Very-high-energy GRB events in novel Fermi-LAT photon data and their emission mechanism

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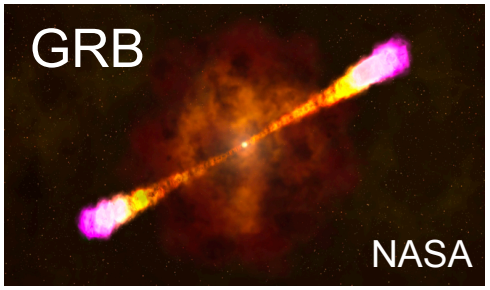
on behalf of
the Fermi-LAT collaboration

Overview

Too high energy for synchrotron



Few photons above tens of GeV

~40-70% increase in statistics

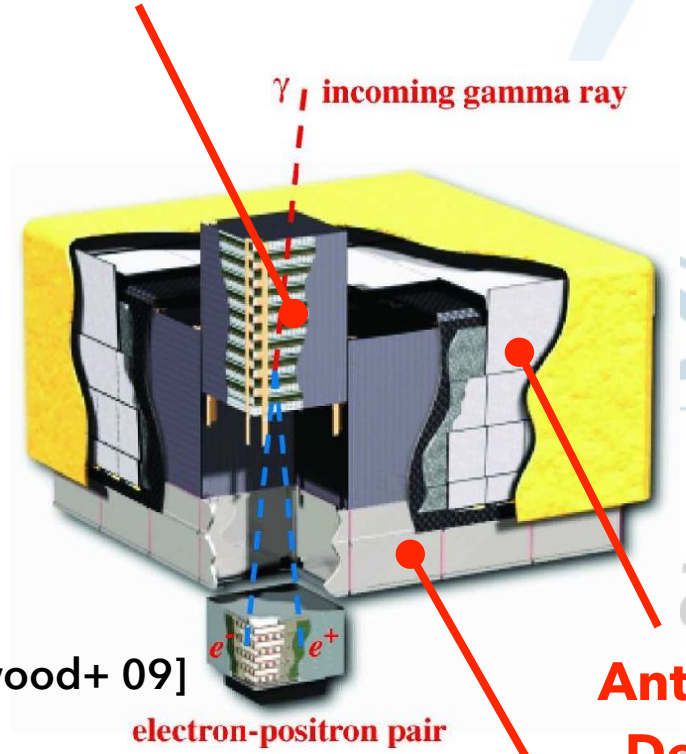
Standard data

Novel data

4 events with >50 GeV coincident with GRBs

Fermi Large Area Telescope

Tracker (TKR)



[Atwood+ 09]

Anti-Coincidence Detector (ACD)

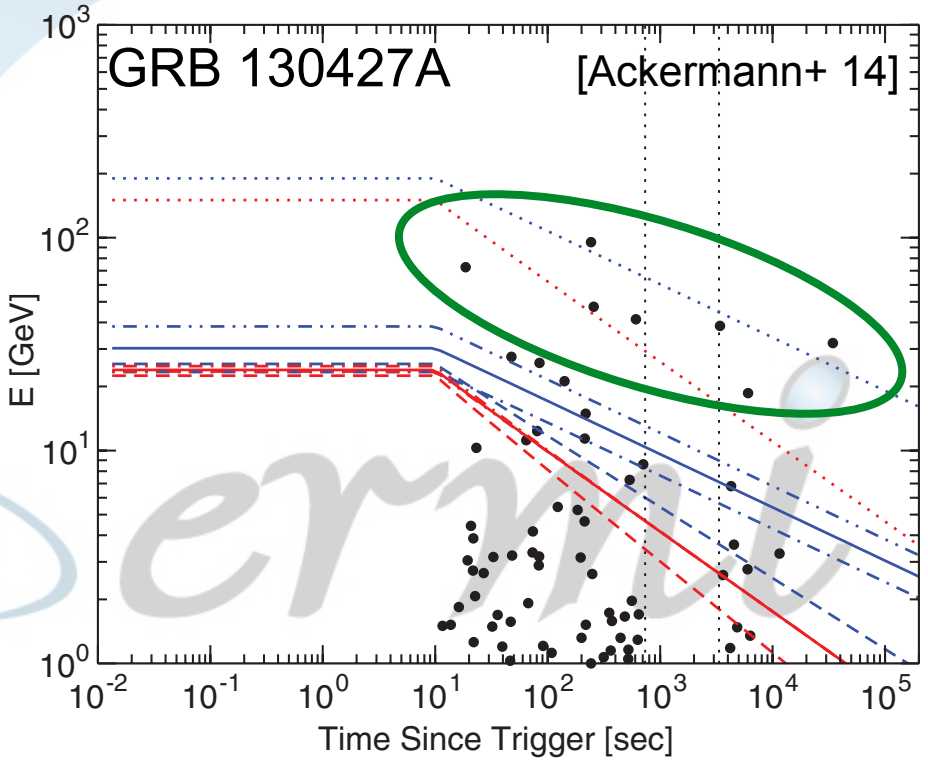
Calorimeter (CAL)

- **Energy range: from ~20 MeV to > 300 GeV**
- **Effective area: >0.8 m² for normal incidence**
- **Field of view: 2.4 sr for 1 GeV**

Sensitivity is limited by signal statistics above 10 GeV

GRB photons with energy > tens of GeV

- **Afterglow of gamma-ray bursts is usually explained by synchrotron emission from external shocks**
- **Photons whose energy is challenging for synchrotron scenario have been detected**
  - LAT: 130427A, etc.
- **Possibly requires another component such as inverse Compton**
- **MAGIC detected emission above 300 GeV from 190114C**
- **Improving LAT sensitivity above tens of GeV is important**



First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; *Razmik Mirzoyan on behalf of the MAGIC Collaboration*
on 15 Jan 2019; 01:03 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

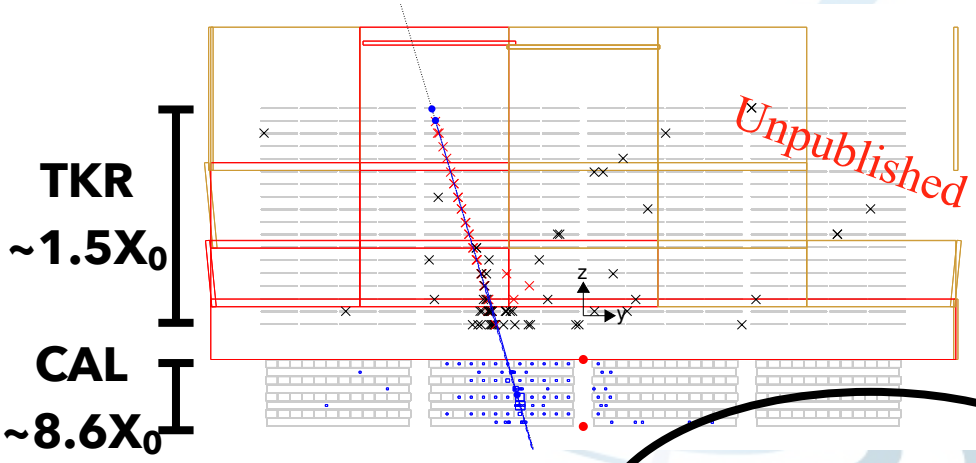
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

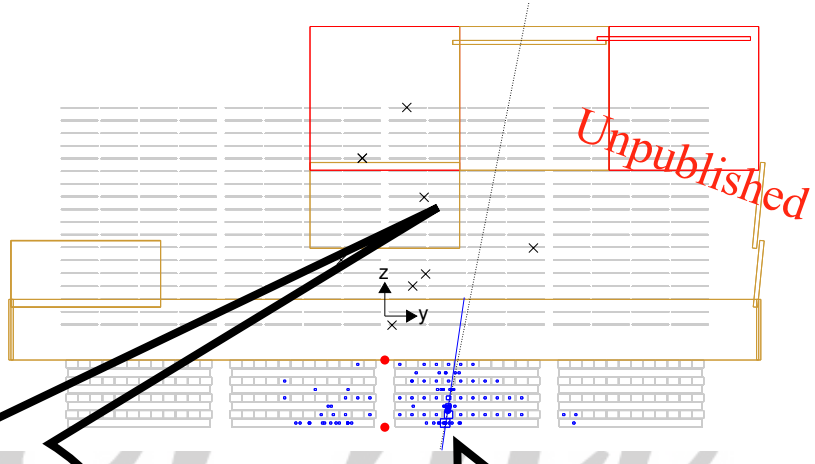
[ATel #12390]

CalOnly classes

Standard event



CalOnly event



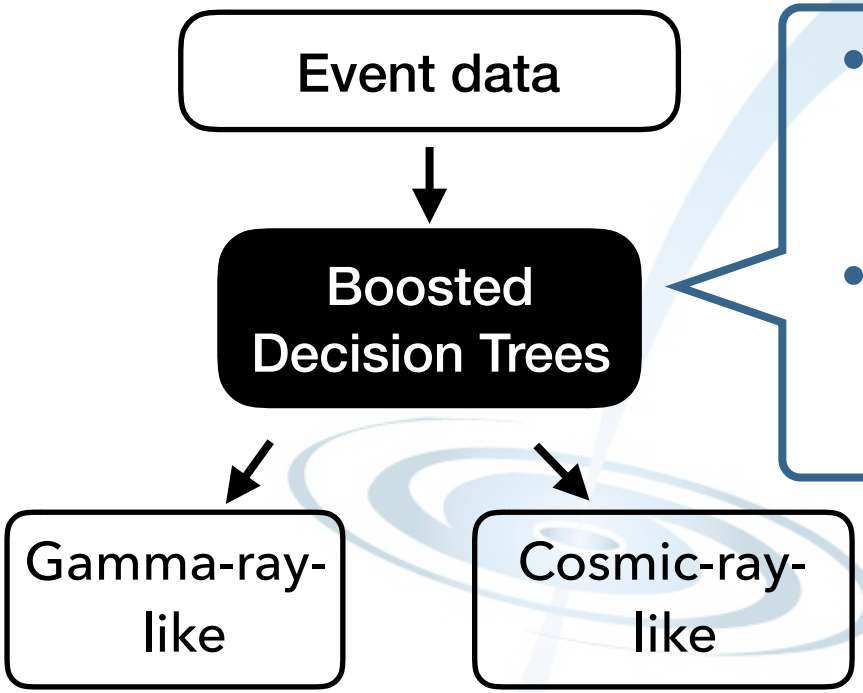
No usable TKR information

Arrival direction is determined by a few degrees

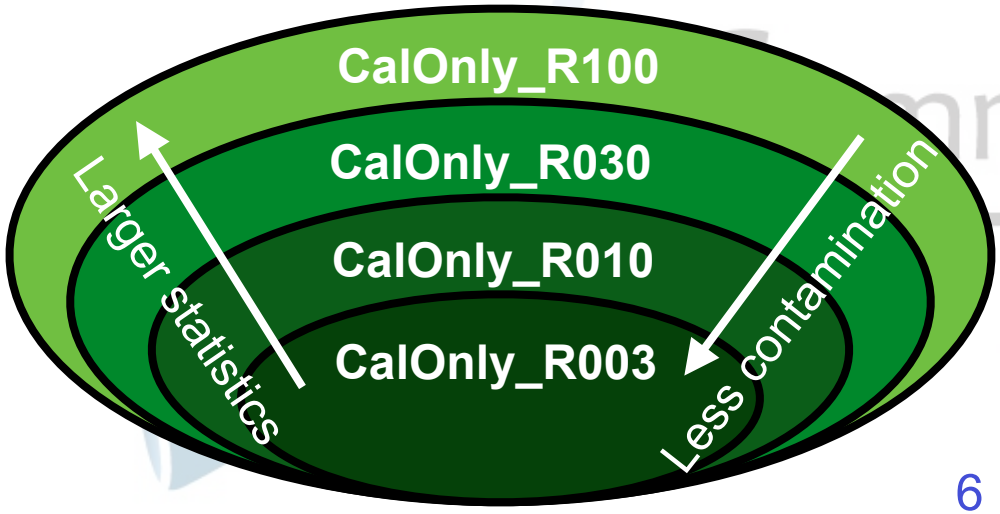
Make CalOnly events with energy >20 GeV usable for analysis

Improve in statistics

Background rejection



- Veto of ACD
  - ACD hit count, correlation with shower axis, *etc.*
- Shower profile in TKR and CAL
  - Transversal RMS, longitudinal maximum, *etc.*

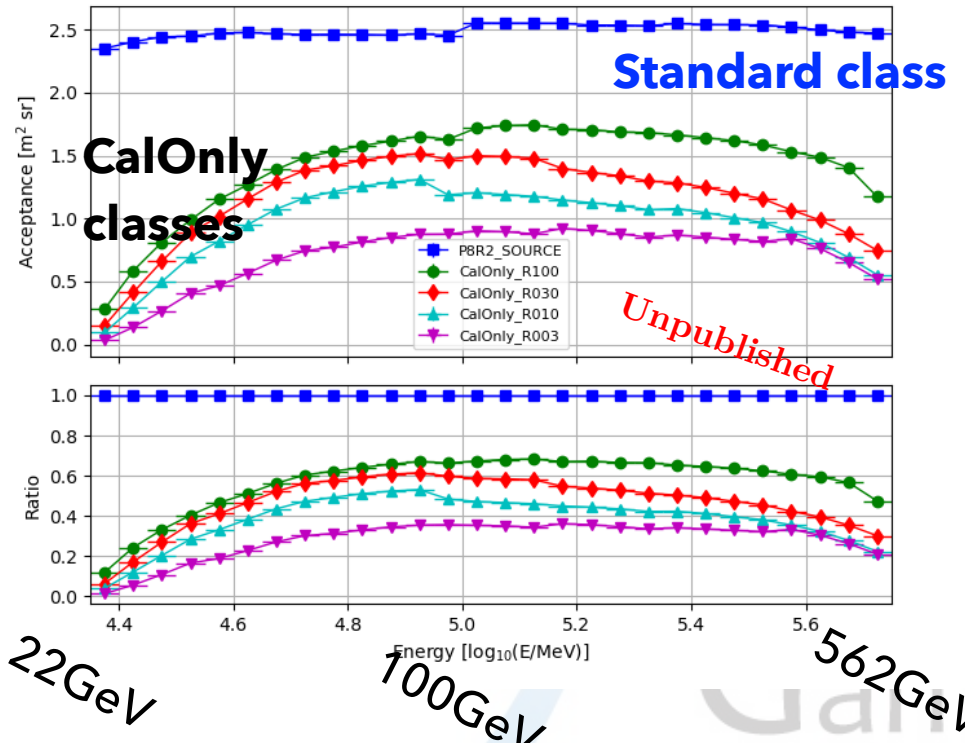


Optimize for CalOnly events

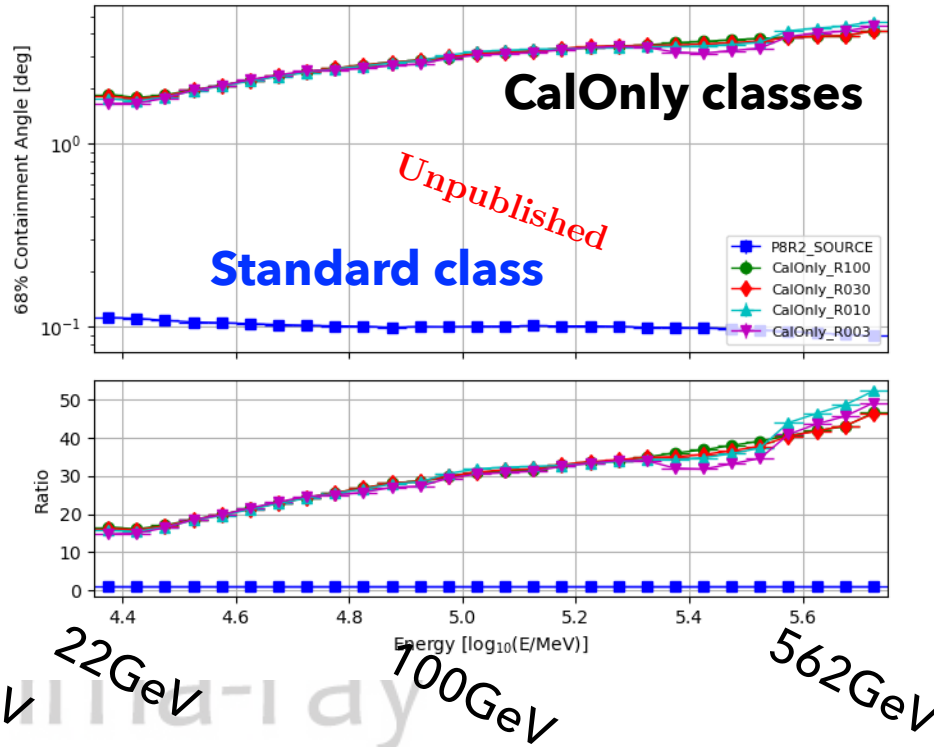
- Find best combination of separators
- Tune configuration
- Introduce new separators

Performance evaluated with MC

Acceptance



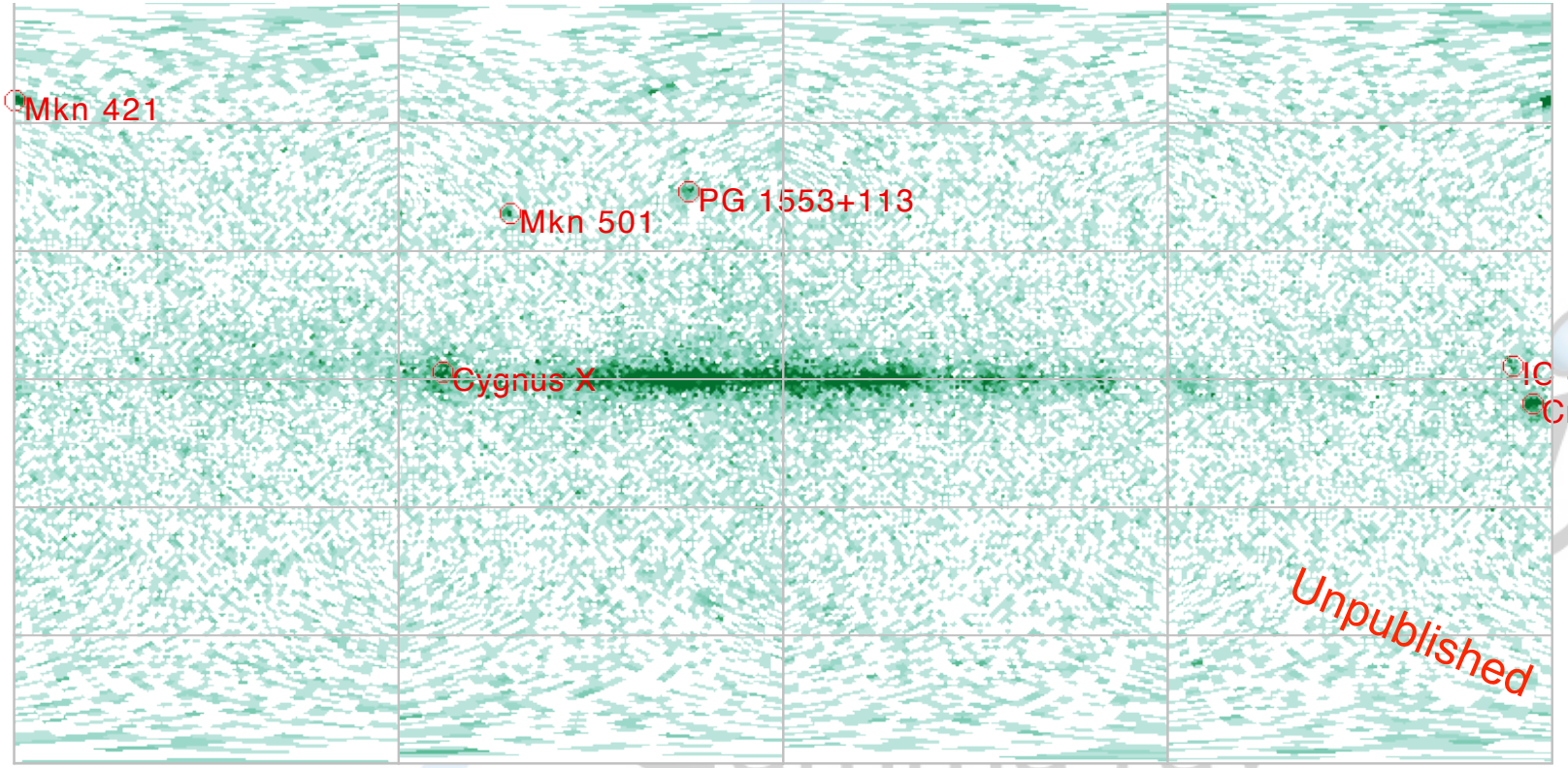
Point spread function



~50% increase in statistics from ~50 to ~300 GeV

~30 times worse PSF

All sky map with CalOnly_R010



- Data for 8.3 years
- Galactic disk and bright point sources are apparently seen

GRB photon search

Sample: 24 GRBs coincident with >10 GeV standard event (up tp 2016)

↓

Data selection

Time: T_0-100 s—T_0+10 ks

RoI: PSF68% + (GRB localization error)

↓

Boosted Decision Trees

↓

4 events found to be coincident with one of GRB 090926A, 150902A and 160509A

Focused in this contribution

Background estimation

✦ **ON/OFF analysis**

ON (GRB) data

OFF (high-galactic-latitude) data

$$N_{BKG} = N_{OFF}\mathscr{E}_{ON}/\mathscr{E}_{OFF}$$

Estimated background in ON

Observed background in OFF

Exposure of ON

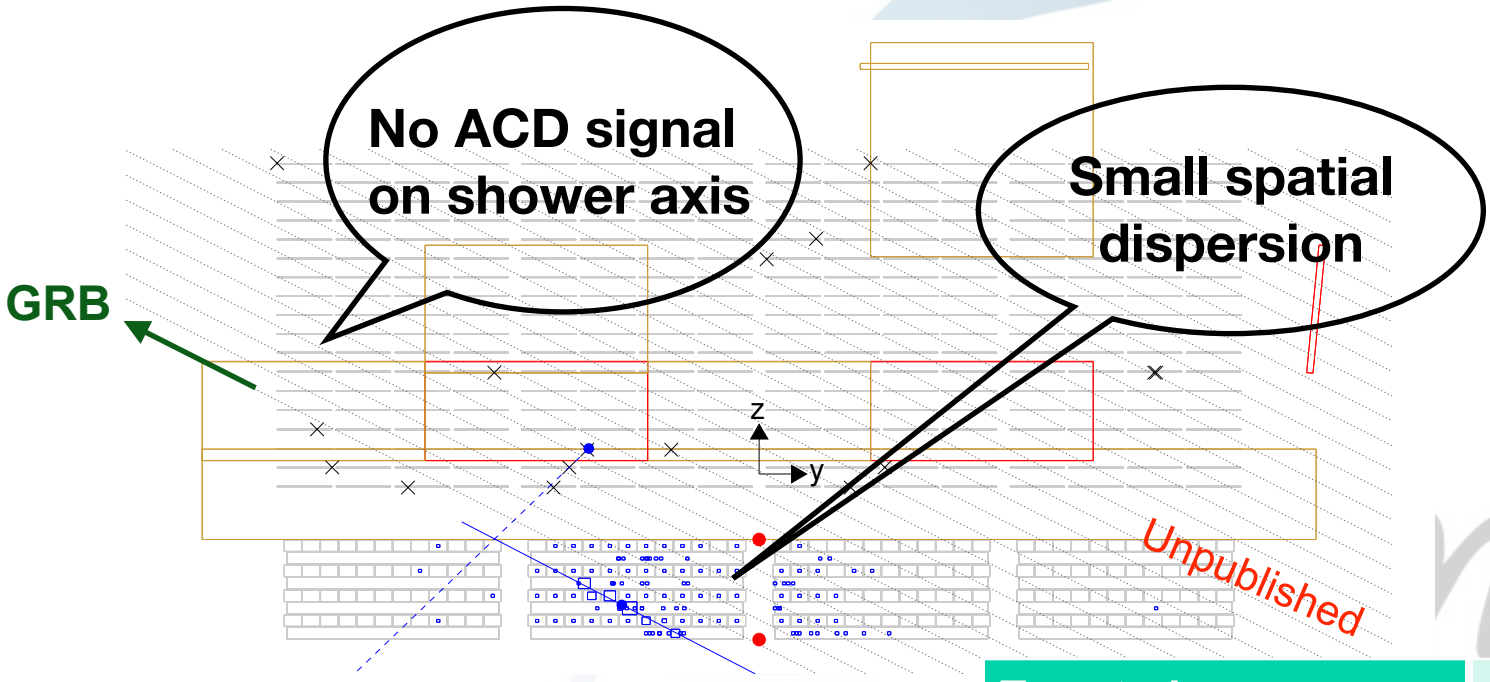
Exposure of OFF

Dependence on **energy**, **off-axis angle** and **zenith angle** is taken into account

Poisson distribution

Fake detection probability p_{BKG}

CalOnly event correlated to GRB 090926A

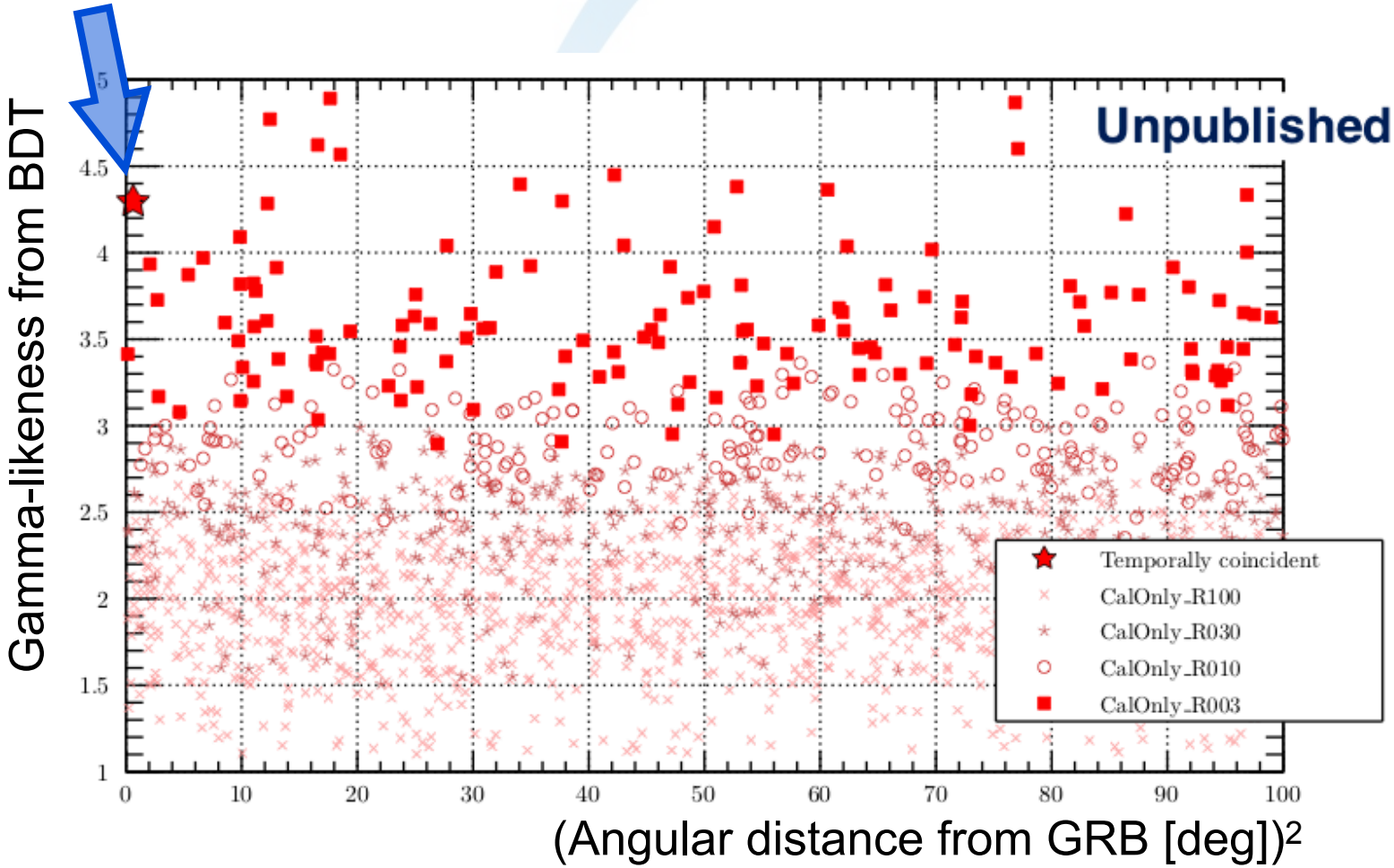


- **Side-entering event (θ=62°)**
  - Good PSF
  - Robust energy reconstruction

Event class	CalOnly_R003
Observed energy (GRB-frame energy)	50 GeV (157 GeV)
Arrival time	T_0+424 s
Angular sep. (cf. PSF68%)	0.8° (1.7°)
BKG prob.	~0.02%

CalOnly events around GRB 090926A for 8.3 yr

Event at T_0+424 s



Discussion

- **50 GeV event arrived at T_0+424 s**
  - Much later than end of prompt phase $T_{95}=T_0+15.9$ s (*Fermi*-GBM)
- **Jet is expected to be decelerated by external matter**
  - Lorentz factor of shocked fluid $\Gamma \lesssim 800$ at T_0+424 s

$$\Gamma(t_{obs}) \sim 55 \left(\frac{E}{10^{53}\mathrm{erg}}\right)^{1/8} \left(\frac{n_1}{\mathrm{cm}^3}\right)^{-1/8} \left(\frac{t_{obs}}{1000\mathrm{s}}\right)^{-3/8}$$

    - based on classic external shock model (adiabatic evolution)
    - uniform ambient matter is assumed
  - Synchrotron limit: 50 MeV × $\Gamma/(1+z) \lesssim$13 GeV
    - CalOnly event energy is ~4 times higher than this
  - Another component is suggested
    - inverse-Compton scattering?
- **Alternative possibility:**
  - Energy injection from central engine to external shock lasted until ~400 s

Summary

- **Afterglow of gamma-ray bursts (GRBs) was usually explained as synchrotron radiation from external shock**
- **Gamma rays with energy above tens of GeV have been observed**
  - may be too high for synchrotron scenario
- **Improving *Fermi*-LAT sensitivity above tens of GeV is important**
  - observe more GRBs
  - cover both prompt and afterglow
- **We have developed novel data classes to increase statistics**
  - Sensitivity is limited by signal statistics for ≳10 GeV
- **In novel classes, four events are found to be spatially and temporarily correlated with LAT GRBs**
  - One of them was coincident with GRB 090926A ($z \approx 2.1$)
    - E_{obs}=50 GeV, $t_{obs}=T_0+424$ s, $p_{bkb}\sim 0.02\%$
      - difficult for synchrotron from decelerated jet
- **Usability for scientific studies is demonstrated**