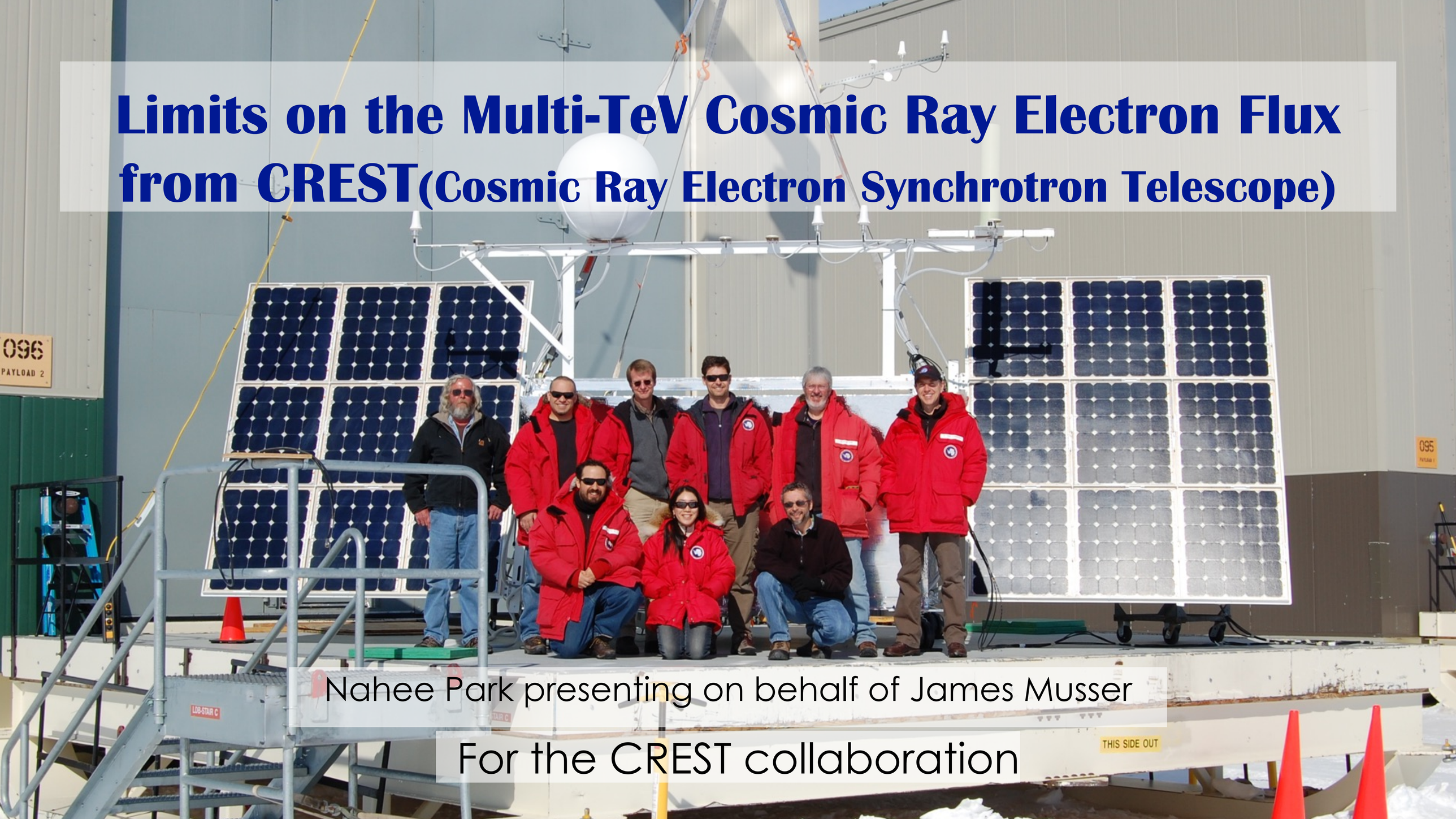
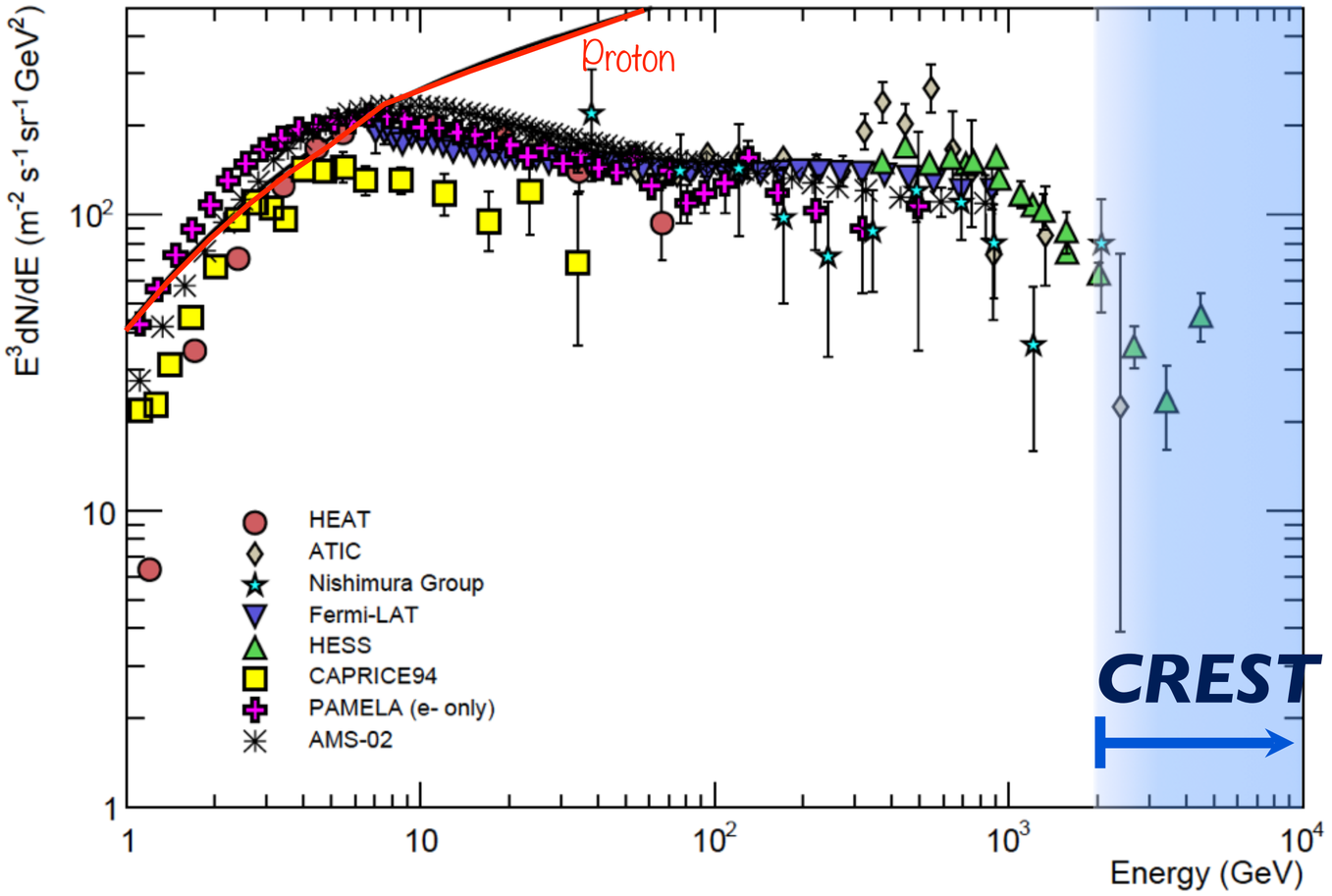
Limits on the Multi-TeV Cosmic Ray Electron Flux from CREST(Cosmic Ray Electron Synchrotron Telescope)

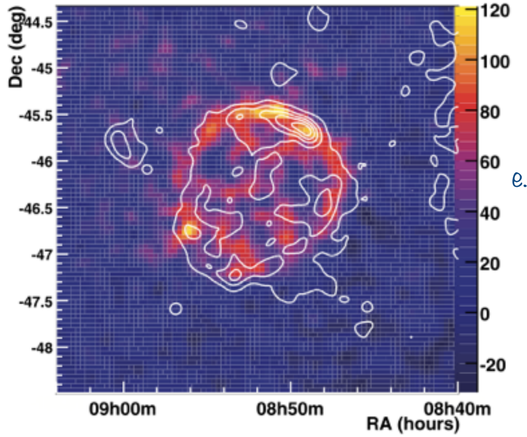


Nahee Park presenting on behalf of James Musser

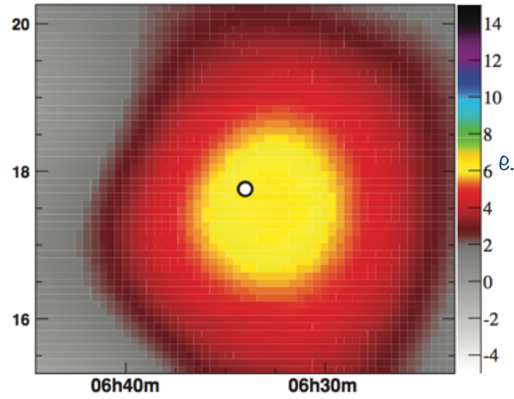
For the CREST collaboration

Multi TeV Cosmic-Ray Electrons





e.g. Vela Jr. (d ~ 0.9 kpc),
gamma-ray up to E~20 TeV



e.g. Geminga (d ~ 0.3 kpc),
gamma-ray map @ E~35 TeV

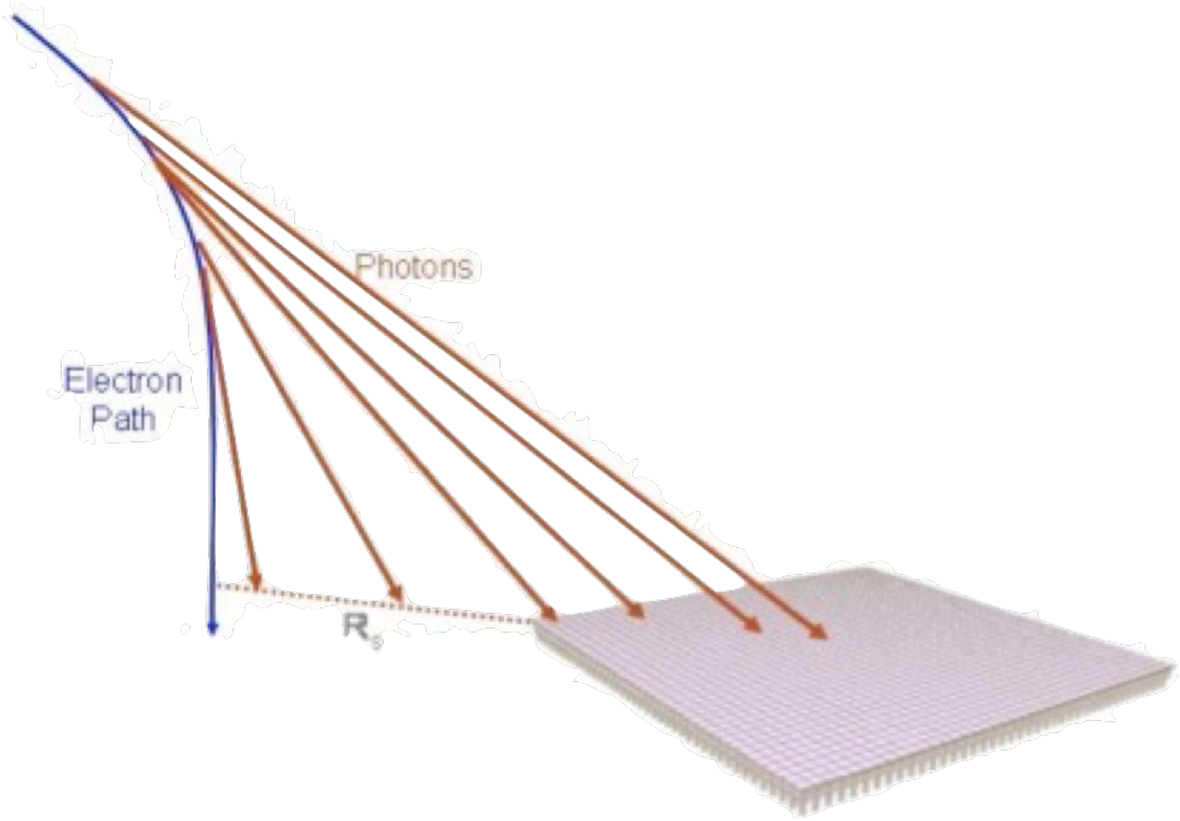
Multi-TeV region largely unexplored, where the potential is greatest for studying local cosmic accelerators (d<1 kpc)

- Difficulty of measurements due to low high energy electron flux and large proton background

Cosmic Ray Electron Synchrotron Telescope

High energy electron (> TeV) detection with synchrotron radiation

- Proposed by Prilutskii (1972) and Stephens & Balasubrahmanyan (1983)
  - Searching for co-linear, simultenous arrangement of X-ray hits in the detector (energy range between 30 keV to few tens of MeV)
- Advantages of the method
  - Increase of the effective area of the instrument
  - Proton does not produce synchrotron radiation
- Challenges
  - Rejection of large background from interactions of charge particles and gamma-rays in the atmosphere



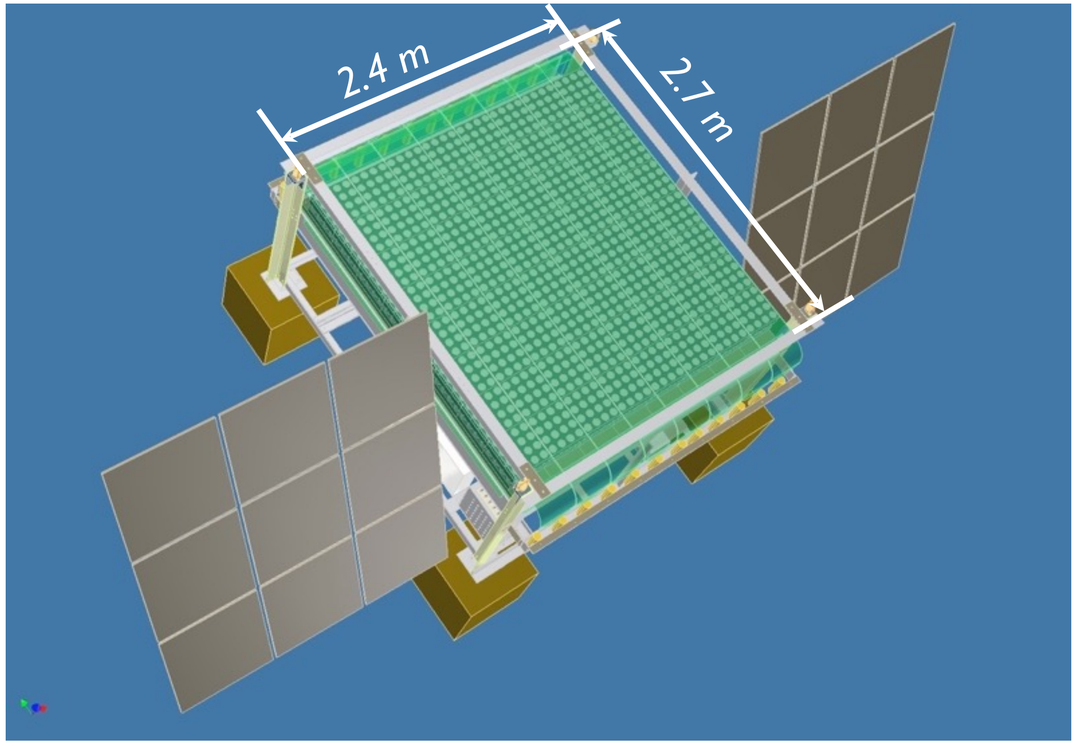
CREST Detector

Crystal array

- 1024 shielded BaF_2 crystals with 2" PMT readout
- 1 nsec timing resolution, 12% energy resolution at 511 keV

Veto paddles

- >99% hermetic thin plastic scintillator array with embedded wavelength shifting fiber readout



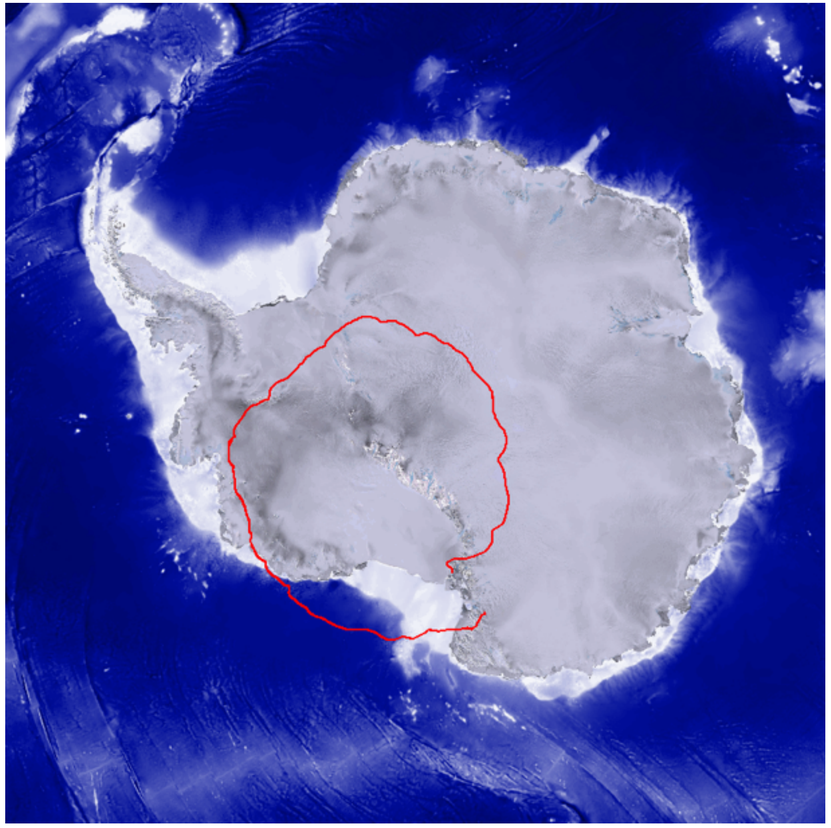
View of one crystal channel

Scintillator with embedded WLS fibers

CREST Flight

Long duration balloon flight at Antarctica during 2011/2012 season

- Total ~ 10 days of flight time
  - Launched on December 25th, 2011
  - Termination on January 5th, 2012

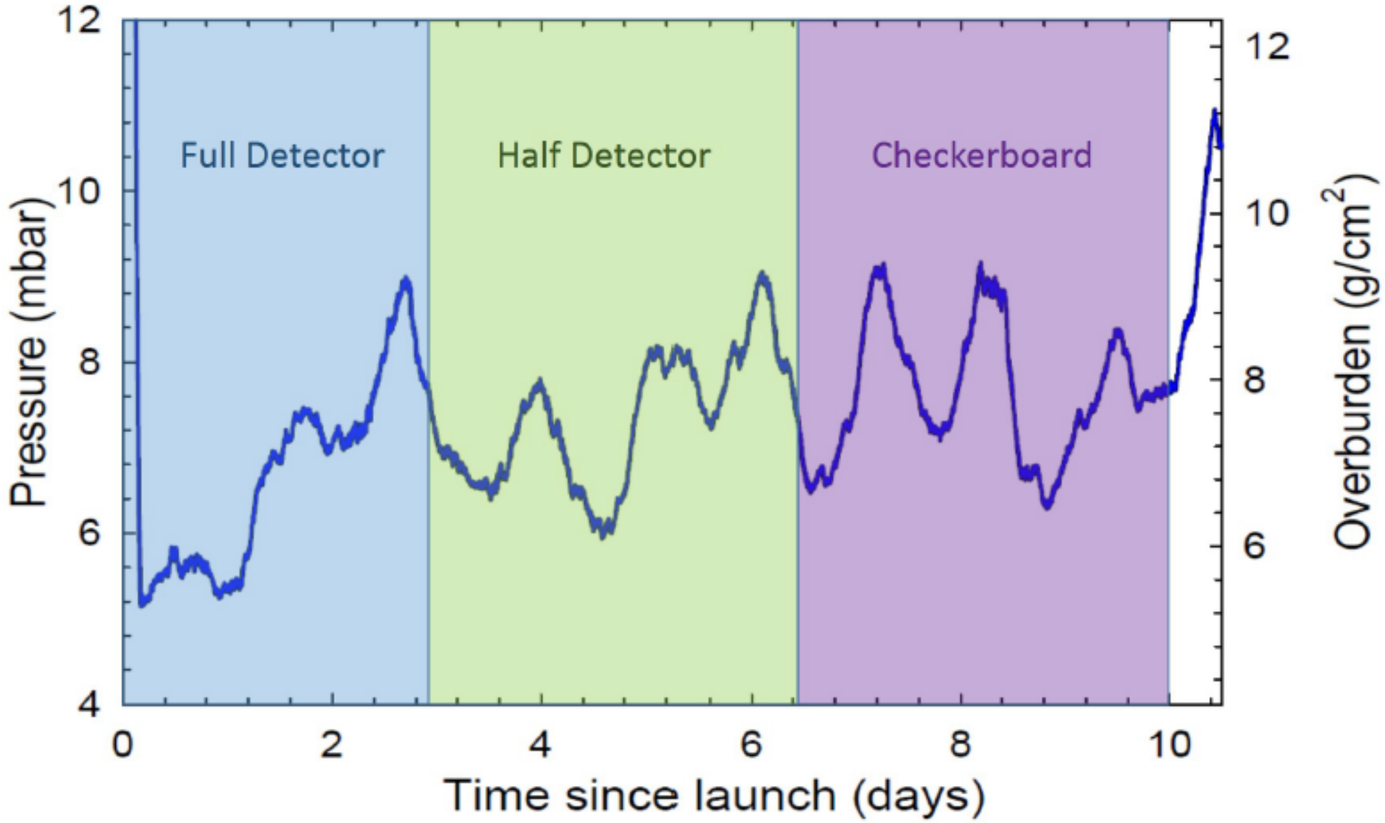


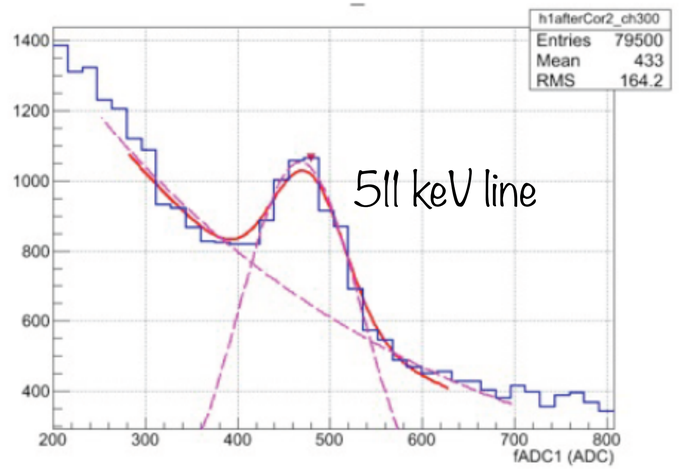
CREST Flight (2)

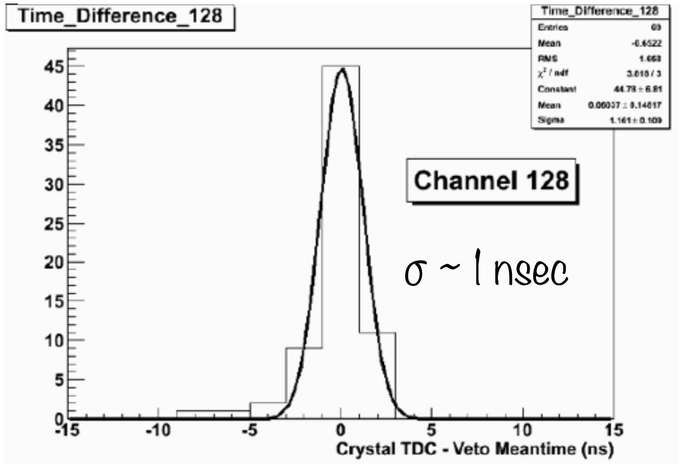
Average grammage : 7.58 g/cm^2

Three configurations during the flight

Calibration during the flight showed stable timing and energy resolution

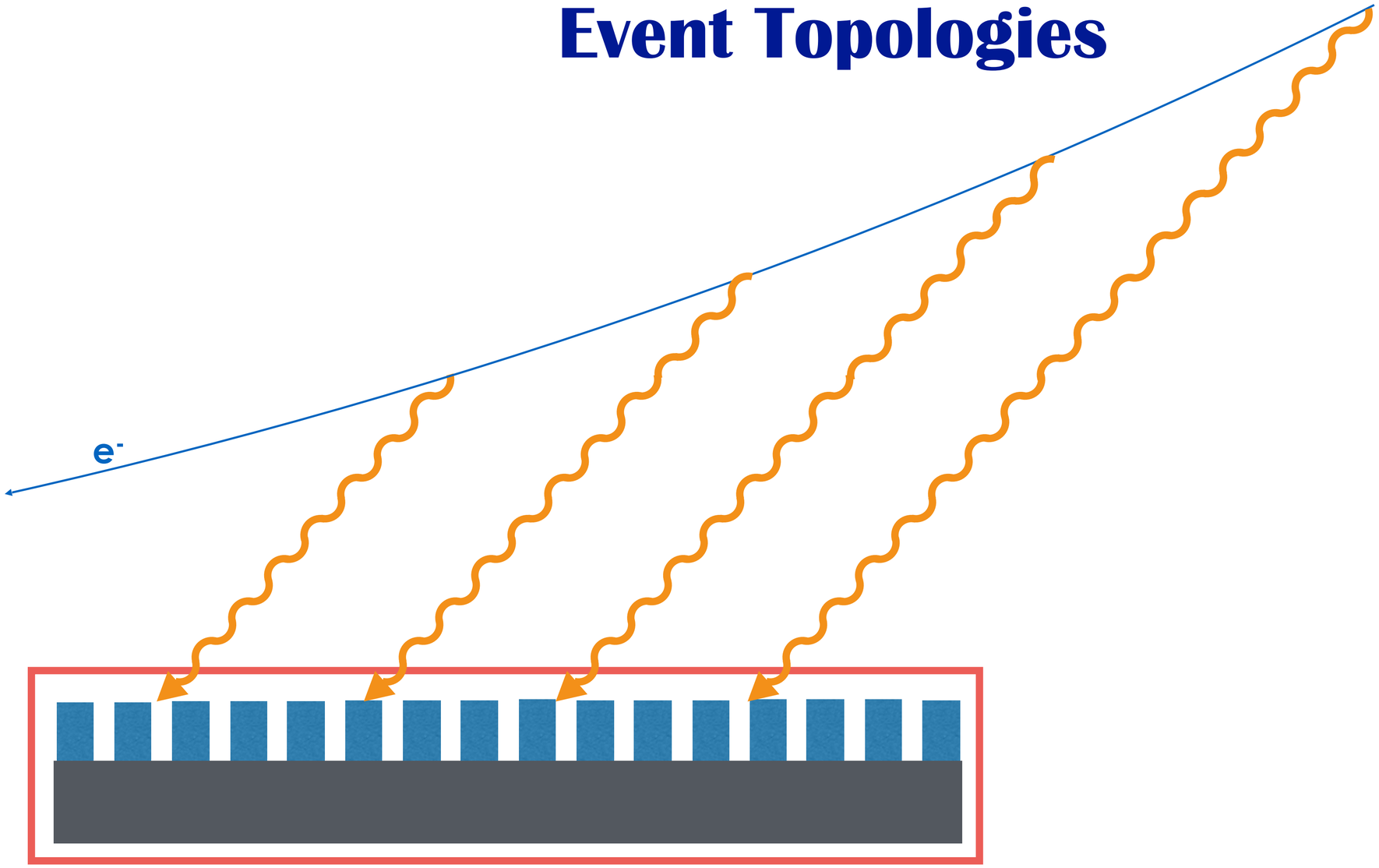






Event Topologies

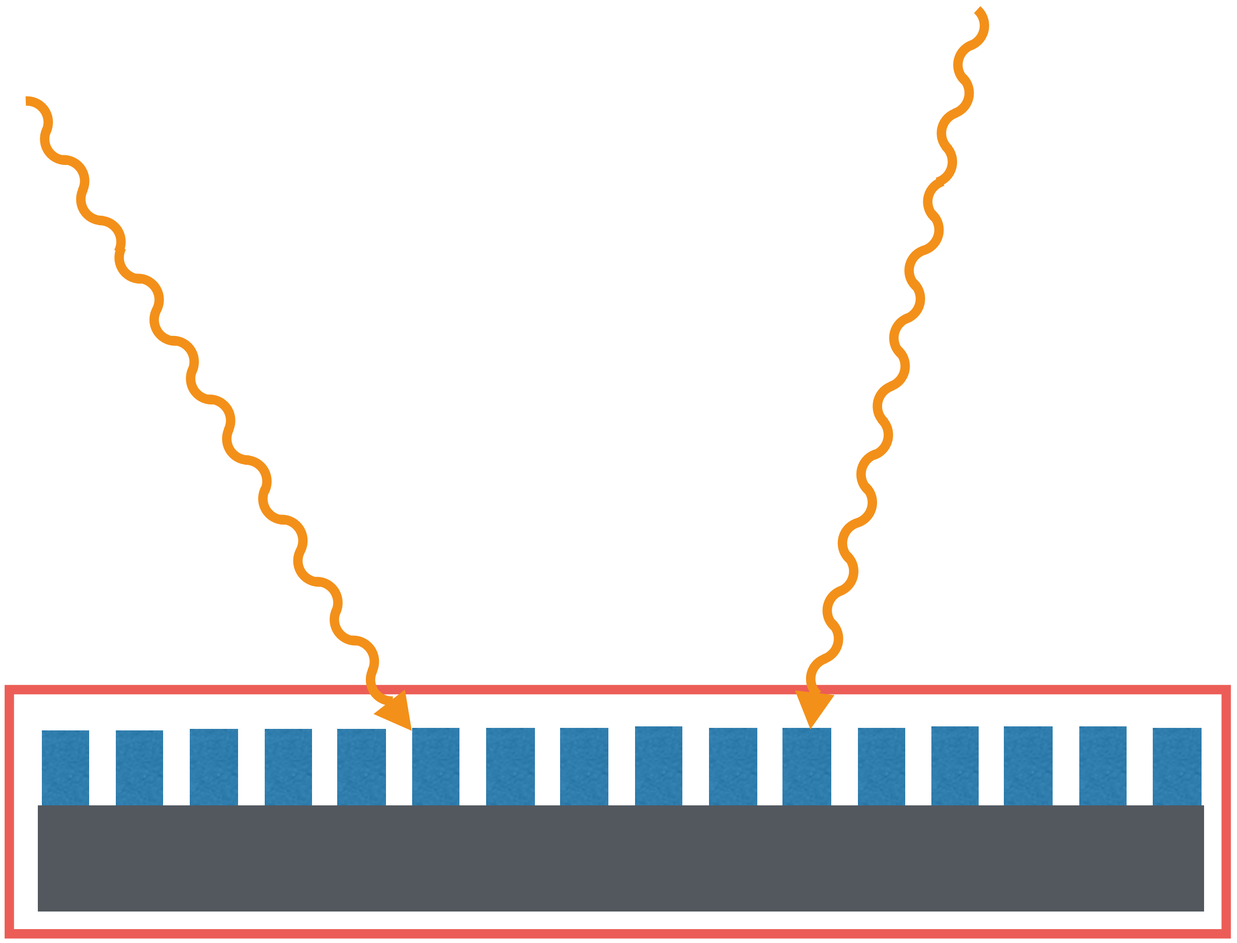
Event Topologies



Good events

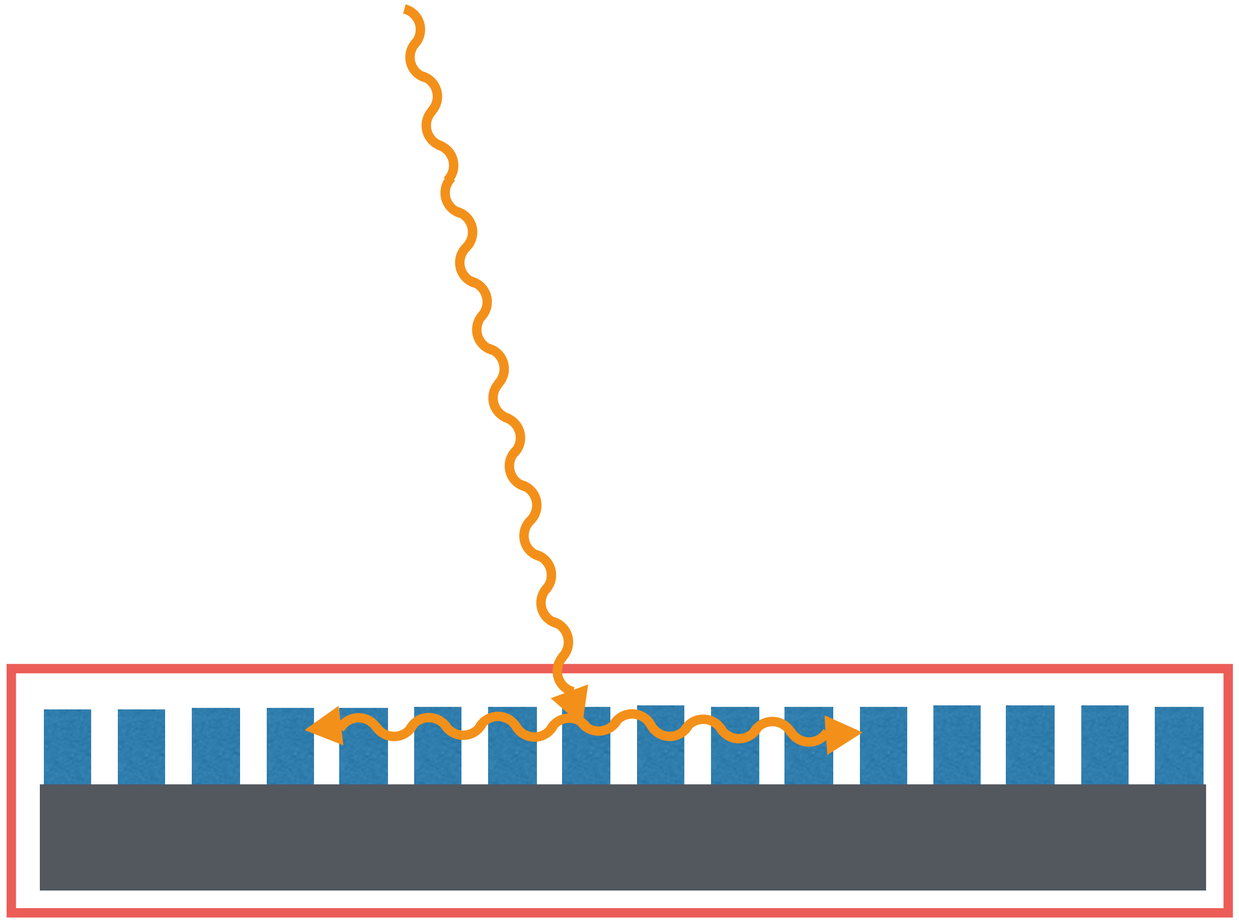
Event Topologies

Event Topologies



Accidental coincidence

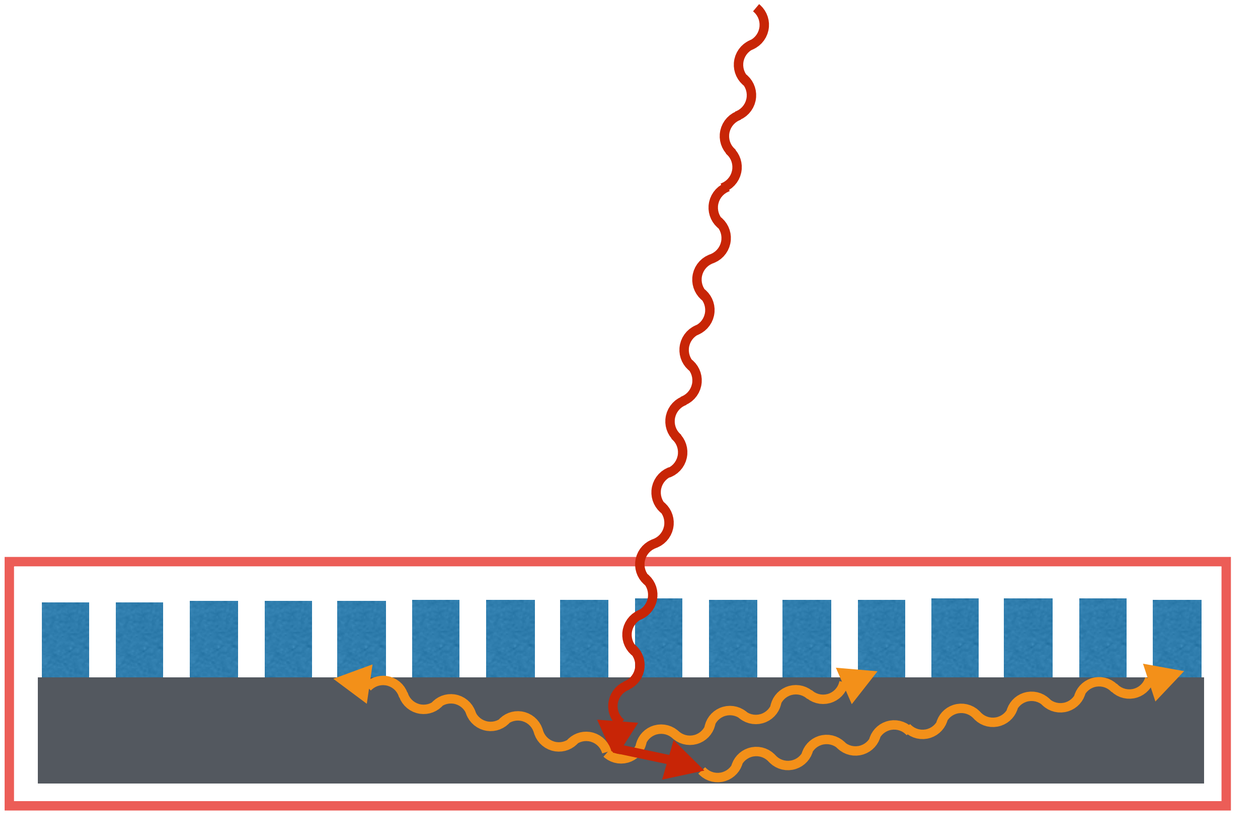
Event Topologies



Accidental coincidence

X-ray Multiple scattering

Event Topologies

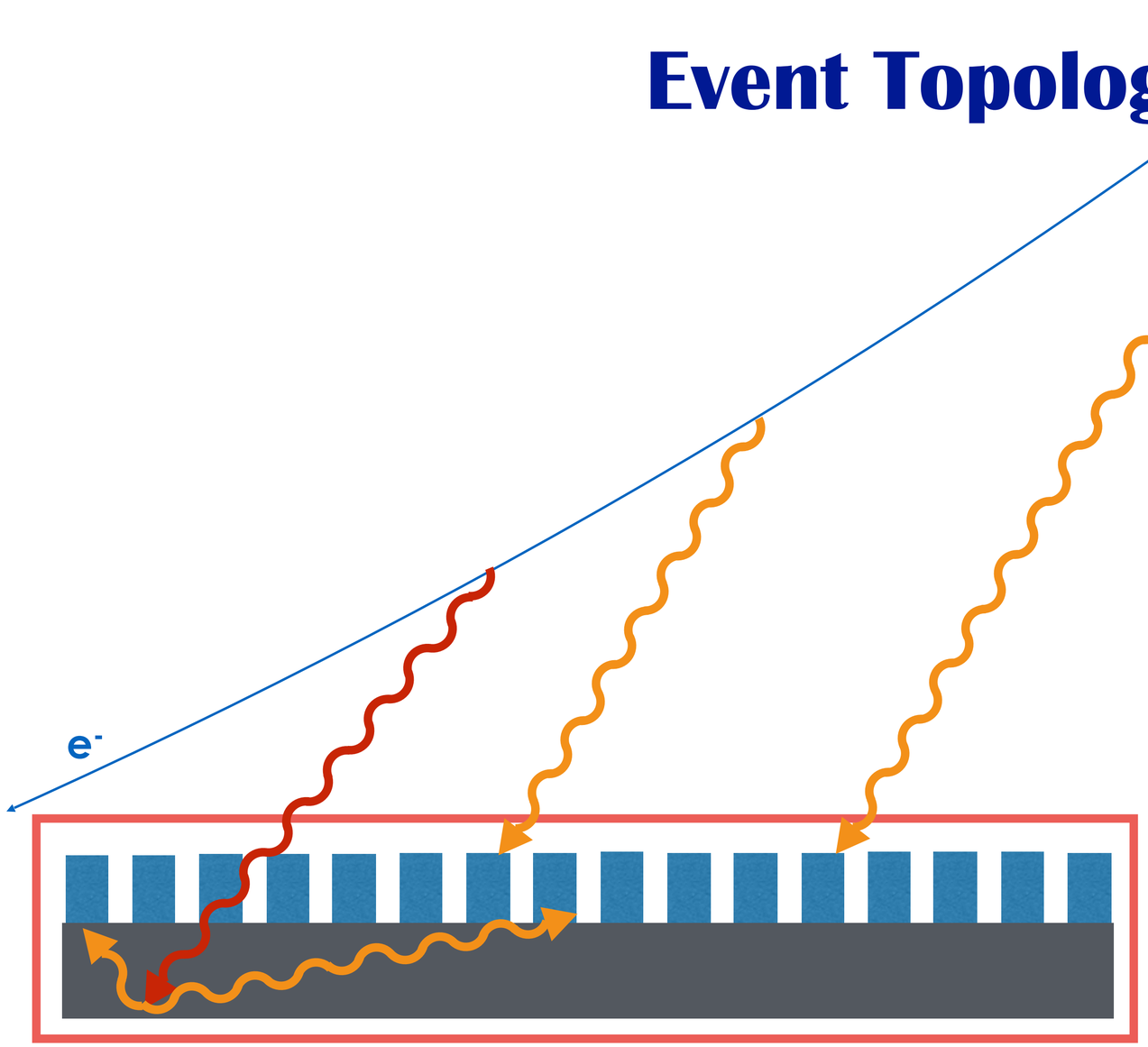


Accidental coincidence

X-ray Multiple scattering

Interaction inside detector

Event Topologies



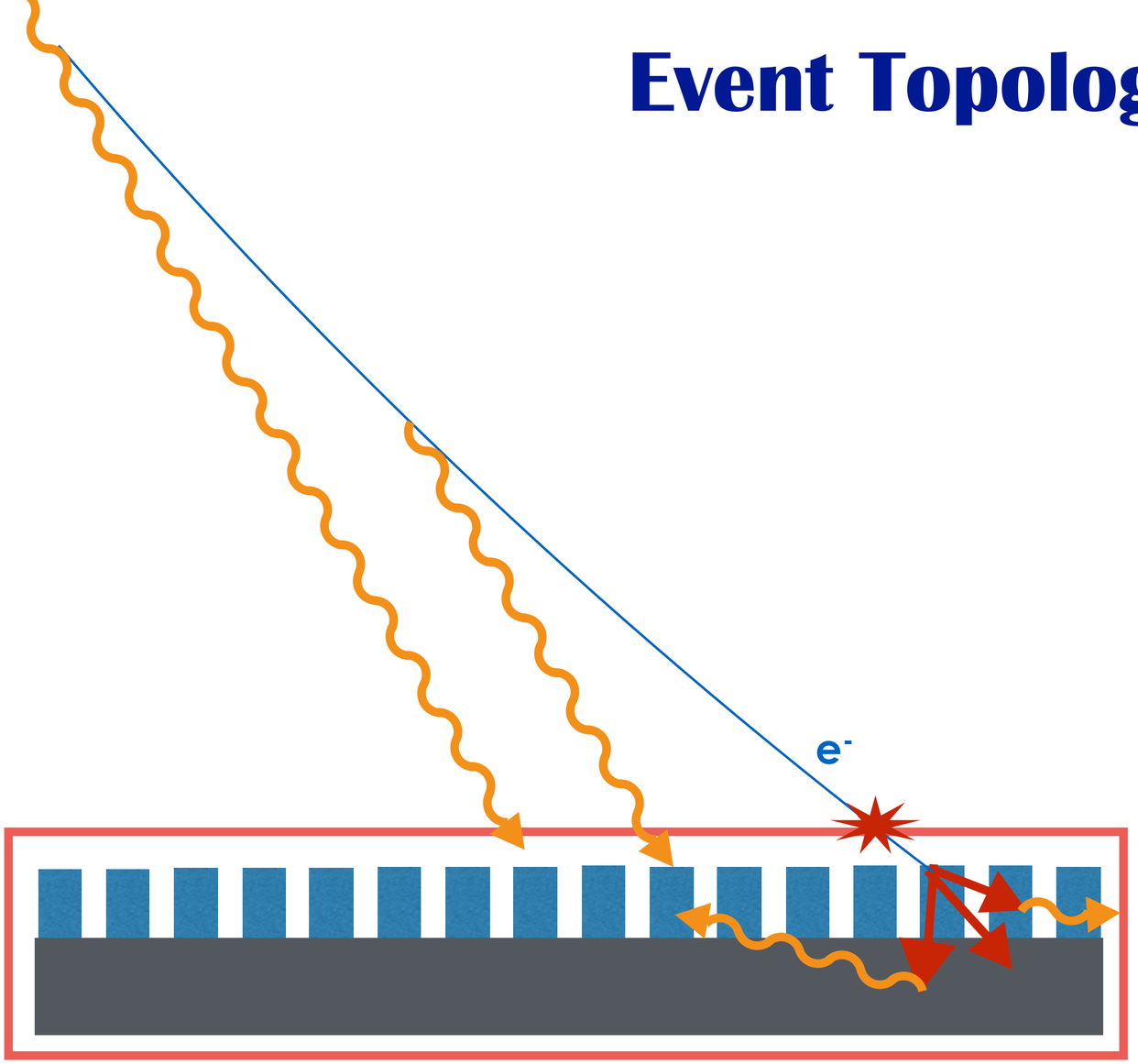
Accidental coincidence

X-ray Multiple scattering

Interaction inside detector

Bremsstrahlung from primary electron

Event Topologies



Accidental coincidence

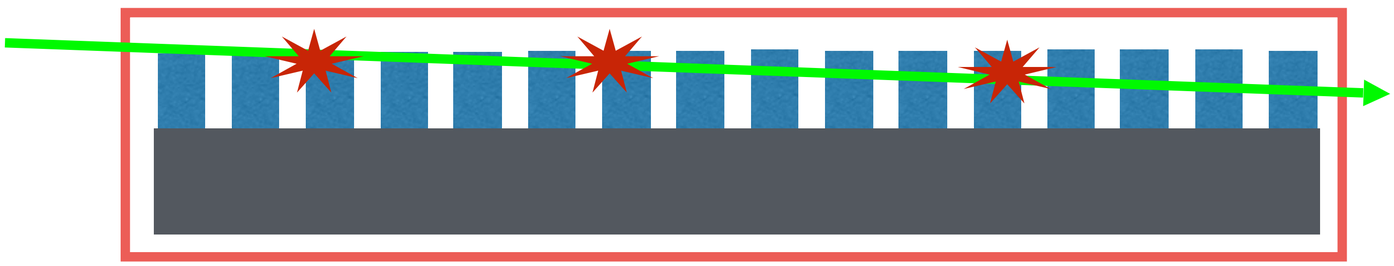
X-ray Multiple scattering

Interaction inside detector

Bremsstrahlung from primary electron

Primary electron passing through detector

Event Topologies



Accidental coincidence

X-ray Multiple scattering

Interaction inside detector

Bremsstrahlung from primary electron

Primary electron passing through detector

Horizontally passing through charged particle

Simulation

To understand background events, huge amount of simulation data processed

- 1.2 M CPU-hours to simulate 50 days of background events
- Background includes primary and secondary cosmic rays
  - Different altitudes, energy range between 30 keV and 100 GeV
  - Two background models (modified GLAST model & QARM model)

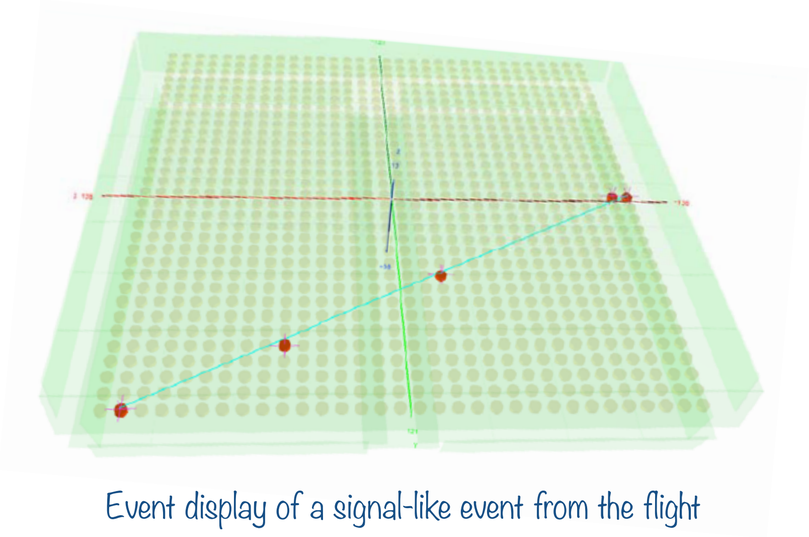
Full Earth-scale simulation for signals

- Full simulation of flight trajectory (altitude, latitude, longitude)
  - Magnetic field : World Magnetic Model (2010 model)
  - Atmosphere : NRLMSISE-01 Model
- Results fed to GEANT4 detector model

Analysis

Instrumental signature of a ‘golden’ synchrotron event

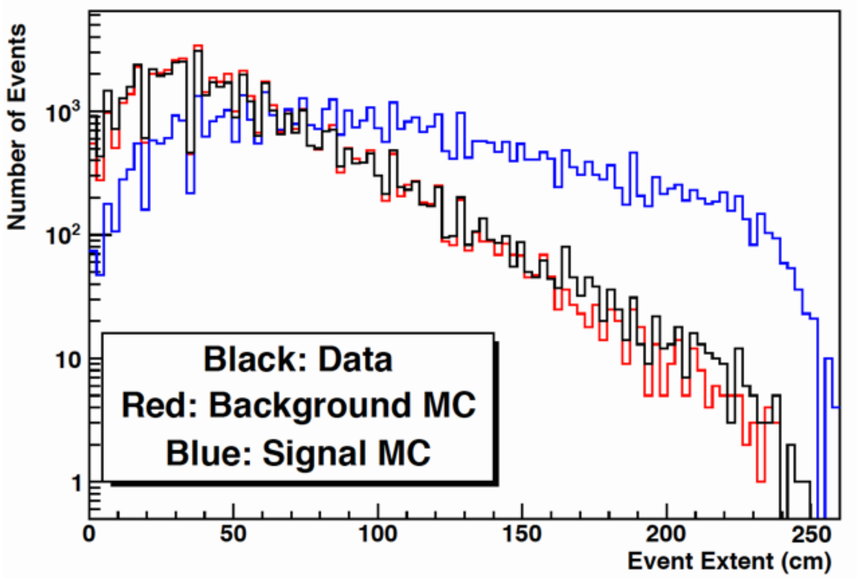
- A set of co-linear, simultaneous crystal hits with no activity in the veto system
  - Events with large extension with isolated hit clusters are more likely to be synchrotron-like events
- Very stringent cuts needed to remove background events
  - For each cut, data/MC consistency verified



Event display of a signal-like event from the flight

Table 1: Event Selection Summary

Event Selection	Rate Hz (Data)	Rate Hz (MC)	20 TeV Electron Selection Eff.
raw (hardware trigger rate)	3055	3177	1.0
no veto activity	277	181	0.14
# clusters > 3	8.4	7.4	0.056
event extent > 75 cm	3.2	2.7	0.86
largest inter-cluster gap > 40 cm	2.2	1.4	0.99
hit time vs position $\chi^2 < 5$	1.9	1.3	0.98
crystal x vs y fit $\chi^2 < 5$	0.064	0.04	0.30

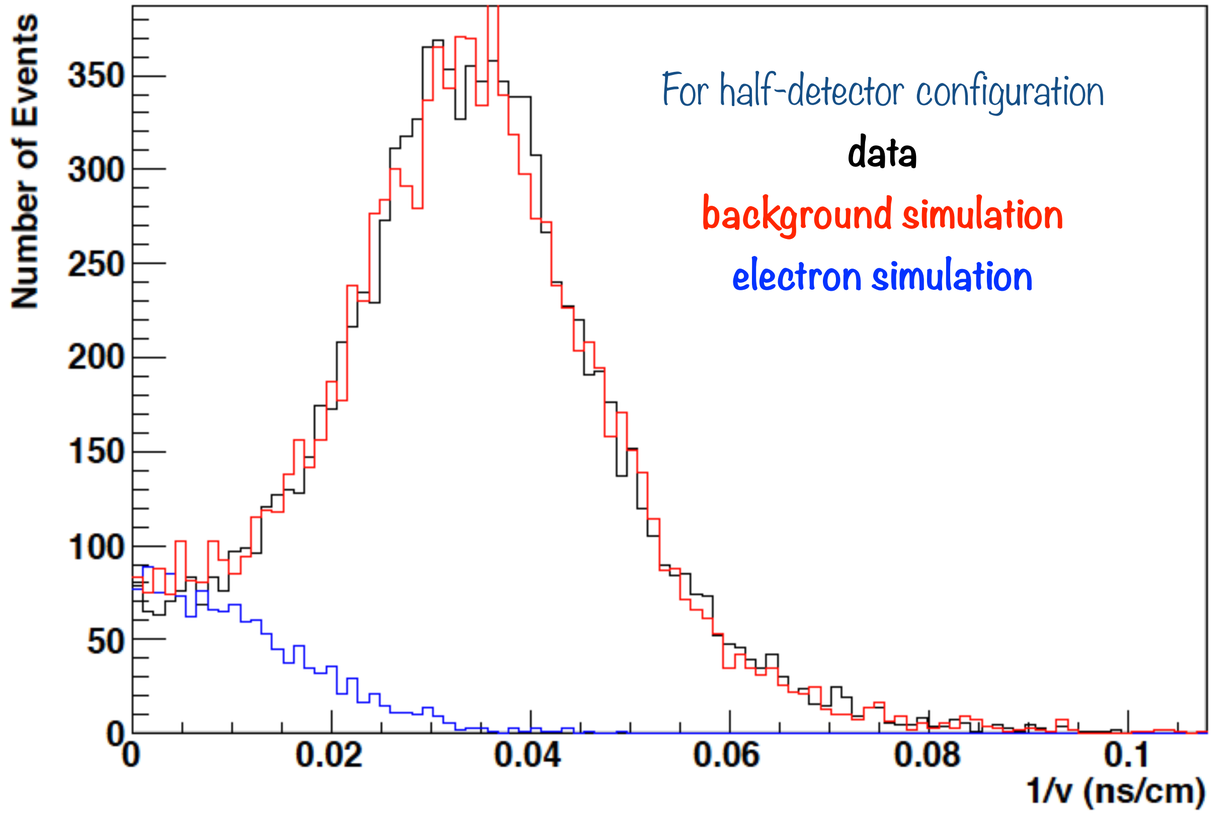


Event extent comparison between data and MC

Results

Final signal/background discriminator : Using propagation velocity of hits

- Signal : peaks at zero
- Background : peaks at speed of light



Preliminary upper limit

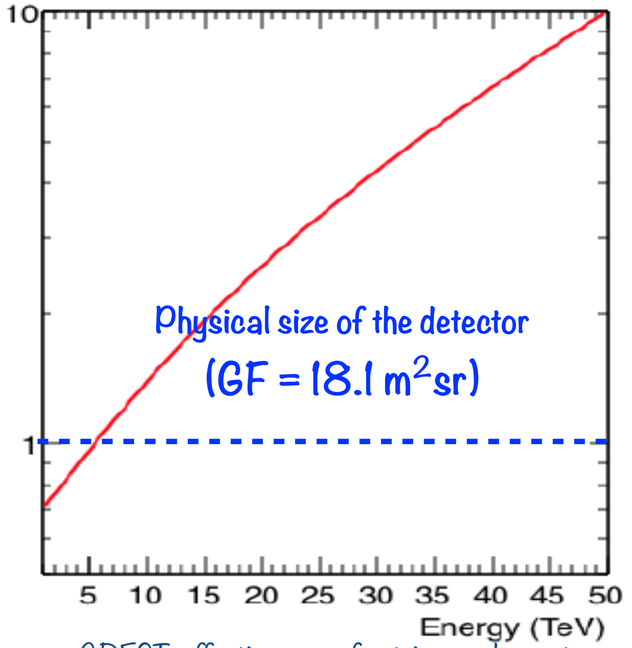
- With E^{-3} electron spectrum: Flux < 7.11×10^{-3} m^{-2} sr^{-1} s^{-1} (with 90% confidence level for E > 15 TeV)

Discussion

CREST signal simulation demonstrates that synchrotron method can provide large effective area

However, high background levels compelled strict cuts at the expense of signal efficiency

- Correlated hits from interacting gammas were particularly hard to reject
- Small residual veto inefficiency during the flight
- Current limit is not constraining



CREST effective area for triggered events

Lessons learned

- Success of method depends on high Q-factor cuts
  - ✦ Some advantages to going to space
    - Reduced secondary particle intensity.
    - Albedo gamma-rays will still be a challenge
- Instrumentation improvements
  - ✦ Better timing resolution with larger detector
  - ✦ Smart & even more hermetic veto system

Table 2: Background event type fraction

Background event type	Fraction of total rate after event selection
Upward secondary gammas	0.3
Downward secondary gamma	0.25
Primary charged particle	0.25
Neutrons	0.07
Low-energy electron	0.055
Secondary charged particles	0.045
Primary gamma	0.03

Summary

CREST was designed to measure very high energy electrons with geo-synchrotron radiations on balloon platform.

- CREST detector achieved 1 nsec timing resolution with 1:1000 dynamic range of X-ray energy estimation to study the simultaneous synchrotron radiations originated from high energy electrons.

CREST had a 10-days of scientific flight at Antarctica in 2011/2012.

Background events were too large to make the method work effectively as a balloon experiment.

- Extensive simulation studies have been carried out to understand the source of background and signal selection efficiency.
- Preliminary upper limit for E>15TeV is presented.