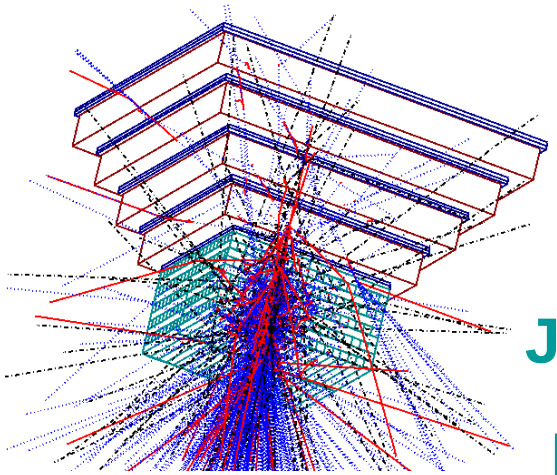


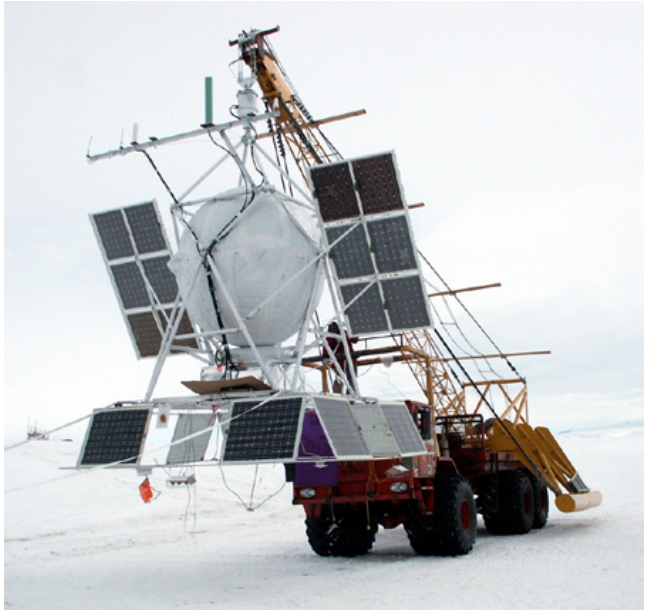
A Brief Review of ATIC Results on Nuclei and Electrons

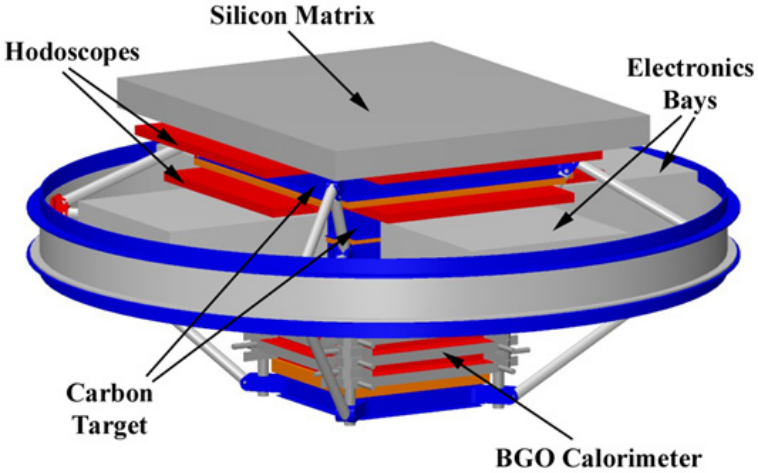
John P. Wefel for the ATIC Collaboration

Department of Physics and Astronomy

Louisiana State University

Baton Rouge, LA 70803

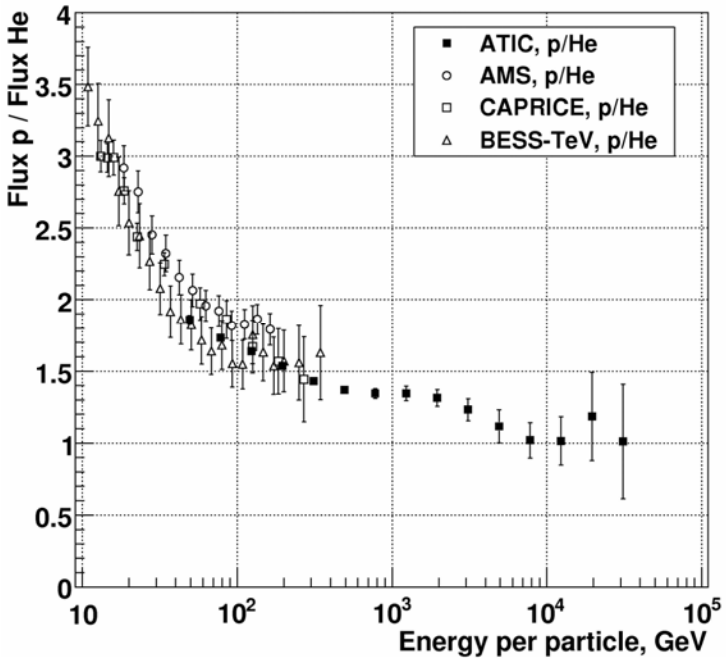


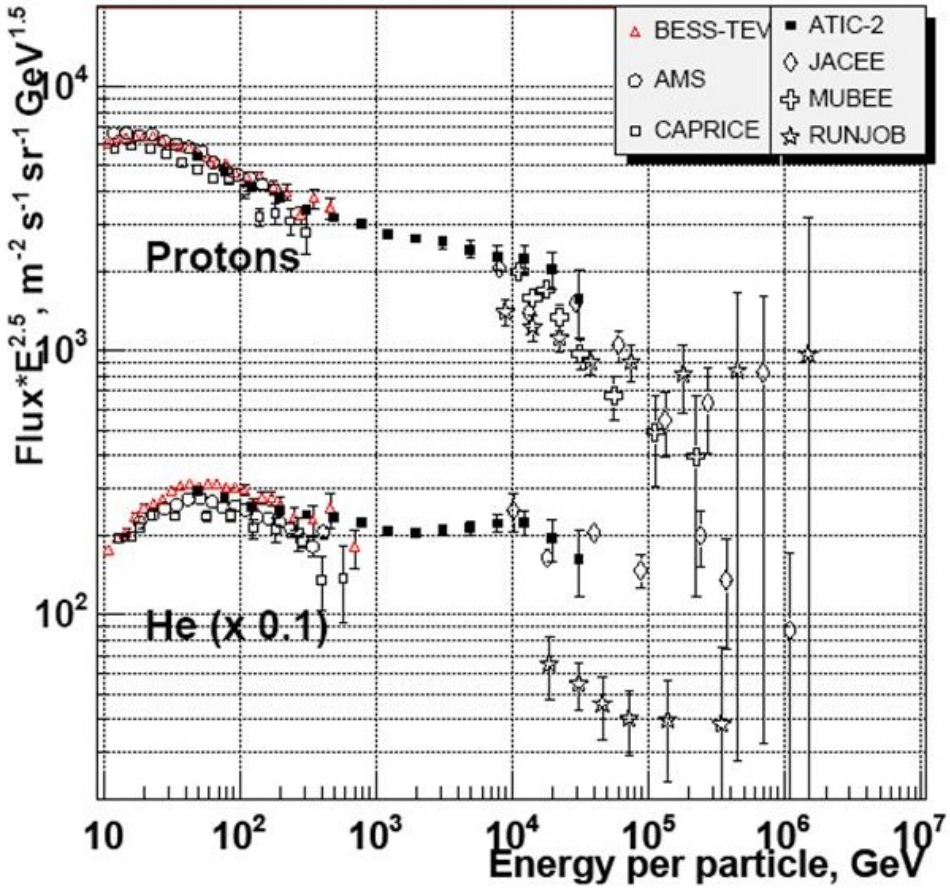


TeV Particle Astrophysics 2013, Irvine CA

The Advanced Thin Ionization Calorimeter (ATIC) Experiment was conceived to answer the question "Are the spectra of H and He different at Very High energy?" as had been reported by the JACEE emulsion chamber project but not found by the RUNJOB emulsion chamber experiments.

ATIC data agreed with the JACEE results and showed that the VHE spectra were changing





The ATIC Instrument

Need an instrument to measure:

⇒ Element type, Particle energy, and the Number of each element and energy

Measure before the cosmic rays break-up in the atmosphere

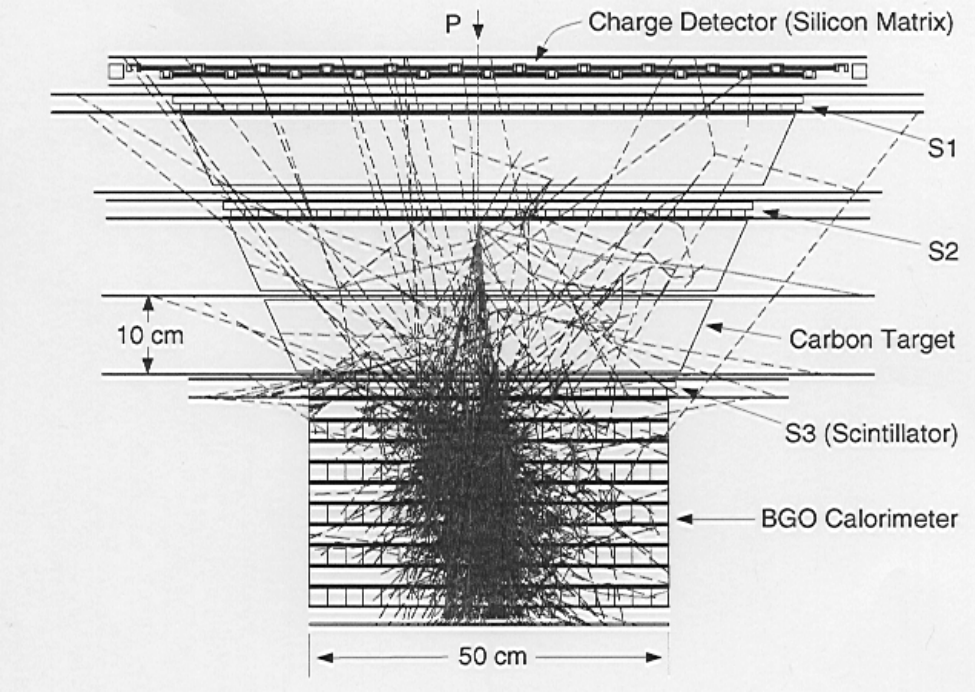
⇒ In space (expensive) or at least at very high altitude (balloon)

Need to measure for as long as possible

⇒ Use a long duration balloon to get 15 to 30 days of exposure

Principle of "Ionization Calorimetry"

- ⇒ **Cosmic ray enters from top**
- ⇒ **Nuclear interaction in target section**
- ⇒ **'BGO Calorimeter' fosters a cascade (or shower) of many sub-particles**
- ⇒ **How this "cloud" of sub-particles develops depends upon the initial cosmic ray energy.**



The ATIC Collaboration

J.H. Adams[2], H.S. Ahn[3], G.L. Bashindzhagyan[4], K.E. Batkov[4], J. Chang[6,7], M. Christl[2], A.R. Fazely[5], O. Ganel[3] R.M. Gunasingha[5], T.G. Guzik[1], J. Isbert[1], K.C. Kim[3], E.N. Kouznetsov[4], M.I. Panasyuk[4], A.D. Panov[4], W.K.H. Schmidt[6], E.S. Seo[3], N.V. Sokolskaya[4], J. Watts, J.P. Wefel[1], J. Wu[3], V.I. Zatsepin[4]

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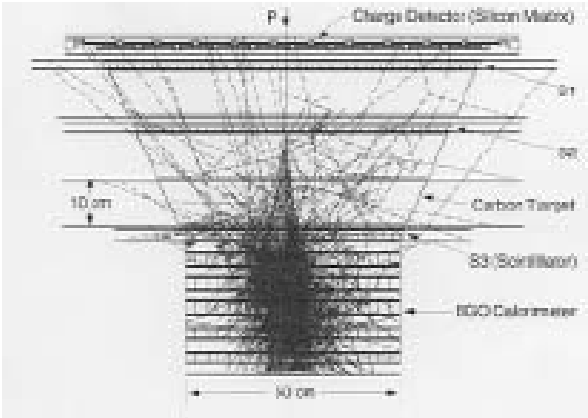
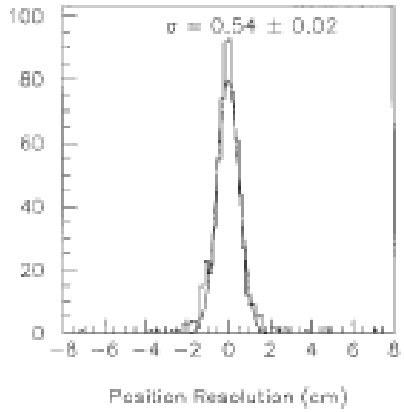
4. Skobeltsyn Institute of Nuclear Physics, Moscow State University, Russia
5. Southern University, Baton Rouge, LA, USA
6. Max Plank Institute für Space Physics, Lindau, Germany
7. Purple Mountain Observatory, Chinese Academy of Sciences, China

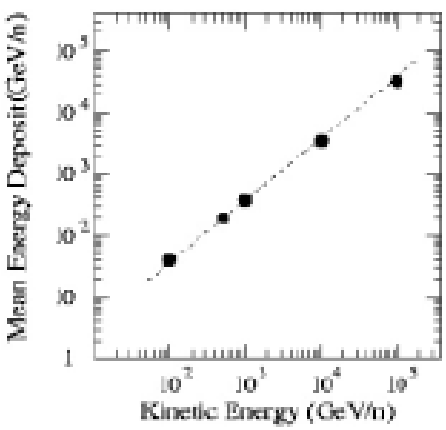
ATIC has been extensively simulated

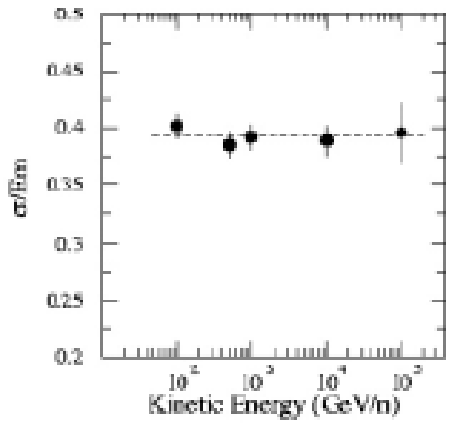


An example of a proton shower in the McMurdo flight configuration

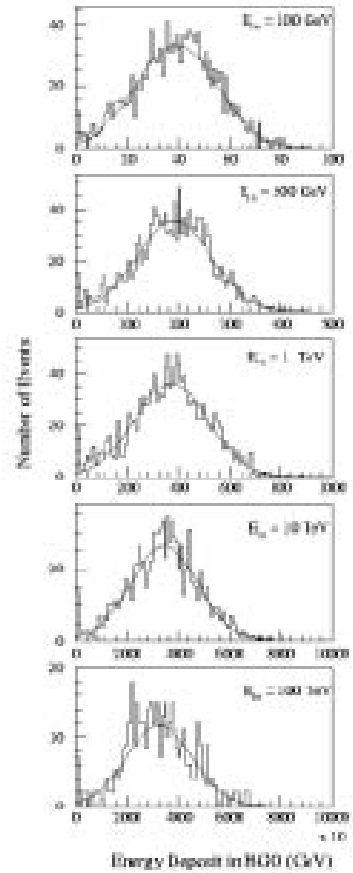


Trajectory resolution in S1 calculated from the BGO shower profile for 1 TeV protons.



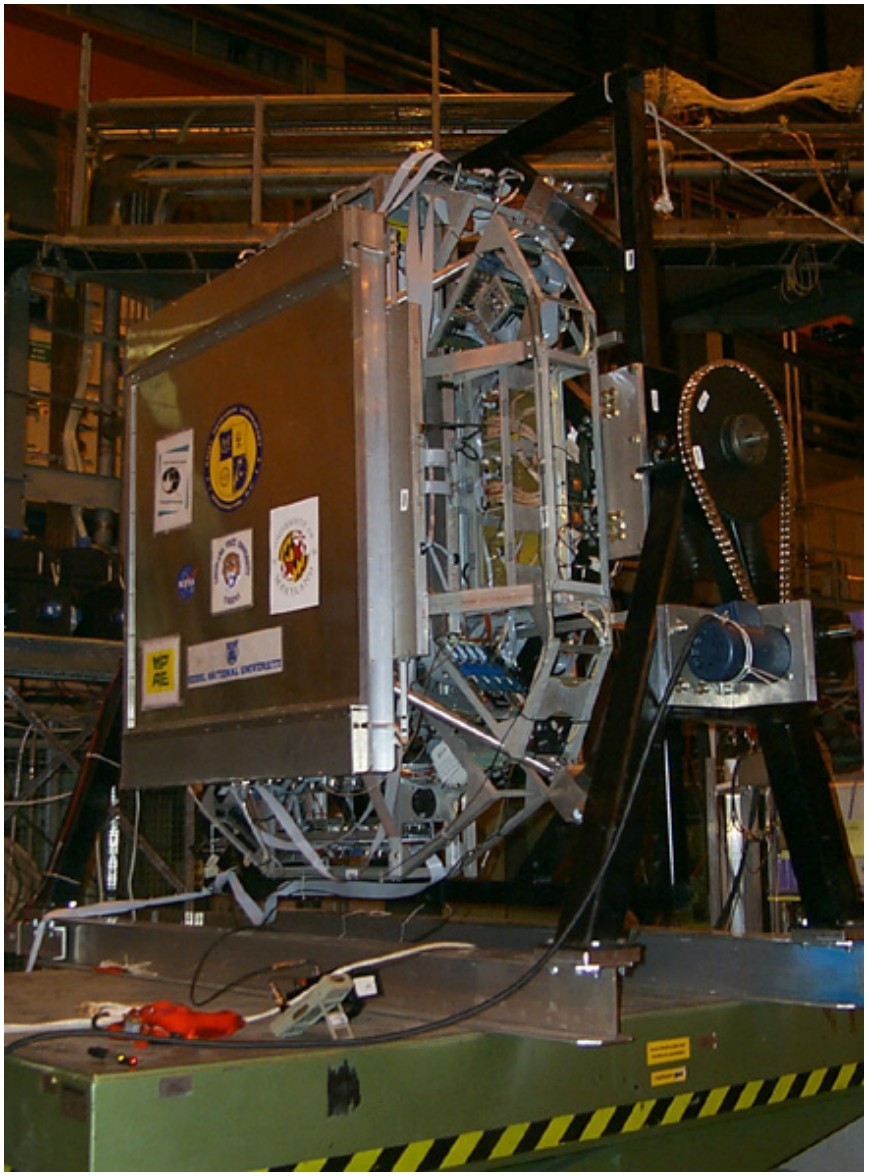


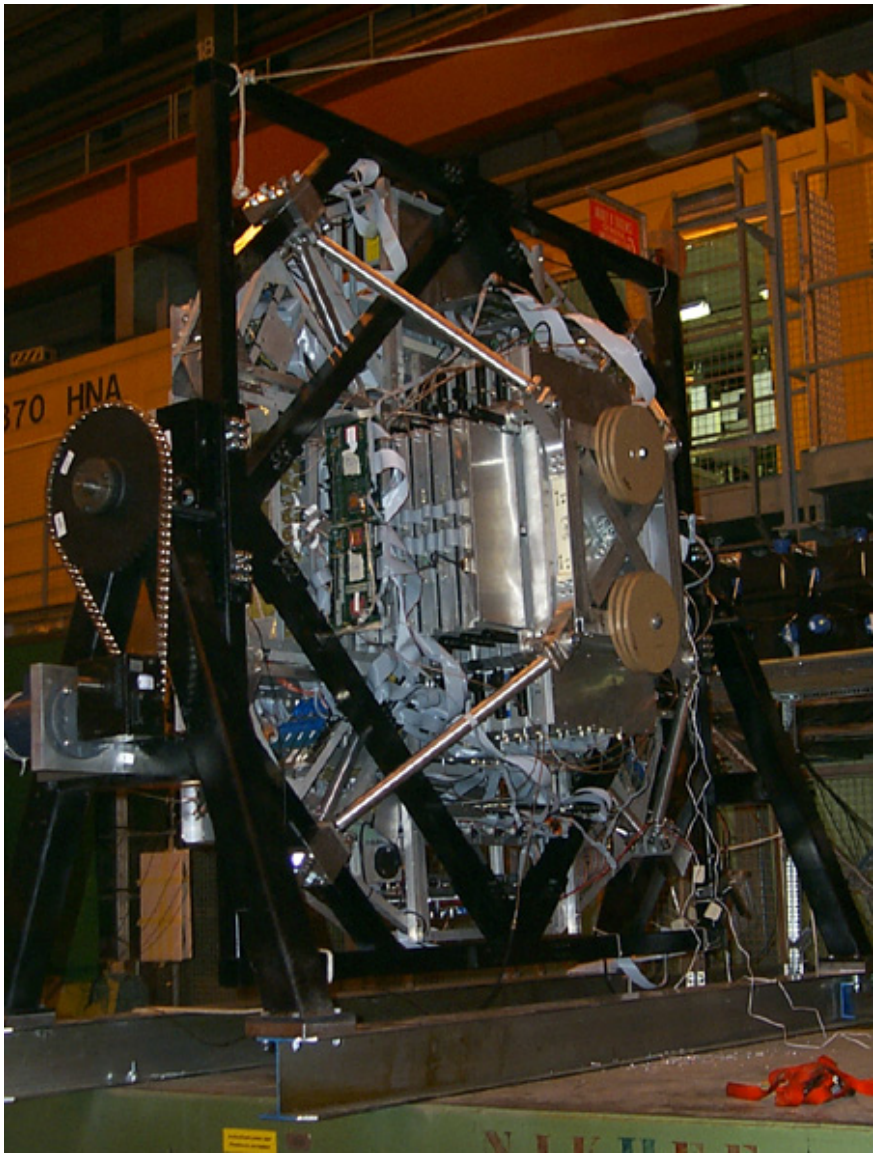
Energy dependence of the proton mean energy deposit and the energy resolution.



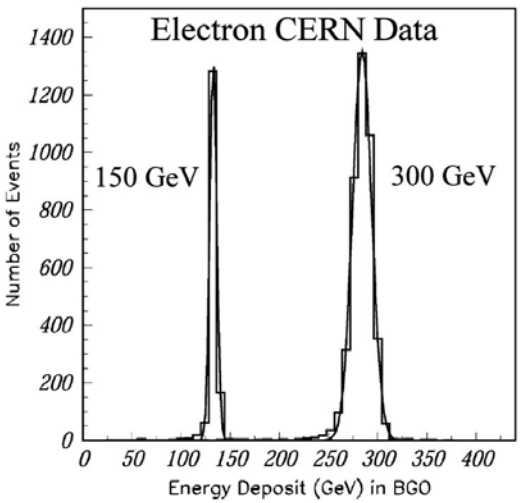
Energy deposition in 20 cm depth BGO calorimeter for 10^2, $5x10^2$, 10^3, 10^4, and 10^5 GeV protons.

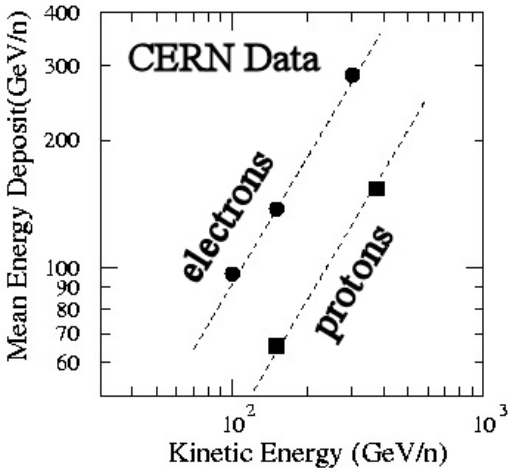
ATIC at CERN





The ATIC Instrument was calibrated at CERN



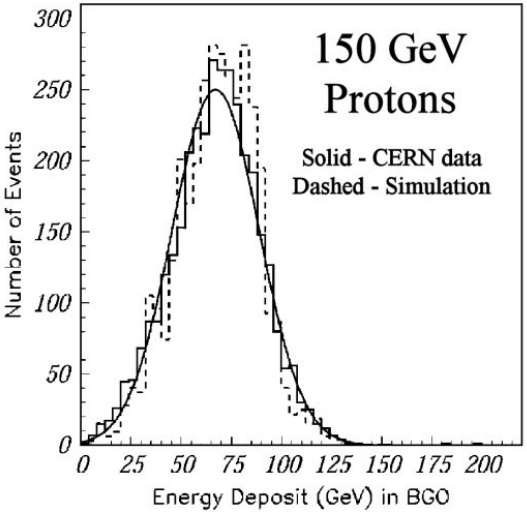


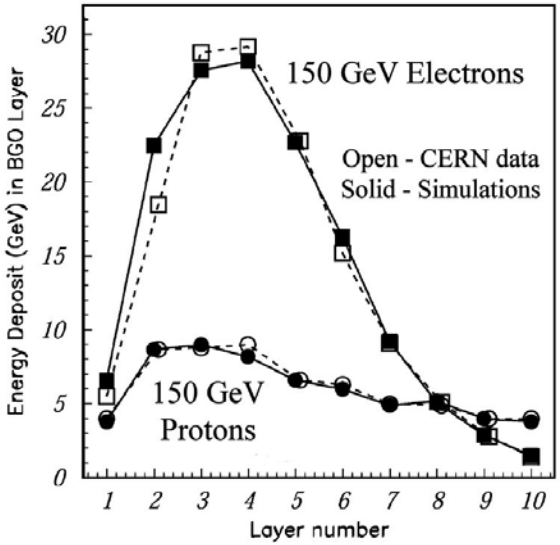
Determine instrument response.

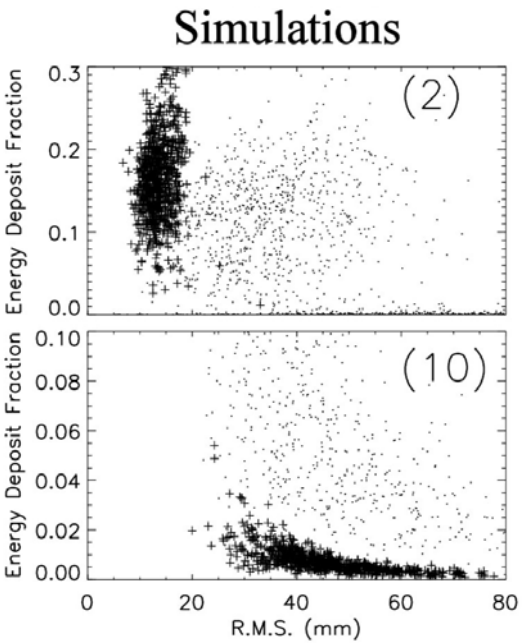
Investigate energy resolution.

Check accuracy of simulations to allow extrapolation to higher energy.

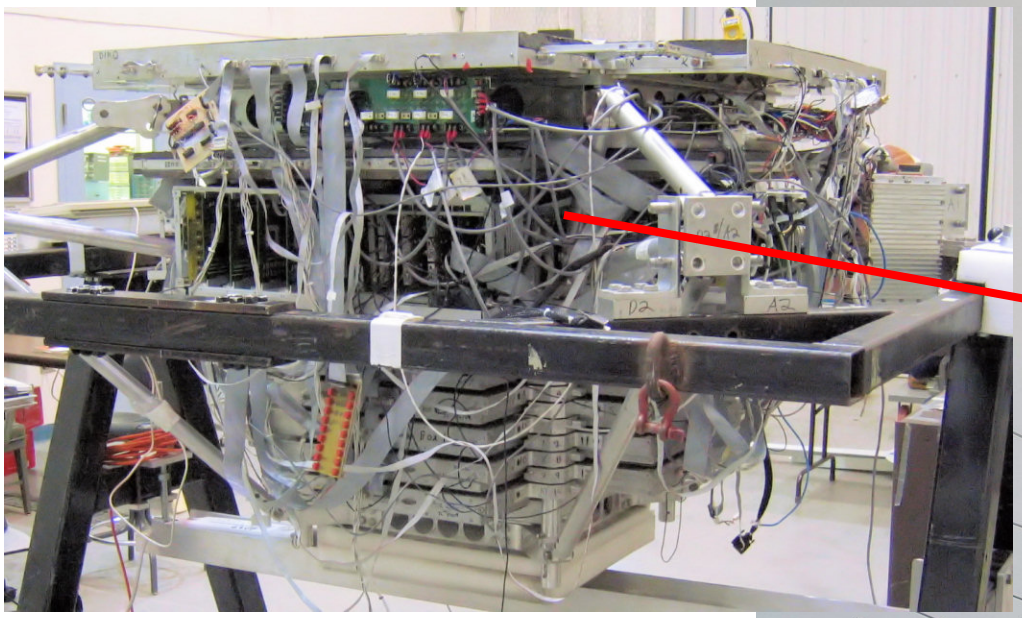
Use 150 GeV electrons and 375 GeV protons to validate electron analysis and evaluate the proton contamination (i.e. 1 in 5000).

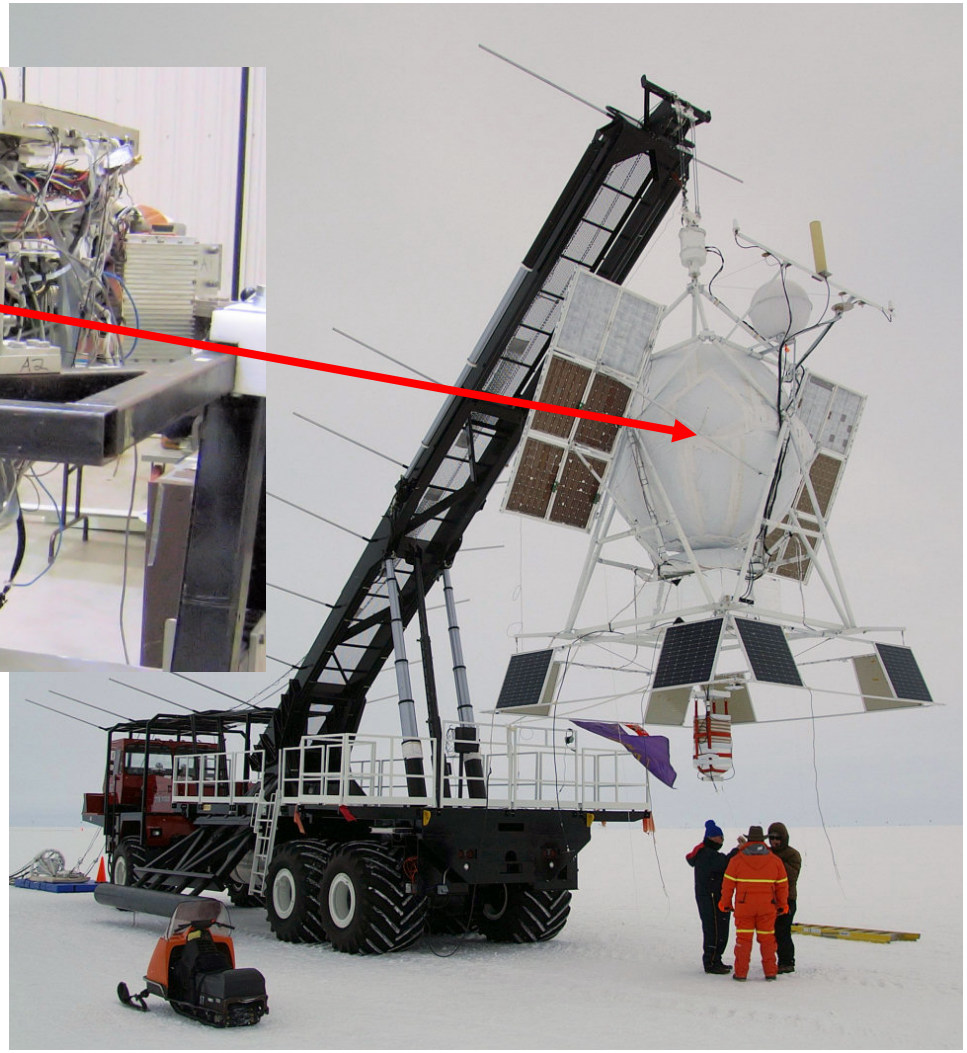






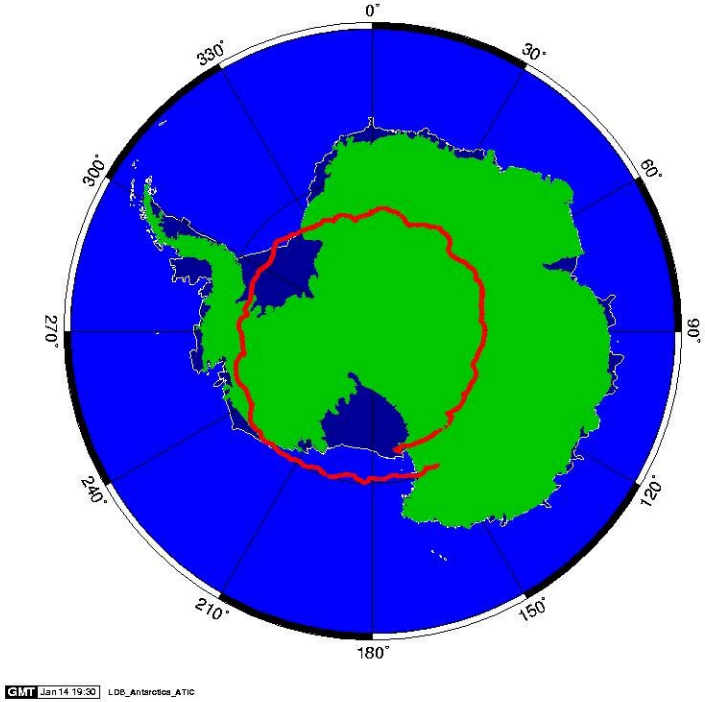
ATIC was constructed as a balloon payload





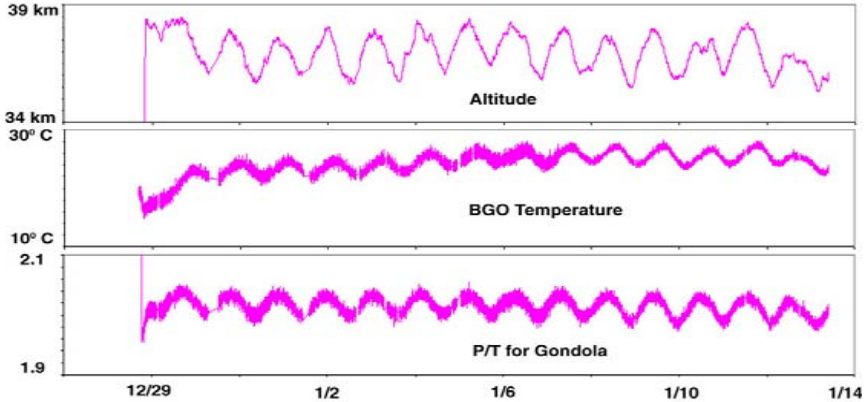
Recoverable – requires field disassembly/removal and **Refurbishable** – to enable re-flight(s)

ATIC-1 Test Flight from McMurdo - 2000

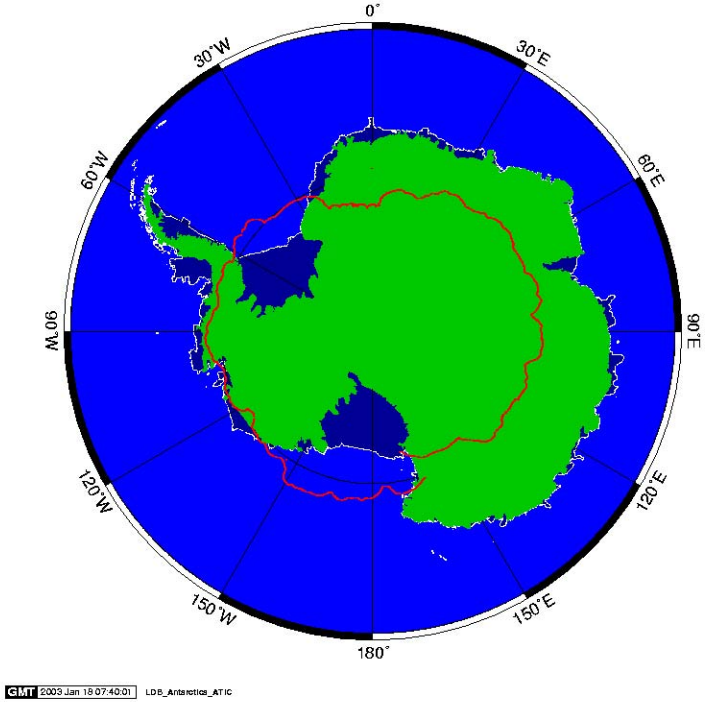


- 43.5 Gbytes Recorded Data
- 26,100,000 Cosmic Ray triggers
- 1,300,000 Calibration records
- 742,000 Housekeeping records
- 18,300 Rate records
- Low Energy Trigger > 10 GeV for protons
- >70% Live-time
- >90% of channels operating nominally
- Internal pressure (~8 psi) held constant
- Internal Temperature: 20 – 30 C
- Altitude: 37 ± 1.5 km

- Launch: 12/28/00 04:25 UTC
- Begin Science: 12/29/00 03:54 UTC
- End Science: 01/12/01 20:33 UTC
- Termination: 01/13/01 03:56 UTC
- Recovery: 01/23/01; 01/25/01

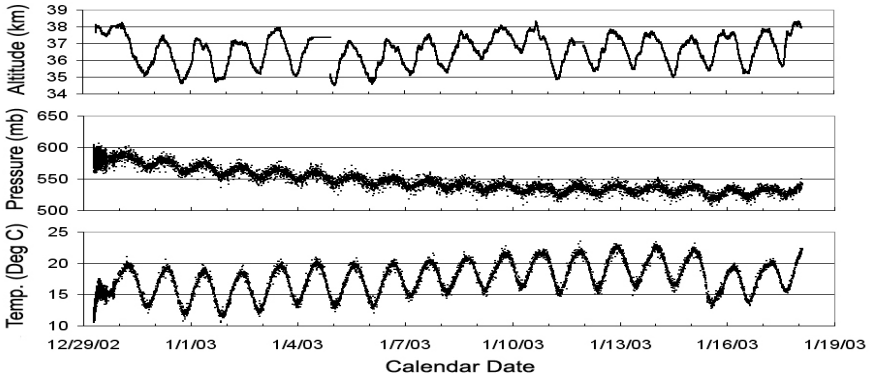


ATIC-2 Science Flight from McMurdo - 2002

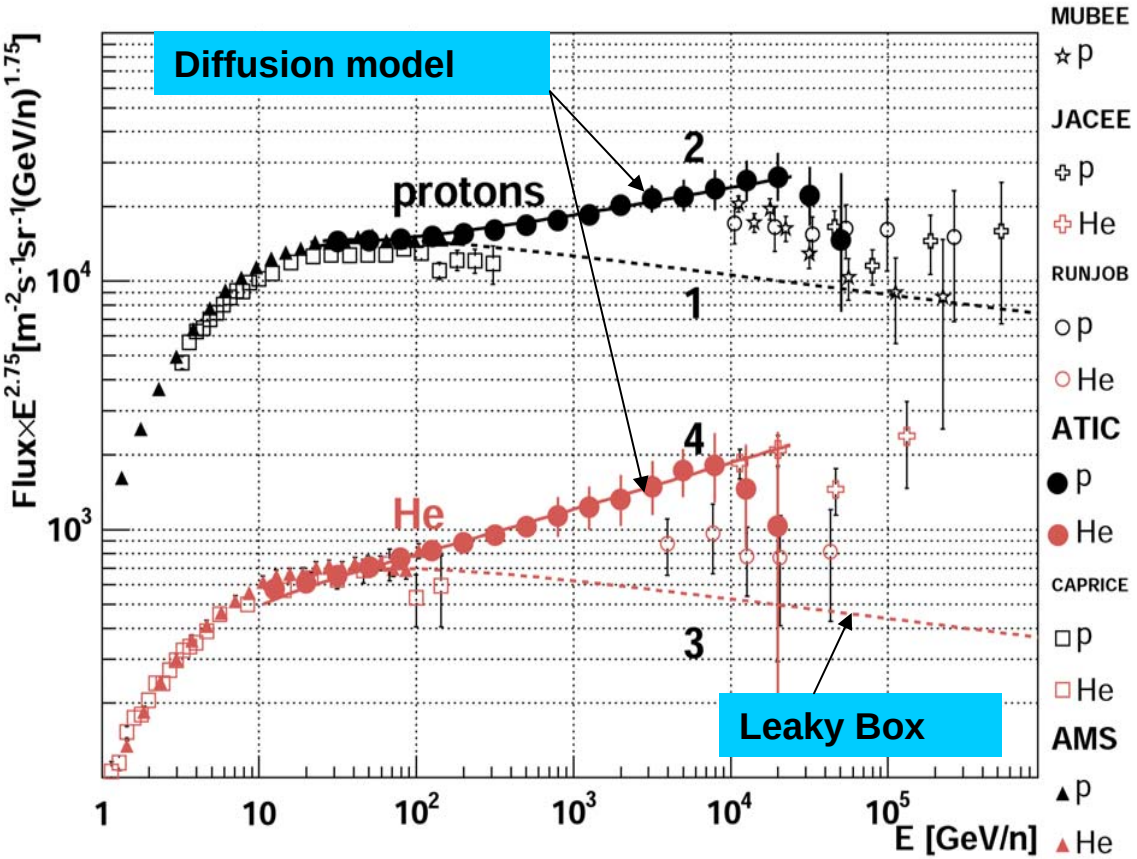


- Launch: 12/29/02 04:59 UTC
- Begin Science: 12/30/02 05:40 UTC
- End Science: 01/18/03 01:32 UTC
- Termination: 01/18/03 02:01 UTC
- Recovery: 01/28/03; 01/30/03

- 65 Gbytes Recorded Data
- 16,900,000 Cosmic Ray triggers
- 1,600,000 Calibration records
- 184,000 Housekeeping records
- 26,000 Rate records
- High Energy Trigger > 75 GeV for protons
- >96% Live-time
- >90% of channels operating nominally
- Internal pressure (~8 psi) decreased slightly (~0.7 psi) for 1st 10 days then held constant
- Internal Temperature: 12 – 22 C
- Altitude: 36.5 ± 1.5 km

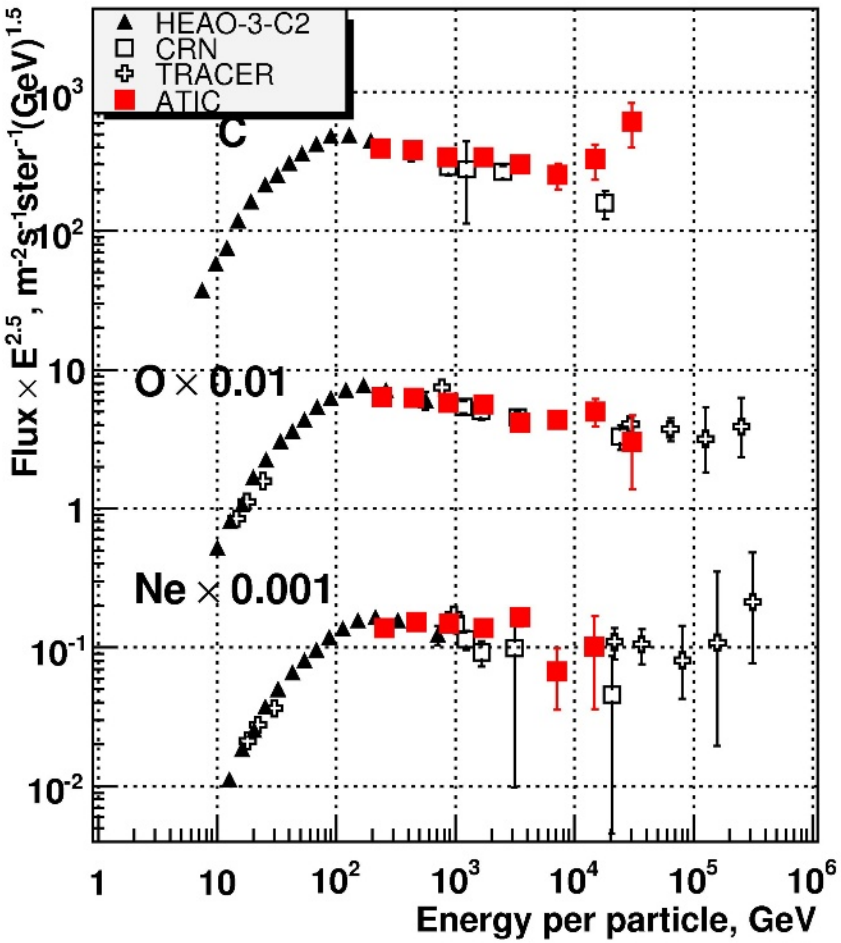


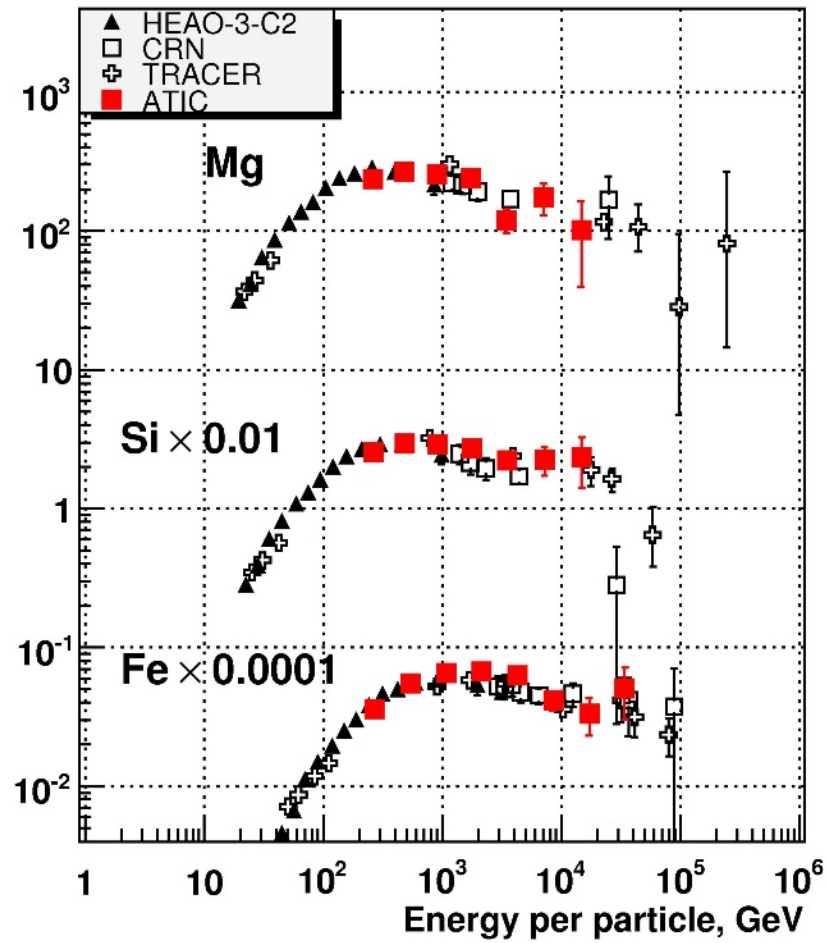
ATIC-2 Results favor the Diffusion Model



The ATIC H and He spectra are fit by a diffusion model that includes weak re-acceleration due to Kolmogorov turbulence (Osborne and Ptuskin, 1988)

Results extended to higher energy by CREAM





There is general agreement with previous experiments on the Hi-Z energy spectra, but with a trend to flatten at the highest energies sampled.

Comparison between experimental results

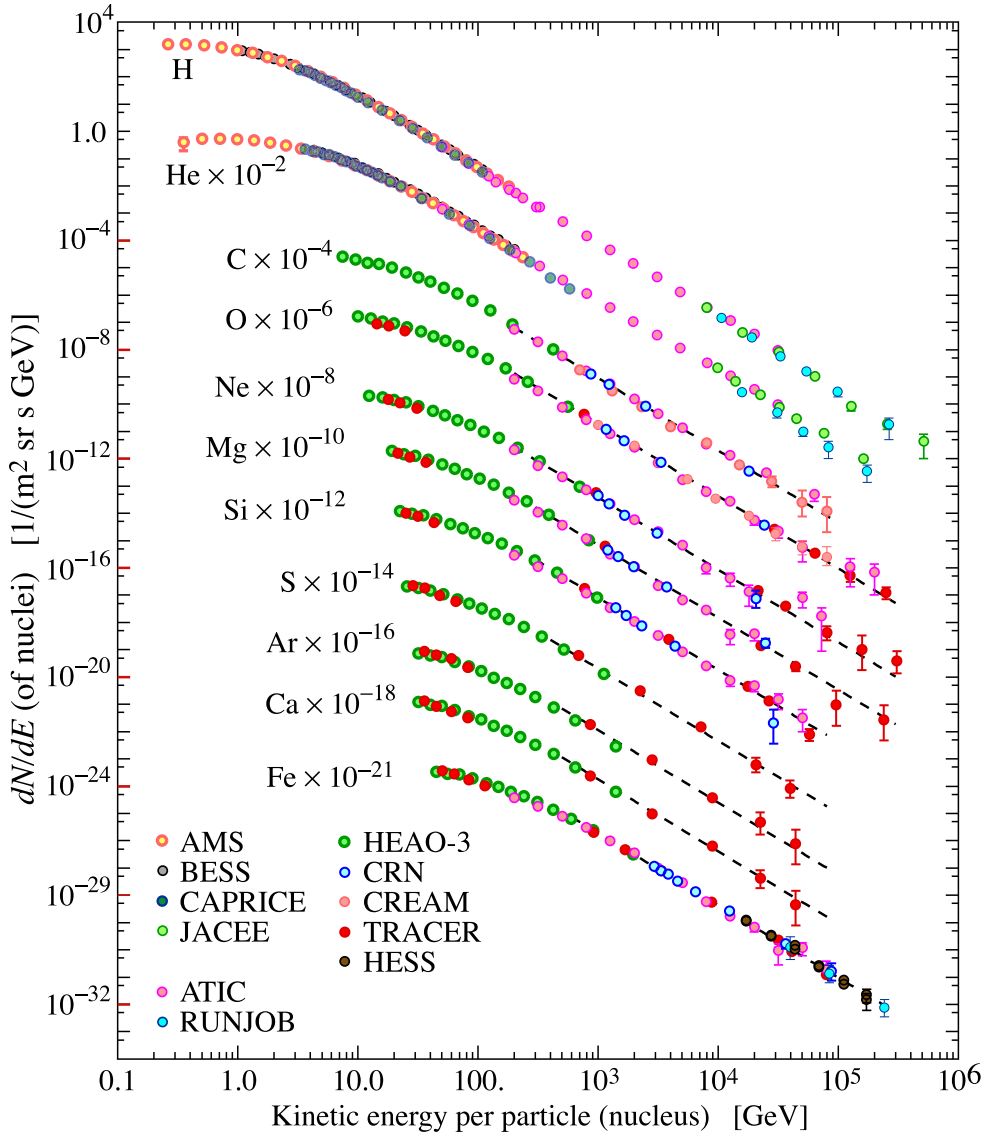
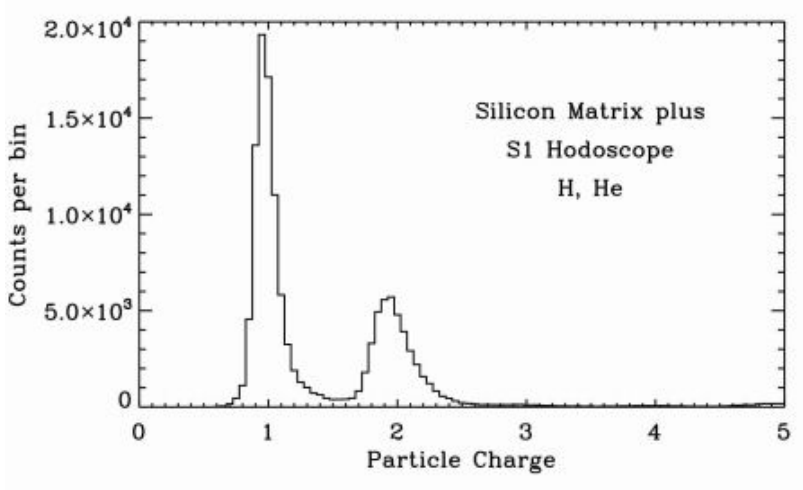
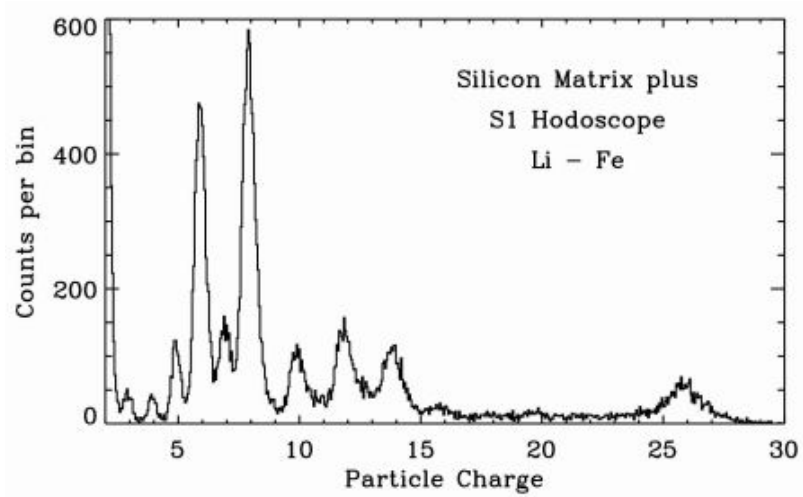
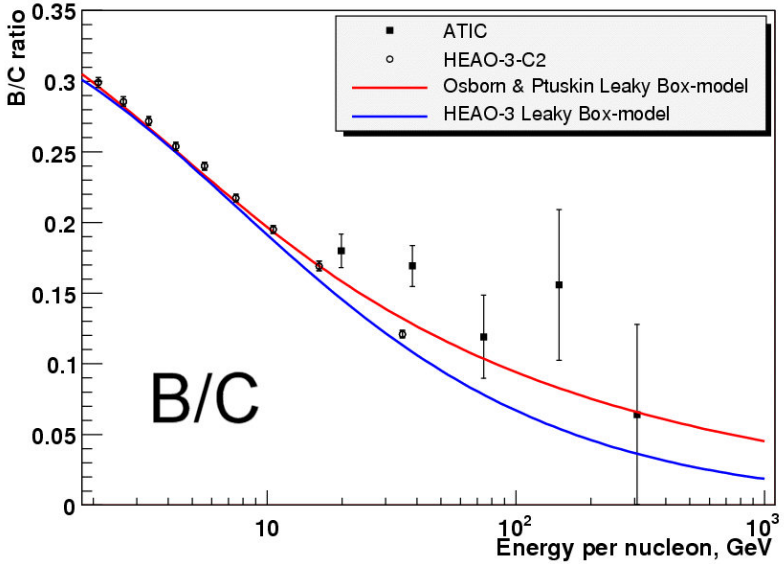


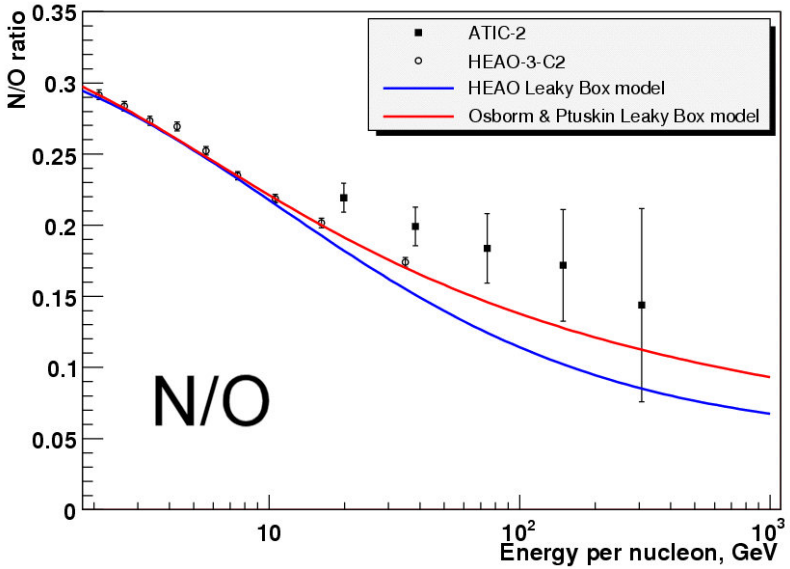
Figure courtesy of P.J. Boyle and D. Mueller

Secondary GCR, such as B & N, are produced from primaries (e.g. C, O) during propagation



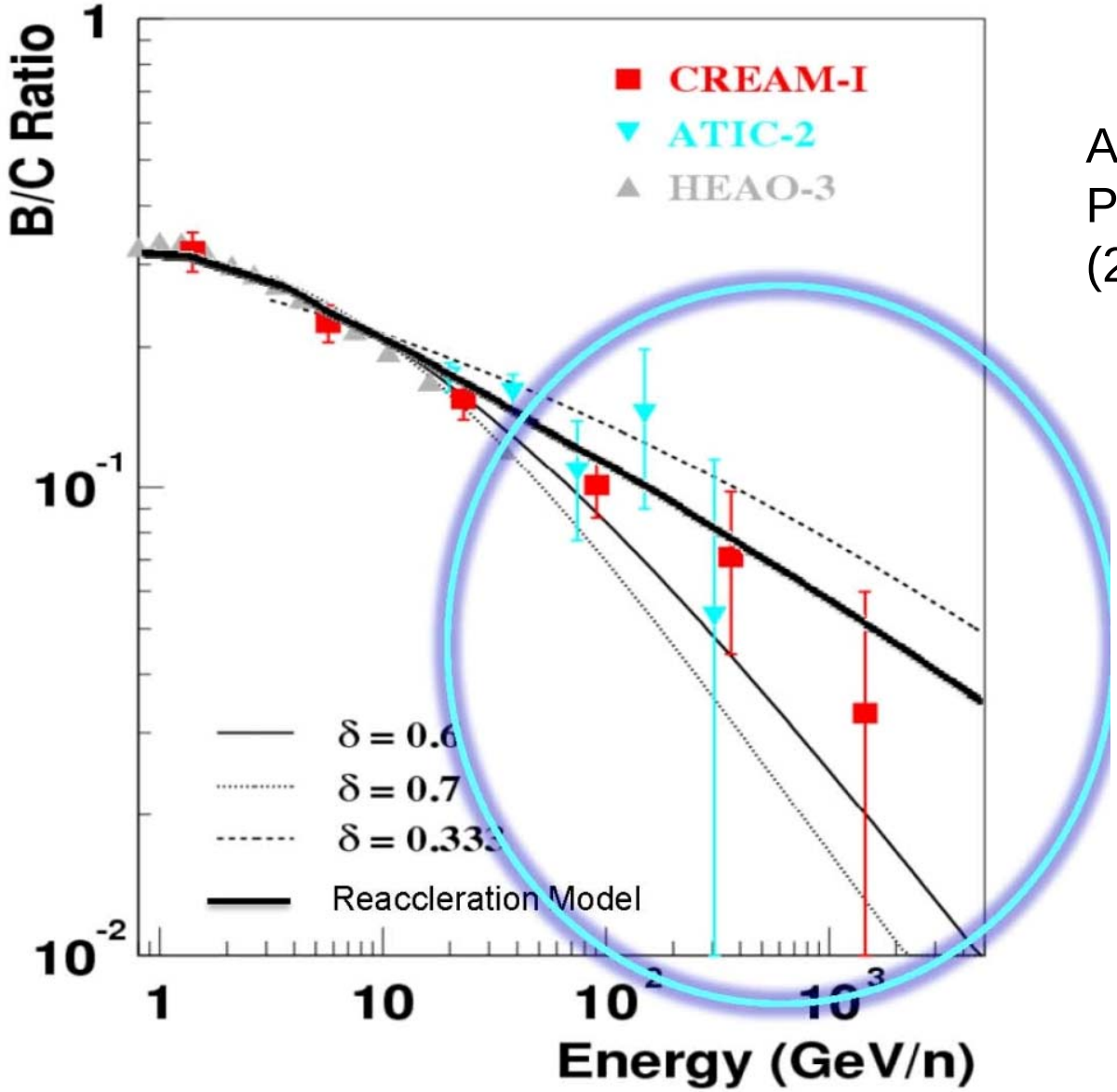






Both ratios appear to favor the diffusion model with weak re-acceleration

CREAM B/C results



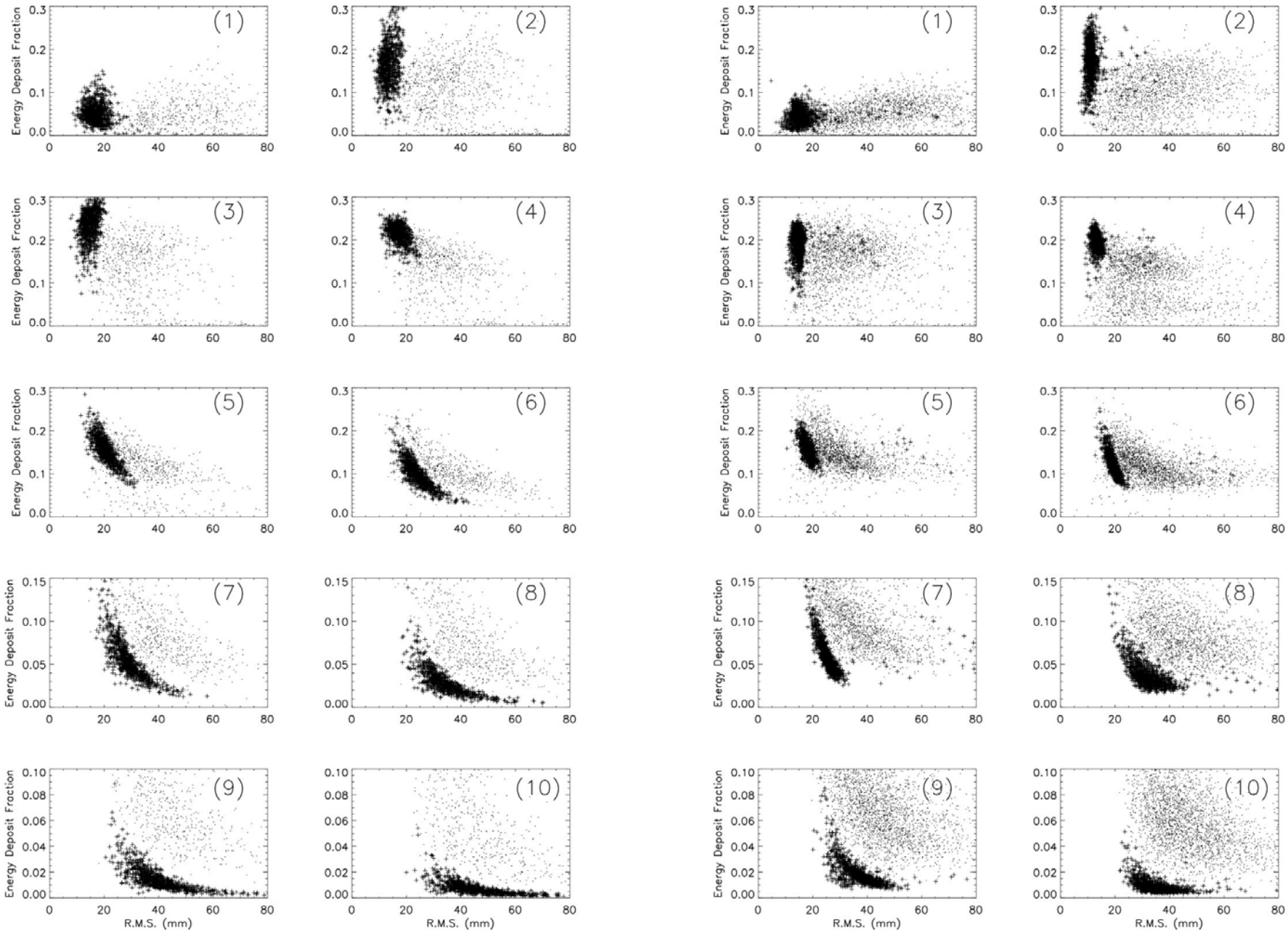
Ahn et al. Astropart. Phys. 30/3, 133-141, (2008)

Courtesy E. S. Seo

Simulation

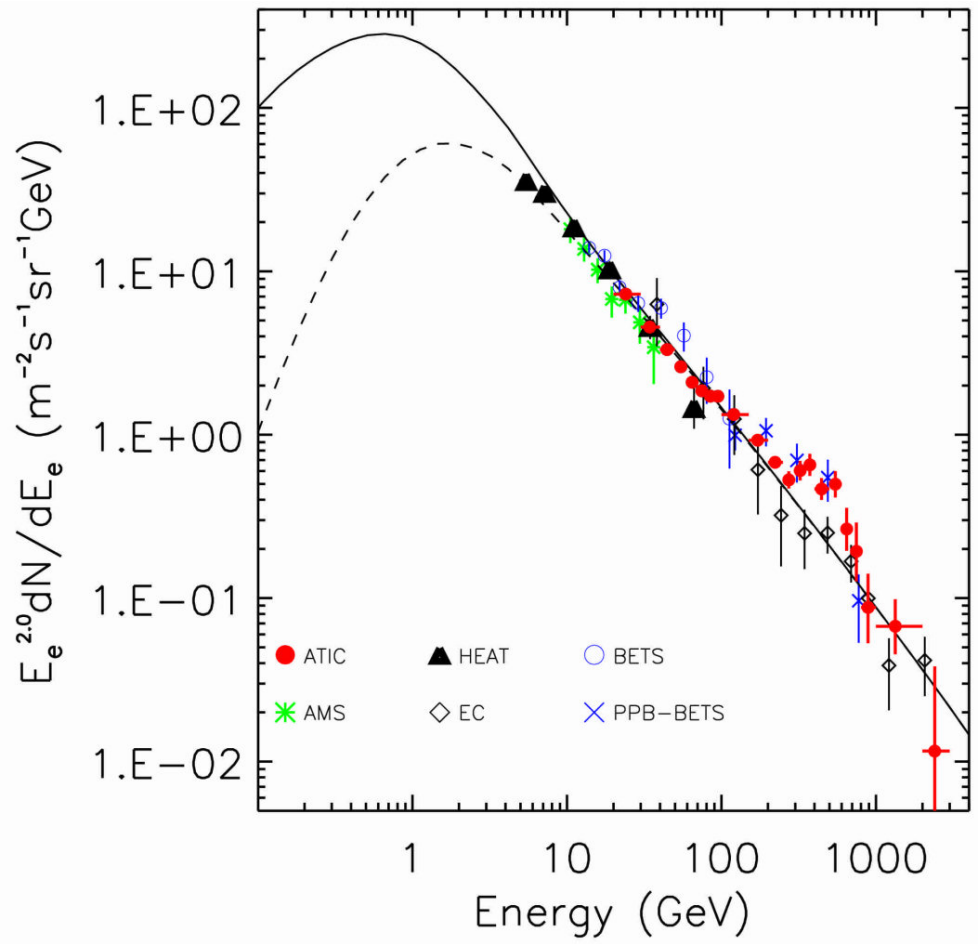
CERN e and p

Data



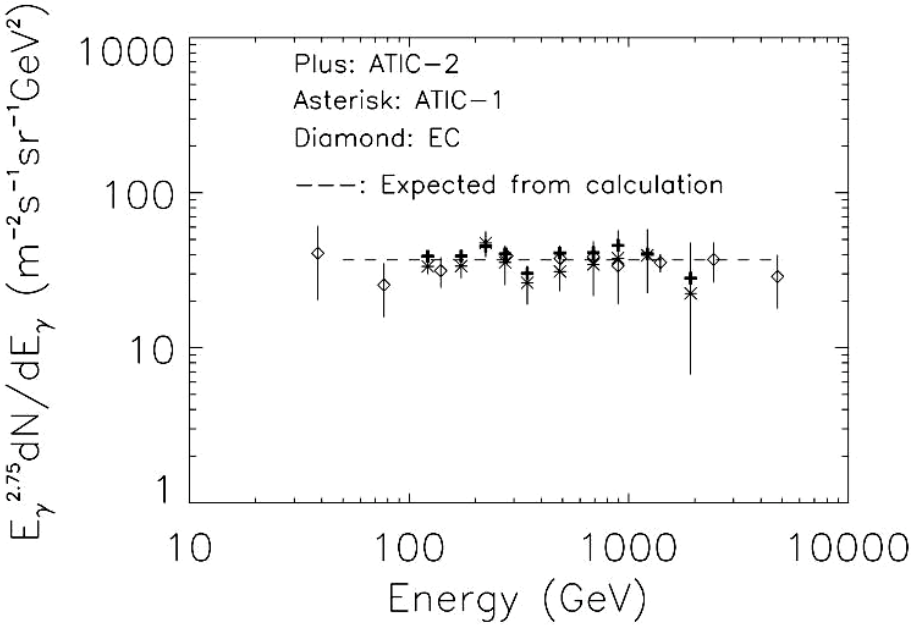
The ATIC electron results exhibit a feature

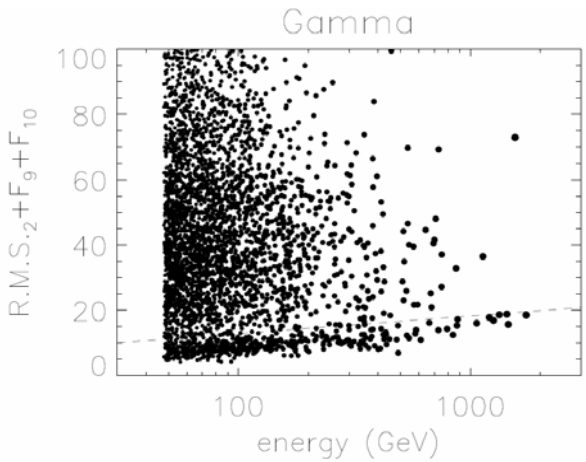
- Curves are from GALPROP diffusion propagation simulation
  - Solid curve is local interstellar space
  - Dashed curve is with solar modulation
- "Bump" at about 400 – 600 GeV
- Also seen by PPB-BETS

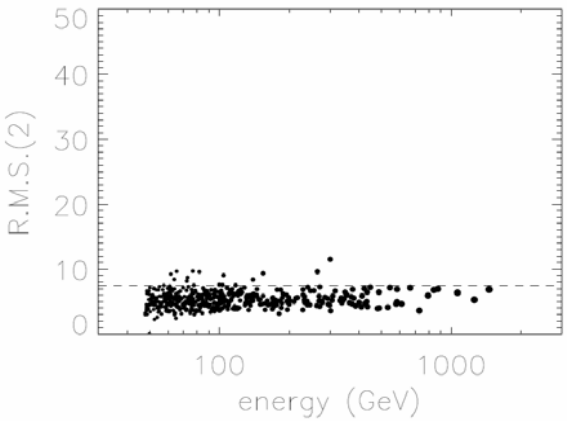


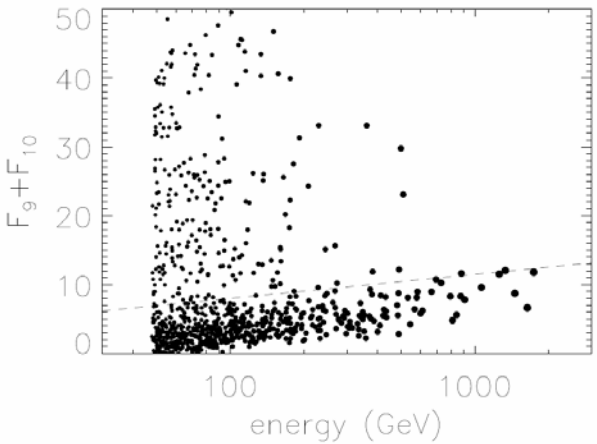
Electron measurement backgrounds

- **The effective proton rejection factor is actually closer to 1 in 46,000**
  - **Protons & electrons deposit energy in the calorimeter differently**
  - **A proton that deposits the same energy as an electron has about three times larger incident energy**
  - **Consequently there is a lower flux of protons mixed with the electrons**
- **The background of secondary electrons is a function of the balloon altitude**
  - **For an average altitude of 122,000 feet the electron background is about 2.7% at 100 GeV rising to about 12% at 1 TeV**
- Secondary gamma rays are also a function of the balloon altitude
  - Identified by requiring no "hit" in the silicon matrix
  - Misidentified gammas provide a background of only ~1% at 1 TeV
  - Flat spectrum agrees with calculations
- Identified gammas provide a method for checking the electron data analysis





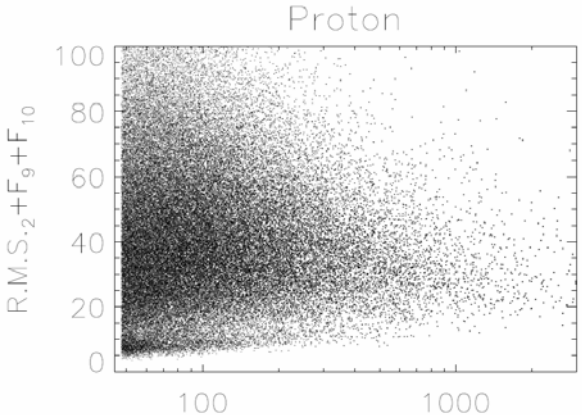


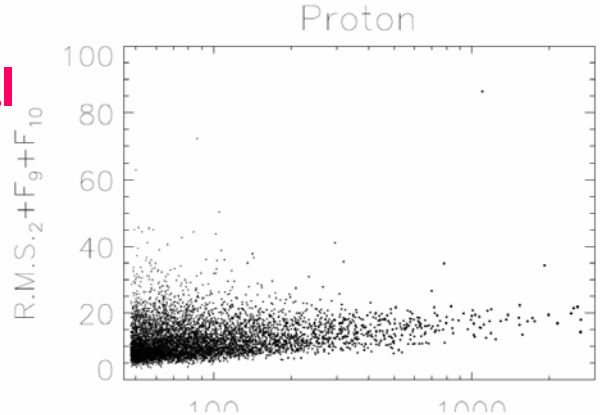


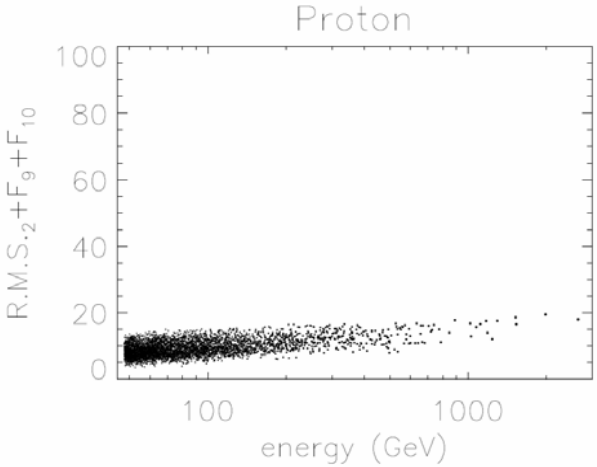
Left: Deriving data cuts from the Gamma-ray like events

Right: Applying the cuts to obtain the electron signal

The use of secondary gamma-rays provides an in-flight calibration for the analysis of the electron data, giving an analysis less dependent upon simulations and less prone to systematic uncertainties. At each step there is substantial agreement between the experimentally determined parameters and the results of the simulations, but the exact parameters to be used are determined from the flight data whenever possible.







The Extended ATIC Flight Program – ATIC-3 and ATIC-4

Increase the calorimeter depth by 25%

This was possible with the new launch vehicle which could support, on the snow, a larger launch weight.

In order to

Investigate the difference between the ATIC-1 and ATIC-2 spectra of H and He

Previous datasets analyzed via different trigger modes suggested a trigger efficiency effect in the data.

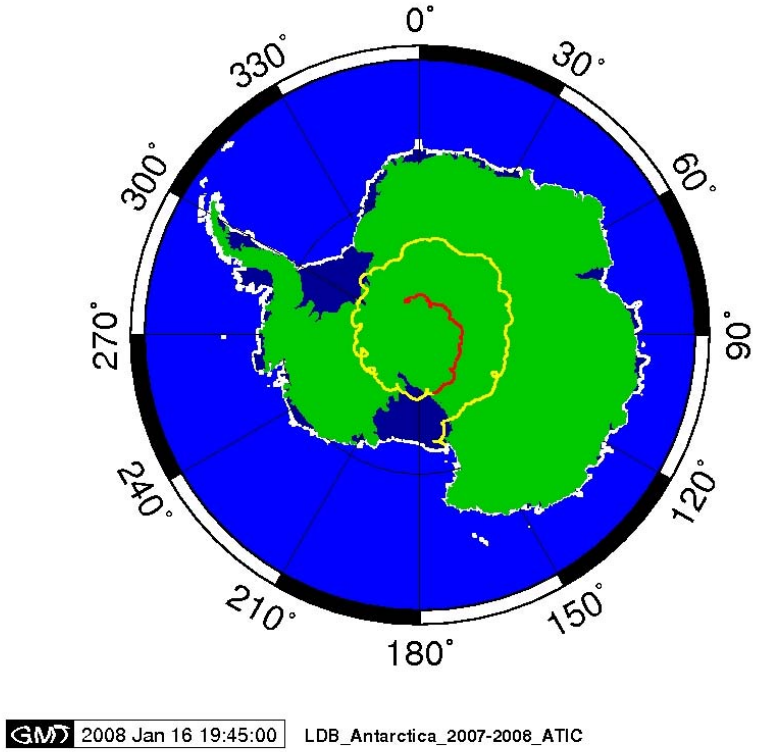
Confirm the previous ATIC-1 and -2 results on the electron spectrum

The ATIC-3 attempt ended in disaster!

- ATIC-3 was launched Dec. 19, 2005
- Balloon failure occurred almost immediately after launch
- Reached only 75,000 feet before starting down
- Had to quickly terminate as ATIC was headed out to sea
- Landed only 6 miles from edge of ice shelf

- The instrument was fully recovered instrument and refurbished in preparation for the 4th and final flight of ATIC in 2007.

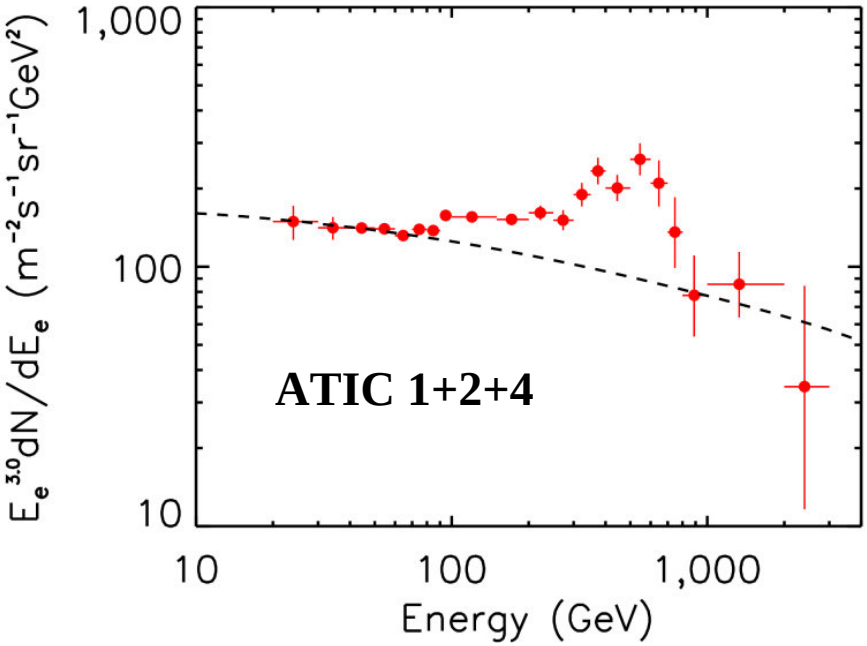
ATIC-4 Science Flight from McMurdo – 2007

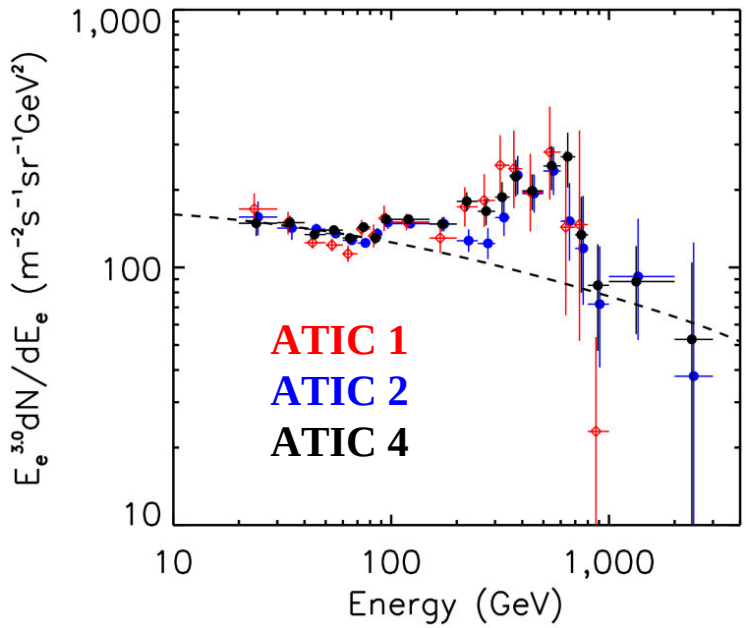


- Launch: 12/26/07 13:47 UTC
- Begin Science: 12/27/07 14:00 UTC
- End Science: 01/11/08 02:00 UTC
- Termination: 01/15/08 00:30 UTC
- Recovery: 2/1/08 from South Pole

- Obtained about **14 ½ days** of science data collection
- Lost pressure within gondola on 1/11/08
- The cause of this pressure loss is still a mystery

All three ATIC flights are consistent



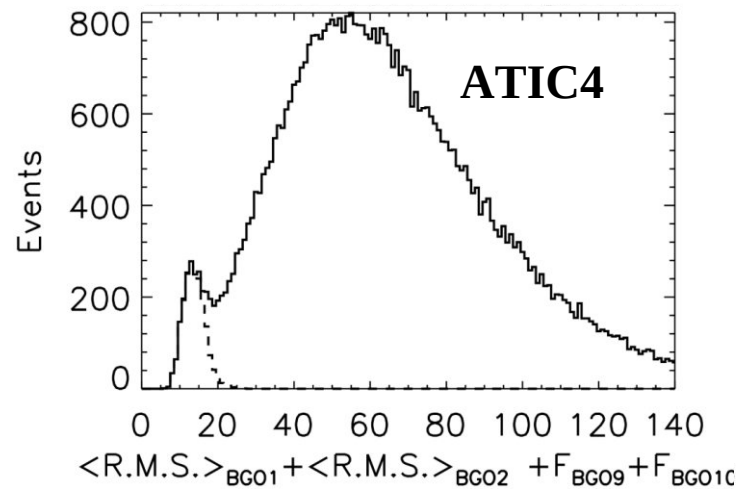


"Source on/source off" significance of bump for ATIC1+2 is about 3.8 sigma

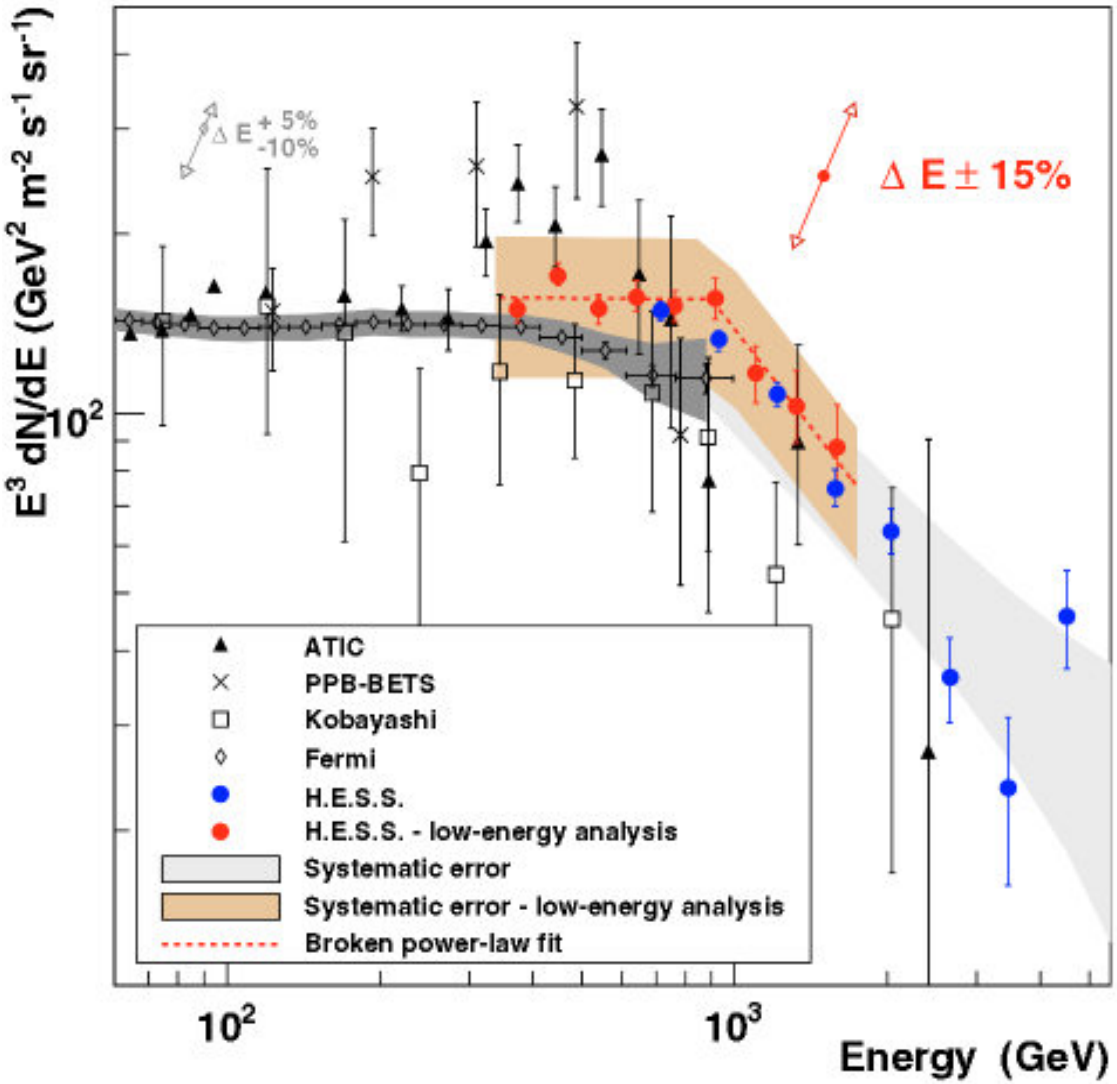
ATIC-4 with 10 BGO layers has improved e , p separation.

"Bump" is seen in all three flights.

Significance for ATIC1+2+4 is 5.1 sigma



ATIC, PPB-BETS, HESS and Fermi Results



Epilogue (Lessons Learned)

ATIC was a pioneering experiment in the use of ionization calorimetry on Long Duration Balloon flights and incorporated a number of new technologies, e.g. Si-martrix detector, Kevlar pressure shells, etc.

ATIC provided new results on the spectra of H, He and the primary heavy elements showing that these spectra are not all the same and are evolving with increasing energy.

ATIC was also able to separate electrons from protons and found a 'feature' in the electron spectrum in the 0.5 TeV energy region which implies a *Nearby source of electrons*.

ATIC demonstrated the power of ionization calorimetry, but learned that the calorimeter thickness (in radiation lengths) is all important.

Future work will use even deeper calorimeters – CALET.

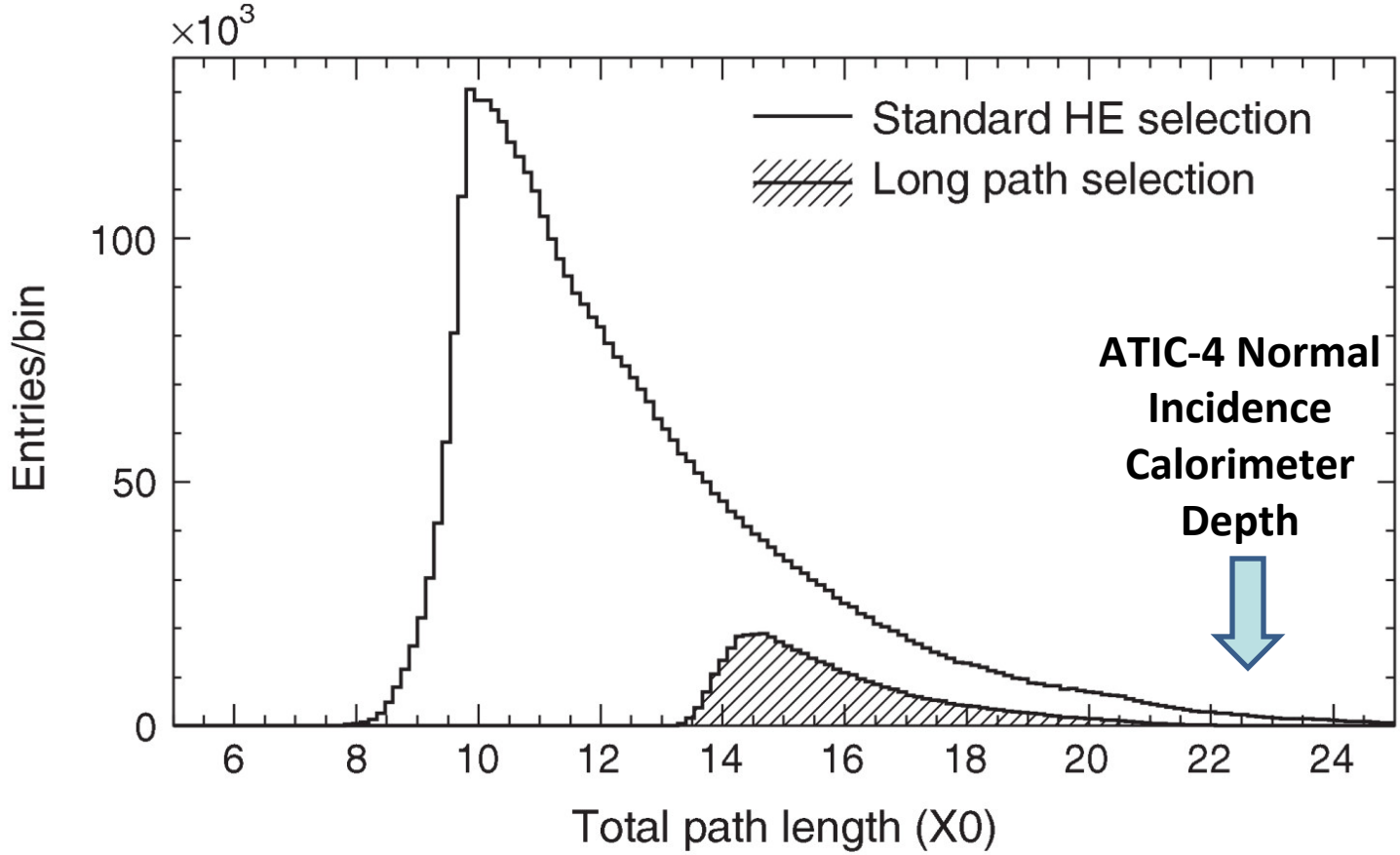


FIG. 15. Distribution of the amount of material traversed by the candidate electrons passing the long-path selection, compared with that for the entire data sample used in the standard analysis (the sharp edge at $\sim 10\ X_0$ in the latter reflects the total thickness of the instrument on-axis). Note the difference in the number of events.

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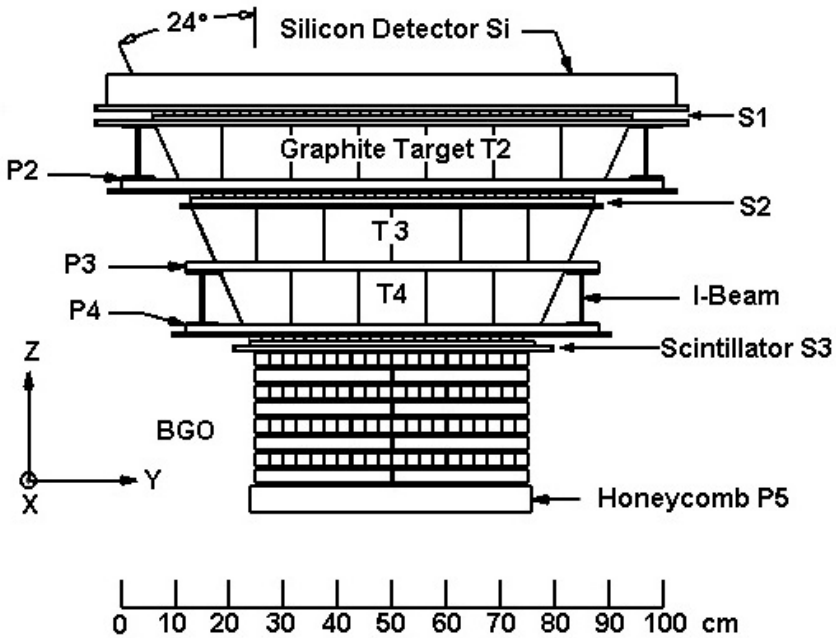
Acknowledgements

A special thanks to all of the people who worked to make ATIC a success, from the undergraduate students who built much of the electronics, to graduate students, postdocs and research associates who developed the subsystems, to the staff of the Technical Services group who fabricated most of the hardware and made it all 'play together'.

We are particularly indebted to NASA for its continuing support and the staff of the Columbia Scientific Balloon Facility without whom none of the flights would ever have happened – a great bunch to work with!

And, thank you to the organizers for inviting me to give this brief review.

ATIC Instrument Details



- **Si-Matrix:** 4480 pixels each 2 cm x 1.5 cm mounted on offset ladders; 0.95 m x 1.05 m area; 16 bit ADC; CR-1 ASIC's; sparsified readout.
- **Scintillators:** 3 x-y layers; 2 cm x 1 cm cross section; Bicron BC-408; Hamamatsu R5611 pmts both ends; two gain ranges; ACE ASIC. S1 – 336 channels; S2 – 280 channels; S3 – 192 channels; First level trigger: S1-S3
- **Calorimeter:** 8 layers (10 for ATIC-4); 2.5 cm x 2.5 cm x 25 cm BGO crystals, 40 per layer, each crystal viewed by R5611 pmt; three gain ranges; ACE ASIC; 960 channels (1200 for ATIC-4).

Data System: All data recorded on-board; 70 Gbyte disk (150 Gbyte for ATIC-3); LOS data rate – 330 kbps; TDRSS data rate – 4 kbps (6+ kbps for ATIC-4); Underflight capability (not used).

Housekeeping: Temperature, Pressure, Voltage, Current, Rates, Software Status, Disk status

Command Capability: Power on / off; Trigger type; Thresholds; Pre-scaler; Housekeeping frequency; LOS data rate, Reboot nodes; High Volt settings; Data collection on / off

Geometry Factors: S1-S3: 0.42 m^2sr; S1-S3-BGO 6: 0.24 m^2sr; S1-S3-BGO 8: 0.21 m^2sr

What are the cuts?

- RMS shower width in each BGO layer

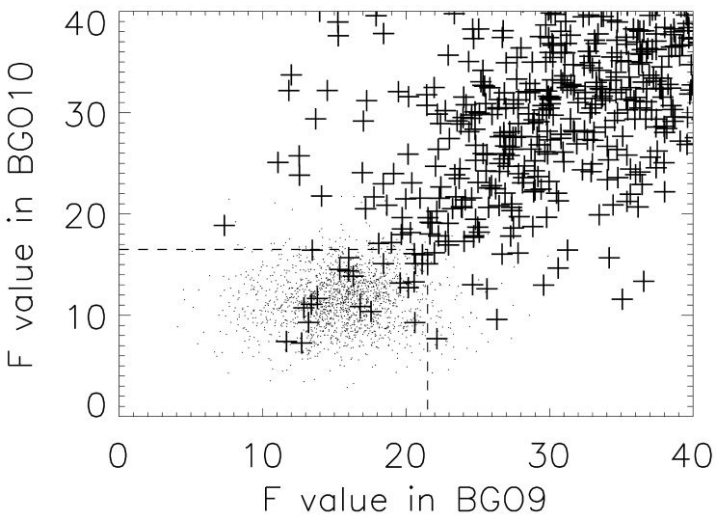
$$\langle r.m.s. \rangle^2 = \sum_{i=1}^{n} E_i (X_i - X_C)^2 / \sum_{i=1}^{n} E_i$$

- Weighted fraction of energy deposited in each BGO layer in the calorimeter

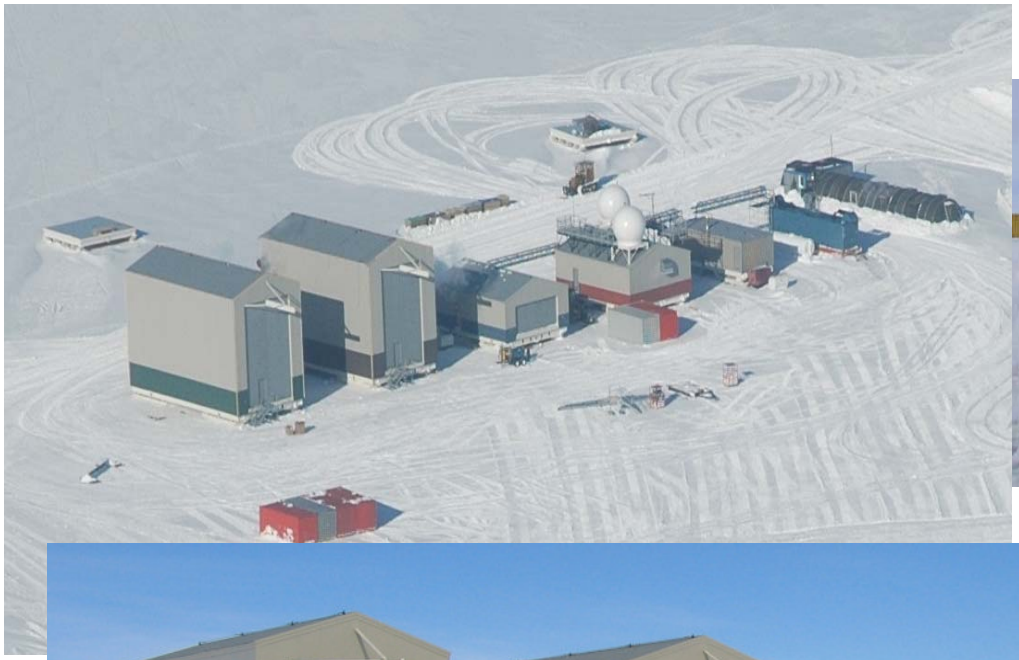
$$F_j = \langle r.m.s. \rangle^2 \left[E_j / \sum_{i=1}^{n} E_i \right]$$

Combine shower characteristics into a single parameter

- Shower lateral spread is calculated as $(r.m.s.)^2 = \sum_{i=1}^{n} E_i \left(x_i - x_c\right)^2 / \sum_{i=1}^{n} E_i$
  - › $\boldsymbol{X_c}$ is coordinate of energy center; $\boldsymbol{X_i}$ is coordinate of crystal "i" center; $\boldsymbol{E_i}$ is energy deposit in crystal "i"
- Energy fraction, *Ef(k)*, is calculated as $Ef(k) = Ed_k / \sum_{j=1}^{m} Ed_j$
  - › $\boldsymbol{Ed_k}$ is total energy deposit in the $\boldsymbol{k^{th}}$ layer of the calorimeter and there are a total of ***m*** layers.
- The F-value for calorimeter layer k is then $F(k) = Ef(k) * (r.m.s.)^2$
- Plotting the F-value for two BGO layers allows protons & electrons to be well separated.
- Reject all but 1 in 5000 protons while keeping 84% of the electrons



The current Antarctic LDB facility became operational in 2005



Flight Preparations