Risultati recenti e prospettive da esperimenti nello spazio

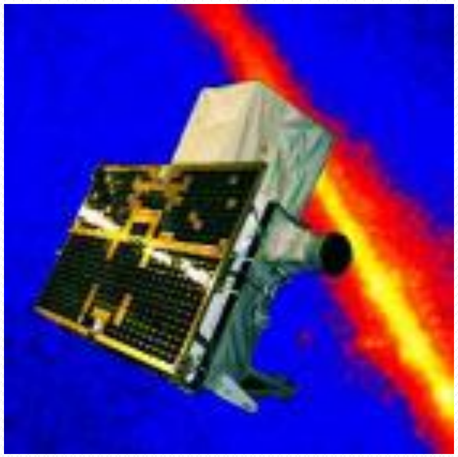
Silvia Rainò
Dipartimento di Fisica , Università di Bari
&
INFN – Sezione di Bari

Introduction

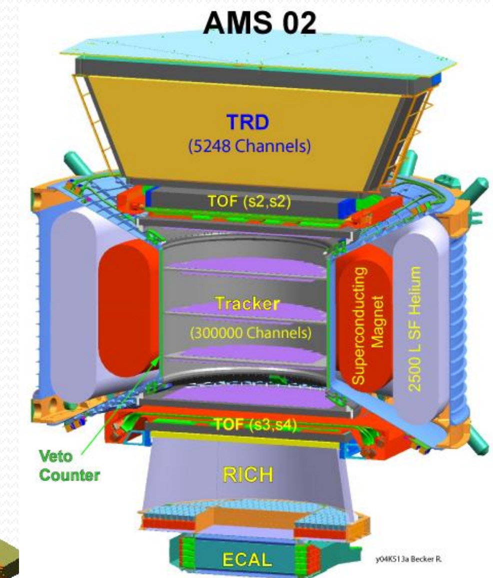
- Actual space experiments are providing an outstanding view of the high energy universe with their great potential for discovery. Recent results from space are allowing significant steps forward in
  - Understanding the mechanisms of particle acceleration in AGNs, pulsars, and SNRs
  - Providing information about particle interaction mechanisms at very high energies
  - Resolving the gamma-ray sky: unidentified sources and diffuse emission.
  - Probing DM and early universe
  - The study of the acceleration mechanisms of CRs to understand their origin, production and propagation

Space experiments

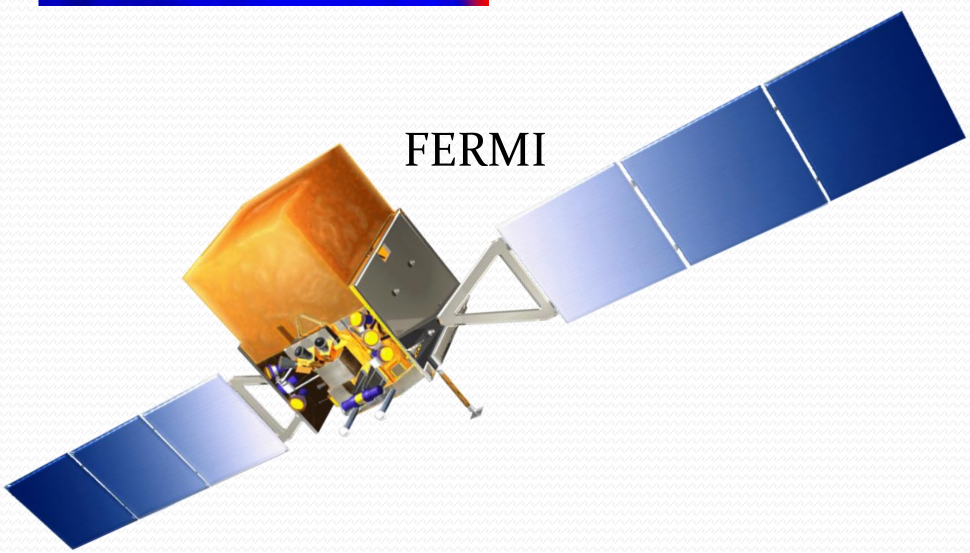
- Big italian effort among the main space experiments

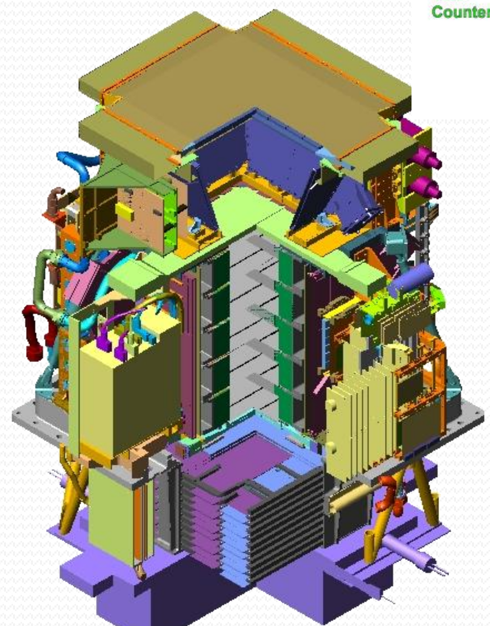


AGILE



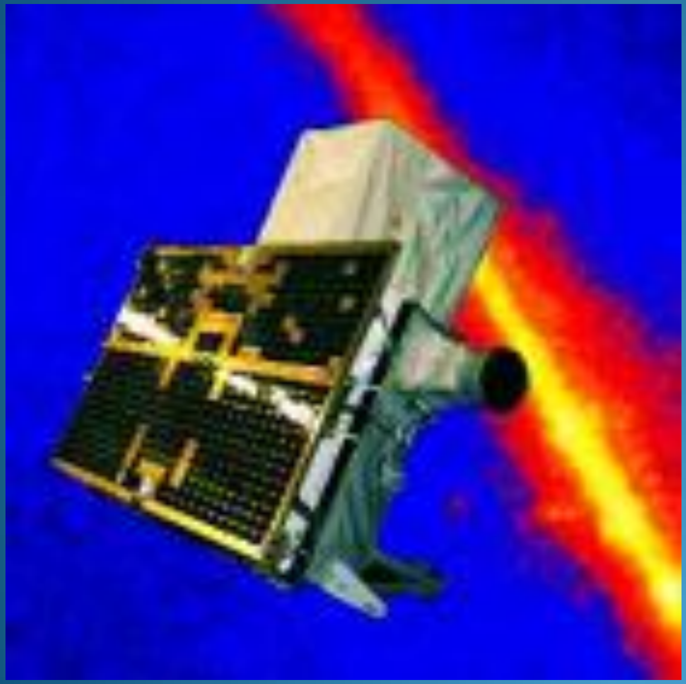
FERMI

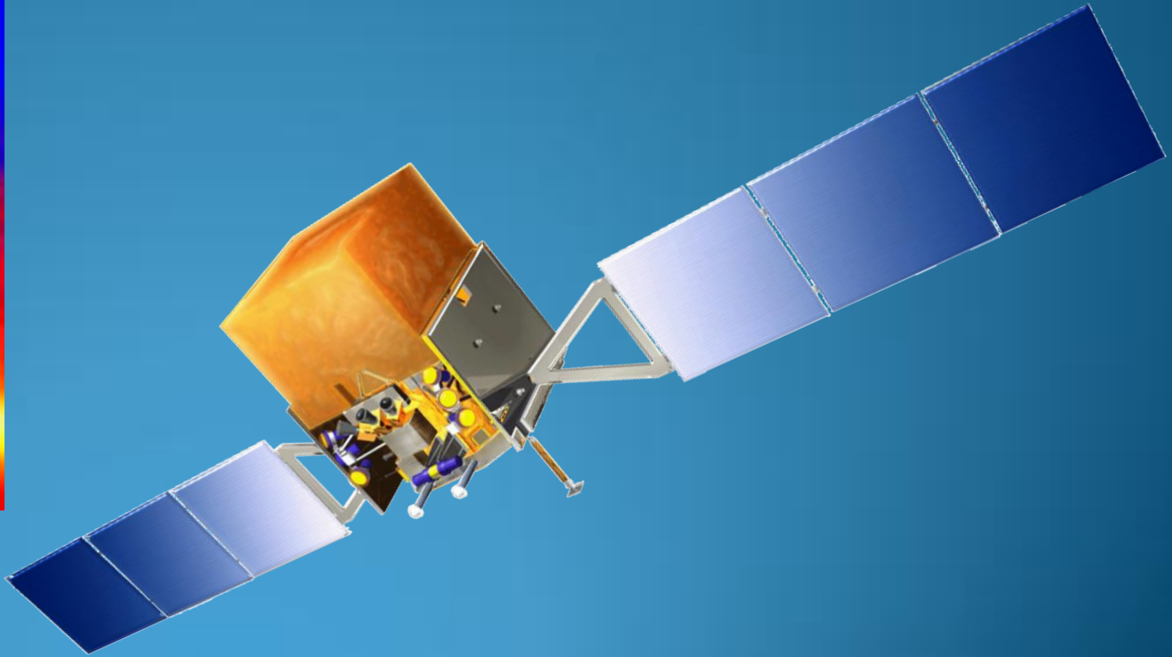




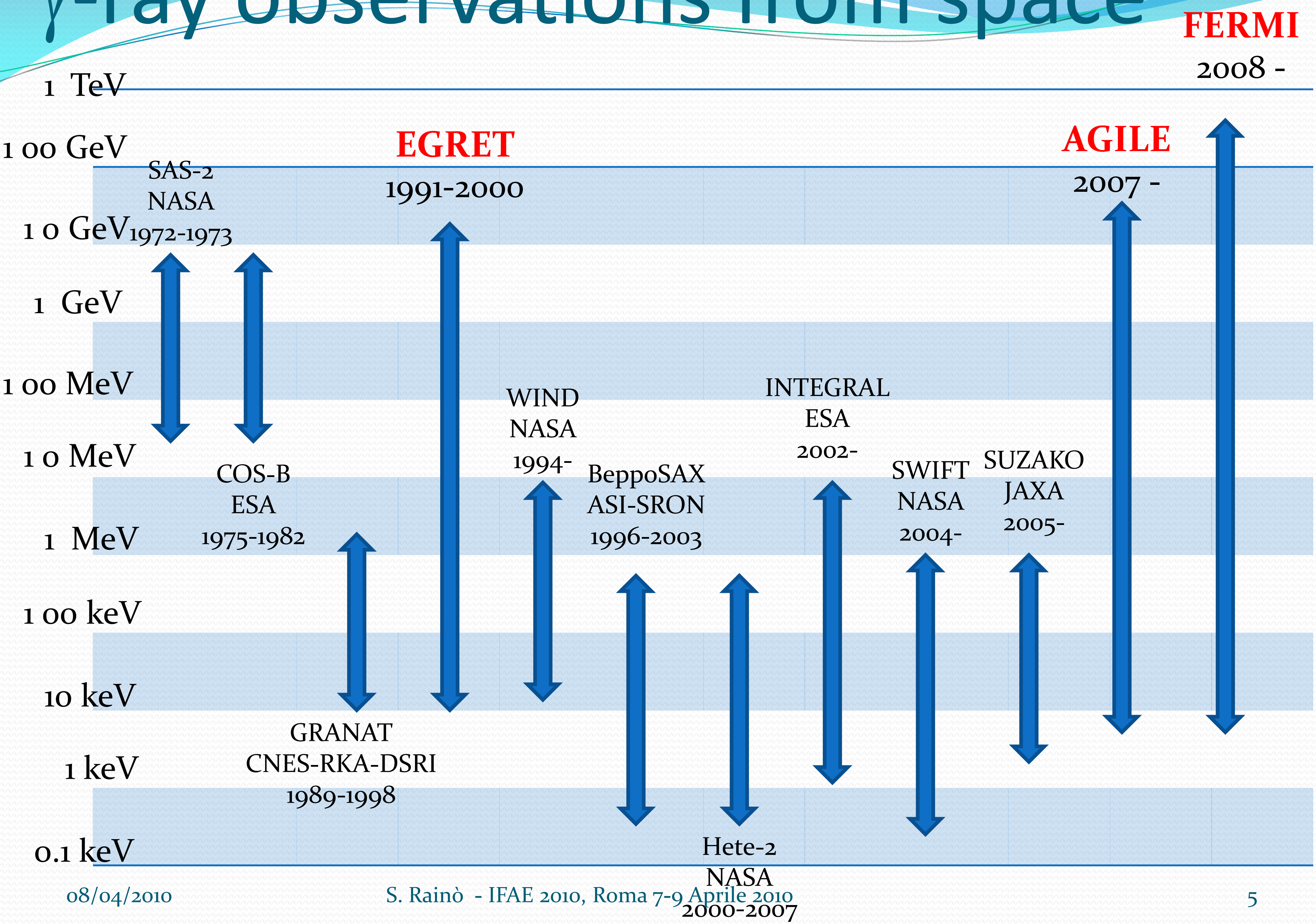
PAMELA

High Energy Gamma-Ray Astrophysics: AGILE and FERMI





γ-ray observations from space

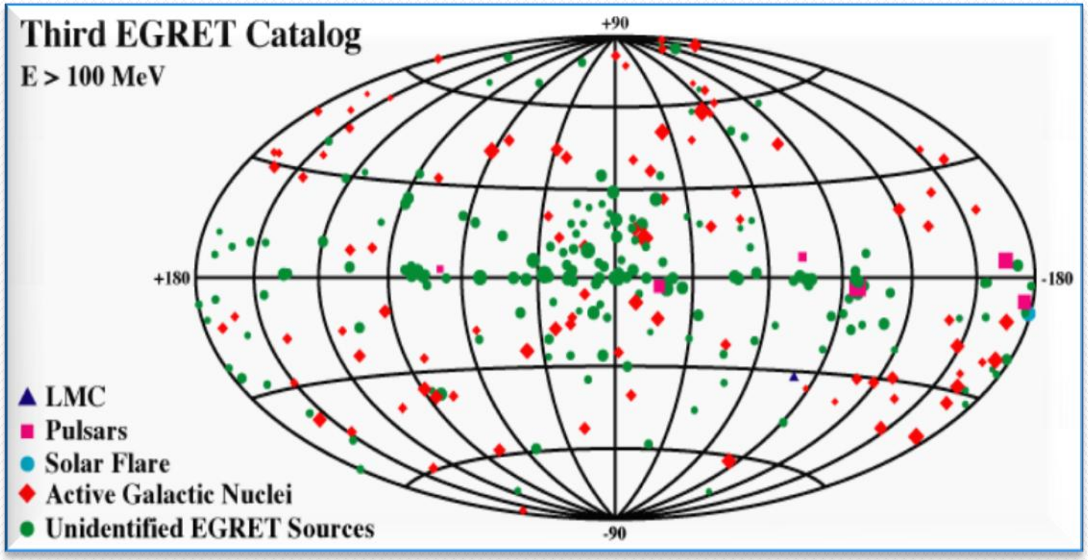


The EGRET heritage

Data from April 5, 1991 to October 3, 1995

3rd EGRET catalog :

- ❖ 271 sources above 100 MeV
  - ✓ 6 pulsars
  - ✓ 73 blazars (AGNs)
  - ✓ 170 unidentified



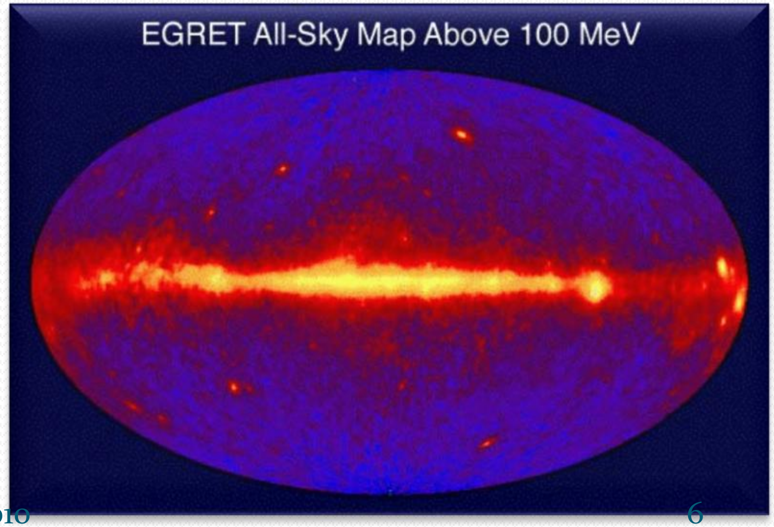
• But some limitations :

❖ Rather poor angular resolution (~6deg at 100 MeV) and limited effective area x field of view

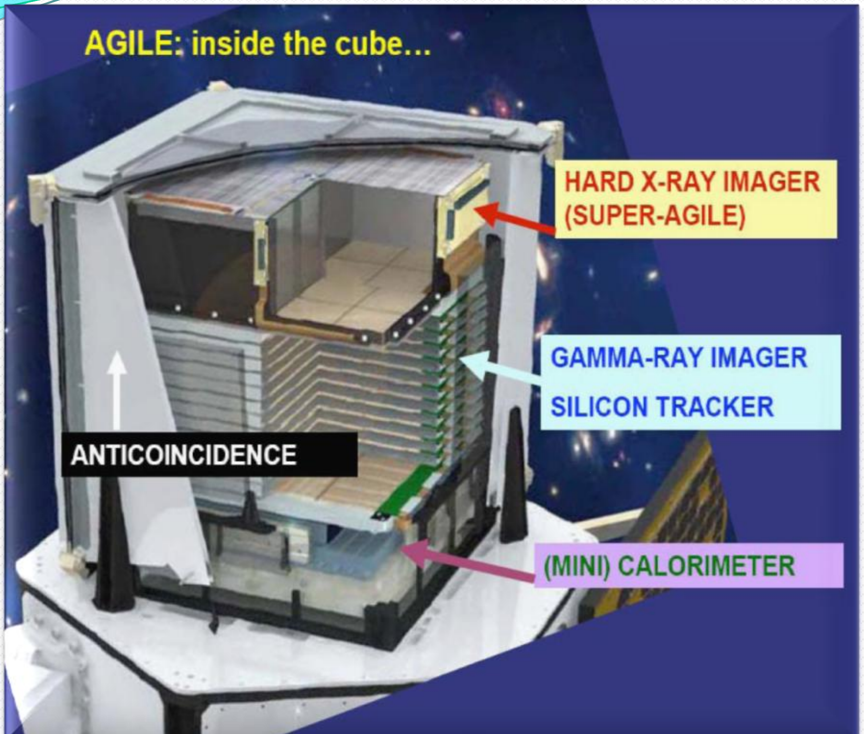
❖ Localization limitation -> identification limitation

❖ Not so many sources to perform population studies

❖ Limited sensitivity to variability



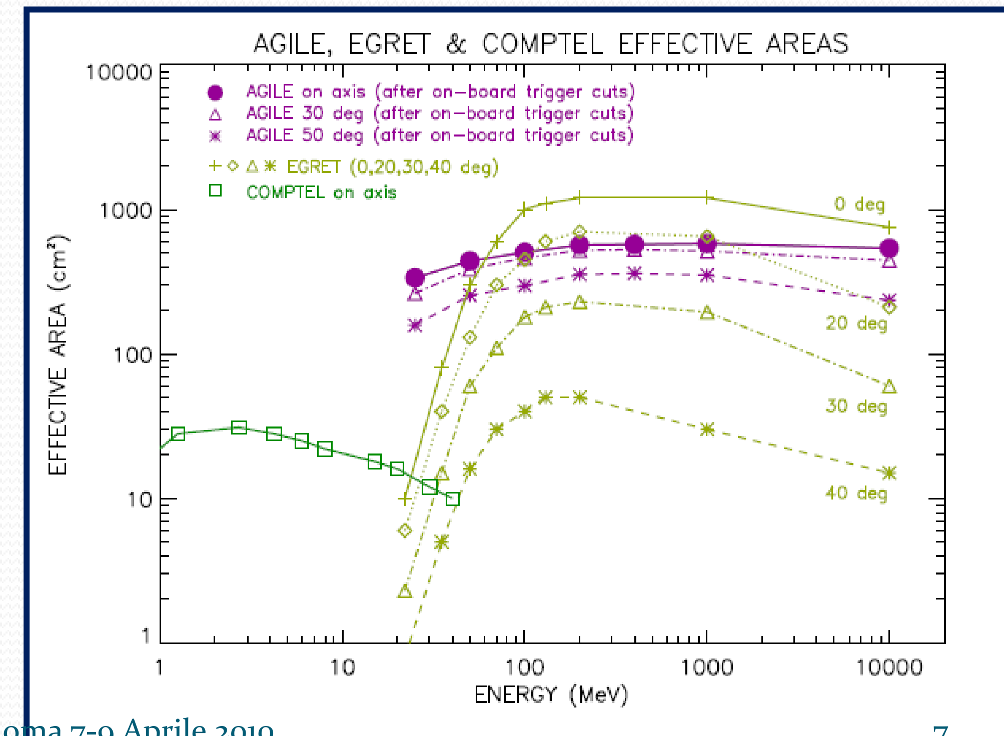
AGILE in orbit since April 2007



AGILE
Astrorivelatore Gamma a Immagini Leggero
combines for the first time
-a gamma-ray imager - GRID
(30 MeV- 30 GeV)

-with a hard X-ray imager - SuperAGILE
(18-60 keV)

Light instrument :
– 100 kg
– Tracker : 12 (x,y) planes
– Calorimeter : 1.5 X0



Effective area as a function of energy for several off-axis angle and comparison with EGRET performance

Fermi in orbit since June 2008

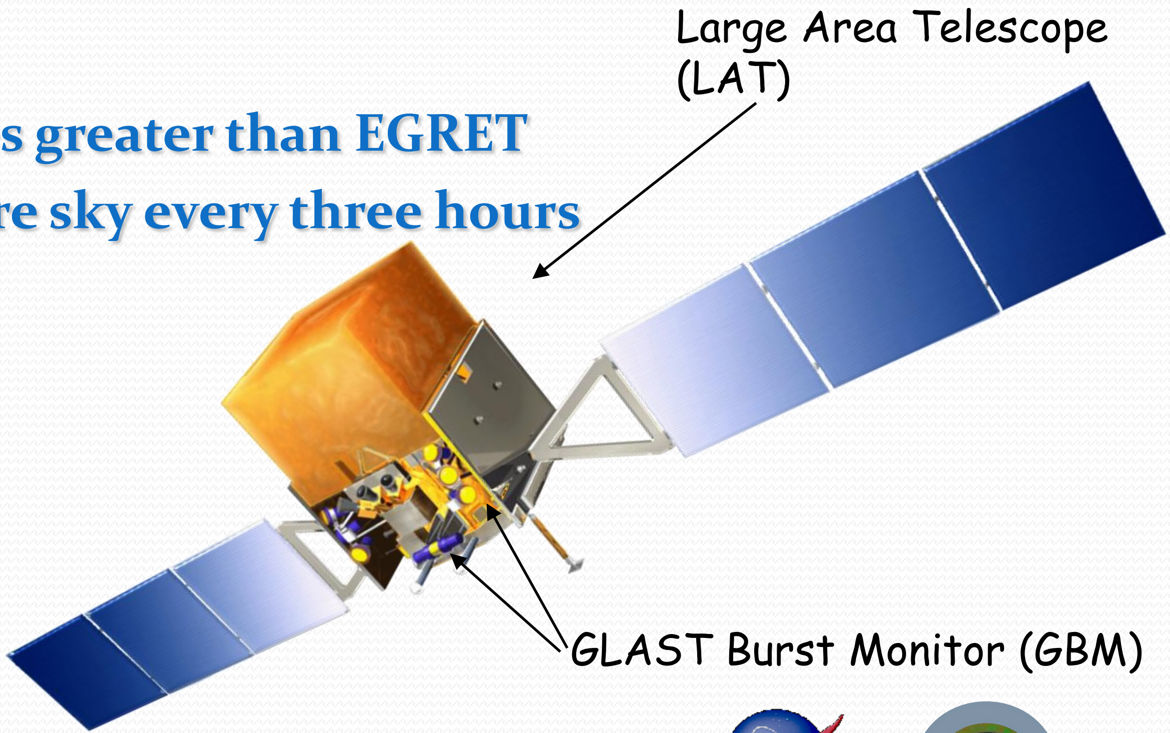
Fermi is an International Science Mission exploring the gamma –ray sky by means of its two main instruments:

- **GLAST Burst Monitor (GBM) : 8 keV to 40 MeV**
- **Large Area Telescope (LAT) : 20 MeV to > 300 GeV**

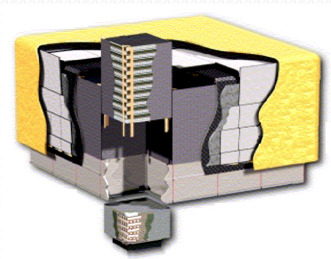
Huge energy range: including largely unexplored band for a total of >7 energy decades!

Strategy:

- **Sensitivity : >10 times greater than EGRET**
- **Survey mode ⇒ entire sky every three hours**

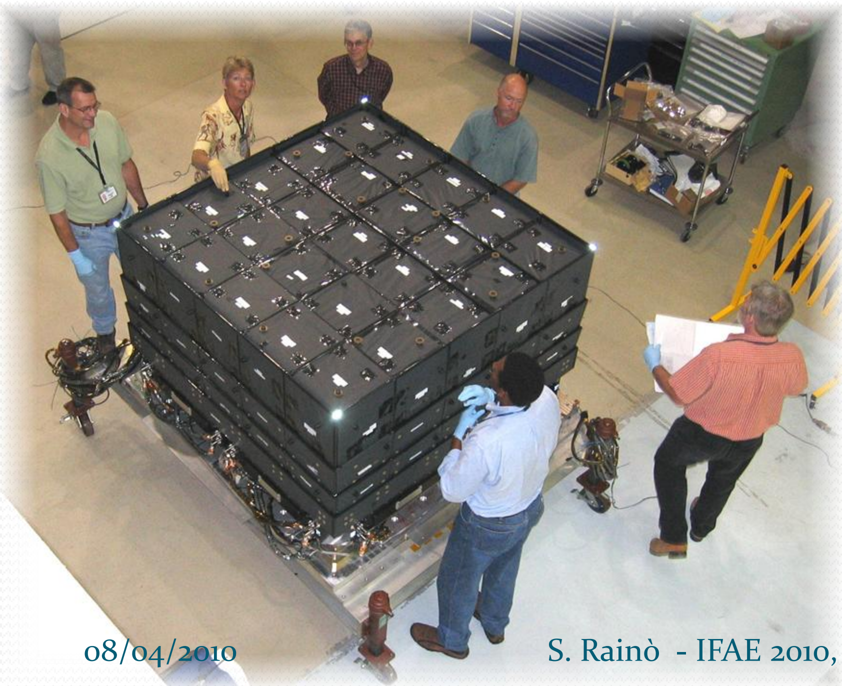


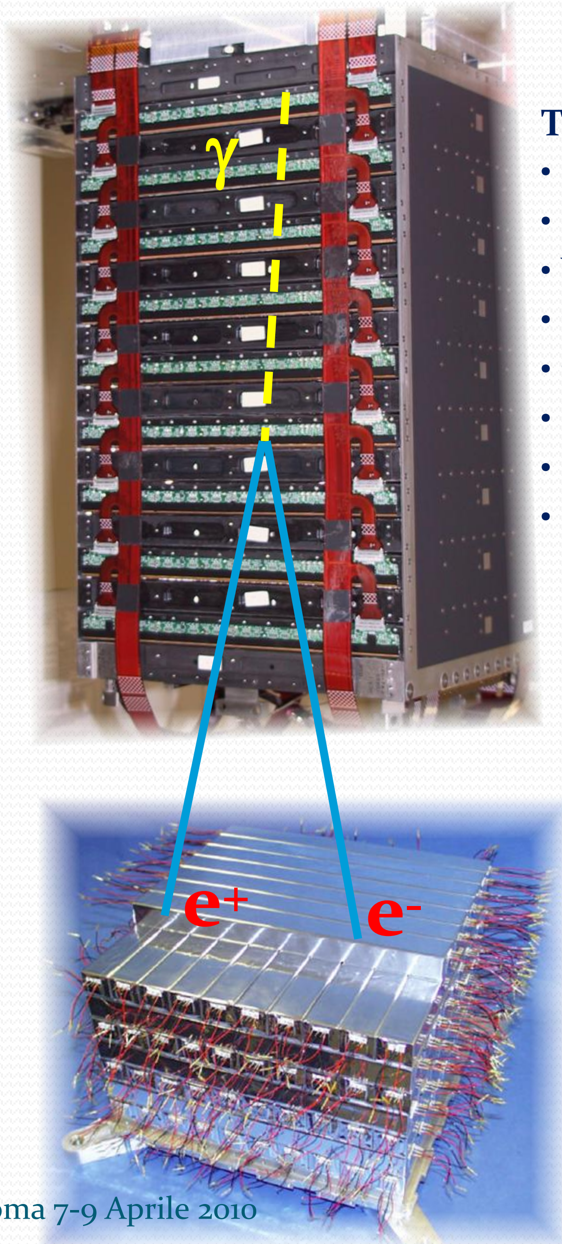
LAT: Large Area Telescope



LAT:
- modular - 4x4 array
- 3 tons – 650 watts

Anti-Coincidence (ACD):
- Segmented (89 tiles + 8 ribbons)
- Self-veto @ high energy limited
- **0.9997 detection efficiency**



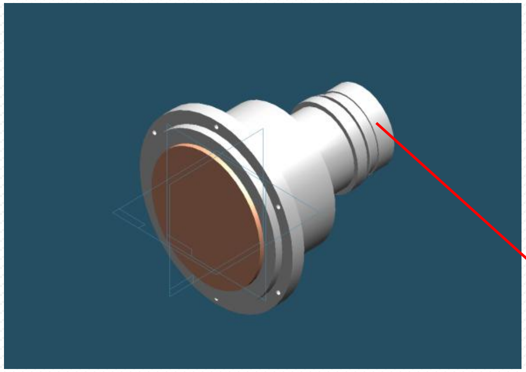


Tracker/Converter (TKR):
- Si-strip detectors
- ~80 m^2 of silicon (total)
- W conversion foils
- **1.5 Xo on-axis**
- 18XY planes
- **~10^6 digital elx chans**
- Highly granular
- High precision tracking

Calorimeter (CAL):
- 1536 CsI(Tl) crystals
- **8.6 Xo on-axis**
- large elx dynamic range (2MeV-60GeV per xtal)
- **Hodoscopic (8x12)**
- Shower profile recon
- leakage correction

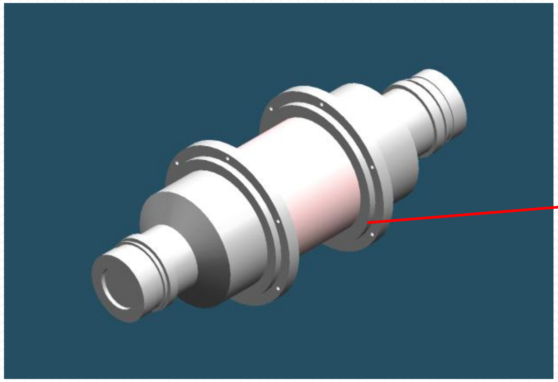
GBM: Gamma-ray Burst Monitor

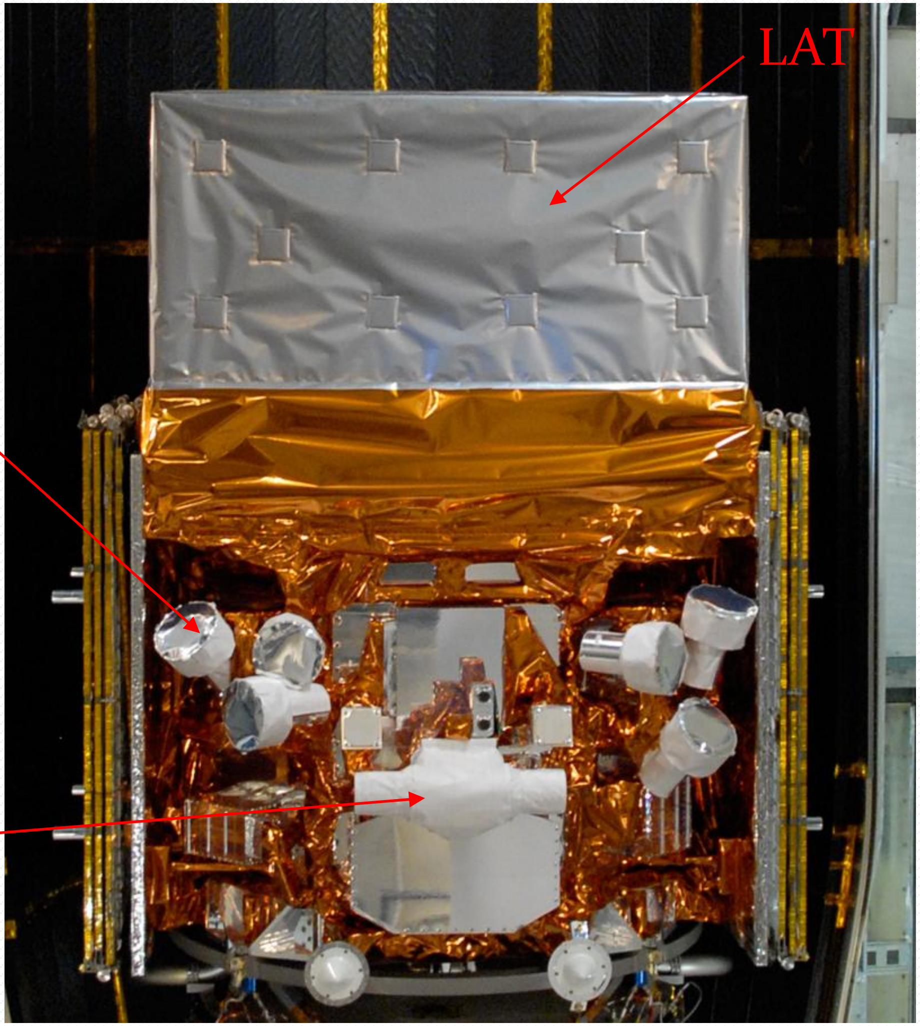
(12) Sodium Iodide (NaI) Scintillation Detectors



– spectral coverage: 8 keV – 1 MeV

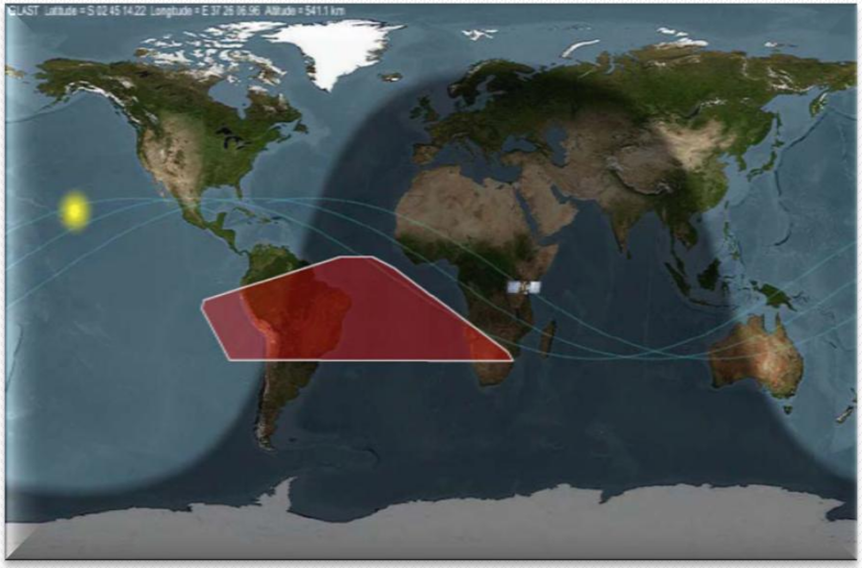
(2) Bismuth Germanate (BGO) Scintillation Detectors

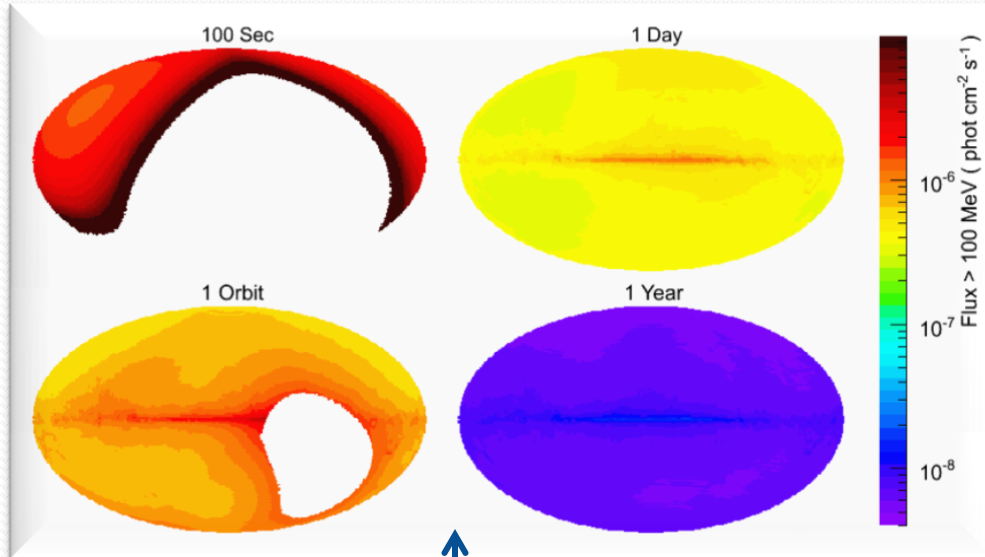


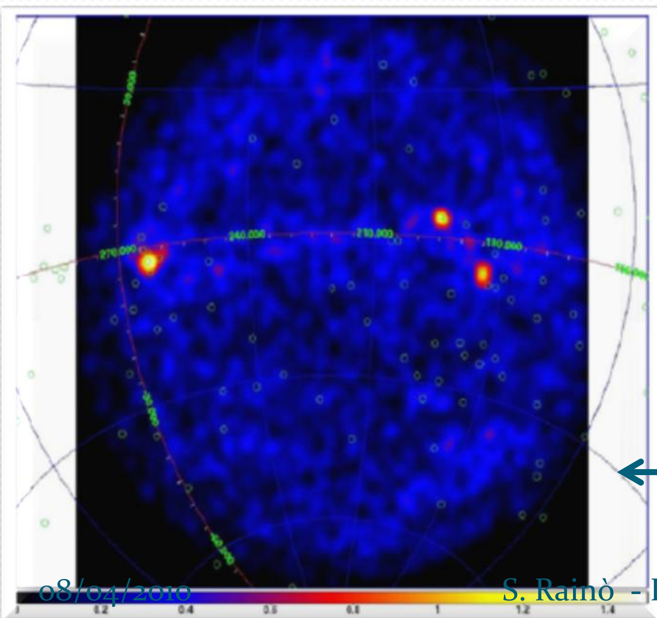


– spectral coverage: 150 keV – 40 MeV

AGILE and Fermi in space



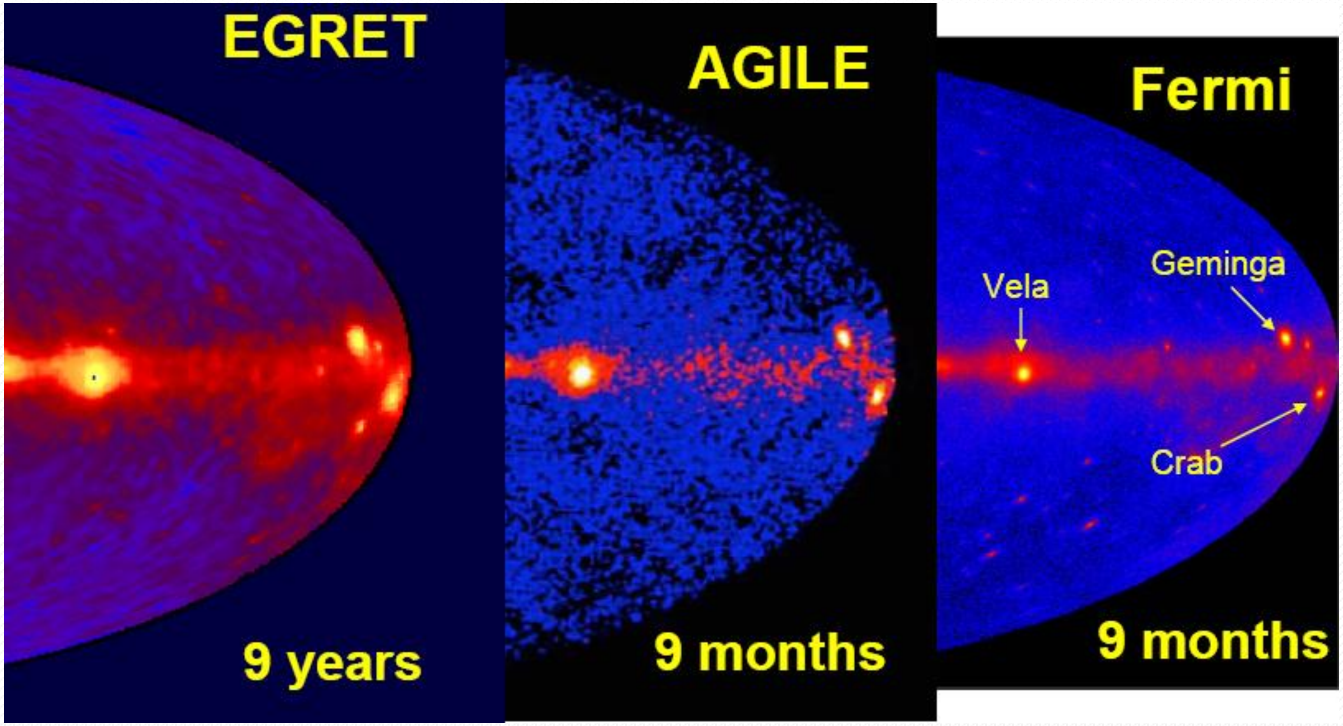




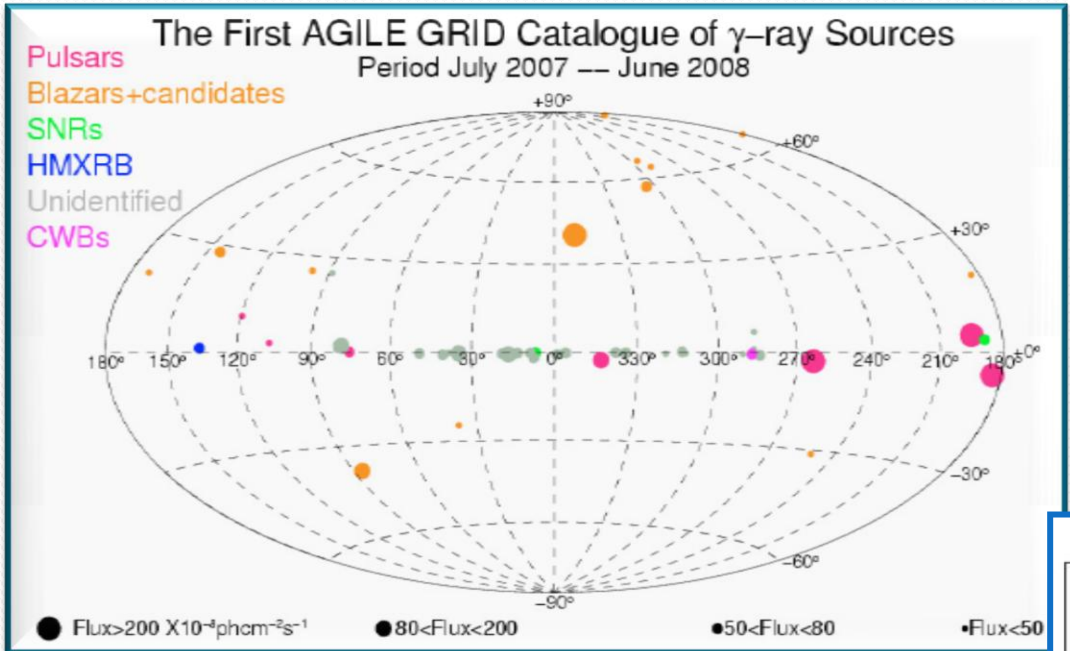
	AGILE	Fermi
Altitude	535 km, 2.5°	565 km 25.6 °
Period	1.5 h	1.5 h
Attitude	Pointing	Survey mode (each source is seen ~30 min every 3 hours)
Livetime	2+4 yr	5+5 yr

The gamma-ray sky above 100 MeV

	Ang Res (>100MeV)	Ang Res (>1 GeV)	Energy Range (GeV)	$A_{eff} \cdot \Omega$ ($cm^2 \cdot s$)	#γ-rays
EGRET	5.8°	0.5°	0.03 – 10	750	$1.4 \cdot 10^6$
AGILE	~4°	~0.15°	0.03 – 50	1500	$4 \cdot 10^6$/yr
Fermi	3.5°	0.1°	0.02 – 300	20000	$80 \cdot 10^6$/yr



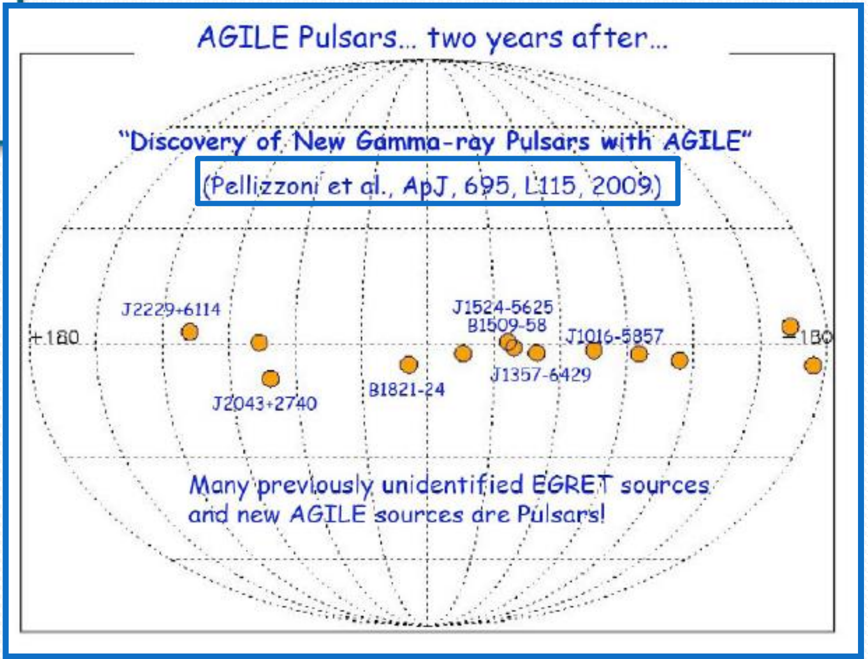
1 year observations of AGILE



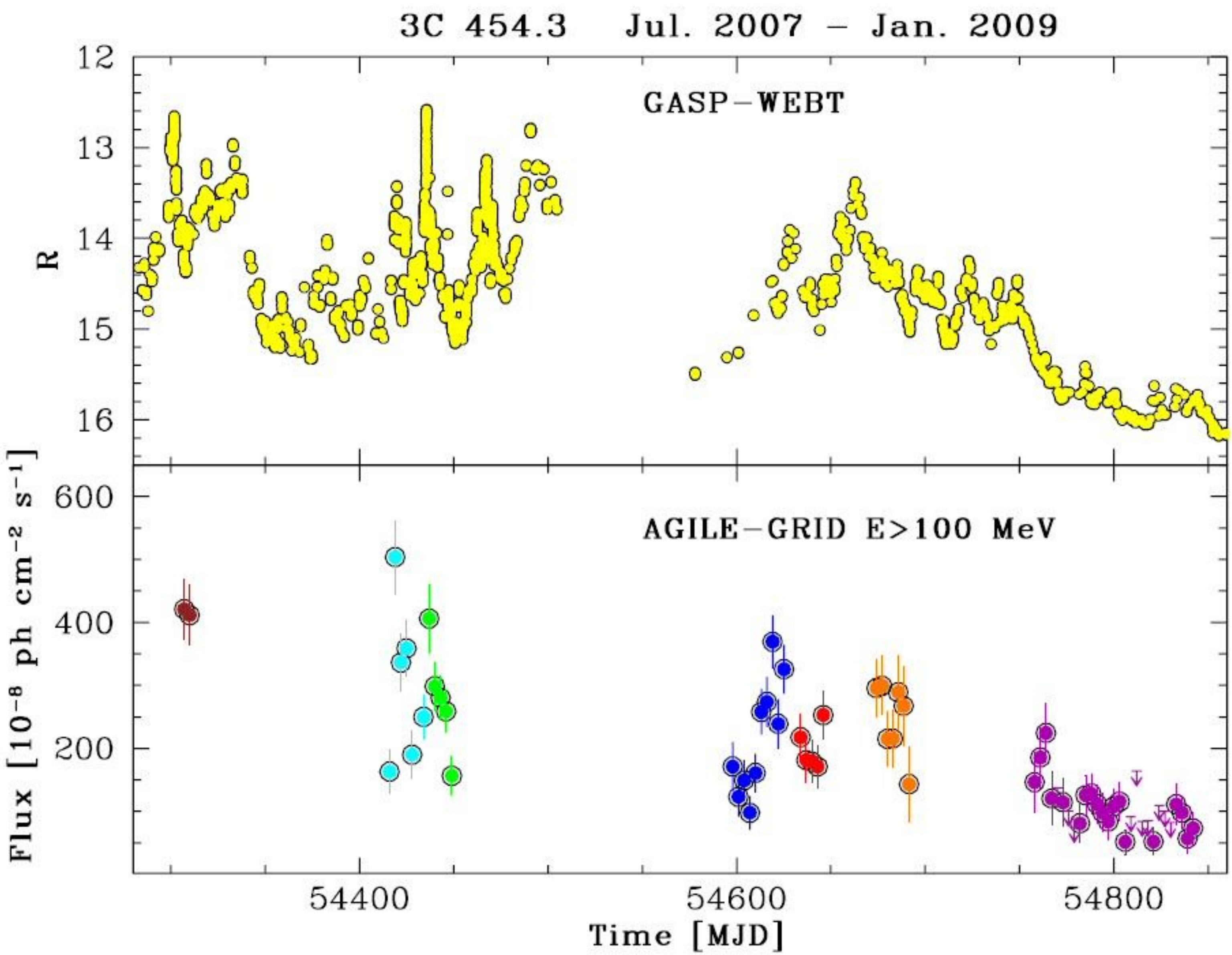
A&A 506, 1563–1574 (2009)

47 sources (>4σ)

- ✓13+7 confirmed or candidate pulsars
- ✓13 blazars
- ✓3 unassociated



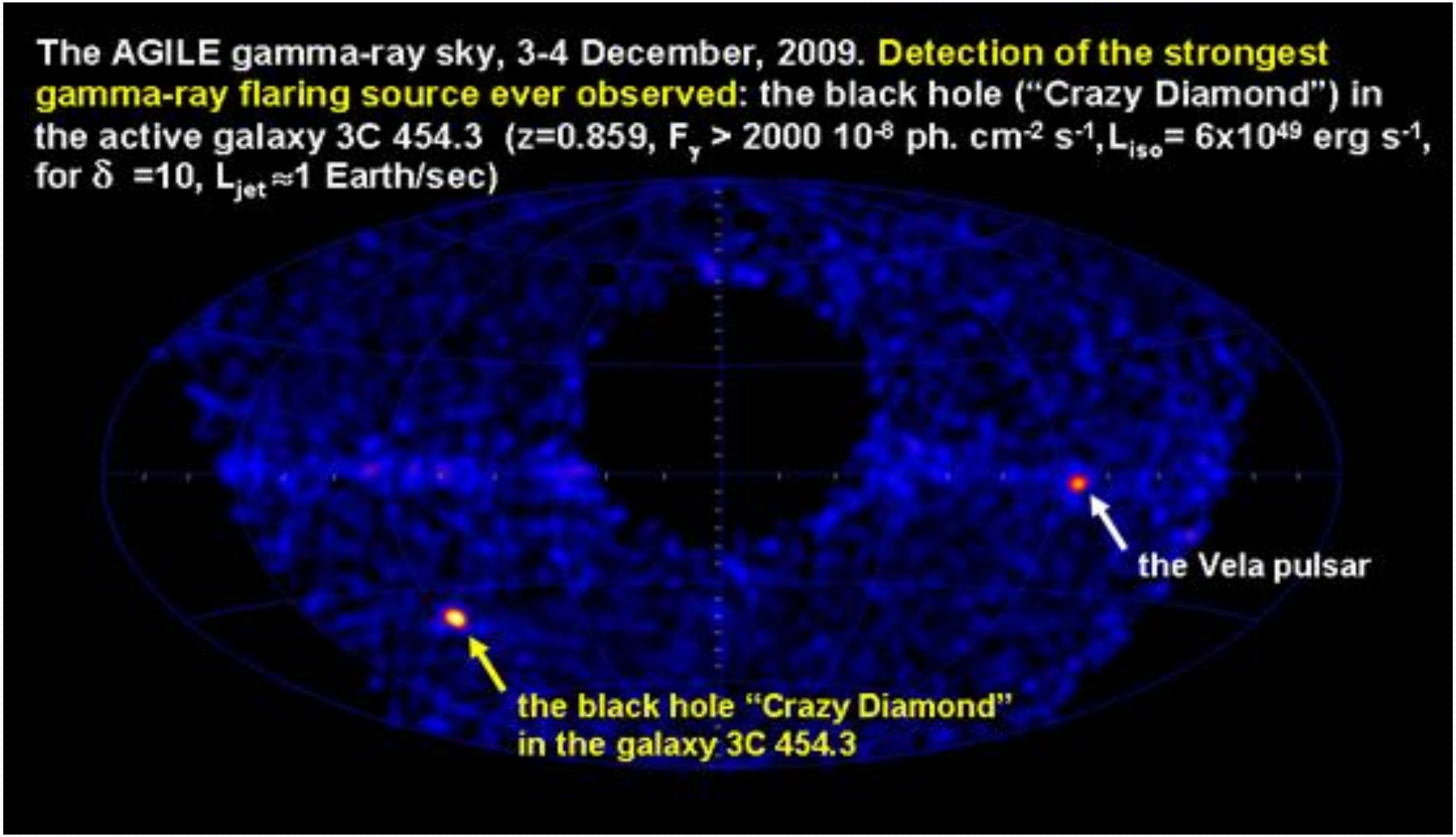
AGILE: 3C 454.3: the Crazy Diamond of 2007-2008 (Vercellone et al. 2007-2008-2009, Donnarumma et al. 2009)



optical

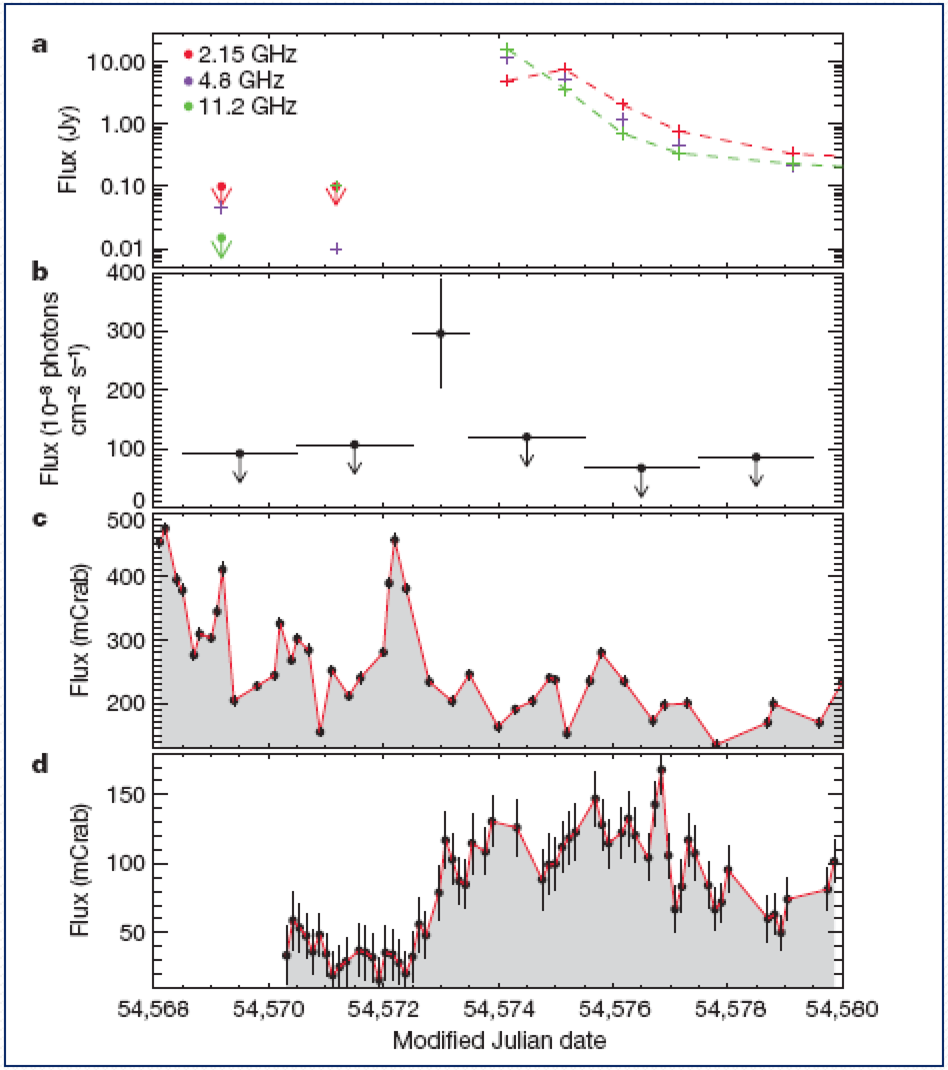
gamma

AGILE: Giant flare of 3C454.3 in Dec 2009



AGILE and Cygnus X-3

- **AGILE detects several gamma-ray flares from Cygnus X-3, and also weak persistent emission above 100 MeV**
- **very interesting correlations with radio and X-ray spectral state changes**
- **gamma-ray flares usually *before* radio flares**

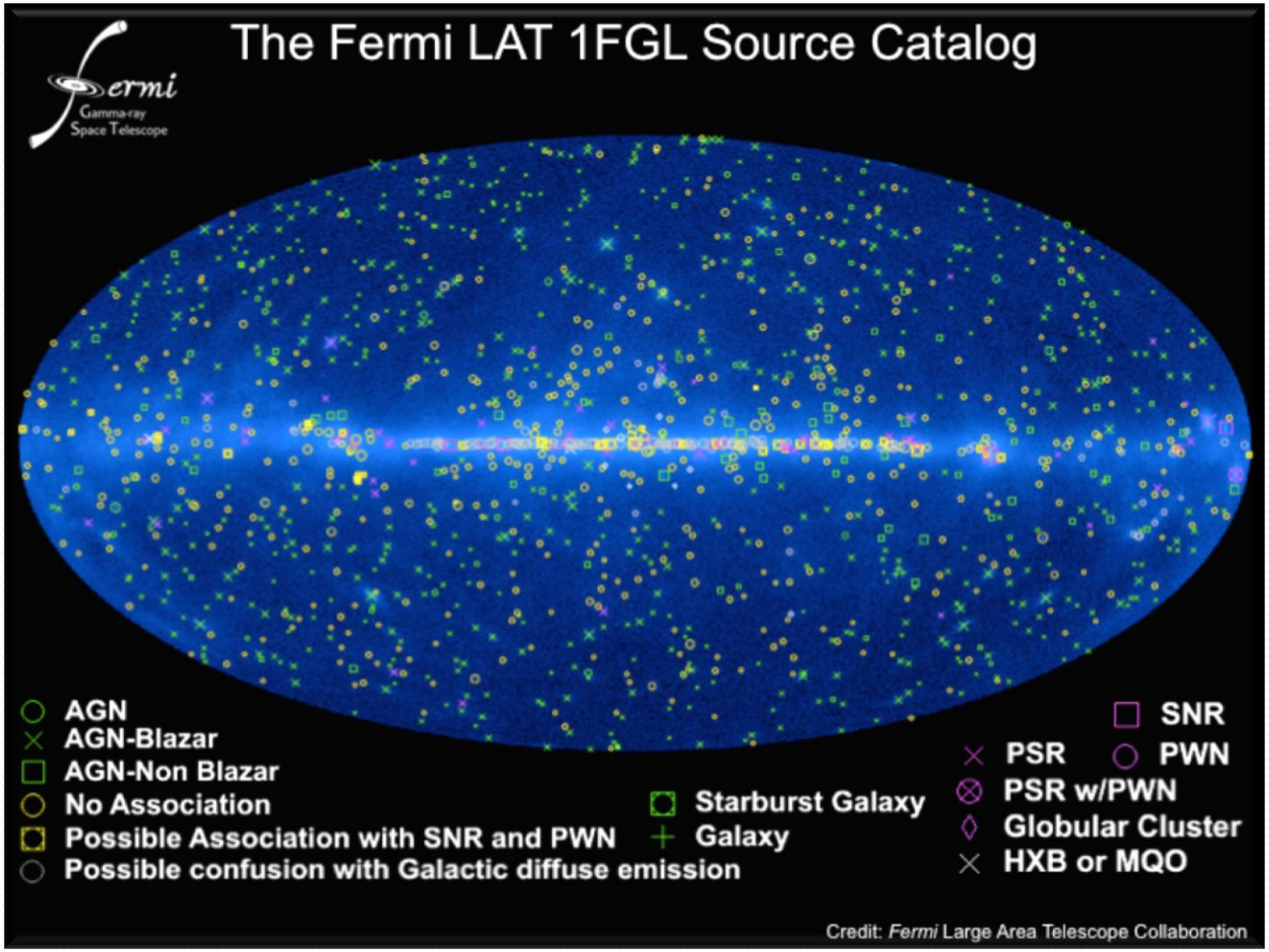


Nature, Nov. 22, 2009

1 year observations: Fermi

1451 sources (>4.1 σ)

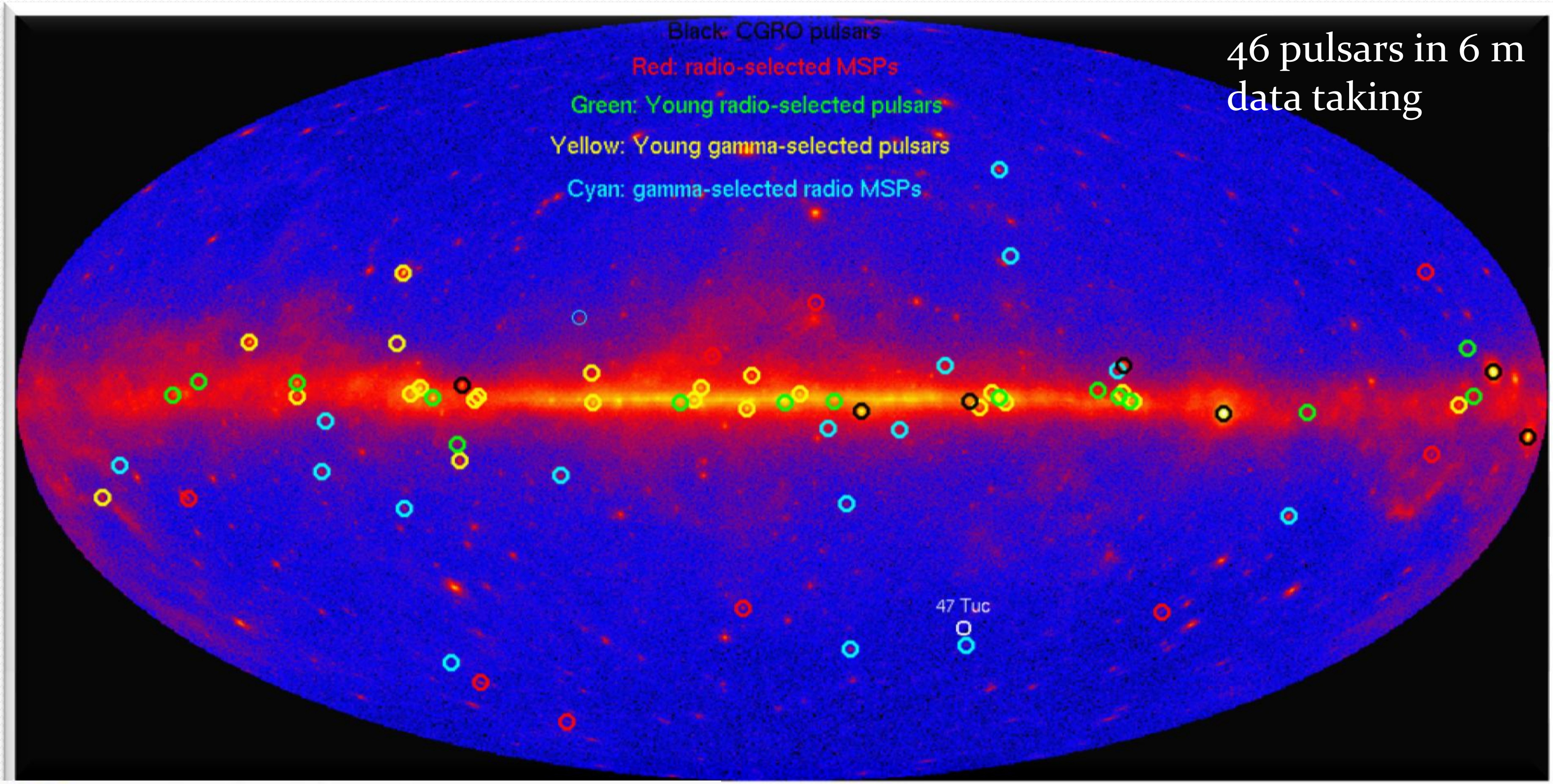
- ✓ **~600 blazars**
- ✓ **~ 60 pulsars**



arXiv: 1002.2280

Fermi observation of pulsars

Gamma ray observations of pulsars in 6 months
from the Fermi Gamma-ray Space Telescope



46 pulsars in 6 m
data taking

16 New pulsars discovered in a blind search
8 Millisecond radio pulsars
23 Young radio pulsars
6 Pulsars seen by Compton Observatory EGRET instrument

Gamma-ray Pulsar catalog:
A.Abdo et al. ApJS, 187, 460

Fermi observation of pulsars

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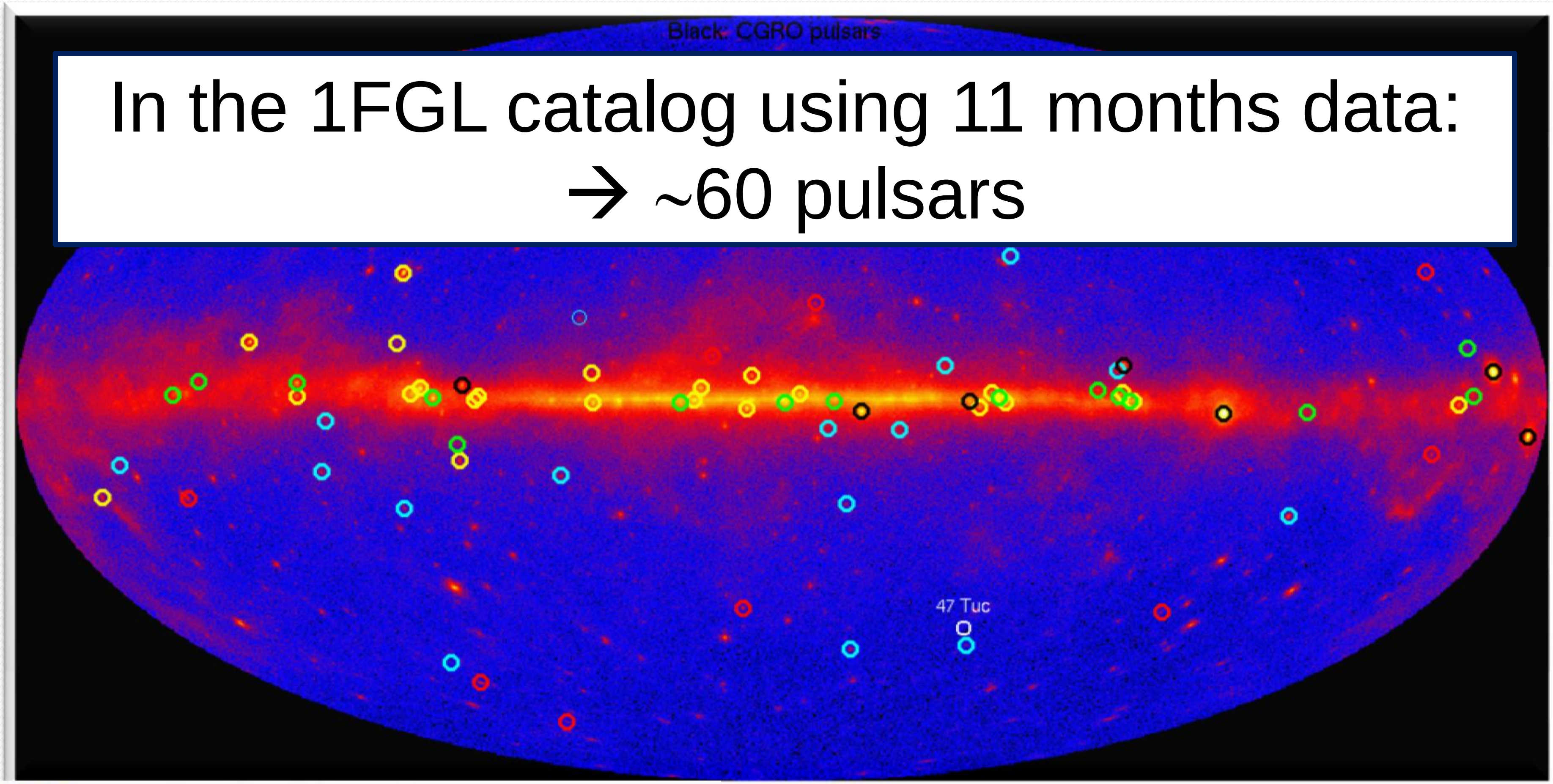

In the 1FGL catalog using 11 months data:
→ ~60 pulsars

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Gamma-ray Pulsar catalog:
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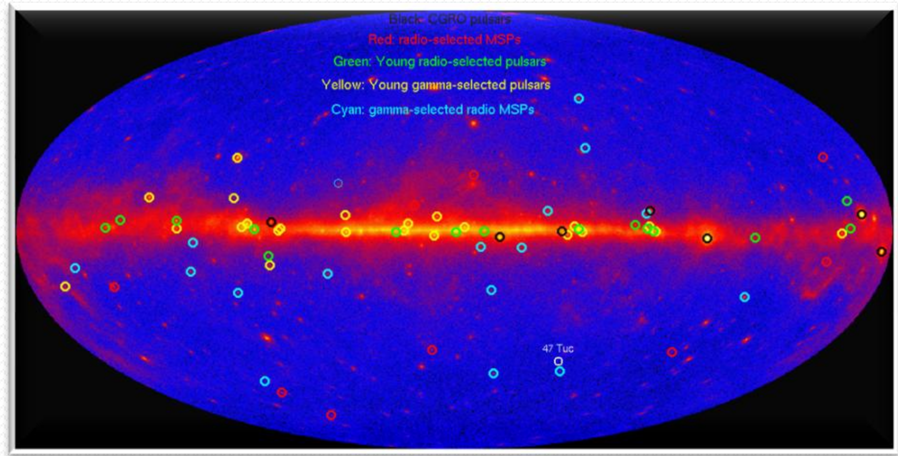
Fermi observation of pulsars



According to Science
Fermi pulsars are 2nd among the
Top 10 Scientific Breakthroughs of 2009

Gamma-ray Pulsar catalog:
A.Abdo et al. ApJS, 187, 460

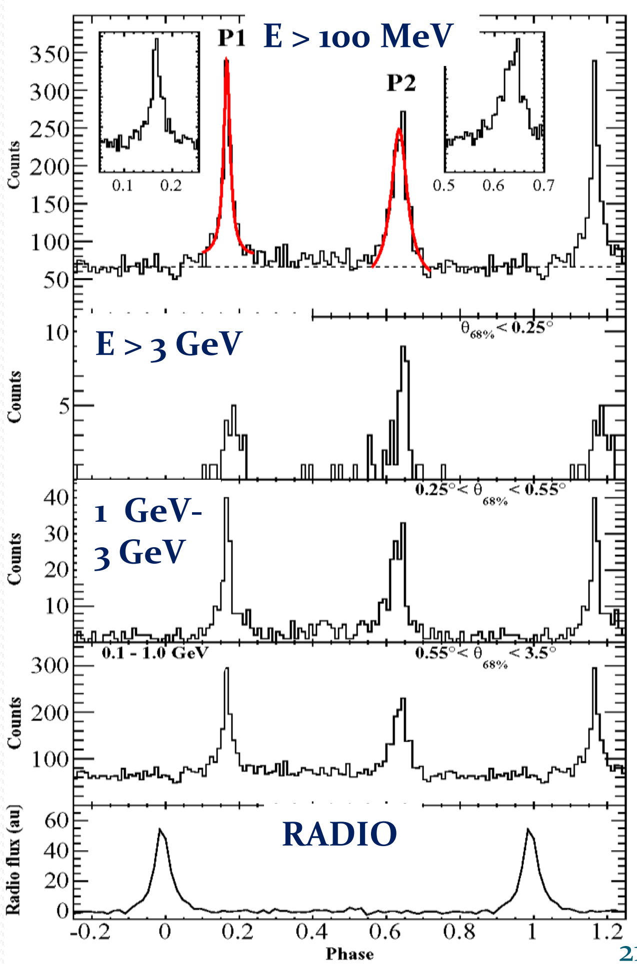
About LAT pulsars

- Generally (but not always), pulse profiles have 2 peaks, separated by ≥ 0.2 of rotational phase.
- Generally (but not always), gamma peak offset from radio.

Pulsed gamma-rays from PSR J2021+3651 with the Fermi Large Area Telescope
Abdo et al. ApJ700, 1059 (2009)

Peak separation = 0.468 ± 0.002

Radio lag = 0.162 ± 0.004



About LAT pulsars

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- Energy spectra well described by a power-law with exponential cut-offs, with cut-off energy at ~1 to ~5 GeV.

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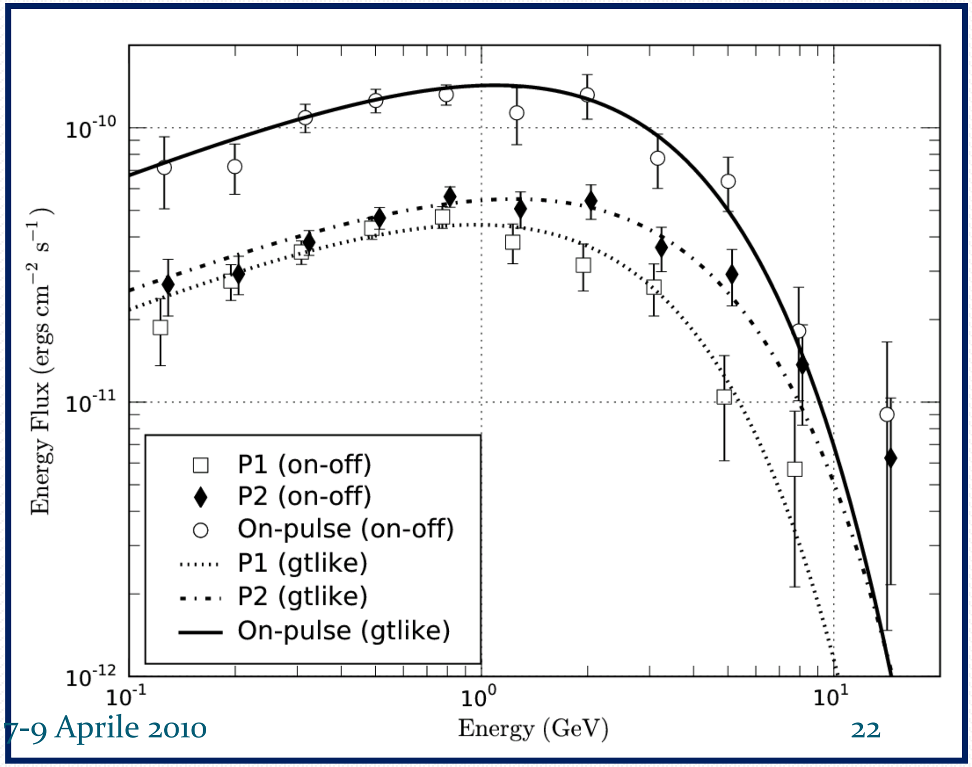

About LAT pulsars

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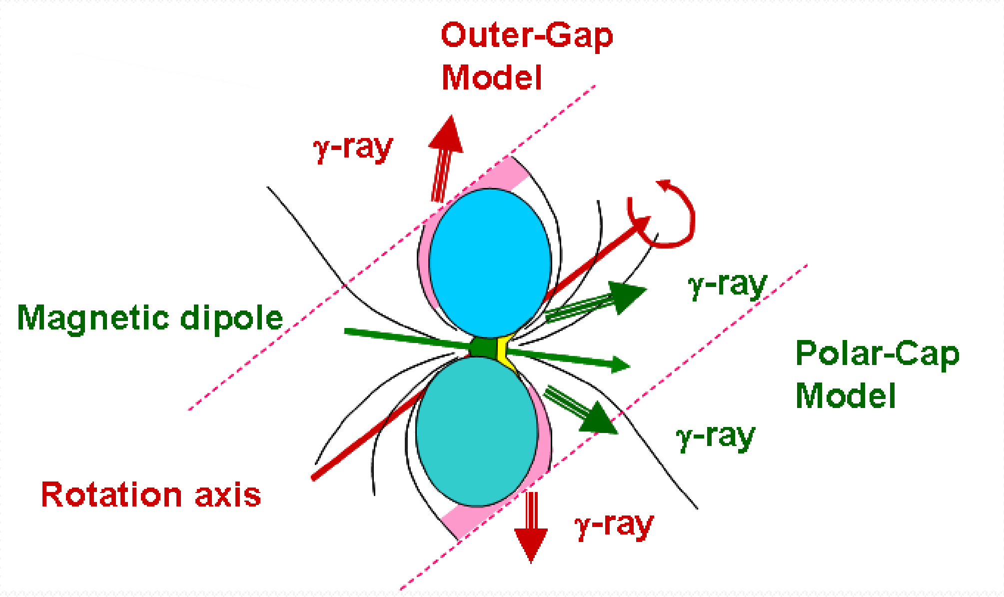
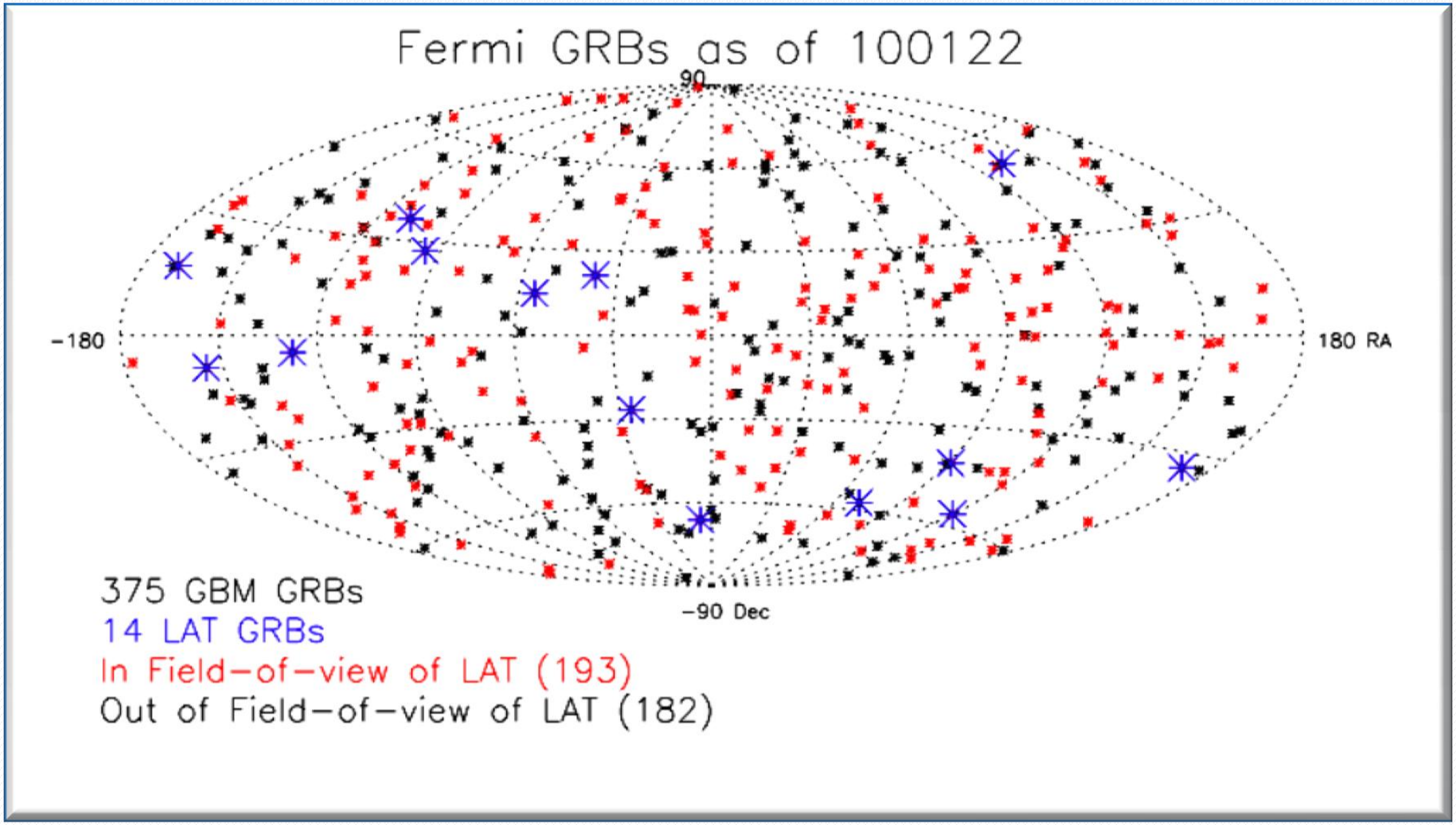
- Generally (but not always), gamma peak offset from radio.
- Energy spectra well described by a power-law with exponential cut-offs, with cut-off energy at ~1 to ~5GeV.
- Favors outer magnetospheric emission.

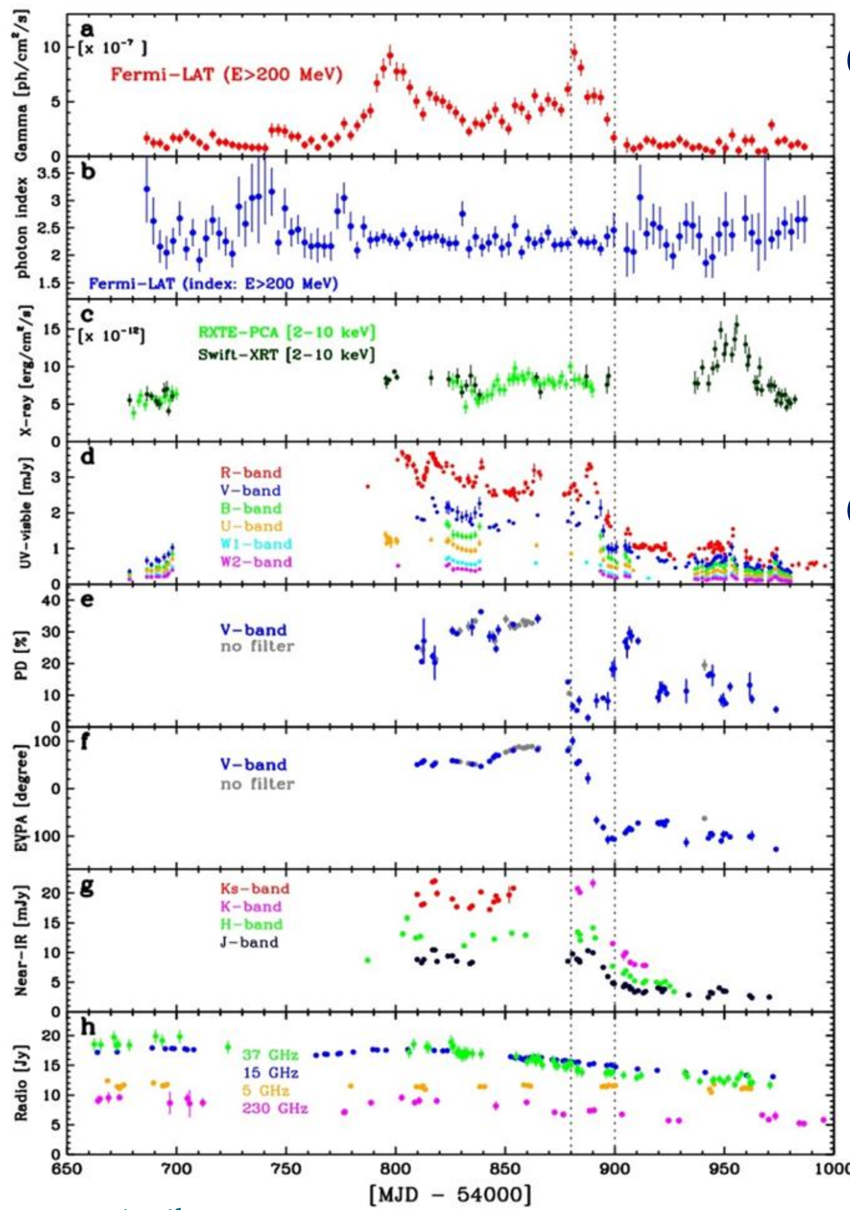


γ -ray Bursts sky map with Fermi



Multi-Wavelength Campaign on 3C 279

- **Bright FSRQ, z=0.536**
- **~300 d intense campaign**
- **Coincidence of γ-ray flare and change in optical polarization (KANATA)**
- **Indicates**
  - **Co-spatiality of γ-ray and optical emission**
  - **Non-axisymmetric structure of the emission zone**
  - **Curved trajectory along the jet**



Gamma

X-ray

Optical

IR

Radio

Abdo et al. 2010 Nature (18 Feb 2010)

High energy electron spectrum

PRL **102,** 181101 (2009)

Selected for a Viewpoint in *Physics*

PHYSICAL REVIEW LETTERS

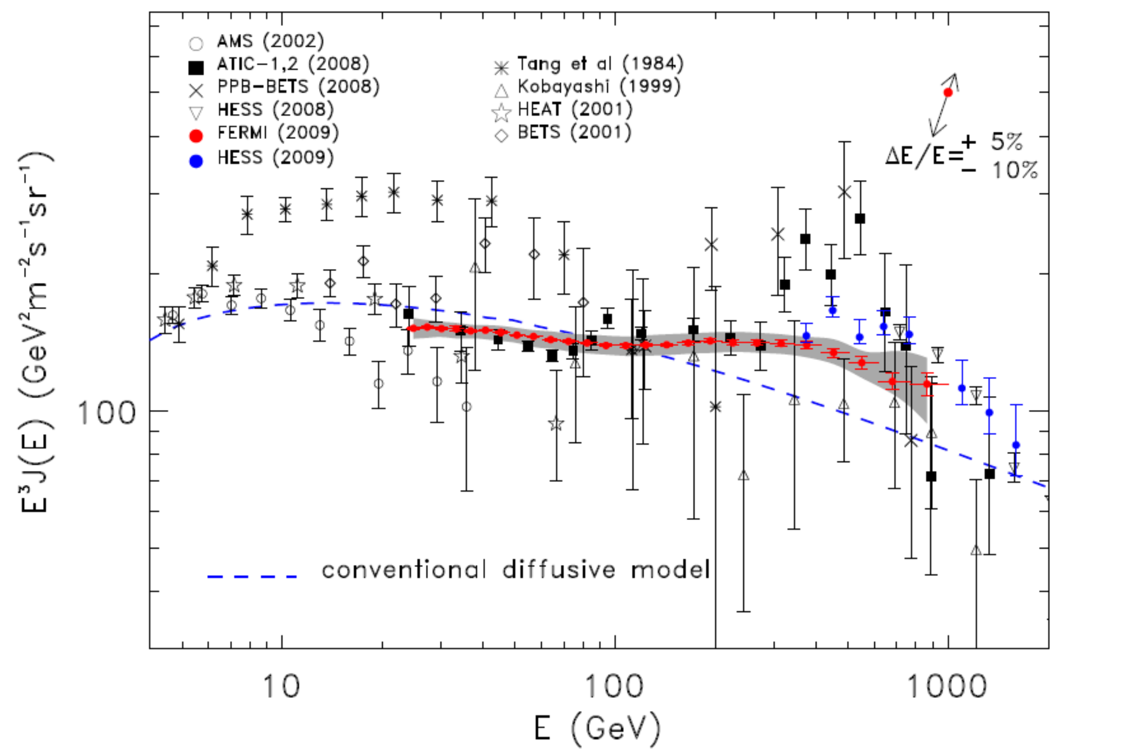
week ending 8 MAY 2009

Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

Total statistics collected for 6 months of Fermi LAT observations:

- **$4 \cdot 10^6$ electrons >20 GeV**
- **> 400 electrons in last energy bin (770-1000 GeV)**

Measurement 20 GeV – 1 TeV
– hard (~ E^{-3})
– flat (no spectral features)



Phys.Rev.Lett.102:181 101,2009. – citations 271

Cited across a broad range - cosmic-ray, astronomy, particle physics (D0, BABAR)

Interpretation of Fermi-LAT results

- Anomalous features in the electron spectrum are excluded (disprove ATIC claim of strong spectral feature)

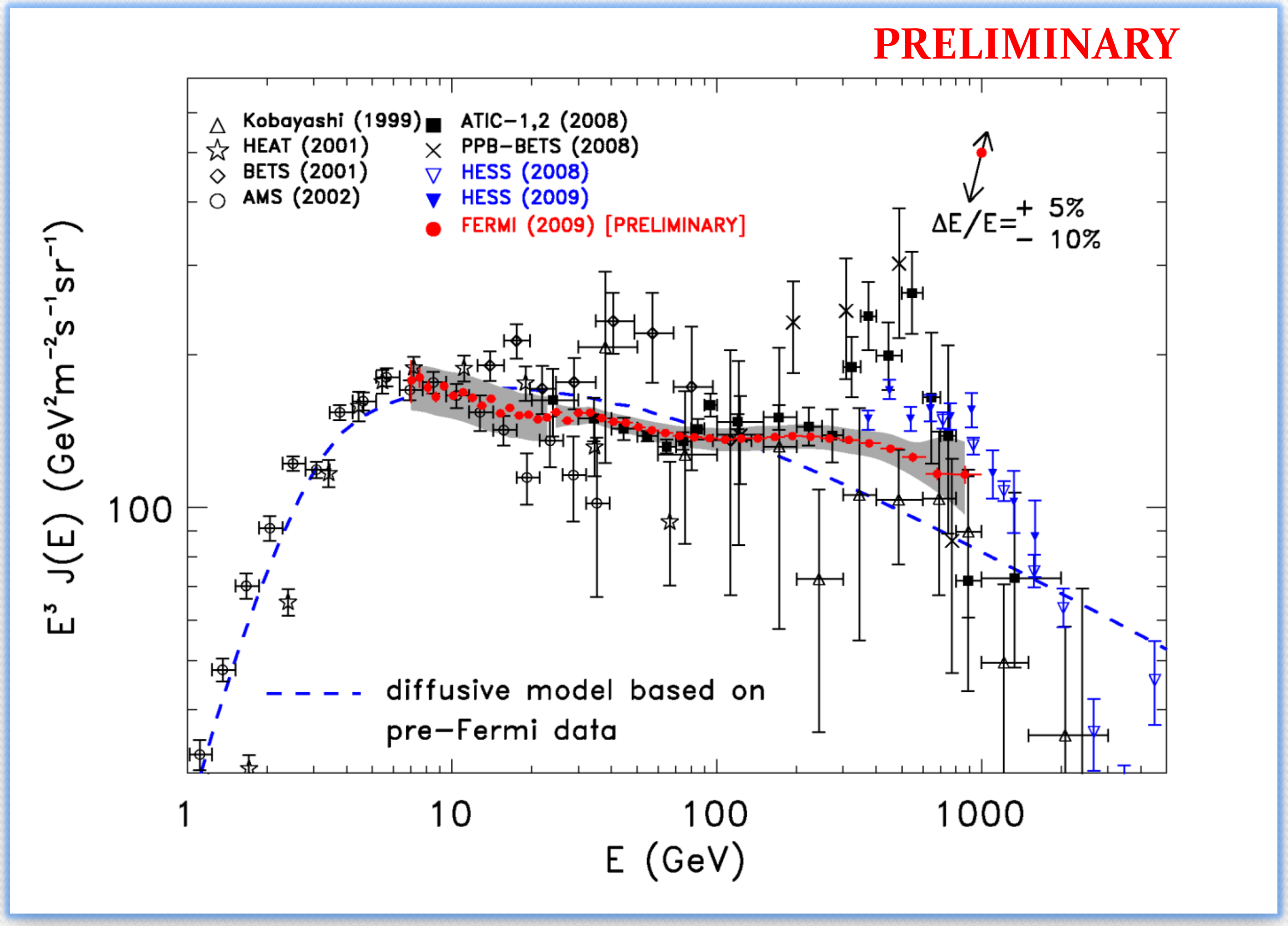
- The electron spectrum is harder than the one expected from conventional diffusive models (GALPROP, based on pre-Fermi data)

- Possible interpretations:
  - harder electron spectrum at the source
    - GALPROP assumes a source electron spectrum with spectral index γ=2.54 above 4 GeV and a diffusive coefficient ~$E^{1/3}$
  - presence of a local source of high energy electrons and positrons
    - Nearby Pulsar or DM annihilation
    - this interpretation allows also to explain the increase in the e+/(e++e-) ratio observed by PAMELA above 10GeV (see next slides)

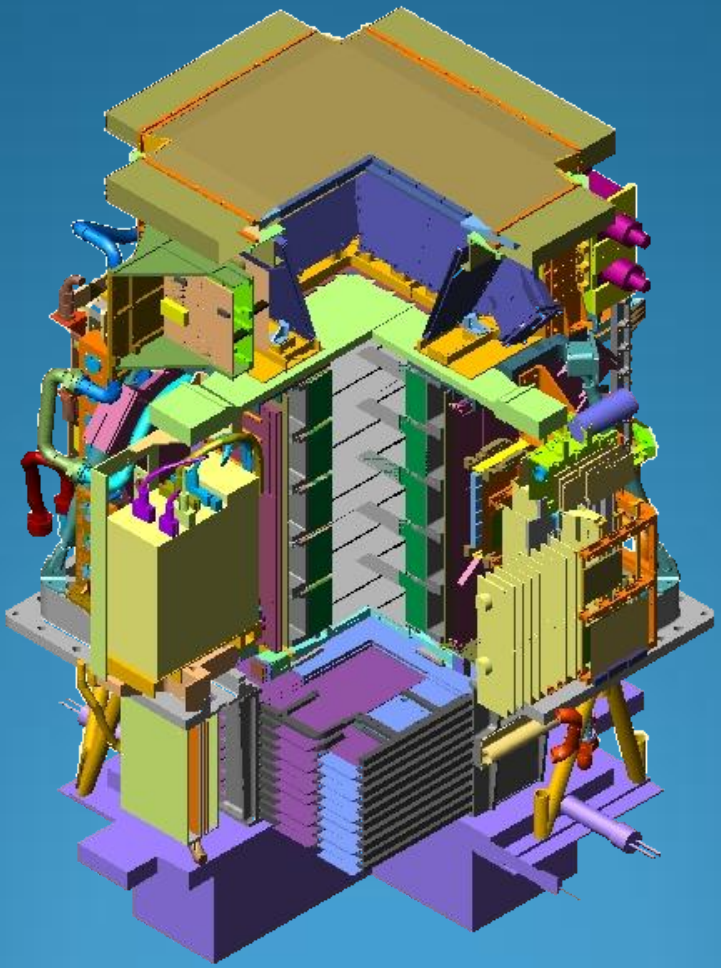
- Potentials for:
  - Anisotropies, thanks to good angular resolution –--> on-going effort
  - Energy extension:
    - Low energy: orbit-dependent
    - High energy (> 1 TeV) to find TeV spectral cut-off : requires specific new CAL recon

Extended electron spectrum

One year statistics: 8 ·10⁶ events
Extended Energy Range: 7 GeV – 1 TeV

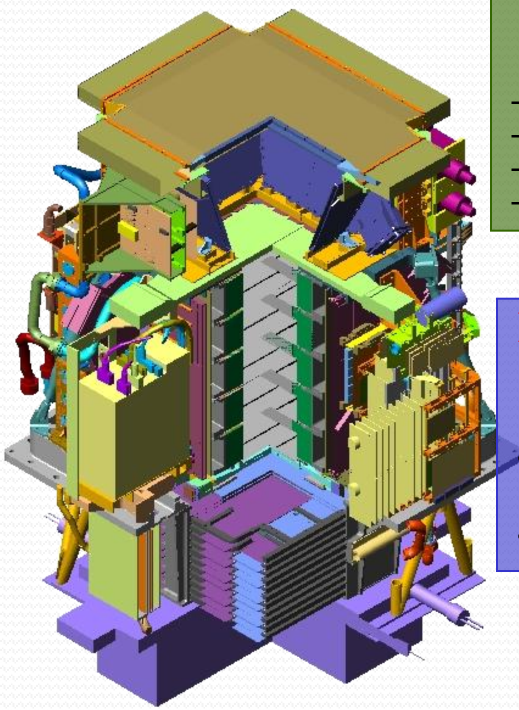


Pamela



PAMELA detectors

Main requirements → high-sensitivity antiparticle identification and precise momentum measure



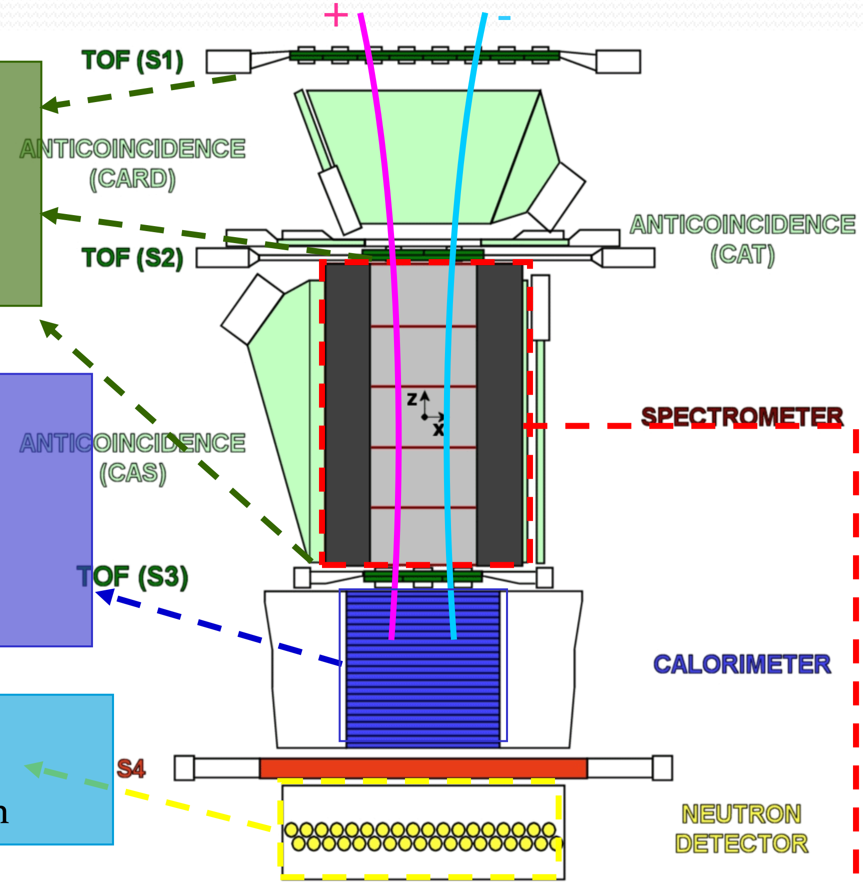
Time-Of-Flight
plastic scintillators + PMT

-Trigger;
-Albedo rejection;
-Mass identification up to 1 GeV;
-Charge identification from dE/dX.

Electromagnetic calorimeter
W/Si sampling
($16.3\ X_0$, $0.6\lambda_I$)

- Discrimination e^+/ p, pbar/e^- (shower topology)
- Direct E measurement for e^-

Neutron detector &
Shower-tail catcher (S4):
-High-energy e/h discrimination



GF: 21.5 cm² sr	
Mass:	470 kg
Size:	130x70x70 cm³
Power Budget:	360W

Credit: F.Cafagna

Spectrometer
microstrip silicon tracking system + permanent magnet

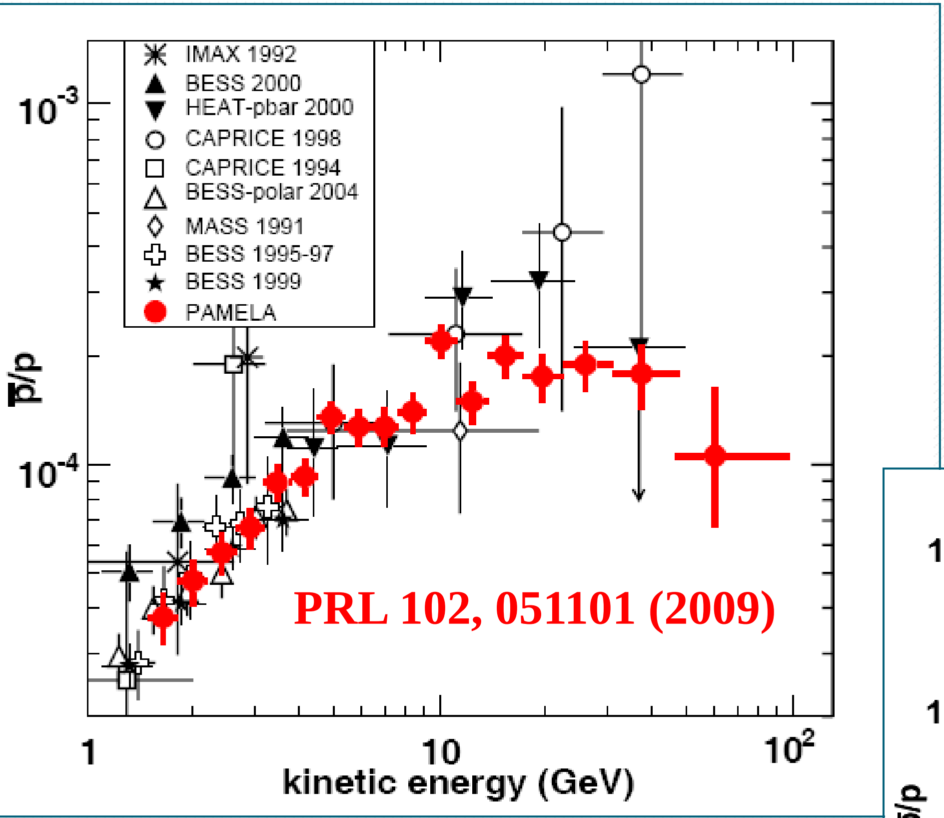
•Magnetic rigidity (R = pc/Ze)
•Charge sign
•Charge value from dE/dx

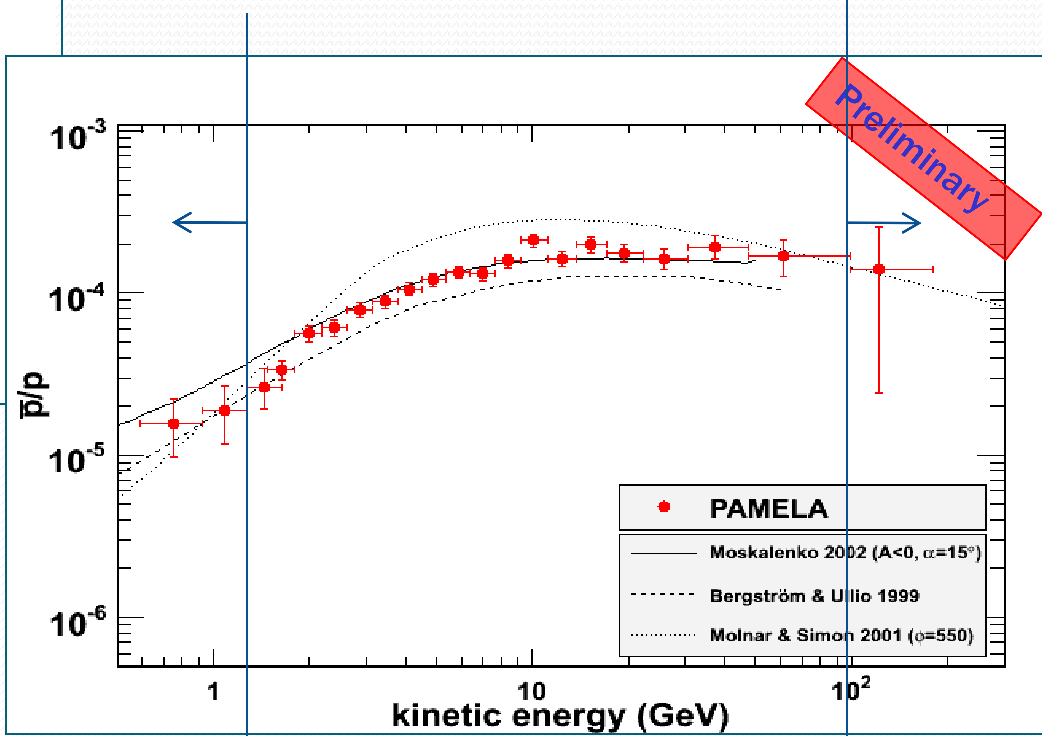
Design Performance

• **Antiprotons**	**80 MeV - 150 GeV**
• **Positrons**	**50 MeV – 270 GeV**
• **Electrons**	**up to 400 GeV**
• **Protons**	**up to 700 GeV**
• **Electrons+positrons**	**up to 2 TeV**
• **Light Nuclei (He/Be/C)**	**up to 200 GeV/n**
• **AntiNuclei search**	**sensitivity of 3×10^{-8} in $\overline{He}$/He**

→ Simultaneous measurement of many cosmic-ray species
→ New energy range
→ Unprecedented statistics

Recent results: antiproton-proton ratio

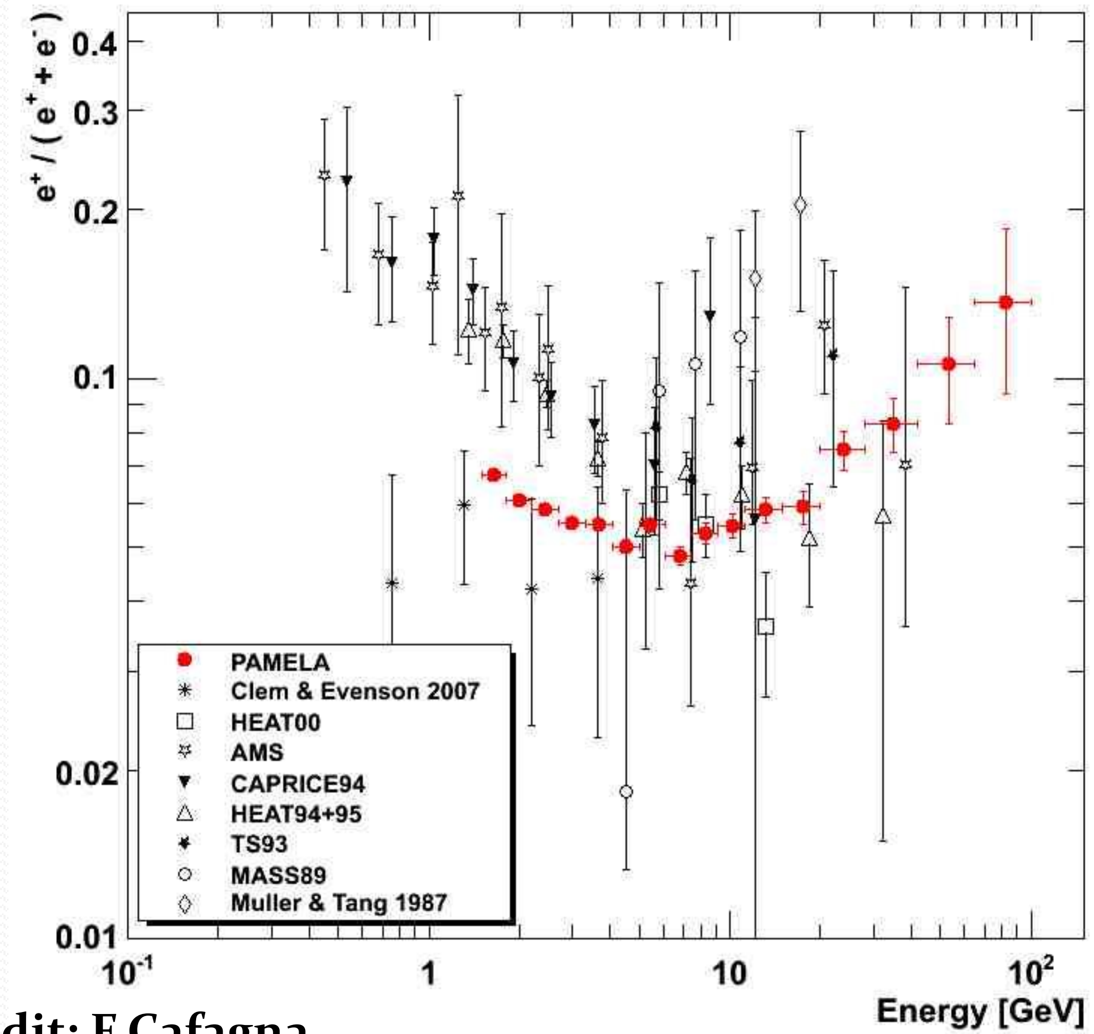




Credit: F.Cafagna

Positron to All Electron Fraction

Nature 458, 697, 2009



The positron fraction

$$\frac{\Phi(e^+)}{\Phi(e^+)+\Phi(e^-)}$$

increases above 10 GeV

Consistent with positrons originating from an additional “primary” source:

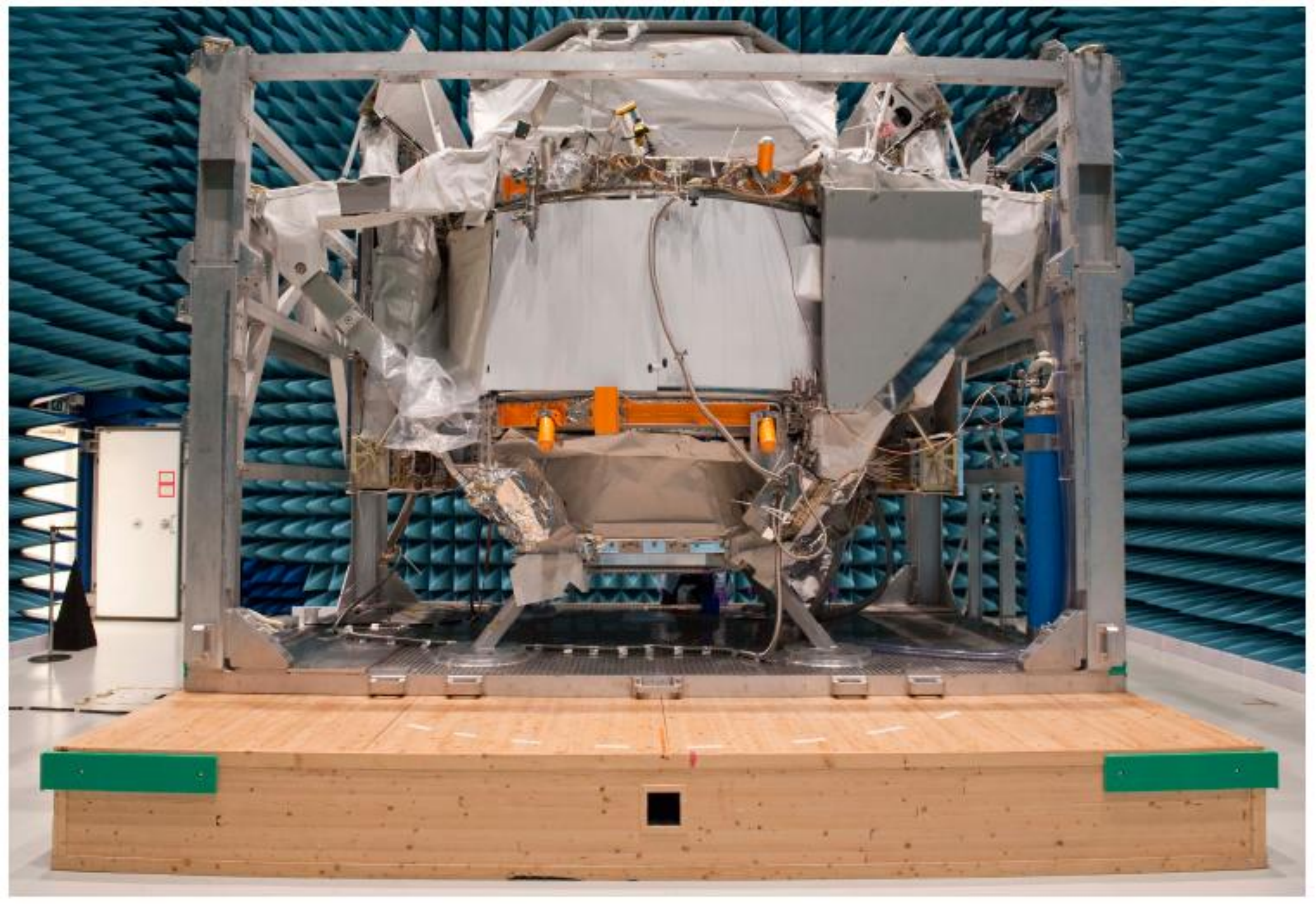
-Nearby Pulsars

-Microquasars

-Dark matter annihilation

Credit: F.Cafagna

AMS experiment



What is aiming AMS ?

- ✓ AMS is a large acceptance ($\sim$ 0.5 m^2.sr) spectrometer designed to operate in the International Space Station (ISS) for a long duration stay (3 years)

- ✓ Good particle identification power (including photons)
- ✓ Able to measure cosmic spectra from 500 MeV to few TeV
- ✓ Charge identification up to Iron (Z=26) and light isotopic separation
- ✓ Search for antimatter and darkmatter with unprecedent sensitivity

Credit: D.Grandi

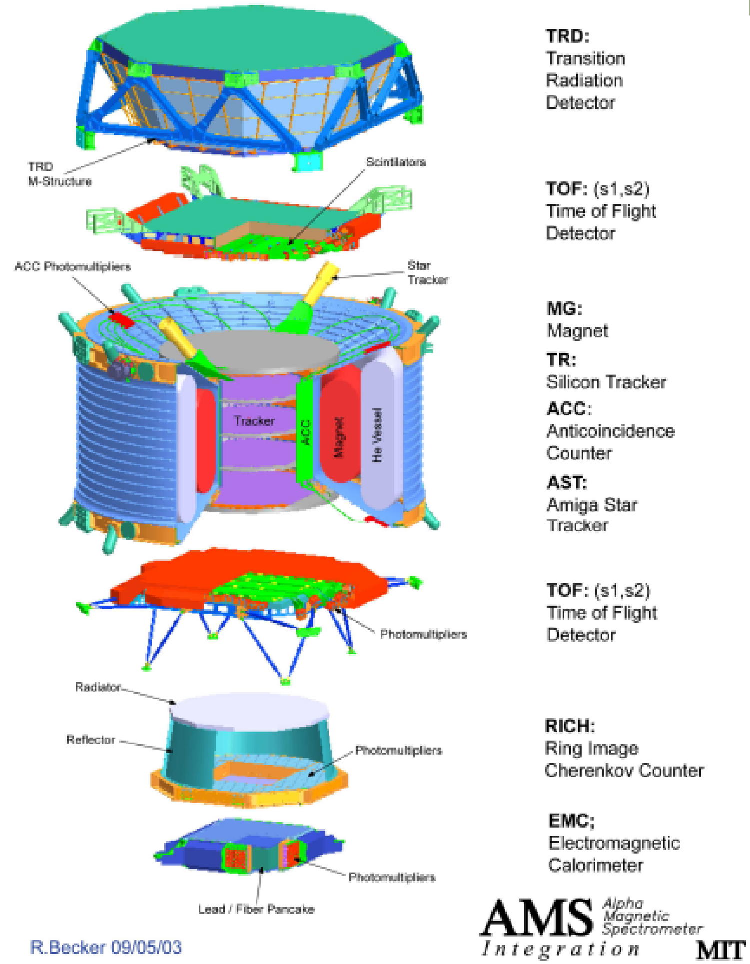
From AMS1 to AMS2

Improved capabilities

- ✓ larger acceptance
  $\sim 0.5\ m^2.sr$
- ✓ Superconducting magnet
  a magnetic field ~ 8 times larger
- ✓ larger silicon Tracker
  8 double-sided layers
  $\sim 6.5\ m^2$ silicon surface
- ✓ a momentum resolution improved
  a factor ~ 10

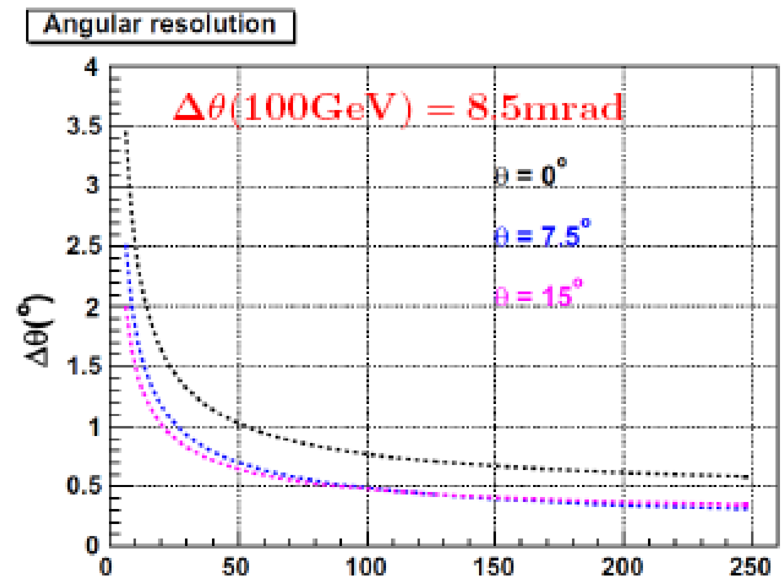
New Detector systems

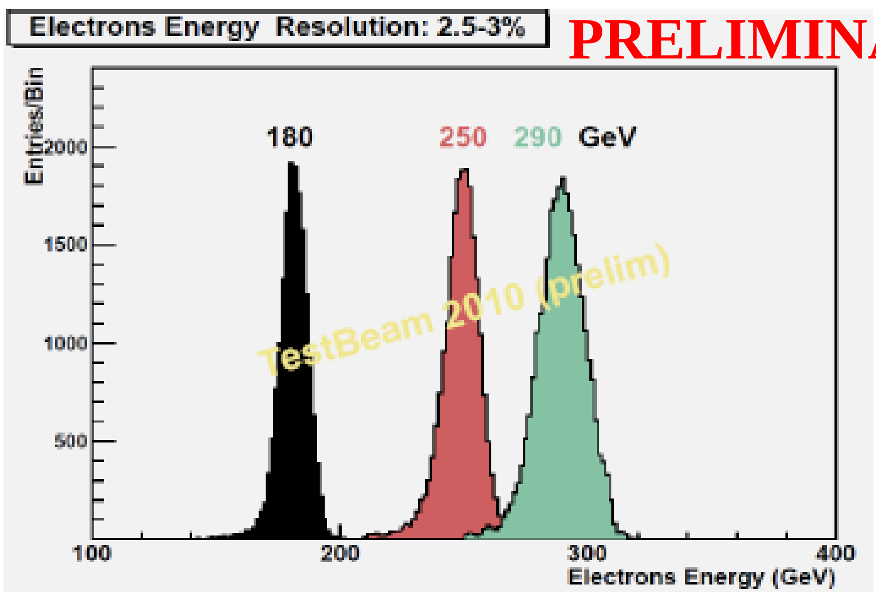
- ✓ New Cerenkov Detector (RICH)
- ✓ Electromagnetic Calorimeter (ECAL)
- ✓ Transition Radiation Detector (TRD)



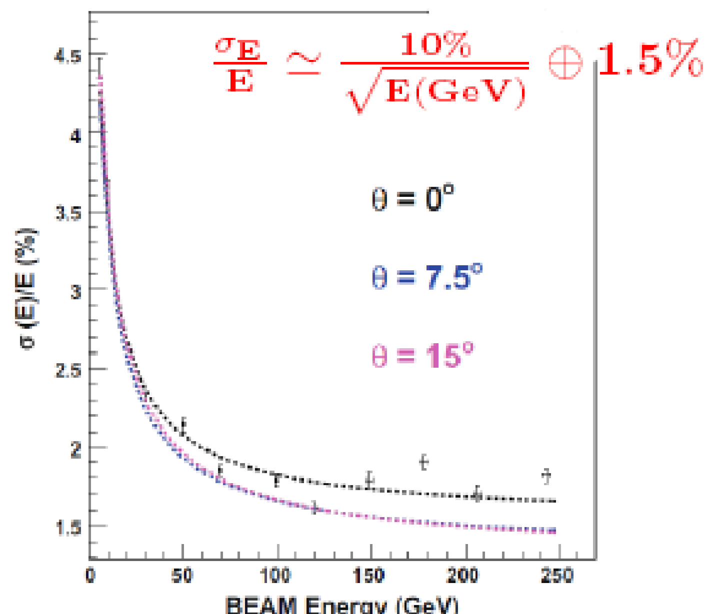
Electromagnetic energy measurement

- ✓ electromagnetic shower sampled 18 times
- ✓ energy linearity within 2% (up to 250 GeV)
- ✓ test beam results : electrons 6-250 GeV





PRELIMINARY



Credit: D.Grandi

Conclusions

Measurement	statistics	energy	physics goals
e^+	$\sim 10^7$	400 GeV	**Dark Matter**
$\bar{p}$	$\sim 10^6$	400 GeV	
γs	$\sim 10^5$	10^3 GeV	
$\overline{\mathrm{D}}$	~ 10	8 GeV/A	
D	$\sim 10^8$	8 GeV/n	**Astrophysics**
^{3}He	$\sim 10^8$	8 GeV/n	
^{10}Be	$\sim 10^5$	7 GeV/n	

Measurement	sensitivity	rigidity	physics goals
$\overline{\mathrm{He}}/\mathrm{He}$	10^{-9}	10^3 GV	**Antimatter**
$\overline{\mathrm{C}}/\mathrm{C}$	10^{-8}	10^3 GV	

Credit: D.Grandi

Conclusions

- The outstanding results from space experiments in orbit are transforming our views of high energy astrophysics
- Data from AGILE, FERMI and PAMELA keep pouring in, so expect more advances in the coming future
- More accurate measurements of CR fluxes are on the way from Fermi and PAMELA. Critical new results are expected from AMS.
- AMS will be launched in the second half of 2010 and installed on the International Space Station

Thank you!

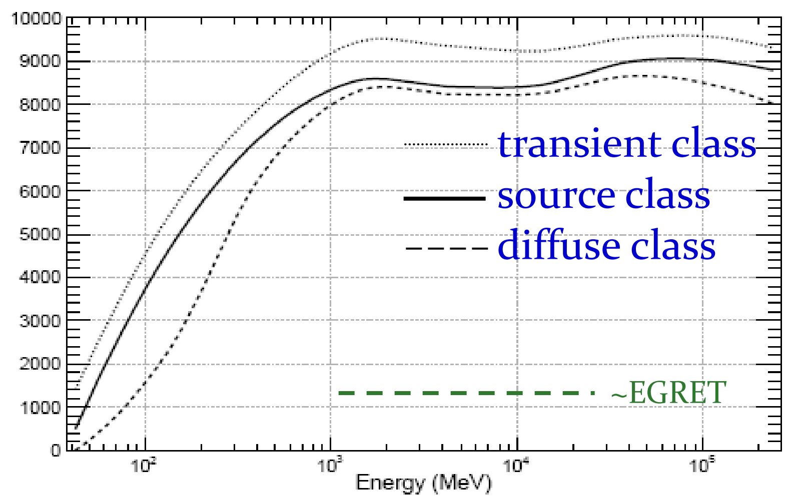
Back-up

Exploring the High Energy Universe

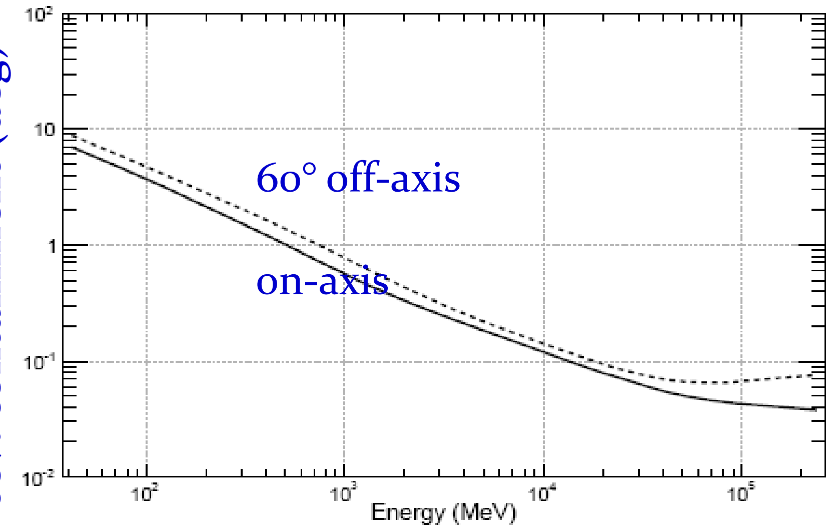
- Space experiments:
  - Photons:
    - Directly pointing towards the source direction
    - Understand the mechanisms of particle acceleration in AGNs, pulsars, and SNRs
    - Probe DM and early universe
    - Resolve the gamma-ray sky: unidentified sources and diffuse emission.
    - Make connections with ground experiments:
      - MW studies
      - Cross calibrations
  - Charged particles:
    - CRs are deviated by magnetic fields
    - Provide information about particle interaction mechanisms at very high energies
    - Study of their acceleration mechanisms to understand their origin: production and propagation
    - Anisotropy studies

Fermi-LAT Instrument Performance

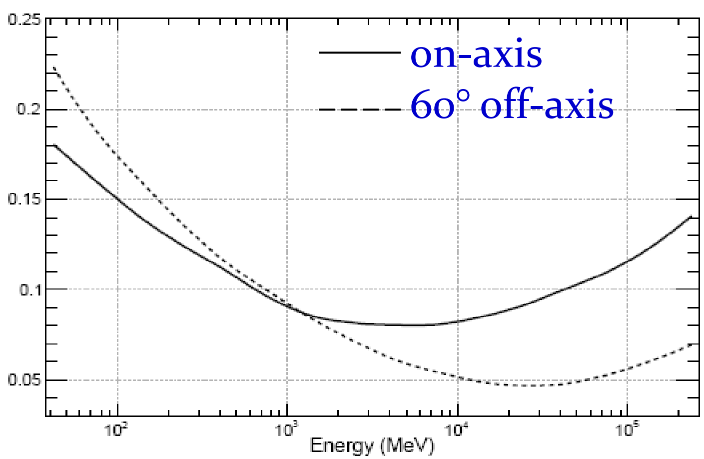
Effective area (cm²)
Normal incidence



Point Spread Function
68% containment (deg)



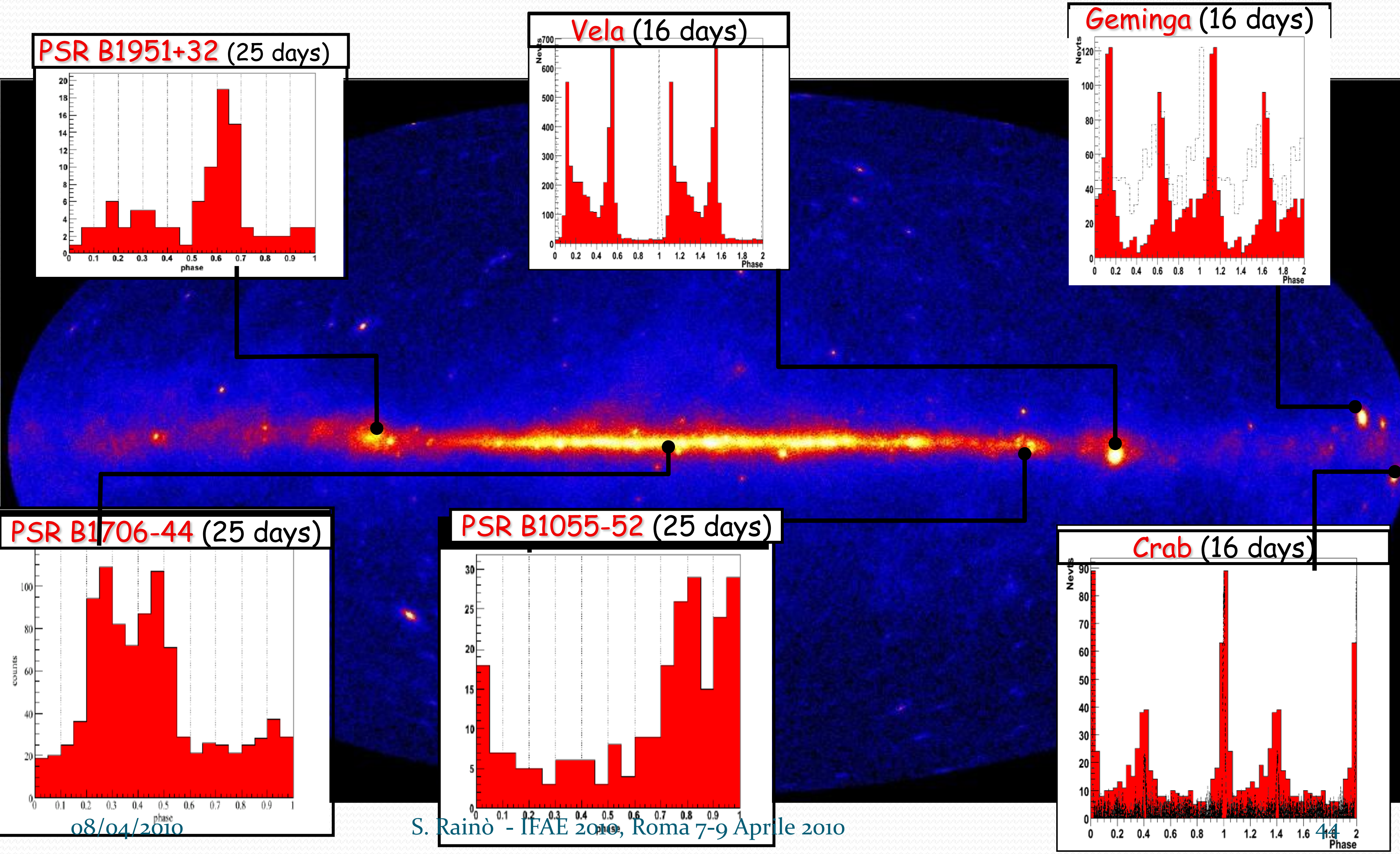
Energy dispersion
68% cont

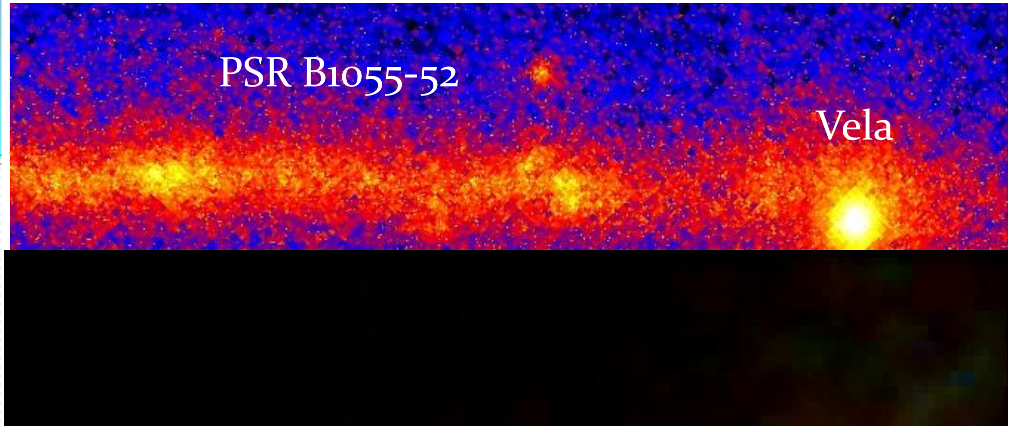


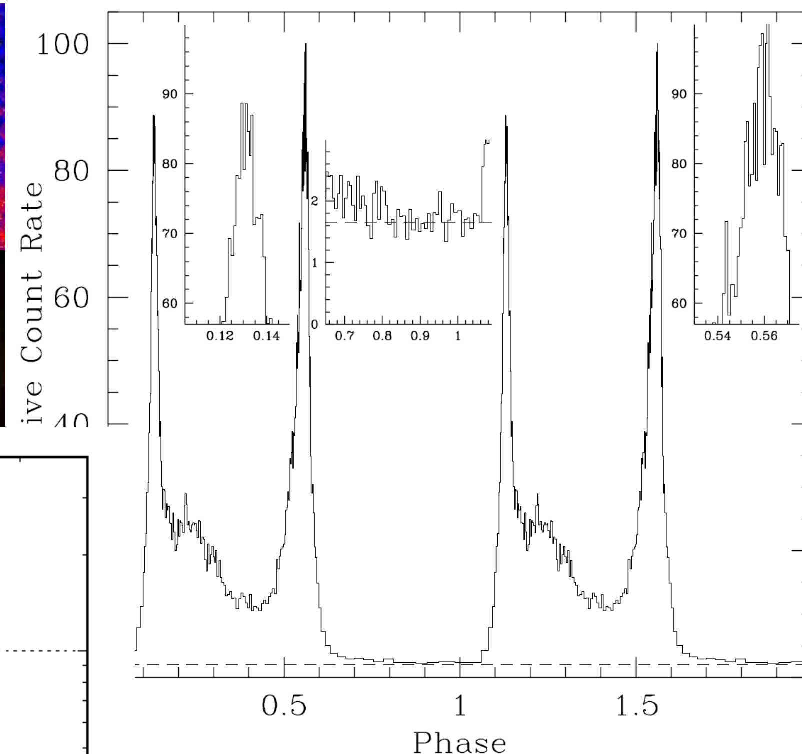
The Large Area Telescope on the Fermi Gamma-ray Space Telescope
Atwood, W. B. et al. 2009, ApJ, 697, 1071

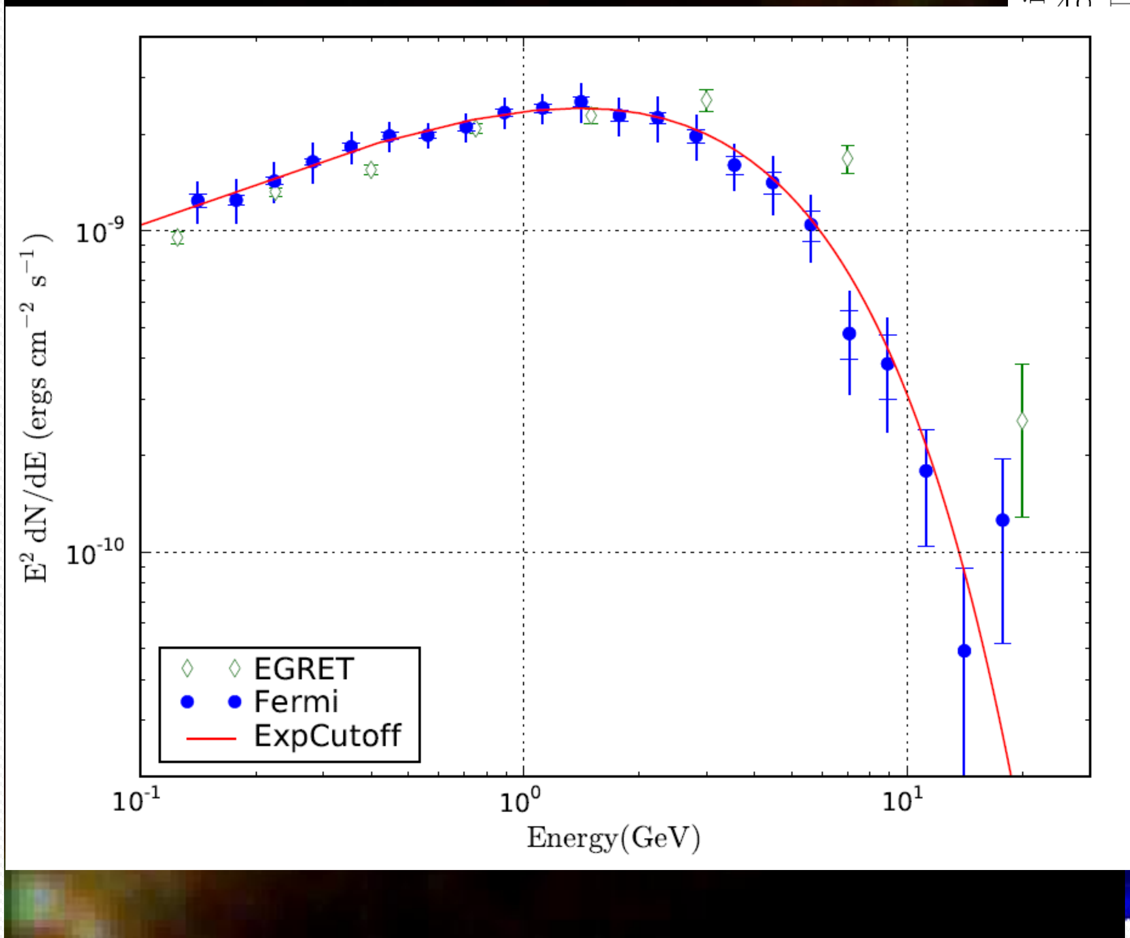
Pulsars: where we started

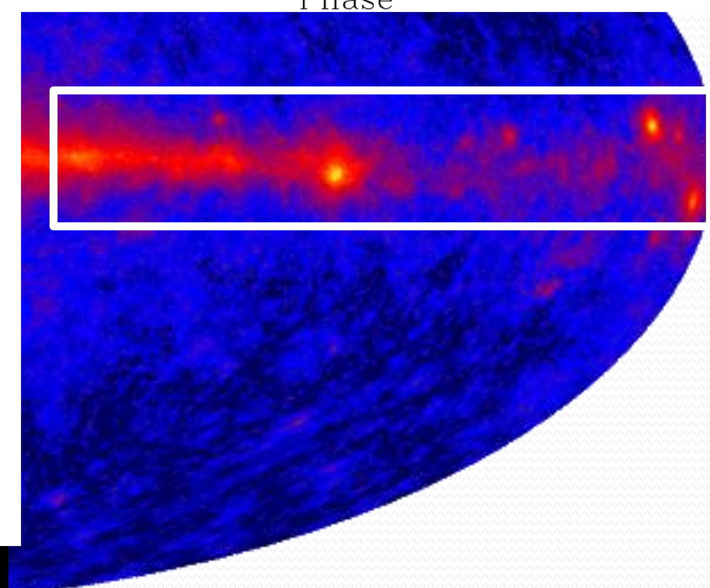
EGRET ---> 6 pulsars



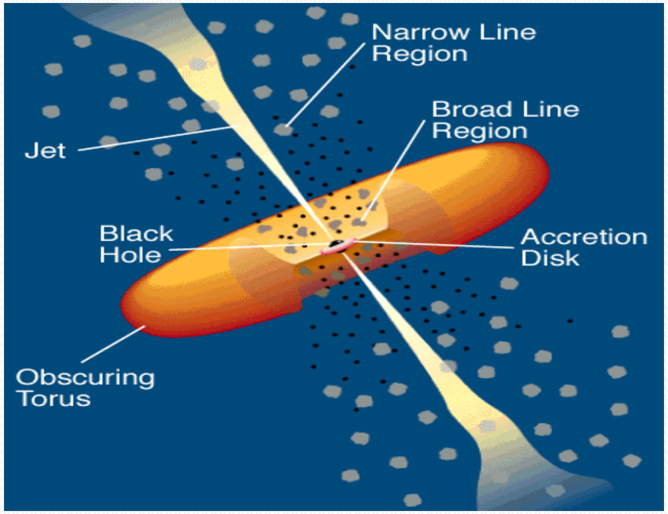

PSR B1055-52
Vela

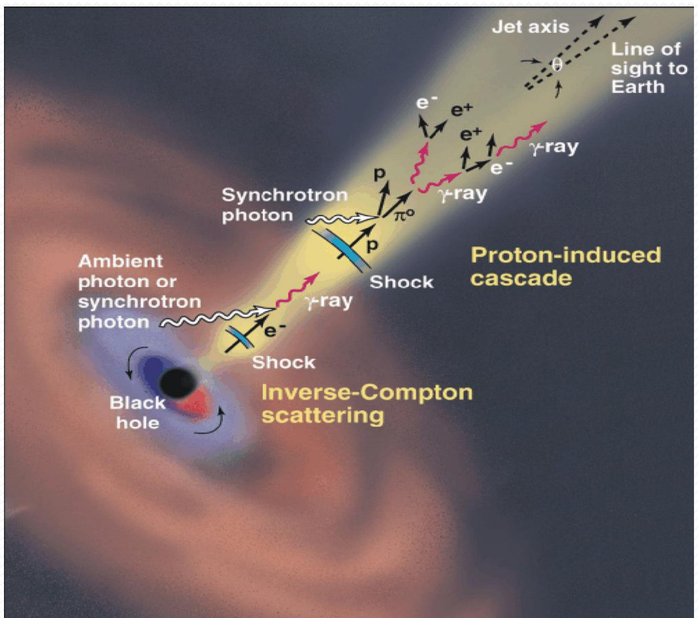

ive Count Rate
100
80
60
0.5
1
1.5
2
Phase
0.12
0.14
0.7
0.8
0.9
0.54
0.56


E^2 dN/dE (ergs cm^{-2} s^{-1})
10^{-9}
10^{-10}
10^{-1}
10^{0}
10^{1}
Energy(GeV)
EGRET
Fermi
ExpCutoff



Active Galactic Nuclei (AGN)

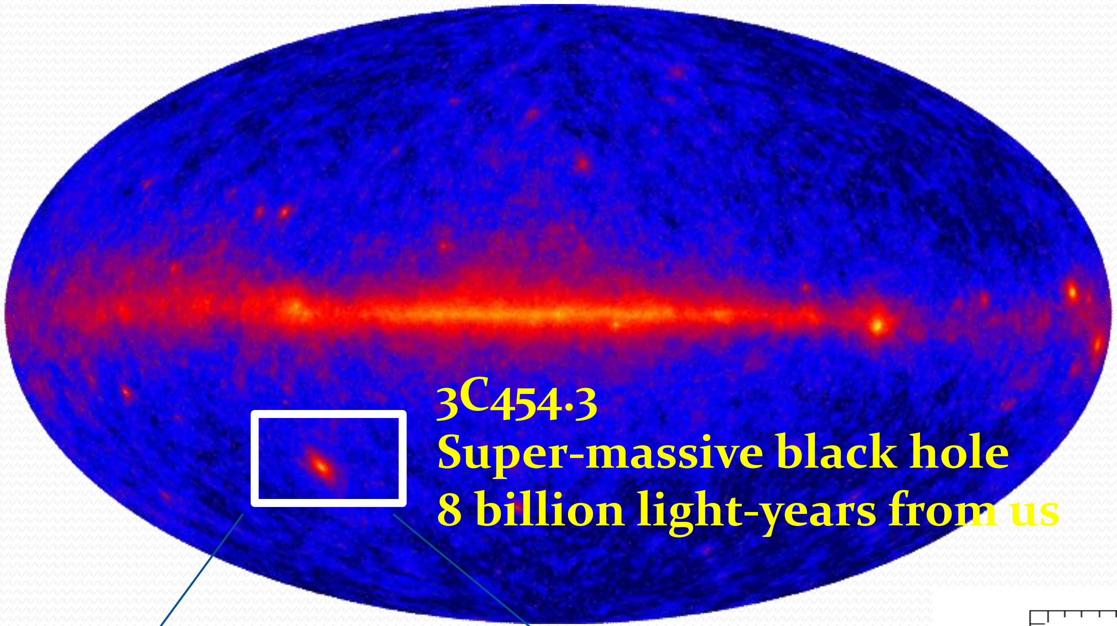


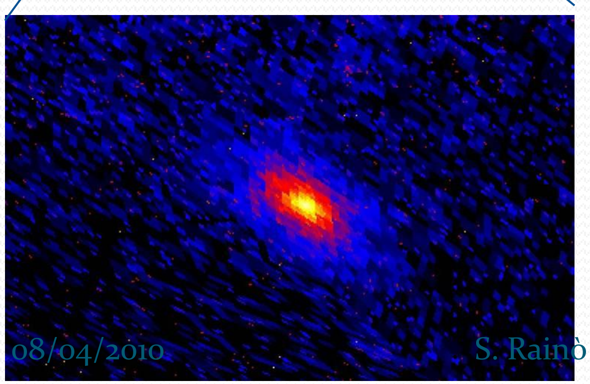


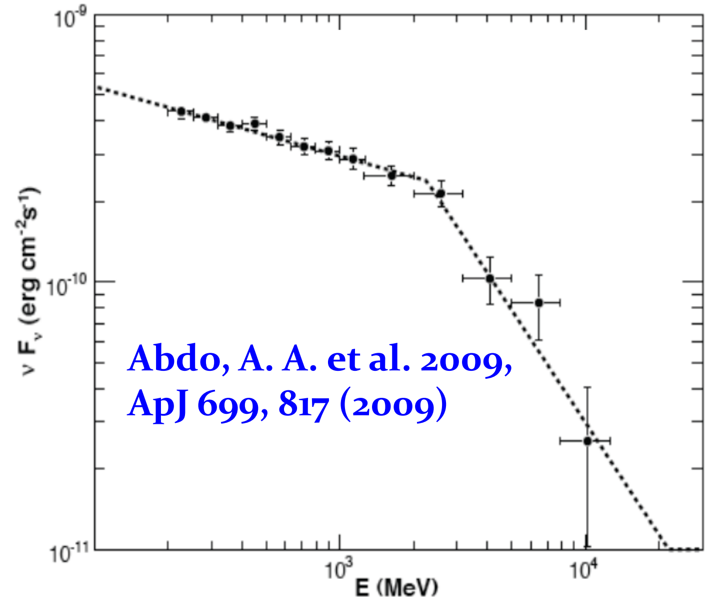
- Active galactic nuclei (AGN) are galaxies with extraordinarily luminous cores powered by super massive black holes
- In the standard model of AGN, cold material close to the central black hole forms an accretion disc
- At least some accretion discs produce jets, twin highly collimated and fast outflows that emerge in opposite directions from close to the disc
- Blazars are objects emitting non-thermal radiation across the entire electromagnetic spectrum from a relativistic jet that is viewed closely along the line of sight

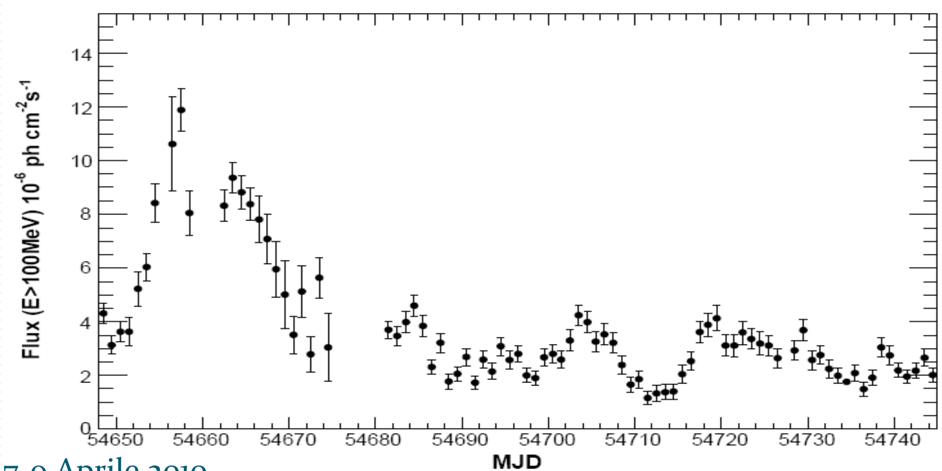
Fermi view of 3C454.3

The brightest gamma-ray extra-galactic source observed in the first 3 months Fermi-LAT survey

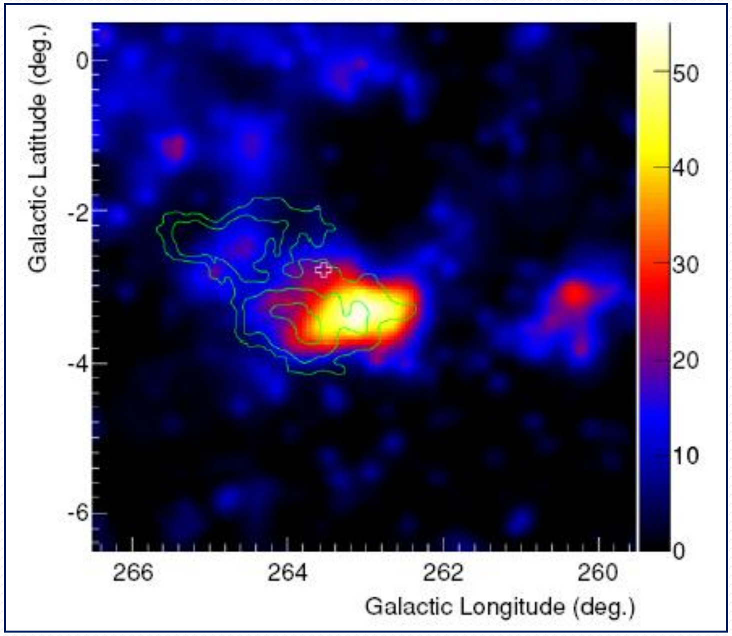




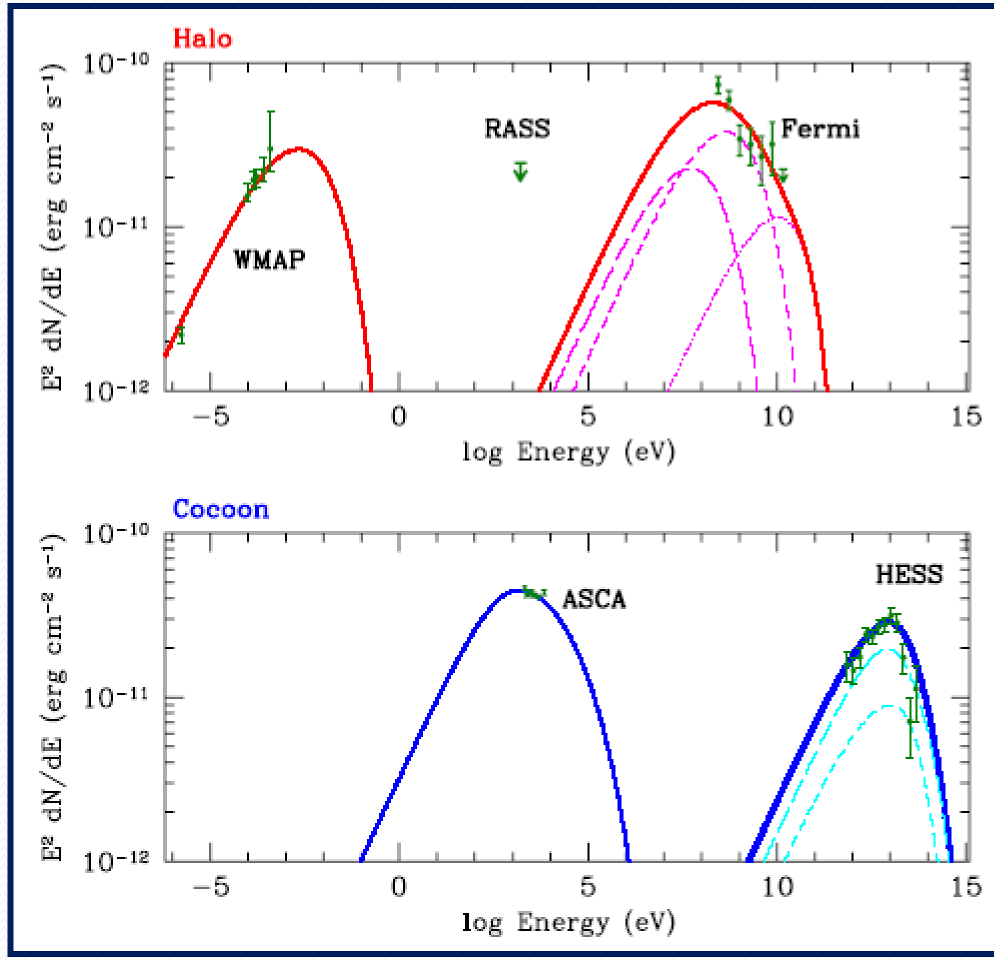


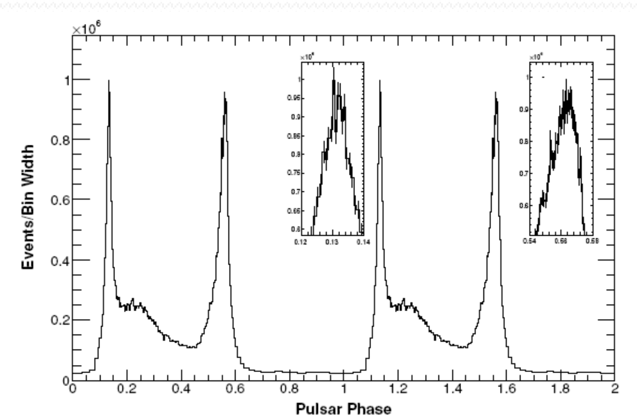


Fermi: Vela X PWN



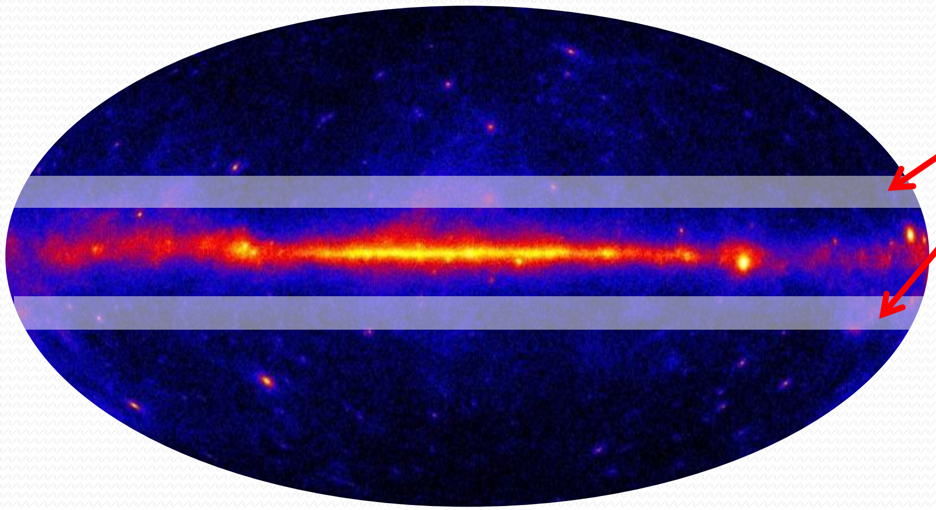
Test statistic map of the PWN Vela-X above 800 MeV.





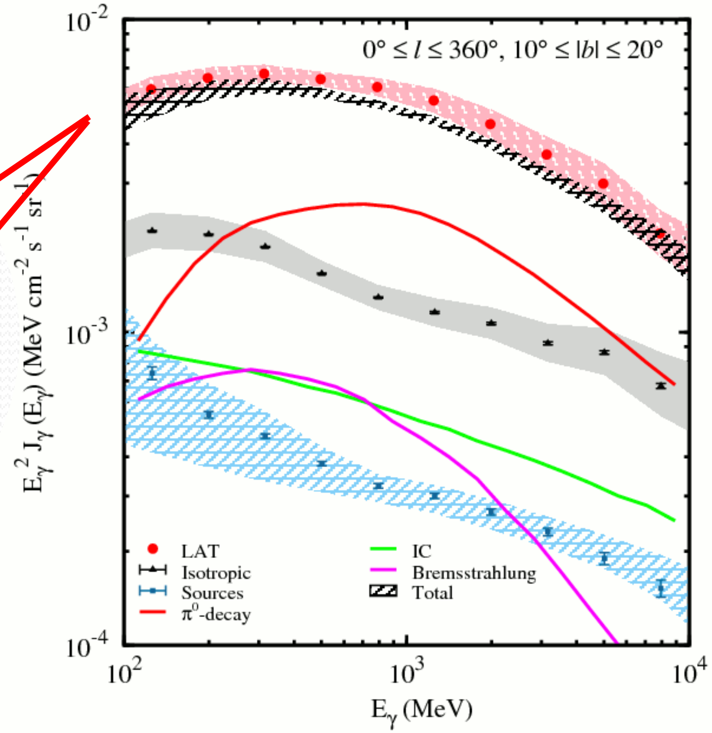
Spectral energy distribution of regions within Vela-X from radio to very high energy gamma rays

LAT mid-latitude diffuse gamma-rays: absence of the EGRET "GeV-excess"



100 MeV – 10 GeV

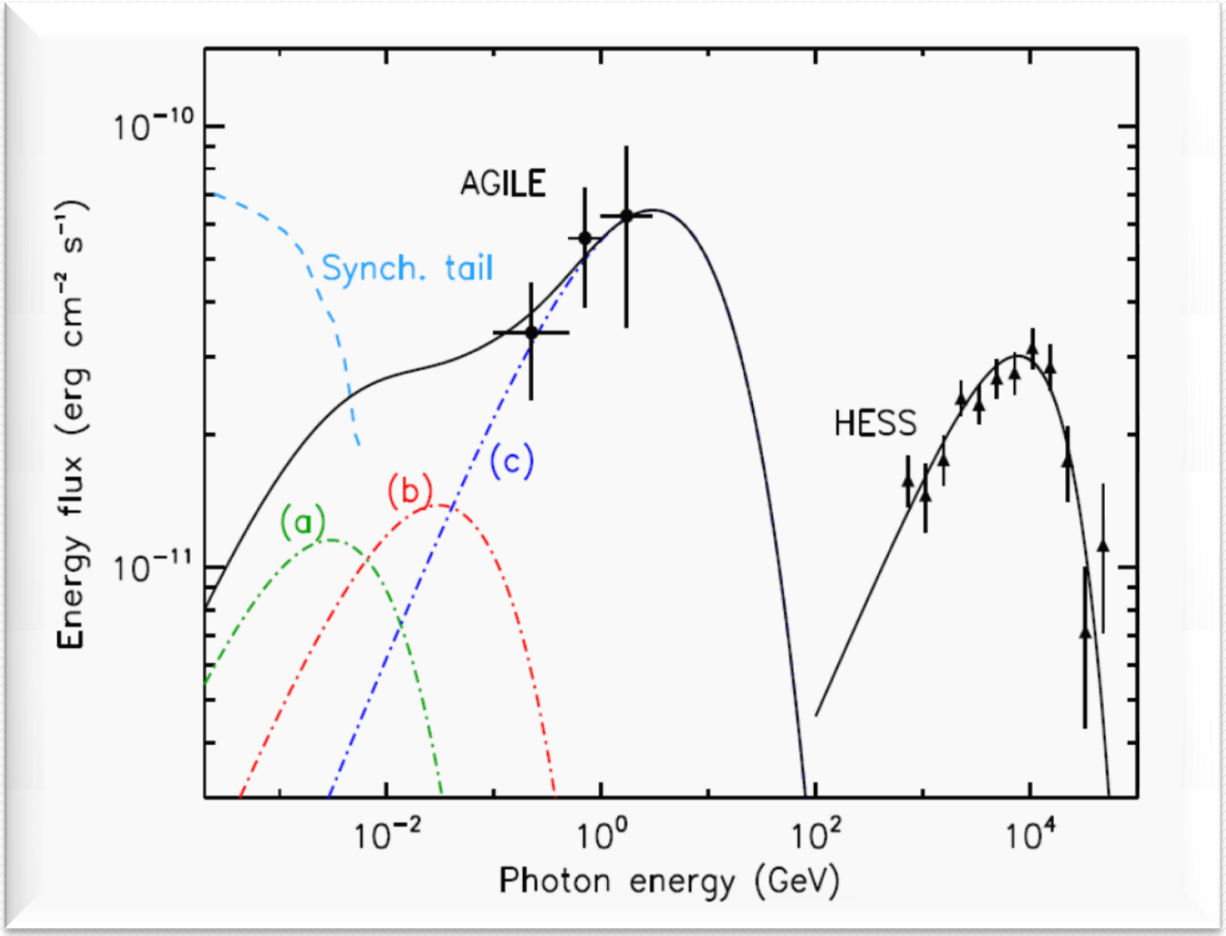
T. A. Porter et al.
arXiv:0907.0294



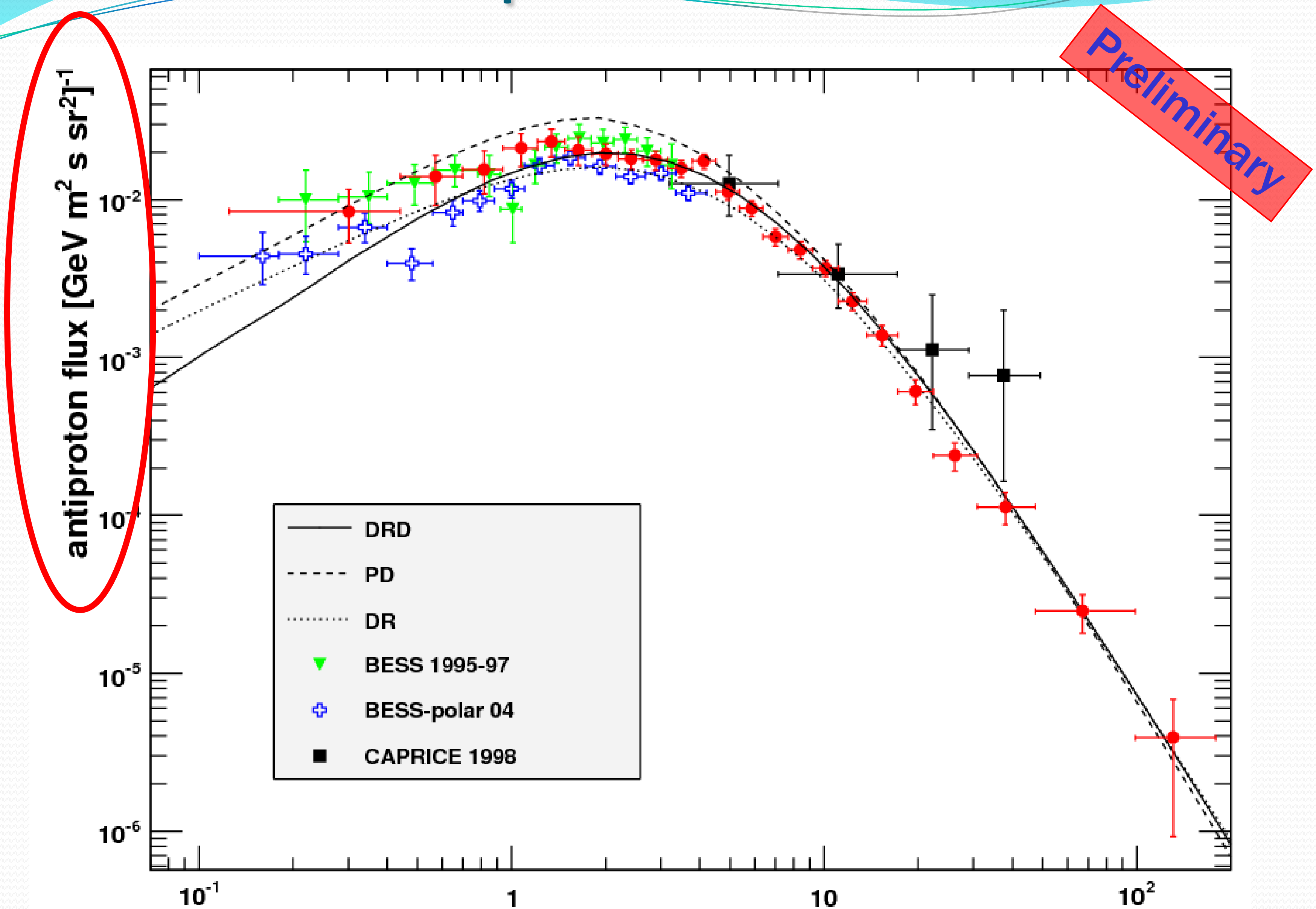
- **Spectra shown for mid-latitude range → EGRET GeV excess in this region of the sky is <u>not</u> confirmed**
- **Sources are a minor component**
- **LAT errors are systematics dominated and estimated ~10%**
- **Work on diffuse emission with some different modeling approaches over the entire sky and broader energy range is in progress**

AGILE: Vela X PWN spectrum

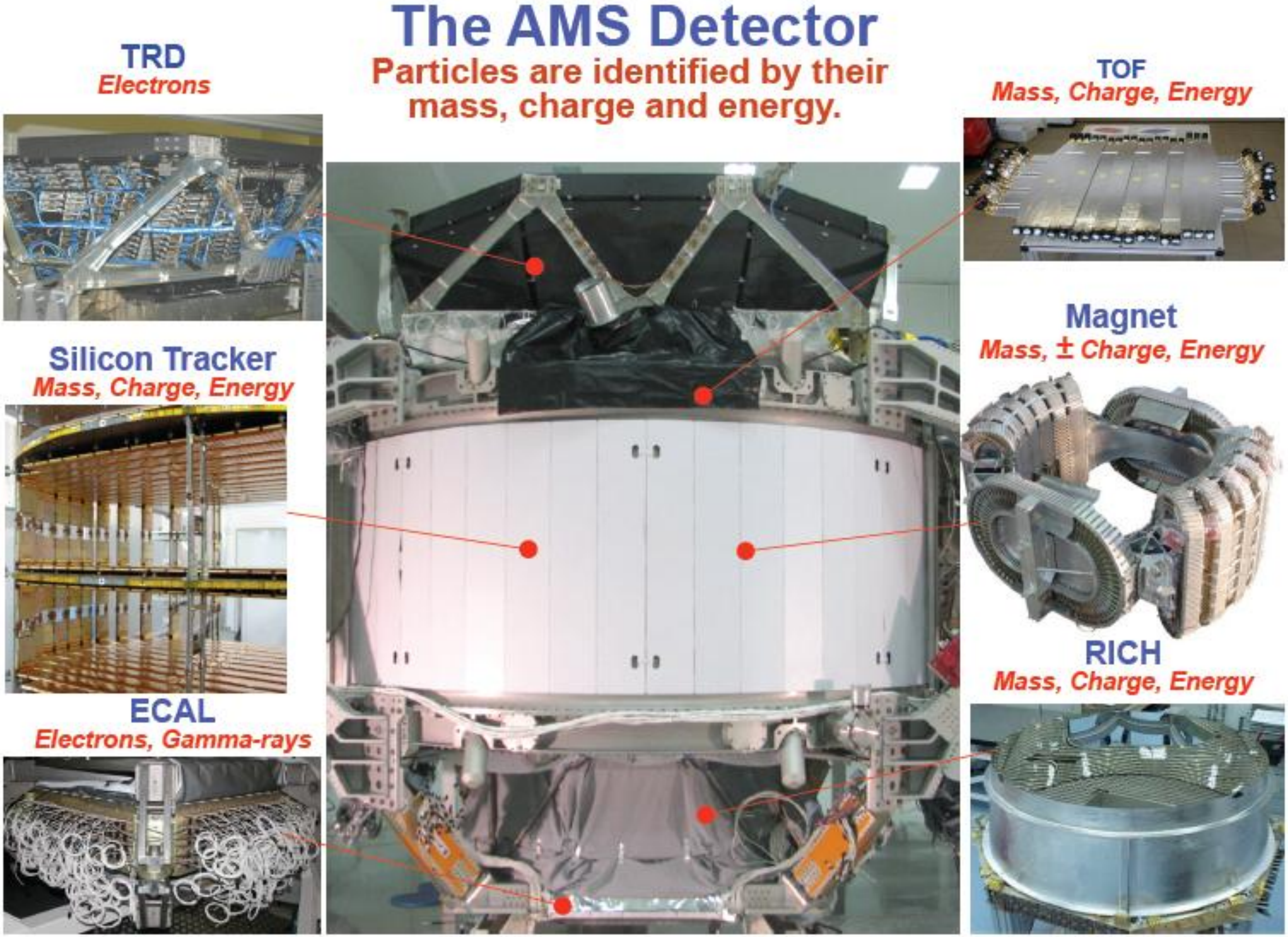
(Pellizzoni et al., *Science*, 30 dic. 2009)



Antiproton Flux



Credit: F.Cafagna



Credit: D.Grandi

Detector Requirements

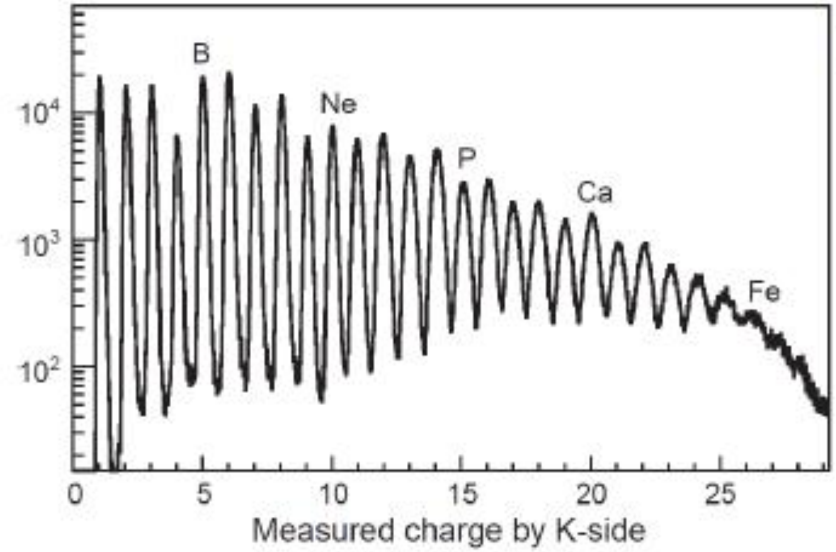
Antimatter	DarkMatter	Astrophysics
antinuclei production from matter collisions is strongly suppressed $(p + ISM \rightarrow \bar{N} + \ldots)$ $\frac{\bar{N}}{\bar{p}} \propto \exp\left(-\frac{M_N - m_p}{80\ MeV}\right)$	• e^+ and $\bar{p}$ produced in $p + ISM$ collisions • physics background : $p/e^+ \sim 10^3$ $e^-/\bar{p} \sim 10^2$	**detection of a large range of nuclei (Z)** **ability to identify different isotopes**
detection of antinuclei would be a clear signal of existence of antimatter	**signals :** $\bar{p}, e^+, \gamma, \bar{d}$	**detection of gamma rays**
	a good e,p separation is needed $B/S \sim 1\% \Downarrow$ Rejection Factor $\sim 10^5$	

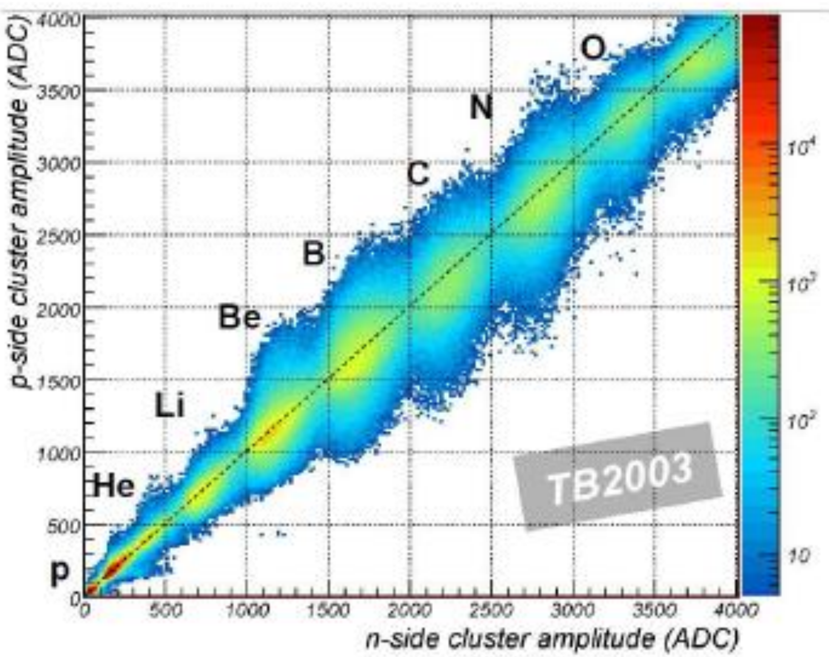
- charge identification
- rigidity measurement
- velocity measurement
- e.m energy measurement
- e/p separation
- albedo rejection
- strong system redundancy

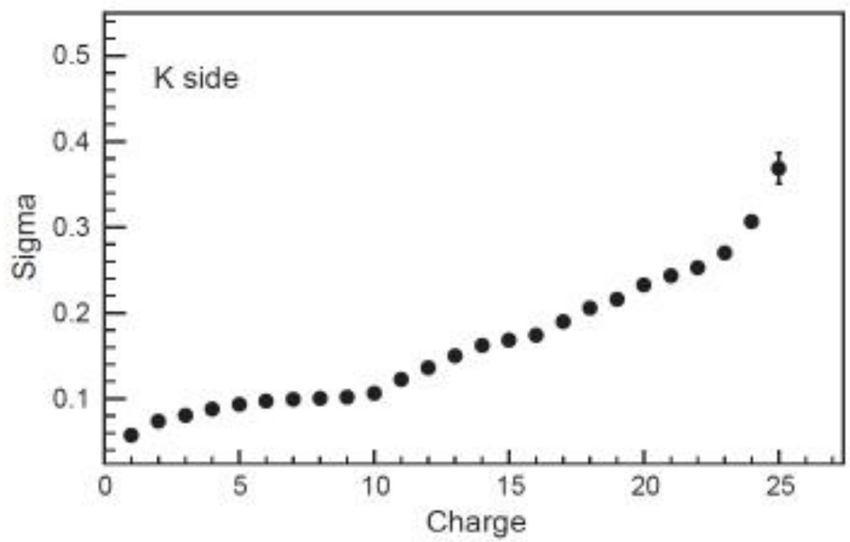
Credit: D.Grandi

Charge measurement (Z) with Tracker

- ✓ energy deposited on silicon sensors (300 μm)
  $\Delta E \propto Z^2$
- ✓ up to 8 ΔE samplings
- ✓ 6 ladders were tested (2003) with fragmented ions
  charge separation up to $Z \sim 26$



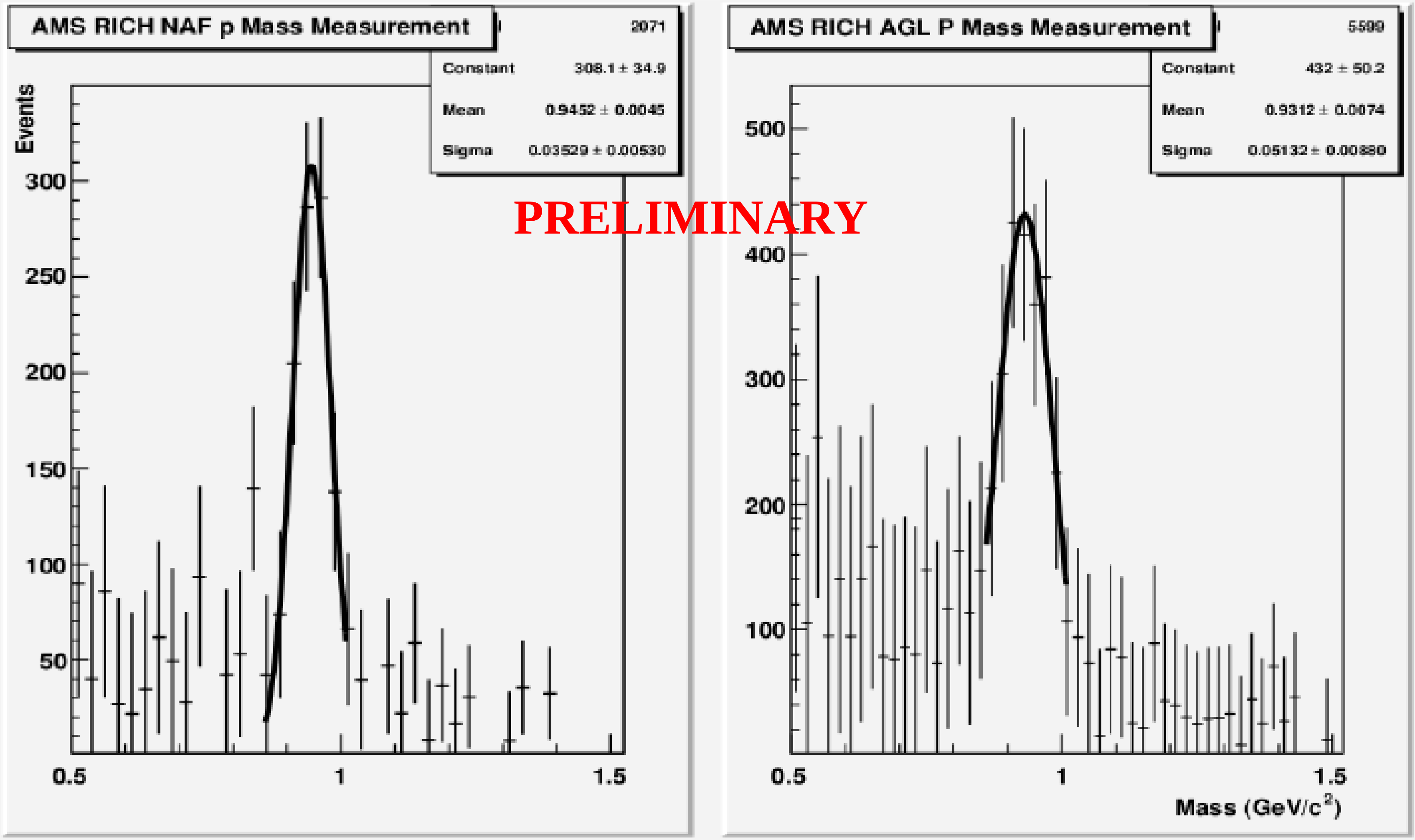




Credit: D.Grandi

Cosmic runs 2009 : RICH mass reconstruction

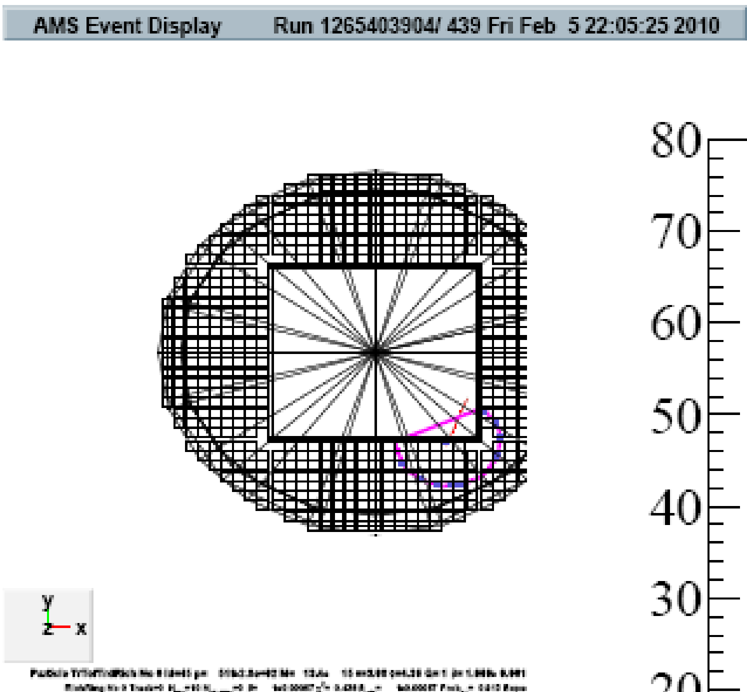
✓ cosmic rays : proton mass reconstructed with the RICH (aerogel and NaF radiators)



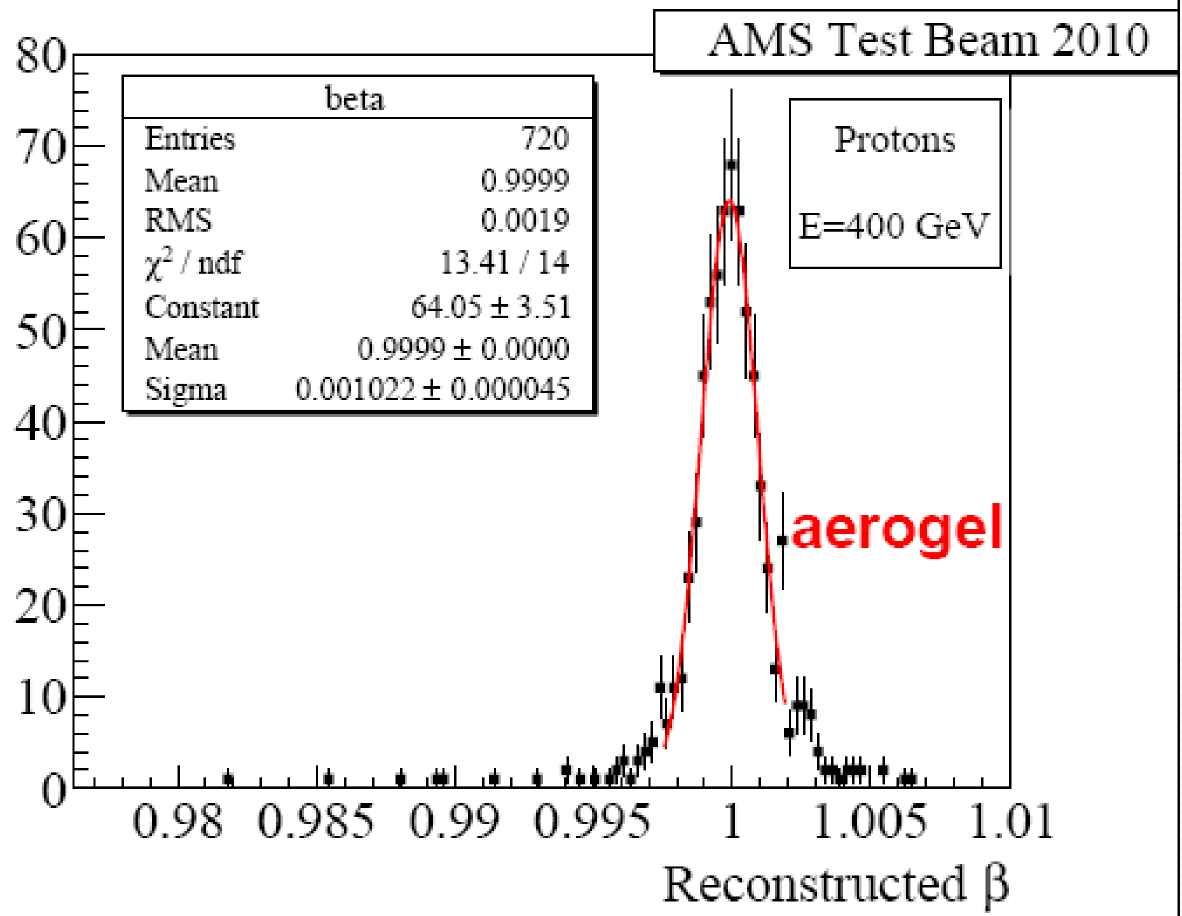
Credit: D.Grandi

Test Beam 2010 : RICH β reconstruction

✓ 400 GeV protons with the magnet switched on at 400 Amps



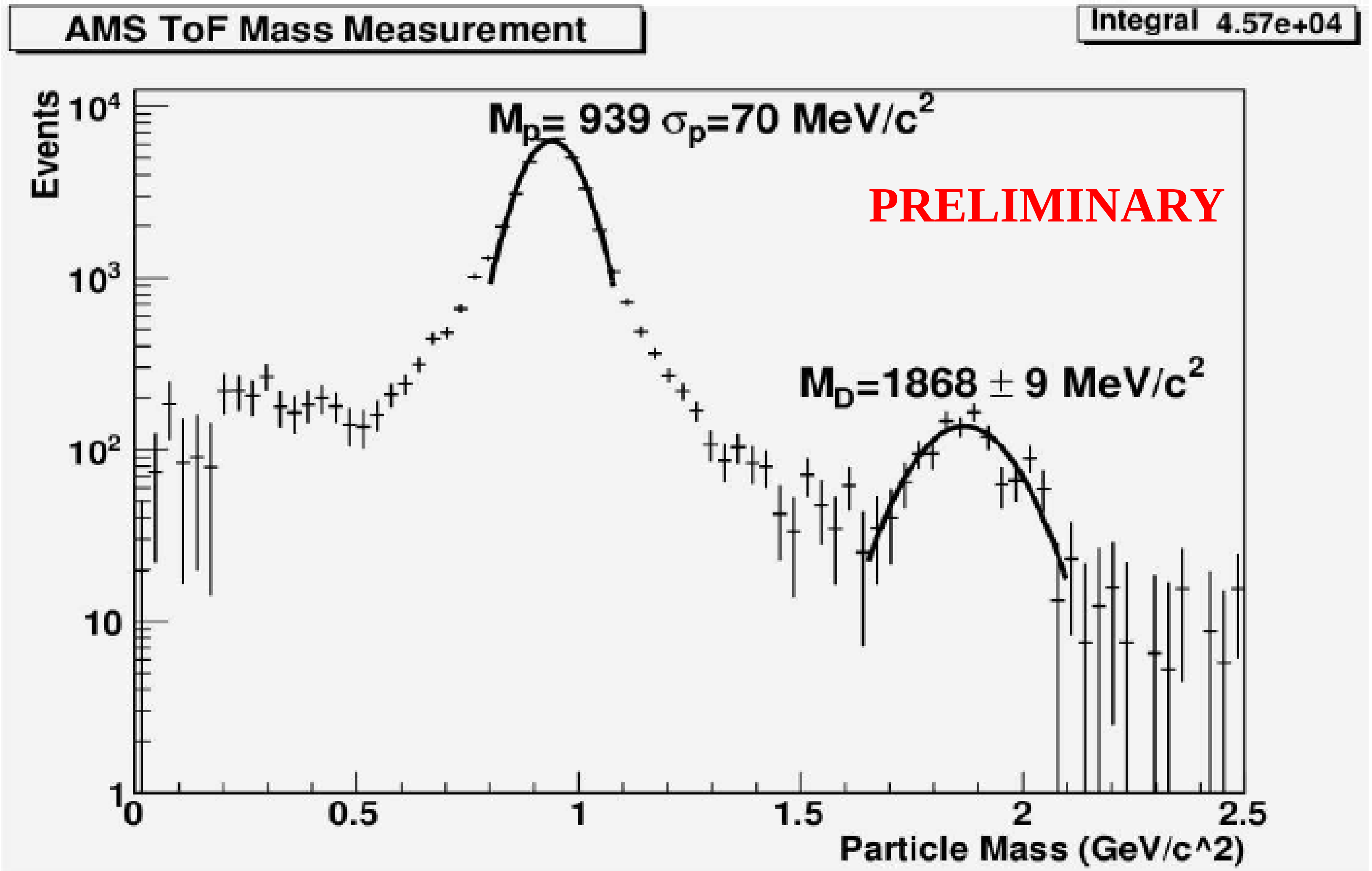
PRELIMINARY



Credit: D.Grandi

Cosmic runs 2009 : TOF mass reconstruction

- ✓ cosmic rays : proton and deuteron masses reconstructed with the TOF



Credit: D.Grandi