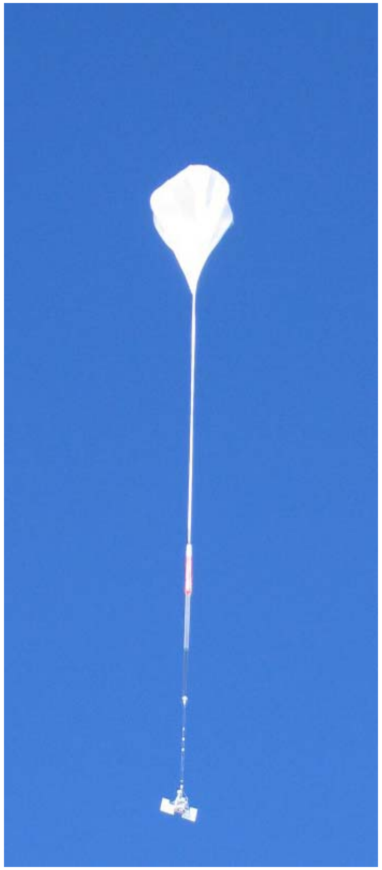
CREAM

Pushing the High Energy Frontier of Directly Measured Cosmic Rays



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For the CREAM Collaboration

C2CR – Prague

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The CREAM Collaboration

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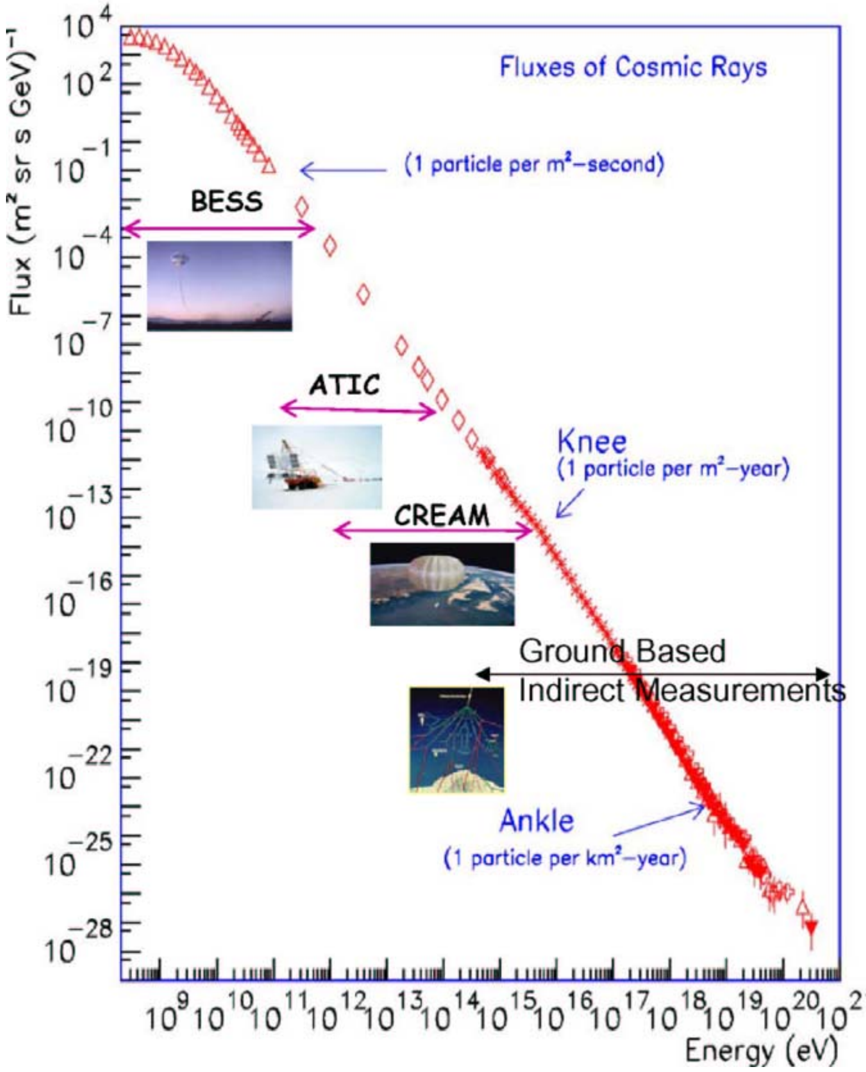
Cosmic Rays – Questions & Models

- Cosmic rays impinge on Earth's atmosphere. Material source, acceleration mechanism, particle propagation history are important open questions.
- Widely accepted SNR model postulates particles from inter-stellar dust or gas, or super-nova ejecta, accelerated by interactions with magnetic fields in super-nova shocks. There are versions of the model that theorize additional re-acceleration after leaving source.
- SNR model predicts this mechanism can only accelerate efficiently up to $\sim 10^{14} \times Z$ eV (where Z is charge of the particle), but ground-based measurements have recorded events with incident energies up to 1,000,000 times that. These are likely of extra galactic origin (possibly accelerated by Active Galactic Nuclei).

All-Particle Spectrum of Cosmic Rays

- Flux drops ×50 for ×10 increase in threshold energy
- Kink in all-particle spectrum (knee) near 10^{15} eV explained by SNR
- Need to confirm corresponding kink in H spectrum expected ~10^{14} eV
- Indications from ground-based experiments support this
- Need single experiment with wide energy range, large geometry factor & direct charge measurement to verify



Covering a Wide Spectrum:

Different Techniques at Different Energies

- At energies up to 10^{12} eV can use solenoids (e.g. Bess, AMS, etc.)
- At energies above 10^{14} eV can use air-shower experiments (e.g. KASCADE, AGASA, Fly's Eye, Auger, etc.)
- Above ~10^{21} eV ground-based experiments run out of statistics – need future space-based down-looking air-shower experiments (e.g. EUSO, OWL)
- In critical interval of 10^{12} eV – 10^{14} eV need direct measurements, initially made by pioneering emulsion experiments (e.g. JACEE, etc.); being improved on by flight calorimeters (e.g. ATIC, CREAM, etc.) and TRDs (e.g. TRACER, CREAM etc.)
- Proton "knee" expected ~10^{14} eV – need calorimeter for proton measurements with reasonable energy resolution

“Division of Labor”

Ground-based detectors (and orbiters looking down):

- Can “see” Cherenkov light, fluorescence, μ’s, RF & shower tails – charge ID of primary is model dependent, “H-like” & “Fe-like”
- Use Earth’s atmosphere as “absorber”, need only detection system; Power, weight & volume not significantly constrained on ground
- Cover huge areas (1000’s of km^2), exposure time of many years – statistical sample allows energy reach of 10^{21} eV or more – good for measuring <u>*all-particle spectrum*</u> and <u>*indications of composition changes*</u> up to ultra high energies

Flight detectors for direct measurement:

- Absorber (if any) and active components must all be carried in payload
- Strict limits on power, weight, volume, flight duration – statistics limited
- Energy & charge can be measured directly, with redundant systems – cross-calibration, good resolution – good for <u>*individual element spectra up to ~10^{15} eV*</u>

CREAM Science Objectives

(*Cosmic Ray Enegetics And Mass*)

Measure elemental spectra from $<10^{12}$ eV to 10^{15} eV

- Measure the proton spectral index vs. those of heavier nuclei
- Search for predicted 'knee' in the proton spectrum near 10^{14} eV
- Check if the elemental composition changes near the all-particle 'knee'
- Measure the secondary/primary ratio in the TeV region to test propagation models of high energy cosmic rays
- Provide overlap with ground-based experiments to 'anchor' their models at the low end of their energy range

→ These Science objectives drive the Measurement Goals

CREAM Measurement Goals

- Collect > 10 each protons and He nuclei above 10^{15} eV in a series of long balloon flights
- Reconstruct 1 – 1000 TeV primary energy with absolute energy scale accurate to < 10% & no non-Gaussian high-end tails
- Reconstruct energy with resolution < 50%
- Reconstruct particle trajectory up to charge detectors
- Reconstruct primary charge well enough to identify elements
- Collect enough B and C data to reconstruct B/C ratio to ~ TeV

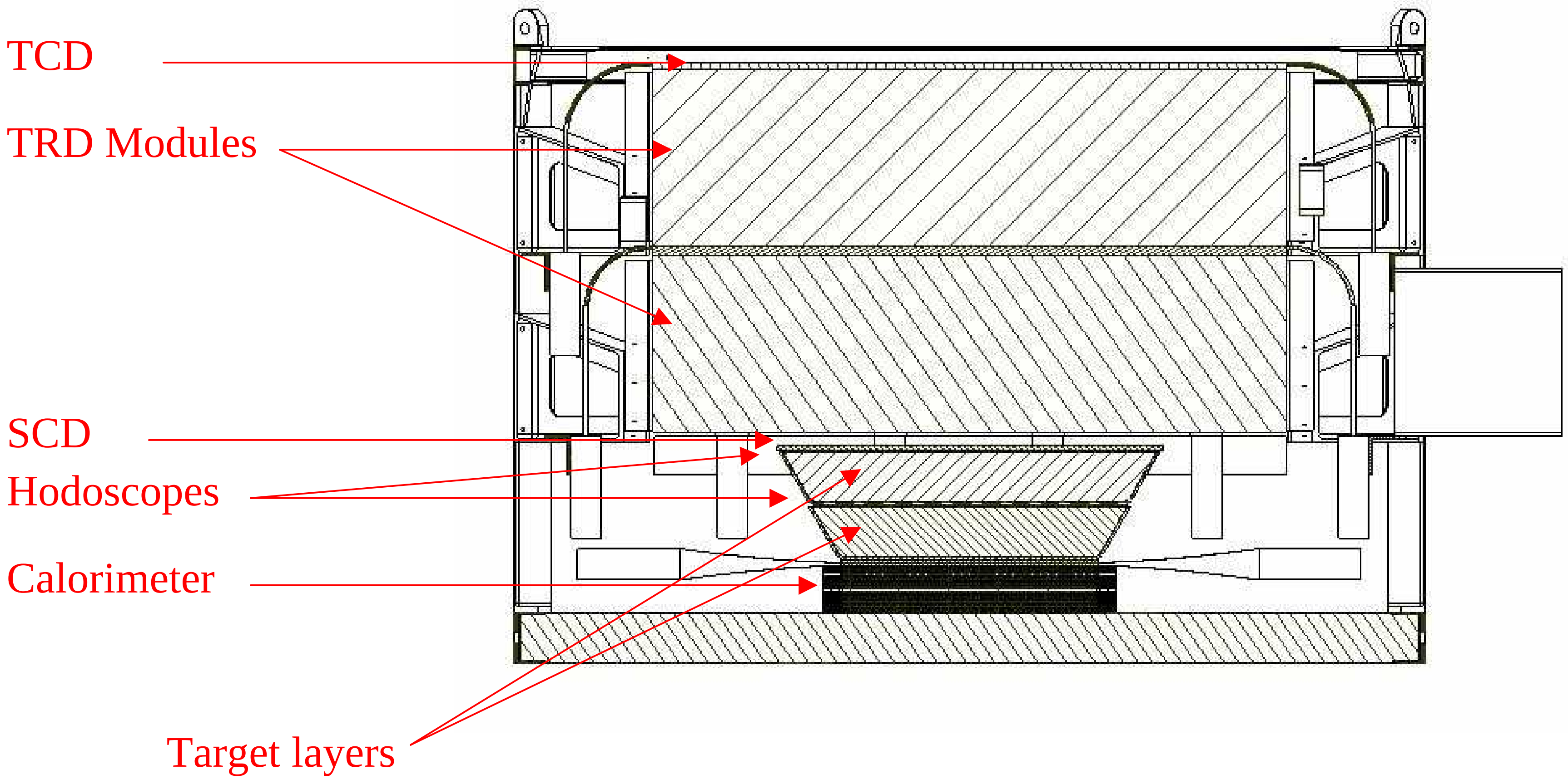
→ These Measurement Goals drive the detector design

Flight Instrument Design Constraints
(typical values)

- Instrument weight ~1100 kg; payload weight ~2700 kg
- Instrument power ~400 W; payload power ~800 W
- Instrument volume ~2$\times$2$\times$1 m^3; payload volume ~2$\times$2$\times$2 m^3
- Flight duration (LDB) typically 10-15 days, record 42 days; ULDB capability being developed for 60 – 100 days
- Temperature cycles (with heaters, insulation, etc.) -10C ~ +40C
- Ambient pressure ~0.003 atmosphere (implications for HV, disks)
    - Need pressure vessel and/or potting

$\rightarrow$ Must optimize components, detector systems, thermal design, mechanical design, HV potting, etc.

Cross Sectional View – CREAM Instrument

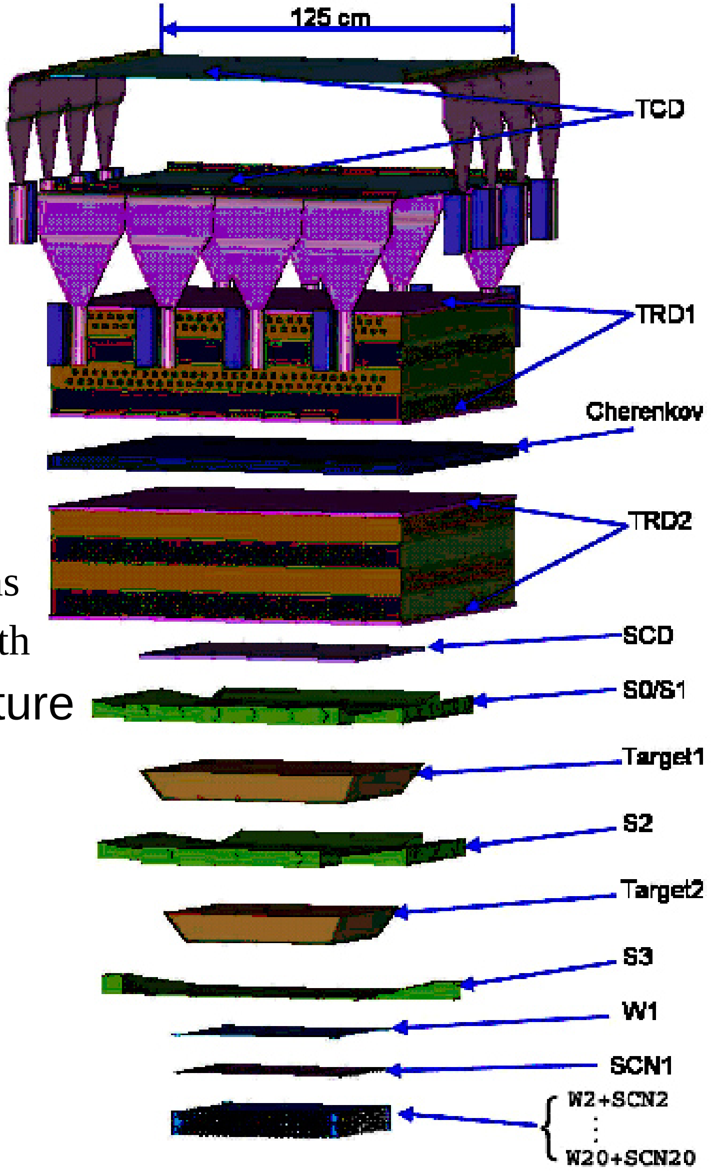


CREAM Detector Systems

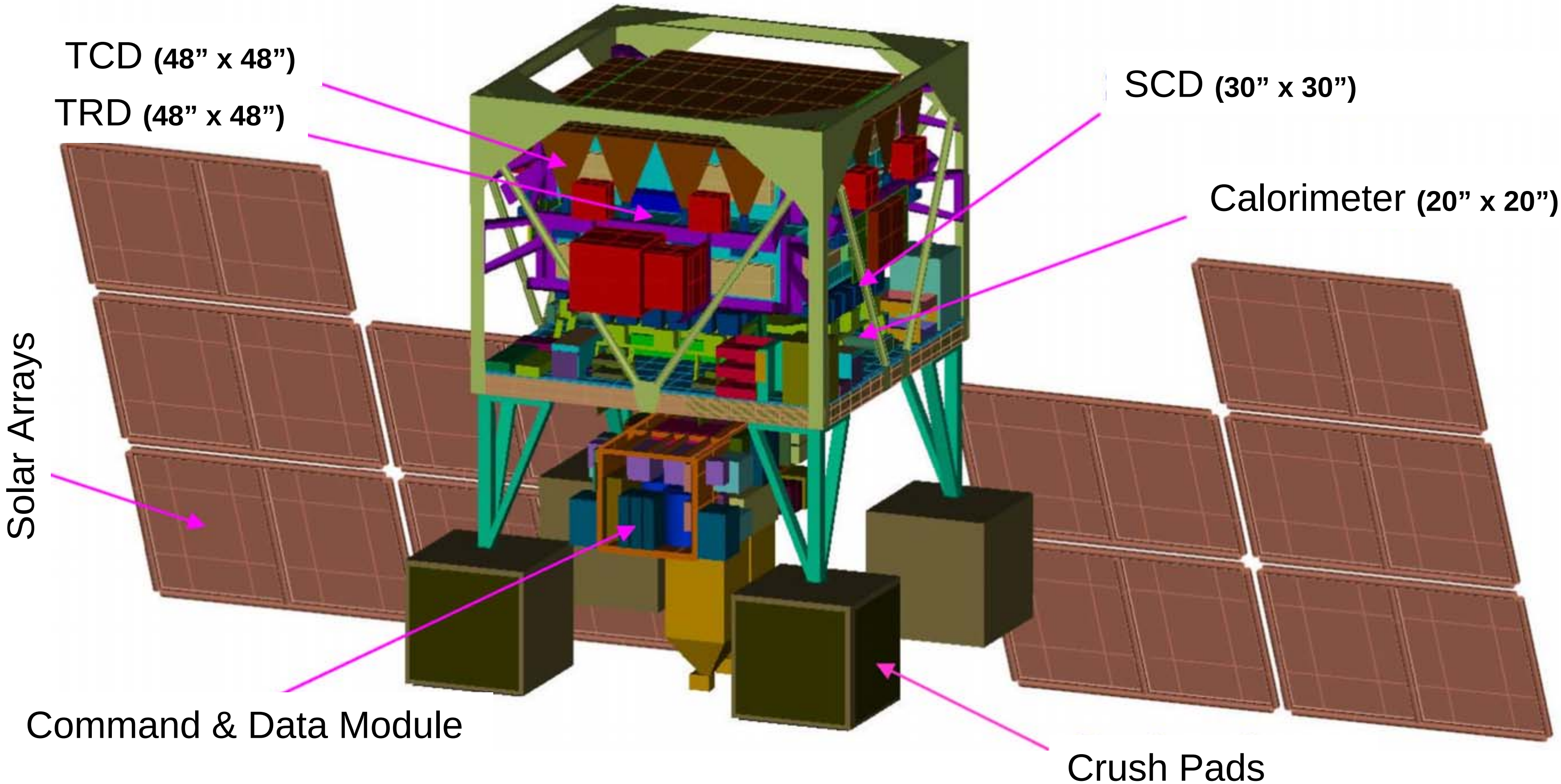
- Timing-based Charge Detector (TCD)
  - 2 layers of scintillator paddles read out by fast PMTs
  - Measures primary charge in 3 nsec, resolution ~0.2e (fast measurement “beats” back-scatter)
  - Provides High Z trigger (for Z>3)
- Transition Radiation Detector (TRD)
  - 2 modules, gas-filled tubes in foam matrix, Cherenkov layer between, low weight, large GF
  - Measures Lorentz factor (for Z>3 nuclei) – provides energy if mass is known
  - No self-trigger, allows tracking
- Calorimeter Module (calorimeter, hodoscopes, silicon charge detector)
  - Induces interaction in flared graphite targets (weight-efficient, improves resolution)
  - Measures energy through partial absorption of shower energy
  - Thin tungsten/scintillating fiber sampling calorimeter, nearly linear response to hadron showers, energy resolution ~45% (leakage fluctuations), weight-efficient GF
  - Provides H-Fe shower trigger (fully efficient ~1 TeV)
  - SCD & hodoscopes measure charge, resolution ~0.1e (segmentation reduces back-scatter)
  - Calorimeter, hodoscopes and SCD provide tracking
- Trigger aperture ~2.2 m^2sr

Exploded View of CREAM Instrument

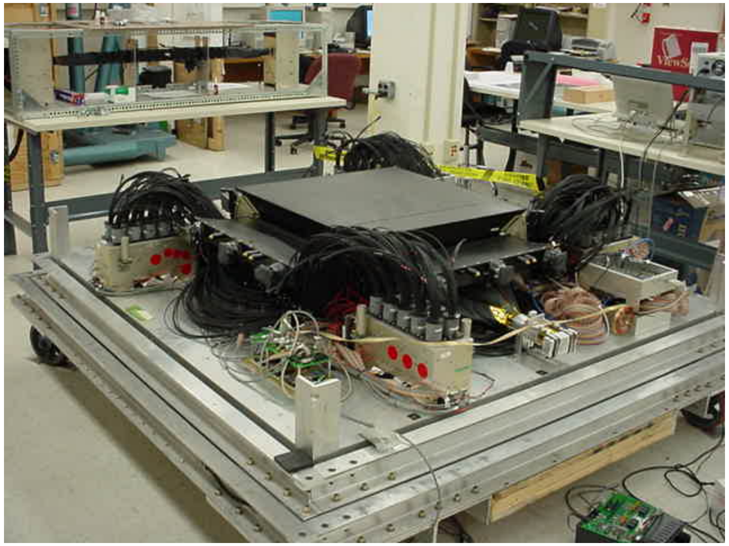
- TRD height provides time for TCD readout
- Low TRD density allows large volume
- Flared low-Z (graphite) target
  - Increases interaction fraction of incident nuclei
  - Improves resolution through secondary interactions
  - Minimizes “shower aging” – only 1 radiation length
- Thin calorimeter maximizes geometrical aperture
- Integrated mechanical design
  - Upper TRD supports TCD
  - Lower TRD supports Cherenkov
  - Upper target supports S0/S1 & SCD
  - Lower target supports S2
  - Calorimeter cover supports S3

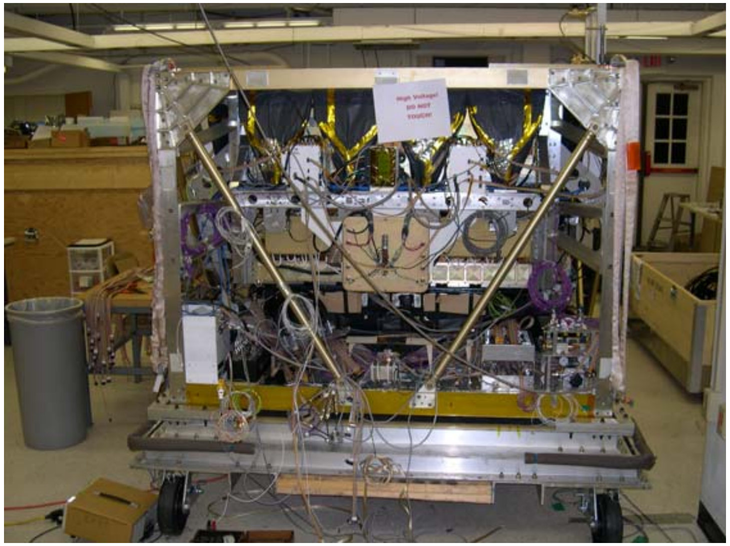


3D Schematic of CREAM Flight Configuration



CREAM Instrument Integration & Testing



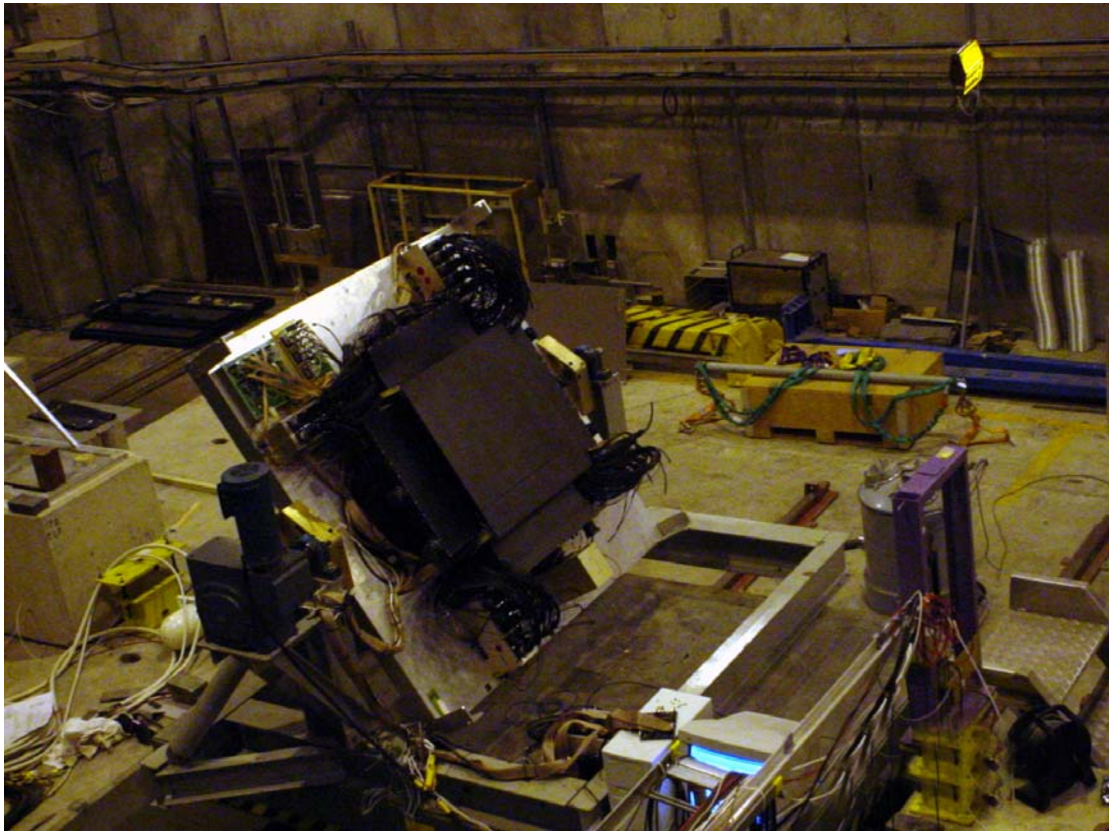


CREAM Calibration

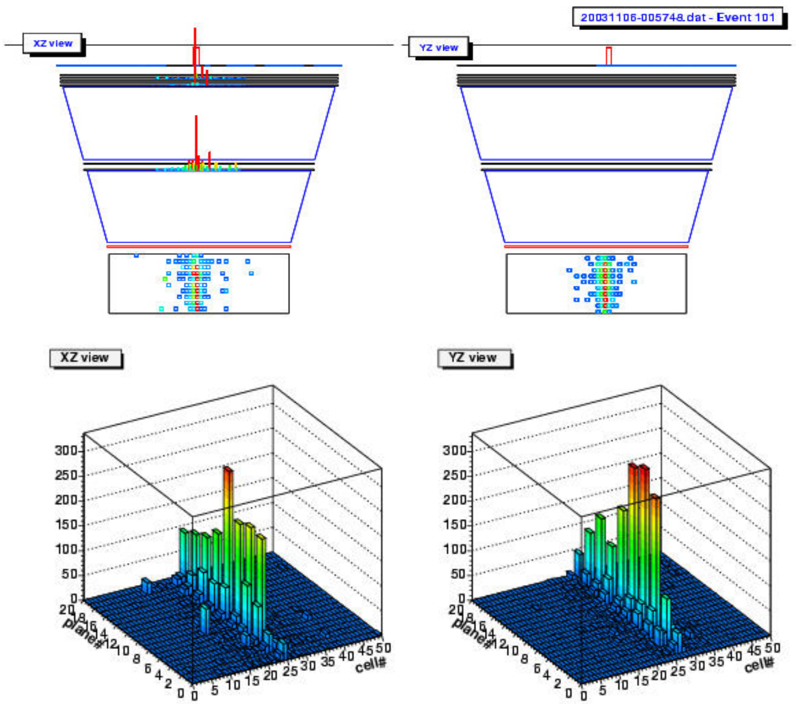
- Challenges:
  - Incident particle energy range of interest ~1 – 1000 TeV; Beam tests <350 GeV
  - Dynamic ranges 12 – 18 bits in calorimeter, TCD and TRD
  - Temperatures may vary from -10^{o}C to +40^{o}C in day/night cycle
  - No access during flight, no assurance of recovery post-flight
- Pre-flight calibration
  - Beam tests with high-energy electrons, protons, nuclear fragments in calorimeter
  - TRD beam test with muons, electrons, protons to cover wide range of γ
  - TCD muon runs, LED pulses, laser flashes, charge injection
- Offline calibration from data
  - Shower data provides inter-range calibration (low, mid, high) in calorimeter
  - Periodic charge injection, LED flashes, pedestal runs
  - TCD – non-interacting nuclei at high end of charge range
  - TRD – minimum ionization levels of C & O events
  - Cross-calibrate energy from TRD/TCD and calorimeter for Z>3 (~20 C,N,O,Fe/hr)

Accelerator Beam Testing at CERN's SPS

- TRD prototype
- TCD pair of crossed paddles
- Calorimeter Module
  - Calorimeter w/targets
  - Hodoscope (2 sets)
  - SCD

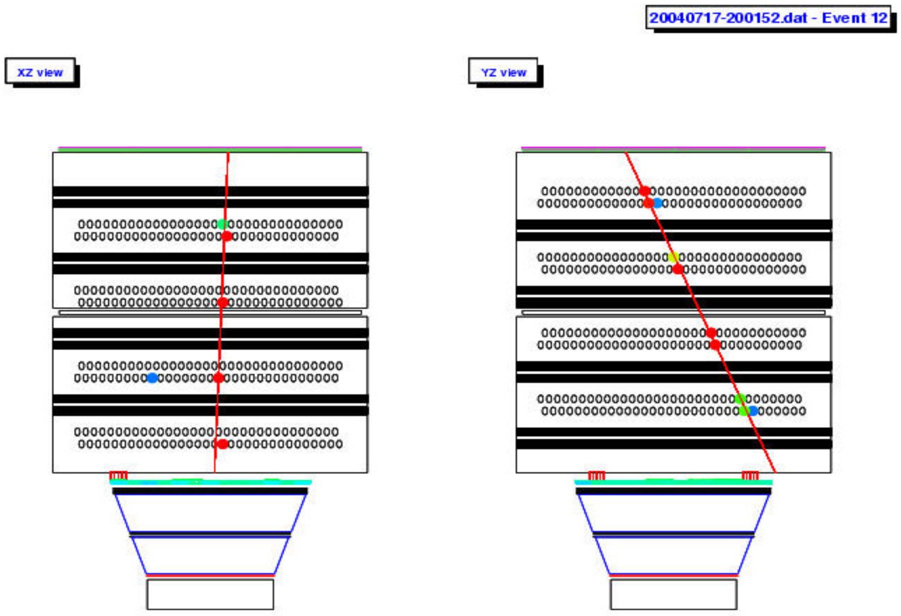


Sample Event Displays



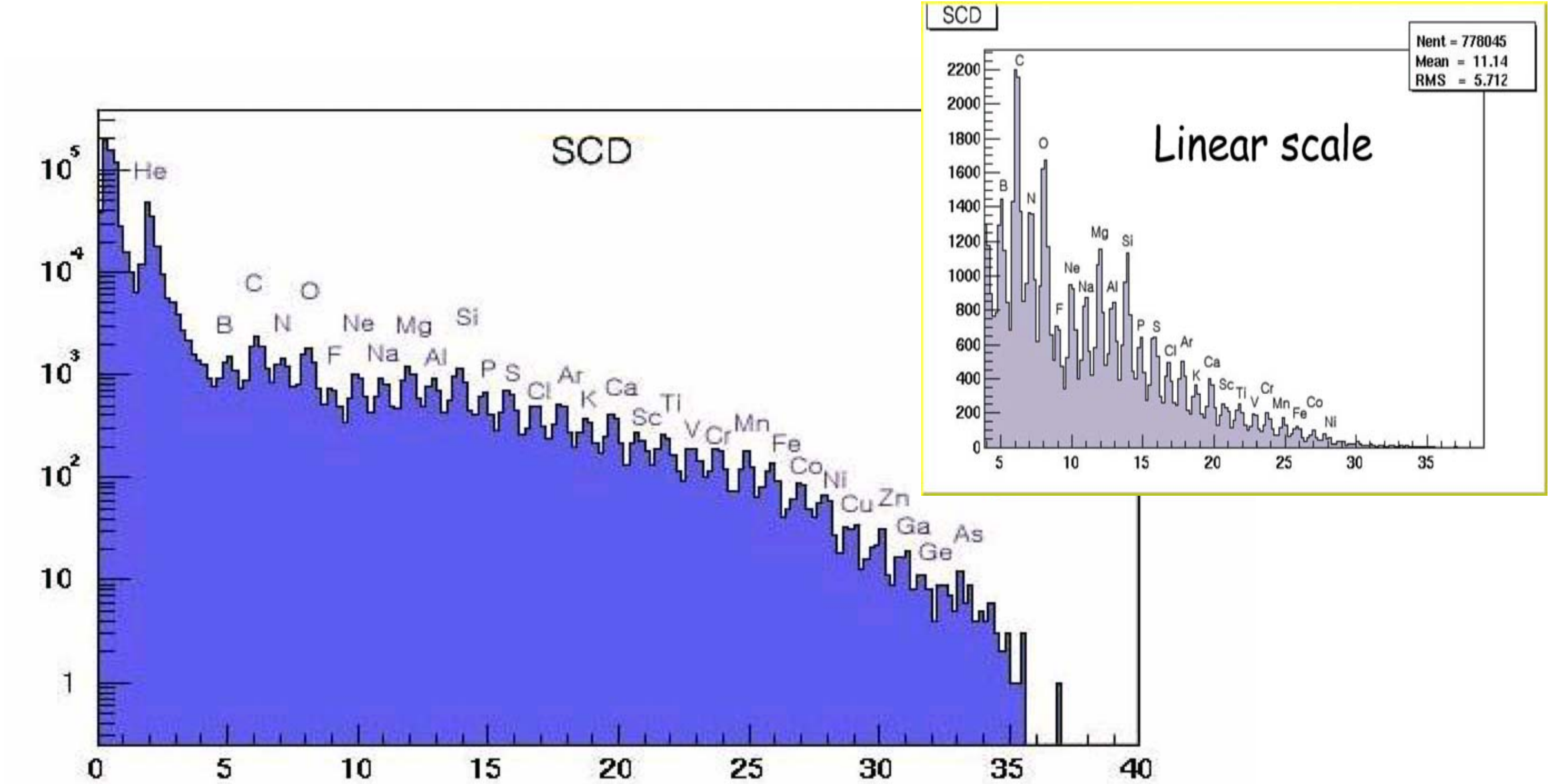
Beam-test nucleus

Cosmic μ



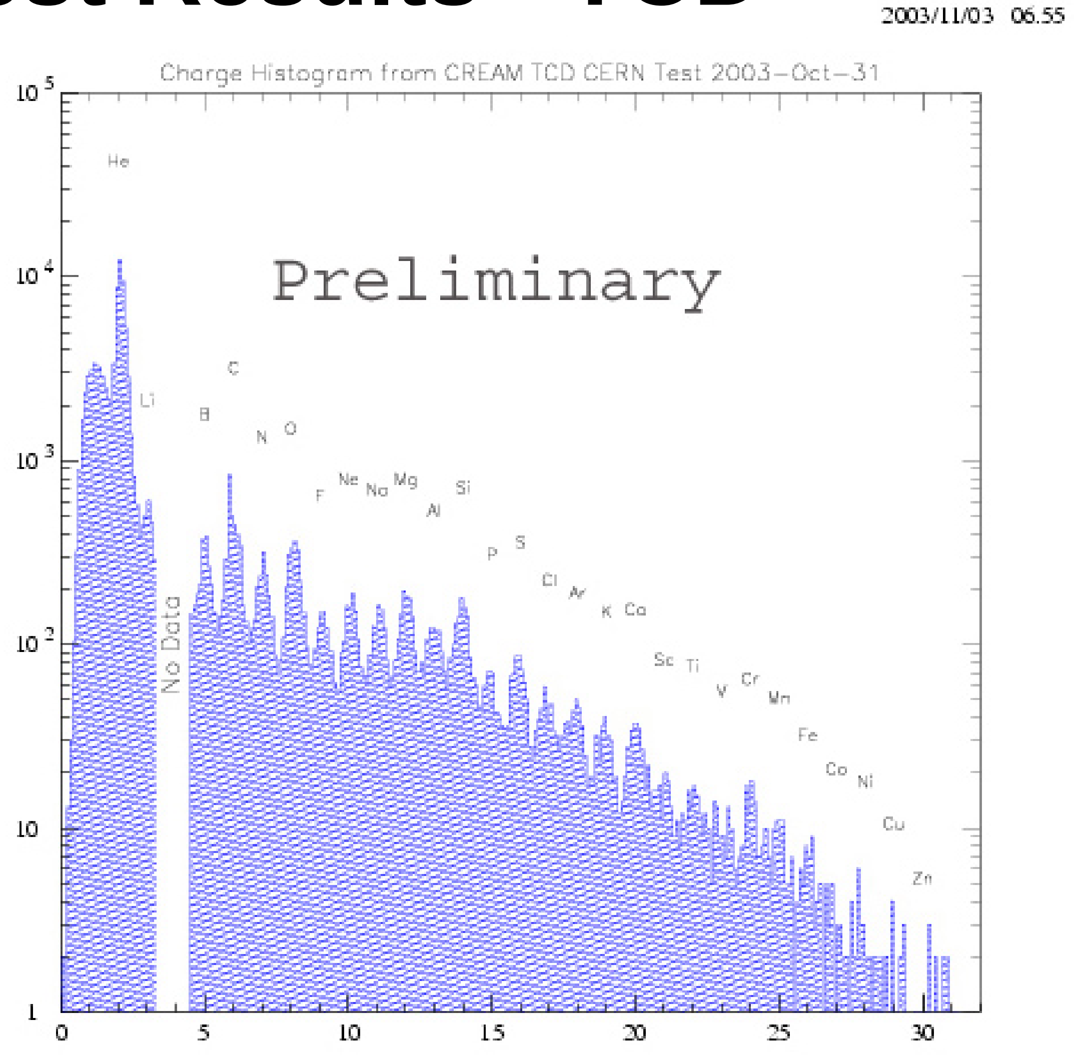
Beam Test Results - SCD

SCD measurement of nuclear fragment charges (preliminary)



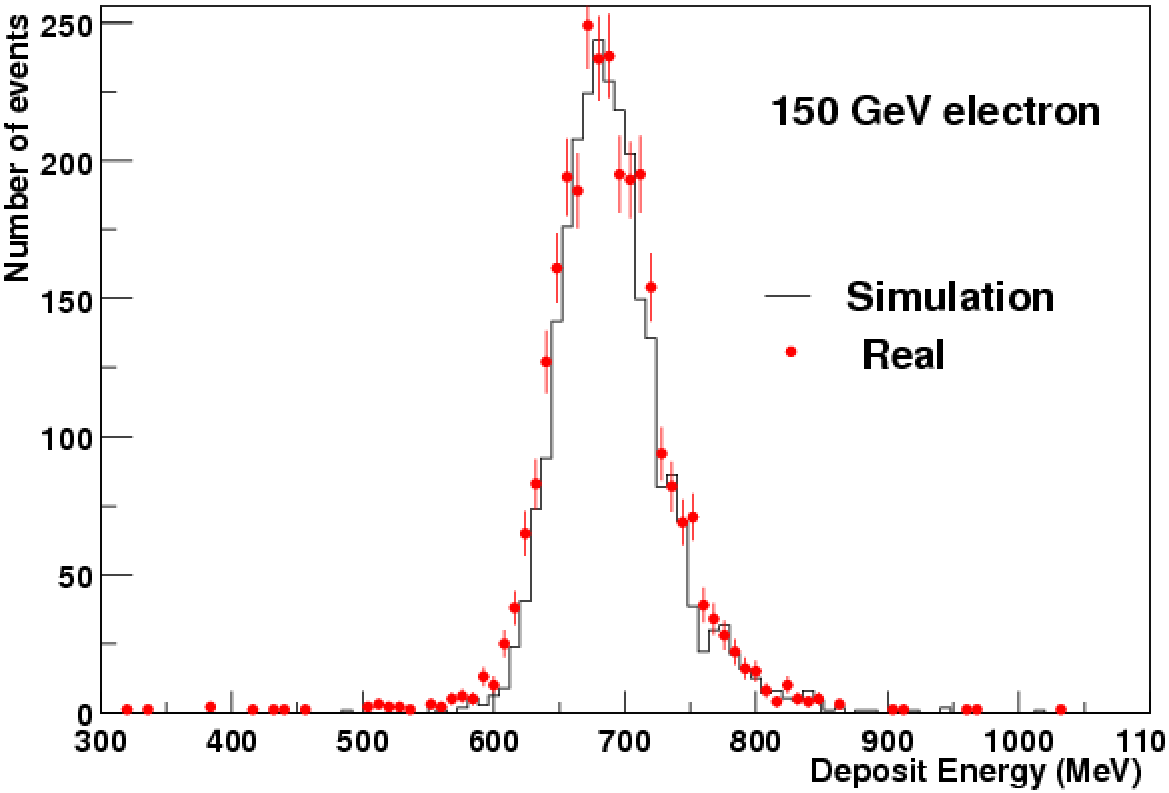
Beam Test Results - TCD

TCD measurement of nuclear fragment charges (preliminary)



Beam Test Results - Calorimeter

Simulation vs. Beam Data

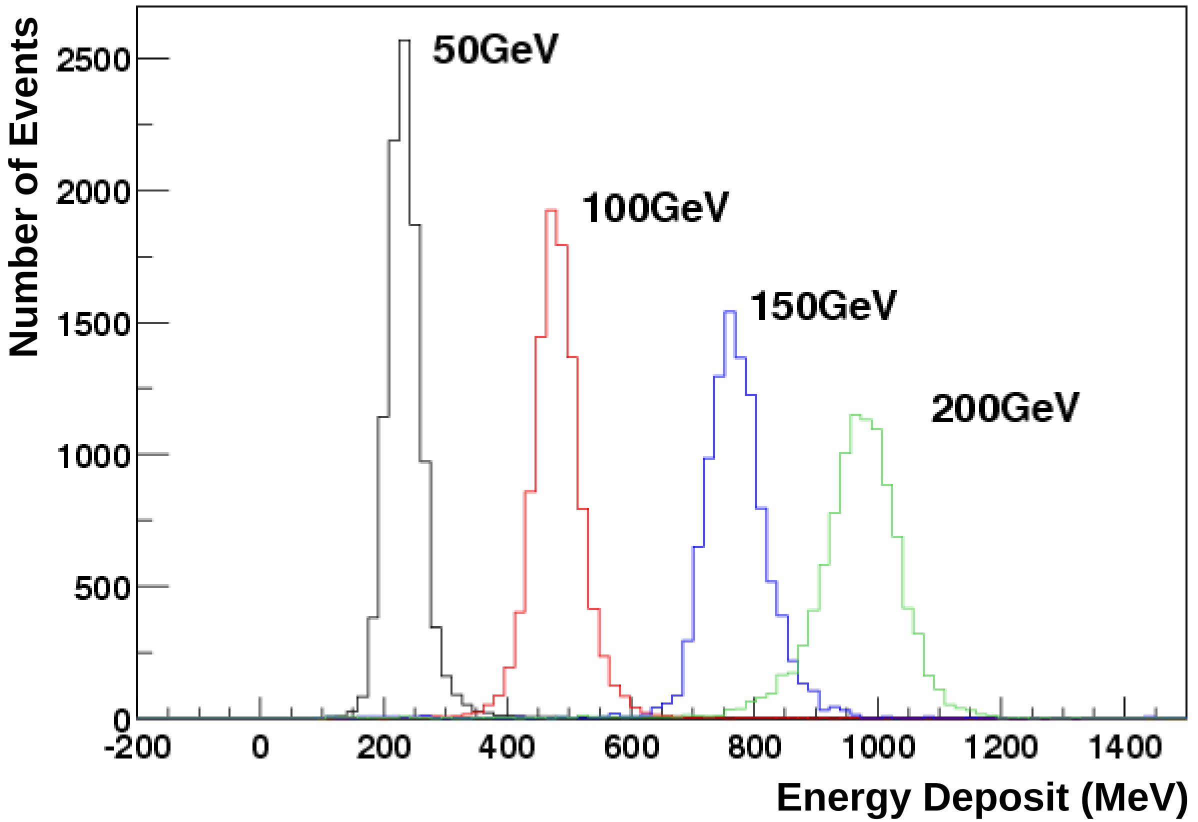


Simulation includes

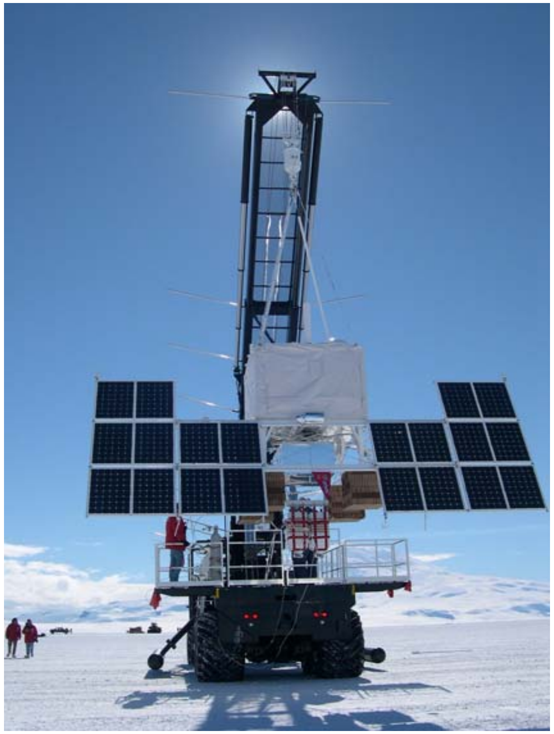
- *Photon statistics*
- *Incoherent noise*
- *Coherent noise*

Beam Test Results - Calorimeter

Response to Electrons from 50 to 200 GeV

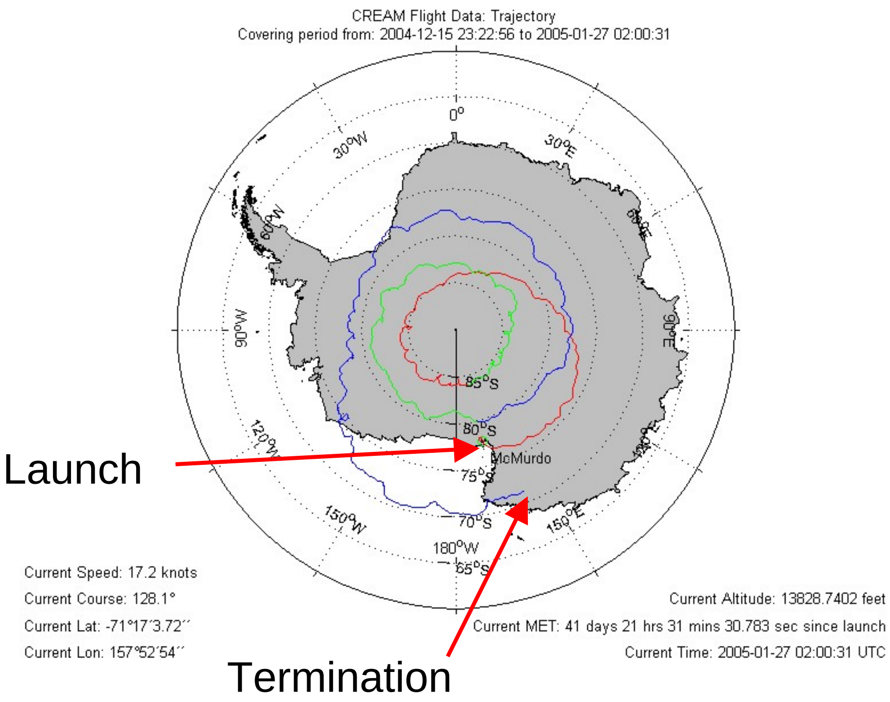


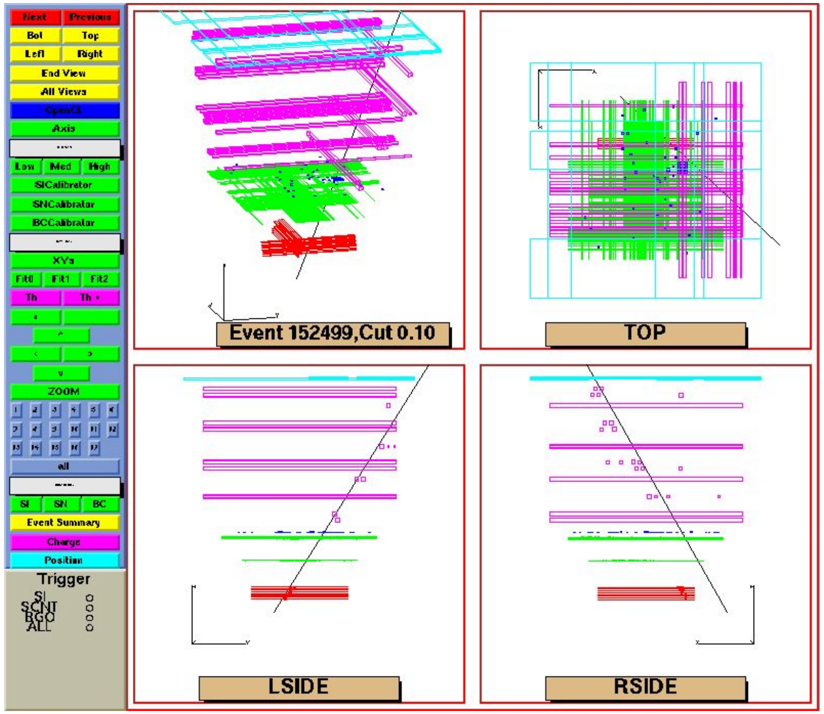
CREAM 2004/05 Flight



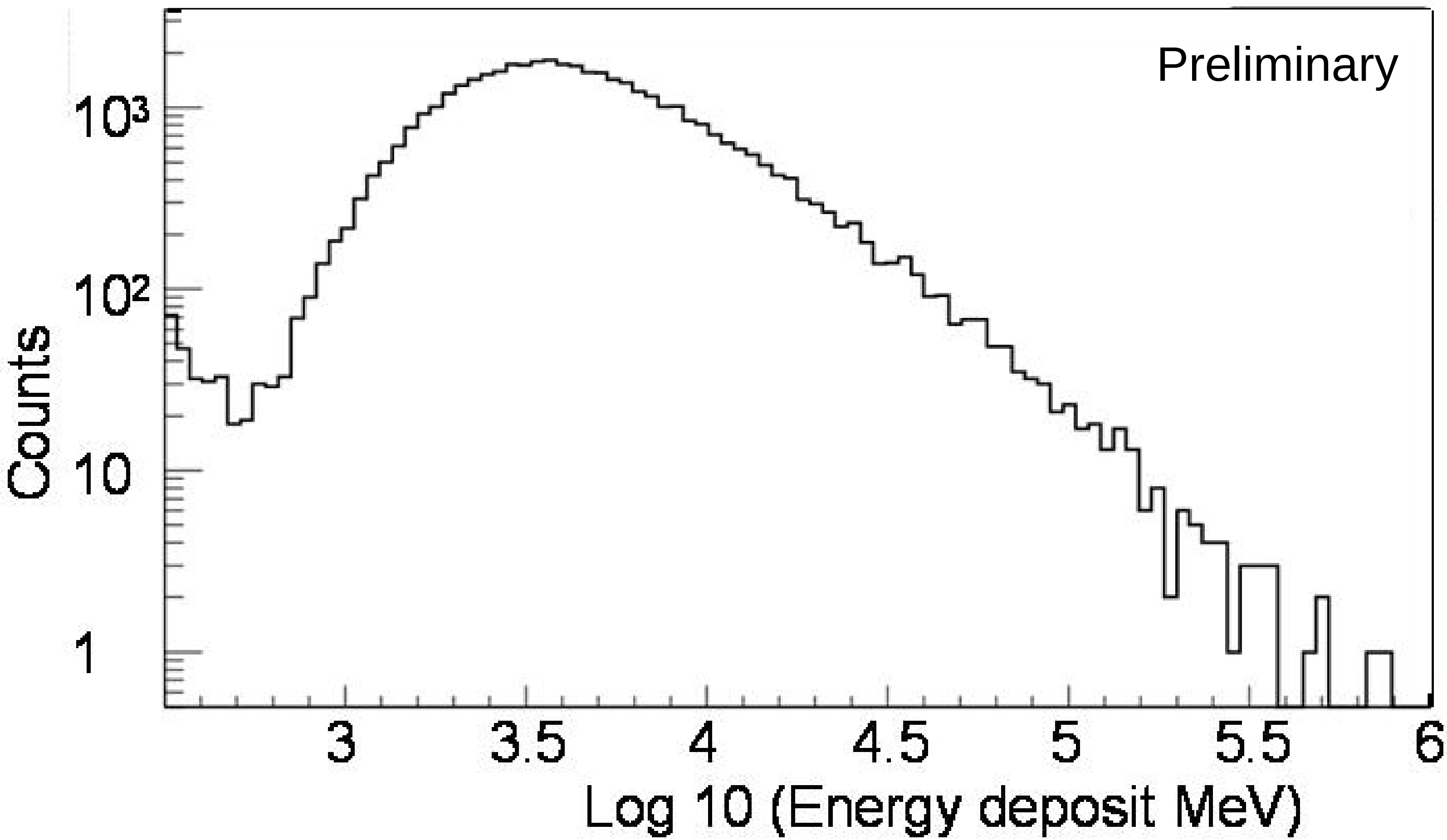
CREAM 2004/05 Flight

- Launch December 16, 2004 from McMurdo Station, Antarctica for nearly 42 days (!) (could have continued operating to design goal of >100 days); collected 4×10^7 events
- Data processing and analysis ongoing; >10 papers presented at ICRC this year
- 2005/06 flight seeks to greatly increase sample of high energy shower events to push the proton and helium **statistical limit to a higher energy**

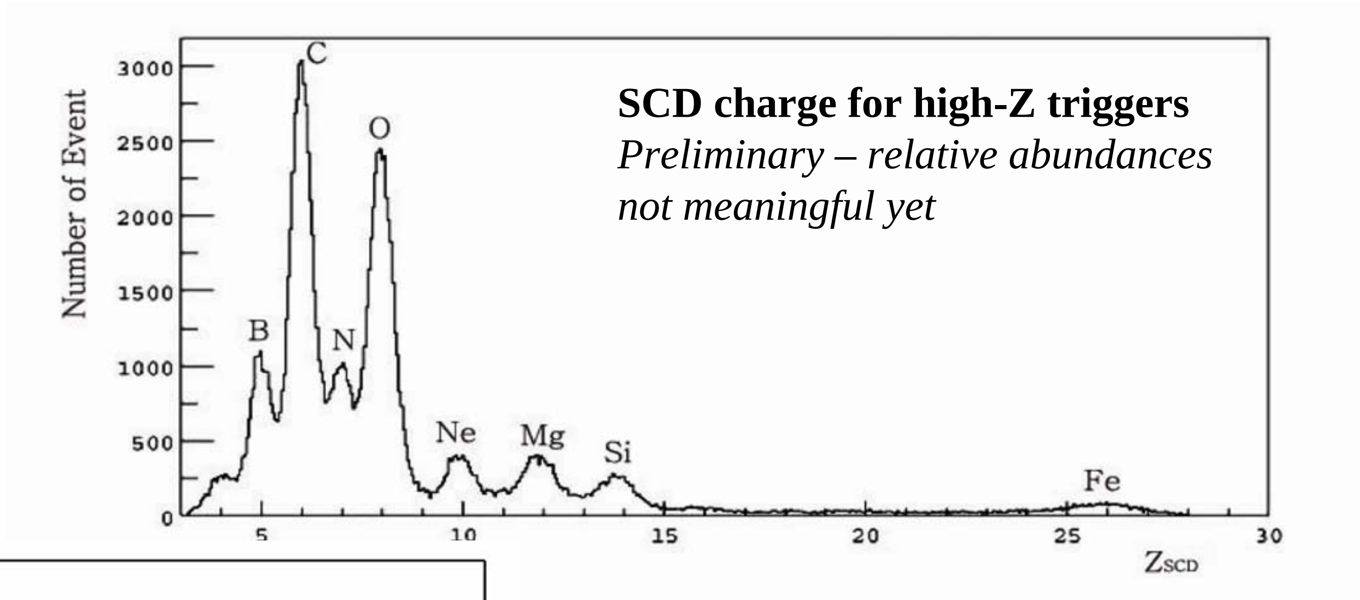


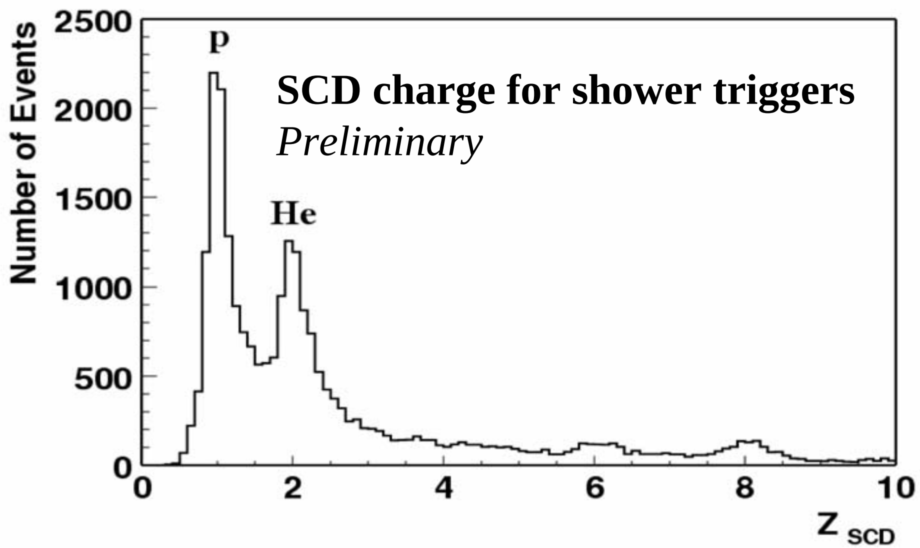


CREAM 2004/05 Flight - Calorimeter

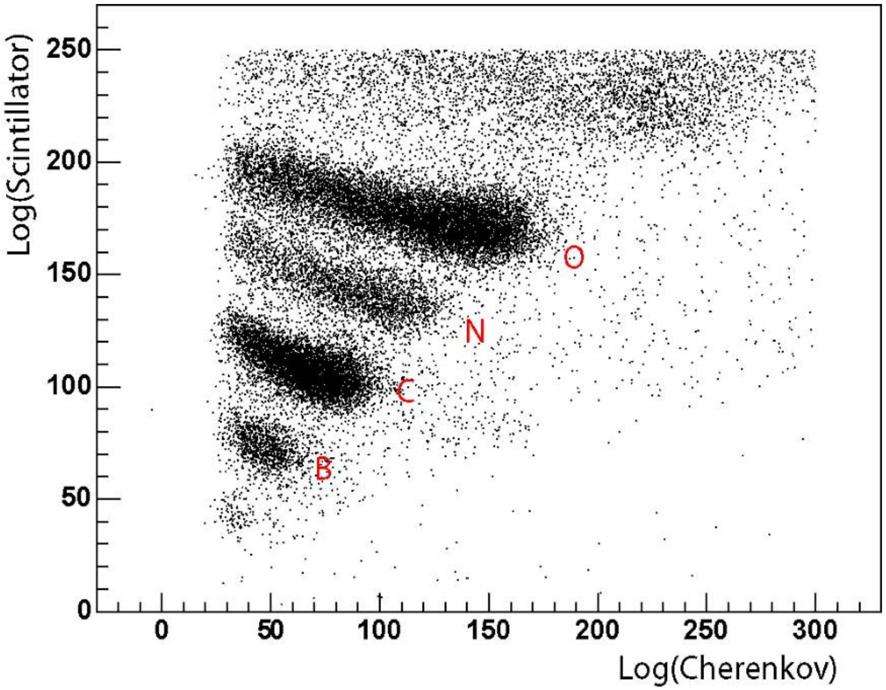


CREAM 2004/05 Flight - SCD

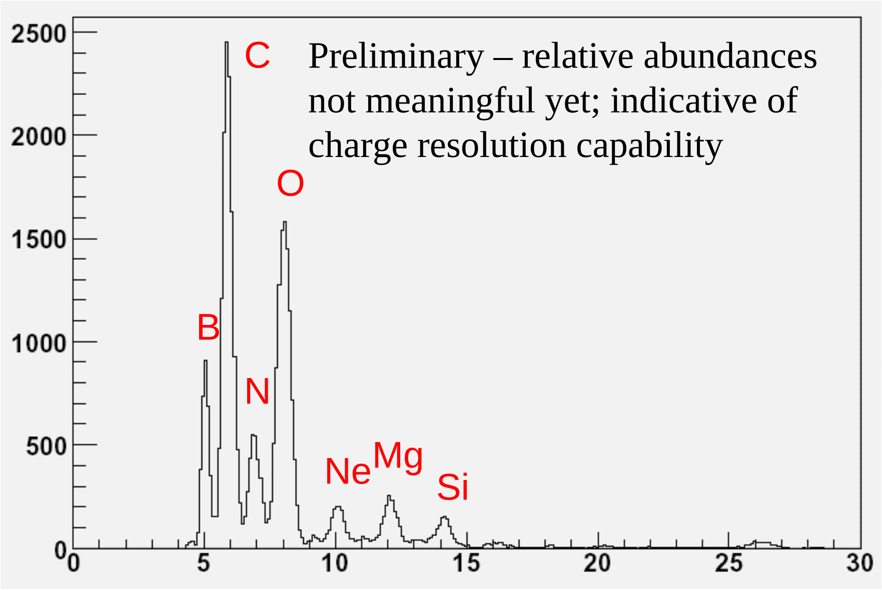




CREAM 2004/05 Flight - TCD



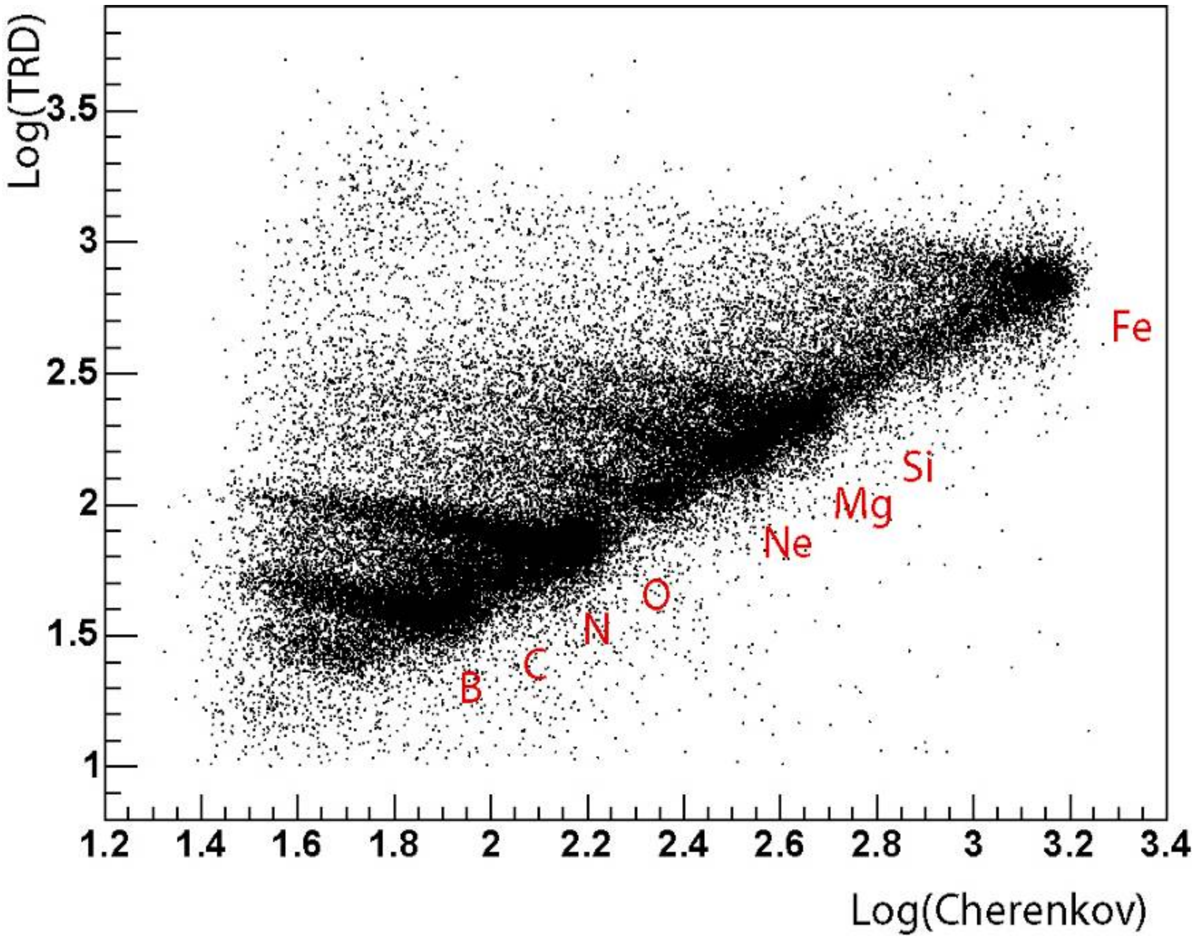
TCD scintillator vs. Cherenkov signals (~1 day).
B,C,N and O populations clearly visible.



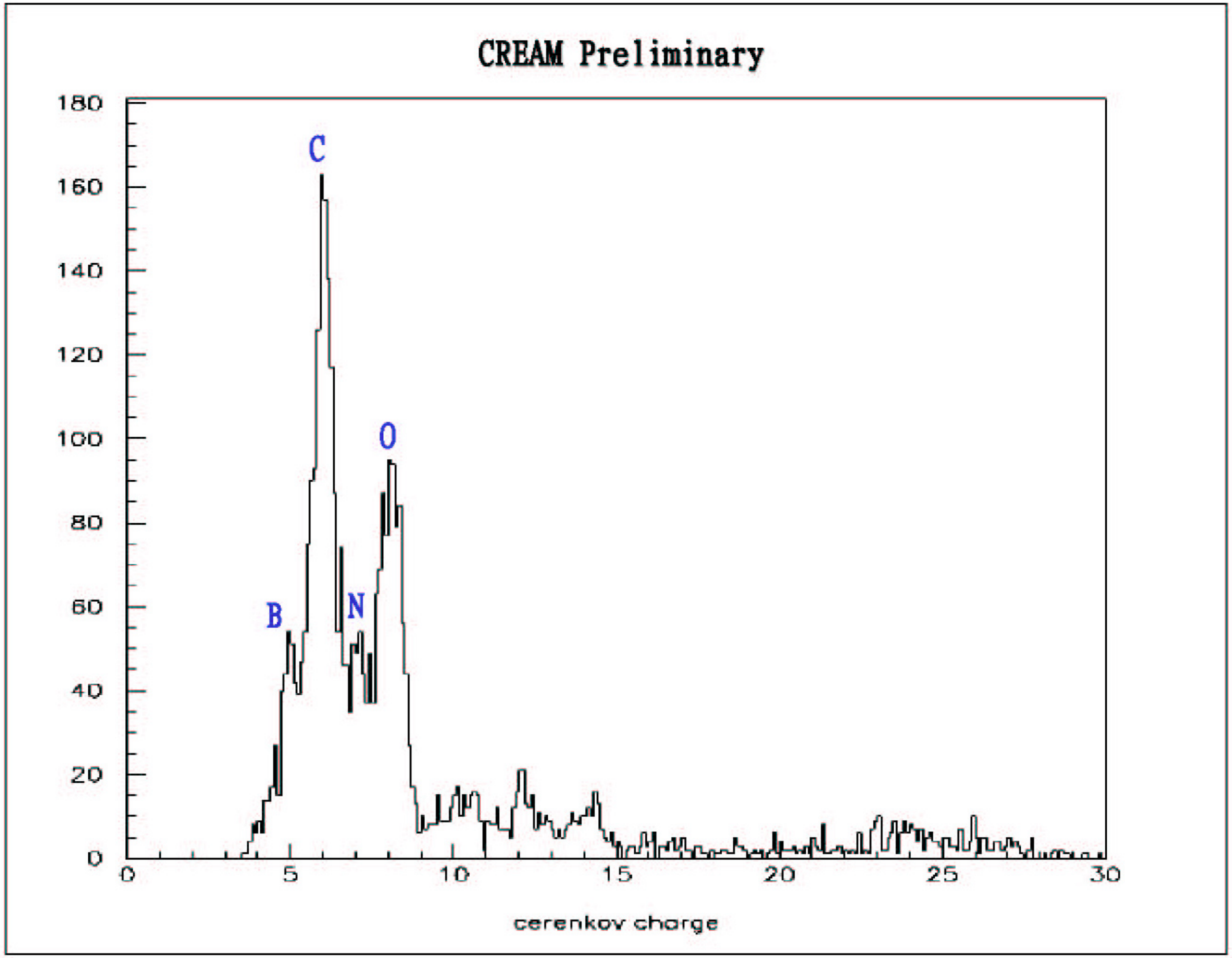
TCD reconstructed charge (~1 day).
B, C, N, O, Ne, Mg, & Si peaks clearly visible.

CREAM 2004/05 Flight - TRD

Measurements of the energy deposited in the TRD tubes versus the normalized Cherenkov light signal during the flight (~1day).



CREAM 2004/05 Flight - Cherenkov



2004/05 Season Landing

2004/05 Season Recovery

Summary

- After nearly a century since their discovery, much is still uncertain about cosmic rays, including their source, acceleration & propagation.
- For different energy ranges and measurement types, different techniques are optimal.
  - For measuring elemental spectra of high energy protons and helium, a flight calorimeter is the only practical solution.
  - For measuring elemental spectra of high energy heavier nuclei a TRD is optimal.
- CREAM combines a calorimeter, TRD, and multiple charge detectors providing good measurement capability with cross calibration, for elemental spectra of $1 \leq Z \leq 26$ up to 10^{15} eV.
- CREAM's first, record-breaking LDB flight of nearly 42 days with ~2.2 m^2sr trigger aperture collected > 4×10^7 events comprising one of the most exciting cosmic ray data samples available. Preliminary results are very promising, and data analysis is proceeding.
- CREAM-II (w/o TRD) is set to launch in December 2005; CREAM is being refurbished for a planned 2006 flight.