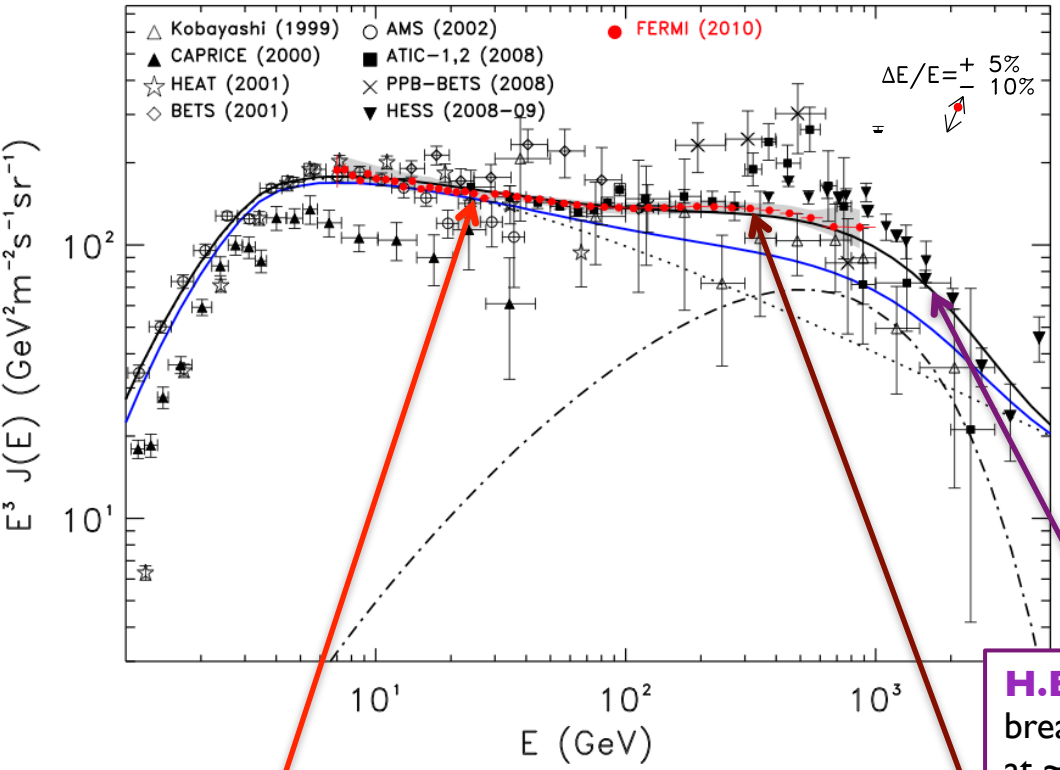
Cosmic Rays Electron Spectrum with the Fermi-LAT

Raffaella Bonino
University and INFN Torino
rbonino@to.infn.it

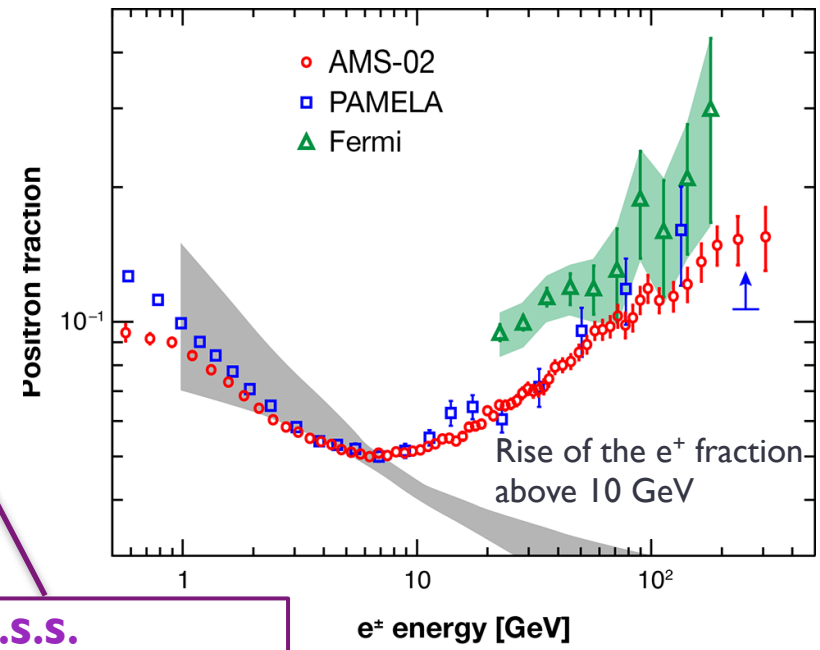
on behalf of the ***Fermi-LAT Collaboration***

CRE experiments

Phys.Rev.D82:092004,2010



Phys. Rev. Lett. 110, 141102 (2013)

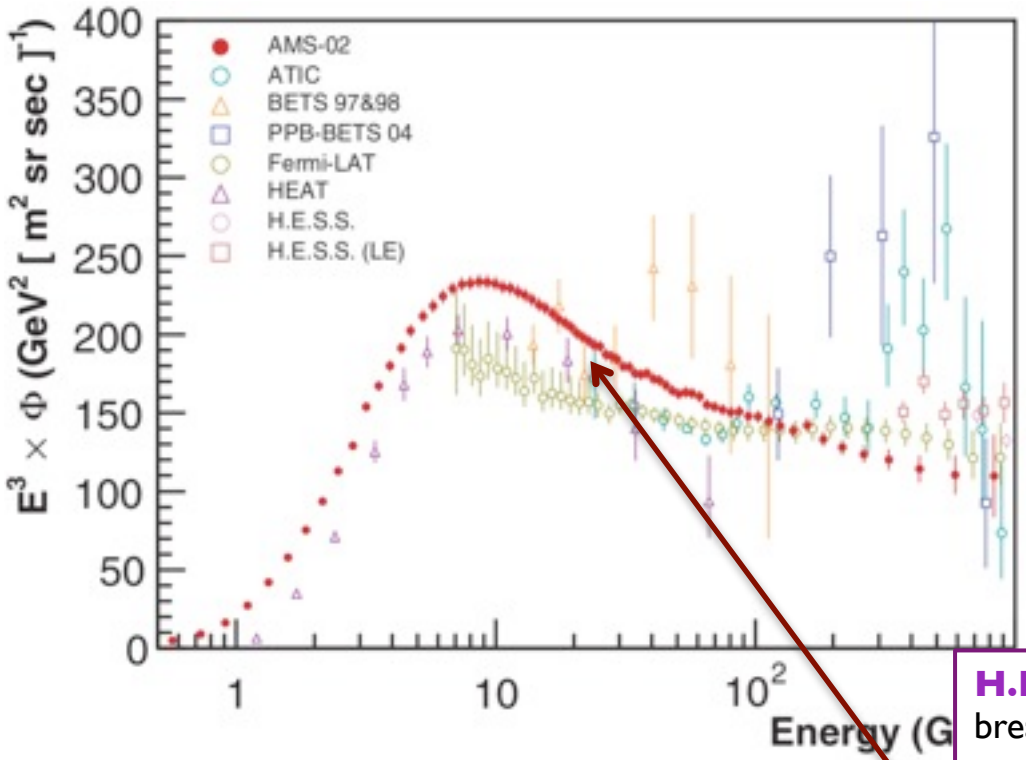


H.E.S.S.
break in the spectrum at ~1 TeV

Fermi
- First high precision measurement of inclusive spectrum between 7GeV and 1 TeV
- Measurements compatible with single power-law over the entire energy range $\propto E^{-3.08\pm0.05}$

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 γ=-3.170±0.008(stat+syst)±0.008(E scale)

CRE experiments



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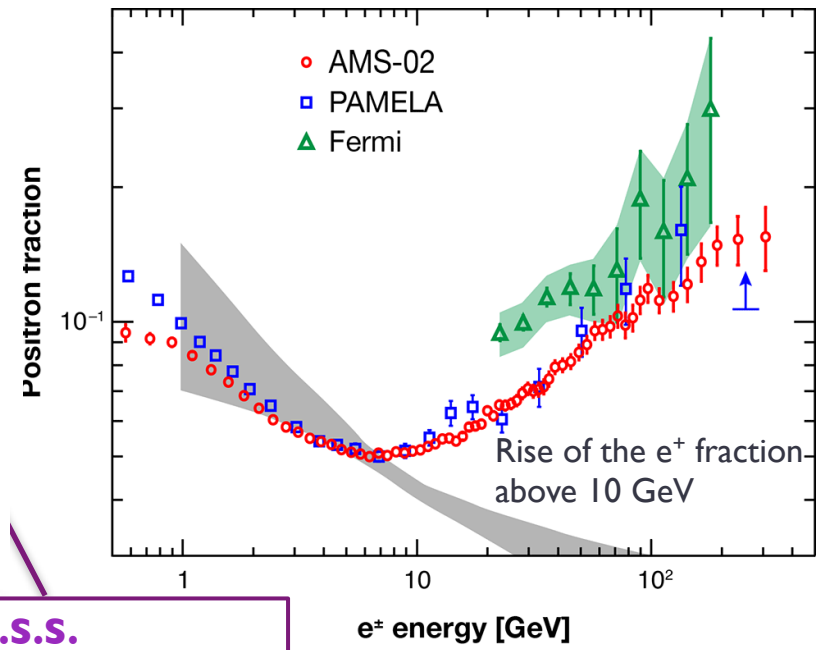

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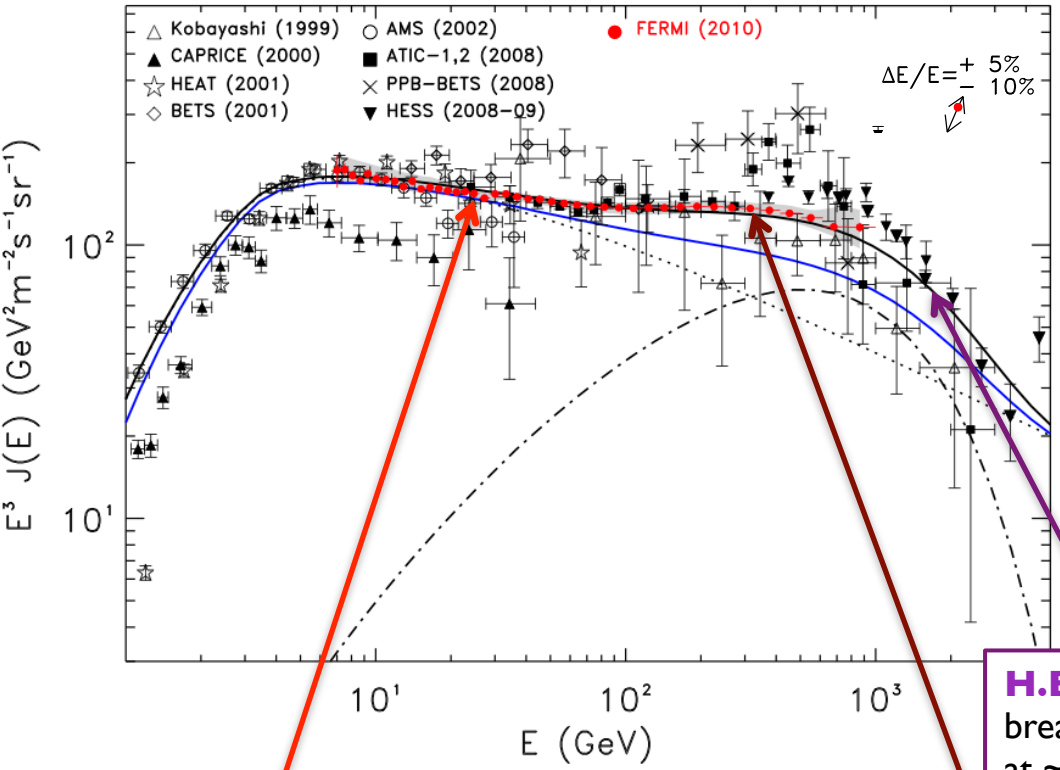

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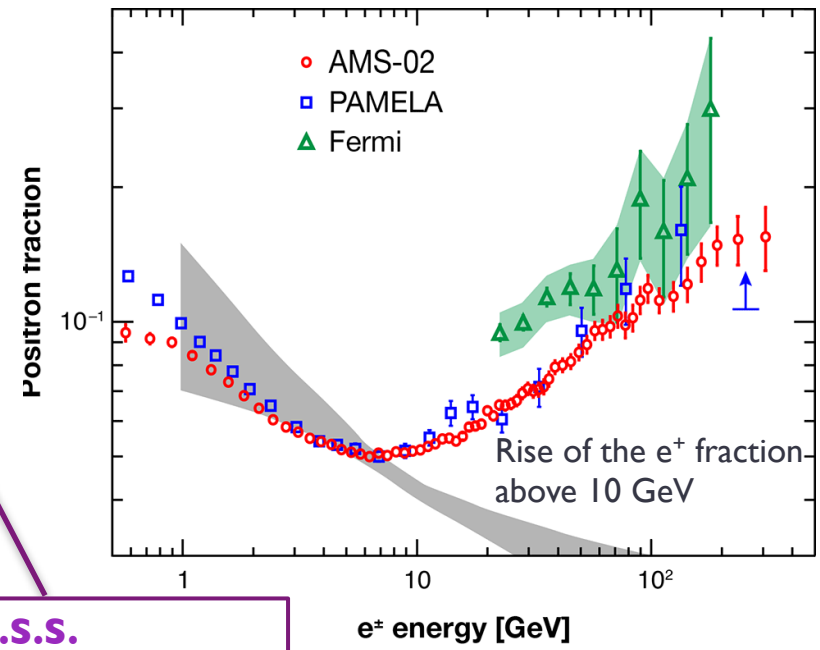

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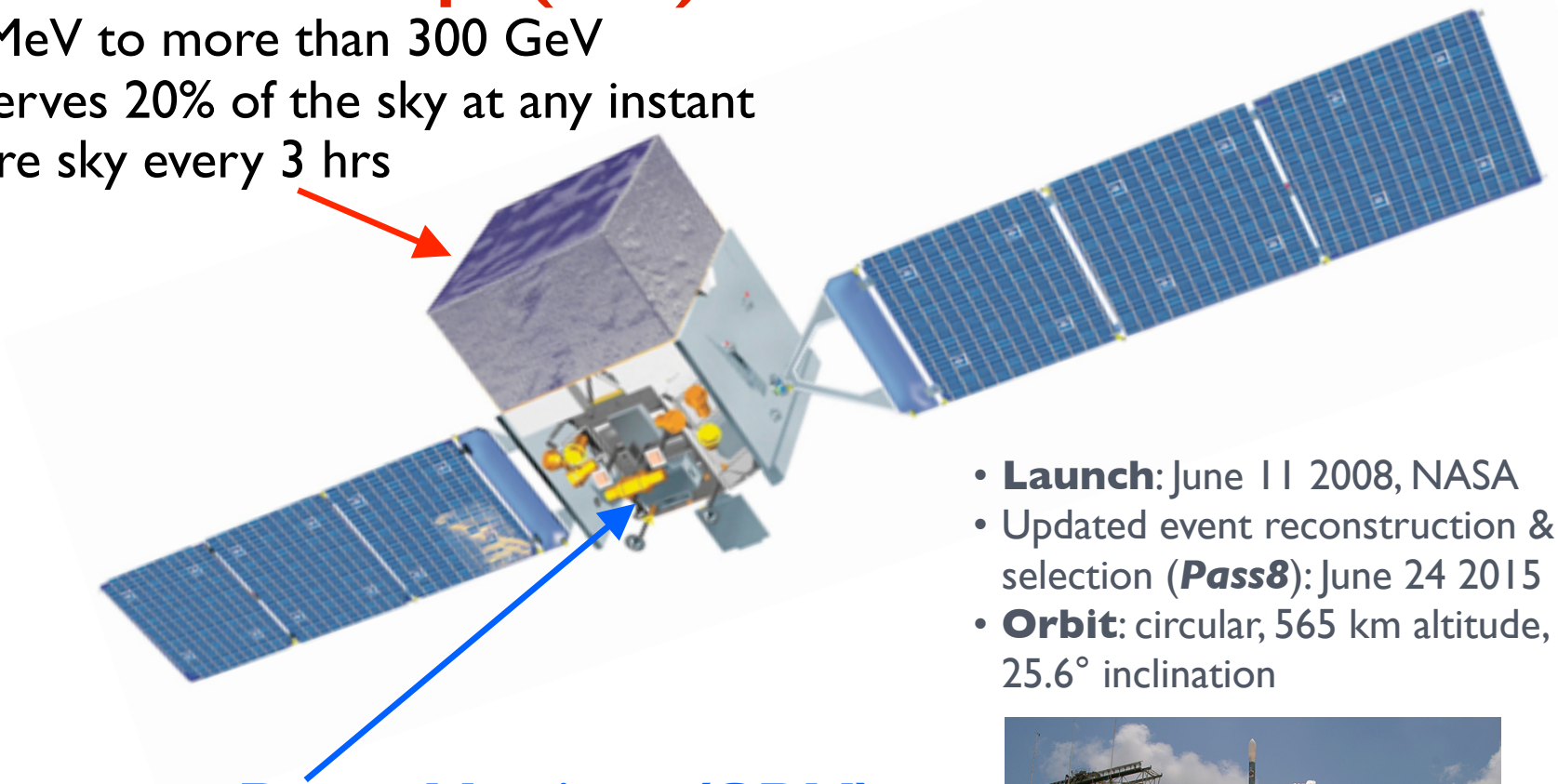
The Fermi observatory

Large Area Telescope (LAT):

- 20 MeV to more than 300 GeV
- observes 20% of the sky at any instant
- entire sky every 3 hrs



- **Launch**: June 11 2008, NASA
- Updated event reconstruction & selection (***Pass8***): June 24 2015
- **Orbit**: circular, 565 km altitude, 25.6° inclination

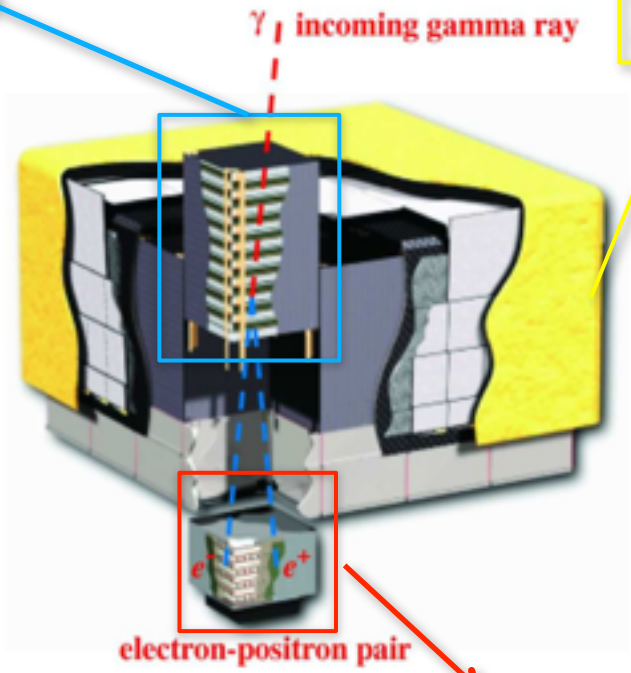
Gamma-ray Burst Monitor (GBM):

- 8 keV to 40 MeV
- observes entire unocculted sky

The Fermi LAT detector

TRACKER-CONVERTER
- Incoming particle direction
- 18 x, y tracking planes: SSD
- 16 planes of tungsten:
  - "FRONT" -> first 12 "thin" layers of 3% radiation length tungsten converters
  - "BACK" -> next 4 "thick" layers of 18% radiation length tungsten converters

ANTICOINCIDENCE DETECTOR
- Charged-particle bkg rejection
- Plastic scintillator, WLS fibers
- Segmented tiles



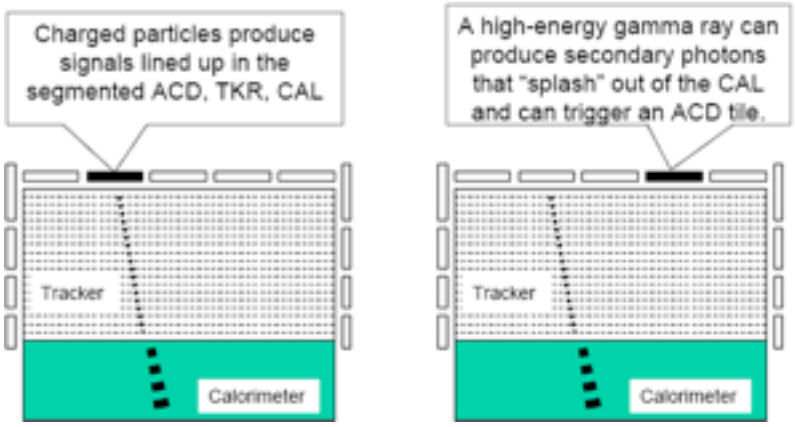
CALORIMETER
- energy deposition
- shower development imaging
- 96 CsI(Tl) crystals

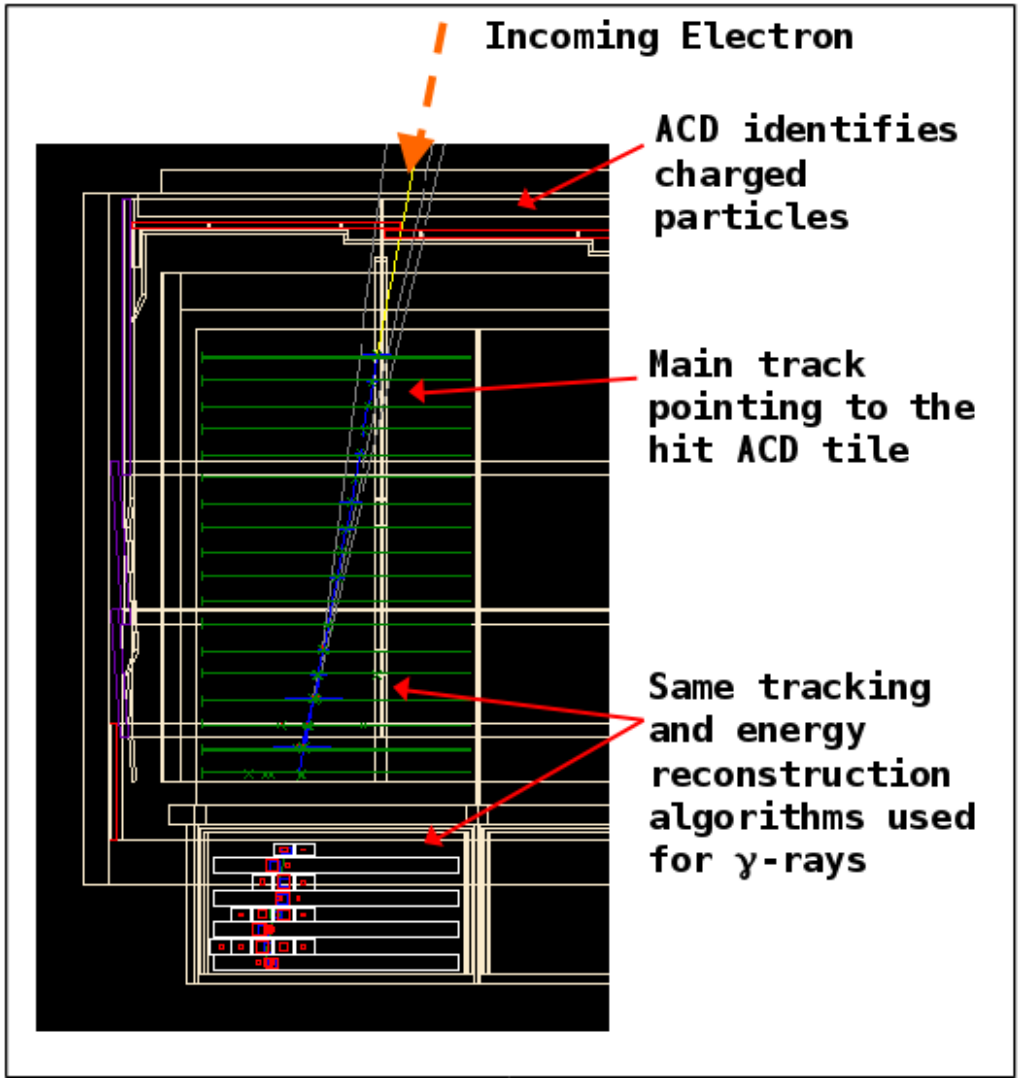
Pass8 = complete revamp of event reconstruction algorithms (2015)
- Improved performances and IRF
- Retroactively updated entire data archive
- Open new discovery space

... also electron detector

- Detector is designed for E. M. showers:
  - ➡ naturally including electrons
  - ➡ event reconstruction works also for electrons

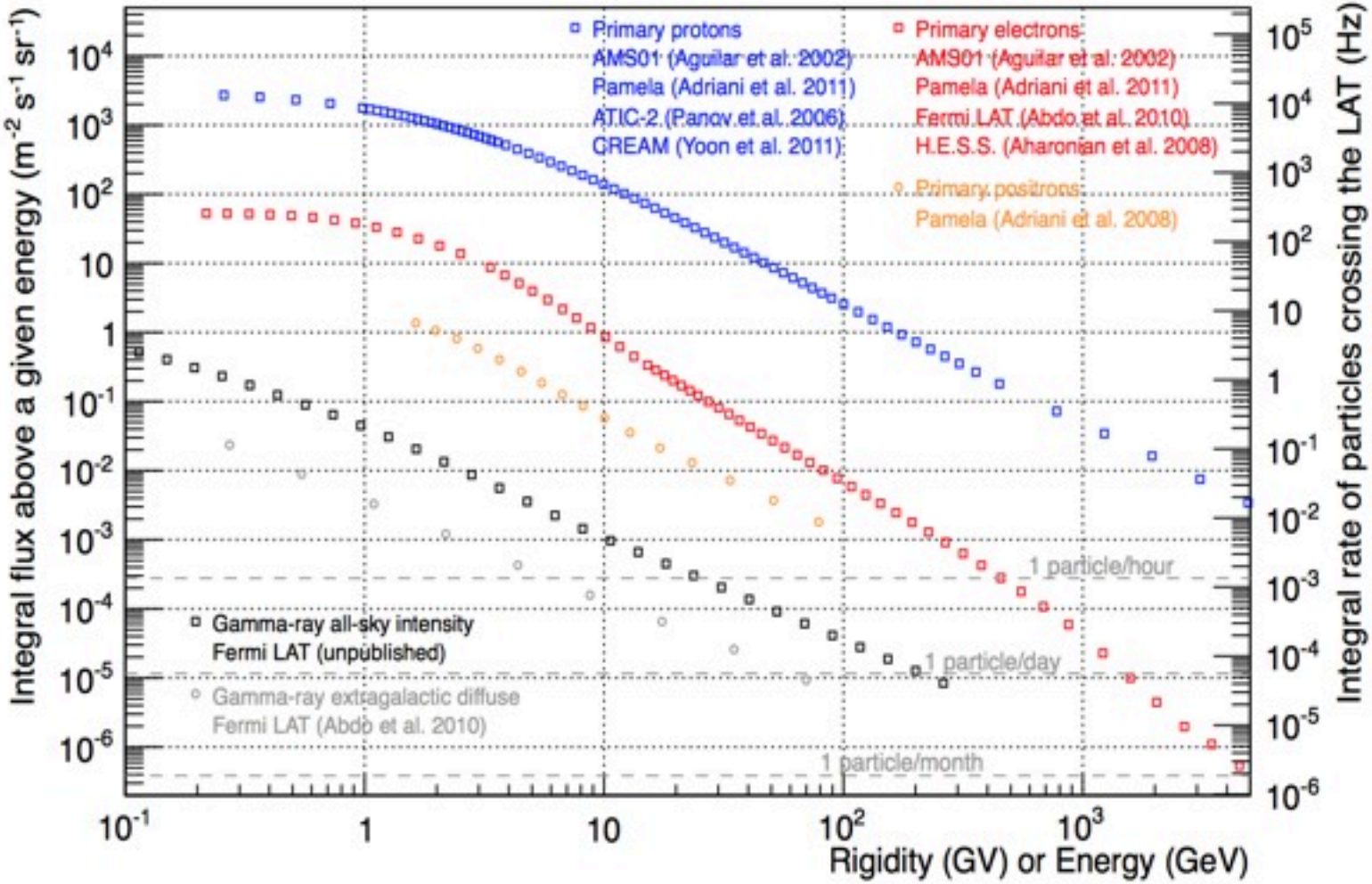
- Electron identification requires dedicated **event selection**



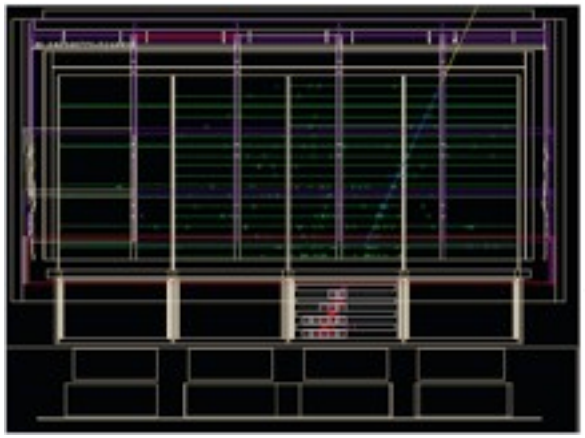


What is our background?

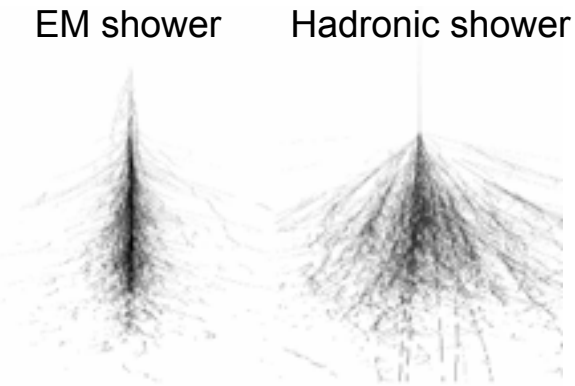
- **CRE selection:** discriminate signal (electrons) from background (hadrons)

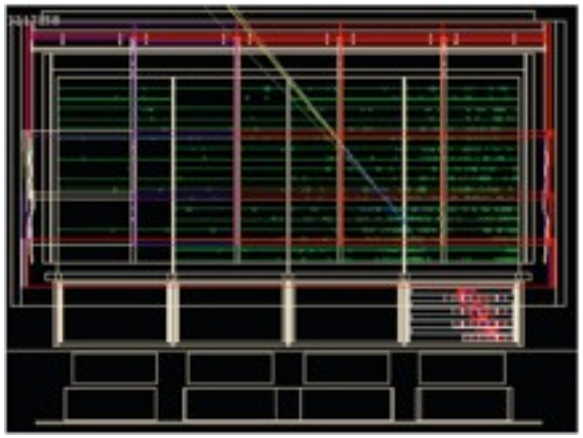


Event Selection

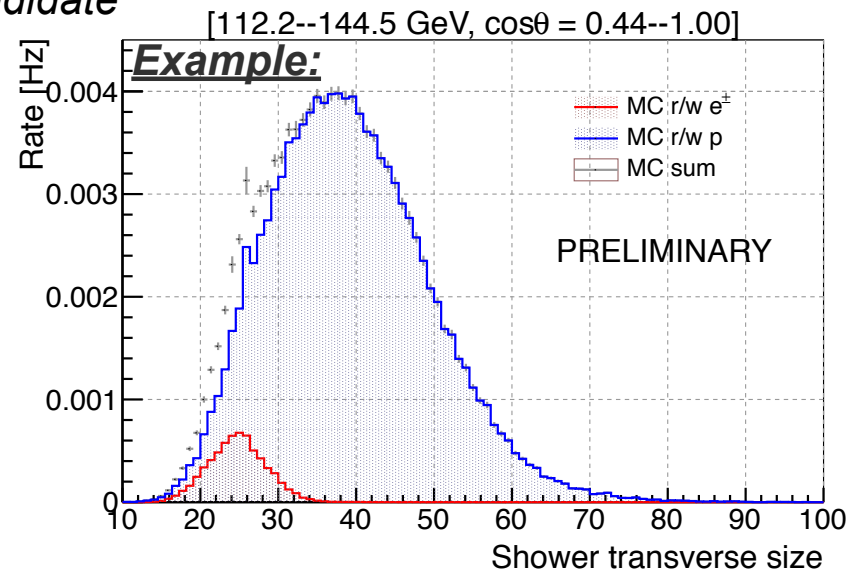


1 TeV electron candidate





1 TeV proton candidate

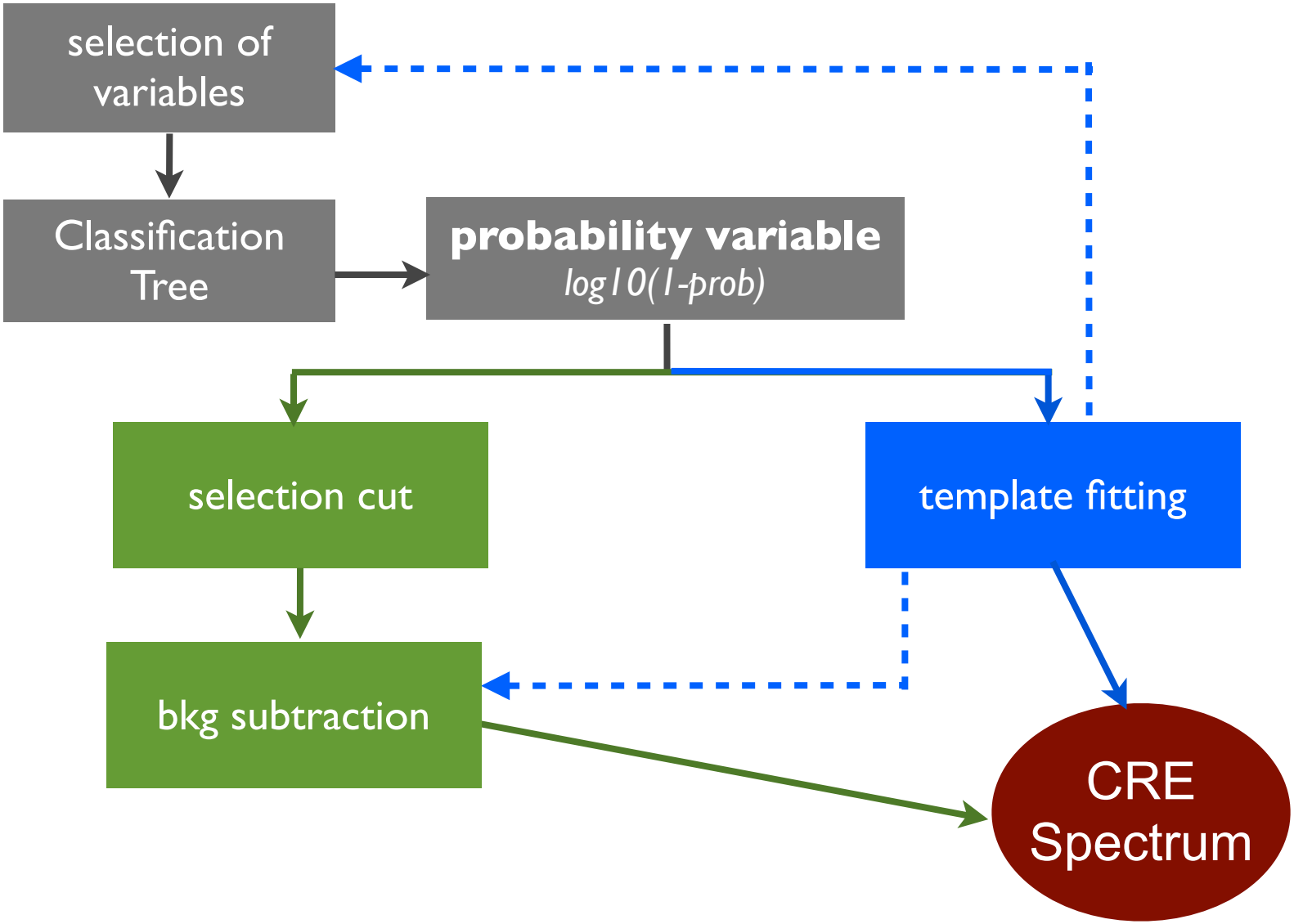


- The LAT uses shower topology information to separate the electron signal from the hadronic background

Analysis features

- **Objective:** discriminate signal (e^+/e^-) from background (mainly p) and compute the CRE energy spectrum
- **Data set:** 6 years
- **Energy range:** 30 GeV - 1.2 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)
- **CRE spectrum**

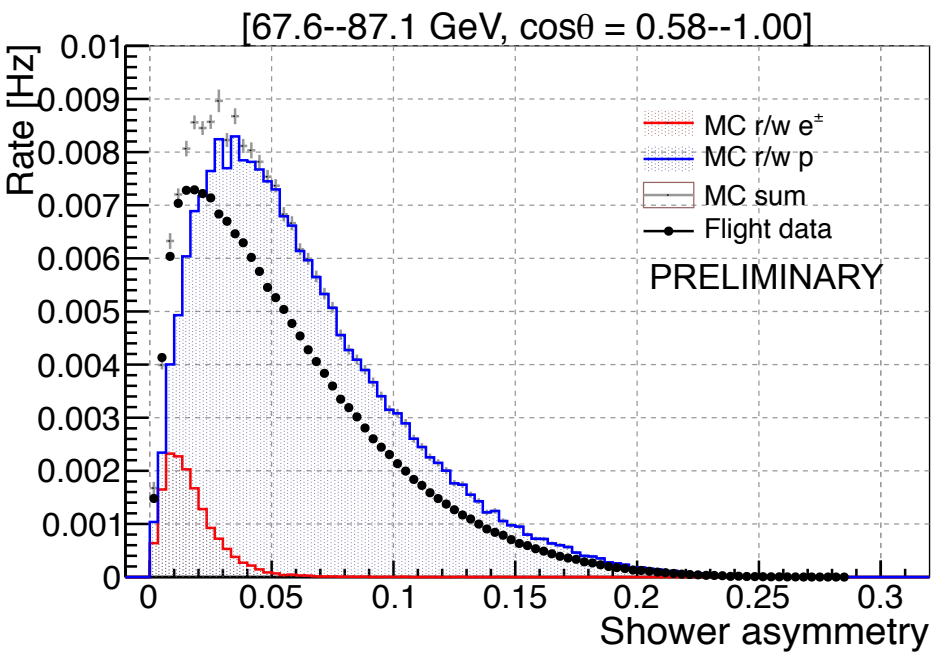
Analysis steps

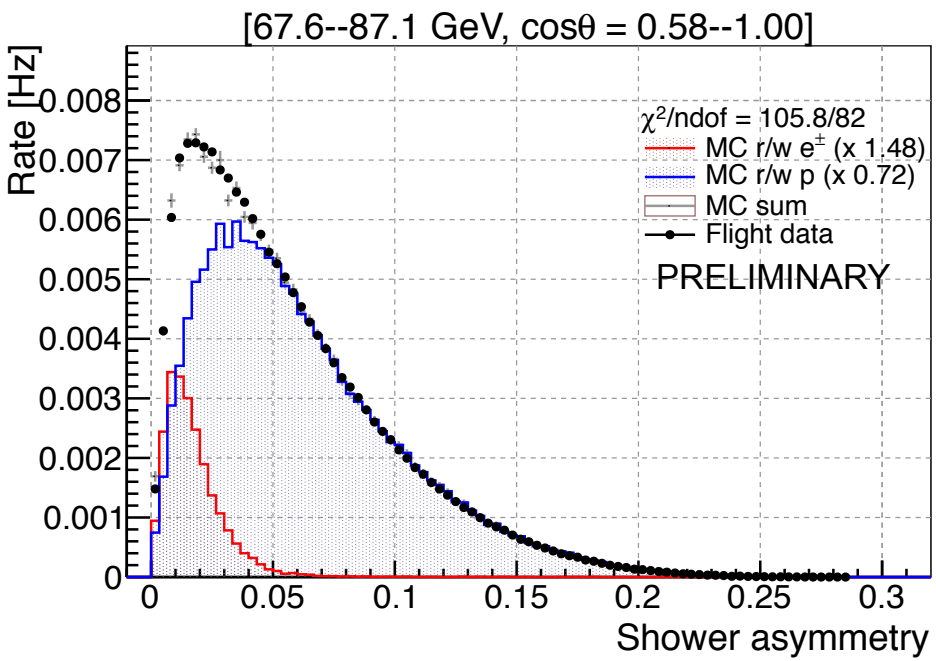


Selection of variables

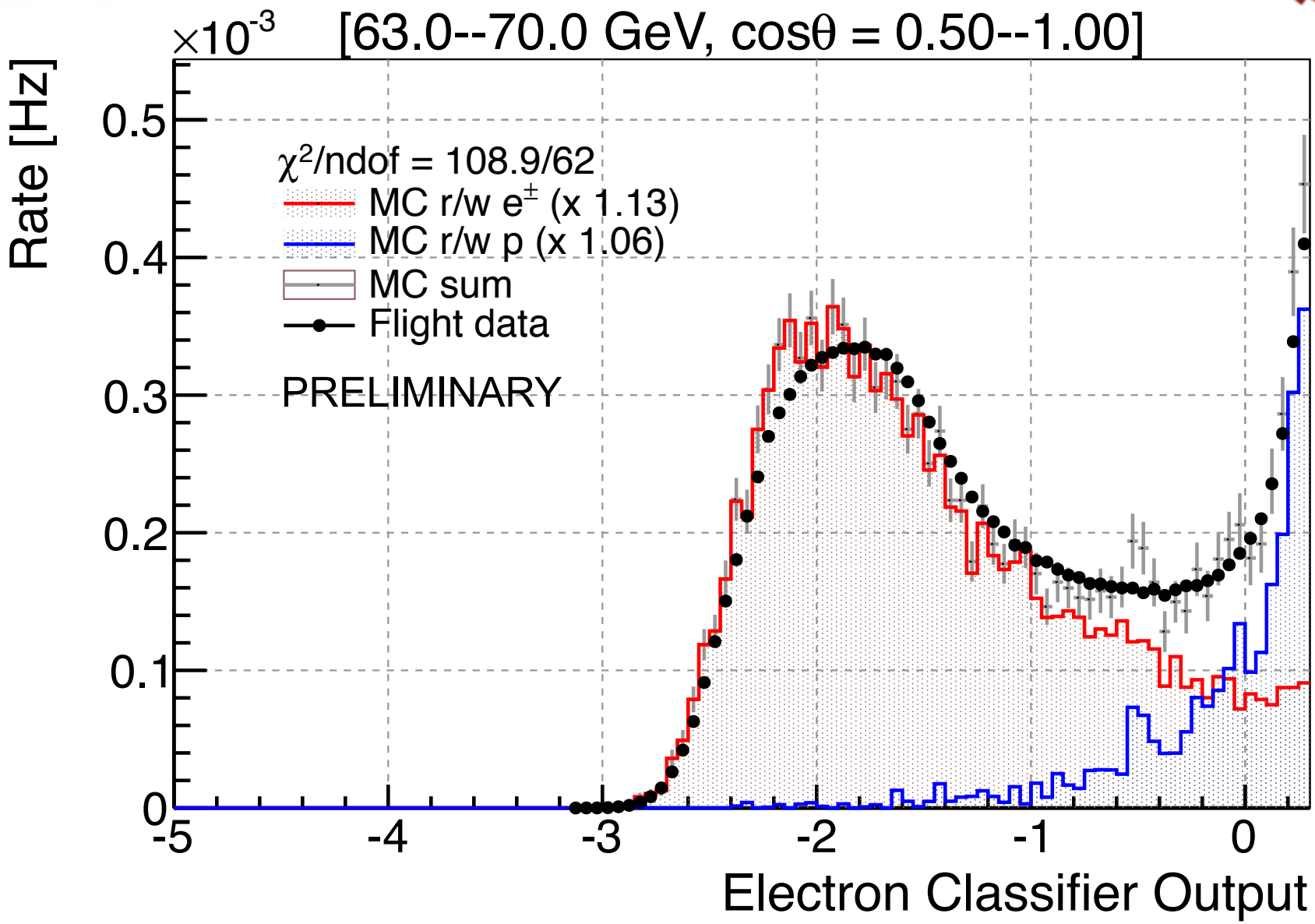
- Variables chosen according to: good MC-data agreement and high separation efficiency

- MC-data agreement studied after applying ***template fitting***
  → fit the data with the MC electron and proton template

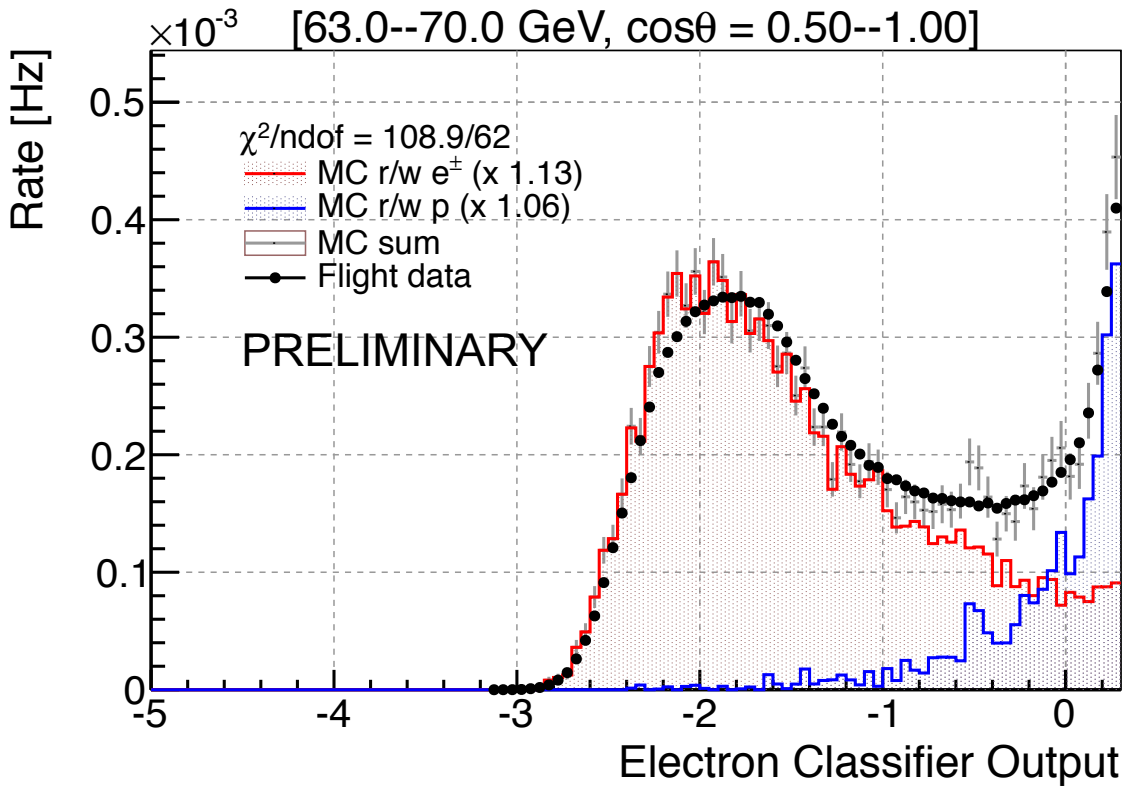




Probability variable



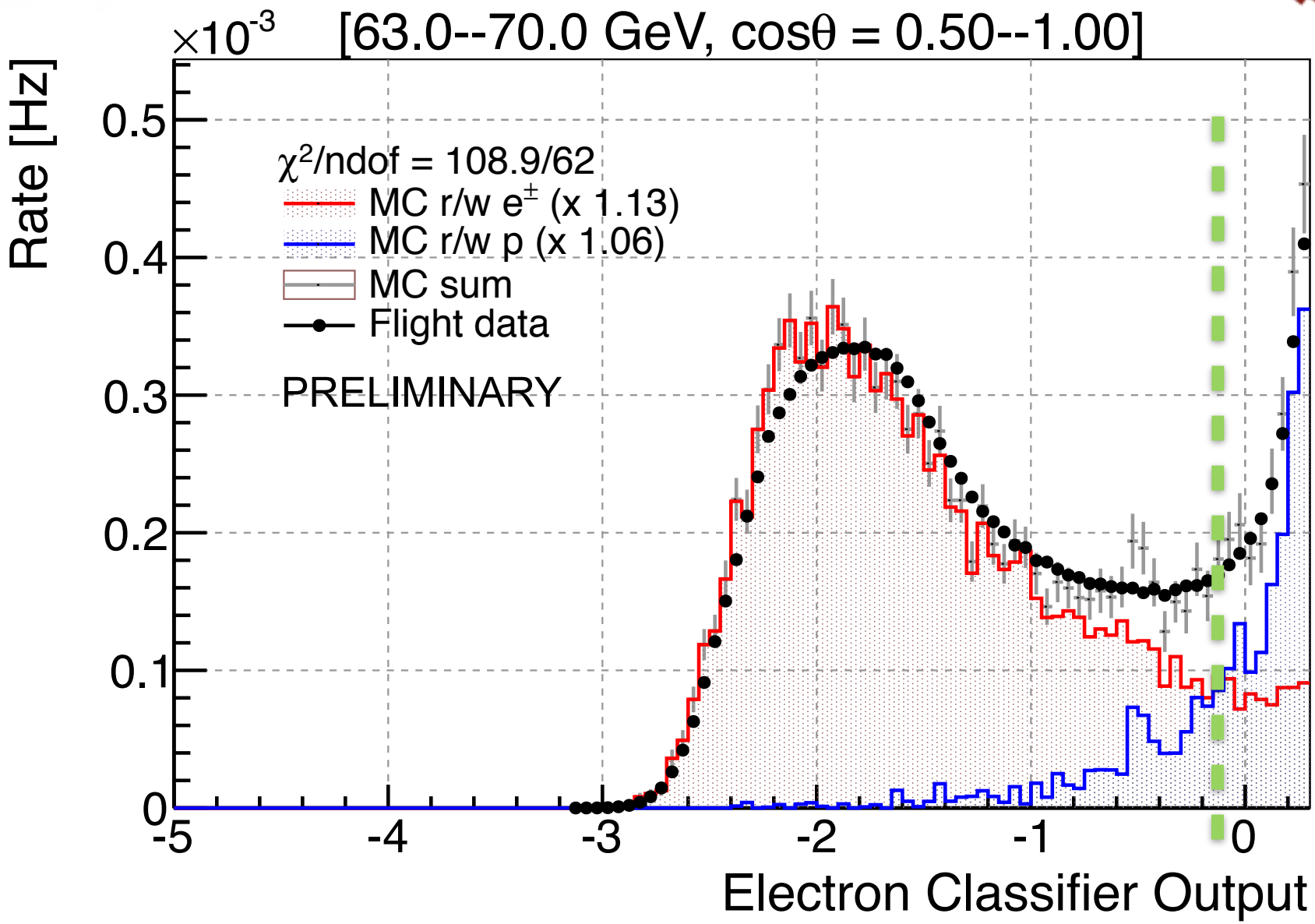
a. Template fitting



- **Fit the data with the MC electron and proton template**
  - signal rate = (rate from flight data) x (fraction of electrons from MC)
  - use that rate for the **spectrum** directly!

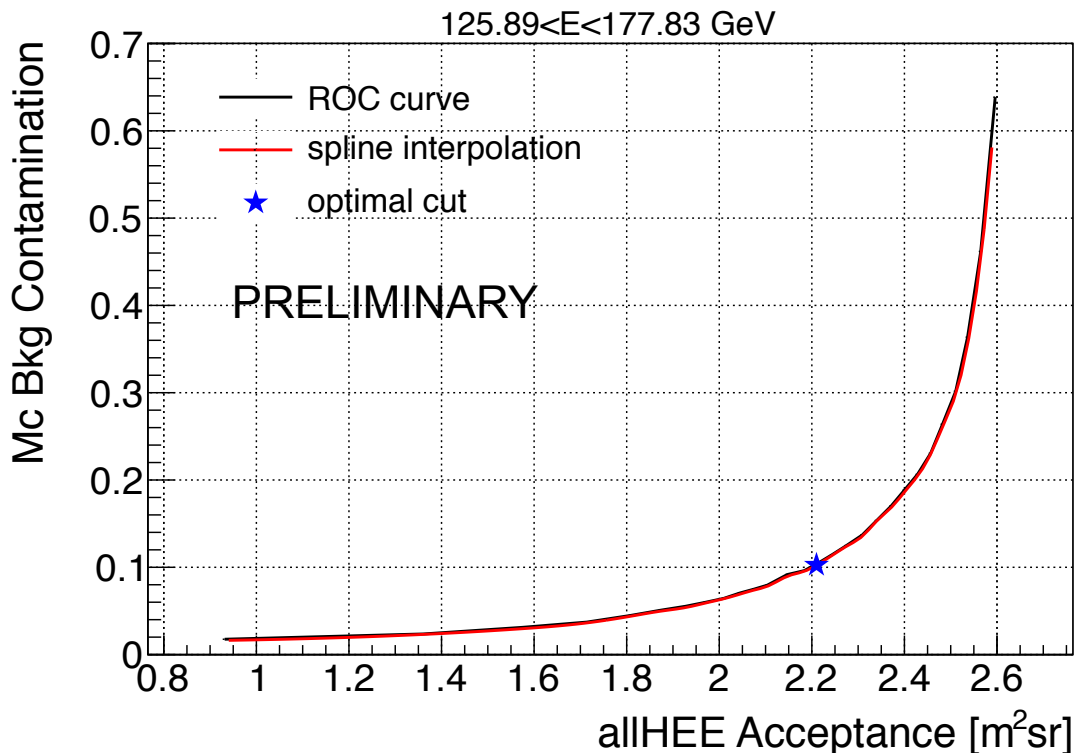
- ***Pro:* the background is effectively fitted to the data**

b. Bkg subtraction



b. Bkg subtraction

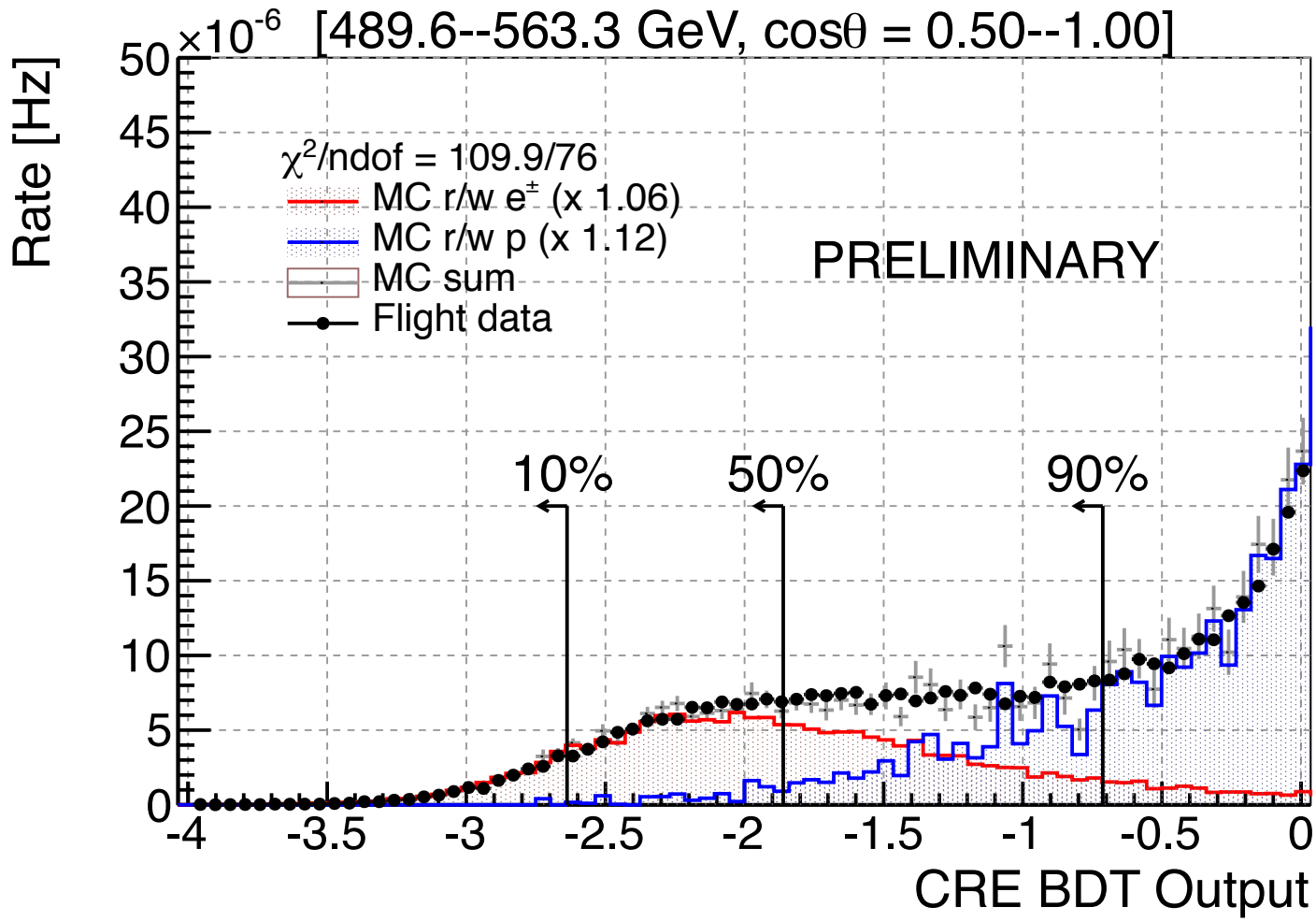
- **Cutting on the CT probability variable** (actually ***log(1-prob)***)
- Beyond the simplistic **const-acceptance** or **const-contamination**:
  - choose the **"optimal cut"** as the point on the performance curve (ROC) in which the slope becomes greater than a defined threshold;
  - fit the cut values as a function of energy → **analytical function of *Prob(E)***



- *Caveat*: can't trust the MC for bkg contamination → correction from template fitting

Efficiency scan

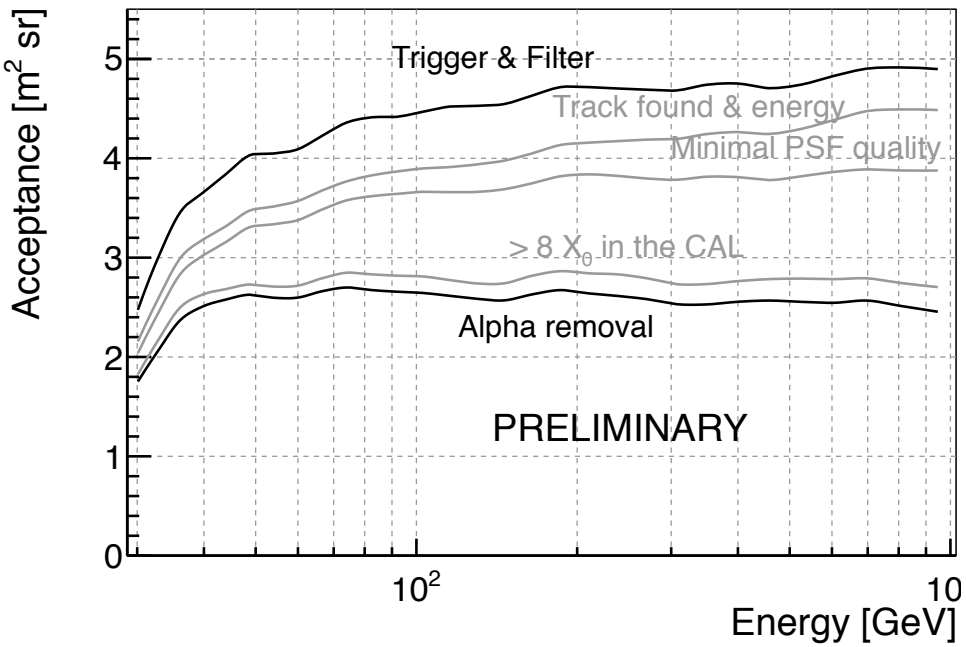
- **Scan in signal efficiency, from 10% to 90% in 9 steps**
- It is used to evaluate the stability of the spectrum as function of the cut.



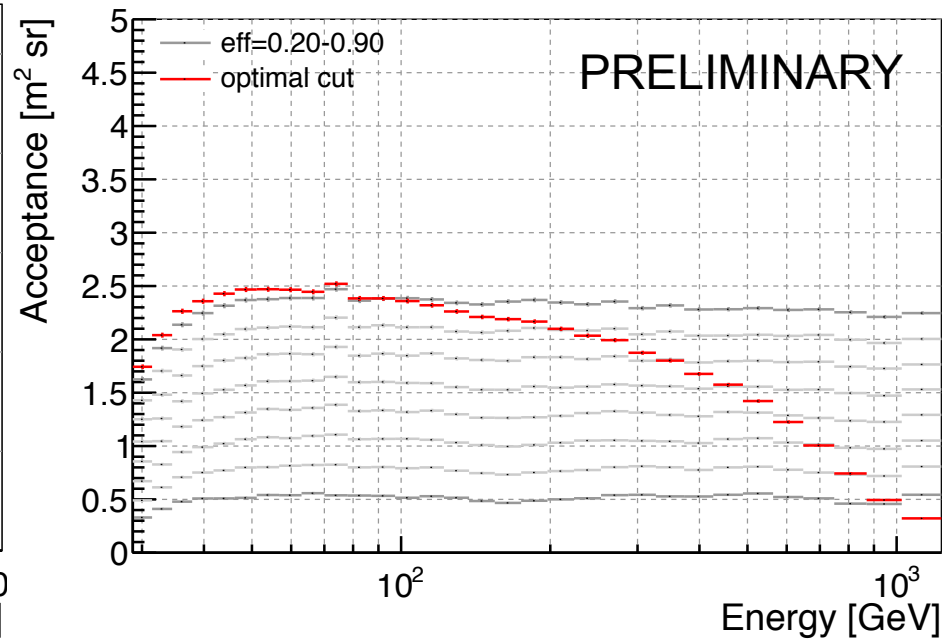
Acceptance

- In addition to PRECUTS, apply also the SELECTION CUT to all the data sets
- **Instrument acceptance:** $EGF_i = A \times \frac{N_i^{pass}}{N_i^{gen}}$

after PRECUTS

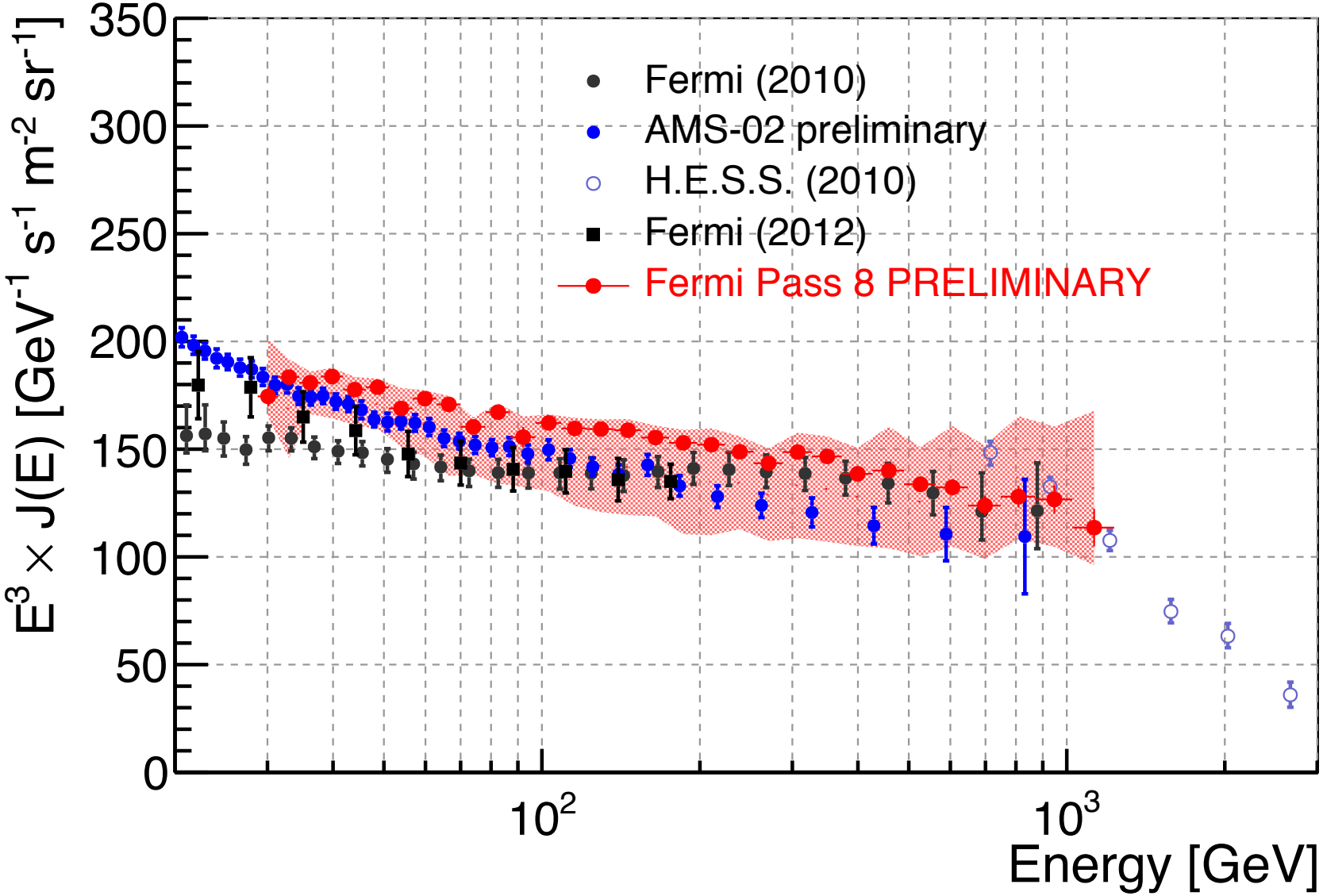


after PRECUTS + SELECTION CUT



- **Spectrum computation:** $\Phi_i = \frac{(R_{evt})_i - (R_{bkg})_i}{EGF_i}$

CRE spectrum



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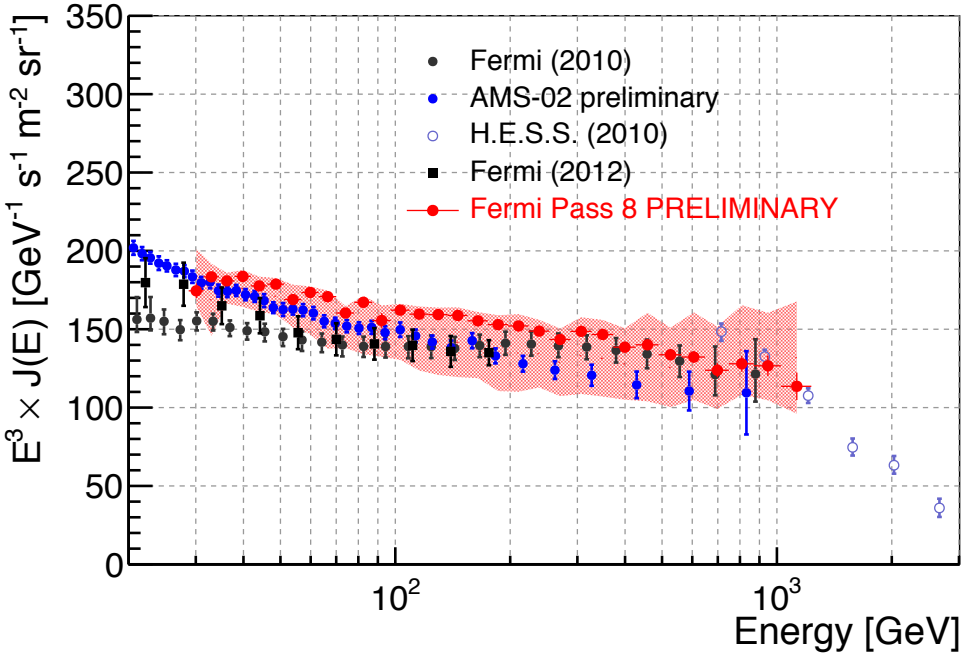
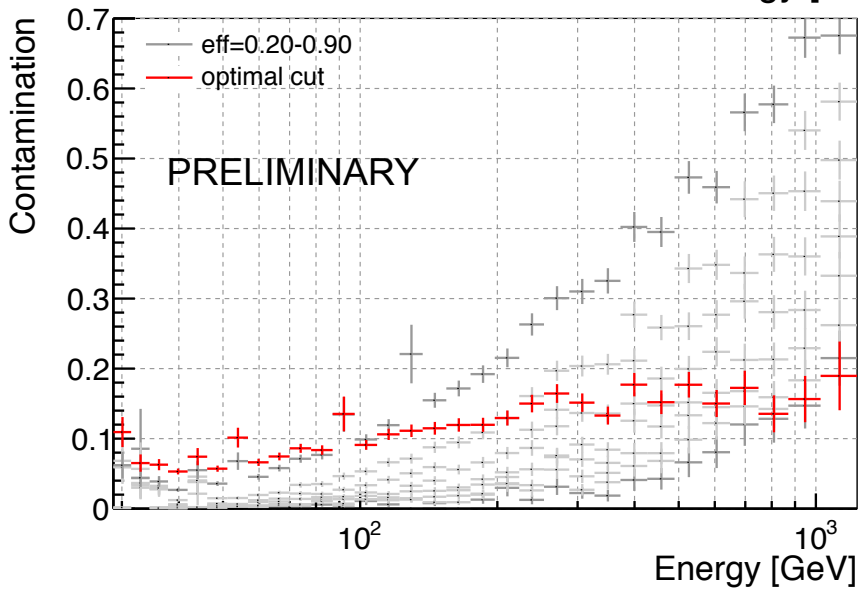




- **Systematics:**
  - shaded band is from min (20%) to max (90%) of all the spectra in the efficiency scan
  - energy scale not taken into account
- **Contamination** below 20%
- Disagreement wrt PRD spectrum:
  - possibly due to "ghost" signal not taken into account in the acceptance in our first analysis
  - probable overestimation of acceptance by 10-15% at ~10 GeV
- **AMS:**
  - similar spectral index
  - the 2 spectra overlap by simply rescaling energy by few percent

Conclusions

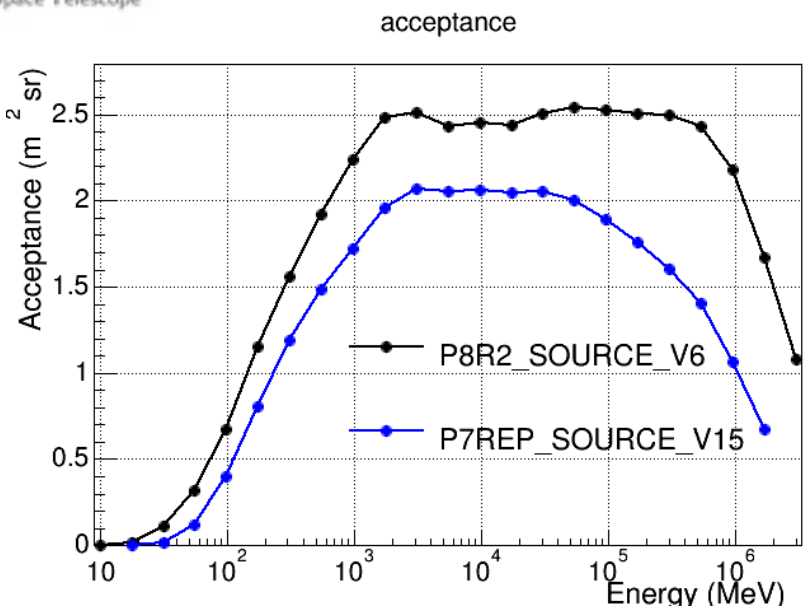
- **We performed a new measurement of the CRE spectrum with the new Pass 8 event-level analysis**

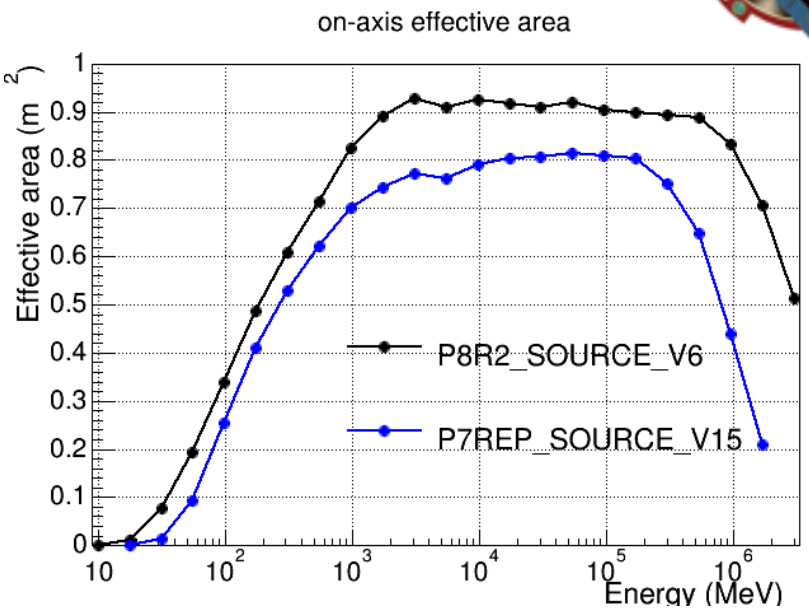
- **It's almost a new analysis!**
  - almost 6 times the PRD data set
  - new event reconstruction & selection (Pass8)
  - new multi-variate analysis tool

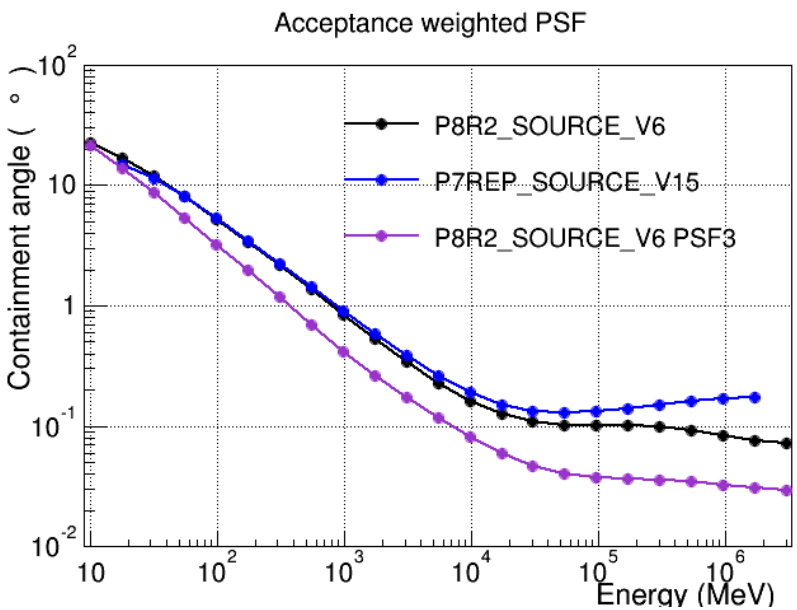
- **Work in progress**
  - Extend the analysis beyond 1.2 TeV to scrutinize the presence of a cut-off
    - new CT under investigation
    - more accurate study of systematics
  - Extend the analysis down to 7 GeV

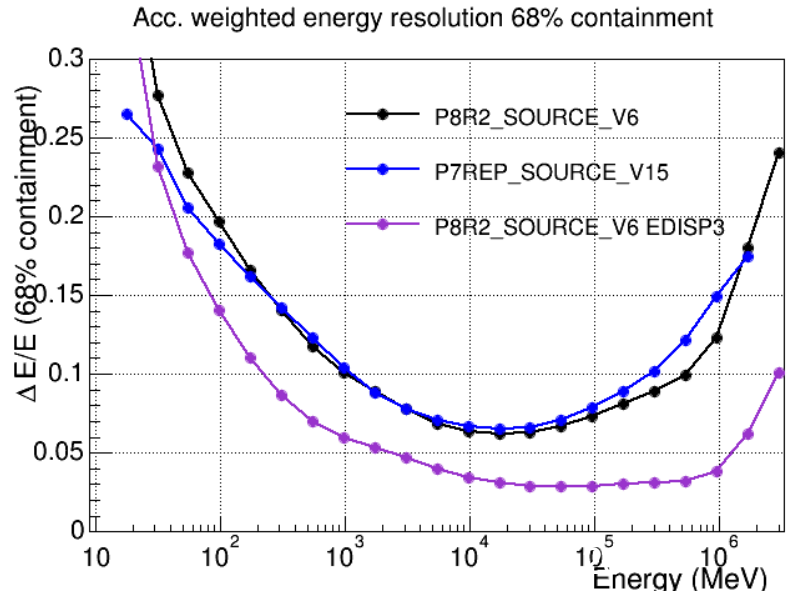
BACKUP SLIDES

Response Function



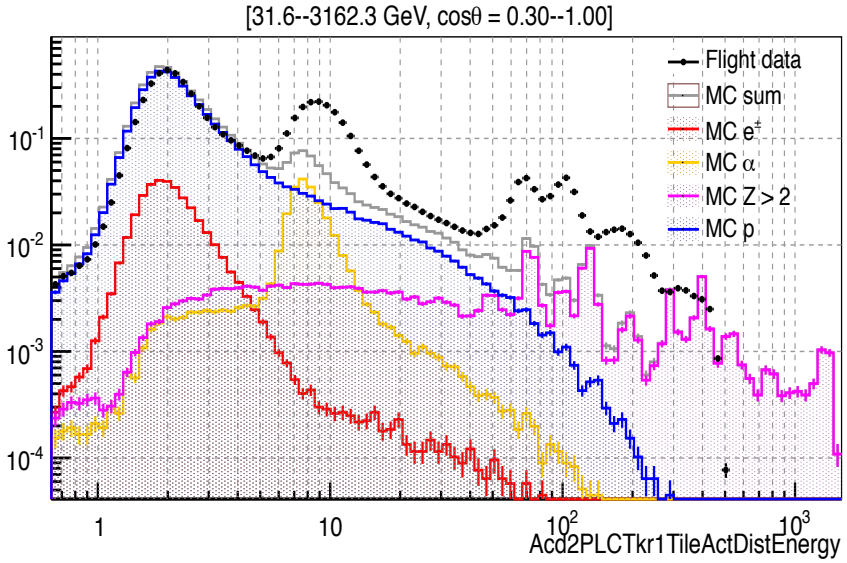


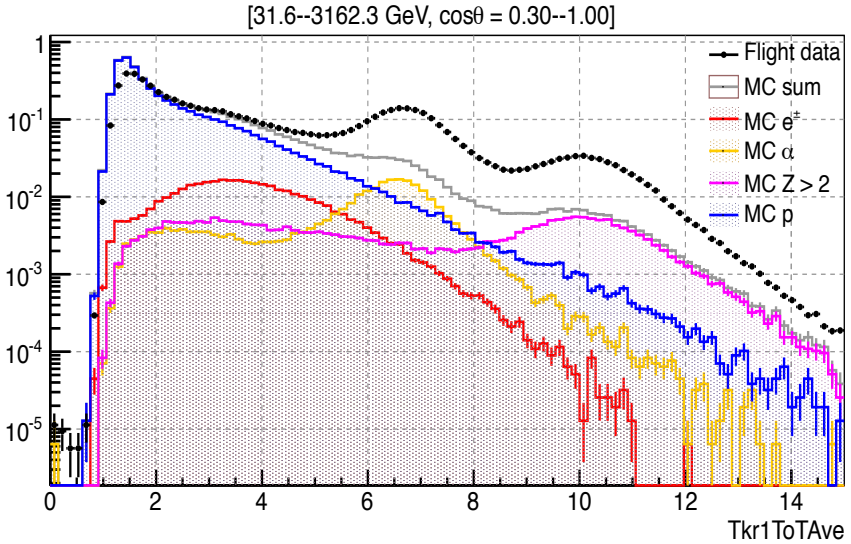




Pre-cuts

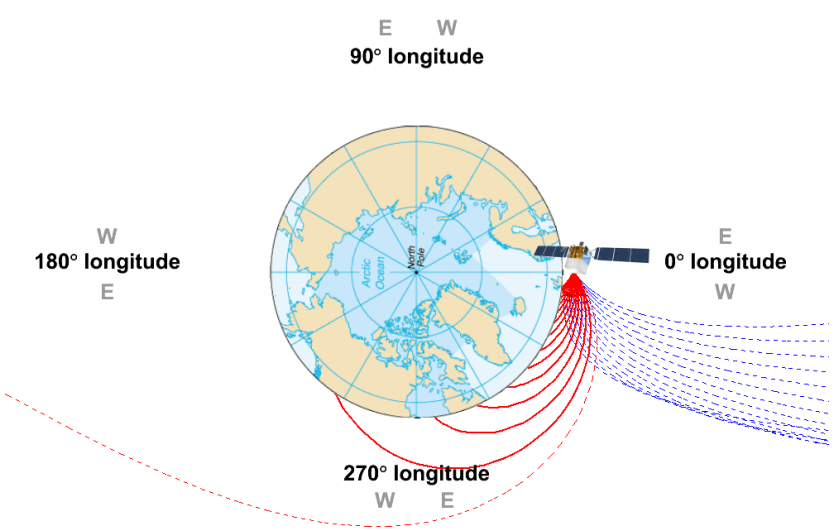
- **PRECUTS** = TRIGGER FILTER + QUALITY CUT + ALPHA CUT
  - **TRIGGER FILTER:** the event triggers the LAT and passes the on-board gamma filter *'(GltGemSummary&0x20)==0 && (GltGemSummary&0x40)==0 && FswGamState == 0'*
  - **QUALITY CUT:** the event has at least a reconstructed track, a minimal PSF quality and the path length in the Cal is larger than the Cal on-axis thickness *'EvtCalCsIRLn>8 && CalIRawEnergySum>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

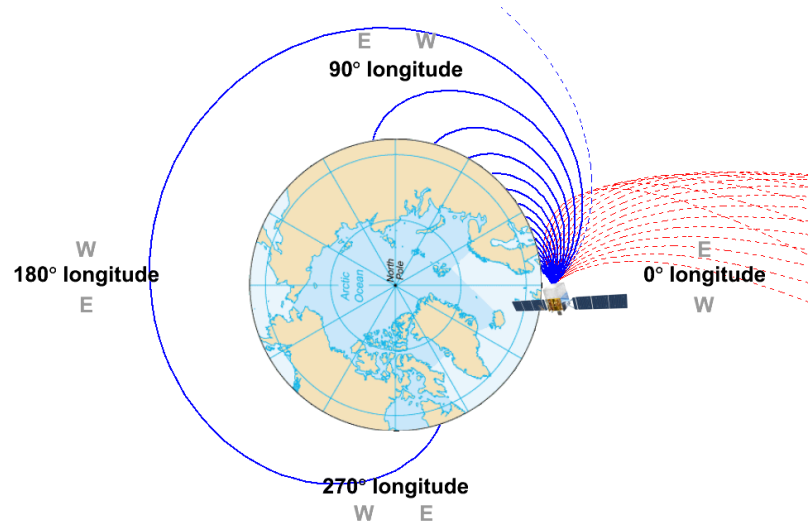




Positron detection

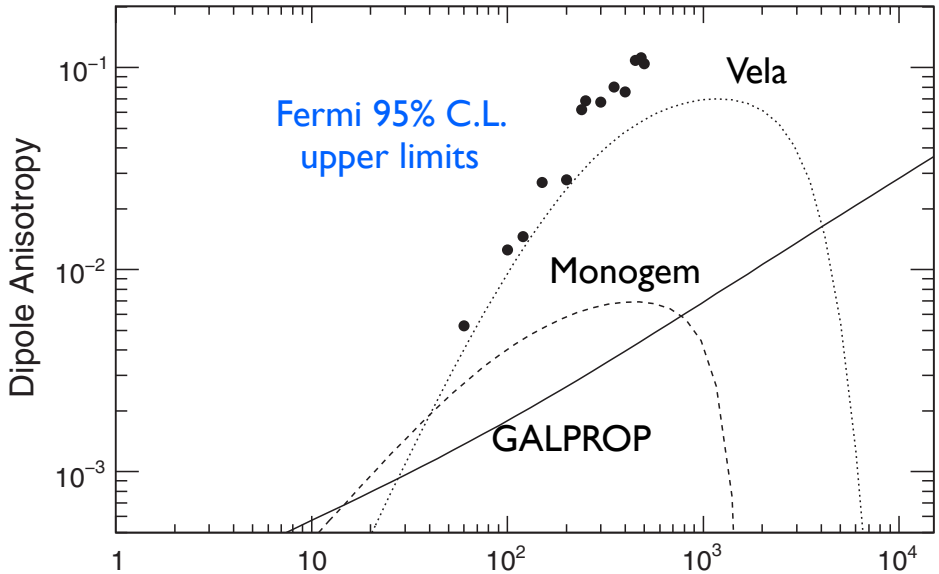
- The LAT doesn't carry a magnet on-board → the only magnet we can use is provided by the Earth
- Earth's Magnetic Field blocks some of the particle trajectories (*continuous lines*)
- There are regions in which only one of the two particle types is permitted
  - Pure e^+ region in the West direction & Pure e^- region in the East direction





CRE anisotropy

Astrophysical scenario



Dark Matter scenario