Observations of High Energy Cosmic Ray Electrons by the ATIC Balloon Experiment

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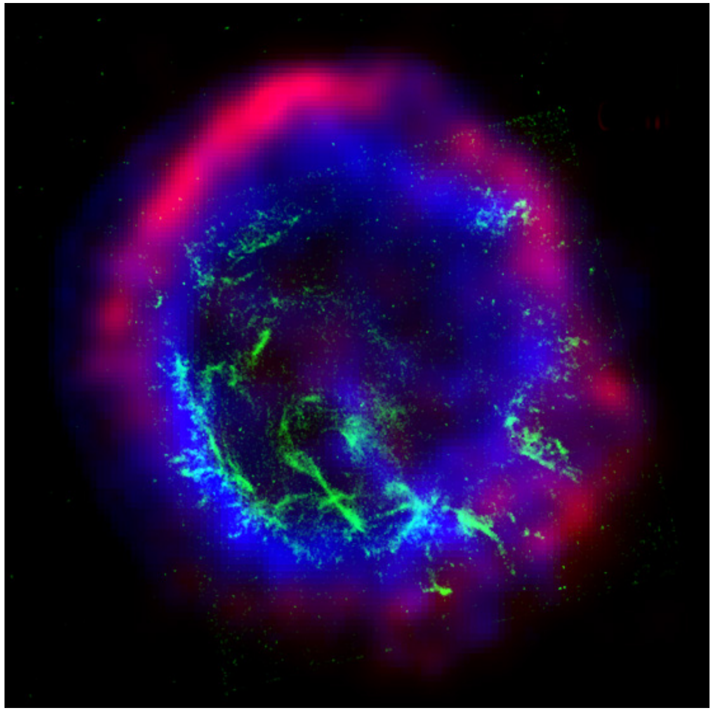
Cosmic Ray Research:
Determines Composition and Energy of Cosmic Rays to understand the "Cosmic Accelerator". Method: Measure Cosmic ray composition and spectrum and propagate back to source composition

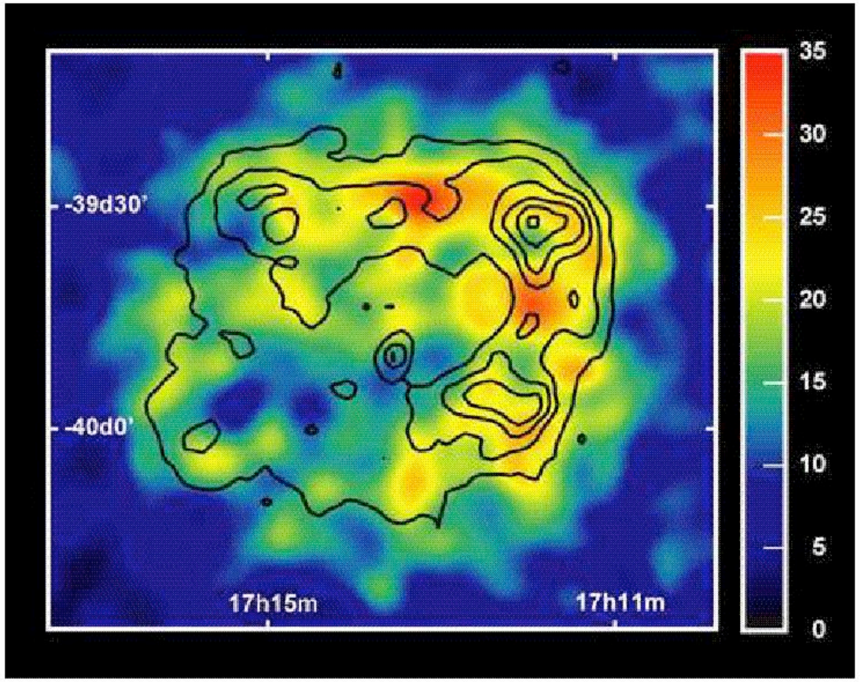
Potential Source candidates: Super Novas, Super Nova Remnants, Pulsars, Microquasars, Dark matter decay?, …..

Color-composite image of E0102-72.3: Radio from ATCA; X-ray from Chandra and Visible from HST.

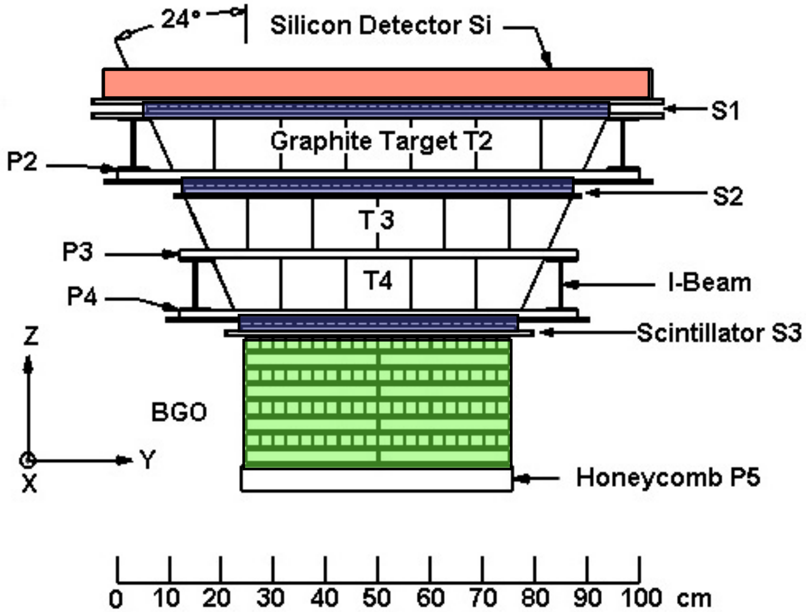


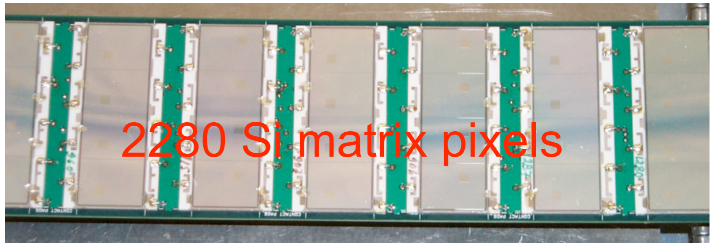
HESS image of RX J1713.7-3946

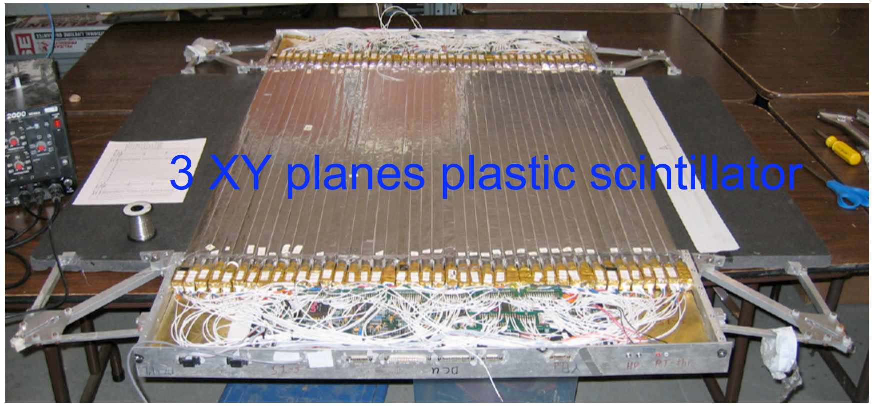
TeV gamma rays



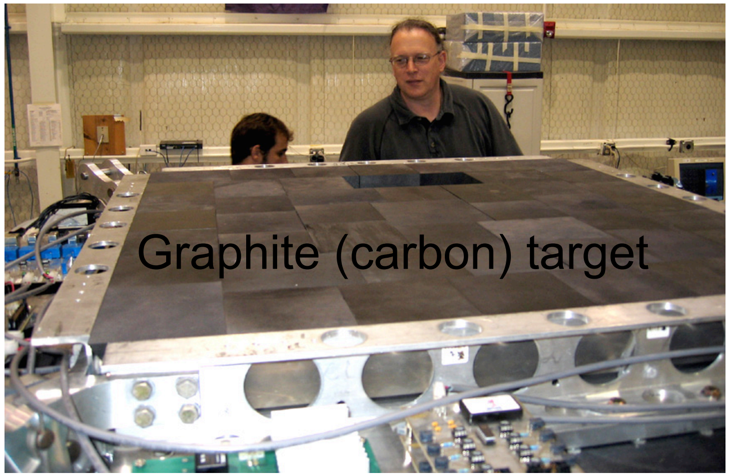
The ATIC Instrument



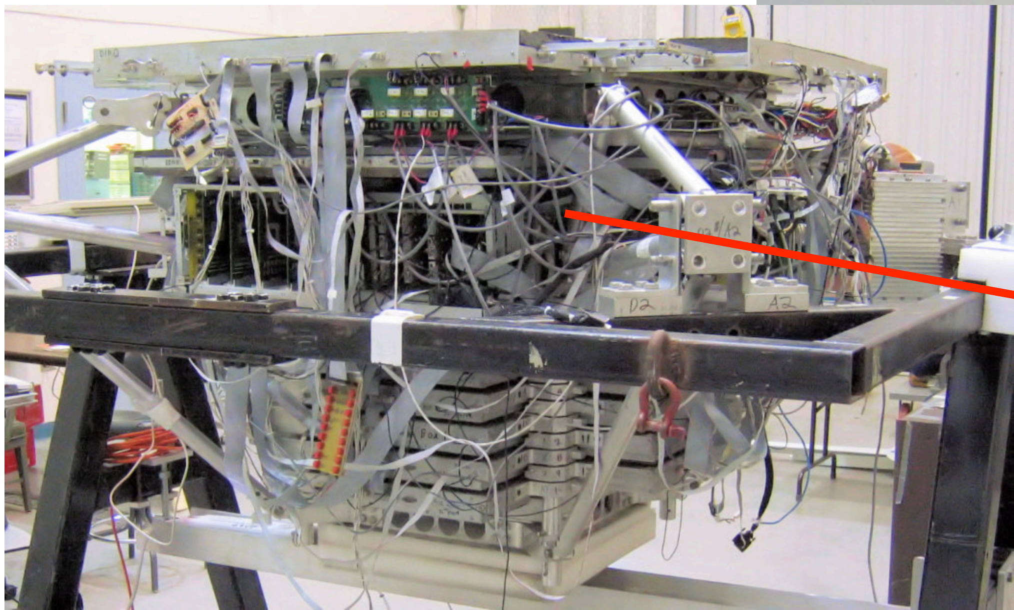


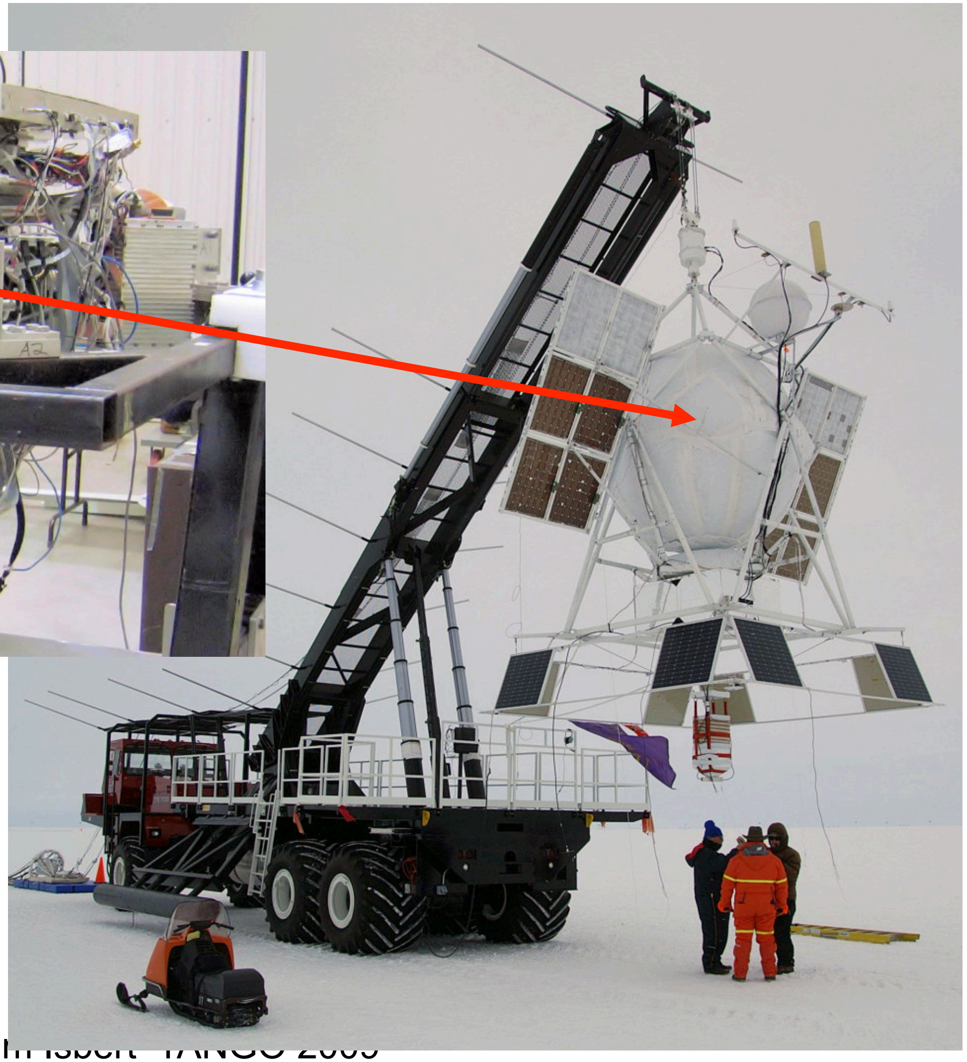


BGO calorimeter,
17.3 rl, 4 XY,
planes, ATIC 1+2,
22.5 rl, 5 XY
planes, ATIC 4

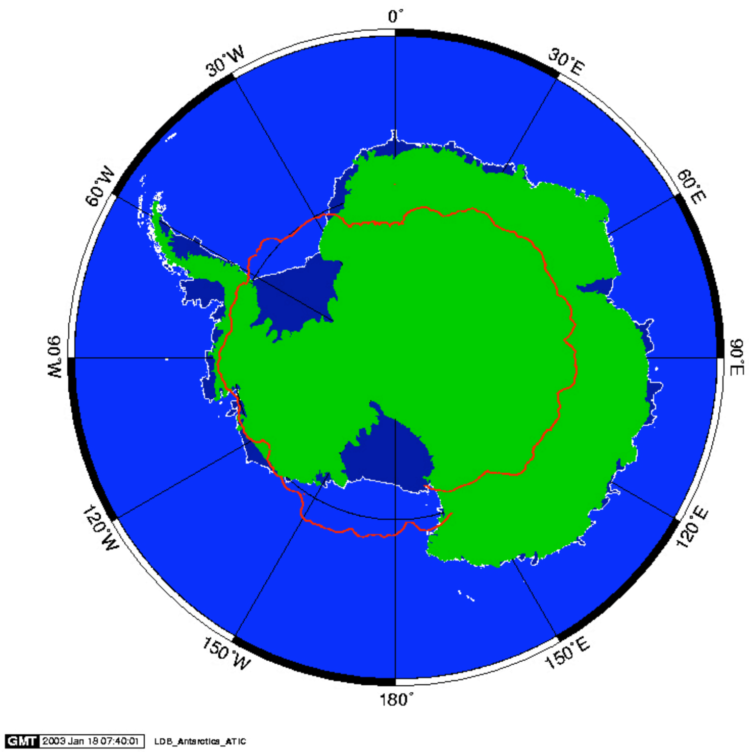


ATIC was constructed as a balloon payload



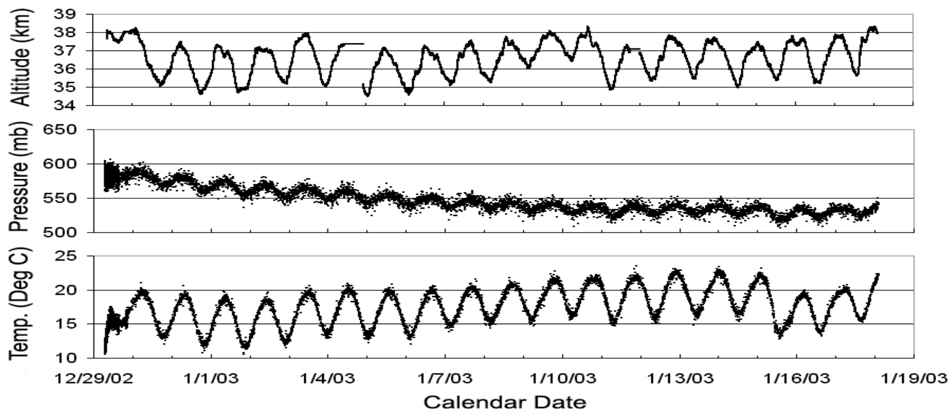


ATIC-2 Science Flight from McMurdo - 2002



- 65 Gbytes Recorded Data
- 16,900,000 Cosmic Ray events
- High Energy Trigger > 75 GeV for protons
- >96% Live-time
- 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

- 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



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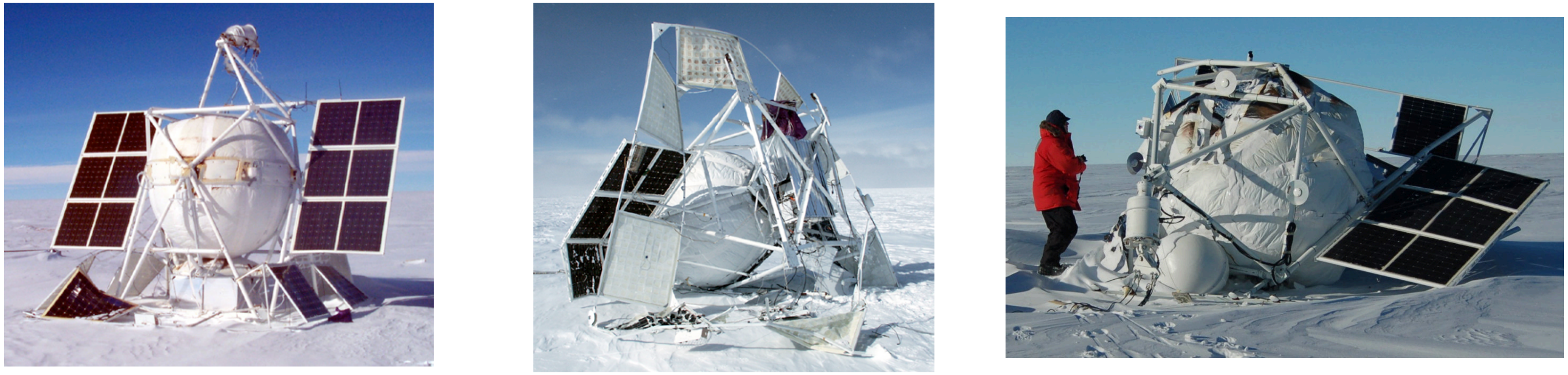
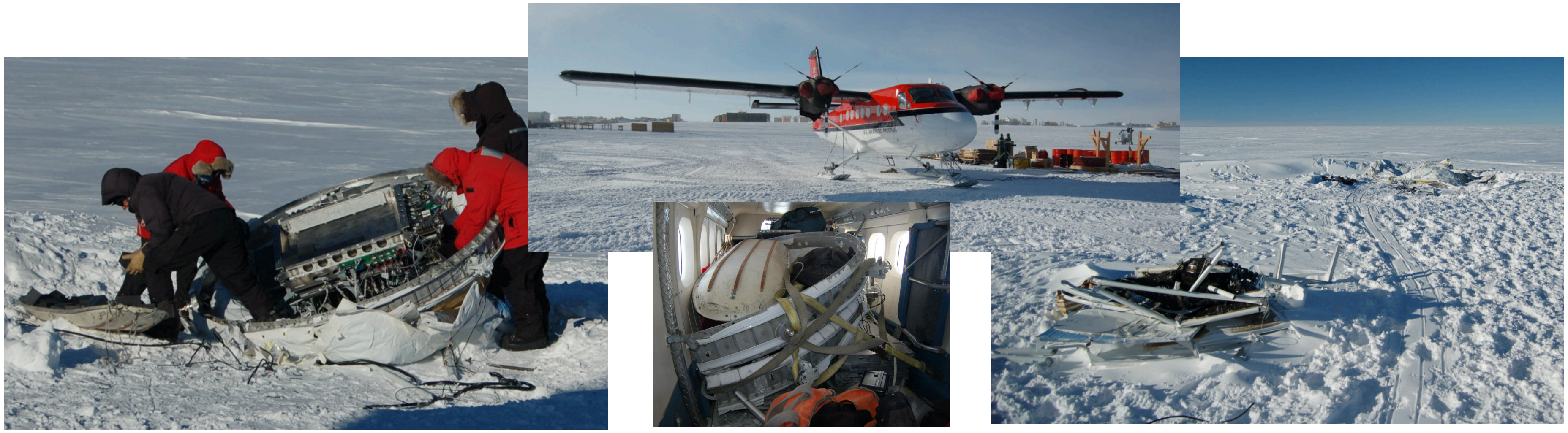
Recovery expeditions to the plateau



The good ATIC-1 landing (left) and the not so good landings of ATIC-2 (middle) and ATIC-4 (right)



ATIC is designed to be disassembled in the field and recovered with Twin Otters. Two recovery flights are necessary to return all the ATIC components. Pictures show recovery flight of ATIC-4

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How are electrons measured?

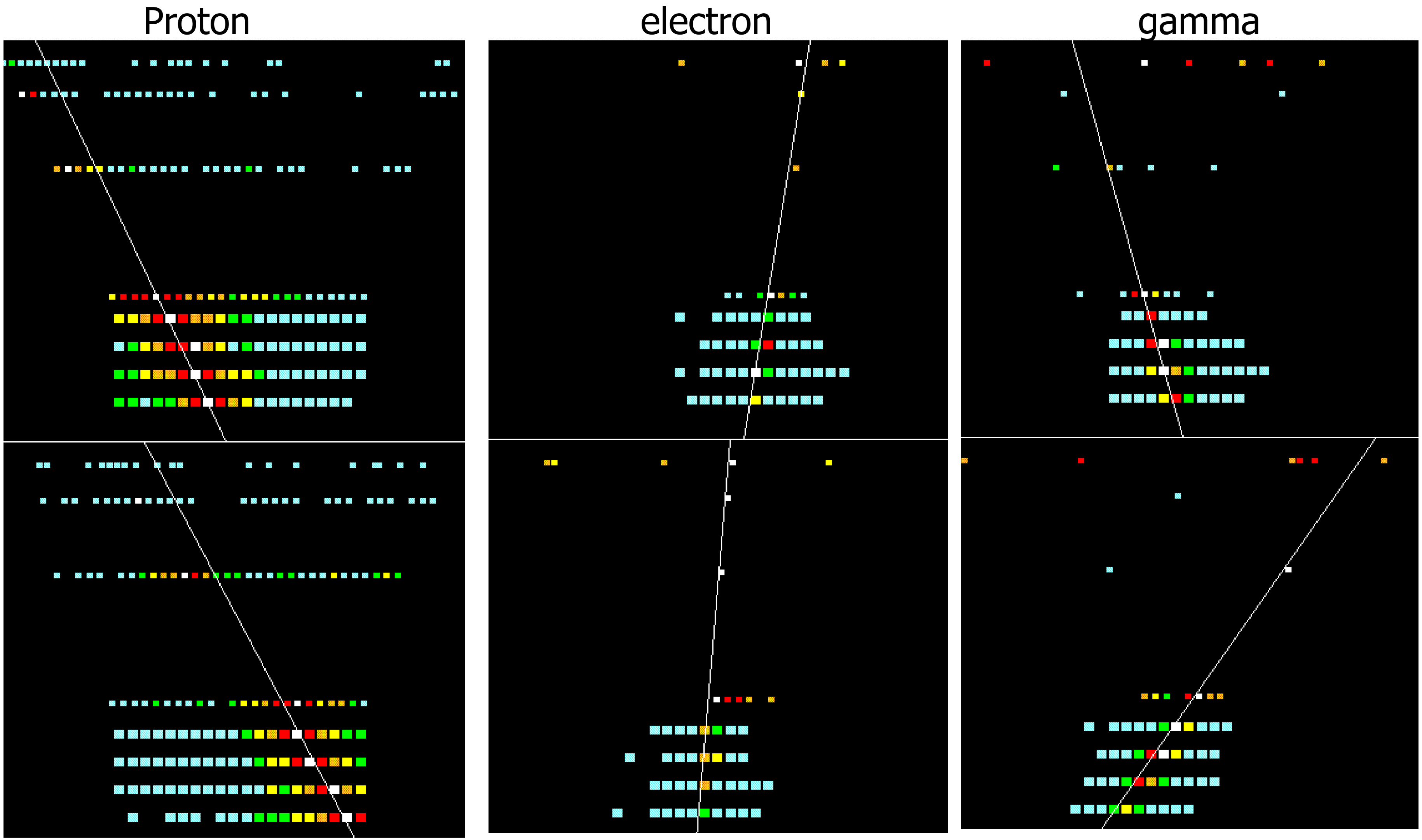
- Silicon matrix identifies charge
- Calorimeter energy resolution= ±2%, Key for identifying spectral features
- Key issue: Separating protons and electrons
  - Use interactions in the target
    - 78% of electrons and 53% of protons interact
  - Energy deposited in the calorimeter helps:
    - Electrons 85%; Protons 35% $\Rightarrow E_p = 2.4XE_e$
    - Reduces proton flux by X0.23
  - Combined reduction is X0.15, then
  - Examine shower longitudinal and transverse profile

p,e, γ Shower image in ATIC (from Flight data)

Energy deposit in BGO ~ 250 GeV

Electron and gamma-ray showers are narrower than proton showers

Gamma shower: No signal in the Si matrix detectors around shower axis



Parameters for Shower analysis

- 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

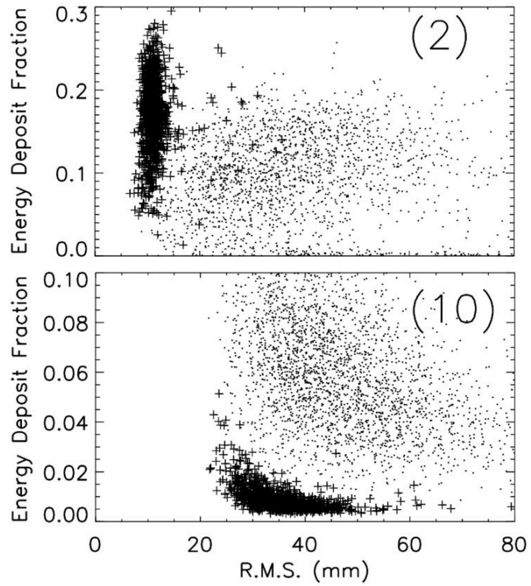
$$F_j = \langle r.m.s.\rangle^2 \left[E_j / \sum_{i=1}^{n} E_i \right]$$

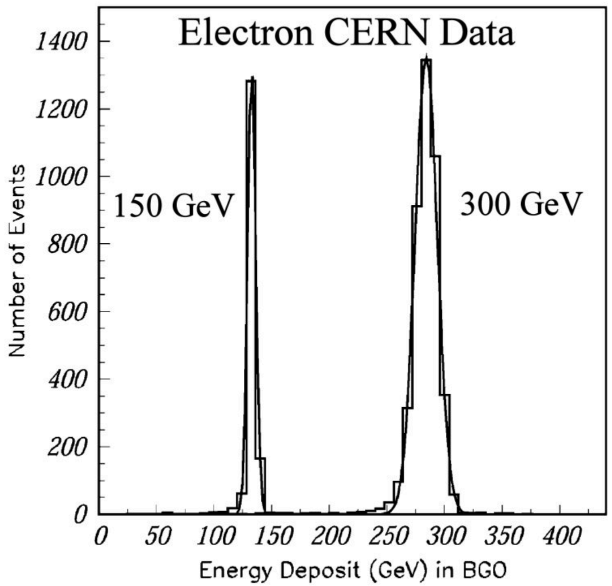
Instrument calibrations at CERN used to verify the Instrument performance and validate Simulations

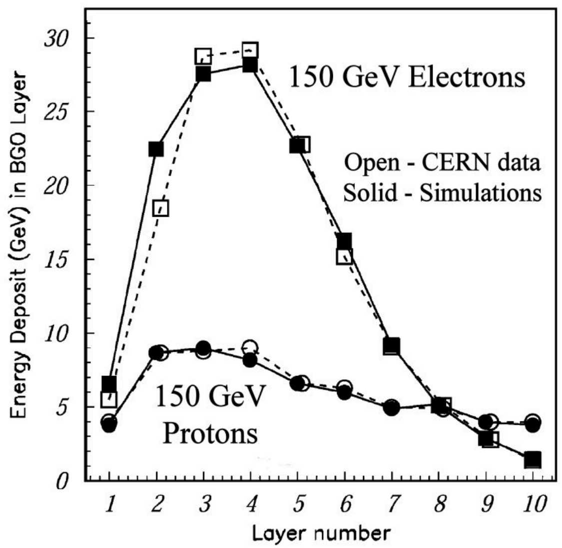
- Used CERN instrument calibration with 150 GeV electrons and 375 GeV protons to validate electron analysis and evaluate the proton contamination.

- CERN data also used to investigate instrument response, energy resolution & check simulations

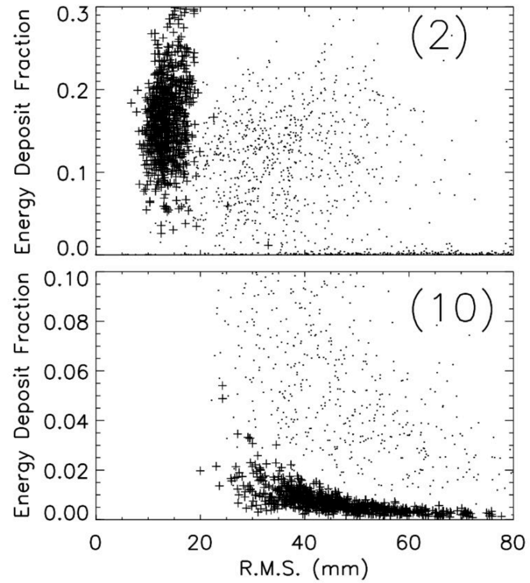
CERN Data







Simulations



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The method to select electron events:

1. Rebuild the shower image, get the shower axis, and get the charge from the Si-matrix detector:

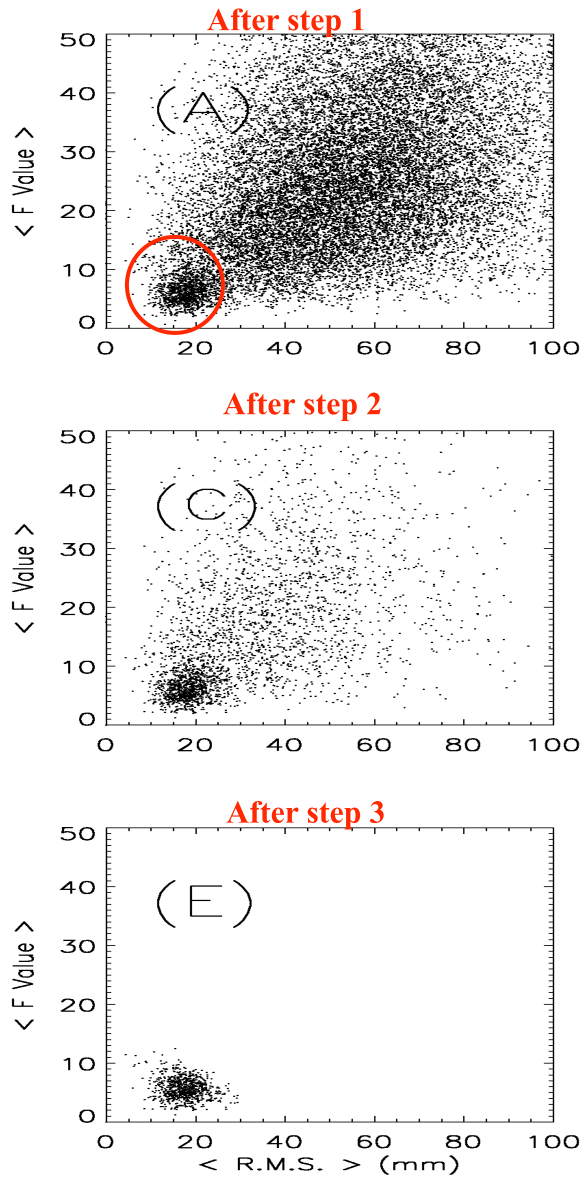
0.8<Z<1.6,   E>50GeV, χ^2<1.5, good geometry

2. Shower axis analysis

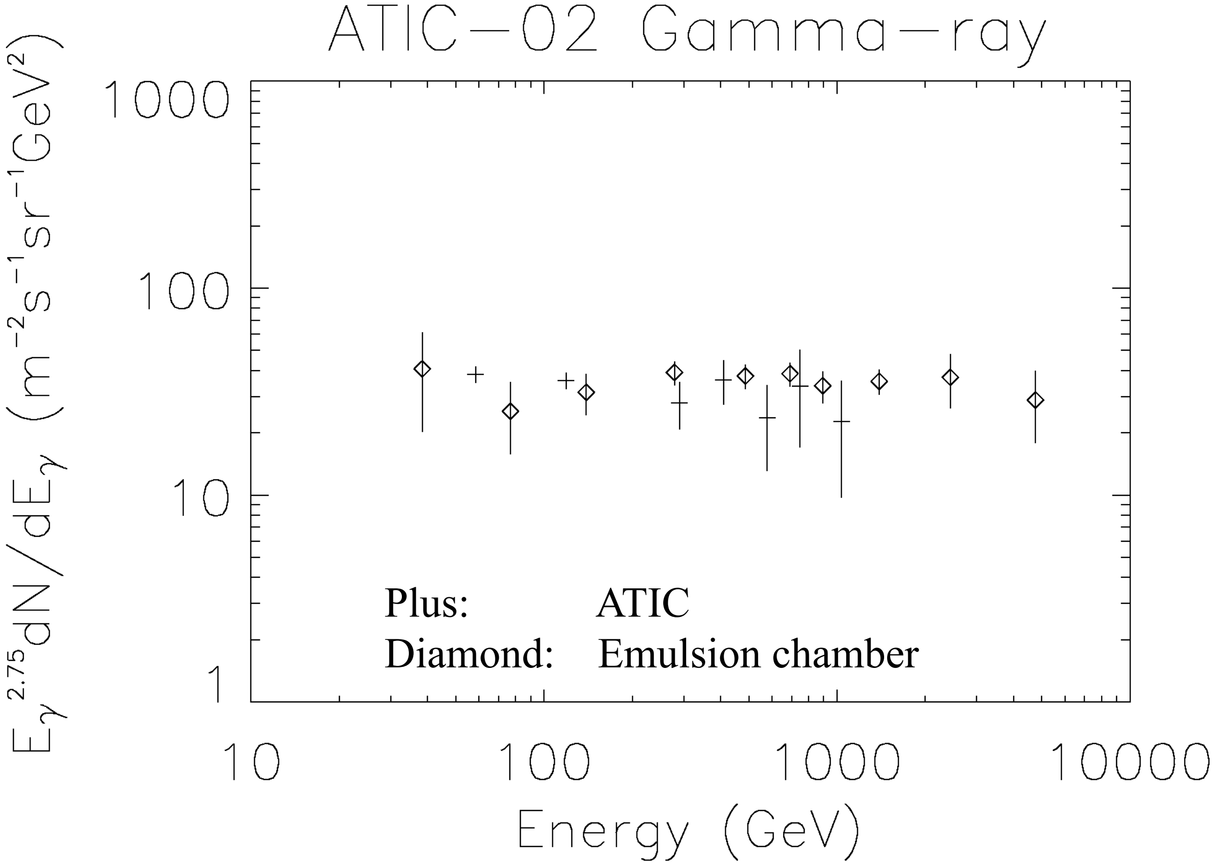
Reject Protons which have their first interaction point in carbon

3. Shower width analysis:

Cut F values for BGO1, BGO2 and BGO7, BGO8



Atmospheric Gamma-rays:
Test of the electron selection method

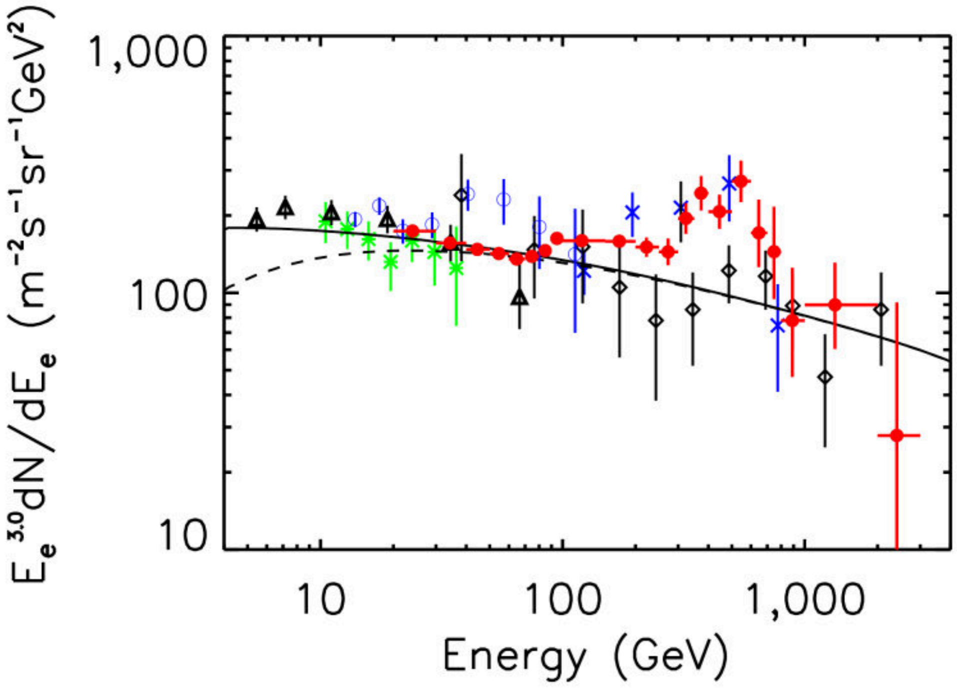


Reject all but 1 in 5000 protons

Retain 85% of all electrons

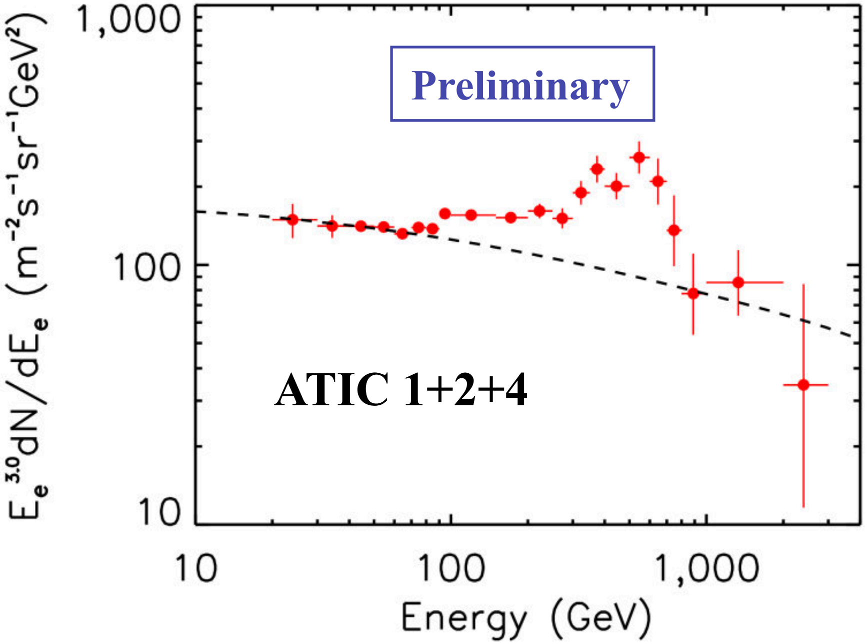
The ATIC electron results exhibits a "feature"

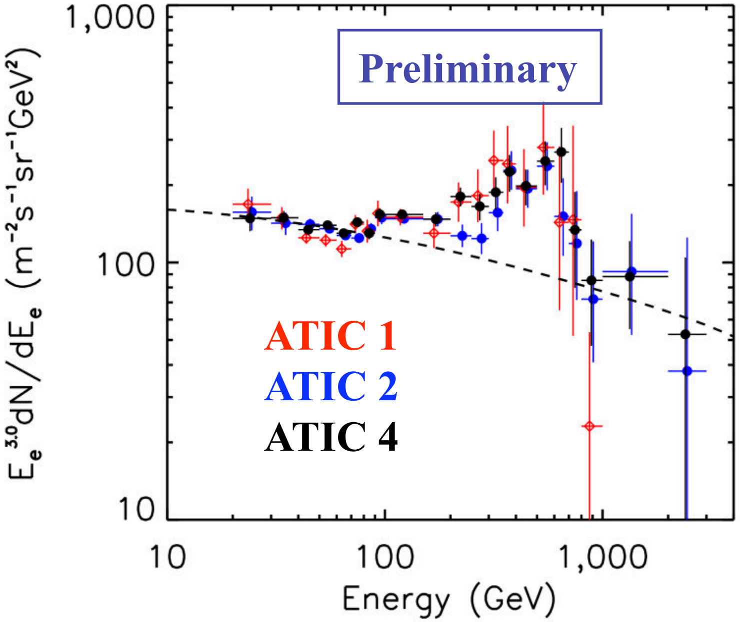
- Sum of data from both ATIC 1 and ATIC 2 flights
- Curves are from GALPROP diffusion propagation simulation
  - Solid curve is local interstellar space
  - Dashed curve is with solar modulation
- Spectral index is -3.23 for below ~ 100 GeV
- "Feature" at about 300 – 800 GeV
- Significance is about 3.8 sigma
- Also seen by PPB-BETS
- Emulsion chamber data is currently being re-analyzed



ATIC 1+2, Alpha Magnetic Spectrometer, HEAT magnetic spectrometer, BETS, PPB-BETS, Emulsion chambers

All three ATIC flights are consistent



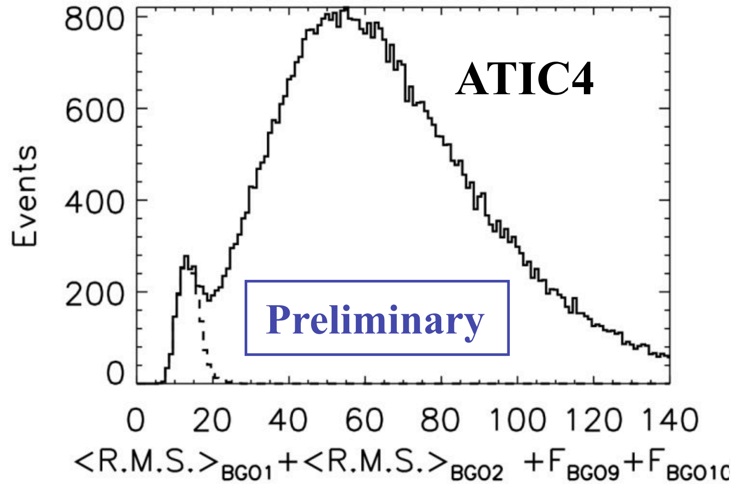


“Source on/source off” significance of bump for ATIC1+2 is about 3.8 sigma

ATIC-4 with 10 BGO layers has improved e , p separation. **(~4x lower background)**

“Bump” is seen in all three flights.

Significance for ATIC1+2+4 is 5.1 sigma



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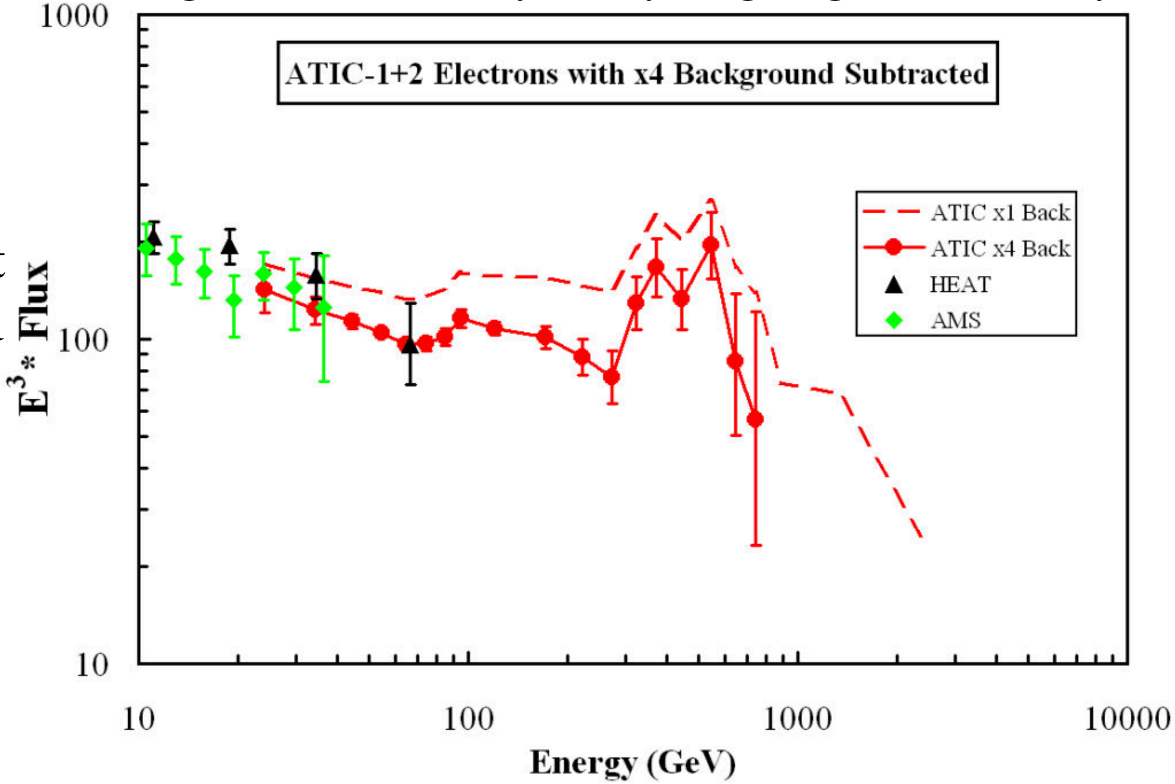
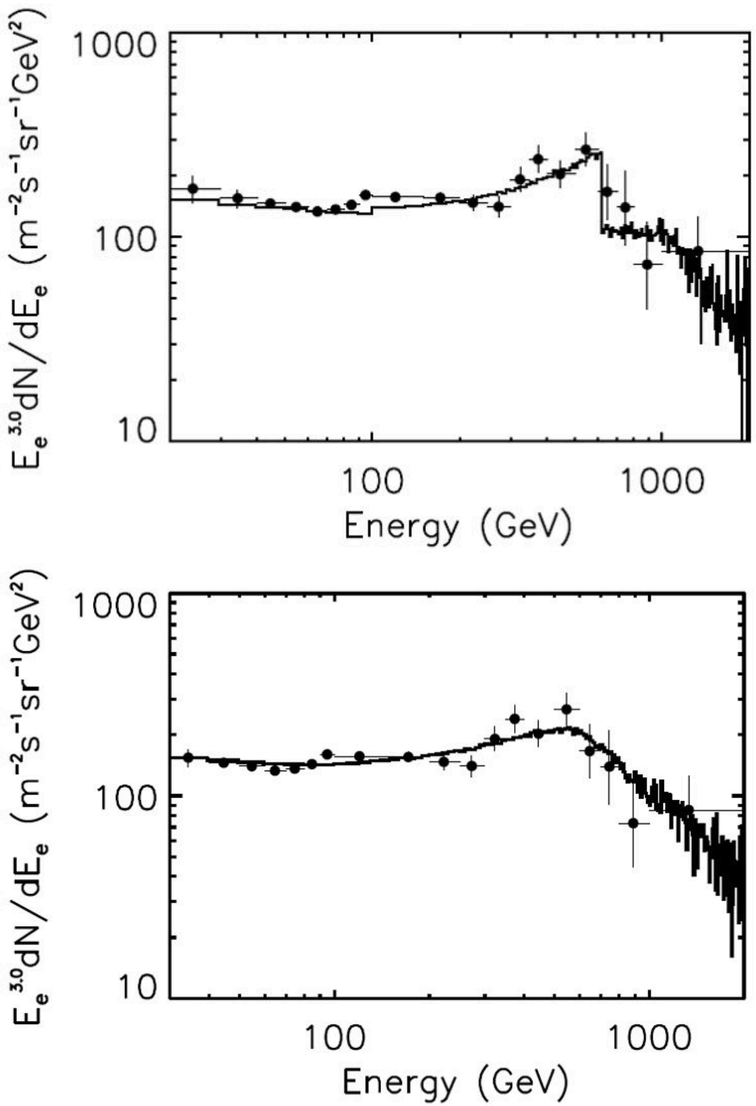
The effect of background subtraction

- Background includes secondary e^- as well as misidentified protons and secondary gamma rays.
- Secondary e-, γ from well established calculations (e.g. Nishimura et al., 1980)
- Proton contamination was studied using CERN data, by analyzing flight secondary γ and from simulations.
- Assume proton background is 4 times higher than estimated
- Electron spectrum is lower but still consistent with HEAT and AMS.
- Spectrum for energies < 250 GeV is steeper.
- Feature at 300 GeV to 800 GeV is still present but larger error bars at high energy edge.



The effect of the energy resolution on the feature

- The ATIC 22 X_o BGO calorimeter essentially fully contains the electron shower and provides an energy resolution of a few %.
- A spectrum with an index of -3.1 up to 1 TeV followed by a softer spectrum of index -4.5
- Add a power law spectrum component with an index of -1.5 and a cutoff at 620 GeV
- Reduce energy resolution to 15%. Features are broadened, peak value is decreased and spectrum appears to have an index of ~-2.9
- Reduce energy resolution to 25%. Features are almost "flattened" and spectrum appears to have an index of ~-3.0



Conclusions

- The ATIC excess is determined with high energy resolution and high background rejection, relying mostly on direct measurements and a minimum simulations.
- The ATIC and PAMELA results taken together could point to a nearby source of electrons <u>and positrons</u>, possibly from dark matter annihilation
- A measurement with high energy resolution of the positron or electron contend in the feature is needed to identify possible sources.