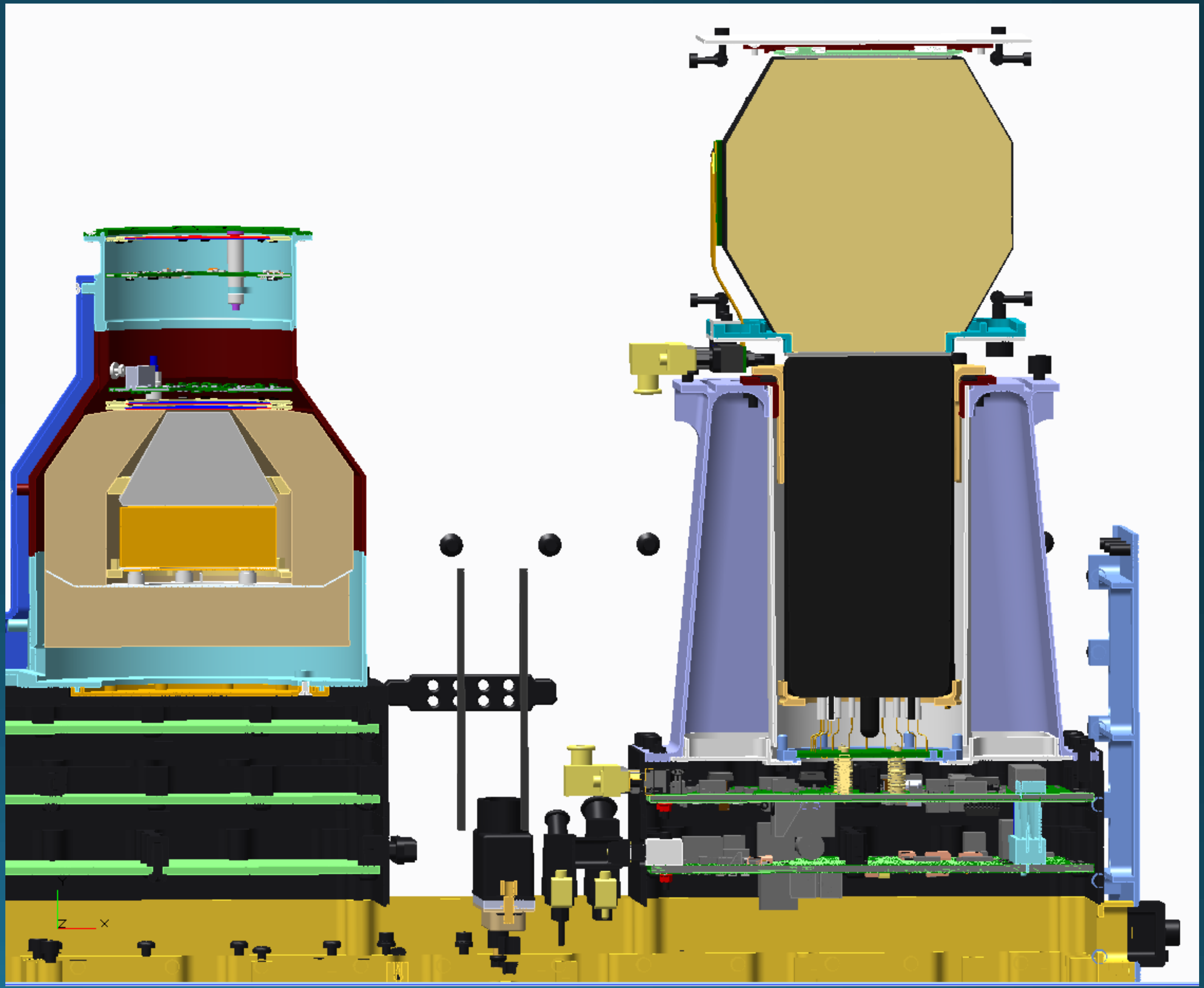
Results from the ISS-RAD Charged Particle Detector and Comparisons to MSL-RAD

Cary Zeitlin, Ryan Rios, Martin Leitgab, Kevin Beard
Leidos/NASA-JSC SRAG

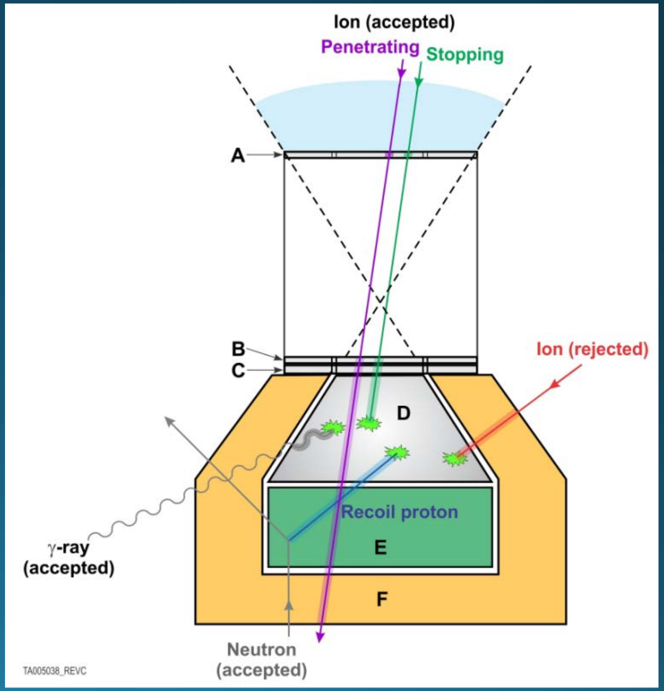
ISS-RAD Concept

- “CPD” on the left, nearly identical to MSL-RAD.
- “FND” on the right: boron-loaded plastic scintillator + PMT to detect neutrons from 0.5 MeV to ~ 10 MeV.
- CPD also detects neutral particles above about 5 MeV.



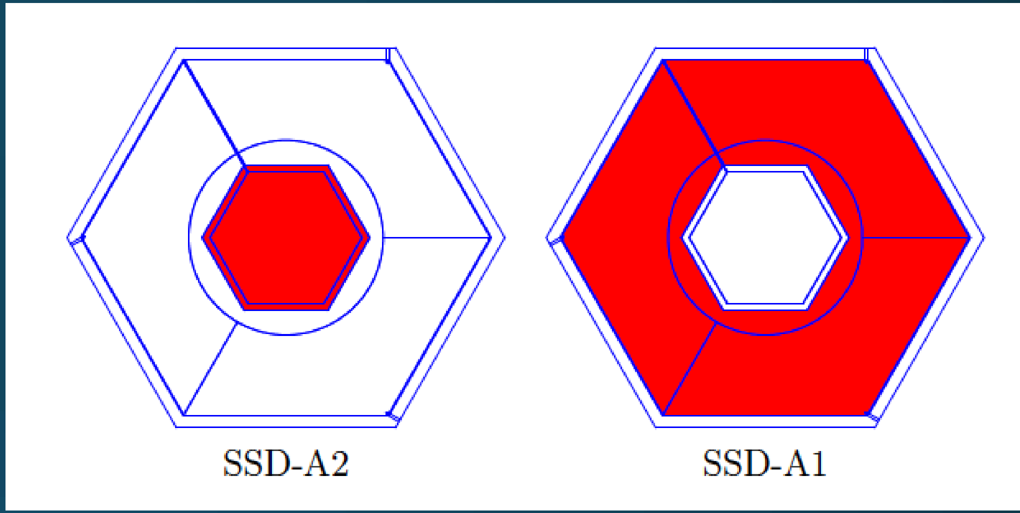
CPD ≈ MSL-RAD

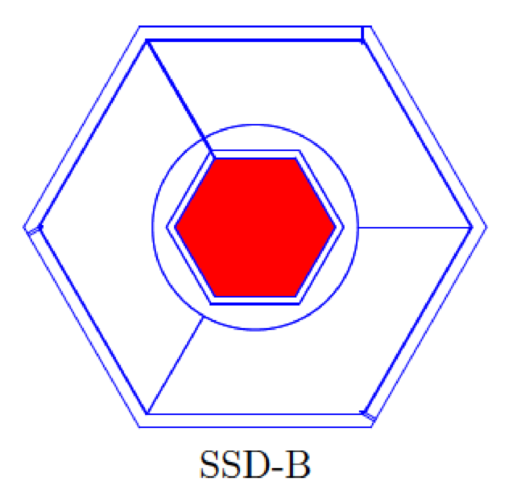
- 3-element silicon detector telescope (A, B, C).
- BGO scintillator = D (CsI in MSL-RAD).
- Plastic scintillators E & F are 1.8 cm thick (F is 1.2 cm thick in MSL-RAD).
- F = anticoincidence, upper (F1) and lower (F2) for neutral detection.
  - D, E, & F have photodiodes attached for collection of scintillation light.
  - 2 diodes each on D and E (3 on MSL-RAD)
  - F1 & F2 optically decoupled.



Diode Segmentation & Fields Of View

- A2, B, C use inner segment of diodes, A1 uses outer.
  - Two fields of view, two geometry factors.
- A2*B cone half-angle ~ 18°, $\langle\theta\rangle \sim 9°$ (isotropic), G=0.34 cm^2 sr.
- A1*B cone half-angle ~ 30°, $\langle\theta\rangle \sim 17°$, G=1.44 cm^2 sr.

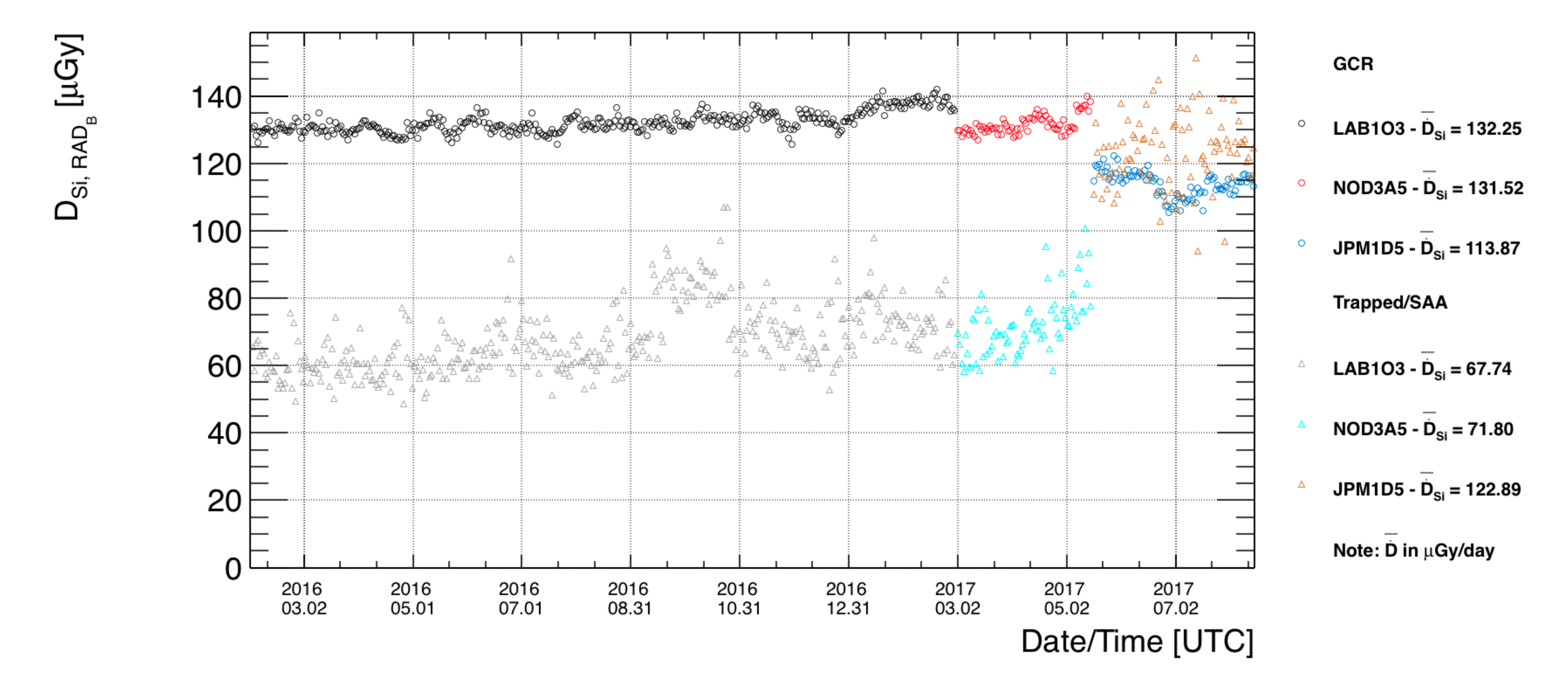




Locations & Orientations

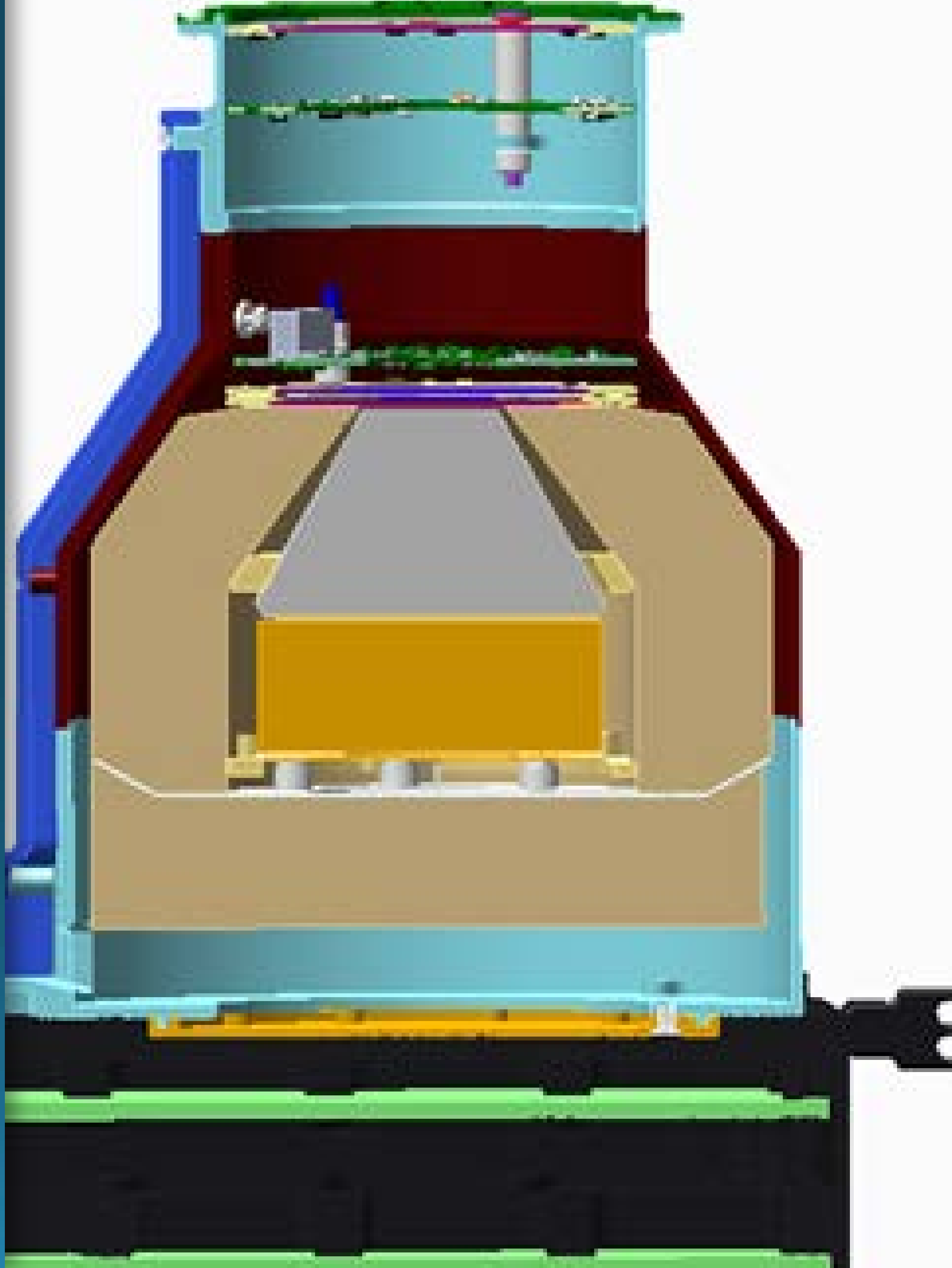
Dates	Location	Top of telescope pointing
2/1/16 – 3/1/17	US Lab O3 (Extended ACO)	Forward (~ 330 days) Nadir (26 days) Aft (30 days)
3/1/17 – 5/16/17	Node 3 A5	Zenith (32 days) Forward (23 days) Starboard (20 days)
5/16/17 – 8/16/17	JPM 1D5	Port (35 days) Zenith (28 days) Starboard (28 days)
8/16/17 –	Columbus 1A2	Zenith

Dose Rate in Silicon (B Detector)



Detector Asymmetry & LET Spectra

- Get LET spectra from coincidences in silicon detectors.
- Treat CPD as a double-ended telescope, but for particles coming in from F, there is ~ 25 g cm^{-2} of self-shielding (mostly BGO).
- Shielding depletes the flux of heavy ions, so the double-ended approximation breaks down.
  - 30% probability for ^{12}C to fragment.
  - 60% probability for ^{56}Fe to fragment.
- Measured flux likely underestimates high LET region and therefore <Q>.
- LET-dependent correction needed.



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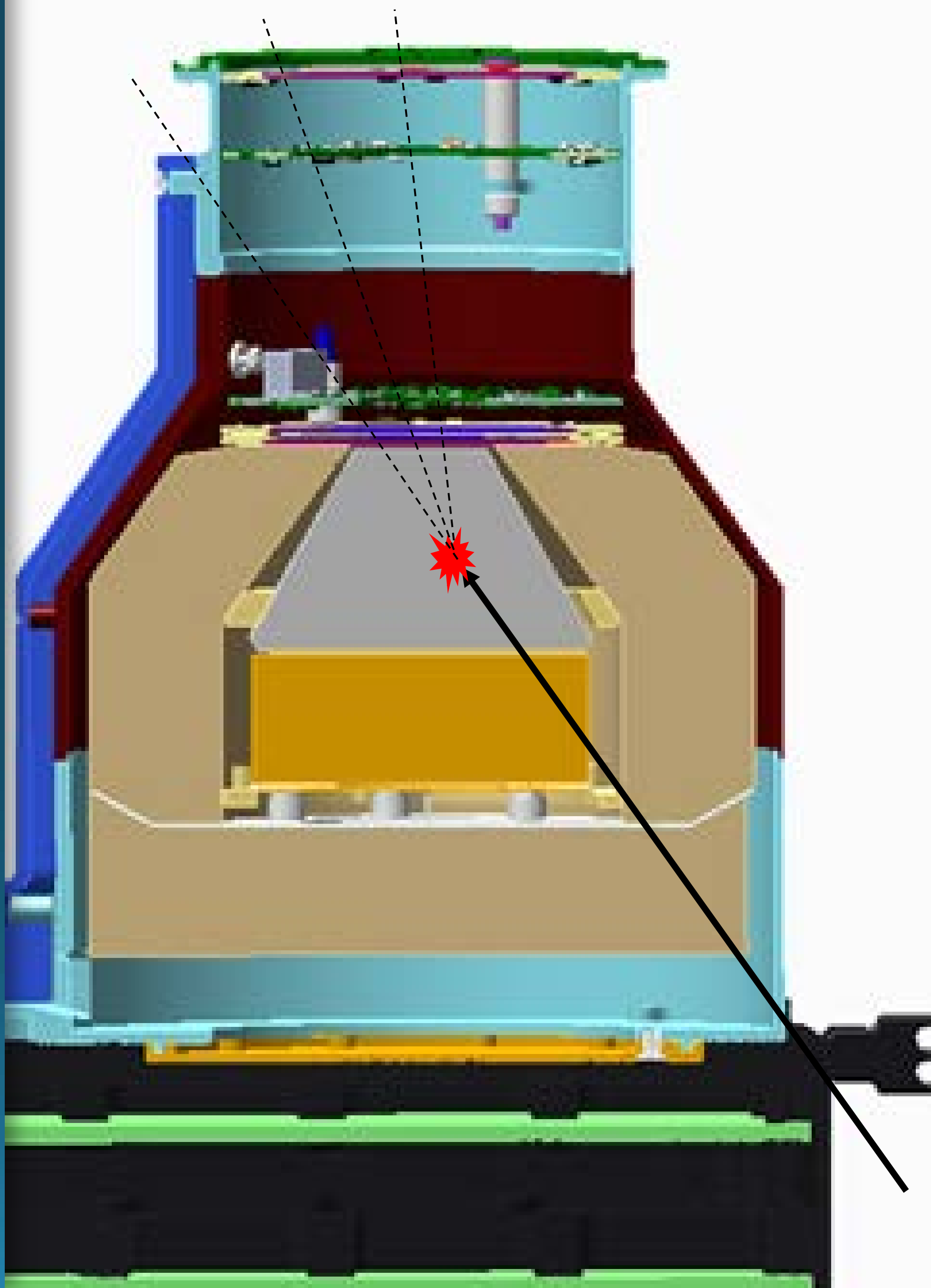
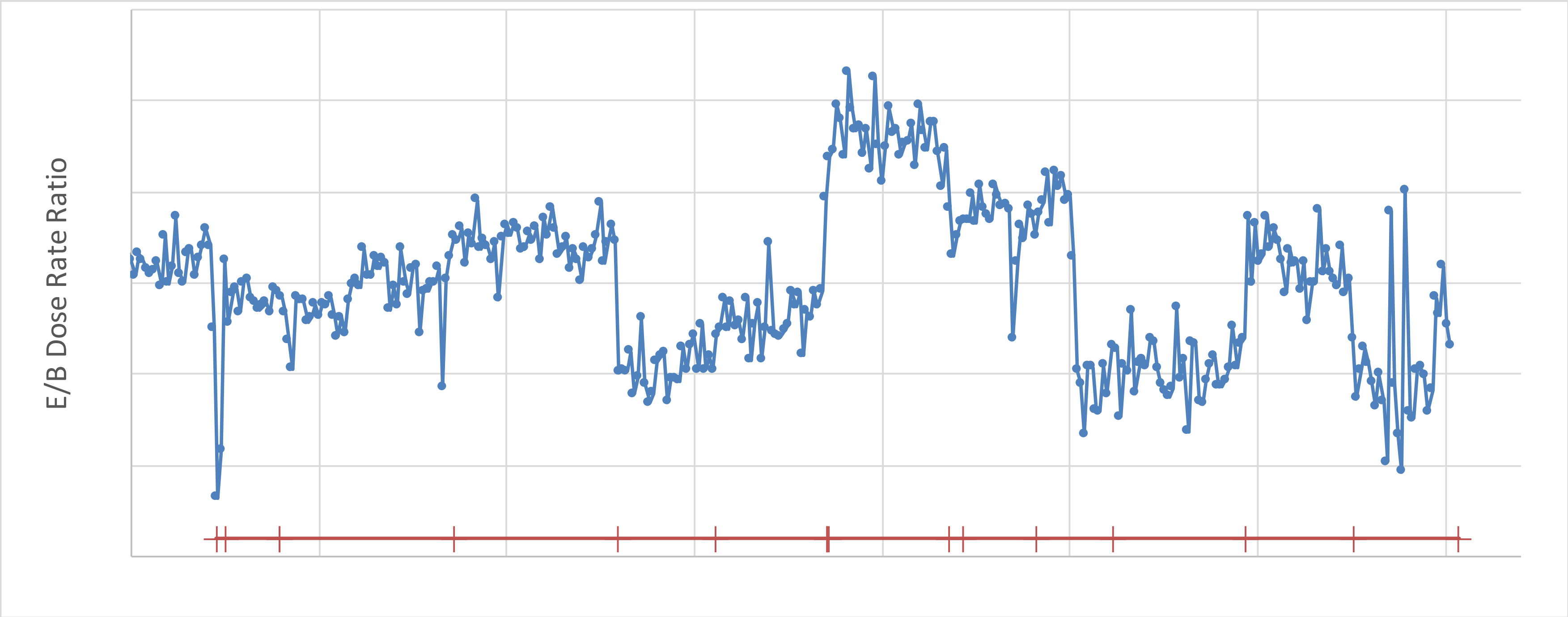
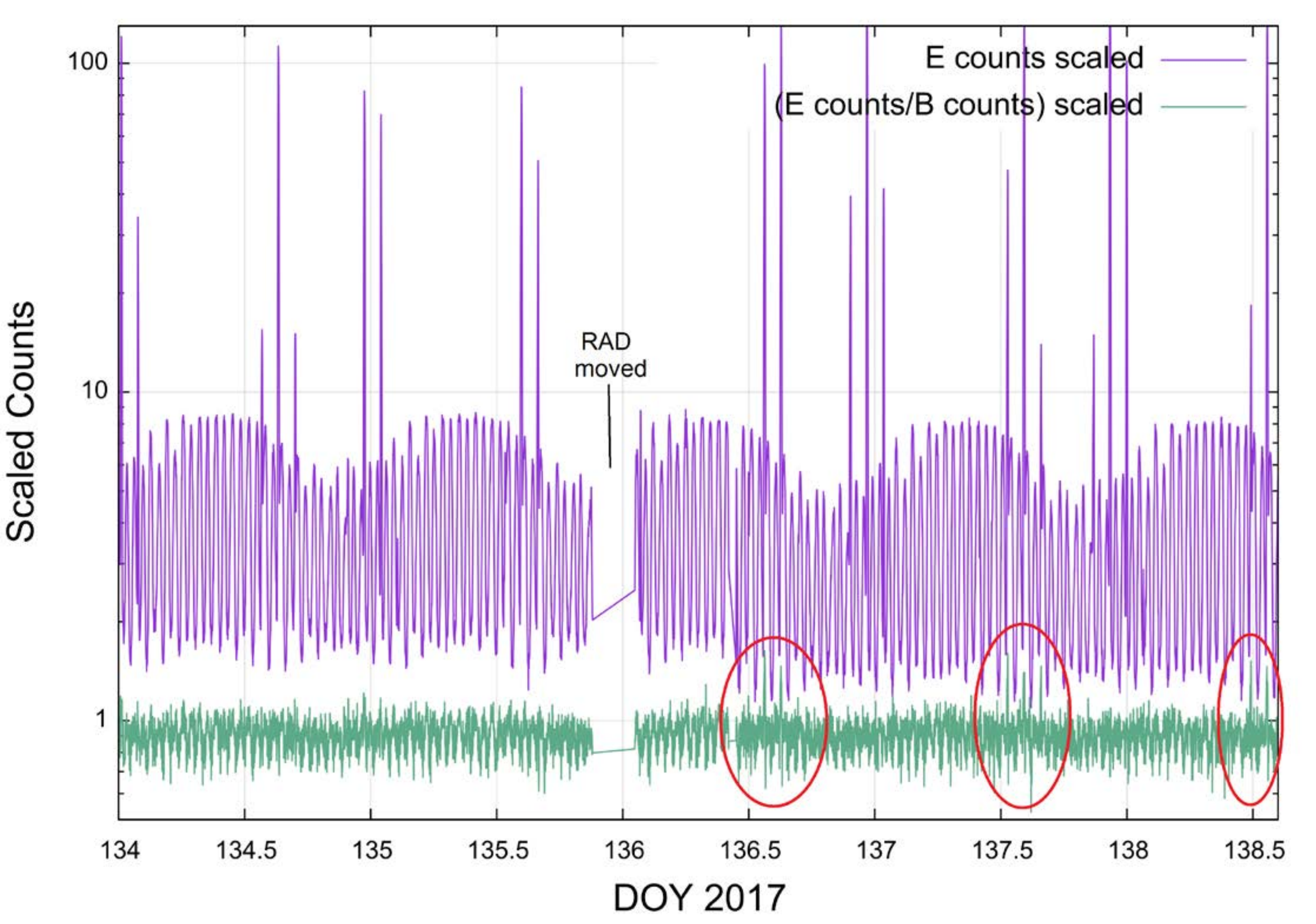


Sensitivity to Location & Orientation



- Daily average (E dose rate)/(B dose rate) shows sensitivity to positioning of detector.
- Likely due to SAA asymmetry & E's relative insensitivity to SAA due to self-shielding.

SAA East-West Asymmetry Observed



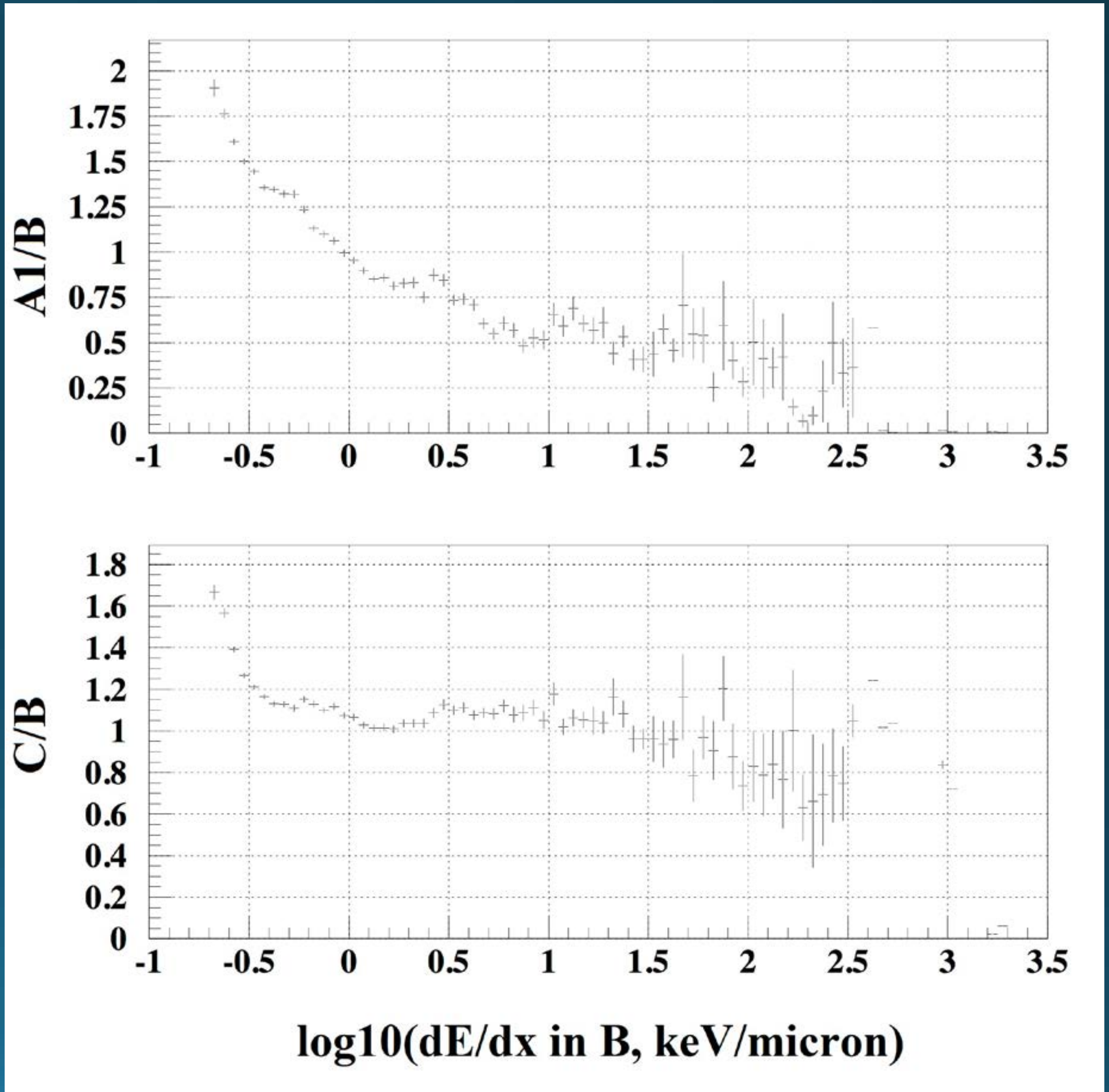
- After move from Node 3 to JPM in May, E/B count rate spikes on ascending SAA passes with CPD pointed port.
- When pointed starboard, spikes seen on descending passes.
- JPM is less shielded than either US Lab or Node 3.

LET Spectra

- Issue discovered with A detector – unexpected large, negative x-talk with B.
  - Not present in ground data.
  - Not very noticeable at low LET.
  - Cause unknown – did a ground connection shake loose?
- Onboard analysis makes cut on A/B ratio, then enters B energy deposit into histogram for events that pass cut.
- x-talk → many high-LET events fail the cut → low <Q>.
  - Same cut was being made in ground analysis.

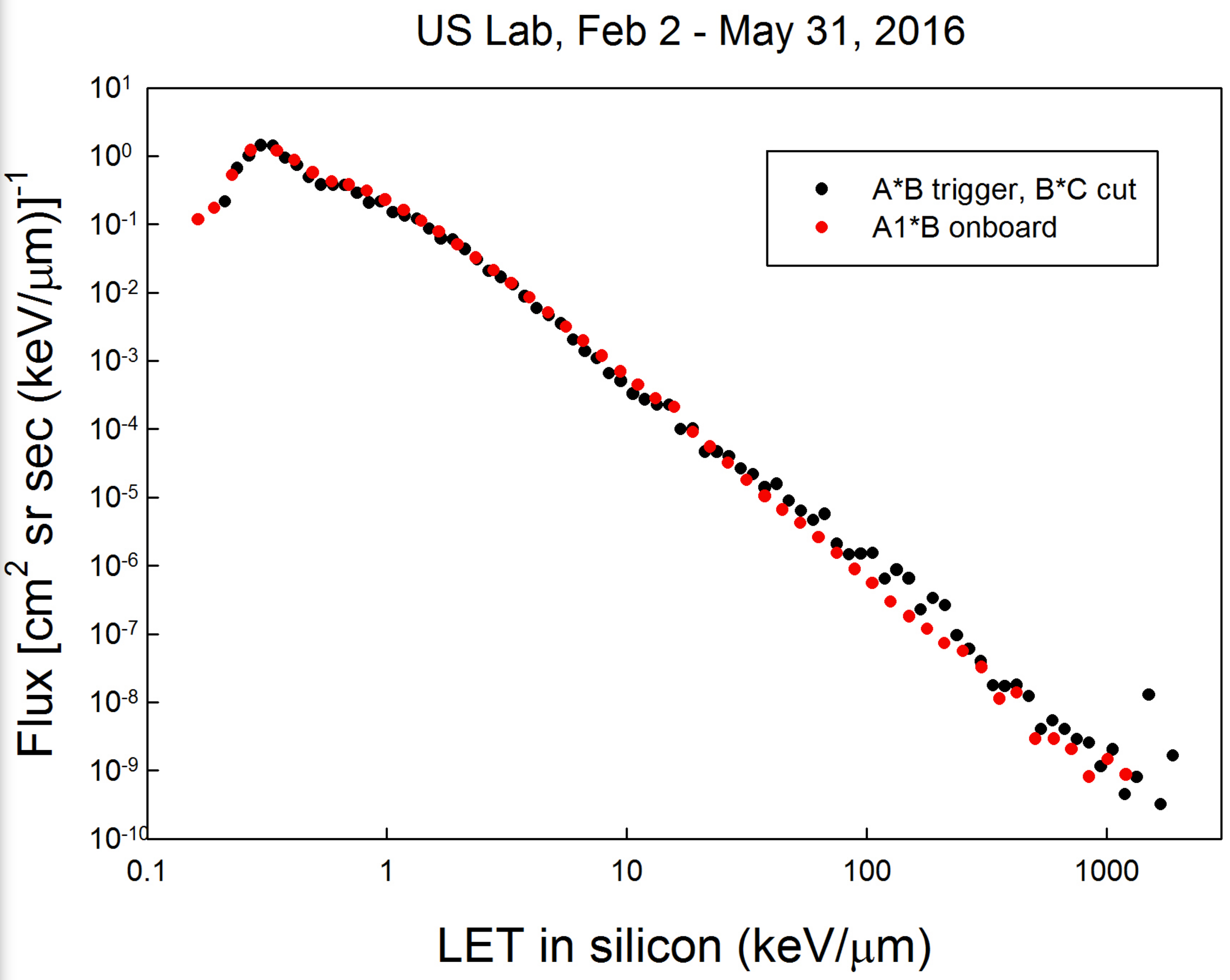
Average Ratios

- Event has to have A/B energy deposit ratio between 0.25 and 4, or onboard histogram is not incremented.
- A1/B ratio average should look like the C/B ratio, but doesn't.
- Fraction of events lost increases with increasing LET in B.



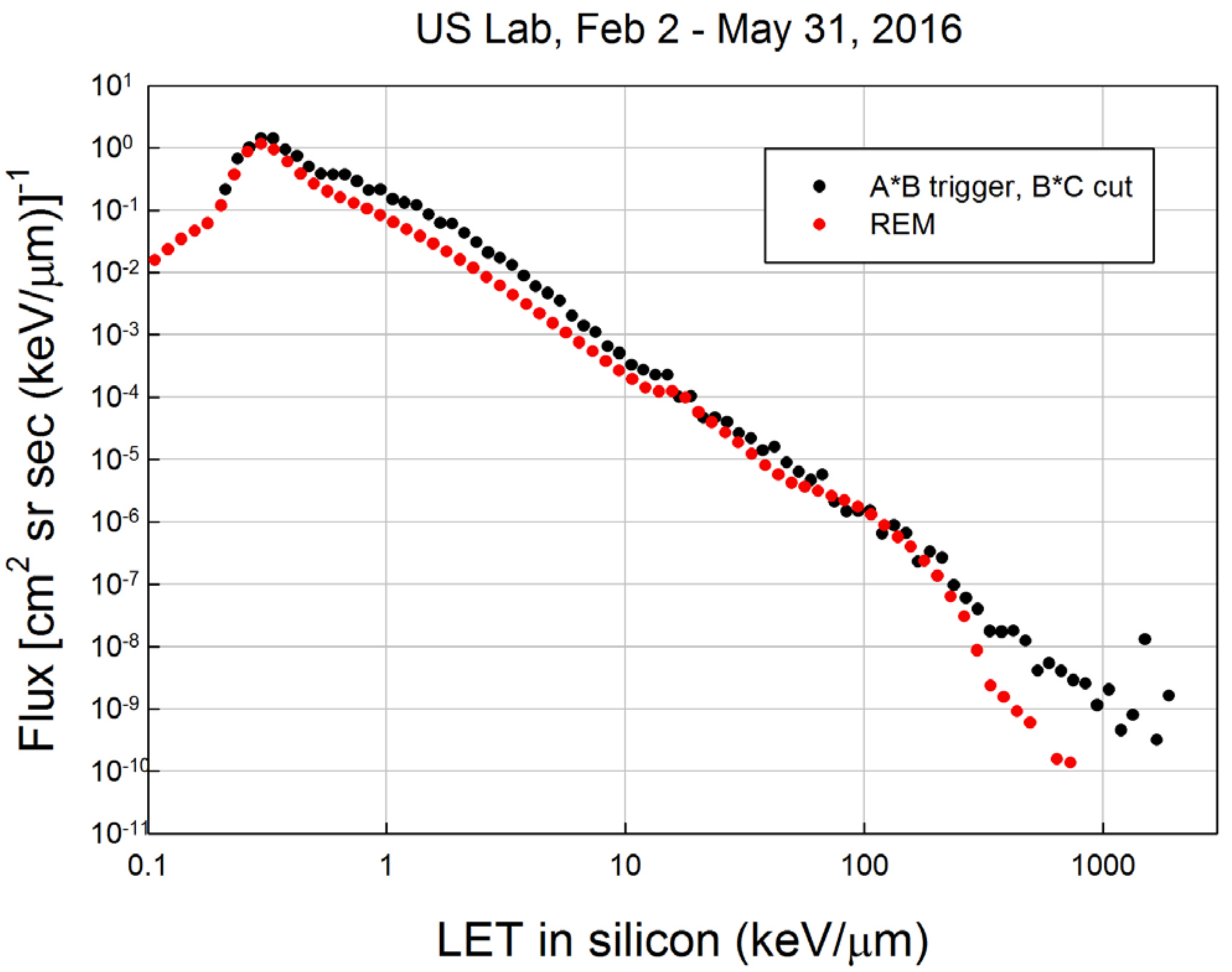
Revised GCR LET Spectrum

- In ground analysis, replace A/B ratio cut with B/C cut.
- Still using events triggered on A*B.
- Spectrum changes only at high-LET compared to result shown in 2016 using onboard histogram.
- In US Lab data, now find <Q> = 1.8, compared to 1.3 w/A*B cut.
- All LET results shown here should be considered very preliminary.



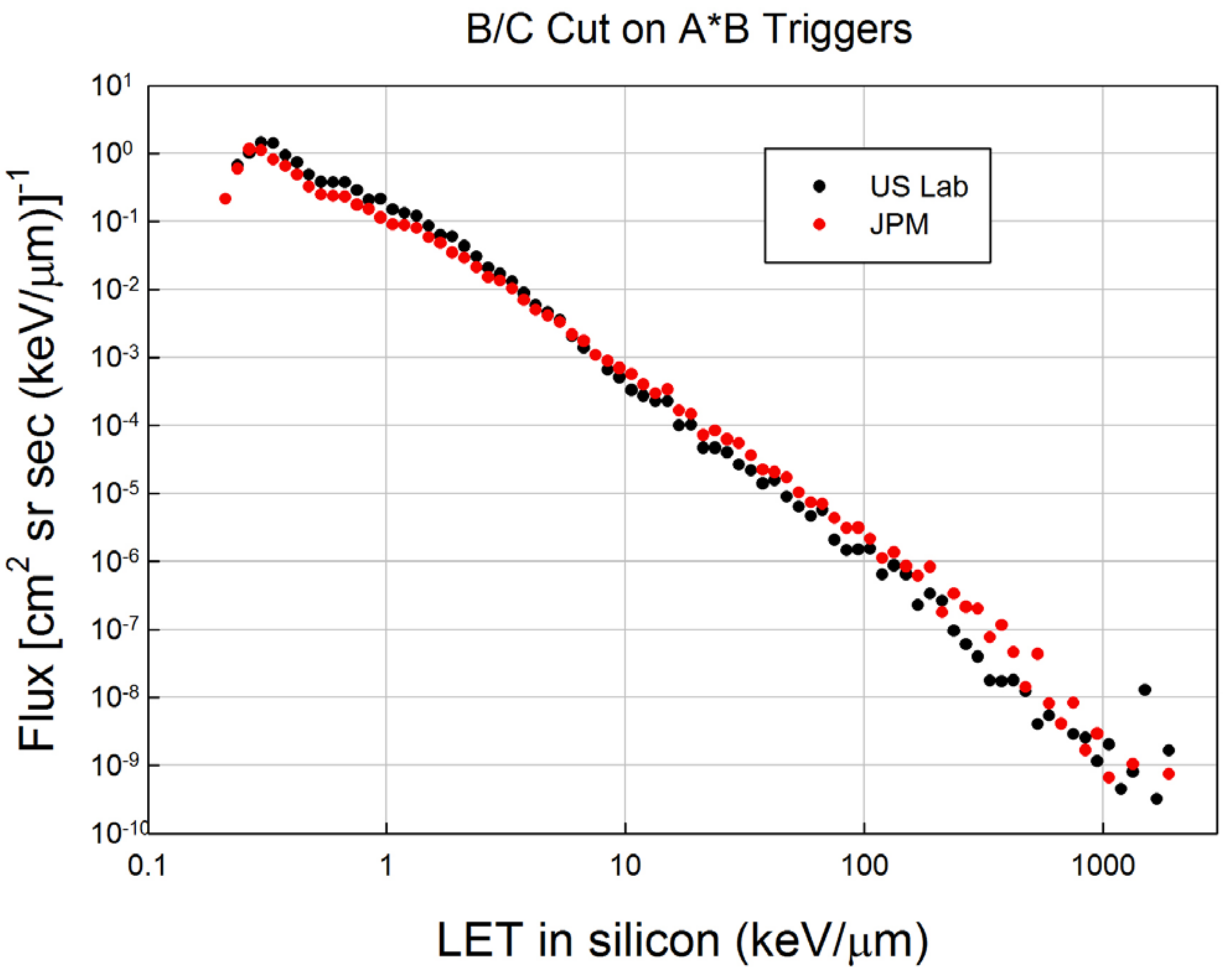
LET in US Lab vs. REM in US Lab

- GCR & SAA combined for both detectors.
- Good agreement for MIPs & from ~ 15 to 150 keV/μm.
- Significant differences from ~ 0.5 to 15 keV/μm and above 150 keV/μm.
- High-LET difference may be due to volcano effect in REM.
- Low-LET difference could be due to shielding.



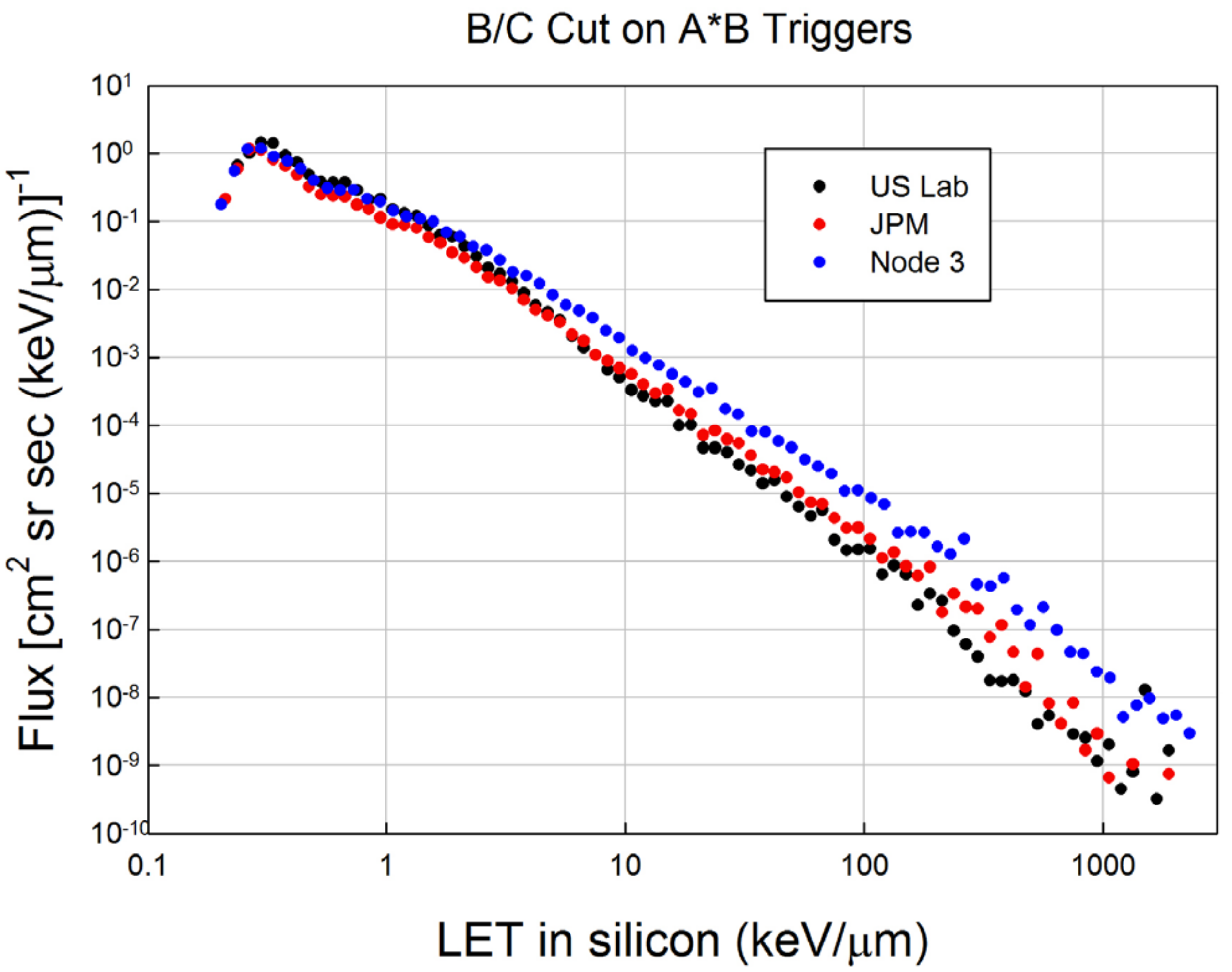
LET in JPM

- <Q> = 2.83
- Fewer low-LET particles, more high-LET.



LET in Node 3

- <Q> = 2.31.
- More high-LET particles than in other locations, low-LET fluxes ~ same as in US Lab.



	MSL-RAD sols 1400-1700	ISS-RAD US Lab	ISS-RAD Node 3*	ISS-RAD JPM*
Omnidirectional charged flux (pfu)	0.41	0.34 GCR 1.77 SAA	0.30 GCR 2.17 SAA	0.26 GCR 3.26 SAA
"Vertical" charged flux from A*B (pfu)	0.65	0.67 GCR 2.38 SAA	0.61 GCR 2.45, 1.36 SAA	0.52 GCR 3.67, 1.54 SAA
Heavy ion count rate** (Hz)	2.60×10^{-3}	1.82×10^{-3}	1.60×10^{-3}	1.44×10^{-3}

*Node3 & JPM data averaged over orientations (port, zenith, starboard).

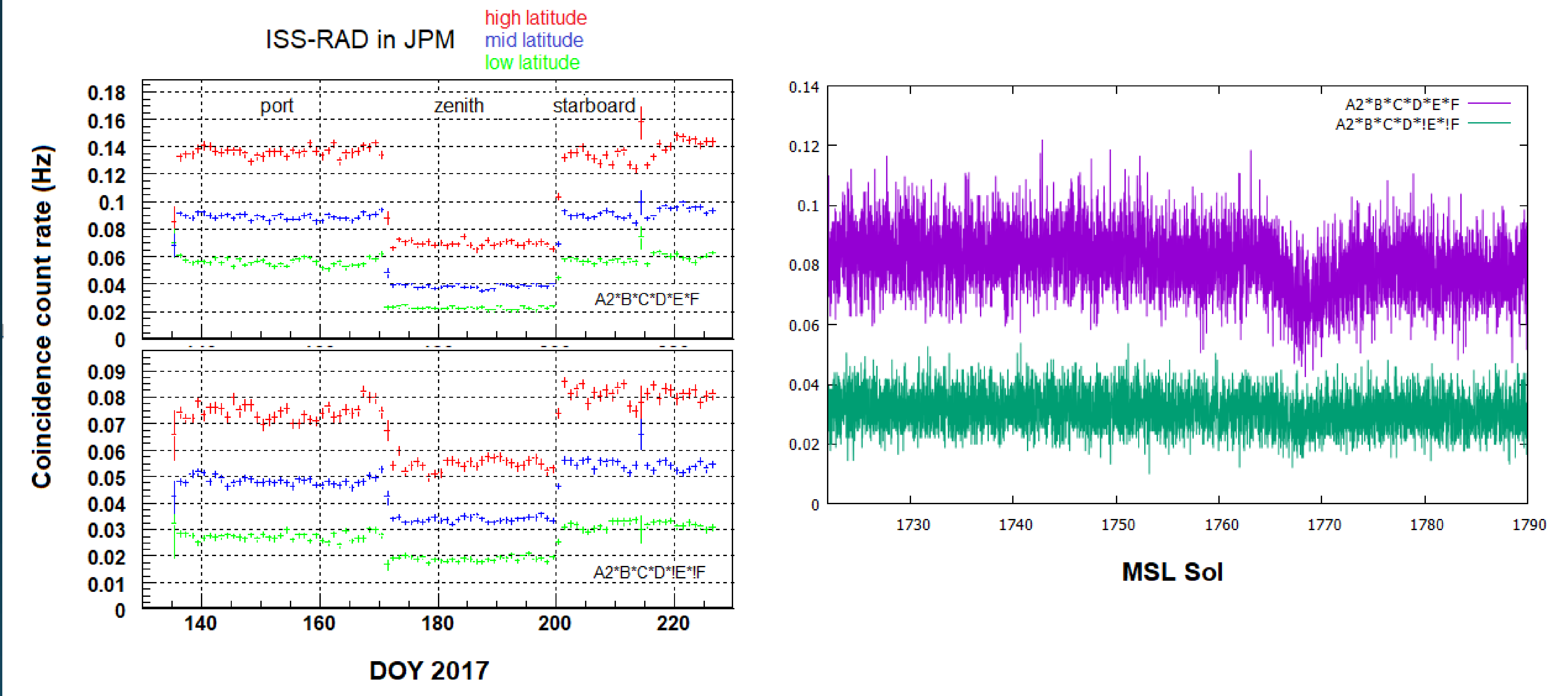
**Heavy ion = LET in silicon > 10 keV/μm, includes slow He.

	MSL-RAD sols 1400-1700	ISS-RAD US Lab	ISS-RAD Node 3	ISS-RAD JPM
B Dose rate converted* to H_2O (μGy/min)	0.148	**0.167 total** 0.128 GCR 1.53 SAA	**0.173 total** 0.129 GCR 1.76 SAA	**0.201 total** 0.113 GCR 2.63 SAA
E/B* Dose ratio	1.12	0.94 GCR 0.87 SAA	0.97 GCR 0.90 SAA	1.01 GCR 0.79 SAA
<Q>	2.4	1.8	2.3	2.8

* Si to water factor = 1.25.

Ignoring shadow factor differences (50% vs. ~33%).

Rotation & Latitude Effects



- Proton energy to reach F ~ 135 MeV in ISS-RAD, ~ 115 MeV in MSL-RAD.

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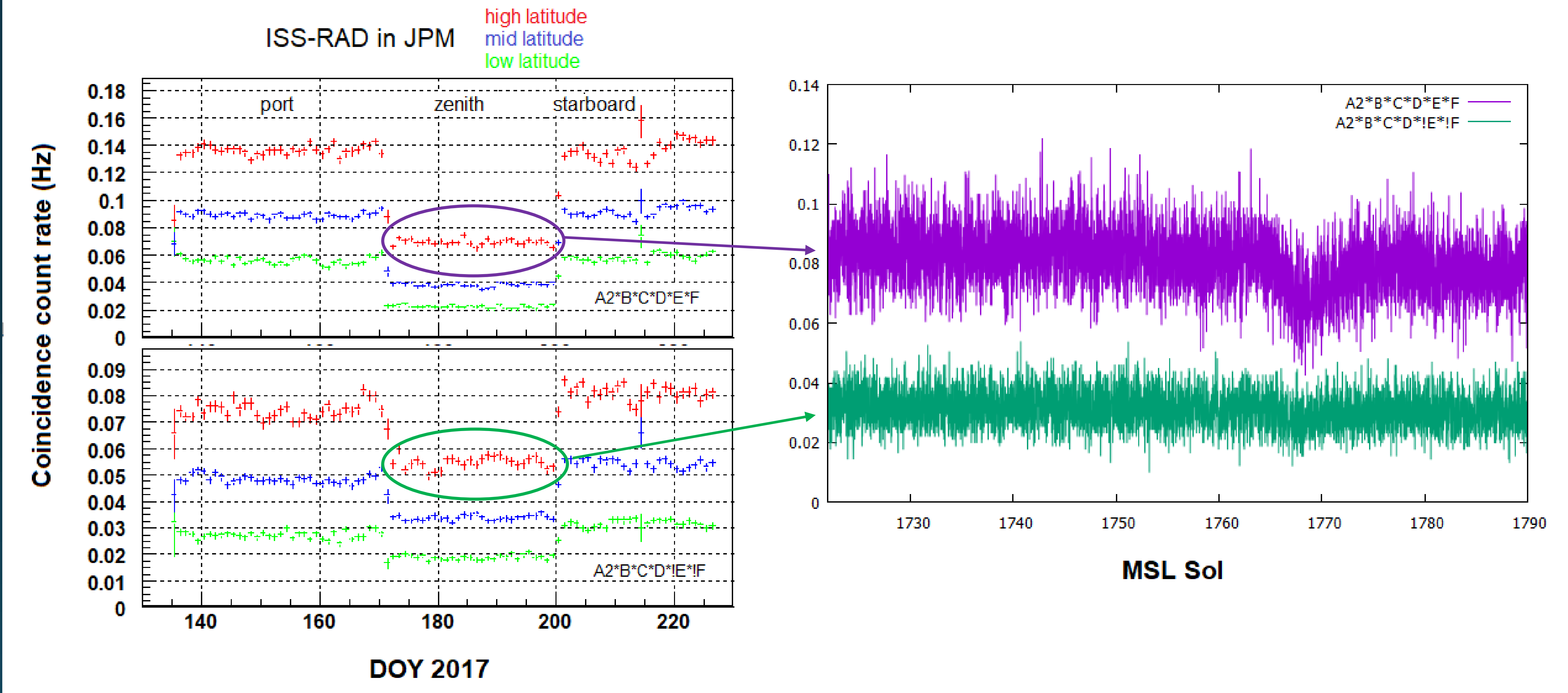

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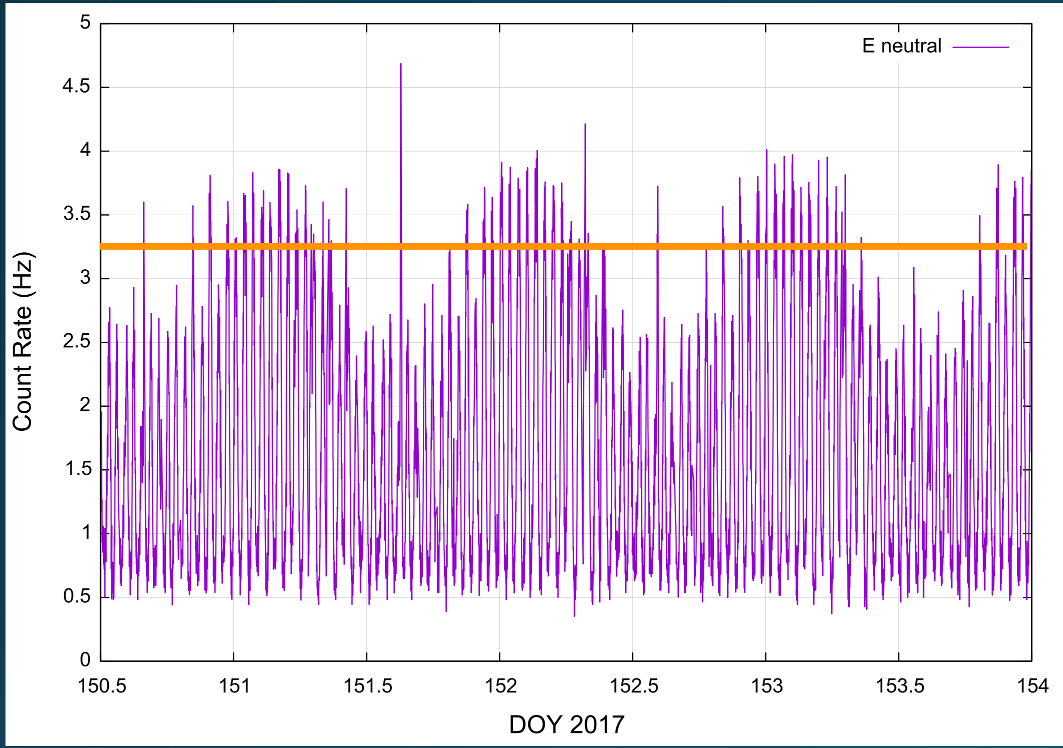
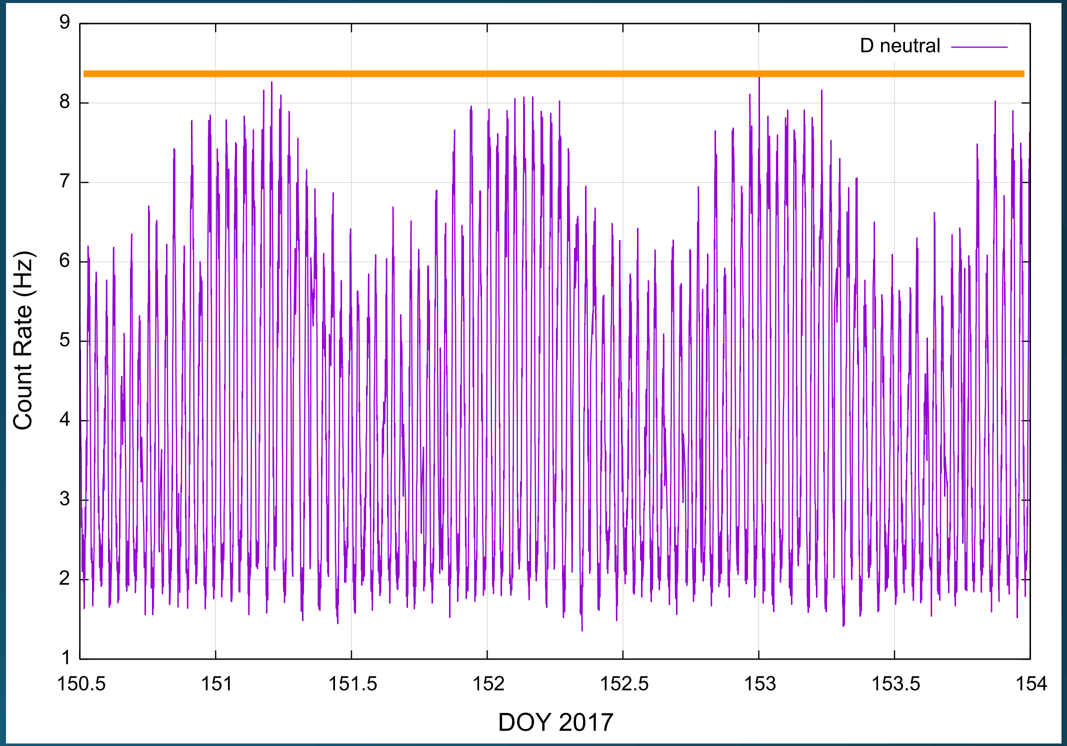
Comparisons to MSL-RAD: Neutral

	MSL-RAD*	ISS-RAD US Lab	ISS-RAD Node 3	ISS-RAD JPM**
E neutral count rate (Hz)	3.20	2.05 GCR 10.8 SAA	2.07 GCR 12.1 SAA	1.56 GCR 11.7 SAA
D neutral count rate (Hz)	8.31	4.99 GCR 12.9 SAA	5.02 GCR 14.1 SAA	3.91 GCR 12.8 SAA
E neutral dose rate*** (nGy/minute)	4.3	3.6 GCR 20.9 SAA	2.7 GCR 28.3 SAA	2.6 GCR 35.6 SAA
D neutral dose rate*** (nGy/minute)	5.9	4.2 GCR 11.5 SAA	2.9 GCR 20.8 SAA	2.9 GCR 23.1 SAA

- * MSL-RAD neutral rates include factor of 4 anticoincidence efficiency correction.
- ** JPM data averaged over orientations (port, zenith, starboard).
- *** Simplified E/m method.

High-Latitude Neutral Rates





- Orange lines indicate corresponding MSL-RAD average values.
- Data from JPM, US Lab results similar.

Neutral Dose Rates

- E/m method underestimates actual dose rates.
- Most of dose comes from large energy deposits.
- PHITS: GCR on 40 g cm^{-2} Al → average E_{neut} ~ 100 MeV.
- Simulate a 100 MeV neutron "beam" on RAD D-E-F
  - ~ 3% chance of energy deposit above D threshold.
  - ~ 2% chance of energy deposit above E threshold.
  - ~ 1% chance of charged particle in F → high % of events lost.
  - Fraction lost will increase with increasing n^0 energy.
- E/m method does not account for this, but roughly agrees with inversion method for dose rate → Question: do DRFs for inversion properly account for anticoincidence?

Conclusions

- ISS-RAD completed ACO phase and is in use as a survey instrument.
- In CPD, x-talk between A and B detectors affects onboard LET spectra, but can be worked around in ground analysis.
  - No obvious effect on A*B triggers.
  - Considering changing onboard triggers to A*B*C coincidence requirement.
- For GCR, daily average B dose rate is less than for MSL-RAD, but GCR+SAA is greater.
- E/B dose rate ratio > 1 on Mars, < 1 on ISS.
  - Ratio decreases with decreasing hardness of energy spectra.
- Neutral rates as seen by CPD are similar to those seen on Mars, especially when ISS is at high latitudes.