Study of Cosmic Ray Electrons with the Large Area Telescope

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Discovered by Victor Hess in 1912 at balloon experiment:

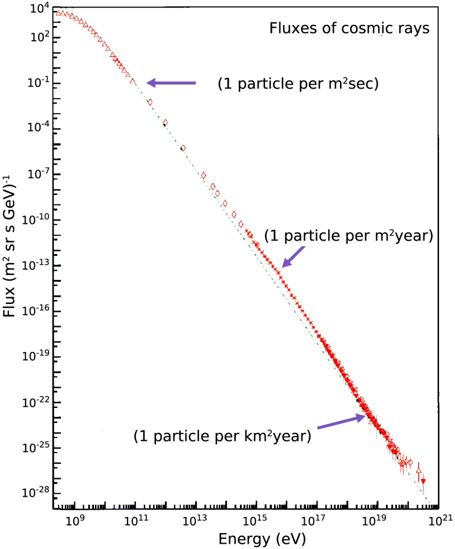
"Extremely penetrating radiation coming from above the atmosphere"

Actually he observed secondary particles.

Primary particles:

- neutral: ν, γ
- charged: p, $\overline{p}$, $e^{\pm}$, α, heavier atomic nuclei

- Overall spectrum well described by a broken power-law $\sim kE^{-\delta}$
- Up to 10^{15} eV (knee): Galactic CRs
- Can be explained in term of acceleration in SNRs + diffusion in the Galactic magnetic field
- $E > 10^{15}$: ExtraGalactic CRs (sources?)



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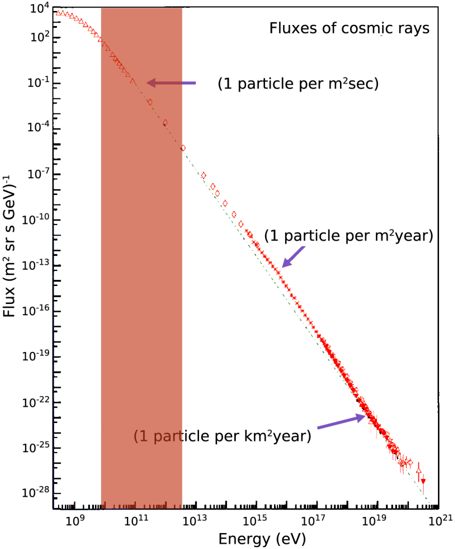
- $E > 10^{15}$: ExtraGalactic CRs (sources?)
- Interesting region for this study: a few GeV - 3 TeV



A peculiar component of cosmic rays observed at Earth

(Note: from now on 'electrons' $\rightarrow e^+ + e^-$)

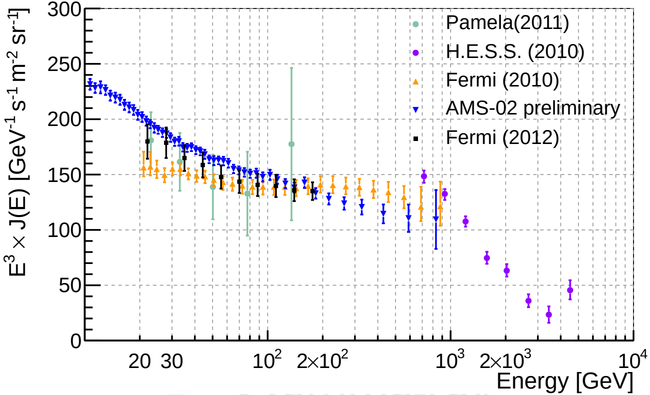
- Rapid energy loss:
  - Synchrotron radiation on galactic magnetic fields
  - Inverse Compton (IC) scattering on interstellar radiation field

$$\frac{dE}{dt} \sim \frac{E^2}{m^2}$$

(ultrarelativistic limit)

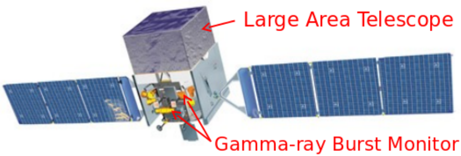
High-energy electrons reaching the Earth are generated 'near' us.

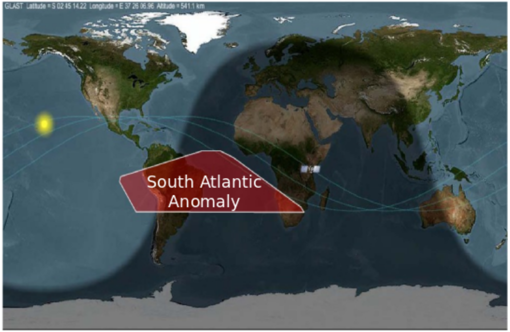
- At 1 TeV:
  - livetime $\simeq 10^5$ year
  - typical diffusion distance is $\simeq 0.6 - 0.9$ kpc
- Possibly showing the effect of near sources:
  - deviation from PL, anisotropies



- Power law of index $\sim (-3)$
- Some tension between different experimental measurements
- Spectral cut-off observed by H.E.S.S above 1.5 TeV

Fermi Space Observatory





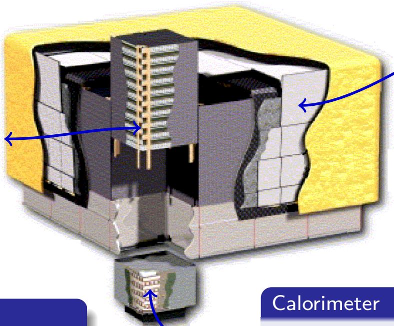
- Launch in June 2008
- Altitude : $\sim$ 565 km
- Inclination : $\sim$ 25.6 deg
- Period : $\sim$ 1.5 h
- Survey mode : rocking between the northern and the southern hemispheres every orbit
- Full sky is observed every $\sim$ 3 h
- 2 instruments: LAT and GBM, covering different energy ranges

The Large Area Telescope

- Overall modular design
- 4×4 array of identical towers (each one including a tracker and a calorimeter module)
- Tracker surrounded by and Anti-Coincidence Detector (ACD)

Tracker/Converter

- 18 planes of silicon strip detectors
- W foils to enhance conversion probability: 1.5 radiation lengths on-axis
- 10k sensors, 80 m^2 of silicon active area, 1M readout channels



Anti-Coincidence Detector

- Segmented (89 tiles) as to minimize self-veto at high energy.
- 0.9997 average MIP detection efficiency.

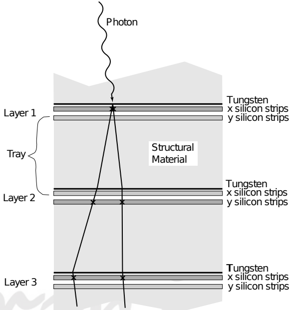
A few numbers

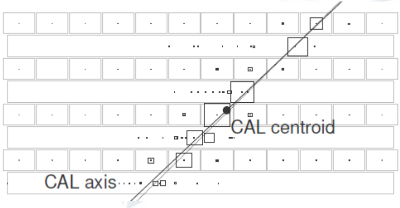
- $\sim 1.5 \times 1.5$ m^2 area
- $\sim$ 3000 kg mass
- $\sim$ 650 W power absorbed

Calorimeter

- 1536 CsI(Tl) crystal; 8.6 radiation lengths on-axis.
- Hodoscopic, 3D shower profile reconstruction for leakage correction.

- Typical γ-ray events start with conversion into e^+e^- pair in the tracker
- Subsequent e.m. cascade registered by the CAL below
- For electrons the first interaction is typically bremsstrahlung, otherwise they are similar





- Each crystal hit gives (x, y, z) coordinates in the CAL
- Moment analysis and fit to the shower profile to estimate energy

Why an update?

- 6 years of data:
  - several 10^7 events above 20 GeV, $\sim$ 10k events above 1 TeV
  - sistematic dominated in the whole accessible energy range
- Improved event reconstruction and selection (Pass 8):
  - Energy reconstruction algorithm updated, now working up to 3 TeV
  - Better handling of "ghost" events thanks (mainly) to clustering in the CAL
- Ghost events: remnants of particles passing through the LAT a few μs before or after the real event

Definition

We compute the *differential intensity* $\mathcal{I}_i(E)$ in the i-th bin (centered at energy E) as:

$$\mathcal{I}_i(E) = \frac{R_{evt,i}(E,s) - R_{bkg,i}(E,s)}{\mathcal{A}_i(E,s)}$$

- $R_{evt,i}(E,s)$ is the event rate after a given selection s.
- $R_{evt,i}(E,s)$ is the estimate background rate.
- $\mathcal{A}(E,s)$ is the Acceptance (or Effective Geometrical Factor):

$$\mathcal{A}(E,s) = \int A_{eff}(E,\theta,\phi,s)d\Omega$$

Effective area:

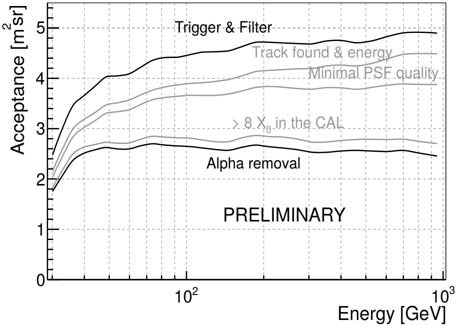
$A_{eff}(E,\hat{v},s)$: product of the geometrical cross section of the detector, the efficiency of selection s and the interaction probability for an incoming particle with energy E and direction $\hat{v}$ in the LAT reference system.

CR electrons selection:

- Trigger and event-quality cuts
- Removal of particles with Z $>$ 1 (easy to tag by ionization in ACD and TKR)
- Main selection, using Classification Trees, for residual hadronic contamination rejection (protons).

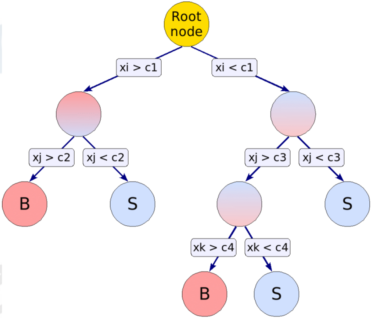
Event quality:

- At least on successfully reconstructed track
- Path length greater than 8 X_0 in the CAL, removing evts close to the edges or not well reconstructed
- Minimum quality of direction reconstruction



Classification Tree:

- Multivariate analysis technique for event classification
- CT $\rightarrow$ sequence of binary split of the sample based on single-variable test
- Each terminal block ('leaf') is associated with a classification probability



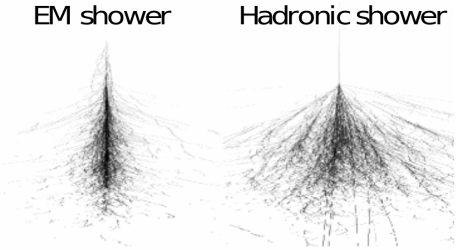
Boosted Decision Trees (BDT):

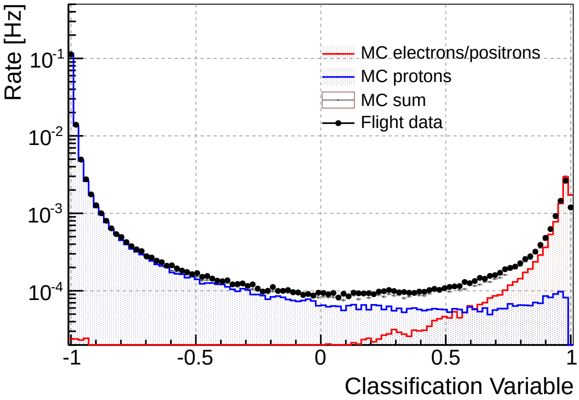
- A whole forest of (hundreds of) 'small' trees
- Each tree derives from the previous, giving higher weights to misclassified events
- The final probability is a weighted average of all the trees

- Example of input variables:
  - Chi-square of the shower three-dimensional fit
  - Shower transverse size in CAL
  - Time over Threshold signal averaged across the planes of the TKR (already used in pre-selection)
  - Hit density along the main track
- The CT combines all the information!

PDG values of X_0, λ, R_M for the CsI

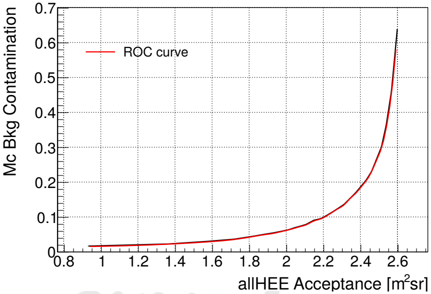
X_0	1.85 cm	$8.39\ \mathrm{g \cdot cm^{-2}}$
R_M	3.8 cm	$15.92\ \mathrm{g \cdot cm^{-2}}$
λ	38.04 cm	$171.5\ \mathrm{g \cdot cm^{-2}}$

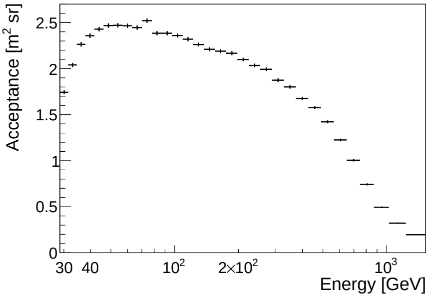


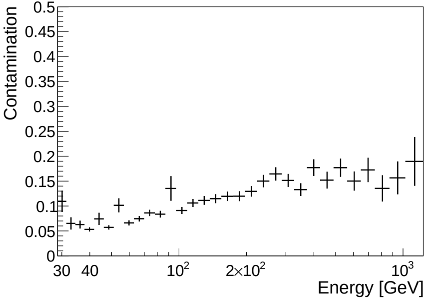


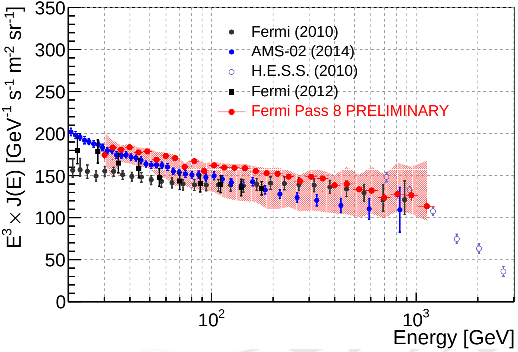
- Normalization of Monte Carlo templates fitted to data in each energy bin.
- Normalization factor used in bkg estimation.

- Working point is a trade-off between acceptance and contamination
- Contamination below 20% in the whole energy range









Current (and future) updates

- Low-energy part of the spectrum: need a dedicated simulation to take into account the effect of terrestrial magnetic field
- Finalizing the selection up to 3 TeV
- Look for anisotropies in their direction of arrival

Backup Slides

- Two different measurements of charge through ionization ($\sim Z^2$):
  - Energy released in the ACD tile
  - Time-Over-Threshold (ToT) signal averaged across the planes of the TKR
- Cut in the plane formed by these two quantities
- Contamination reduced to less than a few per cent (respect to protons)