# Comparison of Radiogenic Neutron Background Calculations

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SLAC

# 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
  - U238 in titanium and a xenon detector
  - U238 in copper and a germanium detector

# Radiogenic neutron backgrounds

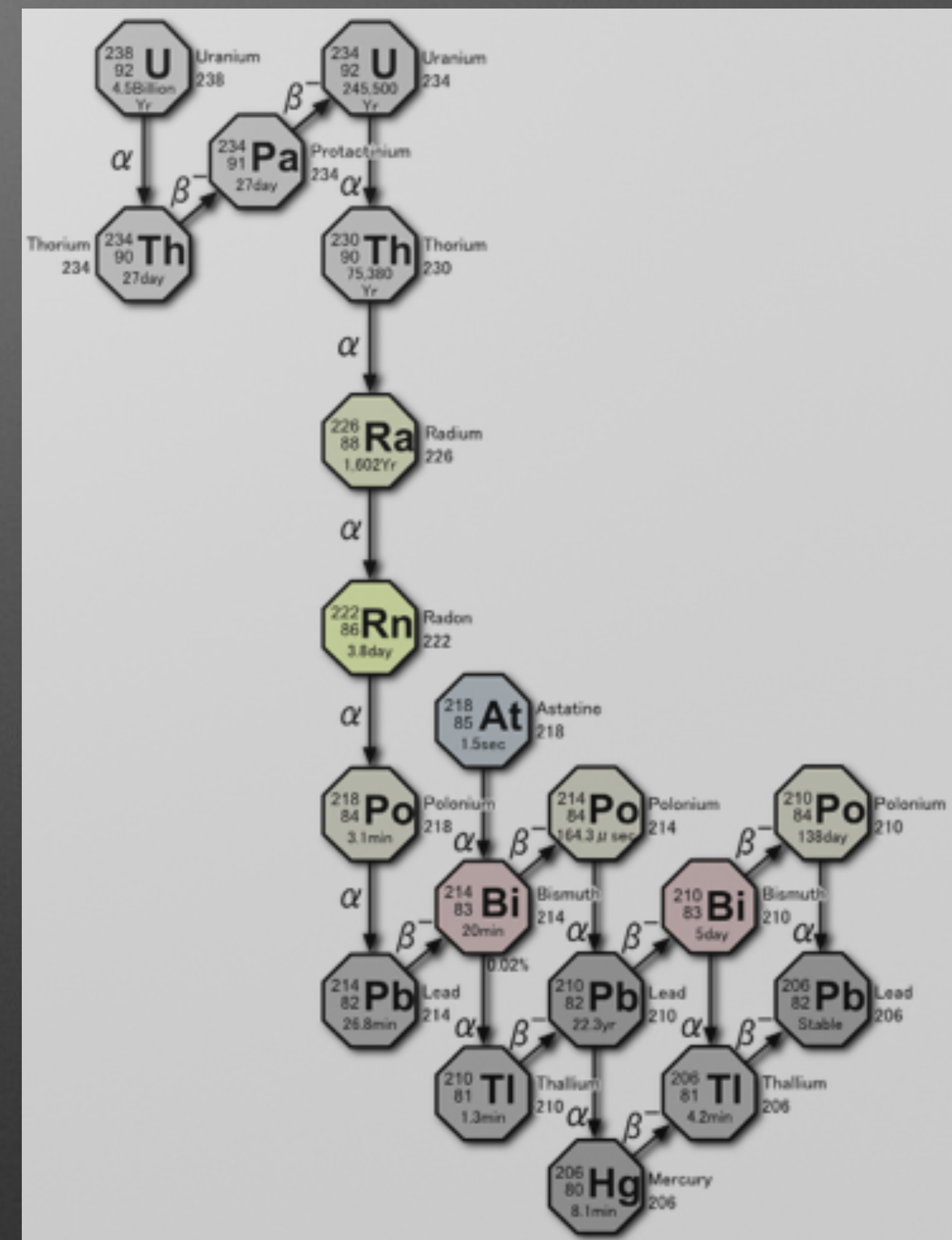
- Neutrons that have a single elastic scatter within a direct dark matter detector are generally indistinguishable from a WIMP

- 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

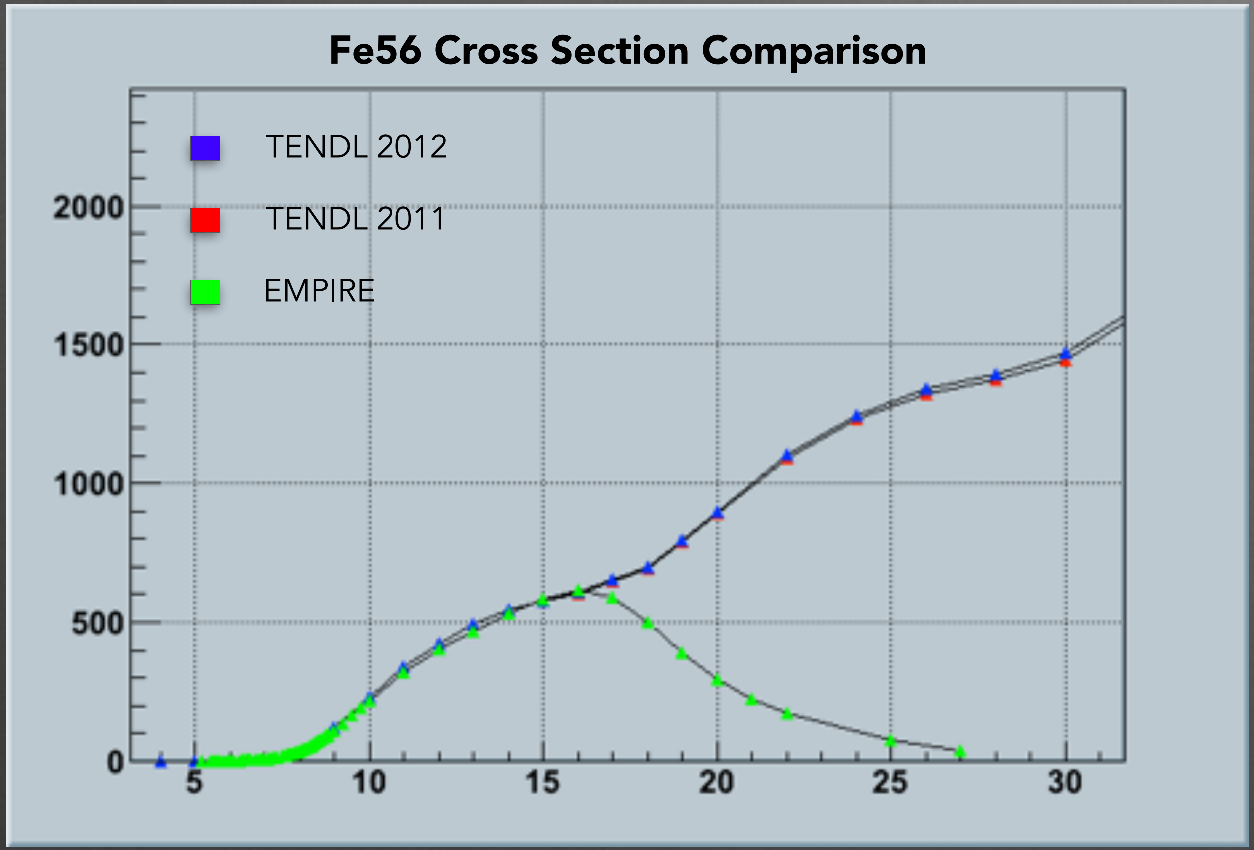
  - Spectral shape differences matter when extracting backgrounds in running experiments

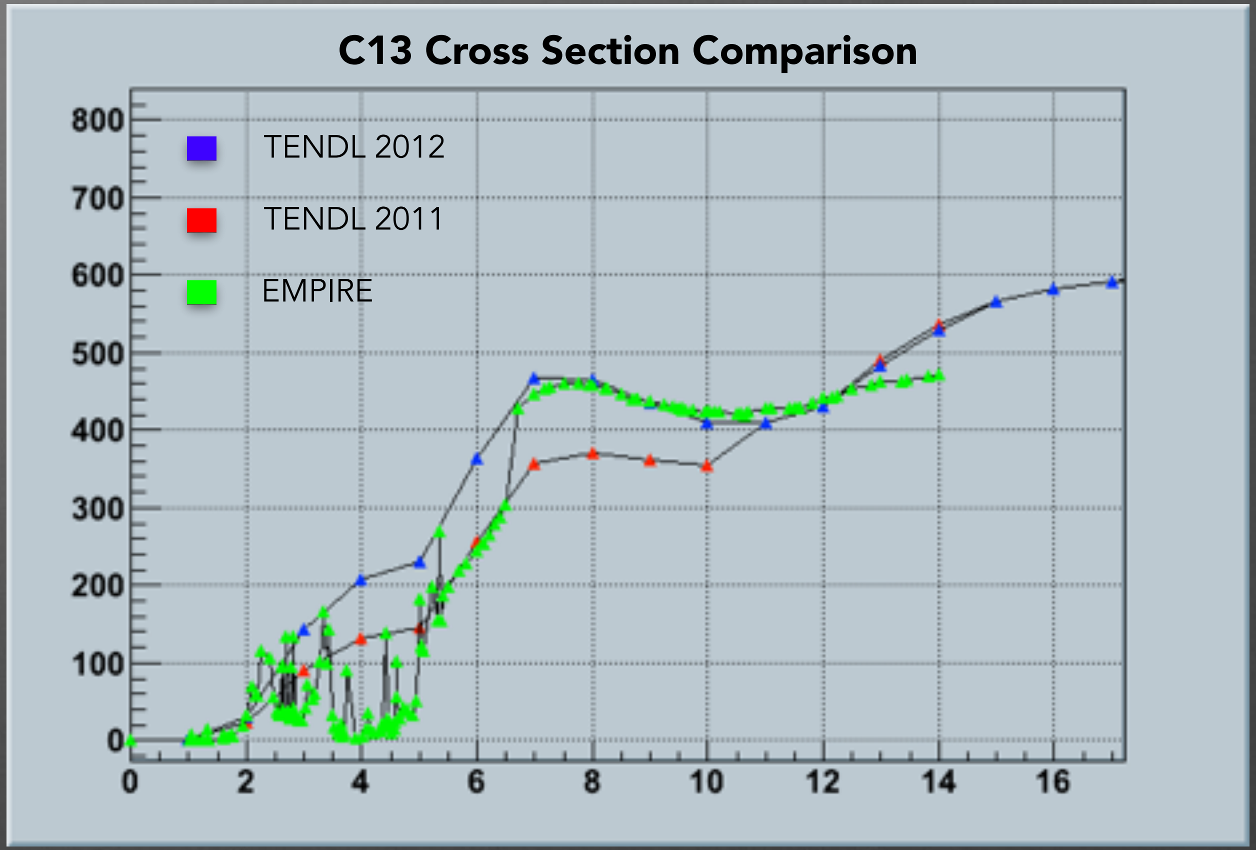


# Alpha-n cross sections

- Required input for calculating the neutron yield
- Two separate databases are 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.

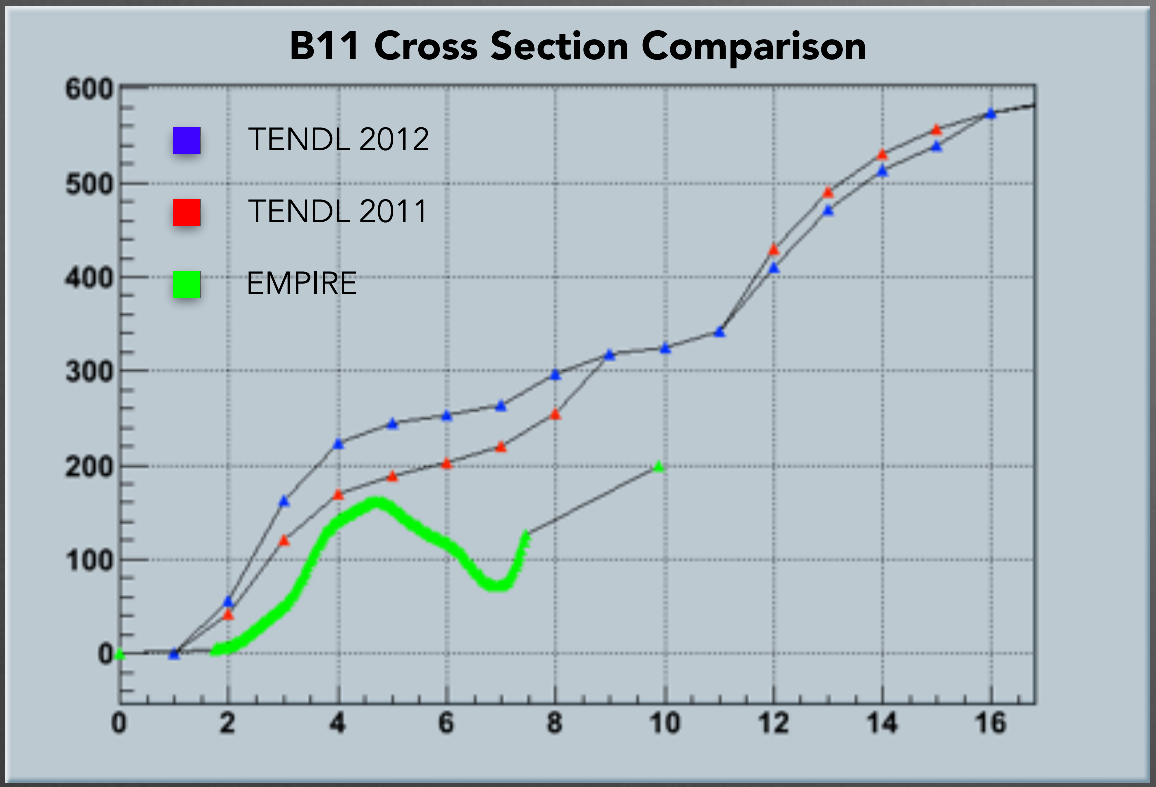
- SOURCES 4A: configurable code run independently to generate neutron spectra up to 10 MeV using cross sections from EMPIRE.

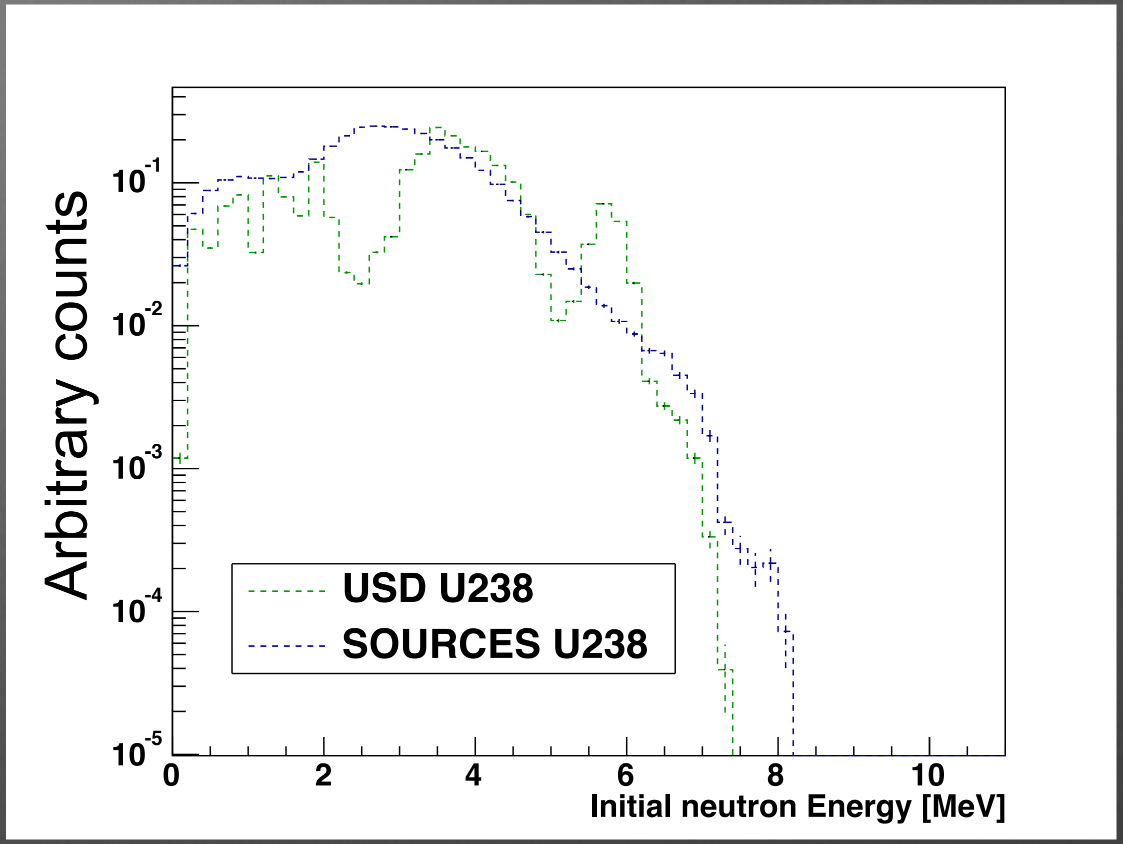
- TALYS-USD: using neutronyield.usd.edu front end to TALYS calculations to generate neutron spectra to 12 MeV using cross sections from TENDL

# 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 < 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

# Neutrons in Borosilicate from U238



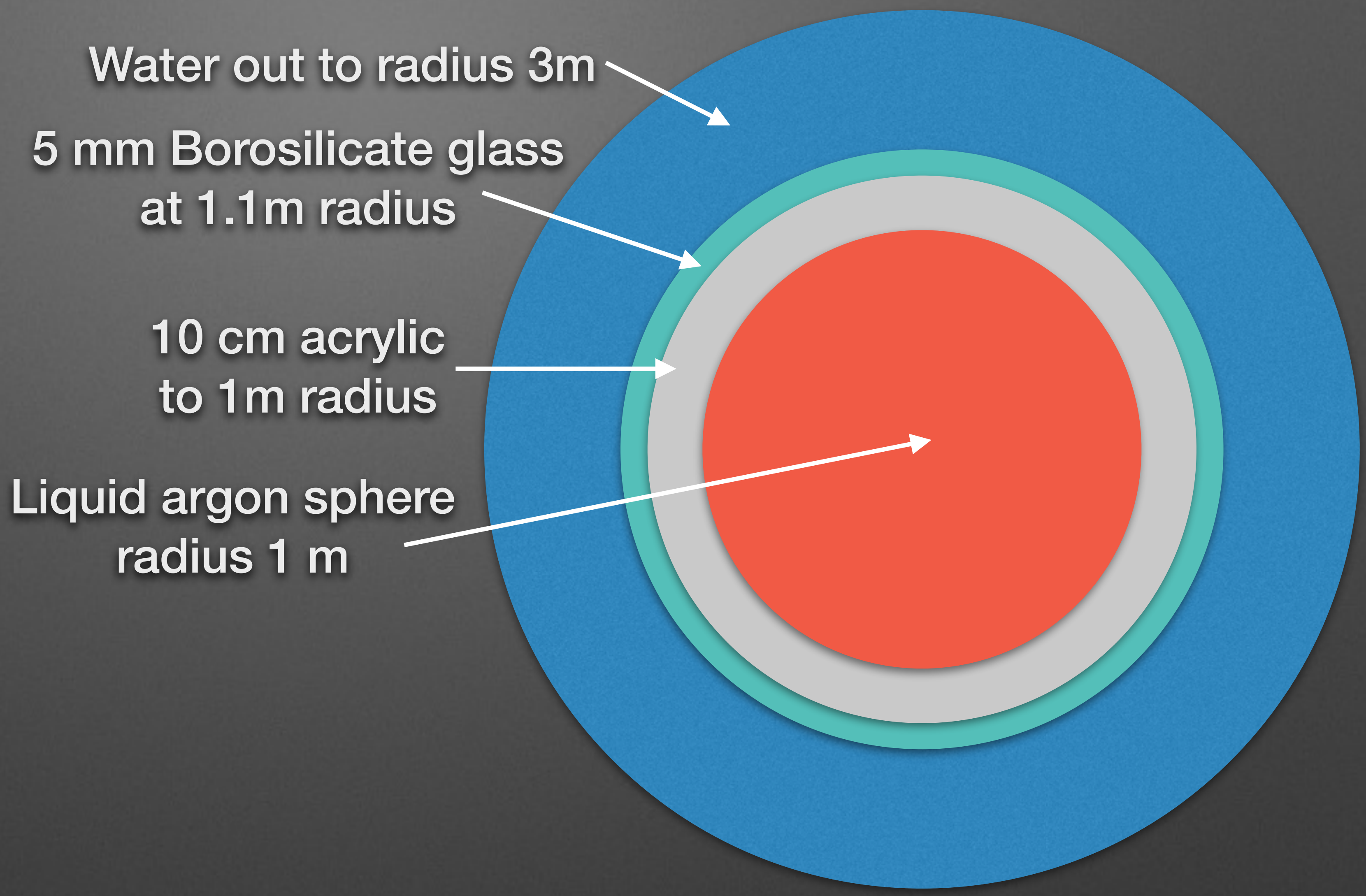




- Neutron spectra are calculated with SOURCES4 and TALYS (through the neutronyield.usd.edu website, hereafter called USD) from the U238 decay chain in borosilicate glass

- 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

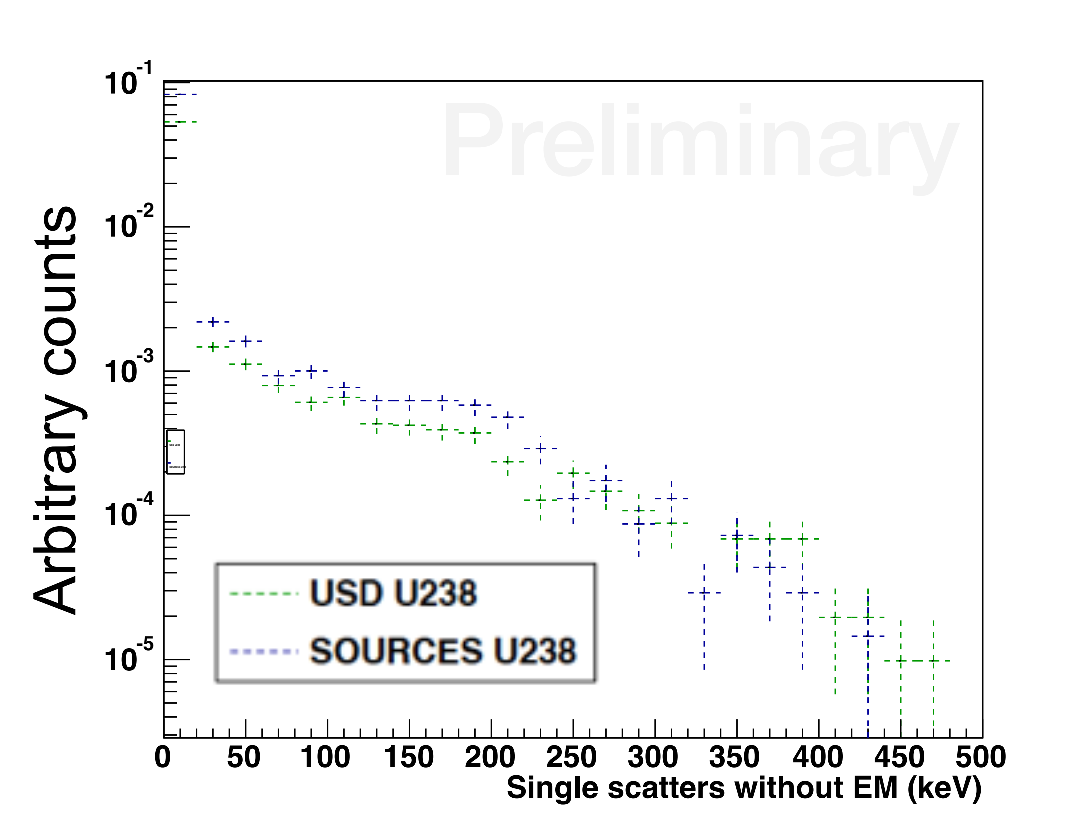
- 250000 neutrons isotropic from borosilicate glass for each simulation
- Neutron recoil threshold of 20 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in argon
- Neutron capture in water needed to externally veto event




Nested spheres geometry

# Argon recoils

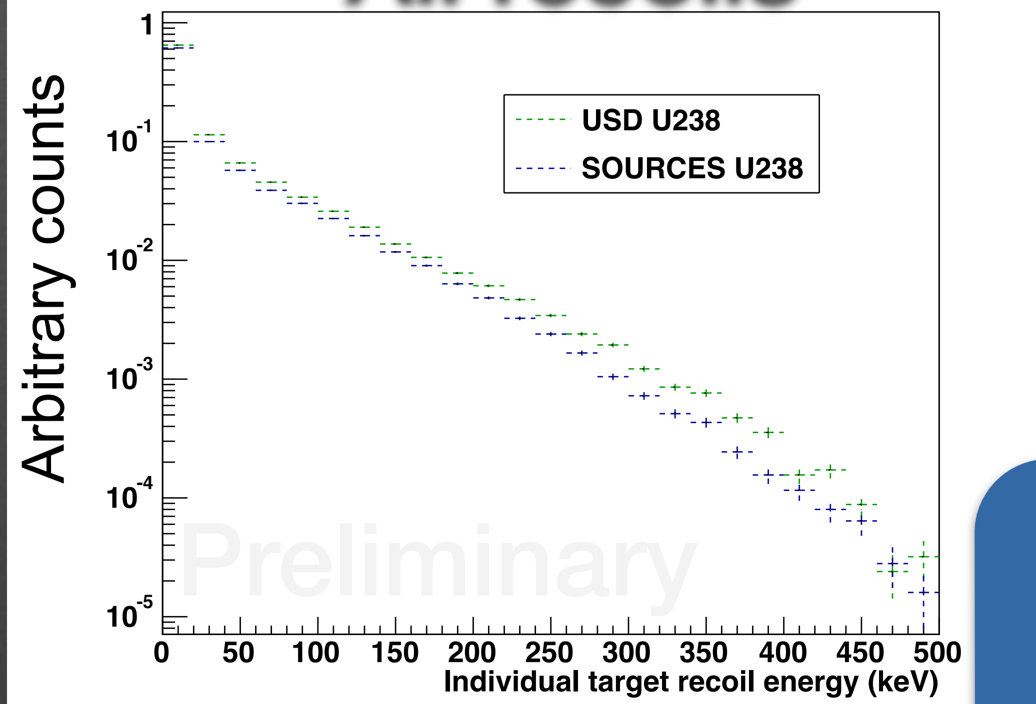
48% higher neutron yield from SOURCES gives 40% more single scatters than USD



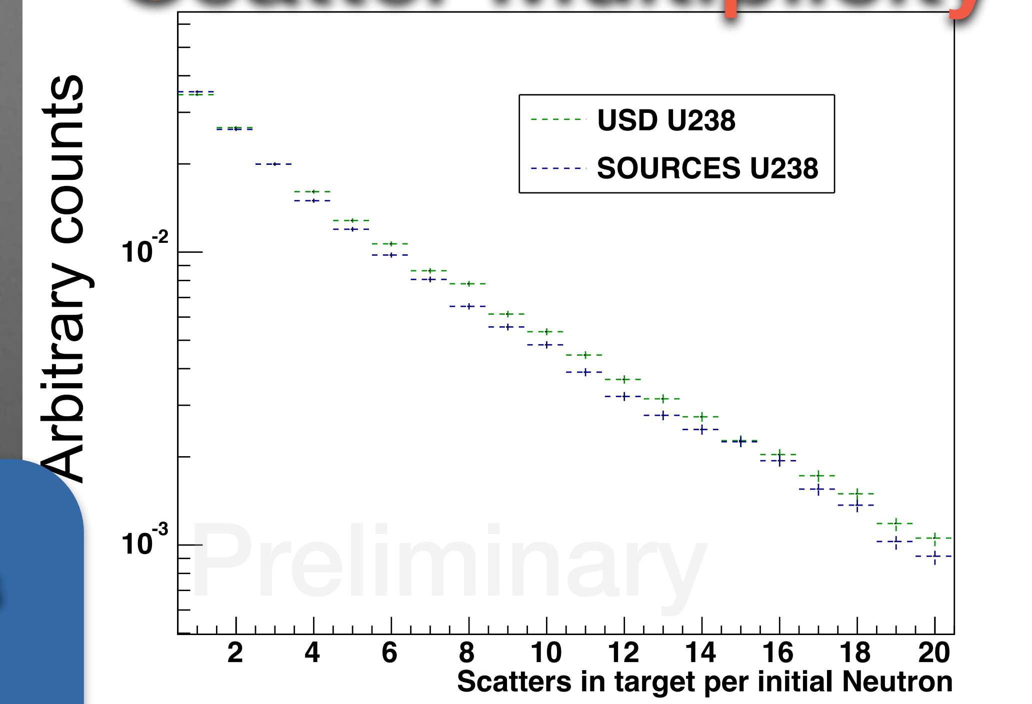

| | Summed nuclear recoils over 20 keV | Single nuclear recoil over 20 keV | Single recoils over 20 keV no capture in veto | Single recoils over 20 keV no electron scatter >1 keV | Ratio of Multiple scatters: single scatters no threshold |
|---|---|---|---|---|---|
| TALYS-USD % of initial sim | 5.2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

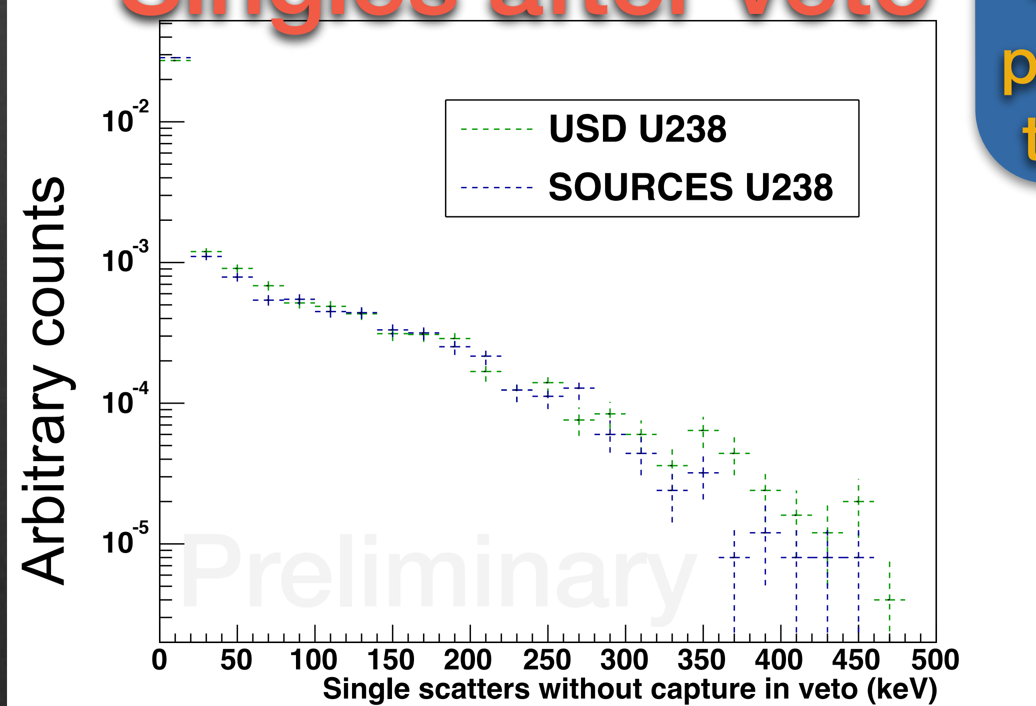



## Scatter Multiplicity

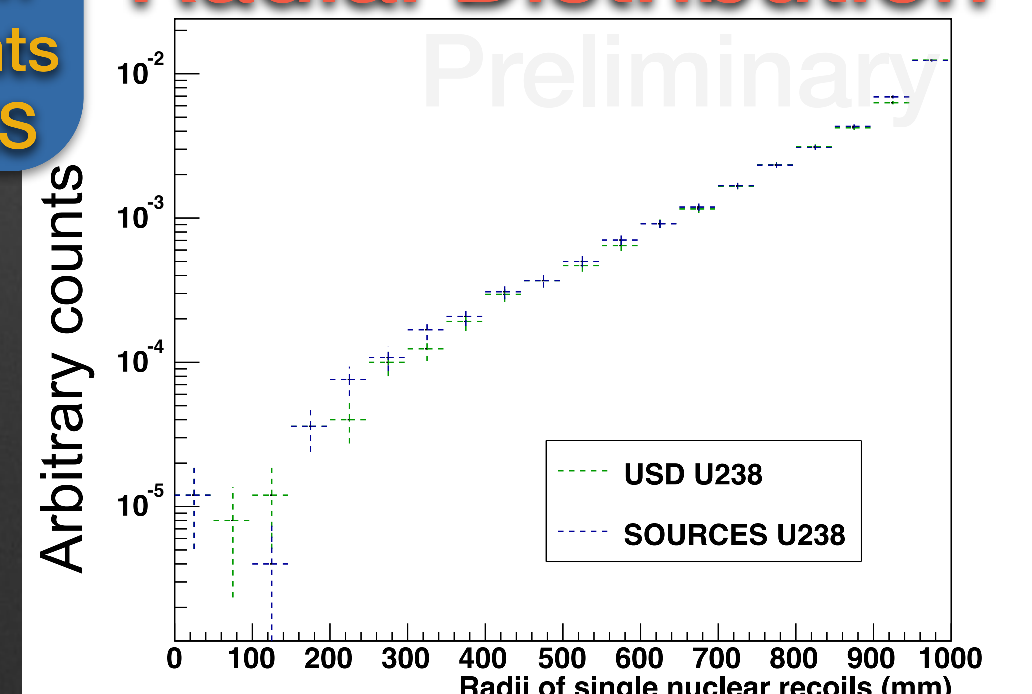



Shape comparisons show small differences: USD ~10% higher in predicted counts than SOURCES

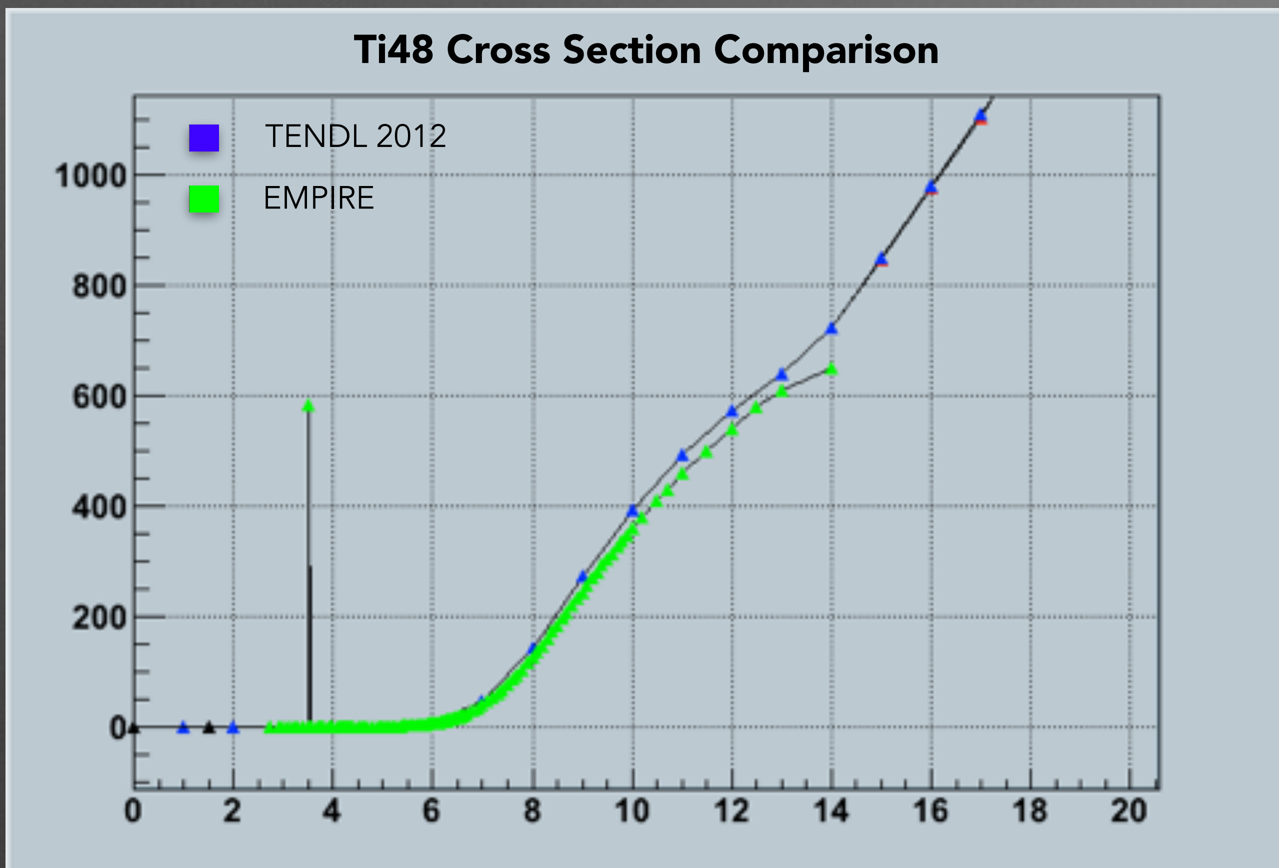
## Singles after veto

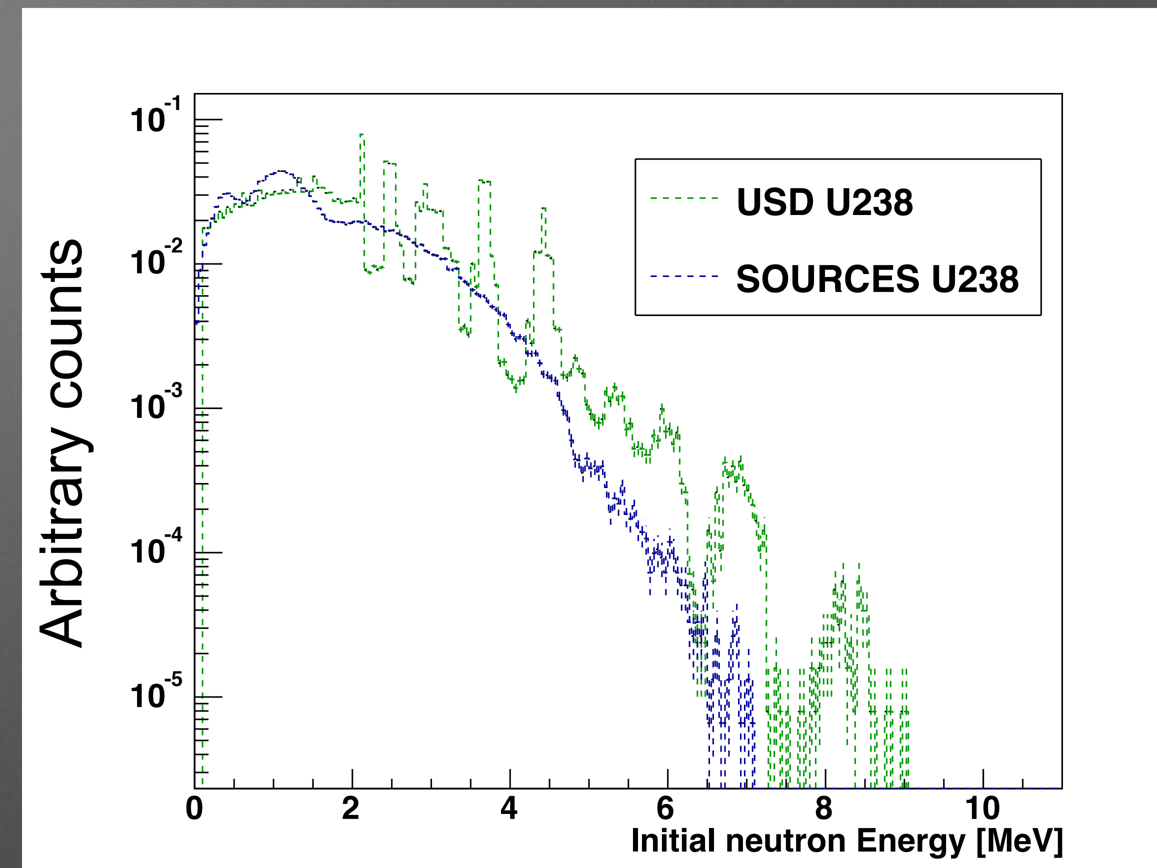



## Radial Distribution



# Neutrons in titanium from U238

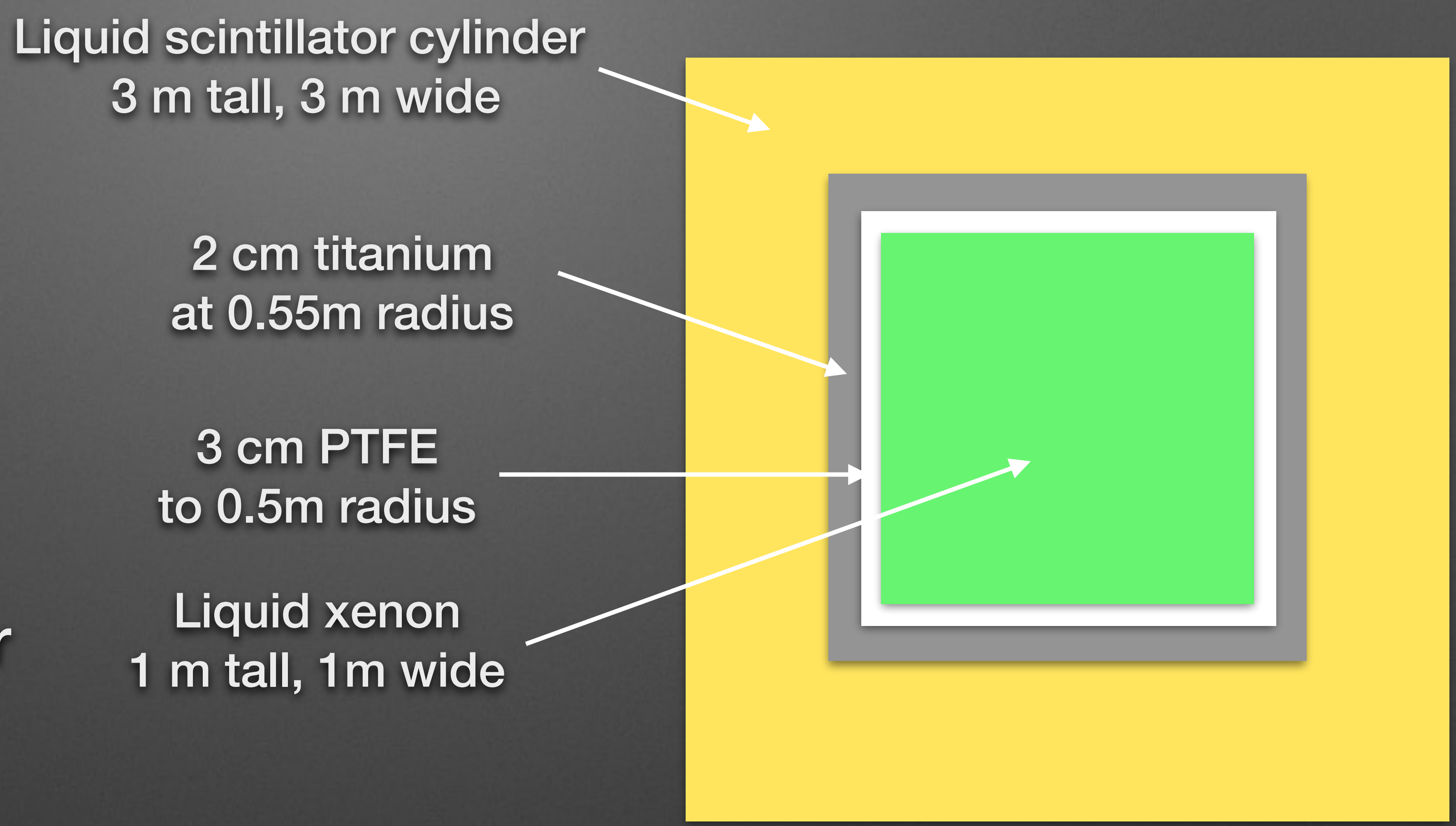



- Large resonant peak in cross sections for SOURCES(shown), hand corrected to remove that point before further calculations per communication with V. Kudryavtsev
- Even with the correction a feature remains in the neutron spectrum
- From 1ppb of U238, USD calculations give a neutron yield of 1.98 E-10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

# Xe Detector Simulations

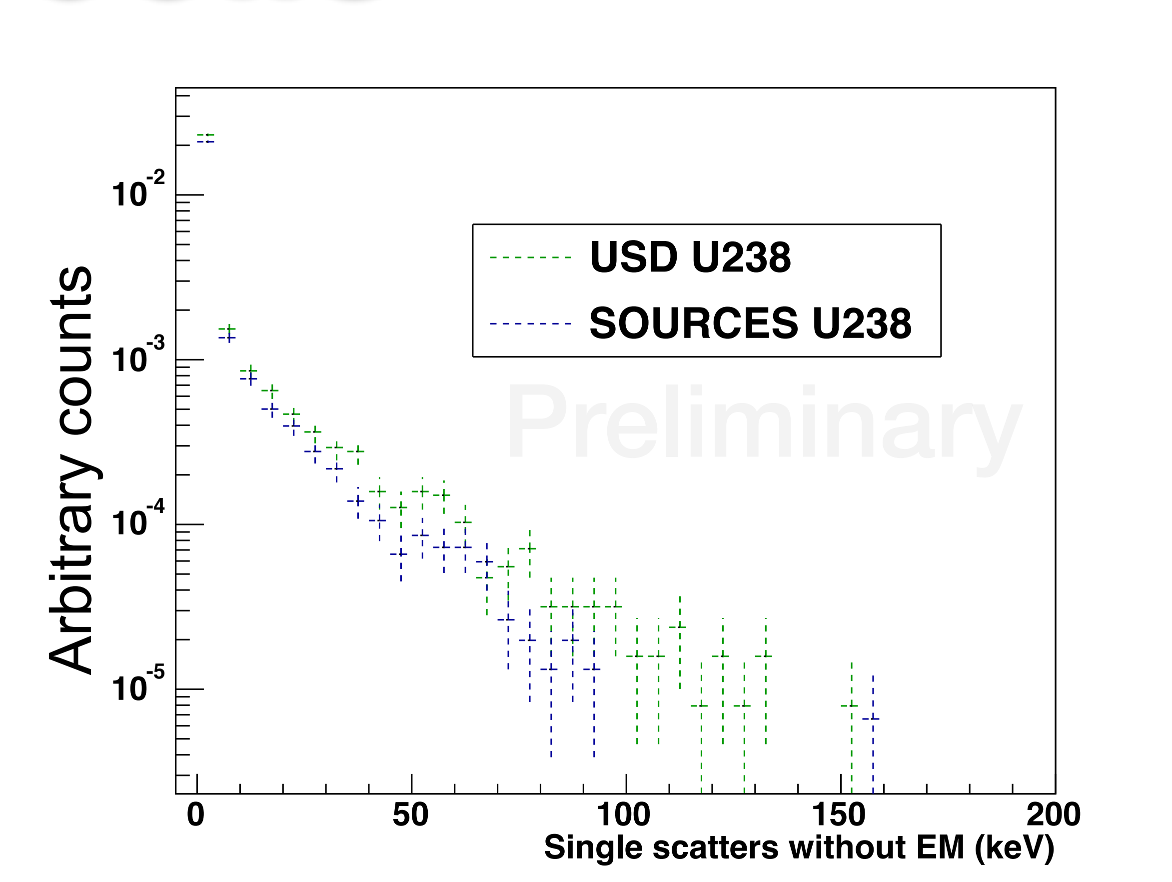
- 250000 neutrons isotropic from titanium or teflon for each simulation
- Neutron recoil threshold of 5 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in xenon
- Neutron capture in oil-based scintillator needed to externally veto event




Nested cylinders geometry

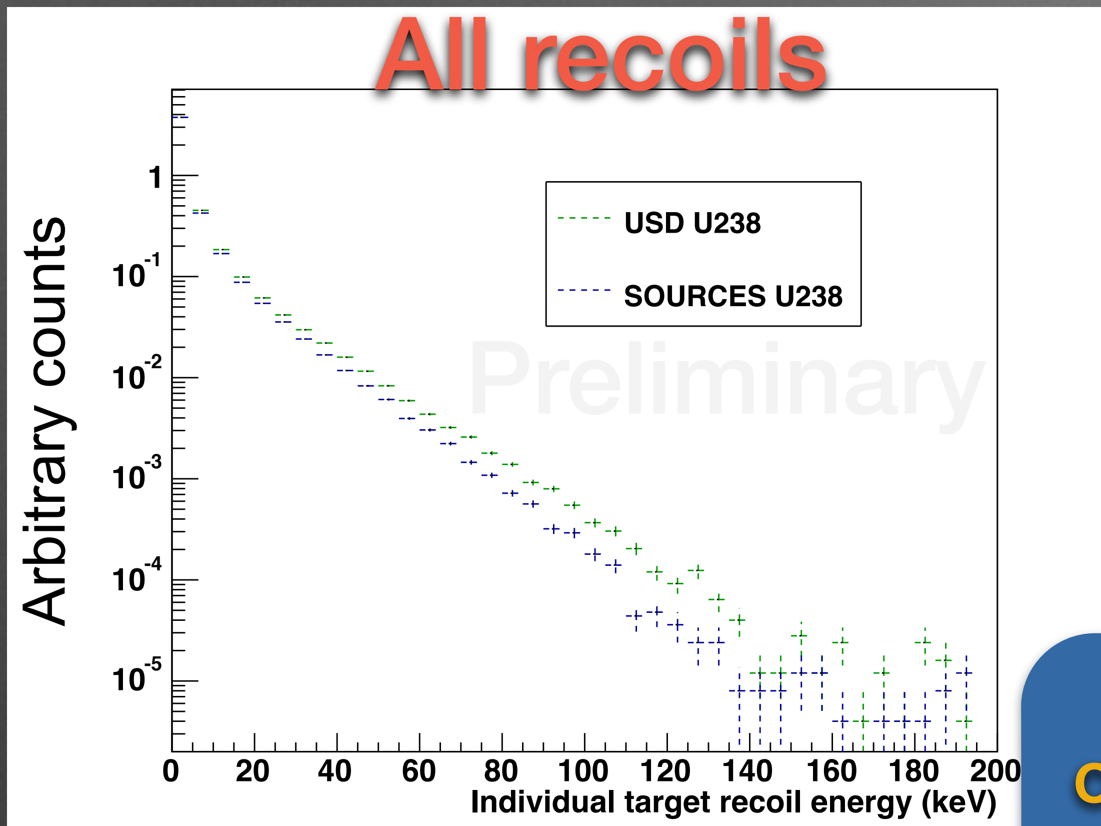
# Xenon recoils

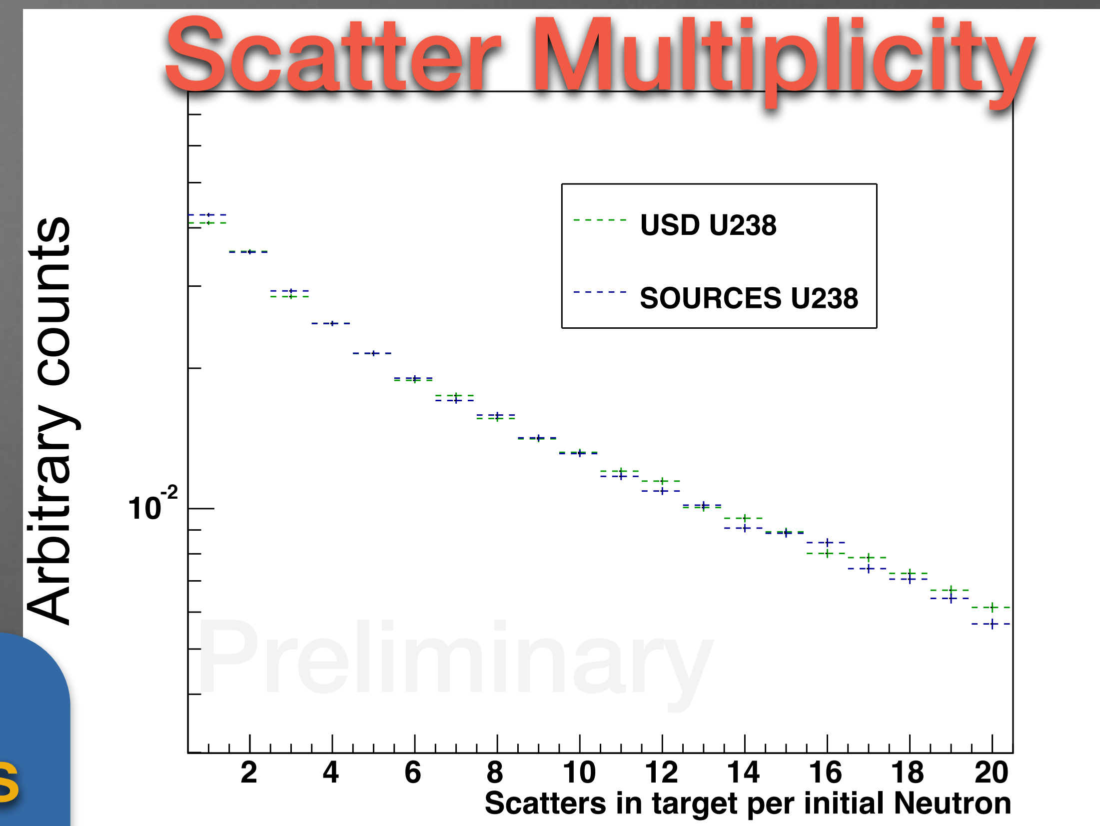
20% higher neutron yield from USD gives 24% more single scatters than SOURCES



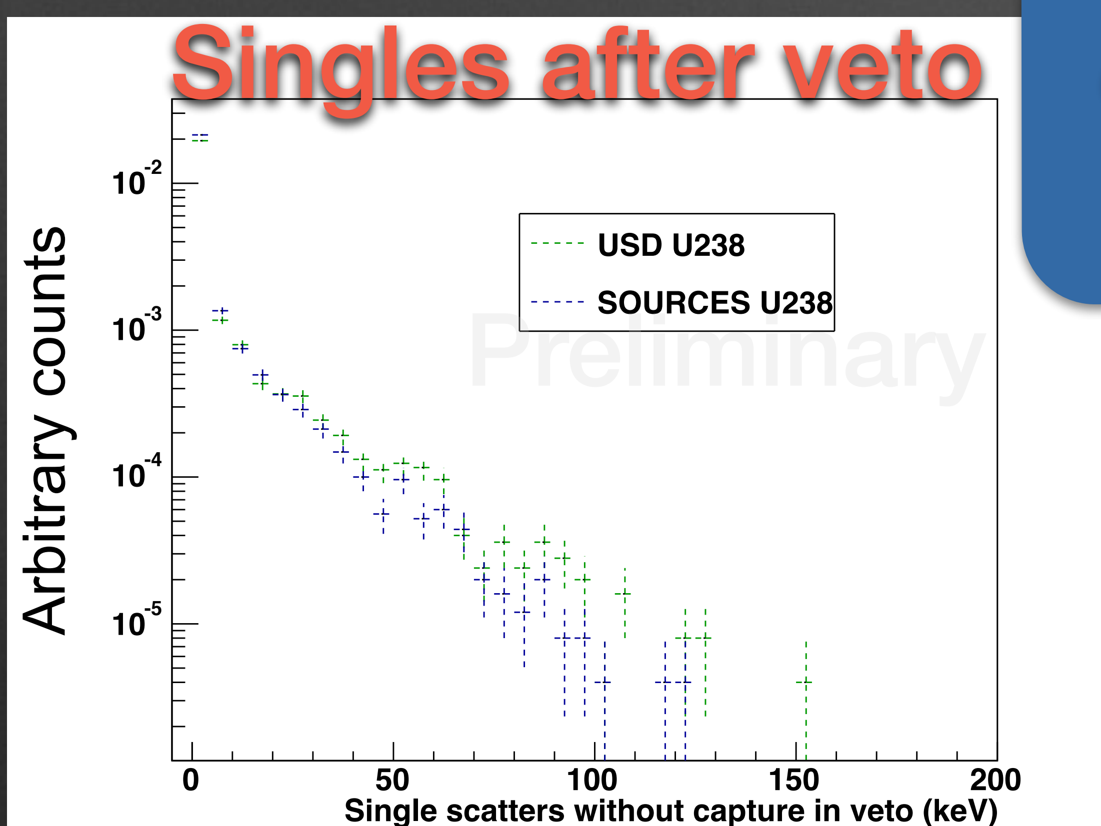

| | Summed nuclear recoils over 5 keV | Single nuclear recoil over 5 keV | Single recoils over 5 keV no capture in veto | Single recoils over 5 keV no electron scatter >1 keV | Ratio of Multiple scatters: single scatters no threshold |
|---|---|---|---|---|---|
| TALYS-USD % of initial sim | 8.9 +/- 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 |

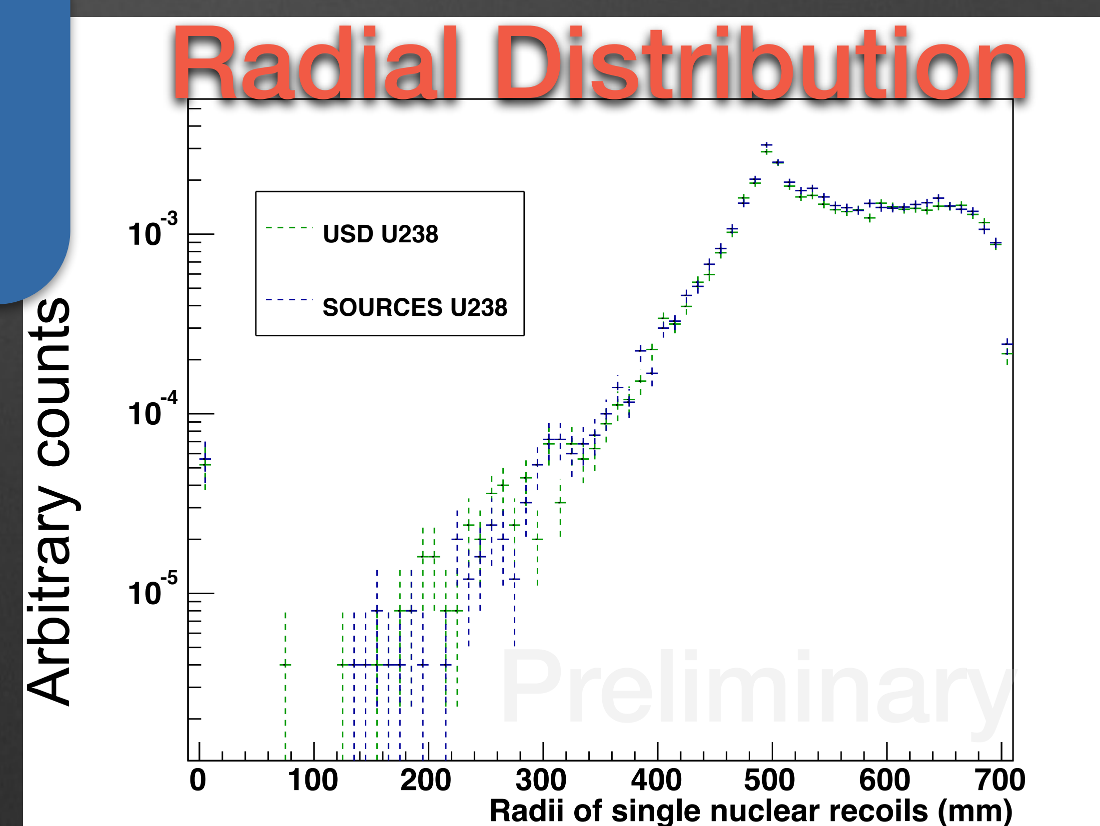
# Spectral shape in Xe detector



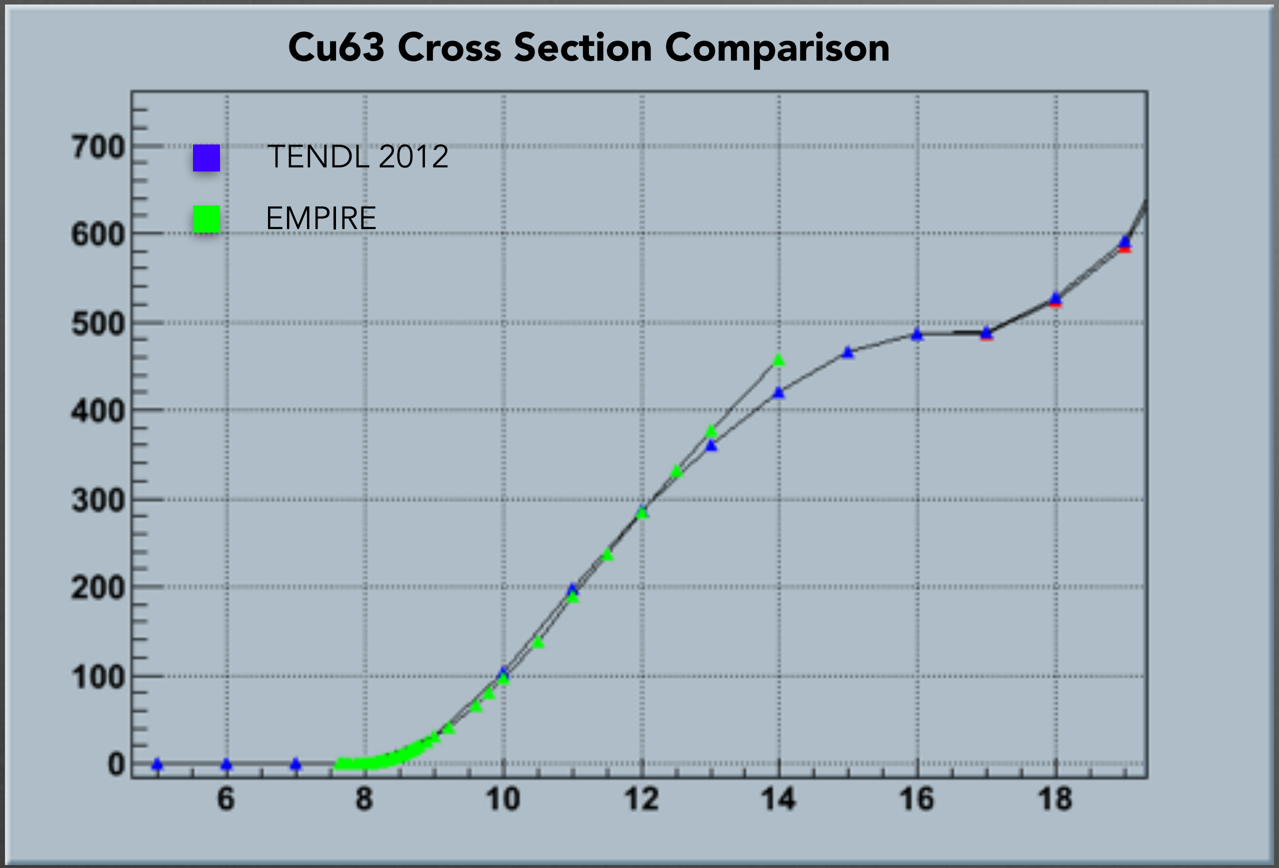



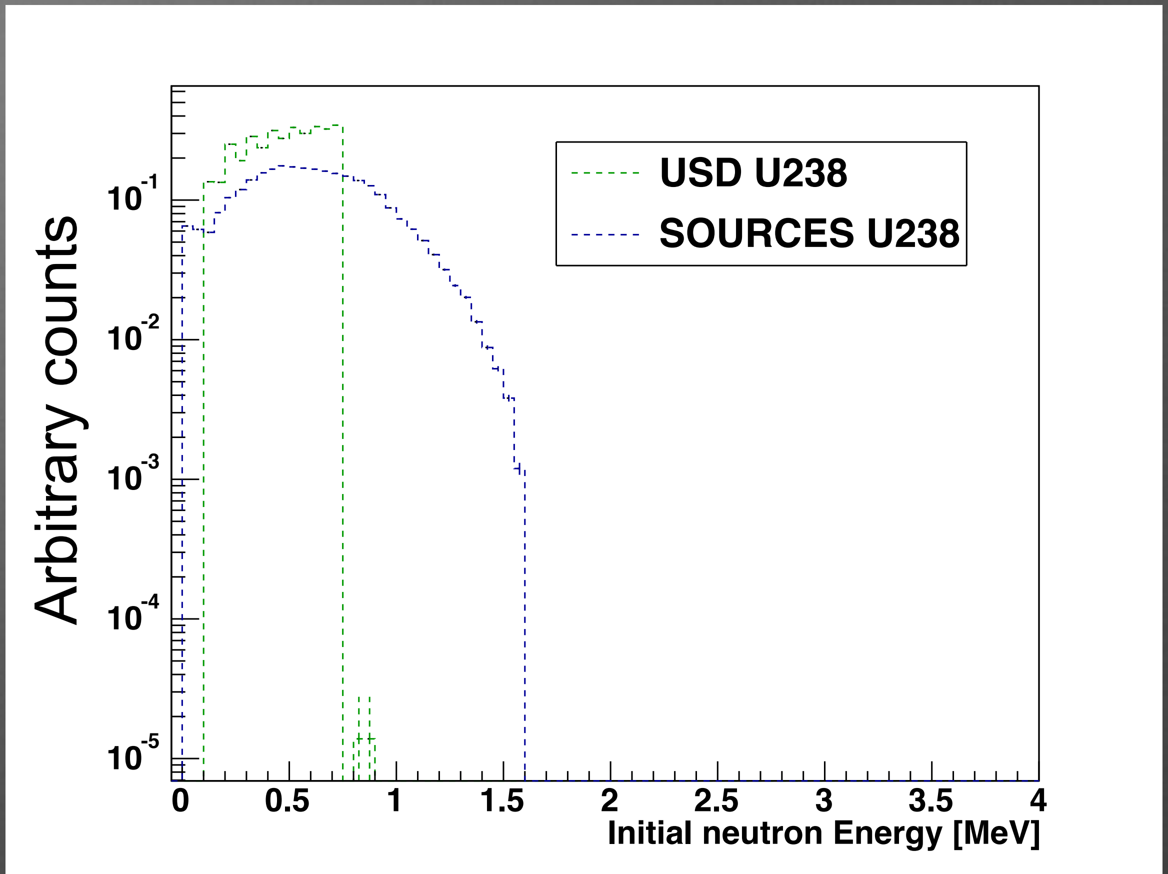

Shape comparisons show no differences once cuts occur



# Neutrons in copper from U238

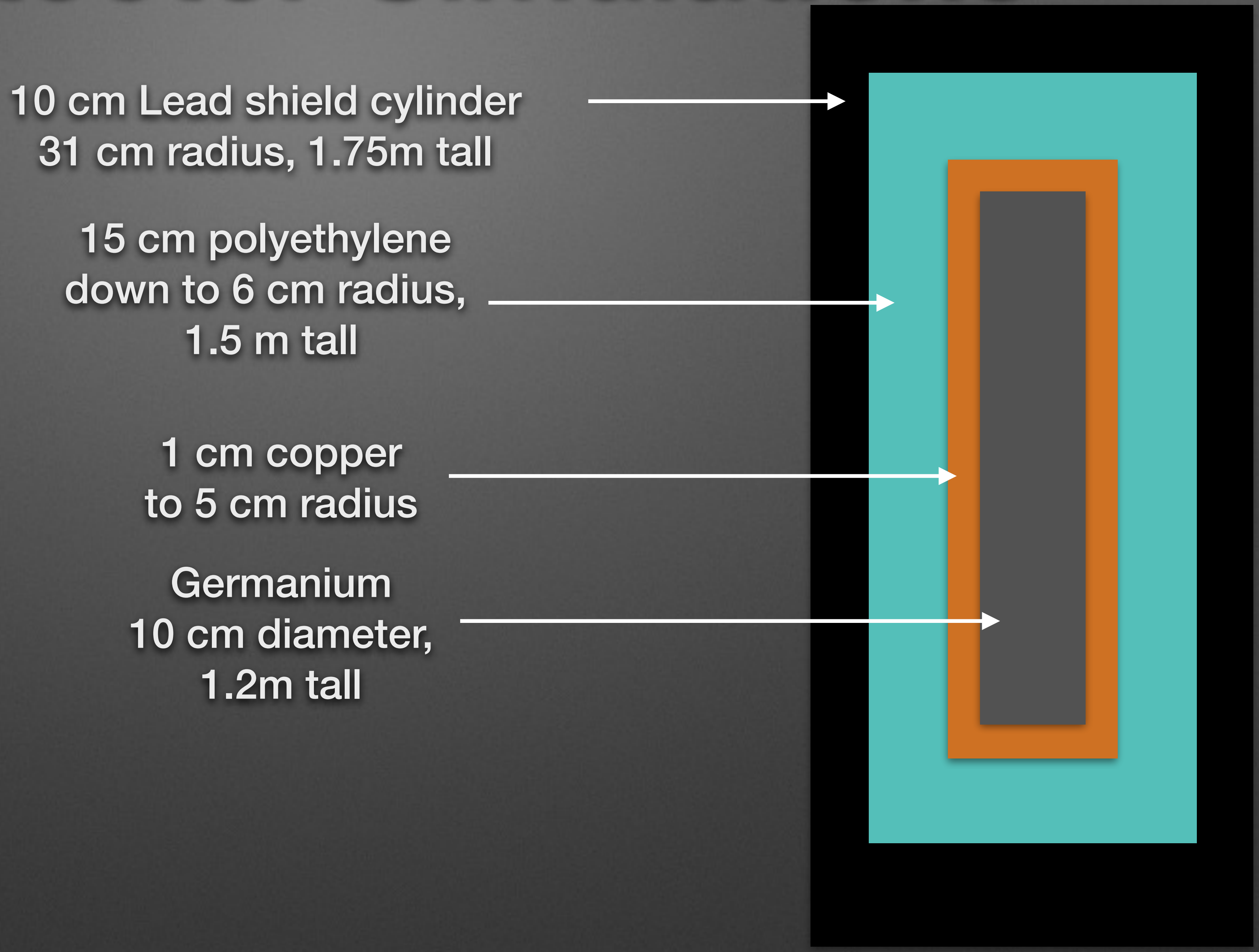



- From 1ppb of U238, USD calculations give a neutron yield of 3.46 E-12 n/s/cm$^3$ while SOURCES gives a neutron yield of 2.90E-12 n/s/cm$^3$, 19% lower
- USD spectrum cuts off at half the energy of SOURCES

# Ge Detector Simulations

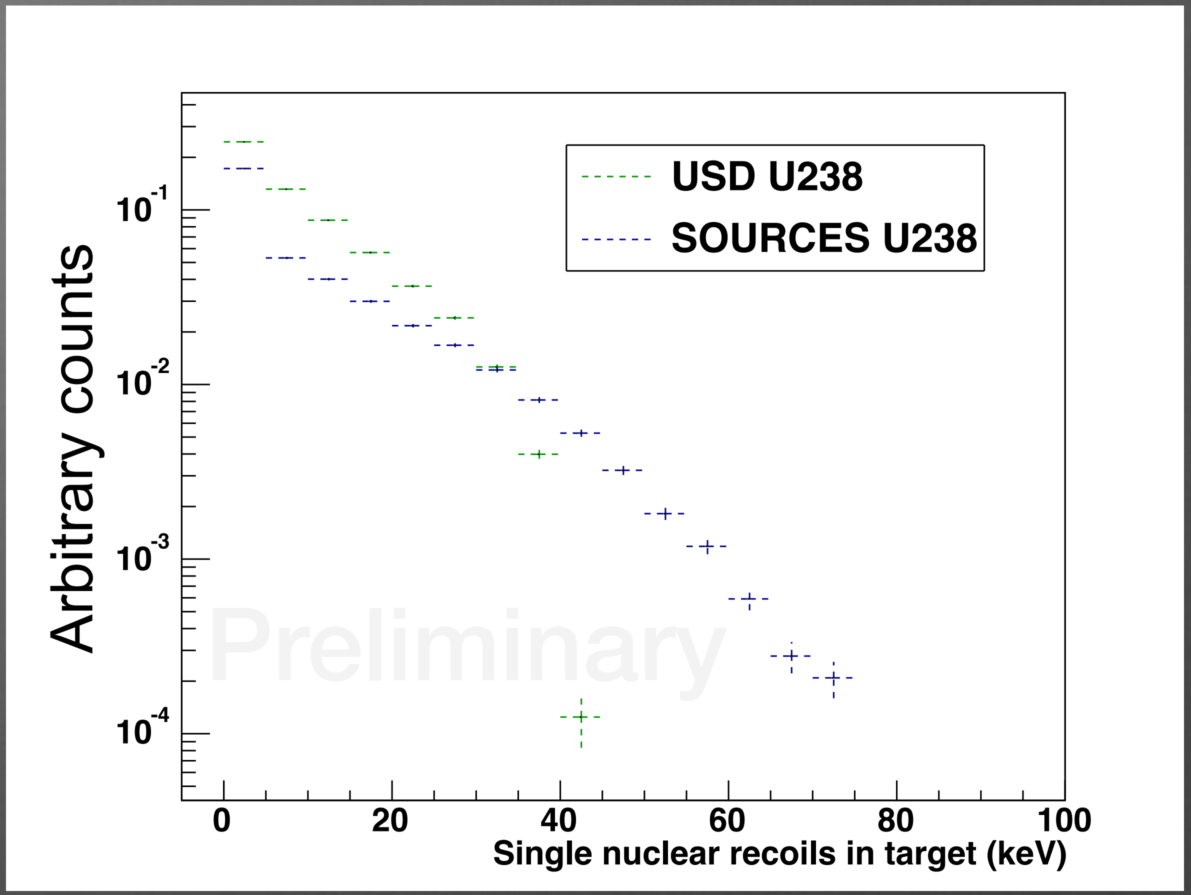
- 250000 neutrons isotropic from copper for each simulation
- Neutron recoil threshold of 5 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in argon
- Neutron capture in plastic scintillator needed to externally veto event




Nested cylinders geometry

# Germanium recoils

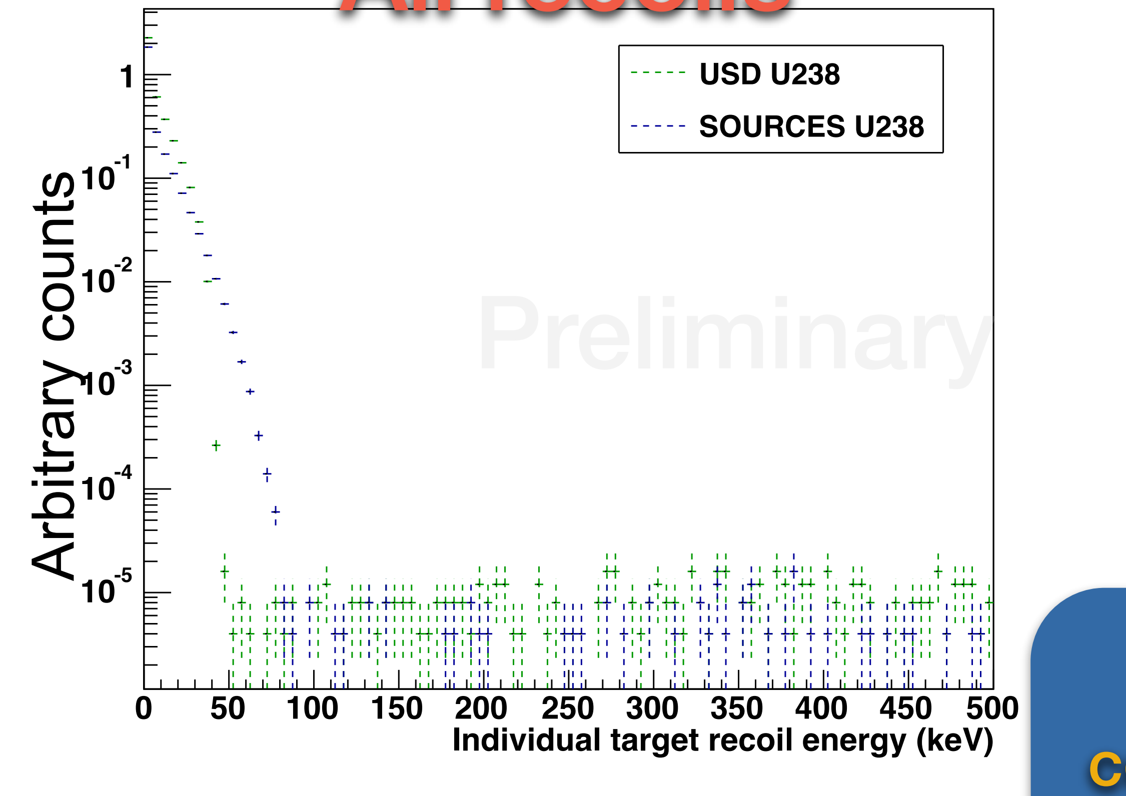
**Shape and yield effects cause an 80% higher prediction of single scatters from USD than SOURCES**



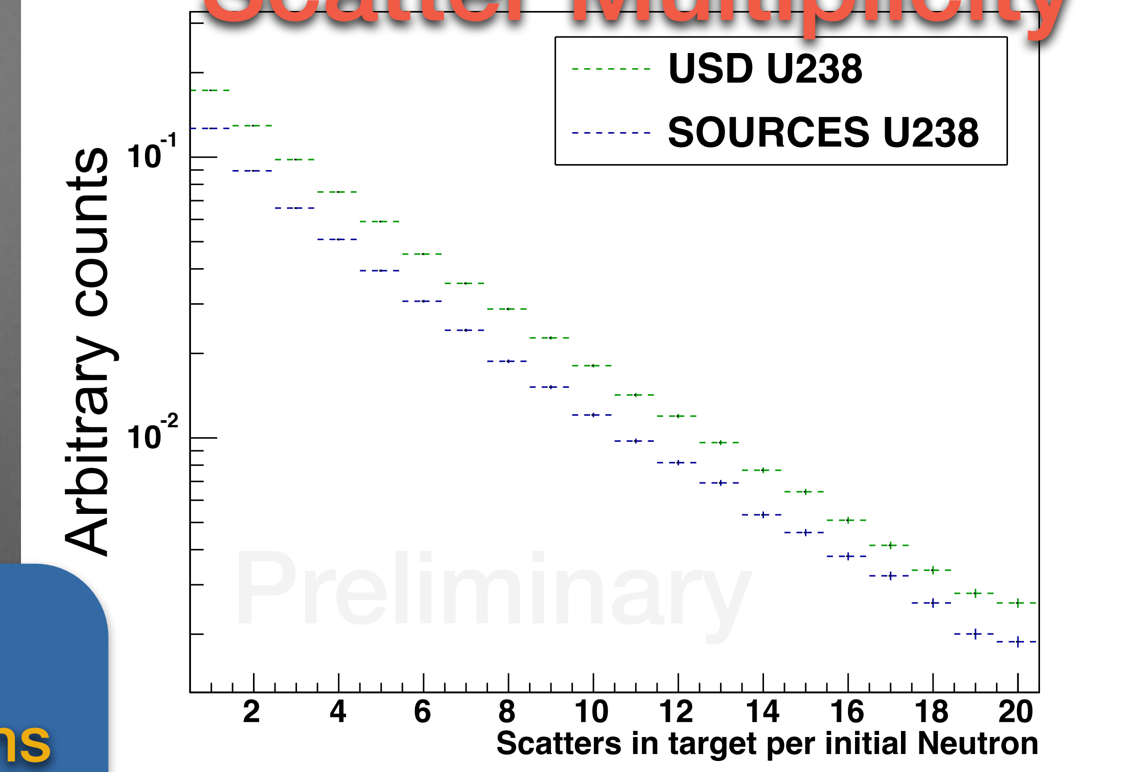

| | Summed nuclear recoils over 5 keV | Single nuclear recoil over 5 keV | Single recoils over 5 keV no capture in veto | Single recoils over 5 keV no electron scatter >1 keV | Ratio of Multiple scatters: single scatters no threshold |
|---|---|---|---|---|---|
| TALYS-USD % of initial sim | 14.2 +/-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

## All recoils

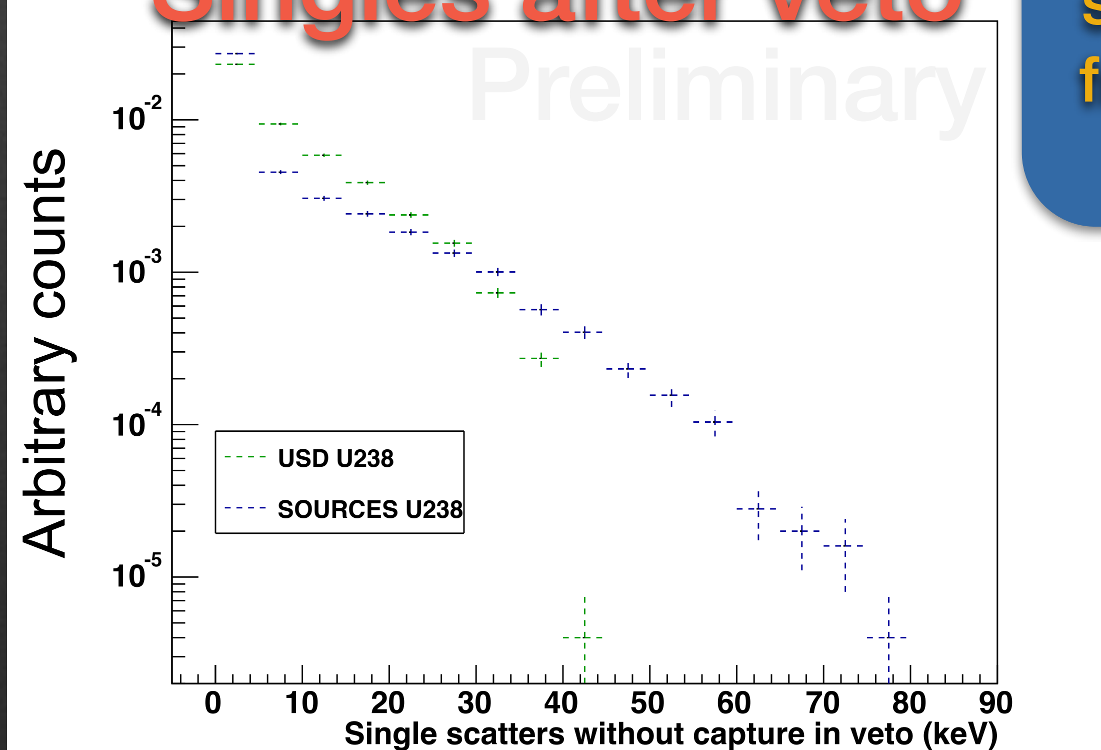



## Scatter Multiplicity

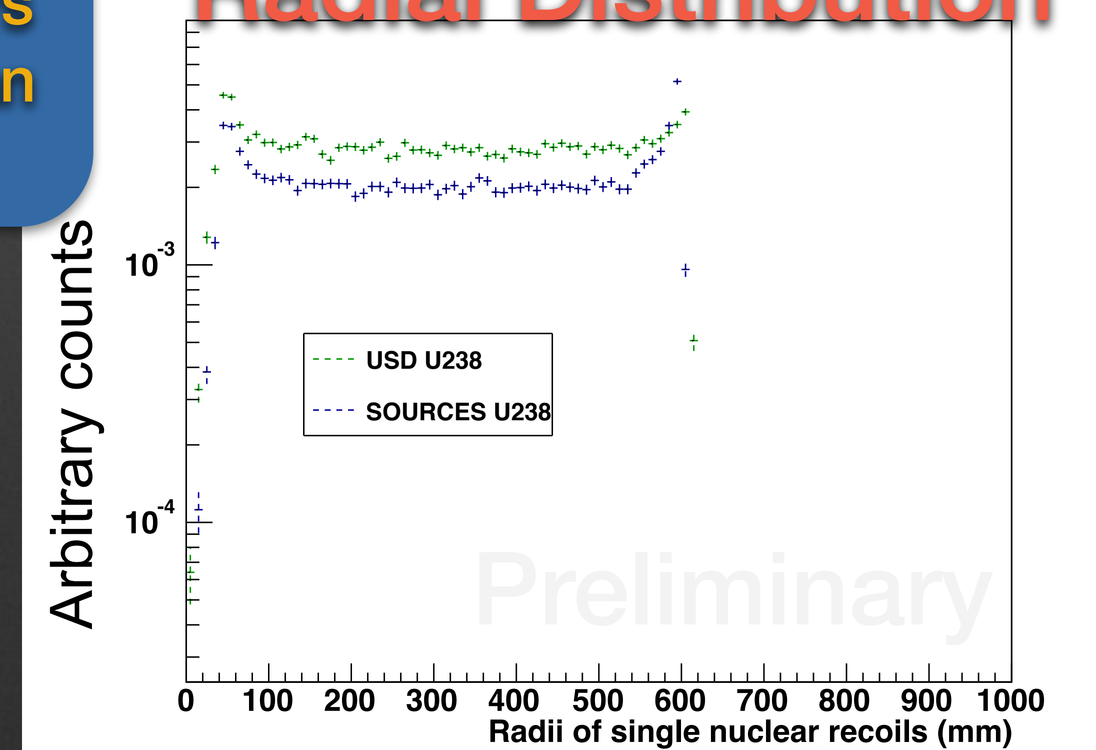



Shape considerations lead to 64% more single scatters from USD than SOURCES

## 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%
  - No systematic differences in the simulated background recoils are seen between SOURCES and TALYS-USD

# Backup Slides