Gamma-ray astronomy with the Fermi-LAT instrument

David Paneque

MPP Project Review 2015

Outline

1 – Brief introduction to the Fermi mission (→ Large Area Telescope)

→ Performance improvement provided by Pass8

→ Great synergy with the MAGIC scientific program

2 – Work done by MPP group members (overview)

→ Technical (development of additional analysis for >30 GeV)

→ Science (AGN, GRB, Pulsars)

3 – Conclusions

MPP has major contributions to MAGIC and CTA (→ LST), including also hosting the spokespersons from both MAGIC and CTA-LST, Razmik and Masahiro, respectively.

Neither MAGIC nor CTA-LST would exist without MPP

→ See talks later on by Razmik and Thomas, reporting about MAGIC and CTA

The MPP contribution to Fermi-LAT is modest

→ *MPP involvement only after 2011, when Fermi was already operating in space for 3 years*

MPP mostly focused on topics with great synergy with the Very High Energy gamma-ray domain (>50-100 GeV).

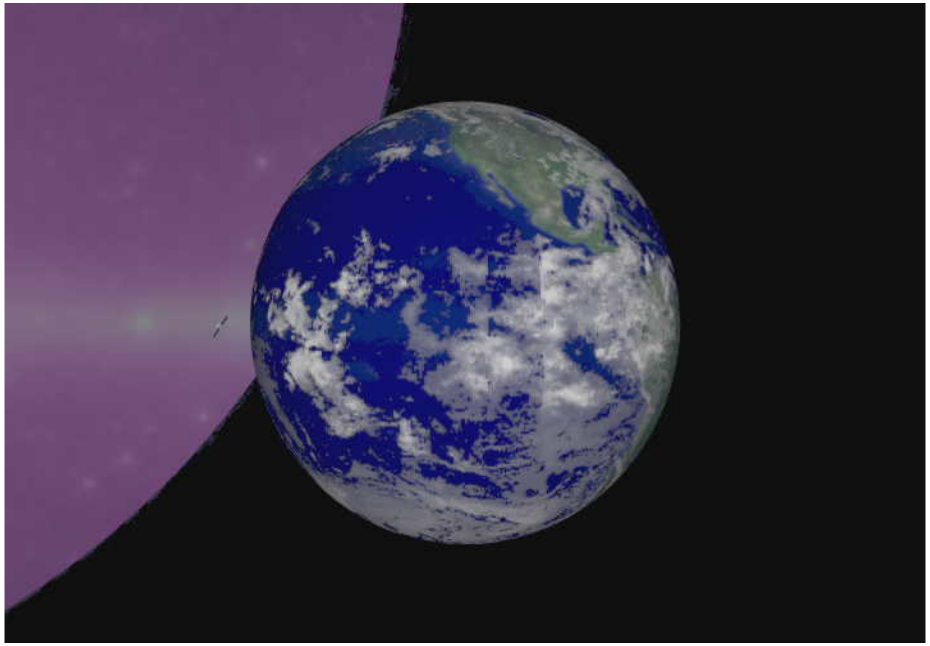
→ Activities visible inside and outside LAT collaboration

The Fermi-LAT instrument

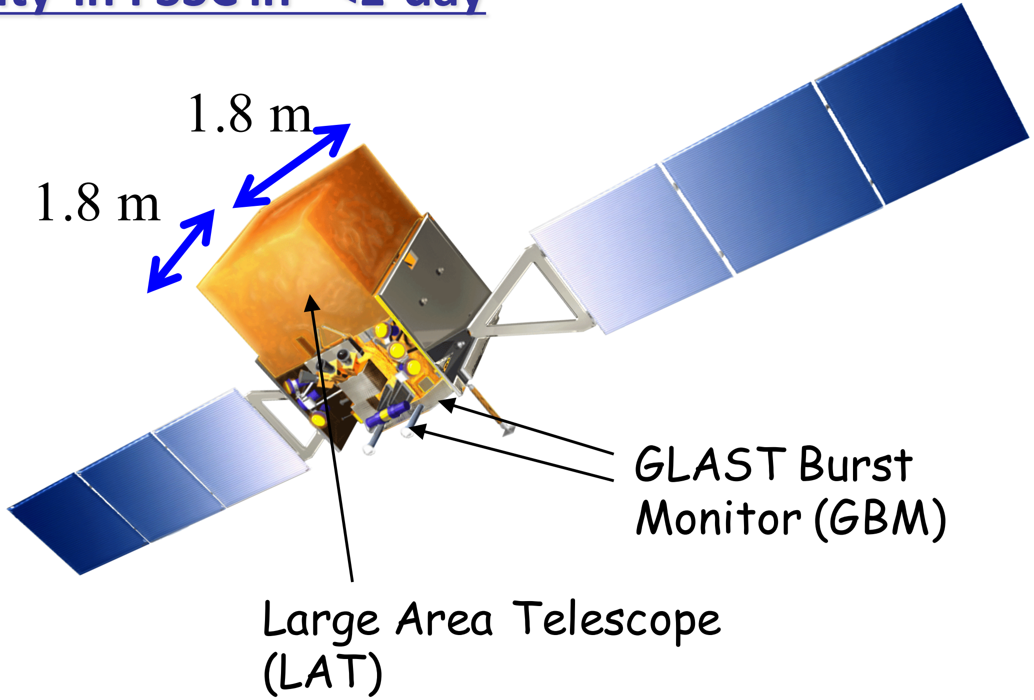
- **Fermi: An International Science Mission to perform gamma-ray astronomy, with an additional X-ray detector for GRBs**
  - Large Area Telescope (LAT); 20 MeV – >300 GeV
  - GLAST Burst Monitor (GBM); 10 keV – 40 MeV

Launch:
June 11th 2008
Cape Canaveral
(Science @Aug2008)

- **The strategy** *(no consumables, operate as long as possible)*
  - **Survey mode (20% sky at any time)⇒ entire sky every three hours (2 orbits)**
  - **Photon data available to community in FSSC in ~<1 day**



Rock north for one orbit and south for the next



The Fermi-LAT collaboration

~400 Scientific Members (NASA / DOE & International Contributions)

→ **But only 130 Full team members**

→ ~270 are affiliated scientists, postdocs and/or grad students

Only five full LAT team members in Germany !!!

http://www-glast.stanford.edu/cgi-bin/people

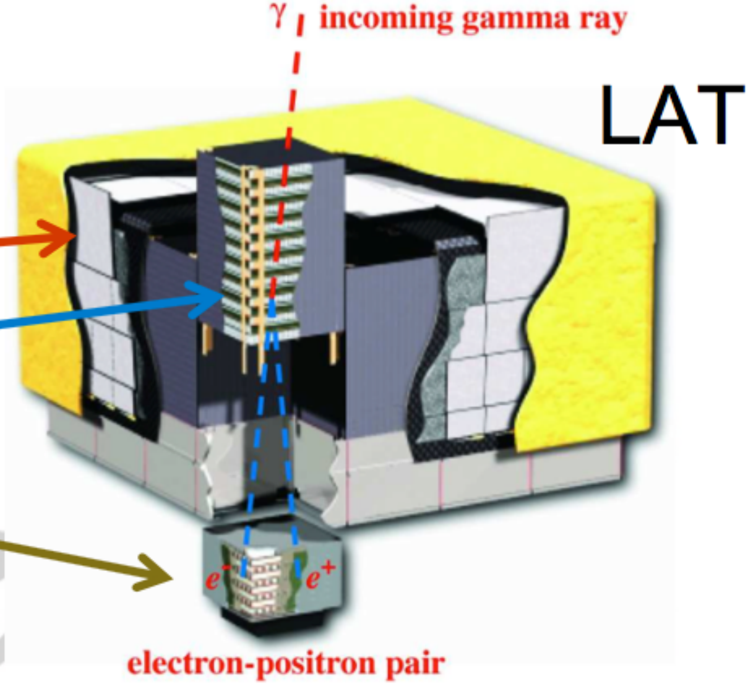
Most of the European LAT full collaboration members are in Italy and France

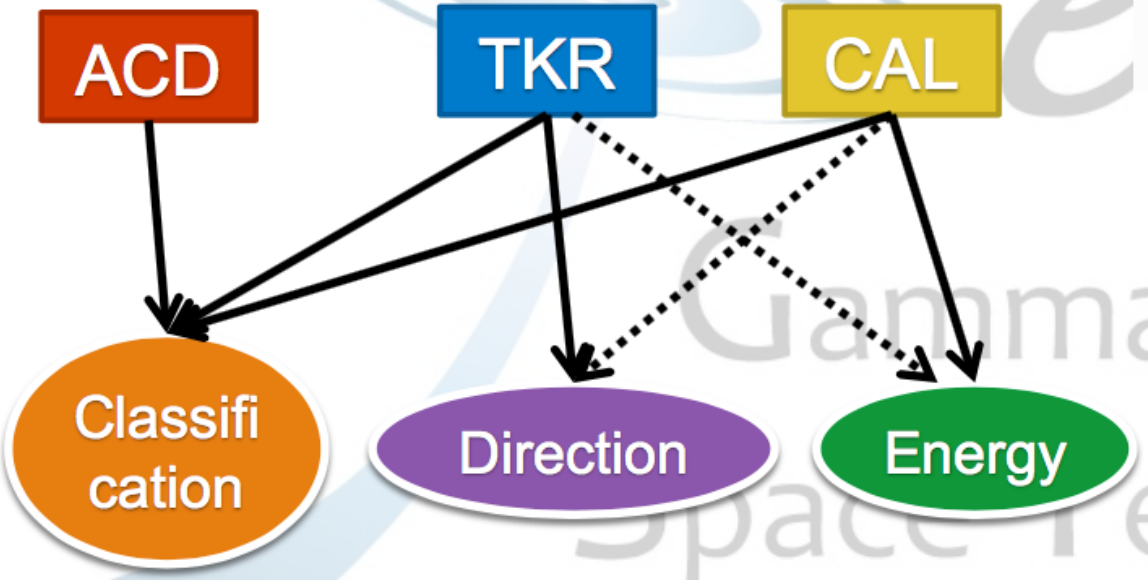
Andy Strong, *Max-Planck Institut für extraterrestrische Physik, München*
David Paneque, *Max-Planck-Institut für Physik, München* **(since Nov 2010)**
Markus Ackermann, *DESY Zeuthen* **(since mid-2011)**
Rolf Buehler, *DESY Zeuthen* **(since fall-2012)**
Stefan Funk, *Erlangen Center for Astro Phys. (ECAP)* **(since summer-2015)**

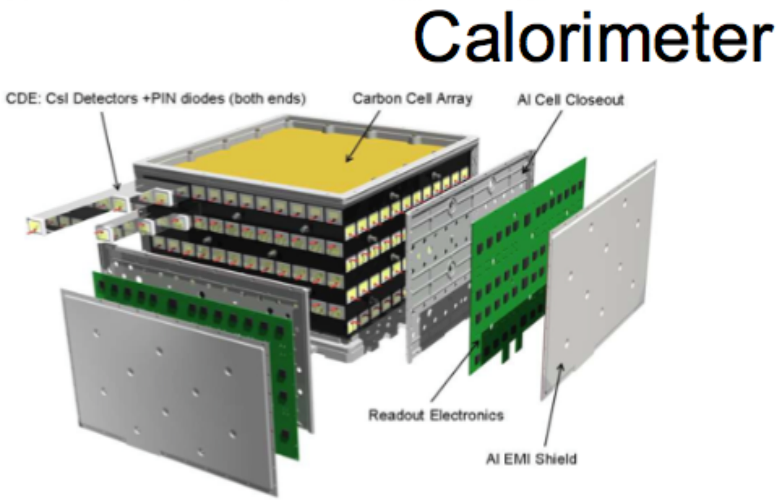
Within German groups, MPP Fermi-LAT activities are substantial

The Fermi-LAT instrument

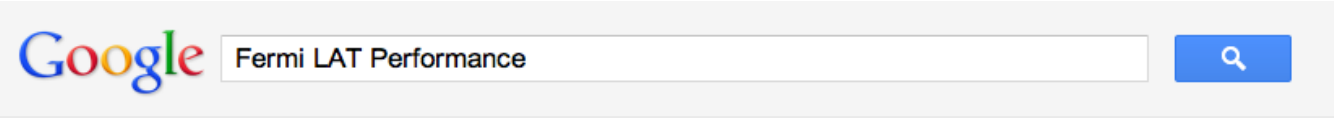
- The Fermi-LAT is composed of three kinds of detectors
  - Anti-Coincidence Detector (ACD)
  - Tracker (TKR)
  - Calorimeter (CAL)




ACD
TKR
CAL
Classification
Direction
Energy



LAT performance improvement (Pass7→Pass8)

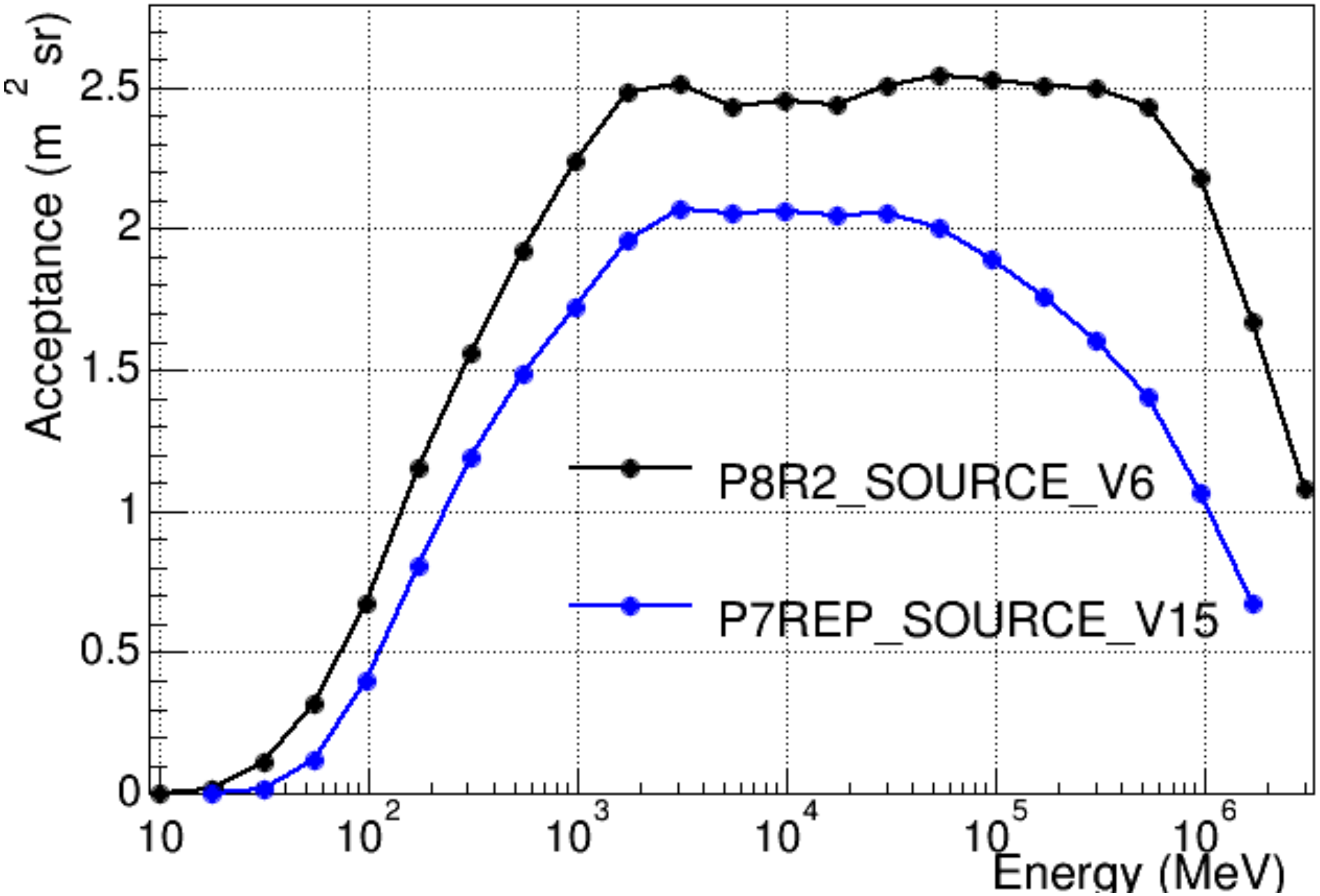


Fermi LAT Performance

Pass 8 is a complete new analysis (*from low-level detector info !!!*)

→ Work ongoing for more than 5 years

→ **Substantial performance improvement with respect to Pass7**



Pass 8 photon data and analysis tools available since Summer 2015 at FSSC

http://fermi.gsfc.nasa.gov/ssc/

LAT performance improvement (Pass7→Pass8)

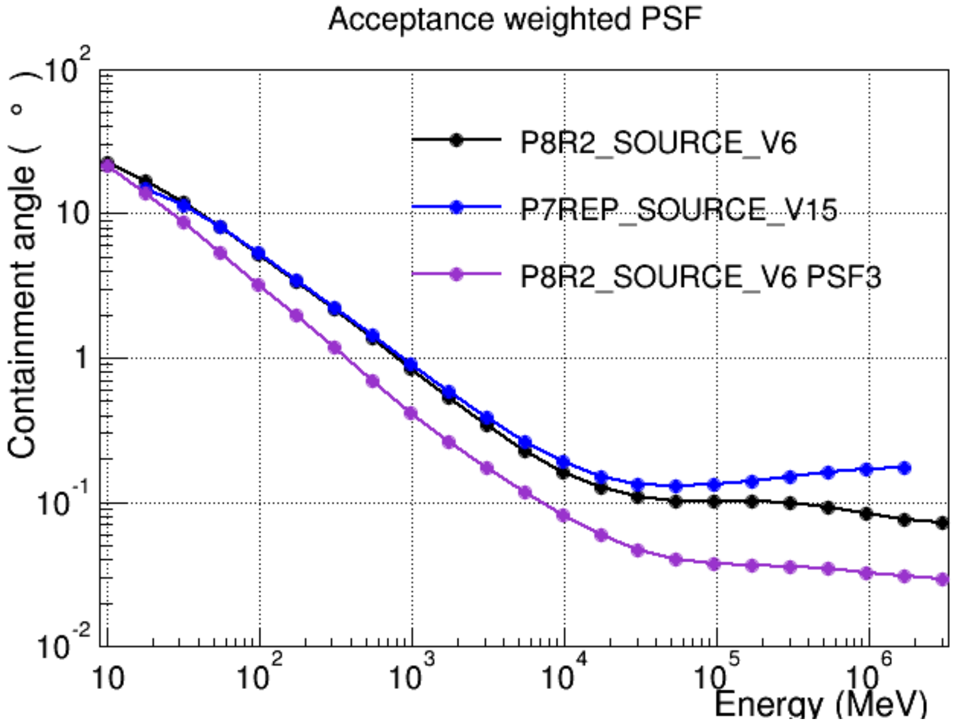
Pass 8 is a complete new reconstruction (from srcatch !!)

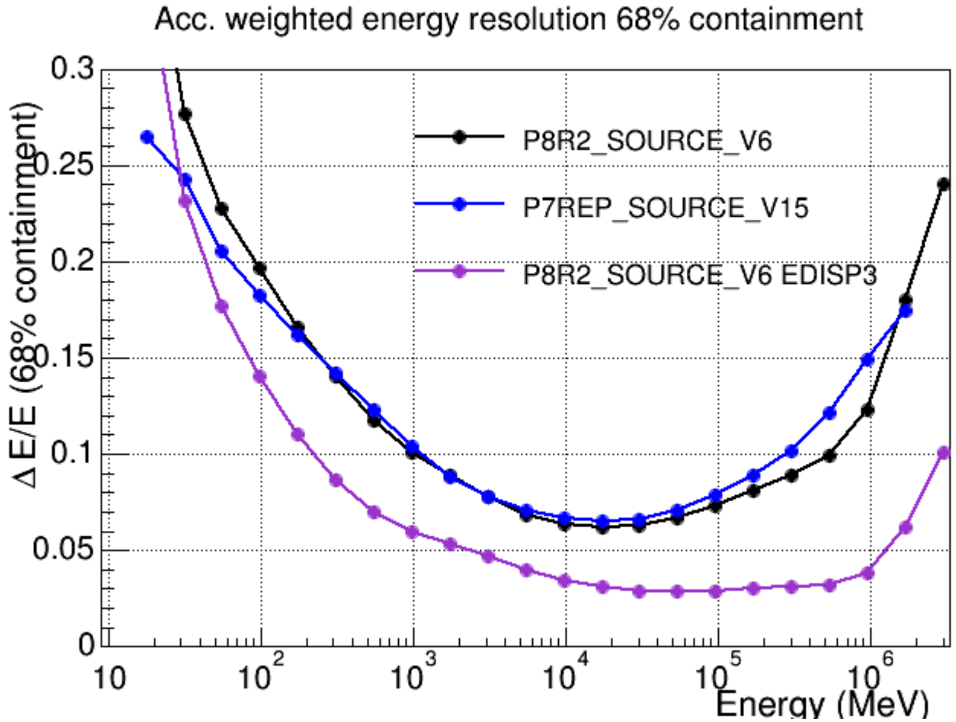
→ Work ongoing for more than 5 years

→ **Substantial performance improvement**

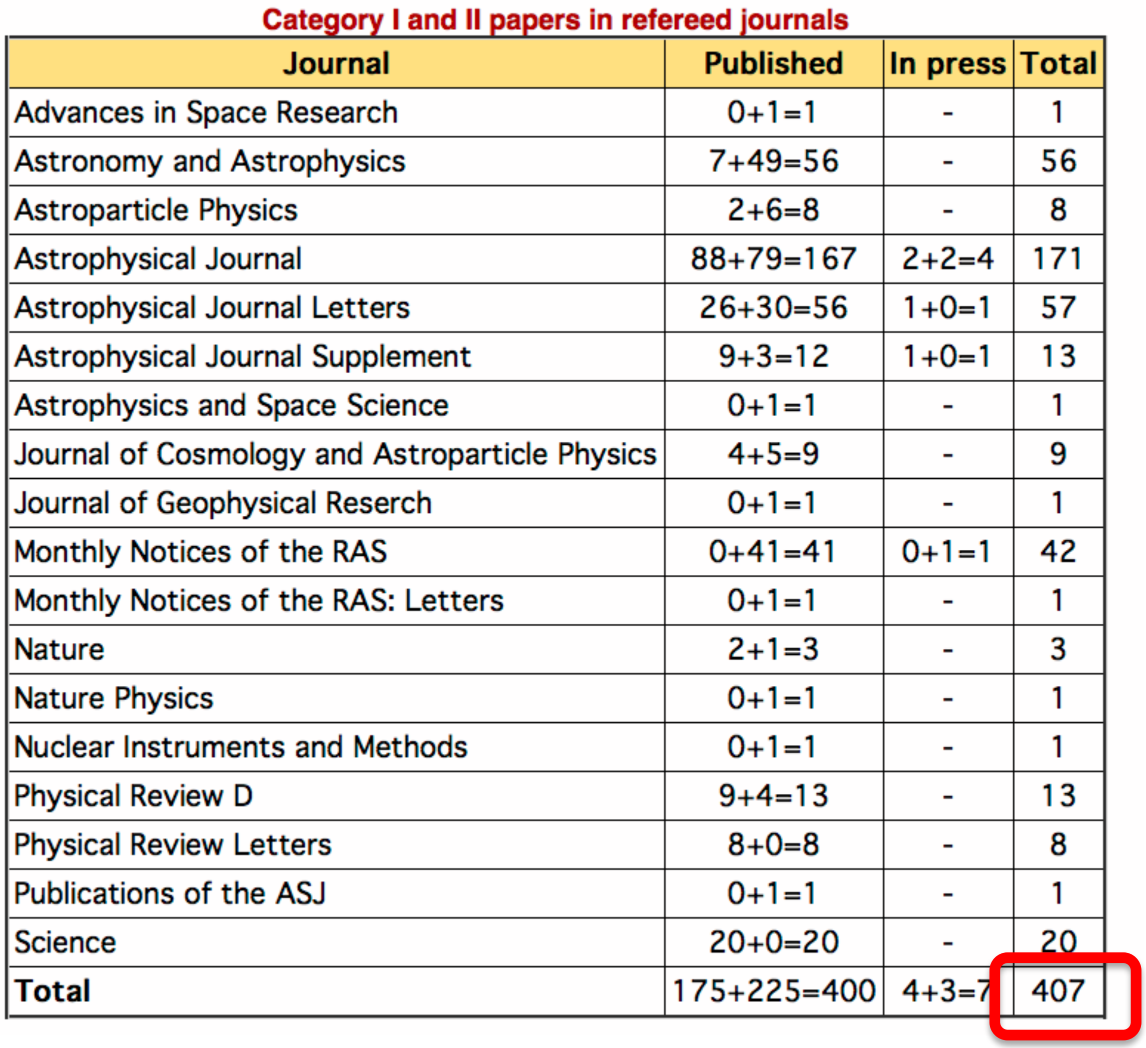
→ **Sub-selections with different angular/energy resolution**

→ Better images & specific spectral analyses (at expense of photons)


Acceptance weighted PSF


Acc. weighted energy resolution 68% containment

More than 600 scientific publications since fall 2008



Category I and II papers in refereed journals

Journal	Published	In press	Total
Advances in Space Research	0+1=1	-	1
Astronomy and Astrophysics	7+49=56	-	56
Astroparticle Physics	2+6=8	-	8
Astrophysical Journal	88+79=167	2+2=4	171
Astrophysical Journal Letters	26+30=56	1+0=1	57
Astrophysical Journal Supplement	9+3=12	1+0=1	13
Astrophysics and Space Science	0+1=1	-	1
Journal of Cosmology and Astroparticle Physics	4+5=9	-	9
Journal of Geophysical Reserch	0+1=1	-	1
Monthly Notices of the RAS	0+41=41	0+1=1	42
Monthly Notices of the RAS: Letters	0+1=1	-	1
Nature	2+1=3	-	3
Nature Physics	0+1=1	-	1
Nuclear Instruments and Methods	0+1=1	-	1
Physical Review D	9+4=13	-	13
Physical Review Letters	8+0=8	-	8
Publications of the ASJ	0+1=1	-	1
Science	20+0=20	-	20
Total	175+225=400	4+3=7	407

Publications include various catalogs of sources (Very useful for the community)

→ 1FGL, 2FGL, 3FGL, 2LAC, 3LAC, GRBs, 1FHL, 2FHL, Pulsars …

+ 203 published Cat3 papers (*no new experimental results*)

+ 26 papers already submitted to journals

346 Astronomer Telegrams + 115 GCN Circulars (informing community about transients)

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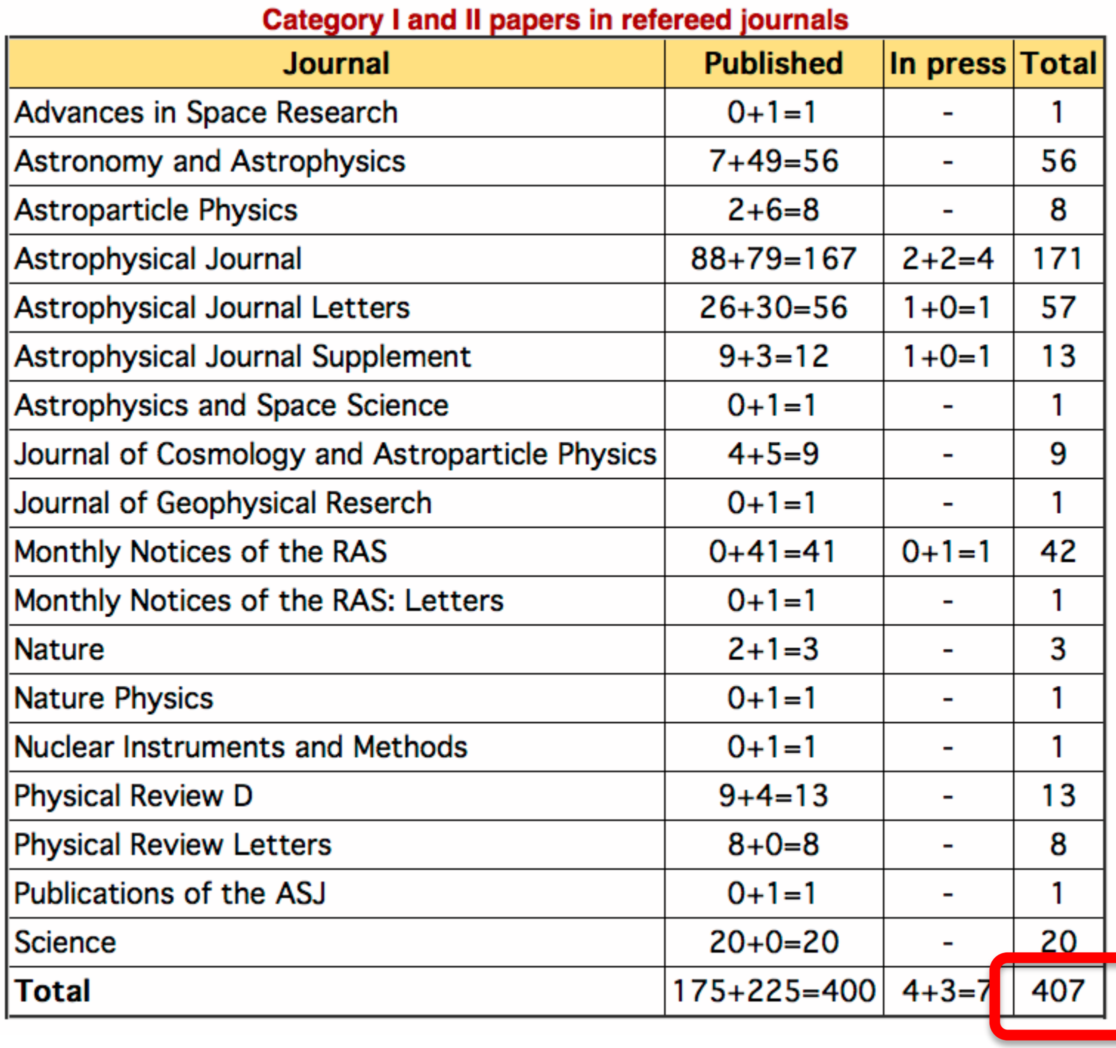

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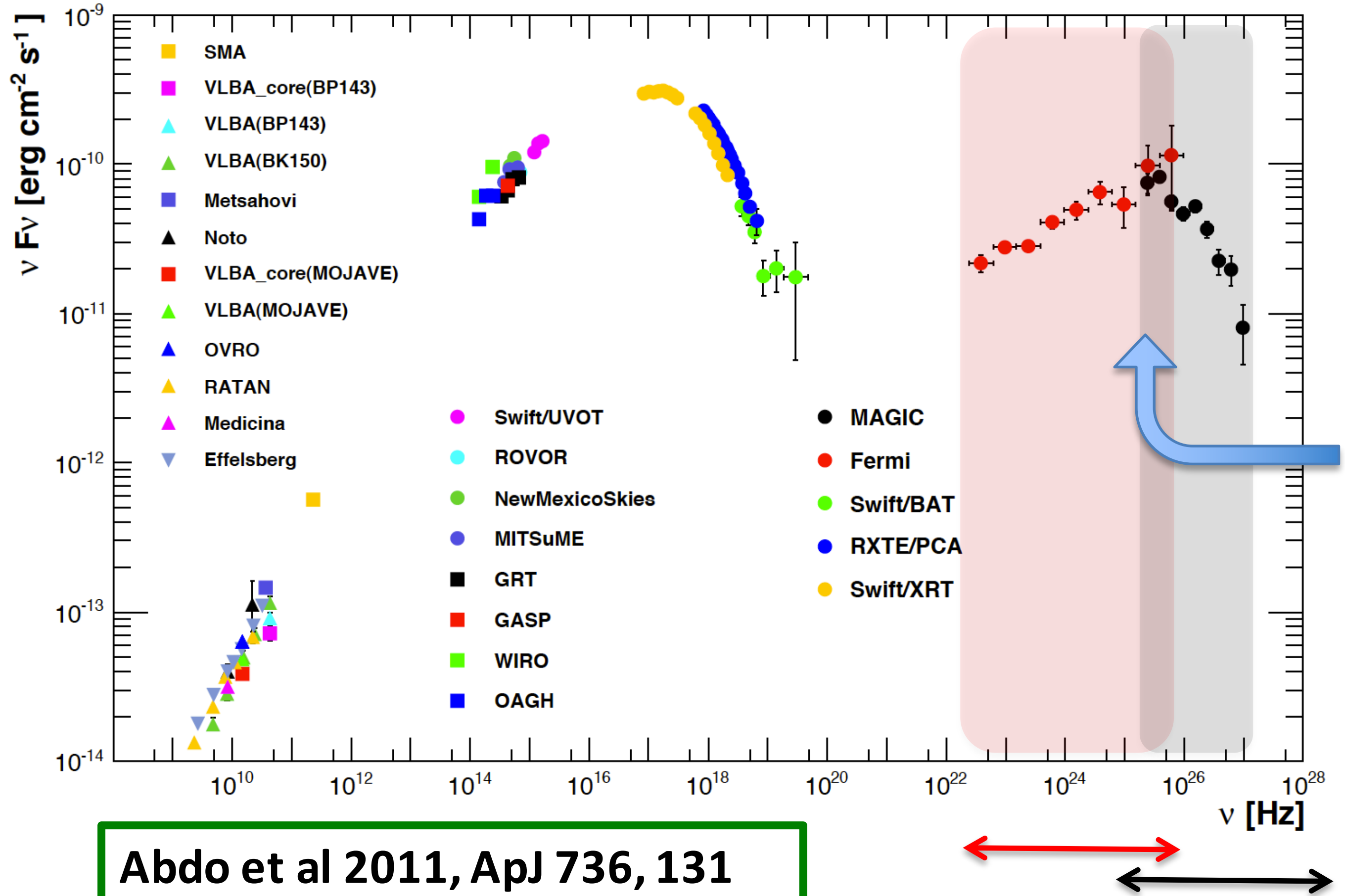
Synergy between MAGIC and Fermi-LAT

Most of the extreme particle accelerators emit radiation over a large energy range

Emission on differerent energy bands could be produced by same population of particles

→ *Need many instruments (covering many bands) to fully study these objects*



Fermi – MAGIC

Spectral energy distribution (SED) of the Blazar Markarian 421

Fermi – MAGIC spectra cover, <u>for the first time</u>, the complete high energy component over 5 orders of magnitude without gaps

→ *Crucial for the theoretical modeling of the broadband emission*

Abdo et al 2011, ApJ 736, 131

Great synergy between Fermi-LAT and Cherenkov Telescopes

→ Particularly with the **MAGIC Telescope**, because it is the one with the lowest gamma-ray energy threshold (~60 GeV)

2 – Work done by MPP group members

- Technical
  - → development of additional analysis for >30 GeV

- Science
  - → Active Galactic Nuclei (AGN)
  - → Gamma Ray Bursts (GRB)
  - → Pulsars

The MPP experimental gamma-ray group

Scientists : 17 physicists (December 2015)

Director: Masahiro Teshima
Senior (3): Razmik Mirzoyan, Thomas Schweizer, **David Paneque**
Postdoc (5): Pierre Colin, Koji Noda, **Elena Moretti,**
Ievgen Vovk, Christian Fruck
PhD Students (7): Francesco Borracci, Takeshi Toyama,
Jezabel Garcia, Priyadarshini Bangale,
Uta Menzel, Marcel Strzys, Kazuma Ishio
Undergraduate (2): Alexander Hahn, Dominik Mueller

Only few members work with Fermi data, names in blue, and only during a relatively small fraction of the time

→ *Although many members (all working on MAGIC science) use Fermi-LAT results*

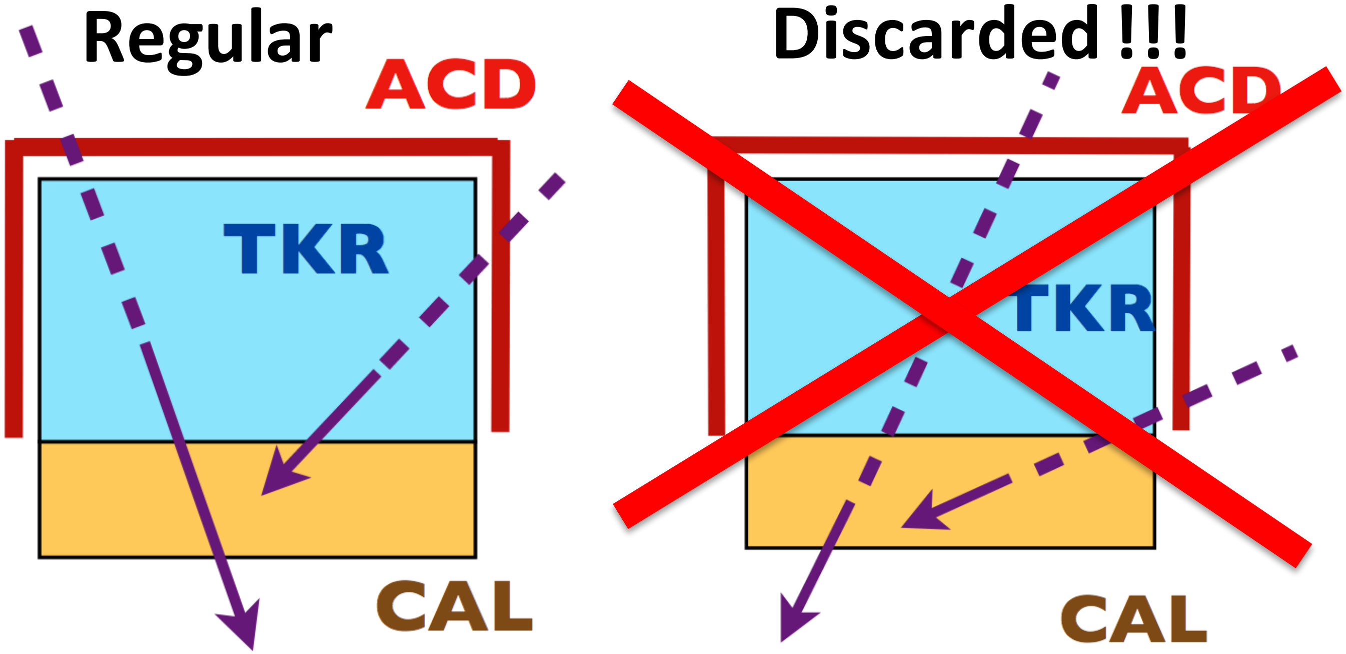
MPP Fermi-LAT related activities (in a nutshell)

Fermi-LAT operations and data analysis (in framework of ISOC)

Development of analysis to use events without tracker information

→ **Mitsunari Takahashi (student at Univ. Tokyo), David**

+ Carmelo Sgro (INFN Pisa, Italy), Regina Caputo (Santa Cruz, USA)



Standard Fermi-LAT analysis requires information from the TKR

→**Many gamma-rays are discarded because they convert in the CAL**

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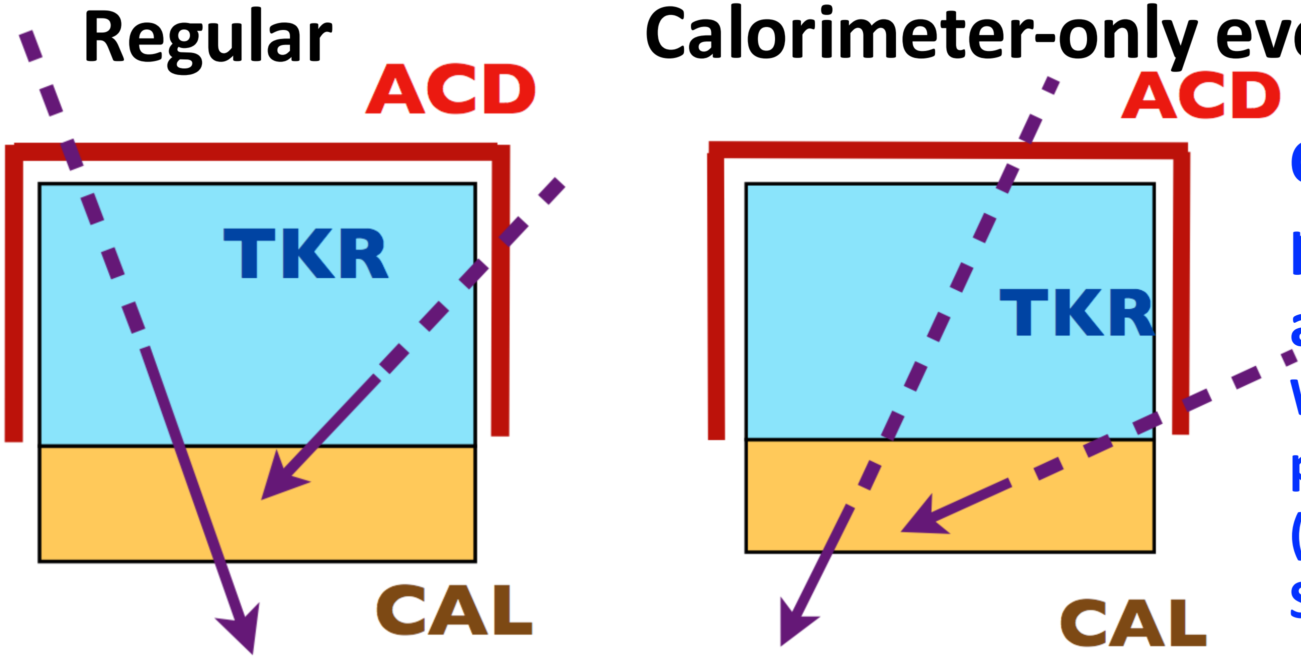
Regular **Calorimeter-only events (CalOnly)**



CalOnly events provide additional acceptance >30 GeV

Where sensitivity is photon statistics limited (worse angular resol. & Sig./Back. separation)

The CalOnly analysis can recover valuable gamma-ray events that are not converted in the TKR, *i.e.* side-entering or TKR-passing events

→ *Most useful to study Transient sources (GRBs or AGN flares) and diffuse or extended regions (i.e. Dark Matter searches)*

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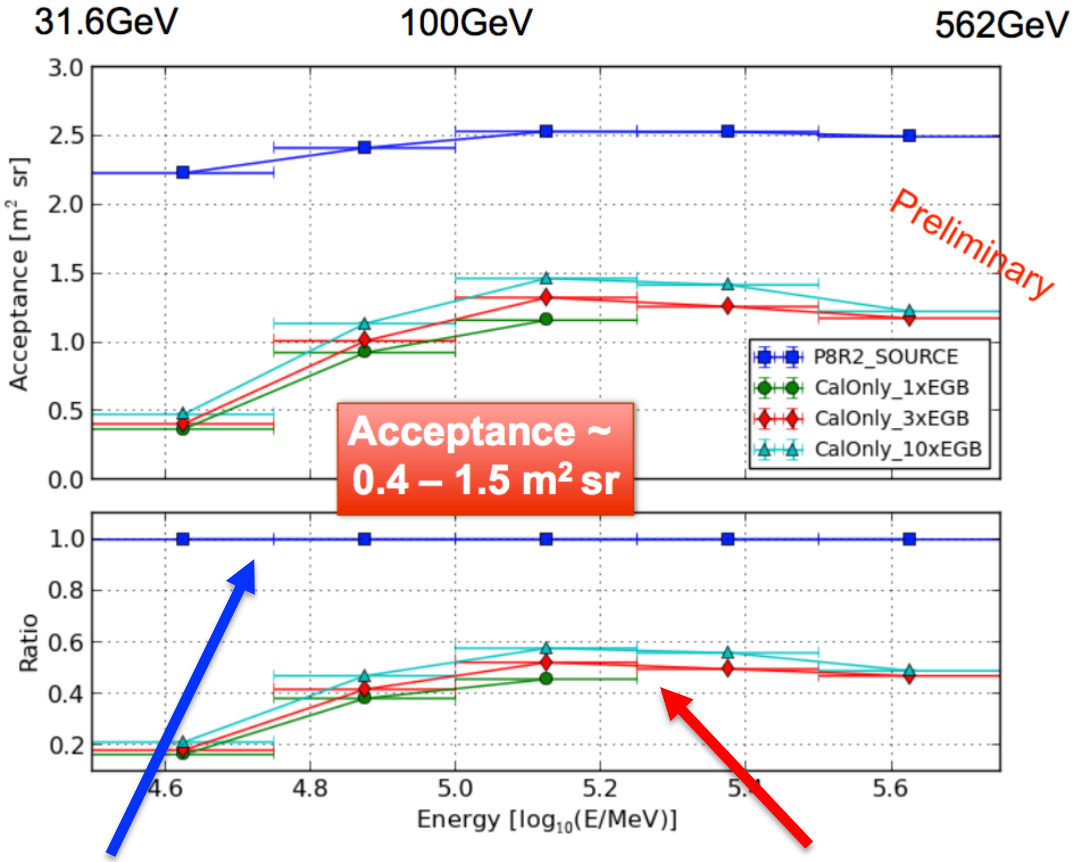
40-60% increase acceptance with respect to regular class (>50 GeV)



Regular class

CalOnly class

(3 “cuts” with different Bkgs)

Outlook:

- Fine tune analysis (try do better)
- Event sub-classes of better energy or angular resolution
- Validation (and potential further improvement) with real flight data

- Implementation in standard Fermi-LAT analysis tools
- Process all data (and further tests)
- Release to gamma community

MPP Fermi-LAT related activities (in a nutshell)

Science related topics (all them show synergy with MAGIC)

Active Galactic Nuclei (AGNs)

- Source characterization >10-50 GeV (→MAGIC observations)
  - → CalOnly information will get into the 3rd High Energy catalog (3FHL)→ **David**
    - → *~80% of Fermi >10-50 GeV sources belong to the AGN class*
  - → Monitor activity of distant sources (→MAGIC observations) → **Ievgen Vovk**
    - *Gravitional (micro)lense effect to improve gamma angular resolution >10^10+*
    - → Neronov, **Vovk**, Malyshev, 2015, Nature Physics 11, 664
    - → **Vovk** and Neronov, Accepted (arXiv:1507.01092)
    - **→ See backup**
      - → B0218+357(z~1), VHE MAGIC (see talk by Razmik later on)
- Deep studies through multi-year and multi-instrument programs → **David**
  - *Multi-year program that involves **Fermi+MAGIC**, and others*

Aleksic et al. 2015, A&A, 576, A126	Furniss et al, 2015, *ApJ* 812 65
Aleksic et al.2015, A&A,578,A22	Balokovic et al, ApJ Accepted (arXiv:1512.02235)

Gamma Ray Bursts (GRB)

- Investigation of Fermi GRBs (→MAGIC observations) → **Elena Moretti**
  - High-E component in GRB080825C, **Moretti**&Axelson, MNRAS submitted

→ See backup

Pulsars

- Pulsars at the highest energies (→ MAGIC observations) → **Jezabel Garcia**

MPP Fermi-LAT related activities (in a nutshell)

“Fermi contact” within the MAGIC collaboration

Foster MAGIC-Fermi collaboration in many scientific projects

→Improve science output by combining Fermi and MAGIC data
(many of them become *“Fermi Category 2 papers”*)

In 2015, the Scientific output of the MAGIC collaboration was large (see more in the report from Razmik Mirzoyan)

Papers published or accepted: 15

→*8 with MPP members as corresponding authors*

Papers submitted: 9 *(4 of them got referee report/iterating, positive)*

→*3 with MPP members as corresponding authors*

Out of the 24 (=15+9) MAGIC papers from 2015, 16 papers contain Fermi data, and 13 of them are “Fermi Category 2 papers”

3 – Conclusions

Fermi-LAT, in scientific operation since August 2008

→ scanning the full sky every 3 hours *("everything" gets observed !)*

→ **Large performance improvement with Pass8 (since Summer 2015)**

Fermi-LAT provides a large leap in capabilities,

→ **Fermi-LAT data provides new challenges to the theoreticians**

→ Keep publishing at high rate **~600 papers in 7 years (~7 papers/month)**

MPP Fermi-related activities:

Fermi-LAT operations and data analysis (sometimes in the framework of ISOC)

→ Development of Calorimeter-only analysis (with student in Univ. Tokyo)

Science related topics great synergy with MAGIC

→ **Active Galactic Nuclei** (*6 scientific papers in 2015*)

→ **Gamma Ray Bursts** (*1 scientific paper in 2015, submitted*)

→ **Pulsars** (*finding good targets for Cherenkov Telescopes*)

→ **MPP activities visible inside and outside LAT collaboration**

Backup

1 - Fermi mission (brief overview): The LAT instrument

modular design

4x4 array of identical towers: Tracker + Calorimeter + Electronics Module.

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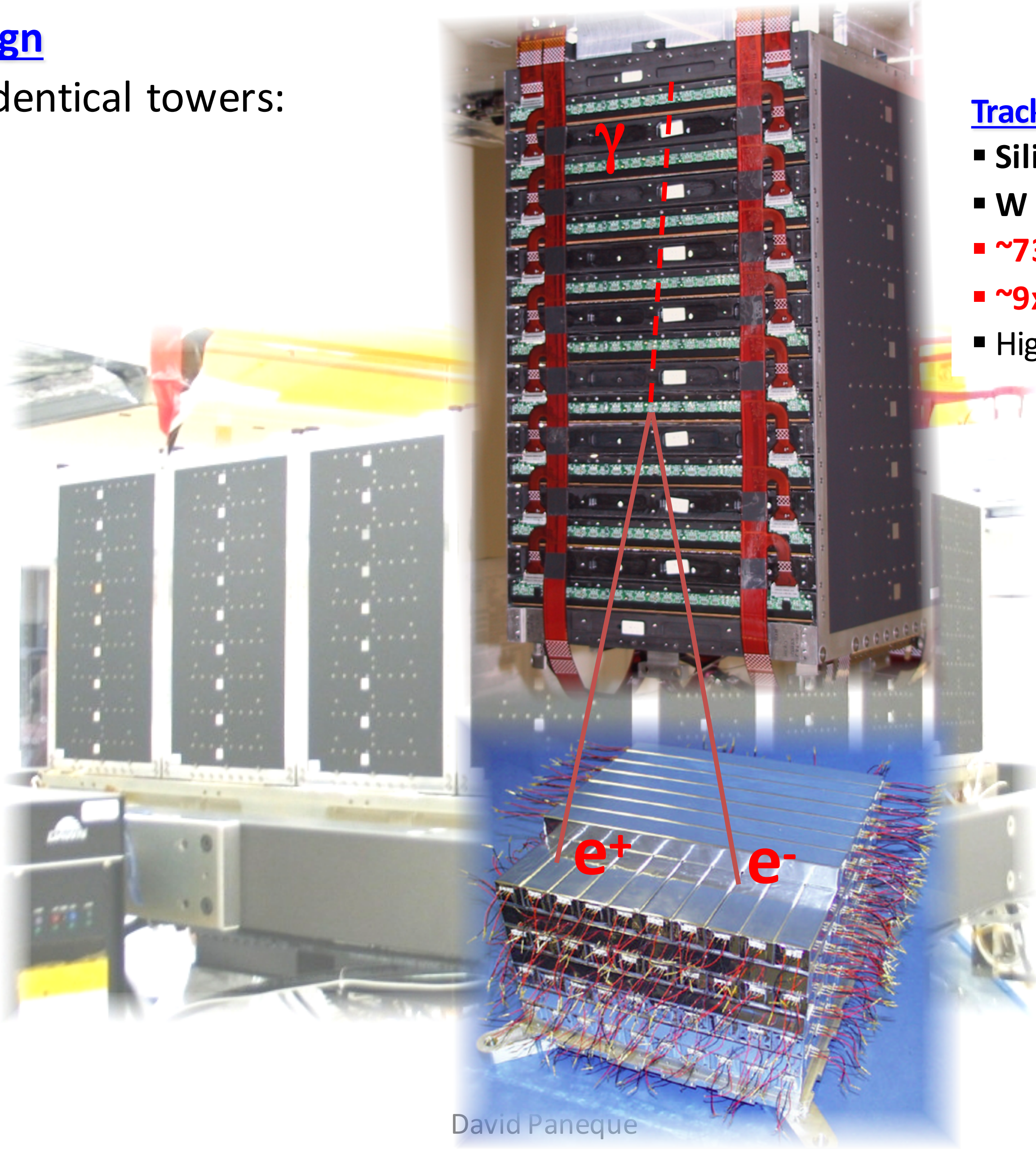
modular design

4x4 array of identical towers:



Tracker/Converter (TKR):

- **Silicon strip detectors.**
- **W conversion foils.**
- **~73 m^2 of silicon (total).**
- **~9x10^5 electronic chans.**
- High precision tracking,

Calorimeter (CAL):

- **1536 CsI crystals.**
- 8.5 radiation lengths.
- Hodoscopic.
- Shower profile reconstruction (leakage correction)

1 - Fermi mission (brief overview): The LAT instrument

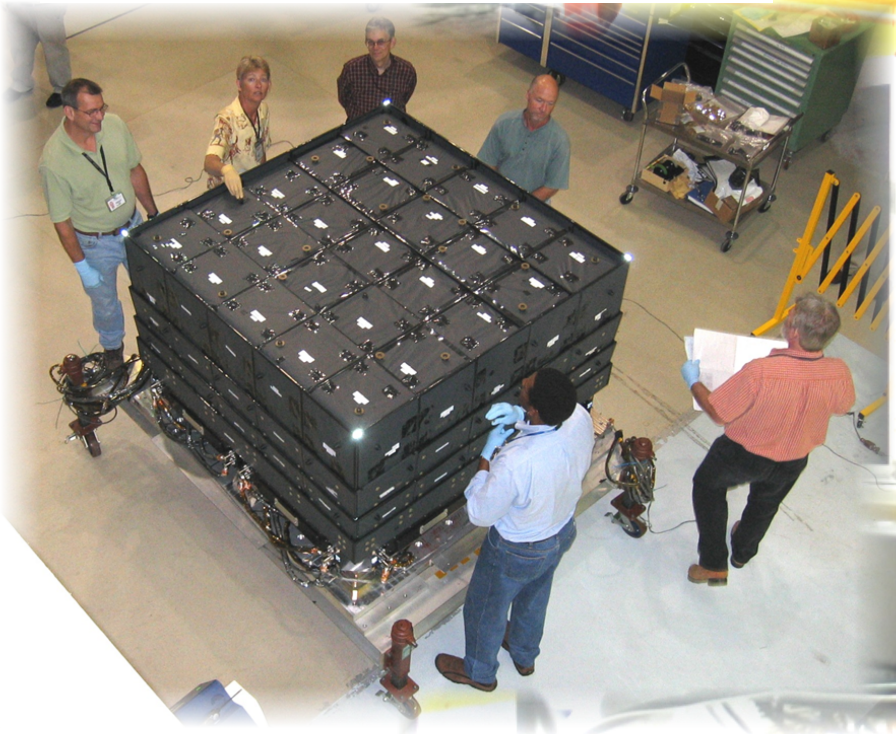
Challenging design: 1.8m x 1.8m x 1.2m ; 2800 kg, 1M channels; but only 650 W

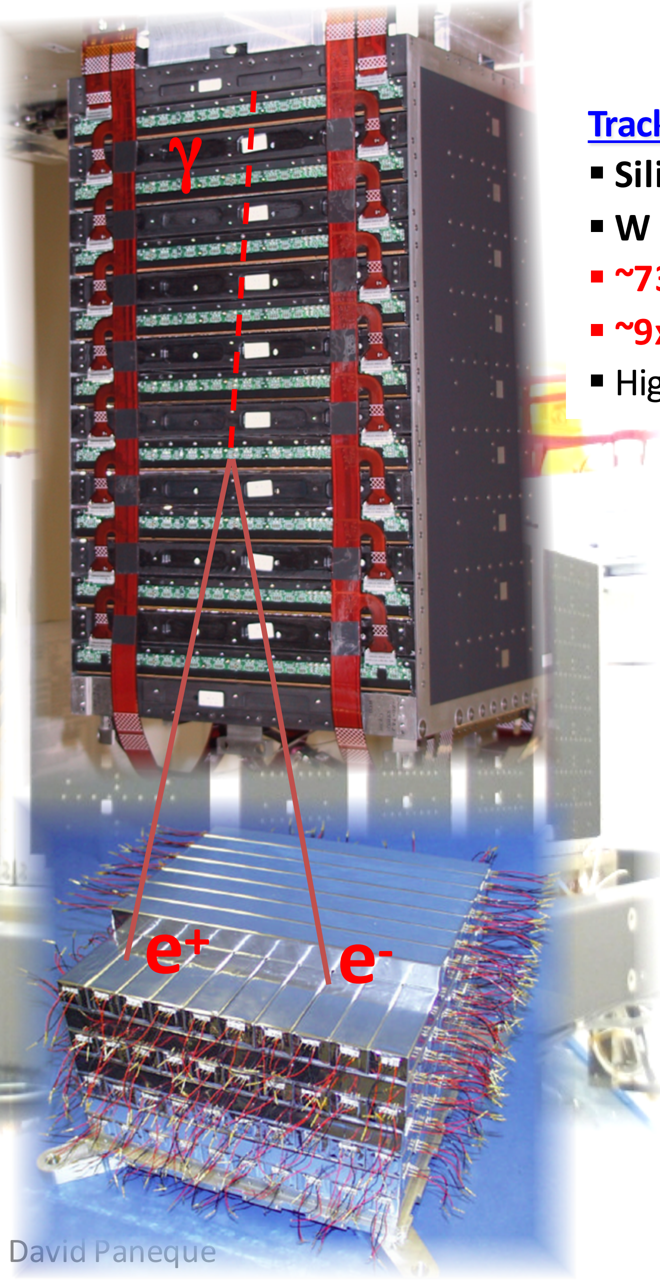
modular design

4x4 array of identical towers:

Anti-Coincidence (ACD):

- Segmented (89 tiles).
- Self-veto @ high energy limited.
- 0.9997 detection efficiency (overall).





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Calorimeter (CAL):

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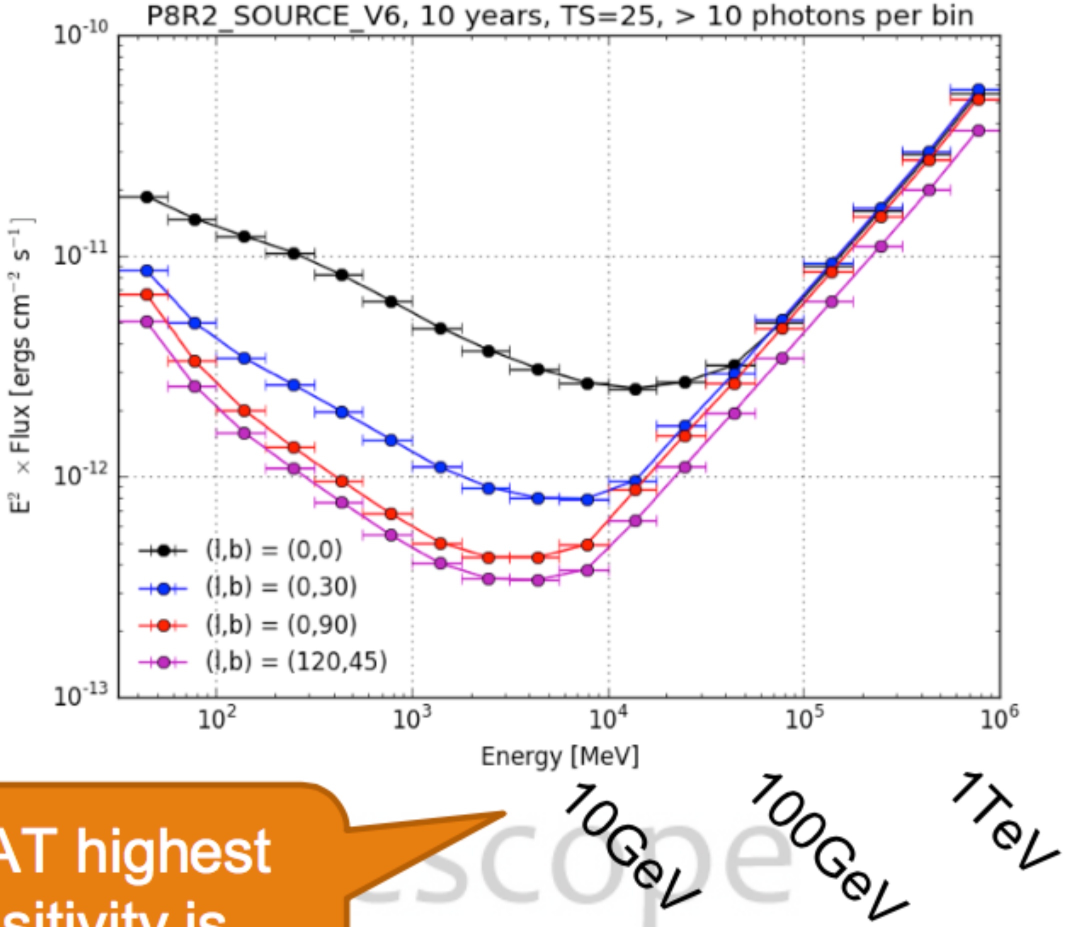
- 8.5 radiation lengths.
- Hodoscopic.
- Shower profile reconstruction (leakage correction)

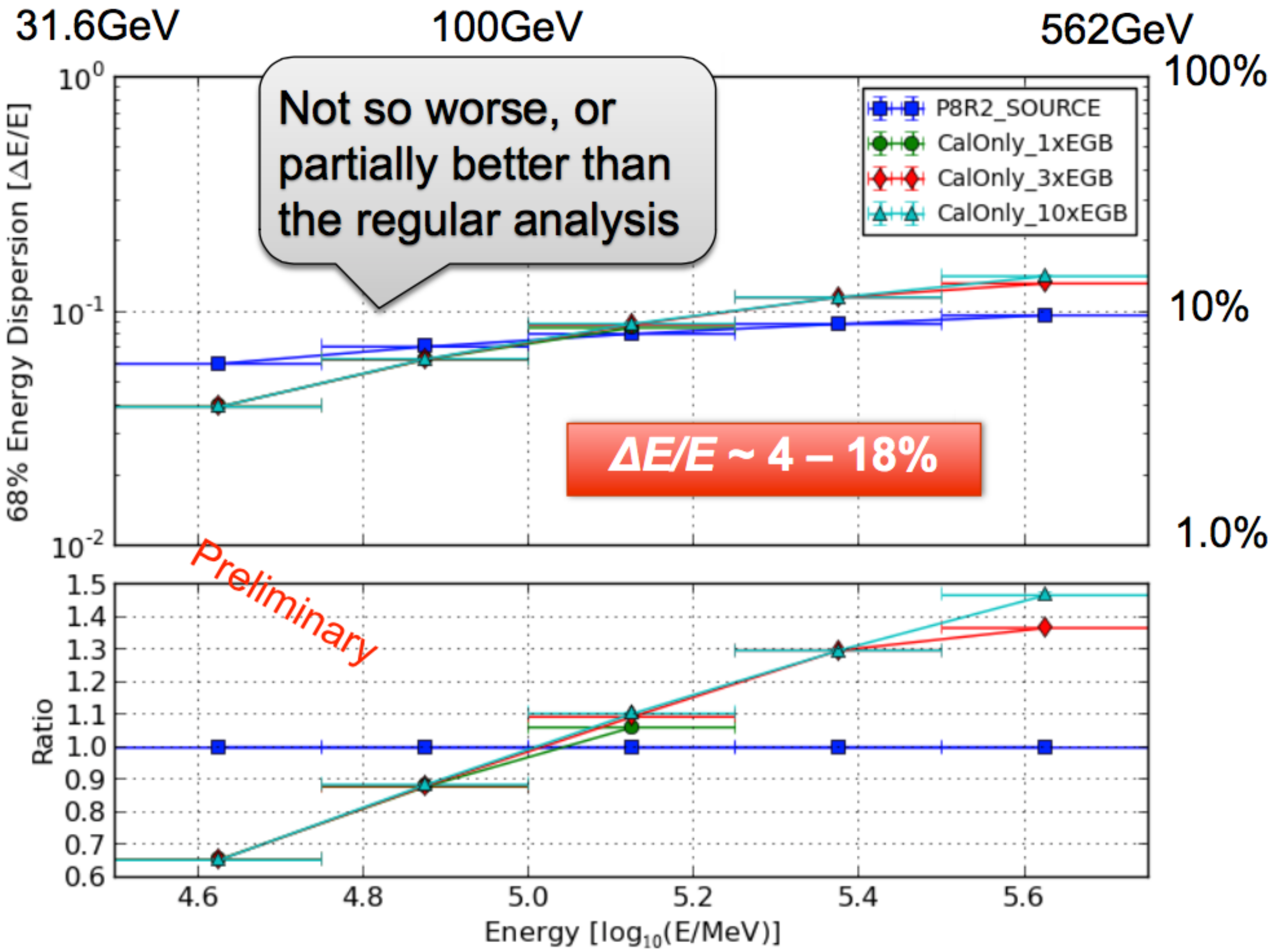
- **Fermi-LAT Pass8 provides a large acceptance, ~2.5m^{2}sr above 1 GeV**
- **The steep falling photon flux with energy of most γ-ray sources results in a substantial sensitivity limitation above few tens of GeV**

Pass8 SOURCE class sensitivity



At the Fermi-LAT highest energies, sensitivity is photon-statistics limited

Energy resolution of CalOnly events (68% containment)

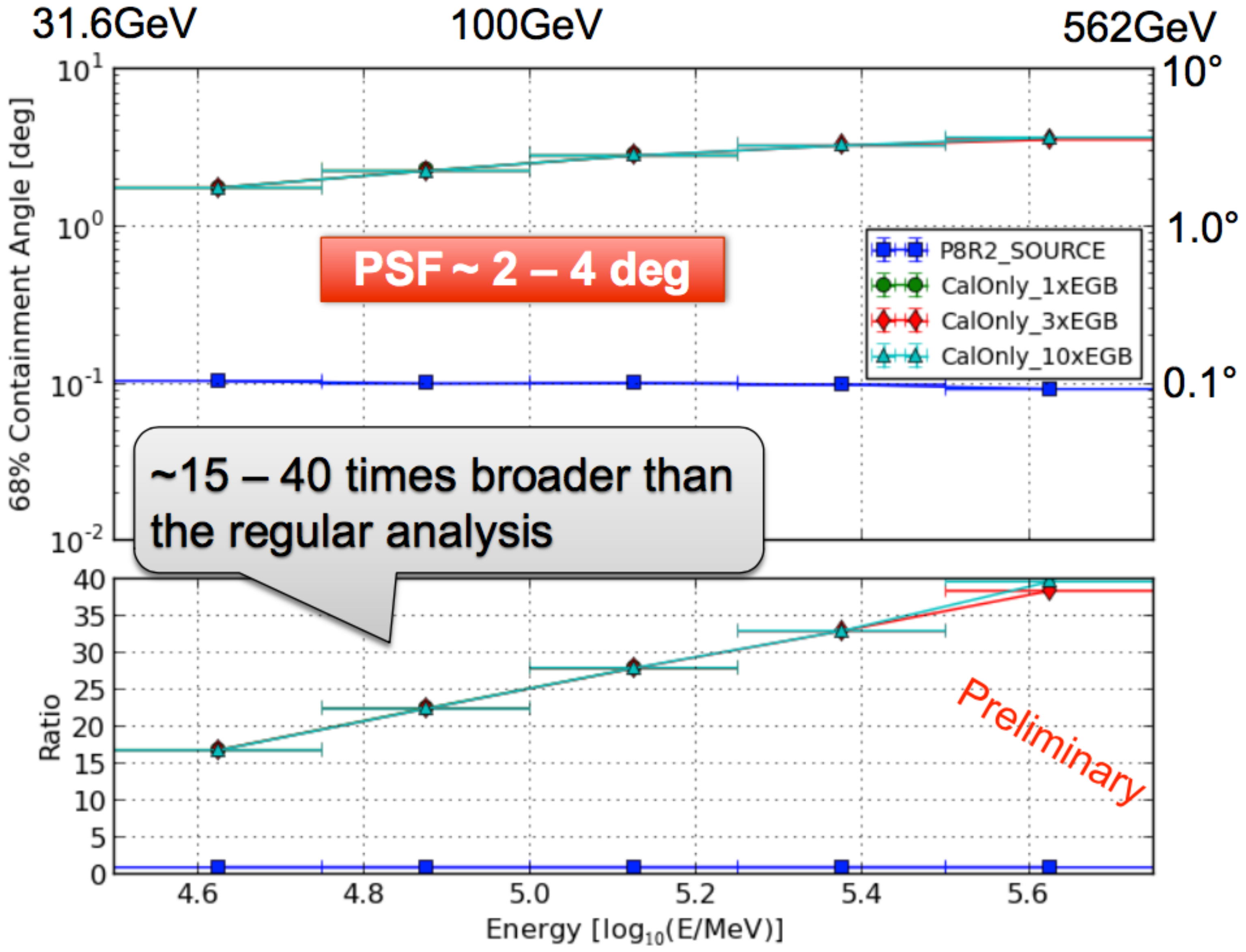


Not so worse, or partially better than the regular analysis

ΔE/E ~ 4 – 18%

Preliminary

Angular resolution of CalOnly events (68% containment)



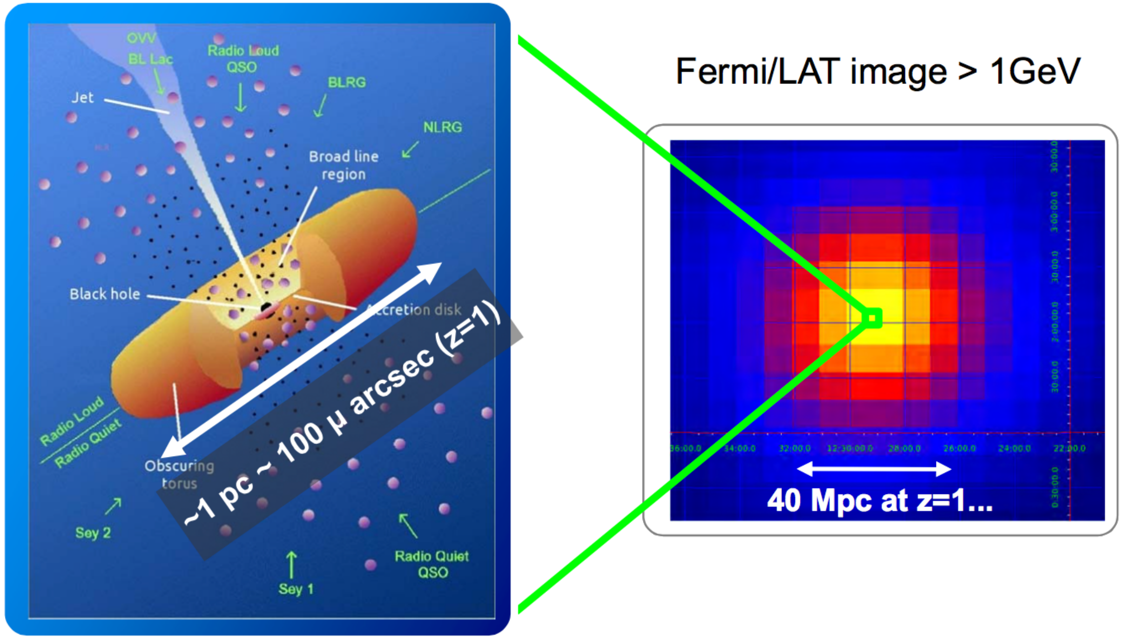
PSF ~ 2 – 4 deg

~15 – 40 times broader than the regular analysis

Science

→ gravitational microlensing

Difficulty of direct-imaging the AGN gamma-ray emission region



Fermi/LAT image > 1GeV

Urry & Padovani (1995)

The apparent size of the central region of an AGN is ~100 μ arcsec at z=1.

The plausible regions of high-energy emission are even smaller – ~1 μ arcsec for accretion disk (10^{-2} pc) and ~0.01 μ arcsec for SMBH (10^{-4} pc).

1 μ arcsec is the size of an ant at the Moon...

The gamma ray source can not be directly resolved with existing and even planned future gamma-ray telescopes.

Resolving the emission region with gravitational microlensing

The idea:

to use the „lenses“ created by the Nature to assist the observations via the effect of the **gravitational microlensing**.

Gravitational microlensing is caused by the stars in the galaxy-lens. The resulting magnification strongly depends on the source size (μ~(R_E/R)^0.5 and hence, if μ is determined by other means, it can be used to infer R.

→ *R_E = Einstein Radius = 4.e16 (M/M_sun)^0.5 cm*

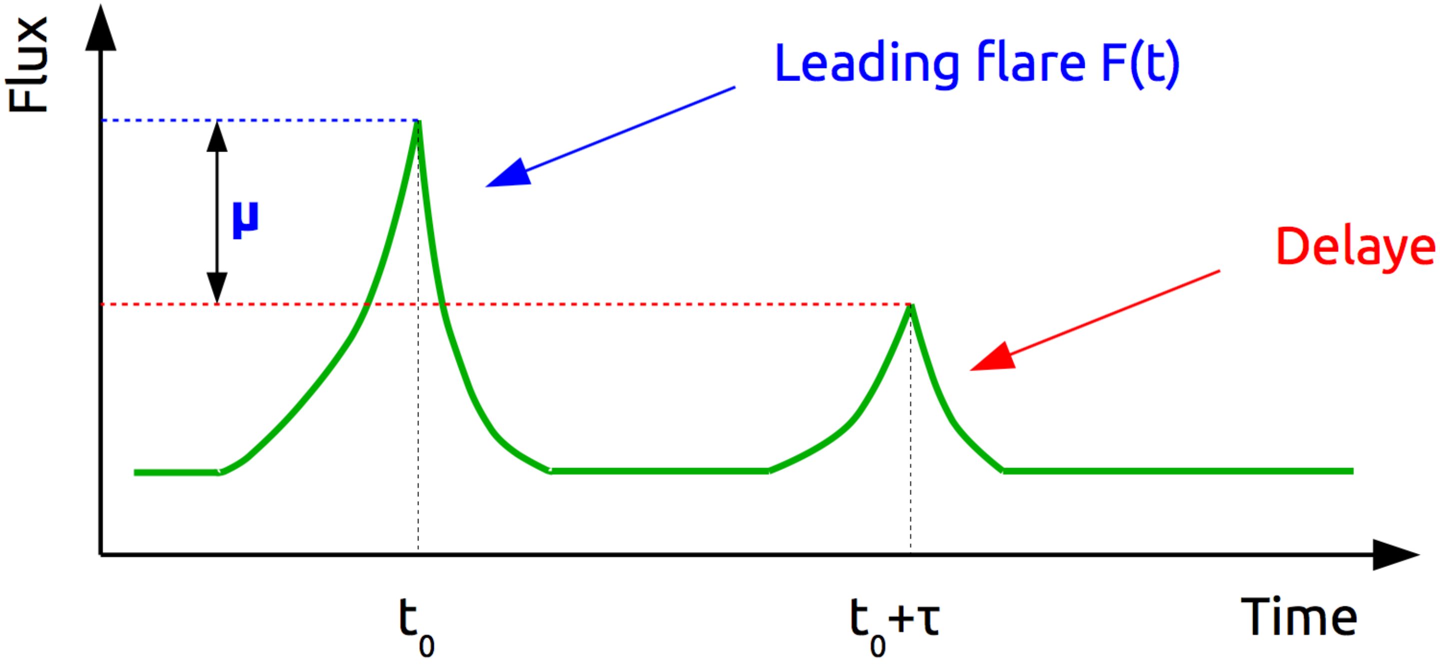
The detection of microlensing has just been suggested by Andrei Neronov and Ievgen Vovk in the GeV band (using LAT data) for PKS 1830-2111 and B0218+3572, leading to gamma-ray source sizes of R~10^{15} cm.

Further observation may address the questions of its stability in time, and also to potentially study the energy-dependence of R

→ unique chance to investigate the shape of the gamma-ray emission region in the GeV-TeV range

In gamma rays we can not resolve separate lensed images, we see only the total flux

$$F_{tot}(t) = \mu F(t)+F(t-\tau)$$



Microlensing acts on top of the normal lensing, leading to variations of magnification factor ratio in range μ/μ_{micro} to $\mu*\mu_{micro}$.

To infer μ it is important to catch both leading and delayed components.

There are only two know gravitational lenses: PKS 1830-211 and B0218+357.

In both cases radio observations indicate the presence of two lensed images and an Einstein ring.
Both objects are relatively bright in the GeV band.

PKS 1830-211

Source redshift: z=2.5 (Lidman+ '99)
Lens redshift: z=0.89 (Wiklind & Combes '96) and, possibly z=0.19 (Lovell+ '96)
Gravitational time delay in radio: 26^{+4}_{-5} days (Lovell+ '98)

Gravitational time delay in gamma: 21^{+2}_{-2} (Neronov+ '15, Barnacka+ '15)
Magnification ratio in radio: 1.52+/-0.5 (Lovell+ '98)
Magnification ratio in gamma: >6 (Abdo+ '15)

B0218+357

Source redshift: z=0.94 (Cohen+ '03)
Lens redshift: z=0.68 (Browne+ '93)

Gravitational time delay in radio: 10.5+/-0.4 d (Biggs+ '99), 10.1+/-1.6 d (Cohen+ '00, Eulares & Magain '11)
Gravitational time delay in gamma: 11.46+/-0.16 d (Cheung+ '14)
Magnification ratio in radio: 3.5-3.7 (Mittal+ '07)
Magnification ratio in gamma: ~1? (Cheung+ '15)

Microlensing reveils small sizes of gamma-ray sources in AGNs

μ_{micro}

- PKS 1830-211: 2-5
- B0218+357 : 10

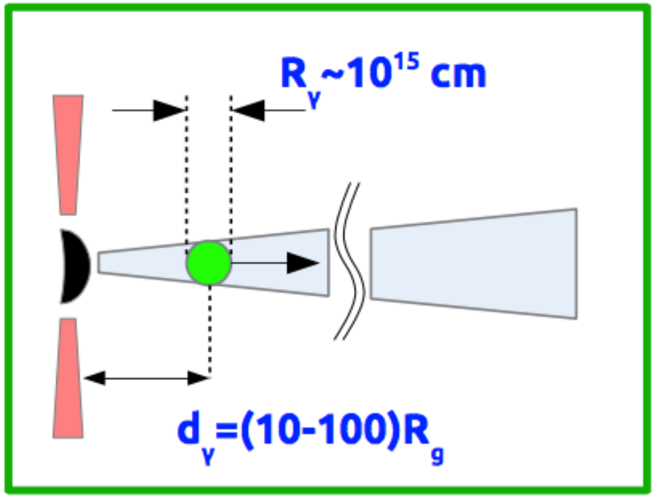
Time scale of variations:

- PKS 1830-211: $1<\Delta t<75$ days
- B0218+357 : ~50 days

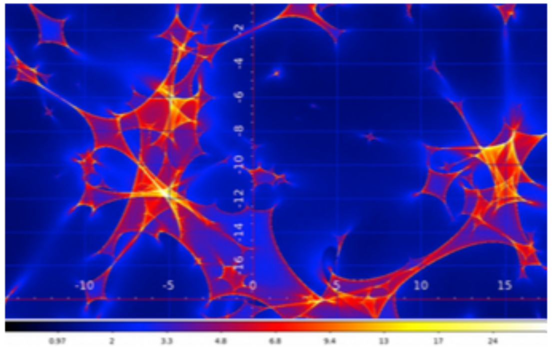
	PKS 1830-211	**B0218+357**
μ_{micro}	10^{15}-10^{16} cm	10^{14}-10^{15} cm
Duration	10^{14}-10^{15} cm	10^{14}-10^{15} cm
Fast variability	$<10^{16}$ (Γ/10) cm	$<3\times10^{15}$ (Γ/10) cm

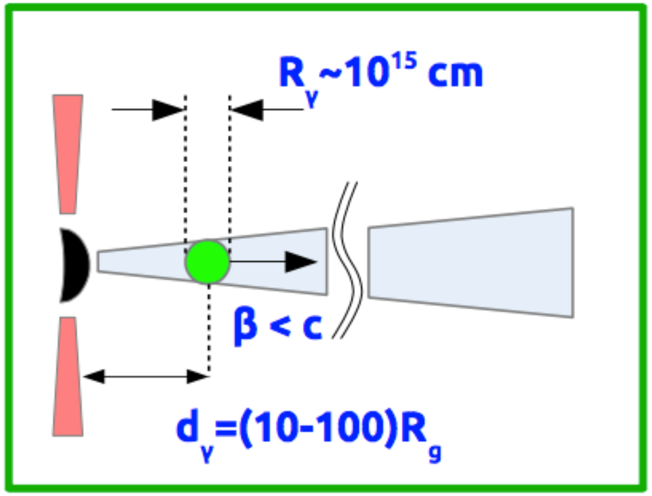
Detection of microlensing suggests that the emitting source is not relativistic.

Microlensing removes the long-standing puzzle of the location of the gamma-ray source in blazars, providing solid arguments in favour of its assosication with the AGN's central black hole.



Potential of microlensing observations





Regular observations of microlensing open a new way to learn about the structure of AGNs:

- ✔ energy dependence of R_γ
- ✔ its variations with time

One of the lenses – B0218+357 – is also detected by MAGIC (ATel #6349) at sub-TeV energies, which allows to study the source size over 3 decades in energy!

Fermi/LAT observations are essential here to detect the flares and measure the magnification ratios in the GeV band.

Microlensing provides a unique opotunity to study the details of the structure of the acceleration sites in AGNs, effectively improving the angular resolution of gamma-ray telescopes by 10^{11} times.

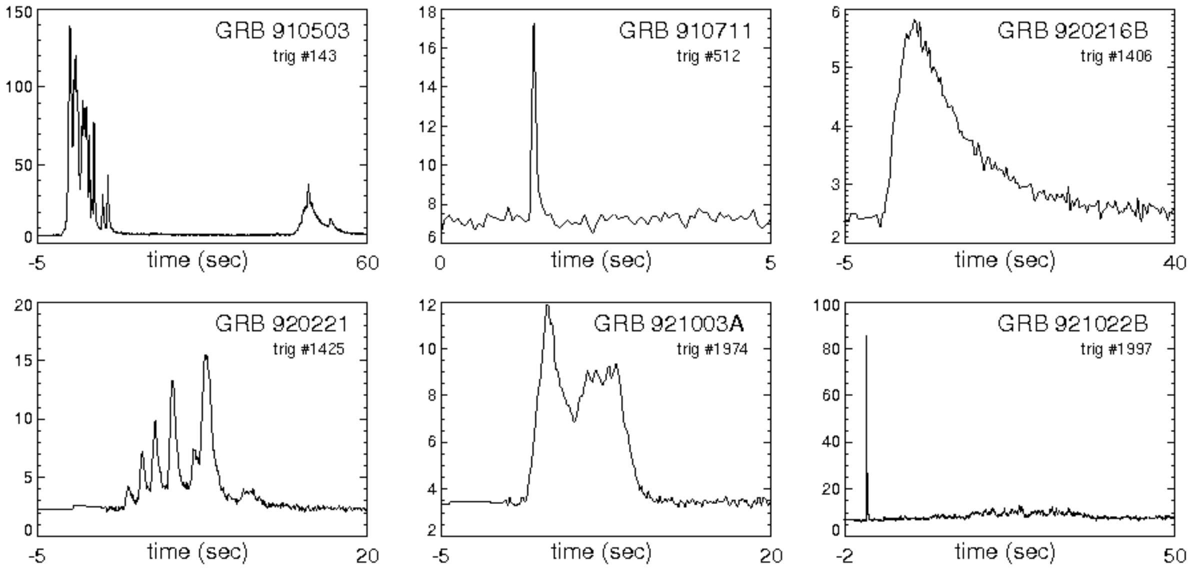
GRB

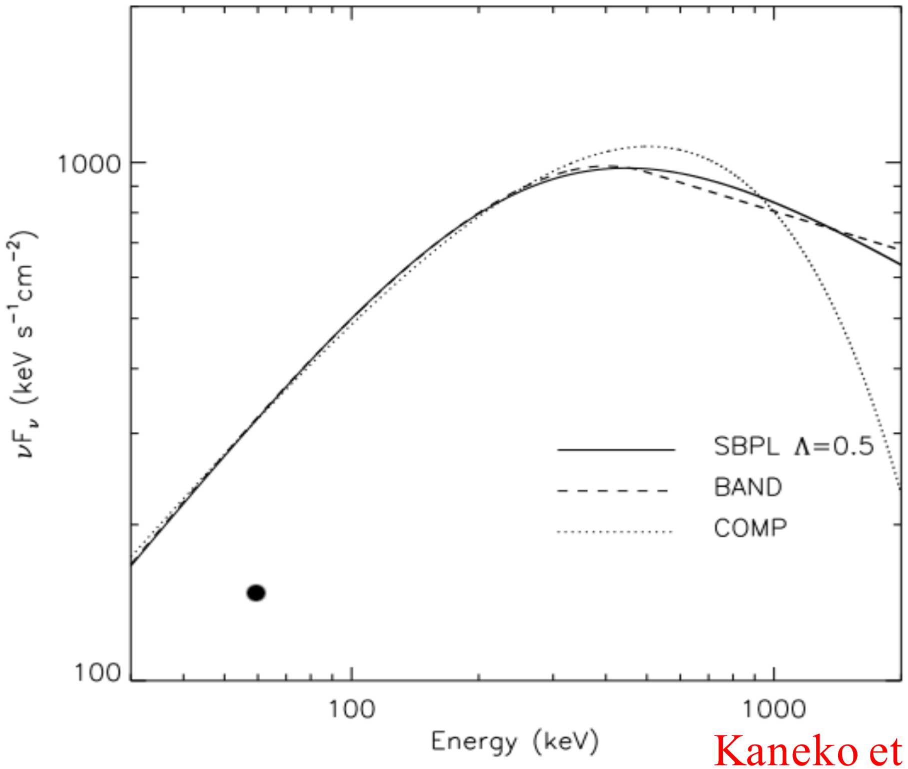
GRBs: general properties

- The lightcurves can be very different from one to another
  - The spectra instead are very similar
  - The general kind of spectrum is not thermal
  - There are some exception that show a thermal spectrum

⬇

Wide energy range needed for GRB observations!



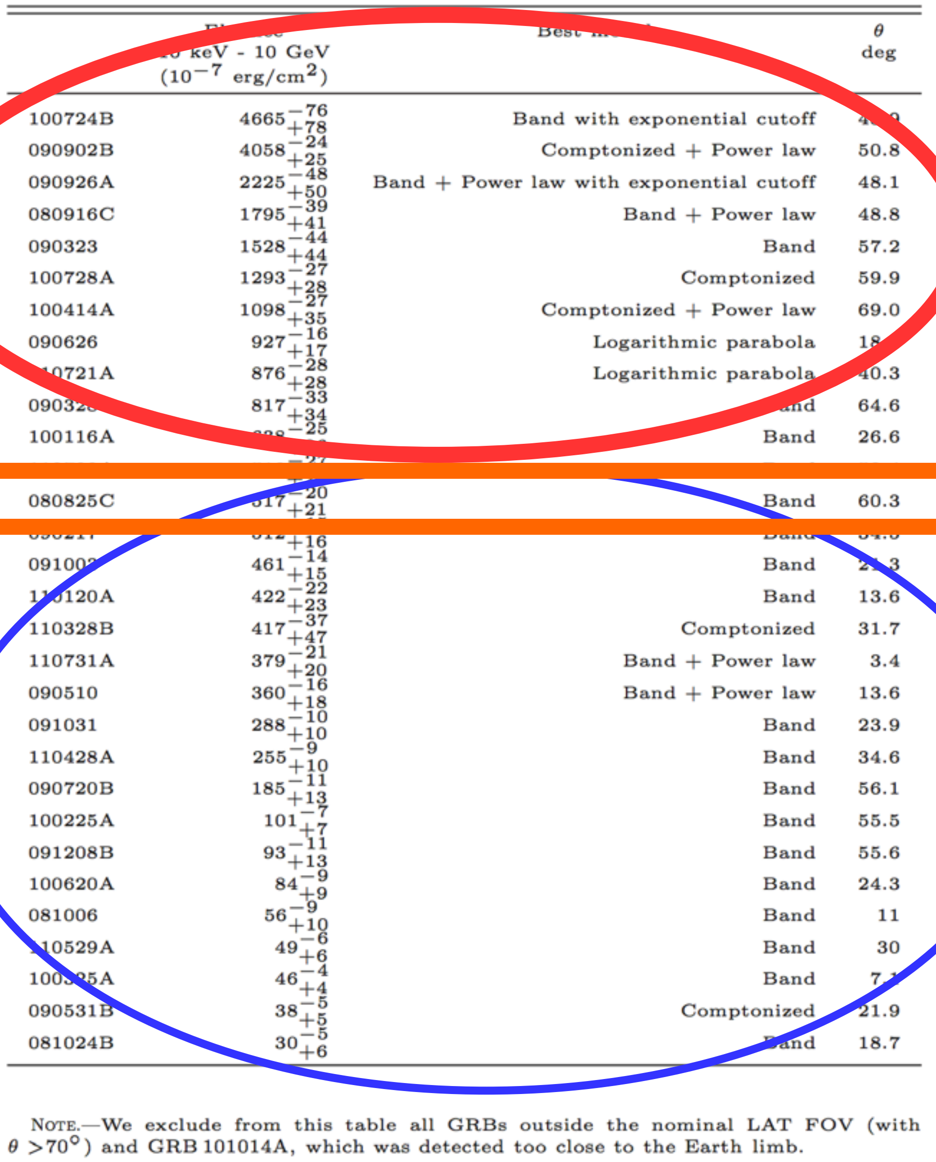


Kaneko et al. (2006)

Motivation: crisis of the Band paradigma

- The Band function was the paradigma for GRB spectral modelling
- Fermi-LAT detected GRBs show a deviation from the Band function in the bright ones
- To study the less bright GRBs the required significance of the deviation must be lowered (less than 5 sigma)
- Case of study: GRB 080825C

Ackermann et. al. 2013, ApJS 209, 11A



	[illegible] keV - 10 GeV (10^{-7} erg/cm^2)	Best [illegible]	θ deg
100724B	4665^{-76}_{+78}	Band with exponential cutoff	[illegible]
090902B	4058^{-24}_{+25}	Comptonized + Power law	50.8
090926A	2225^{-48}_{+50}	Band + Power law with exponential cutoff	48.1
080916C	1795^{-39}_{+41}	Band + Power law	48.8
090323	1528^{-44}_{+44}	Band	57.2
100728A	1293^{-27}_{+28}	Comptonized	59.9
100414A	1098^{-27}_{+35}	Comptonized + Power law	69.0
090626	927^{-16}_{+17}	Logarithmic parabola	[illegible]
[illegible]	876^{-28}_{+28}	Logarithmic parabola	[illegible]
[illegible]	817^{-33}_{+34}	[illegible]	64.6
100116A	[illegible]	Band	26.6
[illegible]	[illegible]	[illegible]	[illegible]
080825C	[illegible]	Band	60.3
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	461^{-14}_{+15}	Band	[illegible]
[illegible]	422^{-22}_{+23}	Band	13.6
110328B	417^{-37}_{+47}	Comptonized	31.7
110731A	379^{-21}_{+20}	Band + Power law	3.4
090510	360^{-16}_{+18}	Band + Power law	13.6
091031	288^{-10}_{+10}	Band	23.9
110428A	255^{-9}_{+10}	Band	34.6
090720B	185^{-11}_{+13}	Band	56.1
100225A	101^{-7}_{+7}	Band	55.5
091208B	93^{-11}_{+13}	Band	55.6
100620A	84^{-9}_{+9}	Band	24.3
081006	56^{-9}_{+10}	Band	11
[illegible]	49^{-6}_{+6}	Band	30
[illegible]	46^{-4}_{+4}	Band	[illegible]
090531B	38^{-5}_{+5}	Comptonized	21.9
081024B	30^{-5}_{+6}	[illegible]	18.7

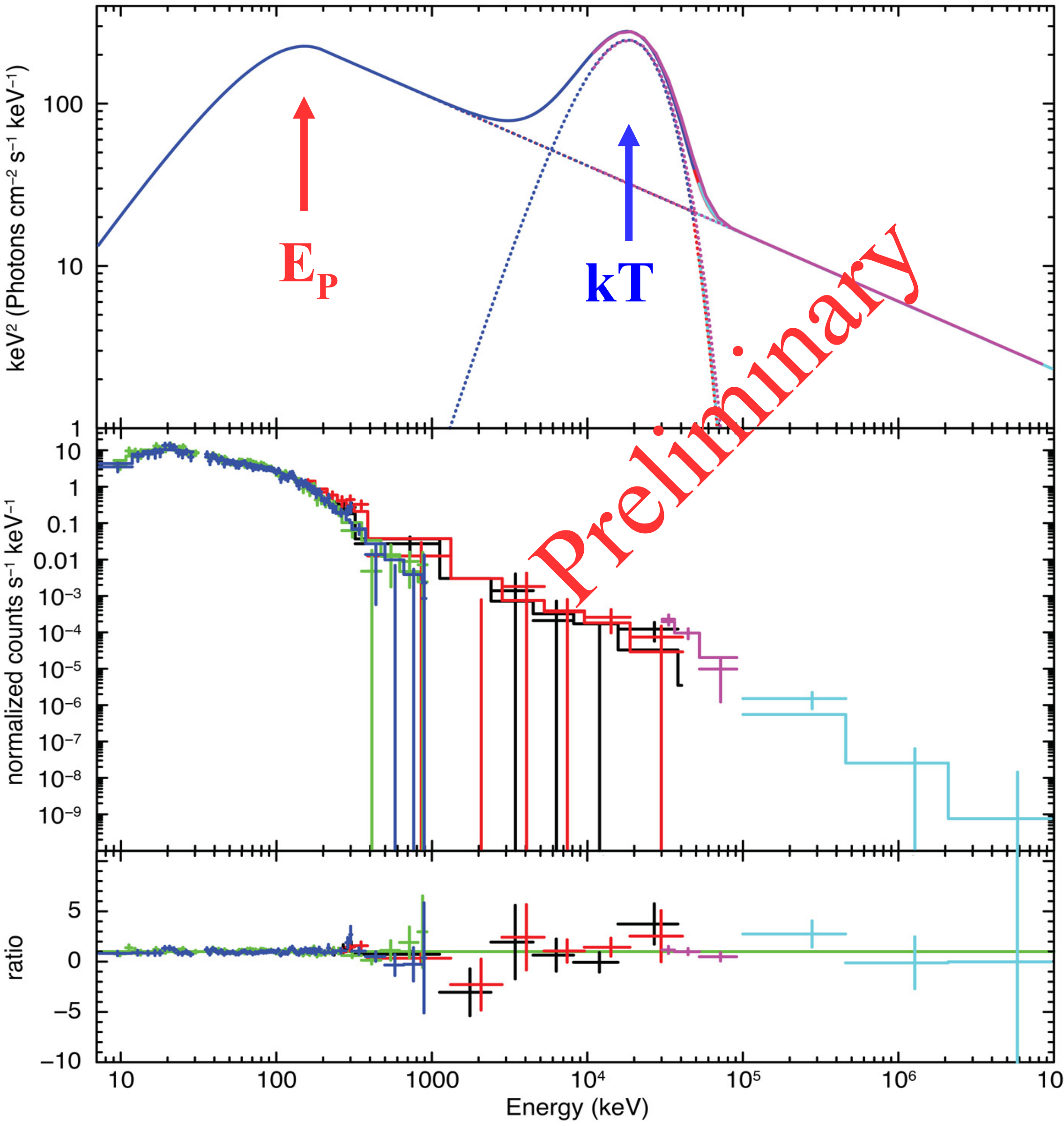
NOTE.—We exclude from this table all GRBs outside the nominal LAT FOV (with $\theta > 70°$) and GRB 101014A, which was detected too close to the Earth limb.

Results

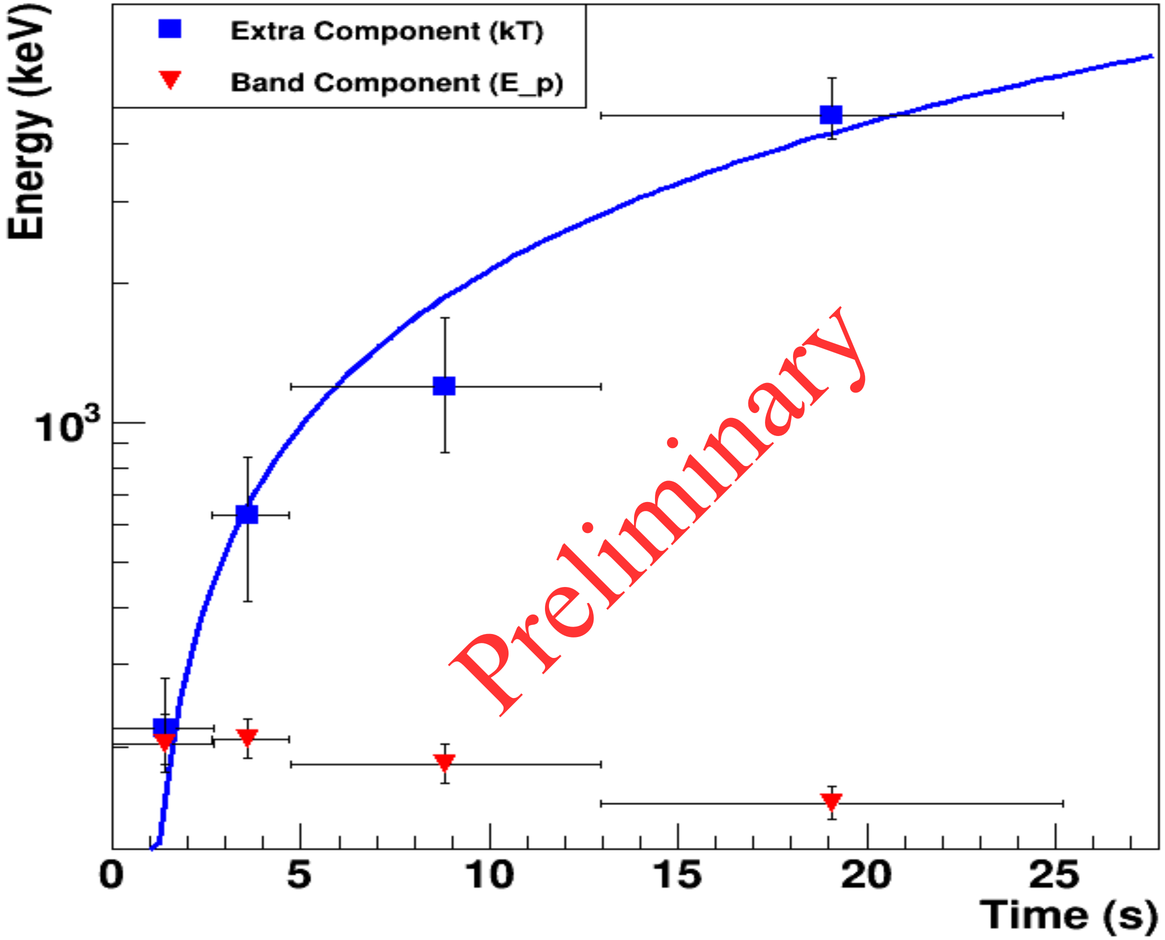
An extra component is found with 3.5σ significance in the first and fourth time bins.

It is not significant in the time bins between, but the recovered parameters follow the same relation throughout the burst.

The simplest model consistent throughout the burst is Band+BB.



Time evolution of the components



- The two components (Band and Black Body) have a different time evolution.

- The energy of the Band peak has a typical hard-to-soft evolution.
- The energy of the second peak (BB) increases linearly with time and reaches almost 16 MeV (similar to 110721).

Time	α	β	E_p^a	N_{Band}^b	kT^a	N_{BB}^b	N_{PL}^b
$0.0 - 2.69$	$-0.56^{+0.08}_{-0.07}$	$-2.6^{+0.1}_{-0.2}$	203^{+31}_{-28}	$0.10^{+0.01}_{-0.01}$	219^{+62}_{-36}	15^{+3}_{-3}	-
$2.69 - 4.74$	$-0.46^{+0.06}_{-0.07}$	$-2.43^{+0.06}_{-0.07}$	208^{+22}_{-19}	$0.14^{+0.01}_{-0.01}$	632^{+208}_{-221}	11^{+8}_{-7}	-
$4.74 - 12.93$	$-0.74^{+0.05}_{-0.05}$	$-2.46^{+0.07}_{-0.08}$	183^{+19}_{-17}	$0.046^{+0.004}_{-0.003}$	1191^{+497}_{-332}	7^{+4}_{-4}	-
$12.93 - 25.22$	$-0.64^{+0.05}_{-0.05}$	$-2.42^{+0.06}_{-0.06}$	151^{+13}_{-13}	$0.050^{+0.004}_{-0.004}$	4613^{+920}_{-508}	$6.0^{+2.0}_{-1.5}$	-
$25.22 - 35.46$	$-1.94^{+0.03}_{-0.04}$	-	-	-	-	-	$8.3^{+1.0}_{-1.4}$

[a] keV
[b] $ph\ cm^{-2}\ s^{-1}\ keV^{-1}$

Conclusions & Interpretation

- It is the first time a consistent extra component it is seen a weaker burst.
- The spectrum can be modelled using Band+BB and the peak energy of the extra/component increases throughout the emission episode, from a few hundred keV to several MeV.
- The results point to a 2 zone emission model disfavouring a single radius origin of the emission.

Multi-zone emission in the case BB is the photospheric emission:

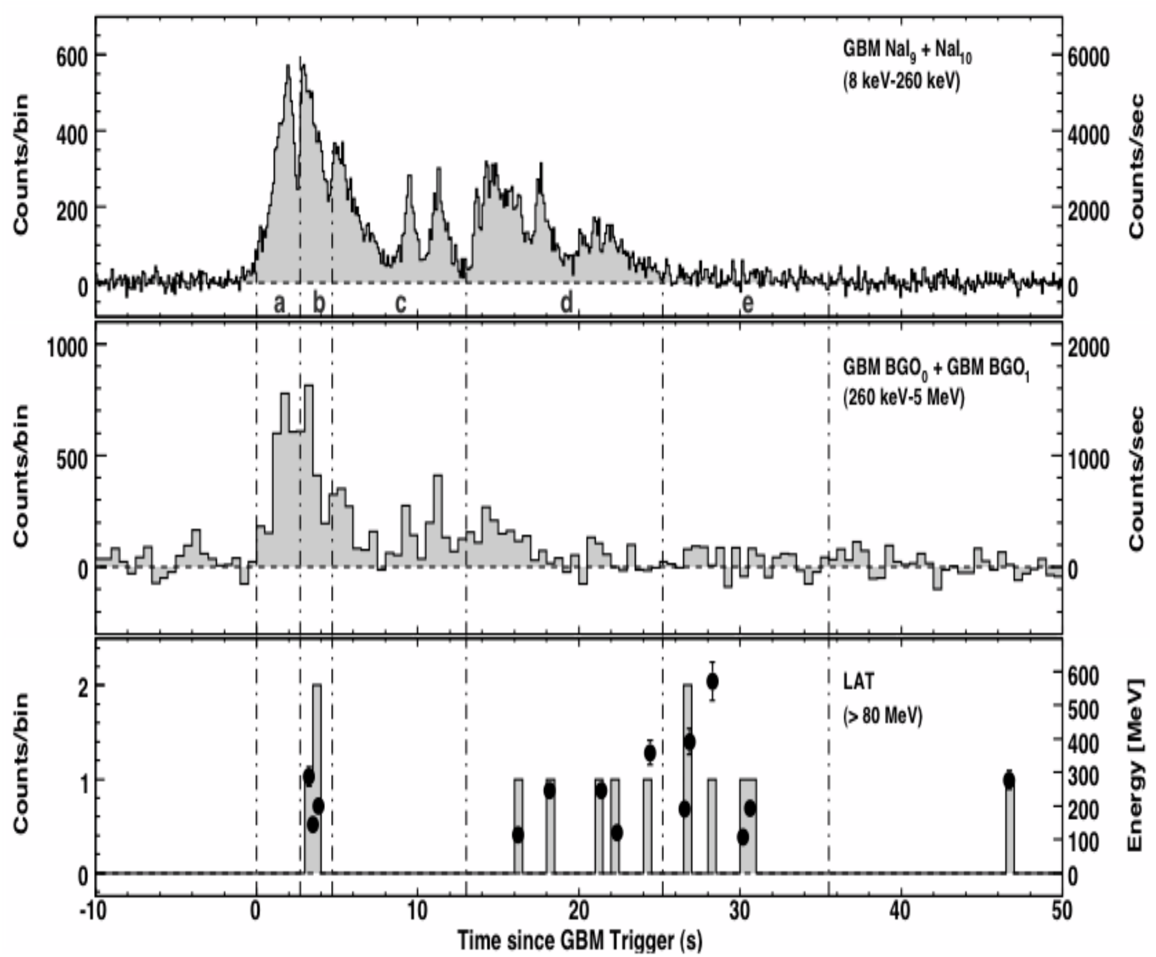
➔ BB from electrons accelerated in magnetic reconnections below the photosphere (kT too high for thermal acceleration; Bégué & Pe'er 2015);

➔ The Band component could be synchrotron emission from electrons accelerated via reconnection (as the ICMART scenario of Gao & Zhang 2015).

➔ The 2 populations of electrons are disconnected from each other (2 different sites of acceleration).

GRB 080825C

Abdo et. al. 2009, ApJ 707, 580-592



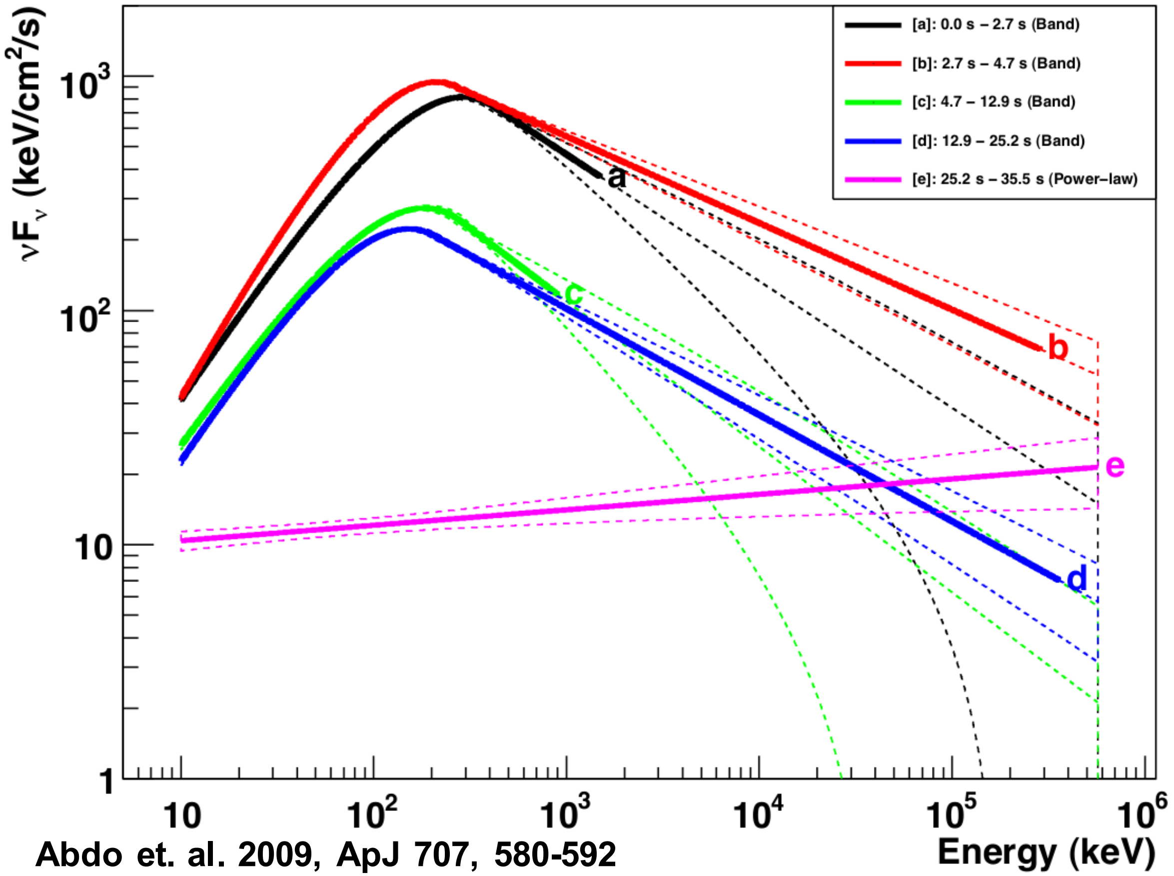
- At 14:13:48 UTC on August 25 2008 (T0), GRB 080825C triggered the GBM (Van der Horst et al. 2008).
- RA = 232.2^o , Dec,= -4.9^o 1-σ error = 1.5^o
- GRB at ~60^o from the LAT boresight

New Analysis

LLE data (30-100 MeV) recent LAT data product for transient events

New data selection in LAT: P7_V6 new event selection of the >100 MeV LAT events

Original spectroscopy

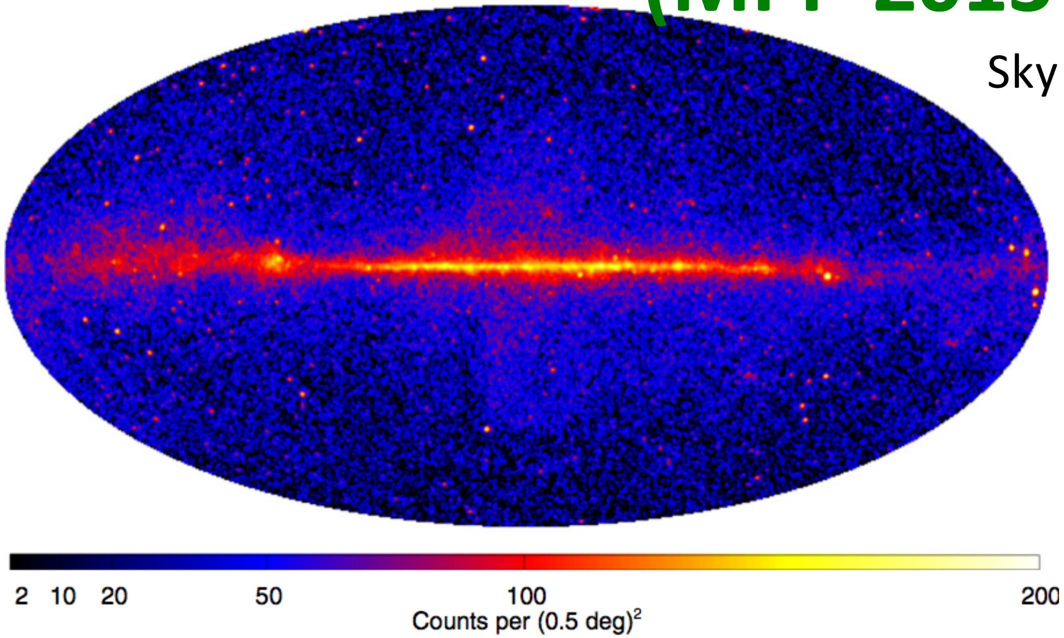


Abdo et. al. 2009, ApJ 707, 580-592

- The Band function was used to model the spectra of the the first 4 time bins.
- A deviation from the Band function (high energy cut-off) was found but considered not significant enough.

Time Range (s)	A (10^{-3} γ cm^{-2} s^{-1} keV^{-1})	α	β	$E_{\rm peak}$ (keV)
a: 0.00 – 2.69	75^{+6}_{-5}	-0.76 ± 0.05	$-2.54^{+0.11}_{-0.17}$	291^{+25}_{-22}
b: 2.69 – 4.74	138^{+13}_{-11}	-0.52 ± 0.06	$-2.37^{+0.06}_{-0.08}$	210^{+14}_{-12}
c: 4.74 – 12.93	44 ± 4	-0.81 ± 0.06	$-2.62^{+0.14}_{-0.25}$	183 ± 13
d: 12.93 – 25.22	47^{+5}_{-4}	$-0.72^{+0.07}_{-0.06}$	$-2.45^{+0.07}_{-0.10}$	152 ± 9
e: 25.22 – 35.46	1.2 ± 0.1 (at 100 keV)	N.A.	-1.95 ± 0.05	N.A.
0.00 – 35.46	37 ± 2	-0.79 ± 0.03	$-2.42^{+0.04}_{-0.05}$	198 ± 8

The First Fermi-LAT Catalog of Sources above 10 GeV (1FHL) Ackermann et al, 2013, ApJS 209, 34 (MPP-2013-174)



Sky map with > 10 GeV events

LAT saw more than $1.5\text{x}10^5$ gamma-rays in only 3 years

Big improvement with respect to EGRET !!! $1.5\text{x}10^3$ evts in 9 years (Thompson et al. 2005)

The analysis pipeline used is the same as that for the 2FGL catalog:
candidate sources ("seeds") are identified and localized, and then a maximum likelihood analysis extracts results on statistical significance, flux, and energy spectrum.
Galactic and isotropic diffuse background models similar to those used for the 2FGL catalog (available through the Fermi Science Support Center)

Only sources with a Test Statistic (TS) larger than 25 are reported

514 sources ***(63 not contained in 2FGL)***

***9 of the 63 sources are extended, while in* 2FGL exist as point-like sources**

All sources could be fitted with a simple power law

~1000 AGNs @ > 0.1 GeV (Fermi low-energy, 2FGL & 2LAC)

~2 times less sources

~400 AGNs @ >10 GeV (Fermi high-energy, 1FHL)

~10 times less sources above 100 GeV. Why ???

1) intrinsic turnovers or cutoffs
2) Extrinsic turnovers or cutoffs (EBL)
3) **Region not sufficiently explored with IACTs**
    IACTs have low duty cycles and small FoV
        → Difficult to make surveys over large areas
            (*HESS Galactic plane scan is special because of high source density)*

~50 AGNs @ >100 GeV (Cherenkov Telescopes)