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COMPARISON OF BORON-LOADED PLASTIC SCINTILLATORS FOR ISS-RAD

CPDS Overview

- JSC operates 4 "CPDS" units.
  - CPDS = Charged Particle Directional Spectrometer.
  - "IV-CPDS" (inside, single telescope).
  - "EV-CPDS" (outside, 3-axis telescope).
- Standard silicon detector telescopes.
- Flying on ISS for nearly 10 years.
- Telescopes very similar to MARIE.

CPDS Instruments

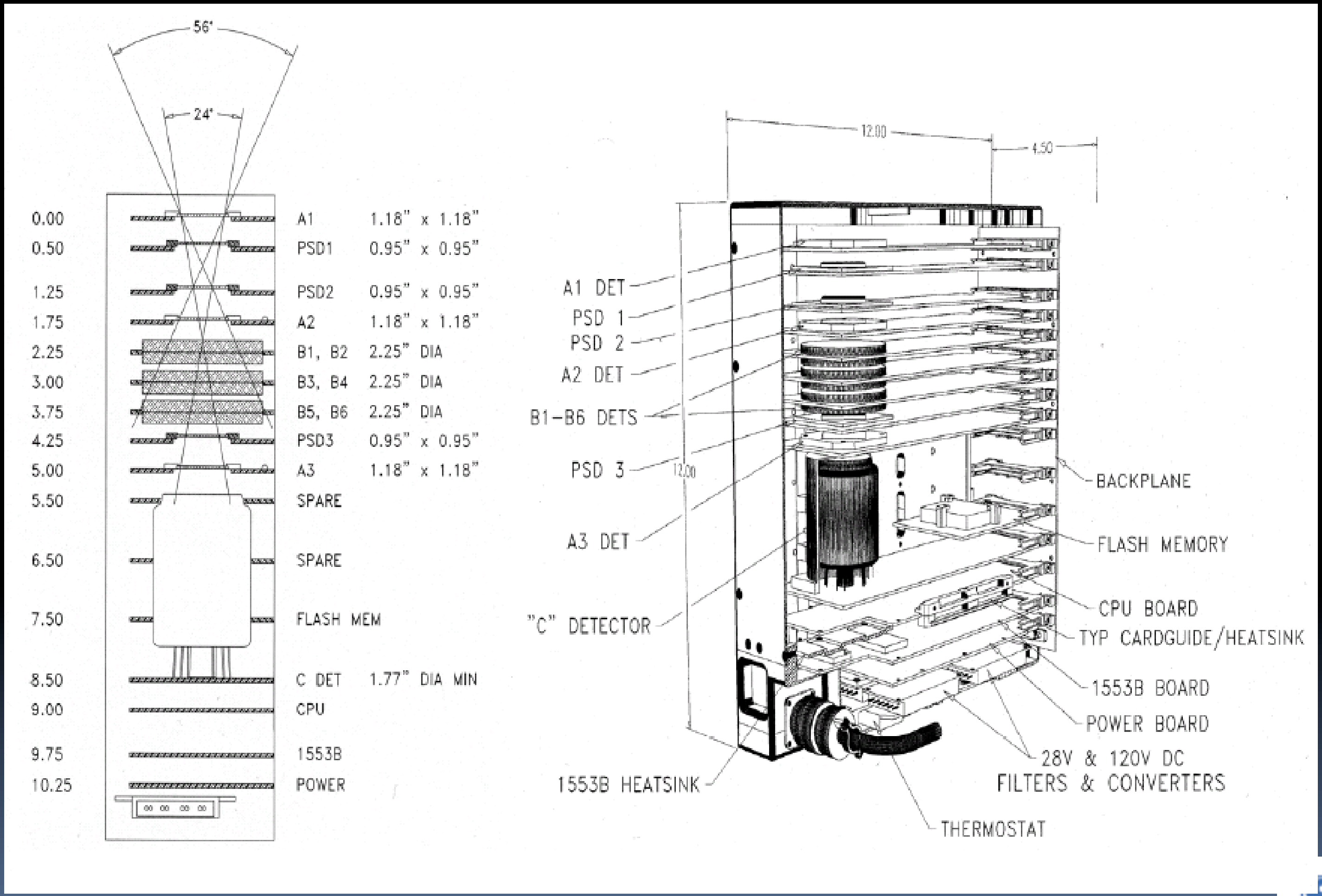
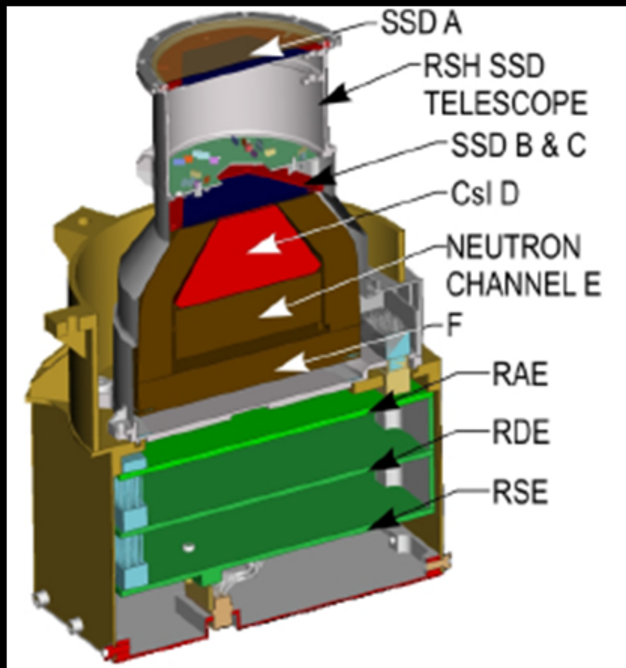


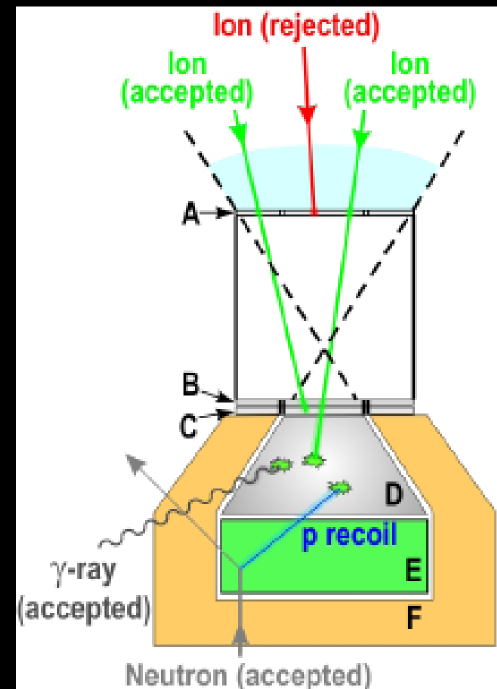
Figure from 2007 WRMISS talk by Kerry Lee.

RAD as CPDS Replacement

- CPDS's are old, 2/4 not operational.
- RAD for MSL was built by a collaboration of SwRI and CAU Kiel.
  - Charged particle telescope similar to DOSTEL.
  - Also neutral detectors (gamma & neutron).
  - Detailed MSL-RAD talk given last year.
- SwRI is building ISS-RAD with support from CAU Kiel team.

RAD Sensor Head (RSH)





- Thin silicon detectors for dE/dx.
- CsI stops protons up to 95 MeV & medium-energy heavy ions (e.g., Fe up to ~ 400 MeV/nuc). Replaced by BGO for ISS-RAD.
- BC-432 plastic for neutron detection (1.8 cm × 6 cm).
  - Hermetic anticoincidence also made of BC-432.
  - Scintillators read out with p-i-n diodes.

ISS Measurement Requirements

- Charged particle requirements similar to those for MSL-RAD, e.g., detect charged particles from Z = 1 to Z = 26.
- Neutral particle requirement is different: must measure neutrons down to 0.5 MeV whereas MSL-RAD lower limit is ~ 5 MeV.
  - MSL RTG power source limits measurement at lower energies (too much background).
  - Plastic scintillator + photodiode method insensitive below about 5 MeV anyway.

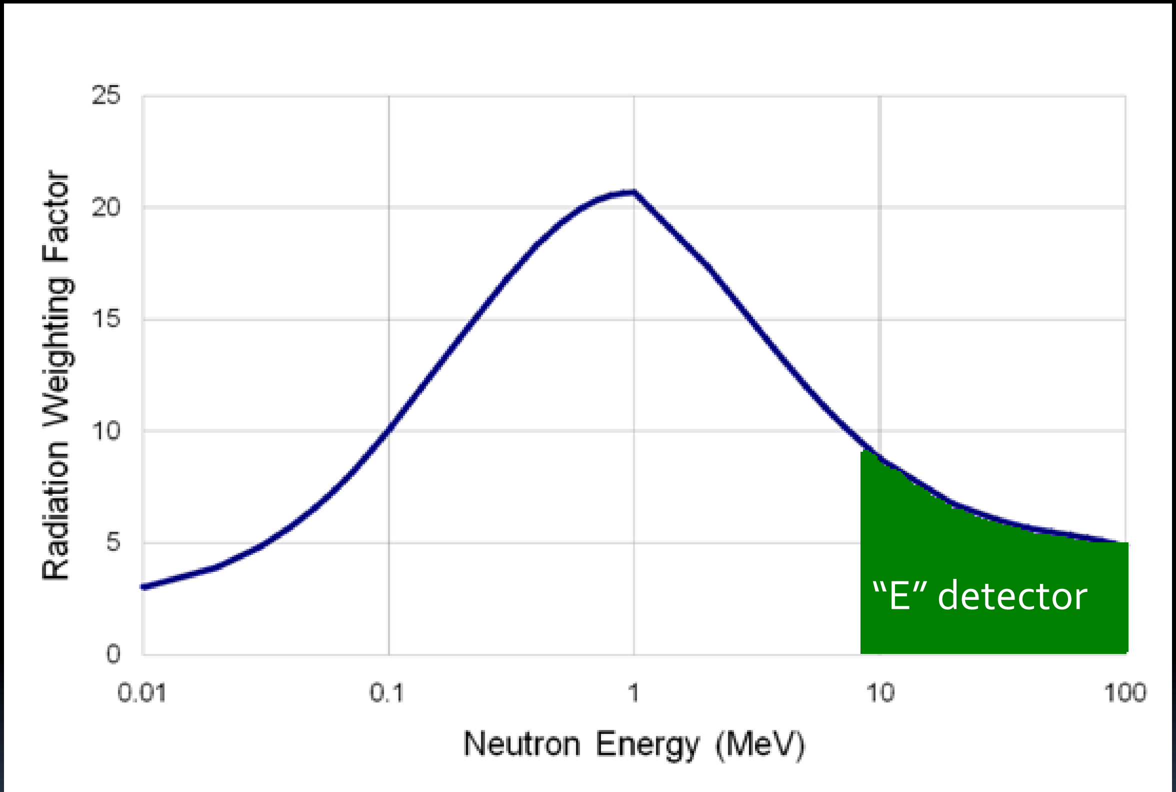
“Fast” Neutron Solution

- Considered several options for 0.5 – 10 MeV neutron detection.
- Settled on a separate detector in conjunction with a RSH that is ≈ same as on MSL.
- The two subassemblies – RSH and FND – will share a common housing and interface to ISS.
- FND will use a boron-loaded plastic scintillator with PMT readout.
  - Use double-pulse technique to identify neutrons and measure their energies.
  - Excellent background rejection.

A Brief History…

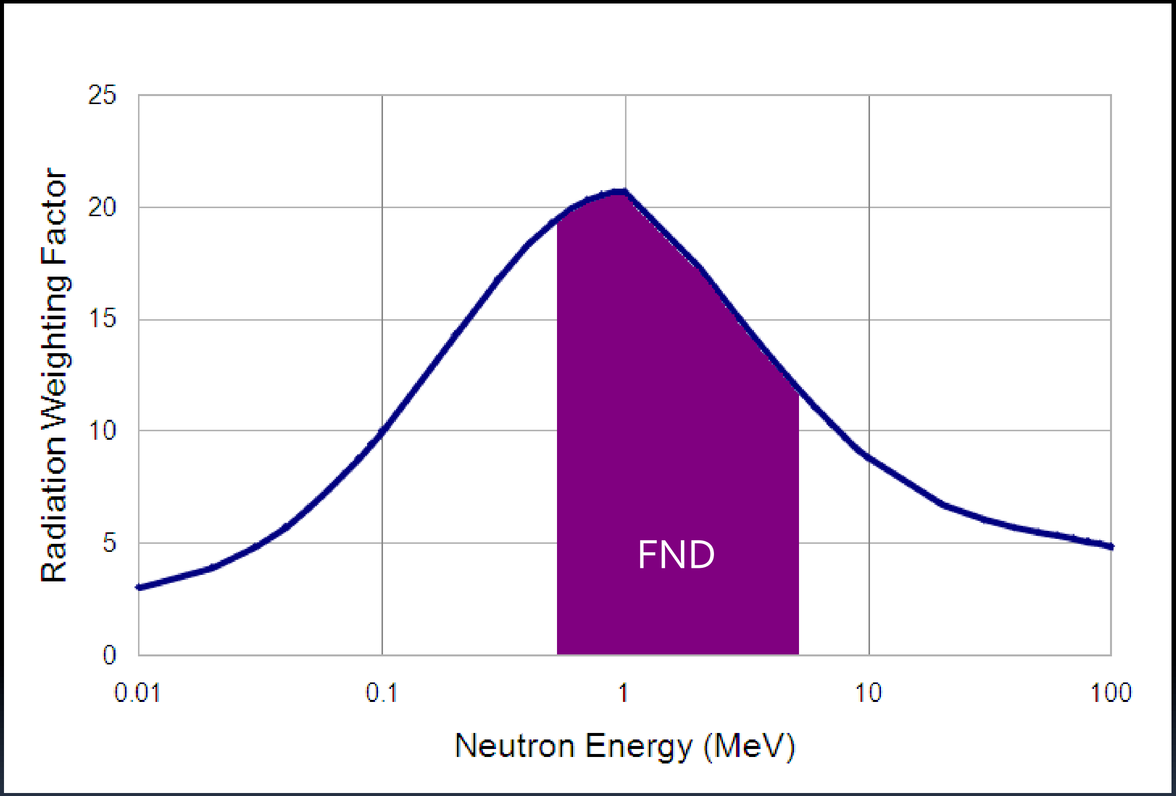
- 1986: 1st boron-loaded plastic scintillator reported by Los Alamos group + inventor of BC-454, Chuck Hurlbutt.
- Previous flight instruments with boron-loaded scintillators:
  - LANL's Neutron Spectrometer on Mars Odyssey.
  - APL's Gamma-Ray and Neutron Spectrometer on Mercury MESSENGER.

Neutron Weighting Factor



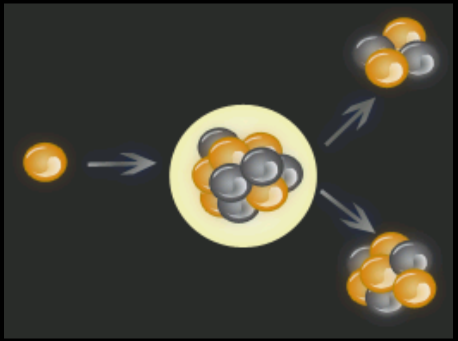
- Can't go much below 5 MeV with plastic scintillator + pin diode approach.

Neutron Weighting Factor



- FND adds sensitivity where w_R is large.

Double-pulse method

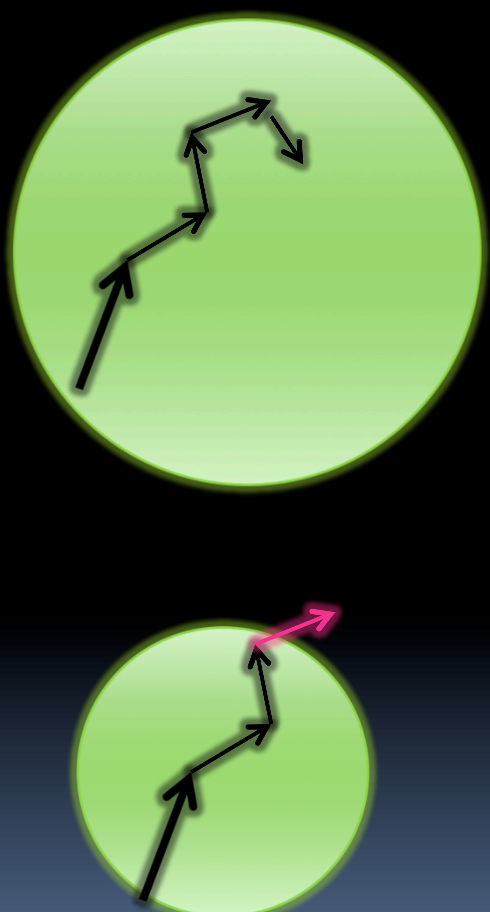


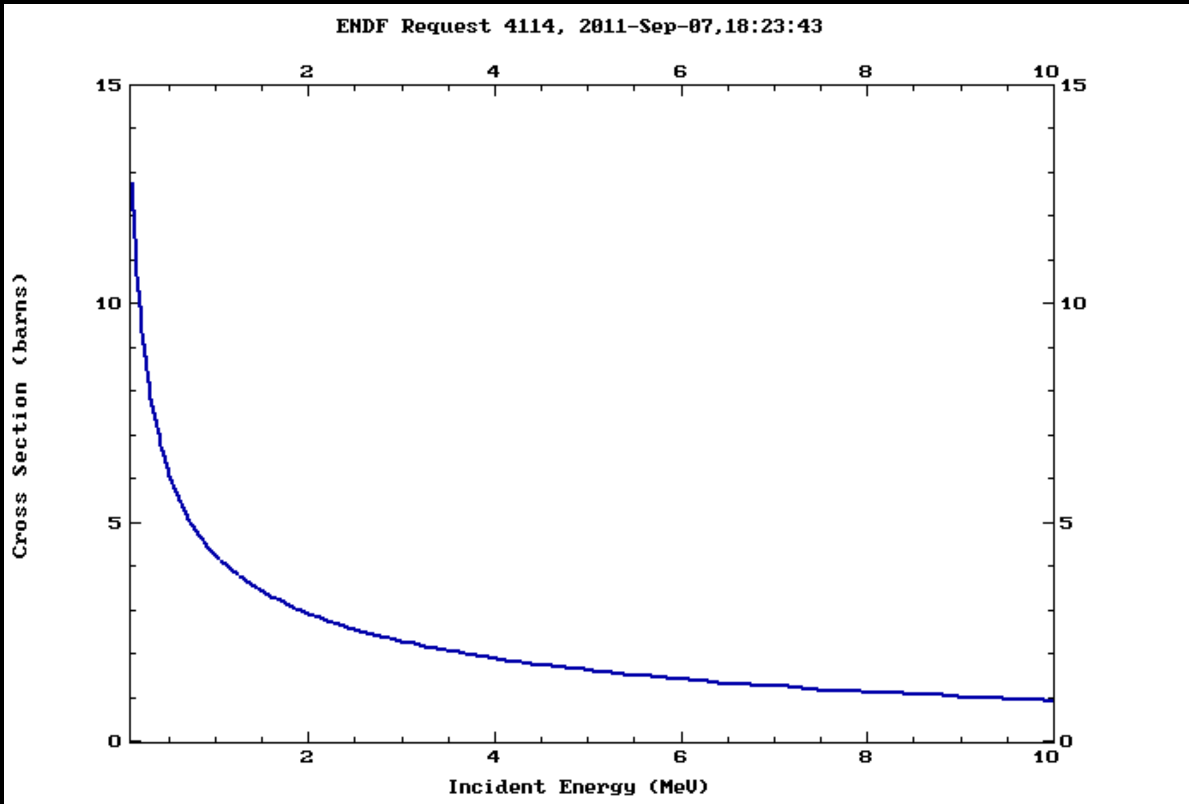
- Neutrons are moderated by interactions with hydrogen in the plastic (recoil protons), producing a light flash.
- Neutrons that lose ≈ all their energy scatter until they escape or are captured by a ^{10}B nucleus.
- n + ^{10}B → ^{7}Li + ^{4}He with 94% chance of coincident γ
  - ^{7}Li has E = 0.84 MeV, α has E = 1.47 MeV, E(γ) = 0.48 MeV
  - Second pulse from capture reaction products, mostly from the α.

Background Rejection

- For a scintillator with 5% boron by weight (20% of which is ^{10}B), average time for capture is ~ 2 μs.
  - Average time of ~ 10 μs for 1% boron.
  - Depends slightly on detector size.
- In electronics, set up two adjustable windows:
  - Time between 1st and 2nd pulse.
  - Amplitude of 2nd pulse.
- Capture-gating strongly rejects coincidence background from charged particles and γ's.
  - No active anti-coincidence required in typical conditions.

Efficiency





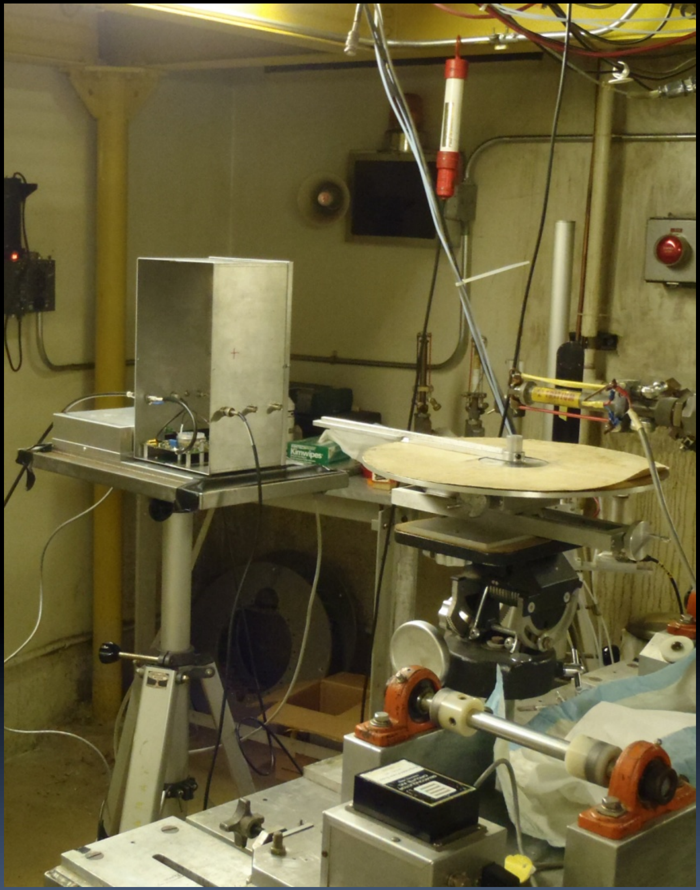
- Multiple interactions required to thermalize incident neutrons.
- Larger scintillator = higher efficiency.
- Larger also means slightly longer average time to capture.
- MCNP model development underway at JSC.

Shielding

- Charged particle background is manageable with time & amplitude windows even in SAA.
- Ambient thermal neutrons possibly a problem → wrap scintillator in a material with large capture cross section, e.g., Cd or (more likely) Gd.
- Gamma & x-ray backgrounds also a concern but probably not too large inside ISS – Gd thermal neutron shield will also absorb γ's.

Scintillator Tests at RARAF

- Radiological Research Accelerator Facility (RARAF) run by Columbia University
- Quasi-monoenergetic neutrons up to 14 MeV.
- We used 0.5, 1, 2, 3, and 6 MeV beams.
- Ran experiment August 3-5, 2011.
- Small cave → considerable "room background" from γ's & scattered neutrons.



Scintillator Materials

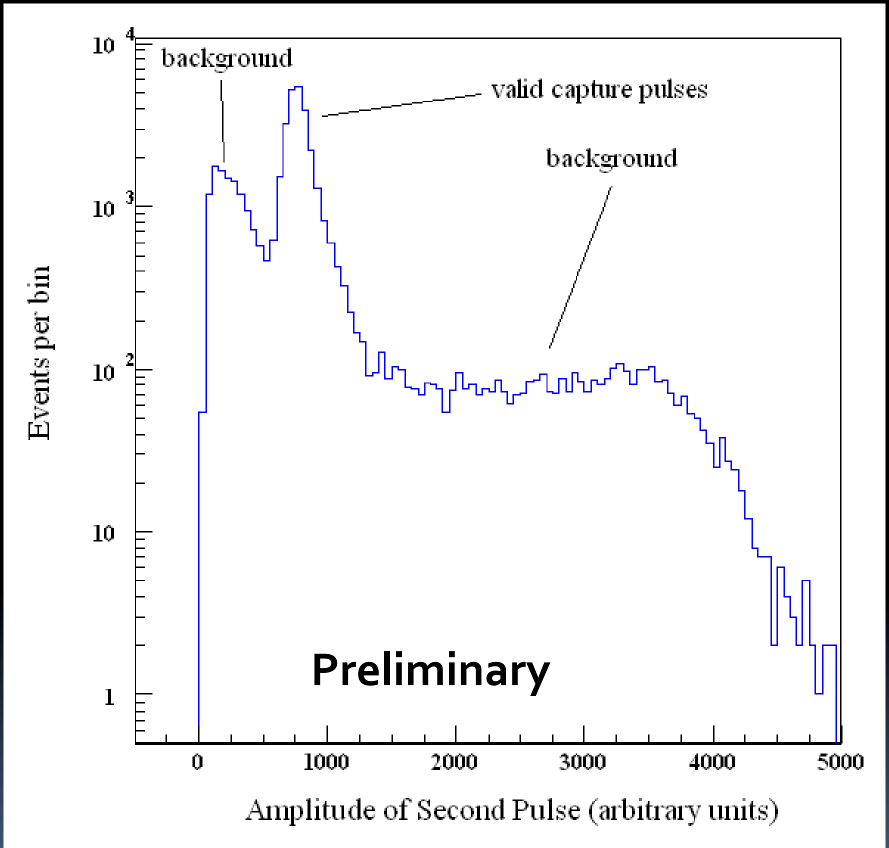
- C. Hurlbutt now at Eljen Technology, got fresh samples from him:
  - Eljen EJ-254 with 5% boron by weight.
  - Eljen EJ-254 with 1% boron by weight.
  - Eljen EJ-200 with no boron.
  - Also, old piece of BC-454 (5% B) from St. Gobain.
- All samples are right circular cylinders, 5 cm diameter, 5 cm length.
- Each scintillator was connected to a PMT and read out by analog and digital electronics, prototypes of flight electronics.

Sensitivity Requirement

- Adding boron to plastic scintillator reduces transparency.
- Capture pulse is faint – 2.3 MeV released into $\alpha + {}^{7}Li$, but light output only ~ 100 keVee due to quenching.
- We have to detect 0.5 MeV neutrons, light output from those < 50 keVee.

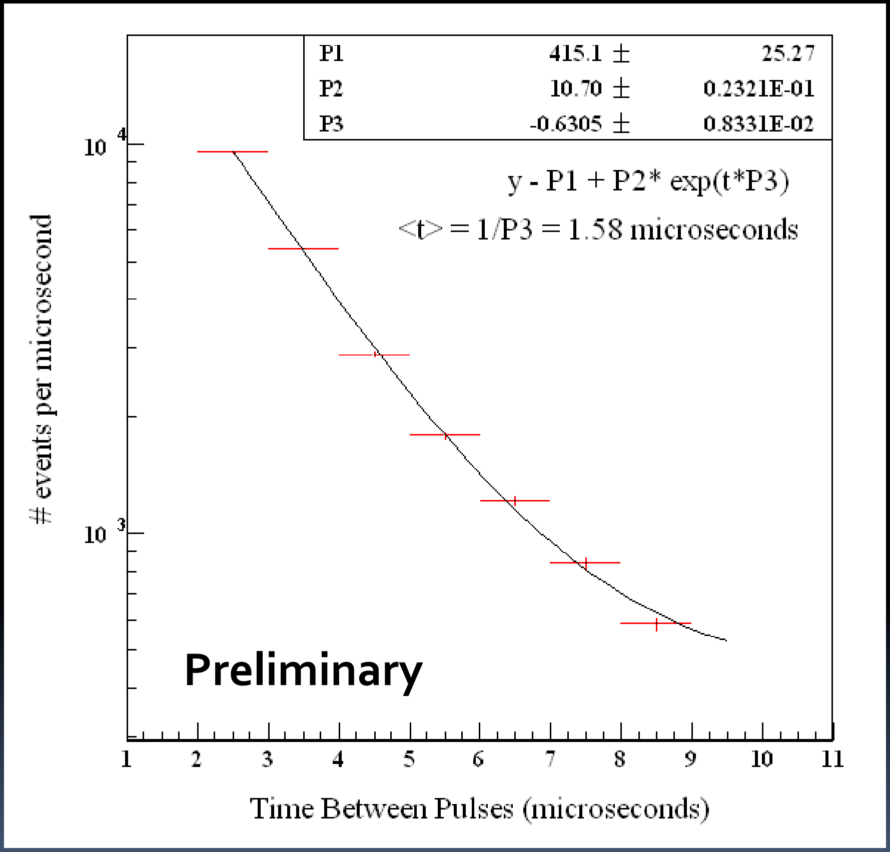
Event Data

- Data acq. triggers on single pulses, looks within a specific time window for a 2nd pulse.
- Depending on neutron energy, see varying % of 2-pulse events.
- More 2-pulse events seen at low energy due to higher probability of incident neutron being thermalized in plastic.



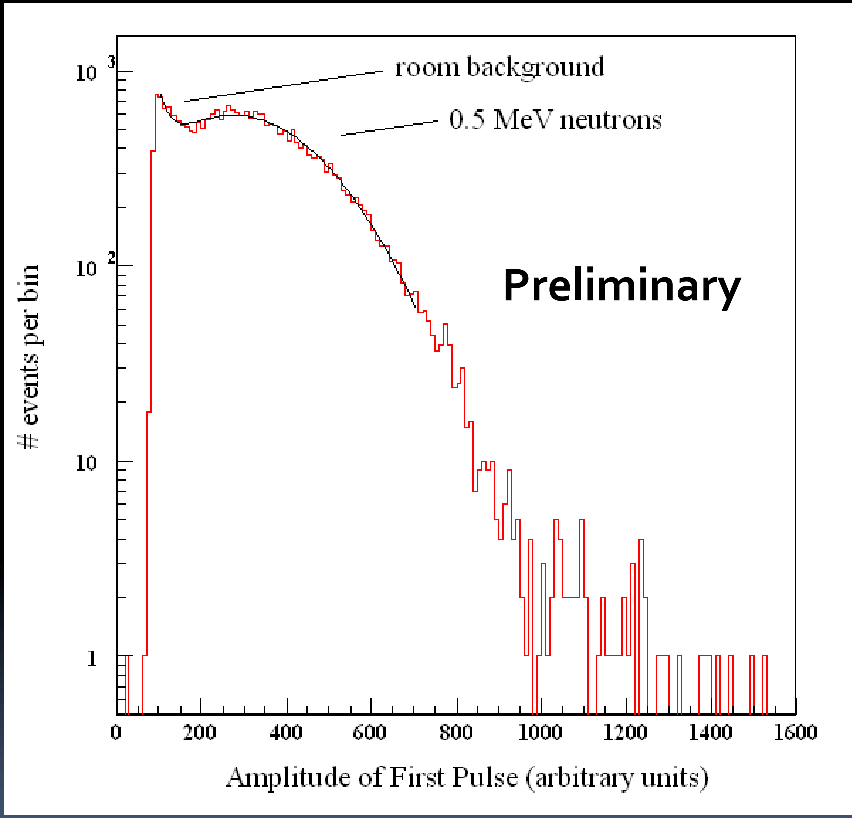
Time-to-capture Distribution

- <Δt> between 1st pulse (recoil protons) and capture pulse predicted to be 1.69 μs (Kamykowski).
- Filter data on 2-pulse events, apply amplitude window on 2nd pulse, plot Δt histogram.
- Expect exponential distribution, data fit better with exponential + const
  - Some residual background is not removed by pulse-height cut.



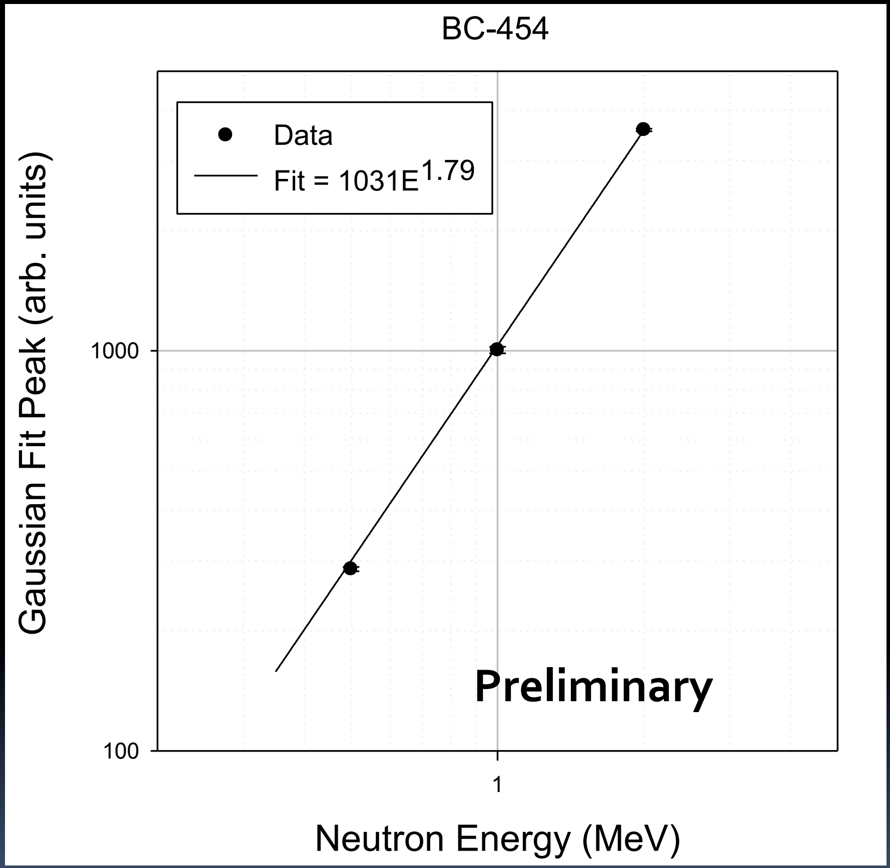
Recoil Proton Energy

- Apply capture pulse amplitude cut and plot amplitude of 1st pulse.
- See room background & 0.5 MeV neutrons.
  - Peak amplitude below that of capture pulse.
- This is BC-454 (5%) data.
- σ/E ~ 30%.



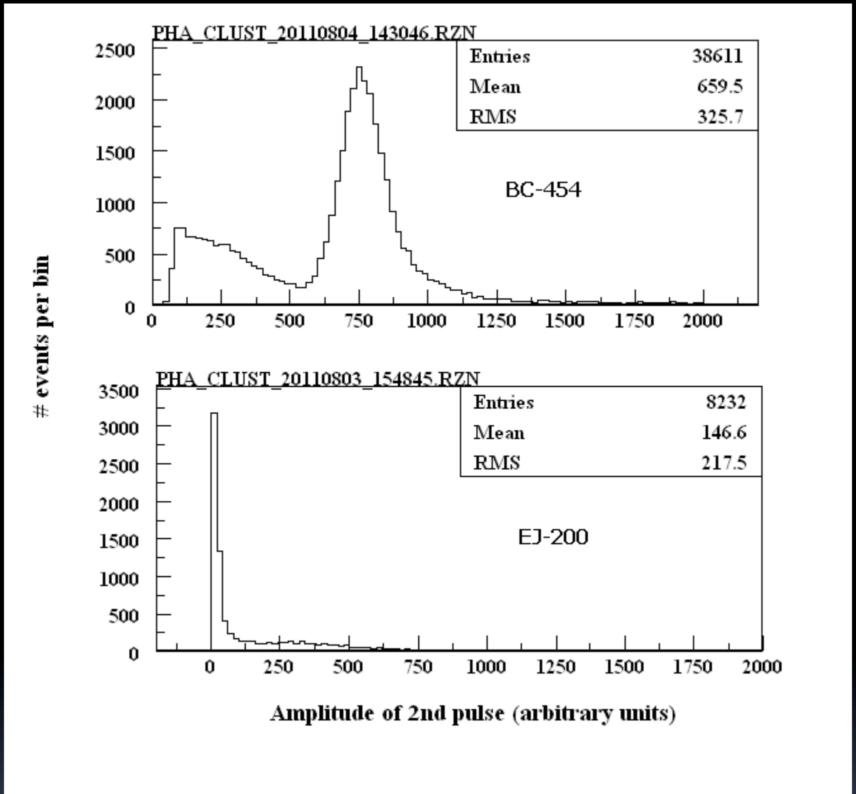
Energy vs. Peak Location

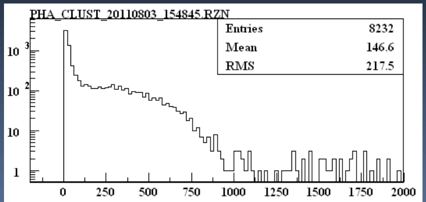
- Neutron peaks look Gaussian – broad, as expected.
- Peaks obey power law:
  - Fit of 0.5, 1, 2 MeV gives exponent of 1.79.
  - Reasonable agreement with $E^{1.6}$ predicted by Byrd & Urban.
  - May change as we improve calibration.



EJ-200 non-loaded scintillator

- Sanity check – look at EJ-200 to make sure we don't see anything that looks like a capture pulse.
- Use 0.5 MeV data.
- Obviously no peak but a few events w/right amplitude.
- On closer inspection this is ~ same distribution as first pulse in BC-454.
  - "Second pulse" in this case is just a second 0.5 MeV neutron.





Conclusions

- All components performed well at RARAF.
- Data analysis just starting.
- 5% boron samples (EJ-254 and BC-254) are ~ identical.
  - This was not obvious given the different manufacturers.
- 1% EJ-254 should be most transparent, but scintillators with 5% boron appear good enough to see 0.5 MeV neutrons.
  - Shorter time window w/5% B → Less background
- Data from non-loaded EJ-200 will allow us to understand the backgrounds in the experiment.