DOSE CALIBRATION OF THE ISS-RAD FAST NEUTRON DETECTOR (FND)

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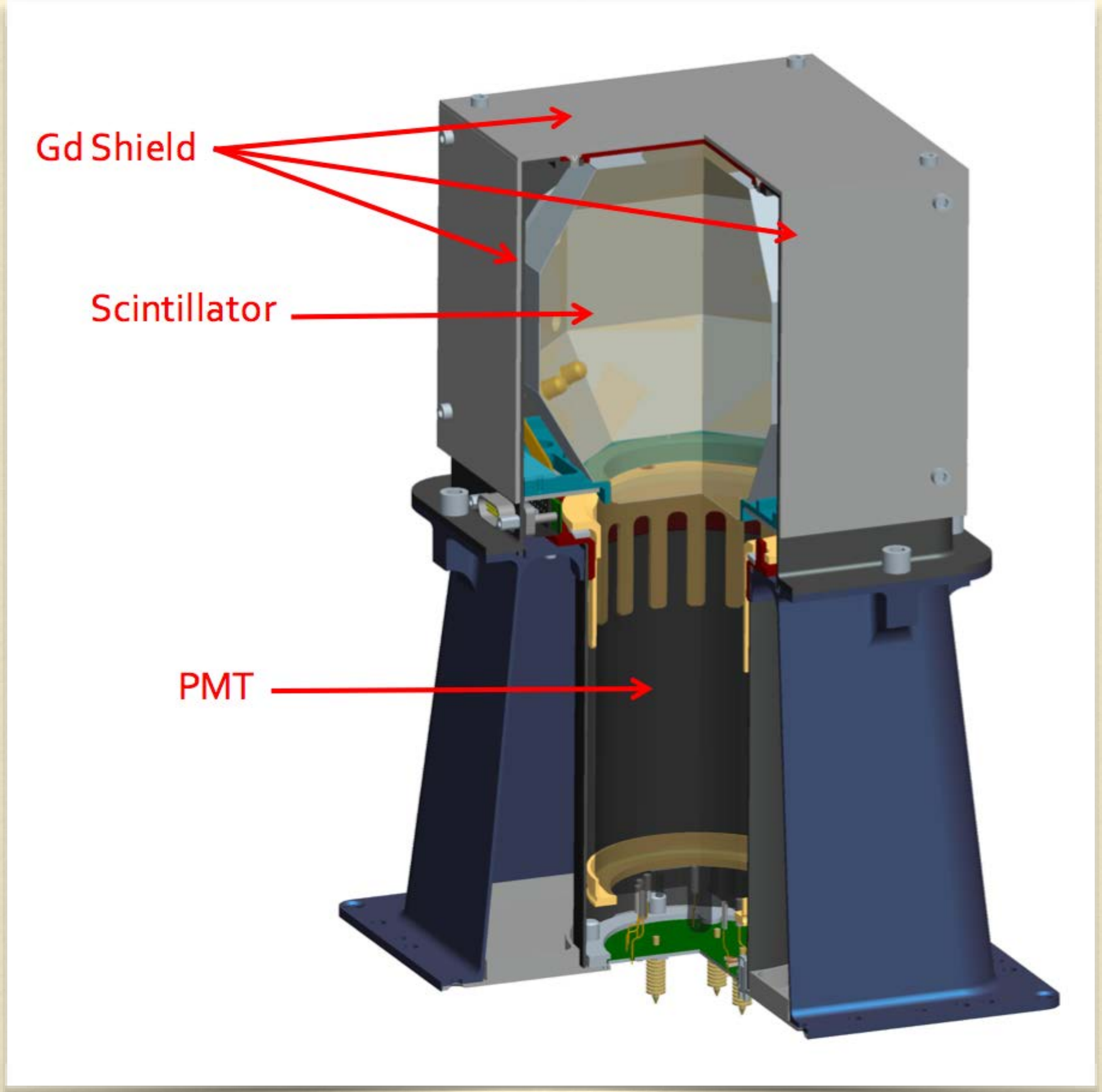
FND REQUIREMENTS & DESIGN

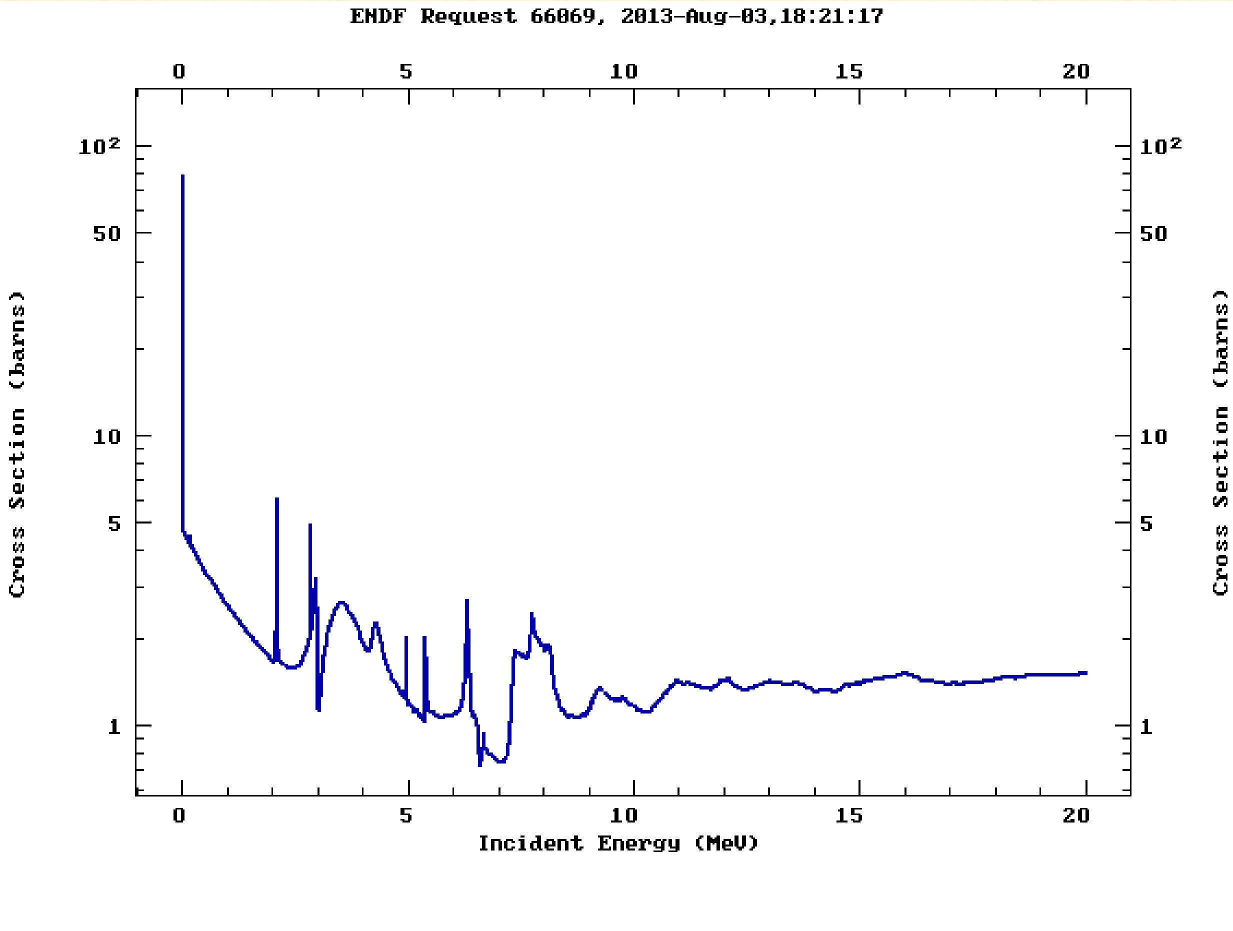


- Detect neutrons with energies from 0.5 to 8 MeV.
- Report dose equivalent to within +- 10% accuracy in known AmBe field — very stringent.
- Considered designs with ^{3}He tubes, or MSL-RAD with enlarged “E” detector (plastic scintillator).
- Boron-loaded plastic scintillator with PMT readout was chosen.

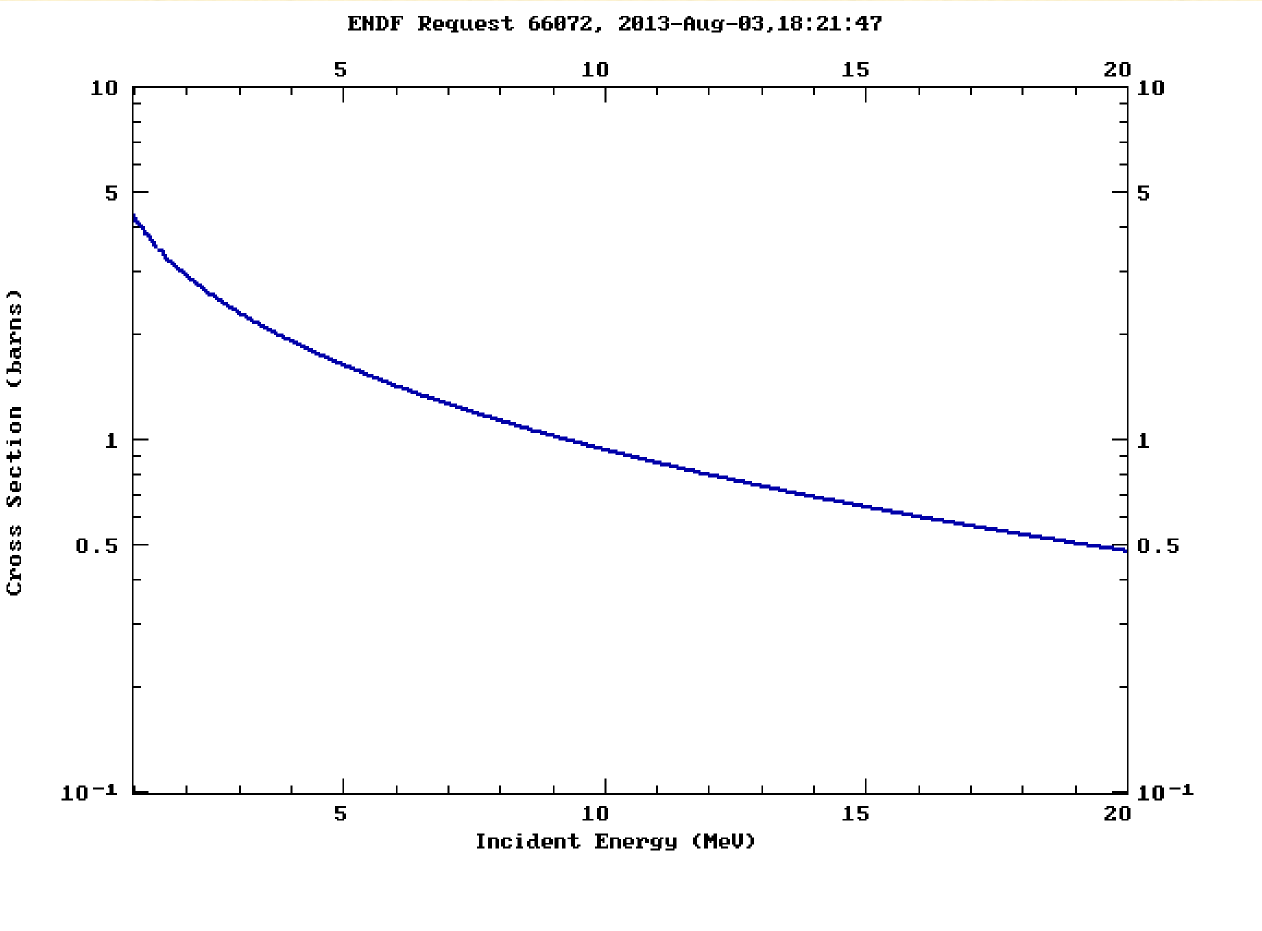
NEUTRON DETECTION WITH BORON-LOADED SCINTILLATOR

- Use capture-gating method, that is, 2-pulse coincidence.
- First pulse from recoil interaction(s) that thermalize the incident neutron.
- Second pulse within ~ few microseconds when thermalized neutron is captured by ^{10}B which then fissions into ^{4}He + ^{7}Li + γ
- For H recoils, amplitude of first pulse is ~ proportional to energy of incident neutron.

INTERACTION CROSS SECTIONS



n + H



n + C

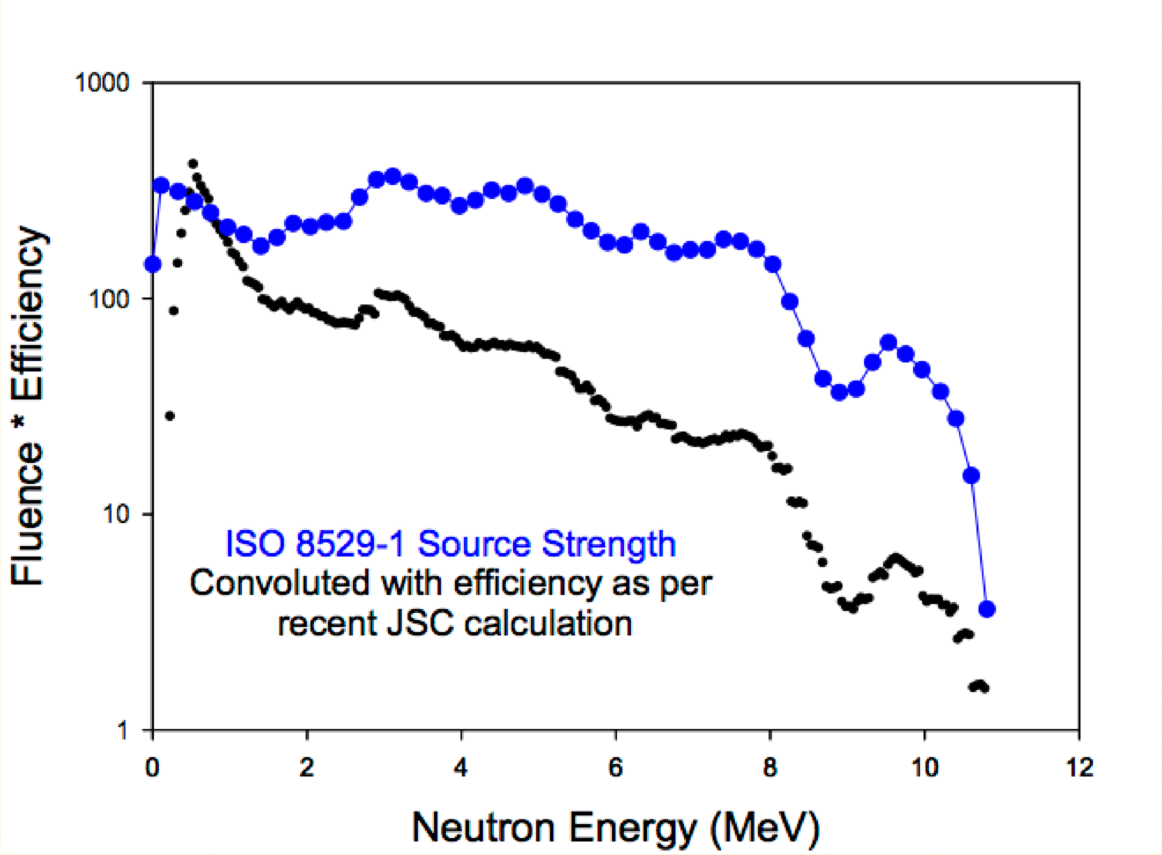
In 0.5 to 10 MeV range, cross sections are comparable, ~ 1 to 3 barns, so ~ equal numbers of interactions on both nuclei. But ~ 0 light output from low-energy neutrons on carbon.

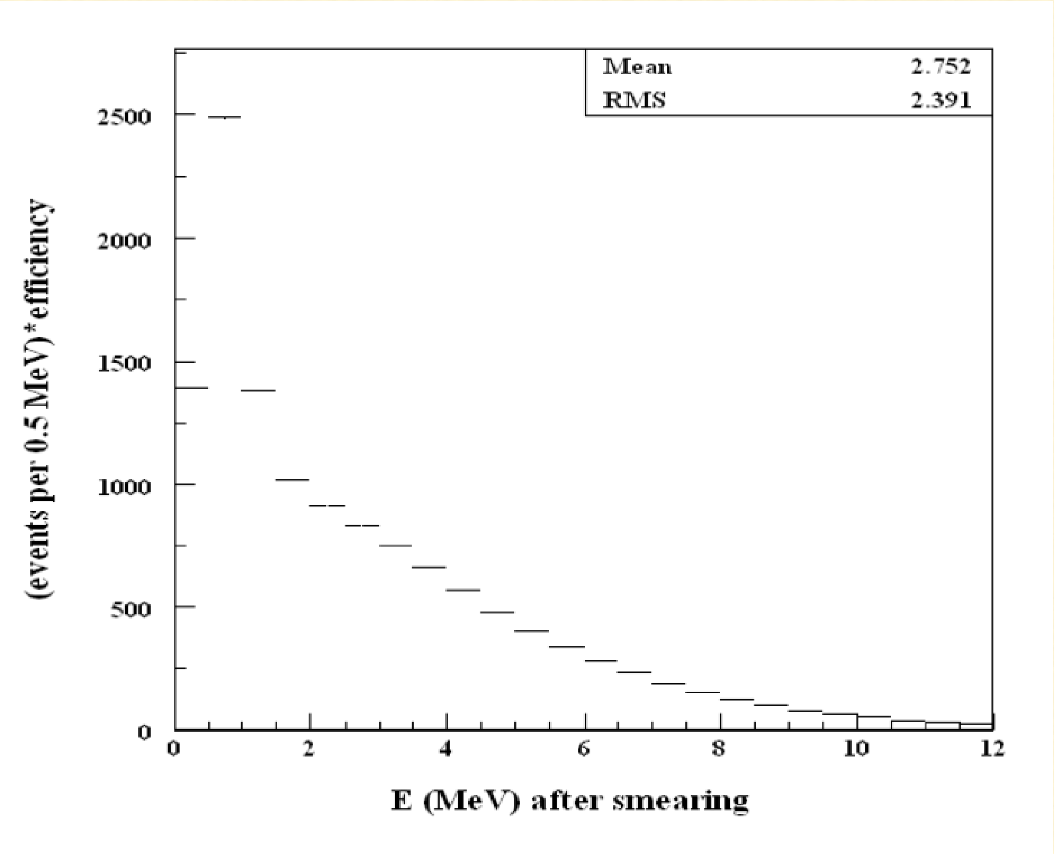
At higher energies carbon recoils become detectable.

BAD NEWS/GOOD NEWS

- The bad news: Inherent resolution is not very good — there are many ways to form the first pulse (H recoils, C recoils, inelastic reactions, variable numbers of recoils).
- Resolution gets worse above a few MeV largely due to carbon recoils.
- The good news: Even with poor resolution, dosimetry is sufficiently accurate.

HOW TO USE AMPLITUDE DISTRIBUTION FOR DOSIMETRY?





- Blue curve: ISO AmBe spectrum
- Black curve: AmBe spectrum with efficiency (early JSC Monte Carlo simulation).

- Simulated energy spectrum after smearing.

BASIC IDEA FROM BYRD & URBAN (LANL REPORT)

- Average amplitude of recoil pulse goes as ~ $E^{1.6}$ where E is the incident neutron energy.
  - Caveat: this seems to only hold for H recoils.
- Associate a given amplitude with a neutron energy by E ~ $A^{(1/1.6)}$. This will be right on average if H recoils dominate.
- Fluence to dose equivalent is weakly dependent on E in this range, so errors/poor resolution may not be critical.

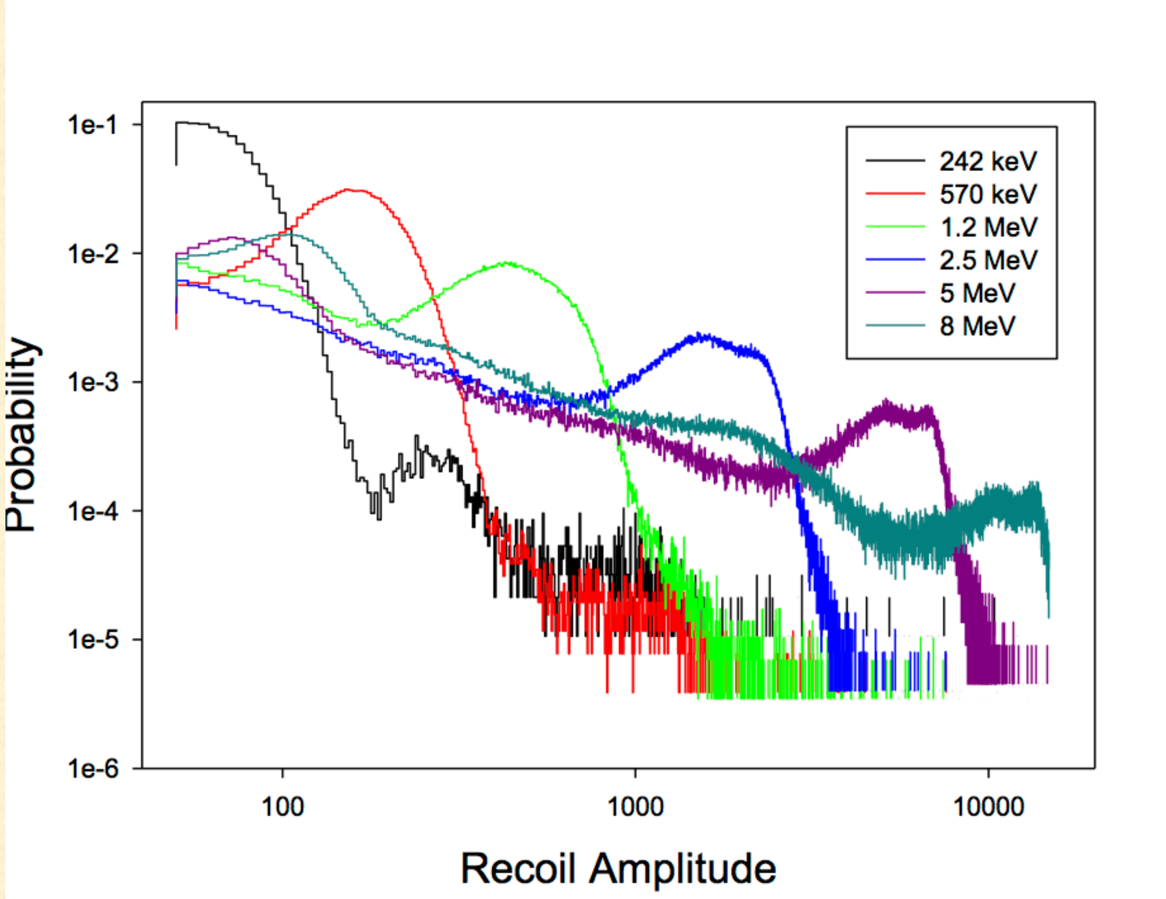
RECIPE

- Measure amplitude and use rough approximation to convert to E.
- PTB calibration data gives us efficiency vs. E curve.
- ICRP 74 gives us fluence to H conversion factors as a function of neutron E.
- We can make a function that incorporates all factors and goes from amplitude to H.

BACKGROUNDS

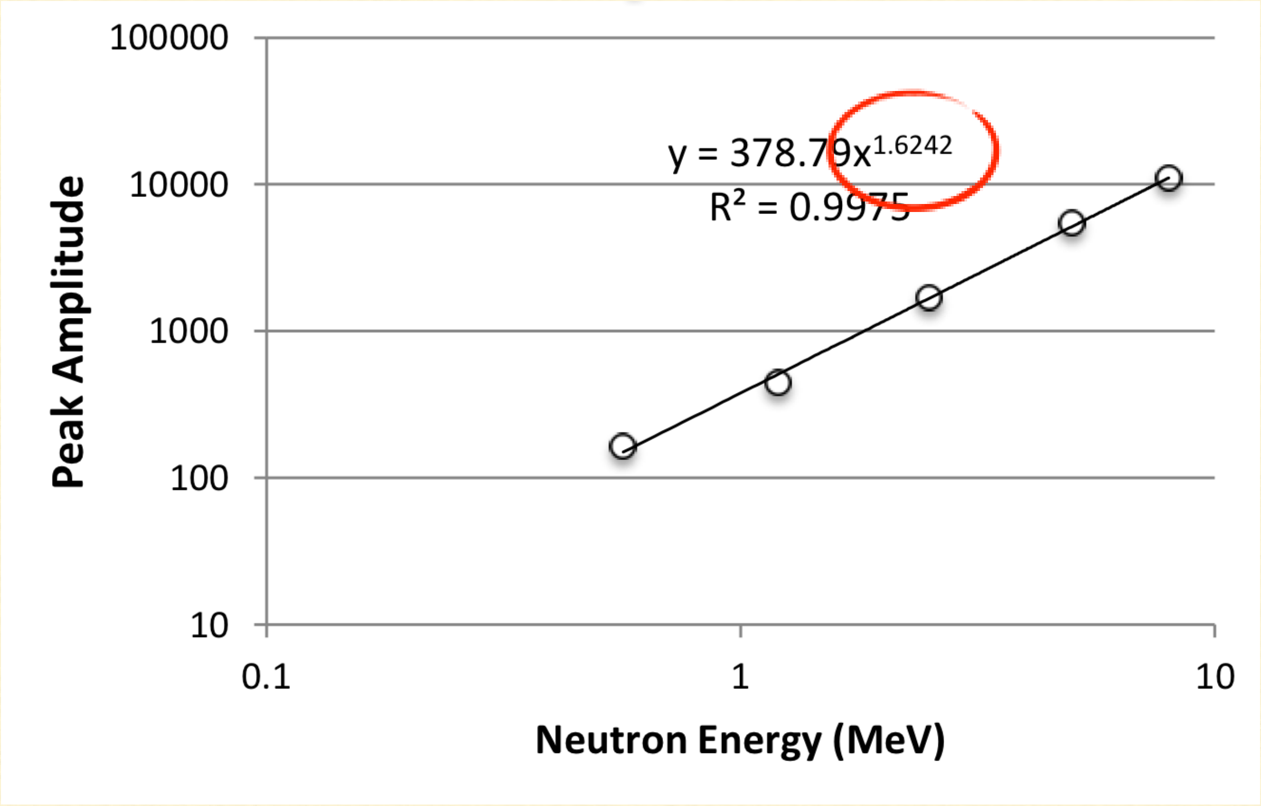
- Two main types of background: chance coincidence & room return.
- Chance coincidence background is determined from spectrum at large Δt between first and second pulse.
  - Neutron capture Δt distribution is exponential, background is flat.
- Room return is determined from shadow-bar runs.

PTB RECOIL AMPLITUDE DATA



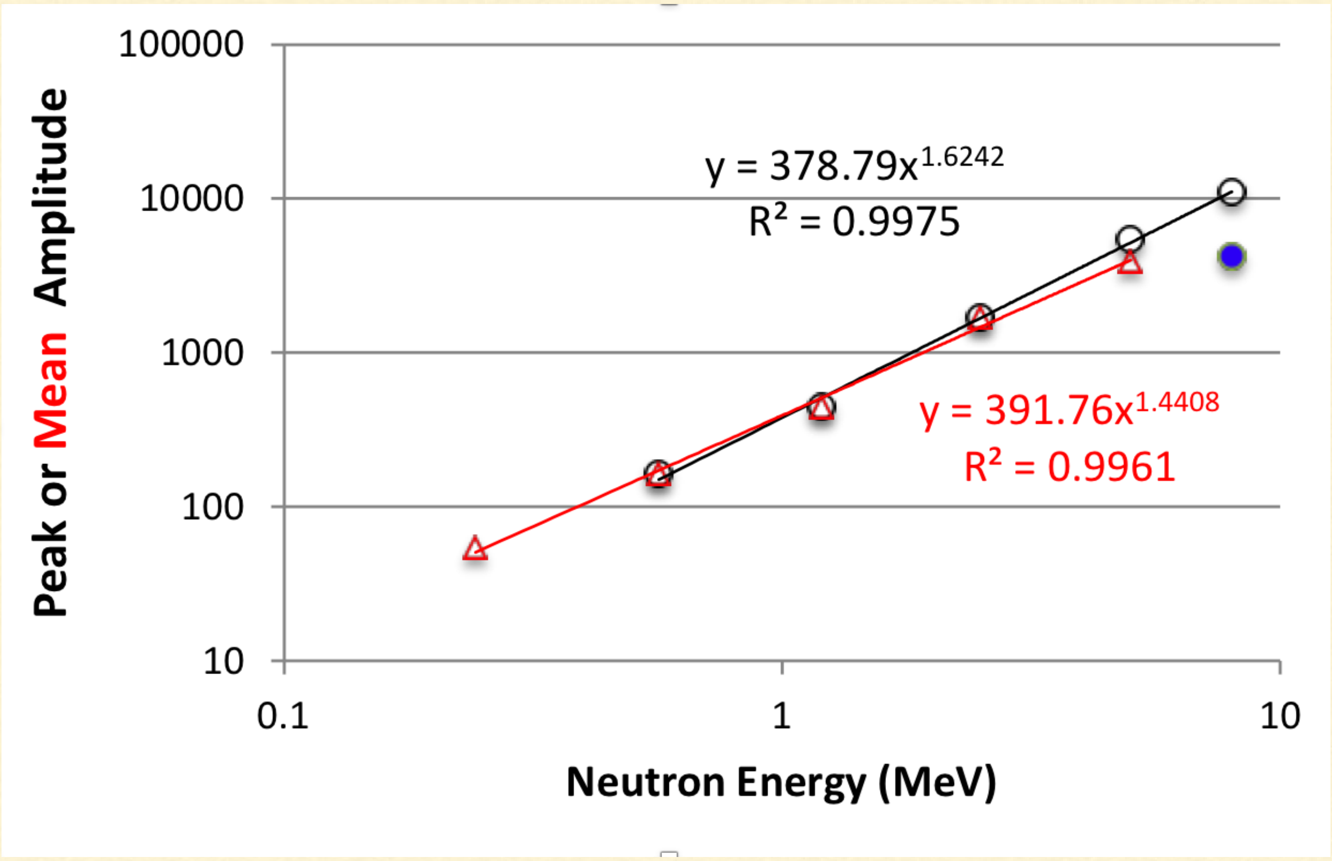
- Make reasonable cuts on capture pulse amplitude & timing, subtract backgrounds.
- Note log-log scales.
- Peaks for lowest energies are well defined but broaden with increasing neutron energy and long tails to low end develop.

FIT PEAKS



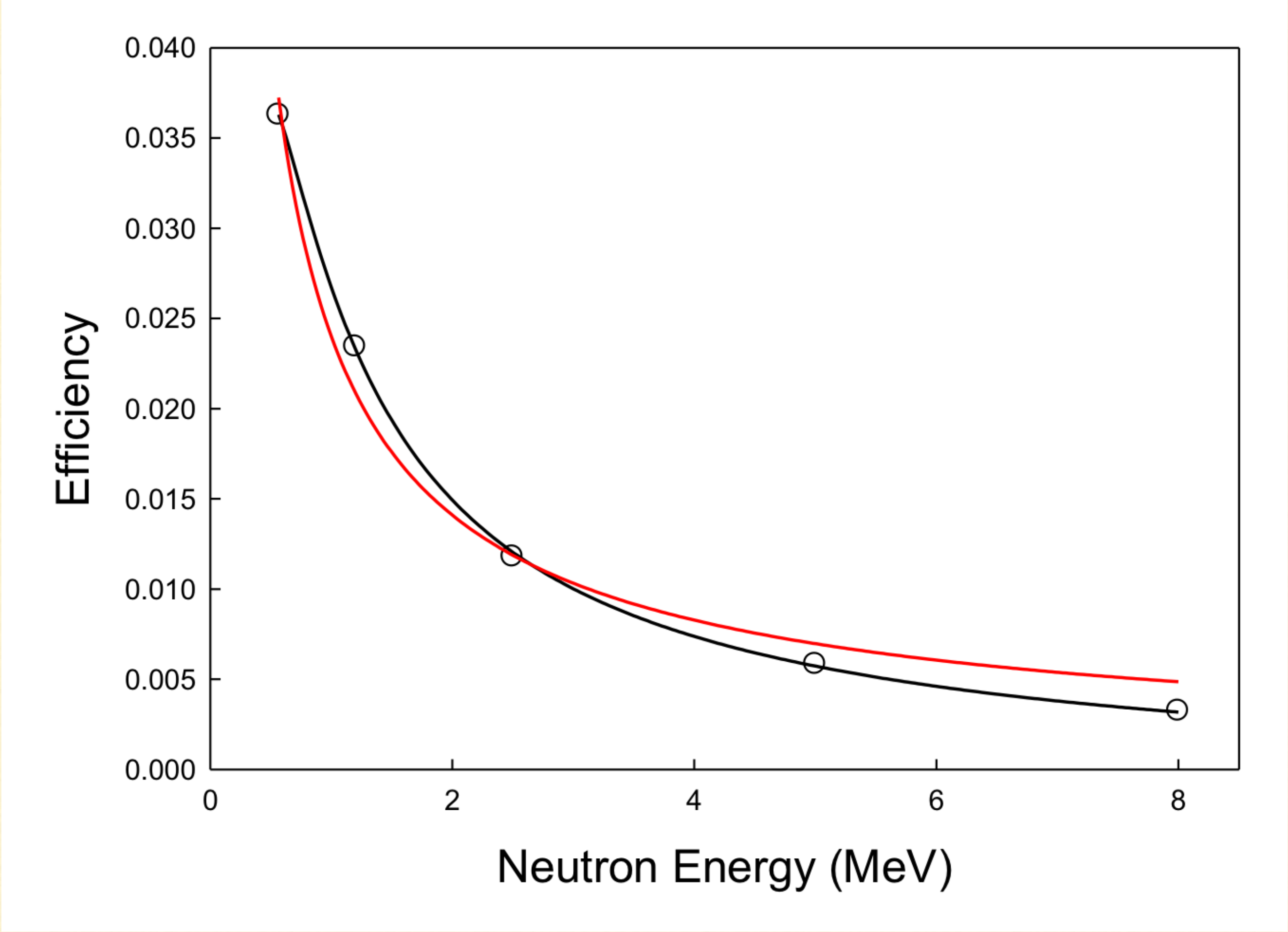
- Get expected exponent of ~1.6.
- Calibration with this curve yields underestimate of dose equivalent because it ignores the low-end tails in the recoil distributions.

MEAN AMPLITUDES VS. E



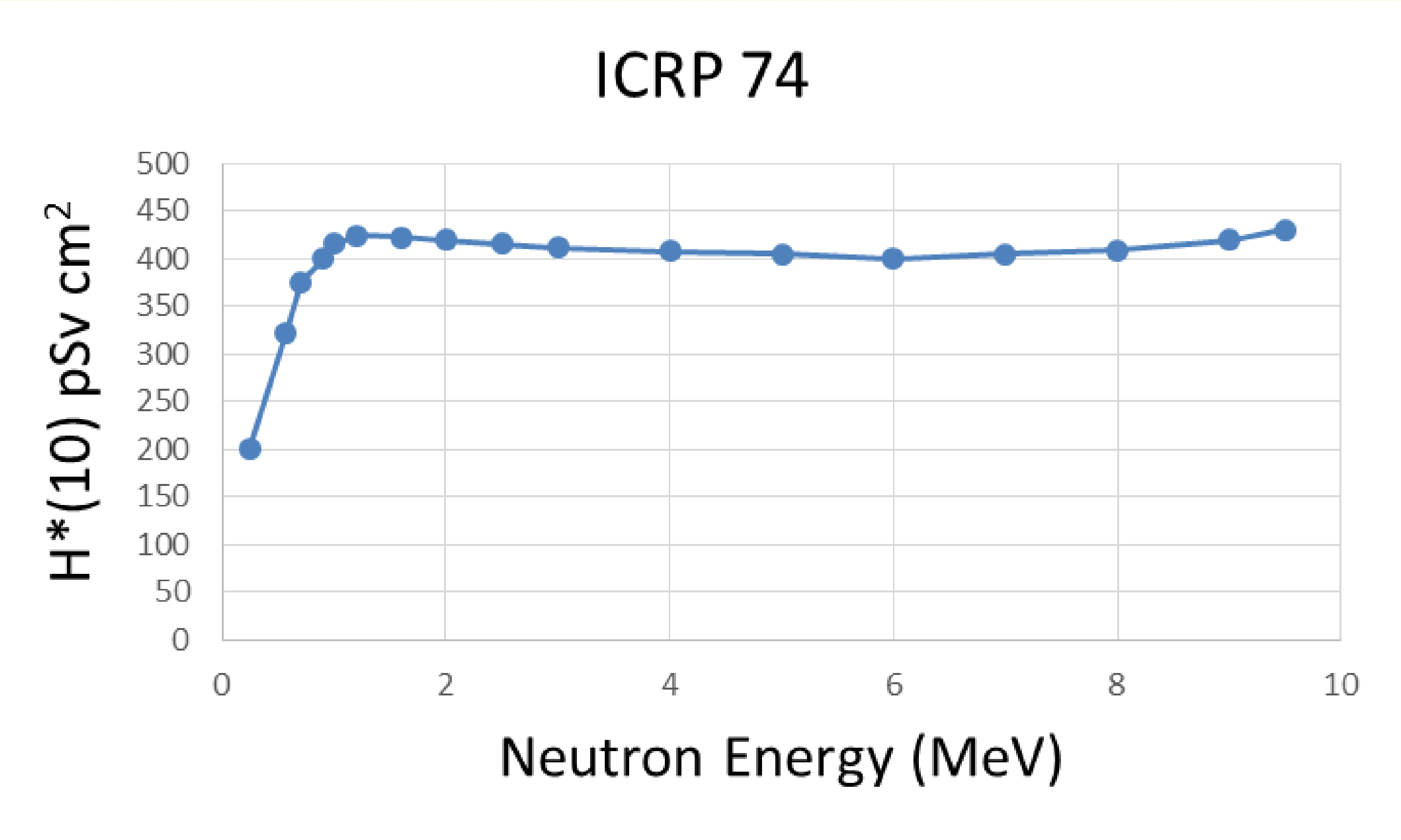
- Using means instead of peaks, the power-law exponent decreases from 1.62 to 1.44.
- 8 MeV data point does not fall on the curve.

EFFICIENCY CURVE



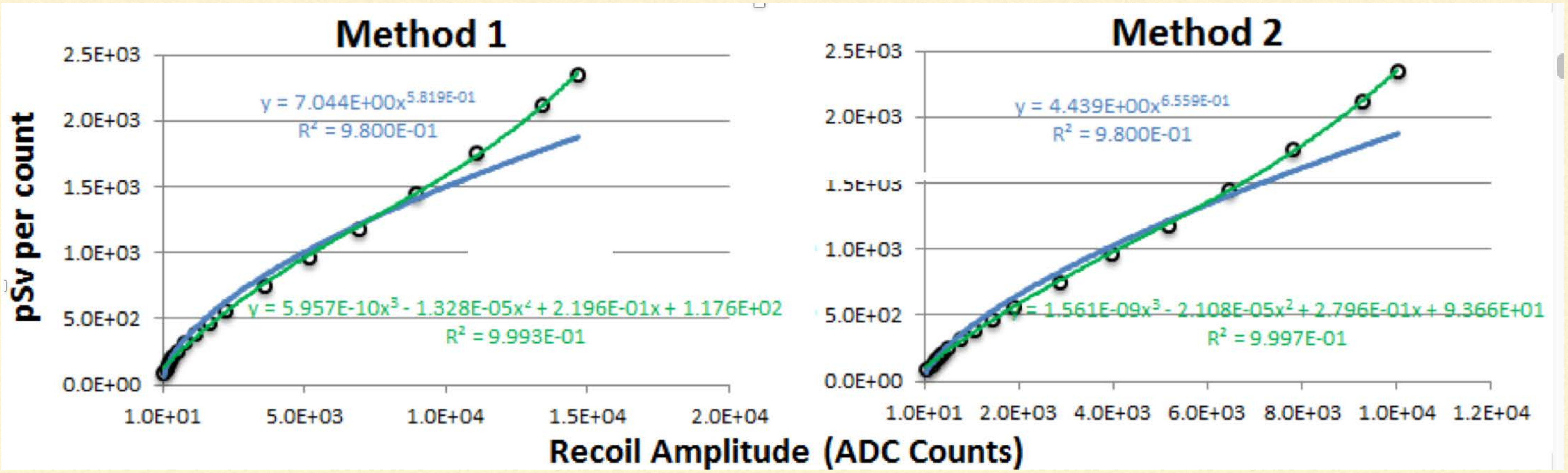
- Initially used power-law fit (red curve) for efficiency vs. energy.
- Inverse form fits better:
- $\varepsilon = \varepsilon_0 + k_1/E + k_2/E^2$

FLUENCE TO DOSE EQUIVALENT



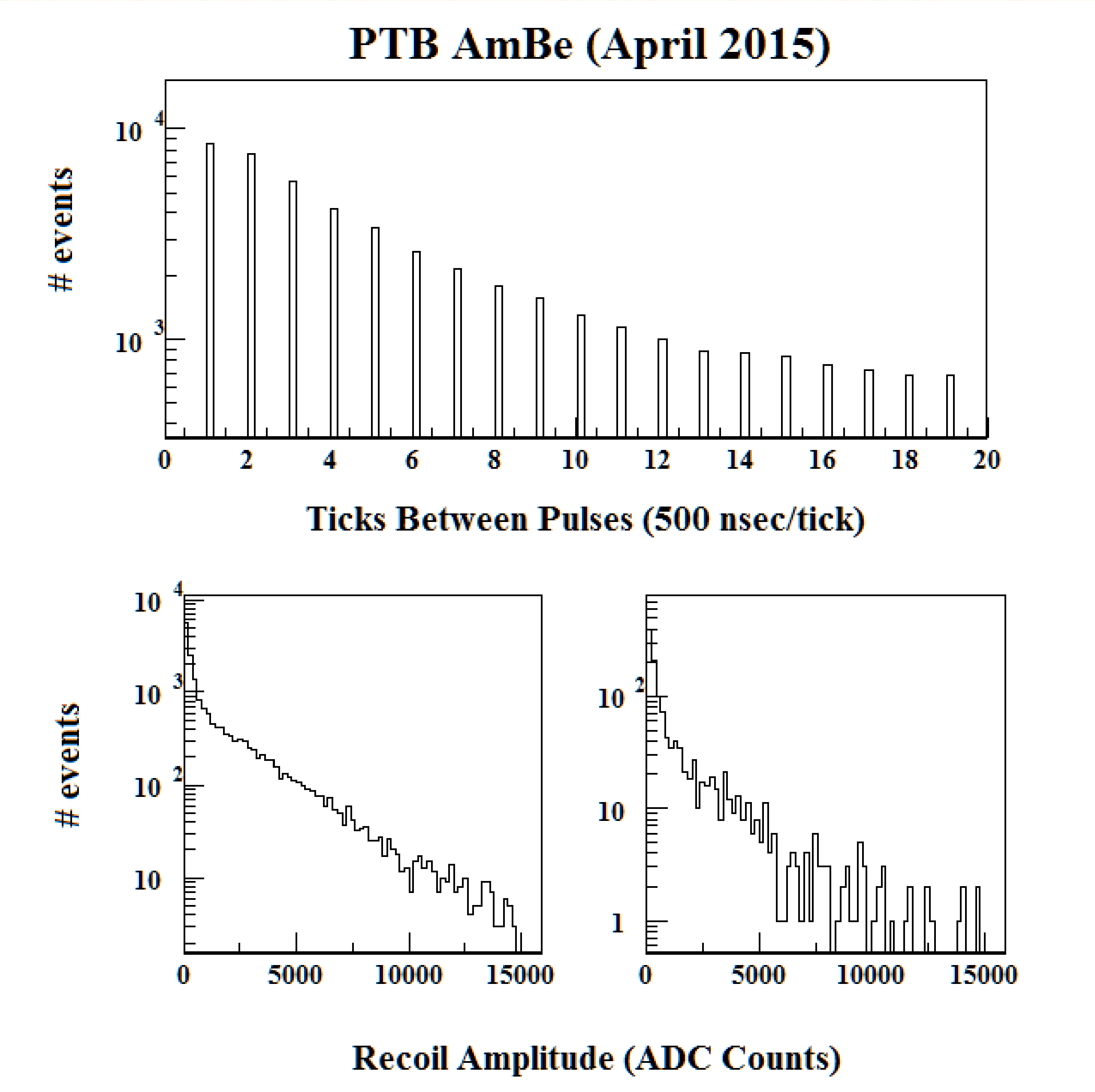
- Use ICRP 74, Table A.42 H*(10)/Φ for the ICRU sphere.
- ~ flat over most of the FND range but consider what happens if neutron energy is underestimated.

CONVERSION FACTORS



- Method 1 uses fit to peaks ($E^{1.62}$), method 2 uses means ($E^{1.44}$).
- Blue curves: power-law fits for comparison, actually use polynomials shown in green.

AmBe DATA



- Distribution of time between first and second pulse (Δt) fit by exponential + constant.
- Short Δt dominated by source neutrons, long Δt dominated by chance coincidence.
- In offline analysis, subtract scaled background from signal.
- In onboard cyclic analysis, use the whole Δt range → need a different conversion function.

RESULTS WITH SOURCES

Method	AmBe H*(10) Rate True = 0.708 μSv/min	^{252}Cf H*(10) Rate True = 0.495 μSv/min
1	0.603	0.483
2	0.691	0.511

- Thanks to Martin Leitgab for calculating the expected "true" rates corresponding to the real FND energy range.
- Method 1 underestimates H rate for AmBe beyond acceptable error.
- Method 2 is reasonably close for both.
- There is clearly a systematic issue relating to amplitude-to-energy conversion but we do not need to address it to meet the accuracy requirement.

CYCLIC ANALYSIS

- Same procedure but without subtracting the long-Δt background. Repeat for all QMN beams.
- Get a different efficiency curve and a different counts to pSv conversion function.
- Apply to AmBe data.

Method	AmBe H*(10) Rate True Rate = 0.708 μSv/min	^{252}Cf Rate True Rate = 0.495 μSv/min
1	0.606 μSv/min	1.047 μSv/min
2	0.673 μSv/min	1.091 μSv/min

CONCLUSIONS

- Relatively simple analysis method meets accuracy requirement for AmBe dose equivalent in both analysis modes (ground and onboard).
- Accuracy of neutron spectrum obtained by this method is questionable due to complexity of the mechanisms that create the recoil pulse.
- Unfolding in some form is likely to yield improved accuracy.