

Pulsar Emission above the Spectral Break:

A Stacked Approach

[with some new results on Geminga From VERITAS]

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University of Chicago

Fermi Symposium-2014
Nagoya, Japan



Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO



Talk Outline

Question:

The VHE pulsar catalogue contains only one source (**the Crab pulsar**)

Is VHE[†] emission above the break common in other pulsars?

Where to look for the answer:

What do we see in the bright Fermi pulsars? (**where we have good statistics above 10 GeV**)

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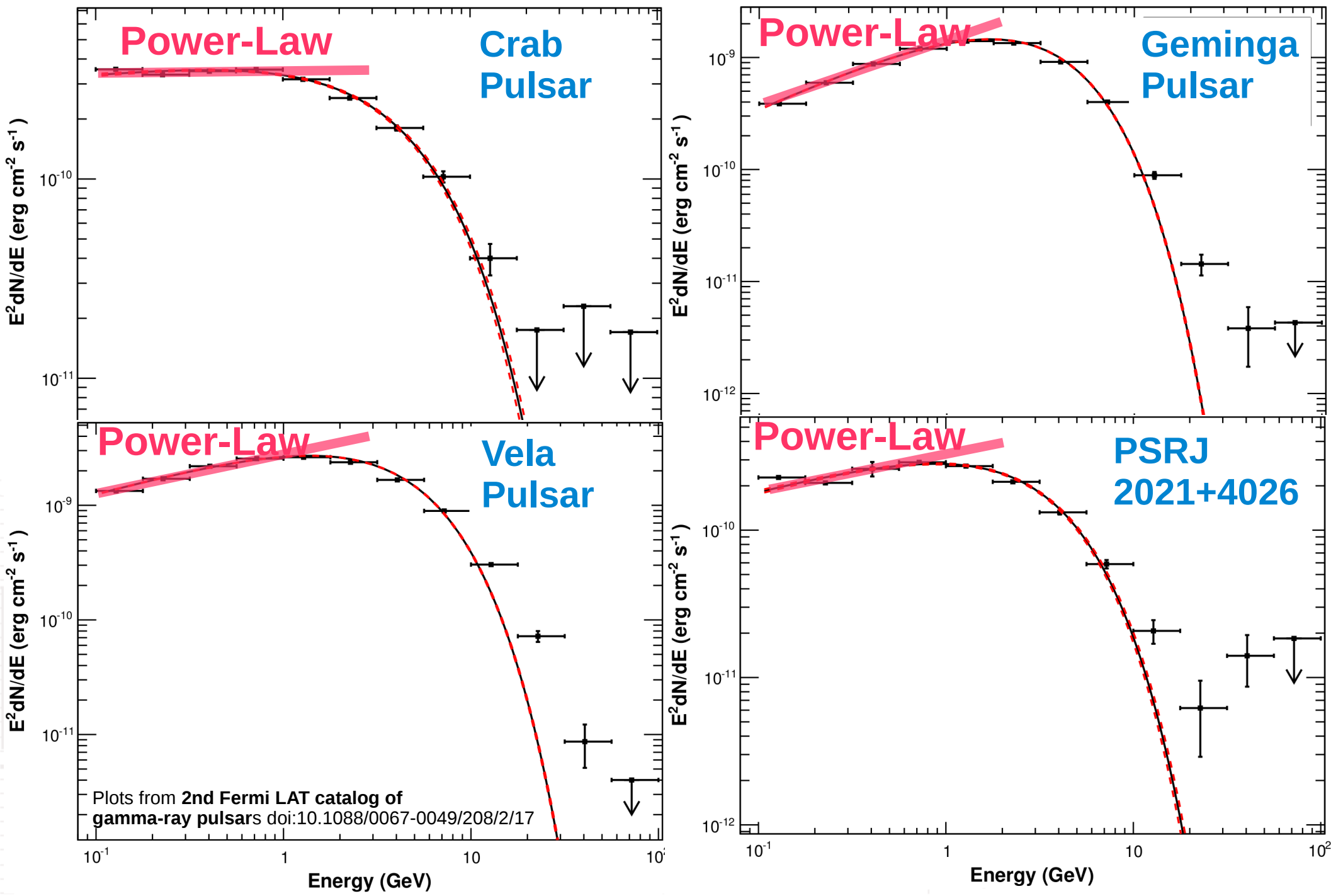
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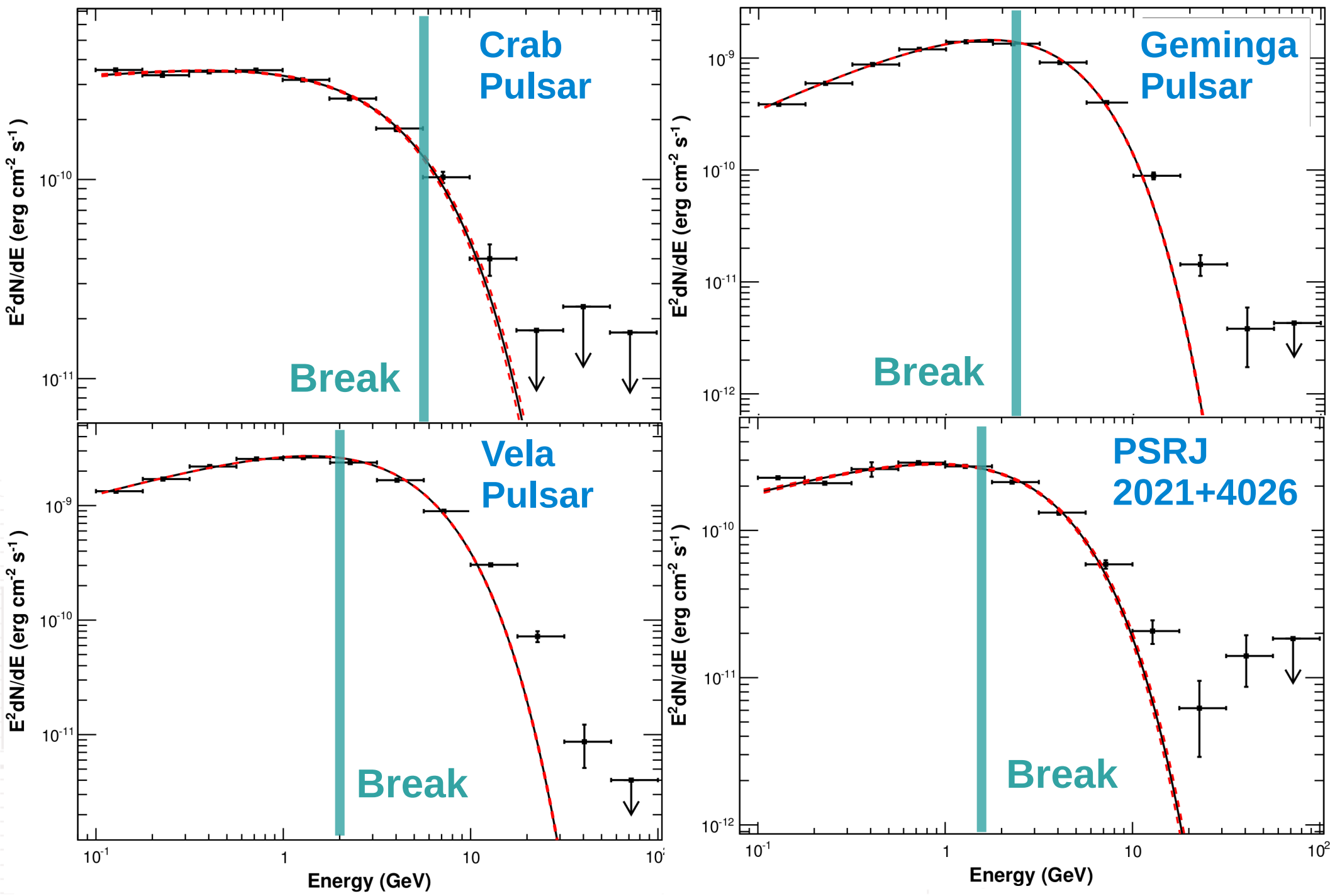
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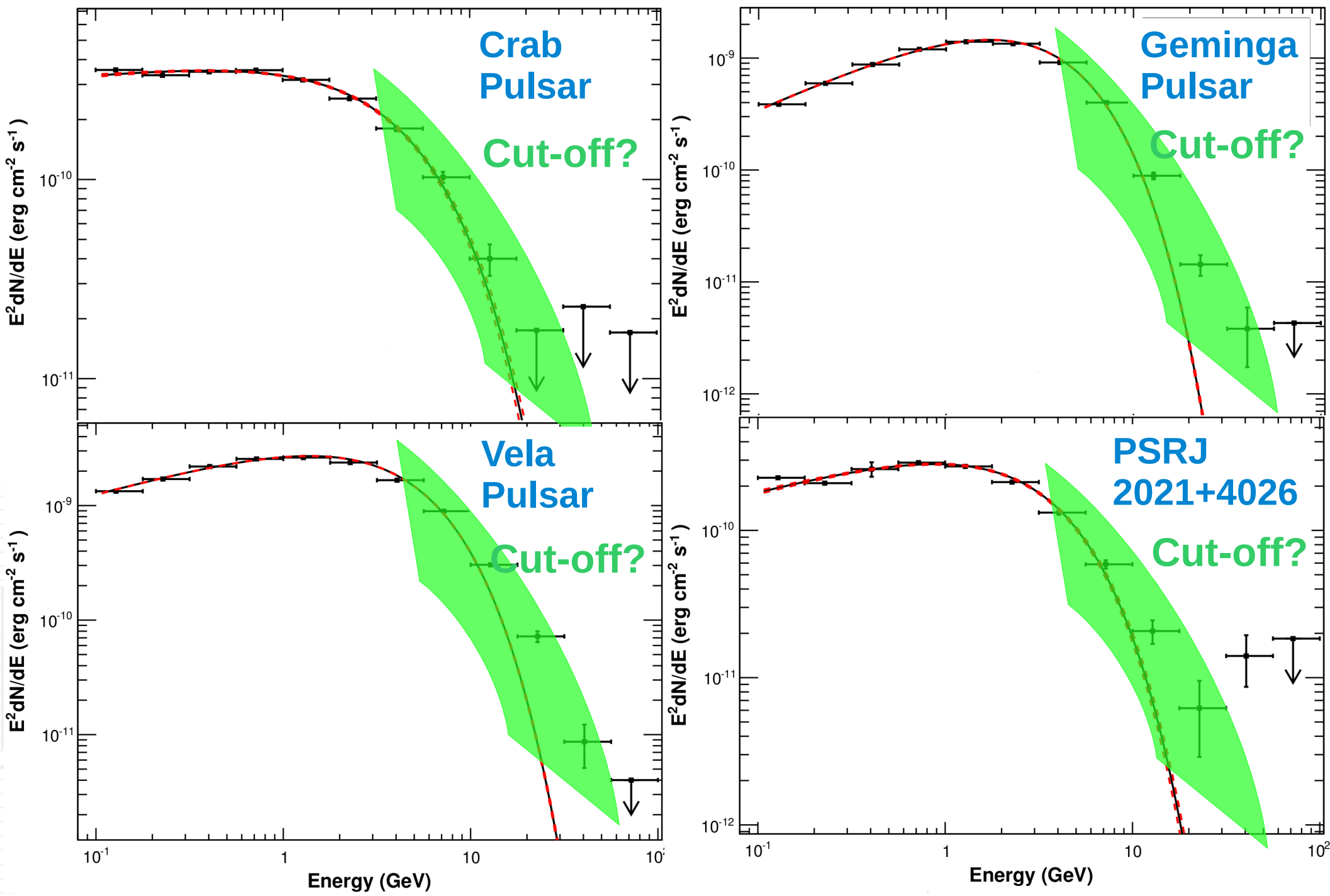
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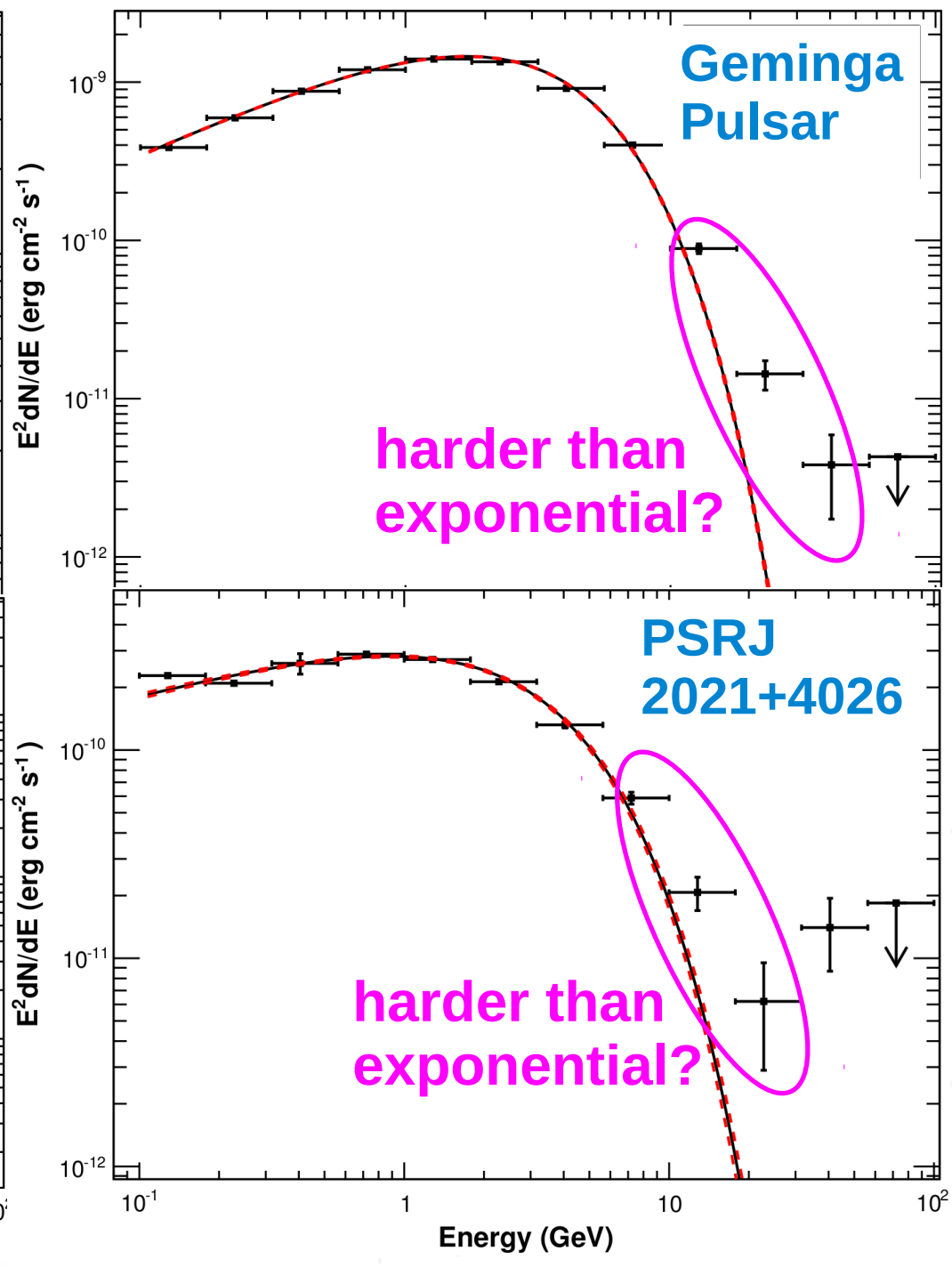
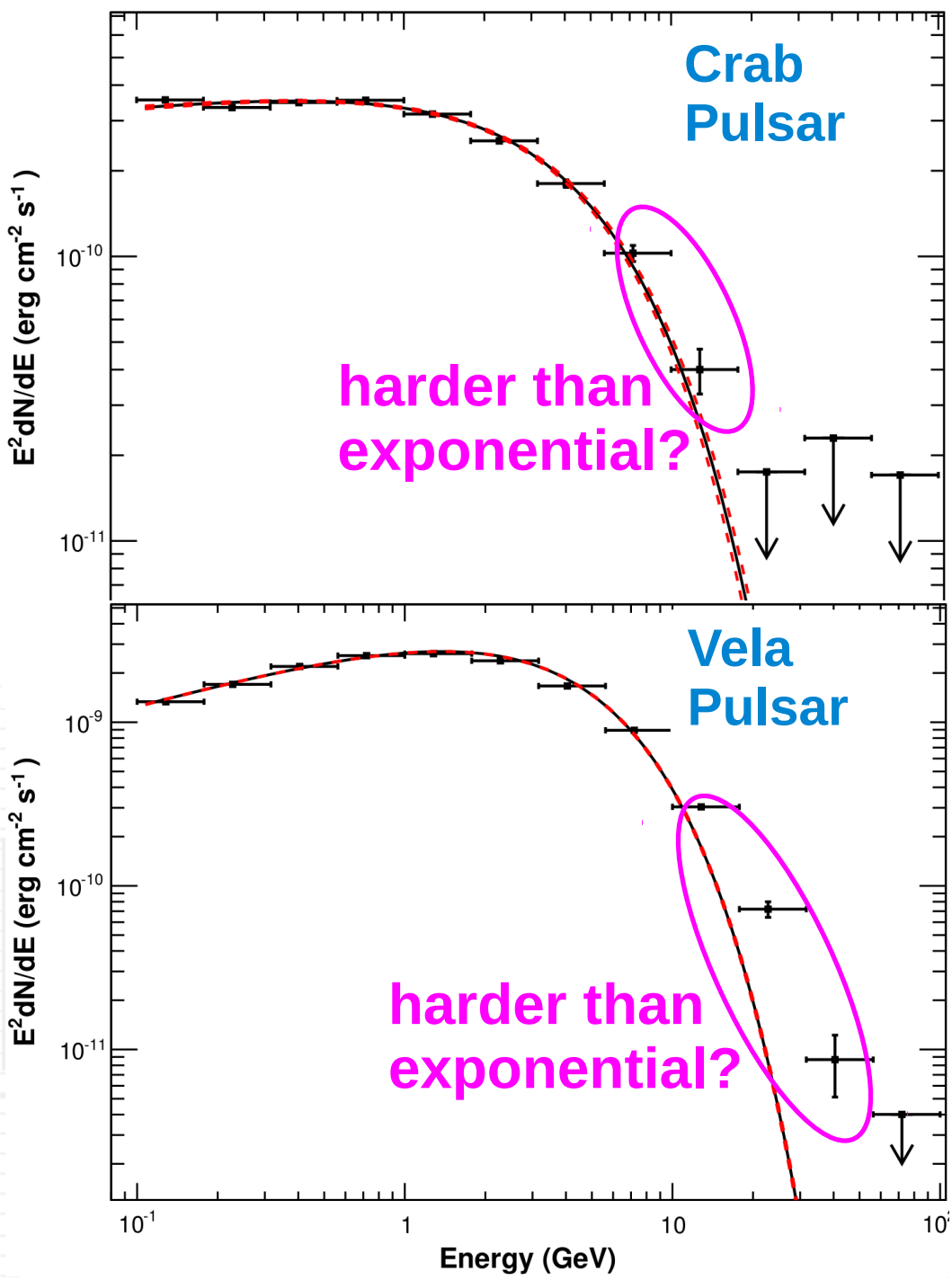
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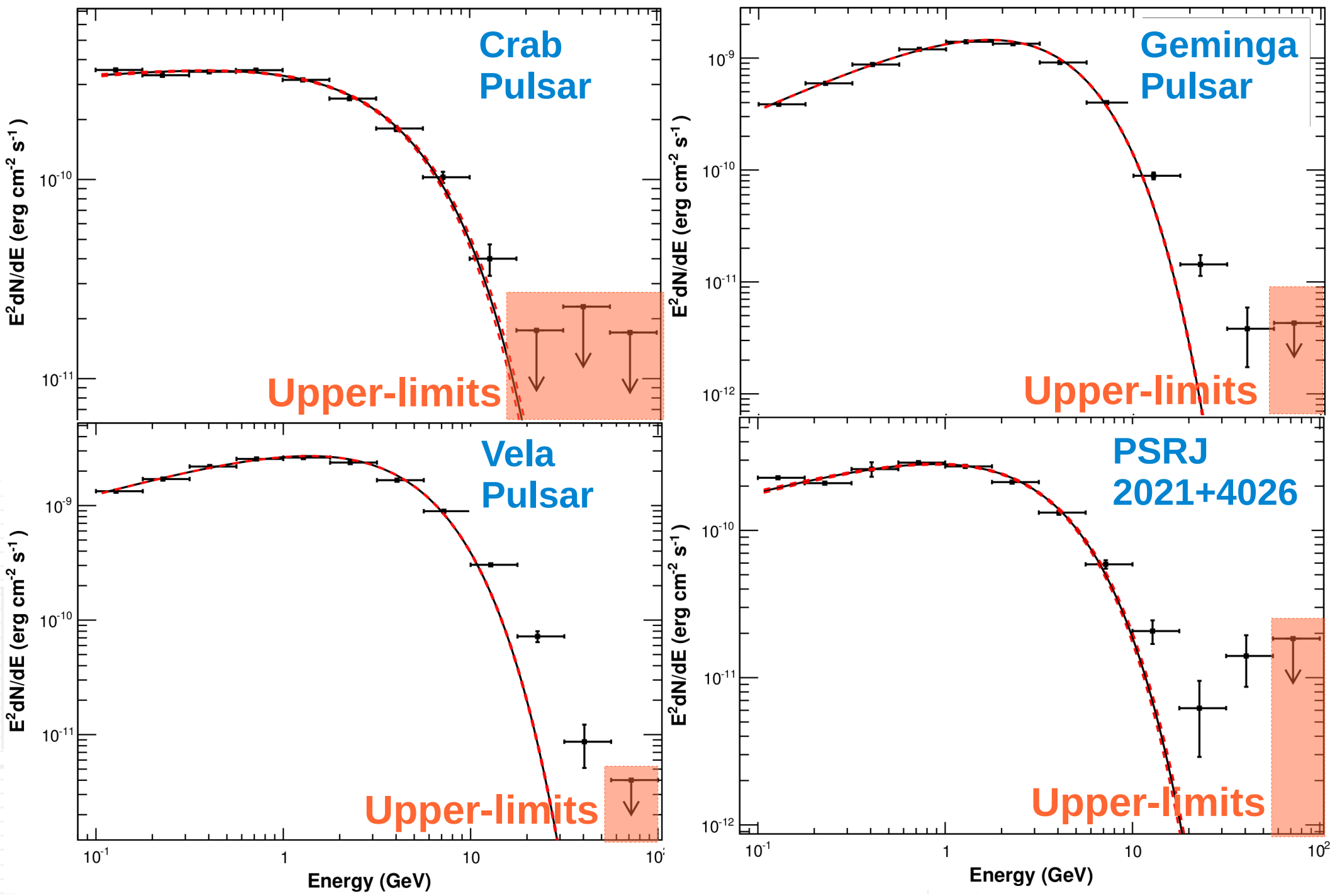
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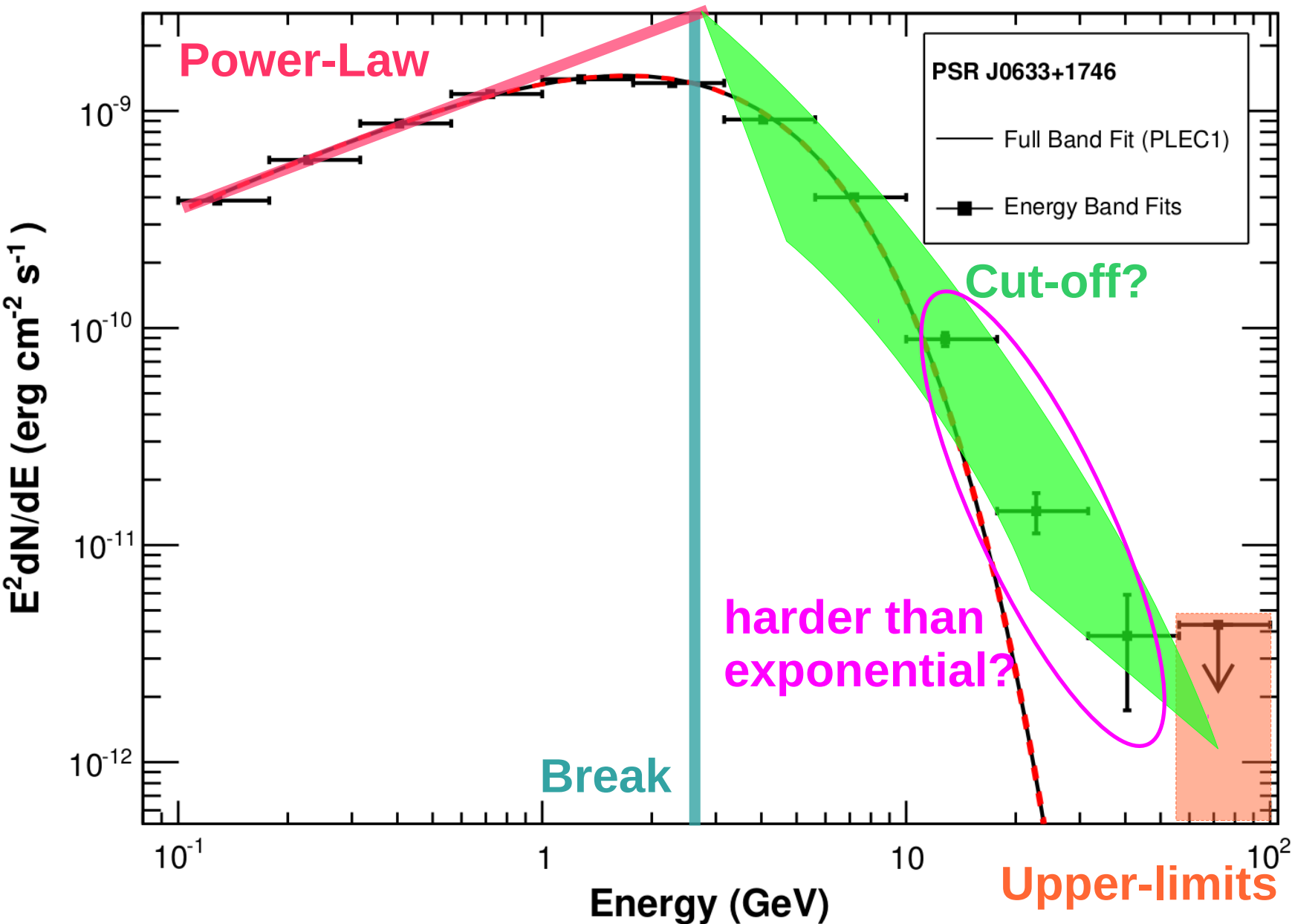
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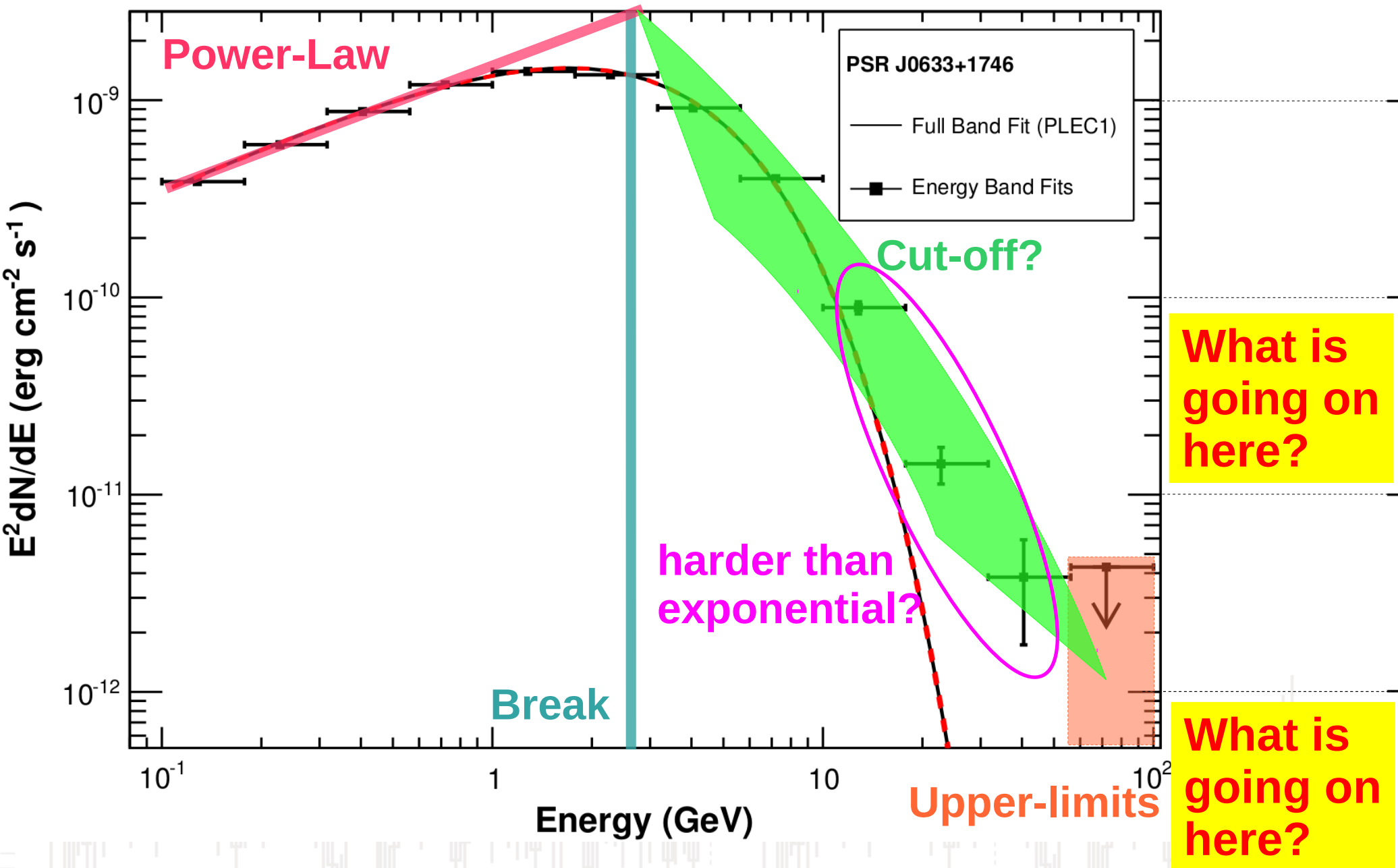
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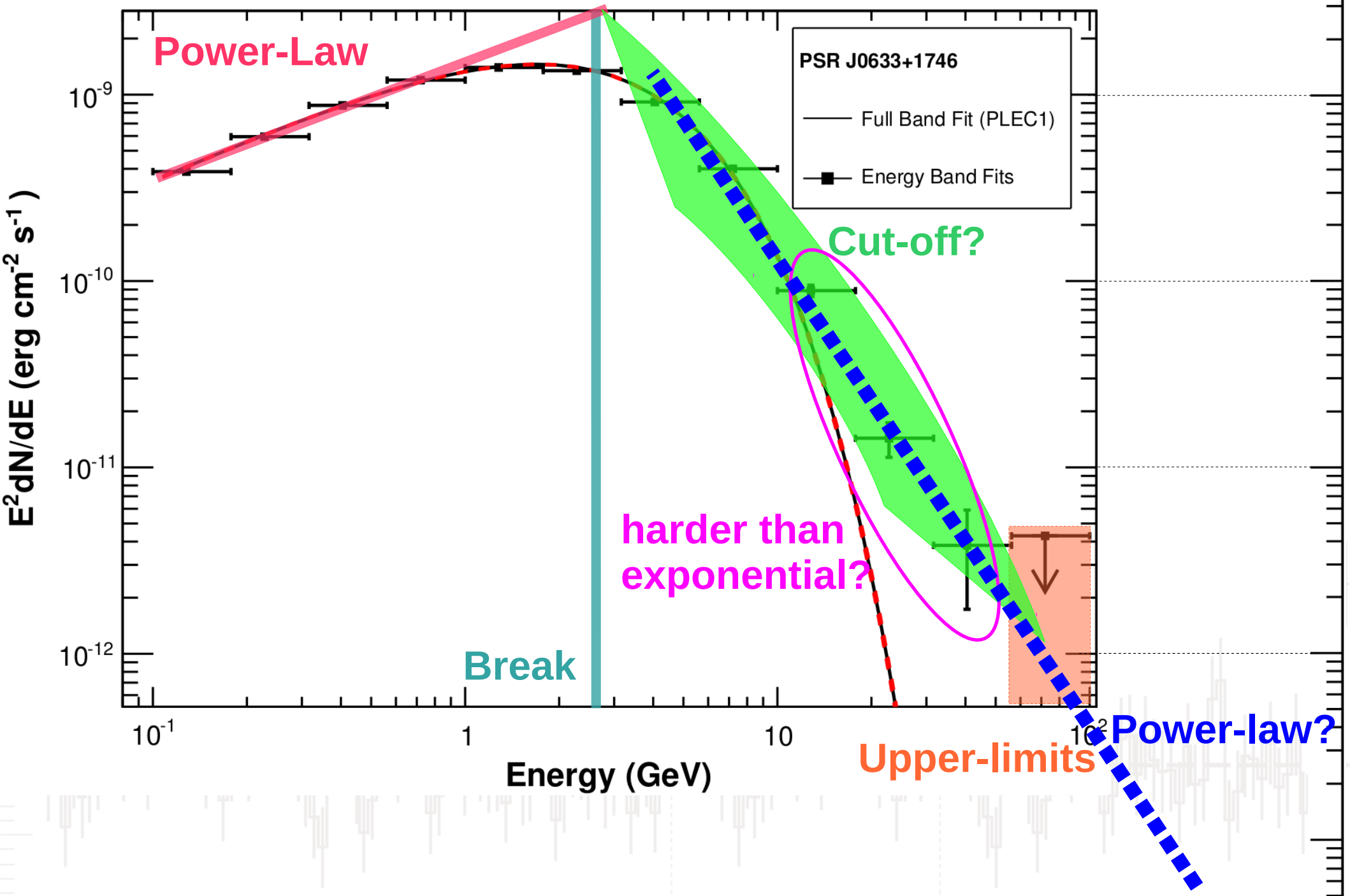
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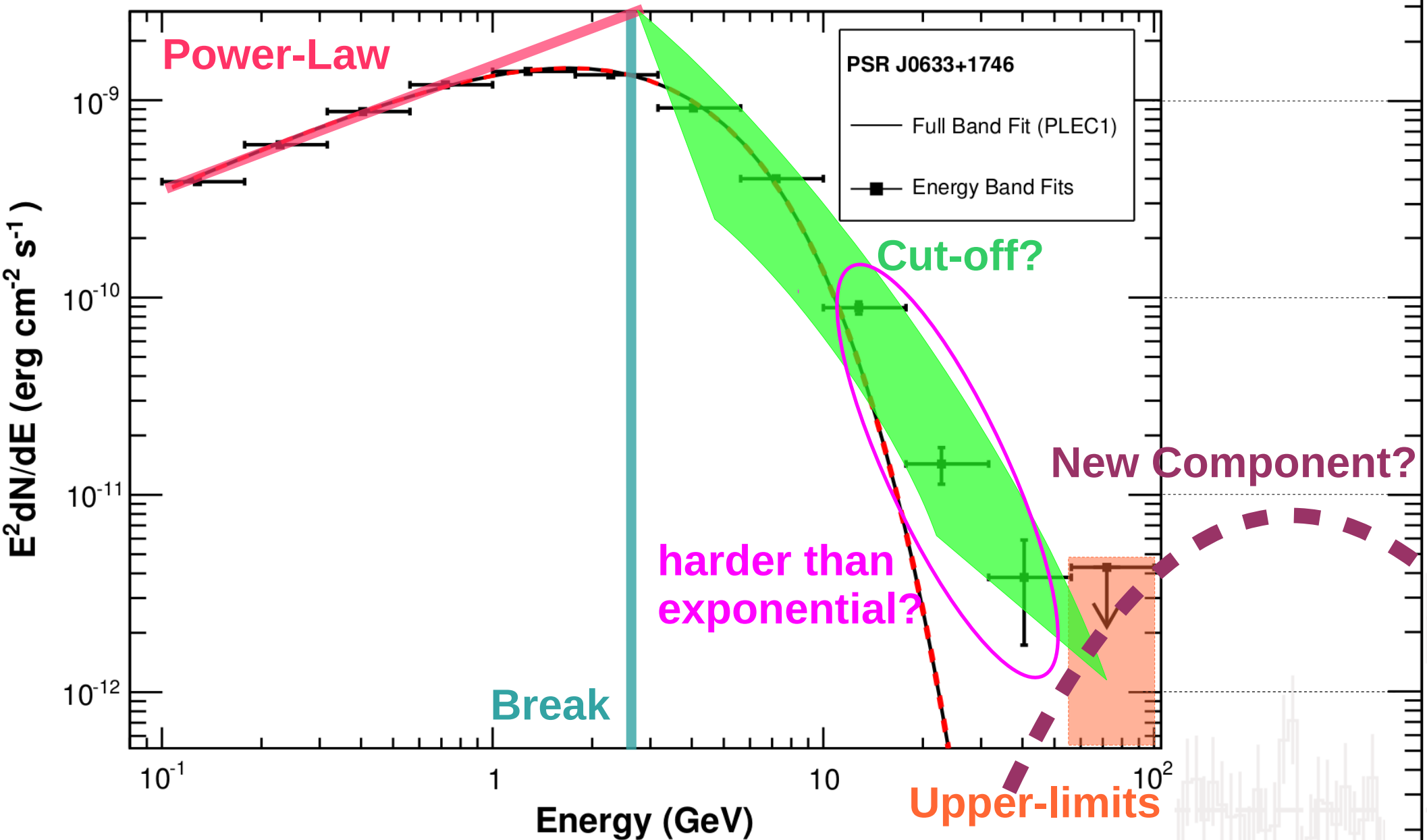
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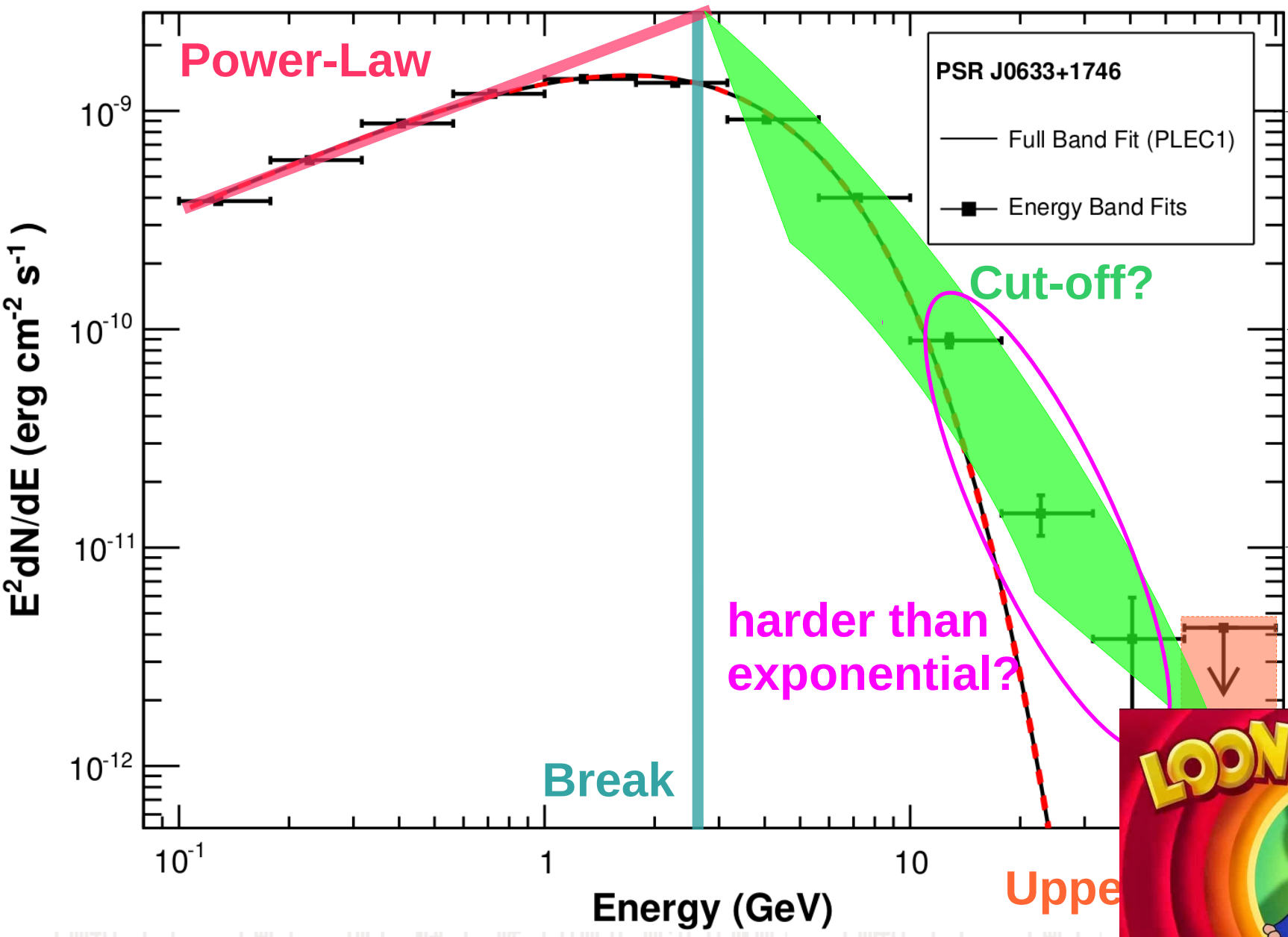
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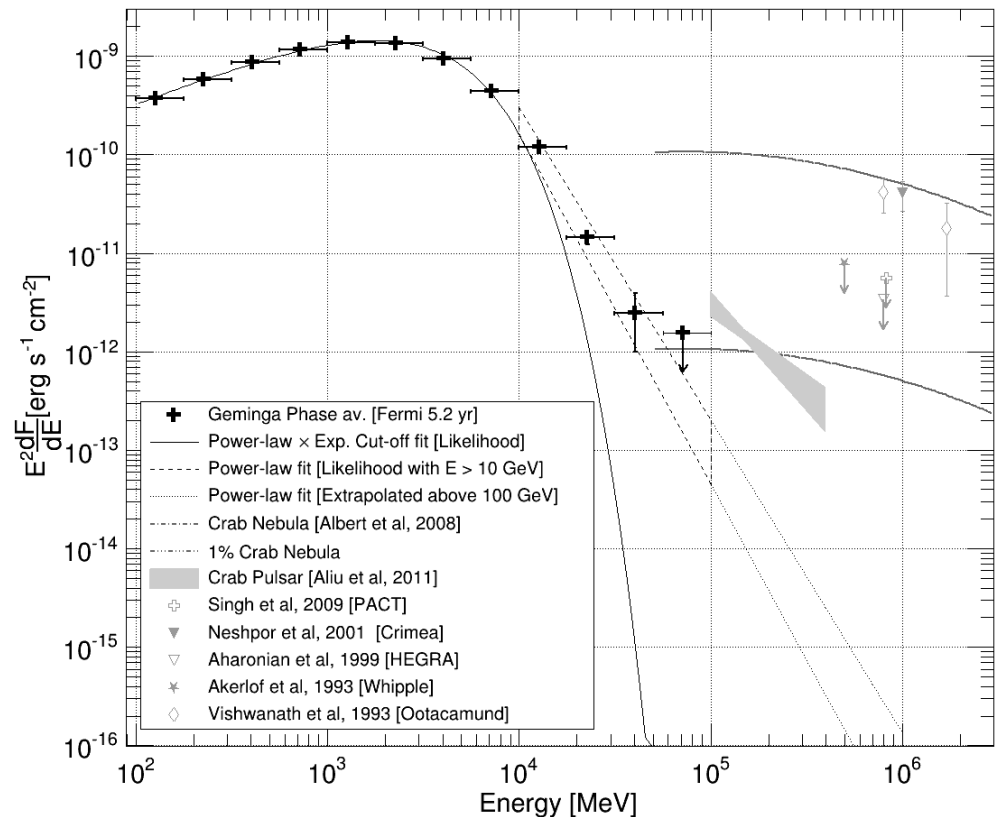
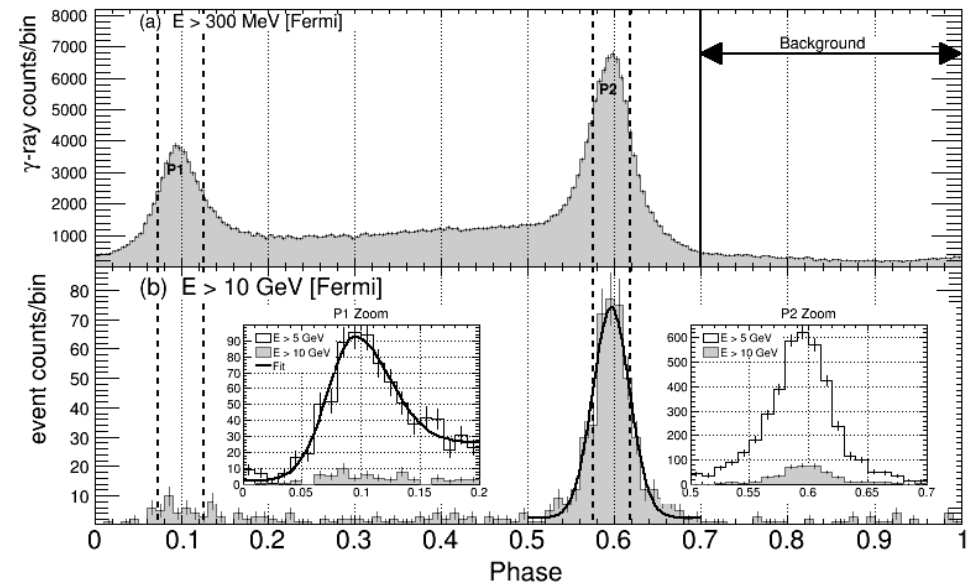
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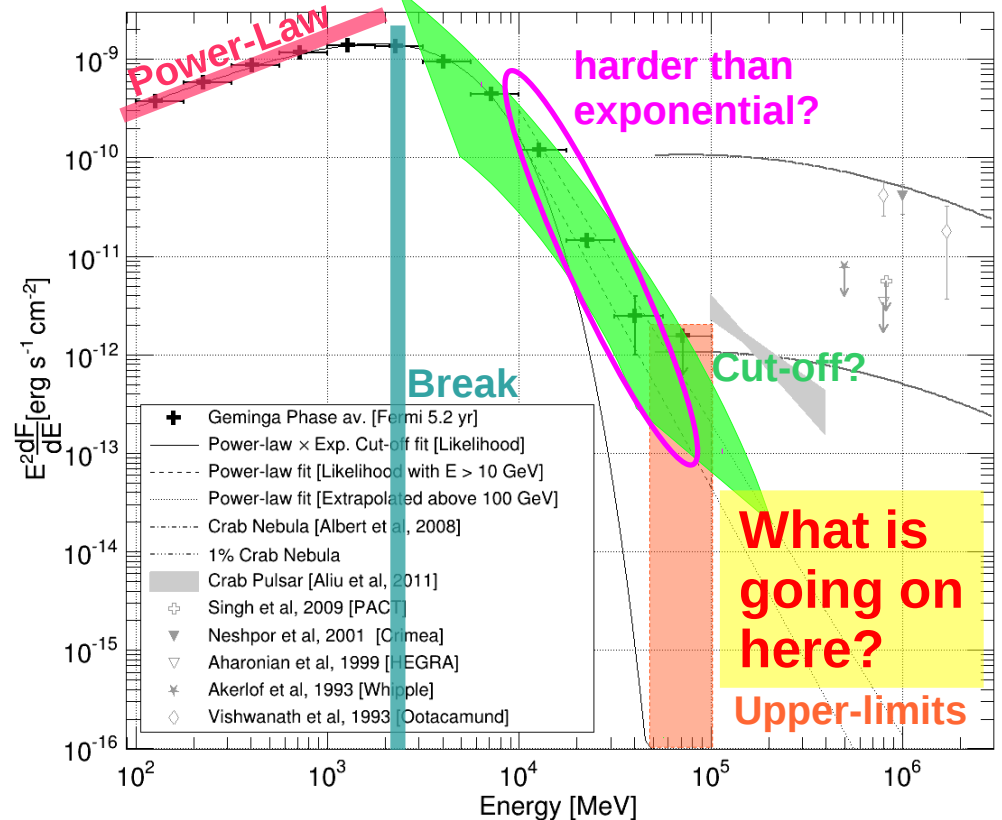
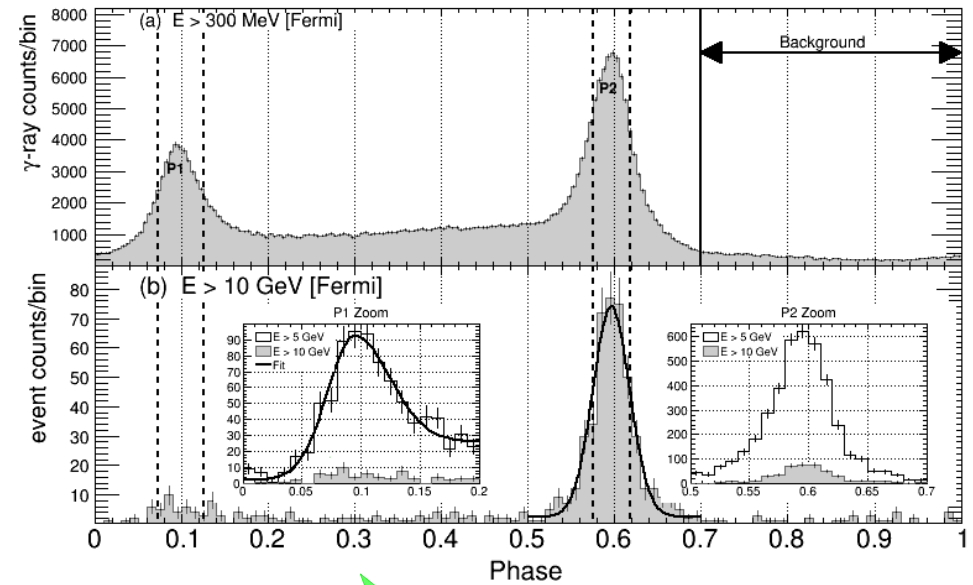
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- 72 hours of VERITAS observations
- 5.2 years of Fermi data
- Fermi profiles fit above 5 GeV for P1 and 10 GeV for P2
- +/- 1 sigma width phase gates for phase resolved SEDs
- P1 [0.072 – 0.125]
- P2 [0.575 – 0.617]
- Background selected from [0.7 – 1.0]
- VERITAS cuts optimised *a priori*



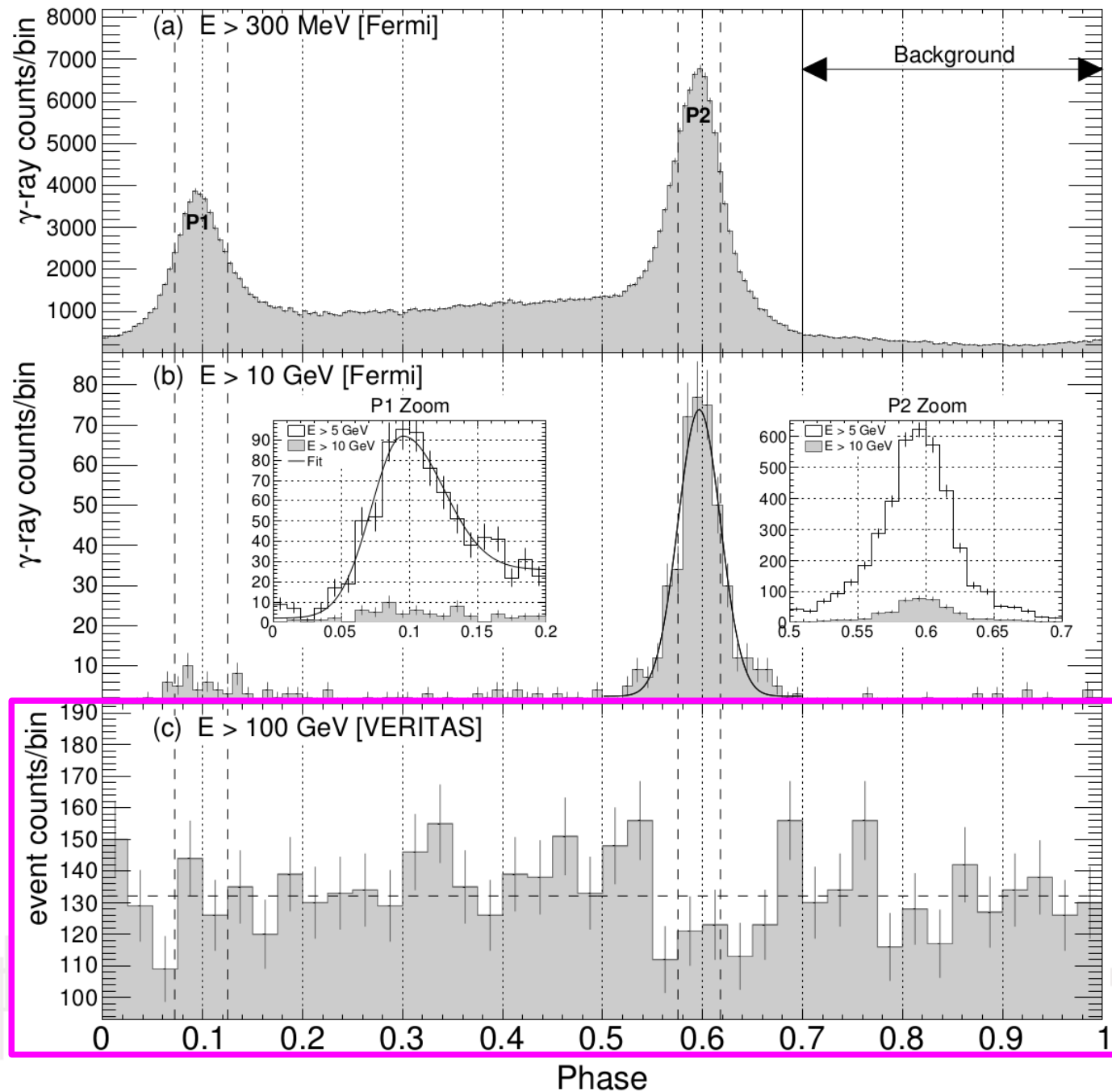
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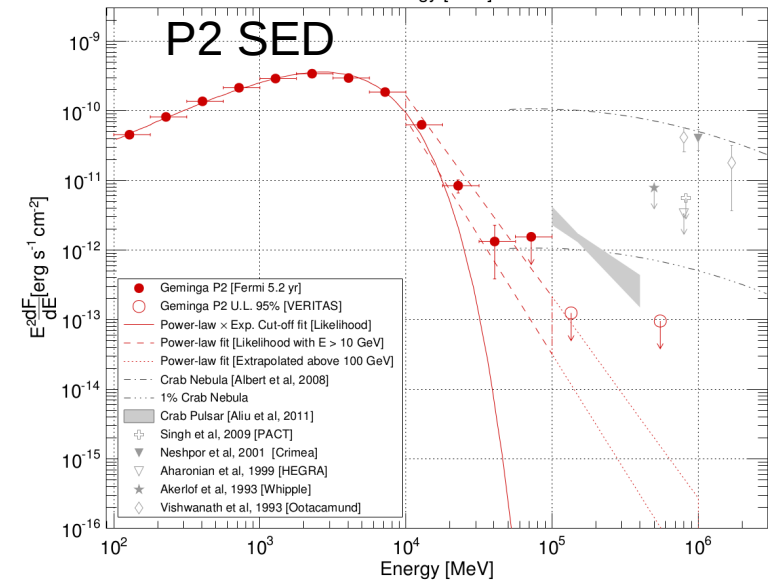
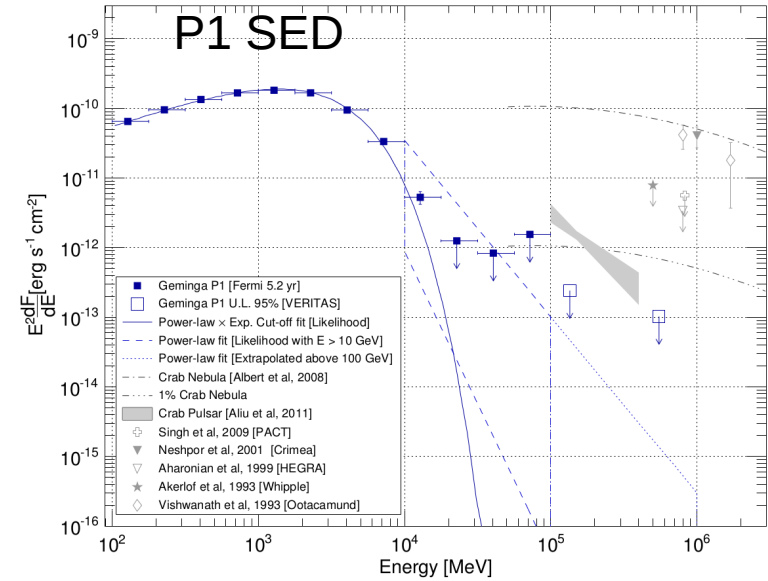
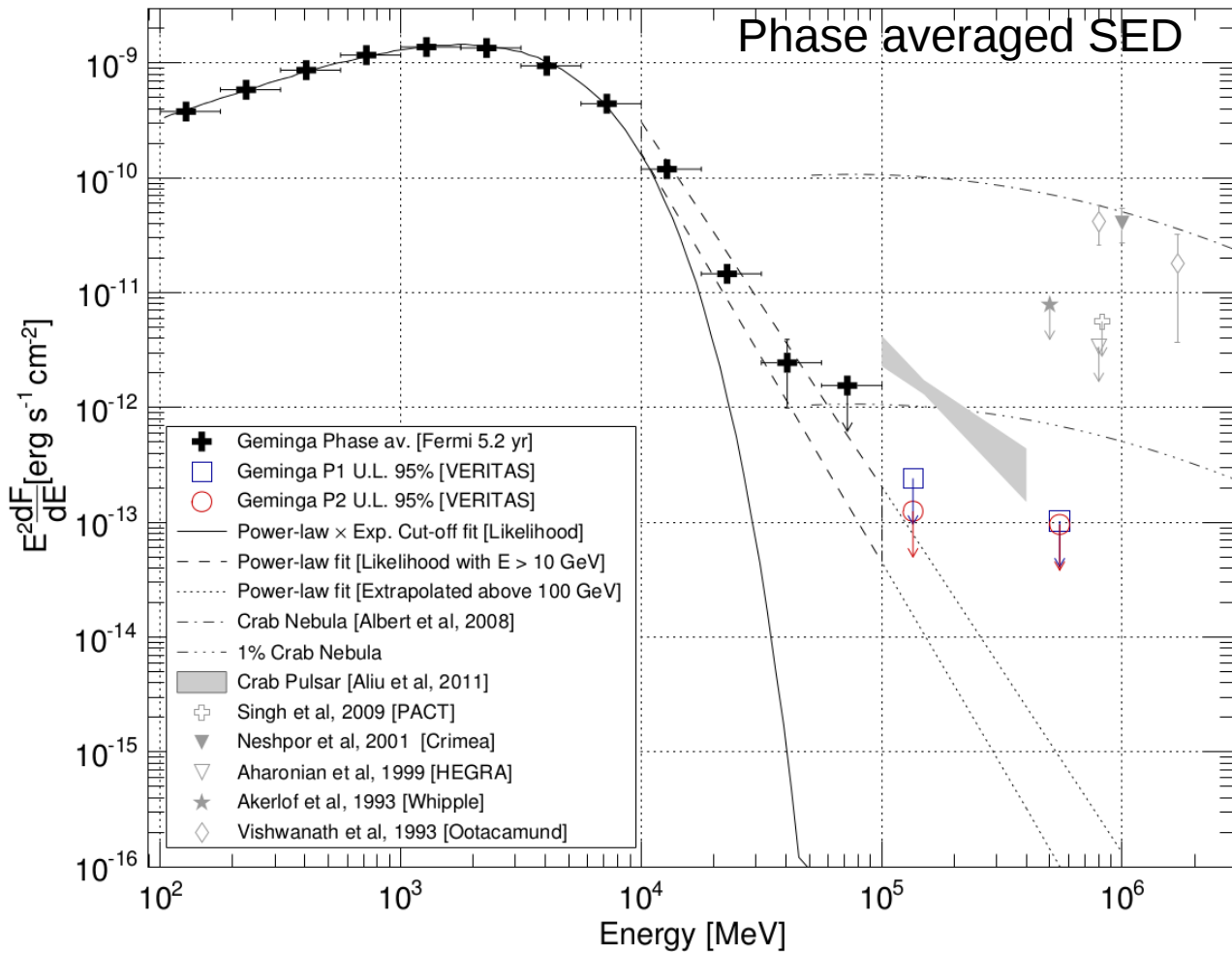


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- No significant emission seen by VERITAS above 100 GeV
- H^2 -Test value of 1.8 which is equivalent to 0.7σ .
- Event counts in P1 and P2 phase gates fully consistent with background counts

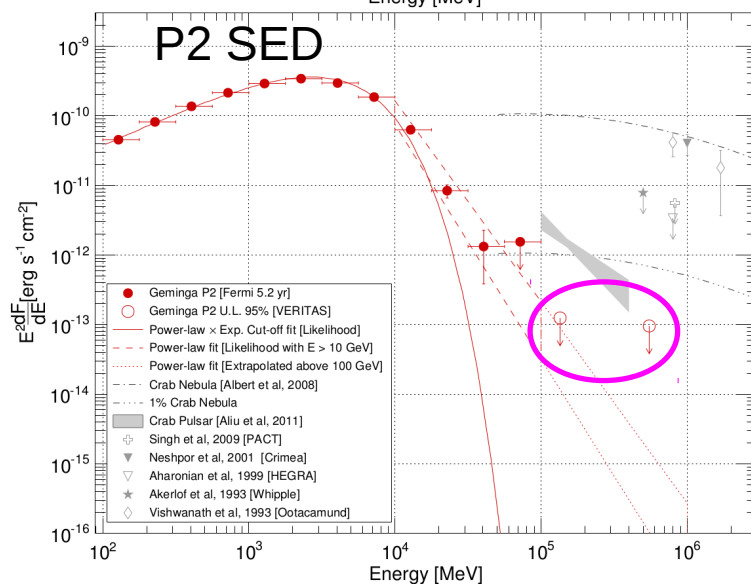
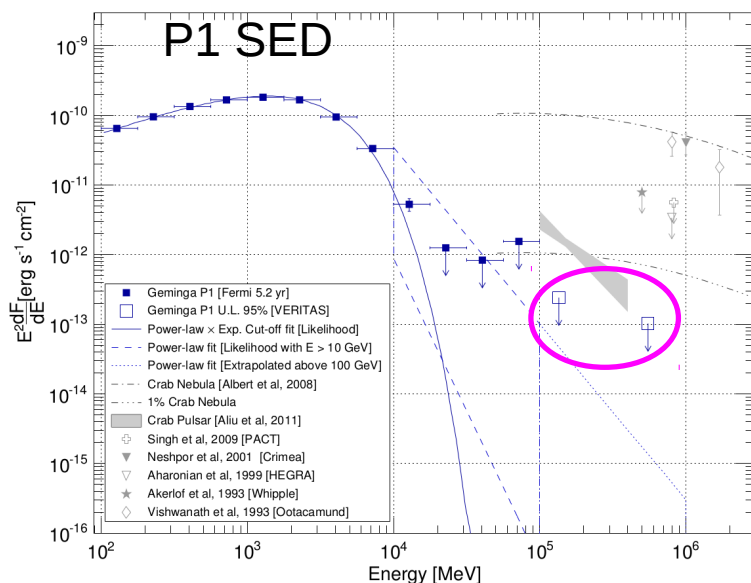
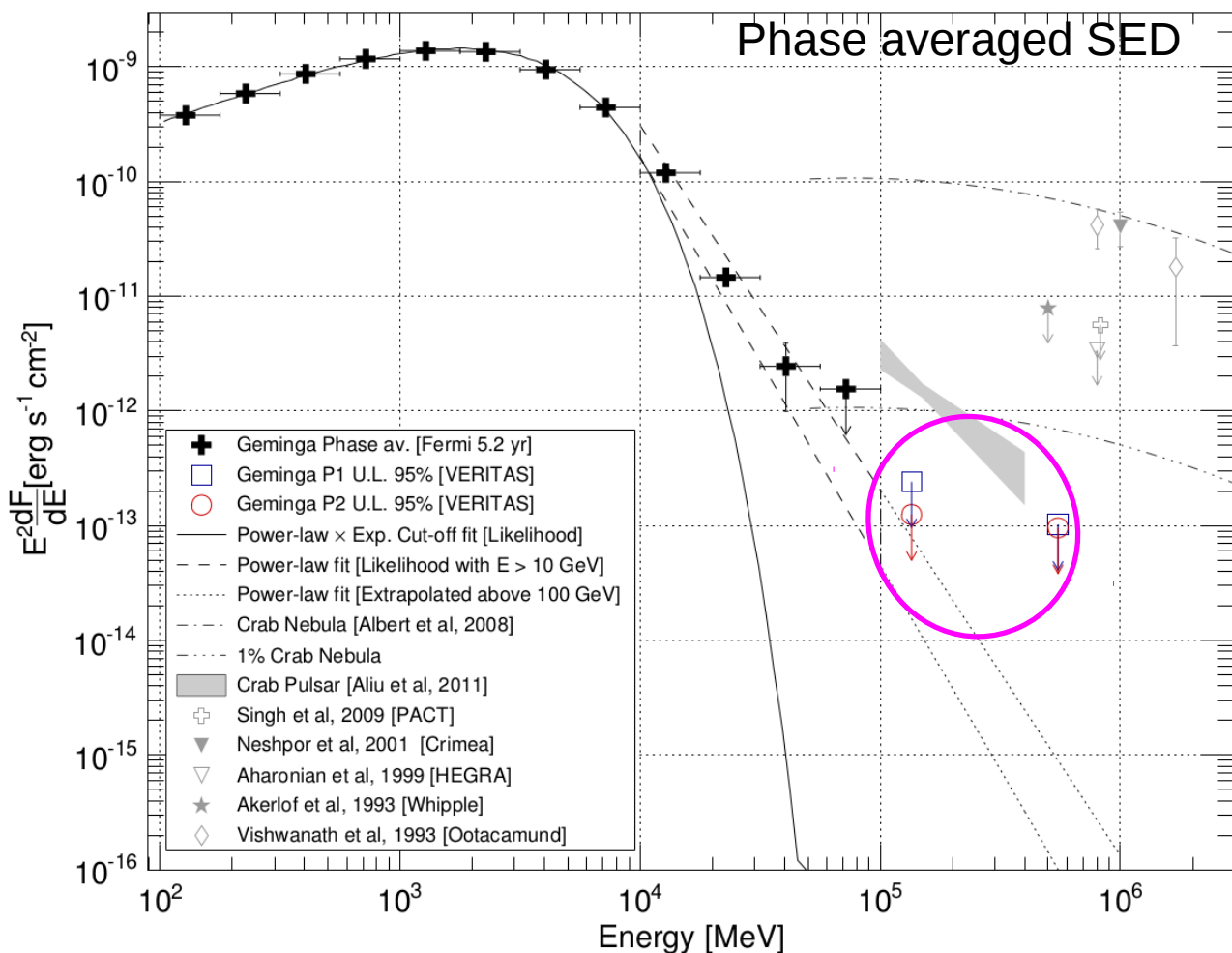


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- VERITAS limits at the 0.3% Crab Nebula flux level above 135 GeV.
- Pure power-law extension of the Fermi SED above 10 GeV below the derived limits.
- Paper submitted to ApJ.

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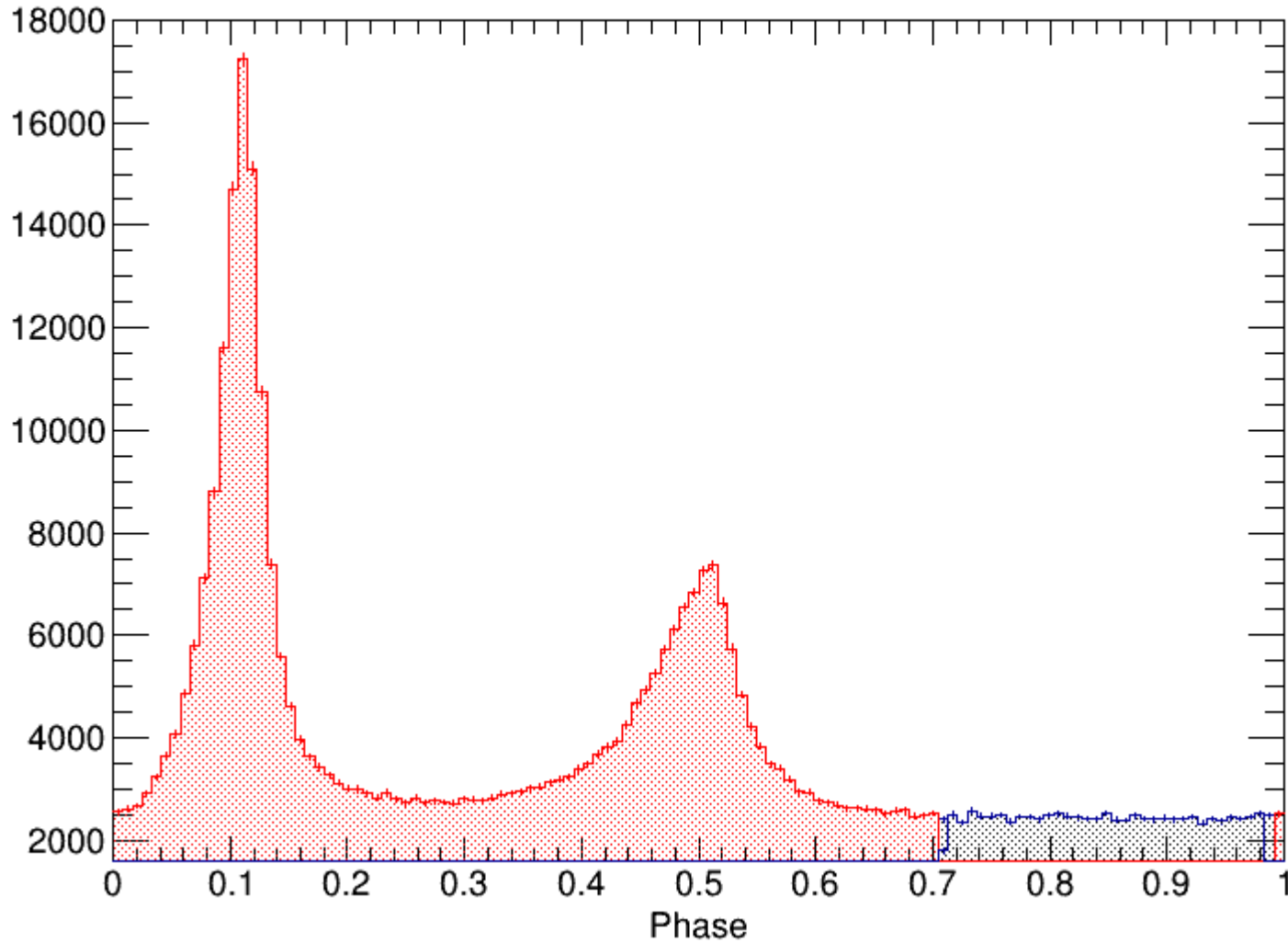
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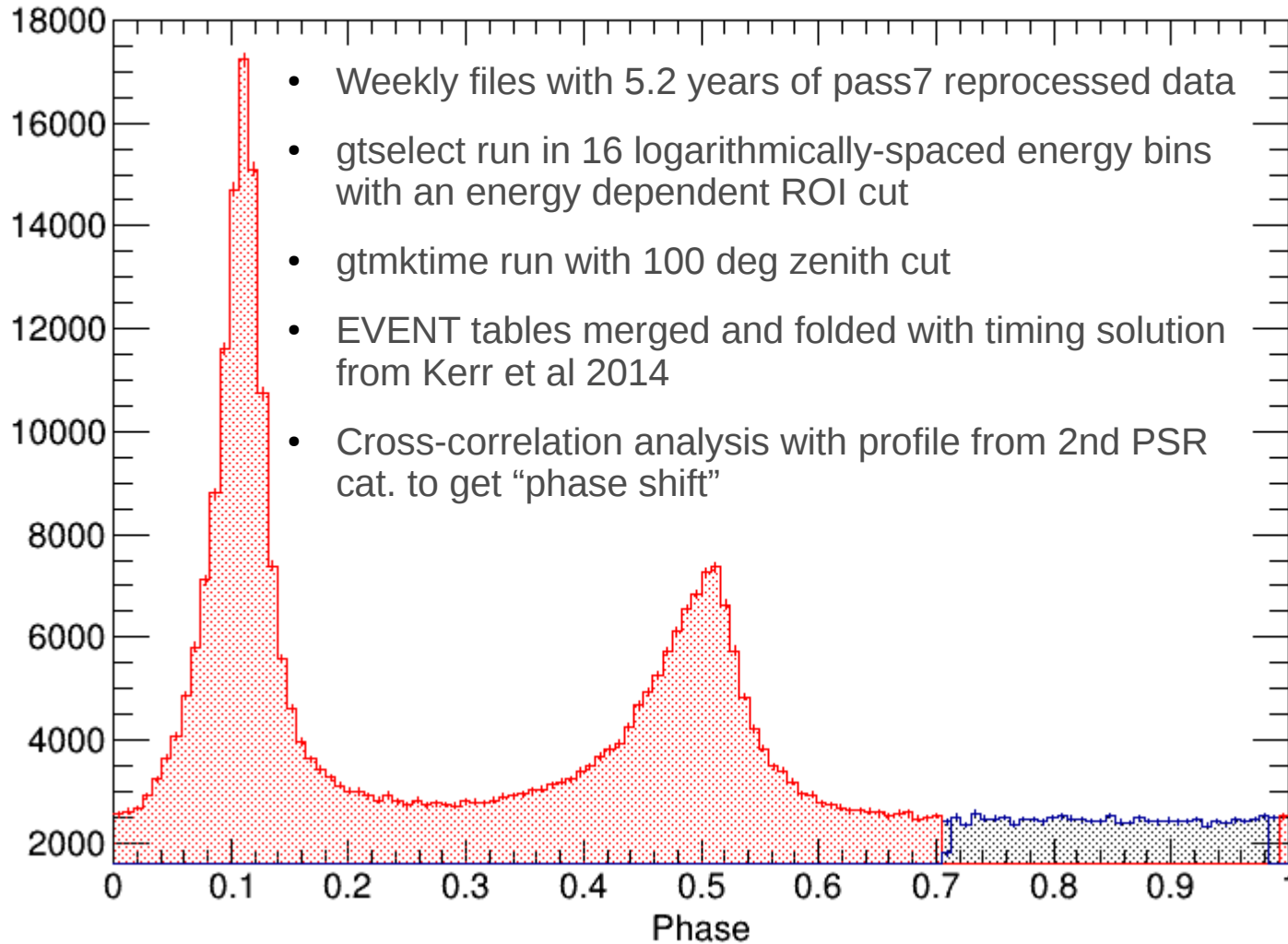
Aperture Photometry with Pulsars

Crab Pulsar



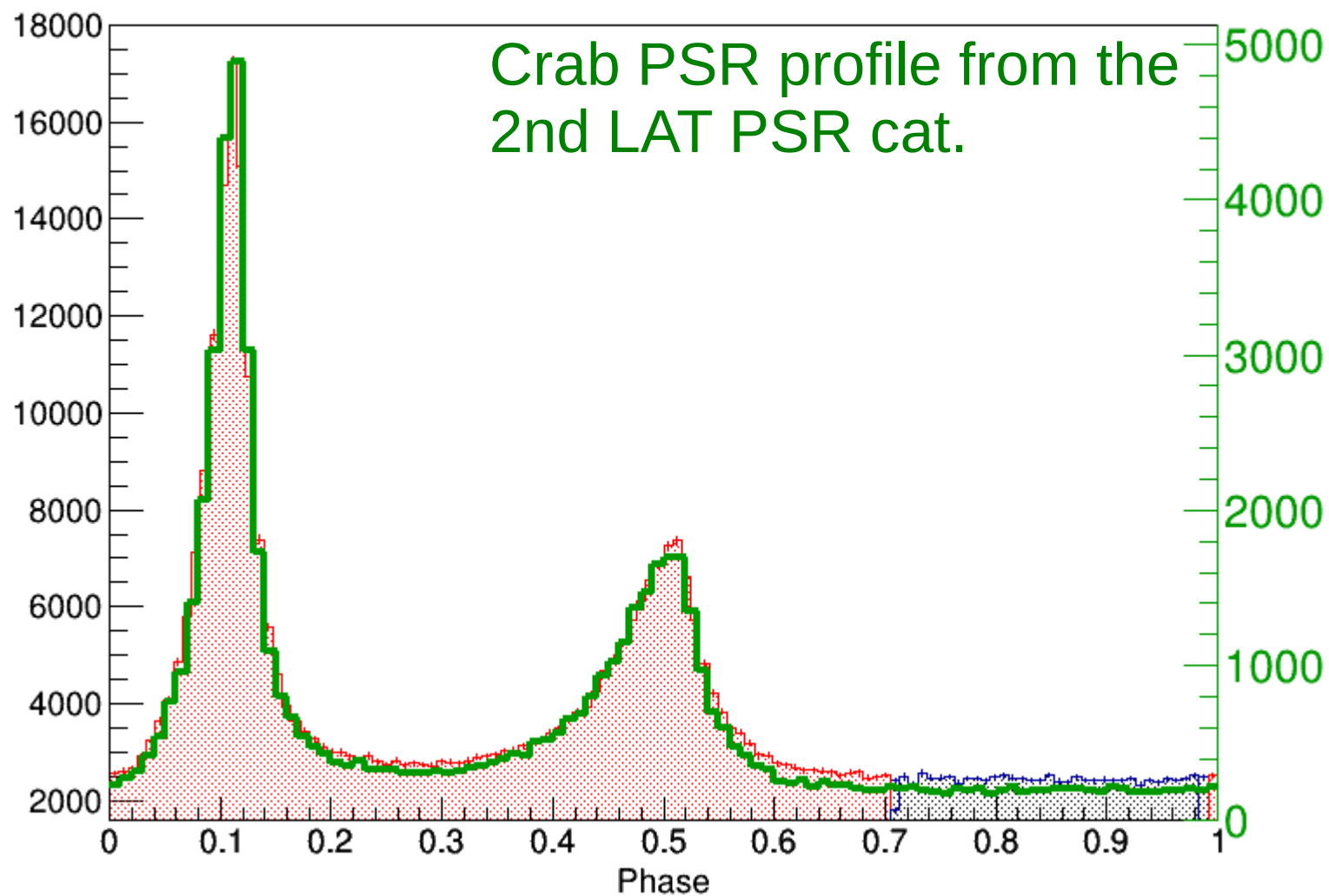
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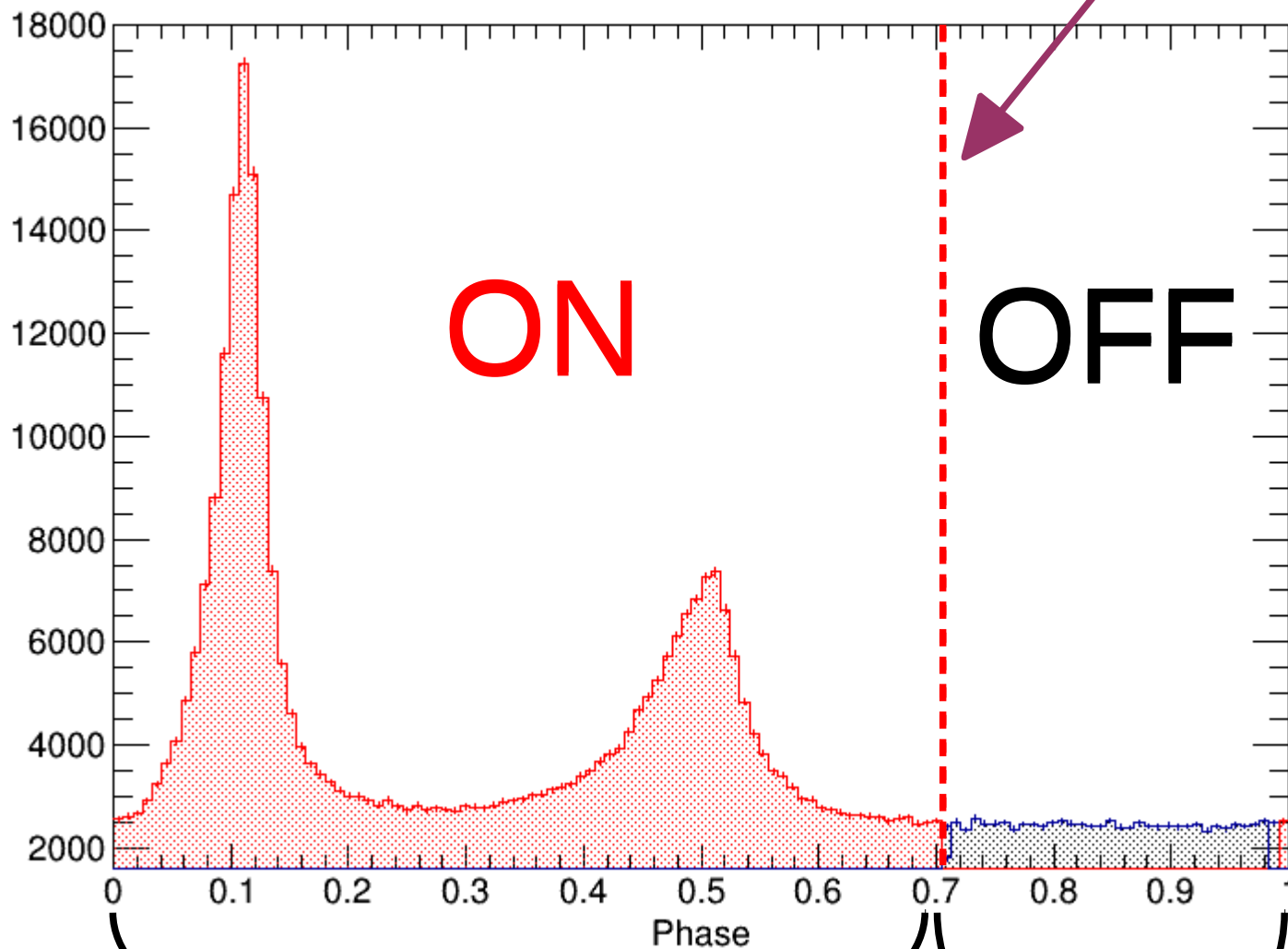
Crab Pulsar



Aperture Photometry with Pulsars

Crab Pulsar

2nd Pulsar Cat.



ON

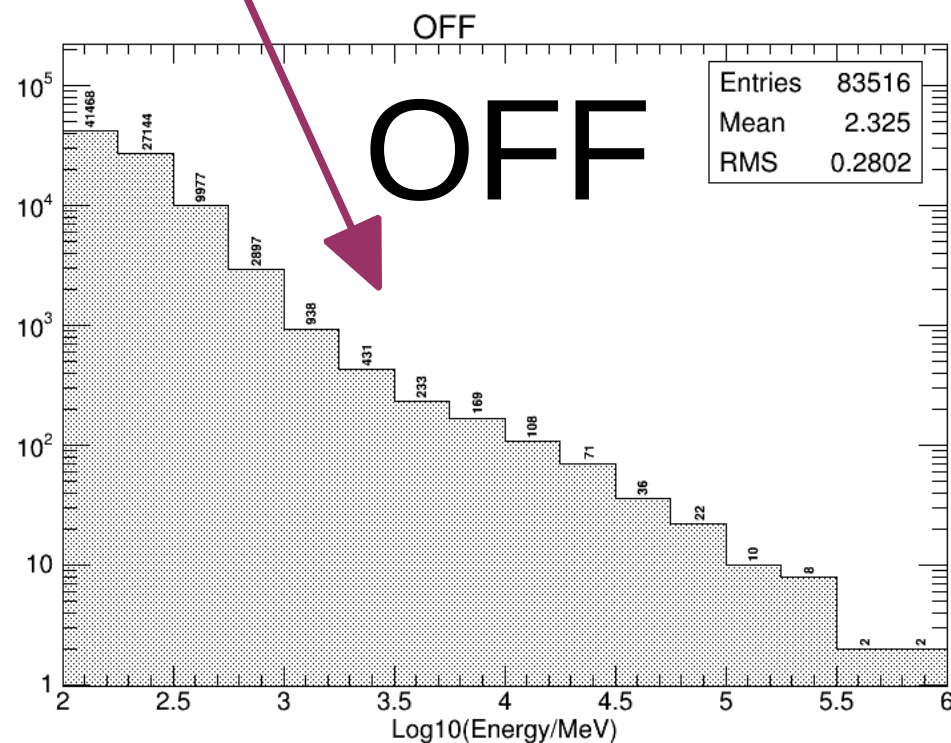
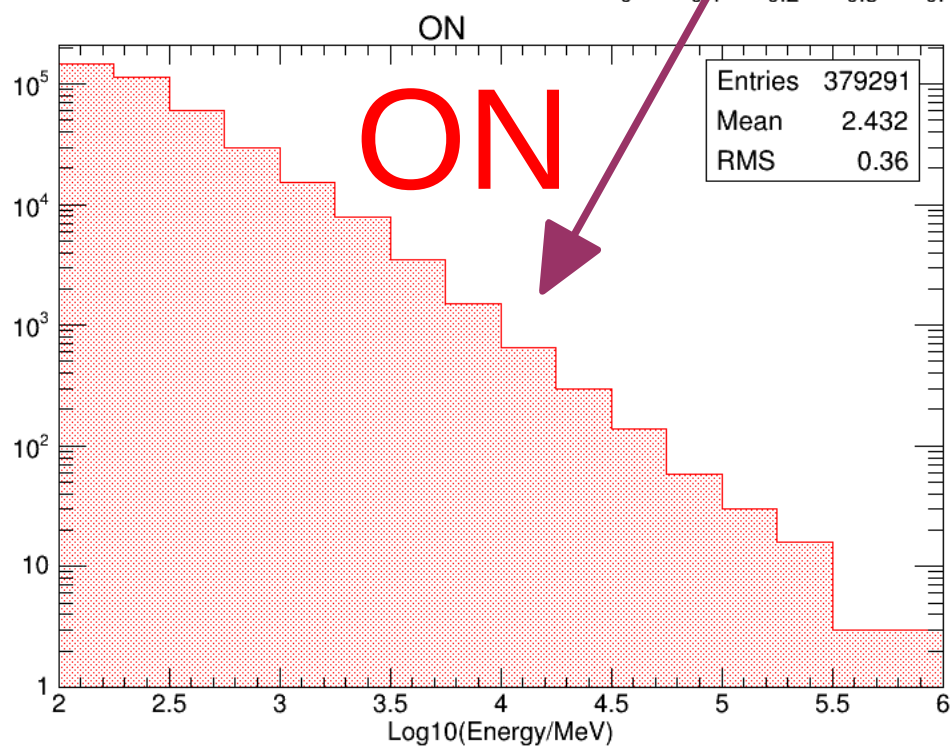
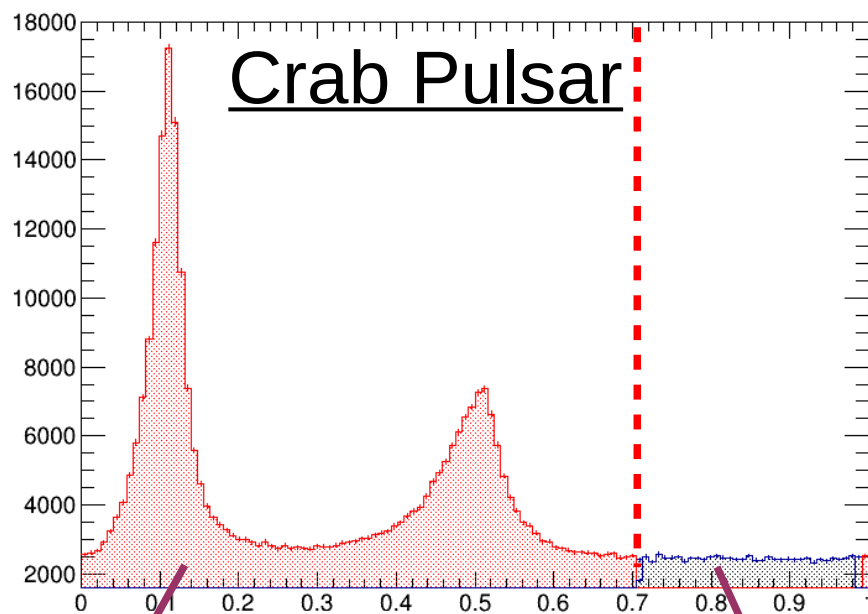
OFF

PR_on

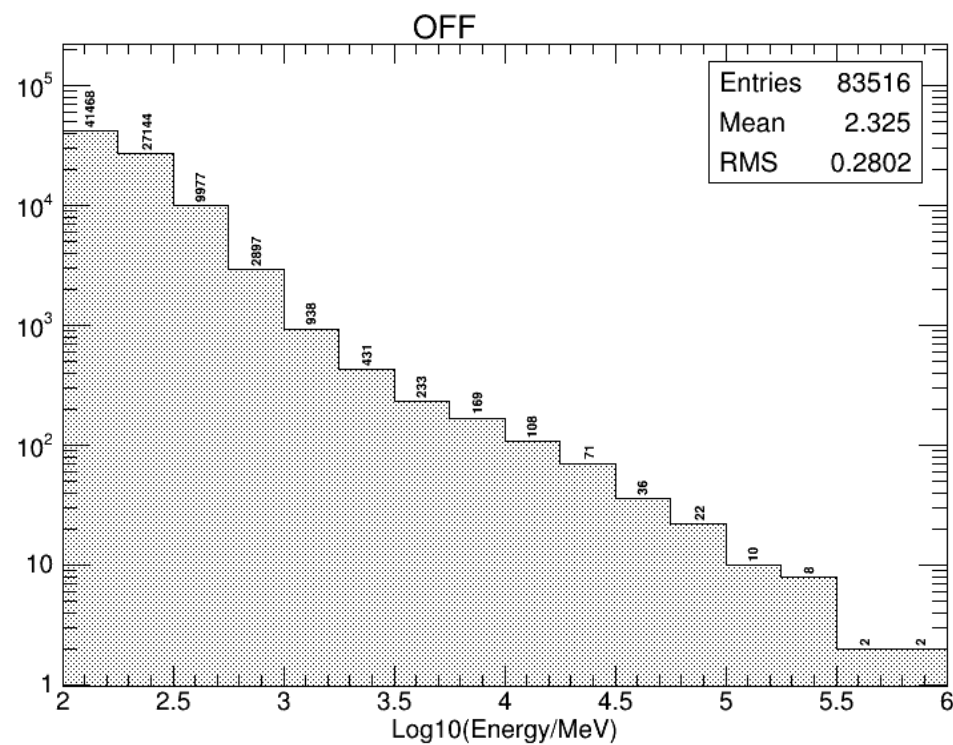
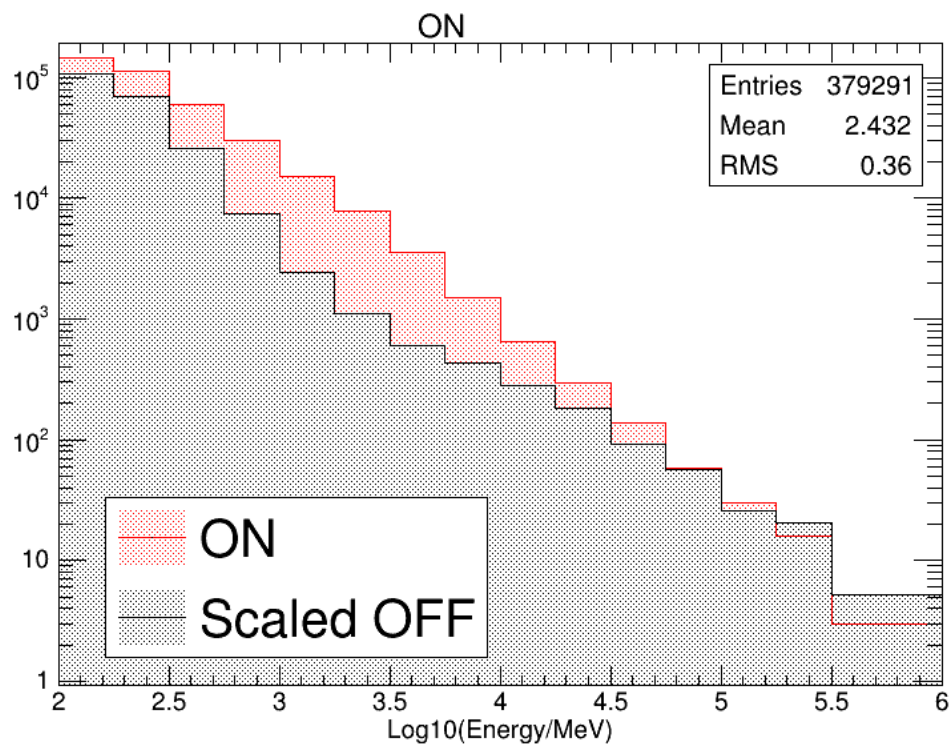
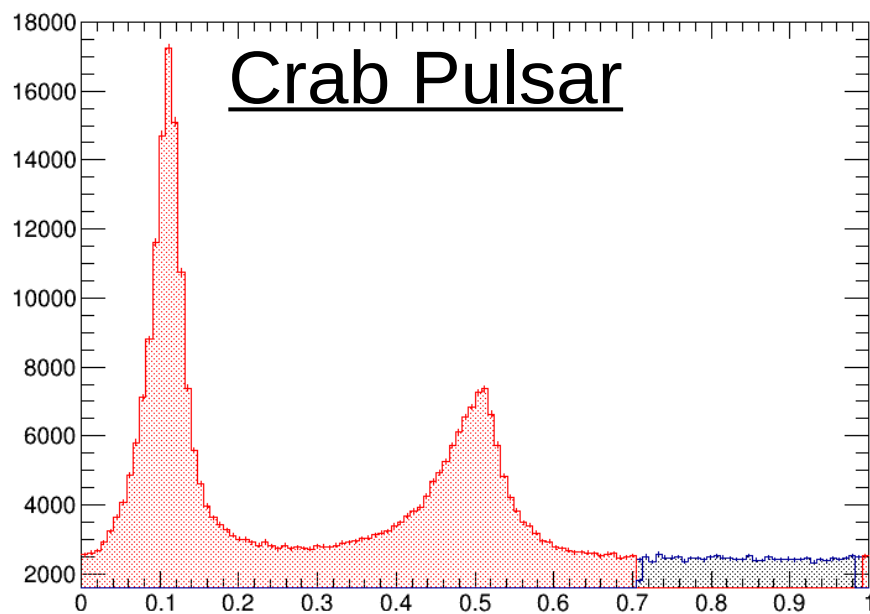
PR_off

$$\alpha = \left(\frac{\text{PR}_{\text{off}}}{\text{PR}_{\text{on}}} \right)$$

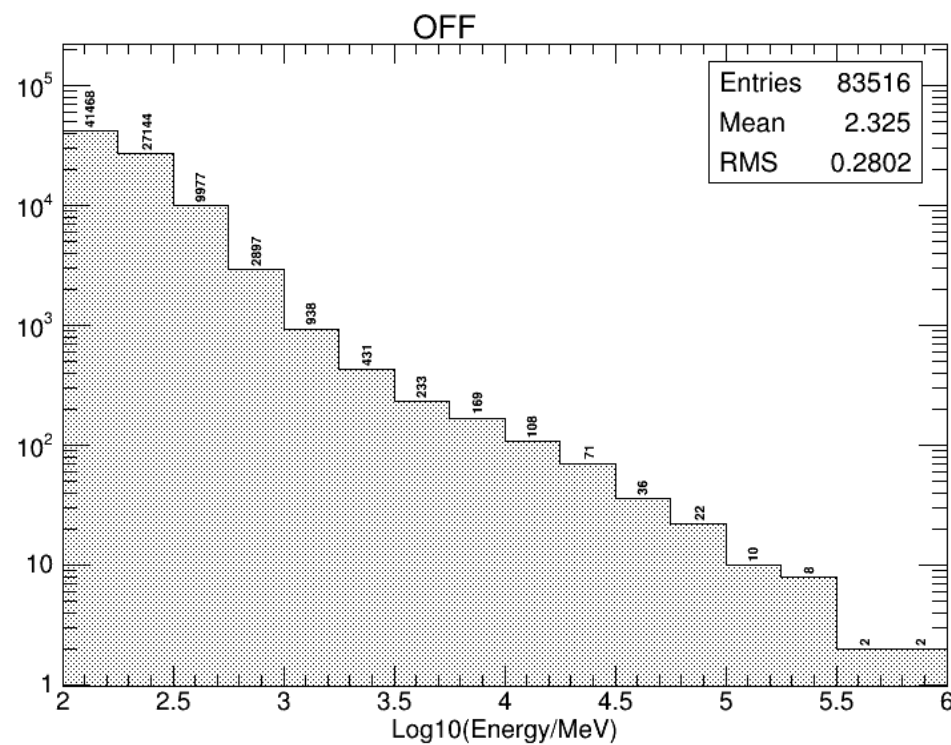
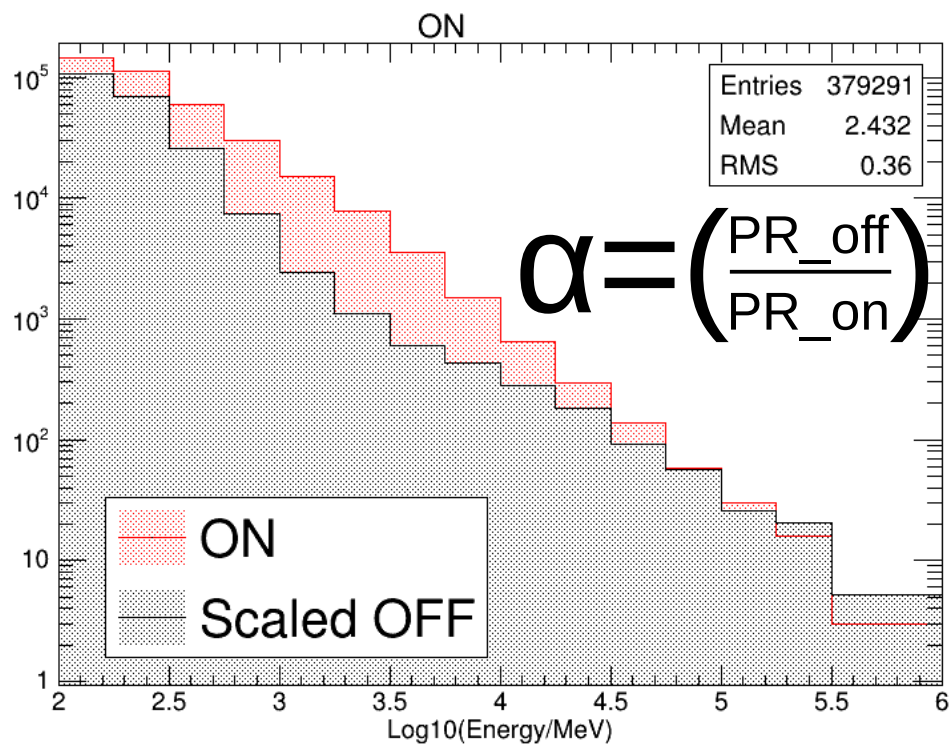
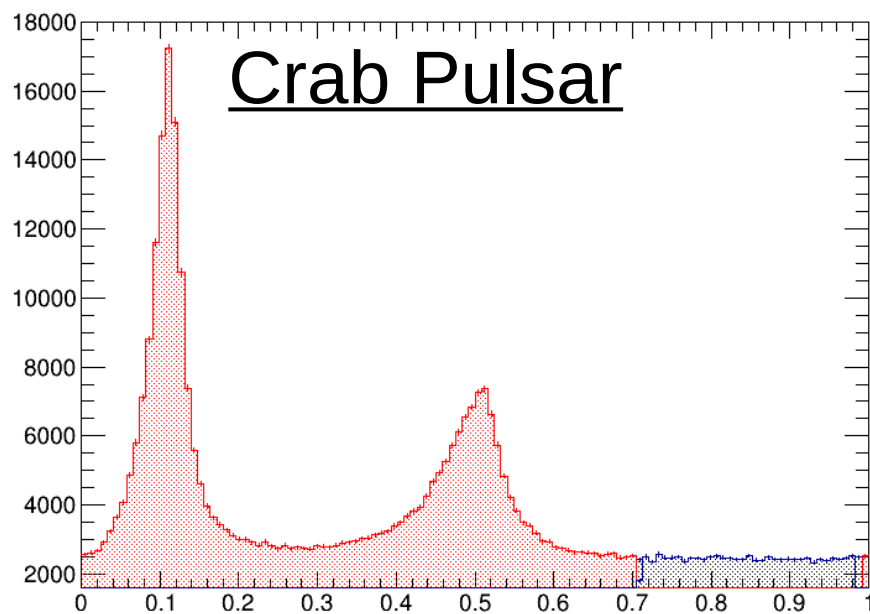
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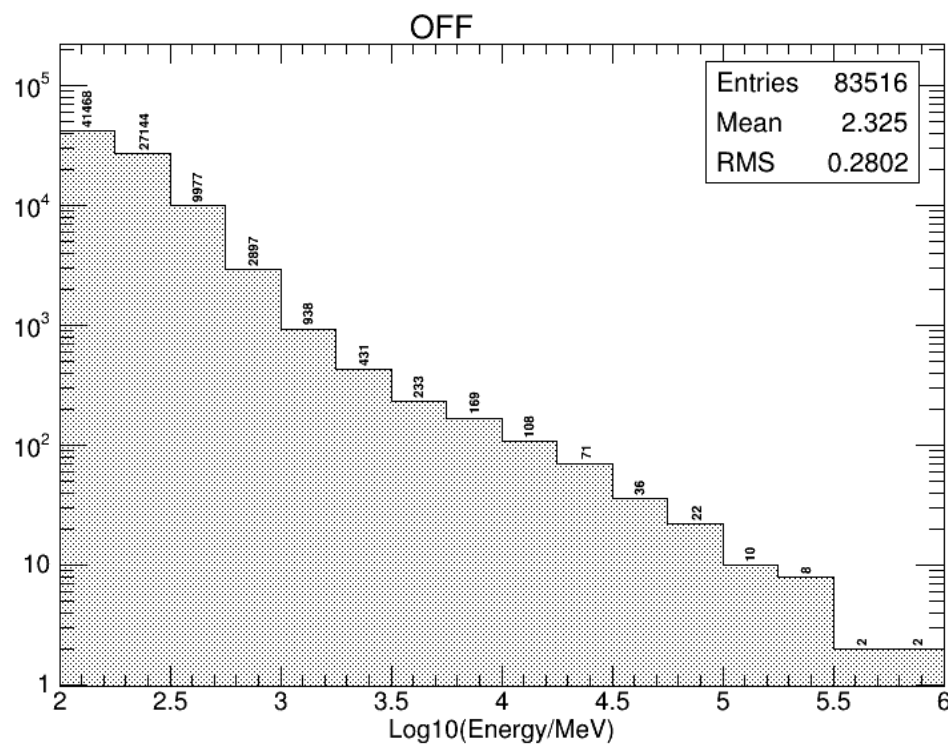
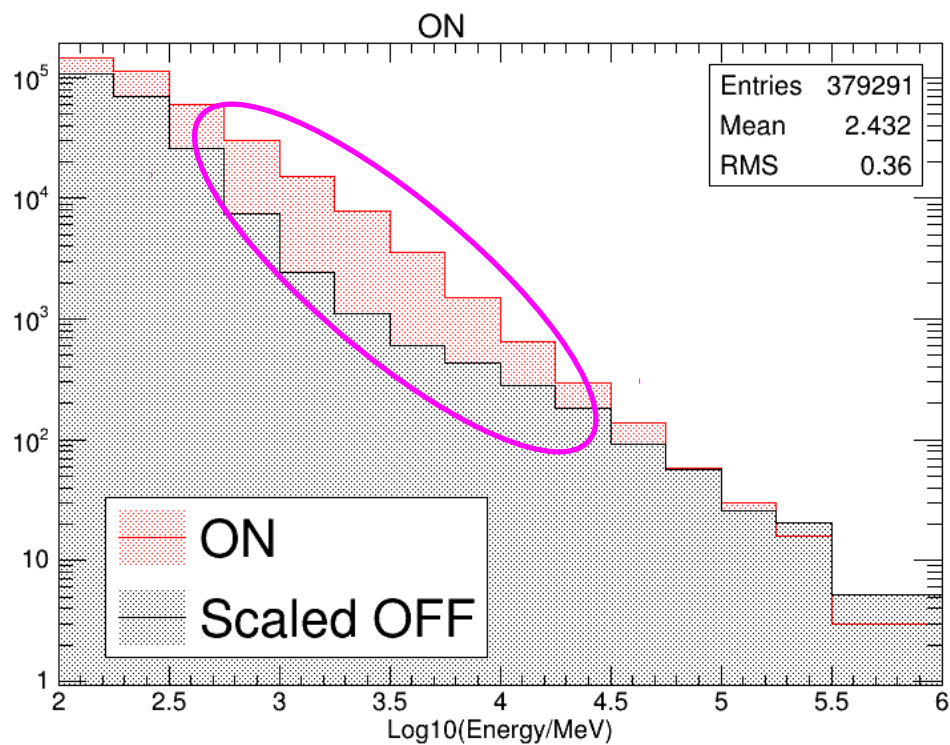
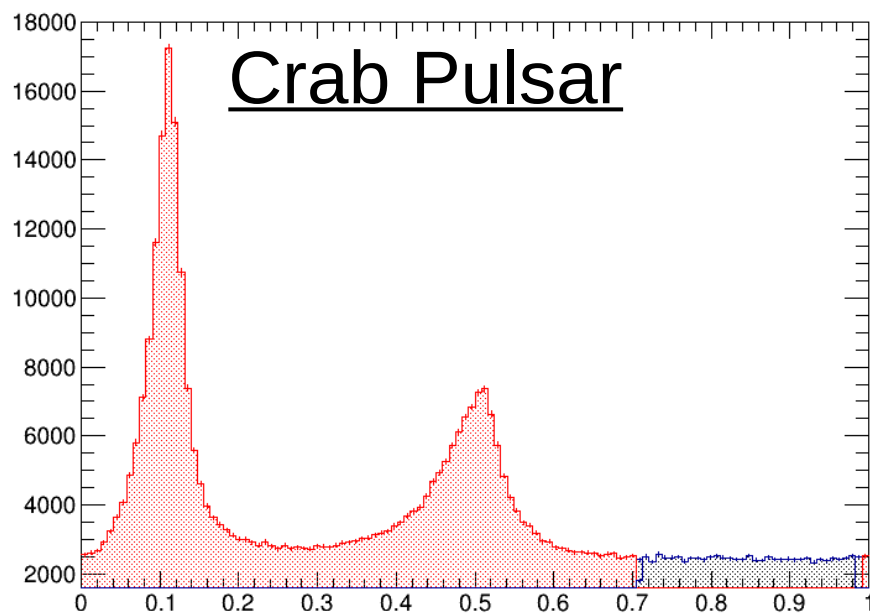
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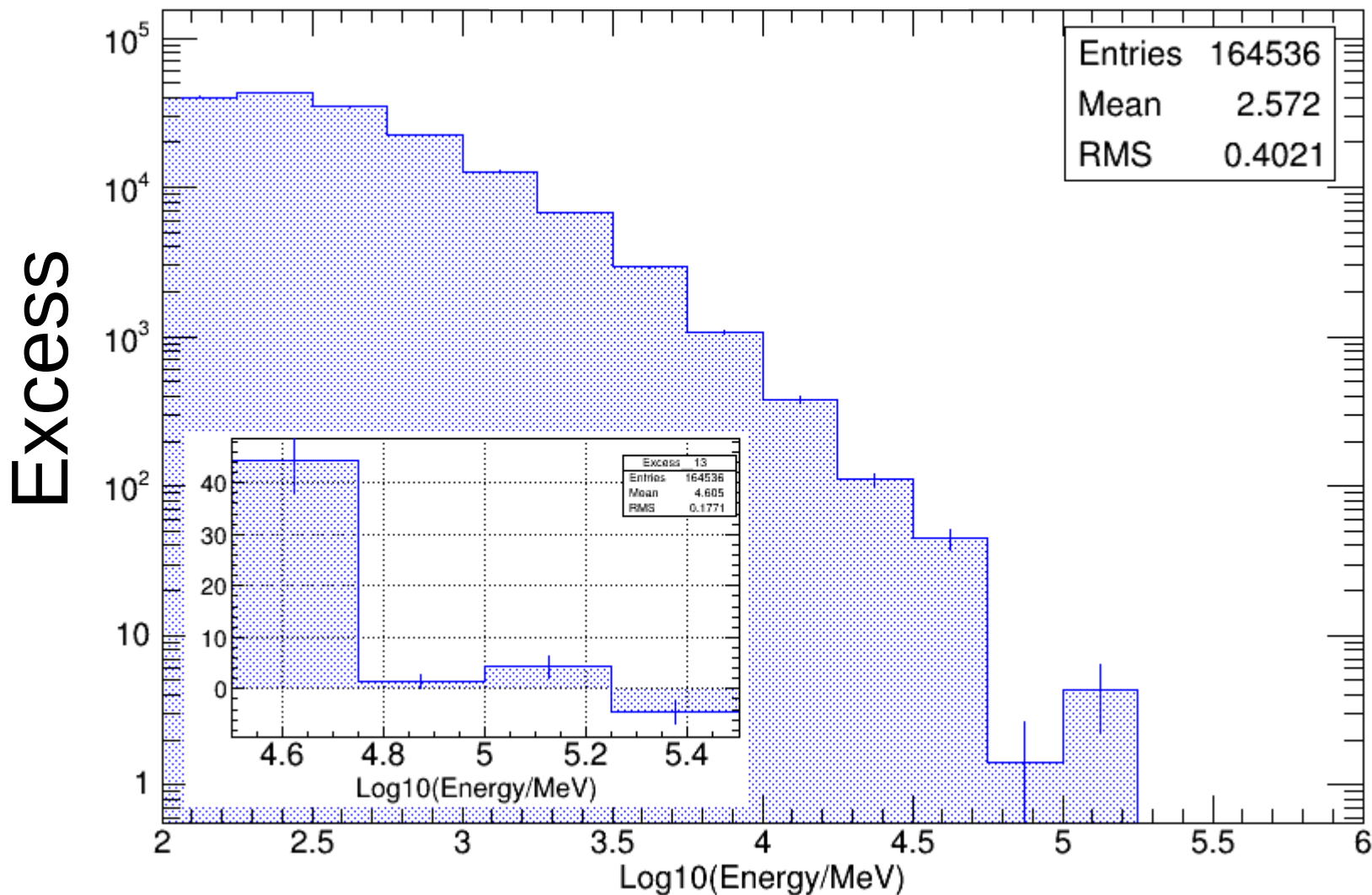


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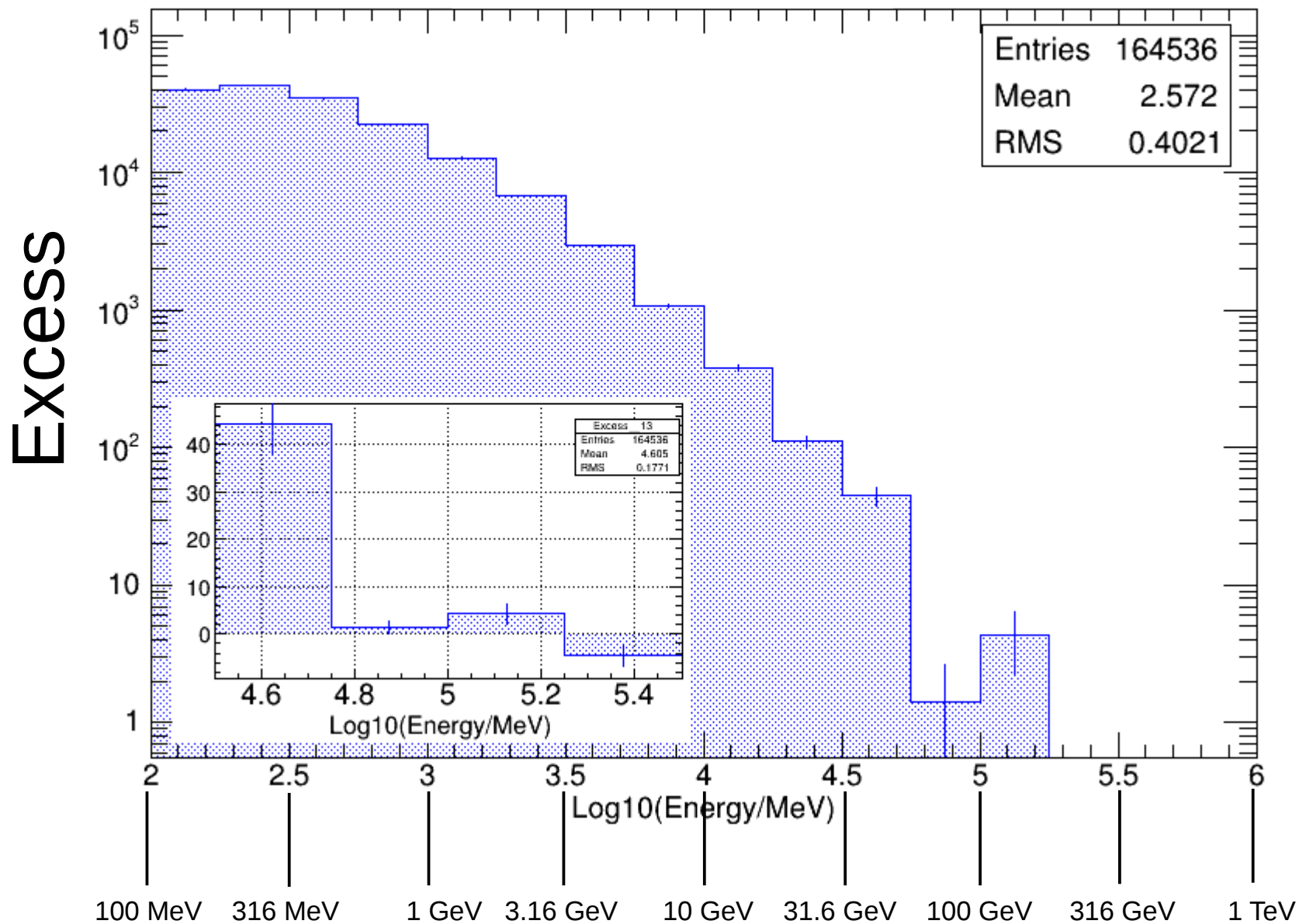
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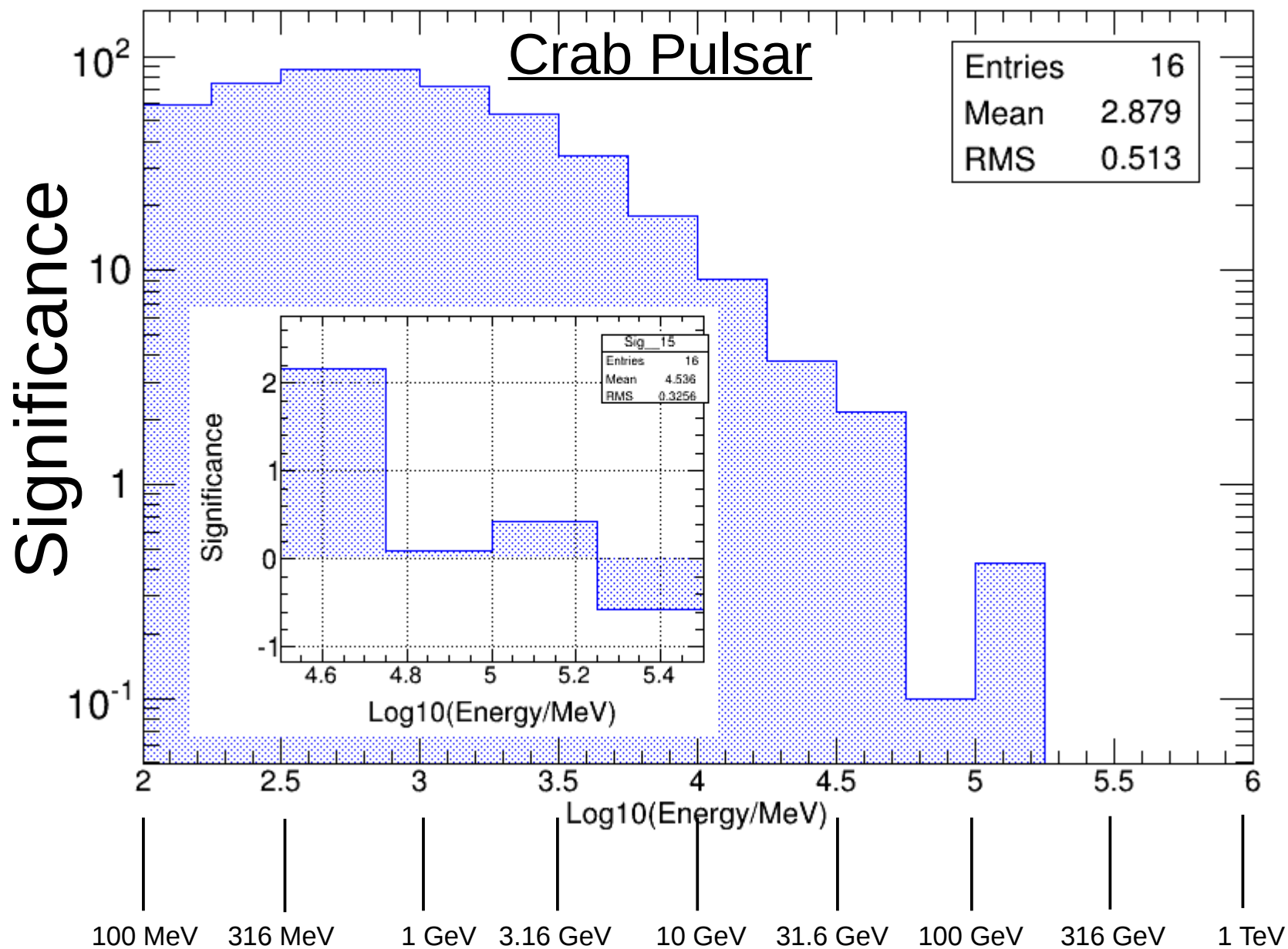


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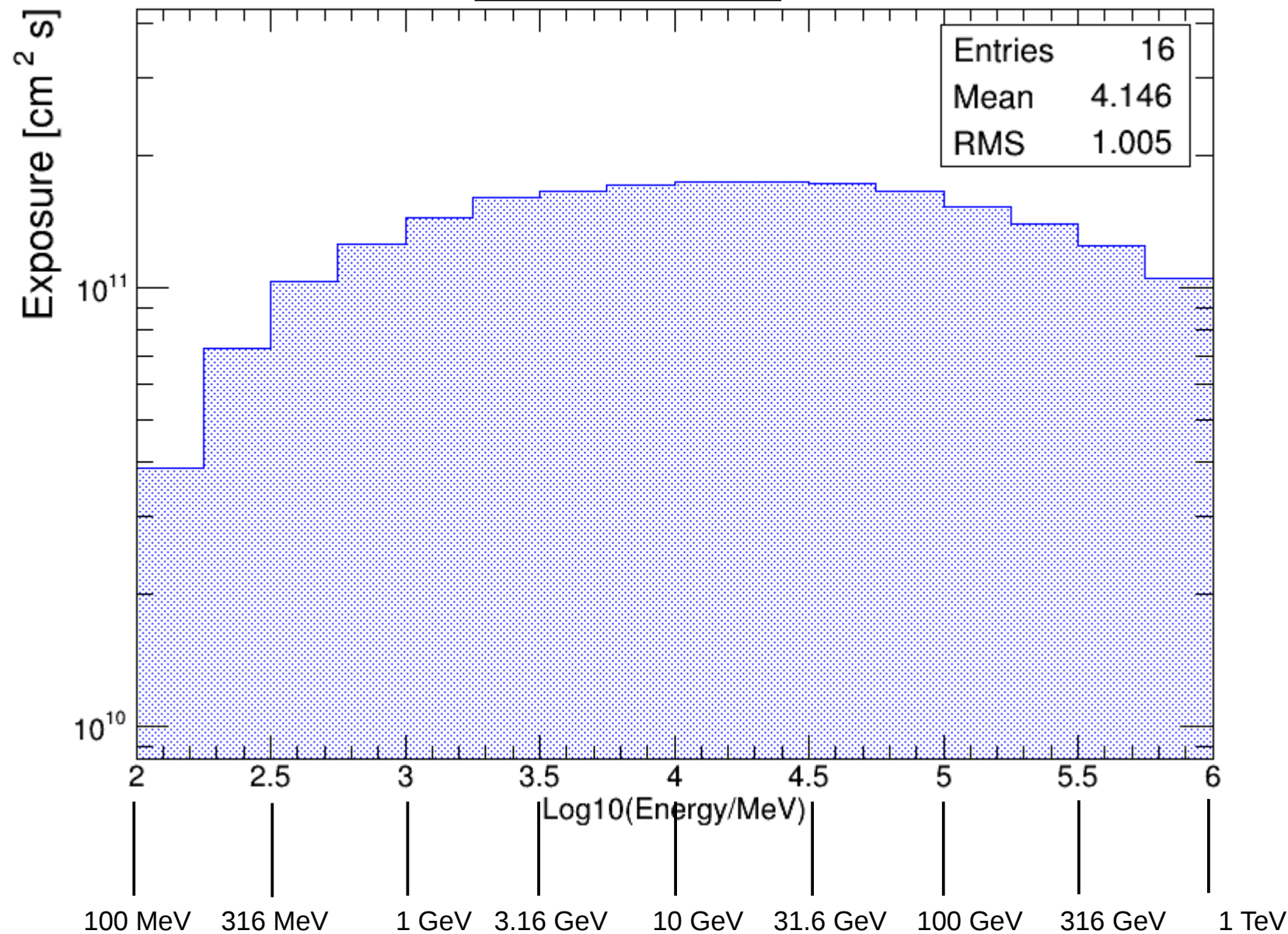


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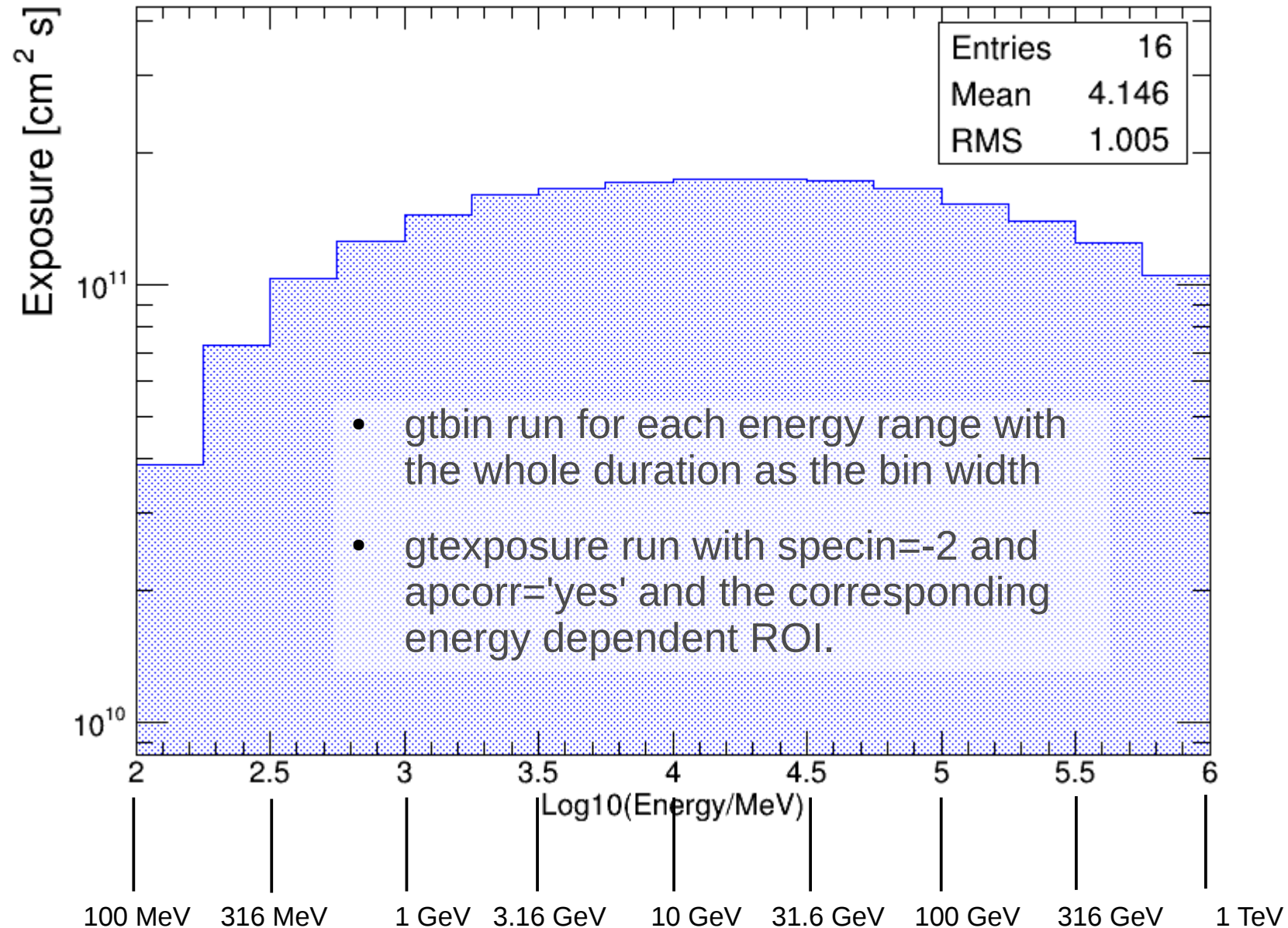
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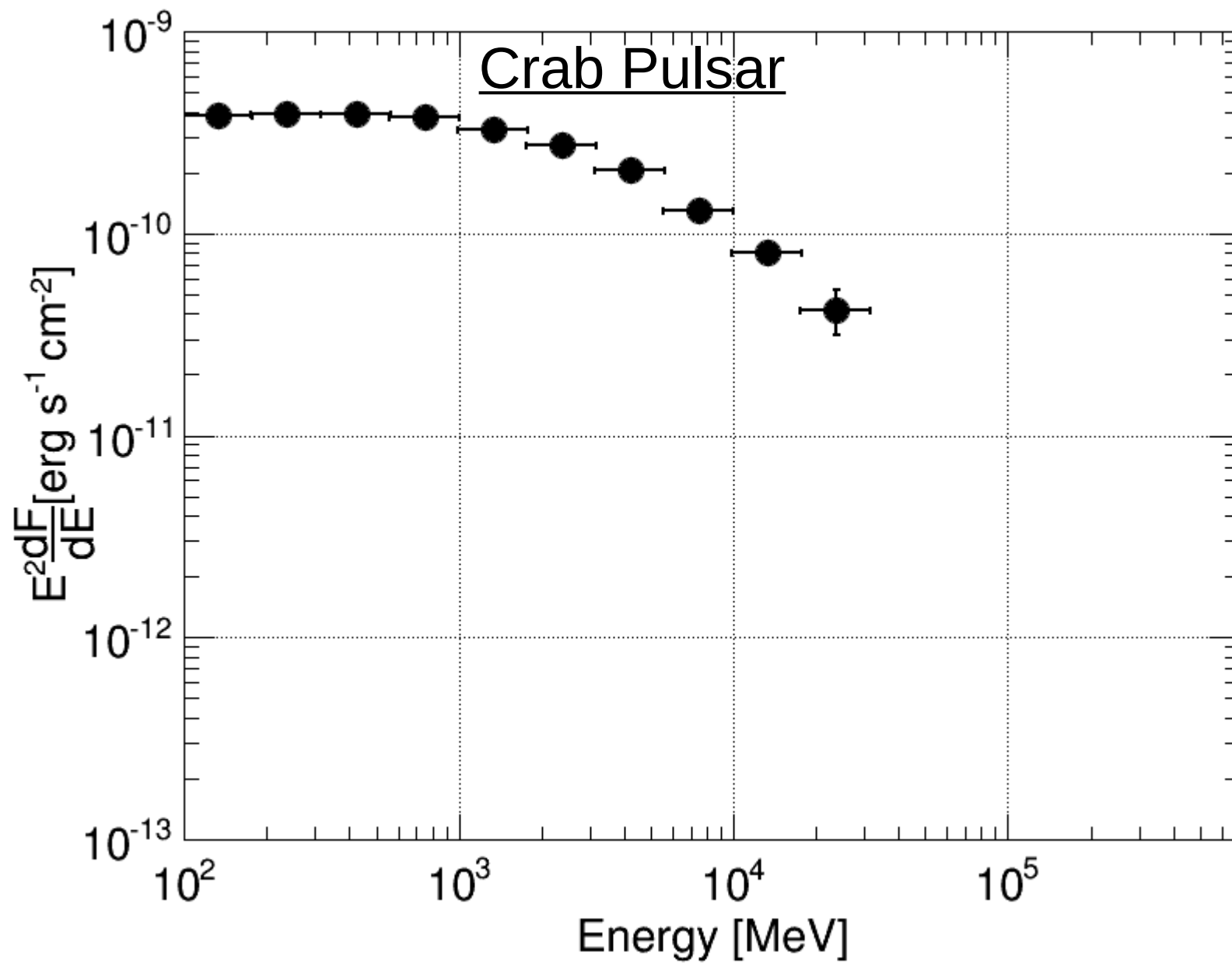


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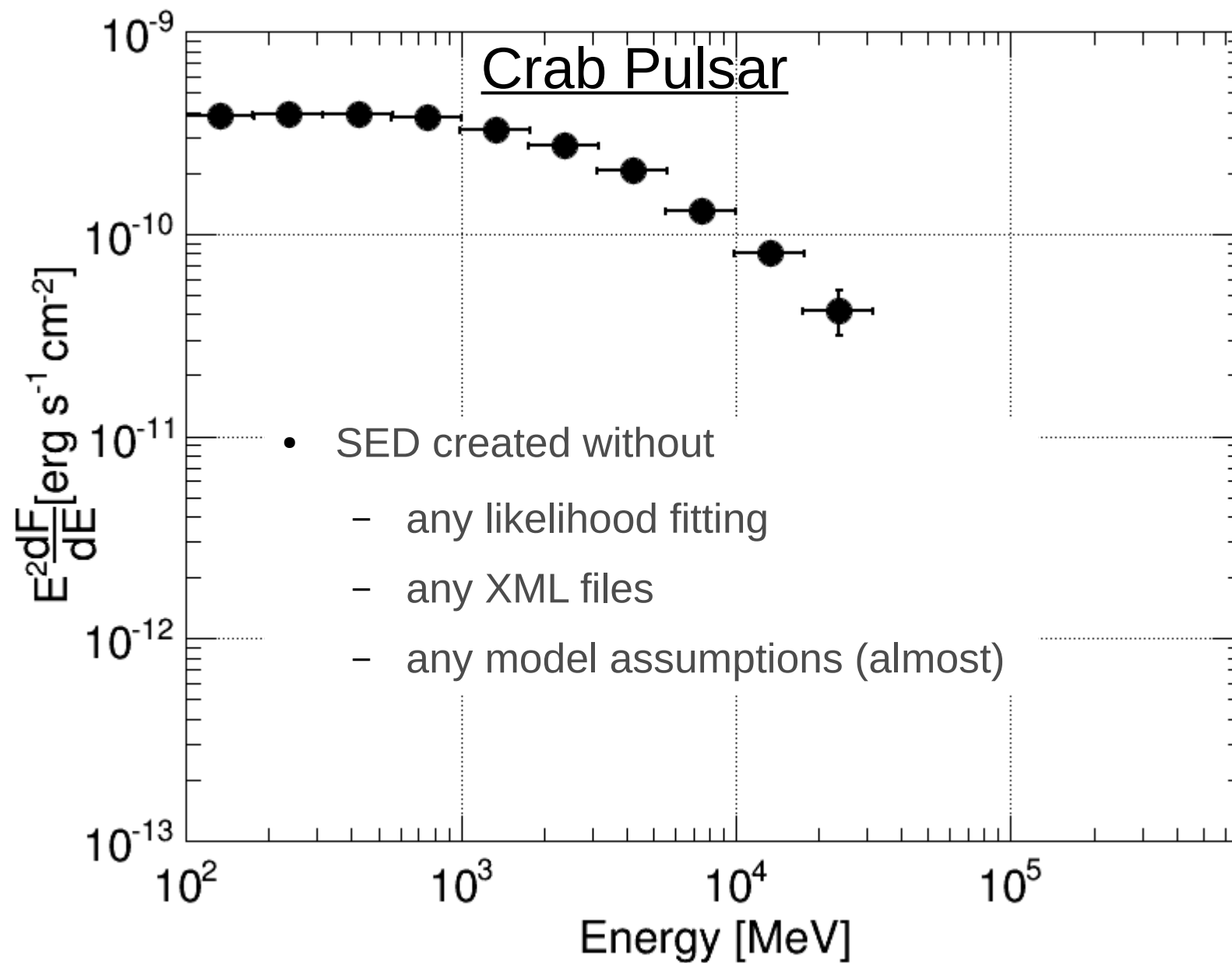
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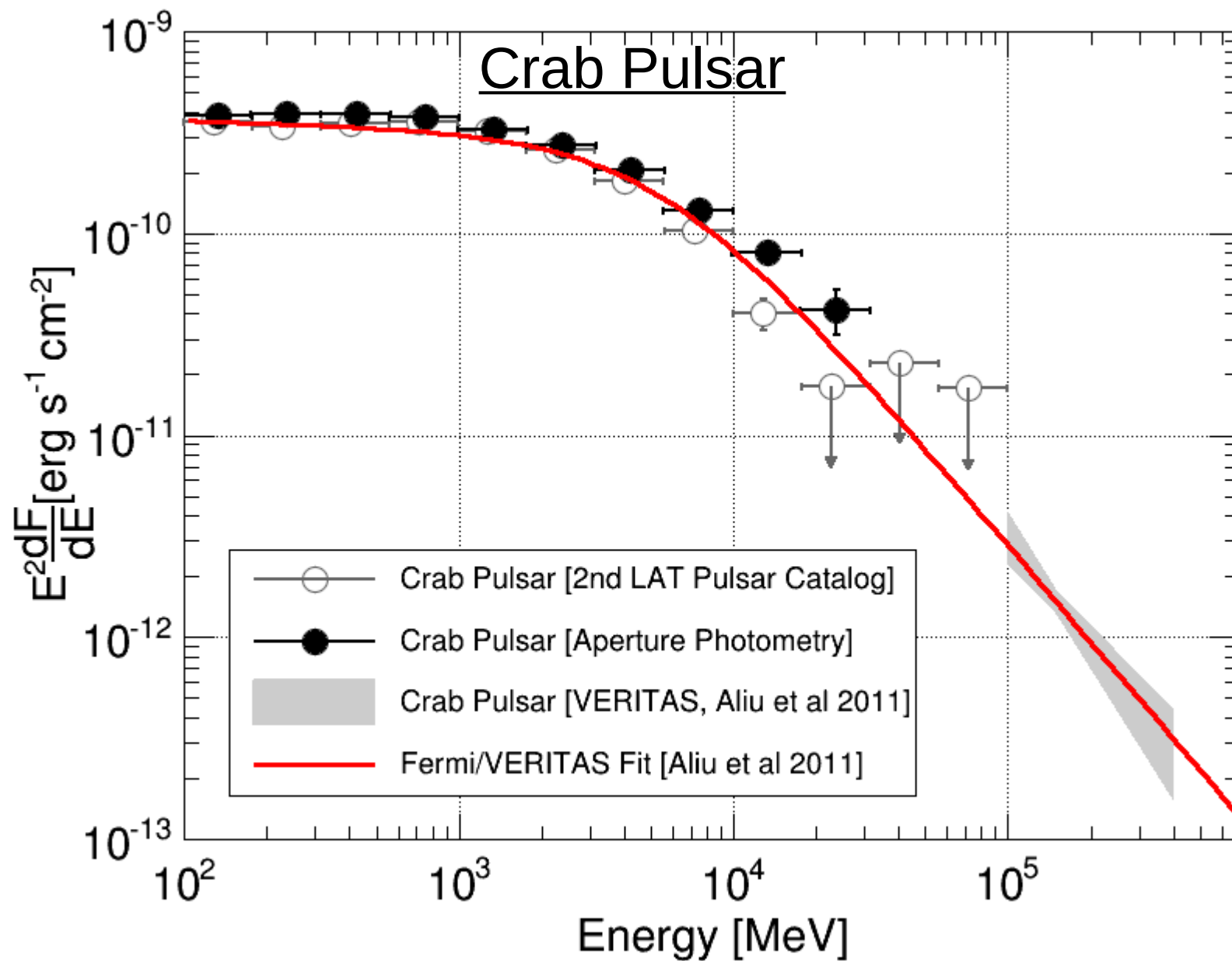
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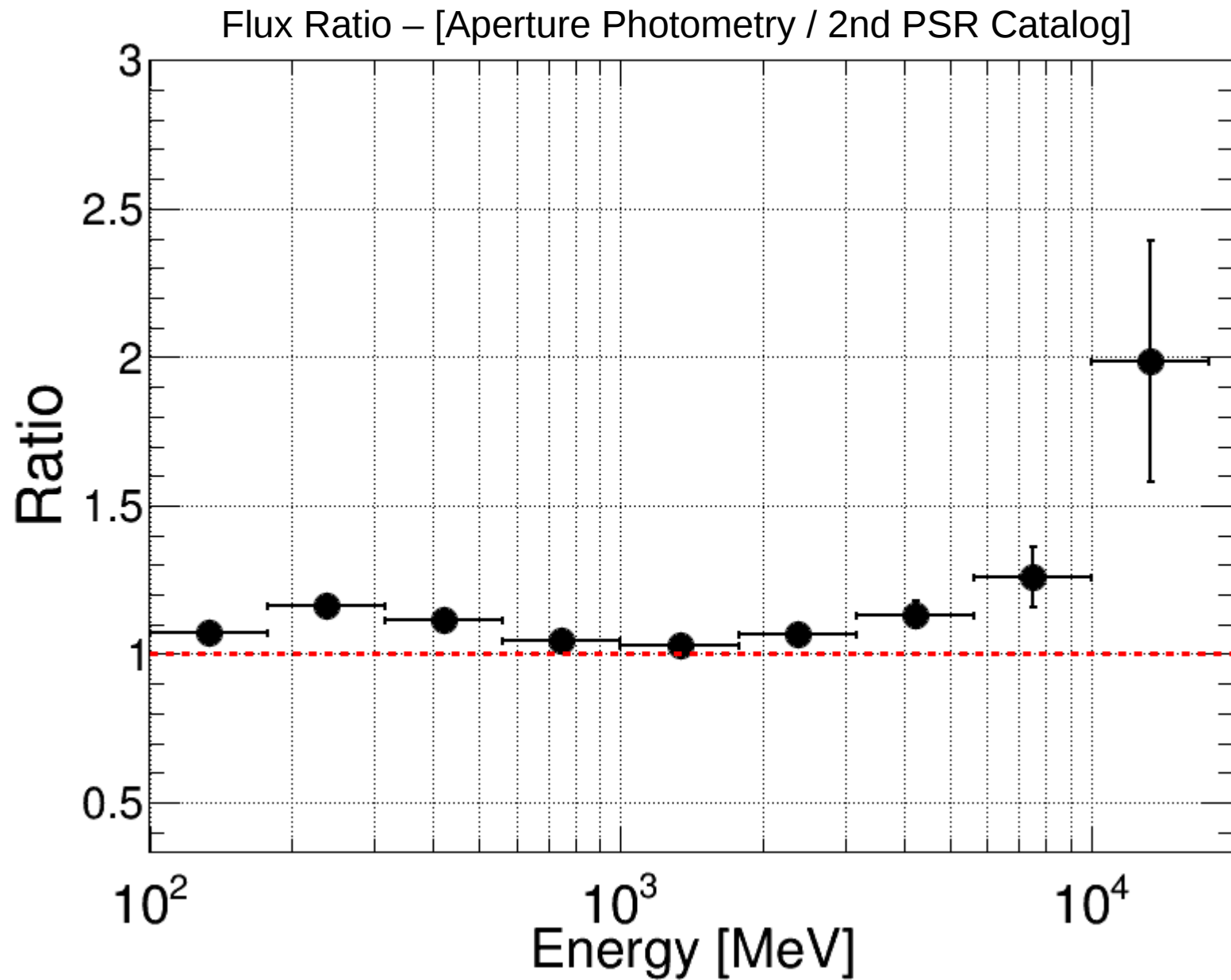
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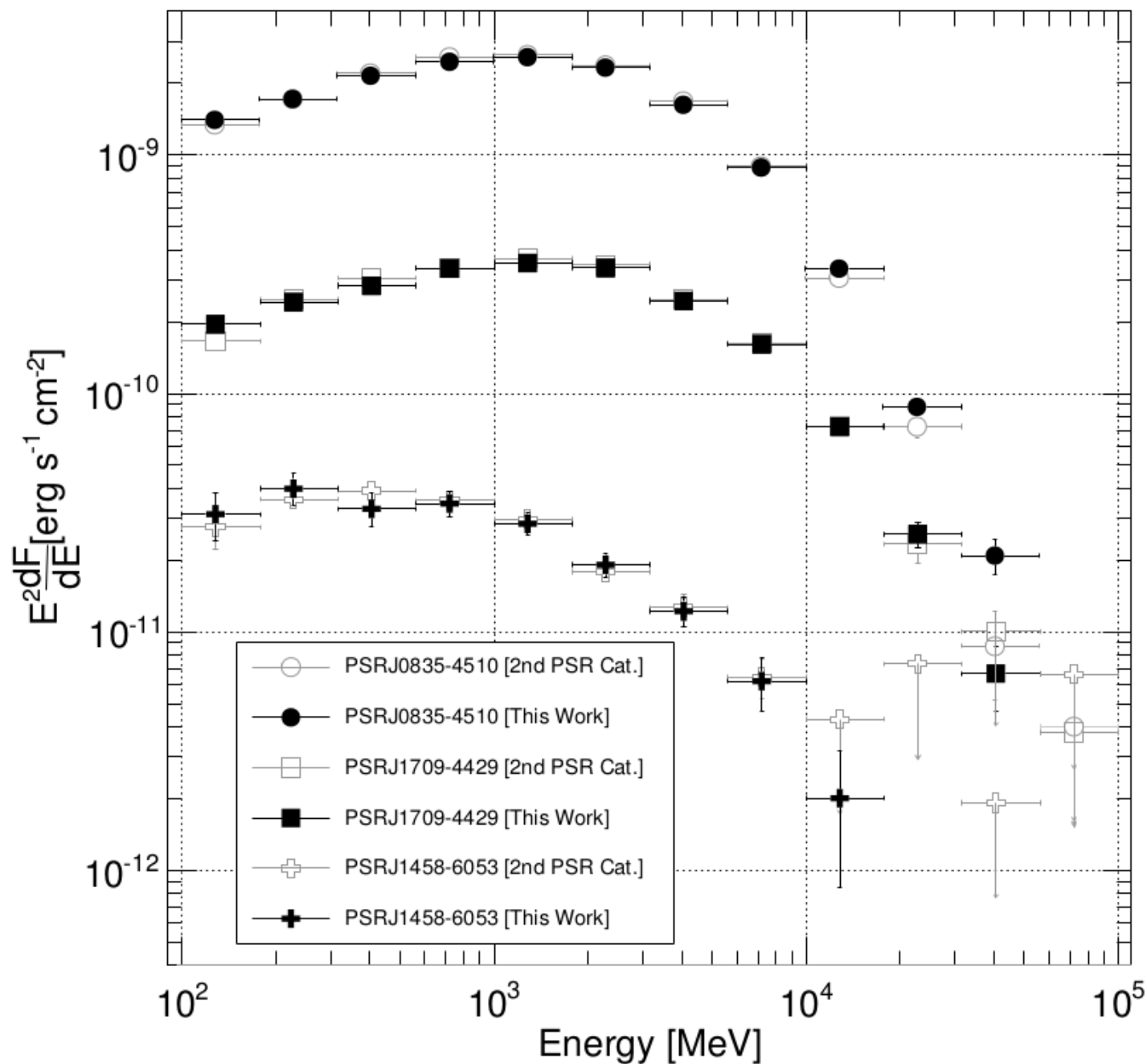
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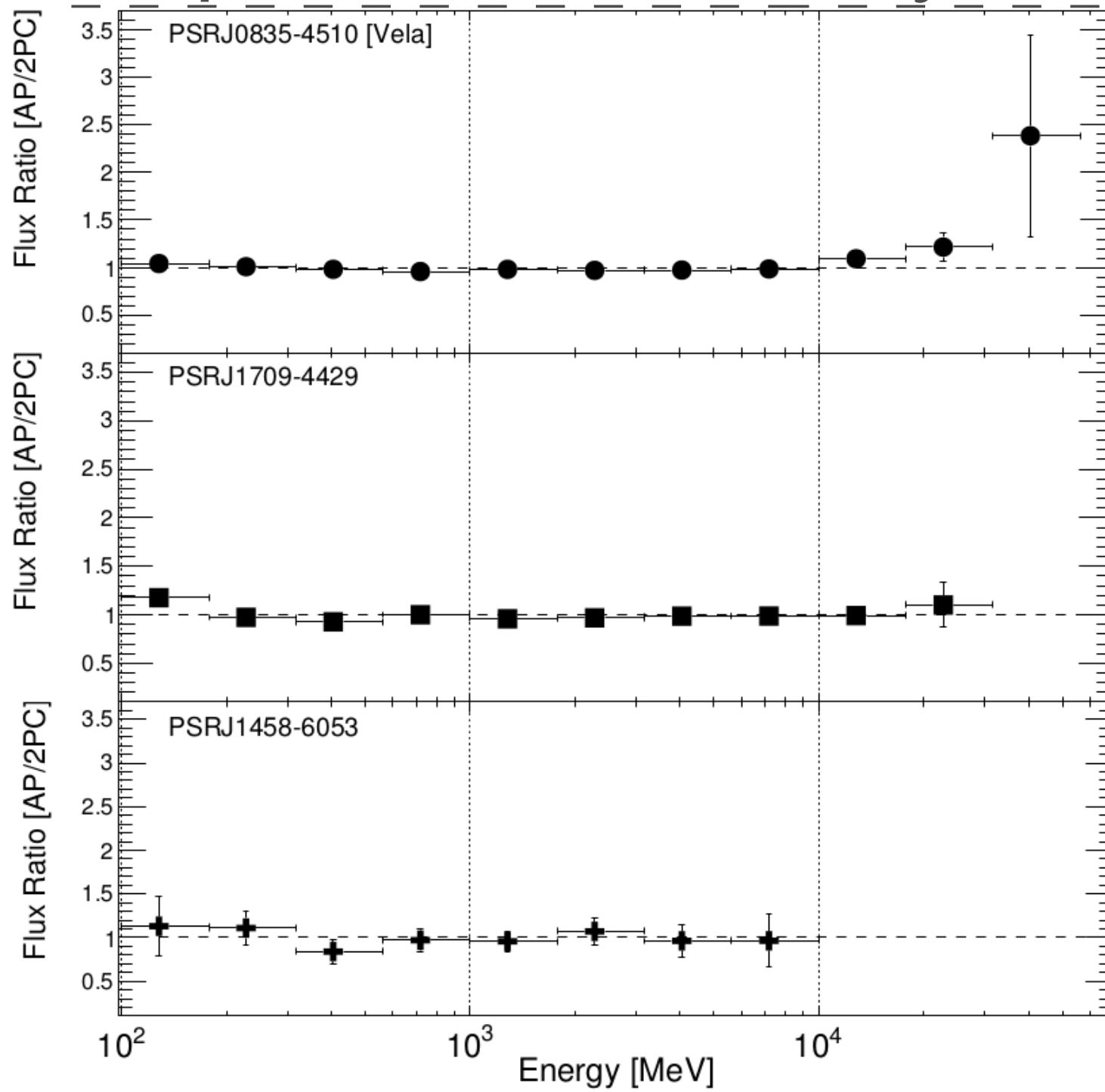


Aperture Photometry with Pulsars



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- Spanning 3 decades in flux, aperture photometry SEDs look very similar to likelihood (2nd pulsar catalogue).

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- Spanning 3 decades in flux, aperture photometry SEDs look very similar to likelihood (2nd pulsar catalogue).
- Agreement within ~10-20%

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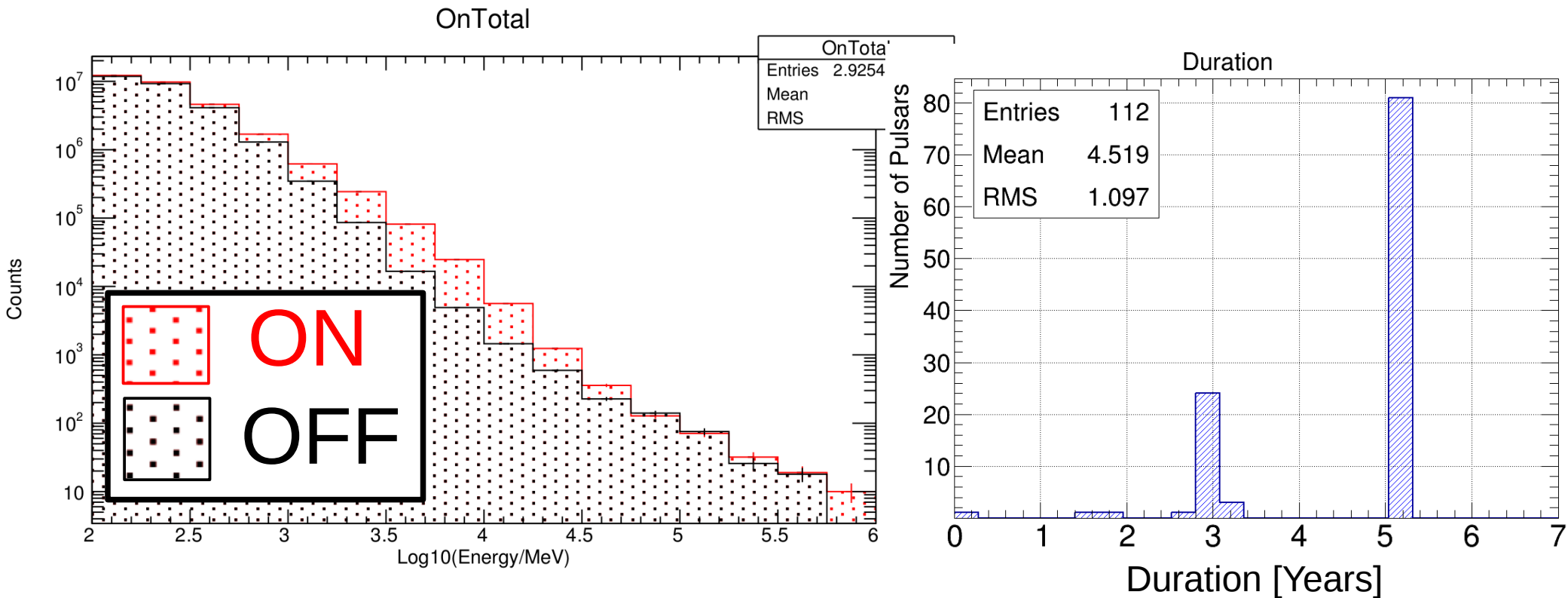
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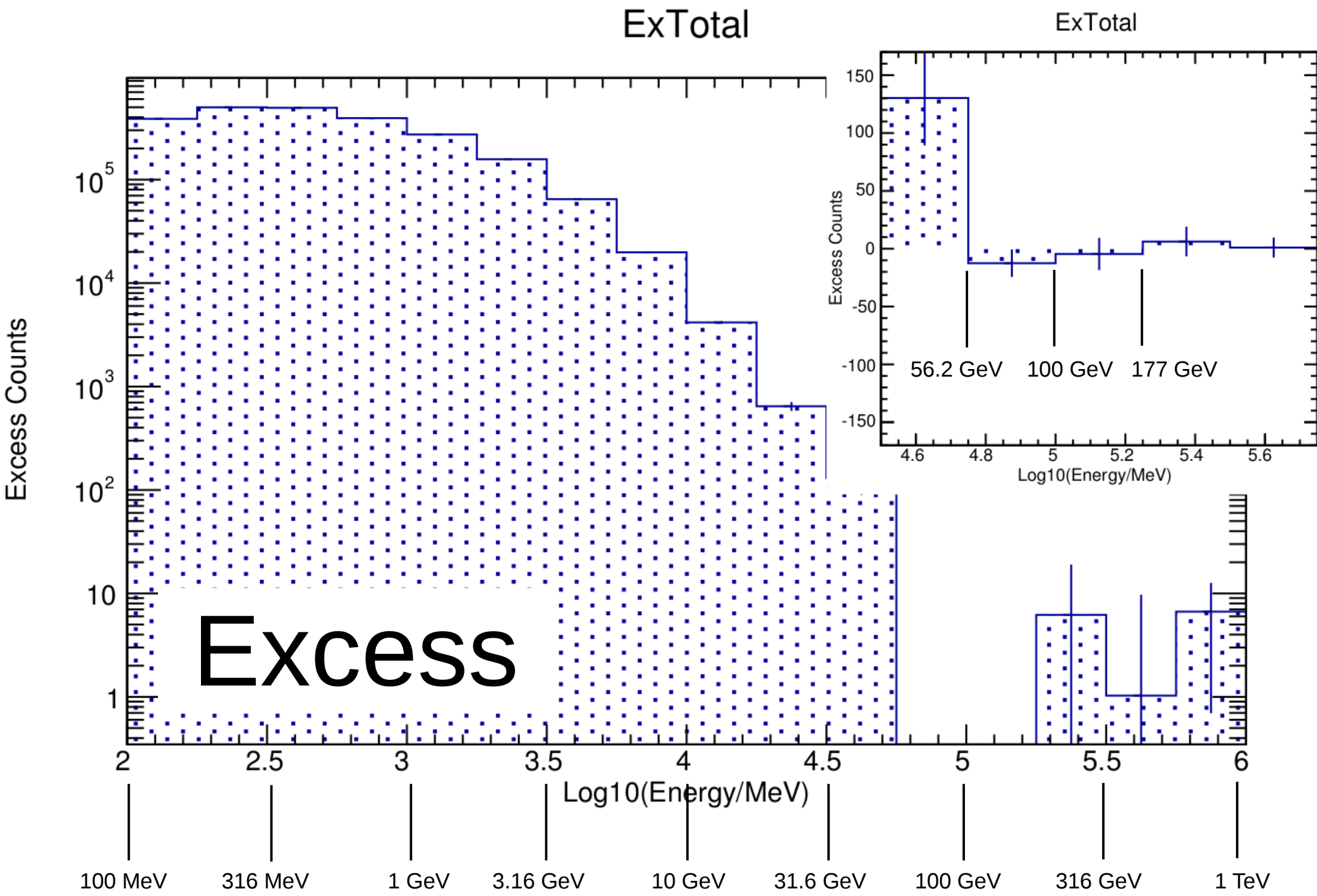
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Aperture Photometry with Pulsars



- **Stack the On/Off regions of 112 pulsars from the 2nd LAT PSR Cat.**
- Average of 4.5 years of data per pulsar (limited by availability of timing solution)
- Crab pulsar excluded
- On/Off phase gates listed in 2nd LAT PSR Cat.

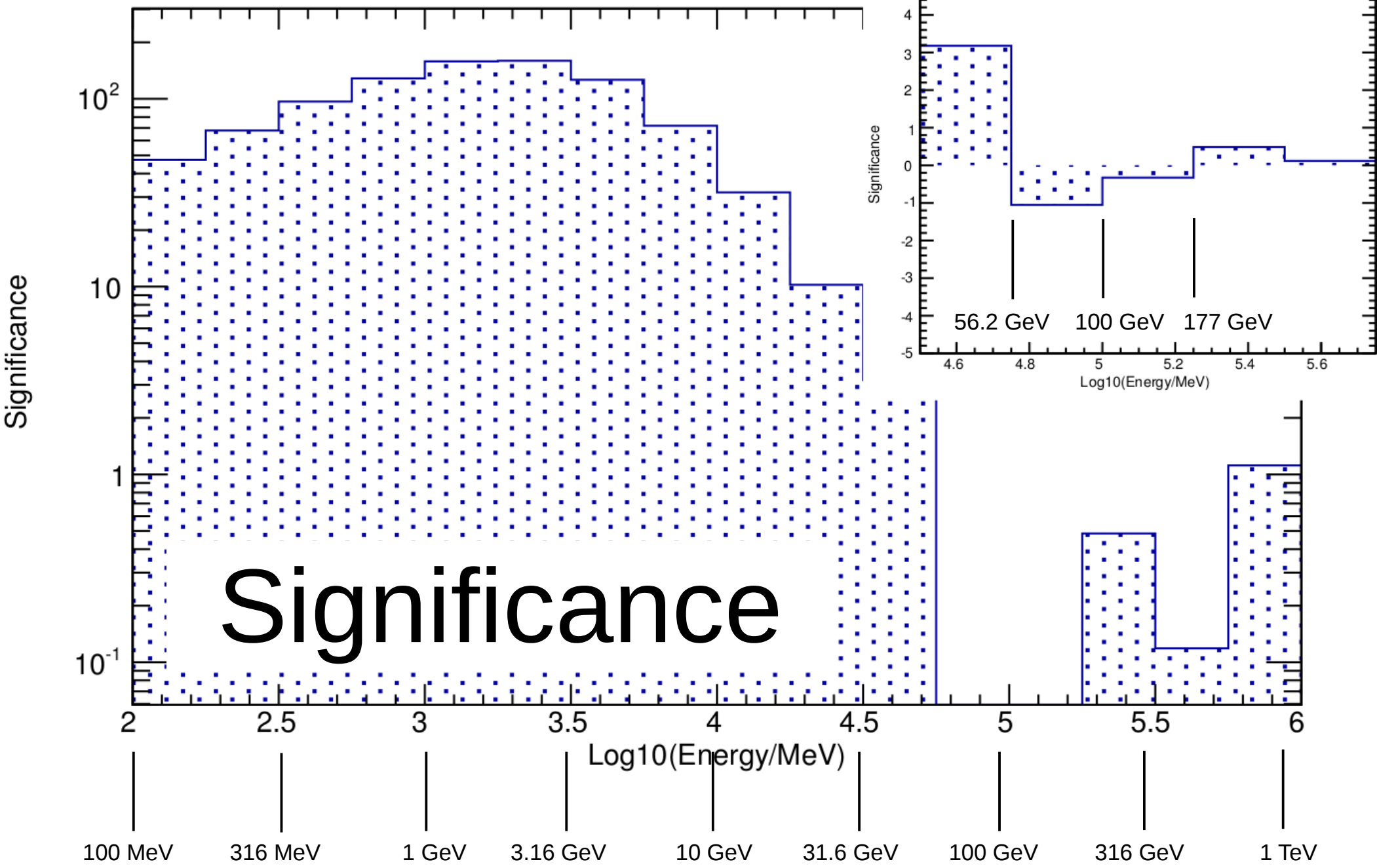
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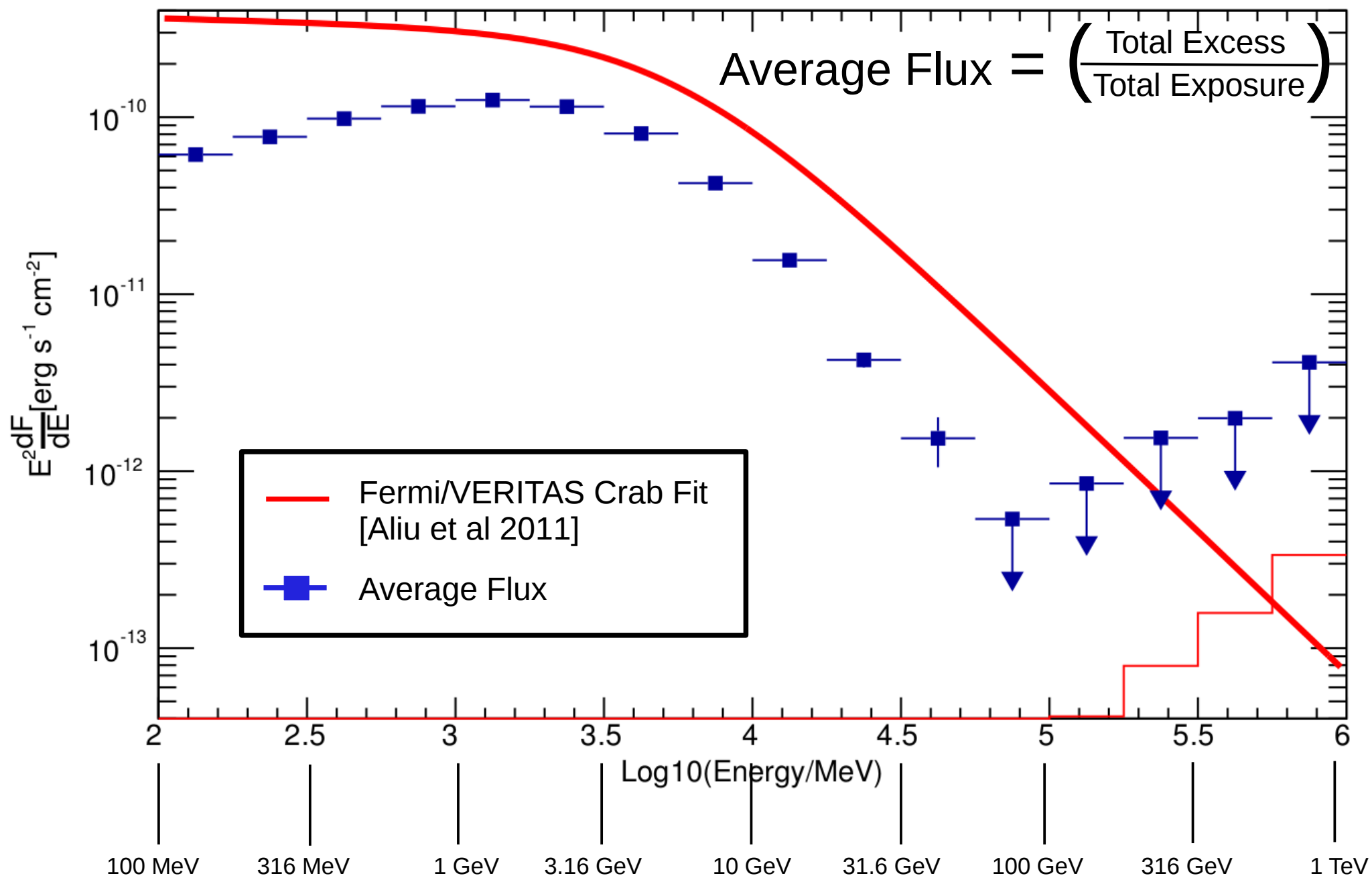
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SigTotal

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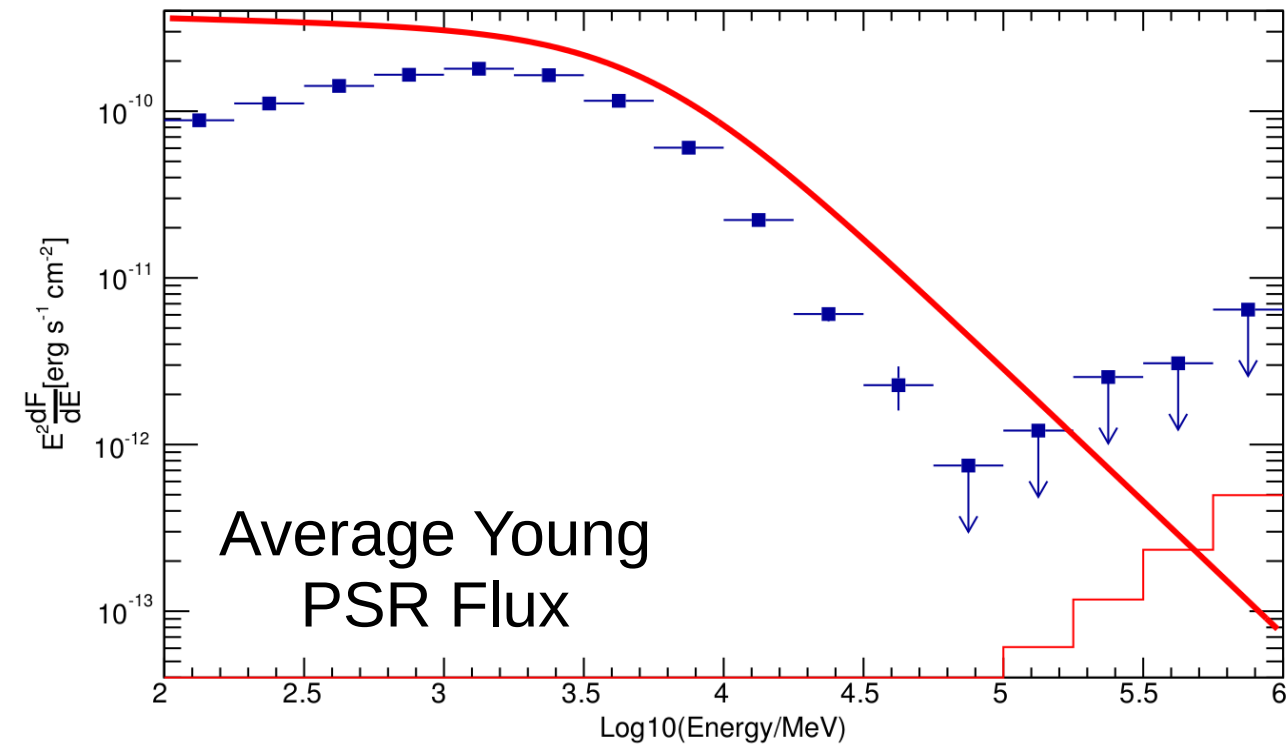


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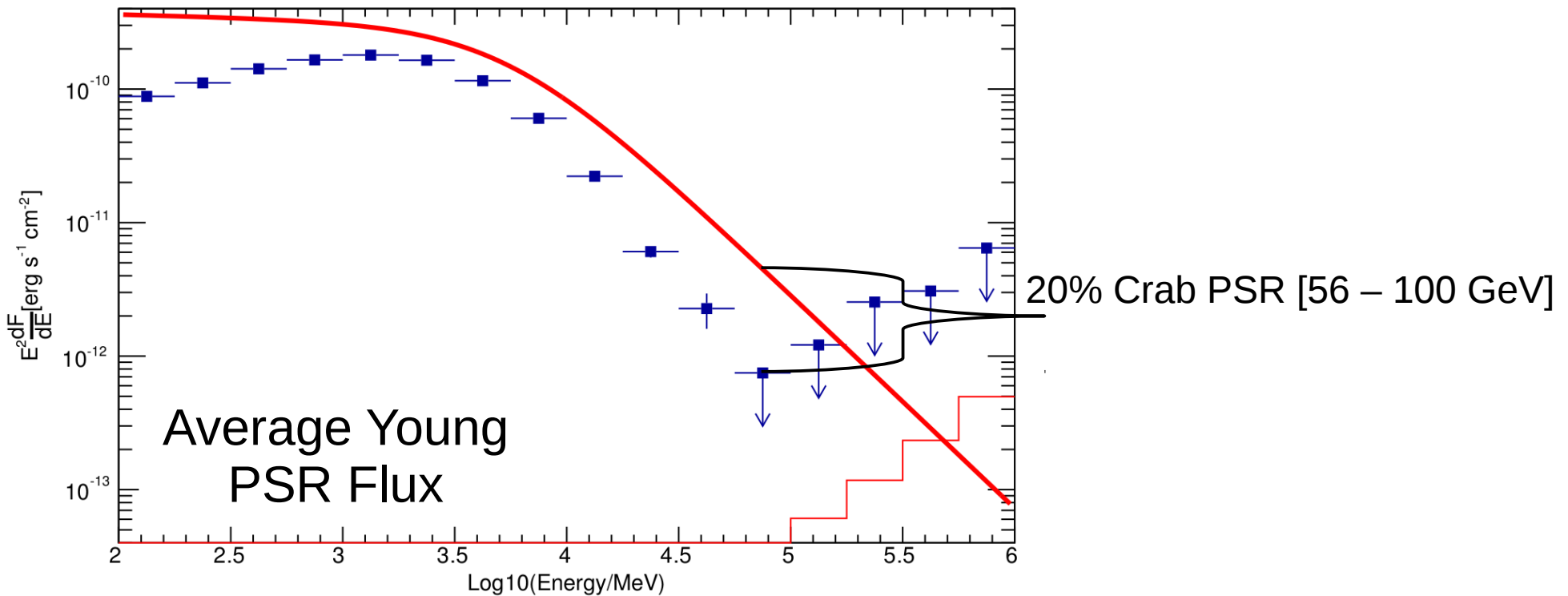
Limits on the emission from pulsars

74 “young” Pulsars



Limits on the emission from pulsars

74 “young” Pulsars



- If there is emission from these 74 pulsars between 56 and 100 GeV, the average level is below 20% of the Crab PSR emission:

- 74 (100%) emitting at 20% Crab PSR

or

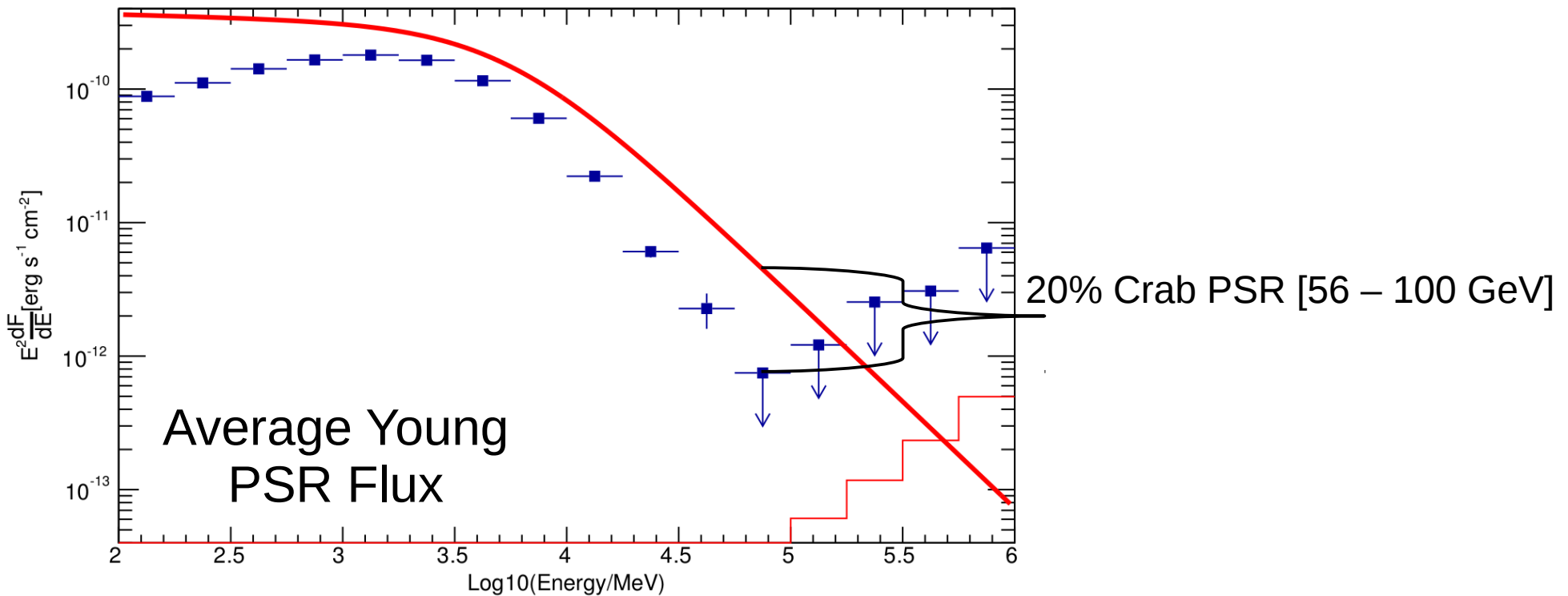
- 14 (20%) emitting at 100% Crab PSR and 60 (80%) at zero Crab PSR

or

- 3 (4%) emitting at 500% the Crab PSR and 71 (96%) at zero Crab PSR

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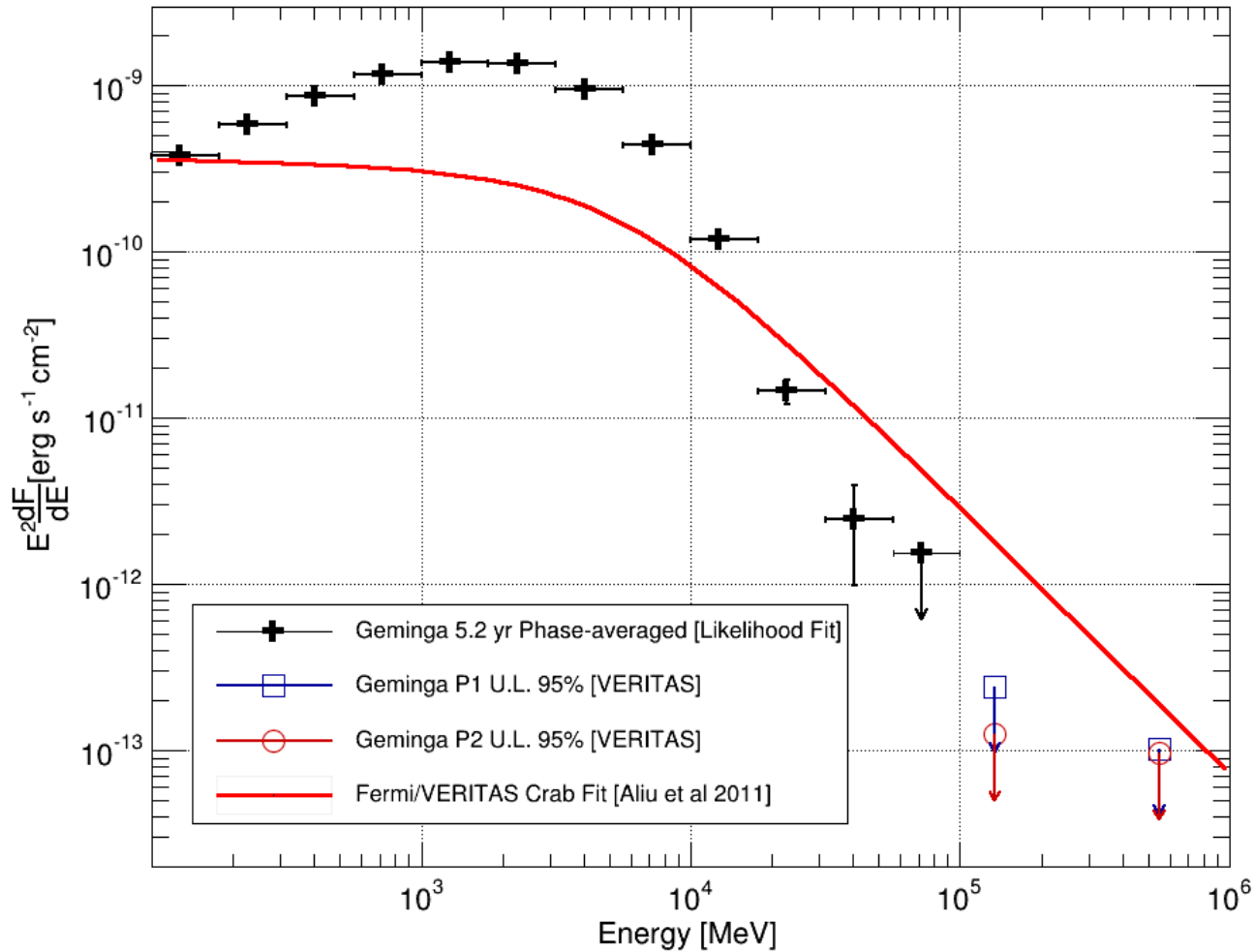
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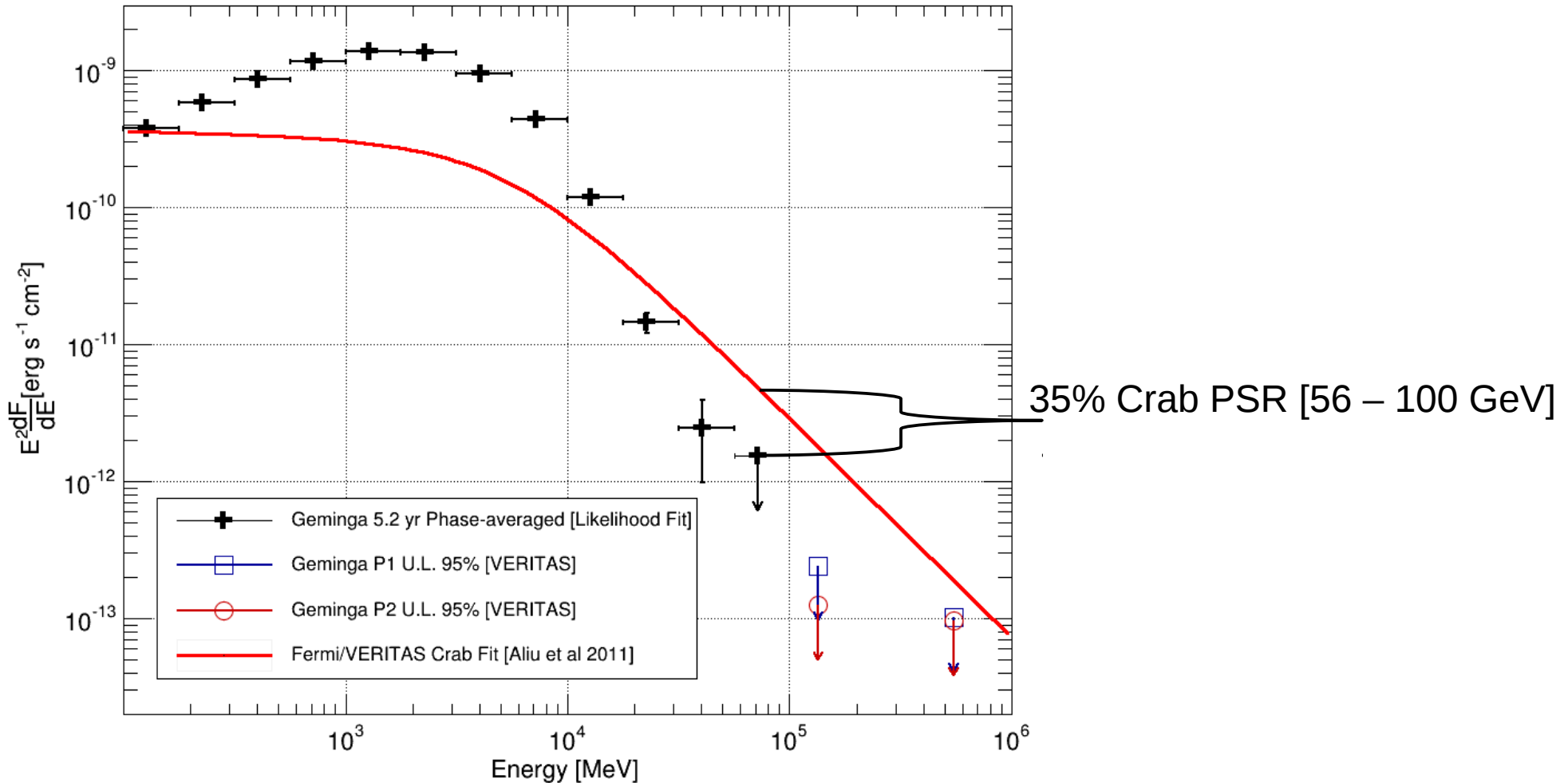
Limits on the emission from pulsars

5.2 years of Geminga



Limits on the emission from pulsars

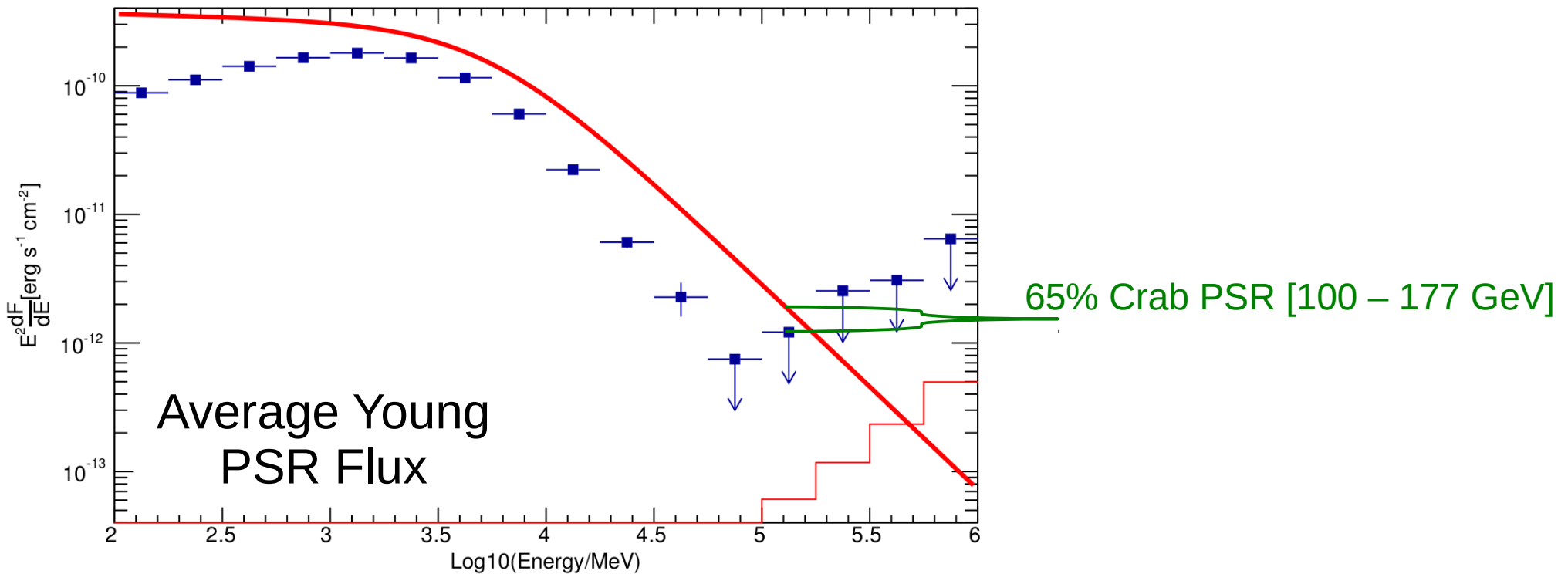
5.2 years of Geminga



- **A dedicated analysis of Geminga (and likely other pulsars) with 5yrs of data can set a limit of $\sim 35\%$ Crab pulsar in the 56-100GeV range**

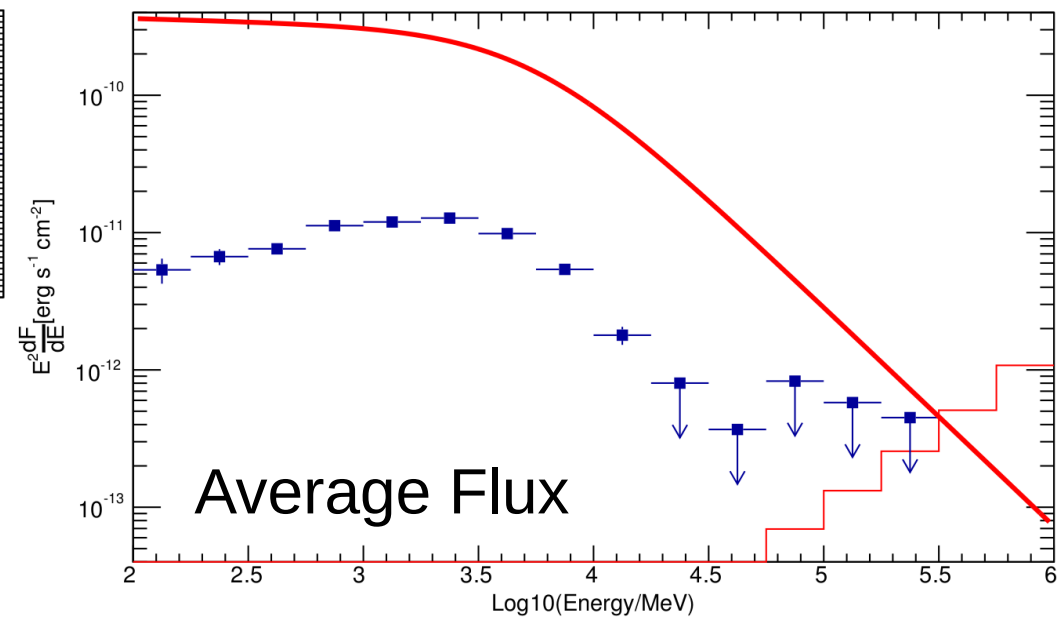
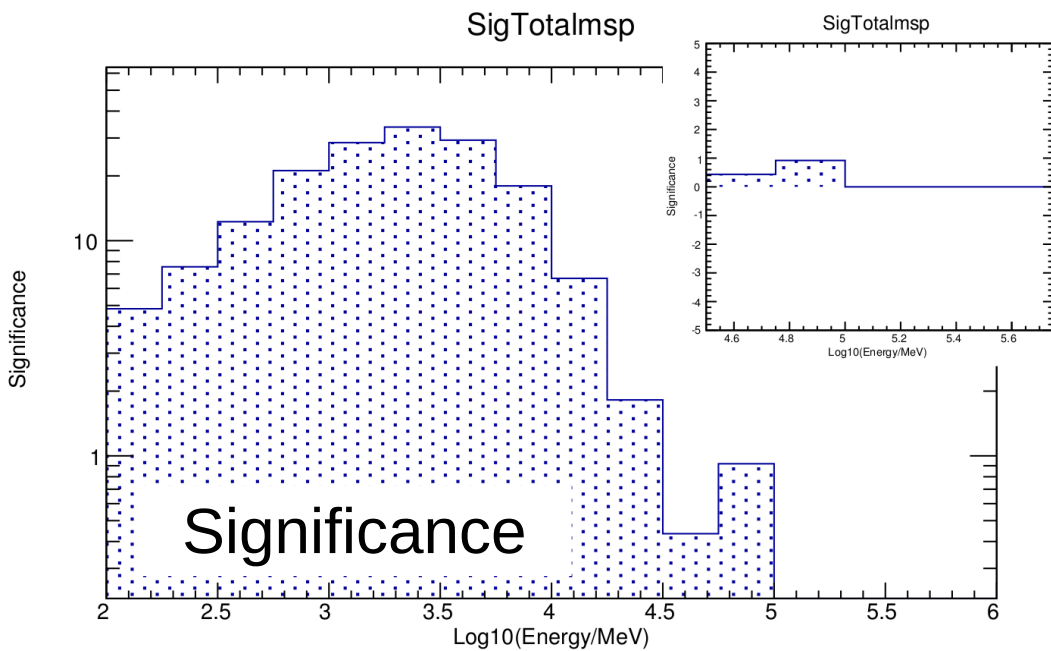
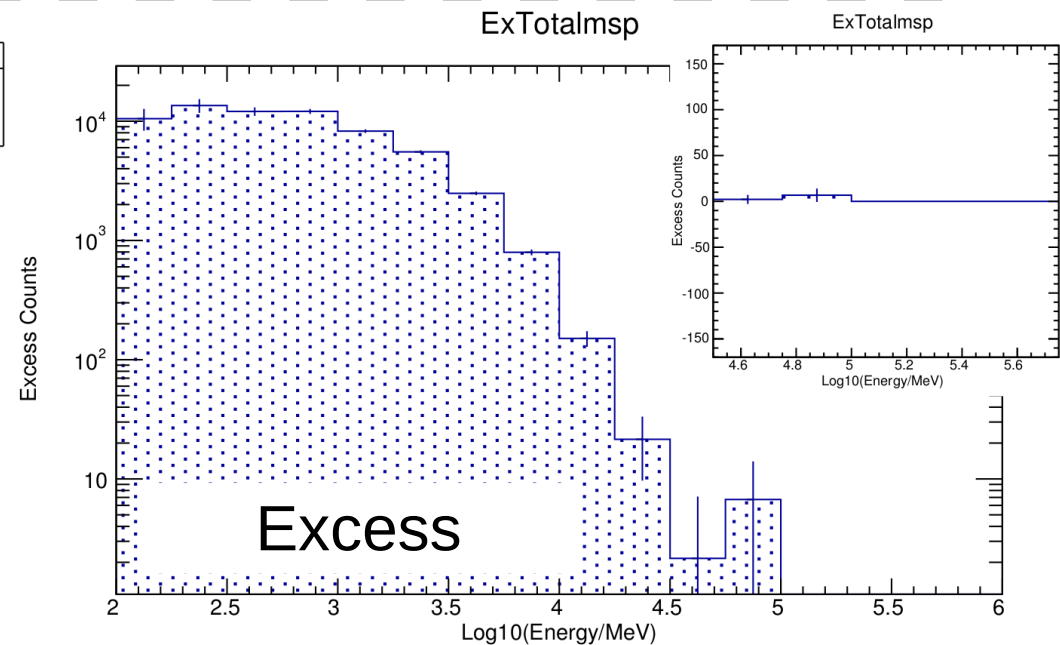
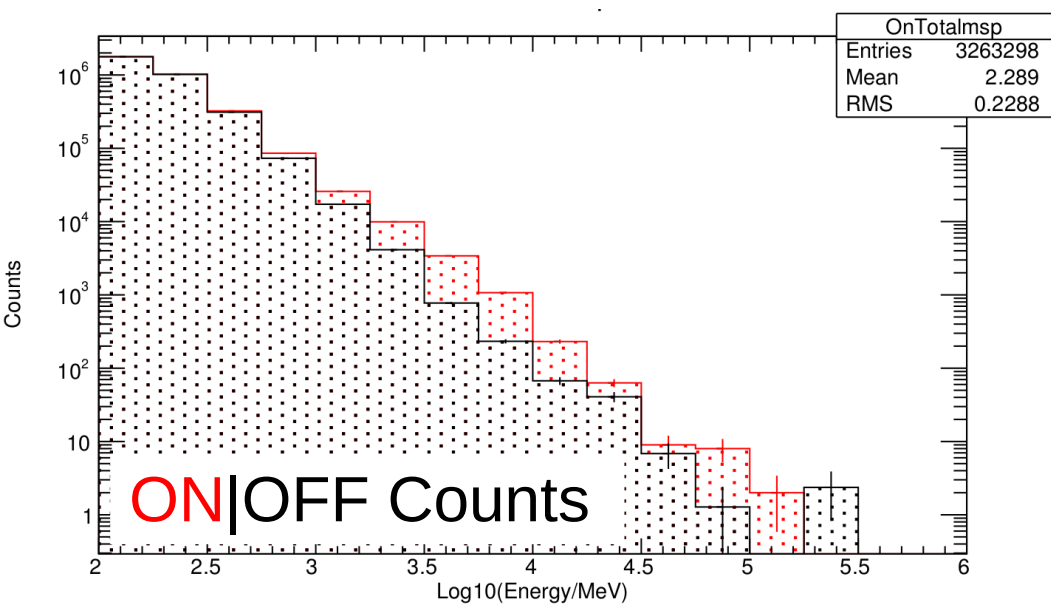
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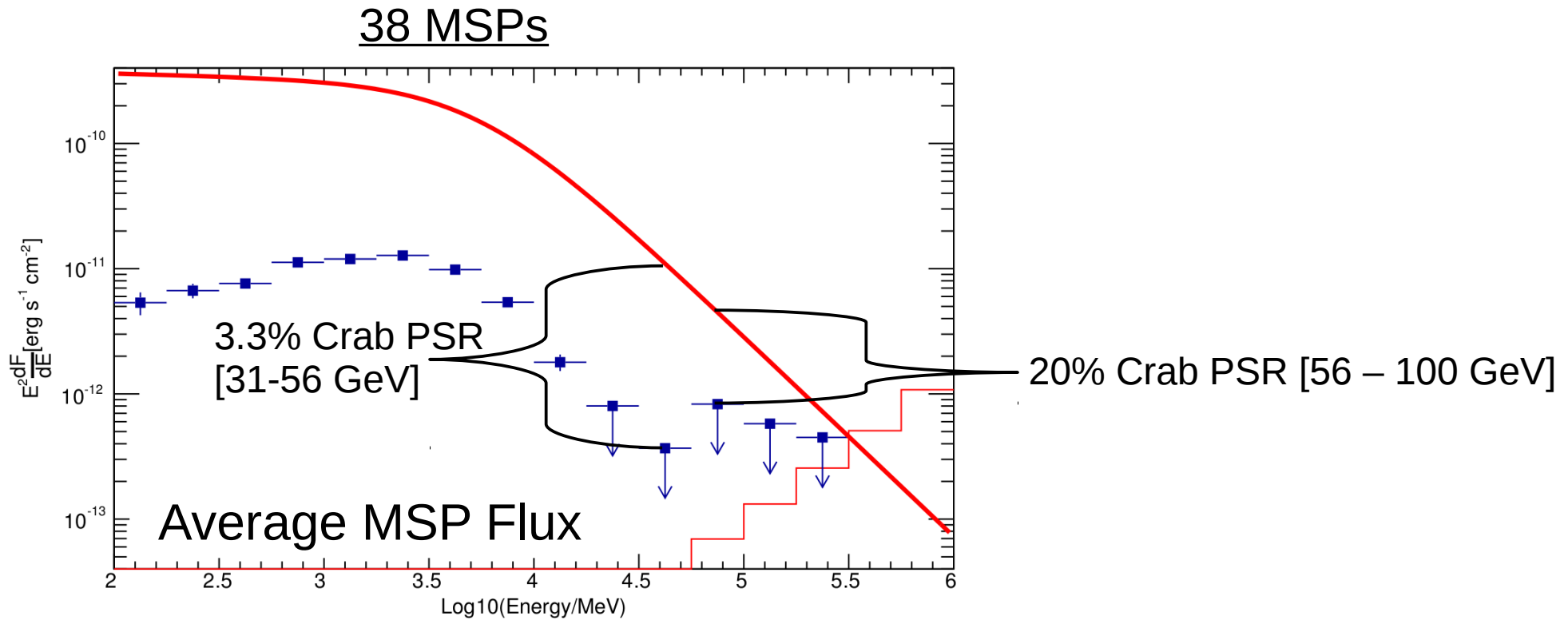


- If there is emission from these 74 pulsars between 100 and 177 GeV, the average level is below 65% of the Crab PSR emission
 - 48 (65%) emitting at 100% Crab PSR and 27 (35%) at zero Crab PSR
- or
- 4 (5.4%) emitting at 1200% the Crab PSR and 70 (94.6%) at zero Crab PSR

38 MSPs



Limits on the emission from pulsars



- If there is emission from these 38 pulsars between 56 and 100 GeV, the average level is below 20% of the Crab PSR emission:

- 38 (100%) emitting at 20% Crab PSR

or

- 7 (20%) emitting at 100% Crab PSR and 31 (80%) at zero Crab PSR

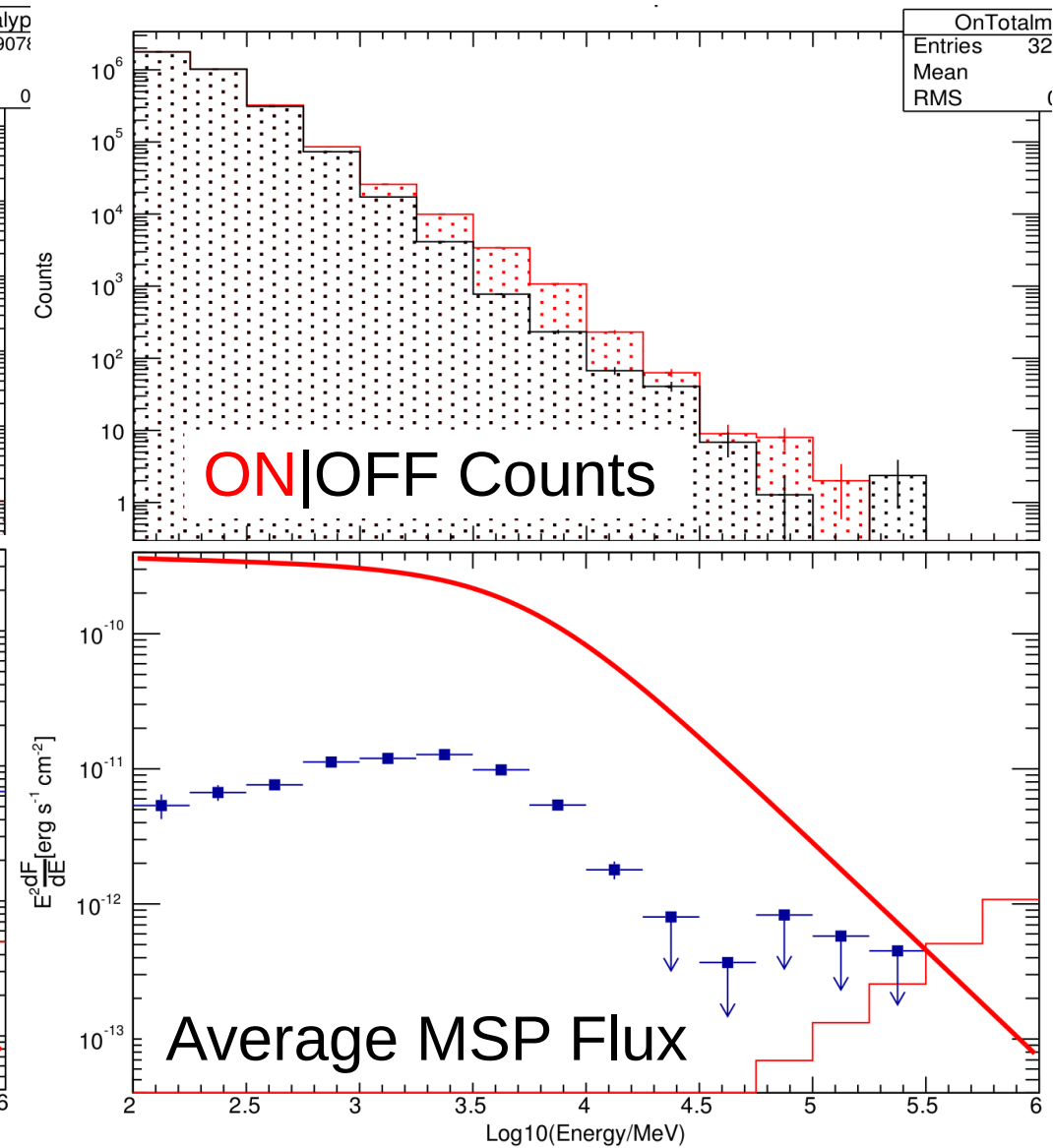
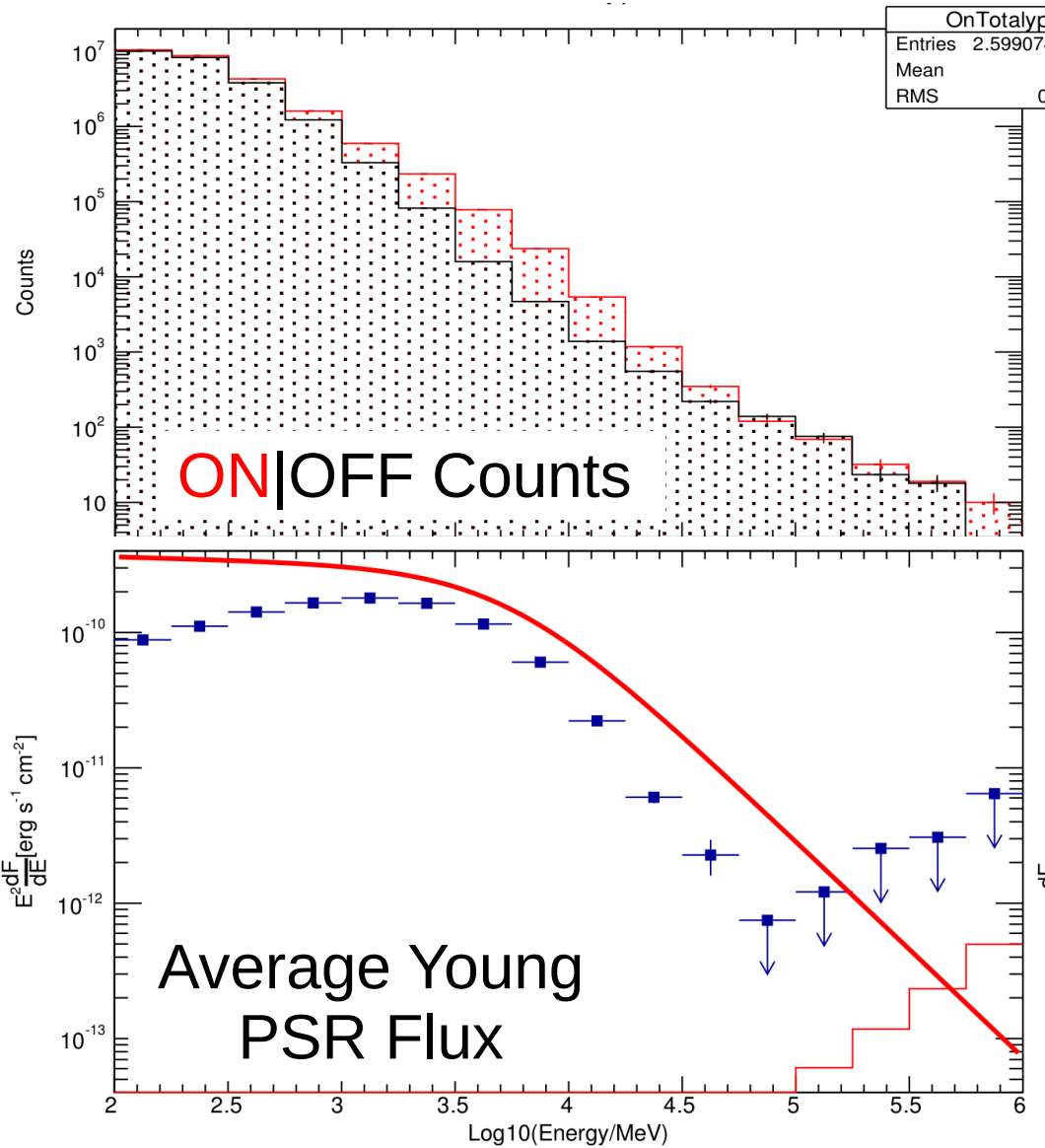
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- 2 (5%) emitting at 380% the Crab PSR and 36 (95%) at zero Crab PSR

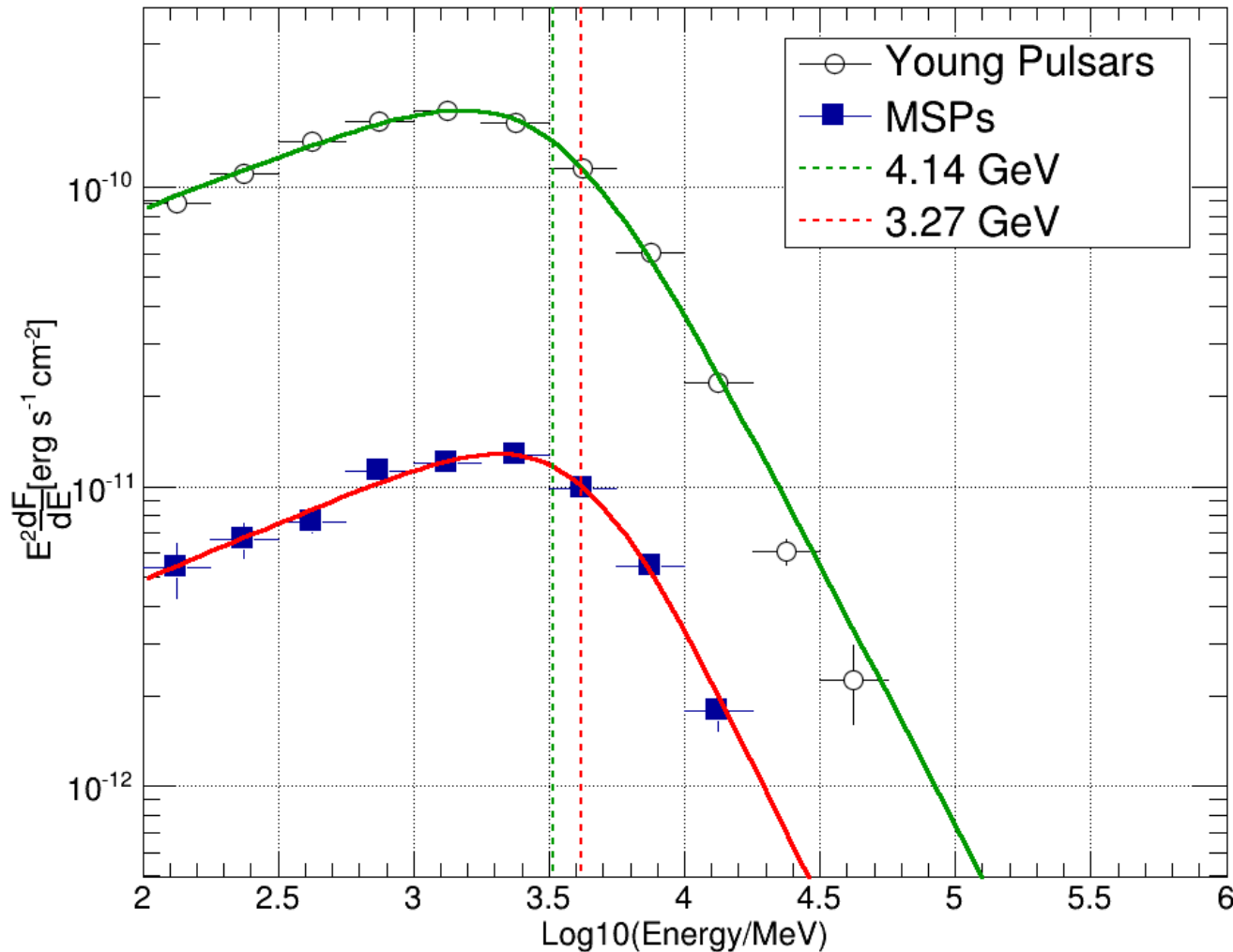
74 “young” PSRs V 38 MSPs

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38 MSPs



74 “young” PSRs V 38 MSPs



- Average spectral shapes look very similar
- Average flux from MSP is ~ 1.5 orders of magnitude lower
- Fit with broken power law
- Power-law index before the break is 1.61 – 1.65
- MSP break energy is ~ 1 GeV higher than YP

Conclusion

- From Fermi we know:
 - There are 147+ gamma-ray pulsars.
 - They have power-laws with spectral breaks between 1-10 GeV.
 - **The bright ones show harder than exponential cut-offs.**
 - **Above ~50 GeV the fluxes are so low that there are only upper-limits.**
- The Geminga Pulsar has been observed by VERITAS for 72hrs.
 - VERITAS sees no emission above 100 GeV from Geminga.
 - **Limits cannot rule out a power-law extension of the Fermi SED.**
- Stacking!
 - An “aperture photometry” method has been shown to work well for pulsar SEDs .
 - A stacking analysis has been performed on 112 Fermi pulsars.
 - No significant signal seen above 50 GeV.
 - **Limits on the average flux from young pulsars & MSPs between 56-100 GeV are 20% Crab PSR.**
 - **Average young pulsar and MSP SEDs very similar. MSP break is ~1 GeV higher.**
 - Future directions – Pass8 + stacking via composite likelihood.