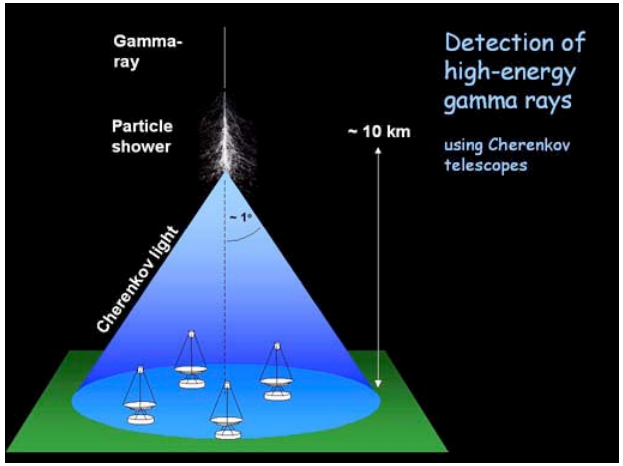
Cross Calibration of Atmospheric Cherenkov Telescopes and the LAT

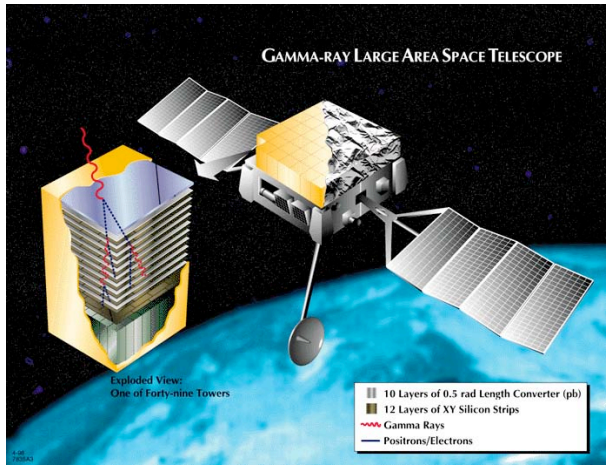
Outline

- Why cross calibration is useful
- Suggestion: use the Crab source
- Potential pitfalls of this method
- Are there other sources/methods?

IACTs and the LAT are complementary instruments

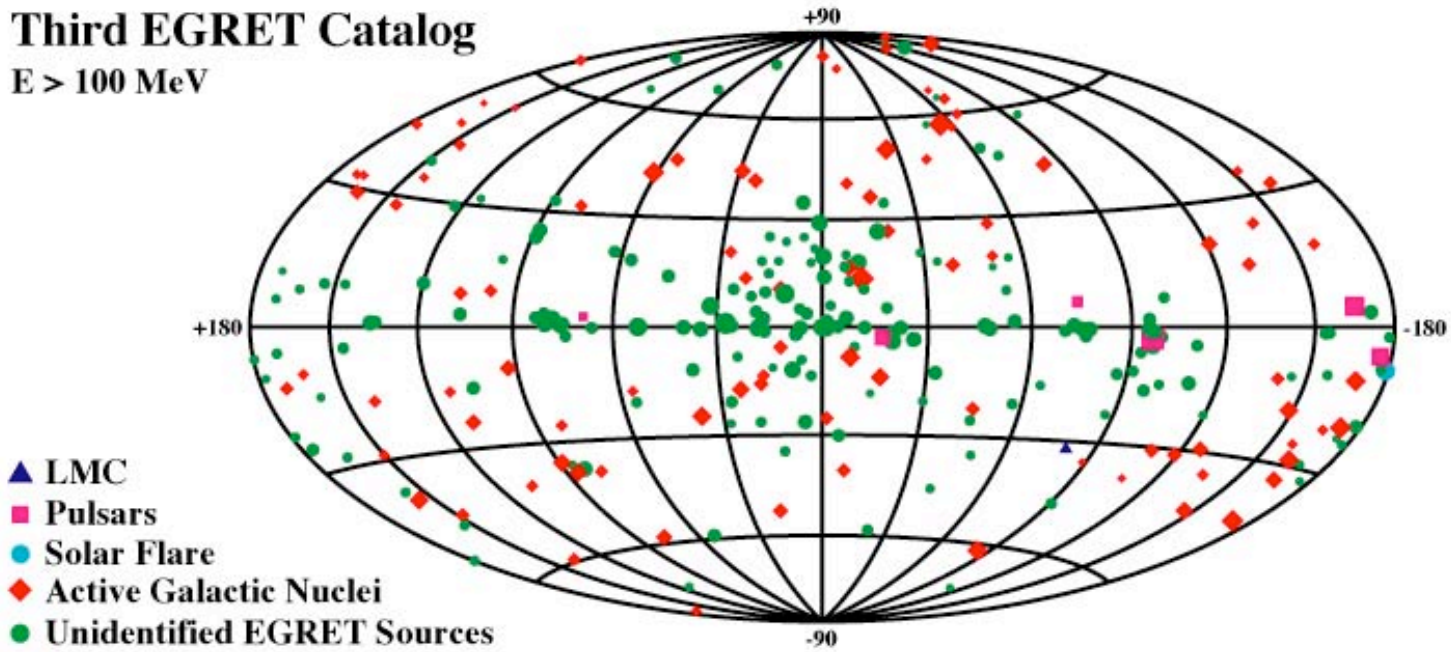
- IACTs:
  - Large Area – 100m^2
  - High threshold – 100-1000 GeV
  - Low acceptance -- ~few degrees
  - Systematics large and model dependent
- LAT:
  - Small area – 1 m^2
  - Large acceptance – 1 str
  - Low Threshold -- ~10s MeV
  - Calibrated on the ground
- Cross calibration will compensate for the weaknesses





Use the LAT to tell IACTs where to look

- The LAT will have plenty of new sources which may have high energy components
- The LAT rapidly runs out of statistics at ~10-100 GeV for most sources
- Discovery does not imply accurate flux or power law measurement



But the current generation has to stretch to make the complementarity work

- EGRET dataset ends two orders of magnitude below threshold of previous atmospheric cherenkov measurements
- Extrapolations may not be reliable…
- (Admittedly the example here is mostly for amusement)
- In order to really compare results for the same source, we need cross calibration

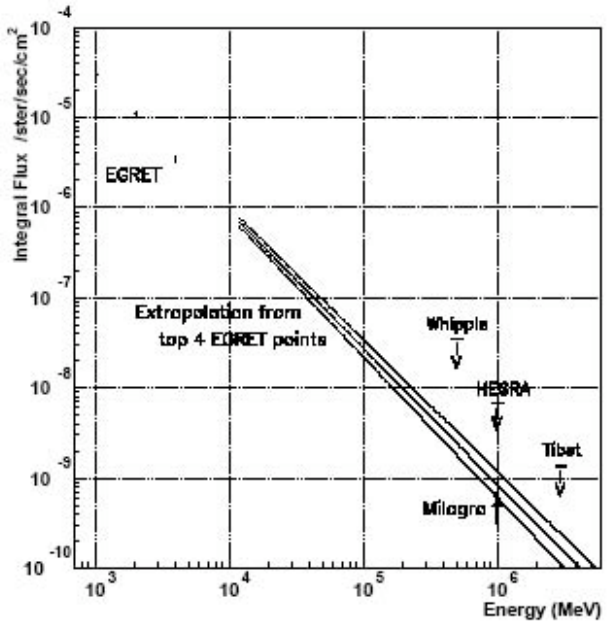


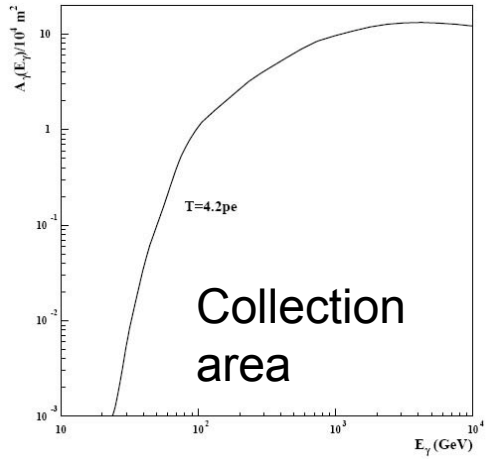
FIG. 5: Integral flux results of Milagro and EGRET, with 99% c.l. upper limits from Whipple ($l \in (38.5°, 41.5°)$, $|b| < 2°$) [8], HEGRA ($l \in (38°, 43°)$, $|b| < 5°$) [9], and Tibet ($l \in (20°, 55°)$, $|b| < 5°$) [10].

A current example: Milagro Measures diffuse galactic gamma rays (Source: astro-ph/0502303)

Why are IACTs systematically limited?

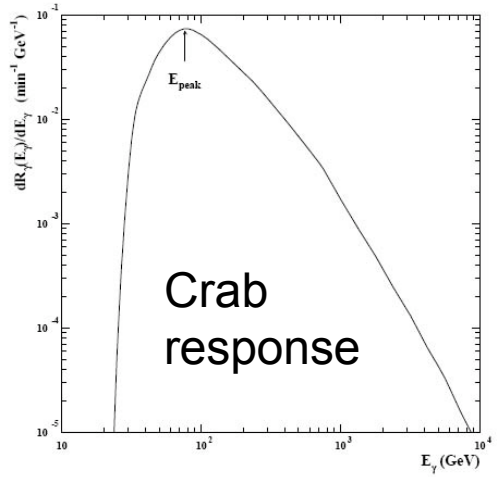
Lots of curves folded together:

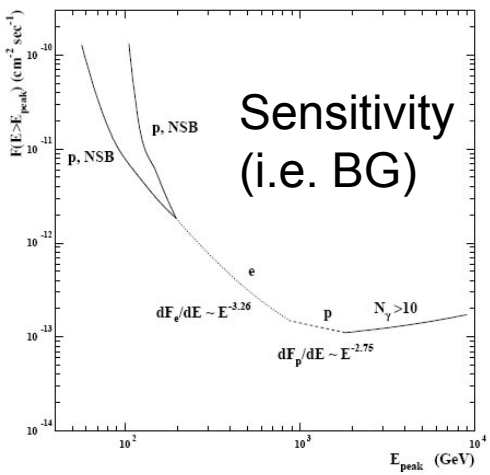
- They rely on models of atmospheric interactions of hadrons and electrons
- Light yield is dependent on atmospheric conditions (water column/etc)
- Response, acceptance, and trigger efficiency is a function of angle of incidence and energy
- Backgrounds are large and variable
- (keep in mind these are log-log plots here)



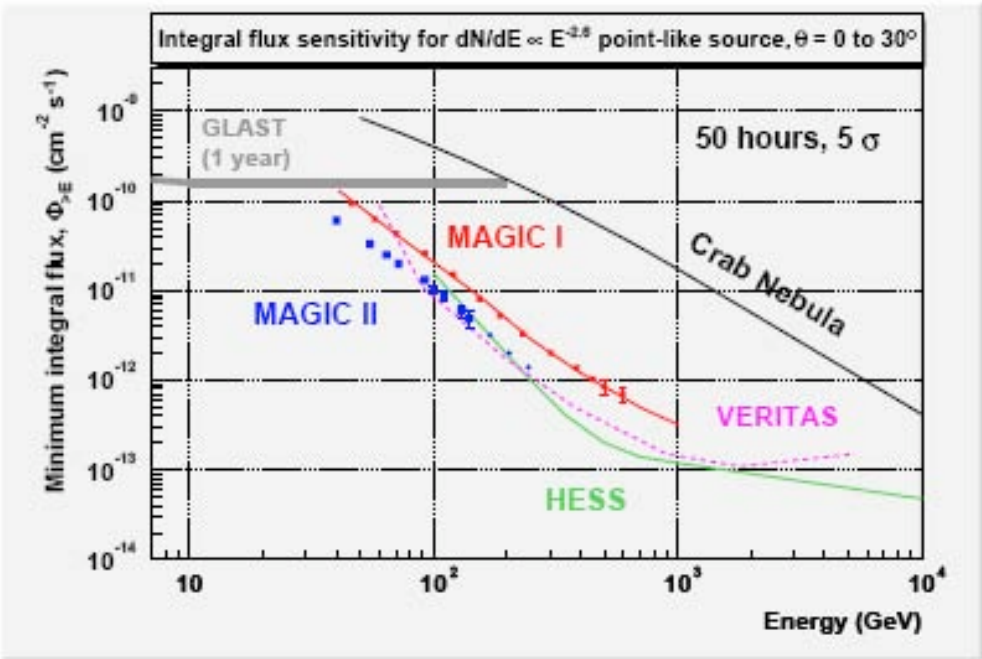
VERITAS,
For example:
Some quantities
Versus E_gamma

Source:
Astropart.Phys.
17 (2002) 221-243





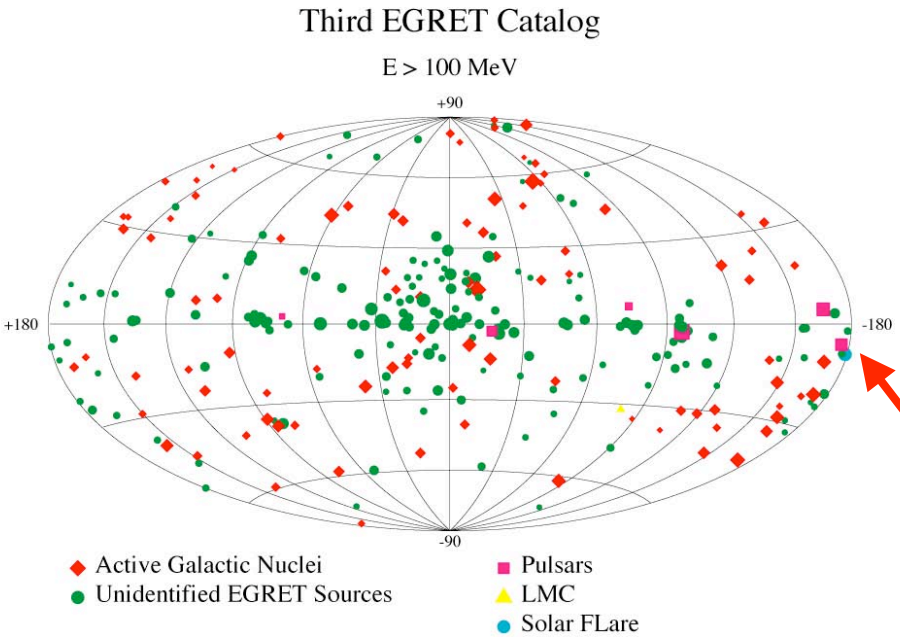
The next generation instruments overlap



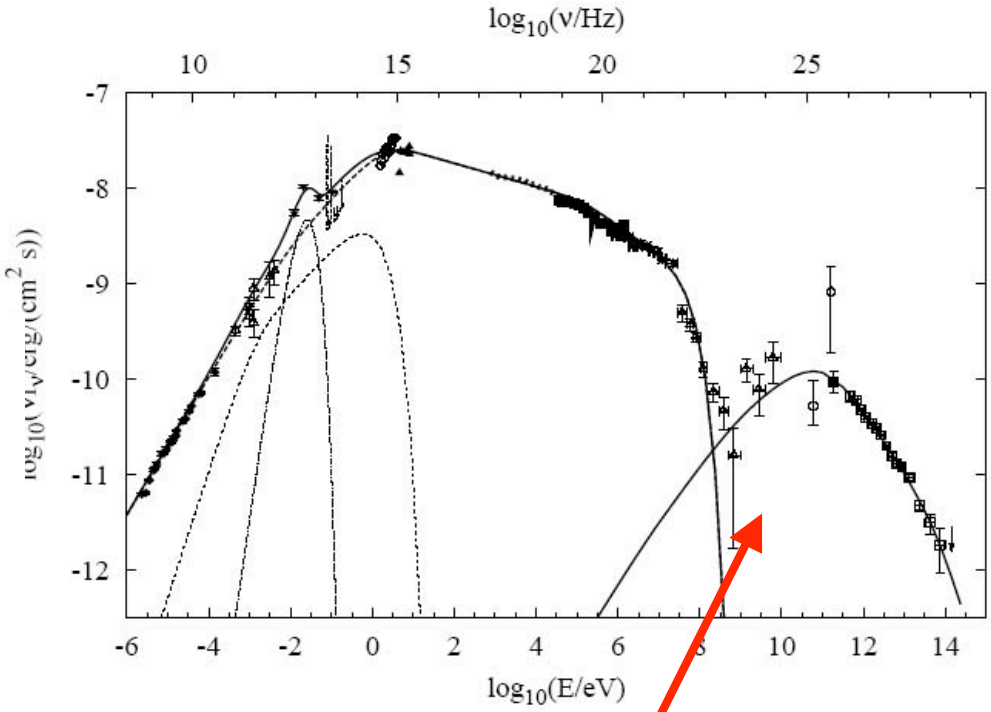
- HESS, VERITAS, and MAGIC can see the Crab where GLAST still has statistical sensitivity
- Suggestion: use the Crab nebula as a cross-calibration source (astro-ph/0504301)

Crab:

- A bright, steady, relatively hard source
- Extensively studied and modeled



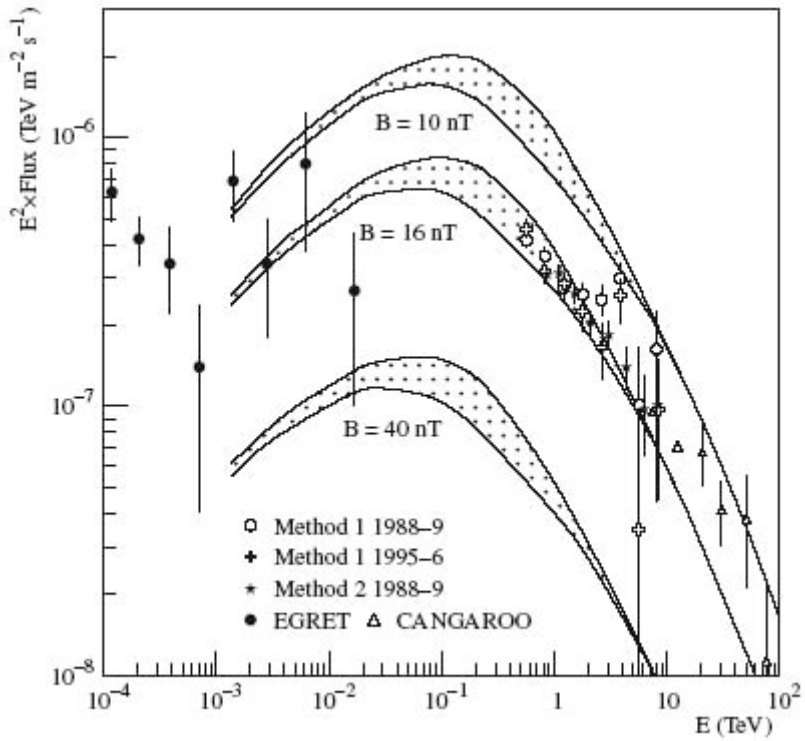
The Crab spectrum (Astrophys.J. 614 (2004) 897-913)



Region we're talking about

Cross Calibration with the Crab

- Non-variable: IACTs look only for hours at a time, LAT collects over a year, so source flux must be stable
- Bright: Need enough statistics for the LAT to get a reliable spectrum to ~200GeV
- Hard: Need enough high energy photons for IACTs above threshold
- Bonus! Break in spectrum in overlap region allows breaking of flux/energy scale degeneracy.

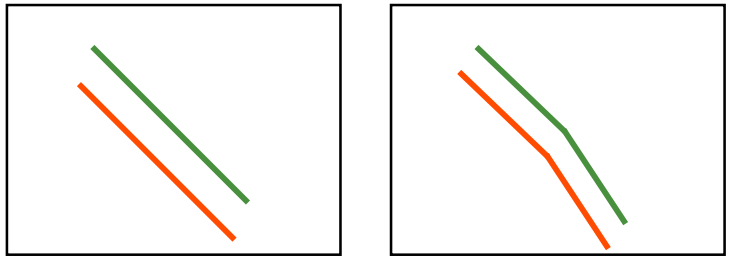


Close-up of current measurements of Crab gamma spectrum. (astro-ph/0504301)

Cross Calibrating with the Crab

- Use the spectrum break to match: allows the IACTs to effectively reduce their systematic uncertainty in energy scale and acceptance to that of the LAT.
- Bastieri et al. estimate statistical uncertainties for resolving the break
- The uncertainty is dominated by LAT statistics, but should give 10% accuracy
- It bears mentioning that finding the break has scientific merit for Crab acceleration models

Courtesy S. Digel



?? Aha!

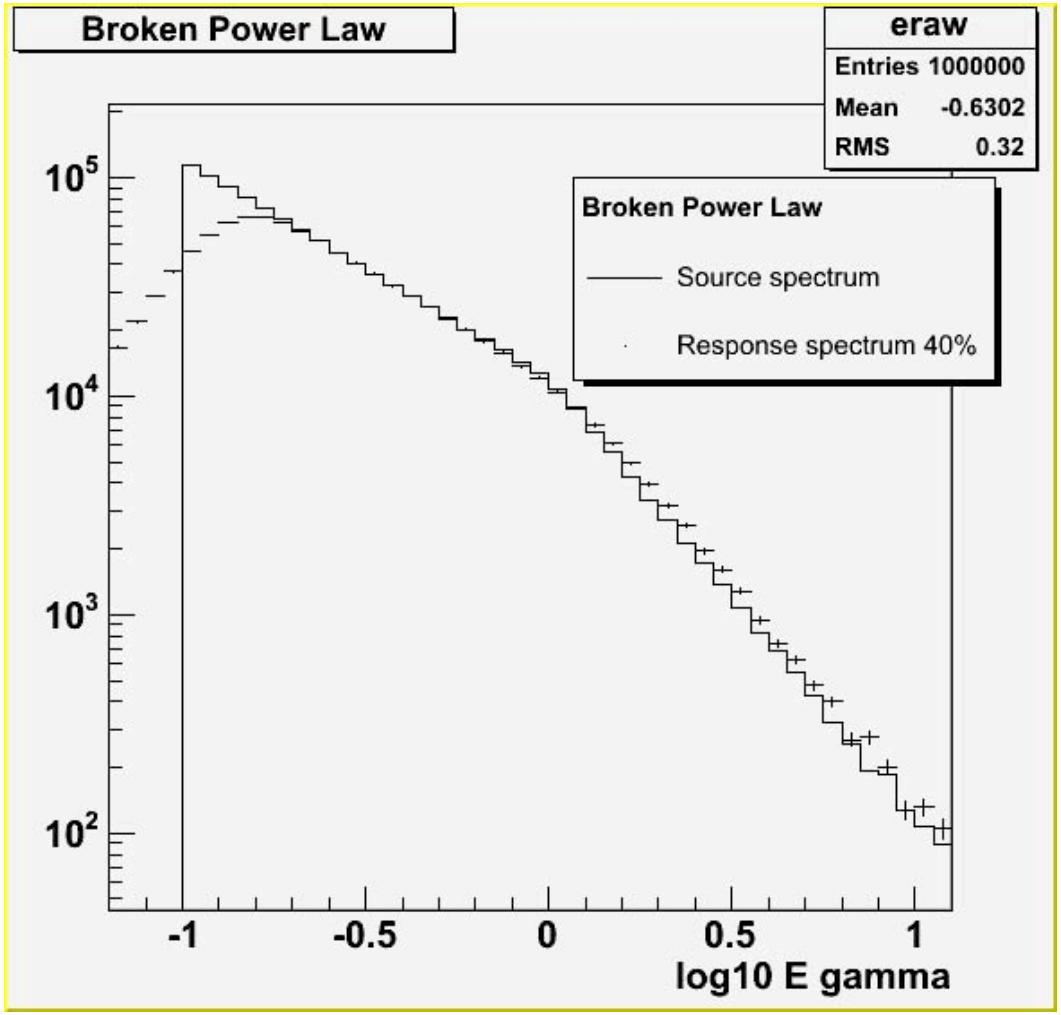
E_{brk} (GeV)	Gammas seen by GLAST	$\delta E_{\mathrm{brk}}/E_{\mathrm{brk}}$	
		GLAST	MAGIC
50	3763	6.2%	4.0%
100	3249	8.2%	3.5%
150	2988	12.7%	2.9%
200	2818	17.2%	5.2%

Sounds great, but: all of your eggs are in one basket

- Accurately measuring a break in a spectrum requires knowledge of acceptance, energy scale, and energy resolution
  - Finite energy resolution tends to move apparent flux upwards for power laws. This is fine; it is what we are trying to calibrate out.
  - However, the measurement of the break point is further moved to higher energy in a power law. Mistakes in estimating this effect will create additional uncertainty
- The IACT functions could be rapidly varying in the region of the break, (especially for the 50 GeV case).
  - You are effectively calibrating the IACTs at one energy for one power/break, especially given energy resolution uncertainties of the IACTs
- If we don't have ground calibrations of the LAT in this energy range, we may have a hard time understanding response.
  - Punch through/leakage become important at these energies
  - Are there self veto/trigger effects in this energy range?

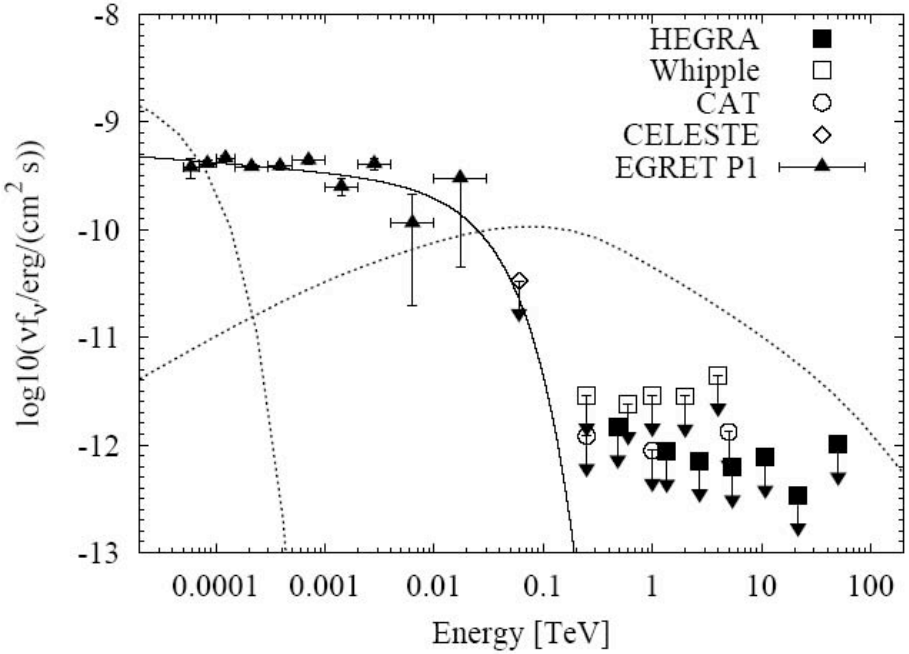
An aside on break finding

- I should mention that I wrote this talk without a good understanding of power laws.
  - They're known as great things for plotting a flea next to an elephant
  - (Or hiding an elephant)
- On the left: a quick measure of a break before and after resolution
  - The naïve measurement (two lines intersect) moves the break three times more than the bias itself
  - (Although effect is <10%)



Crab pitfalls (cont.)

- There is a pulsar in the Crab. While it should be negligible by 100GeV, it may confuse break measurements.
- Finally, what about the southern hemisphere?



The Crab Pulsar spectrum

(Astrophys.J. 614 (2004) 897-913)

Other alternatives for cross calibration:

- Galactic diffuse? (S. Digel)
  - Has all the right characteristics (bright, hard, steady)
  - May be incompatible with IACT On-Off background subtraction.
- How about other sources of gamma rays? Egret catalog top ten:
  - Pulsars Geminga, Vela probably don't go to high energy
  - Blazars are variable
  - But there are a lot of other sources (Mrk 421?)

THE THIRD EGRET CATALOG OF HIGH-ENERGY GAMMA-RAY SOURCES

R. C. Hartman,[1] D. L. Bertsch, S. D. Bloom,[2,3] A. W. Chen,[2] P. Deines-Jones,[2] J. A. Esposito,[4,5] C. E. Fichtel, D. P. Friedlander,[6] S. D. Hunter, L. M. McDonald,[6] P. Sreekumar,[4] and D. J. Thompson
Code 661, NASA Goddard Space Flight Center, Greenbelt, MD 20771
B. B. Jones, Y. C. Lin, P. F. Michelson, P. L. Nolan, and W. F. Tompkins
W. W. Hansen Experimental Physics Laboratory and Department of Physics, Stanford University, Stanford CA 94305
G. Kanbach, H. A. Mayer-Hasselwander, A. Mücke,[7] M. Pohl,[8] and O. Reimer
Max-Planck-Institut für Extraterrestrische Physik, D-85748 Garching, Germany
D. A. Kniffen
Department of Physics, Hampden-Sydney College, Hampden-Sydney, VA 23943
E. J. Schneid
Northrup Grumman Corporation, Bethpage, NY 11714
C. von Montigny[9]
Landessternwarte Heidelberg, D-69117 Heidelberg, Germany
R. Mukherjee
Barnard College and Columbia University, Department of Physics, New York, NY 10027
and
B. L. Dingus
Physics Department, University of Utah, Salt Lake City, UT 84112
Received 1998 August 26; accepted 1999 February 23

SOURCE	F/Fcrab	P	ID
3EG J0834-4511	3.69	1.7	Vela
3EG J0633+1751	1.56	1.7	Geminga
3EG J0534+2200	1.00	2.2	Crab
3EG J2020+4017	0.55	2.1	gam Cyg SNR?
3EG J1746-2851	0.53	1.7	Gal center
3EG J1710-4439	0.50	1.9	PSR B1706-44
3EG J0530+1323	0.41	2.5	blazar
3EG J0210-5055	0.38	2.0	blazar
3EG J1255-0549	0.33	2.0	3C 279
3EG J2033+4118	0.32	2.0	
3EG J1104+3809	0.06	1.6	Mrk 421

One possibility: use many sources

- If you have multiple sources with significantly different power law index, you can disentangle the energy scale/acceptance.
- Larger statistics of sources will help to get out of uniqueness of Crab pitfall, and should have more statistical power than crab alone
- No need to worry about issues involved in measuring a break: measuring fluxes is easier
- However, much careful thought needs to go into deciding what sources are an appropriate set

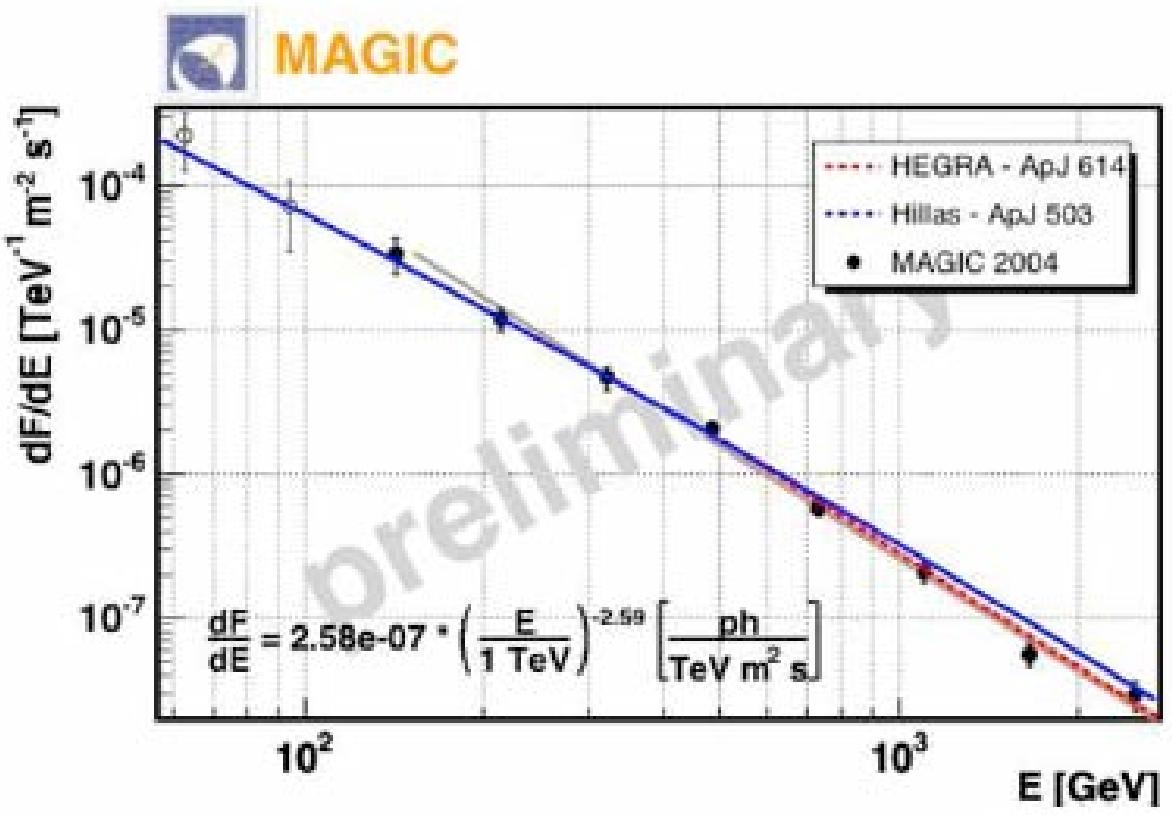
Questions I've been neglecting

- What accuracy do we need from cross-calibration?
  - This requires understanding the physics goals
  - Of course, it's hard to predict the needs before they arise, so now is the time to explore how well we can do
- What are the systematic uncertainties of the LAT at these energies?
  - The SRD is silent on this matter
  - I assume people in the audience know much more than myself on this subject

Conclusion:

- The LAT will greatly increase the measuring power of the IACTs
  - It may even provide useful input to UHECR experiments (which also rely on modeling)
- We need to calibrate the LAT at high energies to understand calorimeter energy scale and resolution at up to 100GeV for cross calibration
- We need to look carefully at the systematics introduced in measuring a power law break
- There is definitely more than one way to skin the cross calibration cat:
  - Look for other sources
  - Use multiple sources together to reduce systematics
  - Allow cross calibration at multiple energies and multiple sites

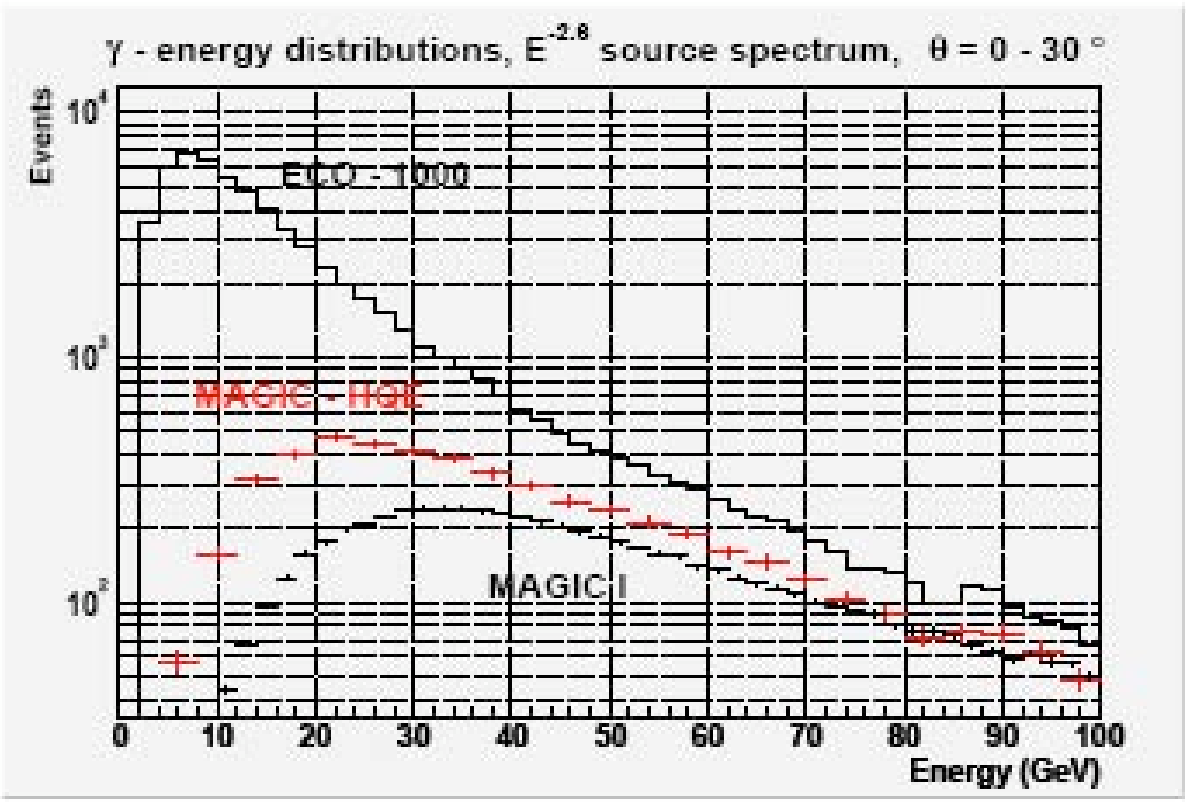
Cross calibration is on the horizon



First MAGIC Crab result (astro-ph/0503534)

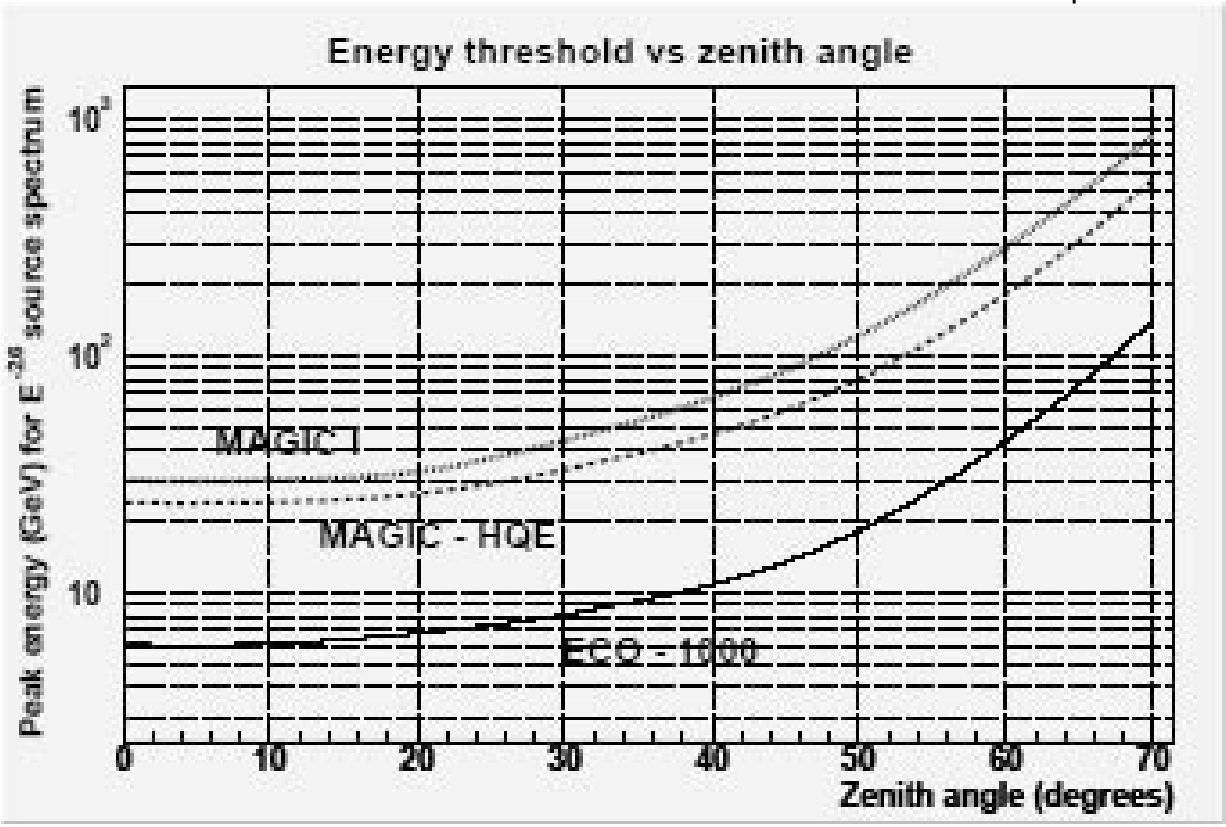
Backup slides follow

Astro-ph/0403180



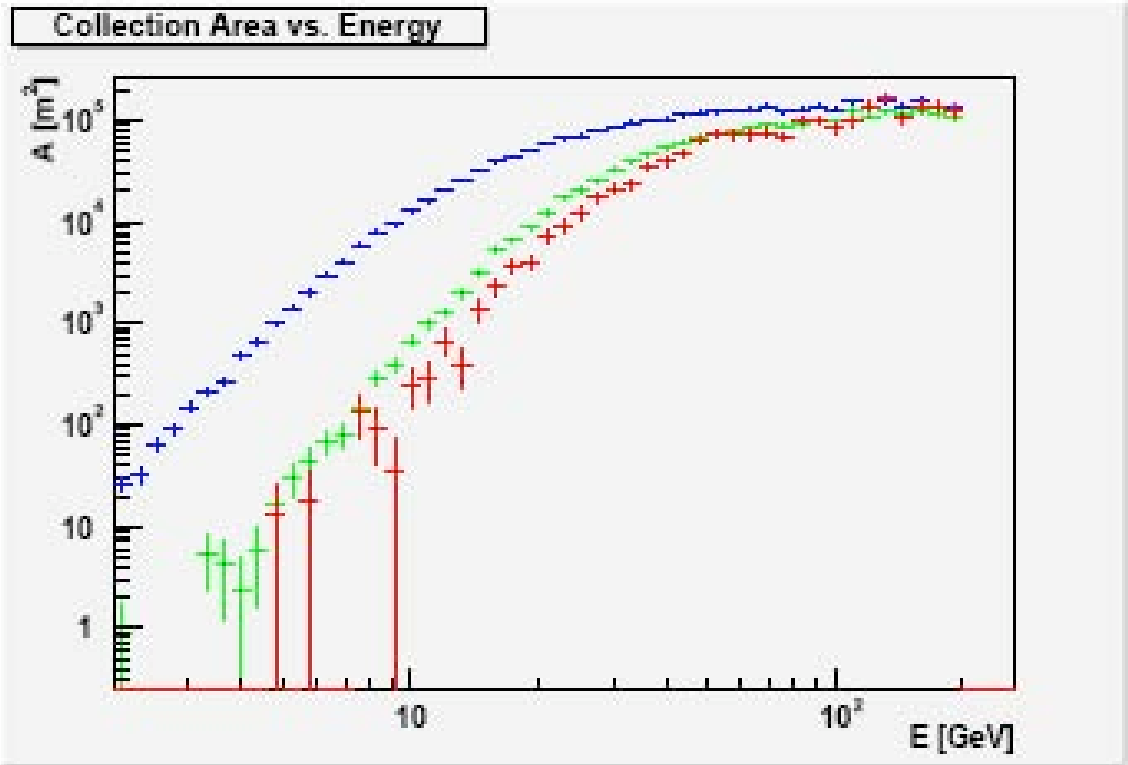
Magic, Magic II, and proposed instrument simulated spectra

Astro-ph/0403180



Magic, Magic II, and proposed instrument threshold vs angle

Astro-ph/0403180



Magic, Magic II, and proposed instrument area vs. Energy