Cosmic Ray Electron Spectrum with the Fermi-LAT

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on behalf of the Fermi-LAT Collaboration
CRE(e^+e^-) experiments

- Fermi
  - First high-statistics measurement of inclusive spectrum between 7 GeV and 1 TeV
  - Measurements compatible with single power-law over the entire energy range \( \propto E^{-3.08 \pm 0.05} \)

- AMS-02
  - Range: 0.5 GeV to 1 TeV
  - No structures observed.
  - From 30 GeV to 1 TeV described by a single power law with \( \gamma=-3.170\pm0.008{\text{stat+syst}}\pm0.008{\text{E scale}} \)

H.E.S.S. (& Cherenkov)
- Break in the spectrum at \( \sim 1 \) TeV

Intensity \( \times 10^3 \) [m^-2 s^-1 sr^-1 GeV^-2]

Energy \( \times 10^2 \) [GeV]
Detector is designed for E. M. showers:
- naturally including electrons
- event reconstruction works also for electrons

Electron identification requires dedicated event selection
**Objective:** discriminate signal ($e^+/e^-$) from background (mainly p) and compute the CRE energy spectrum

**Data set:** ~ 7 years

**Energy range:** 50 GeV - 2.5 TeV

**Event reconstruction:** Pass 8

**Event selection:**
- **PRECUTS**
- **Classification Tree:** TMVA with the Boosted Decision Tree method
  - trained on MC data samples (signal=MC electron, bkg=MC proton)
  - in 0.25 wide log energy bins → training optimized for the whole energy range

**CRE spectrum**
Analysis steps

1. Selection of variables
2. Classification Tree
3. Probability variable: $\log(1 - \text{prob})$
4. Selection cut
5. Bkg subtraction
6. Template fitting
7. CRE Spectrum
The LAT uses shower topology information to separate the electron signal from the hadronic background.
Selection of variables

- Variables chosen according to: good MC-data agreement and high separation efficiency

- Separation efficiency improved after correcting some observables for geometry dependence

- MC-data agreement optimized after correcting for energy and incidence angle dependences
Probability variable

$\chi^2/\text{ndof} = 186.8/186$

- MC r/w $e^\pm$ (x 1.17)
- MC r/w p (x 1.47)
- MC sum
- Flight data

PRELIMINARY

$[281.8--316.2 \text{ GeV, } \cos \theta = 0.50--1.00]$
Fit the data with the MC electron and proton template

- signal rate = (rate from flight data) \times (fraction of electrons from MC)
- use that rate for the spectrum directly!

MC proton template (i.e. parameterization of AMS-01) is renormalized and fit to the data in each energy bin
Cutting on the CT probability variable:

- **“optimal cut”** = point on the performance curve (ROC) in which the slope becomes greater than a defined threshold
- fit the cut values as a function of energy
  - analytical function of \( \text{Prob}(E) \)

Bkg contamination estimated after applying “correction” from template fitting
Resulting CRE spectra

- Background subtraction spectrum PRELIMINARY
- Template fitting spectrum PRELIMINARY

$E^3 \times \text{Intensity} \left[ \text{m}^2 \text{s}^{-1} \text{sr}^{-1} \text{GeV}^2 \right]$
The uncertainty on the absolute energy scale is the largest source of systematics.

Pass 8 in-flight measurement of the absolute energy scale via geomagnetic cutoff study → 3.7% offset around 10 GeV

We have rescaled the whole spectrum by 3.7% and we have estimated the error on this scaling factor to be 2% at 10 GeV and increasing up to 5% at ~ 1 TeV.
A) **Event selection:**
- main uncertainty at this level is due to the estimation of the effective area → we take it into account by varying the signal efficiency between 30% and 90%

B) **Correction factor:**
- the band is calculated by moving the correction magnitude by one sigma

C) **Bkg simulation reliability:**
- the uncertainties related to the MC simulation of hadronic interactions could produce a 30% uncertainty on the residual contamination
CRE inclusive spectrum

$E^3 \times \text{Intensity} \, [\text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1} \cdot \text{GeV}^2]$ vs. Energy [GeV]

- **Fermi Pass 8 PRELIMINARY**
- Fermi (2010)
- HESS (2008)
- HESS (2009) - only stat errors
- AMS-02 (2014)
Central points from the “optimal cut”, the shaded band has been obtained by summing in quadrature all the studied systematics (except for the energy scale)

- Compatible with AMS up to ~ 100 GeV but different spectral index
- Disagreement wrt published spectrum (Fermi 2010):
  - likely due to “ghost” signal not taken into account in the acceptance in our first analysis
**Instrument response**

- **Acceptance** resulting after applying the “optimal cut”
  
- **acceptances** resulting by varying the signal efficiency between 30% and 90% also shown

- **Contamination** below 20% when applying the “optimal cut”
  
- **contamination** resulting by varying the signal efficiency between 30% and 90%
  
- **contamination** resulting by taking into account the bkg simulation reliability
Conclusions

We performed a new measurement of CRE spectrum with Pass 8

Improvements in the new analysis:
- almost 7 times the PRD data set
- new event reconstruction & selection (Pass 8)
- new multi-variate analysis tool
- new selection of variables → variables are now “calibrated”
- new CTs trained in energy bins → training optimized for the whole energy range
  ➞ **new CRE spectrum** and associated systematics

See also the posters:
- More technical details on the event selection and systematics (**M.Negro et al - Diff.6**)
- Analysis extended down to 7 GeV by including the DGN filter effect (**A. Manfreda et al - In/An.10**) → in the overlapping energy region it’s in agreement with this one
- Cross-check the energy scale at TeV energies by measuring the Earth Limb spectrum (**F. Spada et al - In/An.7**)
- Study CRE anisotropies to validate possible astrophys. interpretations (**N. Mazziotta et al - Diff.5**)
- Viable interpretations of our CRE spectrum (**F. Donato et al - Diff.3**)

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BACKUP SLIDES
Systematics: corr. factor

$3.00 < \log E \text{ [GeV]} < 3.25$

Counts

MC electrons

CRE data after optimization

CRE data after optimization $+ 1 \sigma$

CRE data after optimization $- 1 \sigma$

PRELIMINARY

log10(transverse size)
PRE-CUTS = TRIGGER FILTER + QUALITY CUT + ALPHA CUT

- **TRIGGER FILTER**: the event triggers the LAT and passes the on-board gamma filter `(GltGemSummary&0x20)==0 && (GltGemSummary&0x40)==0 && FswGamState == 0`

- **QUALITY CUT**: the event has at least a reconstructed track, a minimal PSF quality and the path length in the Cal is larger than the Cal on-axis thickness 'EvtCalCsIRLn>8 && Cal1RawEnergySum>5000 && TkrNumTracks>0 && WP8CTPSFTail>0.05'

- **ALPHA CUT**: MC doesn’t reproduce accurately interactions of α and heavy ions in the LAT → cut removing the majority of α and heavies

![Graph showing distributions of flight data and MC predictions]

[31.6–3162.3 GeV, $\cos \theta = 0.30$–1.00]