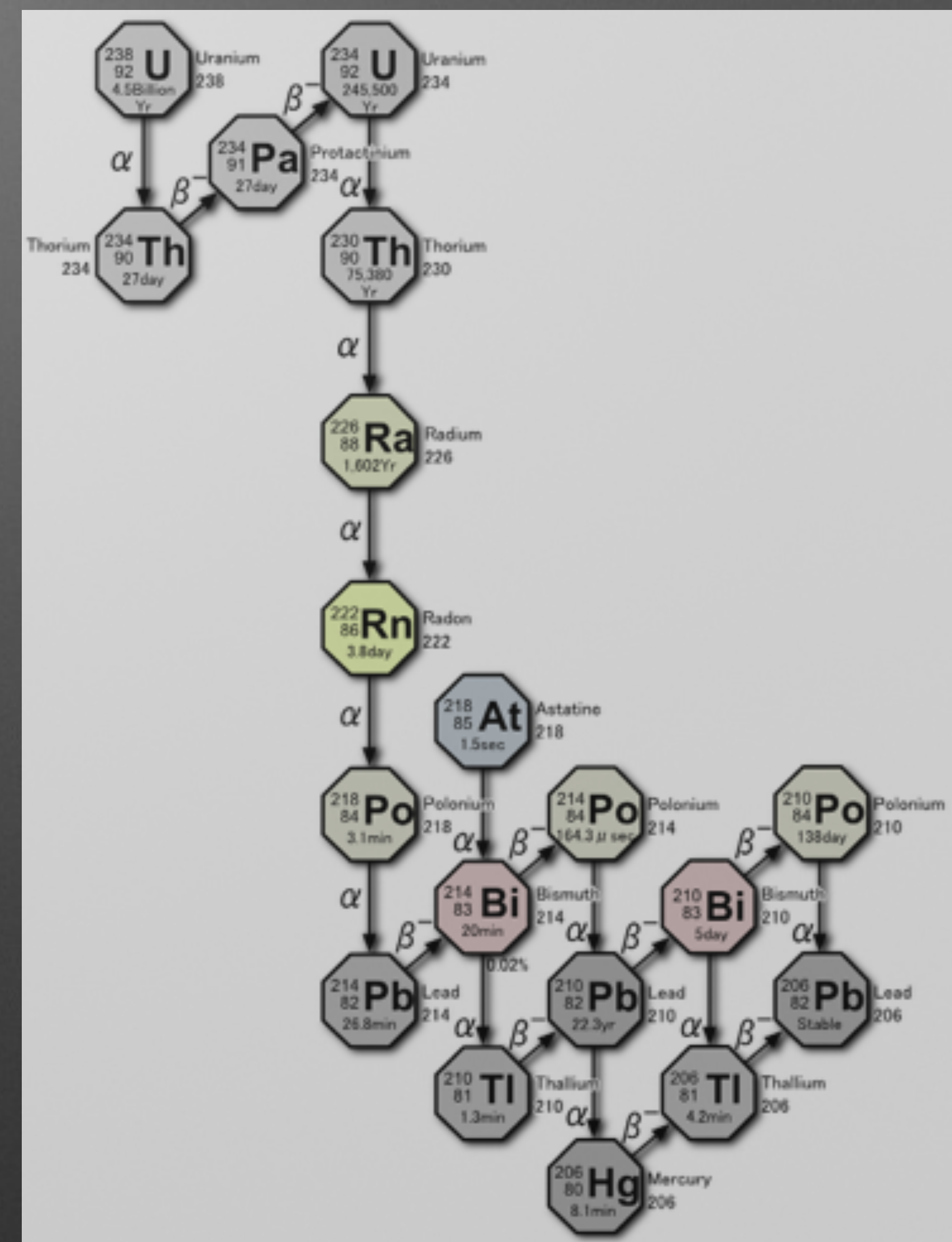
SLAC

Outline

- Initial Alpha-n Neutron Spectra for Radiogenic Backgrounds
    - Cross section libraries : EMPIRE and TENDL
    - Neutron spectra from SOURCES4 and TALYS
- What do these differences mean for background predictions?
    - U238 in borosilicate and an argon detector
    - U238 in titanium and a xenon detector
    - U238 in copper and a germanium detector

Radiogenic neutron backgrounds

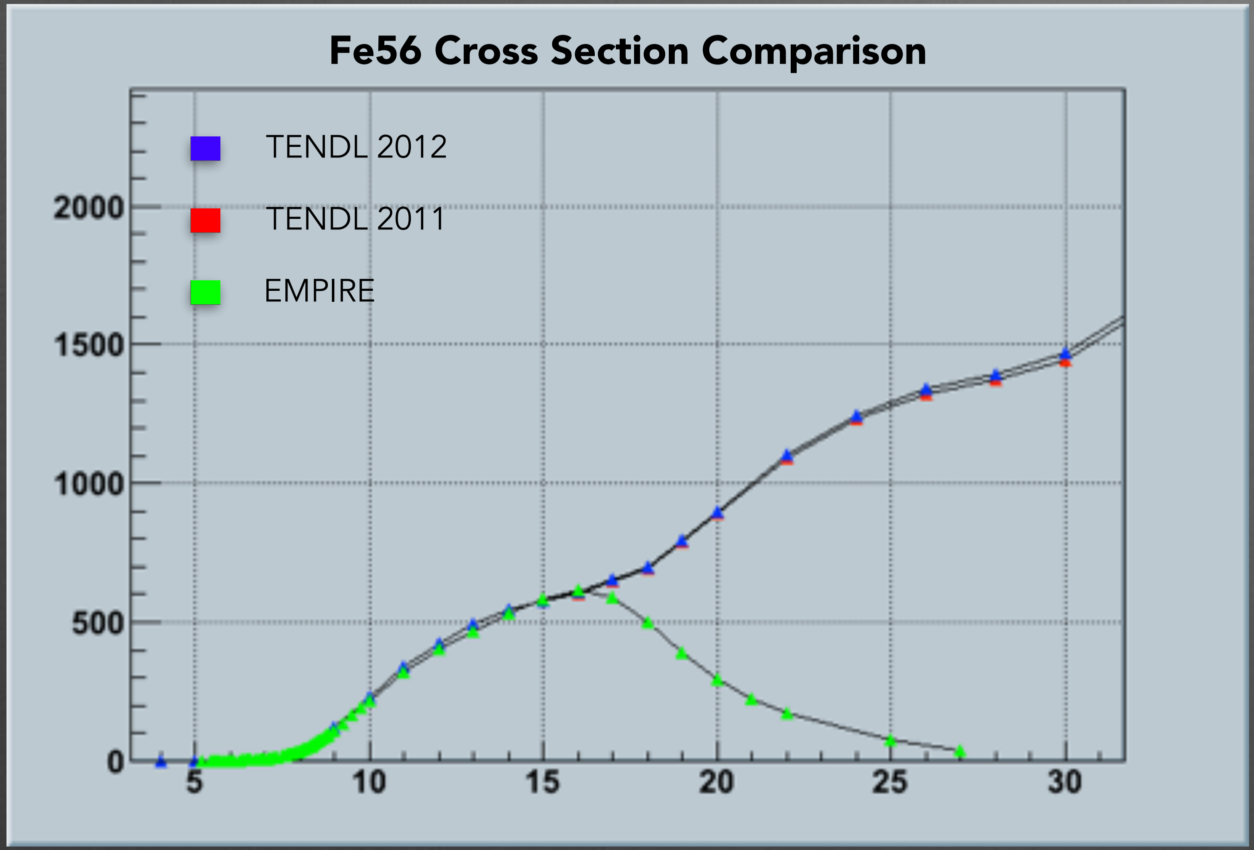
- Neutrons that have a single elastic scatter within a direct dark matter detector are generally indistinguishable from a WIMP
- A common source of these few-MeV neutrons is from alpha-n reactions in detector materials initiated by alphas in the the uranium and thorium decay chains
- Understanding the computational models for alpha-n neutron spectra is important
  - Assay-based background predictions are affected by the total yield
  - Spectral shape differences matter when extracting backgrounds in running experiments

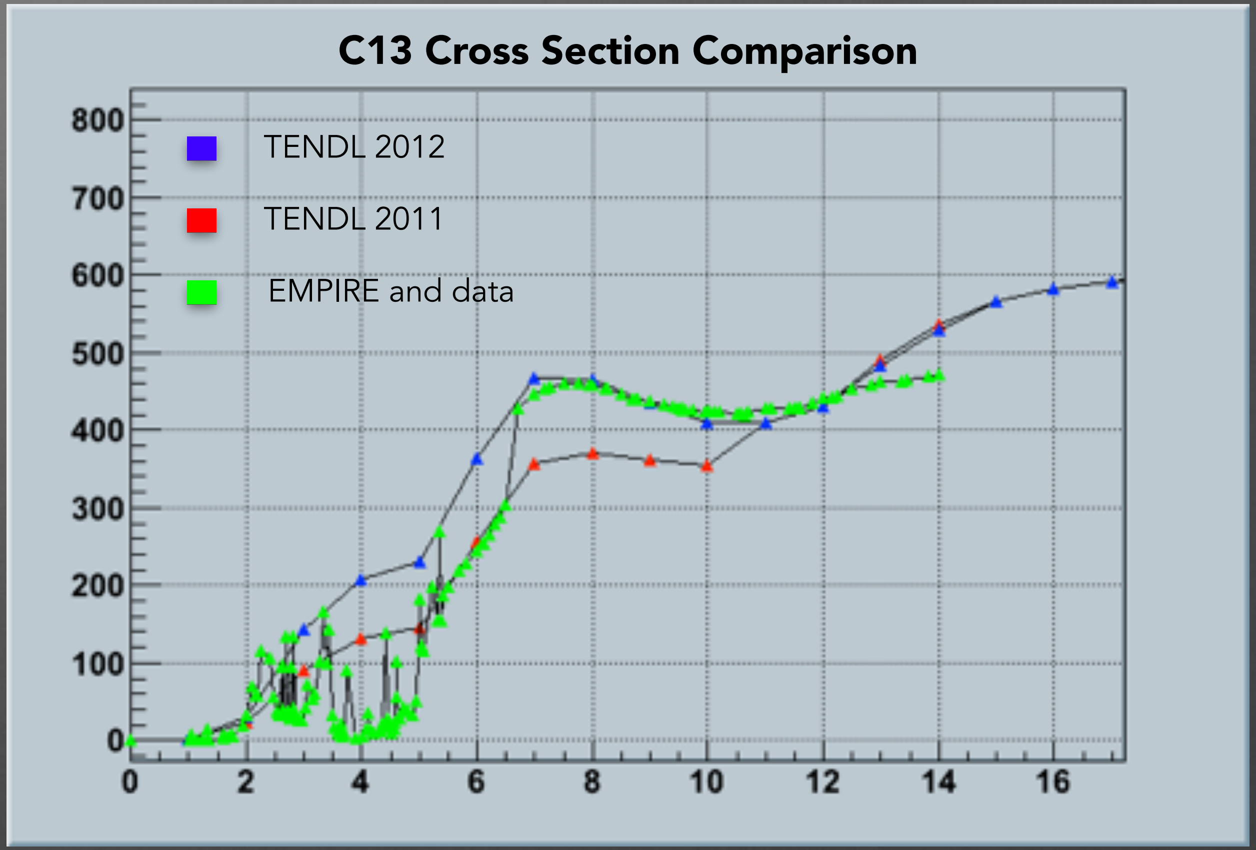


Alpha-n cross sections

- Required input for calculating the neutron yield
- Two separate databases are generally used
  - TENDL2012 : a validated nuclear data library that is evaluated by TALYS and then can be used as inputs to other calculations
  - EMPIRE2.19: recommended by IAEA, calculations cut off at lower energy, SOURCES does not use it exclusively and some isotopes also include measurement data
- Neither library fully reproduces experimentally observed resonances, comparisons with experimental data are still important

Cross Section comparisons





Generally in good agreement: displaying here some of the distinctly different cross sections for comparison

For many more comparisons see:
http://www.physics.smu.edu/cooley/aarm/webpage.html

SOURCES4A and TALYS

- Calculations of the neutron yields and spectra are performed with two code bases which take into account the alpha emission lines from radionuclides, the alpha-n cross sections, and the nuclear transition branching ratios. In our implementations, both assume secular equilibrium of the U and Th decay chains, and a thick target.

  - SOURCES 4A: configurable code run independently to generate neutron spectra up to 10 MeV using cross sections from EMPIRE and experimental data, and including modifications by V. Kudryavtsev and ILIAS collaborators to handle alphas with energies of 6.5-10 MeV.

  - TALYS-USD: using neutronyield.usd.edu front end to TALYS calculations to generate neutron spectra to 12 MeV using cross sections from TENDL. In this implementations the spontaneous fission alphas are not considered.

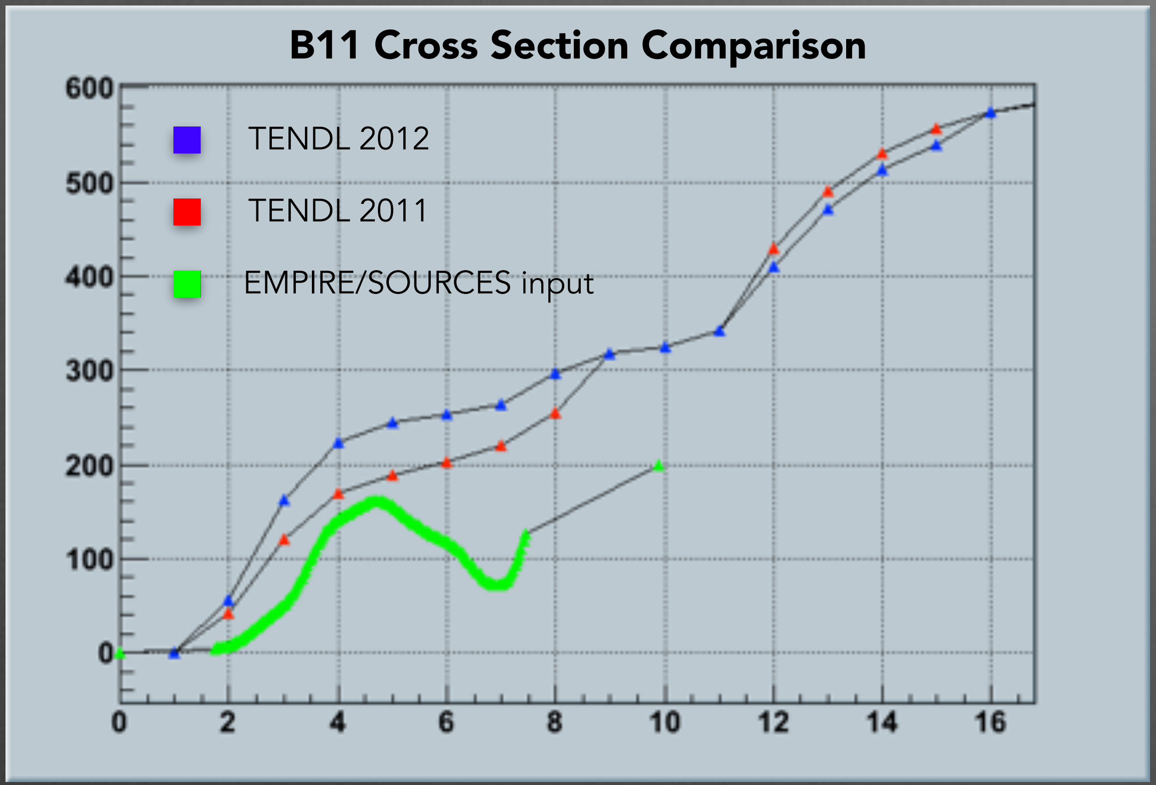
GEANT4 neutron propagation studies

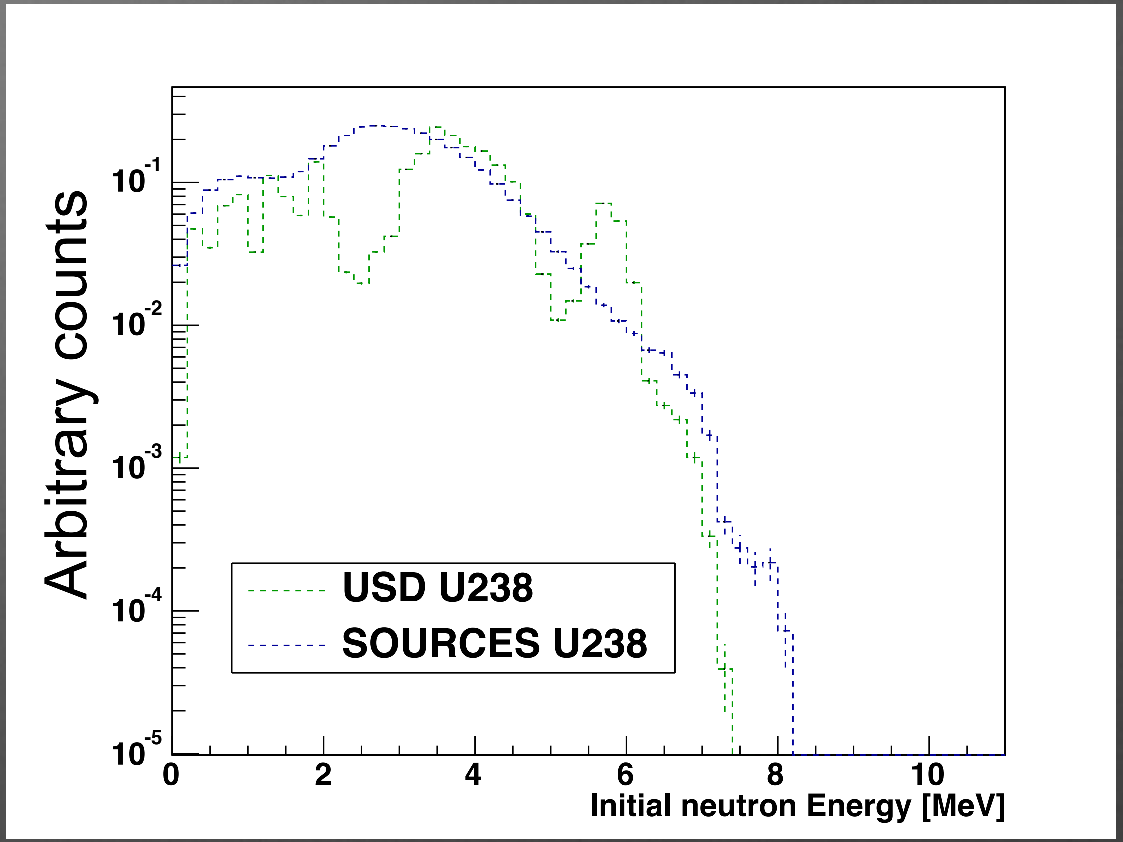
- What do these input neutron spectra differences mean for experimentalists?
- Working with Geant4.9.5.p02 in the simulation package RAT, propagate alpha-n neutrons for the various U238 and Th232 spectra from SOURCES and TALYS-USD
- NeutronHP handles neutrons < 20MeV with cross sections from ENDF
- Create generalized direct dark matter detectors of common materials (argon, xenon and germanium) along with external vetoes
- 3 preliminary case studies discussed here:
  - Borosilicate and argon
  - Titanium and xenon
  - Copper and germanium

RAT Reactor Analysis Tool

Geant 4

Neutrons in Borosilicate from U238



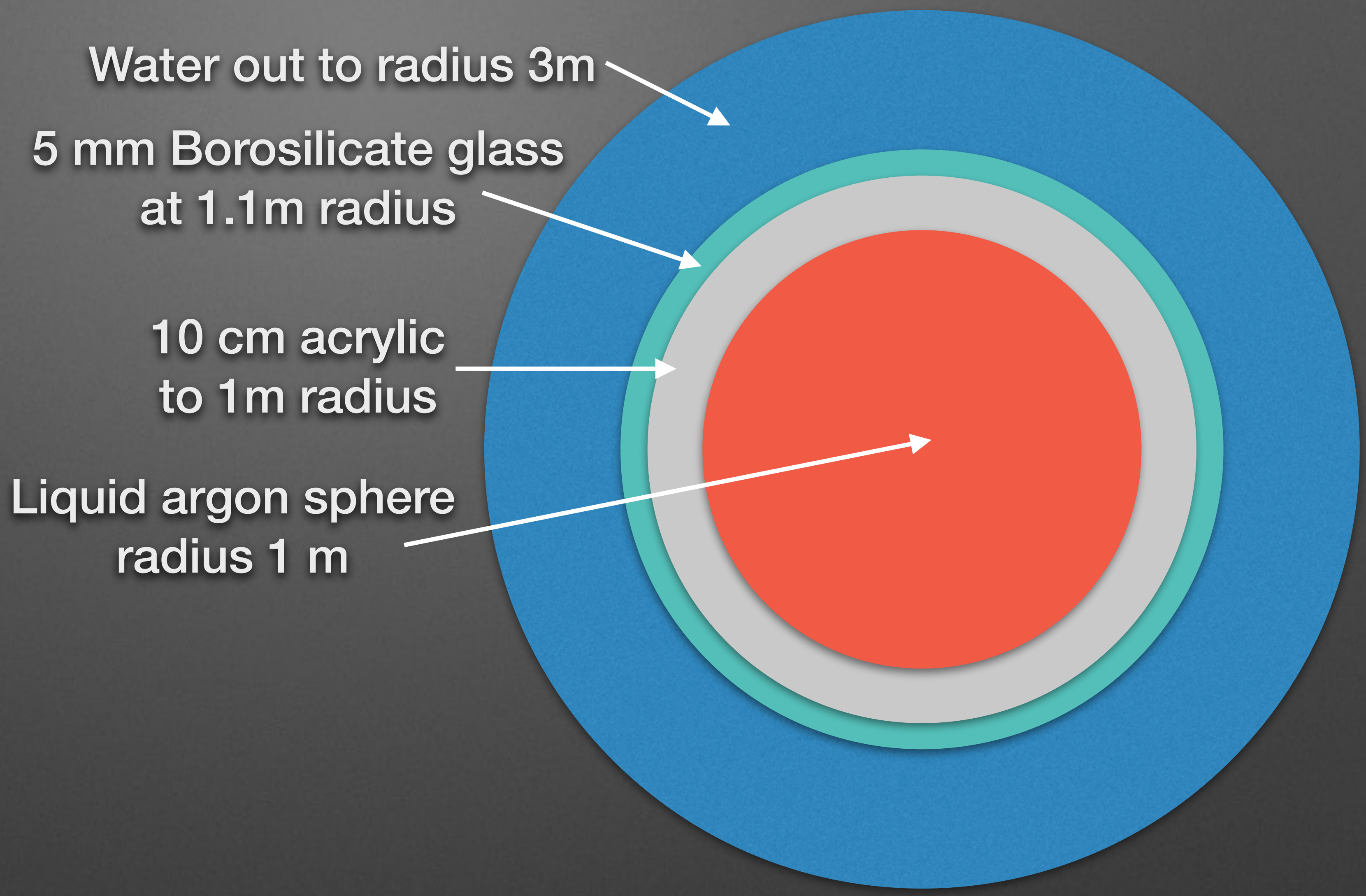


- Neutron spectra are calculated with SOURCES4 and TALYS (through the neutronyield.usd.edu website, hereafter called USD) from the U238 decay chain in borosilicate glass

- From 1ppb of U238, USD calculations give a neutron yield of 2.45 E-10 n/s/cm^3 while SOURCES gives a neutron yield of 3.63E-10 n/s/cm^3, 48% higher

Argon detector simulations

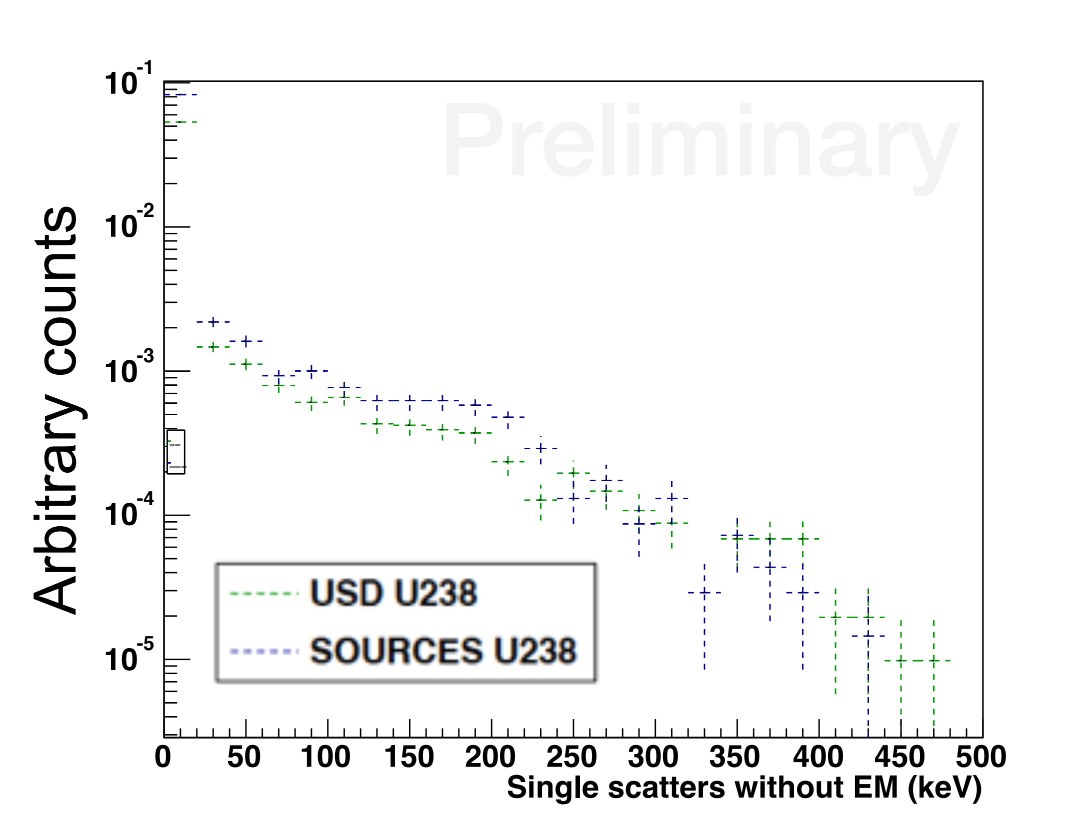
- 250000 neutrons isotropic from borosilicate glass for each simulation
- Neutron recoil threshold of 20 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in argon
- Neutron capture in water needed to externally veto event



Nested spheres geometry

Argon recoils

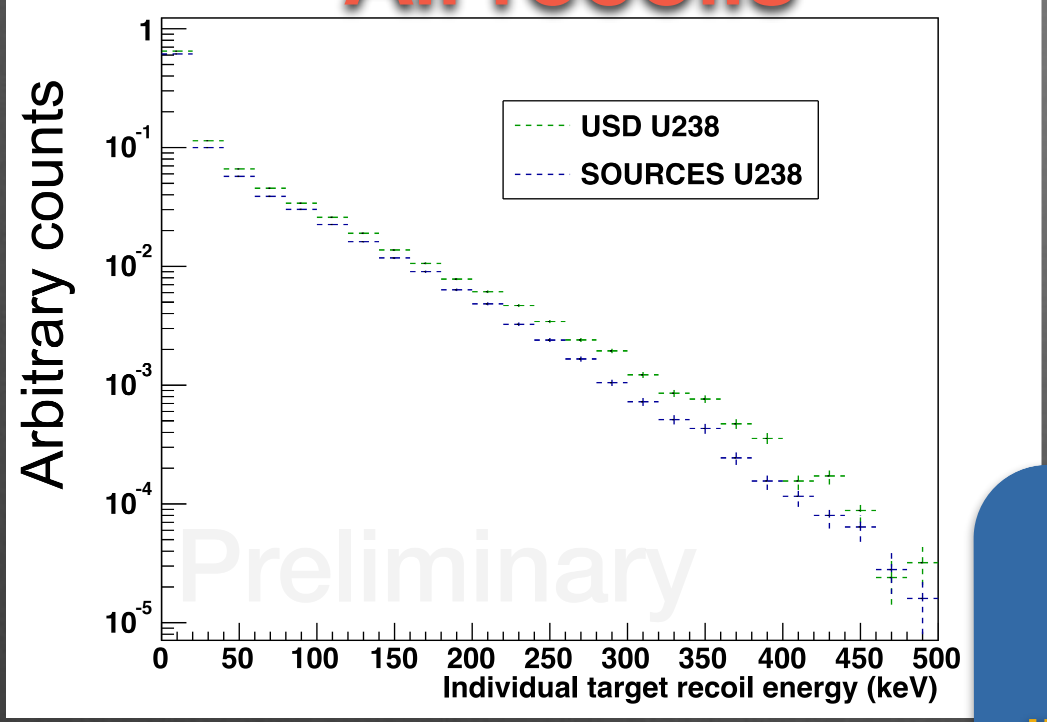
48% higher neutron yield from SOURCES gives 40% more single scatters than USD



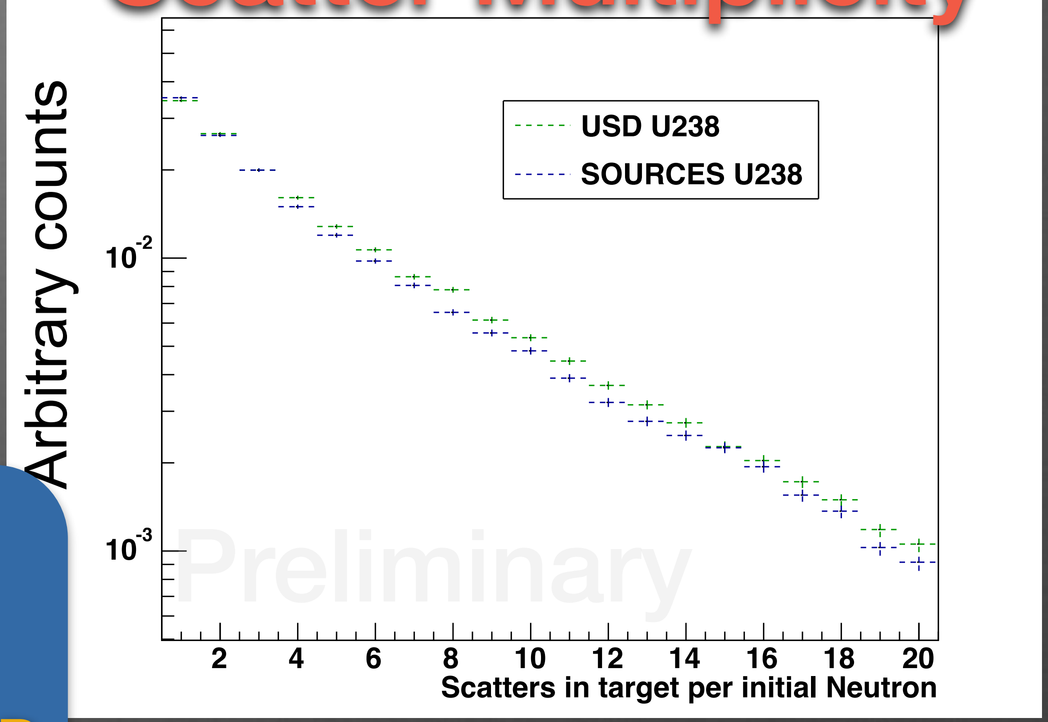
	Summed nuclear recoils over 20 keV	Single nuclear recoil over 20 keV	Single recoils over 20 keV no capture in veto	Single recoils over 20 keV no electron scatter >1 keV	Ratio of Multiple scatters: single scatters no threshold
TALYS-USD % of initial sim	5.2 +/- 0.05%	0.71 +/-0.02%	0.60 +/- 0.01%	0.30 +/- 0.01%	4.2
SOURCES % of initial sim	4.3 +/-0.04%	0.66+/-0.02%	0.55+/-0.01%	0.28+/-0.01%	3.8
TALYS-USD n/s/cm	(1.28+/-0.01)E-11	(1.70+/-0.04)E-12	(1.47+/-0.04)E-12	(0.7+/- 0.03)E-12	(2.8+/-0.02)E-11: (0.84+/-0.01) E-11
SOURCES n/s/cm	(1.57+/-0.01)E-11	(2.40+/-0.06)E-12	(2.0+/-0.05)E-12	(1.0+/-0.4)E-12	(3.9+/-0.08)E-11: (1.28+/-0.01) E-11

Spectral shape in Ar detector

All recoils

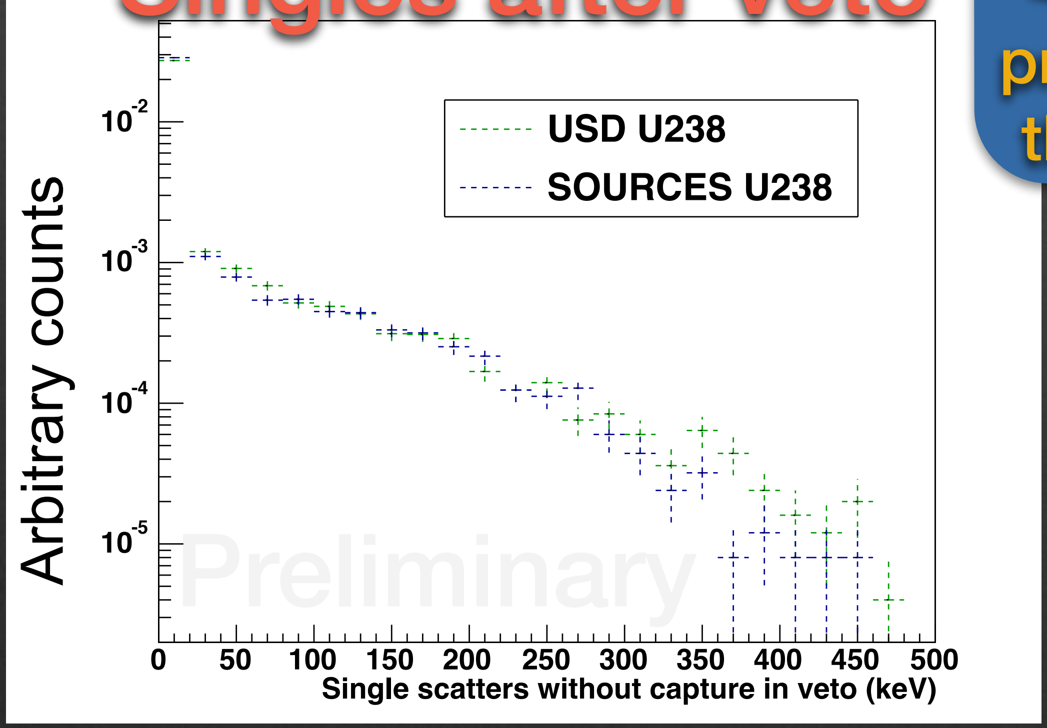


Scatter Multiplicity

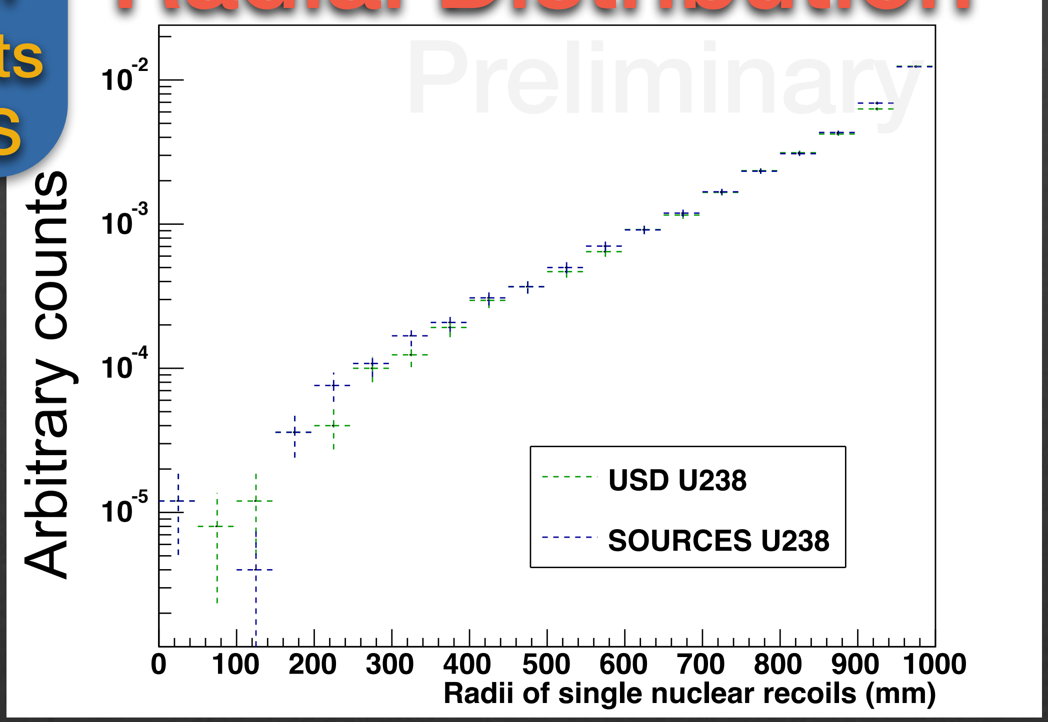


Shape comparisons show small differences: USD ~10% higher in predicted counts than SOURCES

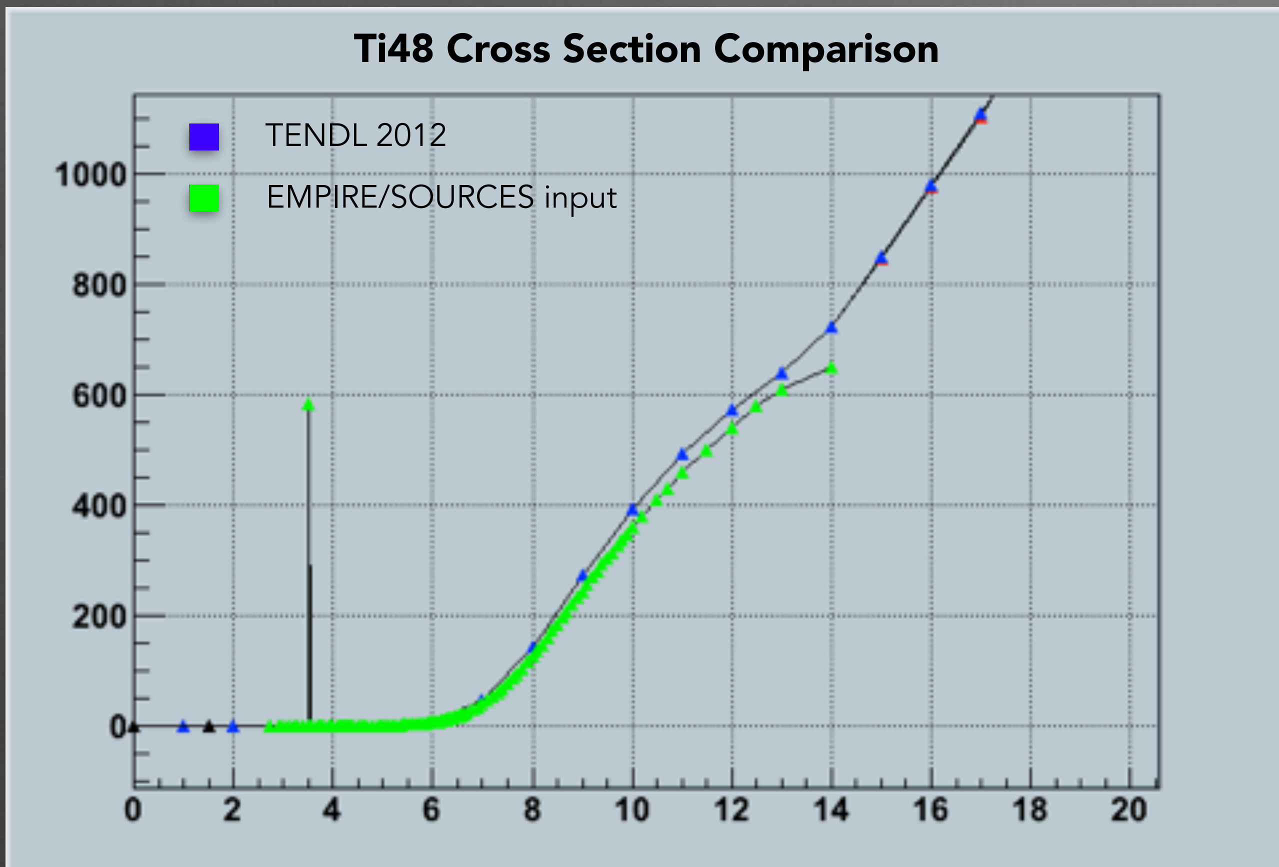
Singles after veto

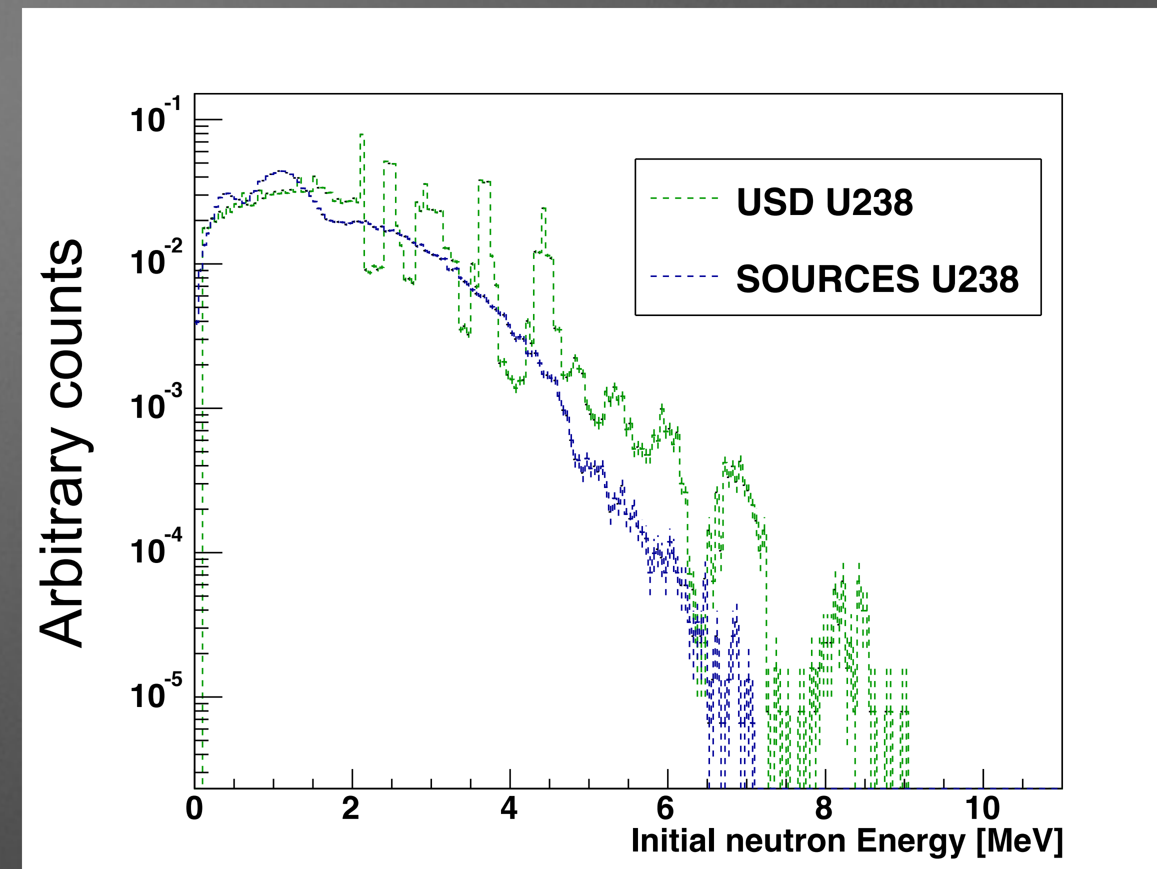


Radial Distribution



Neutrons in titanium from U238

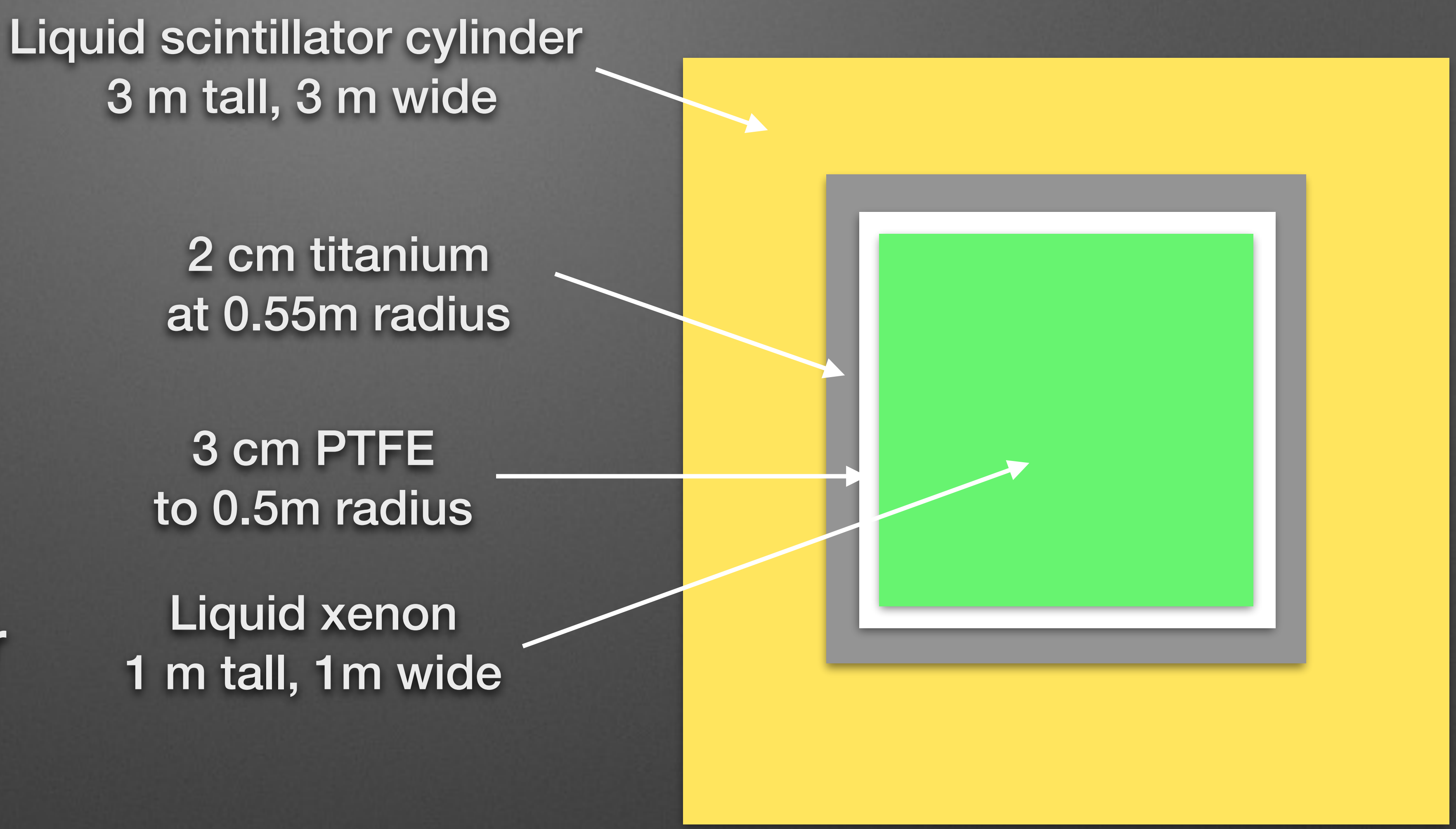




- Large resonant peak in cross sections for SOURCES(shown), hand corrected to remove that point before further calculations per communication with V. Kudryavtsev
- Even with the correction a feature remains in the neutron spectrum
- From 1ppb of U238, USD calculations give a neutron yield of 1.98 E-10 n/s/cm^3 while SOURCES gives a neutron yield of 1.65E-10 n/s/cm^3, 20% lower

Xe Detector Simulations

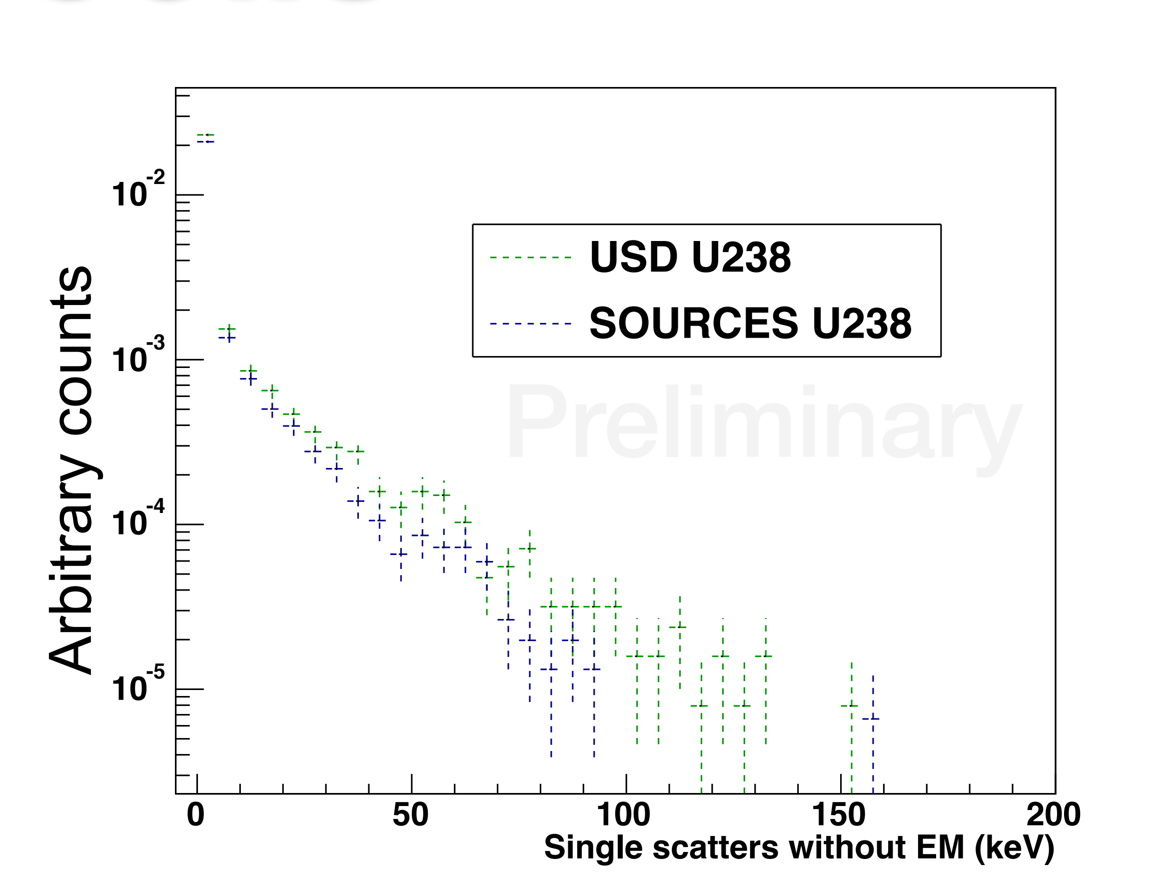
- 250000 neutrons isotropic from titanium or teflon for each simulation
- Neutron recoil threshold of 5 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in xenon
- Neutron capture in oil-based scintillator needed to externally veto event



Nested cylinders geometry

Xenon recoils

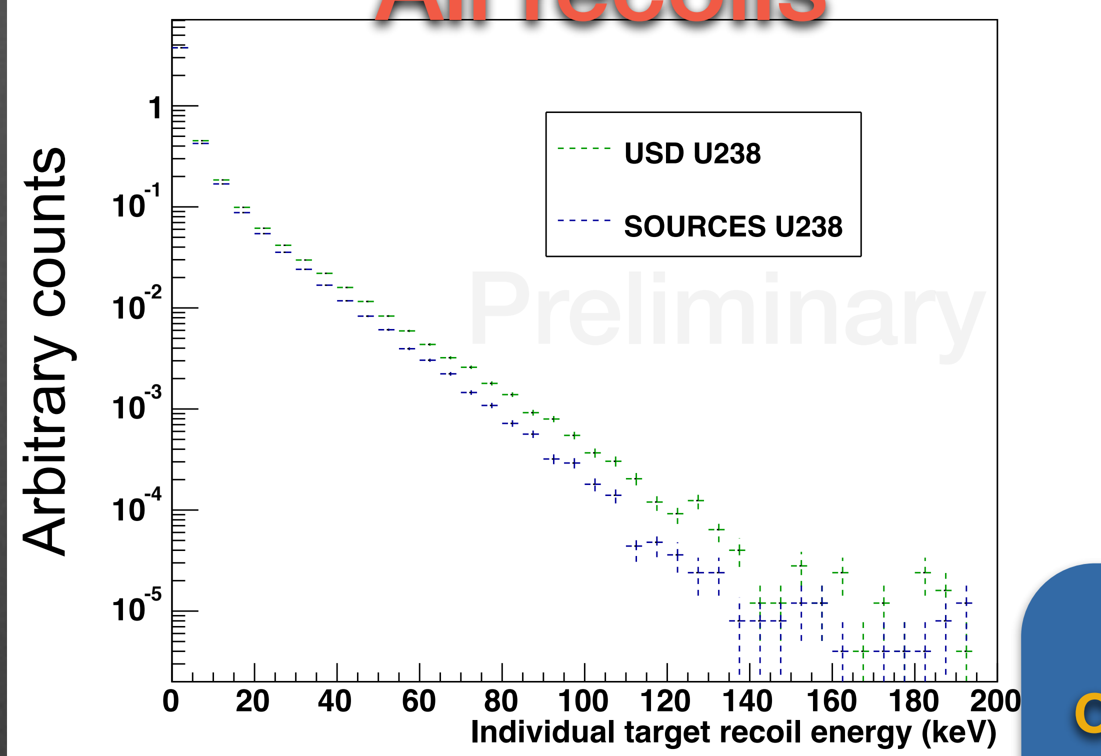
20% higher neutron yield from USD gives 24% more single scatters than SOURCES



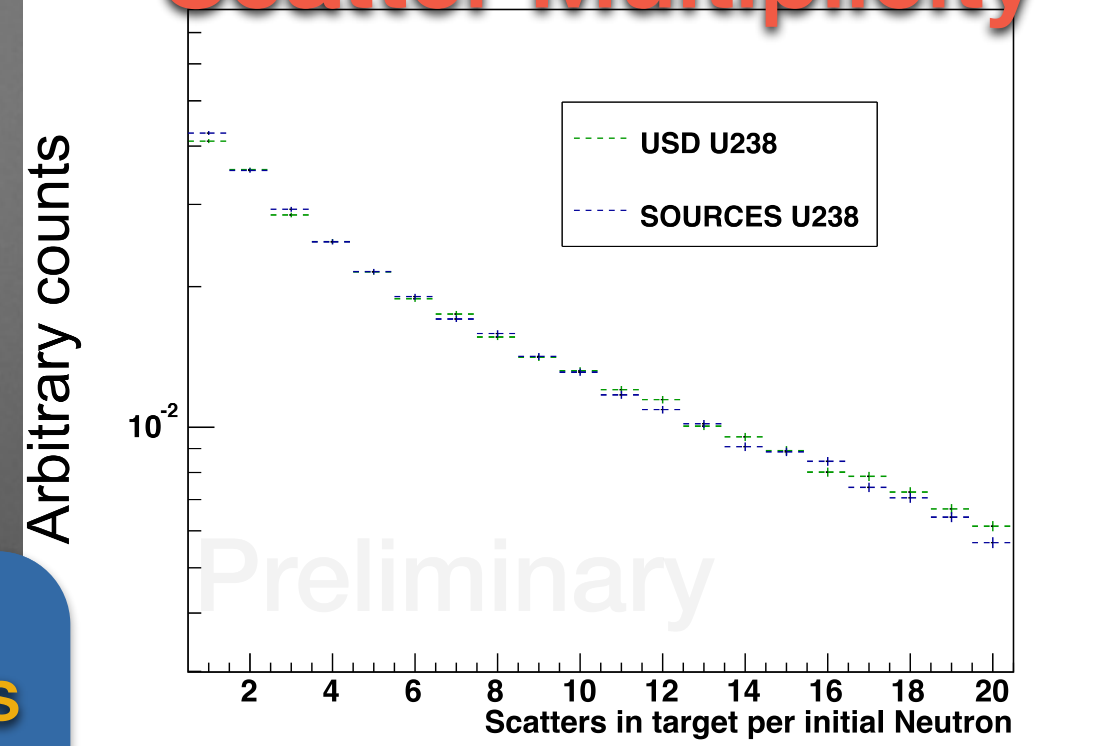
	Summed nuclear recoils over 5 keV	Single nuclear recoil over 5 keV	Single recoils over 5 keV no capture in veto	Single recoils over 5 keV no electron scatter >1 keV	Ratio of Multiple scatters: single scatters no threshold
TALYS-USD % of initial sim	8.9 +/- 0.06%	1.34 +/-0.02%	0.44 +/- 0.01%	0.28+/- 0.01%	8.62+/- 0.086
SOURCES % of initial sim	7.7 +/-0.05%	1.28+/-0.02%	0.41+/-0.01%	0.26+/-0.01%	8.17+/-0.076
TALYS-USD n/s/cm	(1.76+/-0.012)E-11	(2.65+/-0.05)E-12	(8.68+/-0.26)E-13	(5.55+/- 0.21)E-13	(6.99+/-0.007)E-11: (0.81+/-0.008) E-11
SOURCES n/s/cm	(1.26+/-0.009)E-11	(2.11+/-0.04)E-12	(6.79+/-0.21)E-13	(4.22+/-0.17)E-13	(5.74+/-0.006)E-11: (0.70+/-0.007) E-11

Spectral shape in Xe detector

All recoils

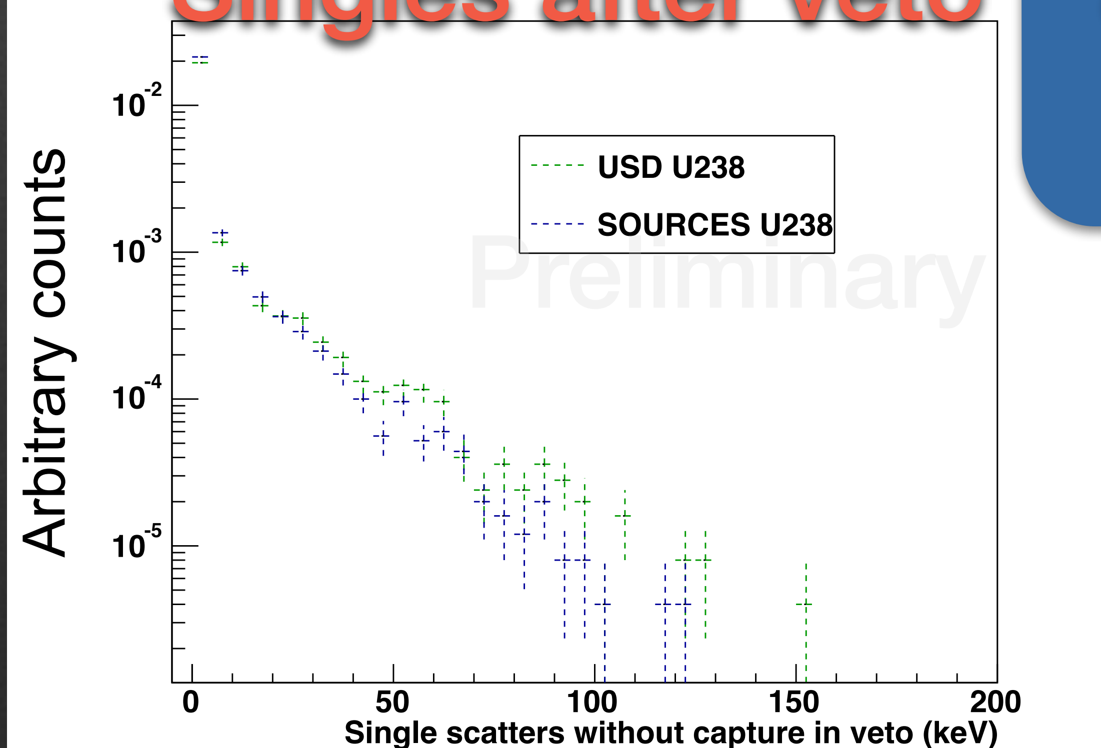


Scatter Multiplicity

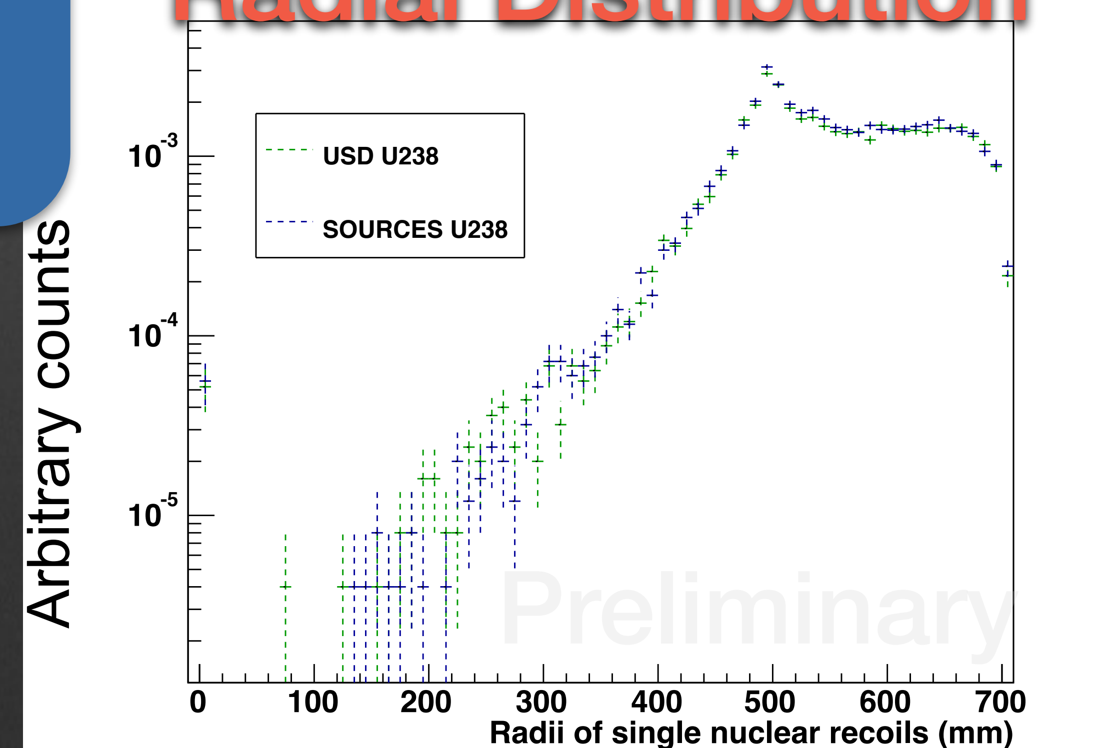


Shape comparisons show no differences once cuts occur

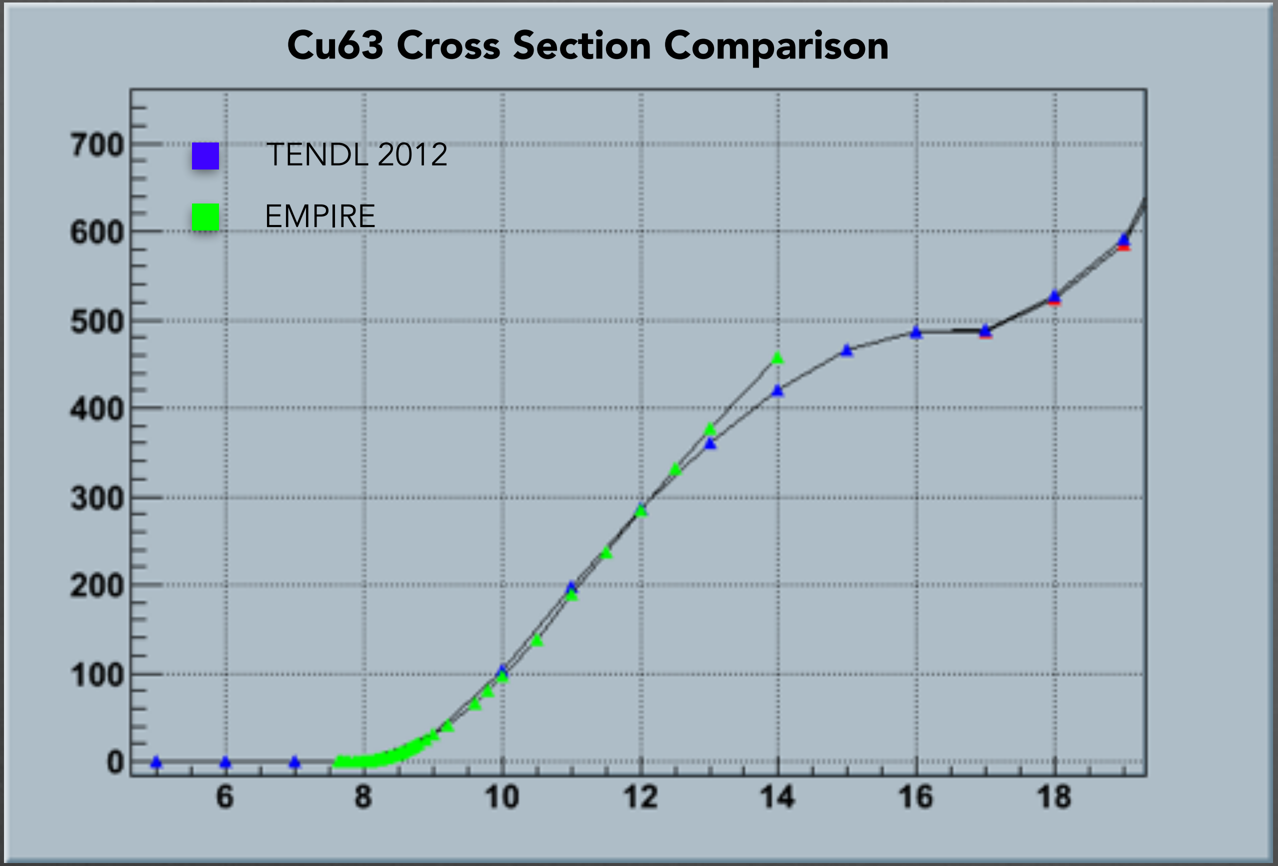
Singles after veto

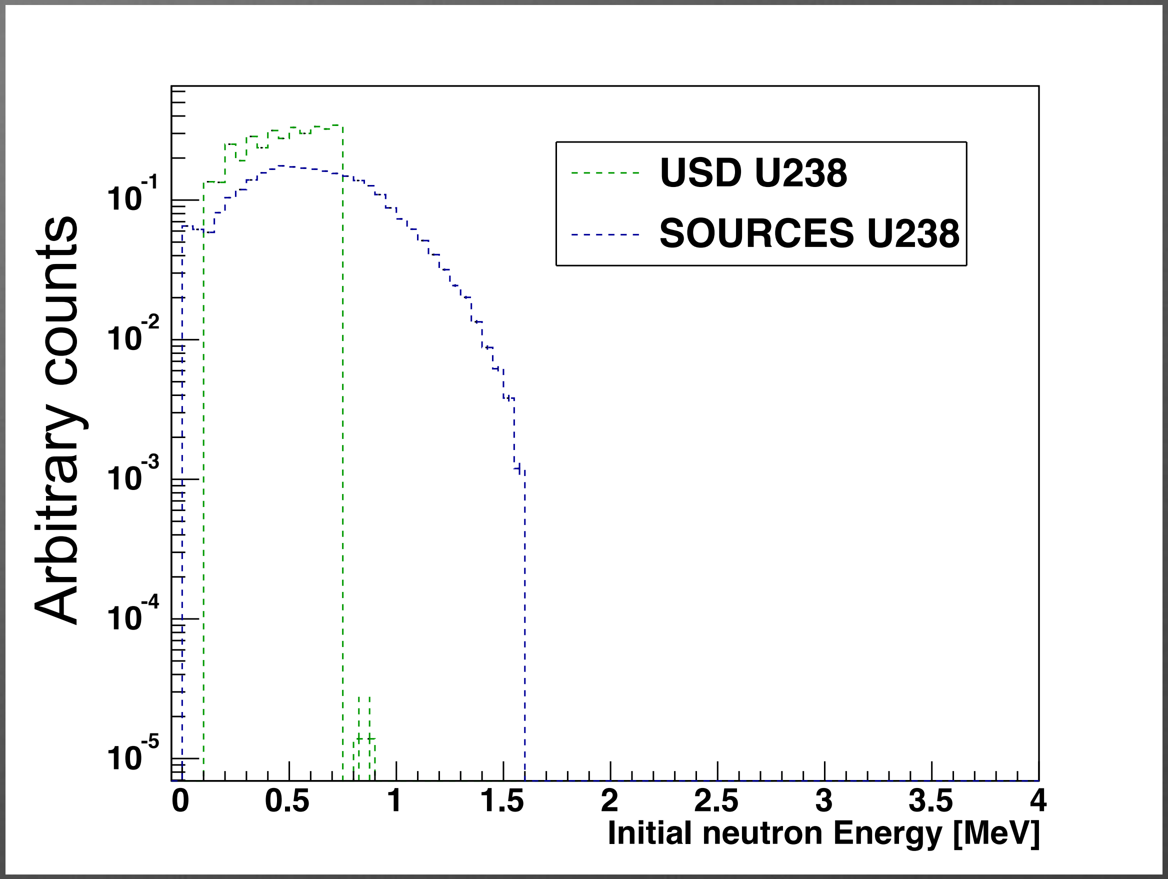


Radial Distribution



Neutrons in copper from U238



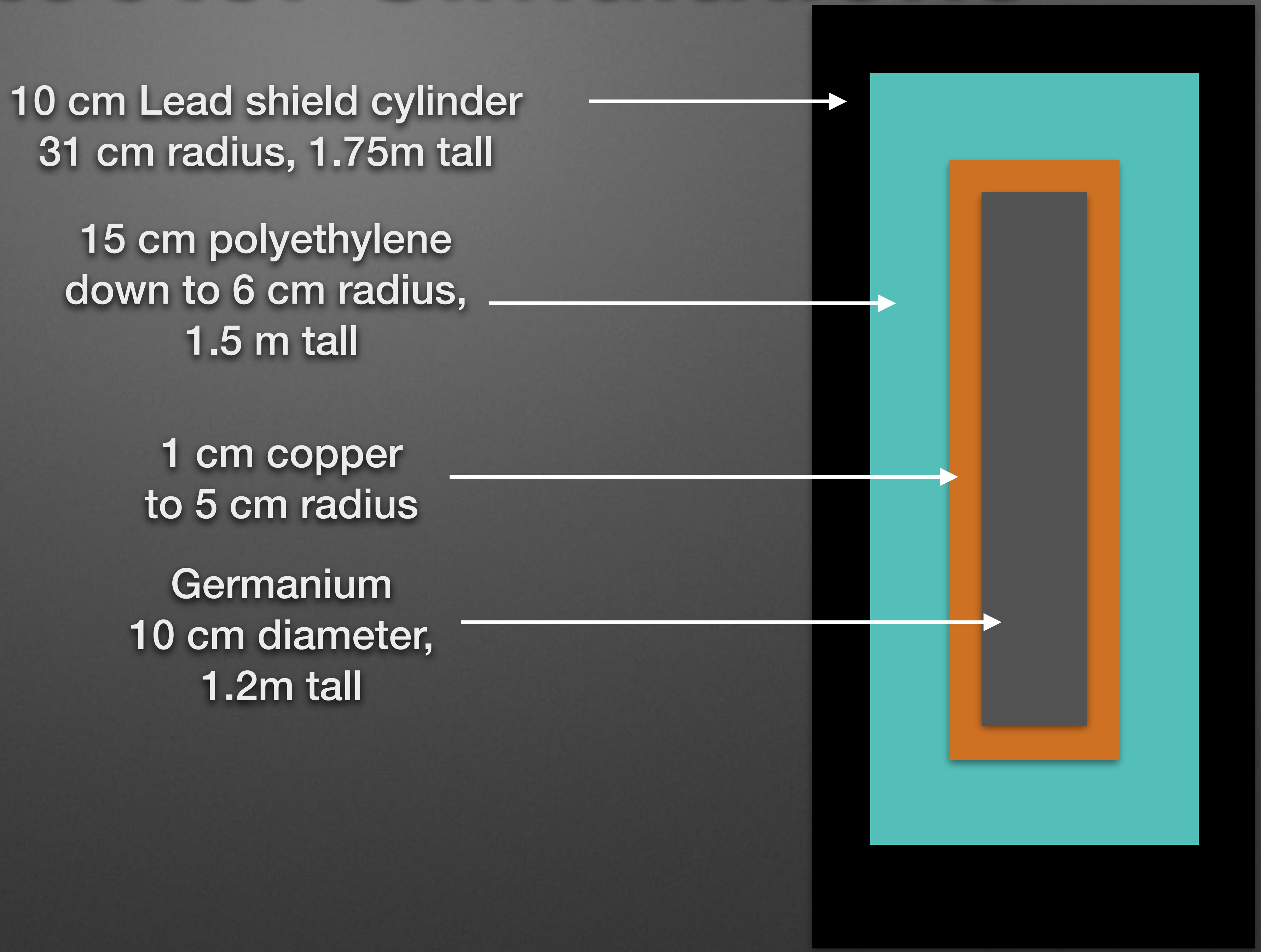


- From 1ppb of U238, USD calculations give a neutron yield of 3.46 E-12 n/s/cm^3 while SOURCES gives a neutron yield of 2.90E-12 n/s/cm^3, 19% lower

- USD spectrum cuts off at half the energy of SOURCES

Ge Detector Simulations

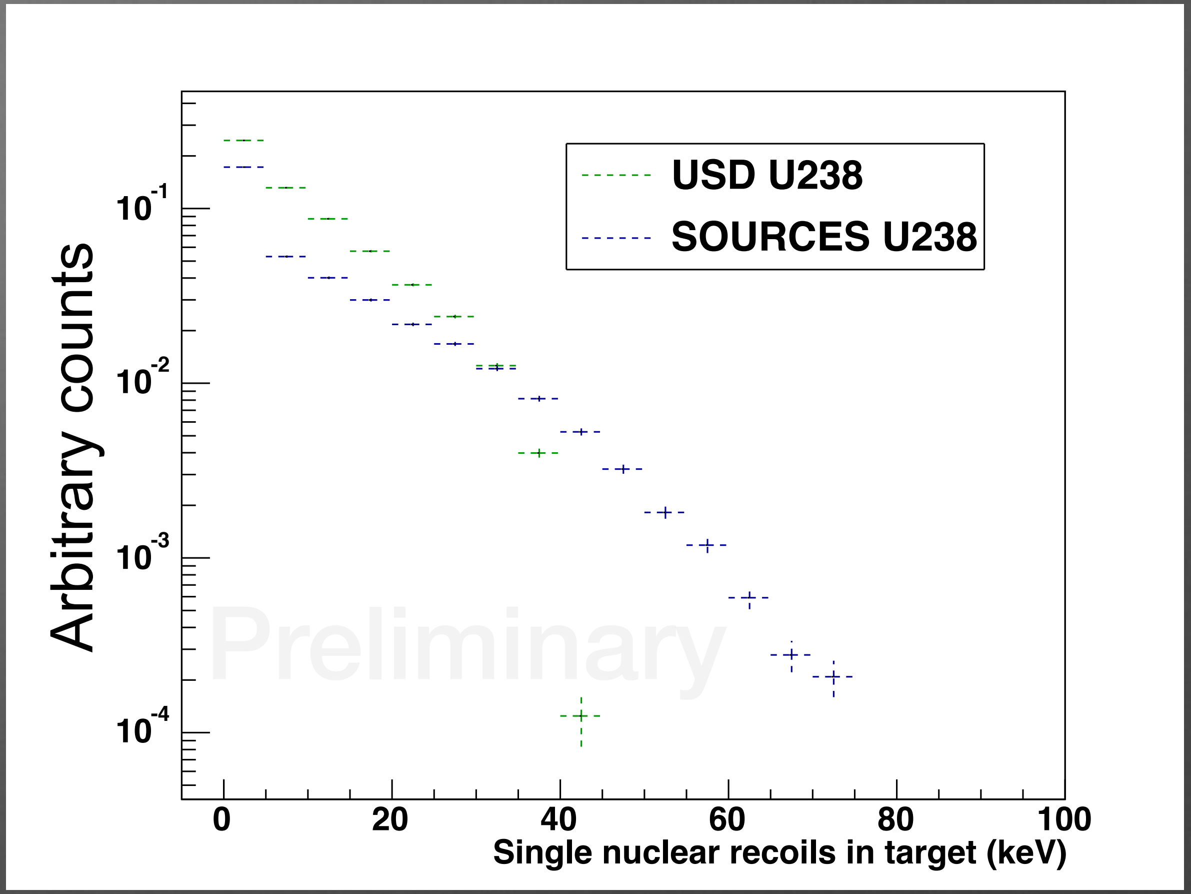
- 250000 neutrons isotropic from copper for each simulation
- Neutron recoil threshold of 5 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in argon
- Neutron capture in plastic scintillator needed to externally veto event



Nested cylinders geometry

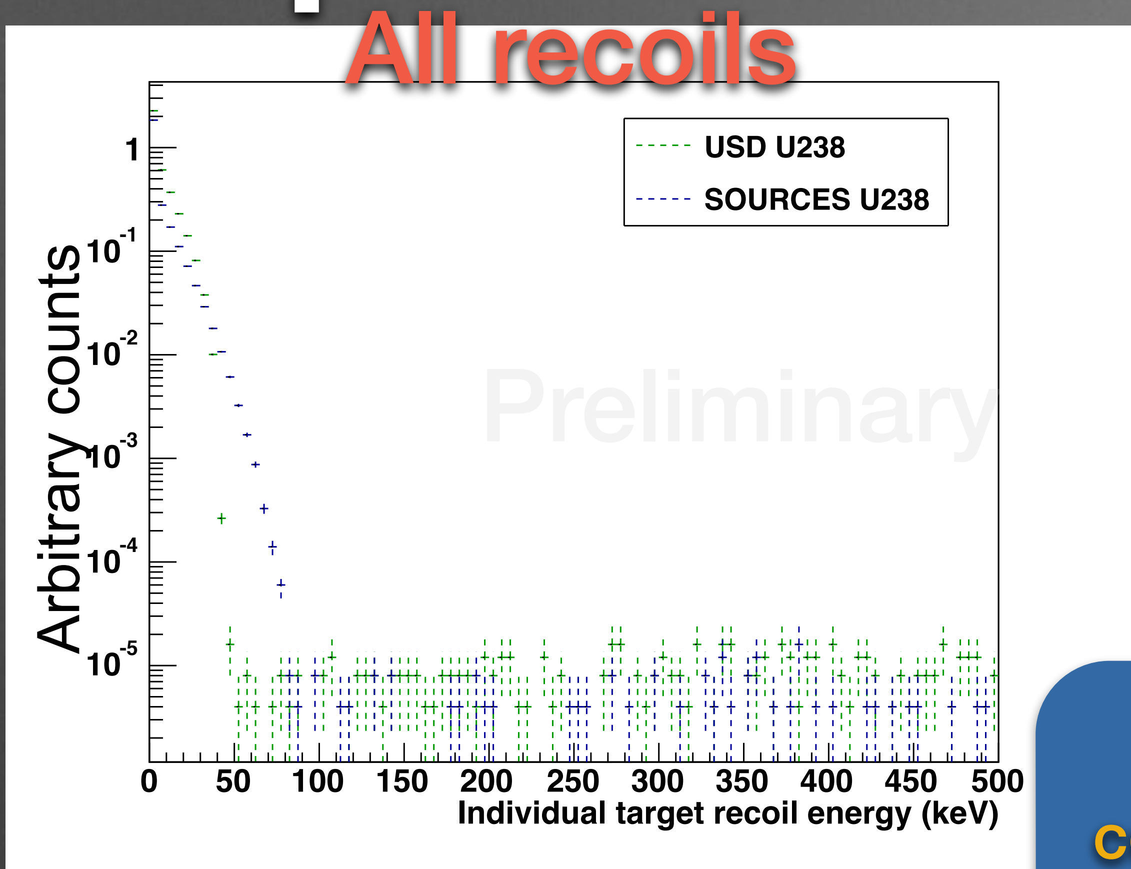
Germanium recoils

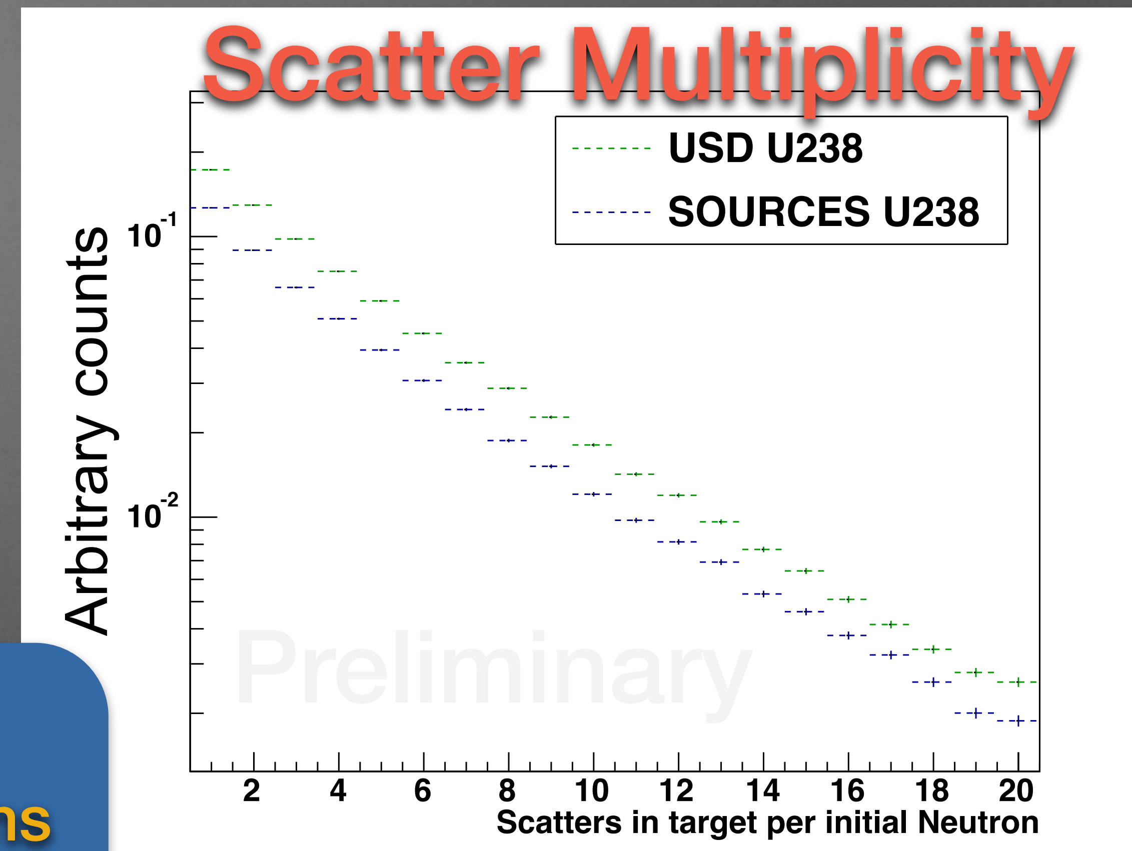
Shape and yield effects cause an 80% higher prediction of single scatters from USD than SOURCES



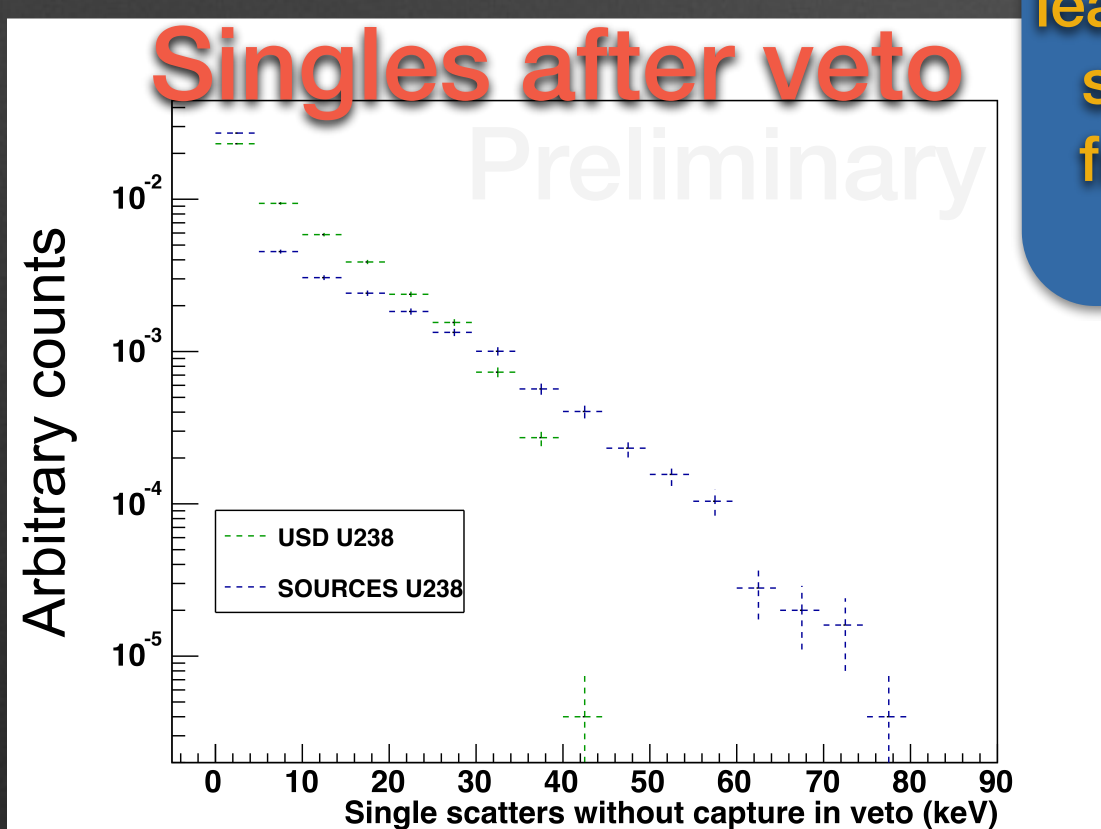
	Summed nuclear recoils over 5 keV	Single nuclear recoil over 5 keV	Single recoils over 5 keV no capture in veto	Single recoils over 5 keV no electron scatter >1 keV	Ratio of Multiple scatters: single scatters no threshold
TALYS-USD % of initial sim	14.2 +/- 0.07%	10.2 +/-0.06%	2.4 +/- 0.03%	8.87+/- 0.06%	3.42+/- 0.017
SOURCES % of initial sim	8.3 +/-0.06%	6.71+/-0.05%	1.6+/-0.02%	5.8+/-0.05%	3.17+/-0.076
TALYS-USD n/s/cm	(4.92+/-0.02)E-13	(3.53+/-0.02)E-13	(8.32+/-01)E-13	(3.07+/- 0.02)E-13	(2.04+/-0.003)E-12: (0.59+/-0.003) E-12
SOURCES n/s/cm	(2.41+/-0.02)E-13	(1.50+/-0.07)E-13	(4.56+/-0.07)E-13	(1.69+/-0.01)E-13	(1.17+/-0.002)E-12: (0.37+/-0.004) E-12

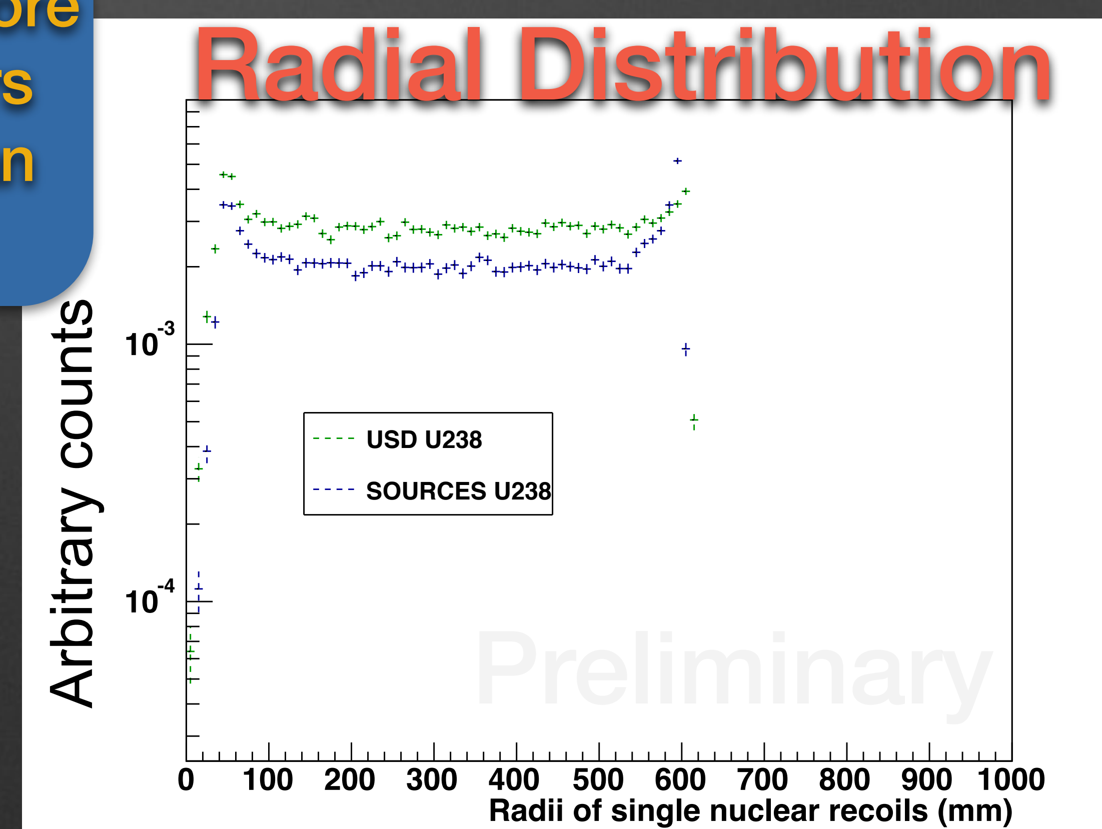
Spectral shape in Ge detector





Shape considerations lead to 64% more single scatters from USD than SOURCES





Conclusions

- Alpha-n cross section libraries TENDL and EMPIRE have been compared and are in agreement for most materials
    - But there are outliers and isotopes of interest should be quickly scanned by eye during background simulation efforts
- Neutron yields from SOURCES and TALYS-USD have been compared and are generally in agreement to a factor of 2. TALYS-USD spectra generally show more features.
- Preliminary propagation studies show single nuclear recoils in detector targets agree within a factor of 2, and spectral shapes agree to within 20%
    - No systematic differences in the simulated background recoils are seen between SOURCES and TALYS-USD