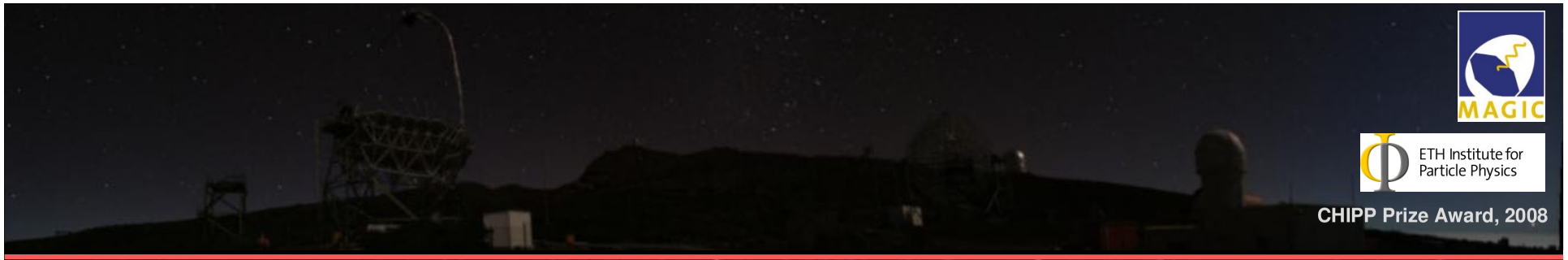


CHIPP Prize Award, 2008

DISCOVERY OF PULSED VERY HIGH ENERGY γ-RAYS FROM CRAB WITH THE MAGIC TELESCOPE USING A NEWLY DEVELOPPED SUM TRIGGER

Michael Rissi, ETH Institute for Particle Physics

CHIPP General Meeting, Lausanne, 2008

THE CRAB PULSAR

MAGIC

ETH Institute for Particle Physics

CHIPP Prize Award, 2008

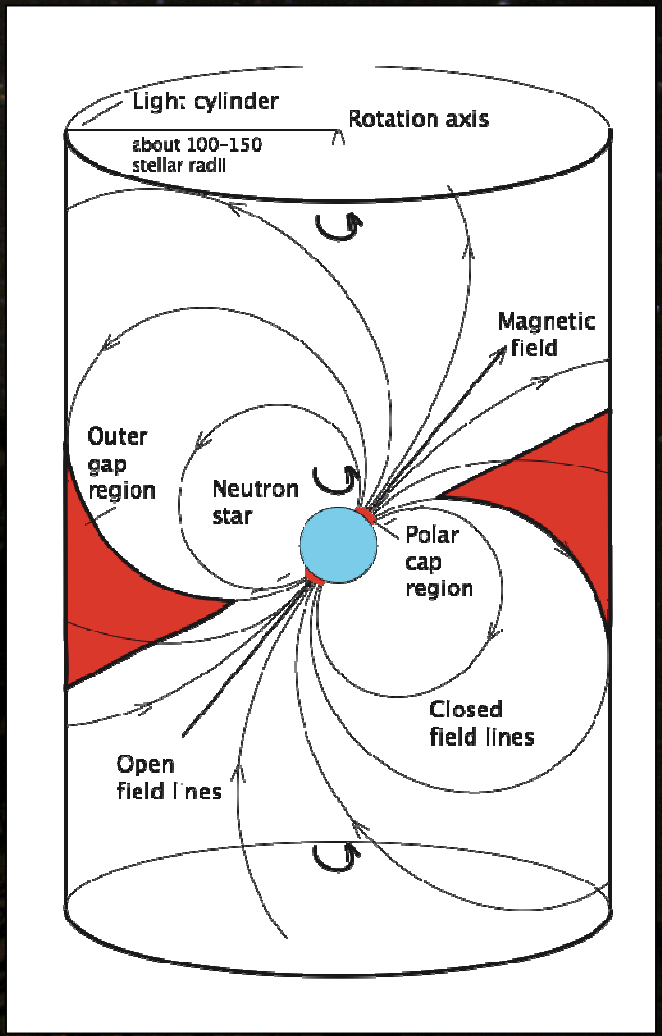
- In the center of the Crab Nebula
- Rotating Neutron star, rotation frequency: ~30 Hz
- Huge magnetic field at the order of 10^8T → huge induced el. field.
- Exact mechanism of γ-emission unknown

Polar cap model

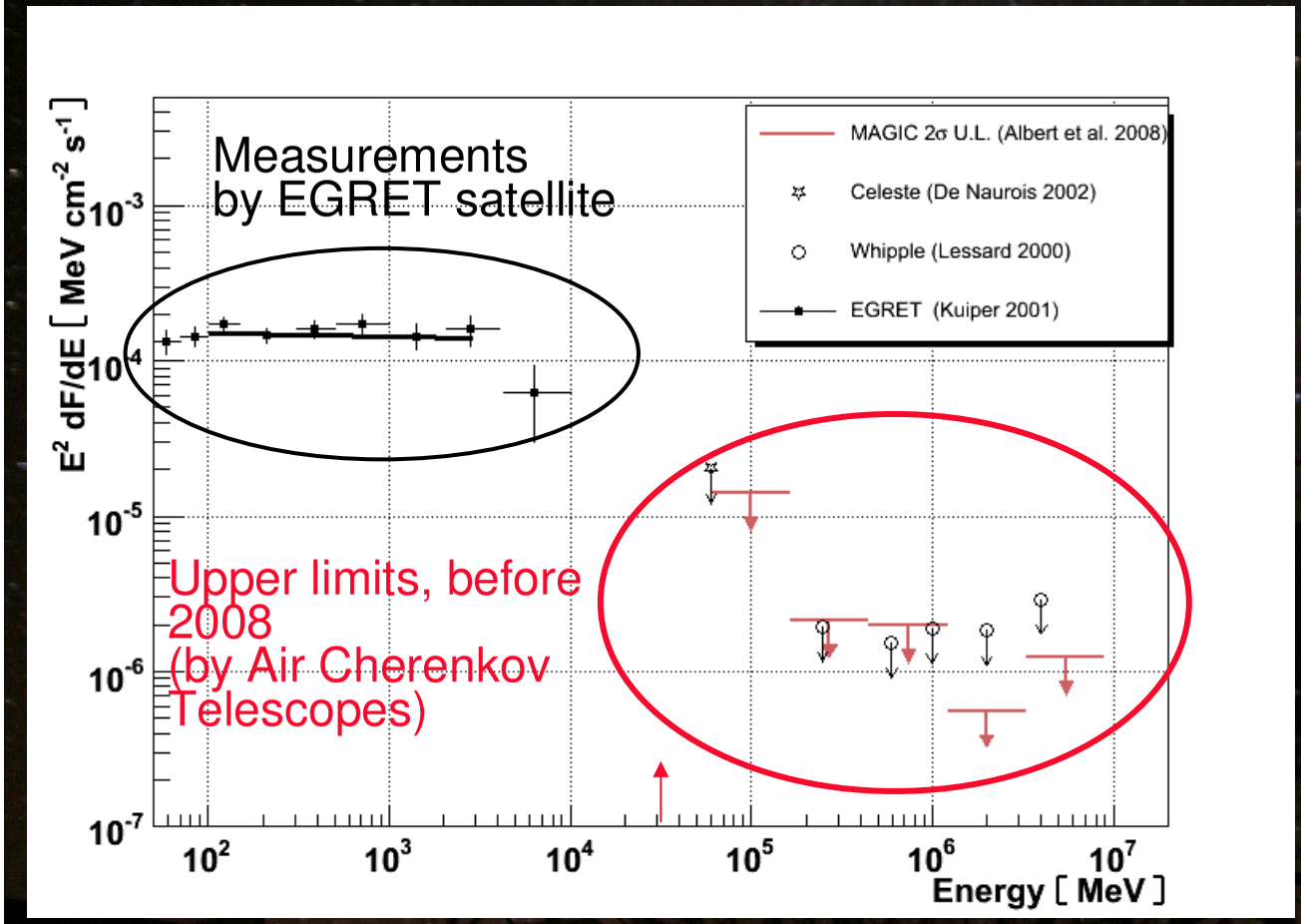
- Absorption of γ-rays via magnetic pair production: $\gamma B \rightarrow e^+e^-$
- → superexp. cutoff

Outer gap model

- Absorption of γ-rays via photon-photon collisions: $\gamma_{HE}\ \gamma_{LE} \rightarrow e^+e^-$
- → exp. cutoff *at higher energy*



CRAB PULSAR: ENERGY SPECTRUM before 2008

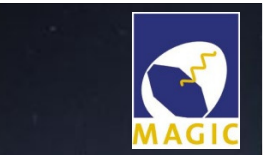


No detection of pulsed VHE gamma rays from Crab before 2008.

→There must be a steep turnover in the spectrum between 5 GeV and ~60 GeV!

(Albert et al, 2008: upper limit on cut off energy: <30GeV)

THE MAGIC TELESCOPE



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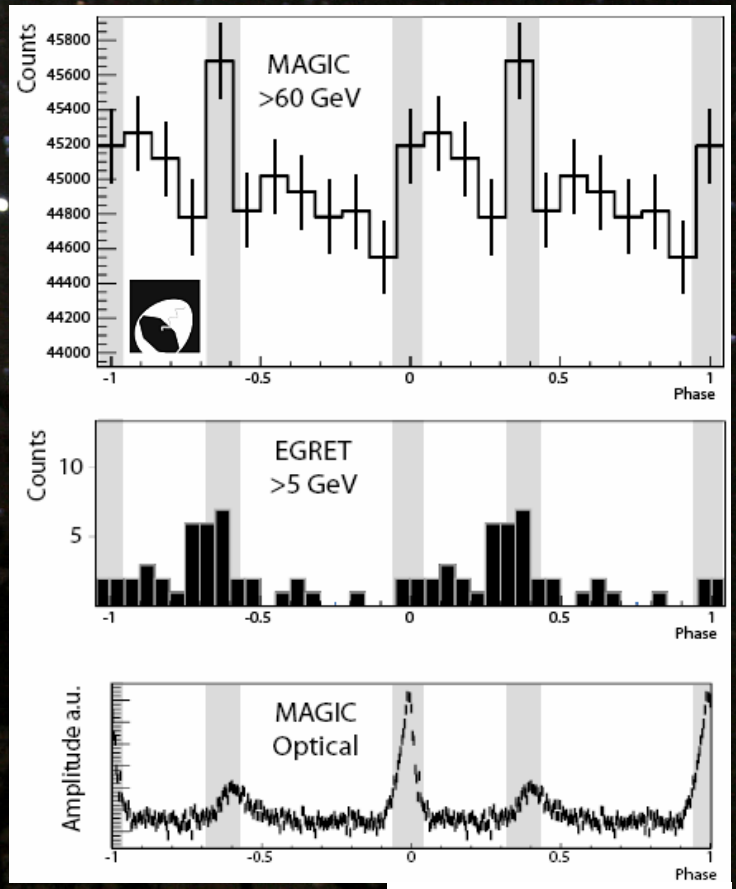
MAGIC:

- Situated on the Canary Island of La Palma (2200m a.s.l.)
- Sensitivity: ~2% Crab in 50 hours of observation time.
- Present Standard Trigger threshold: 55 GeV (for small zenith angles)
- Large mirror (17m diameter)
- Highly sensitive PMT camera
- Design goal: measure gamma rays above 50 GeV, present analysis threshold ~80 GeV (for *steady* sources)

THE CRAB PULSAR (STANDARD TRIGGER AND ANALYSIS)

CHIPP Prize Award, 2008

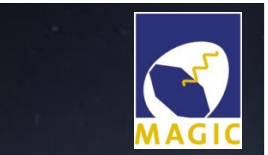
- No detection from ground based γ-ray telescopes for more than 20 years.
- No detection above 60 GeV with MAGIC.
- Situation with standard trigger: 2.9σ from Crab pulsar.
- We need a lower trigger threshold to investigate pulsed γ-rays from Crab!



(Albert et al, 2008)

$$\phi(t) = \nu_0 \cdot (t - T_0) + \frac{1}{2}\dot{\nu}_0 \cdot (t - T_0)^2 + \ldots$$

MAGIC TRIGGER SCHEMES: STANDARD and the NEW SUM TRIGGER



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Standard Trigger

- Digital trigger logic:
- If the signal in *each* of 4 neighboring PMTs is above discriminator threshold, the event is triggered.

New Sum Trigger

- Analog trigger logic:
- if the *summed* signal from *N* PMTs is above discriminator threshold, the event is triggered.

THE NEW LOW ENERGY TRIGGER FOR MAGIC

ETH Institute for Particle Physics

CHIPP Prize Award, 2008

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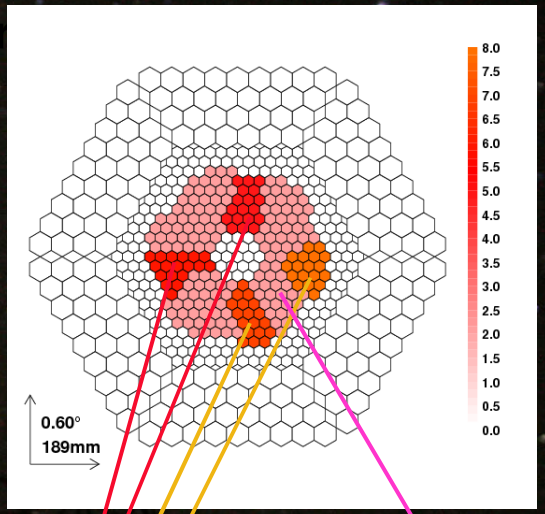
Features:

- Analog sum improves signal/noise ratio. Within one trigger patch: Free choice of pattern, no bias for shower shape
- Also small signals contribute to the trigger signal
- Needs precise timing adjustment (~2ns)



Example patches

Sum Trigger area (0.2° - 0.8°)

The patch size and shapes, the discriminator level, the optimal signal bandwidth and other parameters were optimized by extended Monte Carlo simulations.

PERFORMANCE OF THE SUM TRIGGER

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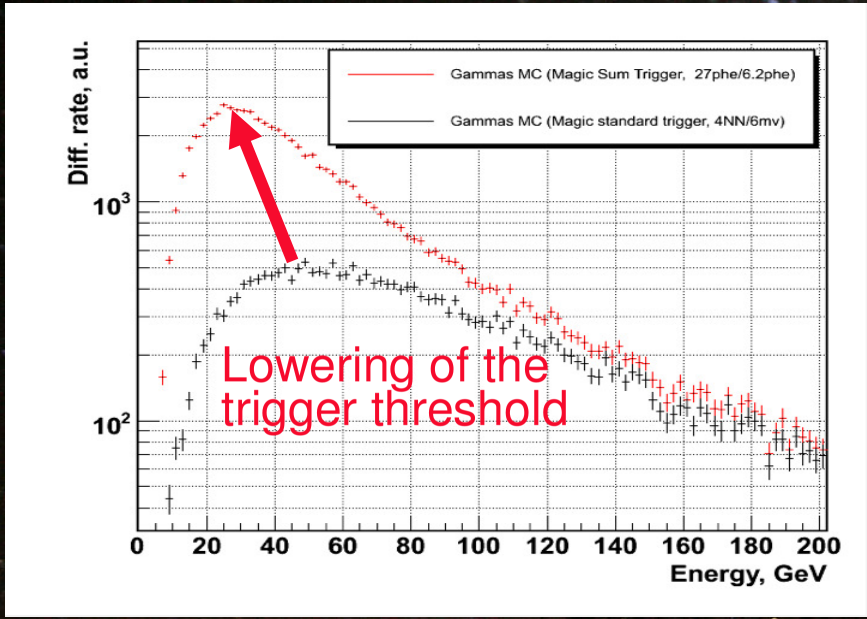
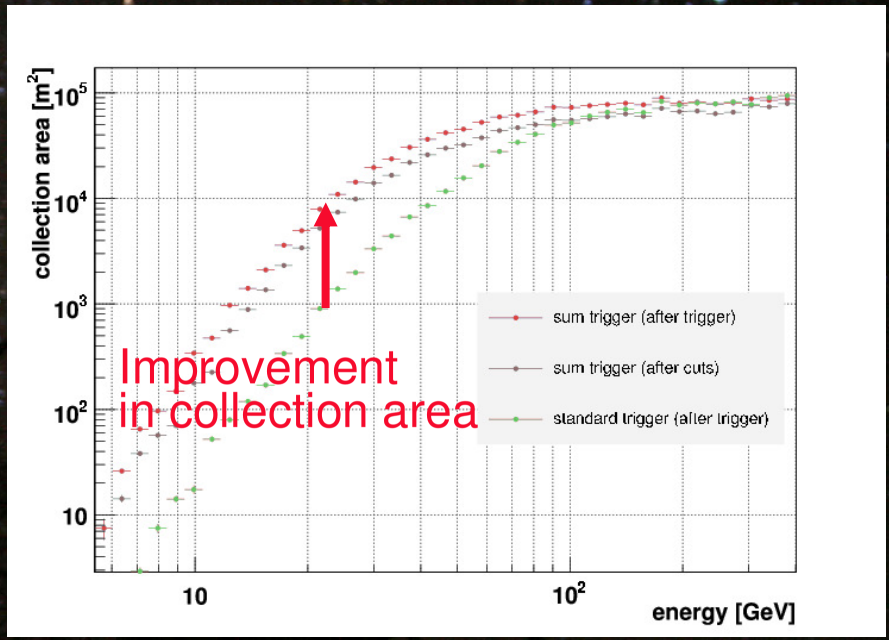




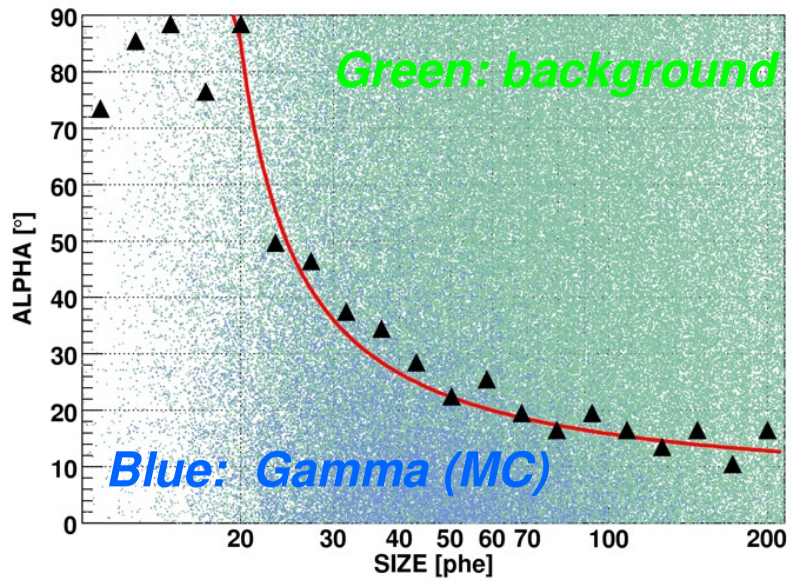
Trigger threshold lowered from 55 GeV to 25 GeV

Collection Area increased at 25 GeV by about a factor 8.

ANALYSIS OF LOW ENERGY SHOWERS

- New software was developed, adjusted to the analysis of γ-ray showers between 20-50 GeV
- To reduce the background, a parameterized cut in the image parameter **ALPHA** was found by comparing Monte Carlo γ's and OFF data (background).

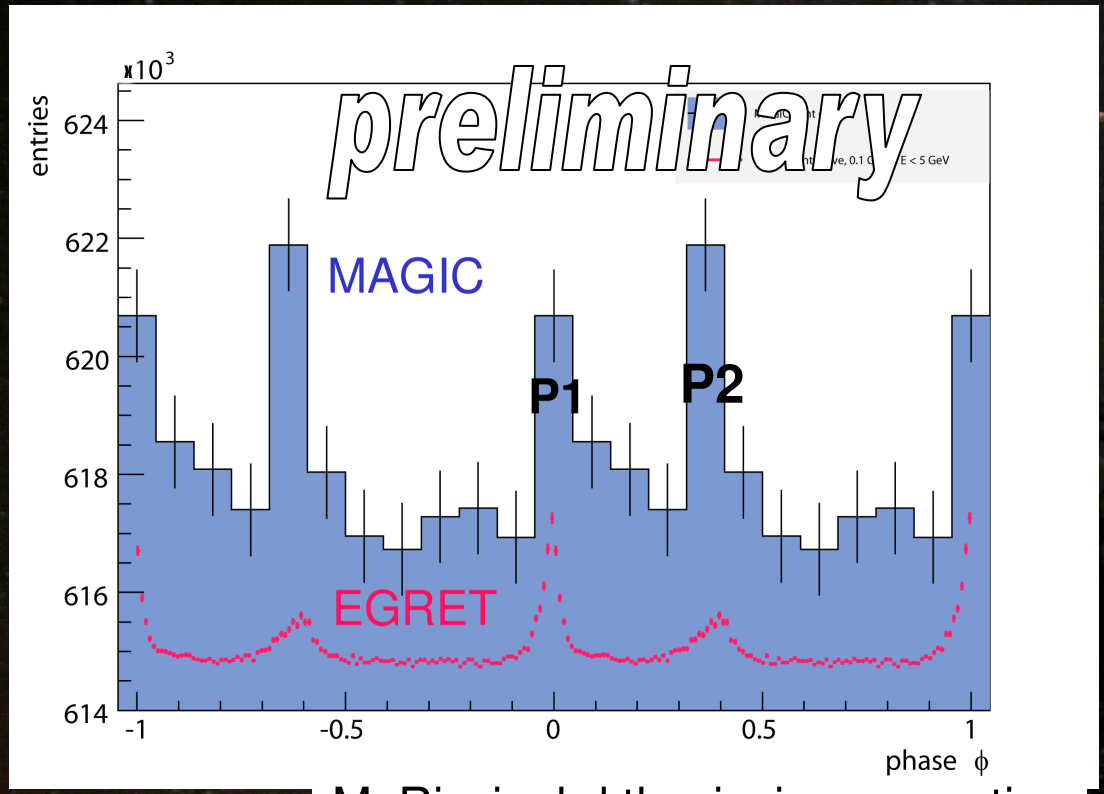
Cut in ALPHA (max. Q-factor)



- The energy was estimated using the parameter SIZE (~ number of Cherenkov photons produced by the γ-ray shower)
- Energy resolution : 45% @ 40 GeV

DISCOVERY OF PULSED GAMMA RAYS FROM CRAB

CHIPP Prize Award, 2008



M. Rissi, phd thesis, in preparation

Discovery with a significance of **6.2σ** (assuming the EGRET signal region)

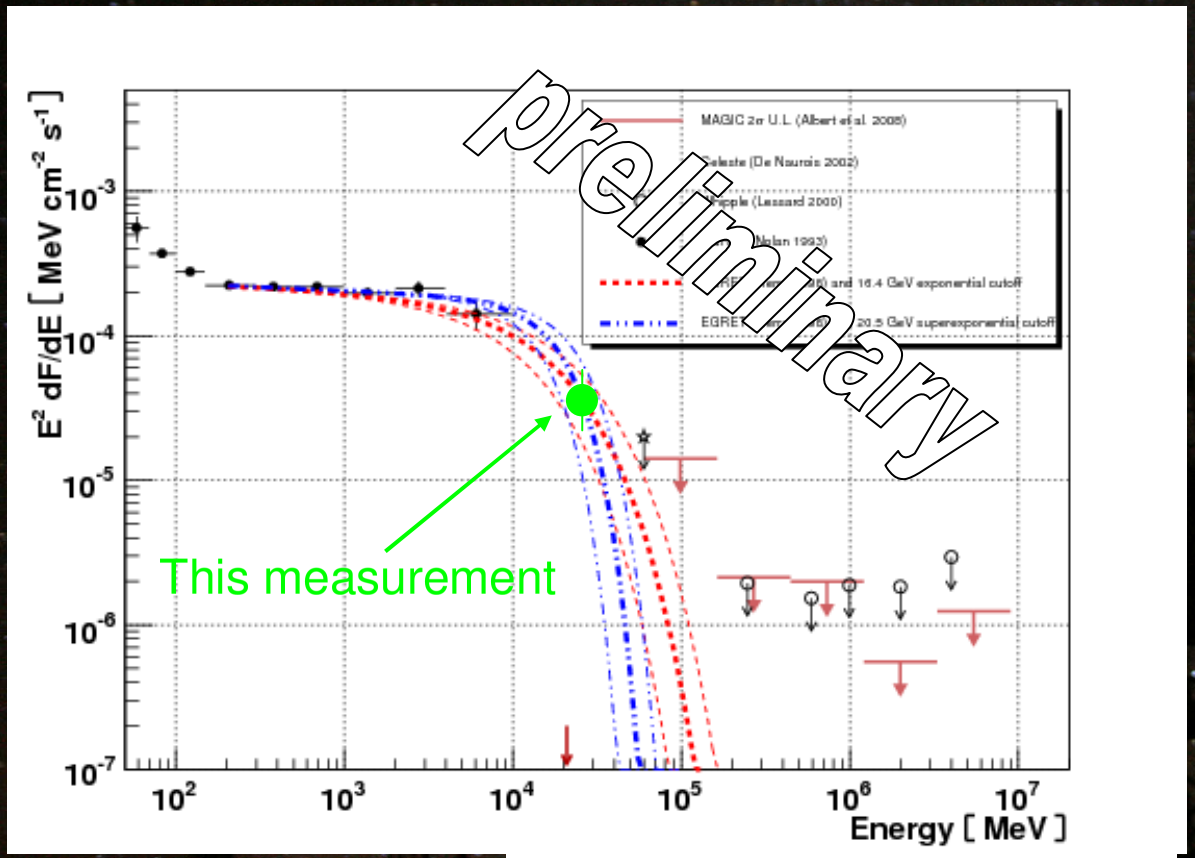
22.3 hours of observation time.

Energy threshold: 25 GeV.

Result confirmed by two additional independent analyses

(N. Otte, M. Lopez)

CUT OFF AND SPECTRUM



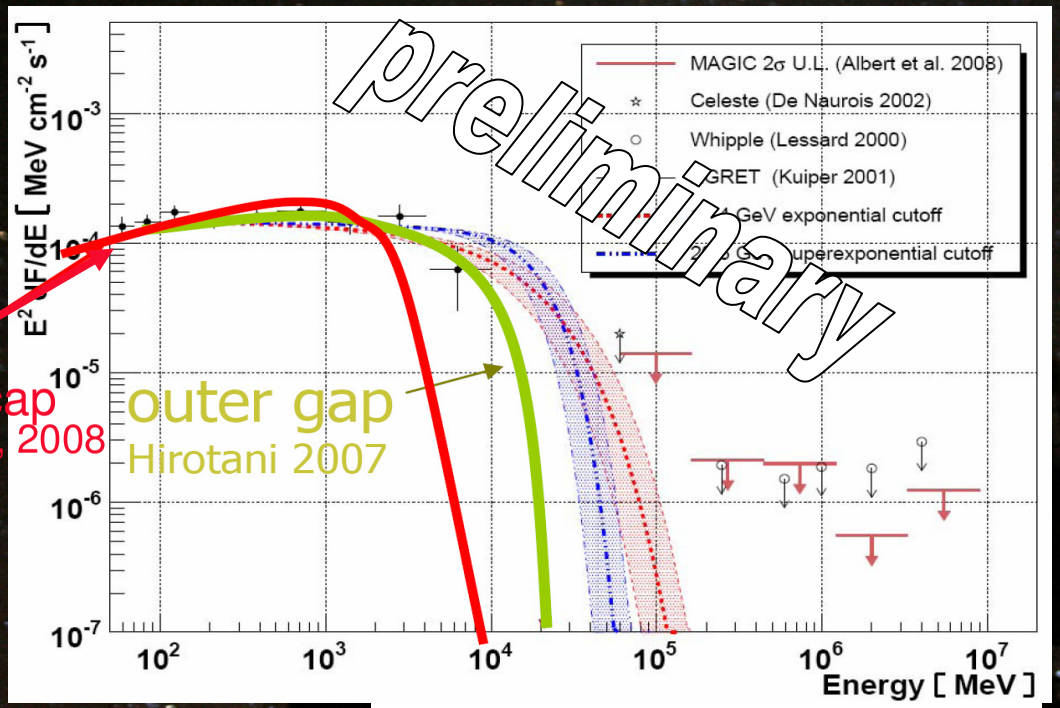
M. Rissi, PhD Thesis, in prep.

Cut off energies:

(17.7 +/- 2stat+/- 5syst) GeV
(exponential, red)

(23.2 +/- 2stat.+/- 5syst) GeV
(super exp., blue)

DISCUSSION: CUT OFF AND SPECTRUM



M. Rissi, PhD Thesis, in prep.

We can compute the minimal emission height:

$$\varepsilon_{\max} \approx 0.4\sqrt{P\frac{r}{R_0}}\max\left\{1,\frac{0.1B_{crit}}{B_0}\left(\frac{r}{R_0}\right)^3\right\}GeV$$

(Baring et al, 2001)

Assuming a magnetic field of 3.8×10^8T we can put a lower limit on the distance to the surface of the neutron star at

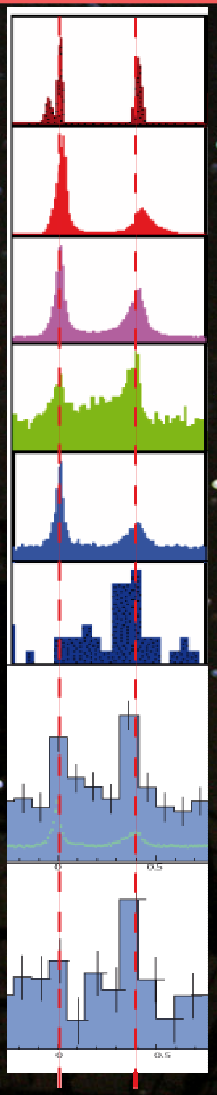
4 stellar radii

⇒ ***classical polar cap model is ruled out.***

CONCLUSION

- The sum trigger has a low energy threshold of ~25 GeV, and an energy resolution of ~45% @ 40 GeV.
- The first detection of pulsed emission from a pulsar with a Cherenkov Telescope
- First detection of the cut off of pulsar-emission.

- Measurement favors γ-ray emission from within the outer magnetosphere.
- Peak position P1 and P2 in the pulse diagram does not change, from Radio up to HE γ-rays!



ACKNOWLEGDEMENT

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  - IPP, ETH Zürich, especially Felicitas Pauss and Adrian Biland
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