ISS-RAD Calibration Campaign

Cary Zeitlin, Southwest Research Institute

On behalf of the ISS-RAD Team

ISS-RAD ≈ MSL-RAD + FND

- Key question is neutron dose equivalent.
- MSL-RAD neutron coverage to ~ 5 - 100 MeV.
- Add "Fast Neutron Detector" to cover range 0.5 – 8 MeV → many design changes.

Capture Gated Neutron Detection

- Neutron in boron-loaded scintillator → double pulse.
- Pulse 1: sum of recoil protons from thermalization.
- Pulse 2: capture of thermalized neutron by ^{10}B.
  - Δt between pulses exponentially distributed with mean ~ 1.5 μsec.
  - Amplitude of capture pulse in a narrow range.
- Amplitude of 1st pulse related to incident E.

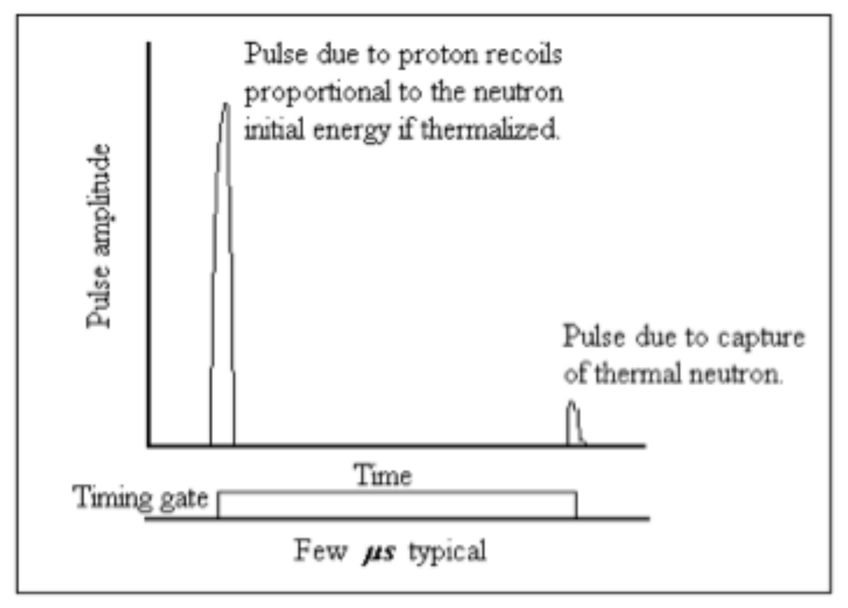
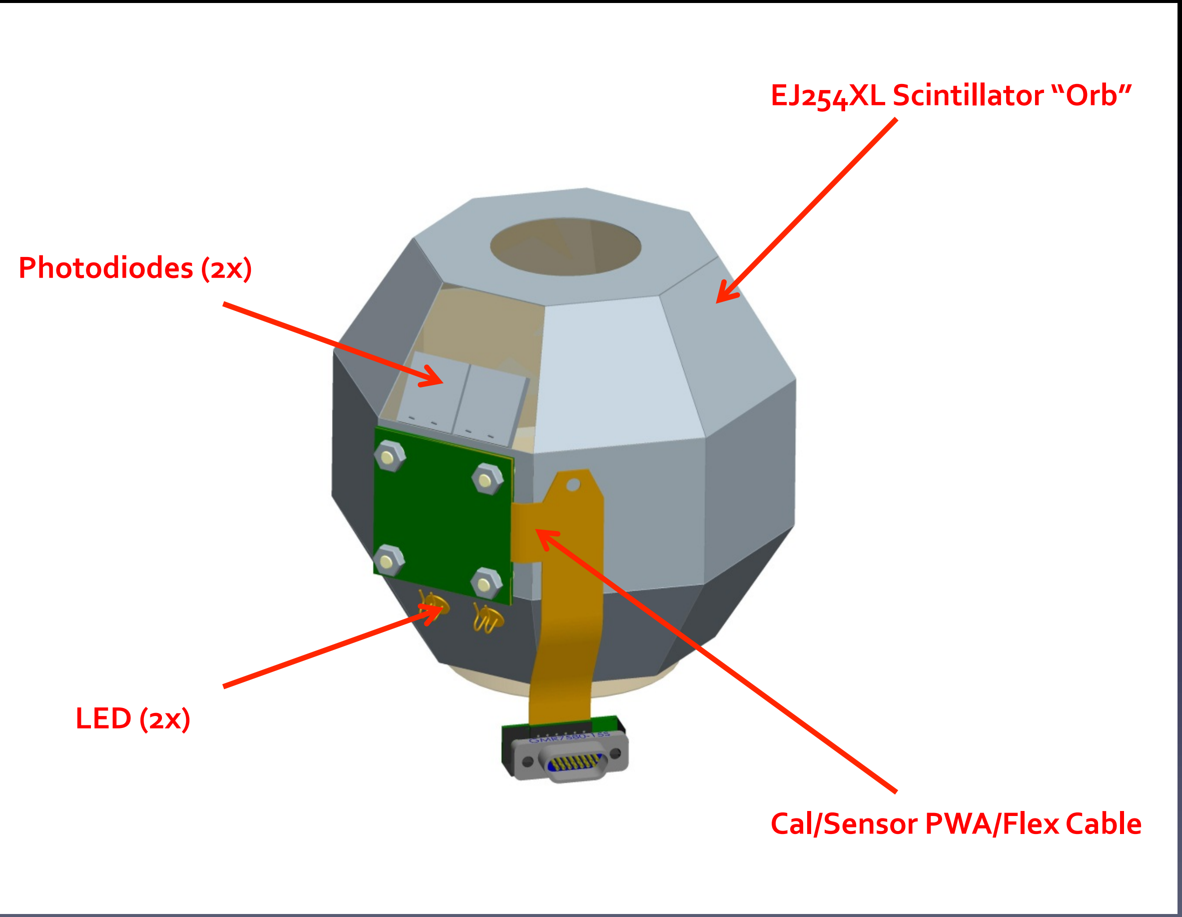
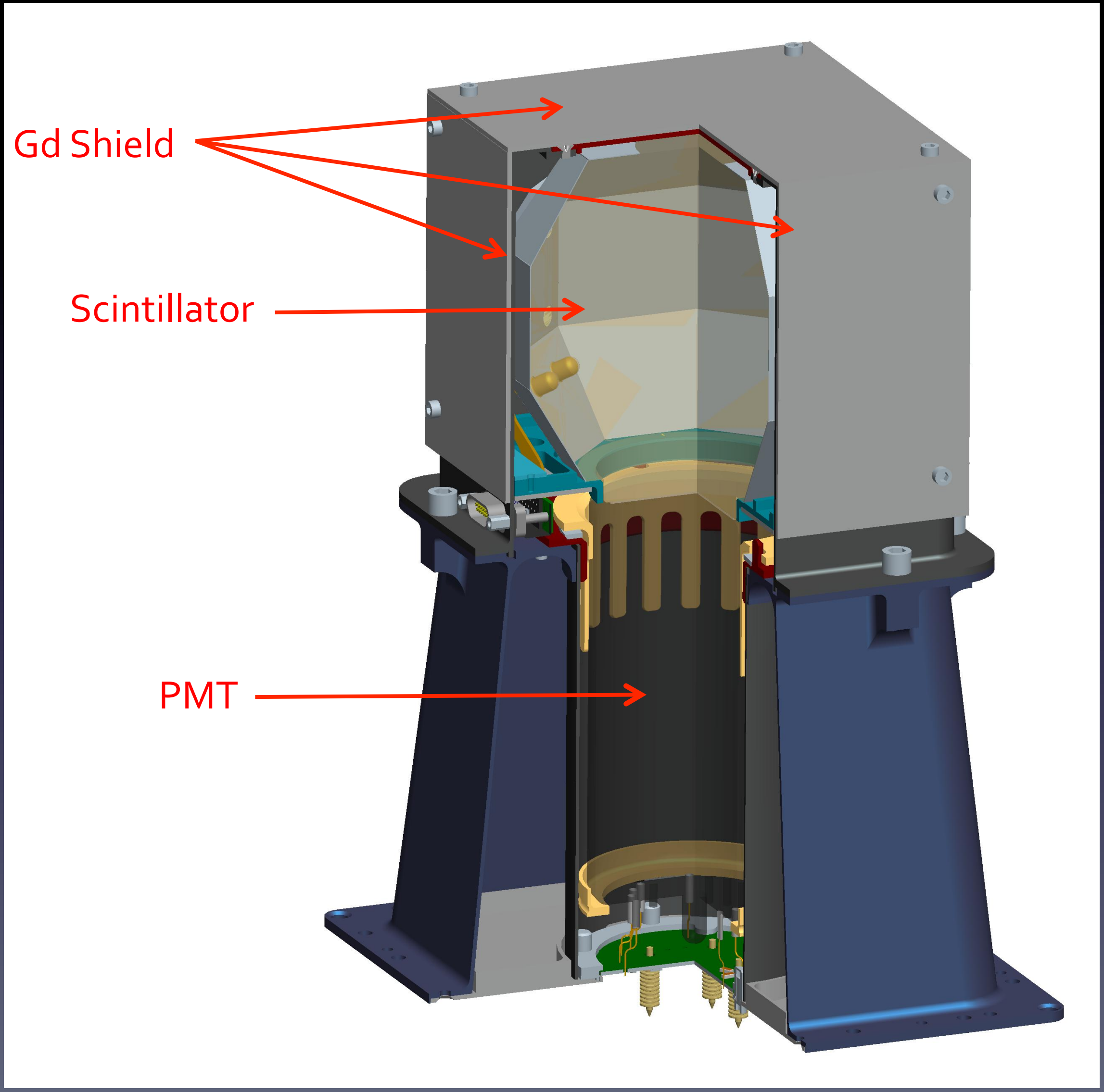


Figure from Sellin et al.

FND Scintillator Orb with Calibration LEDs and Diodes

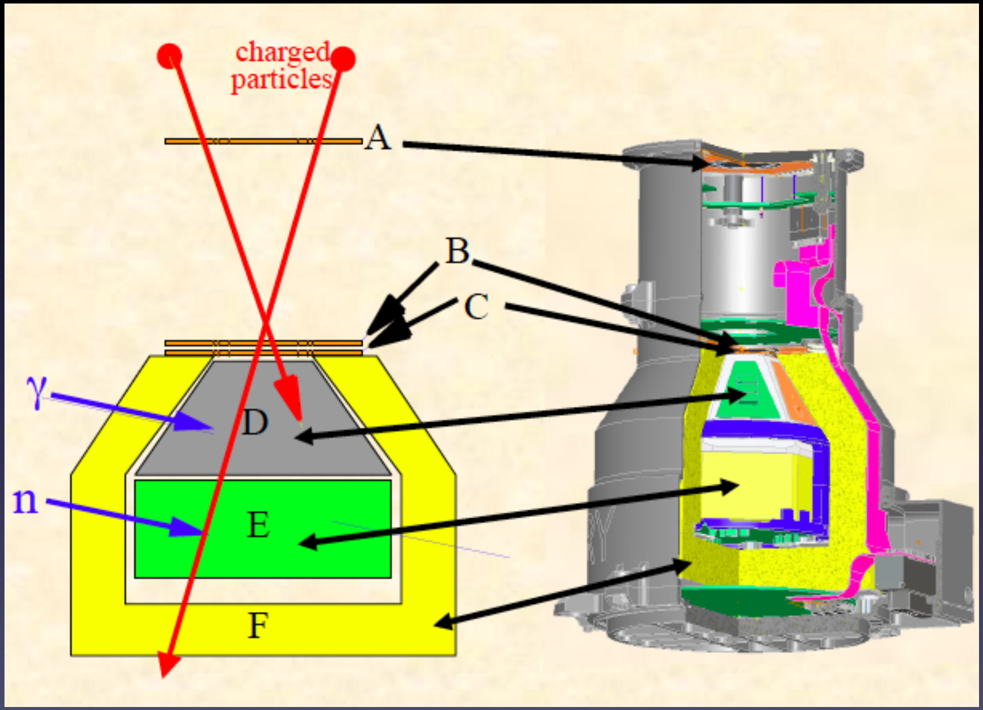


FND Sensor Design



CPD ≈ MSL-RAD

- Humidity on ISS → replace CsI(Tl) crystal with BGO.
- BGO peak emission λ = 480 nm (green), CsI λ = 540 nm (orange).
- Needed green-sensitive diodes.
- Green-emitting plastic for E & F.
  - EJ-260, brighter than BC-432.
- F was 1.2 cm thick, now 1.8 cm.
- Decoupled F1 and F2.



Other New Stuff: RIB & GSE

- RAD Interface Board = “RIB”.
  - Talks to both instruments.
  - Talks to Station via 1553, to laptop via USB.
  - Handles many different packet types.
  - Provides power to instruments from 28V or 120V.
- Complexity → much debugging.
- System has 4 FPGA’s (2 CPD, 1 FND, 1 RIB)
  - 2 have 8051 microcontroller cores (CPD, RIB).
  - 6 processors to program & make work together (3 legacy.)
- GSE software also complex.

ISS-RAD 2013 Tour, or…
“*What does this knob do?*”

- Engineering Model on Tour – dates:
  - The Svedberg Laboratory (TSL), Uppsala, Feb.
  - PTB, Braunschweig, March.
  - NSRL, Brookhaven, NY, April & May.
  - RARAF, Irvington, NY, May.
  - AmBe testing at JSC, June.
- We didn’t break anything (that we know of).

Calibration & Requirements Verification

Beam/Energy (MeV)	Goal	Facility & Date
Neutrons, 0.25, 0.57, 1.2, 2.5, 5.0, 8.0, 14.8	Calibrate light output vs. neutron energy, determine efficiency vs. energy	PTB 3/4 to 3/7 and RARAF 5/6
Neutrons, "Atmospheric" spectrum and 170 MeV QMN	CPD D/E calibration at high neutron energy	TSL 2/26, 27
Protons, 20 MeV	Calibration point & demonstrate that 20 MeV protons get through the housing.	BNL 4/15
Protons, 40 MeV	Calibration point.	BNL 4/15
Protons, 100 MeV	Calibration point near high end of stopping energies.	BNL 4/15
Protons, 1000 MeV	Calibration point for ~ min-I charge 1.	BNL 4/15
Helium, 300 MeV/nuc	Calibrate high-gain channels	BNL 5/3
Silicon, 1000 MeV/nuc	Calibrate low- and medium-gain channels	BNL 5/2
Iron, 500 MeV/nuc	Calibrate low-gain channels, see stopping Fe	BNL 4/16
Iron, 1000 MeV/nuc	Calibrate low-gain channels, penetrating Fe	BNL 4/16

Operating Modes for Calibration

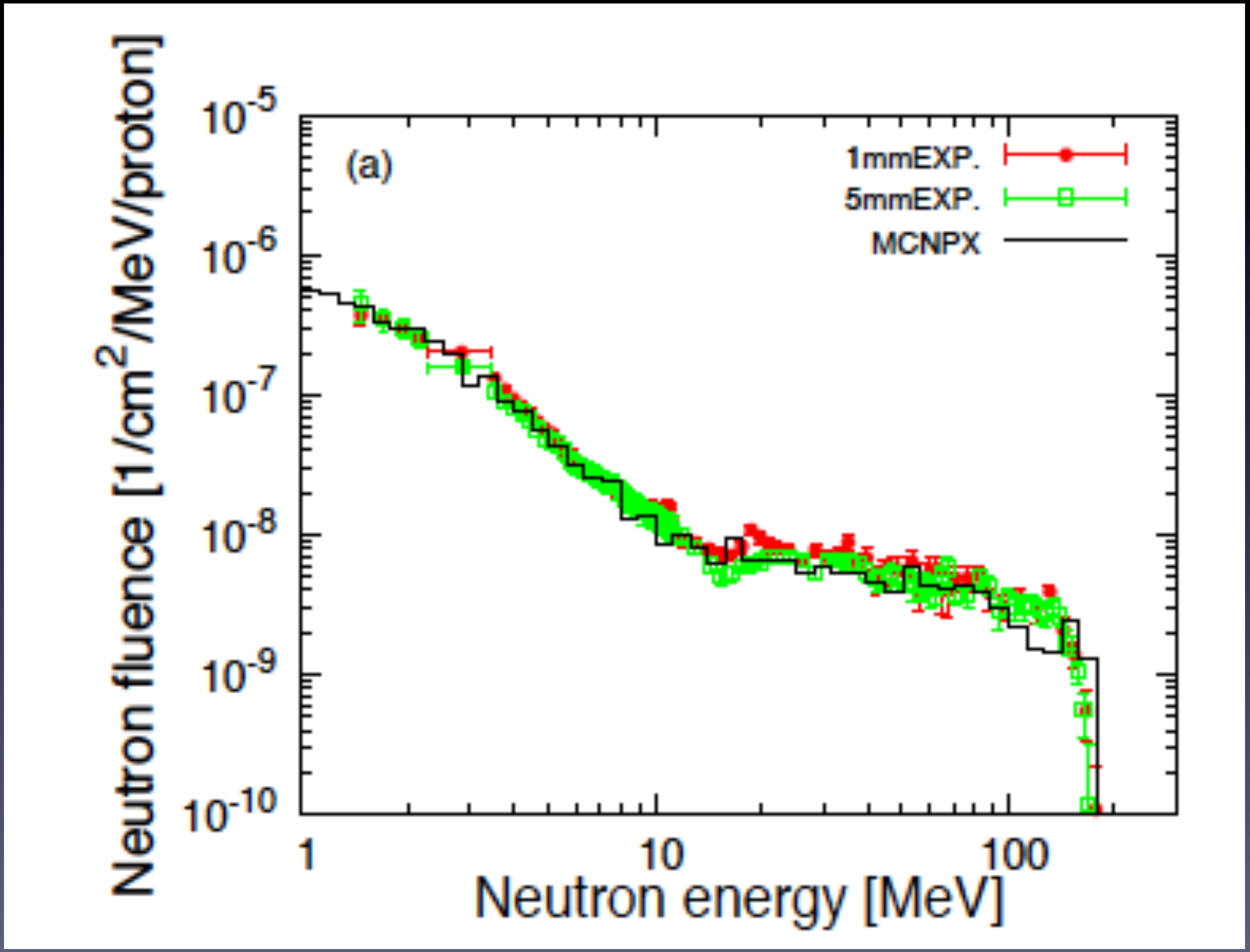
- Only one subsystem enabled at a time.
  - Avoided collisions of data packets in RIB.
  - Not flight-like.
- CPD in “streaming mode” → all Level 2 data (highest fidelity) piped out via USB.
  - Also not flight-like, in flight get “L3” data.
- No hardware failures – occasional GSE hangs.

TSL Run

- 170 MeV QMN and “ANITA” spectrum beams.
- ANITA = Atmospheric-like Neutrons from thIck TArget.
- Mostly for CPD, useful for FND debugging.
  - New FND FPGA hand-carried from San Antonio to Braunschweig.

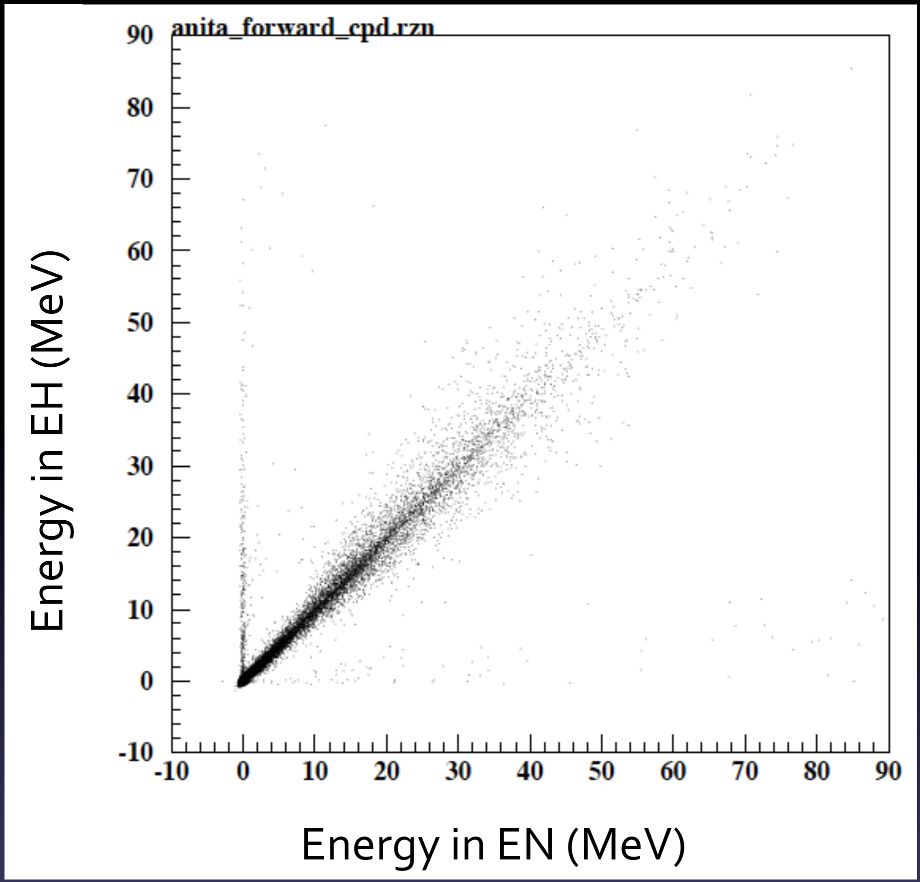
ANITA Neutron Spectrum

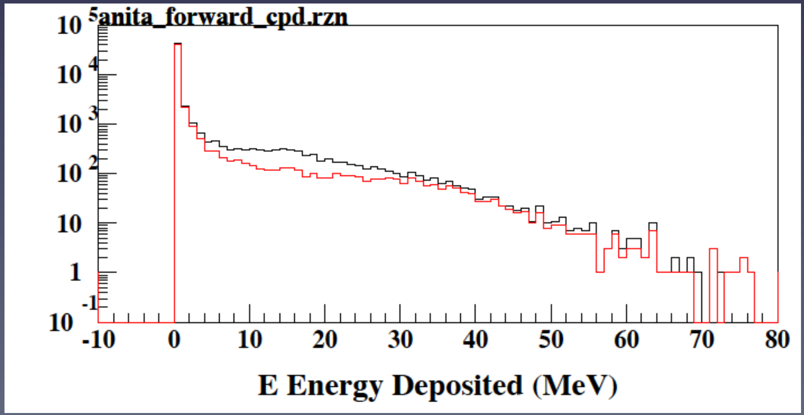
(Figure from Naitou et al.)



ANITA E Spectrum

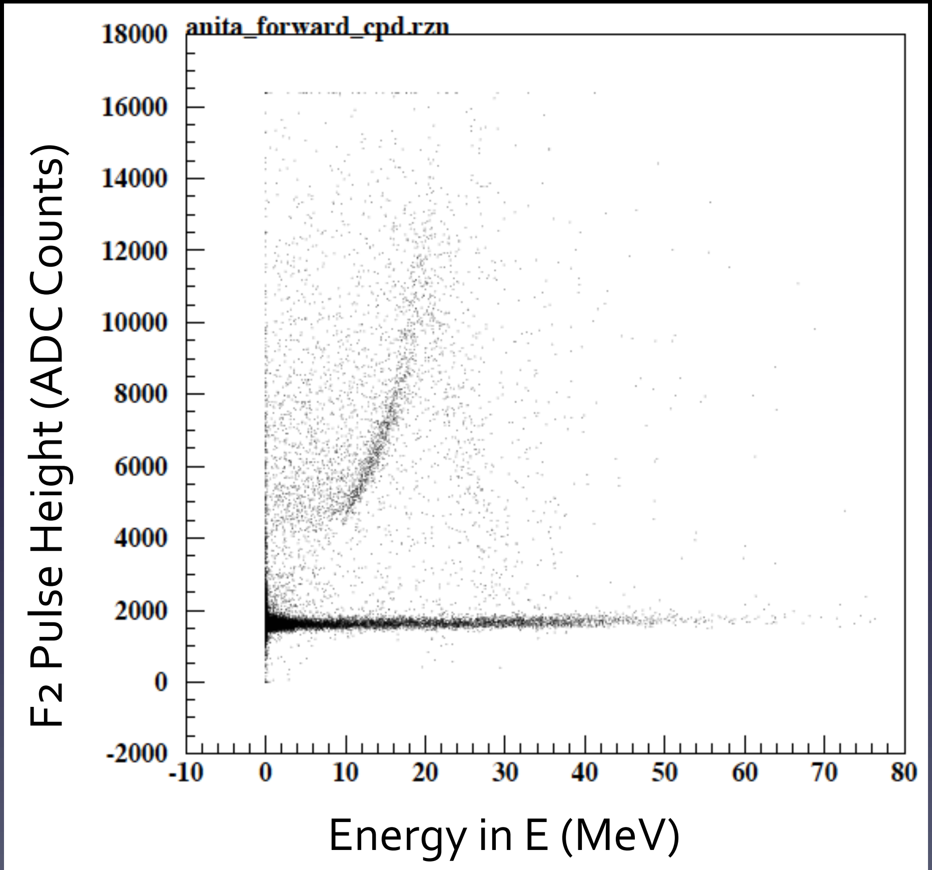
- CPD facing into beam.
- Turned off "D" fast trigger.
  - Beam stops → "γ flash."
- See a few "silicon hits" in EH (EH fast trigger enabled).
- Lower histogram shows average of EH, EN energy, with (red) and without (black) anticoincidence cuts.





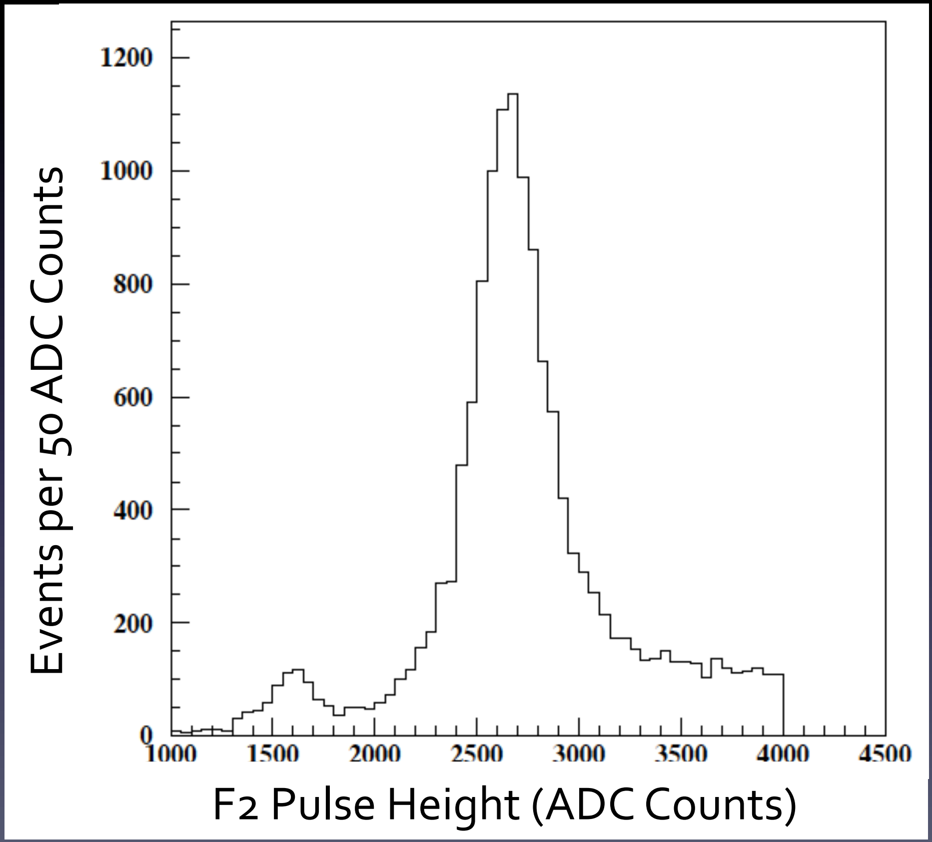
Anticoincidence in ANITA Beam

- Recoil protons knocked from E into F2.
- Some stop in F2.
  - Mostly F2 not hit.
- Good separation between proton ΔE and pedestal.



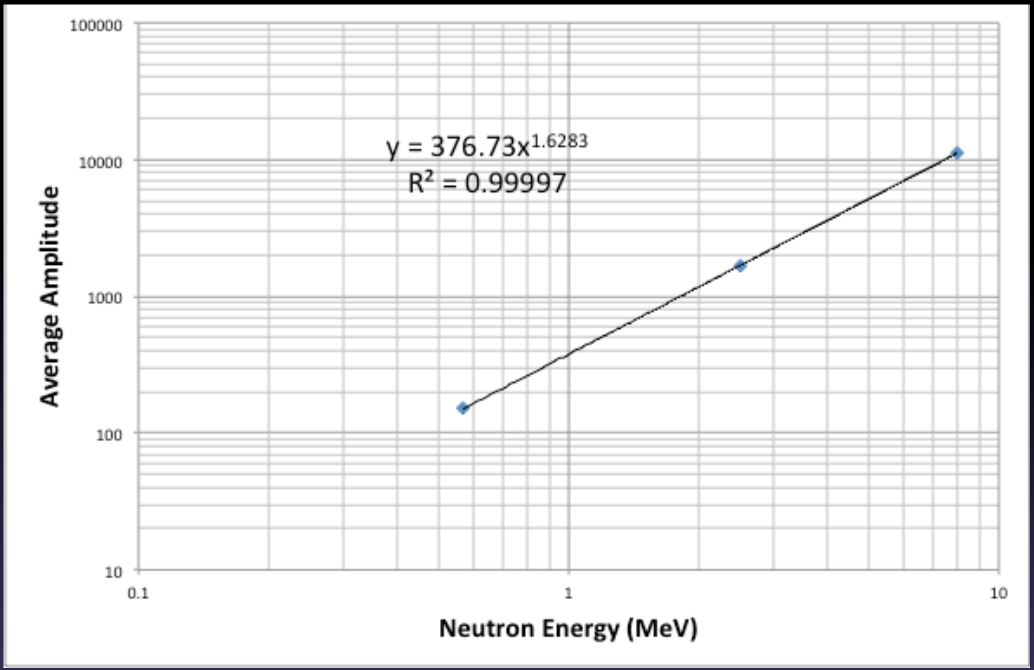
F2 with 1 GeV protons

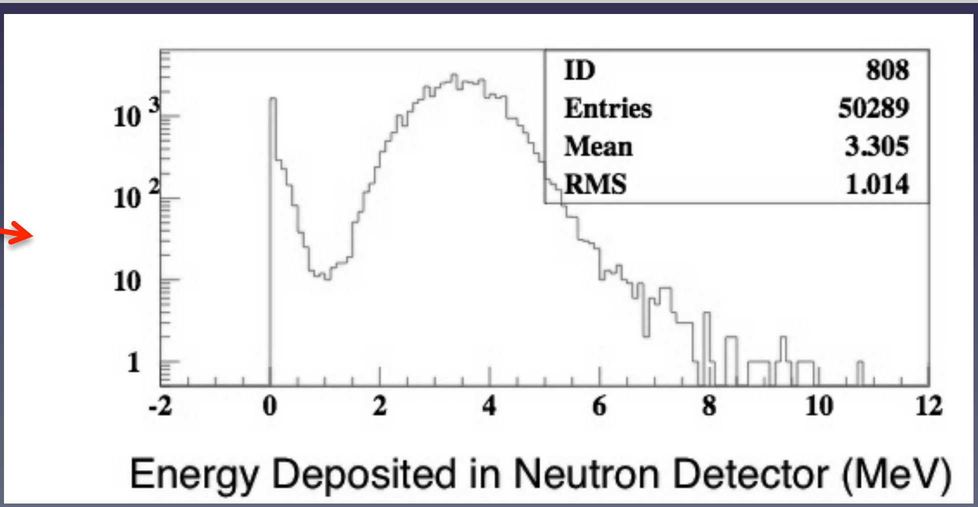
- Proton peak (channel ~ 2750) well separated from pedestal (channel ~ 1600).
- Cleaner than MSL-RAD.



PTB Neutron Data in FND

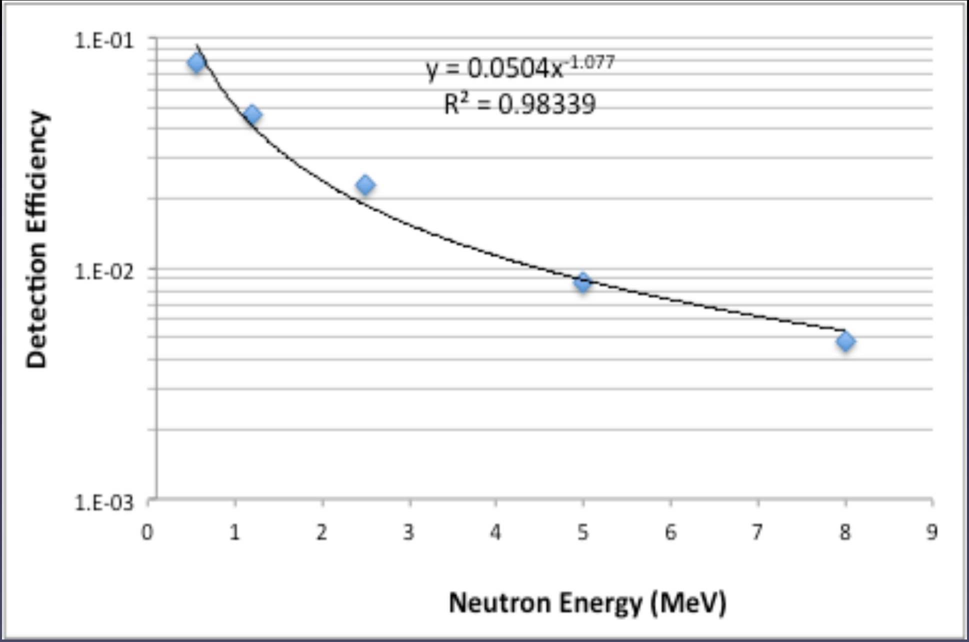
- <u>Average</u> recoil vs. E at 0.5, 2.5, 8 MeV.
  - "Final" PMT voltage.
  - Expected exponent = 1.6, fit gives 1.63.
- <Capture time> = 1.5 μs.
- 8 MeV ε ~ 0.5%.
  - Overlaps response of CPD E.





FND Efficiency

- JSC MCNPX simulations → two ε curves in 2-6 MeV range.
- Fit 1: $\varepsilon = 0.041\ E^{-0.97}$
- Fit 2: $\varepsilon = 0.032\ E^{-1.04}$
- PTB Data: $\varepsilon = 0.050\ E^{-1.08}$
  - Different energy ranges and capture windows in data & simulations.
- All data used, though PMT voltages varied.

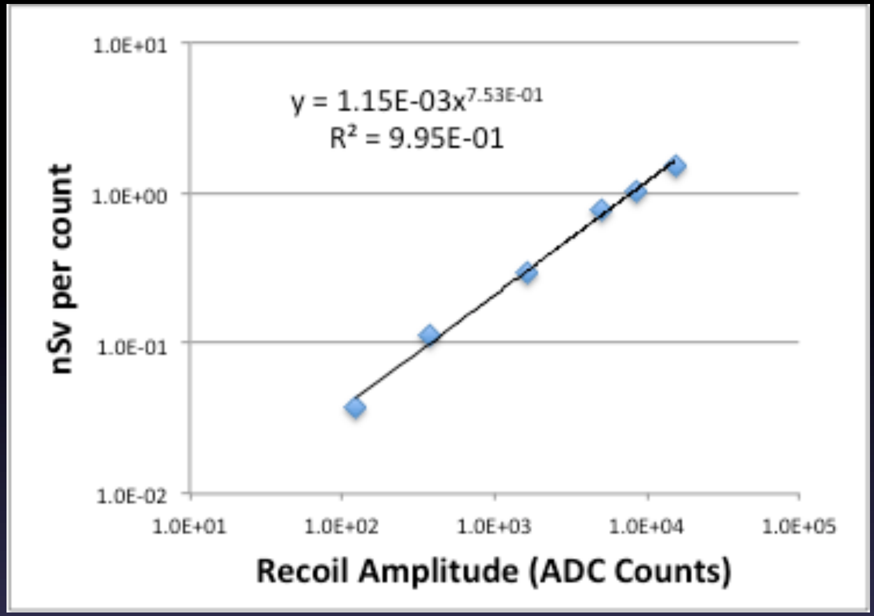


Simple Response Function

Neutron E (MeV)	Conversion factor (pSv cm²) [Cossairt & Vaziri]	Detection efficiency (fit)	nSv per detected neutron	Average recoil amplitude
0.5	257.2	0.106	0.038	120.6
1	365.5	0.050	0.114	369.6
2.5	347.2	0.019	0.291	1625
5	434.0	0.0089	0.766	4984
7	408.5	0.0062	1.036	8586
10	408.5	0.0042	1.521	15283

- Treated FND scintillator as sphere w/D = 9 cm.

Dose Eq. vs. Amplitude



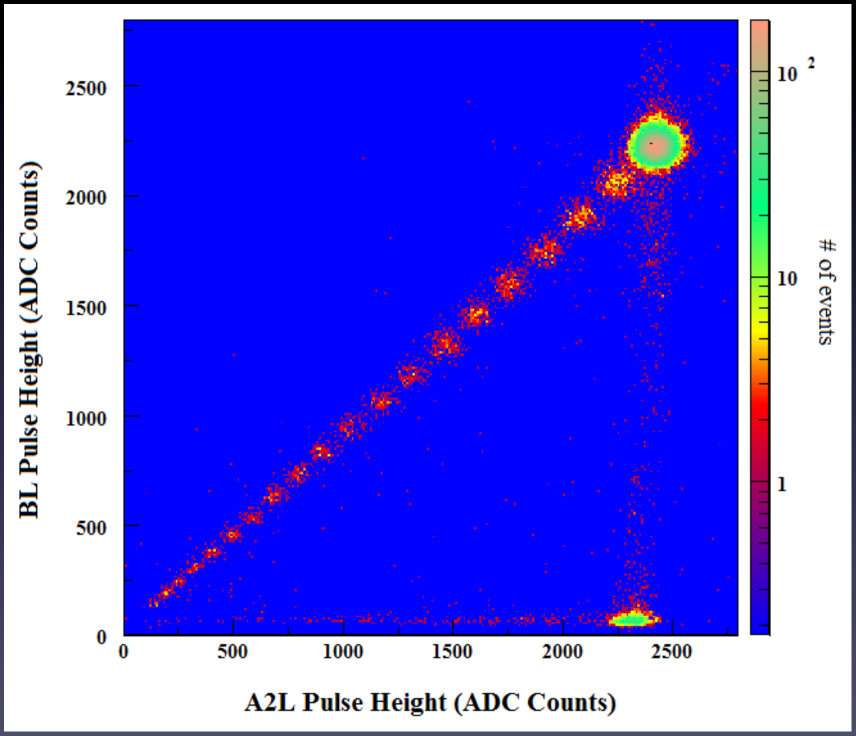
- Apply to spectra obtained in JSC AmBe field.
- Background subtraction not done here, probably ~ 10%.

Test	Measured Dose Equivalent	Expected Dose Equivalent
50 cm distance 2.55 hours	24.1 μSv	28.9 μSv ICRP 74 calculated rate 25.6 +- 5 μSv remmeter estimate
100 cm distance 18.37 hours	58.6 μSv	57.0 μSv ICRP 74 calculated rate 50.5 +- 10 μSv remmeter estimate

Dose Equivalent Accuracy

- May improve accuracy with inversion method.
  - Conversion factor is weak function of E in FND range.
  - It should work with wide bins.
    - Wide bins are appropriate given energy resolution.
- May need to include higher-energy neutrons measured in CPD.
  - CPD neutron spectrum will be unfolded with method developed for MSL-RAD by Wimmer & Köhler at Kiel.

NSRL 1 GeV/amu ^{56}Fe Data



- 1000 MeV/nuc iron as seen in silicon detectors (low gain channels, BL and A2L).
- Iron ions populate brightest spot @ upper right, lighter ions populate other clusters.
- Horizontal band @ small BL pulse height due to ions that hit A2 but miss B (B is slightly smaller).
- Vertical band below iron due to iron ions that fragment in A2 & deposit less energy in B.

Charged Particle Calibration

- Gains & offsets used onboard ("L2").
- Calculated gains in silicon detector channels typically within ~ 5-10% of measured gains.
- Scintillator responses more complicated:
  - Quenching, light yield, light collection efficiency.
  - Within factor of 2 of estimates based on light yield from γ's.

Conclusions

- Got all required data.
- Charged particle data is straightforward.
- FND data looks as expected, simple response function seems to work.
- CPD neutron data not yet analyzed, hoping to bring J. Köhler onboard.