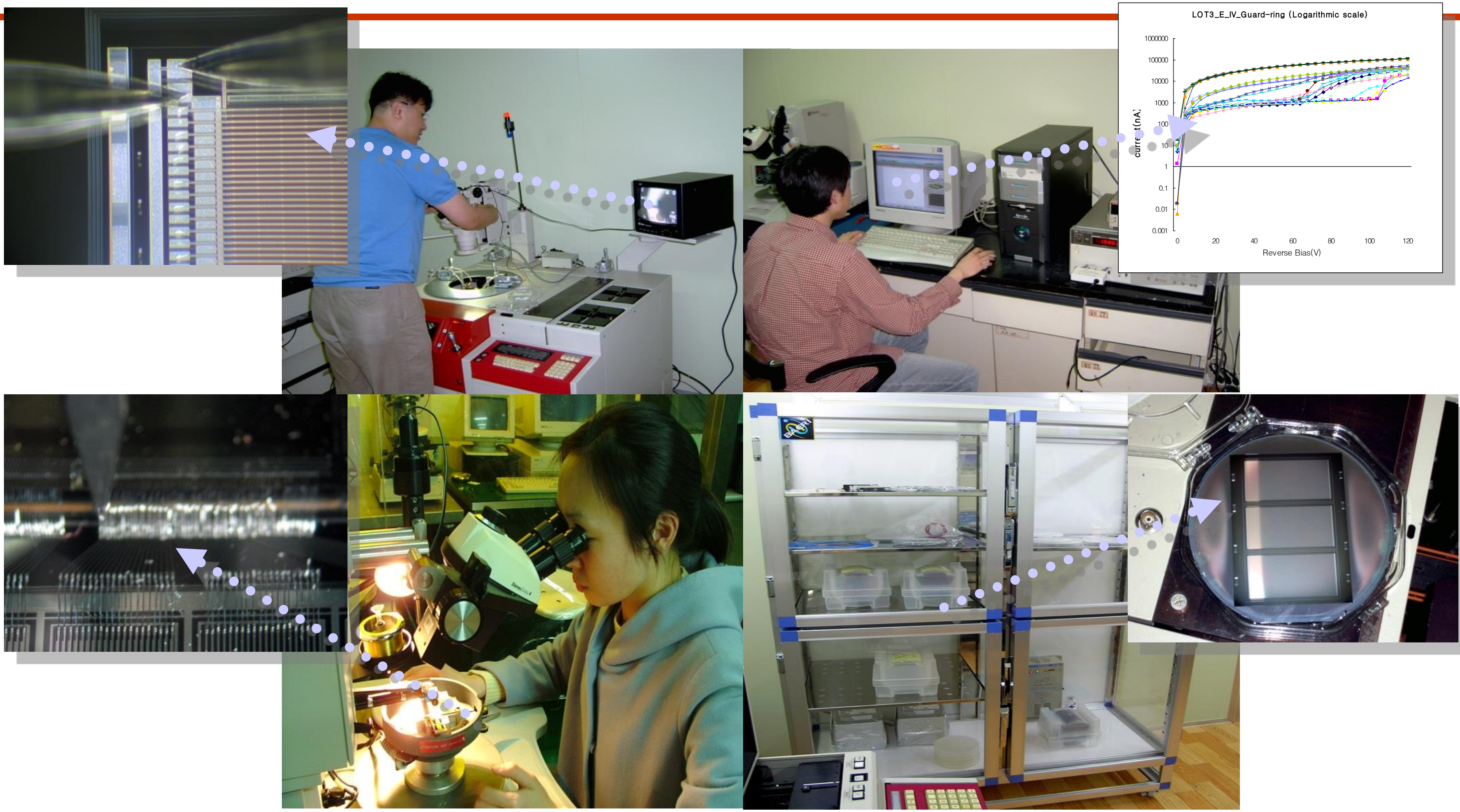
Silicon Detector



KFCC brainstorming workshop: Research Trends with Future High-Energy and Nuclear Physics Facilities
Gyeongju Hilton, 12 Nov. – 14 Nov.

Hwanbae Park
Kyungpook National University

Introduction : Historical Perspective

- **Silicon (large cell-type) sensors around since 50's for energy measurements**
- **Precision position measurements up until 70's done with emulsions**
  or bubble chambers ⇒ limited rates and no triggering!
  Traditional gas detectors: limited to 50-100 μm point resolution
- **First silicon usage for precision position measuring (late 70's):**
  - segmented sensors (strips) with fine pitch
  - secondary vertex tagging (charm) in fixed target experiments
  - first silicon pixel device used in early 80's (NA32) charm experiment

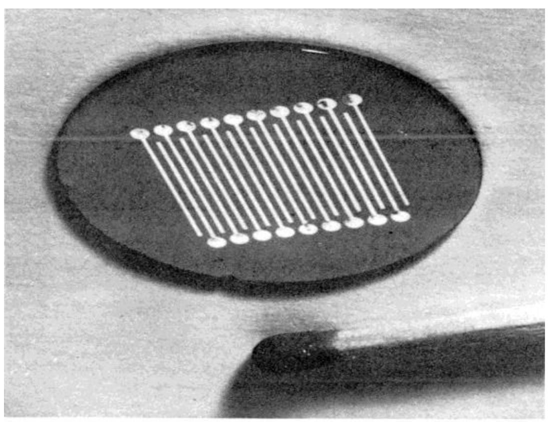


Fig. 2. The MESD after chemical stripping.

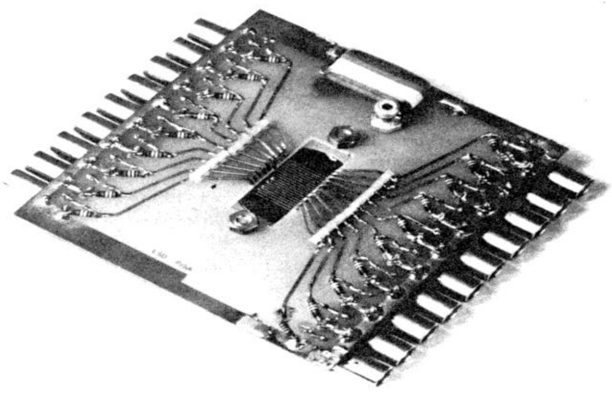
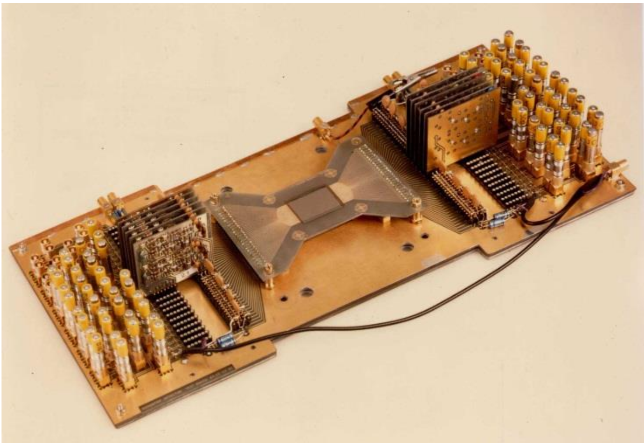


Fig. 3. General assembly of the MESD.

Multi-**E**lectrode **S**ilicon **D**etector



Silicon Surface Barrier Microstrip Detector

Introduction : Historical Perspective

- **Why wasn't silicon used earlier?**

  Needed micro-lithography technology ⇒ cost

  Small signal size (need low noise amplifiers)

  Needed read-out electronics miniaturization (transistors, ICs)

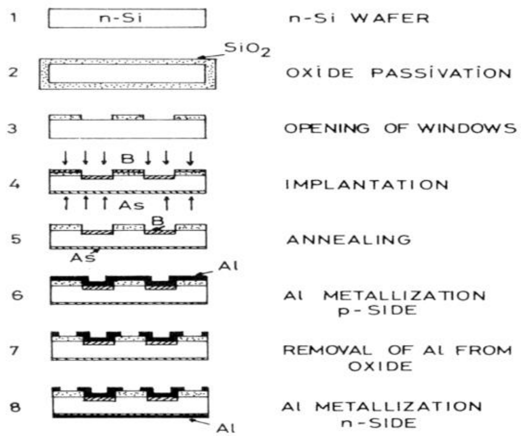


Fig. 1 : Successive steps of the manufacturing process of passivated ion-implanted silicon detectors

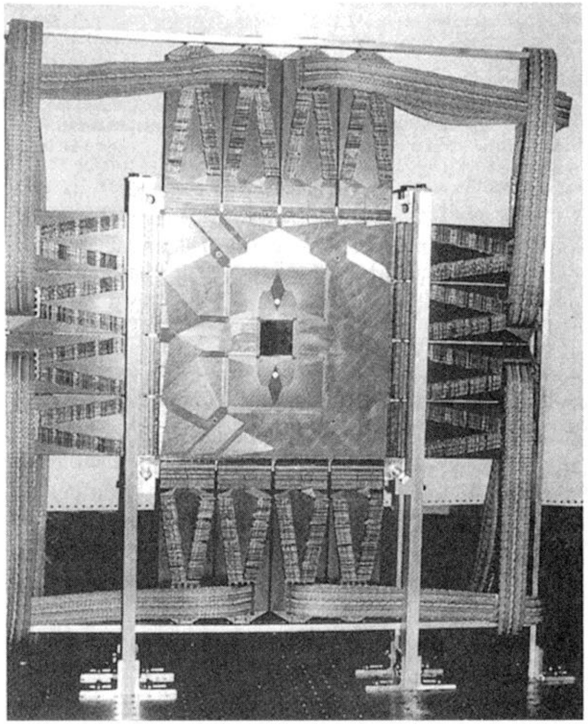
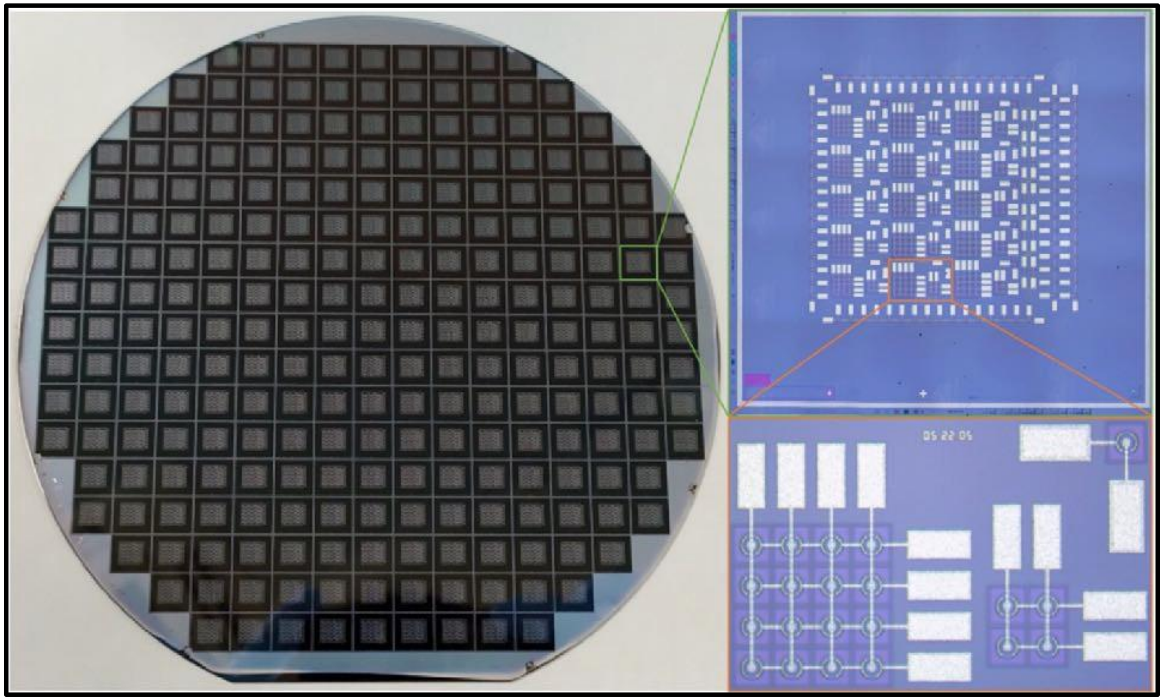


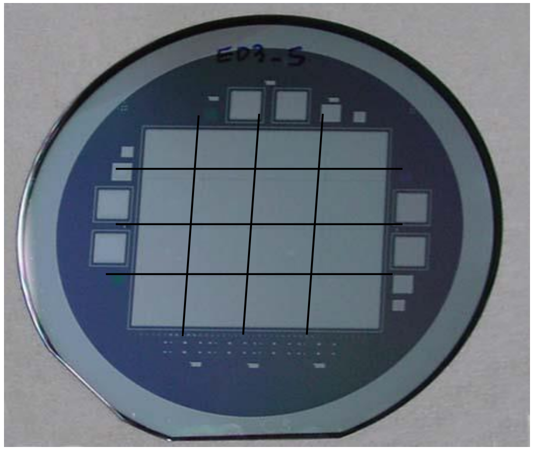
Fig. 2. The early years: experimental setup with silicon strip detectors in a fixed target experiment (E706 at FNAL). The 5 × 5 cm² silicon detectors are seen in the center, with the fanout cables and amplifier banks dominating the picture. From [17].

After this, the use of silicon detectors quickly took off

Type of Silicon Sensor

- **Pixel devices**
  - True 2-D measurement (20 μm pixel size)
  - Small area but best for high track density environment
- **Pad devices ("big pixels or wide strips")**
  - no position resolution
  - Pre-shower and calorimeters (charge measurement)

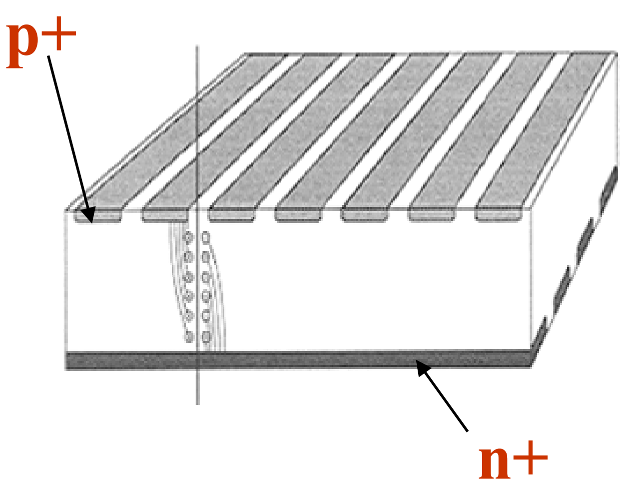


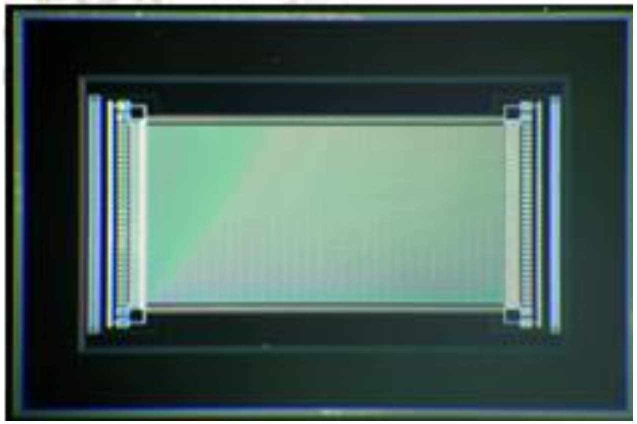


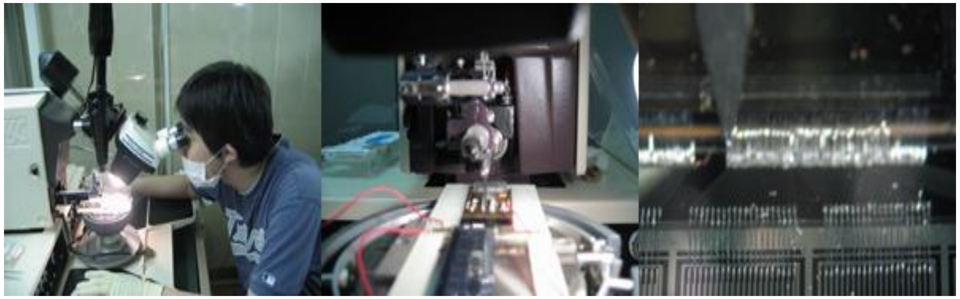
SCD sensor for CREAM (I.H. Park et al.)

Type of Silicon Sensor

- **Strip devices**
  - **High precision (< 5 μm) 1-D coordinate measurement**
  - **Large active area (up to 10 cm x 10 cm from a 6-inch wafer)**
  - **Inexpensive processing (single-sided strip devices)**
  - **2-D coordinate possible (double-sided strip devices)**
  - **Most widely used silicon detector in HEP**







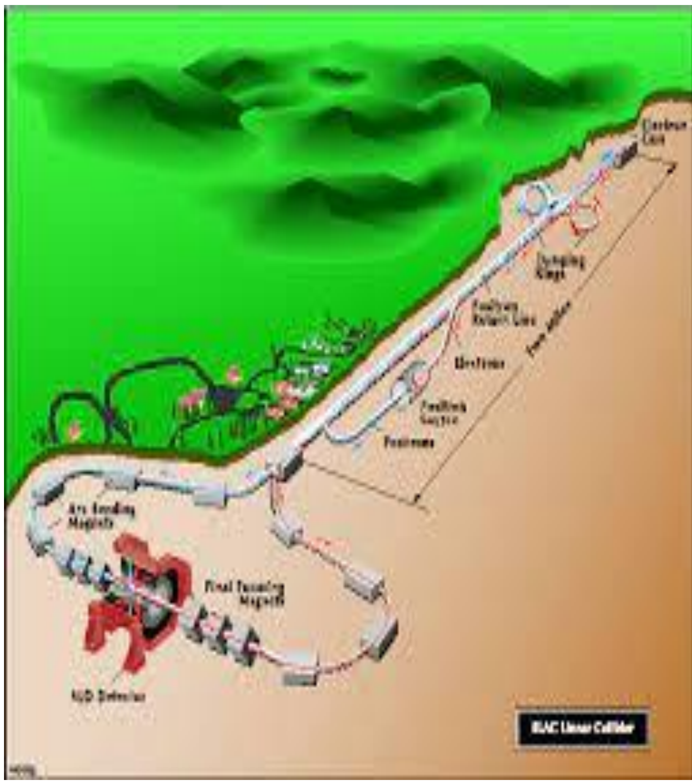
Silicon Calorimeter at SLD

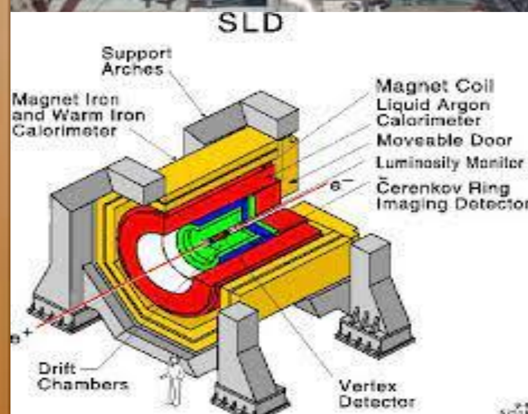
SLAC-PUB-5694
OREXP-91-1101
JULY 1992
(I)

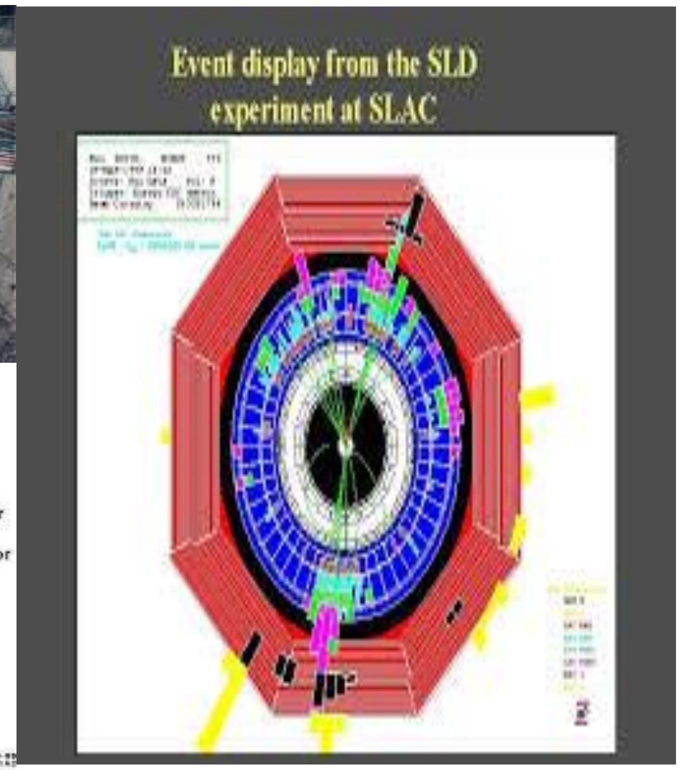
FIRST RESULTS FROM THE SLD SILICON CALORIMETERS*

S.C. Berridge[b], J.E. Brau[a], W.M. Bugg[b], R. Frey[a], K. Furuno[a],
A. Gioumousis[c], G. Haller[c], J. Huber[a], H. Hwang[a], R.S. Kroeger[b],
H. Park[a], K.T. Pitts[a], P. Seward[c], A.W. Weidemann[b], S.L. White[b], C.J. Zeitlin[a]

a. Department of Physics, University of Oregon, Eugene, Oregon 97403
b. Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996
c. Stanford Linear Accelerator Center, Stanford, California 94309

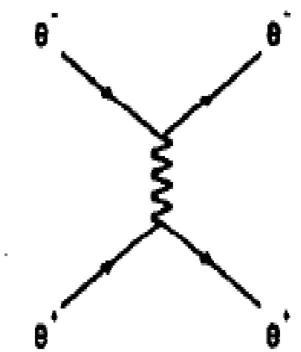




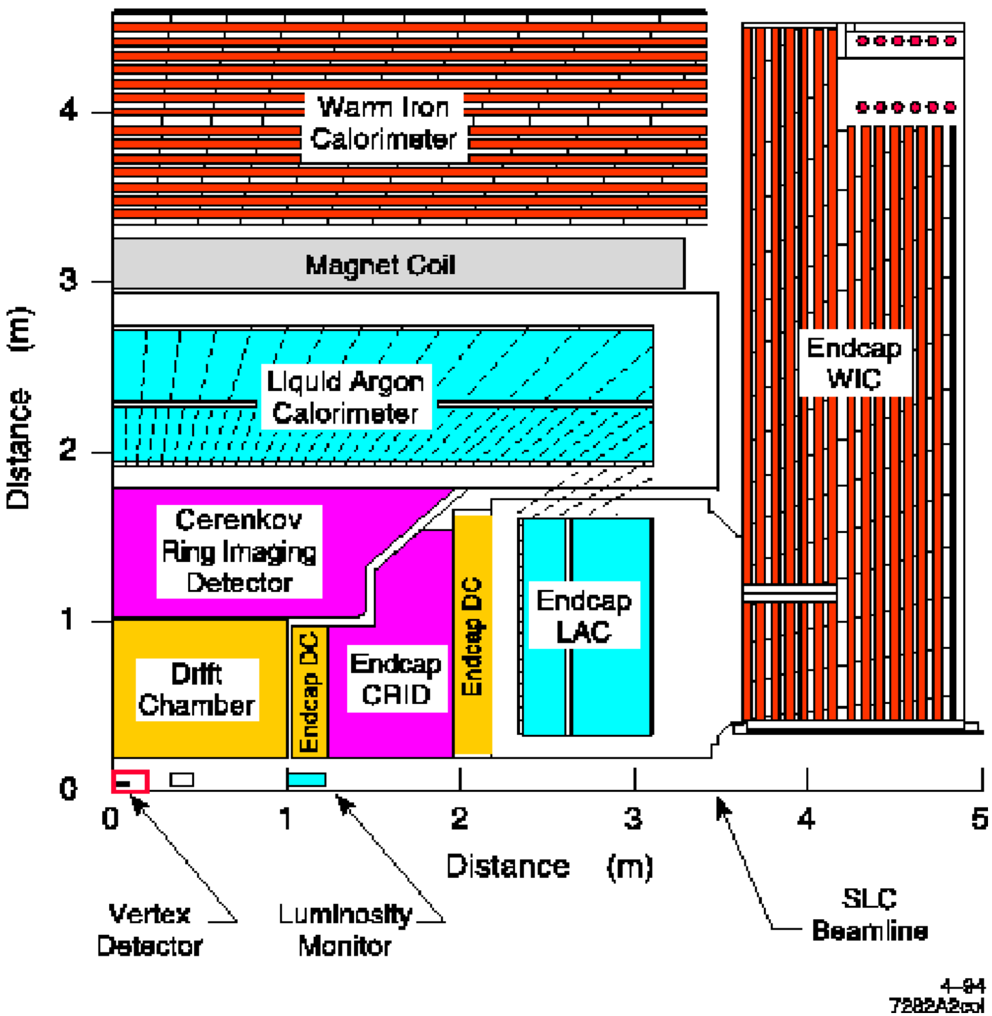


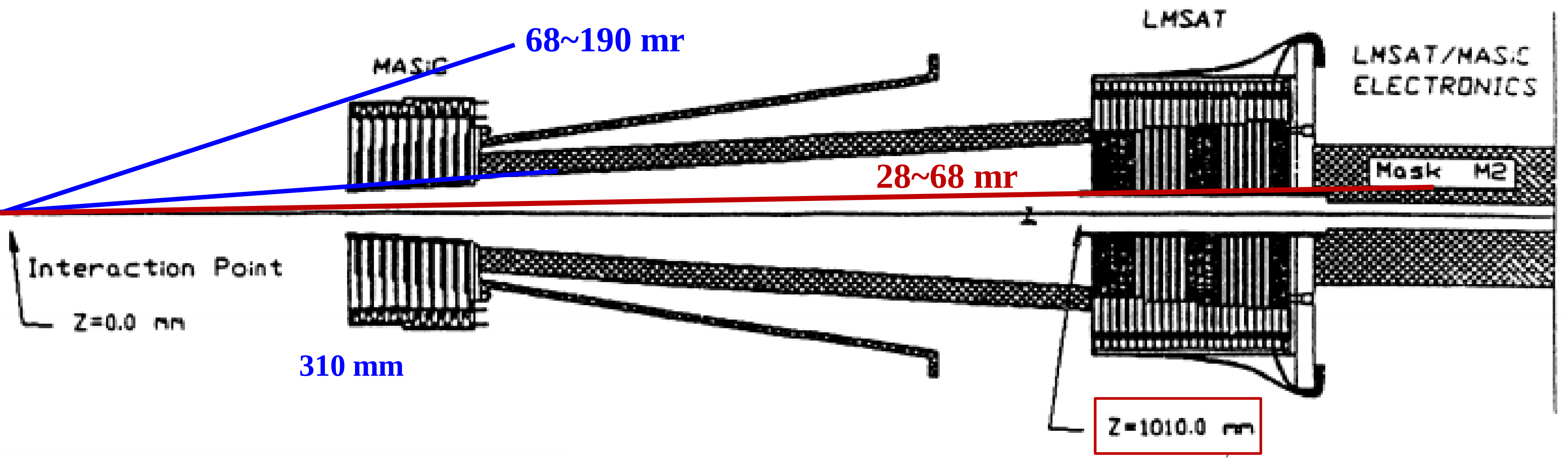
Silicon Calorimeter(Luminosity Monitors)

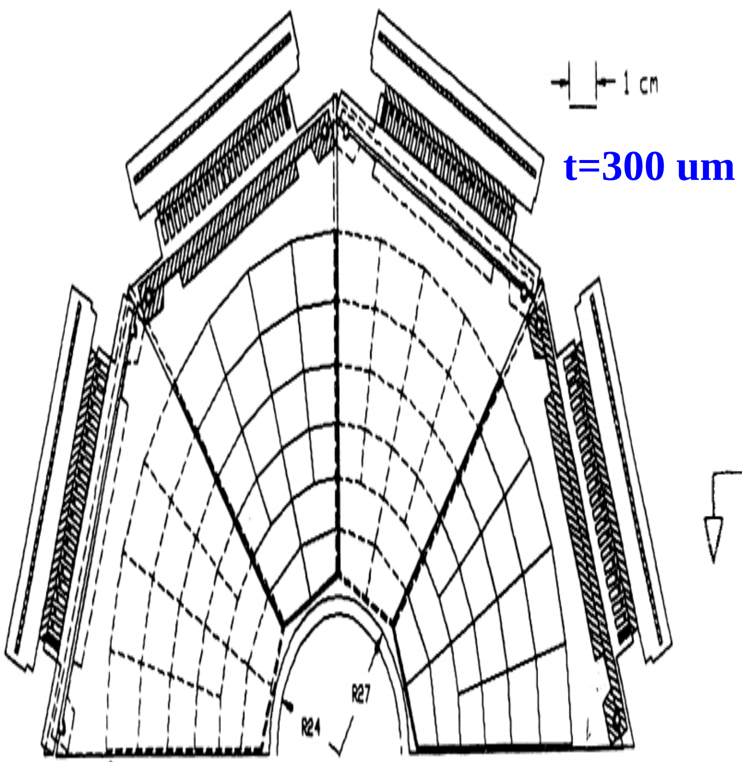
To determine the luminosity delivered to SLD, we measure the rate of Bhabha scattering ($e^+e^- \to e^+e^-$) into the LMSAT and MASC. The cross section for this process (shown diagramatically in Figure 1) is well known and at small angles is essentially free from interference with the Z^0. We expect approximately 4 Bhabha events in the LMSAT per hadronic Z^0 event, and about 1 Bhabha in the MASC per hadronic Z^0. At small angles, $d\sigma/d\theta \sim 1/\theta^3$.

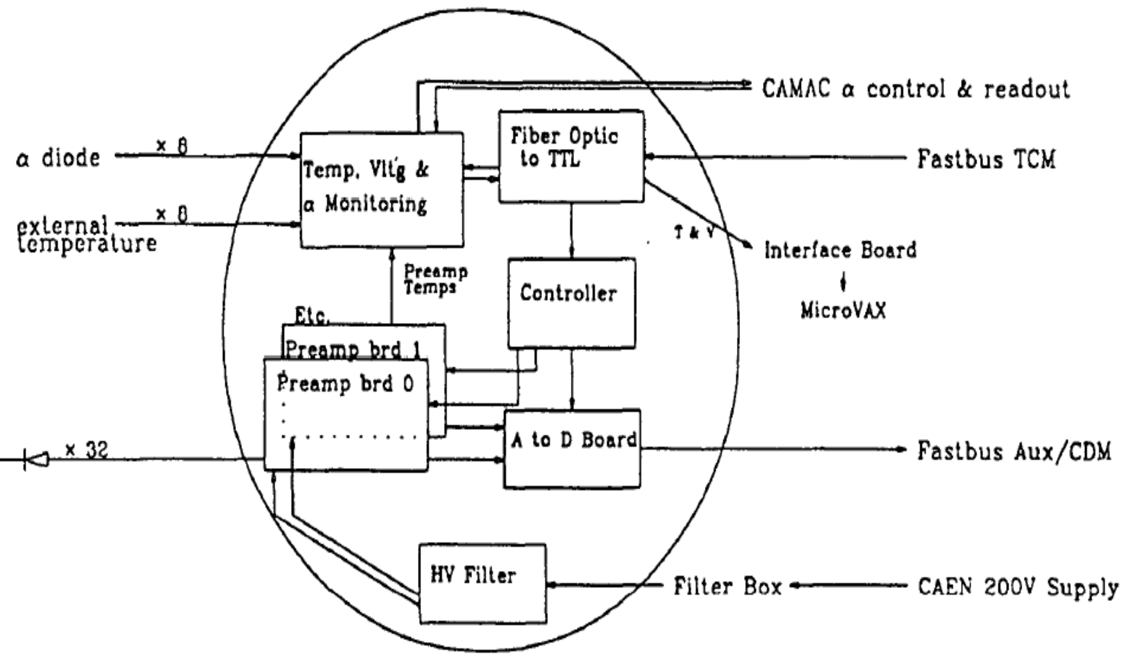


Feynman diagram of the t-channel contribution



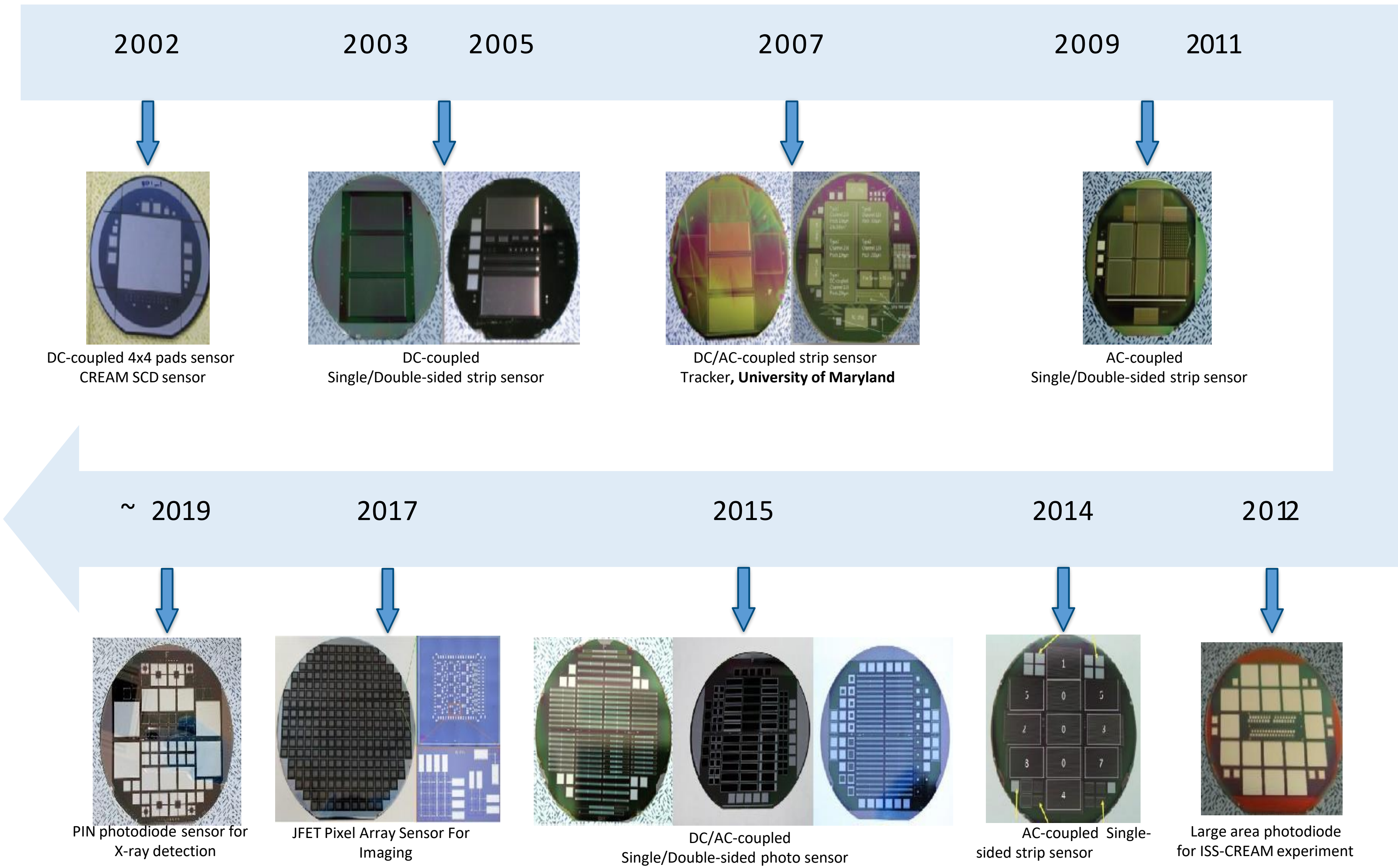






Block diagram of the LMSAT/MASC electronics.

Sensor R&D Activities



Sensor Specification

Sensor type			Size (cm^2)	No. of Ch.	Pitch (um)
Strip	**Single-sided**	**DC**	3.5 x 3.5	32	1000
			3.8 x 2.8	64	200
			3.5 x 3.5	64	500
		AC-coupled	3.8 x 2.8 (Photo)	128	200
			3.8 x 2.8	256	100
			4.0 x 2.55	32	730
	Double-sided	**DC**	5.5 x 3.0	512	50
			2.8 x 2.8	256	100
		AC-coupled	2.8 x 2.8	521	50
Pad	**Double-sided process**	**AC-coupled**	3.3 x 0.4 (Photo)	-	-
			2.3 x 0.8 (Photo)	-	-
		DC	2.3 x 2.3 (Photo)	-	-
			1.0 x 1.0 (Photo)	-	-
			2.0 x 2.0 (Photo)	-	-
			3.0 x 3.0 (Photo)	-	-
JFET Pixel	**Double-sided process**	**DC**	0.795 x 0.825	matrix	30, 100,200

CREAM-I Collaboration

H.S. Ahn, O.Ganel, K.C. Kim, M.H.Lee, L. Lutz, A. Malinin, E.S. Seo, R. Sina, J. Wu, Y.S.Yoon, S.Y. Zinn
University of Maryland, USA
J.H. Han, H.J. Hyun, J.A. Jeon, J.K. Lee, S.W. Nam, I.H. Park, N.H. Park, J. Yang
Ewha Womans University, S. Korea
M.G. Bagliesi, G. Bigongiari, P. Maestro, P.S. Marrocchesi, R. Zei
University of Siena & INFN, Italy
P. Boyle, S. Swordy, S. Wakely
University of Chicago, USA
N.B. Conklin, S. Coutu, S.I. Mognet
Penn State University, USA
P. Allison, J.J. Beatty
Ohio State University, USA
J.T. Childers, M.A. Duvernois
University of Minnesota, USA
K.I. Seon, W.Y. Han
Korea Astronomy Observatory, S. Korea
S. Nutter
Northern Kentucky University, USA
S. Minnick
Kent State University, USA
H. Park
Kyungpook National University, S. Korea
K.W. Min
Korea Advanced Institute of Science and Technology, S. Korea

CREAM

Cosmic Ray Energetics And Mass

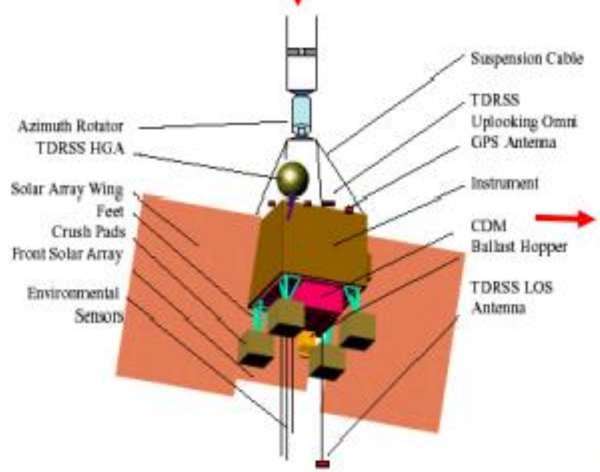
An ULDB Cosmic Ray Astrophysics Mission

- ✓ **Elemental composition near the knee**
- ✓ **Direct measurement of Energy & Charge of primary cosmic rays**
- ✓ **Optimized arrangement of several components**

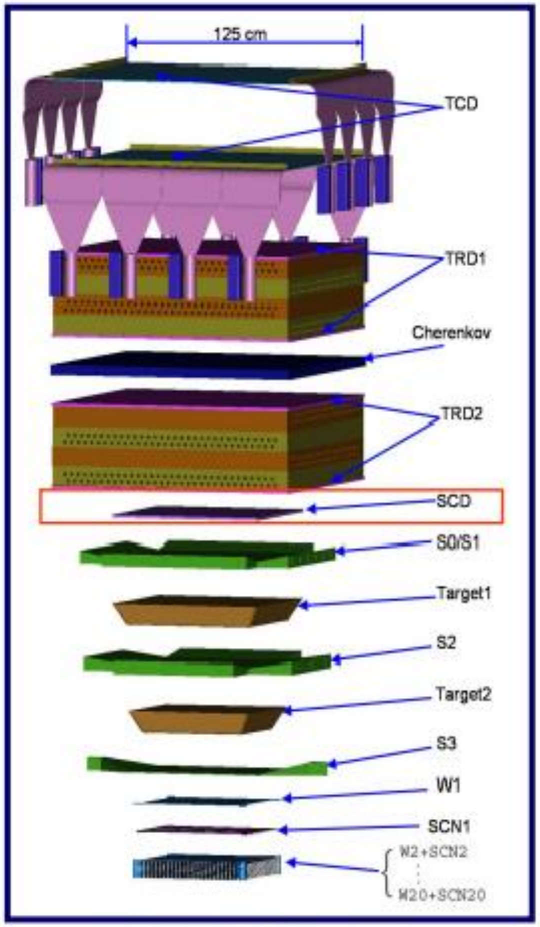
- **TCD (Timing based Charge Detector)**
  - Charge measurement
  - Plastic scintillator + PMT
- **TRD (Transition Radiation Detector)**
  - Measure Lorentz factor for $Z \geq 3$ for low energy
- **SCD (Silicon Charge Detector)**
  - *Charge measurement*
  - *Pixellated silicon*
- **HDS (Hodoscope)**
  - Track Reconstruction, charge identif.
  - Plastic scintillator + PMT
- **CAL (Calorimeter)**
  - Energy measurement for $Z \geq 1$
  - Scintillator-Tungsten with C targets

- **Energy measument**
  - **TRD, CAL**
- **Charge measurement**
  - **TCD, SCD**
- **Trigger**
  - Z-low trigger : CAL + TCD
  - Z-Hi trigger : TCD + TRD-chrenkov

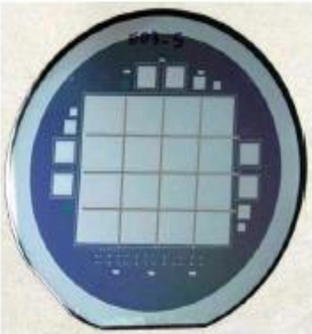
NASA ULDB Balloon



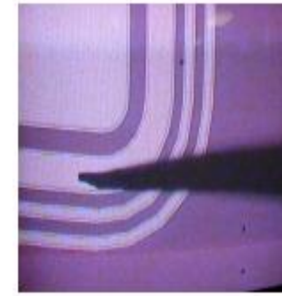
CREAM Payload



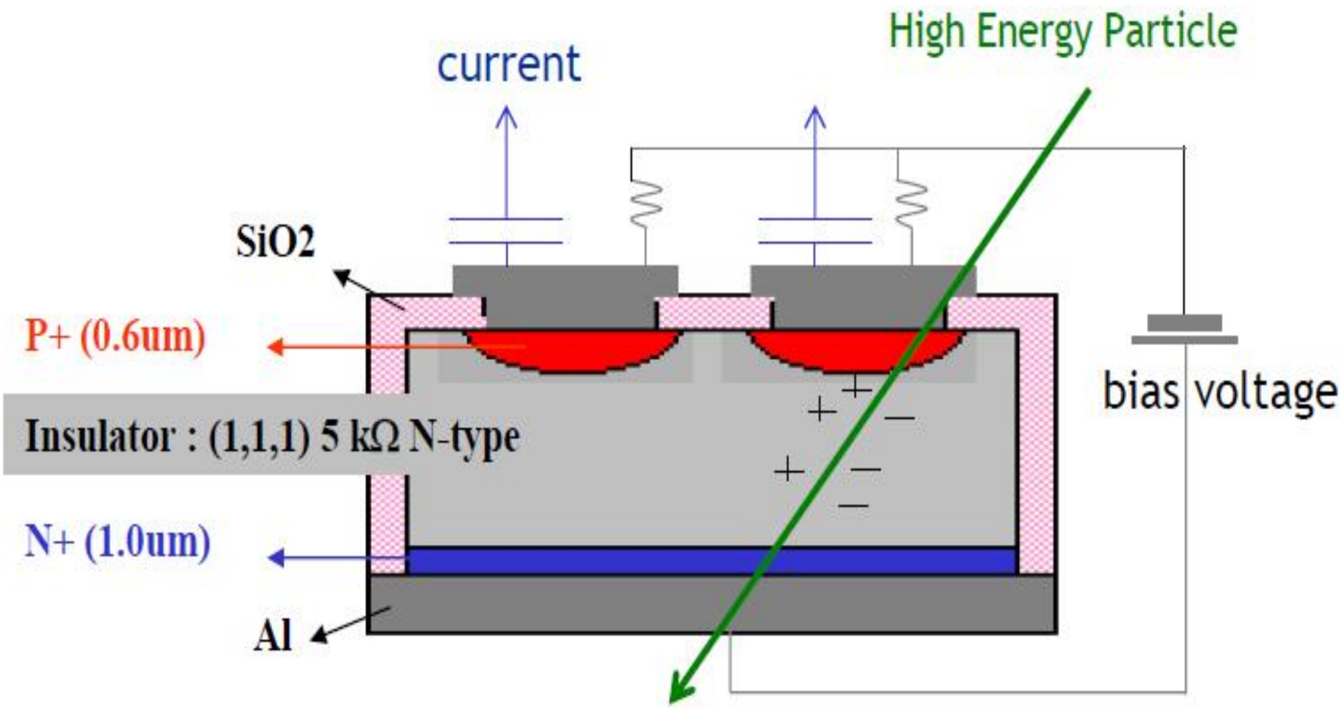
CREAM Baseline configuration



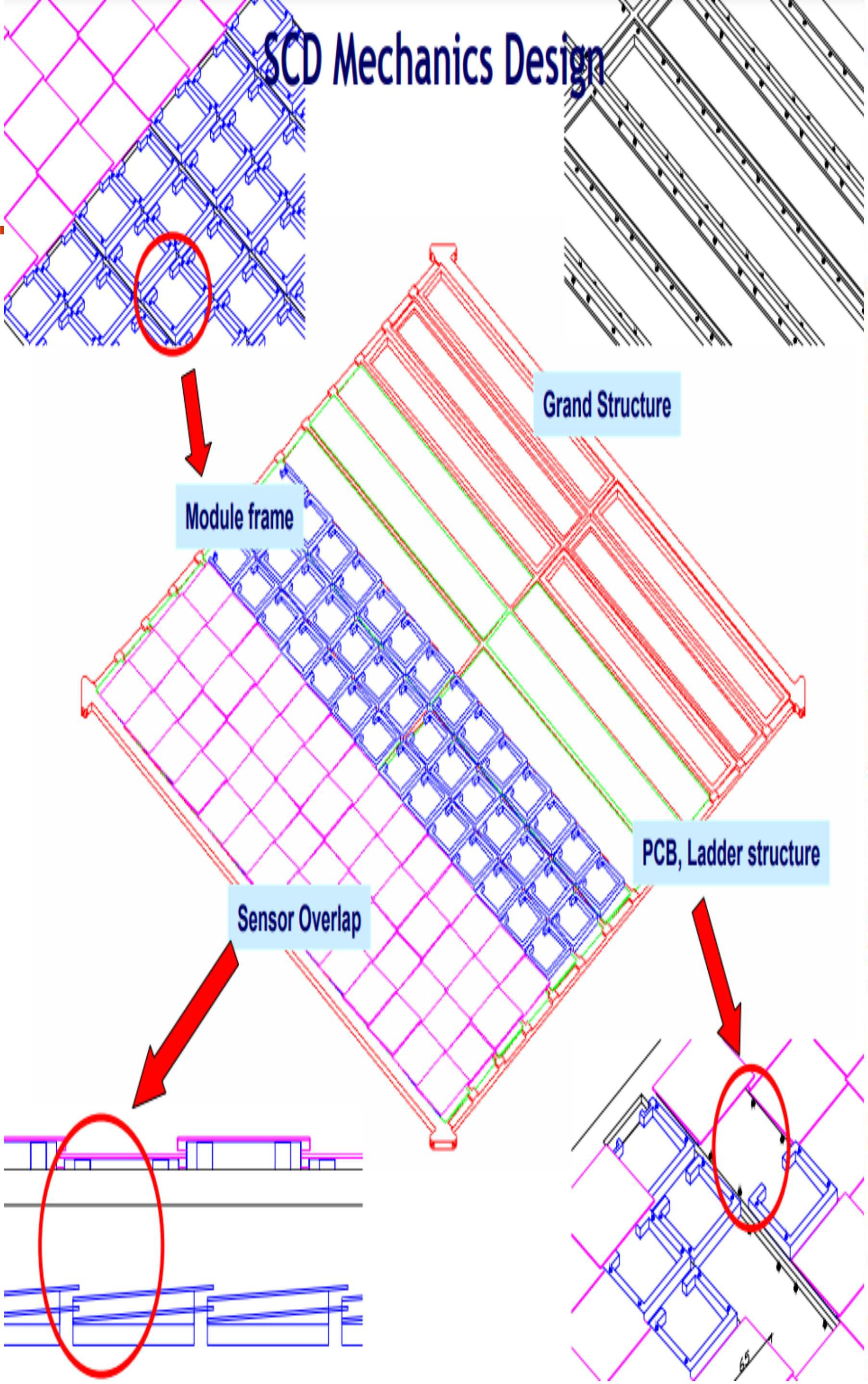
Silicon Sensor Structure



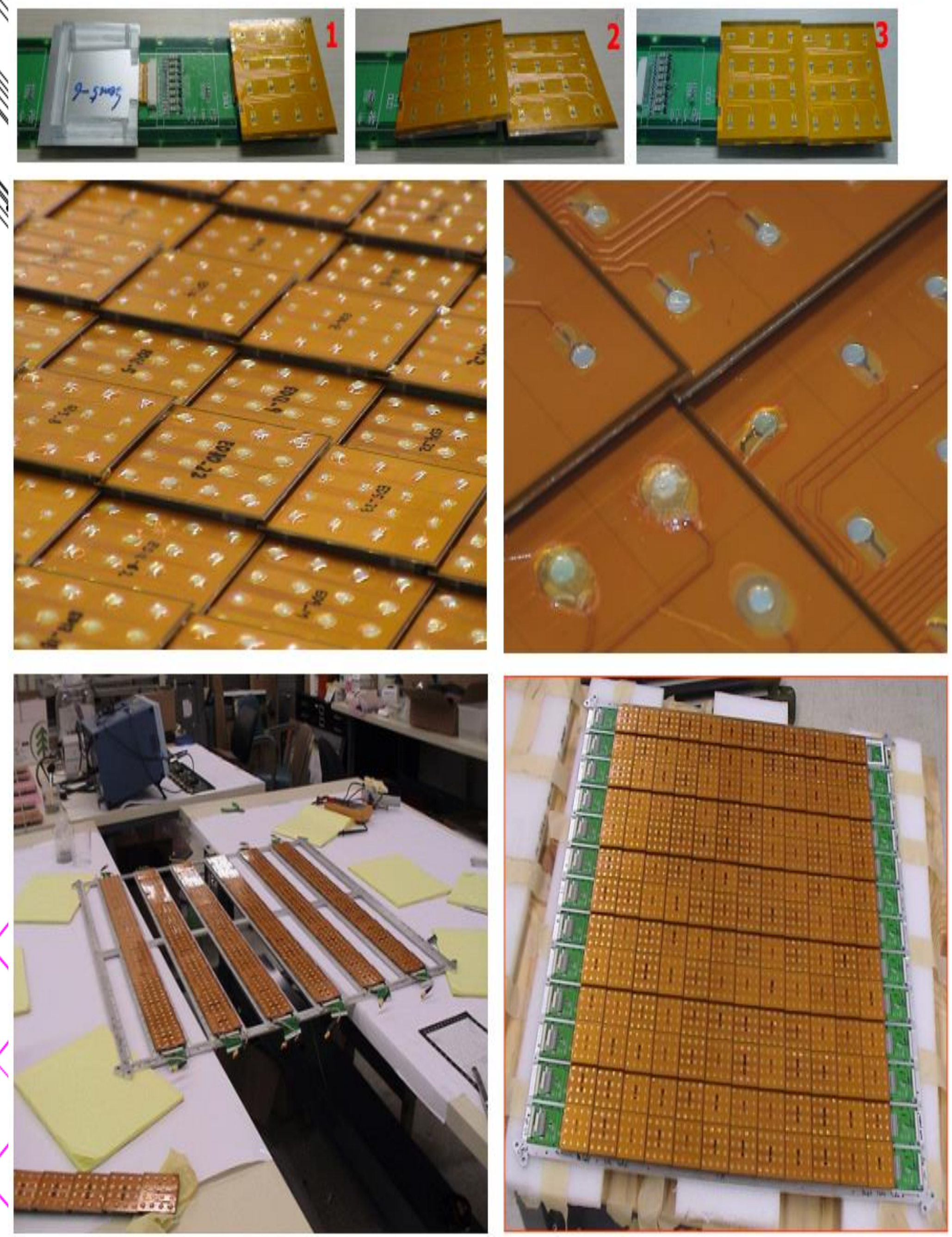
- PIN diode
- DC type
- Wafer: (1,1,1) type, 380 um, 5”, double polished, Wacker
- P+ implantation process, while N+ diffusion process
- Three guard rings



SCD Mechanics Design

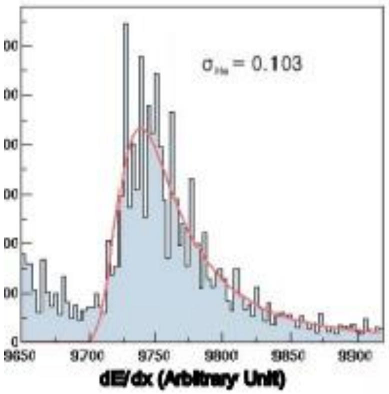


Mount of 7 Sensors on to an electronics board : “detachable design”

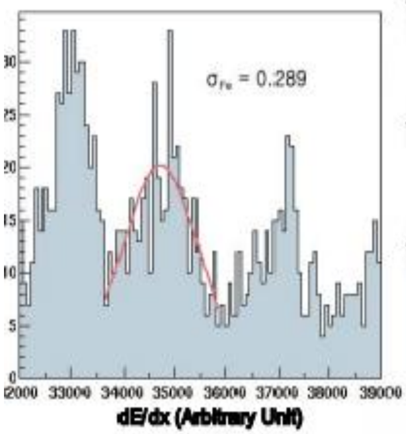


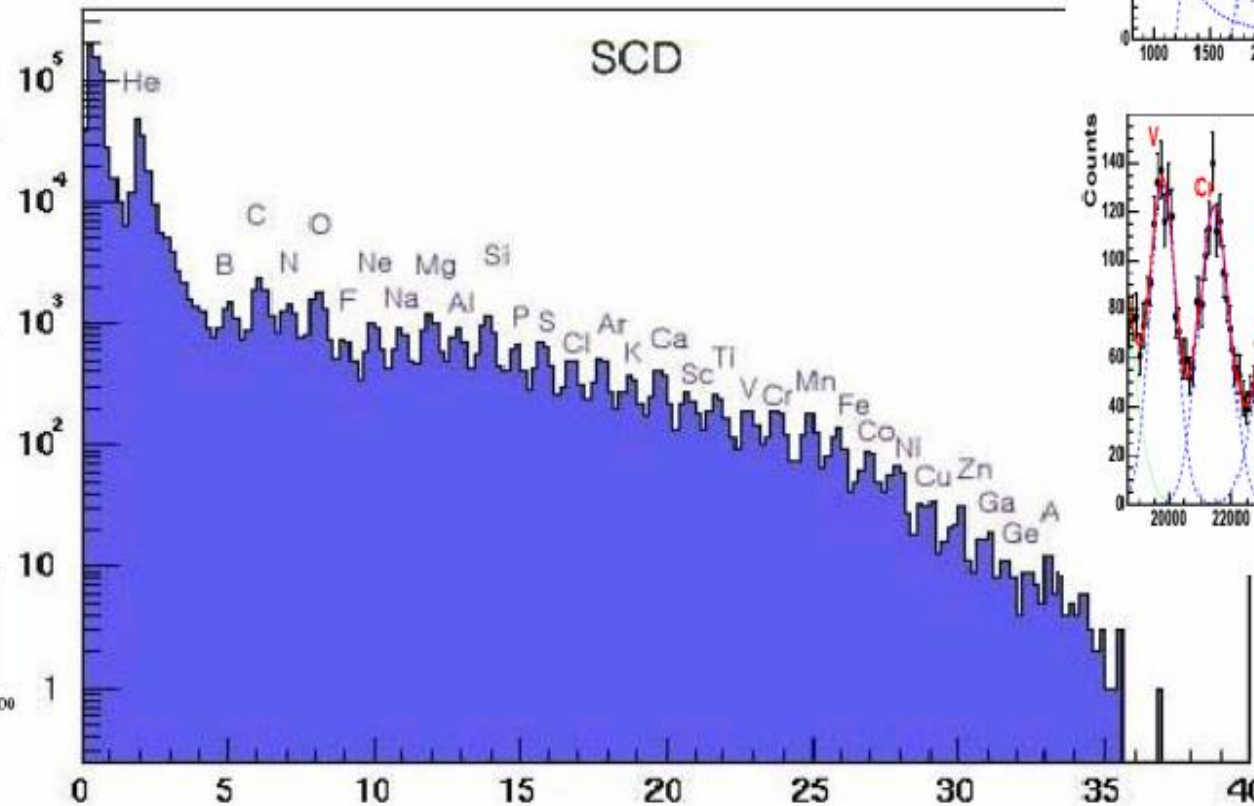
- Charge distribution of beam fragments detected in SCD
- Excellent charge identification up to Z=33

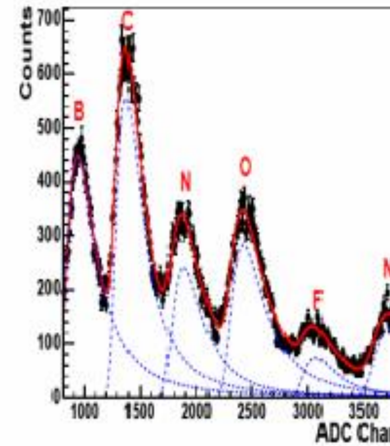
He

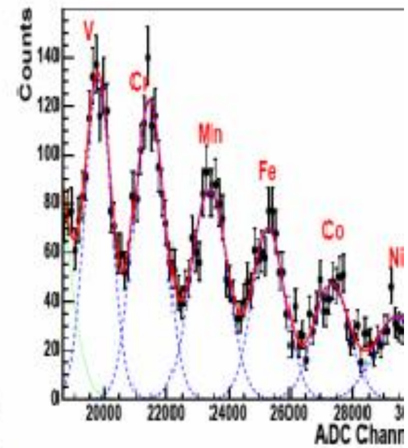


Fe

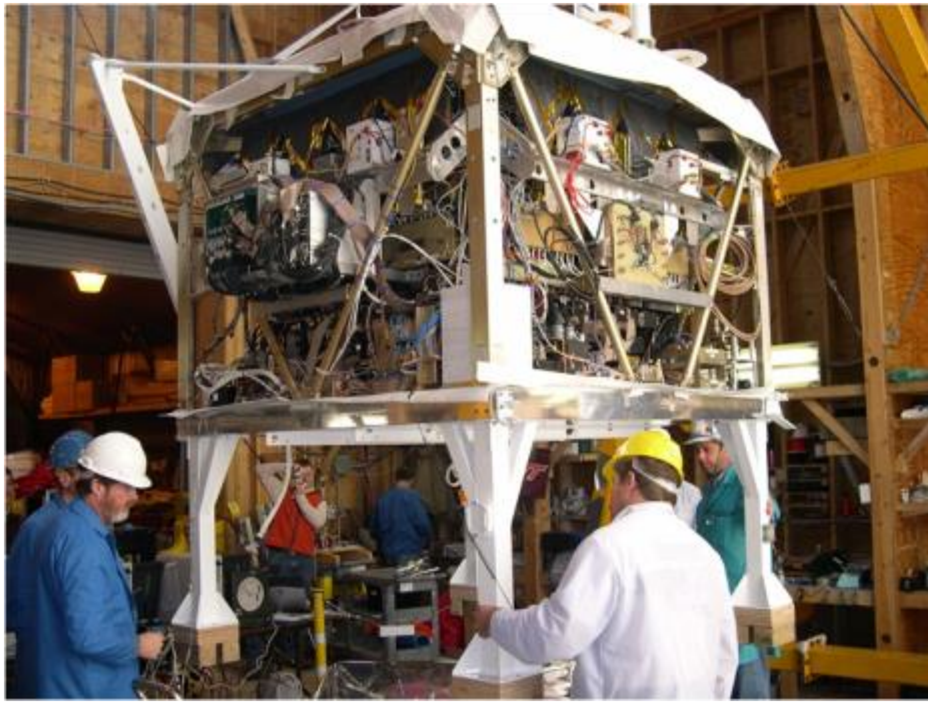


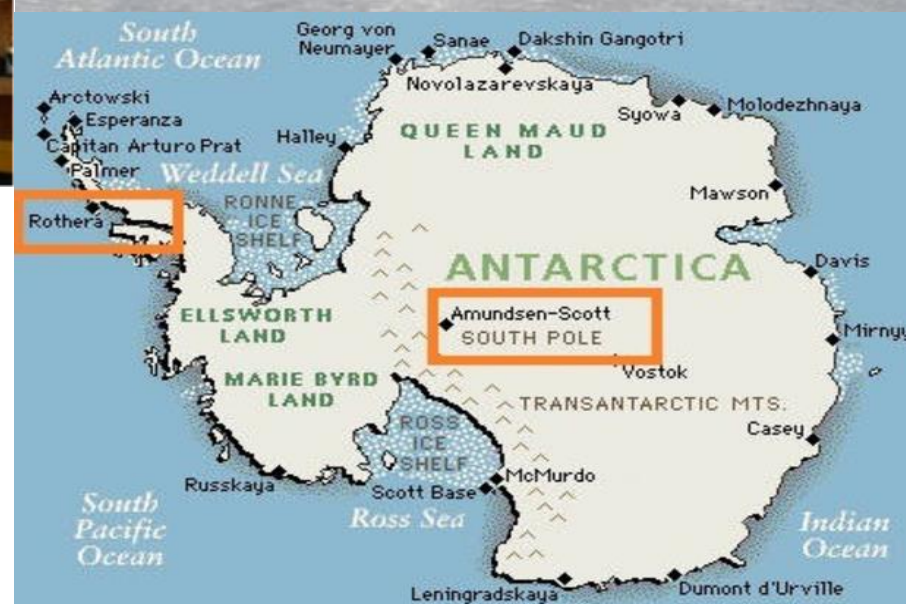






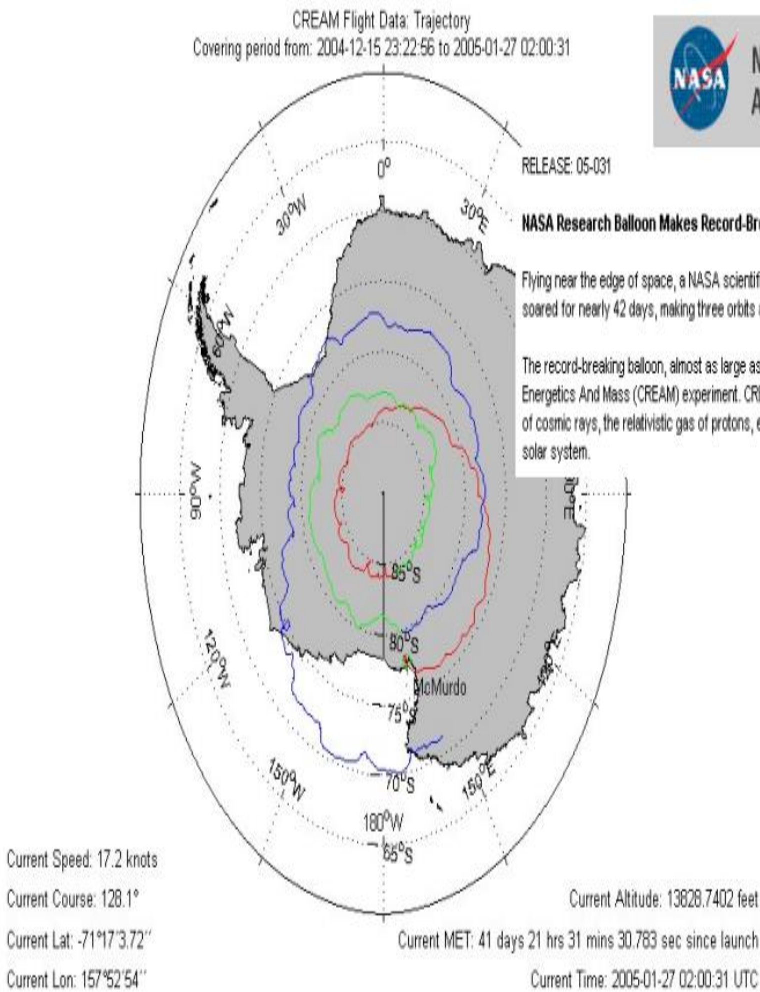
Integration of CREAM-I at Antarctica





The first flight at Antarctica Dec. 2004

- Flight trajectory
- Total flight time : 41 days 21 hours 31 mins
- CREAM broke both duration and distance records for a long duration balloon



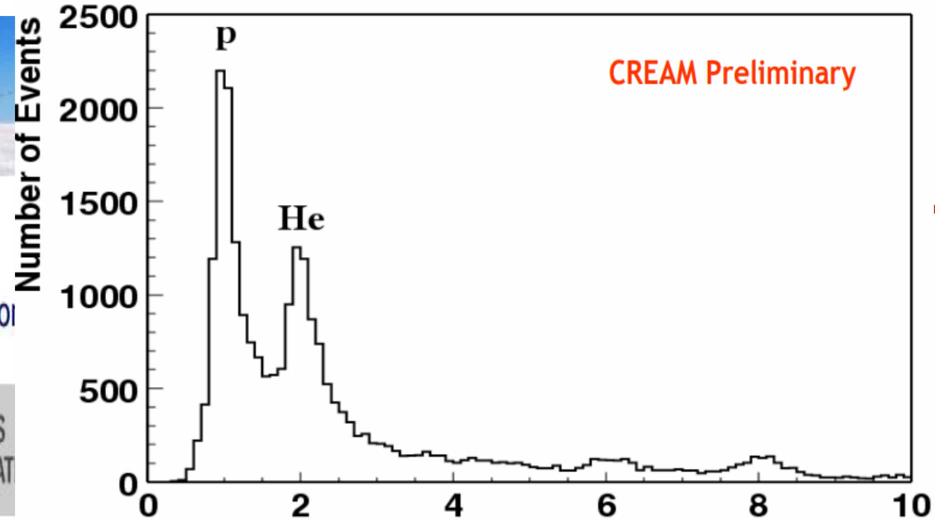
NATIONAL AERONAUTICS AND SPACE ADMINISTRAT

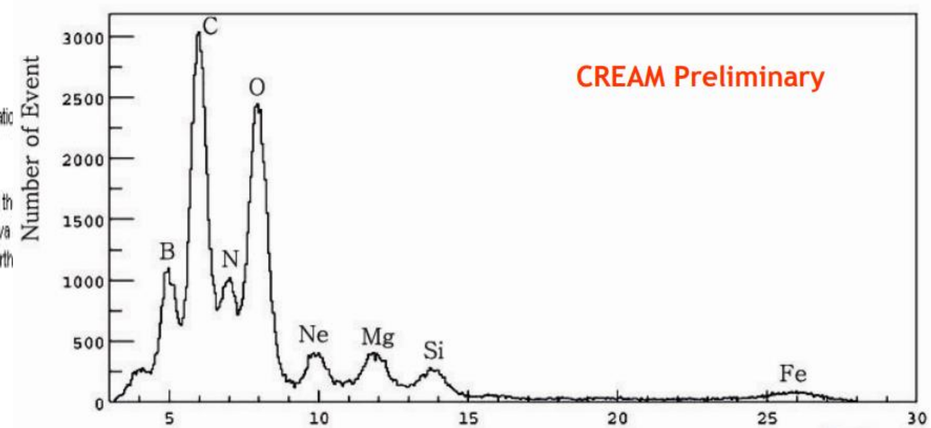
RELEASE: 05-031

NASA Research Balloon Makes Record-Breaking Flight

Flying near the edge of space, a NASA scientific balloon broke the flight record for duratic soared for nearly 42 days, making three orbits around the South Pole.

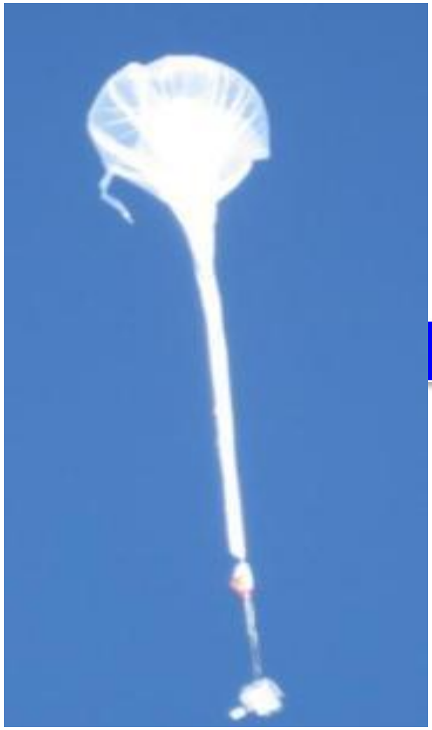
The record-breaking balloon, almost as large as one and one half football fields, carried th Energetics And Mass (CREAM) experiment. CREAM is designed to explore the supernova of cosmic rays, the relativistic gas of protons, electrons and heavy nuclei arriving at Earth solar system.





Instruments came back to UMD in good shape. (2005/04/01)

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**

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

J.A. Jeon, J. Lee, H.Y. Lee, H. Lim, H.A. Park, I.H. Park **SungKyunKwan University, Korea**

Y.S. Hwang, H.J. Hyun, H.B. Jeon, H. J. Kim, J. Lee, J.M. Park, H. Park **Kyungpook National University, Korea**

S. Nutter **Northern Kentucky University**

J.T. Link, J.W. Mitchell **NASA/Goddard Space Flight Center**

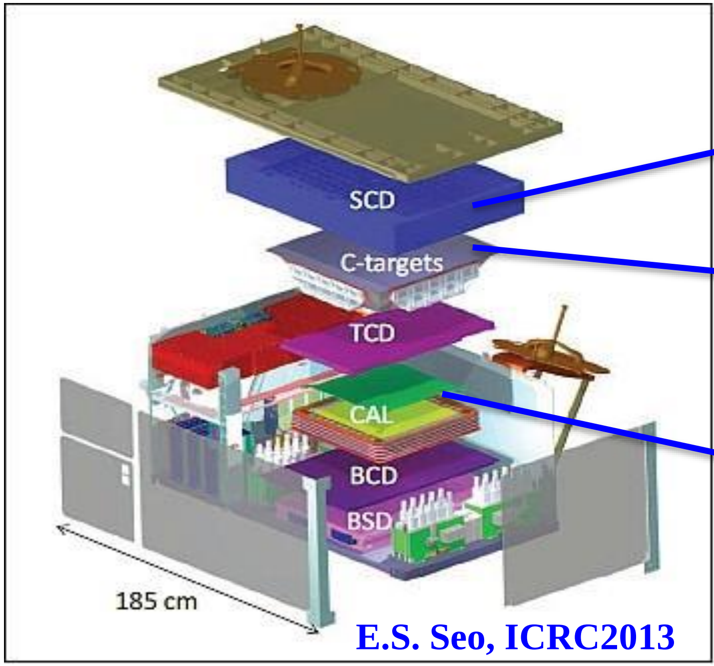
M. Buénerd, L. Derome, L. Eraud **Laboratoire de Physique Subatomique et de Cosmologie, Grenoble, France**

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

ISS-CREAM Instrument

• **CREAM instruments consists of complementary and redundant particle detectors**

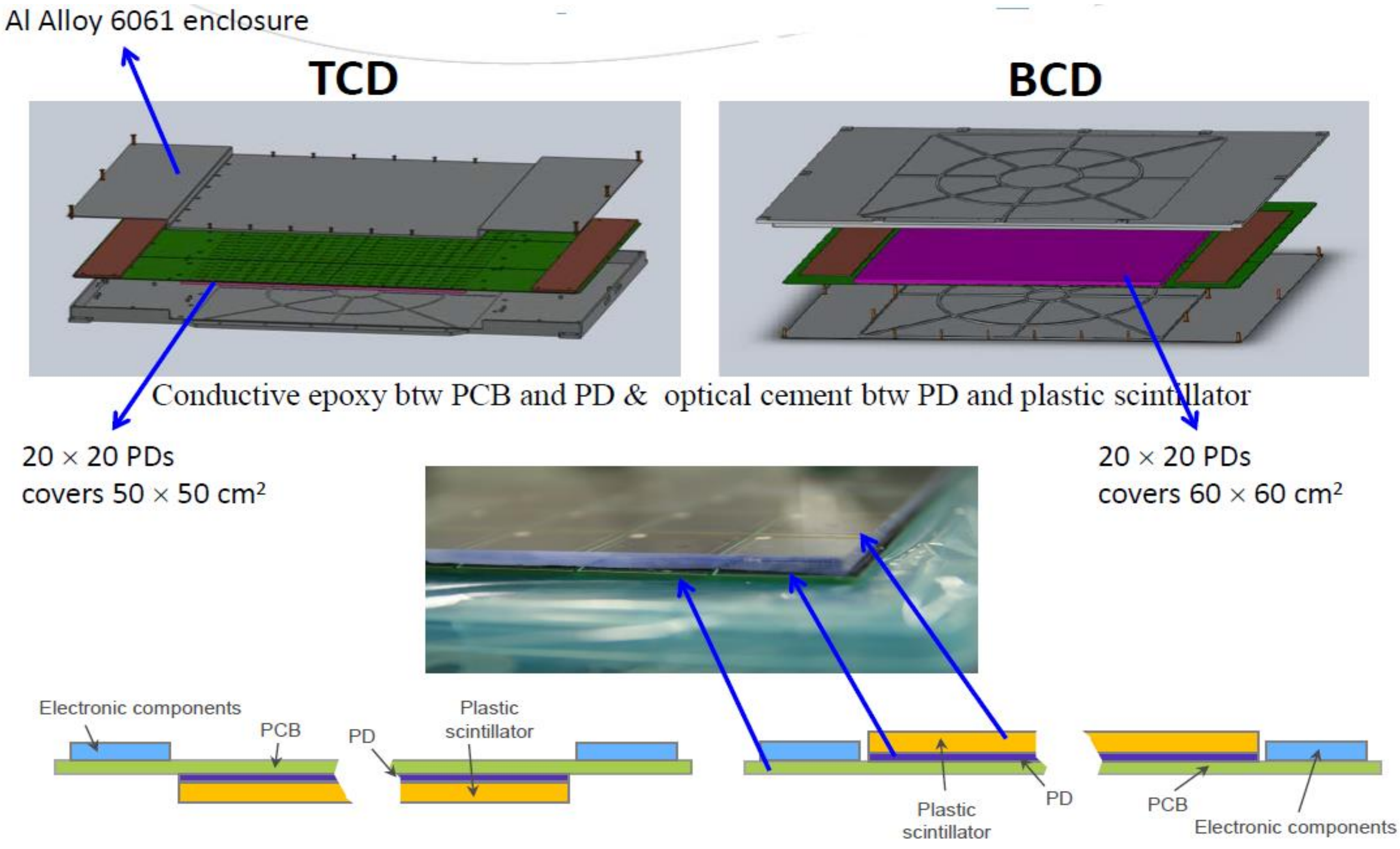
- Silicon Charge Detectors provide precise charge measurements
- **Top/Bottom Counting Detectors** provide shower profiles for electron/hadron separation
- ionization Calorimeter determines the energy of the cosmic ray, provide tracking and event trigger
- Boronated Scintillator Detector provides additional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



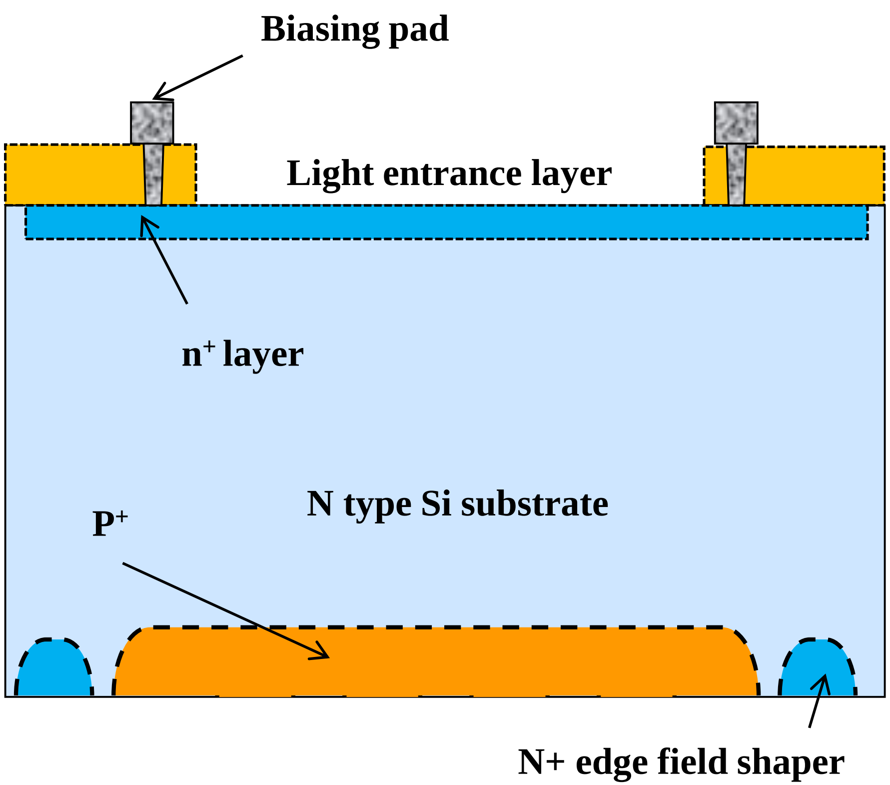
E.S. Seo, ICRC2013

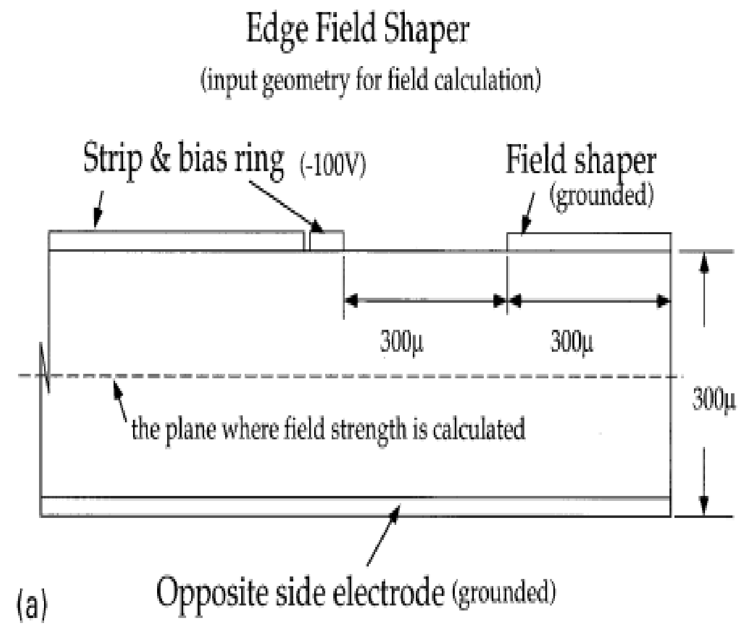
- 4 layers of SCD
  - 525 μm thick, 2.12 cm^2 pixels
  - 79 cm × 79 cm active detector area
- Carbon Target
  - 0.5 λ_{int}
  - induces hadronic interactions
- Calorimeters
  - 20 layers W + Scn Fibers

Design of TCD/BCD



Photodiode Sensor

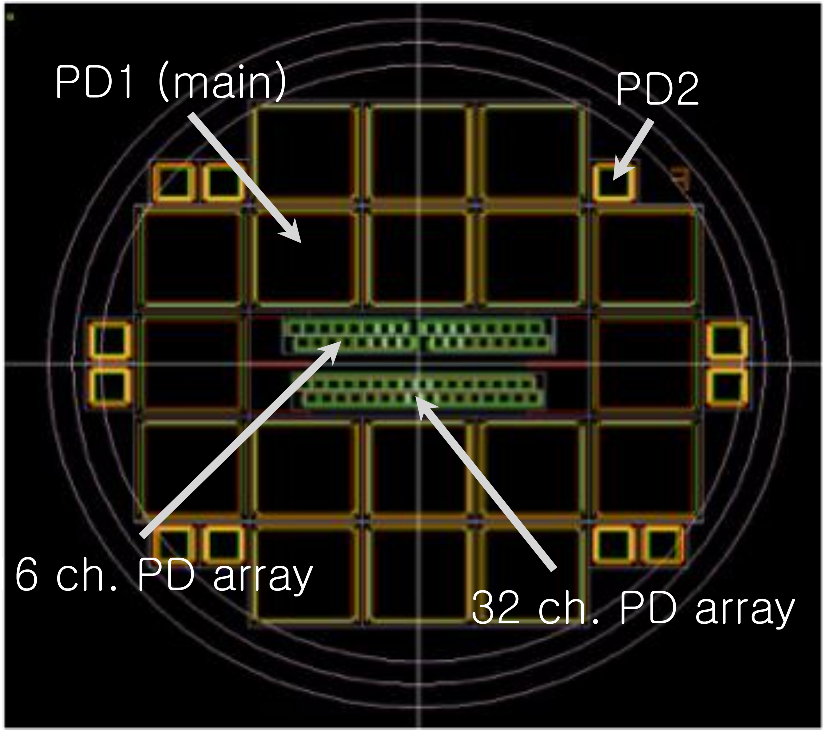


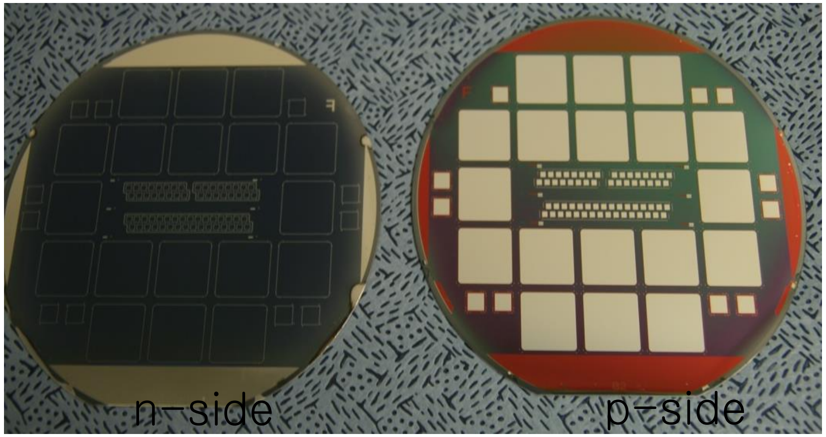


T. Ohsugi, et al., NIMA 436 (1999) 272-280

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

Photodiode Sensor





- Wafer
  - 6 inch, 650 μm thick, n-type 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

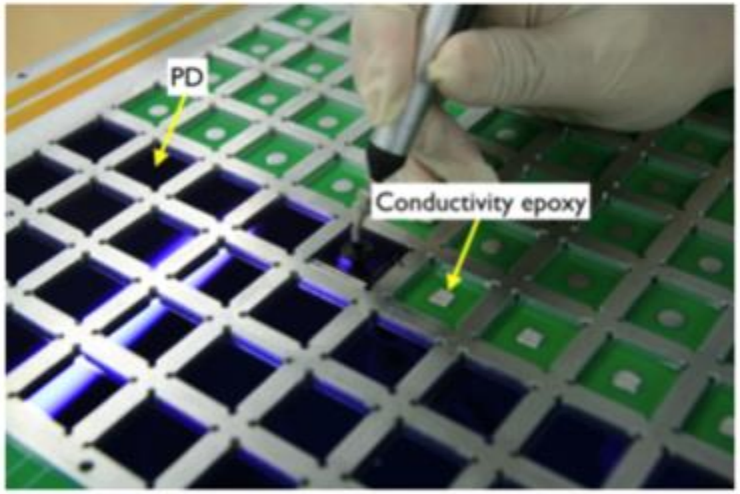
    PD1 (main) : 18 EA / wafer
- The PDs are fabricated at ETRI in Daejeon, Korea
- Test patterns

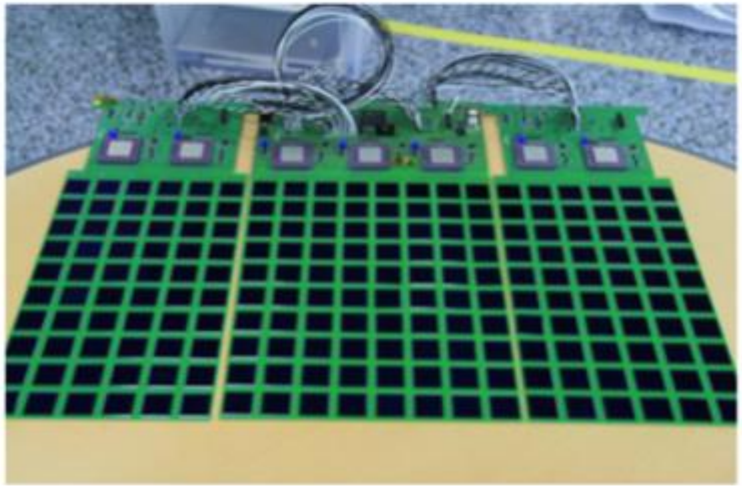
  PD2 (1.0 × 1.0 cm^2) : 11 EA / wafer

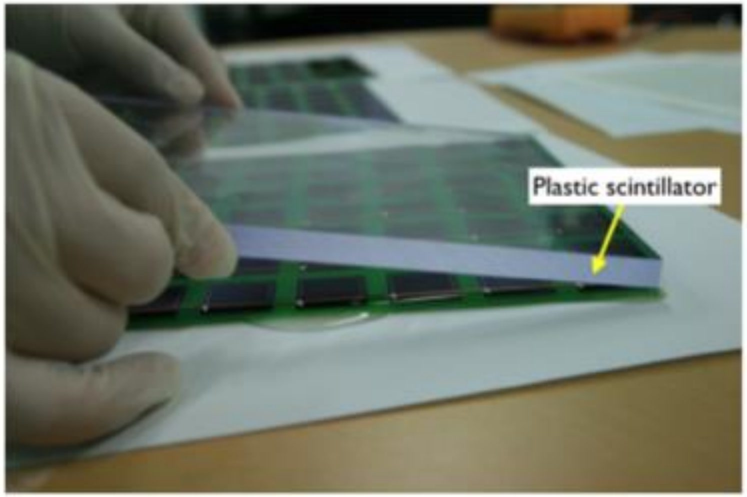
  16 ch. PD array : 2 EA / wafer

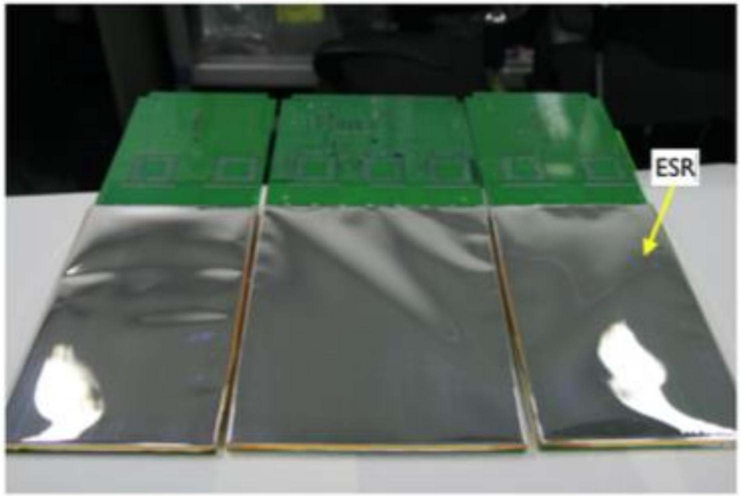
  32 ch. PD array : 1 EA / wafer

Detector Parts of TCD/BCD

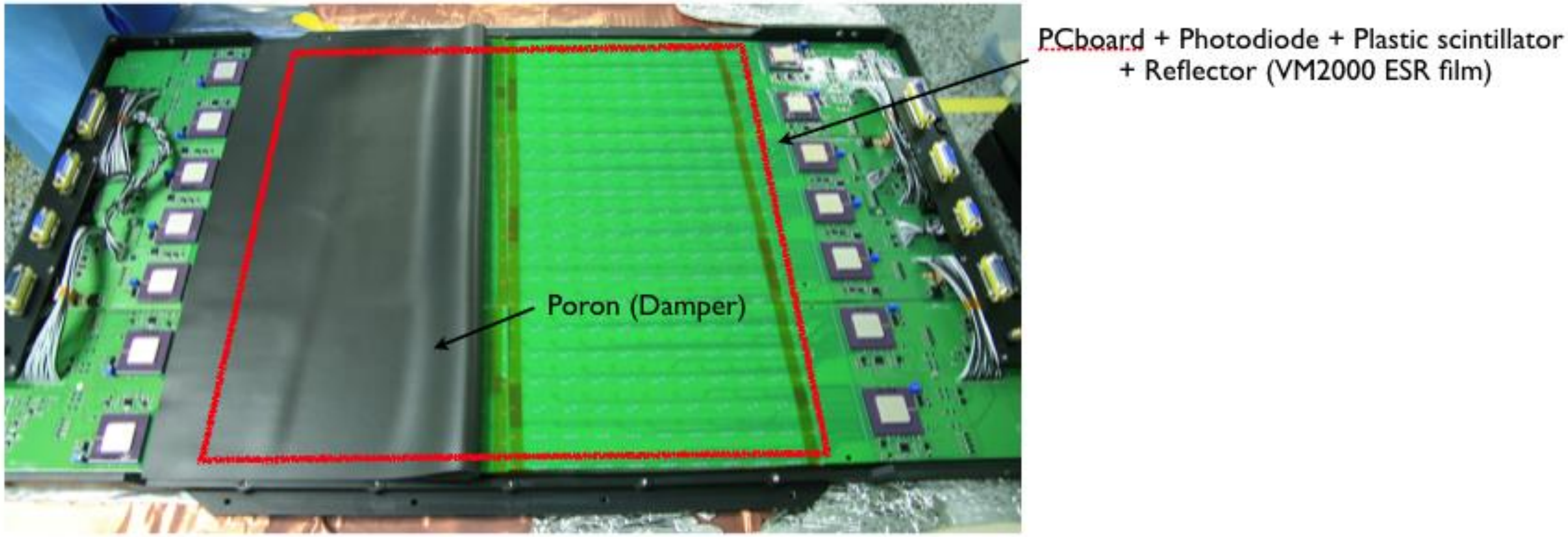








Top Counting Detector



non-conductivity coating

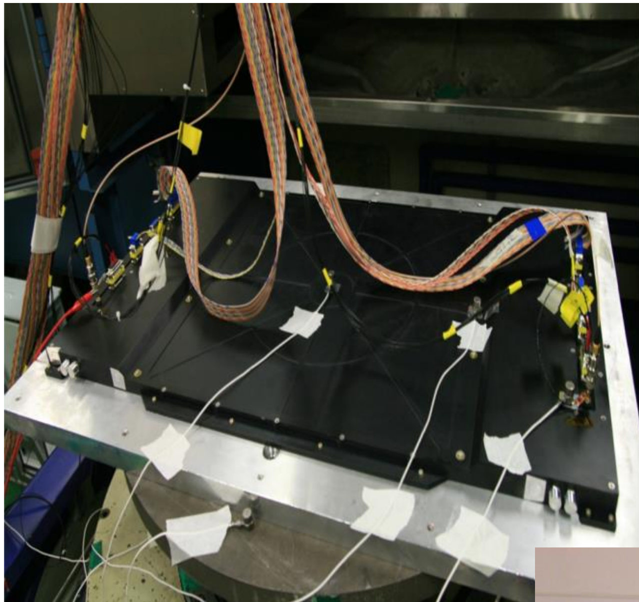
- Dimension: 901 mm x 551 mm x 30 mm
- Weight: 9.6 kg

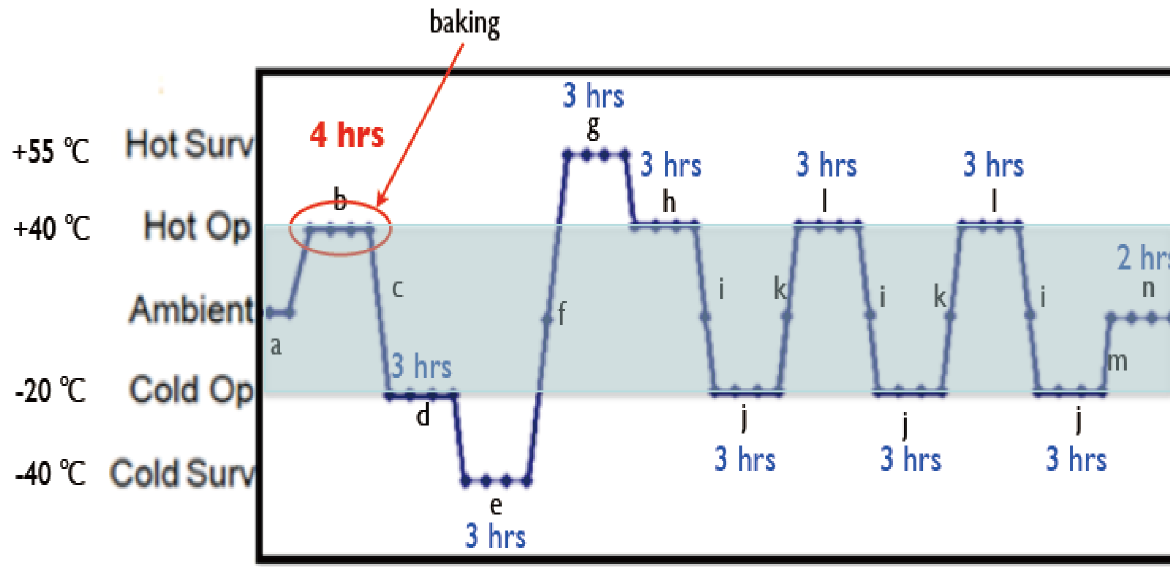
Bottom Counting Detector

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

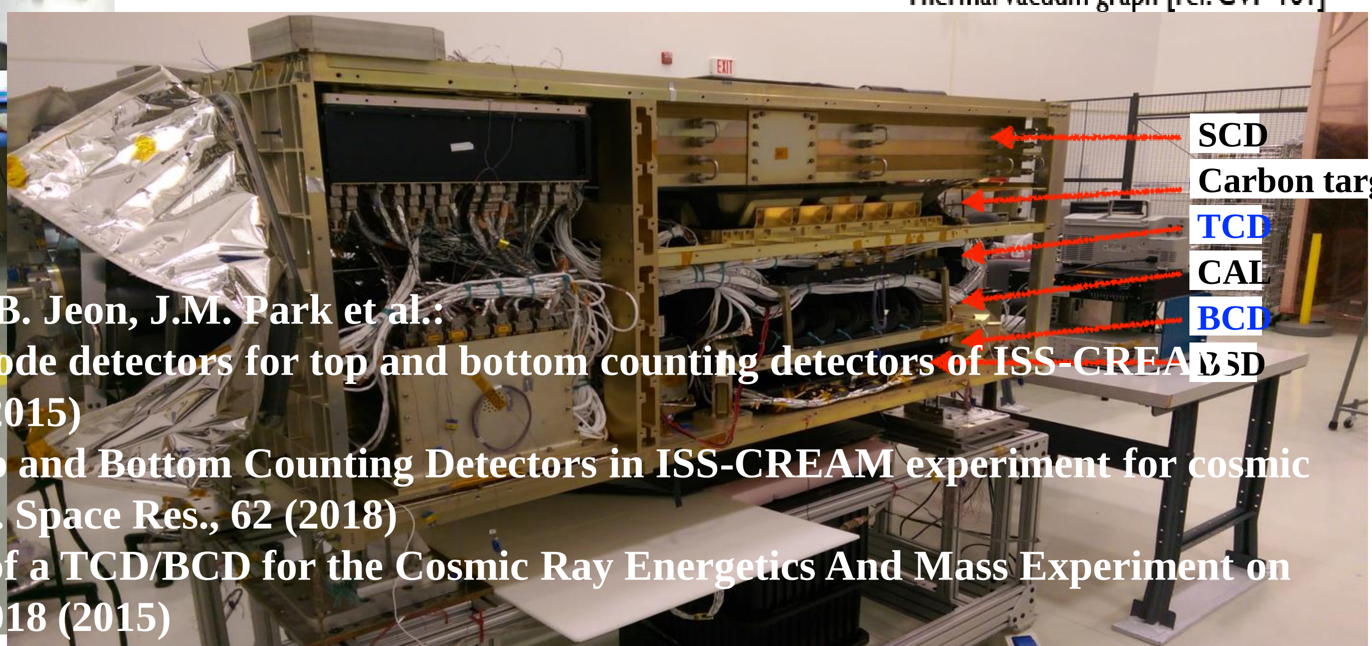
- Dimension: 950 mm x 650 mm x 33 mm
- Weight: 15.6 kg

Vibration/Thermal-Vac Tests





Thermal Vacuum graph [ref. CVP-101]

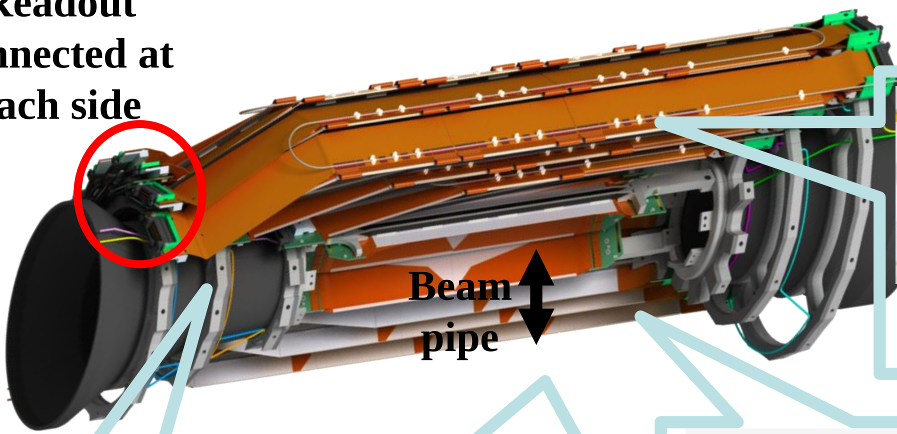


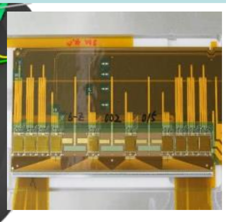
H.J. Hyun, Y.S. Hwang, H.B. Jeon, J.M. Park et al.:

- Performances of photodiode detectors for top and bottom counting detectors of ISS-CREAM experiment, NIMA 787 (2015)
- A simulation study of Top and Bottom Counting Detectors in ISS-CREAM experiment for cosmic ray electron physics, Adv. Space Res., 62 (2018)
- Construction and testing of a TCD/BCD for the Cosmic Ray Energetics And Mass Experiment on
- the ISS, JINST 10 P070018 (2015)

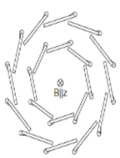
SVD at Belle II
(벨 실험 대표: 권영준 교수/ 과제 책임자: 천병구 교수)

Readout connected at each side

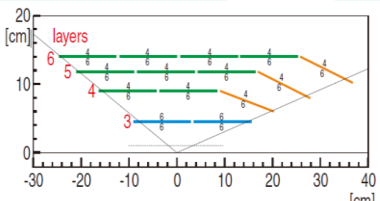




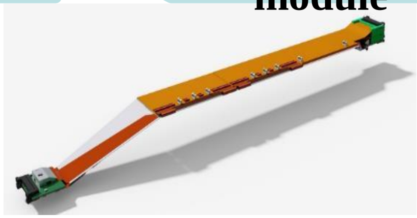
Chip on Sensor module



- Side view Windmill structure



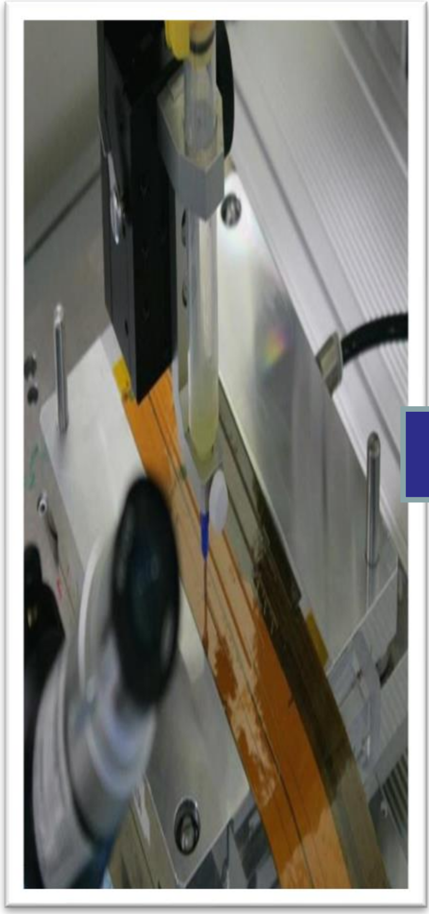
The SVD consists of 4 layers



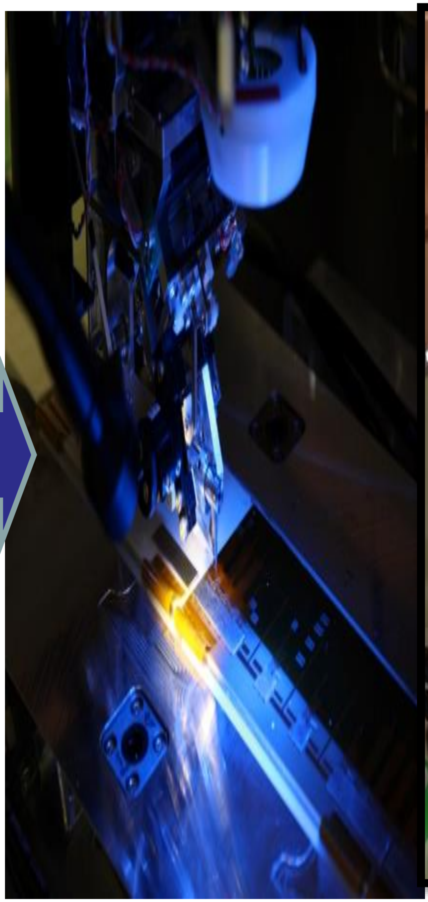
The layer is consisted of several ladders

- **SVD Ladder Mock-up Assembly for the Belle II Experiment, K. Kang, H. Hyun, H. Jeon, D.H. Kah etc. New Physics: Sae Mulli 65 (2015)**

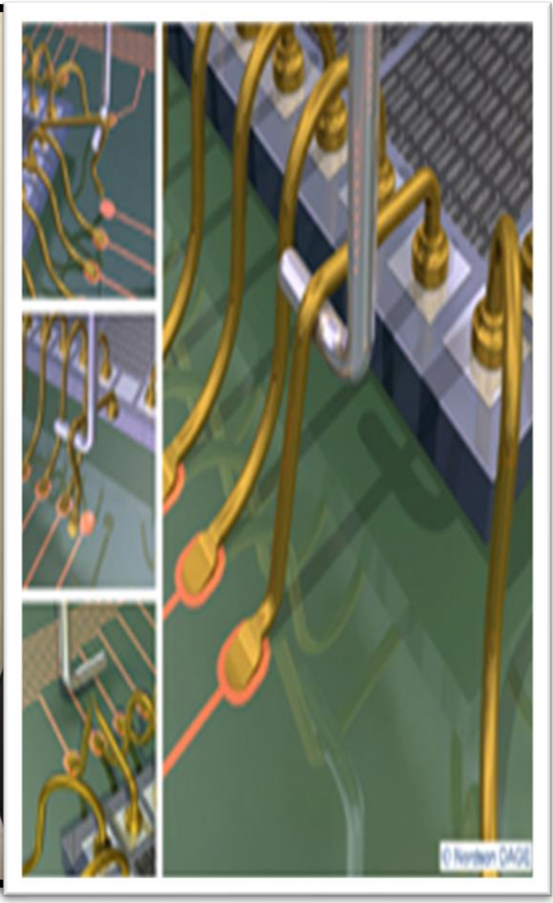
- Study of gluing and wire bonding for the Belle II silicon vertex detector, K. Kang, H. Hyun, H. Jeon, etc. NIMA 763 (2014)
- A bonding study toward the quality assurance of Belle-II silicon vertex detector modules, K.H. Kang, H.B. Jeon, etc. NIMA 831 (2016)



Gluing
- Gluing on detector material



Wire bonding
- Electrical connecting



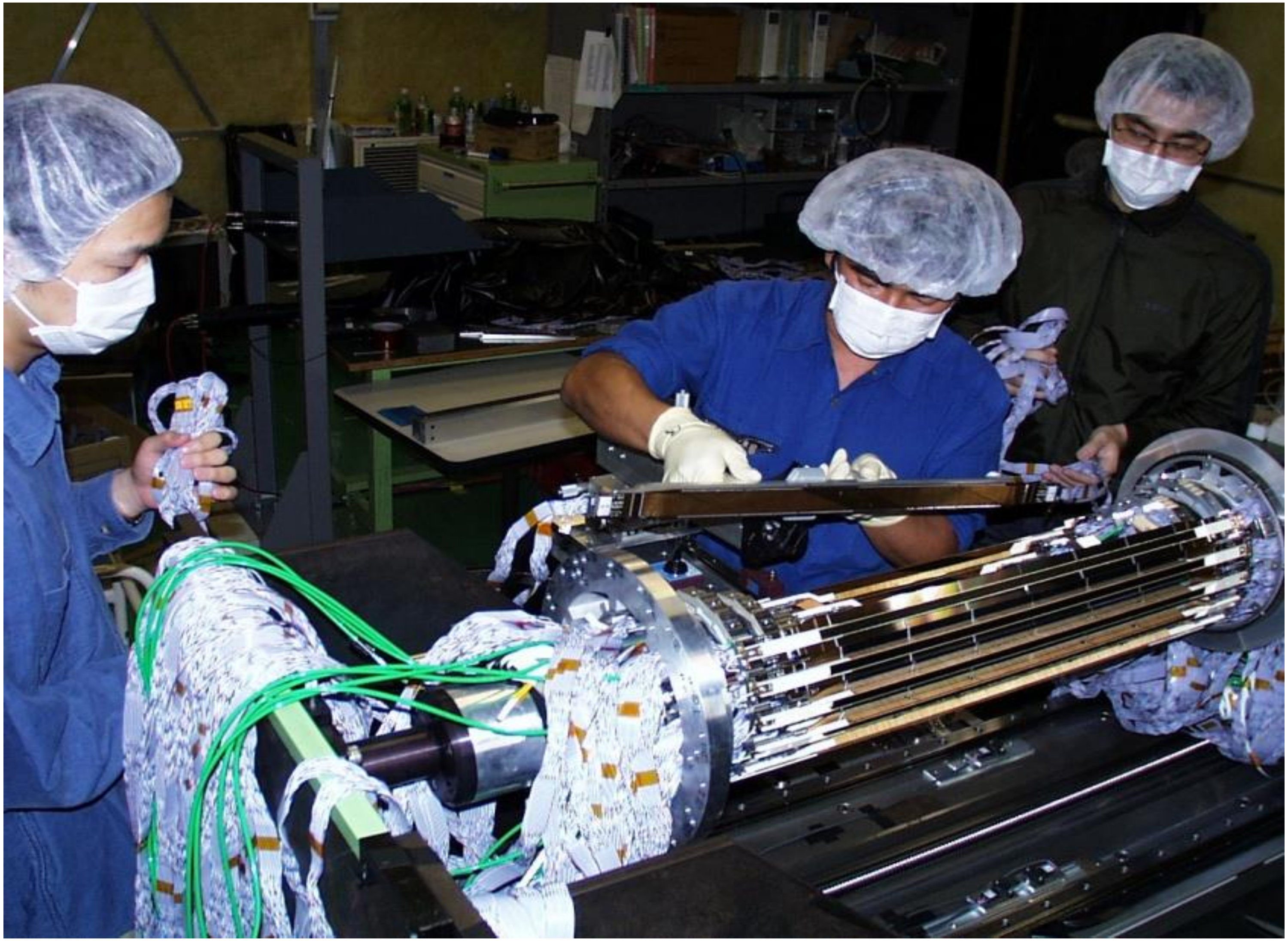
Bonding pull test
- Checking pull force

Outermost Ladder(L6) at IPMU

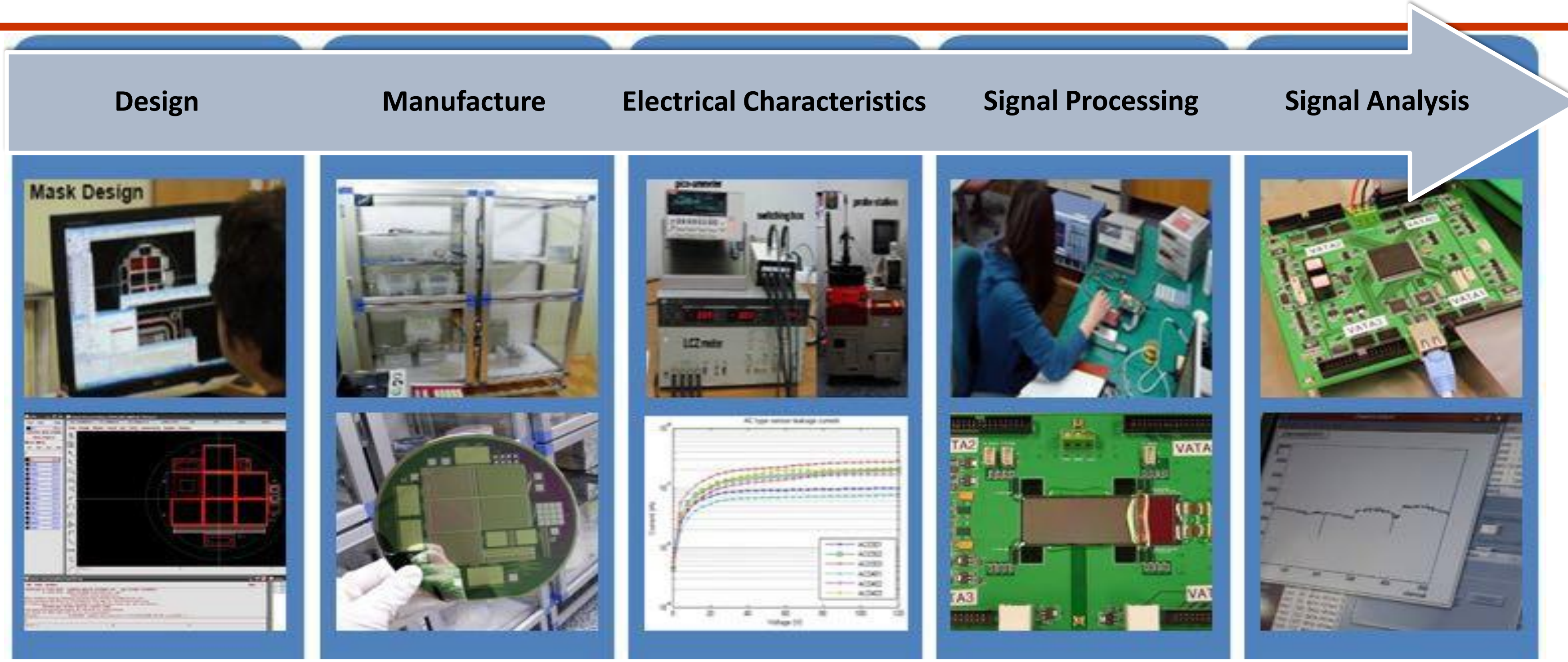




Belle II SVD



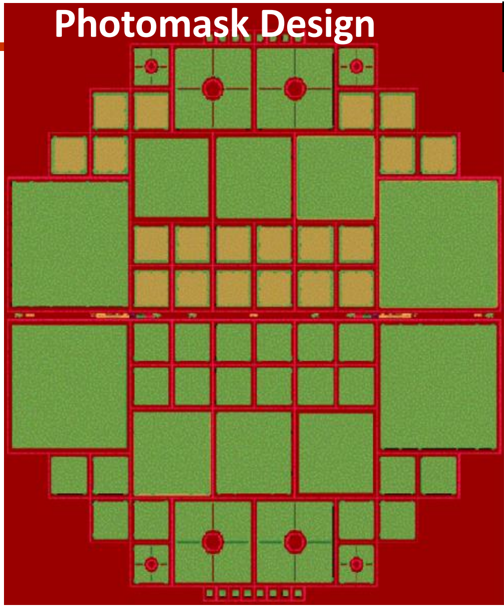
R&D of Silicon Detectors

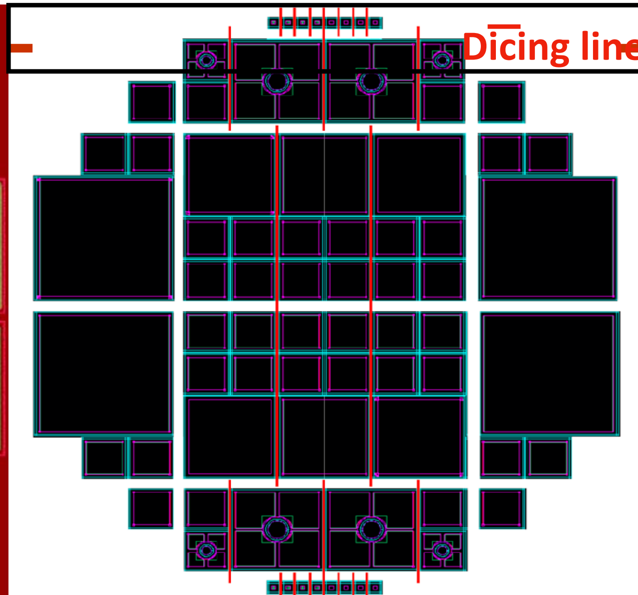


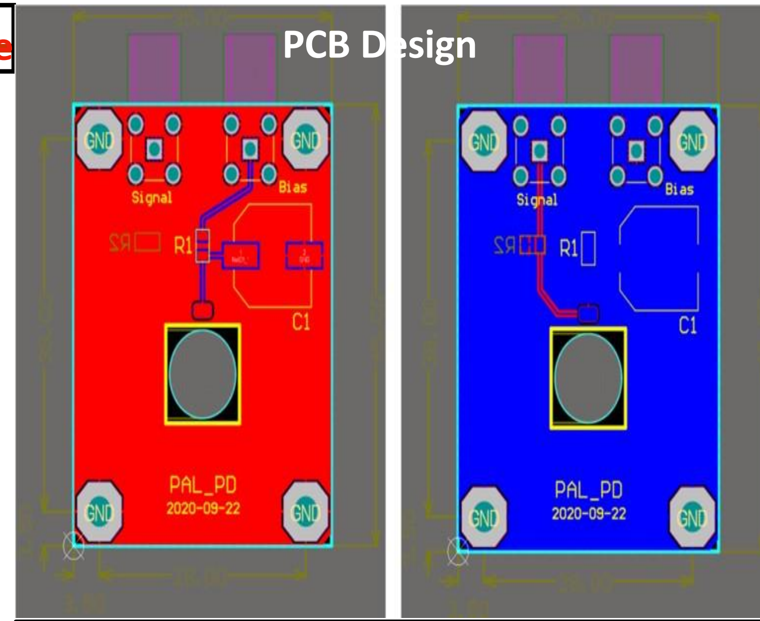
- Mask manufacture : PKL (Photomask Manufacture Institute, Cheonan in Korea)
- Sensor manufacture : ETRI (Electronics and Telecommunications Research Institute, Daejeon in Korea)
- Quantum efficiency measurement : KRISS (Korea Research Institute of Standards and Science, Daejeon in Korea)

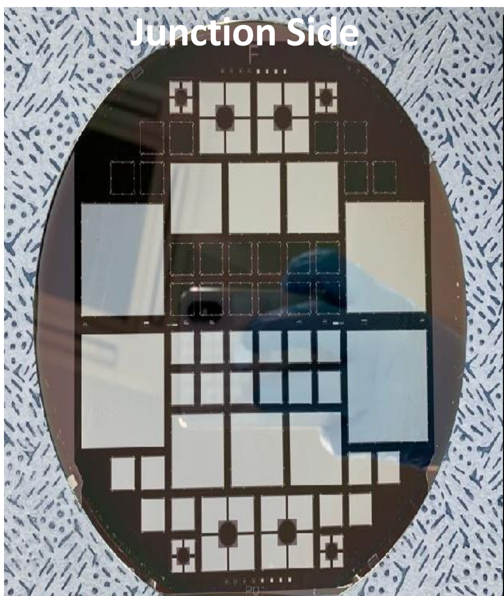
S.C. Lee et al.:

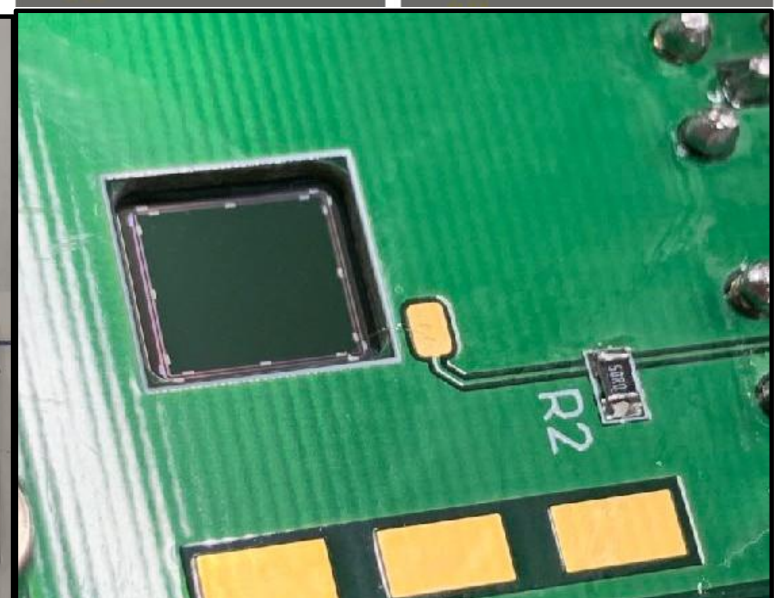
- Study of Silicon PIN Diode Responses to Low Energy Gamma-Rays, JKPS 69 (2016)
- Study of silicon photodiode performance for X-ray detector in cargo system, NIMA 912 (2018)
- Photo-Responses of Silicon Photodiodes with Different ARC Thickness for Scintillators, JKPS 75 (2019)
- Performance test for a pixelated silicon sensor with junction field effect transistor, NIMA 978 (2020)

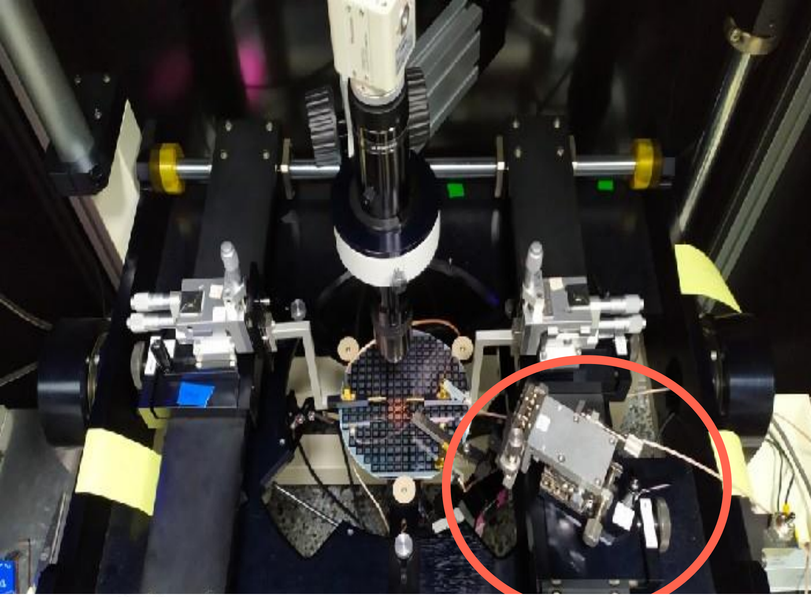

Photomask Design

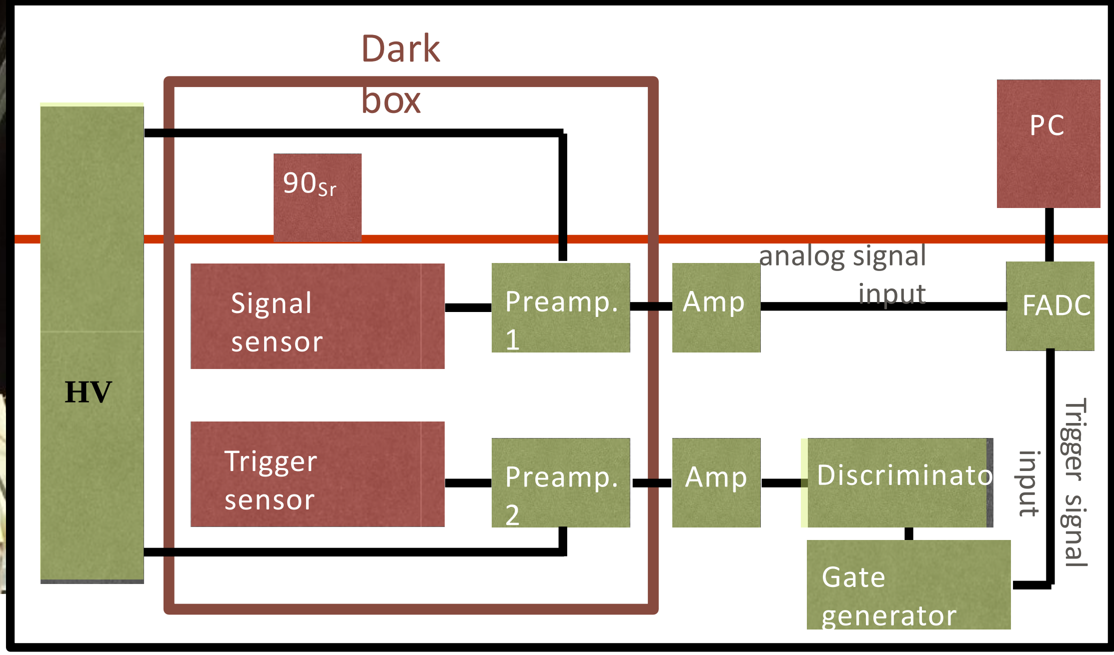

Dicing line

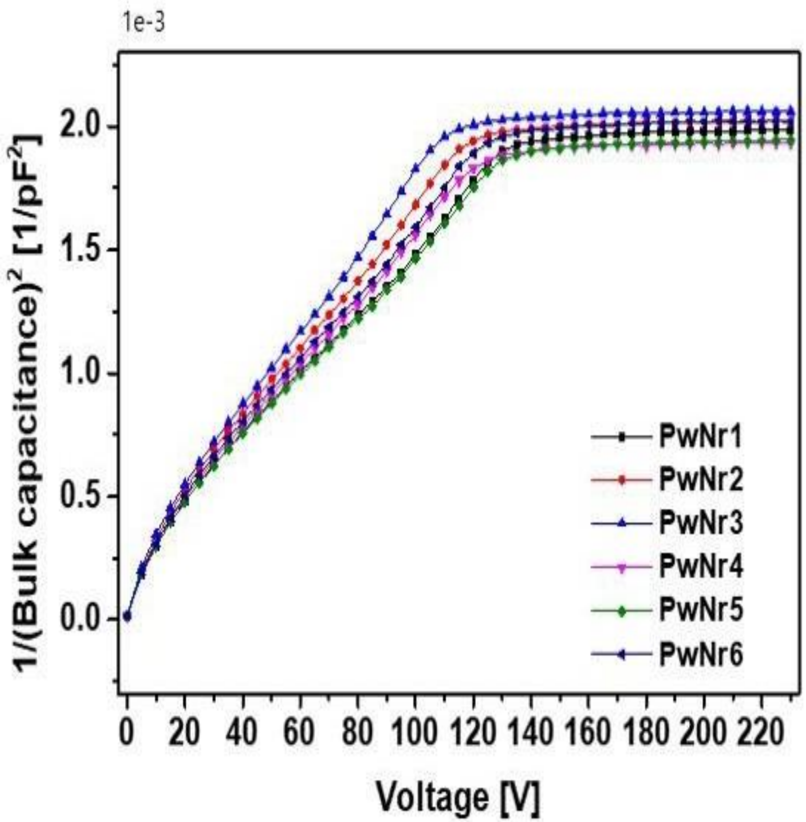

PCB Design
GND
Signal
Bias
R1
C1
PAL_PD
2020-09-22

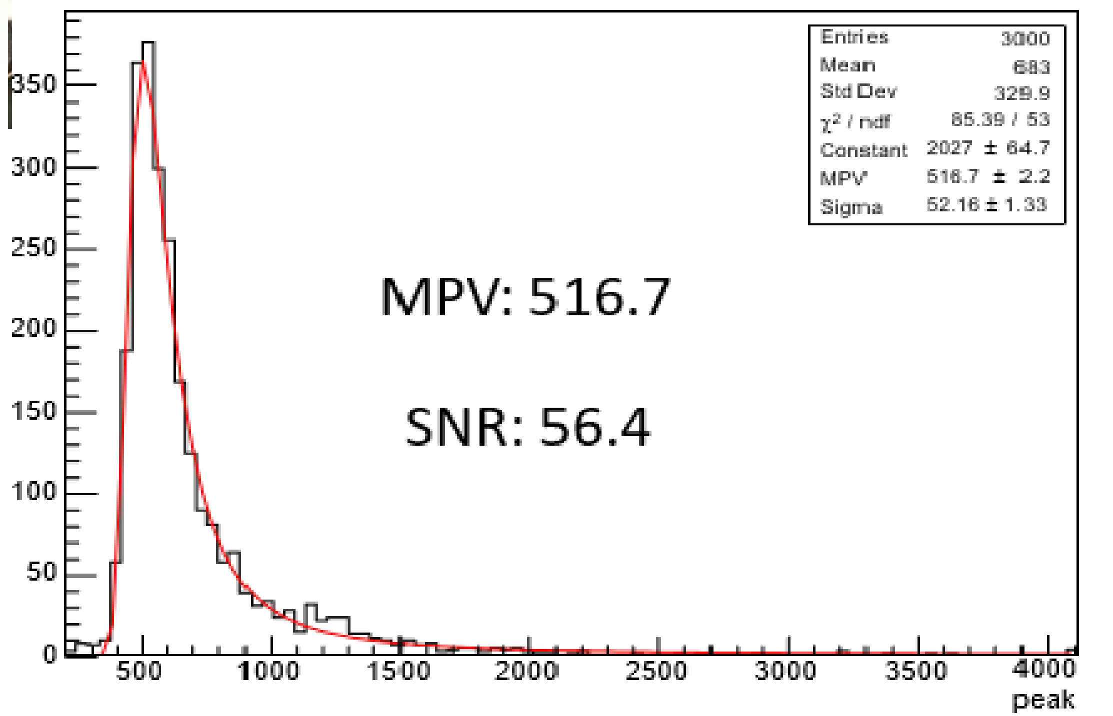

Junction Side

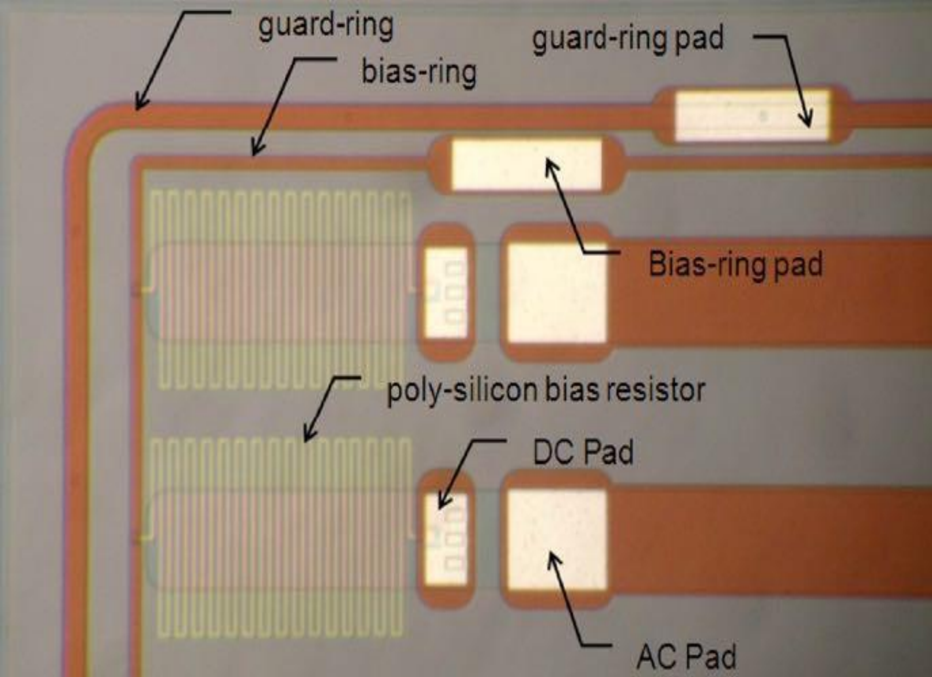

R2

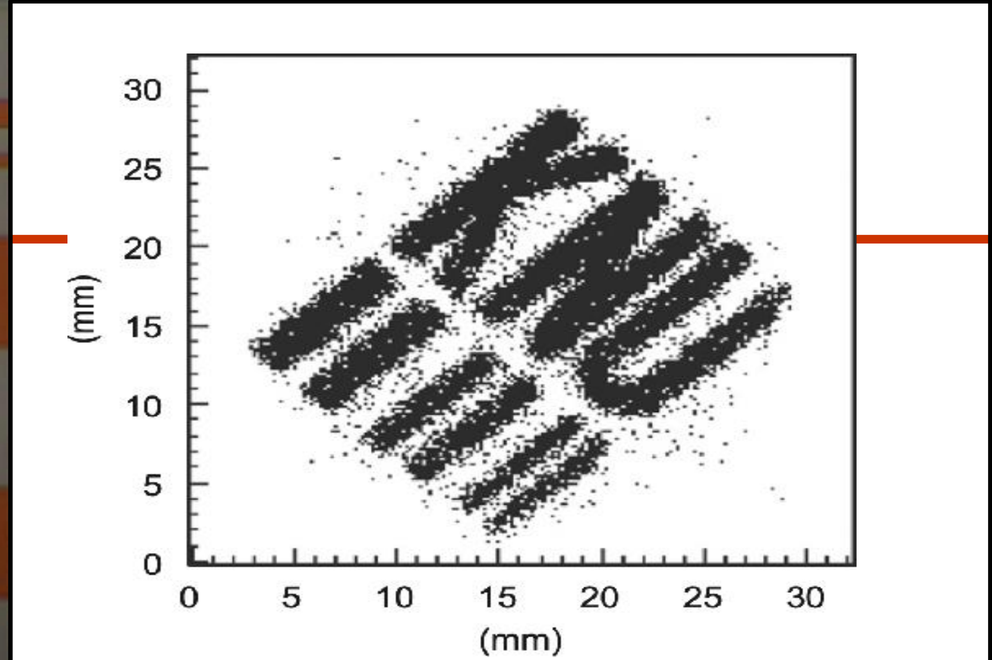


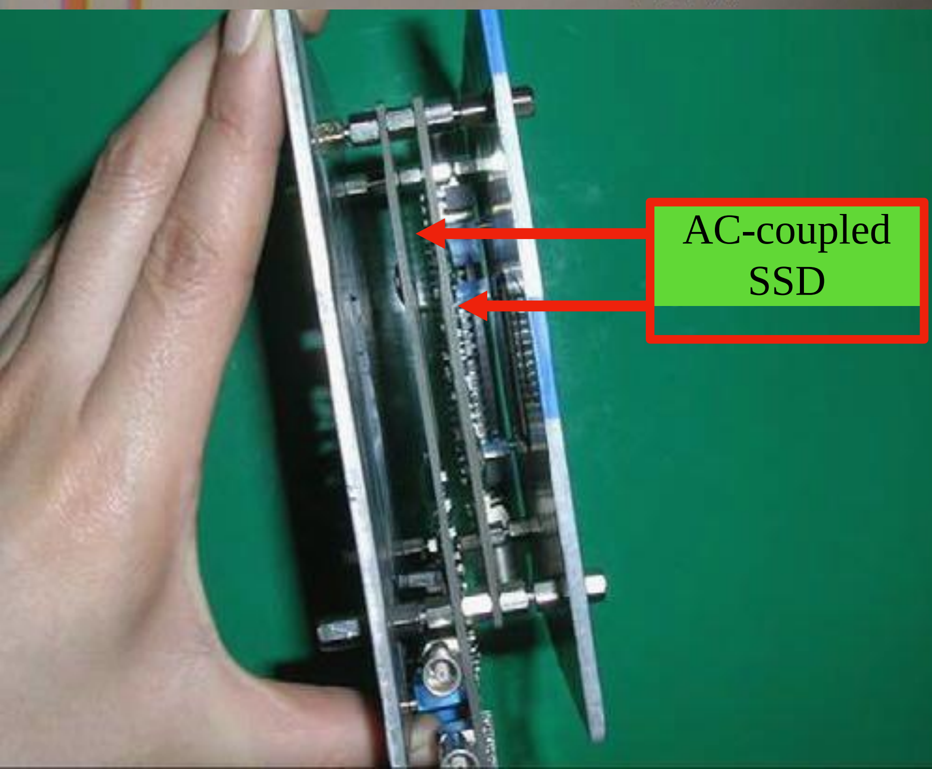

Dark box
PC
90Sr
HV
Signal sensor
Preamp. 1
Amp
analog signal input
FADC
Trigger sensor
Preamp. 2
Amp
Discriminato
Gate generator
Trigger signal input

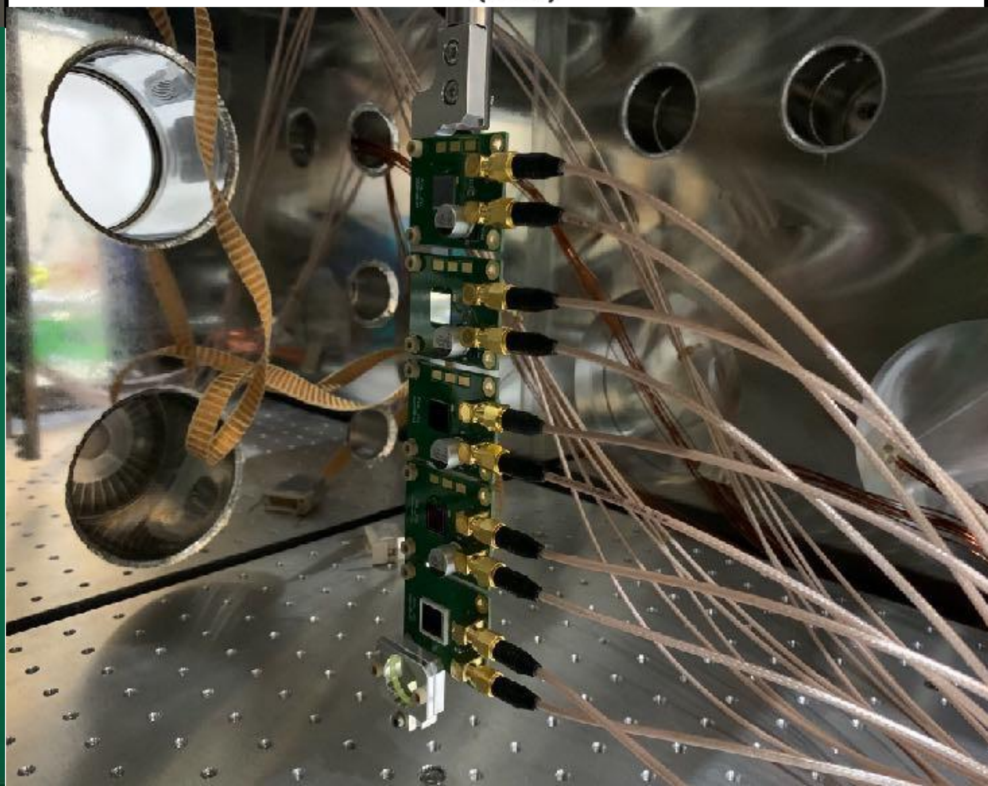

1e-3
1/(Bulk capacitance)² [1/pF²]
Voltage [V]
PwNr1
PwNr2
PwNr3
PwNr4
PwNr5
PwNr6


Entries 3000
Mean 683
Std Dev 329.9
χ² / ndf 85.39 / 53
Constant 2027 ± 64.7
MPV 516.7 ± 2.2
Sigma 52.16 ± 1.33
MPV: 516.7
SNR: 56.4
peak


guard-ring
bias-ring
guard-ring pad
Bias-ring pad
poly-silicon bias resistor
DC Pad
AC Pad


0
5
10
15
20
25
30
(mm)
(mm)


AC-coupled
SSD



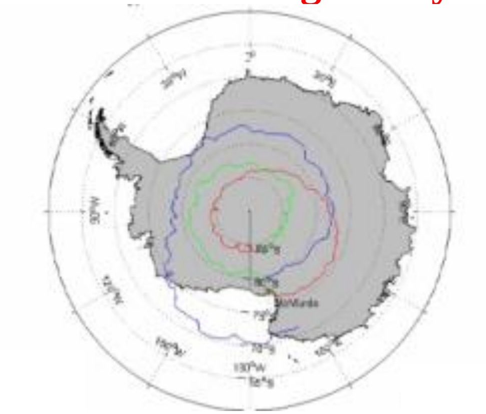

IPMU clean room
Seungcheol Lee
Hwanbae Park
Kookhyun Kang
L4 members
Hyebin Jeon

감사합니다

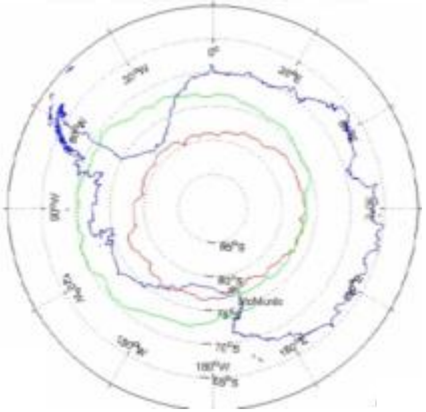
Slides from M.H. Lee

CREAM: About 161 day cumulative exposure

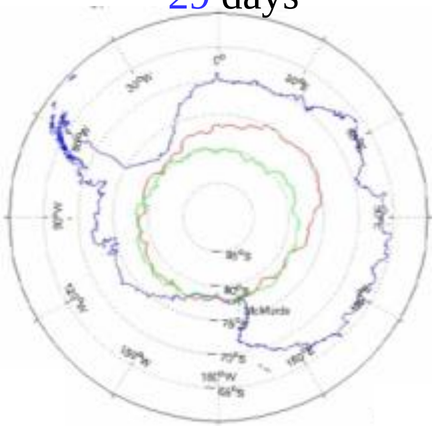
CREAM-I
12/16/04 - 1/27/05
Record breaking 42 days



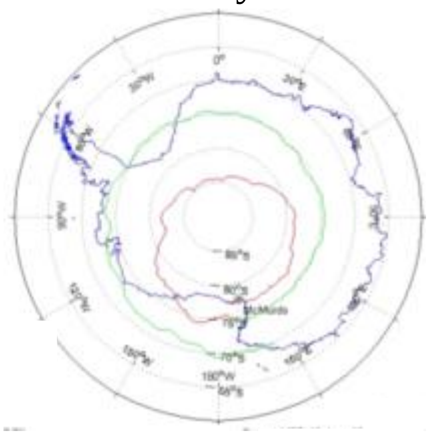
CREAM-II
12/16/05 - 1/13/06
28 days



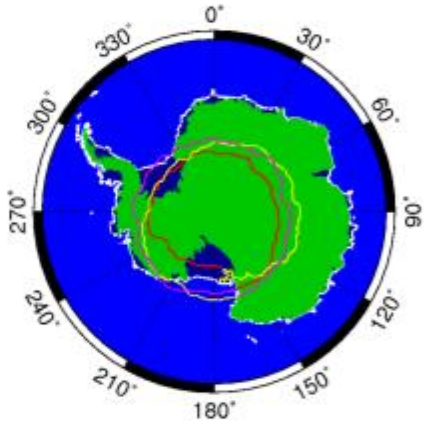
CREAM-III
12/19/07-1/17/08
29 days



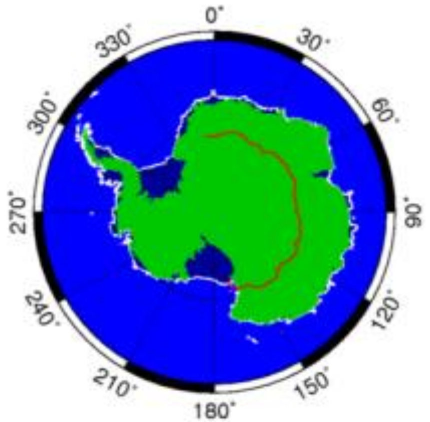
CREAM-IV
12/19/08-1/7/09
19 days



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



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



Sensor R&D

Kyungpook National University
Semiconductor Detector Lab

Master Candidate
Jongmin Baek
(백종민)

Aug. 2021

KNU