Results from ISS-RAD

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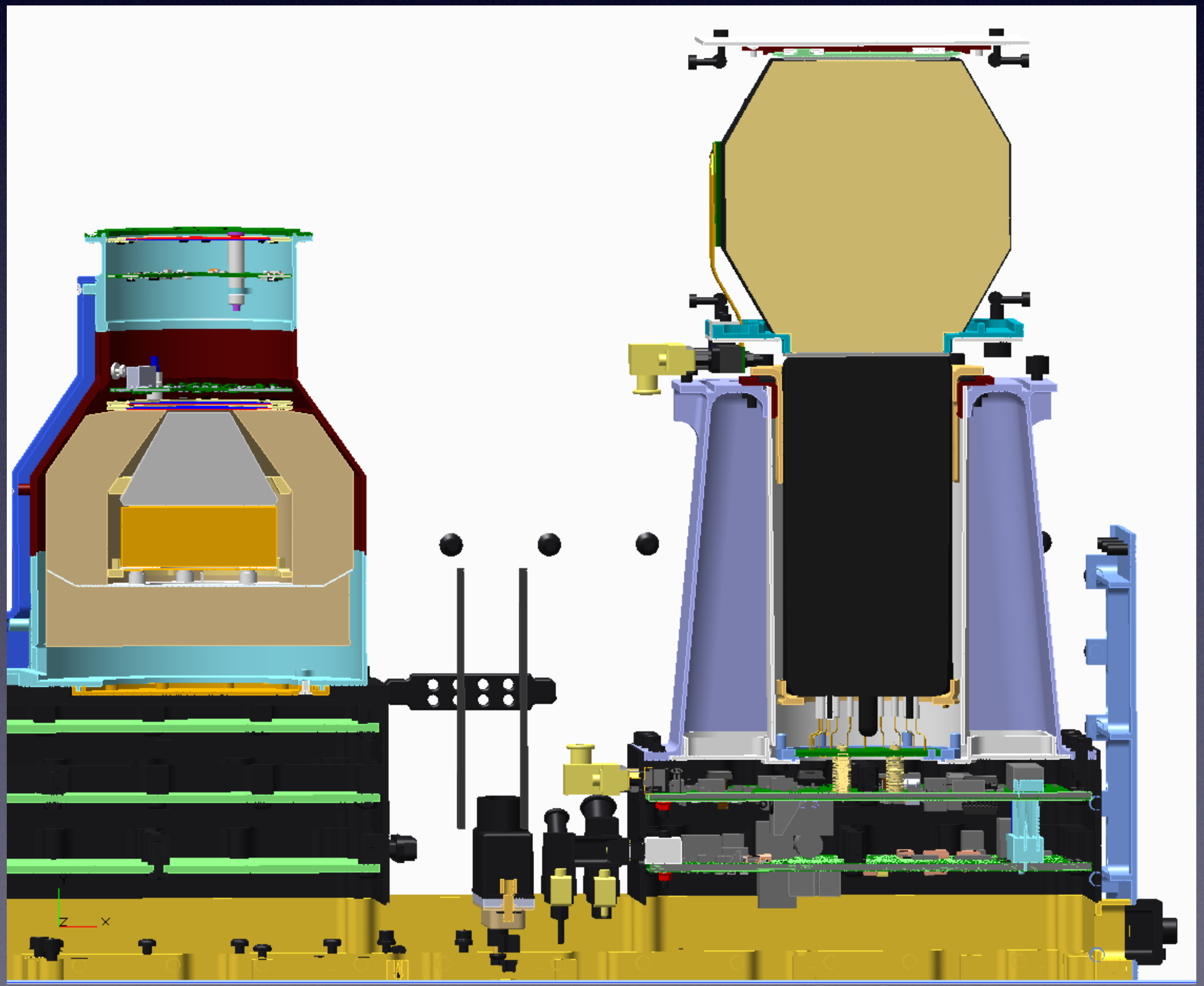
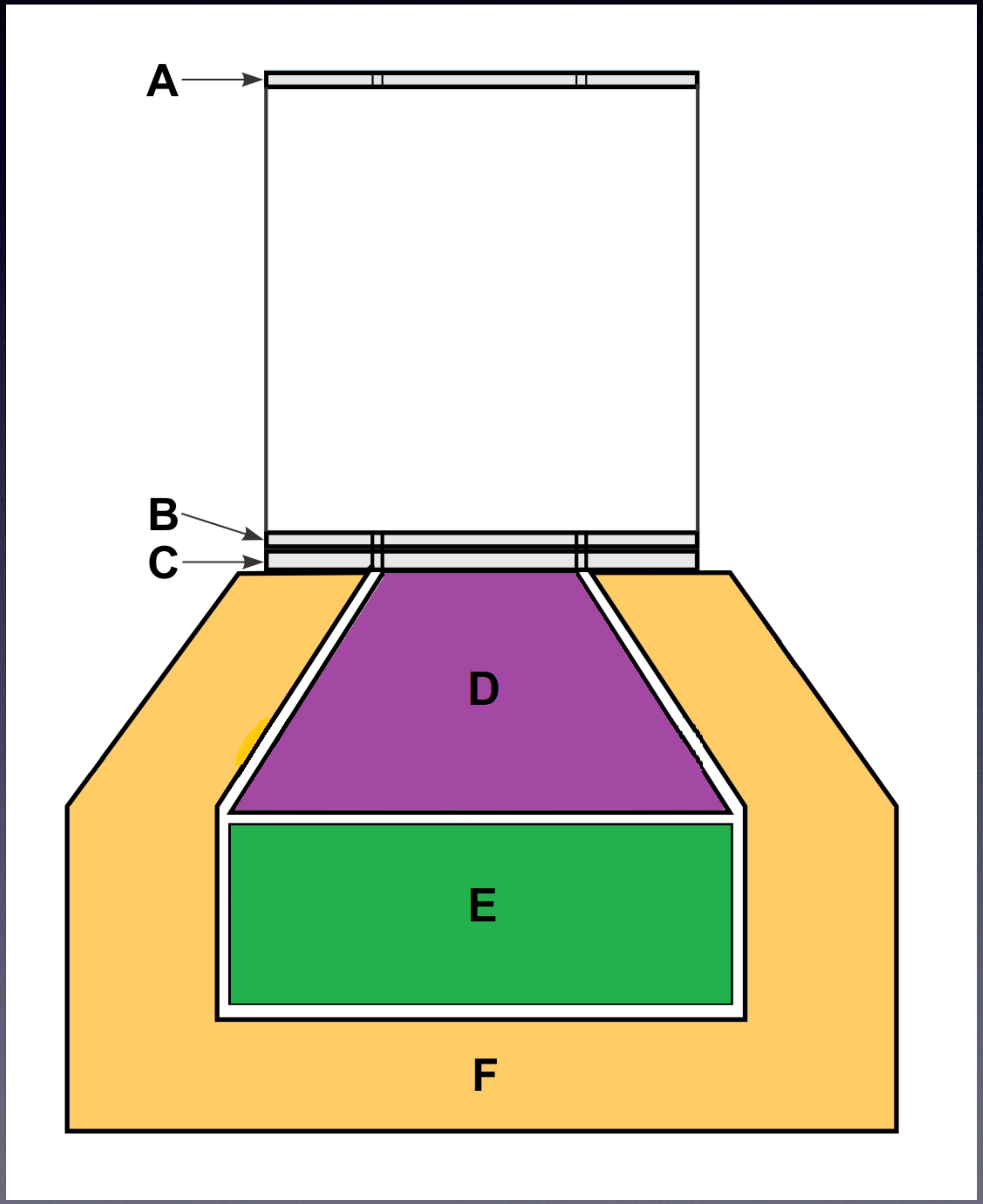
ISS-RAD Concept

- "CPD" = Charged Particle Detector, nearly identical to MSL-RAD.
- "FND" = Fast Neutron Detector, dedicated boron-loaded, capture-gated plastic scintillator optimized for detecting 0.5 to 10 MeV neutrons.
- ISS-RAD total mass = 9 kg, compare to 1.5 kg for MSL-RAD.
    - FND is 3 kg, interface board at bottom is 1.5 kg.
    - Self-shielding of CPD & shielding by FND affects dose rates and <Q>.



Self-Shielding of A×B Field of View

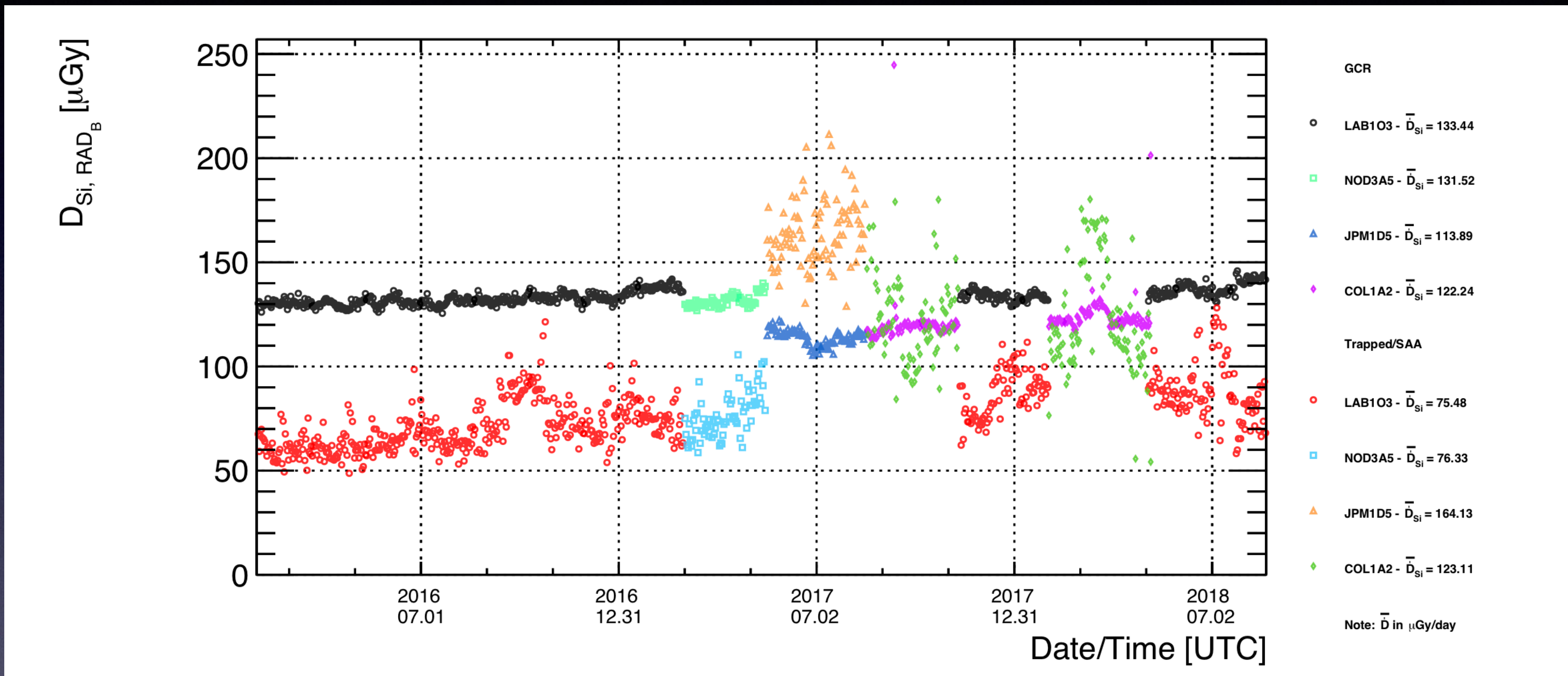
- Particles coming in from top pass through ~ 0.2 g cm^{-2} to get in the FOV.
- From below, pass through ~ 25 g cm^{-2} to reach A (most of mass is BGO).
- A large share of heavy ions coming in through F fragment before reaching the FOV.
- GEANT4 modeling → correction factor may be needed for <Q>.
- Work being done by Ana Firan at JSC.



Survey Locations

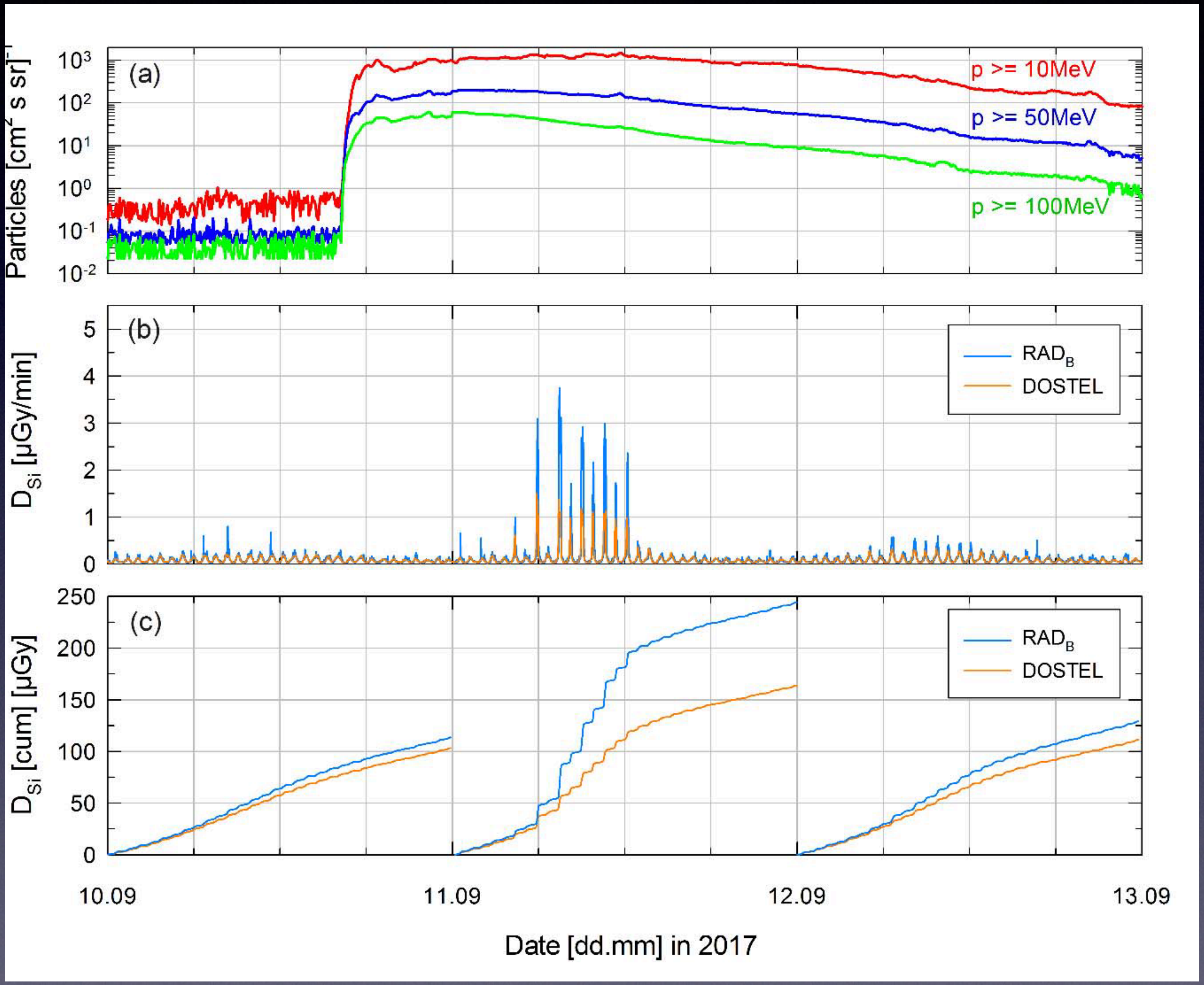
Dates	Location	Top of telescope pointing
2/1/16 – 3/1/17	US Lab 1O3 (Extended ACO)	Forward (~ 330 days) Nadir (26 days) Aft (30 days)
3/1/17 – 5/16/17	Node 3 A5	Zenith (32 days) Forward (23 days) Starboard (20 days)
5/16/17 – 8/16/17	JPM 1D5	Port (35 days) Zenith (28 days) Starboard (28 days)
8/16/17 – 11/10/17	Columbus 1A2	Zenith (34 days) Port (24 days) Starboard (28 days)
11/10/17 – 2/1/18	US Lab 1O3	Forward (68 days) Port (28 days) Starboard (24 days) Aft (35 days)
2/1/18 – 5/3/18	Columbus 1A2	Forward (29 days) Nadir (55 days) Zenith (27 days)
5/3/18 – present	US Lab 1O3	Forward (29 days) Port (31 days) Starboard (31 days) Port (current)

Dose Measurements



- GCR dose rate is a little sensitive to position & orientation, SAA dose rate much more. SAA share of dose ranges from 36% (Lab) to 59% (JPM).
  - Note B “omnidirectional” dose rate is shown.
  - Slowly rising GCR dose rates are due to weakening solar modulation.

September 2017 SPE

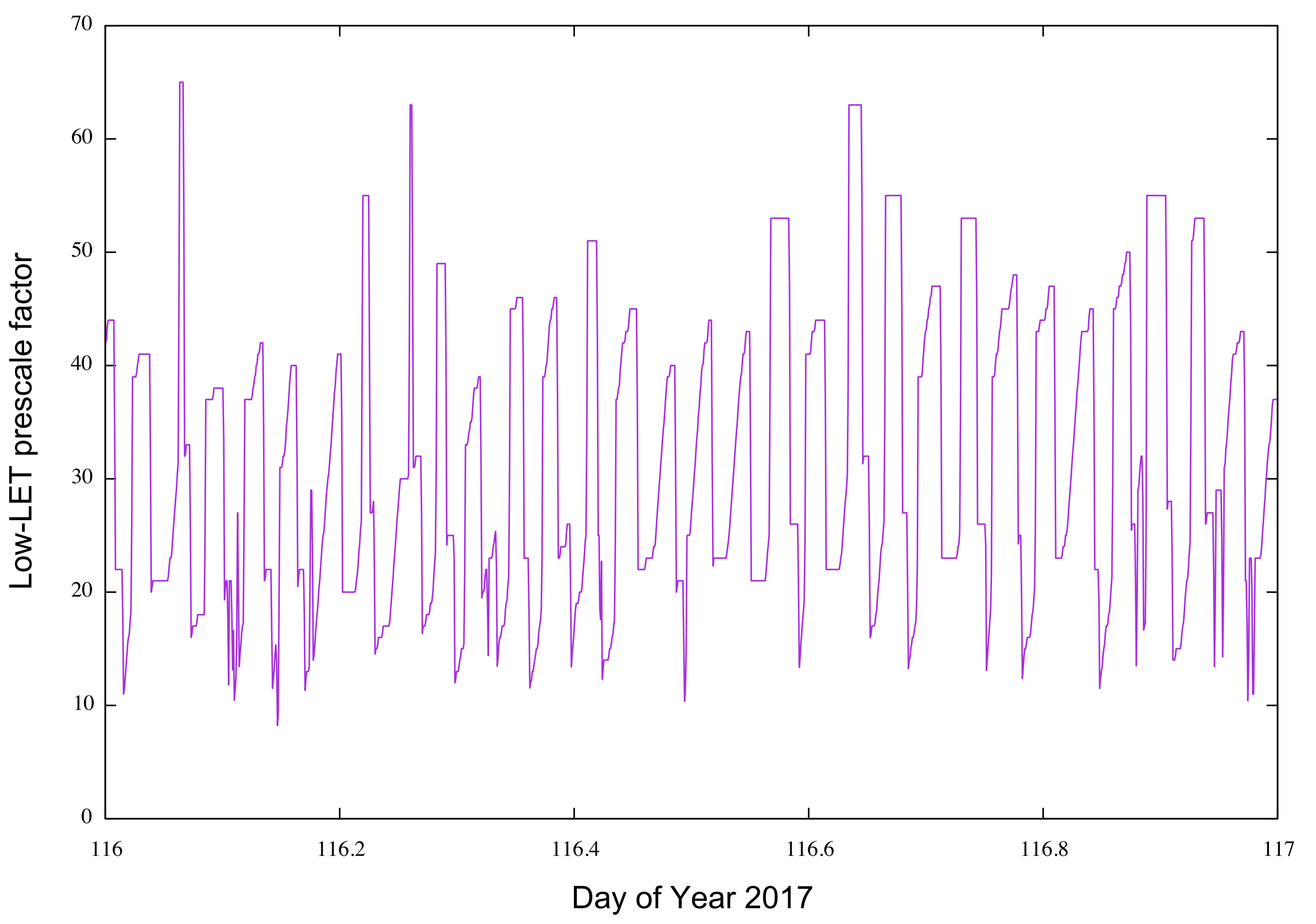


- Figure from The Solar Particle Event on 10 September 2017 as observed onboard the International Space Station (ISS), T. Berger et al.
- SEPs only reached ISS when passing through regions where R_{VC} < 1 GV.
- Cumulative SPE dose in RAD ~ 1.5x DOSTEL compared to ~ 1.1x in quiet time.

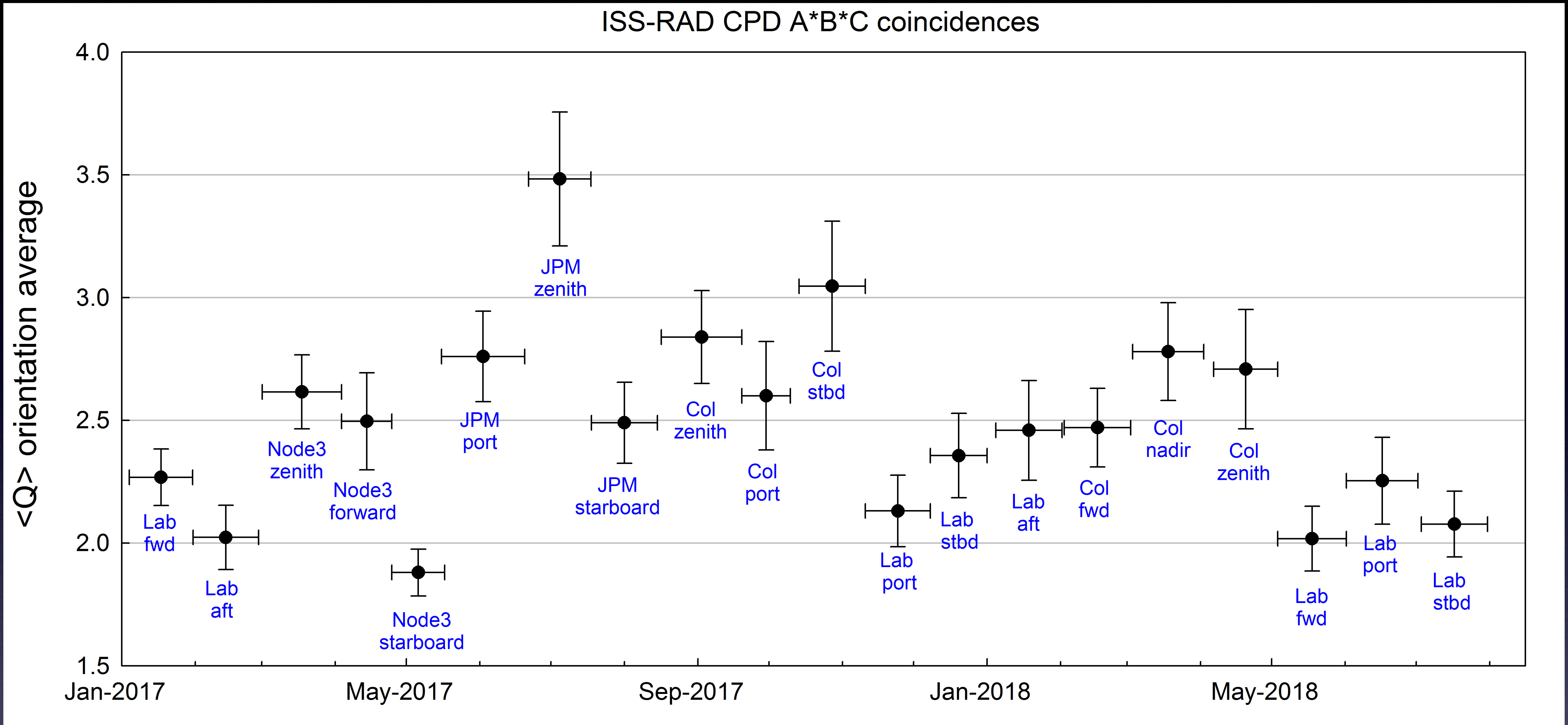
<Q> Measurements

- Because of issues with incomplete charge collection in the A detector on high-LET events, must use telemetered pulse-height event records and select B×C coincidence events for analysis.
- Low-LET events are heavily prescaled to reduce data volume — factor of 30 is typical, but factor autonomously increases when rates get high as in SAA. As a result:
  - Few events from SAA are telemetered.
  - <Q> results may over-represent GCR.

Prescale Factor

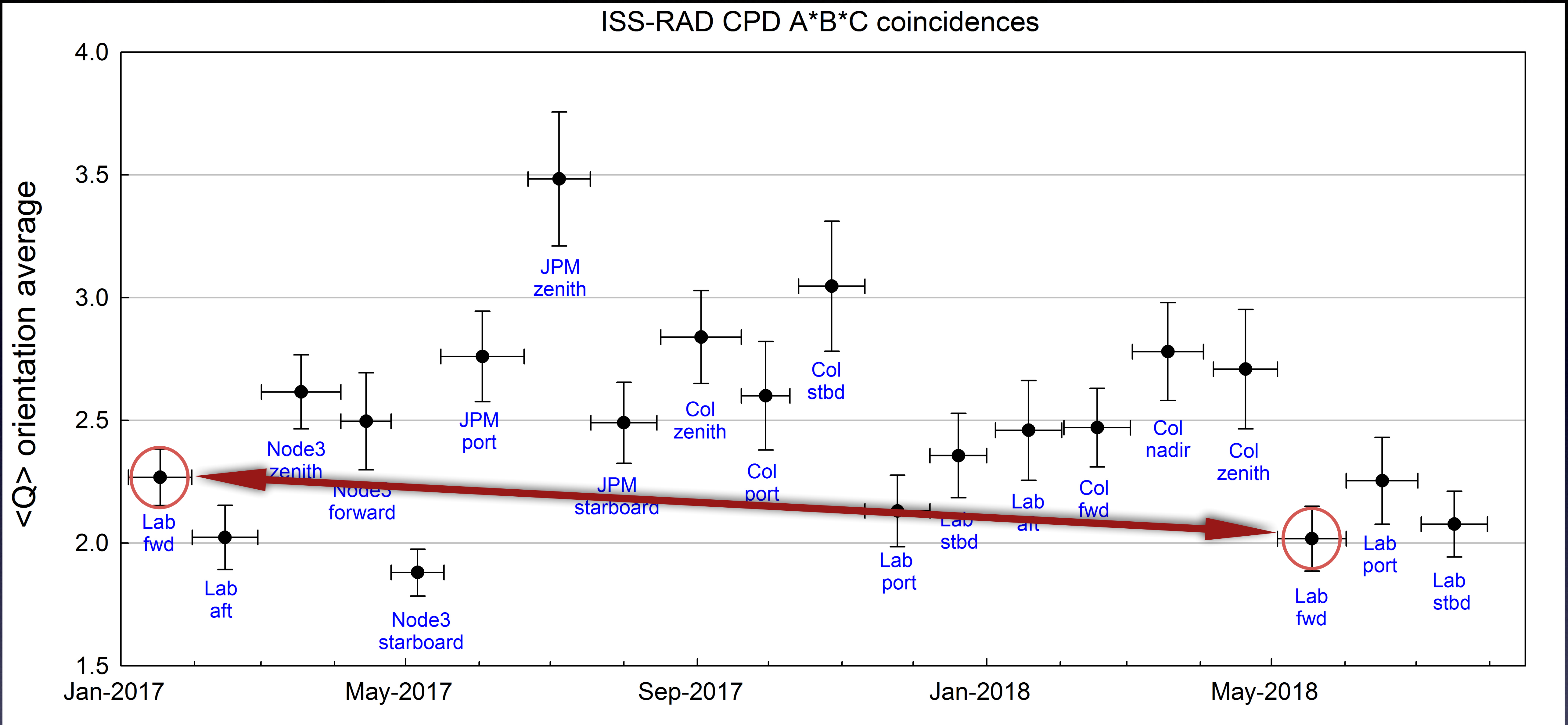


- Factor self-adjusts, trying to keep weekly data volume ~ constant at 50 MB (25 MB CPD, 25 MB FND).
- Workaround will be implemented soon - turn off auto adjust, use constant factors. Should ~ double number of events from SAA.



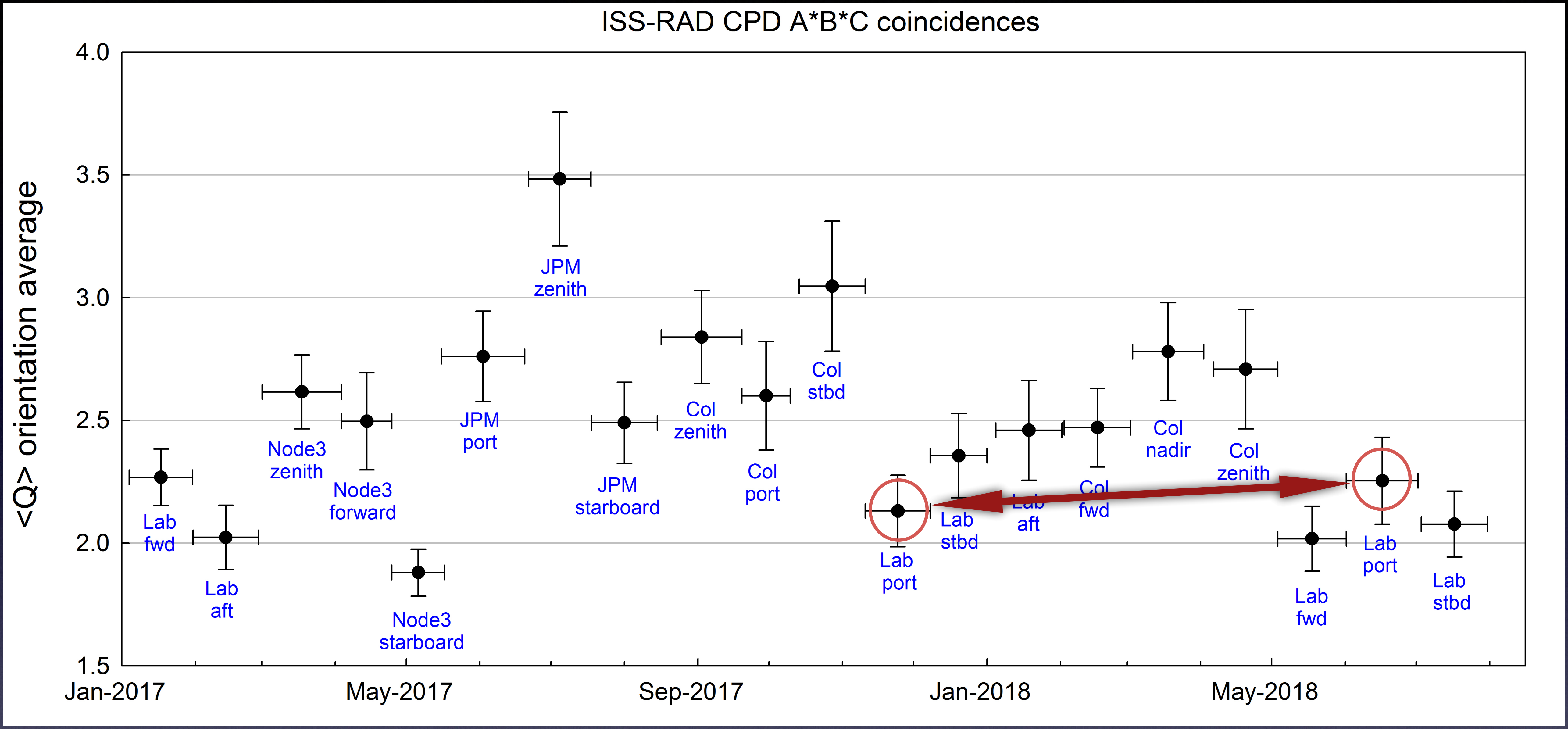
<Q> Results

- <Q> varies from ~ 1.8 to 3.5.
- Statistical errors are driven by small statistics at high LET.



<Q> Results

- Results look reproducible within errors at a given location.



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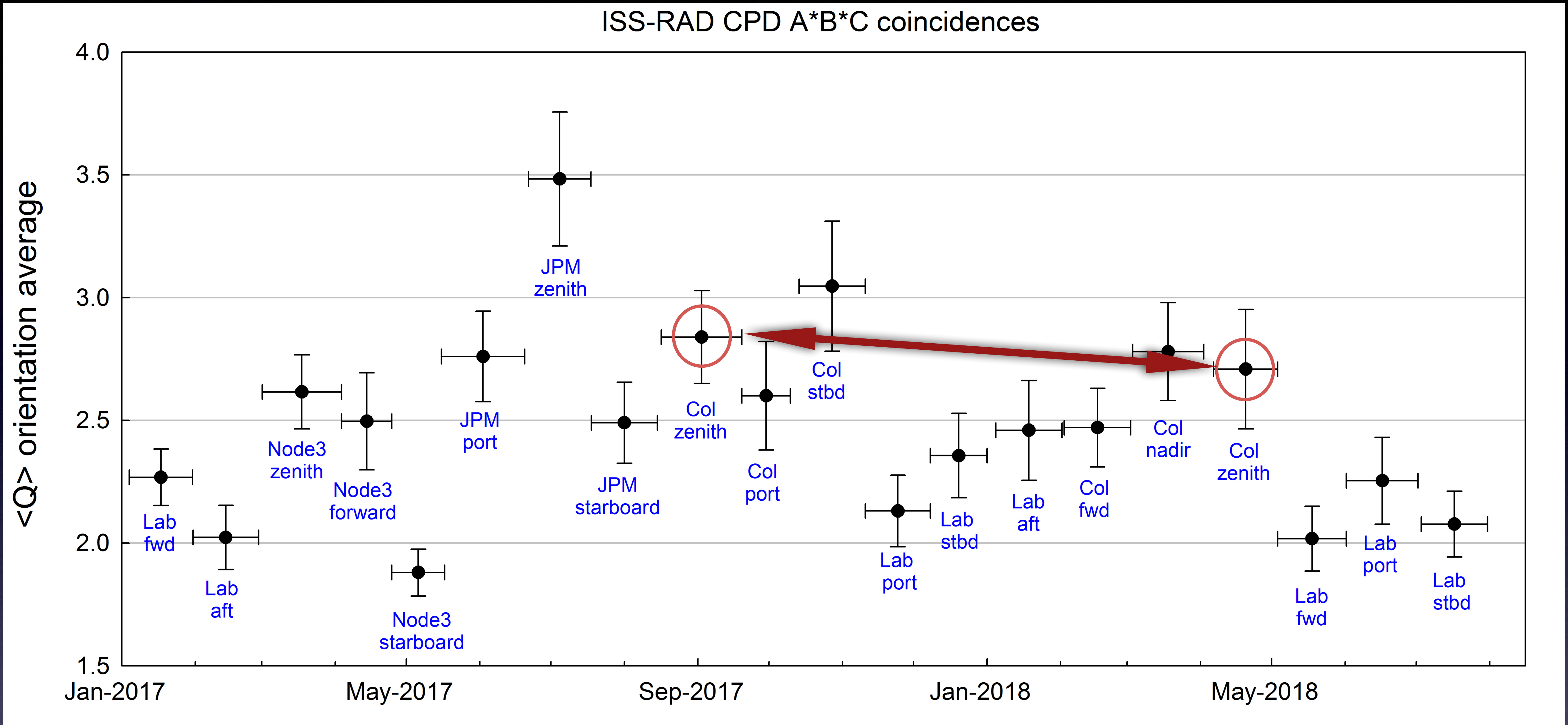

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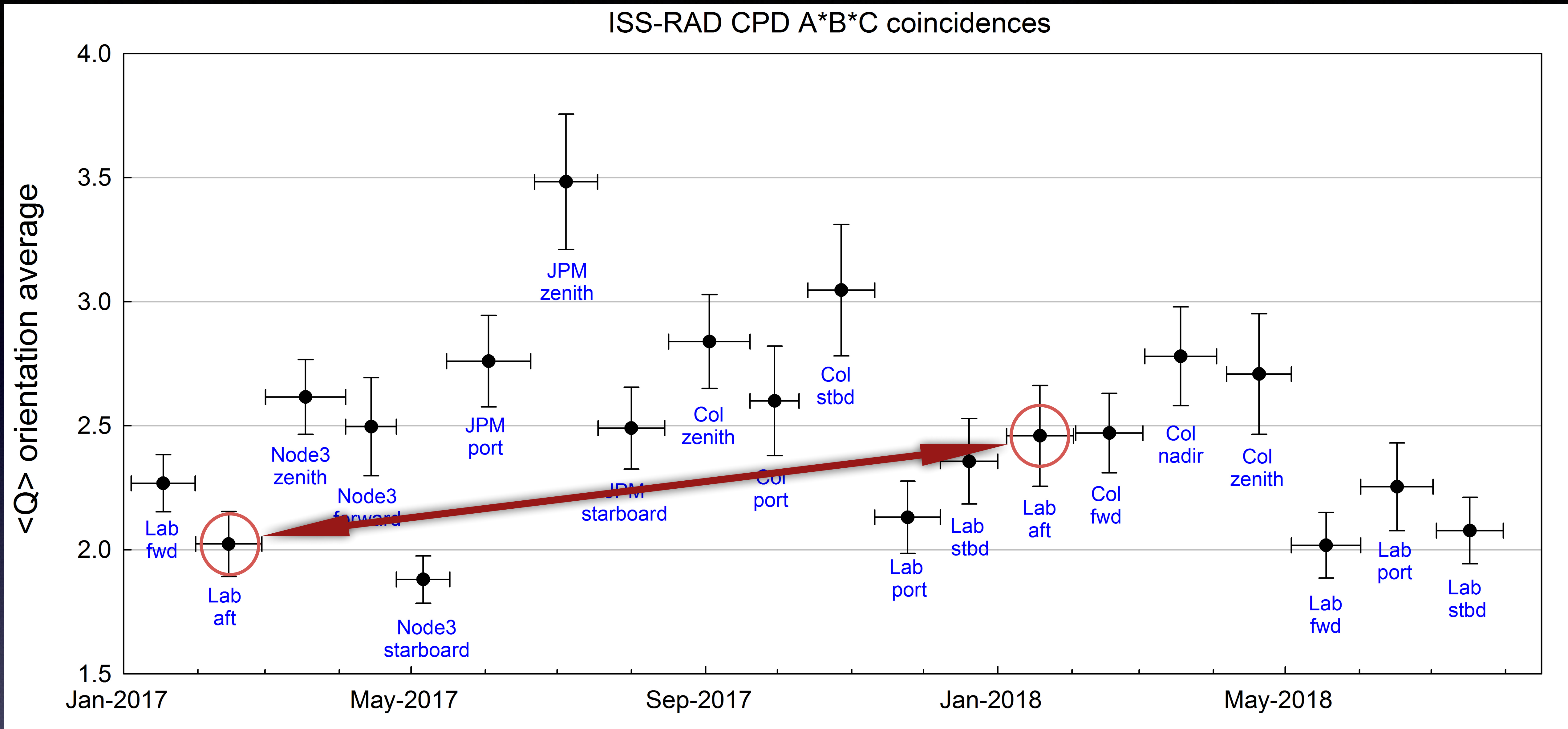


<Q> Results

- χ^2 for agreement between pairs of points is 5.8 for 4 df, reasonable assuming environments are ~ constant.

<Q> by Location

- Average over orientations for each location.
- Standard deviation of measurements shown to capture variations in <Q> by orientation.

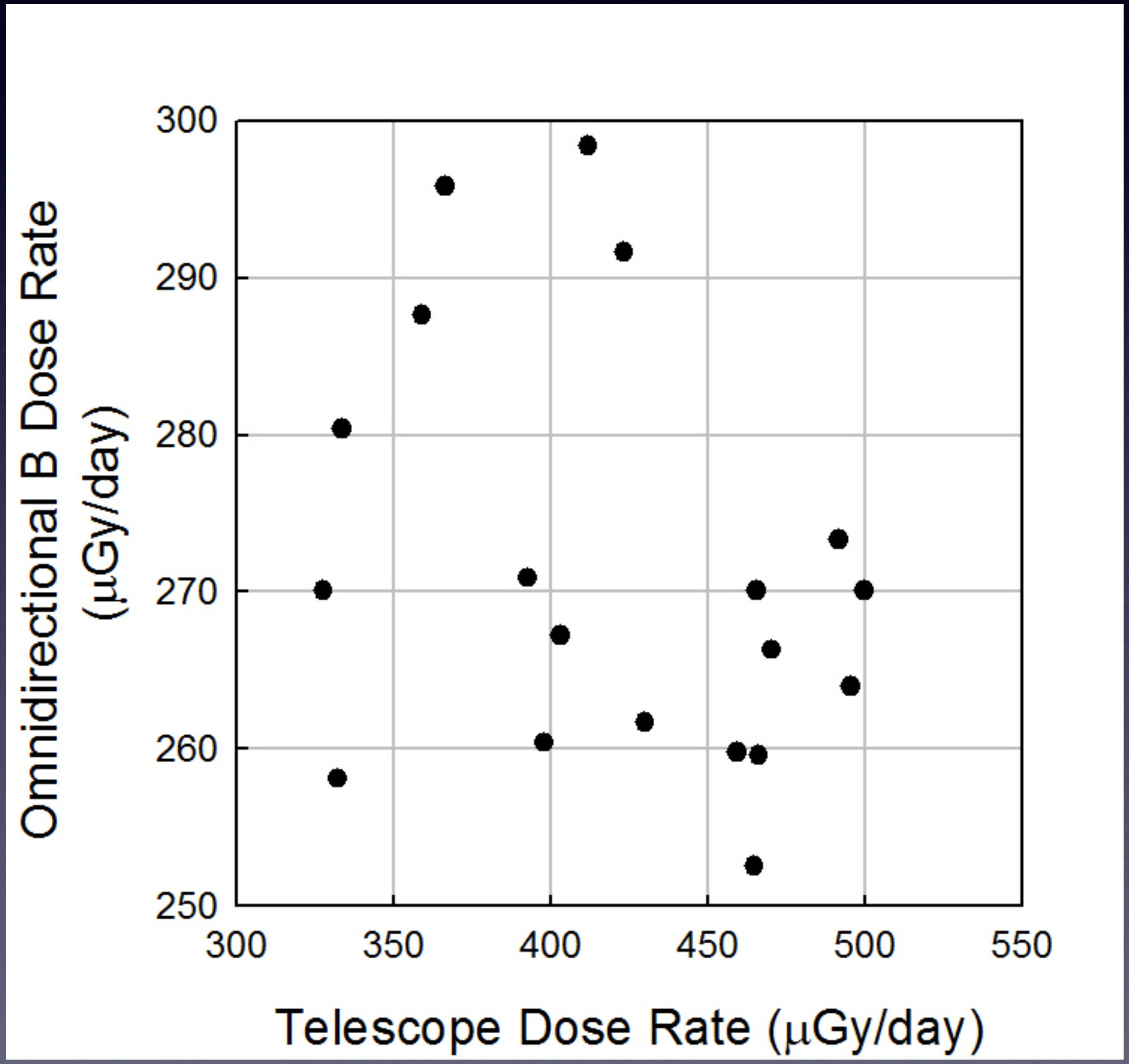
Location	**<Q>**	**St. Dev.**	**# data points**
USLab	2.17	0.16	8
Node3	2.15	0.39	3
Columbus	2.70	0.20	6
JPM	2.76	0.51	3

Telescope vs. Omnidirectional Dose Rates

- Omnidirectional dose rates are ~ insensitive to orientation as particles from all directions contribute.
- Telescope dose rate uses dose obtained from A×B LET spectrum obtained for <Q> calculation.
- Accounting for Earth's shadow at 410 km, extrapolate to solid angle of

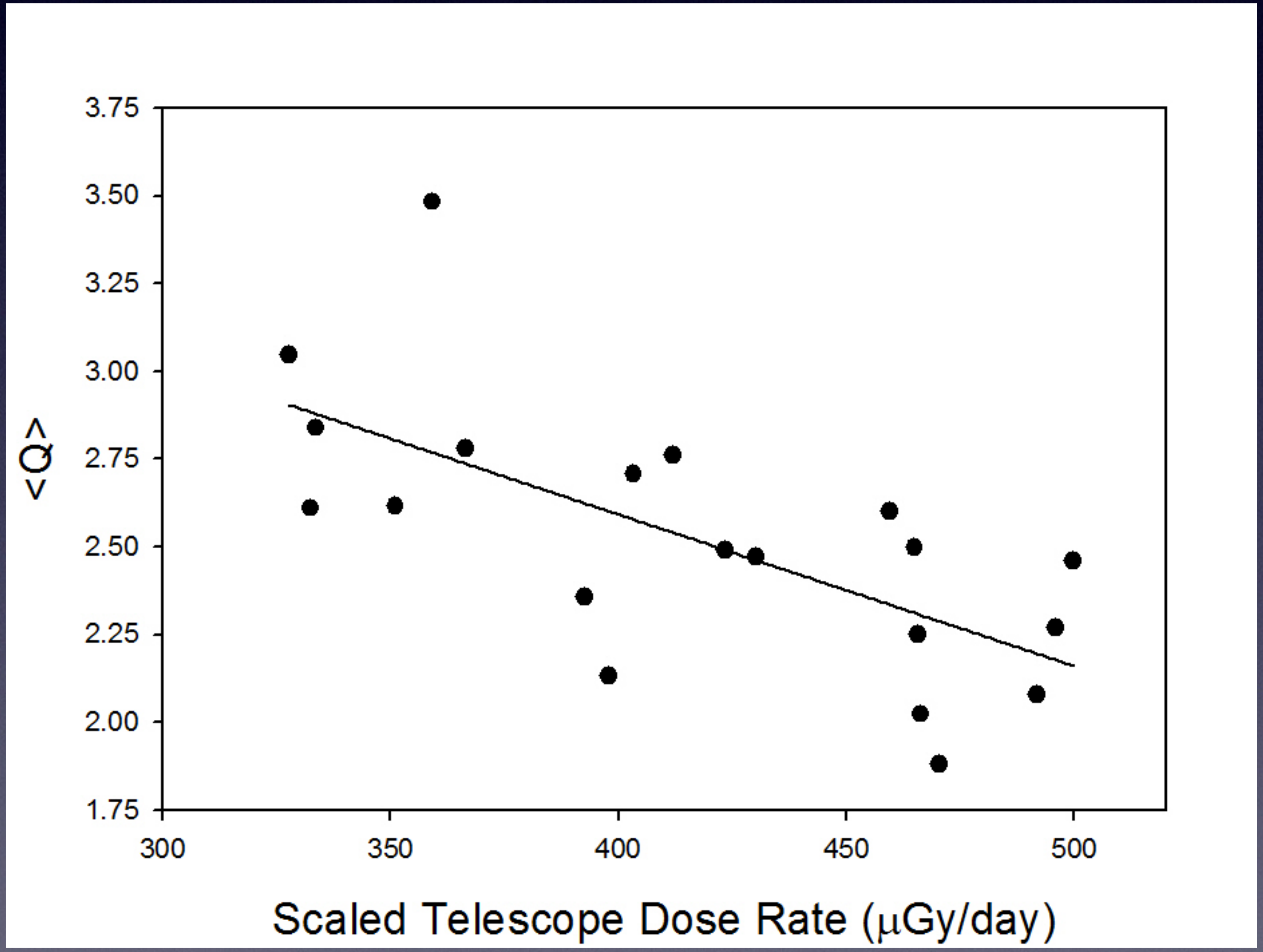
$$\Omega = 4\pi(1 - 0.33)$$

- Telescope dose rates are ~ 50% larger than omnidirectional.
- Correlation/anti-correlation not obvious — two populations?



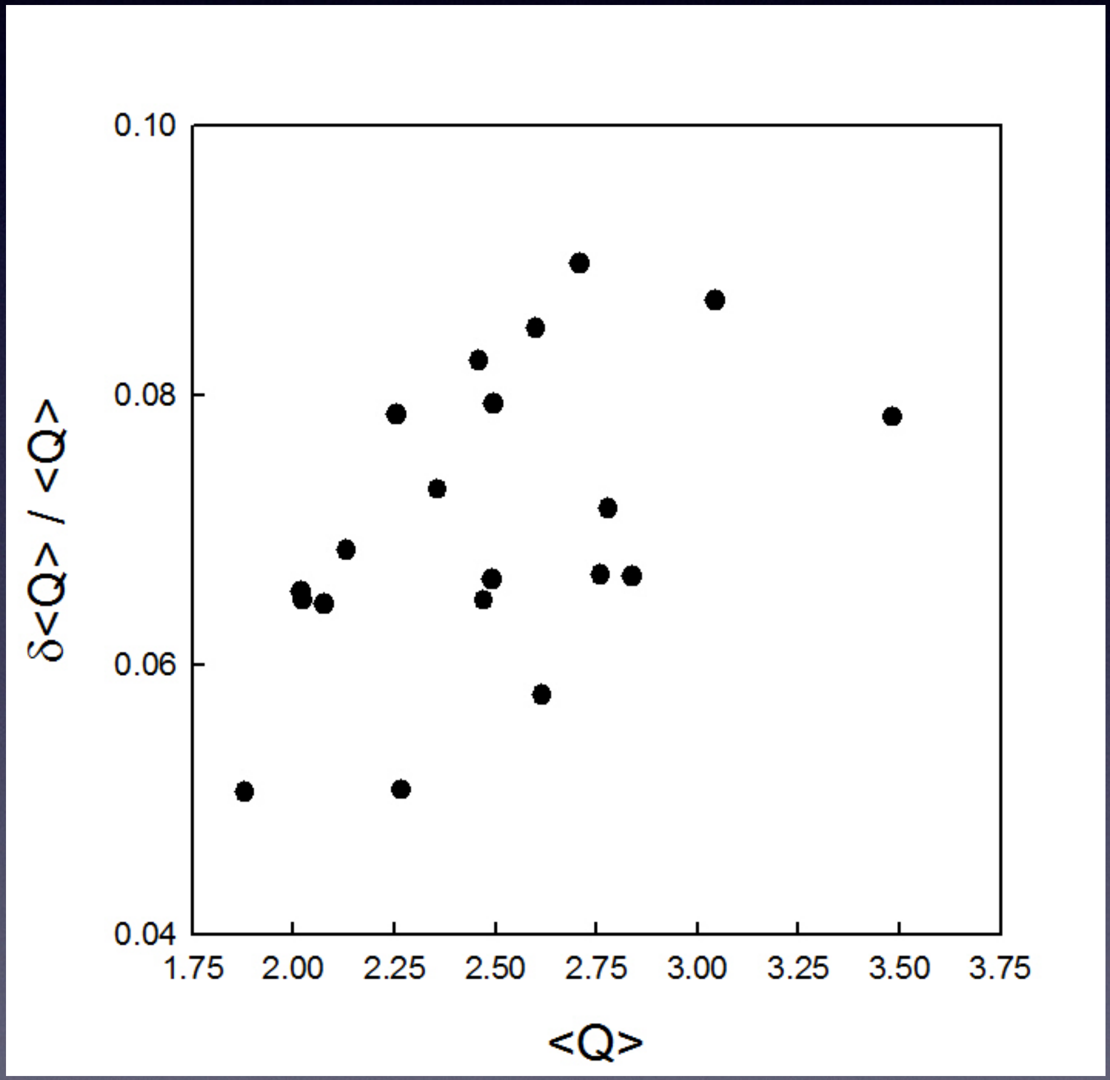
<Q> and Telescope Dose Rate

- Trend is ~ consistent with effect of SAA driving up dose rate and reducing <Q>.
  - Shielding of CPD by FND may be significant for SAA.
  - Comparatively large telescope dose rates may be due to extrapolating from a cone that has smaller average shielding and sees more SAA.
- Trend also consistent with behavior of GCR in Al shielding as depth increases: dose increases, <Q> decreases.

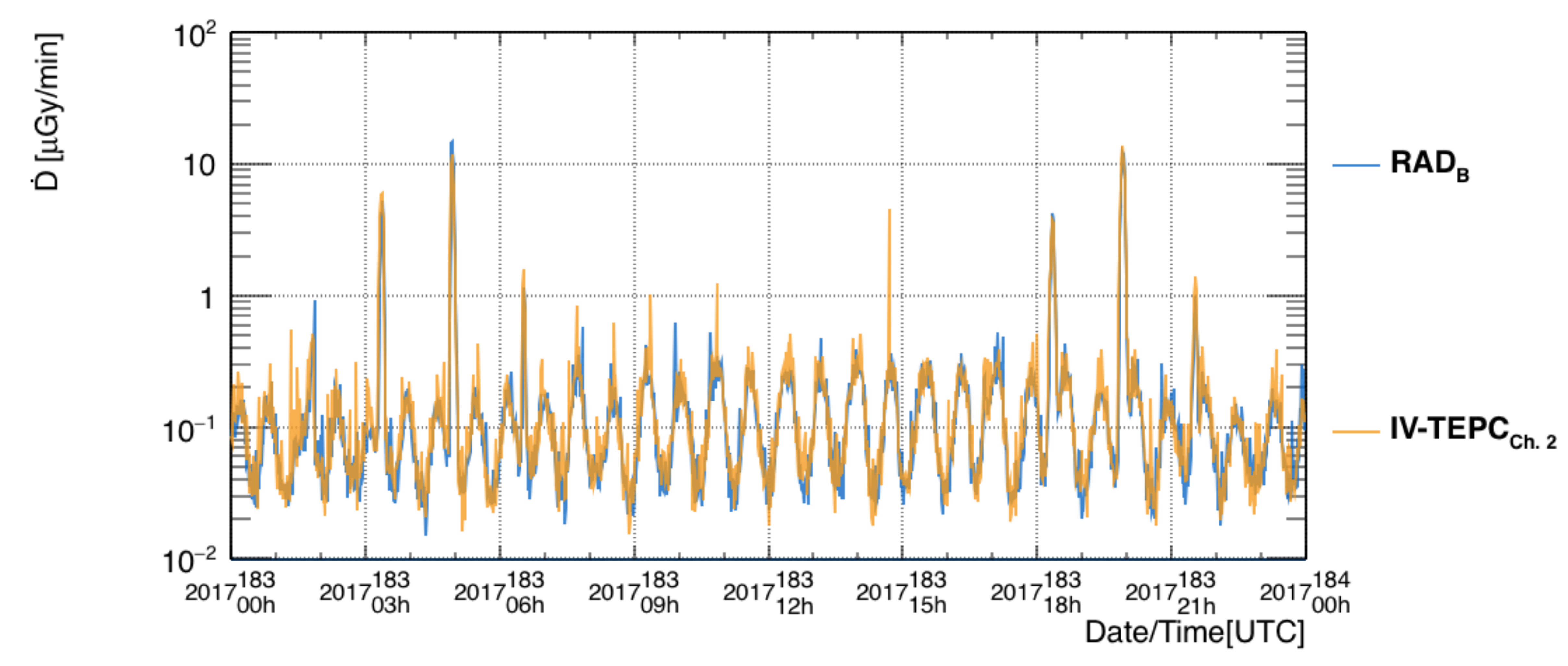


Summary of <Q>

- Recall earlier point re: detector asymmetry and possible need for upward, model-based correction.
- No similar effect in MSL-RAD since heavy ions only come from above.
- Uncertainties in <Q> driven by fluctuations in small numbers of high-LET events, as shown by correlation of <Q> with propagated statistical errors.
    - Less than 1 event/day for LET greater than 100 keV/micron even in places where <Q> is large, so for ~30-day measurement there is a ~ ± 20% uncertainty in this region.



Check of Omnidirectional Dose Rate



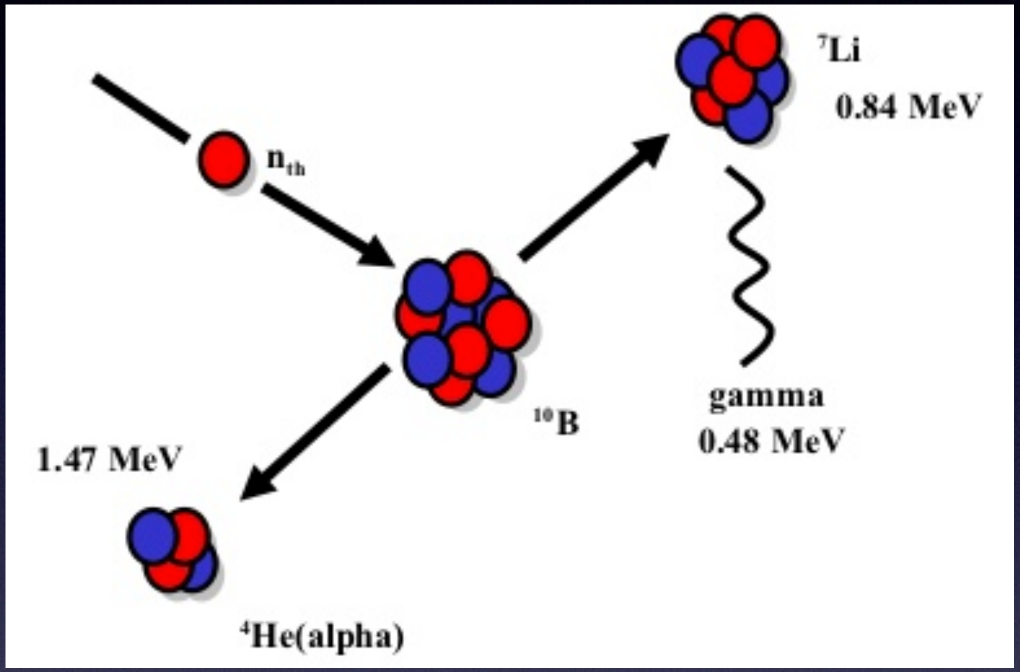
- Data from period of IV-TEPC/RAD co-location.
- RAD omnidirectional data from B, converted to H_2O with factor of 1.25.

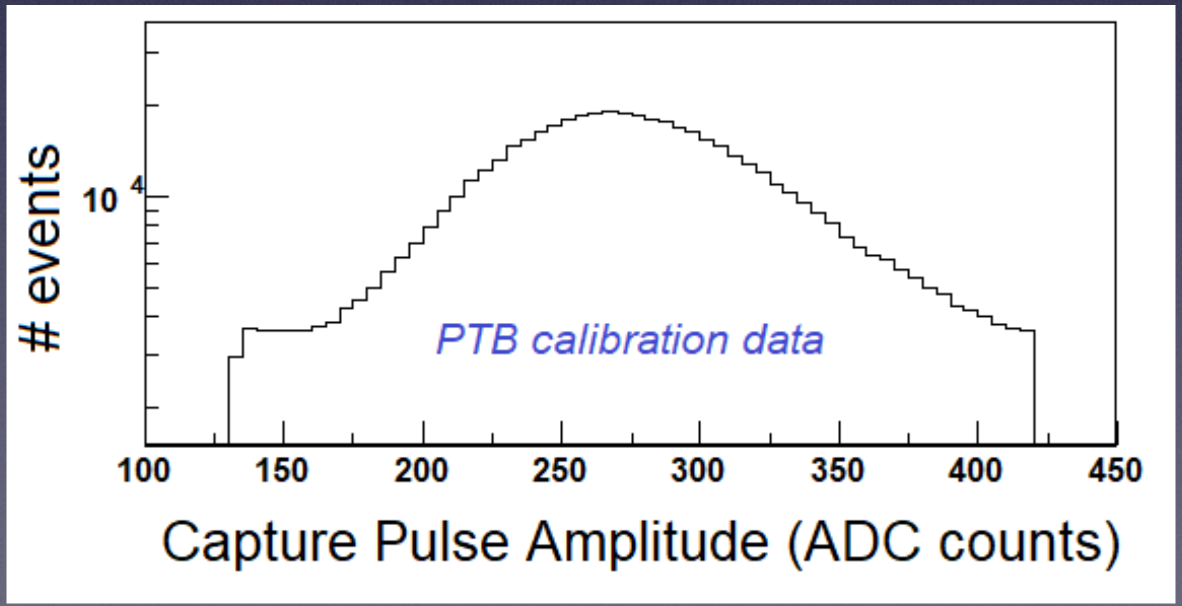
FND Status & Results

- Boron-loaded plastic detects neutrons via capture gating.

$$^{10}B + n \rightarrow ^{4}He + ^{7}Li + \gamma$$

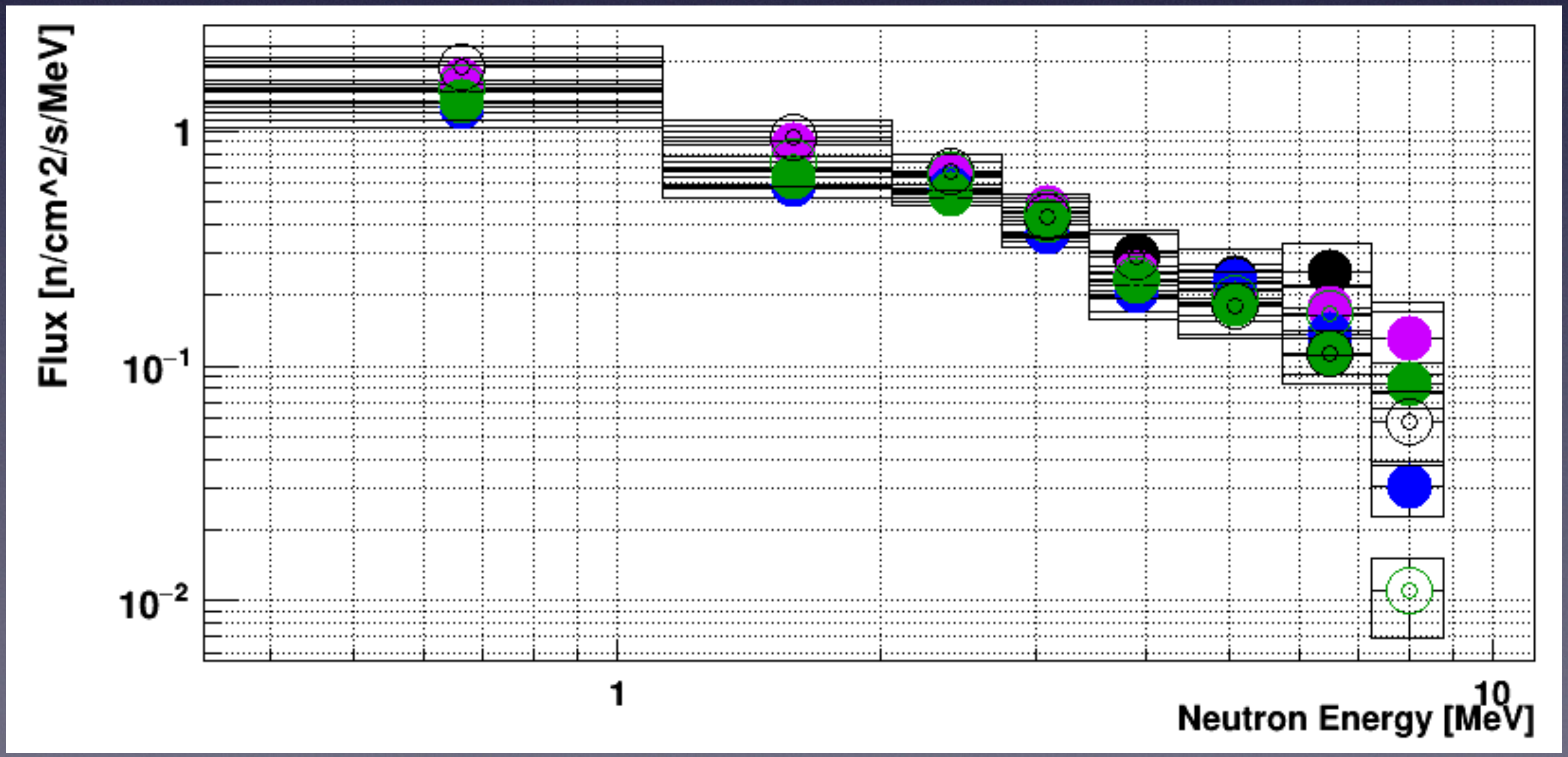
- Decay pulse appears ~ few microseconds after first pulse & produces a characteristic amplitude that is used to track gain & make corrections.

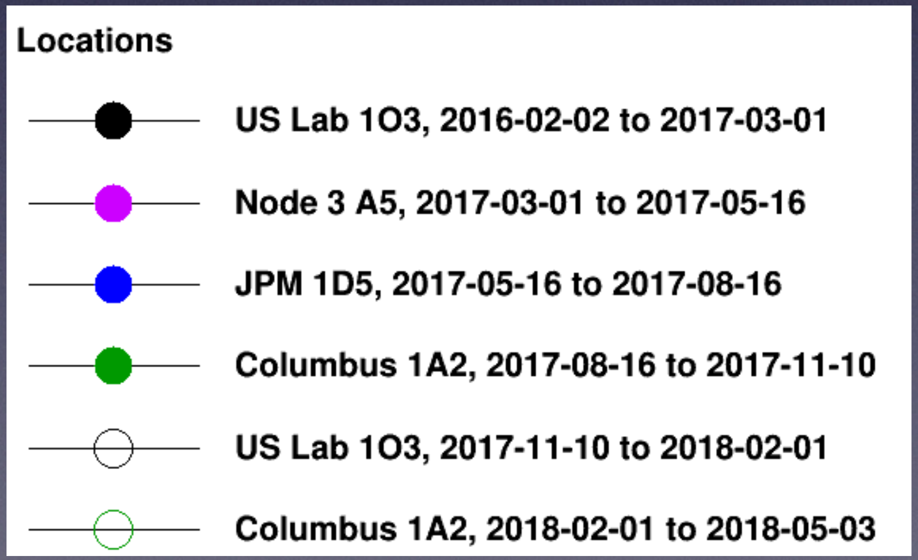




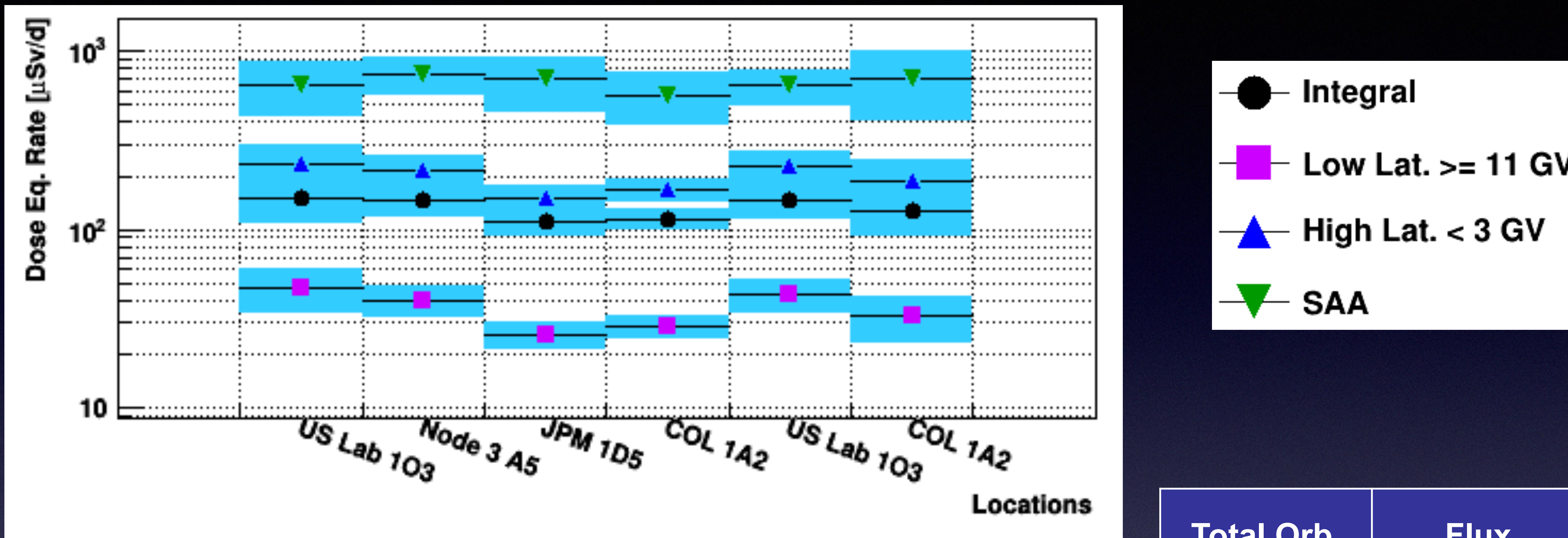
Unfolded Neutron Energy Spectrum from FND

- Work by Martin Leitgab.
- Highest energy bin is impacted by boundary effects in the unfolding; work in progress to improve.
- Significant variations with location.





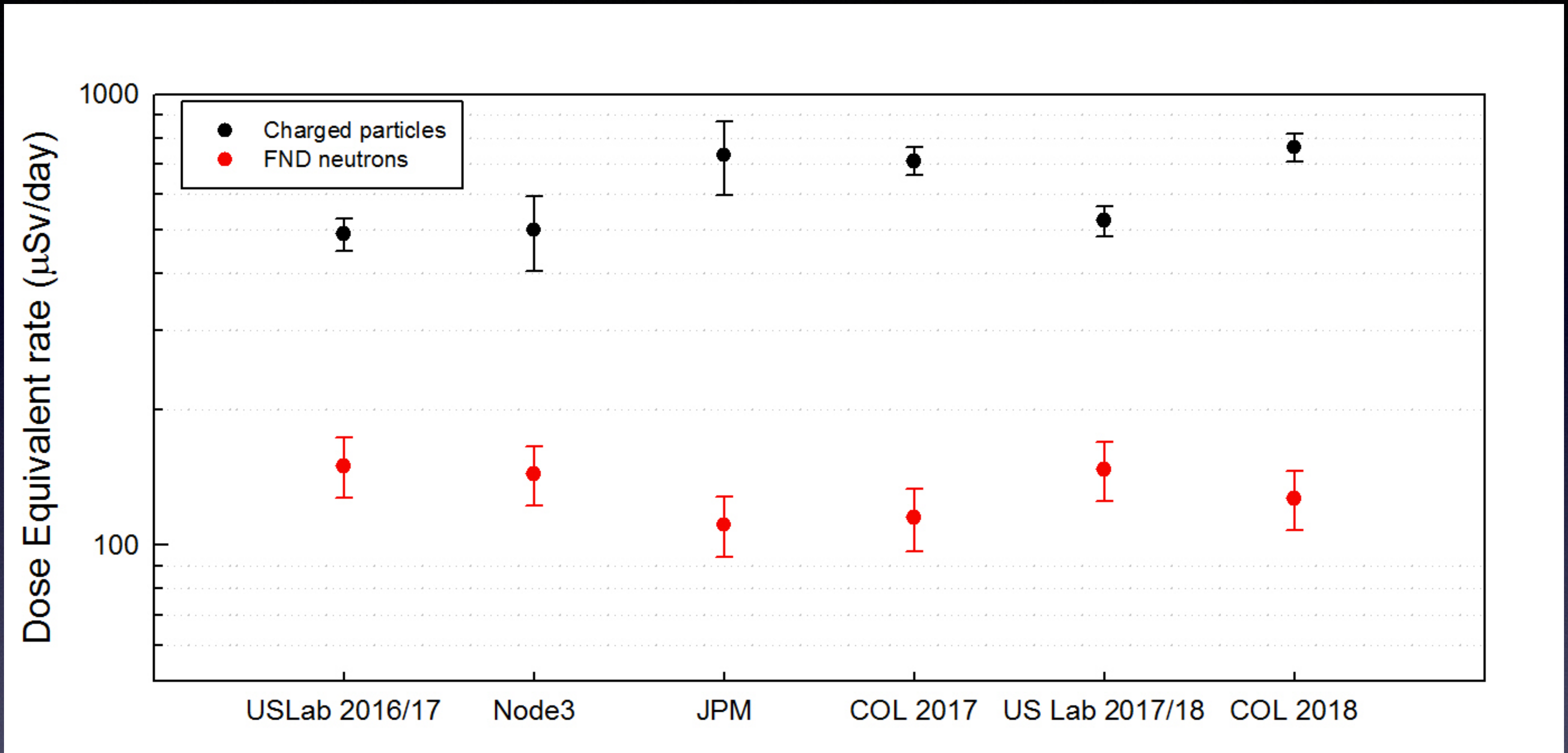
Neutron Dose Equivalent



Total Orb. Avg. Data	Flux [n/cm²/s]	H*(10) dose eq. rate
US Lab 2016-2017	4.5	150
Node 3 2017	4.3	144
JPM 2017	3.3	111
COL 2017	3.4	115
US Lab 2017/2018	4.4	147
COL 2018	3.8	127

- Location dependence: US Lab and Node3 are similar, JPM ~35% lower, COL 15% lower; data through May 2018.
- Lower neutron rates in JPM and Columbus are consistent with higher charged-particle <Q>'s measured by CPD in those locations (less shielded).

Charged & Neutron Dose Equivalents



- Neutron share ranges from 14% to 23%.
- Charged particle rates may be slightly overestimated due to prescaling issue — recall GCR may be over-represented in event samples used for <Q>.

Conclusions

- ISS-RAD continues to work well.
- Minor hardware issues are easily worked around in ground analysis.
- For charged particles, dose rates & <Q> yield H.
- For FND neutrons, unfolded energy spectrum yields H. Neutron share 14-23% depending on location.
- Charged particle H rate is 0.5 to 0.76 mSv/day, similar to 0.4 to 0.7 mSv/day range found by MSL-RAD on Mars.