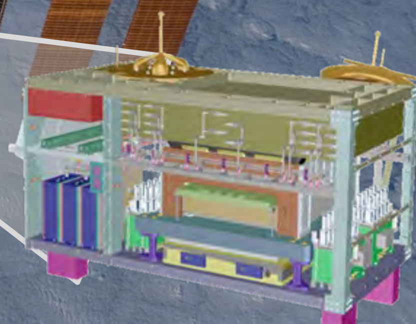
NextGAPES-2019
Moscow – June 21-22, 2019

Cosmic Ray Energetics And Mass
CREAM for the ISS (ISS-CREAM)



Eun-Suk Seo
University of Maryland
for the ISS-CREAM Collaboration

ISS-CREAM Collaboration

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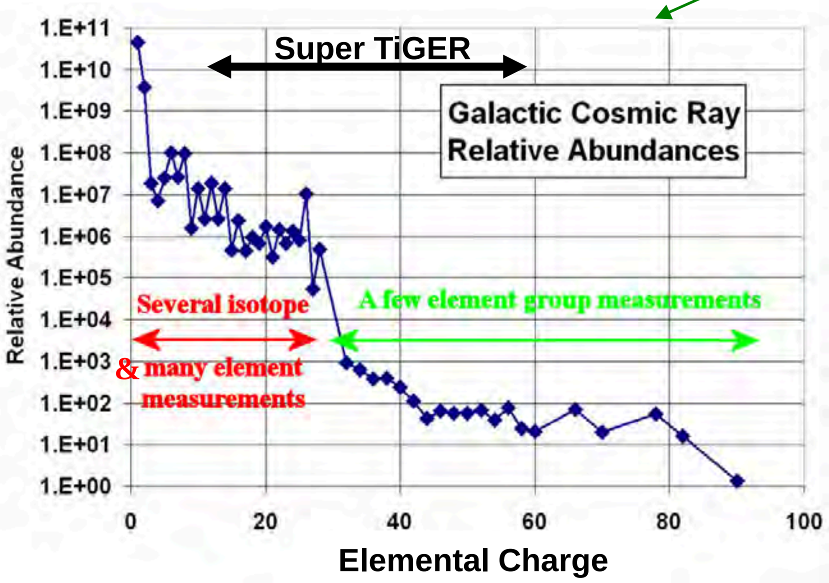
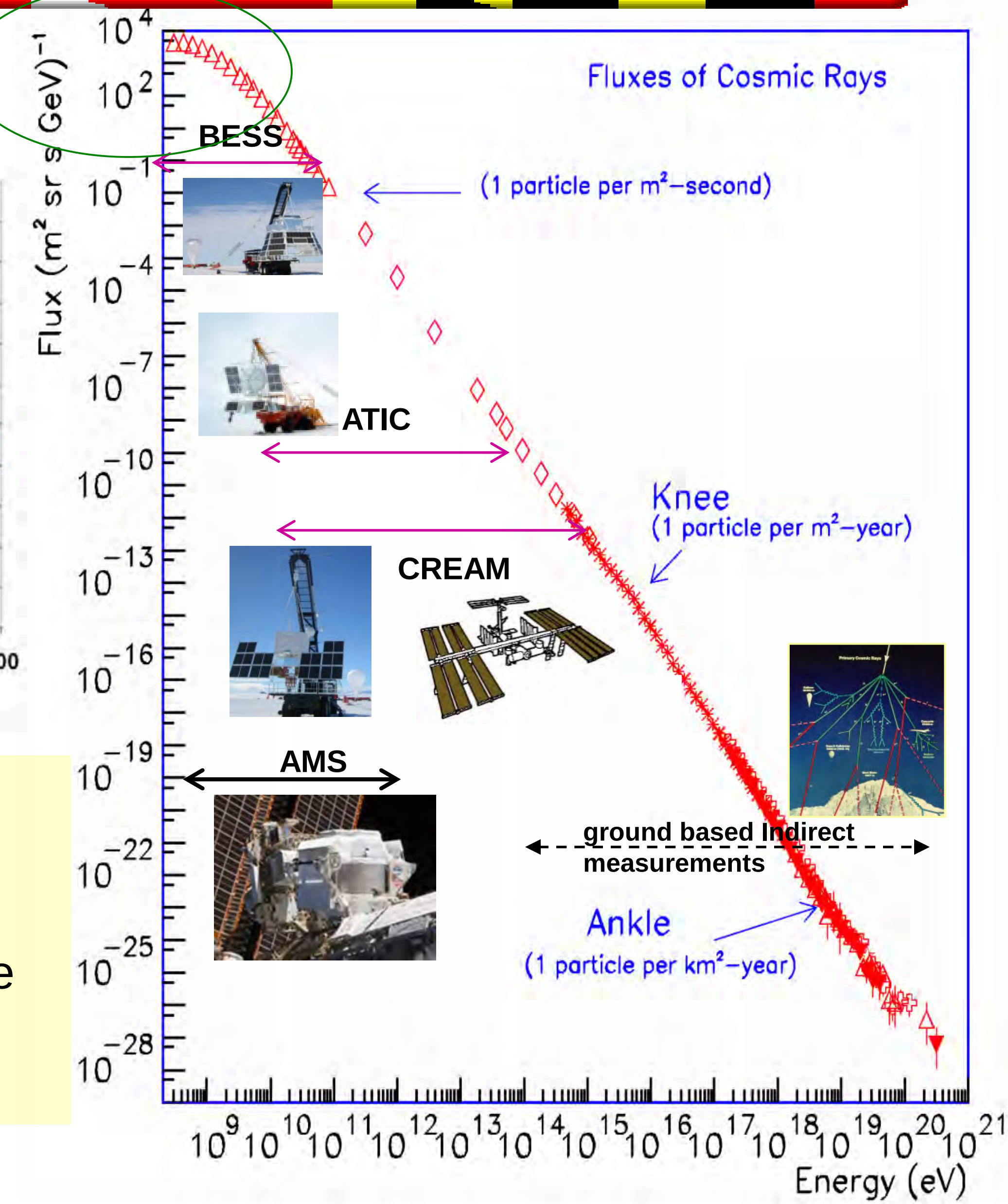
How do cosmic accelerators work?

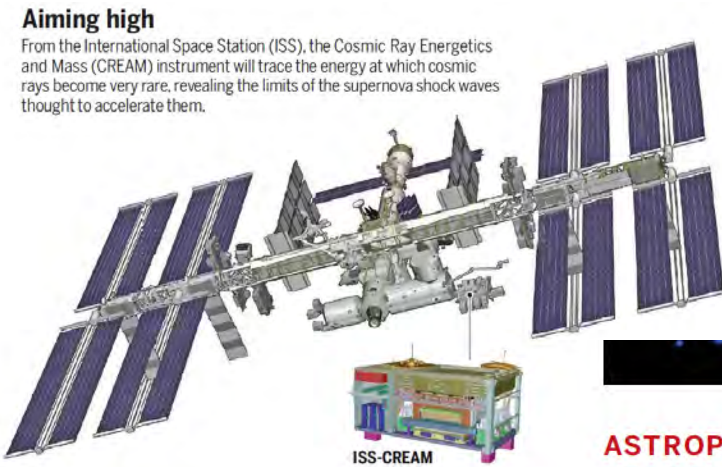


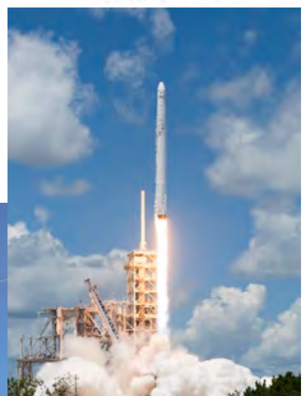


Mission Goal

Extend the energy reach of direct measurements of cosmic rays to the highest energy possible to investigate cosmic ray origins, acceleration and propagation.

ISS-CREAM launch on SpaceX-12, 8/14/17





ASTROPHYSICS

Cosmic ray catcher will probe supernovae from new perch

Balloon-borne detector moves to space to trap rare, high-energy particles that carry clues to their origin

By **Eric Hand**

After 191 days aboard balloons sailing the stratosphere, an experiment designed to probe the galaxy's natural particle accelerators will move to higher ground: the International Space Station (ISS). The Cosmic Ray Energetics and Mass (CREAM) instrument and its successors floated above Antarctica seven times to collect high-energy cosmic

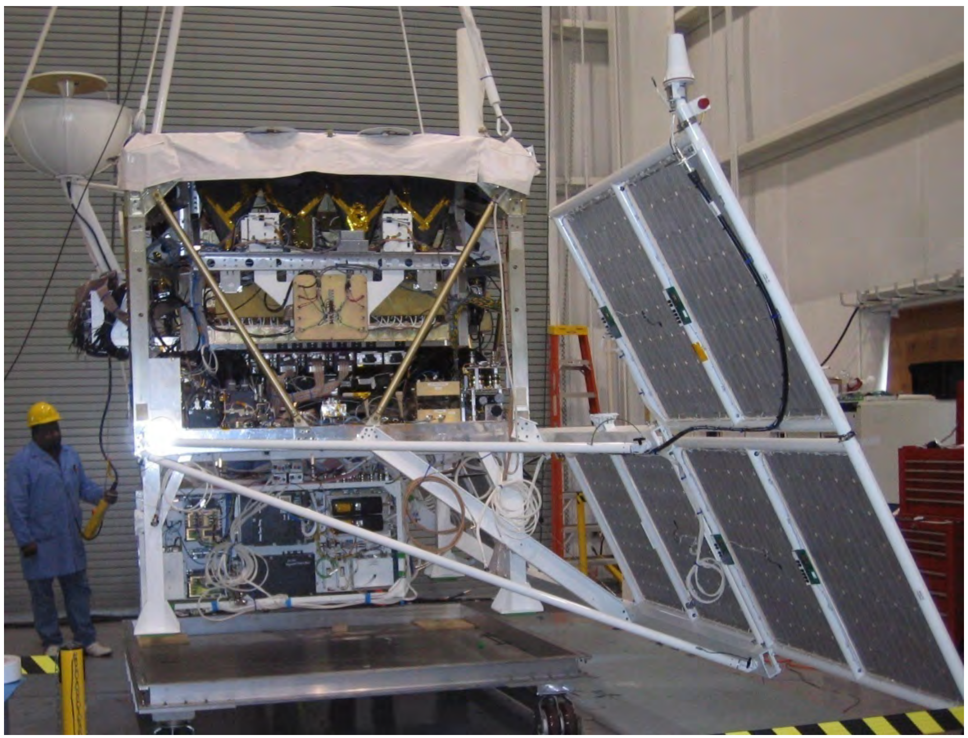
that a few smash into Earth with extraordinarily high energies—higher than today's most powerful atom smashers can generate. Their abundance drops sharply with increasing energy, following what's known as a power law distribution. In 1949, Italian-American physicist Enrico Fermi came up with a mechanism that could explain that and the cosmic rays' mind-boggling energies: supernova shock waves. In the centuries after a supernova,

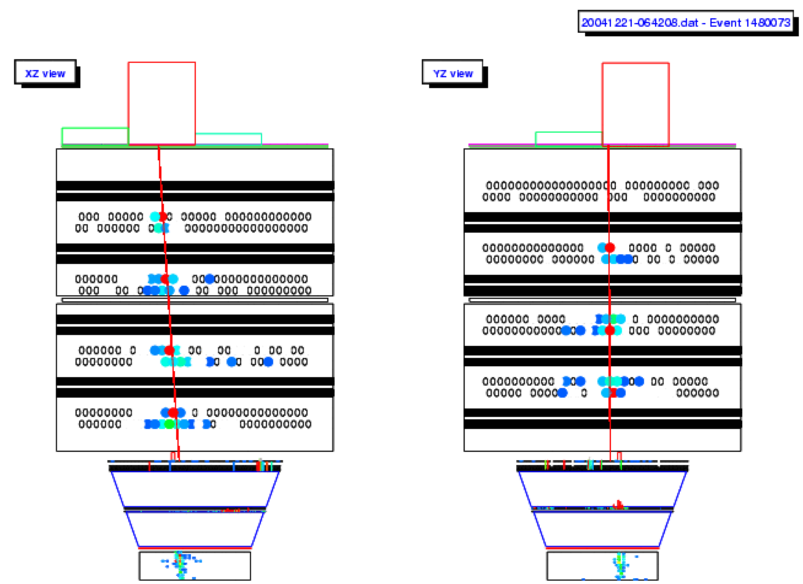
CREAM Cosmic Ray Energetics And Mass

Seo et al. Adv. in Space Res., **33** (10), *1777*, 2004; Ahn et al., NIM A, **579**, 1034, 2007

- Transition Radiation Detector (TRD) and Tungsten Scintillating Fiber Calorimeter
  - In-flight cross-calibration of energy scales

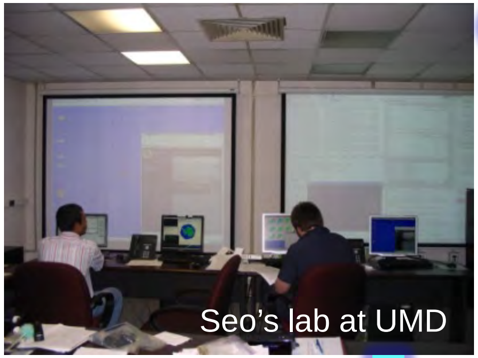
- Complementary Charge Measurements
  - Timing-Based Charge Detector
  - Cherenkov Counter
  - Pixelated Silicon Charge Detector

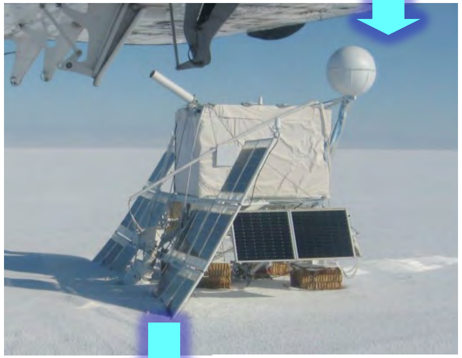




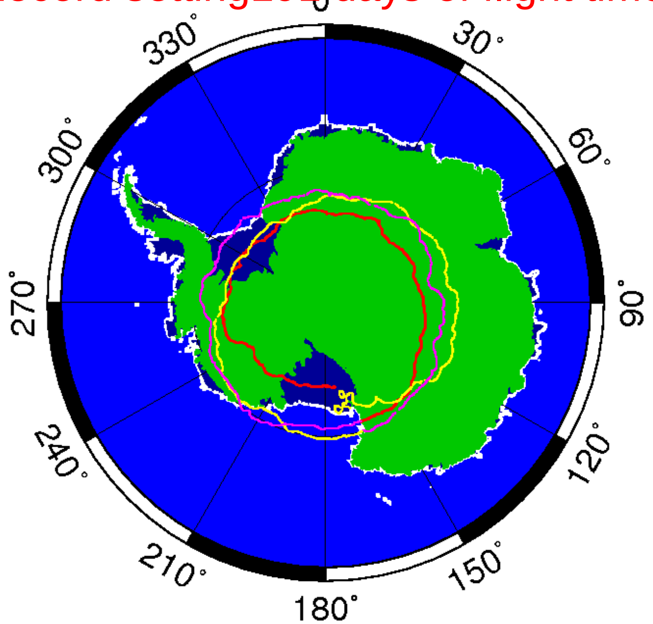
Balloon Flights in Antarctica Offer Hands-On Experience

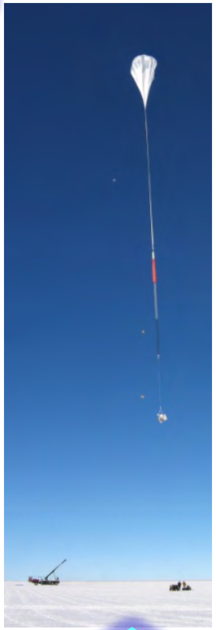
CREAM has trained >100 students





Record setting191 days of flight time





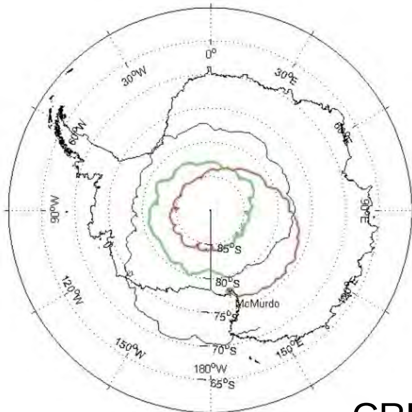
- Seven successful balloon flights and have accumulated 191 days of data.
- The instruments are for the most part **<u>built in-house by students</u>** and young scientists.

Instruments are fully recovered, refurbished & reflown.

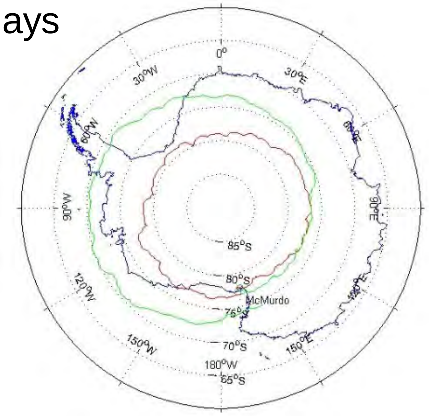
CREAM Balloon Flight Heritage

Seven Balloon Flights in Antarctica: ~ 191 days Cumulative Exposure

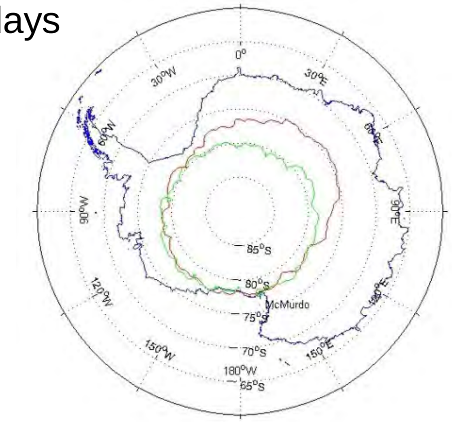
CREAM-I
12/16/04 – 1/27/05
42 days



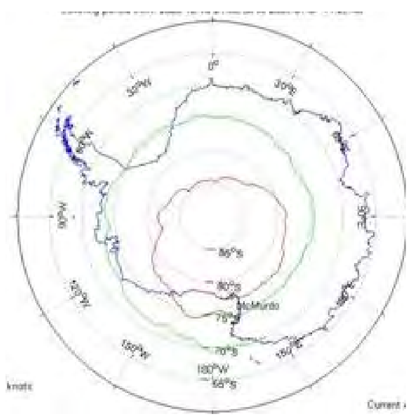
CREAM-II
12/16/05-1/13/06
28 days



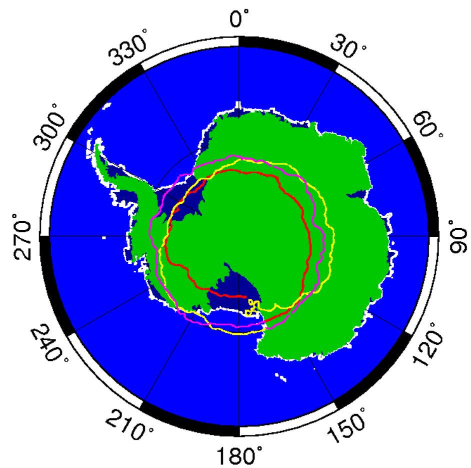
CREAM-III
12/19/07-1/17/08
29 days



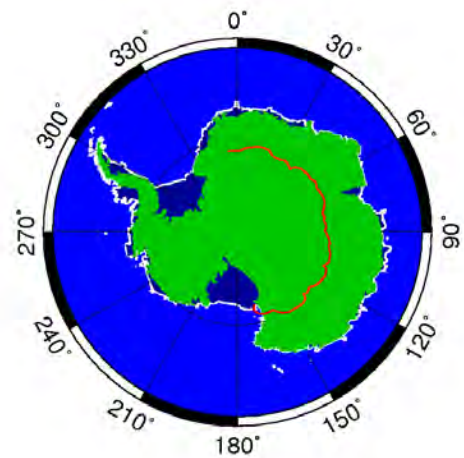
CREAM-IV
12/19/08 – 1/7/09
19 days 13 hrs



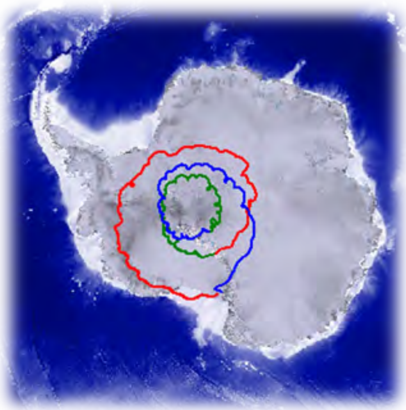
CREAM-V
12/1/09 – 1/8/10
37 days 10 hrs



CREAM-VI
12/21/10 – 12/26/10
5 days 16 hrs

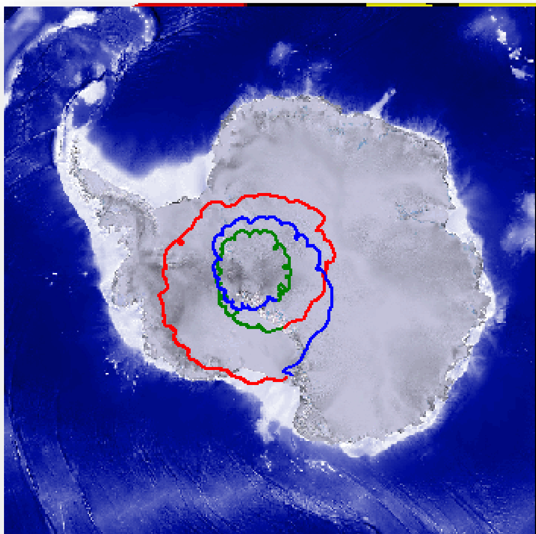


BACCUS
11/28/16-12/28/16
30 days 2 hrs



BACCUS Balloon Payload 30 Days Flight

Kim et al. Proc. 35th ICRC, Busan, 182, 2017

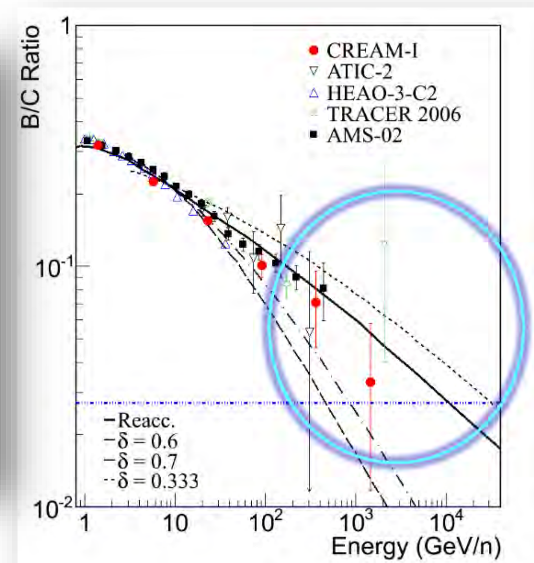


BACCUS flight trajectory
Nov. 28 – Dec. 28, 2016

- Boron And Carbon Cosmic rays in the Upper Stratosphere (BACCUS) set two records: the earliest launch, i.e., the first LDB to launch in November and (2) the closest landing to the launch site.
- BACCUS is to investigate cosmic ray propagation history using Boron to Carbon ratio at high energies where measurements are not available.
- The BACCUS experiment provides simultaneous measurements of cosmic-ray nuclei from Z = 1 to Z =26 using segmented silicon charge detector and timing charge detector. Both calorimeter and transition radiation detector provide energy measurements.

BACCUS was recovered with 1 Twin Otter and 1 Helicopter flight after landing on the Ross Ice Shelf only 55 nautical miles east of McMurdo Station.

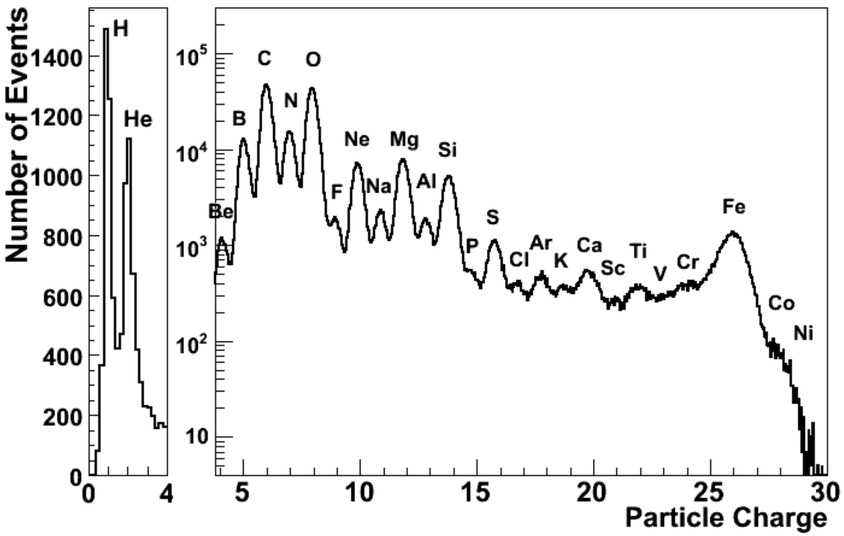
BACCUS payload at CSBF during the end to end test.



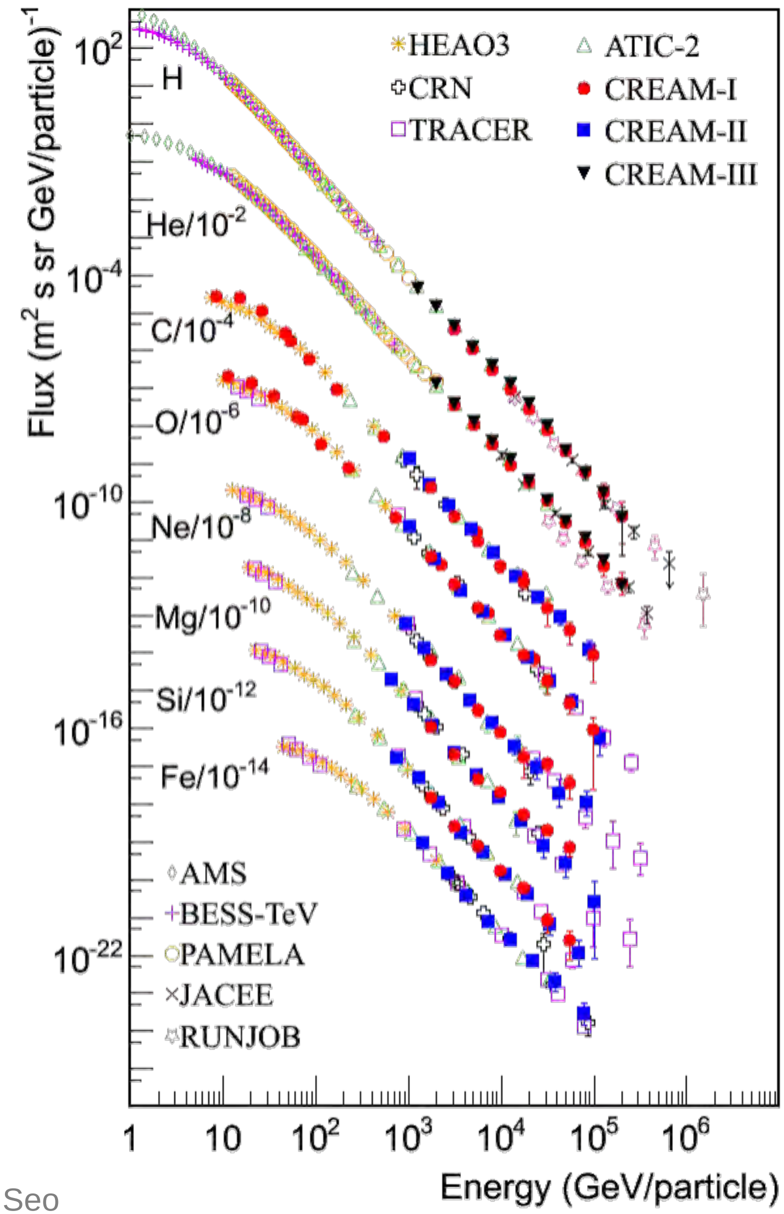
Elemental Spectra over 4 decades in energy

Yoon et al. ApJ **728**, *122*, 2011; Ahn et al., ApJ **715**, *1400*, 2010; Ahn et al. ApJ **707**, *593*, 2009

Excellent charge resolution from SCD

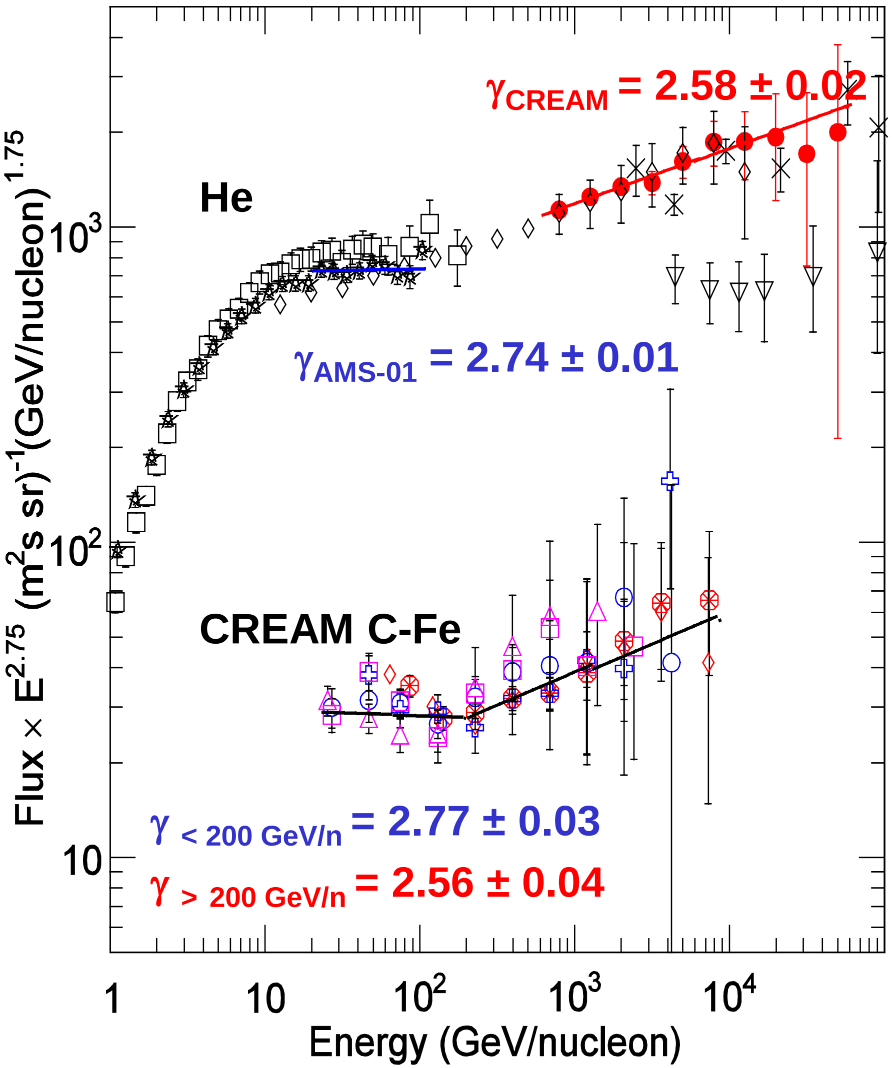


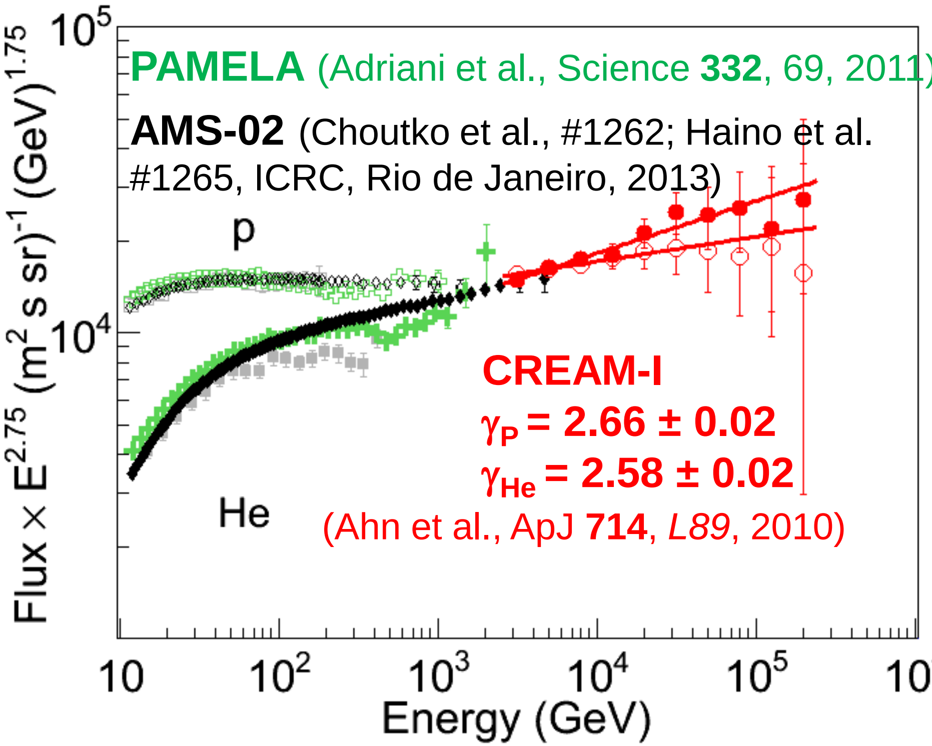
Distribution of cosmic-ray charge measured with the SCD. The individual elements are clearly identified with excellent charge resolution. The relative abundance in this plot has no physical significance.



CREAM spectra harder than prior lower energy measurements

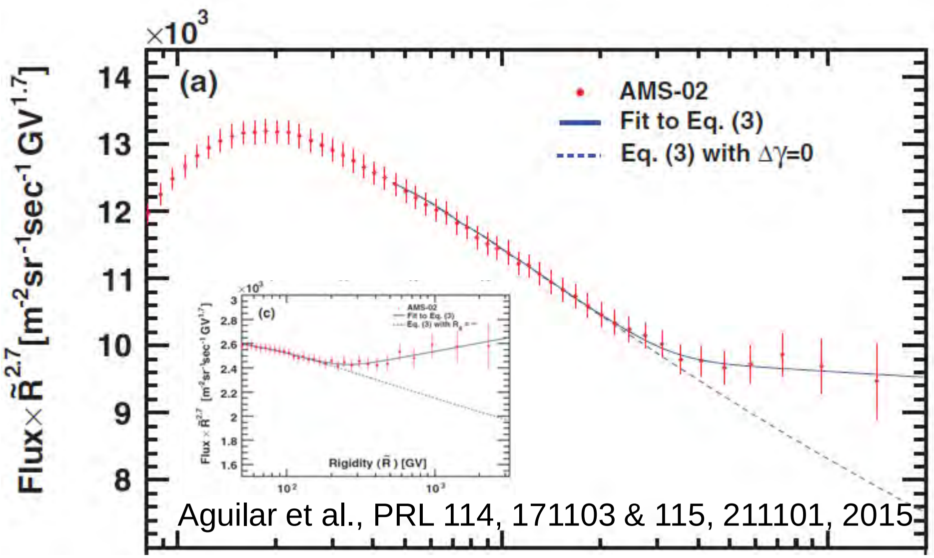
Yoon et al. ApJ **728**, *122*, 2011; Ahn et al. ApJ 714, L89, 2010

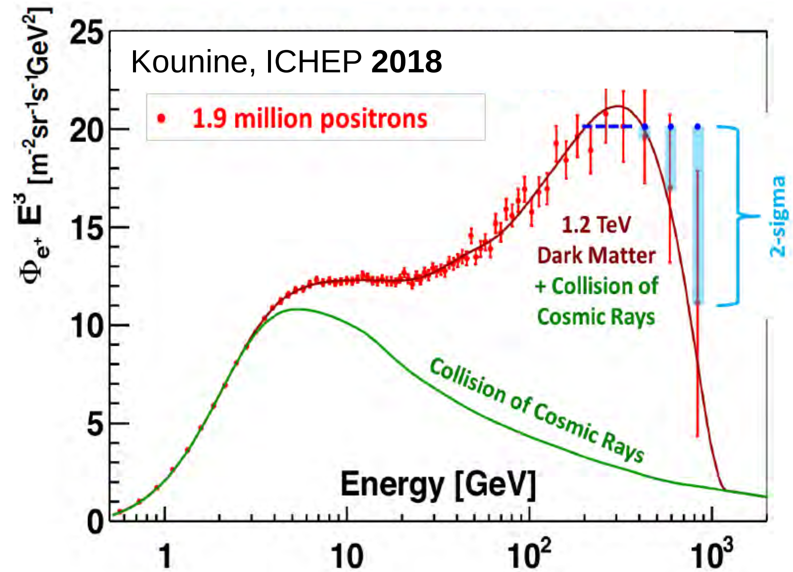


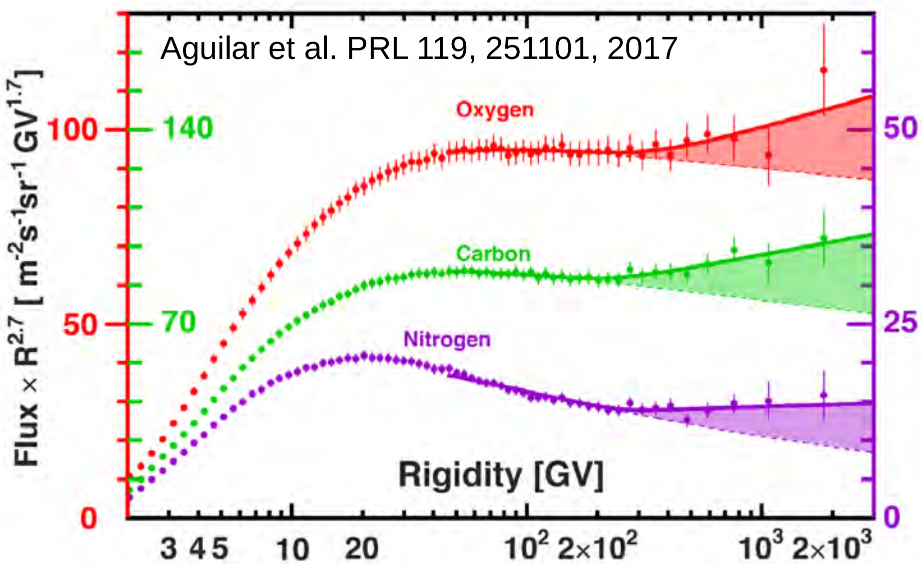


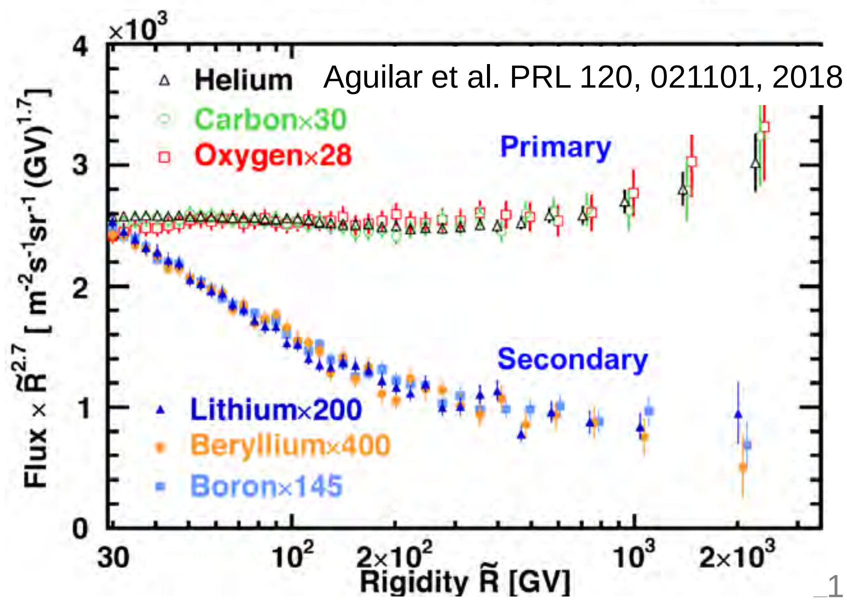
It provides important constraints on cosmic ray acceleration and propagation models, and it must be accounted for in explanations of the e^+e^- anomaly and cosmic ray “knee.”

Spectral Hardening Confirmed



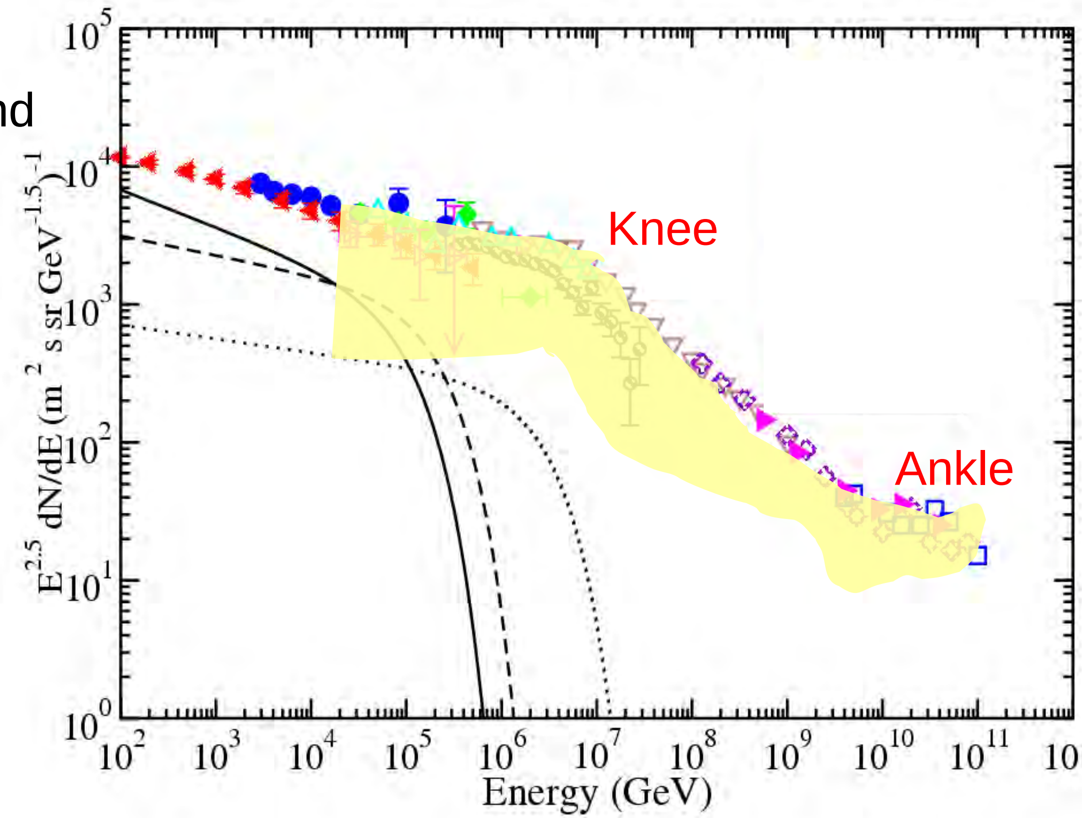






Is the “knee” due to a limit in SNR acceleration?

- The all particle spectrum extends several orders of magnitude beyond the highest energies thought possible for supernova shock acceleration
- And, there is a “knee” (index change) above 10^{15} eV
- Acceleration limit signature: Characteristic elemental composition change over two decades in energy below and approaching the knee
- Direct measurements of individual elemental spectra can test the supernova acceleration model



SNR acceleration limit:

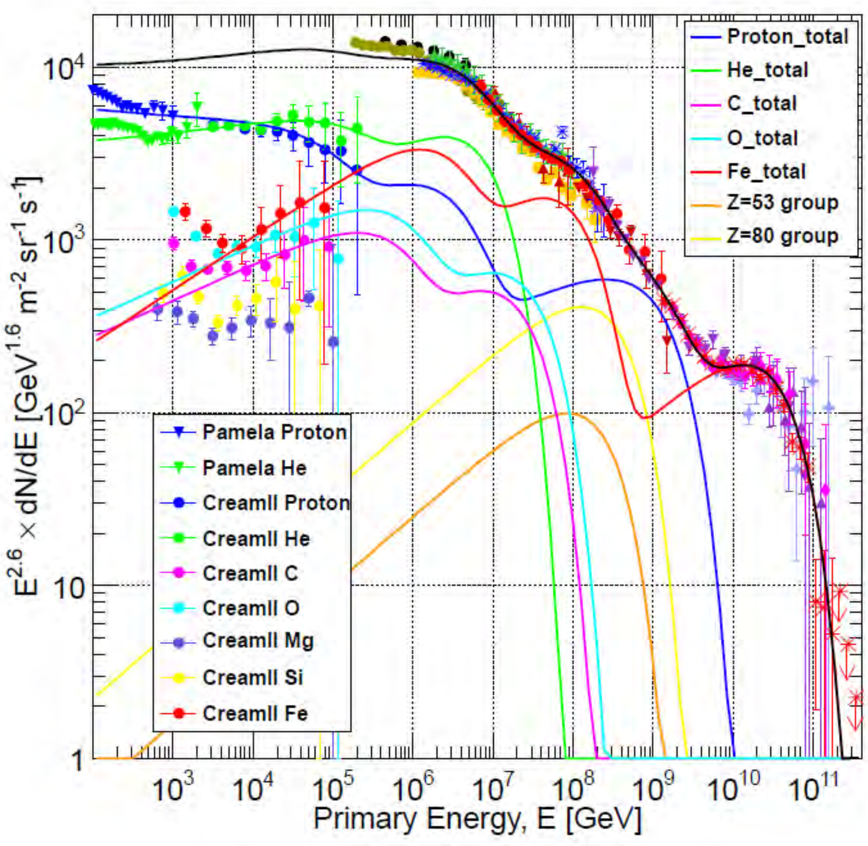
$$E_{max} \sim \frac{v}{c} ZeBVT \sim Z \times E_{max\_p}$$

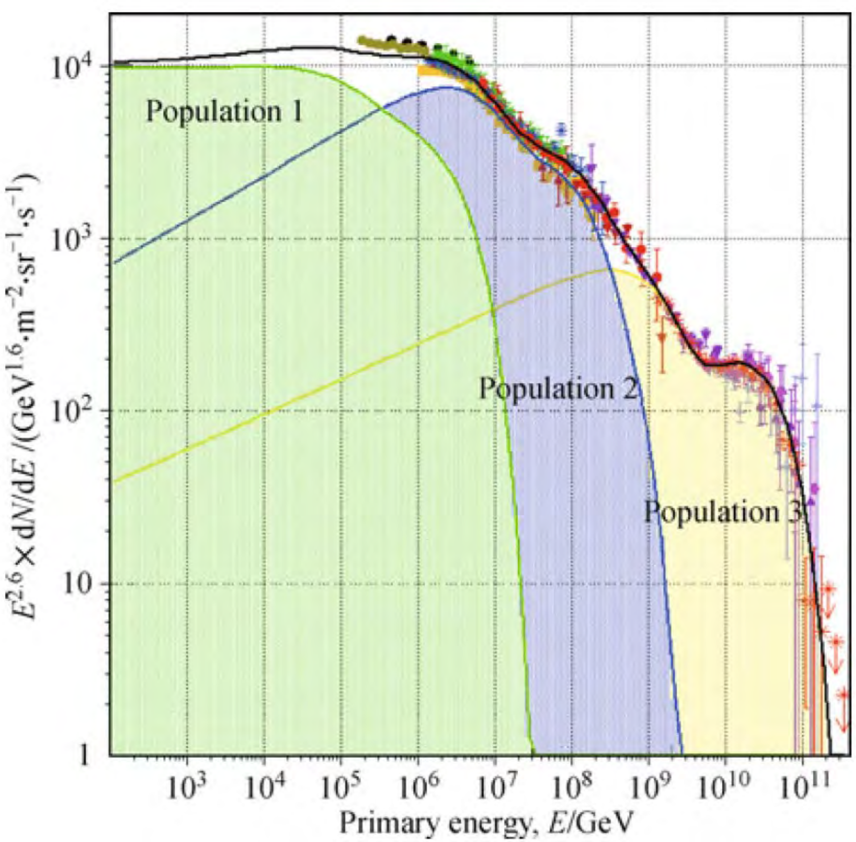
Multiple Sources?

T. K. Gaisser, T. Stanev and S. Tilav, Front. Phys. 8(6), 748, 2013

Acceleration limit:

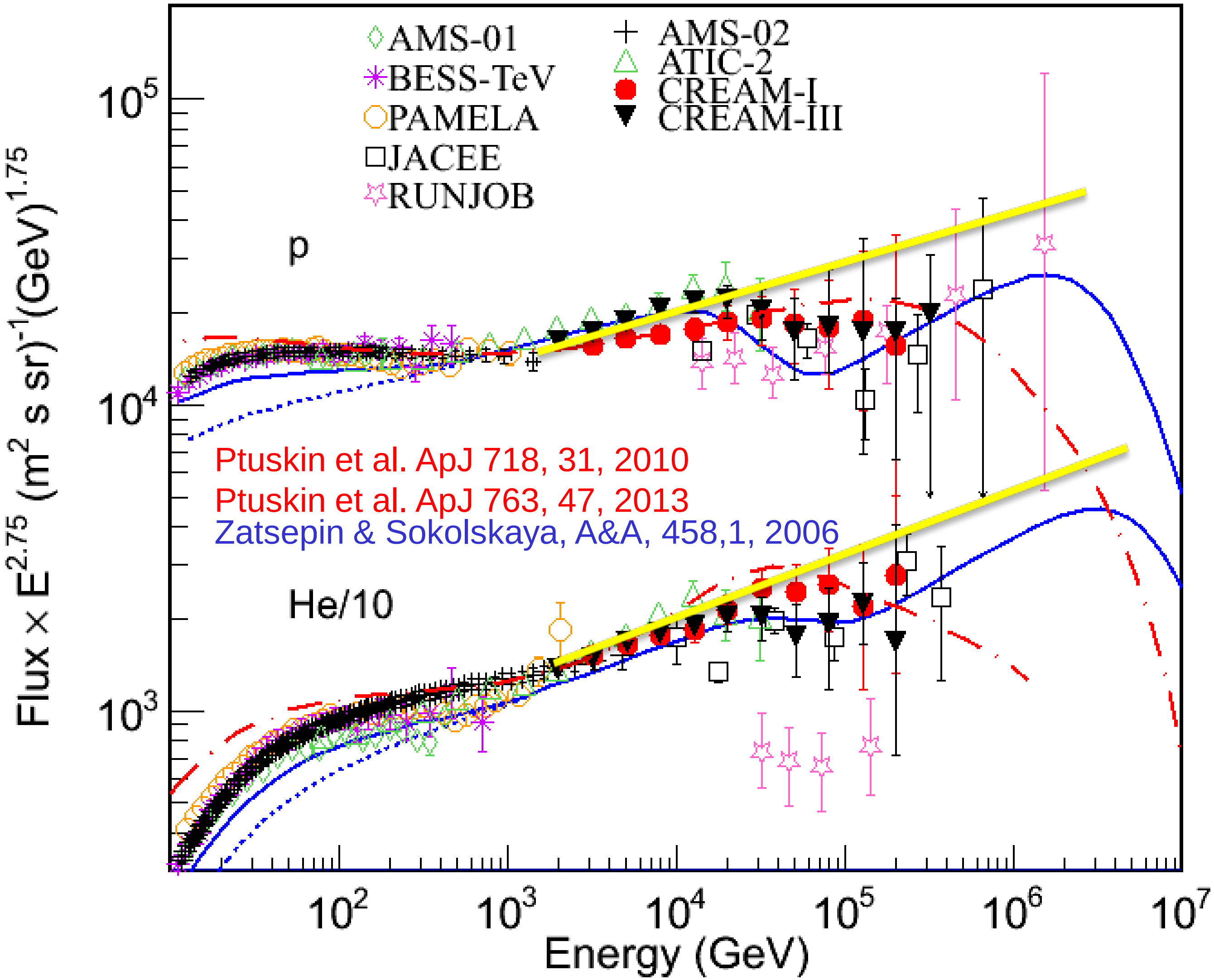
E_{max_z} = Ze x R = Z x E_{max_p}, *where rigidity R = Pc/Ze*





Need to extend measurements to higher energies

Yoon et al. (CREAM Collaboration) ApJ 839:5, 2017

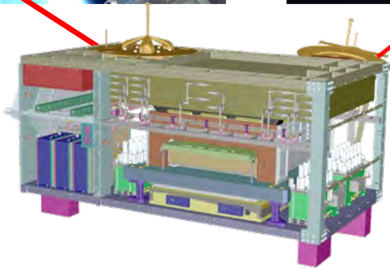


ISS-CREAM: CREAM for the ISS

E. S. Seo et al, Advances in Space Research, **53**/10, *1451*, 2014

SpaceX-12 Launch on 8/14/2017

ISS-CREAM installed on the ISS 8/22/17

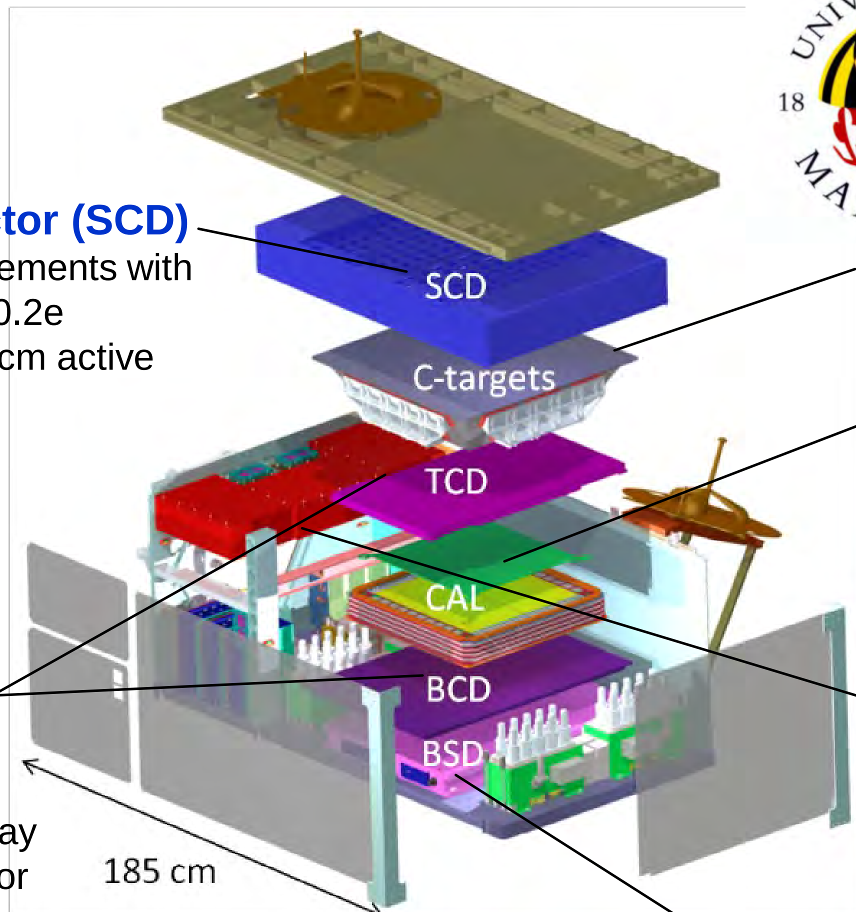


Mass: ~1258 kg
Power: ~ 415 W
Data rate: ~500 kbps

- Building on the success of the balloon flights, the payload was transformed for accommodation on the ISS (NASA's share of JEM-EF).
  - Increase the exposure by an order of magnitude
- ISS-CREAM will measure cosmic ray energy spectra from 10^{12} to $>10^{15}$ eV with individual element precision over the range from protons to iron to:
  - Probe cosmic ray origin, acceleration and propagation.
  - Search for spectral features from nearby/young sources, acceleration effects, or propagation history.

ISS-CREAM Instrument

Seo et al. Adv. in Space Res., **53**/10, *1451*, 2014; Smith et al. PoS(ICRC2017)199, 2017



Silicon Charge Detector (SCD)

- Precise charge measurements with charge resolution of ~ 0.2e
- 4 layers of 79 cm x 79 cm active area (2.12 cm^2 pixels)

Carbon Targets

- Induces hadronic interactions

Calorimeter

- 20 layers of alternating tungsten plates and scintillating fibers
- Determines energy
- Provides tracking and high energy trigger

Top/Bottom Counting Detector (T/BCD)

- Plastic scintillator instrumented with an array of 20 x 20 photodiodes for e/p separation
- Low energy trigger

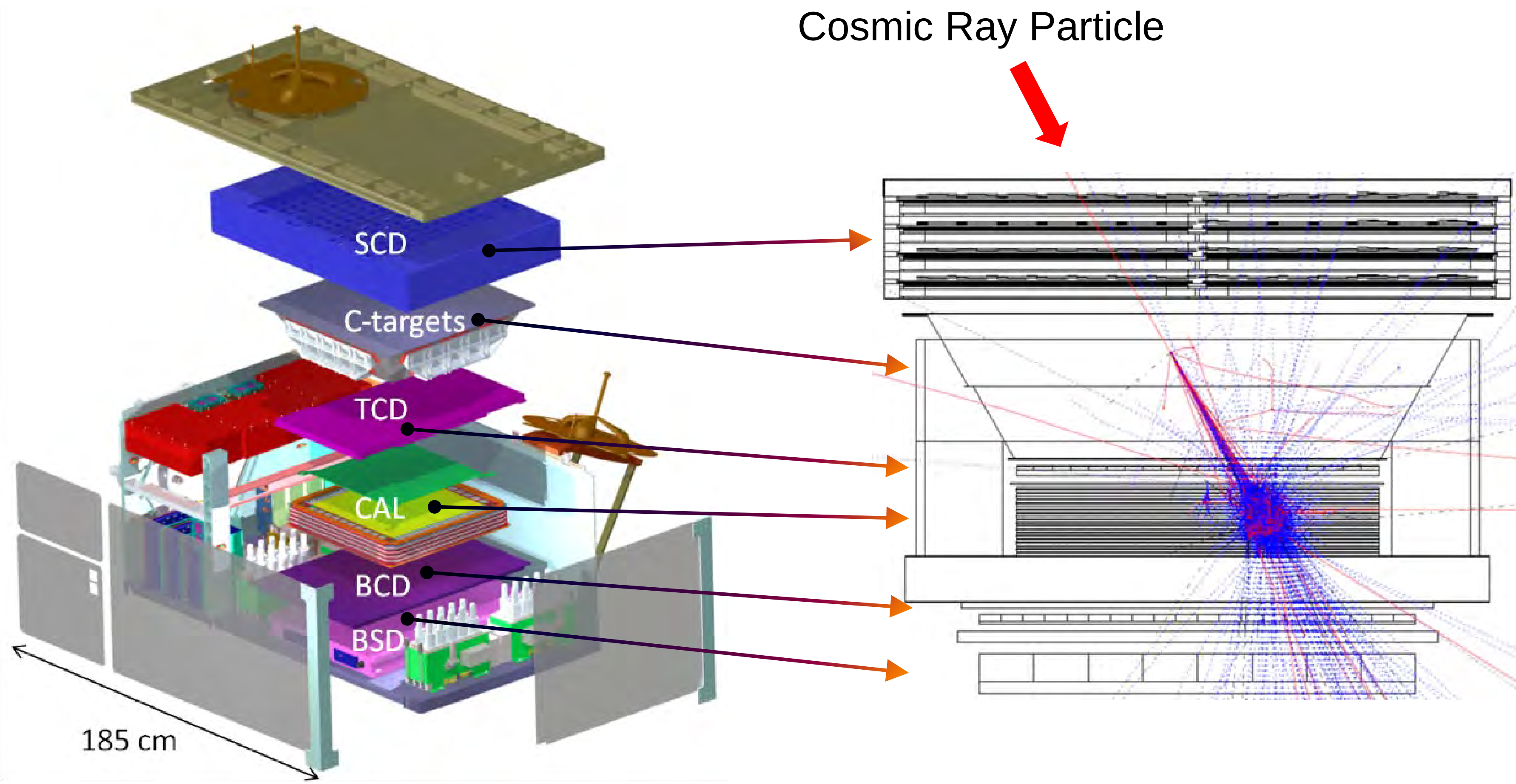
SFCs and common electronics inc. Trigger, CMD, HSK, Power

Boronated Scintillator Detector (BSD)

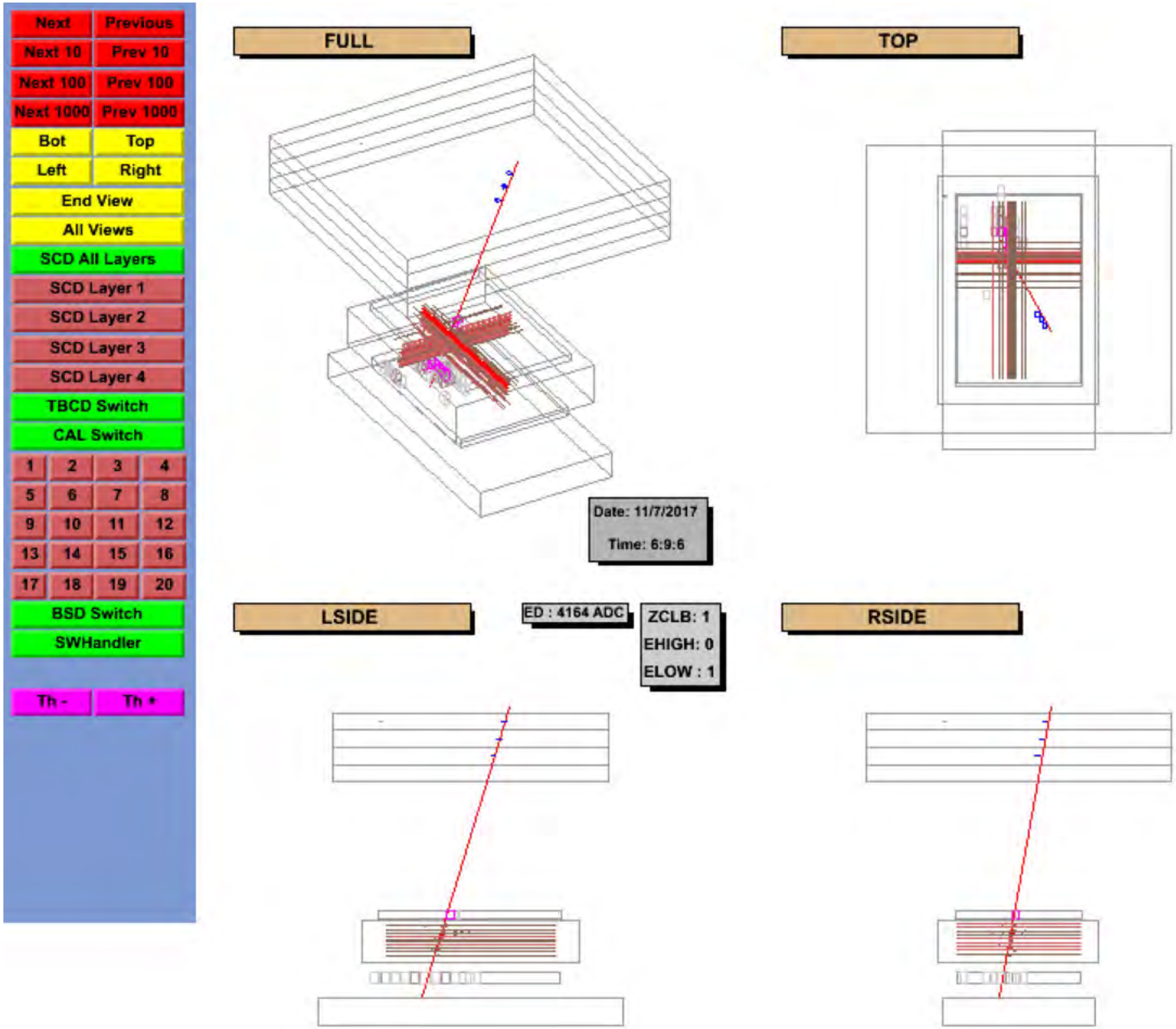
- Additional e/p separation by detection of thermal neutrons

Cosmic Ray Event Simulation

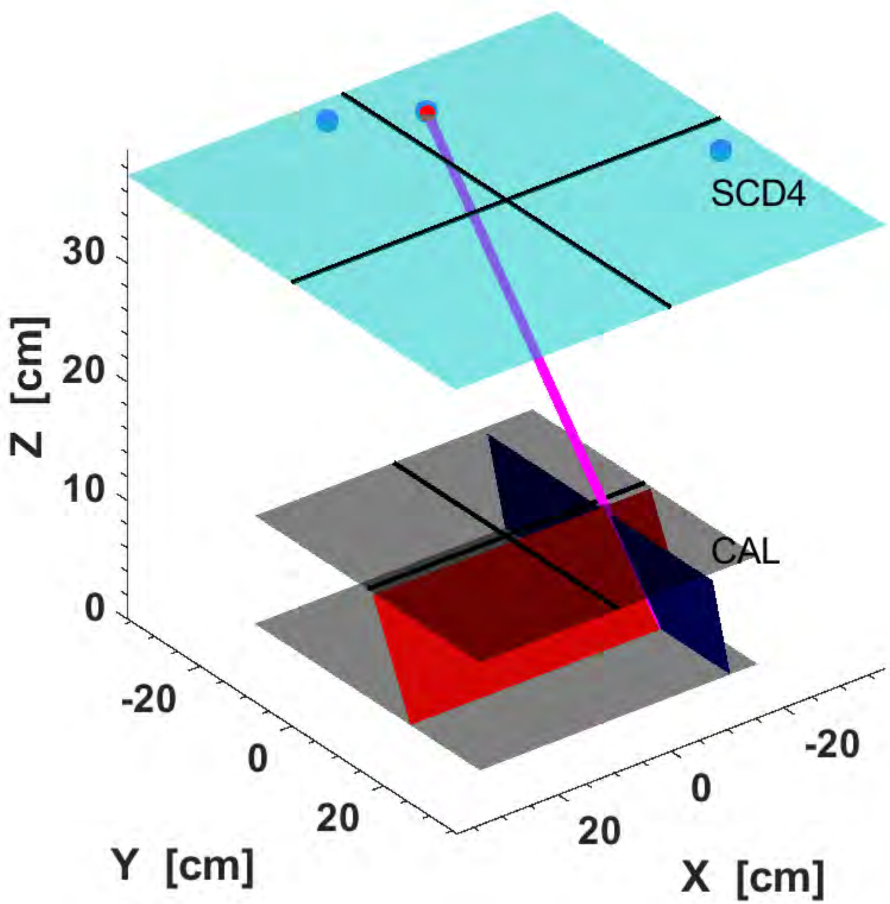
Seo et al. Adv. in Space Res., **53**/10, *1451*, 2014; Smith et al. PoS(ICRC2017)199, 2017



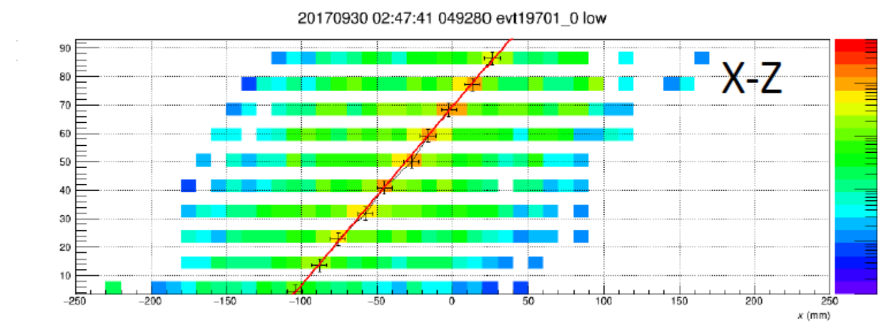
Flight data: Cosmic Ray Detection



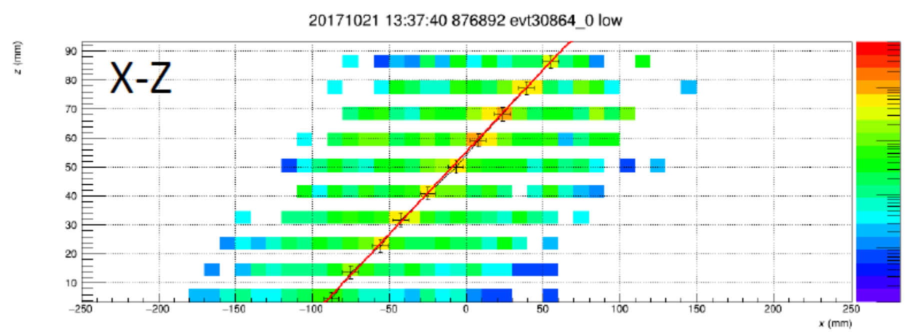
Examples of high energy events



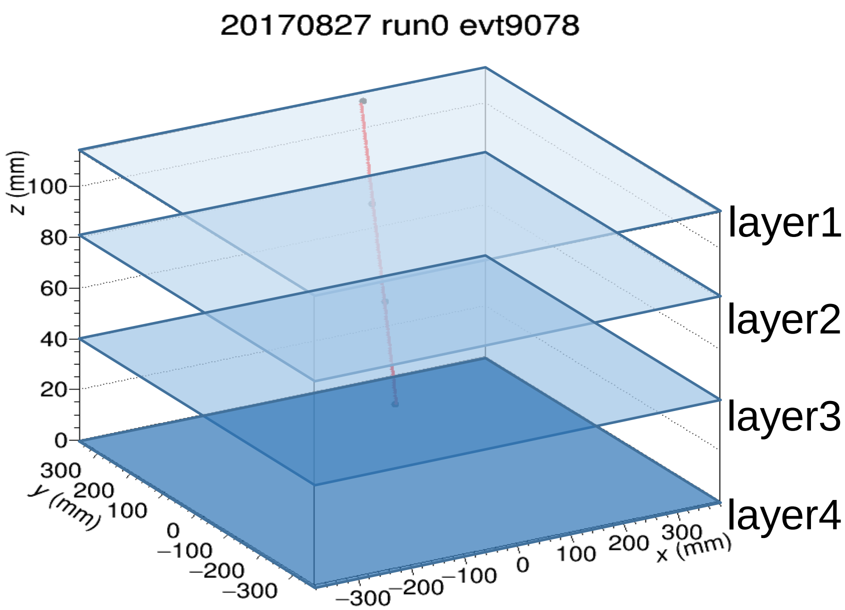
20170930 02:47:41
E = 1.88 PeV

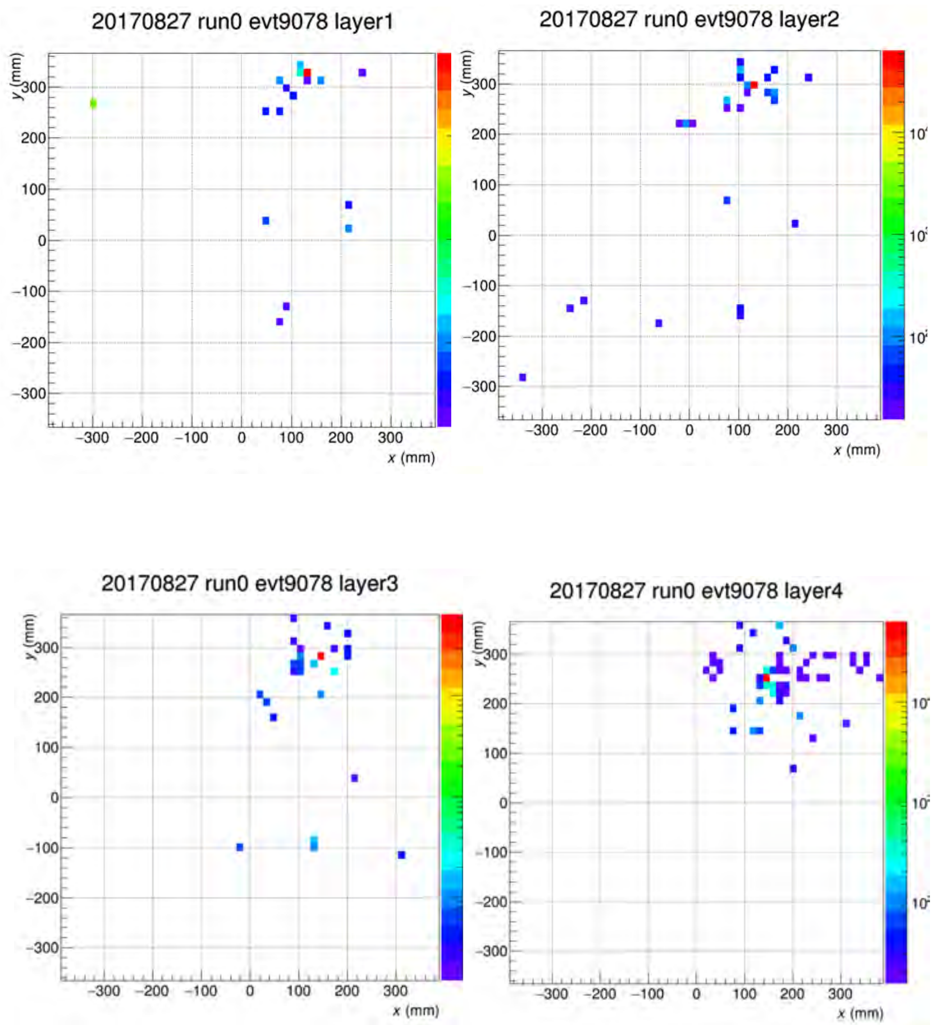


20171021 13:37:40
E = 748 TeV

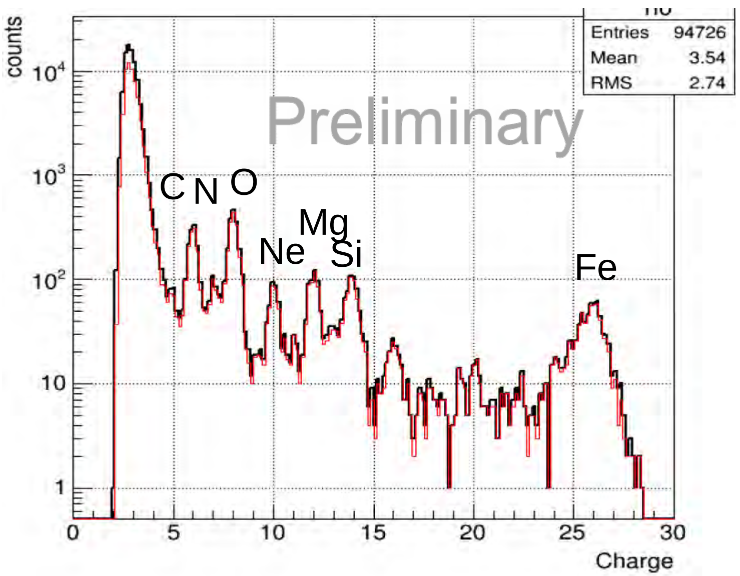


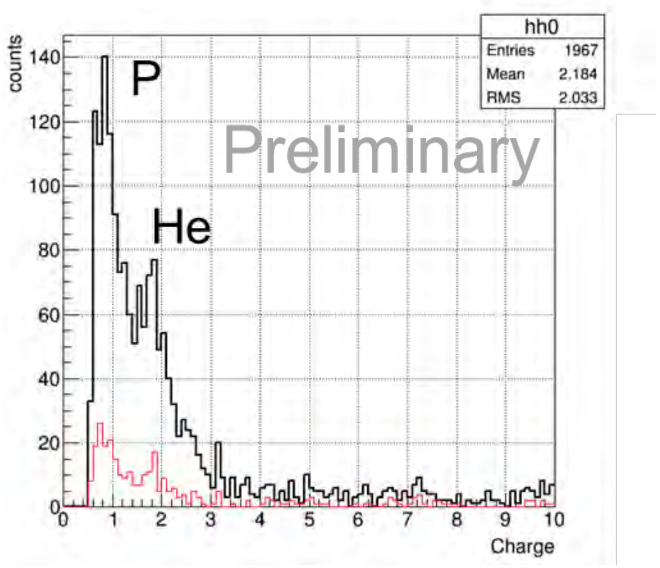
SCD provides particle charge identification



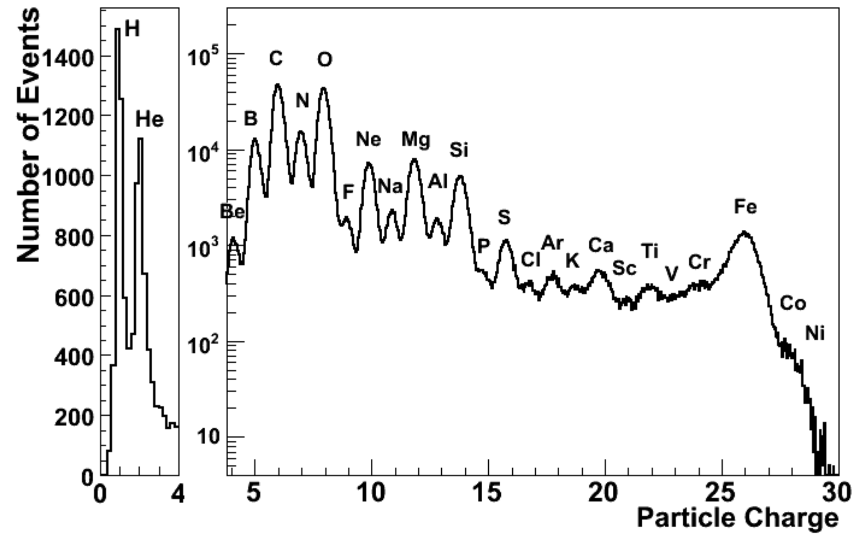


SCD: individual elements are clearly identified





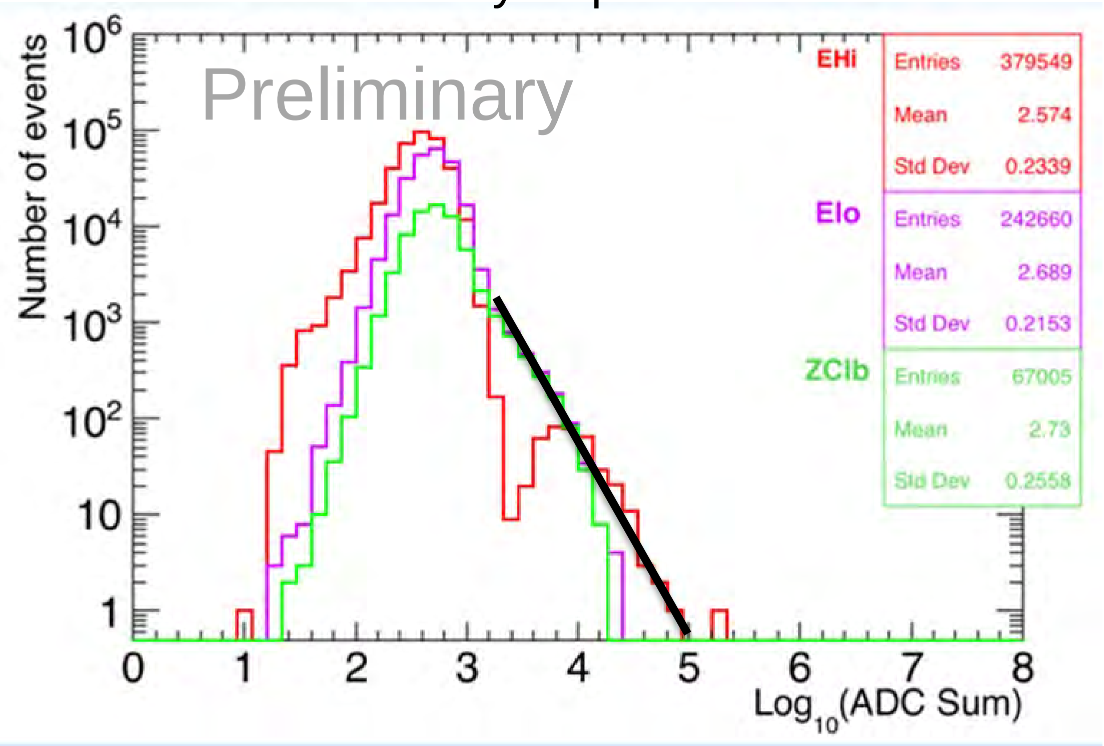
Ahn et al. ApJ 714, L89, 2010



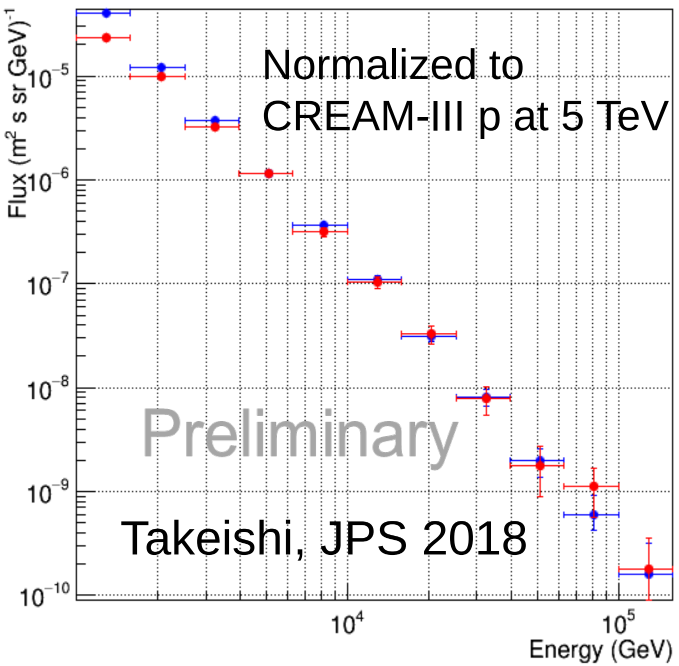
Distribution of cosmic-ray charge measured with the SCD. The individual elements are clearly identified with excellent charge resolution. The relative abundance in this plot has no physical significance

CAL provides energy measurements

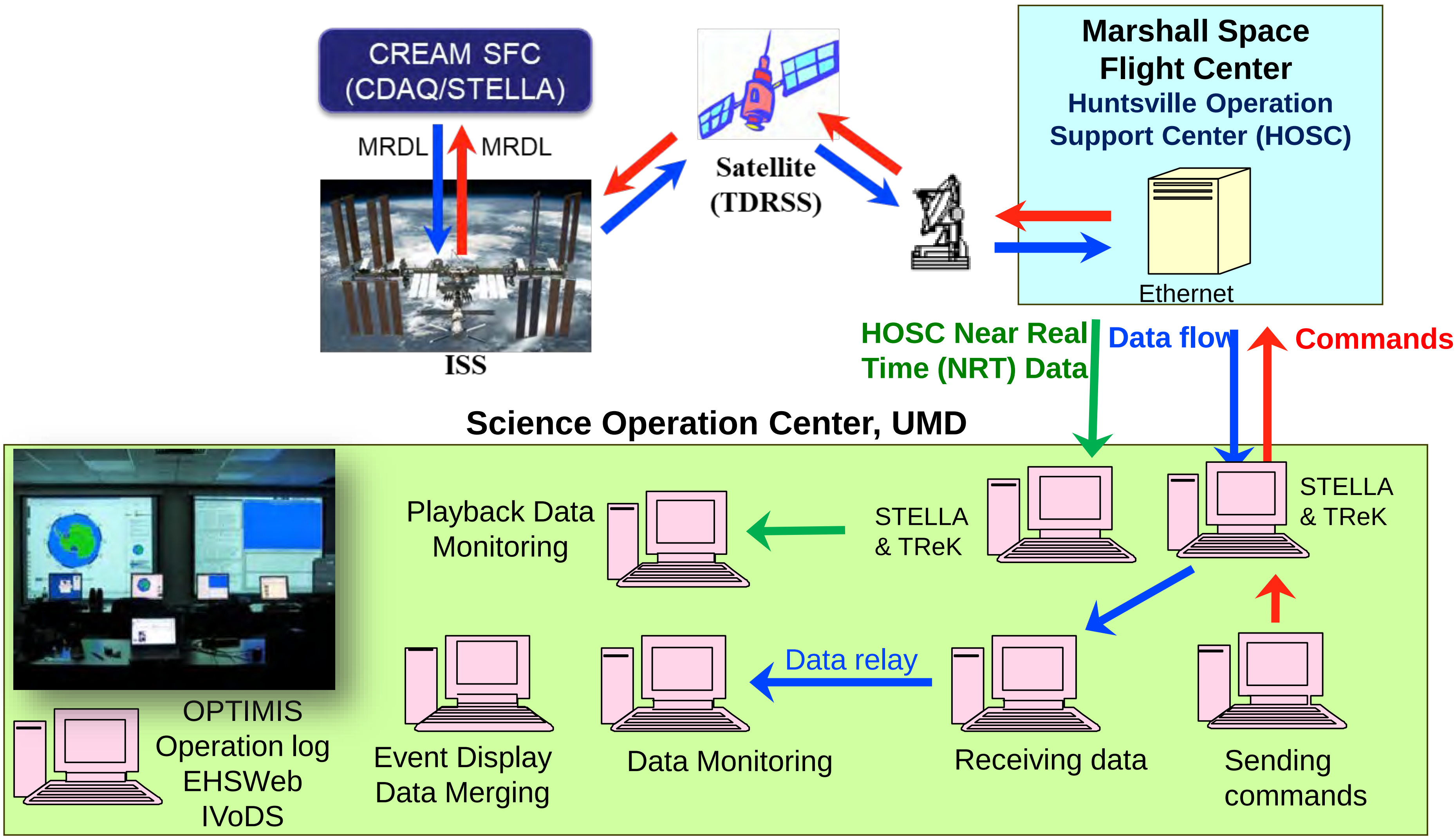
Cosmic ray all particle counts



Spectrum Consistency Check



ISS-CREAM Science Operation

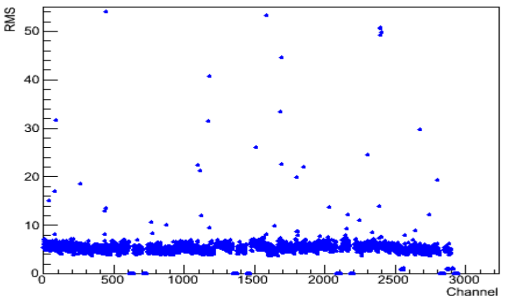


Web Monitoring and Data Distribution

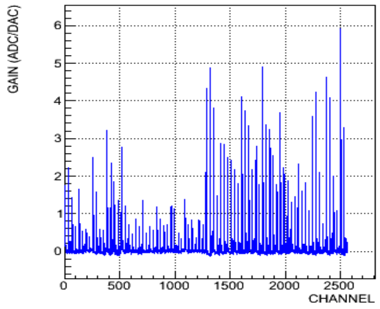
http://cosmicray.umd.edu/iss-cream/data

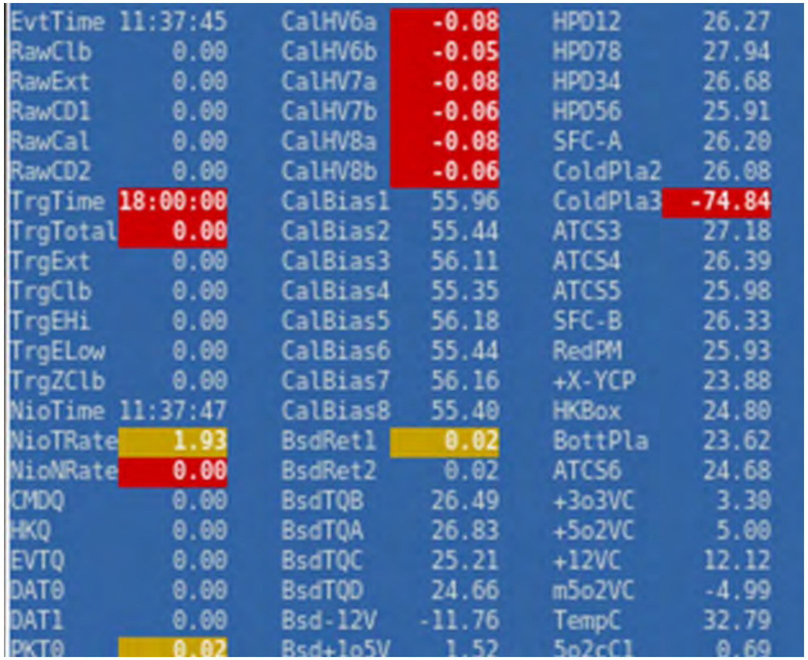
- Monitor performance of CREAM instrument using in-flight calibration data
  - Every hour: Noise level (pedestal runs) of Calorimeter, SCD, and TCD/BCD
  - Every two hours: Charge gain, HPD aliveness etc.
- Relay the housekeeping data to a web server for worldwide monitoring
  - 1558 housekeeping parameters every 5 sec
  - Provides warning by color display when values are out of range.
- Visualize interactions of cosmic rays in CREAM by generating event display plots of science events.
- Process all data and distribute them in ROOT format for analysis.
  - Refine the initial pre-launch detector calibrations channel by channel to reflect the actual flight conditions, including time-dependent effects

Noise level of one layer of SCD



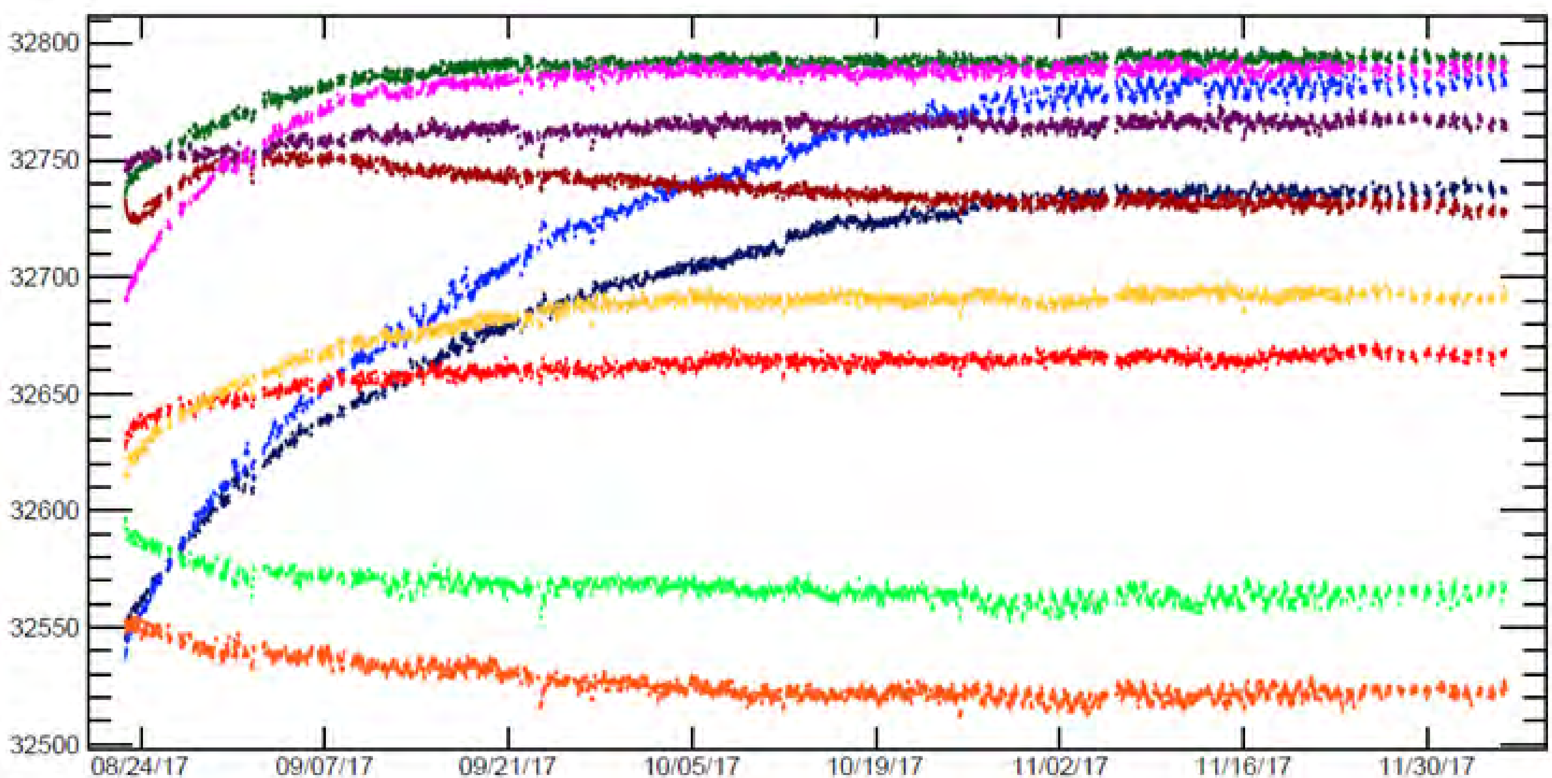
HPD aliveness of CAL

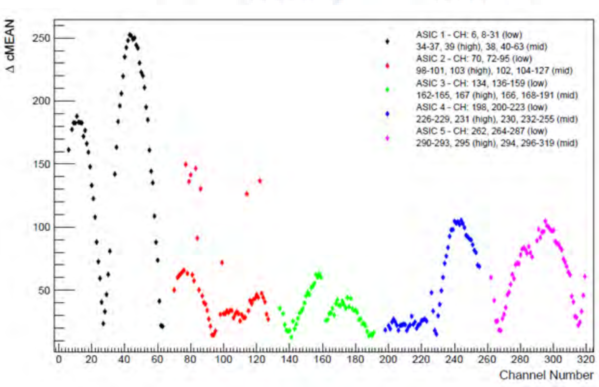


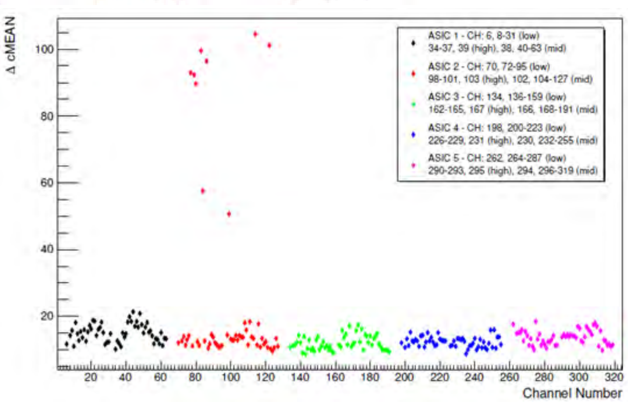


EvtTime	11:37:45	CalHV6a	-0.08	HPD12	26.27
RawClb	0.00	CalHV6b	-0.05	HPD78	27.94
RawExt	0.00	CalHV7a	-0.08	HPD34	26.68
RawCD1	0.00	CalHV7b	-0.06	HPD56	25.91
RawCal	0.00	CalHV8a	-0.08	SFC-A	26.20
RawCD2	0.00	CalHV8b	-0.06	ColdPla2	26.08
TrgTime	18:00:00	CalBias1	55.96	ColdPla3	-74.84
TrgTotal	0.00	CalBias2	55.44	ATCS3	27.18
TrgExt	0.00	CalBias3	56.11	ATCS4	26.39
TrgClb	0.00	CalBias4	55.35	ATCS5	25.98
TrgEHi	0.00	CalBias5	56.18	SFC-B	26.33
TrgELow	0.00	CalBias6	55.44	RedPM	25.93
TrgZClb	0.00	CalBias7	56.16	+X-YCP	23.88
NioTime	11:37:47	CalBias8	55.40	HKBox	24.80
NioTRate	1.93	BsdRet1	0.02	BottPla	23.62
NioNRate	0.00	BsdRet2	0.02	ATCS6	24.68
CMDQ	0.00	BsdTQB	26.49	+3o3VC	3.30
HKQ	0.00	BsdTQA	26.83	+5o2VC	5.00
EVTQ	0.00	BsdTQC	25.21	+12VC	12.12
DAT0	0.00	BsdTQD	24.66	m5o2VC	-4.99
DAT1	0.00	Bsd-12V	-11.76	TempC	32.79
PKT0	0.02	Bsd+1o5V	1.52	5o2cC1	0.69

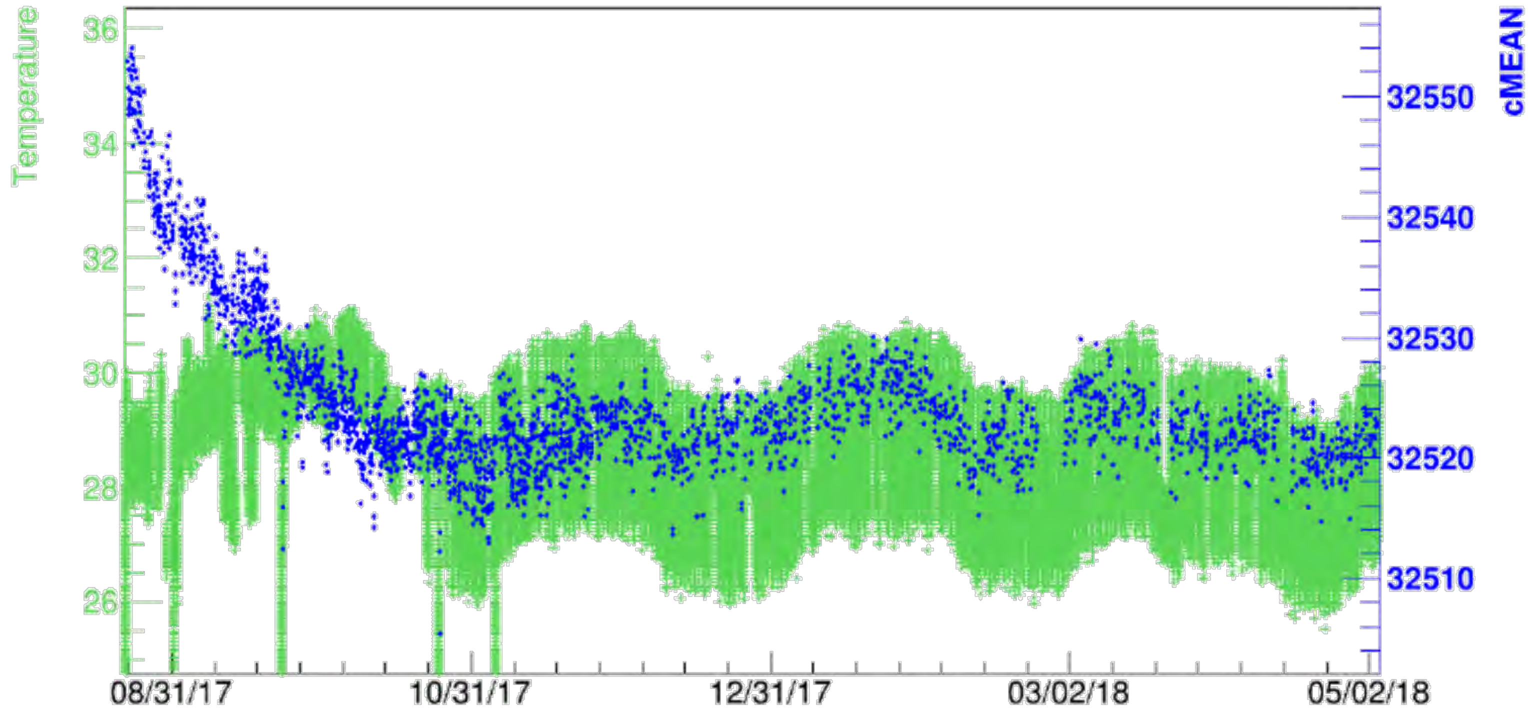
CAL pedestal reached a plateau in November 2017

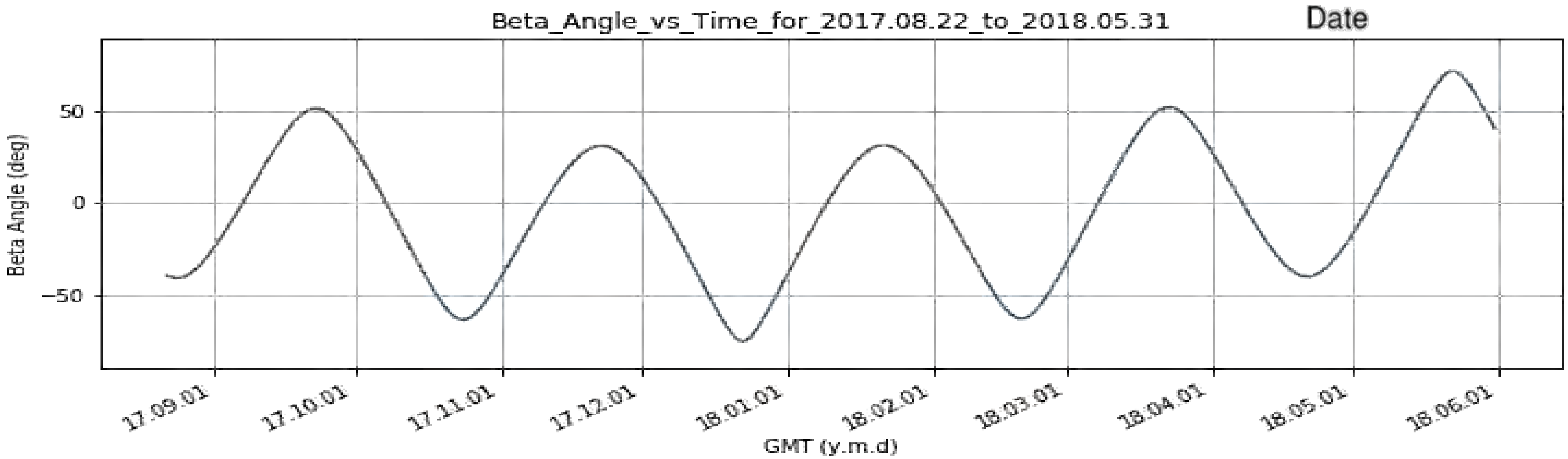




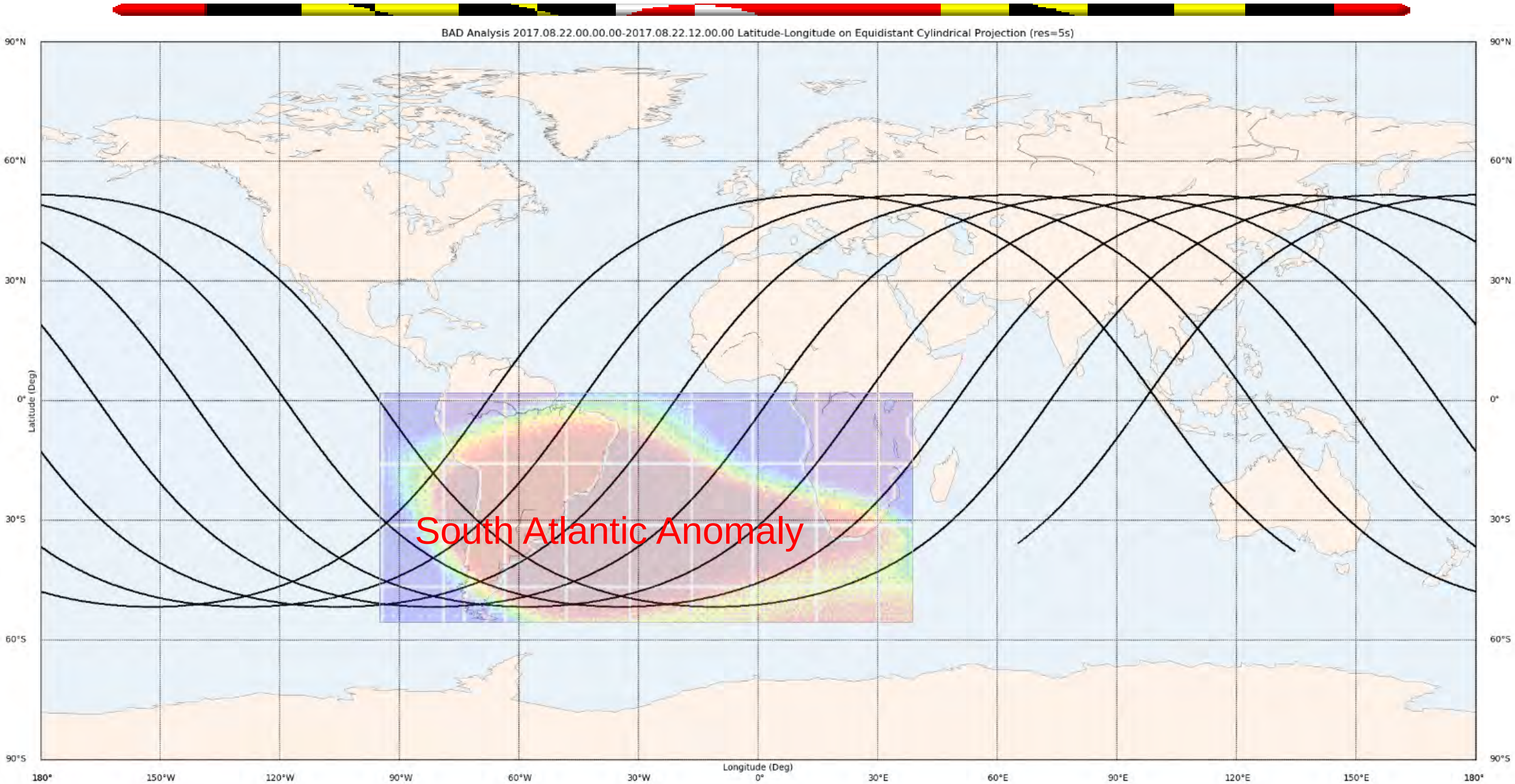


Temperature Dependence





ISS orbit and SAA



- August 2017 – August 2018: Instrument on only during non-SAA orbit to avoid potential radiation damage
- September 2018 – February 2019: Instrument on continuously

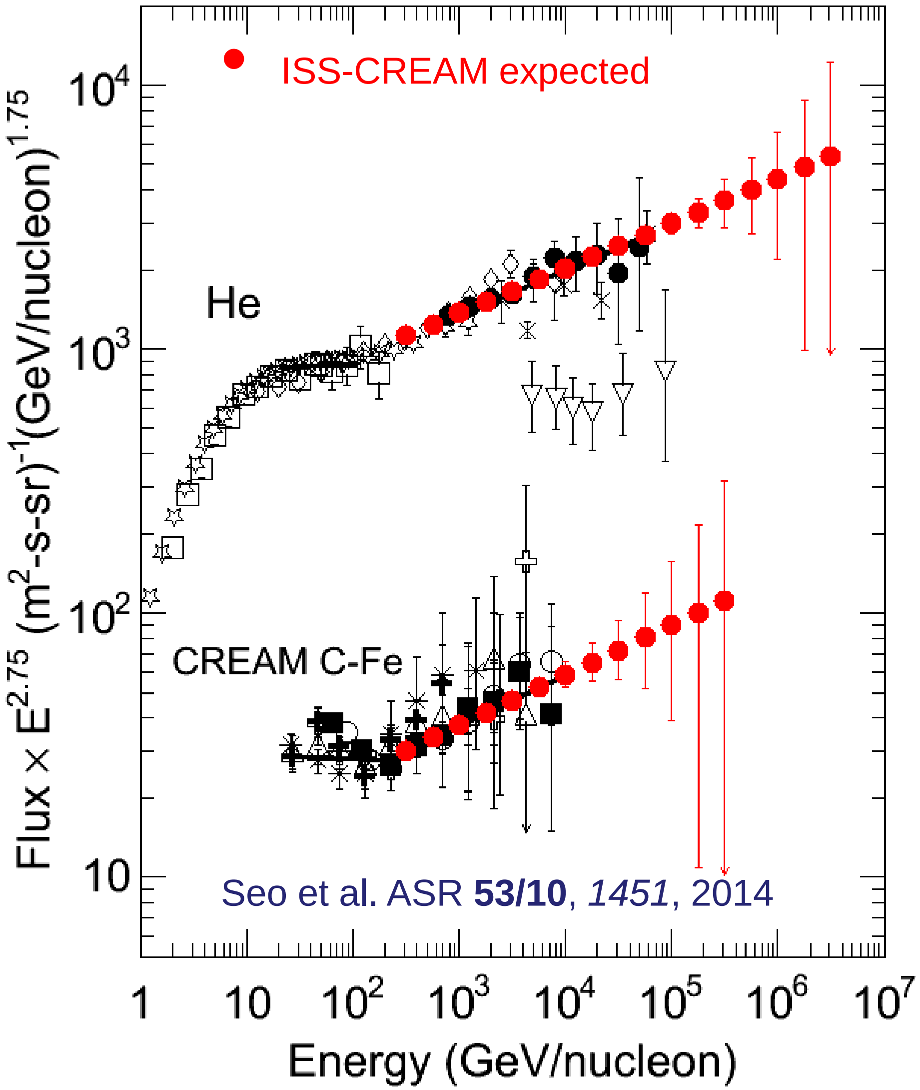
ISS-CREAM met Minimum Mission Success Criteria

- ✓ The payload survives the launch and is safely placed on the ISS without any damage that precludes minimum success
- ✓ Science data are received at the Science Operation Center and commands can be sent to the payload
- ✓ The science instrument provides publishable science data

- Mission Minimum Success:
  - ✓ Launch and operation for > 300 days
  - ✓ **The instrument will be considered functional if at least one layer of the SCD identifies charges and CAL provides energy measurements**
- Mission Comprehensive Success:
  - Launch and operation for >1000 days
  - ✓ CAL provides its own event trigger, energy measurements, and x,y,z tracking coordinates
  - ✓ SCD provides particle charge identification
  - ✓ TCD/BCD provides its own event trigger and shower profile
  - ✓ BSD measures both prompt shower particles and delayed neutron signals

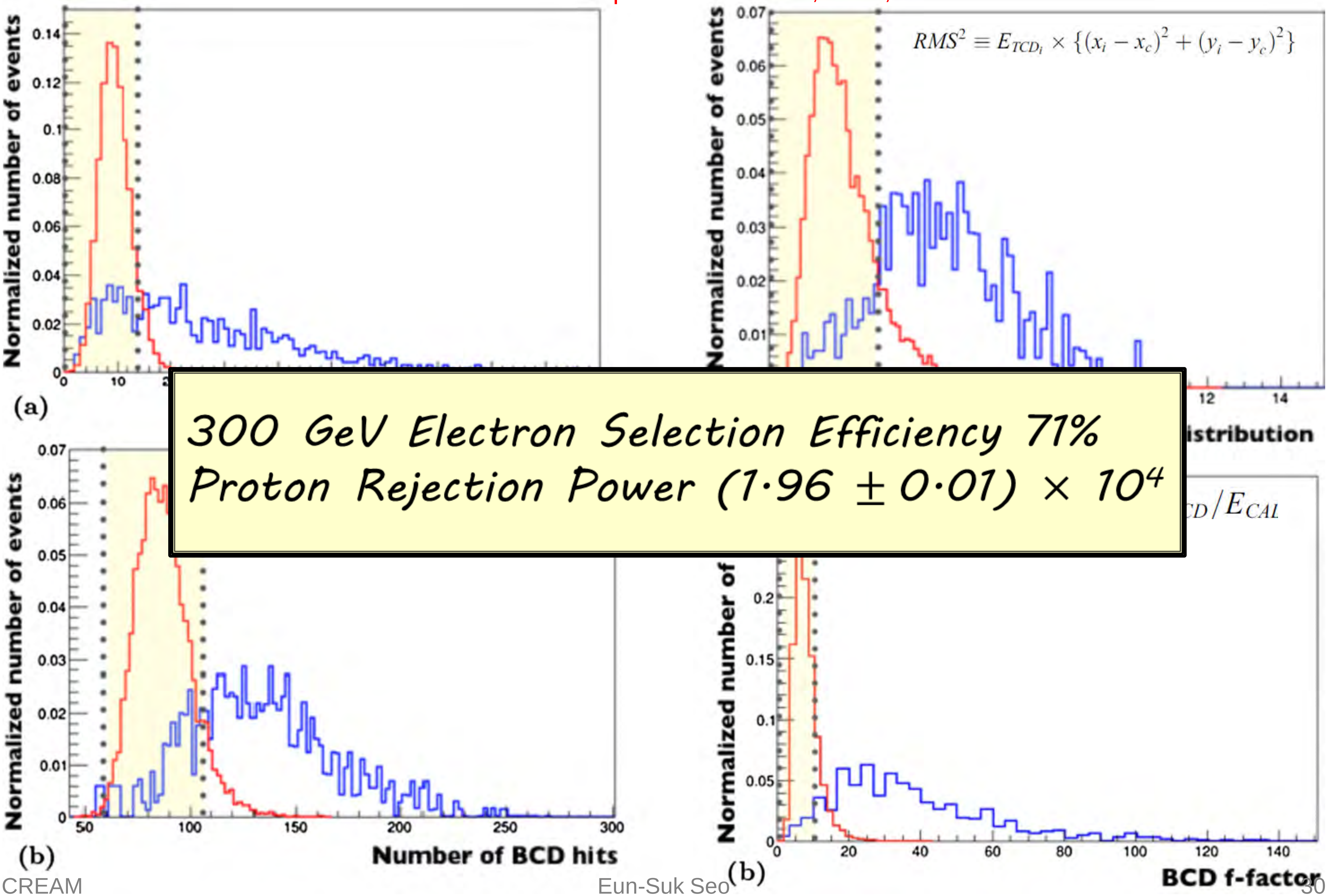
ISS-CREAM takes the next major step

- The ISS-CREAM space mission can take the next major step to 10^{15} eV, and beyond, limited only by statistics.
- The 3-year goal, 1-year minimum exposure would greatly reduce the statistical uncertainties and extend CREAM measurements to energies beyond any reach possible with balloon flights.



Electron Proton Separation

Park et al. Adv. In Space. Res. 62/10, 2939, 2018



300 GeV Electron Selection Efficiency 71%

Proton Rejection Power $(1.96 \pm 0.01) \times 10^4$

Cosmic Ray Observatory in Space
DAMPE
AMS
Voyager
ISS-CREAM
CALET
Pamela