



# Fermi

Gamma-ray Space Telescope



## PASS 8: MAXIMIZING THE SCIENCE RETURN FROM THE FERMI LARGE AREA TELESCOPE

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on behalf of the Fermi LAT  
Pass 8 working group

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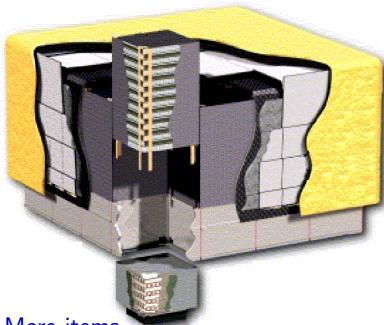
# HISTORY AND MOTIVATIONS

- ▶ Current LAT event-level analysis was largely developed before launch using Monte Carlo simulations
  - ▶ In a series of iterations that we call *Passes* (Pass 6 being in use now and Pass 7 about to be released to the Community)
- ▶ Real life experience while on orbit has revealed some neglected and overlooked issues...
  - ▶ Primarily (but not only) the instrumental pile-up (aka *Ghost Events*)
- ▶ ...in addition to the aspects of the simulation and analysis software that couldn't be developed before launch due to time constraints
- ▶ Clear improvements—with the potential to greatly extend the LAT science capabilities—have been identified in all the main areas:
  - ▶ Monte Carlo simulation
  - ▶ Event reconstruction
  - ▶ Background rejection
- ▶ All of them are now being deployed in a systematic and coherent fashion in the context of Pass 8

# QUICK OVERVIEW OF DEVELOPMENT AREAS

## —Tracker

Kalman fit measurement errors, Point Spread function analysis, Tracker buffer truncation, tree-based pattern recognition, Cosmic-ray tracking, ghost tracking, neutral energy and vertexing. . .



## —More items

periodic trigger event overlays, GEANT 4 update, background rejection, extended analysis classes, tools for analysis and validation. . .

- ▶ First opportunity to use real data during the development
- ▶ Each item has a name attached, the vast majority of them has a first iteration in place, **all integrated together in the first complete Pass 8**

## —Anti-Coincidence Detector

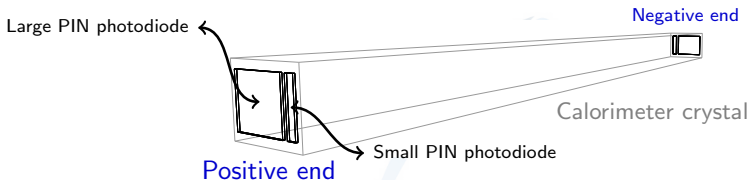
Error propagation, track-tile association finding and sorting. . .

## —Calorimeter

Crystal simulation and reconstruction, clustering, cluster classification, moments analysis and direction reconstruction, failure mitigation, crystal saturation and energy reconstruction beyond 1 TeV. . .

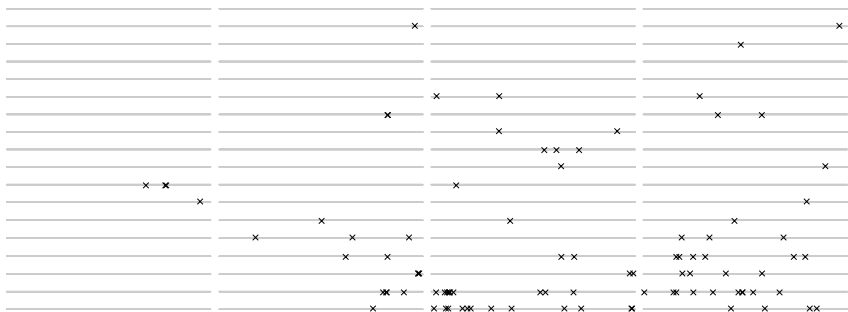
# MAJOR AREAS OF IMPROVEMENT: MONTE CARLO

## CALORIMETER CRYSTAL SIMULATION



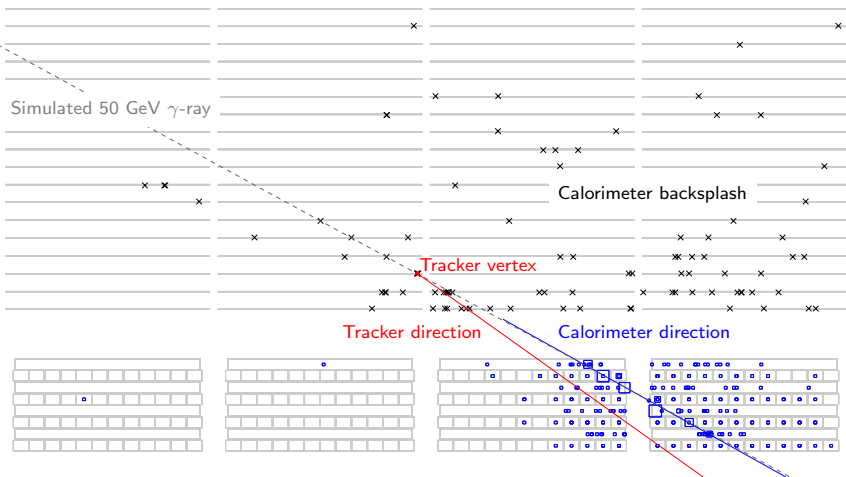
- ▶ Each crystal element read out from both ends—gives three-dimensional image of energy deposition:
  - ▶ two coordinates by crystal position
  - ▶ third coordinate by end-to-end light asymmetry
- ▶ Anomalous response due to *direct light* within  $\approx 2$  cm from each end
- ▶ Pre-launch simulation completely missing end-effects
  - ▶ This affects the longitudinal position measurement...
  - ▶ ... and the calorimeter direction measurement...
  - ▶ ... and the background rejection (tracker-calorimeter matching)
- ▶ Now properly simulated and compensated for in the reconstruction!

# MAJOR AREAS OF IMPROVEMENT: TRACKER



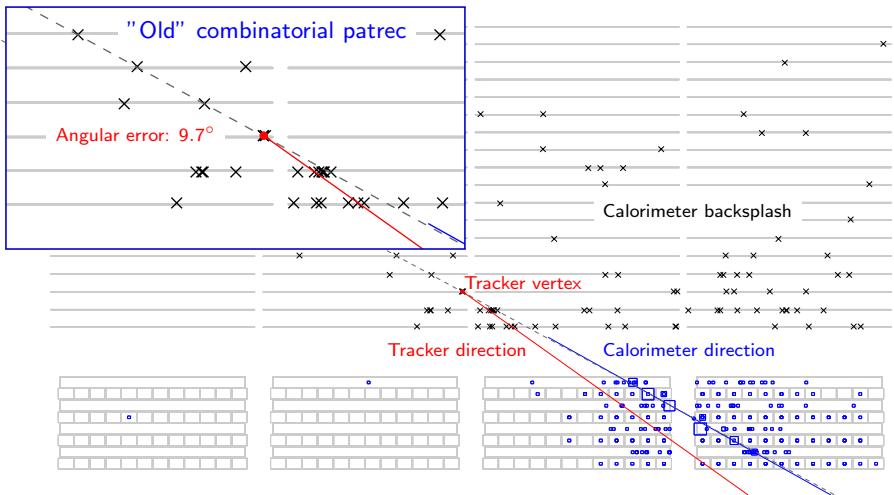
► A "typical" 50 GeV  $\gamma$ -ray (can you guess where it's coming from?)

# MAJOR AREAS OF IMPROVEMENT: TRACKER



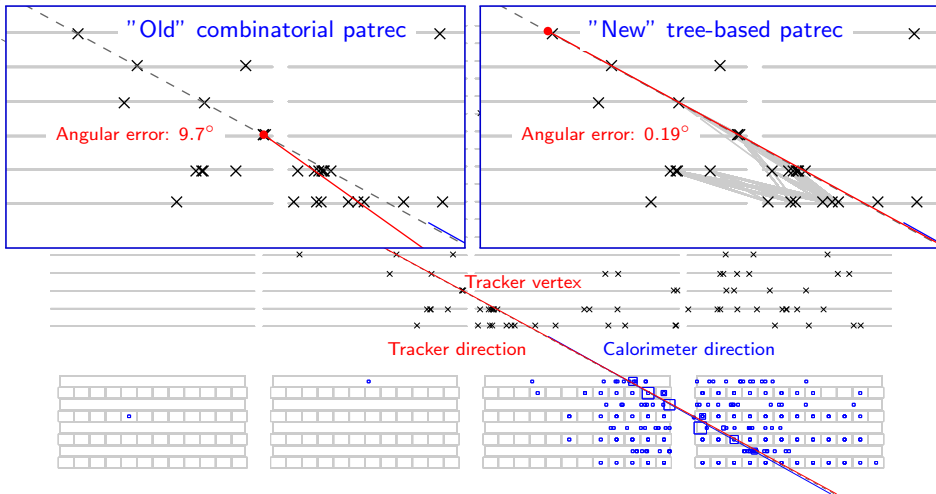
- ▶ A "typical" 50 GeV  $\gamma$ -ray
- ▶ Track-by-track pattern recognition sub-optimal at high energy

# MAJOR AREAS OF IMPROVEMENT: TRACKER



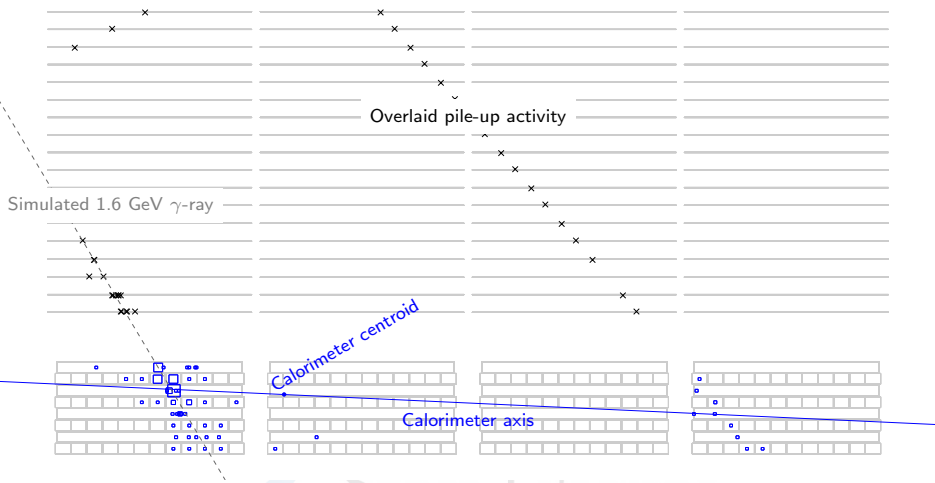
- ▶ A "typical" 50 GeV  $\gamma$ -ray
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# MAJOR AREAS OF IMPROVEMENT: TRACKER



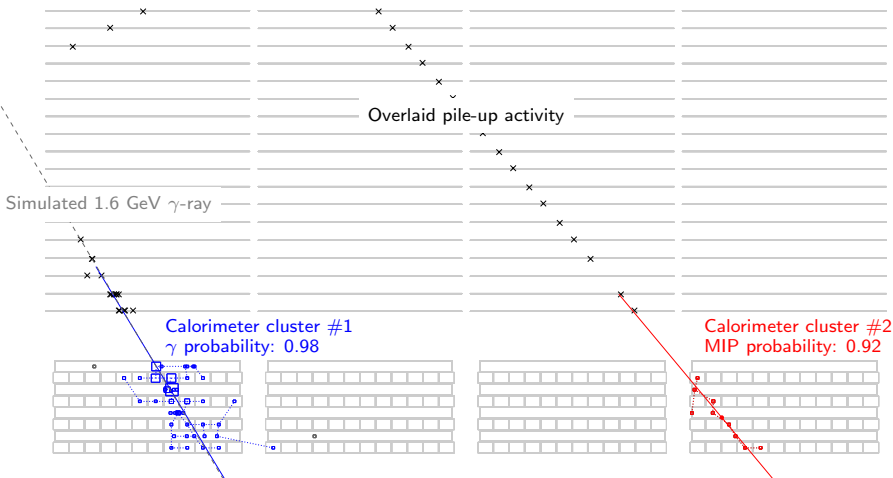
- ▶ A "typical" 50 GeV  $\gamma$ -ray
- ▶ Track-by-track pattern recognition sub-optimal at high energy
- ▶ A *global* approach is on average more effective

# MAJOR AREAS OF IMPROVEMENT: CALORIMETER



- ▶ Simulated  $\gamma$ -ray overlaid with instrumental pile-up (pre-Pass 8)
  - ▶ Estimate of the deposited energy is wrong
  - ▶ Calorimeter centroid and axis are wrong
  - ▶ Overall calorimeter topology is wrong: **a good  $\gamma$ -ray is rejected!**

# MAJOR AREAS OF IMPROVEMENT: CALORIMETER



## ▶ Simulated $\gamma$ -ray overlaid with instrumental pile-up (Pass 8)

- ▶  $\gamma$  and ghost separated; energy deposit, centroid and axis are right
- ▶ Classification stage added downstream the clustering
- ▶ The first cluster looks like a  $\gamma$ -ray: **the event is recovered!**

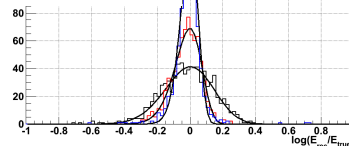
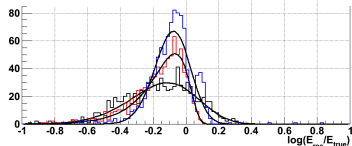
- ▶ Lower backgrounds
  - ▶ New ACD reconstruction, additional information from the tree-based patrec, standalone cosmic-ray tracking, calorimeter clustering
- ▶ Better control over the systematic uncertainties
- ▶ Extension of the energy reach
  - ▶ **Below 100 MeV**: better energy resolution thanks to the new tracker reconstruction/analysis, lower background (GRBs, pulsars)
  - ▶ **Above 100 GeV**: less tracking confusion in high multiplicity events (diffuse photon spectra)
  - ▶ **Above 1 TeV**: better compensation for crystal saturation (Cosmic-ray electron spectrum)

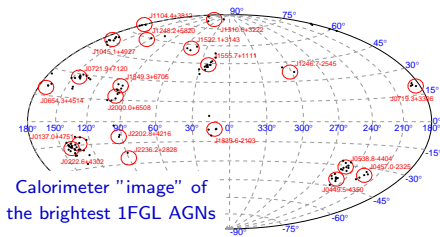
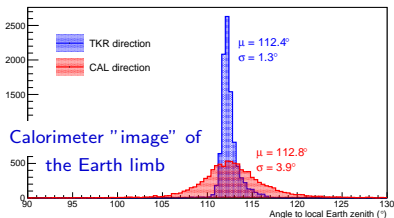


Energy dispersion @ 3 TeV

Current stage (w/o unbiasing)

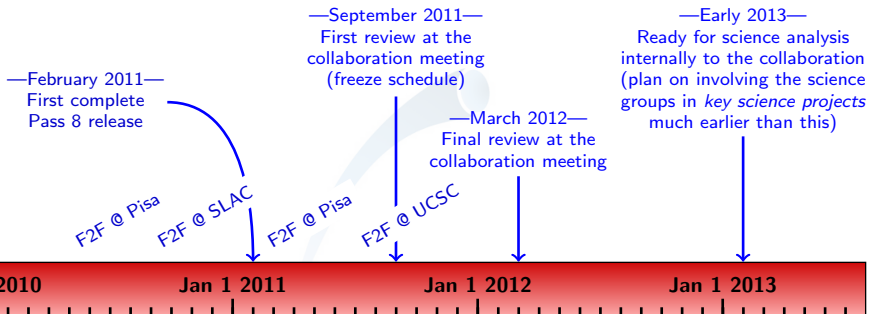
Target result (w/ unbiasing)





- ▶ Recover the CAL-only events for the science analysis
  - ▶ Can increase  $A_{eff}$  by 50% above  $\approx 20$  GeV (onboard hi-pass)
- ▶ Tracker pointing resolution improvement
  - ▶ Current high-energy PSF  $\times 2$  worse than expected (AGN pair halo)
- ▶ Multi-photon events
  - ▶ Coherent  $\gamma$ -ray production in GRBs and AGNs, BH evaporation
- ▶ Identify and flag events converting in the silicon sensors
  - ▶ "Gold plated" events:  $\approx 20\%$  of conversions in front (thin radiators) tracker section with a much better PSF—currently one of the main limitations at low energy
  - ▶ Seriously investigate the potential for  $\gamma$ -ray polarimetry

# STATUS AND SCHEDULE



Event reconstruction<sup>1</sup>

Event-level analysis<sup>2</sup>

Reprocessing<sup>3</sup>

Infrastructure, development of analysis tools, validation

<sup>1</sup>Event reconstruction at the subsystem (TKR, CAL, ACD) level. Ready.

<sup>2</sup>Definition of the event structure, PSF and energy analysis, background rejection.

<sup>3</sup>Massive reprocessing of all the flight data since mission day 1 ( $\approx$  6 months)

# CONCLUSIONS

*Pass 8 will come close to realizing the full scientific potential of the Fermi Large Area Telescope.*

*It incorporates the knowledge gained from the first two years of on-orbit operations and completes the analysis that was time limited prior to launch.*

*Fermi*  
Gamma-ray  
Space Telescope