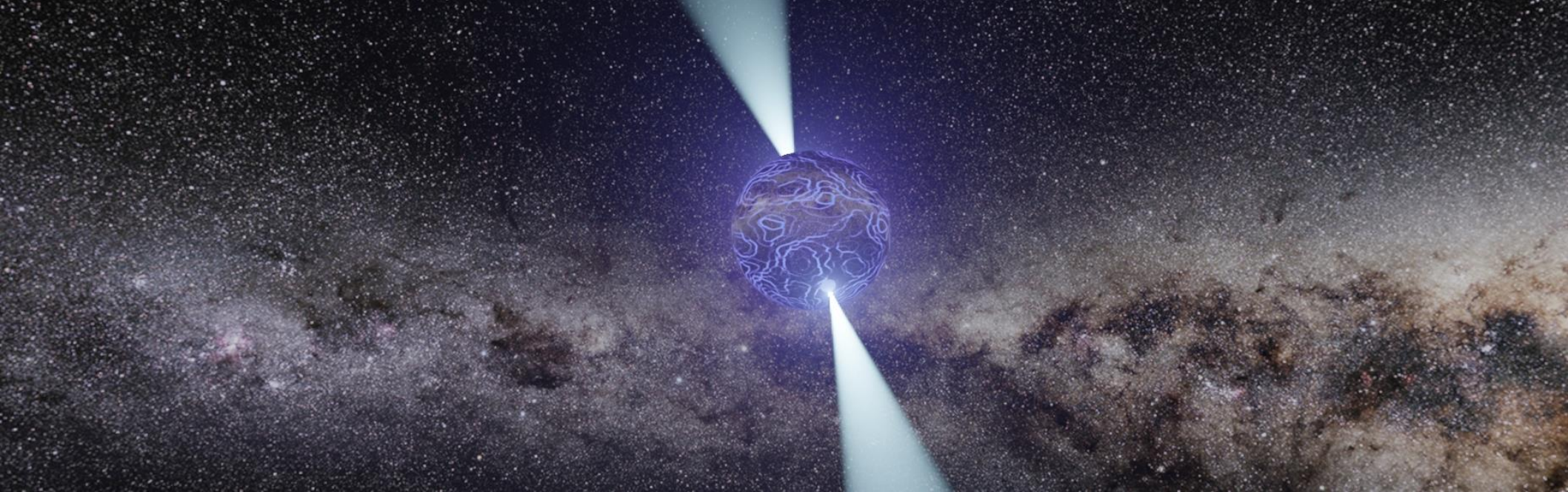




MAGIC DETECTION OF GEMINGA: AN INVERSE COMPTON TAIL?

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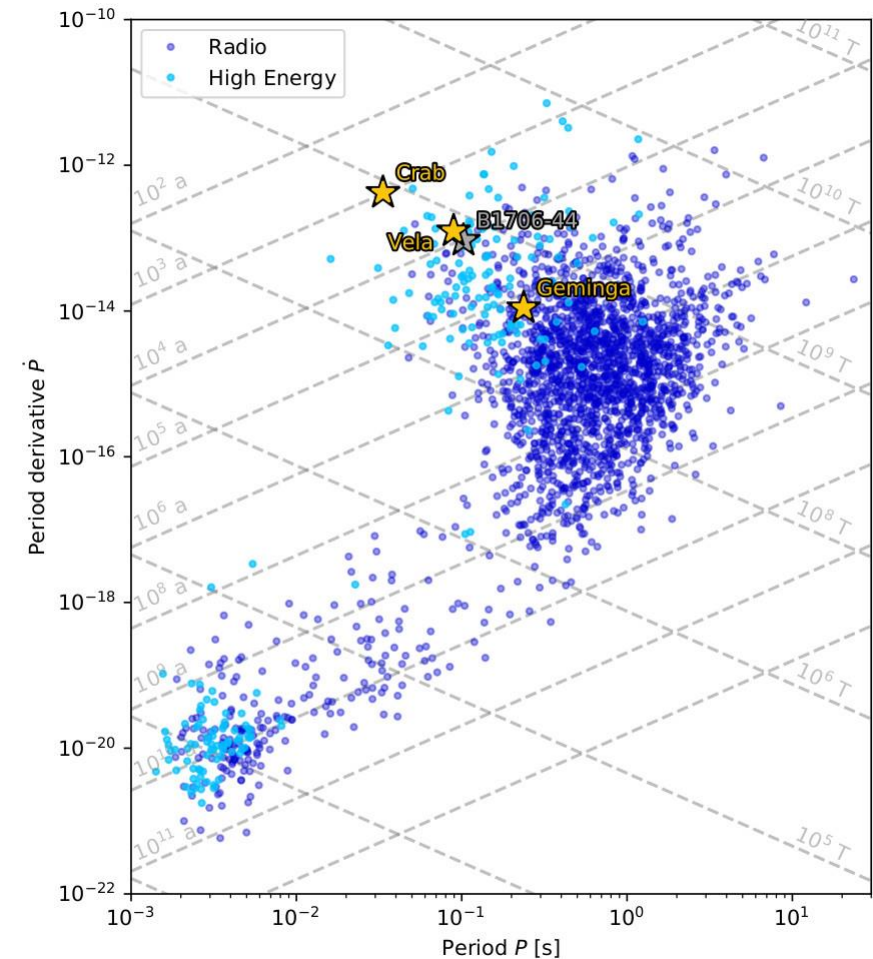
for the **MAGIC Collaboration**



VHE PULSARS



- **Few pulsars known to emit at the Very High Energies:**
 - Crab, Vela, **Geminga**, B1706-44
- **Crab (PSR J0534+2200):**
 - Radio-loud, 1 ky, d=2 kpc, $L_{\text{sp}}=10^{31}$ W
 - Bright nebula, standard candle
- **Geminga (PSR J0633+1746):**
 - Radio-quiet, 300 ky, d=250 pc, $L_{\text{sp}}=10^{27}$ W
 - Embedded in vast **TeV Halo** (HAWC, Fermi-LAT,...)

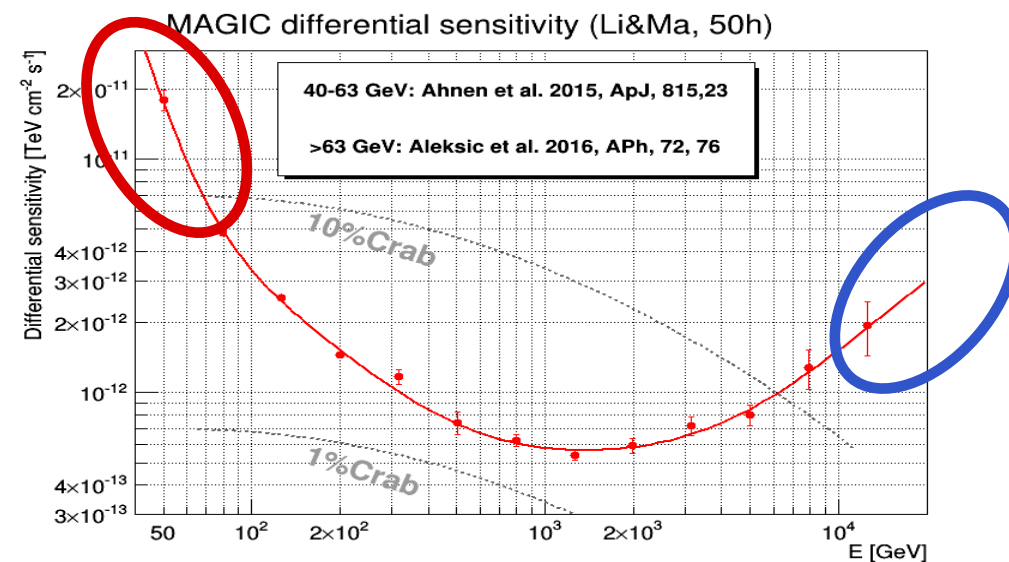


Pulsar data from: *ATNF pulsar catalog*

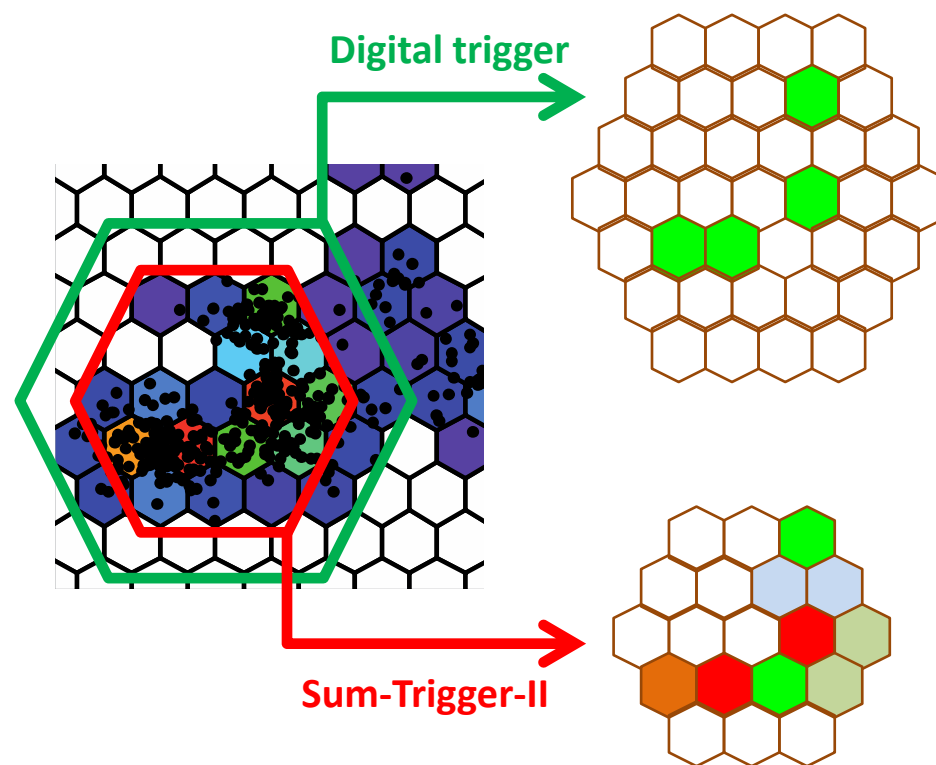
MAGIC TELESCOPES



- **Stereoscopic system of two IACTs** on the Canary island of La Palma (Spain, 2200 m a.s.l.)
- Energy range: **~30 GeV** to **~100 TeV** (source dependent)
- **Improvements at the lowest energies: Sum-Trigger-II**
 - Aiming at **pulsars** and soft sources, far **AGNs, GRBs,...**
- At the **highest** energies: **very large zenith angle observations**



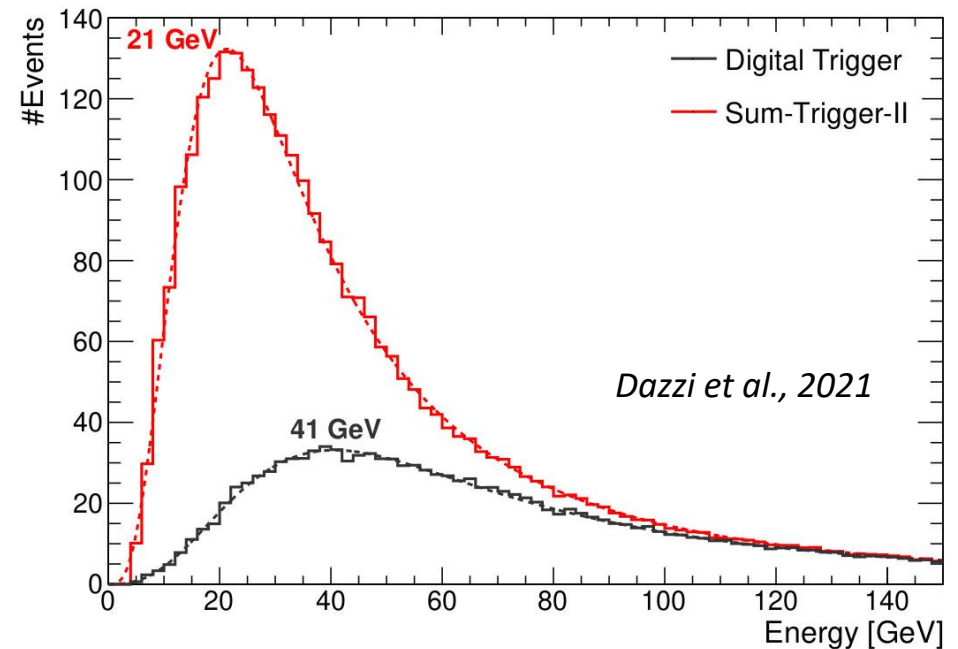
- **Stereoscopic trigger** for low-energy events
- **Stacking analogue signals** of neighboring pixels
- **55 hexagonal patches** (19 pix) matching typical **low-energy image size** (0.5 deg)
- Vastly improves the **collection efficiency** at energies below **70 GeV**



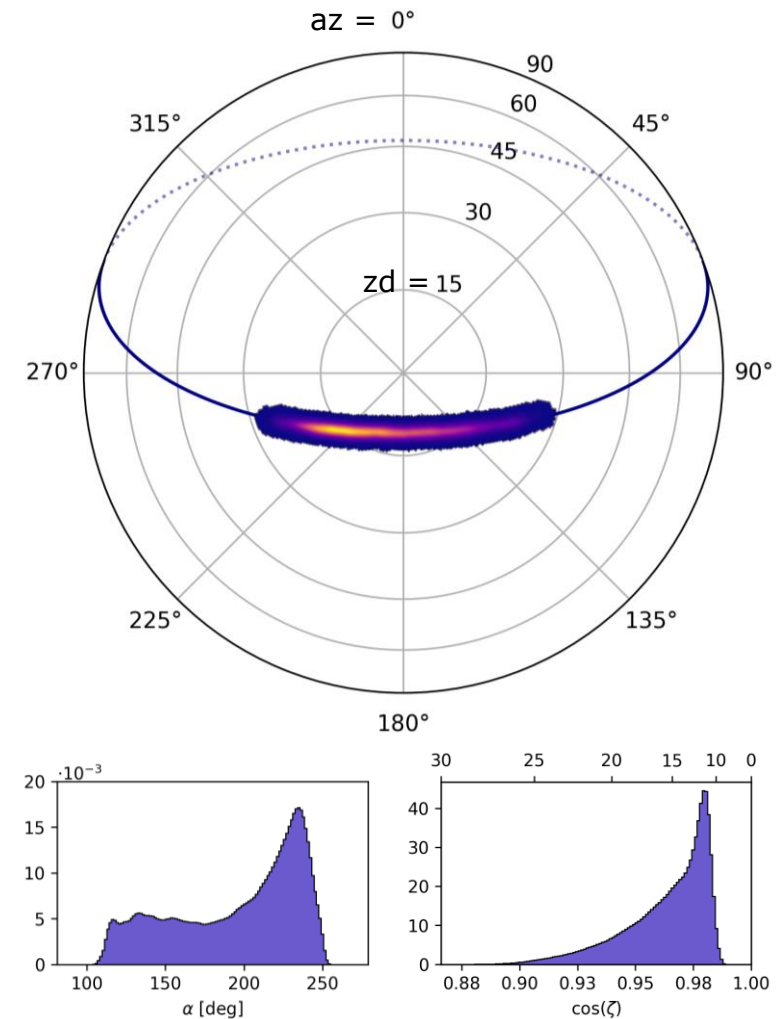
Scheme of the MAGIC Sum-Trigger-II principle.
Adapted from *Dazzi et al., 2012*

- **Halved** trigger energy **threshold: 20 GeV** (Crab-nebula like)
- **Four-fold** increase of the **collection area** at 20 GeV
- Confirmed with direct **Crab pulsar and nebula** observations
- **Sum-Trigger-II** reference publication:

F. Dazzi et al., *The Stereoscopic Analog Trigger of the MAGIC Telescopes* (2021)
DOI: [10.1109/TNS.2021.3079262](https://doi.org/10.1109/TNS.2021.3079262)



- Observation time: **80h** (2017 – 2019)
- Stringent **quality cuts**
 - Zenith distance < 25 deg
- Contemporary **Crab pulsar** and **nebula** observations
- Pulsar **ephemeris** from *Fermi*-LAT data (11y)
- **Signal** and **background** ROI selection in **phase space**.



GEMINGA: PHASE DIAGRAM



- **Detection of the Geminga pulsar with MAGIC!**

- Third known VHE Pulsar
- First “middle-aged” one

- **Significance: 6.25σ**

- **In phase with *Fermi*-LAT**

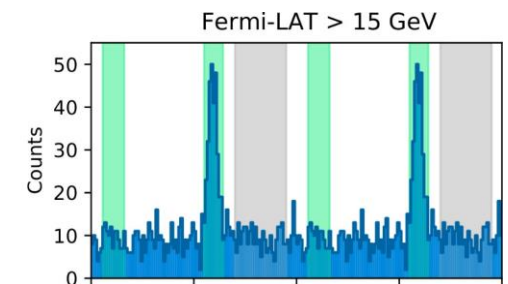
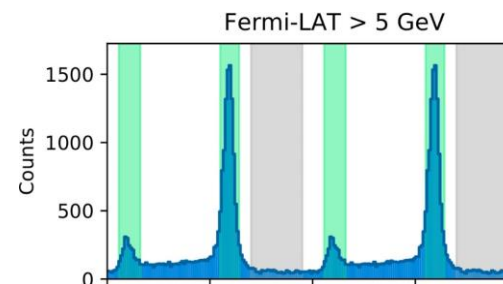
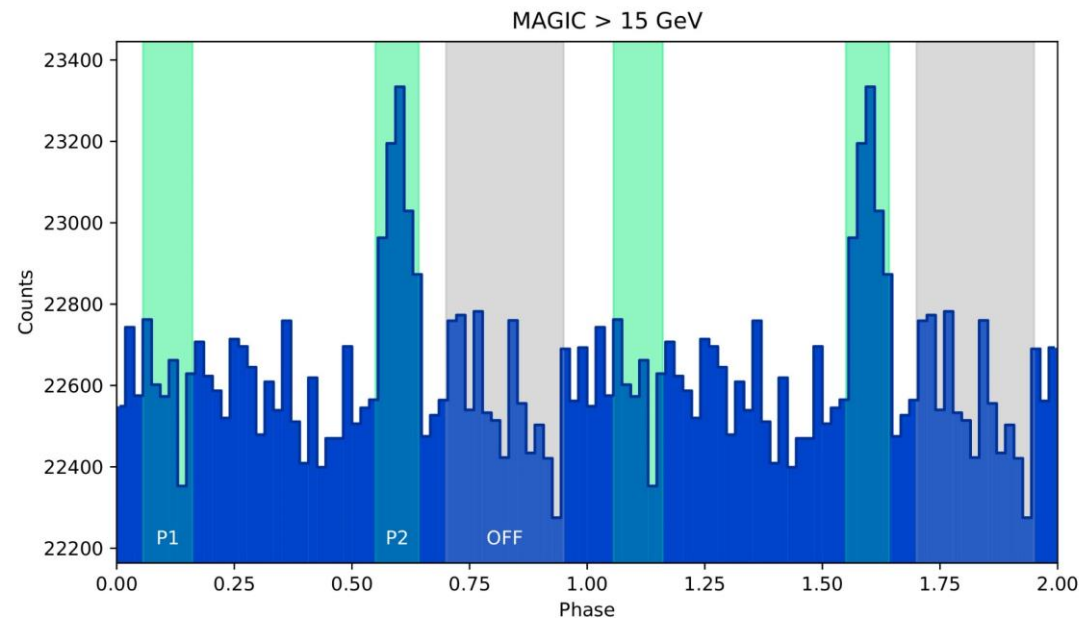
- **Energy threshold: 15 GeV**

- **Highlight letter of A&A:**

Detection of the Geminga pulsar with MAGIC hints at a power-law tail emission beyond 15 GeV (2020)

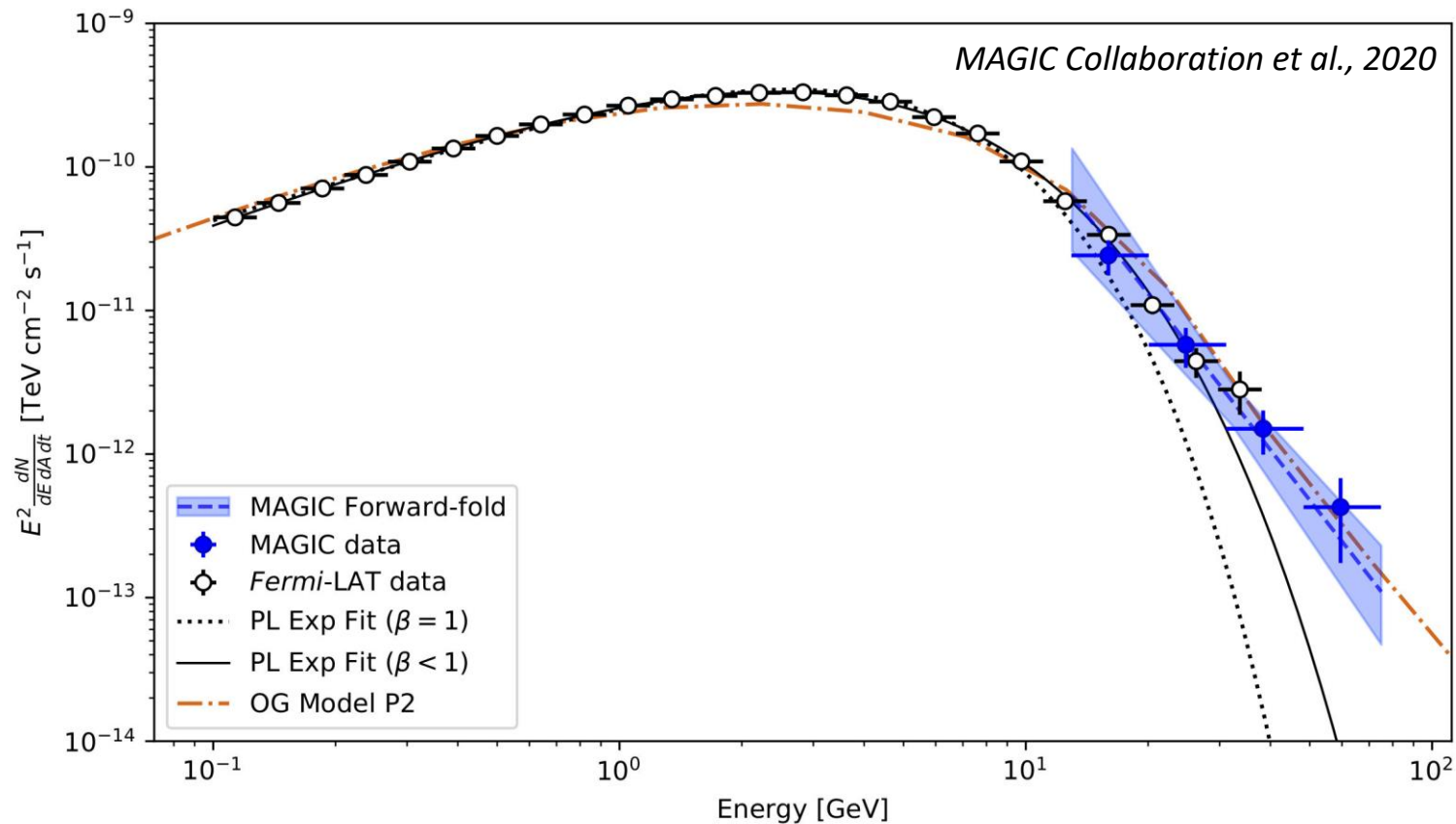
DOI: [10.1051/0004-6361/202039131](https://doi.org/10.1051/0004-6361/202039131)

ArXiv: [2011.10412](https://arxiv.org/abs/2011.10412)



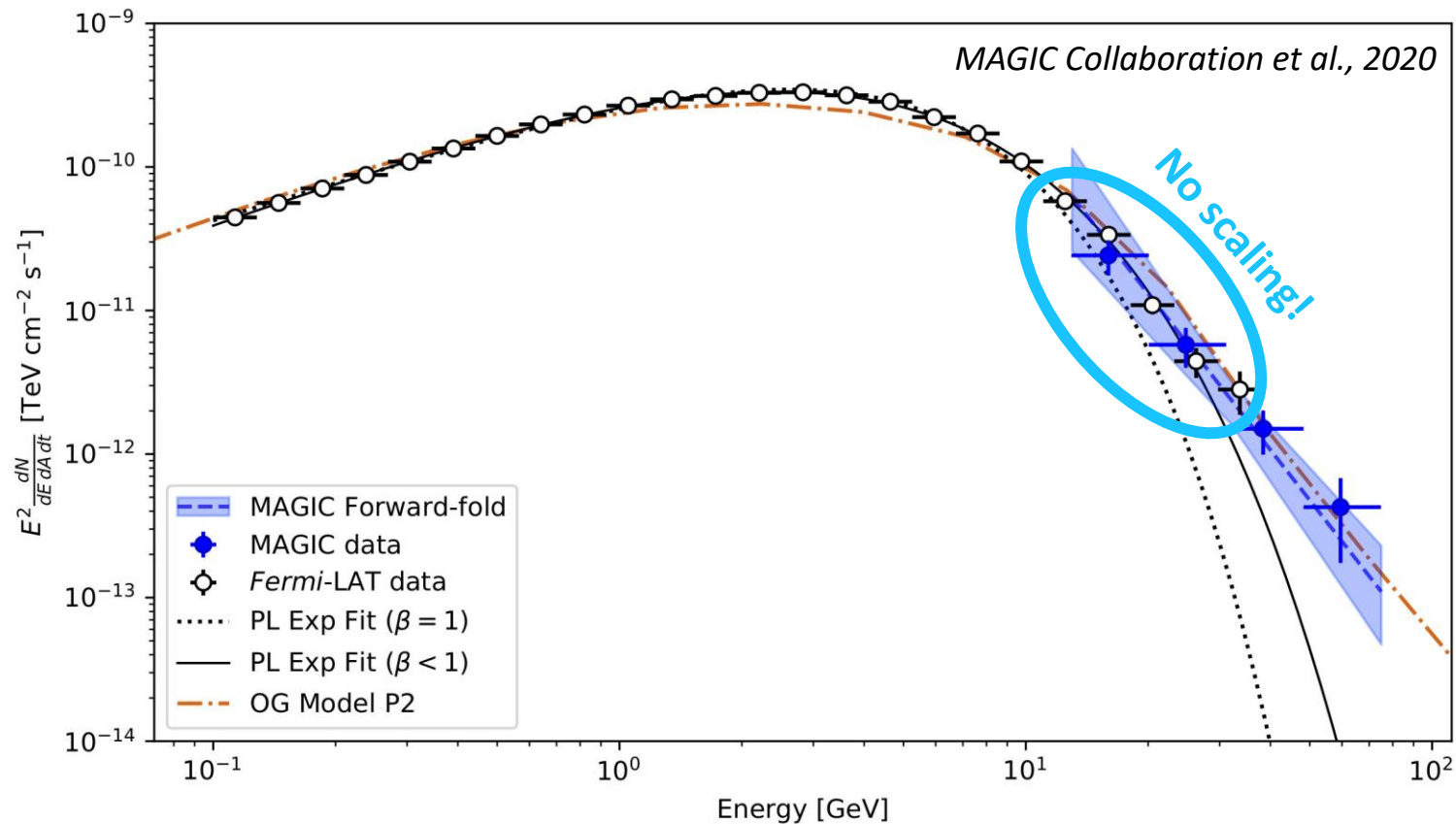
MAGIC Collaboration et al., 2020

GEMINGA: SPECTRUM



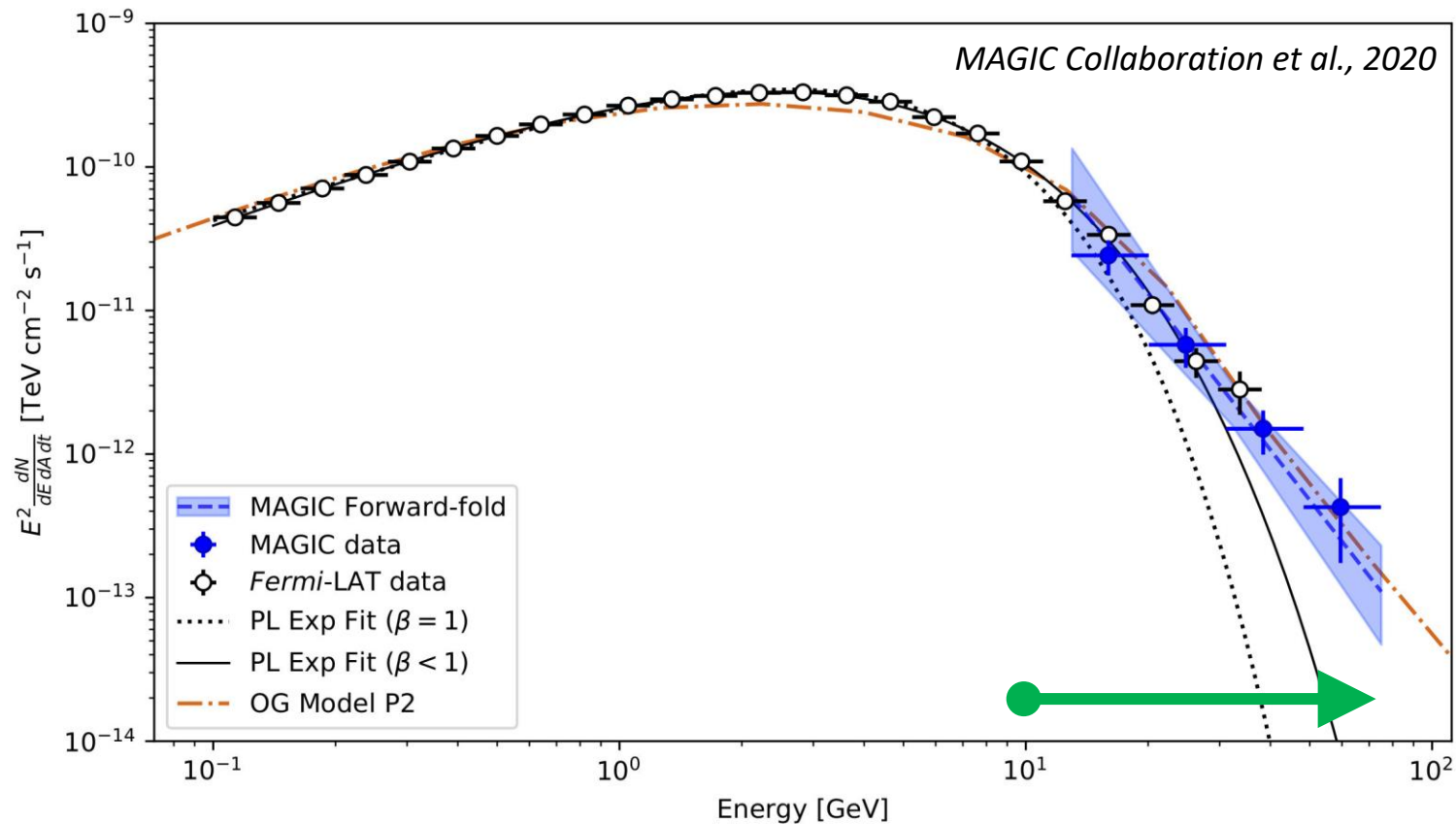
- **MAGIC measured P2 spectrum in the 15 GeV – 75 GeV range**
- **Single smooth power-law with index $\Gamma = 5.6 \pm 0.5$**

GEMINGA: SPECTRUM



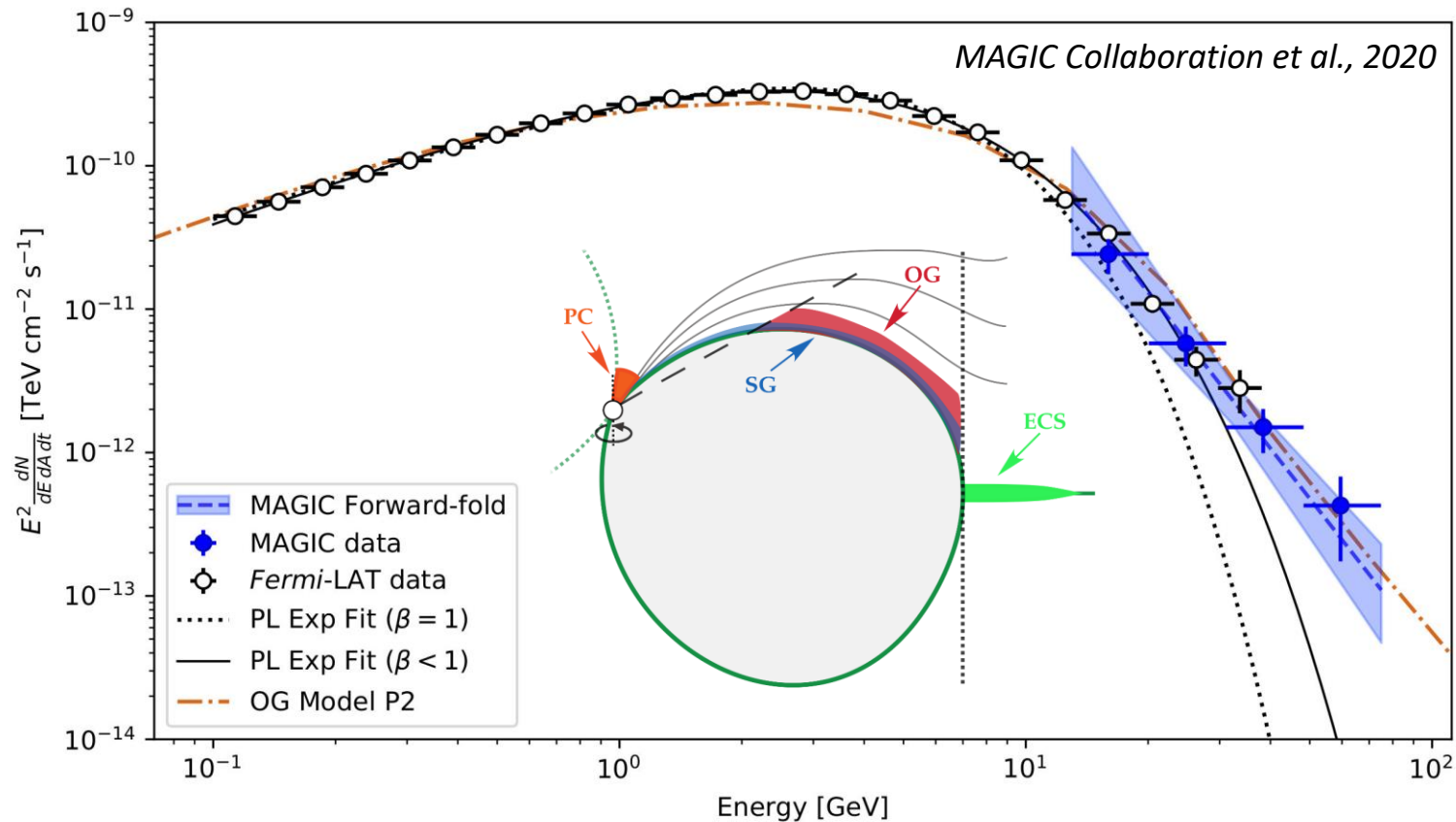
- Joint MAGIC and *Fermi*-LAT spectral fits (cutoff power law)
- Pure exponential cutoff case rejected with $>18\sigma$ significance

GEMINGA: SPECTRUM



- **Sub-exponential cutoff power law in tension with data** (3.6σ significance)
- **Power-Law vs. Log-Parabola ($E > 10$ GeV): no preference for curvature**

GEMINGA: SPECTRUM

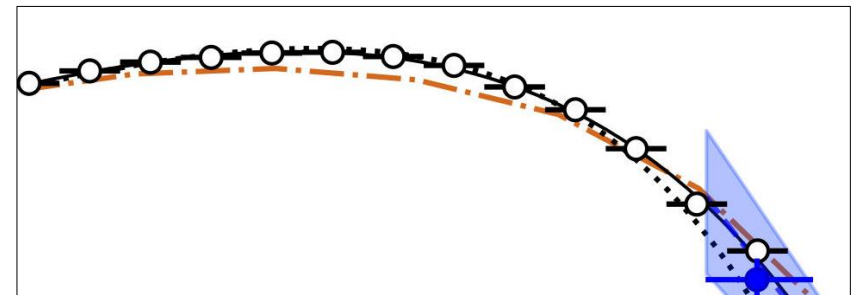
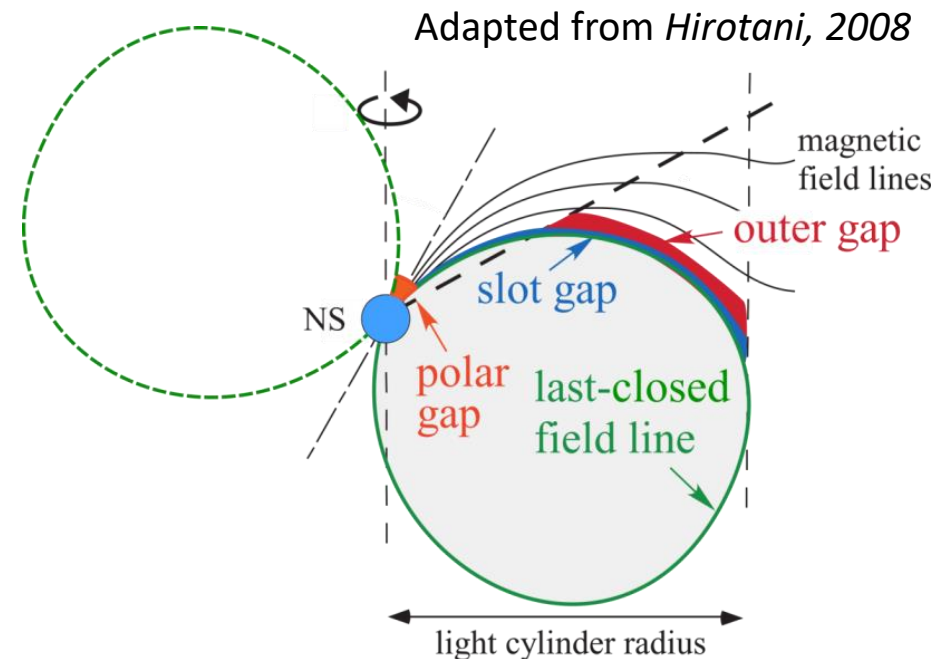


- Inverse Compton component?
- Outer gap model study: IC possible, but limited agreement with data

GEMINGA: OUTER-GAP MODELLING



- **Inverse Compton** efficient only with **head-on collision**
- **Electrons** accelerated **towards the star** up-scatter thermal **X-rays**
- **VHE** emission **in phase** with **HE** if viewing angle ~ 90 deg
- **Disagreement** with **GeV** energy fluxes:
 - Review of the **OG** model
 - **Alternative** scenarios



- The **MAGIC Telescopes** extended their energy range well below **70 GeV** with the novel **Sum-Trigger-II** hardware.
- **Discovery** of pulsed VHE emission from **Geminga**: the **third VHE pulsar** and the **oldest one** to date ($3 \cdot 10^5$ y).
- Steep **power law** spectrum between **15 GeV** and **75 GeV**. **No indication for a cutoff**. Excellent **agreement** with *Fermi-LAT* measurements up to 40 GeV.
- The classic **outer gap** model can be **adapted** to include the **inverse Compton** emission. However, **discrepancies** appear at the **GeV** scale.
- There are **more VHE gamma-ray pulsars** yet to be discovered...