From CREAM to ISS-CREAM Projects

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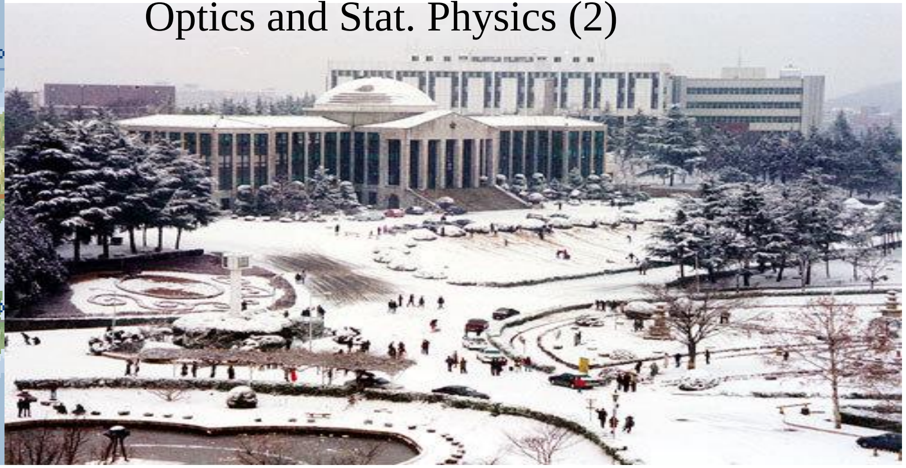
IMPU (June 14, 2017)

Kyungpook National Univ.(KNU) in Daegu

- South Korea
  - ~ 50 Millions, ~100 Universities
- Daegu
  - ~2.5 Millions, 3rd big city
- Kyungpook Nat'l Univ.
  - ~30,000 students
  - ~1,300 professors
  - ~15 colleges
  - ~100 departments
- Dept. of Physics
  - 19 faculties
  - High Energy Physics
    - - Exp. 7, Theo. 2
  - Condensed Matter (6), Nuclear Physics (2)
  - Optics and Stat. Physics (2)



CONTENT

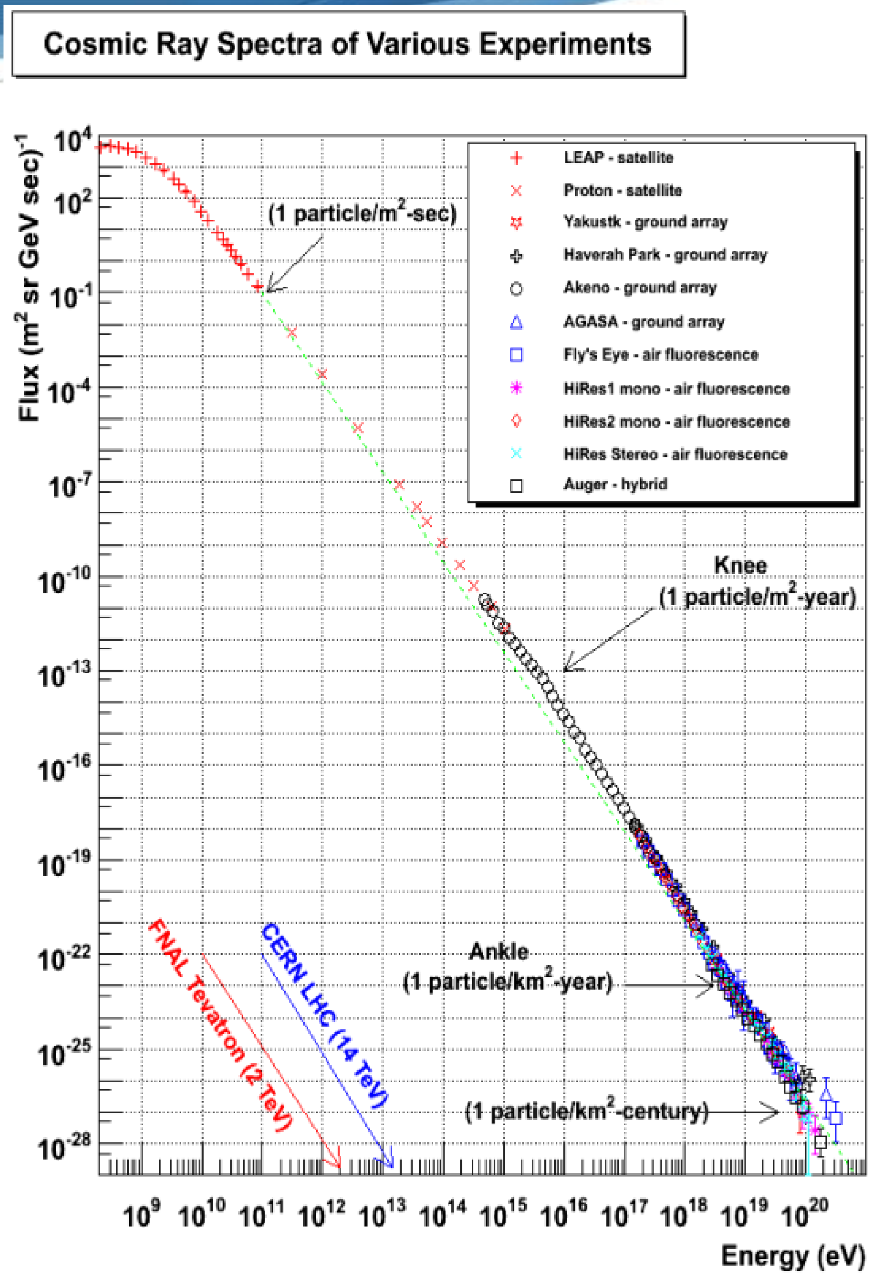
- **Introduction**
  - CREAM Project
  - Some of Results
  - Motivation for ISS-CREAM
- **Status of ISS-CREAM**
  - Top and Bottom Counting Detectors
- **Summary**

Cosmic Ray Spectrum

- Cosmic rays follow a broken power law, one at ‘knee’ and one at ‘ankle’

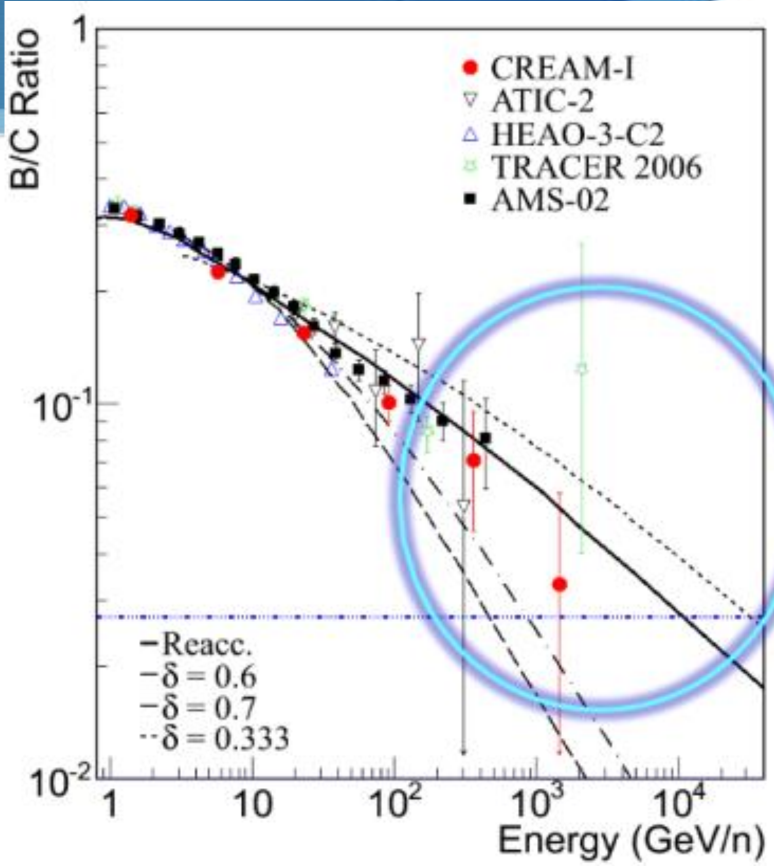
  - one explanation is that the knee marks the point where galactic accelerators reach their energetic limits

  - the ankle marks the point where the galactic cosmic ray intensity falls below the intensity of cosmic rays from extragalactic sources, the so called ultra high-energy (UHE) cosmic rays (Swordy, 2001)



Propagation history of cosmic rays in the Galaxy?

• Measurements of the relative abundances of secondary cosmic rays (e.g., B/C) in addition to the energy spectra of primary nuclei will allow determination of cosmic-ray source spectra at energies where measurements are not currently available.



• B/C ratio at these high energies to distinguish among **propagation models**:

$$X_e \propto R^{-\delta}$$

X_e: Escape length, R: Rigidity

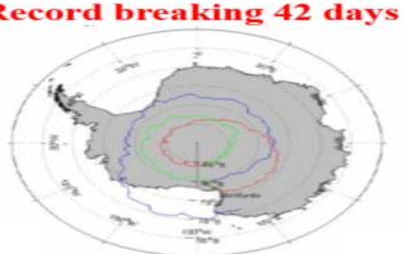
H. Ahn et al., Astrpart. Phys., 30/3, 133-141, 2008

CREAM

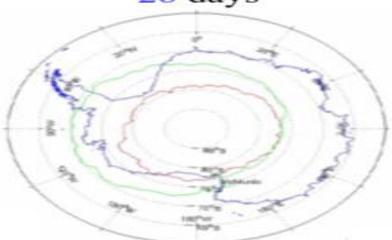
- **Cosmic Ray Energetics And Mass (CREAM) : (PI : E.S. Seo ,U. of Maryland)**
  - measure cosmic ray elemental spectra using a series of LDB flights
  - capable of precise measurements of elemental spectra for Z=1~26 nuclei over energy range ~10^2 GeV to 10^6 GeV
  - provide a key to understanding cosmic ray acceleration and propagation

- **CREAM mission have had six successful flights over Antarctica from 2004 to 2010**
  - 1.1 million cubic meter balloon carried each payload to its float altitude of ~40 km
  - after each flight the instrument was recovered and refurbished for subsequent flights
  - cumulative exposure of ~161 days, which is the longest exposure for a single Balloon-borne experiment, has been achieved

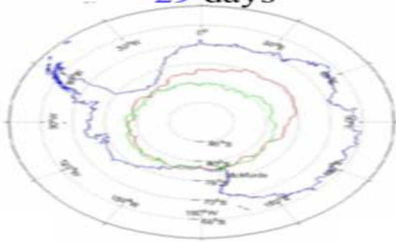
CREAM-I
12/16/04 - 1/27/05
Record breaking 42 days



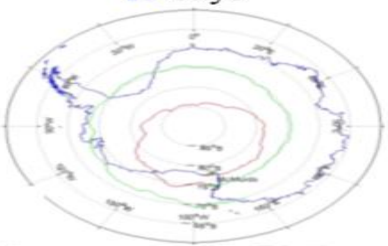
CREAM-II
12/16/05 - 1/13/06
28 days



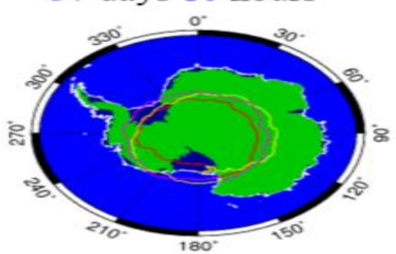
CREAM-III
12/19/07-1/17/08
29 days



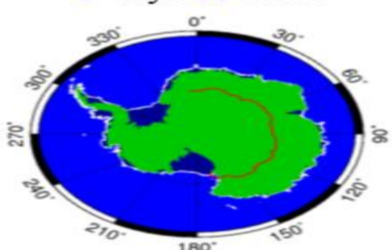
CREAM-IV
12/19/08-1/7/09
19 days



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



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



CREAM Instruments

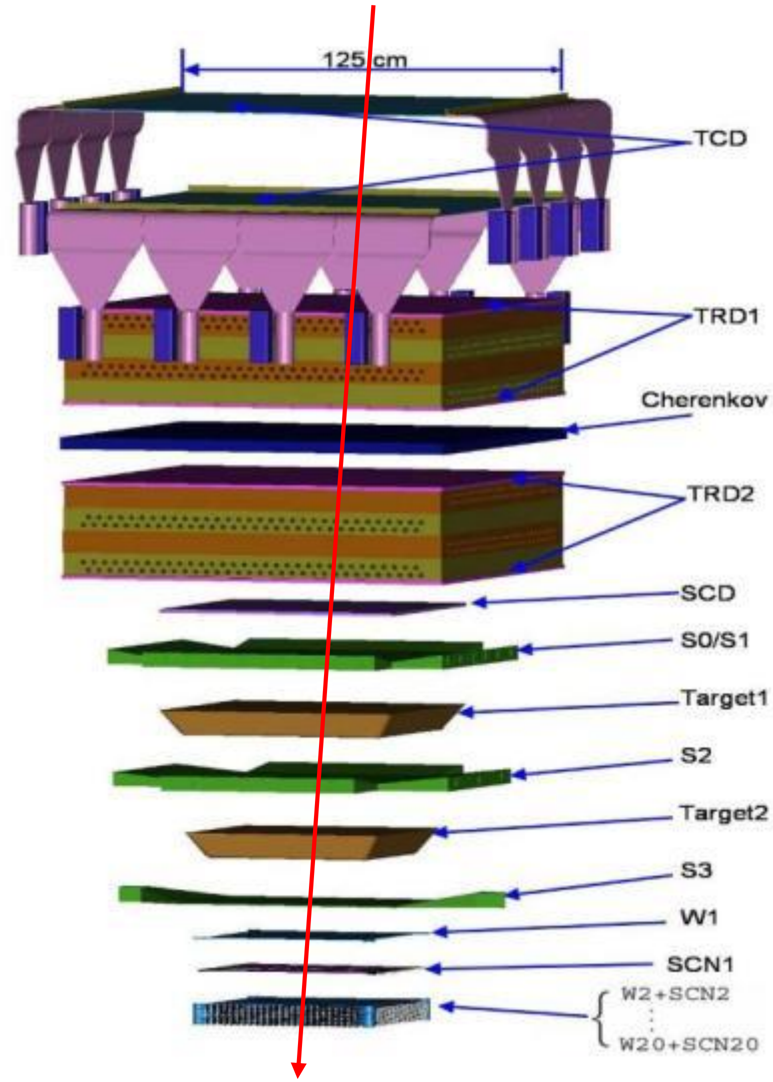
CREAM Collaboration

- 7 institutes, 4 countries

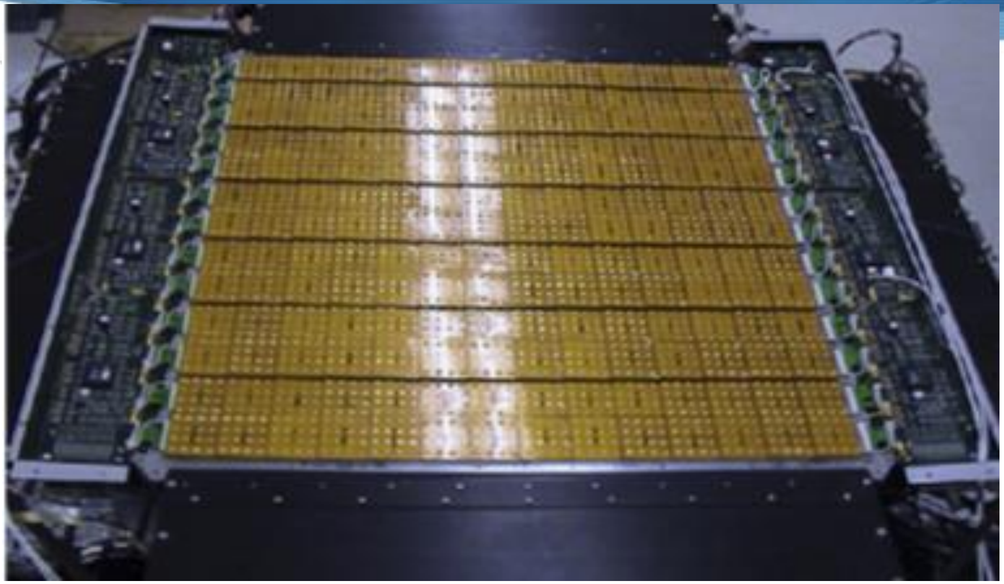
CREAM Instruments

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

Cosmic-ray particles (p,He…)



Silicon Charge Detector (SCD)

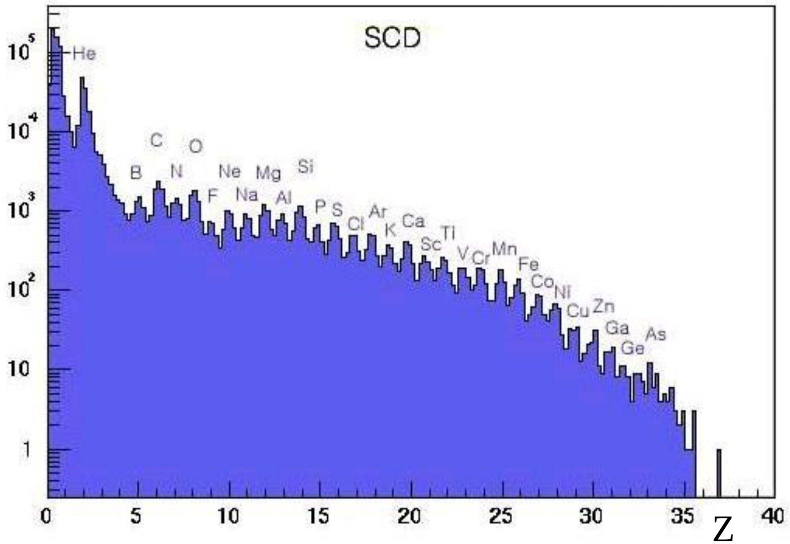


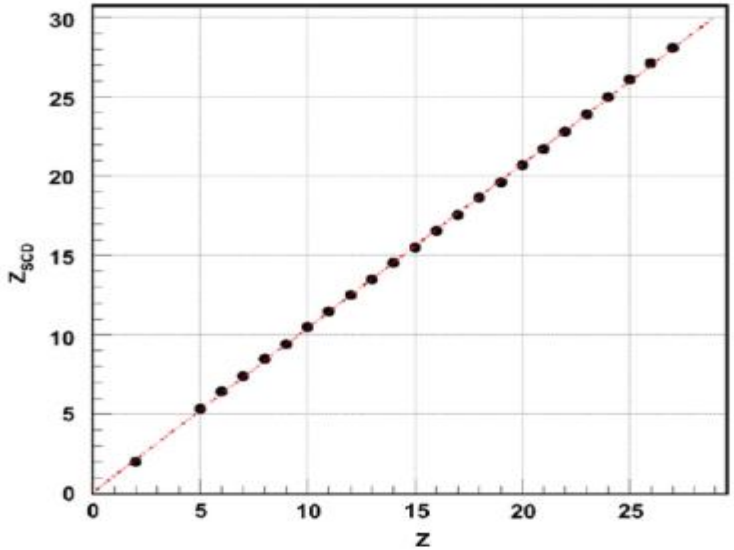
- Work in high backsplash from Calorimeter/Target
- Measure particle's charge up to Z ~ 28
- Charge resolution dZ = 0.2
- **182 of 16 pixel 380 ㎛ thick DC type silicon sensor** with AC coupling readout
- **182 of CR1.4 ASIC chips** (dynamic range 1:4000) with 16 bit ADC (2944 channels)
- **7 ladders, 26 pixel arrays/ladder, 2 motherboards**

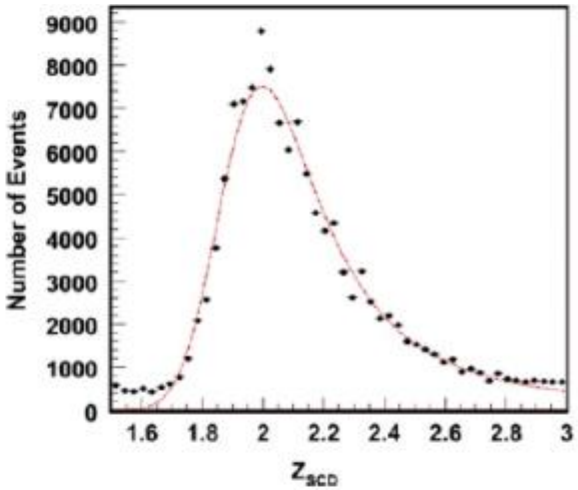
UNIVERSITY OF MARYLAND

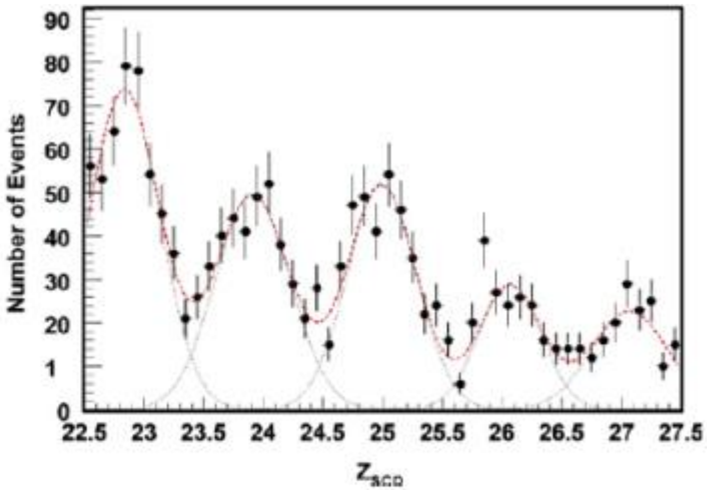
KAIST

Charge distribution at CERN BT, Nov 2003



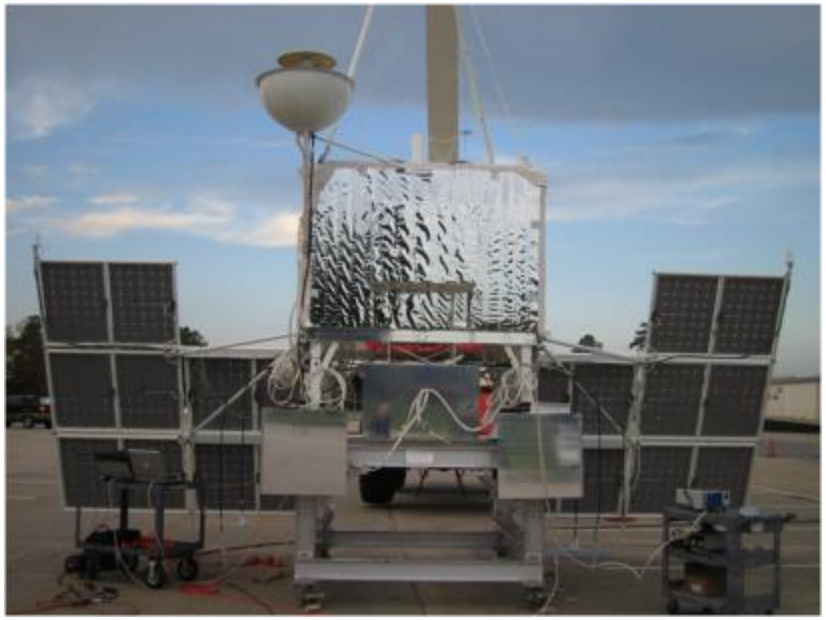






H.S. Ahn et al., NIMA 579, p1034–1053 (2007)

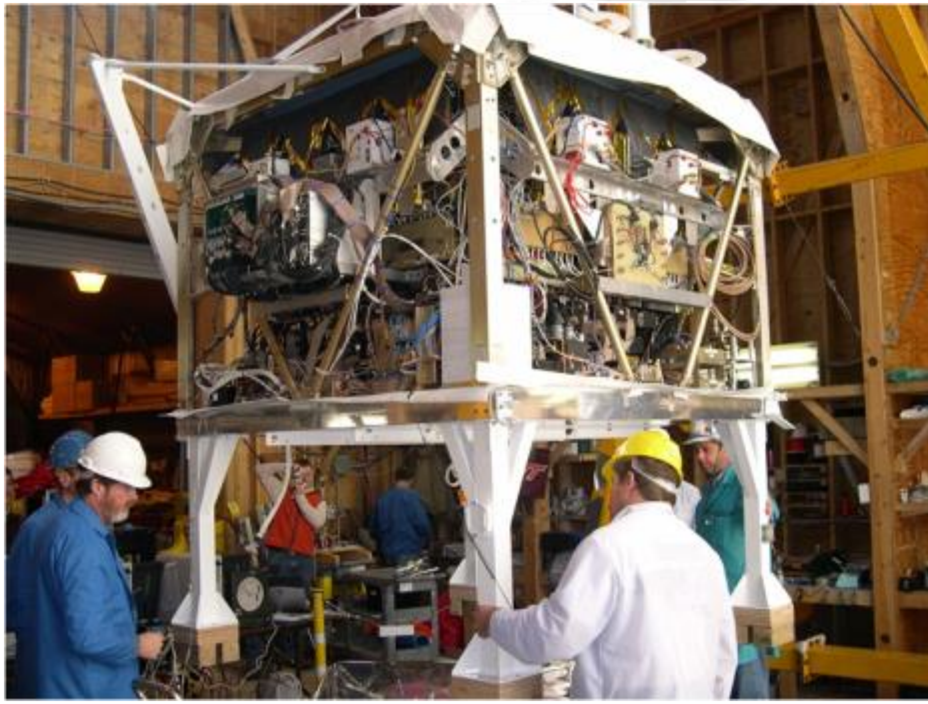
Integration & Hang Test at WFF (Oct. – Nov. 2004)

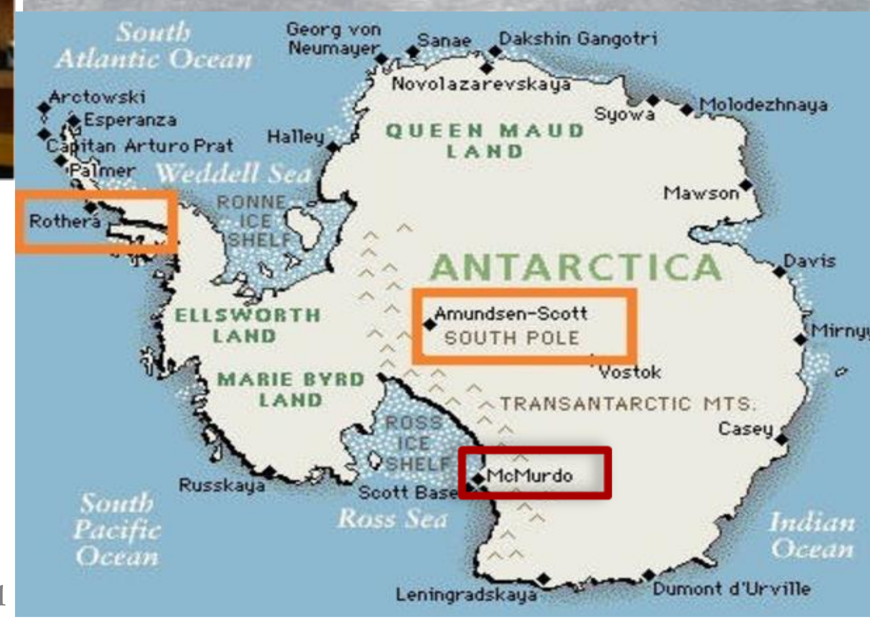


Hang test: Test in flight mode

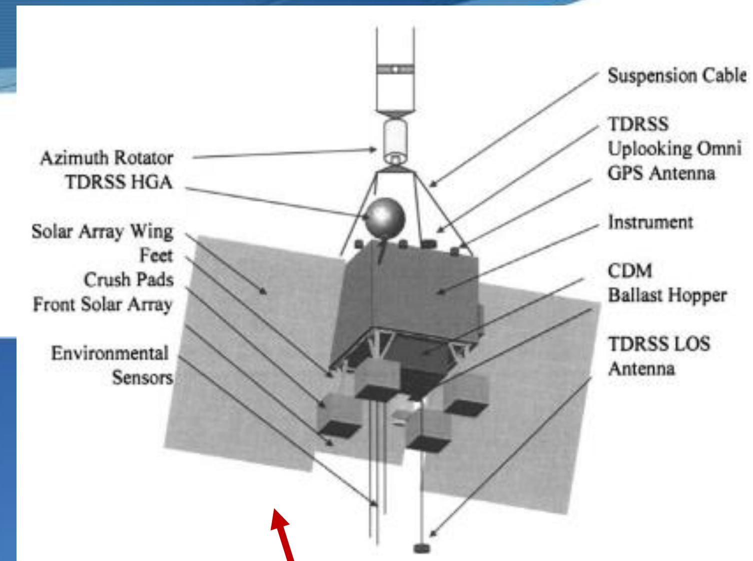
Ballooncraft(2813 kg) = Instrument package(1086 kg) + support system(967 kg)+ Flight control and flight train(423 kg)+ Ballast(337 kg)

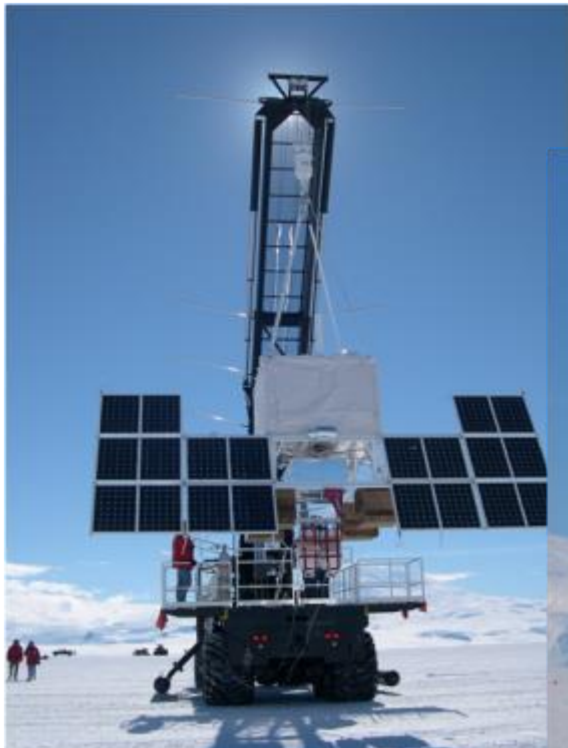
Integration of CREAM-I at the Antarctica





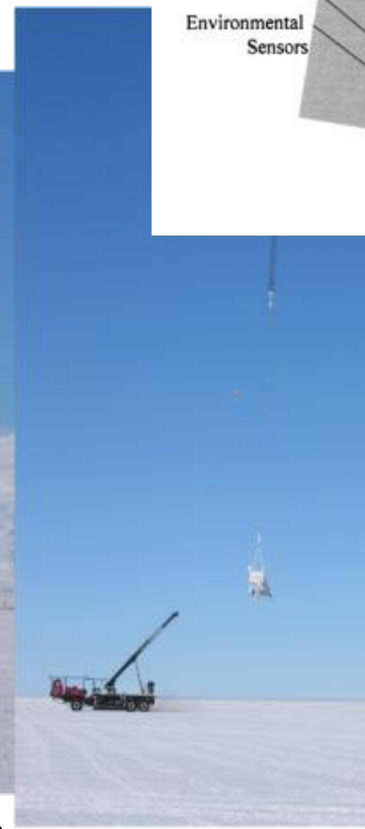
CREAM-I launch: December 15th 2004

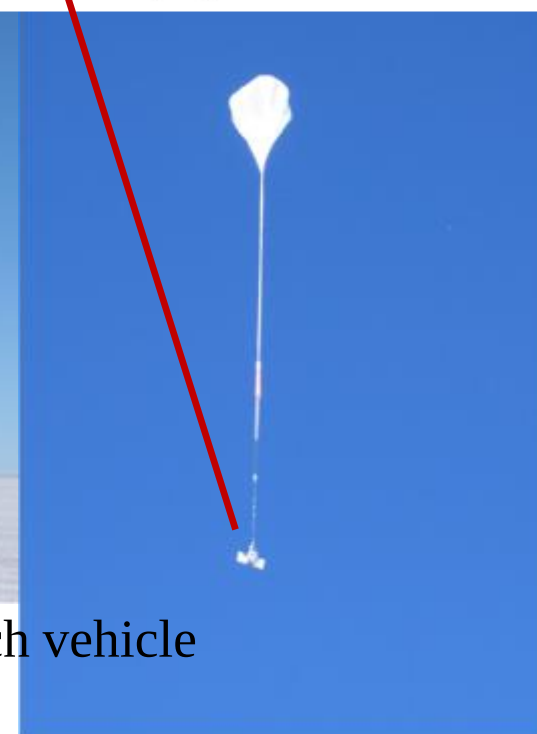




Williams Field

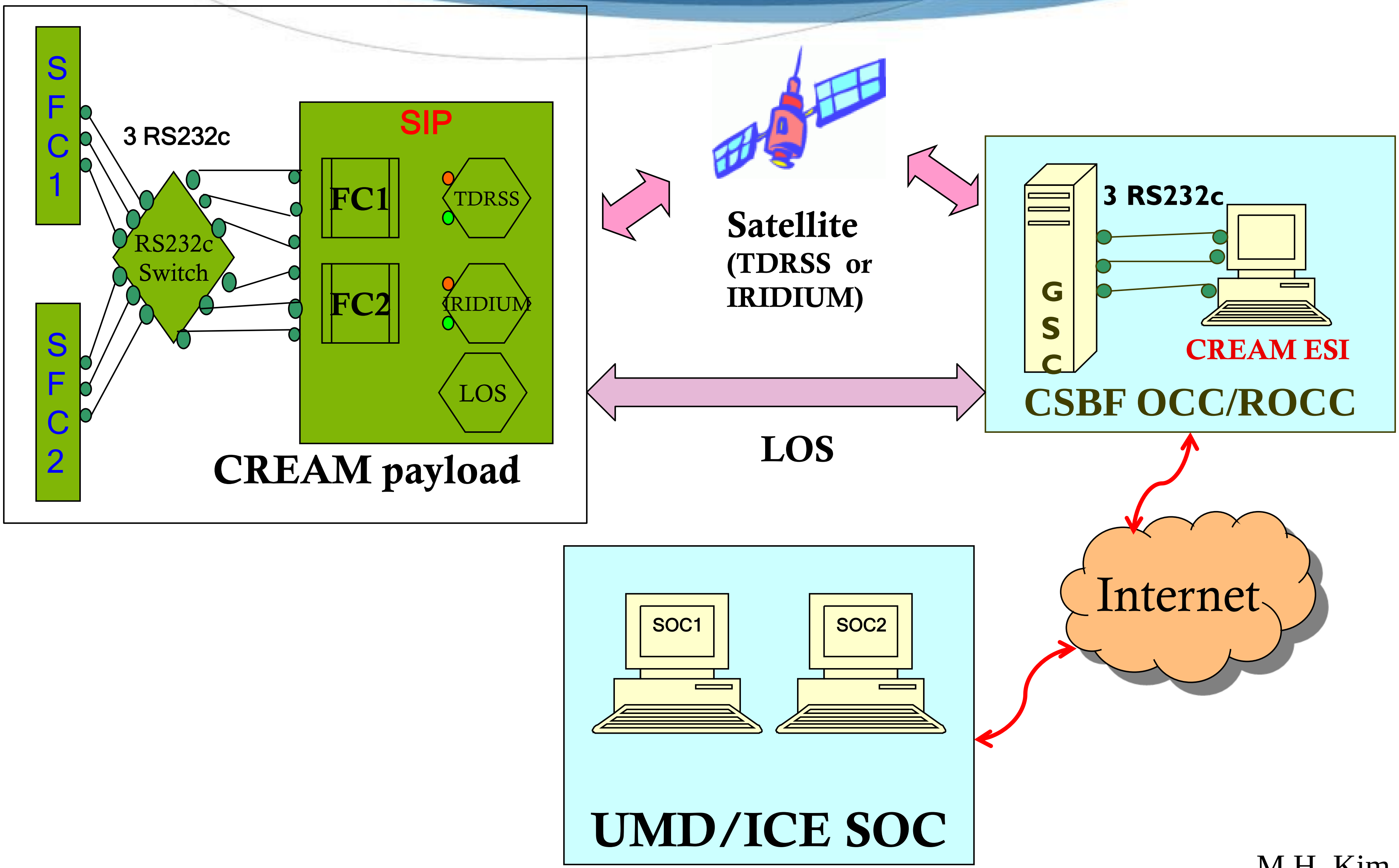
Balloon diameter: 180 m





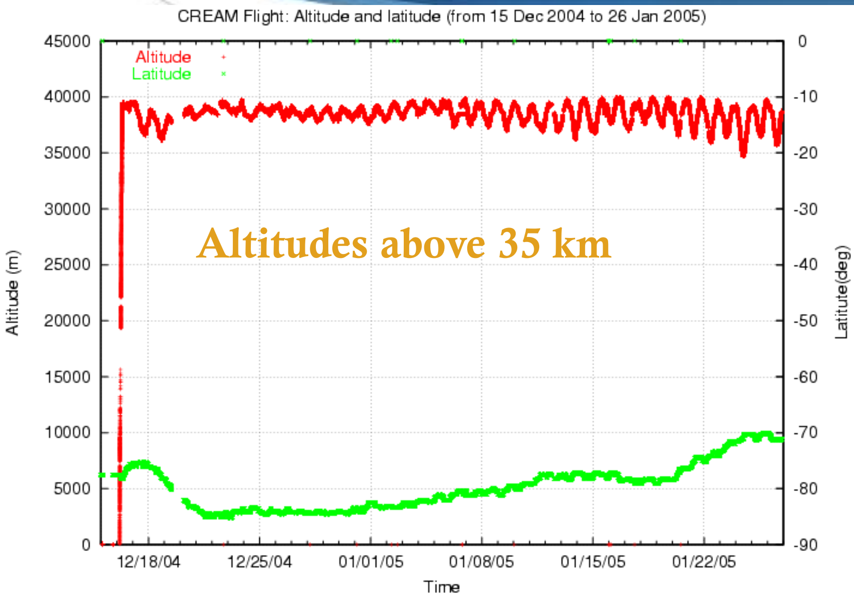
Balloon launch vehicle

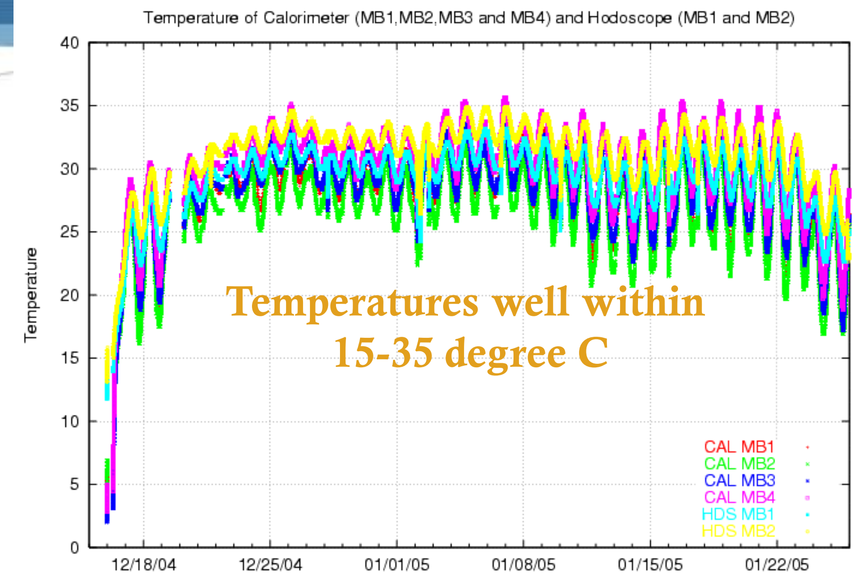
CREAM Operation Concept

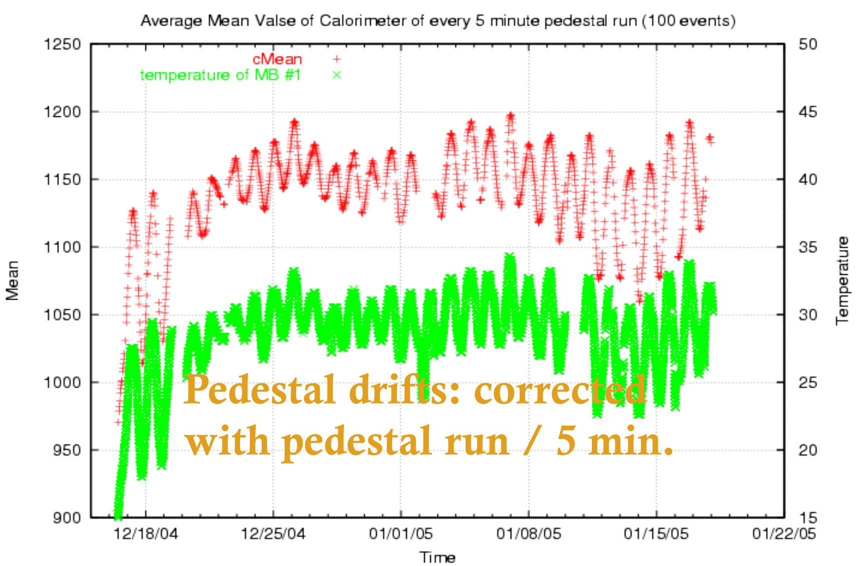


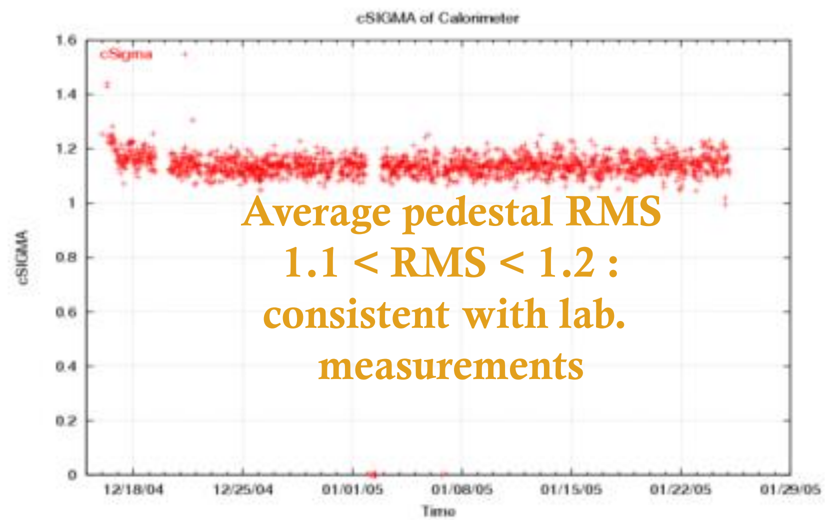
M.H. Kim

Parameters in CREAM-I flight data





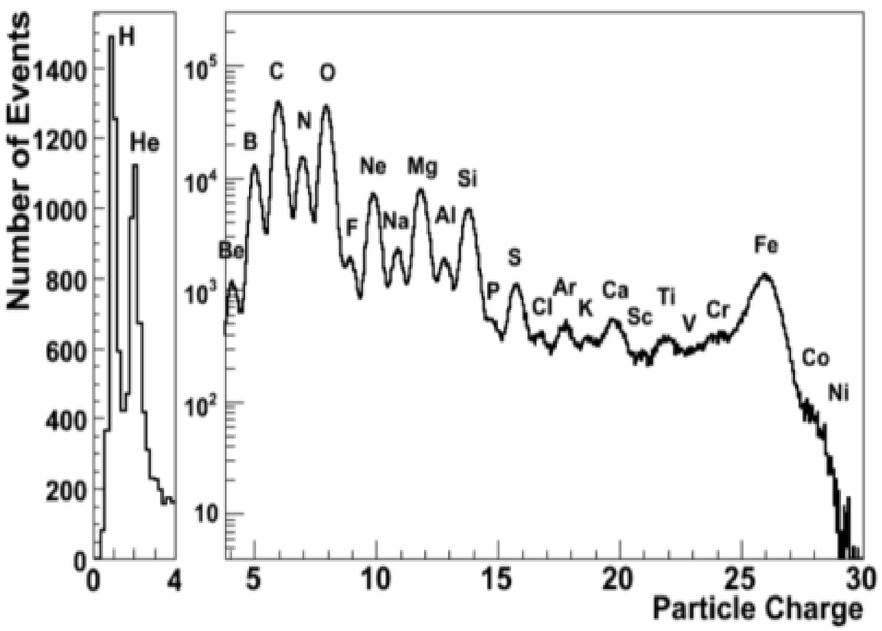




Moo Hyun Lee

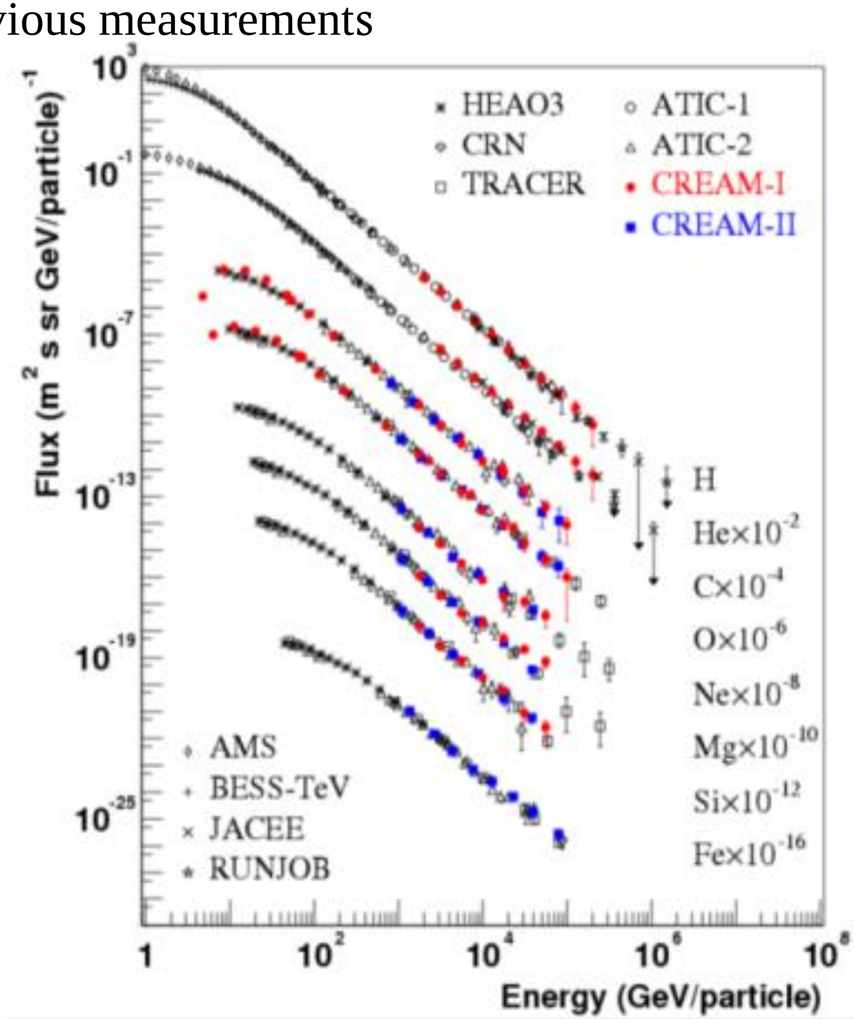
Cosmic Ray Elemental Spectra

- 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

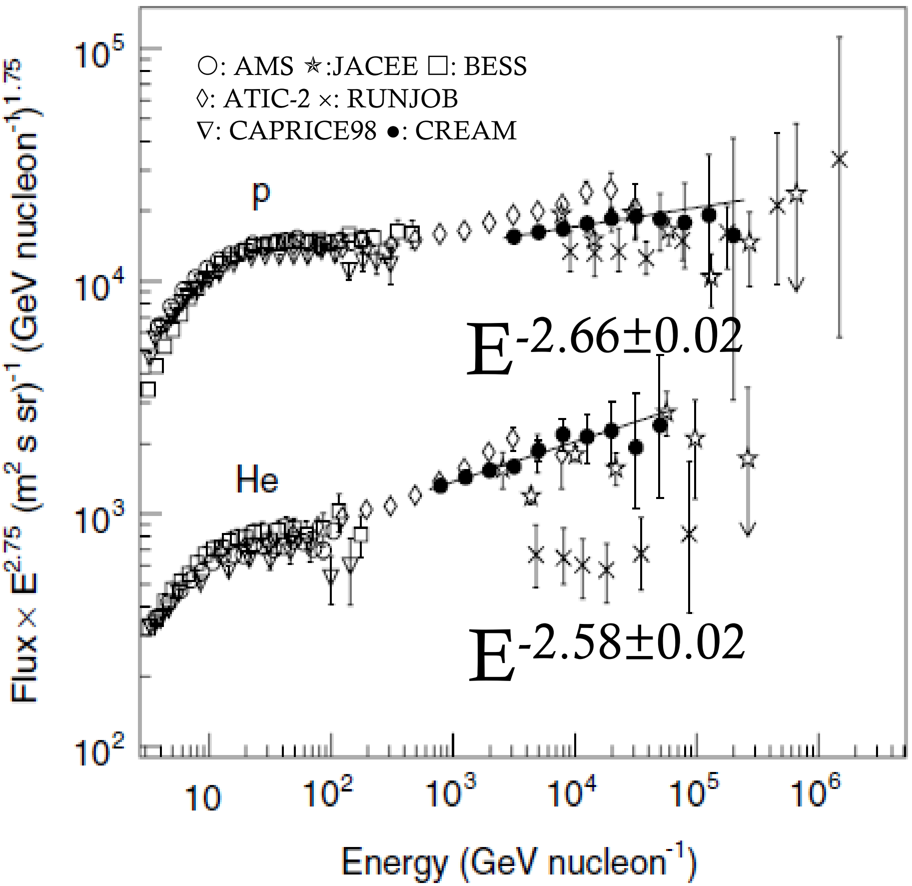
H.S. Ahn et al. (ApJL. **714**, L89-L93,2010)



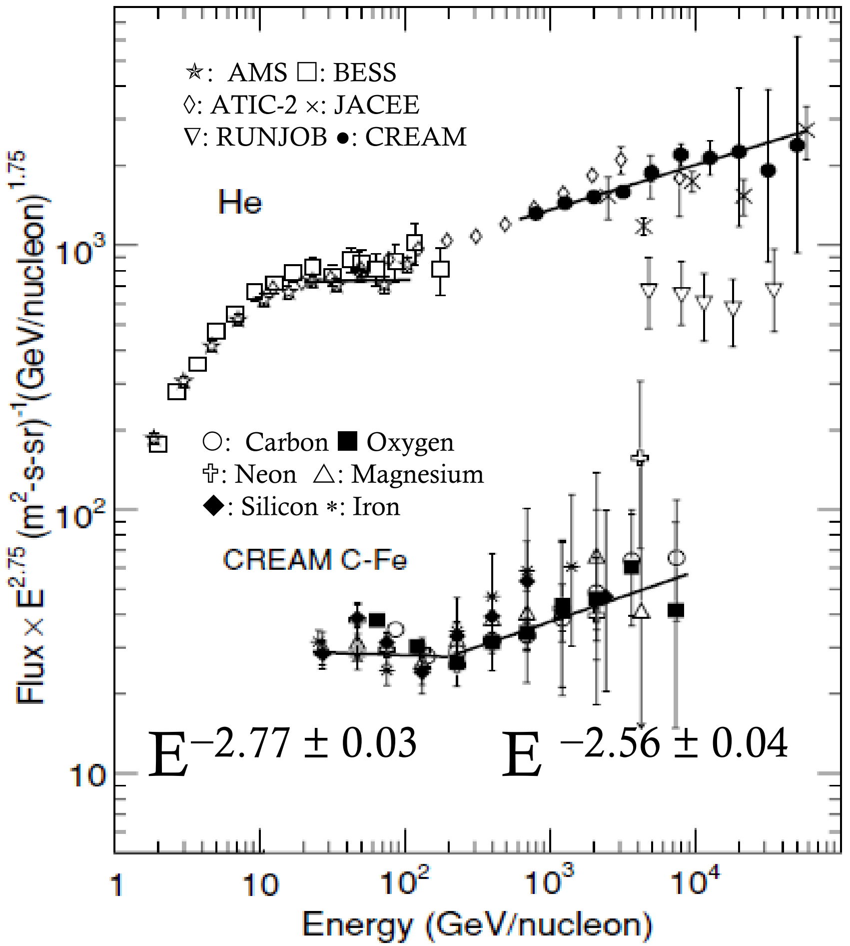
H.S. Ahn et al. (ApJ. **707**, 593-603, 2009)

Discrepant hardening of spectra

- Different spectra in **proton** and **Helium**
- Discrepant hardening of all the observed spectra above ~ 200 GeV/n

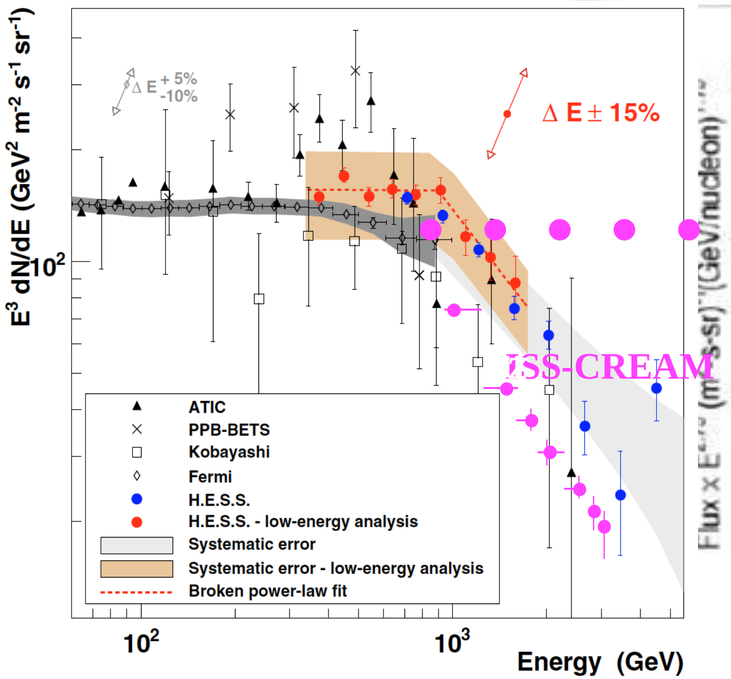


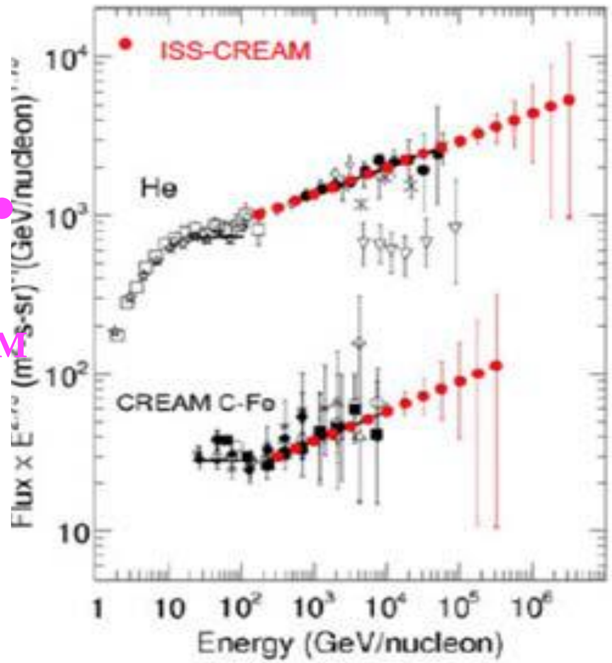
Y.S. Yoon et al. (ApJ. **728**, 122-129, 2011)

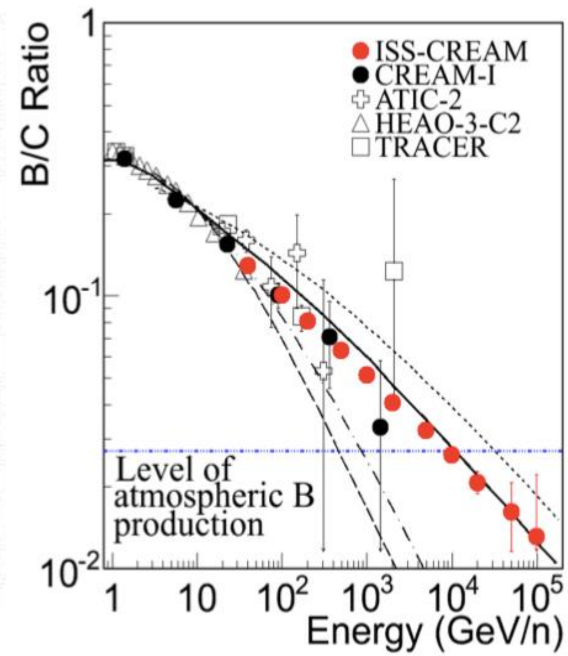


H.S. Ahn et al. (ApJL. **714**, L89-L93, 2010)

Motivation for ISS-CREAM

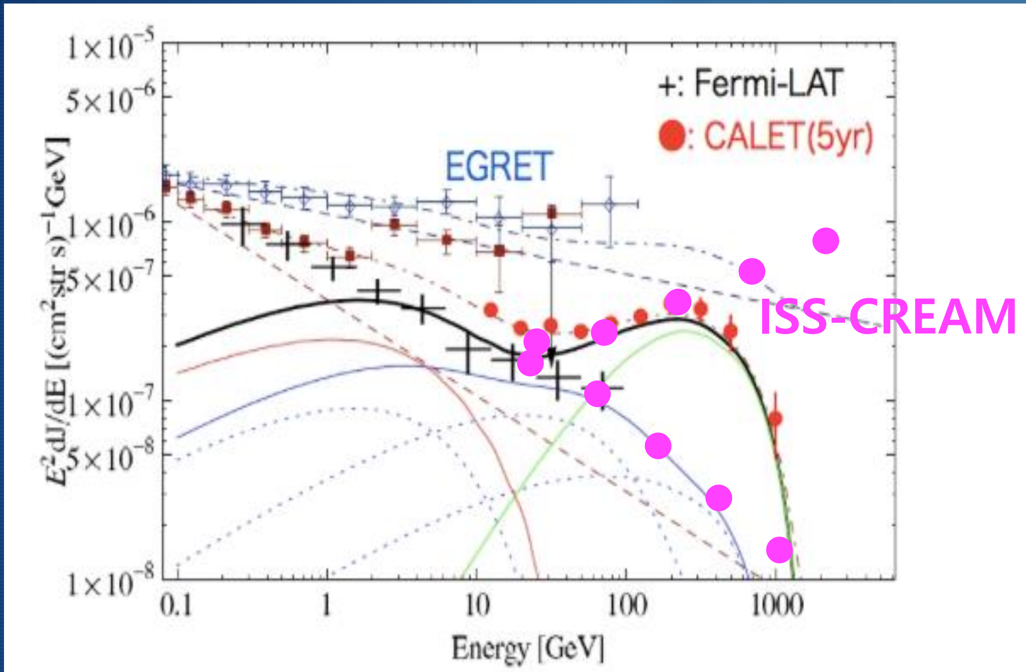


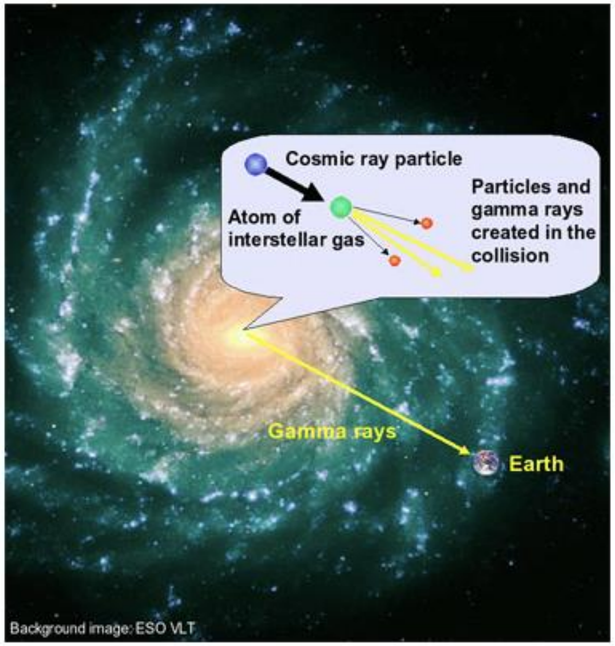




- 3-year goal, 1-year minimum exposure would greatly reduce the statistical uncertainties
- Extend to energies beyond any reach possible with balloon flights
- Provide keys to understanding the origin, acceleration and propagation of cosmic rays

Gamma Physics





- Gamma-ray Physics

- ISS-CREAM measures the diffuse gamma-ray background

-ISS-CREAM can provide a key to understanding the gamma spectra by measuring the energies above ~ 100 GeV

Shoji Torii, Astroparticle Physics 2014 Amsterdam & arXiv:astro-ph/03080460v1

From CREAM to ISS-CREAM

Y. Amare, D. Angelaszek,, M. Copley, C. Ebongue,, I. Faddis, B. Fields, M. Gupta, J.H. Han, I. J. Howley, H.G. Huh, D.Y. Kim, K.C. Kim, M.H. Kim, K. Kwashnak, M.H. Lee, J. Liang, L. Lutz, A. Malinin, J. Meade, O. Ofoha, N. Picot-Clemente, E.S. Seo, J. R. Smith, P. Walpole, R.P. Weinmann, J. Wu, Y.S. Yoon **University of Maryland**

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S. Nutter **Northern Kentucky University**

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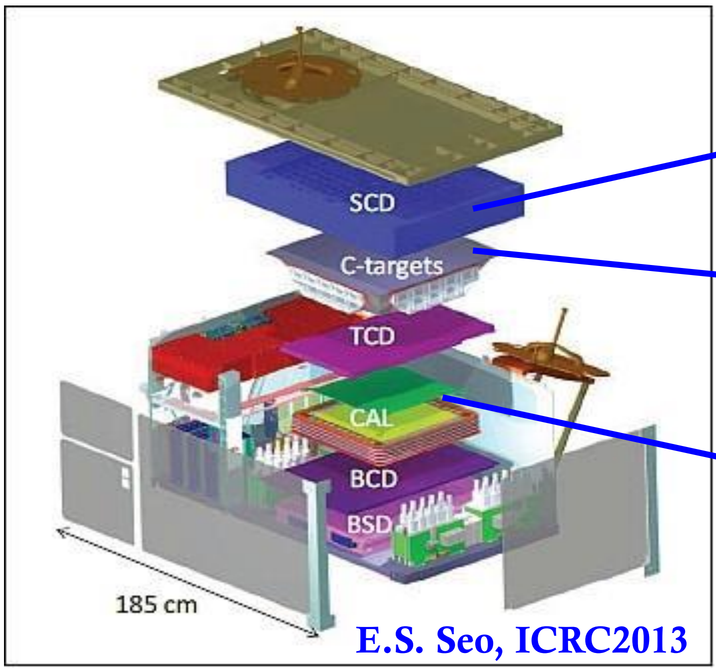
A. Menchaca-Rocha **Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico**

ISS-CREAM Instrument

- **CREAM instruments consists of complementary and redundant particle detectors**
  - ionization Calorimeter determines the energy of the cosmic ray, provide tracking and event trigger
  - Silicon Charge Detectors provide precise charge measurements
  - Boronated Scintillator Detector provides additional electron/hadron discrimination using thermal neutrons produced by particles that interact with the calorimeter
  - **Top/Bottom Counting Detectors** provide shower profiles for electron/hadron separation



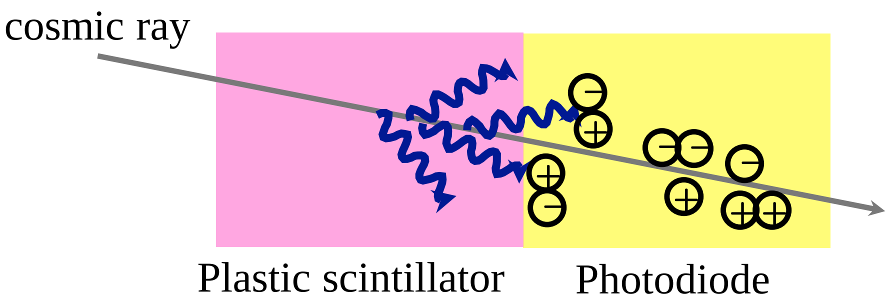
E.S. Seo, ICRC2013

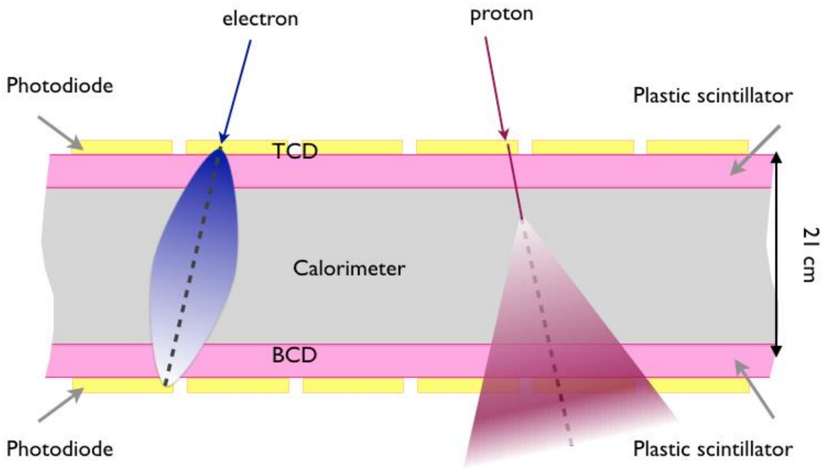
- 4 layers of SCD
  - 525 μm thick, 2.12 cm^2 pixels
  - 79 cm × 79 cm active detector area
- Carbon Target
  - 0.5 λ_{int}
  - induces hadronic interactions
- Calorimeters
  - 20 layers W + Scn Fibers

Top/Bottom Counting Detectors

- **Goals**
  - Electron/proton separation for electron and gamma-ray physics
  - Provide redundant trigger for the Calorimeter
  - Provide a low energy electron trigger

- By using a plastic scintillator coupled with photodiodes





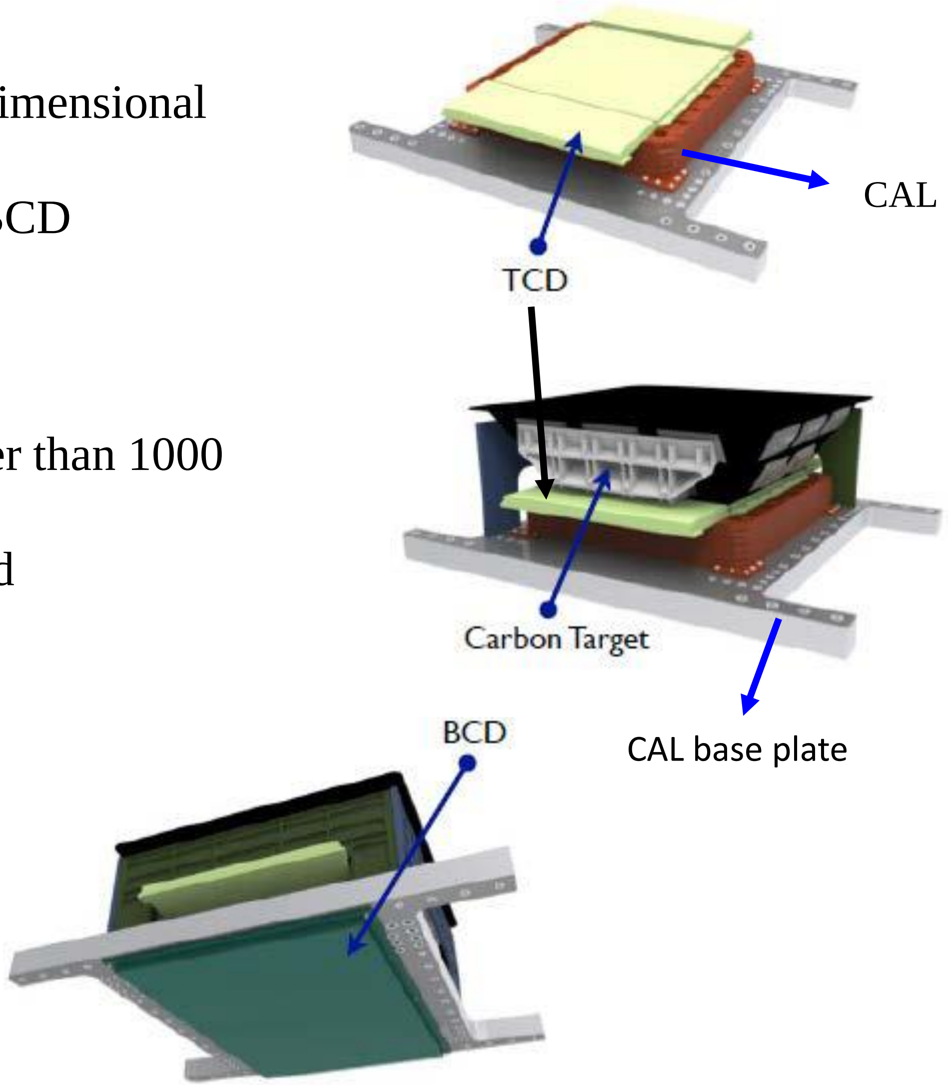
Electron-hole pairs are produced by scintillation light and penetrating cosmic rays

Top/Bottom Counting Detectors

- **Instrument**
  - plastic scintillators (PS) coupled with 2- dimensional photodiode arrays
  - 5 mm and 10 mm-thick PS for TCD and BCD
  - $2.5 \times 2.5\ cm^2$ PD (650 μm thick)

- **Performance Specification**
  - Electron/proton separation capability better than 1000
  - Redundant trigger capability
  - MIP identification with S/N > 5 for ground calibration of SCD and TCD/BCD

- **Resource Allocations**
  - operation power not exceed 20 Watts for each detector
  - mass for TCD and BCD not exceed 13 kg and 16 kg



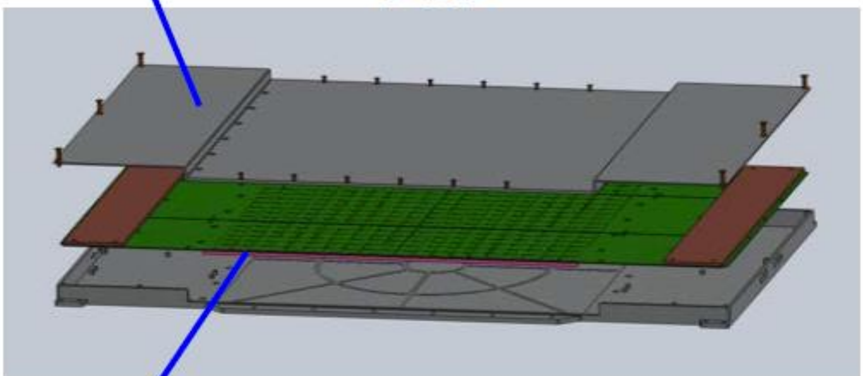
Critical Requirements for T/BCD

Items	Critical requirements	
	Real	Budget
Mass (TCD/BCD)	9.6 kg / 15.6 kg	13 kg / 16 kg
Power	22 W	40 W
Temperature range	-40 °C ~ 55 °C @10^{-5} Torr	
Vibration	Sine burst (max 25 G), Swept sine vibration (-3 dB, 0 dB), Random (-12 ~ +3 dB), Low-level sine survey (20 ~ 2000 Hz)	
Material	pass outgassing and residual magnetism tests	

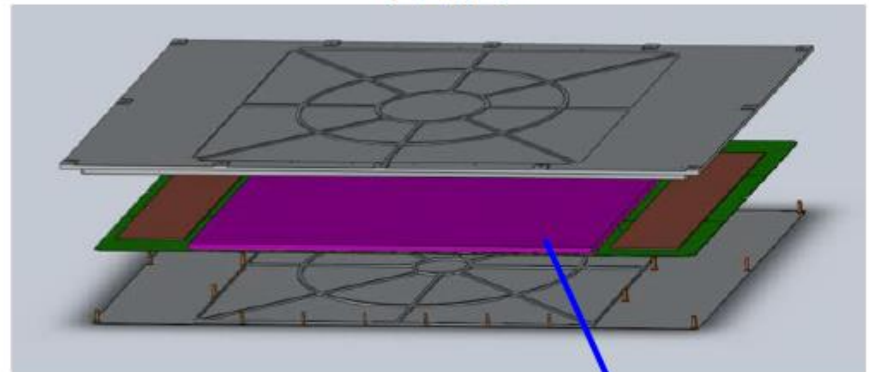
Design of TCD/BCD

Al Alloy 6061 enclosure

TCD



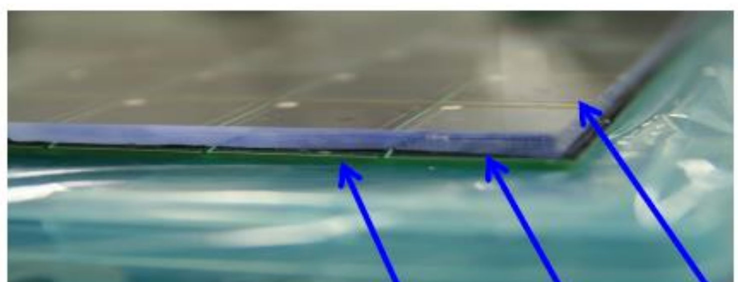
BCD

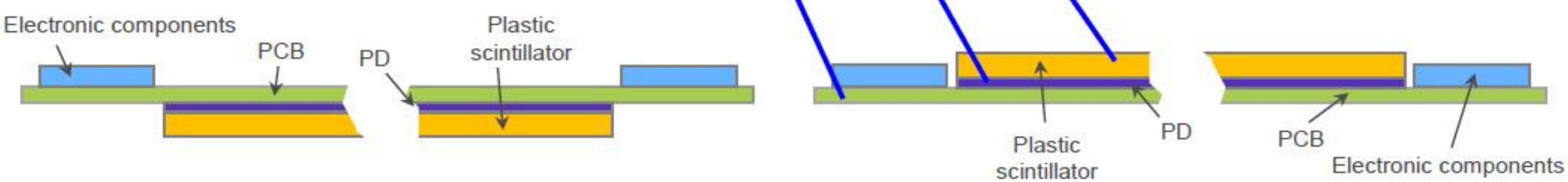


Conductive epoxy btw PCB and PD & optical cement btw PD and plastic scintillator

20 × 20 PDs
covers 50 × 50 cm^2

20 × 20 PDs
covers 60 × 60 cm^2

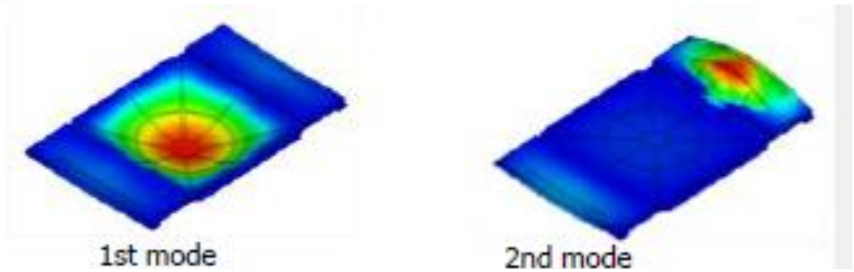




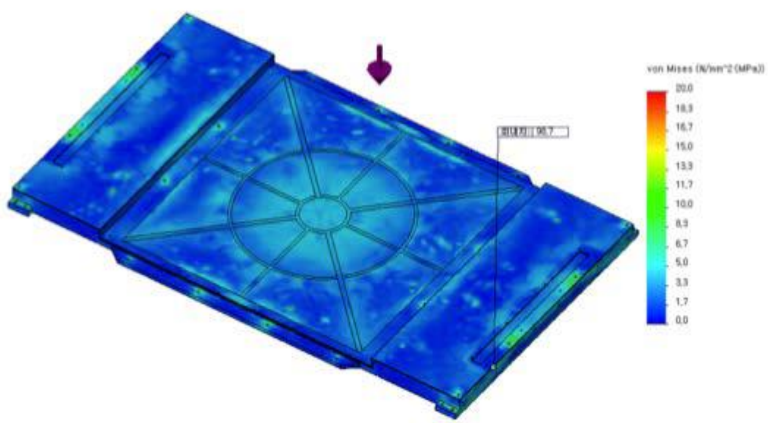
Mechanical Analysis

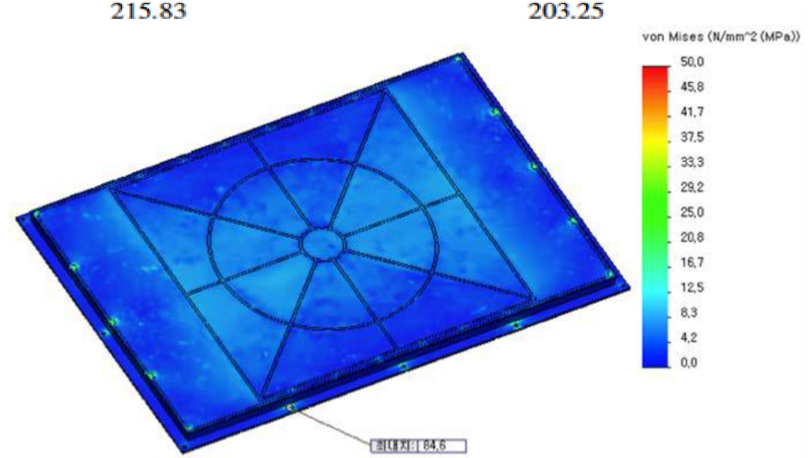
- **Requirements**
  - Stiffness : Fundamental frequency of TCD/BCD should be more than 100 Hz
  - Positive Margin of Safety (MS) : Calculated MS values using the stress values from Quasi-Static Analysis and Random vibration should be positive

- **Using SolidWorks**
  - Modal : > 100 Hz
  - Strength : MS > 1.80
  - Fastener Interaction : MS > 8.61
  - Fail Safe Fastener : MS > 1.5

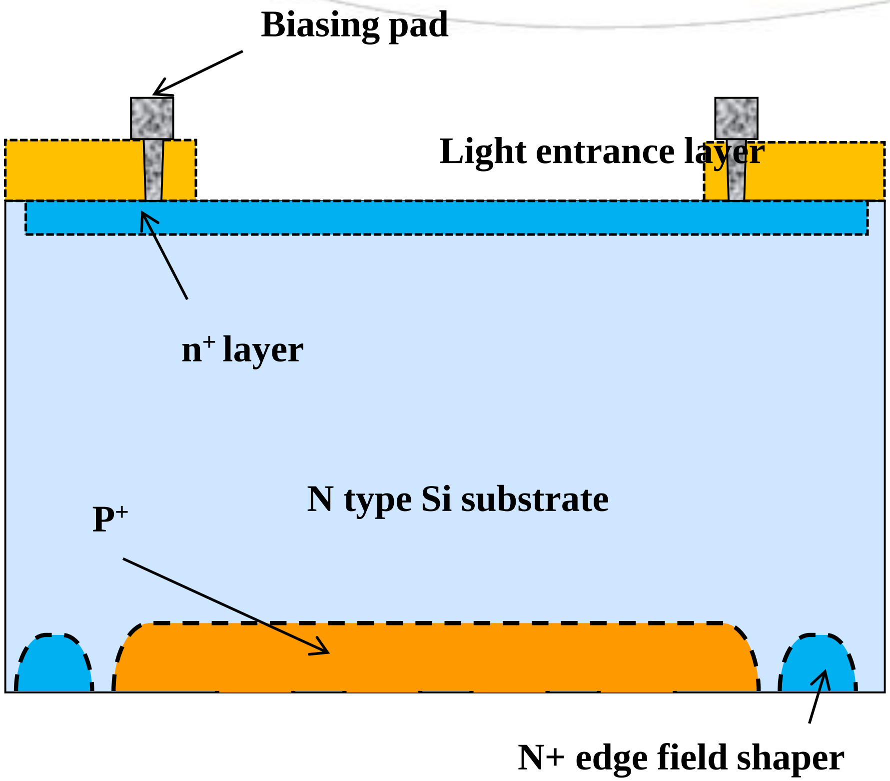


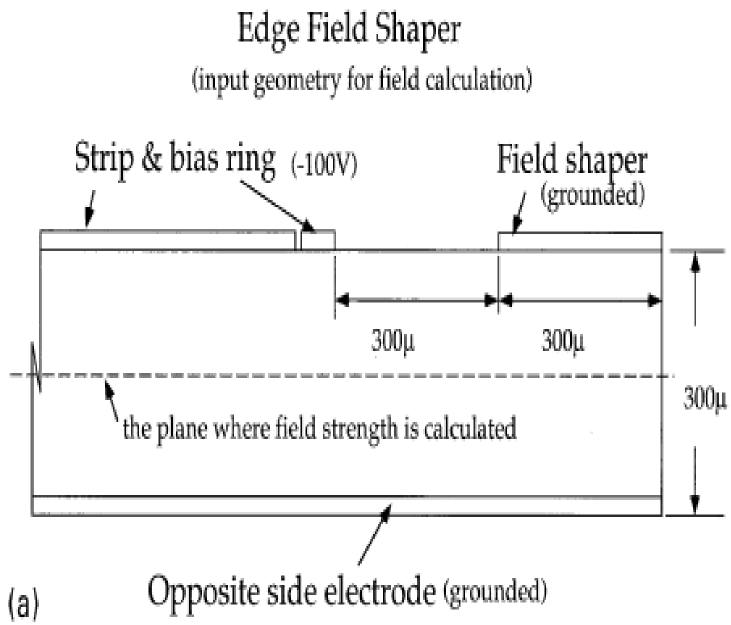
Num.	TCD Fundamental Frequency (Hz)	BCD Fundamental Frequency (Hz)
1st.	201.43	161.94
2nd.	215.83	203.25





Photodiode Sensor

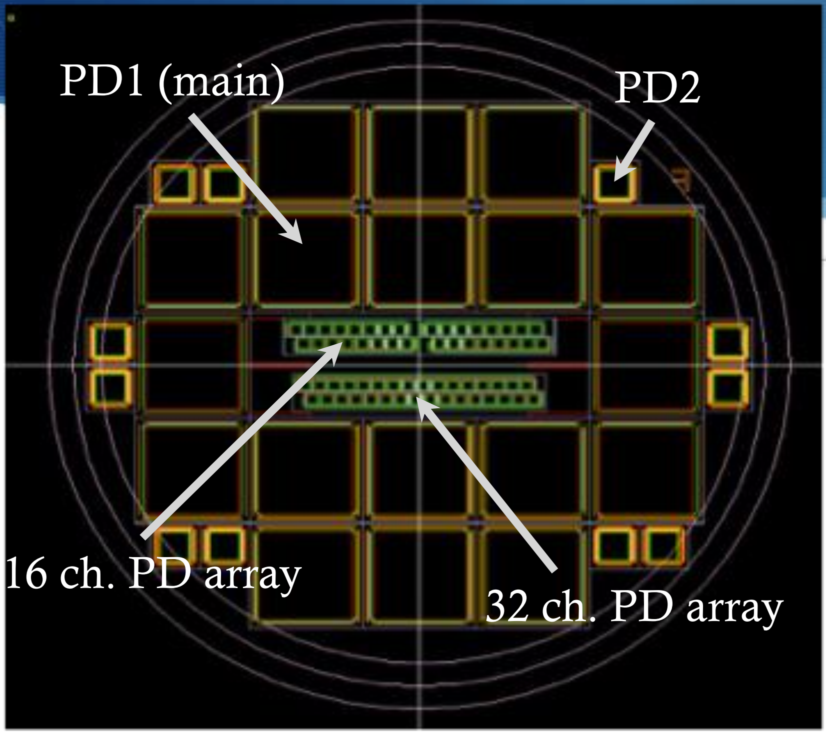


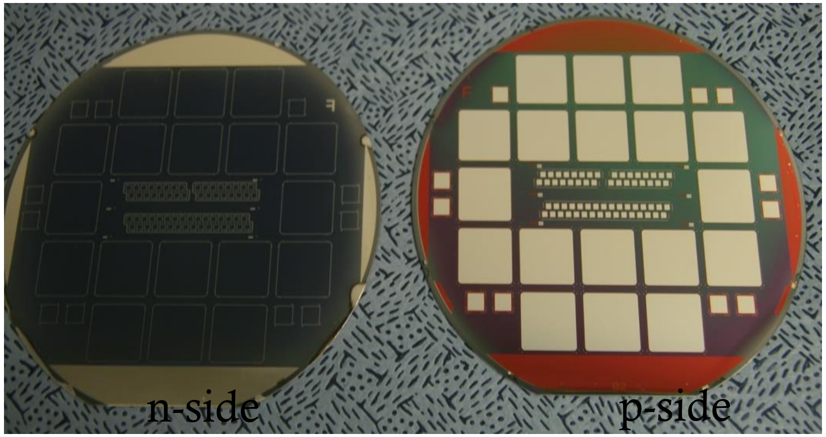


T. Ohsugi, et al., NIMA 436 (1999) 272-280

- A total of 6 photo-masks
  - light-entrance layer was optimized for ARC
  - field shaper was introduced

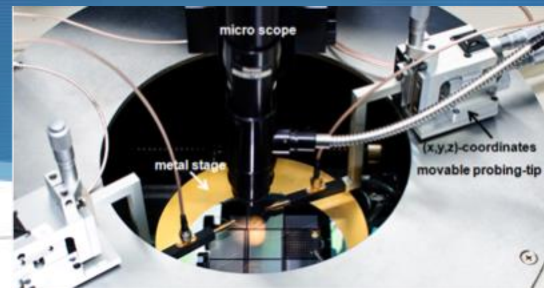
Photo-PIN Diode : Design and Fabrication

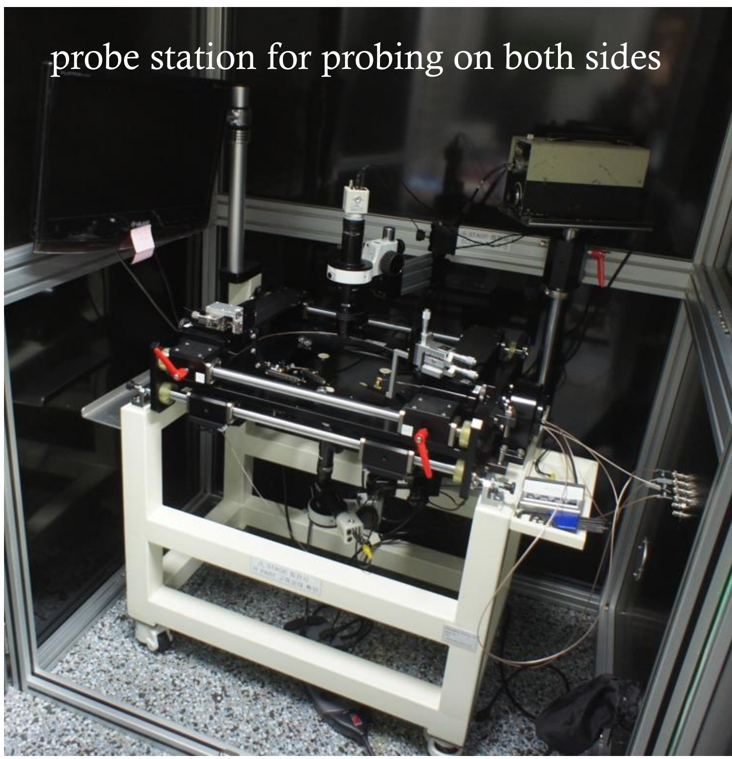


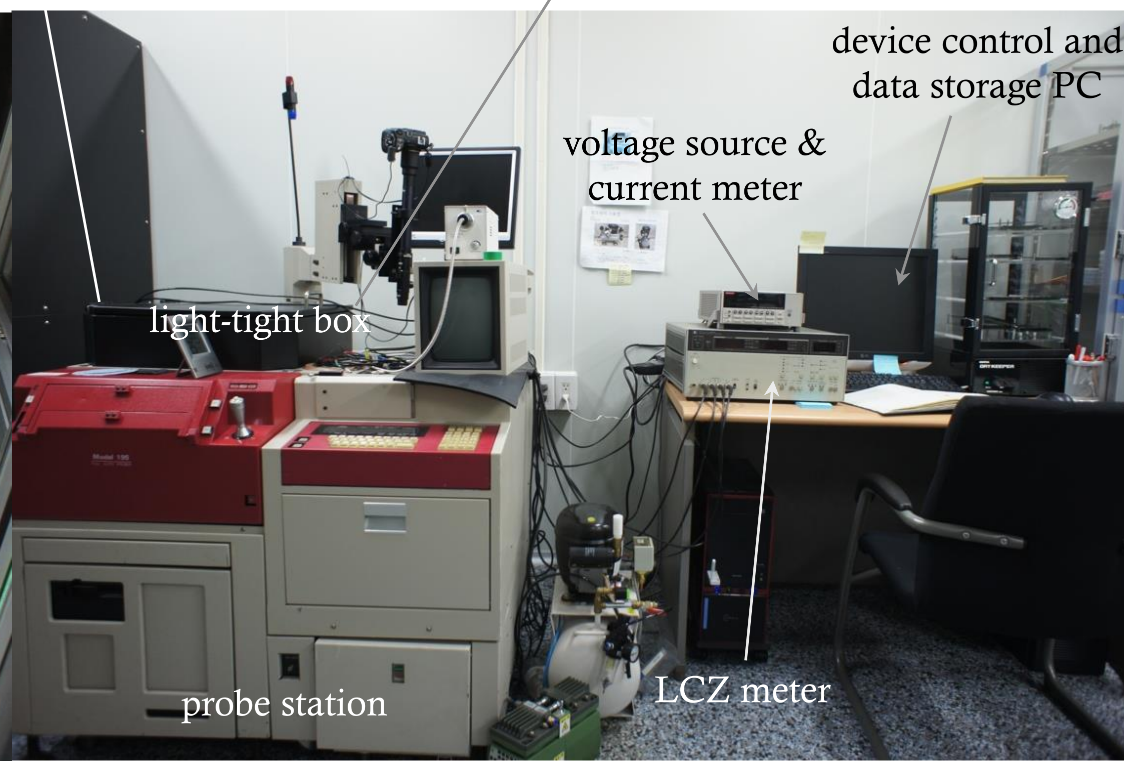


- Wafer
  - 6 inch, 650 μm thick, high resistivity (>5 kΩcm)
  - Double-sided polished
  - Photo-diode
    - real size : 2.3 × 2.3 cm^2
    - active area : 2.0 × 2.0 cm^2
    - PD1 (main) : 18 EA / wafer
- The PDs are fabricated at ETRI in Daejeon, Korea
- Test patterns
  - PD2 (1.0 × 1.0 cm^2) : 11 EA / wafer
  - 16 ch. PD array : 2 EA / wafer
  - 32 ch. PD array : 1 EA / wafer

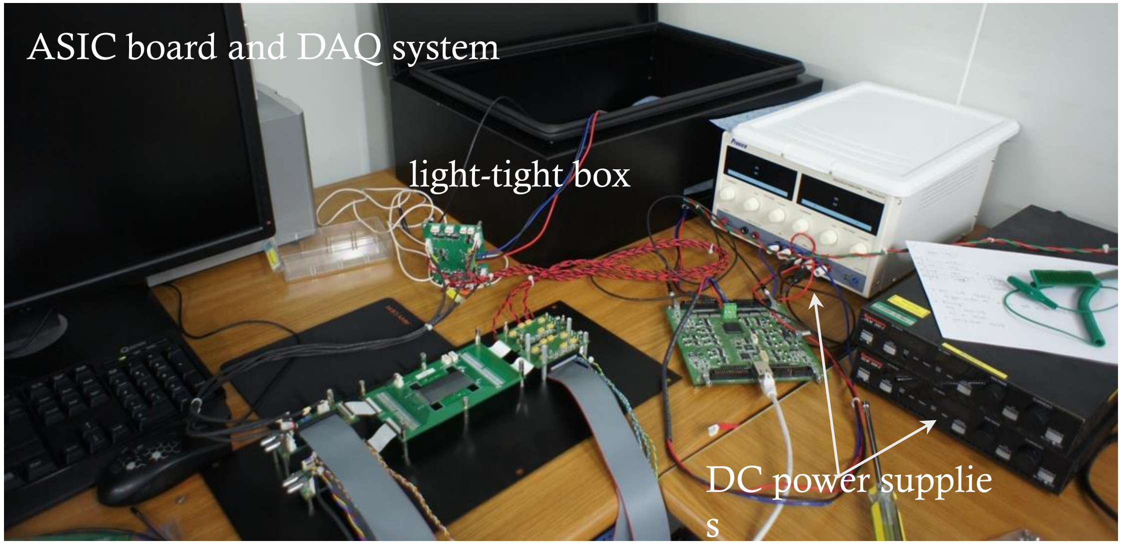
Measurement Equipments



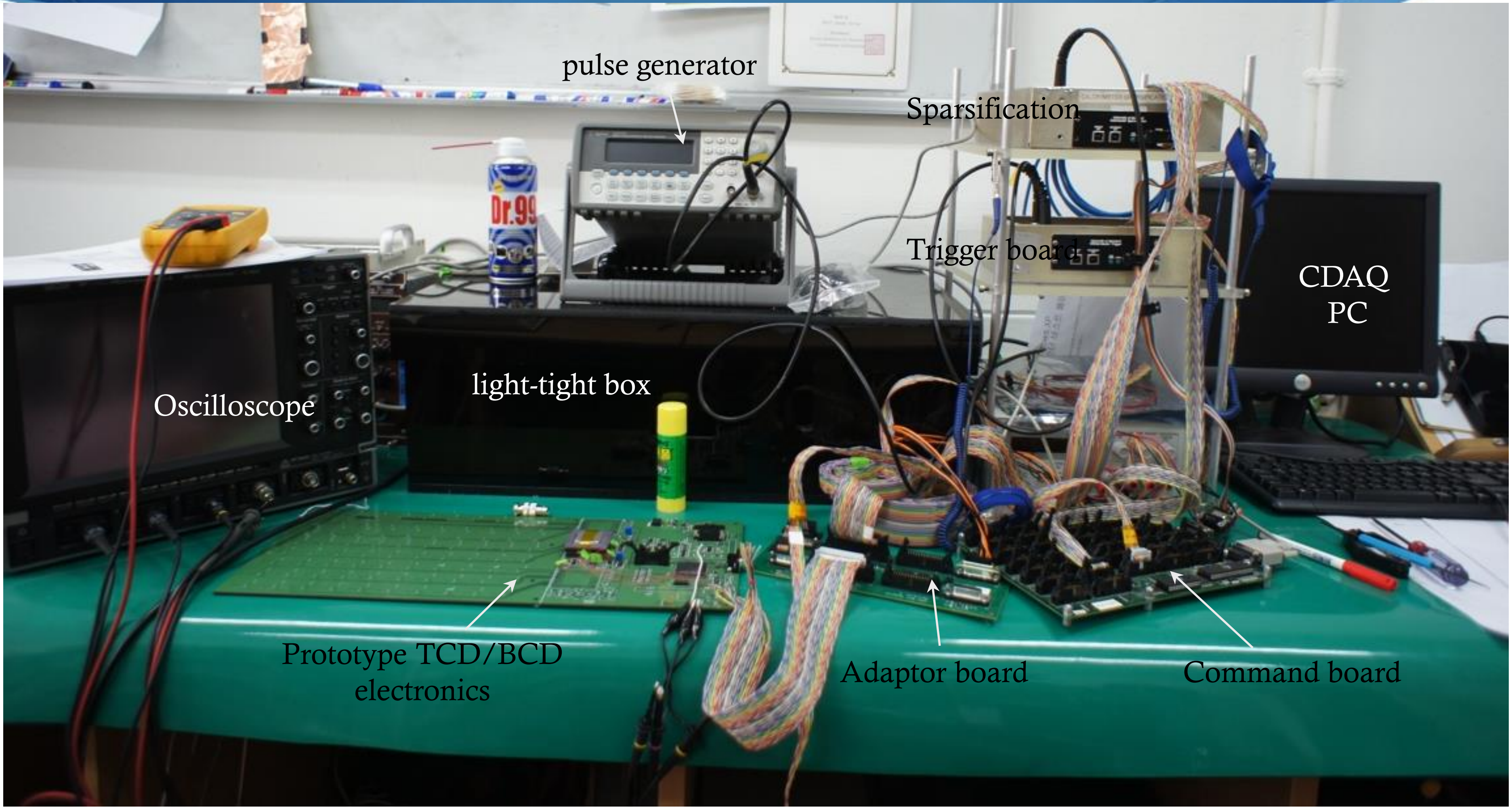




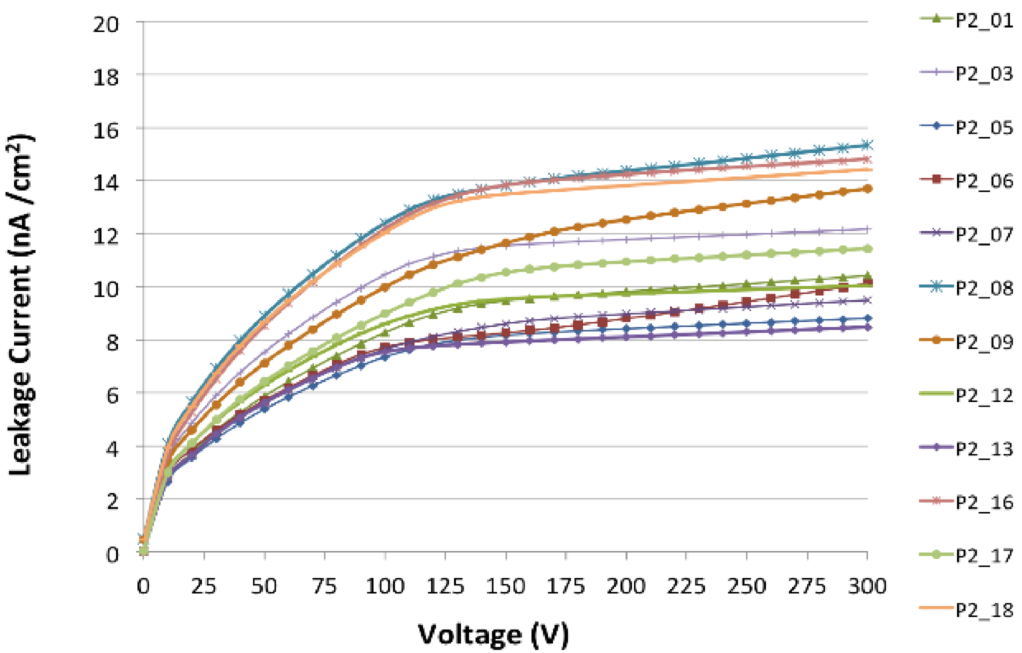
Facilities-I

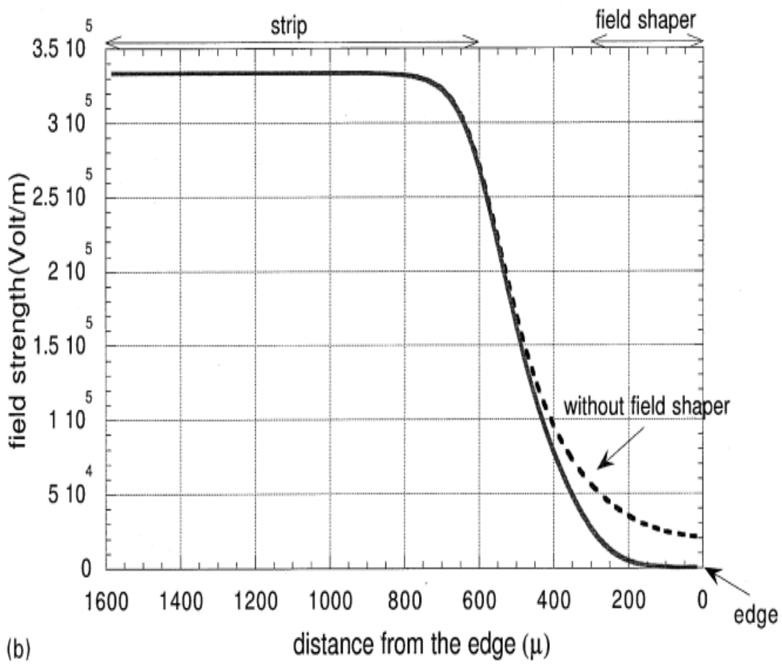


Facilities-II



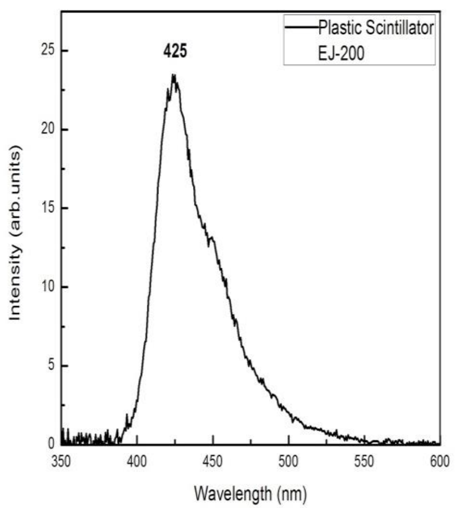
PD Characteristics



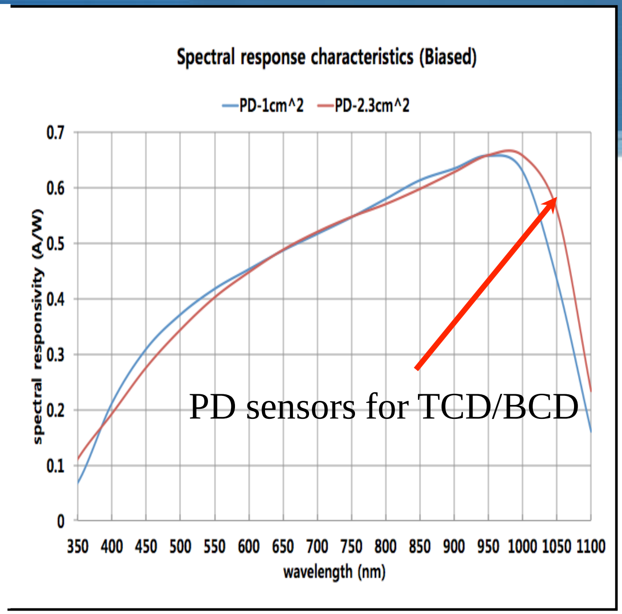


- PD sensors are fully depleted at 200 V and bulk capacitance is 110 pF at operation voltage 250 V
- Leakage current is below 20 nA/cm^2
- Stability test is performed during 5 hours and the leakage current at constant HV has been stable

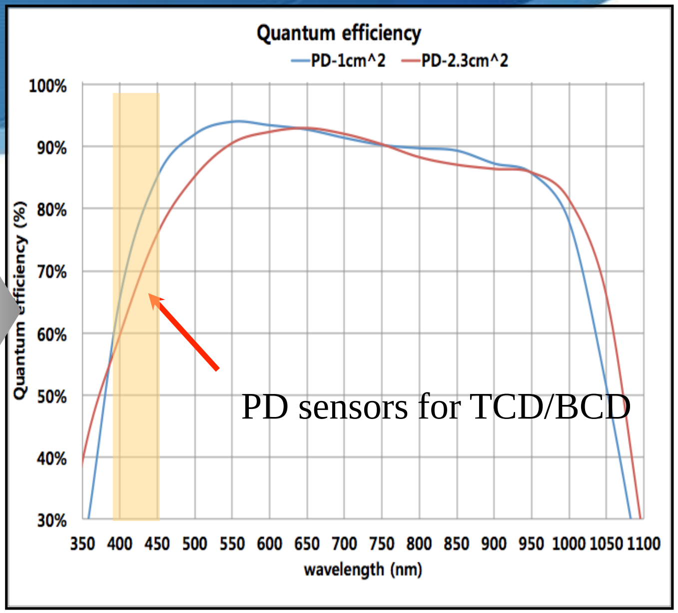
Photodiode : Photo-response



Spectral response characteristics



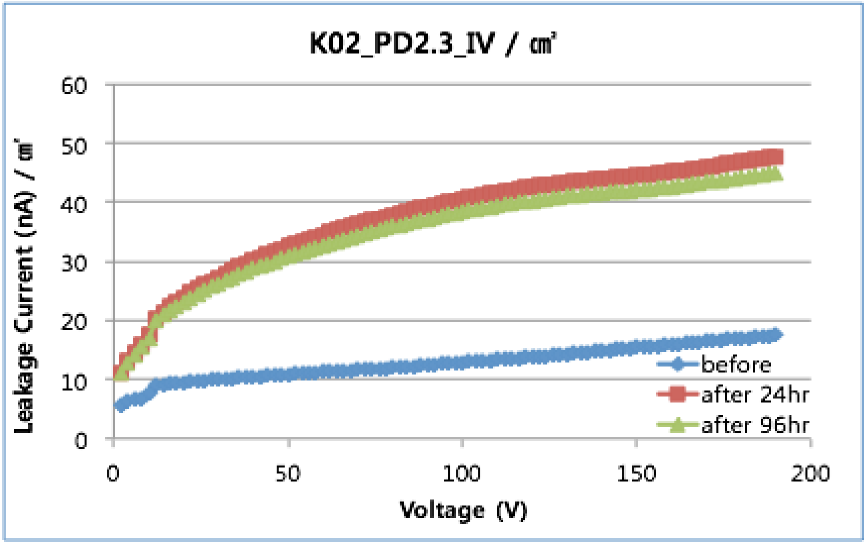
Quantum efficiency

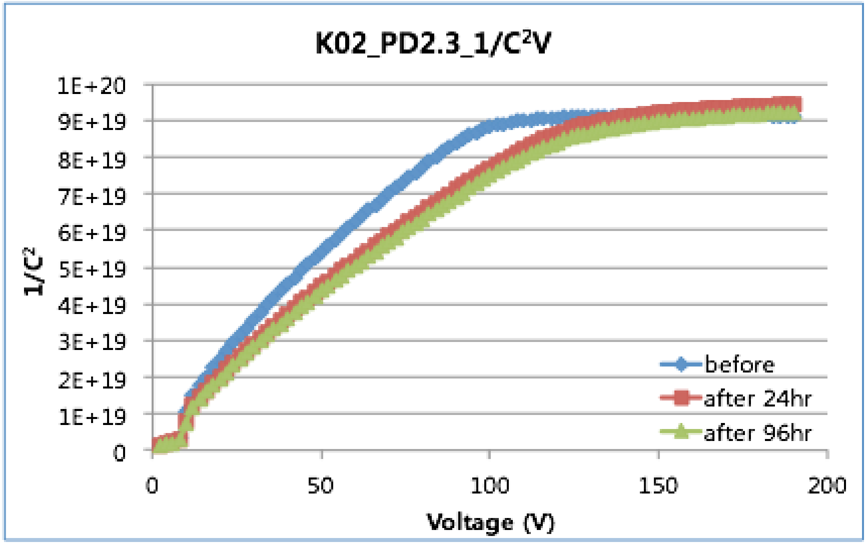


- The photo response for the wavelength range from 350 to 1100 nm of the fabricated PD sensors is measured at KRISS(Korea Research Institute of Standards and Science) in Daejeon, Korea
- The quantum efficiency is measured to be 60 ~ 75% for the wavelength range from 400 to 450 nm, which is the wavelength range of plastic scintillator (marked by orange region)

Photo-diode : Radiation Hardness

- The radiation hardness is tested by using a 45 MeV proton beam at KIRAMS (Korea Institute of Radiological and Medical Sciences) in Seoul, Korea
- The PD sensor is located at the front of the proton beam exit and is exposed to 1.18×10^{11} protons/cm^2 (> 5000 rad)
- The leakage current is increased up to about 50 nA/cm^2 but the quality of the PD sensor does not changed in our criteria for the good sensor (< 100 nA/cm^2)



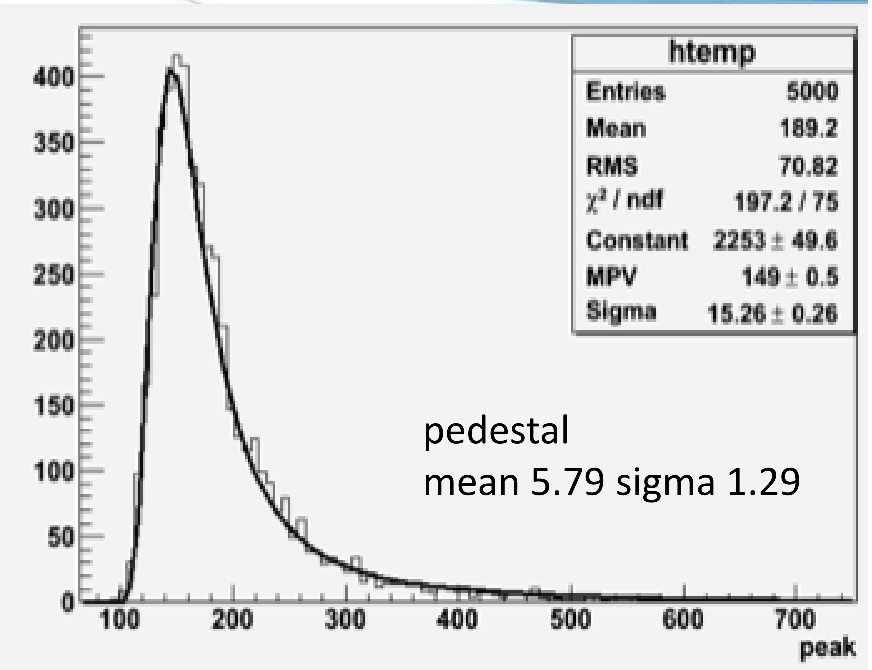


1 MeV neutron/cm^2 Φ_{eq} = (Beam current × Beam time) / (Charge × Sensor Area) × hardness factor(κ)

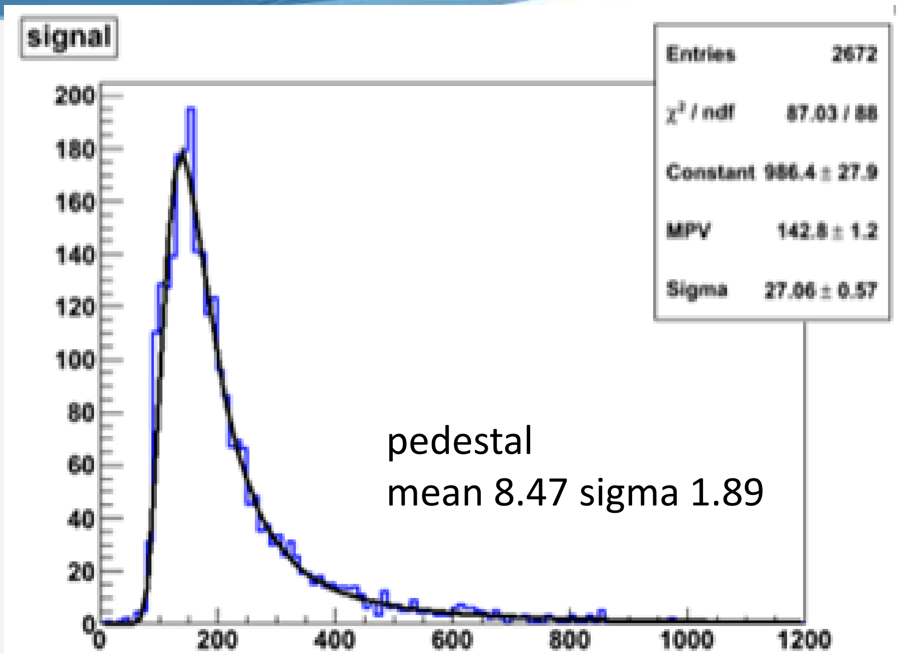
$\Delta I/V = \alpha\Phi eq \rightarrow \alpha = 0.0337\times(10^{-17}$ A/cm)

PD Signal-to-Noise Ratio

^{90}Sr radioactive source

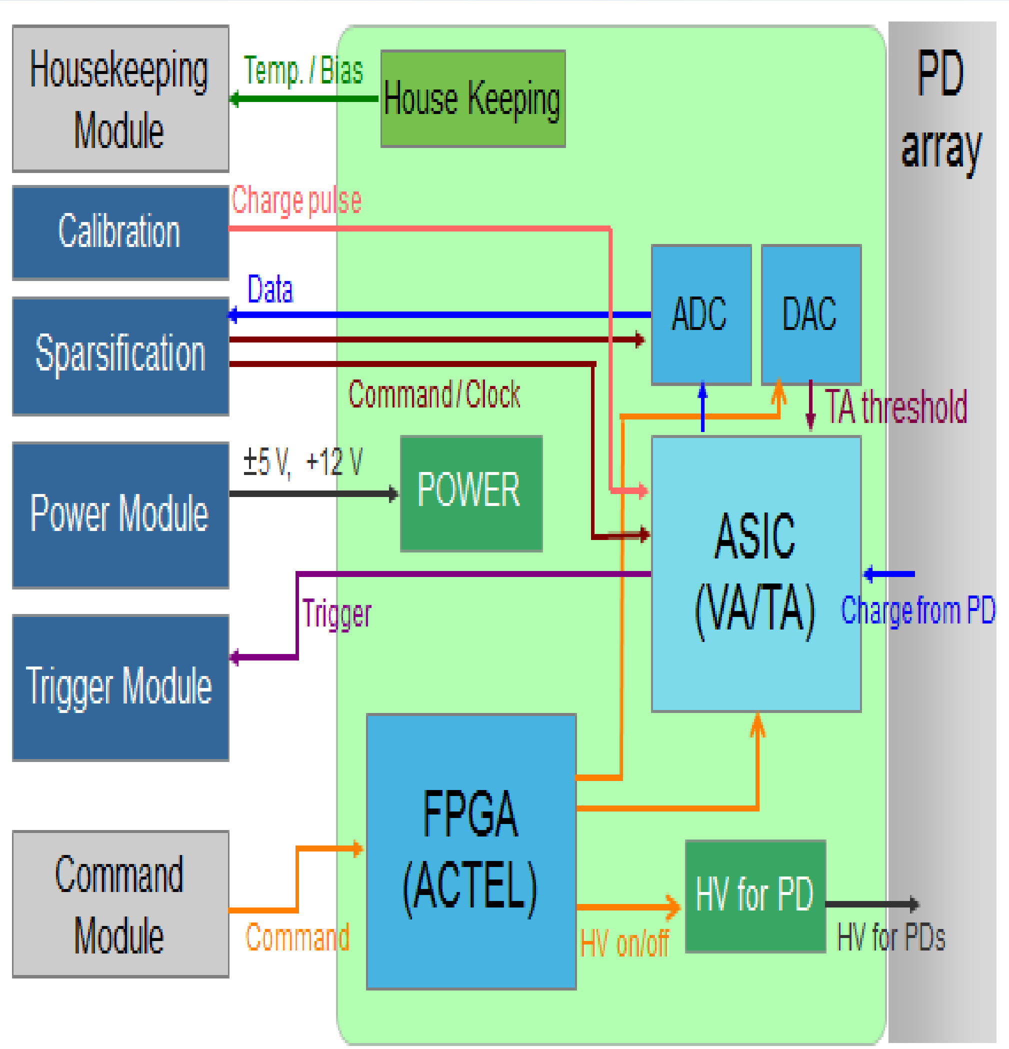


Cosmic ray muon



- The signal-to-noise ratio of PD sensors are measured using ^{90}Sr radioactive source and cosmic ray muon
- The SNRs are better than 70 with commercial electronics

Readout Electronics Block Diagram



• All readout electronics are based on CREAM calorimeter

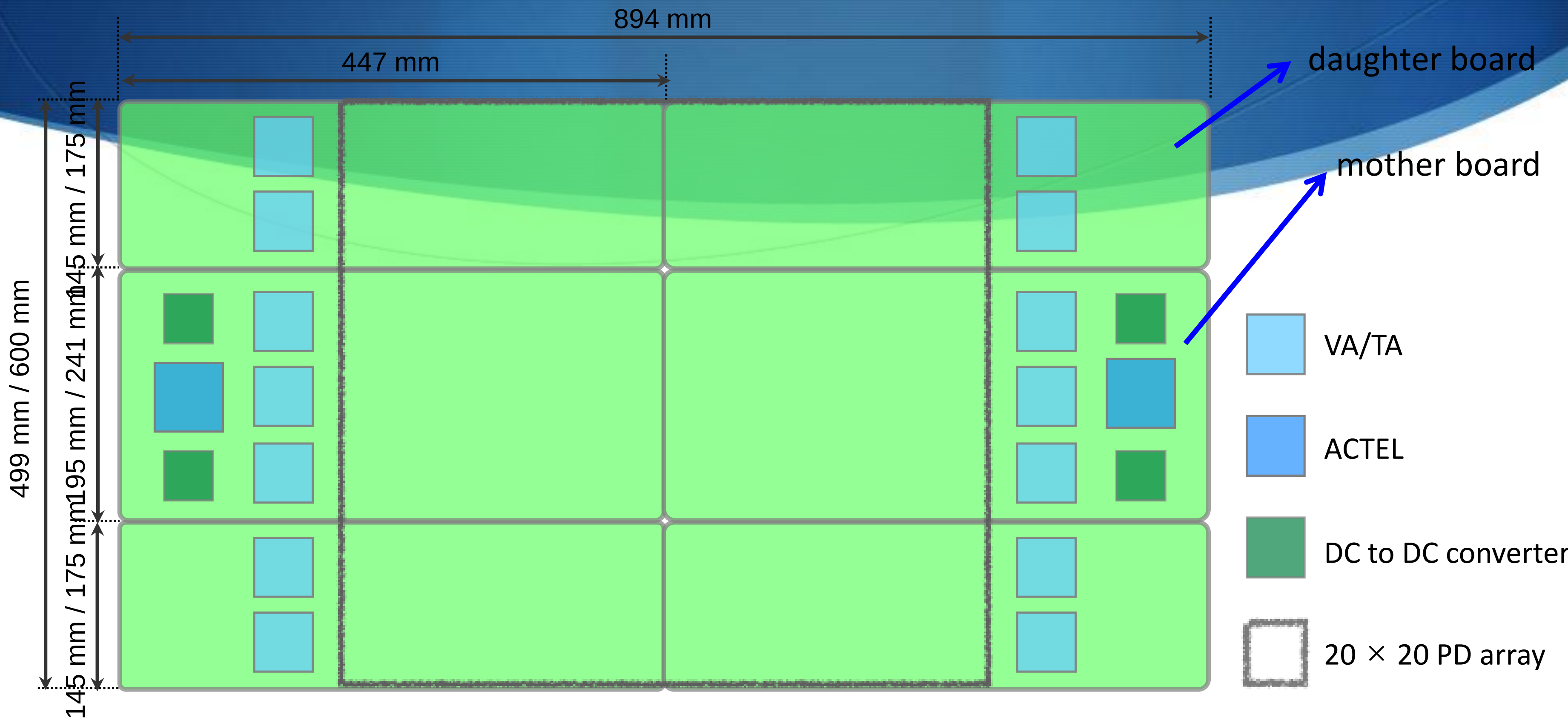
- VA/TA chips receive the charge signal from the PD sensor, perform signal amplification followed by shaping, and provide trigger signal

- ADC digitizes the sample/hold signals of VA/TA

- Commands from the Sparsification and Command boards pass through FPGA and control the VA/TA, ADC, and DAC

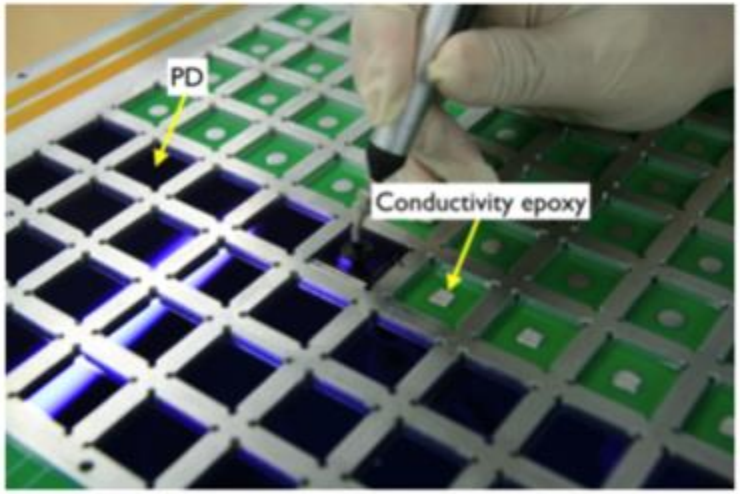
- TA chip sends trigger signals to the trigger module

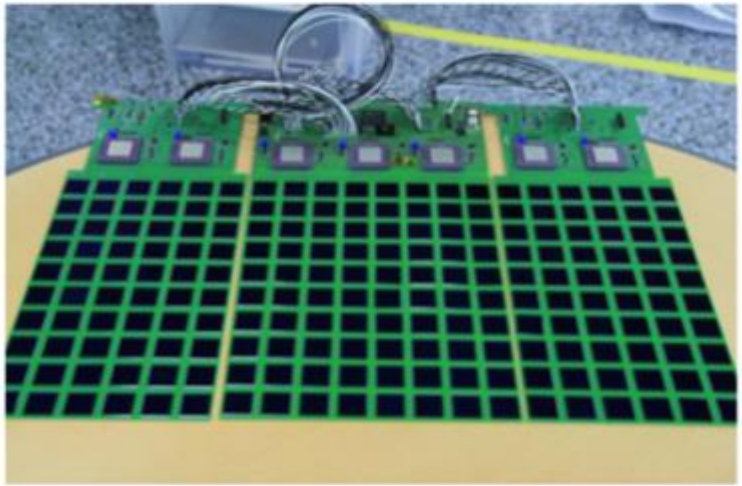
Readout Electronics Design

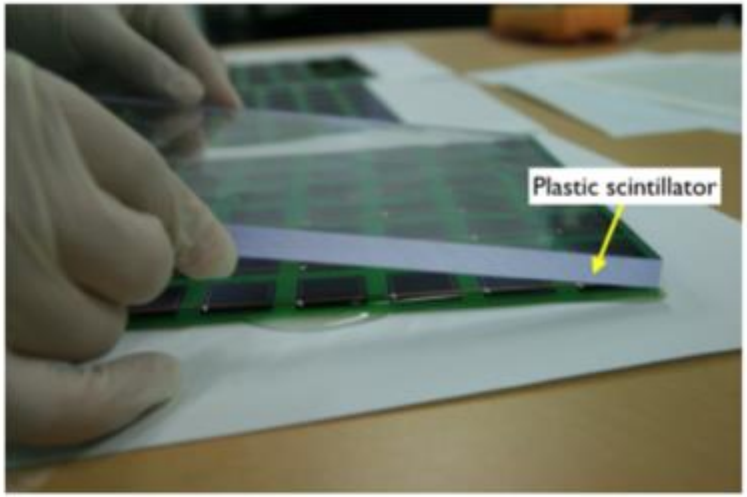


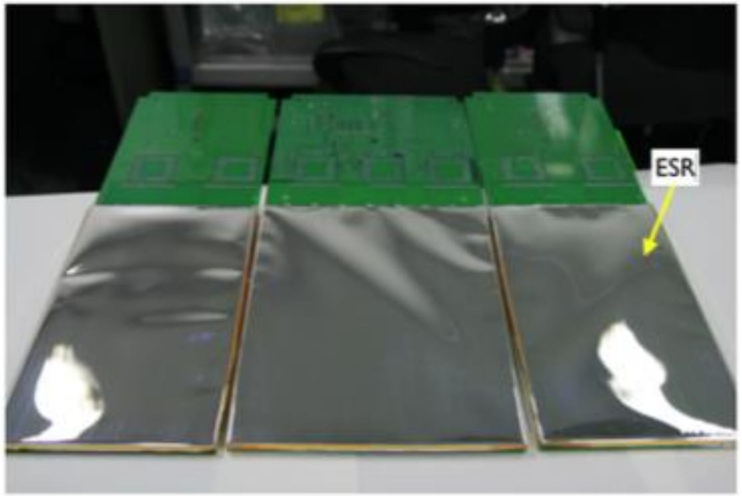
- Readout electronics consists of 2 mother boards and 4 daughter boards for each TCD and BCD.
- A total of 28 VA/TA and 4 ACTEL chips are needed for both detectors.
- In one mother board, there are two DC to DC converters for PD biasing. One DC to DC converter is redundant.

Detector Parts of TCD/BCD

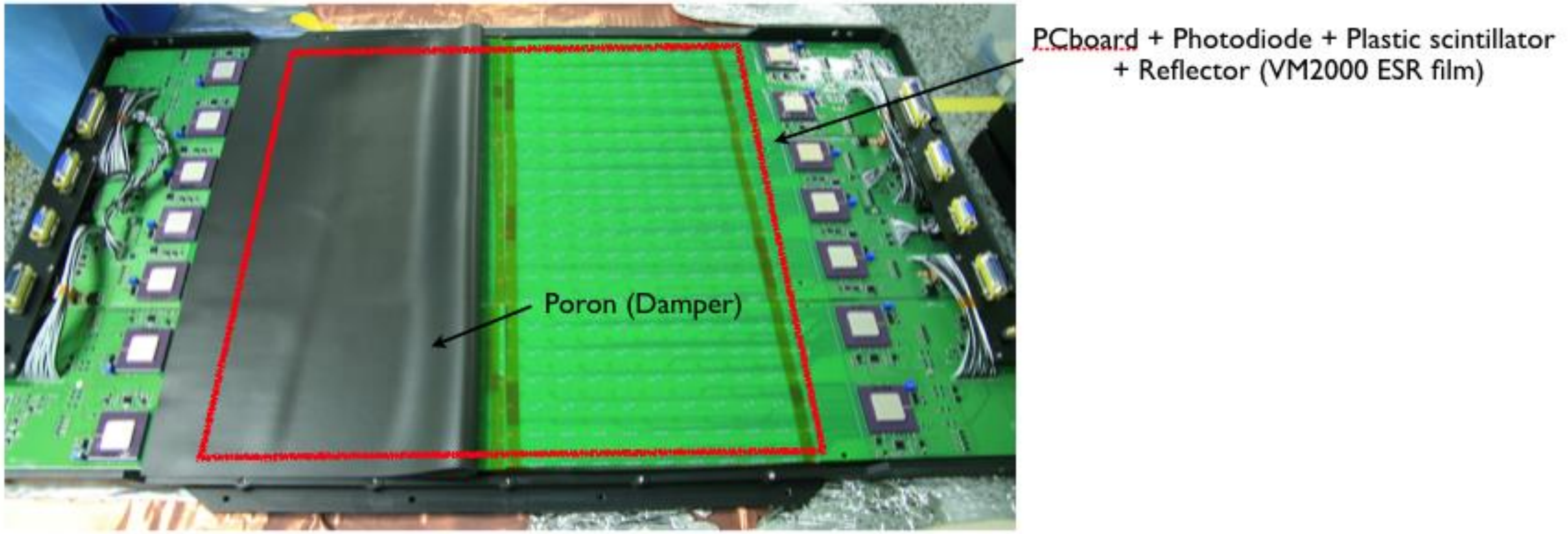








Top Counting Detector



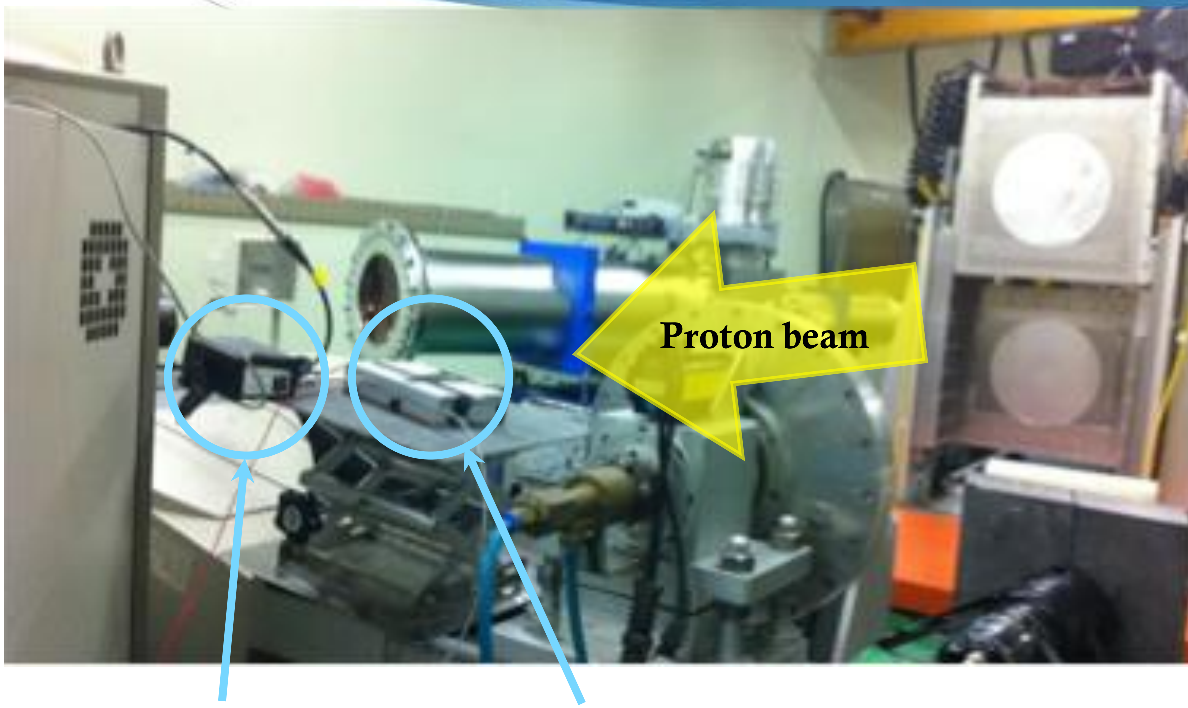
- Dimension: 901 mm x 551 mm x 30 mm
- Weight: 9.6 kg

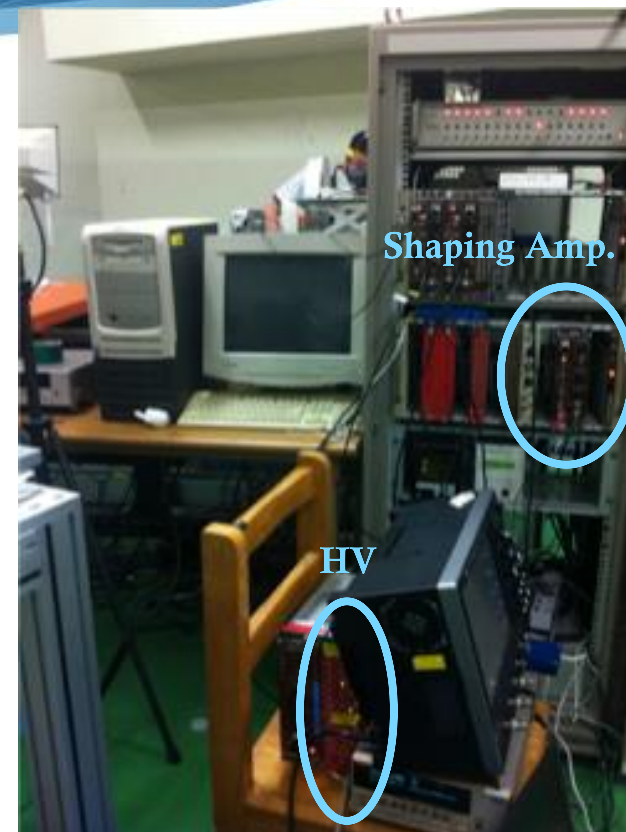
Bottom Counting Detector

PCboard + Photodiode + Plastic scintillator
+ Reflector (VM2000 ESR film)

- Dimension: 950 mm x 650 mm x 33 mm
- Weight: 15.6 kg

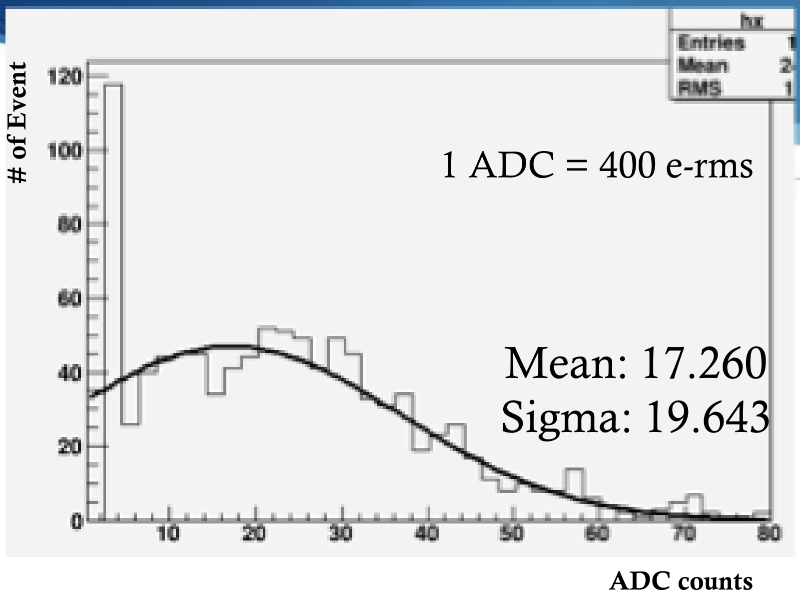
Proton Beam Test : Set-up



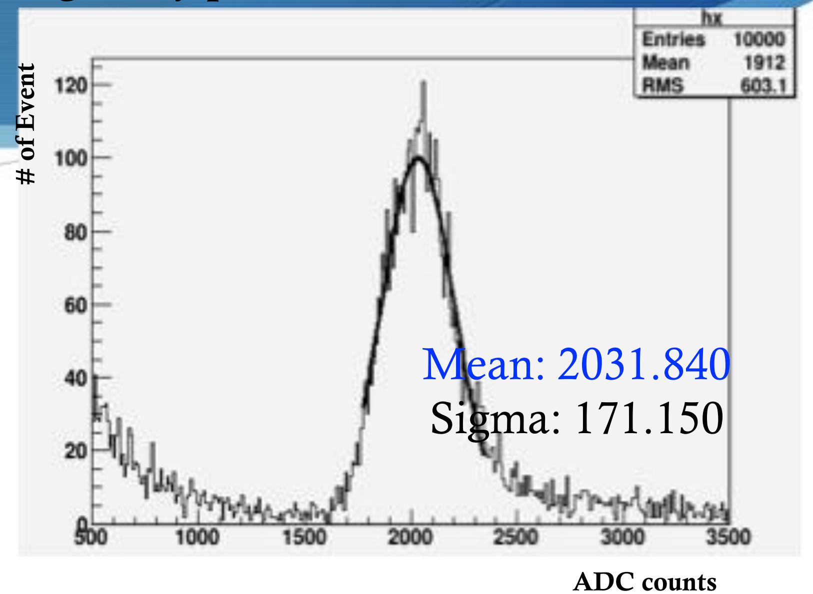


Proton Beam Test : Results

Pedestal



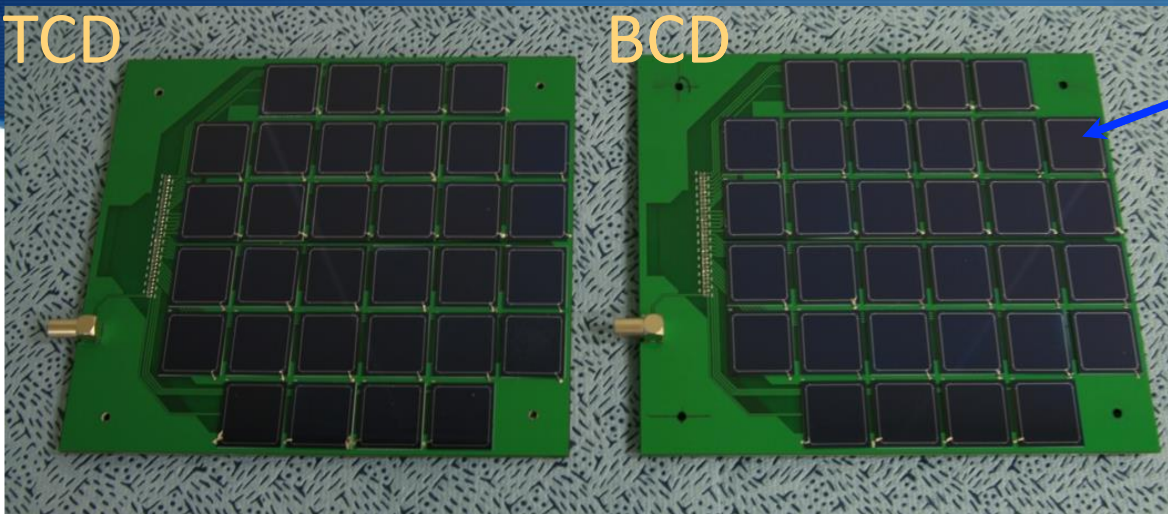
Signal by proton beam



- Test conditions : HV (-120 V) supplied, Gain 20, and Shaping time 3 μs
- 45 MeV proton beam current : 1 nA

$$\mathrm{SNR} = \frac{2031.84 - 17.26}{19.64} = 102.57$$

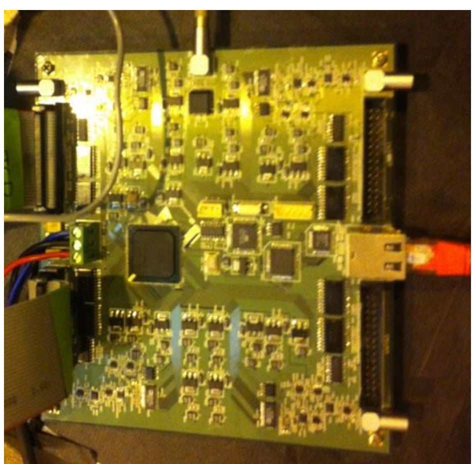
TCD/BCD Prototypes for Beam Test

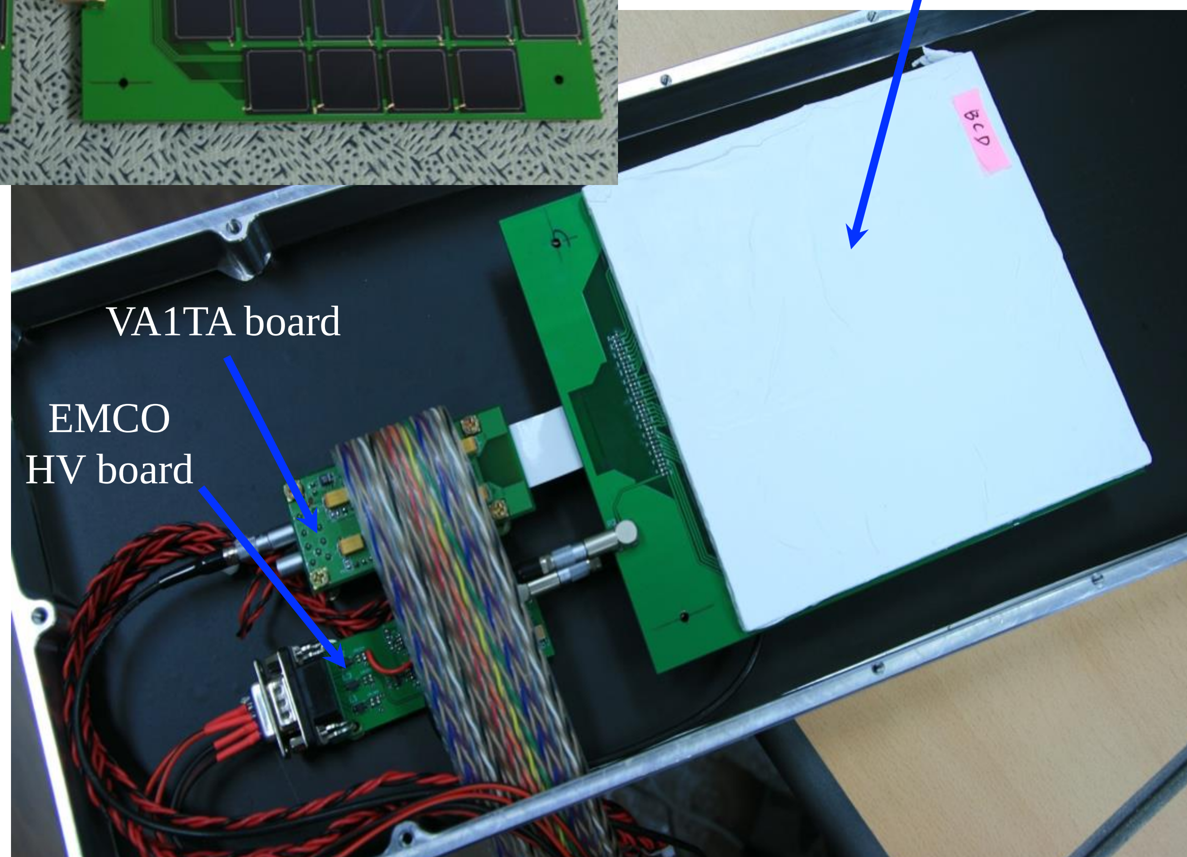


Photodiode sensor
2.3 cm × 2.3 cm

5 mm thick Plastic scintillator
15.0 cm × 15.0 cm

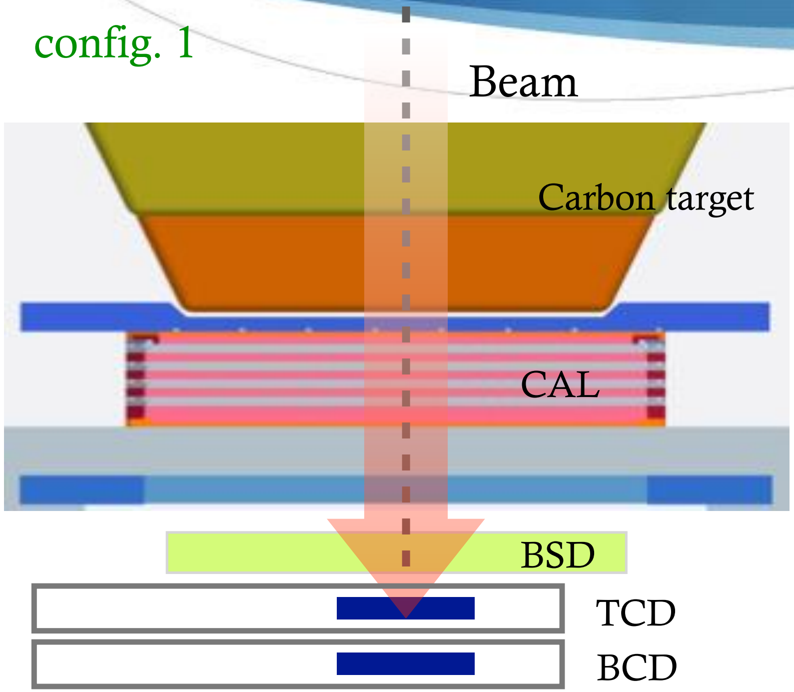
DAQ board



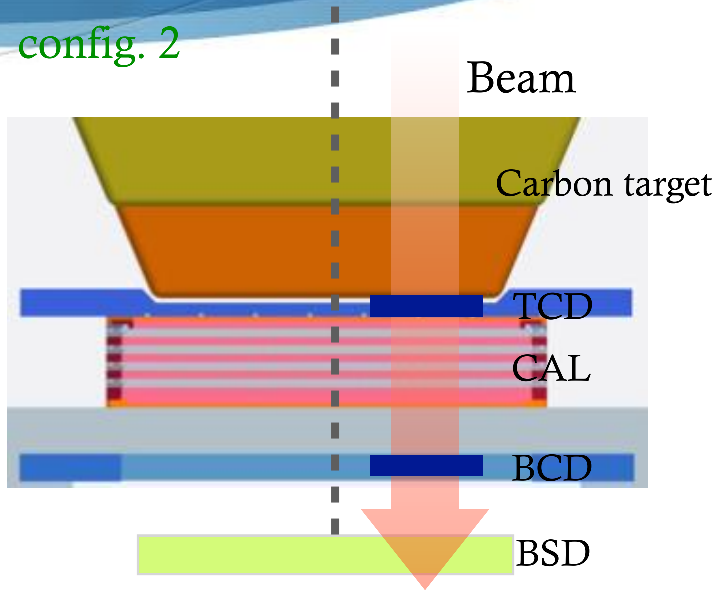


Test Configurations

config. 1

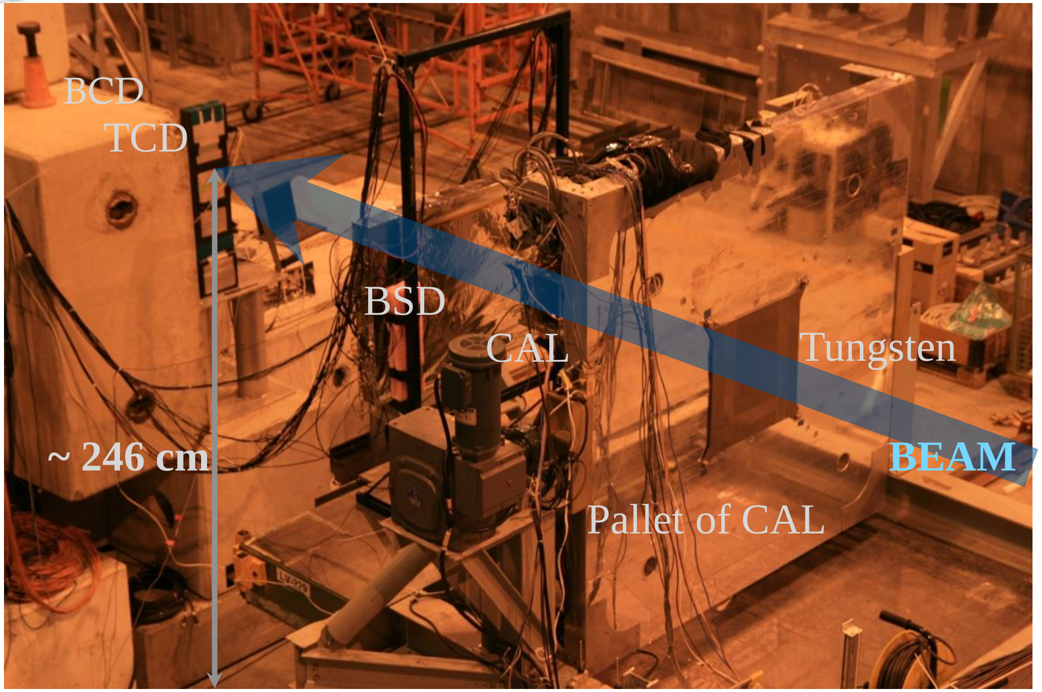


config. 2



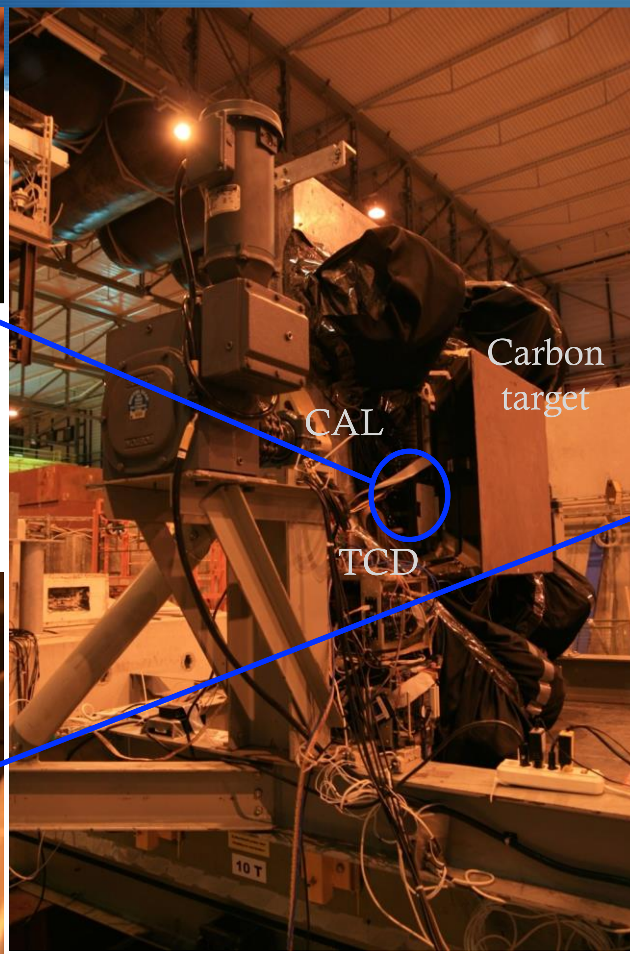
: PD sensor + plastic scintillator position

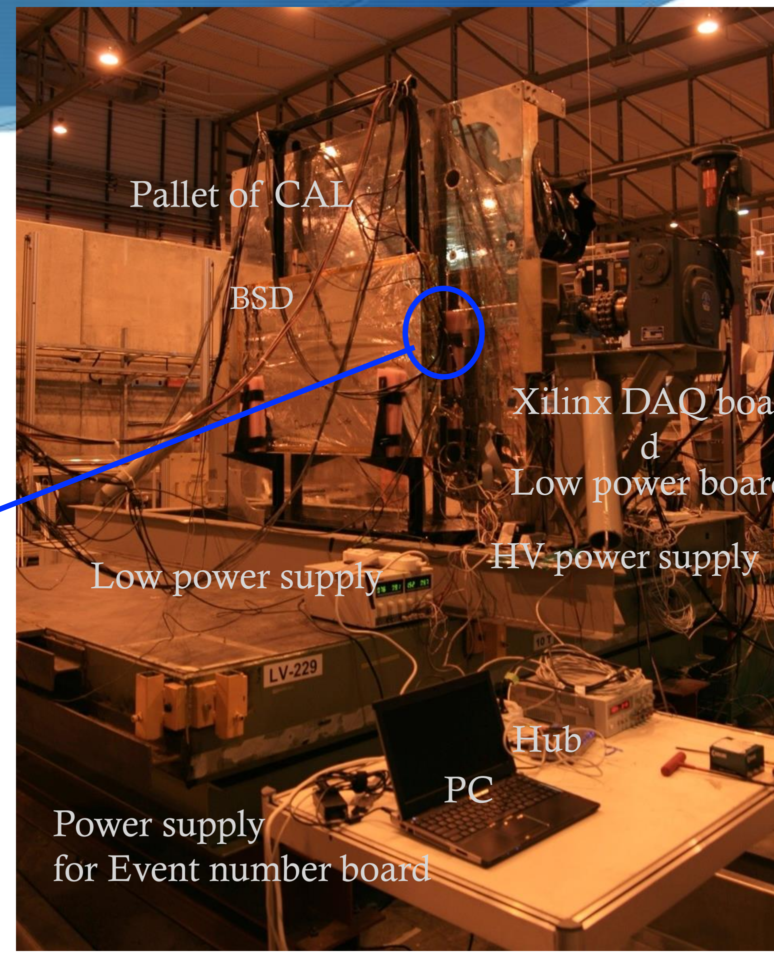
CERN Beam Test in H2



Test Configuration 2

up stream down stream

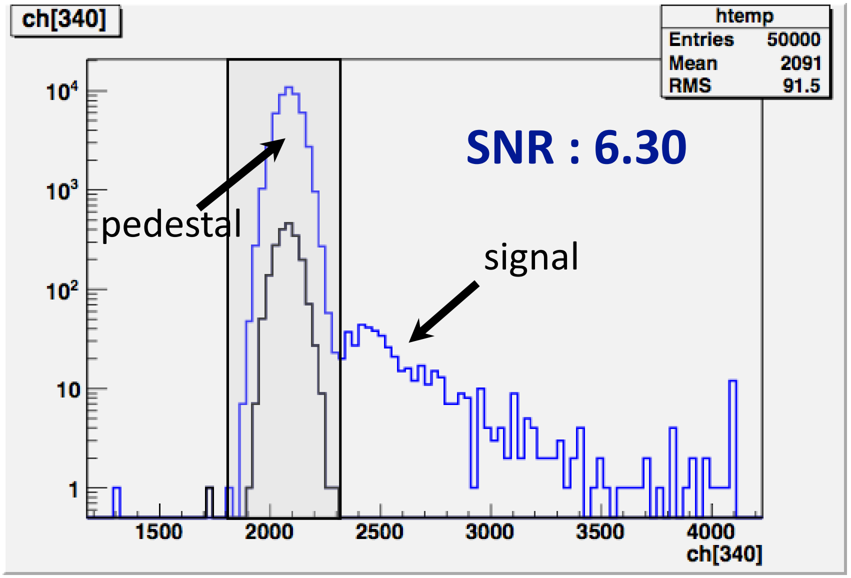




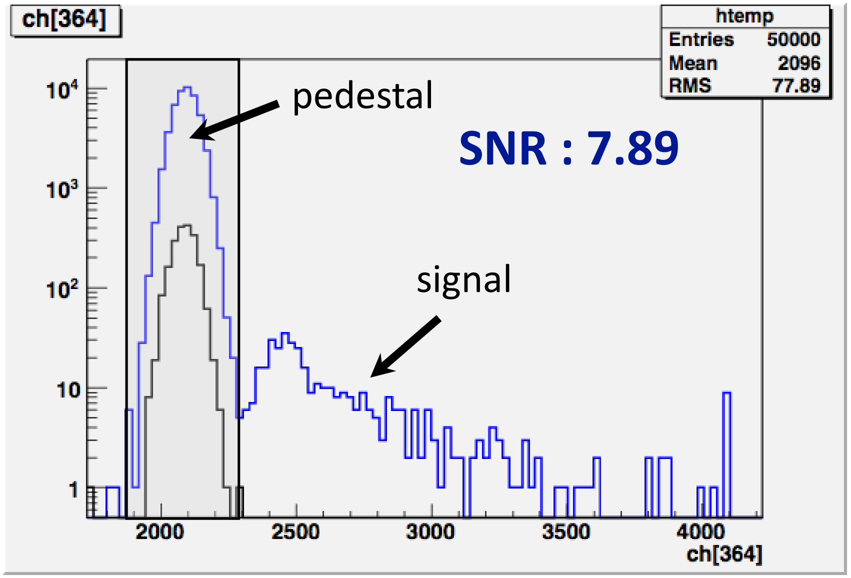
MIP measurements

- 150 GeV electron beam includes muon and MIP is measured by using this muon
- SNR is measured to be 7.1on average

Blue : signal 50k events
Black : pedestal 2k events



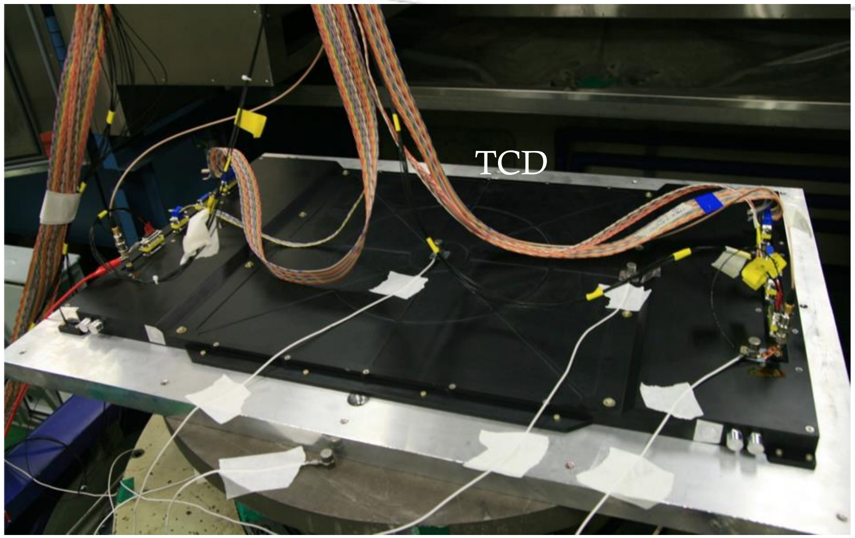
pedestal mean & sigma : 2084.87, 54.94
signal MPV : 2430.98

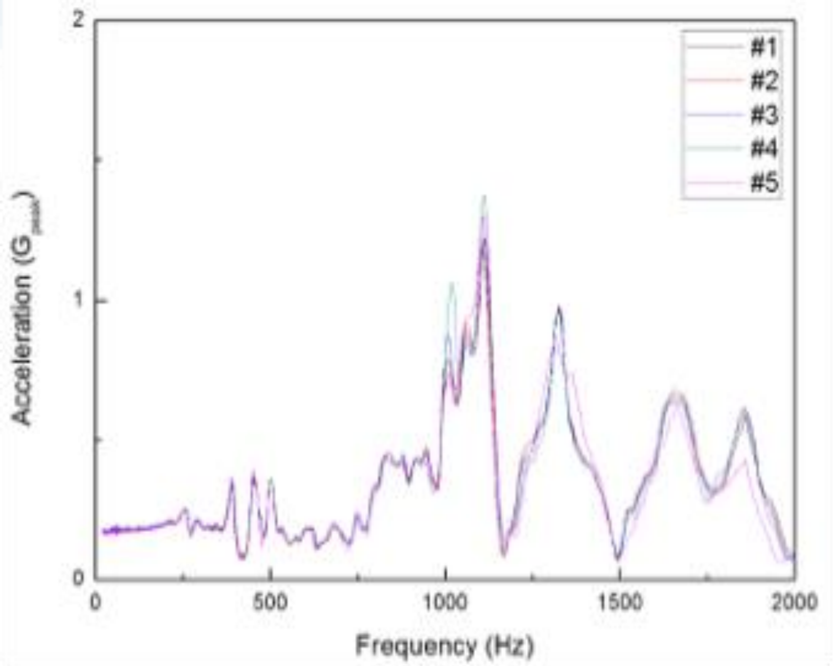


pedestal mean & sigma : 2092.04, 45.85
signal MPV : 2453.70

Vibration Test

- ❑ Identify 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.

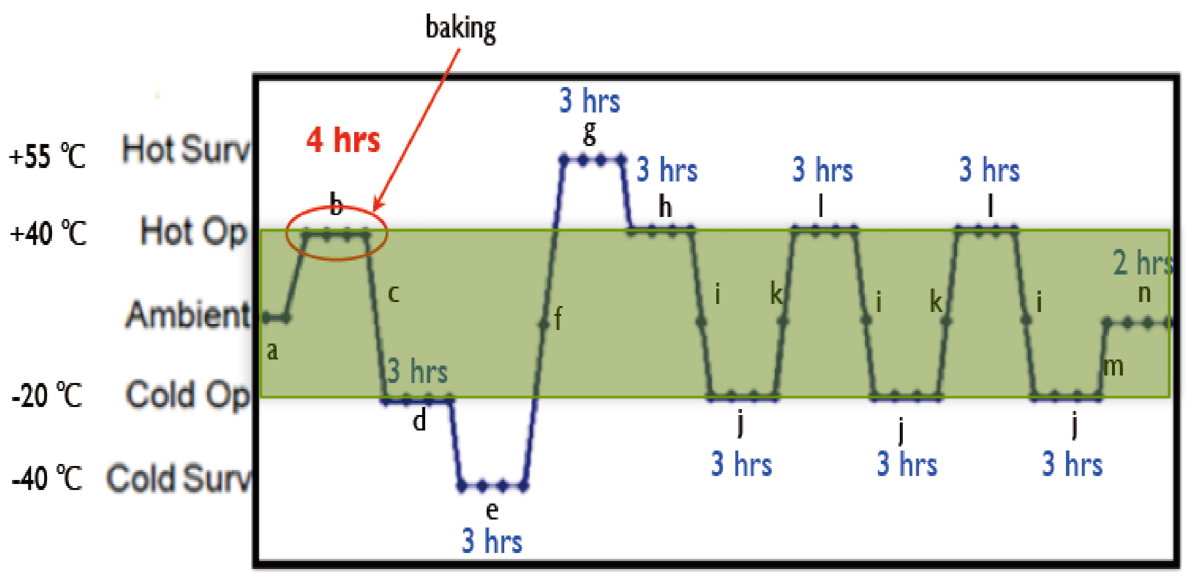




- Rigidity check by comparing distributions of resonant frequencies and by functionally test before/after each Sine burst test
- The modules are normally operated during the test, and no crack and no broken parts were seen after test

Thermal-Vacuum Test

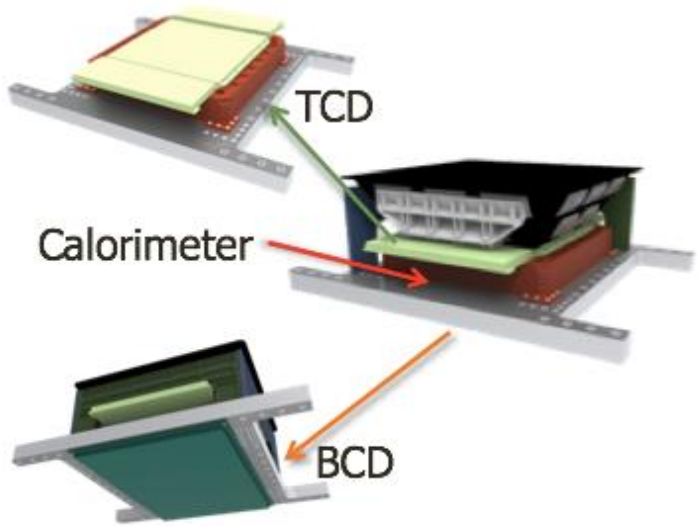
- ❑ Identify parts with their operation/survival temperature ranges.
- ❑ Design heating/cooling of instruments based on the temperature analysis.
- ❑ Assemble components with better heat dissipation.
- ❑ Test components/instruments in a thermal cycle of hot and cold temperature at vacuum to confirm

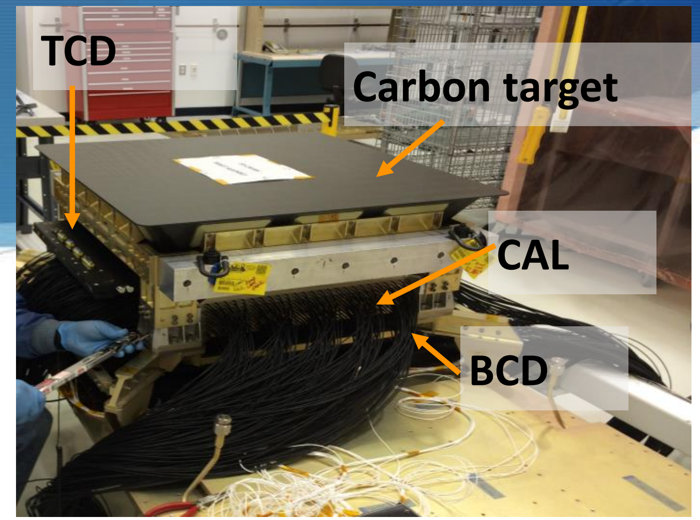


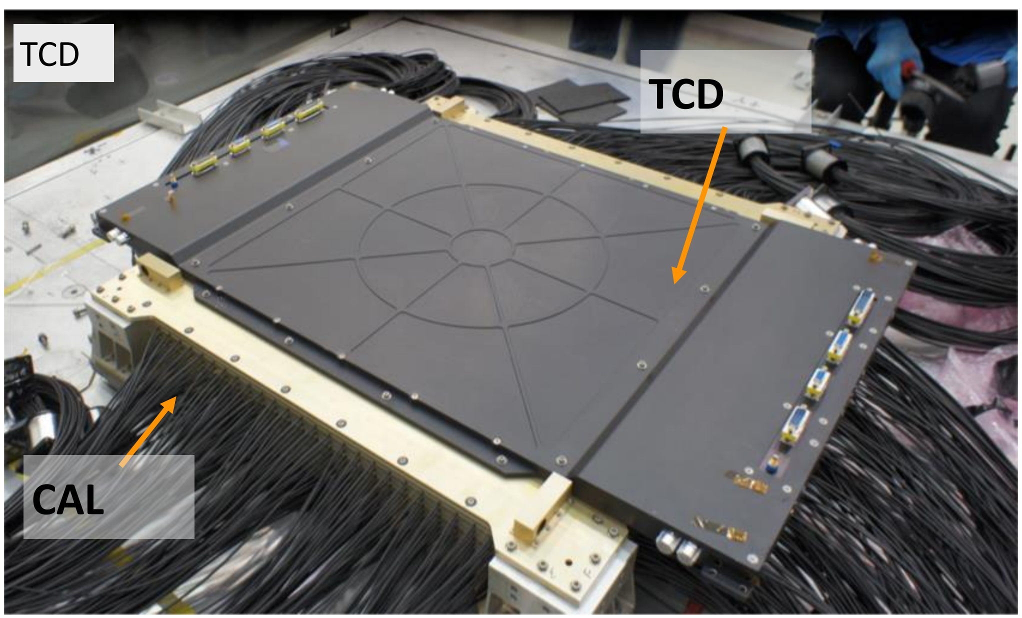
Thermal Vacuum graph [ref. CVP-101]

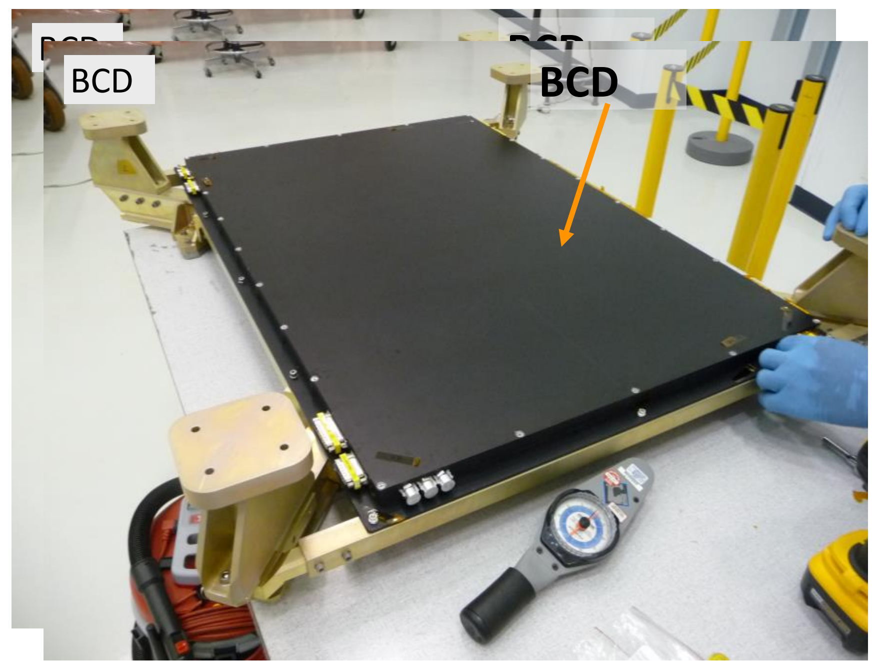
• T/BCD operated normally during the thermal cycles (76 hrs) and any changes in noises were not observed before and after the tests

Integration with Payload @WFF

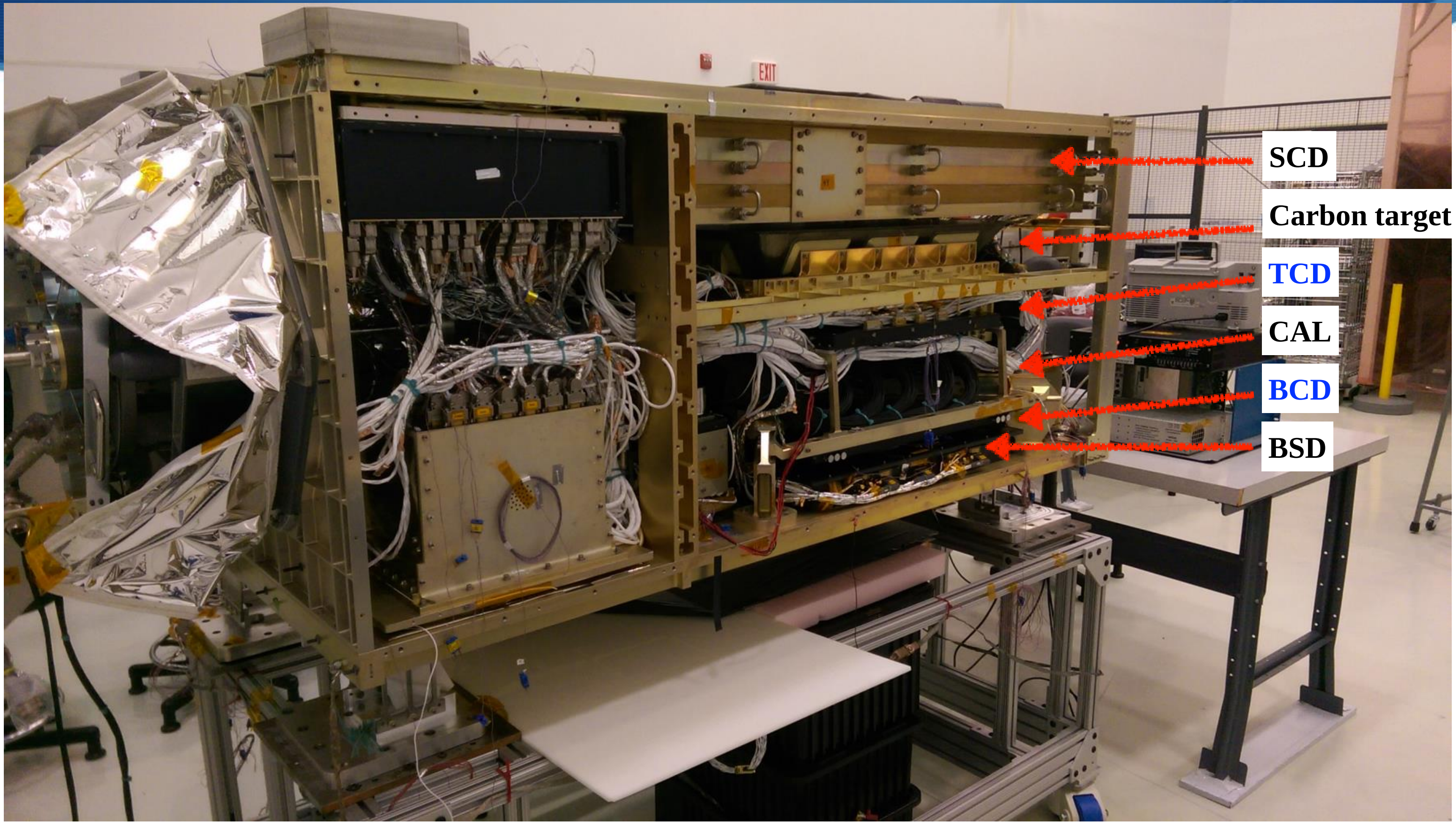






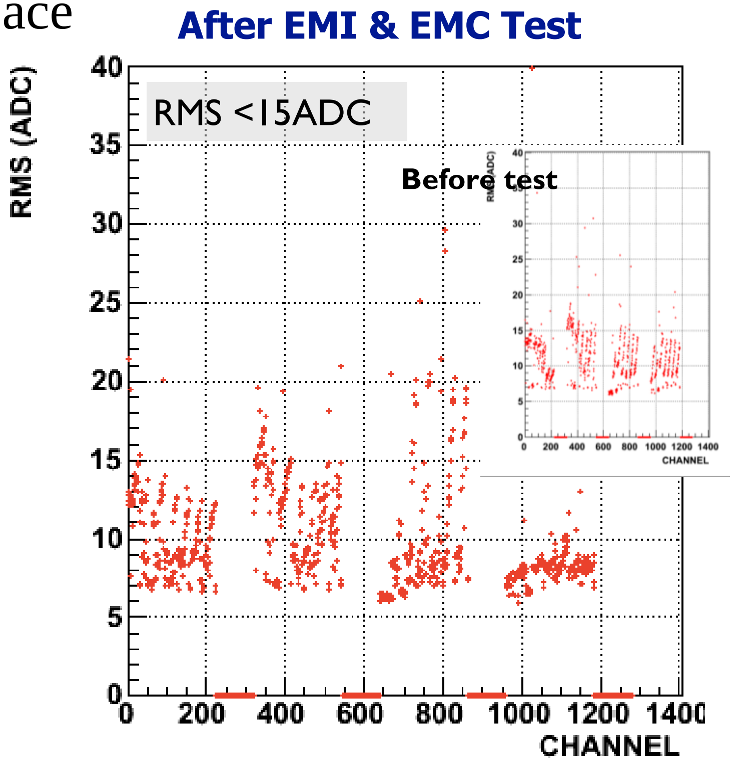


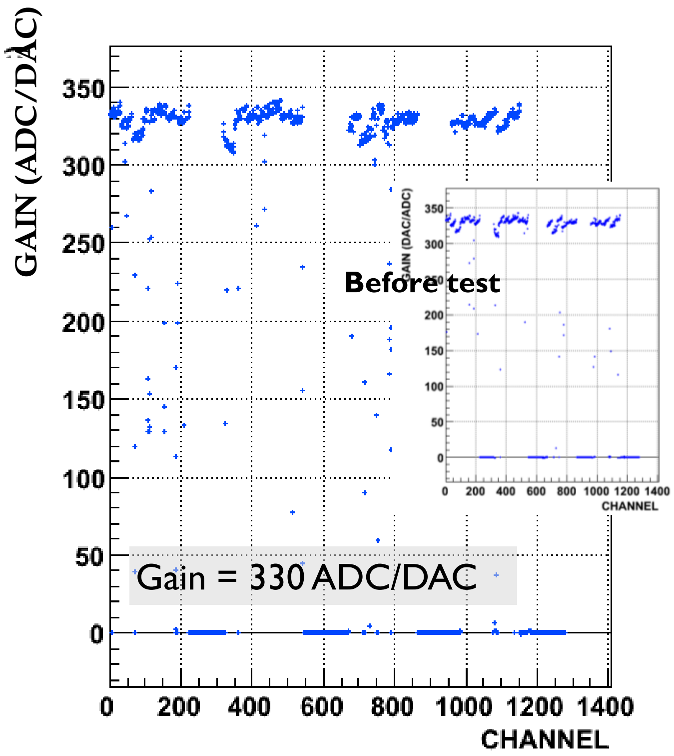
Integration with Payload @WFF



EMI and EMC Tests @GSFC

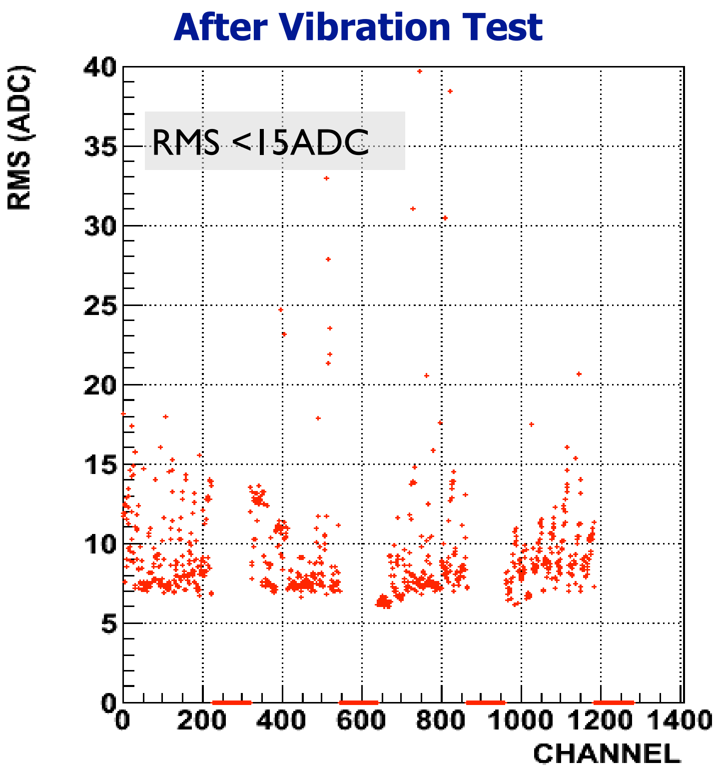
- Electro-Magnetic Interference (EMI) test
  - ISS-CREAM instrument should not give any damages to other instruments in space
- Electro-Magnetic Compatibility (EMC) test
  - ISS-CREAM instrument should not have any damages from other instruments in space

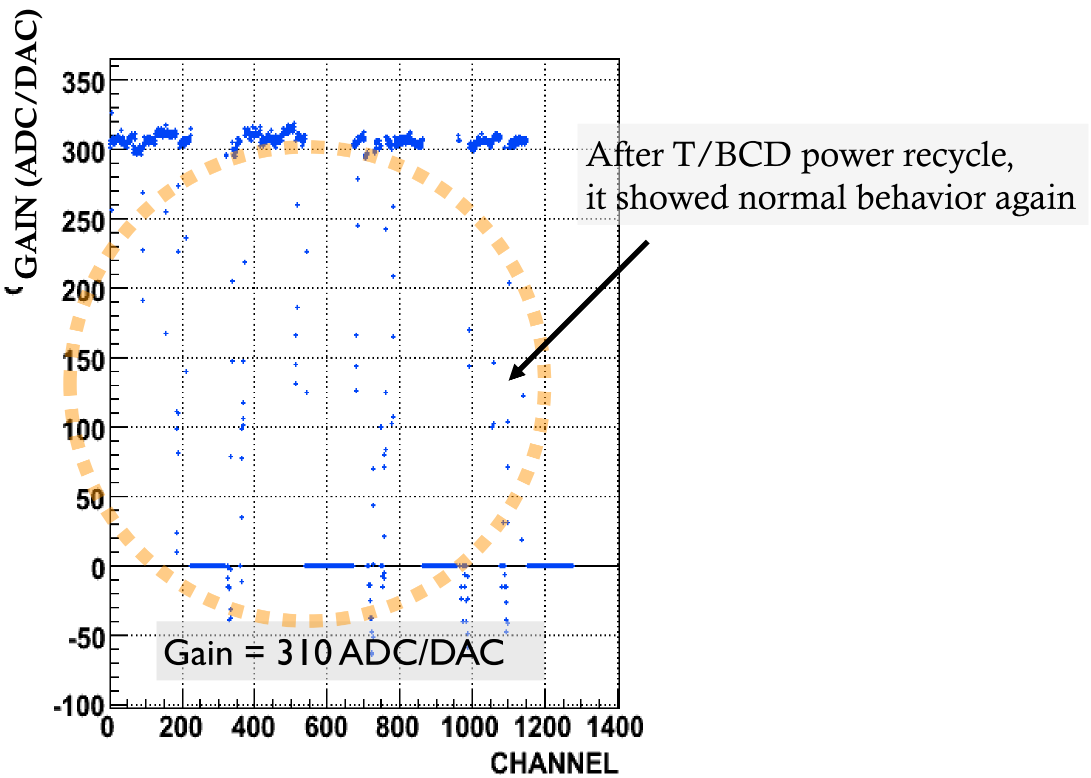




Vibration Test @GSFC

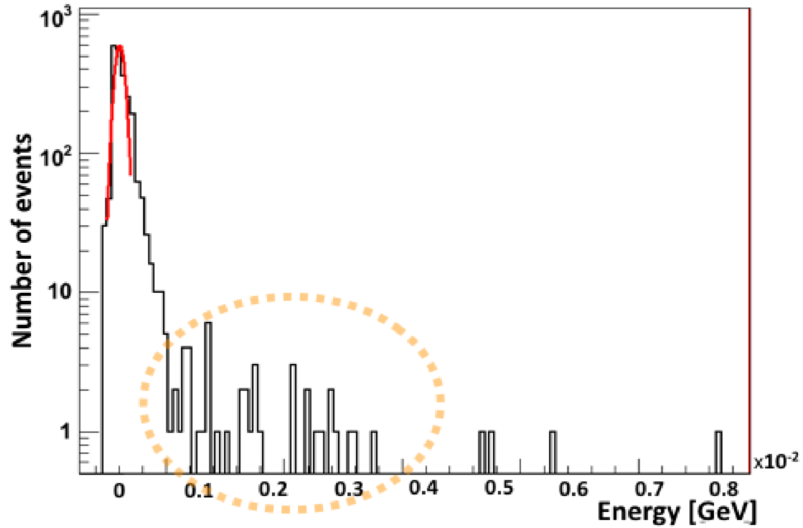
- ISS-CREAM instruments should not have any damages during launch environments
  - The vibration test qualifies the mechanical design and the workmanship
  - Verify the fundamental frequency
  - The test levels exceed the maximum expected launch environments

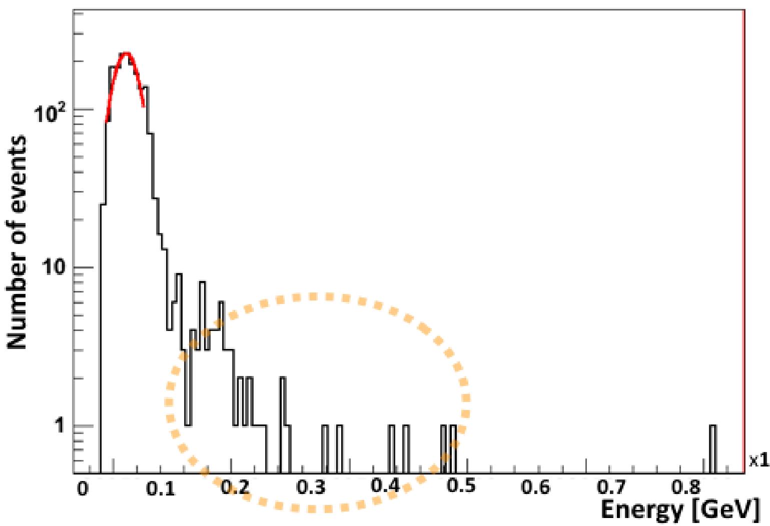


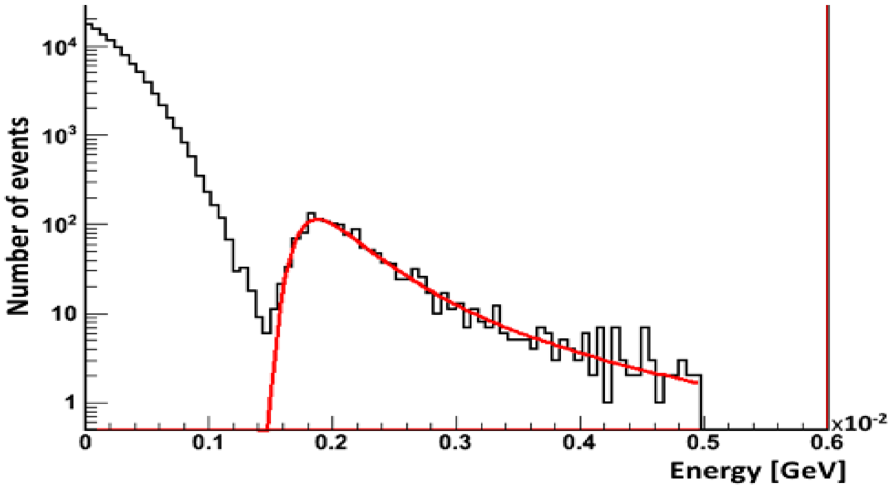


Cosmic Ray Test

Cosmic ray muon responses in the experimental data for the TCD (left) and BCD (right)

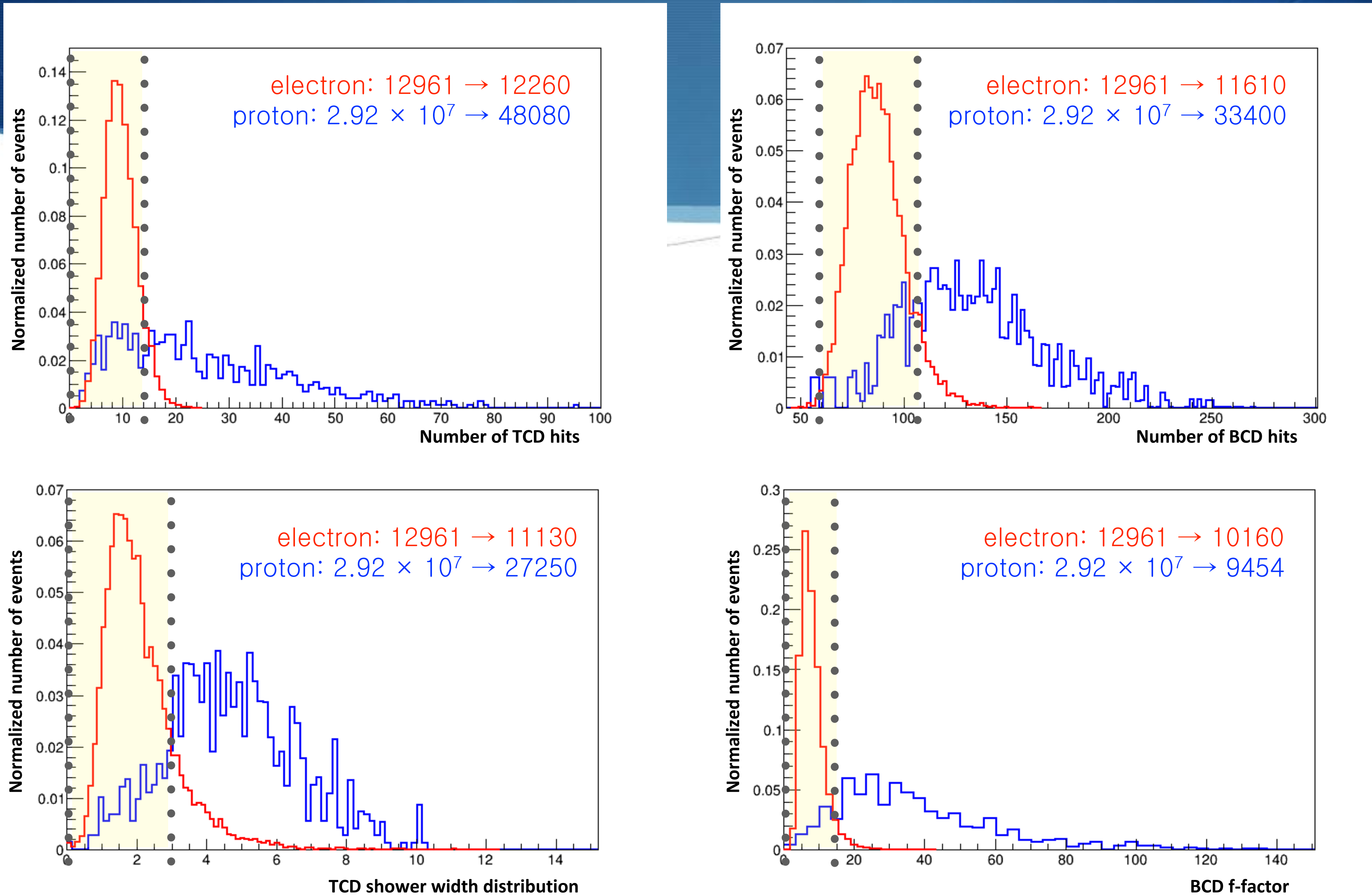






- These results show that the TCD/BCD have possibility for providing low energy trigger
- SNR is measured to be 6.7

MC Simulation : Cut Criteria



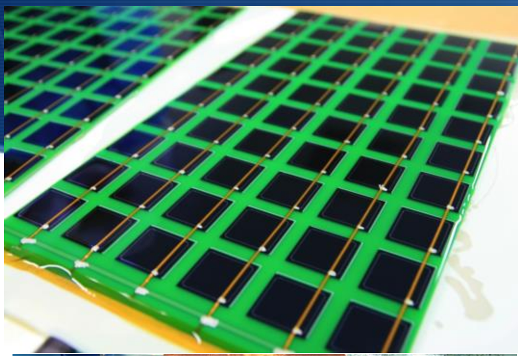
JeongMin Park

Summary of MC Study

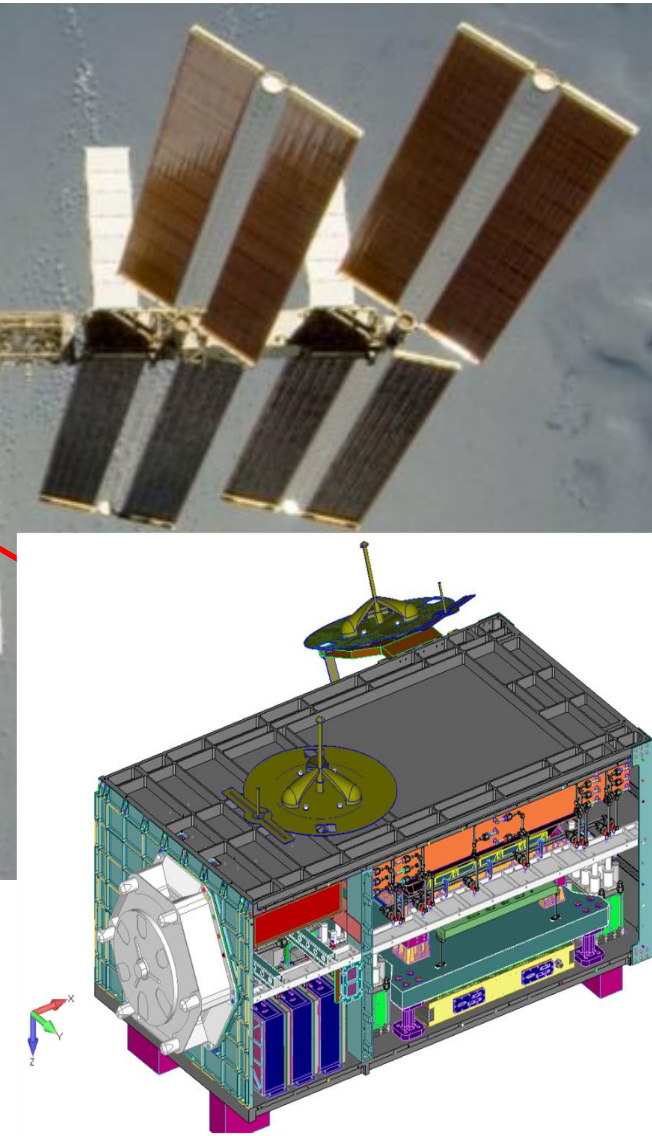
- Capability of the T/BCD to separate electrons from protons has been studied with GEANT simulation
  - The proton rejection power is 1.96×10^4 and the electron efficiency is 71.4 % for 300 GeV electrons

- The ISS-CREAM can measure 24,700 electron events with 300 GeV ~ 600 GeV during 3-year goal exposure date

KNU ISS-CREAM Members



ISS-CREAM (CREAM at the ISS)



Will be deployed as an attached payload on NASA's share of the Japanese Experiment Module Exposed Facility (JEM-EF) in the ISS

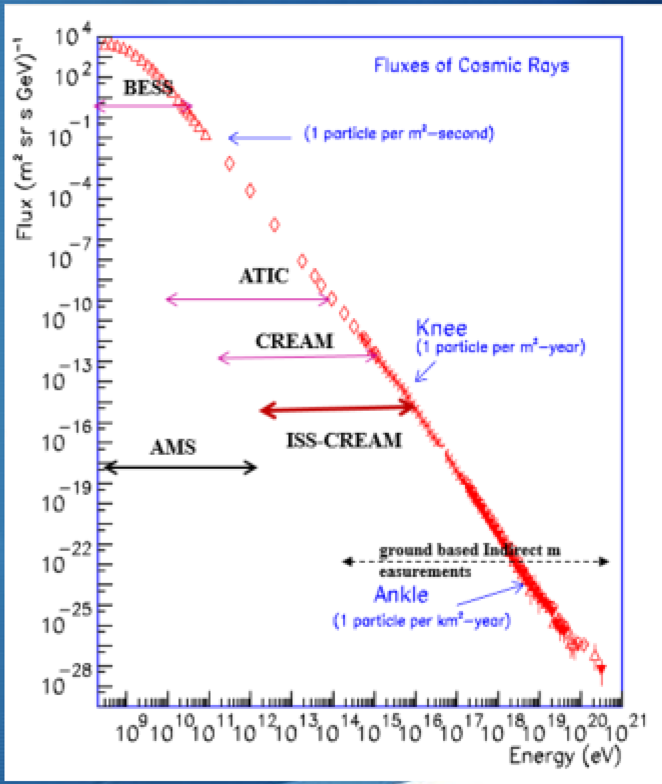
Summary

• CREAM has had six very successful and rewarding flights with about 161 days.

• ISS-CREAM will extend the CREAM energy reach to higher energies to have enough overlap with ground-based indirect measurements

• The CREAM instruments have improved performances with new electronics and detectors.

• The CREAM instrument at KSC is now being prepared for the ISS (International Space Station) to reach higher energy and more accurate measurement.



• The CREAM is scheduled to launch to the ISS on August this year.

Thank you

Autumn and winter
in front of Physics building