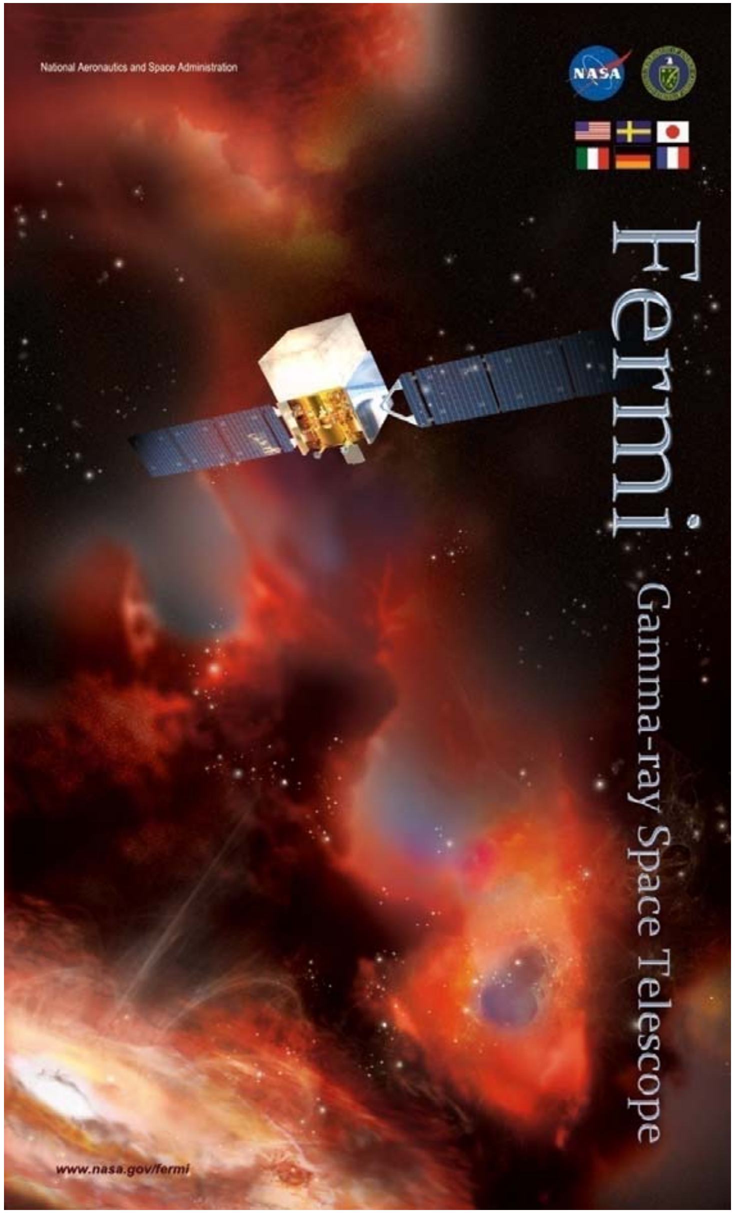

The Fermi Gamma-ray Space Telescope :

reconstruction, systematics, and some results about galatic diffuse and electrons

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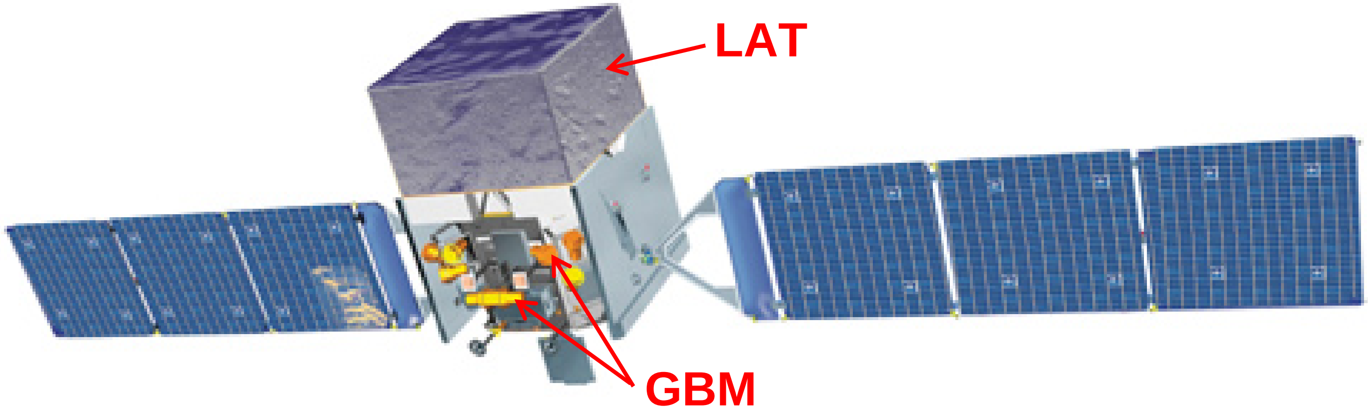
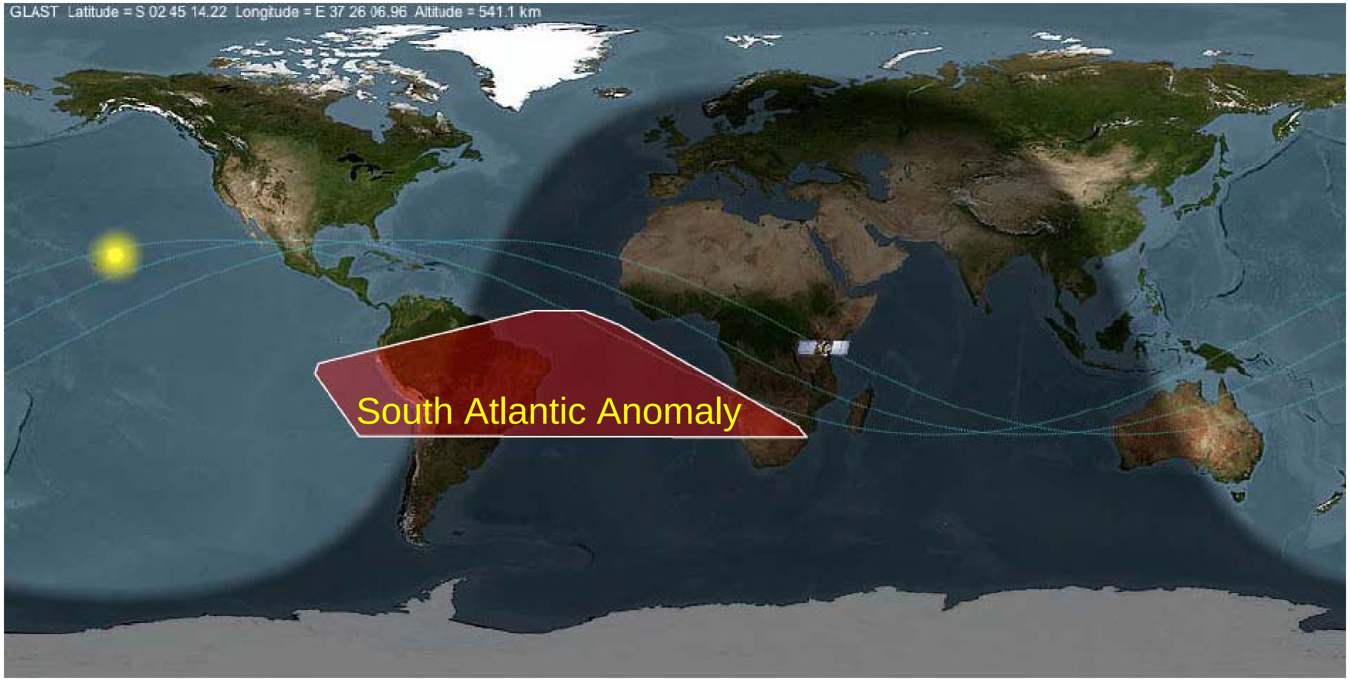
LLR - Ecole polytechnique/CNRS

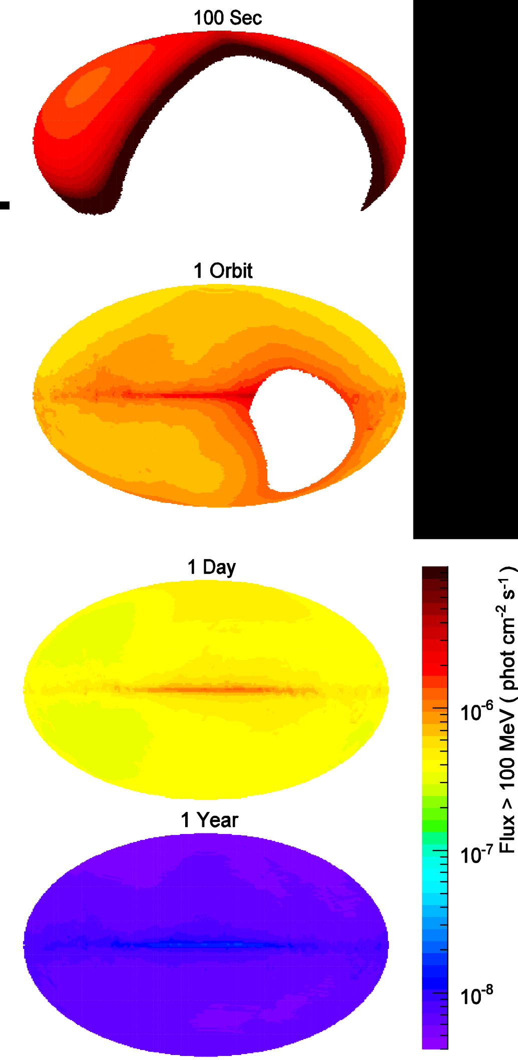
Fermi satellite

- Two instruments:
  - Large Area Telescope (LAT), 20 MeV - >300 GeV
  - Gamma-ray Burst Monitor (GBM), 8 keV - 40 MeV



Fermi in space





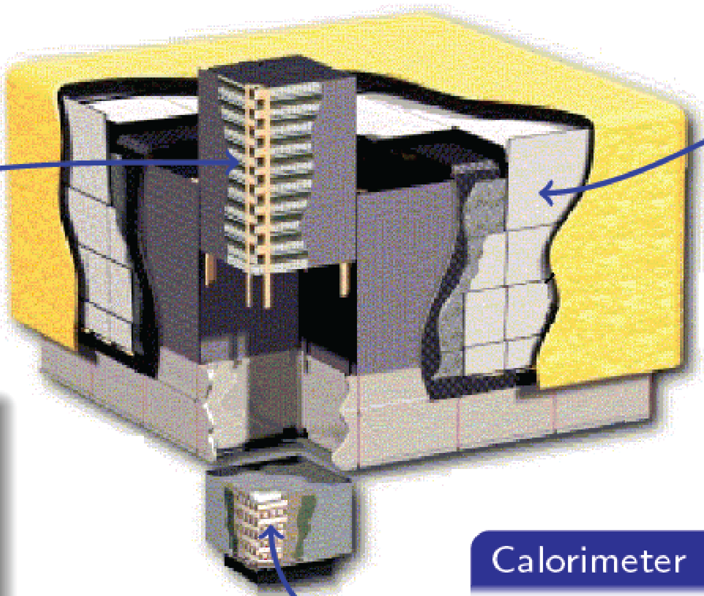
- Launch : June 11 2008
- Orbit : 565 km, circular
- Inclination : 25.6°
- Design life : 5 years (minimum)

- One orbit in 1.5h
- The whole sky in 3h

Large Area Telescope

Large Area telescope

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



Tracker

- Silicon strip detectors, W conversion foils; 1.5 radiation lengths on-axis
- 10k sensors, 80 m^2 of silicon active area, 1M readout channels
- High-precision tracking, short dead time

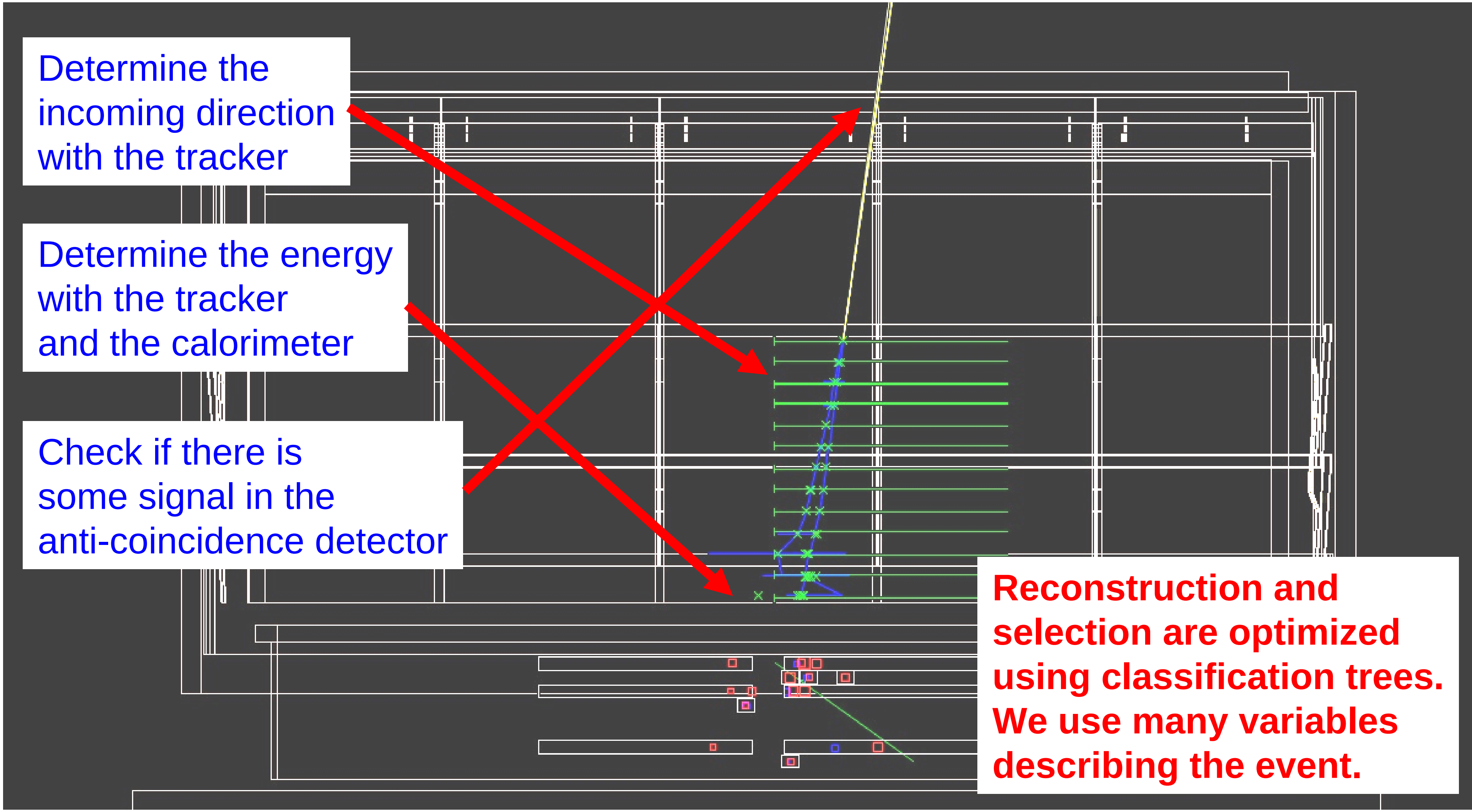
Anti-Coincidence Detector

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

Calorimeter

- Hodoscopic tower of 1536 CsI(Tl) crystals; 8.6 radiation lengths on-axis
- 3D shower profile reconstruction for leakage correction and hadron rejection

Event reconstruction



Determine the incoming direction with the tracker

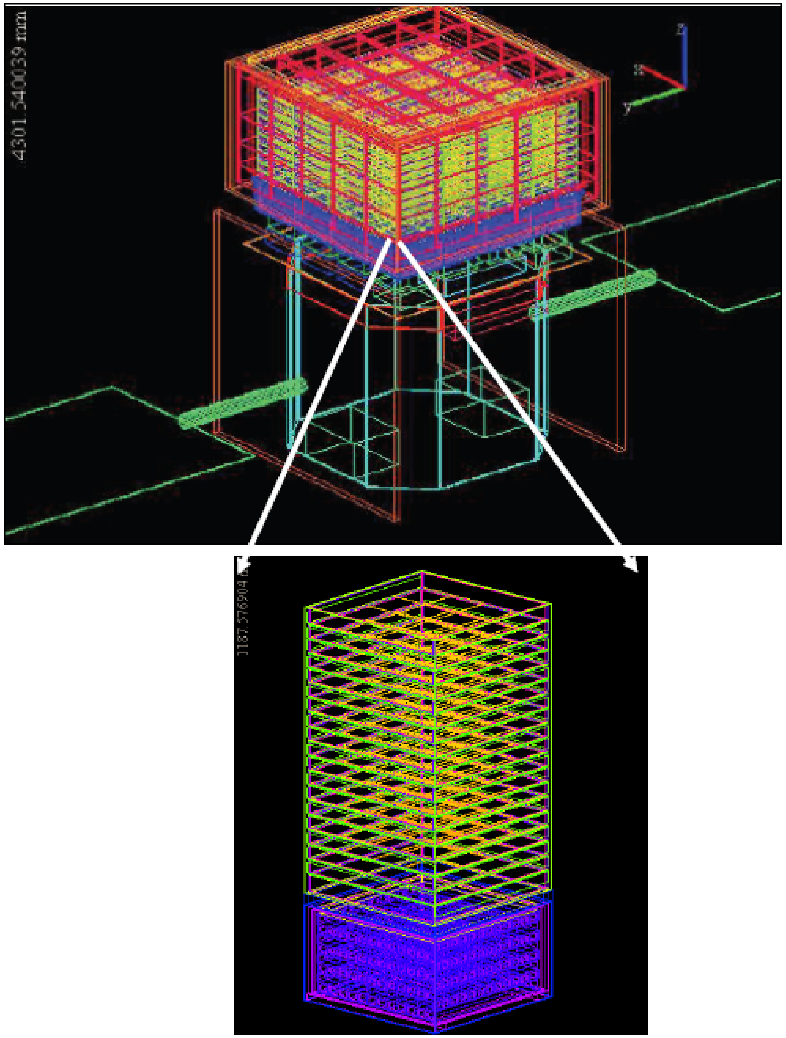
Determine the energy with the tracker and the calorimeter

Check if there is some signal in the anti-coincidence detector

Reconstruction and selection are optimized using classification trees. We use many variables describing the event.

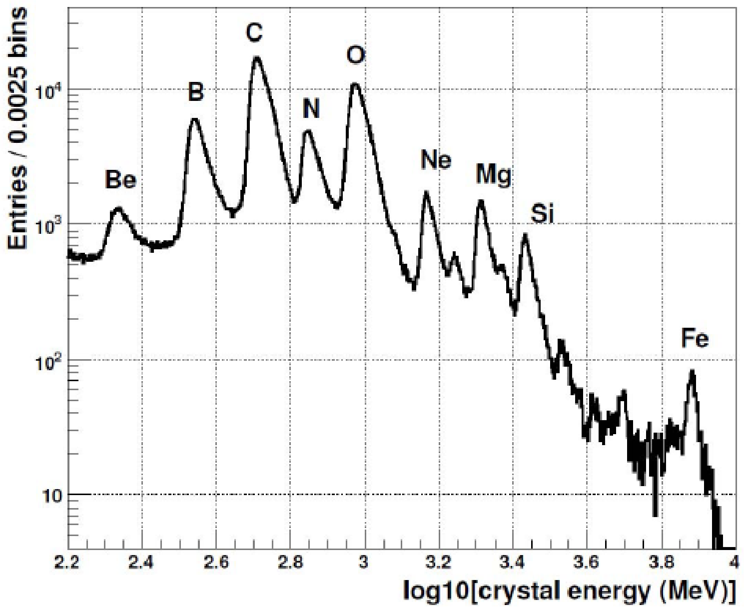
Detailed instrument simulation with Geant4

- **MC crucial for**
  - **Reconstruction tuning**
  - **Event selection and performance**
  - **Estimate residual contamination**
    - 400 CPUs ran for 80 full days only for CRE analysis
- **Accurate detector model**
  - **over 45000 volumes**
- **Physical interactions with Geant4**
  - **Optimized ElectroMagnetic (EM) and Hadronic (HAD) physics**
    - EM: LHEP + Fermi-debugged routines for
      - Multiple scattering
      - Landau-Pomeranchuck-Migdal
    - HAD: custom physics lists
      - Bertini for E < 20GeV
      - QGSP for E > 20GeV
- **Utilizes real LAT calibrations**



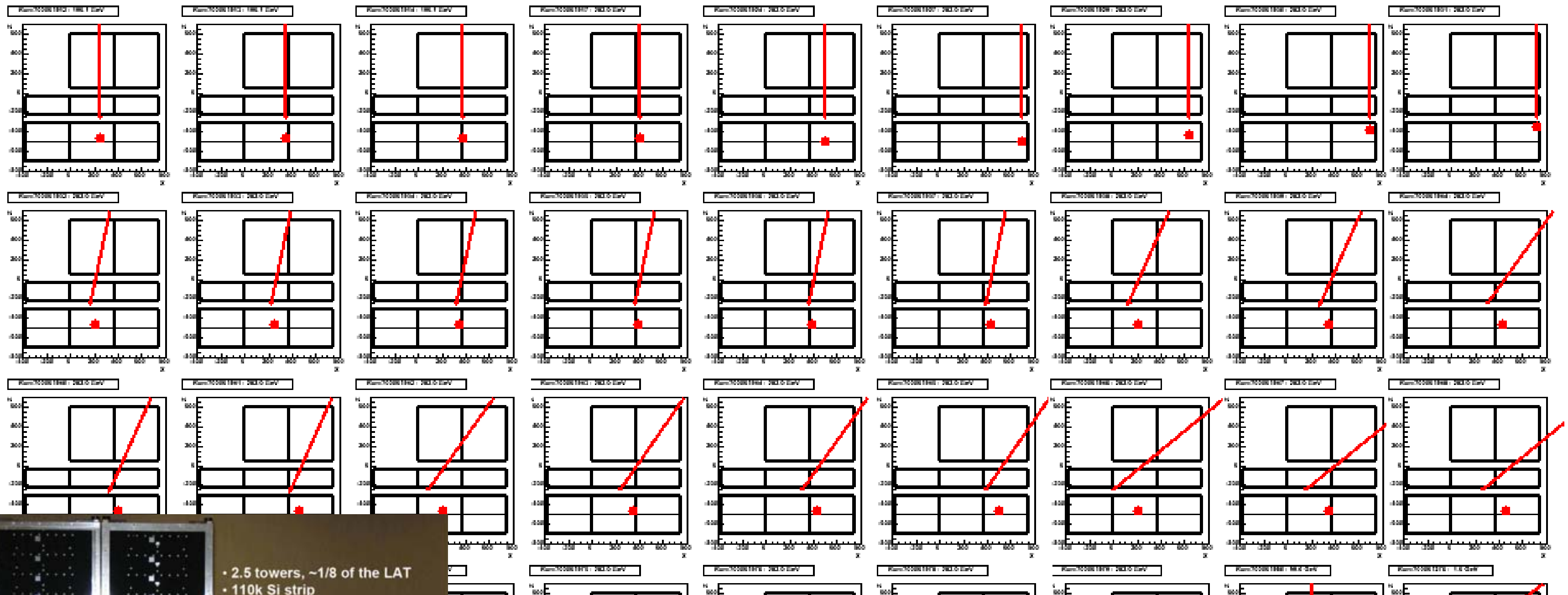
Ensuring the most realistic simulation

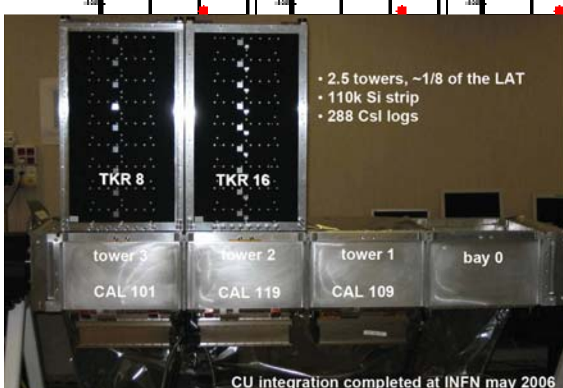
- Calibrations
  - Using muons (on ground) and protons et al. (in orbit)
  - Signal in ACD, tracker and calorimeter
  - Position calibration
  - Intra tower and tower to tower alignment
  - Stability



Ensuring the most realistic simulation

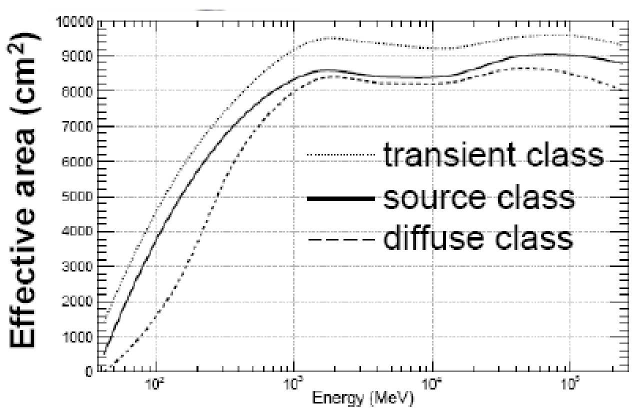
- Beam tests (the last one at CERN in 2006)
  - Calibration Unit (2.5 towers) with electrons, gammas, protons, pions, from 100 MeV to 300 GeV in many configurations (94M evts)

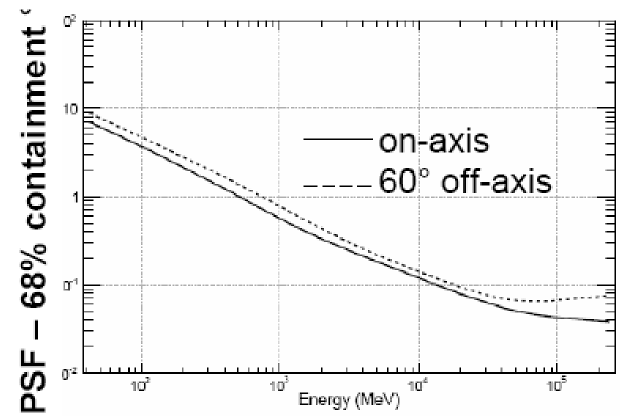


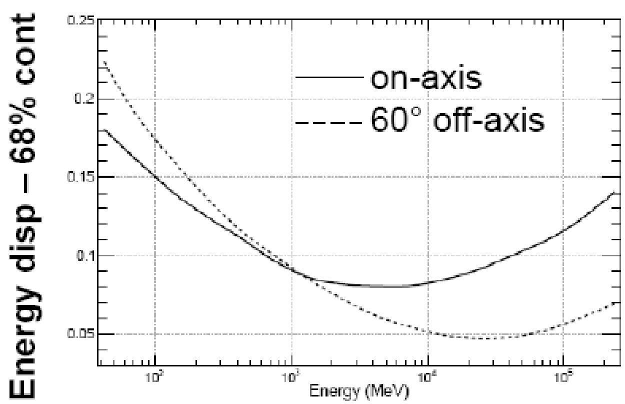


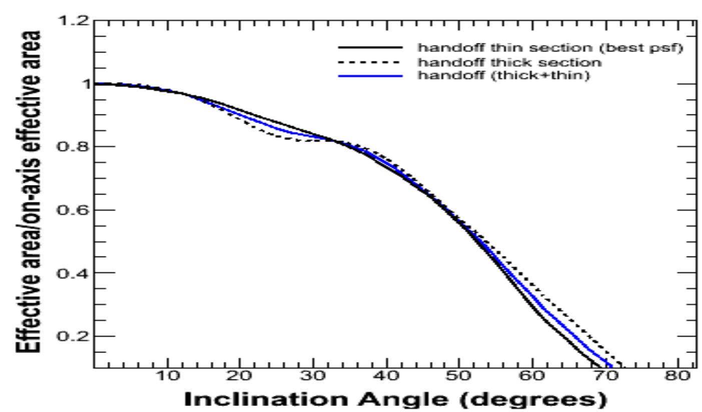
Instrument performances

	Years	Ang. Res. (100 MeV)	Ang. Res. (10 GeV)	Eng. Rng. (GeV)	$A_{eff}\,\Omega$ (cm^2 sr)	# γ-rays
EGRET	**1991–00**	**5.8°**	**0.5°**	**0.03–10**	**750**	**1.4×10^6/yr**
***Fermi* LAT**	**2008–**	**3.5°**	**0.1°**	**0.02–300**	**25,000**	**1×10^8/yr**

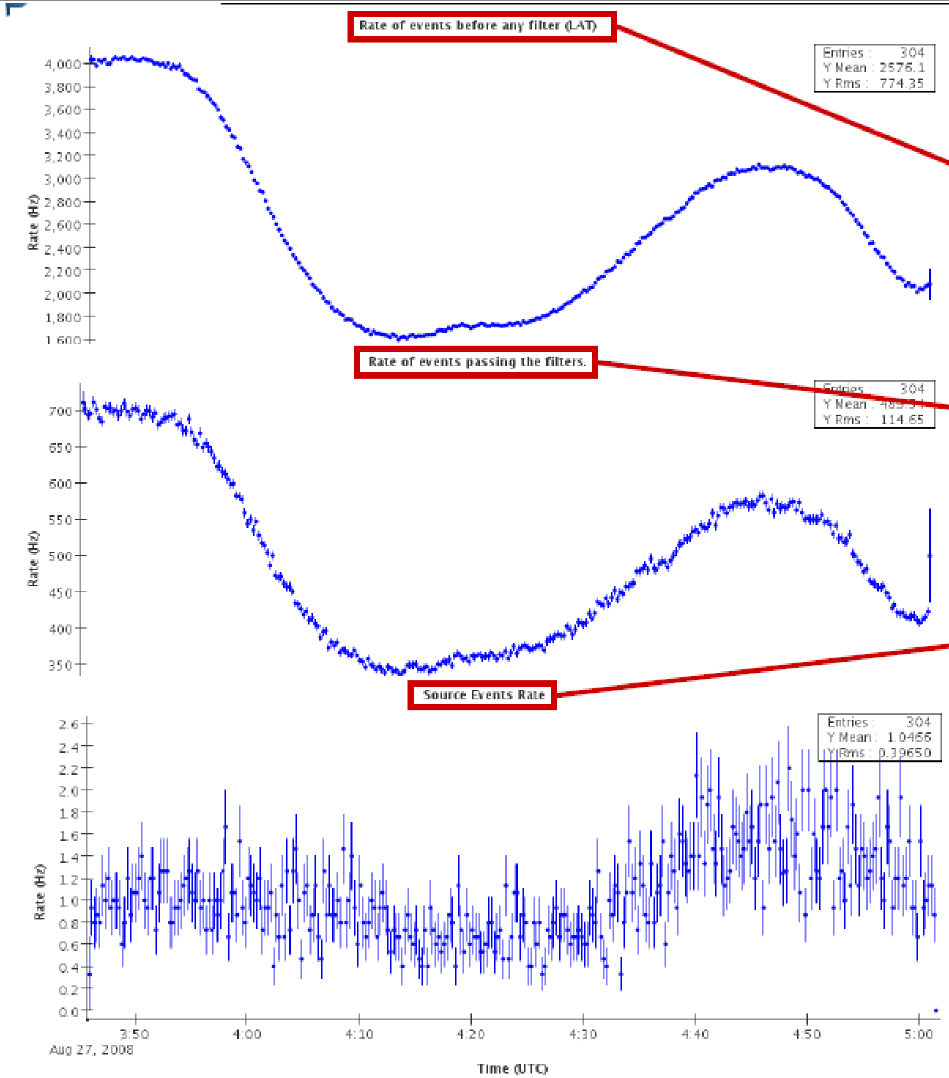








On orbit rates



- ✓ Overall trigger rate: ~few KHz
  - ✓ Huge variations due to orbital effects.

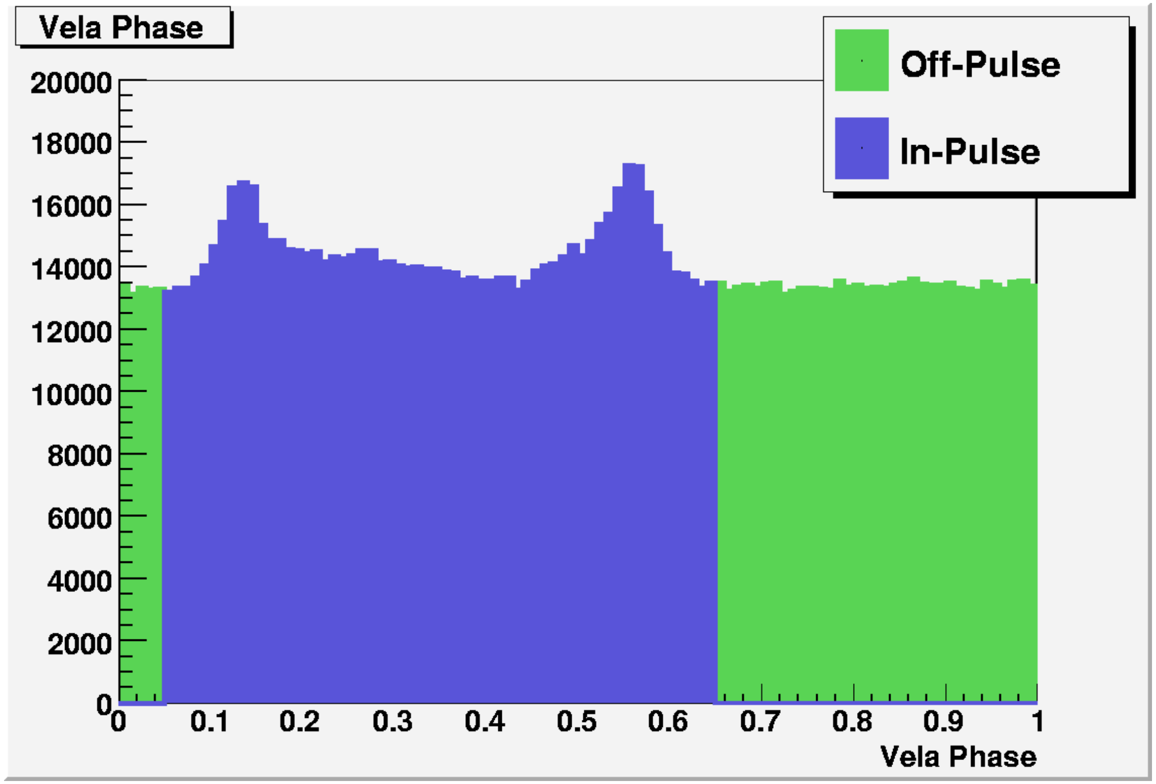
- ✓ Downlink rate: ~400—500 Hz
  - ✓ ~90% from GAMMA filter
  - ✓ ~20—30 Hz from DGN filter
  - ✓ ~5 Hz from HIP filter

- ✓ Rate of photons after the standard background rejection cuts for source study: ~1 Hz

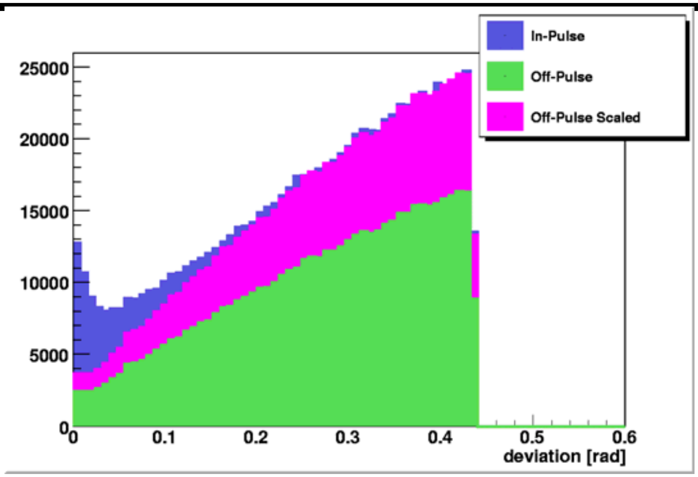
- ✓ Most of the downlinked events are in fact background, final ~ 1000:1 rejection is done in ground processing.

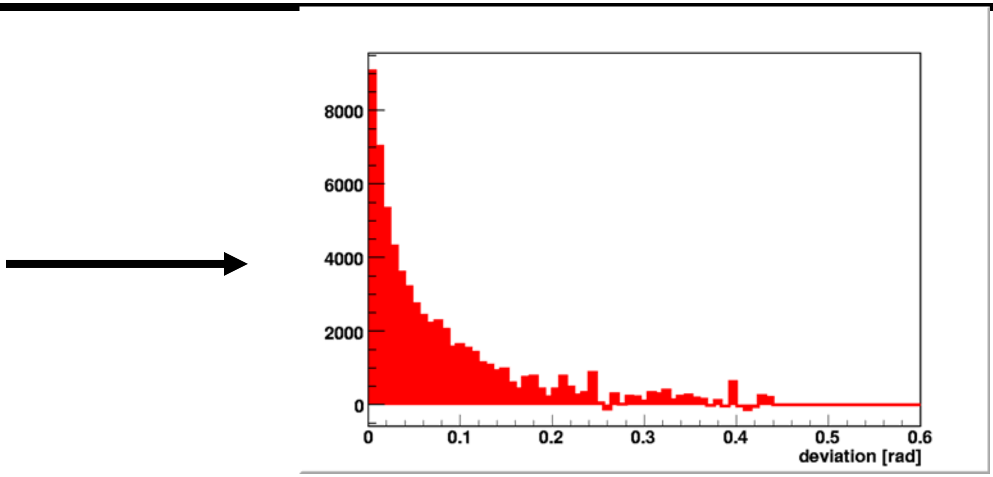
On orbit performance validation

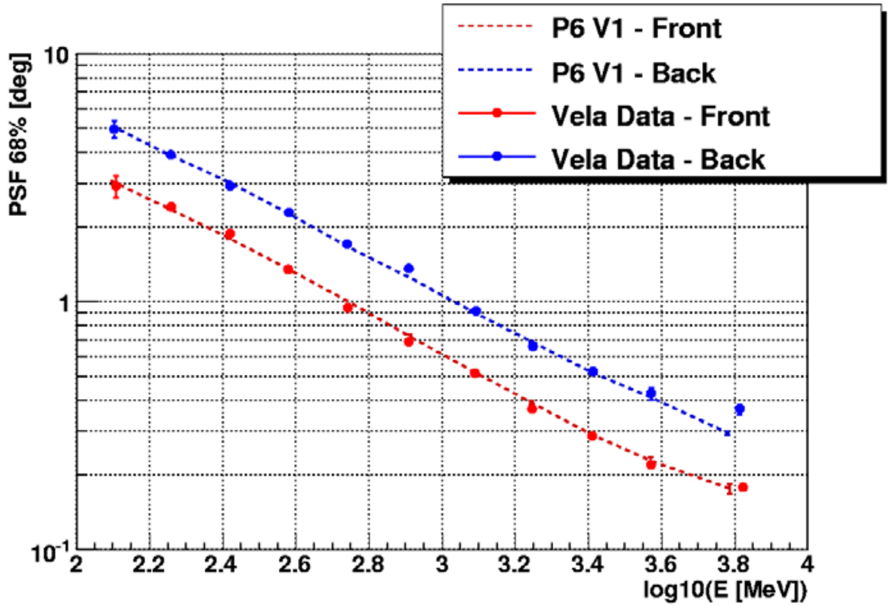
- Main method : using bright pulsars (i.e. Vela)
  - Selecting events in-pulse and off-pulse
  - Subtracting off-pulse component to get a pure gamma signal



On orbit PSF validations

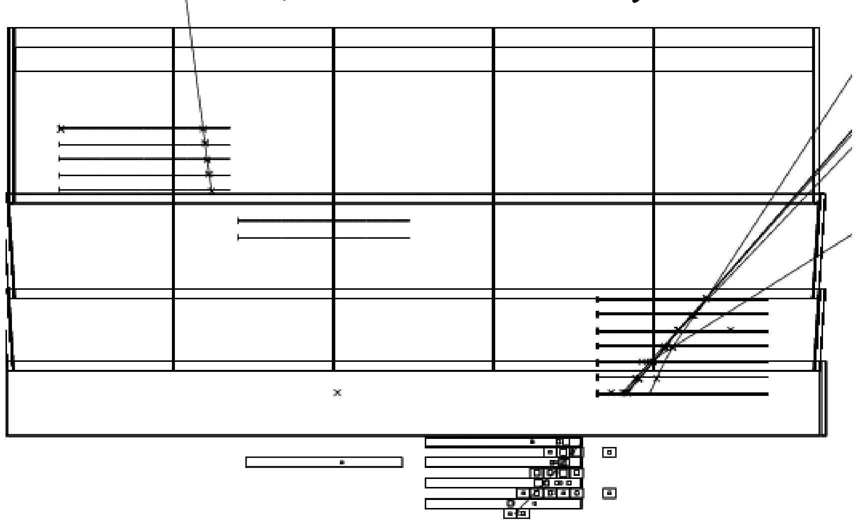


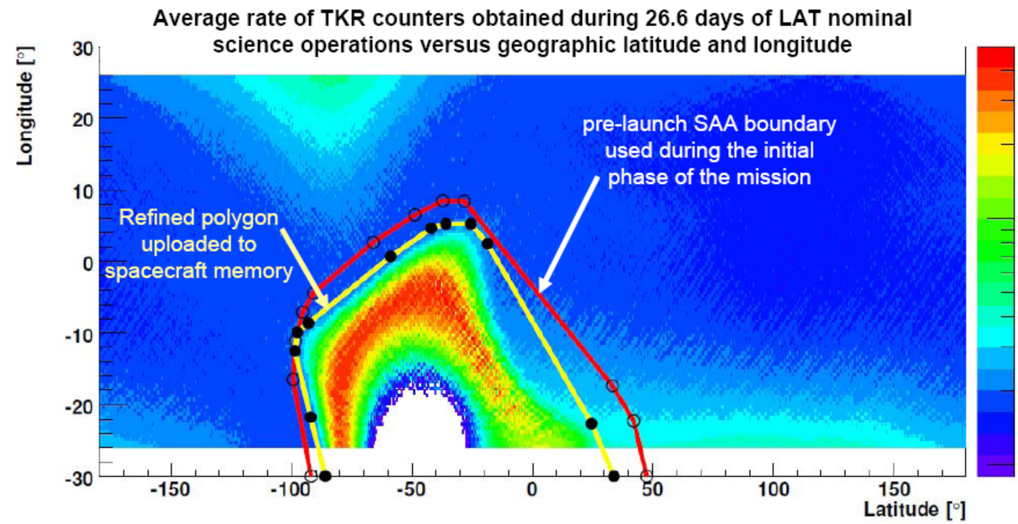




On orbit effective area validation

- We discovered a pure orbit effect that must be taken into account in order to have a realistic effective area : off-time cosmic rays passing through the LAT decrease the effective area (~30% at 200 MeV, 10% at 1 GeV, ~0 at 10 GeV)

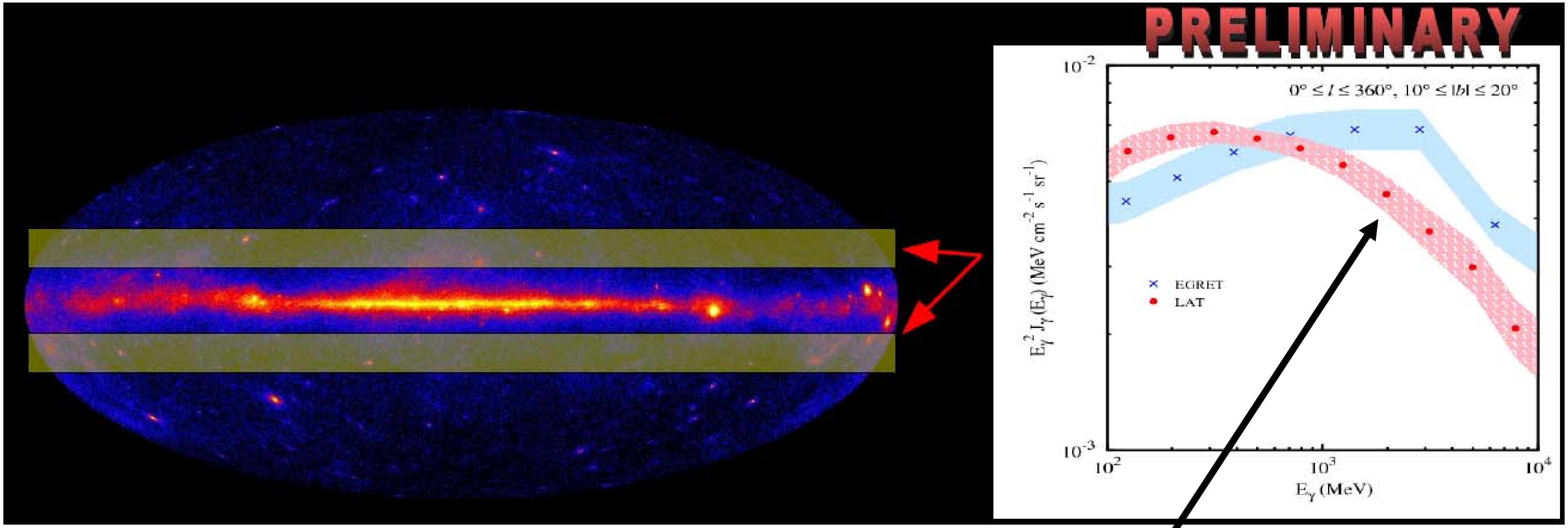




- Using random triggered events, we can simulate this effect and get a good agreement between selection efficiency in data and simulation.
- Systematics : 10% at 100 MeV, 5% at 600 MeV, 20% at 10 GeV

Galactic diffuse at intermediate latitudes

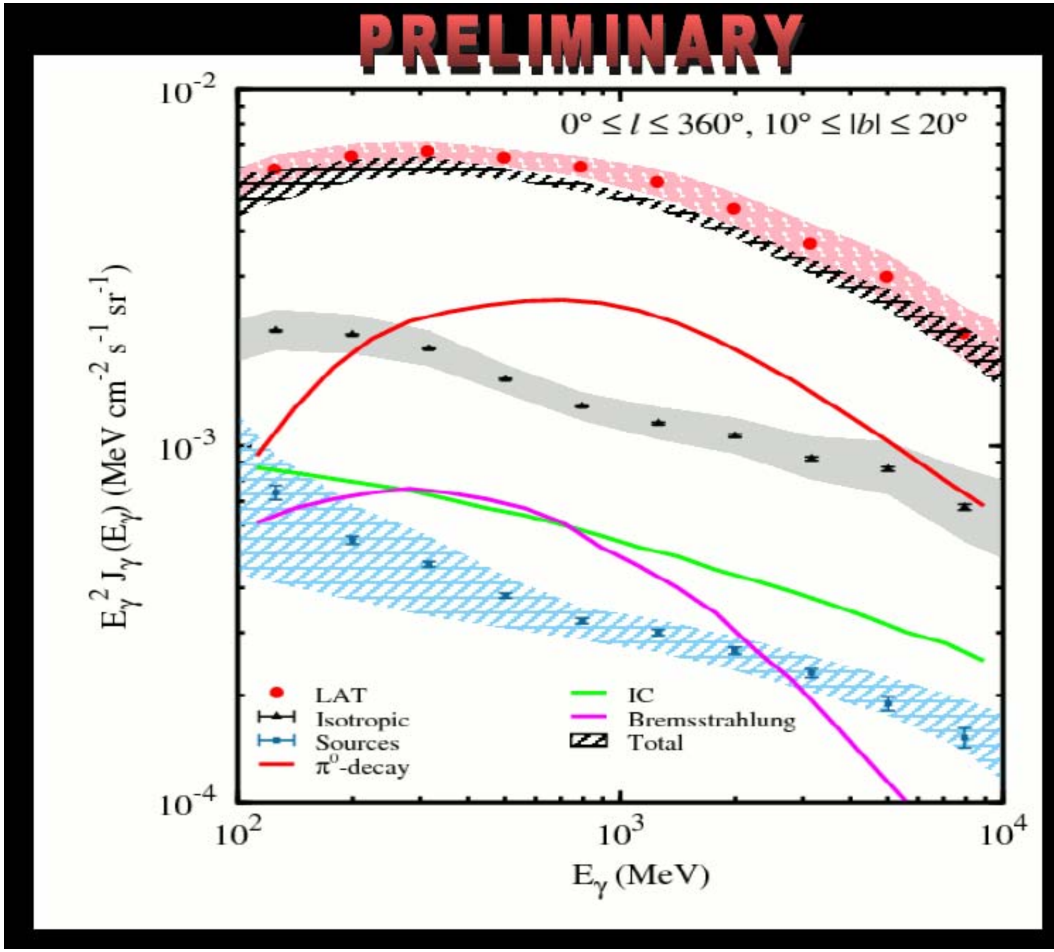
- LAT data averaged over longitudes and latitudes range 10°<|b|<20° (no point source and background subtraction)



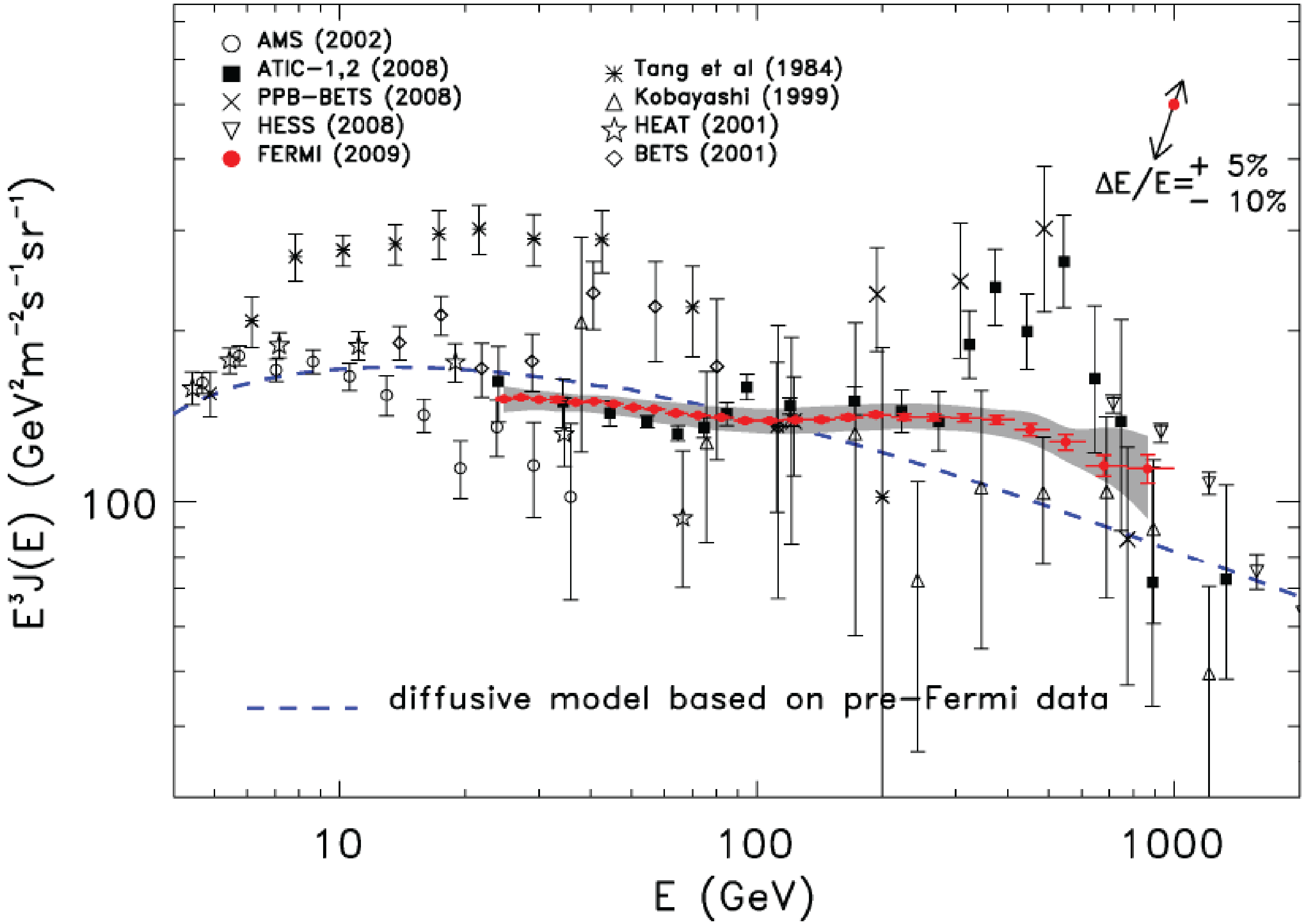
Only systematic uncertainty in the effective area.
Additional systematic uncertainty on the energy : 5% at 100 MeV and 10% above 1 GeV, with energy likely overestimated.

Galactic diffuse at intermediate latitudes

- Model is assumed (based on pre-Fermi data)
  - π° decay
  - Bremsstrahlung
  - Inverse Compton
- Source and isotropic (including residual background) component come from fitting the data with model fixed
- Spectral shape is consistent with data but overall emission lower for whole energy range
- Systematic uncertainty comes from the systematic uncertainty in the effective area propagated through the source and isotropic component

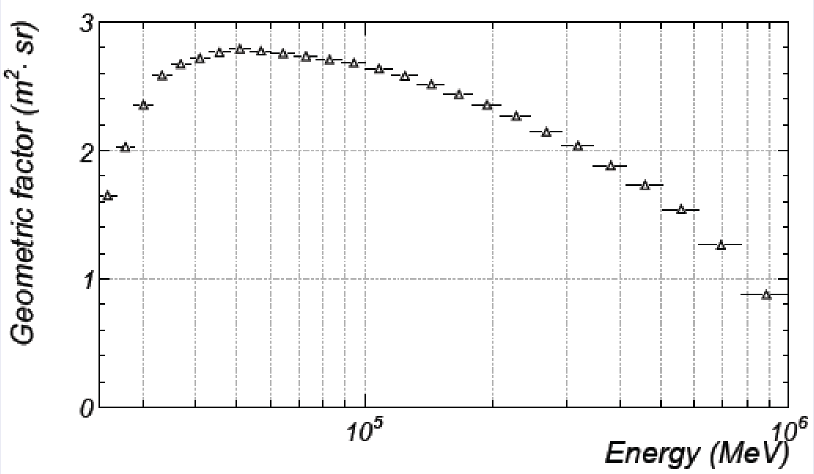


High energy cosmic ray electron spectrum



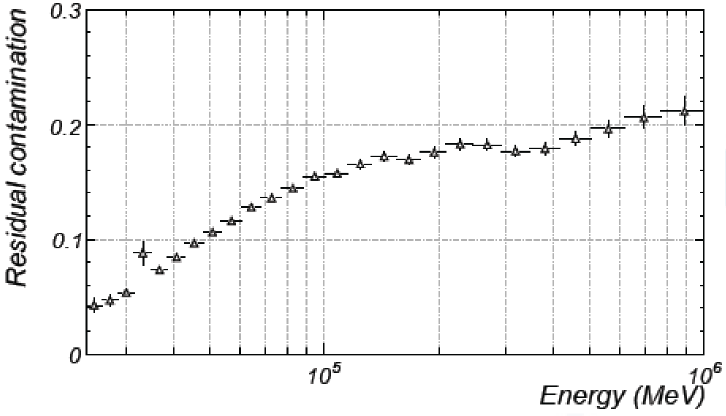
High energy cosmic ray electron spectrum

CRE geometry factor

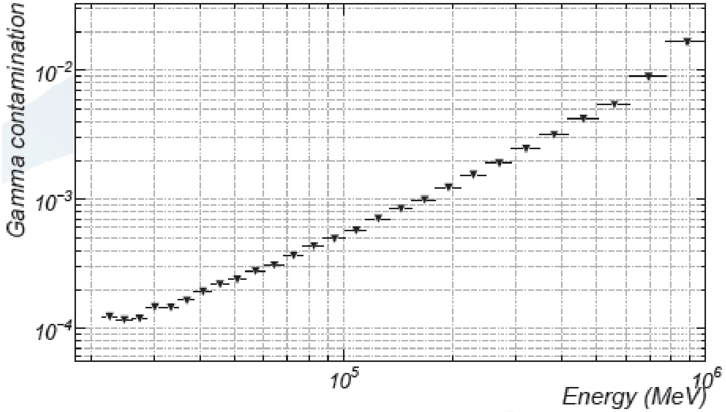


- 2.8 m^2 peak geometry factor
- 2 m^2 at 300 GeV
- almost 1 m^2 at 1 TeV
- an order of magnitude bigger than previous experiments

Residual hadronic contamination

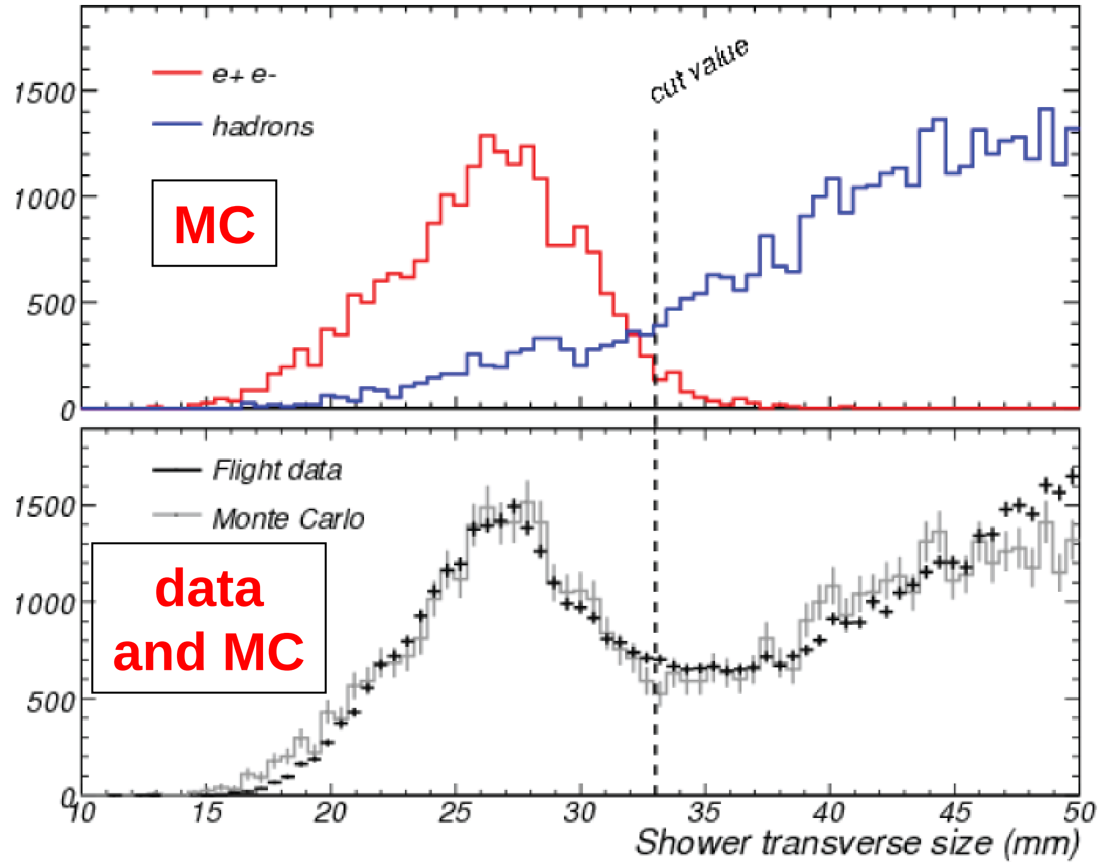


Expected γ-ray contamination

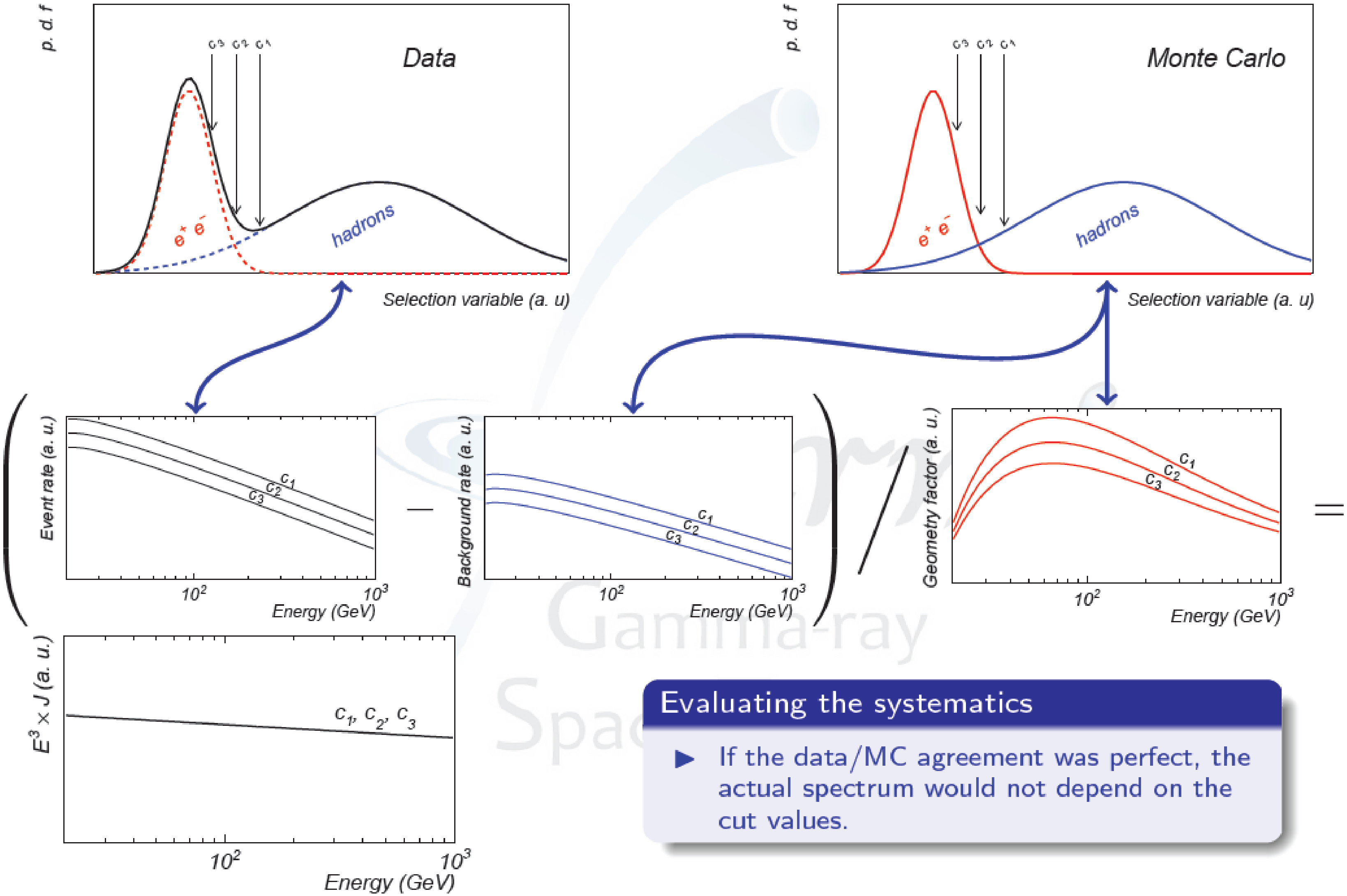


Data/MC agreement and contamination

- Good agreement data/MC
- Estimate of the proton contamination



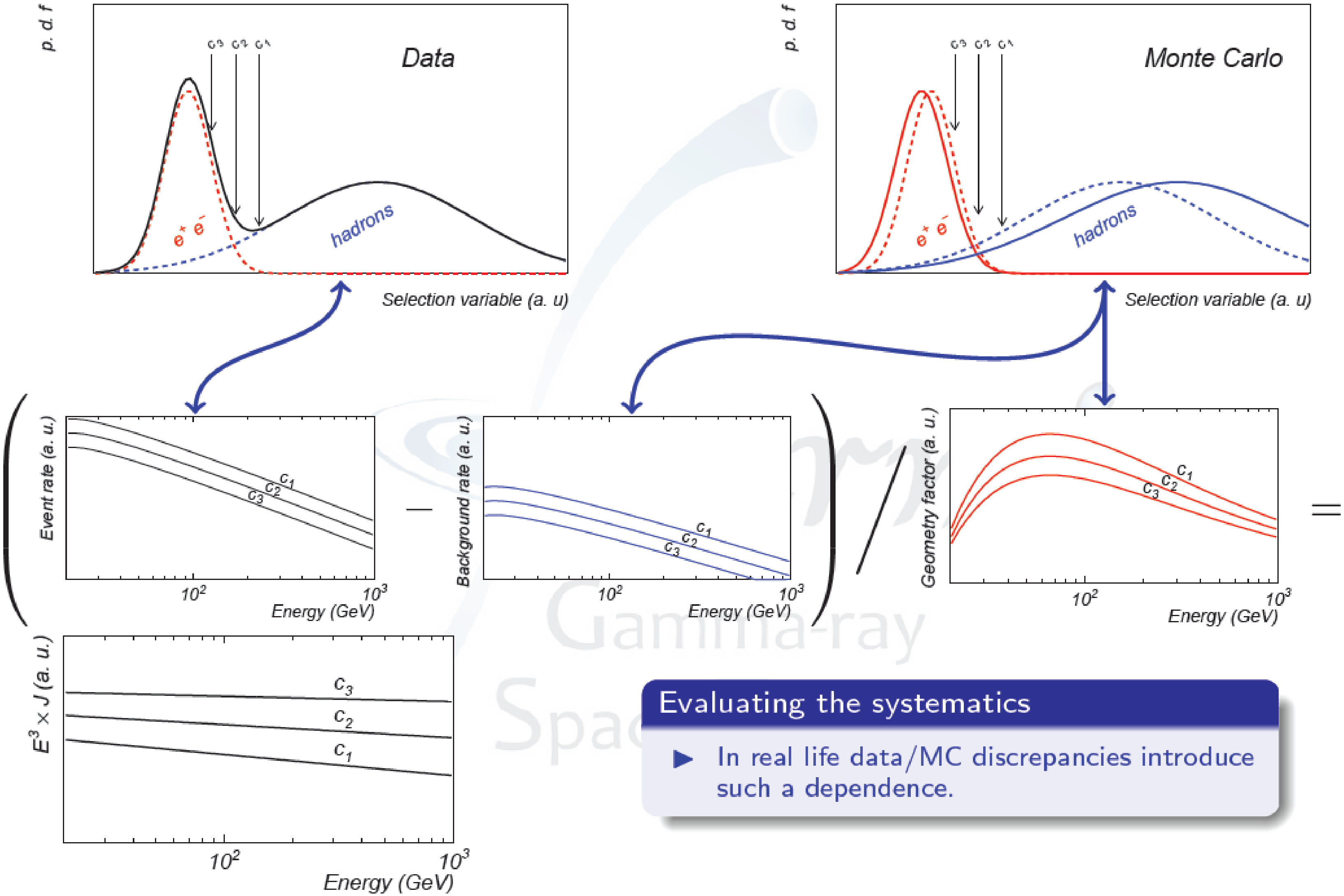
Systematic uncertainty



Evaluating the systematics

- If the data/MC agreement was perfect, the actual spectrum would not depend on the cut values.

Systematic uncertainty

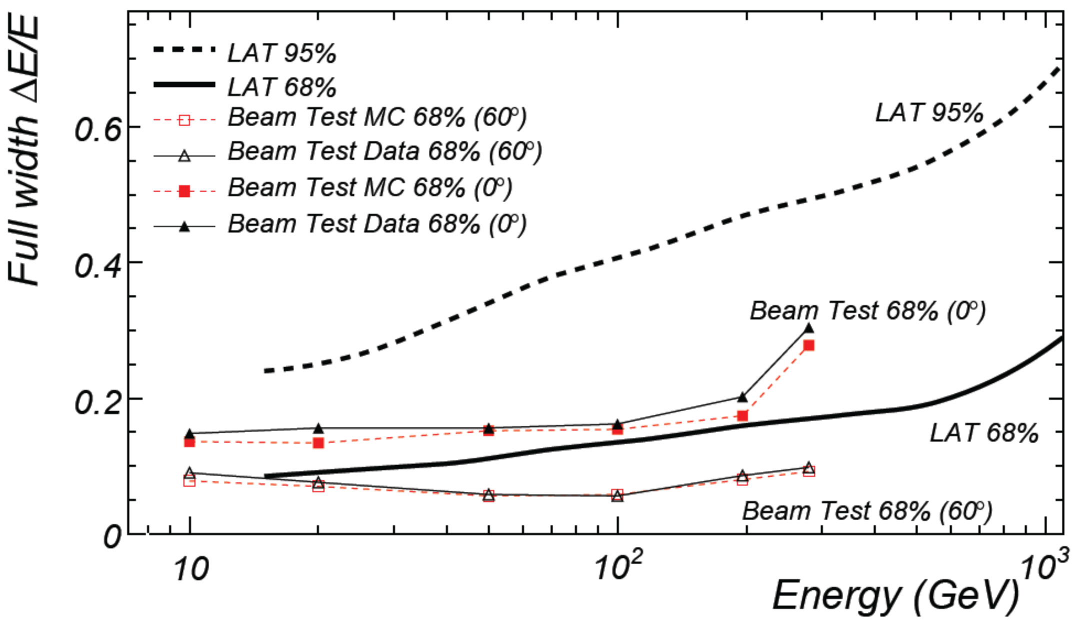


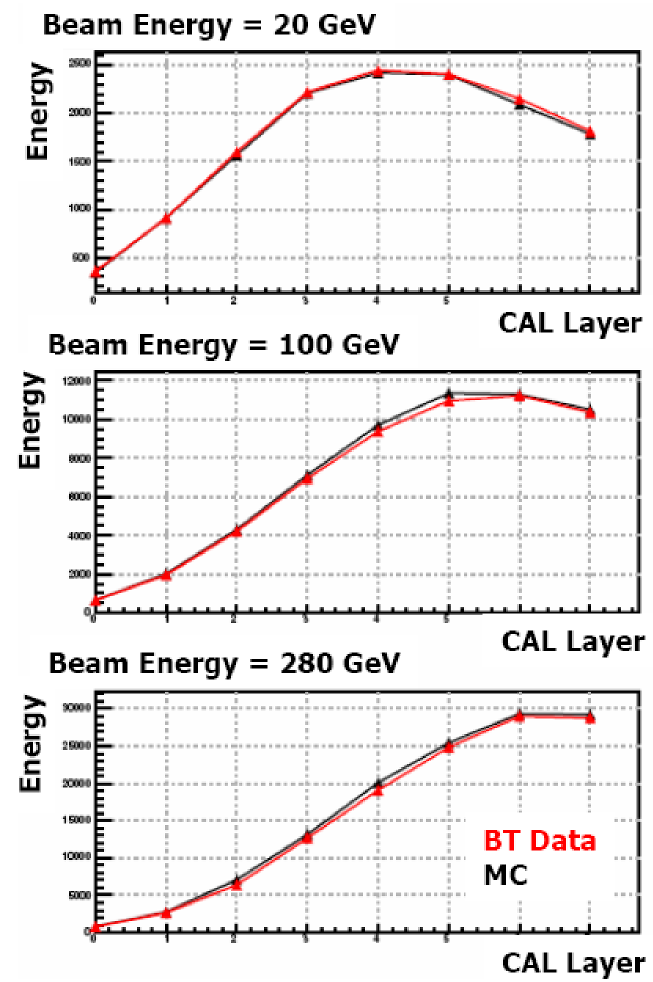
Evaluating the systematics

- In real life data/MC discrepancies introduce such a dependence.

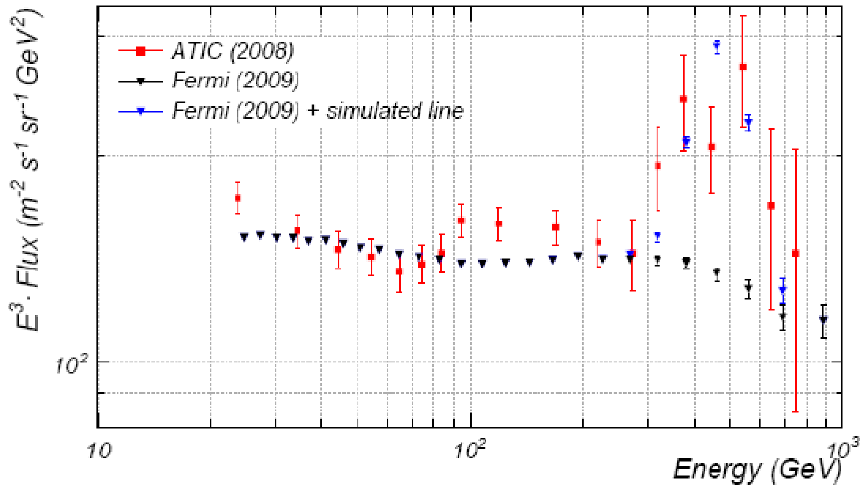
Energy reconstruction

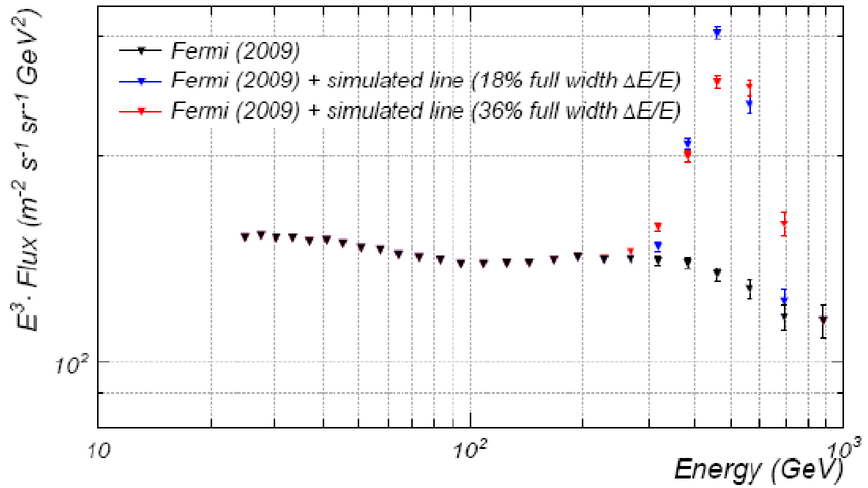
- Energy estimation at high energy relies on profile fitting
- Energy resolution tested up to 300 GeV at CERN





Detecting an ATIC-like bump





- **Given our energy resolution we would have seen a prominent feature such as the ATIC bump**
  - **ATIC excess: 70 electrons between 300 and 800 GeV**
  - **we would have seen an excess of 7000 electrons**
- **Test by adding a simple gaussian signal (450 +- 50 GeV) to our spectrum**
  - **Even if we worsen our energy resolution by a factor of 2, the feature would have been clearly seen**

Conclusions

- Still improving the understanding of the instrument (new reconstruction, new selection) : larger effective area (especially at low energy) and smaller systematic uncertainties, less residual background
- For electrons+positrons : spectrum below 20 GeV, improving the reconstruction above 1 TeV
- Diffuse emission : new results this summer/fall (when the data becomes public), with more point sources to be subtracted