A new measurement of the Cosmic-Ray Electron and Positron Spectrum with the Large Area Telescope

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on behalf of the *Fermi*-LAT collaboration

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More than an update

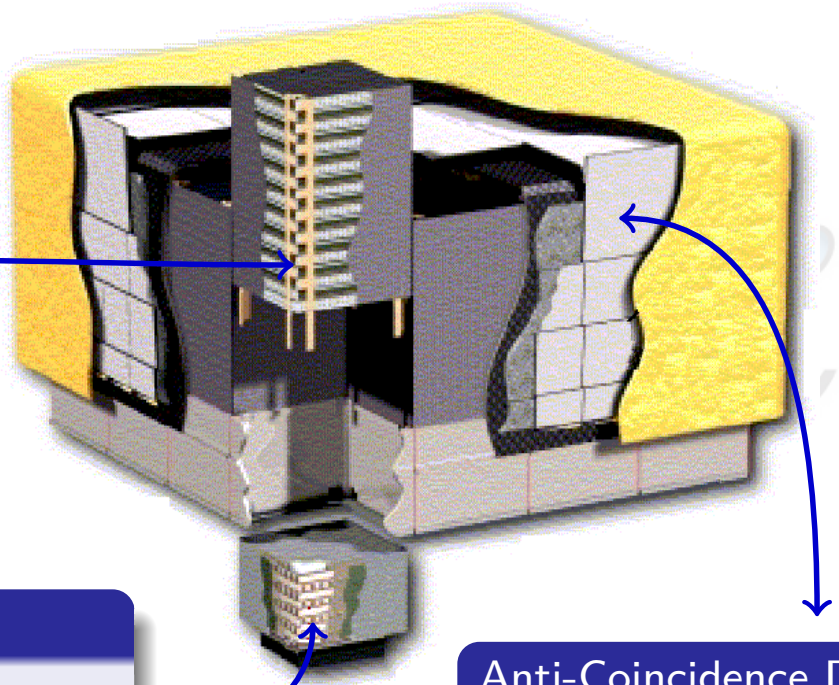
Previous Fermi measurement of the spectrum from 7 GeV to 1 TeV published in 2010 [*Ackermann et al., Phys. Rev. D 82, 092004*]

The analysis is new in many respects

- Almost seven times the amount of data available
- Completely revised event reconstruction provided by the *Fermi* collaboration (Pass 8)
- Upper energy range extended to 2 TeV
- Improved selection algorithms
- Better understanding of the environment in which the LAT operates
- Better modelling of the systematic uncertainties
- New detailed study of the geomagnetic field effects in the GeV energy range

Fermi LAT

- Launched by NASA on June 2008 at 565 km altitude, 25.6° inclination
- Large field of view (20% of the sky), full sky observed every ~ 3 h
- Designed to detect EM showers, naturally including e^+ and e^-



Tracker/Converter (TKR)

- 18 x-y planes of silicon strip detectors
- $\sim$ 10 k sensors, ~ 80 m^2 of silicon active area, 1M readout channels

Calorimeter (CAL)

- 1536 CsI(Tl) crystal (96 per tower); 8.6 radiation lengths on-axis
- Hodoscopic, 3D shower profile reconstruction for leakage correction

Anti-Coincidence Detector (ACD)

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

Datasets

Two slightly different analyses, for two different datasets:

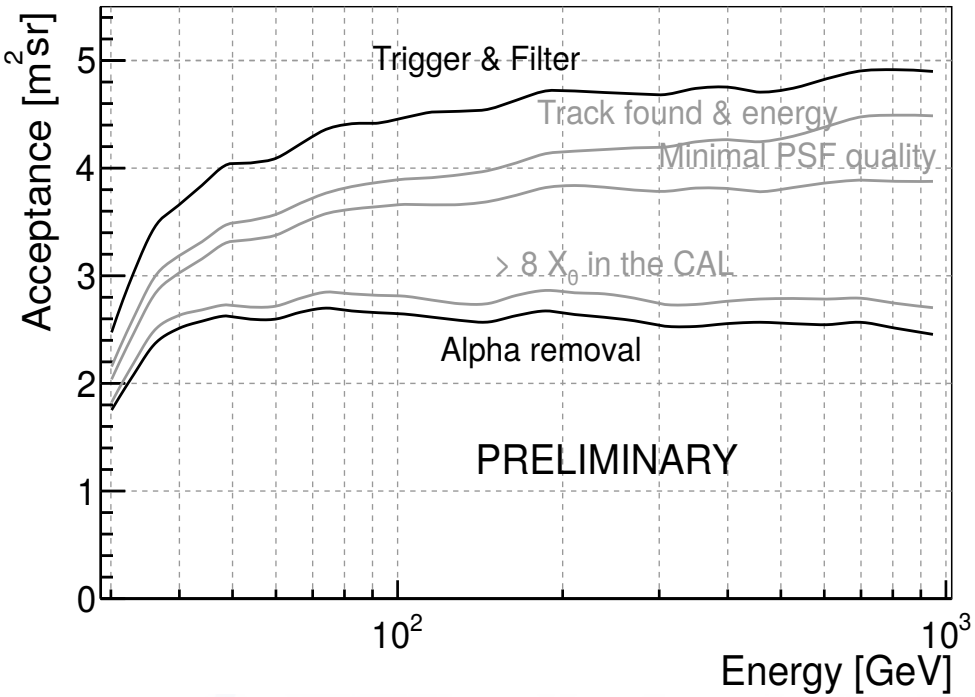
- High Energy (HE): 42 GeV - 2 TeV using events from the standard on-board filter
  Accept all events with more than 20 GeV released in the CAL (fully efficient for electrons above $\sim$ 40 GeV)

- Low Energy (LE): 7 GeV - 70 GeV using events from the diagnostic (DGN) filter
  Unbiased sample of all triggers, pre-scaled by a factor 250

Overall live time is 4.68 years - outside SAA and in standard operation modes

Field of view reduced to $\leq 60^\circ$ from the instrument zenith (avoid Earth limb photons contamination).

CRE selection

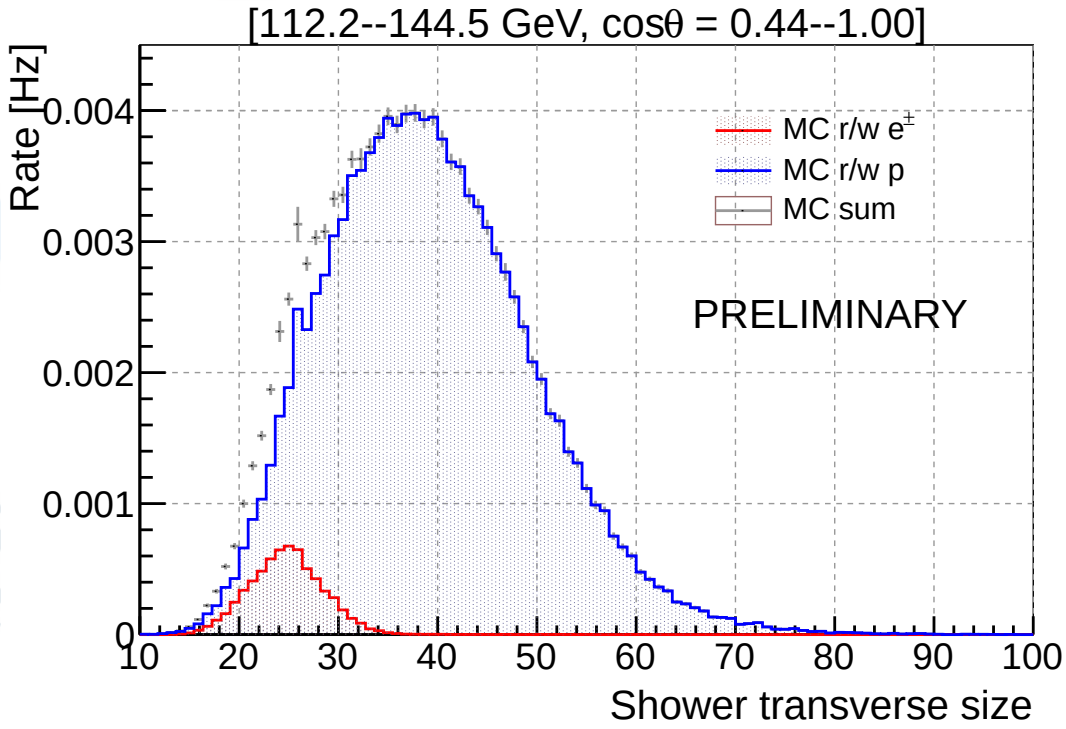


- Event-quality cuts (good direction and energy reconstruction)
- Removal of particles with $Z > 1$, tagged by ionization in ACD and TKR
- Boosted Decision Trees (BDTs) selection, for proton rejection
- LE: additional orbital selection for geomagnetic field effects

Proton removal selection

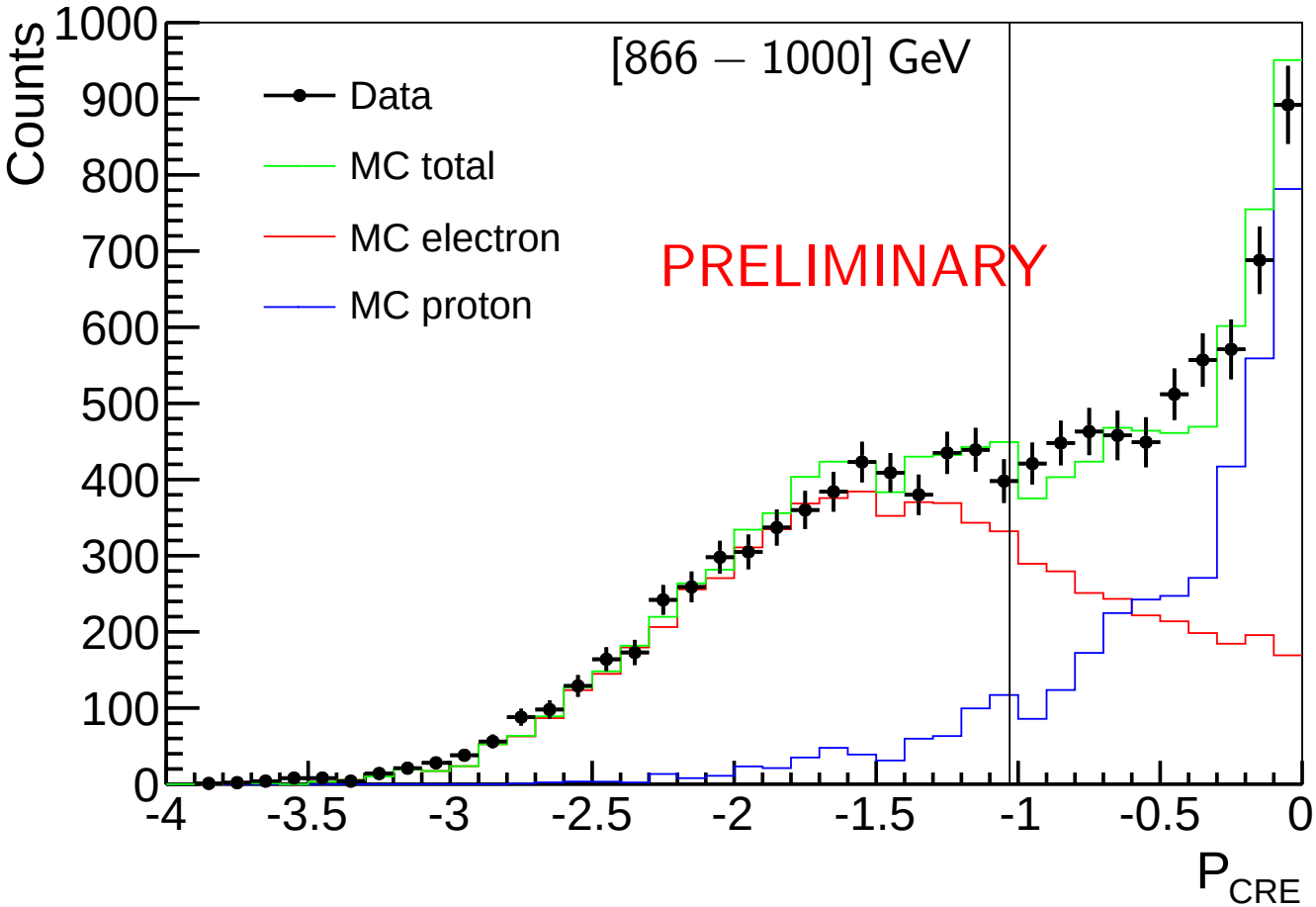
- Exploits differences between leptonic and hadronic events in the detector:
  - Shower development in the CAL
  - Number of δ-rays produced in the TKR
- A few variables have been individually rescaled, to improve their data/MC agreement

Example:



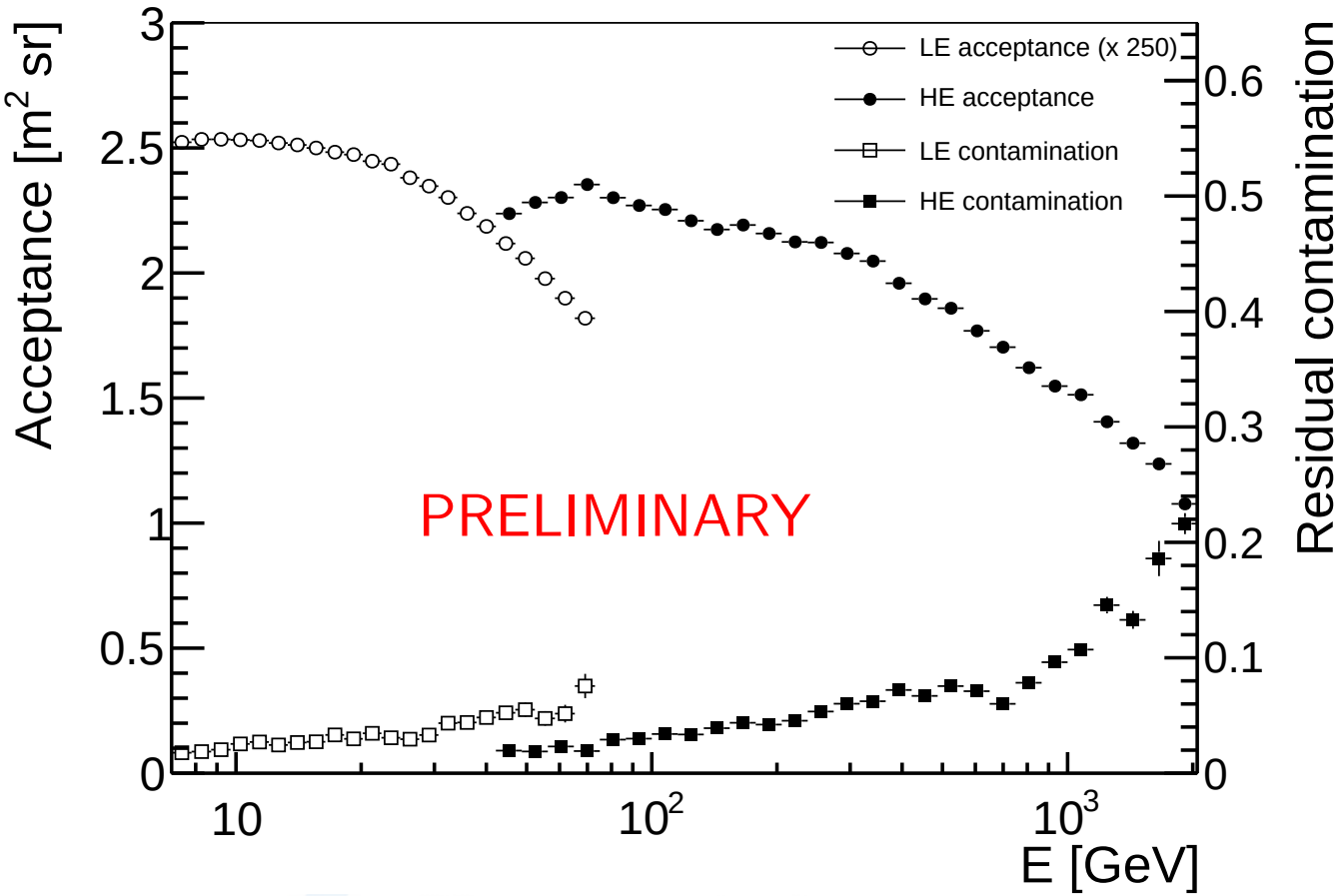
  - The BDT combines all the information into a single estimator of 'leptonicity' (P_{CRE}).
  - 8 BDTs used for HE analysis, optimized for different energy ranges (plus 1 for LE)

BDT output



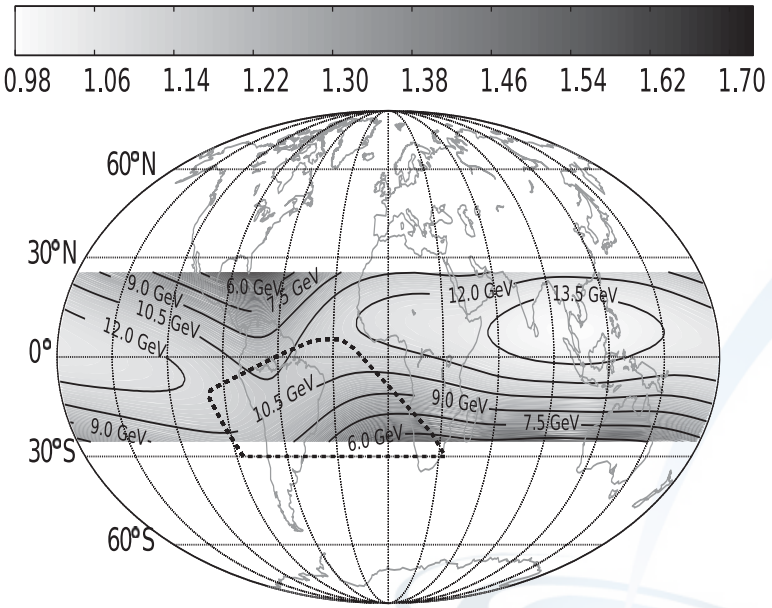
- Cut on P_{CRE} optimized in each energy bin
- Normalization of Monte Carlo templates fitted to data for residual background estimation

Performance



- Selection increasingly difficult at higher energy
- Contamination below 20% in the whole energy range

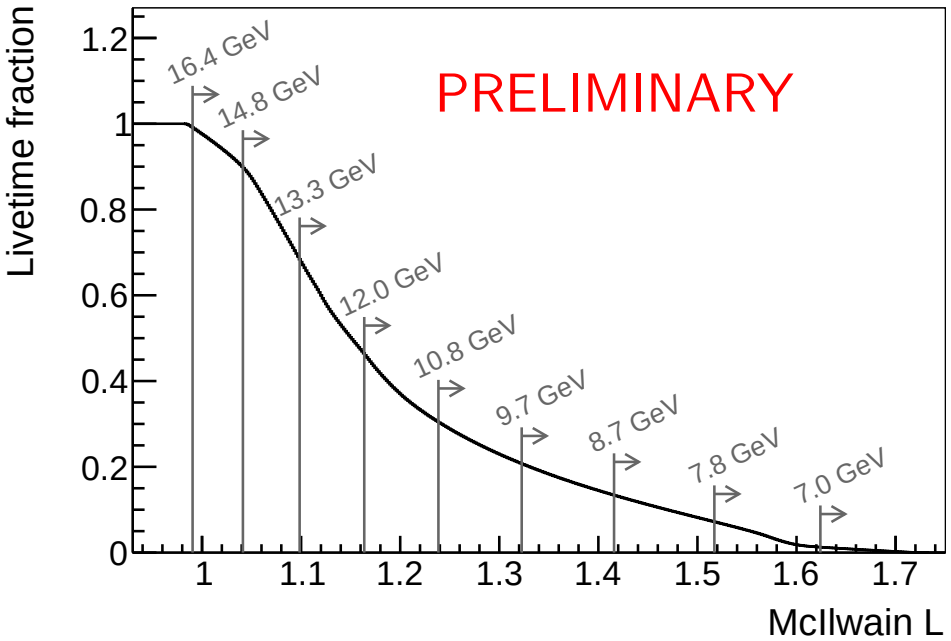
LE Orbital Selection



McIlwain L and rigidity cut-off values across the LAT orbit

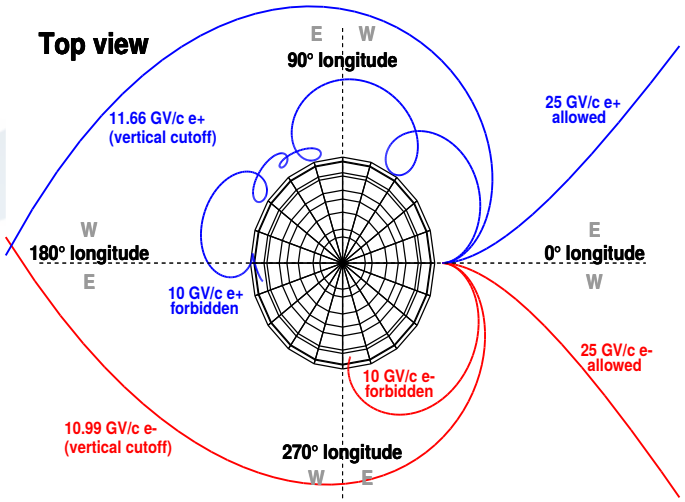
- GeV range: shielding effect of the Earth magnetic field
- LAT orbit: 0.98 - 1.73 McIlwain L, vertical rigidity cut-off from $\sim$ 6 GeV to $\sim$ 14 GeV.

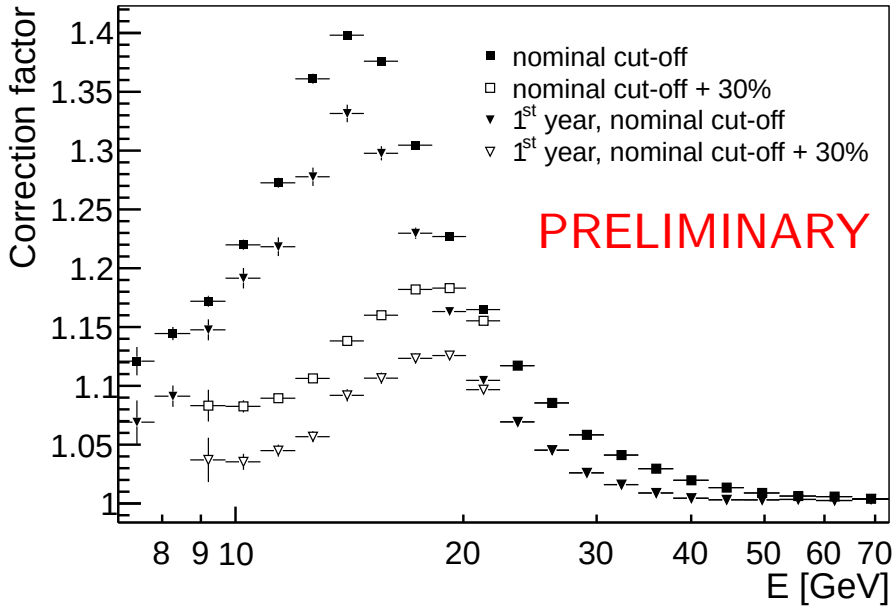
- Energy dependent selection: in each bin accept only orbital regions where the whole bin is above the cut-off
- Optimized directly on data, by fitting the count spectrum in several McIlwain L bins



Geomagnetic correction

- Cut-off is smooth: residual particle loss even after the selection
- Recovered with a tracing technique: simulated realistic flux of $e^+ + e^-$ in the LAT, traced back in a model of the Earth magnetic field
- Estimated correction factors (up to 40%) applied to the observed flux
- Separate corrections for first year of data (due to rocking angle increase from 35 to 50 degree in 2009)

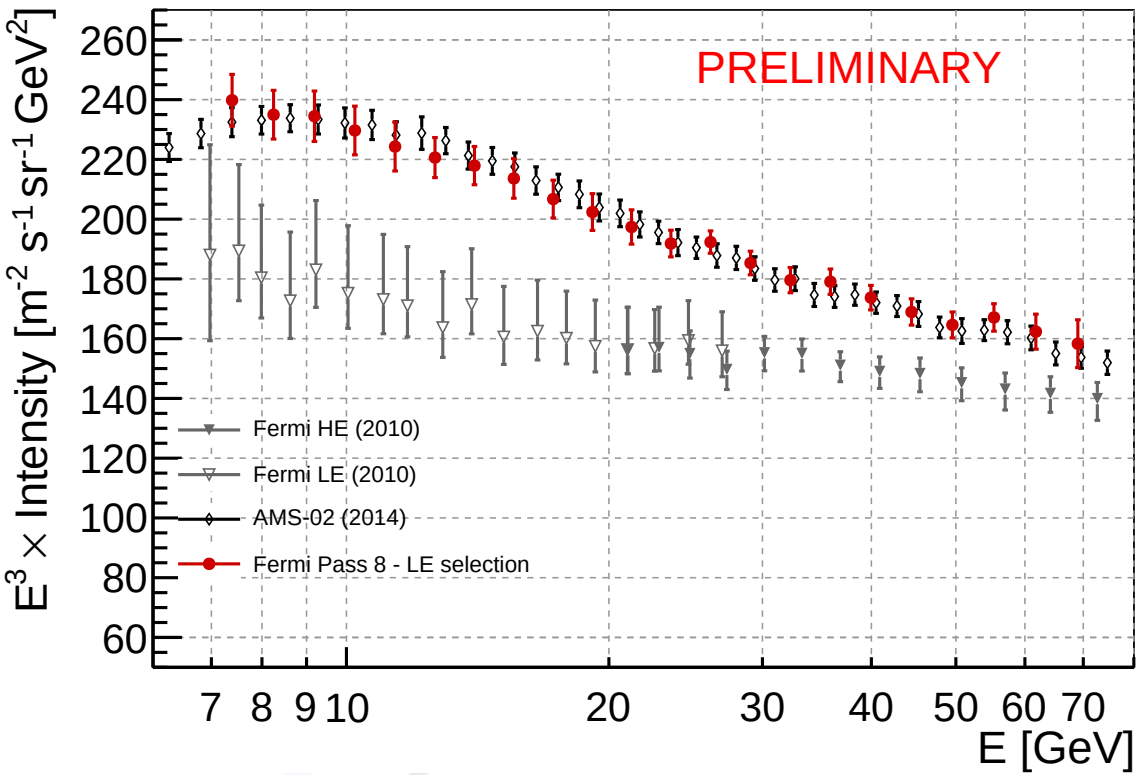




Systematics uncertainties

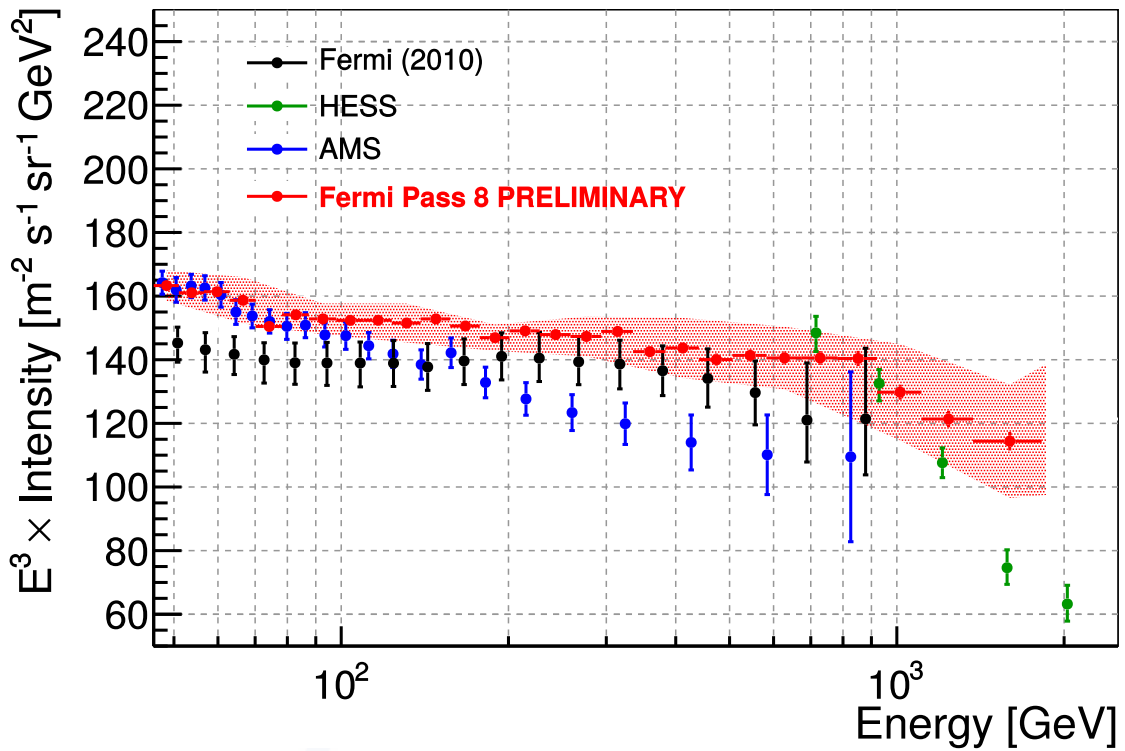
- Acceptance uncertainty:
  - Studied with a scan on the selection cut
- Residual background uncertainty:
  - Given by MC simulation uncertainties in reproducing the most electron-like hadronic showers.
- Energy scale bias uncertainty:
  - At 10 GeV given by comparison of observed CRE cut-off with tracer prediction
  - At 1 TeV study of data/MC disagreement of key energy reconstruction variables
- Individual variable calibration uncertainty (HE analysis):
  - Estimated by bracketing with different sets of corrections
- Geomagnetic corrections uncertainty (LE analysis):
  - Studied by varying the orbital selection and recomputing the corrections

Results: LE spectrum



- Significant difference wrt the previous Fermi publication
  - Geomagnetic correction (new)
  - 'Ghost' signals effect not included in previous simulation (corrected in Pass 8)

Results: HE spectrum



- Shaded band is sum in quadrature of systematic uncertainties
- Energy scale uncertainty not included
- Spectrum is harder than that reported by AMS-02
- Our systematic errors do not allow to confirm or exclude the cut-off observed by H.E.S.S.

Conclusions

- New measurement of the CRE spectrum, pushing the Fermi LAT to its limits in all metrics
- New event-level analysis (Pass 8)
- Energy range extended to 2 TeV (first direct measurement above 1 TeV)
- Better handling of the geomagnetic effects in the evaluation of the low-energy spectrum
- Better characterization of the systematic uncertainties
- Paper submitted to the journal (stay tuned)
- CRE selection will be used for anisotropies study update, currently under publication (again, stay tuned!)