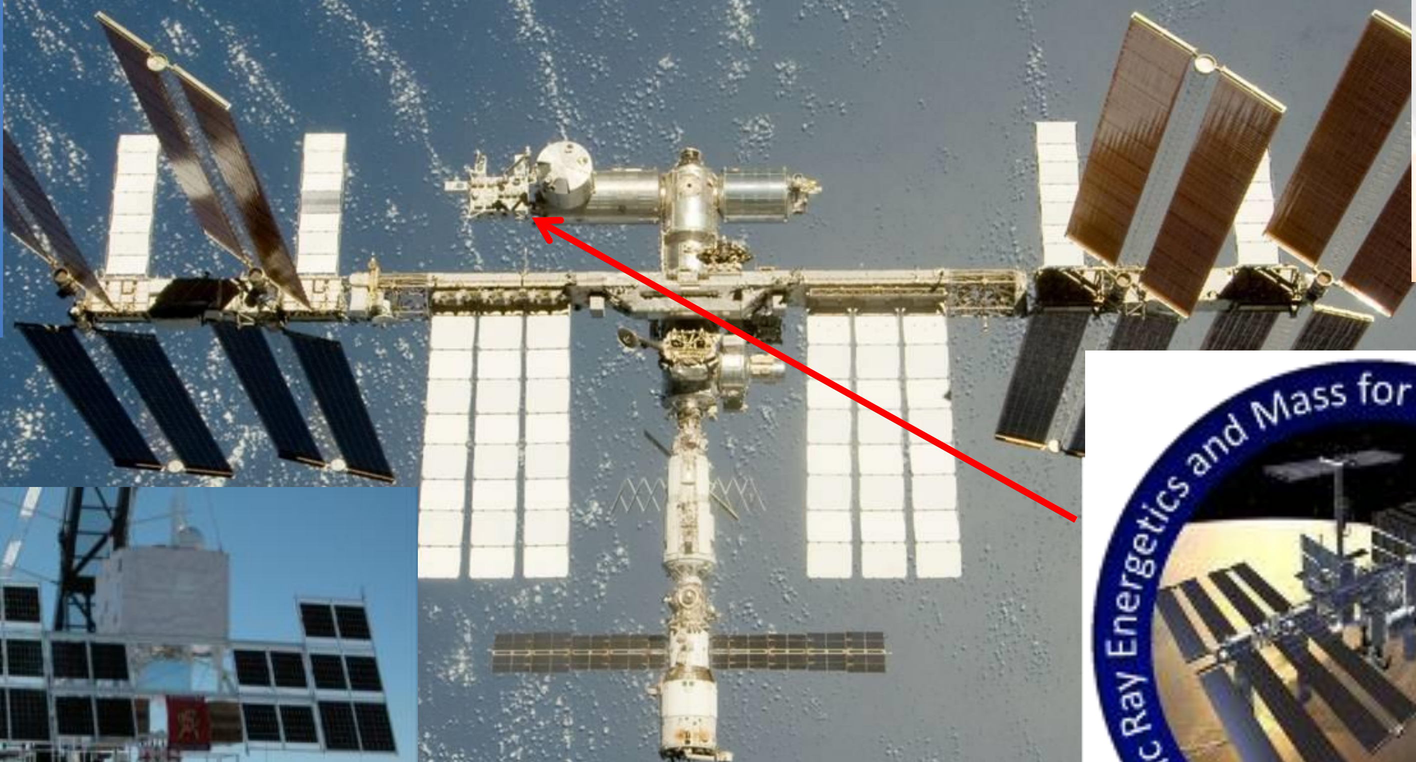
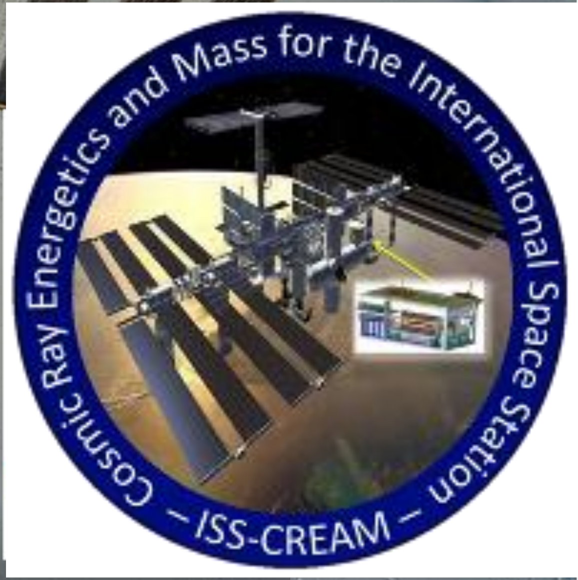
입자검출기워크샵 2026 (Particle Detector Workshop) 6-7 Feb. 2026, Science Culture Center, IBS HQ

High Energy Cosmic Ray Experiment Instruments: CREAM and ISSCREAM





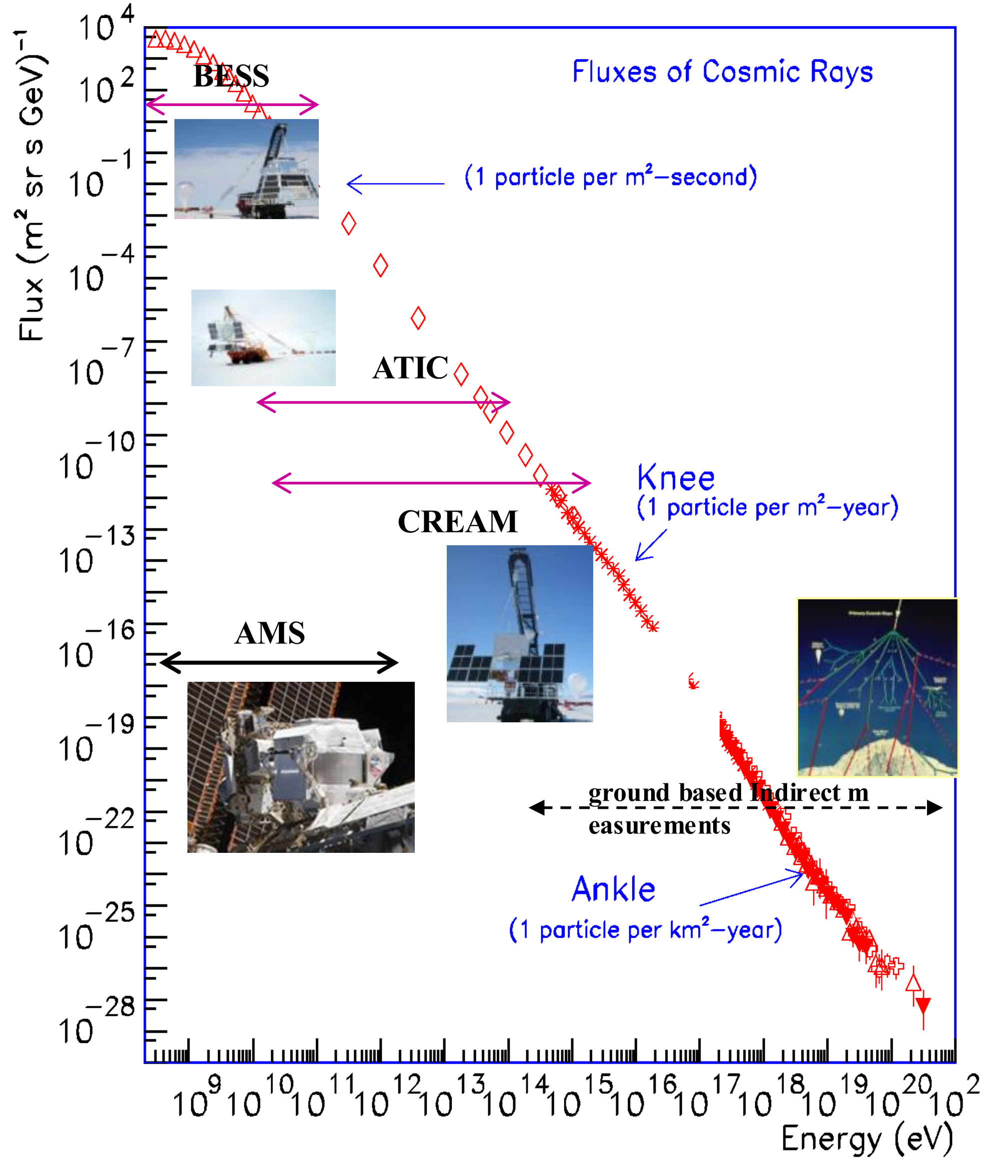
이무현
기초과학연구원 지하실험연구단

Cosmic-Ray and CREAM Experiment

❑ The rate of particles drops × 50 for ×10 increase in energy.

❑ Direct measurement is critical for accurate knowledge of particle type, so we must fly experiments at top of atmosphere or in low Earth orbit.

❑ CREAM extends direct measurements of cosmic rays to the highest energy practical in a series of balloon flights to explore the Super Nova acceleration limit.

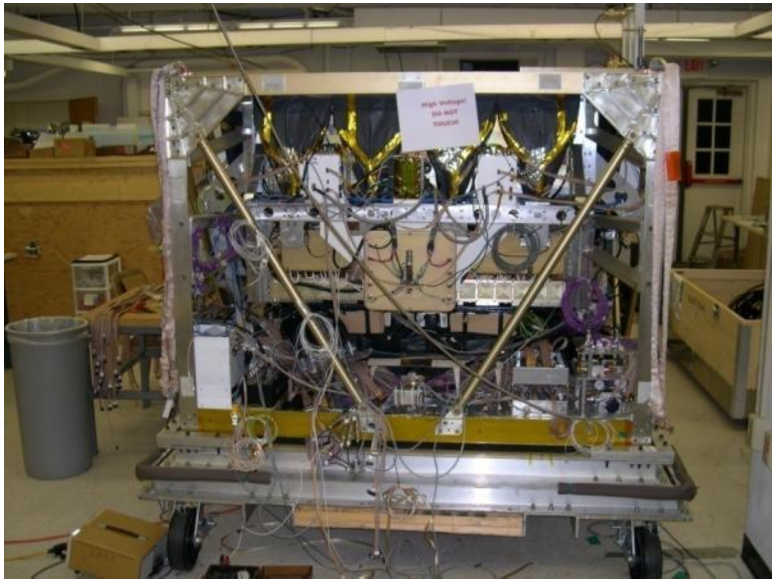


The CREAM Experiment

❑ Built and operated by a collaboration with participants from 4 US universities and NASA, as well as institutions from Korea, France, Mexico, and Italy.

❑ UMD is the lead group and has involved many graduate and undergraduate students in physics, chemistry, biochemistry, engineering, computer science, and even philosophy!

❑ CREAM was conceived and proposed in 1998, developed, built & tested from 1999 to 2004, flown in 2004, 2005, 2007, 2008, 2009, 2010, and 2016.



CREAM Collaboration (2014)

D. Angelaszek, M. Copley, C. Ebonge, M. Gupta, J.H. Han, I. J. Howley,
H.G. Huh, P. M. King, K.C. Kim, M.H. Kim, K. Kwashnak, M.H. Lee, L. Lutz, A. Malinin,
J. Meade, O. Ofoha,, E.S. Seo, J. Smith, J. Wu, Y.S. Yoon
University of Maryland

T. Anderson, S. Coutu, Sai Im
Penn State University

J.A. Jeon, I.S. Jeong, J. Lee, H.Y. Lee, H. Lim, G.W. Na, I.H. Park
SungKyunKwan University, Korea

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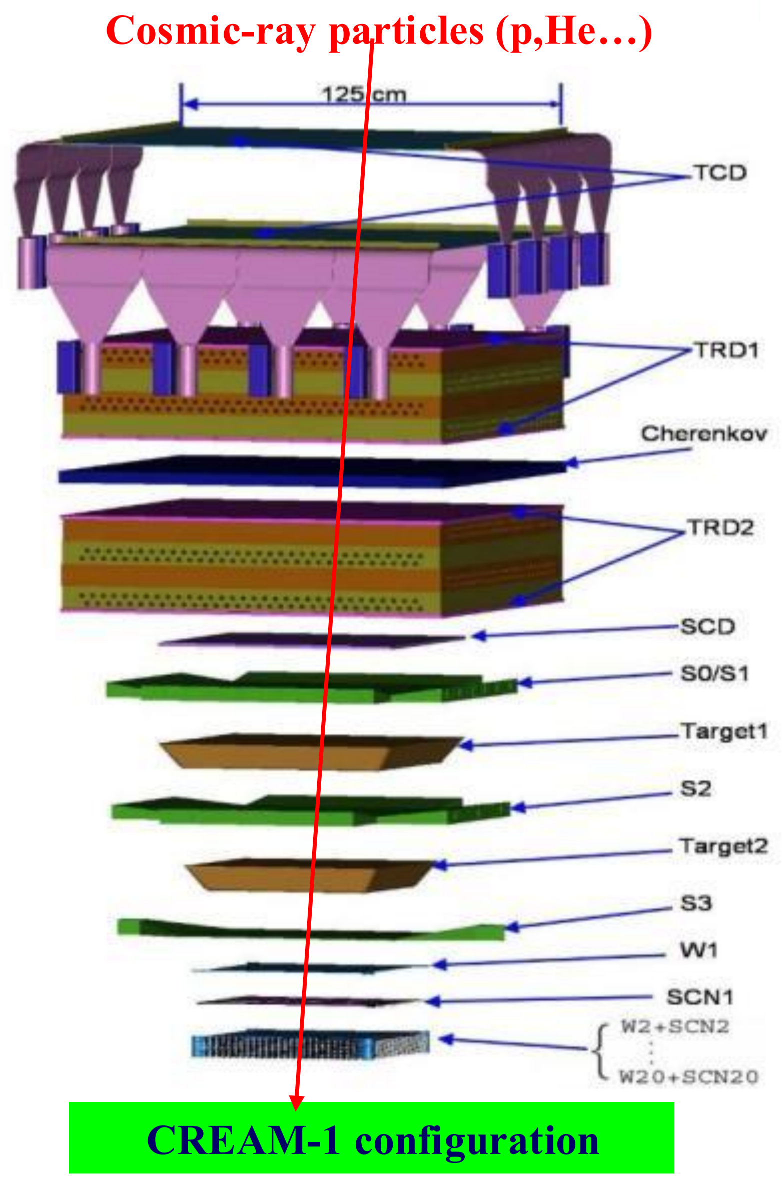
CREAM instrument

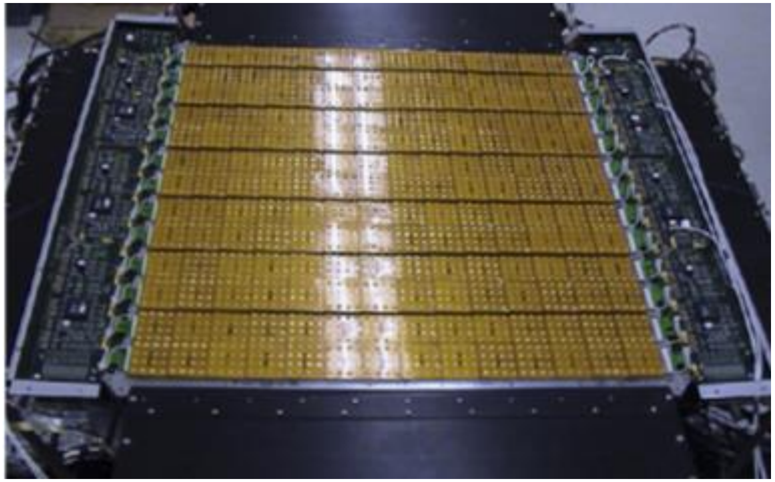
Seo et al. Adv. in Space Res., **33** (10), *1777*, 2004;
Ahn et al., NIM A, **579**, 1034, 2007

- **TCD (Timing based Charge Detector): to trigger and measure charges of incoming particles**
- **TRD (Transition Radiation Detector): to measure velocity for Z≥3**
- **CD (Cherenkov Detector): to trigger and measure charges of relativistic particles**
- **SCD (Silicon Charge Detector): to identify particles charges for 1≤Z≤28**
- **S0-S2: Hodoscopes, supplemental particle ID, tracking**
- **S3: Trigger counter**
- **CAL: Tungsten-SCN Calorimeter to trigger and measure energy for Z≥1**

- **In-flight cross calibration between TRD and CAL**
- **Trigger aperture: 2.2 m²sr**

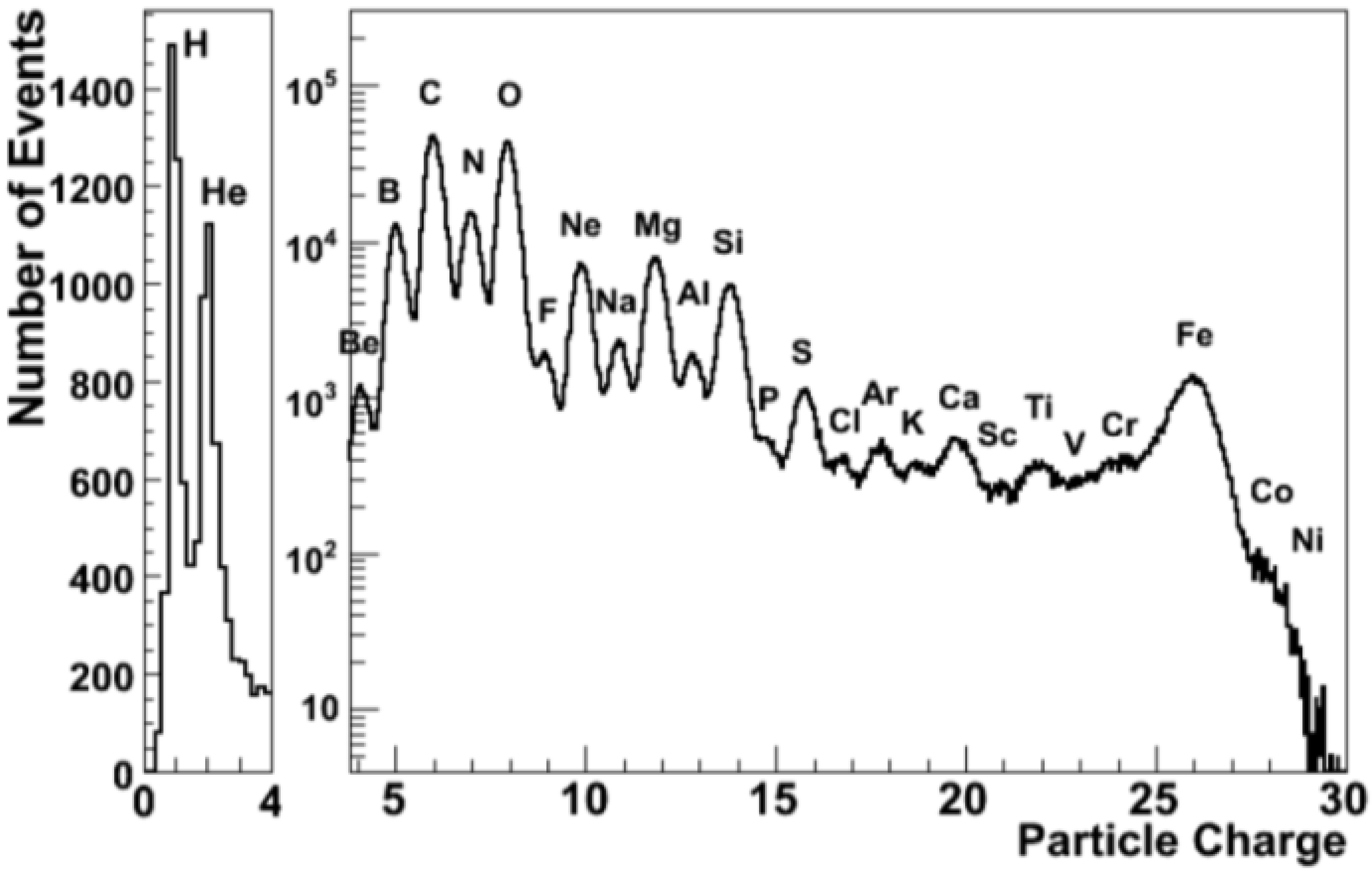


Silicon Charge Detector (SCD)



- Measure particle's charge up to Z ~ 30
- Charge resolution dZ = 0.2
- Work in high backsplash from Calorimeter/Target
- 182 of CR1.4 ASIC chips (dynamic range 1:4000) with 16-bit ADC (2944 channels)
- 182 of 16 pixel 380 ㎛ thick DC type silicon sensor with AC coupling readout

Charge distribution from SCD in CREAM-I flight data

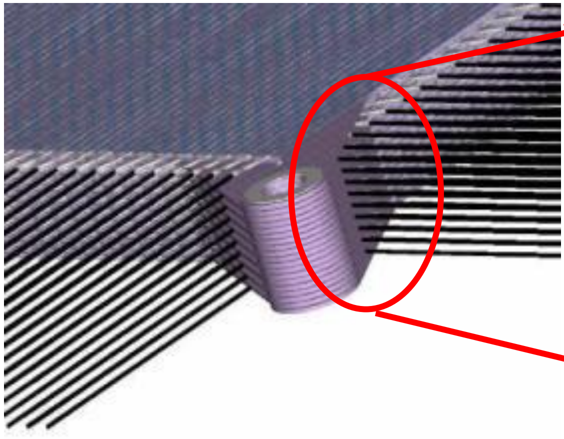


H.S. Ahn et al. (ApJL. **714**, L89-L93,2010)

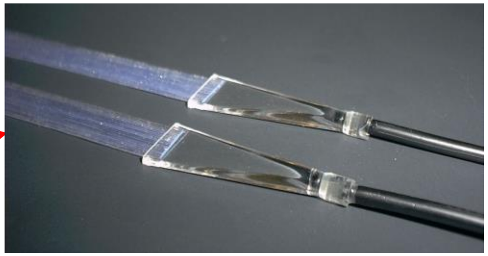
Calorimeter

- Flared(30˚) carbon target to increase hadronic interactions
- Measure energies of incident particles from ~10^{11} to 10^{15} eV: Optical division with different # of clear fibers + neutral density filters at the cookie assembly + 73 pixel Hybrid Photo Diode (HPD) + 2560 channels readout with IDE VA32-HDR2/TA-32C chips
- Thin calorimeter for higher trigger rates: alternating tungsten (1 X_0) and scintillating fiber ribbon layers in x and y directions (20 layers) with a size of 50 cm × 50 cm
- Imaging capability to reconstruct particle trajectories: 50 of 1 cm wide ribbons (~1 ρ_M of W) made of 19 of 0.5 mm ø BCF-12 scintillating fibers per layer
- Absolute energy scale accurate to < 10%
- Energy resolution < 50%

Calorimeter components and principle



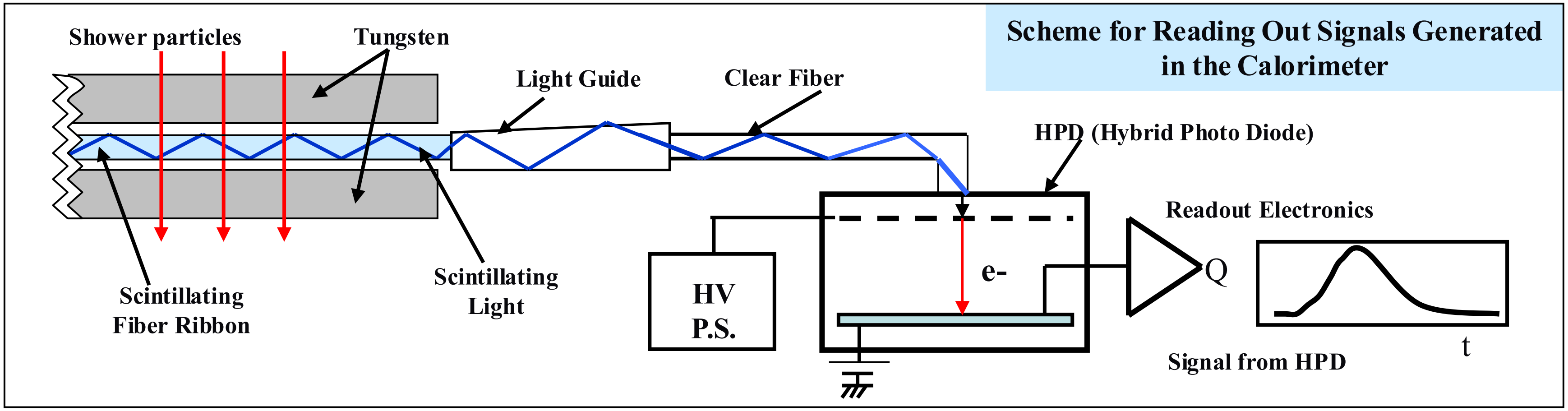
Tungsten / Scintillating Fiber Stack



Fiber Light Guides

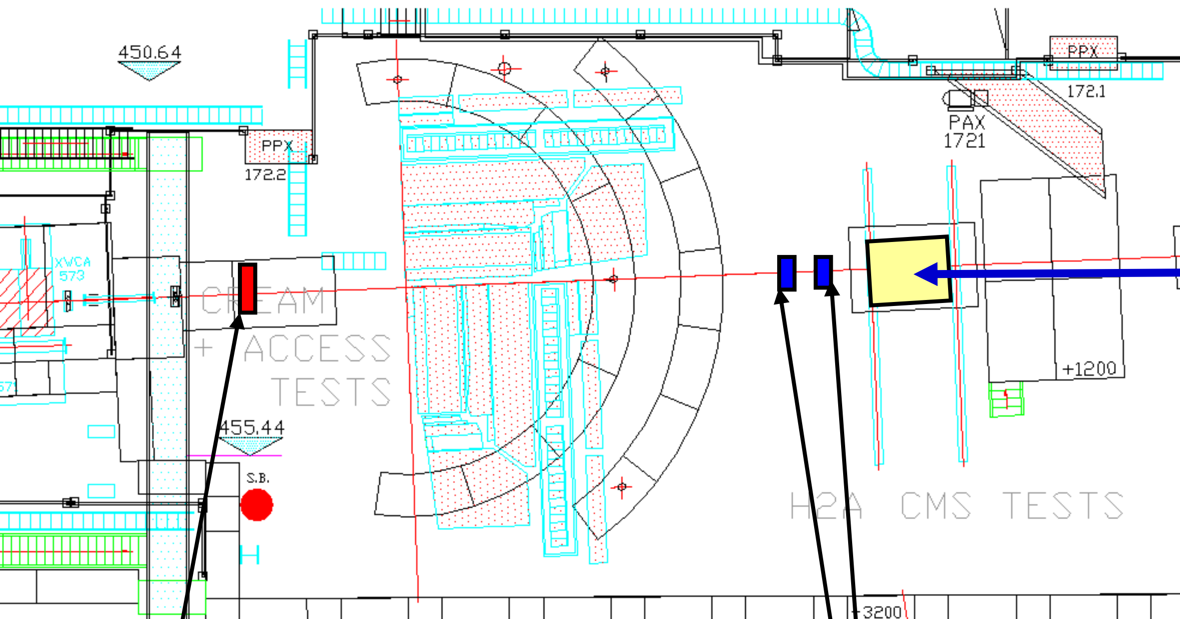
Cookie

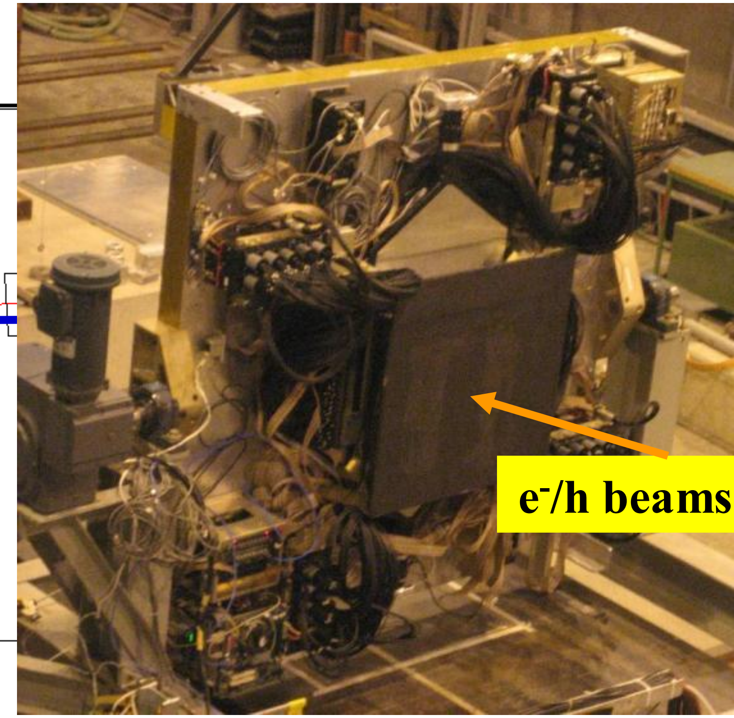
Tungsten Plates



CERN H2A beam line for CAL calibration

CREAM beam test lay out



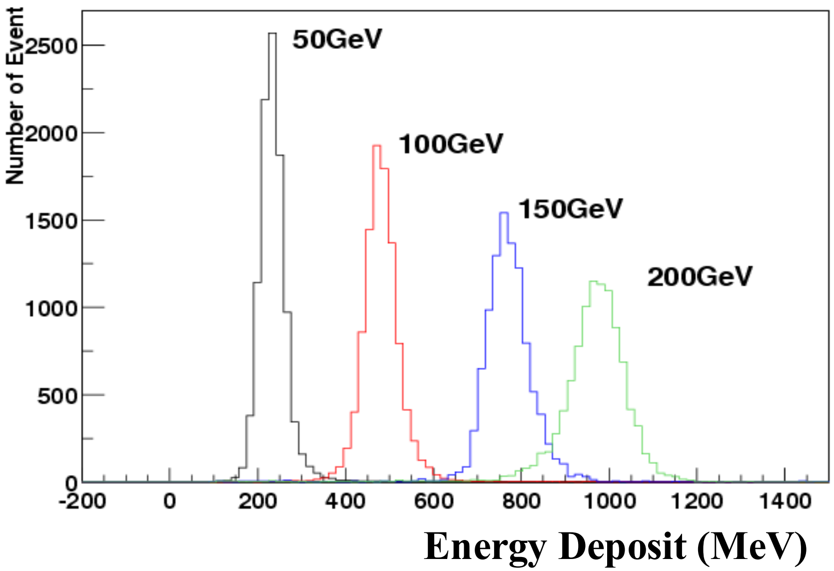


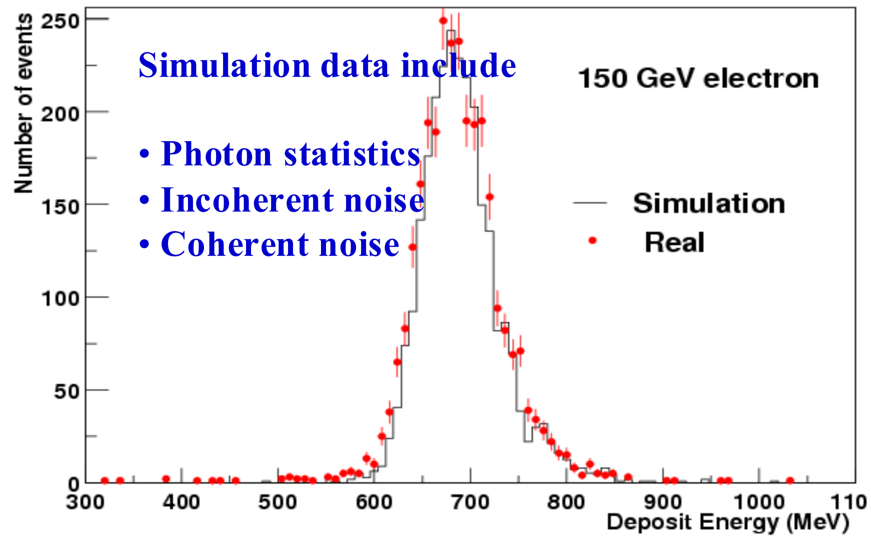
Trigger counters(2×2cm²)

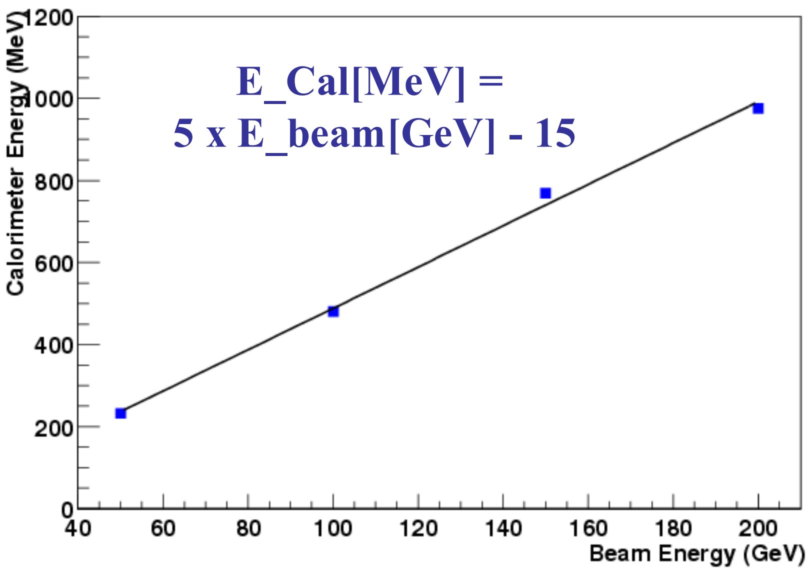
Si-Beam Trackers

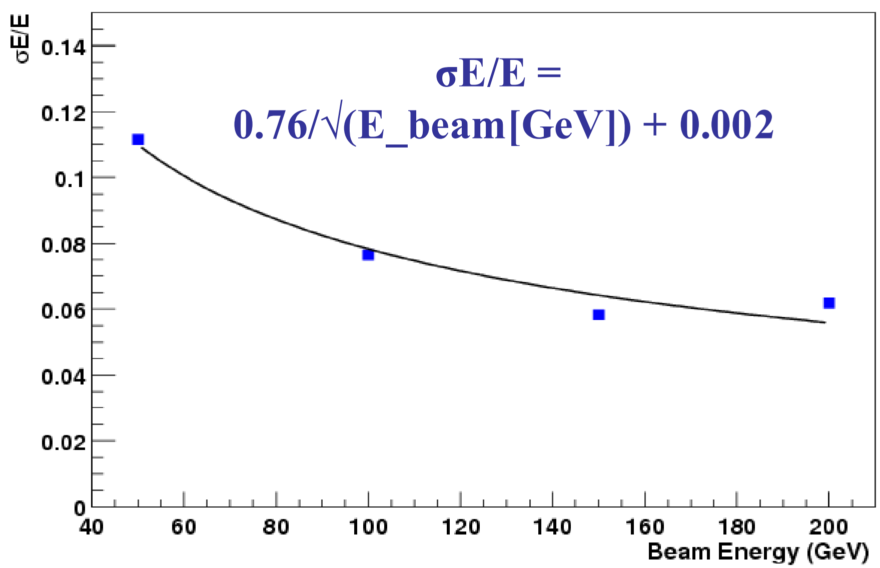
CREAM calorimeter on the moving table

Responses to Electrons from 50 to 200 GeV

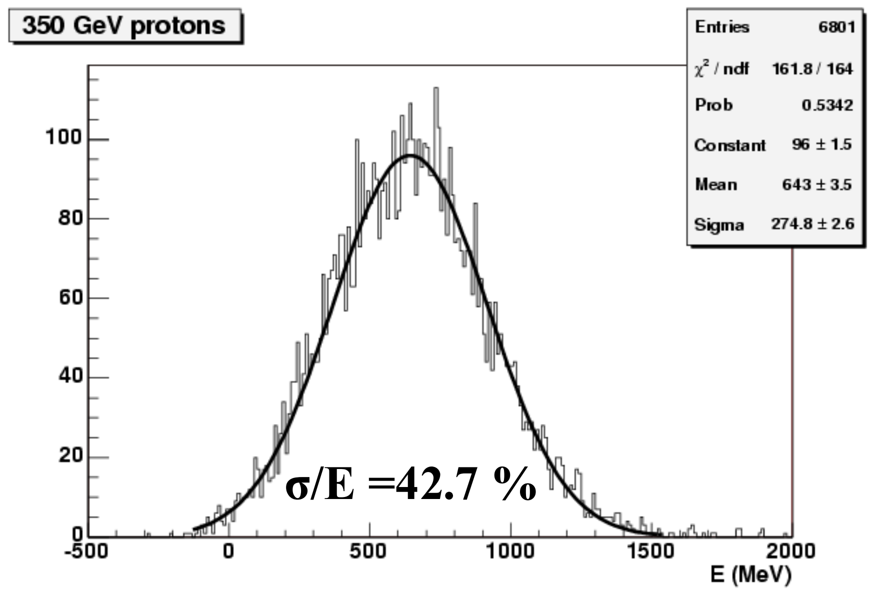


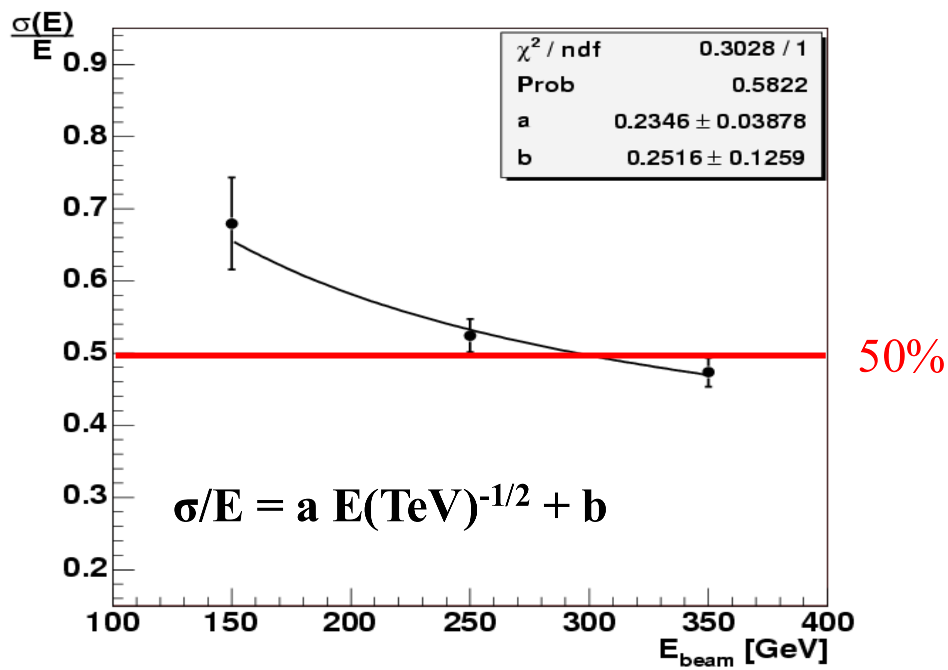




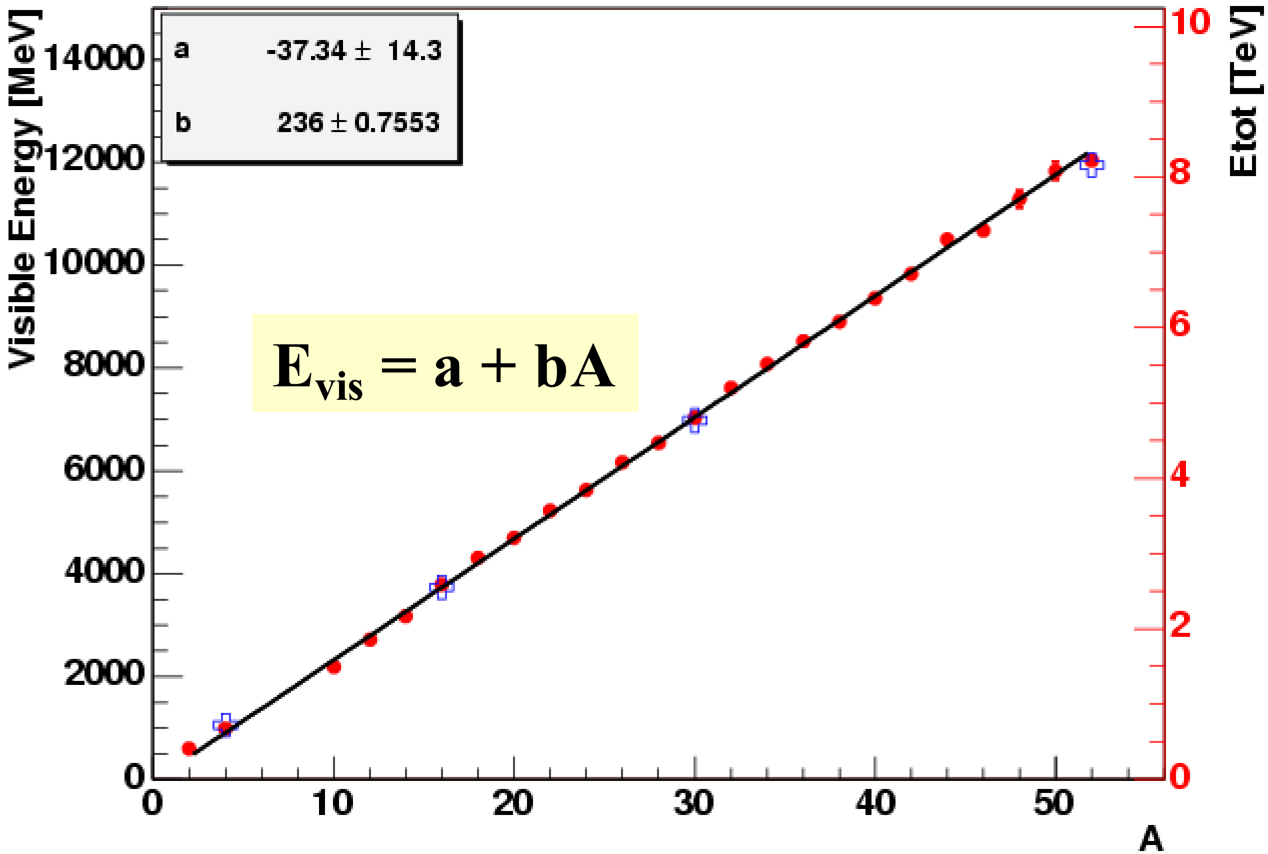


Beam test results: Protons



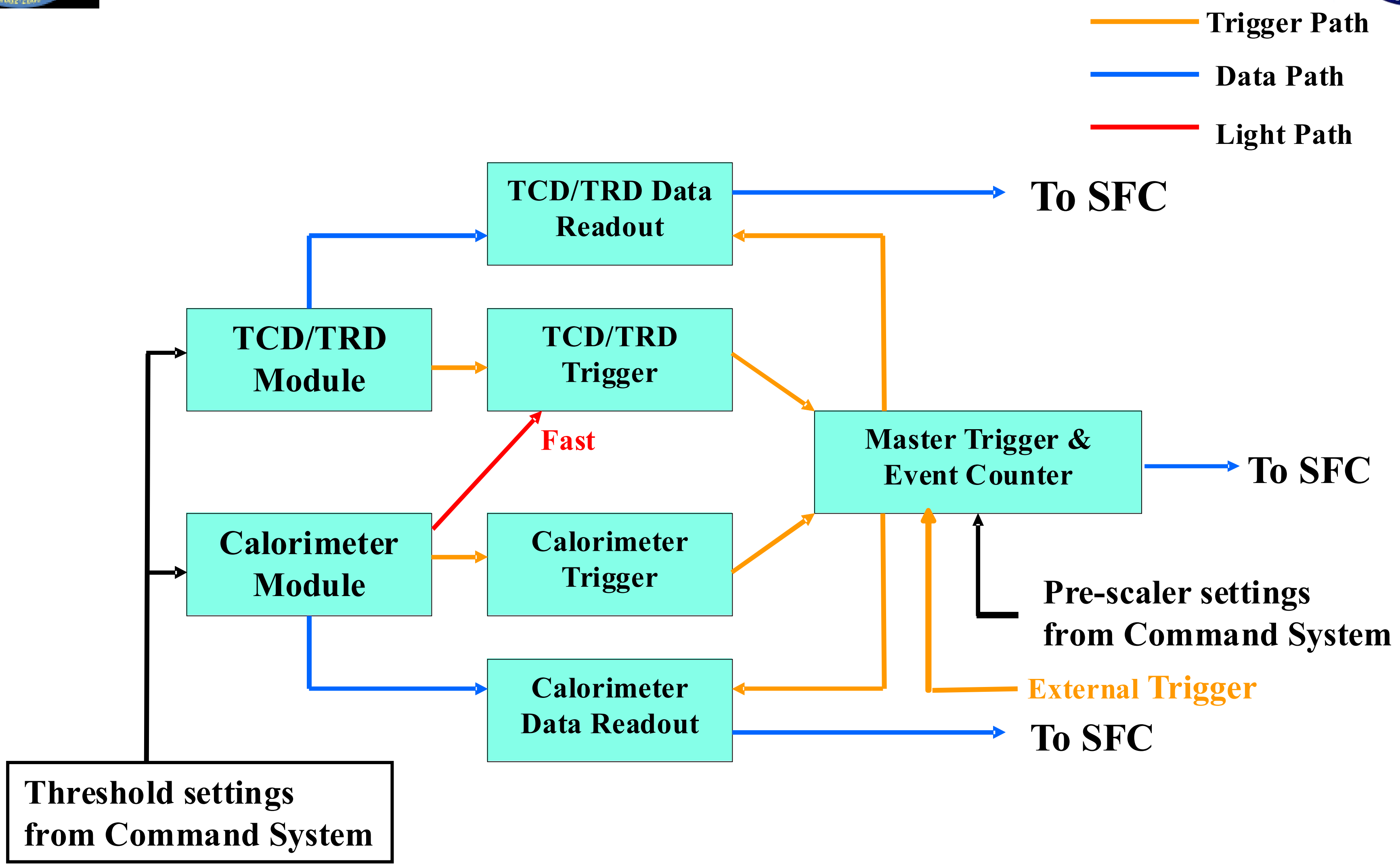


Response with Heavy Ions at CERN

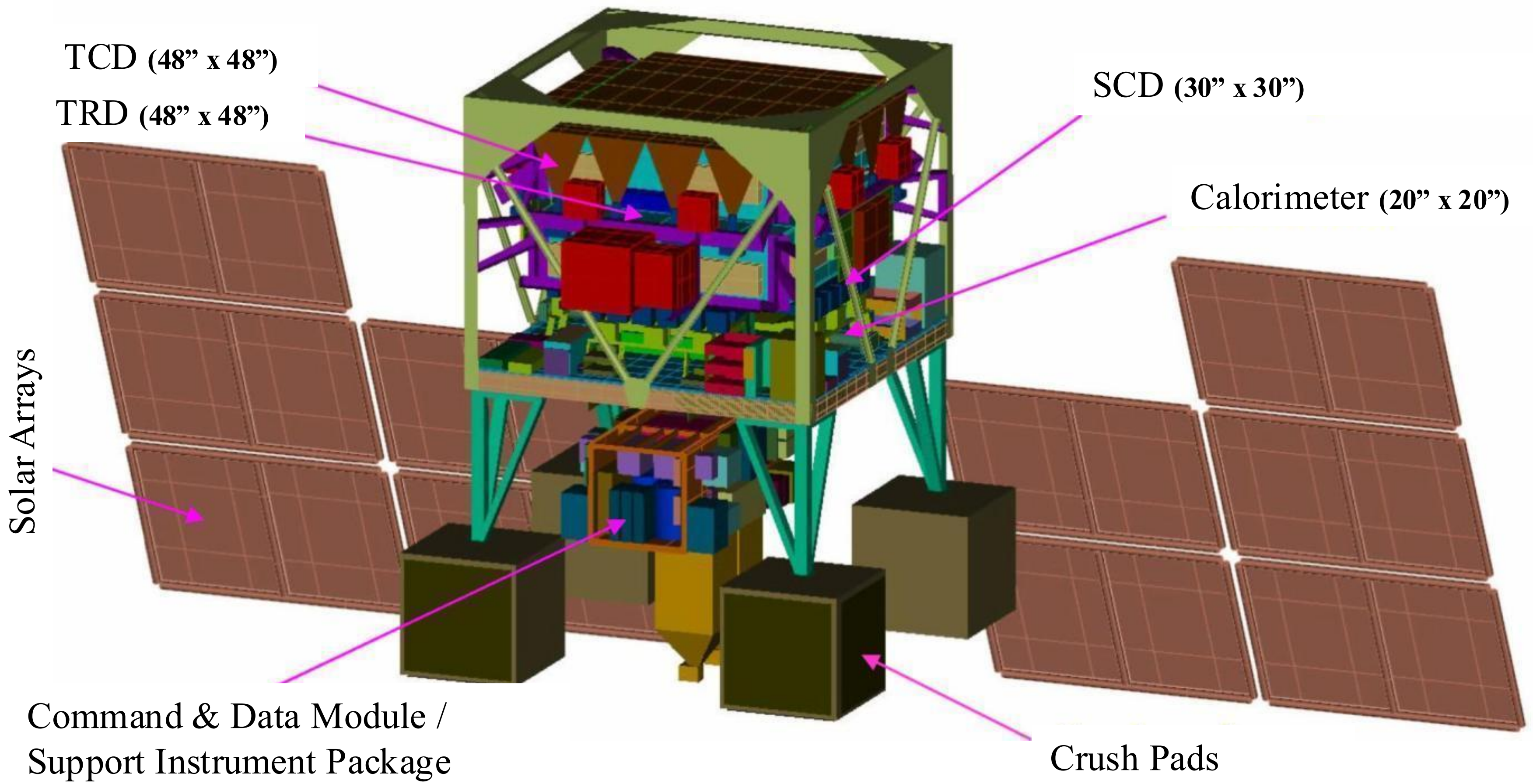


(Atomic Mass)

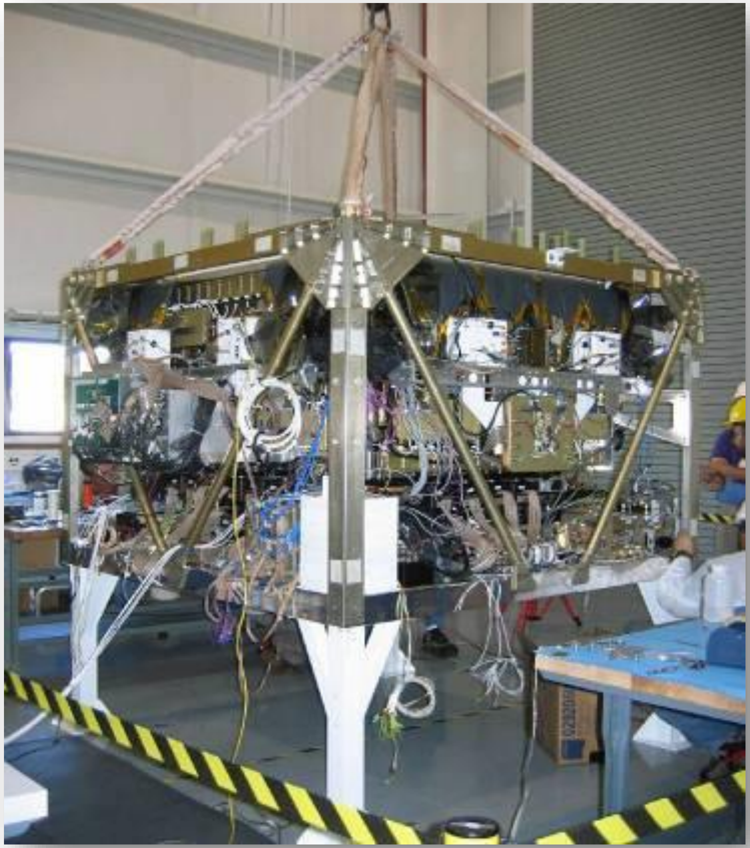
Trigger and Signal Flow (CREAM-I)



3D Schematic of CREAM Flight Configuration

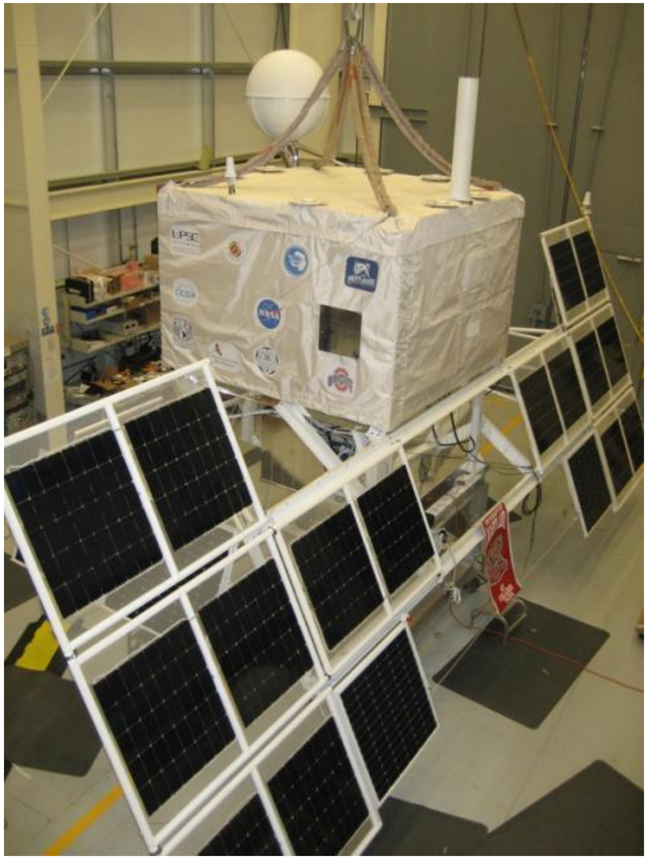


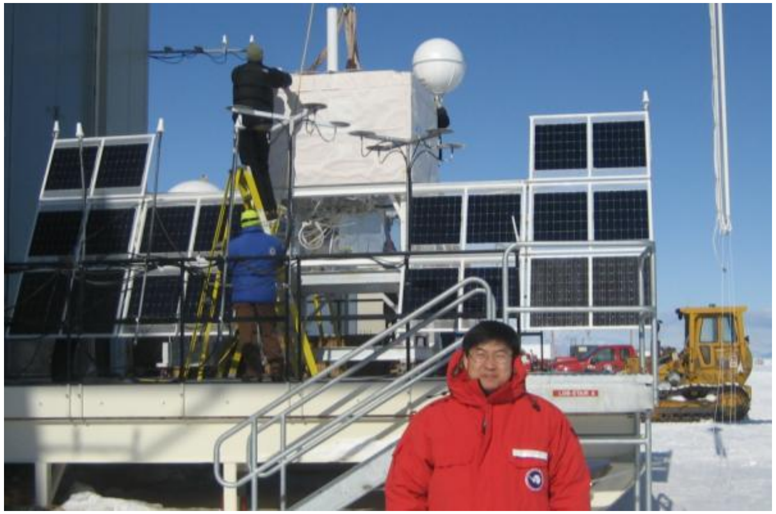
Integration & hang test at NASA



Hang test: Test in flight mode

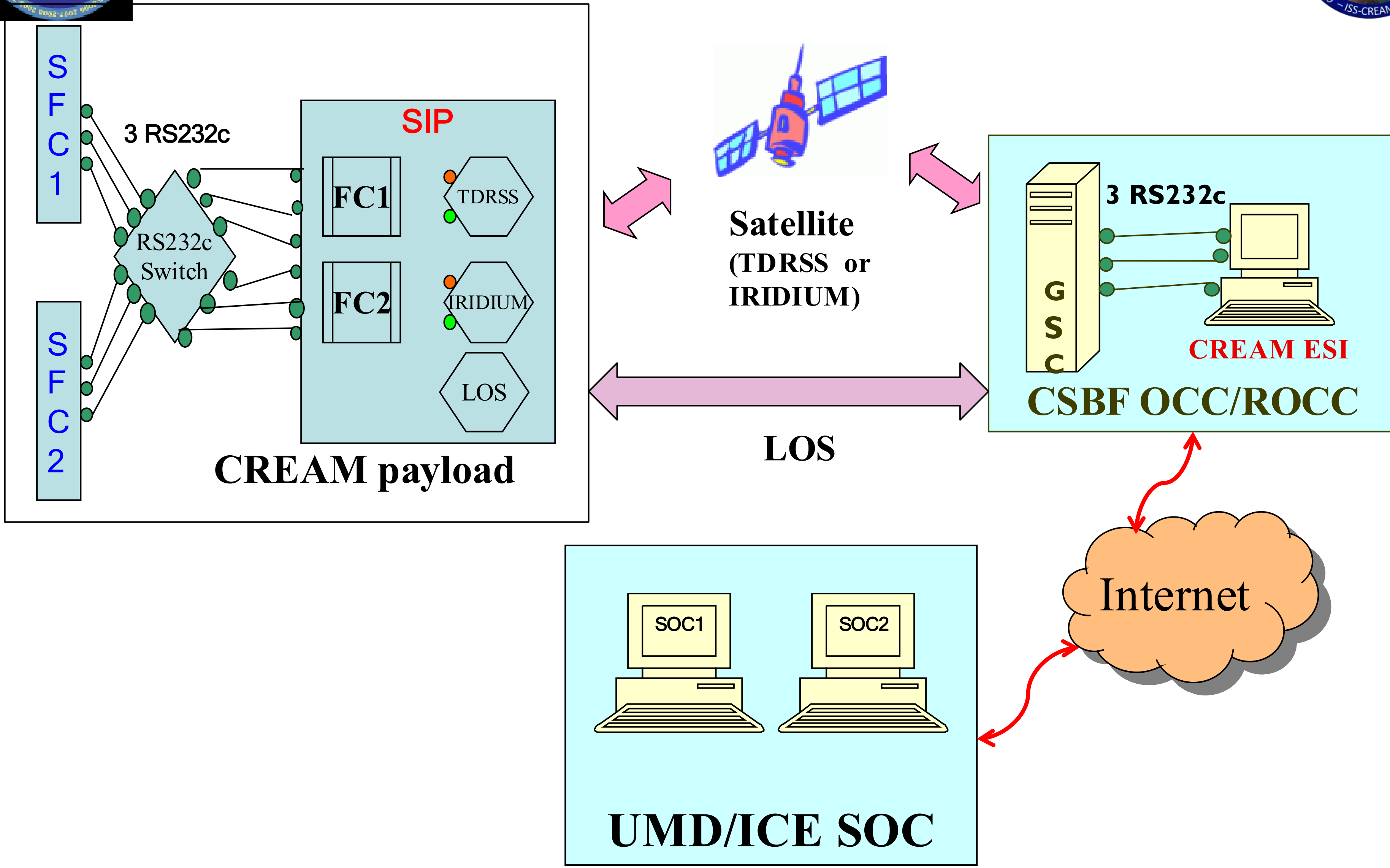
CREAM at the Antarctica



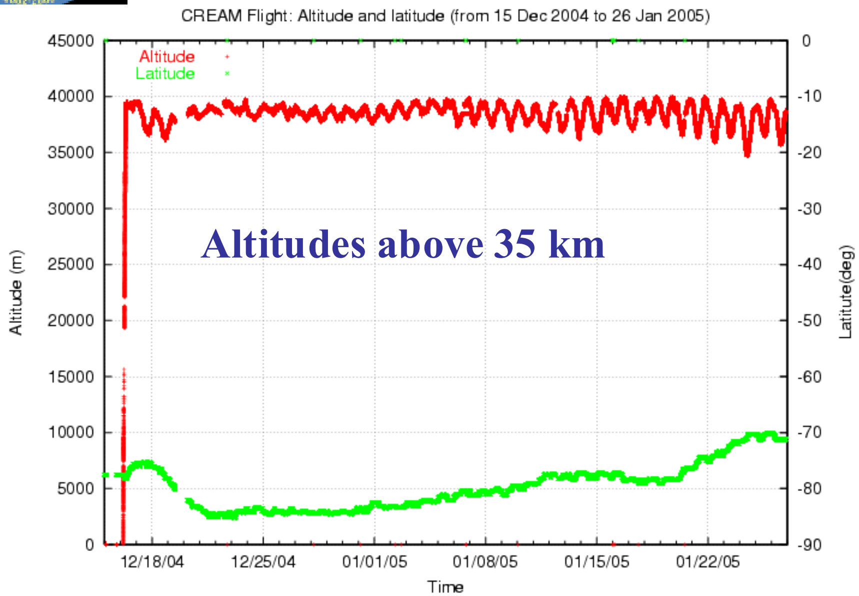


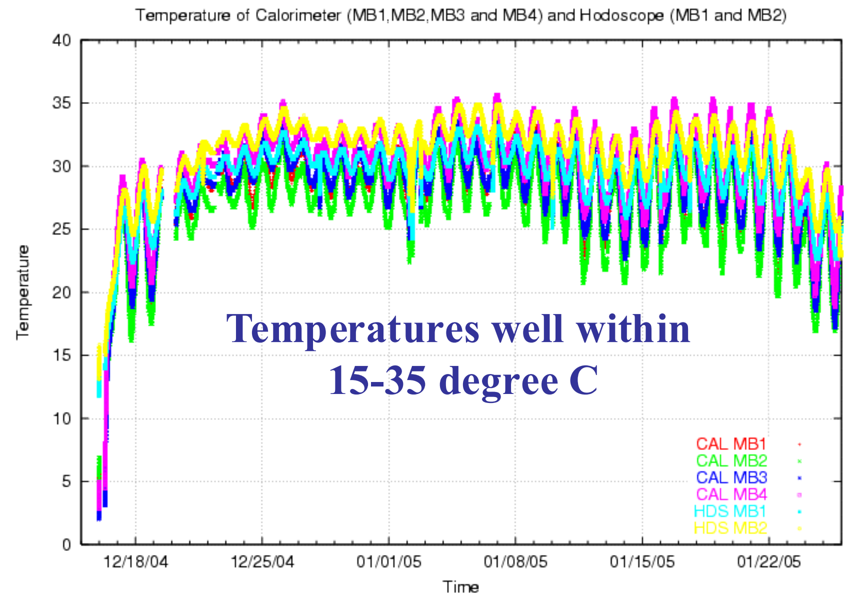
CREAM-IV Launch: Dec. 18th, 2008

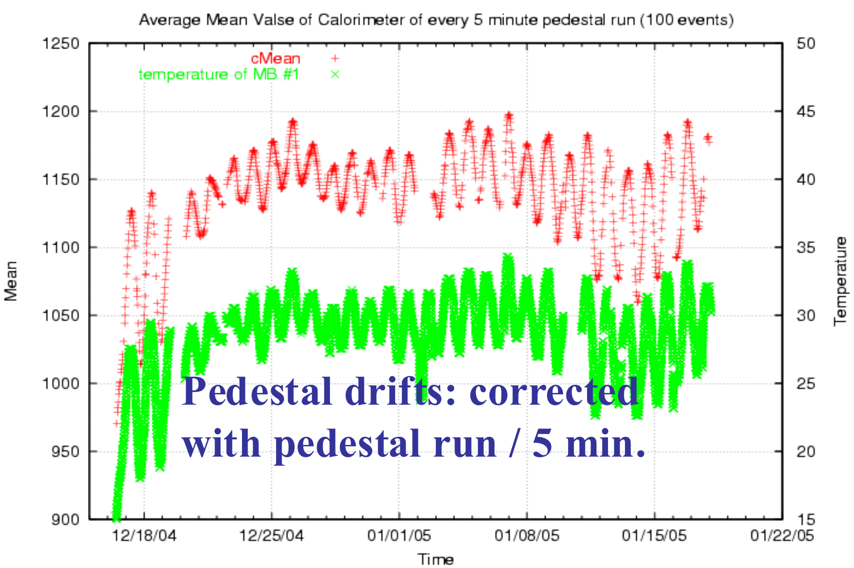
CREAM operation configuration

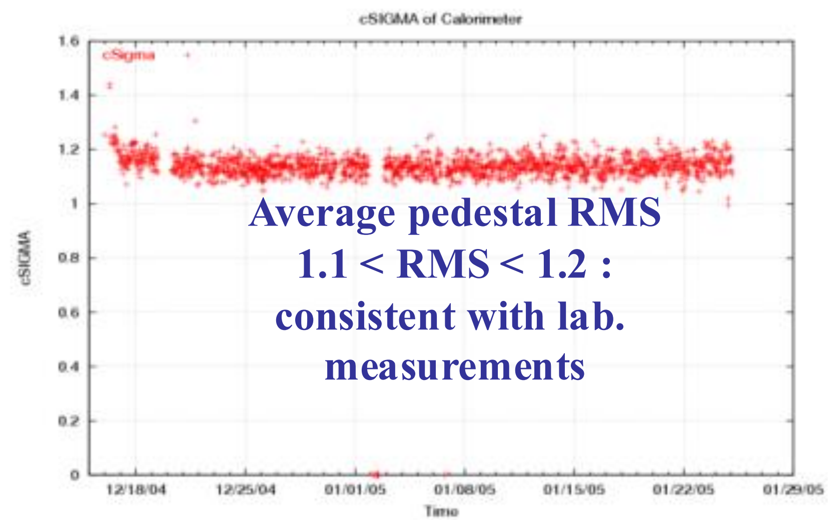


Parameters in CREAM-I flight data

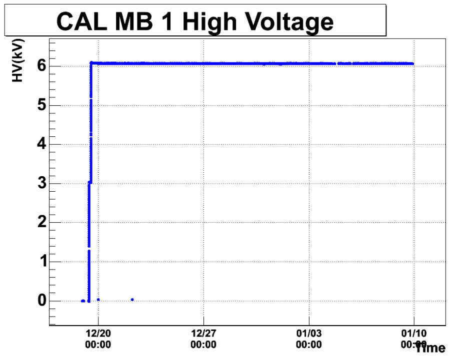


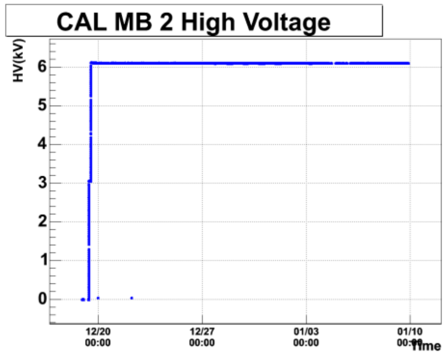


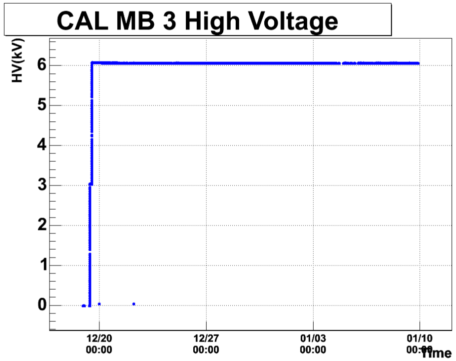


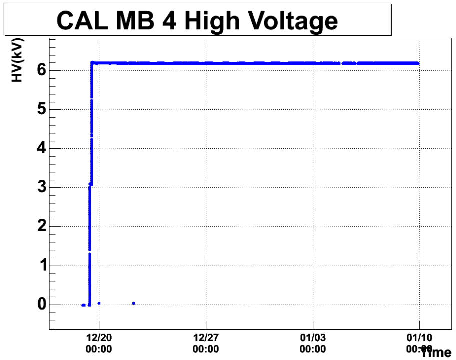


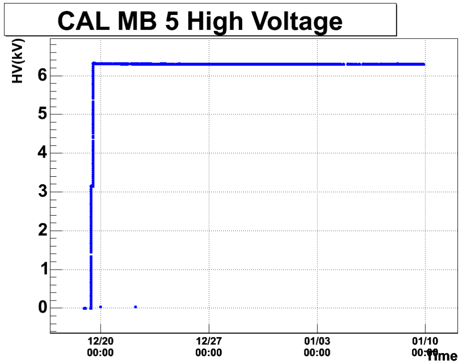
Calorimeter High Voltages

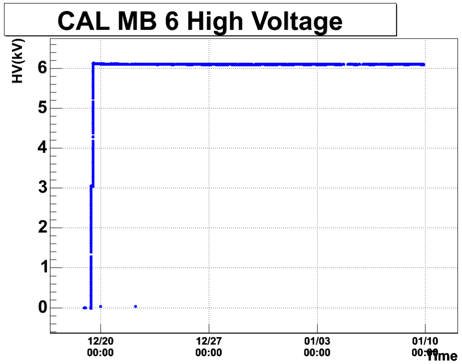


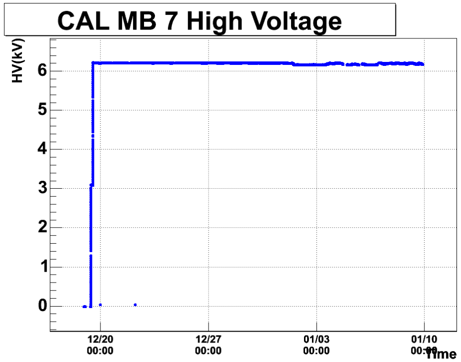


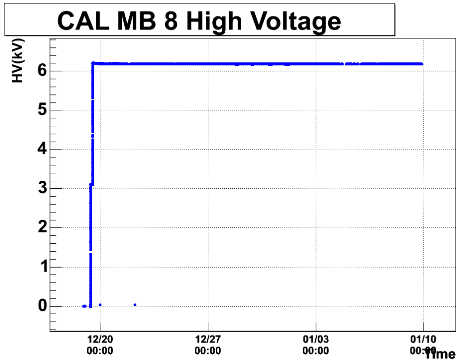






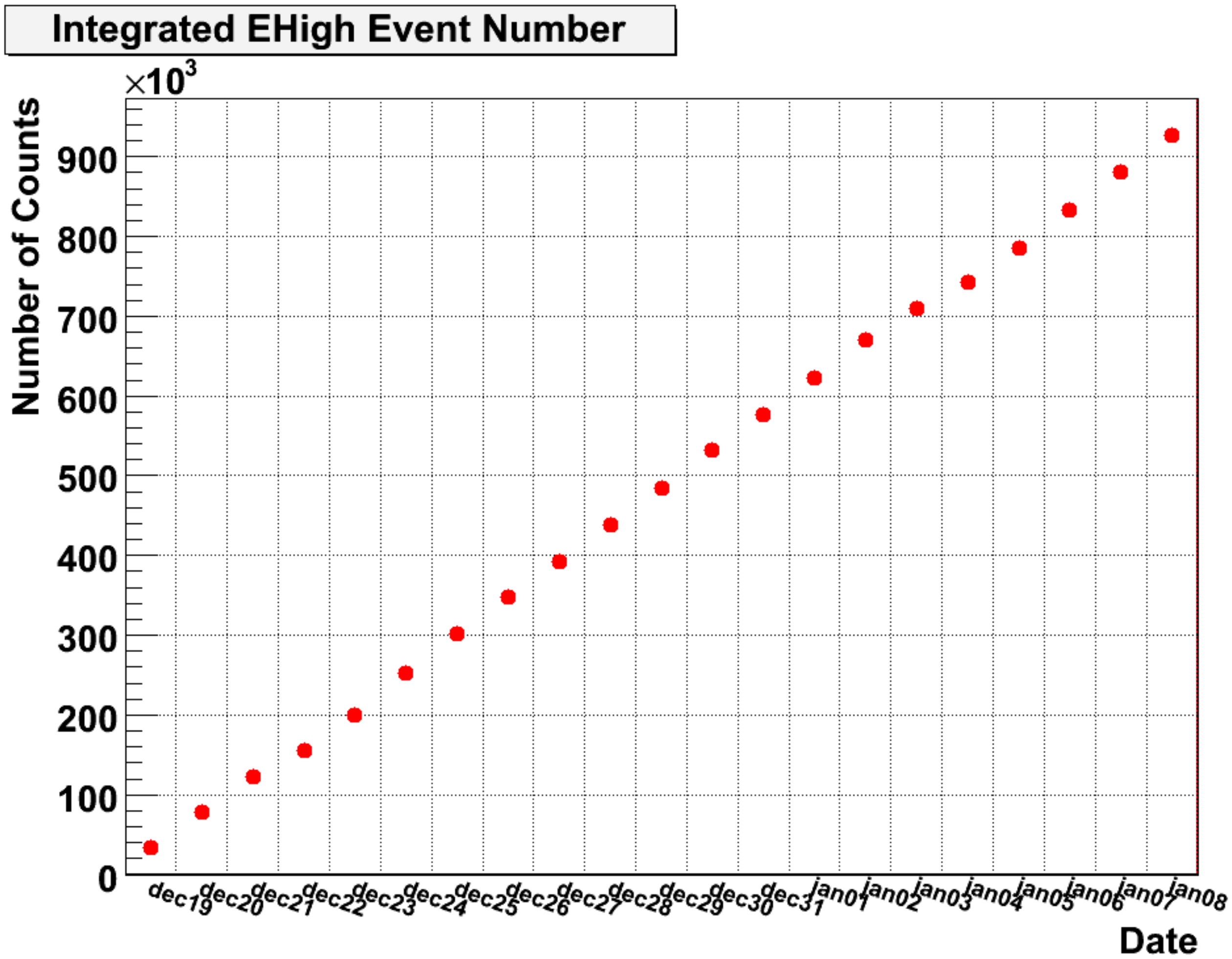




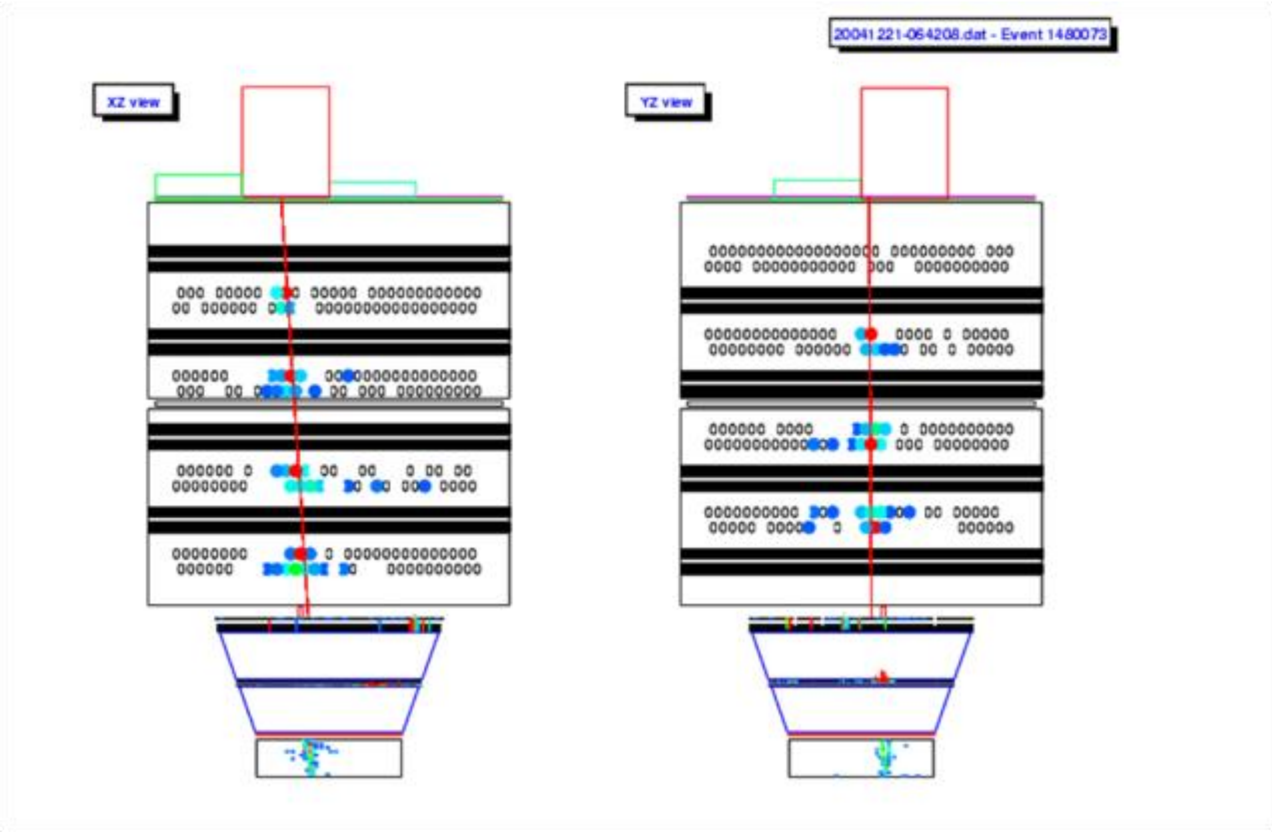


Statistics of EHi (=CAL) trigger events in CREAM-III

~ 45 k events per day, ~ 900 k by the end of Jan. 8th



A CREAM-I event : ~ 10 TeV Fe candidate

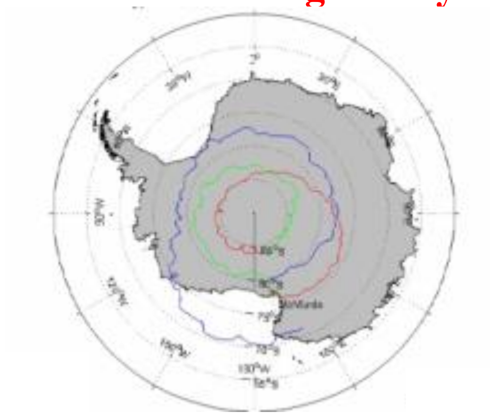


Landing on the Ice …

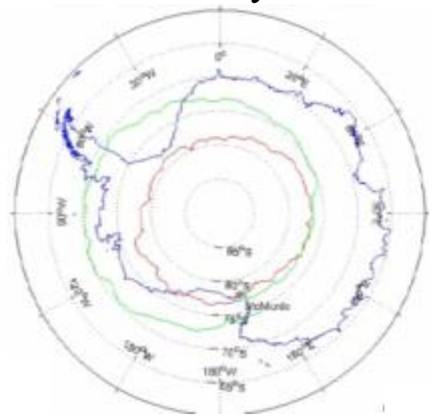
Disassemble and recover … in the cold …

CREAM: About 161 day cumulative exposure

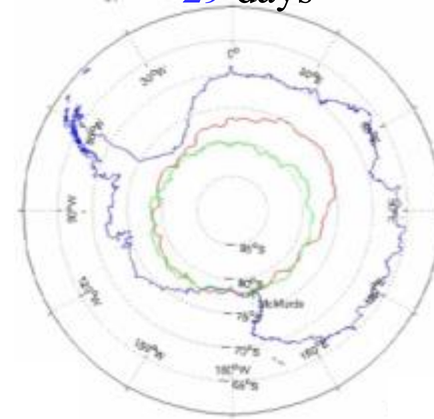
CREAM-I
12/16/04 - 1/27/05
Record breaking 42 days



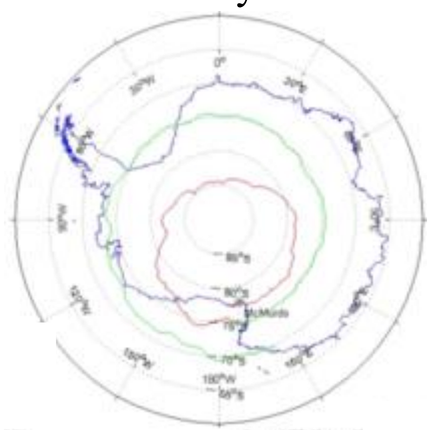
CREAM-II
12/16/05 - 1/13/06
28 days



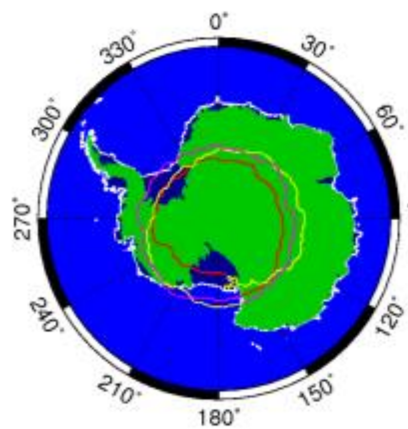
CREAM-III
12/19/07-1/17/08
29 days



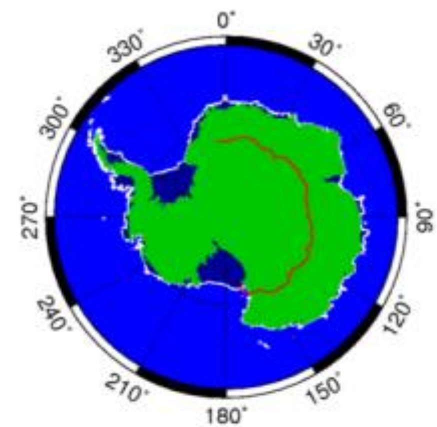
CREAM-IV
12/19/08-1/7/09
19 days



CREAM-V
12/01/09 - 1/8/10
37 days 10 hours

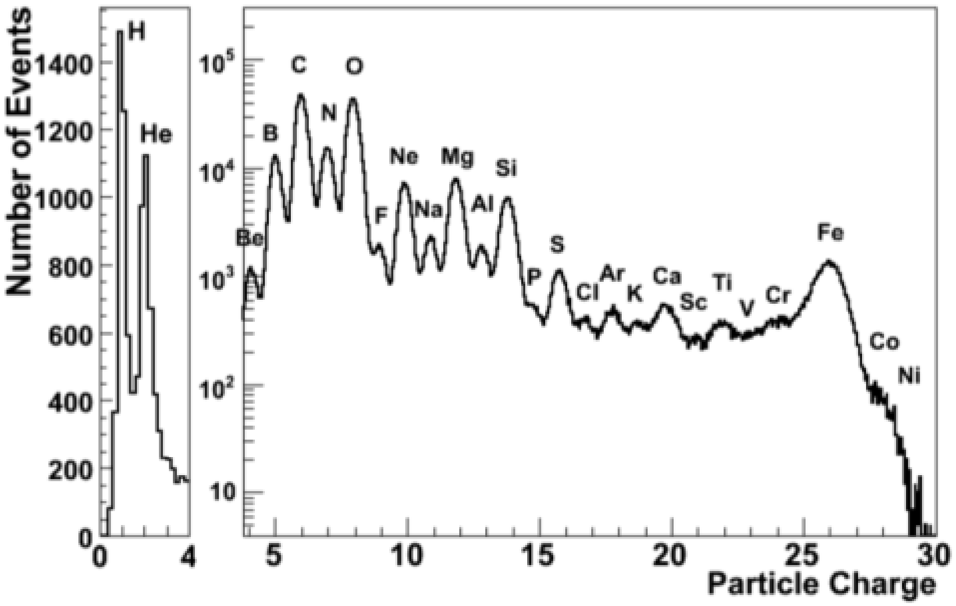


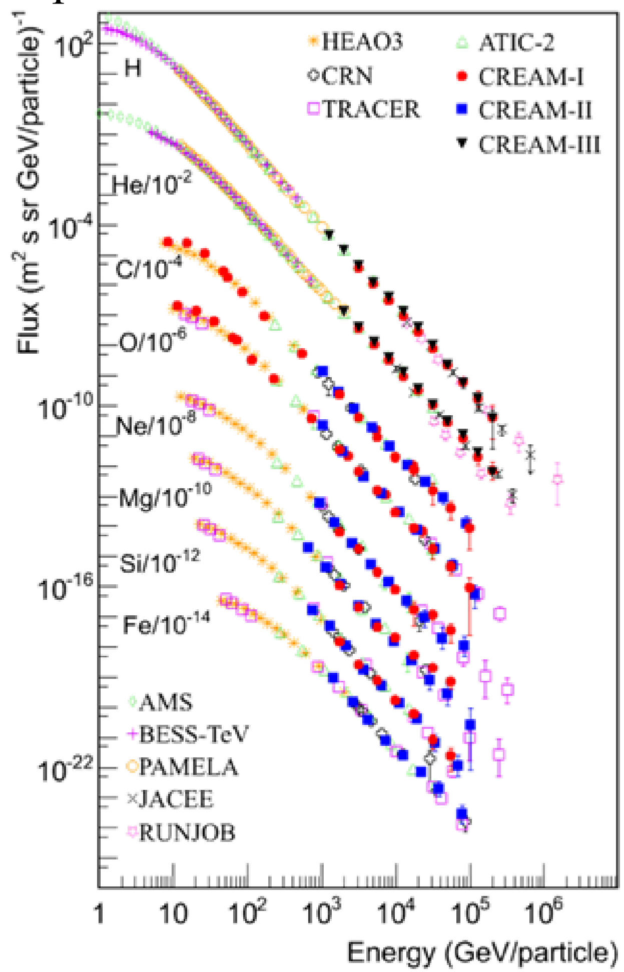
CREAM-VI
12/20/10 - 12/26/10
5 days 16 hours



Cosmic Ray Elemental Spectra

- ❑ CREAM results span **~4 decades in energy**: ~ 10 GeV to ~ 100 TeV
- ❑ Elemental spectral shape/fluxes agree with previous measurements





❑ Distribution of cosmic-ray charge measured with the SCD.

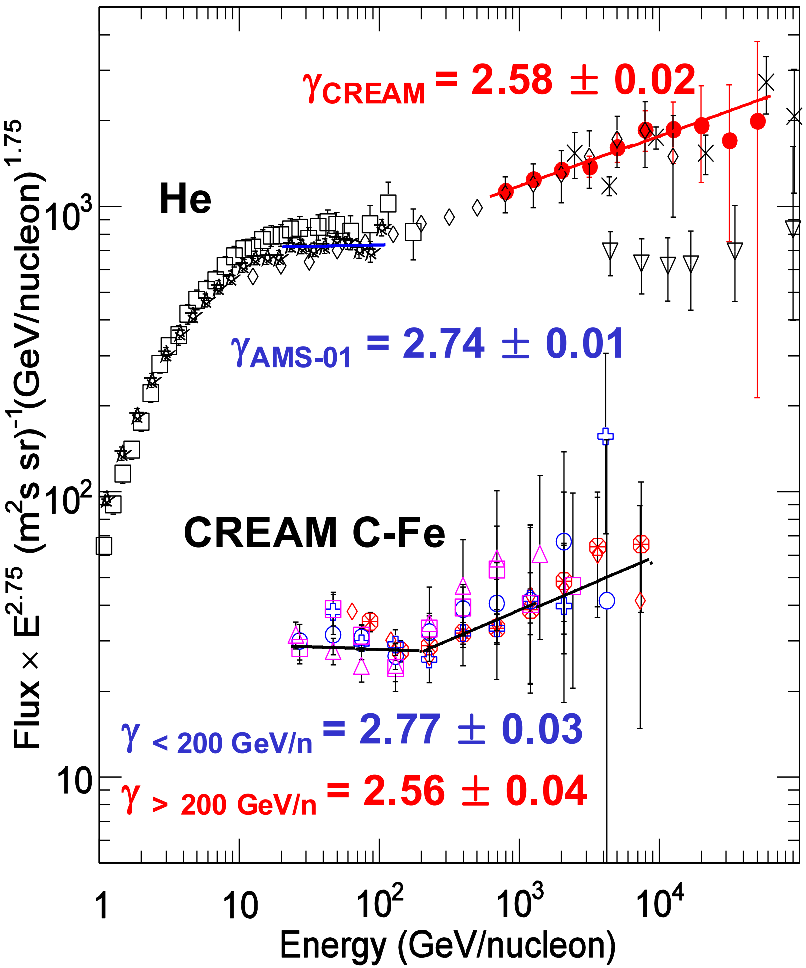
❑ The individual elements are clearly identified **with excellent charge resolution**. The relative abundance in this plot has no physical significance.

H.S. Ahn et al. (ApJL. **714**, L89-L93,2010);
H.S. Ahn et al. (ApJ. **707**, 593-603, 2009)

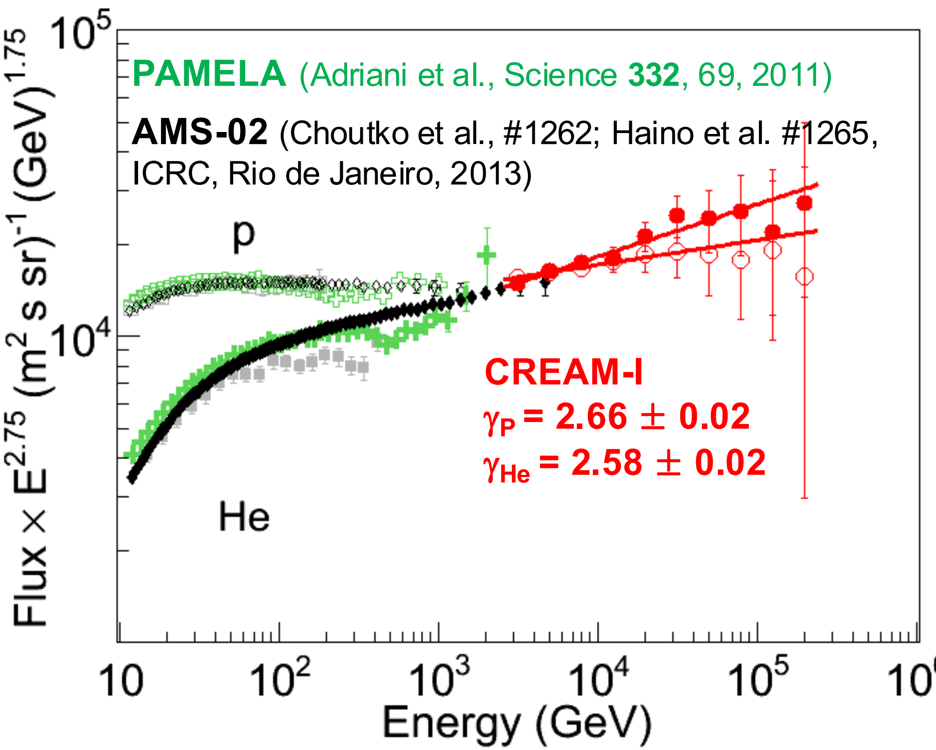
Yoon et al. ApJ **728**, *122*, 2011

Discrepant hardening of spectra

❑ CREAM spectra are harder than prior lower-energy measurements.



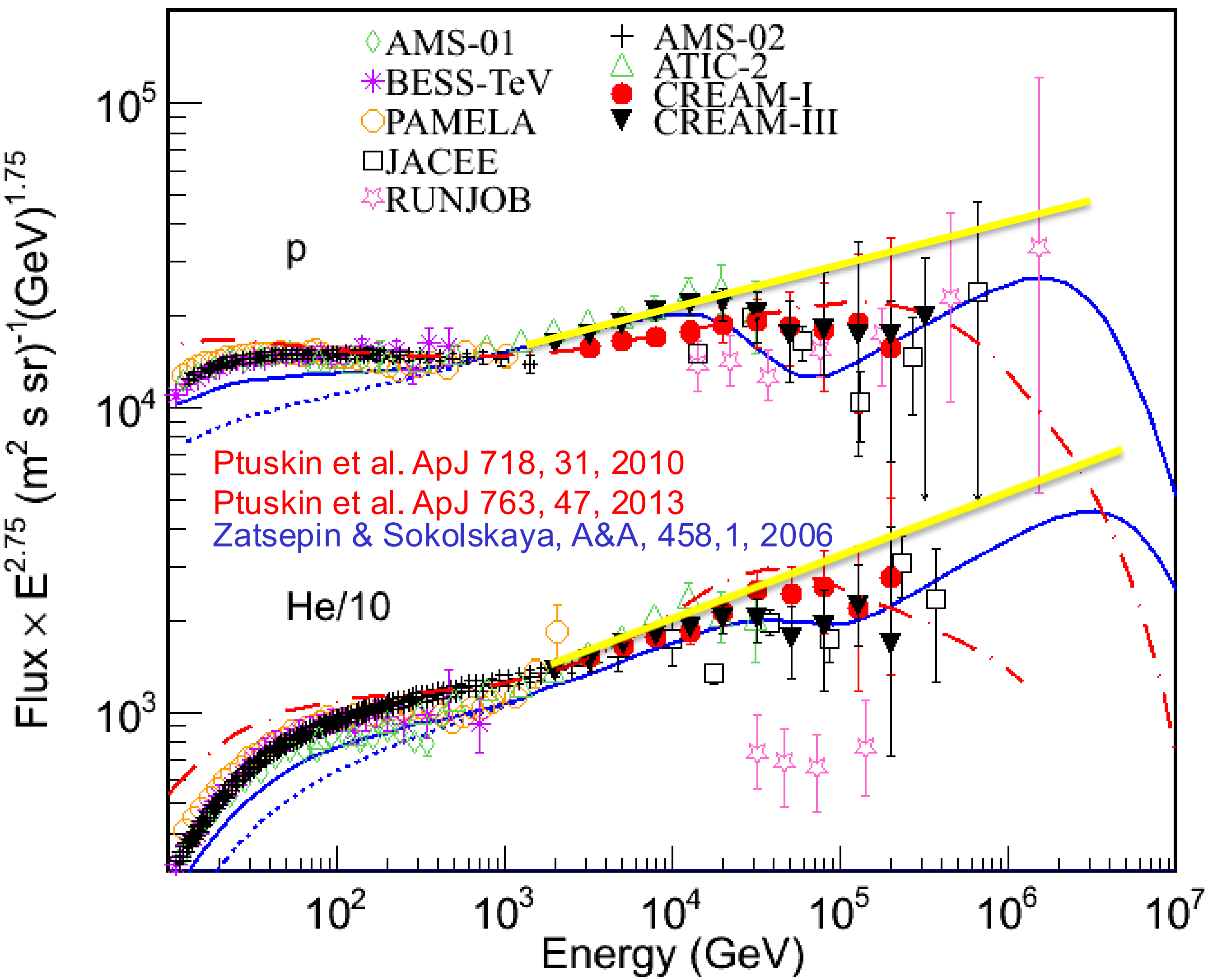
Y.S. Yoon et al. (ApJ. **728**, 122-129, 2011)



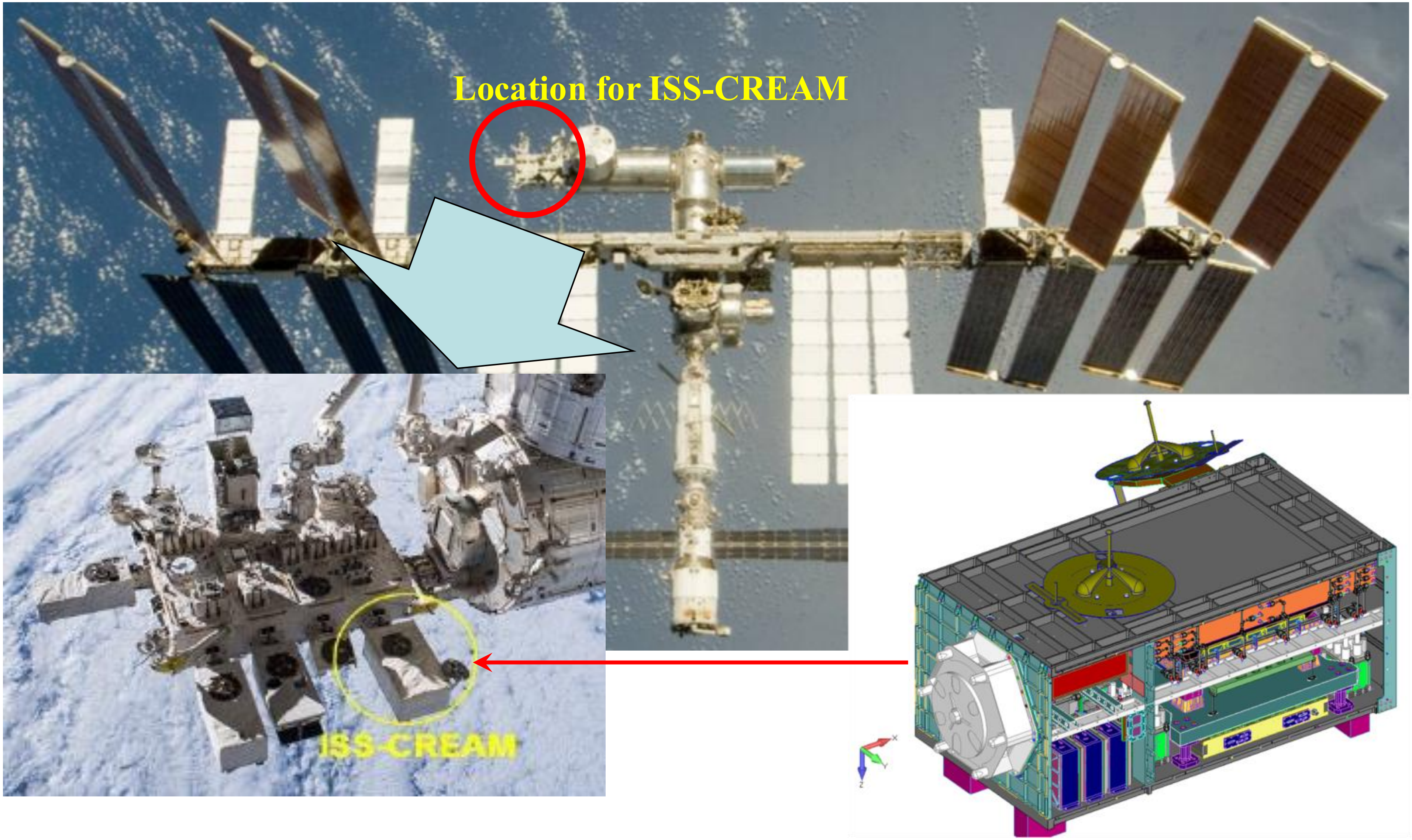
H.S. Ahn et al. (ApJL. **714**, L89-L93, 2010)

Need to extend measurements to higher energies

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



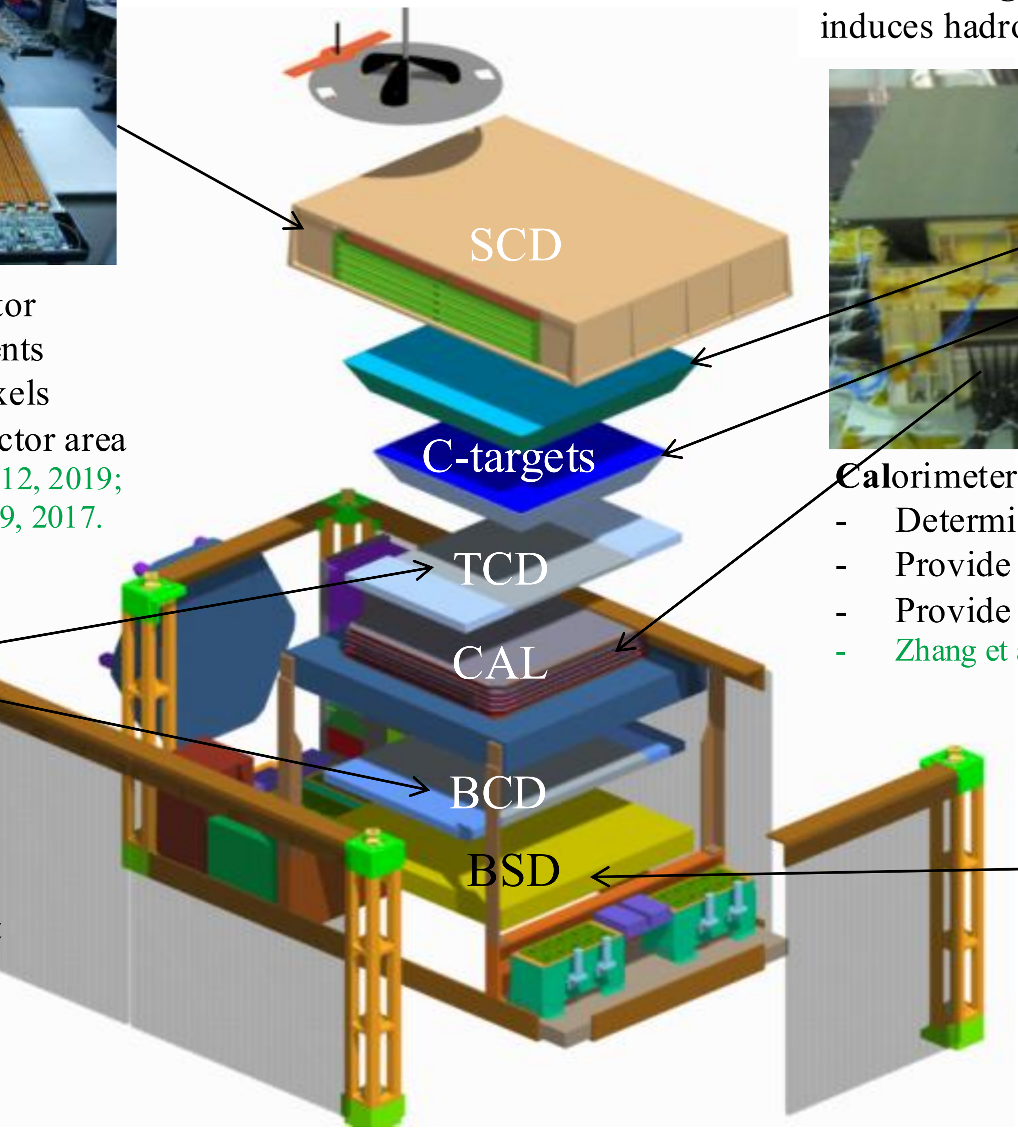
ISS-CREAM (CREAM at the ISS)



ISS-CREAM Instrument

Yoon et al. Astroparticle Phys. 158, 2024.

Carbon **Targets** (0.5 λ_{int})
induces hadronic interactions



4-layer **S**ilicon **C**harge **D**etector

- Precise charge measurements
- 380-μm-thick 2.12 cm^2 pixels
- 79 cm x 79 cm active detector area
- Lee et al. Astroparticle Phys. 112, 2019;
- Hong et al. PoS(ICRC2017)229, 2017.

Calorimeter (20 layers W + Scn Fibers)

- Determine Energy
- Provide tracking
- Provide Trigger
- Zhang et al. Astroparticle Phys. 130, 2021.

Top & **B**ottom **C**ounting **D**etectors

- Segmented for e/p separation
- Independent Trigger
- Plastic Scintillators with 400 Photo Diodes readout (2.3 x 2.3 cm^2)
- Kang et al. Adv. Space Res. 64, 2019;
- Hwang et al. JINT10 (07), P07018, 2015.

Boronated **S**cintillator **D**etector

- Additional e/p separation
- Neutron signals
- Amare et al. NIMA, 1, 943, 2019.

Design for the space and the rocket launch

Radiation

- ❑ Select available radiation-hard parts for replacement if necessary.
- ❑ If not available, test new chips in heavy-ion beams and estimate the upset rates in the ISS for selection.

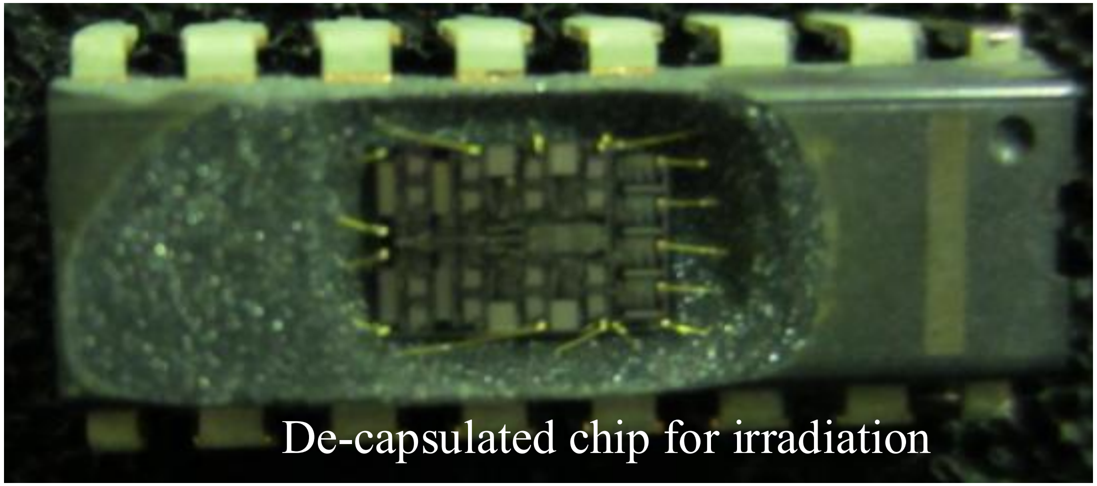
Thermal/Vacuum

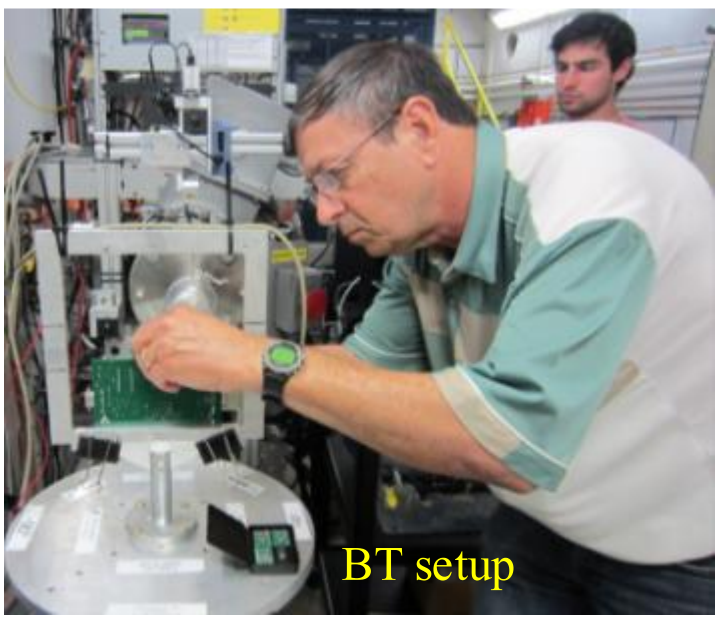
- ❑ Identify parts with their operation/survival temperature ranges.
- ❑ Design heating/cooling of instruments based on the temperature analysis.
- ❑ Assemble components with better heat dissipation.
- ❑ Test components/instruments in a thermal cycle of hot and cold temperatures in a vacuum to confirm.

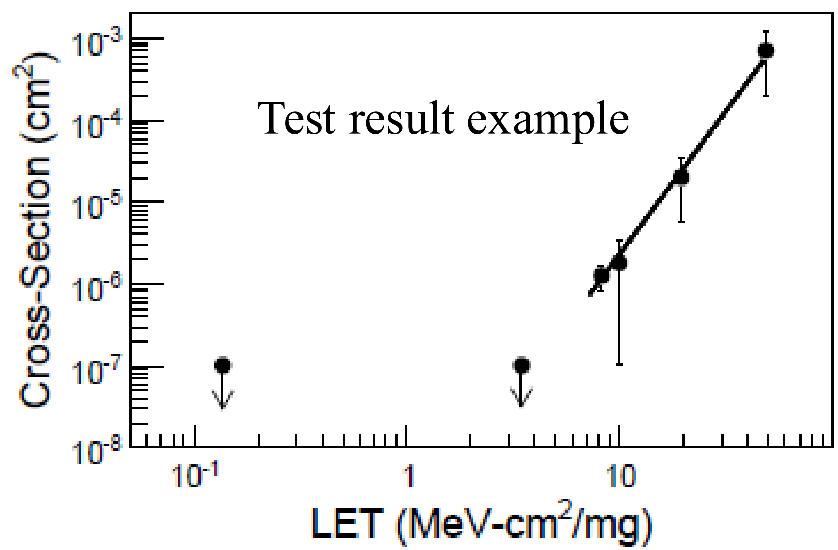
Mechanical

- ❑ Identify the mechanical shock to the instrument during the rocket launch.
- ❑ Design instruments based on the analysis of the mechanical stress coming from the identified shock levels.
- ❑ Perform vibration test of components/instruments to confirm the design parameters.

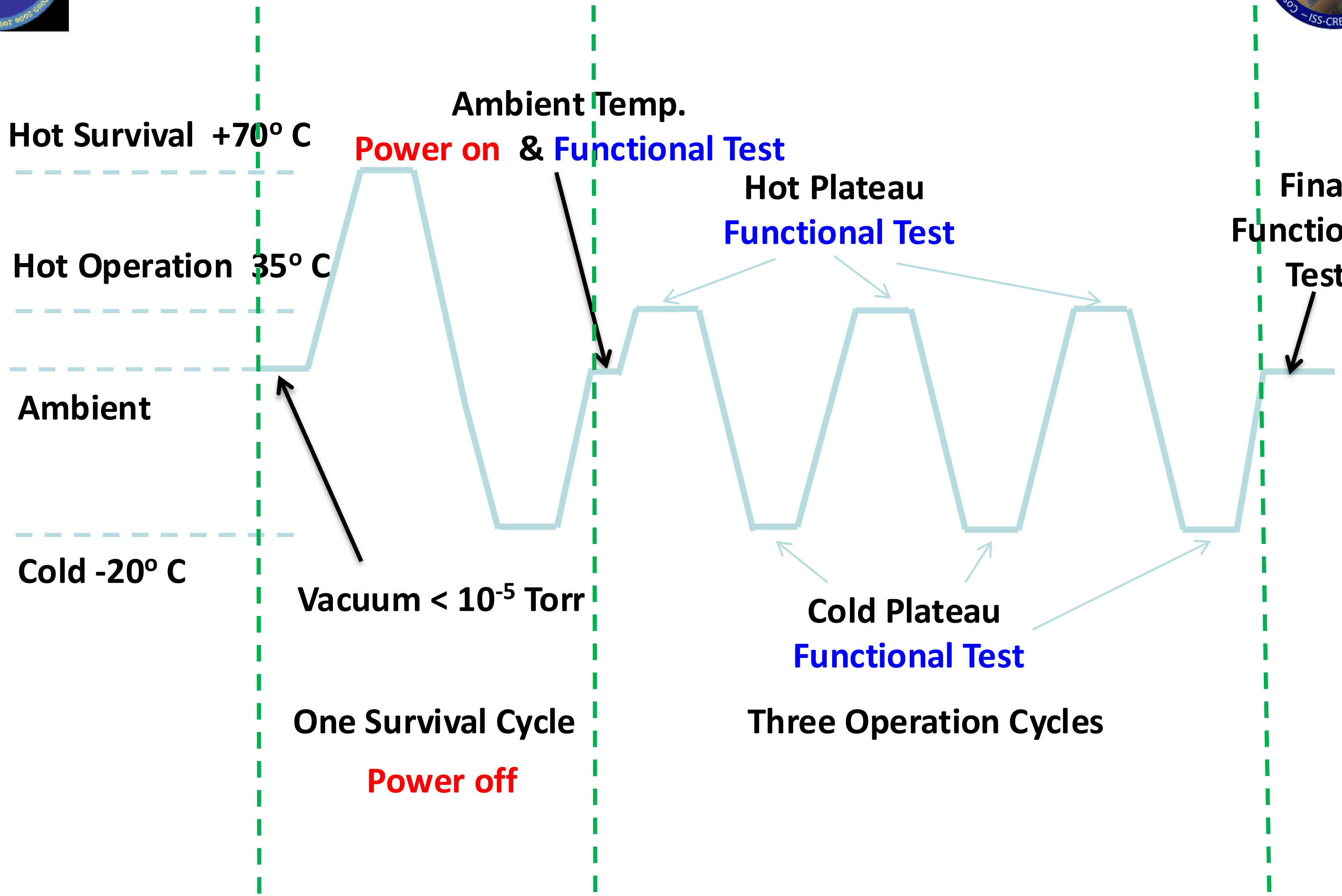
Radiation: Single event upset test facility at TAMU







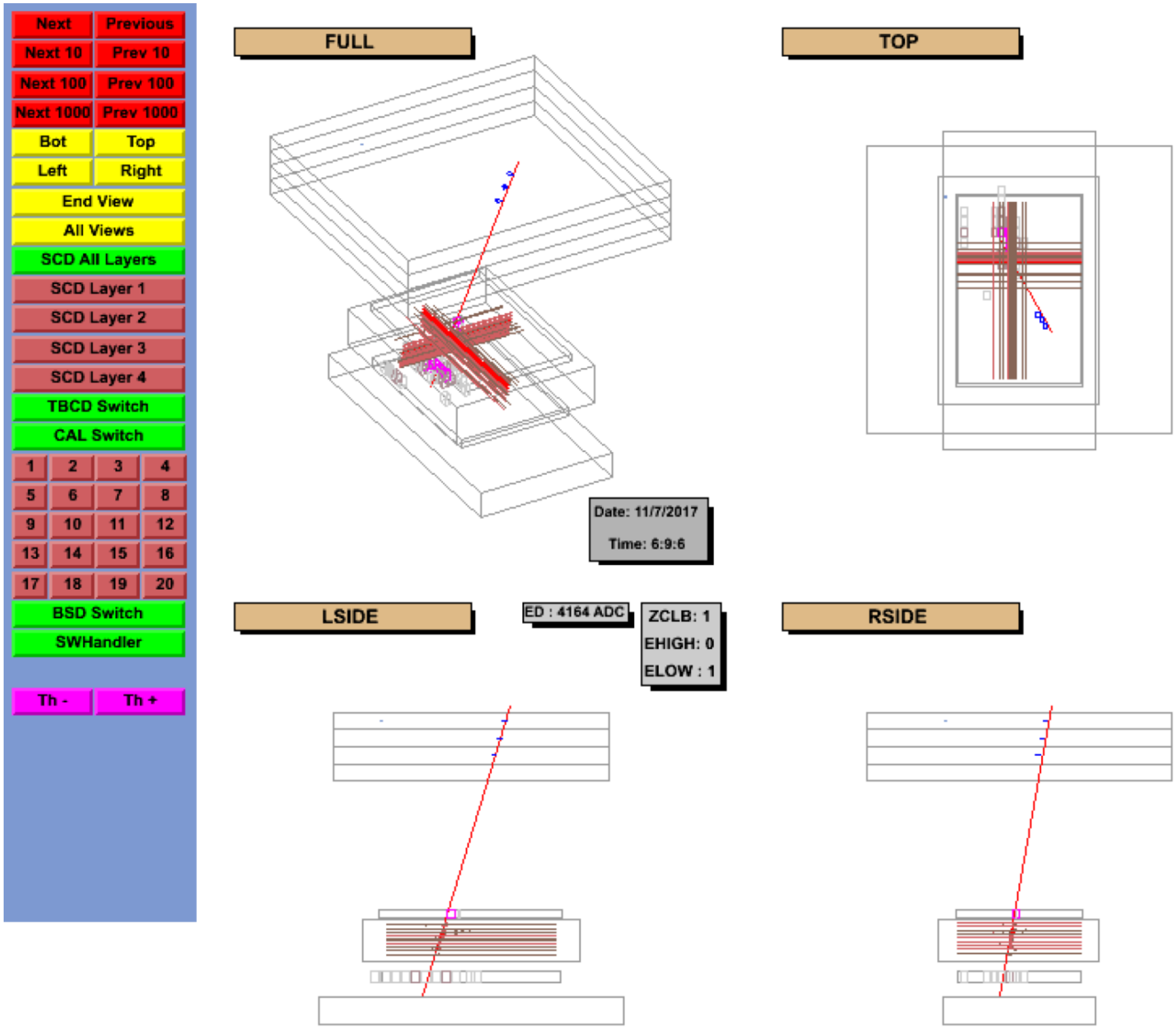
Thermal and vacuum: T/V test cycle



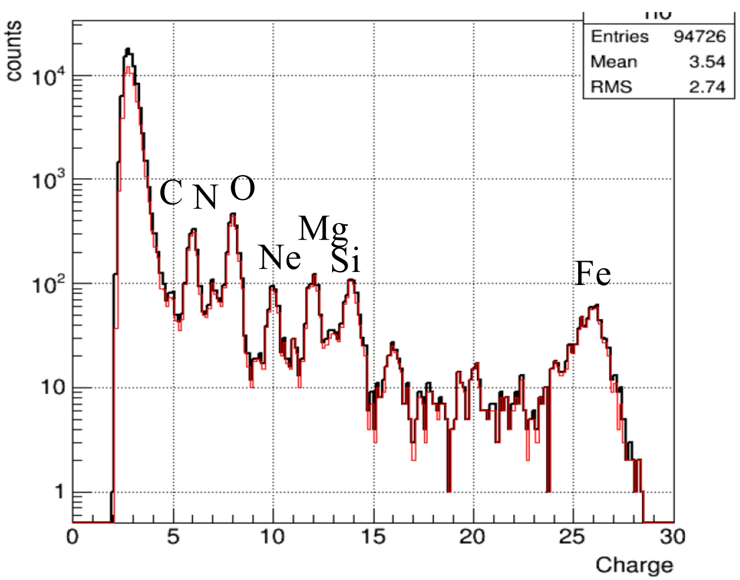
Vibration test at JHU/APL in July 2014

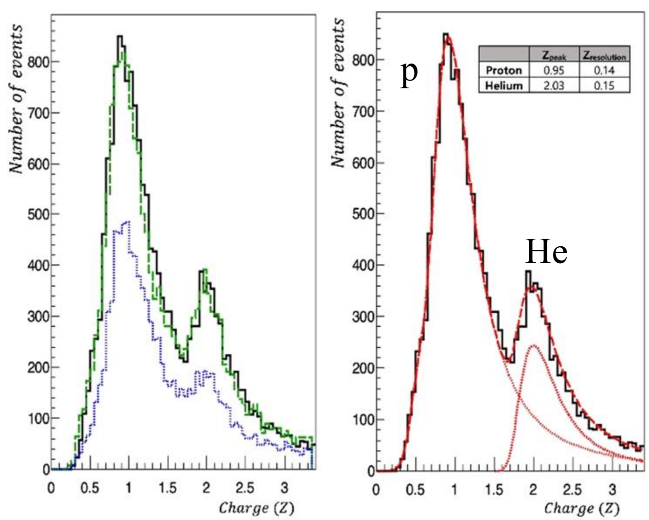
Space-X Falcon-9 Launch video (instagram) August 15th, 2017 (KST)

ISS-CREAM Flight data: Cosmic Ray Detection



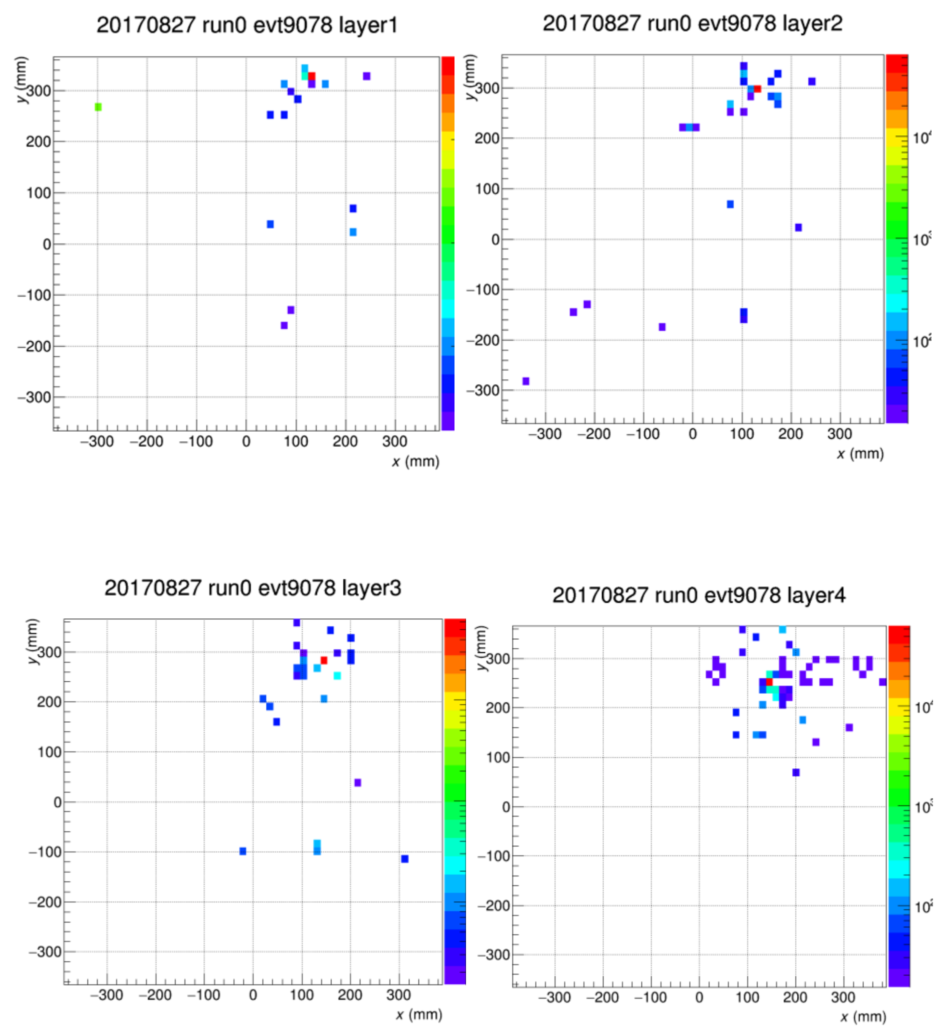
SCD: individual elements are clearly identified





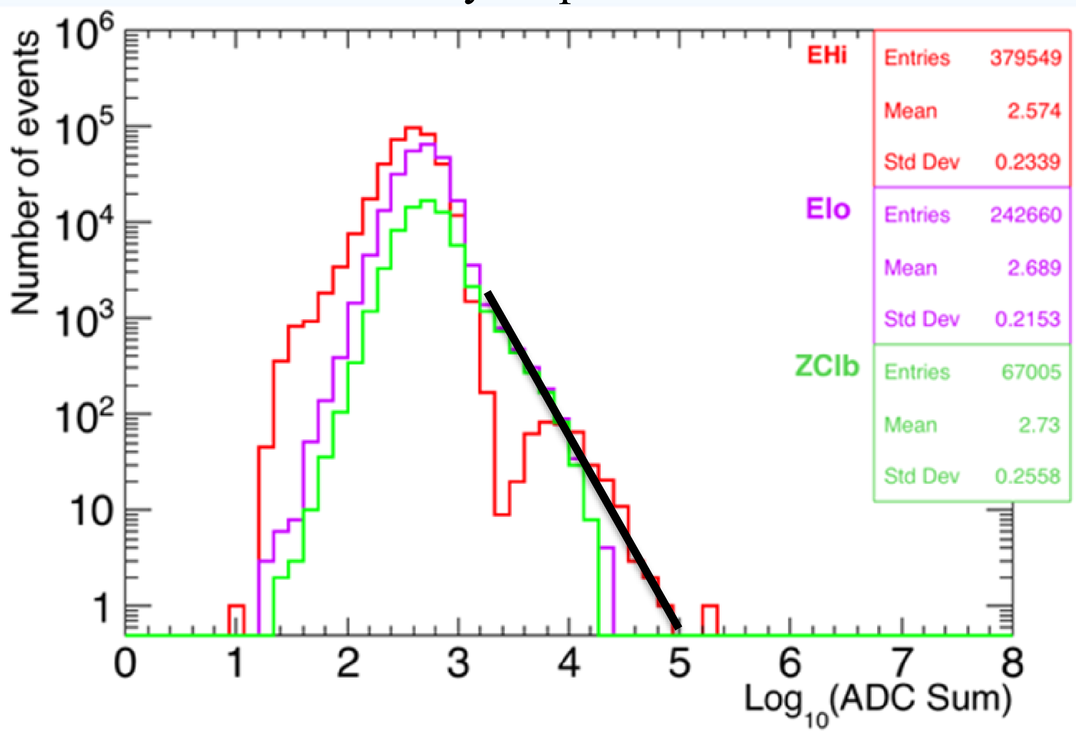
(a) (b)

G. H. Choi et al., Astrophys. J., 2022

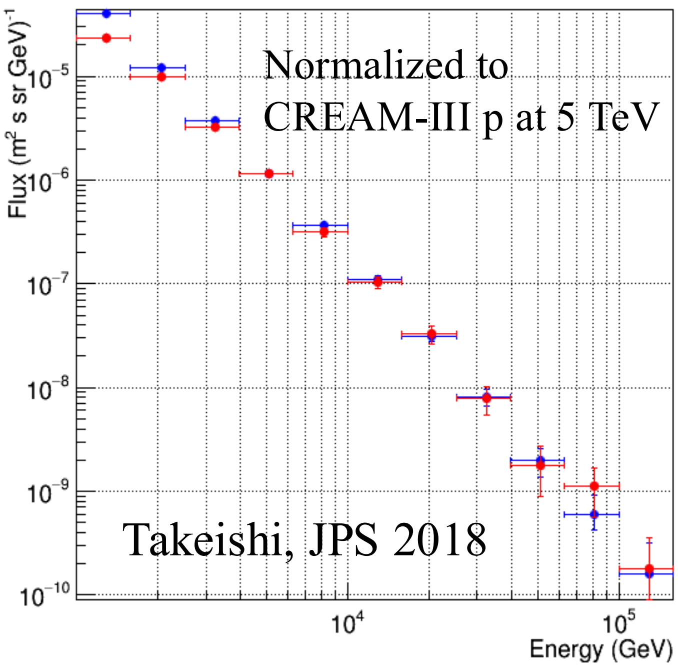


CAL provides energy measurements

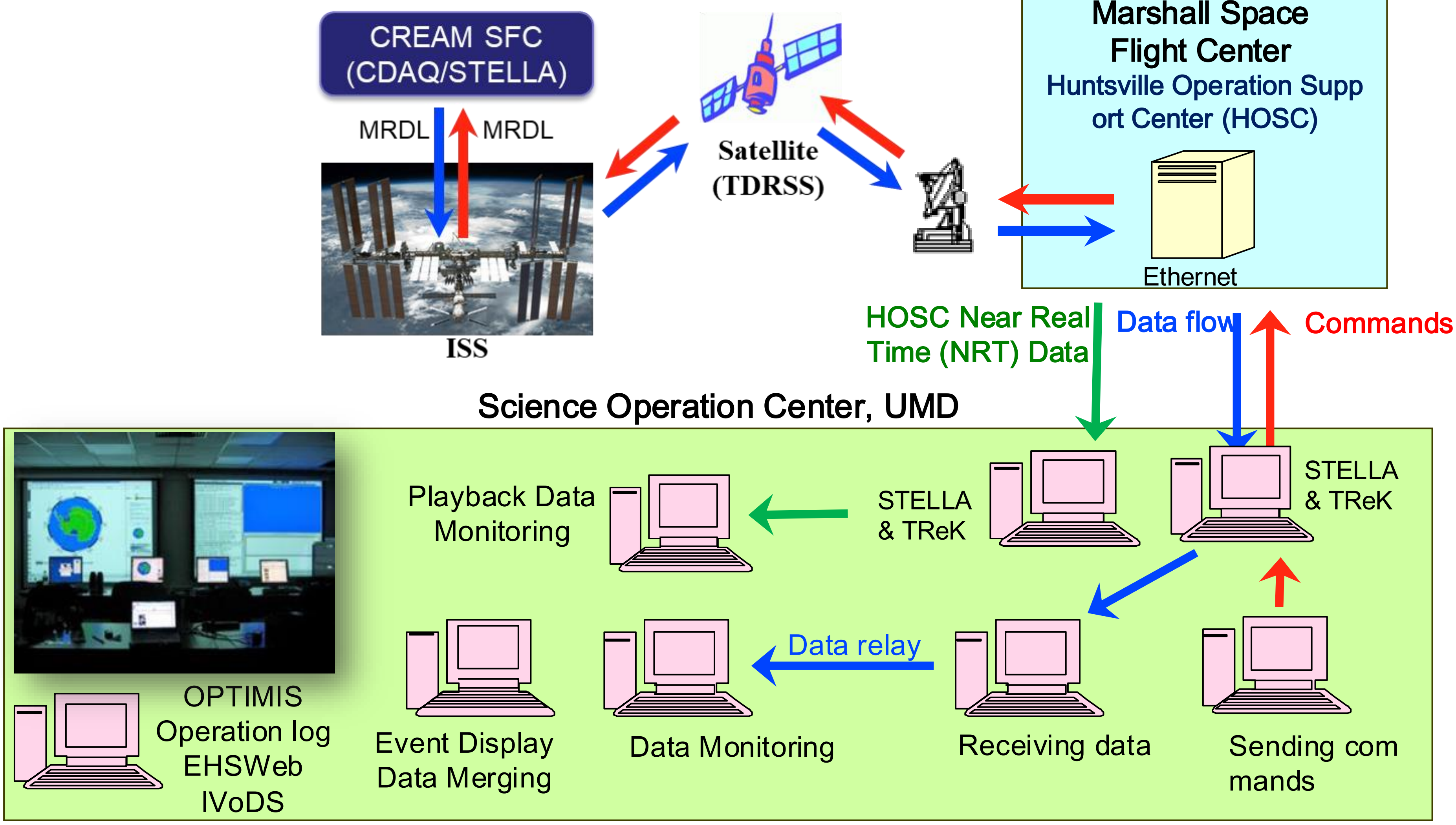
Cosmic ray all particle counts



Spectrum Consistency Check



ISS-CREAM Science Operation



Summary of CREAM flights

	Launch	Termination	Duration
CREAM-I	2004.12.16	2005.1.27	41 days 22 hrs
CREAM-II	2005.12.15	2006.1.13	28 days 10 hrs
CREAM-III	2007.12.19	2008.1.17	28 days 22 hrs
CREAM-IV	2008.12.18	2009.1.7	19 days 13 hrs
CREAM-V	2009.12.1	2010.1.8	37 days 10 hrs
CREAM-VI	2010.12.21	2010.12.26	5 days 16 hrs
BACCUS	2016.11.28	2016.12.28	30 days 2 hrs
ISS-CREAM	2017.8.14	2019.2.12	546 days

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ISS-CREAM Collaboration

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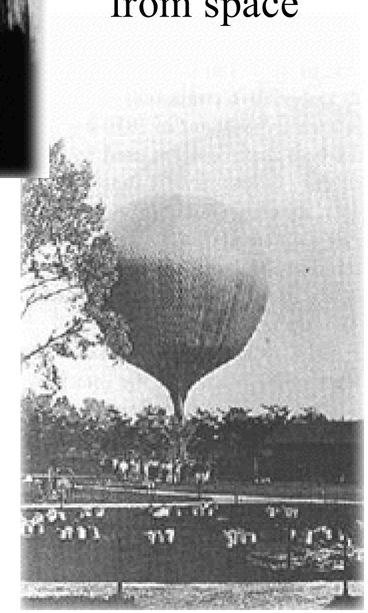
Backup slides

High Energy Cosmic-Ray Research

- For nearly a century, scientists have known that some form of radiation from space hits the Earth's atmosphere.
- At first, we did not know the nature of this radiation, but after decades of research, we have learned that it is composed mainly of atoms with all electrons stripped away. The same elements are present in cosmic rays as on Earth and the Sun.
- We are still working on some big questions:
  - What is the source of these particles?
  - How do they get such enormous energies?
  - What happens as they travel ~10,000,000 years until they reach the end of their journey?

In 1912, Victor Hess flew with a radiation counter in a balloon up to 5 km without oxygen (!) and proved radiation was arriving from space

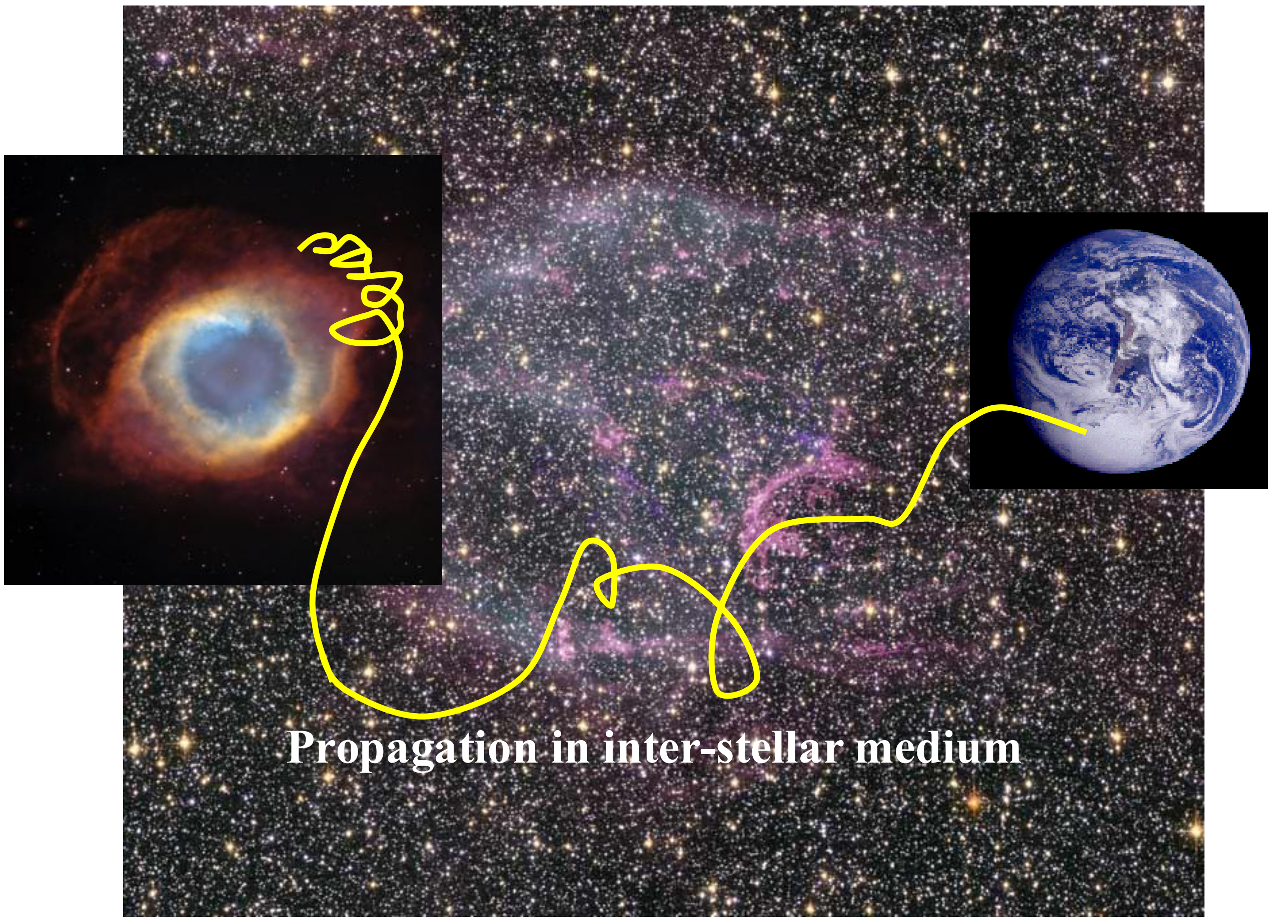


The Super Nova Remnant (SNR) Model

- Particles ejected from stars that explode as a supernova, or that are in the interstellar gas around such exploding stars, are “kicked” as the shockwave from the supernova sweeps by them.
- The intense, rapidly changing magnetic fields may cause particles to cross the shock front multiple times, receiving repeated kicks at each crossing until they leave the supernova's vicinity with very high energies.

Propagation and arrival at Earth

Traveling through the interstellar medium for millions of years, through magnetic fields, plasmas, and gases, some particles interact and break up into lighter nuclei, but most remain intact. Ultimately, a tiny fraction reaches the Earth, where they can be measured directly at the top of the atmosphere. If not intercepted, these particles cause large air showers.



The atmosphere shields us from all but the harmless "tails" of such showers, which can be seen in the lab.

These energetic cosmic rays are a crucial sample of extra-solar matter we can study in our quest to understand our Universe.

Cosmic Ray Particles in the atmosphere