Pulsars with MAGIC

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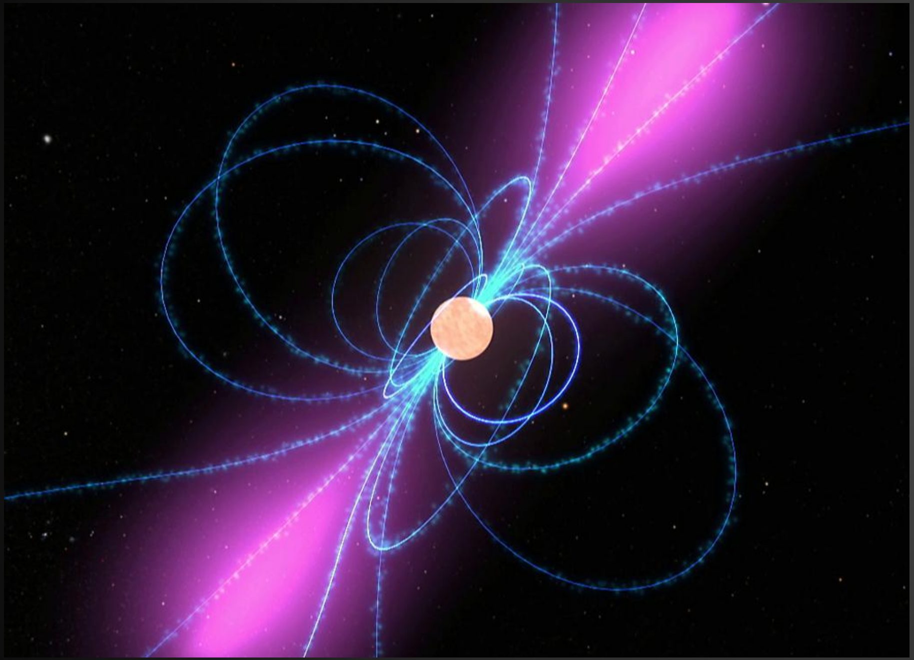
on behalf of the MAGIC collaboration

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Introduction to MAGIC

- **Energy range:**
  ~50 GeV to 50 TeV
- **Energy resolution:**
  15% (@1TeV) – 23% (@100 GeV)
- **Angular resolution:**
  0.06 deg @ 1TeV - 0.1 @100 GeV
- **Sensitivity:**
  ~ 0.66% Crab (5σ in 50h above 220 GeV)

Introduction to Pulsars



- Pulsars are rapidly rotating highly magnetized neutron stars, born in SN explosions of massive stars.

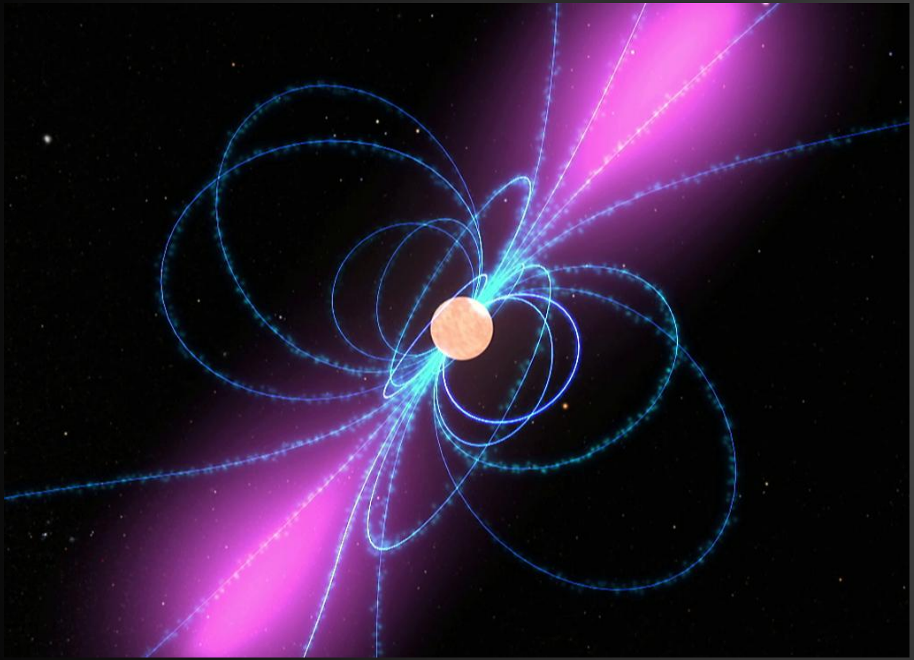
- Masses: 1.2 - 2 Msun, Radii 10 km.

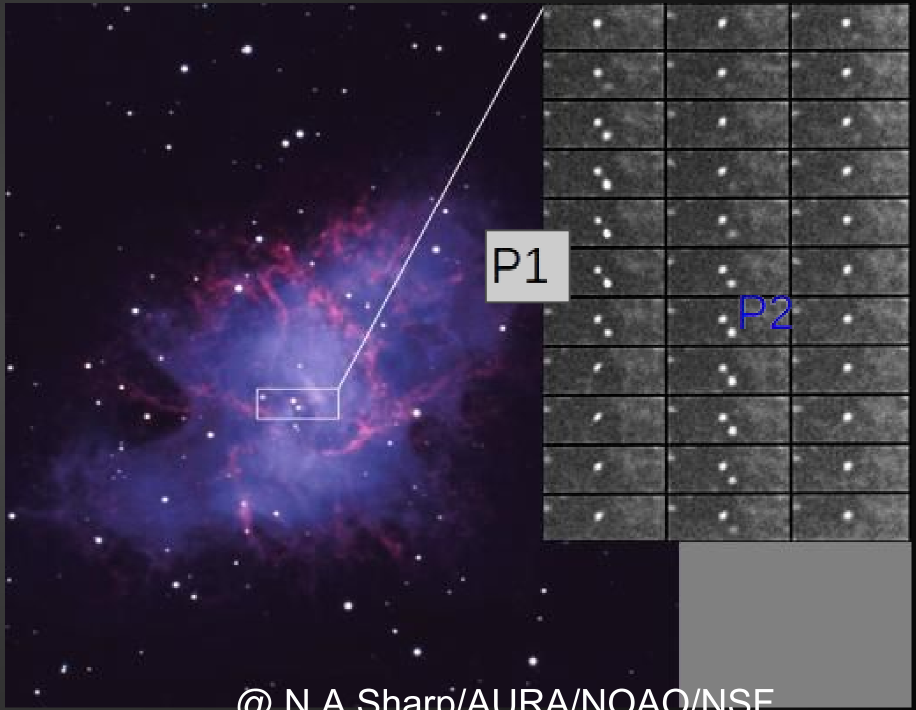
- Dense plasma co-rotating with it.

- Magnetic field.

- Emission Mechanisms originate due to fast rotation of the intense magnetic field. (light cylinder, lighthouse model)

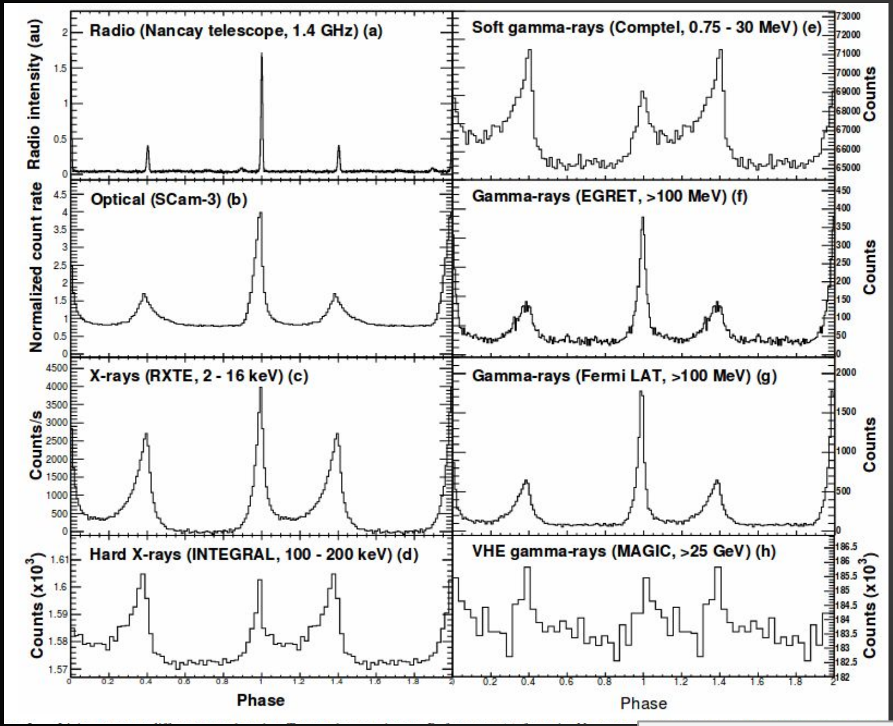
Introduction to Pulsars





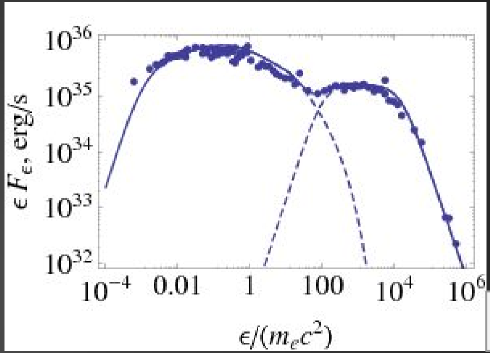
Introduction to Pulsars at VHE

- Crab Phaseogram



arXiv:0911.2412

- SED: Broadband spectrum of the Crab pulsar

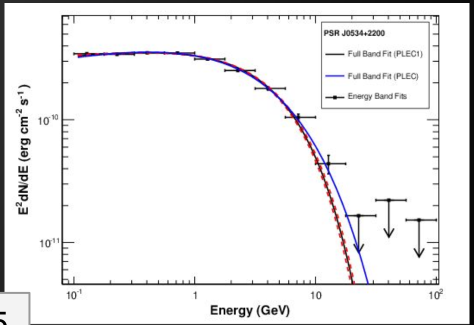


arXiv:1209.2282

> 2200 radio pulsars
> 200 Pulsars in Fermi
> 2 Pulsars VHE
> Crab unique source

- Typical HE SED

Power law with
Spectral break &
Exponential cut-off



arXiv:1305.4385

PULSARS at VHE: THE ROLE OF MAGIC

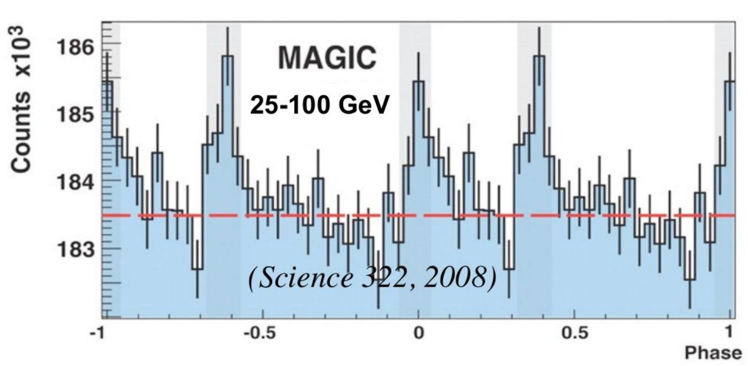
- **2008: Crab Pulsar VHE Discovery, Ruled out polar cap model.** *Aliu E. et al.(MAGIC Collab.) Science(2008) 322, 1218*

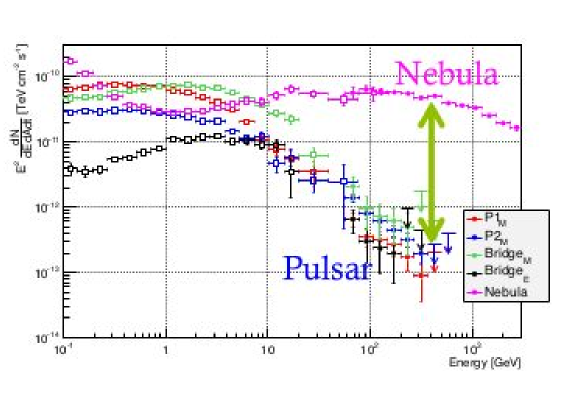
- **2011: Detection up to 100 GeV. Excluded the cutoff at more than 6σ.** *Aleksic et al. (MAGIC Collab.) ApJ 742 (2011) 43; Aliu E. et al. (VERITAS Collab.) Science(2011) ,334, 6052*

- **2012: Detection up to 400 GeV. Existence of a hard component.** *Aleksic et al. (MAGIC Collab.) A&A 540 (2012) A69*

- **2014: Detection of the Bridge emission.** *Aleksic et al. (MAGIC Collab.) A&A 565 (2014) 12)*

Next, I will present the state-of-the-art MAGIC results





Latest Results

(Using Standard MAGIC Trigger)

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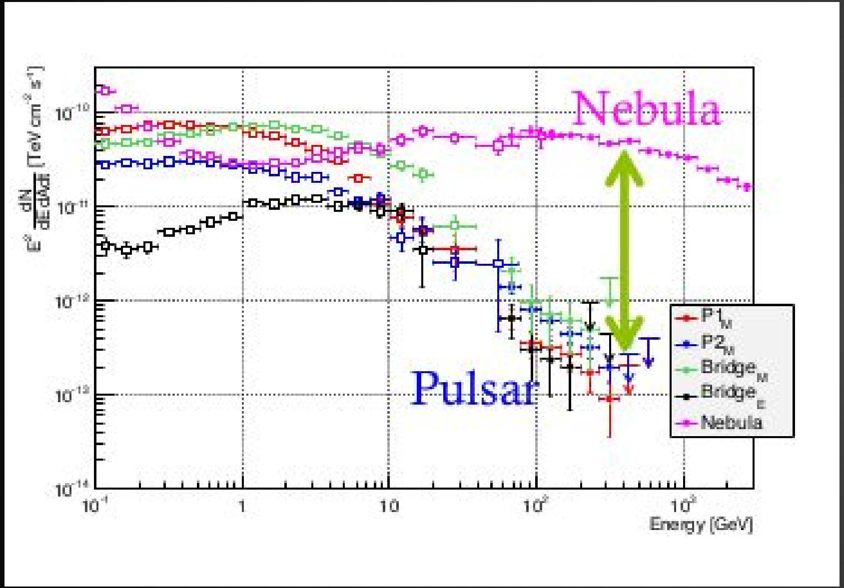
The Crab pulsar at TeV with MAGIC



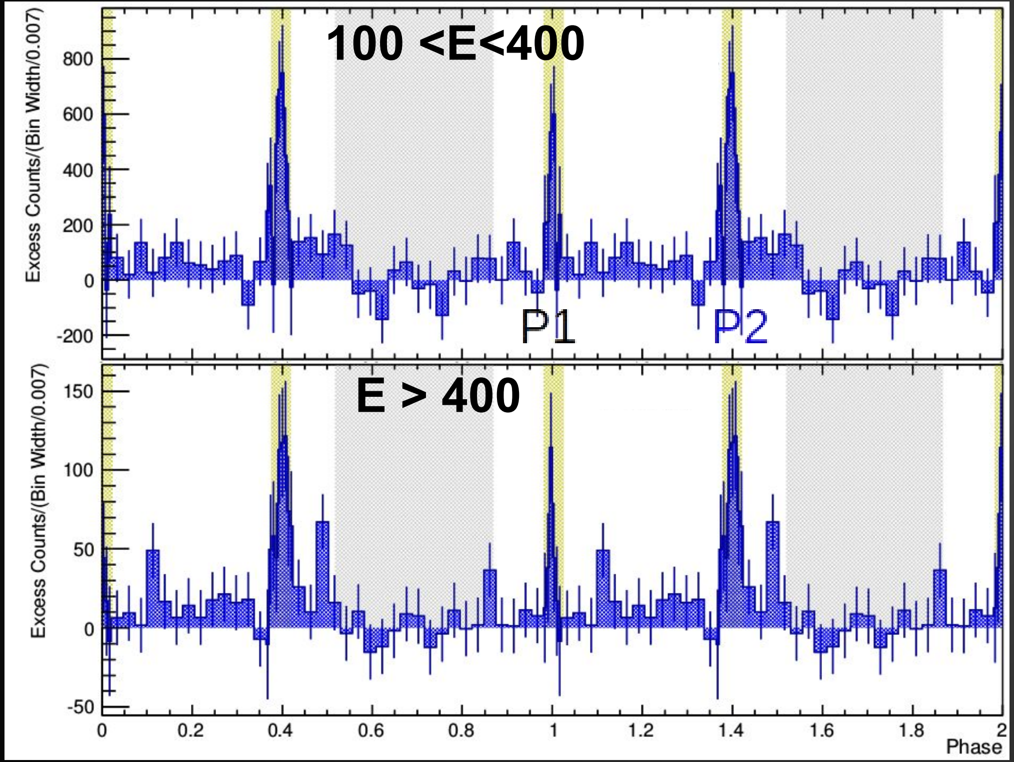
- **All data available from 2007 to 2014 was combined : Observations taken over 8 years, many different performance periods combined.**

- **After quality selection cuts ~320 h**

- **All that data was necessary due to the observed big Flux difference between Pulsar and Nebula at TeV energies.** *(green arrow in the plot)*

Teraelectronvolt pulsed emission from the Crab Pulsar detected by MAGIC. *S. Ansoldi al. (MAGIC Collab.) A&A 591,(2016) A133*

The Crab pulsar at TeV with MAGIC



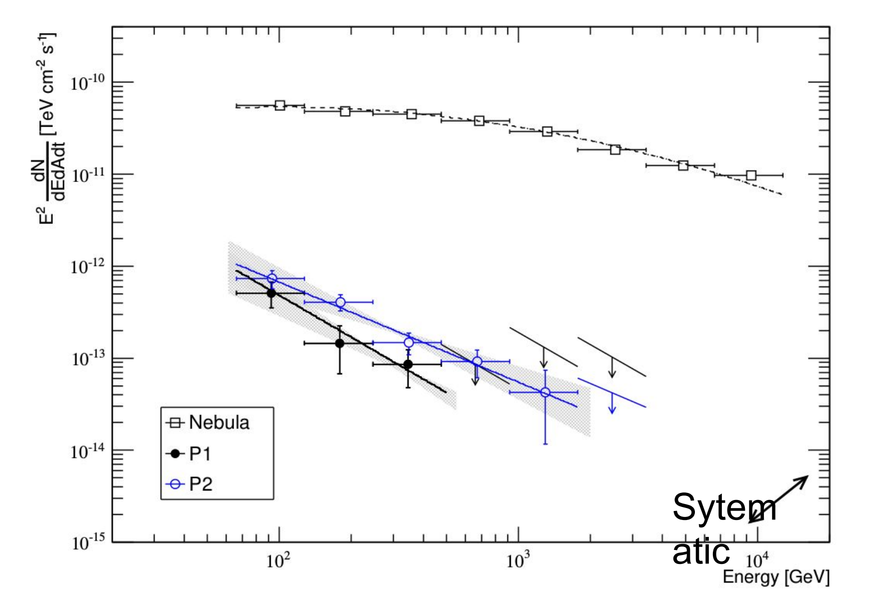
-**Pulse detection above 400 GeV:**

P1: 2.2σ

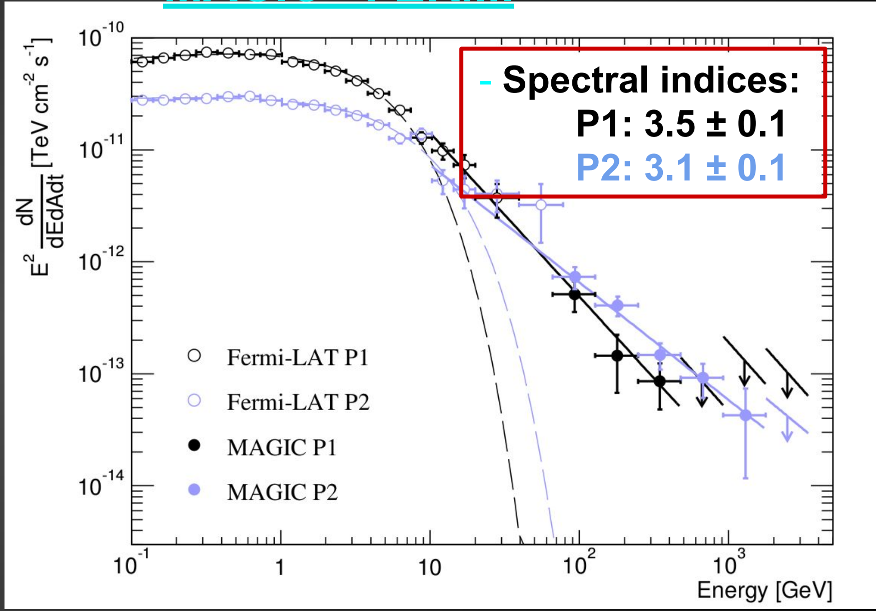
P2: 6.0σ

-**Pulse profile variation (2σ effect):**
P1 FWHM above 400 GeV is half of the one in the energy range from 100 to 400 GeV

The Crab pulsar at TeV with MAGIC



MAGIC +FERMI



- MAGIC detected the most energetic pulsed photons from the Crab, up to about 2 TeV.
- P1 could not be measured beyond 500 GeV. Power-law 3.5.
- P2 power-law spectrum extends up to ~2 TeV with a photon index of 3.1.

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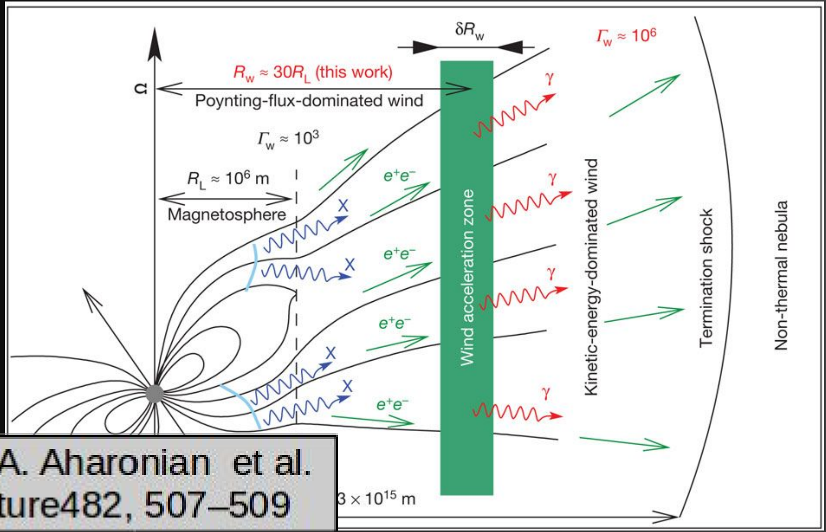
The Crab pulsar at TeV: Physics Outcomes

-The detection of TeV photons implies that they are emitted Via inverse Compton, Synchrotron-curvature ruled out. It would require unrealistic curvature radii (RC~20RLC)

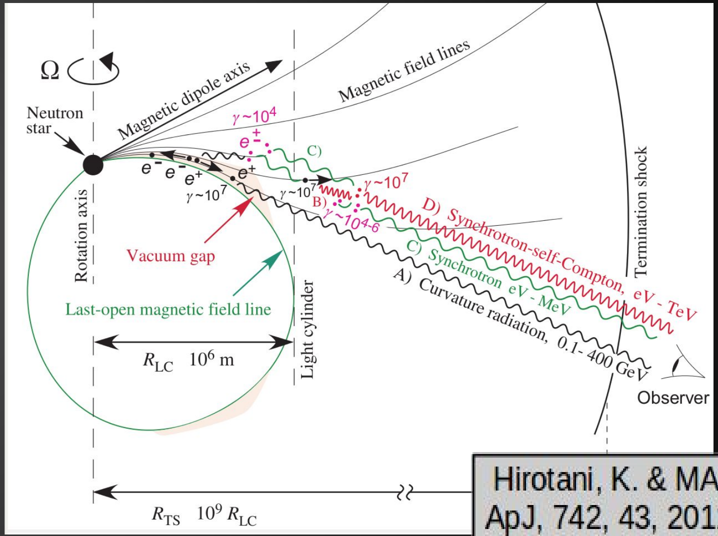
1. Inverse Compton in the pulsar wind region



F. A. Aharonian et al.
Nature482, 507–509

* Fails to achieve TeV pulsed emission

2. Magnetospheric synchrotron-self-Compton



Hirotani, K. & MAGIC,
ApJ, 742, 43, 2011

* In disagreement with GeV-TeV pulsation synchronization

* Both fail in reproducing the energy dependence of the pulses in the Phaseogram.

Lorentz Invariance using the Crab Pulsar

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- **Gamma-ray observations provide sensitive tests of LI.**

- **LI implies that the speed of light *C* is constant and, in particular, that it does not depend on the photon energy. Test this assumption by adding to *C* an energy dependent terms (E/ELIV)^n . With ELIV energy scale at which LI violating effects appears.**

- **Best test from transient events, but limited time observation and in most of the cases it can not be confirmed by other experiments.**

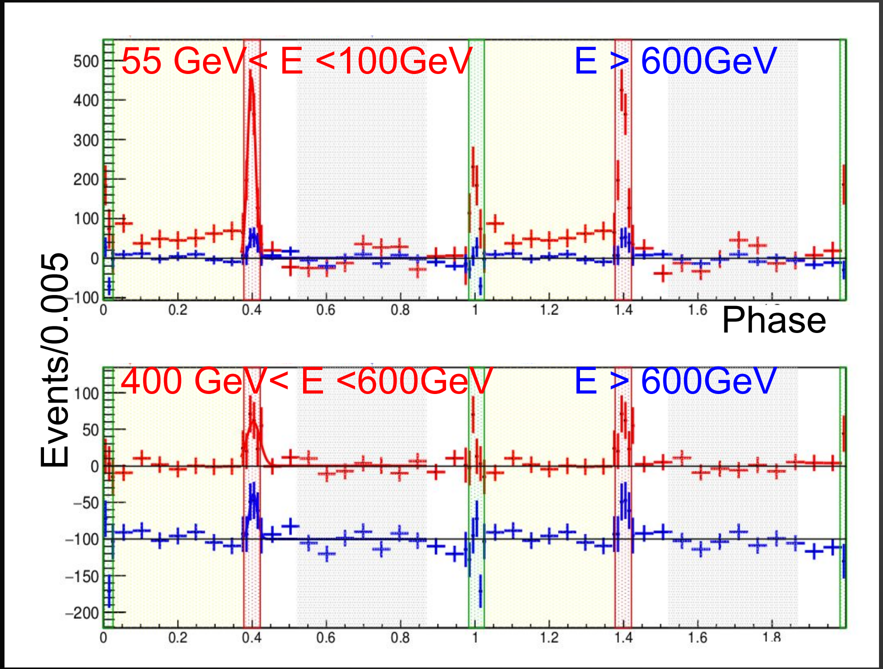
- **Time the positions of the peaks in the phaseogram and search for an energy dependent shift of the peak positions. Uses the detection at TeV of the Crab Pulsar**

$$\Delta\phi = \frac{d_{\mathrm{Crab}}}{c\,P_{\mathrm{Crab}}} \cdot \xi_n \frac{n+1}{2} \frac{E_h^n - E_l^n}{E_{QG_n}^n}$$

→

$$E_{QG_n} \gtrsim \left(\xi_n \frac{n+1}{2} \frac{d_{\mathrm{Crab}}}{c\,P_{\mathrm{Crab}}} \frac{E_h^n - E_l^n}{\Delta\phi} \right)^{1/n}$$

Lorentz Invariance using the Crab Pulsar



$E_{LIV\ (Linear)}$ > **4.5-4.6 x 10^17 GeV**

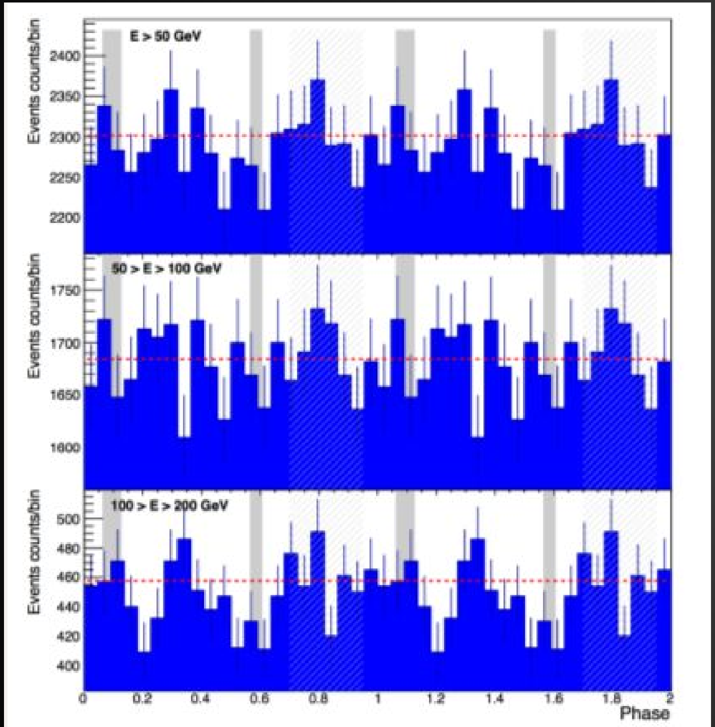
$E_{LIV\ (Quadratic)}$ > **5.3-5.9 x 10^10 GeV**

Constraining Lorentz Invariance violation using the Crab pulsar emission observed up to TeV energies by MAGIC *Submitted*

Looking for Geminga:

(Using Standard MAGIC Trigger)

Search for VHE gamma-ray emission from Geminga pulsar and nebula with the MAGIC telescopes. *Aleksic et al. (MAGIC Collab.) A&A 591, A138 (2016)*



Geminga is one of the most interesting targets since:

- It is the one of the brightest pulsar in X-Ray
- At 3 GeV, 5 times brighter than Crab
- Nearby 157 pc
- Power-law-like extension after the break is reported based on Fermi data
- 25 GeV pulsation is also detected (1FHL)

No detection after 63h (after quality cuts), data with standard trigger, and analysis trigger around 70 GeV

Looking for Geminga:

- Cutoff power law fit to LAT data above 0.1 GeV

$$\frac{dF}{dE} = N_0 \left(\frac{E}{E_0}\right)^{-\alpha} exp(-(E/E_c)^b$$

	N_0	α	E_c [GeV]	b
P1	3.0 ± 0.3	1.12 ± 0.04	1.2 ± 0.1	0.81 ± 0.04
P2	4.3 ± 0.4	0.78 ± 0.03	1.1 ± 0.1	0.70 ± 0.03
PA	28.3 ± 1.8	0.94 ± 0.02	0.8 ± 0.1	0.67 ± 0.02

< 1

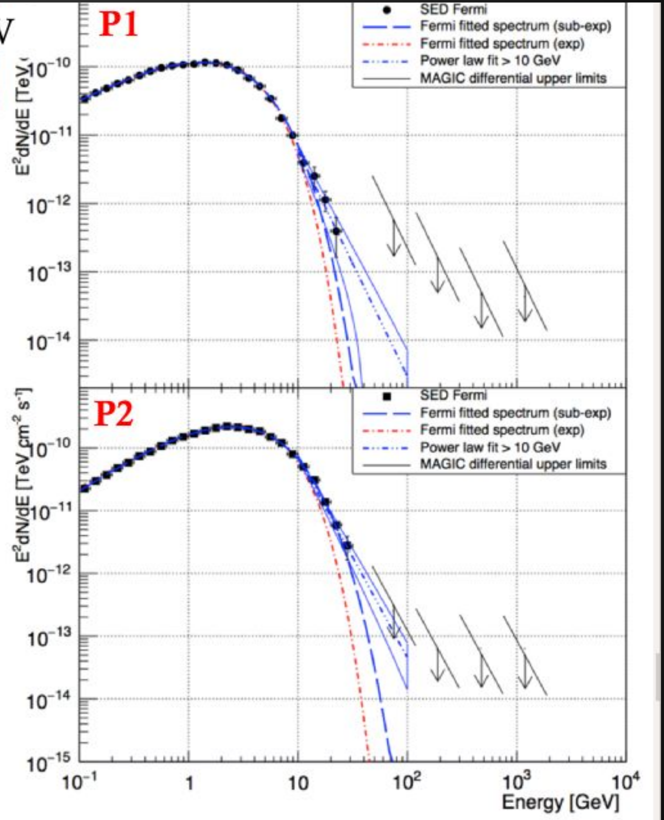
- Power law fit to LAT data above 10 GeV

$$\frac{dF}{dE} = N_0 (E/10GeV)^{-\alpha}$$

	N_0	α
P1	$(5.9 \pm 1.4) \times 10^{-5}$	5.3 ± 0.7
P2	$(7.2 \pm 0.1) \times 10^{-4}$	5.2 ± 0.3

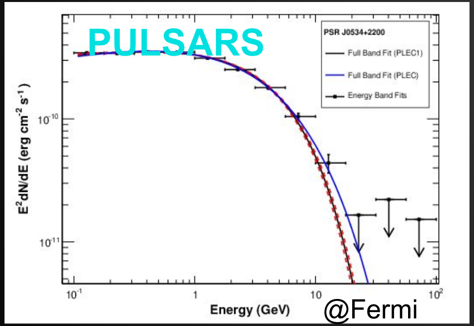
N_0 $[10^{-10} MeV^{-1} s^{-1} cm^{-2}]$

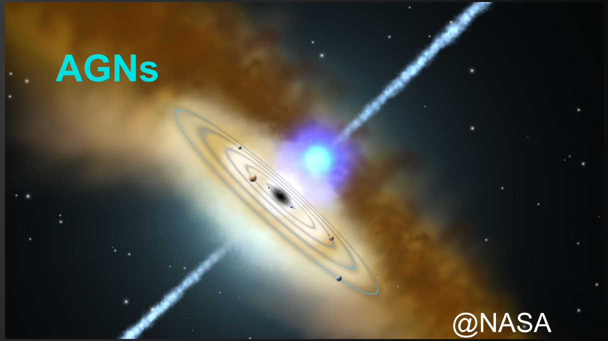
- P2 limits are close to but slightly above the power law extension.
- <u>Lowering energy threshold is important.</u>



New Stereo Analog Trigger for low energy observations

The SumTrigger-II





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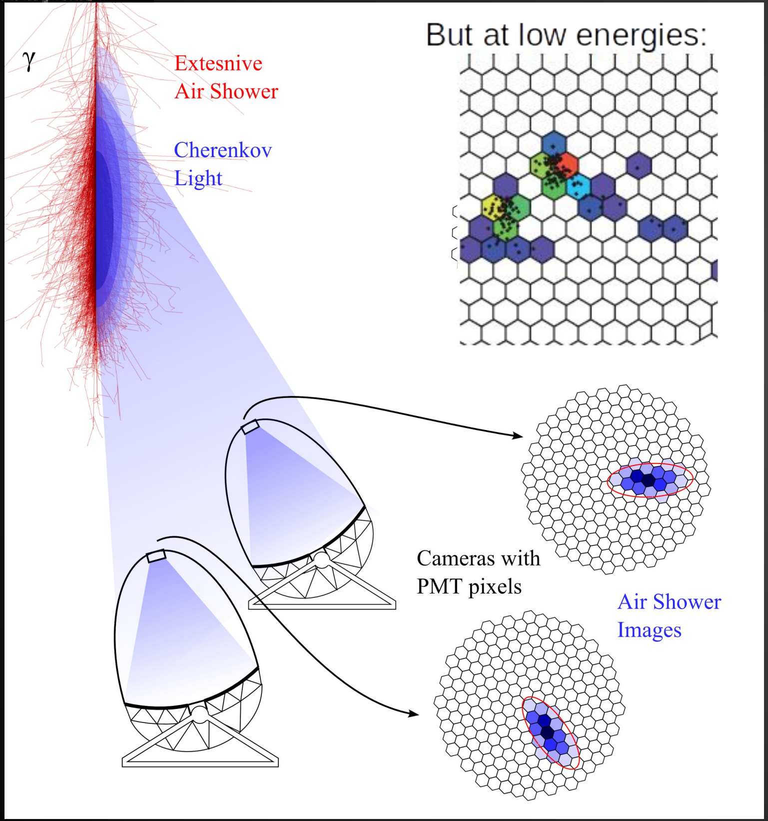

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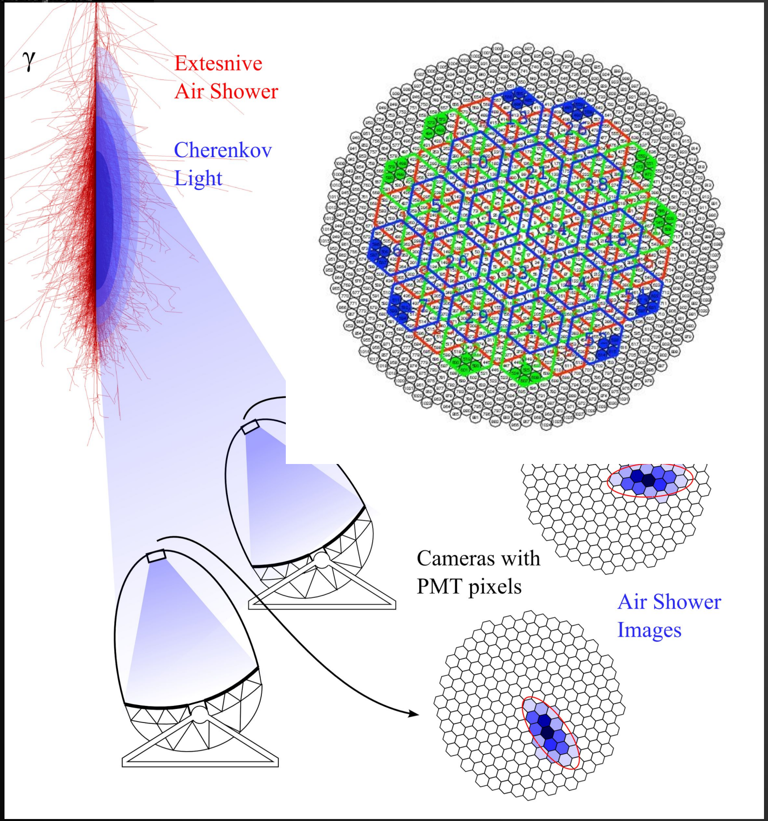


- New Stereo Analog Trigger for low energy observations

- Sum of analog signals of a patch of PMTs of the expected size of the low energy images.

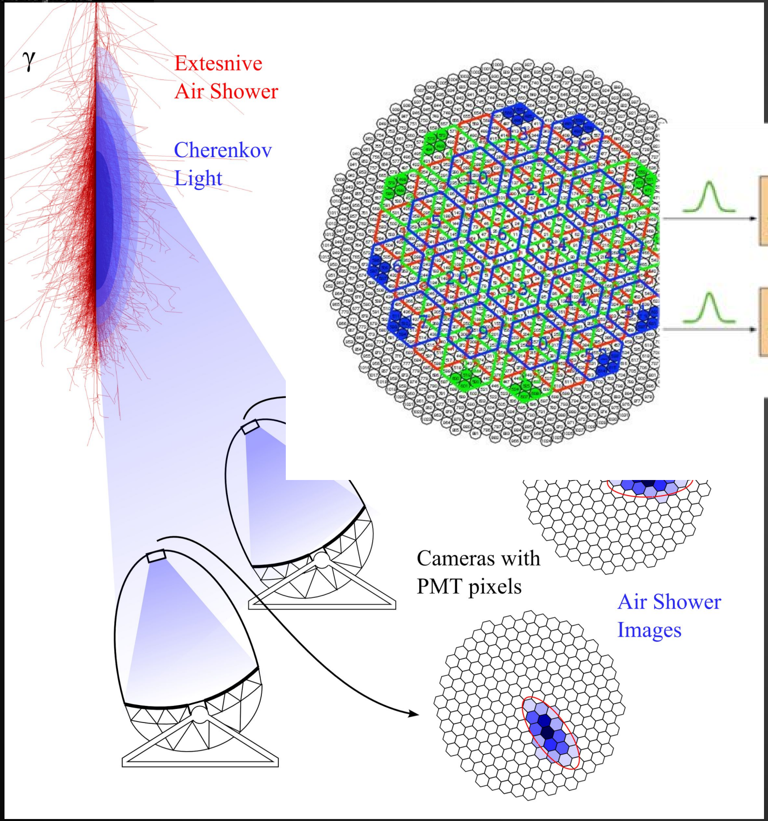
- Use small photon signals below the single channel threshold.

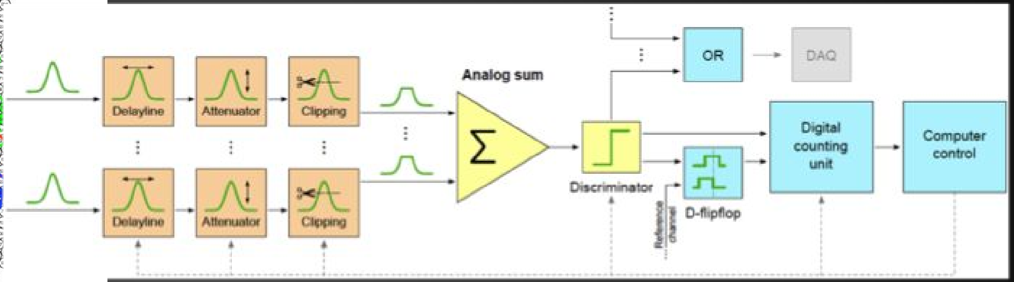
- Integration of larger area (size shower) increases S/N.

- Camera subdivide in 55 patches that operate independently. This patches are distributed in 3 overlapping layers .

- The final trigger is a Global OR of the local macrocells trigger.

The SumTrigger-II:

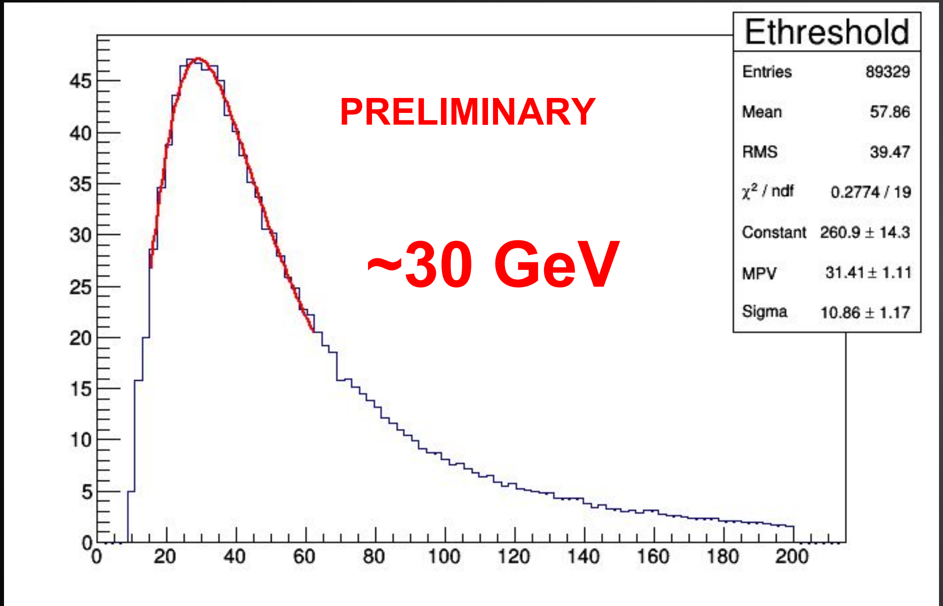




- Signals equalization is needed.
- Also amplitud flat fielding.
- Clipping the signals to avoid PMTs afterpulses.
- The final trigger is a Global OR of the local macrocells trigger.

The SumTrigger-II:

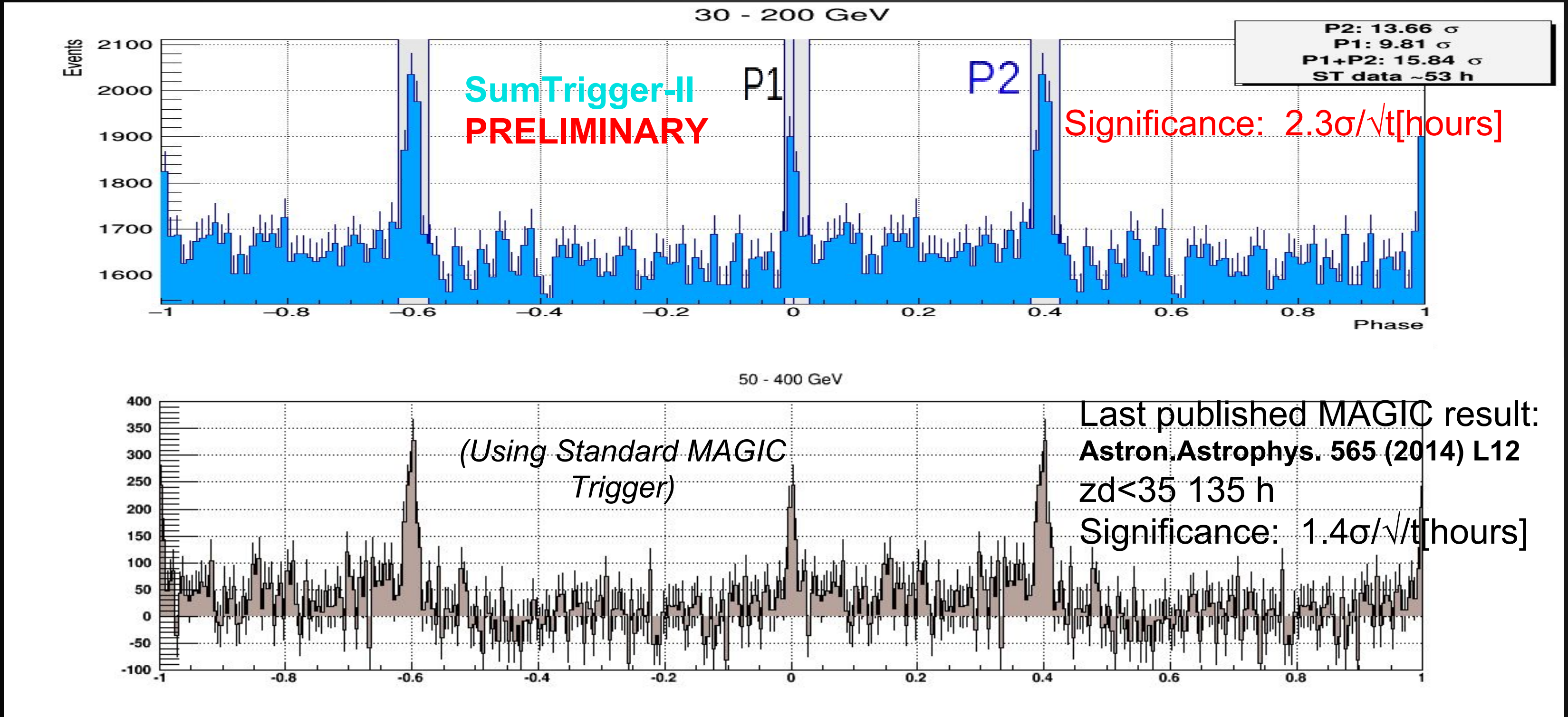
MC trigger energy threshold:

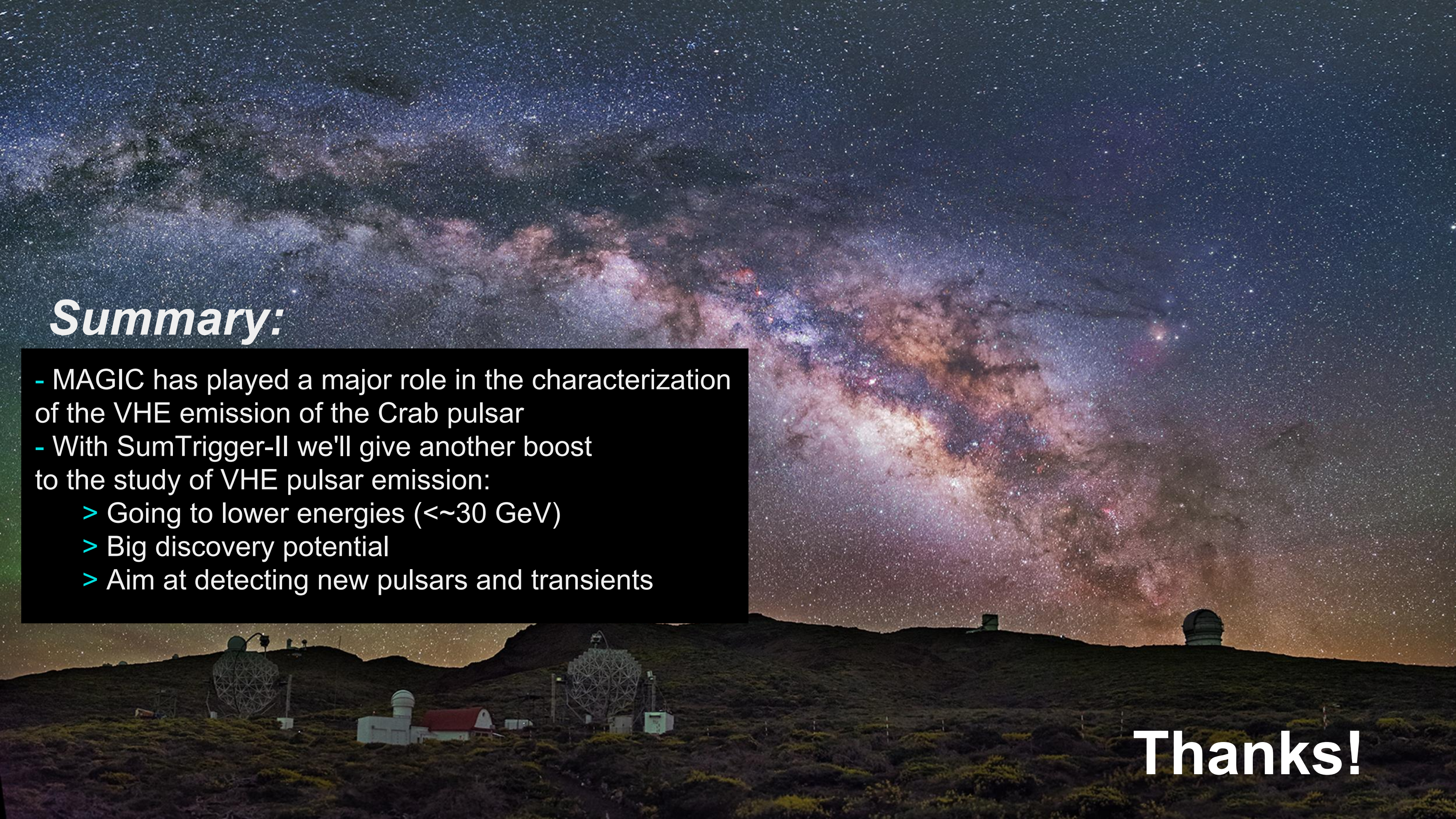


In comparison with 50 GeV for the standard Trigger

The SumTrigger-II:

Double significance per sqrt of time





Summary:

- MAGIC has played a major role in the characterization of the VHE emission of the Crab pulsar
- With SumTrigger-II we'll give another boost to the study of VHE pulsar emission:
  > Going to lower energies (<~30 GeV)
  > Big discovery potential
  > Aim at detecting new pulsars and transients

Thanks!