



PULSARS AT THE VERY HIGH ENERGIES: AN UPDATE FROM MAGIC

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for the **MAGIC** Collaboration

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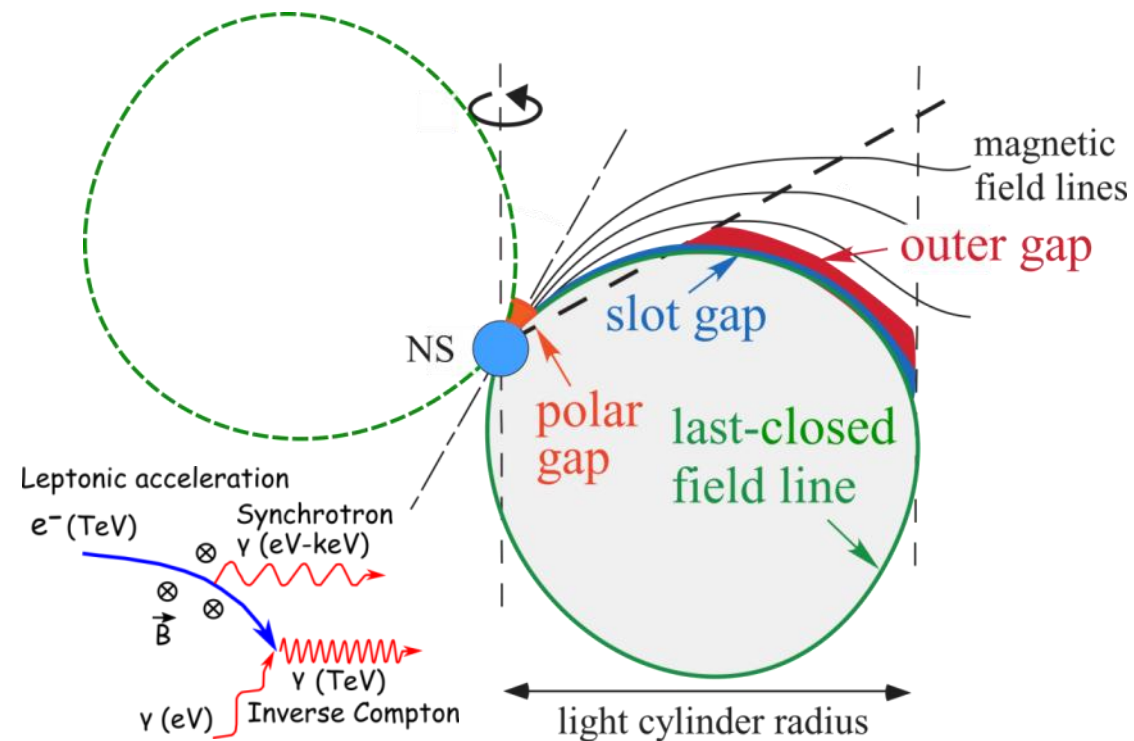
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PULSARS AT THE VHE



- ❖ Among the most **compact γ -ray sources** in the universe
- ❖ Many **open questions**:
 - **Where** does the emission come from?
 - **Up to which energy** do they radiate?
 - How do they **evolve**?
 - How do they interact with Pulsar Wind **Nebulae**?
 - ...

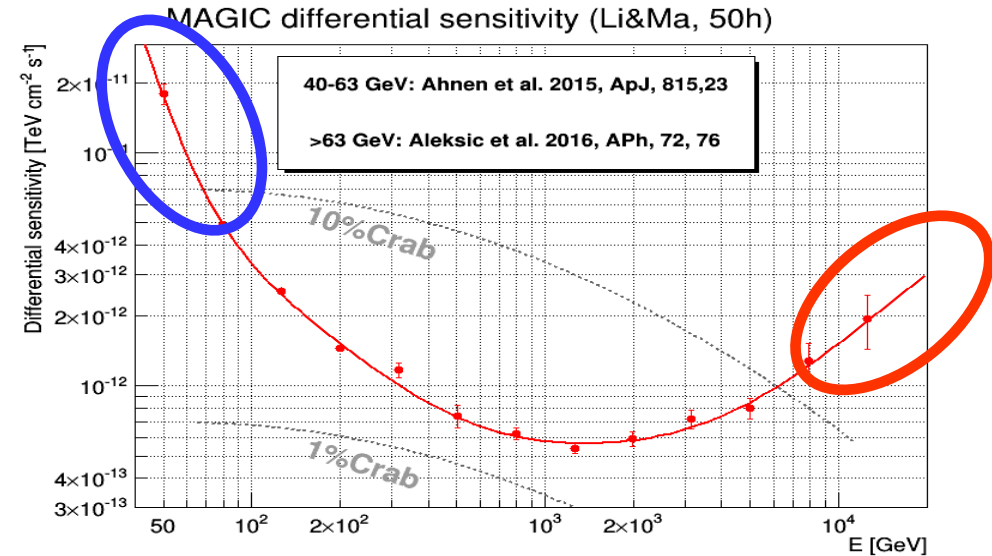


Adapted from *Hirovani, 2001*

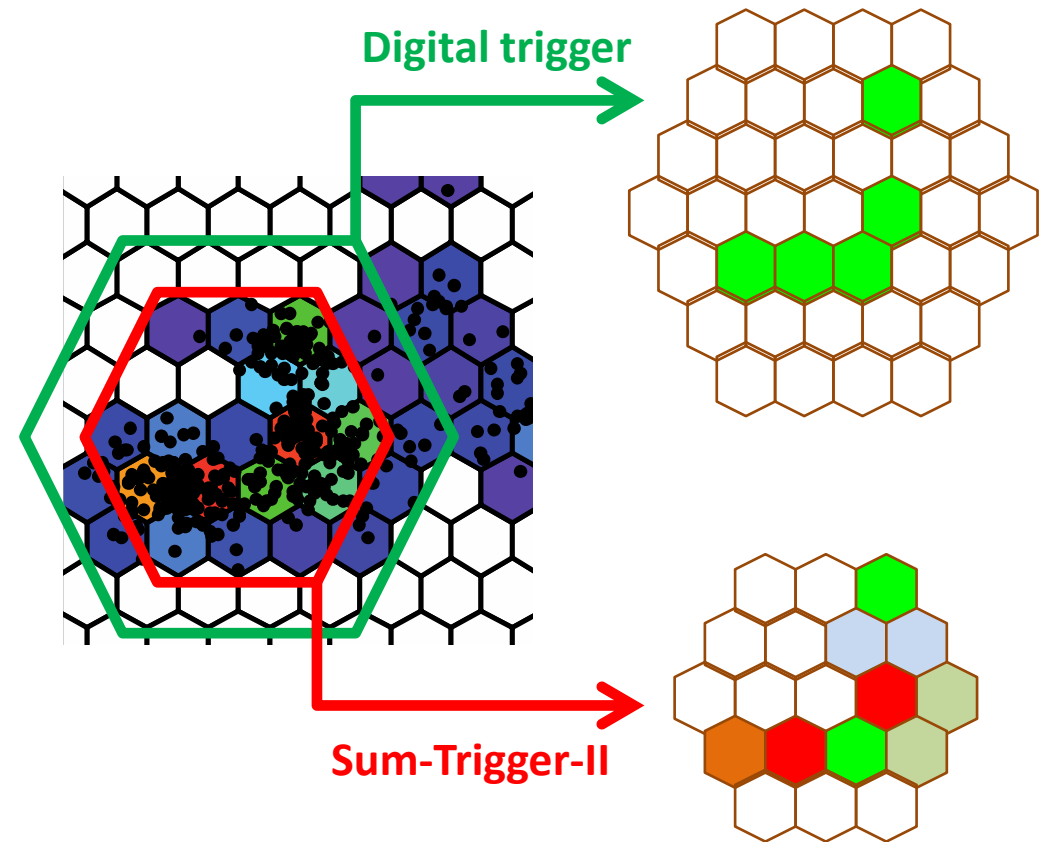
MAGIC TELESCOPES



- ❖ **Stereoscopic system of two IACTs** on the Canary island of La Palma (Spain)
- ❖ Camera of 1039 PMTs
 - Field of view: 3.5 degrees
- ❖ Energy range: **tens of GeV** to several **tens of TeV**
- ❖ Recent improvements at the **lowest** (Sum-Trigger-II) and **highest** (Very High Zenith-angle observations) energies.



- ❖ Stereo analog trigger for dimmer air showers
- ❖ **Stacking PMT signals** and applying a higher threshold:
 - Signal clipping to cope with afterpulse
 - Software controlled delay/attenuation
- ❖ Huge development in the past years (hardware, software)
- ❖ Improved **energy threshold at lower energy: 30 GeV**



Scheme of the MAGIC Sum-Trigger-II principle.
Adapted from *F. Dazzi, 2012.*

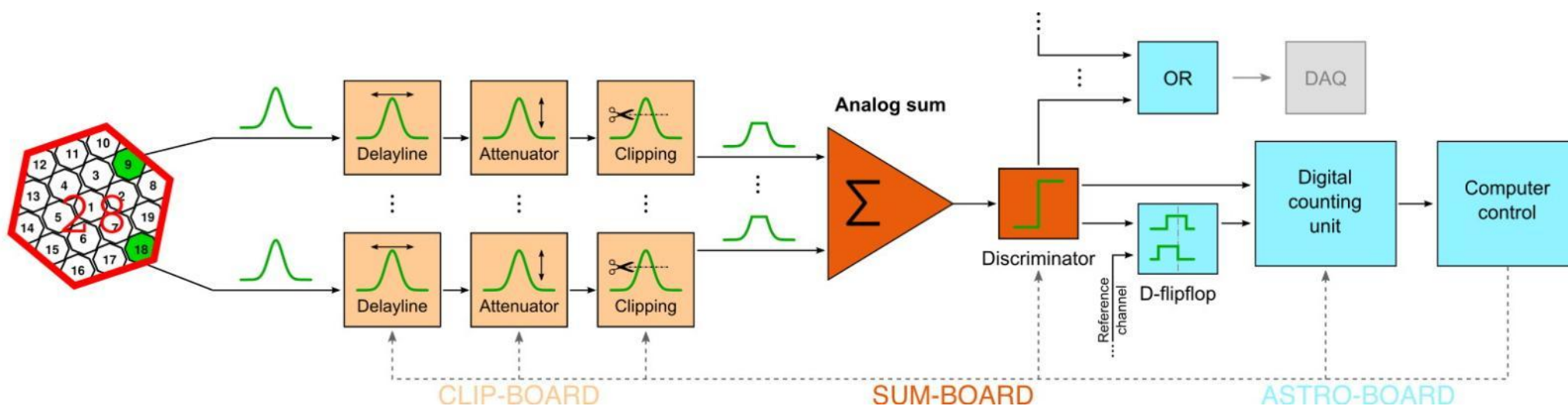
SUM-TRIGGER-II: HOW DOES IT WORK?



Timing adjustment and flat-fielding

Coping with afterpulsing

Signals sum and trigger formation



Workflow of the Sum-Trigger-II. Adapted from *F. Dazzi, 2012*.

Threshold and timing controller

MAGIC PULSAR RESULTS



2008 Discovery of pulsed VHE emission of the **Crab** ($>25\text{GeV}$) [2]

➤ Excludes polar-cap model

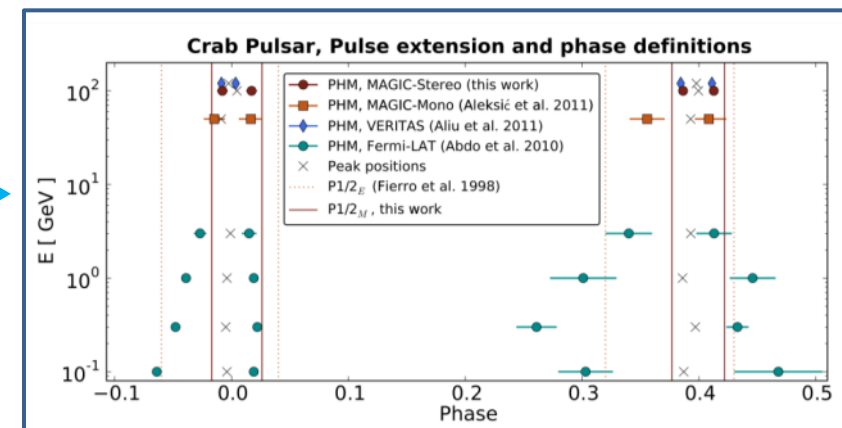
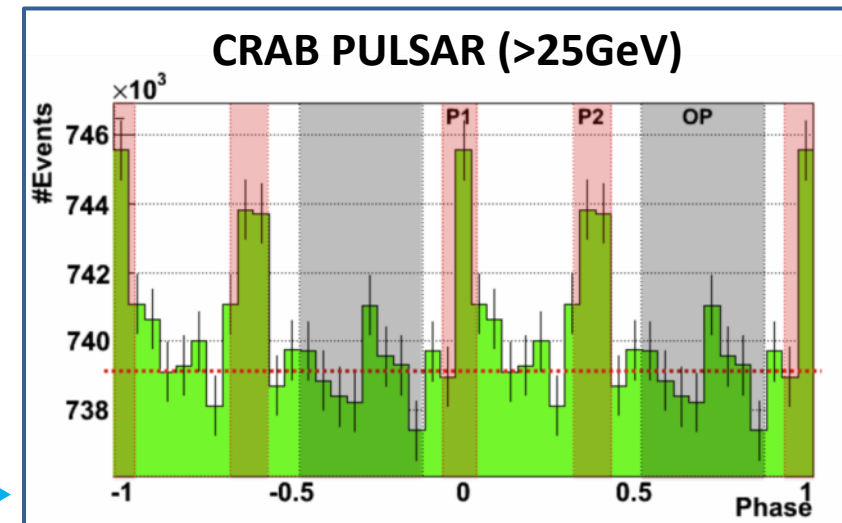
2011 VERITAS: Crab pulsar above 100 GeV

2011 Pulsed emission detected up to **100GeV** [3]

➤ Consistent with a power-law!

2012 Phase-resolved spectrum up to **400GeV** [4]

➤ Peak width decreases with energy



MAGIC PULSAR RESULTS



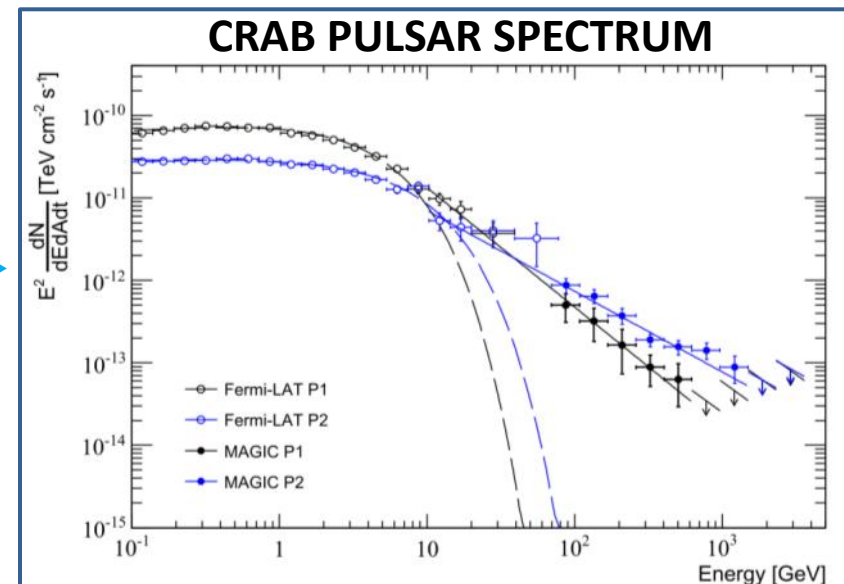
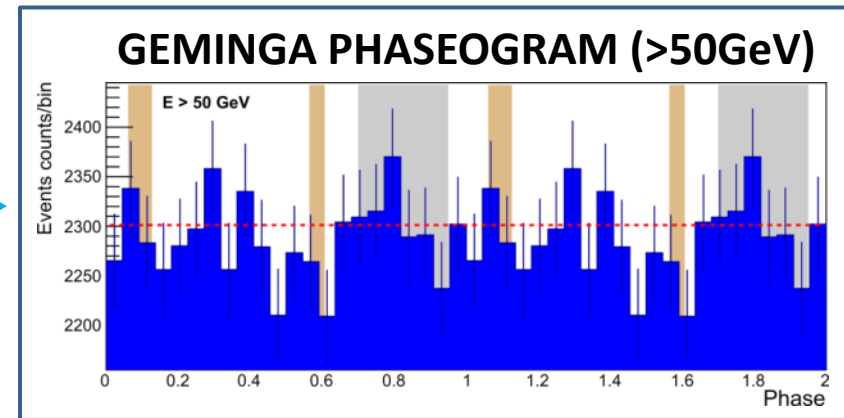
2014 **Crab Bridge** emission above **50GeV** [5]

2016 **Geminga** searches with standard trigger above 50GeV [8]

2016 **TeV** pulsed emission from the **Crab!** [6]

➤ **Inverse Compton** component

2017 **Lorentz Invariance Violation** studies with the **Crab pulsar** [7]

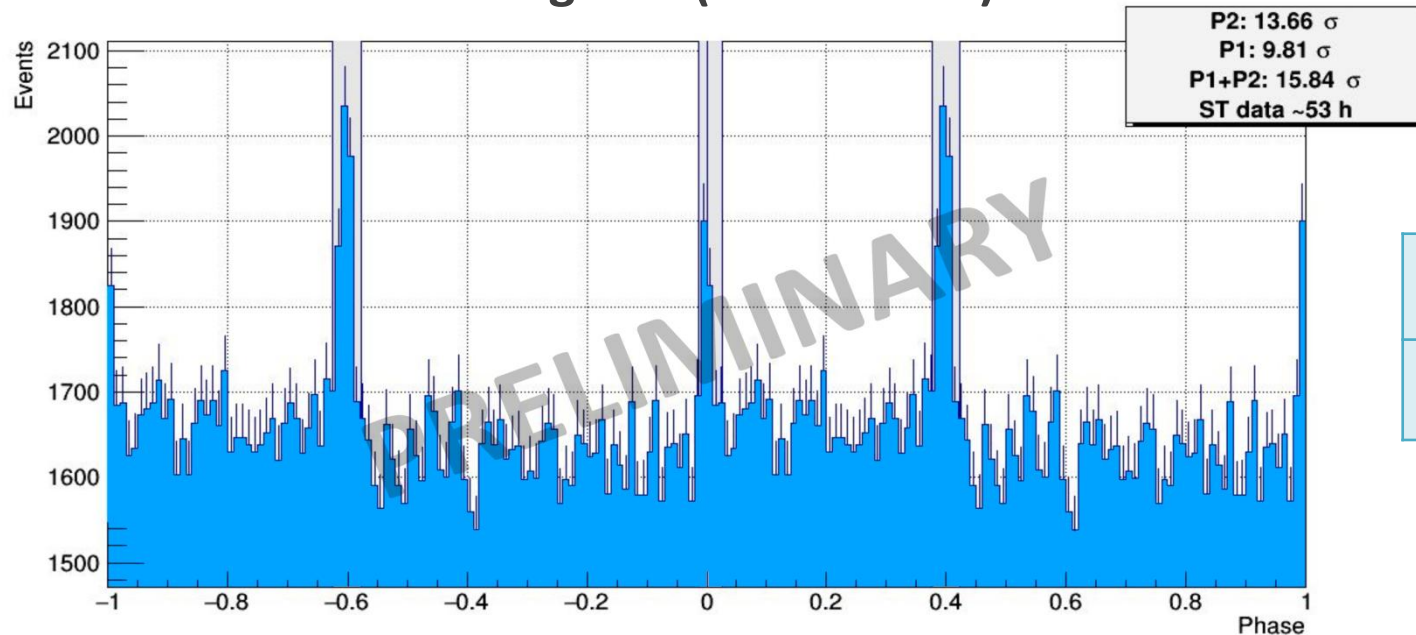


SUM-TRIGGER-II RESULTS



- ❖ Higher sensitivity for pulsars (on the Crab: **5 hours** → **5 sigma**)
- ❖ Enhanced collection area and better background rejection:
 - Precise light-curves and spectra in the tens of GeV range
 - Short-time monitoring of the pulsed emission

Crab Pulsar Phaseogram (30-200 GeV)



Standard trigger	1.4 σ/v_h
Sum-trigger-II	2.3 σ/v_h

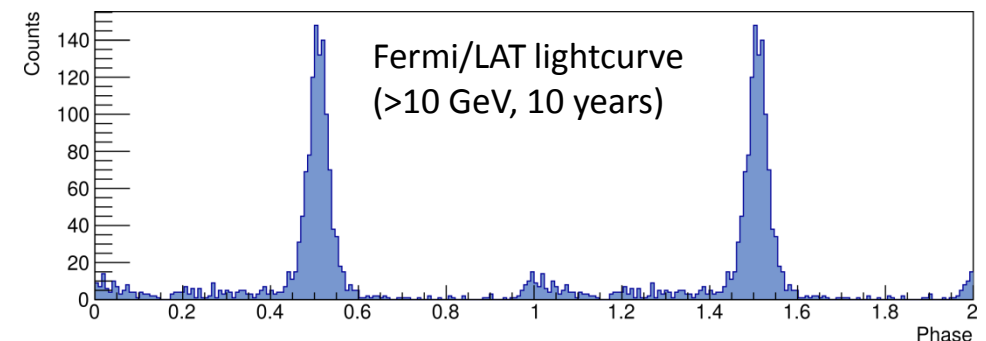
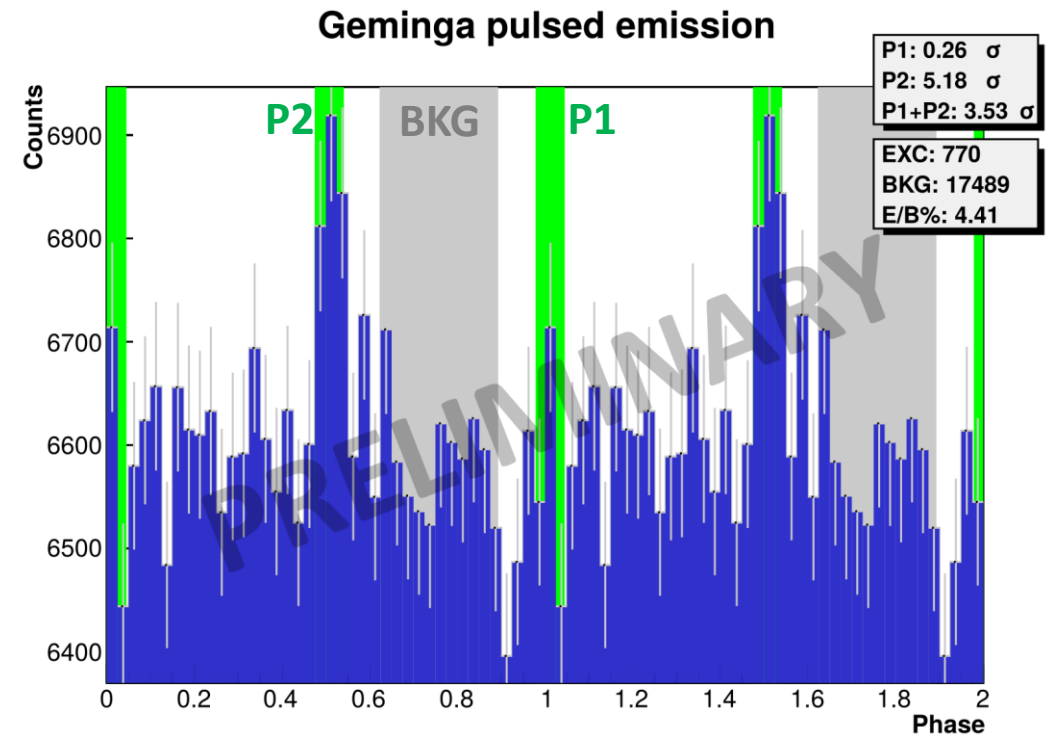
Adapted from *J. R. García, 2017*

SUM-TRIGGER-II RESULTS



❖ Detection of Geminga pulsar at VHE!

- Third known VHE pulsar
- ❖ ~30 h of Sum-Trigger-II observations, winter 2017
- ❖ Rotational parameters derived from 10 years of Fermi/LAT data
- ❖ Clear detection of P2 (5.2σ)
- ❖ No detection of P1
 - Expected from Fermi/LAT spectra
- ❖ Work on-going, **stay tuned!**



- ❖ **MAGIC** and other **IACTs** contributed significantly to **pulsar physics at the VHE**
- ❖ Recent **hardware upgrades** enable us to improve our potential in this field
- ❖ With the discoveries of **Crab** (MAGIC), **Vela** (H.E.S.S.) and **Geminga** (MAGIC) we start to have kind of a “**population**” of **VHE pulsars**:
 - **Age dependence** of the VHE emission?
 - How do different pulsars relate to their **nebulae**?
 - Are there **other VHE pulsars** out there?
- ❖ ... next challenges for us and for future instruments.

REFERENCES: MAGIC



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- 4) The MAGIC collaboration, *Phase resolved energy spectra of the Crab pulsar in the range of 50-400 GeV measured with the MAGIC telescopes*, A&A 2012.02;
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SUM-TRIGGER-II macrocell layout

