# The H.E.S.S. Experiment : High-Energy Stereoscopic System for VHE Gamma-Ray Astronomy

M. Punch,
PCC/APC Collège de France
for the H·E·S·S· Collaboration

# The HESS collaboration

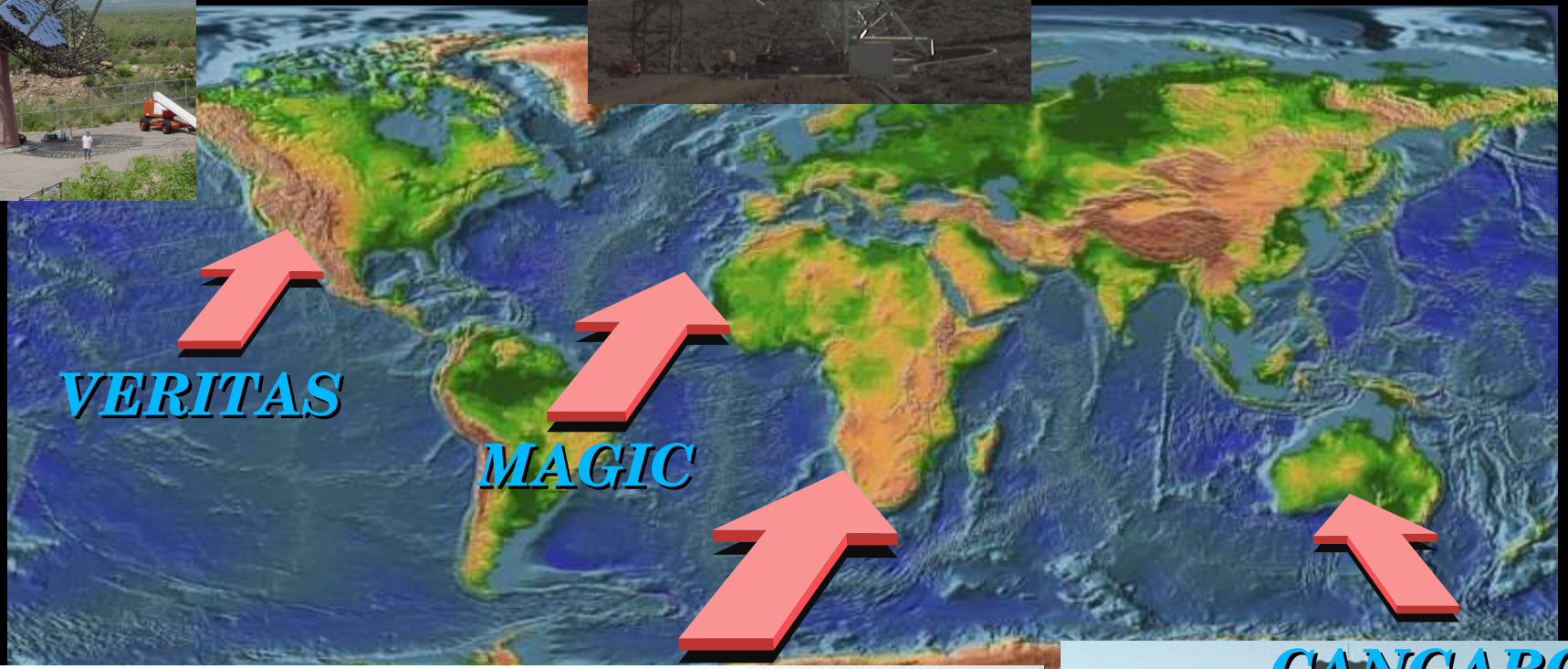
MPI Kernphysik, Heidelberg
Humboldt Univ. Berlin
Ruhr-Univ. Bochum
Univ. Hamburg
Landessternwarte Heidelberg
Univ. Kiel
LLR, Ecole Polytechnique, Palaiseau
PCC, College de France, Paris
LPNHE-Paris, Univ. Paris VI-VII
CEA Saclay
CESR Toulouse
LAOG Grenoble
Observatoire de Paris
GAM, Montpellier
Durham Univ.
Charles Univ., Prag
Yerewan Physics Inst.
Dublin Inst. for Adv. Studies
Univ. Namibia, Windhoek
Univ. Potchefstroom

3 continents
8 countries
19 institutions
69 physicists
100 engineers and technicians

**HESS**

*High Energy Stereoscopic System Collaboration*

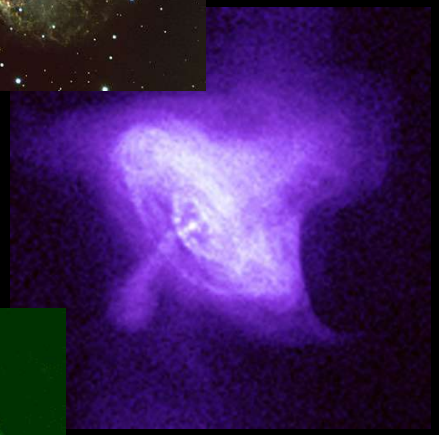
# Next-Generation ACTs (planned/completed)

# Physics Targets For Gamma-Ray Astronomy

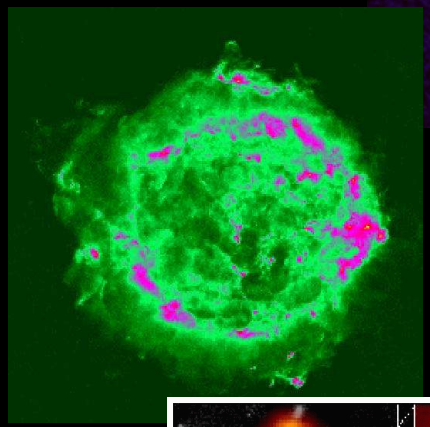
**What ?**

- Galactic:
  - Supernova Remnants (SNR), Pulsars, $\mu$Quasars
- ExtraGalactic:
  - Active Galactic Nuclei (AGN)
- Exotic:
  - Gamma-Ray Bursts
  - Spectral or line emission from WIMP annihilation ...



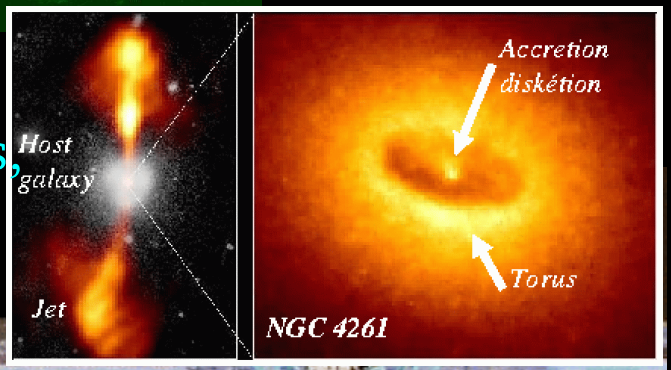
**Why ?**

- Test of the hypothesis of SNR as the source of Galactic Cosmic Rays (or ...)
- Understanding of the acceleration mechanisms, identification of emitting particles, mechanisms of jet formation
- Probing the Infra-Red Background...



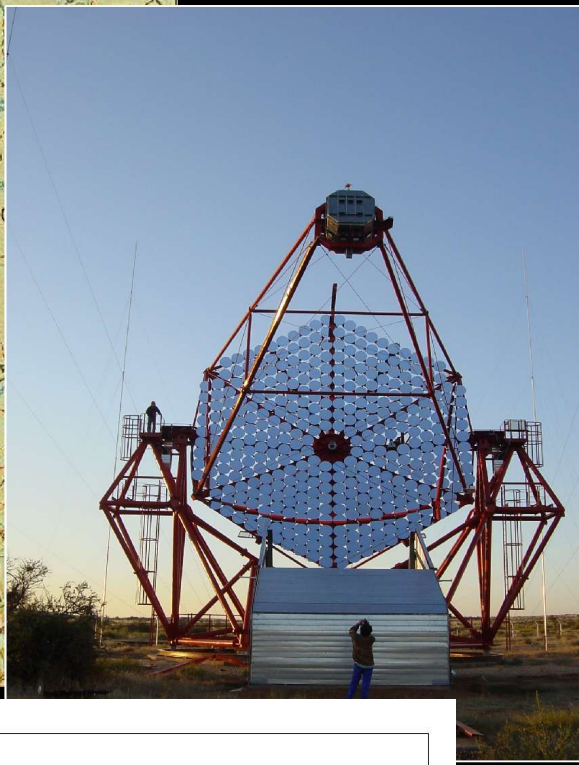
**How ?**

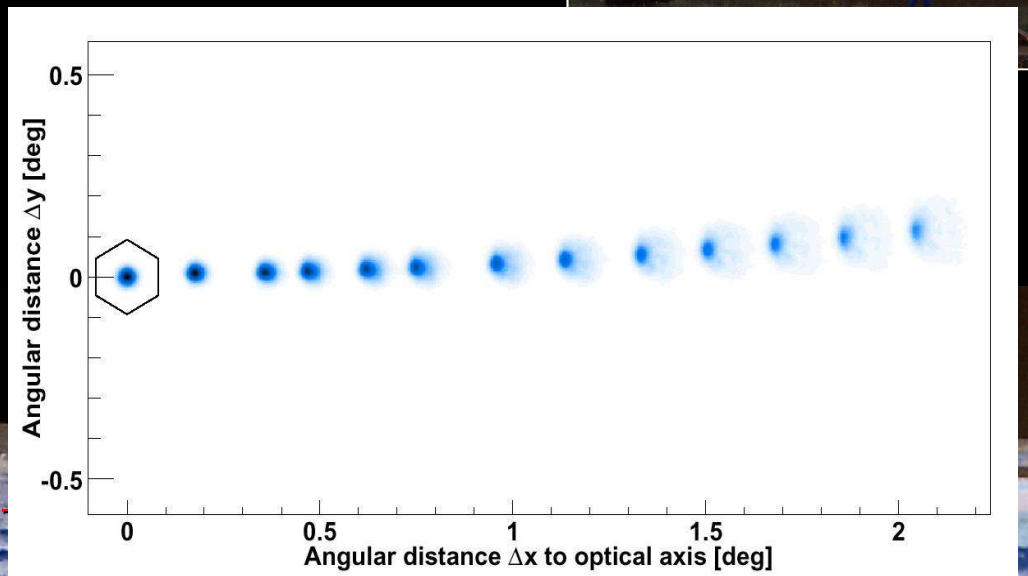
- Using the Ground-based Imaging Atmospheric Cherenkov Technique
- Correlations with Gamma- and X-ray satellite detectors, radio and optical telescopes

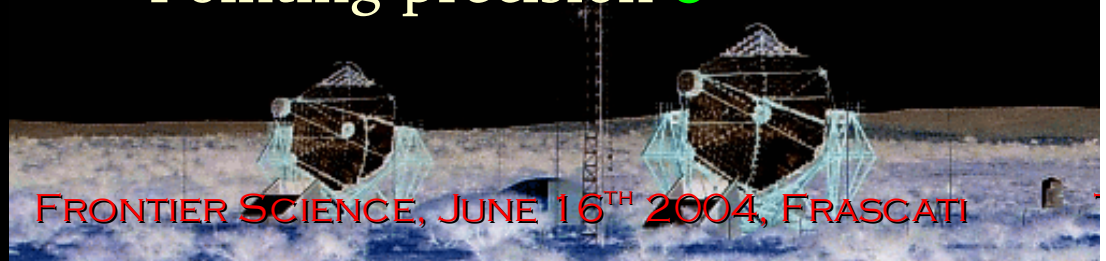


# HESS Phase-I Essential Characteristics

- Four-Telescope network
  - Sited in Namibia, 23°S, 15°E, 1800 m altitude
  - Telescope separation: 120 m
- Telescope Structures
  - Mirror dishes: 4 × 107 $m^2$
  - Diameter: 12 m, Focal length: 15 m
- Mirrors
  - 380 × 60cm circular facets
  - PSF after alignement ($r_{80\%}$)
    1.3' / 0.38 mrad on axis
  - Pointing precision 8”

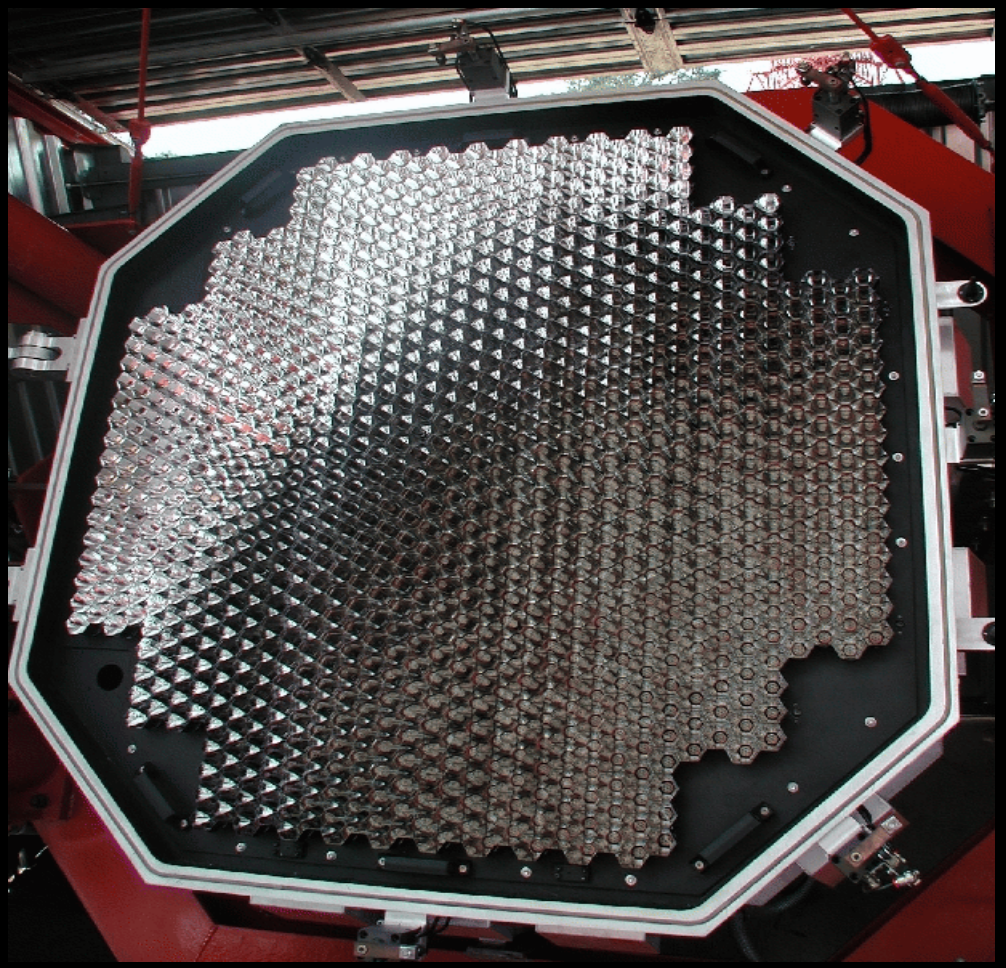





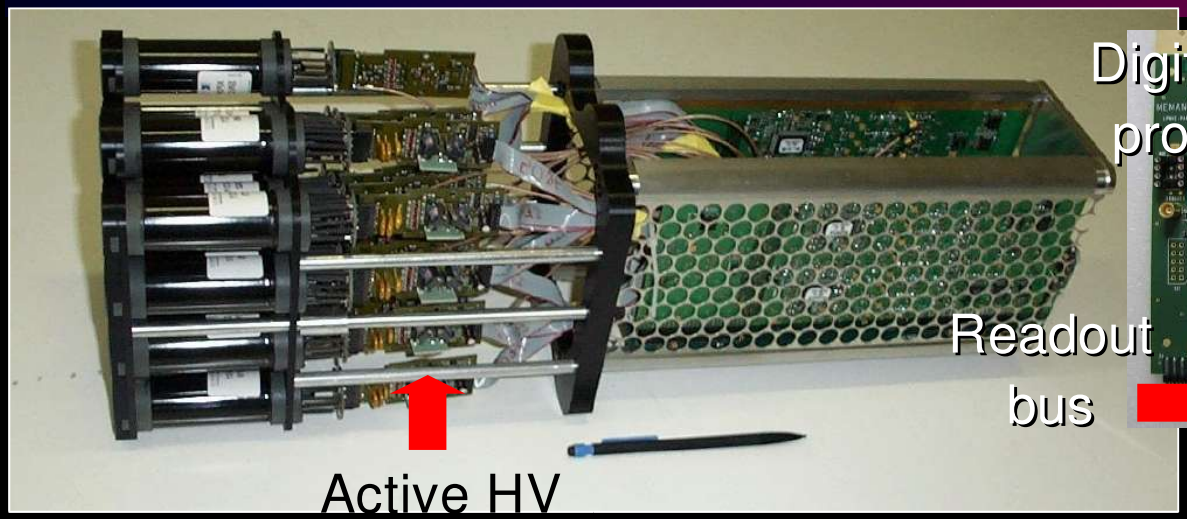
# HESS Phase-I Essential Characteristics

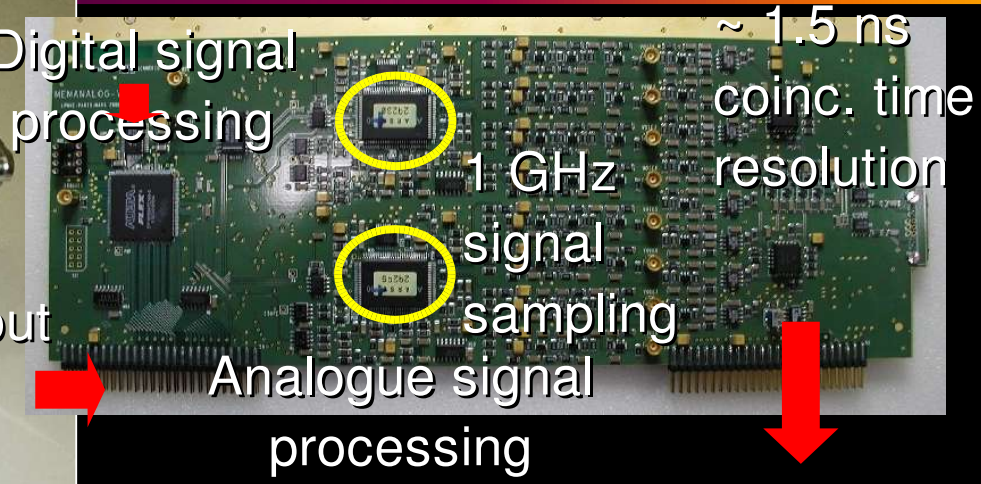
- Cameras
  - 960 photomultiplier pixels
  - Pixels of 0.16° / 2.8 mrad
  - Wide field of view, 5°
  - 16ns integration window, fast trigger coincidence
  - All electronics integrated in-camera
  - 3 cables (1 power , 2 optic fibres)
  - Fits in 2 m cube
  - Weight ~ 900 kg



- Telescope Threshold ~100 GeV

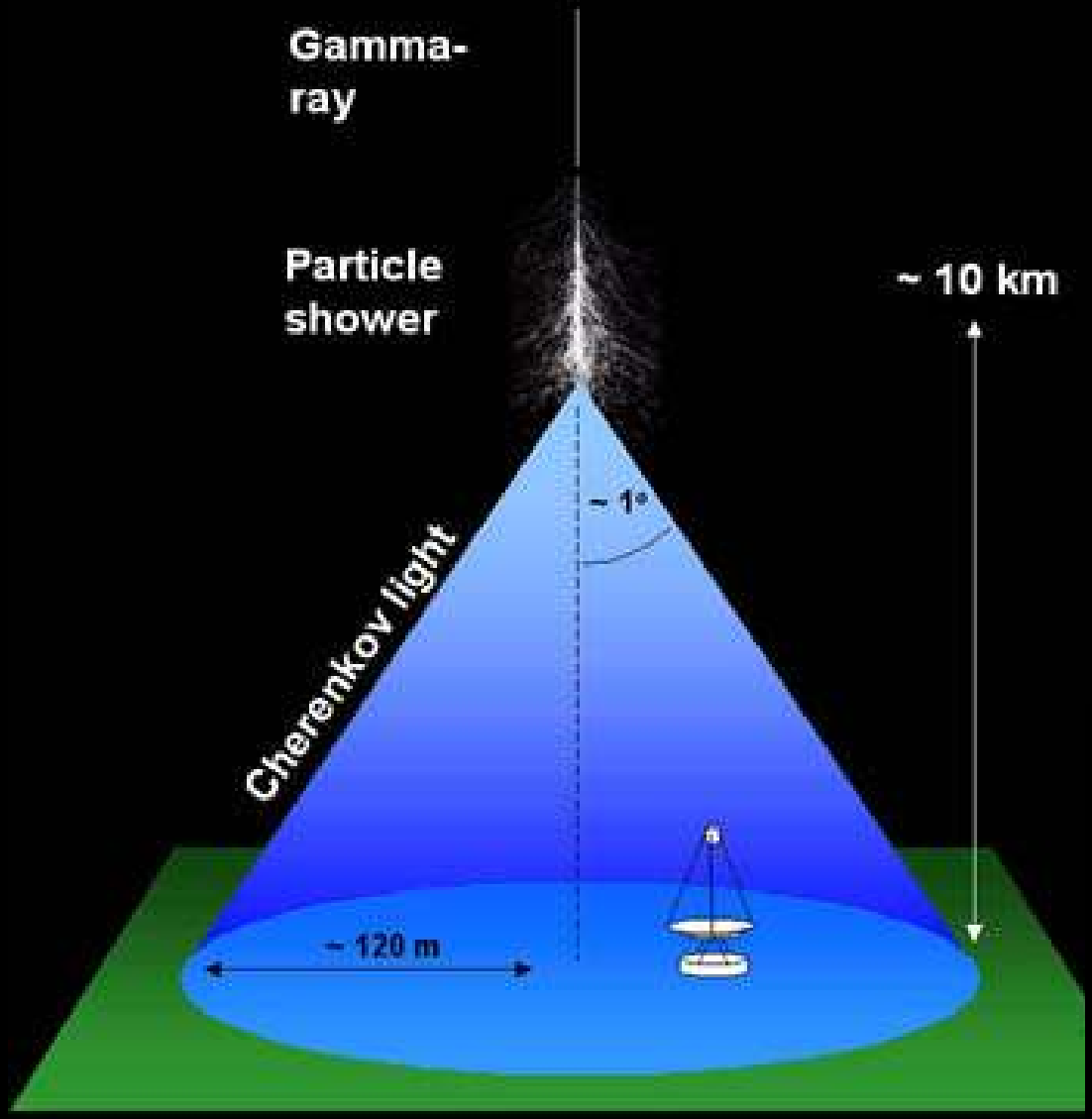
# Electronics Front-End



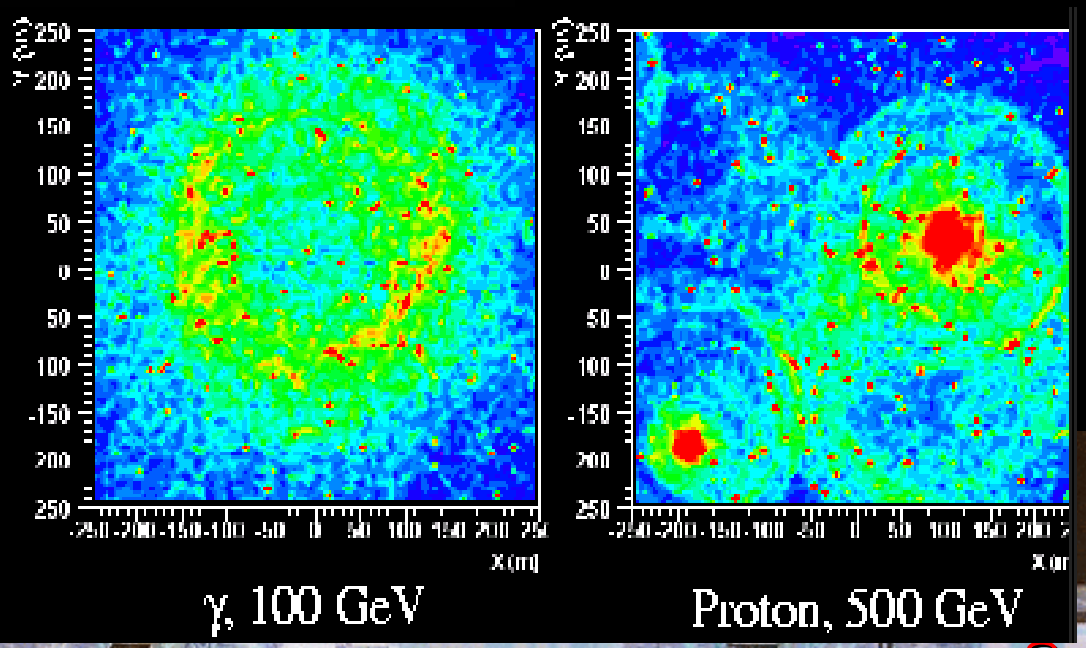

- Large dynamic range, good linearity (up to 1600 γe)
- Single photoelectron peak resolution (at 80 d.c.)
- Storage of signal in analogue memory during trigger formation time (~70ns)
- On-board data acquisition

# The Atmospheric Cherenkov Technique



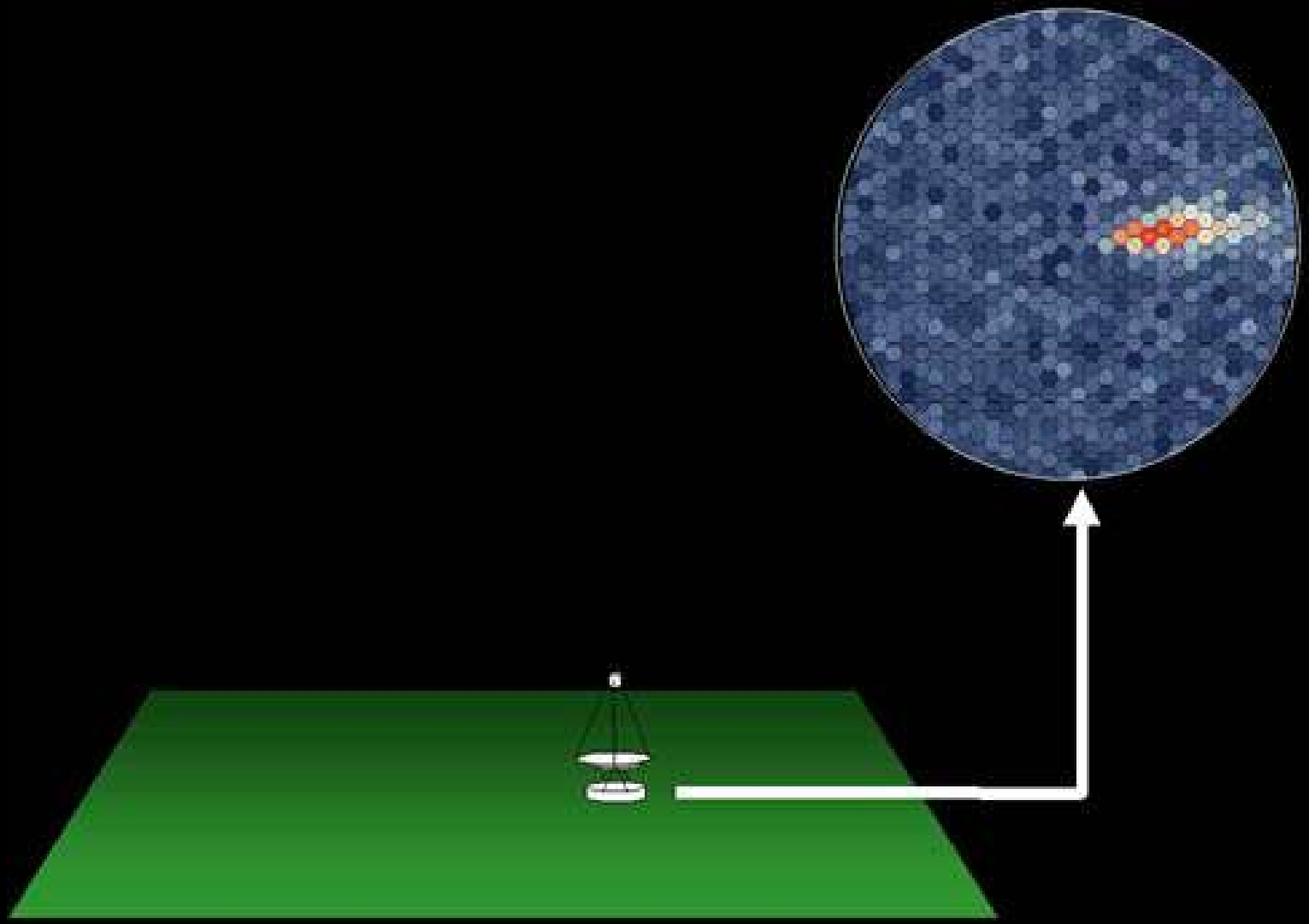

Detection of high-energy gamma rays

using Cherenkov telescopes



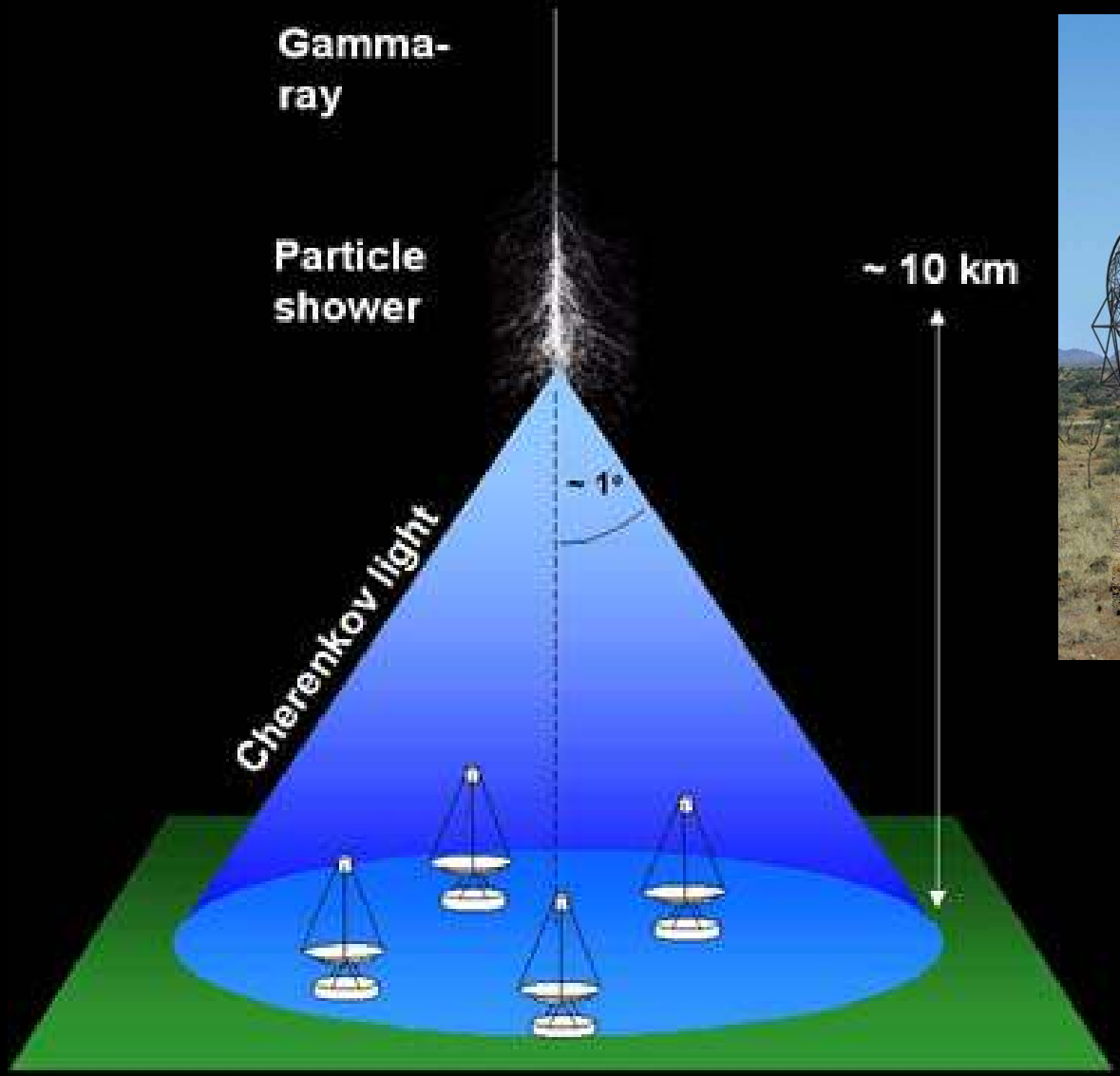

Sequence from W. Hofmann

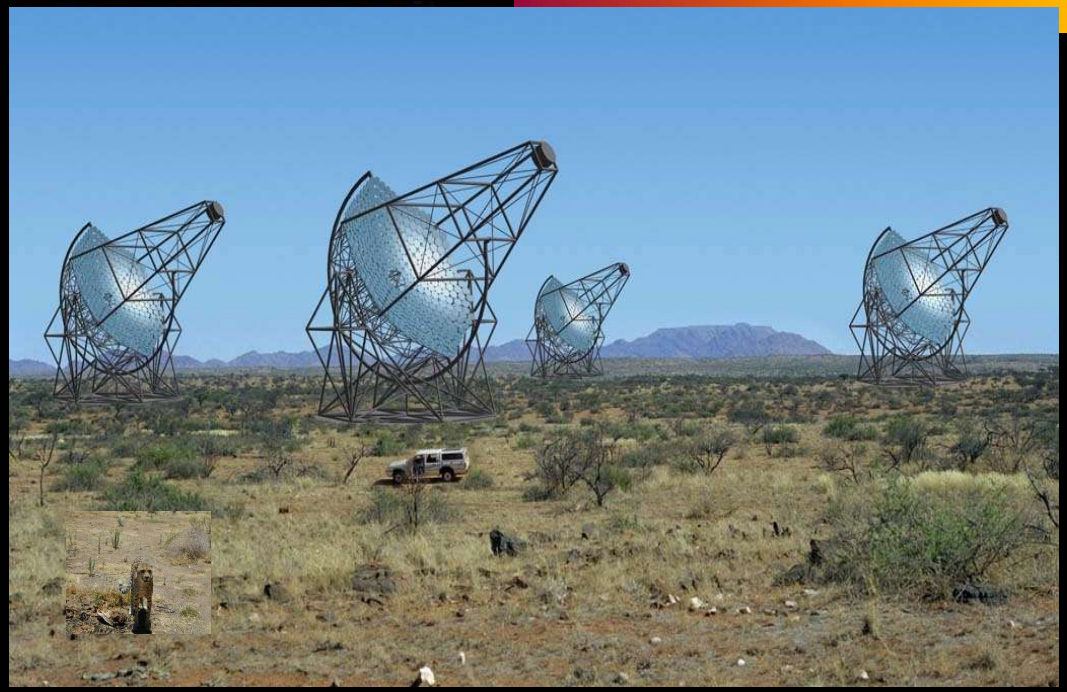
# The Atmospheric Cherenkov Technique



Sequence from W. Hofmann

# The Atmospheric Cherenkov Technique

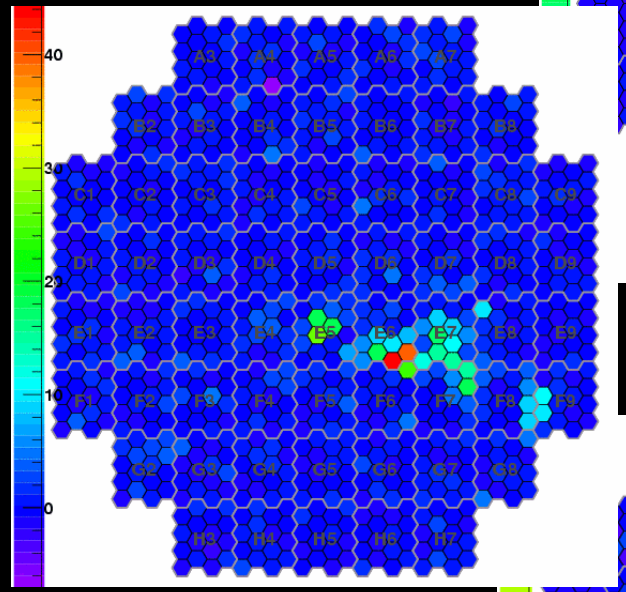


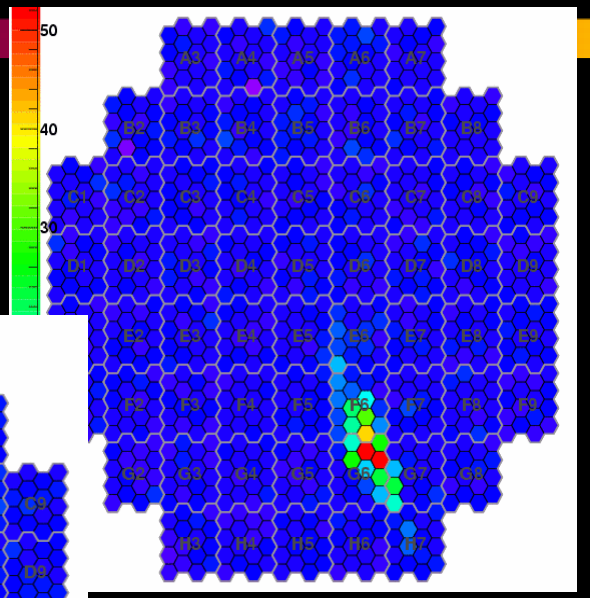
Sequence from W. Hofmann

# ACT: Advantages of Stereoscopy

- Shower seen from different angles:
  Better discrimination between gammas and hadronic background
- Geometrical determination of the gamma-ray origin on the sky
- Geometrical determination of the shower impact parameter on the ground
  ⇒ better energy resolution
- Triggers from isolated muons are over half of mono-telescope events
  Muon elimination ⇒ lowering of threshold

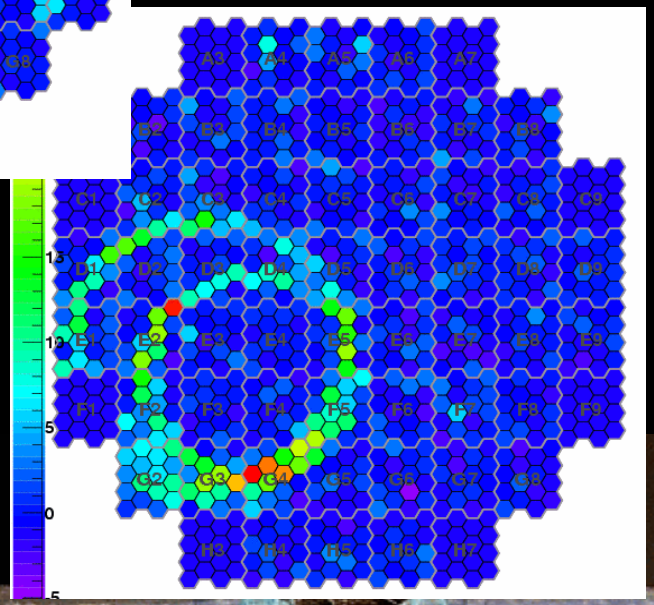


hadrons

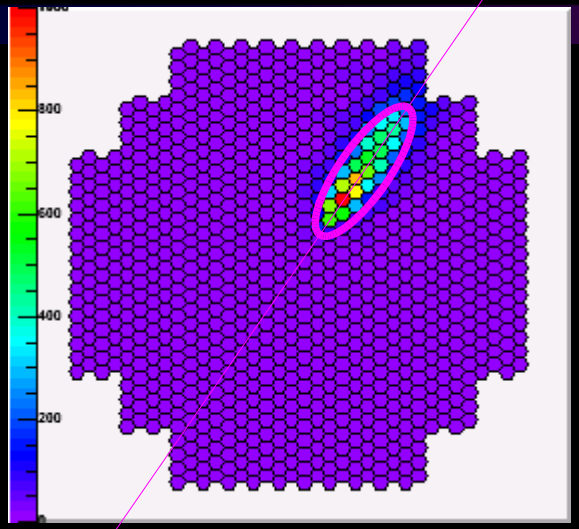


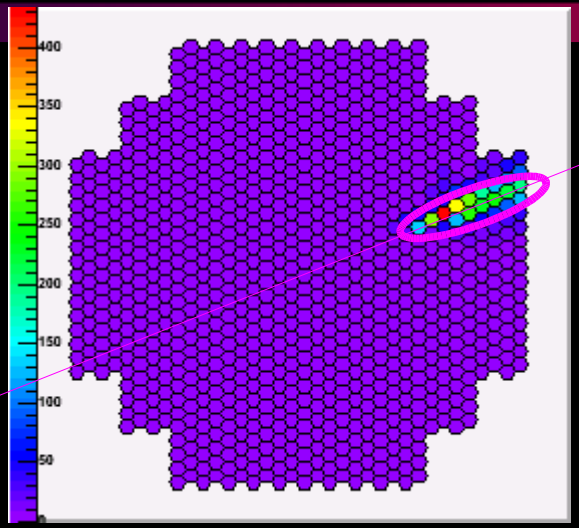
gamma

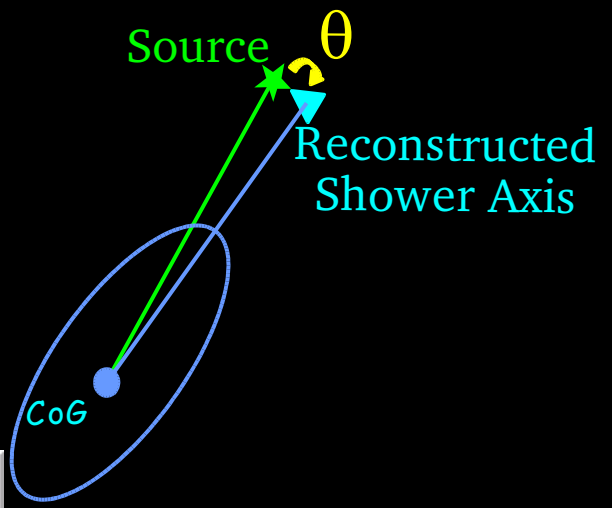
muons



# Stereo: Tells where the shower came from

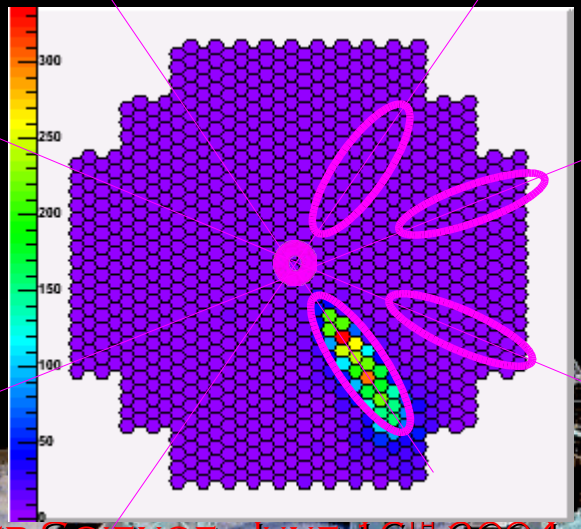


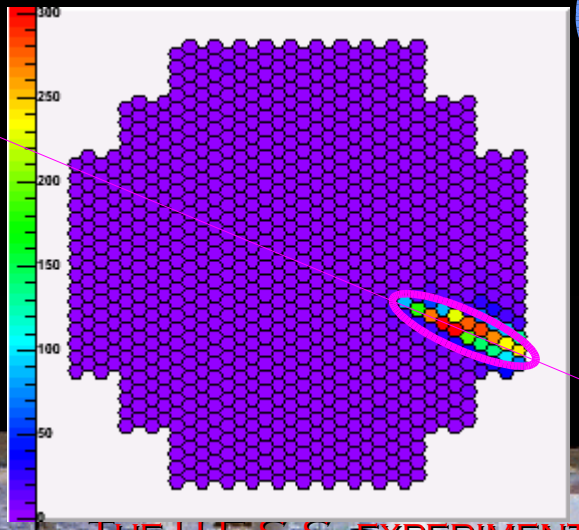




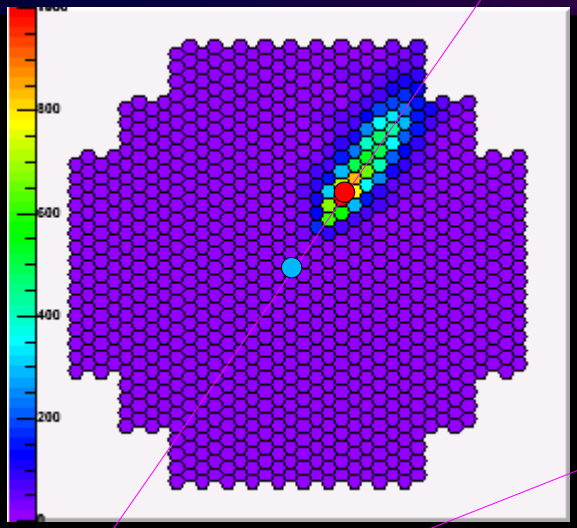

Geometrical determination of
the source position in the camera

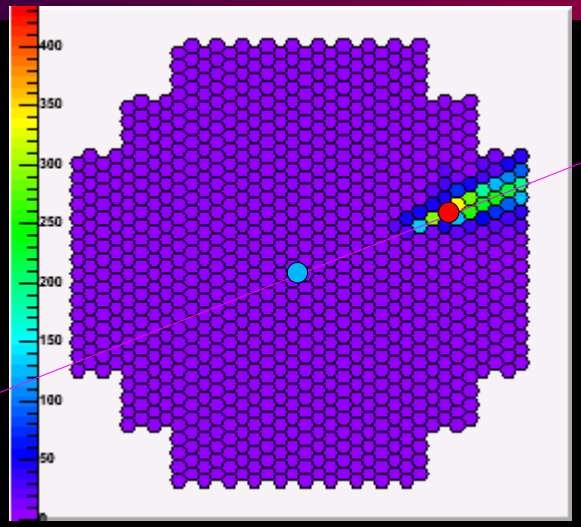
... HESS angular resolution 0.10→0.06° per photon





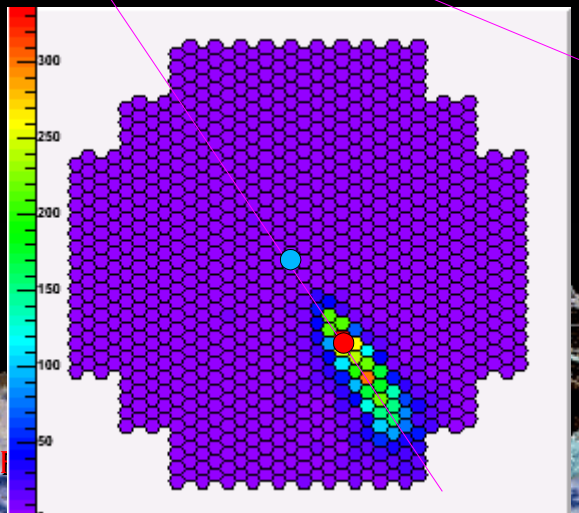
# Stereo: Tells where the shower hit

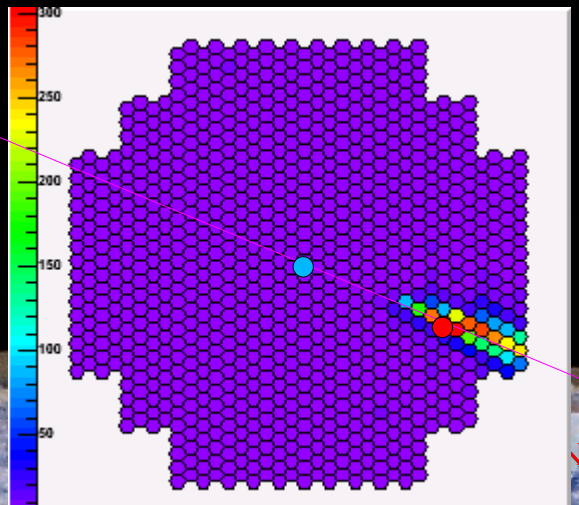




- *Shower origin*
- *Image centre of gravity*

Geometrical determination of the
shower impact point on the ground
⇒ resolution of the energy / impact parameter degeneracy
HESS energy resolution ~15%

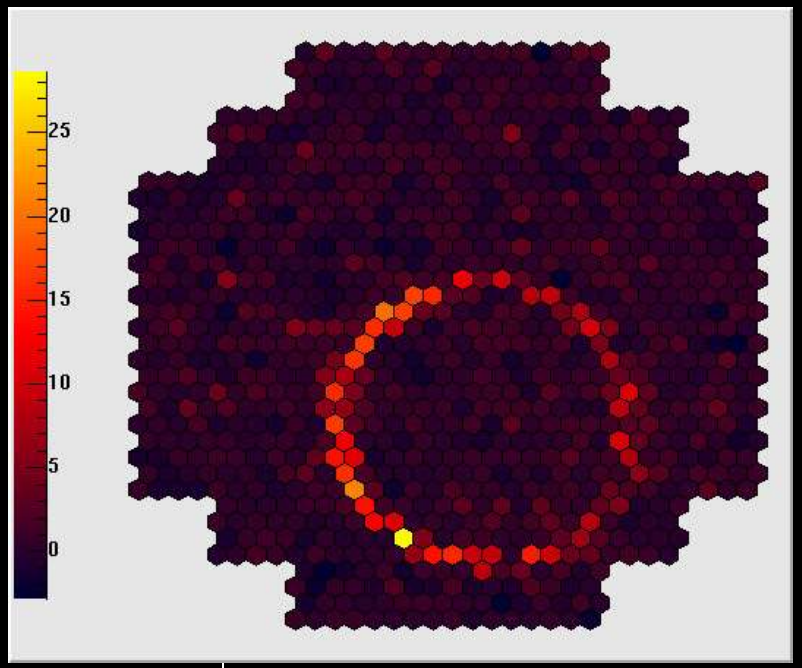


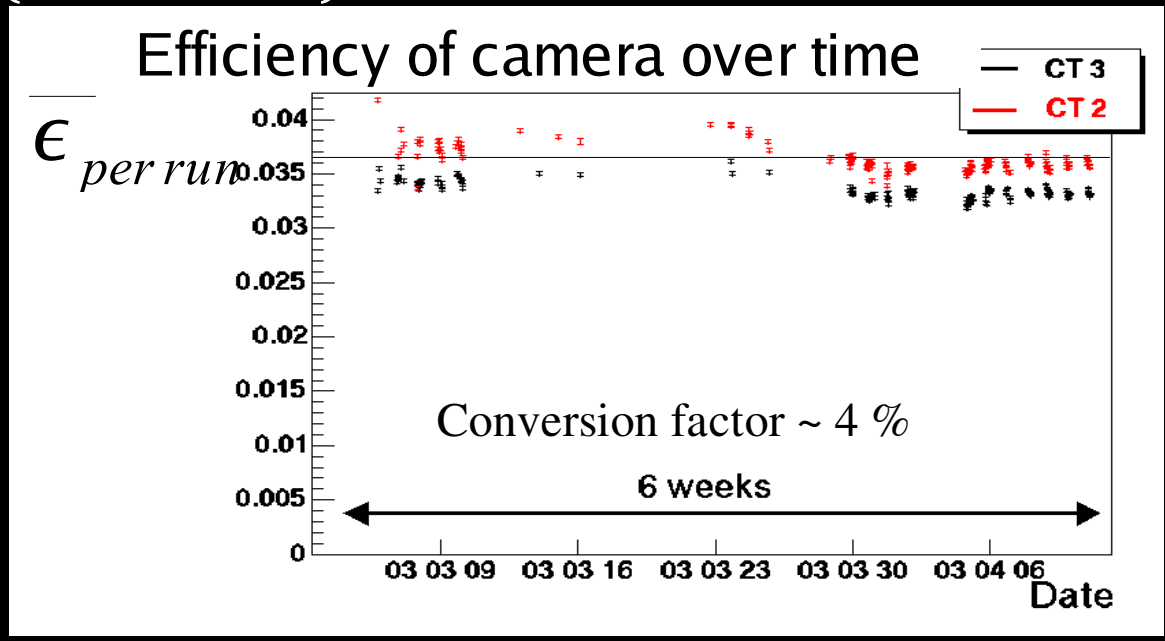


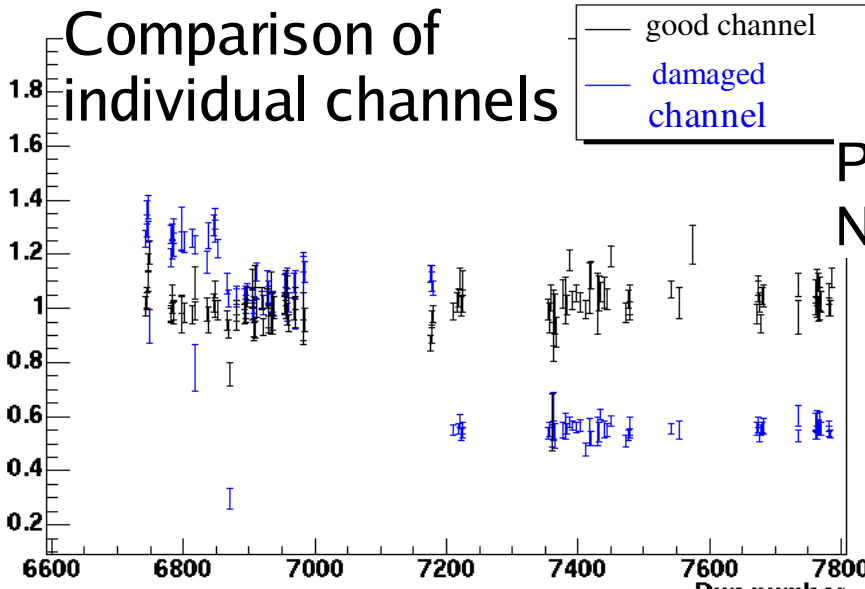
Not to scale

# Muon Supression with Stereo Trigger

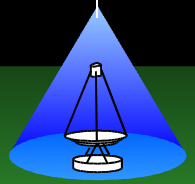
Muons: In single telescope mode, give rings (as in RICH) ⇒ useful for calibration.



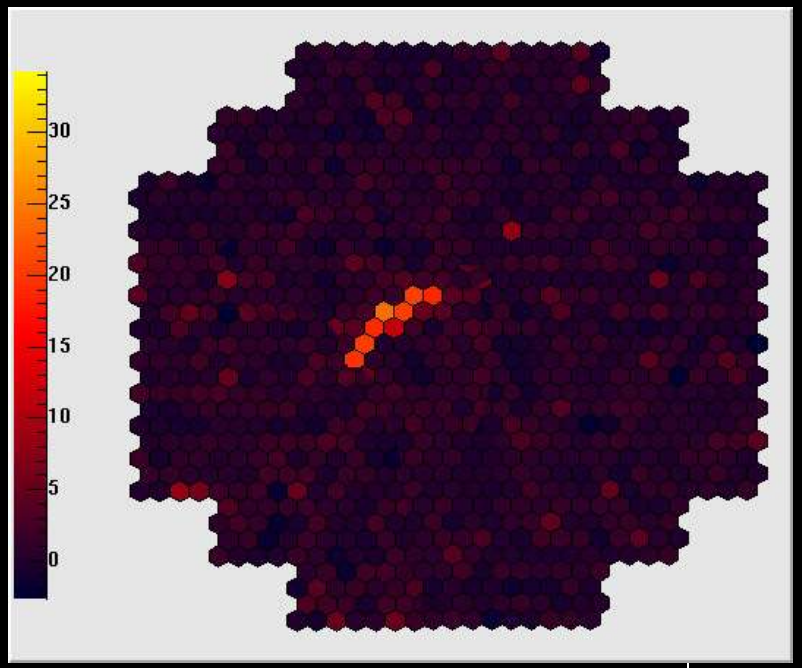




Plots from N. Leroy, LLR



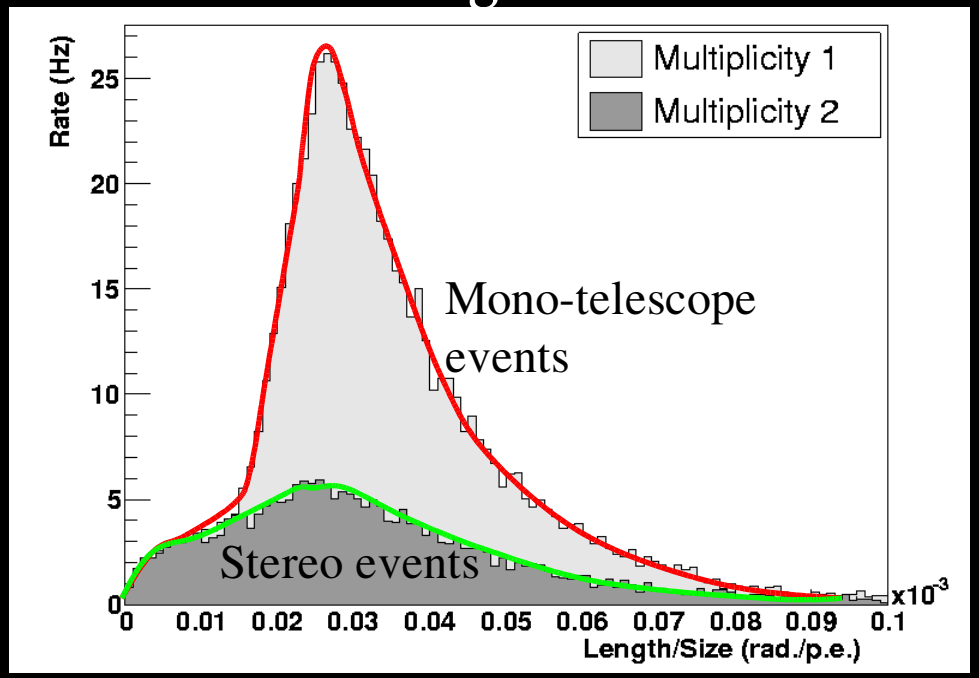
# Muon Supression with Stereo Trigger




*But*

Far from telescope muons give events which can mimic gamma-ray images

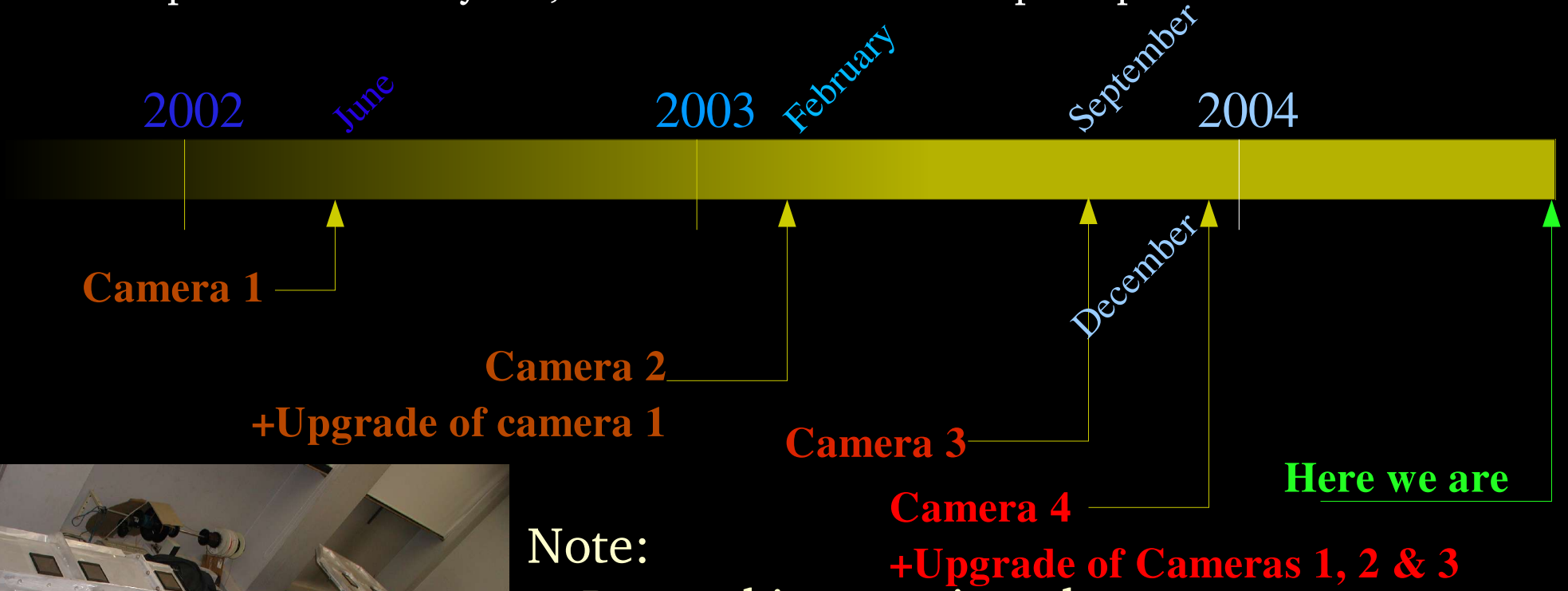
⇒ difficult background




Muon background eliminated by Stereo !

# HESS-I: A TIGHT INSTALLATION SCHEDULE

First design: '96; Collaboration founded '98; Groundbreaking '00;
First telescope structure July '01; Mirrors on 1st telescope September '01




Note:

Data taking continued throughout the installations

⇒ Heterogeneous data-set

- Varying thresholds, Complicated analysis

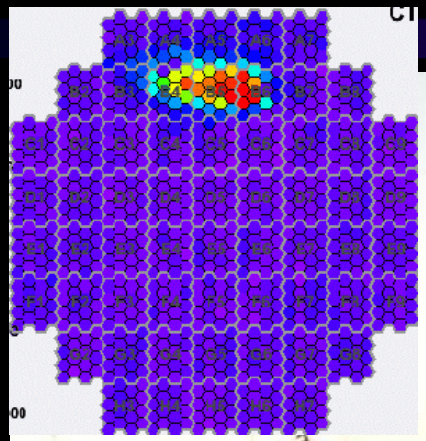
# HESS-I: A Heterogenous Data-set

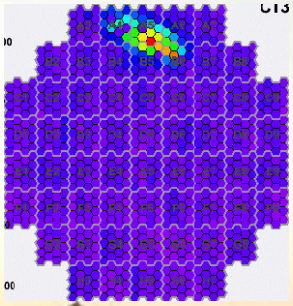
| Time | Telescopes | Telescope rate | System rate |
|---|---|---|---|
| July 2002 – Feb. 2003 | CT 3 | ~ 250 Hz | - |
| Mar. – July 2003 | CT 2 , 3 (independent) | ~ 250 Hz | ~ 30 Hz |
| Aug. – Sept. 2003 | CT 2, 3 (coincidence) | ~ 2 kHz | ~ 110 Hz |
| Oct. – Nov. 2003 | CT 2, 3, 4 (2 out of 3) | ~ 2 kHz | ~ 210 Hz |
| **Since Dec. 2003** | CT 1, 2, 3, 4 (2 out of 4) | ~ 2 kHz | ~ 350 Hz |

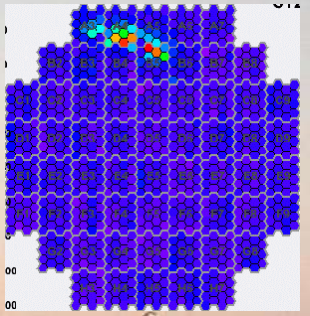
Increased Single-telescope rate $\Rightarrow$ decreased threshold

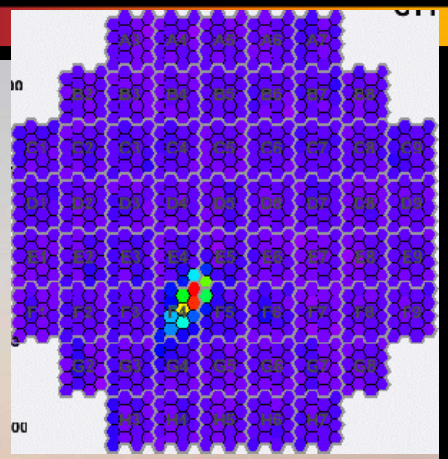
Increased System rate $\Rightarrow$ increased collection area

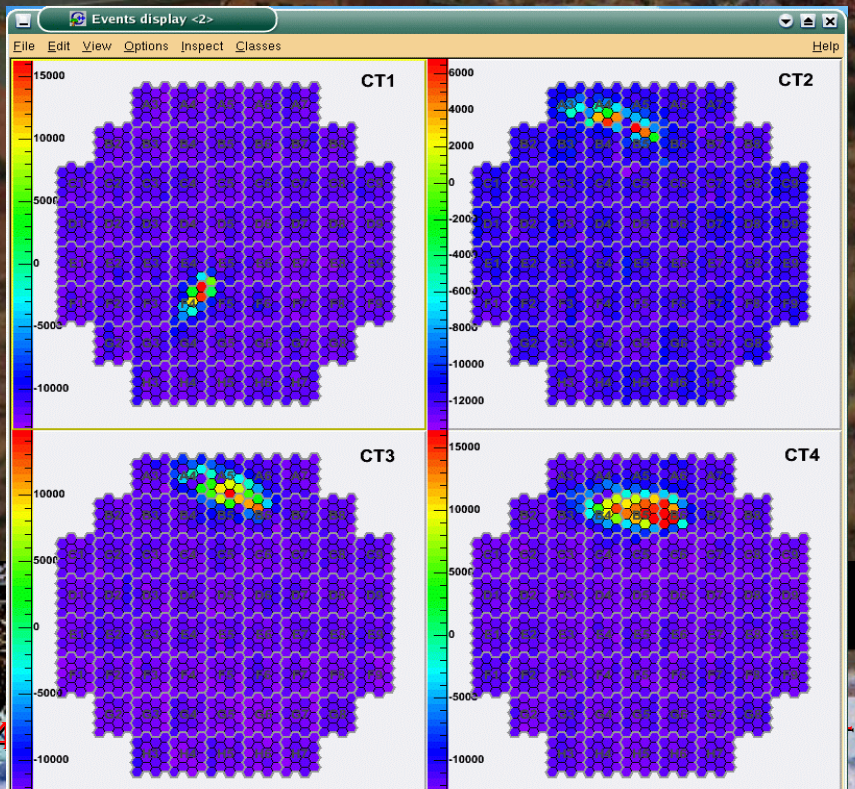
# The Completed HESS Phase I System





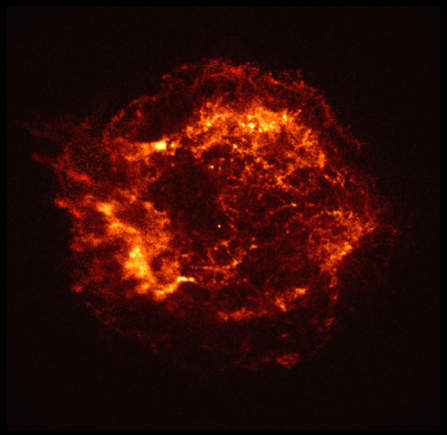






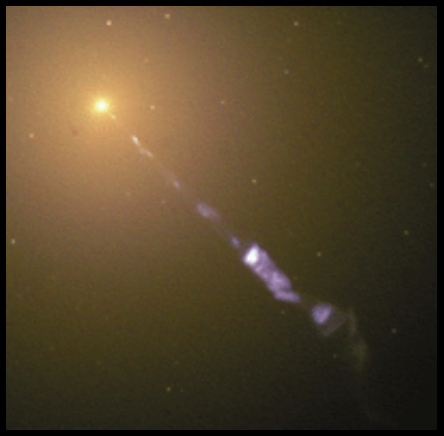

***First 4-fold event***
***December 10, 2003***

# An overview of the HESS observations



Prime Target - Crab Nebula

| Galactic | Extragalactic |
|---|---|
| PSR B1706 (43h) | PKS 2155 (92h) |
| Vela (26h) | PKS 2005 (52h) |
| SN 1006 (107h) | M 87 (32h) |
| RX J1713 (50h) | NGC 253 (34h) |
| Sgr A (34h) | |
| Cen X-3 (32h) | |



Plus other sources with less observation time ...

Publications underway

# Our Calibration source: The Crab Nebula

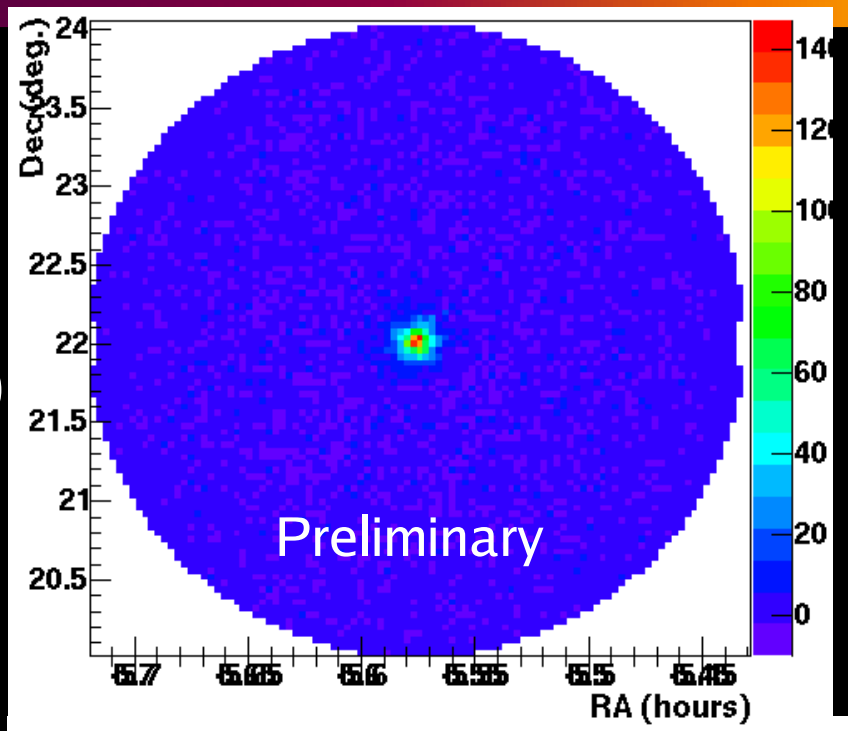
October 2003 (3 tel.)

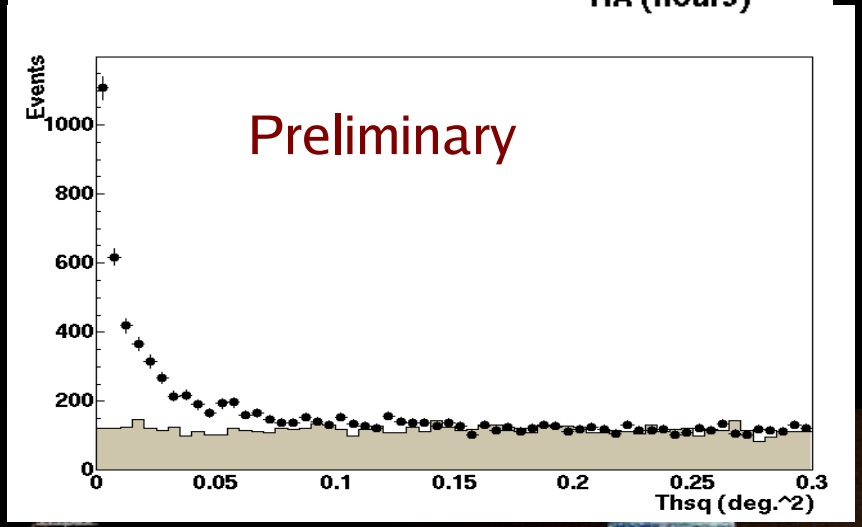
- Live time: $4^h1^m53^s$
- Mean zenith angle ($Z$): 47°
- Energy Threshold: 325 GeV (at this $Z$)

Standard Analysis:

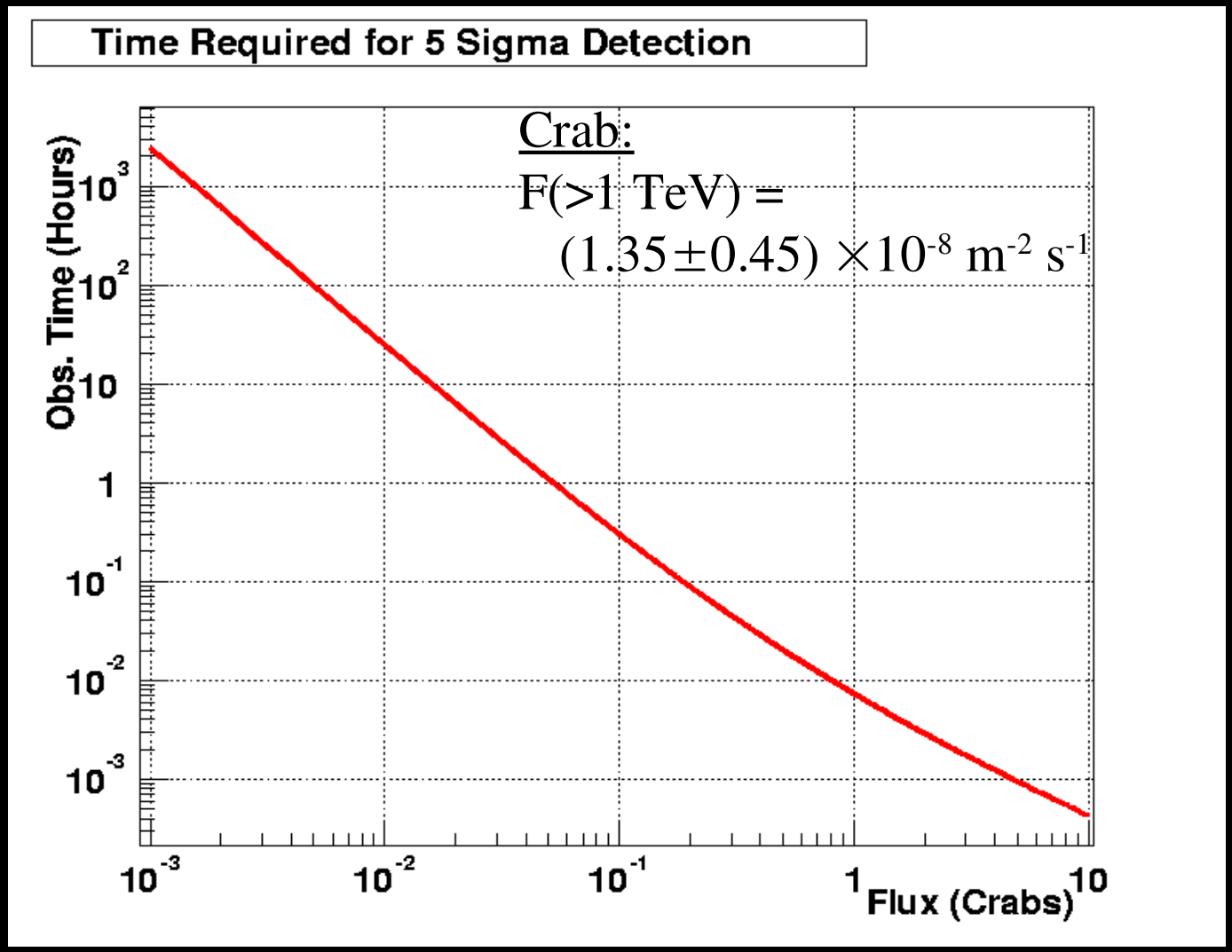
- Significance: 53.5 $\sigma$ (26.6 $\sigma/hr^{-0.5}$)
- Excess: 10.8 ± 0.2 $\gamma.min^{-1}$

Signal easily detected,
stable in time



# HESS Sensitivity, current standard analysis




At 20° zenith angle, full array, after selection cuts

Sensitivity:

- 0.01 Crab in ≈25 hrs
- 0.05 Crab in ≈1 hr
- 0.10 Crab in ≈20 min
- 0.50 Crab in ≈75 sec
- 1.00 Crab in ≈30 sec

Threshold (trigger, selected):

- (105,125) GeV at 0°
- (115,145) GeV at 20°
- (265,305) GeV at 45°
- (785,925) GeV at 60°

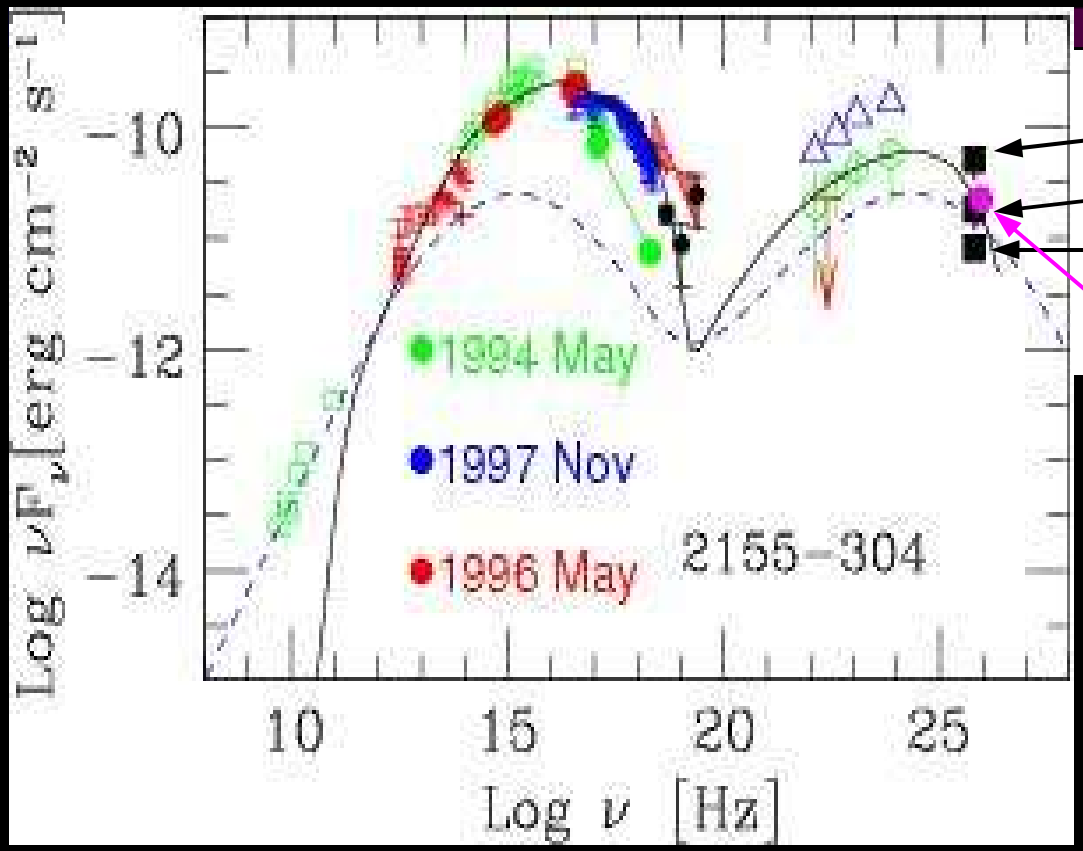
with current standard analysis
(threshold = peak in event rate for Crab-like spectrum)

# PKS2155-304

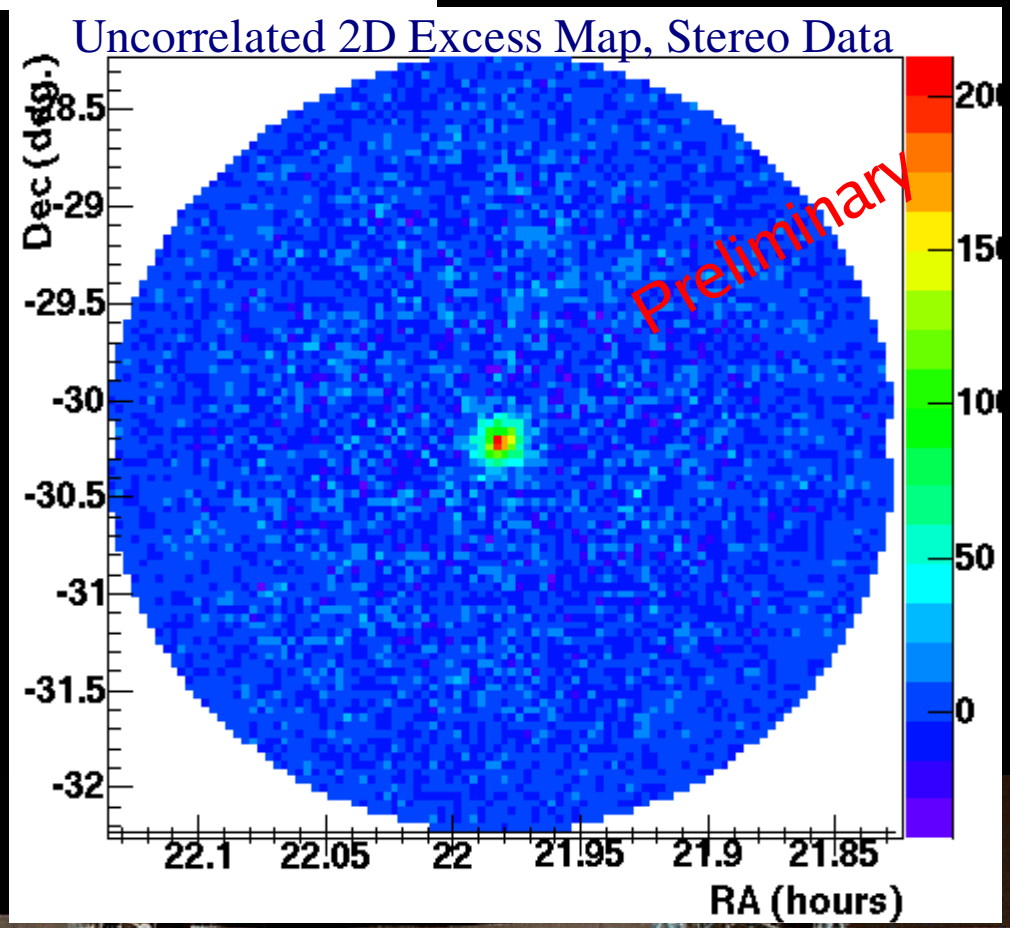
- Prototype HBL (high-peaked BL Lac),
  peak energy density in X-rays
- Redshift $z$=0.116
  $\Rightarrow$ ~4 times more distant than Mrk421/501
- Very bright AGN at all wavelengths, few bright emission lines
  $\Rightarrow$ previous observing campaigns in '90s (X-ray, optical, radio...)
- First "Southern" TeV blazar (Durham collab., Chadwick et al, '99)
- Observed by HESS in 2002/2003

| Observation period | Observation time | Observing mode | Post-cuts Threshold (Z=20°) |
|---|---|---|---|
| July 2002 | ~4 hrs | Single dish | 305 GeV |
| Oct. 2002 | ~10 hrs | Single dish | 305 GeV |
| June 2003 | ~10 hrs | 2 independent tels. | 255 GeV |
| July-Oct. 2003 | ~50 hrs | 2/3 tel. in coincidence | 165 GeV |

# HESS flux measurements of PKS2155-304




HESS Preliminary
July 2002
October 2002
June-Oct. 2004
Durham 1996/97




Model from Costamante et al., A&A 2002

45 σ, (5.7 σ/hr$^{0.5}$)

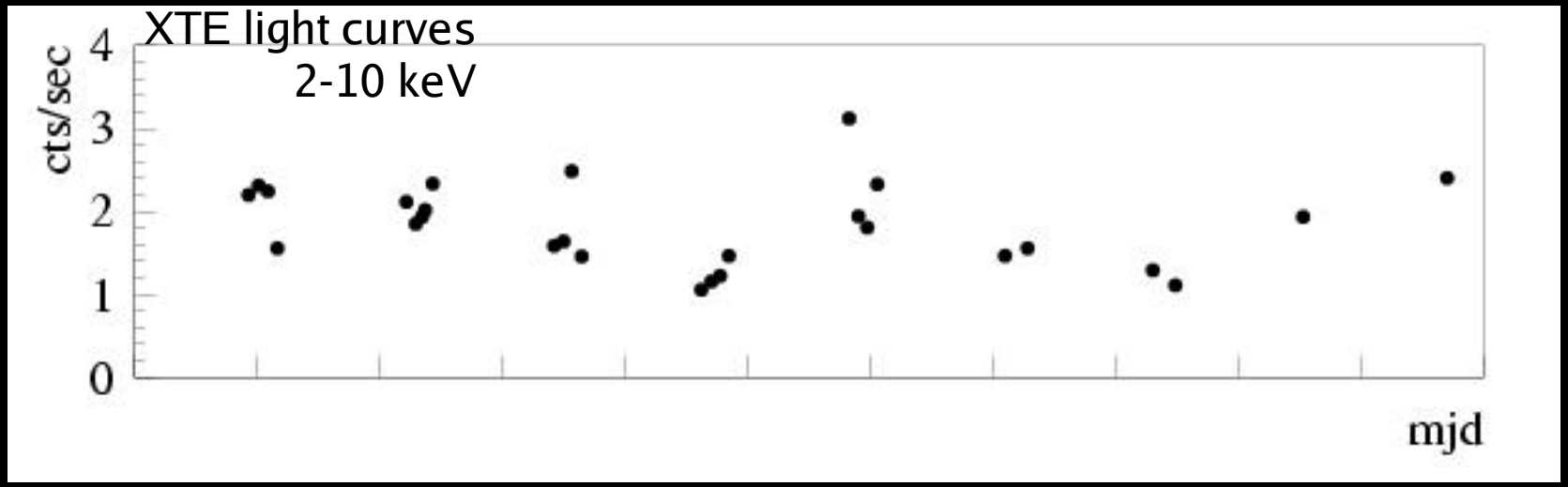
1.20 ± 0.03 γ/min

hard spectral index ...

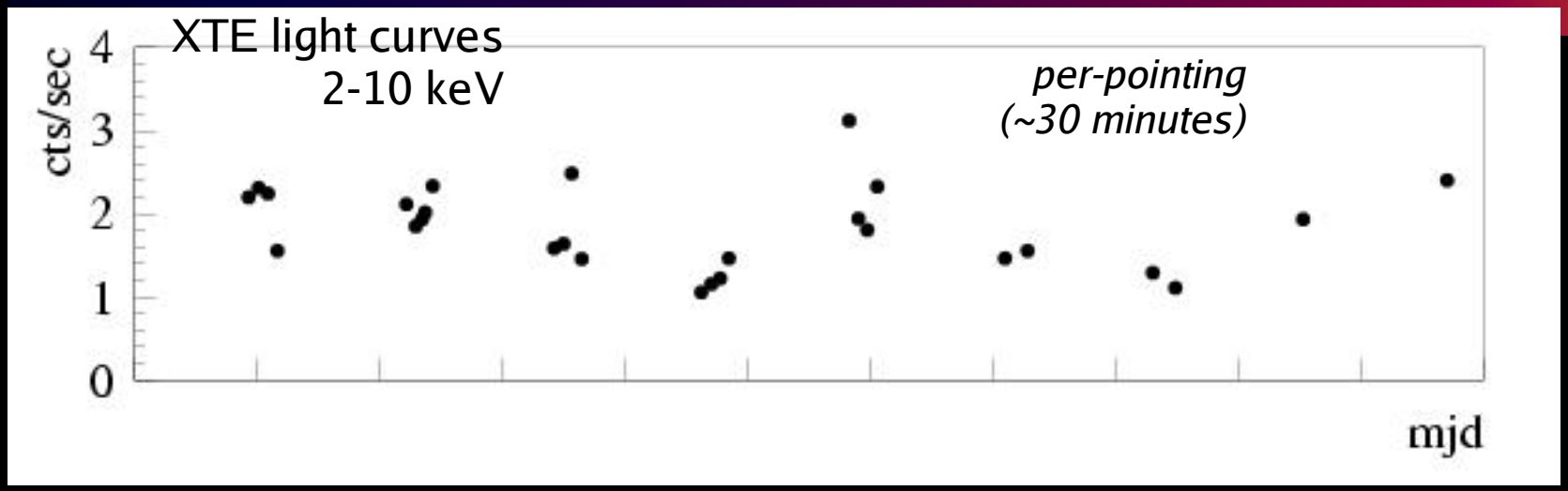
... link to IR absorption ?

# RXTE / HESS Observation Campaign

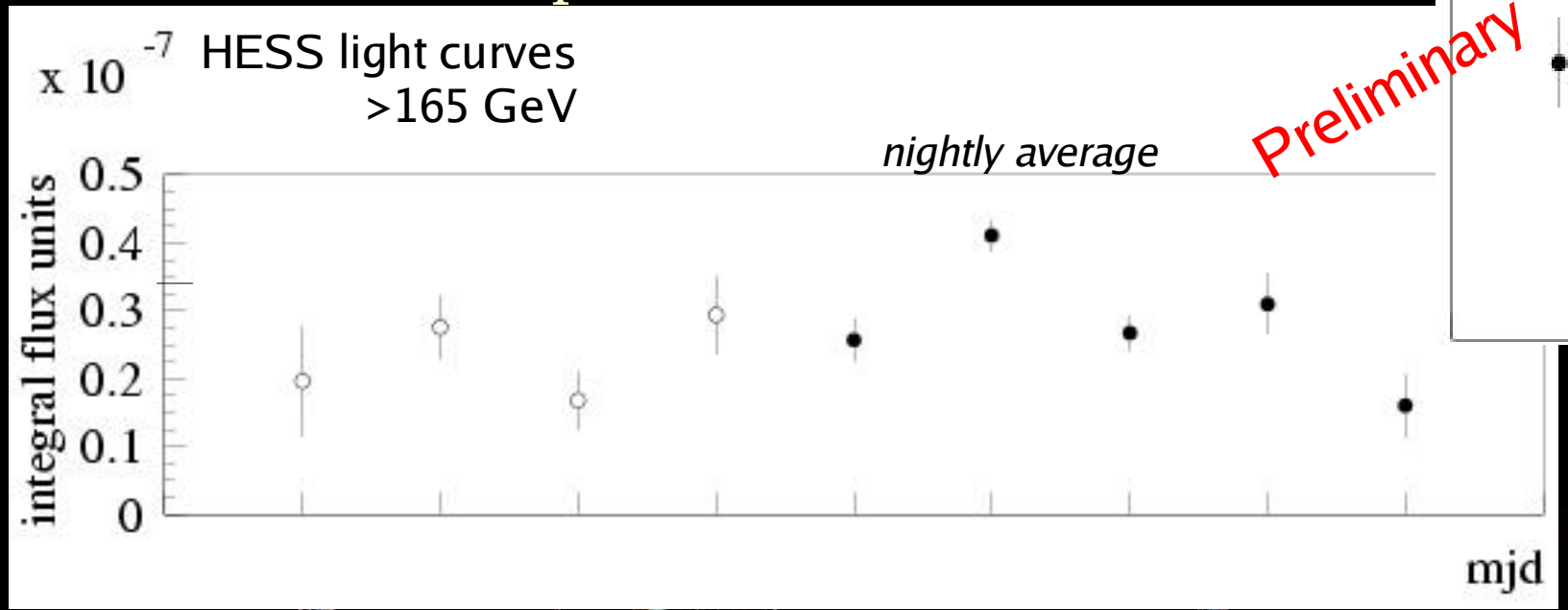
- HESS Target of Opportunity (ToO) proposal for RXTE on PKS2155-304, triggered by HESS on 18th October 2003
- 52 ksec in October, 19 ksec in November, 2-10 ksec/night
- Quasi-simultaneous observations, ~14h in October (2/3 tel.), November still under analysis (some technical problems)

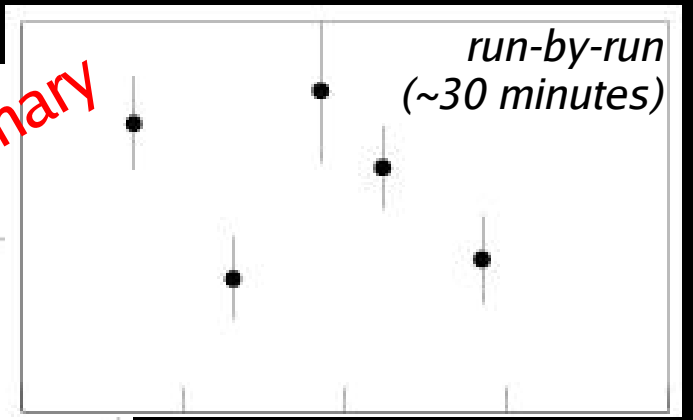


# RXTE / HESS Observation Campaign




- Blind-test comparison of HESS/RXTE data



# Future on PKS2155-304

- More work to be done:
  - Investigation of short-term flux variability
  - Cross-correlation of lightcurves
  - Spectrum and spectral variability
  - Source modelling
  - Comparison to other blazars at varying $z$ for IR background studies
- Future campaign
  - August 2004
  - 14 nights HESS (larger zenith-angle range)
  - 230 ksec RXTE
  - Other telescopes...

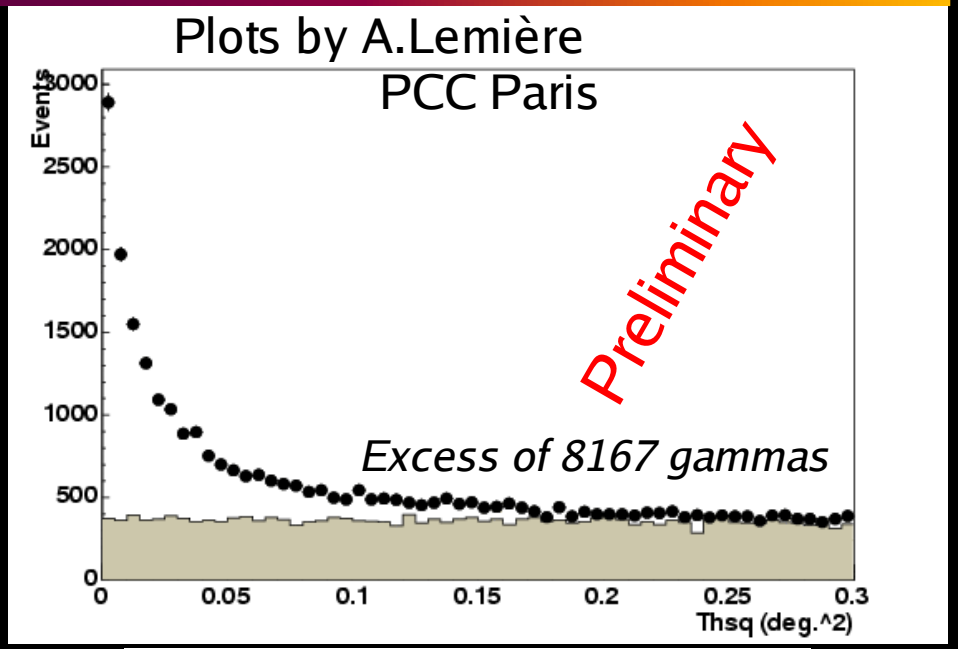
- ***RXTE ASM***
  Useful for trigger,
  not for correlation studies
- ***RXTE ToO (October 2003)***
  [2 - 10 keV] PCA
  90 min orbit with Earth occultation
  58 min / orbit on source
- ***HESS-RXTE campaign August 2004***
  230 ksec (63,8 h)
  90 min orbit with Earth occultation
  58 min / orbit on source
- ***NANCAY radio data***
  9 or 11 cm + 21 cm
- ***ROTSE optical data***

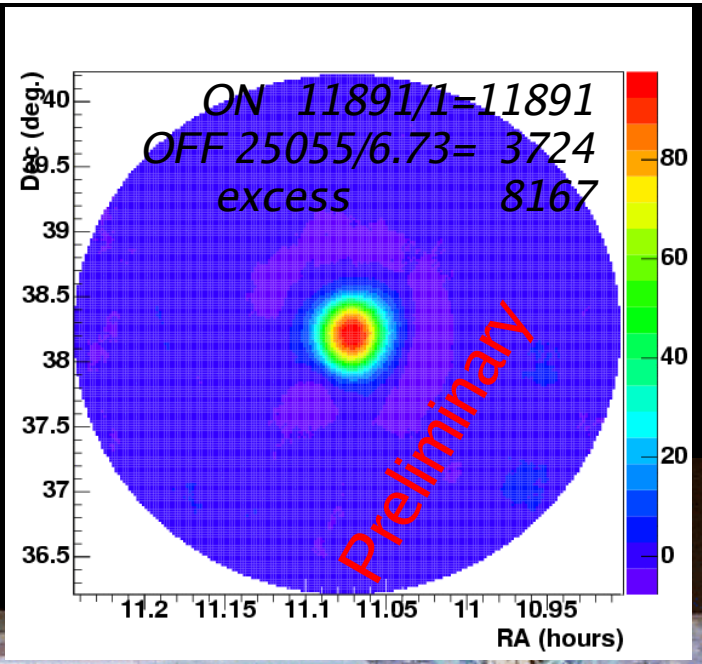
# A "New" source: Mrk 421

- First extragalactic VHE source (Whipple, Punch et al., Nature, 1992).
- Nearby: $z$=0.03, "Northern source" (dec. 38°12'31.8")
- Source culminates at Zenith angle > 60° at HESS latitude
  - High threshold
  - Very large collection area, so
    possibility to determine spectrum at highest energies
- Strong activity seen by ASM aboard RXTE
  - Historical level of 110 mCrab in mid-April !!
  - Decreasing to 20-40 mCrab late April
- April Campaign of observations also with
  Whipple, Bordeaux radiotelescopes, others...

# HESS Observations of Mrk 421

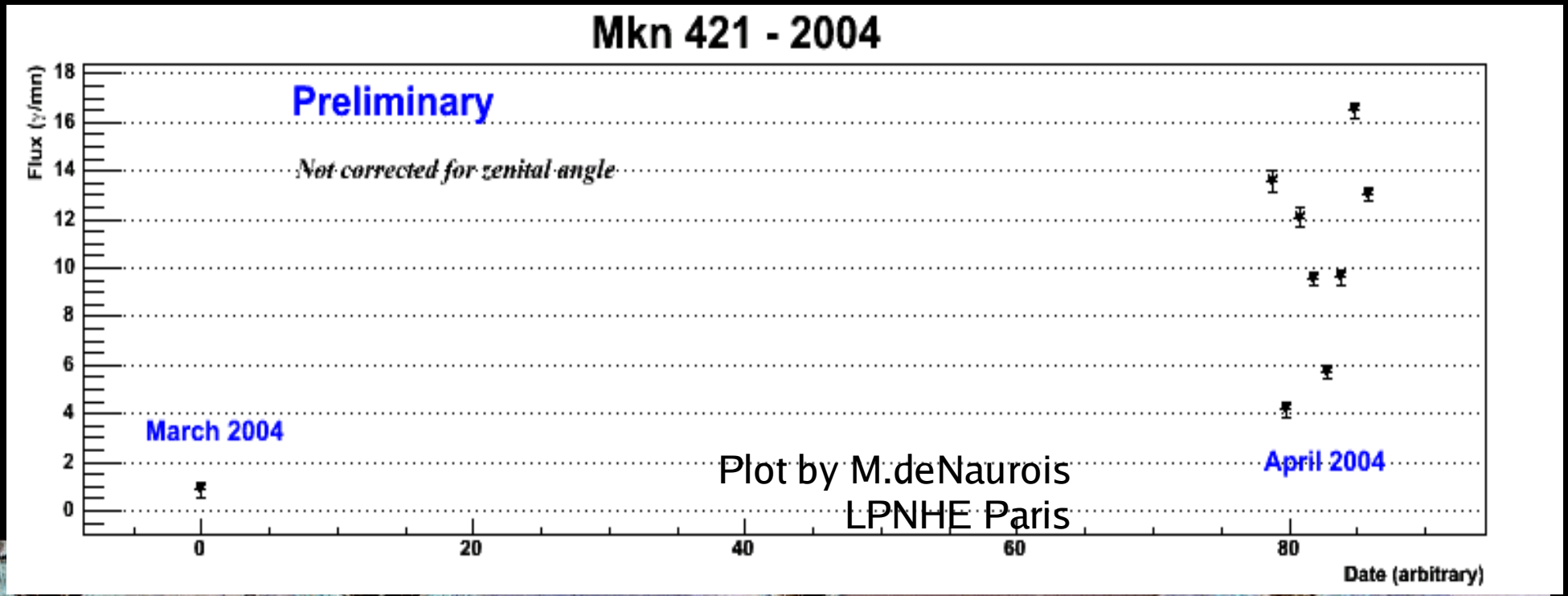
- All Mrk 421 data taken with 4 telescopes
  - Average zenith angle 62°
- Jan 2004, low-state
  - 6 σ in 2.12h,
    (vs. ~10 sigma/hr$^{0.5}$ for Crab, @ Z=62°)
- April 2004 active state !!
  - Excess of 8167 gammas in 11.5h
  - 95.7 σ (28.16 σ/hr$^{0.5}$) !!!
  - ~ 11.8 γ/min
  - 1-2 Crab flux level (@ Z=62°)



# Mrk 421 Time Variability in April

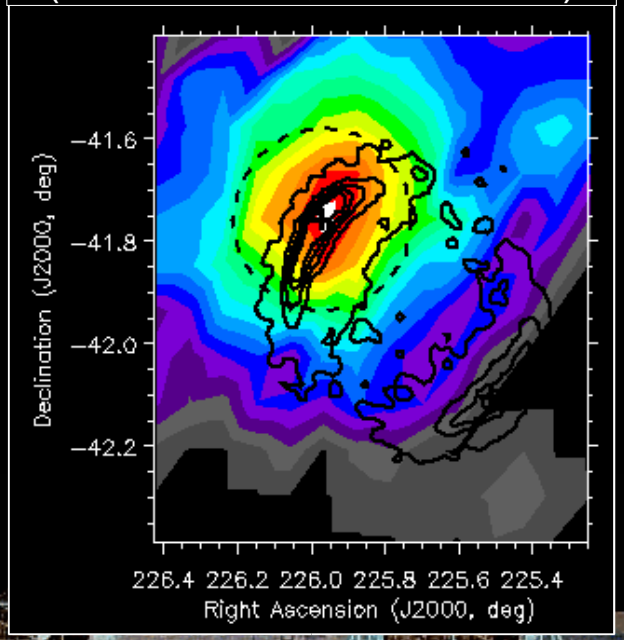
- HESS Mrk 421 flux goes up to roughly ~3 Crab at maximum
- Whipple first results reported at 3 Crab in April also
- Bordeaux radiotelescopes show high-level, but stable emission
- Campaign should provide much information on this source up to the highest energies

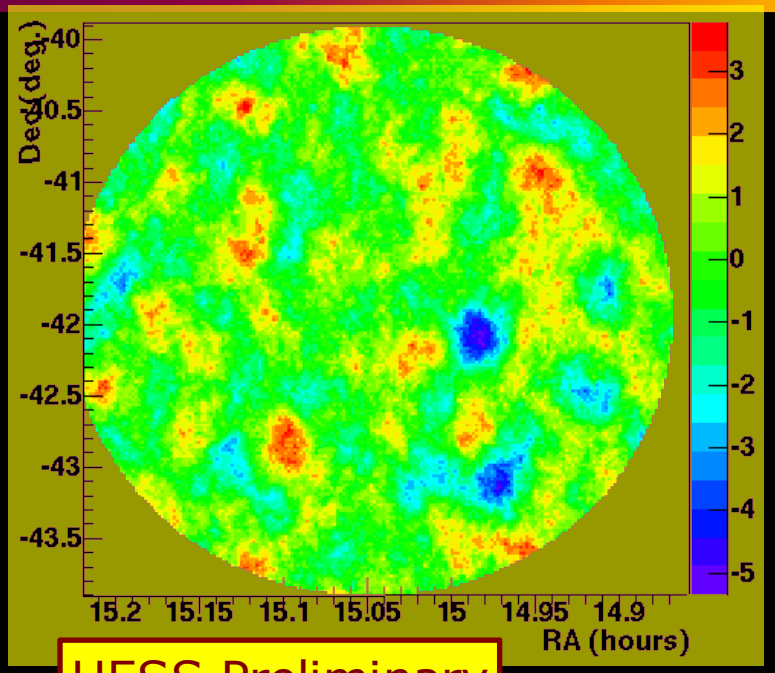


# SN1006

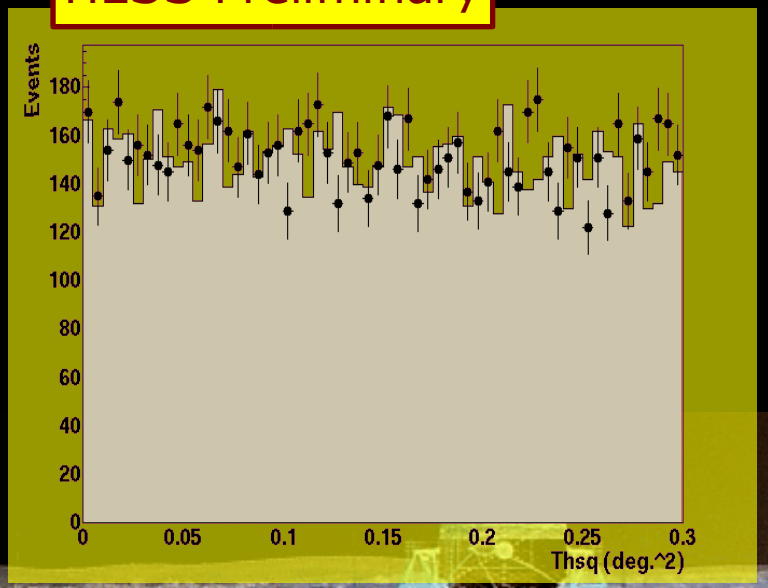
- Shell-type SuperNova Remnant
- Observed by HESS in 2003 (14 h)
  - No signal seen by HESS
  - Signal has been claimed by CANGAROO

CANGAROO
(Tanimori *et al*, 2001)
(1996: 5.3$\sigma$ ; 1997: 7.7$\sigma$)




HESS Preliminary



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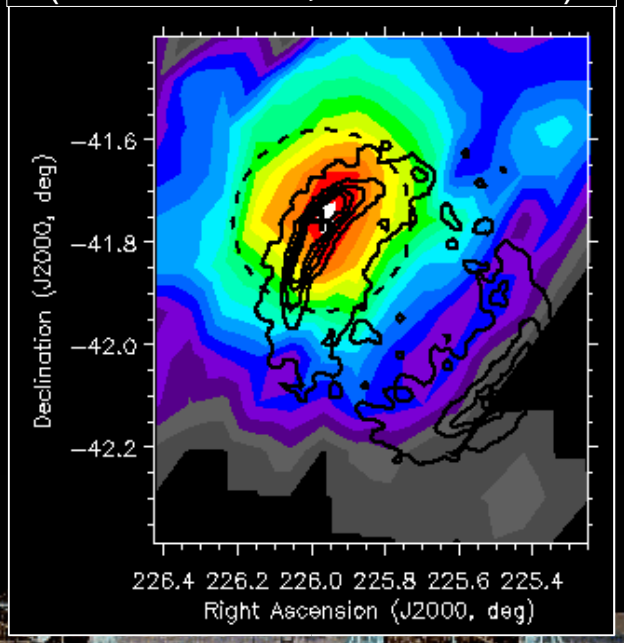


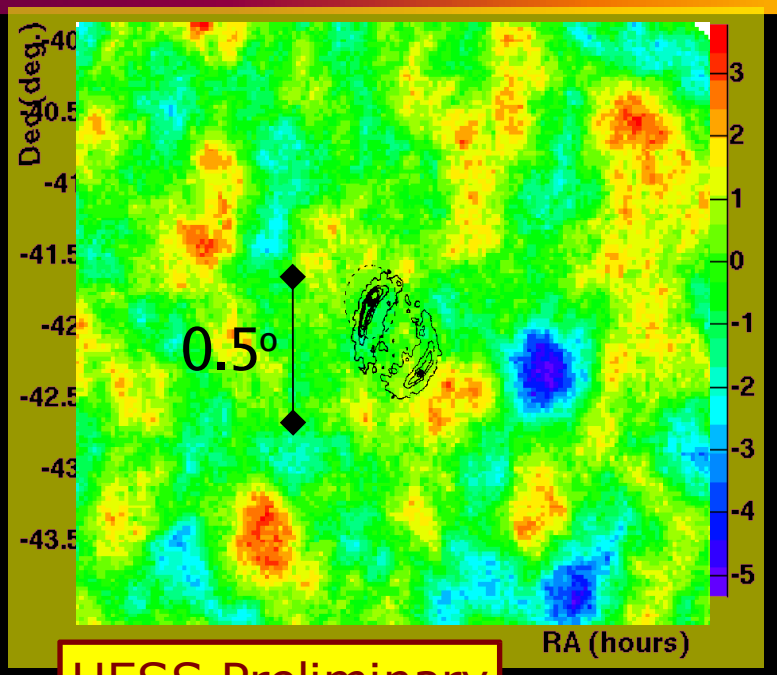


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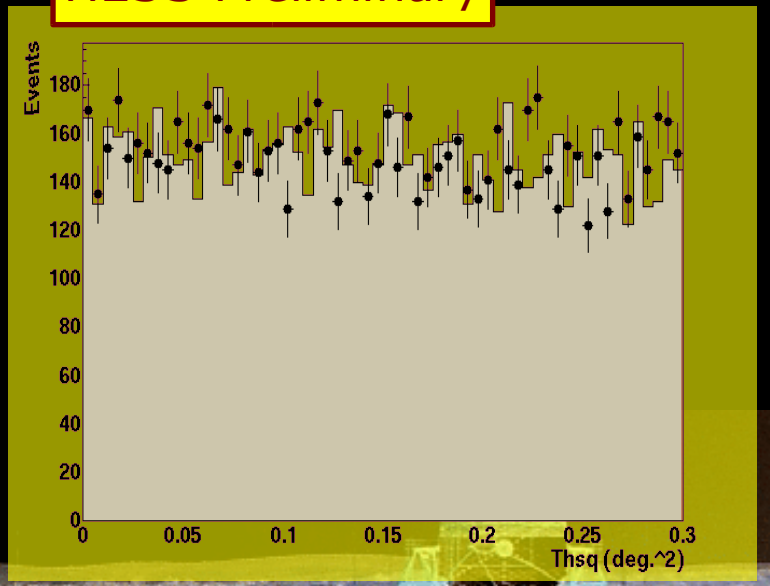


# SN1006: NE RIM ("Hot-Spot")

Nuclear γ-ray emission

$\propto (N_H)^2$ !

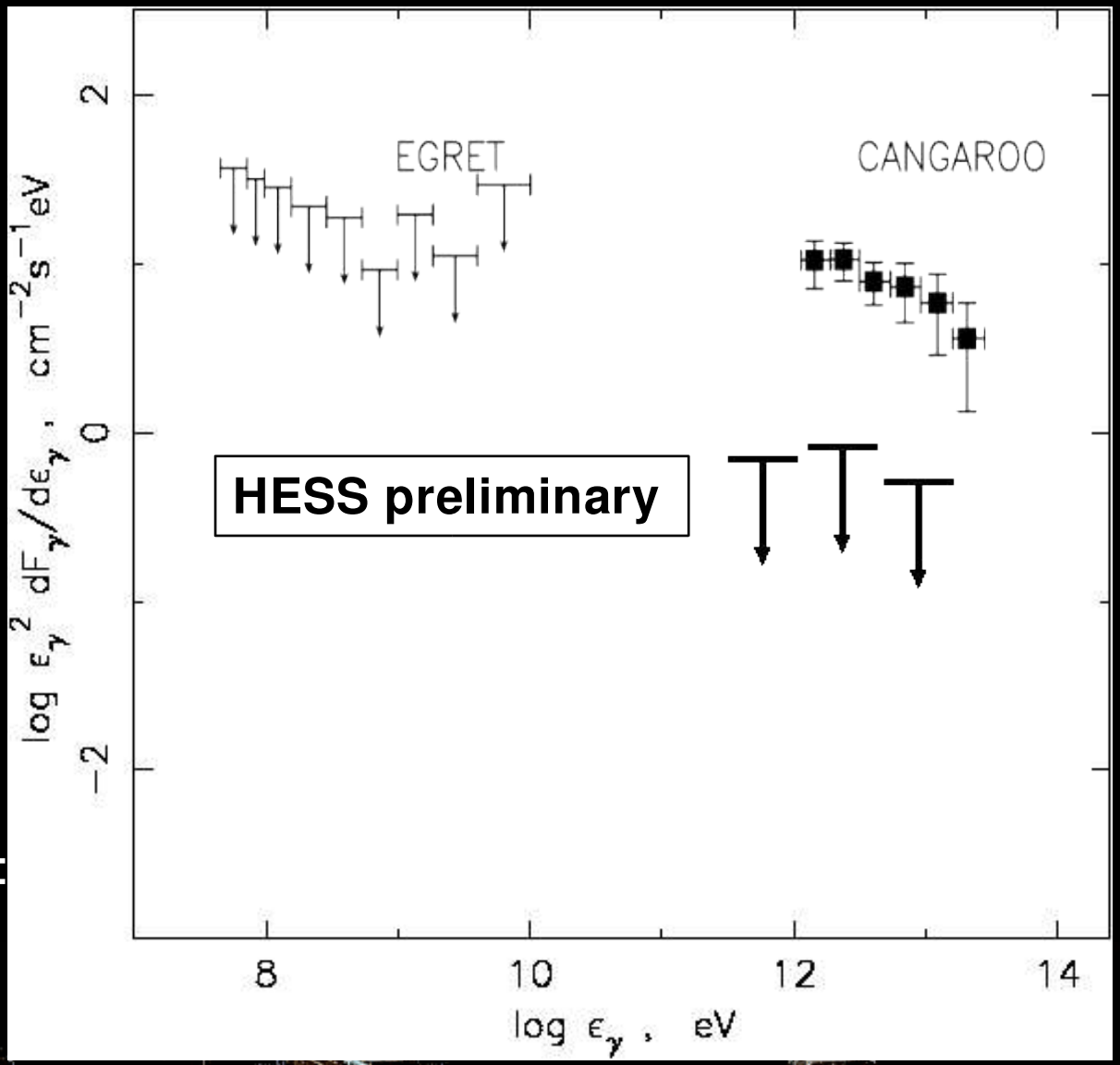
Parameters favoured from other wave-bands:

D = 2.2 kpc

$N_H \approx$ 0.05-0.2 $cm^{-3}$

Broad-band synchrotron + X-ray structure:

$B_{int}$=120 - 150 μG



# SN1006 : Whole Remnant

Nuclear γ-ray emission
$\propto (N_H)^2$ !

Parameters favoured from other wave-bands:
D = 2.2 kpc
$N_H \approx$ 0.05-0.2 $cm^{-3}$

Broad-band synchrotron + X-ray structure:
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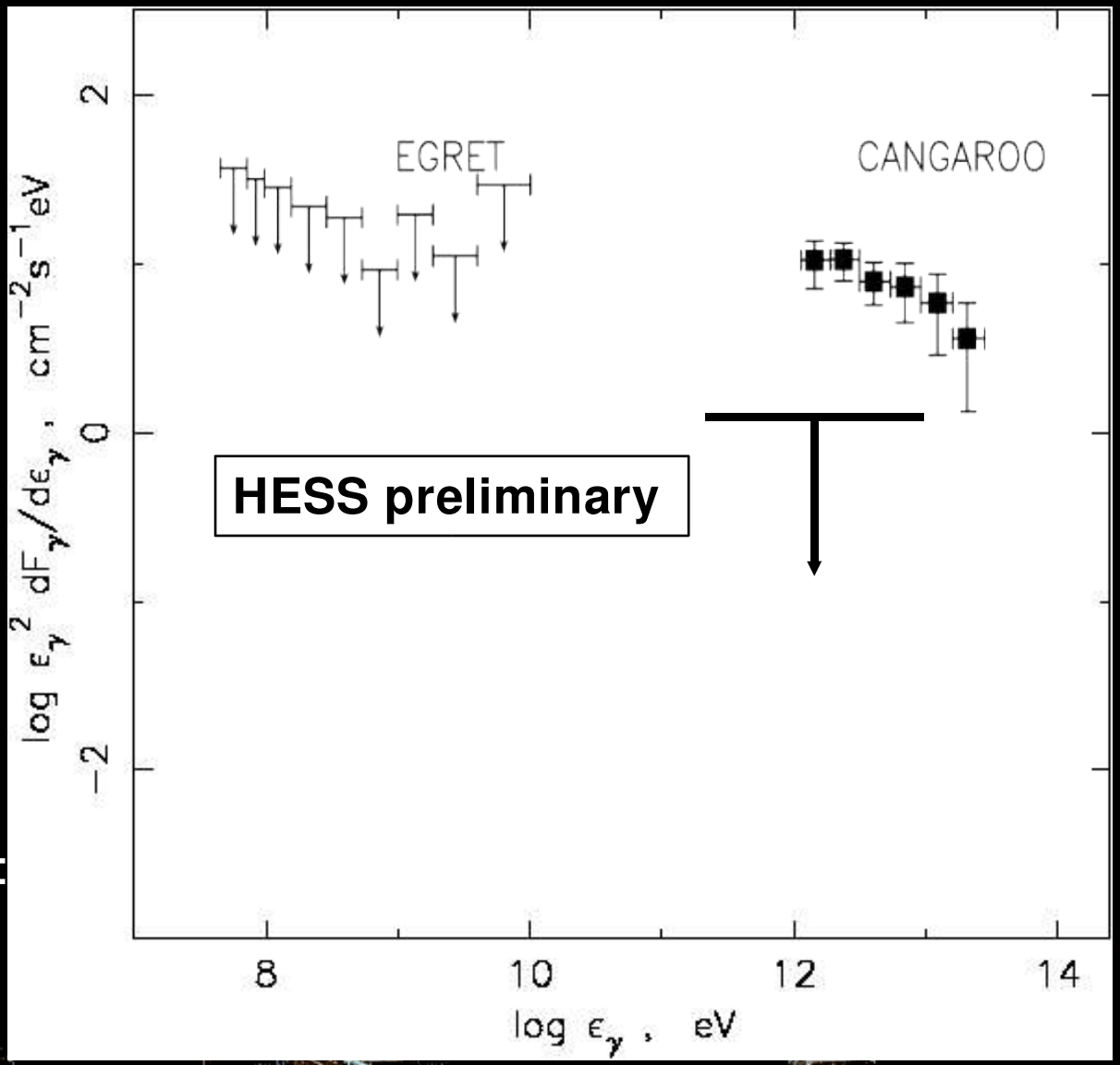

# Other Galactic Sources

- PSR 1706-44
  - SuperNova Remnant
  - Upper limit...
  - See preceding talk from W. Hofmann
- PSR B1259-63
  - Binary system with pulsar in eccentric orbit about Be star
  - Detection by HESS near to periastron
  - See following talk from M. Beilicke
- Etc...

# Conclusions

- HESS-I installed and now functioning at full sensitivity
  - Most sensitive detector worldwide: 0.01 Crab in 25 h
- Galactic Sources:
  - Crab, PSR 1259-53 detected
  - Upper limits on SN1006, PSR1706-44
  - Other sources, articles in preparation (publication embargo)
- AGNs:
  - PKS 2155-304 Multi-wavelength campaigns
  - Mkn 421 Very large zenith angle observations
- Many exciting results, on various sources ... papers to follow...

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