NN’ ORNL-UT-UKY-LU Zoom meeting • May 26, 2026

Agenda

1. Charlie 10' Conclusion on GEANT4 simulations for fast neutrons in GP-SANS
2. Yuri (for Alina) 10' Progress in the nTMM 2025 data analysis
3. Yuri 10' Result of regeneration limit from 33 B=0 runs in 2024 for PRD paper
4. Yuri 15' Is it correct plotting an envelope of 3 measurements (Paper Fig 9)?
5. Linus 10' Updates from LU
6. Mubi 10' Updates from UKY
7. AOB

Neutron Absorption Simulations Update

By Charlotte Snow

University of Denver

May 26, 2026

Set Up

Simulating: 2,000,000 neutrons

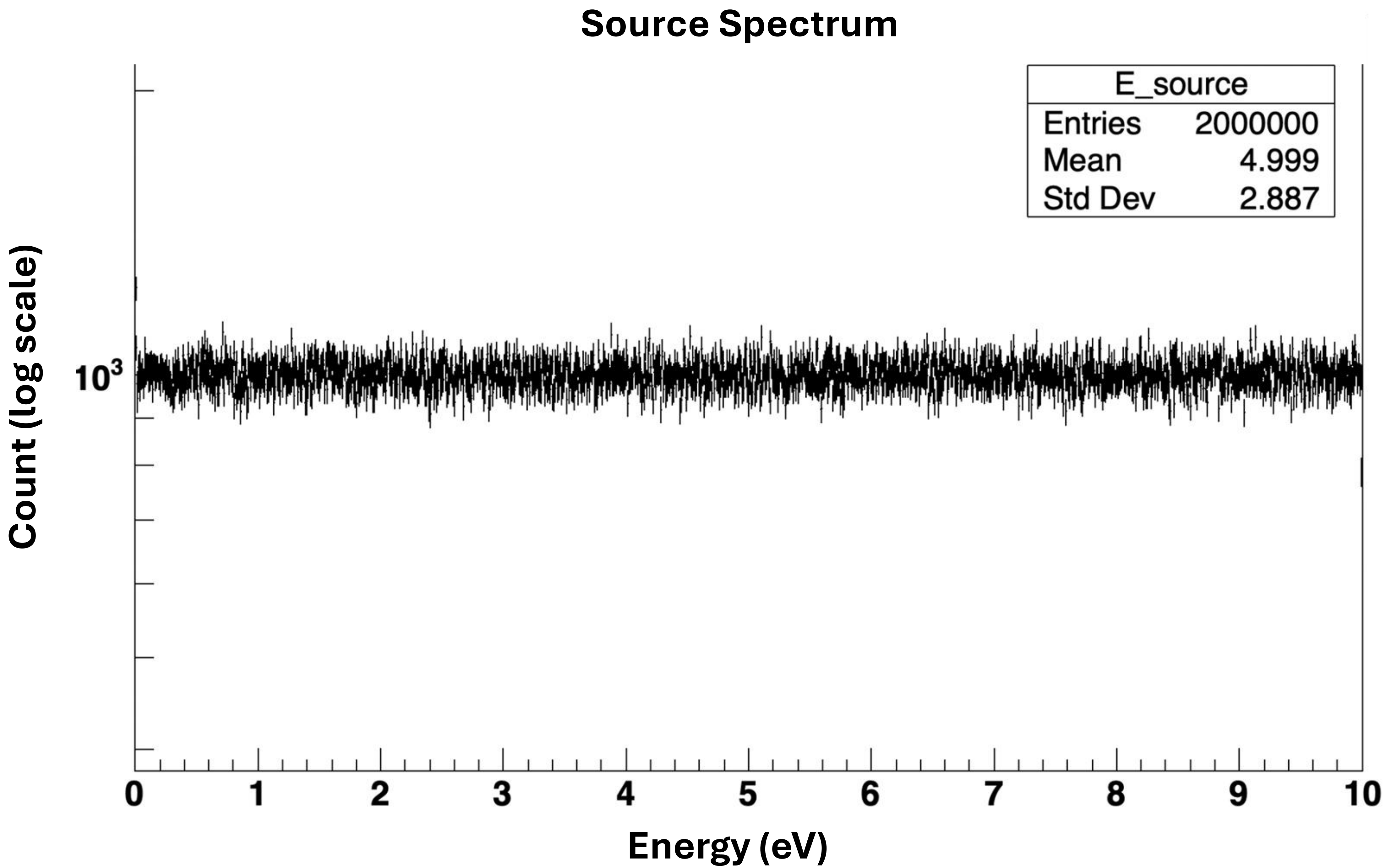
Plotting: 0 to 10 eV with 2,000 bins

- Source Neutrons
- Transmitted Neutrons

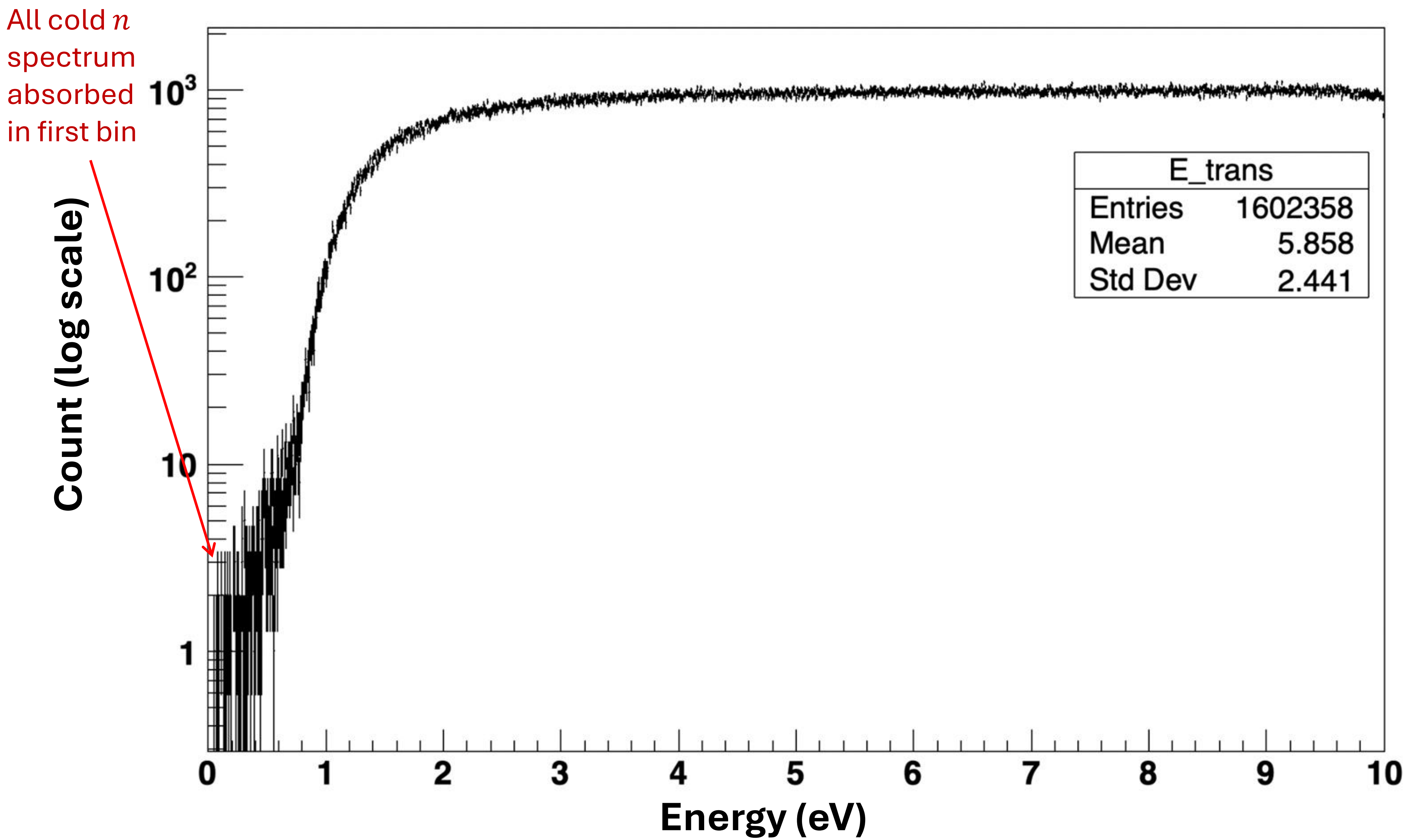
Material cross-sections come from QGSP_BIC_HP Physics List from Geant4

For Materials

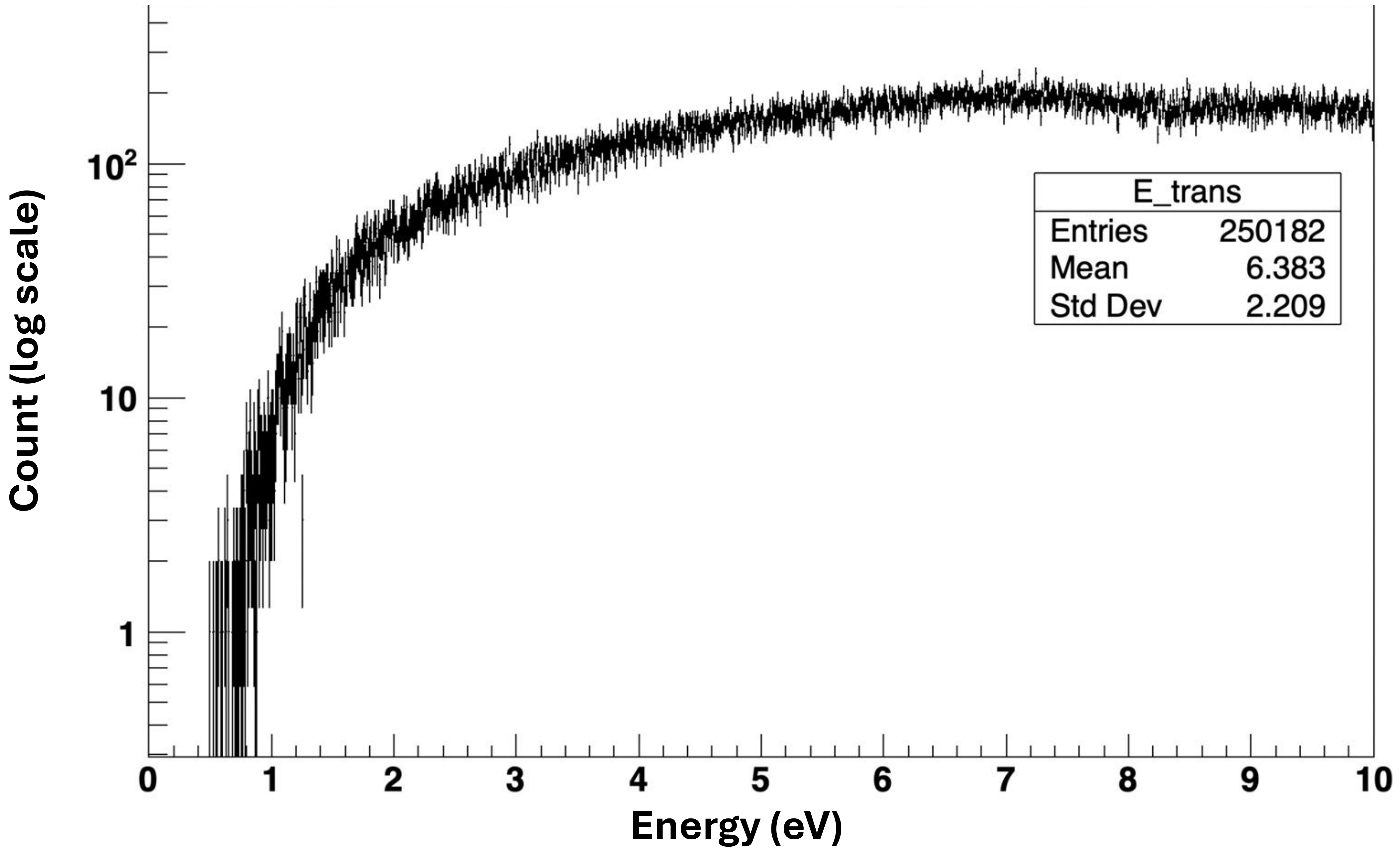
(1) Cd (3.5 mm)
(2) Cd (3.5 mm) + BN (6.35 mm)
(3) BPE (10 mm) + Cd (3.5 mm)
(4) BPE (50 mm) + Cd (3.5 mm)
(5) BPE (100 mm) + Cd (3.5 mm)
(6) Shutter 1 + Cd (3.5 mm)
(7) Shutters 1 & 2 + Cd (3.5 mm)

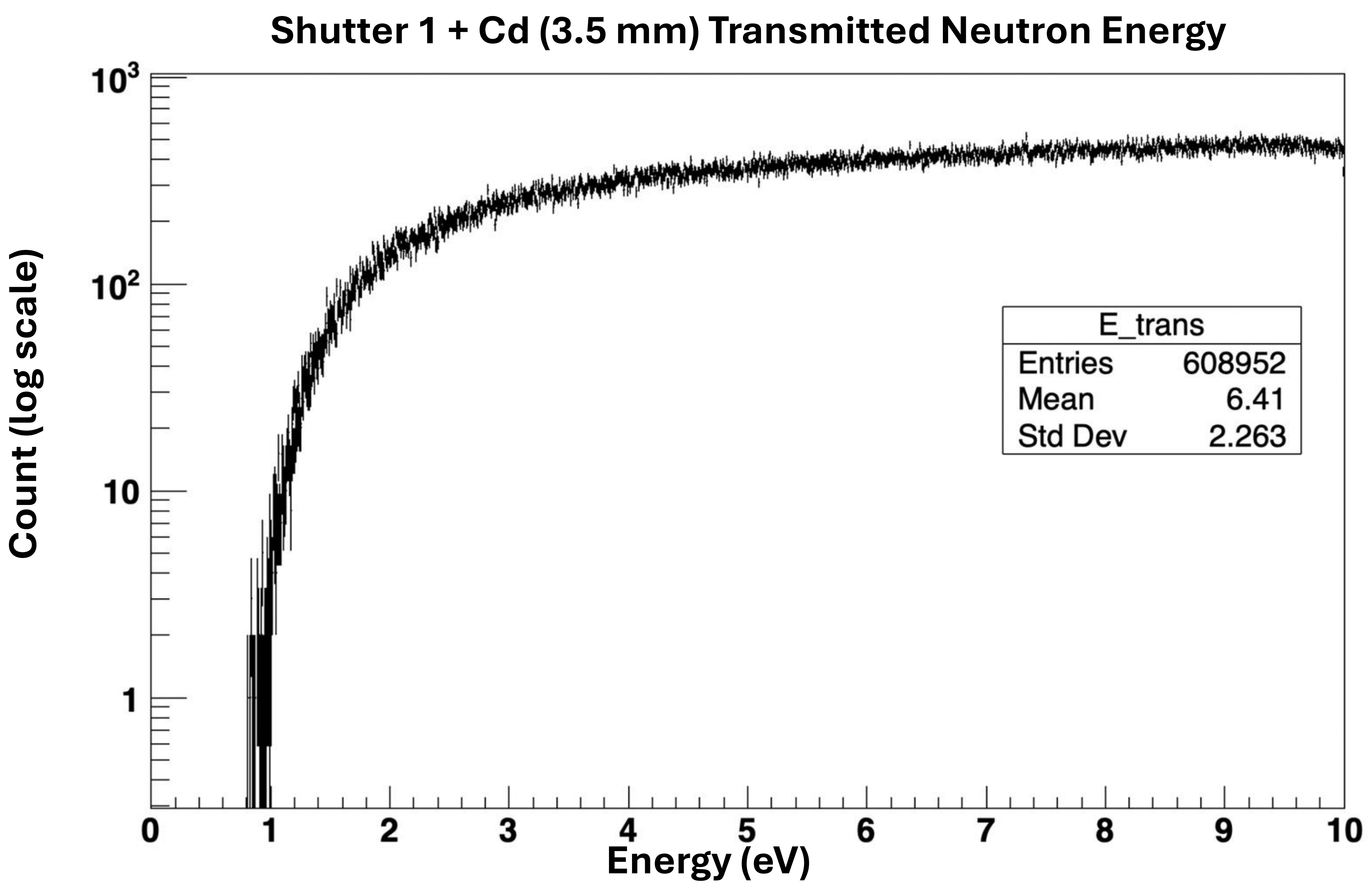

Source Spectrum
E_source
Entries 2000000
Mean 4.999
Std Dev 2.887
Count (log scale)
10^3
0
1
2
3
4
5
6
7
8
9
10
Energy (eV)

Cd (3.5 mm) Transmitted Neutron Energy

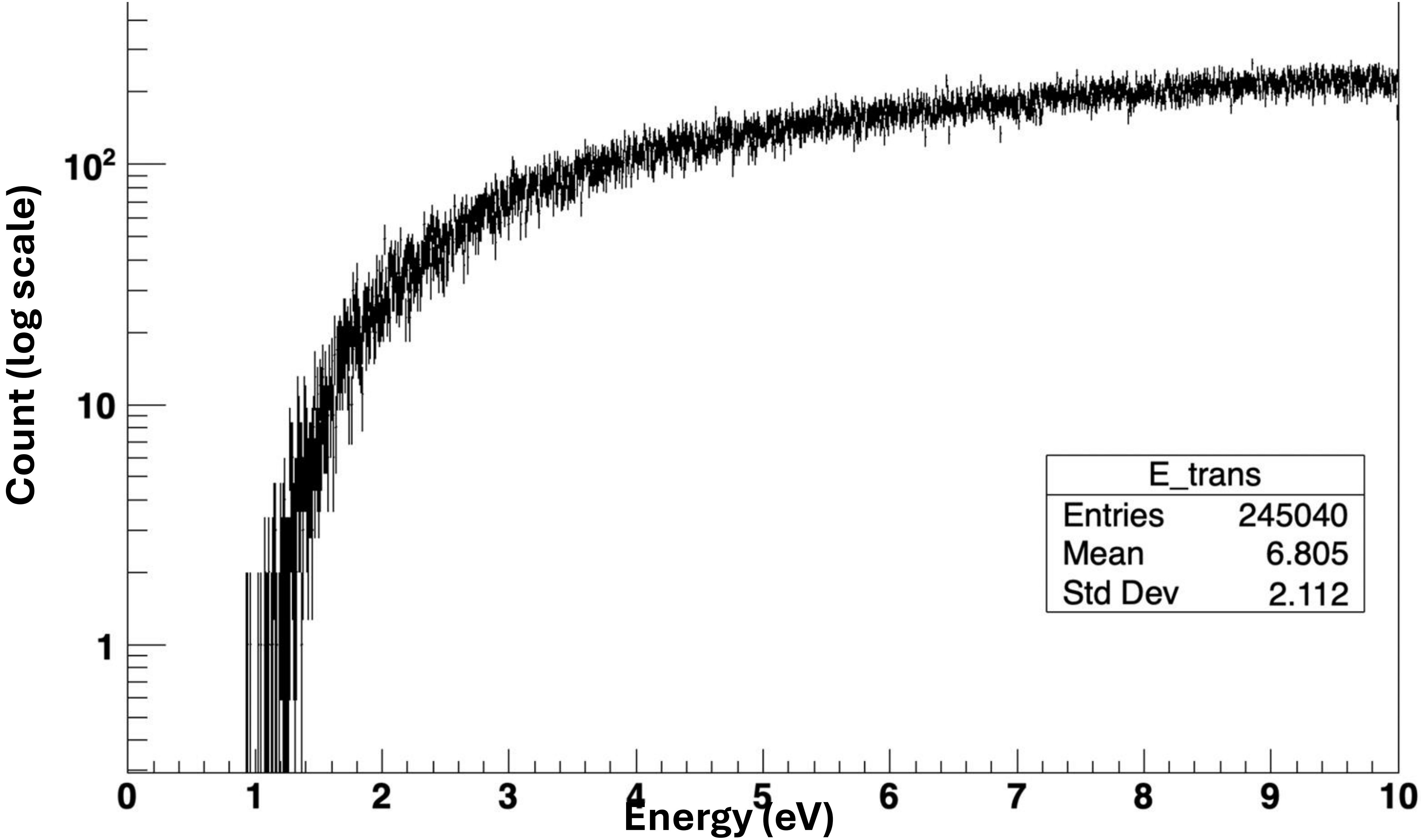


Cd (3.5 mm) + BN (6.35 mm) Transmitted Neutron Energy




Shutter 1 + Cd (3.5 mm) Transmitted Neutron Energy
Count (log scale)
10^3
10^2
10
1
E_trans
Entries 608952
Mean 6.41
Std Dev 2.263
0 1 2 3 4 5 6 7 8 9 10
Energy (eV)

Shutters 1 & 2 + Cd (3.5 mm) Transmitted Neutron Energy

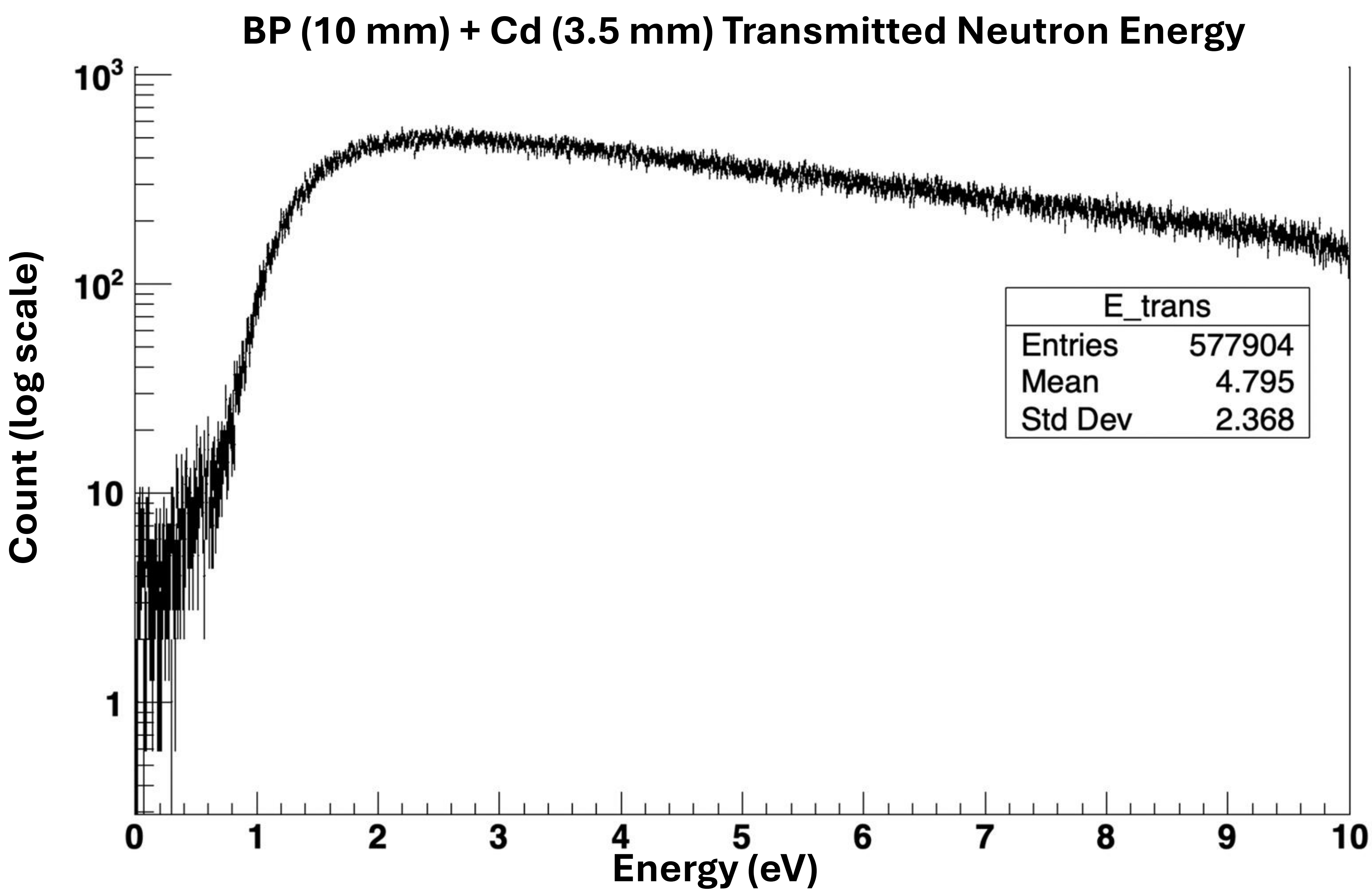


Reduction in Transmission

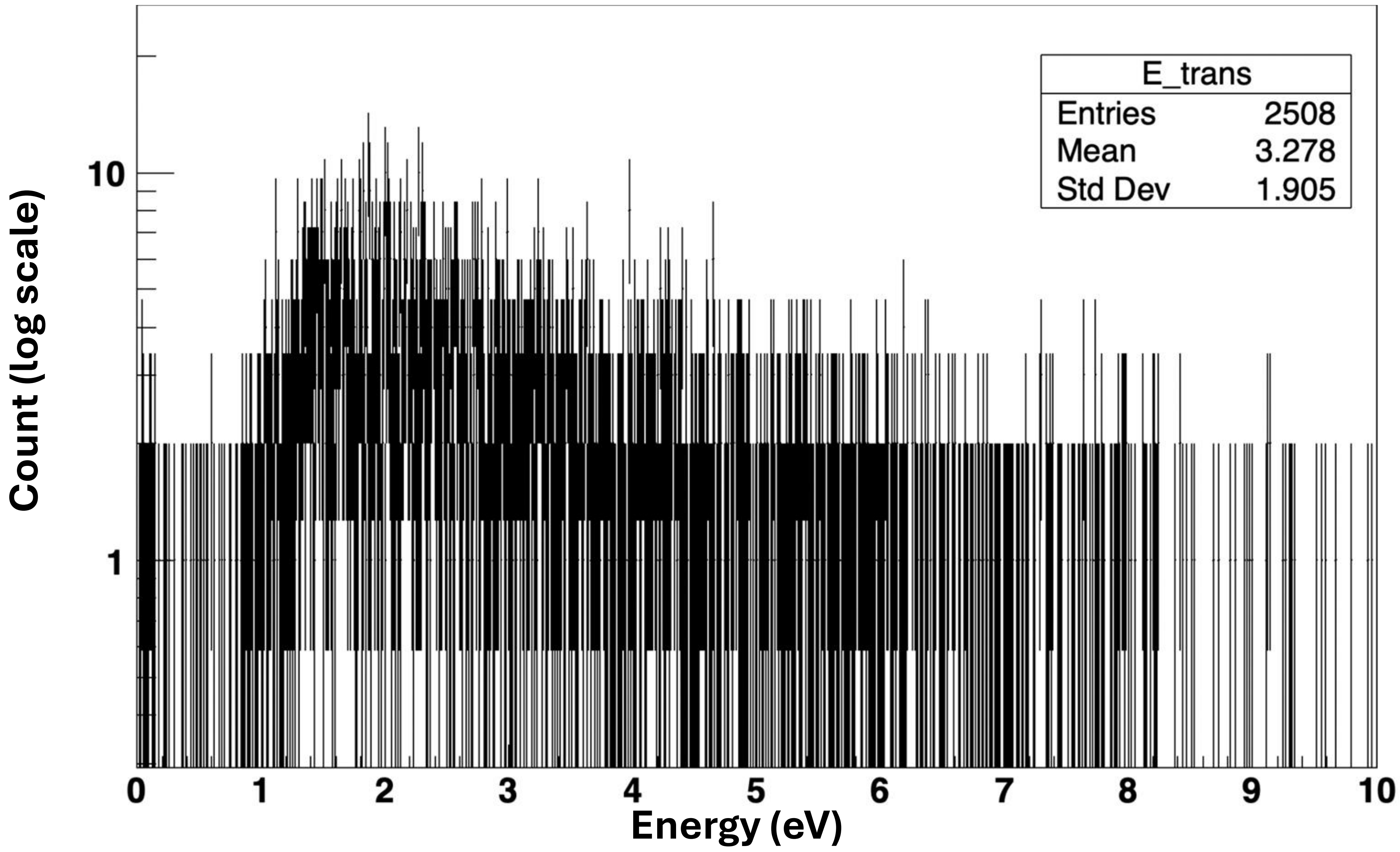
Geometry	Source (0 - 10 eV)	Transmitted	Reduction Factor (Compared with Cd)	Intensity (Carolyn's Numbers)	Predicted Reduction Factor (From Carolyn)
Cd (3.5 mm)	2,000,000	1,602,358		2.8272	
Cd (3.5 mm) + BN (6.35 mm)	2,000,000	250,182	6.40	0.416	6.79
BP (10 mm) + Cd (3.5 mm)	2,000,000	577,904	2.77		
BP (50 mm) + Cd (3.5 mm)	2,000,000	2508	638.69		
BP (100 mm) + Cd (3.5 mm)	2,000,000	1	1,600,000		
Shutter 1 + Cd (3.5 mm)	2,000,000	608,952	2.63	0.649	4.36
Shutters 1 & 2 + Cd (3.5 mm)	2,000,000	245,040	6.54	0.035	80.78

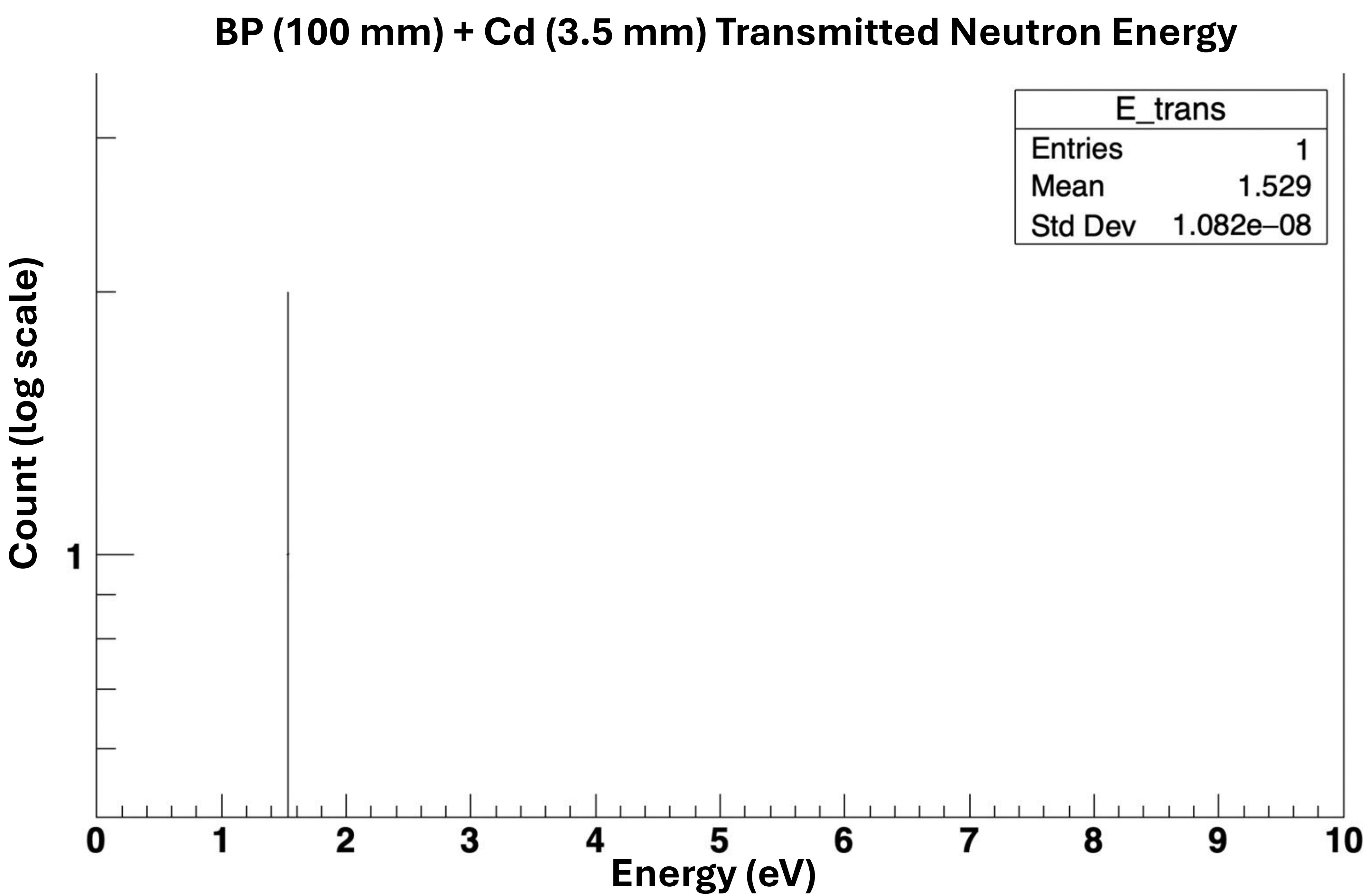
Comparison to Previous Simulation

Geometry	Source (0 - 10 eV)	Transmitted (May)	Transmitted (March)
Cd (3.5 mm)	2,000,000	1,602,358	1,603,031
Cd (3.5 mm) + BN (6.35 mm)	2,000,000	250,182	250,523
BP (10 mm) + Cd (3.5 mm)	2,000,000	577,904	491,727
BP (50 mm) + Cd (3.5 mm)	2,000,000	2508	1049
BP (100 mm) + Cd (3.5 mm)	2,000,000	1	Nothing to Compare
Shutter 1 + Cd (3.5 mm)	2,000,000	608,952	Nothing to Compare
Shutters 1 & 2 + Cd (3.5 mm)	2,000,000	245,040	Nothing to Compare


BP (10 mm) + Cd (3.5 mm) Transmitted Neutron Energy
Count (log scale)
Energy (eV)
E_trans
Entries 577904
Mean 4.795
Std Dev 2.368
10^3
10^2
10
1
0
1
2
3
4
5
6
7
8
9
10

BP (50 mm) + Cd (3.5 mm) Transmitted Neutron Energy





BP (100 mm) + Cd (3.5 mm) Transmitted Neutron Energy
E_trans
Entries 1
Mean 1.529
Std Dev 1.082e−08
Count (log scale)
1
0
1
2
3
4
5
6
7
8
9
10
Energy (eV)

Conclusion

- Though the spectrum is not a perfect match to the actual beam used in the experiment, simulation results of Cd (3.5 mm) + BN (6.35 mm) confirm simulation cross sections match up with experimental

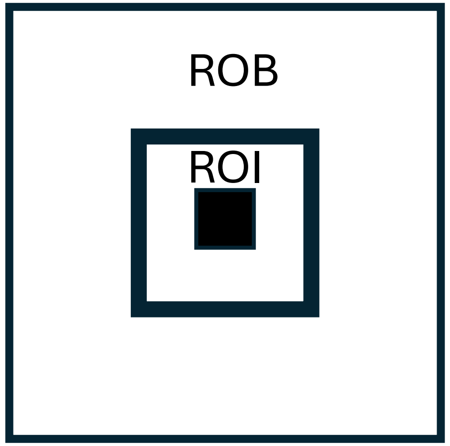
- Based on the results of these simulations, 100 mm of Borated Polyethylene should absorb much of the neutron spectrum left by the 3.5 mm of Cadmium.

Progress in the nTMM 2025 data analysis

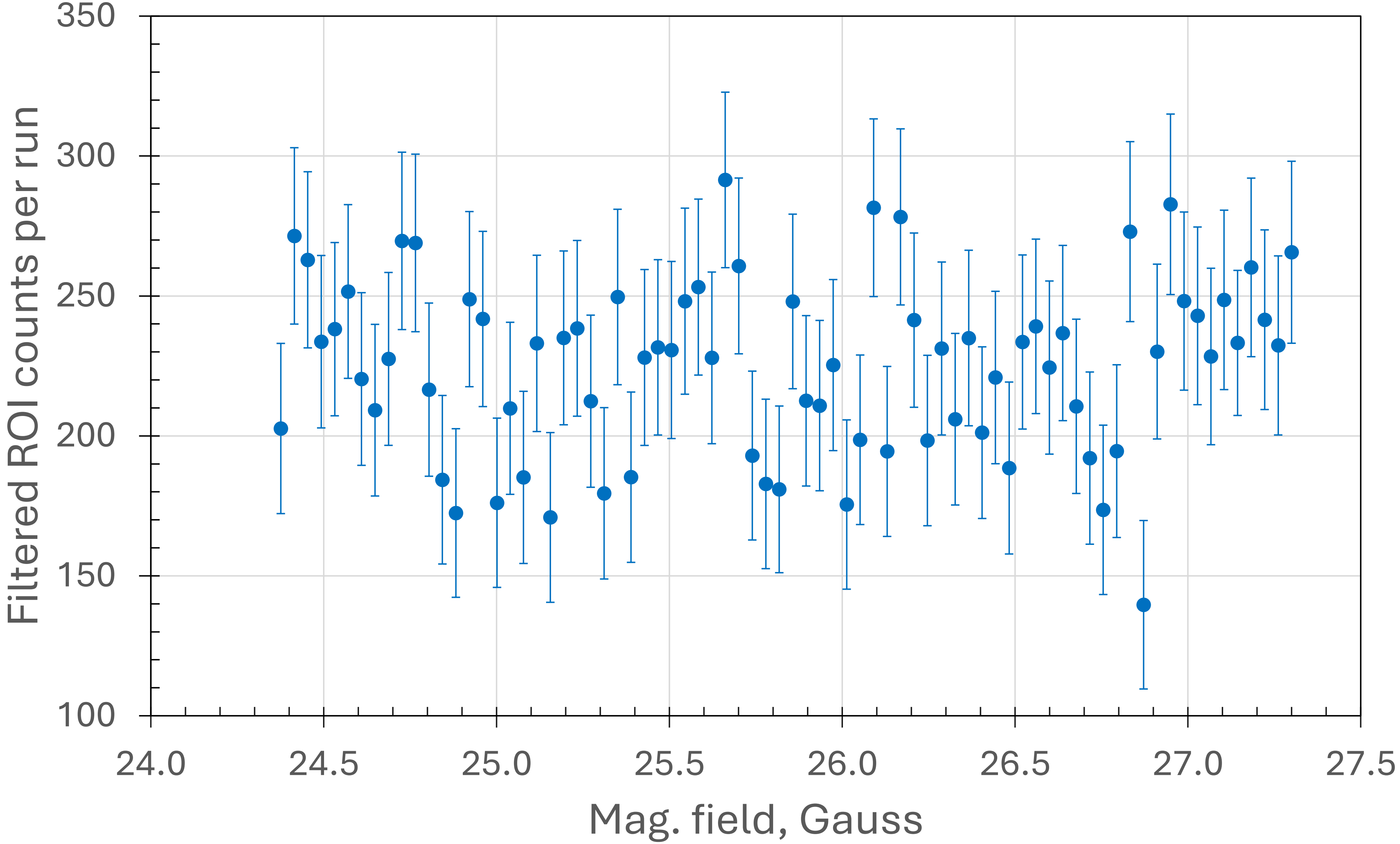
Data selection for 30-min and 20-min runs of September 2025

1. GPM relative intensity correction with ref. run **253** for 30-min series
2. GPM relative intensity correction with ref. run **346** for 20-min series
3. ROI 30 x 36 cm^2 with fast n peak removed area 13.4 x 13 cm^2
4. ROI area 905.8 cm^2 ; ROI efficiency 90.15%
5. ROB 94 x 96 cm^2 - dead rim 5 cm around ROI 40 x 46 cm^2
6. ROB area 7376 cm^2, with $A_{ROI}/A_{ROB} = 0.1228$
7. Corrected counts in ROI :

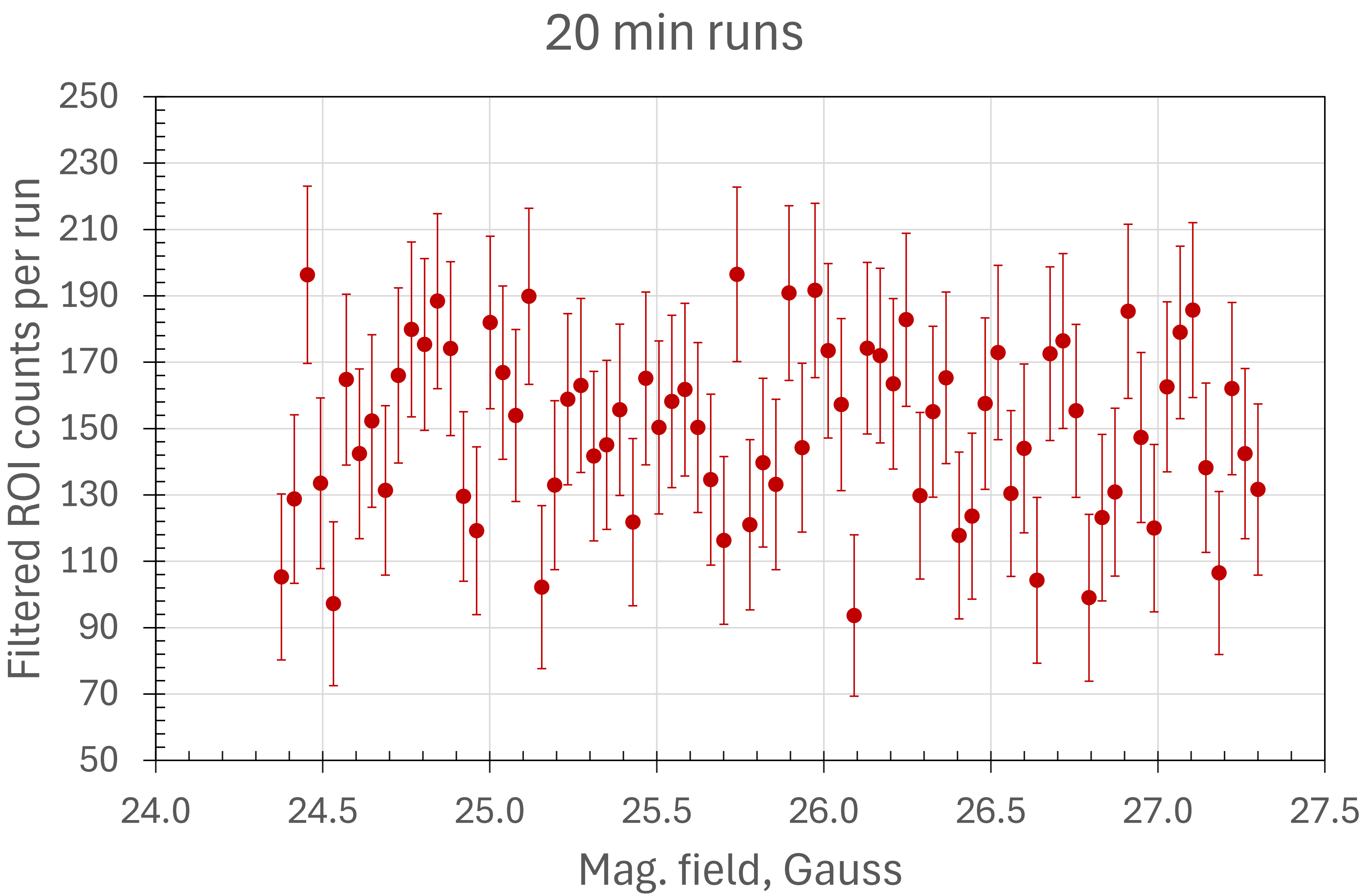
$$C_{corr} = C_{ROI} - C_{ROB} \cdot \frac{A_{ROI}}{A_{ROB}}$$



30 min runs

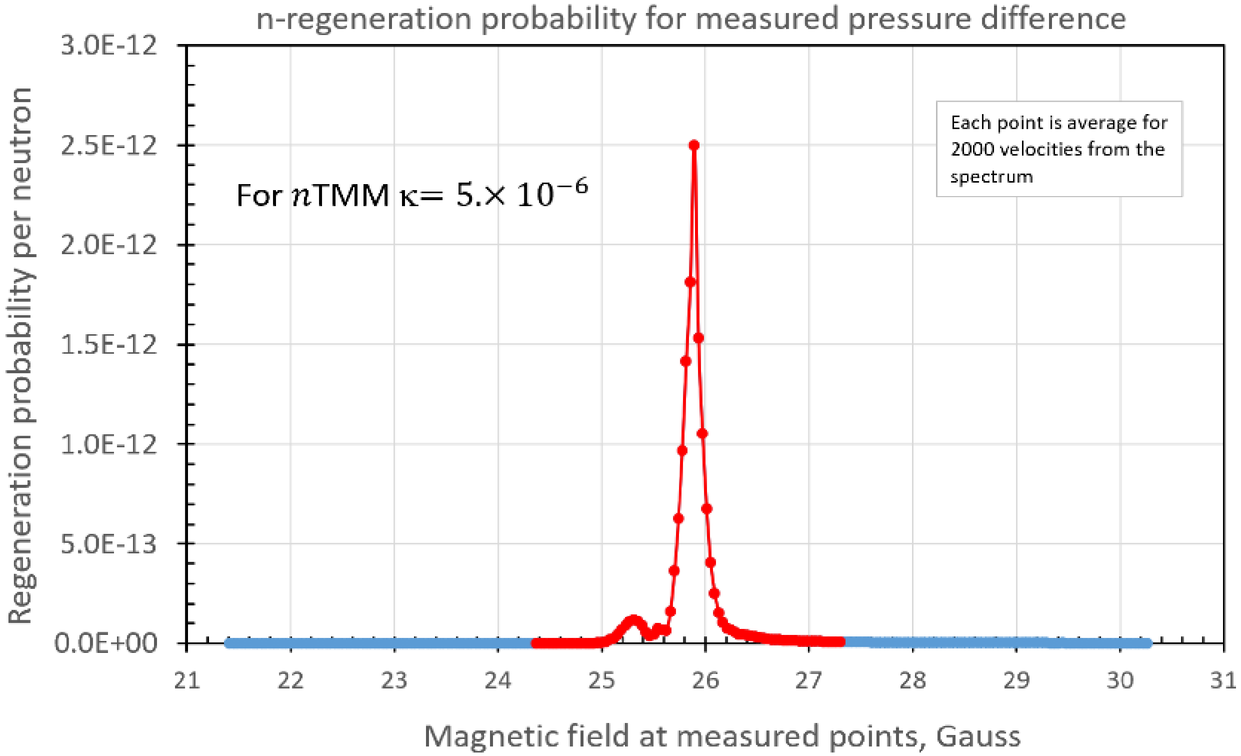


350
300
250
200
150
100
Filtered ROI counts per run
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5
Mag. field, Gauss

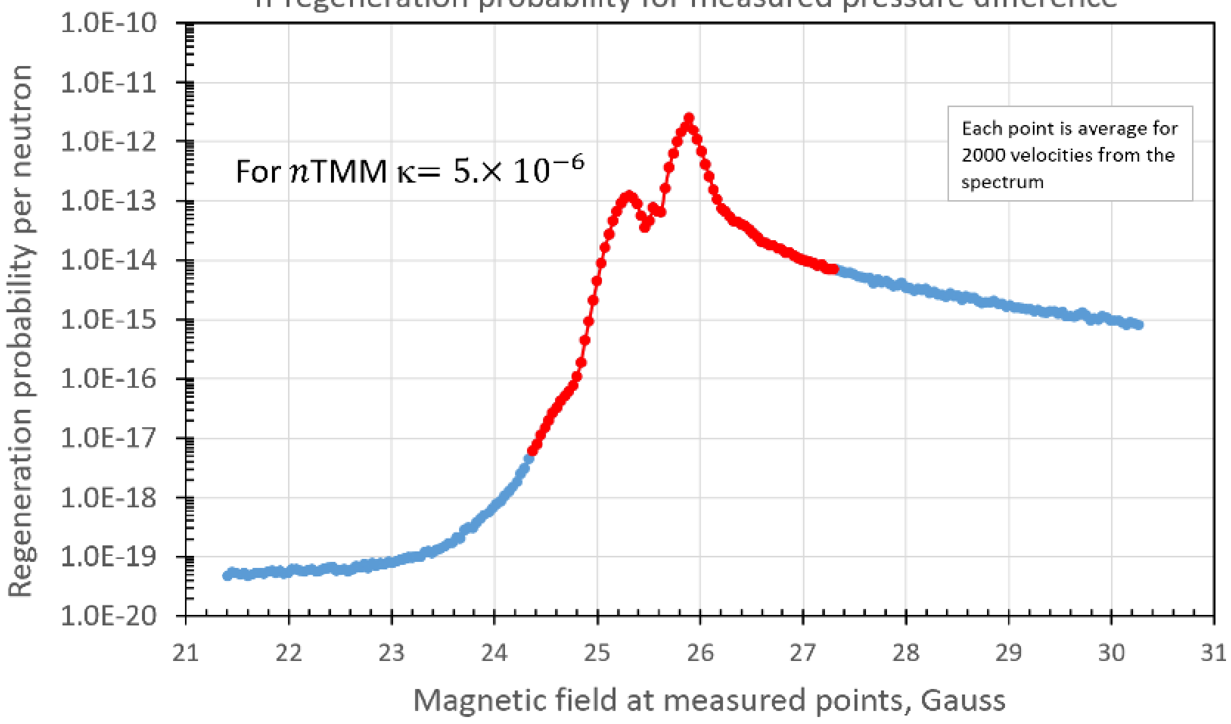

20 min runs
Filtered ROI counts per run
Mag. field, Gauss
250
230
210
190
170
150
130
110
90
70
50
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5

Effect of nTMM regeneration $f(B)$ for two different pressures in magnets

Lin scale



Log scale

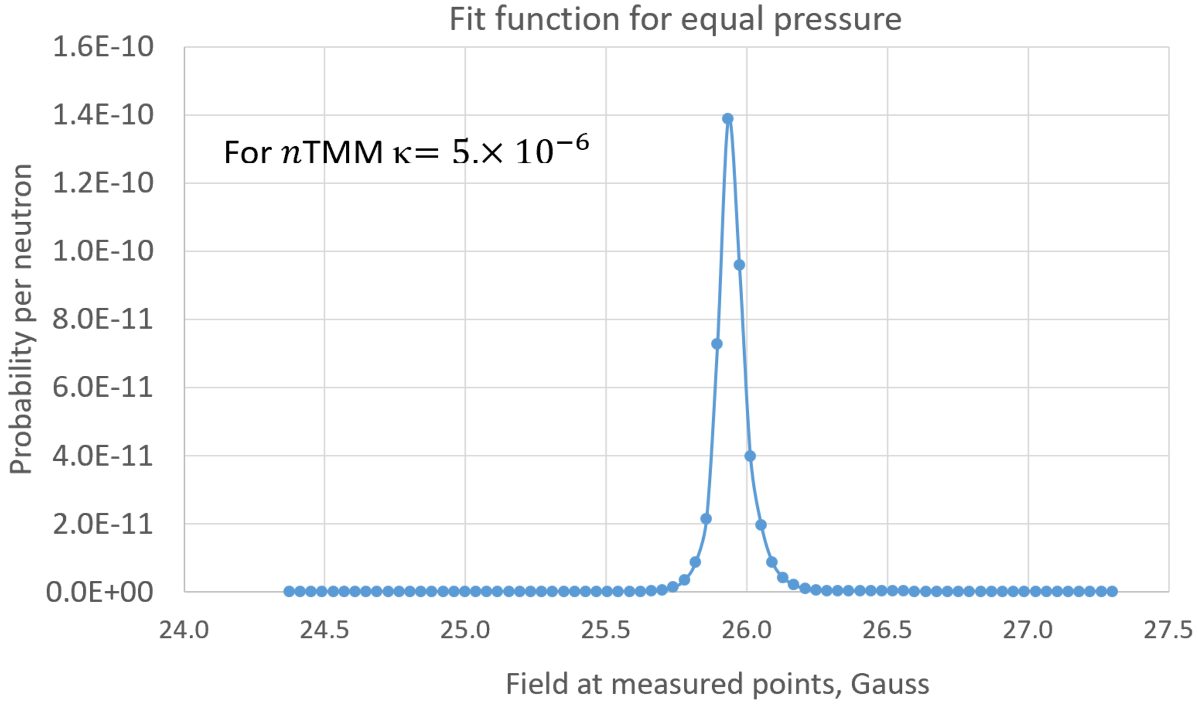


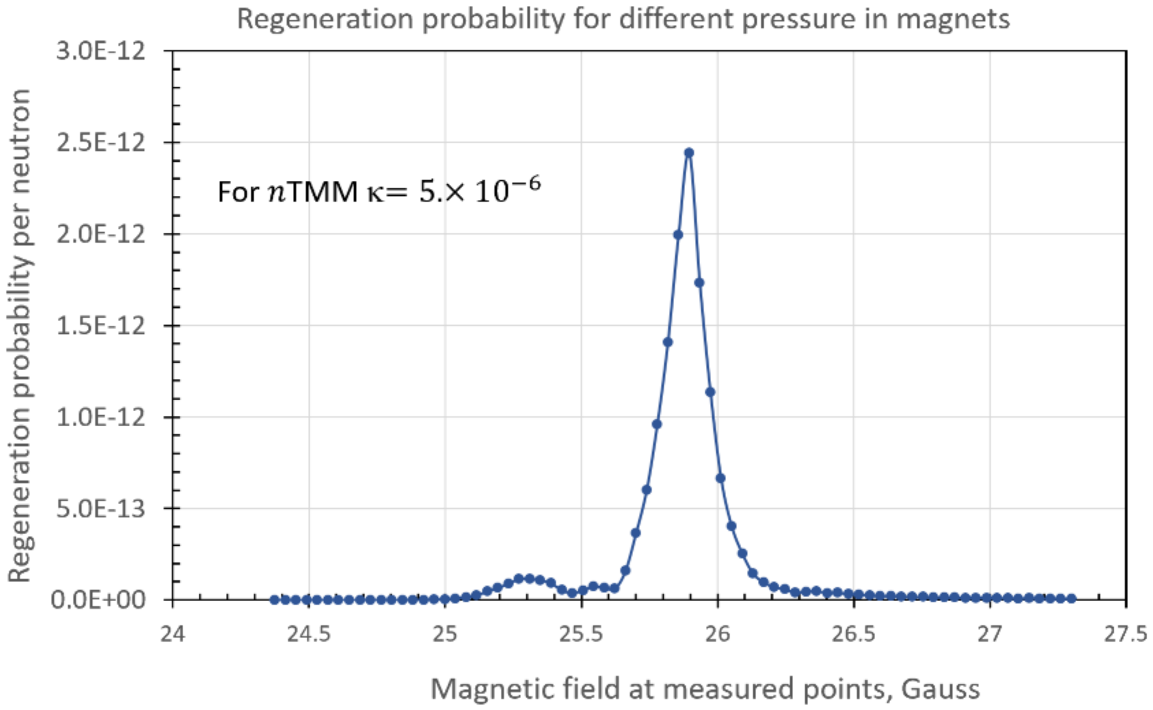
Fit function at every point i: $b_i + a_i \cdot 10^{14} \cdot f(B_i - B_n)$, fit for points $n = 1 - 76$

Peak value is regeneration probability 2.5×10^{-12} for $\kappa = 5 \times 10^{-6}$

Effect of pressure difference

Just to fit, retry fit with this function

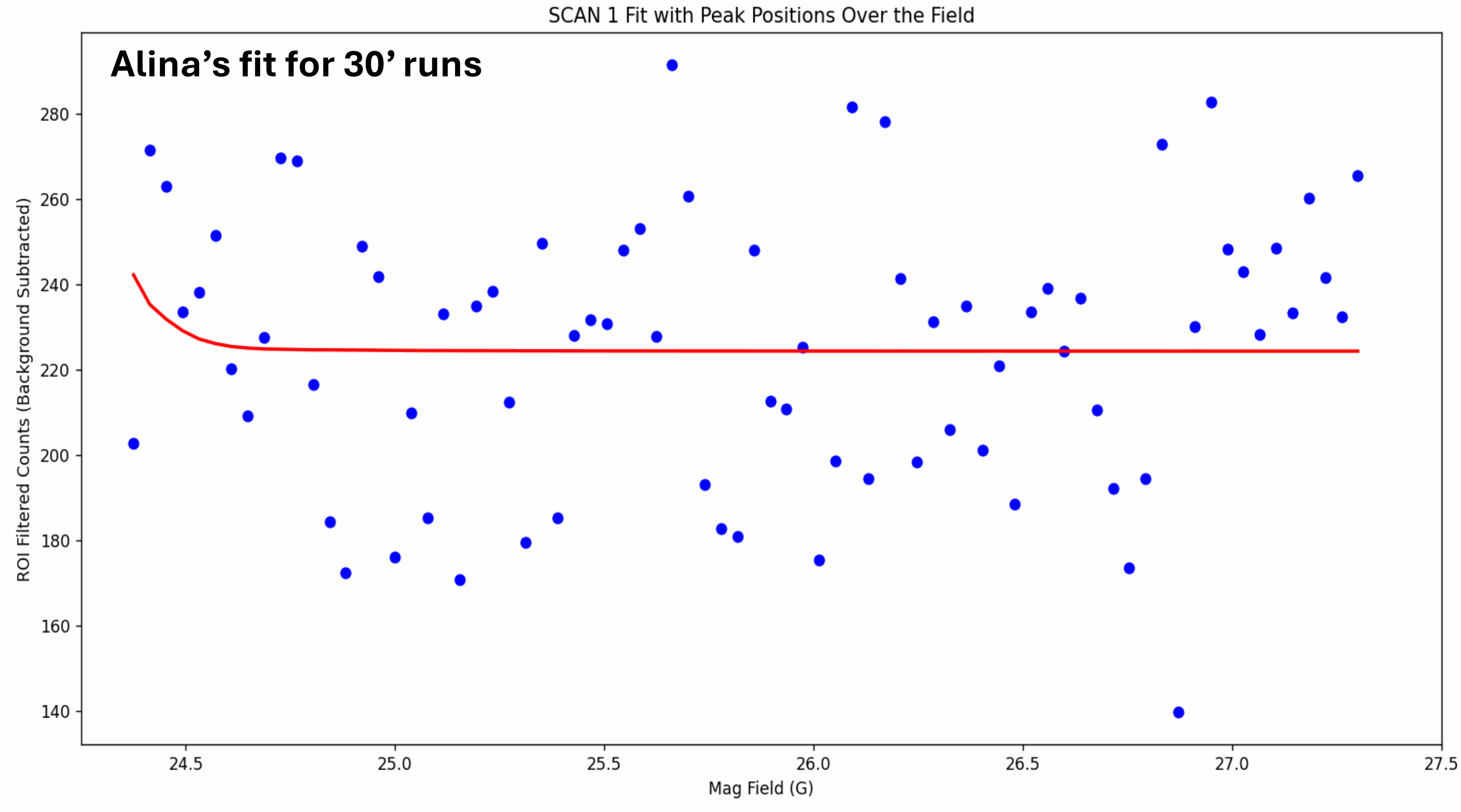




Peak 1.39×10^{-10}

Peak 2.5×10^{-12}

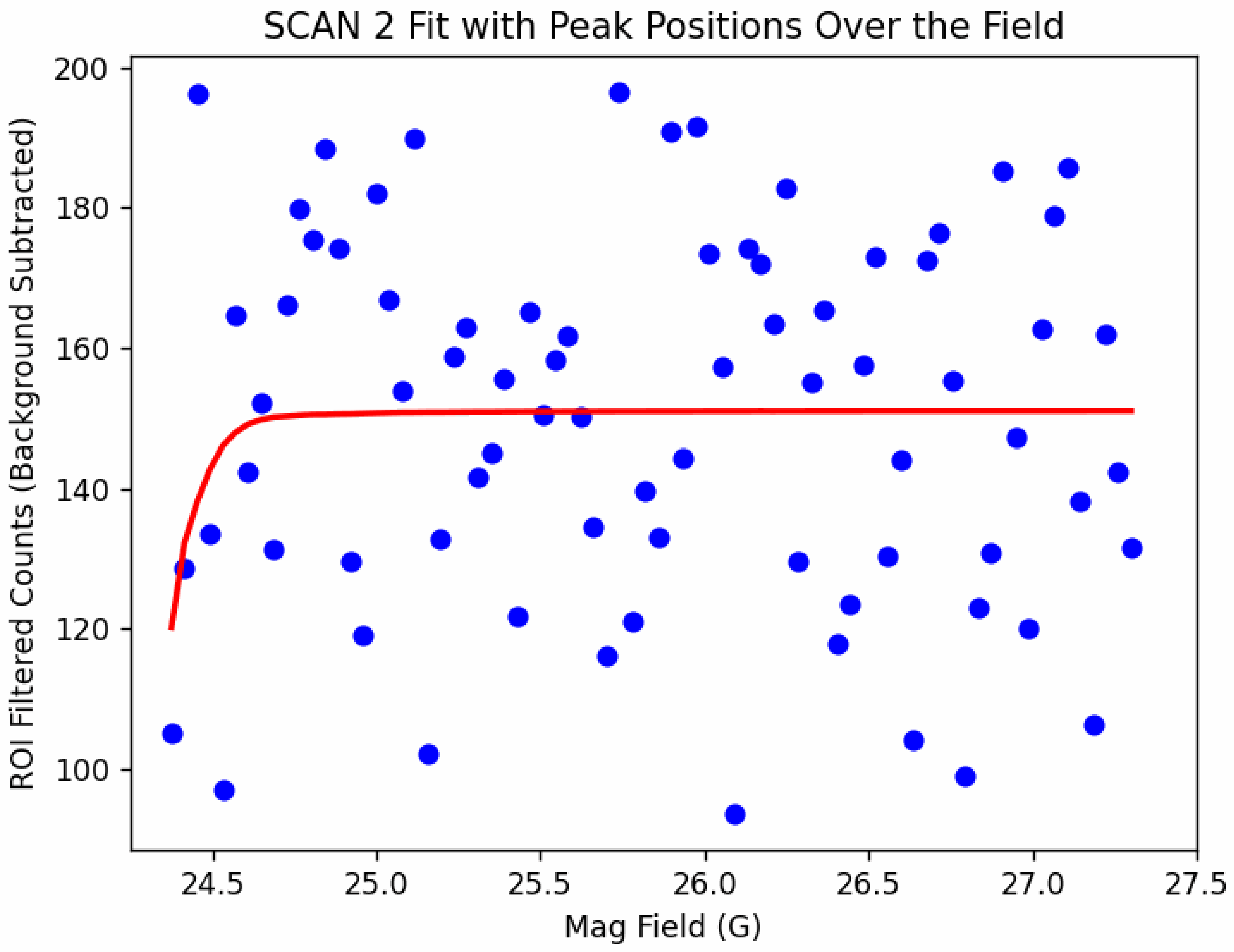
Reduction by 56x

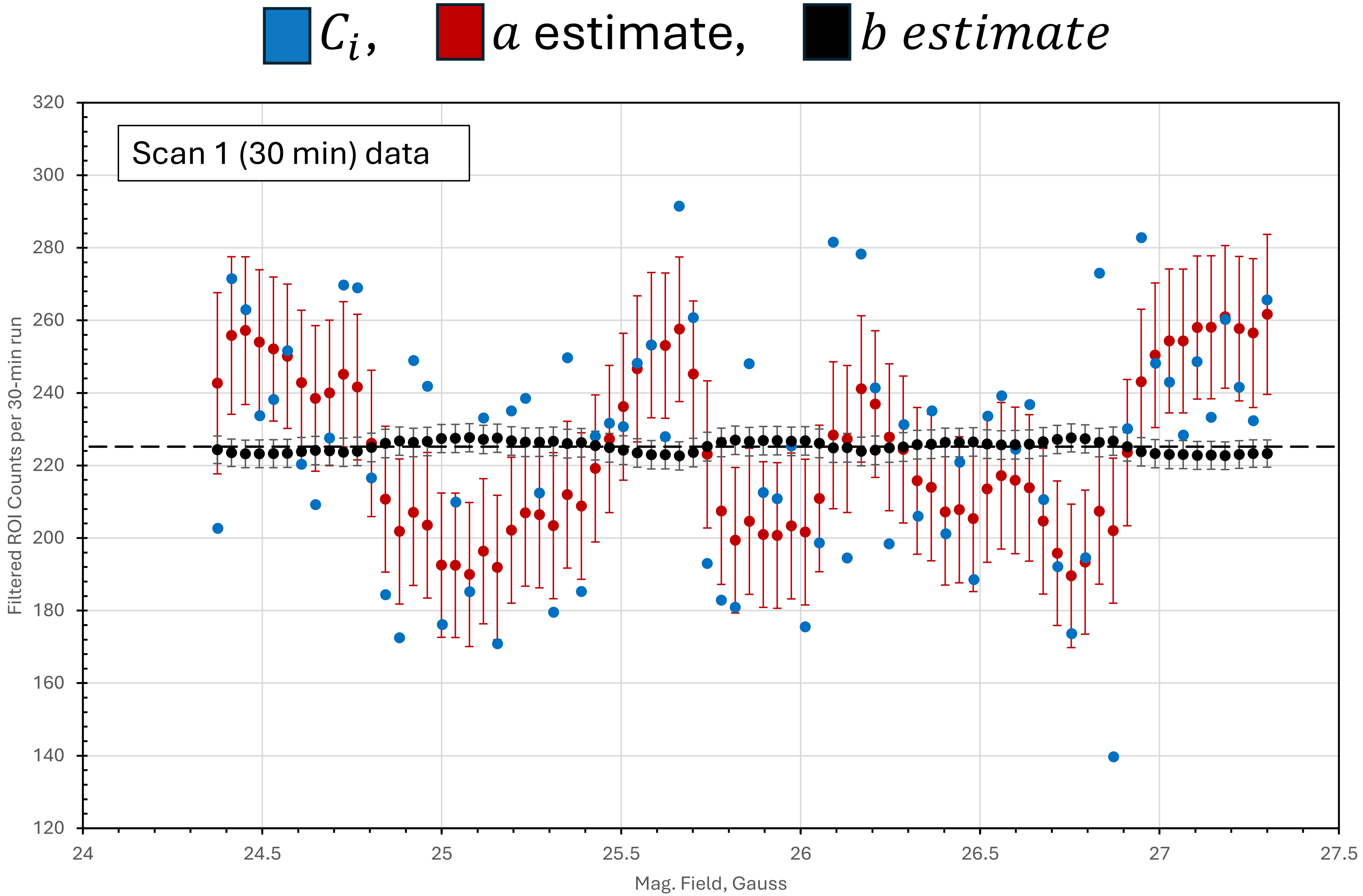


Fit function : $F(B) = a \cdot f(B^* - B) \cdot 10^{14} + b$

$\langle a \rangle \pm \langle \delta a \rangle = 0.0827 \pm 0.0827$; $\langle b \rangle \pm \langle \delta b \rangle = 225.185 \pm 3.909$

Alina’s fit for 20’ runs



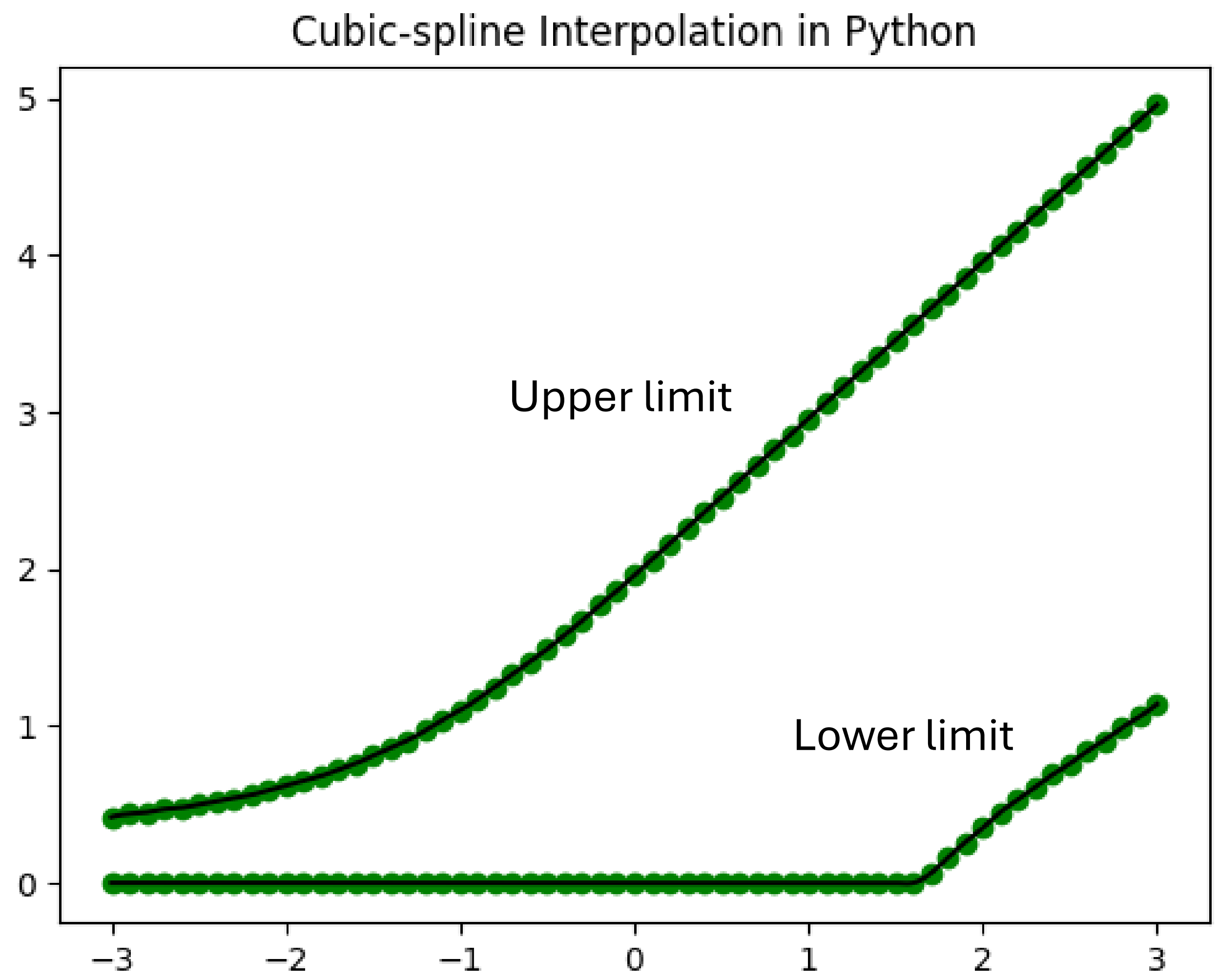


Scale for parameter a here?

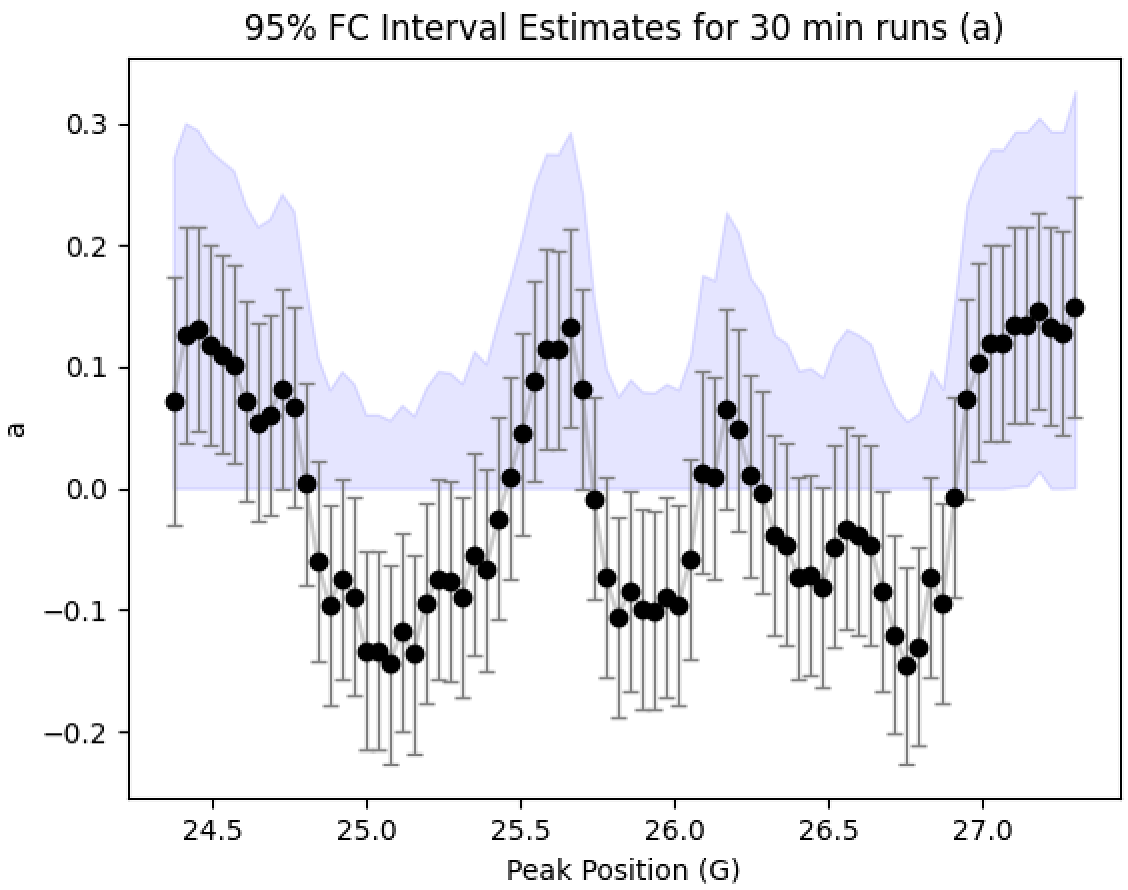
Applying F-C limits

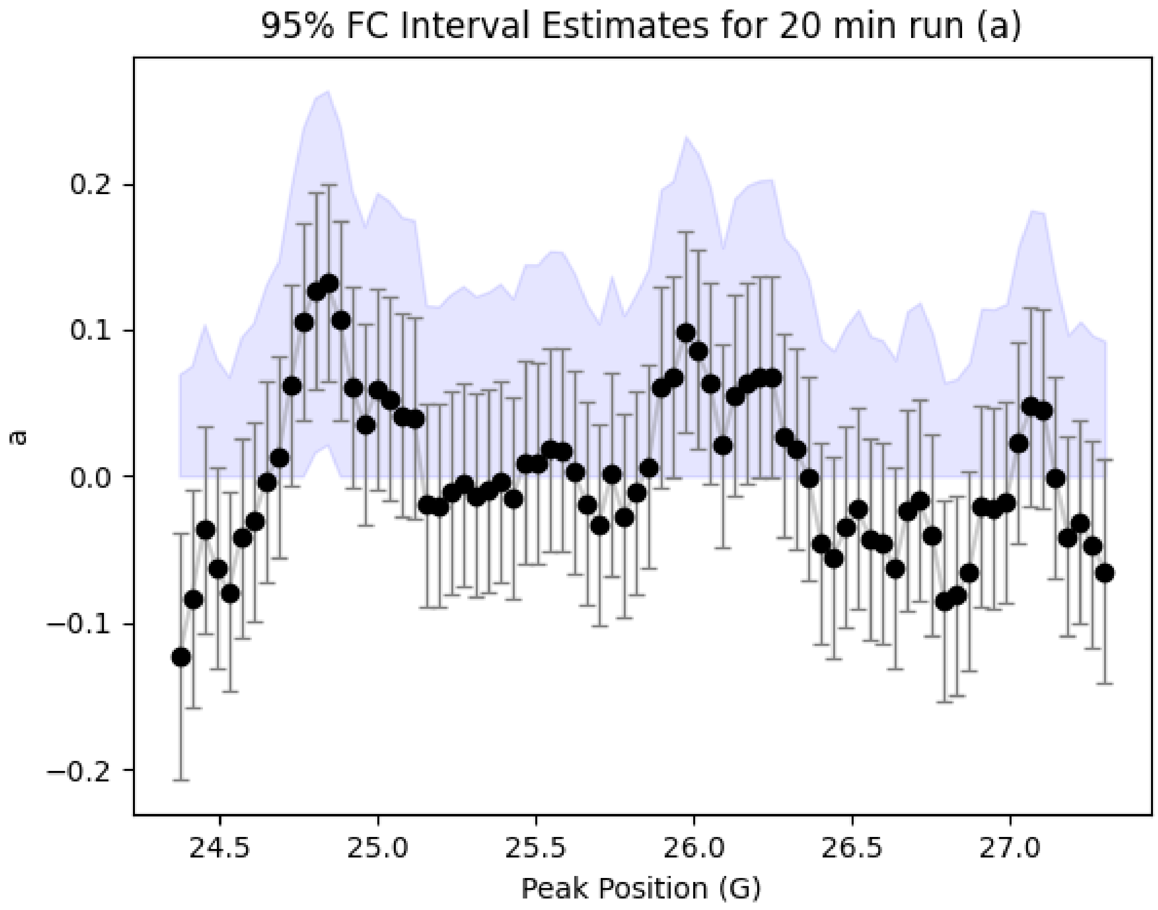
Scipy cubic spline used to interpolate between the points given in the paper's table X for 95% confidence level for in-program application

Green points are the listed ones in the table



96% CL intervals in terms of *a* parameter (with errors of *a*)





Anticipated next steps

1. "Calibration" of parameter a in terms of nTMM κ $(a \propto \kappa^4)$
2. Extraction of a from the large statistics sample of background b

Result of regeneration limit from B=0 33 runs in 2024 for PRD paper

Area selection parameters for background subtraction

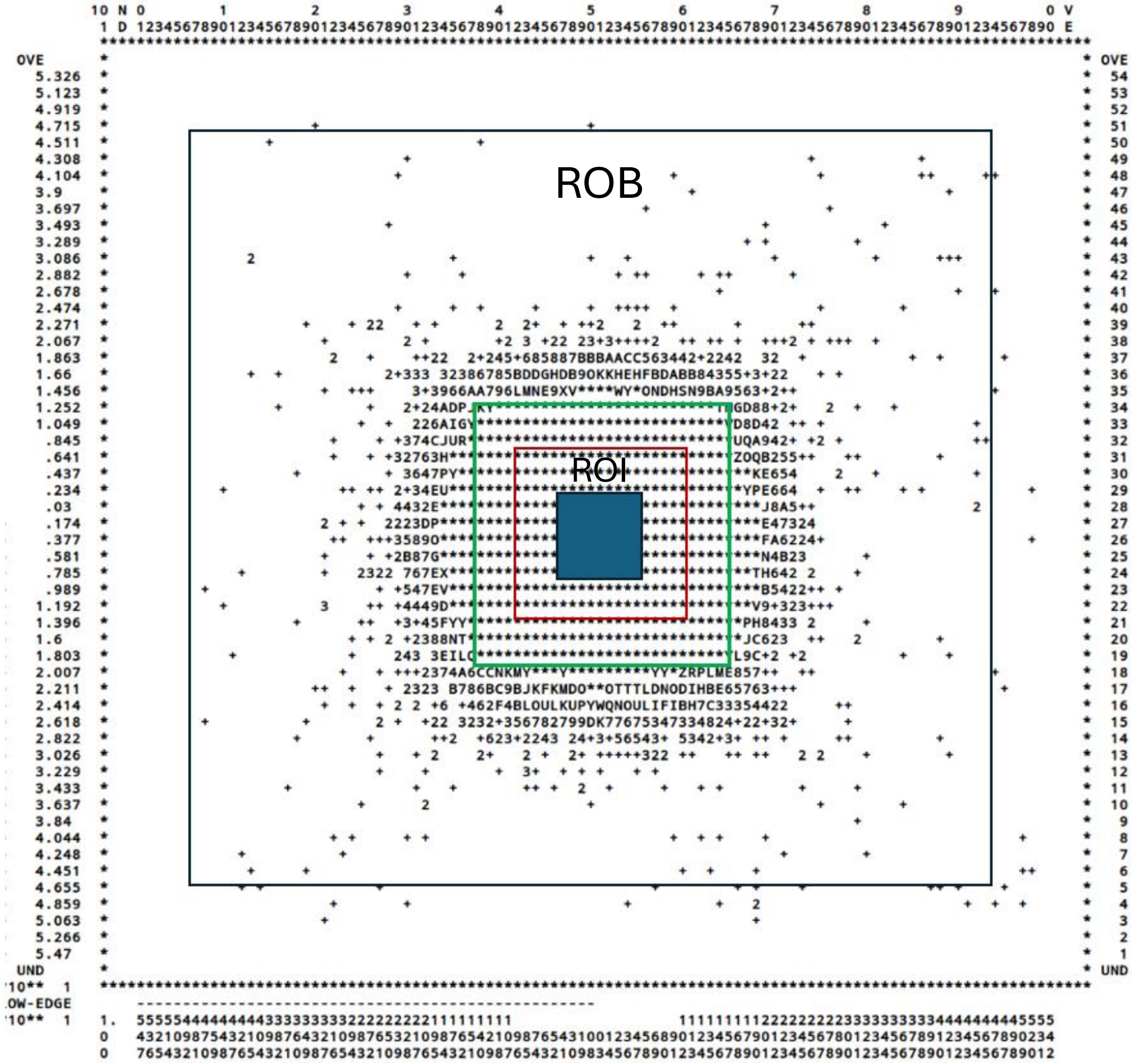
Fast peak position from 1-h runs X: -4.5 to + 5.5 cm
Y: -6.35 to +3.65 cm
Area: 100 cm^2

Global Detector Size X: -48 to + 48 cm
Y: -46 to + 46 cm
Area: 8832 cm^2

Standard ROI X: -10 to + 10 cm
Y: -12 to + 8 cm
Area: 400 cm^2

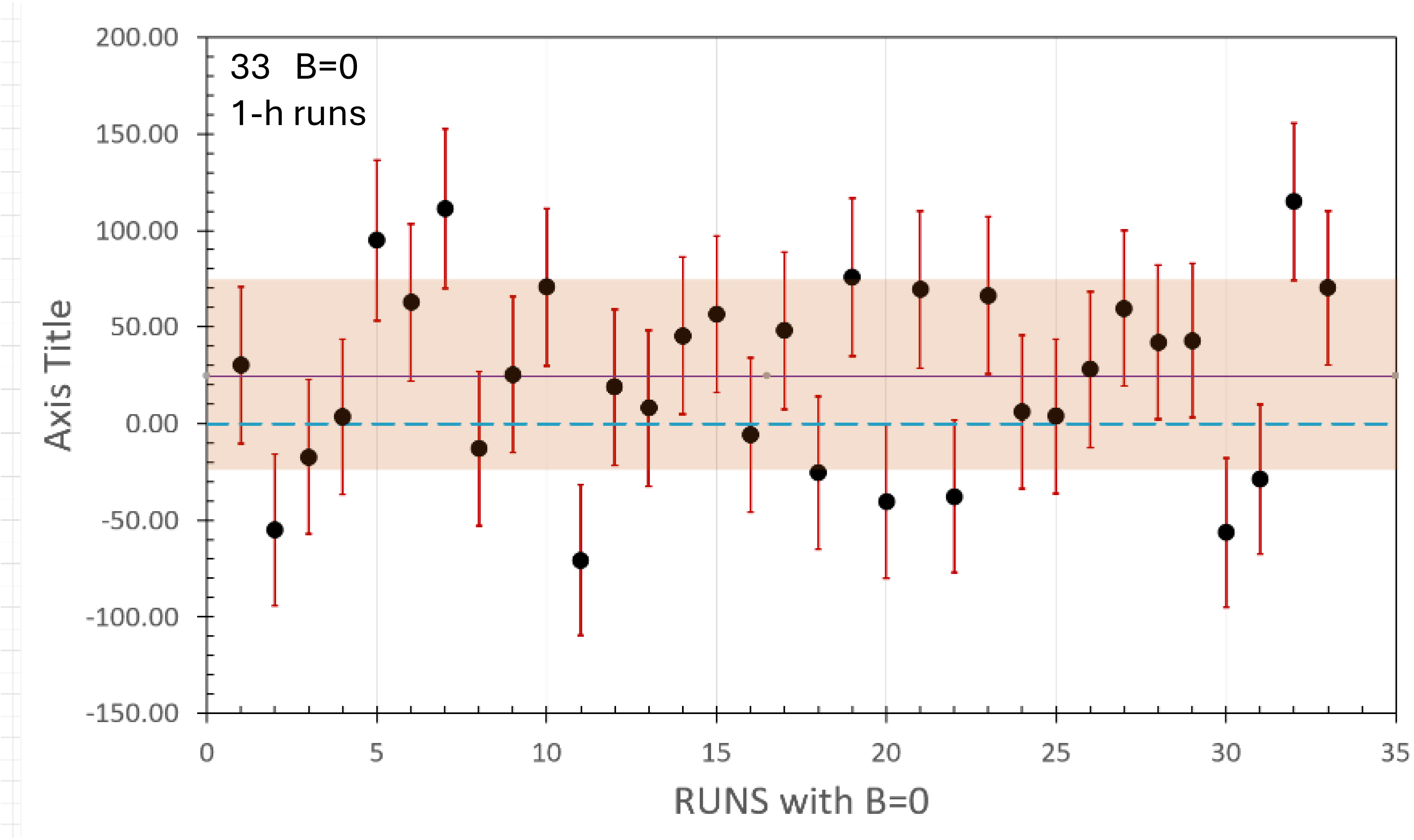
Exclusion box parameters: X: -15 to + 15 cm
Y: -18 to + 12 cm
Area: 900 cm^2

Beam footprint in the detector
from 31 sec attenuated run 89847



ROI 20x20 cm^2 result with area-scaled background subtraction

Statistical values: Mean = 23.0 ± 7.0 ; Systematic values: Mean=24.4 ±49.2 (pink area)



Detector counts normalization in 2024:

In calculation of effect with Field B – Field 0

- Beam intensity on Cd $(6.10 \pm 0.24) \times 10^8\ s^{-1}$
- Only one polarization 1/2
- Si transmission $91 \pm 2\%$
- Detector efficiency $96 \pm 1\%$
- ROI cut efficiency 87.9%
- Time 1 hour 3600 s

General normalization factor:

$$(1.43 \pm 0.07) \times 10^{12}\ h^{-1}$$

In calculation of effect with B=0 – area background

- Beam intensity on Cd $(6.10 \pm 0.24) \times 10^8\ s^{-1}$
- ~~Only one polarization 1/2~~
- Si transmission $91 \pm 2\%$
- Detector efficiency $96 \pm 1\%$
- ROI cut efficiency 52.43%
- Time 1 hour 3600 s

General normalization factor:

$$(4.79 \pm 0.23) \times 10^{12}\ h^{-1}$$

Calculation of the effect from 33 runs with B=0

Effect determined by systematics: $24.4 \pm 49.2\ h^{-1}$

Normalization factor: $(4.79 \pm 0.23) \times 10^{12}\, h^{-1}$

Effect per neutron: $(5.1 \pm 10.3) \times 10^{-12}$

F-C 95% CL limit: $<1.25 \times 10^{-11}$

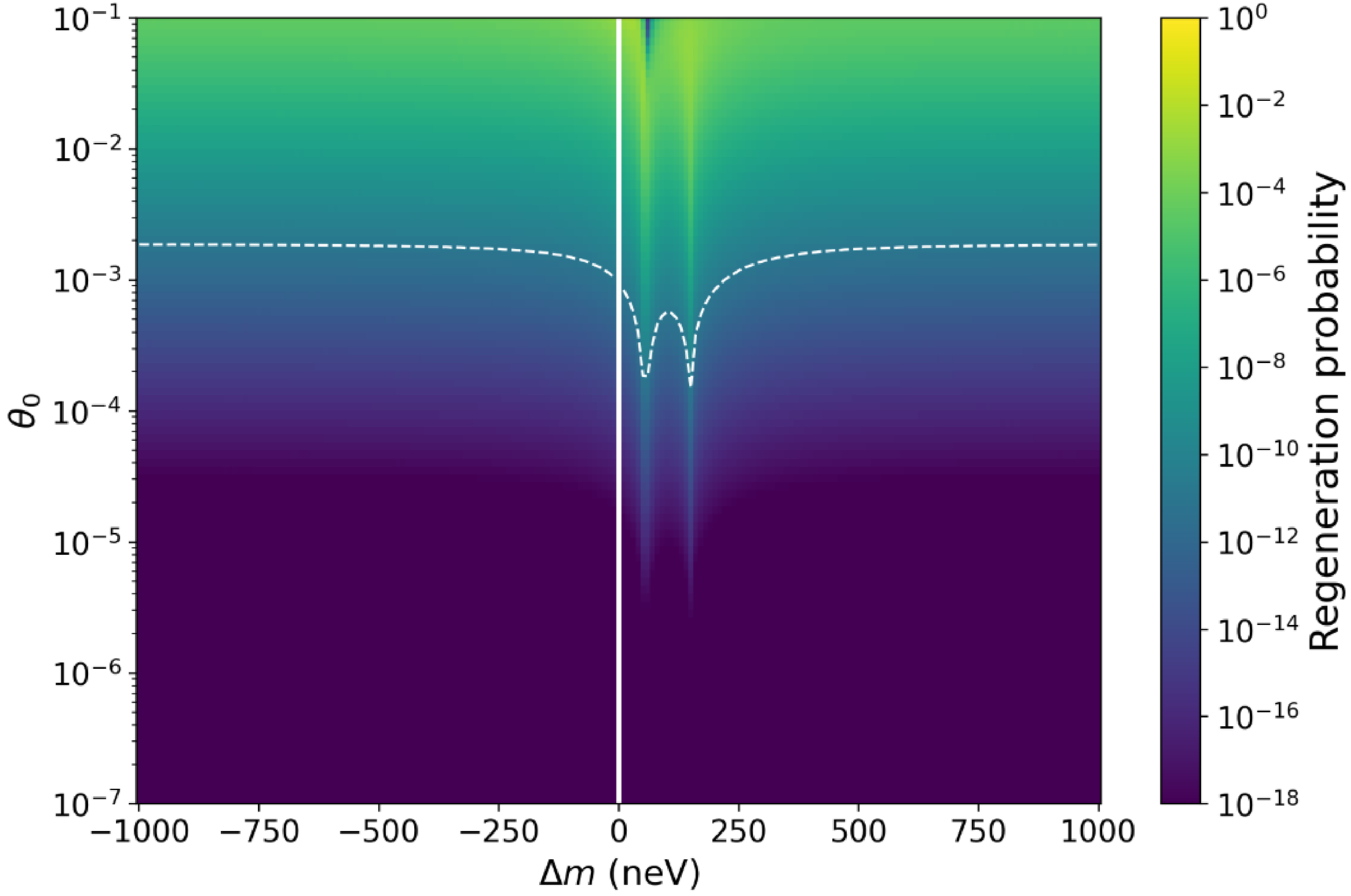
Compare with:

B-Field (T)	Counts, h^{-1}	Signal ($\times 10^{-12}$)	95% CL
2.40	-9 ± 21	-6.34 ± 14.7	2.28×10^{-11}
3.60	13 ± 20	9.1 ± 14.0	3.65×10^{-11}
4.80	-3 ± 20	-2.1 ± 14.0	2.55×10^{-11}
All fields	0.63 ± 12	0.42 ± 8.4	1.69×10^{-11}

TABLE I. Limits on the $n \to n' \to n$ regeneration probability per neutron at 95% CL [22] with Cd absorber for different values of magnetic field settings. Data of 2024 run.

This limit can be shown as a white dash line in Linus butterfly plot for B=0

Linus butterfly plot for B=0



Is it correct plotting an envelope of 3 measurements (Paper Fig 9) or the limits can be better?

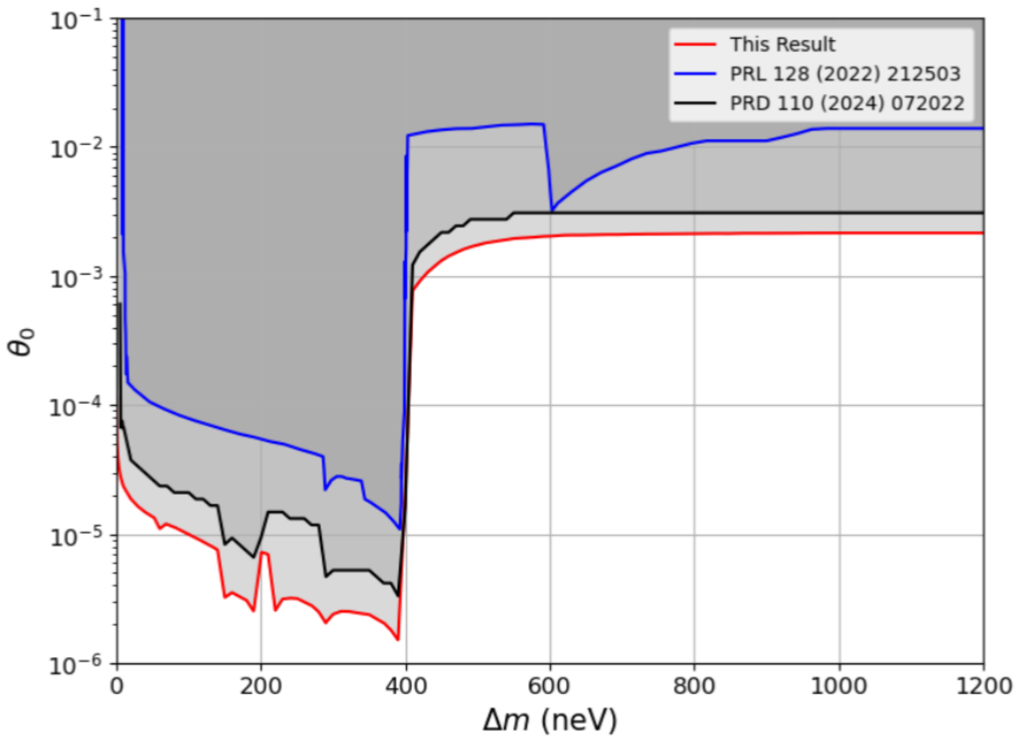


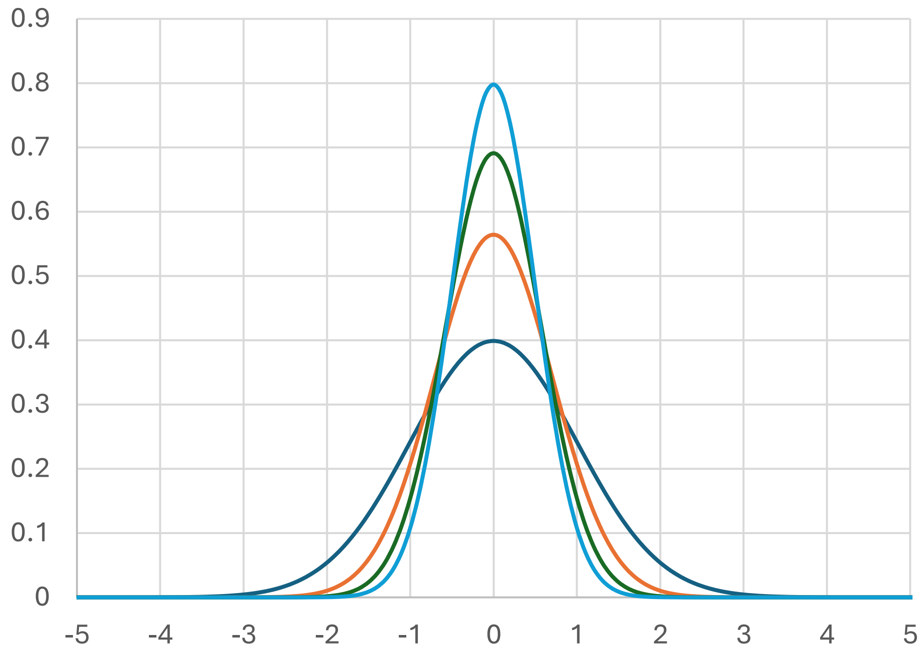
FIG. 9. Comparison of the probability limits of 2 SNS and current HFIR experiments (color online).

Simplified Gaussian Example

- multiple measurements with $\mu = 0$ and $\sigma = 1$.
- each measurement measure 0 with error σ represented by pdf
- the goal is improving accuracy of measurement of zero.
- will combine similar measurements by multiplying pdfs
- and renormalizing them since we need one improved number
- If we interested in the HIGH , say 97.5%, CL limit (area 2.5%)

  it is improving with number of measurements as

$$97.5\%\ CL = \frac{2.08}{\#}$$



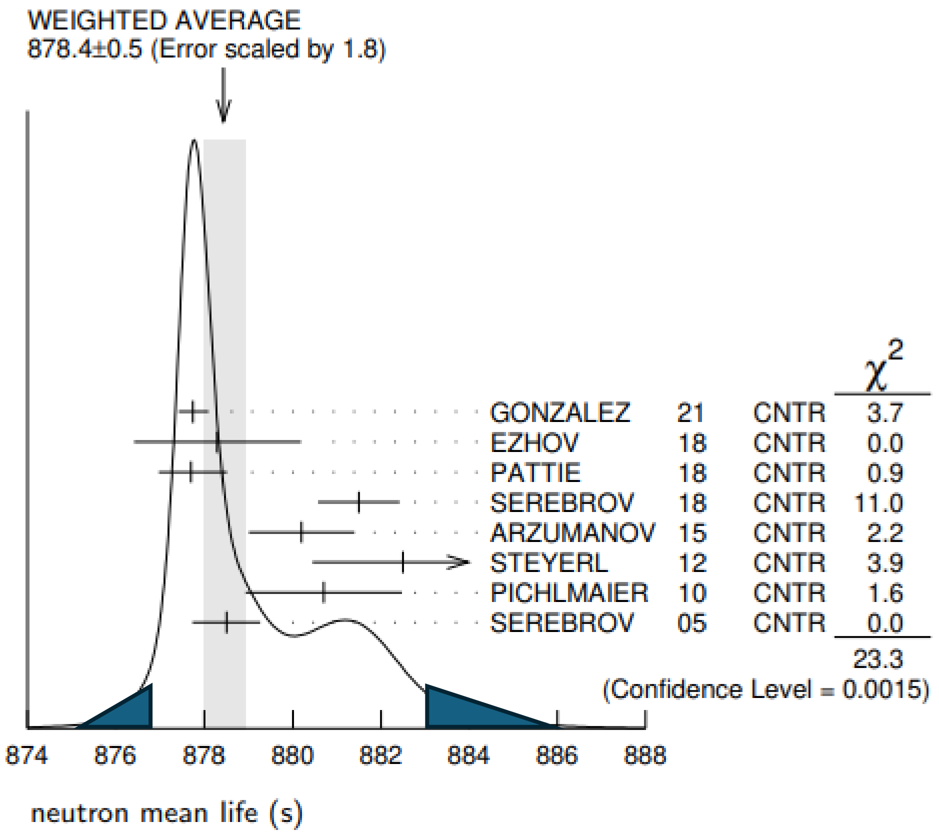
In case of multiple measurements with different μ and different σ the Gaussian normalized pdf functions are multiplied as for independent measurements.

The function $PDF(x) = \prod_i pdf_i(x, \mu_i, \sigma_i)$

is not a normalized function. If normalized, it can be used for calculation of confidence interval for the value being measured.

We can do the same for our four independent $n \to n' \to n$ probability limits (4.8, 3.6, 2.4 T, 0.0), where ***x value* of pdf** should be **angle $\boldsymbol{\theta_0}$** at any fixed value of Δm provided by the "butterfly matrix".

We need to construct that the pdf(θ_0) as function of θ_0 at every fixed value of Δm for every measurement with different magnetic field.



BTW, NIST cold beam result (making n lifetime anomaly) is ignored in PDG plot

Is that correct that in Figure 9 we plot the envelope of the limits of 3 fields?

If three measurements were the same they RMS of average would be reduced by factor $\sqrt{3} \approx 1.7$.
Thus, the limits (tails of a distribution) should be reduced by the same scaling factor.
Several independent measurements with different $\bar{x}$ and different σ should contribute to the improvement of the combined limit in different regions of Δm.

B-Field (T)	Counts, h^{-1}	Signal ($\times 10^{-12}$)	95% CL
2.40	-9 ± 21	-6.34 ± 14.7	2.28×10^{-11}
3.60	13 ± 20	9.1 ± 14.0	3.65×10^{-11}
4.80	-3 ± 20	-2.1 ± 14.0	2.55×10^{-11}
0.0	24.4 ± 49.2	5.1 ± 10.3	1.25×10^{-11}

Gaussian $pdf\ (x)$ → One-sidesd "F-C $pdf\ (x)$" with $x > 0$. Integration of this pdf provides CL limit

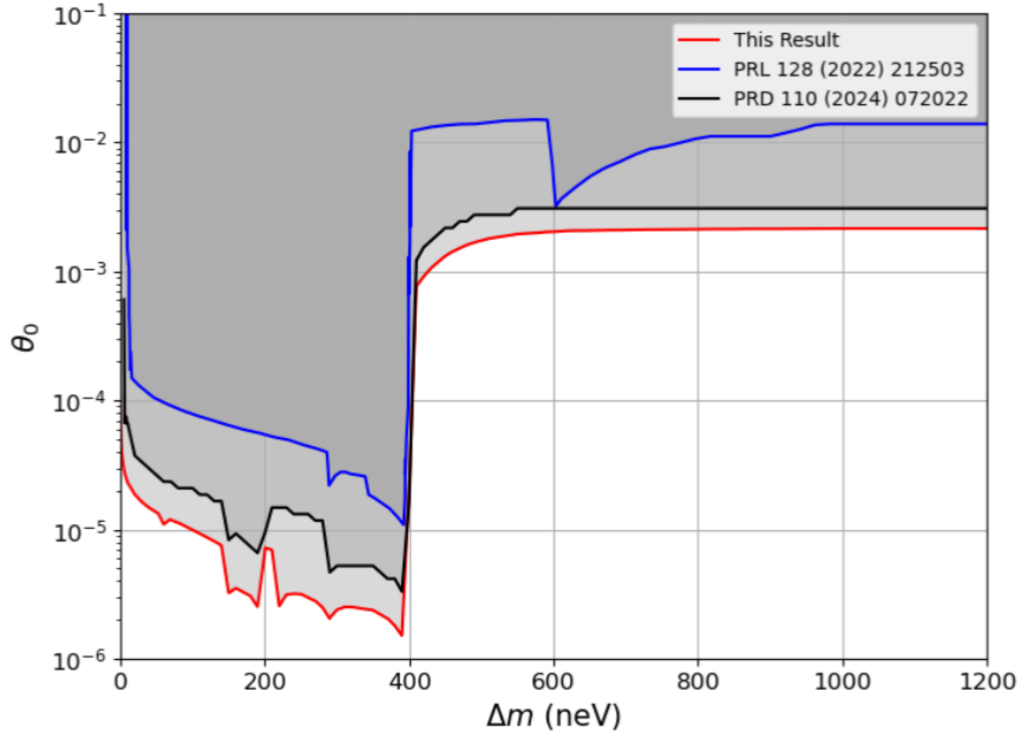


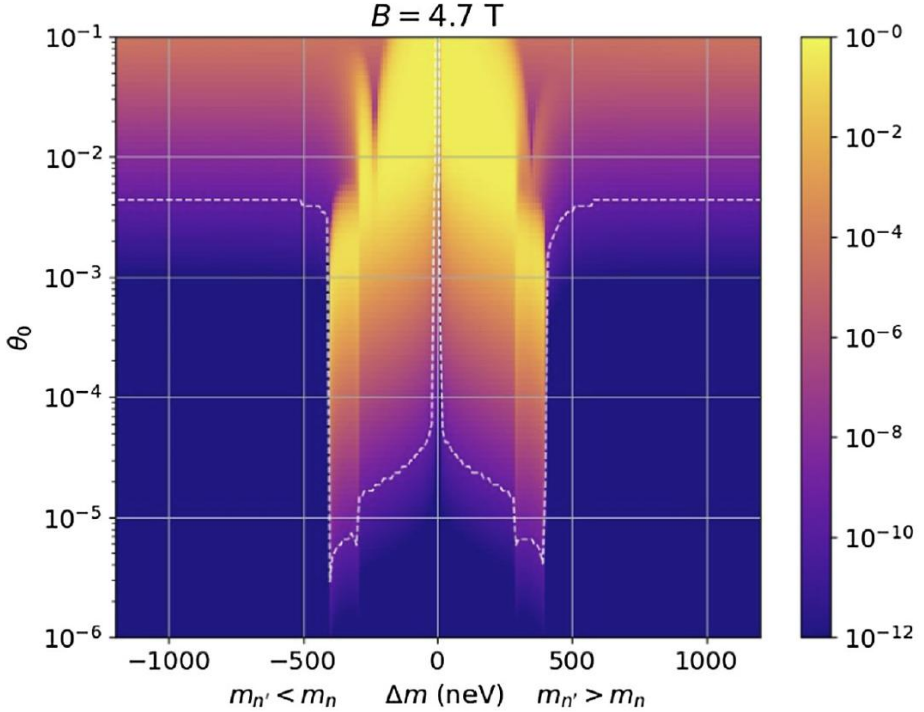
FIG. 9. Comparison of the probability limits of 2 SNS and current HFIR experiments (color online).

For every independent k-th ($k = 1,2,3,4$) measurement we have initially a 95% CL limit in terms of the **value $\boldsymbol{x}$** as an effect of regeneration probability.

B-Field (T)	Counts, h^{-1}	Signal ($\times 10^{-12}$)	95% CL
2.40	-9 ± 21	-6.34 ± 14.7	2.28×10^{-11}
3.60	13 ± 20	9.1 ± 14.0	3.65×10^{-11}
4.80	-3 ± 20	-2.1 ± 14.0	2.55×10^{-11}
0.0	24.4 ± 49.2	5.1 ± 10.3	1.25×10^{-11}

This limit is arising as Feldman-Cousins modified pdf where probability value cannot be negative. The $pdf_k(\boldsymbol{x})$ defines the limit μ_k in the Table by integration of the pdf tail.

Our butterfly plots for every Δm give the effect of regeneration probability as function of θ_0 .



$\mu_k \Rightarrow z(color) = F(\theta_0, \Delta m)$.

For every fixed Δm^* we can have

$\theta_0 = F^{-1}(x, \Delta m^*)$ where $\boldsymbol{x}$ is any possible regeneration probability

By using the F-C $pdf_k(x)$ for x, we can reconstruct

a the new $pdf_k(\theta_0)$ and normalize it.

$\theta_0 = F^{-1}(x, \Delta m^*)$

if x is distributed as F-C $pdf_k(x)$, the distribution $pdf_k(\theta_0)$ (k=1-4) can be calculated for any Δm^*

Let's try to understand that with one fixed value of Δm

$e.g.\ \Delta m = 150$

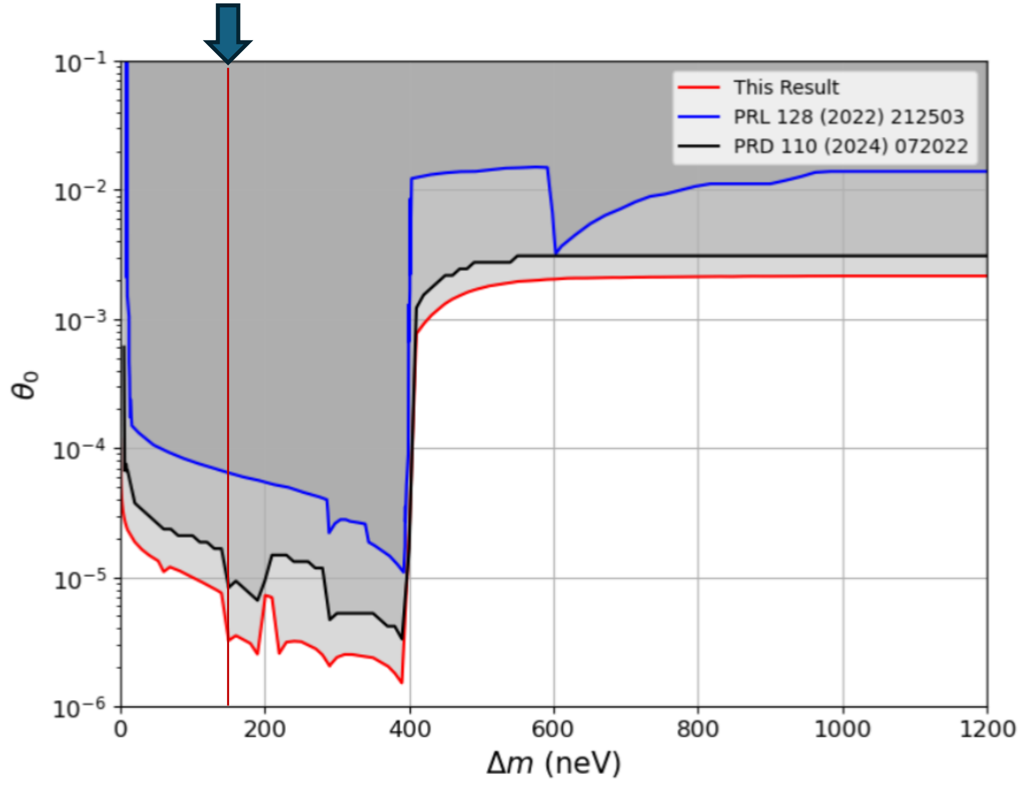
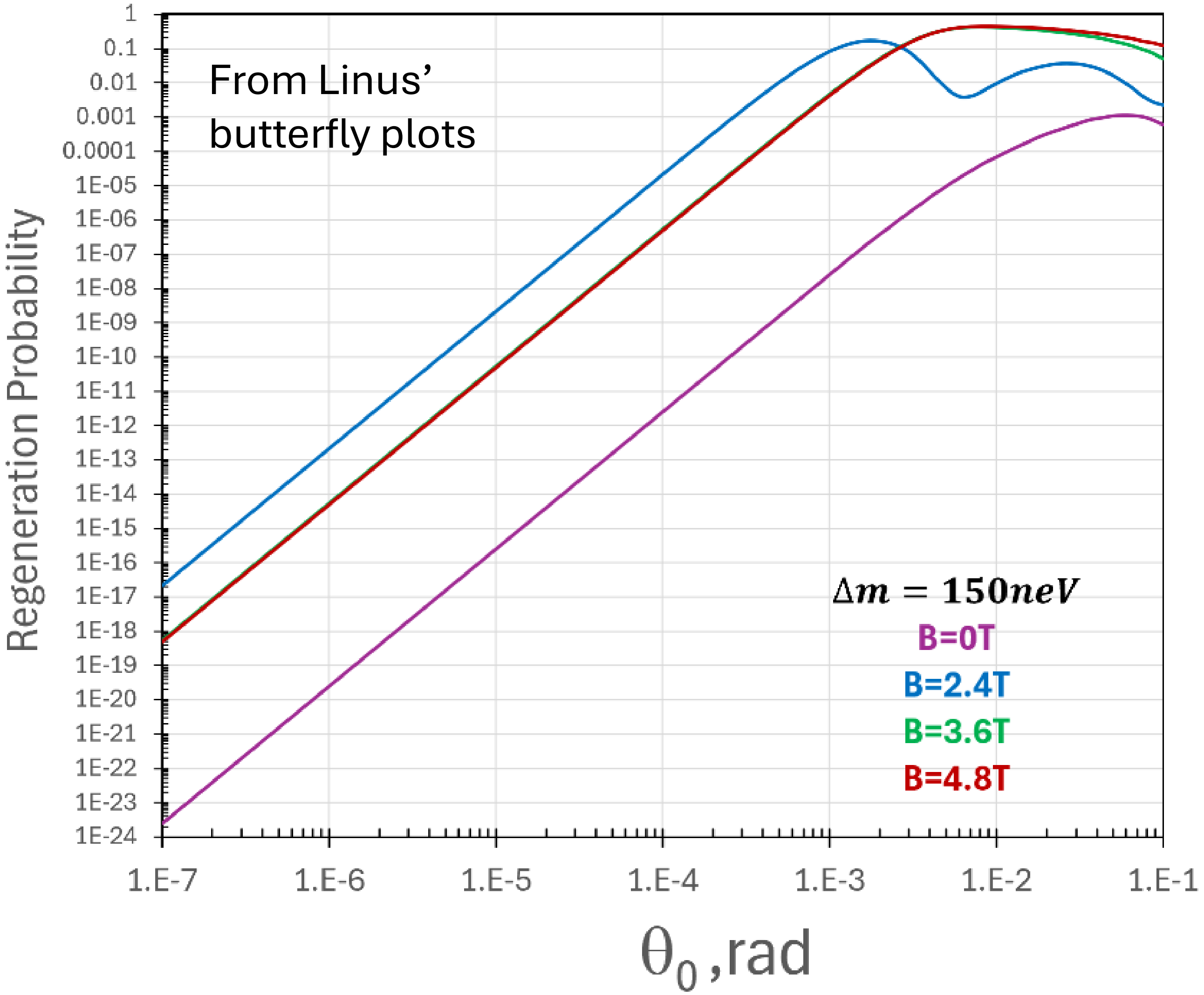


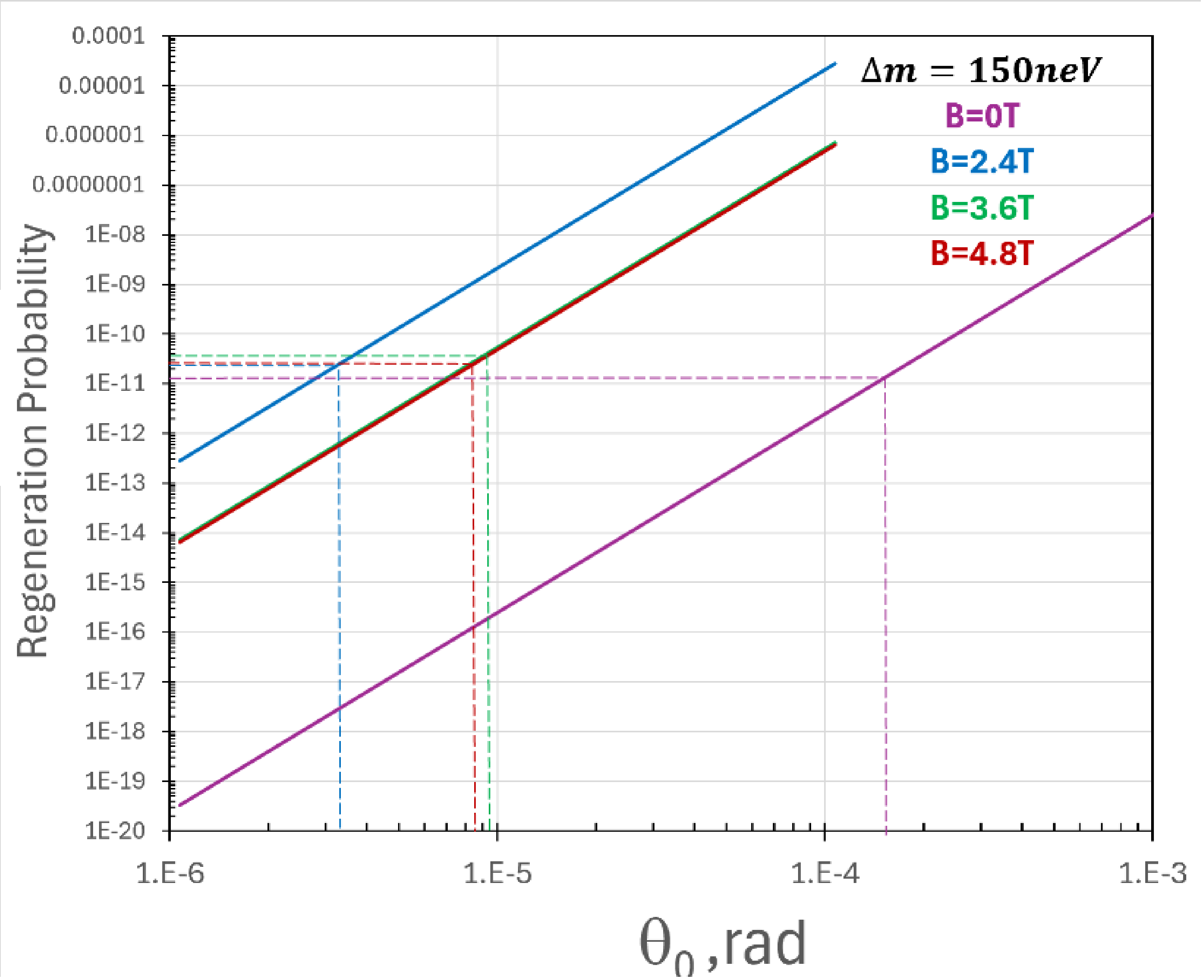
FIG. 9. Comparison of the probability limits of 2 SNS and current HFIR experiments (color online).



Applying 95% CL F-C limits

Reflection of Probability on θ_0

B-Field (T)	Counts, h^{-1}	Signal ($\times 10^{-12}$)	95% CL
2.40	-9 ± 21	-6.34 ± 14.7	2.28×10^{-11}
3.60	13 ± 20	9.1 ± 14.0	3.65×10^{-11}
4.80	-3 ± 20	-2.1 ± 14.0	2.55×10^{-11}
0.0	24.4$\pm$49.2	5.1 ± 10.3	1.25×10^{-11}



In this process we will have four normalized $pdf_k(\theta_0)$ for $k = 1,2,3,4$ for different fields that can be multiplied and normalized at every Δm. It will be one-sided PDF for only possible positive $|\theta_0|$ values.

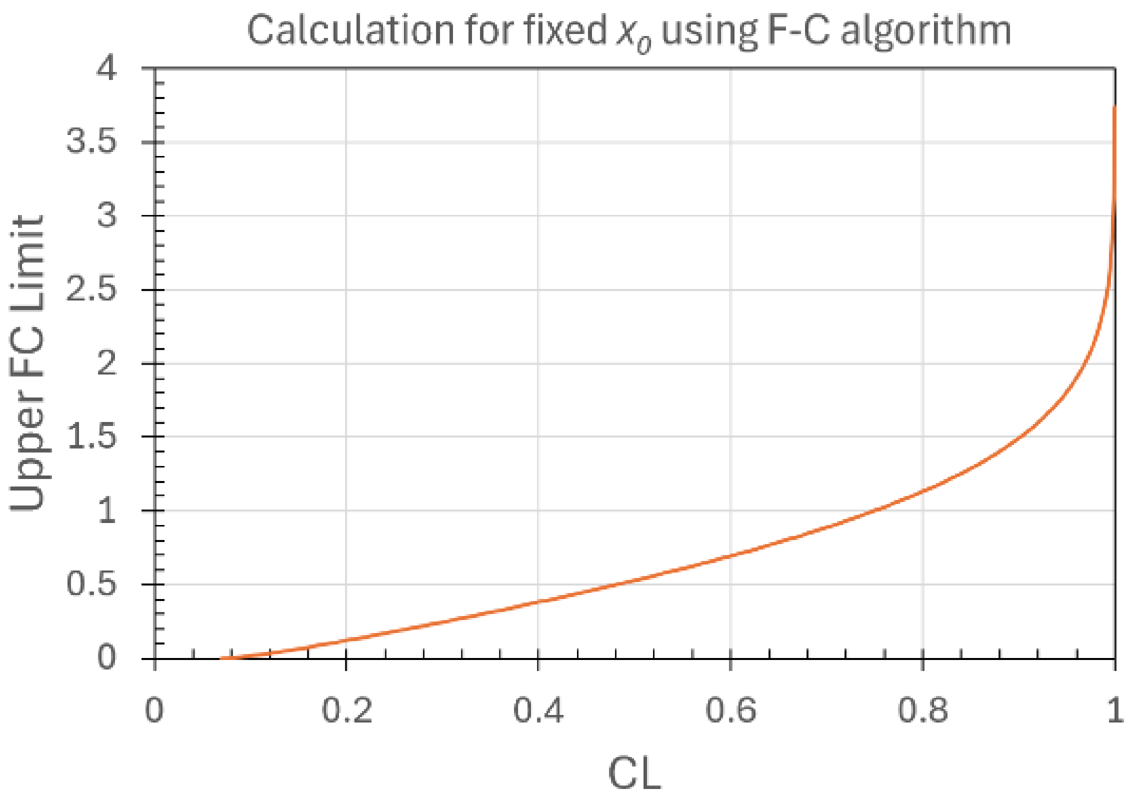
After that the high-end tail of the product distribution $PDF(\theta_0) = \prod_k pdf_k(\theta_0, \Delta m^*)$ can be integrated to 5% (corresponding to 95% CL).

Technical nuisance here is a reconstruction of four F-C differential $pdf(x)$ for measured regeneration probabilities (C-F Table 10 & formulas & algorithms provide for given CL the upper limit x.

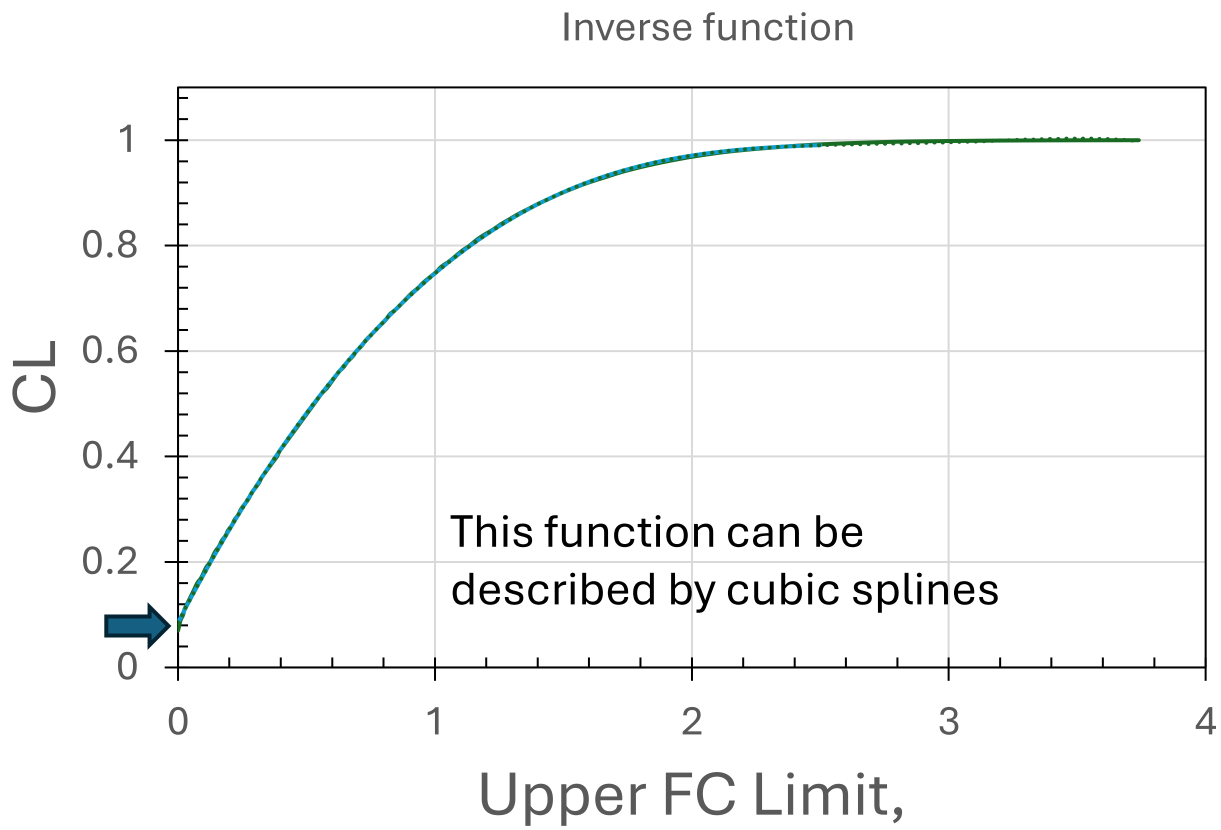
Calculating for given measured x_0 all CL values from 0 to 1 is providing the cumulative (integrated) distribution of $pdf_k(x)$. This cumulative distribution can be numerically differentiated and normalized to get $pdf_k(x)$. These calculations are in units of corresponding σ_K.

Example of calculation for B=4.8 T limit

B-Field (T)	Counts, h^{-1}	Signal ($\times 10^{-12}$)	95% CL
2.40	-9 ± 21	-6.34 ± 14.7	2.28×10^{-11}
3.60	13 ± 20	9.1 ± 14.0	3.65×10^{-11}
4.80	-3 ± 20	-2.1 ± 14.0	2.55×10^{-11}
0.0	24.4 ± 49.2	5.1 ± 10.3	1.25×10^{-11}



Calculated at 103 points from 0.01 to 0.9999

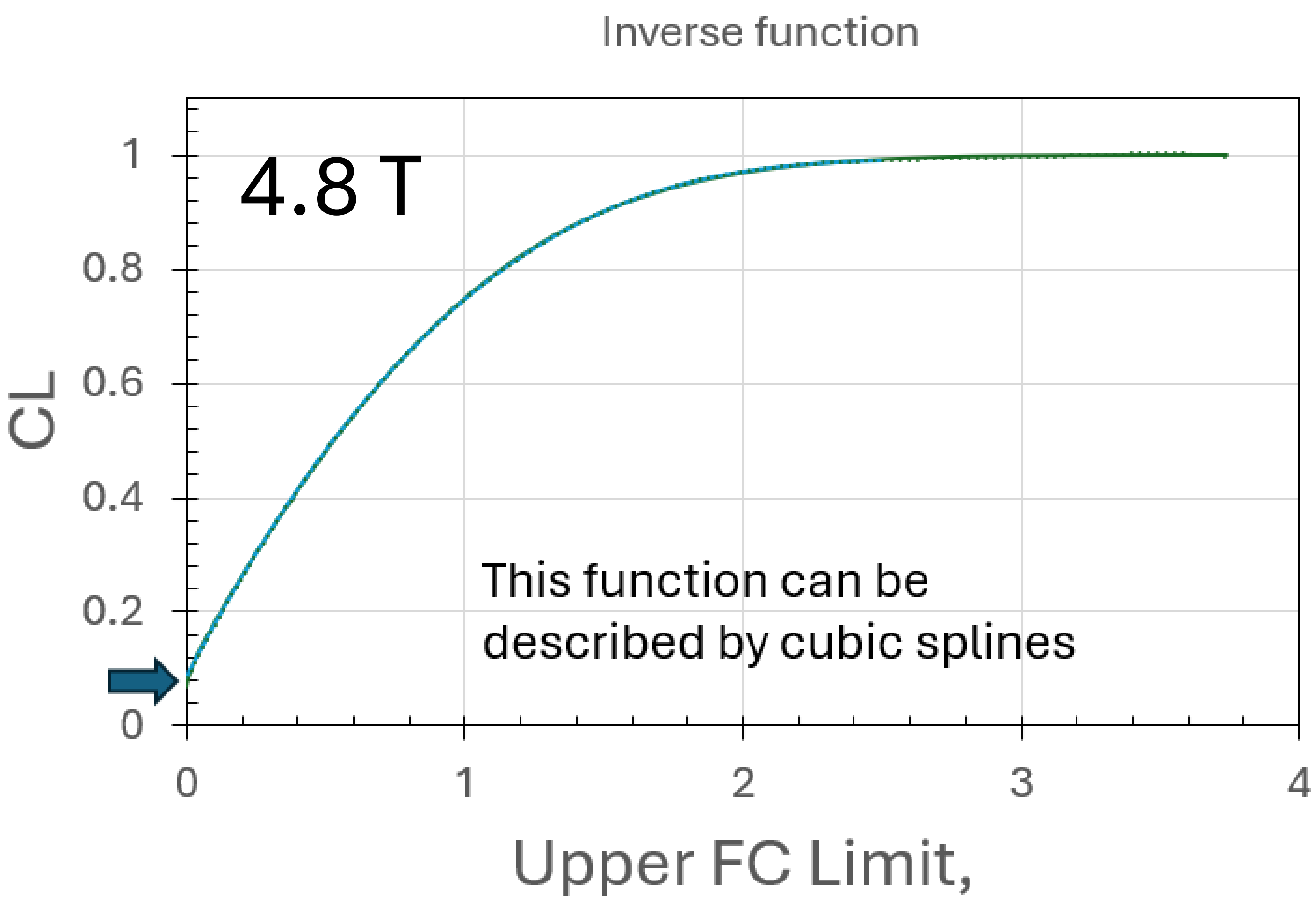


Here is a problem (it is present for all fields)

- CL covers the range from 0.1 to 1.0
- If differentiated the integral will be < 1
- If renormalize it then tail integration will not reproduce the reference values of F-C limits

- at this point the idea of the limit's improvement doesn't yet work. More study will be needed.

- One reason might be that F-C calculation soft that I am using correctly reproduce all upper level limits in F-C paper Table X, but it does correctly reproduce lower limits (which I am not using)



I propose to stay with the overlay envelope method for paper submission and study possible limits improvements in the future.