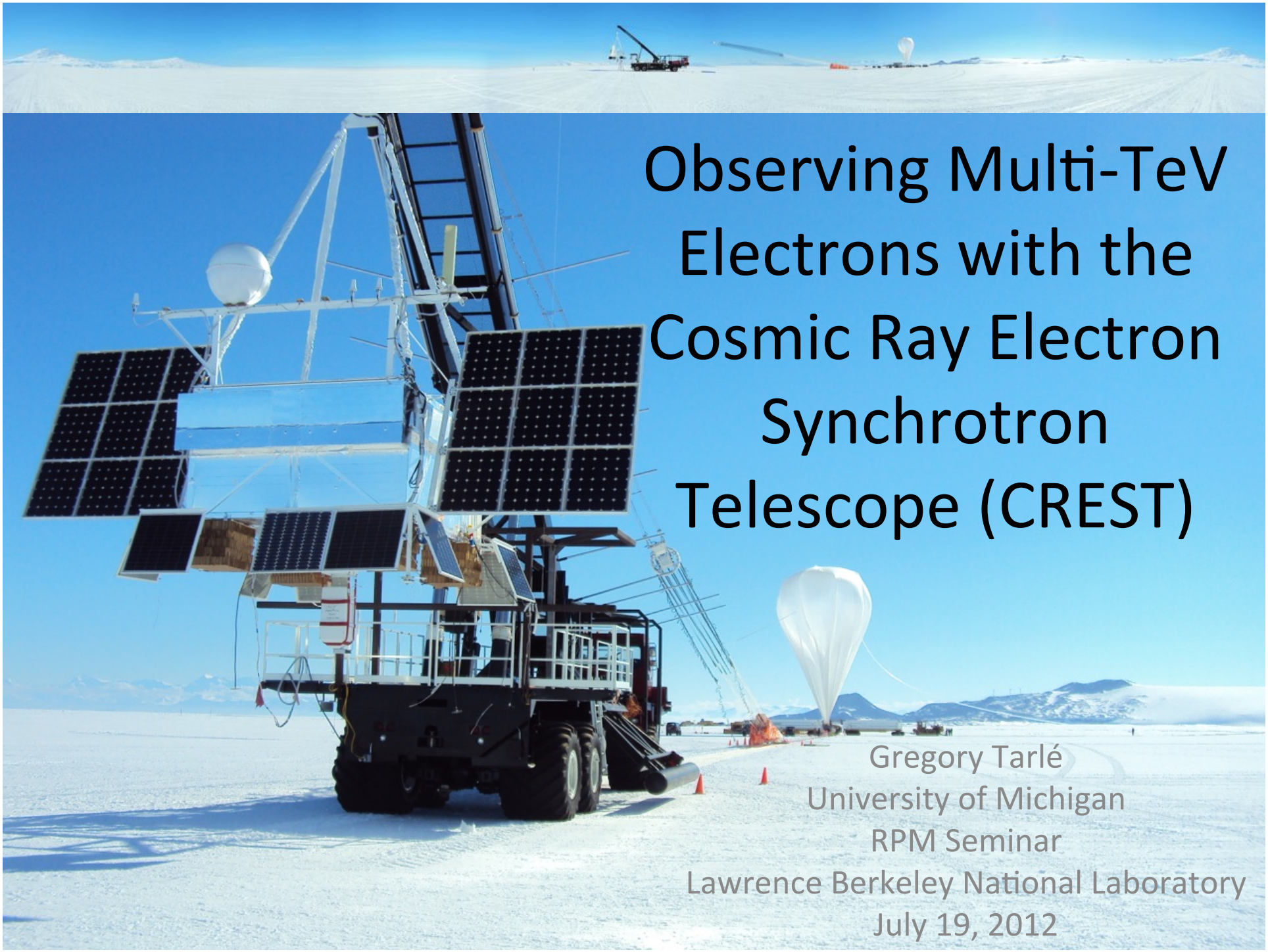
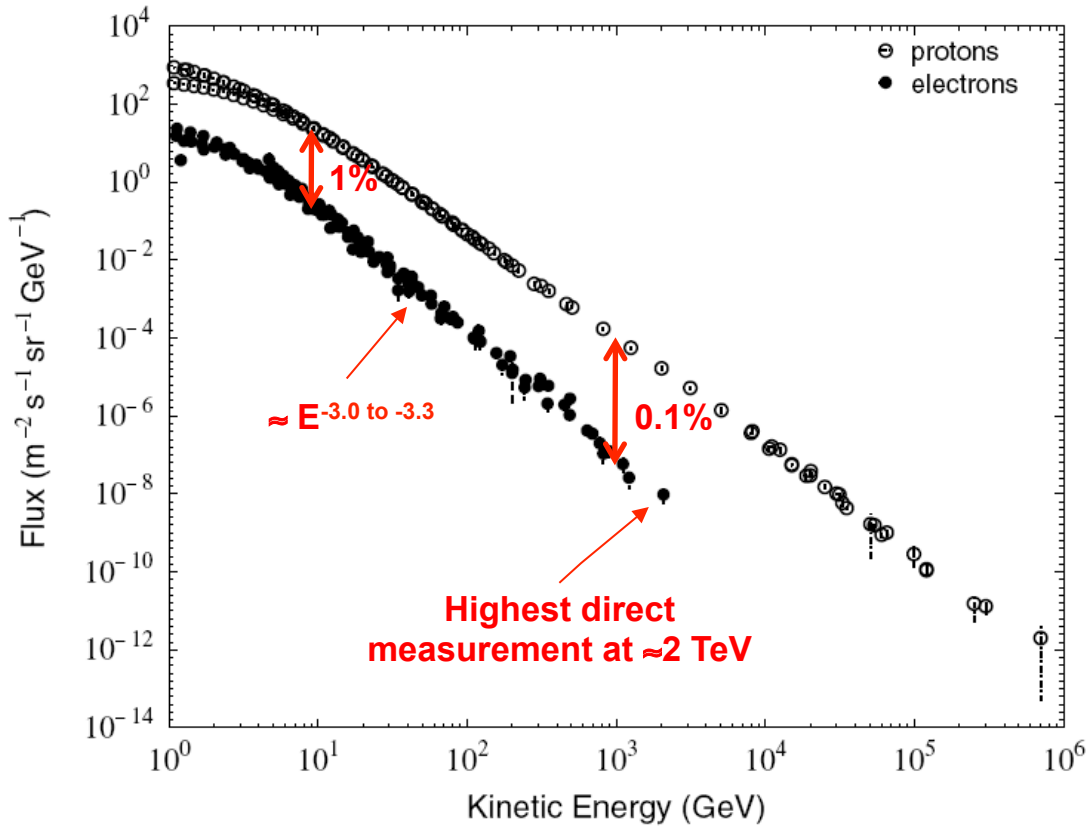


Observing Multi-TeV Electrons with the Cosmic Ray Electron Synchrotron Telescope (CREST)

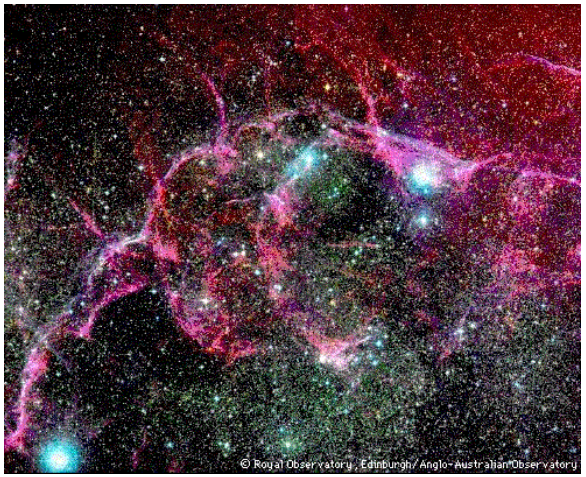
Gregory Tarlé
University of Michigan
RPM Seminar
Lawrence Berkeley National Laboratory
July 19, 2012

Cosmic-Ray Electrons



Yoshida – Adv. Sp. Res. 42, 477 (2008)

- Energy loss of electrons more rapid (~E^2) than for protons; inverse Compton (interstellar photons), synchrotron (~ 1μG interstellar fields). Explains softer spectrum for electrons.
- TeV electron horizon ~1 kpc (10^5 yr propagation);
- TeV sources are local (e.g., SNRs: Vela 250 pc, Cygnus Loop 460pc, Monogem 300 pc).



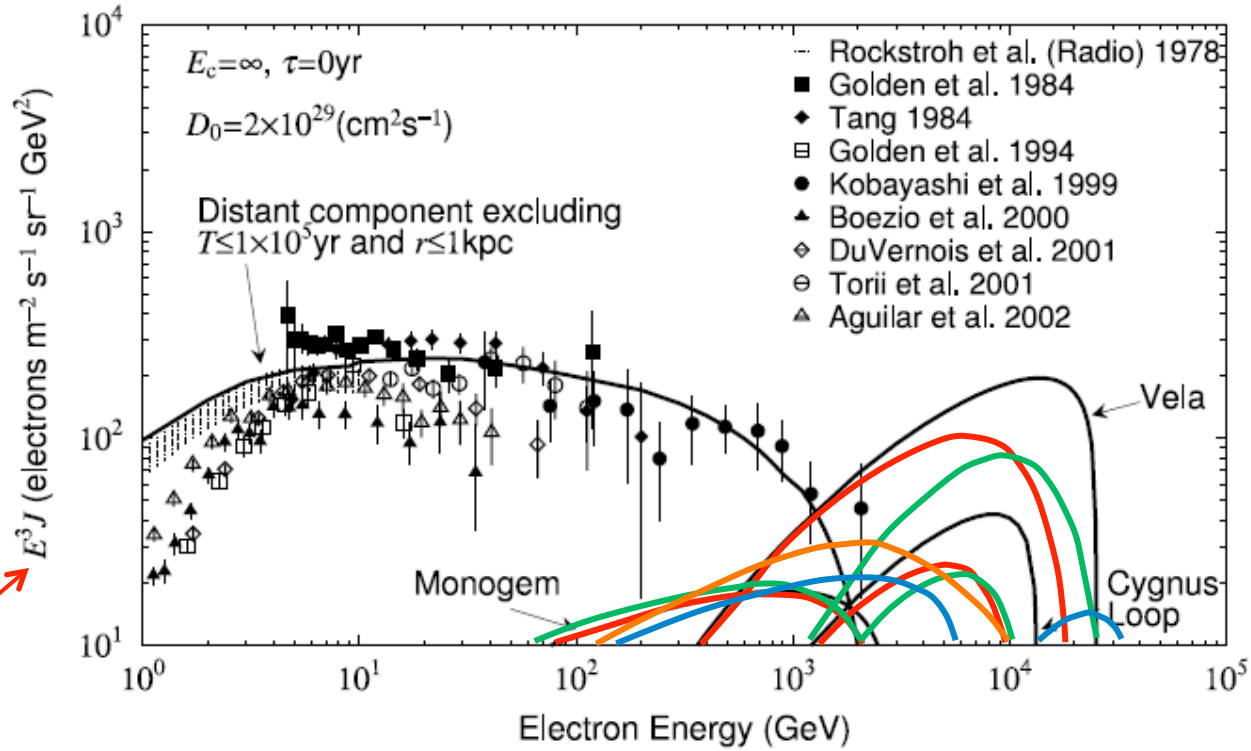
Vela SNR

Measurements and Predictions

At Earth expect contributions from:
- distant accelerators;
- nearby SNRs;
- secondaries;
- exotics?

Contribution from SNRs depends on:
- diffusion coefficient D_0
- release time τ
- energy cutoff E_c

Kobayashi. *Ap J.* 601, 340 (2004)



Note rescaling by E^3

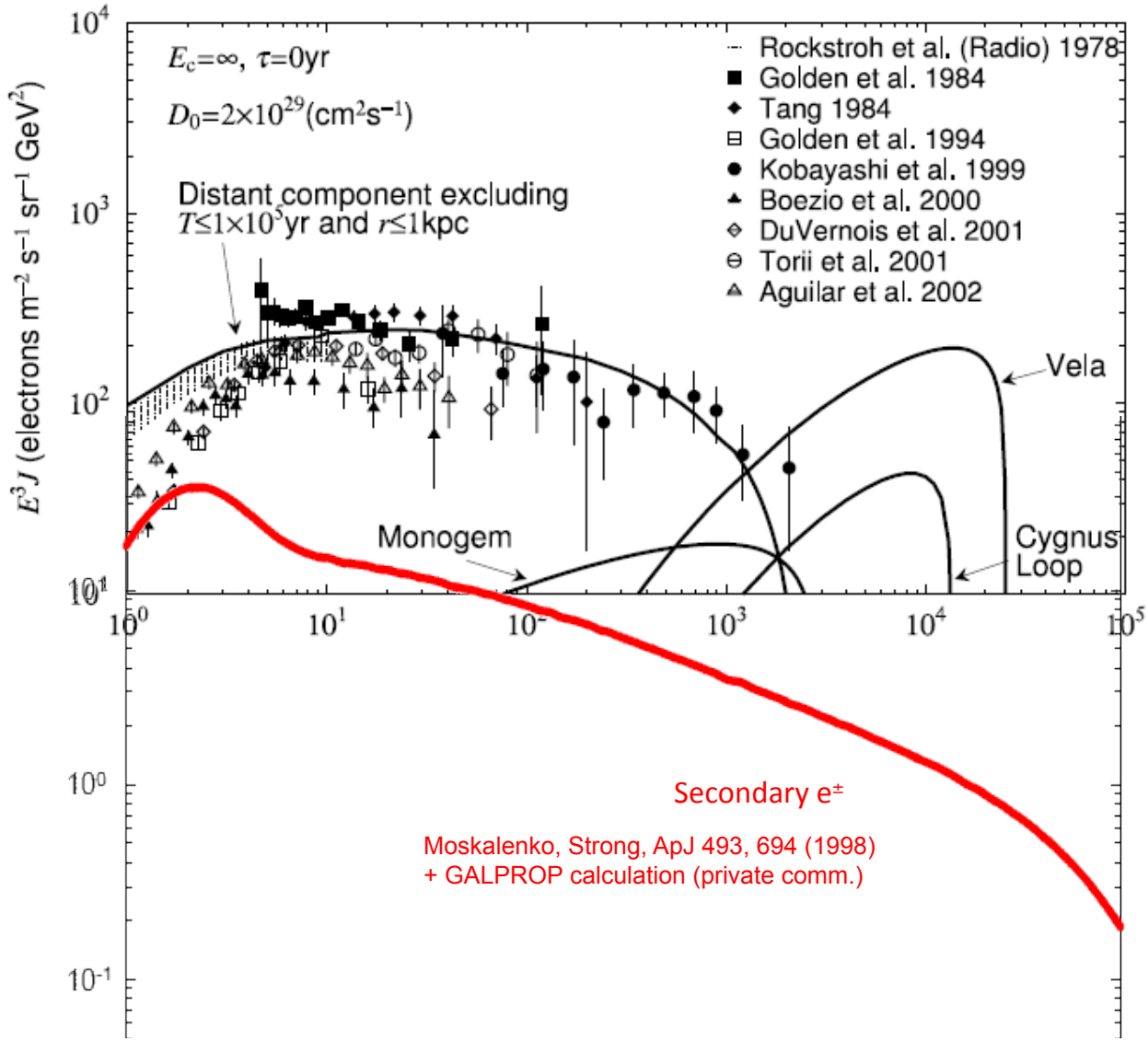
E_c = 20 TeV, τ = 0 yr, D_0 = 2×10^{29} cm^2/s
E_c = 20 TeV, τ = 5000 yr, D_0 = 2×10^{29} cm^2/s
E_c = 20 TeV, τ = 10^4 yr, D_0 = 2×10^{29} cm^2/s
E_c = 20 TeV, τ = 0-1×10^5 yr, D_0 = 2×10^{29} cm^2/s

Plenty of parameter space for exploration;

TeV range can reveal features of nearby sources.

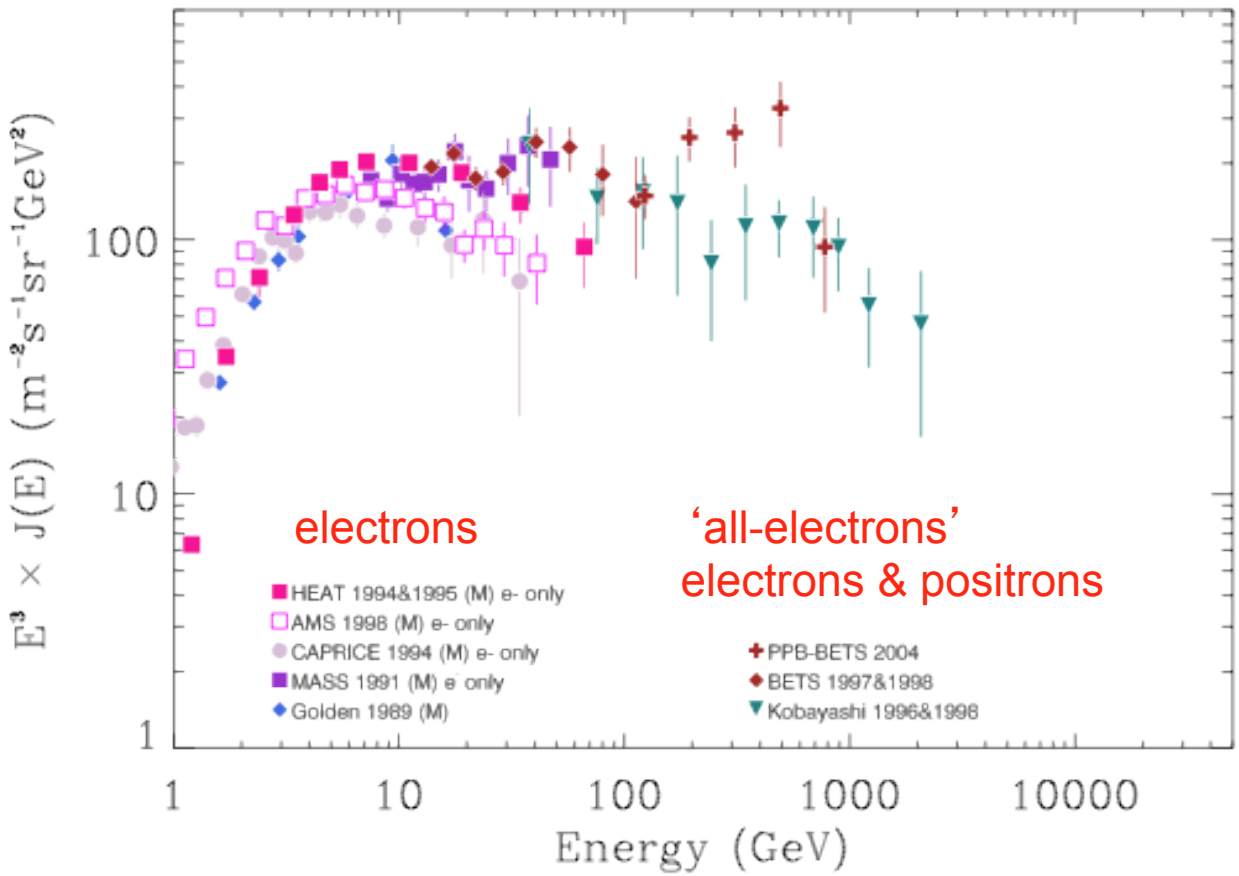
Secondary Electrons

- Secondary $e^{\pm}$ produced by CR interactions in Galaxy
- Will eventually contribute at some very small level.



Cosmic Ray Electron Observations

measured electron spectrum in 2008

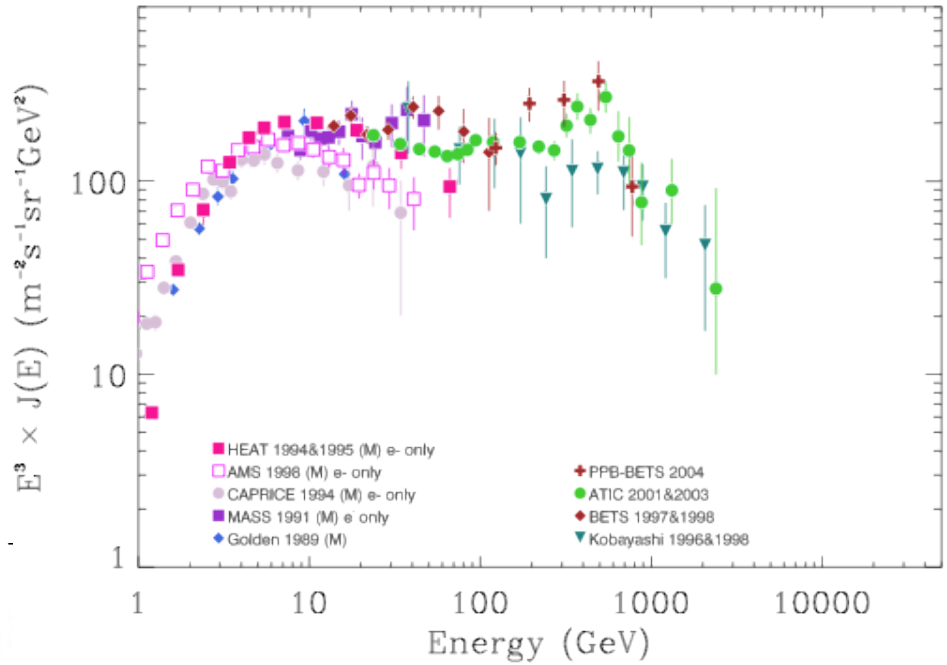


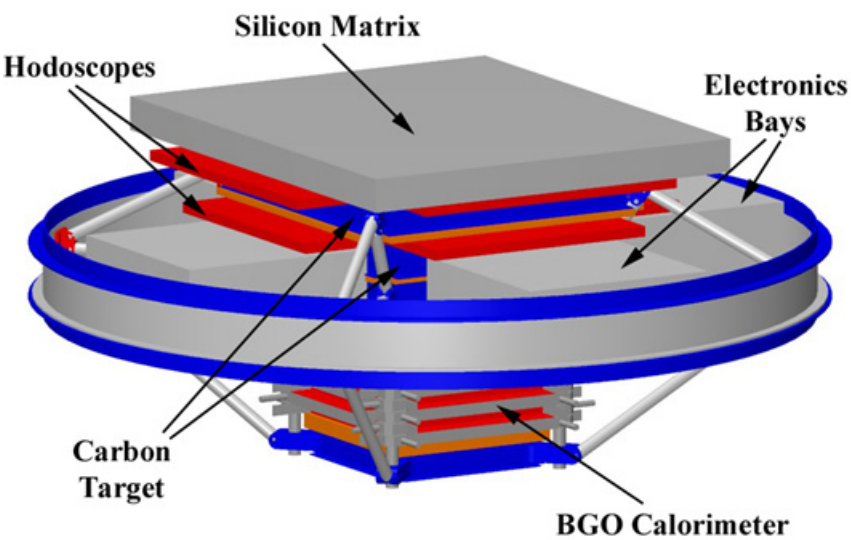
CR Electron Observations

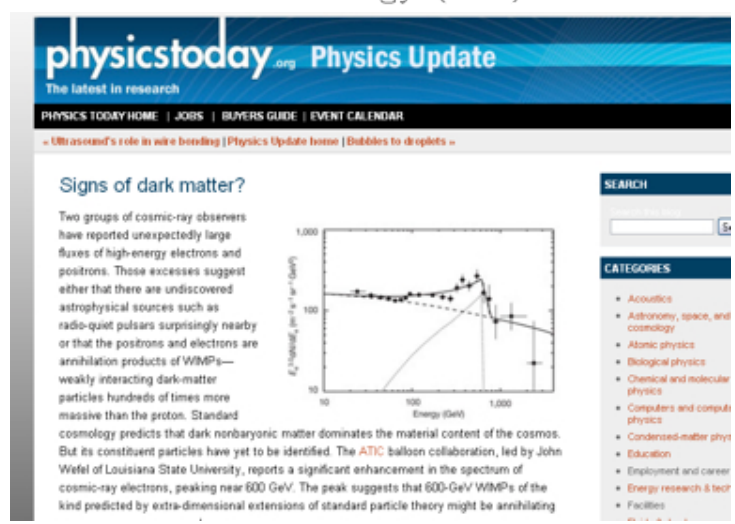
2008: ATIC experiment reports ‘exciting’ data.

However, many experts in the field are skeptical..

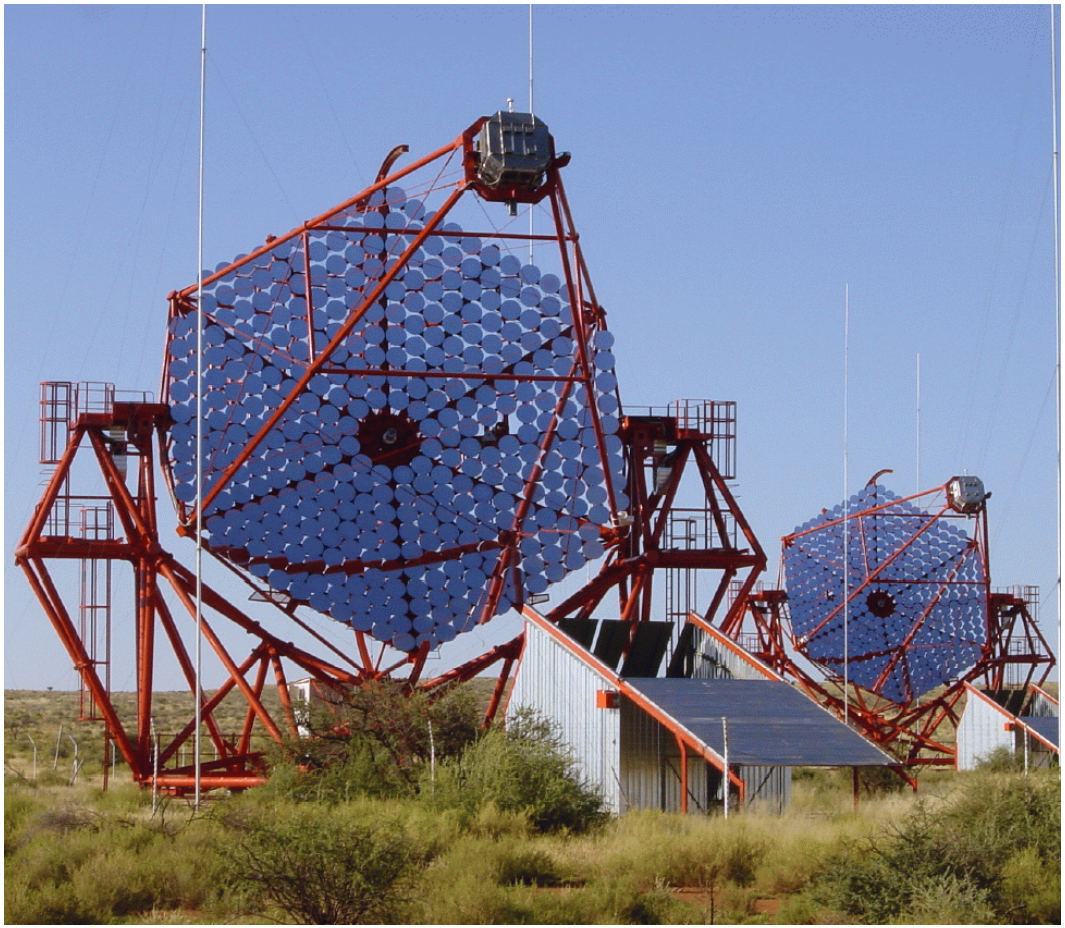
Designed to measure nuclei, not e^-. “Structure” most likely hadronic contamination.

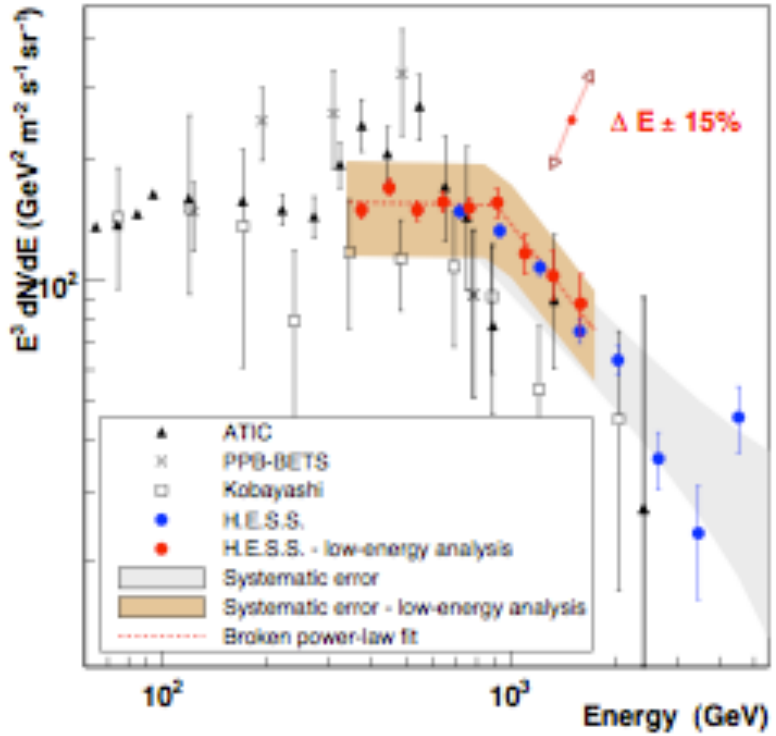






2009 ... Air Cherenkov Array Weighs in



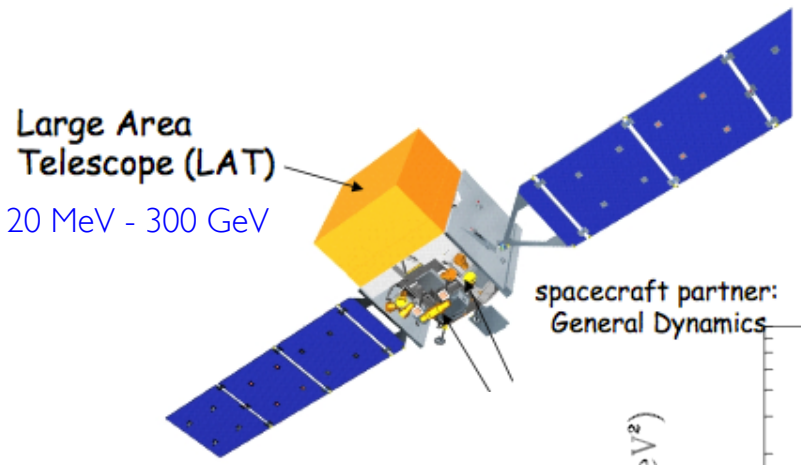


Aharonian et al., arXiv 0905.0105

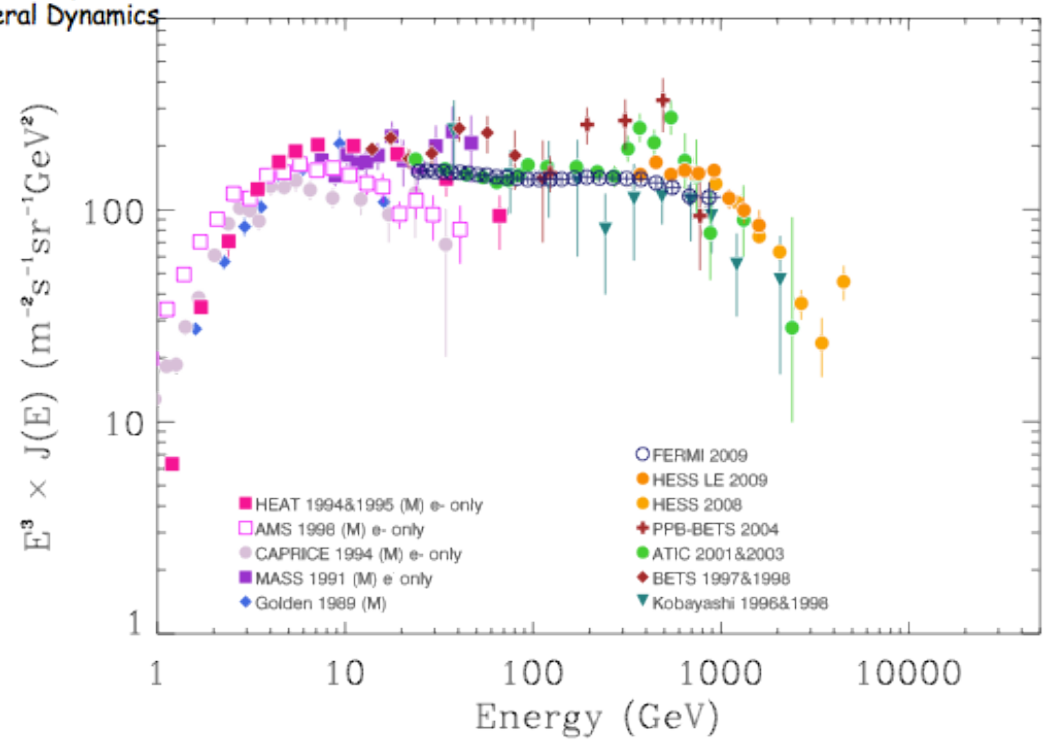
The H.E.S.S. data show no indication of an excess and sharp cutoff in the electron spectrum as reported by ATIC. Since H.E.S.S. measures the electron spectrum

HESS sees expected decline in all-electron spectrum above 1 TeV

Then FERMI clears it up



Satellite experiment optimized for detection of gamma rays and electrons

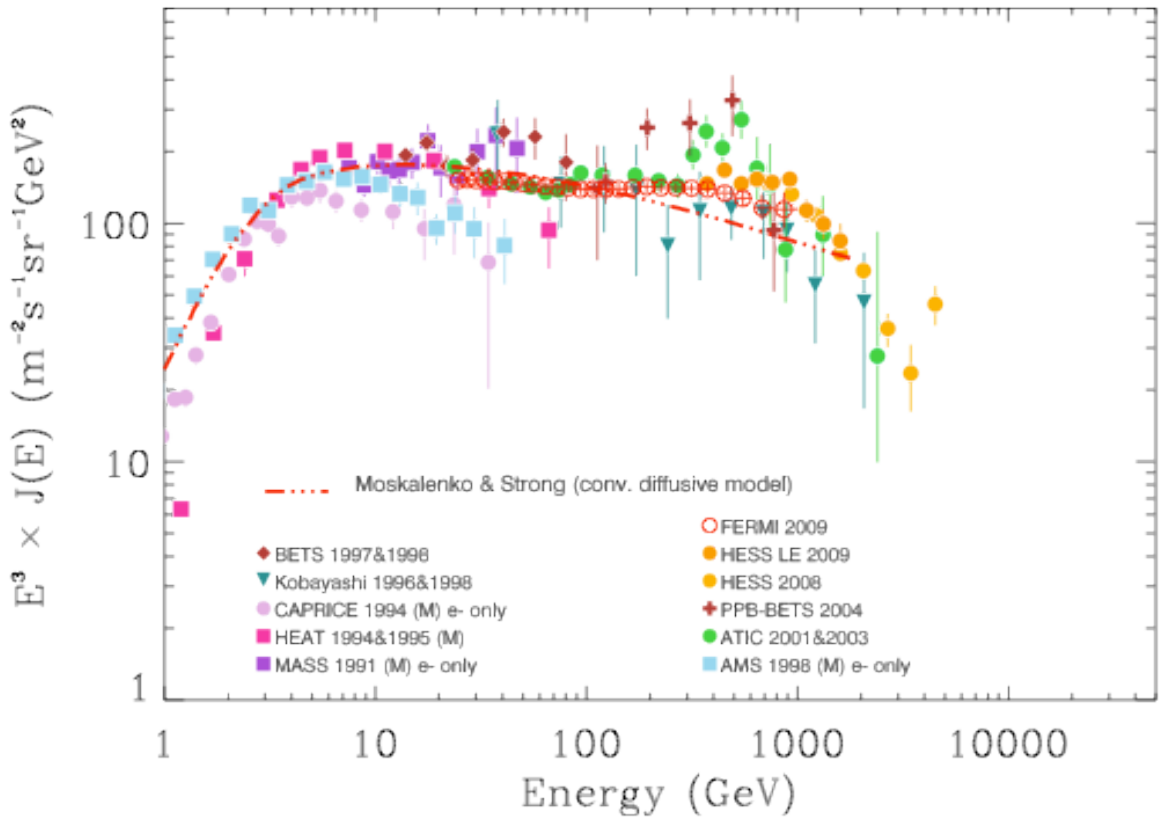


Fermi LAT does not confirm ATIC excess
(but spectral index does not match conventional diffusion model)

Cosmic Ray Electron Observations

Grasso et al., arXiv: 0905.0636

Conventional diffusion model (Galprop).

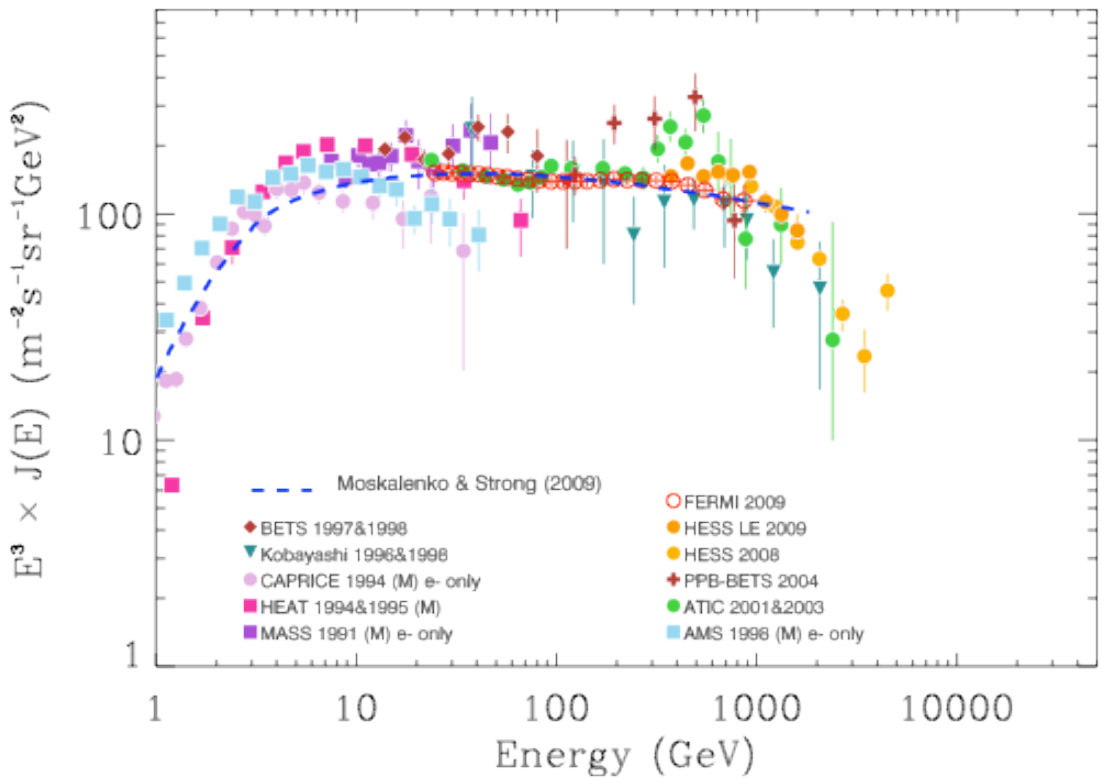


Adjusting the Diffusion Model

Grasso et al., arXiv: 0905.0636

Galprop w/ injection spectrum modified to fit FERMI data

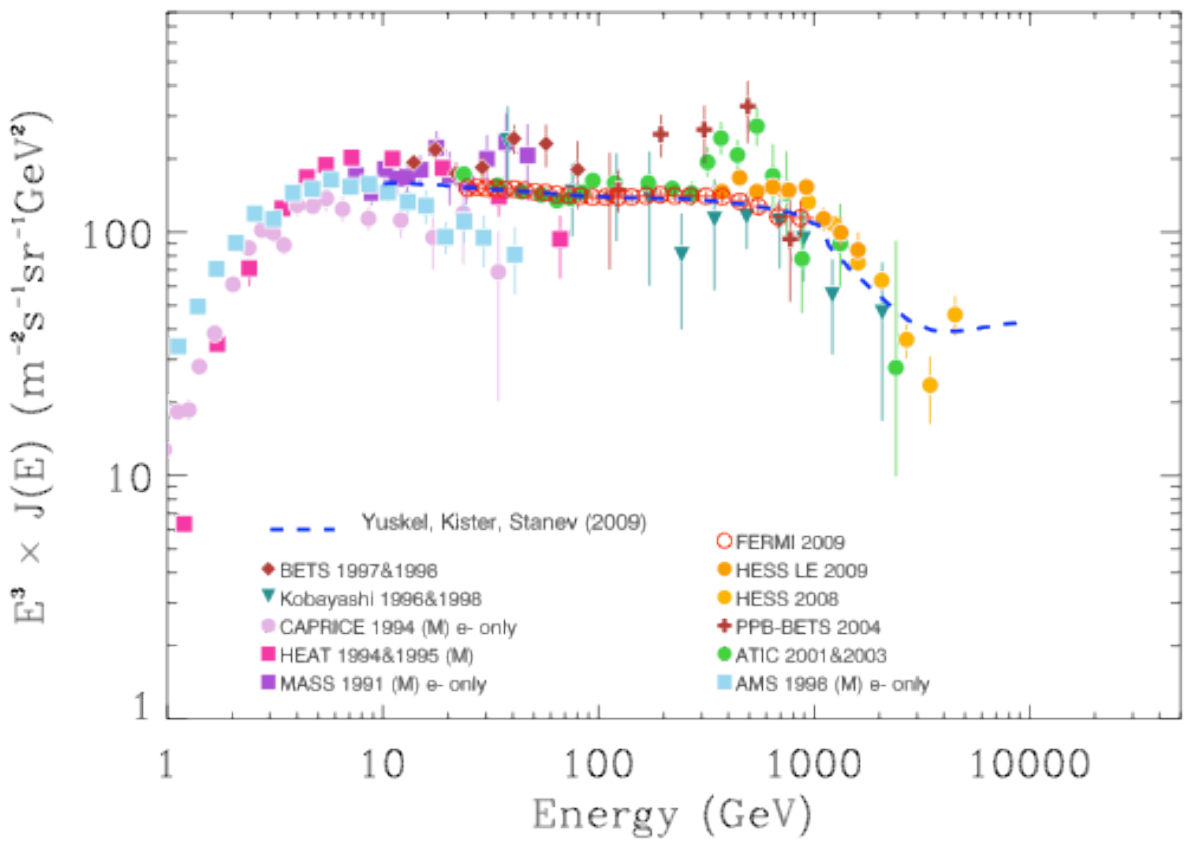
No reason to believe simple diffusion model can fit data over wide energy range (solar modulation issues at low energy, local sources at high energy).



Conventional Diffusion Model + Local Source

Yuskel, Kistler & Stanev, arXiv 0810.2784

Fermi, HESS data can also be reproduced using modified Galprop + contribution from GEMINGA



AMS
(Alpha Magnetic Spectrometer)

Can measure CRs up to:

e^+ ~ 300 GeV
$\bar{p}$ ~ 400 GeV
e^- ~ 1.5 TeV

ECAL 15 X_0
(p-rejection 10^3)

Deployed on ISS May 16, 2011

CALET

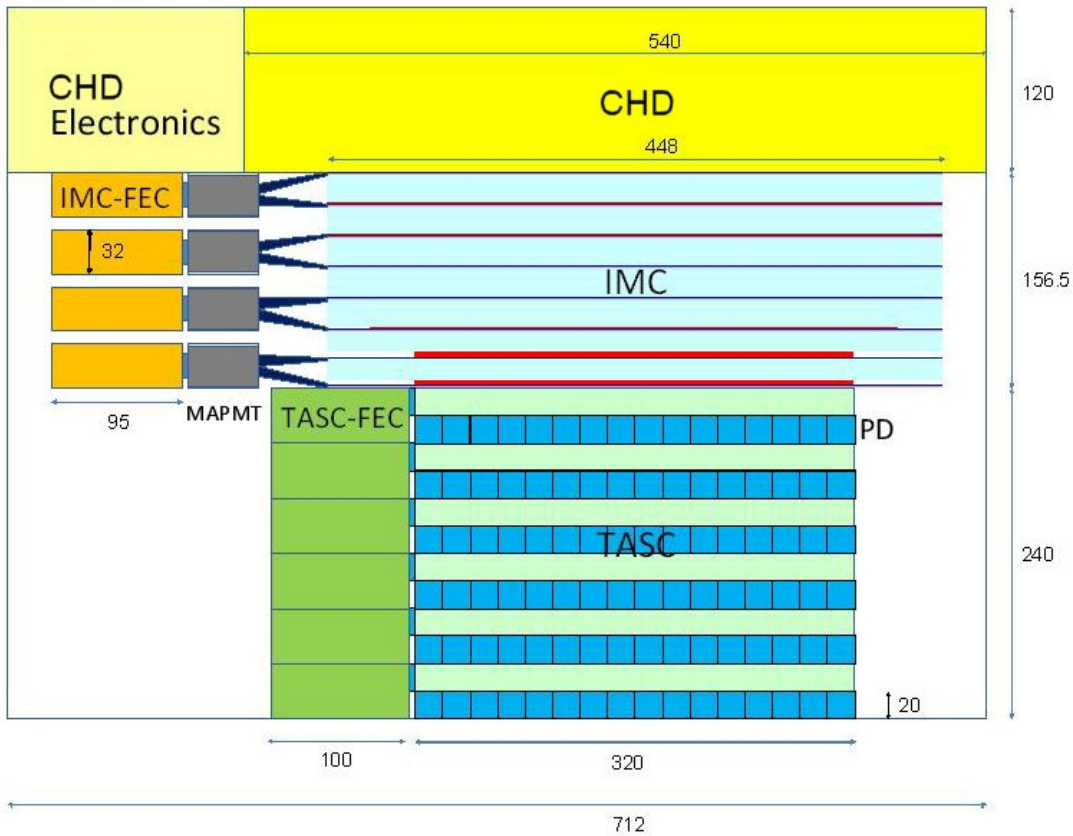
(CALorimetric Electron Telescope)

ISS module (2013?)

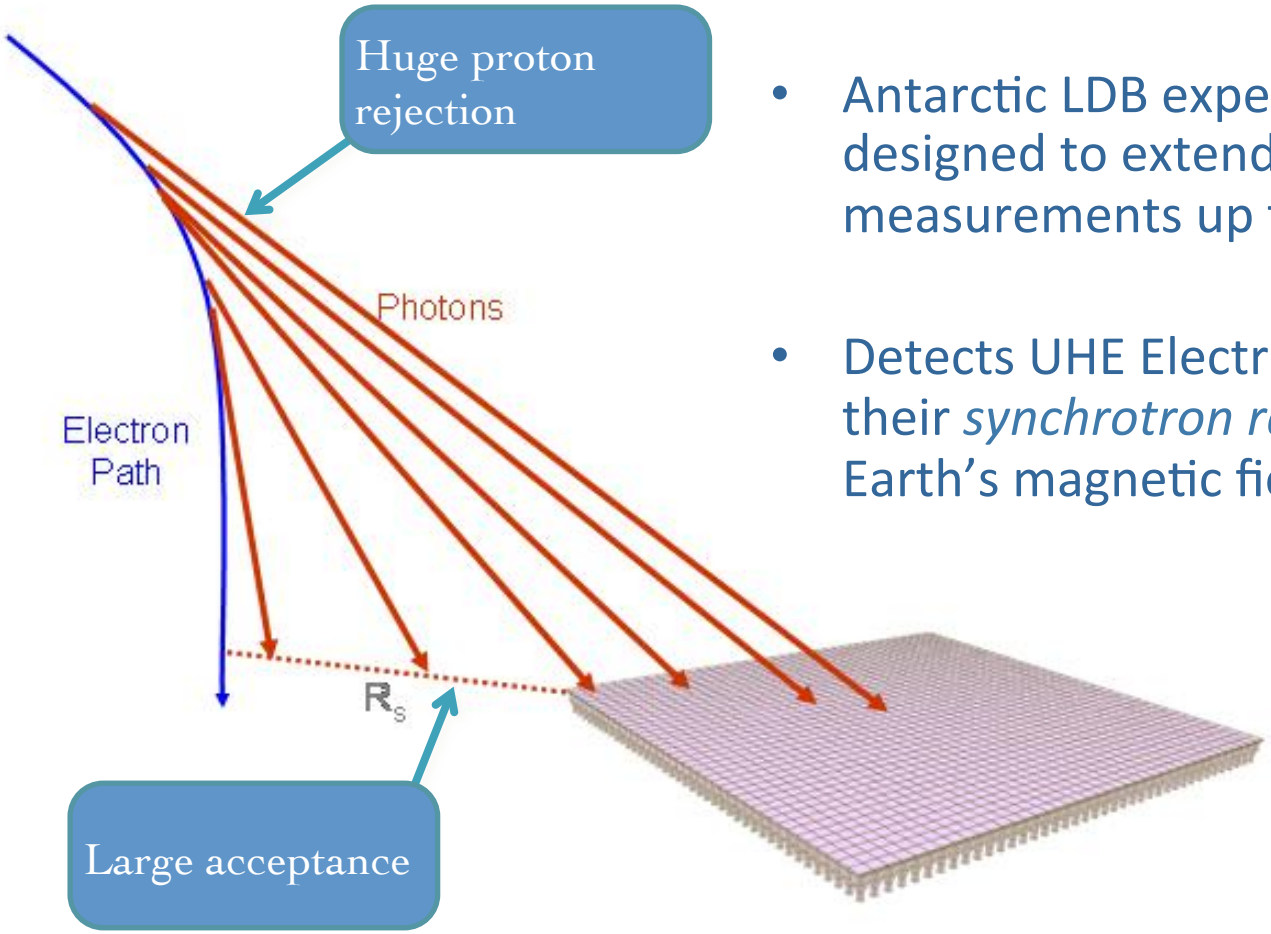
Imaging & total absorption calorimeters

electrons up to 10 TeV

Geometric Factor
~ 0.5 - 1 m^2 sr



Cosmic Ray Electron Synchrotron Telescope (CREST)



- Antarctic LDB experiment designed to extend electron flux measurements up to 50 TeV.
- Detects UHE Electrons through their *synchrotron radiation* in the Earth's magnetic field.

Technique first described in 70's by O.F. Prilutskiy, and further developed in 80's by A. Stephens & V.K. Balasubrahmanyan

CREST Collaboration

- University of Chicago: Scott Wakely, Nahee Park, Dietrich Müller
- Indiana University: Jim Musser
- University of Michigan: Gregory Tarlé, Michael Schubnell, Joe Gennaro
- Northern Kentucky University: Scott Nutter
- Penn State University: Stephane Coutu, Matt Geske

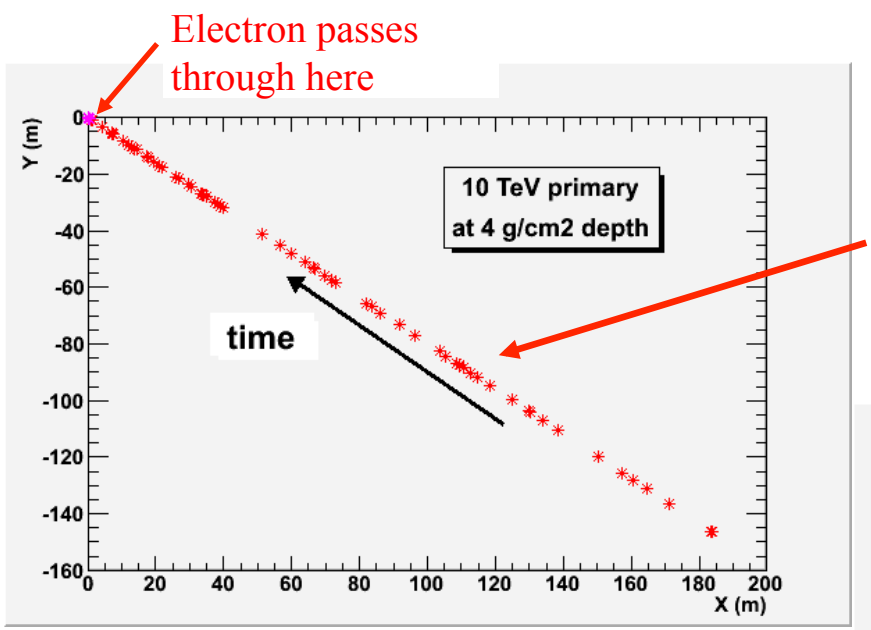
CREST Technique

Effective aperture of CREST instrument given by the *spatial extent of the synchrotron photons*, not by the physical size of the instrument.

Discrimination between signal and background X-ray events:
- formation of a line
- very short time intervals

→ CREST instrument designed as a spatially segmented detector with excellent timing resolution

Signal



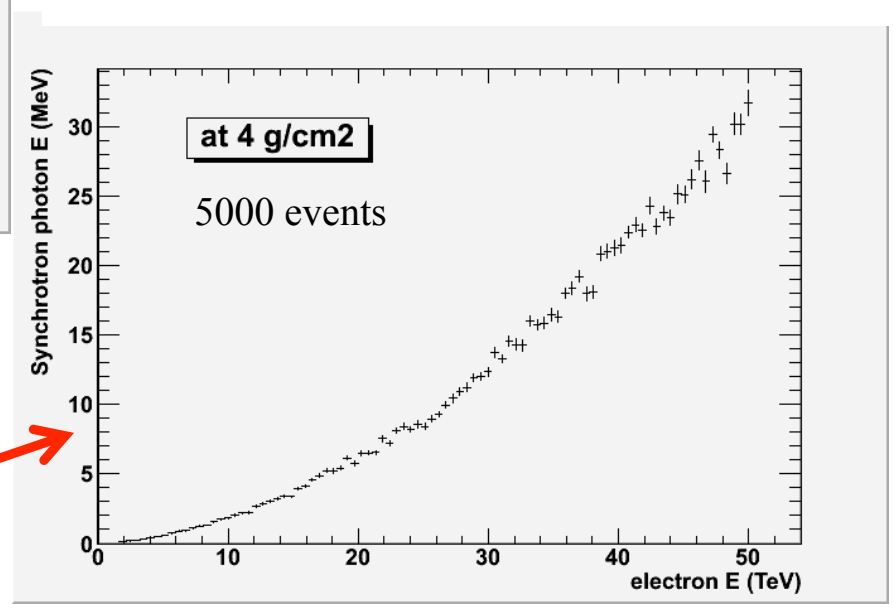
10 TeV primary electron at McMurdo

GEANT4-based; 1976 standard atmosphere in 20 mg/cm^2 layers; round Earth

Line of photons extends over several hundred meters at balloon altitudes.

Mean photon energy related to primary electron energy

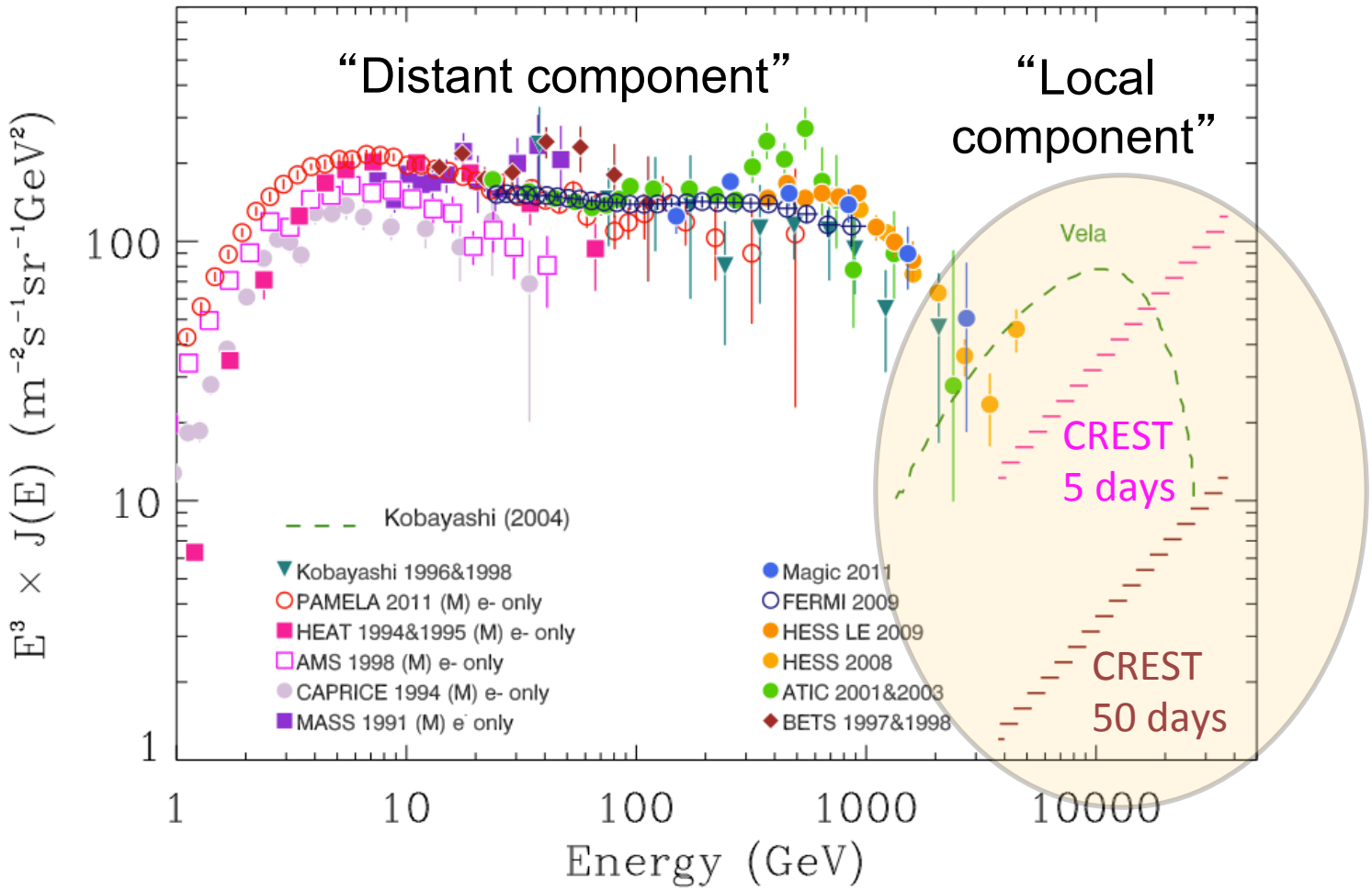
$$\varepsilon \approx 10keV\left[\frac{E}{TeV}\right]^2$$



Backgrounds

- Protons “leak” through veto.
  - ~10^4 p/m^2/sr s (huge!) reduced to 1 p/m^2/sr s with 99% veto efficiency (still huge!)
  - Only “horizontal” protons can leave a line in crystals
  - Will move across detector at v = c
  - Topological discrimination
- Compton scattering within instrument
  - One photon fires more than one crystal
    - Not a problem unless scatter is in line with other photon hits
    - Mitigated by adding lead shielding around crystals (weight penalty)
- Bremsstrahlung
  - Mass mean free path of ~2 g/cm^2 in air
  - For a 10 TeV electron:
    - There are ~50x more synchrotron photons produced than bremsstrahlung photons.
    - Only ~10x more synch photons survive to 4 g/cm^2 than bremsstrahlung photons.

CREST Sensitivity



CREST Instrument

- Crystal Array:

  1024 BaF_2 crystals + PMT (Custom Hamamatsu 2" PMT w/low power Cockroft-Walton base)

  Photon energies from ~30 keV to 30 MeV

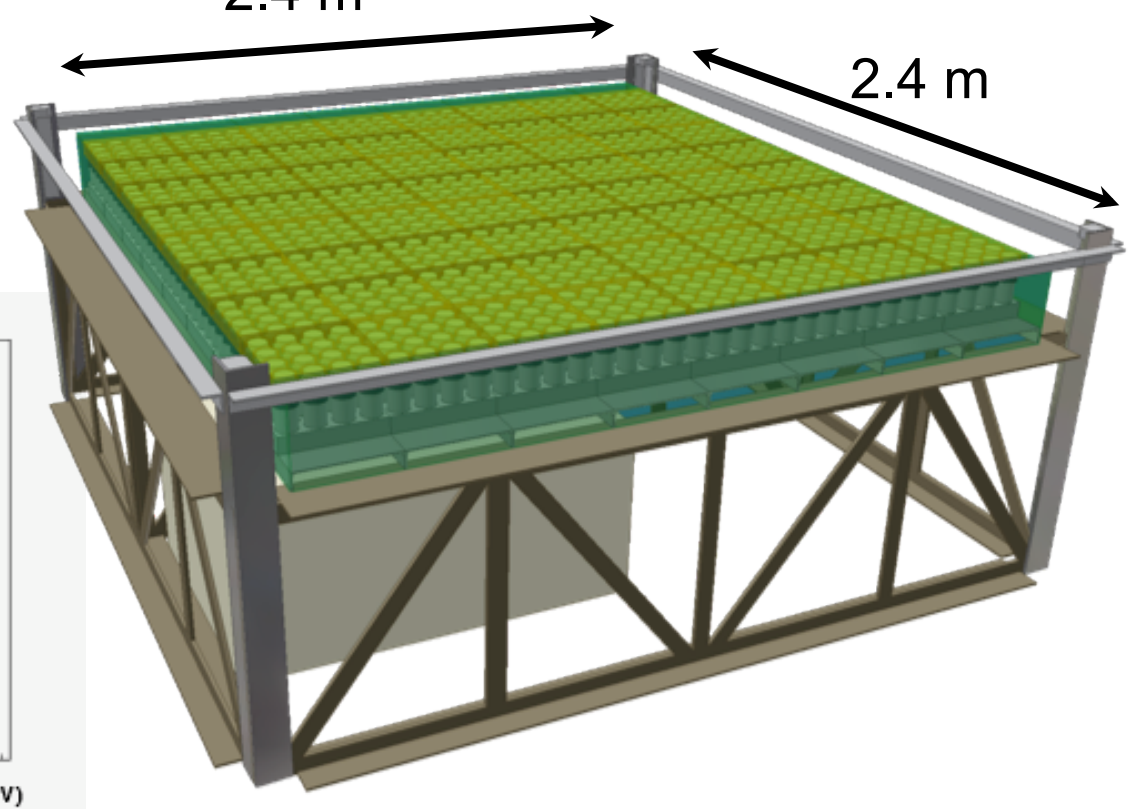
- Triggerless DAQ:

  Pipelined data stream; assembles 'events' on the fly; Fast (ns) timing helps reduce accidentals.

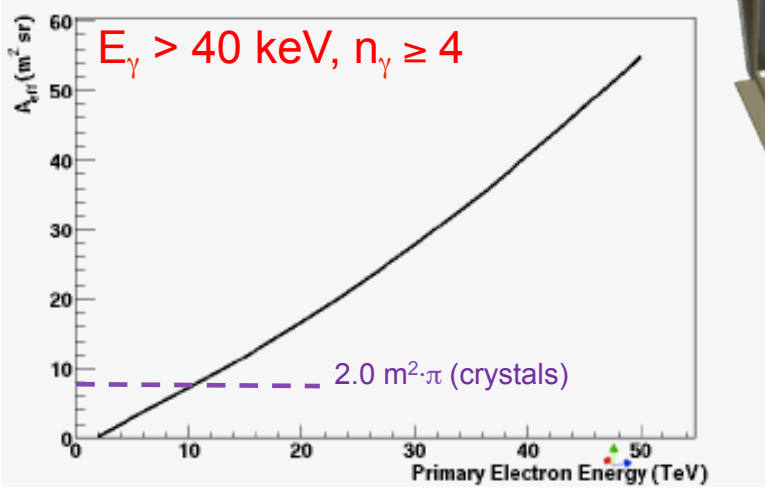
- Veto Shield:

  99+% hermetic plastic scintillator with wave-shifting fiber read out by 2" PMTs

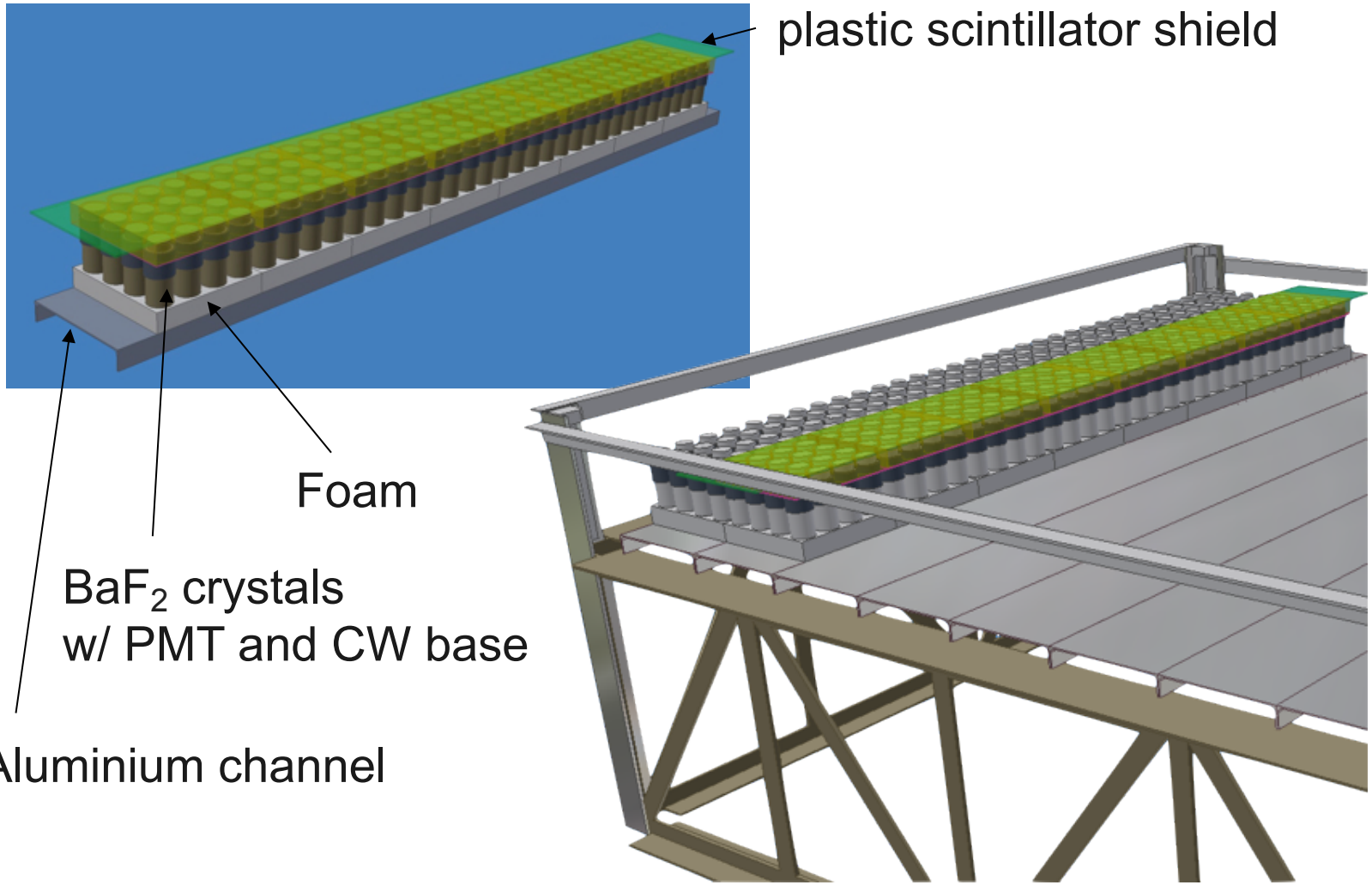
total crystal area: 2.0 m^2



CREST acceptance vs E_e

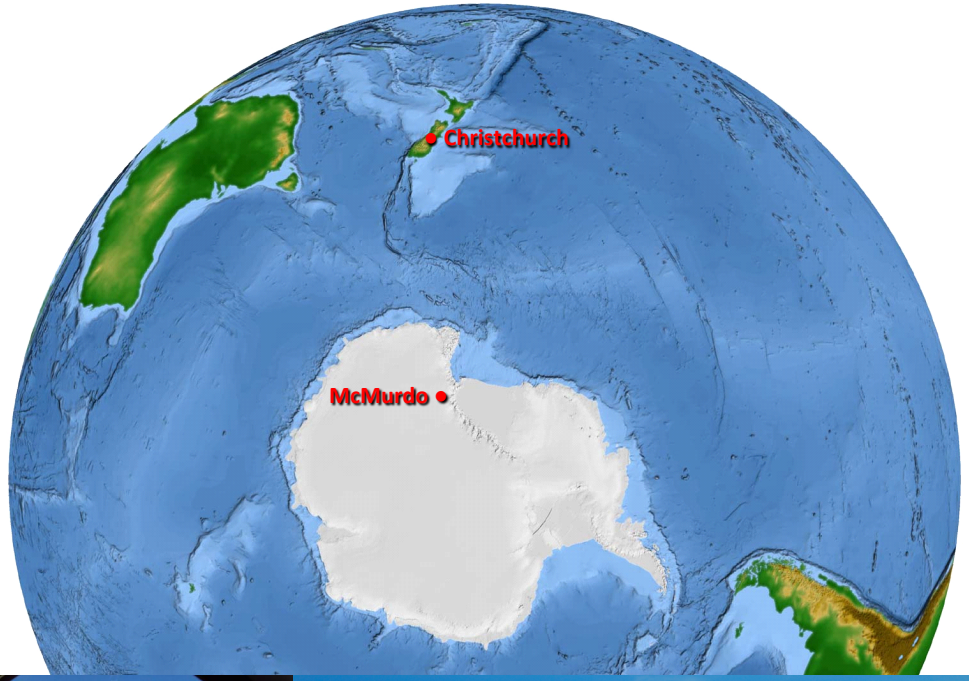


CREST Modular Structure



Getting to Antarctica: step 1

Getting to Antarctica: step 2



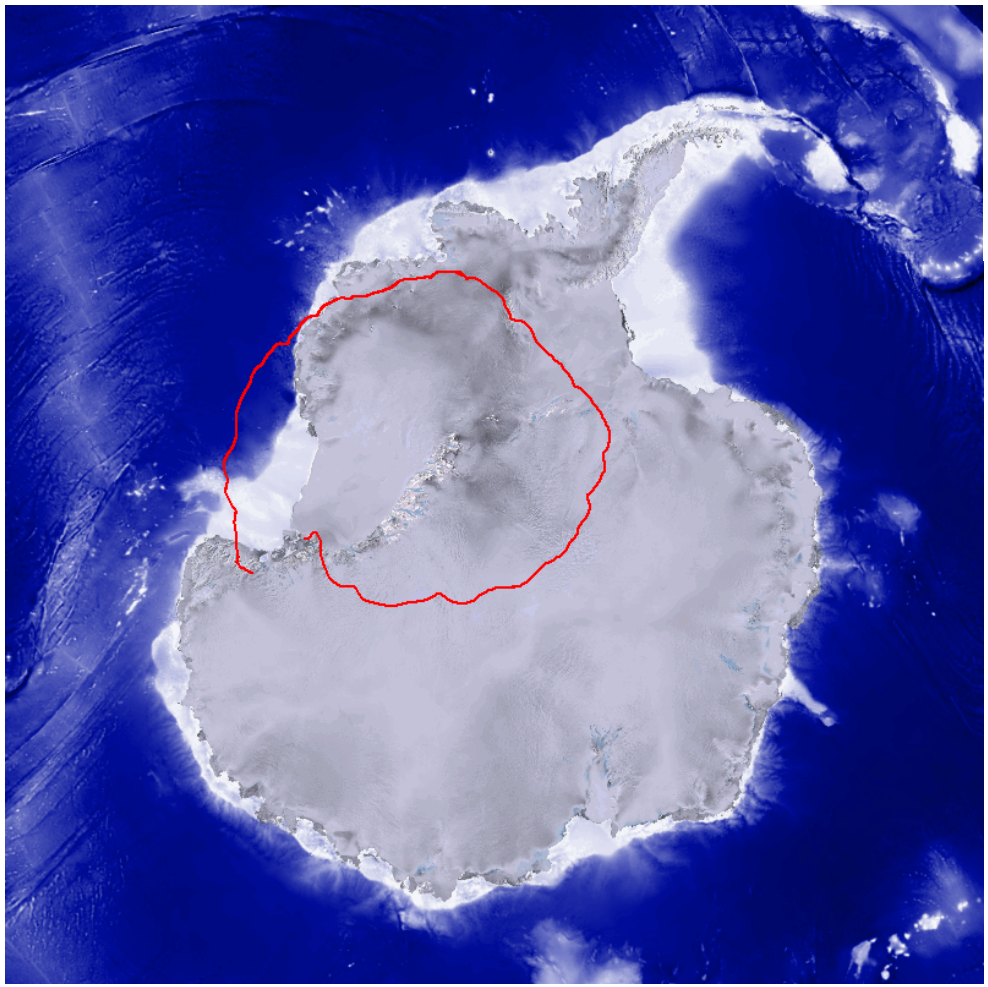
Antarctica! McMurdo Station

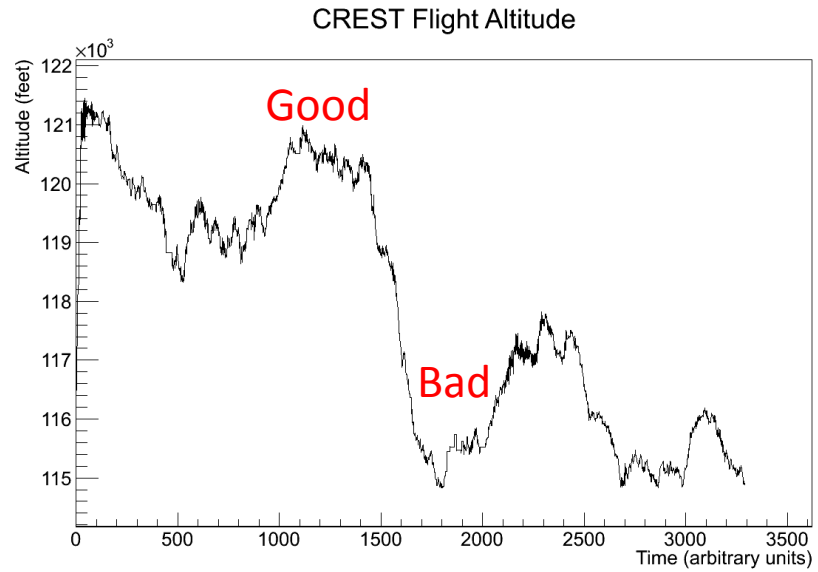
CREST - The Movie!

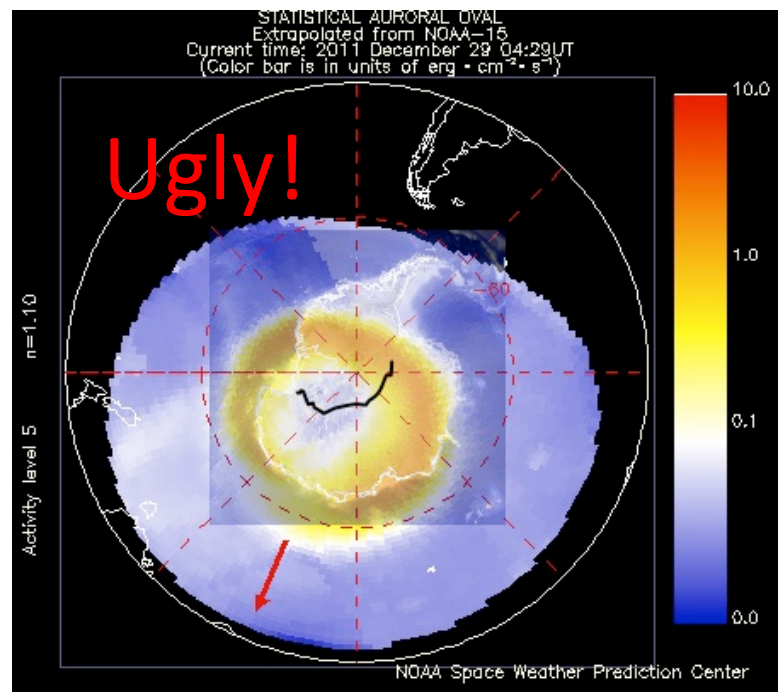
CREST Flight Statistics

- Launch Christmas Day 12/25/2011 6:00pm NZDT
- 10 days at solar max.
- Average altitude 117,000 ft. (~10 mbar)
- Survived* several solar storms
- Limited TDRSS and Iridium satellite telemetry
- 500 Gb data collected (on board)
- 750 million events
- # synchrotron events: ?
- Landing Jan. 4, 2012 beyond trans-Antarctic Range, ~500 km from McMurdo
- Recovery, March 2012

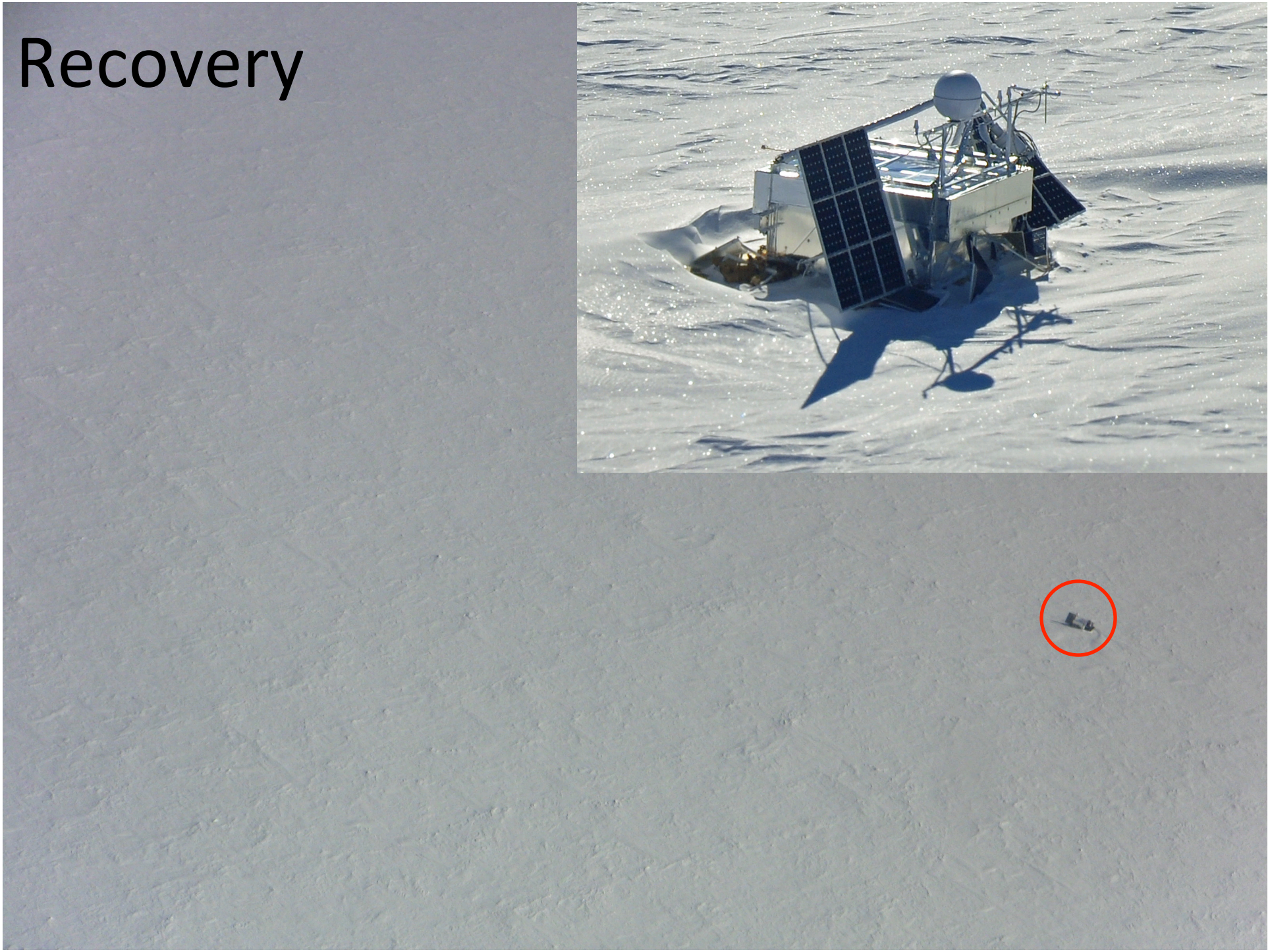
Flight Profile



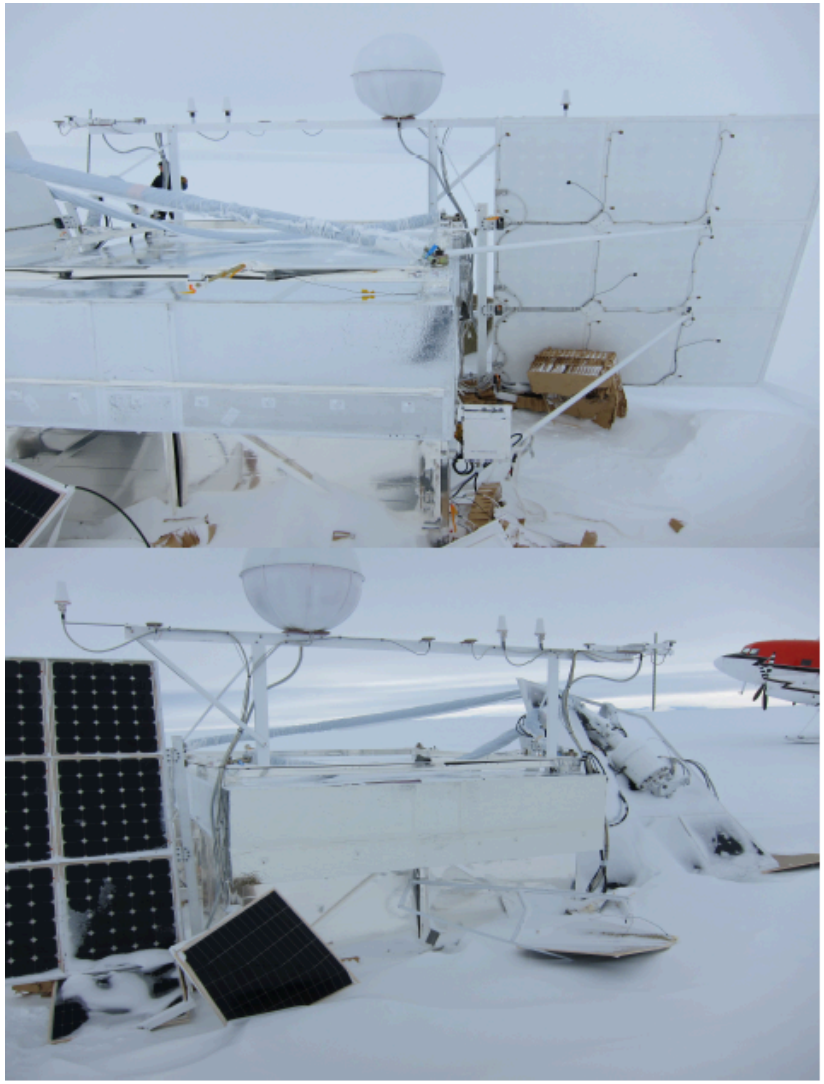


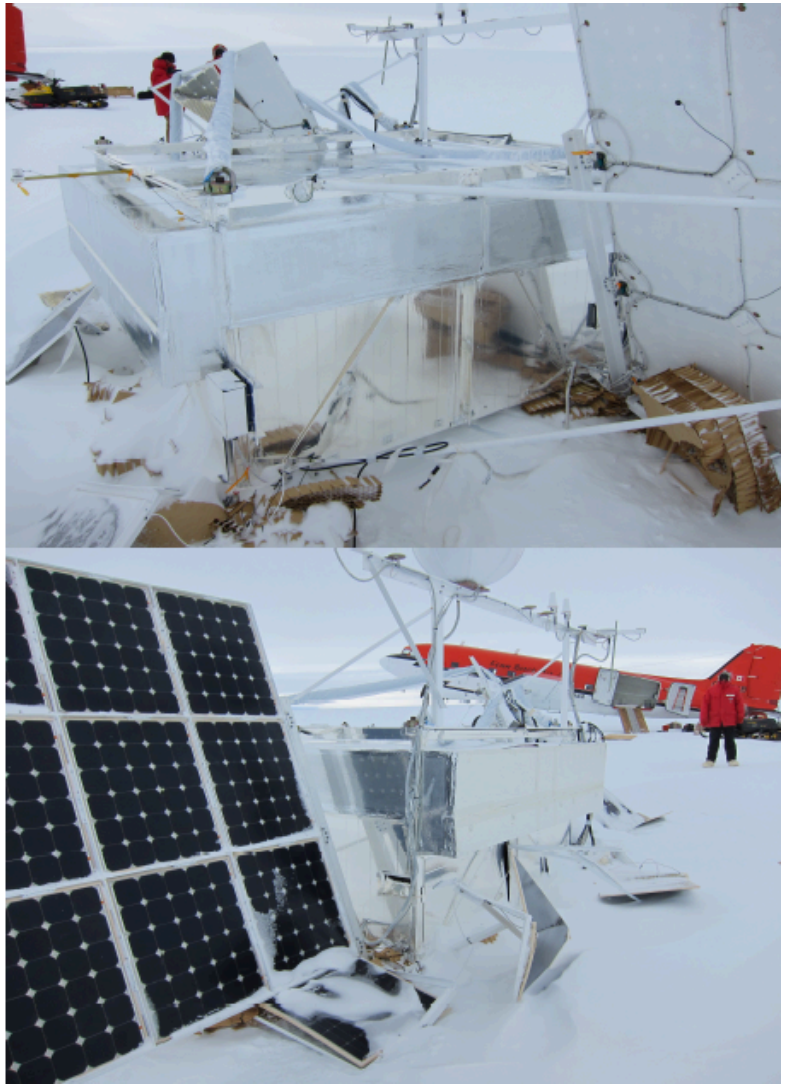


Recovery

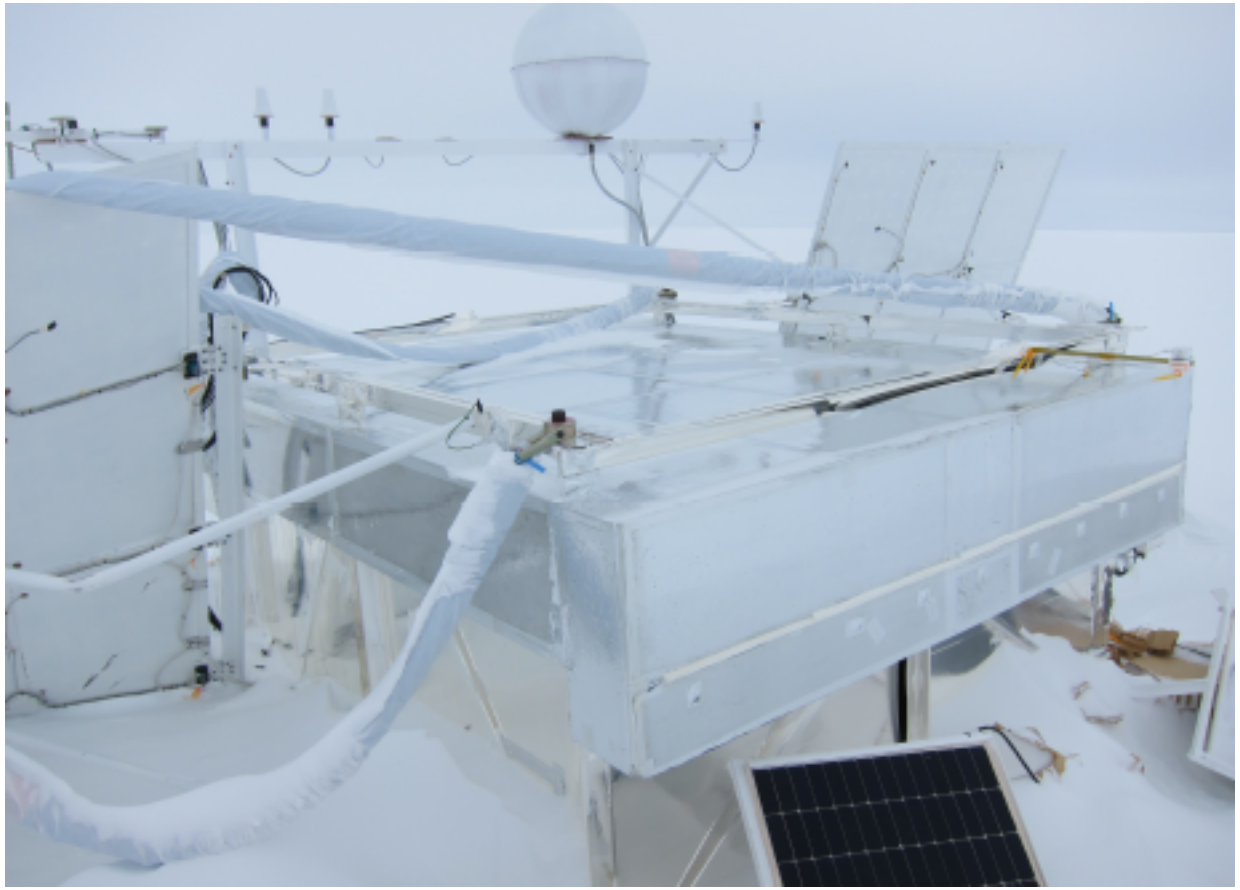


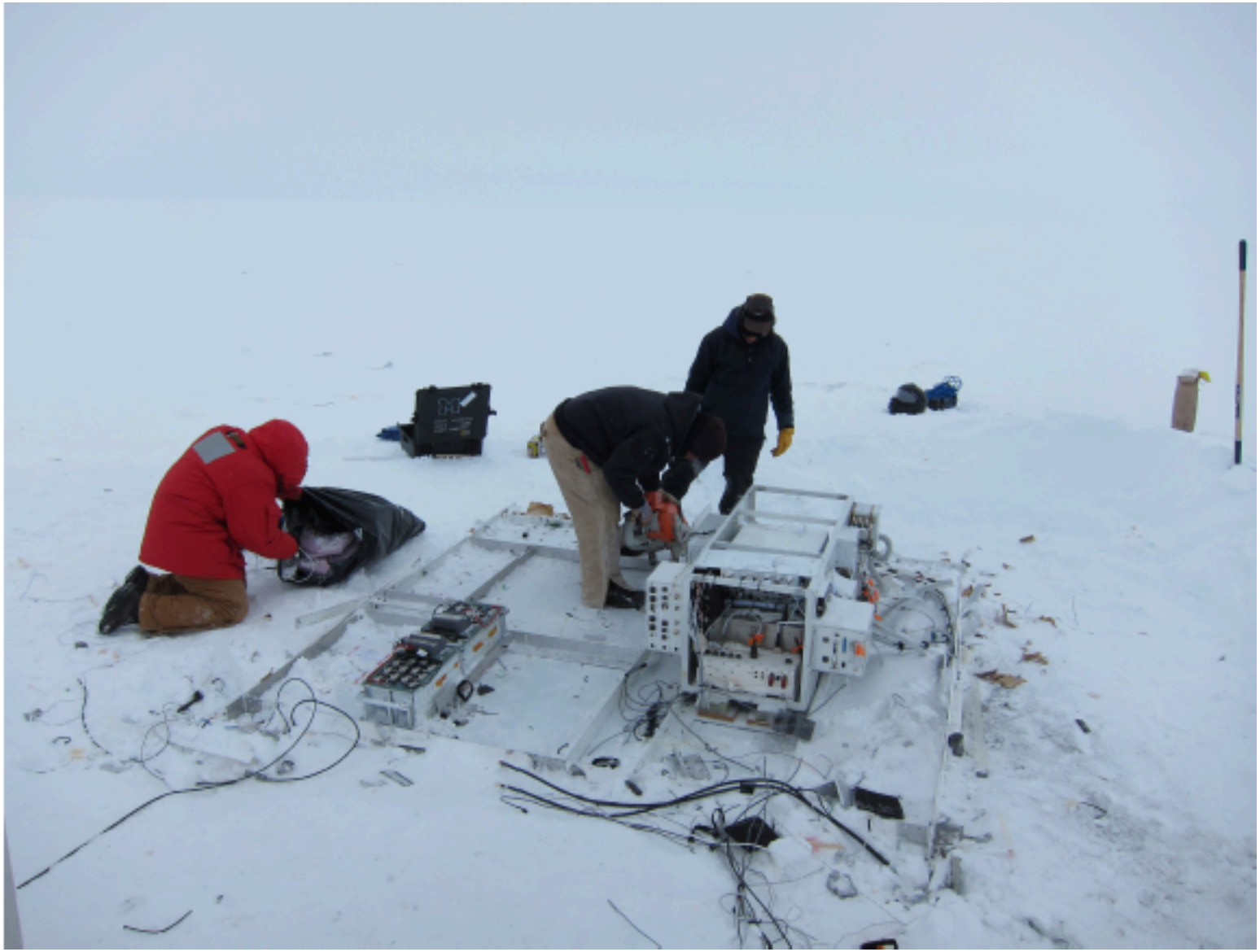
Landing Site





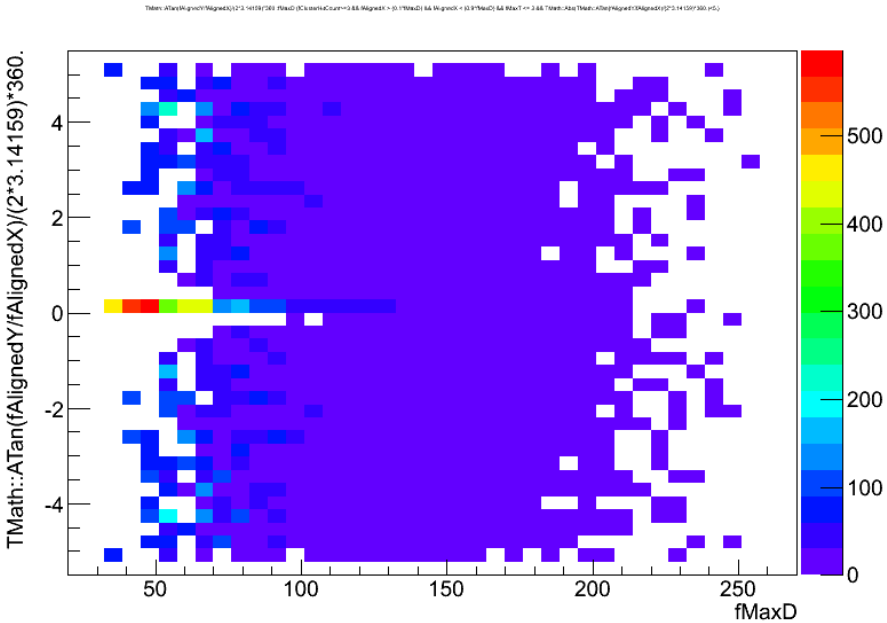
How do we get this through the door of the airplane?





Analysis (In Progress)

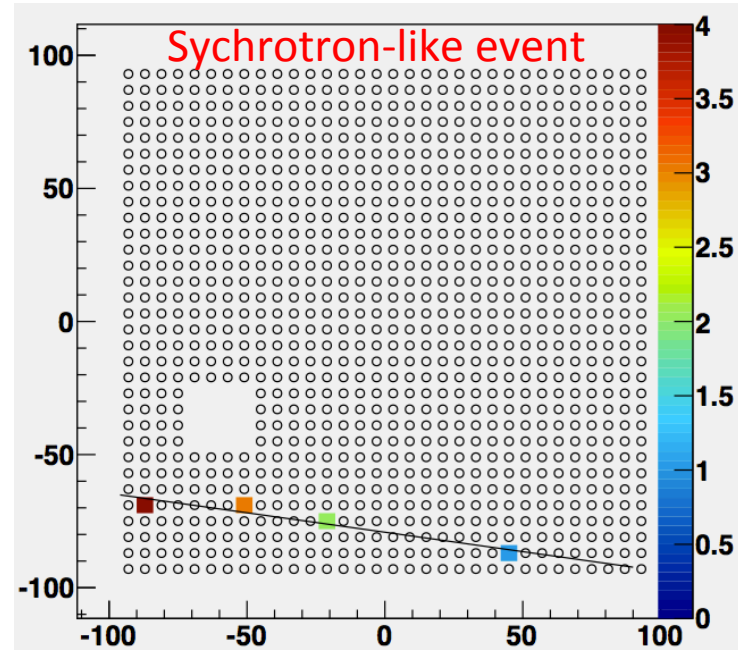
- Data disks returned to USA late March, 2012
- First look mid-April
  - many crystal hits in a line
  - peak @ small displacements

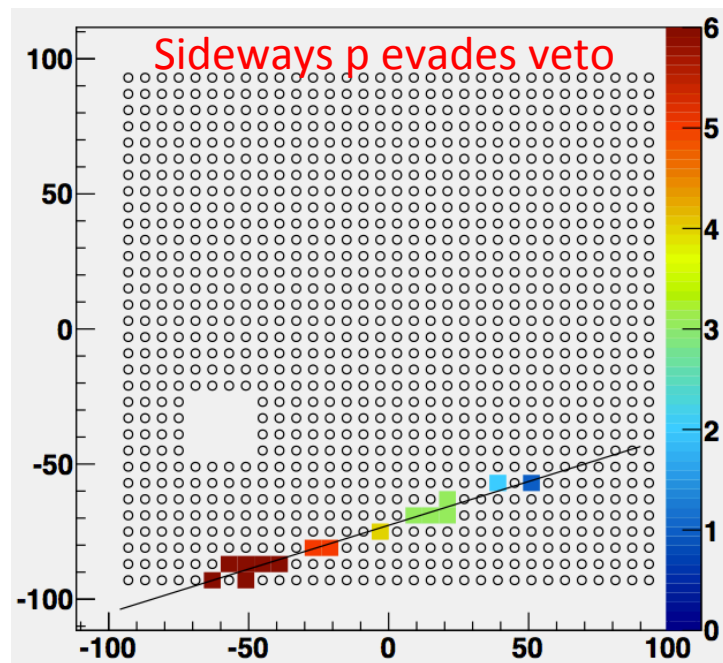


- Calibrations
  - Veto timing and ADC calibrations (position to ~ 10 cm) ✔
  - Precision (< 1 ns) channel-by-channel crystal array T0 calibrations ✔
  - Crystal array ADC calibrations ☐ (not so critical)

Topological Selection

- No veto activity
- Cluster nearby crystal hits (time and space)
- > 3 clusters
- Linear fit $X_r^2 < 5$
- Time fit $X_r^2 < 10$
- > 1m long

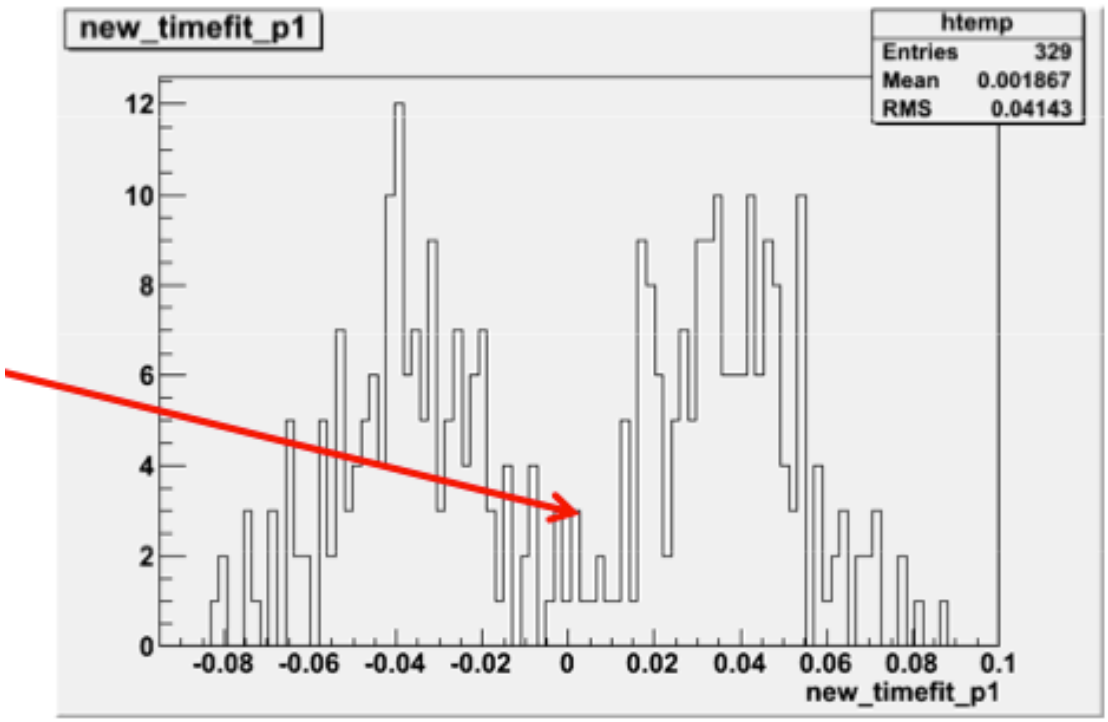




Time fit velocity distribution

Events that survive these "topological" cuts exhibit propagation across the detector at v = c consistent with sideways protons leaking through the veto

Electron (synchrotron) events) will lie in the gap between the peaks

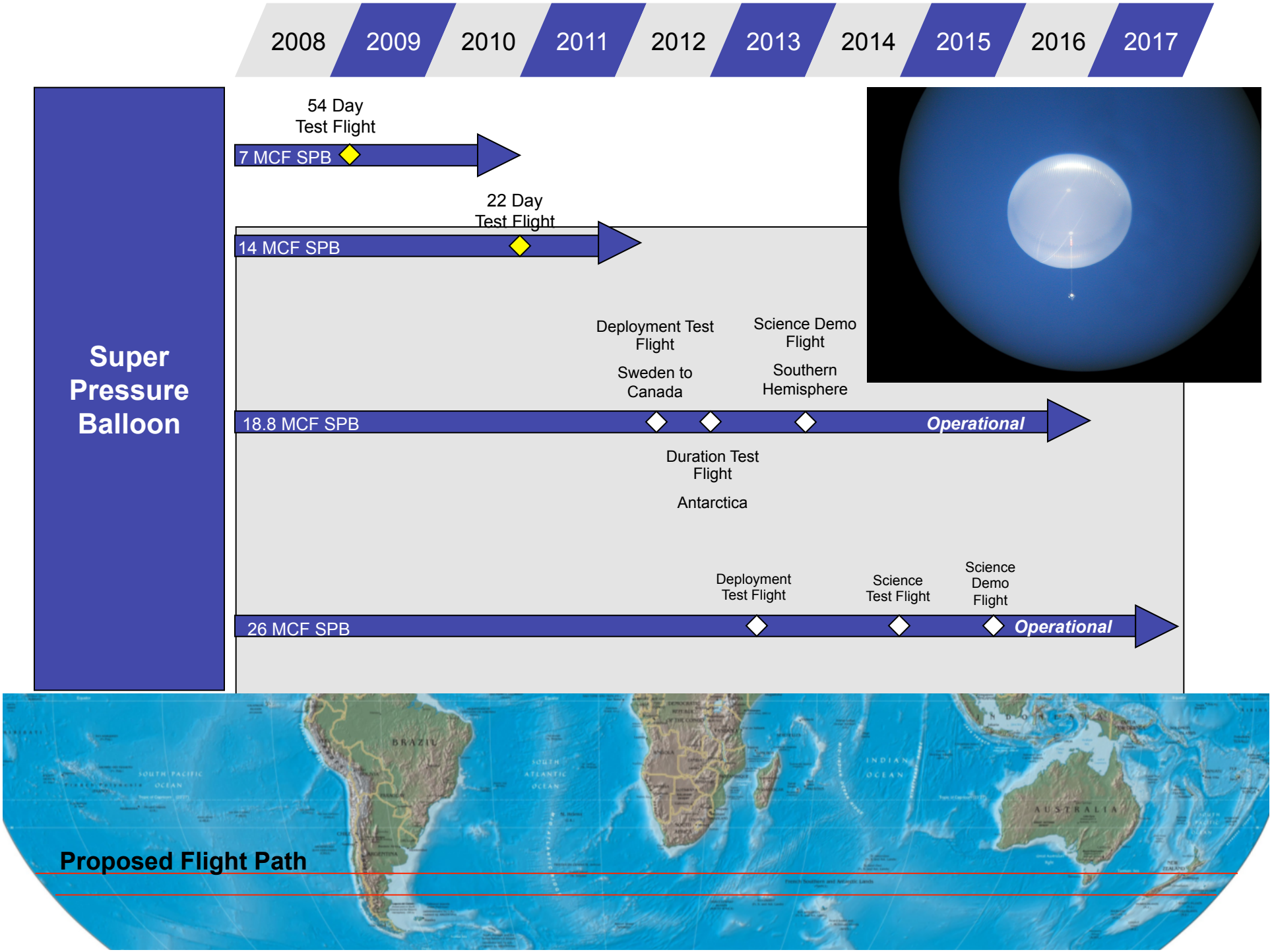


Background Rejection!

- Time evolution
- Event topology distributions: Compare to events with side veto activity – alignment, gap distributions, veto-efficiency check, energy deposition distributions…
- Pulse height distribution
- Geomagnetic orientation
- Accompanying bremsstrahlung photon clusters with unique timing signatures "light cones."
- Comparisons with MC simulations (includes instrument embedded in atmosphere, with geomagnetic environment and realistic generators for backgrounds.

Future flights of CREST

- Next CREST LDB flight December, 2014
  - Refurbished, lightweight version to insure longer flight (try for 3—5 weeks), higher altitude
- CREST ULDB (100+ days) on Super-pressure balloon 2016?


2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Super Pressure Balloon
54 Day Test Flight
7 MCF SPB
22 Day Test Flight
14 MCF SPB
Deployment Test Flight
Sweden to Canada
Science Demo Flight
Southern Hemisphere
18.8 MCF SPB
Operational
Duration Test Flight
Antarctica
Deployment Test Flight
Science Test Flight
Science Demo Flight
26 MCF SPB
Operational
Proposed Flight Path

Conclusions

- December 2011 10 day CREST "maiden" flight demonstrates synchrotron technique. May detect local sources or set upper limit on their contribution.
- Future CREST LDB and ULDB flights will achieve required sensitivity to reveal the nature of local cosmic ray accelerators.

Stay Tuned!