CREST: The **C**osmic **R**ay **E**lectron **S**ynchrotron **T**elescope

The search for TeV cosmic ray electrons with the CREST experiment

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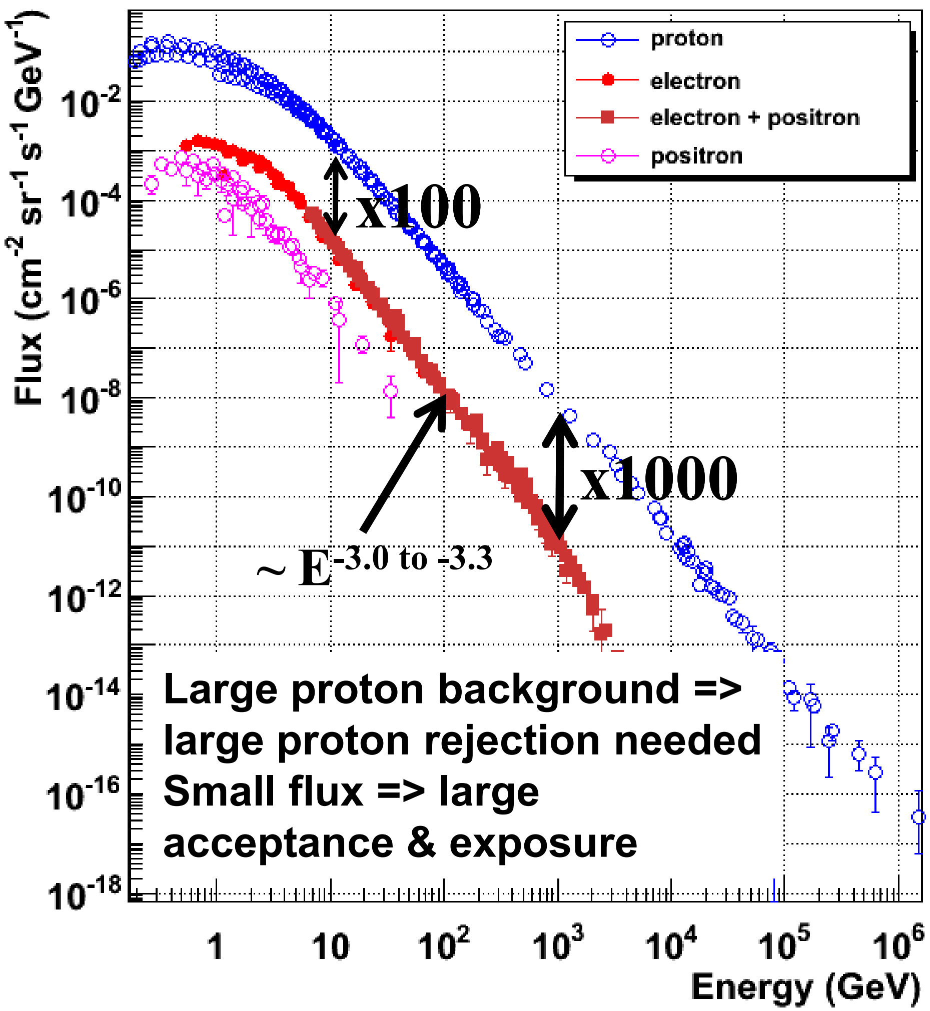
TeVPA Stockholm

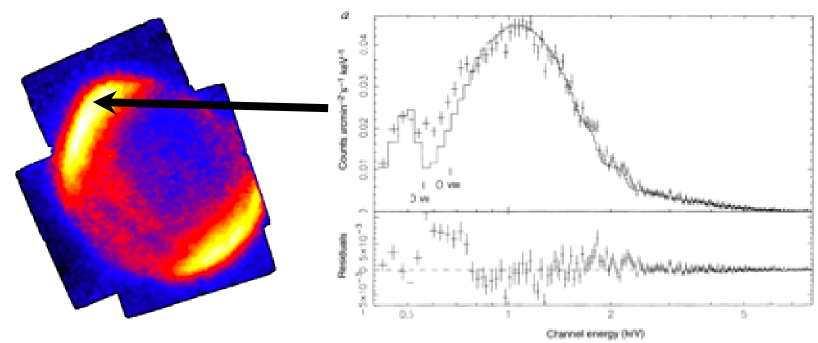
Cosmic Ray Electrons



Compiled data up to Jan. 2010 from CR database
(A.W.Strong et al, 2009 ICRC)

Acceleration

- Evidence of acceleration in SNR



X-ray image of SN1006 (Koyama et al, Nature 1995)

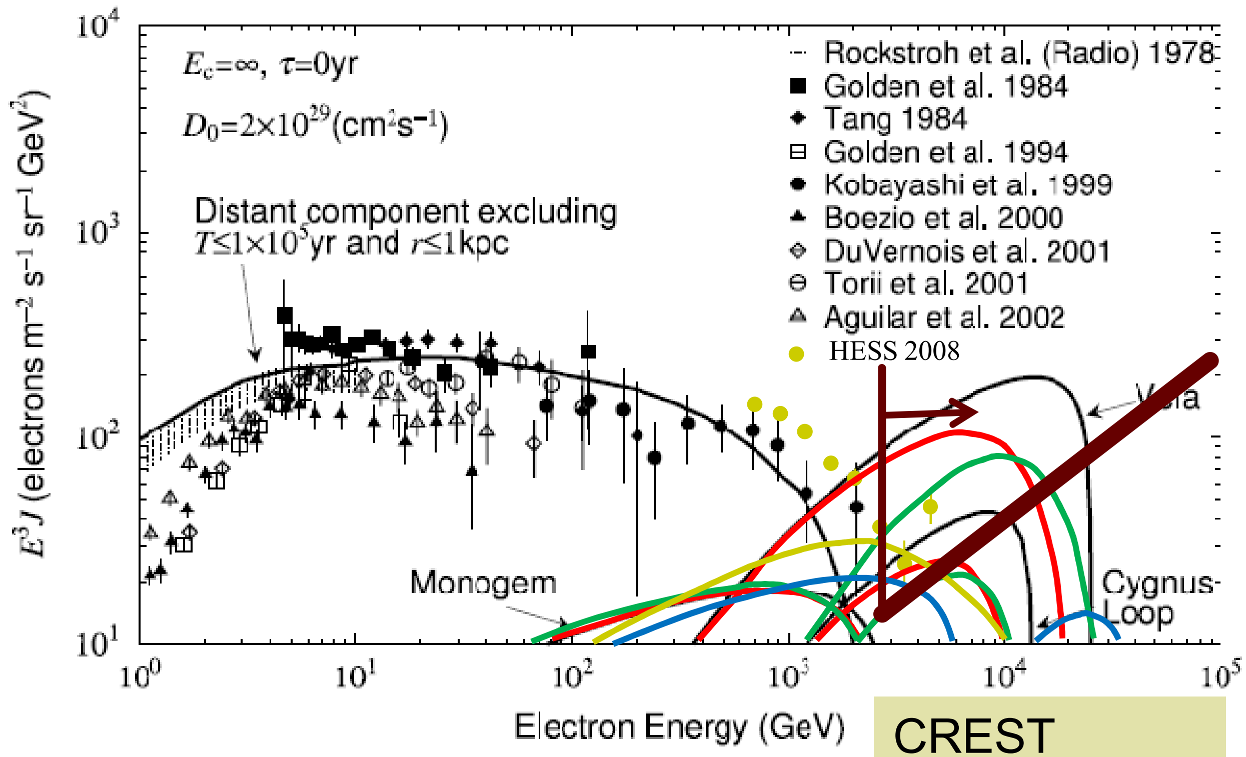
Propagation

- TeV electrons: short propagation distance in Galaxy (~ 1kpc)
  - Energy loss ∝ E^2
    (~10^5 yrs to lose energy to below ~1 TeV)
  - Additional loss mechanisms: Inverse Compton & synchrotron
  - Local source (e.g. SNR)
- Substantial fraction of electrons are primary

Measurements and Predictions

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

- Contribution from SNRs depends on various SNR parameters: e.g. diffusion coefficient, release time, energy cutoff;
- Plenty of parameter space for exploration;
- TeV range can reveal features of nearby sources.



CREST sensitivity

E_c = 20 TeV, τ = 0 yr, $D_0 = 2\times10^{29}$ cm^2/s

E_c = 20 TeV, τ = 5000 yr, $D_0 = 2\times10^{29}$ cm^2/s

E_c = 20 TeV, $\tau = 10^4$ yr, $D_0 = 2\times10^{29}$ cm^2/s

E_c = 20 TeV, τ = 0-1×10^5 yr, $D_0 = 2\times10^{29}$ cm^2/s

"Local component"

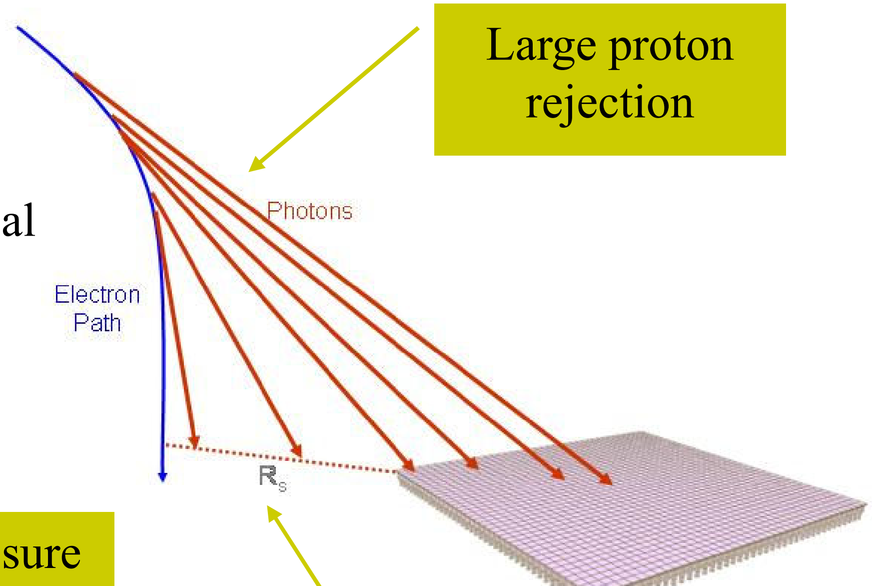
SEE Pannuti et al, ApJ 721:1492 (2010) for comprehensive list of galactic sources and cutoff parameters.

CREST: Cosmic Ray Electron Synchrotron Telescope

- Technique: Detect synchrotron radiation of primary electron as it passes through Earth's magnetic field
  - Advantage: Effective area of instrument greatly increased.
    - Area determined by R_S, not physical size.
- Plan: Antarctic long duration balloon flights

Balloon-borne

Large proton rejection



Long exposure time

Large acceptance

Method:
- Prilutskiy, O.F., Pisma ZhETF, 16,320, (1972).
- Stephens S.A., Balasubrahmanyan V.K., J. Geophys. Res., A10, 7822 1983.

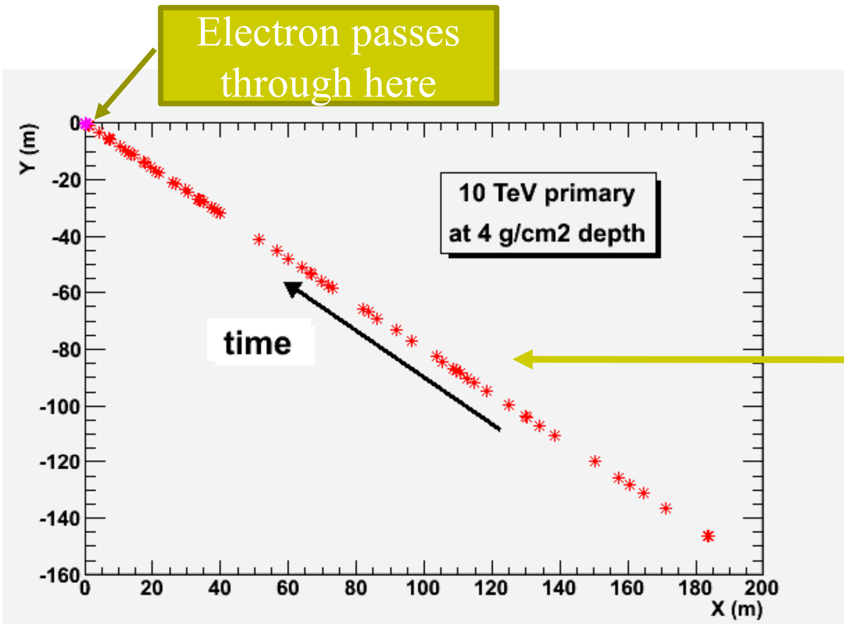
CREST:
"Pathfinder" or
"Discovery" experiment

Signal and Background

- **Signal:** Electron events appear as a line of synchrotron photons arriving nearly simultaneously.
  - ***Mean photon energy related to primary electron energy.***
    - Synchrotron radiation characterized by critical energy $E_c=3\mu_B(E_0/m)^2B_{\perp;}$
    - E_c = 40 keV for 2.5 TeV electron; 17 MeV for 50 TeV
  - Strong atmospheric absorption below ~30keV
    - Sets electron low energy detection threshold for technique from balloons at about 2 TeV

- **Backgrounds**
  - Random cosmic and CR shower x-ray photons and large charged particle flux (mostly low energy protons)
    1. "Fake" events caused by random chance aligned contemporaneous hits
    2. Photons or low energy charged particles coincident with synch photons in real event
  - Requires 4π, efficient discrimination against charged particles
  - Requires fast timing to reduce random x-ray coincidences

Simulations: Synchrotron generator

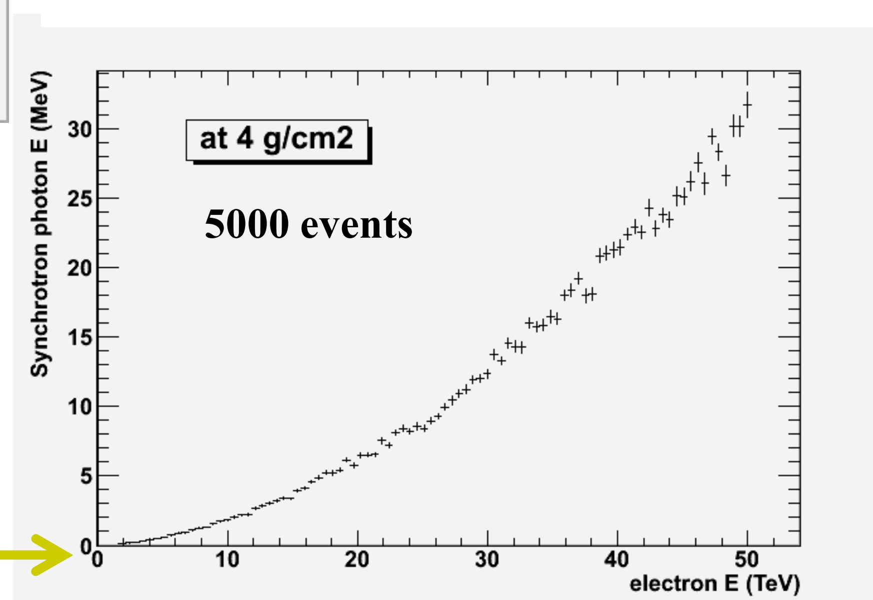


GEANT4-based; 1976 standard atmosphere in 20 mg/cm^2 layers; round Earth; WMM magnetic field for McMurdo

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

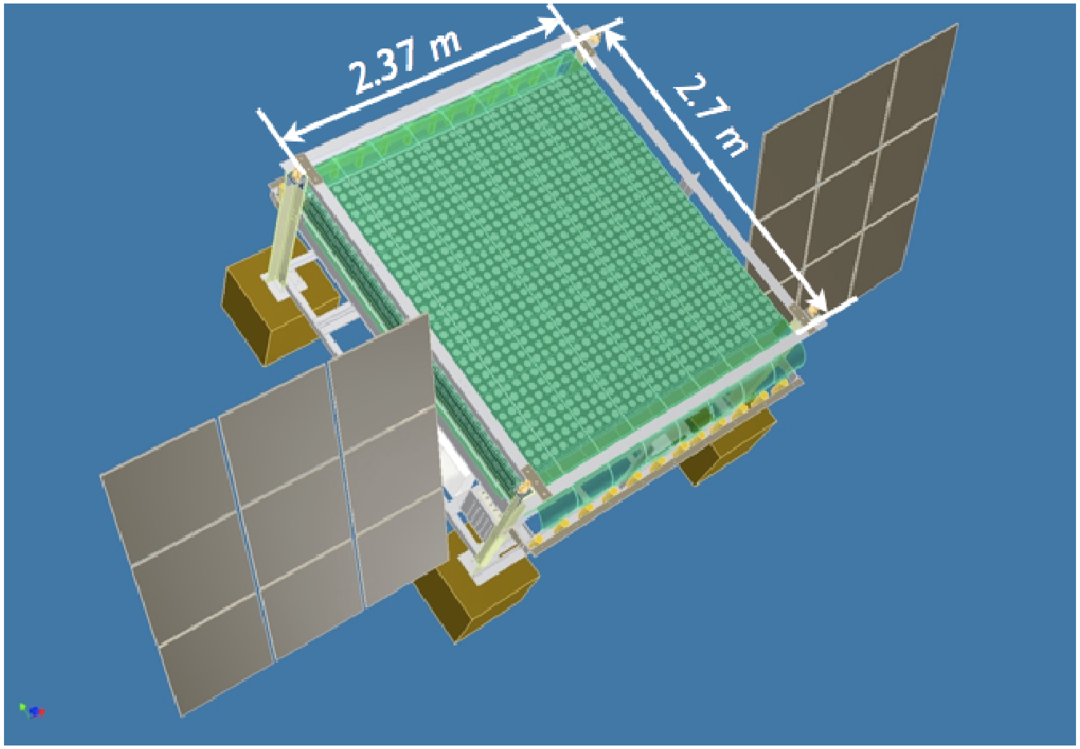
10 TeV primary electron at McMurdo

Surviving synchrotron photons show expected energy dependence.



CREST Detector Design

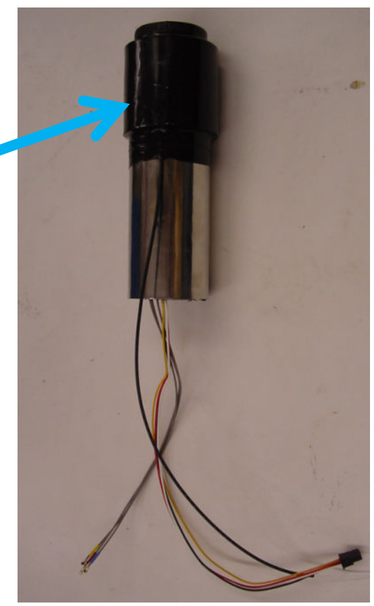
- Crystal Array
  - 1024 BaF_2 crystals w/ 2” PMT readout, embedded in foam matrix
  - Photon energies from 40 keV to ~30 MeV
- Veto paddles
  - Form a plastic scintillator box around crystals
  - > 99% hermetic
  - Thin plastic scintillator with waveshifting fiber readout into 2” PMTs
- Triggerless DAQ
  - Pipelined data stream assembles ‘events’ on the fly
  - Fast (ns) timing helps reduce accidentals.



BaF_2/PMT Assembly

- BaF_2 (2 cm $\times$ 5 cm OD) on Hamamatsu R7724CW custom 2” PMT;
  - Cockroft-Walton low power base (30 mW);
  - Individual HV control;
  - Potted against vacuum;

- High density, high light yield;
  - fast component: 15%, 0.8 ns decay time (timing);
  - slow component: 85%, 630 ns (energy);
  - 1.15 pe/keV $\Rightarrow$ 13% FWHM energy resolution @ 662 keV (^{137}Cs);



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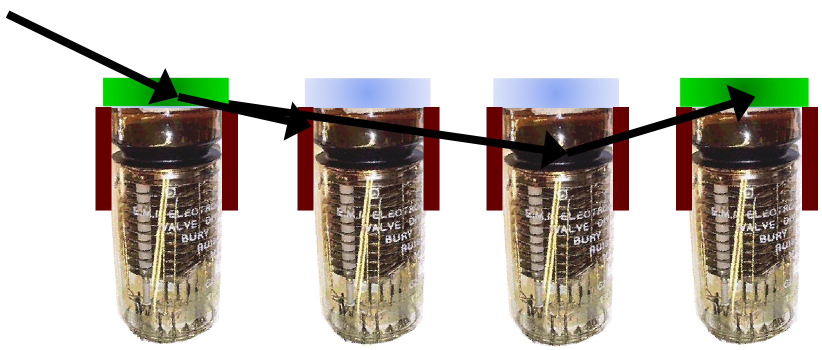
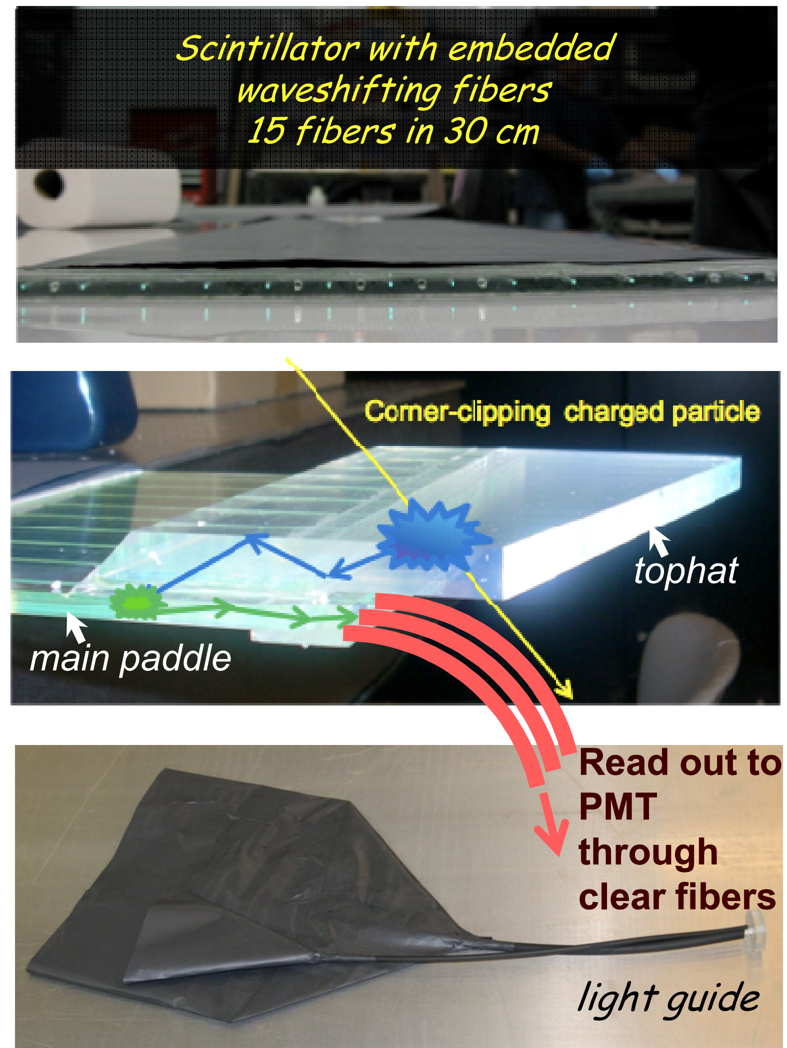
Multiple Compton scatterings of x-rays within instrument components can cause artificially increased crystal hit multiplicity:
  - Solution: 4 mm lead shielding around each PMT (+1000 lbs!).



Veto system

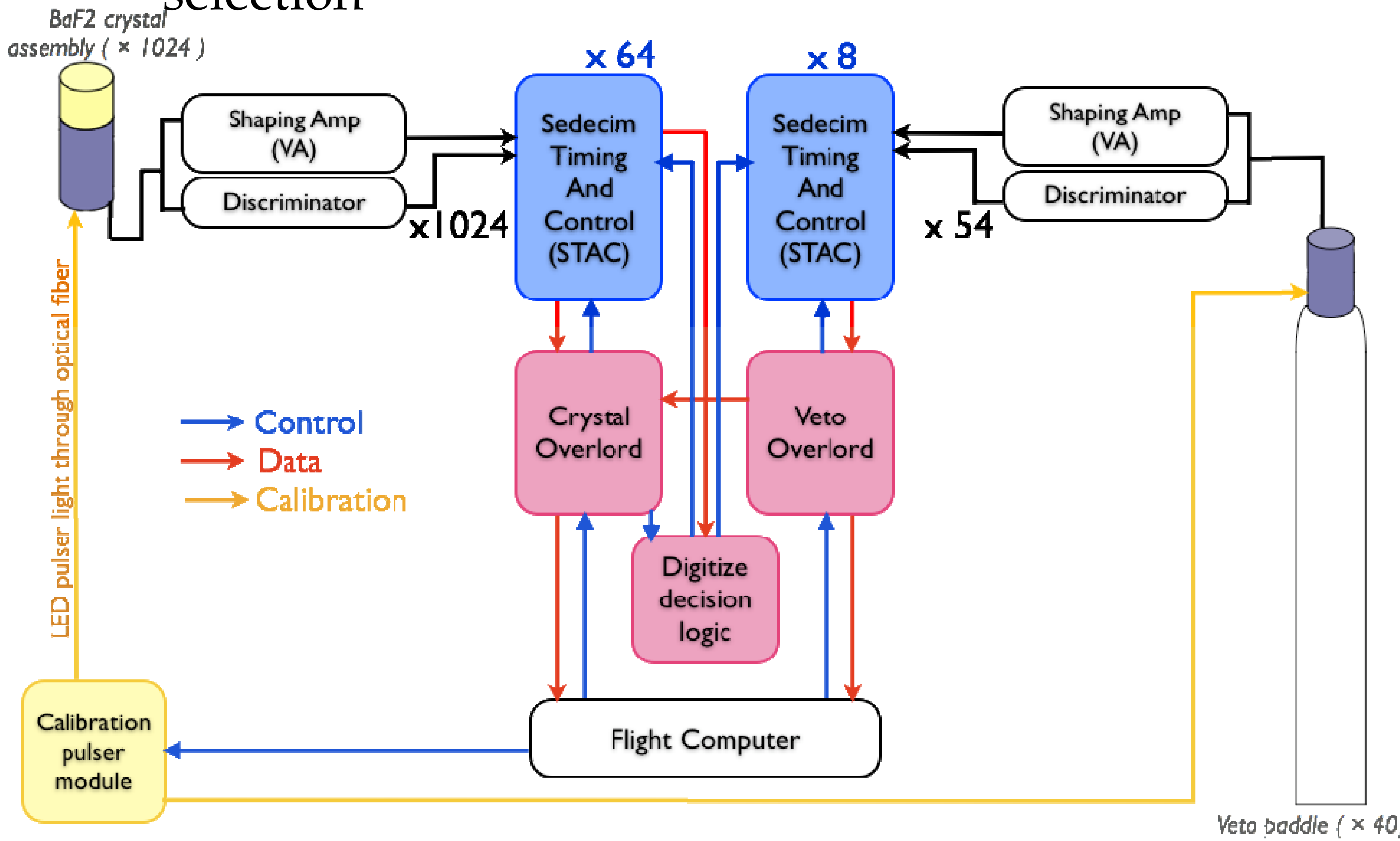
- Hermetic charged particle veto coverage on all sides
  - Eljen EJ-200 scintillator with embedded green waveshifting fiber
  - Clear fiber light guides for flexible positioning
  - "Tophat" design for coverage in tight corners

- Muon tests
  - ~ 40 p.e. summed response
  - Flat response along 2.6 m paddle length
  - End to end timing ~2 ns corresponding to ~30 cm (4 crystals)



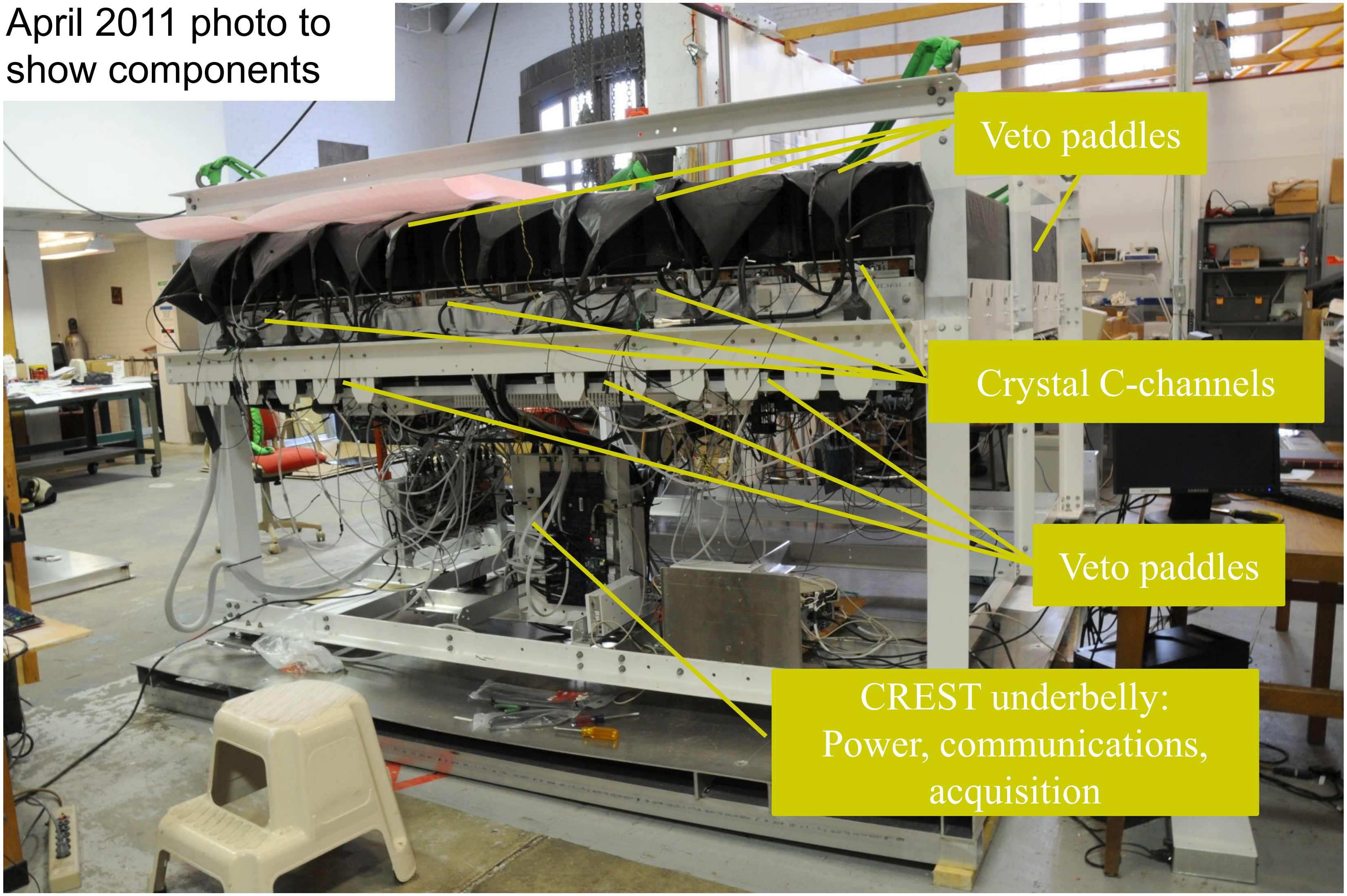
DAQ

- Trigger-less system with software patterning event selection



CREST Instrument Status

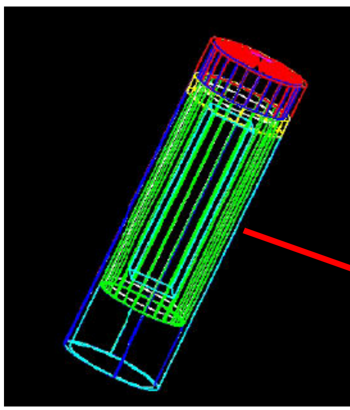
April 2011 photo to show components

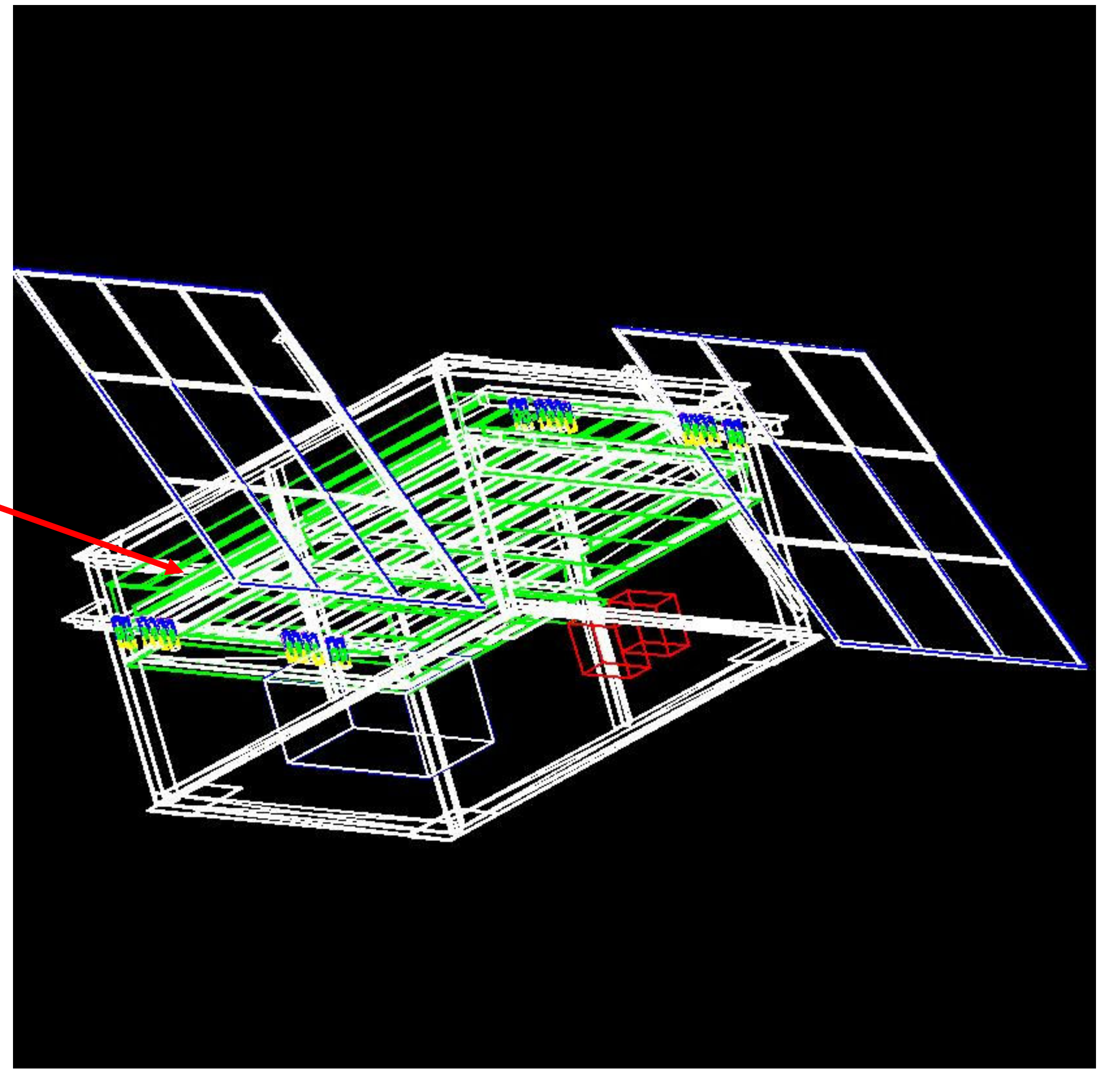


Assembly completed, integration at NASA/CSBF in progress

Instrument simulations

Output of synchrotron event generator simulation is input to a detector simulation.





Detailed GEANT4 detector mass model

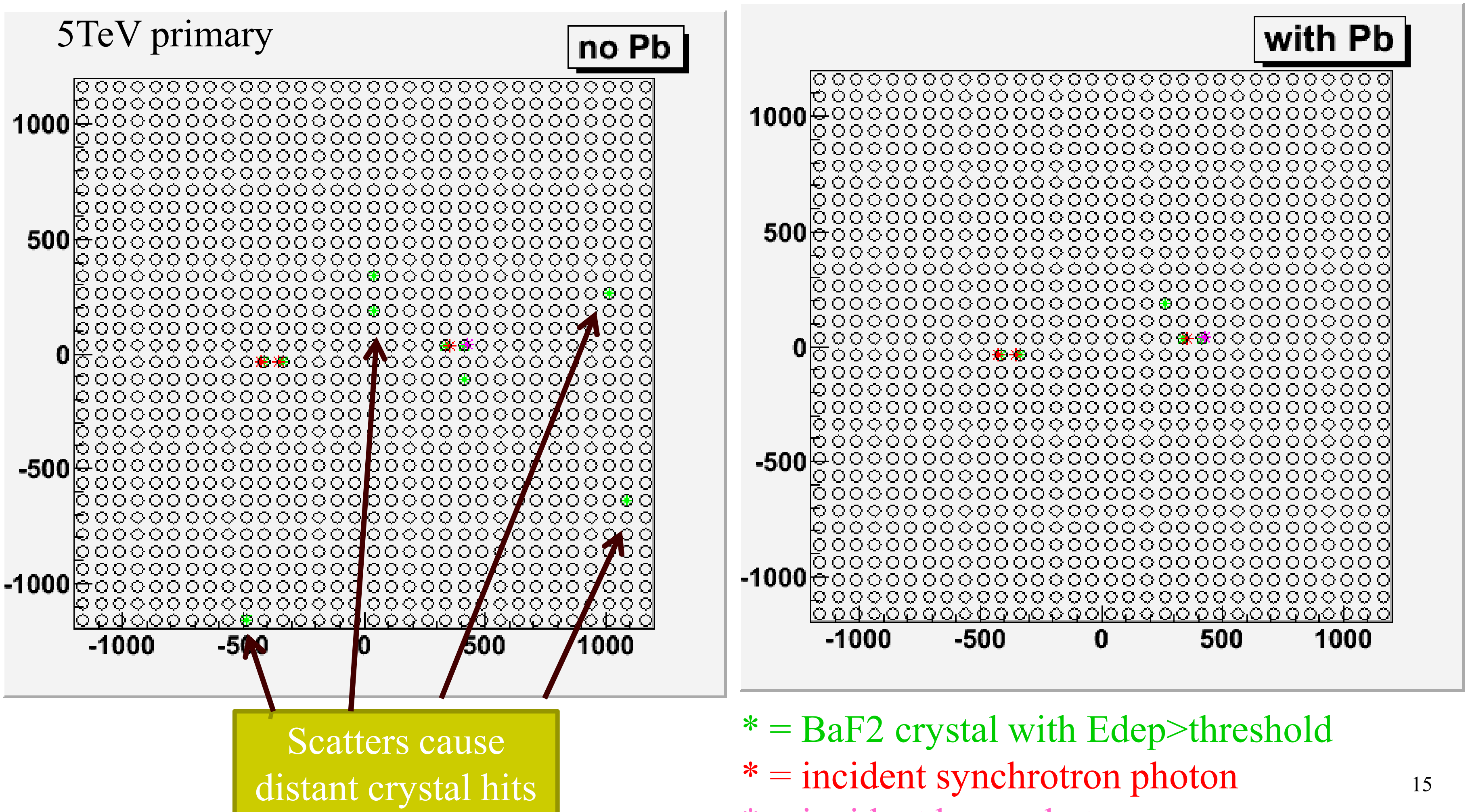
Simulations revelations

- **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 to instrument at cost of weight

- **Bremsstrahlung from primary electron**
  - Mass mean free path of ~2 g/cm^2 in air
  - Synchrotron photons are produced along whole length of electron path; brem photons are produced close to instrument, where there is most air.
  - For a 10 TeV electron:
    - There are ~50x more synchrotron photons produced than brem photons.
    - Only ~10x more synch photons survive to 4 g/cm^2 than brem photons.

Example event: lead stops scatters

Simulations



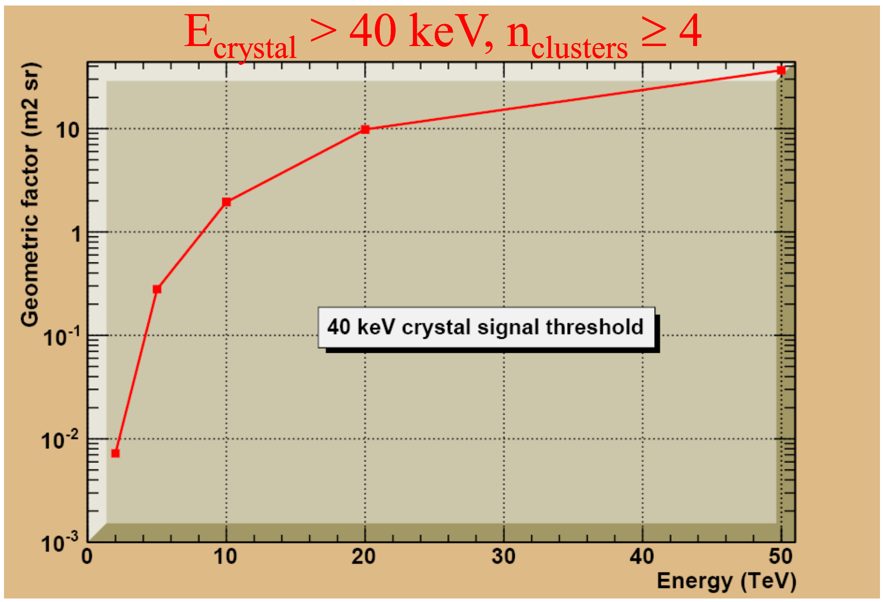
* = BaF2 crystal with Edep>threshold

* = incident synchrotron photon

* = incident brem photon

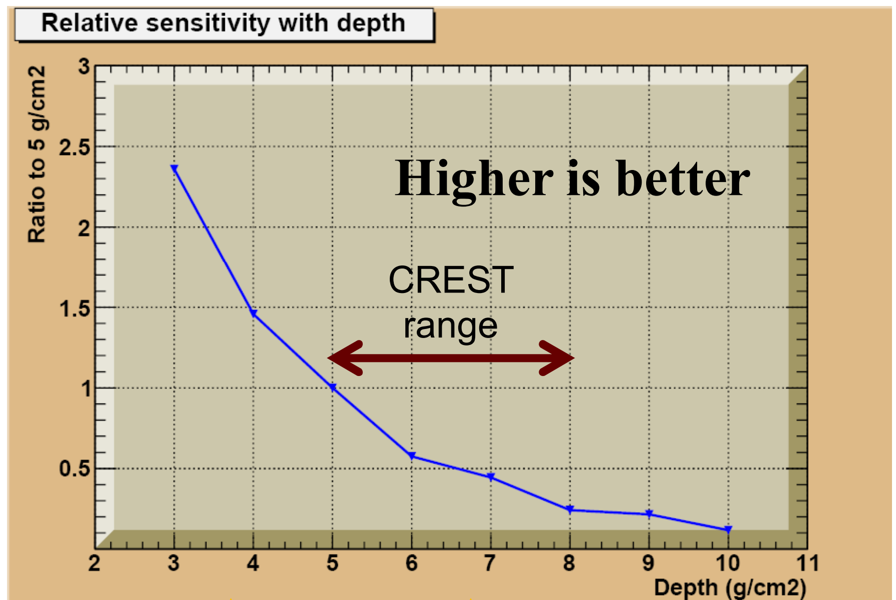
Detector Effective Area

CREST effective area vs E_e at 5 g/cm2



Low energy threshold at ~2 TeV.
Rapid increase in effective area.

Acceptance relative to 5 g/cm^2 for 5 TeV primaries



38 km
125 kft

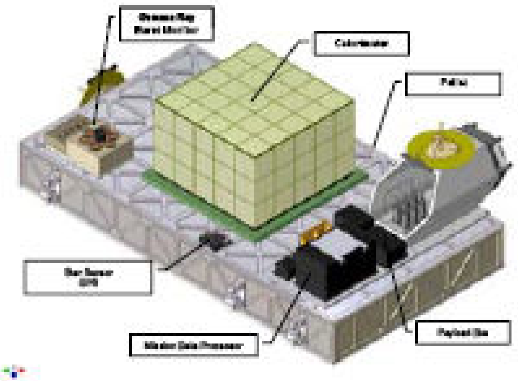
34 km
112 kft

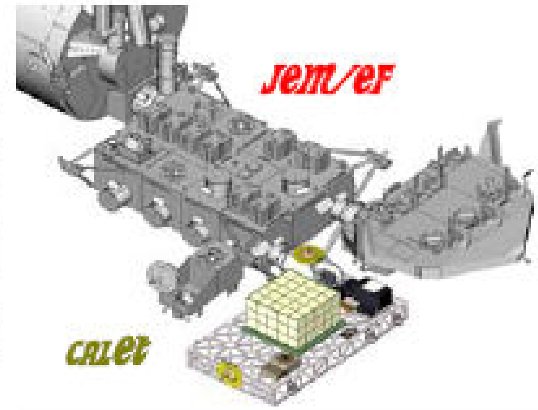
Photon attenuation ⇒ reduced acceptance with depth ⇒ higher altitude desirable.

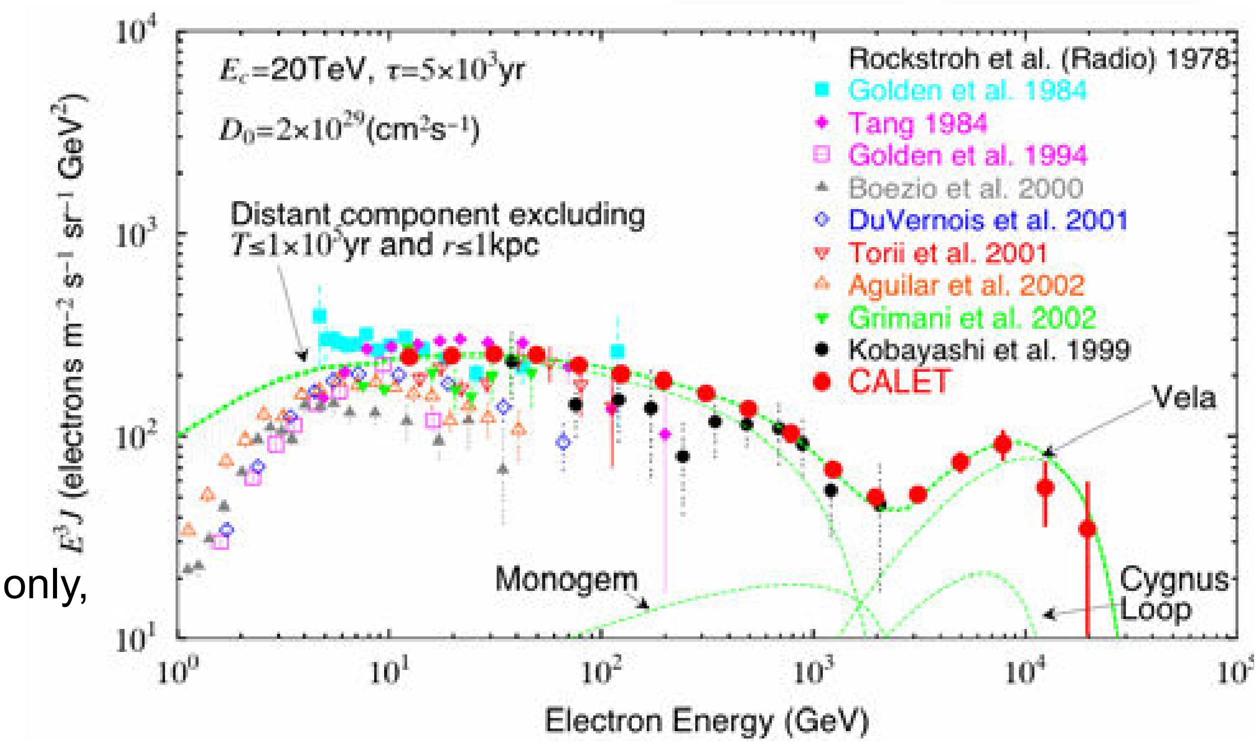
Other Efforts

- CALET: Potential for direct detection in space, up to ~20 TeV
  - On International Space Station.
  - Launch planned for summer 2013
- Air shower detectors: HESS, VERITAS?
- At < 1TeV, also PAMELA, Fermi-LAT, HESS, AMS, VERITAS, PEBS…

Most use calorimetry technique only, which suffers from large proton background.







Summary

- The electron flux at several TeV will reflect the distribution of local acceleration sites
- CREST will discover/set limits on the electron spectrum >2 TeV through the detection of the x-ray synchrotron photons generated as the electron traverses the Earth's magnetic field.
  - ~2 events per day above 2 TeV
    - Assuming $E^{-3.3}$ spectrum with no cutoff
  - ~1 background event in 30 days from random x-ray coincidence
    - Requiring 4-fold or greater coincidences, co-linear, 6 ns time window
  - Energy resolution of ~factor of 2
  - Mature simulations
- Full instrument on target for flight this Antarctic season. Second flight in later season.

CREST is lowered into the second largest thermal vacuum chamber in the world at Plum Brook NASA.