# The HESS experiment - Status, Results and Future

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LLR Ecole Polytechnique

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- The HESS detector (Phase 1)
- Galactic Sources
- Extragalactic Sources
- The future: Phase 2
- Summary

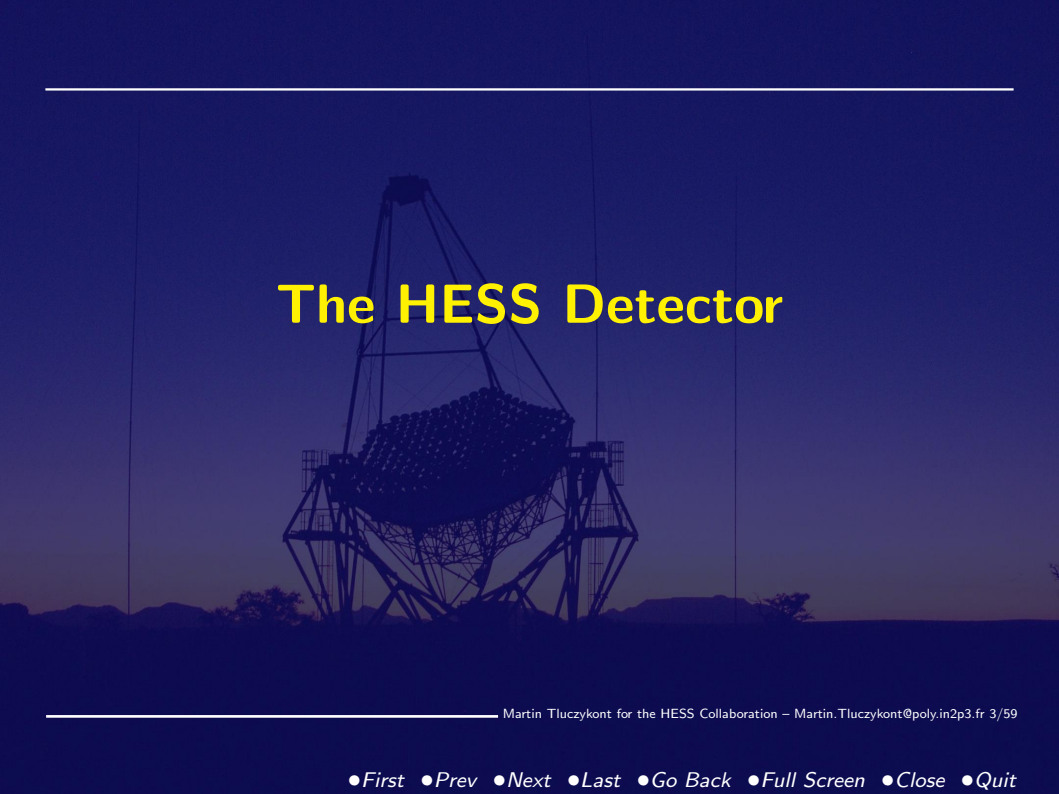
# Sources seen by H.E.S.S. ($S > 5\,\sigma$)

| Object | Flux level [Crab] | First detection | Conf. | Contradiction |
|---|---|---|---|---|
| Crab Nebula | 1.00 | Whipple | Many | – |
| RXJ 1713.7-3946 | 0.70 | CANGAROO | HESS | Spectrum |
| Vela Junior | ? | CANGAROO | HESS | ?? |
| G0.9-0.1 | 0.02 | HESS | | |
| Sgr A* | 0.1-0.4 | CANGAROO | HESS | Spectrum |
| HESS J1303-63 | 0.10 | HESS | – | – |
| PSR B1259-63/SS2823 | 0.05 | HESS | – | – |
| Mkn 421 | 0.2->1 | Whipple | Many | – |
| PKS 2155-304 | 0.1-0.6 | Durham | HESS | – |

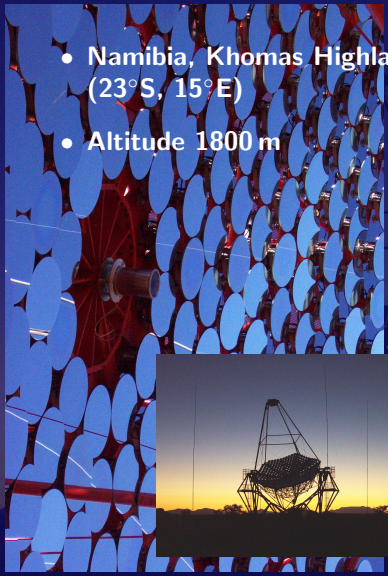
**no detection of :**

**SN 1006, Vela, PSRB1706-44**

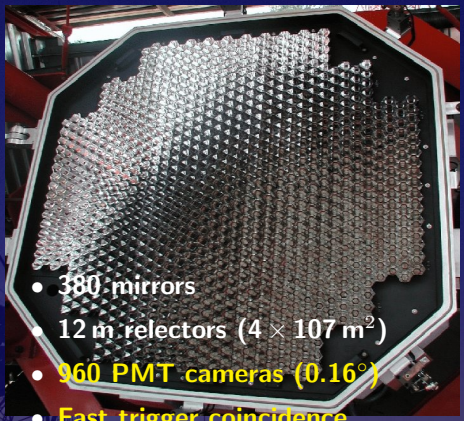
# The HESS Detector



# HESS 1: Stereoscopic System of 4 Cherenkov Telescopes



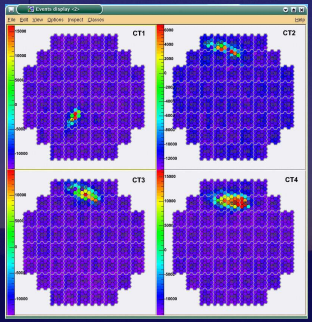
- Namibia, Khomas Highlands (23°S, 15°E)
- Altitude 1800 m



- 380 mirrors
- 12 m relectors ($4 \times 107\,m^2$)
- 960 PMT cameras (0.16°)
- Fast trigger coincidence
- Electronics integrated in Cameras
- 5.3° FoV
- Energy threshold 100 GeV

# HESS I – Phase 1 Completed

| | | |
|---|---|---|
| First light telescope 1 | : | June 2002 |
| Two telescopes | : | March 2003 |
| Stereoscopy | : | July 2003 |
| Three telescopes | : | September 2003 |
| Four telescopes | : | December 2003 |




**Phase 1 completed & fully operational !**

- 0.01 Crab in 25 h
- $E_{thr}$ = 100 GeV (max. diff. E-spec.)

# Simulation, Calibration & Analysis

Monte Carlo simulations

- CORSIKA + sim_hessarray
- KASKADE + smash

2 Calibration chains

- Heidelberg
- Paris

Background subtraction

- Geometric models
- Template-model
- Likelihood-based model

Different Calibration methods

- Single ph.e.
- Muon rings
- Laser System

Shower reconstruction methods

- Standard Hillas reconstruction
- Semi-analytical model
- 3D-Model

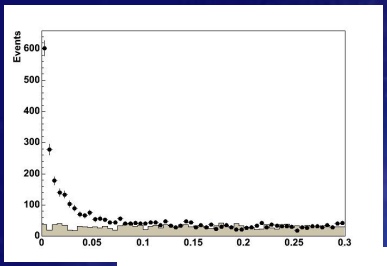
**Redundance gives confidence: Robust results**

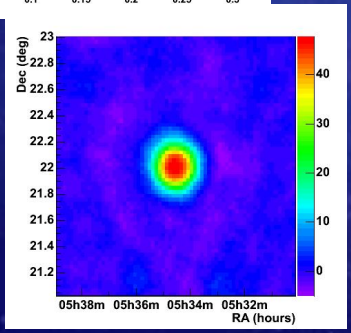
# Galactic Sources

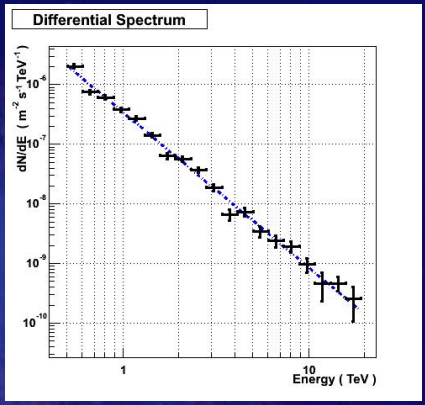
Physics: Origin/acceleration of Cosmic Rays, new sources, Dark matter ...

# SNRs

# The Crab Nebula as seen by HESS (preliminary)



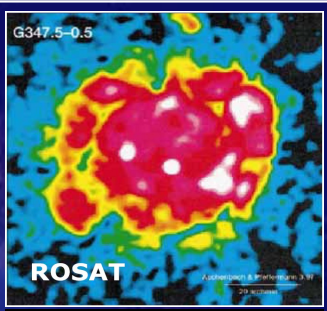




- High zenith angle ($E_{thr} \approx 325$ GeV)
- Independent analyses give consistent results
- Spectral index: $\alpha = 2.62 \pm 0.02$
- Compatible with previous results

# The Shell-Type Supernova Remnant RXJ 1713-3946

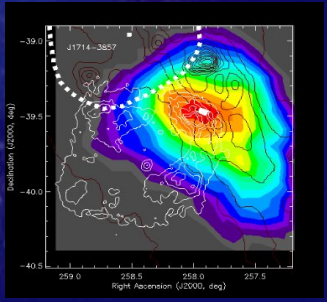
Discovery in X-rays

- ROSAT All-Sky survey source
- Non-thermal X-rays
- Distance: 1 kpc (CO survey)
- Angular extension: 1 deg




First TeV-detection: CANGAROO II
(Muraishi, A. et al. 2000; Enomoto, R. et al. 2002)

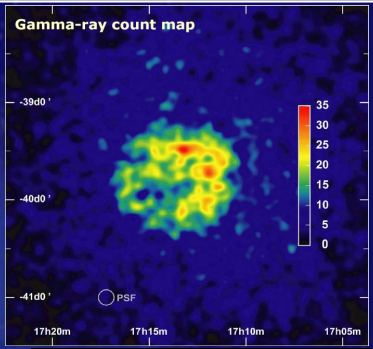
- ≈0.7 Crab
- Question of Cosmic ray acceleration ⟶ controversial discussions (Pohl et al. 2002)



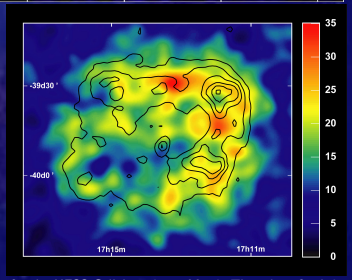
# RXJ 1713.7-3946 as seen by HESS

Recent GeV/TeV-confirmation: HESS 2004
(D. Berge, Gamma 2004 & Nature acc. f. publ.)

- High quality data 18.1 h
- $>20\,\sigma$ total remnant
- *The first ever astronomical TeV-image*
- Shown here: High resolution data sub-sample (E>800GeV)




Superposition:
ASCA X-ray data contours



# RXJ 1713.7-3946 – The spectrum

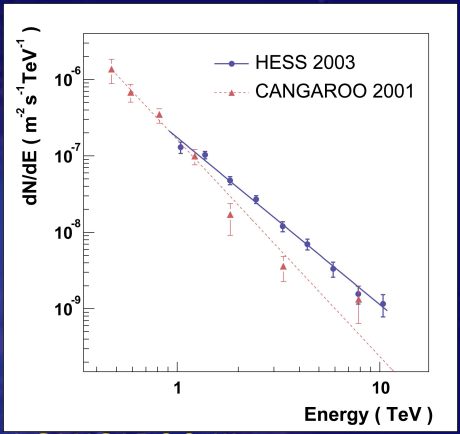
Spectrum: inconsistent spectral indices

HESS:

- $\alpha = 2.19 \pm 0.09 \pm 0.15$
- consistent results in independent analyses

CANGAROO II:

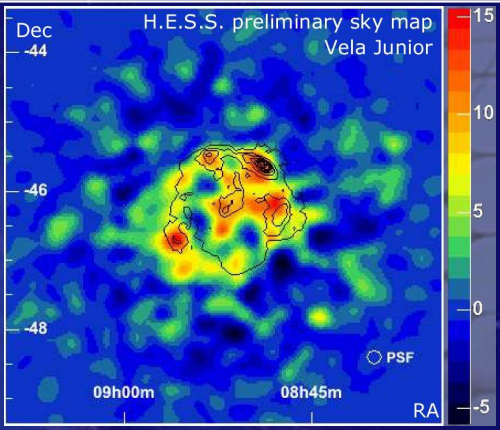
- $\alpha = 2.84 \pm 0.15 \pm 0.20$




$\longrightarrow$ Further observations by HESS and CANGAROO III
$\longrightarrow$ GLAST observations of 70 MeV bump ?

# Vela Junior

- shell-type SNR, diameter 2 deg
- superimposed with Vela
- distance 200 pc - 2 kpc ?
- non-thermal component of X-ray emission (ROSAT, ASCA, XMM)
- detection by CANGAROO




H.E.S.S.-observations

- 3.2 h 4-telescope data at 25 deg
- hard cuts : 675 GeV threshold
- bg : 6.8 h off source data

Texas Symposium, N. Komin, D. Berge, M. Lemoine-Goumard, M. de Naurois

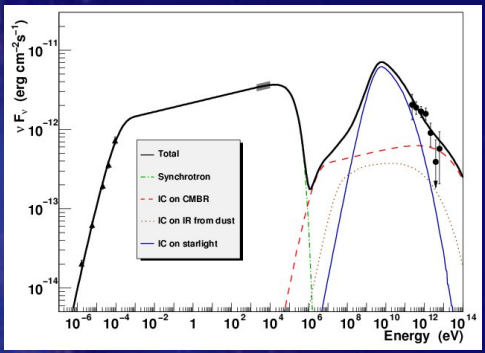
- overall spectrum : $\gamma = 2.3 \pm 0.2$
- $\Phi(> 1TeV) = (2.0 \pm 0.5)10^{-11}$

# G0.9-0.1

- *composite* SNR
- $\approx$ 0.13 deg diameter shell
- $\approx$ 0.03 deg core region: pulsar wind nebula

H.E.S.S.-observations

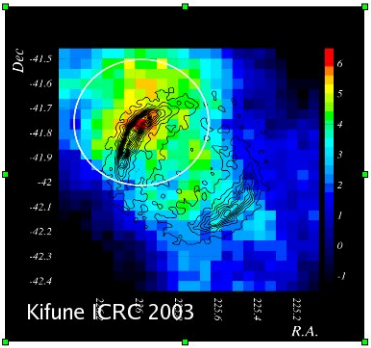
- 50 h at 18 deg Z.A.
- $E_{thr}$ = 170 GeV, 13 $\sigma$
- $\Phi(> \ 200\,GeV) = (5.7 \pm 0.7 \pm 1.2) 10^{-12} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- power law index $\gamma = 2.4 \pm 0.11 \pm 0.20$



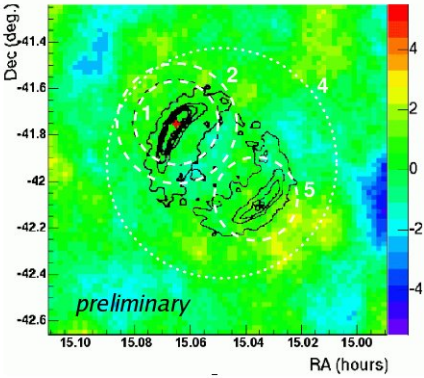

A&A submitted
origin of gamma-rays in core
well explained by IC

# The shell-type Supernova Remnant SN 1006: Inconsistency

CANGAROO SN 1006




H.E.S.S. significance map




Tanimori et al., Ap J 497 (1988) L25
3.8 m telescope
+ conference proceedings

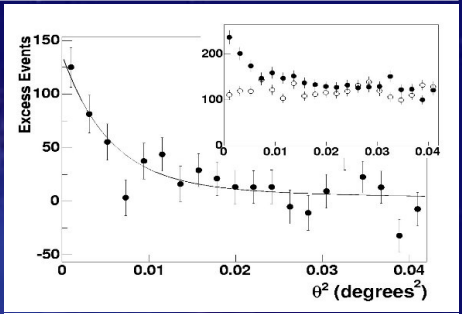
Hofmann, Gamma 2004

# Other Galactic Sources

# The Galactic Center (Sgr A*): HESS data

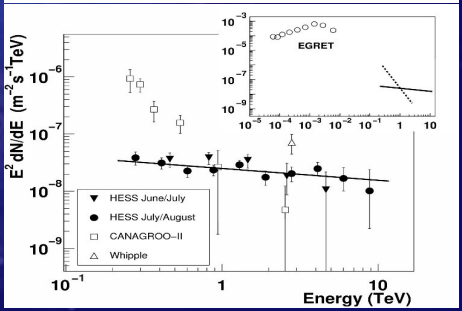
The Signal:

- 2-Telescope data
- Average zenith angle: 20°
- Two detector configurations
  - 4.7 h at $E_{thr} = 255$ GeV
  - 11 h at $E_{thr} = 165$ GeV
- Total significance: $9.2\,\sigma$

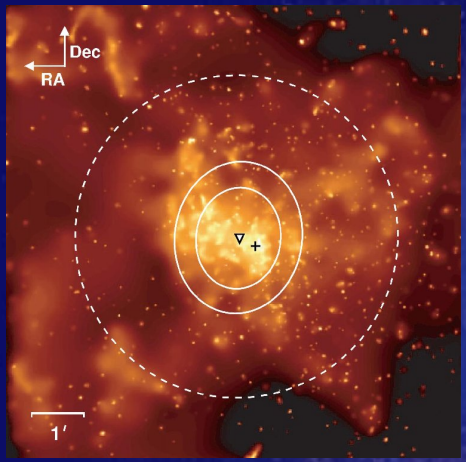



Spectrum:

- Power-law, $\alpha = 2.21 \pm 0.09 \pm 0.15$
- Steady state 0.05 % (E> 165 GeV)
- Strong contradiction to CANGAROO II



# The Galactic Center (Sgr A*)




**Chandra X-ray image**

**HESS superimposed:**

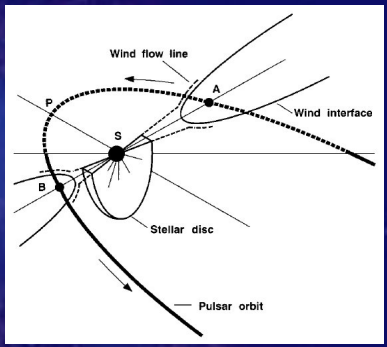
- 68 % & 95 % confidence regions for source position
- 95 % upper limit on rms source size
- Position compatible within errors (30") with SgrA*
- $\Omega_{\mathbf{err}}$ reduced by 100 (as cmp to previous measurements)

**Dark Matter hypothesis**: HESS spectrum + angular distribution $\Longrightarrow$ $M\chi > 12\,\mathrm{TeV}$ (90 % C.L.) (Horns, astro-ph/0408192, also: Aharonian & Neronov, astro-ph/0408303)

# PSRB 1259-63 / SS 2883

## The Binary Pulsar system PSRB 1259-63 / SS 2883 at 1.5 kpc

- 10 $M_\odot$ Be star $L = 3\times10^{30}$ W
  dense stellar disk, high mass outflow
- 48 ms radio Pulsar
  $L_{spindown} = 8\times10^{28}$ W
- Pulsar orbit around Be star
  - 3.4 years
  - Periastron : 23 $R_\odot$
  - Apastron : 331 $R_\odot$
  - Inclination : 35 deg
  - Diameter: 350 $R_\odot$ (Point-like)




CANGAROO 3.8 m: 4.8 $\sigma$ (1994), 10 m: Upper limits (2000), after periastron
HESS-observations at last periastron passage : $7^{th}$ of March 2004

# PSRB 1259-63 / SS 2883 – HESS Results (S. Schlenker, Gamma 2004)

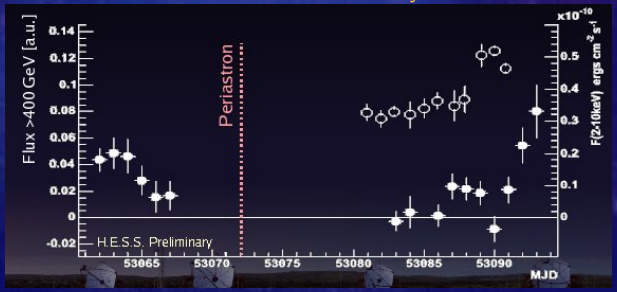
Pre-Periastron

- High quality data : 7.8 h
- Significance : $9.1\,\sigma$
- Excess rate : $\approx 0.4\,\gamma$/min

Post-Periastron

- High quality data : 17.4 h
- Significance : $6.3\,\sigma$
- Excess rate : $\approx 0.2\,\gamma$/min

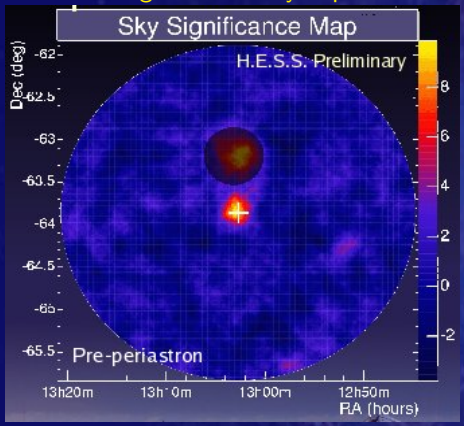
Overall $> 10\sigma$ detection by HESS



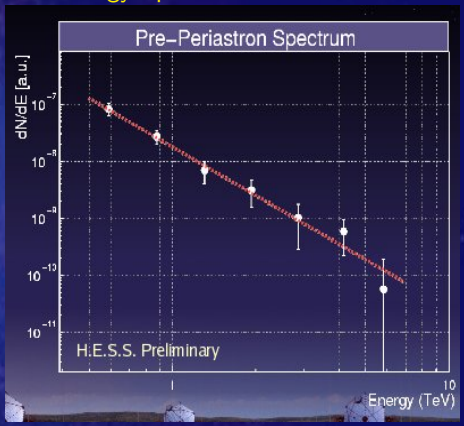

Flux E>400 GeV $\approx 5\,\%$ Crab

# PSRB 1259-63 / SS 2883 – HESS Results (S. Schlenker Gamma 2004)

Significance Skymap




Energy Spectrum $\alpha = 2.8 \pm 0.3$



# HESS J1303-63 (M. Beilicke, Gamma 2004)

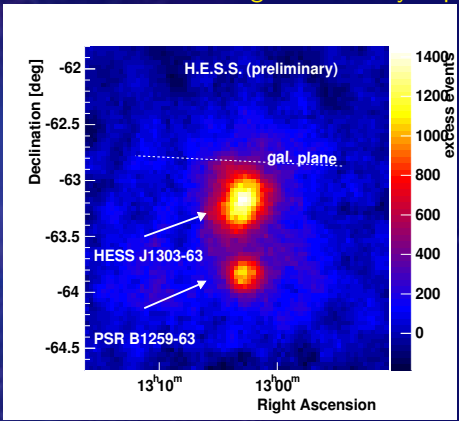
Surprise in PSRB 1259-63 observations:

- Second signal in FoV !
- 0.7 deg from Pulsar position
- Steady state signal ($18\,\sigma$)

Calibration or Physics ?

- High data quality
- Consistent results for different algorithms
- ...

Significance Skymap

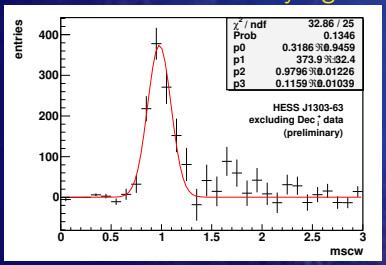


# HESS J1303-63 (M. Beilicke, Gamma 2004)

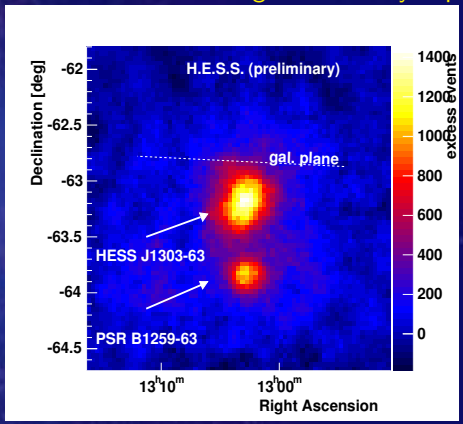
Surprise in PSRB 1259-63 observations:

- Second signal in FoV !
- 0.7 deg from Pulsar position
- Steady state signal ($18\sigma$)

HESS 1303-63: Gamma-ray signature

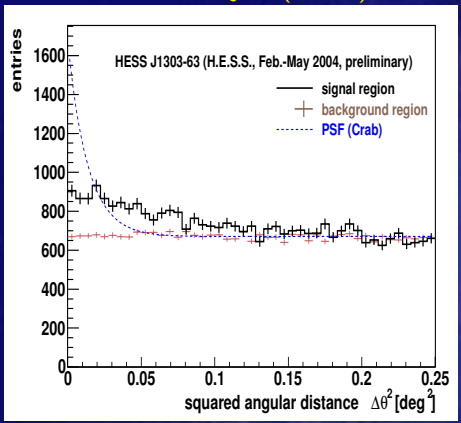



Significance Skymap

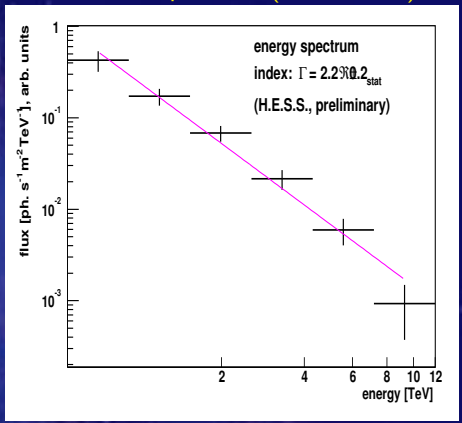


# HESS J1303-63: The $2^{nd}$ unidentified TeV-source

Extended object ($\approx 0.2^\circ$)




Powerlaw spectrum ($\alpha = 2.2 \pm 0.2$)

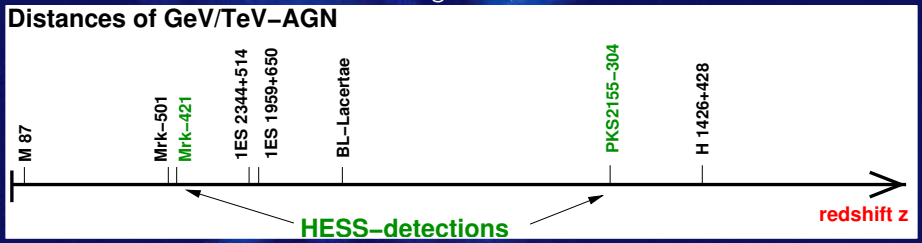



Populated corner of the sky but ...
No obvious radio / optical / X-ray counterpart found

$\longrightarrow$ Further HESS & Future GLAST observations

# Extragalactic Sources

Physics: Production mechanisms, understanding the AGN family, Extragalactic Background, ...

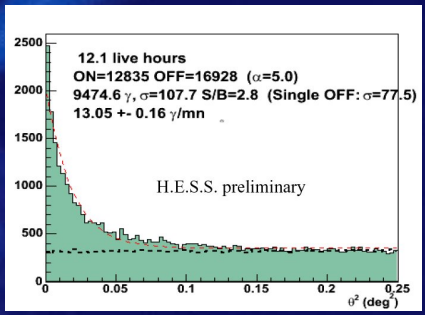


# Mrk 421: HESS Detection


First Detection: Whipple (Punch et al. 1992), subsequently confirmed by many

HESS observations

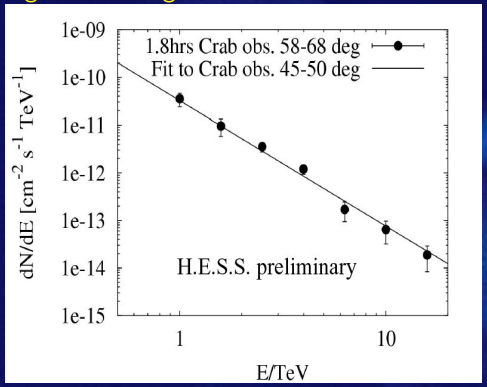
- 13.6 h observation full 4-telescope-system
- Average zenith angle: 63 deg
- Low state: 01/2004 - $6\sigma$ (2.1 h)
- High state: 04/2004 - $\approx 100\,\sigma$ 11.5 h, 11 $\gamma$/minute
- More than 8000 $\gamma$-ray events



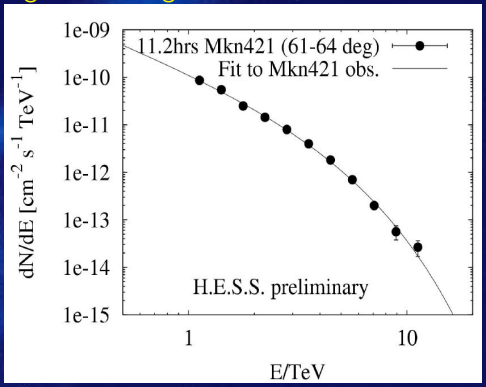

See contributions to GAMMA 2004 by D. Horns & A. Lemière

# Mrk 421: Energy Spectrum


High zenith angles: Crab




High zenith angles: Mrk 421

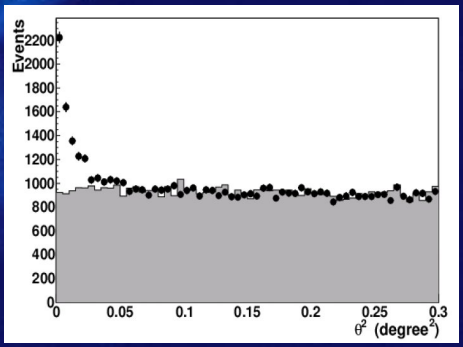


# PKS 2155-304

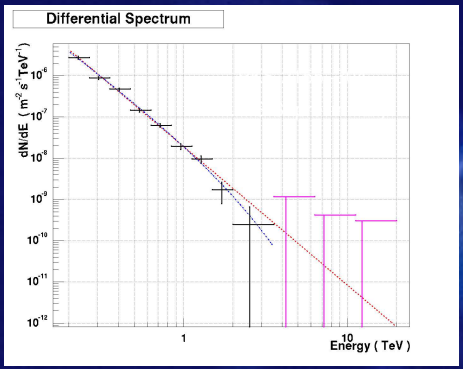

- High Frequency Peaked BL-Lac Object
- First detection: Durham Mark 6 Telescope
- $z = 0.116 \longrightarrow$ second most distant GeV/TeV emitter so far

HESS Data

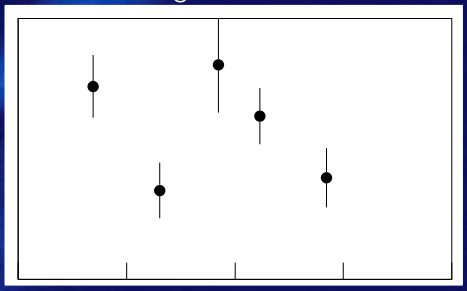
- Observation time ≈60 h
- Different data sets: varying Energy threshold 165 GeV - 305 GeV
- Significance: $>50\,\sigma$
- Many photons collected (>4000)
- Flux level consistent with Durham Mark6 detection
- No strong flux variations observed



# PKS 2155-304: Energy Spectrum & Flux Variation

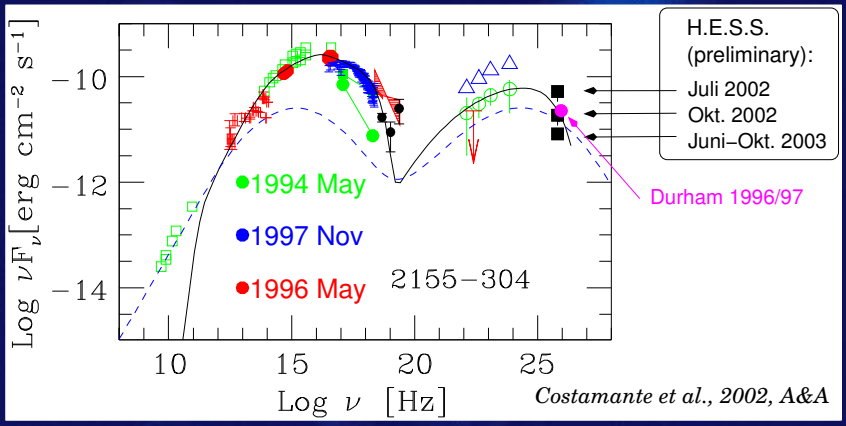

Intra-night flux variation:



No strong flux variations observed

Object is detected *every night* $\longrightarrow$ Observation of a ≪ground state≫(first ever!)

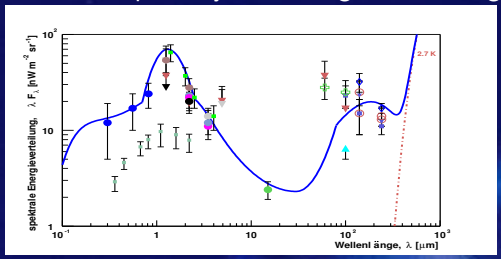
# PKS 2155-304: SSC model

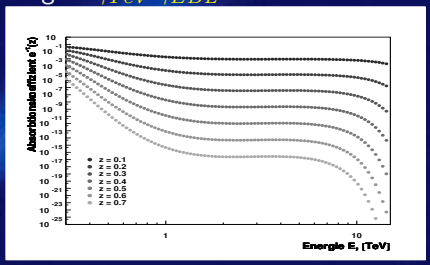



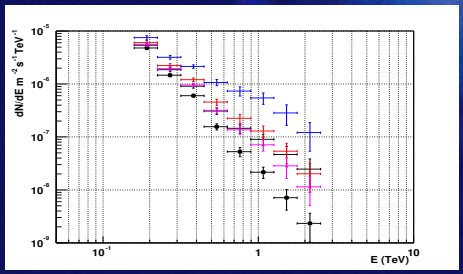

One-zone homogeneous SSC-model, Costamante et al. 2002

# PKS 2155-304 & EBL Absorption


Absorption by the Extragalactic Background Light: $\gamma_{TeV}\,\gamma_{EBL} \longrightarrow e^+e^-$



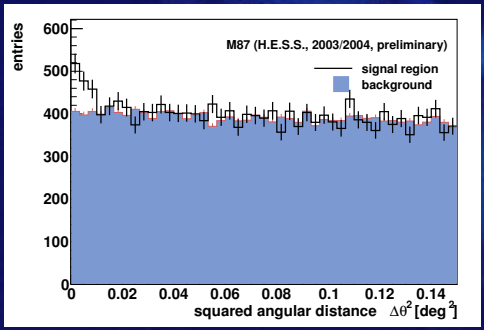



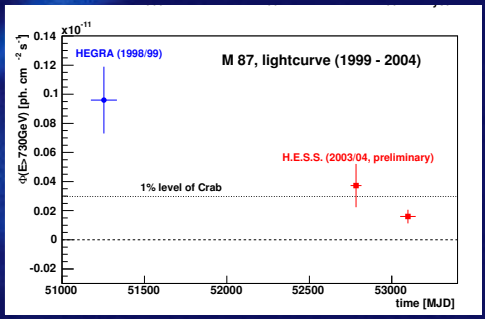

← PKS 2155-304 by HESS

- $z = 0.116$
- Several EBL models tried
- No cutoff seen yet
- Wait for higher statistics (2004) at high energies (?)

# The Radio Galaxy M87


- distance 16 Mpc (z≈0.004)
- central BH : 2-3×$10^9$ $M_\odot$
- first evidence for TeV emission : HEGRA, 4 $\sigma$-level ($\approx$ 80 h)
- 45 h H.E.S.S.-data : $> 4\sigma$



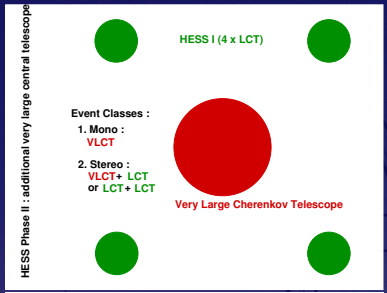




M. Beilicke et al., Texas Symposium

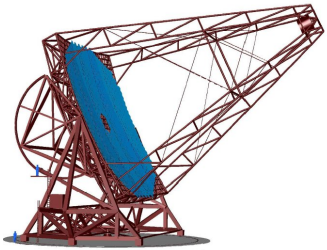
weakest GeV/TeV-source so far

# The Near Future: HESS Phase 2

# HESS Phase 2 = HESS 1 + Very Large Cherenkov Telescope



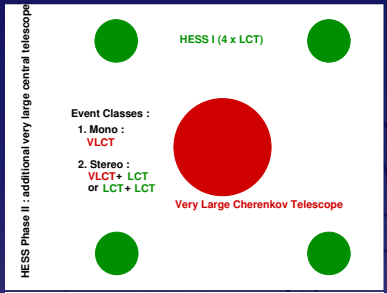

MAN Design: conventional alt-az mount



## Very Large Cherenkov Telescope:

- Reflector : 28 m ($\approx 600\,m^2$)
- Focal distance $\approx 35$ m
- Camera: diam. 2.5 m ($\approx 2000$ kg)
- 2048 PMTs ($0.07^\circ$/pixel)
- FoV : $3.5^\circ$
- Trigger rate 2-20 kHz
- Faster ARS memories needed
- Minimize data flow: 2$^{nd}$ level trigger

# HESS Phase 2 = HESS 1 + Very Large Cherenkov Telescope

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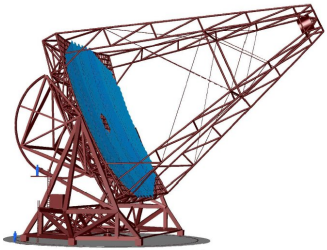
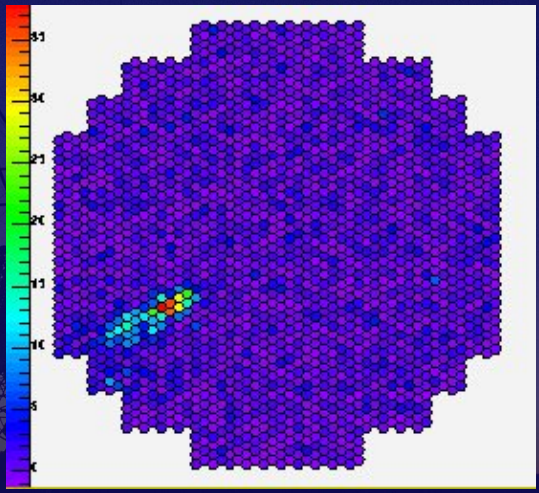


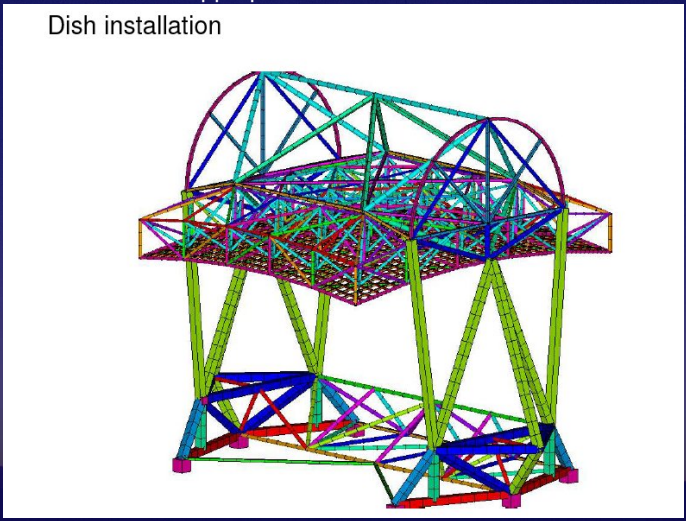
Simulation: 30 GeV $\gamma$



# HESS Phase 2 in Namibia

# Dish installation

No appropriate crane in Namibia ...



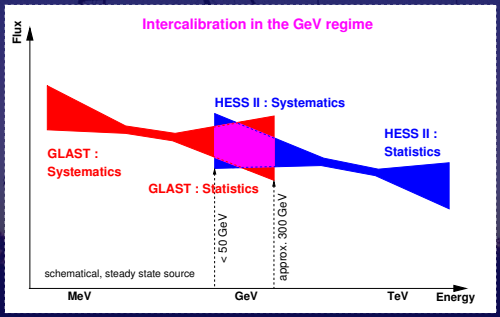
## Motivation

- **Lower energy threshold / cover wider energy range**
  - $\longrightarrow$ Pulsars : cutoff at low energies / soft sectra
  - $\longrightarrow$ AGNs at large $z$ : less absorbtion at low energies
  - $\longrightarrow$ other sources EGRET (...GLAST) : cutoff
- **complementarity with GLAST**
  - $\longrightarrow$ time resolution of H.E.S.S.
  - $\longrightarrow$ large field of view of GLAST

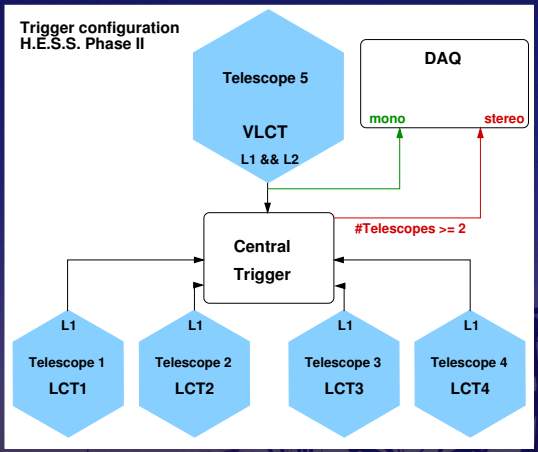
**Objective : operation in best possible conditions**
**$\longrightarrow$ lowest threshold & highest $\gamma$ count rates**

# Future collaboration with GLAST

- Overlapping energy regime : Observations of the same particle population
  - GLAST trigger for HESS-observations
  - HESS will produce sensitive variability studies
- Simultaneous observations of a steady source $\longrightarrow$ Intercalibration



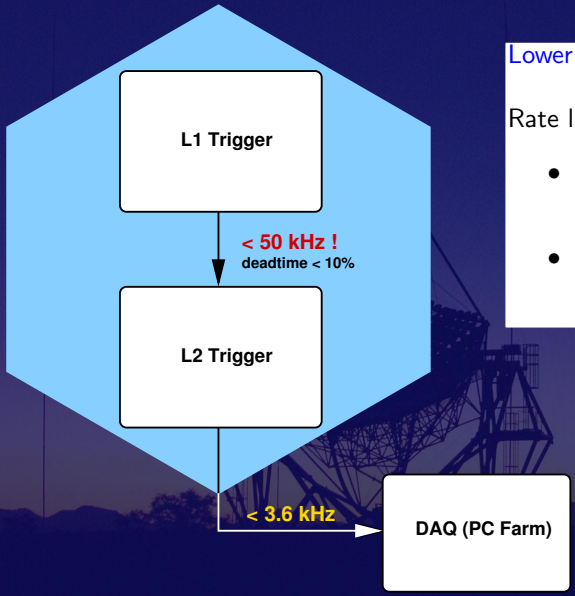
# The Trigger System for Phase 2




each camera contains L1

- $> 100$ GeV
  - stereoscopy $\geq 2$ LCT + VLCT
  - improvement of resolutions
  - imrovement of sensitivity
- 50 GeV - 100 GeV
  - stereoscopy LCT + VLCT
  - „new“/ *improved* event class
- 10 GeV - 50 GeV
  - monoscopy VLCT
  - new event class

# Constraints on the trigger system




Lower $E_{thr}$ $\Leftrightarrow$ lower PM thresholds

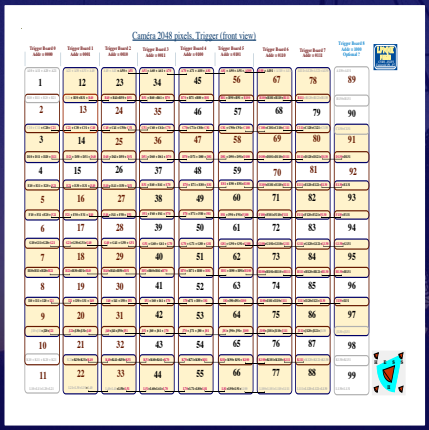
Rate limitations

- L1 : $<$50 kHz
  (dead time)
- L2 (if needed) : $<$ O(4 kHz)
  (data flow)

# The L1 Trigger

- $A_{pix}$ amplitude threshold of PMs (photoelectrons)
- $N_{pix}$ number threshold of PMs in one sector

**L1 trigger: at least $N_{pix}$ PMs with amplitude $>A_{pix}$ in one sector**




## LCT (Phase I)

- 38 sectors (64 PMs)
- $N_{pix} = 4$, $A_{pix} = 3$
- trigger rate mono : $R \approx 2$ kHz
- dead time : $T \approx 20\,\%$ (current ARS)
- trigger rate stereo : 350 Hz (total DAQ)

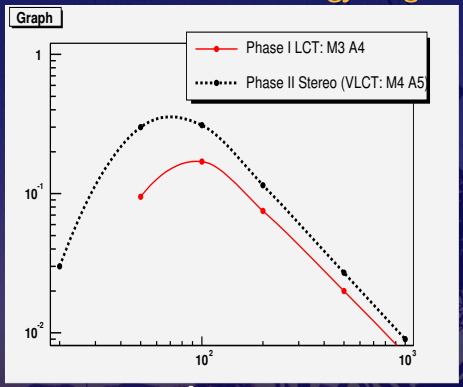
## VLCT

- 96 sectors (64 PMs)
- new improved ARS memories
- $T < 10\,\%$ for $R < 50$ kHz

# Performance of H.E.S.S Phase II in stereoscopic mode

## hybrid stereoscopic system

**Energy range $\approx$ 50 GeV - n$\times$10 TeV**




- stereo : 4 $\times$ LCT + VLCT 2 of 5
- VLCT : N=3, A=4 ; LCT : N=3, A=4

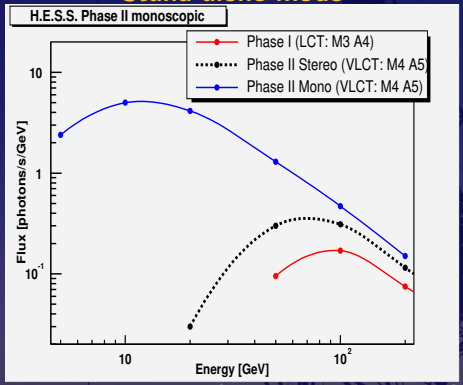
- # $\gamma$ $\times$ 2.3 (peak)
- additional image : resolution
- $E_{thr} \approx$ 50 GeV
- sensibility order of % Crab

**Improvement $\Longrightarrow$ add monoscopic events**

# Performance of the stand alone VLCT without L2 Trigger

## First step : add monoscopic VLCT events

### Stand alone mode




- monoscopy
- L1 : $N_{pix} = 4$, $A_{pix} = 5$
- no L2 trigger !

- $E_{seuil} \approx 20$ GeV
- # events $\gamma \times 20$ (peak)
- trigger rate : 2.5 kHz
- dead time $<< 5\,\%$

$\Longrightarrow$ improvement using stereo + mono VLCT

You whant even more improvement ? $\Longrightarrow$ Lower PM thresholds

## Motivation for a second level trigger

Objective: lowest possible energy & maximum $\gamma$ count
$\longrightarrow$ lower PM threshold

$\Downarrow$

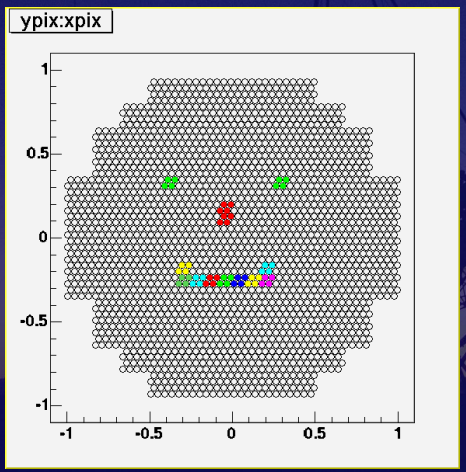
increased NSB & hadron (& $\mu$) trigger rate
$\longrightarrow$ reduce rate : L2 trigger

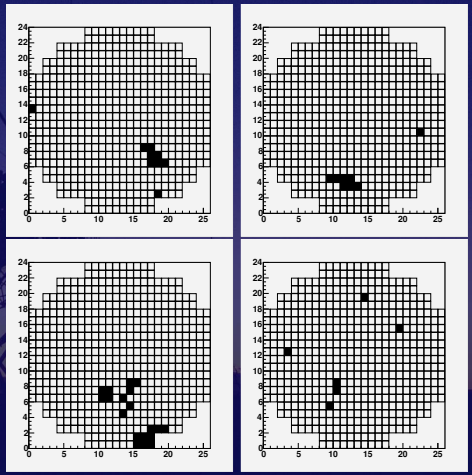
# Available information at L2

## Trigger level image :

- information unit : *bloc*
- 1 *bloc* = 4 PMs
- 1 bloc *active* = 2 PMs triggered

**Binary information !**
Images based on blocks :
$\gamma$, $\mu$, proton, NSB



## Concepts pour un déclenchement L2

| Criterion | Particle species |
|---|---|
| Hillas-type analyses (moments) | All |
| Curvature analysis | $\mu$'s |
| Symmetry of $\mu$s | $\mu$'s |
| Clustering/Irregularity | Hadrons / Nightsky background |
| Isolated Pixels | Hadrons / Nightsky background |

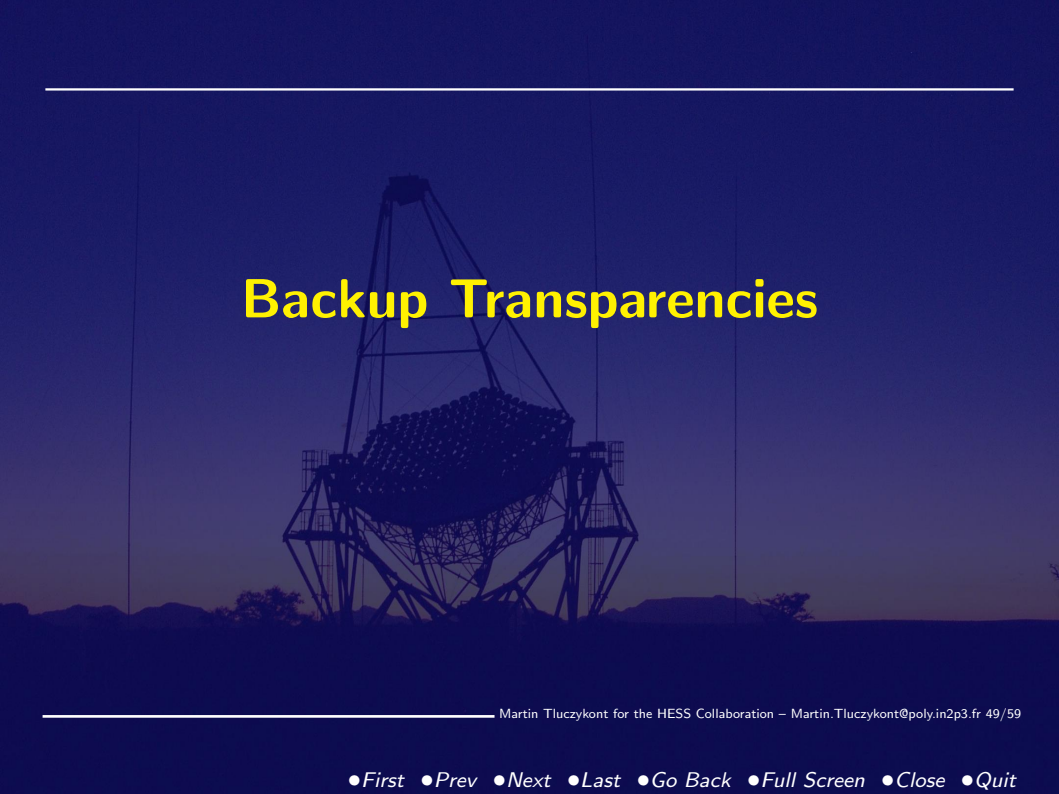
**tested concepts :**

- **binary Hillas analysis : ineffective**
- **clusterisation : encouraging results $\rightarrow$ >50% bg rejection (low PMT thresholds)**

## Summary

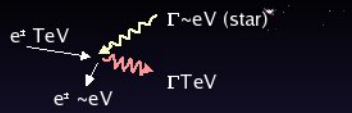
- HESS Phase I completed and fully operational Planned performance achieved
- Outstanding new results
  - $1^{st}$ astronomical GeV/TeV image (RX J1713.7)
  - New object class (Psr B1259-63)
  - $1^{st}$ time two sources in one FoV
  - $1^{st}$ observation of BL Lac at low state? (PKS 2155-304)
- $\longrightarrow$ Potential for more
- HESS Phase II is being planned:
  - Objective: close the gap to GLAST
  - Method: additional Very Large Central Telescope
  - Towards 10-30 GeV

# Backup Transparencies



# Gamma Ray Emission Models

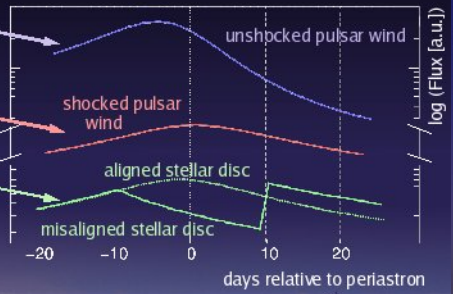
TeV gamma ray production via Inverse Compton Scattering of the star's photon field and accelerated particle populations from:




5) Unshocked pulsar wind *Ball, Kirk* 2000

6) Pulsar wind termination shock induced by star's photon field *Ball, Dodd* 2001

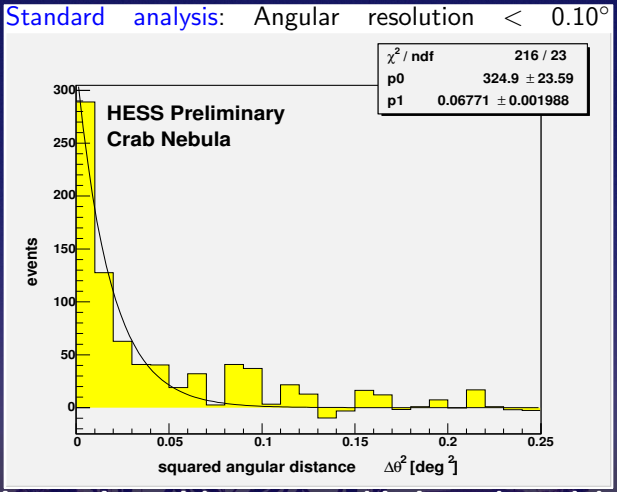
7) Interaction region of star mass outflow and pulsar wind *Kawachi et al.* 2004




All models predict flux variation dependent on orbital phase

Probe particle acceleration with star's photon field!

# HESS 1 Performance: Angular resolution




**Improving with more sophisticated models (Semi-Analytical model & 3D-Model)**

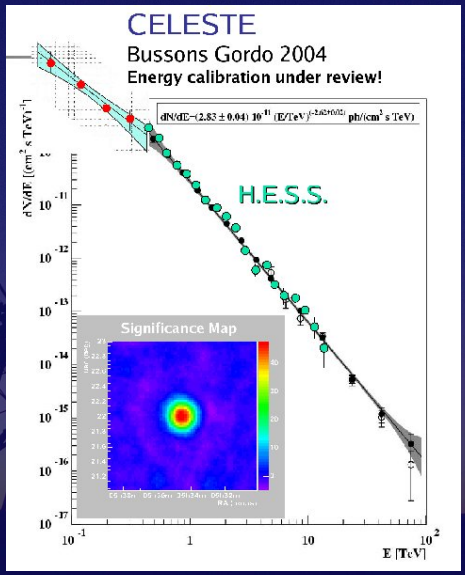
# HESS 1 Performance: Energy Reconstruction

**MC**

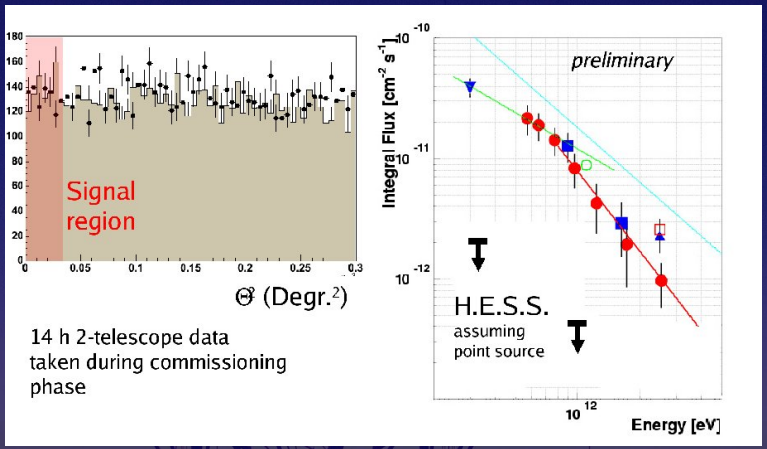
- Energy resolution: 10-20 %
- Reconstruction bias $< 10\,\%$

**Crab Nebula Spectrum**

- $\alpha = 2.59 \pm 0.04^{stat}$
  - Whipple: $\alpha = 2.49 \pm 0.07$
  - HEGRA: $\alpha = 2.62 \pm 0.05$
  - CAT: $\alpha = 2.76 \pm 0.04$
- Flux (E>1 TeV): $2.16 \pm 0.08 \times 10^{-7}\ \mathrm{m}^{-2}\mathrm{s}^{-1}$
  - Whipple: $2.15^{\pm 0.43} \cdot 10^{-7}\ \mathrm{m}^{-2}\mathrm{s}^{-1}$
  - HEGRA: $1.75^{\pm 0.37} \cdot 10^{-7}\ \mathrm{m}^{-2}\mathrm{s}^{-1}$
  - CAT: $1.78^{\pm 0.39} \cdot 10^{-7}\ \mathrm{m}^{-2}\mathrm{s}^{-1}$

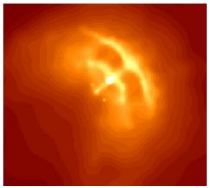


# PSR B1706-44 by HESS



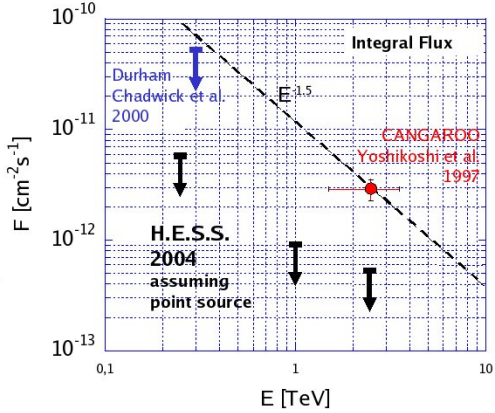

Hofmann, Gamma 2004

# Vela by HESS



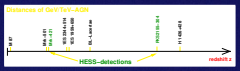
Chandra

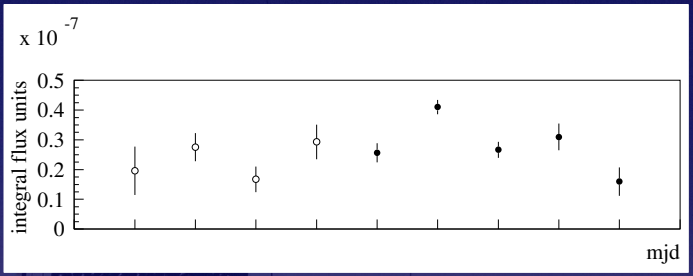
- CANGAROO source 0.13° off pulsar
- H.E.S.S. limits similar for both CANGAROO and pulsar location

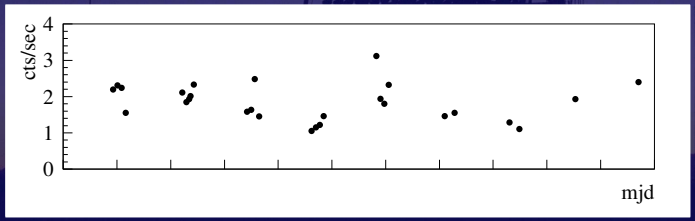



Hofmann, Gamma 2004

# PKS 2155-304: Multi Wavelength Campaigns



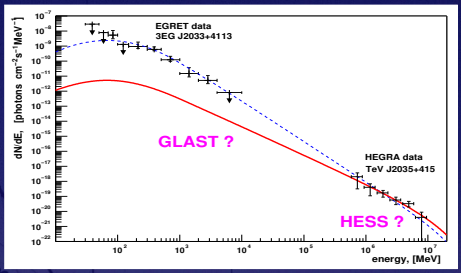



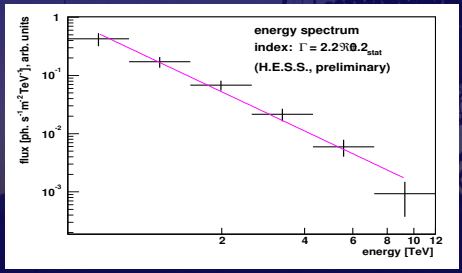




Multiwavelength campaigns carried out, results in preparation (B. Giebels)

# What kind of objects to observe for inter calibration?

- Steady state source: simplifies a lot
- Hadronic
  - Naive: straight power law
  - More efficient acceleration at GeV energies ?
- Leptonic ?



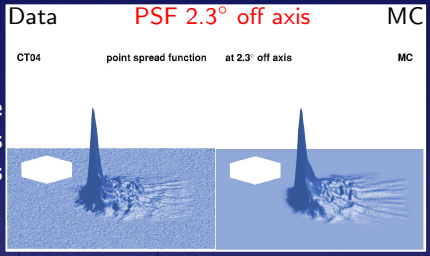




Possible Candidate: HESS 1303-63

- Power law: $\alpha = 2.2$
- Flux: 0.1 Crab (E>1 TeV)
- GLAST-detection: O(days)

# The Mirror Alignment

Individual mirror facets steerable
Alignment of facets using stars
PSF well within specifications



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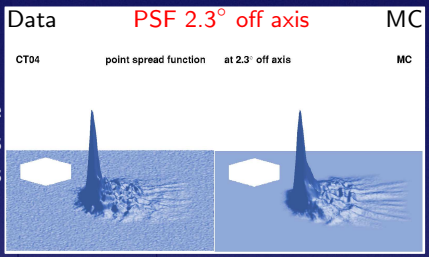


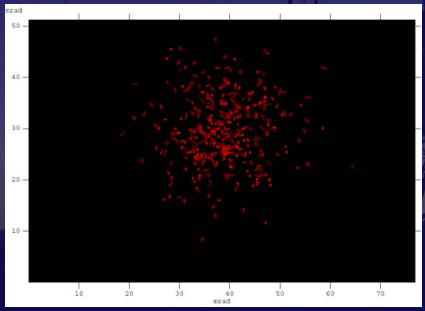

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