Detection of Geminga with MAGIC

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for the MAGIC collaboration

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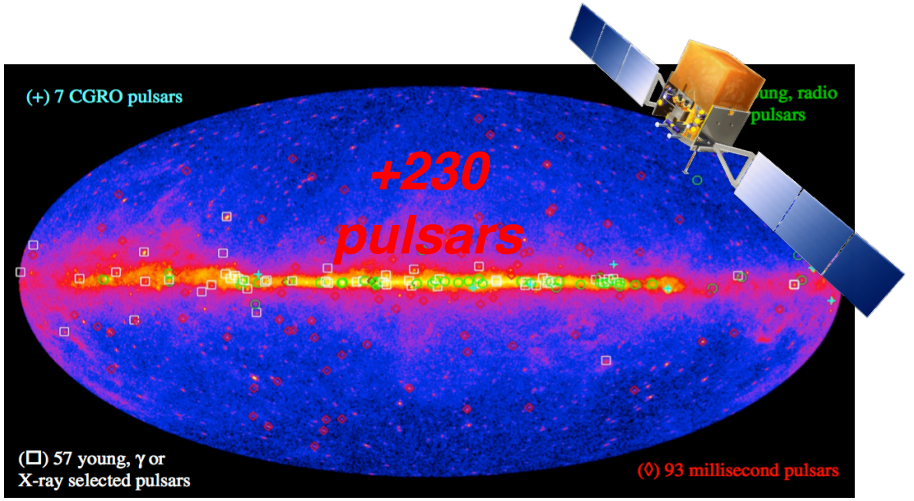
Pulsars from radio to γ-rays

Radio

- First discovered in radio in 1967
- **+2600** radio pulsars known today



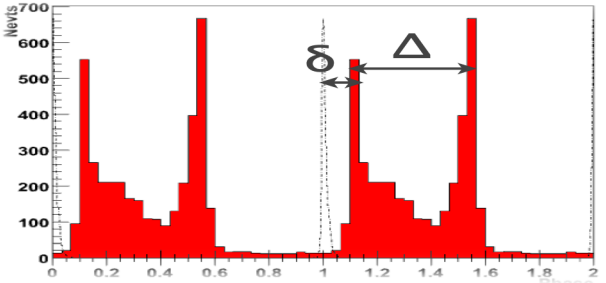
γ-Rays

- Only **7** seen by EGRET in the 90's
- **+230** detected by Fermi-LAT

What we learn from Fermi

Light curves

- Typically 2 peaks

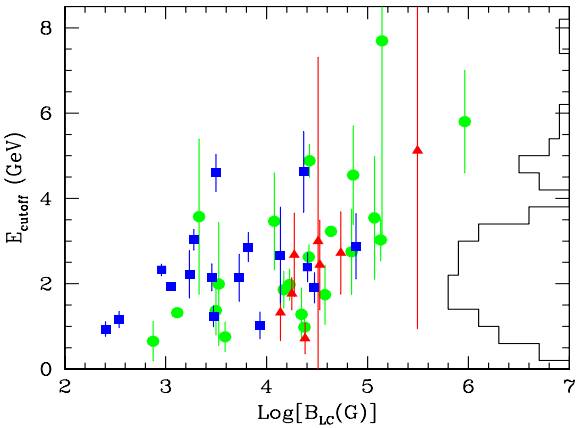


Spectra

- PL + sub-exp. cutoff with Ec < 10 GeV

$$\frac{dN}{dE} = N_0 \cdot E^{-\Gamma} \cdot \exp\left(\frac{E}{E_c}\right)^{-b}$$

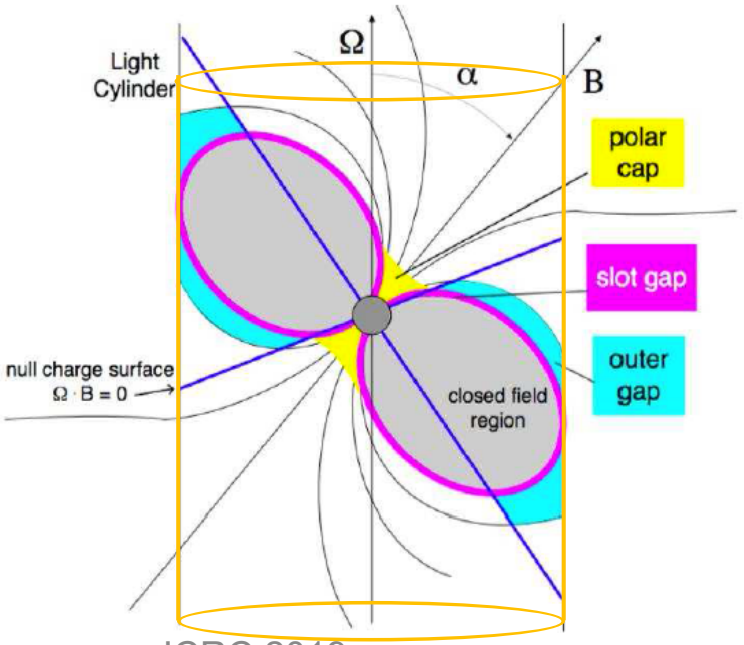
b=1: exp.
b<1: sub-exp.
b>1: super-exp.



Pulsars at VHE?

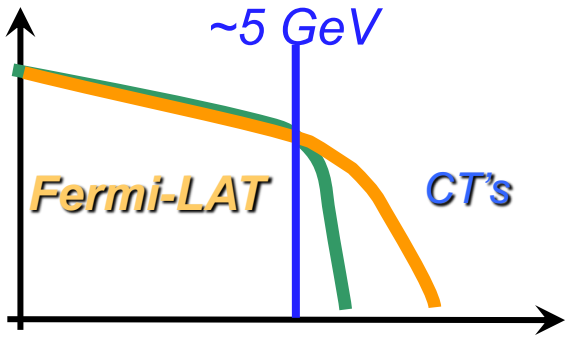
Seemed unlike until recently

- Accelerated particles in gaps (close to the NS or to the Light cylinder) emit gammas via synchro-curvature radiation
- Expected sharp cut-offs @ few GeV, as seen by Fermi-LAT



But Crab & Vela detected

- **2008:** Crab above 25 GeV by MAGIC
  ➔ Rule out low altitude models
- **2011:** Crab up to 400 GeV by MAGIC & VERITAS
  Follow power-law ➔ No cutoff seen
- **2016**: Crab pulsation @ TeV
  ➔ Curvature Radiation questioned
- **2017:** Vela detected below 100 GeV and @ TeV by H.E.S.S.



What about Geminga?

Geminga

One of the 3 strongest GeV pulsars, along with Crab and Vela

Pulsar

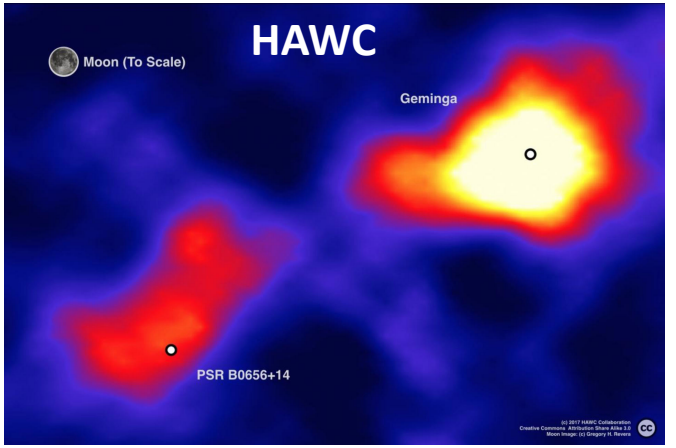
- Prototype of radio-quiet pulsar
- Period: 237 ms
- Very different from Crab:

	Geminga	Crab
Radio	Quiet	Loud
Age (kyr)	340	1
Distance (pc)	150	2000
Edot (erg/s)	$3 \cdot 10^{34}$	$5 \cdot 10^{38}$

Different emission properties @ VHE?

Nebula

- Extended emission detected by MILAGRO (~2.6º) and HAWC Unfeasible for current CTs
- May account for up to 20% of e^+ excess

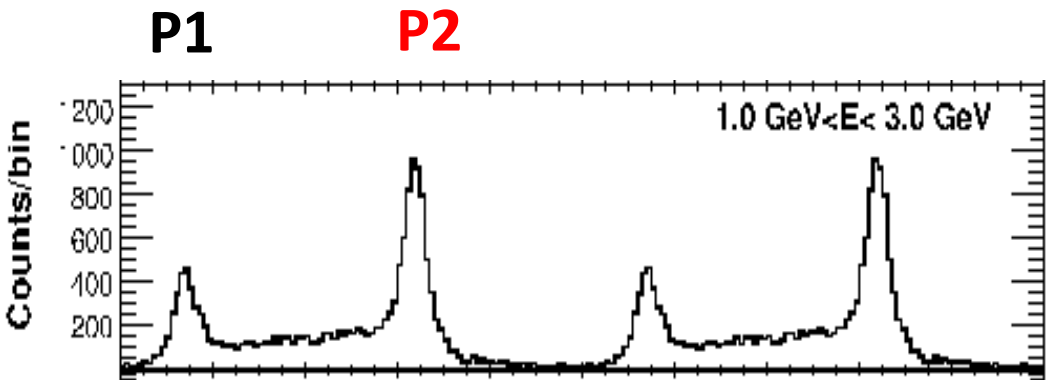


Science 6365 (2017)

Geminga by Fermi-LAT

Light curve

- 2 narrow peaks per rotation
- P2 dominant at GeVs

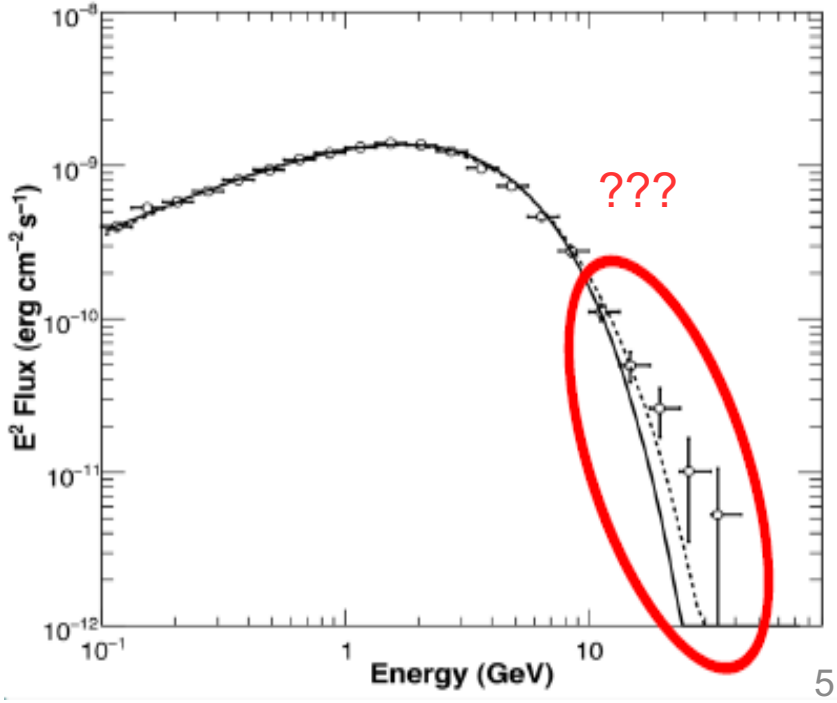


Abdo et al., ApJ 720, 2010

Spectrum

- Pulsation seen above 10 GeV
- Spectrum deviates from Exp. cutoff

→ Motivated VHE observations

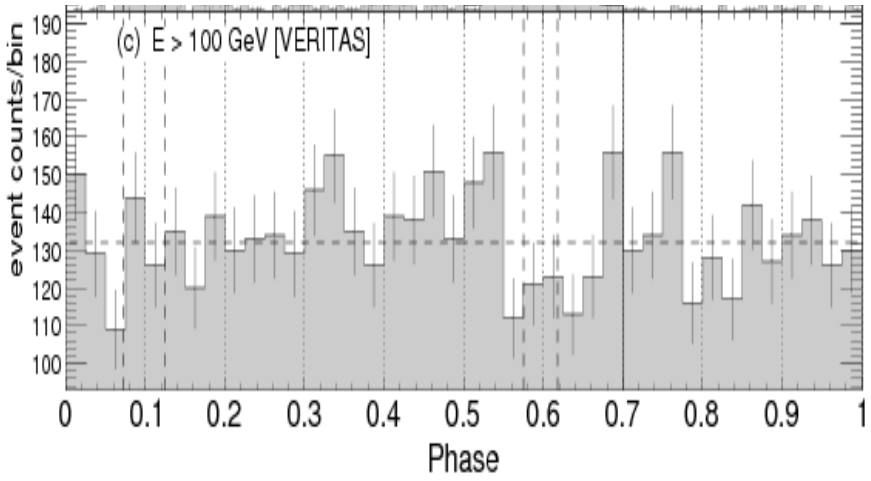


Previous Geminga observations by CT's

VERITAS (2007-2013)

- **72 h** between 2007 and 2013
- Search above **100 GeV**
- No detection

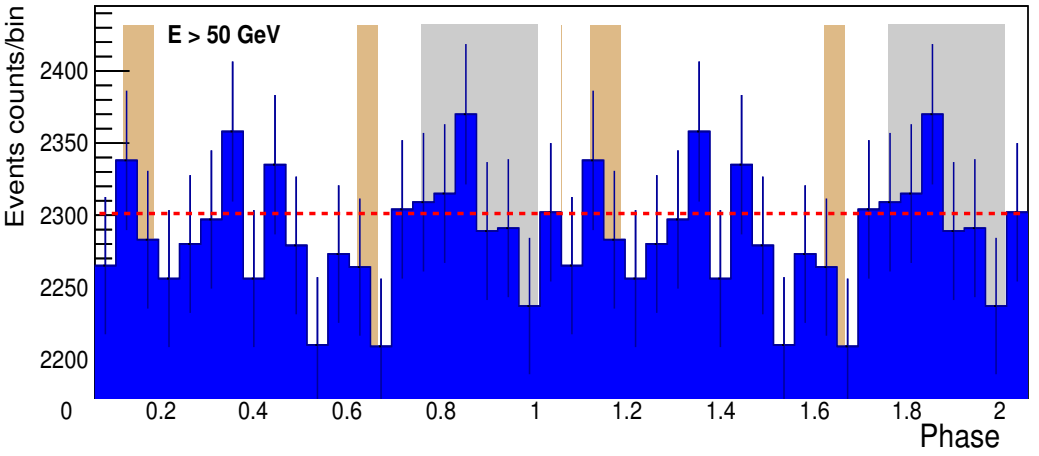
E. Aliu et al., ApJ 800:61, 2015



MAGIC Std.Trigger (2012/13)

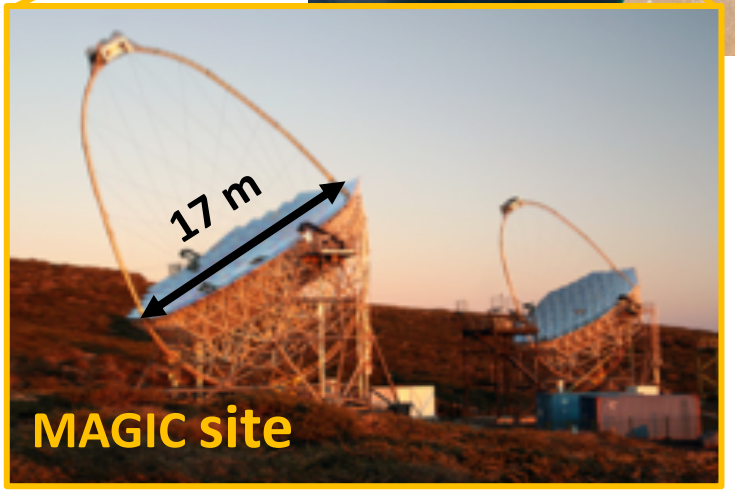
- **63 h** in winter 2012/13 with Std. trigger
- Search above **50 GeV**
- No detection

Ahnen et al., A&A 591 A138 (2016)



Need for a lower threshold → MAGIC SumTrigger-II

The MAGIC telescopes



Characteristics

- 2 Imaging Atmospheric Cherenkov Telescopes
- 17 m diameter with active mirror control

Performance with std. trigger

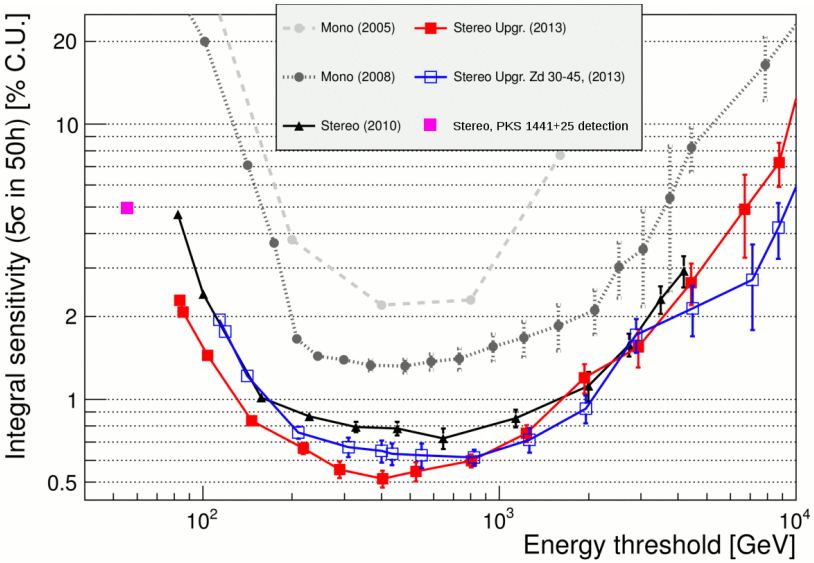
- Energy range: 50 GeV to 50 TeV
- Sensitivity: 10% Crab in 1 h above 100 GeV
- Angular resolution: ~0.1º

MAGIC continuous improvement

- 4x improvement sensitivity over last decade
- 10x at the lowest energies !

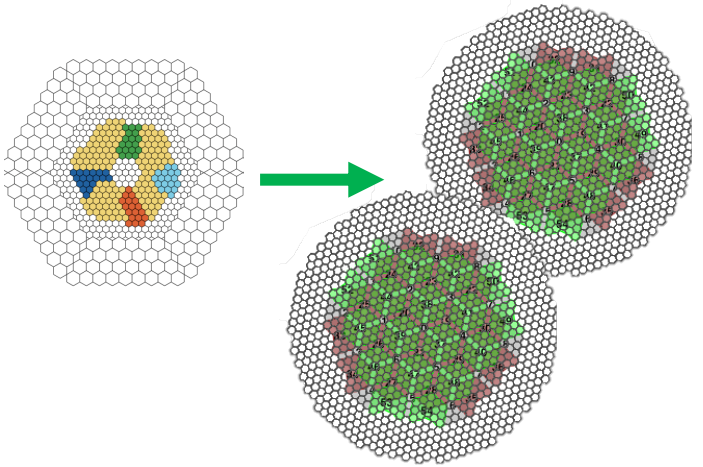
Dedicated hardware for pulsars

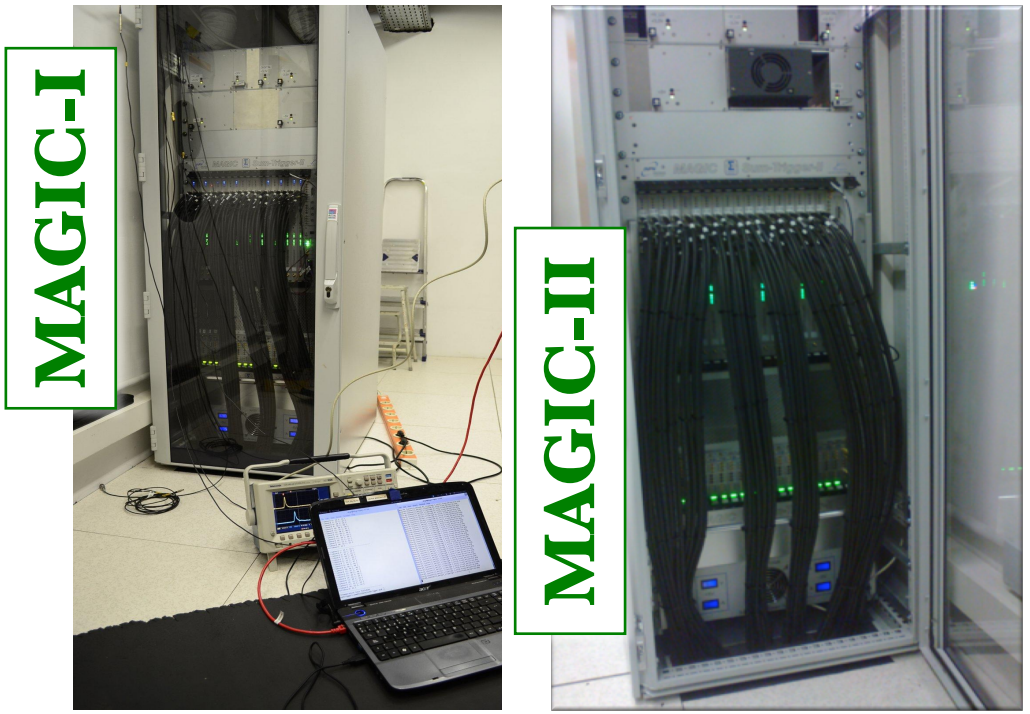
- Central pixel for optical observations
- Analogue SumTrigger system



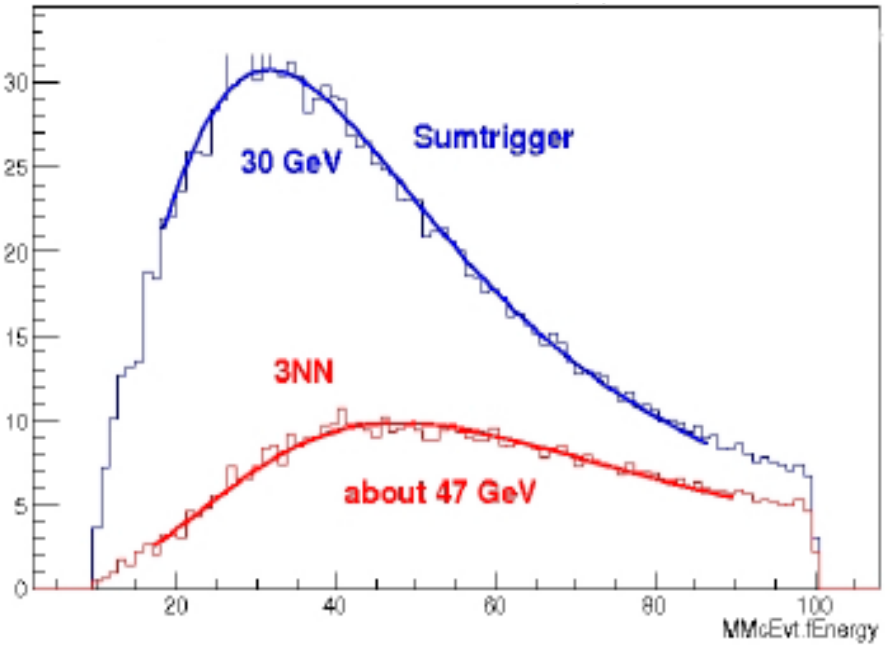
MAGIC stereo SumTrigger-II

- Old SumTrigger which led to Crab detection not suitable for Stereo observations
- Improved design:
  - Covers whole trigger area (and not only a ring)
  - Semi-automatic calibration.
  - Higher reliability
- Installed in 2014





SumTrigger-II Eth for Crab-like spectrum



See D. Strom's poster PS3-81 @ ICRC2019

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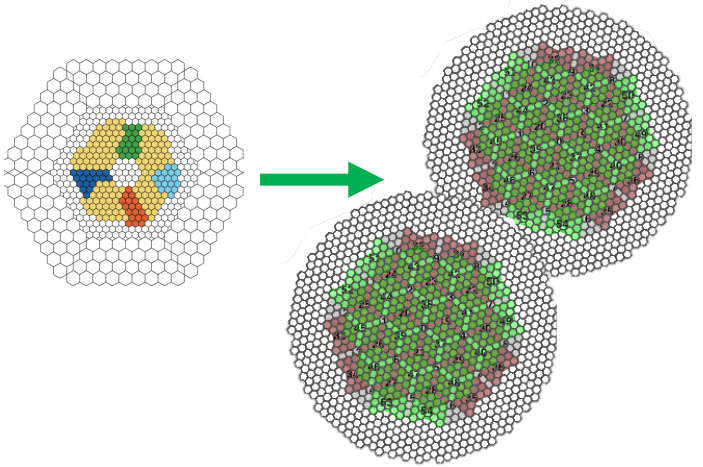
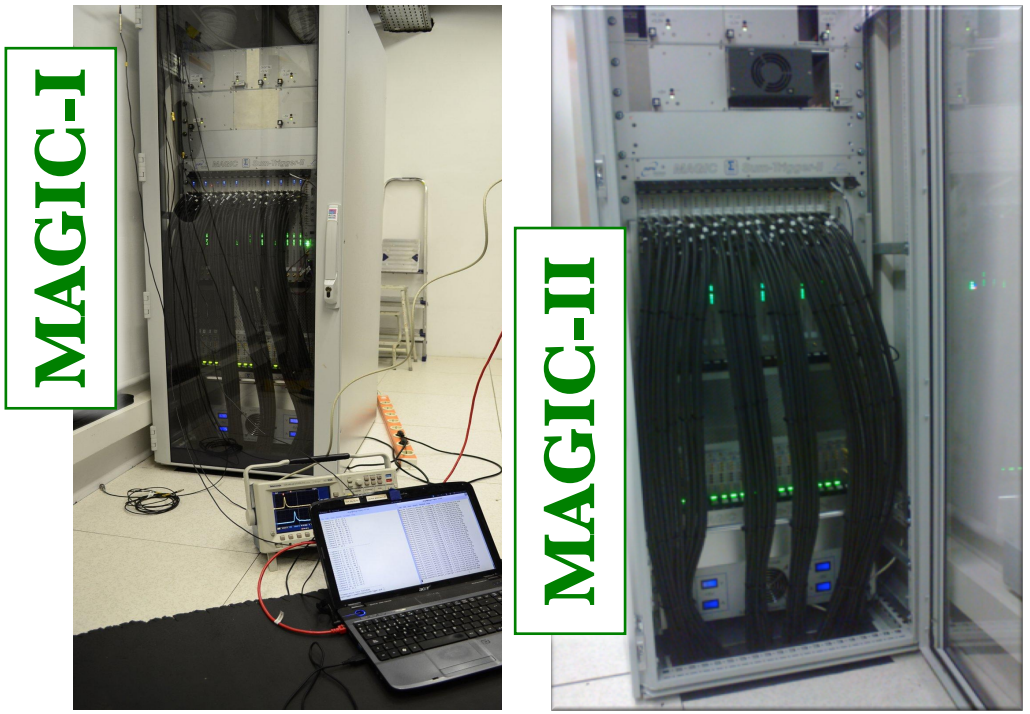




Tested with Crab pulsar

- Improved performance for pulsars:
  - Crab pulsar with Std. Trigger:

    $1.4\,\sigma\sqrt{t[hour]}$ *(A&A 565 2014 L12)*
  - Crab pulsar with SumTrigger-II:

    $2.0\sigma\sqrt{t[hour]}$

See G. Ceribella's talk, Tuesday 30 @ ICRC 2019

MAGIC Geminga observations

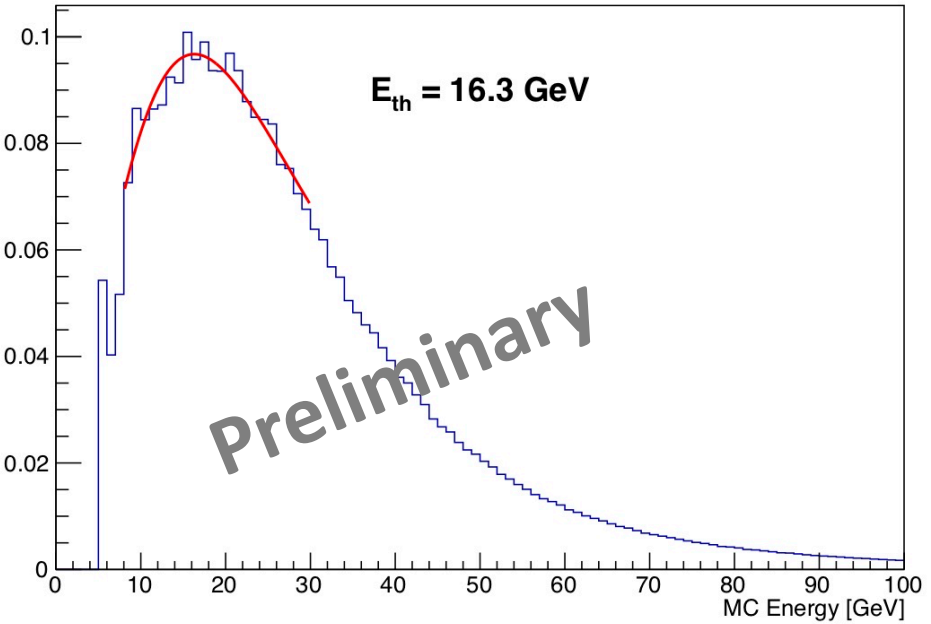
Data set

- ~80 h before cuts taken from 2017 to 2019 with MAGIC SumTrigger-II
- Low zenith observations to assure the lowest Eth

Events Reconstruction

- Dedicated calibration and image cleaning exploiting the low Eth
- MCs following the path of the source on the sky to account for Geomagnetic Field
- Expected Eth ~16 GeV for a source with spectral index of -5

SumTrigger-II Eth for Geminga-like spectrum



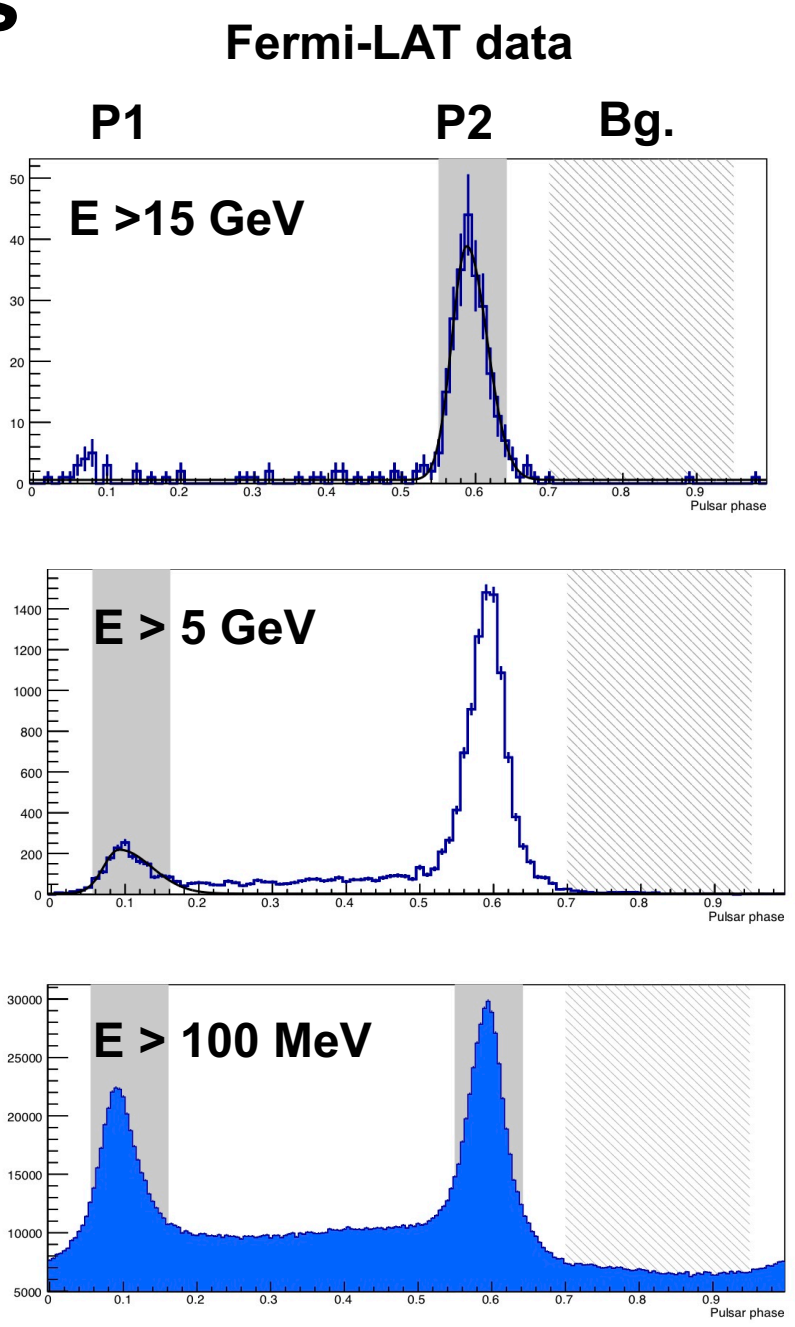
Analysis

Timing Analysis

- Ephemeris extracted by Matthew Kerr from Fermi-LAT data
- Arrival times epoch folded with tempo2
- Phase signal region from analysis of 10 years of Fermi-LAT data

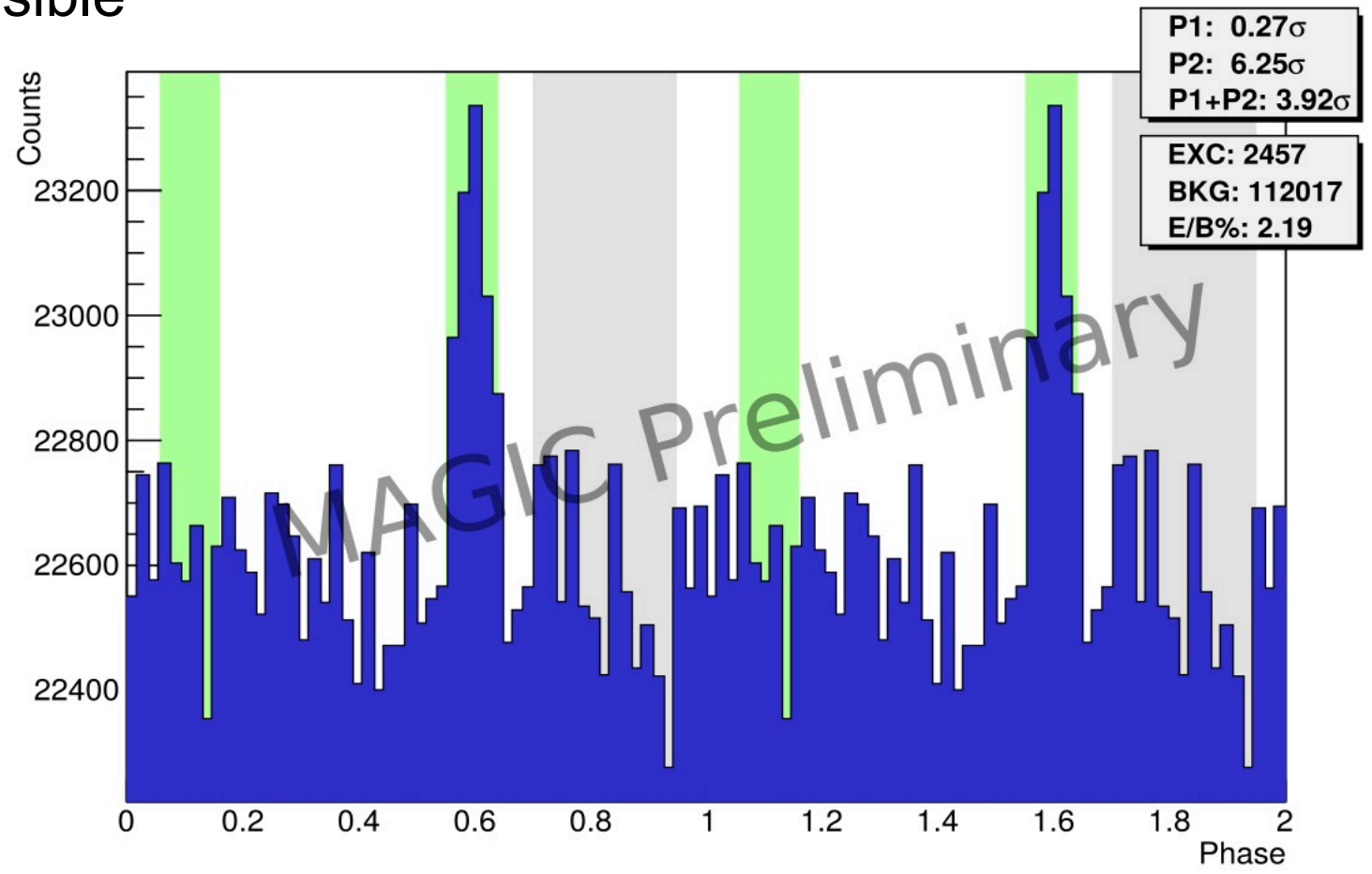
Fermi-LAT dedicated analysis

- Light curves fitted at the highest possible energies to get expected peak position and widths for MAGIC analysis
  - P1 > 5 GeV
  - P2 > 15 GeV
- SED computed using the previously defined phase regions (same for MAGIC)



MAGIC Geminga Light curve

- P2 detected at **6σ** level
  - E range: 20 – 80 GeV
  - Pulse width similar to the one seen by Fermi-LAT
- P1 not visible



Summary

- Detecting pulsars with CT's seemed unlikely, until recently:
  - **Crab** and **Vela** pulsars detected from GeV to TeV energies.
  - Now, also **Geminga** detected by MAGIC *(& PSR B1706 by HESS-II)*
- Detection possible thanks to the development of the MAGIC SumTrigger-II system.
- Geminga results:
  - P2 detected from 20 GeV. Pulse morphology similar to the one seen by Fermi-LAT.
  - Spectrum extends up to 80 GeV, compatible with a power law.
  - Sharp exponential cutoff ruled out.