

Comparison of Radiogenic Neutron Background Calculations

Kimberly Palladino
with

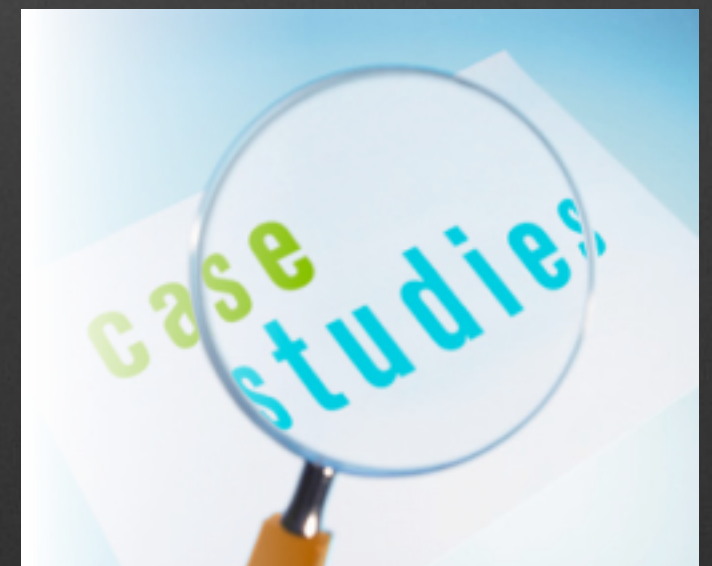
J. Cooley, D.-M. Mei, S. Scorza, M. Selvi, H. Qiu, C. Zhang

LRT 2015 University of Washington



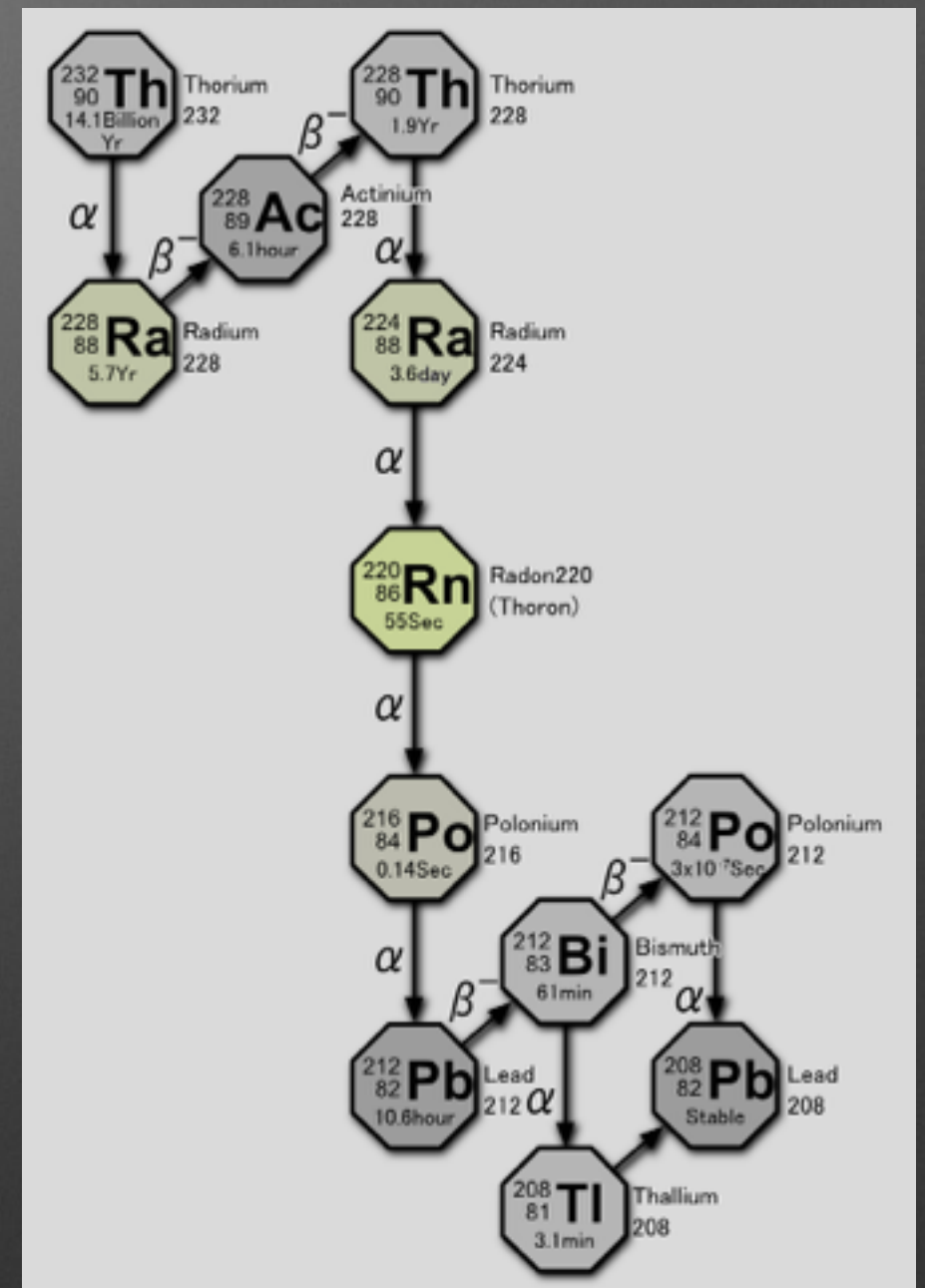
Outline

- Initial Neutron Spectra from Radiogenic Neutron 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
 - Th232 in titanium and a xenon detector
 - U238 in copper and a germanium detector



Radiogenic neutron backgrounds

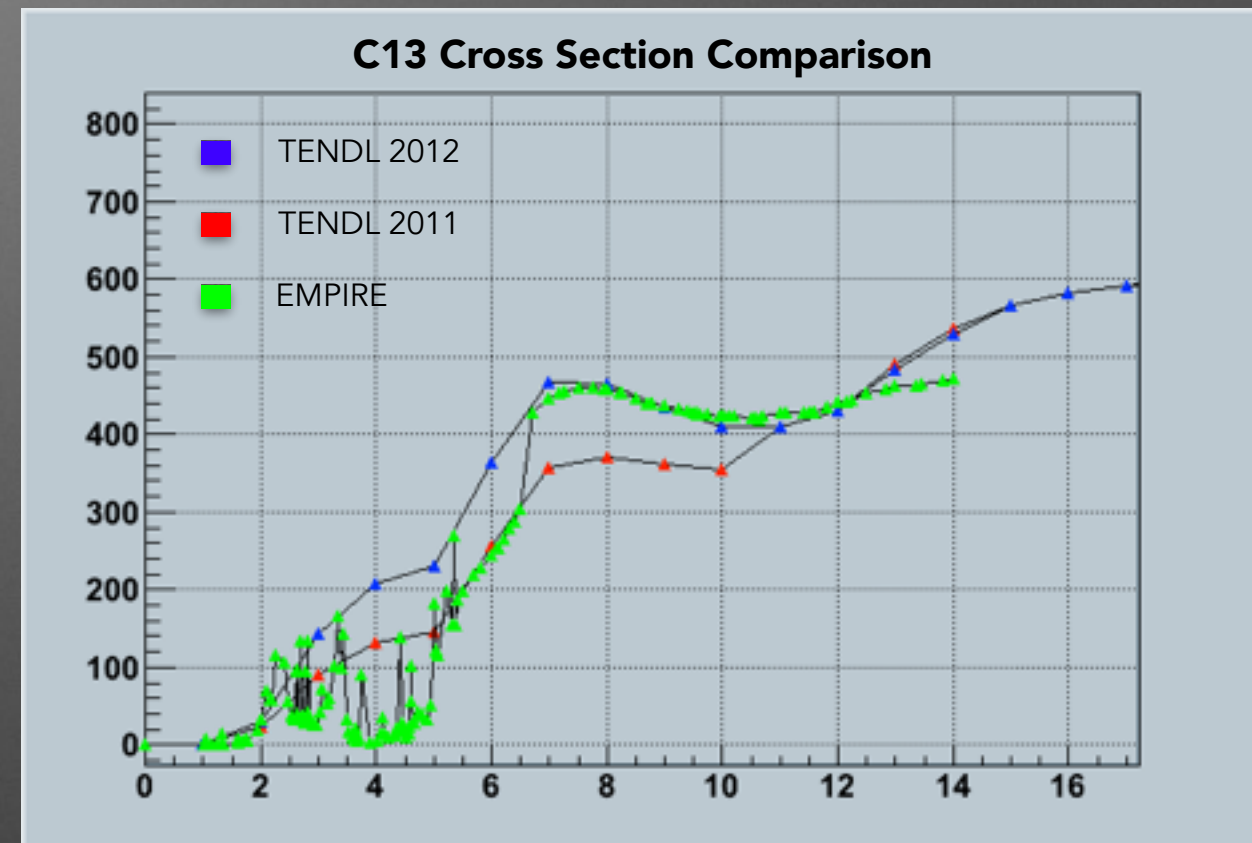
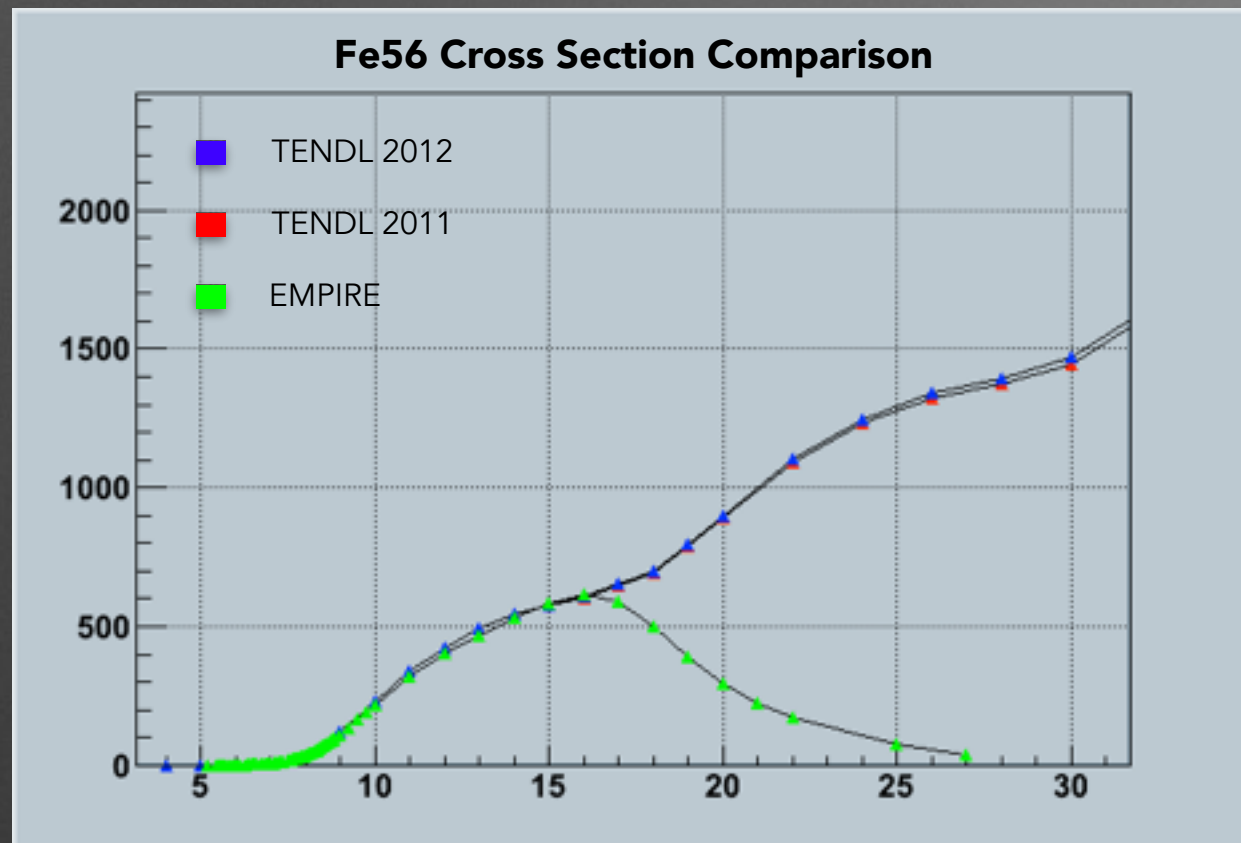
- Neutrons that have a single elastic scatter within a direct dark matter detector are generally indistinguishable from a WIMP
- A common source of these few-MeV neutrons is from alpha-n reactions in detector materials initiated by alphas in the the uranium and thorium decay chains
- Understanding the 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 currently used
 - TENDL2012 : a validated nuclear data library
 - EMPIRE2.19: recommended by IAEA, calculations cut off at lower energy, some isotopes also include measurement data
- Neither library fully reproduces experimentally observed resonances

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.



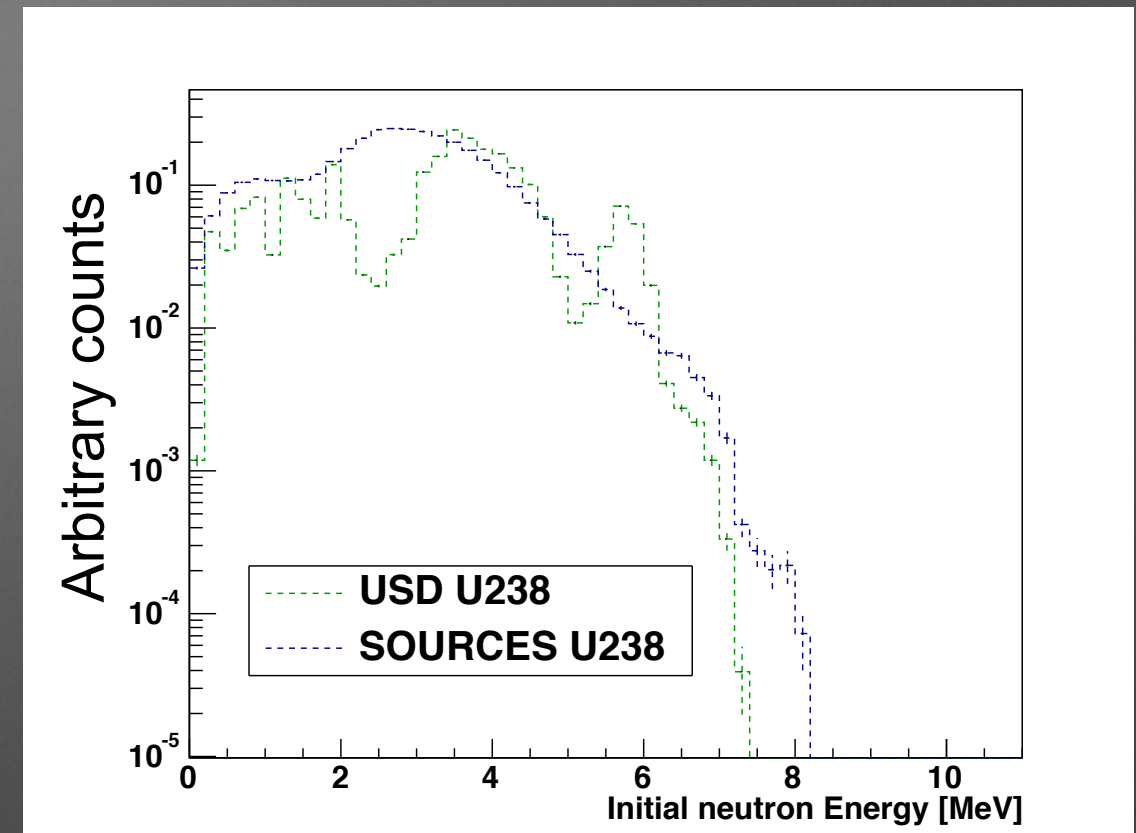
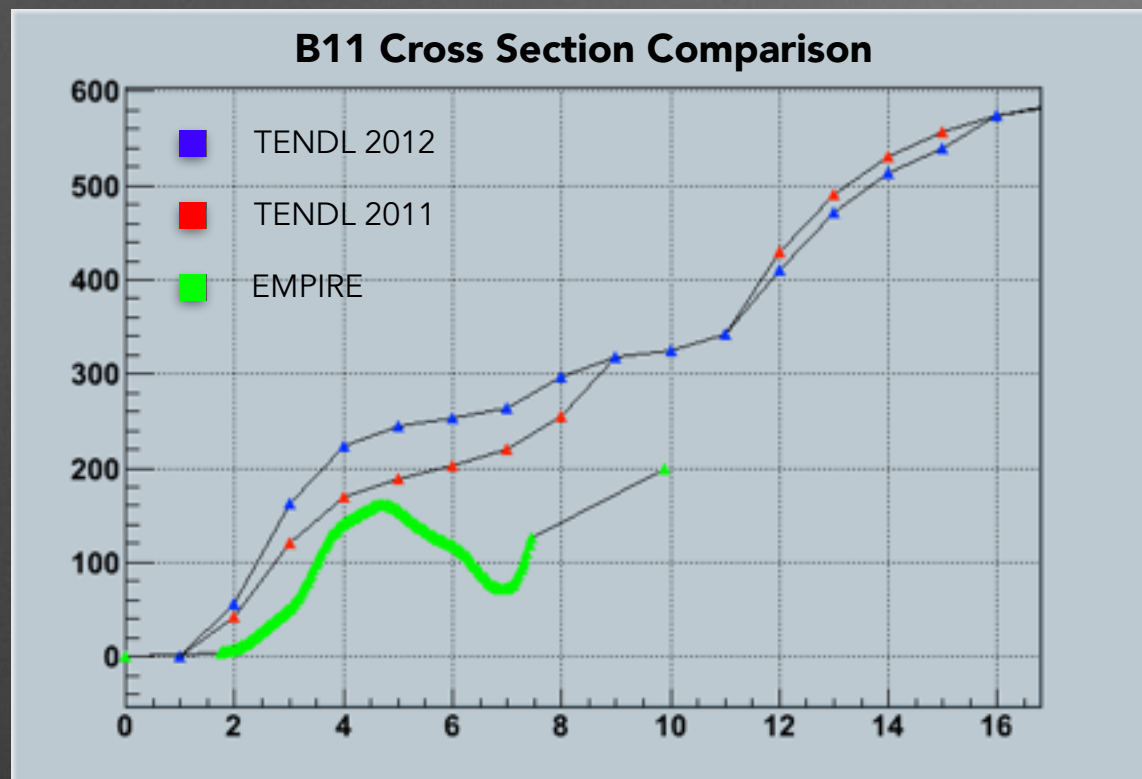
- **TALYS-USD**: using neutronyield.usd.edu front end to TALYS calculations to generate neutron spectra to 12 MeV using cross sections from TENDL

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 $< 20\text{MeV}$ 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



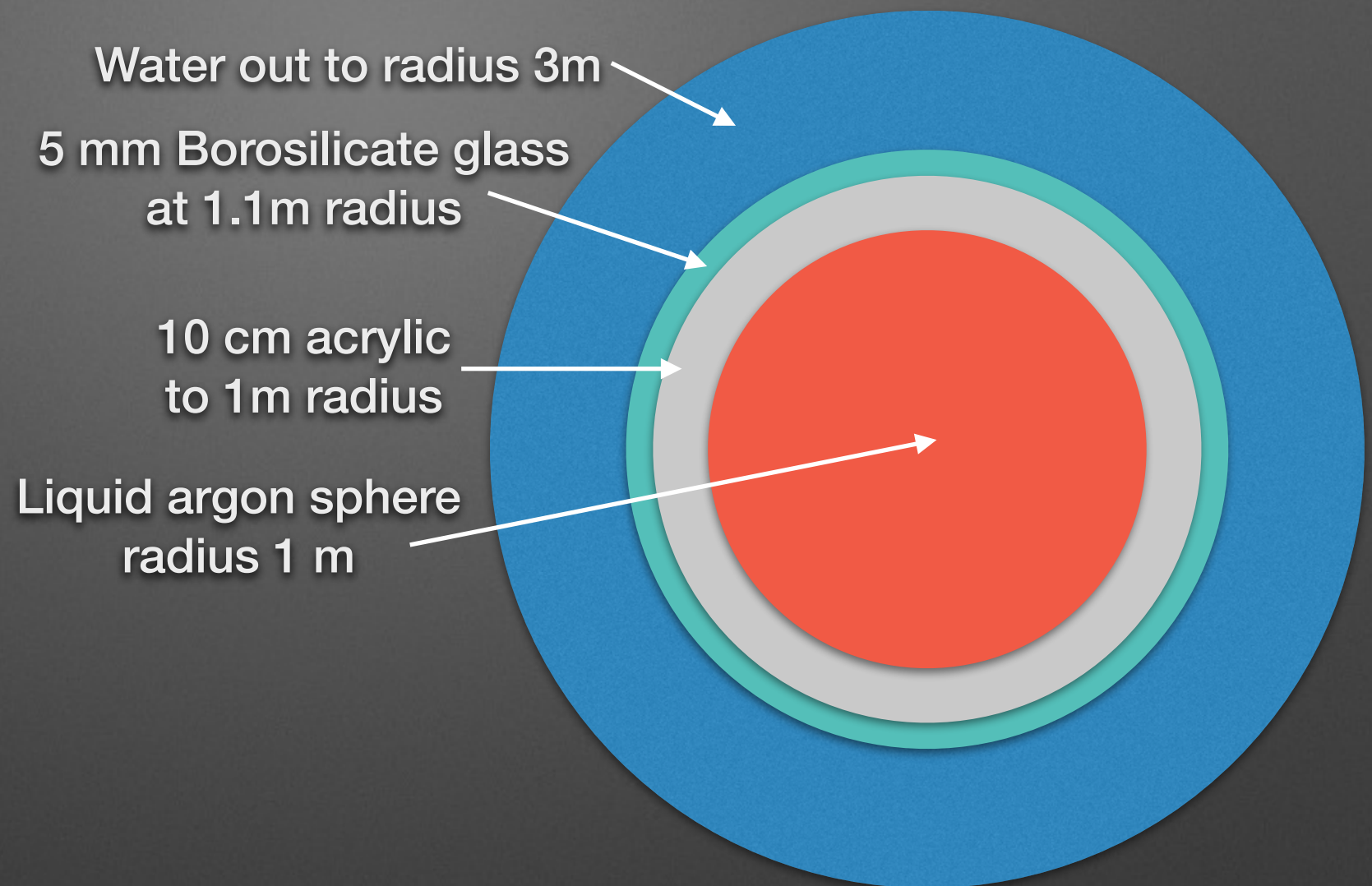
Neutrons in Borosilicate from U238



- Neutron spectra are calculated with SOURCES4 and TALYS (through the neutryield.usd.edu website, hereafter called USD) from the U238 decay chain in borosilicate glass
- From 1 ppb of U238, USD calculations give a neutron yield of $2.45 \text{ E-}10 \text{ n/s/cm}^3$ while SOURCES gives a neutron yield of $3.63 \text{ E-}10 \text{ n/s/cm}^3$, 48% higher

Argon detector simulations

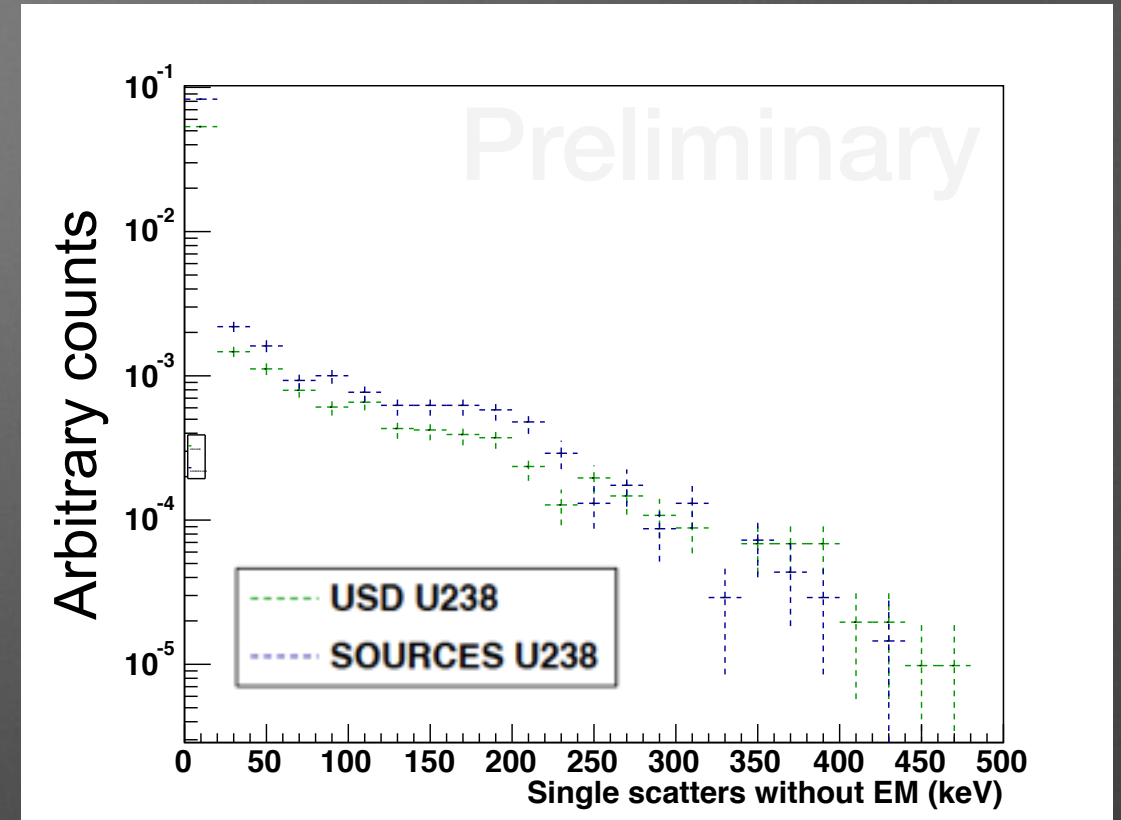
- 250000 neutrons isotropic from borosilicate glass for each simulation
- Neutron recoil threshold of 20 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in argon
- Neutron capture in water needed to externally veto event



Nested spheres geometry

Argon recoils

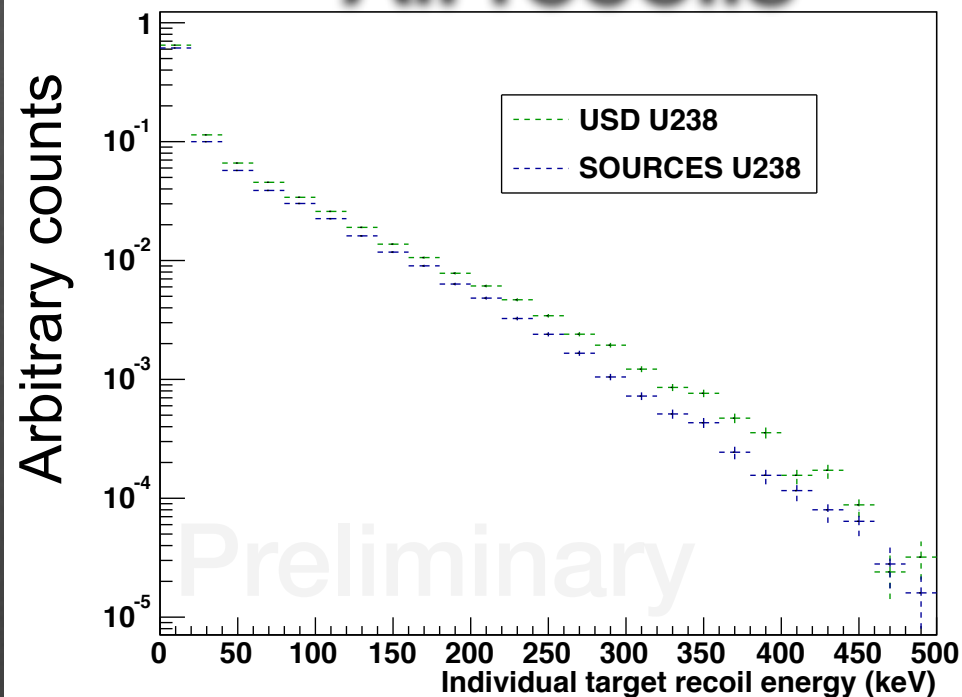
48% higher neutron yield from
SOURCES gives 40% more
single scatters than USD



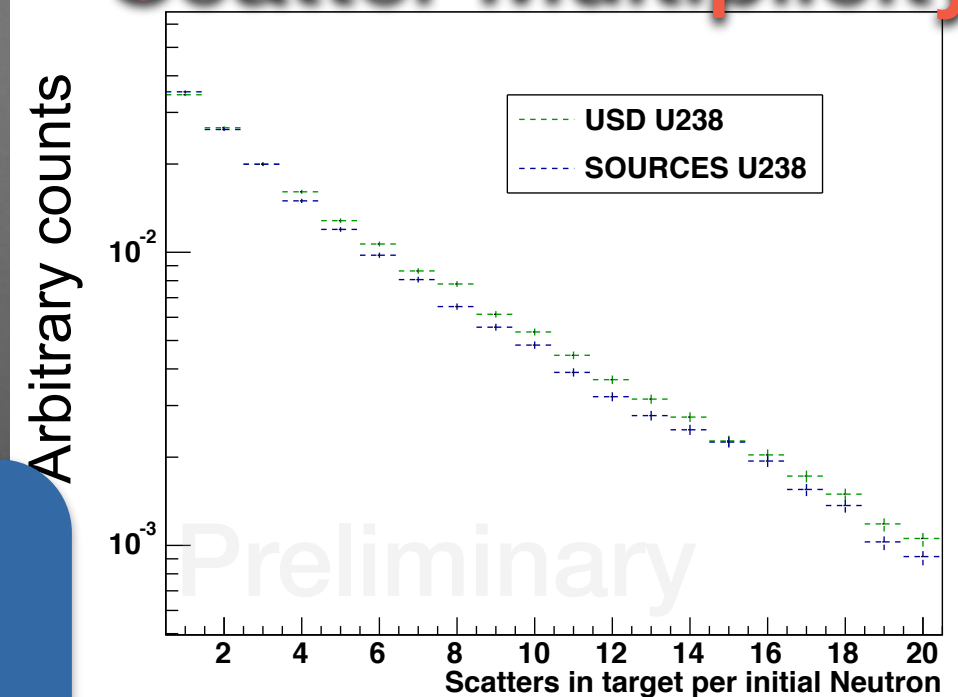
	Summed nuclear recoils over 20 keV	Single nuclear recoil over 20 keV	Single recoils over 20 keV no capture in veto	Single recoils over 20 keV no electron scatter >1 keV	Ratio of Multiple scatters: single scatters no threshold
TALYS-USD % of initial sim	5.2 +/- 0.05%	0.71 +/-0.02%	0.60 +/- 0.01%	0.30 +/- 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

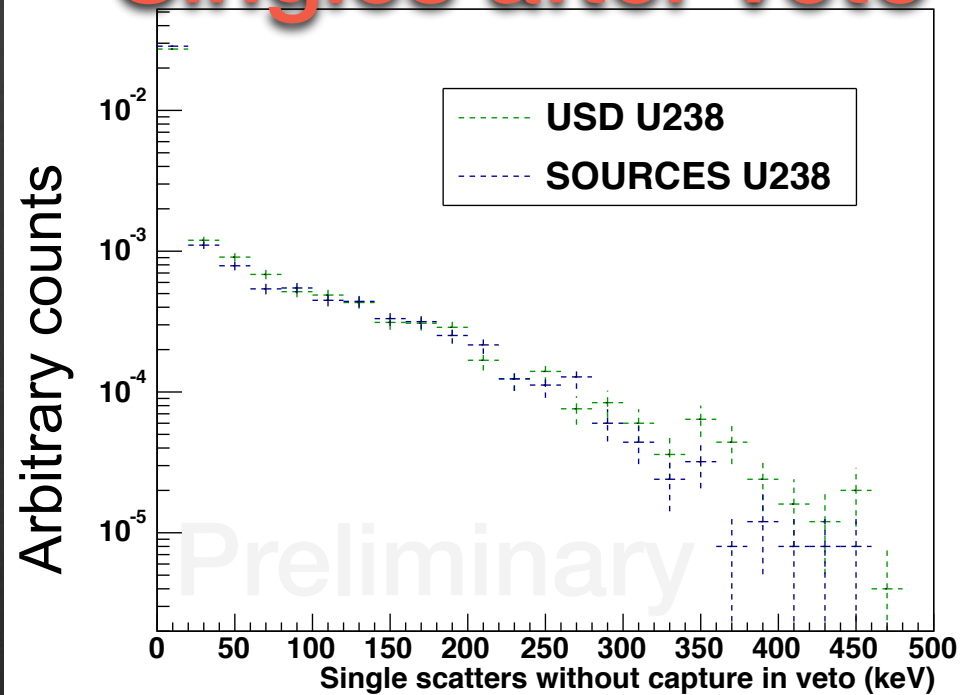


Scatter Multiplicity

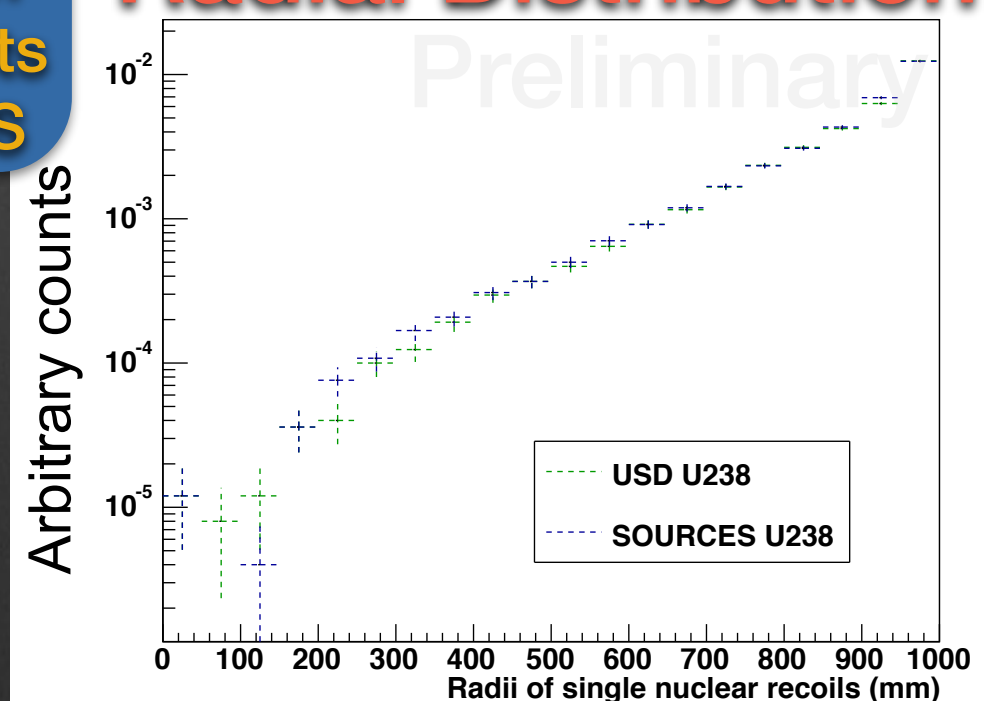


Shape comparisons show small differences: USD ~10% higher in predicted counts than SOURCES

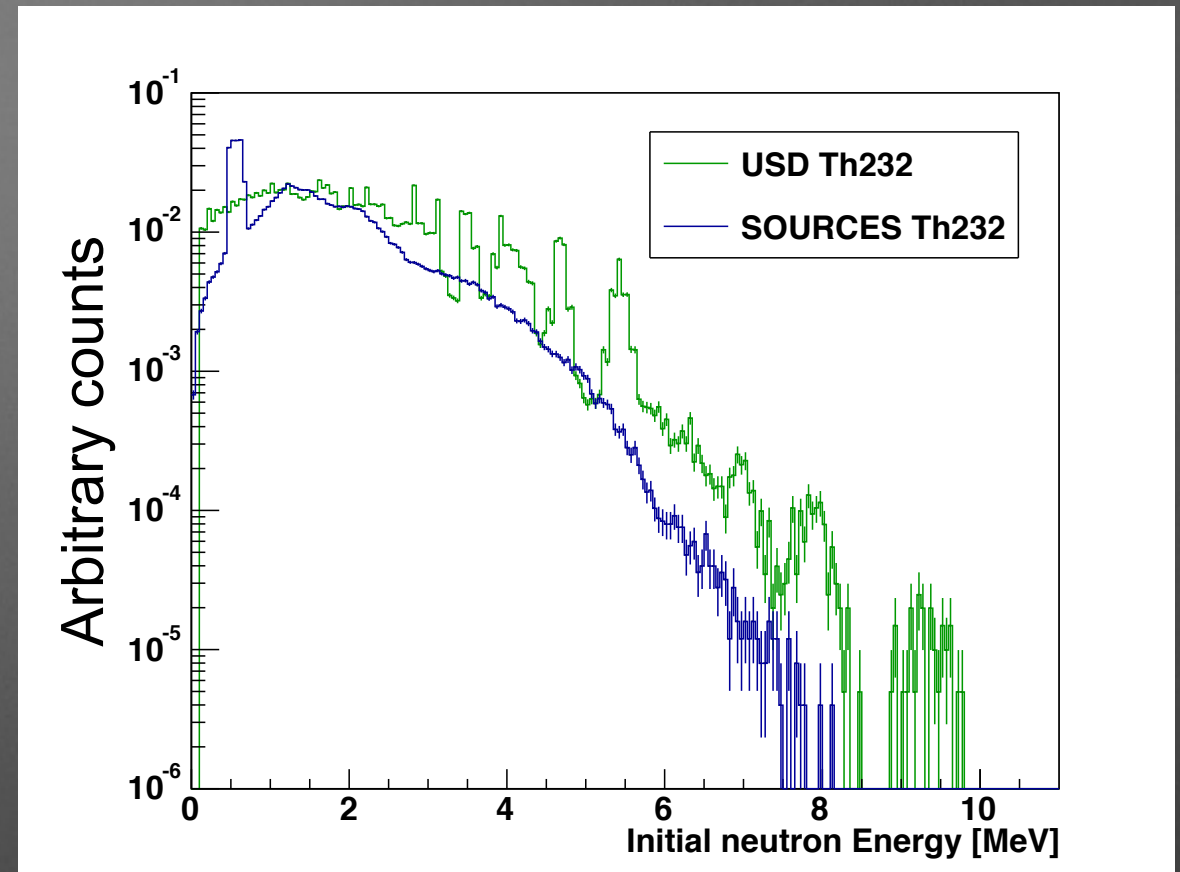
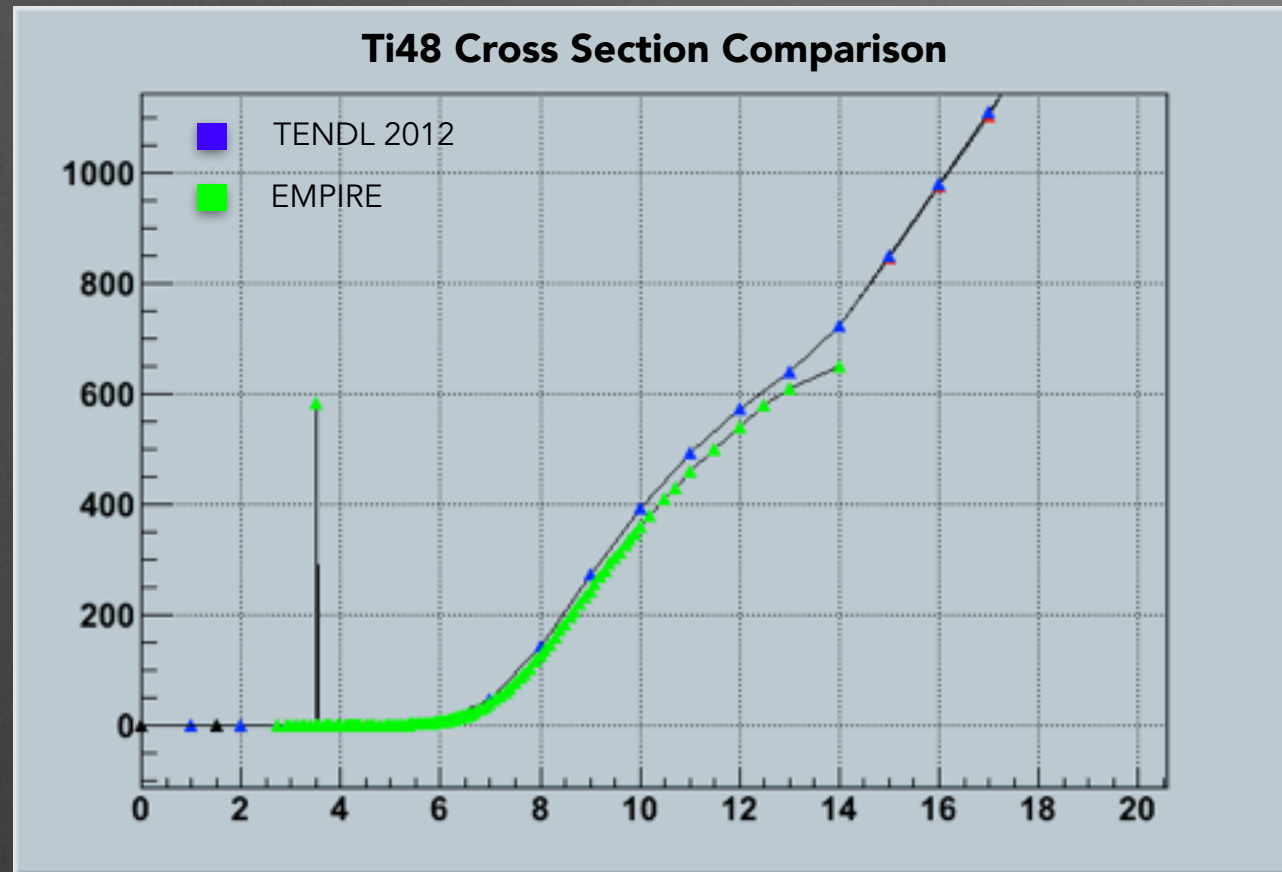
Singles after veto



Radial Distribution



Neutrons in titanium from Th232



- Large resonant peak in cross sections for SOURCES(shown), hand corrected before further calculations per communication with V. Kudryavtsev
- Even with the correction a feature remains in the neutron spectrum
- From 1ppb of Th232, USD calculations give a neutron yield₃ of $1.24 \text{ E-}10 \text{ n/s/cm}^3$ while SOURCES gives a neutron yield of $9.96\text{E-}11 \text{ n/s/cm}^3$, 25% lower

Xe Detector Simulations

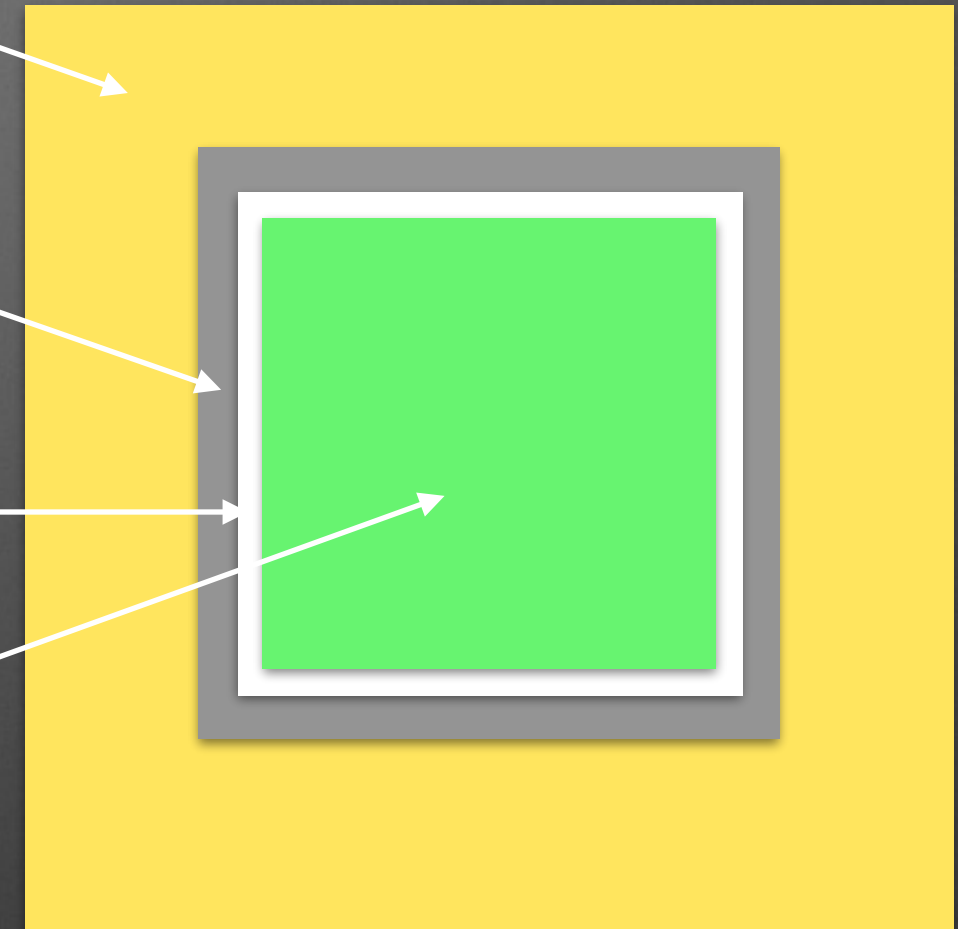
- 250000 neutrons isotropic from titanium or teflon for each simulation
- Neutron recoil threshold of 5 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in xenon
- Neutron capture in oil-based scintillator needed to externally veto event

Liquid scintillator cylinder
3 m tall, 3 m wide

2 cm titanium
at 0.55m radius

3 cm PTFE
to 0.5m radius

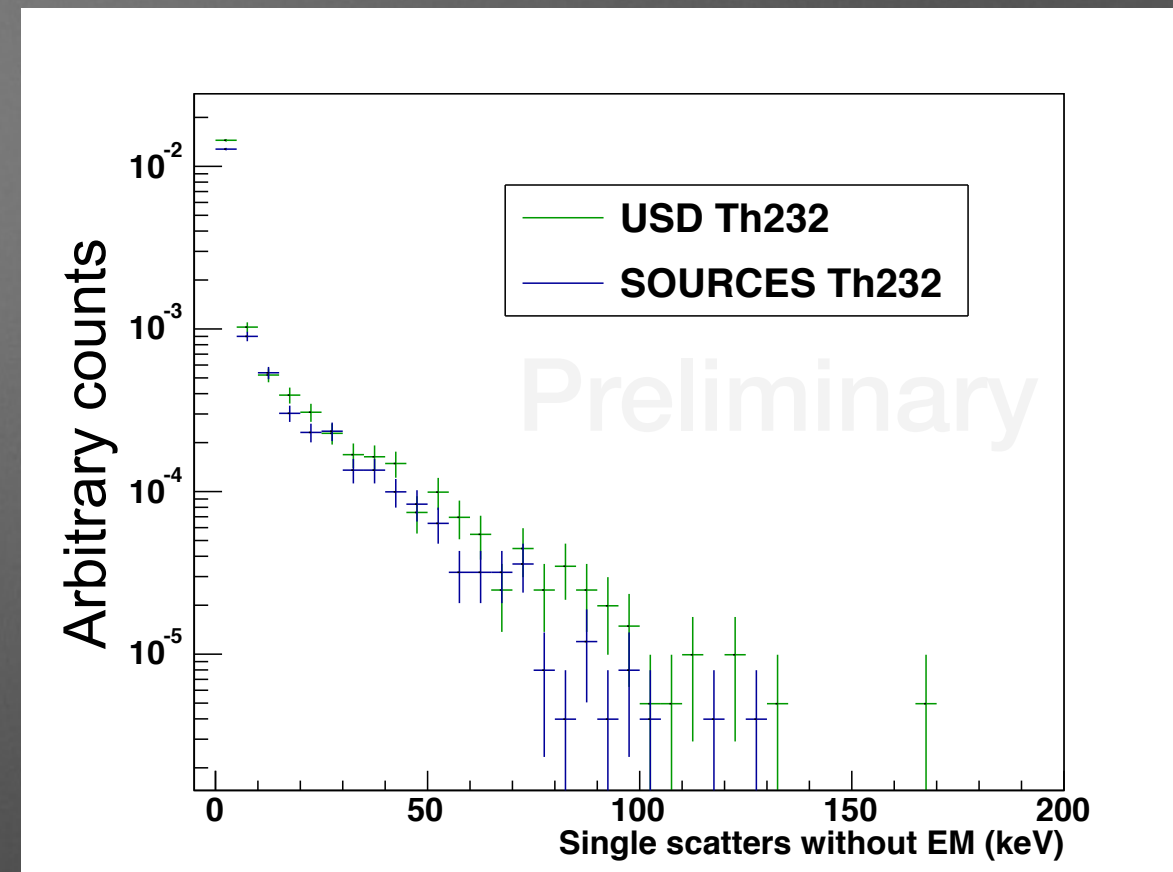
Liquid xenon
1 m tall, 1m wide



Nested cylinders geometry

Xenon recoils

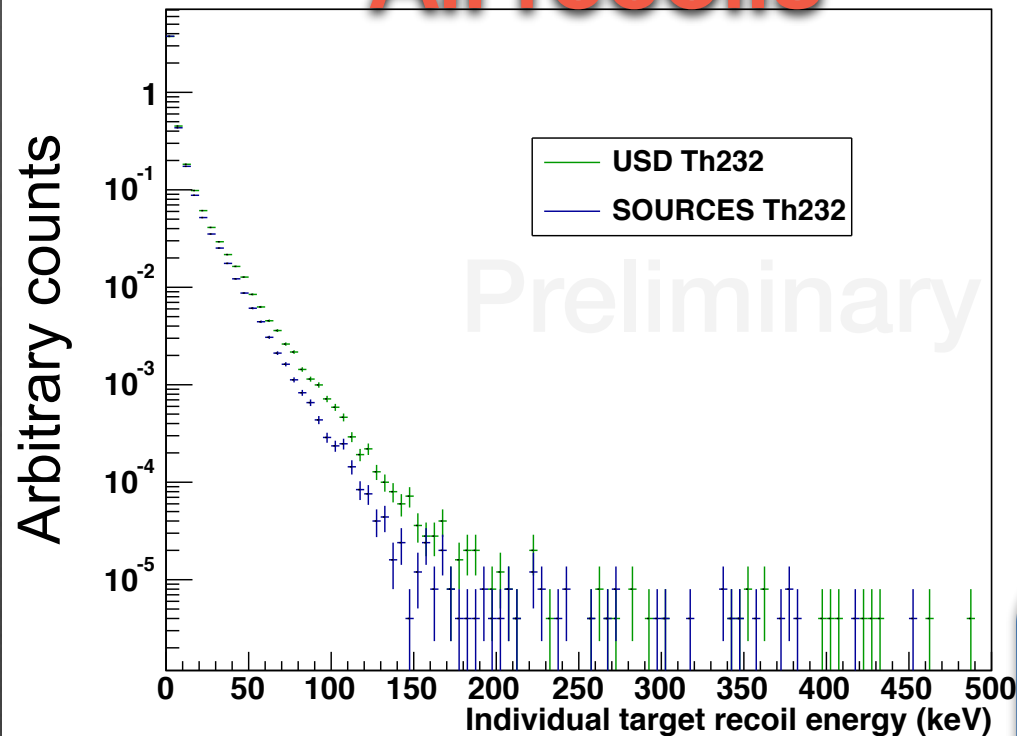
24% higher neutron yield from
USD gives 27% more single
scatters than SOURCES



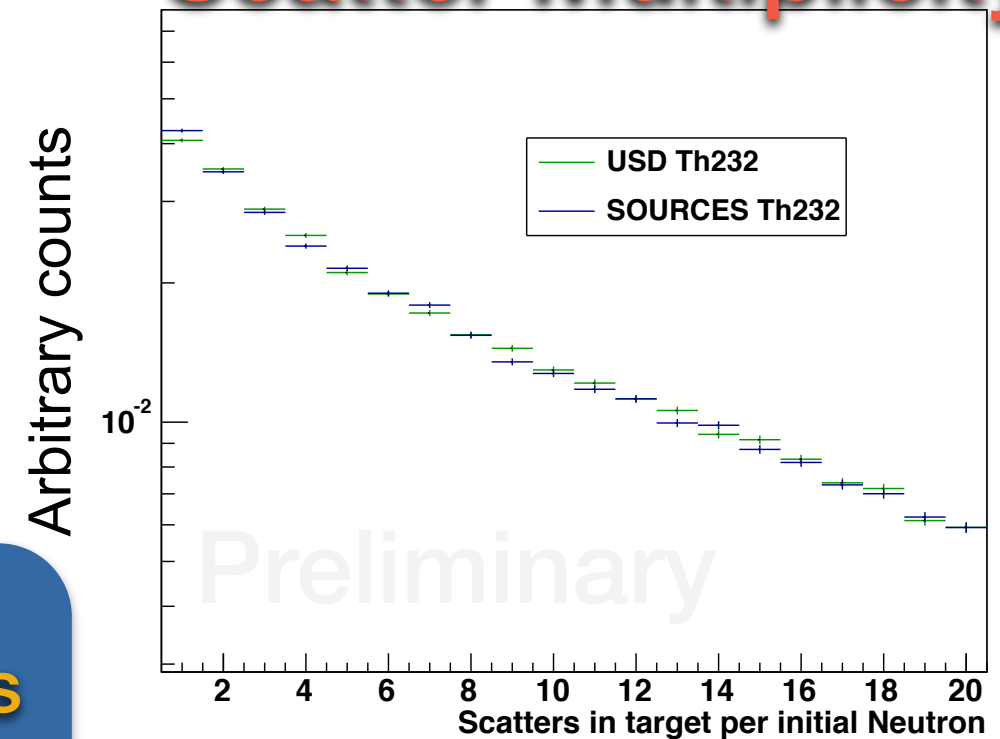
	Summed nuclear recoils over 5 keV	Single nuclear recoil over 5 keV	Single recoils over 5 keV no capture in veto	Single recoils over 5 keV no electron scatter >1 keV	Ratio of Multiple scatters: single scatters no threshold
TALYS-USD % of initial sim	8.9 +/- 0.06%	1.37 +/-0.02%	0.45 +/- 0.01%	0.29+/- 0.01%	8.70+/- 0.086
SOURCES % of initial sim	7.7 +/-0.05%	1.34+/-0.02%	0.45+/-0.01%	0.29+/-0.01%	8.12+/-0.076
TALYS-USD n/s/cm	(1.11+/-0.007)E-11	(1.70+/-0.03)E-12	(5.58+/-0.17)E-13	(3.48+/- 0.13)E-13	(4.36+/-0.004)E-11: (0.50+/-0.005) E-11
SOURCES n/s/cm	(0.77+/-0.006)E-11	(1.34+/-0.02)E-12	(4.46+/-0.13)E-13	(2.90+/-0.11)E-13	(3.45+/-0.003)E-11: (0.425+/-0.004) E-11

Spectral shape in Xe detector

All recoils

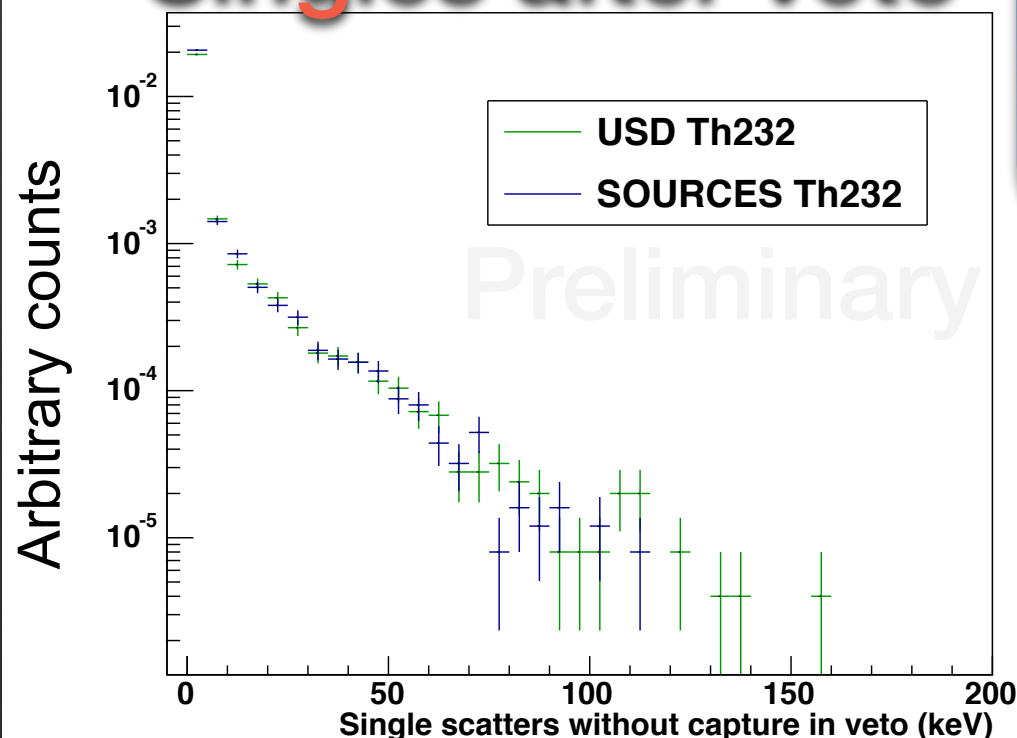


Scatter Multiplicity

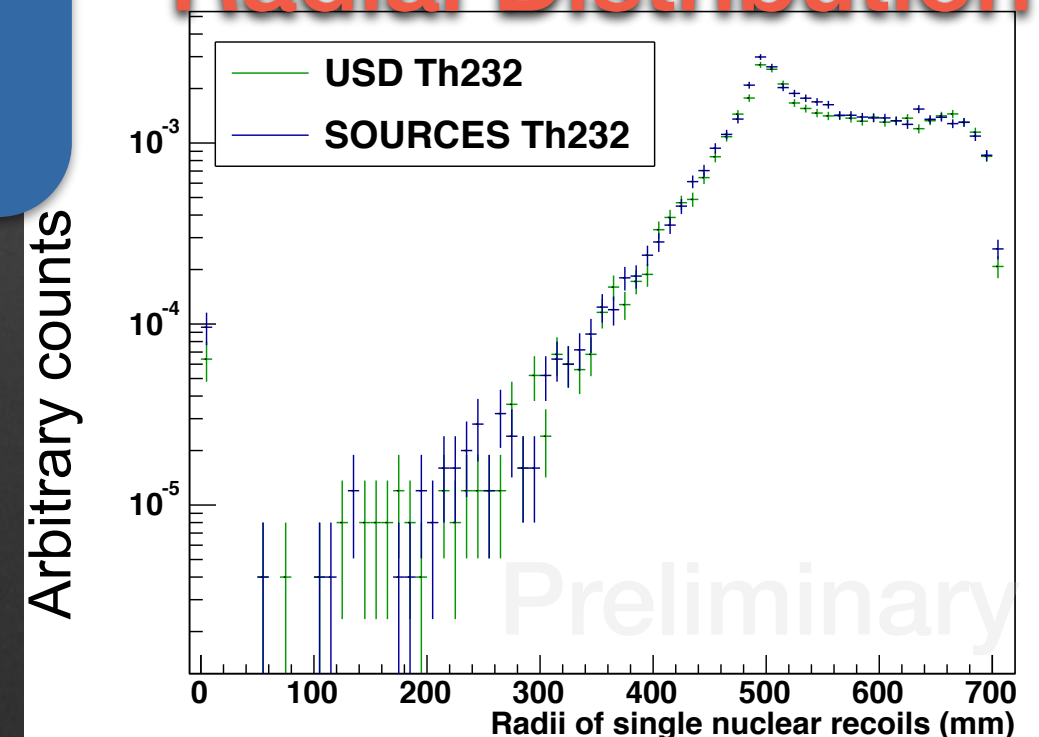


Shape comparisons show no differences once cuts occur

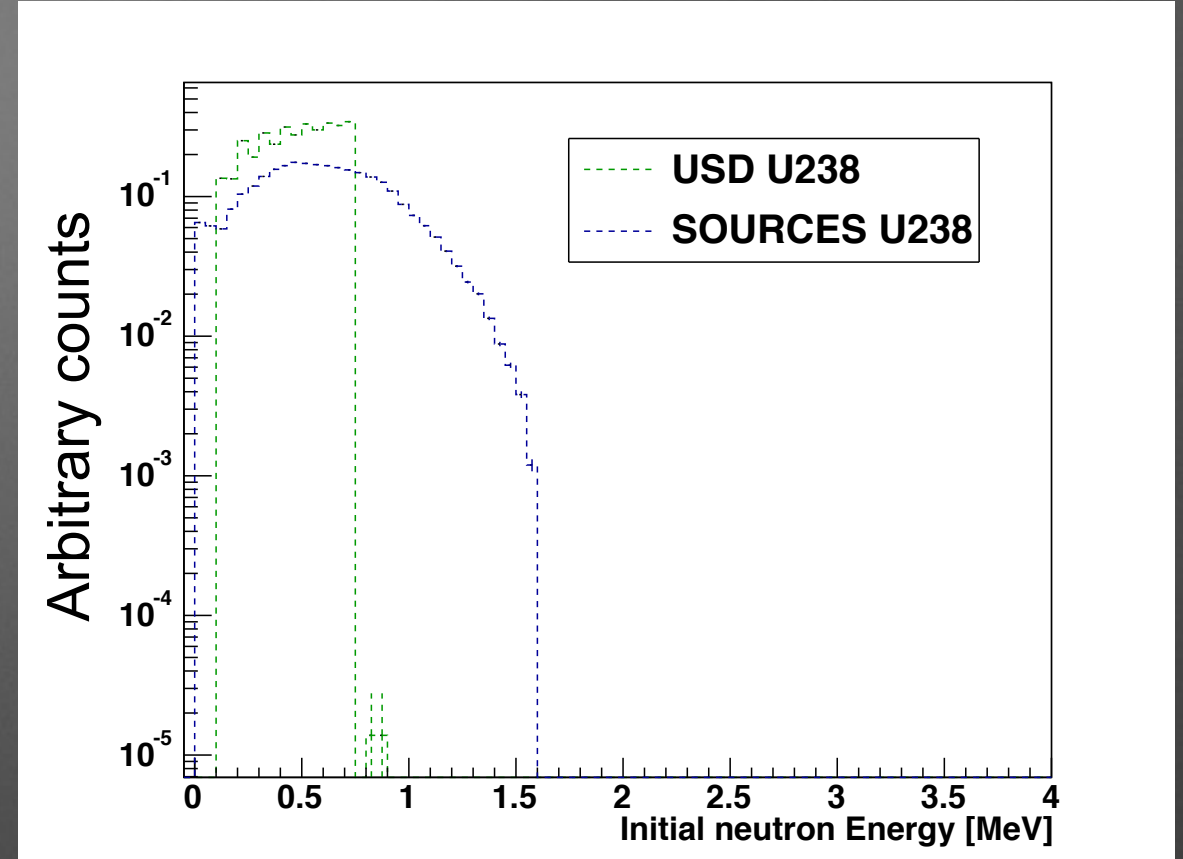
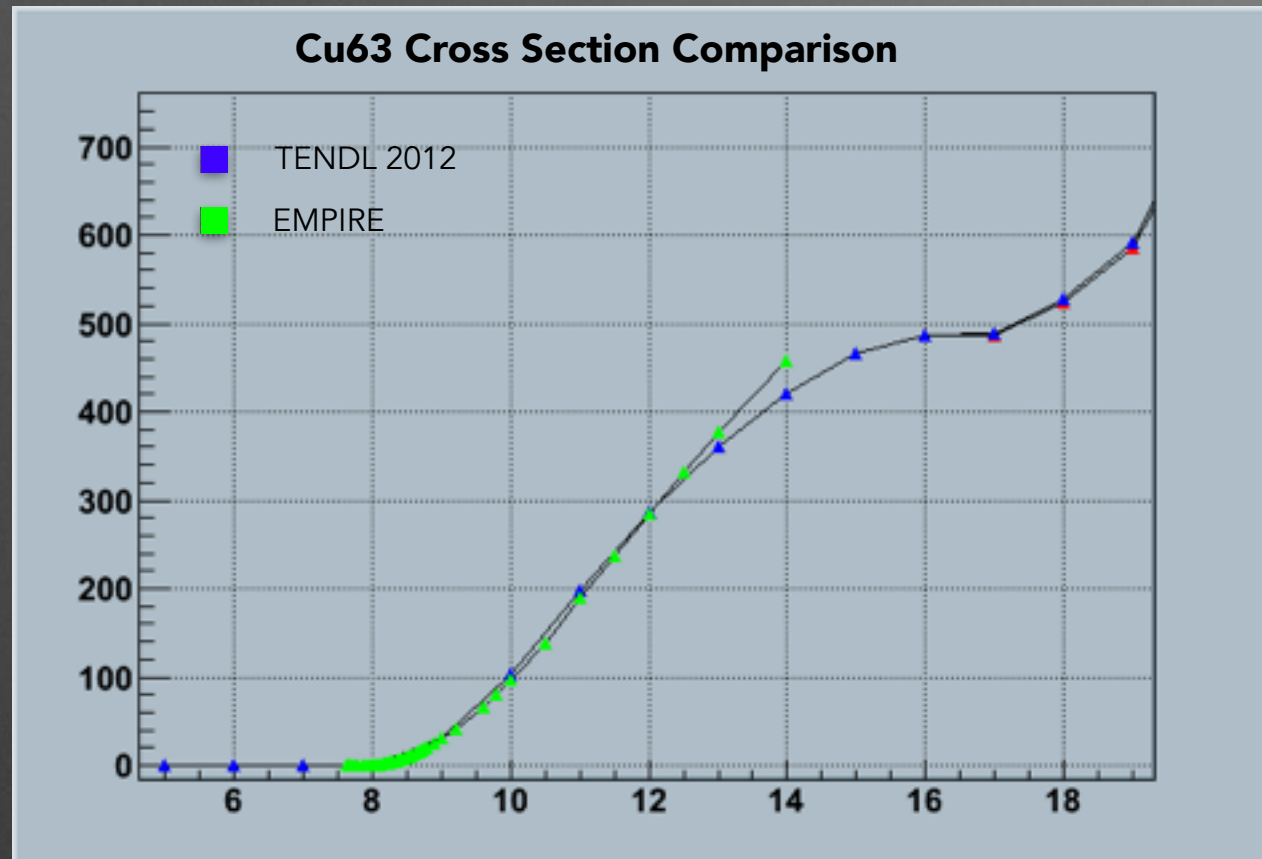
Singles after veto



Radial Distribution



Neutrons in copper from U238



- From 1ppb of U238, USD calculations give a neutron yield of $3.46 \text{ E-12 n/s/cm}^3$ 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

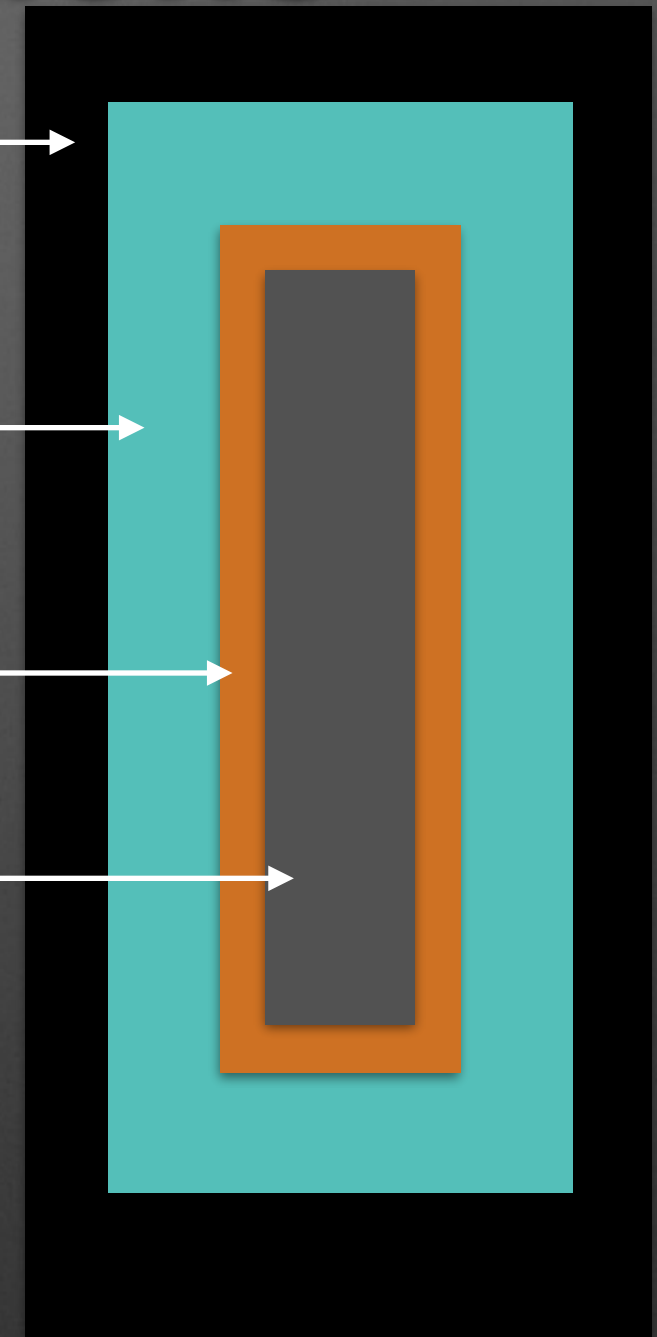
- 250000 neutrons isotropic from copper for each simulation
- Neutron recoil threshold of 5 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in argon
- Neutron capture in plastic scintillator needed to externally veto event

10 cm Lead shield cylinder
31 cm radius, 1.75m tall

15 cm polyethylene
down to 6 cm radius,
1.5 m tall

1 cm copper
to 5 cm radius

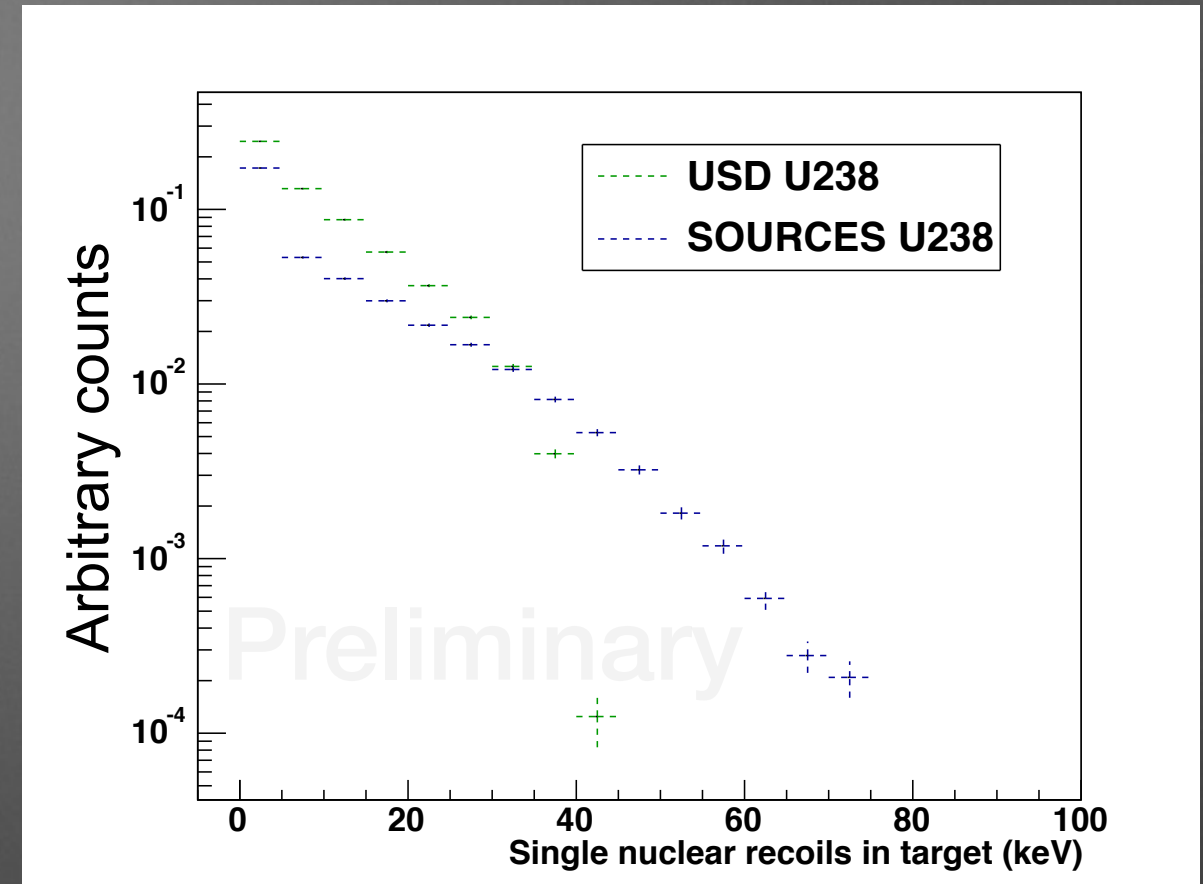
Germanium
10 cm diameter,
1.2m tall



Nested cylinders geometry

Germanium recoils

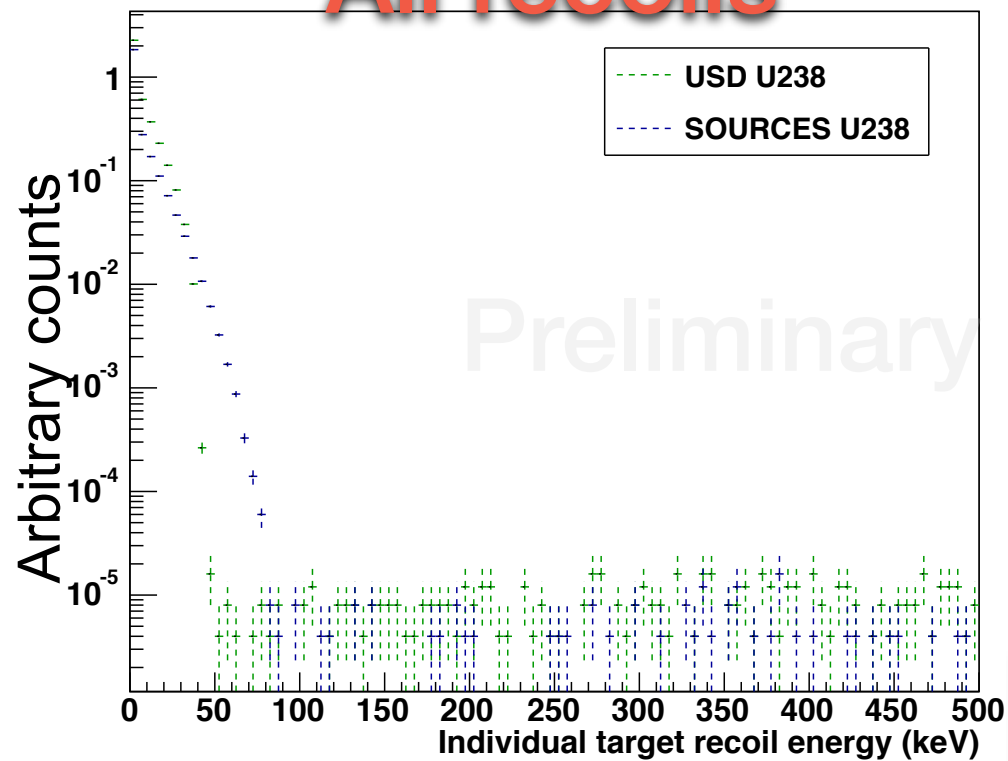
Shape and yield effects cause an 80% higher prediction of single scatters from USD than SOURCES



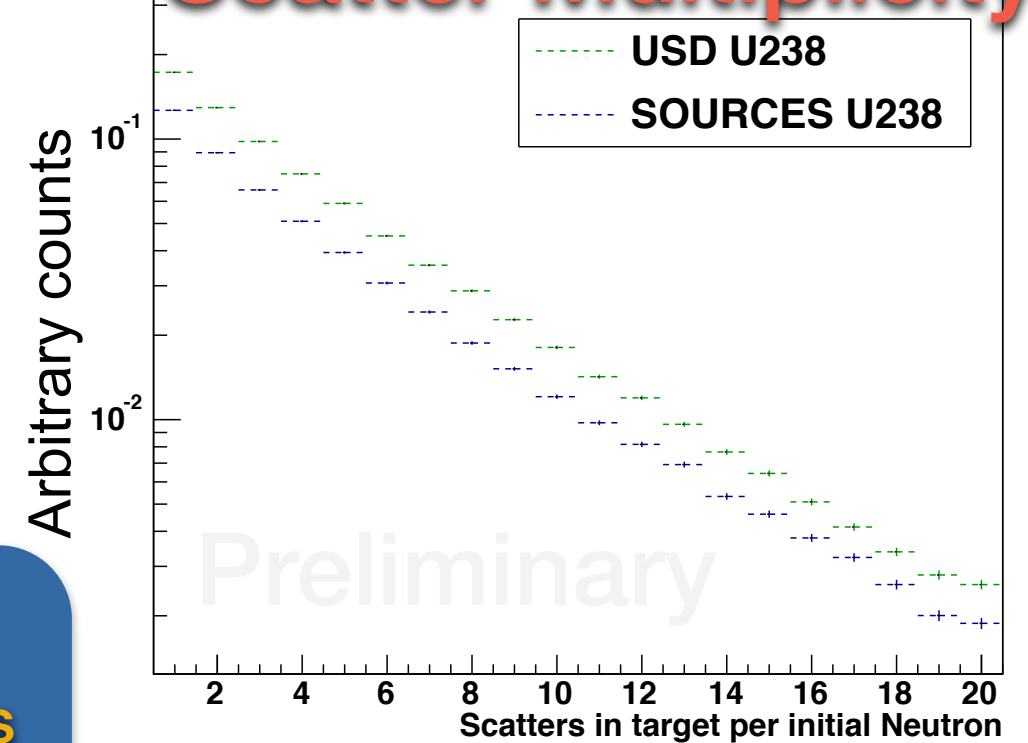
	Summed nuclear recoils over 5 keV	Single nuclear recoil over 5 keV	Single recoils over 5 keV no capture in veto	Single recoils over 5 keV no electron scatter >1 keV	Ratio of Multiple scatters: single scatters no threshold
TALYS-USD % of initial sim	14.2 +/- 0.07%	10.2 +/-0.06%	2.4 +/- 0.03%	8.87+/- 0.06%	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

All recoils

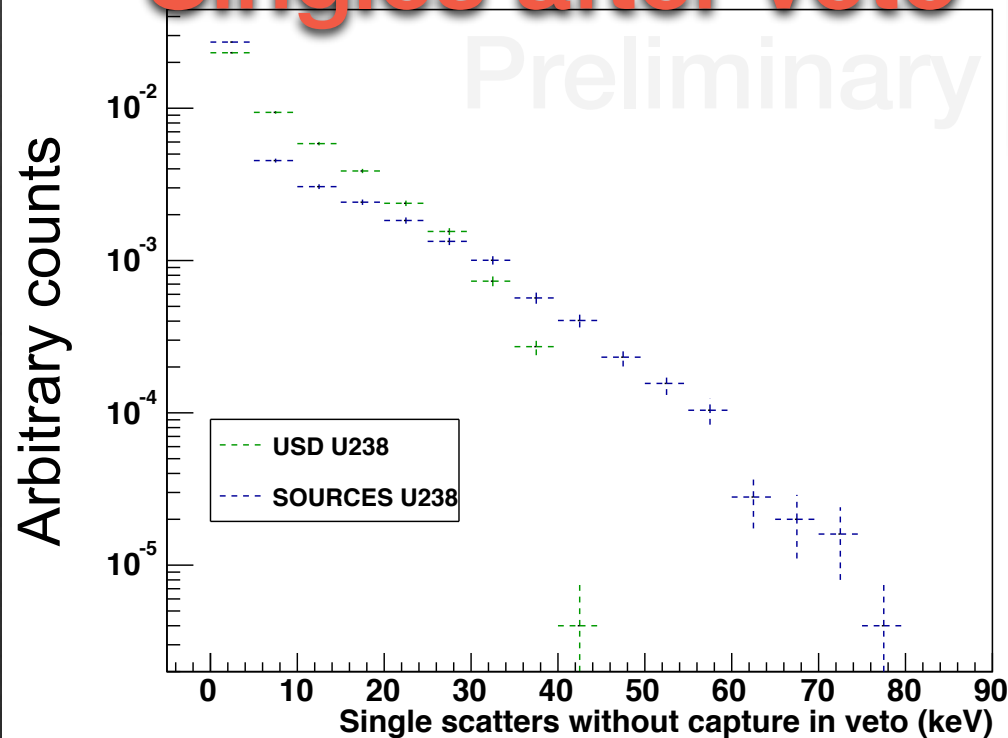


Scatter Multiplicity

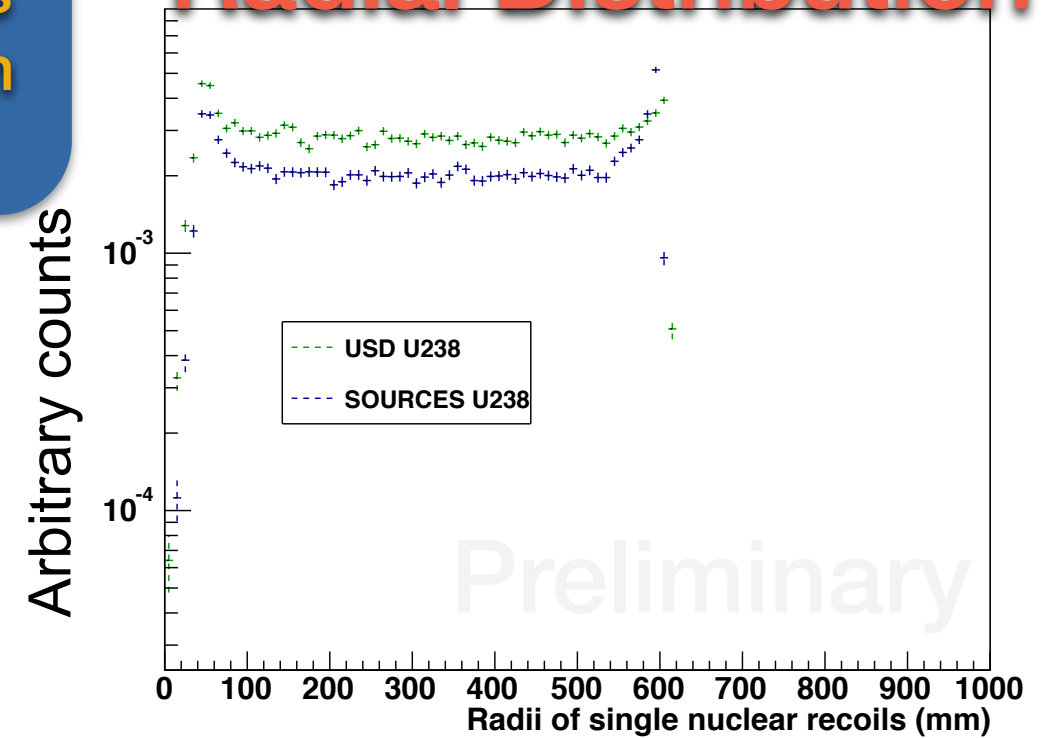


Shape considerations lead to 64% more single scatters from USD than SOURCES

Singles after veto



Radial Distribution



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%