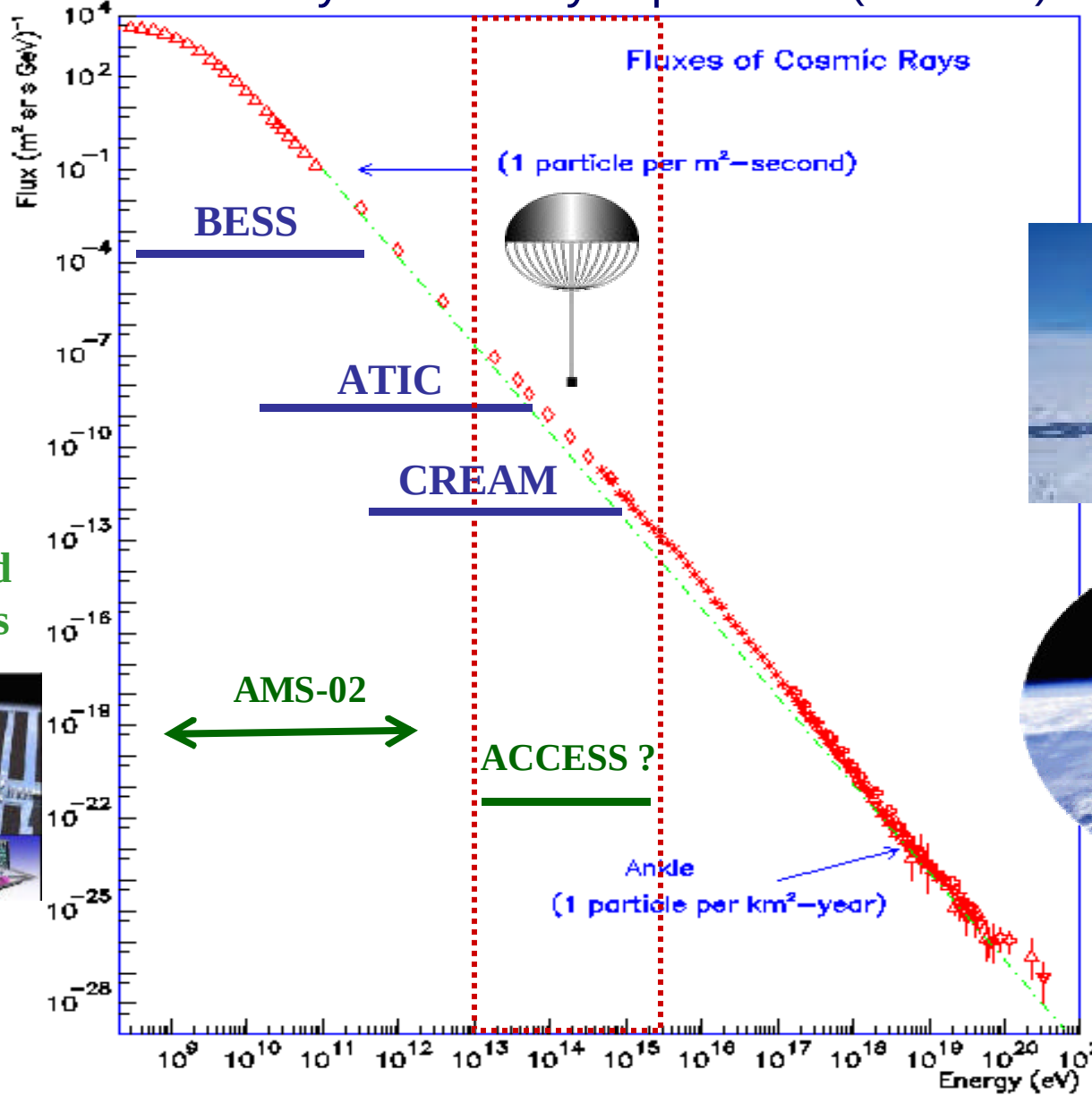
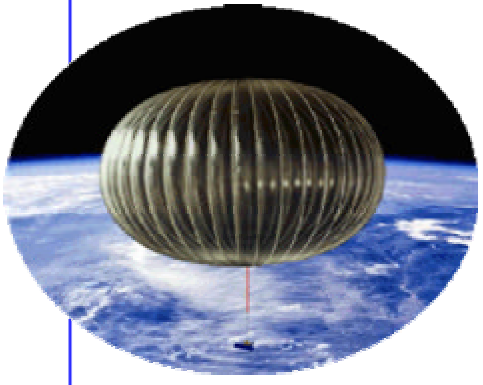
Cosmic Ray Energetics And Mass

Launched from Antarctica on Dec 16, 2004

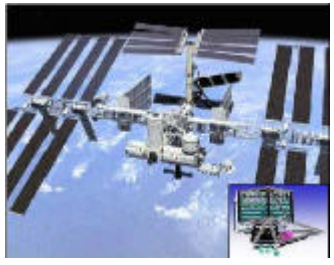
Primary cosmic rays spectrum (inclusive)



Balloon experiments

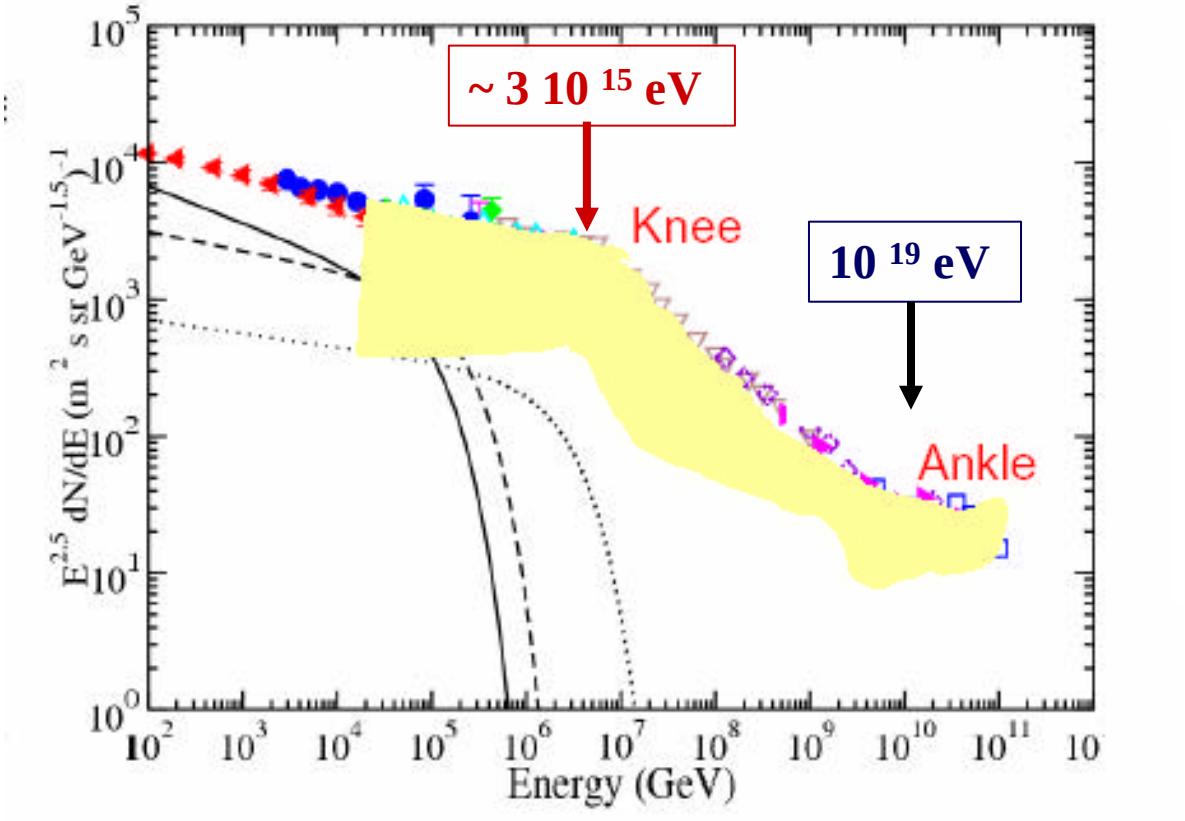


Space-based experiments



The power law spectrum is broken : the observed spectral features are enhanced when the all particle (inclusive) spectrum is plotted as :

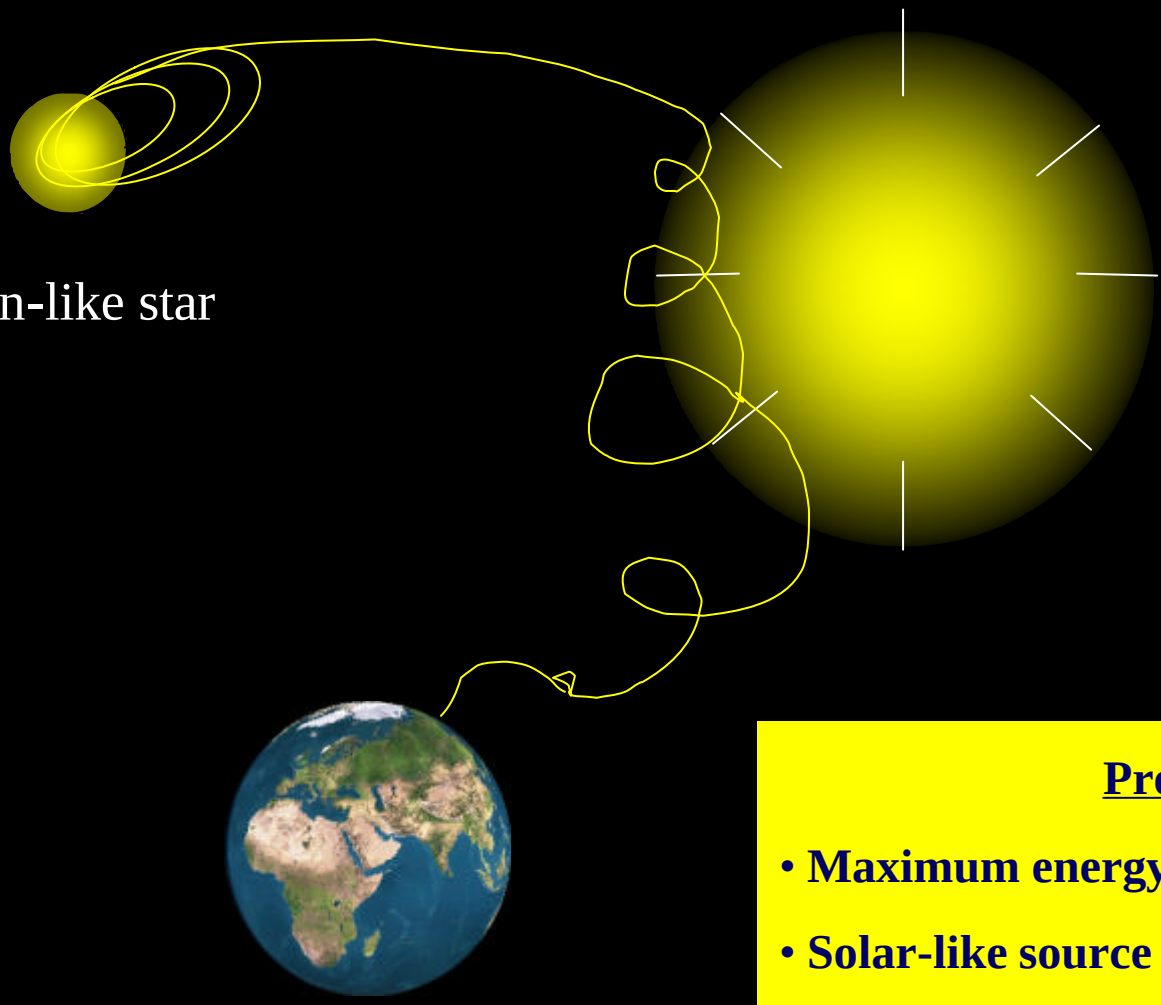
$E^{2.5}$ x Flux



Two well known spectral index features to be explained :

- **KNEE**
- **ANKLE**

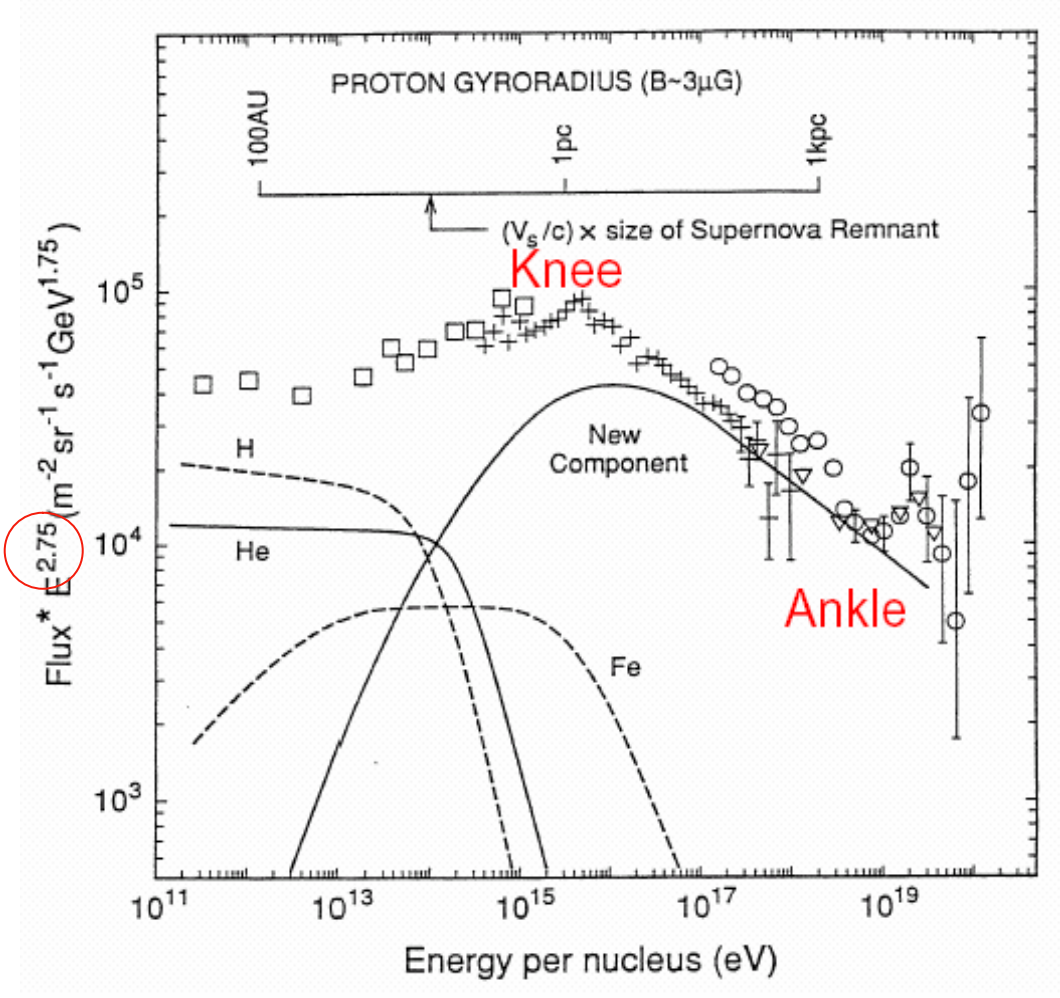
Standard Model of Origin, Acceleration and Propagation of Galactic Cosmic Rays



Predictions

- **Maximum energy ~ Z 10^{14} eV**
- **Solar-like source composition**
- **Depletion of "non-ionized" component**

- A **change in elemental composition** above **Z x 10^{14} eV** is predicted by a class of models (Lagage & Cesarsky, 1983) based on supernova acceleration shock waves.
- **Cutoffs in individual spectra are predicted**



SNR acceleration limit

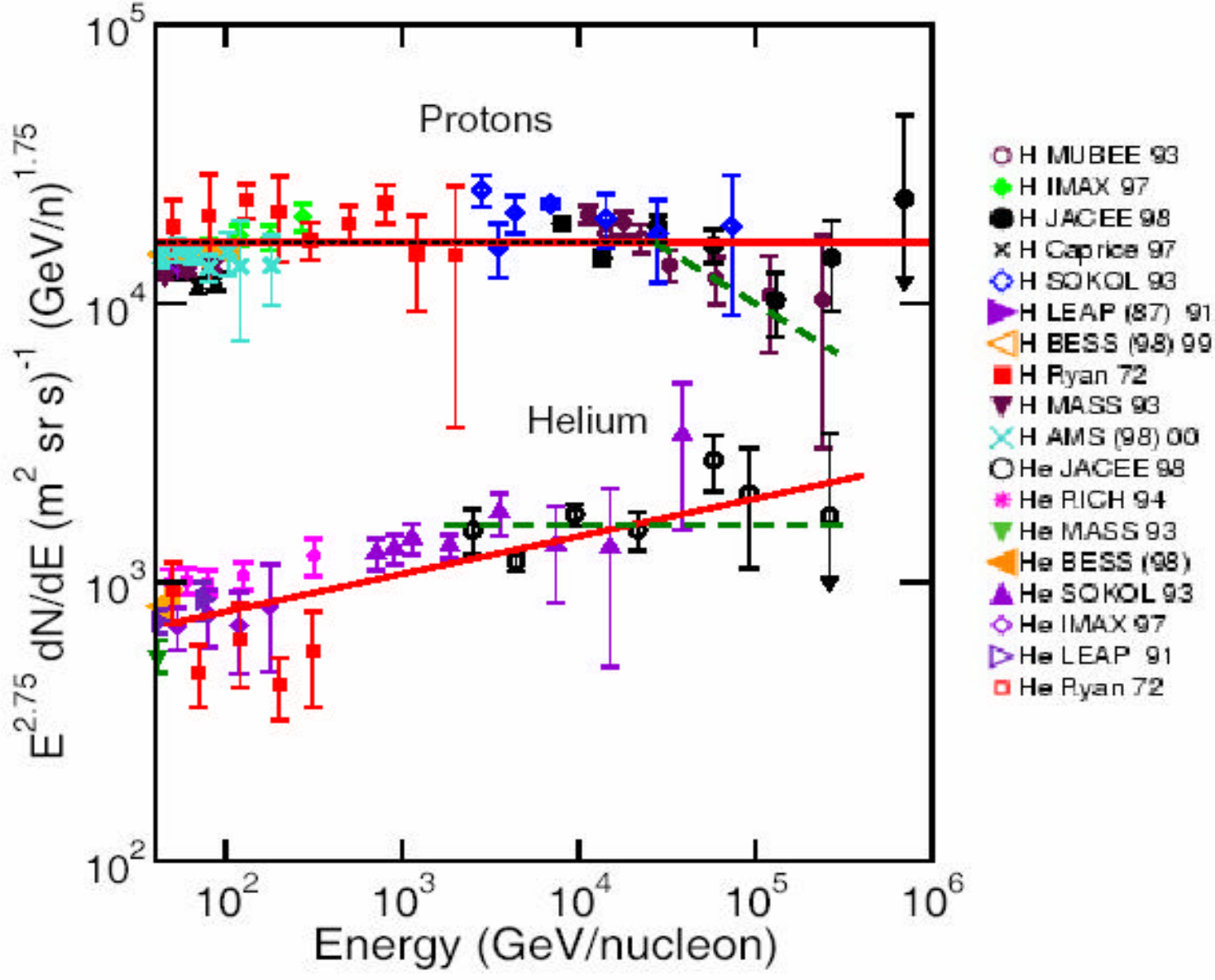
$$E_{max} \sim Z\ E_c$$

E_c is the critical energy where the SN acceleration becomes inefficient :

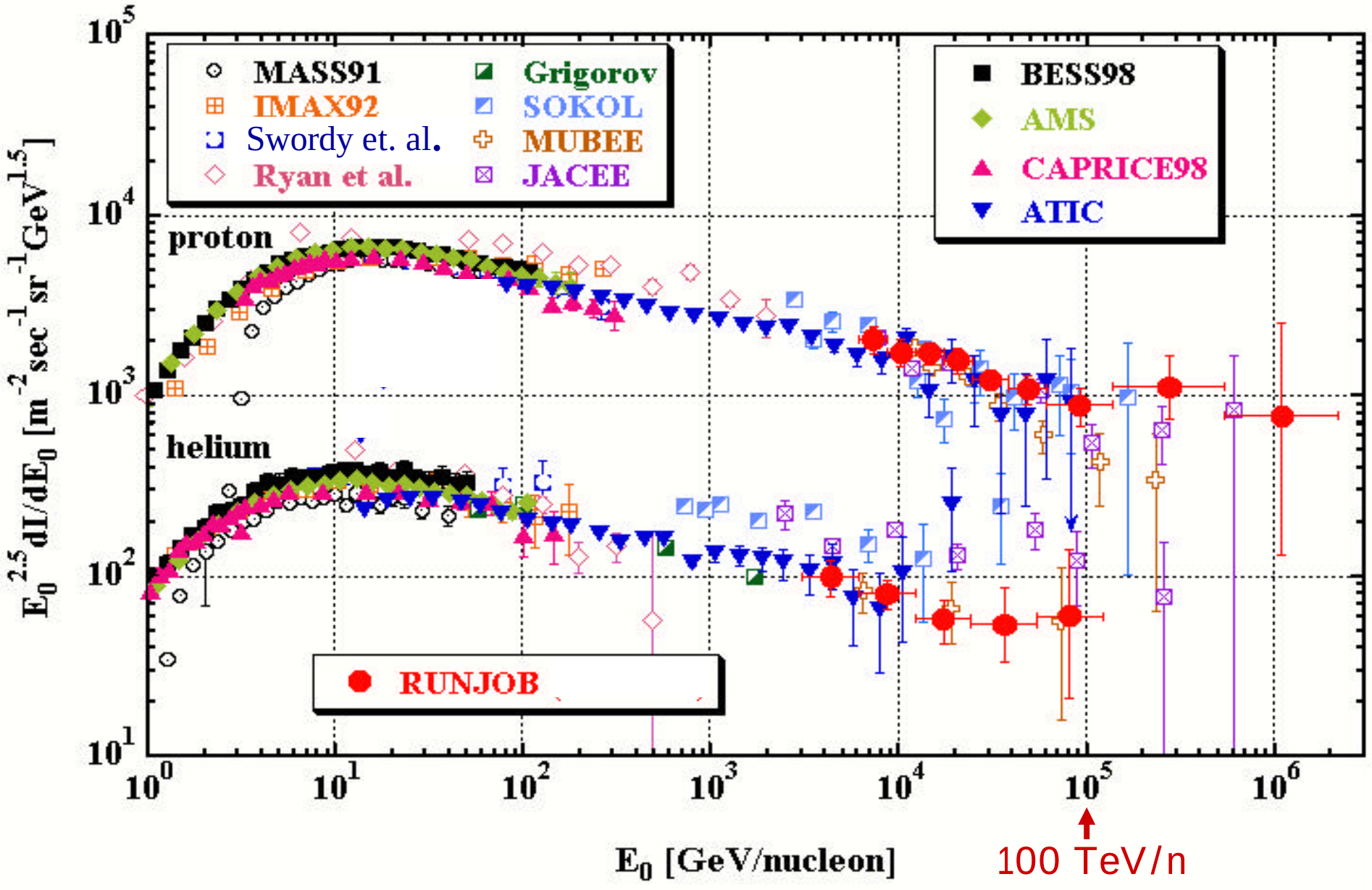
$E_c = 10^{14}$ ... 10^{15} eV

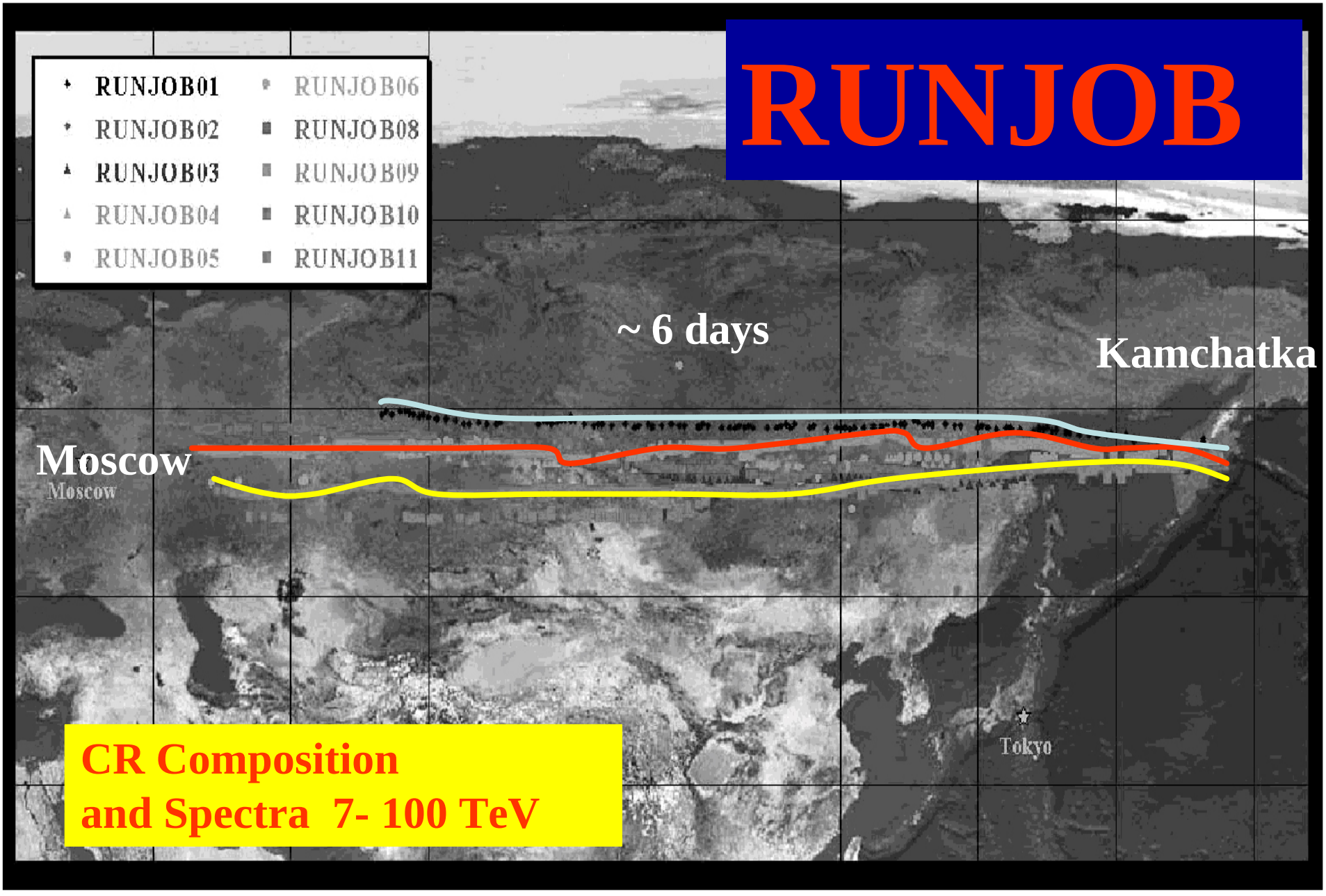
(according to the model)

Is there a composition change at high energies?



p and He spectra from direct measurements ICRC – 2003 (Tsukuba)




RUNJOB
RUNJOB01
RUNJOB02
RUNJOB03
RUNJOB04
RUNJOB05
RUNJOB06
RUNJOB08
RUNJOB09
RUNJOB10
RUNJOB11
~ 6 days
Kamchatka
Moscow
Moscow
Tokyo
CR Composition
and Spectra 7- 100 TeV

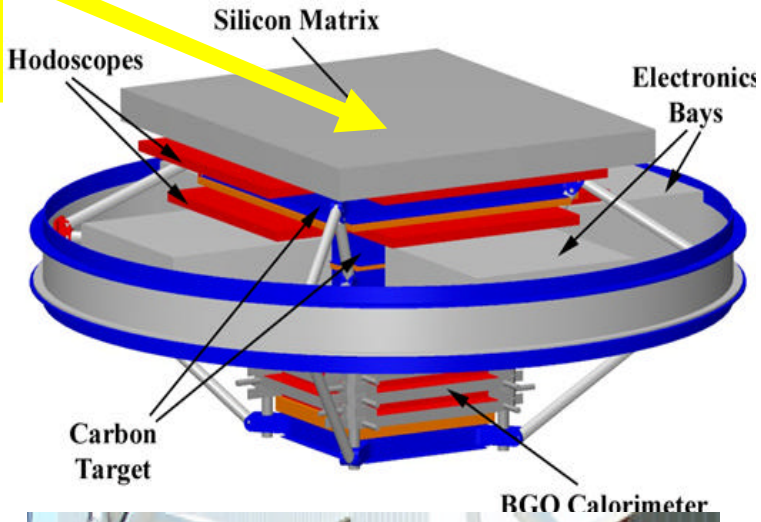
ATIC { 0.25 m^2 sr ; 1500 Kg ; 350 W

Silicon Matrix :

charge identification from H to Fe

pad structure to fight "backscatter" from calorimeter

4,480 pads (~2 cm x 1.5 cm)



Target :

3 x 10 cm layers of graphite (**1.6 X_0** and **0.75 l_{int}**)

3 Hodoscopes (one per target layer) :

each hodo is made of 2 crossed X-Y planes of scintillators 2.0 cm wide and 1 cm thick

Calorimeter :

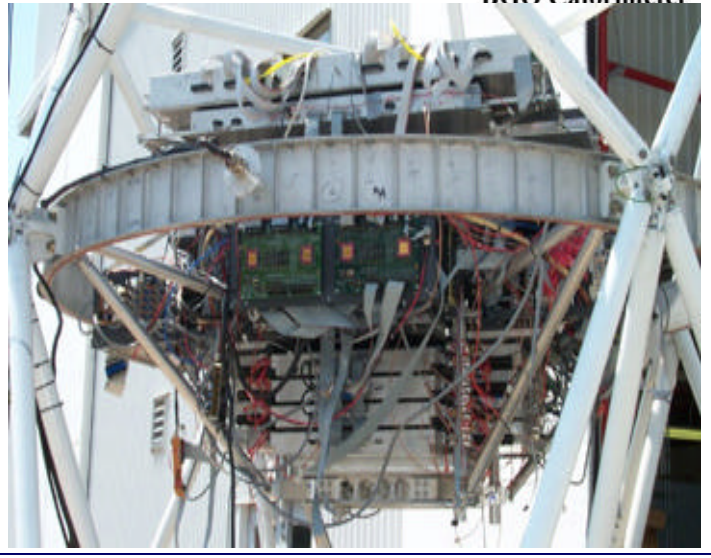
array of BGO crystals : 2.5 x 2.5 x 25 cm^3 each

40 crystals per layer

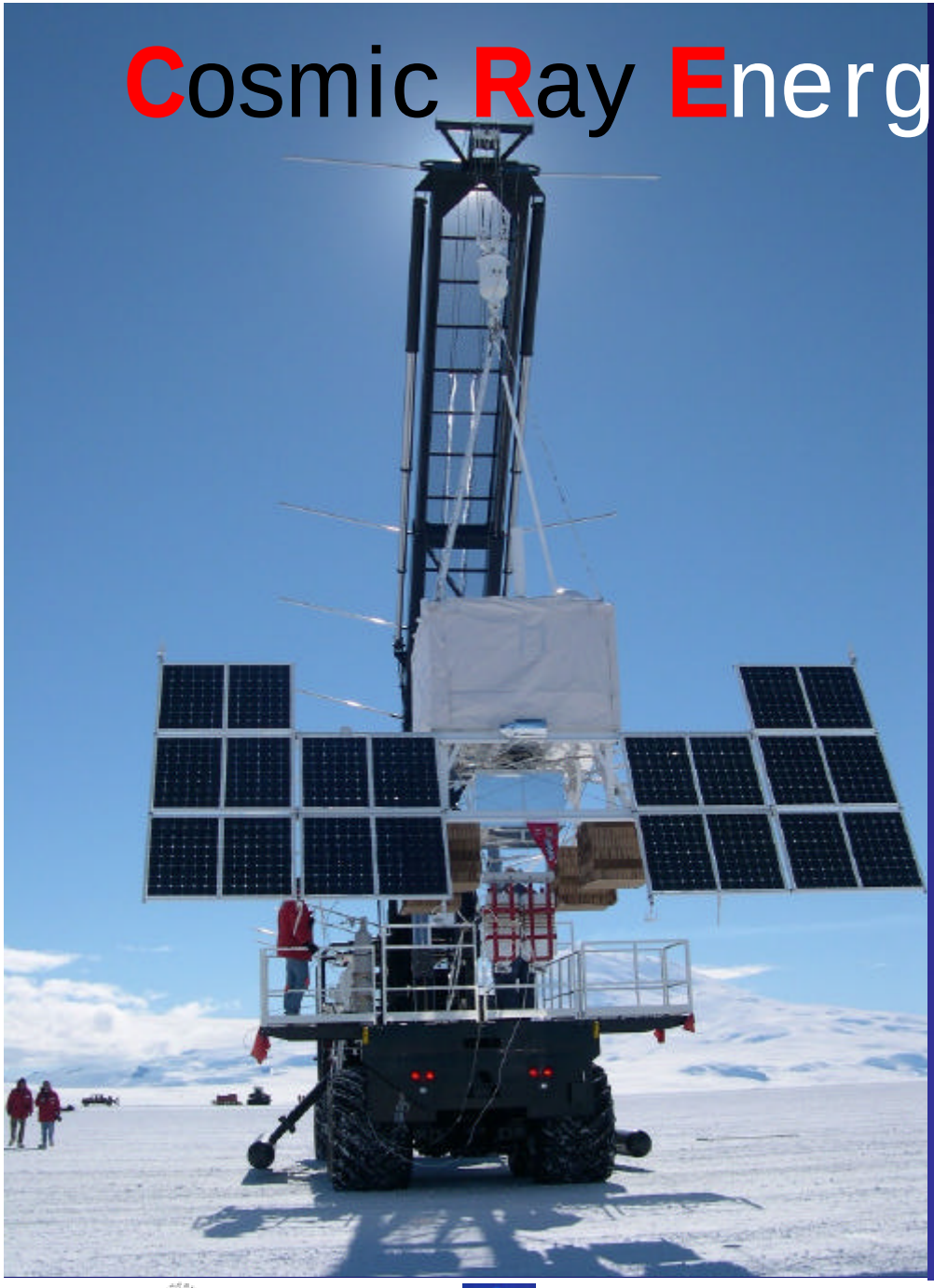
10 alternate X-Y layers

22 radiation lengths

1.14 nuclear interaction lengths



Cosmic Ray Energetics And Mass



- CREAM can measure individual energy spectra and elemental composition (1 = Z = 26 and above) of cosmic rays from **1 TeV up to 1000 TeV**

- search for a **cutoff in the proton spectrum** at E = 100 TeV

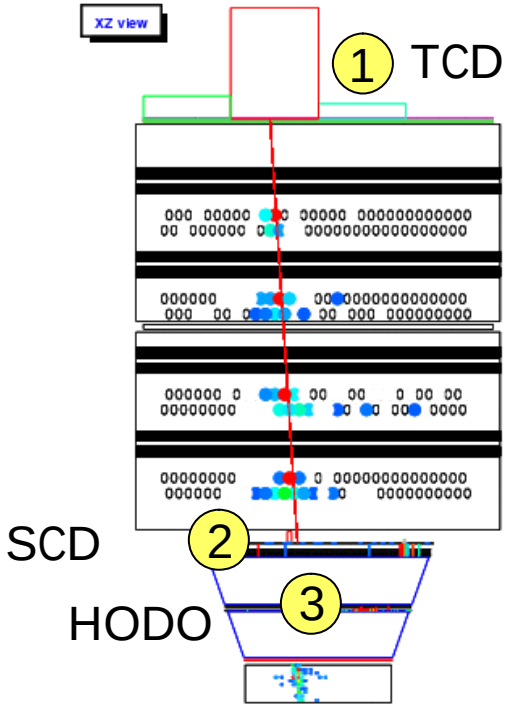
- expected to **reach 500 TeV** with 30% statistical accuracy with 3 flights

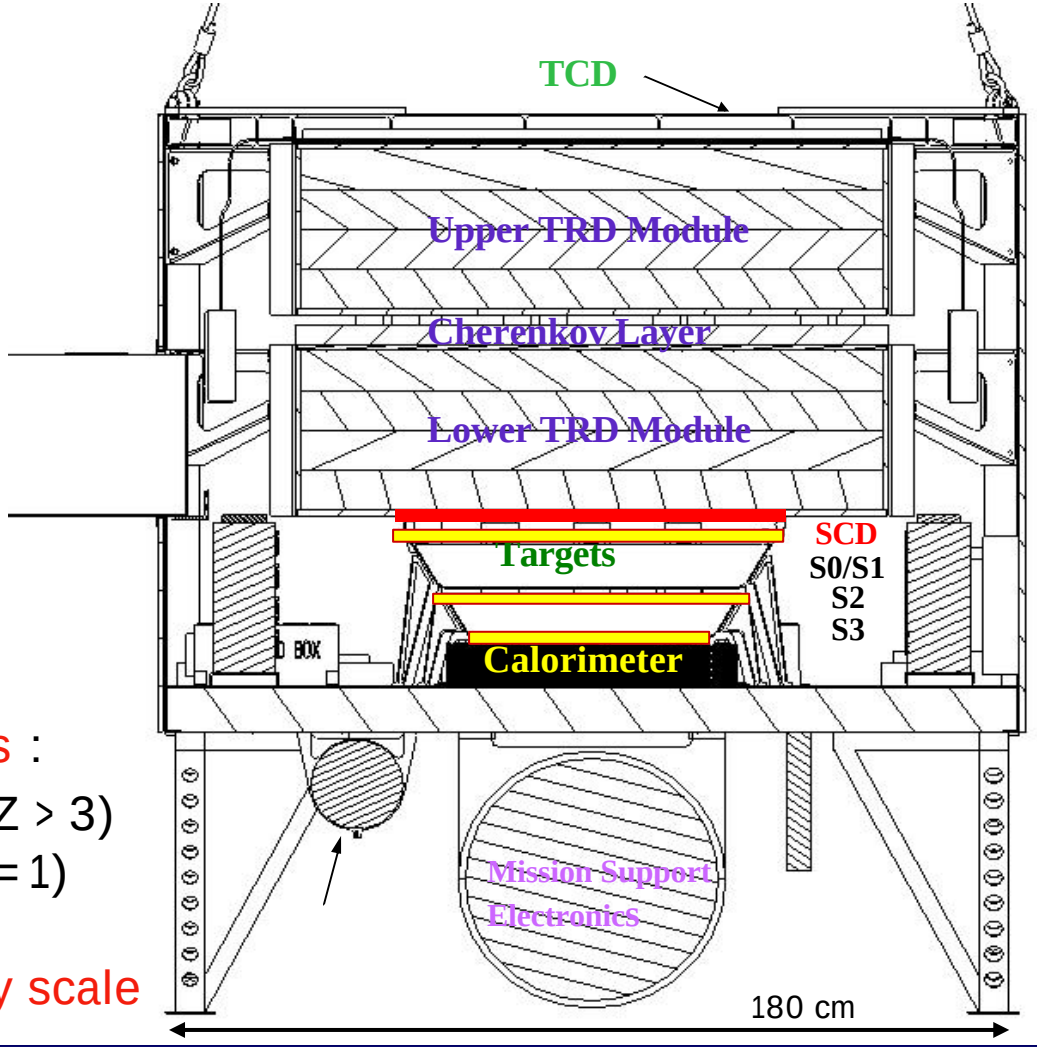
- **measurement of B/C** ratio up to **500 GeV/n** (test of propagation models)

CREAM Detector Concept

3 independent charge measurements :

- Timing-based Charge Detector (TCD)
- Pixelated Silicon Detector (SCD)
- Scintillating fiber Hodoscope

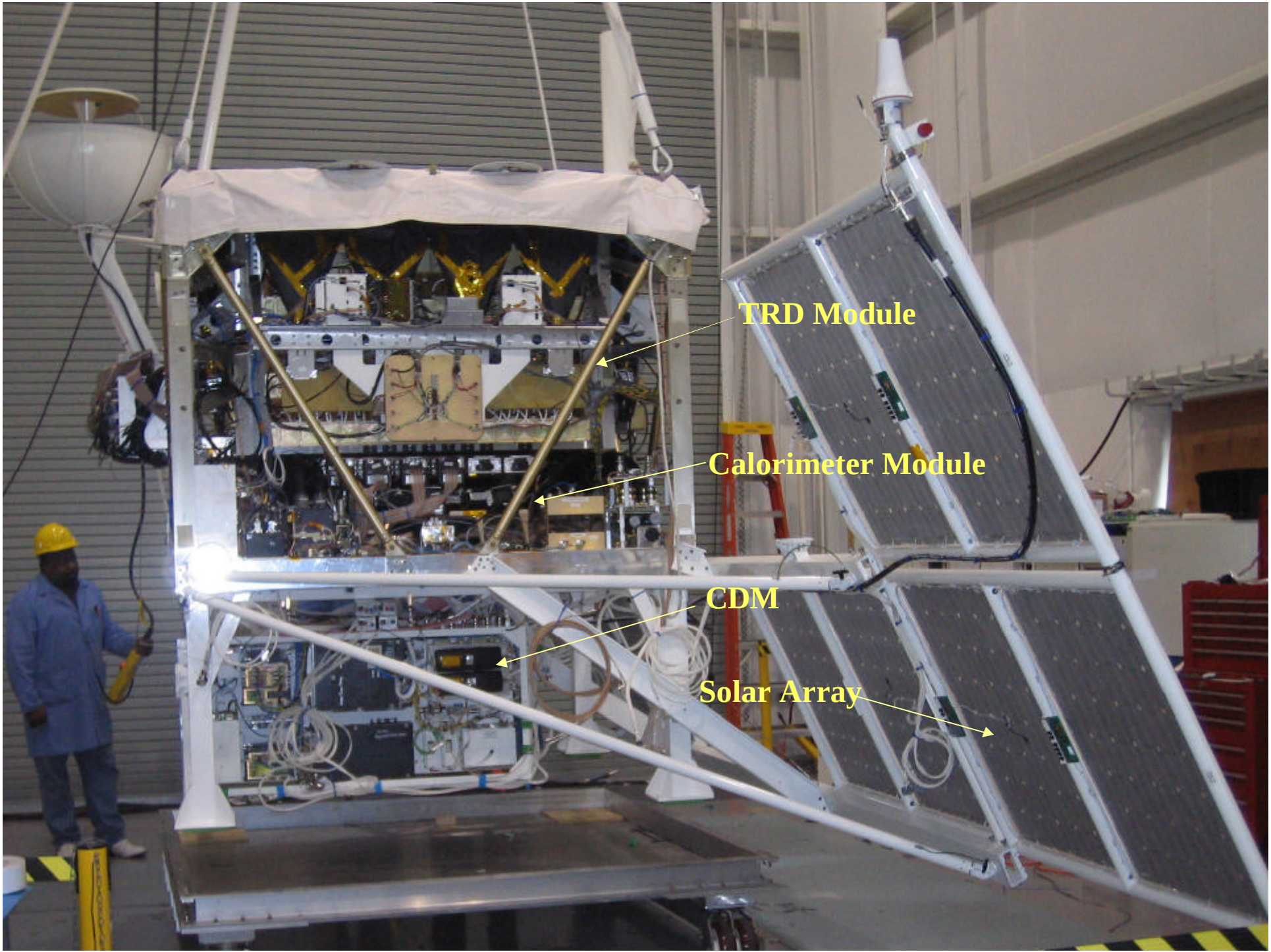




2 independent energy measurements :

- Transition Radiation Detector (Z > 3)
- Tungsten Sci/Fi calorimeter (Z = 1)

In-flight cross calibration of energy scale


TRD Module
Calorimeter Module
CDM
Solar Array

Timing Charge Detector (TCD) :

CREAM

- 5mm thick fast (< 3 ns) scintillator paddles
- **backscatter rejection** by fast pulse shaping

TRD :

- 2 modules (**120 x 120 cm^2**)
- Cherenkov trigger layer to veto low energy particles
- polystyrene foam radiator ; Xenon proportional tubes
- **measurement of Lorentz** g **for nuclei Z = 3**
- energy resolution at $\gamma = 3\ 10^3$ ~ **15 % (C)** ; 7% (Fe)
- **in-flight cross calibration of energy scale with calorimeter**

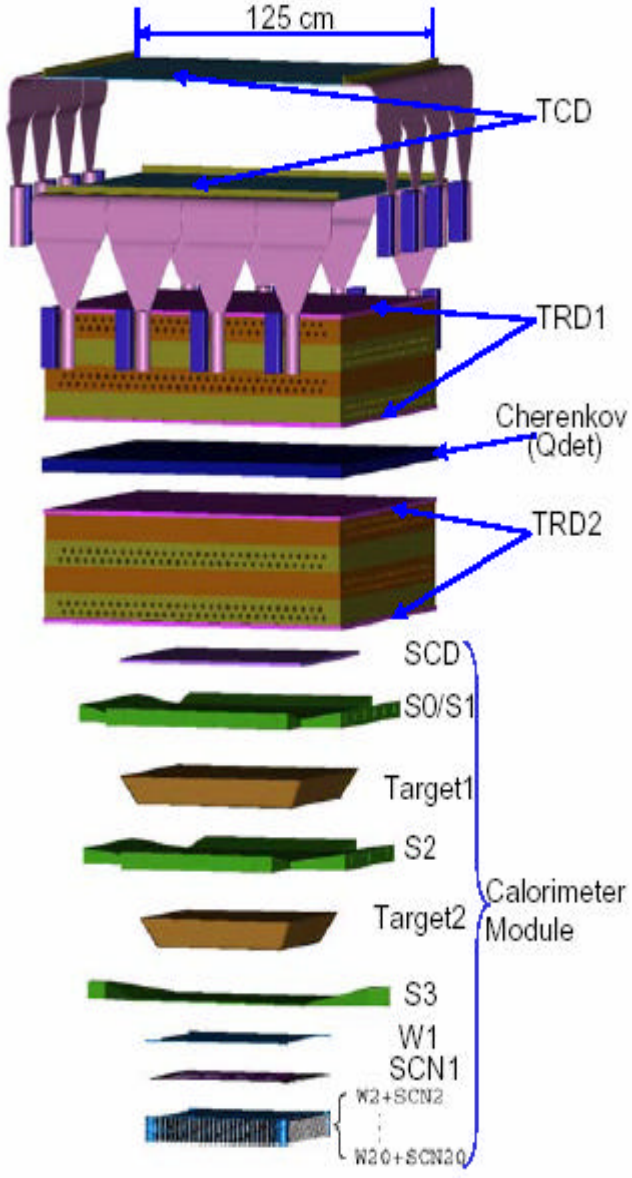
Hodoscopes : 6 planes of 2 mm x 2mm square scintillating fibers

Target : 19 cm densified Graphite

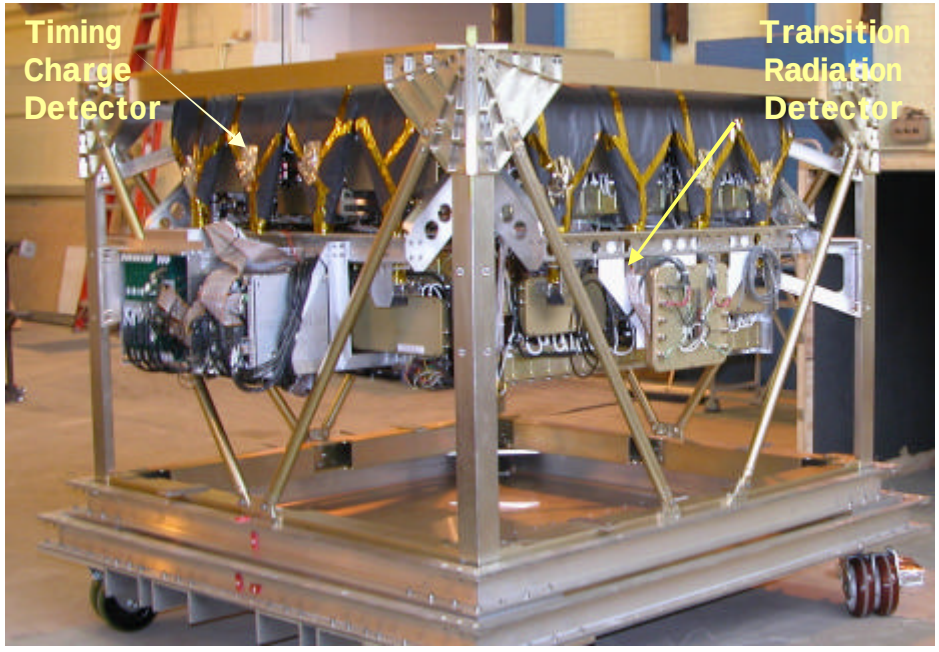
($0.45\ \lambda_I$ **;** ~ **1** X_0) ; slant = 30^0

Tungsten-SciFi calorimeter :

- **50 x 50 cm^2** active area ; **20** X_0
- **1 cm** lateral sampling

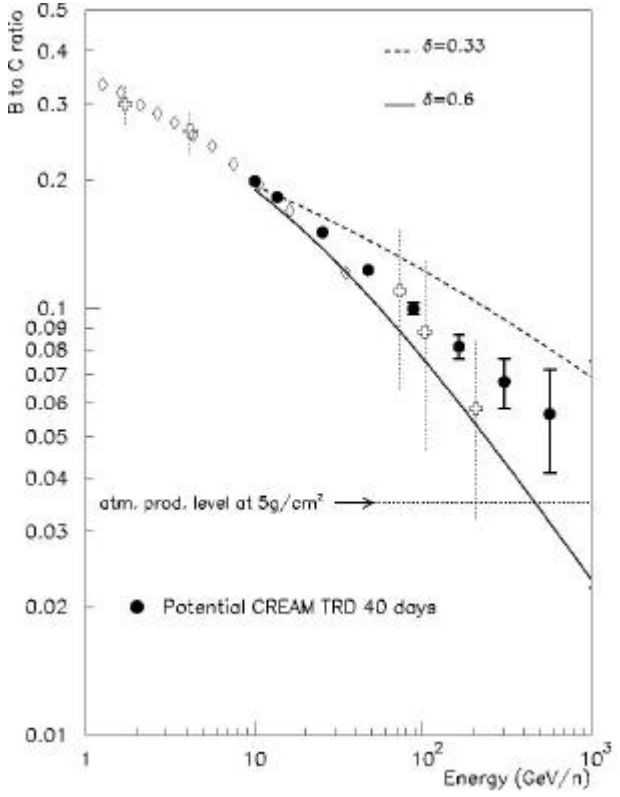


What is the history of cosmic rays in the Galaxy ?



TRD Module

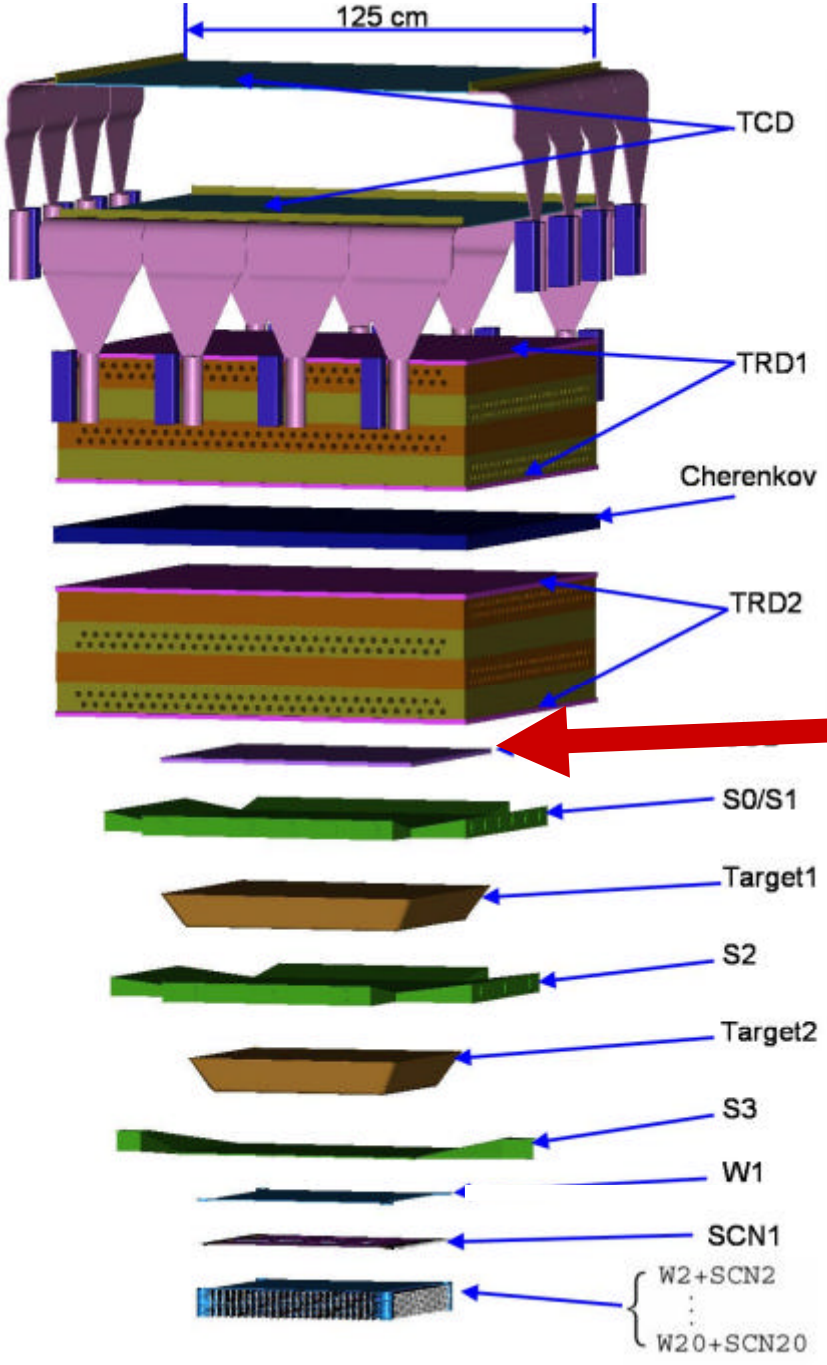
- The **Timing Charge Detector (TCD)** provides event trigger and particle charge identification. The TCD has 2 layers of 4 paddles each.
- The **Transition Radiation Detector (TRD)** has 2 modules separated by a Cherenkov threshold counter

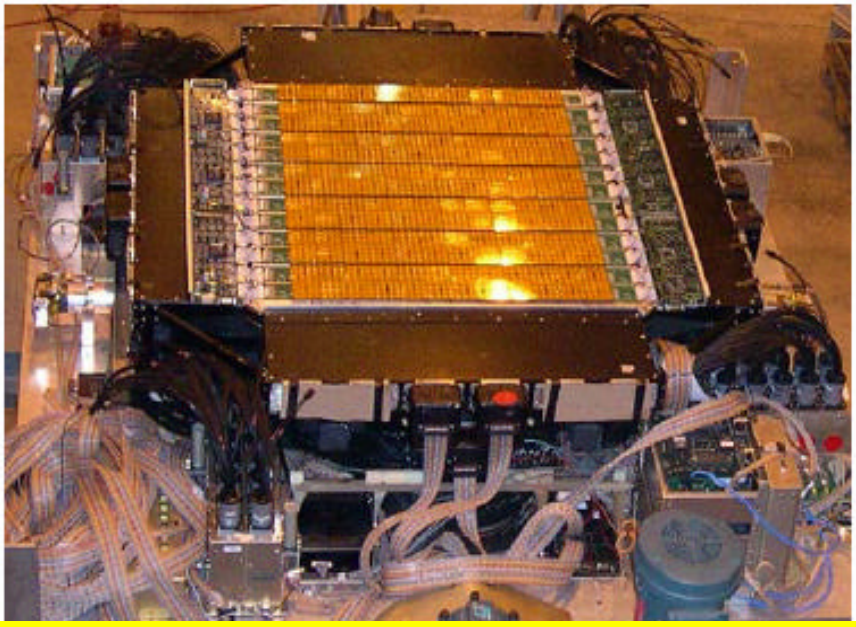


TRD Science Objectives

- The above figure compares TRD data expected from a 40-day flight (black circles) with prior data
- The TRD is expected to provide the first **B/C ratio** in this energy range in more than a decade

CREAM





Silicon Charge Detector (SCD)

~ 2 cm^2 pixels

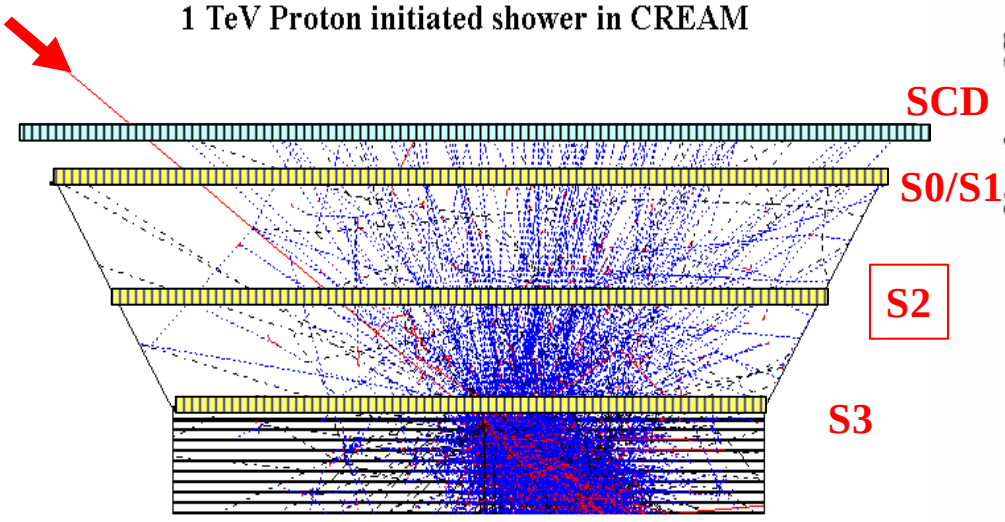
16 pixels / sensor

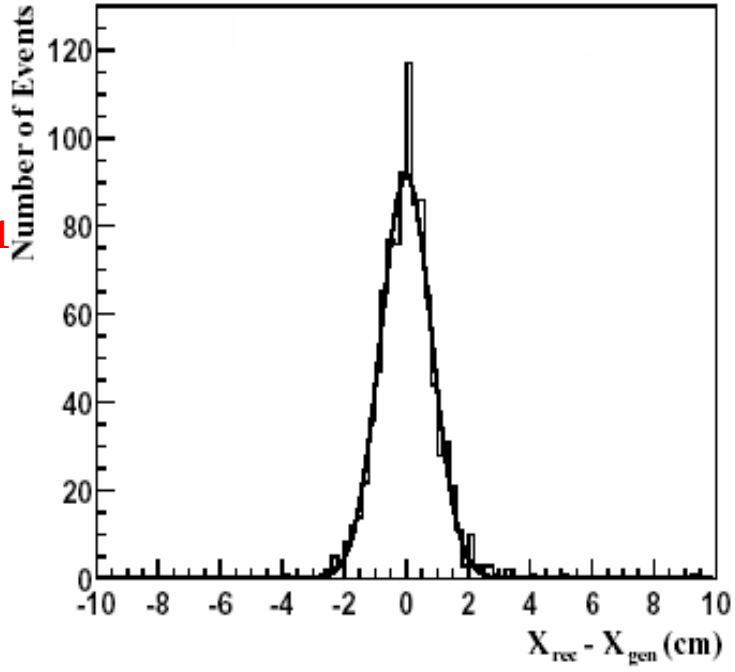
79 x 79 cm^2 active area

MC SIMULATION

Incident position reconstruction

- calculating entrance position at the top of carbon target





Distribution of the difference between reconstructed and generated incident positions

Scintillator Hodoscopes S0/S1 , S2, S3

(not in scale)

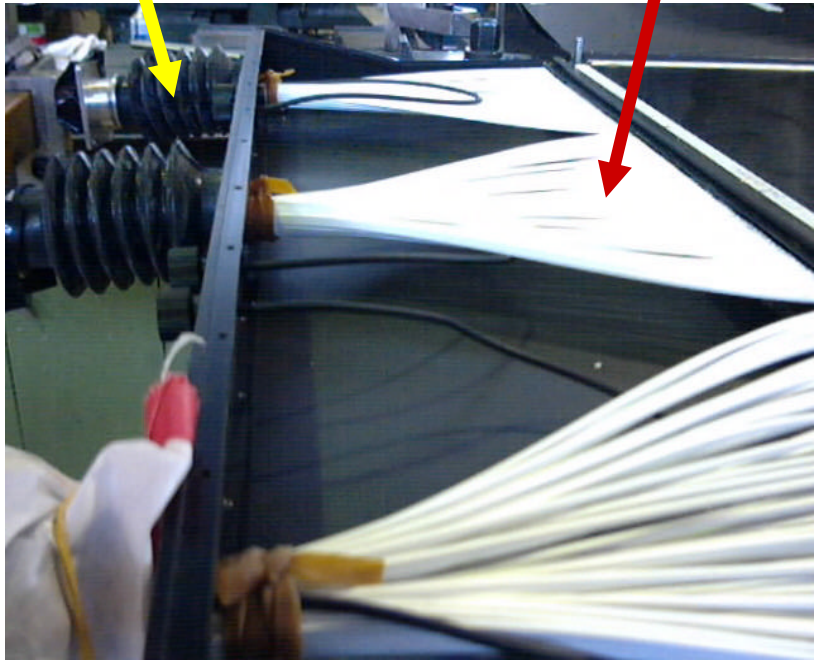
S2 HODOSCOPE

FLIGHT MODEL

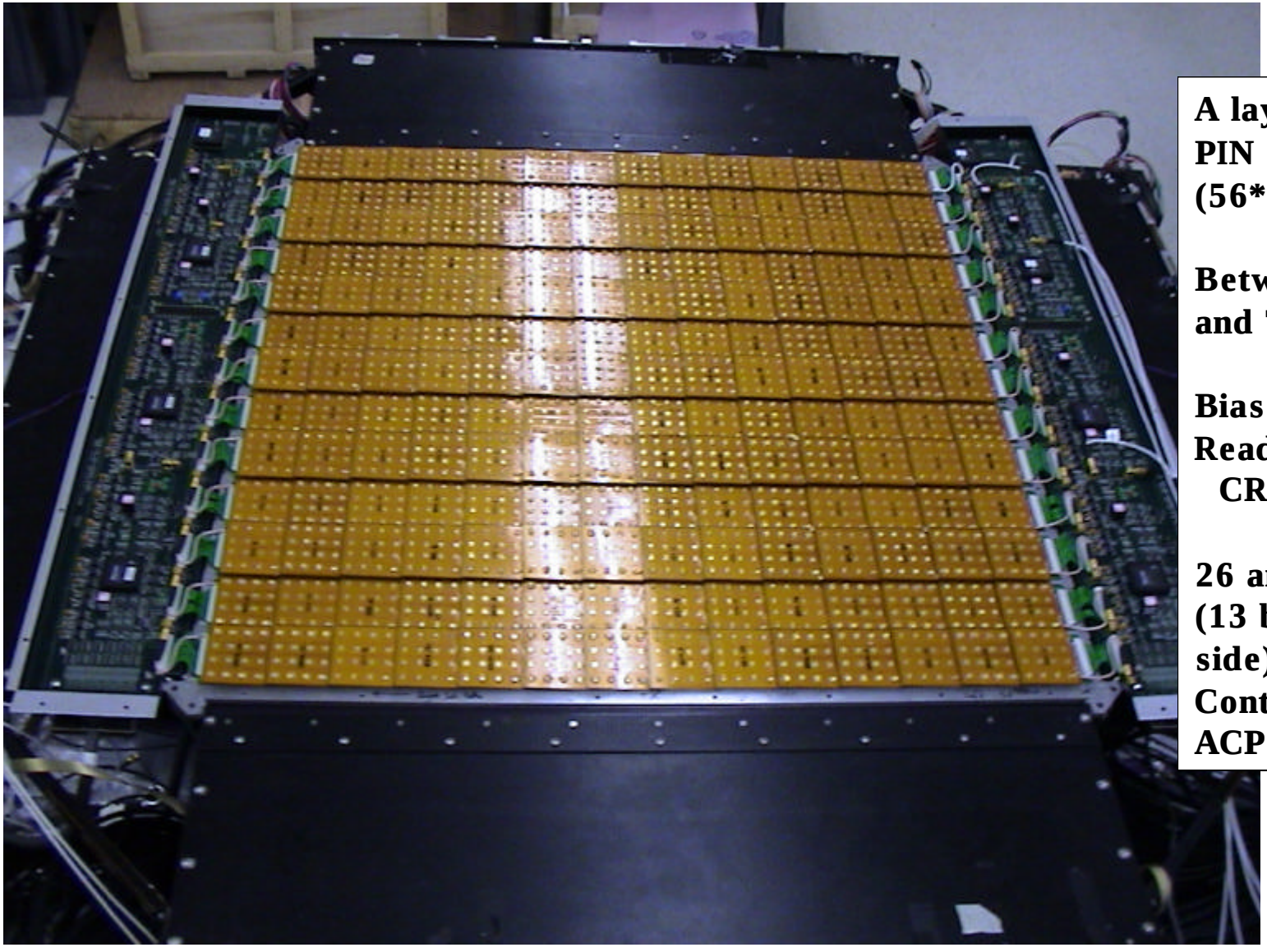
(PISA - JUNE 2002)

HPD cookie + elastic bellow

Clear fibers



Silicon Charge Detector (SCD)



A layer of Silicon PIN diode array (56*52 pixels)

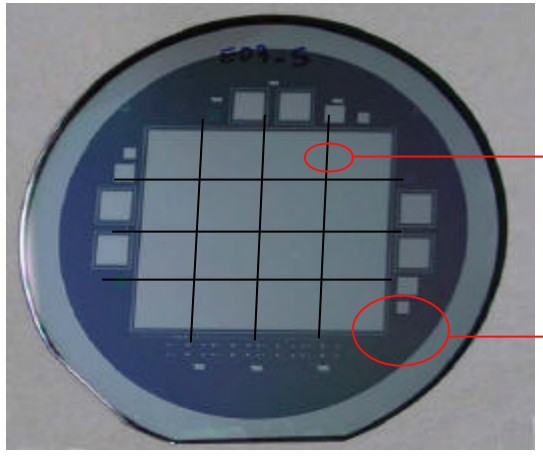
Between Hodoscope and TRD

Bias : 100 V
Readout with CR1.4

26 analog boards (13 boards each side)
Controlled by two ACPs

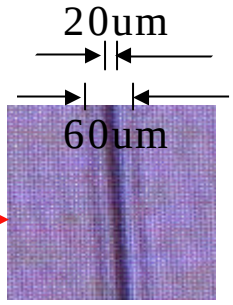
Fabrication of Silicon Sensor

Step 1



Fabricated sensor on 5 inch wafer

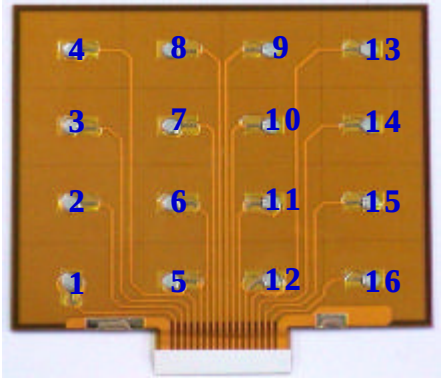
Pixel size: 1.55 x 1.37cm^2



Gap between sensors

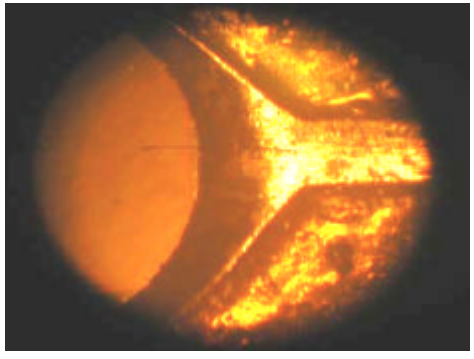
3 Guard Rings

Step 2



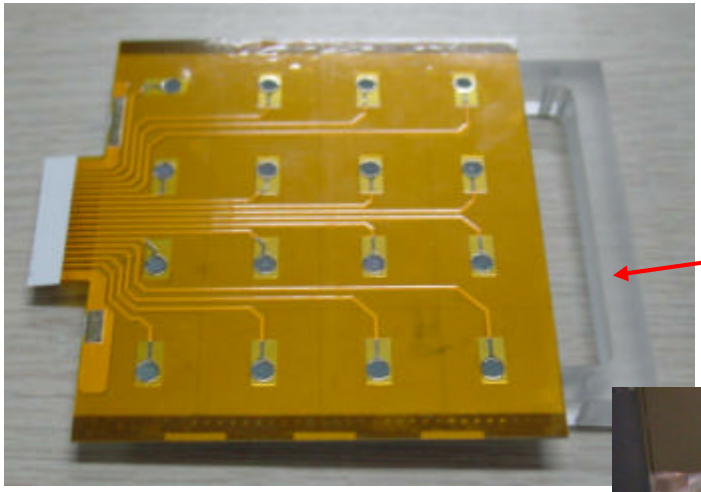
Kapton cable for connection with electronics

Step 3

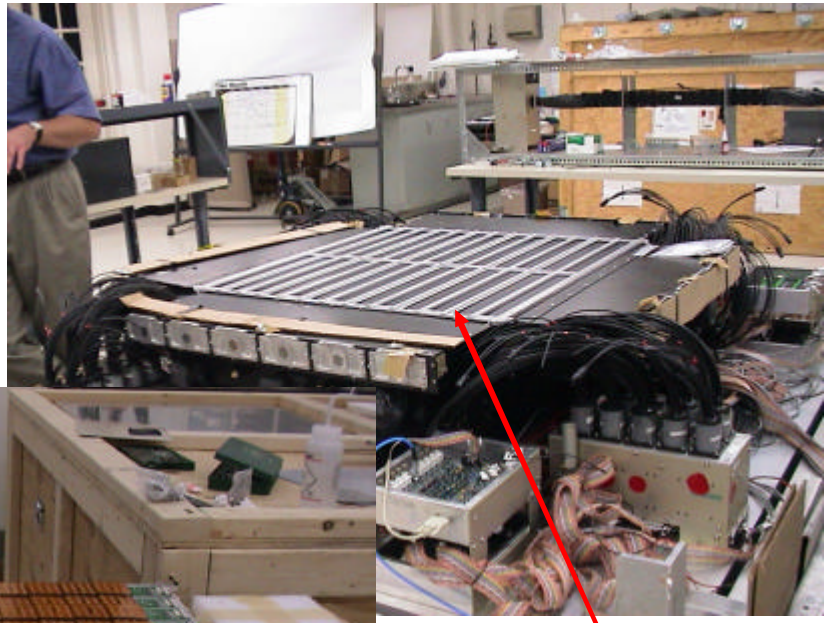


Wire (wedge) bonding,

glob top ; DCE, DP100, 5 min epoxy

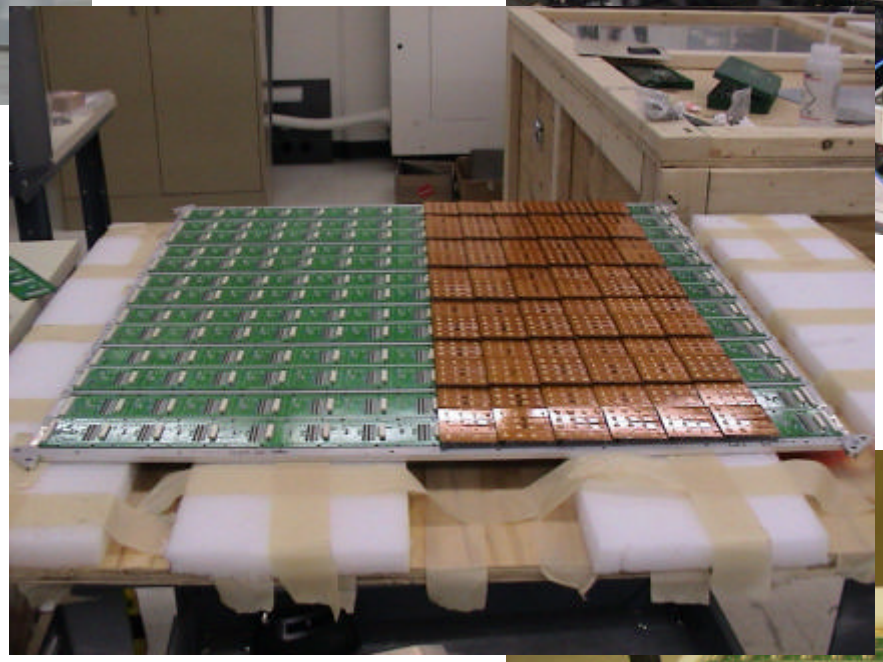


Module Frame

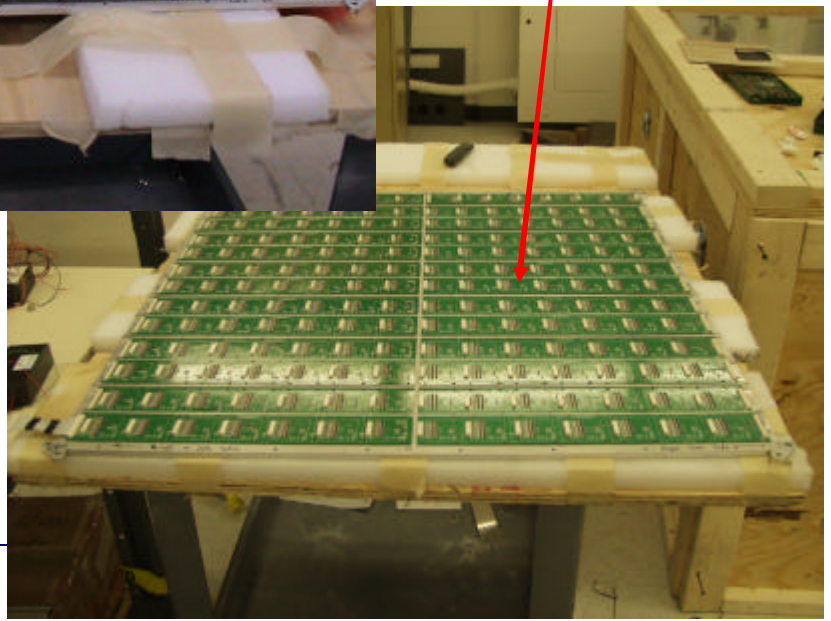


Grand Structure

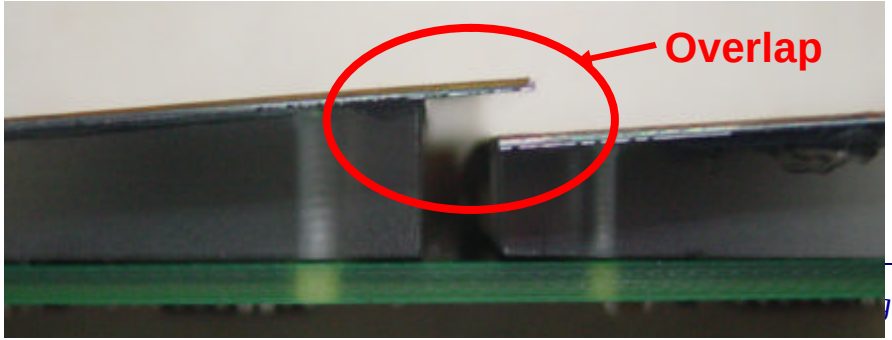
Mechanical Structure



PCB (Analog Board)

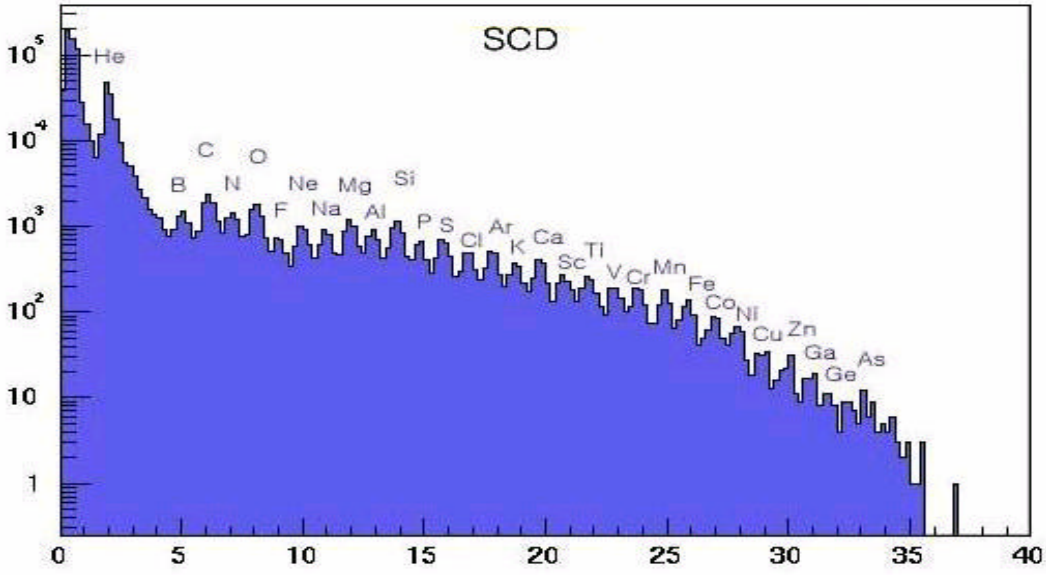


- Total size = 818.39 ´ 818.39 ´ 7 (mm)
- Total sensor area = 779 ´ 797 (mm)
- Active area = 777 ´ 795 (mm)
- Total Height = 21.5 mm (include shielding box)



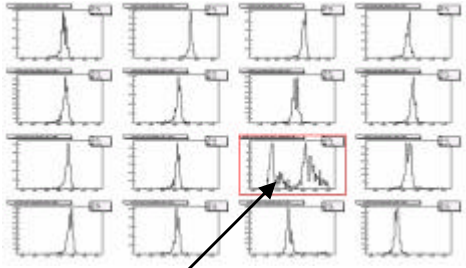
Overlap

Beam Test Results

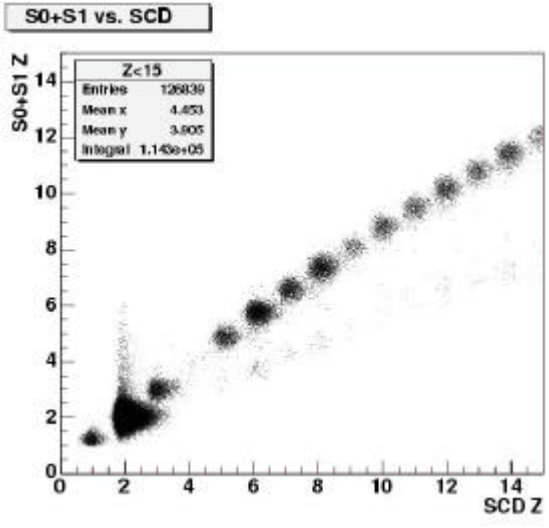


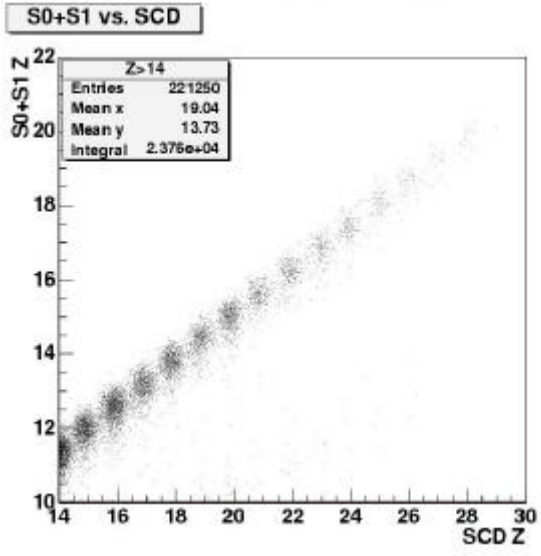
Charge Distribution of Beam Fragments detected in SCD

Excellent Charge Indentification to Z=33

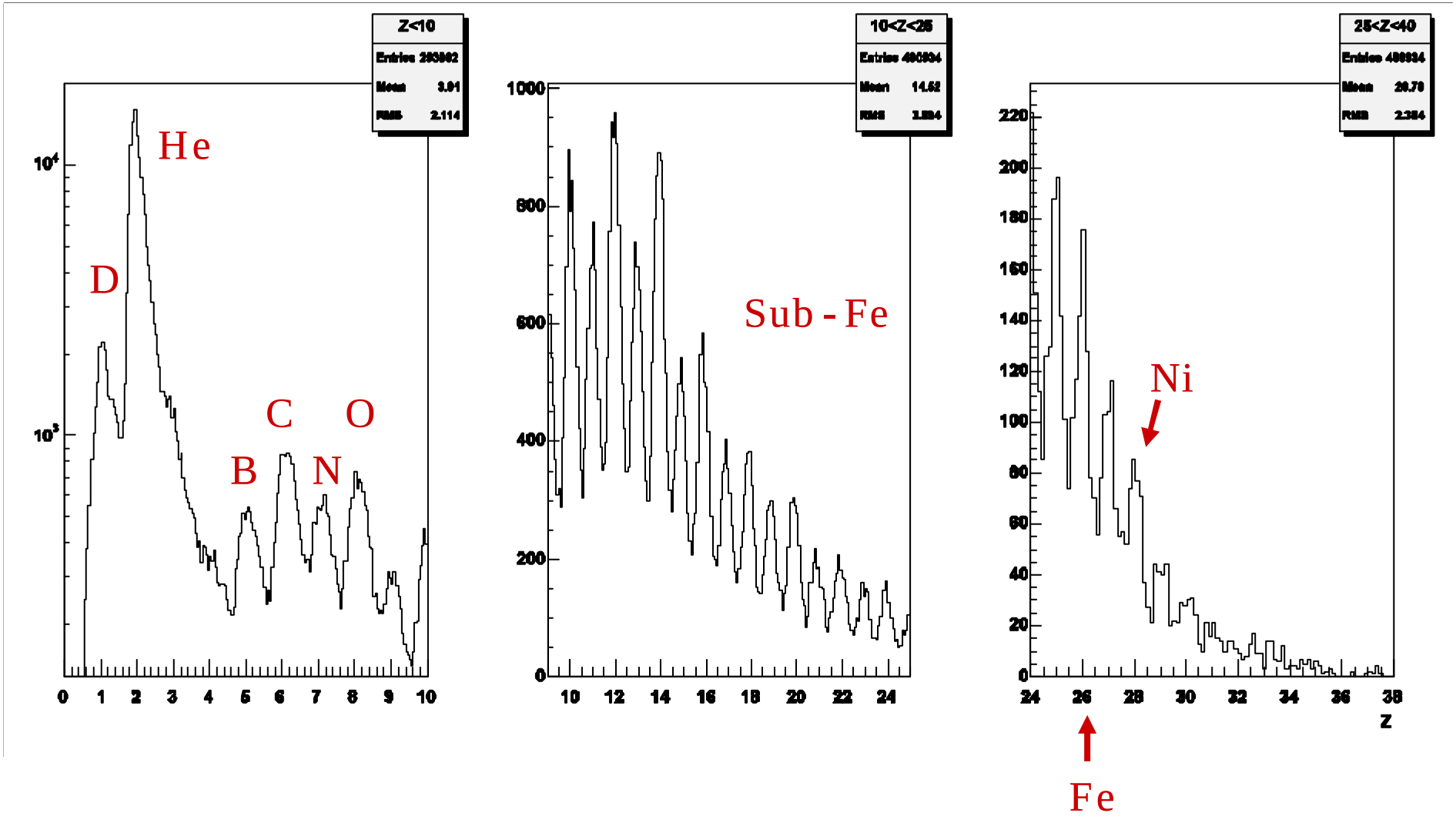


Pixel hit in a sensor





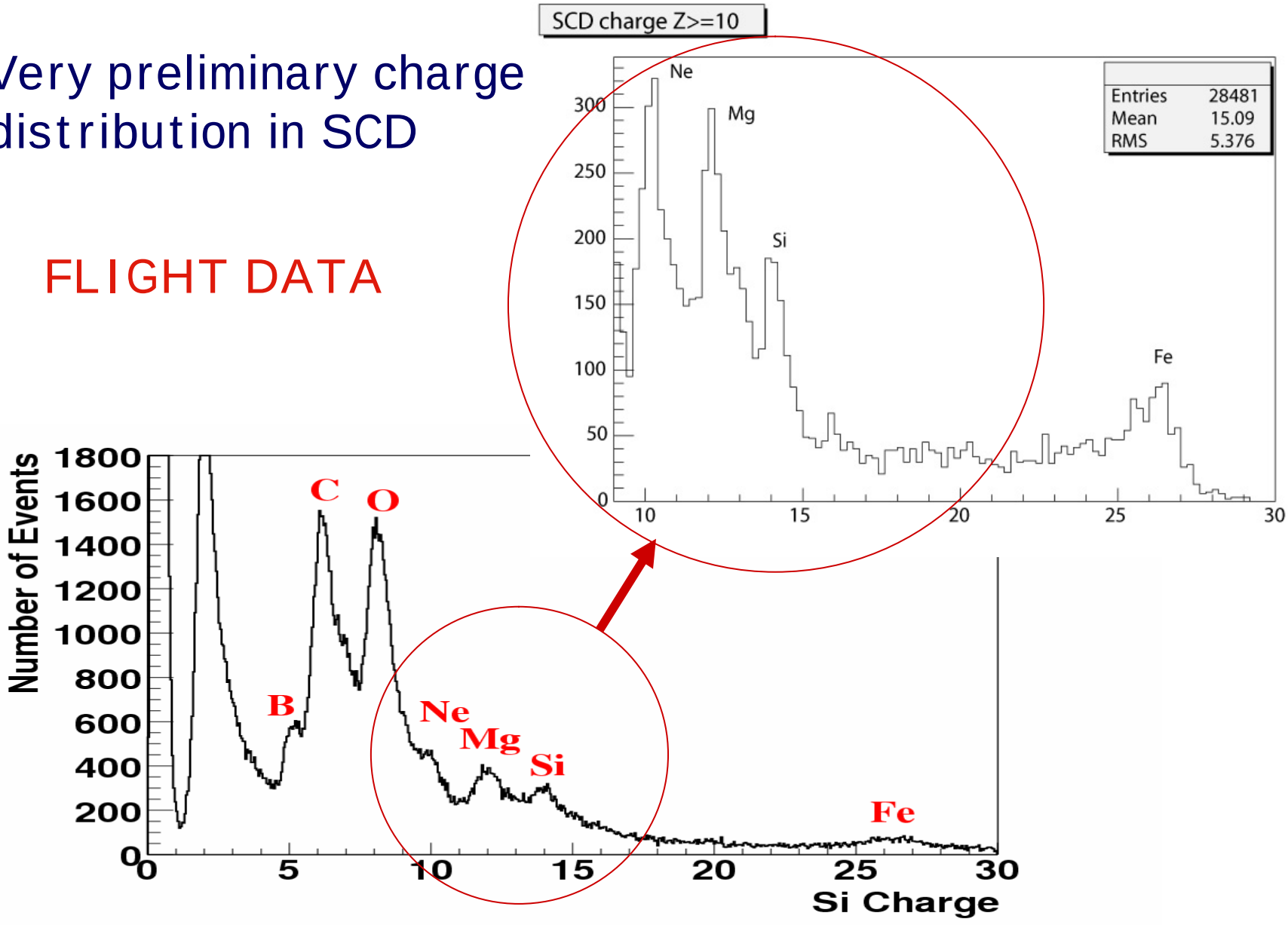
Charge Correlation : hodoscope Clusters vs SCD



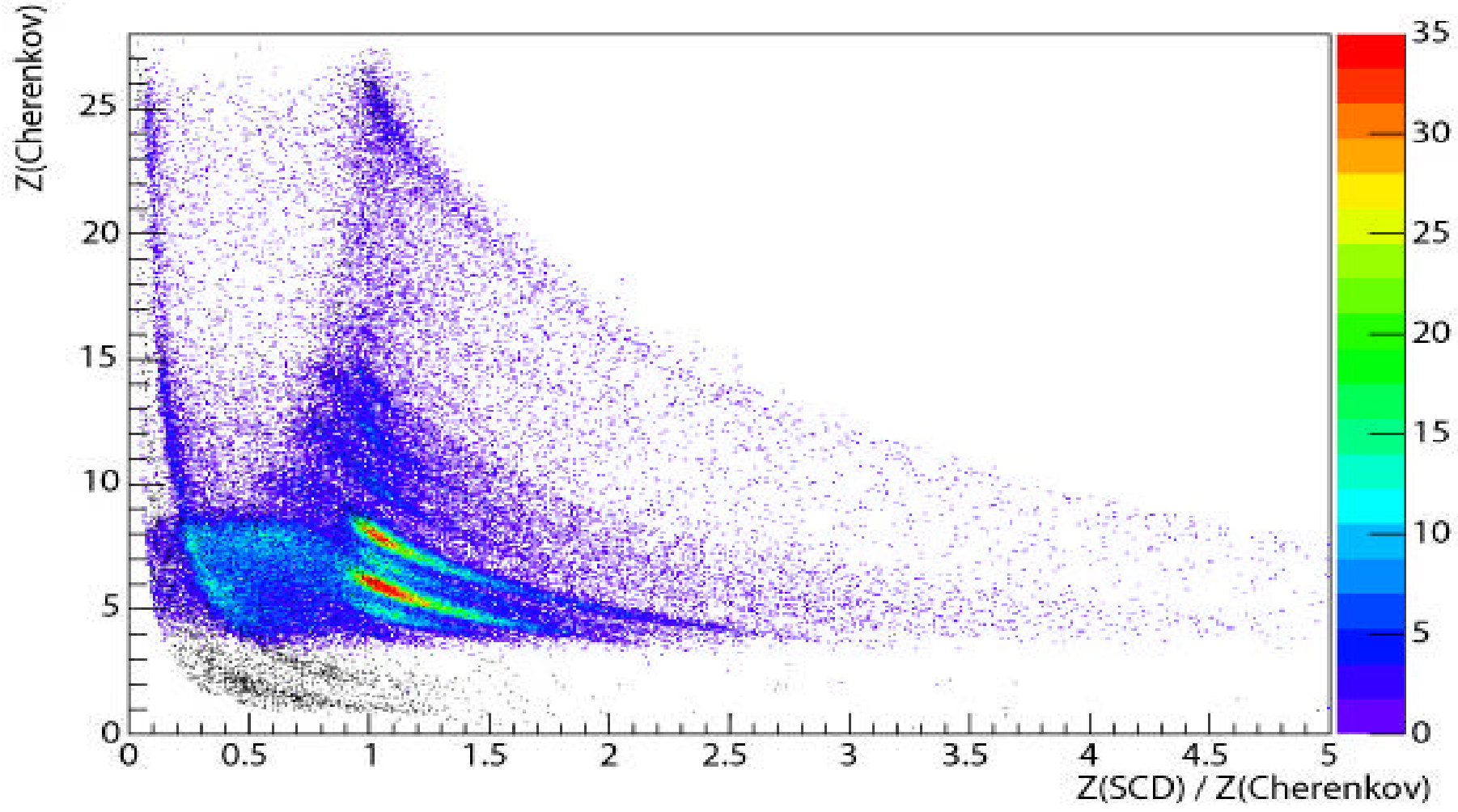
Fragments from primary 158 GeV/n Indium beam with **A / Z = 2**

Very preliminary charge distribution in SCD

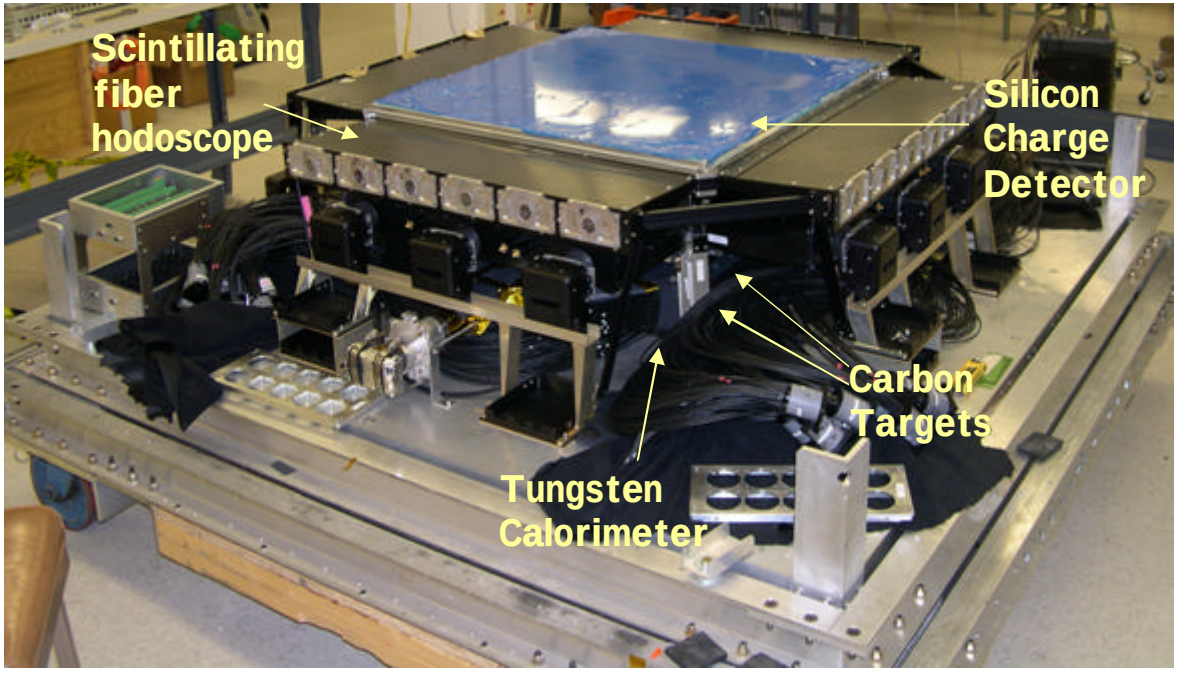
FLIGHT DATA



Preliminary charge correlation in the Cherenkov and SCD

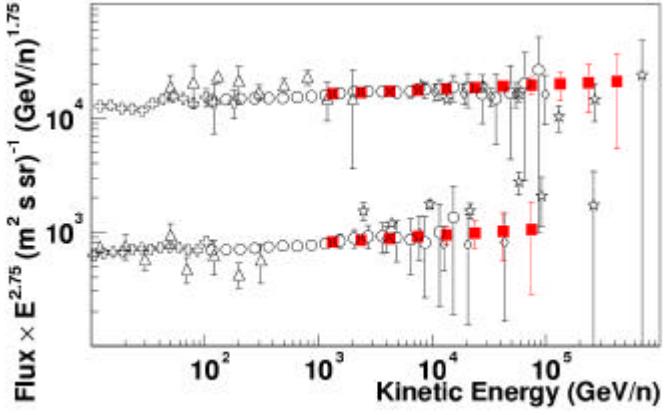


Exploring Supernova Acceleration Limit



Calorimeter Module

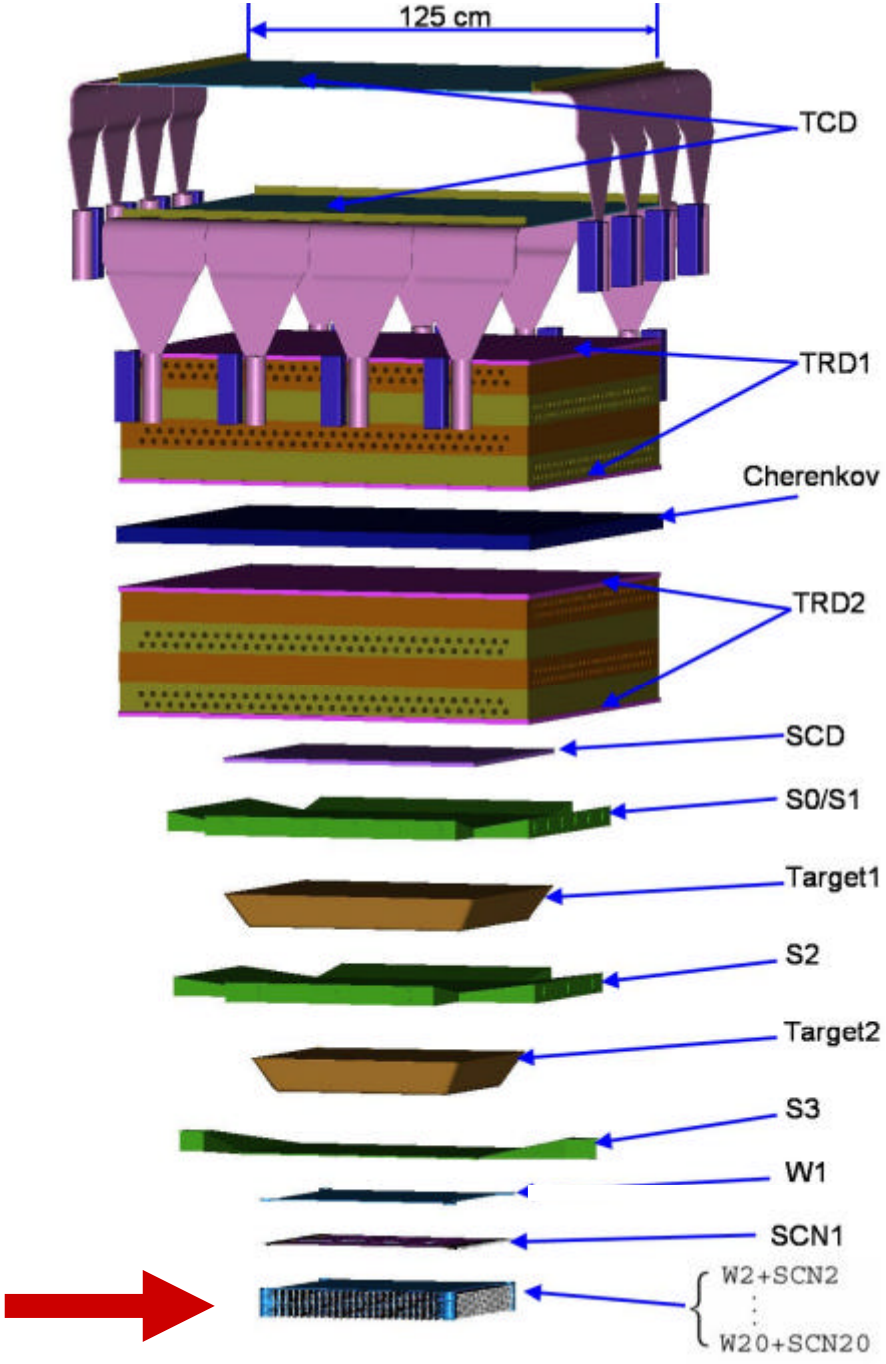
- The **Silicon Charge Detector (SCD)** provides particle charge identification
- The 20-layer **tungsten-scintillating fiber calorimeter** provides its own event trigger and x,y,z tracking coordinates
- The **scintillating fiber hodoscope** provides x,y tracking coordinates at fixed z above the calorimeter



Comparison of Calorimeter data (red squares) for protons (upper) and Helium (lower) with prior data

Calorimeter Science Objectives

- The Figure (left) shows **p** and **He** spectra measurements with the Calorimeter as **expected from a 40-day flight**
- Simultaneous measurements of Z > 3 particles provides inflight cross calibration of Calorimeter and TRD

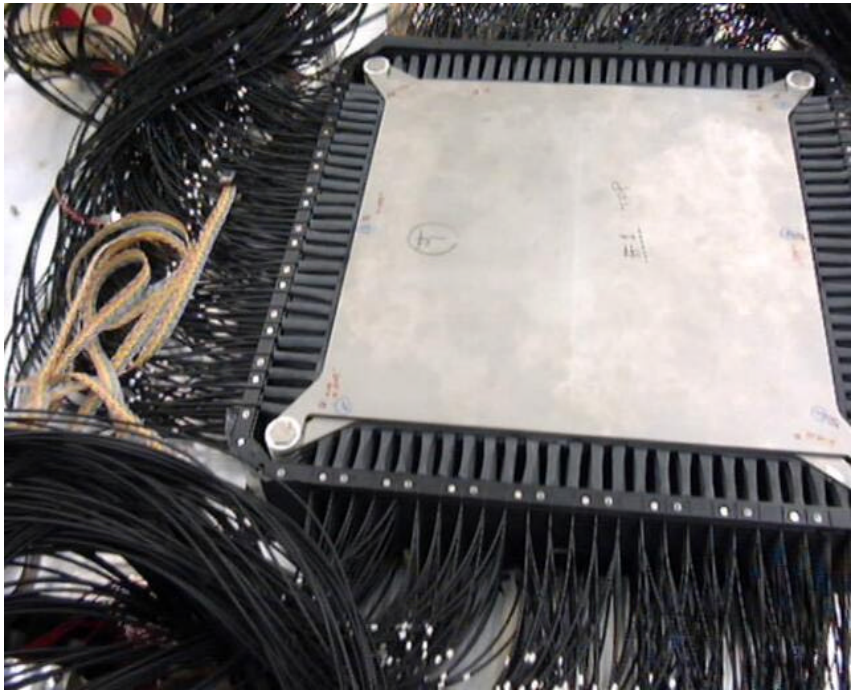


Tungsten/SciFi calorimeter

20 radiation length

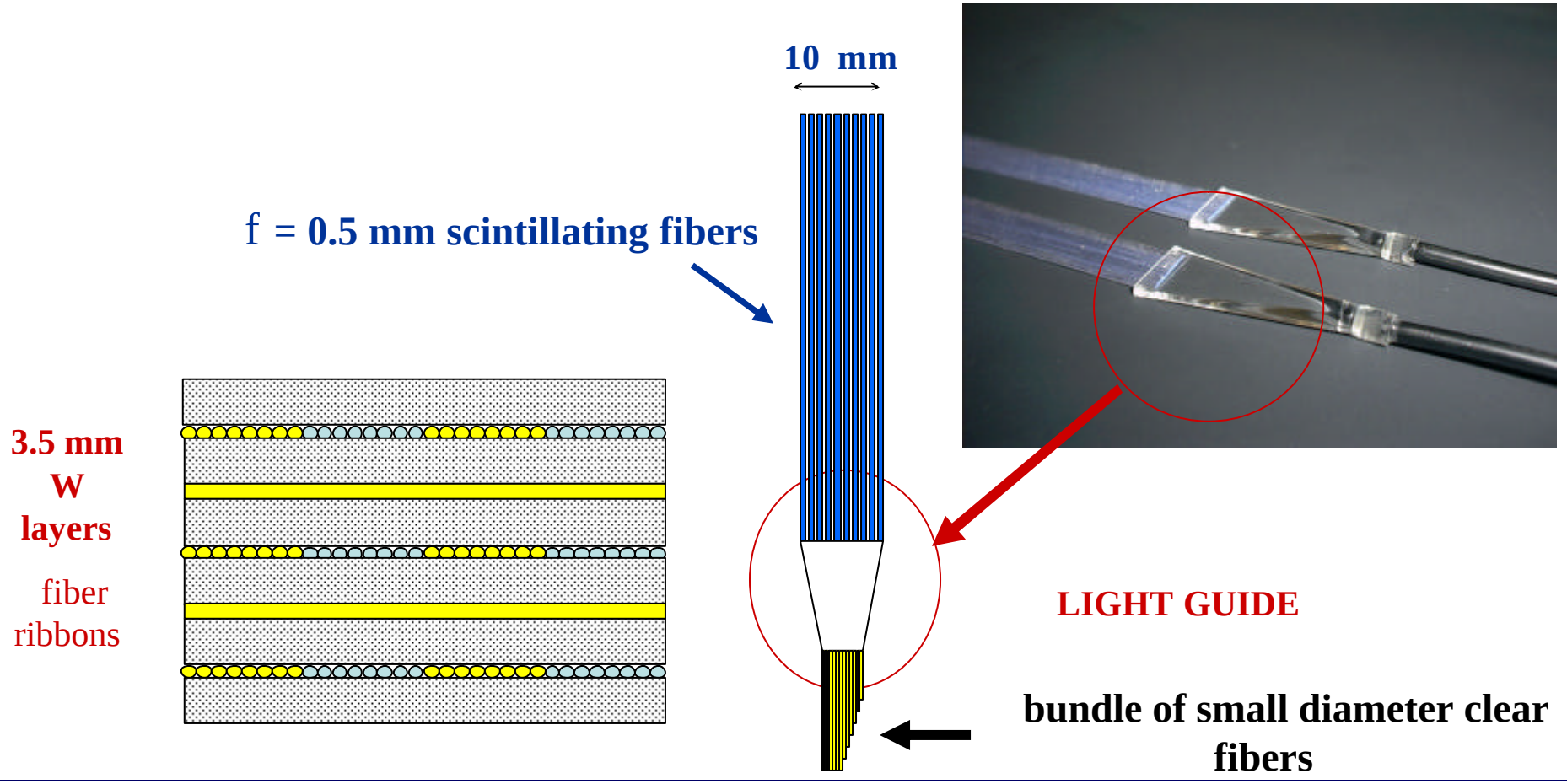
~ 0.7 nuclear interation length

50 x 50 cm^2 active area

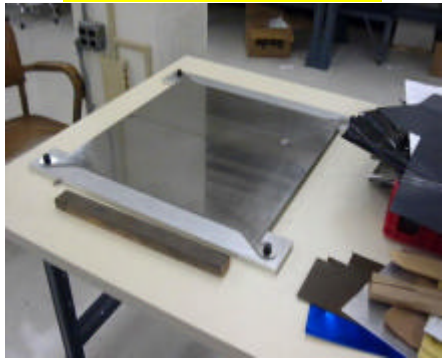


Tungsten / Sci-Fi CALORIMETER

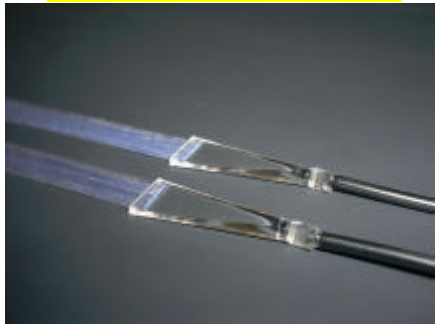
- longitudinal sampling : 3.5 mm W ($1\ X_0$) + 0.5 mm scintillating fibers
- total of 20 superlayers (**$20\ X_0$**) : alternate views x- y
- transverse granularity : 10 mm (20 fibers) (Moliere radius ~ 9.0 mm)



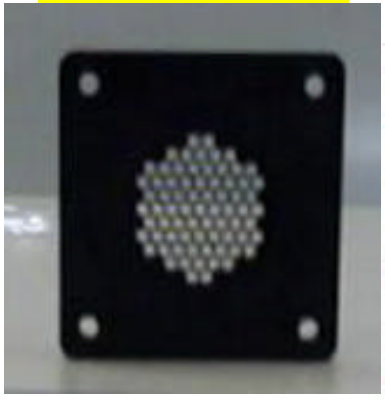
Tungsten plate



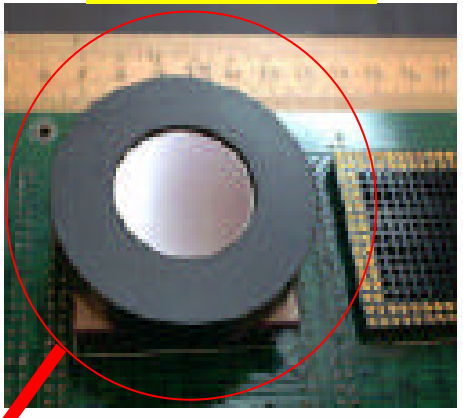
Scinti-Fi ribbons
light mixer
clear-fibers bundle

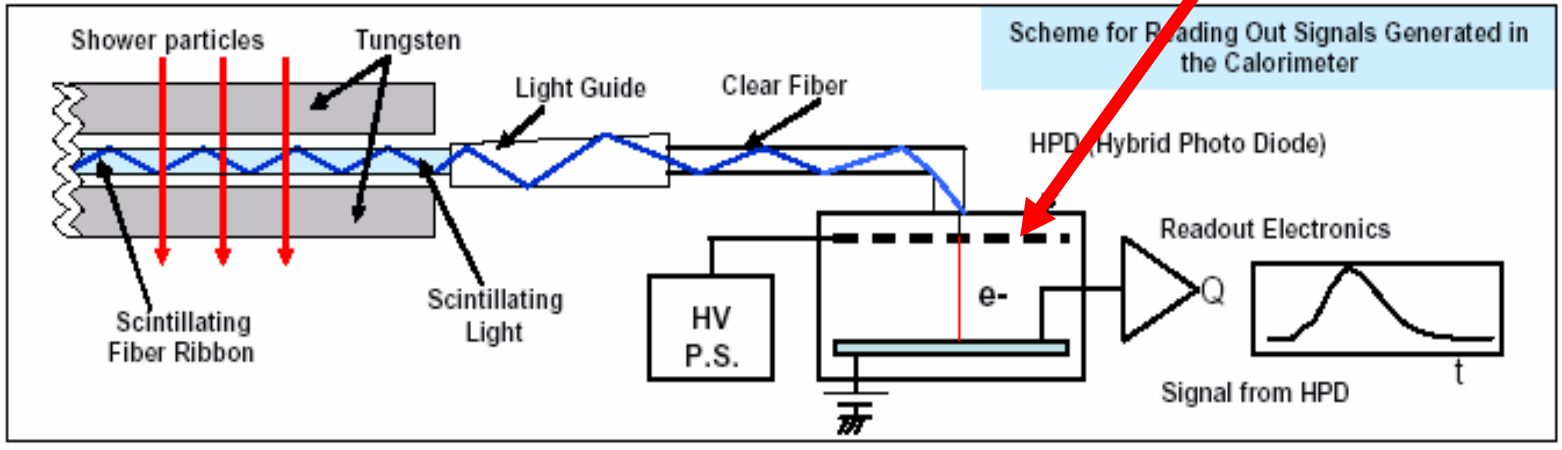


Fibers-to-HPD
optical interface
"Cookie"
(73 pixels)



Proximity focus
HPD





Scheme for Reading Out Signals Generated in the Calorimeter

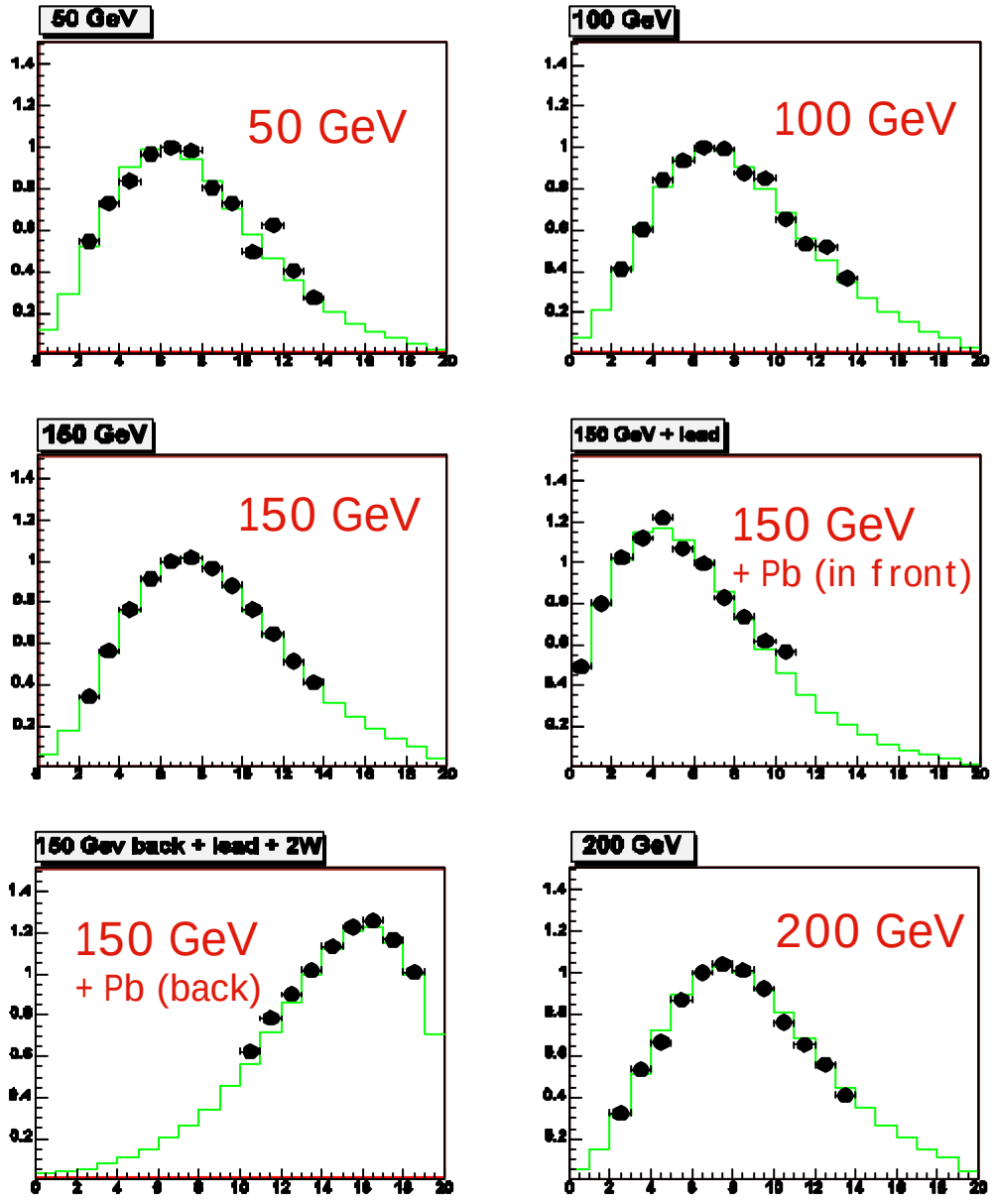
HPD (Hybrid Photo Diode)

CREAM calorimeter beam tests @ CERN

- September 2003 in the H2 beam line
  - e^- @ 50, 100, 150, 200 GeV
  - p @ 150, 250, 350 GeV
- November 2003 in the H2 beam line
  - heavy ions @ 158 GeV/n
- September 2004 (electrons + protons)

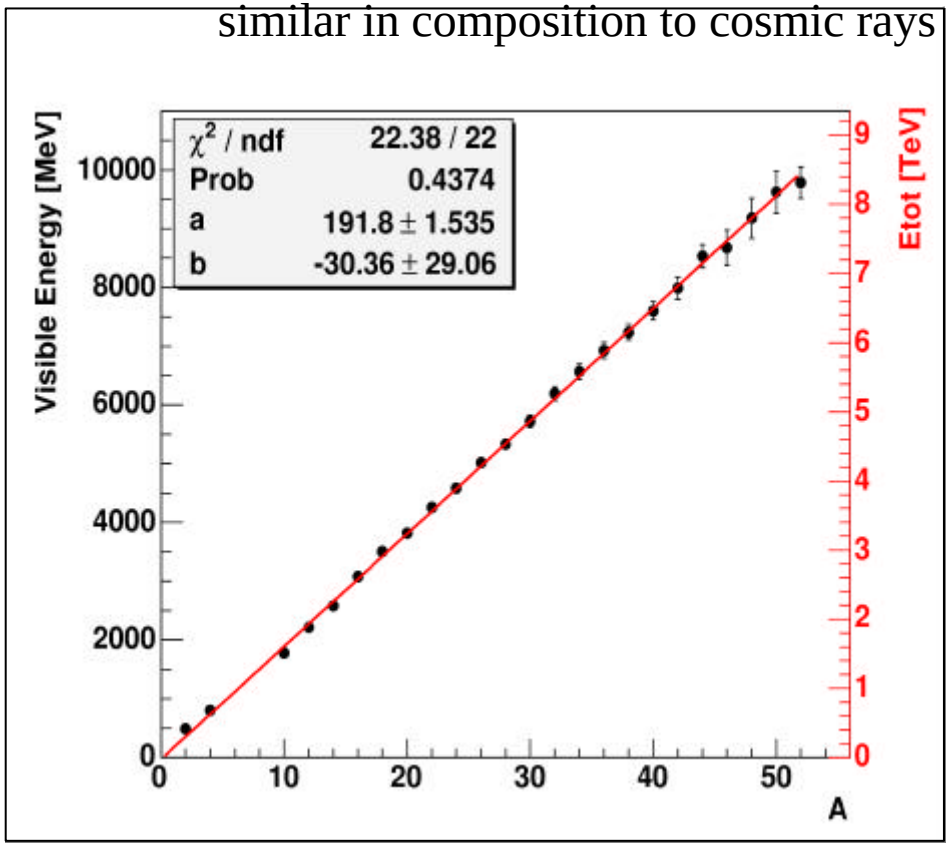
  CREAM-2 calorimeter was fully calibrated for the flight :

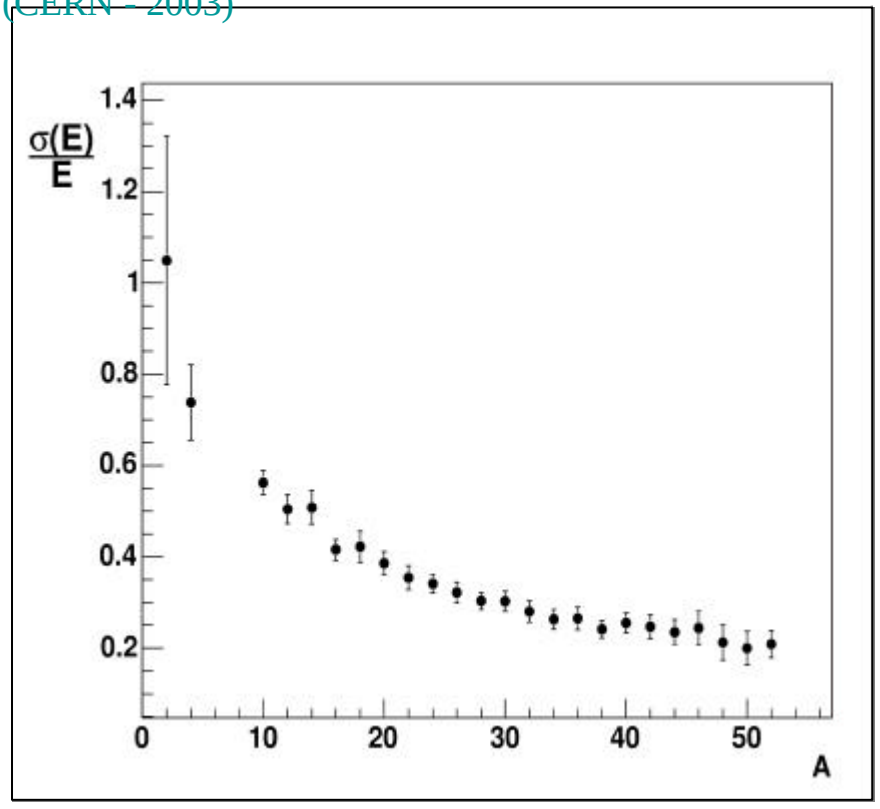
  - complete horiz.+vert. scan for channel equalization
  - energy scan
  - angular scan
  - HV scan



Beam Test : Calorimeter response to Heavy Ions

- 158 GeV/n primary Indium beam + fragmentation target ⇒ A/Z=2 fragments similar in composition to cosmic rays (CERN - 2003)



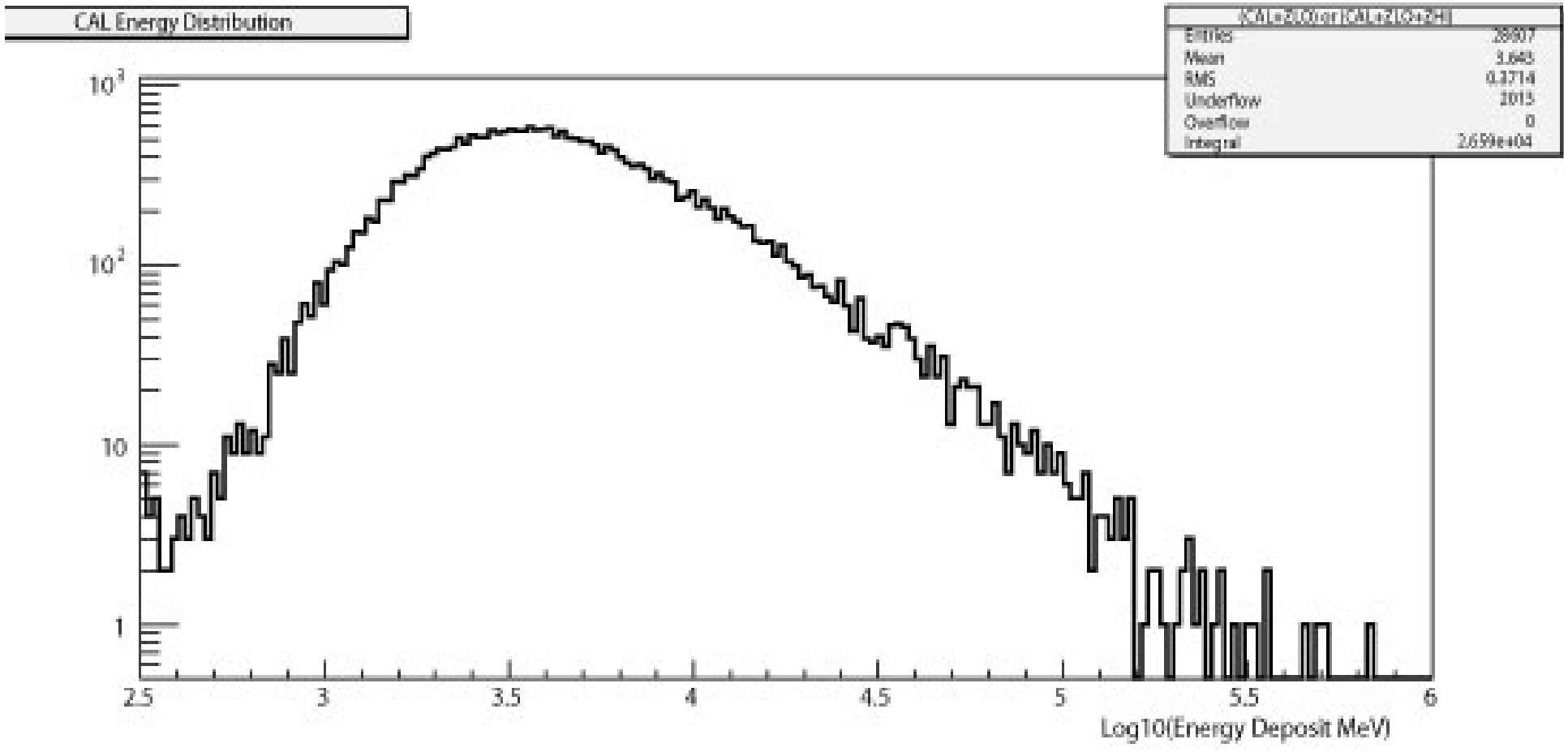


Good linearity up to 8.2 TeV total particle energy

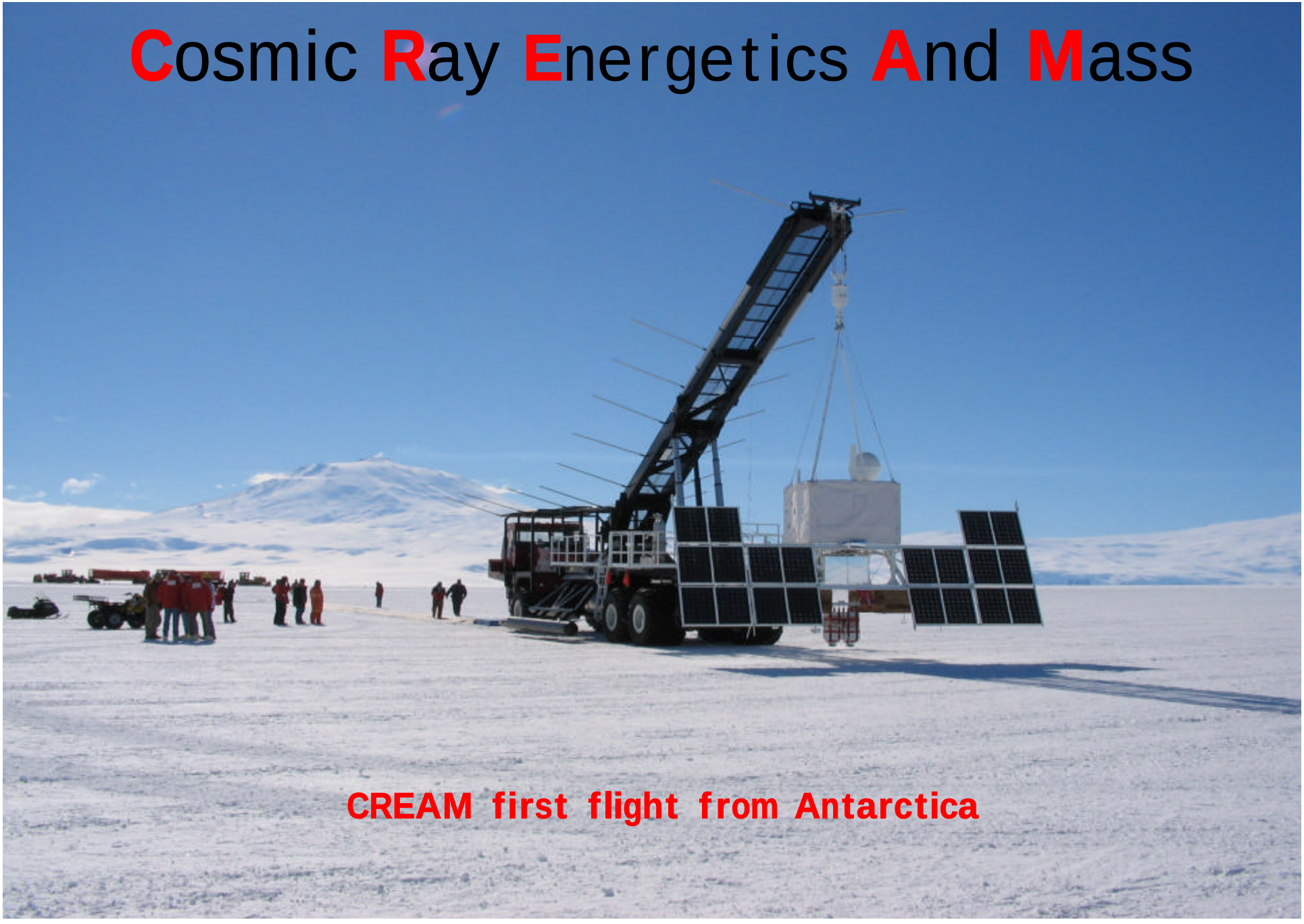
Resolution ≈ 20% for Iron @ 158 GeV/n

Very preliminary : energy deposit in the calorimeter

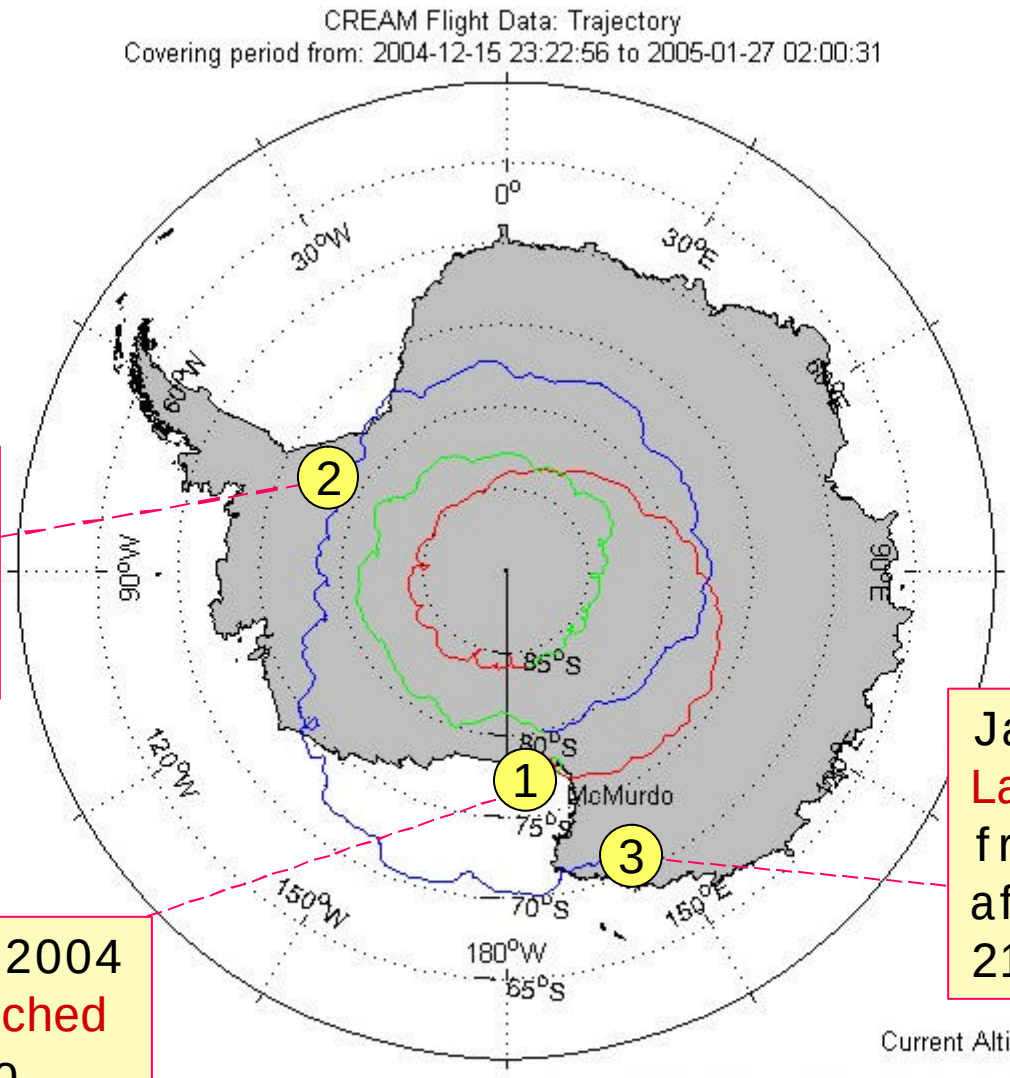
(CAL + ZLO) .OR. (CAL + ZLO + ZHI) triggers



Cosmic Ray Energetics And Mass



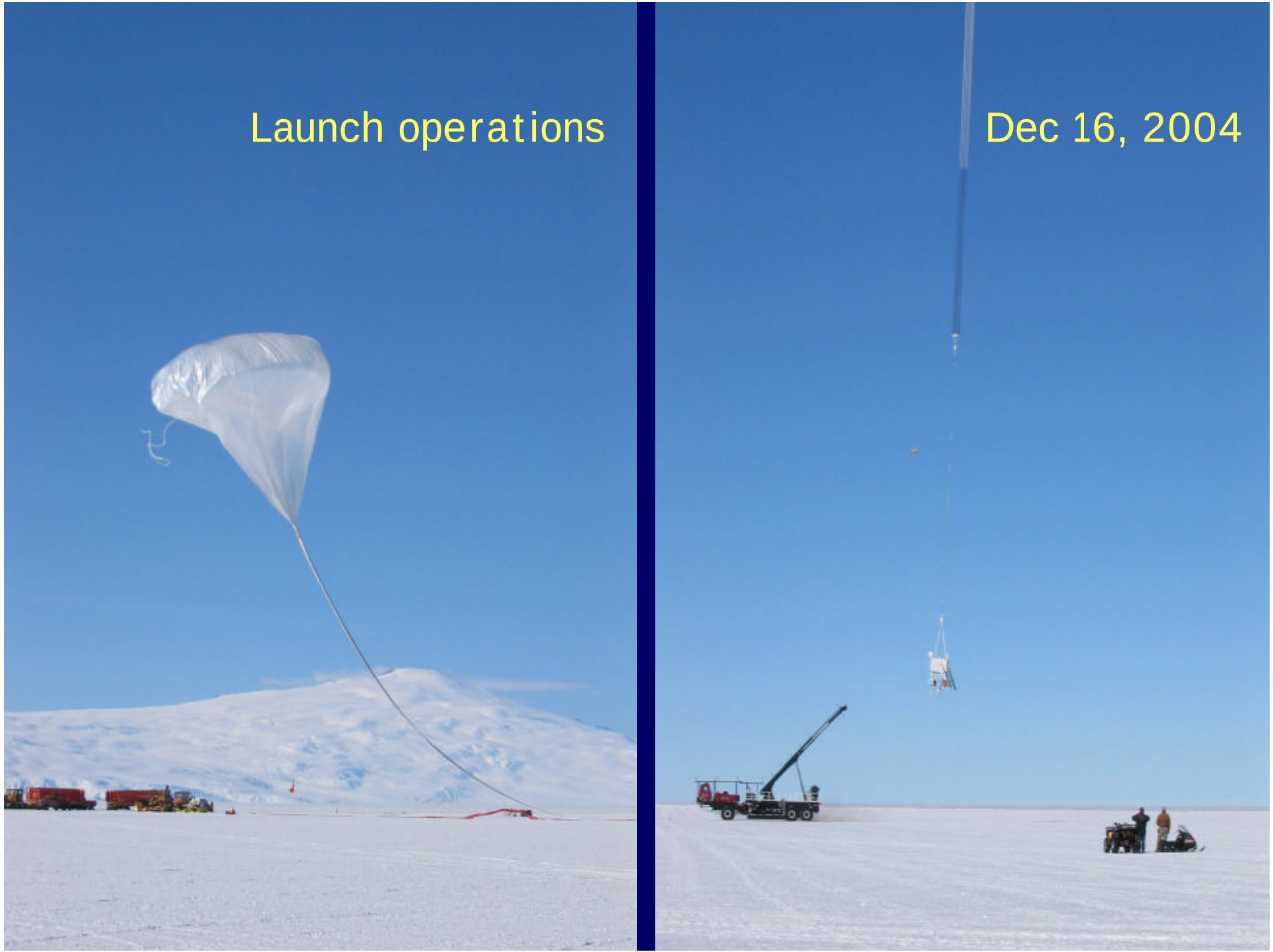
CREAM first flight from Antarctica



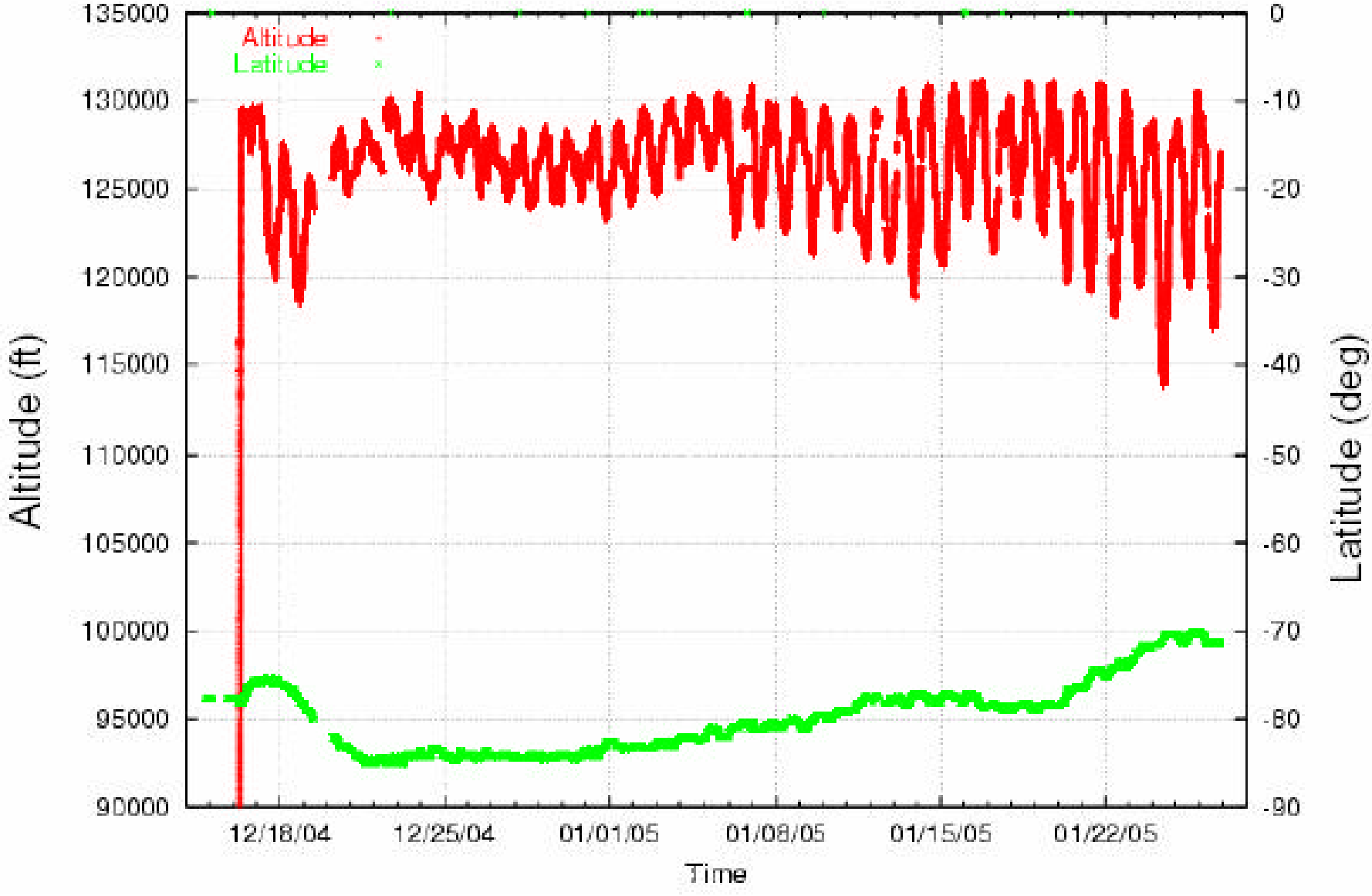
January 16, 2005
Break the record of 31 days and 20 hrs

December 16, 2004
CREAM is launched from McMurdo

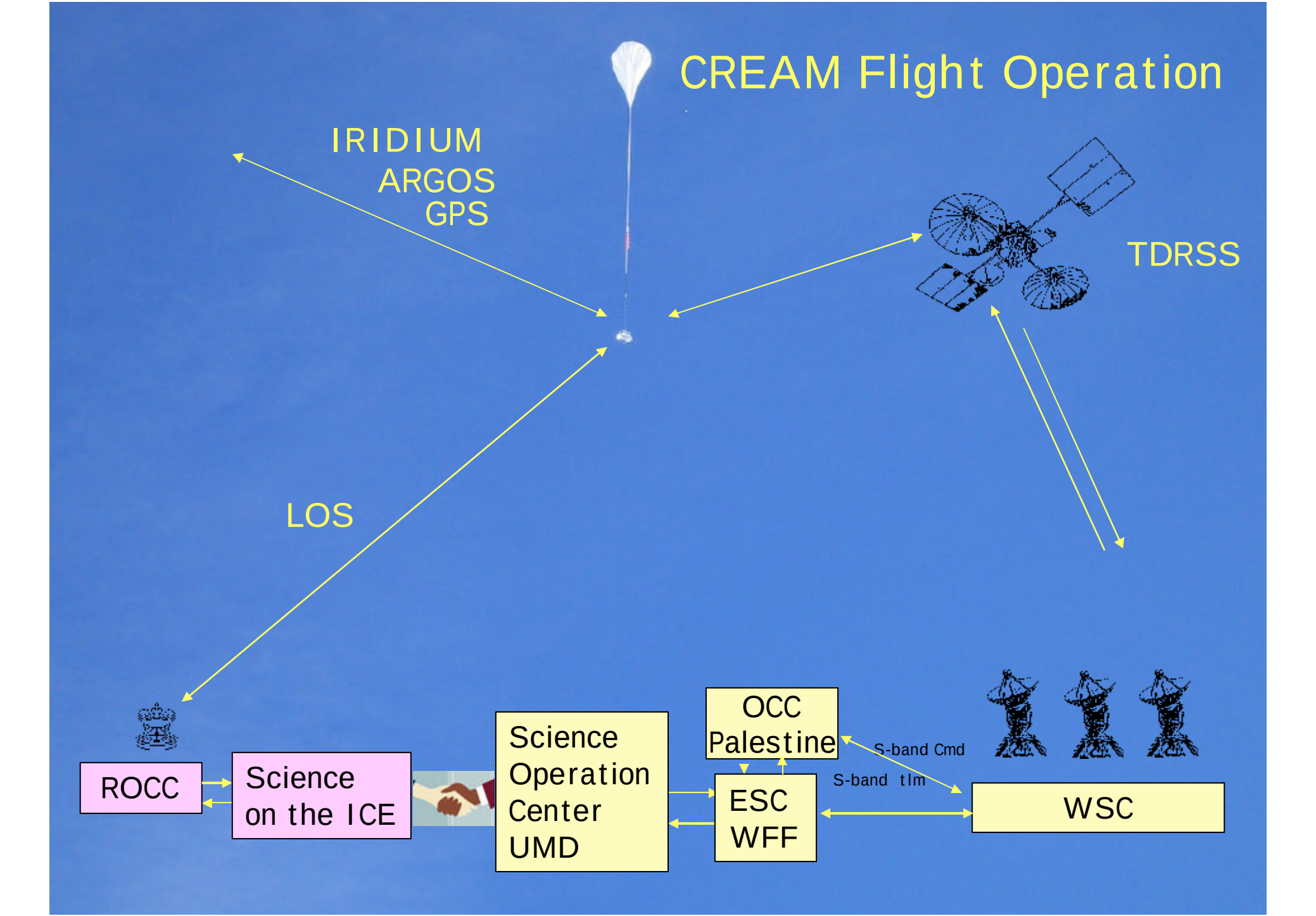
January 27, 2005
Landing 417 miles from McMurdo after 41 days and 21 hrs


Launch operations
Dec 16, 2004

Flight profile

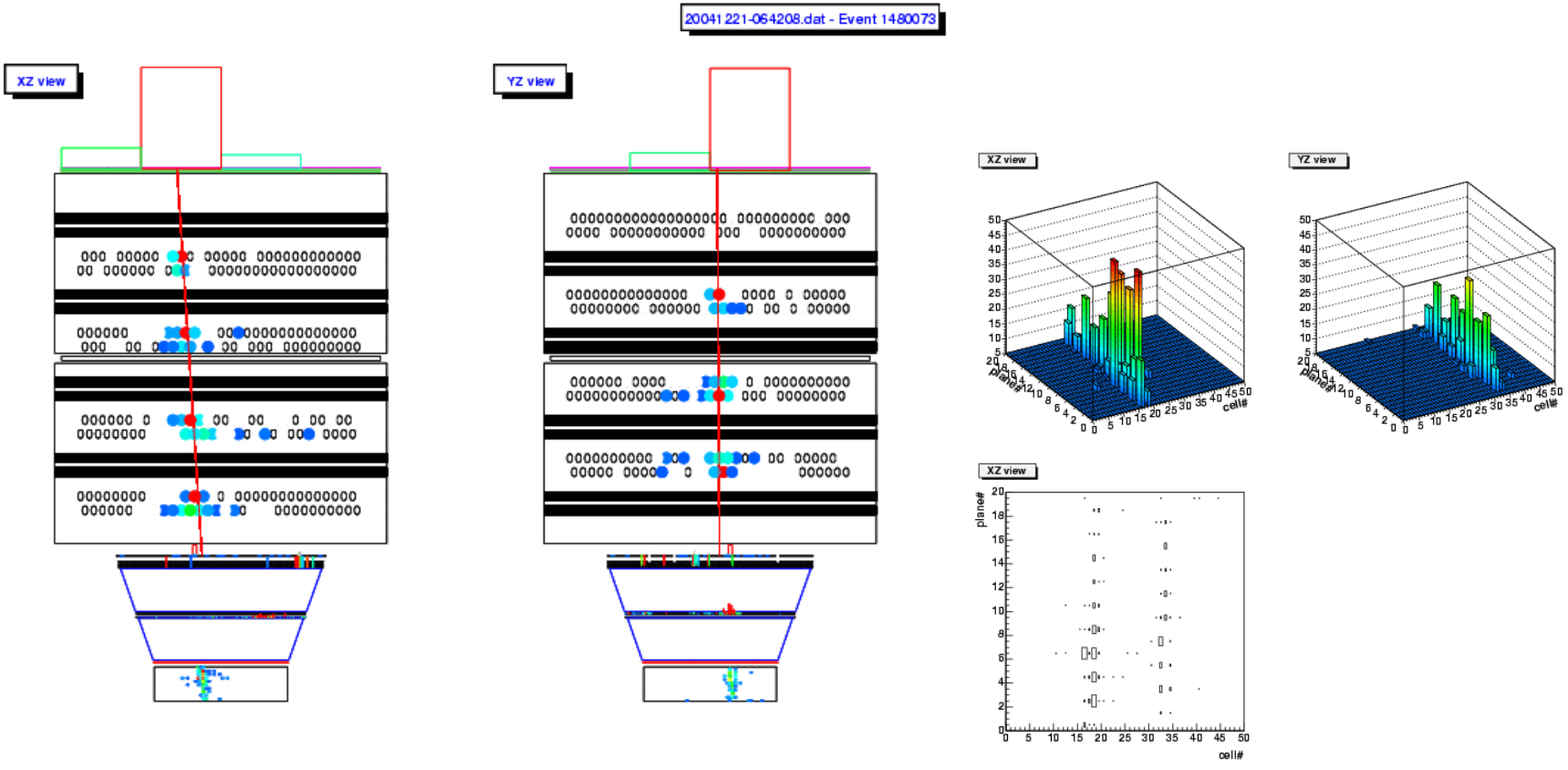


CREAM Flight Operation

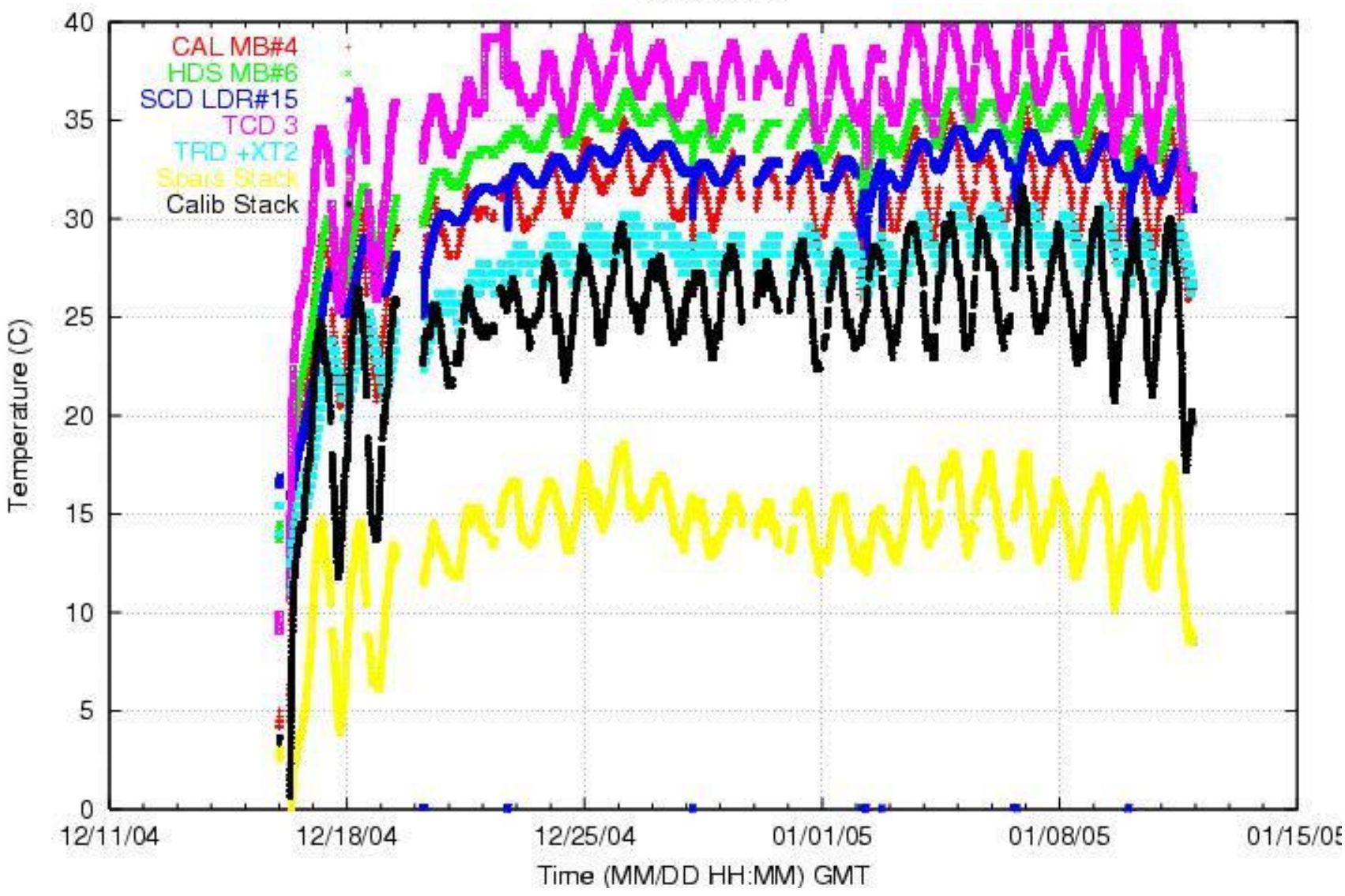


Instrument functions well

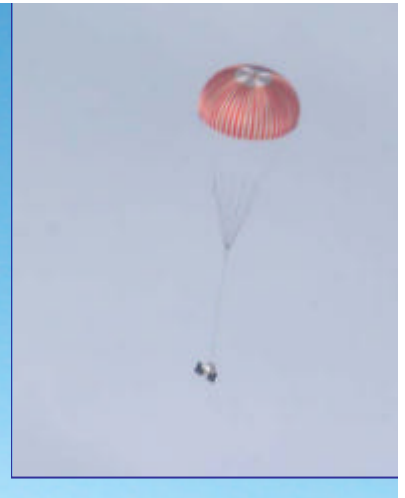
An example event: ~10 TeV Fe



Thermal history



Impact site



Recovery operations

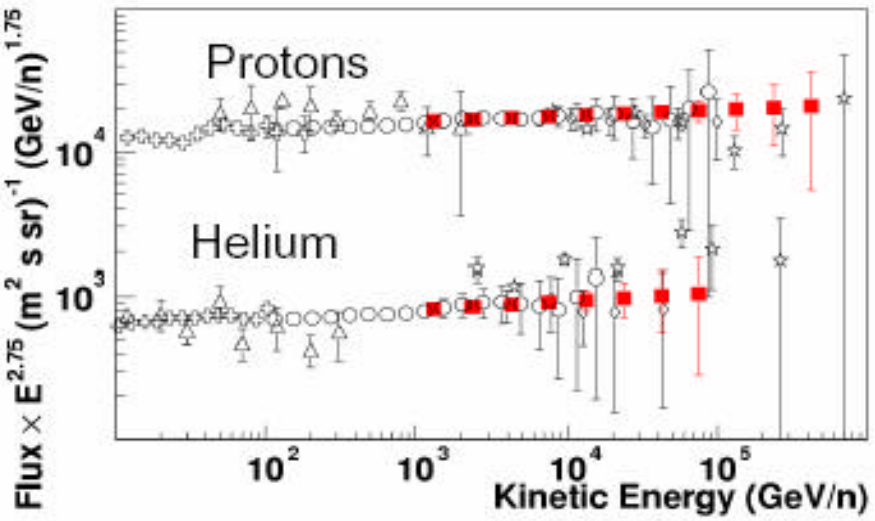
- NSF/OPP set up field camp at impact site
- Payload was disassembled to fit inside the Twin Otter aircraft and returned to McMurdo with five flights

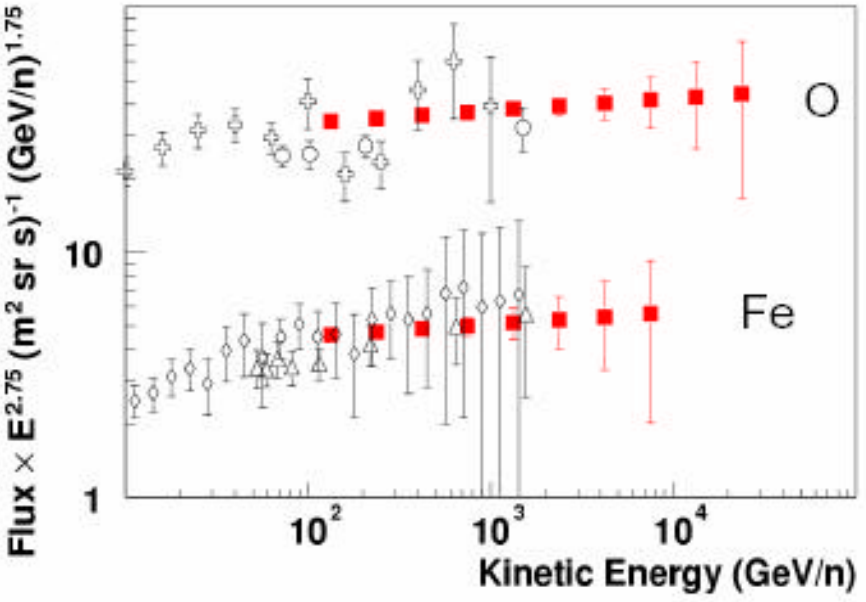
CREAM Measurement Capabilities

- Element Coverage — H to Fe (Z=1 through Z = 26) and above
  - Calorimeter — Z = 1
  - TRD — Z > 3
- Charge Resolution : — Individual elements Z < 15
  Individual or element groups Z = 15
- Energy Resolution : — CAL : Better than 50% (E independent)
  TRD : ~ 15 % (C) ; 7% (Fe)

- Collecting Power :
  0.3 m^2 sr for Z=1 & 2 (considering interaction fractions)
  1.3 m^2 sr for Z > 3 (efficiency not included)

Expected energy reach after the first flight

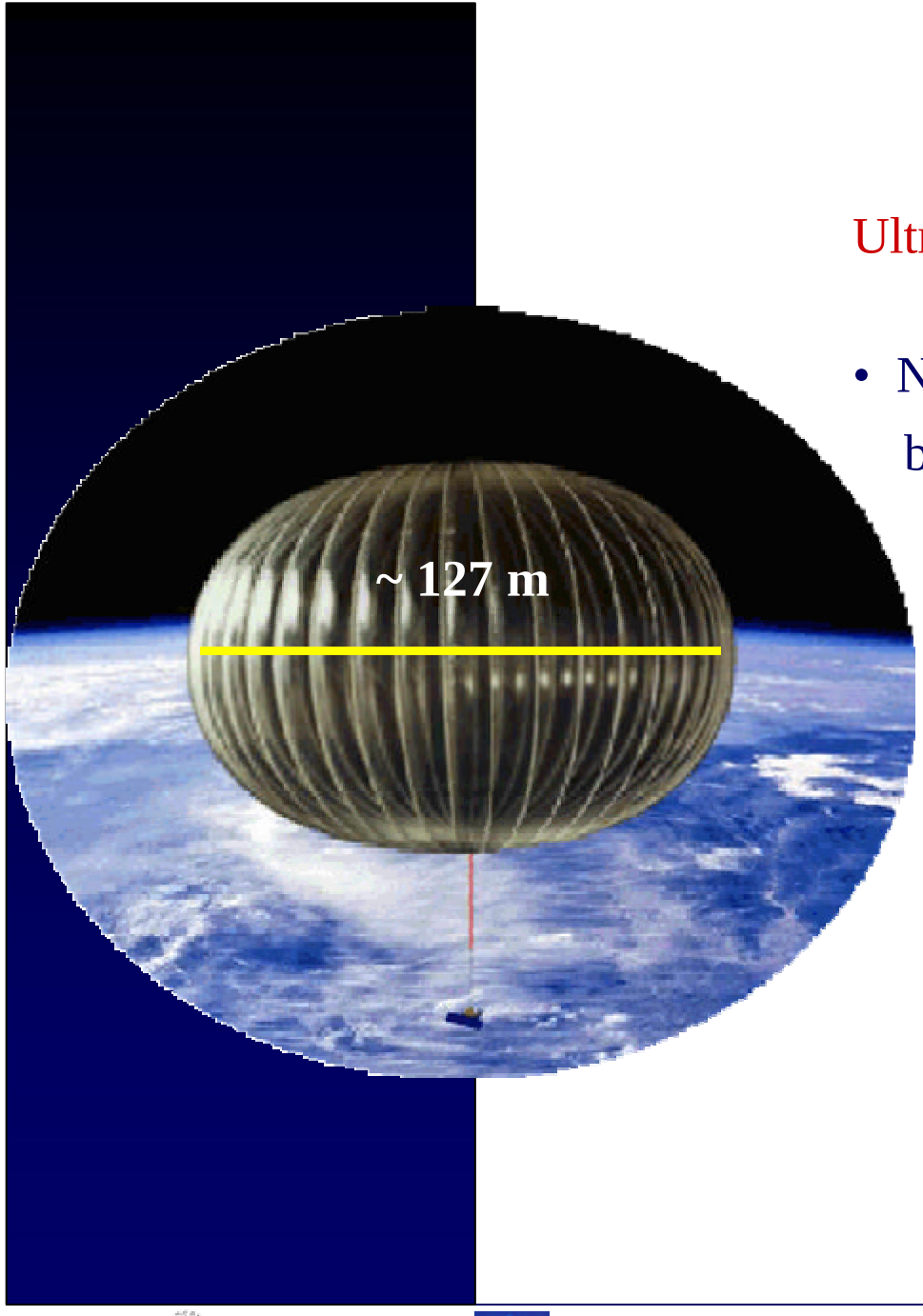




- The left Figure compares simulated data (red squares) for protons (upper) and Helium (lower) from a 40-day flight of the Calorimeter with prior data
  - These are the highest energy direct measurements of p and He
  - These are unique Calorimeter data below the TRD threshold

- The right Figure compares simulated data (red squares) for Oxygen (upper) and Iron (lower) from a 40-day flight of the TRD with prior data

ULDB Flights

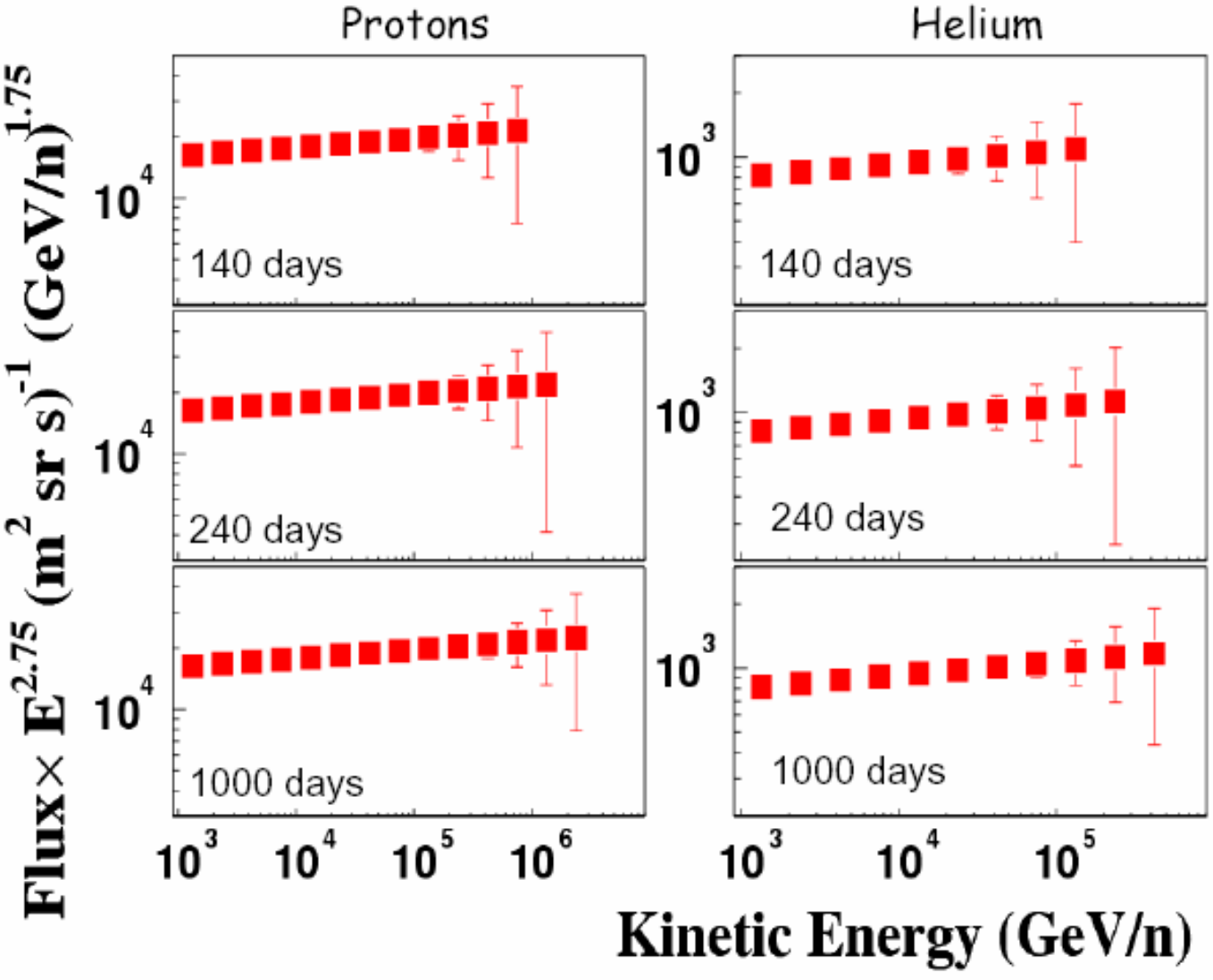


Ultra Long Duration Balloon (ULDB) Project :

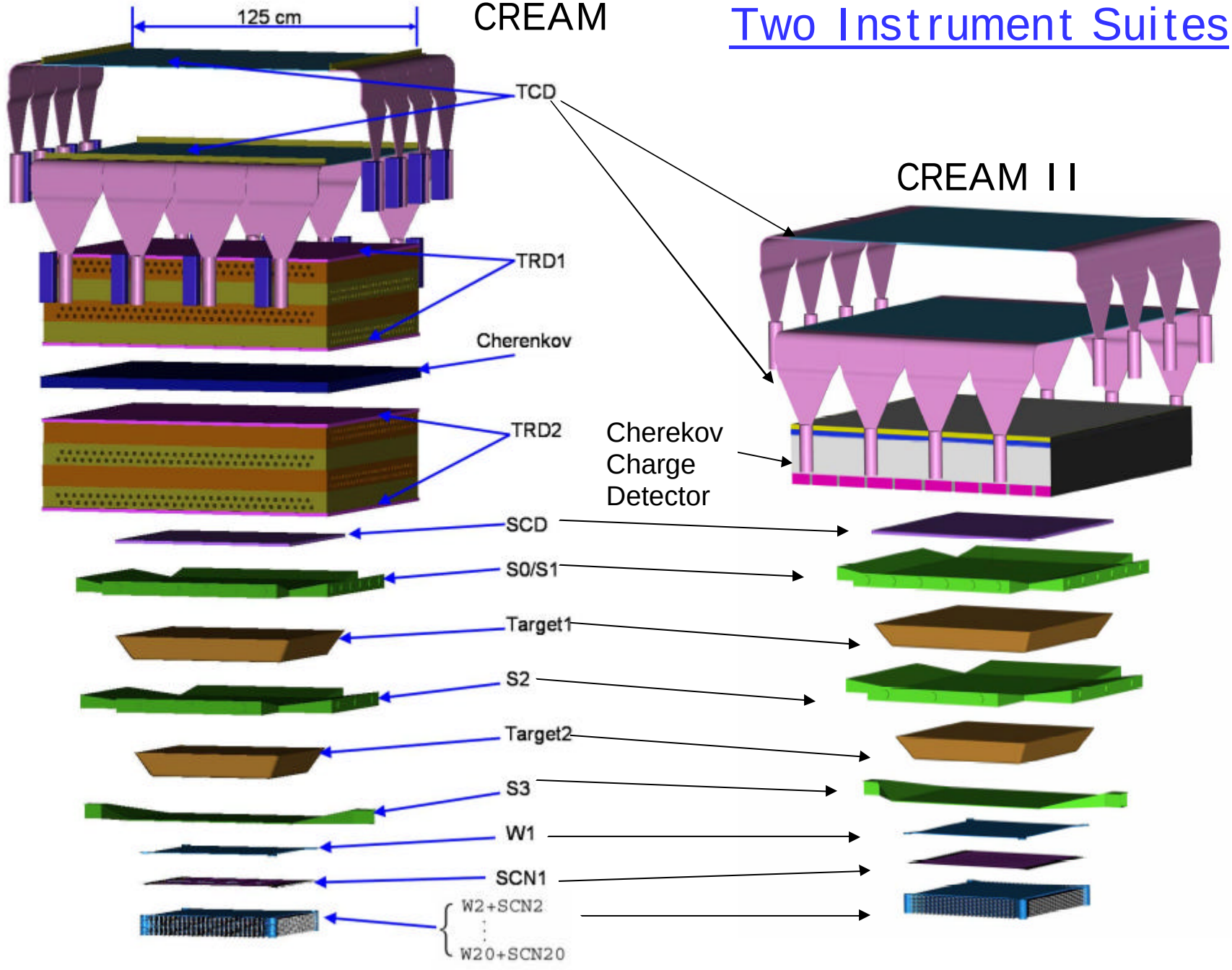
- NASA development of super-pressure balloon systems for 100 days flight duration
- Still under development
- Possibility to fly around the Artic ?
- Test flights from Kiruna in 2005

CREAM has been designed to be the first ULDB mission

Cumulative Energy Reach of CREAM



Two Instrument Suites



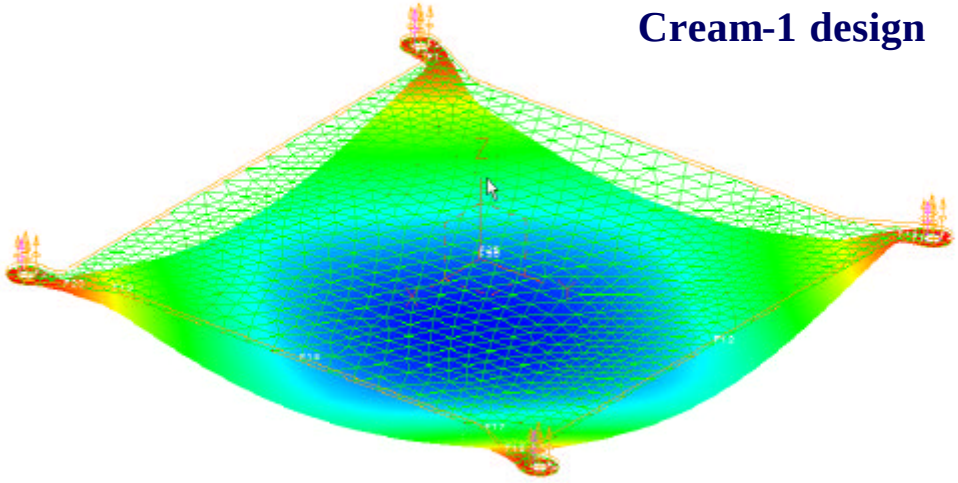

CREAM - II
Calorimeter

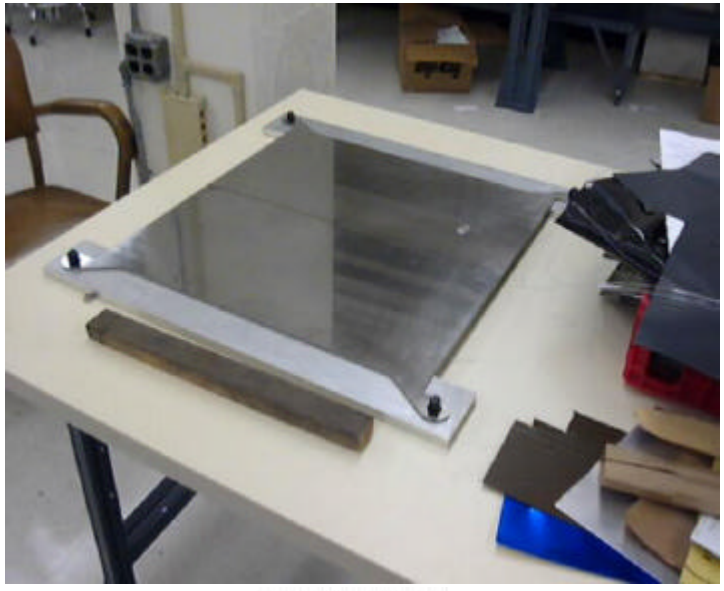
T:\disegni\ms_analisi.mf1
RESULTS: 1- B.C. 1, DISPLACEMENT_1, LOAD SET 1
DISPLACEMENT - Z MIN -6.09E-03 MAX 9.60E-06
DEFORMATION: 1- B.C. 1, DISPLACEMENT_1, LOAD SET 1
DISPLACEMENT - MAG MIN 3.08E-21 MAX 6.09E-03
FRAME OF REF: PART

VALUE OPTION ACTUAL

9.60D-06
-6.01D-04
-1.21D-03
-1.82D-03
-2.43D-03
-3.04D-03
-3.65D-03
-4.26D-03
-4.87D-03
-5.48D-03
-6.09D-03

Cream-1 design



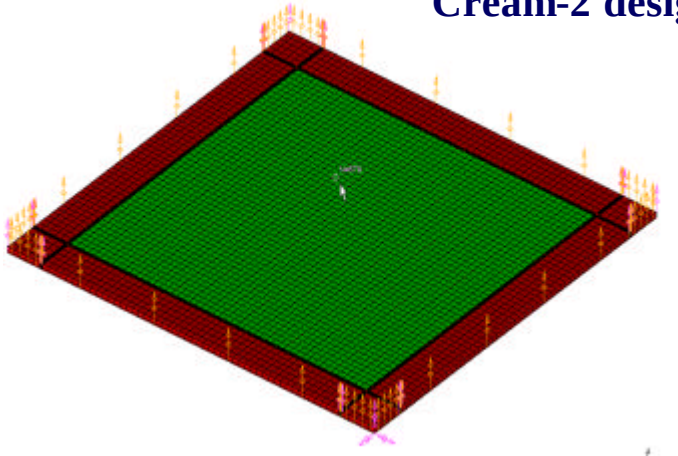


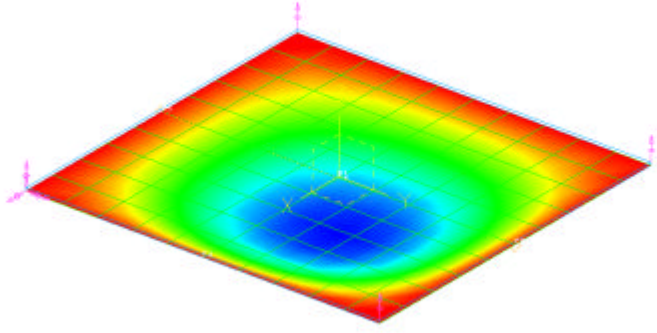
T:\disegni\ms_analisi.mf1
RESULTS: 1- B.C. 1, DISPLACEMENT_1, LOAD SET 1
DISPLACEMENT - Z MIN -1.28E-03 MAX 0.00E+00
DEFORMATION: 1- B.C. 1, DISPLACEMENT_1, LOAD SET 1
DISPLACEMENT - MAG MIN 0.00E+00 MAX 1.28E-03
FRAME OF REF: PART

VALUE OPTION ACTUAL

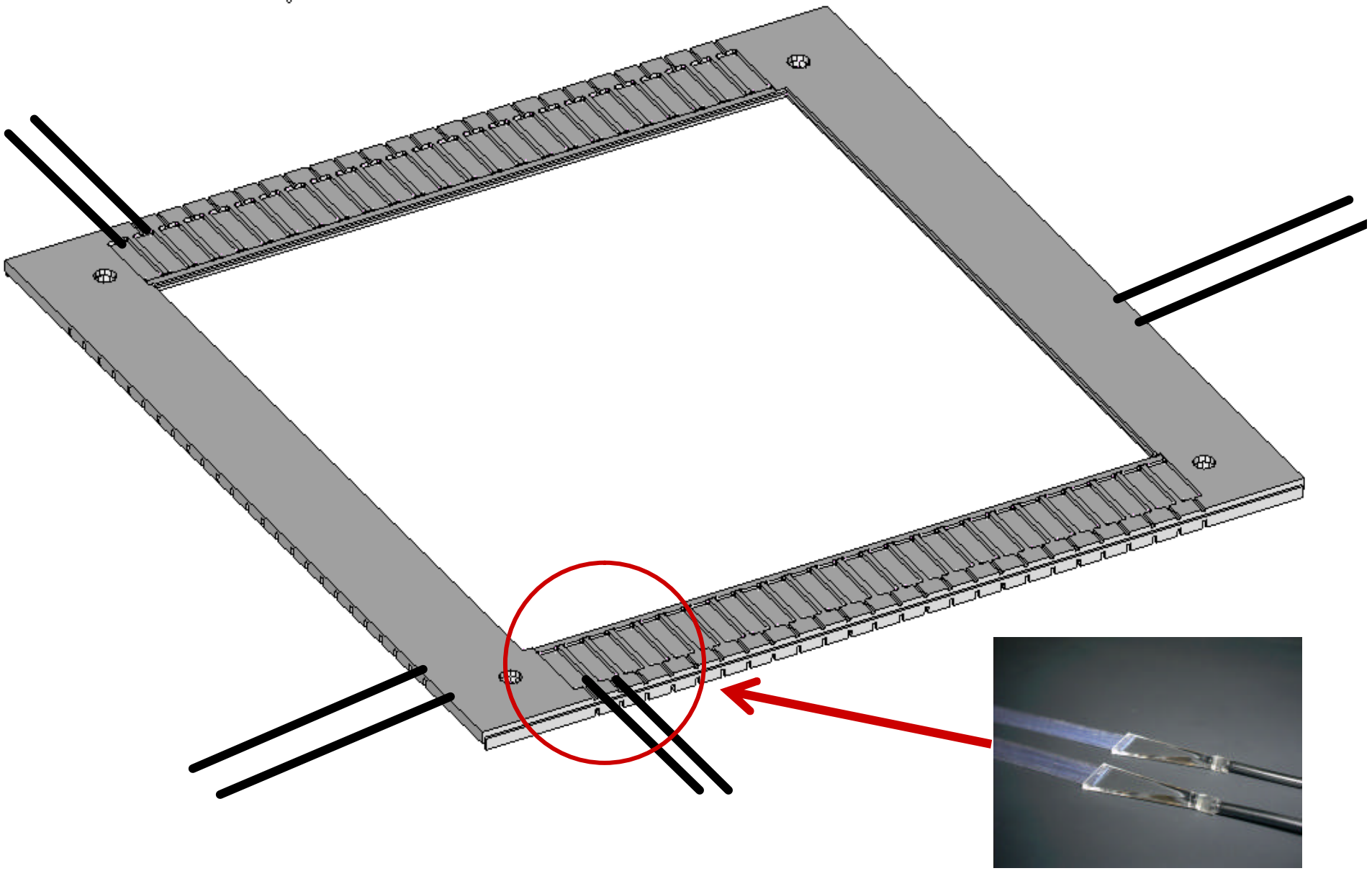
0.00D+00
-1.28D-04
-2.57D-04
-3.85D-04
-5.13D-04
-6.42D-04
-7.70D-04
-8.99D-04
-1.03D-03
-1.16D-03
-1.28D-03

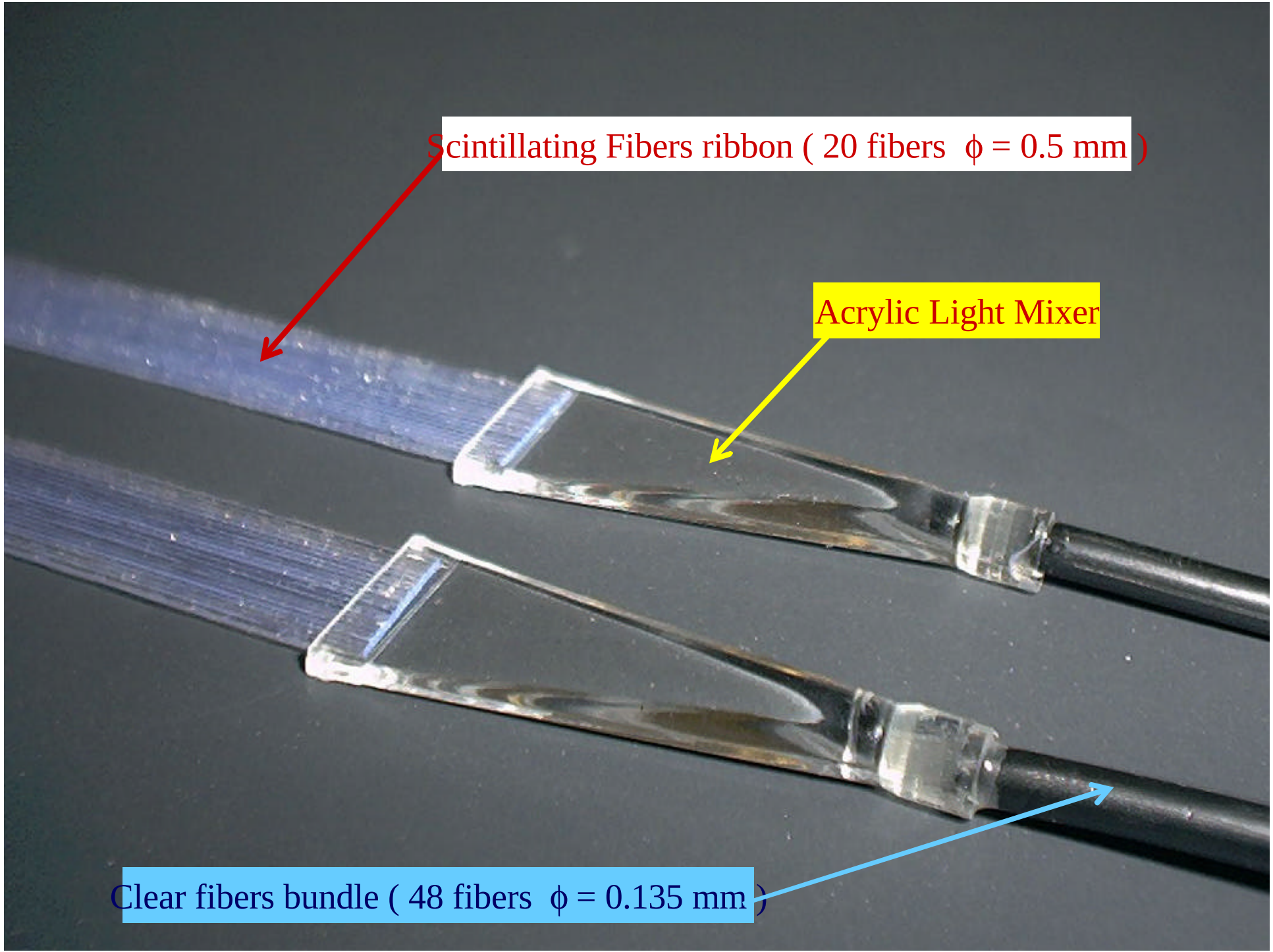
Cream-2 design





Assembly of 2 frames (X-Y pair)

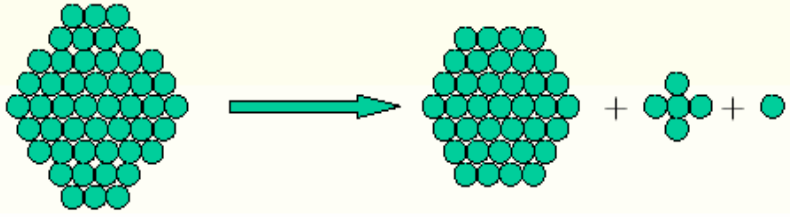



Scintillating Fibers ribbon (20 fibers ϕ = 0.5 mm)
Acrylic Light Mixer
Clear fibers bundle (48 fibers ϕ = 0.135 mm)

Scintillating Fibers Ribbons being glued in Siena

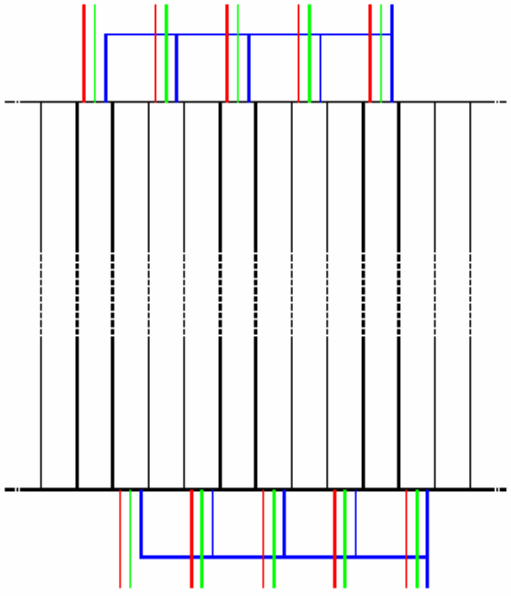
Calorimeter:
Optical Division for High Dynamic Range

Incoming signal from light-mixer split into three ranges:



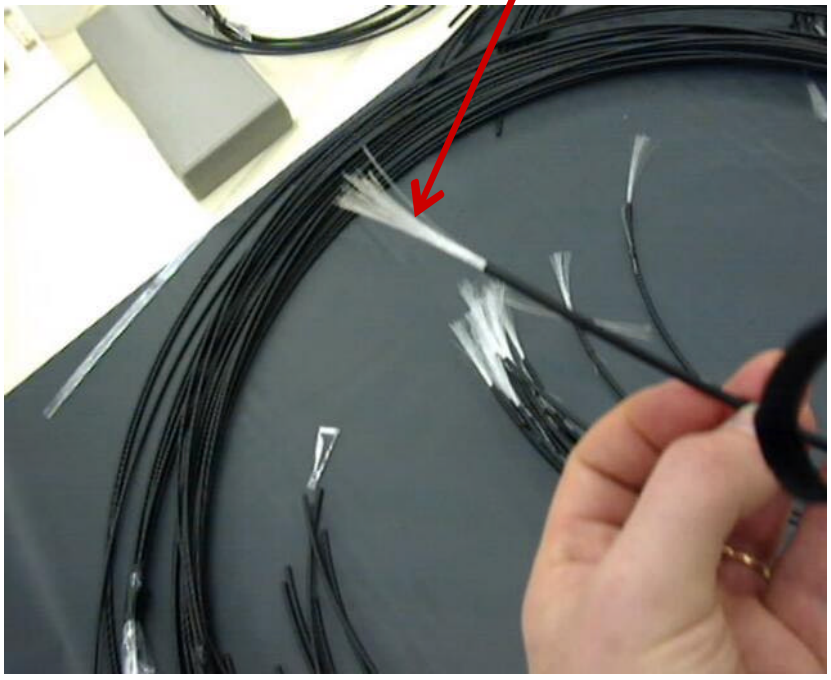
48 42 5 1 (x5)

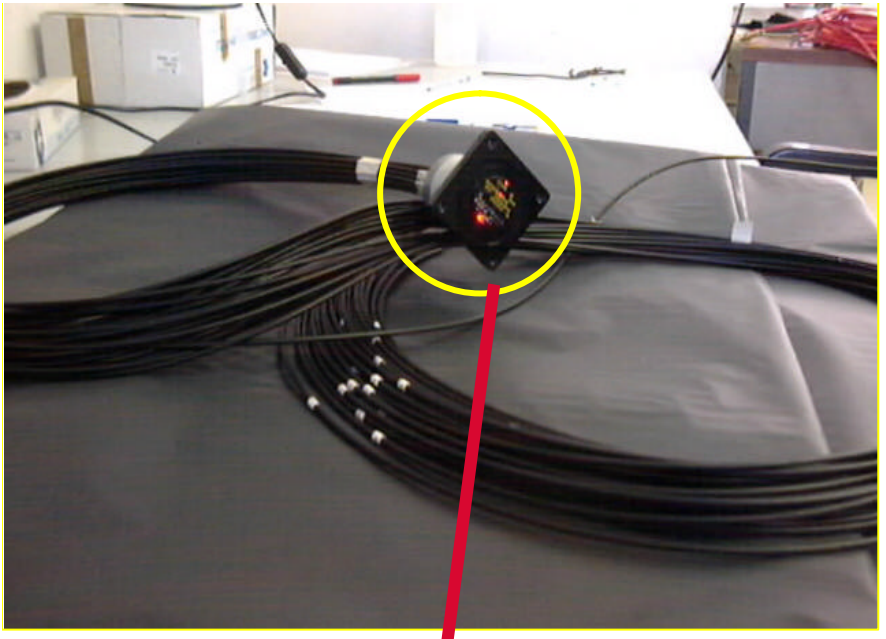
Optical division and 3 ranges

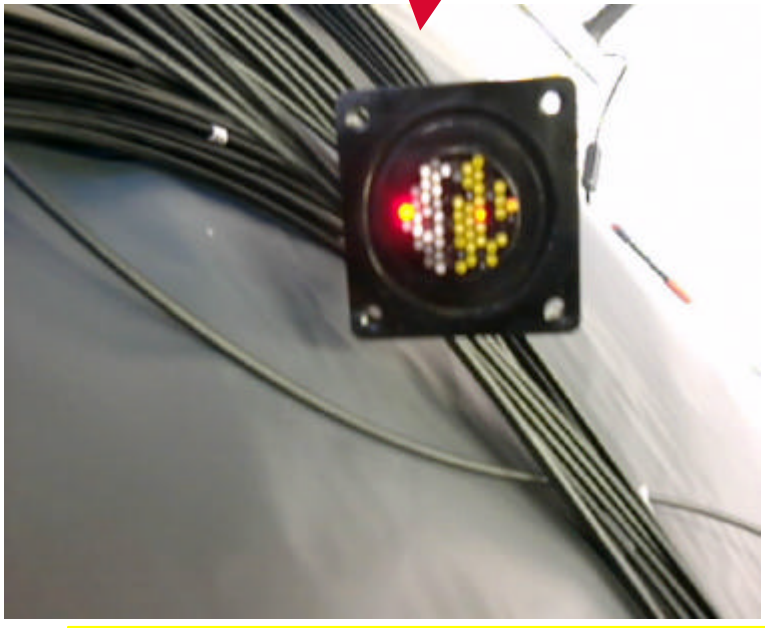


Low range : 42/48
Middle range : 5/48
High range : 1/48 (5 ribbons)

Clear fibers bundle (48 fibers ϕ = 0.135 mm)



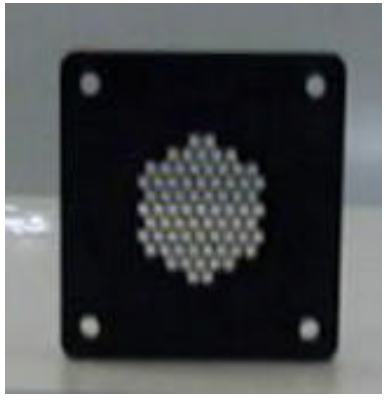


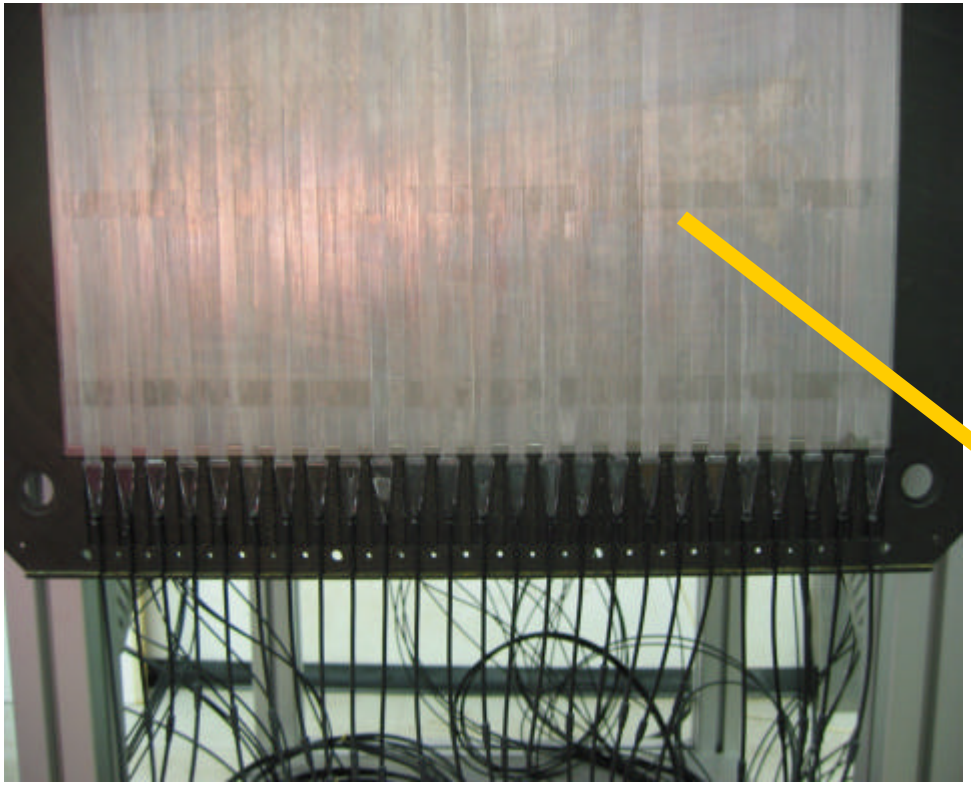


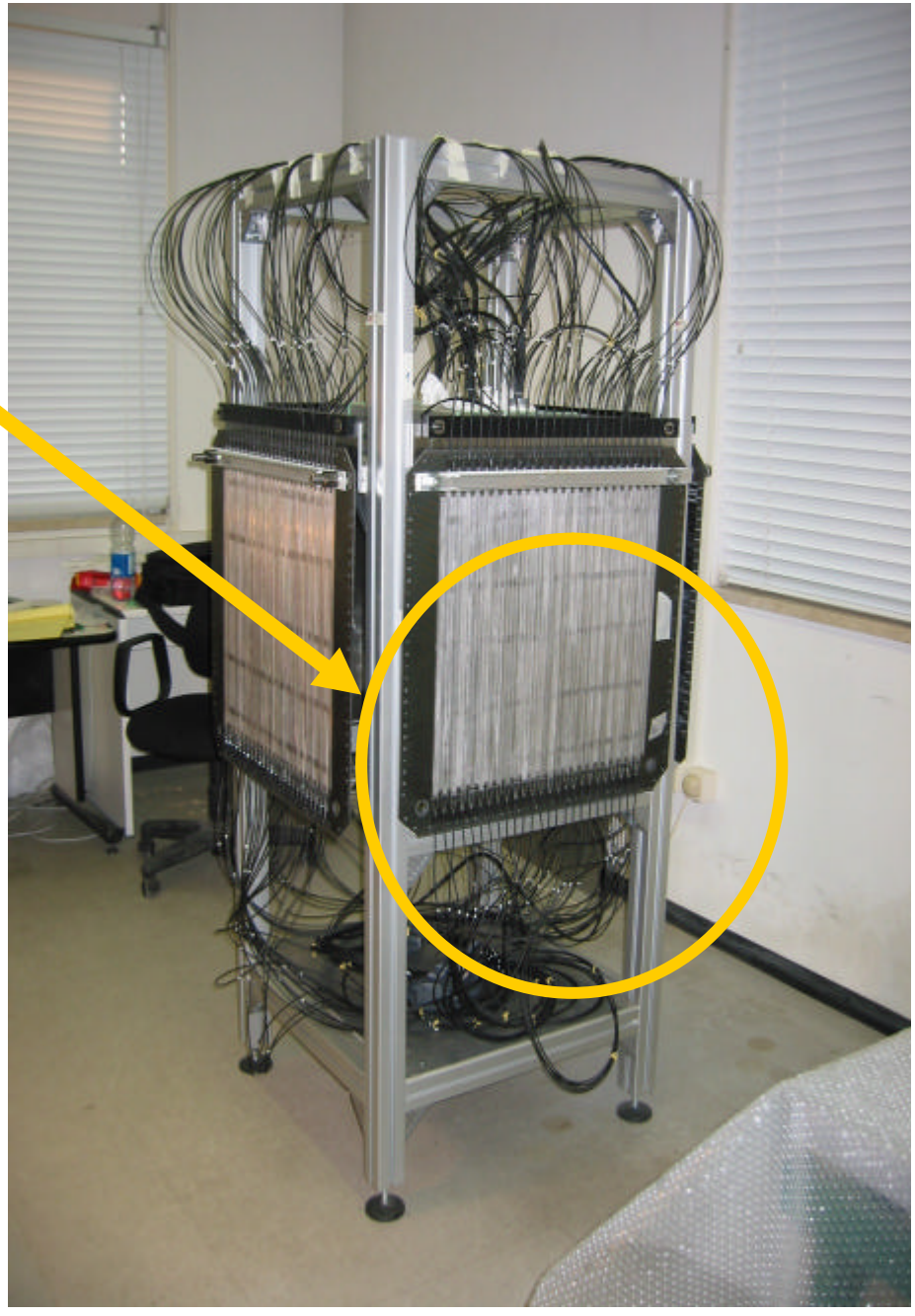
HPD Optical Interface (73 pixels)

Calorimeter cookie

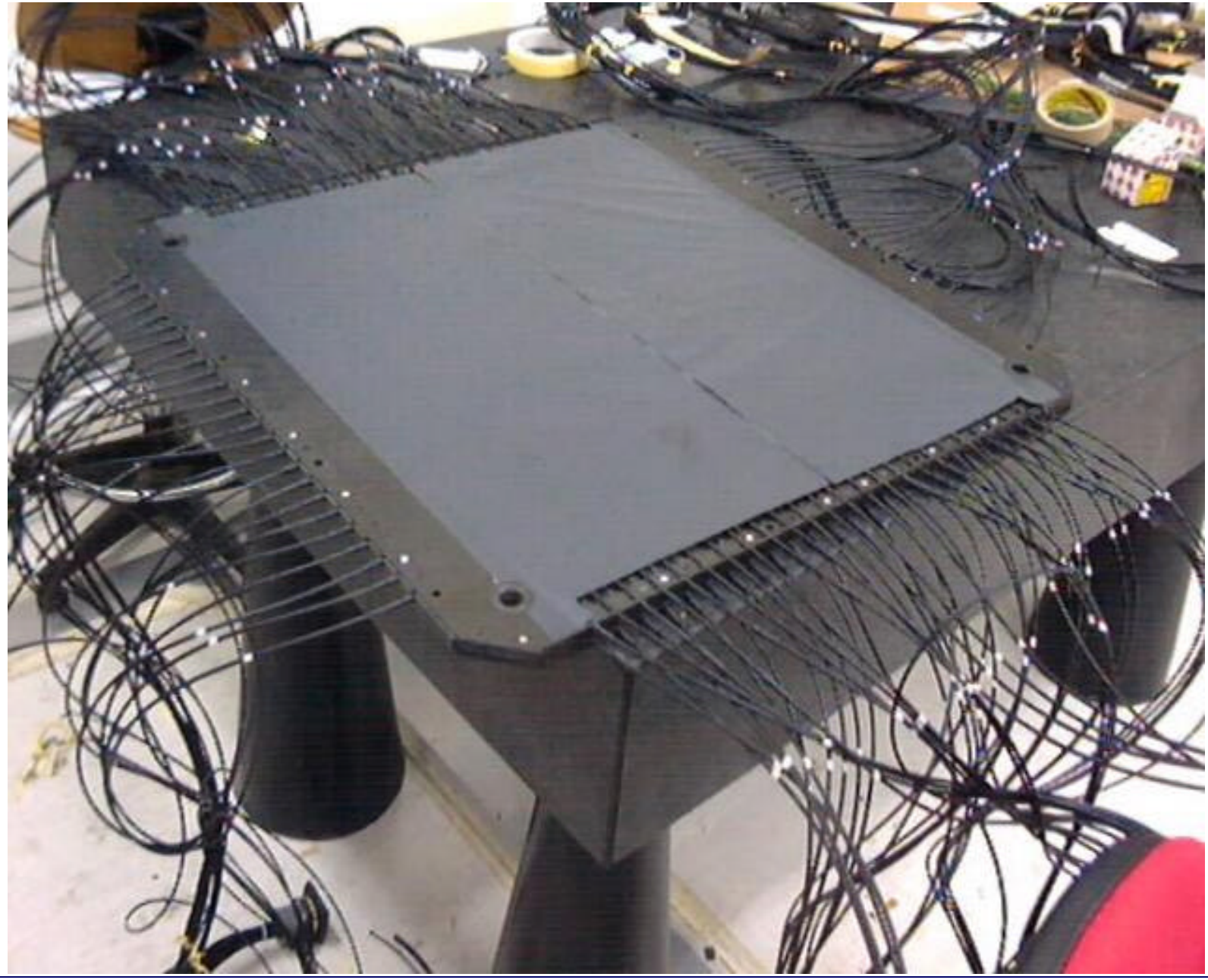
(73 pixels)

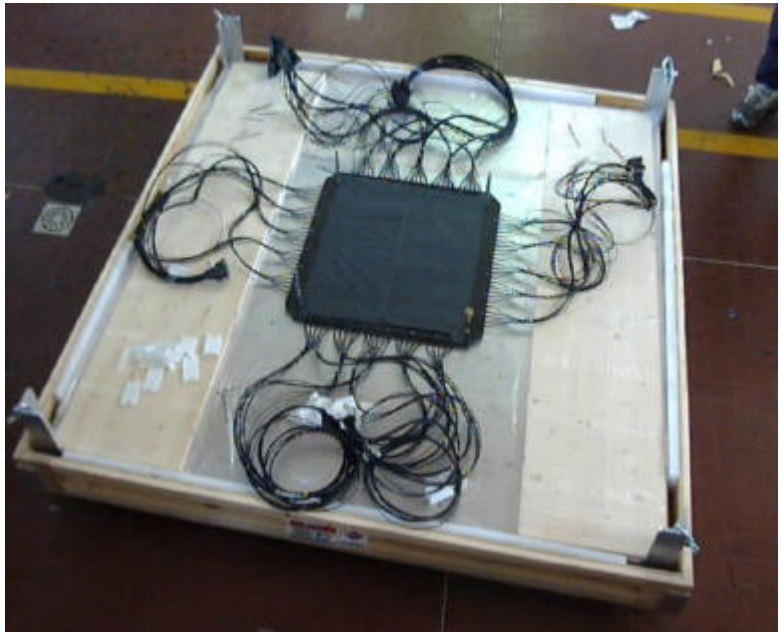


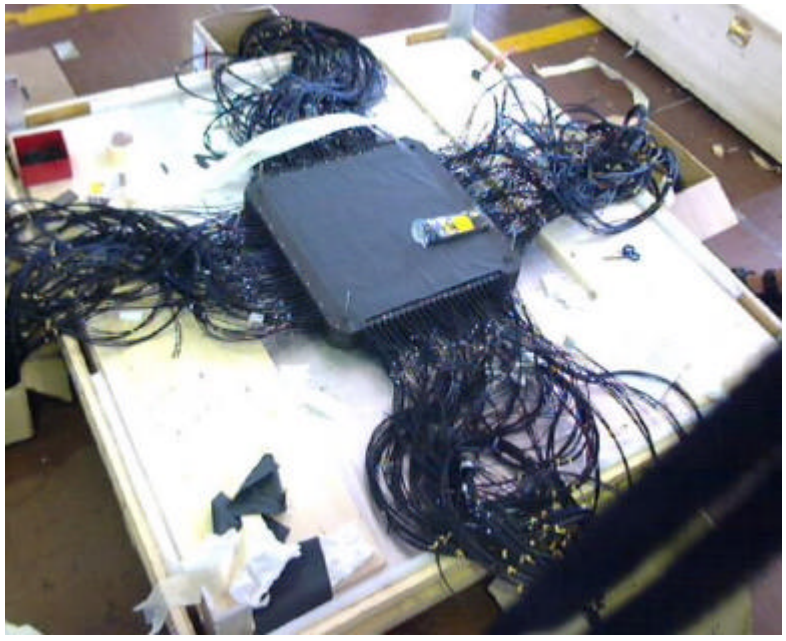


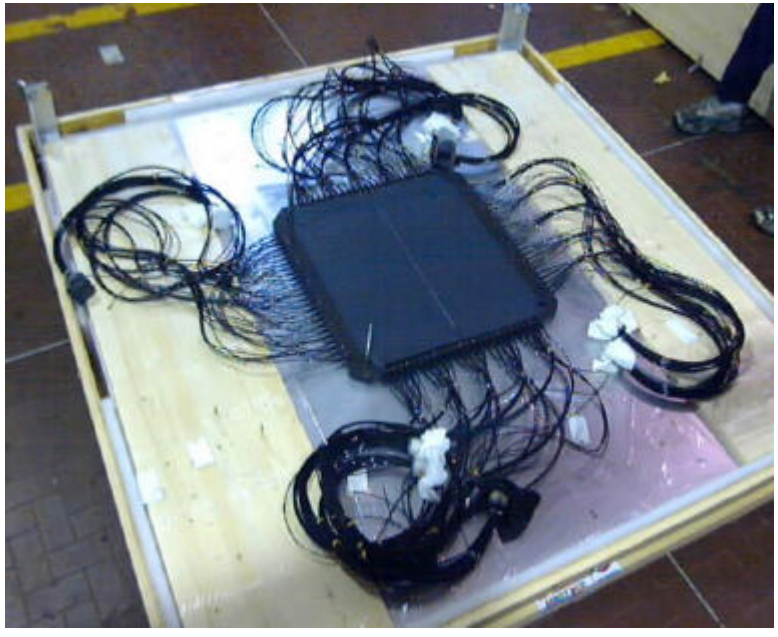


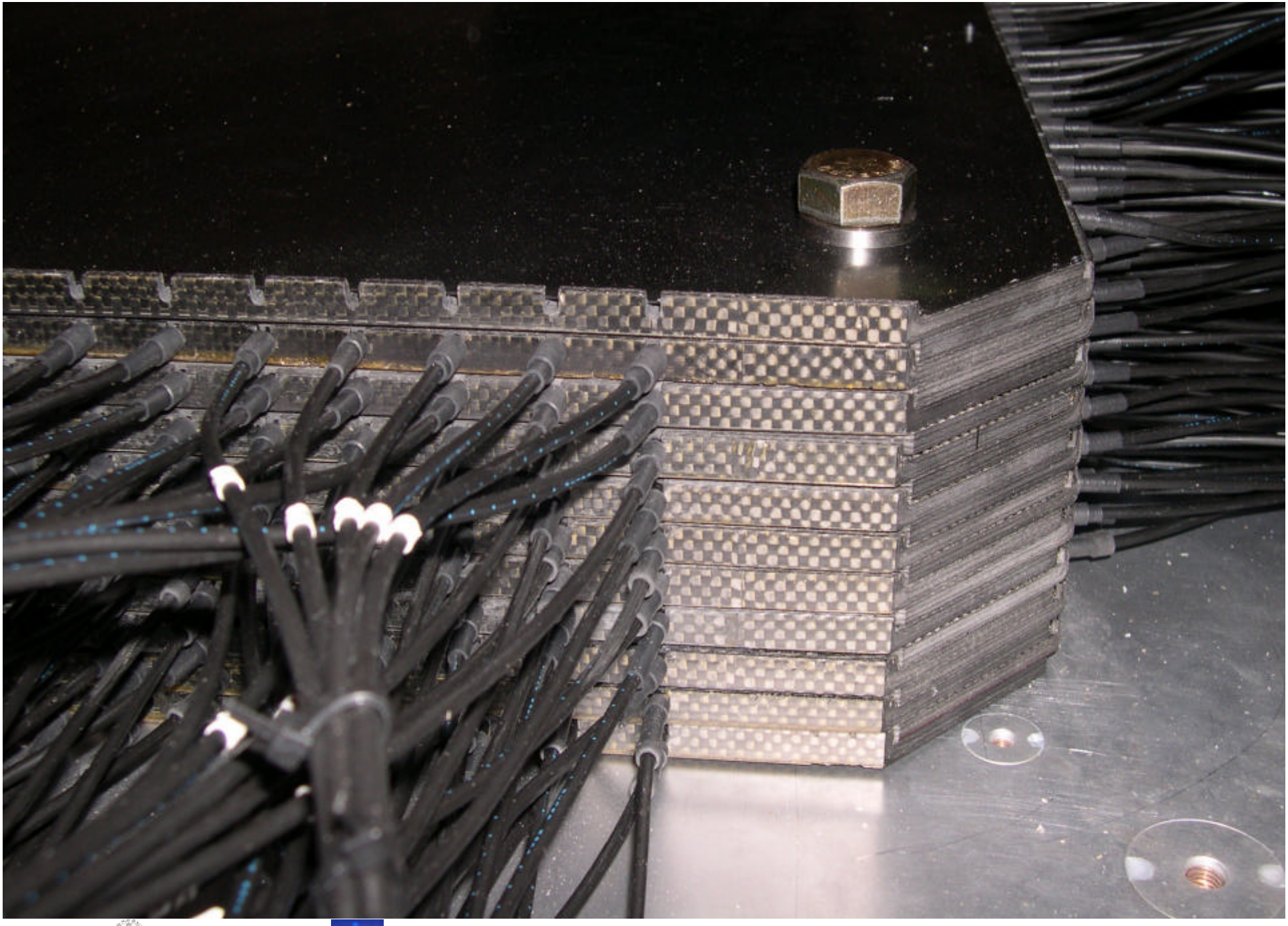
Optical fiber bundles are glued to the light guides (25 per side)

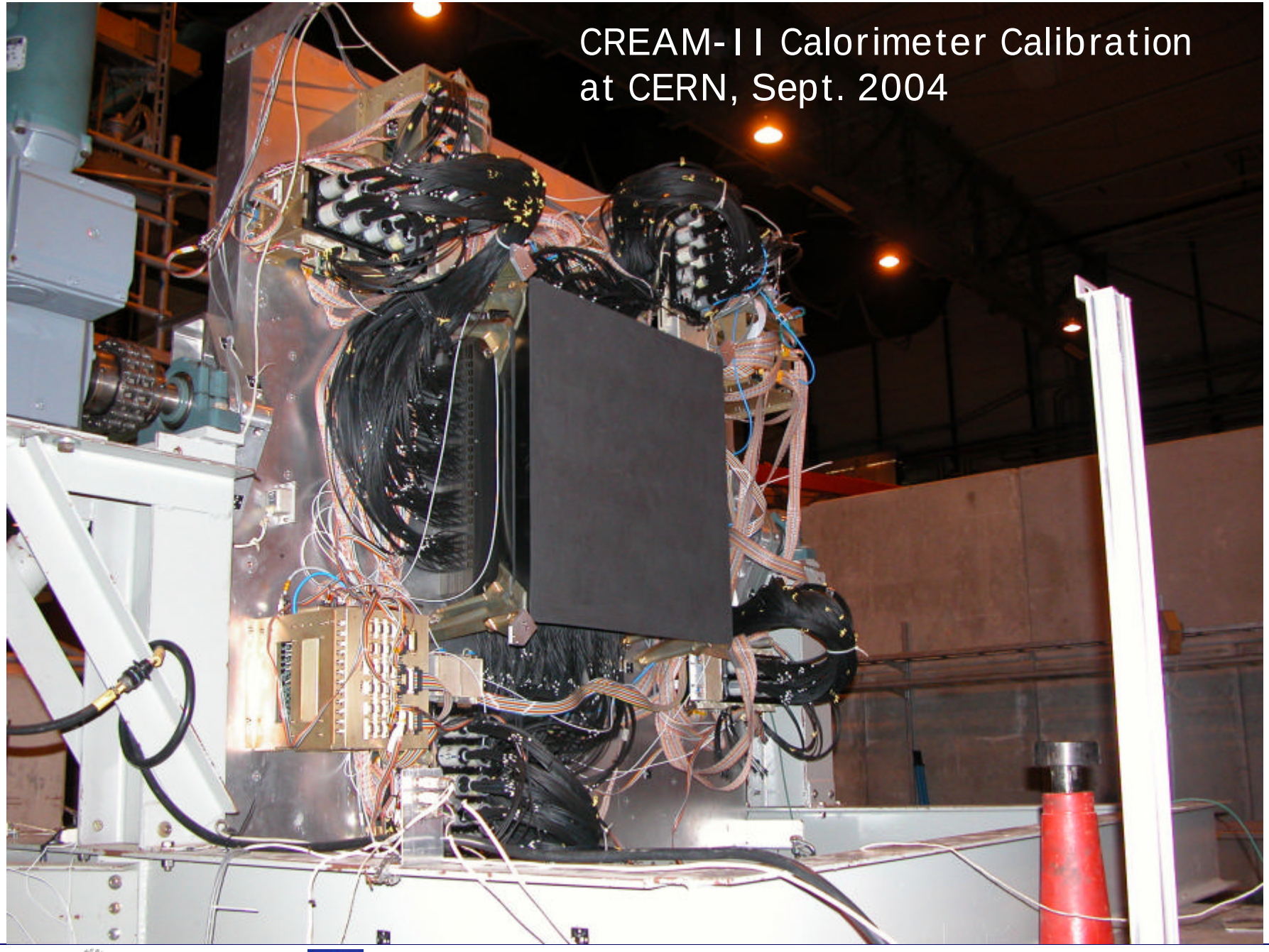










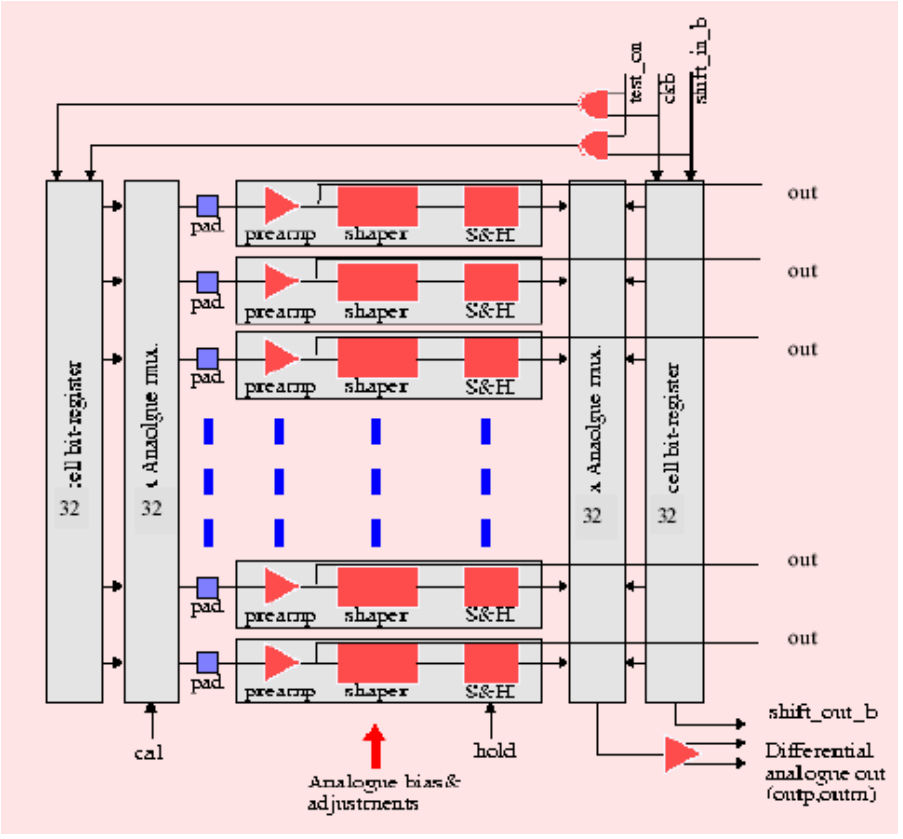

CREAM-II Calorimeter Calibration
at CERN, Sept. 2004

VA32_HDR14

A new low-power, low-noise **front-end chip** with **large dynamic range** was developed by IDEAS under specs by Univ.of Kanagawa (Tokio) and Univ. of Siena (PRIN 2000)

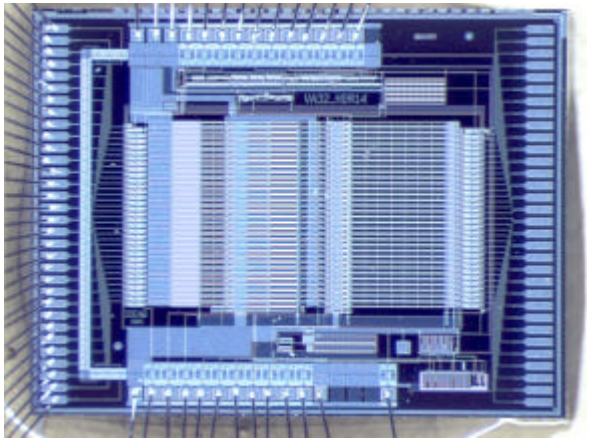
The VA32_HDR14 chip is designed to work for positive and negative input charges, but it is optimized for negative input signals.
It can be used, for example, for the readout of:

- MAPMT
- HPD
- SILICON ARRAYS



It is a 32 channels **charge sensitive preamplifier-shaper circuit** with:

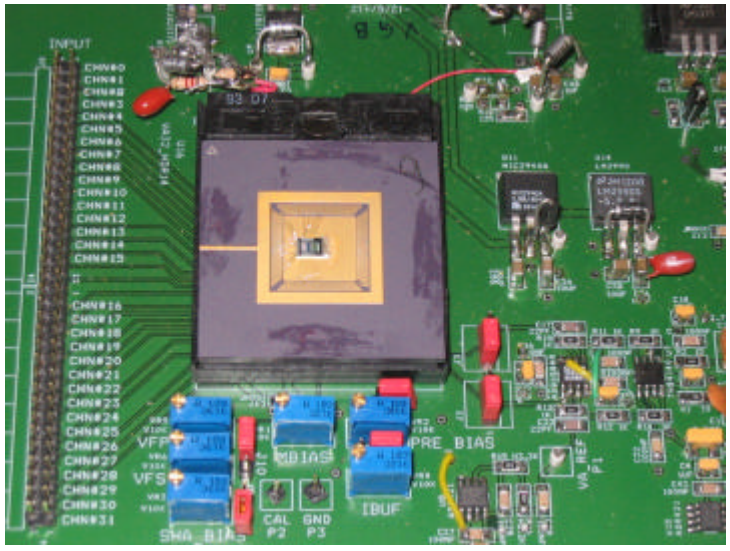
- **low noise** (~0.8 fC),
- **low power** dissipation: ~109 mW (~3.4 mW/channel),
- **large dynamic range**: -15 pC to 10pC,
- less then 2% non linearity in range –8pC to +8pC
- peaking time: 1.85µs
- simultaneous sample-and-hold,
- multiplexed analog read-out,
- calibration facilities,
- gain: 73µA/pC



CREAM Collaboration

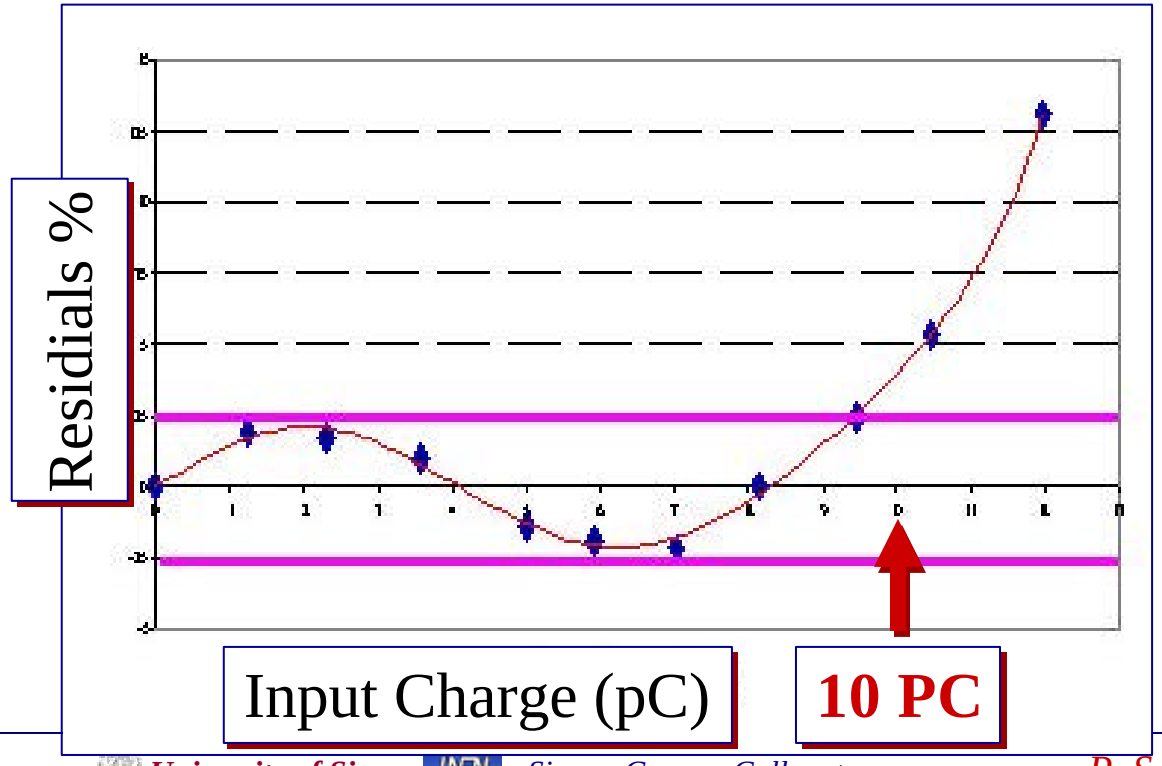
University of Maryland
H.S. Ahn, O. Ganel, K.C. Kim, M.H. Lee, L. Lutz, A. Malinin, E.S. Seo, Y.S.Yoon, S.Y. Zinn
University of Chicago
J. Capodagli, C. Smith, S. Swordy
Penn State University
N.B. Conklin, S. Coutu, S.I. Mognet
Ohio State University
J.J. Beatty
University of Minnesota
J.T. Childers, M.A. Duvernois
Northern Kentucky University
S. Nutter
University of Siena & INFN, Italy
M.G. Bagliesi, G. Bigongiari, P. Maestro, P.S. Marrocchesi, R. Zei
Ewha Womans University, S. Korea
J.H. Han, H.J. Hyun, M.Y. Kim, J.K. Lee, S.W. Nam, I.H. Park, N.H. Park, J. Yang
Kyungpook National University, S. Korea
H.J. Kim, Y.J. Kim, H. Park
Laboratorire de Physique Subatomique et de Cosmologie, Grenoble, France
M. Buenerd, A, Barrau, L. Derome, K. Protasov
Centre d'étude Spatiale des Rayonnements, Toulouse, France
R. Bazer-Bachi
Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico
A. Menchaca-Rocha

VA32_HDR14 test board



- two stage r/o : voltage feedback amplifier for current to voltage conversion + fully differential input and differential output device

- **16 bit**, 1 MSPS, fully differential ADC
- **linearity** within 2.5 % up to +10 pC
- **rms noise** ~ 1.1 fC (inclusive : chip + board)
- **dynamic range** ~ 12500



HDR14 ASIC-board 64 chans – 16 bit ADC