Cosmic Rays in SPIDER and Space

03Dec2017 - Jeff Filippini

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and the SPIDER collaboration

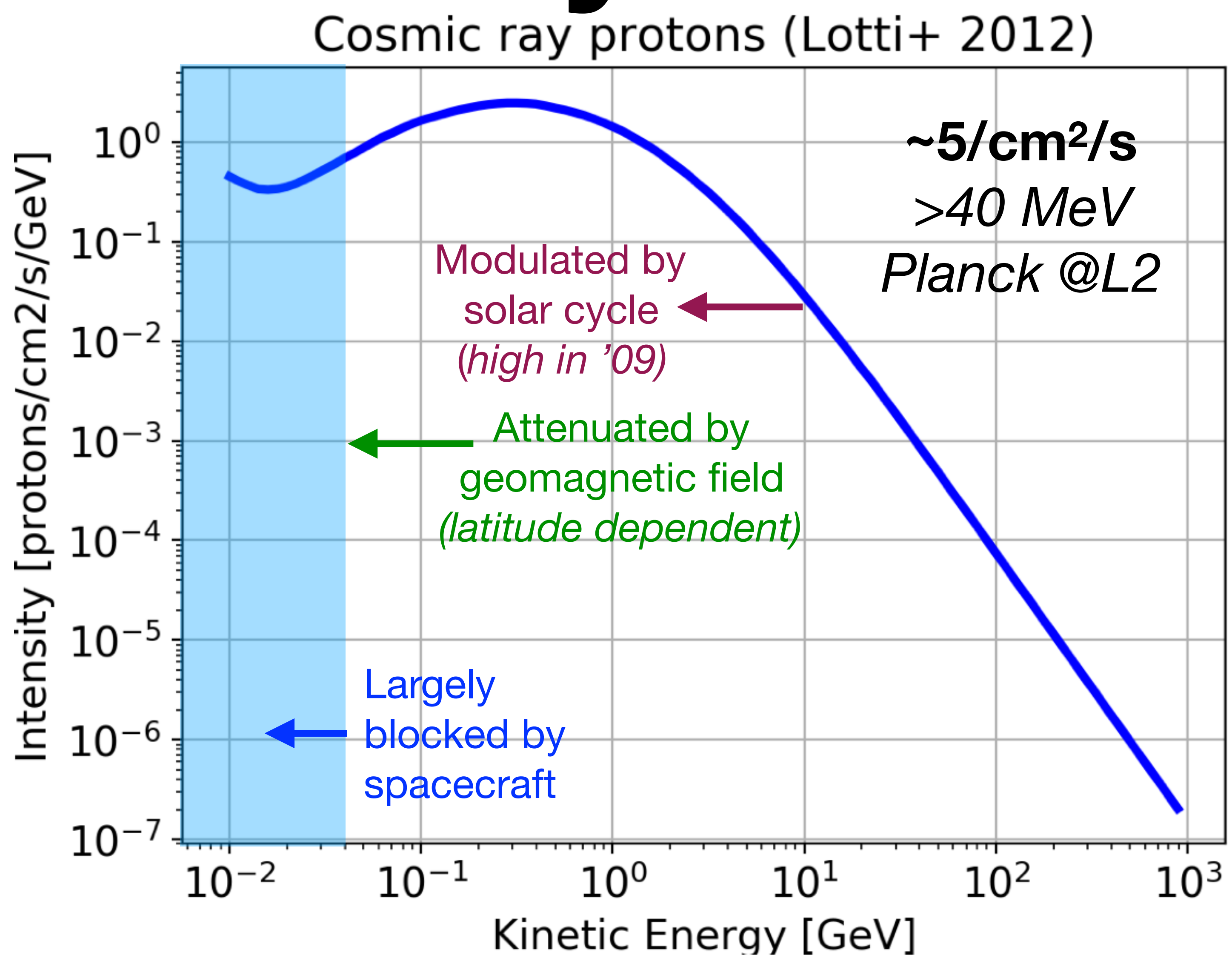
ILLINOIS

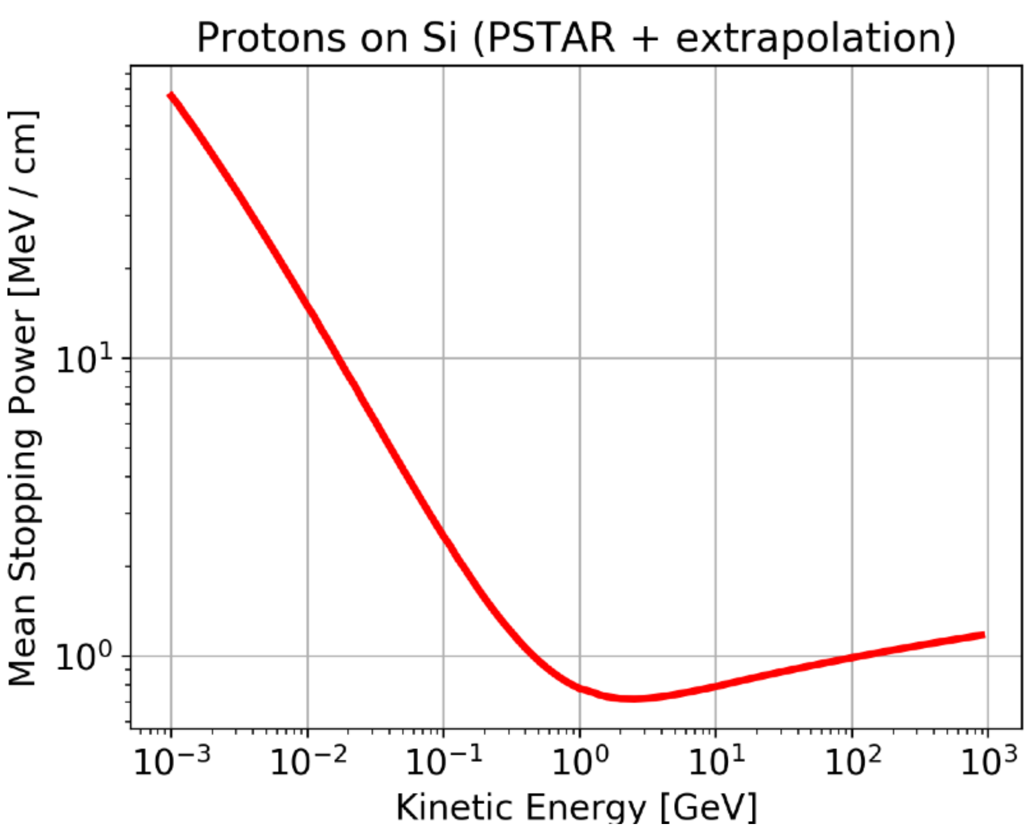
NASA
APRA + SAT

Cosmic Rays

COMPOSITION

- **Space**: "primaries", largely galactic **protons** (*some alphas, nuclei, e+/e-*)
- **LDB**: similar, but geomagnetic cutoff
- **Ground**: ~100x lower, mostly secondary **muons**

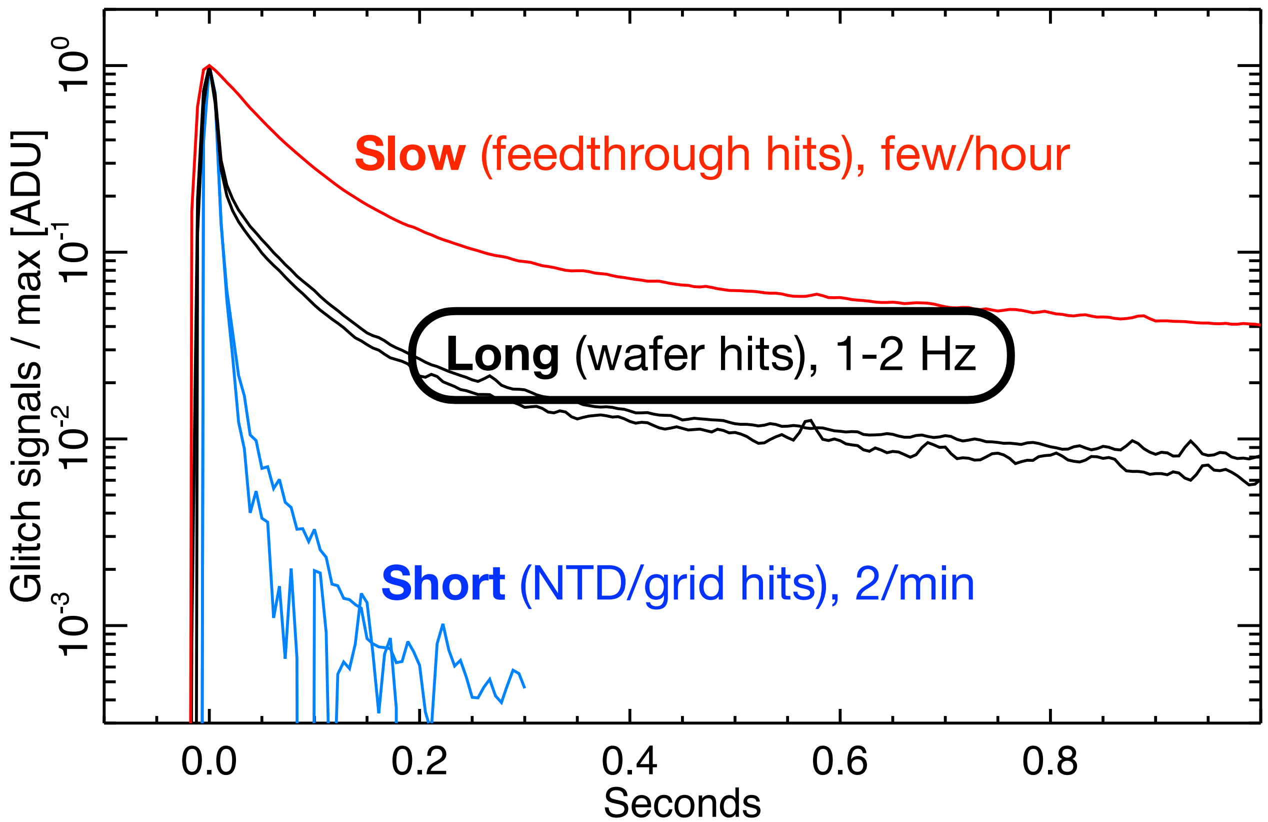


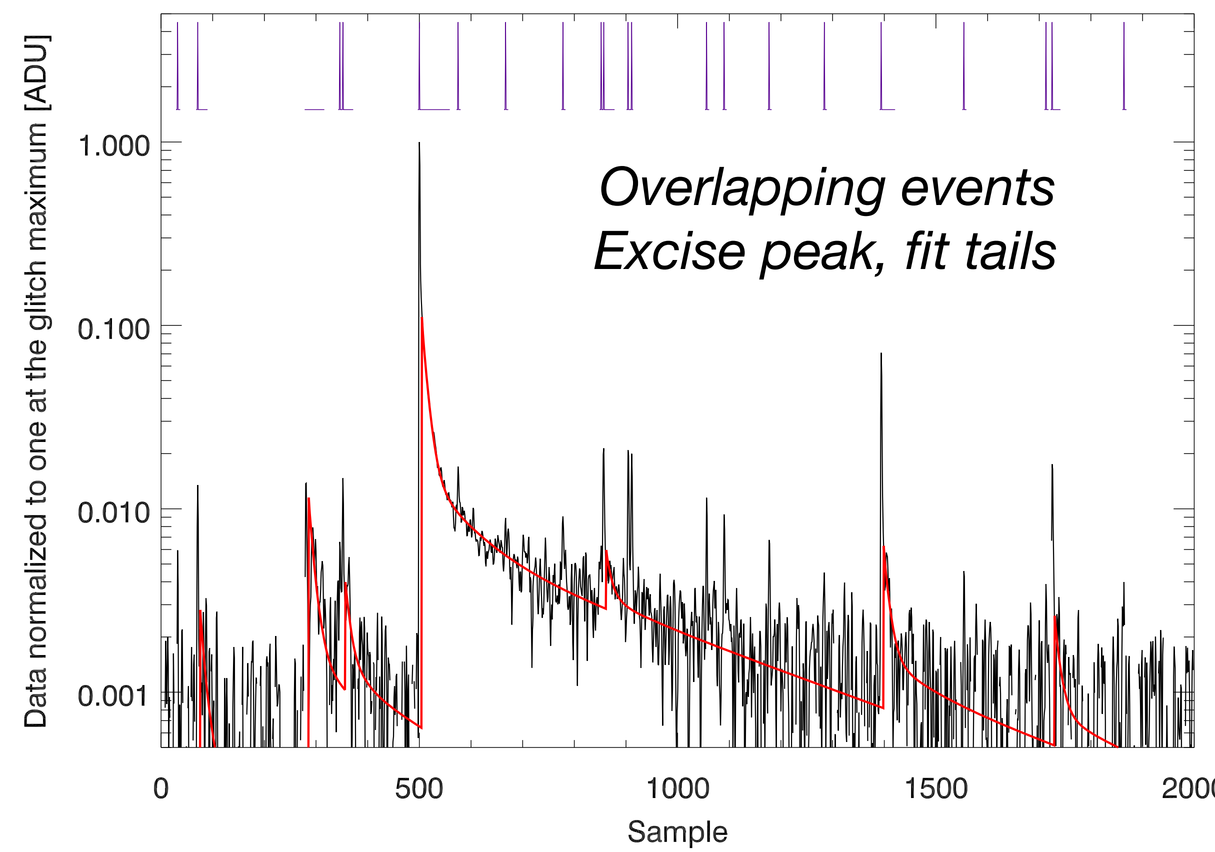


INTERACTIONS

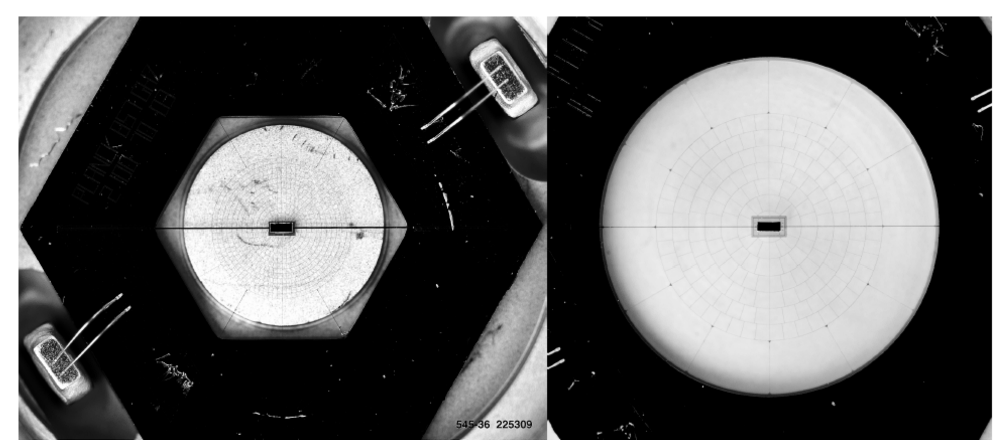
- Mean energy deposition set primarily by **thickness**
  Bolometer (150x300x2.5μm): ~250 eV, ~1/minutes
  Wafer ($50cm^2$x500μm): ~50 keV, 250 Hz
- Scatter, long tail to high-E, secondaries, …
  need Monte Carlo sims (GEANT, Fluka)

Planck-HFI at L2





- **Laboratory tests** identified origins of event classes *Catalano+ 2014, Planck 2013 X*
    - ***Bolometer*** hits manageable: $\Delta t_{between}/t_{recovery}$ ~ *10*^{3}
    - ***Wafer*** hits problematic: $\Delta t_{between}/t_{recovery}$ ~ *1*
- Two coupled problems
    - **Strong response to wafer hits** ⇨ high rate
    - **Long time constants** ⇨ long excisions/fits
- Also cold plate power loading, rare high-multiplicities, …

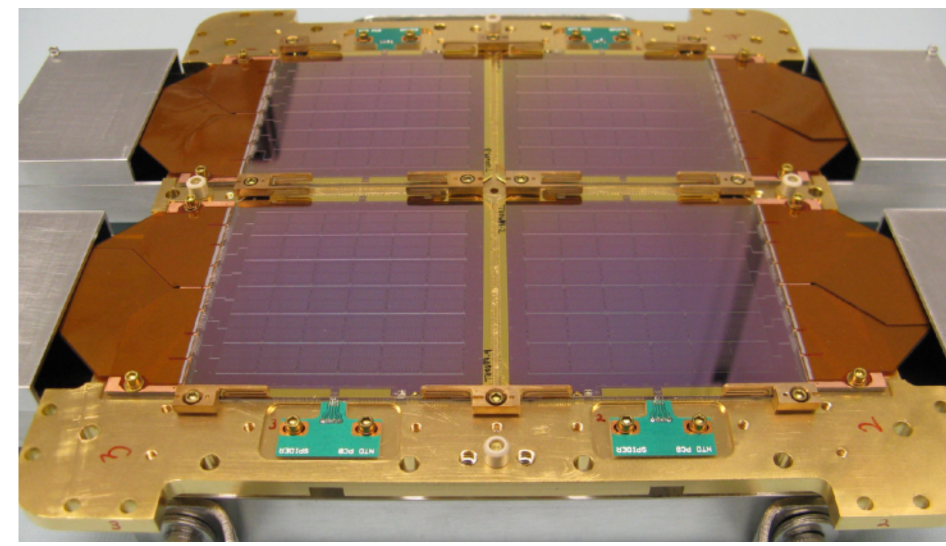


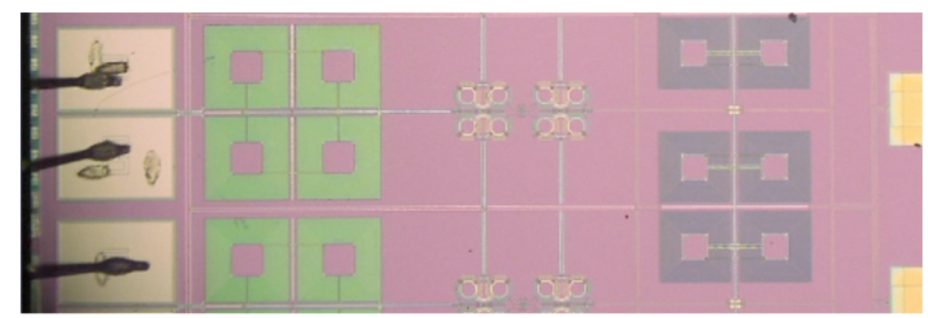
Wafer area: 0.4-0.8 cm^2

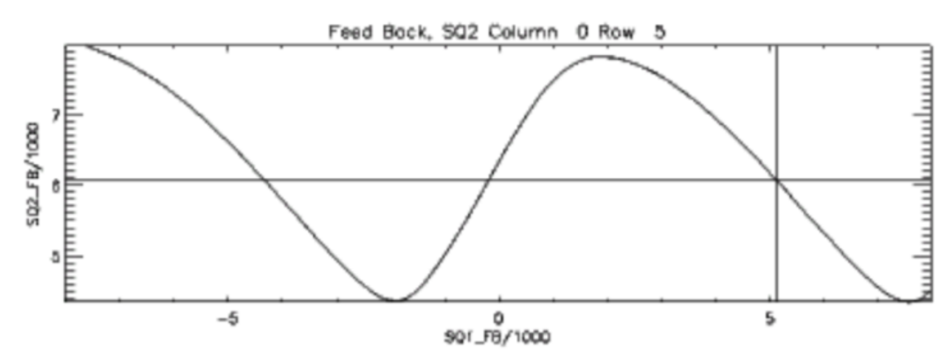
Planning for Space

WHAT'S NEW?

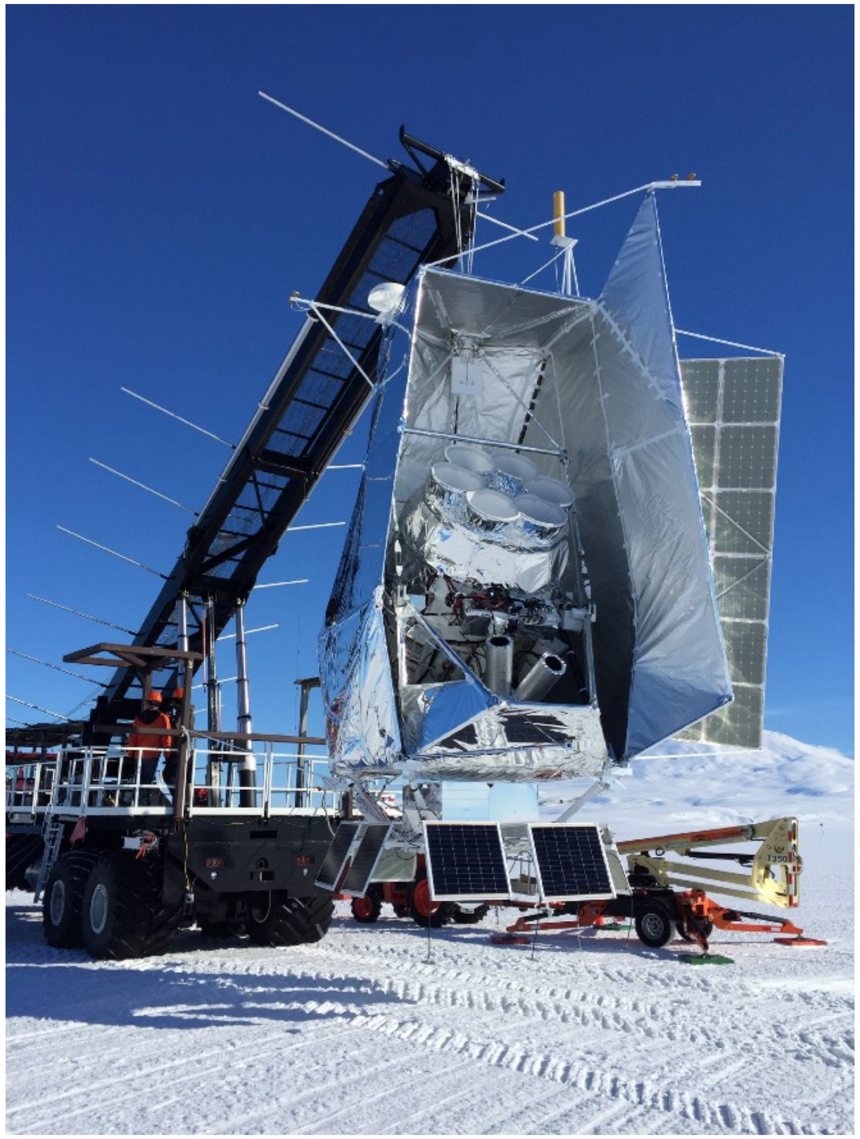
- **Monolithic detector arrays**
  - Large (4"-6") wafers ⇨ expected rate >100 Hz!
  - 100+ bolometers per wafer ⇨ high multiplicity?
  - **Thermal architecture**: Long time constants? Wafer temperature excursions?
  - **Ballistic phonon response**: How large an area does each bolometer respond to?
- **Multiplexed readout electronics**
  - Shared readout ⇨ high multiplicity?
  - **Readout crosstalk**: How big? Nonlinear crosstalk for large bolometer ΔR?
  - **Direct effects on readout** (SQUIDs, resonators)?

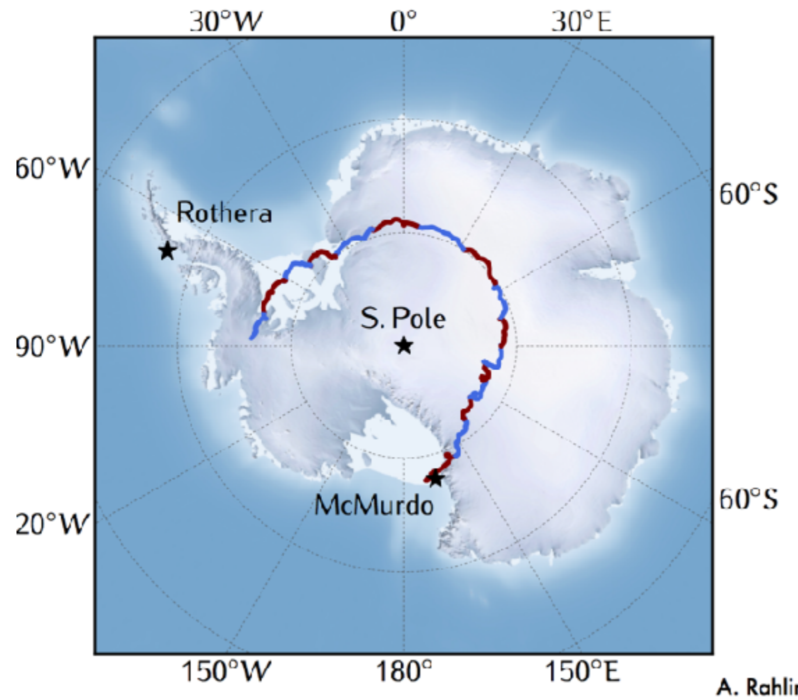






SPIDER



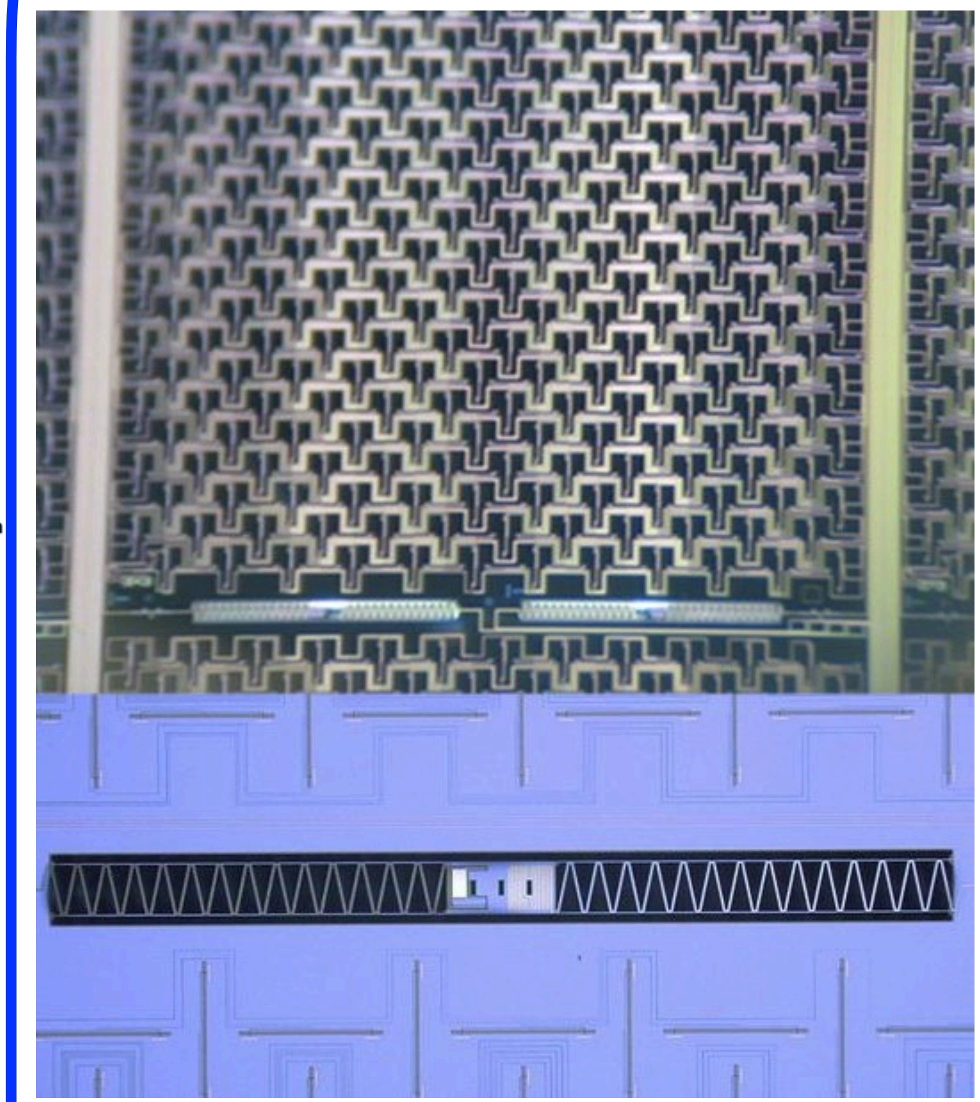


McMurdo LDB flight

January 1-18, 2015
Altitude ~36 km
Mapped ~10% sky

- Six monochromatic refracting telescopes, HWPs
- CIT/JPL antenna-coupled TES arrays
  - 1488 (816) at 150 (95) GHz, 96 dark, >80% yield
  - Time-division multiplexer (UBC MCE)
  - *2018: add NIST feedhorn-array 285 GHz receivers*

TES ARRAYS



- 24x 4” wafers: $50cm^2$x500μm
- Bolometers: 150x300x2.5μm
- Ti TES: T_{fpu}=0.3K, T_c=0.5K
- 100s of Au wire bonds/wafer

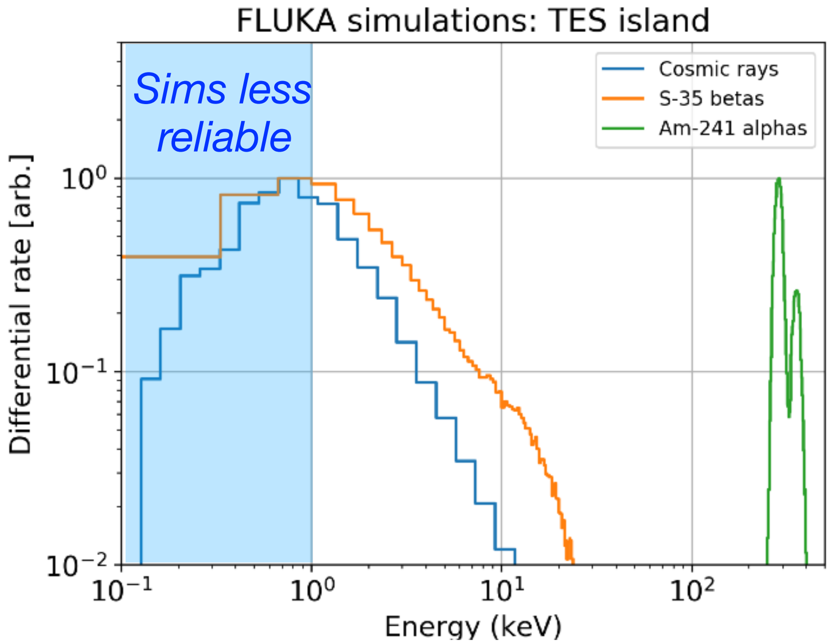
Supporting Data

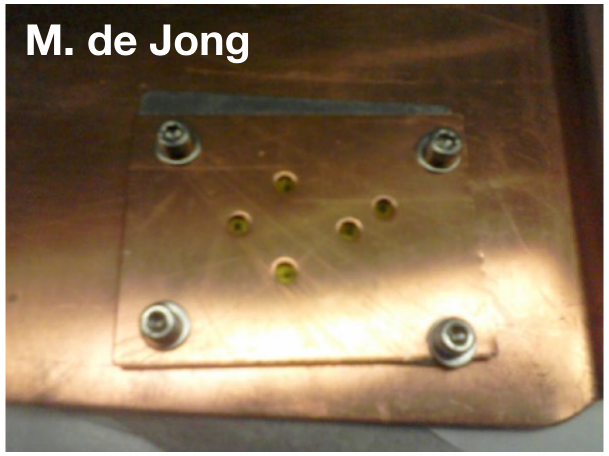
South Pole 2010-12: BICEP2

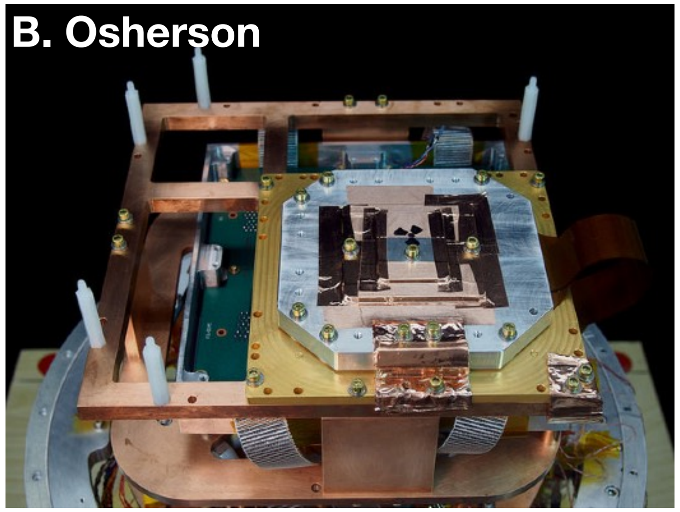
- Glitches ~daily / bolometer
  Disfavors large wafer response
- Rare “steps” in data DC level
  Speculated to be cosmic rays

Caltech 2012: S-35, Keck wafer

- 167 keV endpoint beta
- Proxy for cosmic rays hitting the **island**





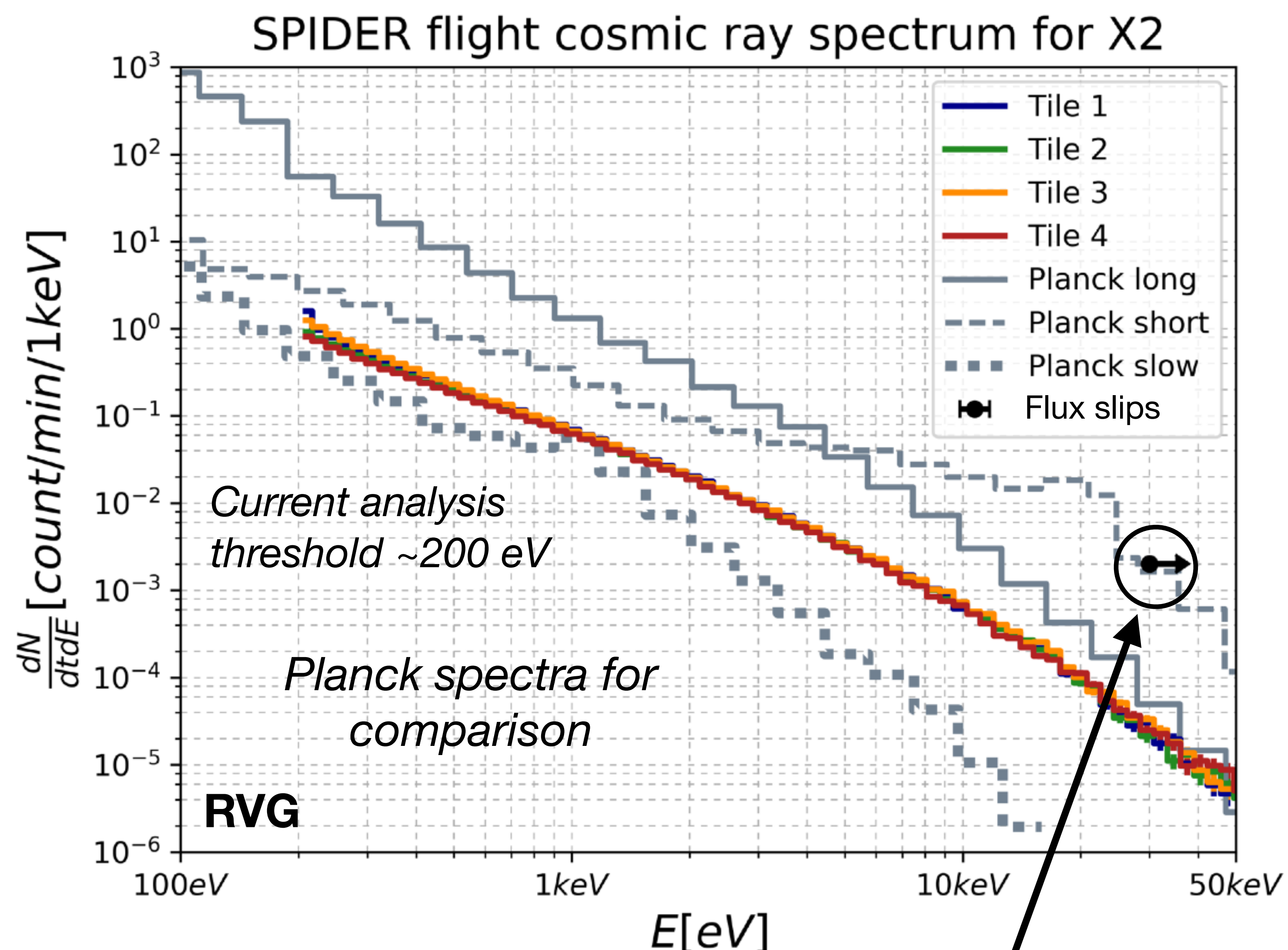


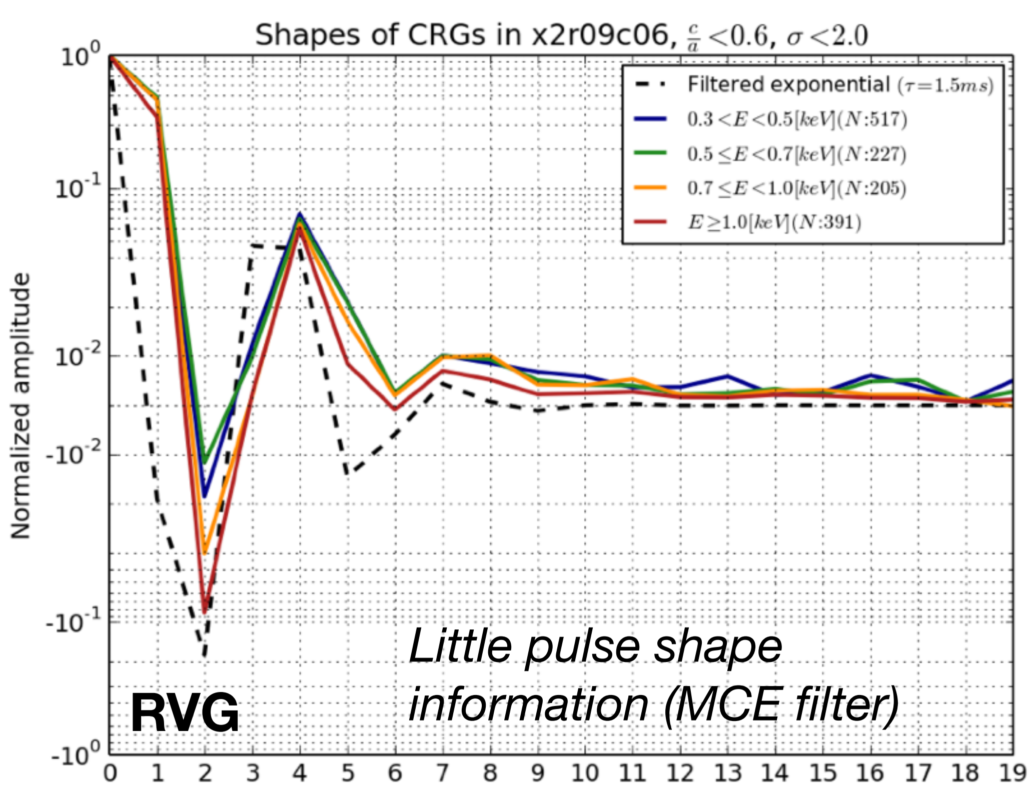
UIUC 2017: Am-241, SPIDER wafer

- 5.5 MeV alpha
  ~fully absorbed in wafer
- Proxy for cosmic rays hitting the **wafer**
  Comparable to bigger (<1 Hz) depositions

SPIDER 2015

- Identify glitches in otherwise unflagged flight data
- Template fit and shape cuts
- Integrate in power units for approximate energy (E_{ETF}) Significant *nonlinearity above a few keV*





Samples @119 Hz

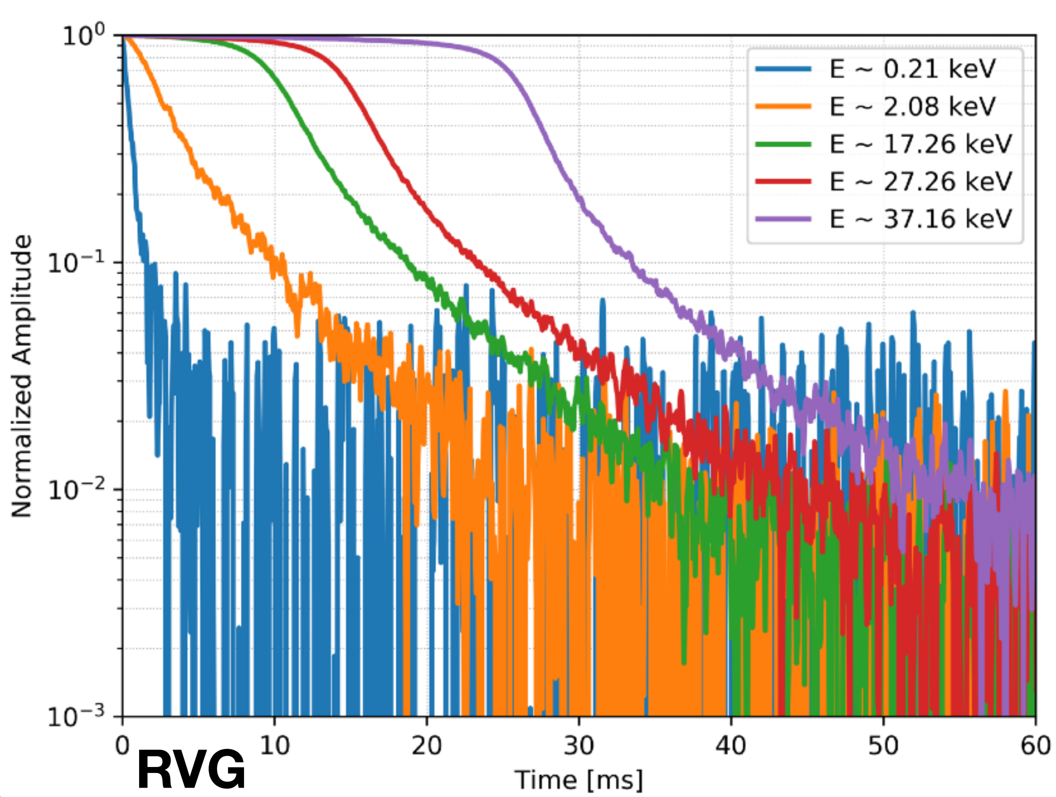
Per-detector event rates
Detectable: ~1/(3 min)
Flux slips: ~hourly
Coincidence: ~0.03%

Step discontinuities "flux slips"
from high-E cosmic rays
Detector dependent cutoff in glitch rates

Glitch Types

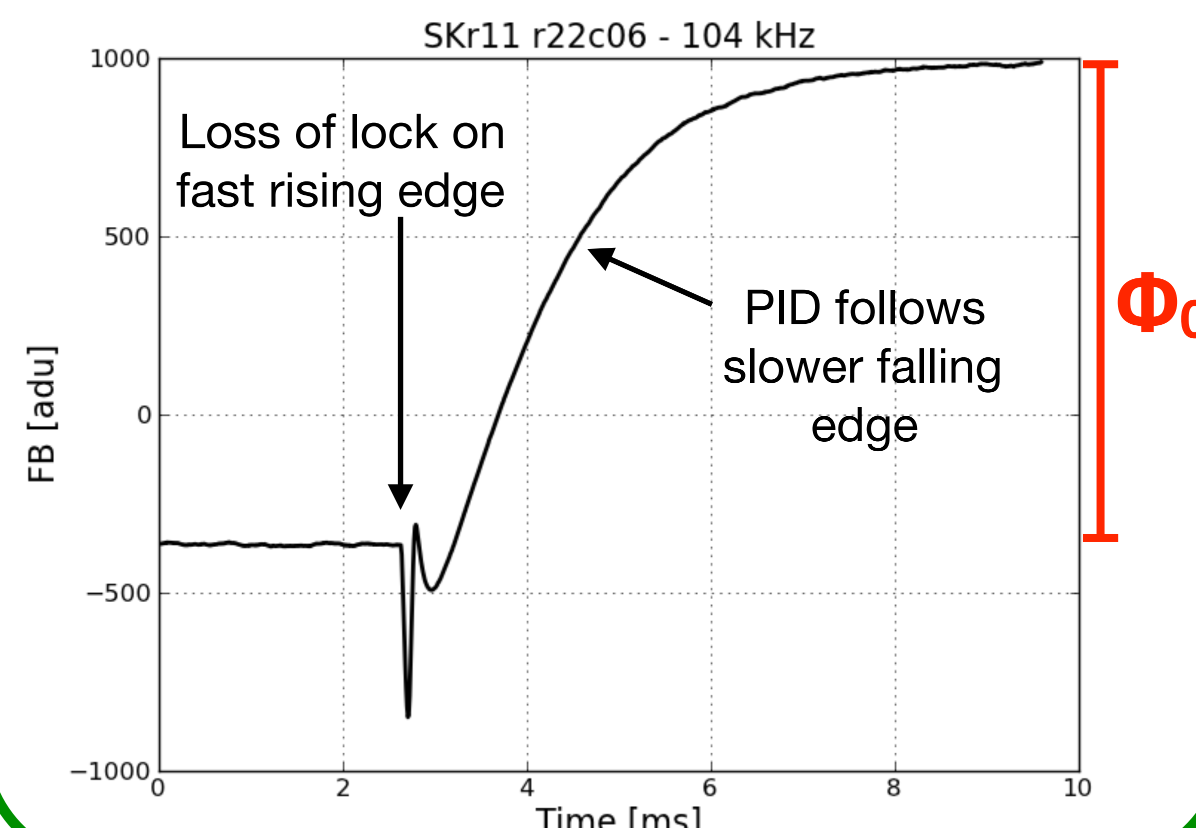
"Standard" Glitches

- Stacked α data, 15 kHz sampling
  Similar performance in β data (S35)
  - Primary time constant 1-3 ms
  - Additional time constants <10 ms
  - TES saturation at O(10 keV)
- Known ~0.5% nearest-neighbor **crosstalk** from SQUID multiplexer

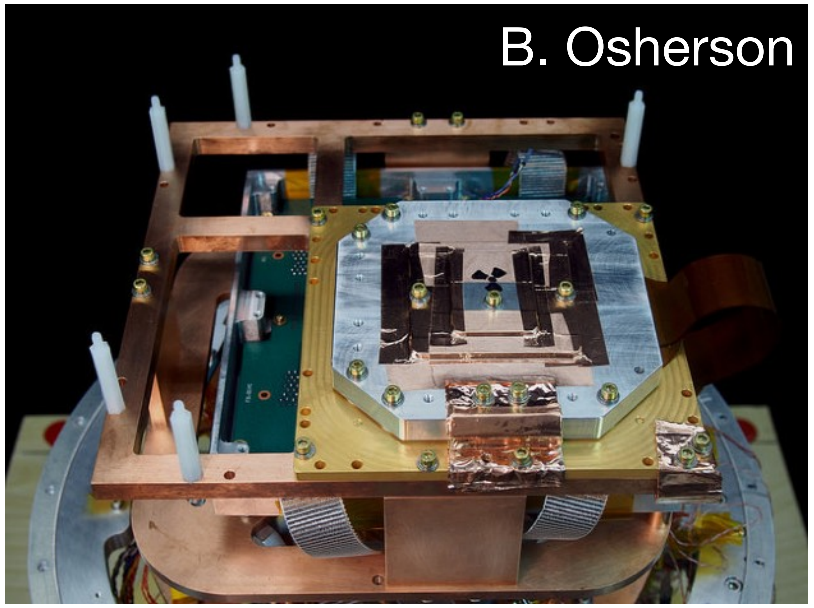


"Step" Glitches

- Lab β data, 104 kHz sampling
- **"Flux slips"**: Mux loses lock on large events, baseline shifts by SQUID period
- Threshold similar to saturation
  can be tuned away in new design
- *Also identified in BICEP2 ground data*



Wafer Hit Tests



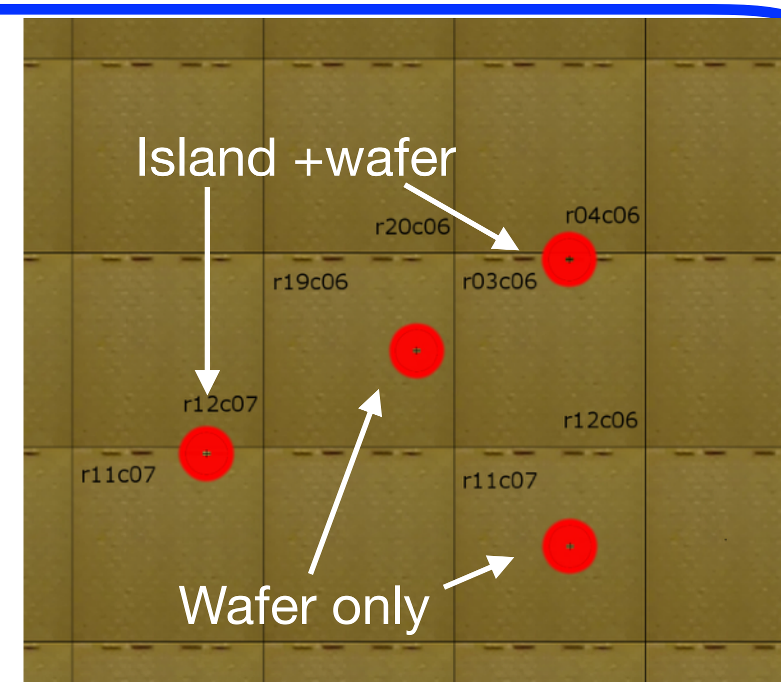
Am-241 test jig

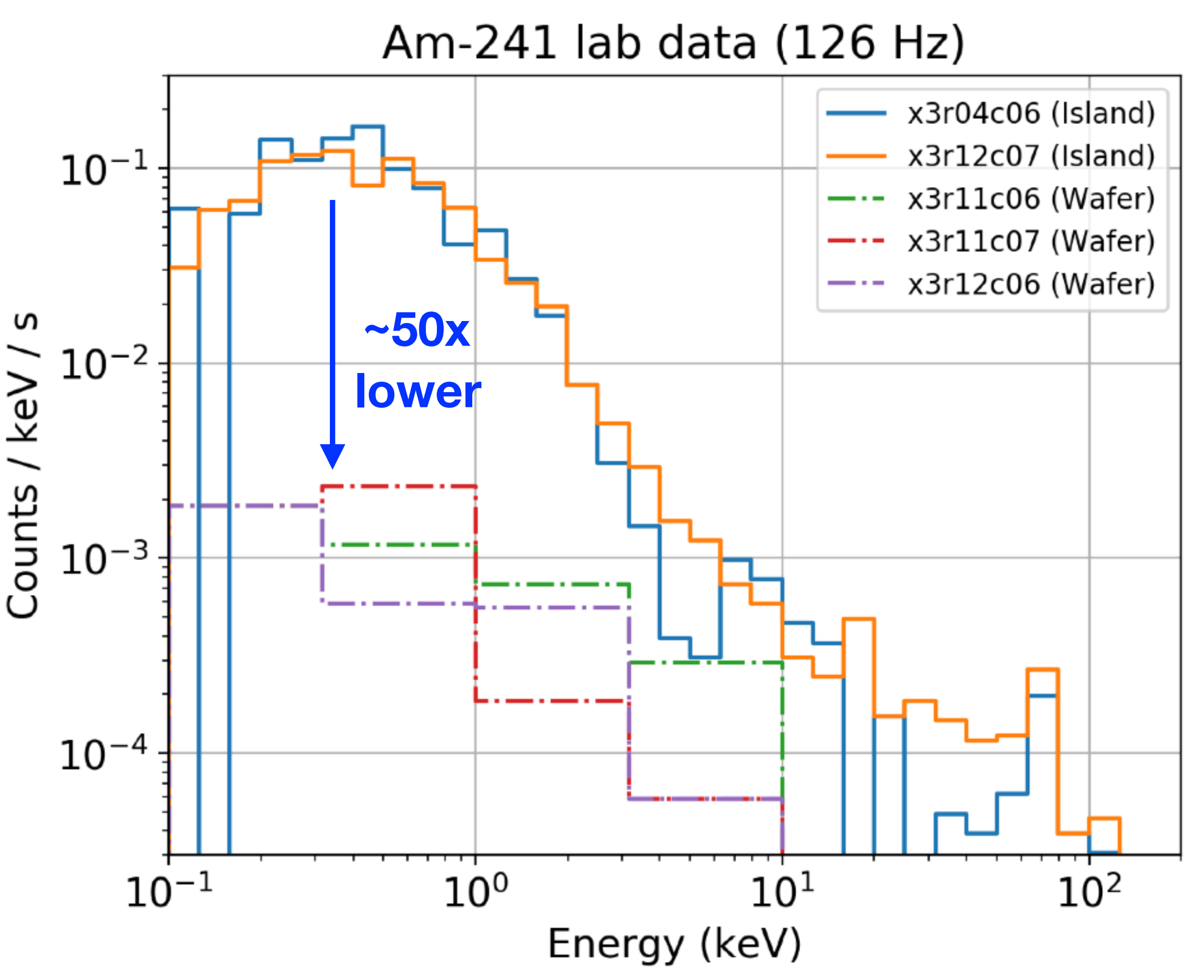
SPIDER-1 150 GHz tile

Collimated Am-241
(*5.5 MeV α, 60 keV γ*)

~6 Hz/spot on *wafer*

~0.1 Hz/spot on *island*





- Am-241 data, 126 Hz sampling
- Source over **island** (and wafer)
  Steps ~0.07 Hz (likely alphas)
  Glitches ~0.14 Hz
- Source over **wafer**
  Glitch and step rate ~1/ (5 min)
- Coincidence rate negligible
  Skewness and noise correlation analysis in progress

Conclusions

- SPIDER LDB 2015
  - Modest data loss from CR glitches
  - Low coincidence rate
  - Rate comparable to island hit expectations
- Laboratory tests clarify phenomenology
  - Low coincidence rate, saturation
  - Multiplexer effects: flux slips, crosstalk
- Future work
  - Closer look at position dependence?
  - Constraints on multiplexer design?
  - Move to 100mK: thermal design gets harder!