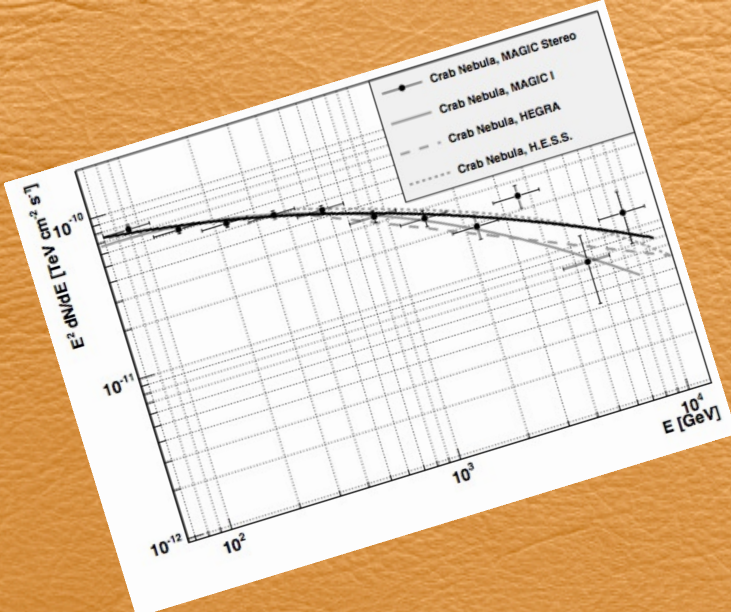

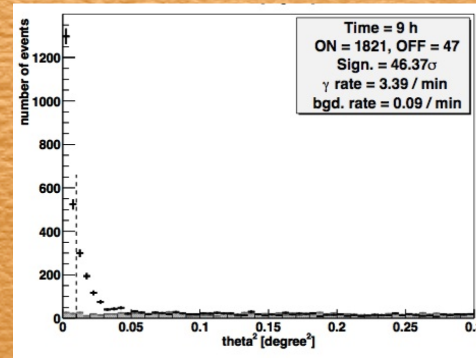

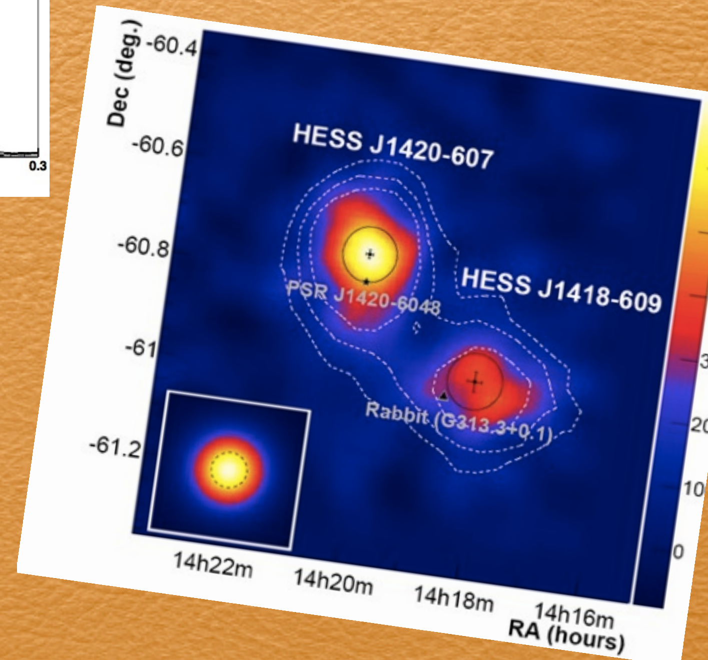

Physical Results

Elisa Prandini
Padova University

MeraTeV – 5 October 2011

Summary

Summary

* Intro

Summary

* Intro
* The data taking

Summary

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* Signal extraction

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* Sky maps

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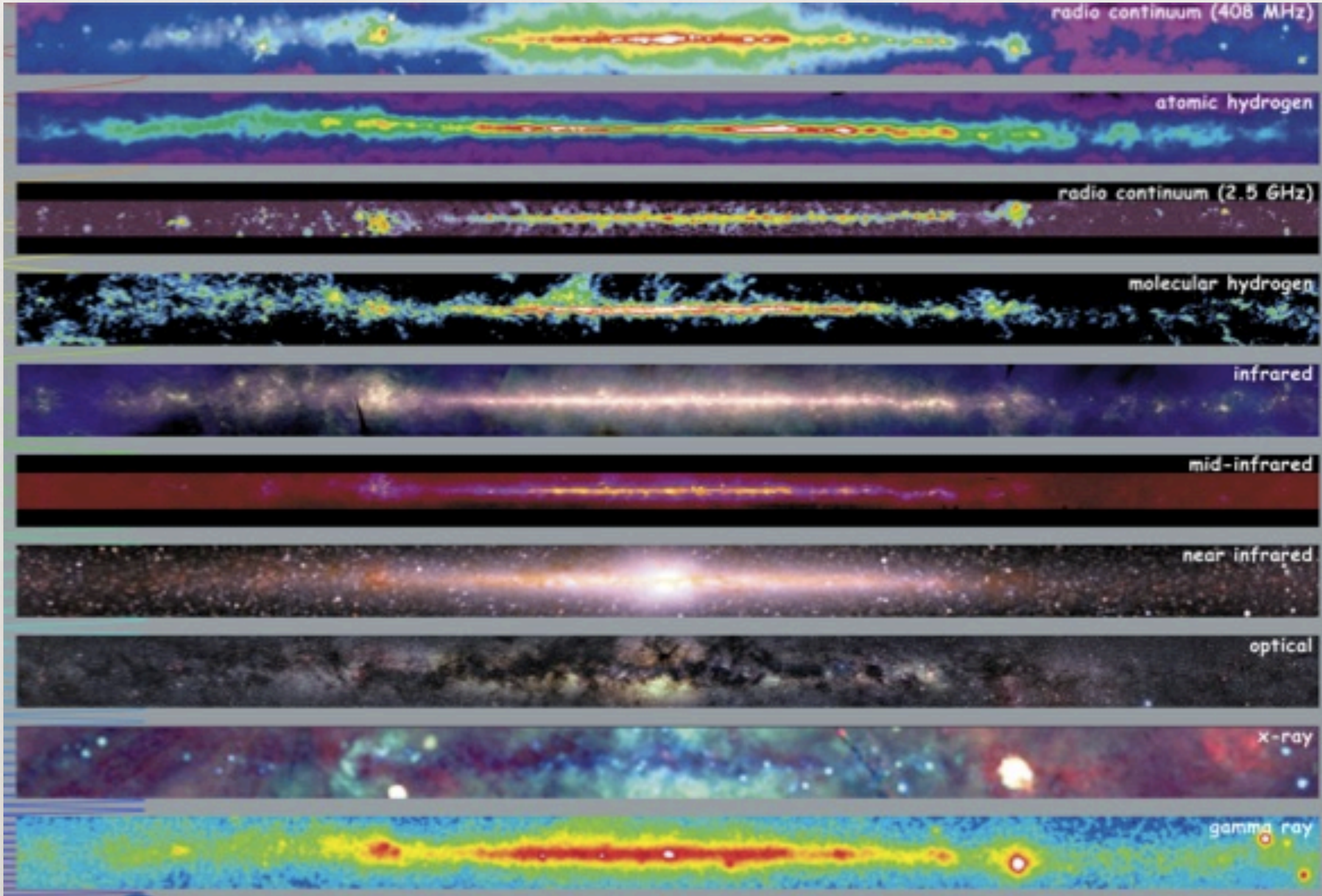
* Integral and differential fluxes

The Milky Way emission



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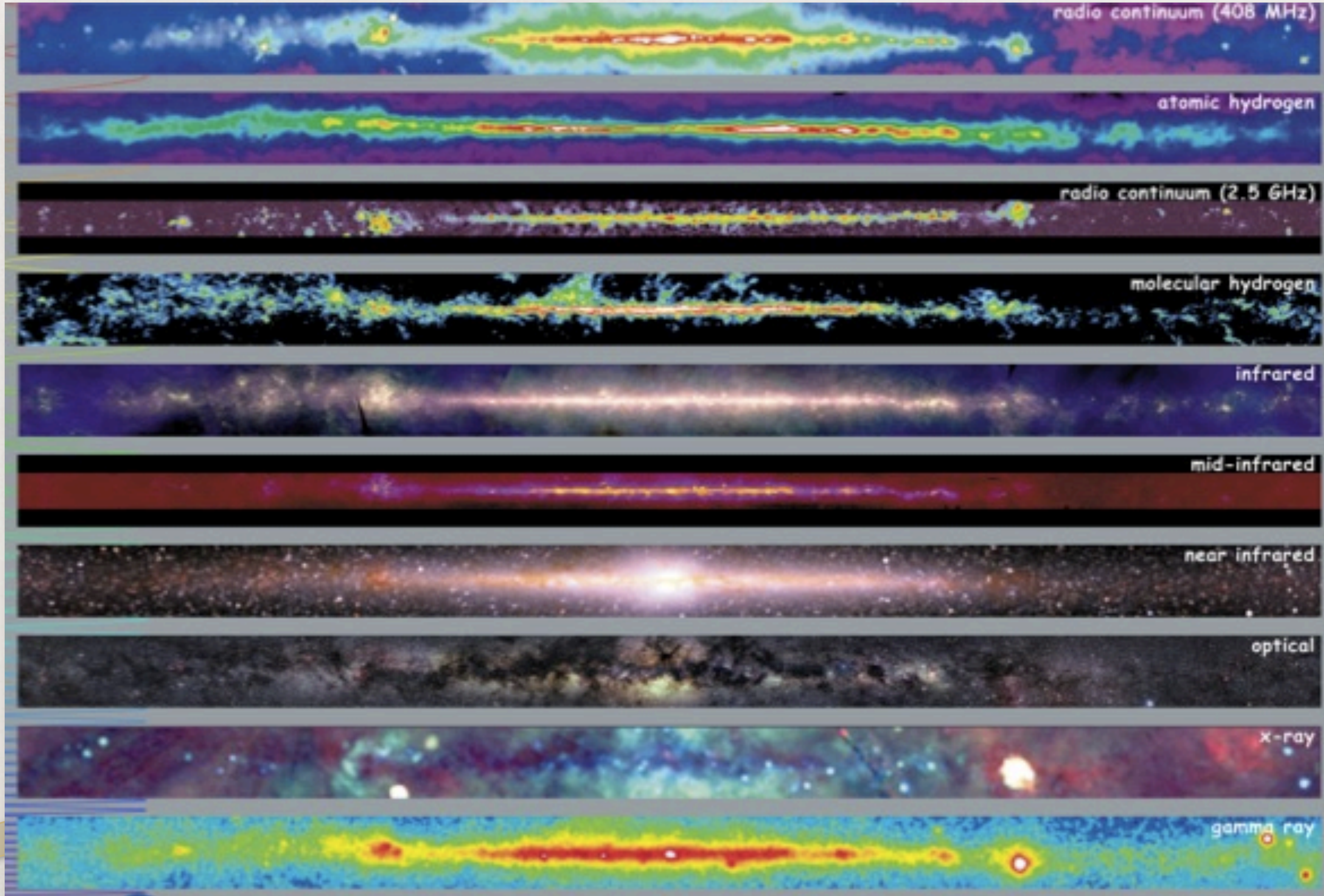
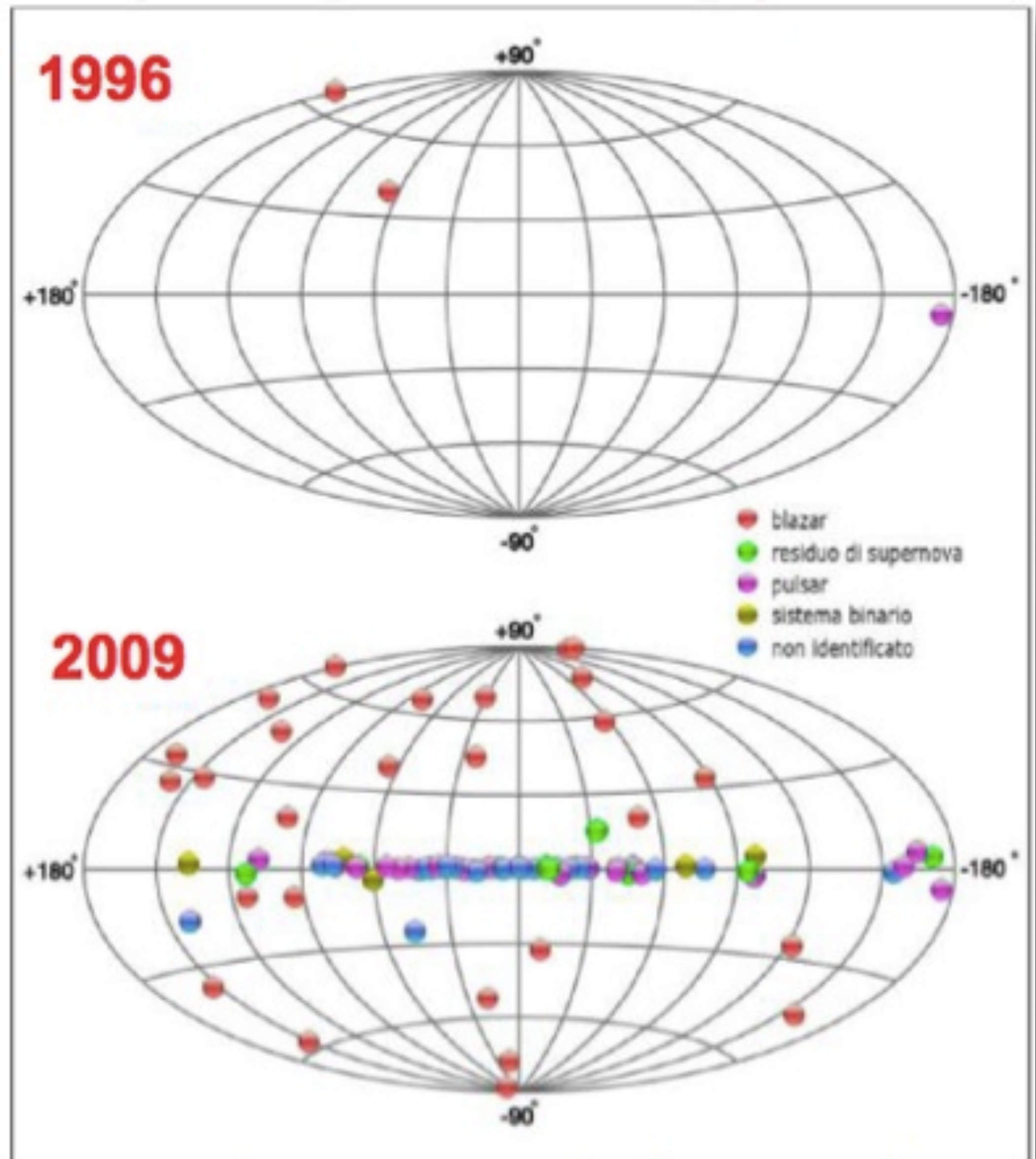


… WE ARE HERE

The VHE gamma-ray sky



IACTs in the

MAGIC

VERITAS

H.E.S.S.

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LIGHTCURVE

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EVENT → SET OF PARAMETERS CHARACTERIZING THE SHOWER

REMEMBER: EVENT → IS A SHOWER (INDUCED BY A CR)

The analysis

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- Image cleaning and Hillas Parameters calculation
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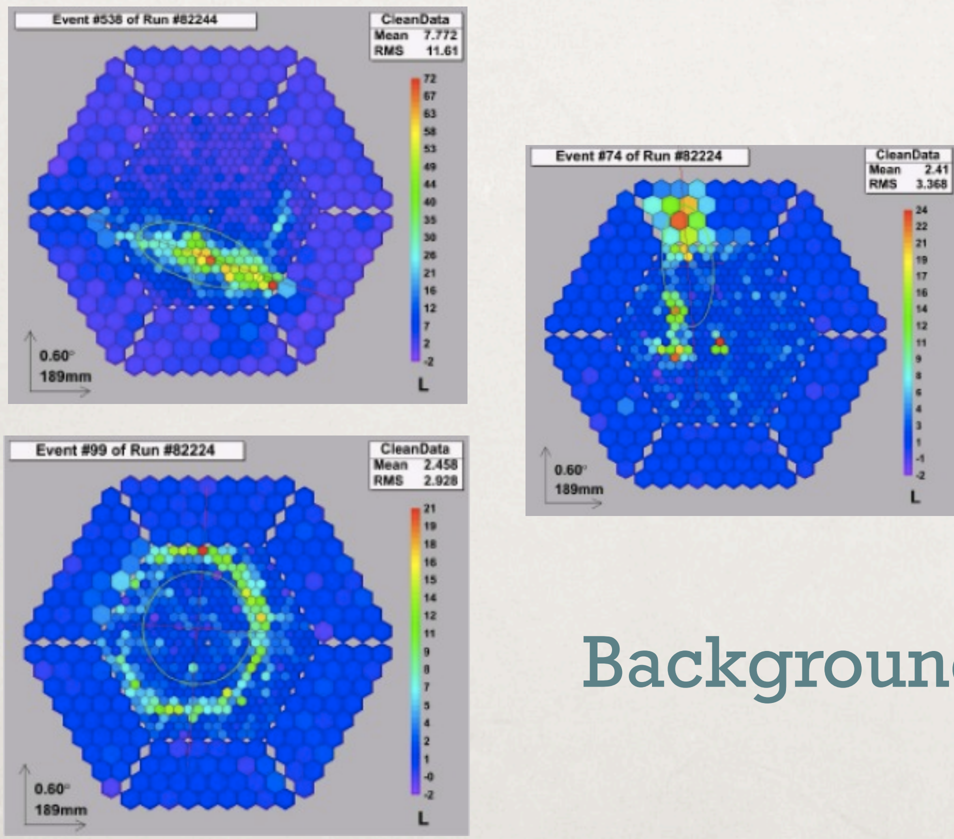
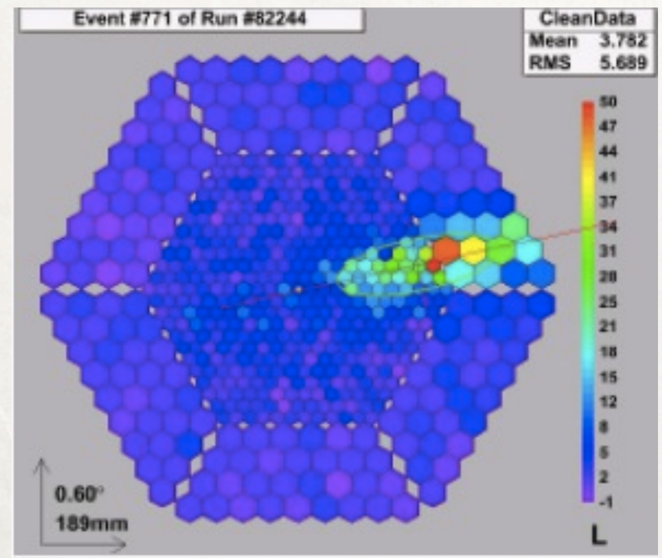
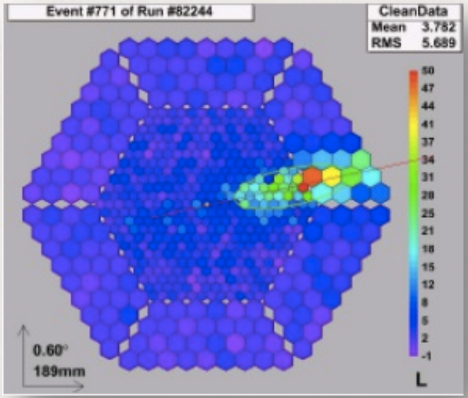


Background



Gamma-like

Characteristics of a γ-like event



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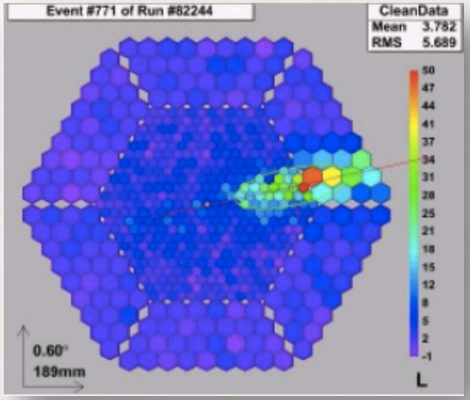

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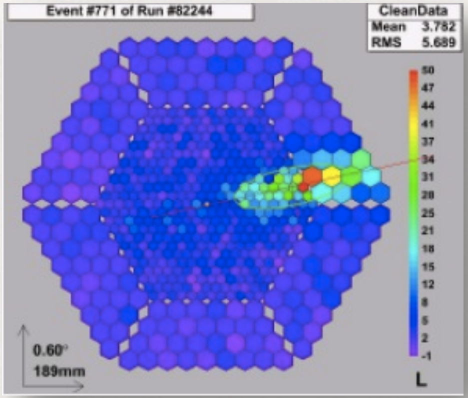

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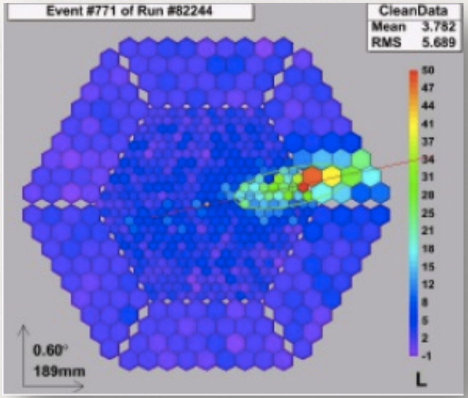

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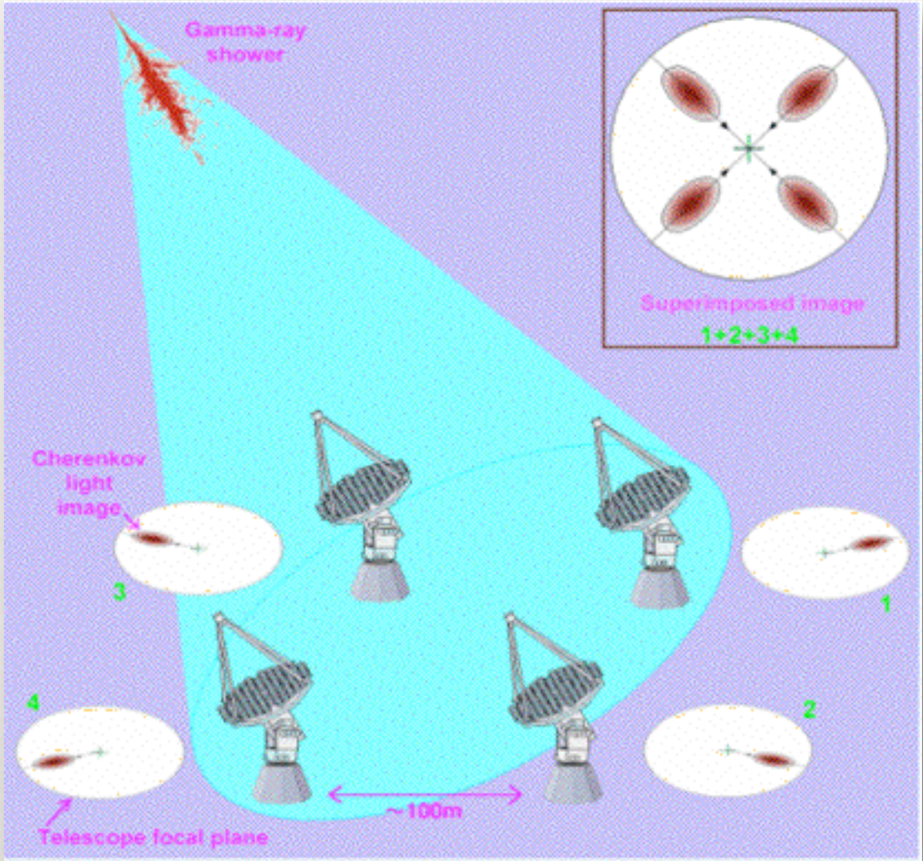

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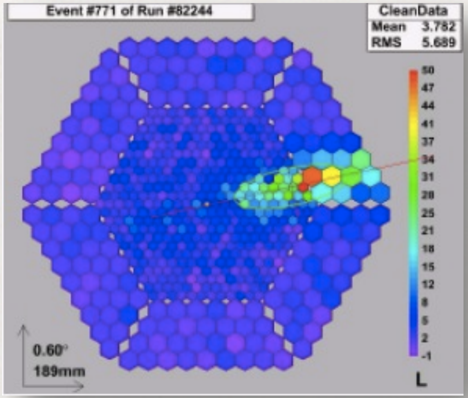

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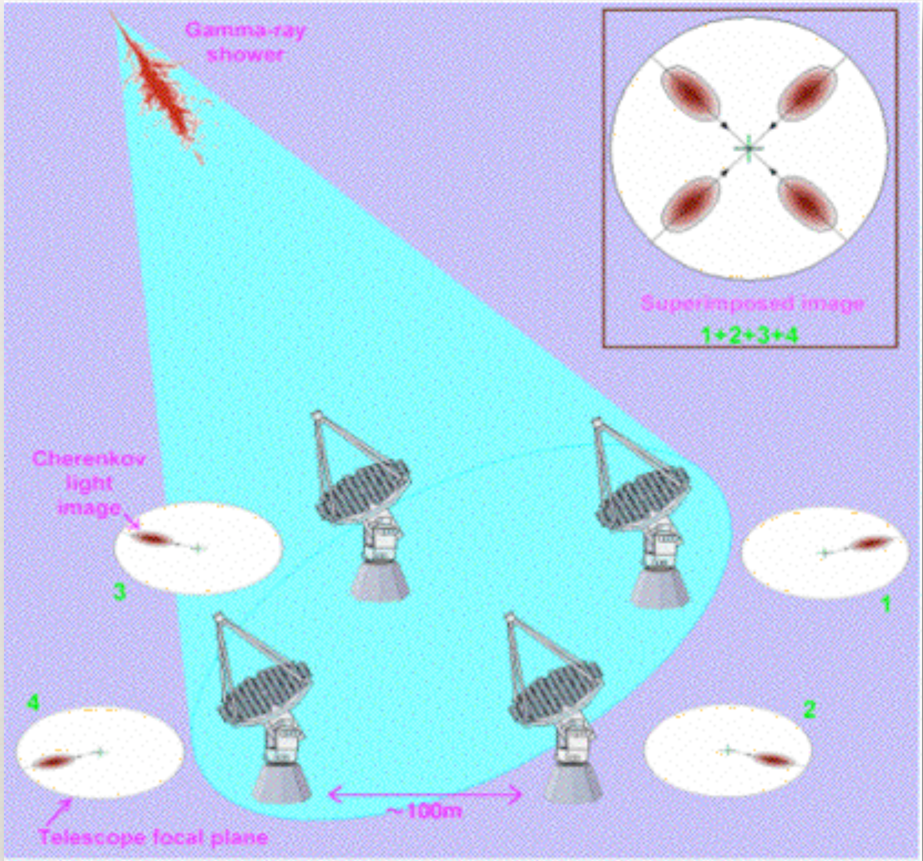

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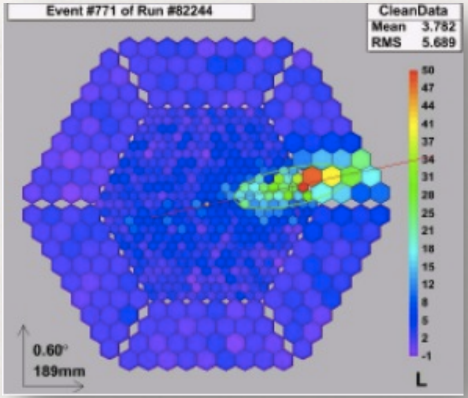

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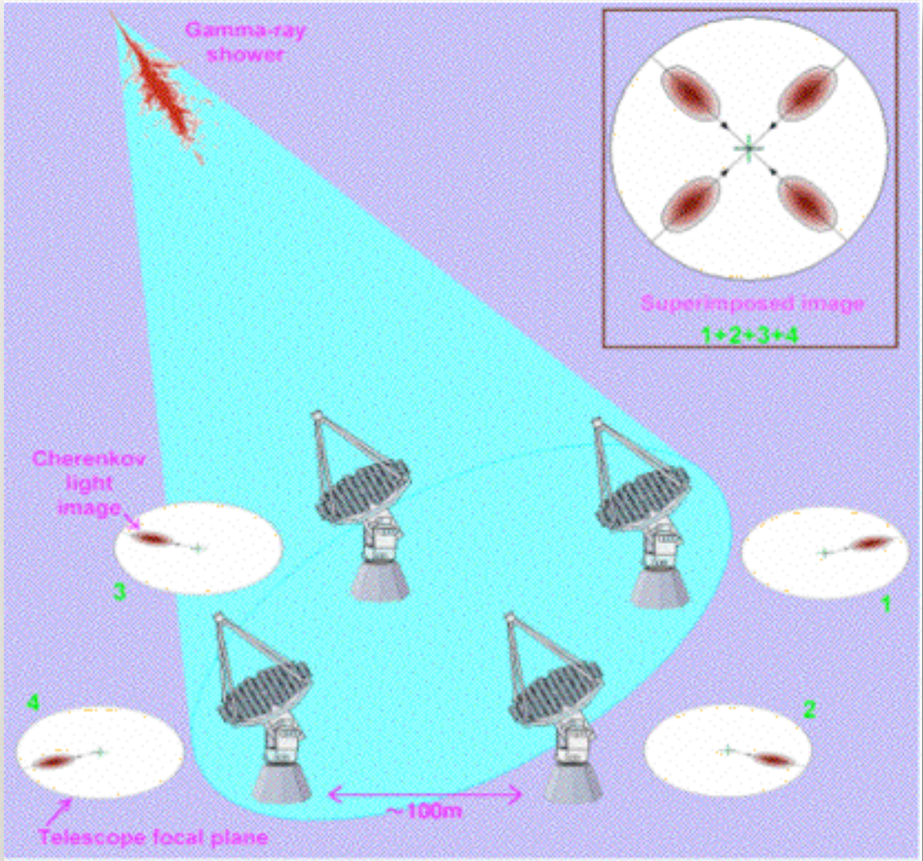
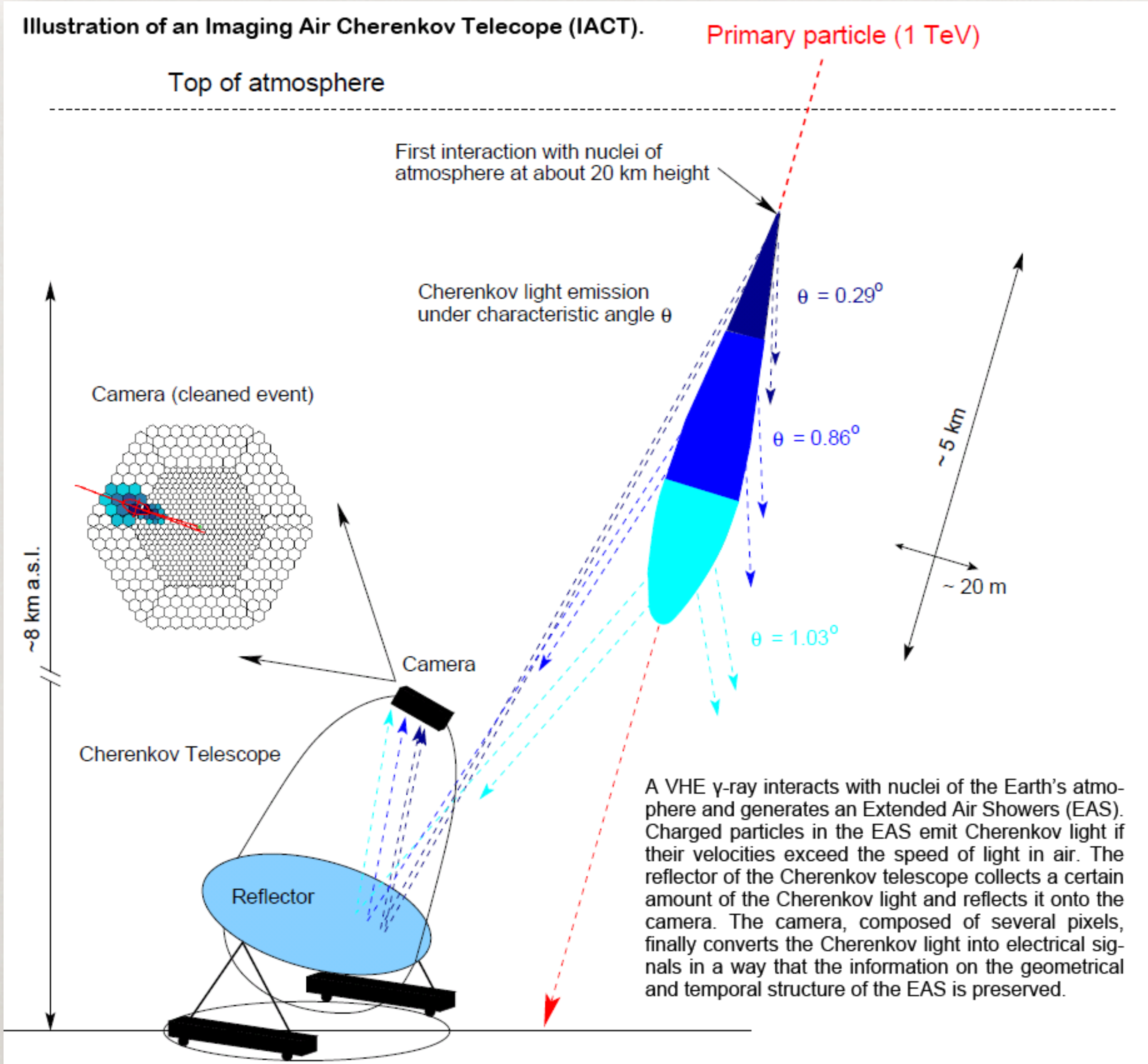
Helpful to "detect the signal"

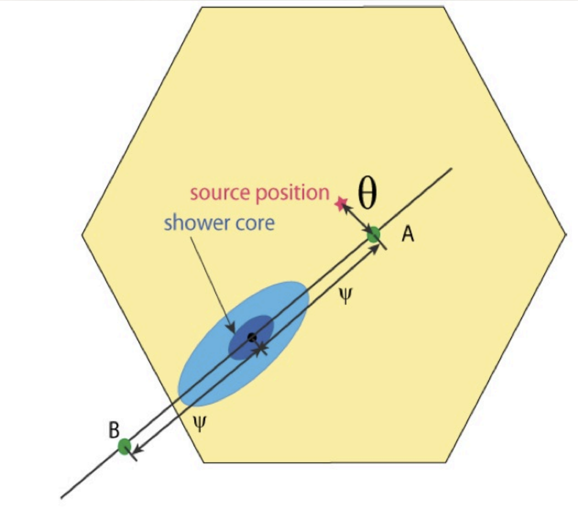


The incoming direction



Characteristics of a γ-like event

Therefore if we plot the parameter related to the **reconstructed incoming direction**, the gamma-like events will have it close to the telescopes pointing direction



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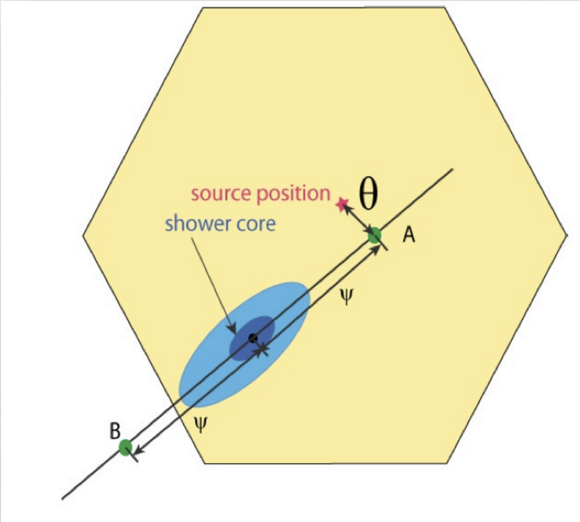

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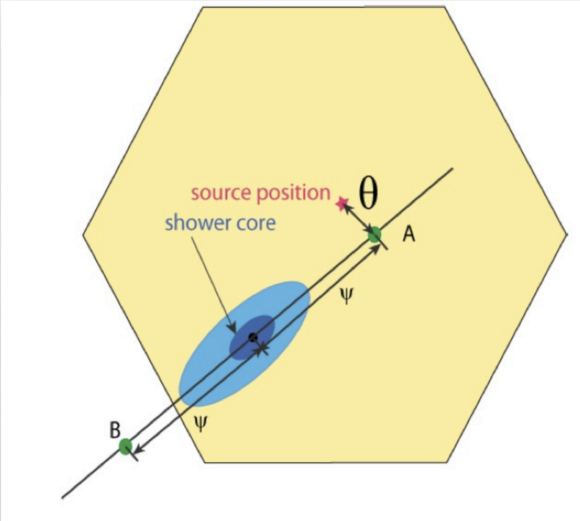

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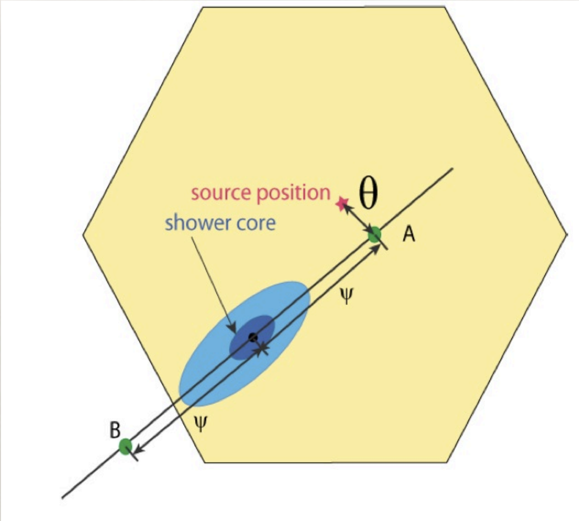

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AND WHAT ABOUT THE HADRONS?

They are randomly distributed!

A better position reconstruction

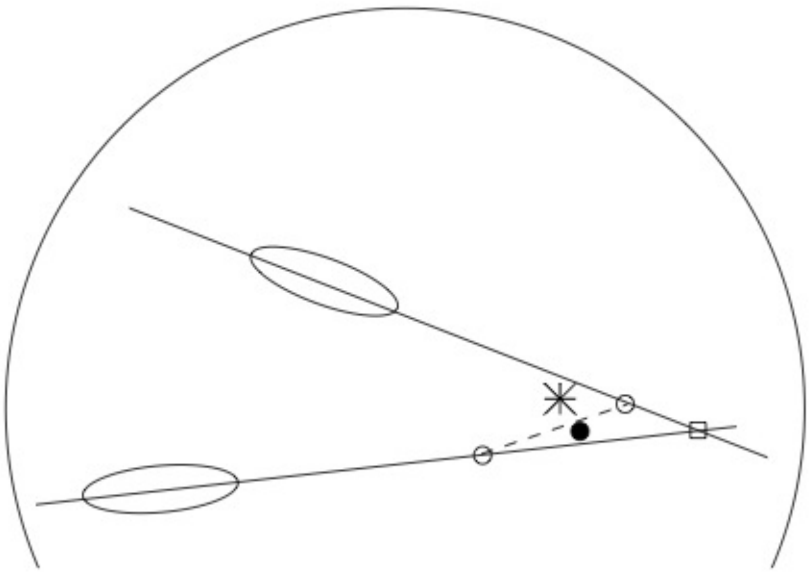
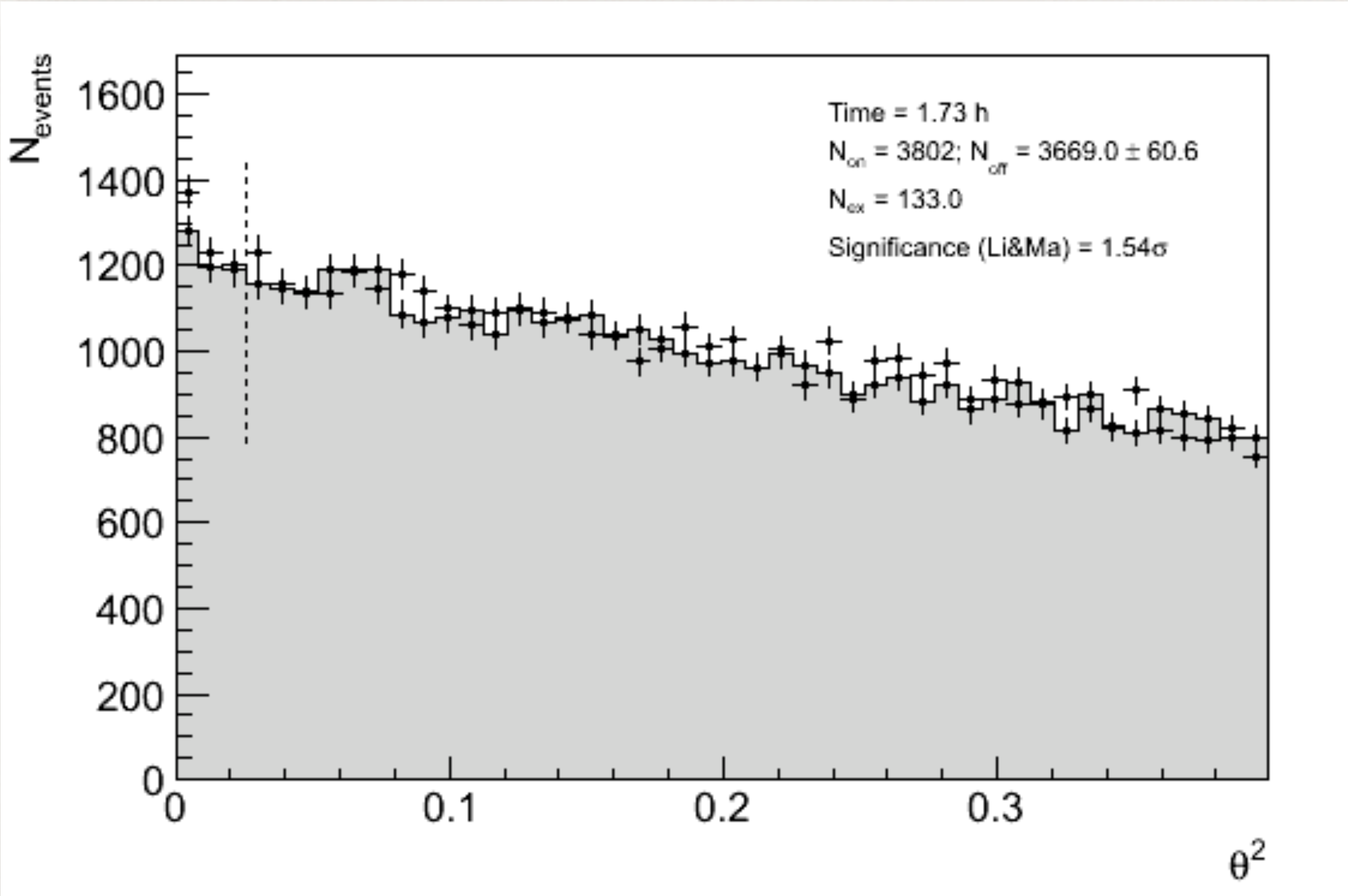


Figure 5: Principle of the Stereo DISP RF method. The crossing point of the main axes of the images is shown as an empty square, and the DISP RF reconstructed position from each telescope is an empty circle. The final reconstructed position (full circle) is a weighted average of those three points. The true source position is shown with a star.

* We use RF to reconstruct the most probable incoming direction in the camera plane
* Better reconstruction!

Finally: a Theta^2 plot!



* Where is the signal???

?

We have a problem…

?

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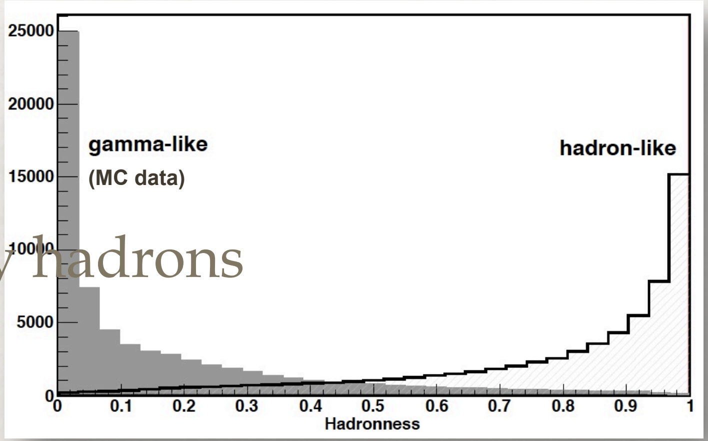
We have to reduce the number of bkg events:

→ *HADRONNESS* PARAMETER!

We apply a cut and reject the events that are likely hadrons



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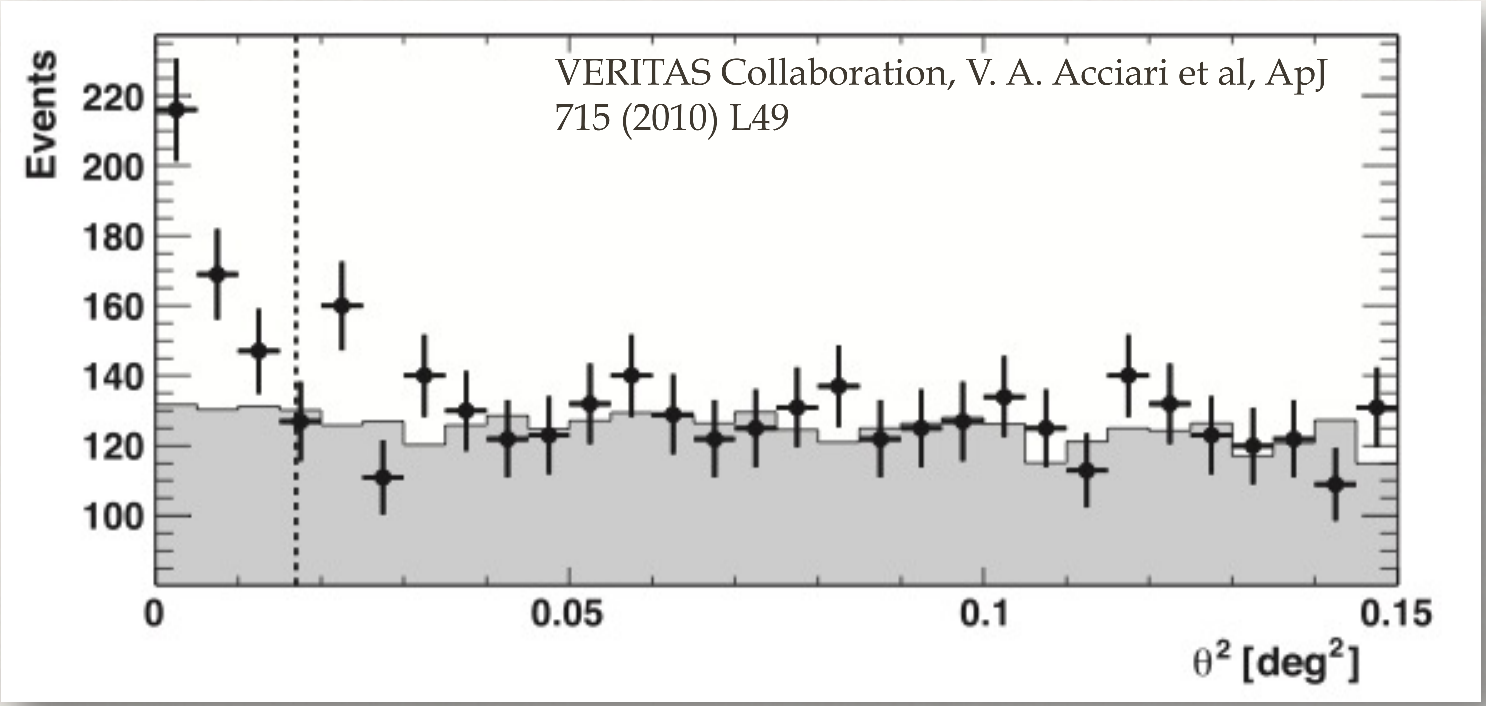

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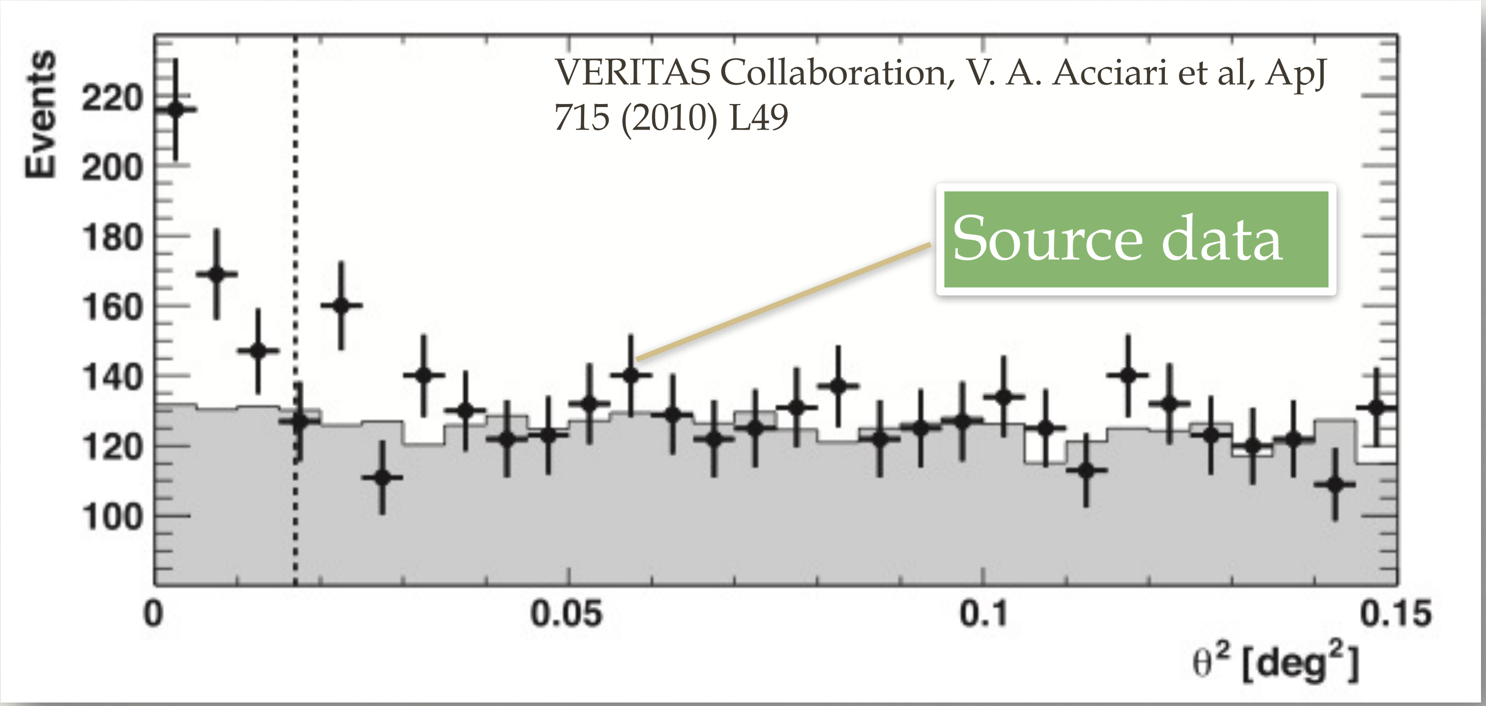

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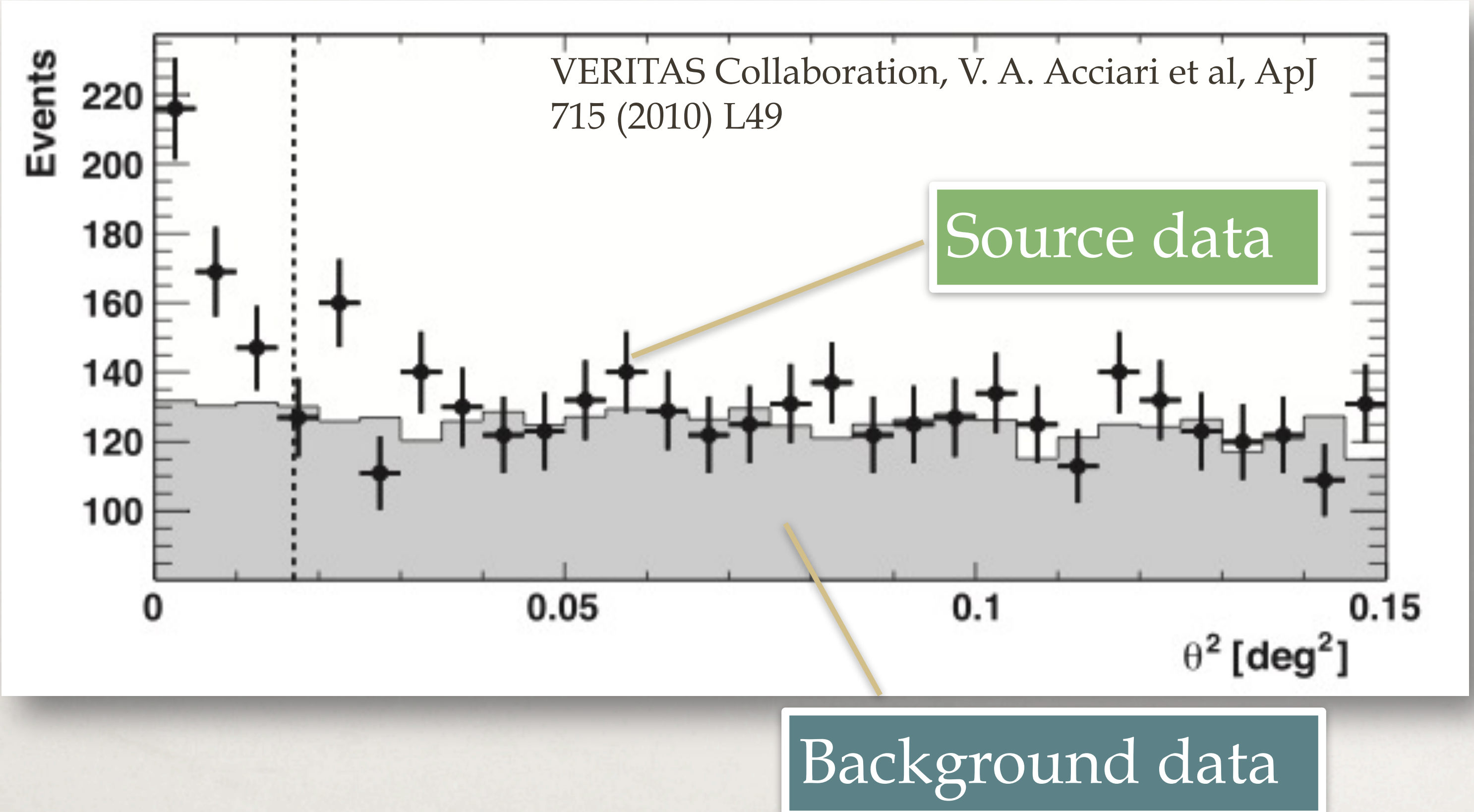

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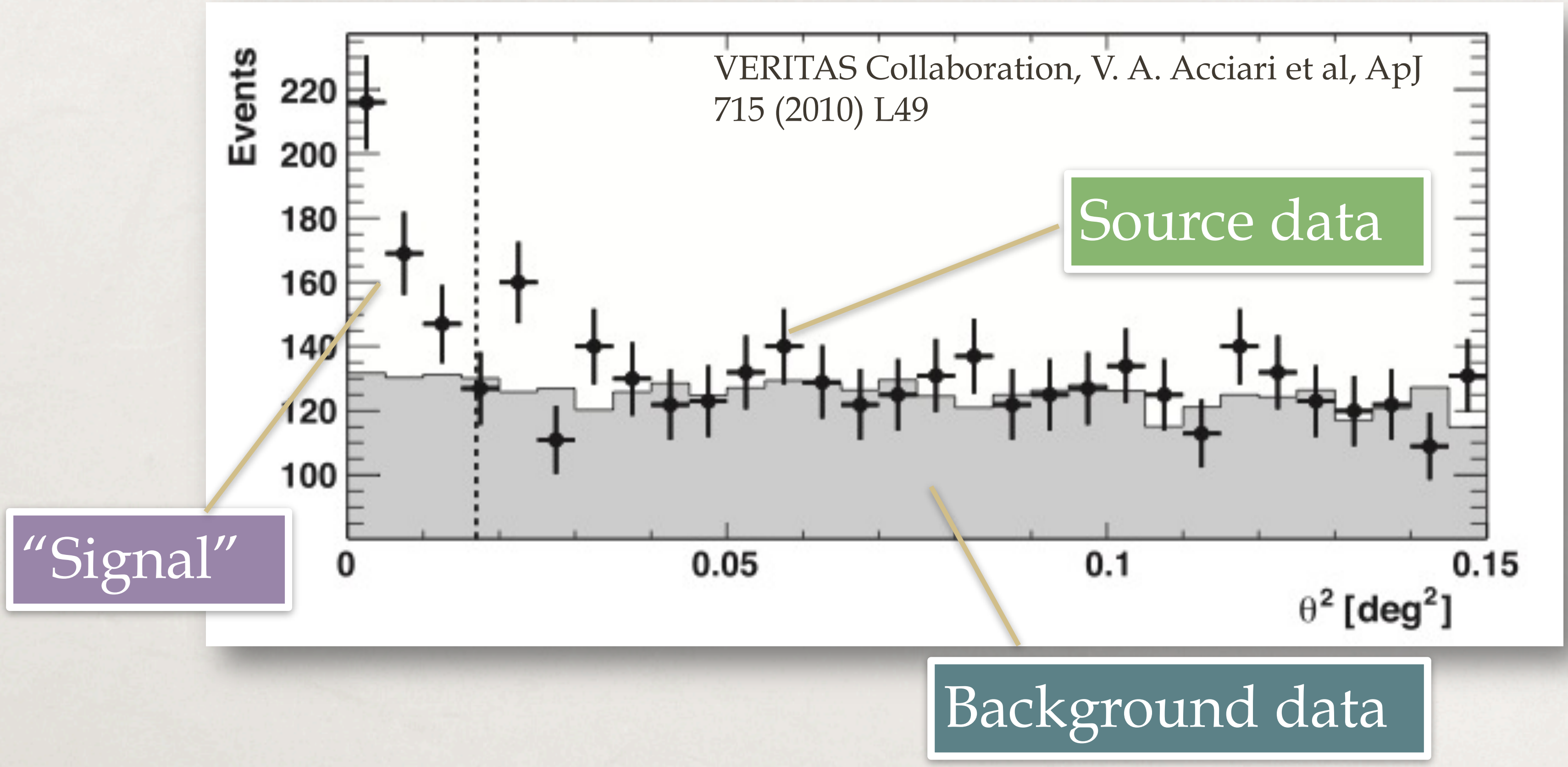

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  * PROBLEMS: - time consuming!
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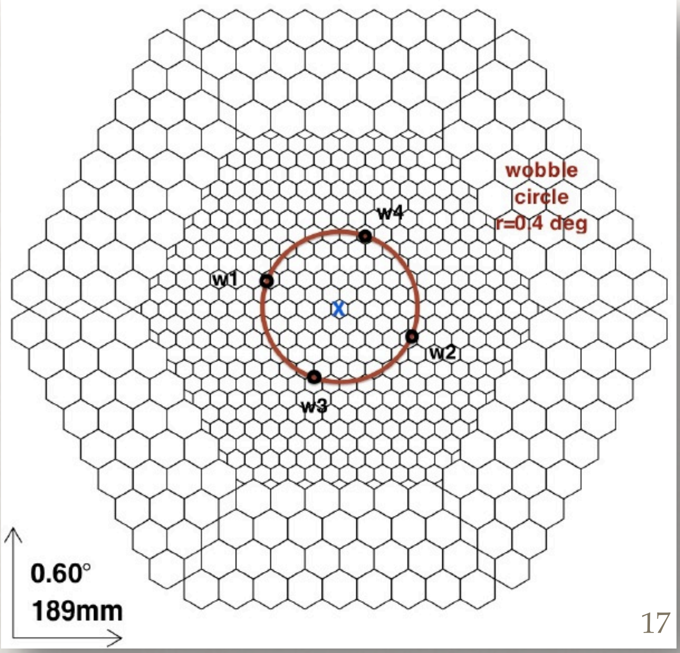
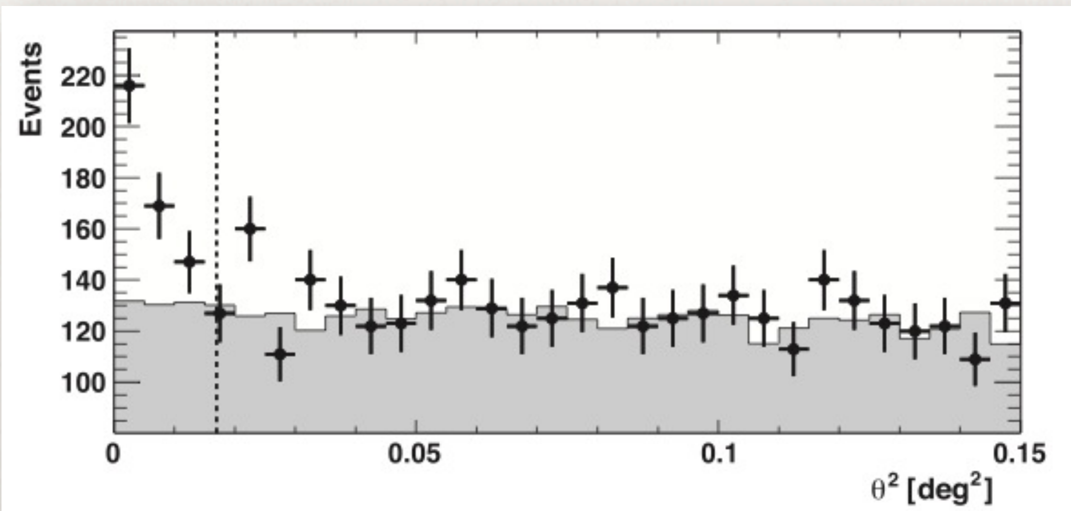
* **SOLUTION**: find an observing mode which allows to collect ON and OFF data simultaneously!
* *Wobble mode*: the telescopes point to a region 0.4 deg offset from the source (and the background can be extracted)

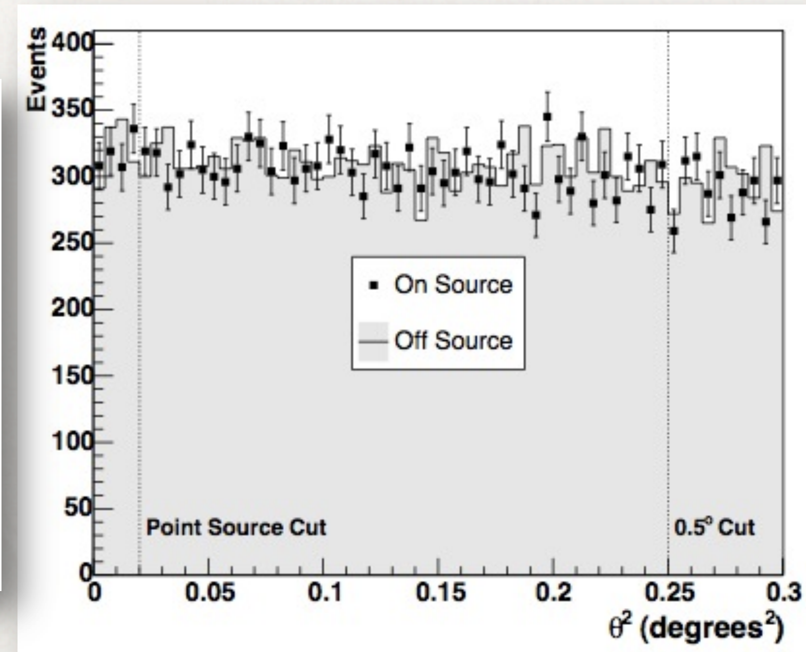


The Detection

* Some theta^2 plots:



VERITAS Collaboration, V. A. Acciari et al, ApJ 715 (2010) L49



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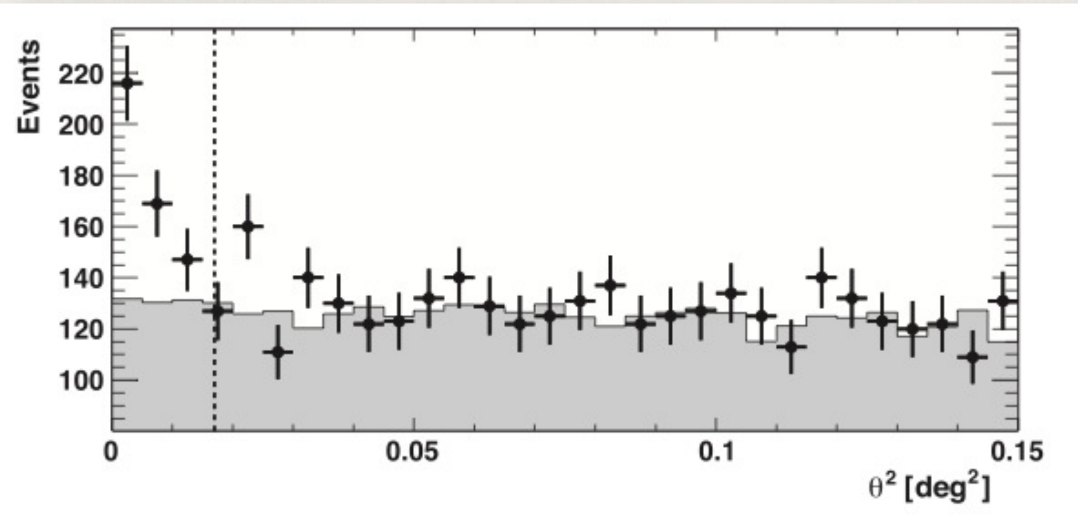

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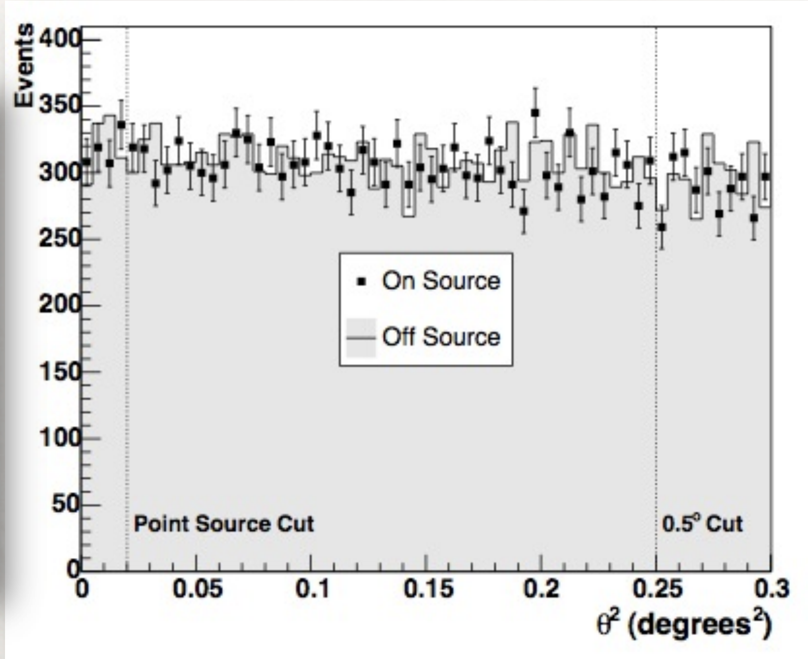

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Not always there is a detection of course…

The Significance

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* The common rule is that a source is detected if the significance of the signal **exceeds 5 sigma**!

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Examples

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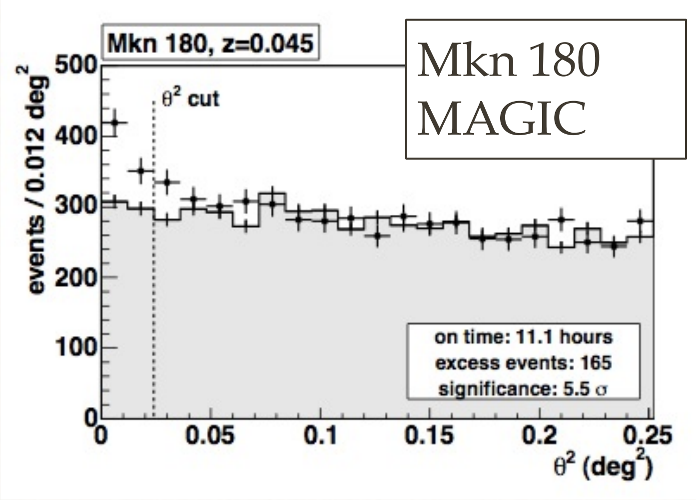

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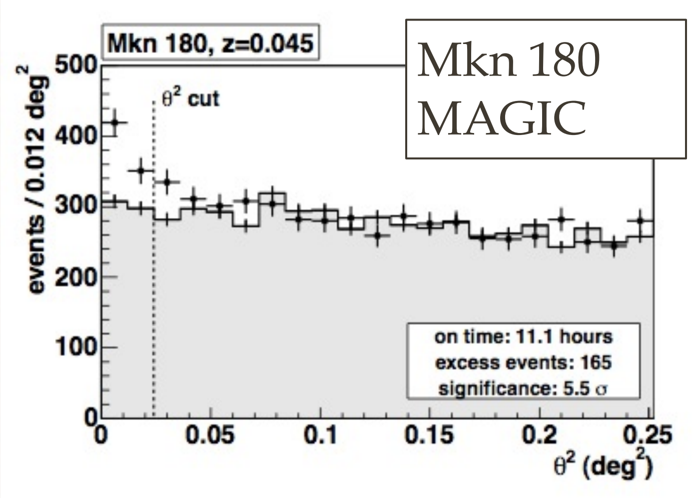

* A 10 sigma signal

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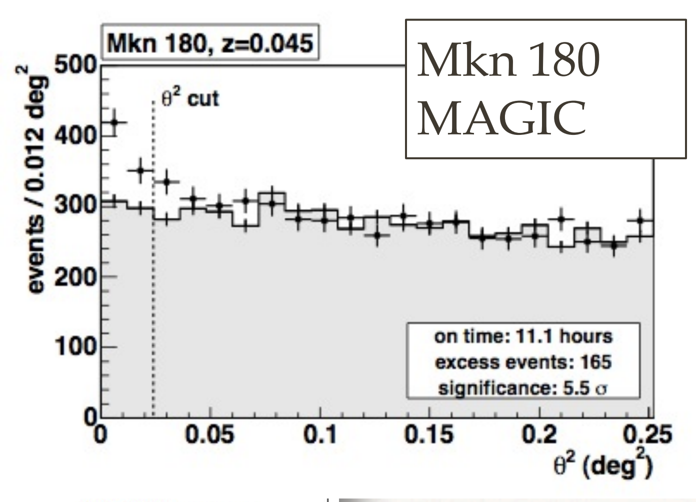

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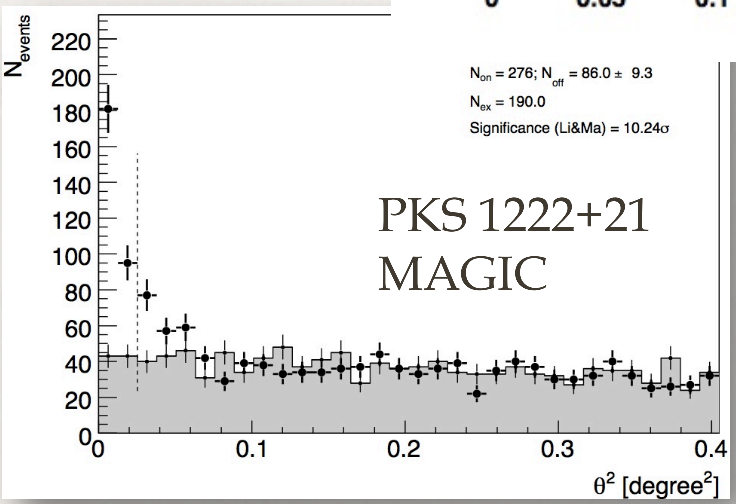

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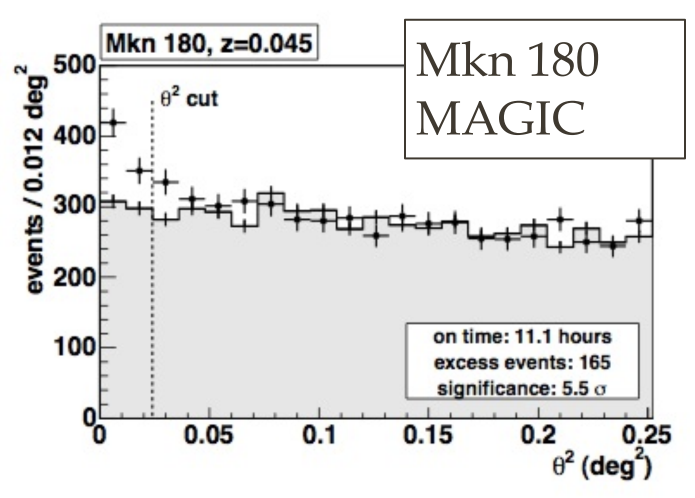

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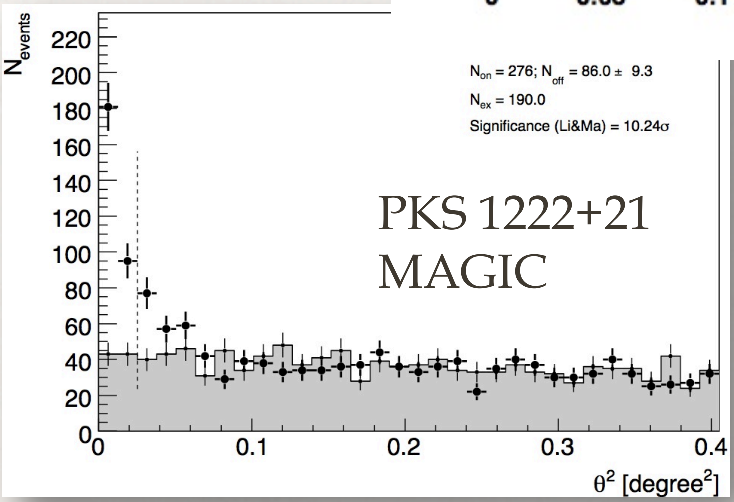

* A four sigma signal

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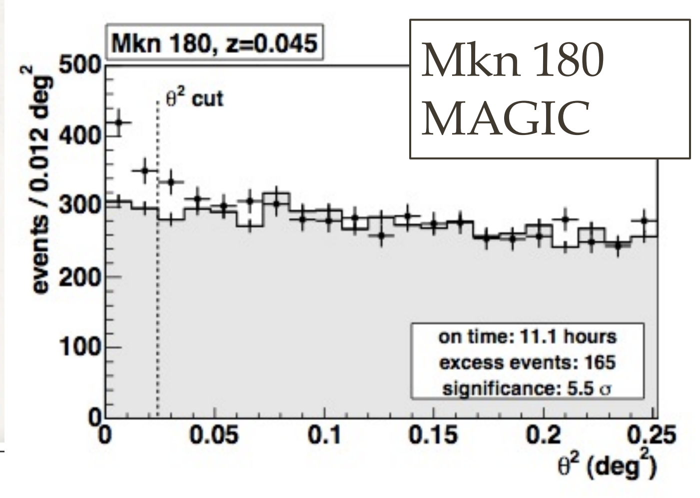

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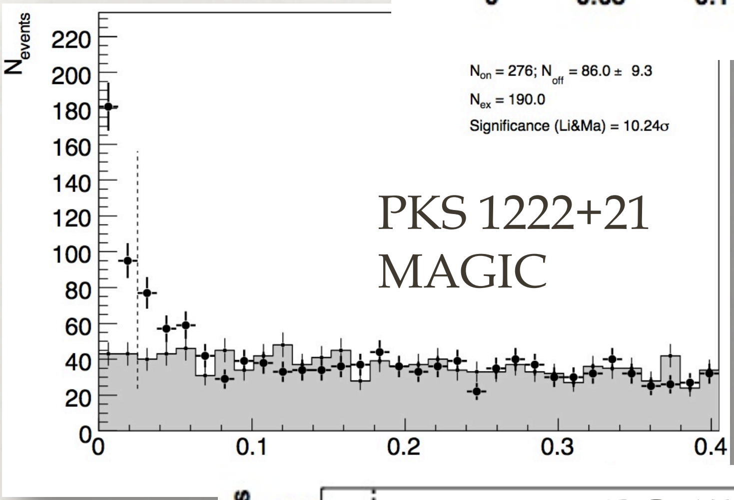

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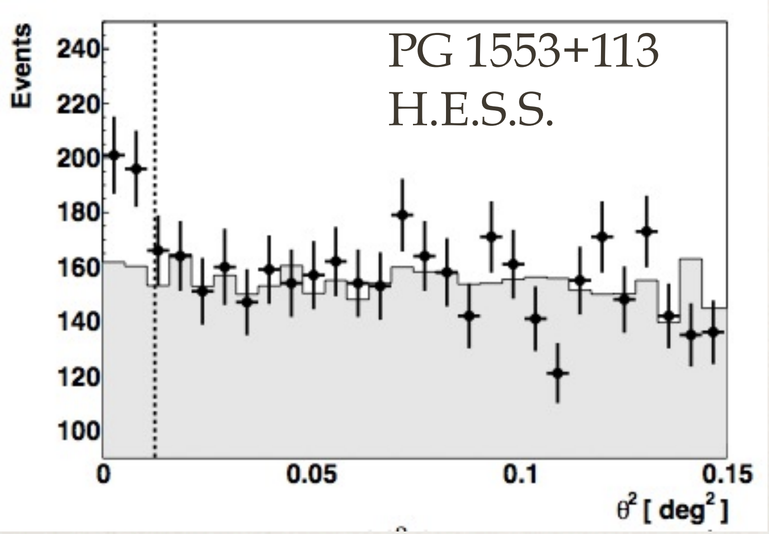
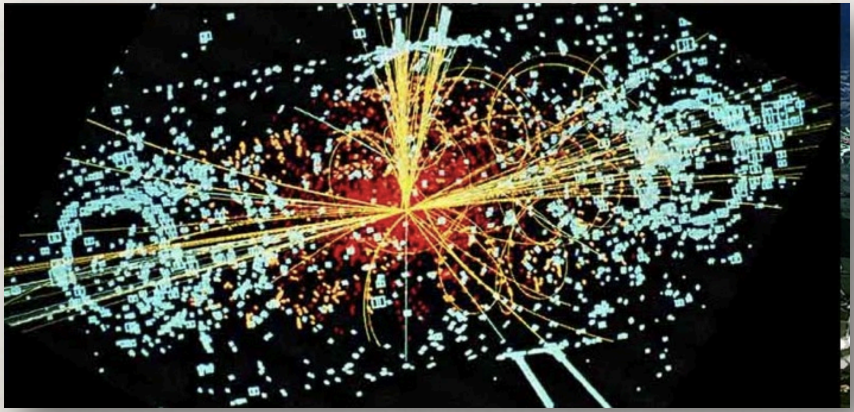
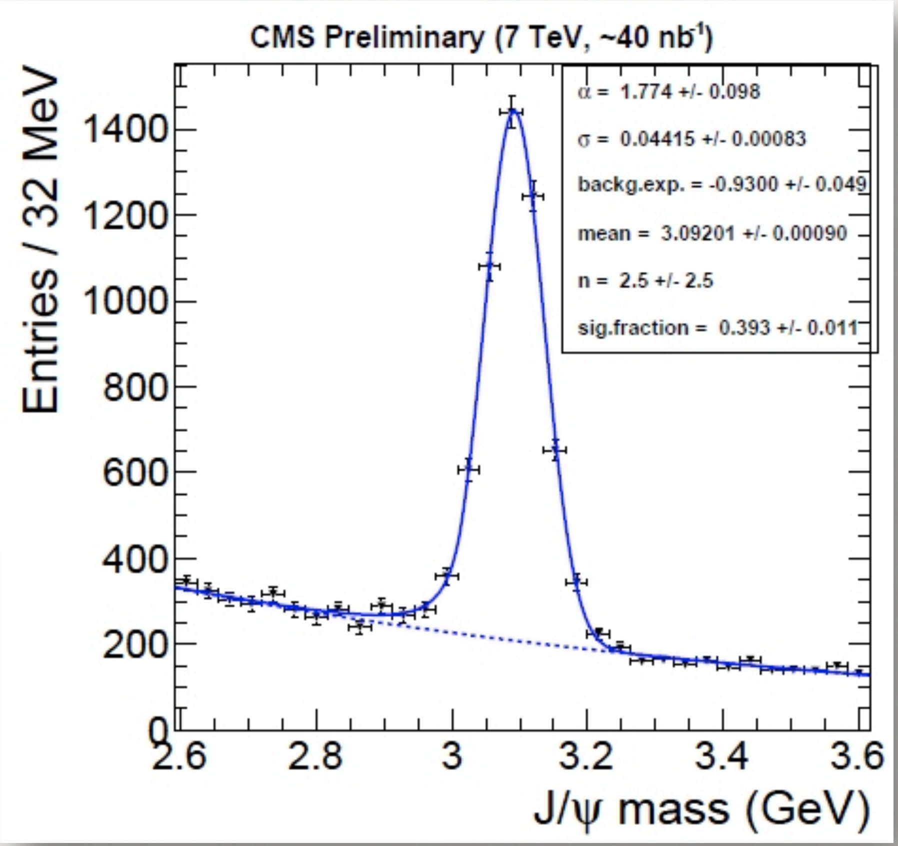


Where does this come from?

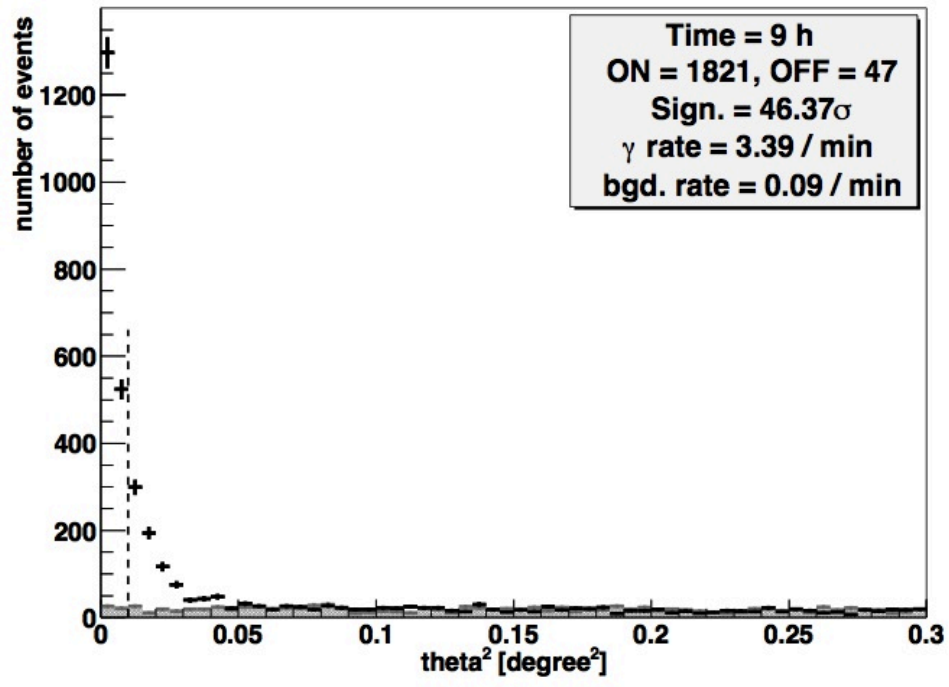
* Our language and tools come mainly from the particle physics community!

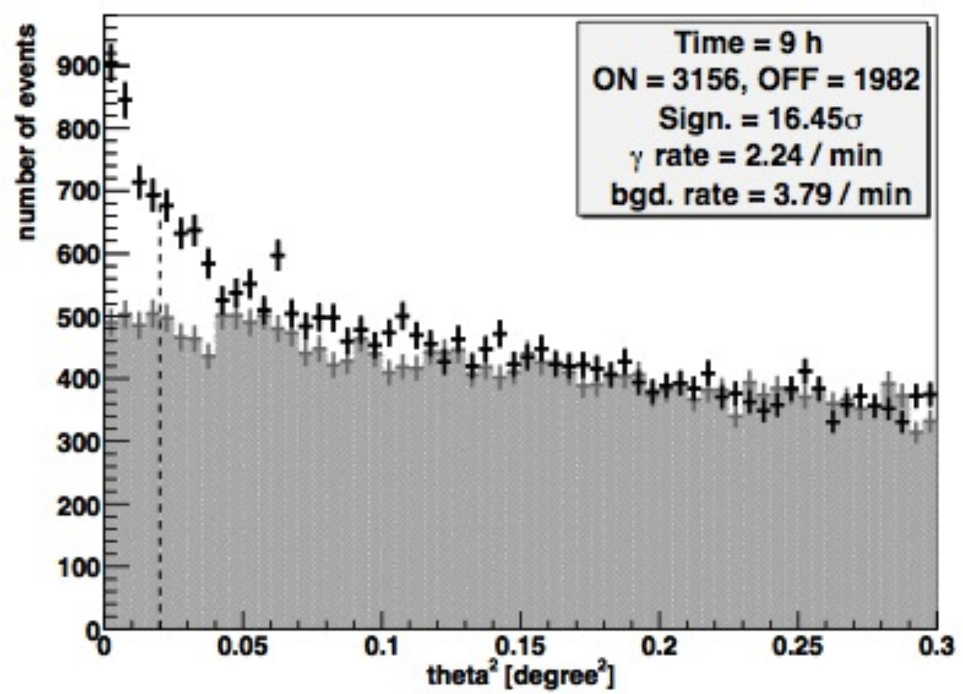




Standard Example: the Crab Nebula

* MAGIC observations of the Crab Nebula:





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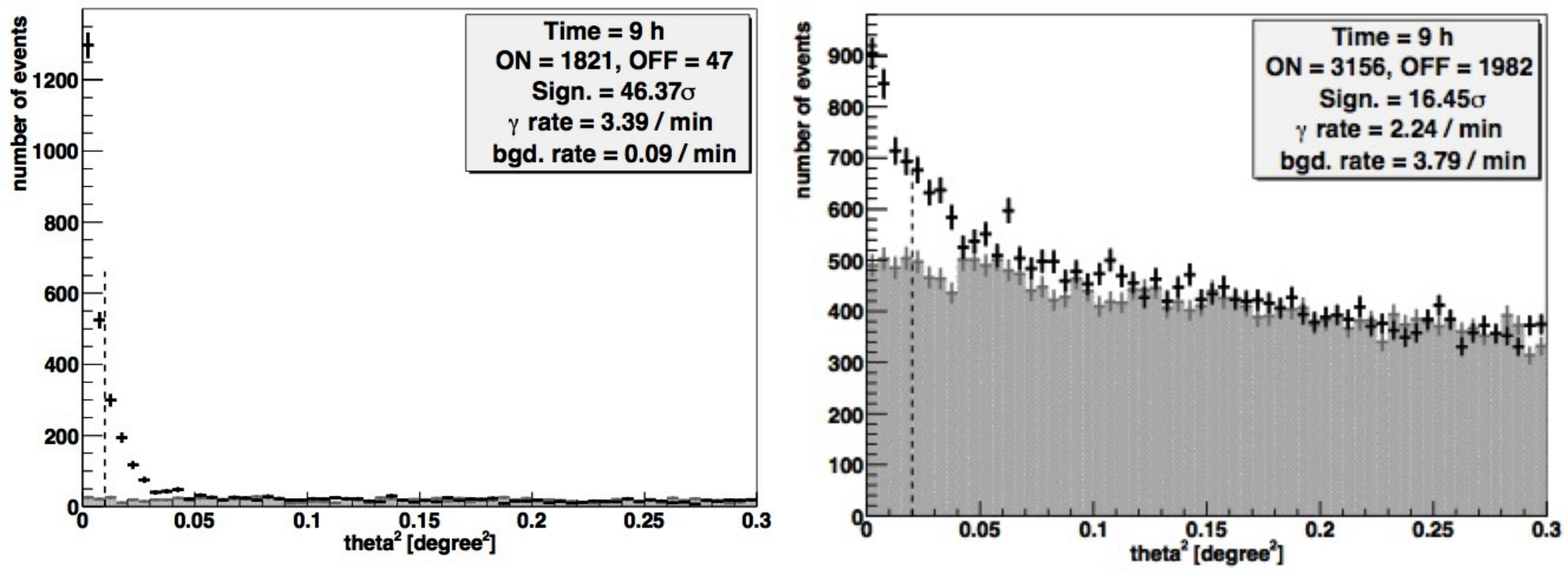

WHICH IS THE DIFFERENCE?

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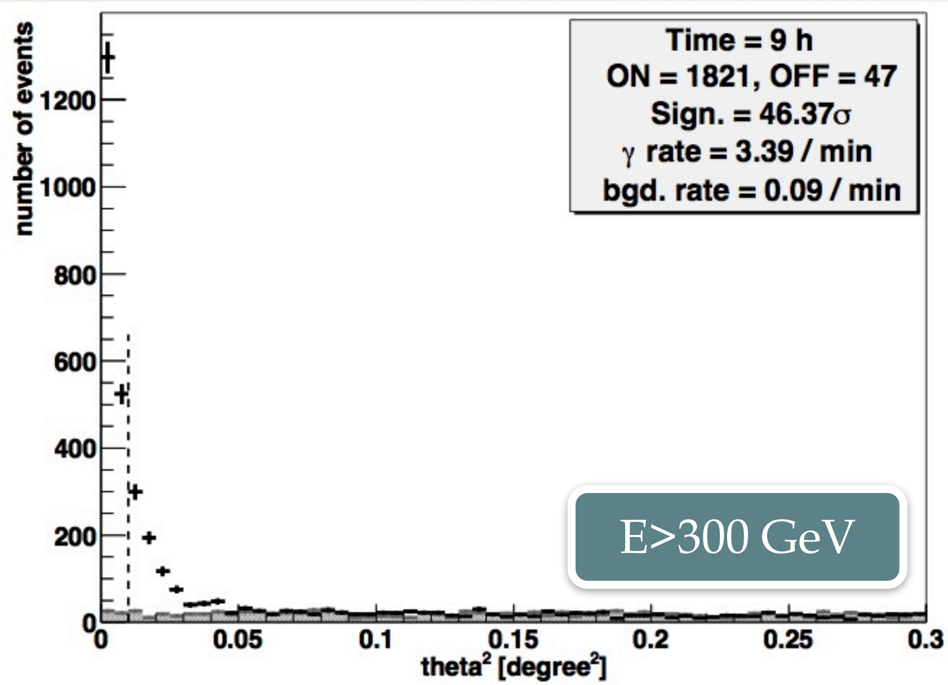
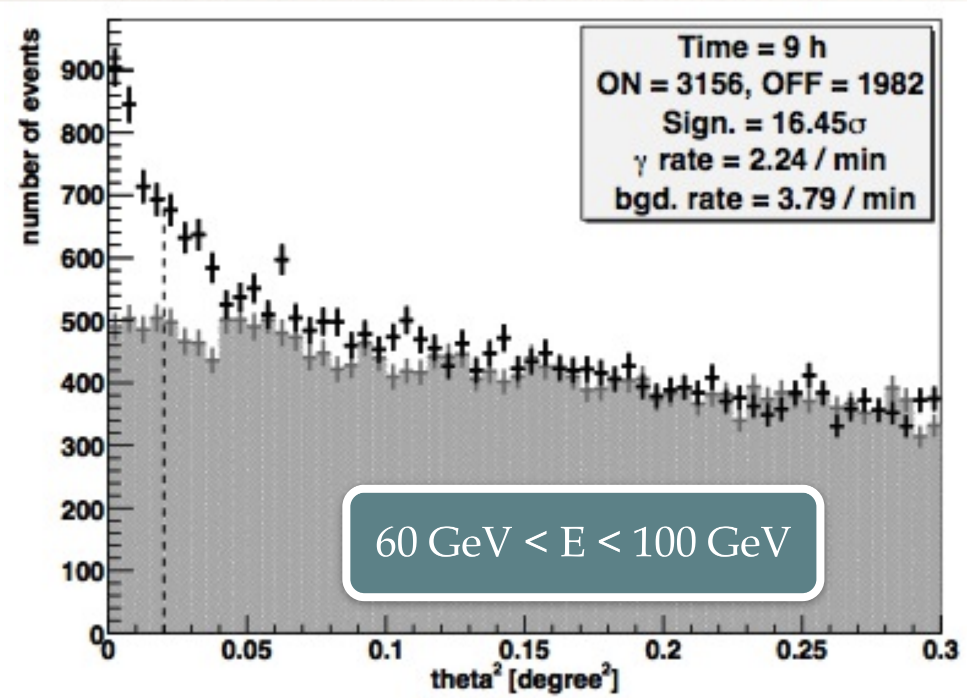
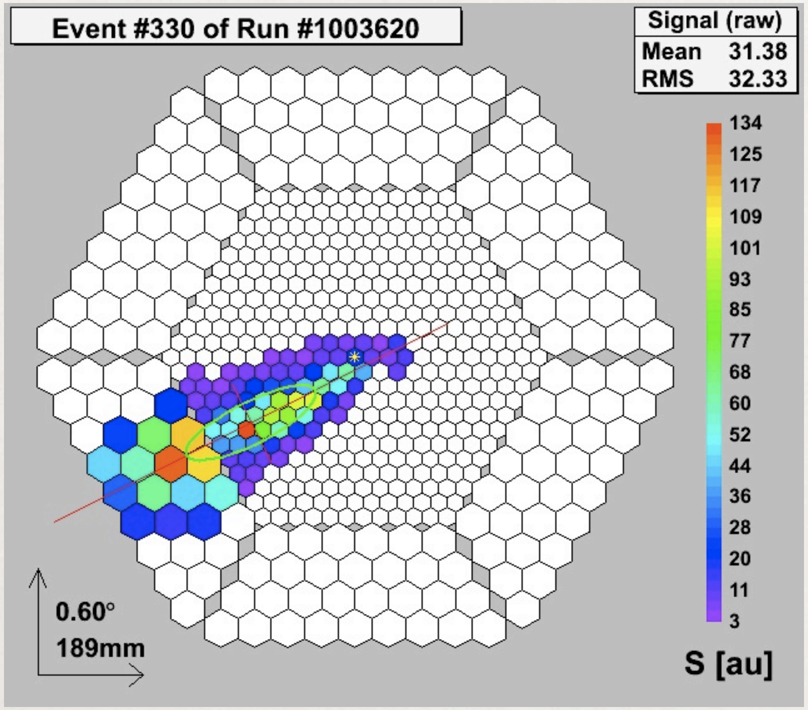
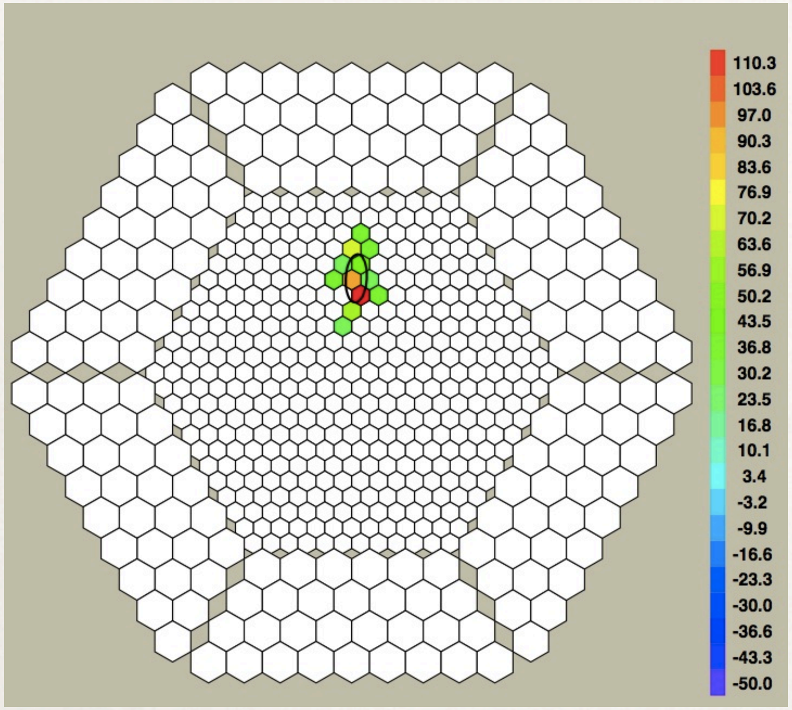




WHICH IS THE DIFFERENCE? → The energy range considered!

Images and Energy





At low energies the characterization of a gamma-like is much more difficult!!!

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THE ANALYSIS CAN CONTINUE

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  * Extended sources: are galactic and very large regions
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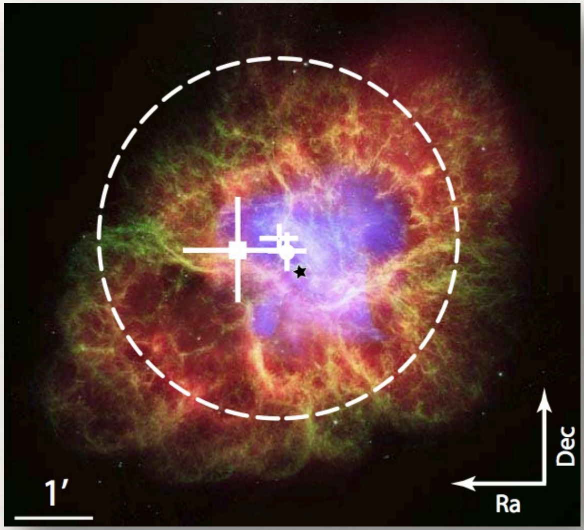
In order to localize the emission, we perform the so-called SKY MAP, that is a bi-dimensional map of the reconstructed incoming directions of the primary gamma rays

The sky map



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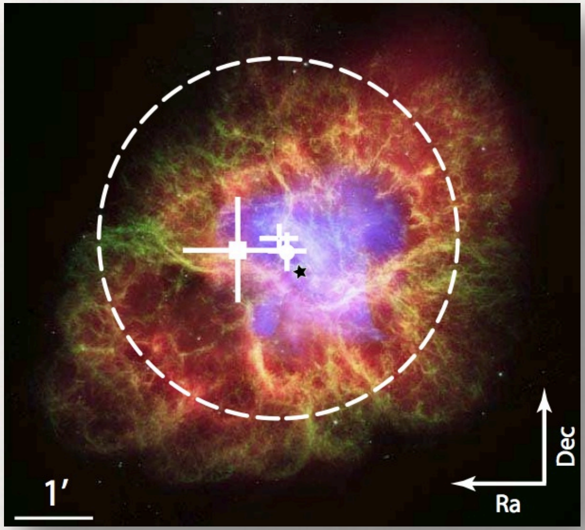

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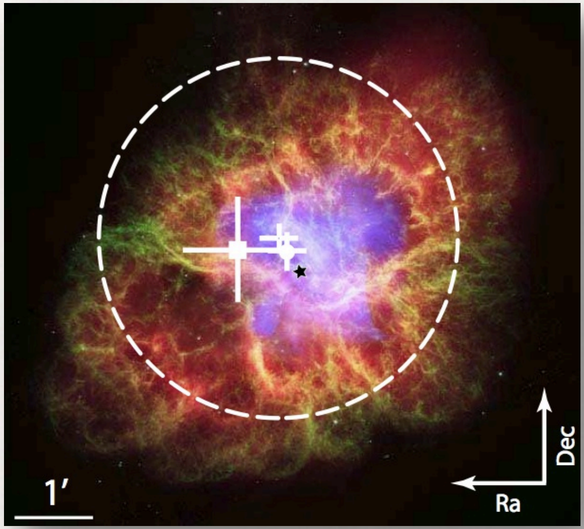

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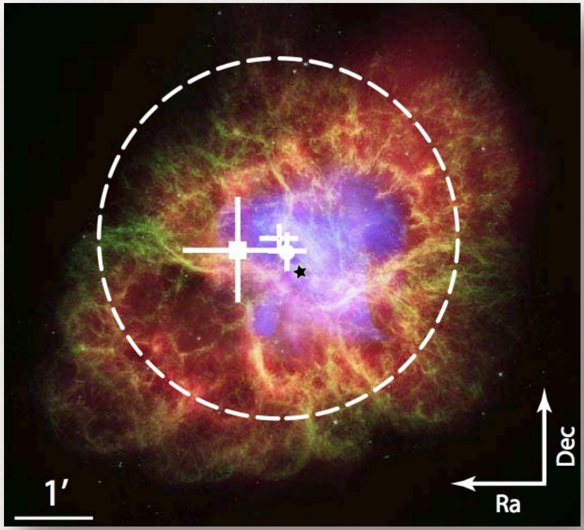

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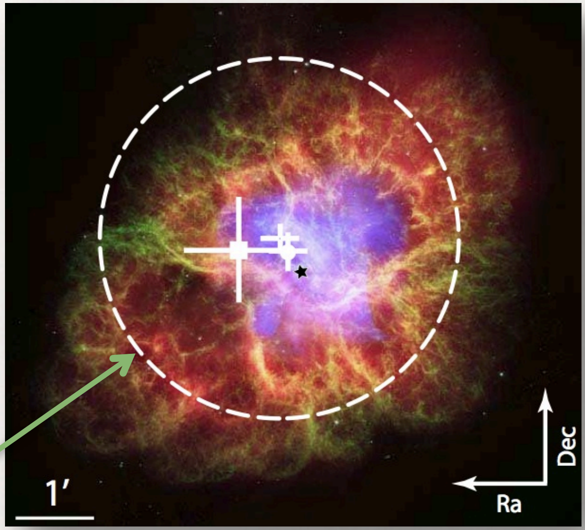

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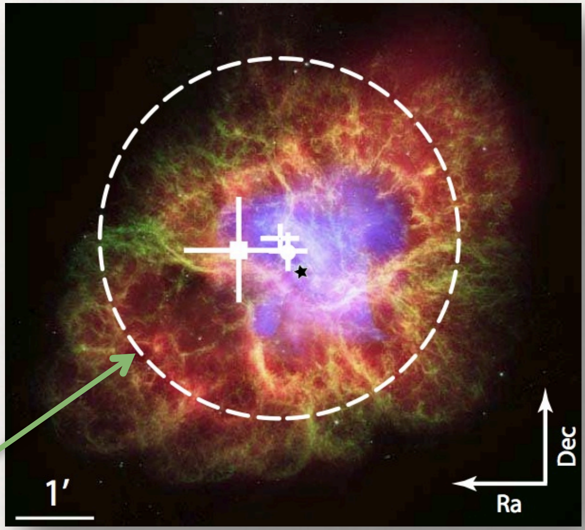
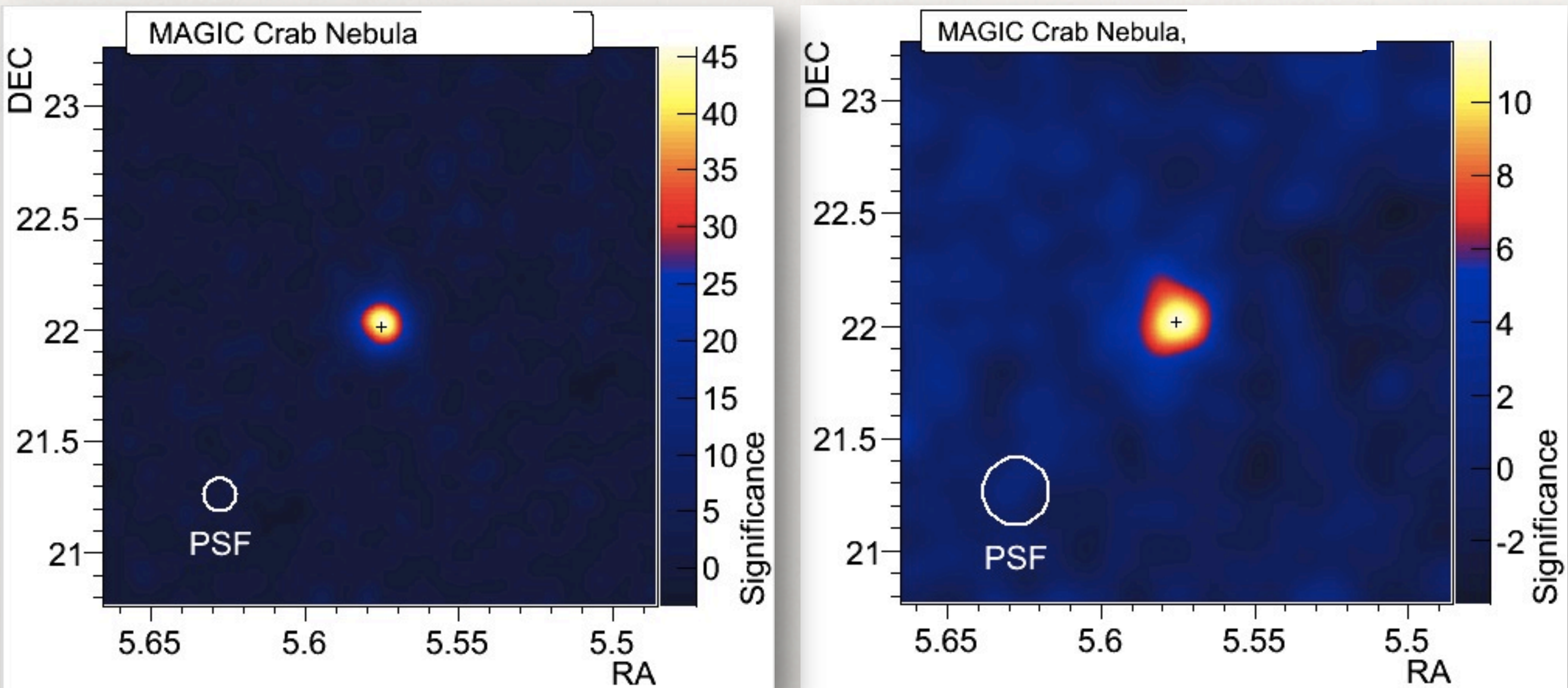


WE USE IT:

- As a check tool

- In few cases: extended emission or multiple sources in the field

Example: the Crab Nebula



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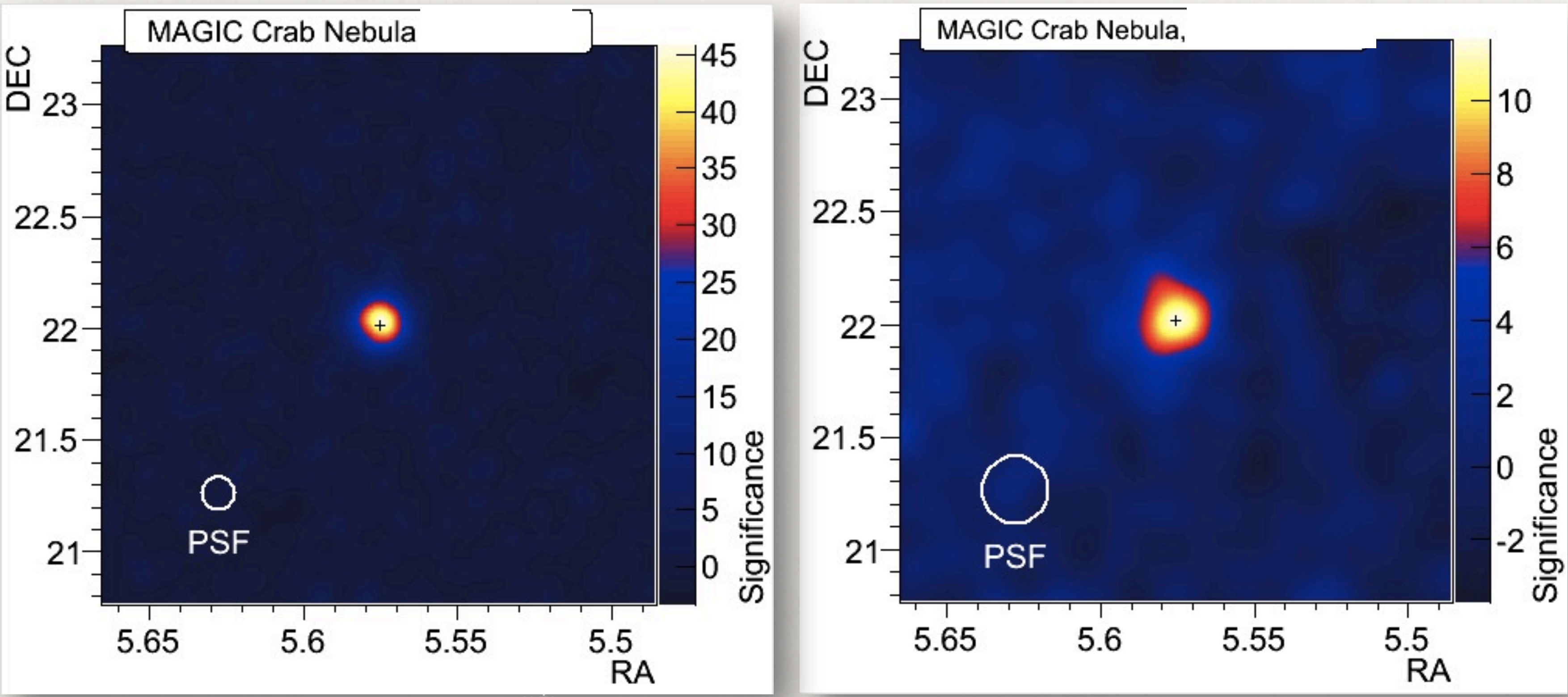
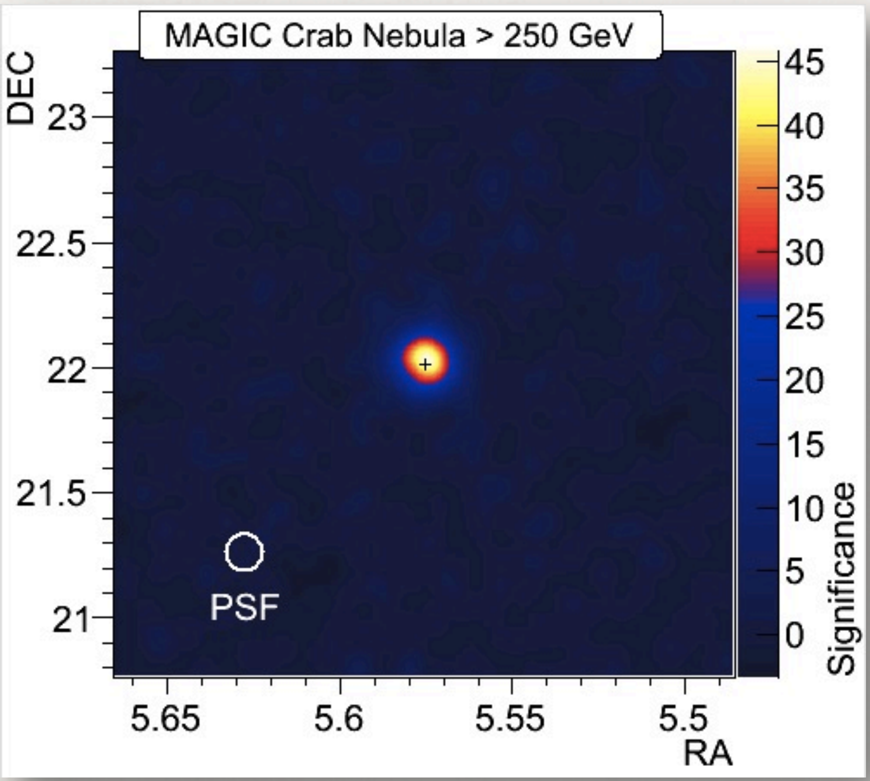
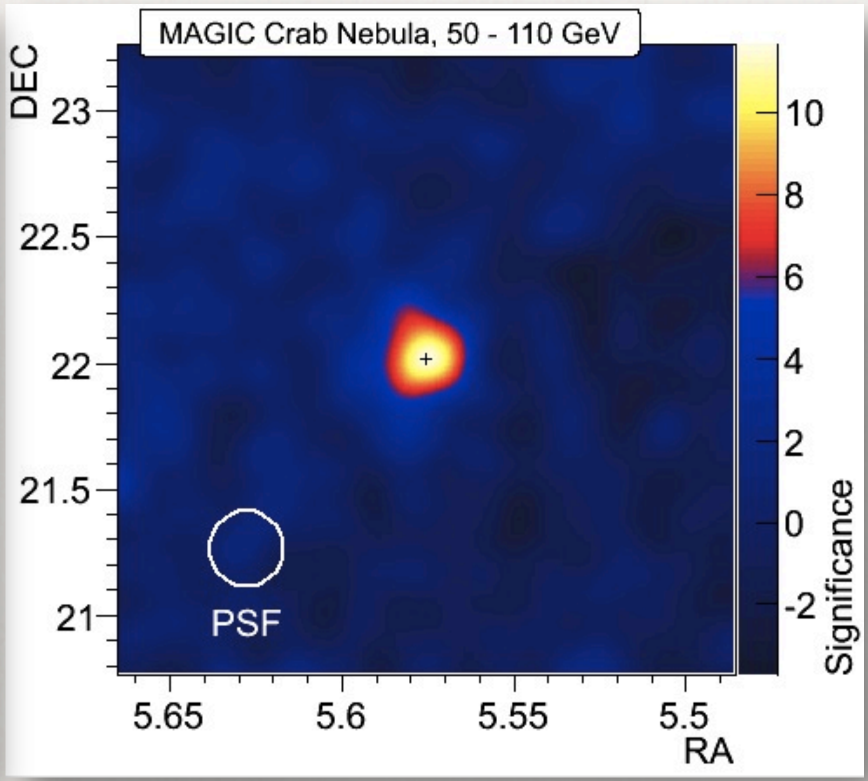


Find the difference!

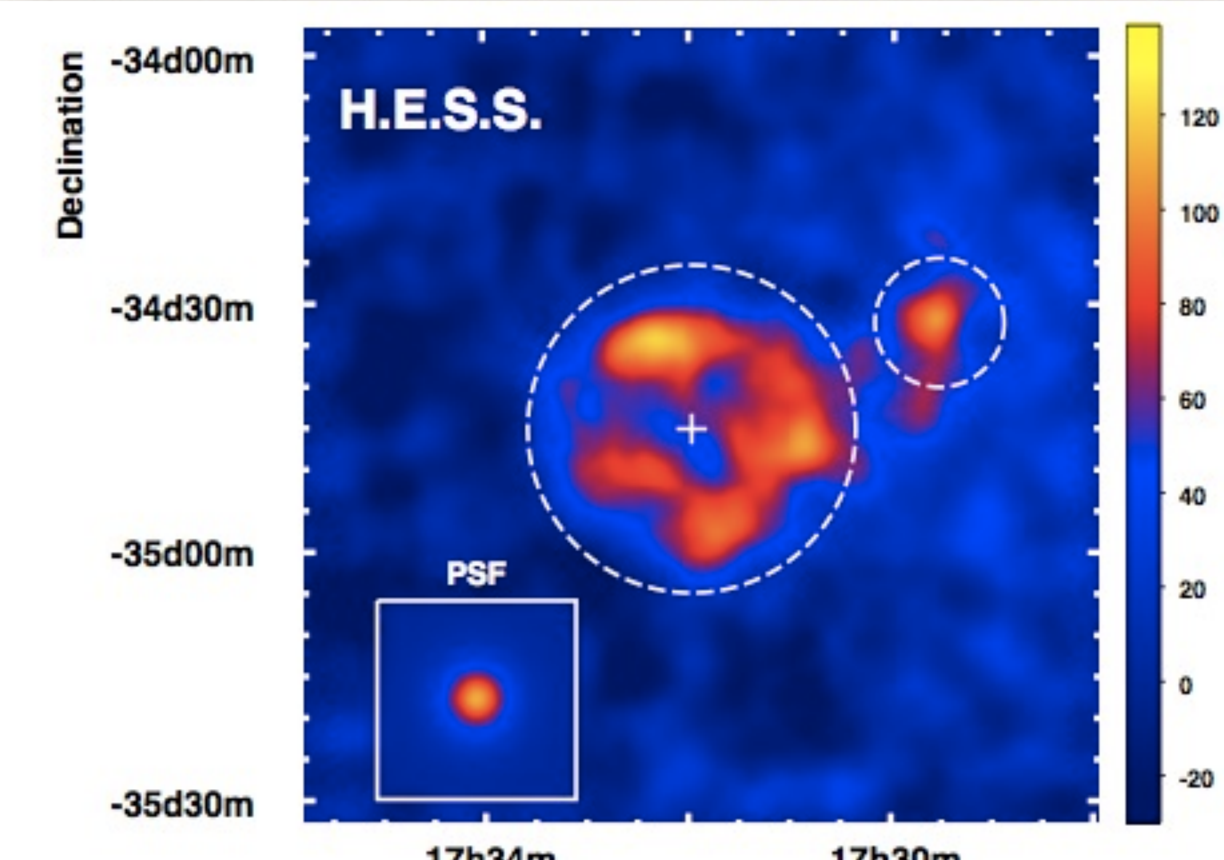
Example: the Crab Nebula





The angular resolution is strictly related to the **ENERGY RANGE!**

Extended sources



H.E.S.S. collaboration,
A. Abramowski et al. A&A 531 (2011) A81

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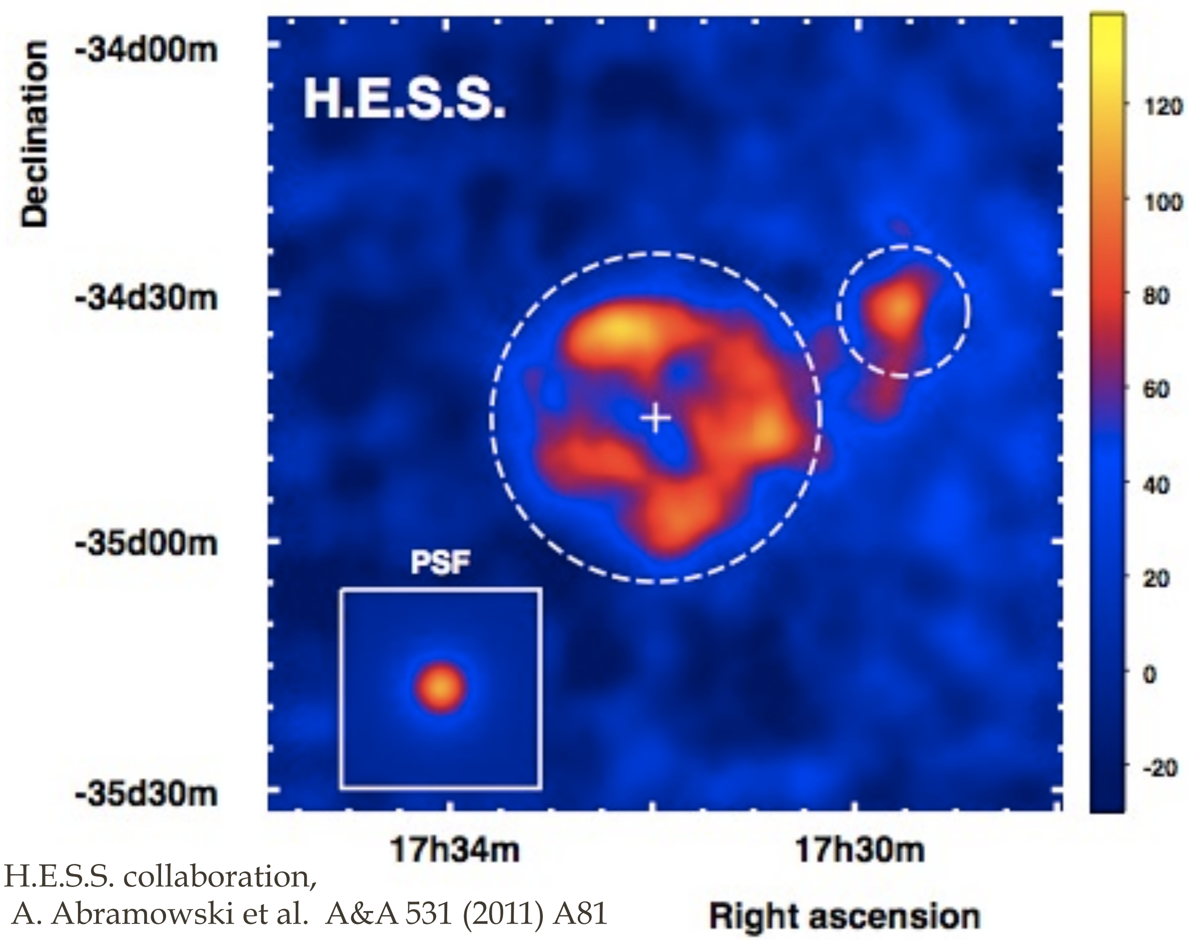

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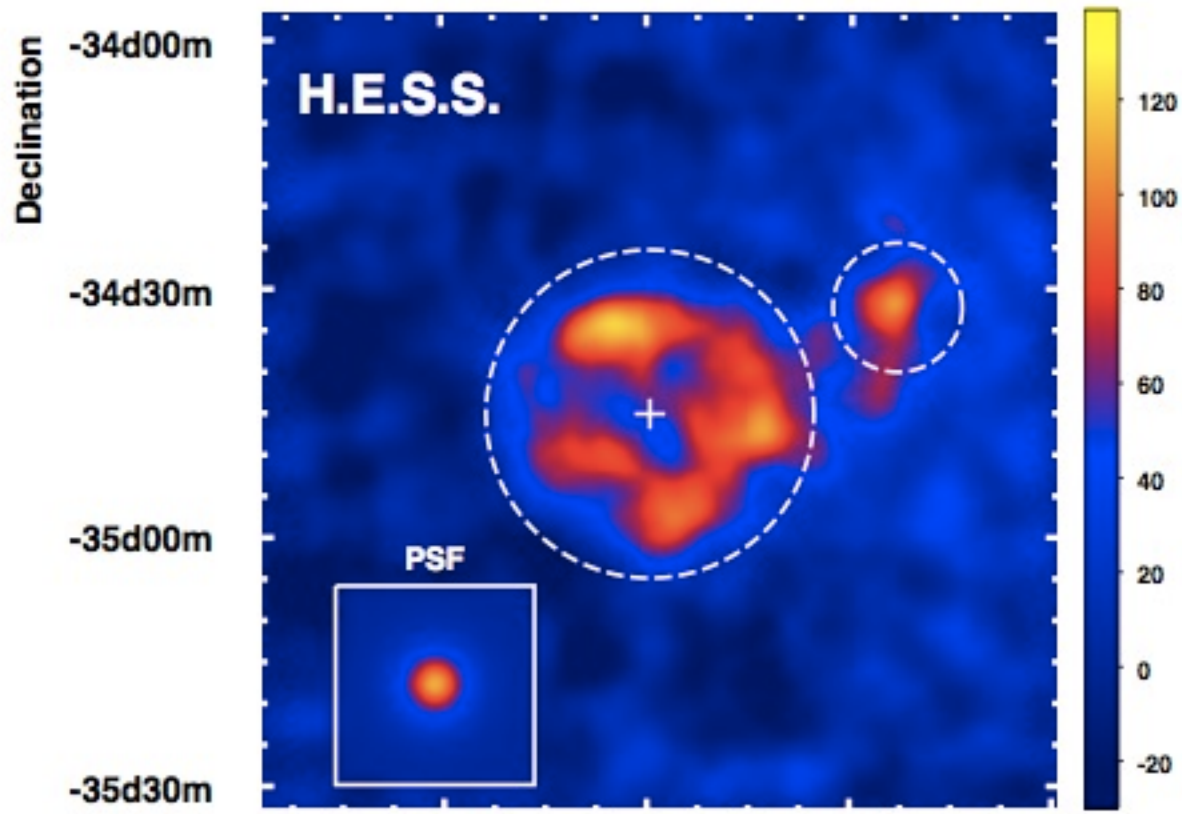

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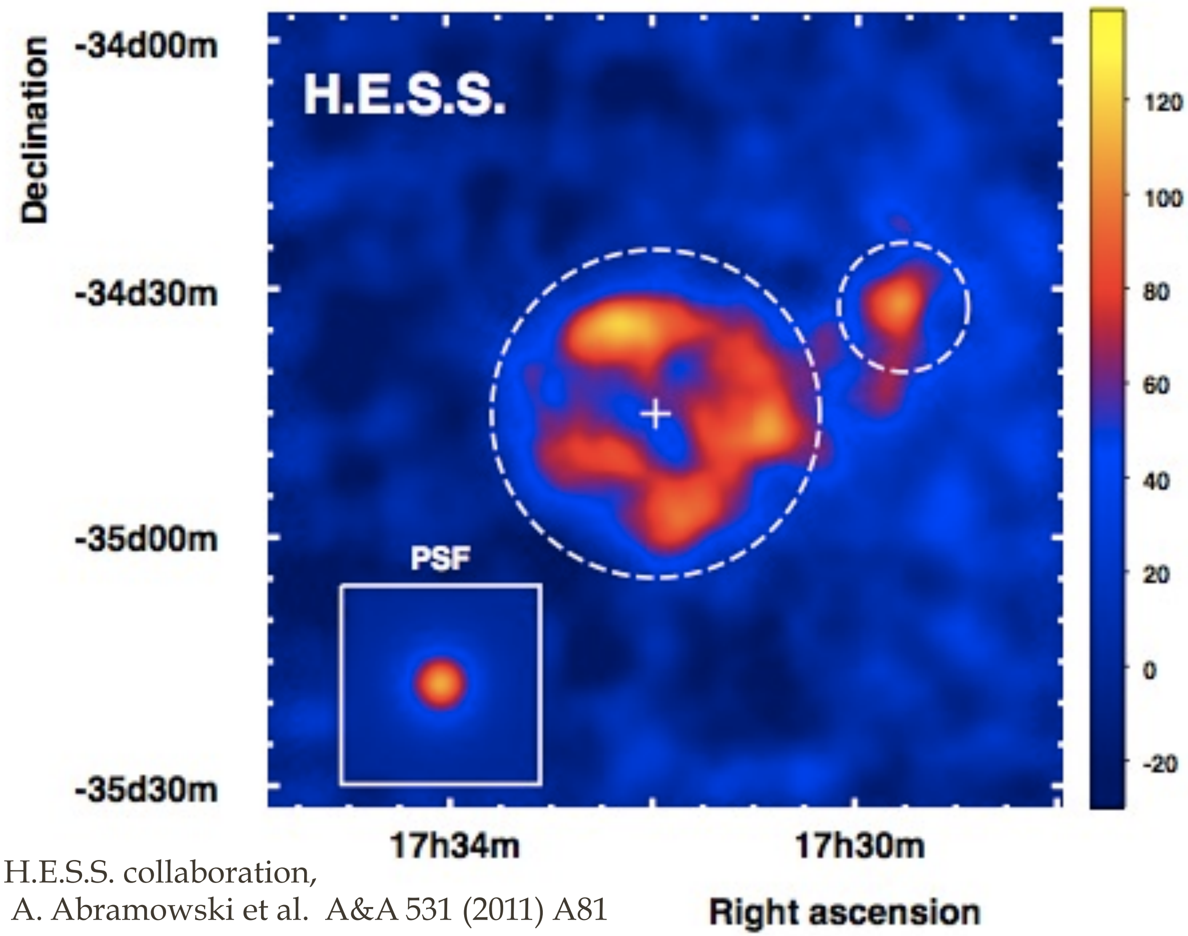

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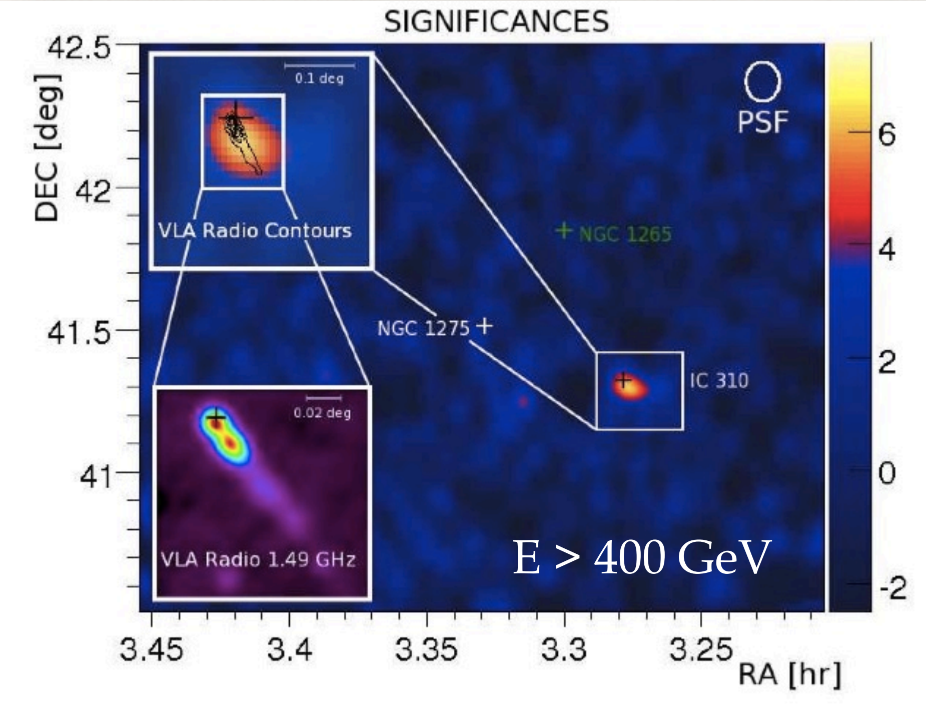
* Some galactic sources are extended enough to be mapped nicely at TeV energies
* SNR **HESS J1731-347**
* Very interesting studies on acceleration sites!



NGC 1275 region

* Clear signal from the head tail RG IC 310 at E > 400 GeV
* And below this energy?

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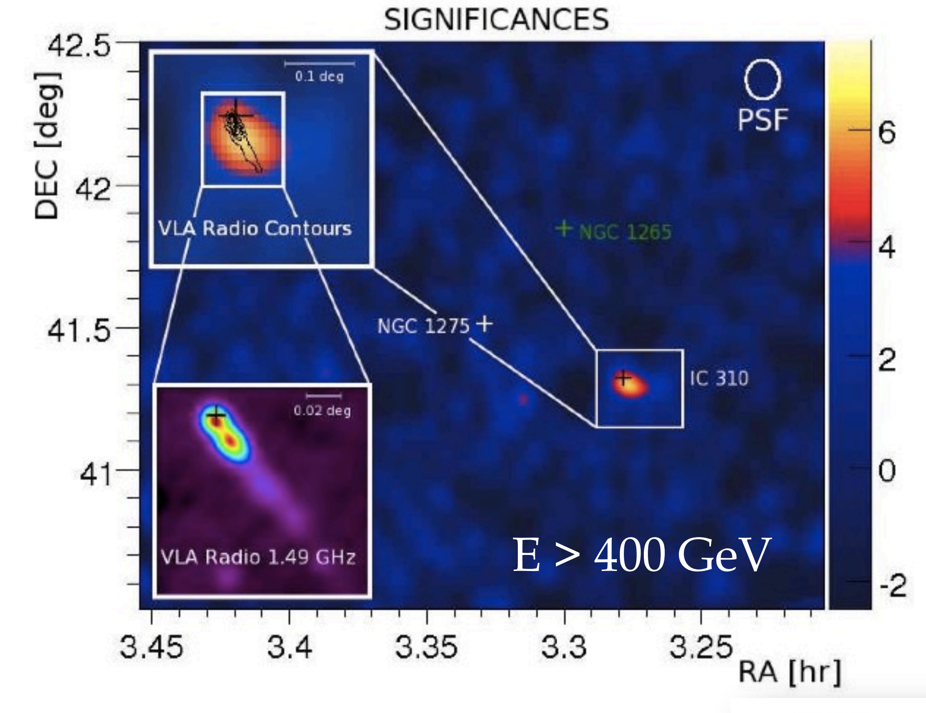

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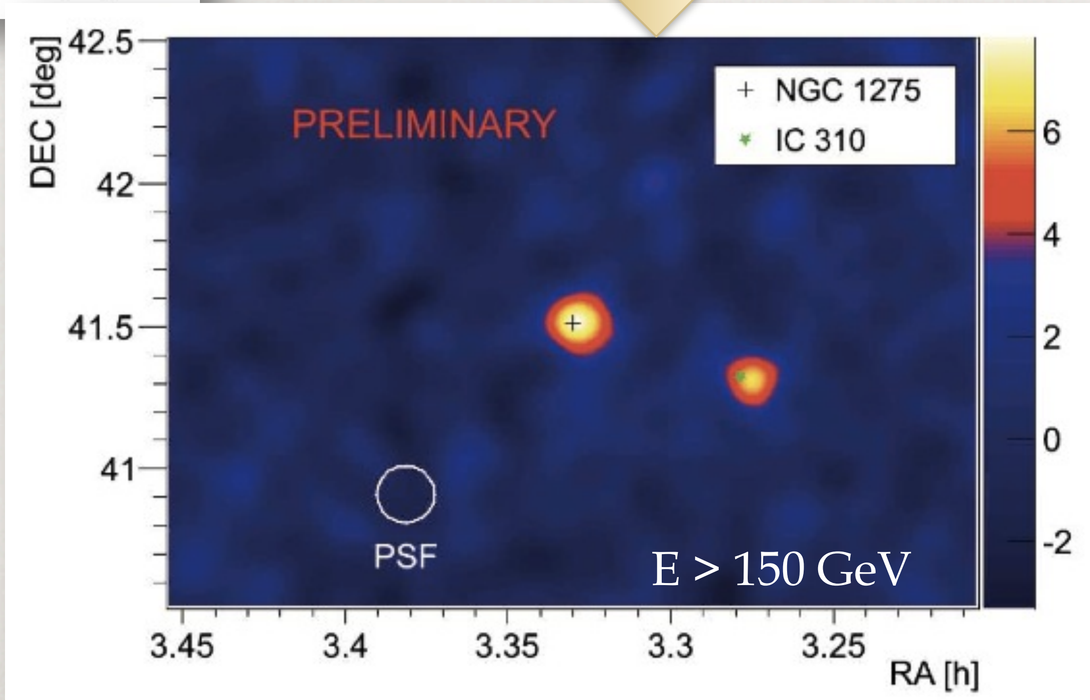
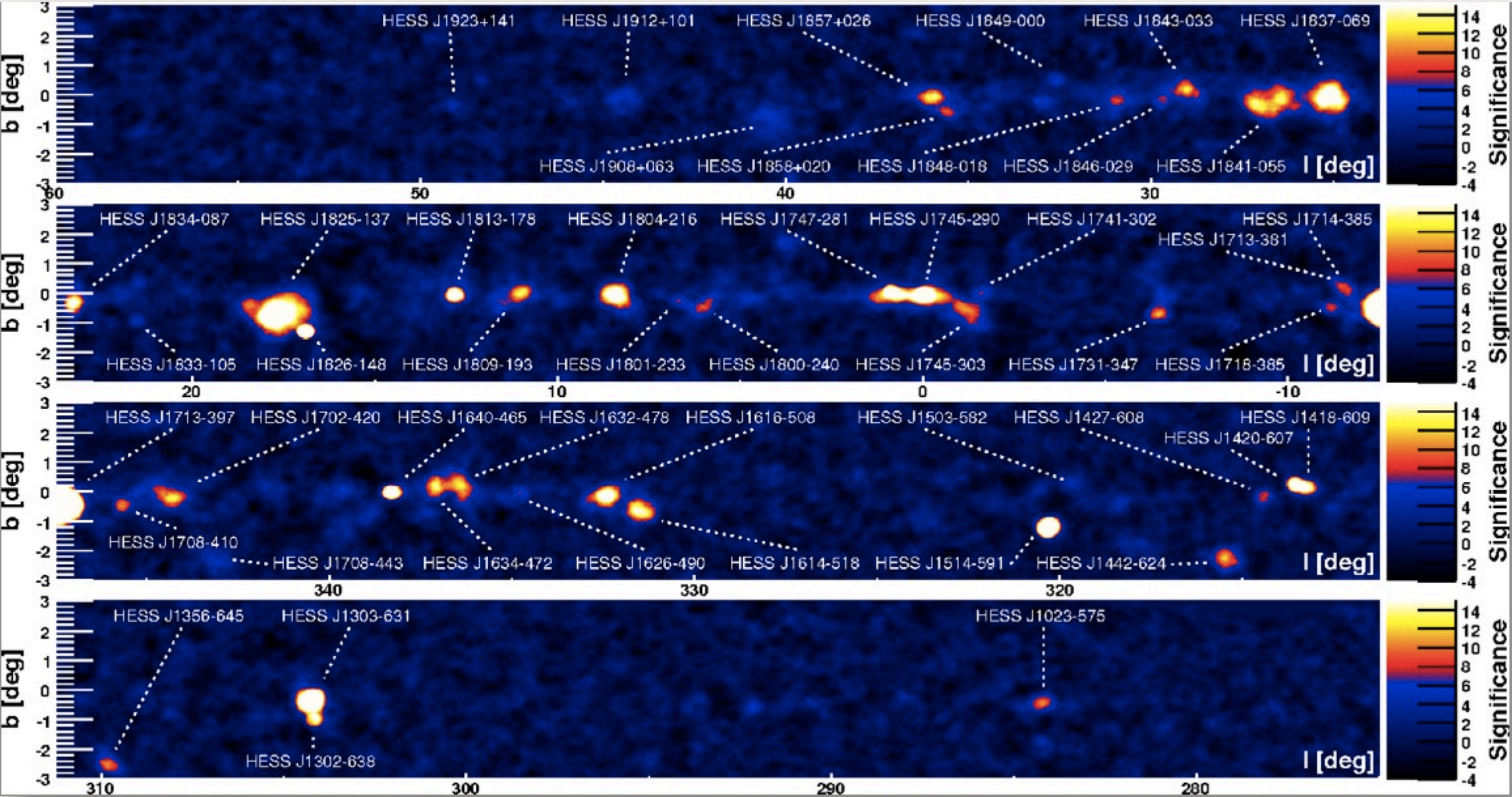


* If we go down to 150 GeV, a signal from the RG NGC 1275 becomes significant!

The galactic scan



HESS Coll. ICRC 2009 Proceedings

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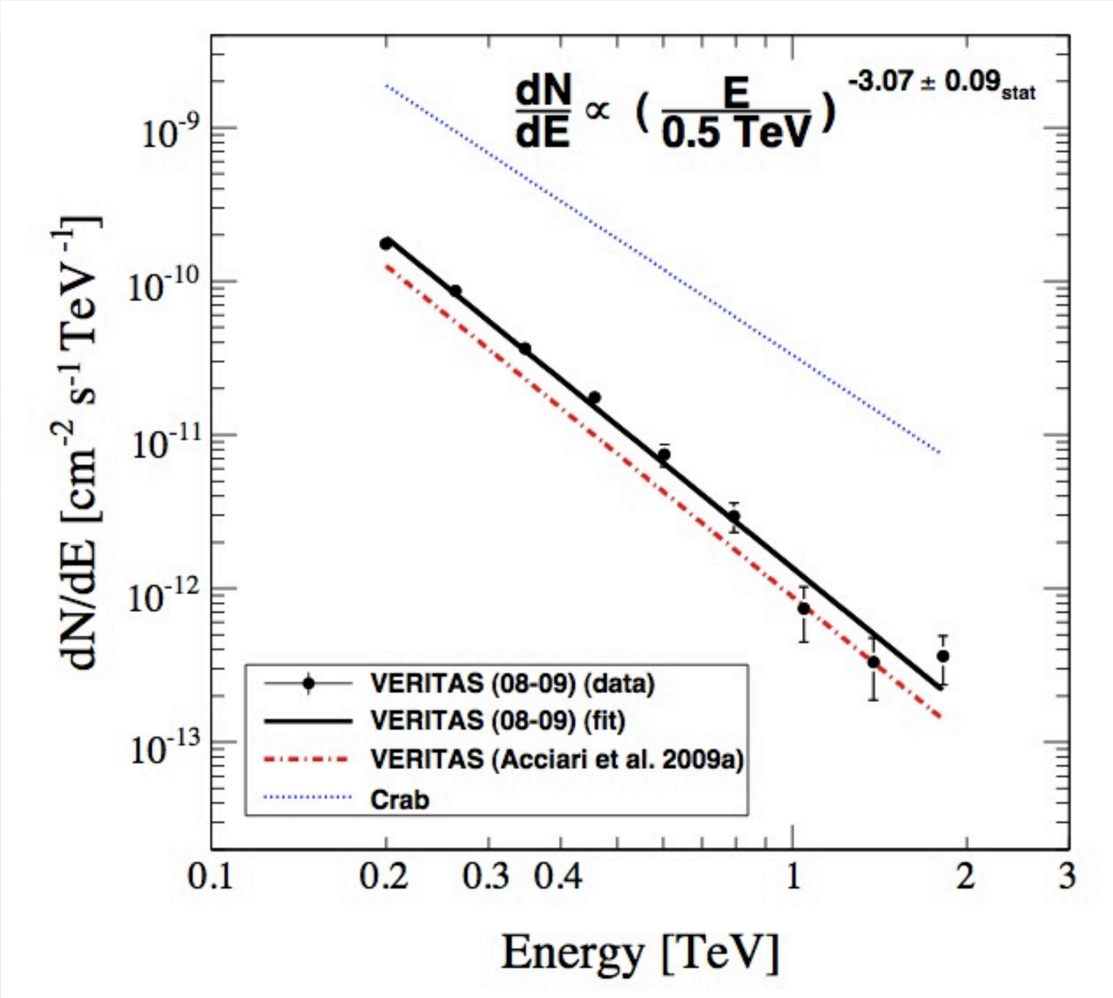
3. Now?
   * Spectrum
   * Light curve

The differential energy spectrum



VERITAS Coll. APJ Letters, 709, L163-L167 (2010)

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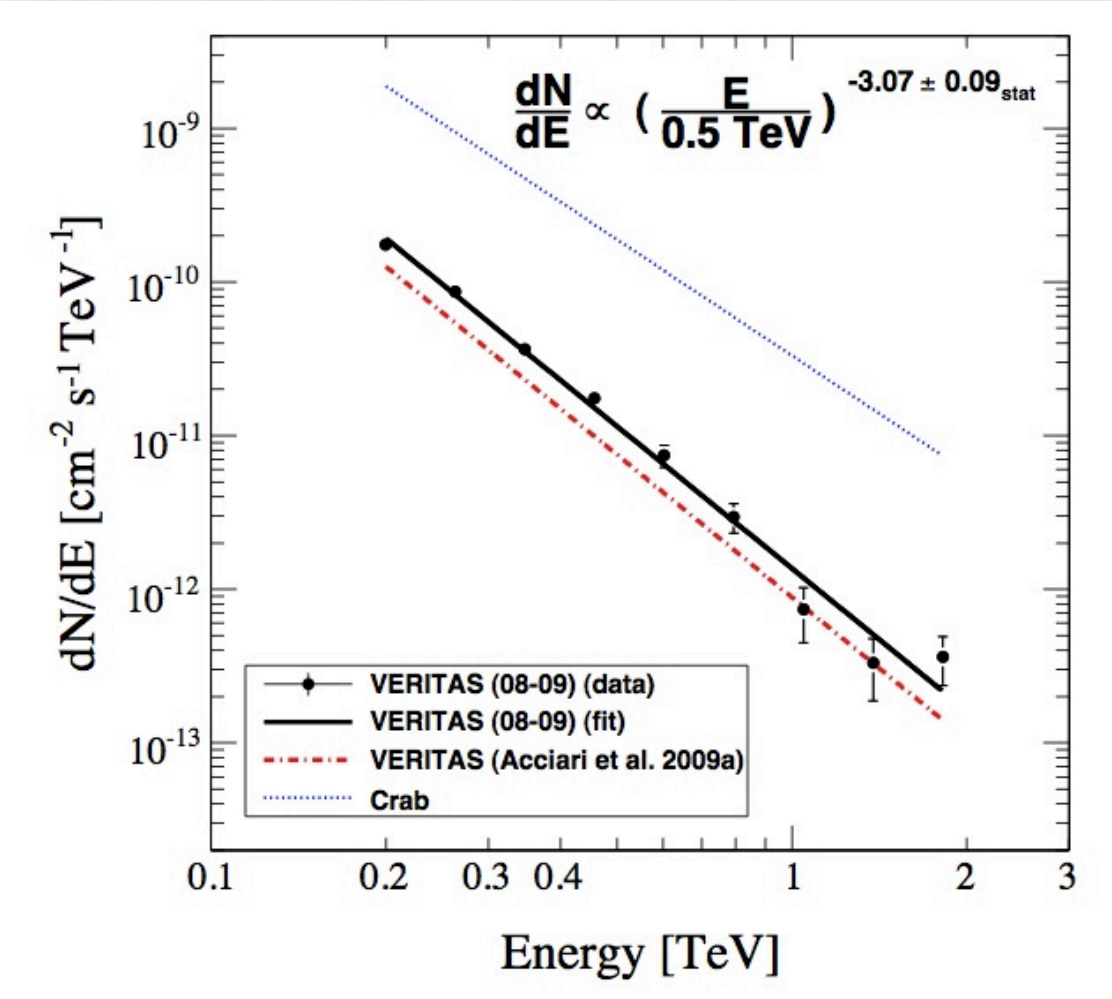

The spectrum is essential in our study

* Allows the characterization of the emission
* A comparison is possible (also between different experiments and energy thresholds!)

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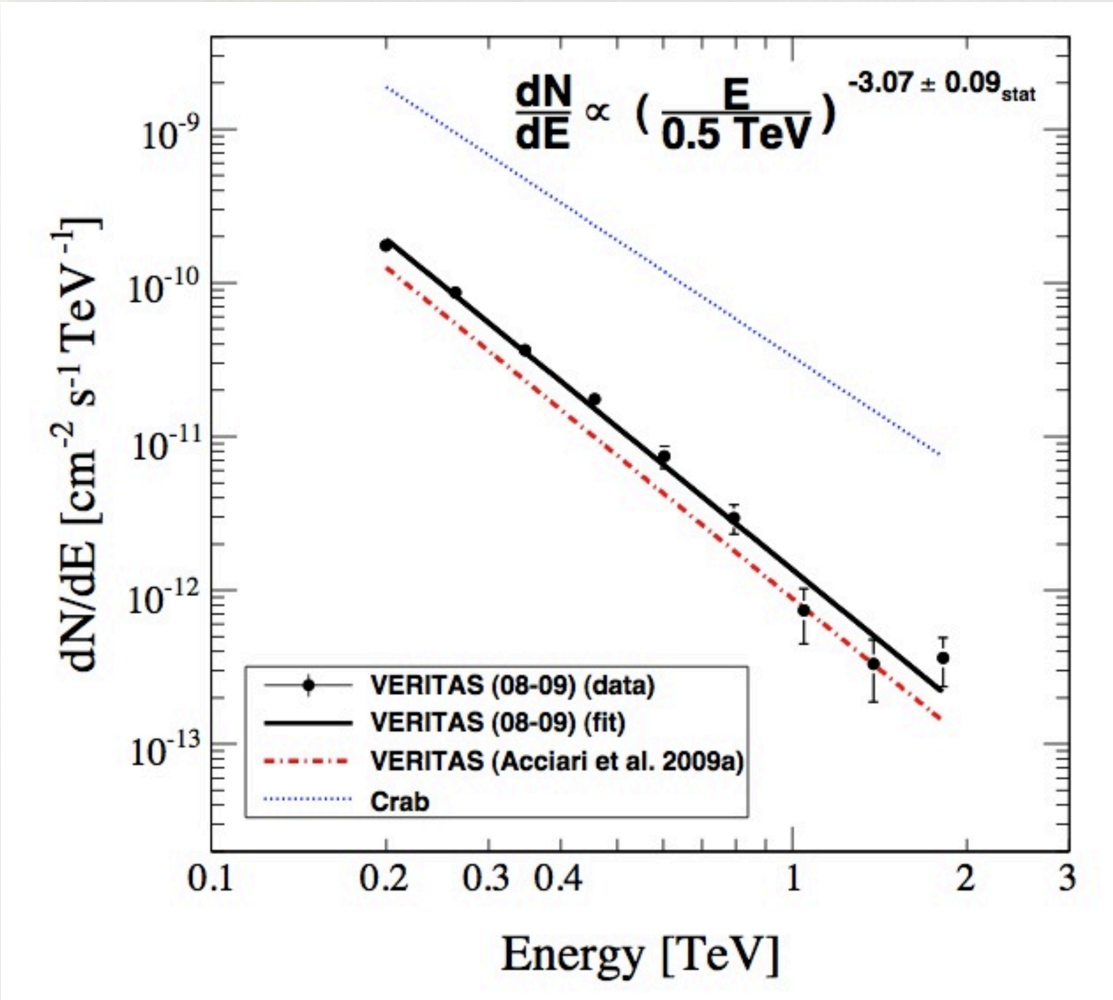

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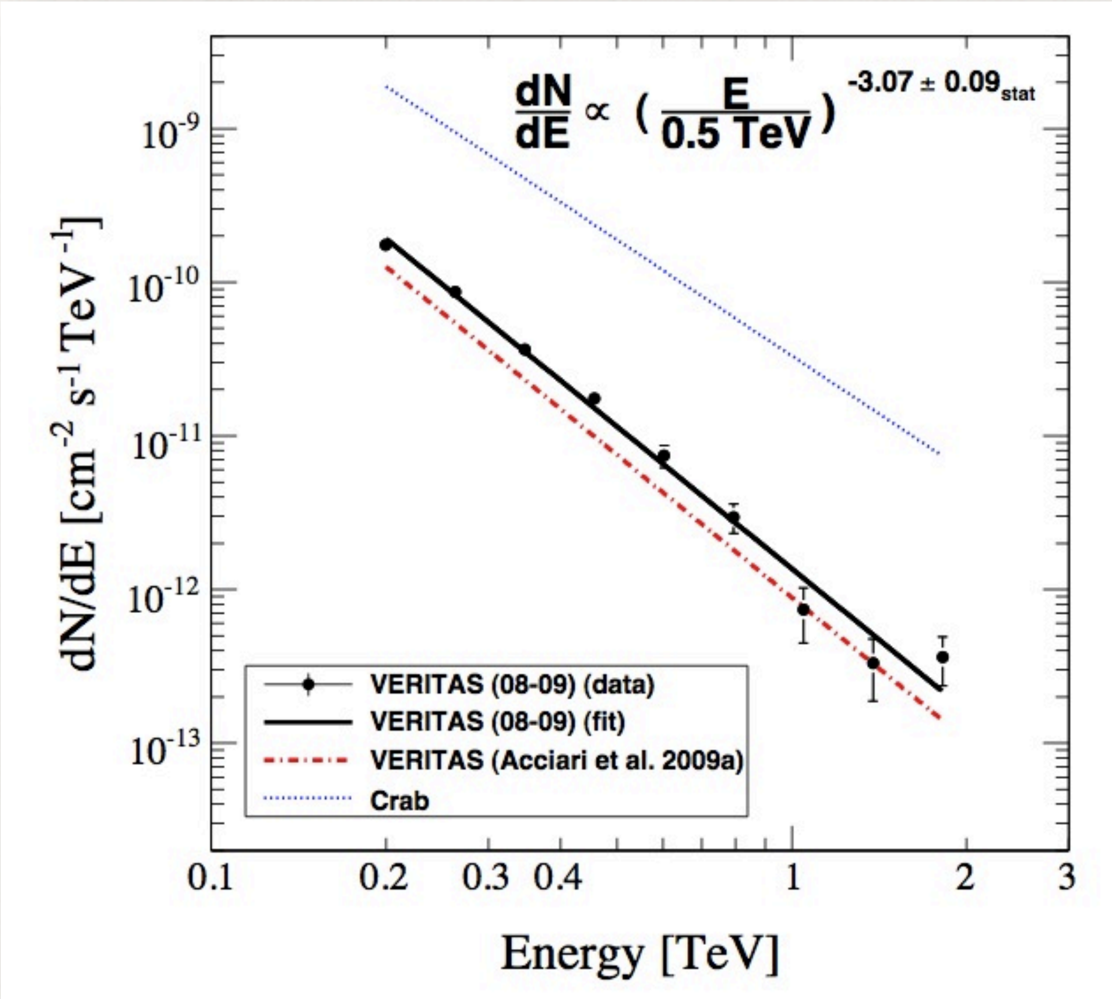

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What is it?

THE NUMBER OF VHE PHOTONS PER AREA AND TIME

VERITAS Coll. APJ Letters, 709, L163-L167 (2010)

Definitions

* *γ-ray flux*: rate of γ-rays per unit area

$$\Phi = \frac{d^2 N_\gamma}{dS\,dt}$$

* units: $[L^{-2}]\,[T^{-1}]$ (e.g. $cm^{-2}\,s^{-1}$)
* Needed ingredients: a *number* of γ-rays, a collection *area* and an observation *time*

Related concepts:

* *Differential energy spectrum*: flux per interval in γ-ray energy ($cm^{-2}\,s^{-1}\,TeV^{-1}$)

$$\frac{d\Phi}{dE} = \frac{d^3 N}{dS\,dt\,dE}$$

* *Integral flux*: integrated in a given energy range ($cm^{-2}\,s^{-1}$), e.g. :

$$\Phi_{E>200\ GeV} = \int_{200\ GeV}^{\infty} \frac{d\Phi}{dE}\,dE$$

* *Light curve*: time evolution of integral flux: Φ vs. *t*

Courtesy of A. Moralejo

Differential energy spectrum: the observables

$$\frac{d\Phi}{dE} = \frac{d^3N}{dS\ dt\ dE}$$

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NUMBER OF DETECTED γ-RAYS: obtained from the observed excess

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EFFECTIVE COLLECTION AREA

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EFFECTIVE COLLECTION AREA

EFFECTIVE OBSERVATION TIME: not equal to the *elapsed* time!

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EFFECTIVE COLLECTION AREA

ESTIMATED ENERGY of the events

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Number of γ-rays per energy

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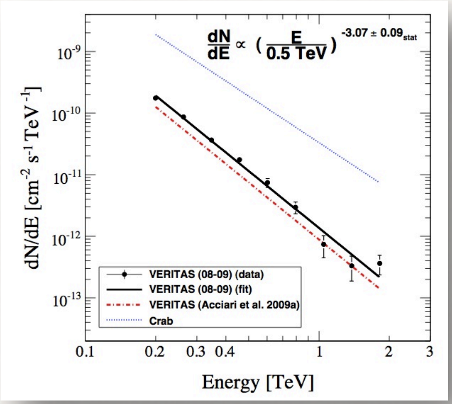

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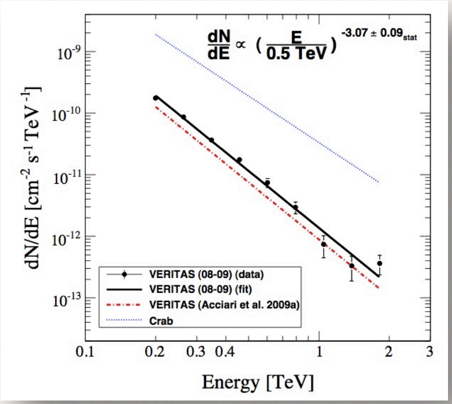

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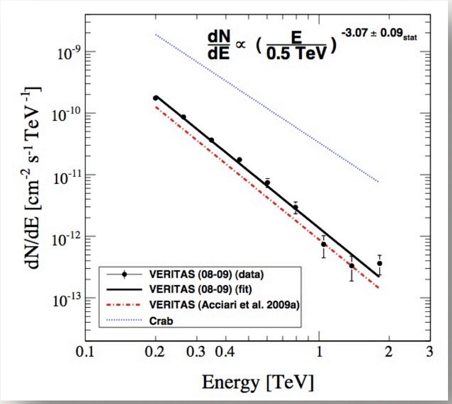

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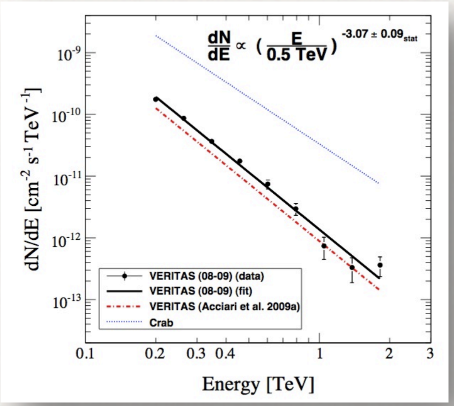

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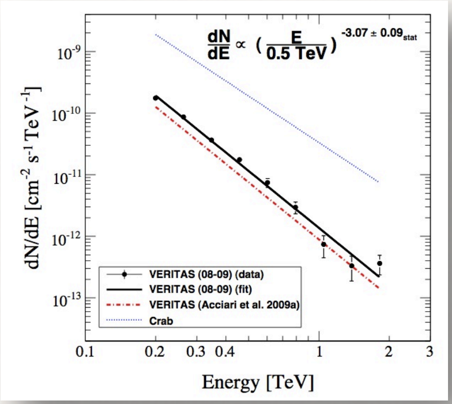

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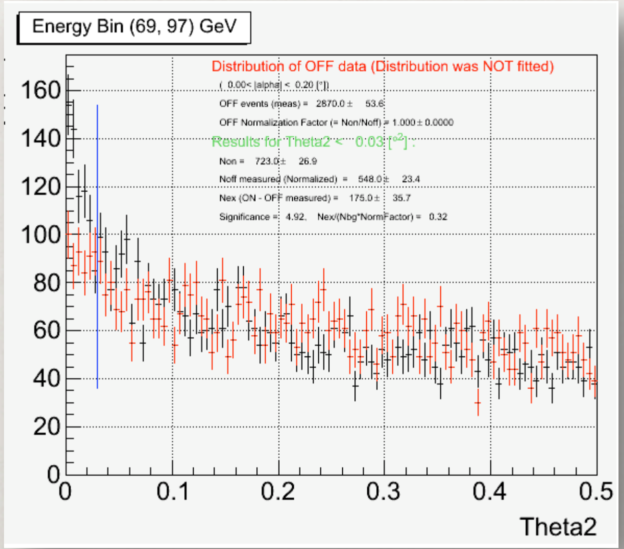

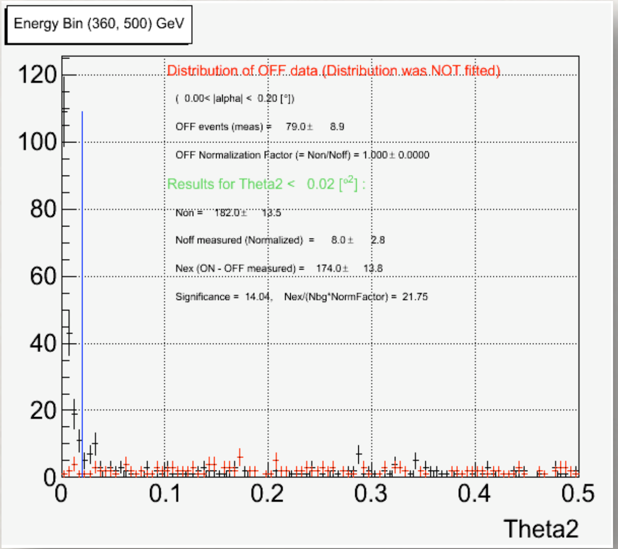

Effective observation time

$$\frac{d\Phi}{dE} = \frac{d^3N}{dS\,dt\,dE}$$

Courtesy of A. Moralejo

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probability of observing n events in time t, given event rate λ

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$$P(t_{next} > t) = P_{Poiss}(0,t) = e^{-\lambda t}$$

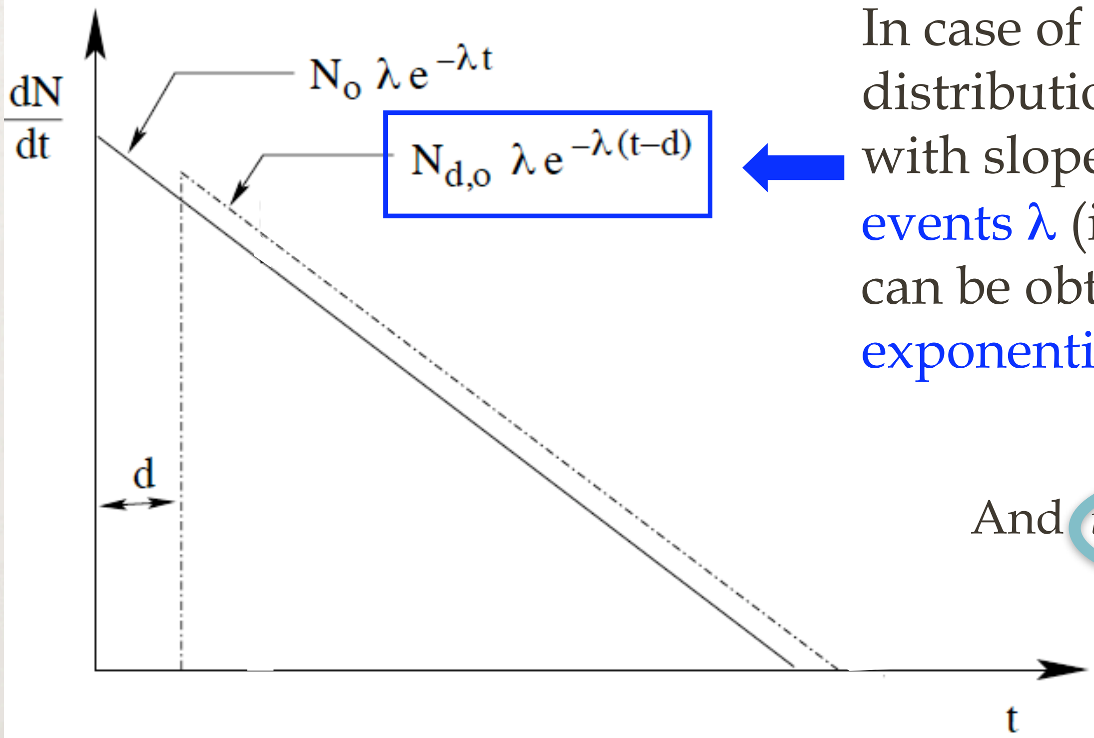
probability that the next event comes *after* time t

$$P(t_{next} > t) = \int_t^{\infty} \frac{dP(t_{next} = t)}{dt}\, dt \quad \Rightarrow \quad \frac{dP(t_{next} = t)}{dt} = \lambda e^{-\lambda t}$$

Courtesy of A. Moralejo

Calculation of effective observation time

* Distribution of the time differences:



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And $t_{eff} = N_{d,0} / \lambda$

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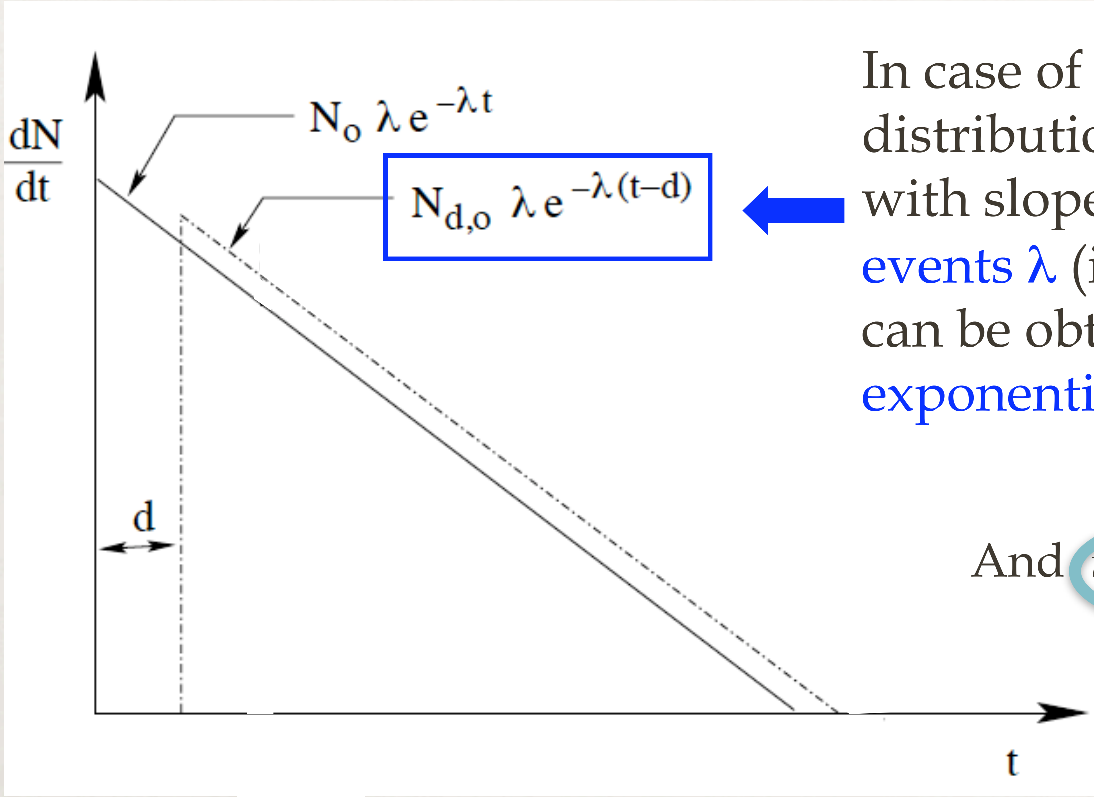

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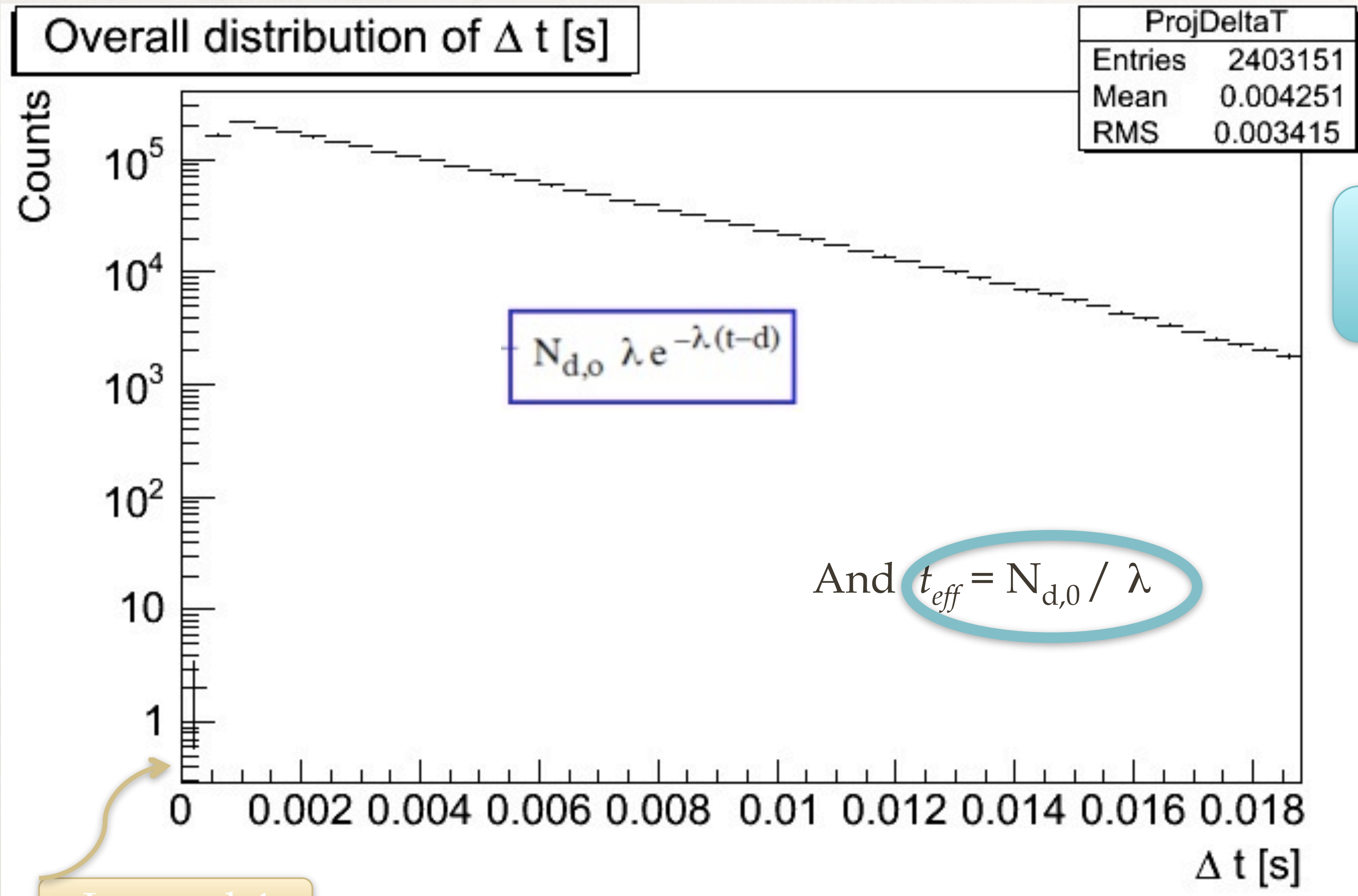
Example *effective time*



λ → slope
N → intercept

And $t_{eff} = N_{d,0} / \lambda$

Log scale!

Effective Area

$$\frac{d\Phi}{dE} = \frac{d^3N}{dS\,dt\,dE}$$

* Order of magnitude?

Estimated from MC (gamma) data!

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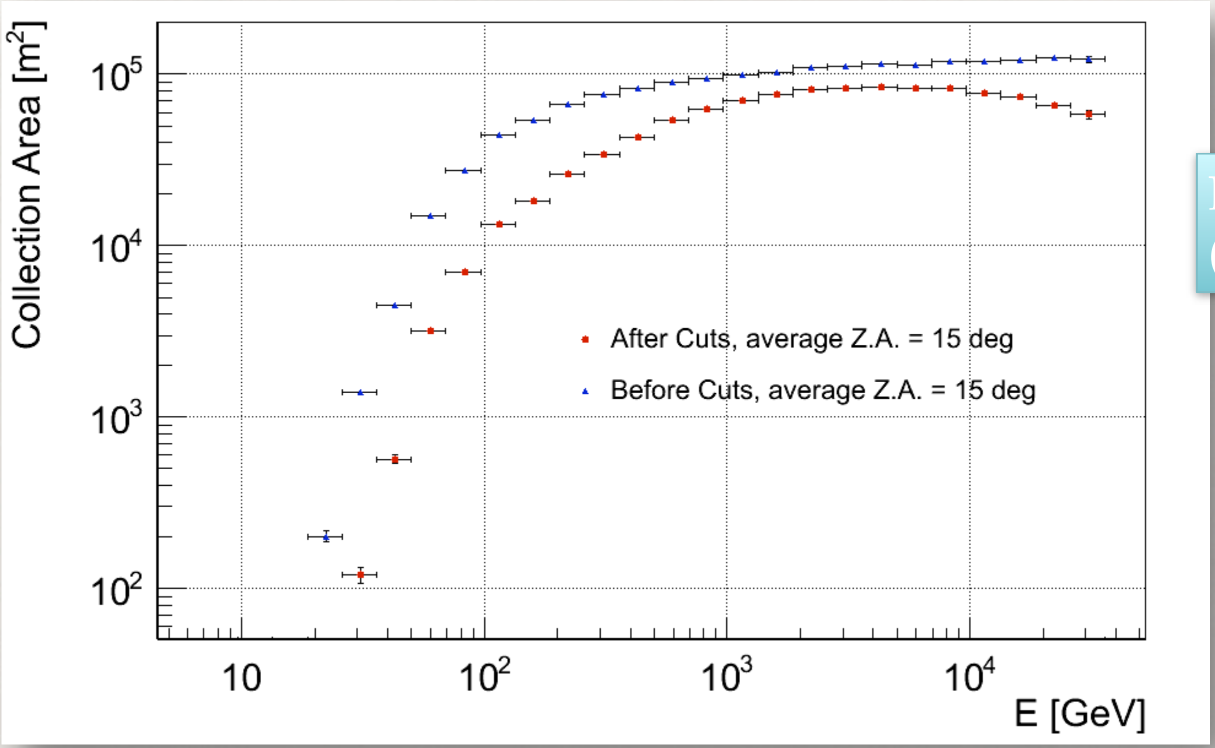

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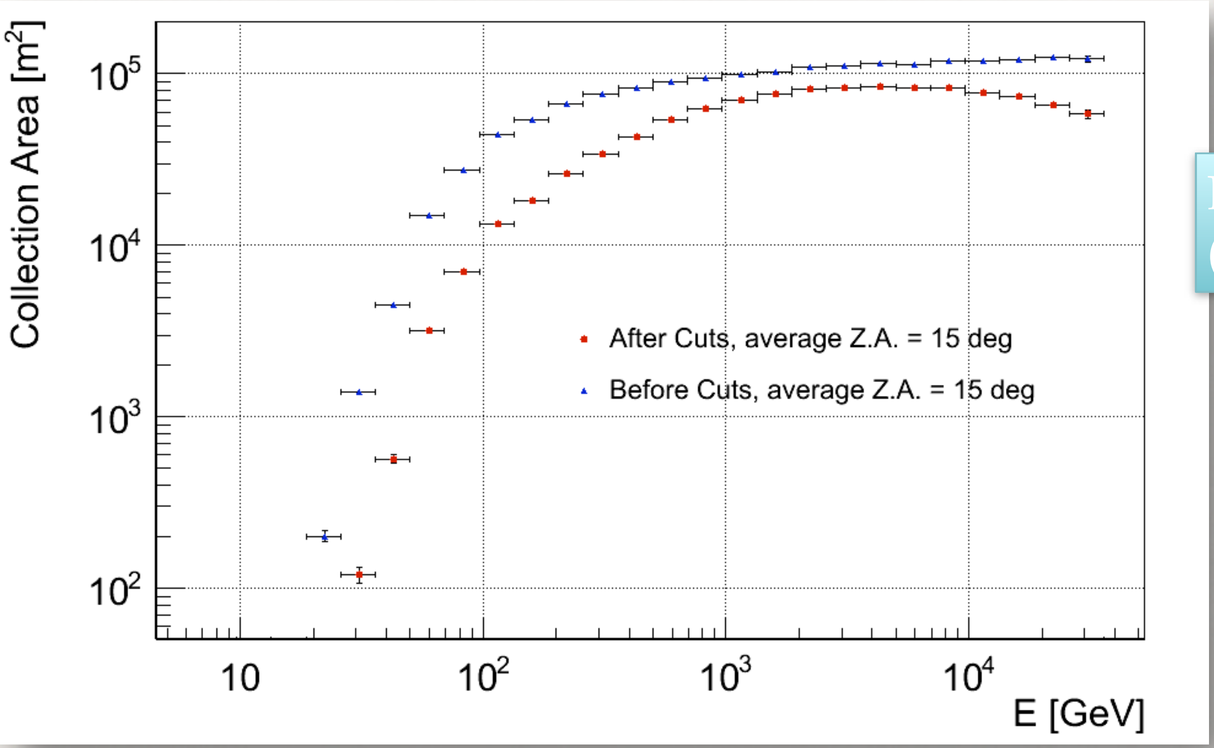
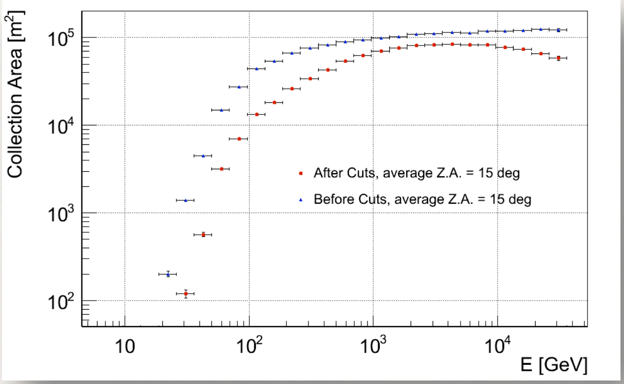


Estimated from MC (gamma) data!

$A_{eff} \sim 10^5$ m^2

Effective Area



* Order of magnitude → $\mathbf{A_{eff} \sim 10^5\ m^2}$

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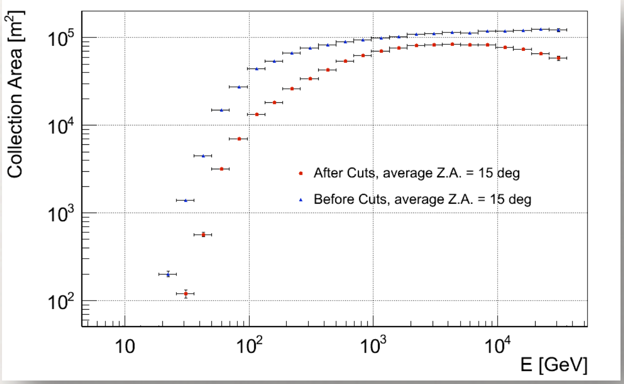

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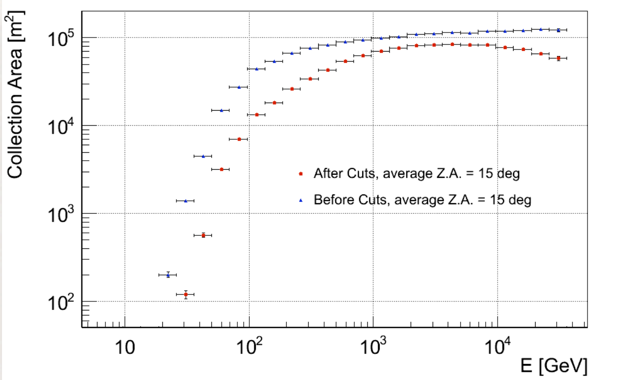
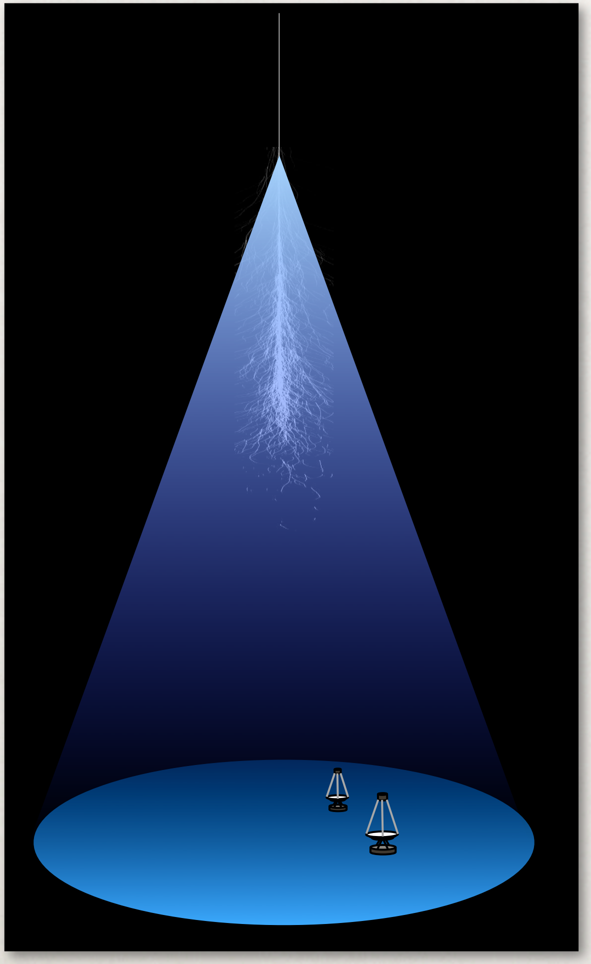


* Order of magnitude → A_{eff} ~10^5 m^2



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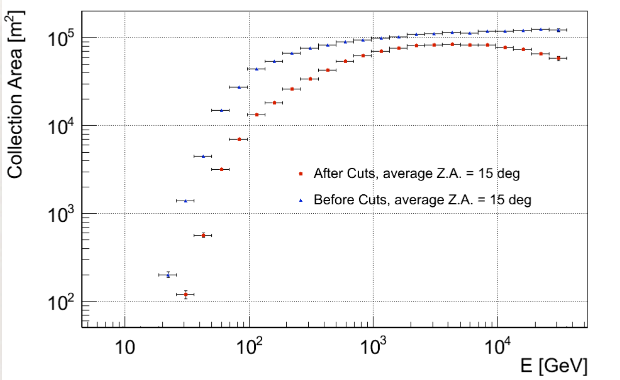

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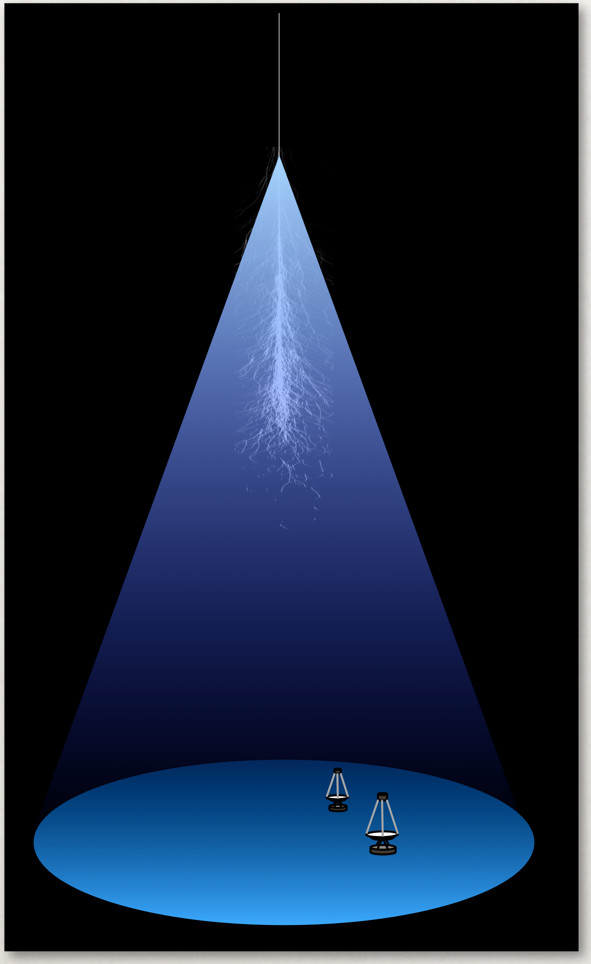

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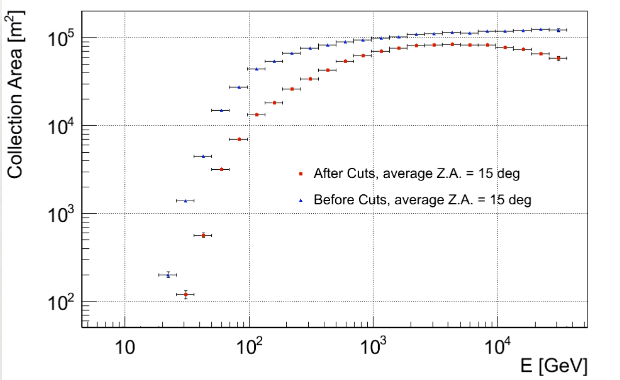

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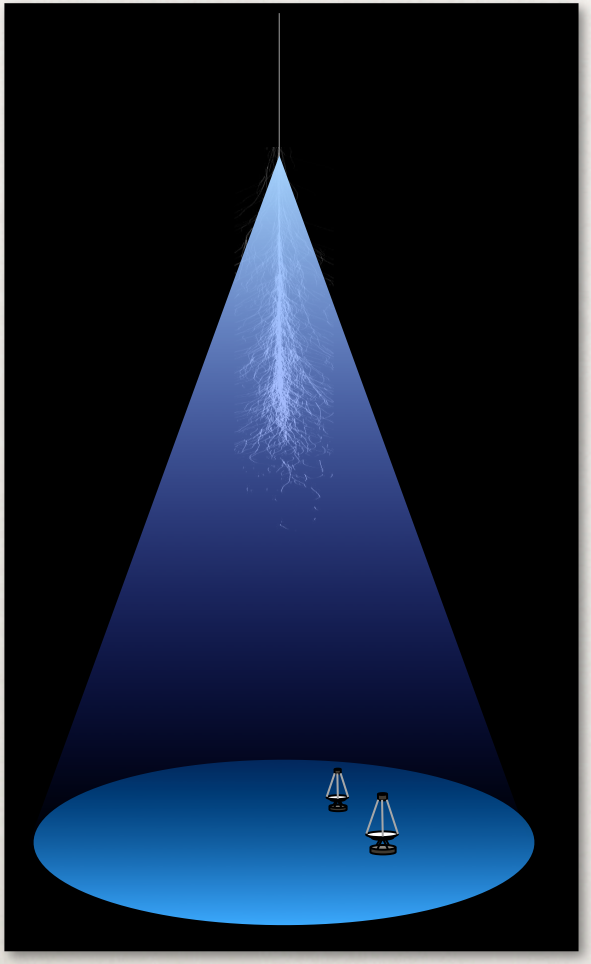

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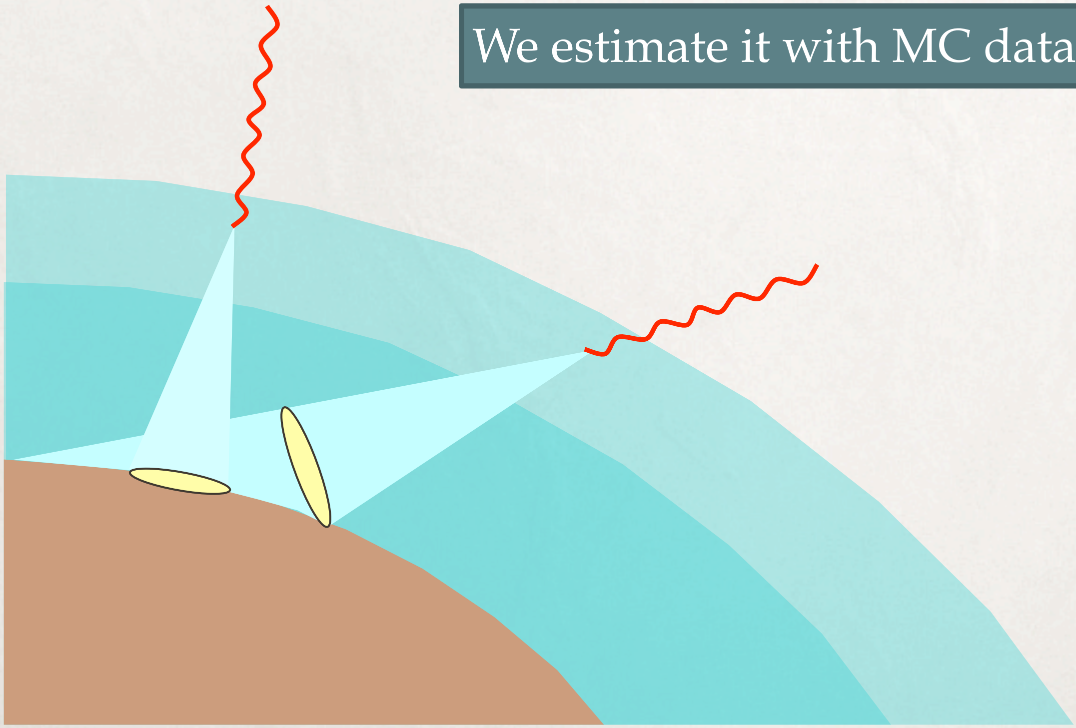
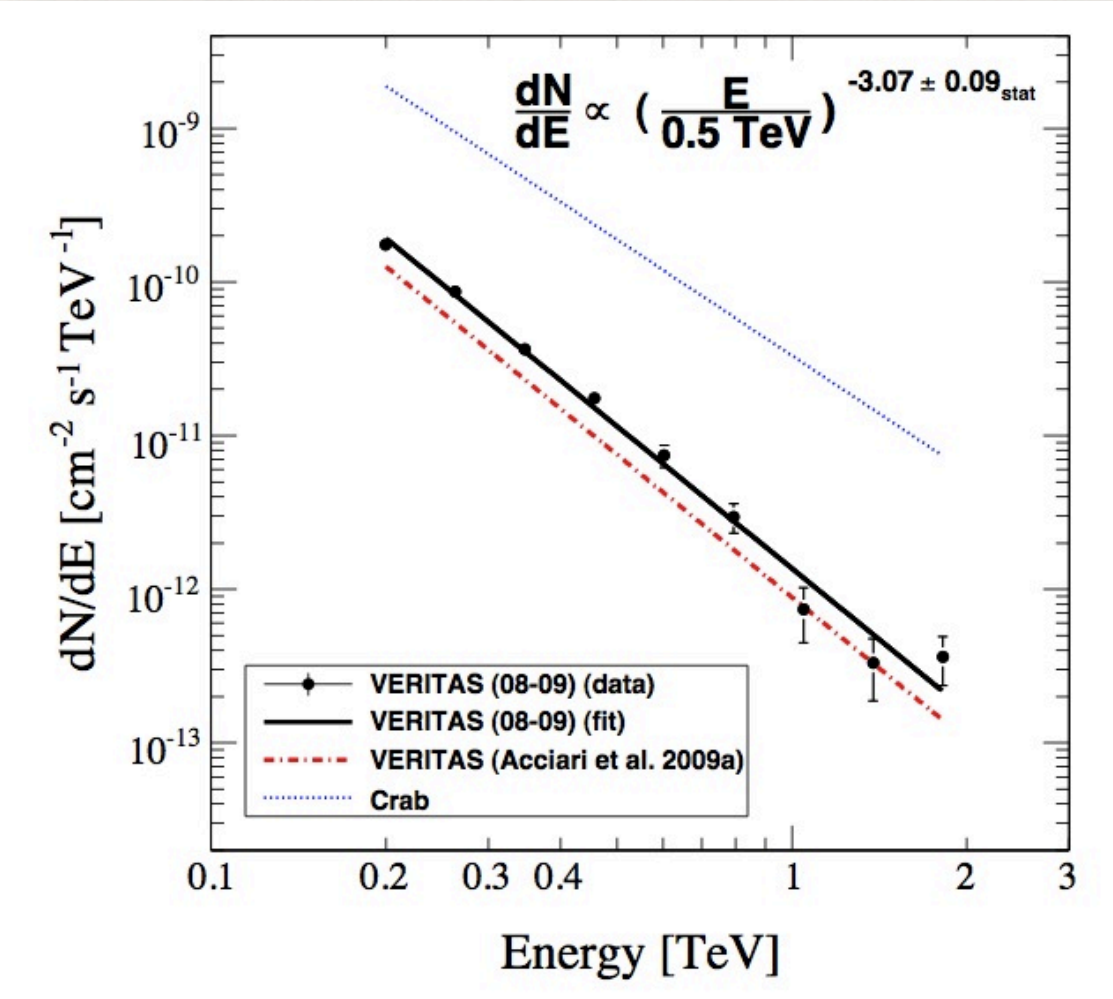
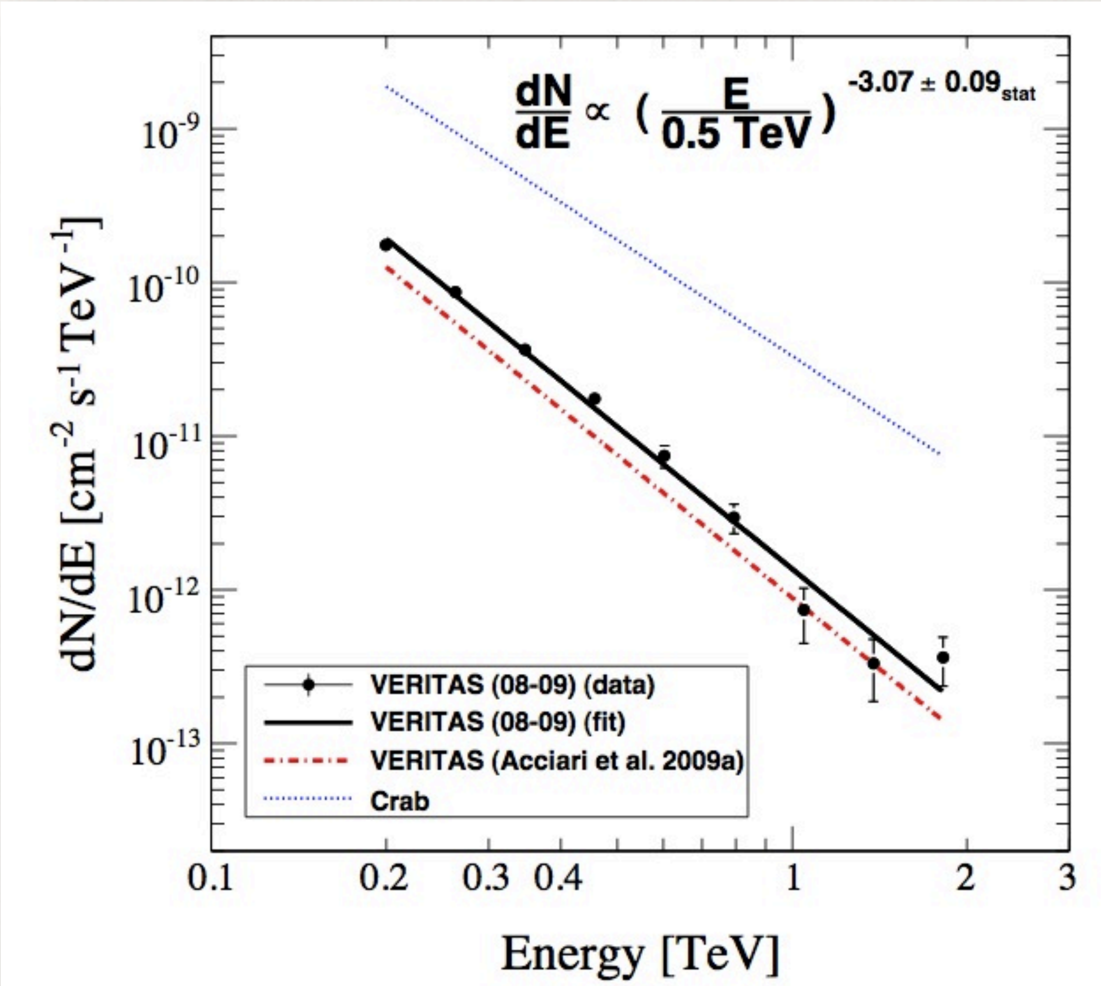
We estimate it with MC data



Differential energy spectra

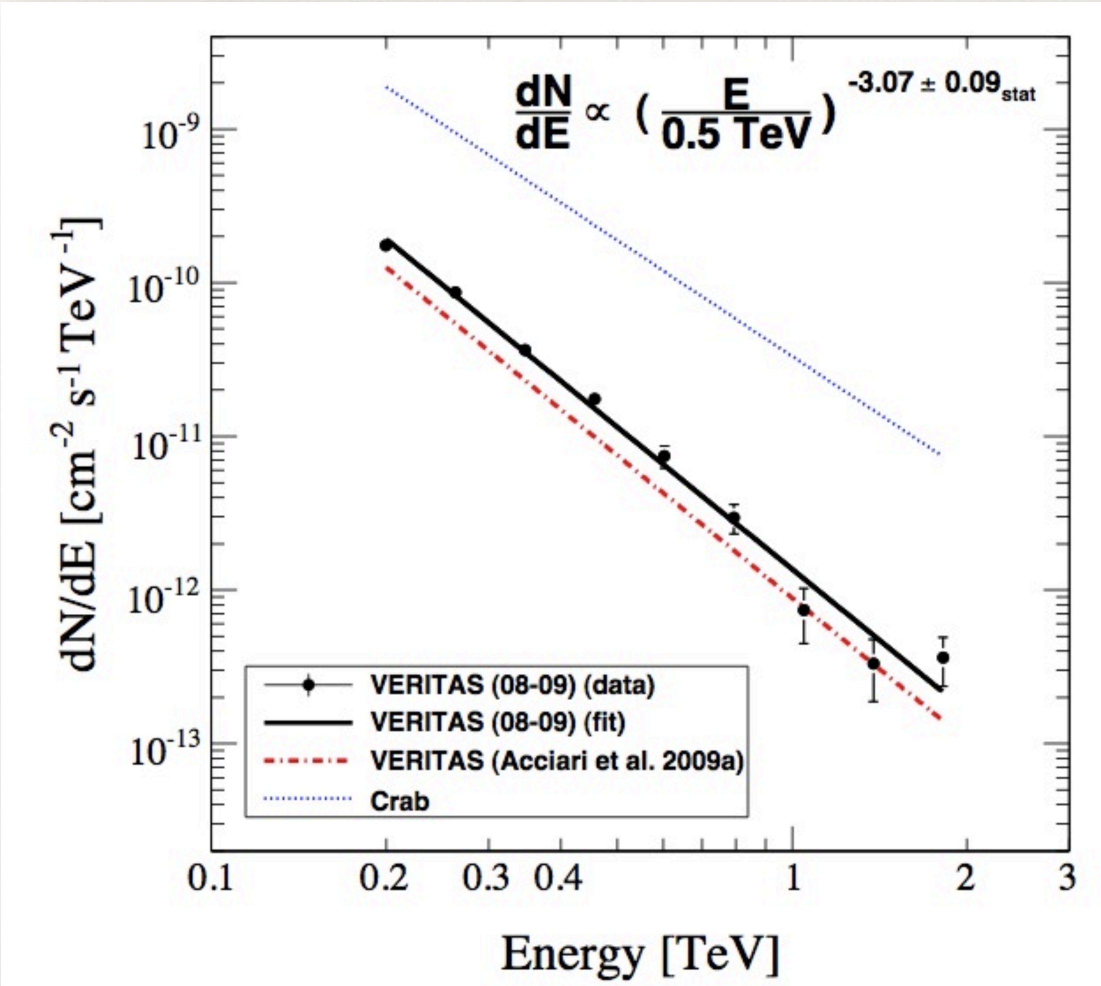


Differential energy spectra



* Numbers of bins is of course variable and set by the analyzer

Differential energy spectra



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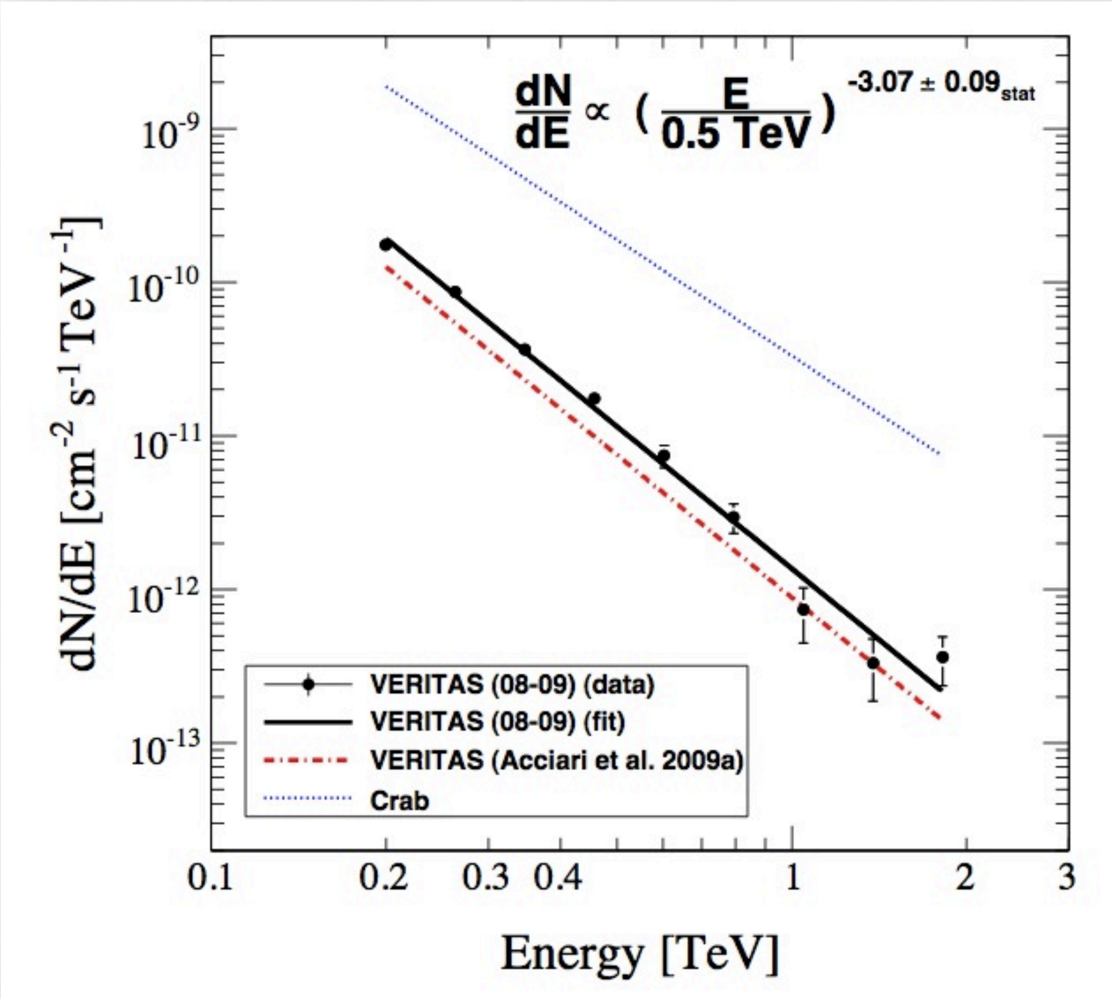
Differential energy spectra



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- Usually fitted with power laws

The unfolding

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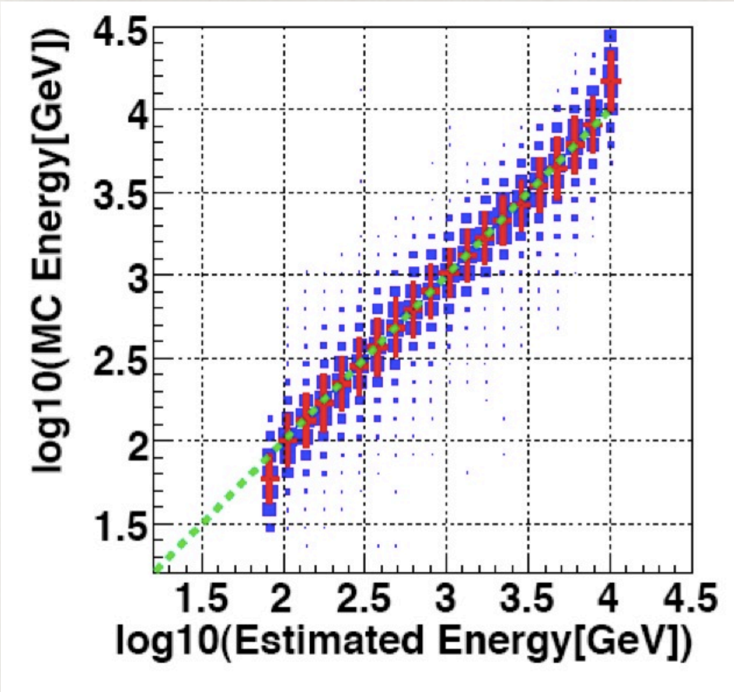
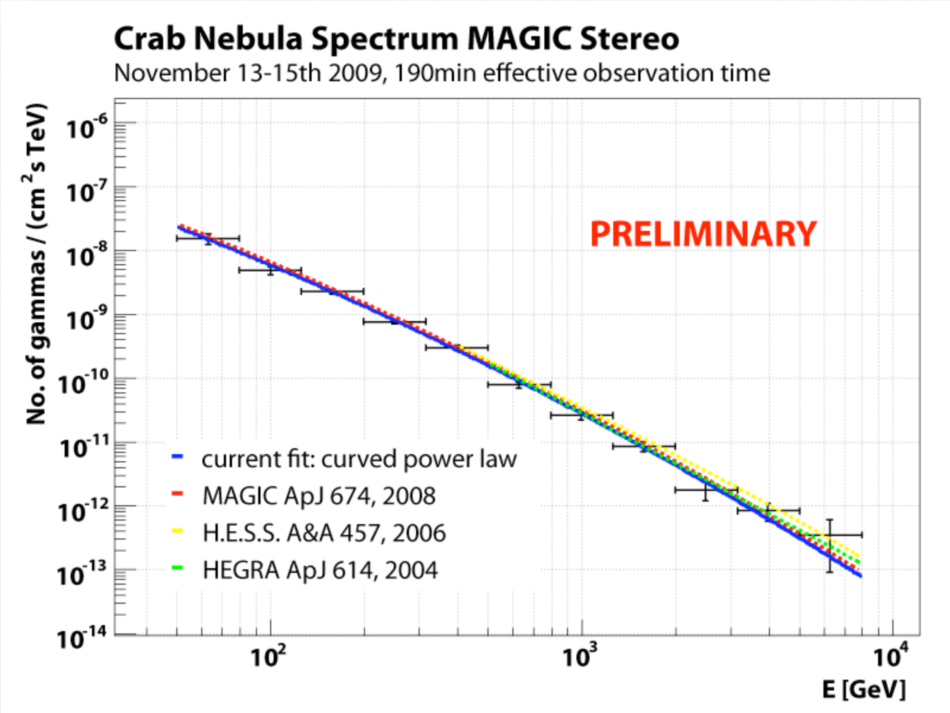


How?

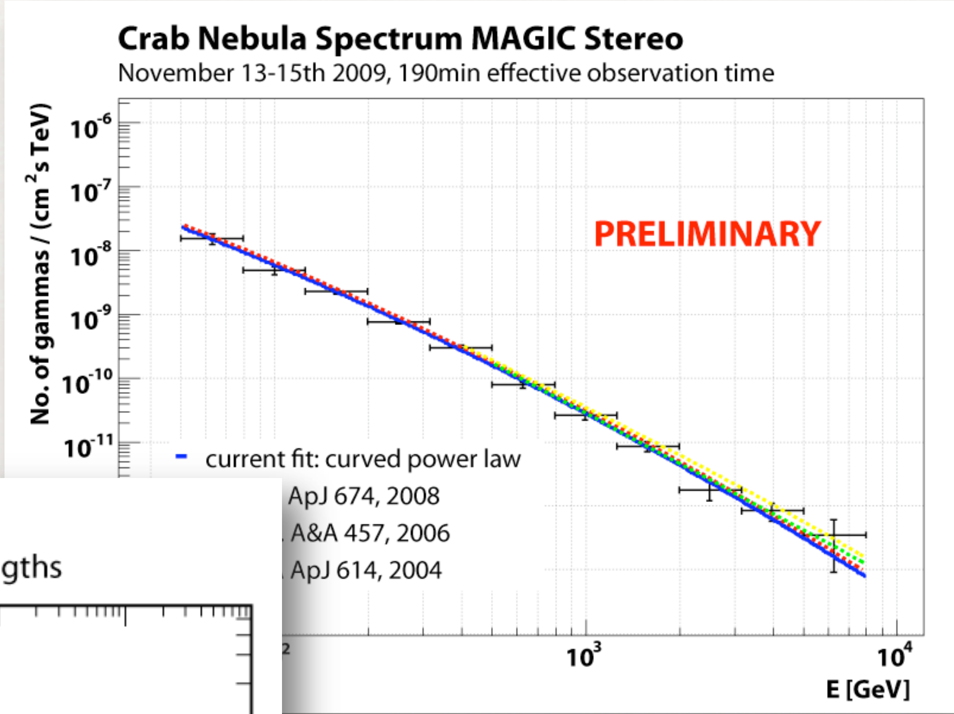
→ With a matrix (correlation matrix) correlating the *true Energy* (from simulations) to the *reconstructed Energy* (estimated through RF)

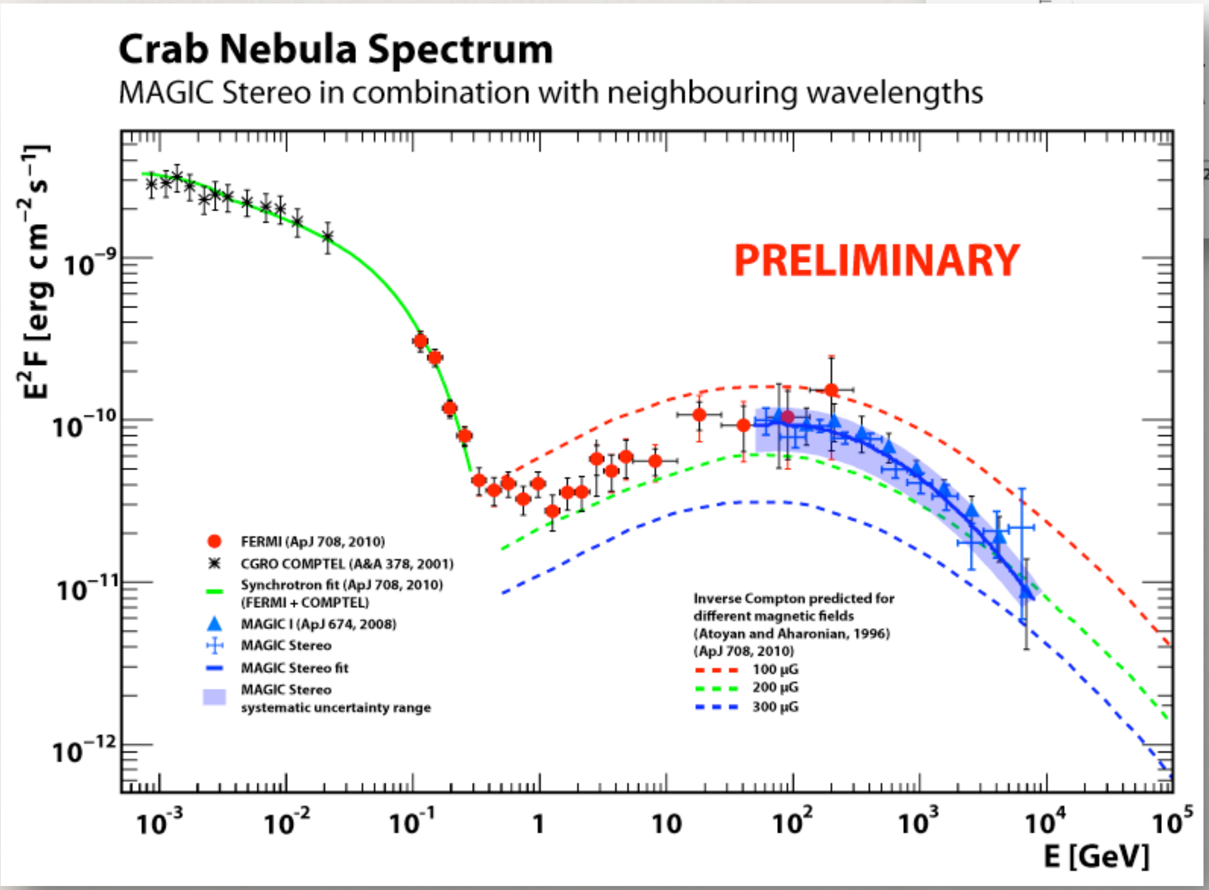
Crab Nebula



Crab Nebula Spectrum MAGIC Stereo
November 13-15th 2009, 190min effective observation time
PRELIMINARY
No. of gammas / (cm^2 s TeV)
E [GeV]
current fit: curved power law
MAGIC ApJ 674, 2008
H.E.S.S. A&A 457, 2006
HEGRA ApJ 614, 2004

Crab Nebula



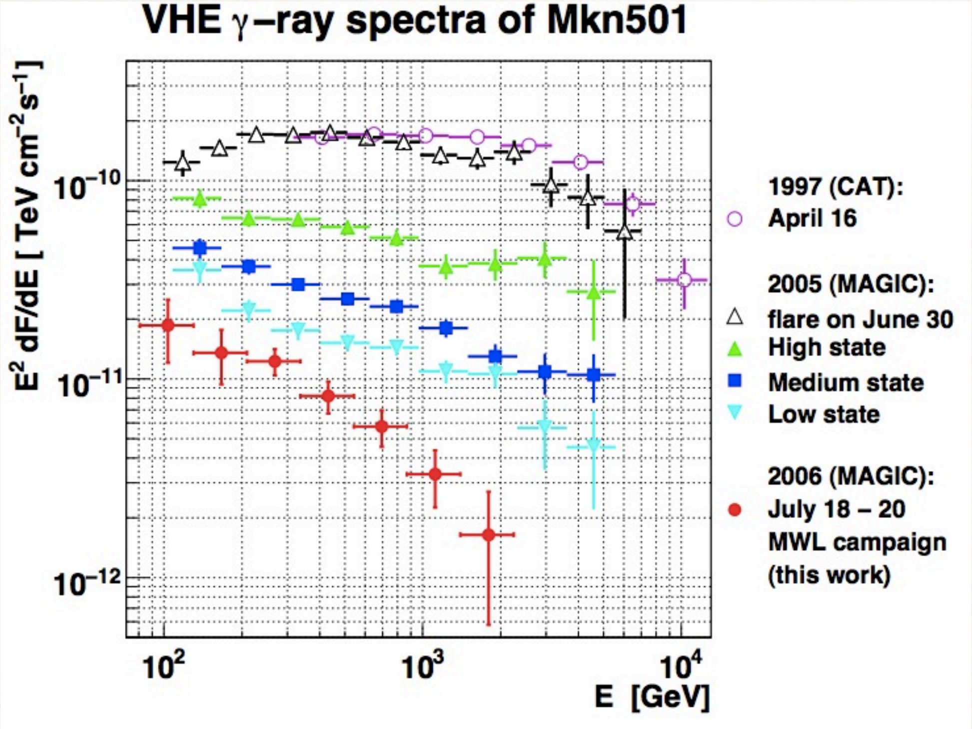


…and SED

Other examples

Other examples

* Extremely variable objects



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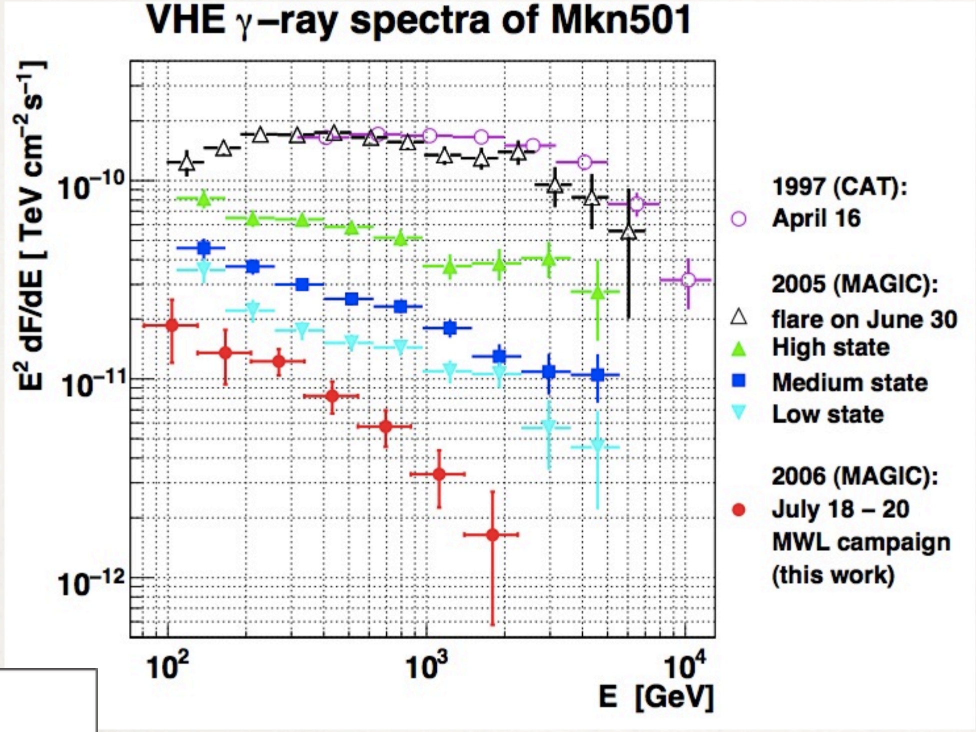

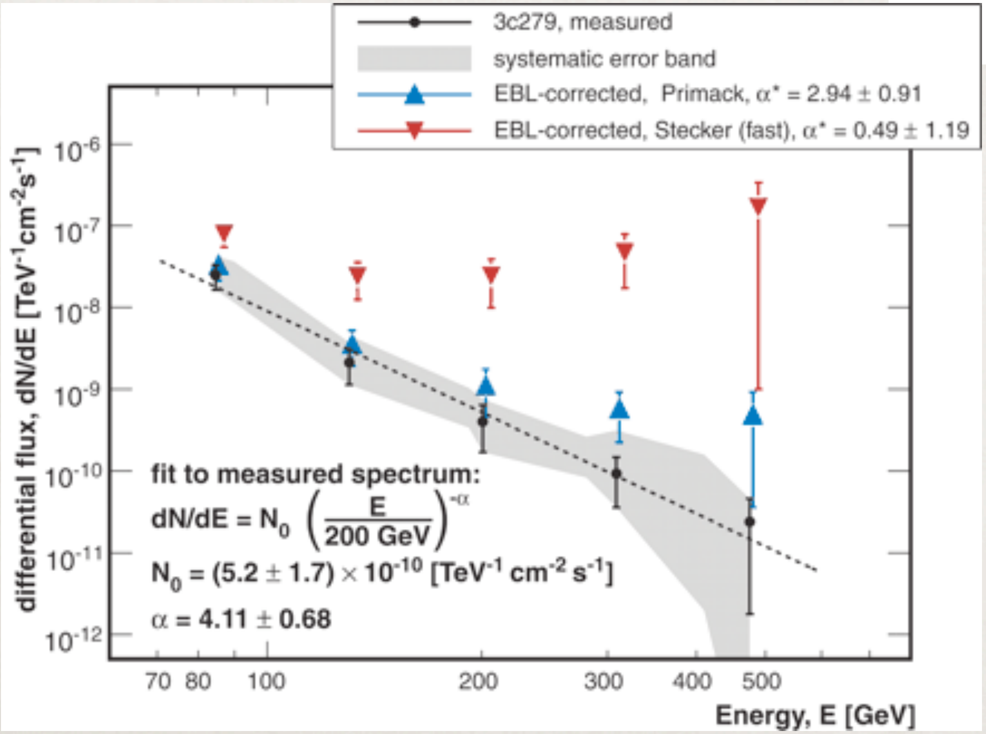

* Extremely distant objects (z=0.536)

Integral Flux

$$\Phi_{E>200\ GeV} = \int_{200\ GeV}^{\infty} \frac{d\Phi}{dE}\, dE$$

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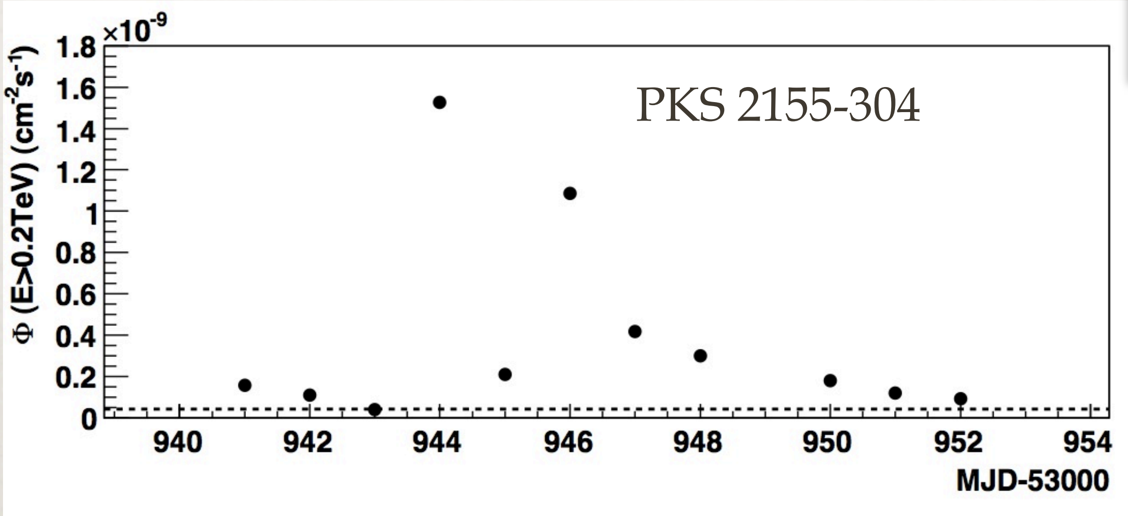
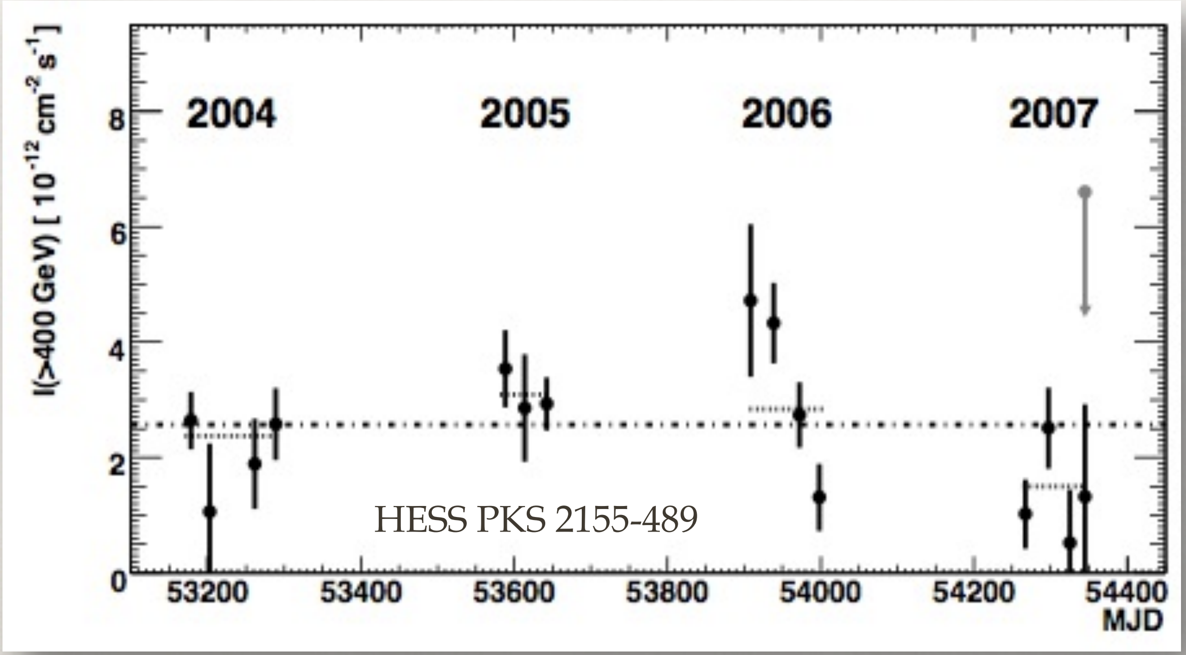
Time evolution studies



H.E.S.S. collaboration, A. Abramowski et al. A&A. 520 (2010) A83

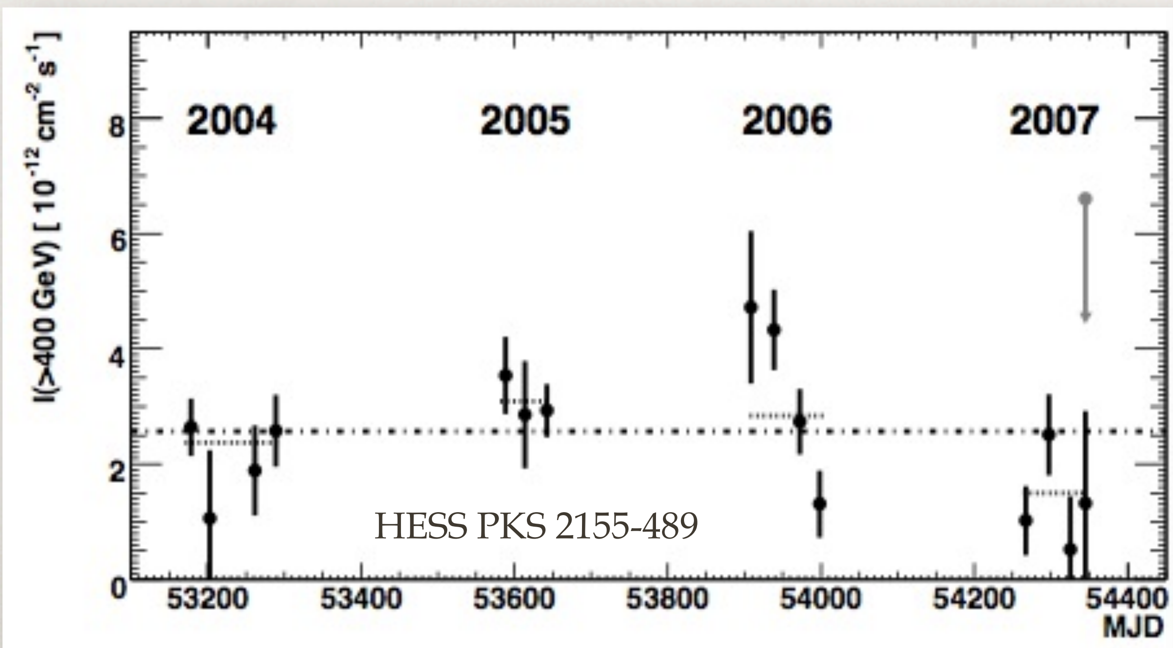
LC Examples

LC Examples



I(>400 GeV) [10^-12 cm^-2 s^-1]
2004
2005
2006
2007
HESS PKS 2155-489
0
2
4
6
8
53200
53400
53600
53800
54000
54200
54400
MJD

LC Examples



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2004
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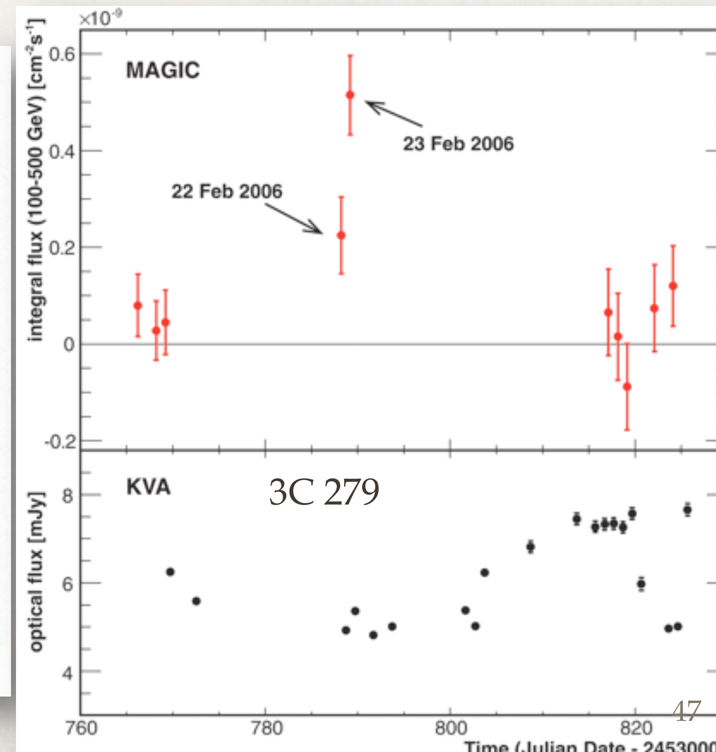
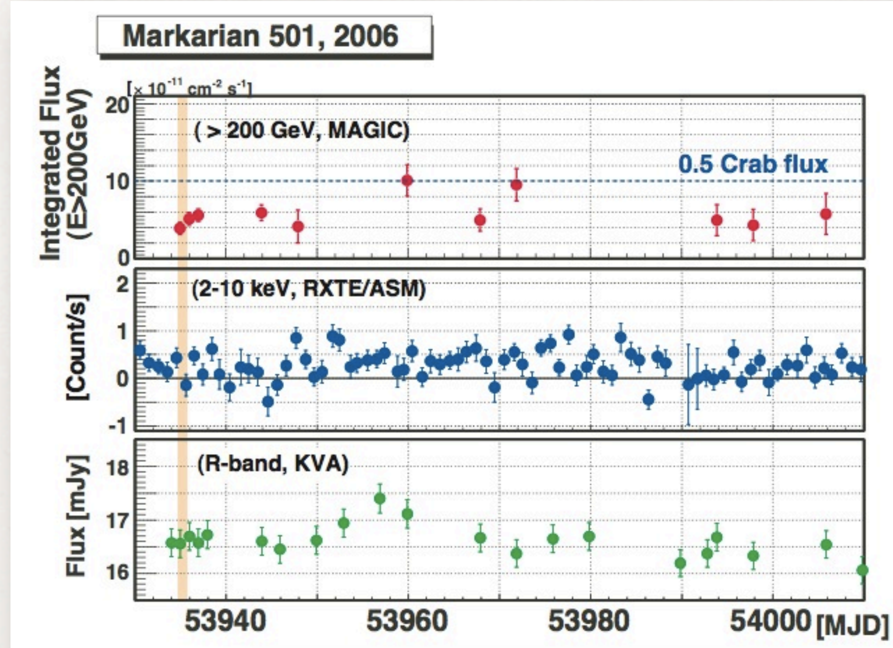
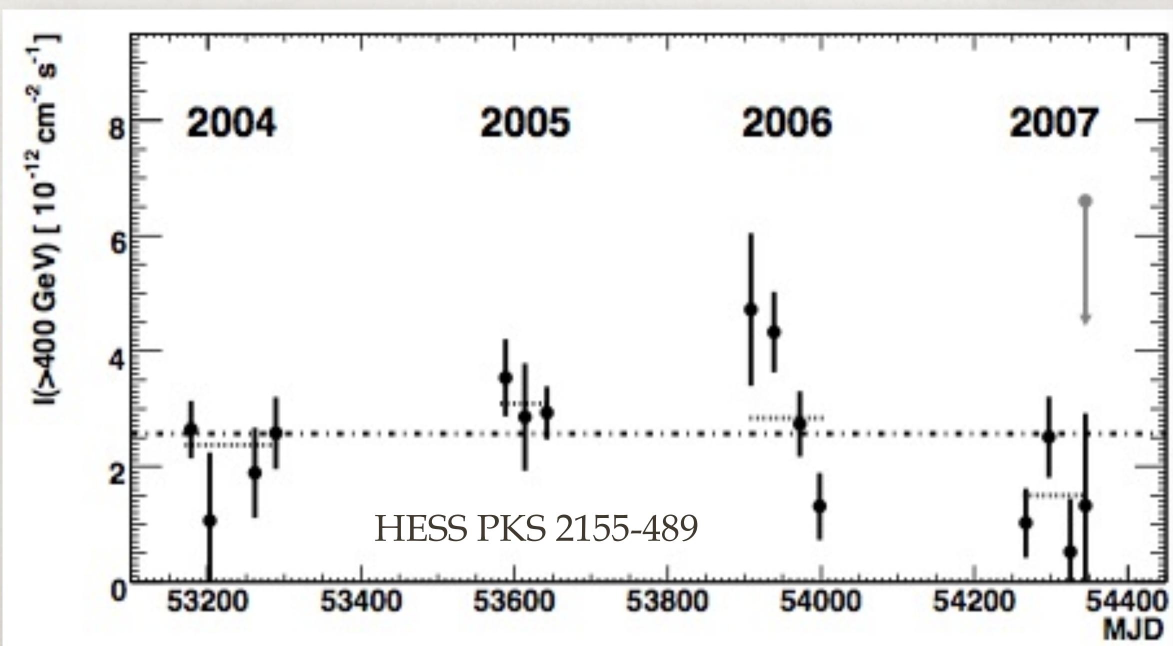


×10⁻⁹
MAGIC
23 Feb 2006
22 Feb 2006
integral flux (100-500 GeV) [$cm^{-2}s^{-1}$]
0.6
0.4
0.2
0
-0.2
KVA
3C 279
optical flux [mJy]
8
6
4
760
780
800
820
Time (Julian Date - 2453000)

LC Examples



Markarian 501, 2006
Integrated Flux (E>200GeV)
[x 10^-11 cm^-2 s^-1]
(> 200 GeV, MAGIC)
0.5 Crab flux
[Count/s]
(2-10 keV, RXTE/ASM)
Flux [mJy]
(R-band, KVA)
53940
53960
53980
54000 [MJD]



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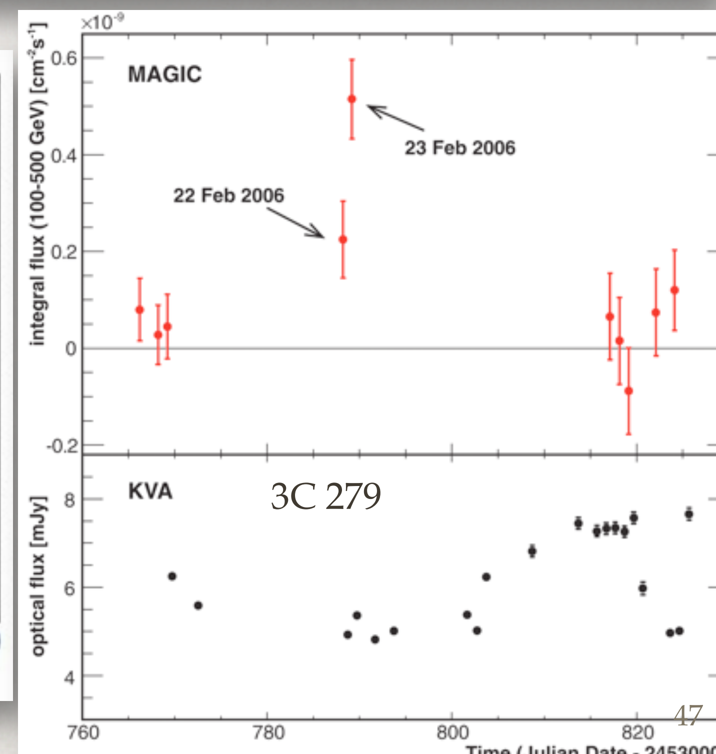
2004
2005
2006
2007
HESS PKS 2155-489
53200
53400
53600
53800
54000
54200
54400
MJD



x10^-9
integral flux (100-500 GeV) [cm^-2 s^-1]
MAGIC
23 Feb 2006
22 Feb 2006
KVA
3C 279
optical flux [mJy]
760
780
800
820
Time (Julian Date - 2453000)

… we are

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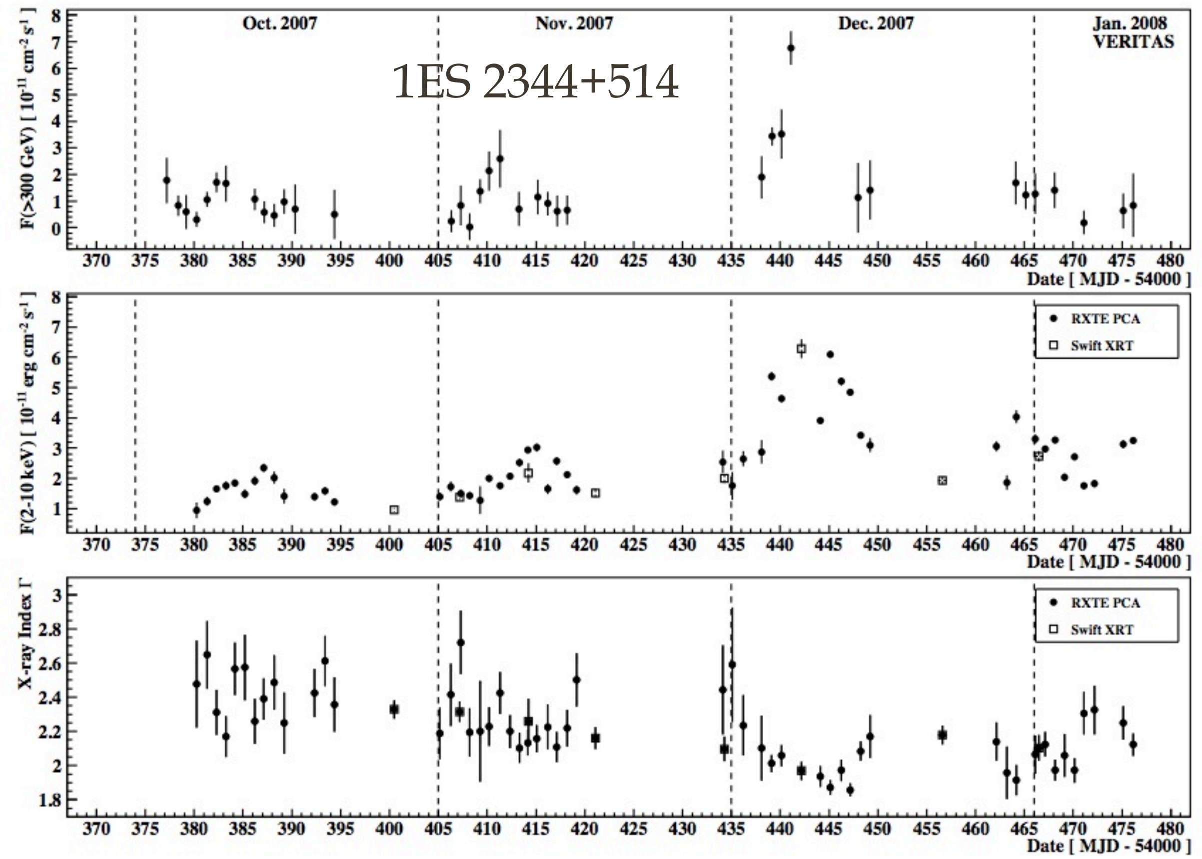
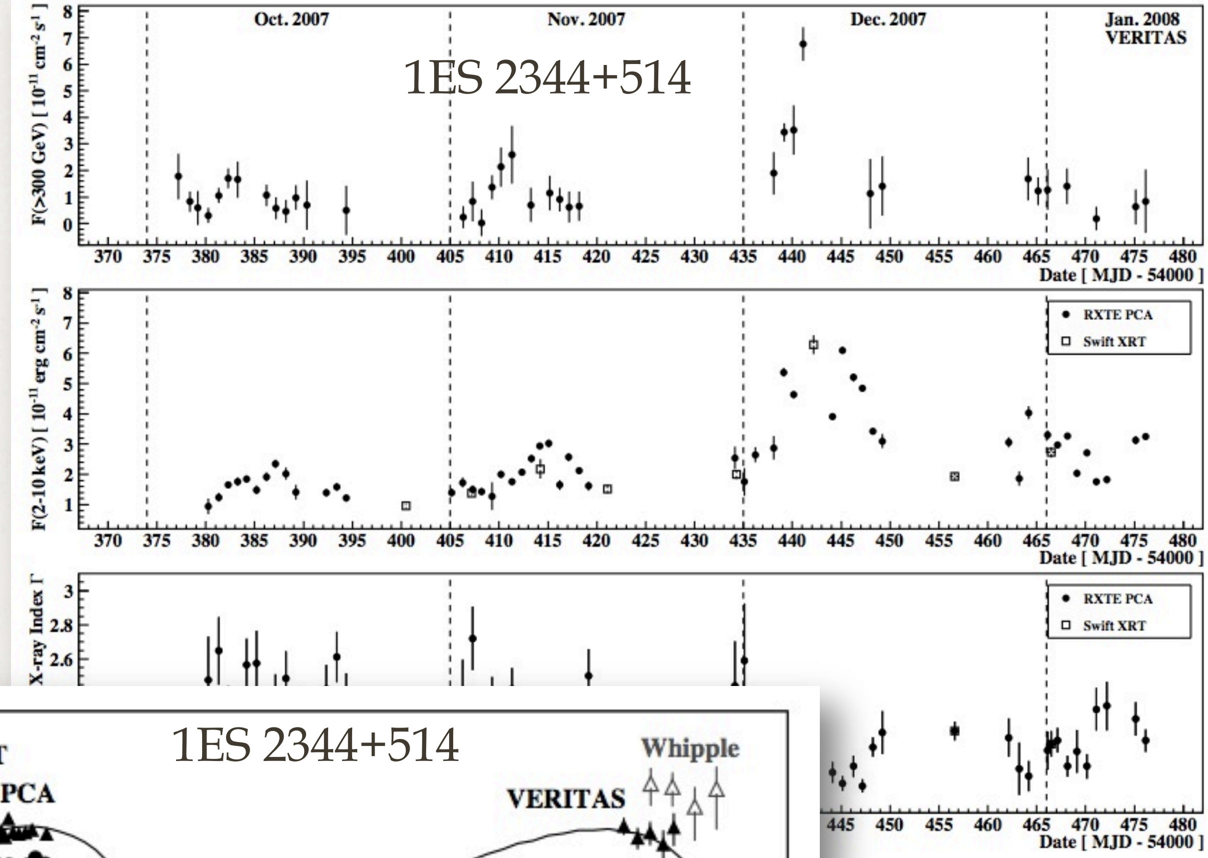
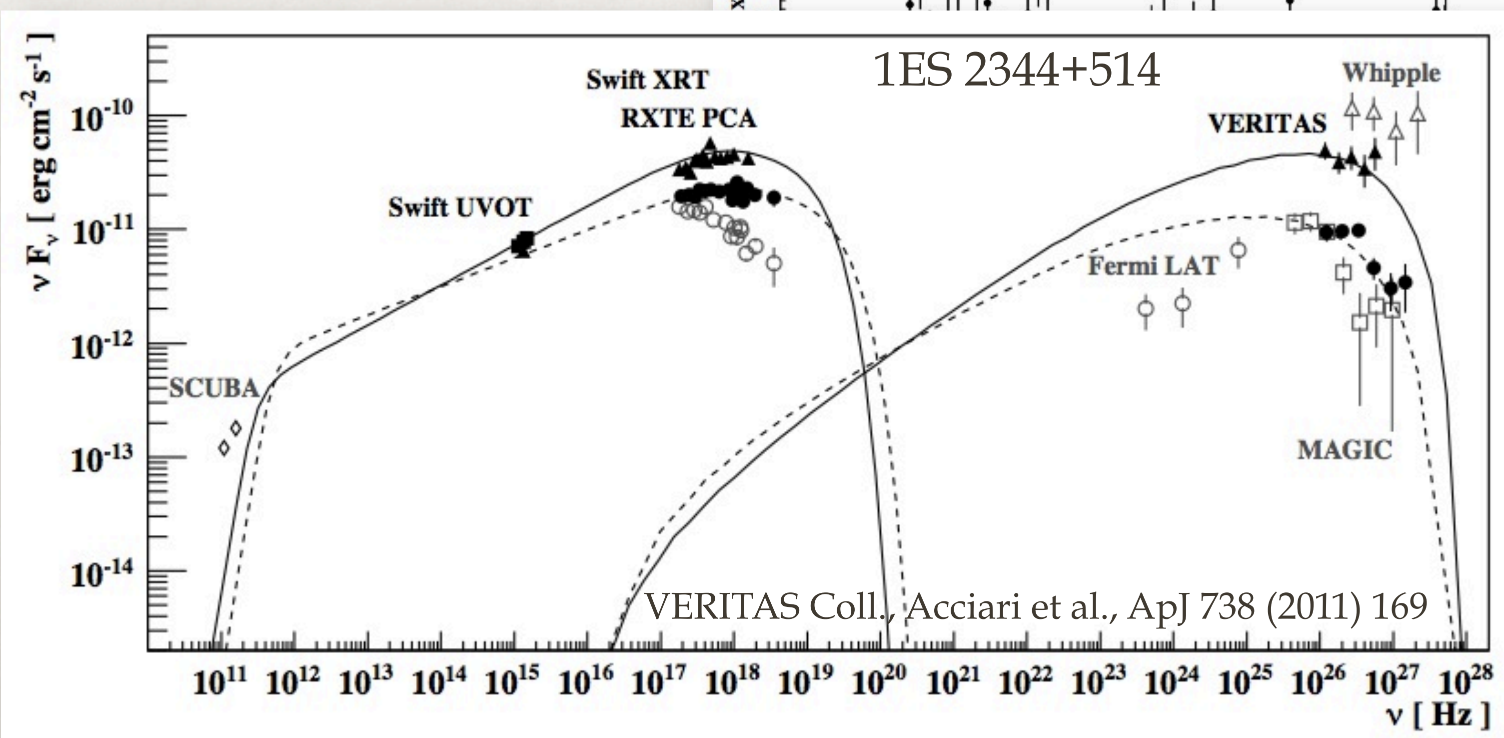


1ES 2344+514
Oct. 2007
Nov. 2007
Dec. 2007
Jan. 2008
VERITAS
F(>300 GeV) [10^-11 cm^-2 s^-1]
F(2-10 keV) [10^-11 erg cm^-2 s^-1]
X-ray Index Γ
RXTE PCA
Swift XRT
Date [MJD - 54000]

… we are





VERITAS Coll., Acciari et al., ApJ 738 (2011) 169

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MULTI-INSTRUMENT!

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THANK YOU!

Exercise… how many Crab gammas in 1 hour?

$$dN/dE = (3.3 \pm 0.11) \times 10^{-11} E^{-2.57 \pm 0.05} cm^{-2} s^{-1} TeV^{-1}$$