Radiogenic Neutron Code Comparison

USD website and SOURCES4A

Zhang-Mei-Hime code
NIM A606, 651 (2009)
http://neutronyield.usd.edu

4A modified version – Sheffield group
Wilson et al. Sources4A. Technical Report, LA-13639-MS (1999);
Tomasello et al., NIMA 595 (2008) 431.

Outline

- Initial radiogenic neutron spectra from (alpha,n) reactions
  - Input (alpha,n) cross section per material
  - Input alpha decay data
  - Code calculation check against experimental nuclear data
  - Spectra shape and yield integral
- Extensive simulation work to understand how the discrepancies from USD website and SOURCES4 calculations can affect experimental background predictions
  - U and Th in borosilicate seen by an argon detector
  - U and Th in titanium seen by a xenon detector
  - U and Th in copper seen by a germanium detector

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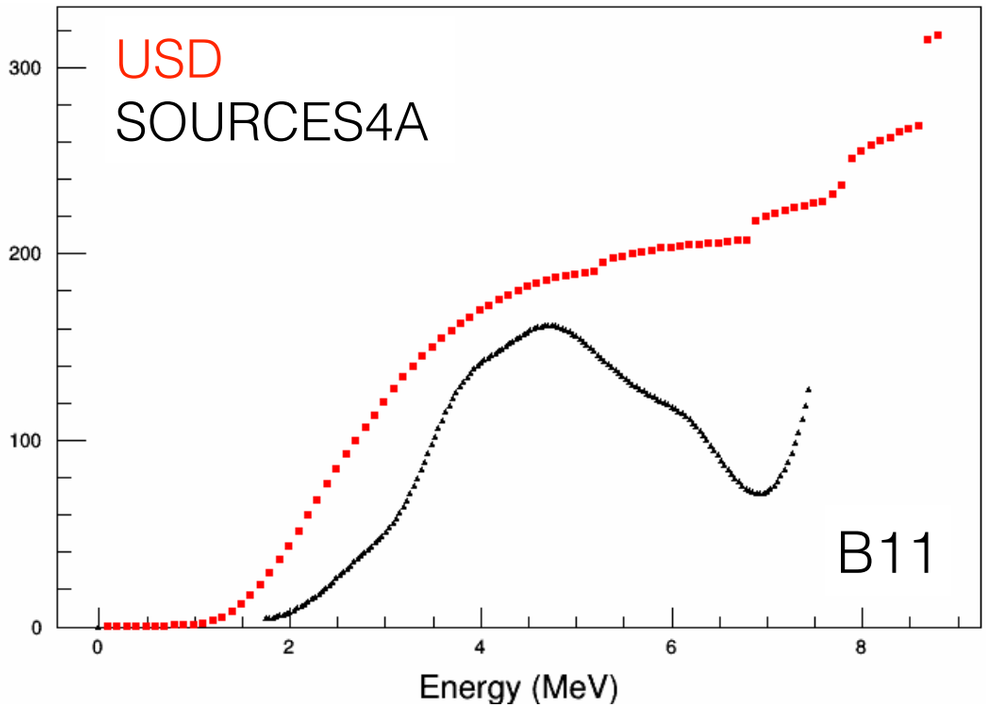
Input code check

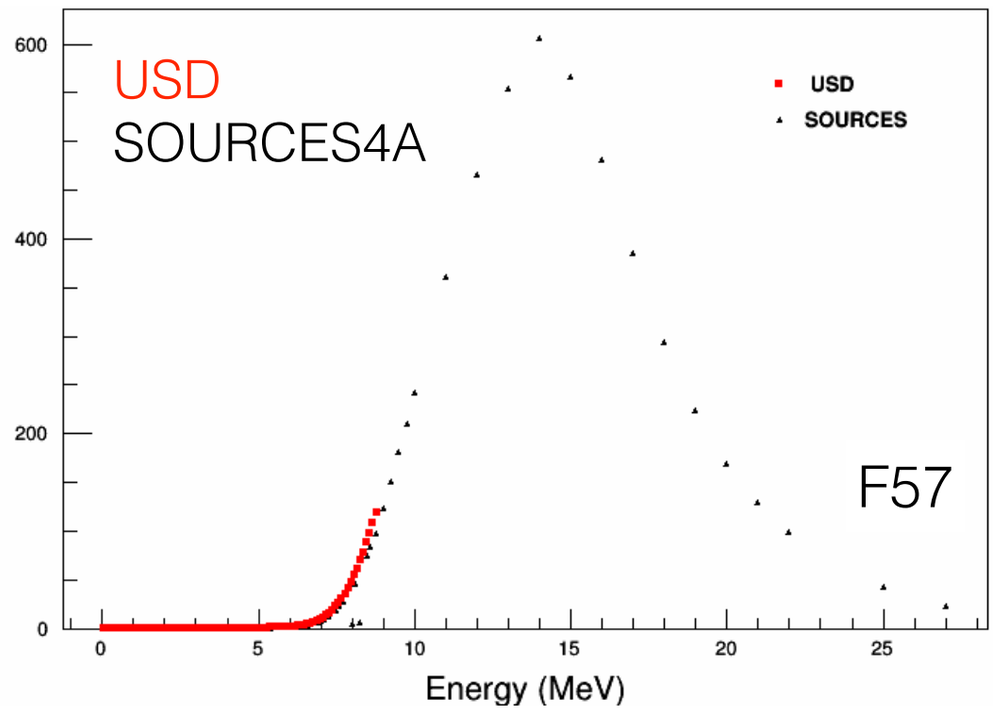
- **Target (alpha,n) cross section**
  USD: TENDL 2011 and 2012 have been considered as inputs. TENDL is a nuclear data library (validated) which provides the output of the TALYS nuclear model code system
  SOURCES4: cross section input libraries come from EMPIRE calculations and for some isotopes a combination of measurements and EMPIRE calculations

  see webpage

- **Alpha particle decay data library**
  USD: only decays with visible energy larger than 100 keV or branching ratio more than 0.5% are considered
  SOURCES: no threshold

Good agreement in the (alpha,n) ROI (0-10MeV) for most of the isotope considered





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  Checking cross section we found and corrected typos ~25 target isotopes

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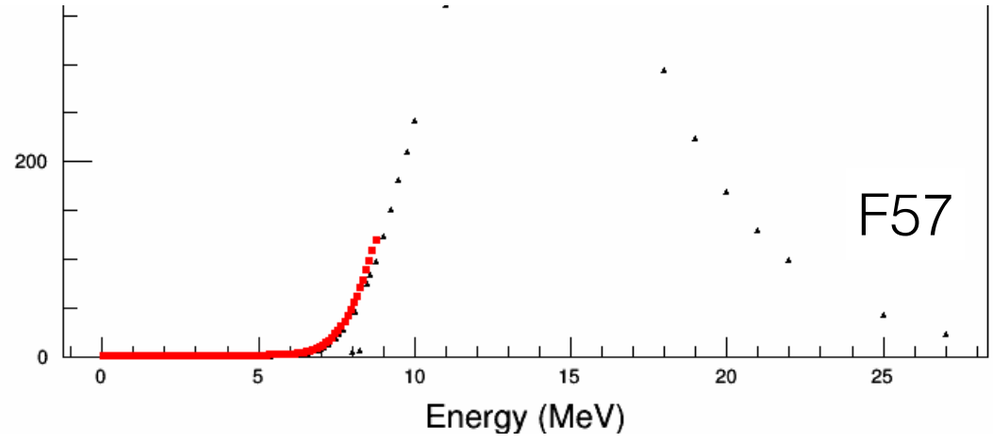
Neither library fully reproduces experimentally observed resonances, comparisons with experimental data are still important



Benchmarking calculations against experimental nuclear data.

A validation of SOURCES4 code problems has been detailed here

We have considered an easy alpha-beam problem to benchmark both SOURCES4C and USD calculations - Alpha Beam (5.5 MeV) on Mg

SOURCES4 - Alpha Beam (5.5 MeV) on Mg

Title: Alpha Beam (5.5 MeV) on Mg
Beam problem input (idd = 3)
Magnitudes and spectra computed (id = 2)
Ascending energy structure for output (erg = 1) Alpha beam energy is 5.500E+00 Mev.
Number of elemental constituents: 1
Solid stopping cross-sections used (isg = 0)

Elemental Constituents:

Z-value	Atom Fraction
12	1.0000000000

Number of neutron spectrum energy groups: 81
Maximum neutron energy is 8.150E+00 MeV.
Minimum neutron energy is 5.000E-02 MeV.

Number of target nuclides to be used: 2
4000 Alpha energy groups used.

Target Nuclides:

ZAID	Atom Fraction
120250	1.000E-01
120260	1.101E-01

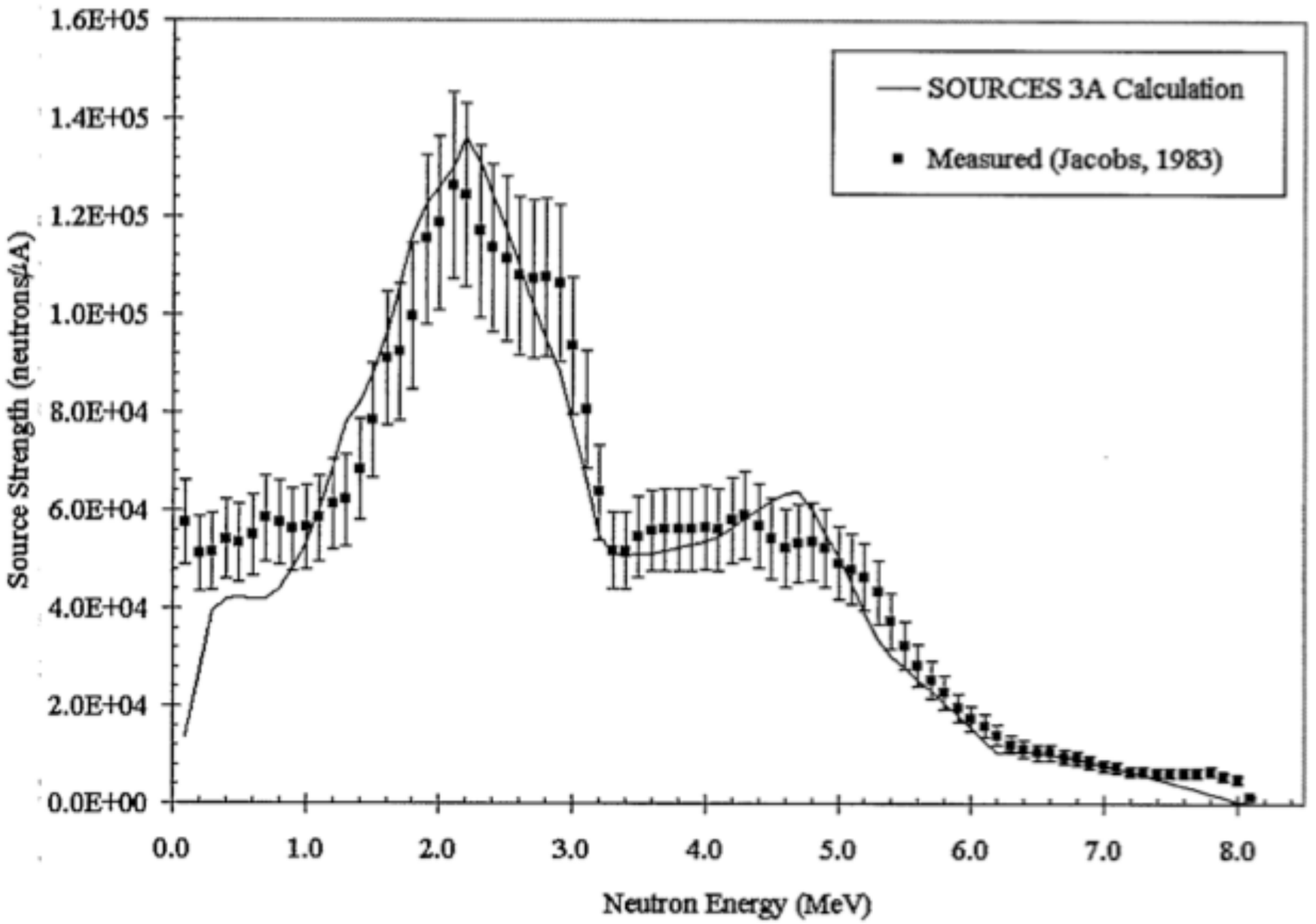


Fig. 21. Energy-Dependent Neutron Source Strength from 5.5 MeV α-Particles Incident on Magnesium Slab as Calculated by SOURCES 4A and Compared to Measured Data.

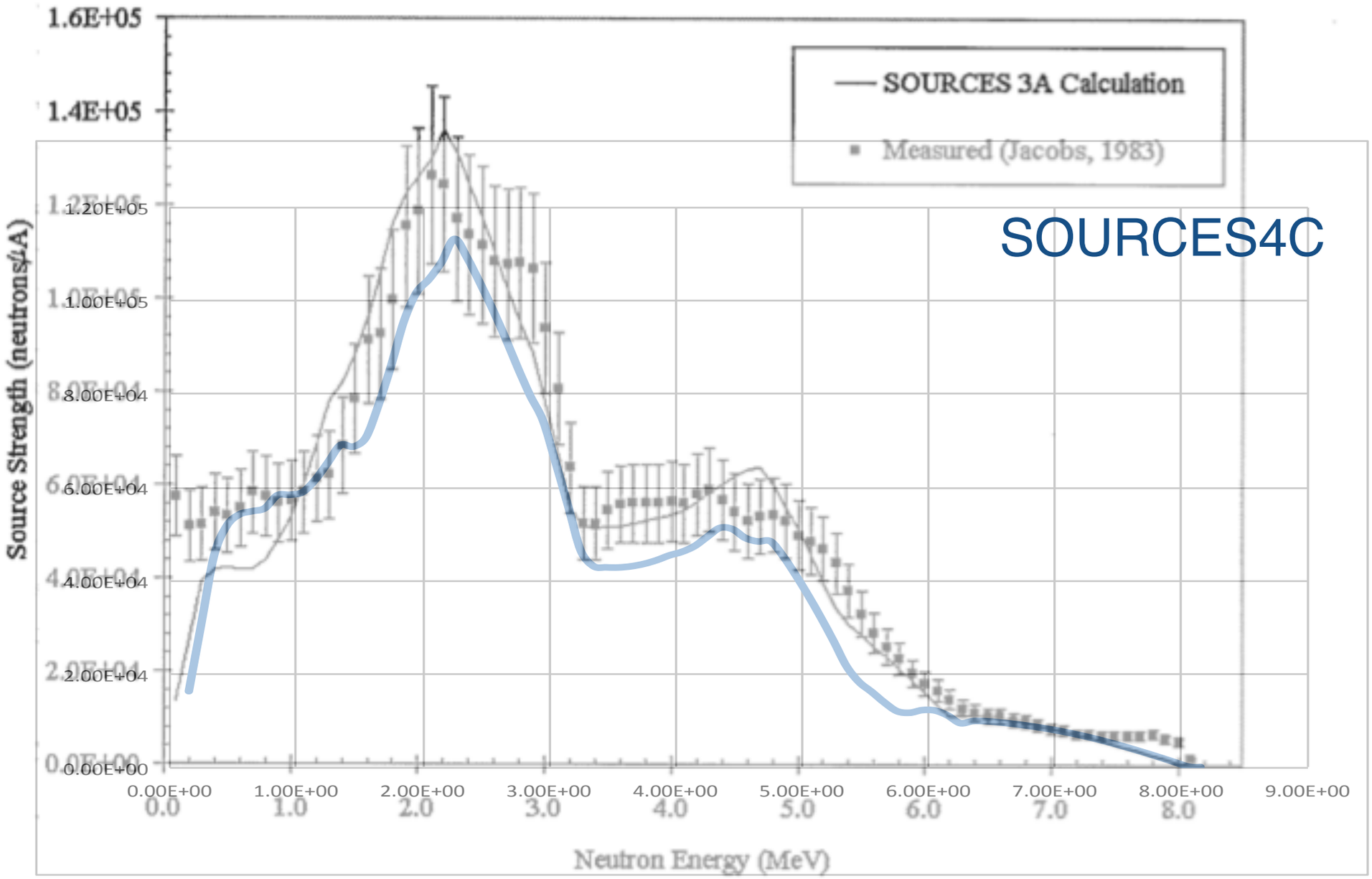
Output - 4A(modified) vs 3A(original)

Total (alpha,n) neutron source from all sources and targets: 3.992E+06 n/sec-microamp.
Average (alpha,n) neutron energy: 3.039E+00 MeV.
Portion of Total Neutron Source Rate Accounted for in the Total Energy Spectrum: 99.9%.

	target	target atom frac.	alpha source	alpha energy	alphas/sec /microamp	p(e) neut/alpha	neuts/sec /microamp
+	mg 25	1.0000E-01	beam	5.500	3.1209E+12	5.2789E-07	1.6475E+06
	mg 26	1.1010E-01	beam	5.500	3.1209E+12	7.5131E-07	2.3448E+06
		+					
						Total (all targets):	3.9923E+06

Total (alpha,n) neutron source from all sources and targets: 3.613E+06 n/sec-micro amp.
Average (alpha,n) neutron energy: 2.897E+00 MeV.
Portion of Total Neutron Source Rate Accounted for in the Total Energy Spectrum: 95.6%.

	target	target atom frac.	alpha source	alpha energy	alphas/sec /microamp	p(e) neut/alpha	neuts/sec /microamp
+	mg 25	1.0000E-01	beam	5.500	3.1209E+12	4.5949E-07	1.4340E+06
	mg 26	1.1010E-01	beam	5.500	3.1209E+12	6.9817E-07	2.1789E+06
		+					
						Total (all targets):	3.6129E+06



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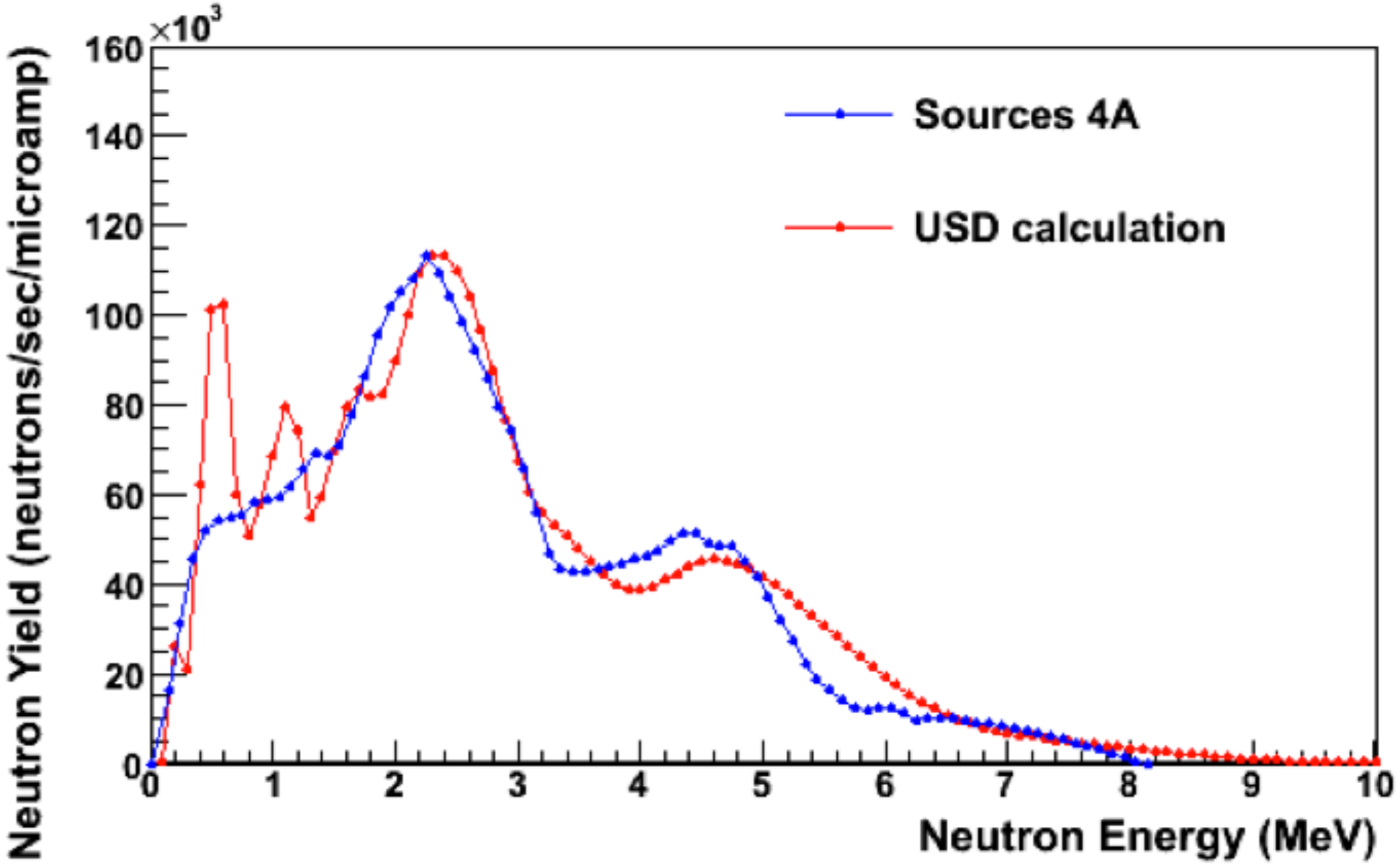


Some discrepancies in shape…but good agreement

USD: 11.7249e-07 per alpha decay.
SOURCES4A: 11.5766e-07 per alpha decay

Spectra shape and yield

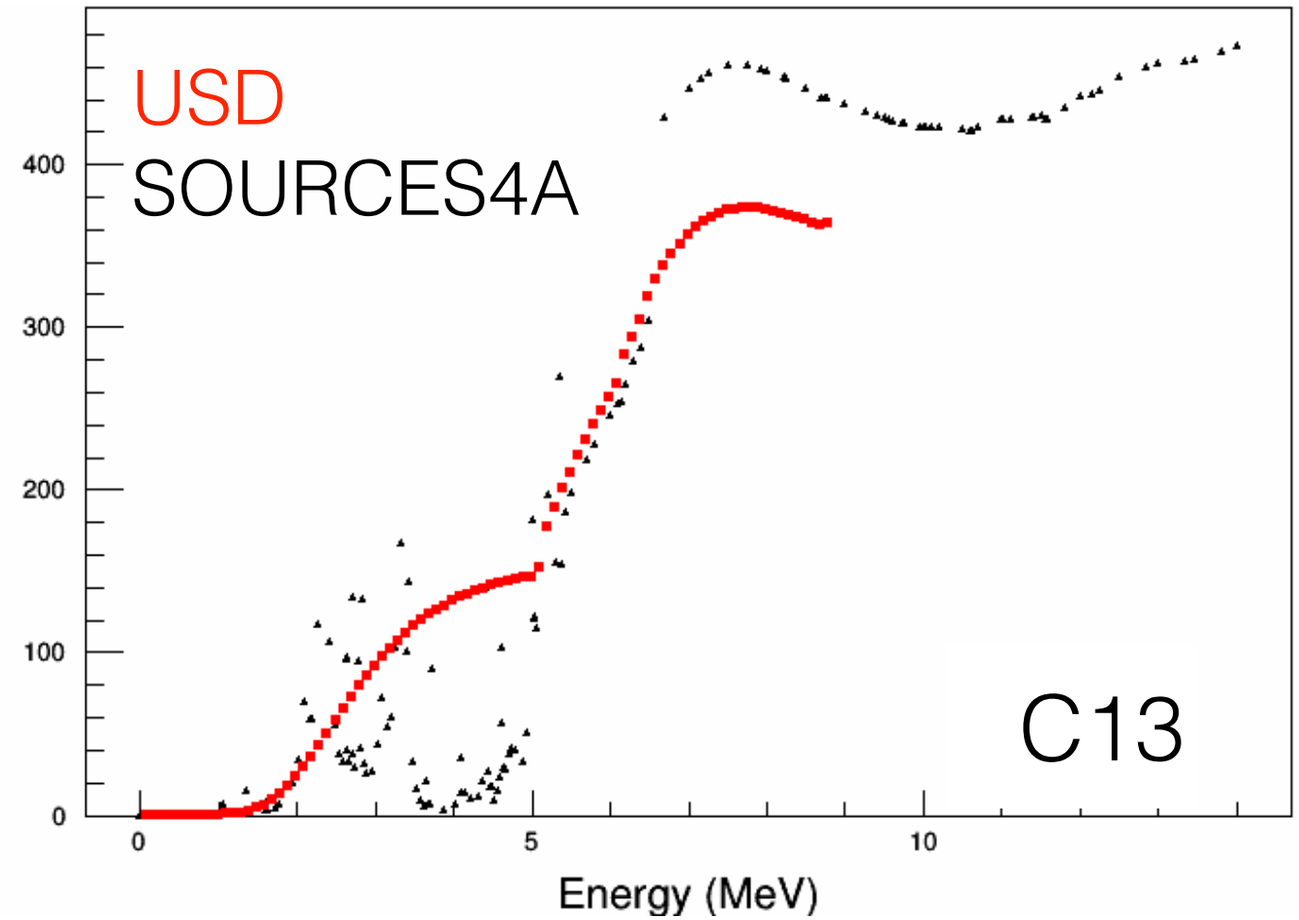
Extensive comparison for material giving important alpha,n reactions (Cu, Ti, Borosilicate glass, SS, PE, PTFE, Al_2O_3, ...)

Spectra calculated via:

- USD code,
- SOURCES4A spectrum with original input crossX
- USD input cross section (TALYS) into SOURCES4A

Polyethylene

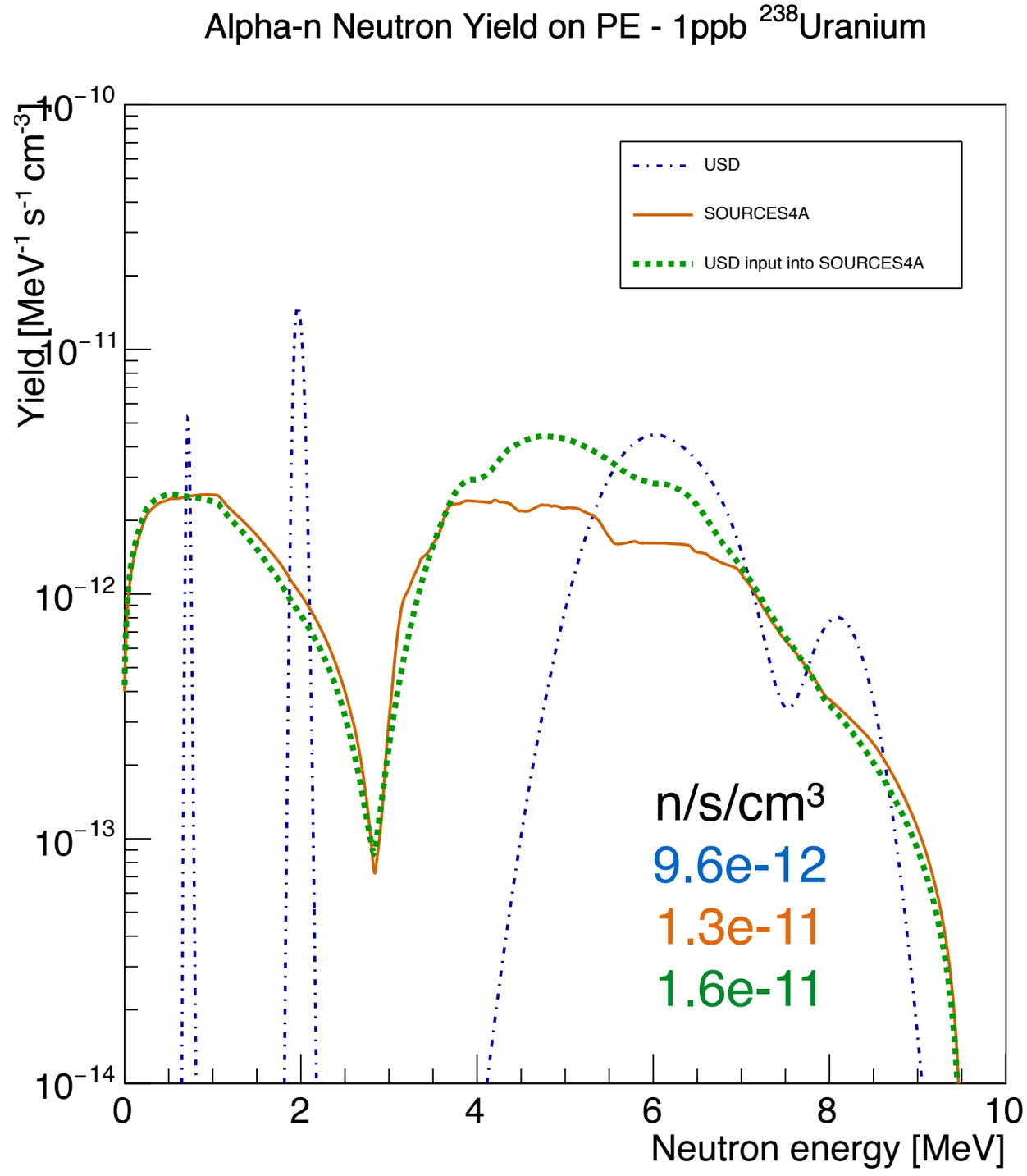
C13 alpha input cross section shows discrepancies at low energy

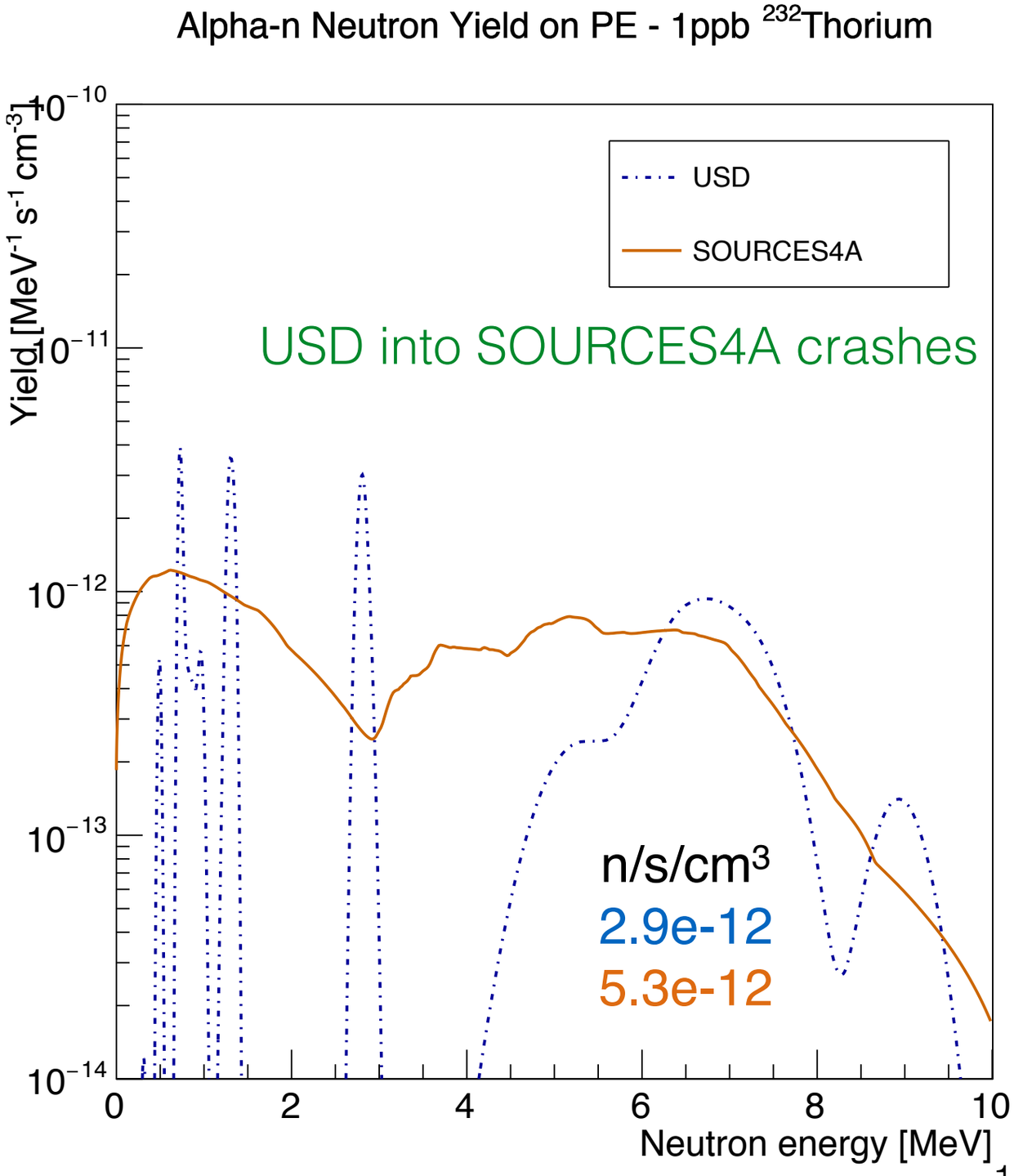


C13_SOURCES4A: ba73b fig. 3 13c(a,n) x sec + EMPIRE2.19

Polyethylene

Different input CrossX





Polyethylene

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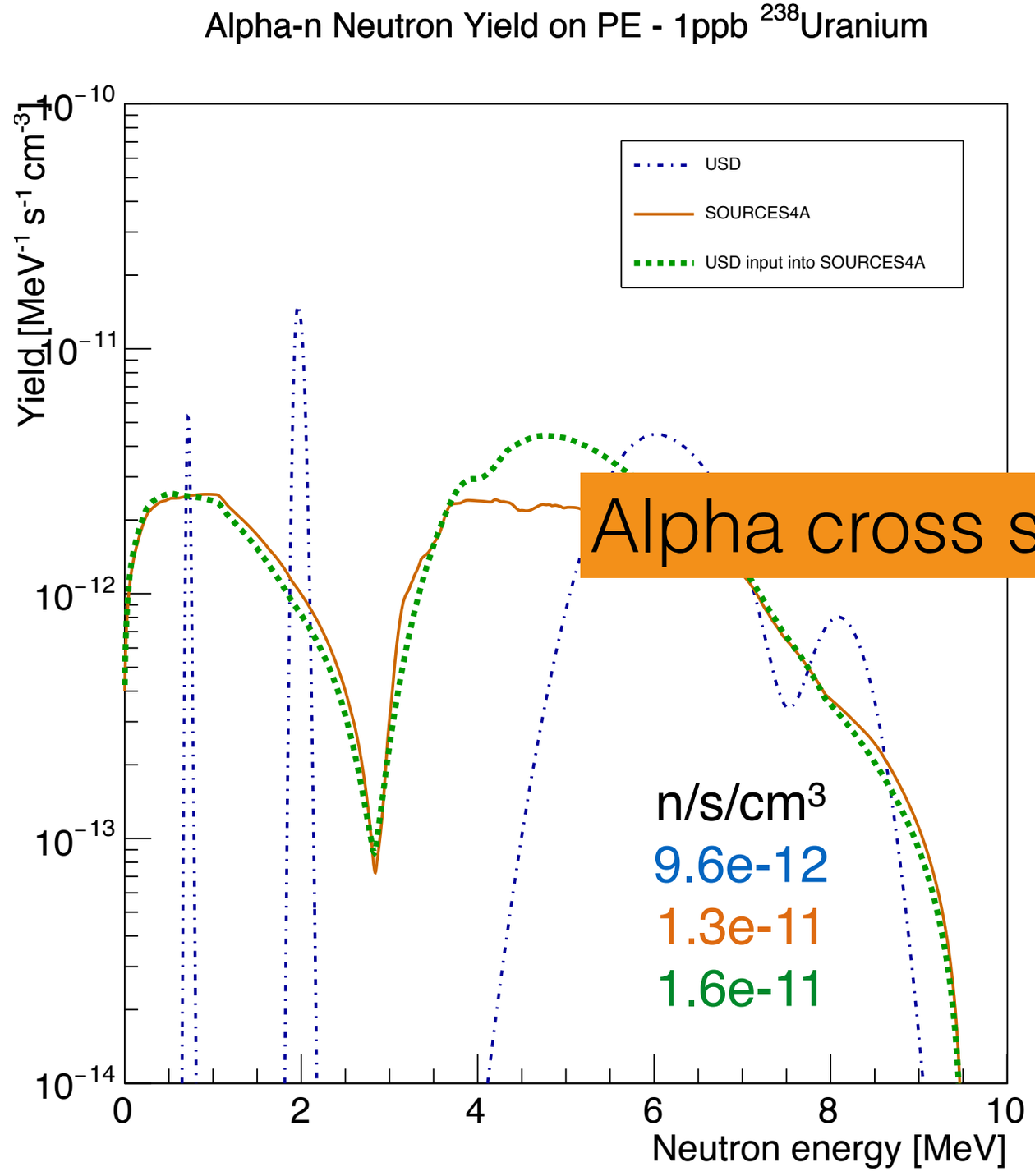
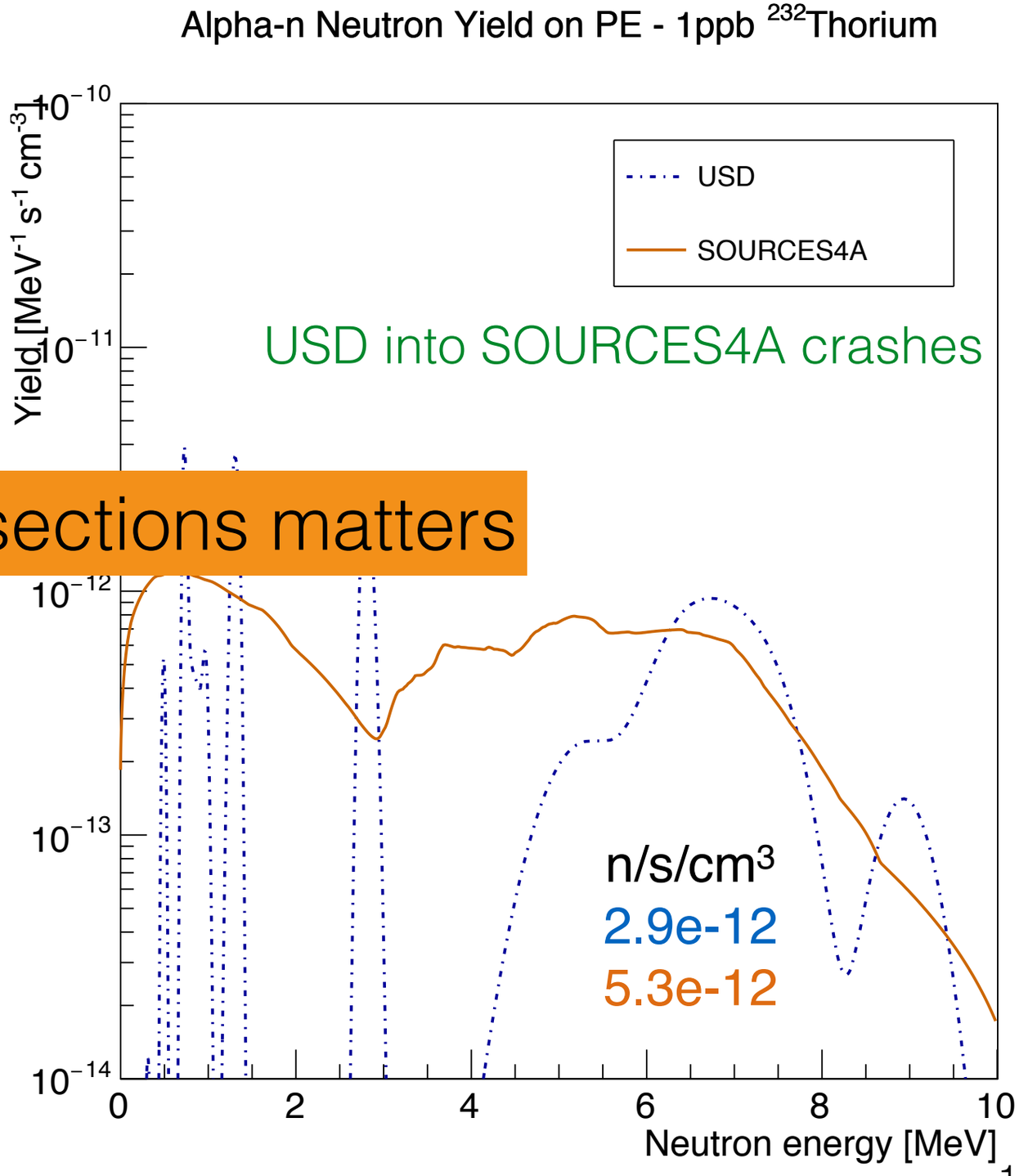
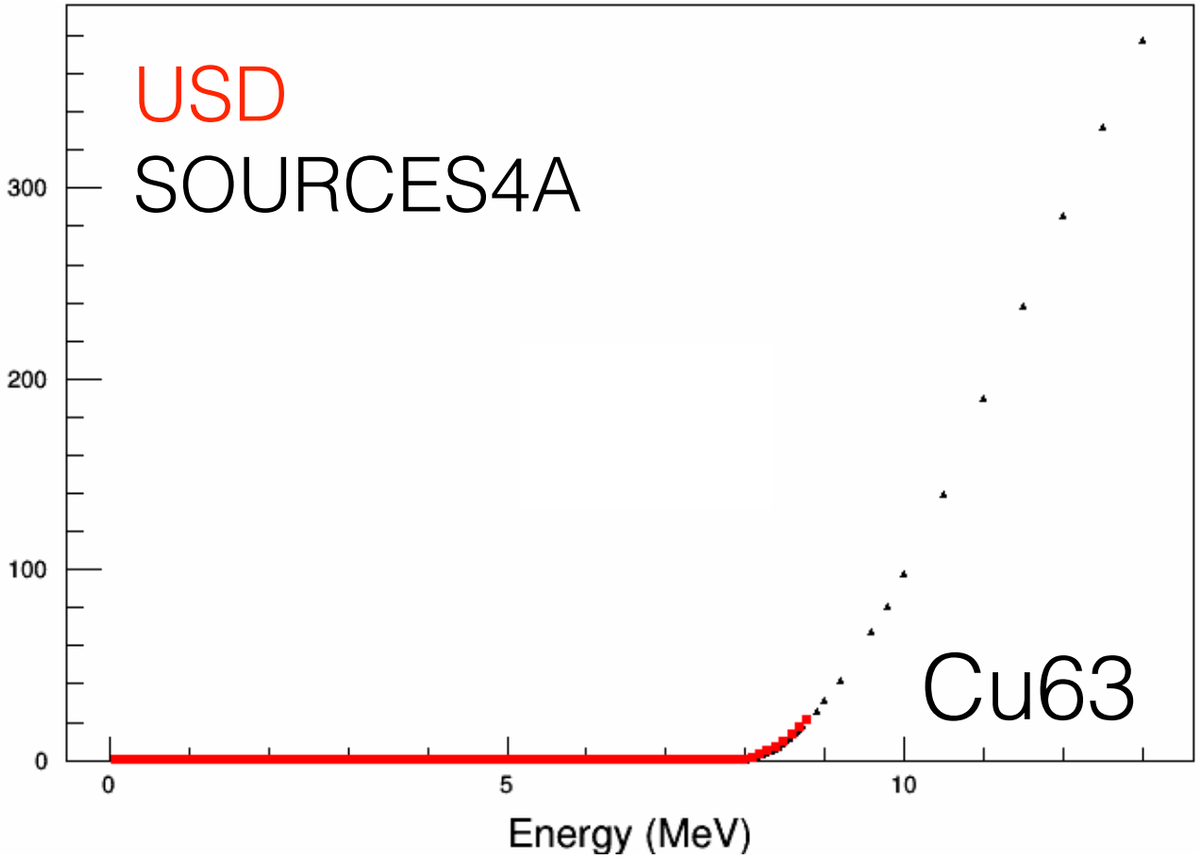


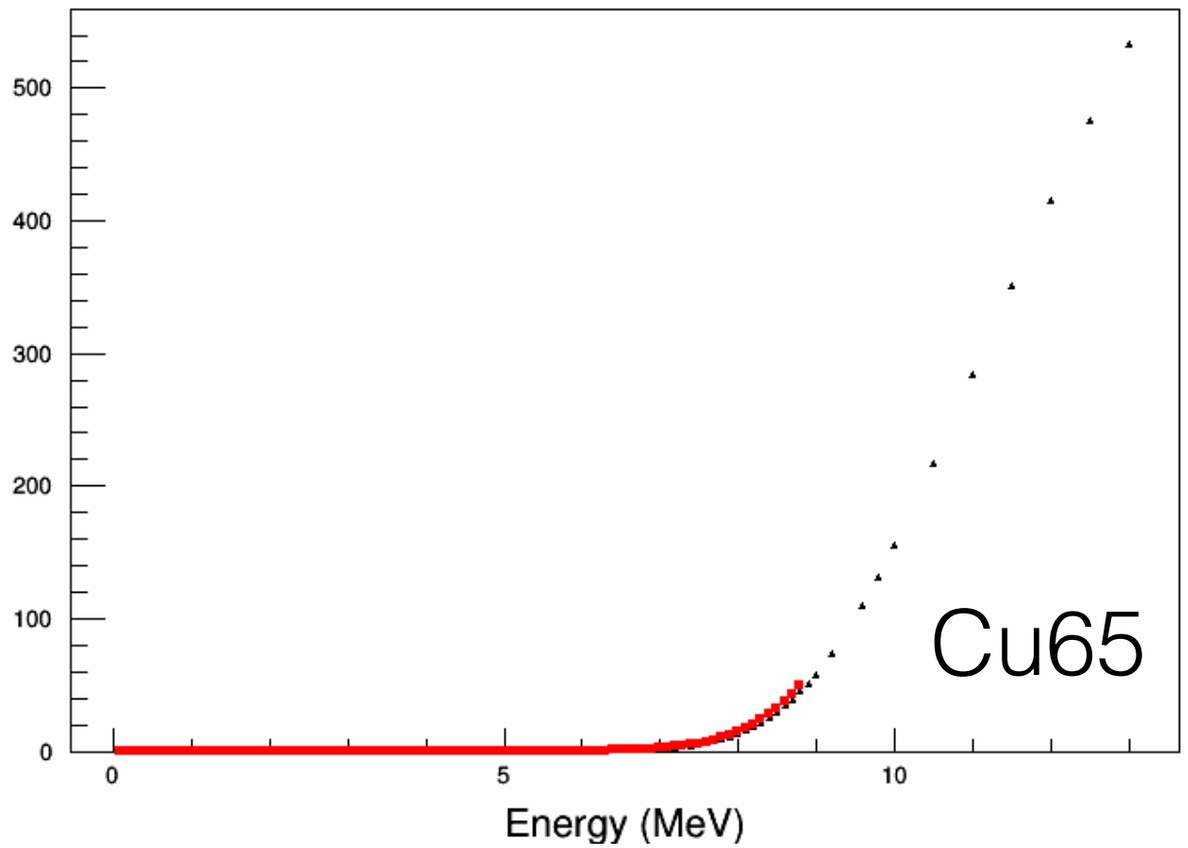


Alpha cross sections matters

Copper

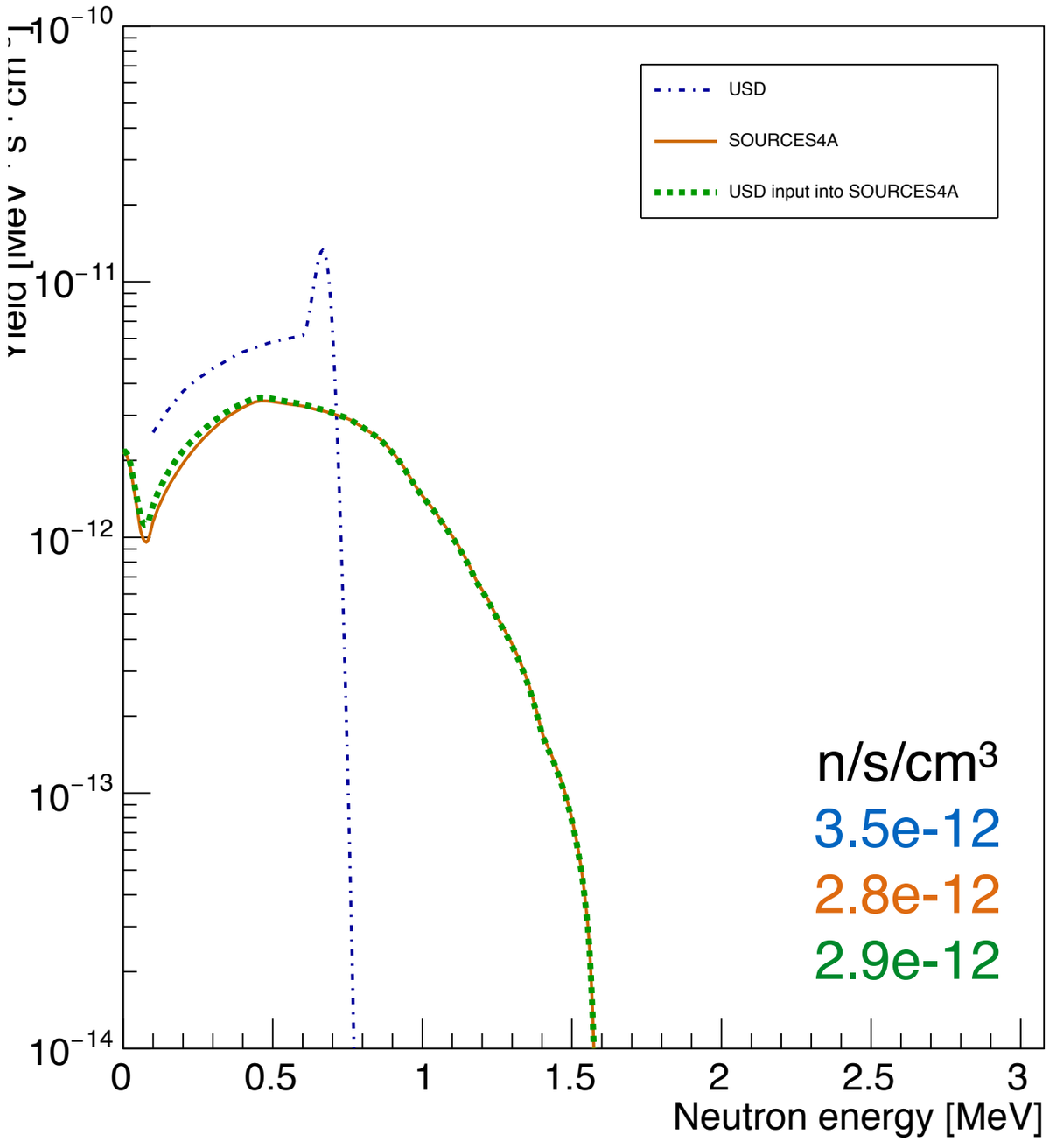
Check code calculation for matching USD and SOURCES4A input alpha cross sections

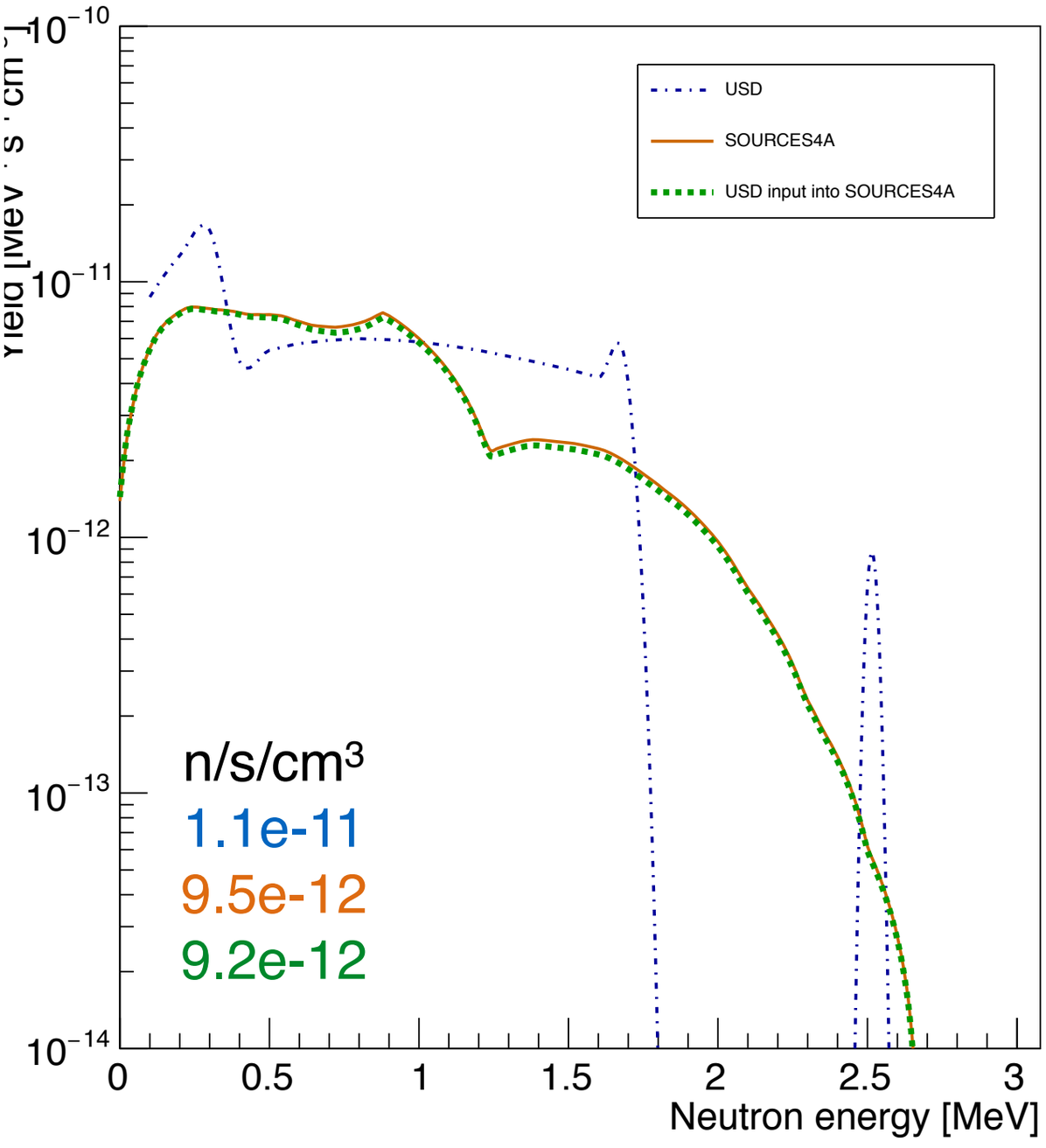




Copper

Input CrossX matching





Material	Decay Chain	Neutron/s/cm³ USD	SOURCES4A	USD crossX into SOURCES4A	Ratio Sources4A/ USD	Sources4A/ USDintoSources
Cu	238U	3.46E-12	2.84E-12	2.93E-12	0.8	1.0
	232Th	1.11E-11	9.49E-12	9.18E-12	0.9	1.0
PE	238U	9.56E-12	1.26E-11	1.64E-11	1.3	0.8
	232Th	2.87E-12	5.28E-12		1.8	

- Looking at the first ratio column:
  SOURCES4 code differs by factor <2 USD calculation

- Looking at the second ratio column:
  different input cross section may account up to 20% in calculation

GEANT4 neutron propagation studies

by KJPalladino

What do these input radiogenic 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

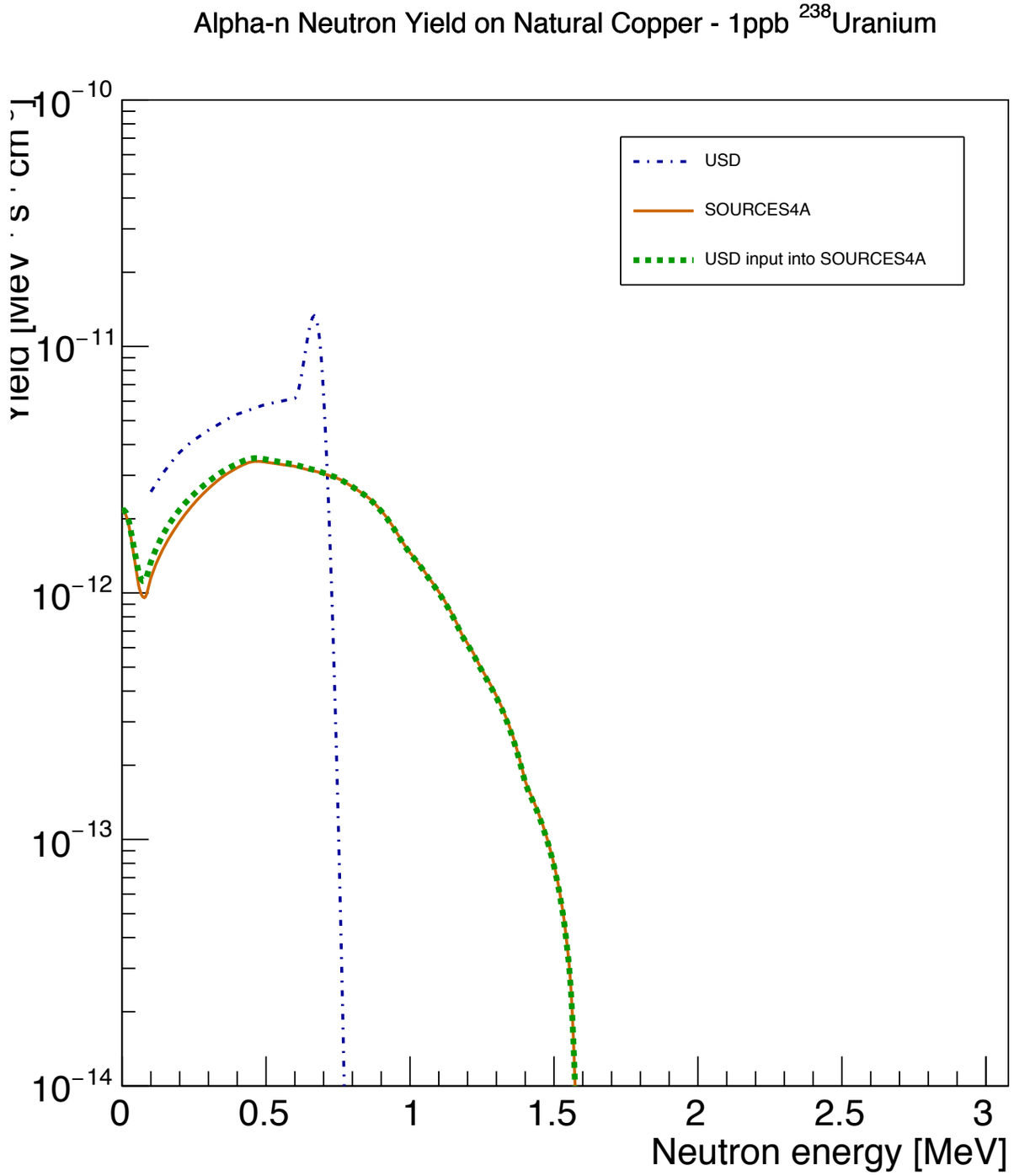
Create generalized direct dark matter detectors of common materials (argon, xenon and germanium) along with external vetoes

LRT 2105

Neutrons in copper from ^{238}U

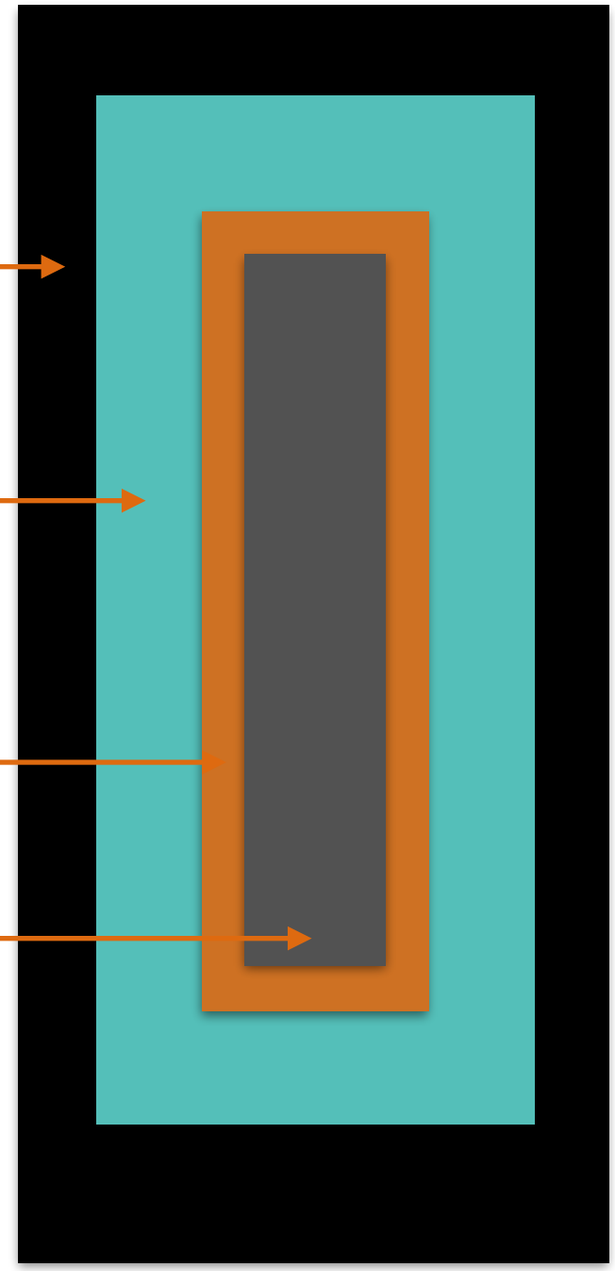
From 1ppb of U238, USD calculations give a neutron yield of 3.46 E-12 n/s/cm3 while SOURCES gives a neutron yield of 2.90E-12 n/s/cm3, 19% lower

USD spectrum cuts off at half the energy of SOURCES



Ge Detector Simualtion

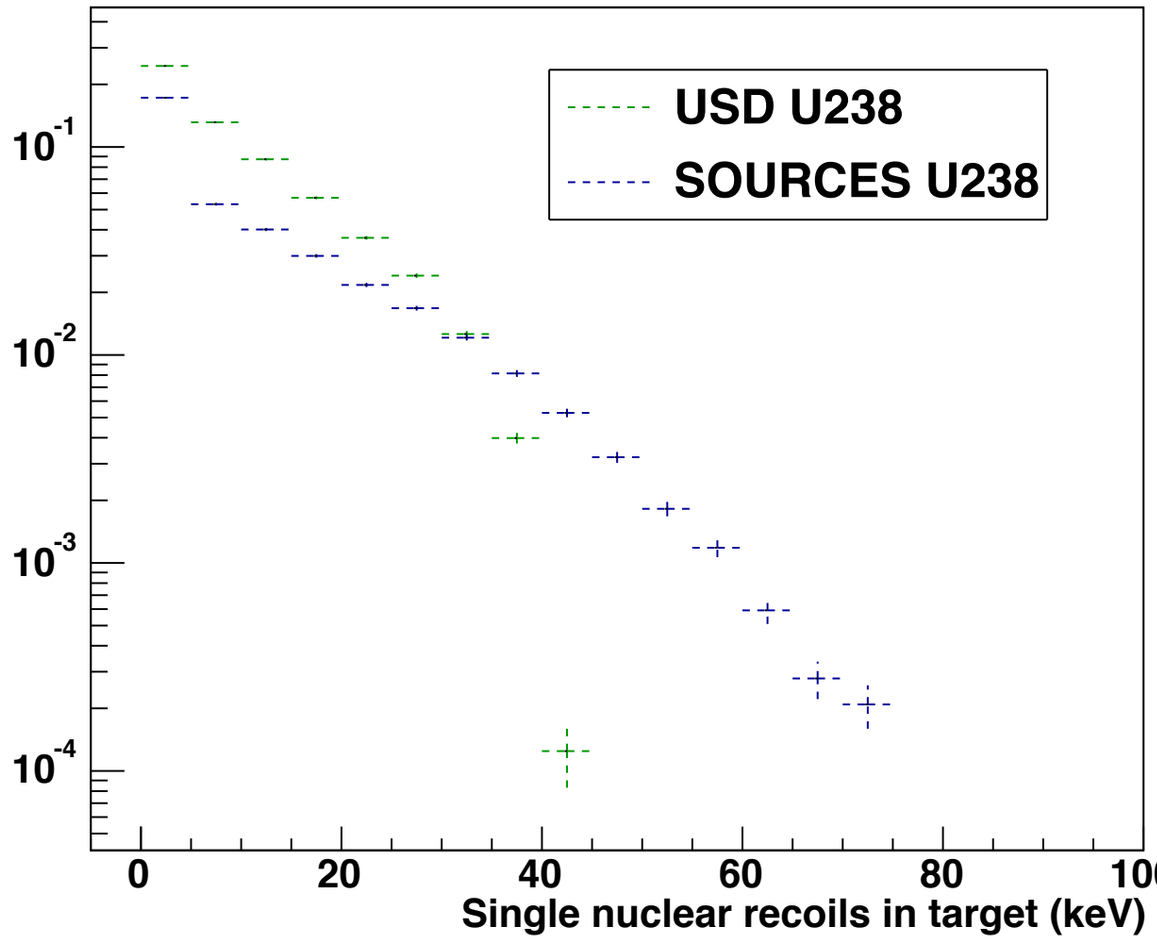
- 250000 neutrons isotropic from copper for each simulation
- Neutron recoil threshold of 5 keVnr used in analysis
- 1 keVee threshold for EM deposits to veto event in argon
- Neutron capture in plastic scintillator needed to externally veto event



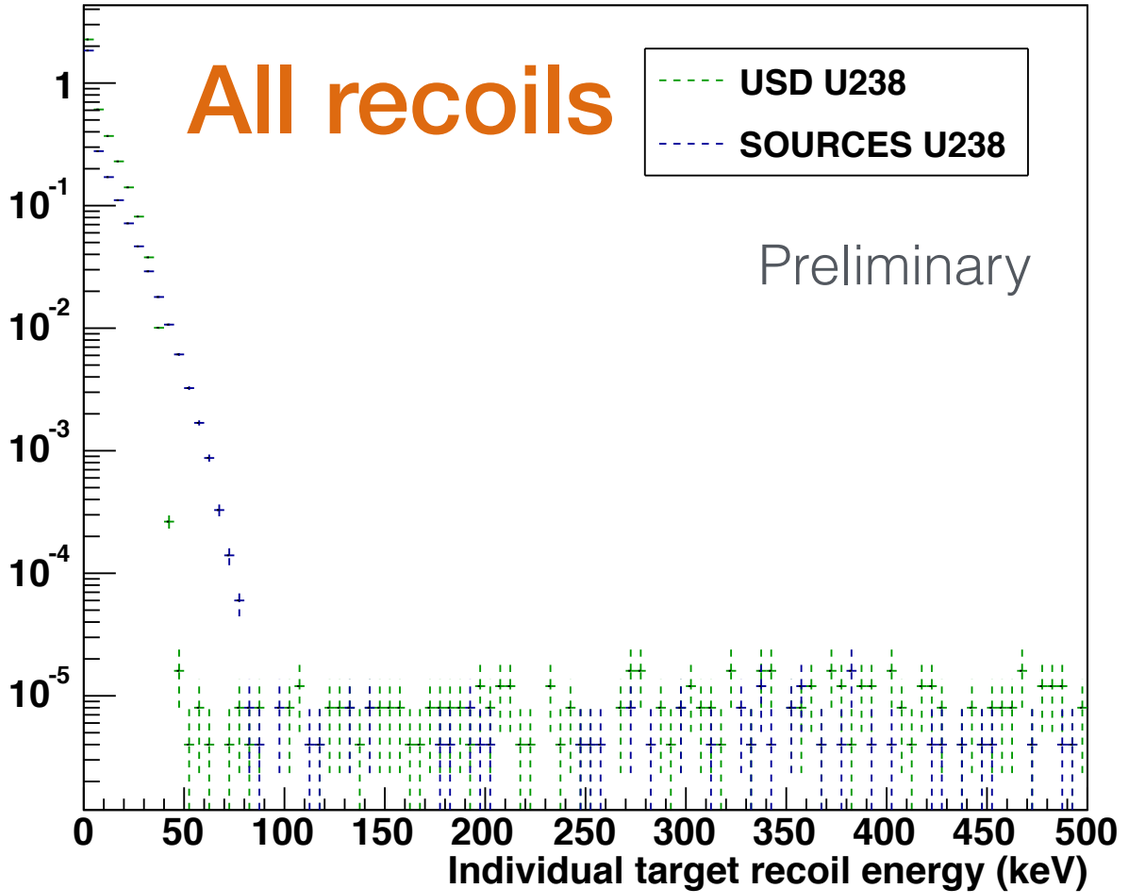
Nested cylinders geometry

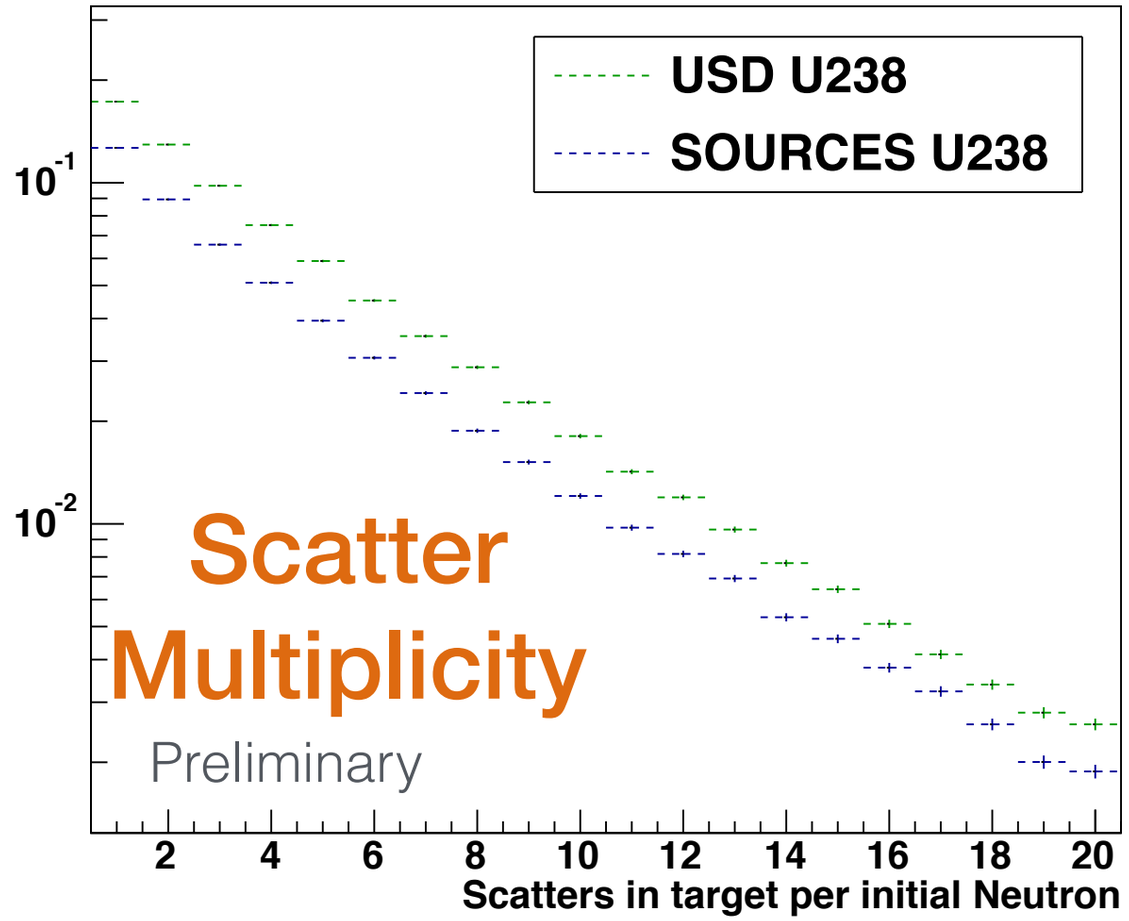
Ge recoils

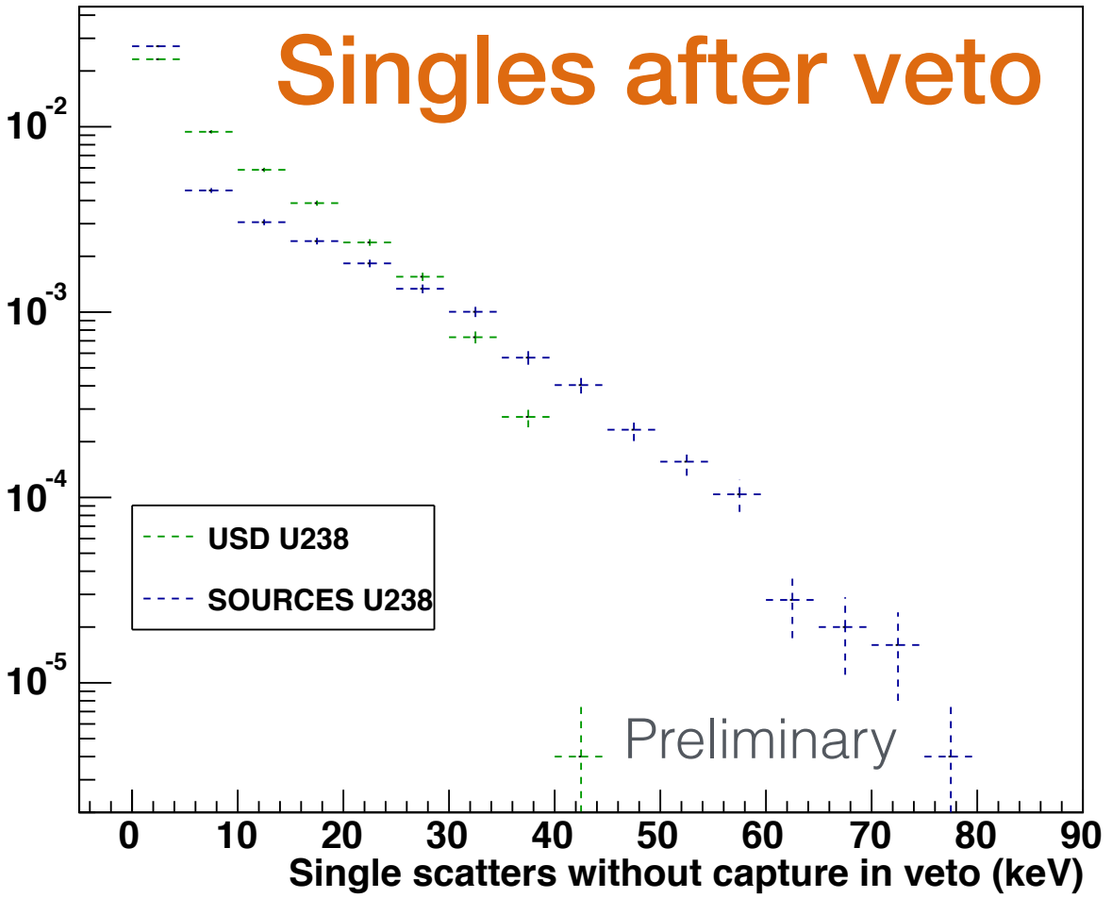
Shape and yield effects cause an 80% higher prediction of single scatters from USD than SOURCES

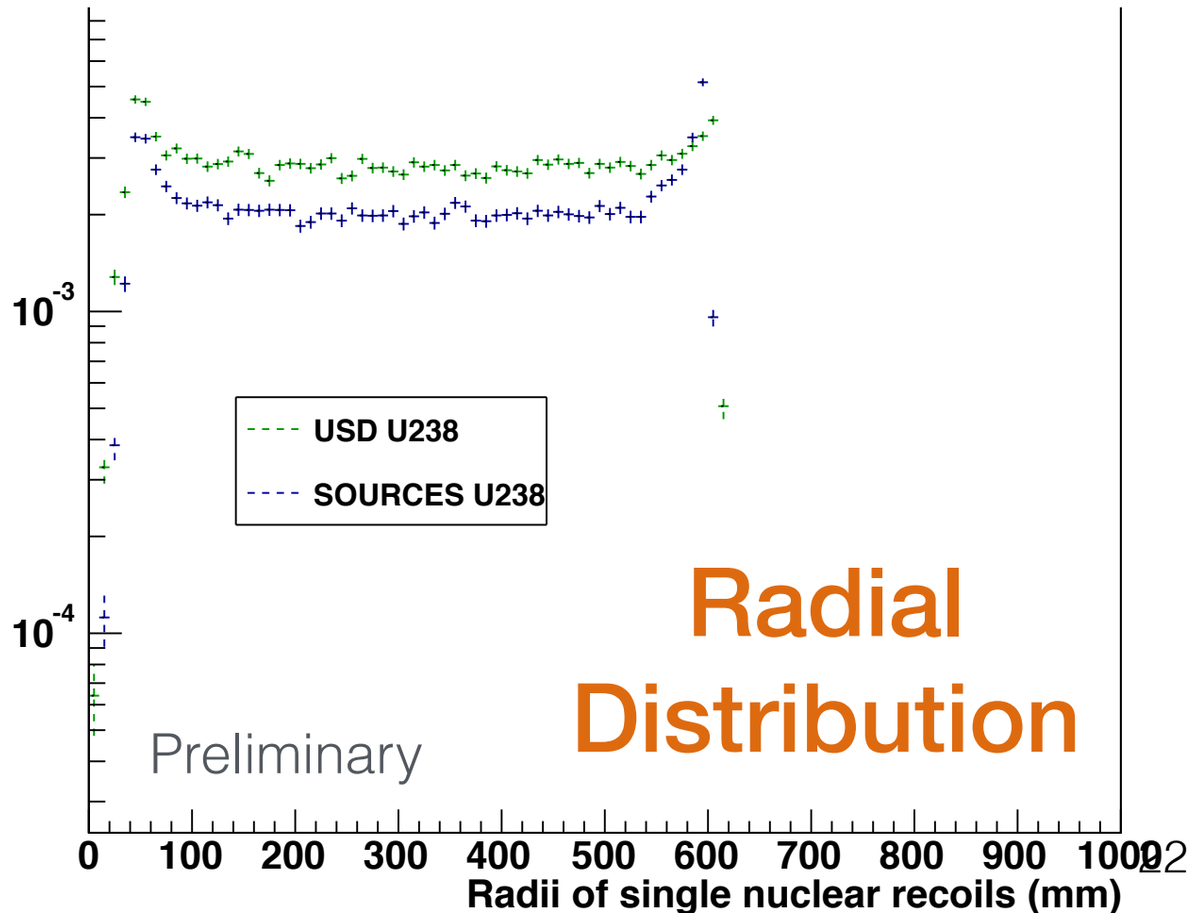


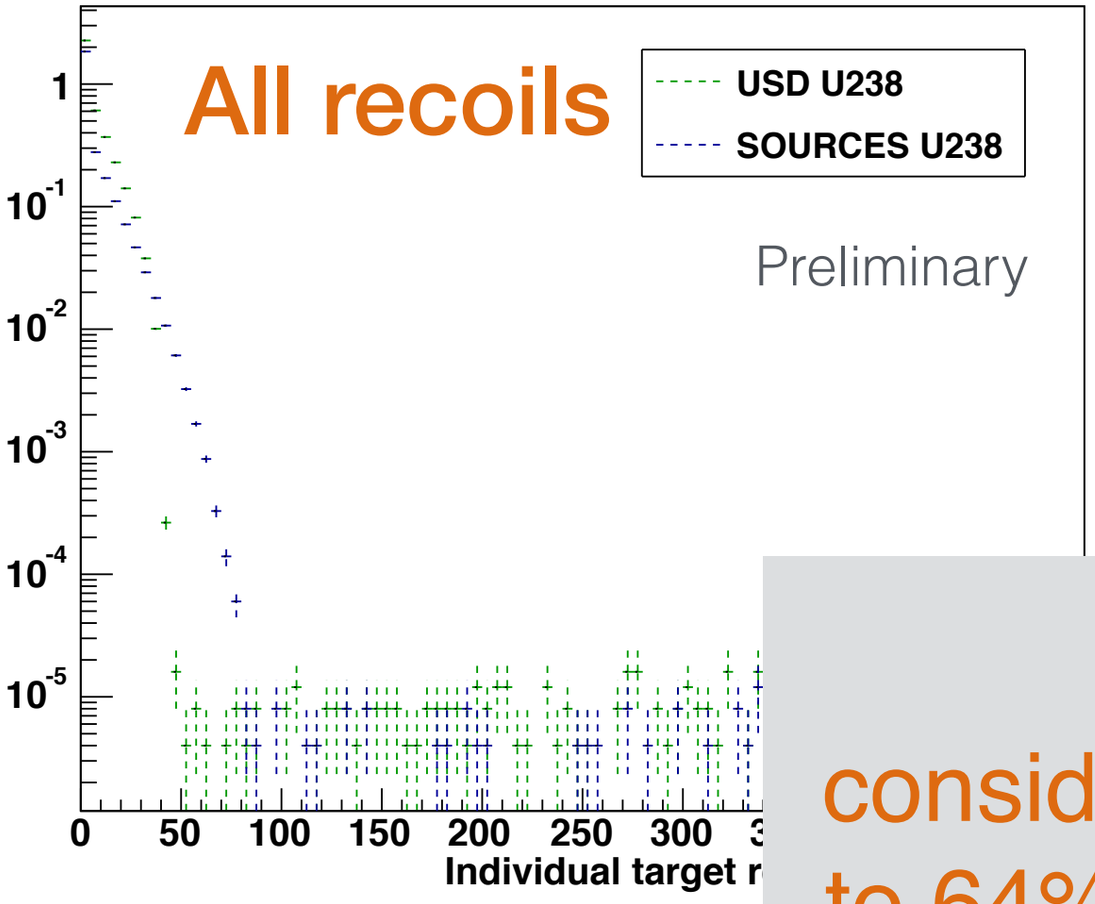
	Summed nuclear recoils over 5 keV	Single nuclear recoil over 5 keV	Single recoils over 5 keV no capture in veto	Single recoils over 5 keV no electron scatter >1 keV	Ratio of Multiple scatters: single scatters no threshold
TALYS-USD % of initial sim	14.2 +/- 0.07%	10.2 +/-0.06%	2.4 +/- 0.03%	8.87+/- 0.06%	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^3/ppb	(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^3/ppb	(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

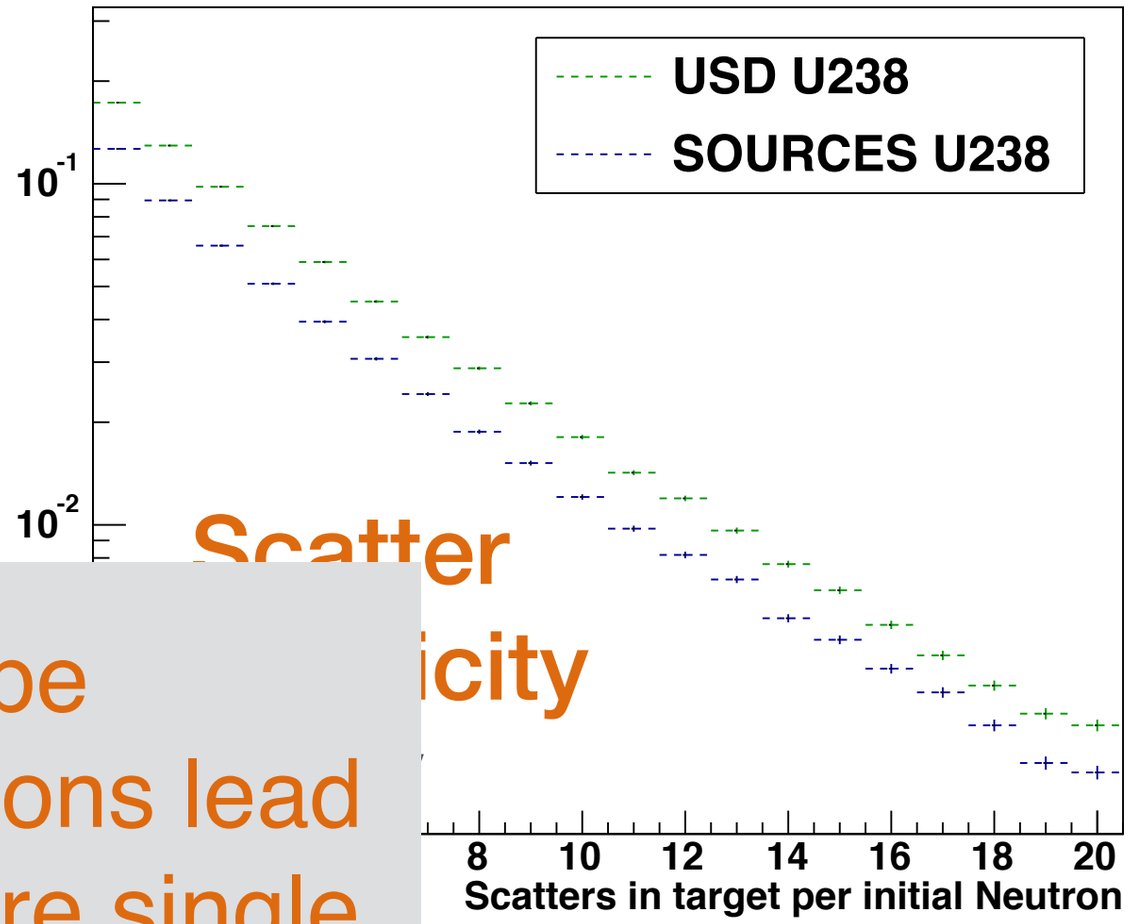

All recoils
USD U238
SOURCES U238
Preliminary
Individual target recoil energy (keV)


USD U238
SOURCES U238
Scatter Multiplicity
Preliminary
Scatters in target per initial Neutron

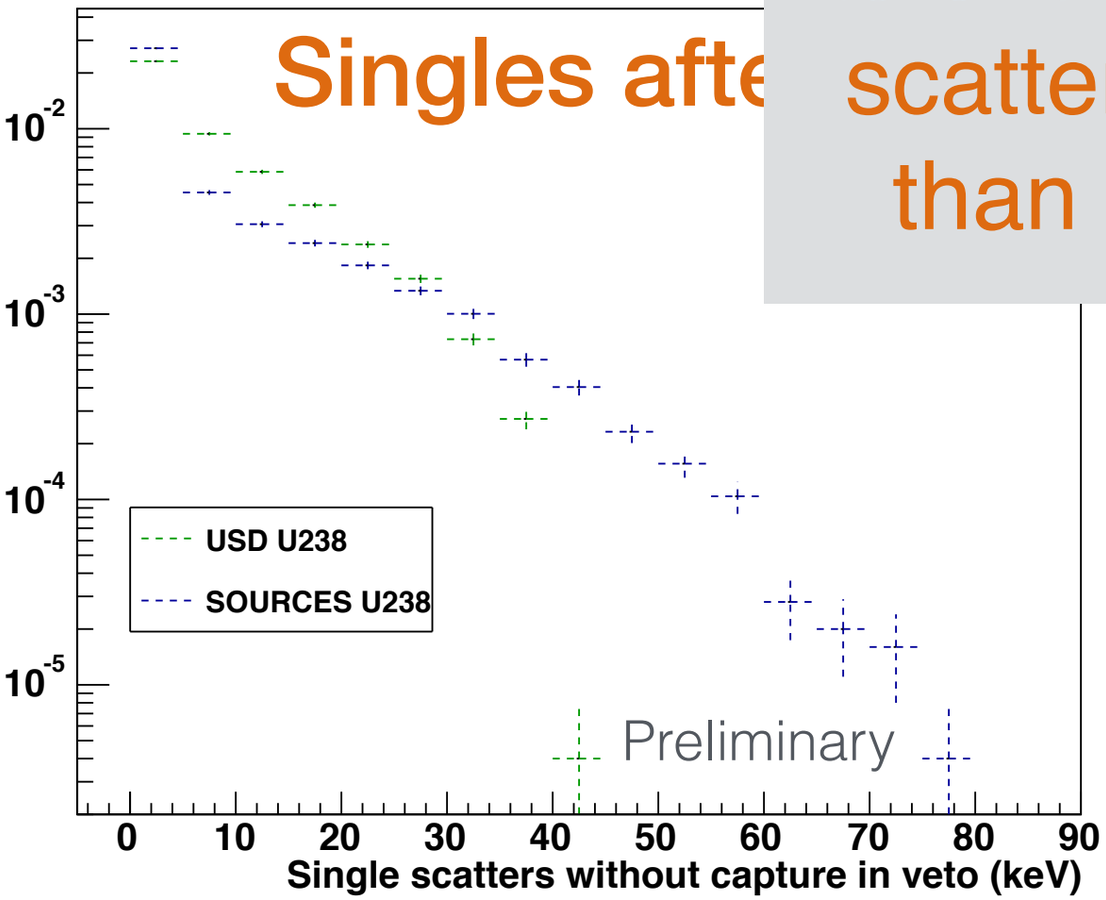

Singles after veto
USD U238
SOURCES U238
Preliminary
Single scatters without capture in veto (keV)

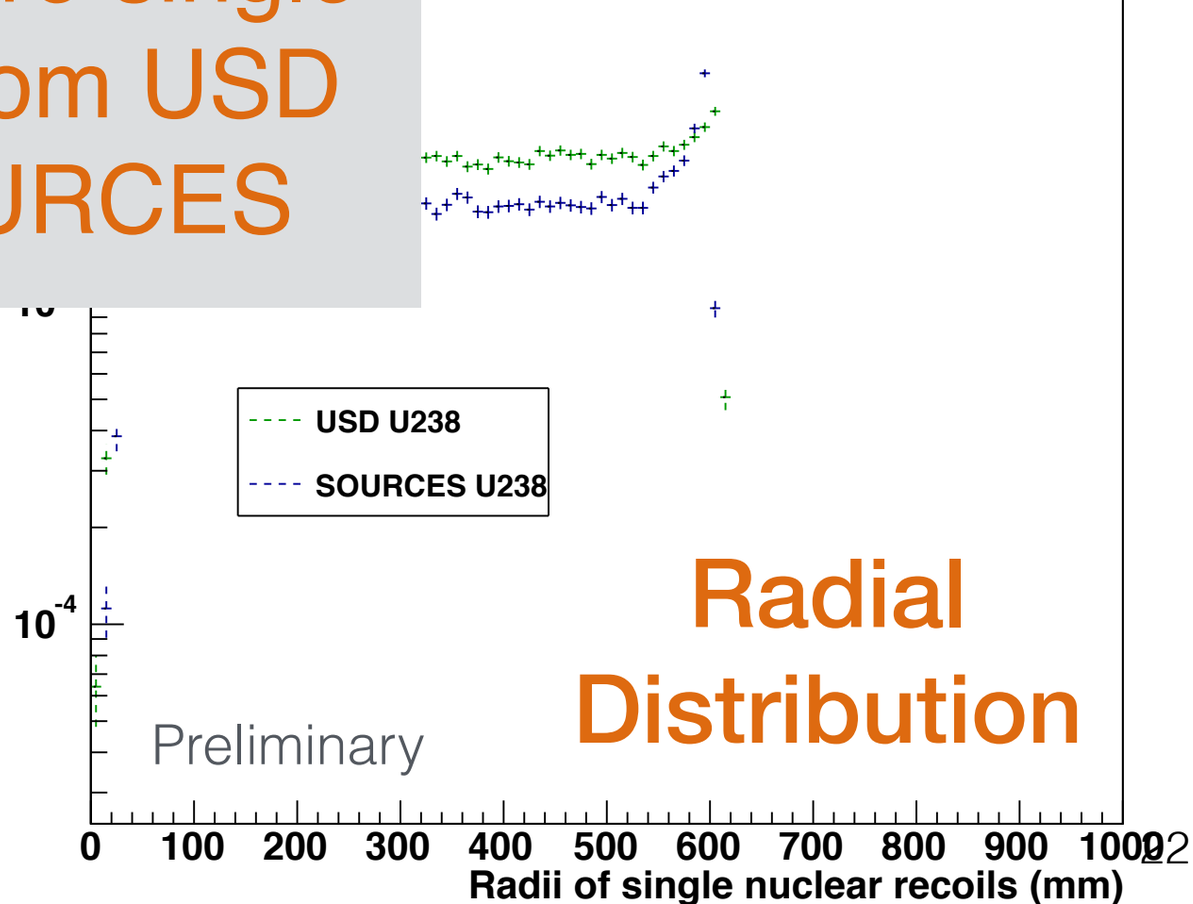

USD U238
SOURCES U238
Radial Distribution
Preliminary
Radii of single nuclear recoils (mm)





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





Conclusions

- Exhaustive comparison code study has been carried out.
- Extensive simulation work has been performed to check the influence of radiogenic neutron spectrum for experimentalist
- Wrap everything up in a paper

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