

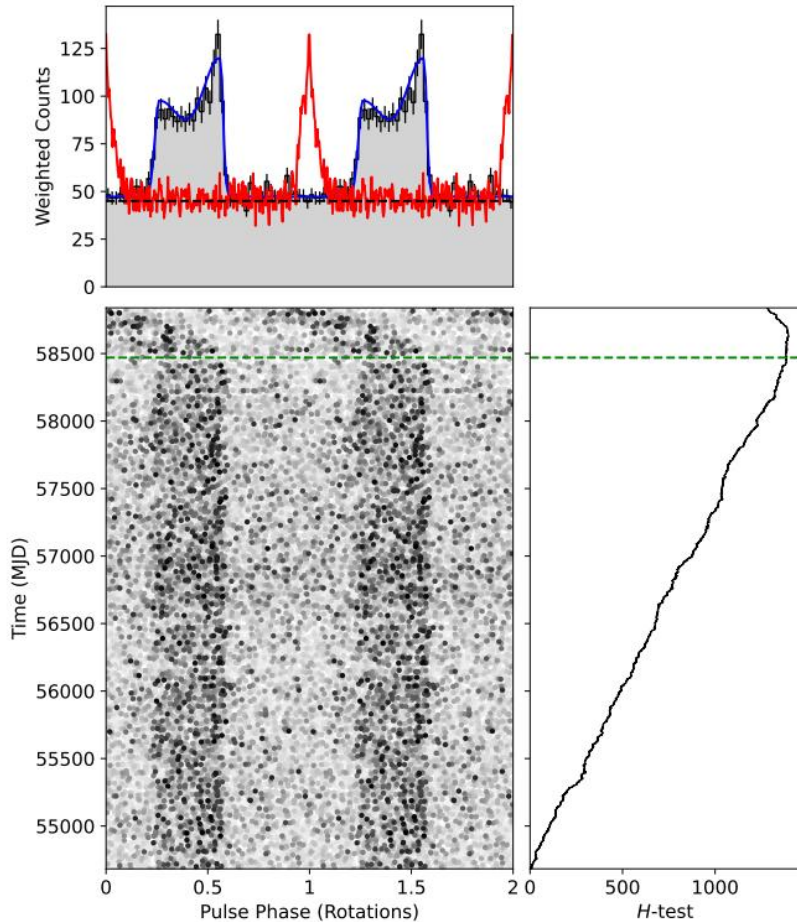
Search for Pulsed Neutrino Emission from TeV Pulsars

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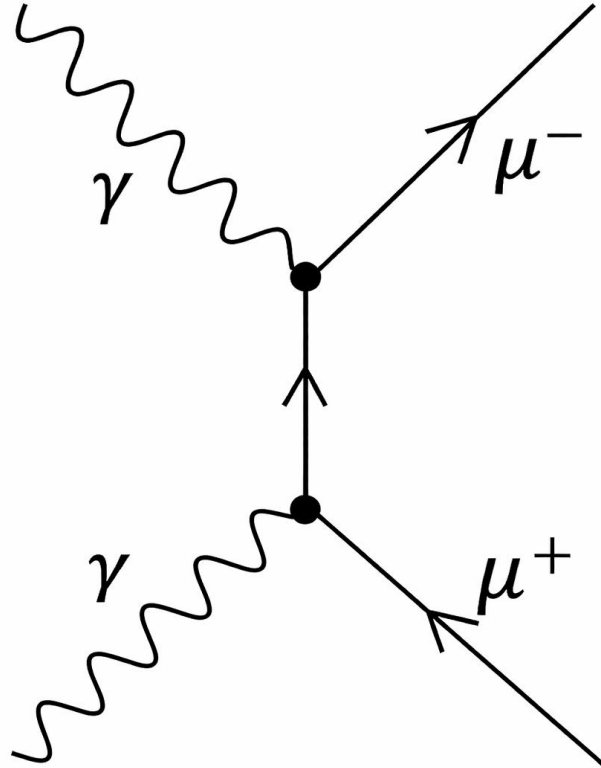
Introduction: Pulsars



- Pulsars are efficient cosmic accelerators.
- Particle will be accelerated in its relativistic magnetospheres and exhibit periodical structure in phase.
- Fermi Large Area Telescope (Fermi-LAT) has detected pulsed GeV gamma-ray signals from many pulsars.
- TeV emissions from Crab, Vela, Geminga and PSR B1706–44 have been detected as pulsed emission.

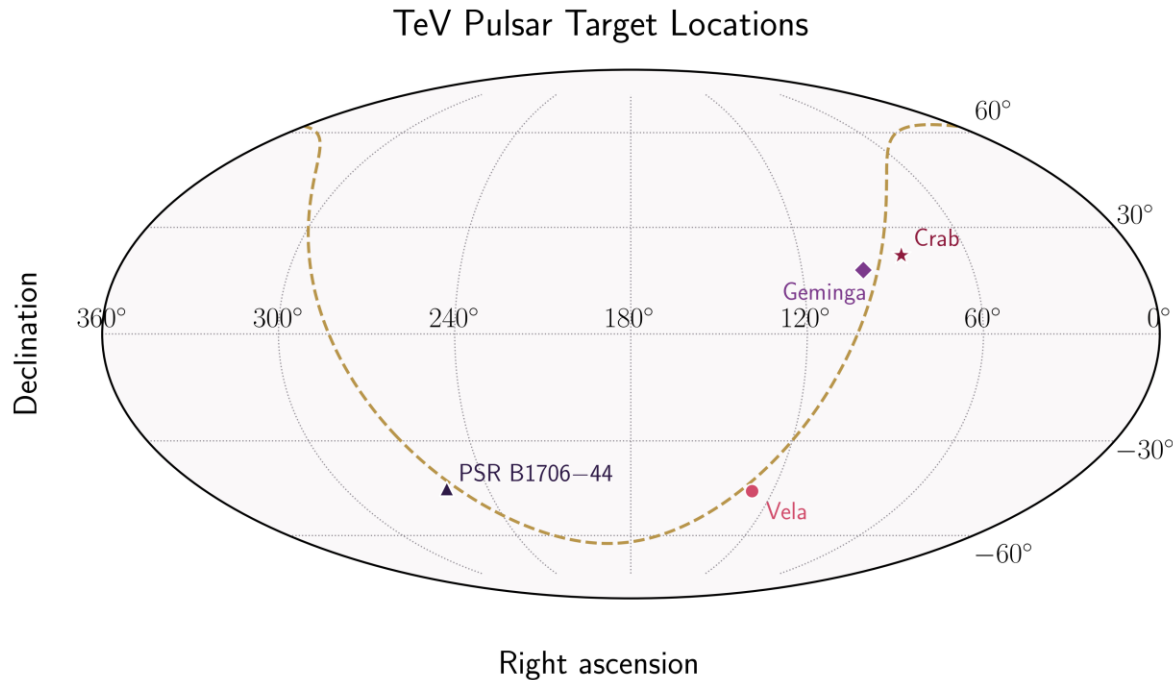
PSR J1648-4611 phasogram from Fermi-LAT
3PC paper [[Smith, David A., et al \(2023\)](#)]

Introduction: Pulsed Neutrinos



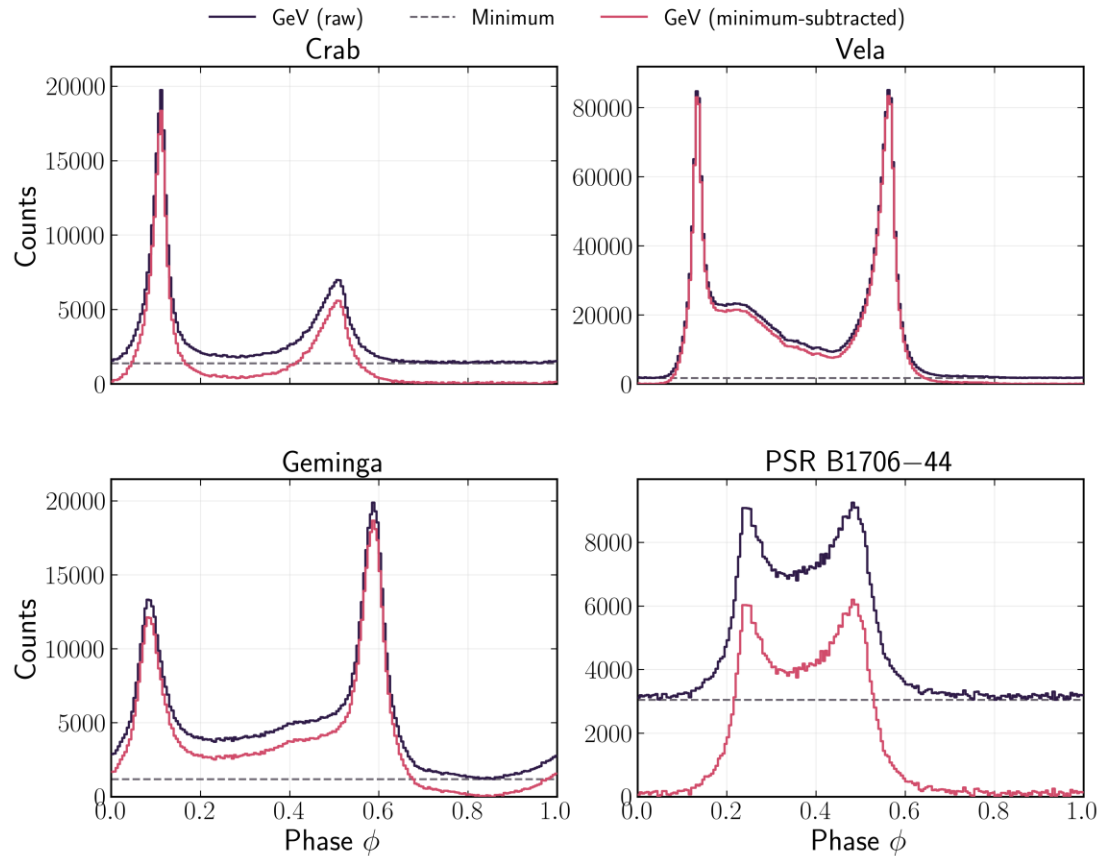
- When two photons collide with enough combined energy, the muon pair-production channel will open.
- In pulsar high energy pulsed photons will interact with local soft photon field.
- The produced muon will be accelerated in the same area and decay, yielding the pulsed high energy neutrinos.

This Analysis



- Targets: Crab, Vela, Geminga and PSR B1706-44 (TeV related pulsars)
- Methods:
 1. Template-based method
 2. Weighted H-test
- Goal: Detect pulsed neutrino signal from pulsars and set limits on this process

Analysis Method: Template-based Method



- A well measured gamma-ray template may improve the sensitivity.

$$S_i = S_{space,i} S_{energy,i} S_{phase,i}$$

$S_{phase,i}$ is the binned signal template.

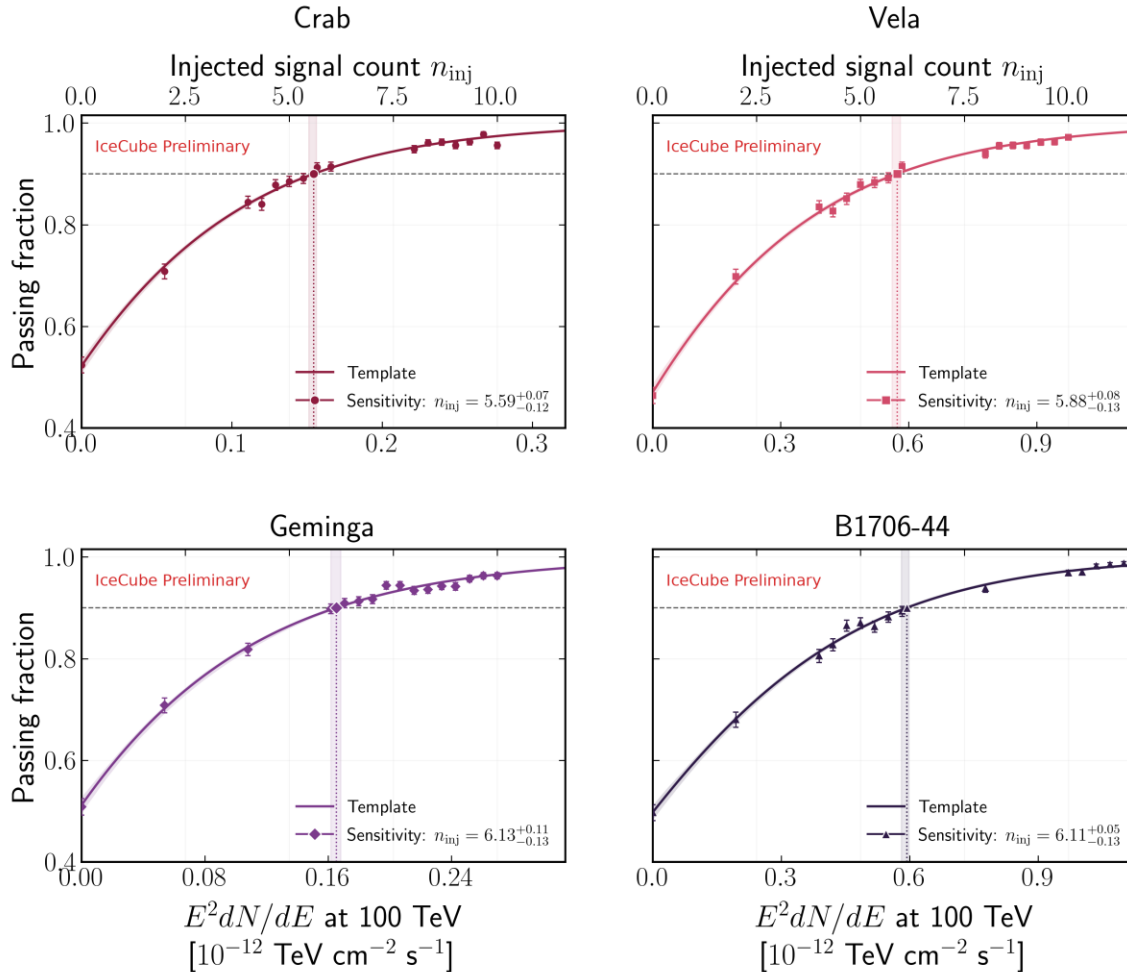
- The pulsed gamma-ray and pulsed neutrinos might be generated from the same area.
- So the template used here is GeV gamma-ray phasogram from Fermi-LAT 3PC with minimum subtracted.

Template-based Method Performance



Template Sensitivity

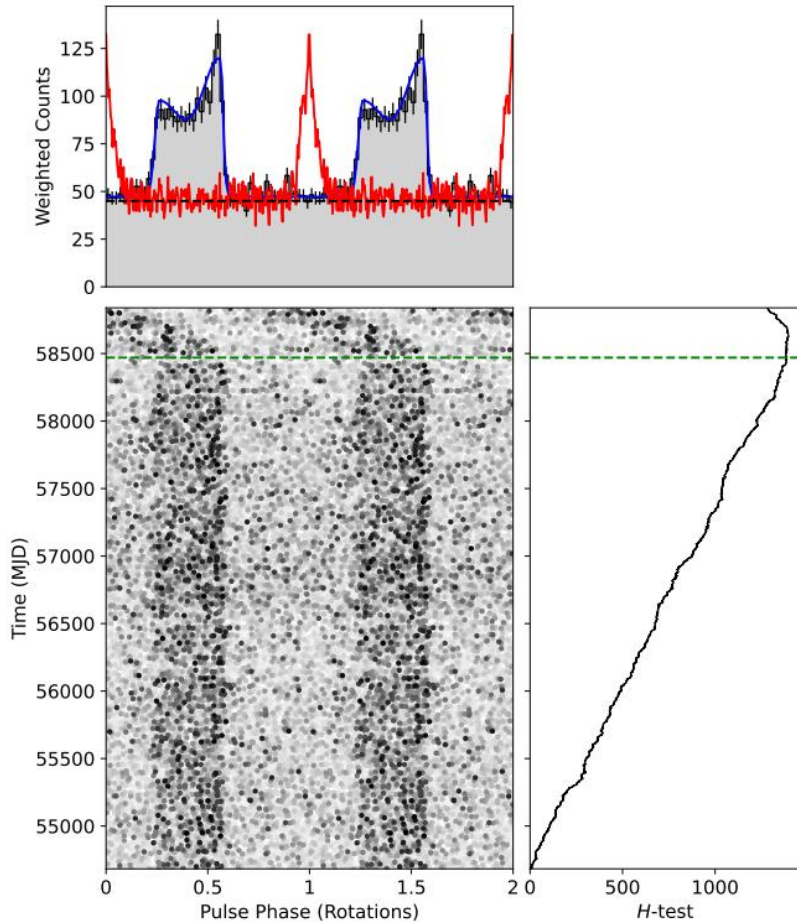
GeV minimum-subtracted template and injection



Method	Sensitivity
Time-integrated	7.76
Template-base	5.58

- Time-integrated method only use the spatial and energy information.
- Template-based method adds the phase information
- Template-based method does improve the sensitivity.

Analysis Method: Weighted H-test



- H-test uses Fourier harmonics to test whether the pulse profile is non-uniform:

$$H = \max H_m$$

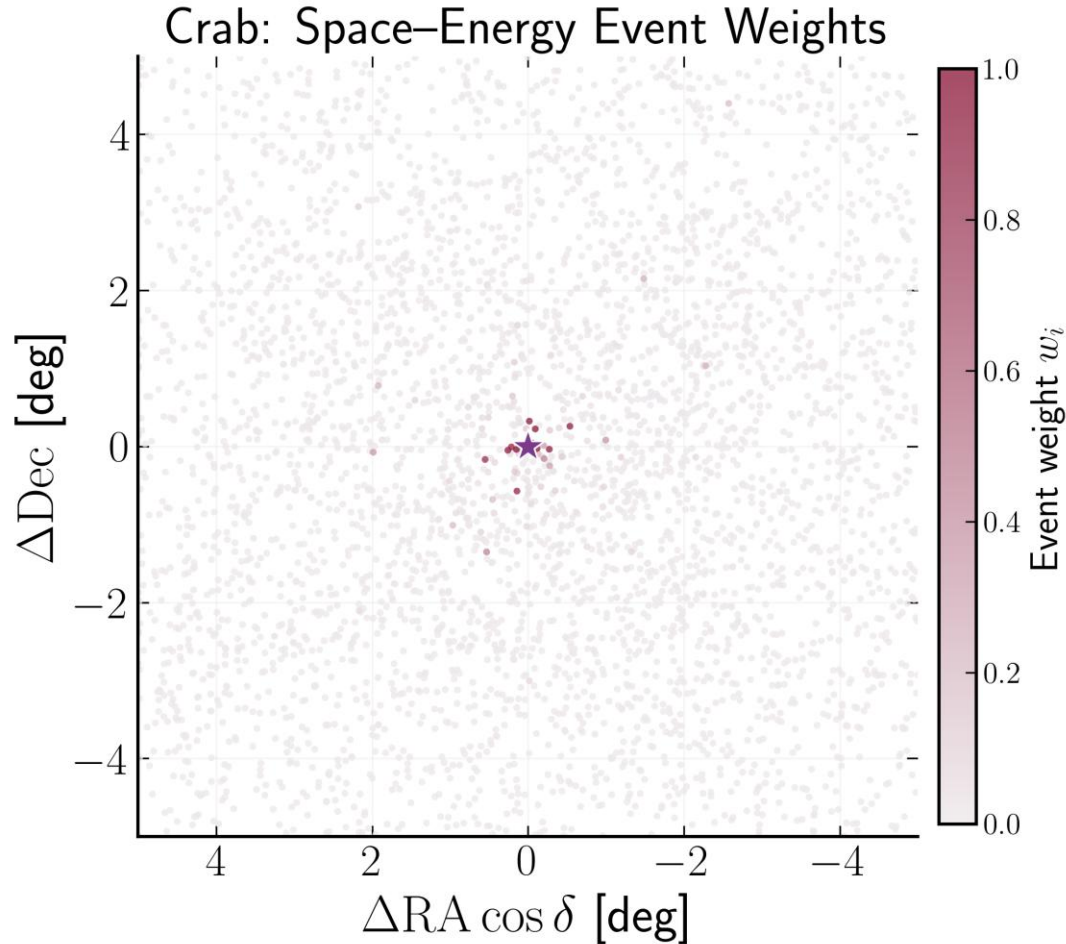
$$H_m = Z_m^2 - 4(m - 1),$$

$$Z_m^2 = 2 \sum_{k=1}^m \left[\left(\sum_{i=1}^N \cos 2\pi k \varphi_i \right)^2 + \left(\sum_{i=1}^N \sin 2\pi k \varphi_i \right)^2 \right].$$

- Used by Fermi-LAT to detect gamma-ray pulsars and measure their significance.

PSR J1648-4611 phasogram from Fermi-LAT
3PC paper [[Smith, David A., et al \(2023\)](#)]

Analysis Method: Weighted H-test



- The weighting is used to improve the sensitivity.
- The spatial and energy information are used to calculate the weight:

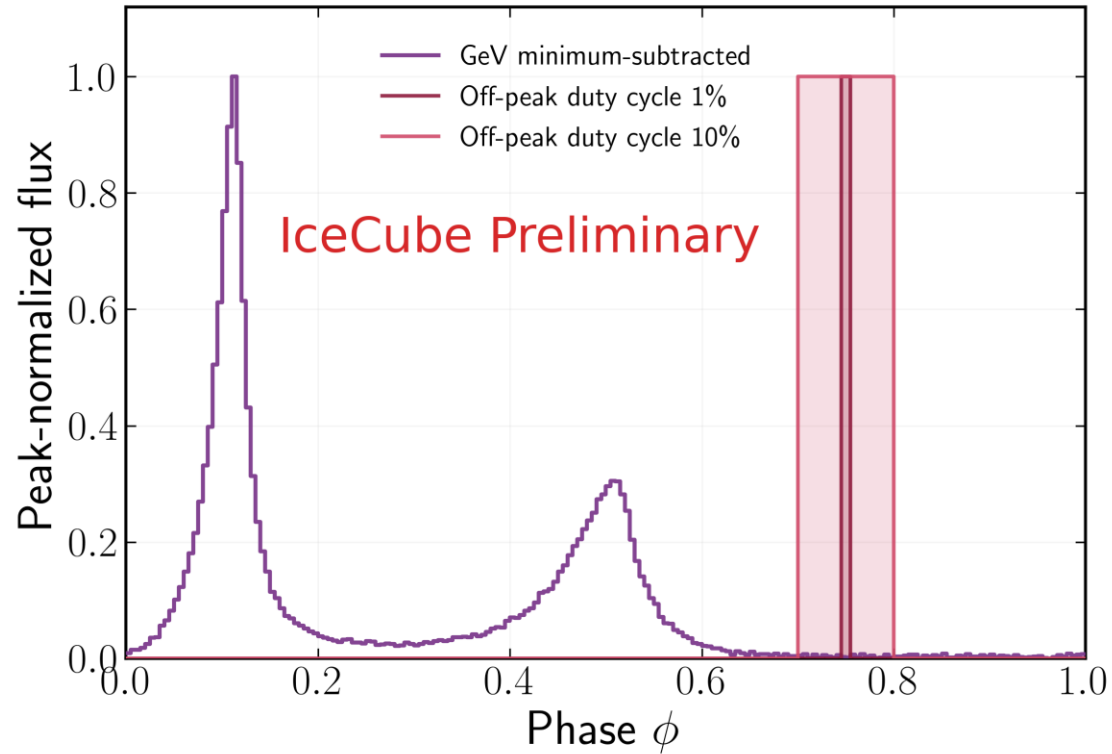
$$w_i = \frac{n_s S_i}{n_s S_i + n_B B_i},$$

- Weight will be larger if the event is more signal-like according to the spatial and energy information.

Comparing Two Methods

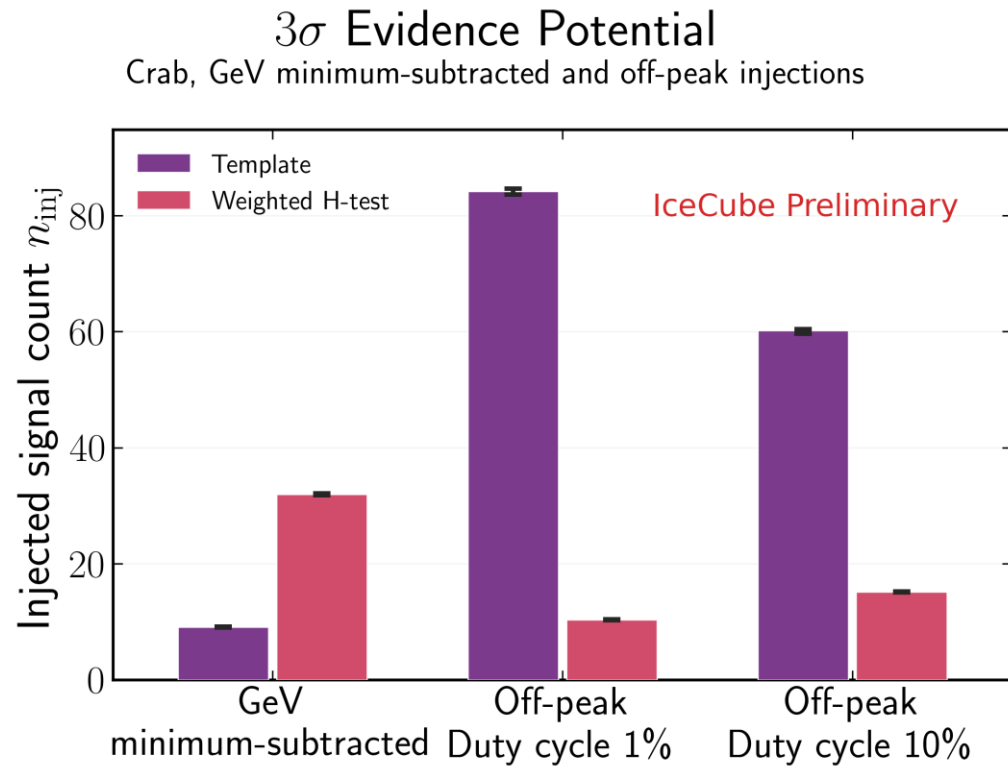


Crab Injection Phasograms



- To compare these two methods, we inject different phasograms.
- One phasogram is the same as the signal template.
- Other two phasograms are two off-peak rectangular phasograms.

Comparing Two Methods



- The GeV minimum-subtracted phasogram is the signal template for the template-based method.
- When the injection matches the template, the template-based method is more sensitive.
- When the phasogram is narrow and off-peak, the weighted H-test is more sensitive.

Conclusions



- A template-based method and the weighted H-test are used to search for pulsed neutrino signal from pulsars.
- Sensitivity, 3σ evidence potential and bias for representative cases are calculated.
- Compared between template-based method and weighted H-test. Template-based method will have better performance when the signal's peaks align well with template peaks. While weighted H-test has better sensitivity for off-peak signal.



Thanks for listening!



Backup slides

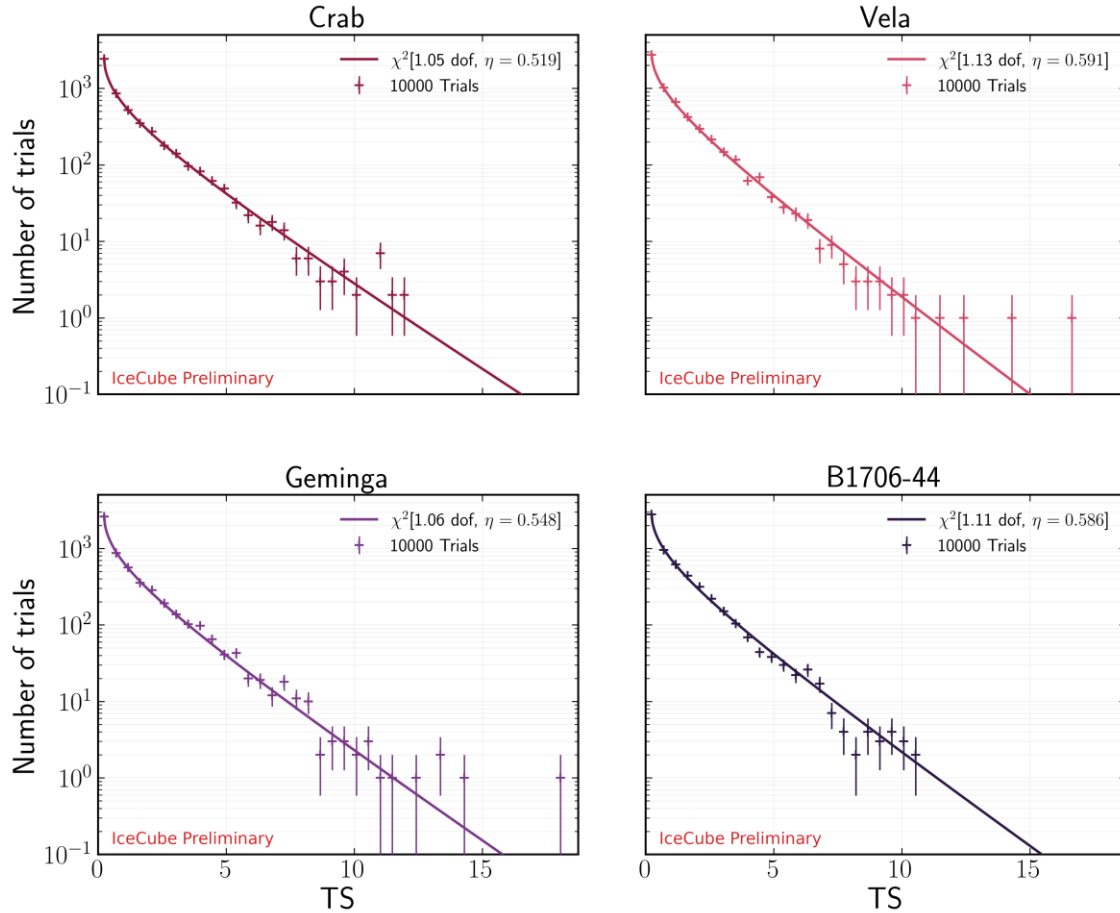
Pulsar	Declination (°)	Distance (kpc)	$\dot{E}(\text{erg s}^{-1})$	$\dot{E}/d^2(\text{erg s}^{-1} \text{ kpc}^{-2})$	TeV spectral index	Period (ms)
Crab (PSR J0534+2200)	+22.01	2.0	4.6×10^{38}	1.15×10^{38}	P1: 3.2 P2: 2.9	33
Vela (PSR J0835−4510)	−45.18	0.29	6.9×10^{36}	8.2×10^{37}	1.4	89
Geminga (PSR J0633+1746)	+17.77	0.25	3.2×10^{34}	5.1×10^{35}	2.34	237
PSR B1706−44 (PSR J1709−4429)	−44.49	2.3	3.4×10^{36}	6.4×10^{35}	2.0	102

Source	Declination [deg]	Template Sensitivity	Template Evidence Potential (50%)	Weighted H-test Sensitivity	Weighted H-test Evidence Potential (50%)
Crab	+22.01	5.59	9.05	8.57	31.95
Vela	−45.18	5.88	9.76	13.84	75.38
Geminga	+17.77	6.13	9.53	10.72	60.79
PSR B1706−44	−44.49	6.11	10.45	11.68	67.64

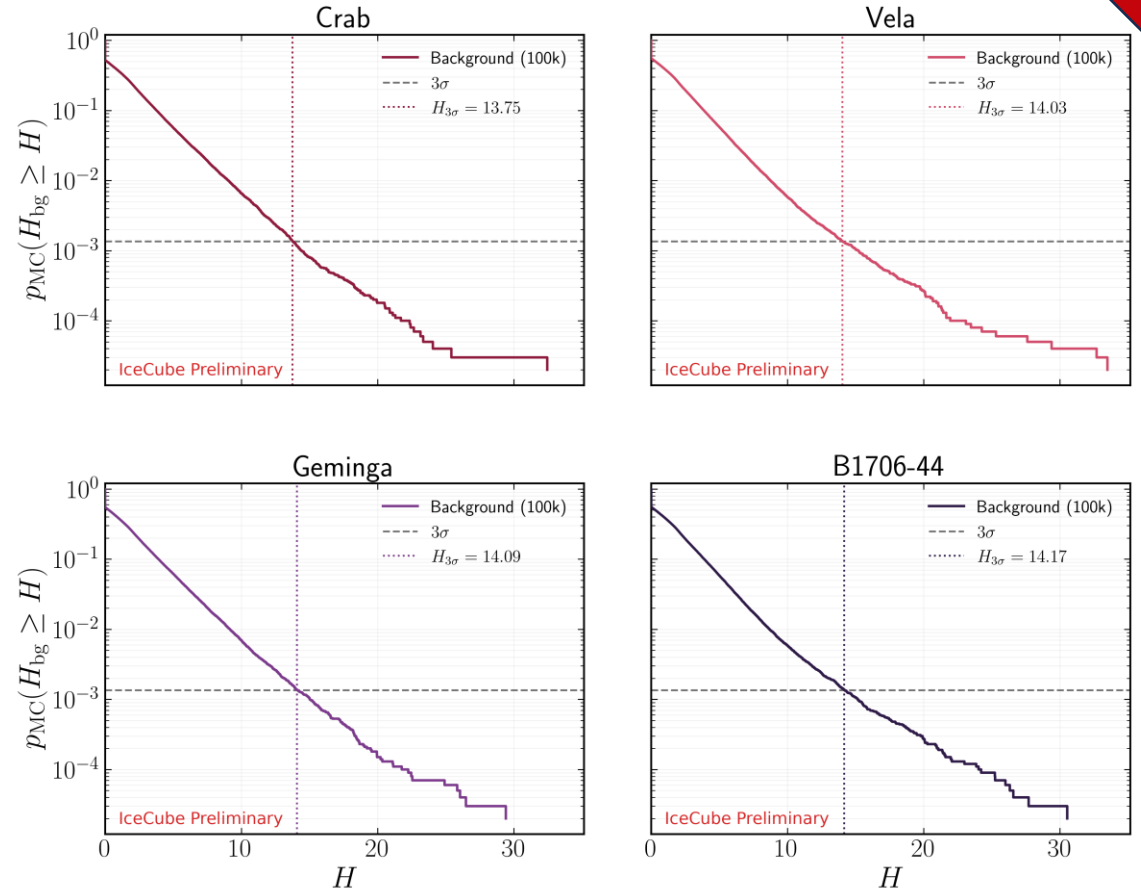
Background Test Statistics Behavior



Template Background TS Distributions



Weighted H-test Background Survival

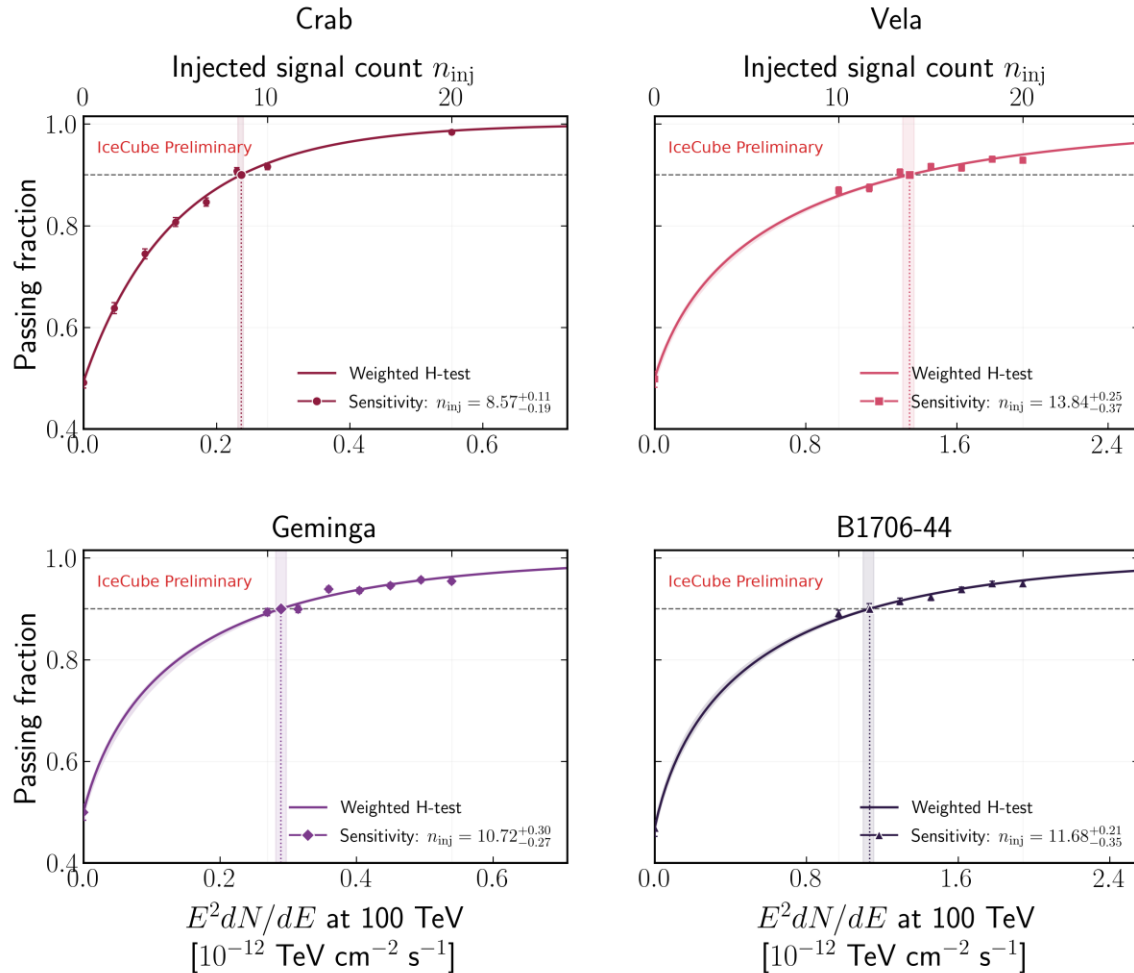


Passing Fraction Plots for Sensitivity



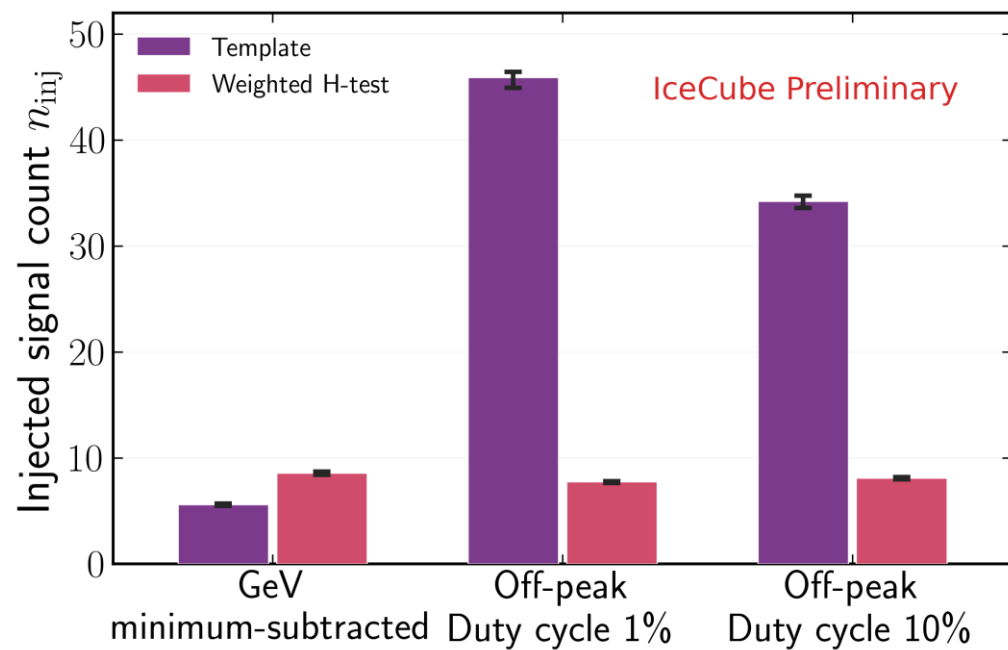
Weighted H-test Sensitivity

GeV minimum-subtracted injection



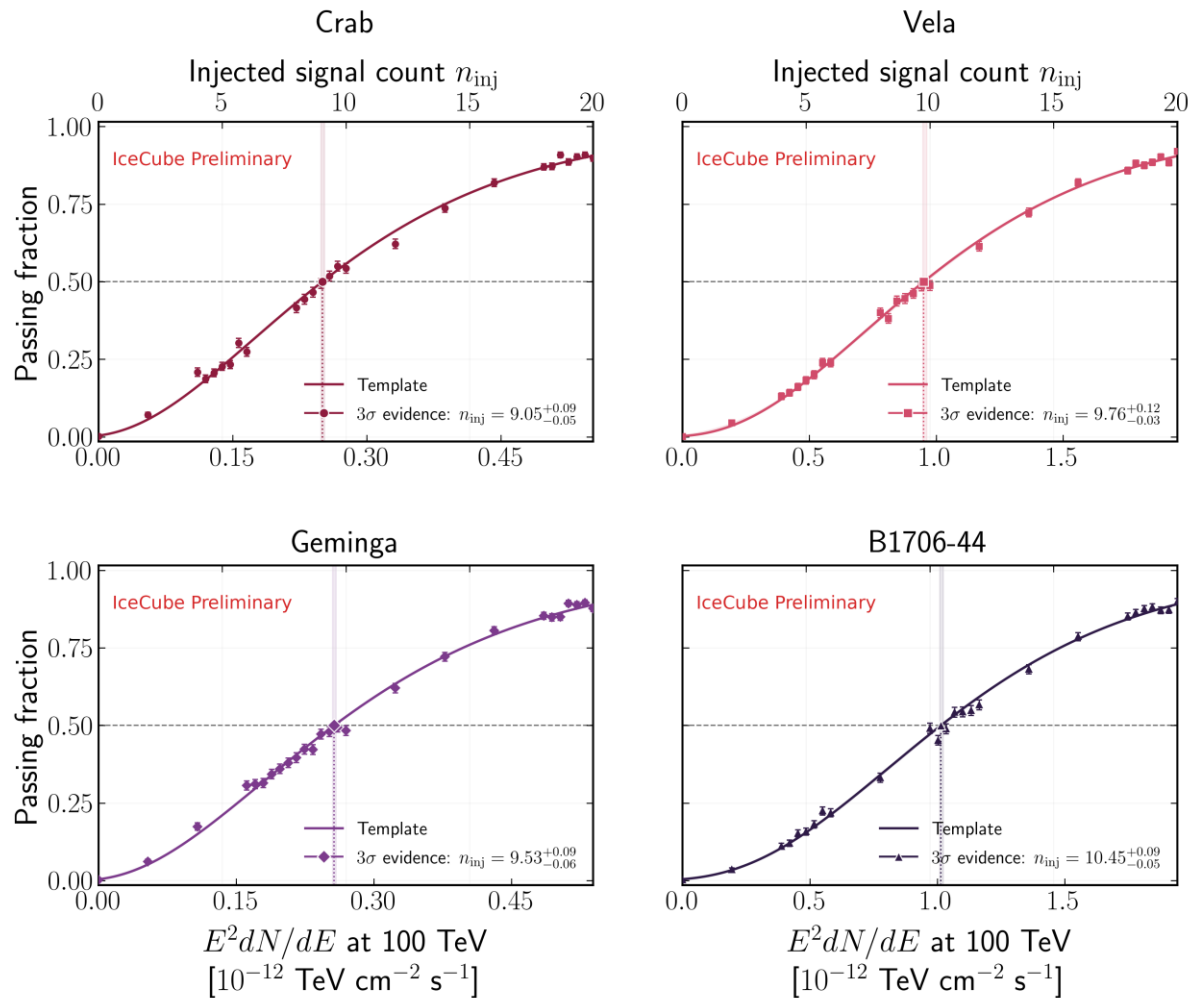
Sensitivity

Crab, GeV minimum-subtracted and off-peak injections



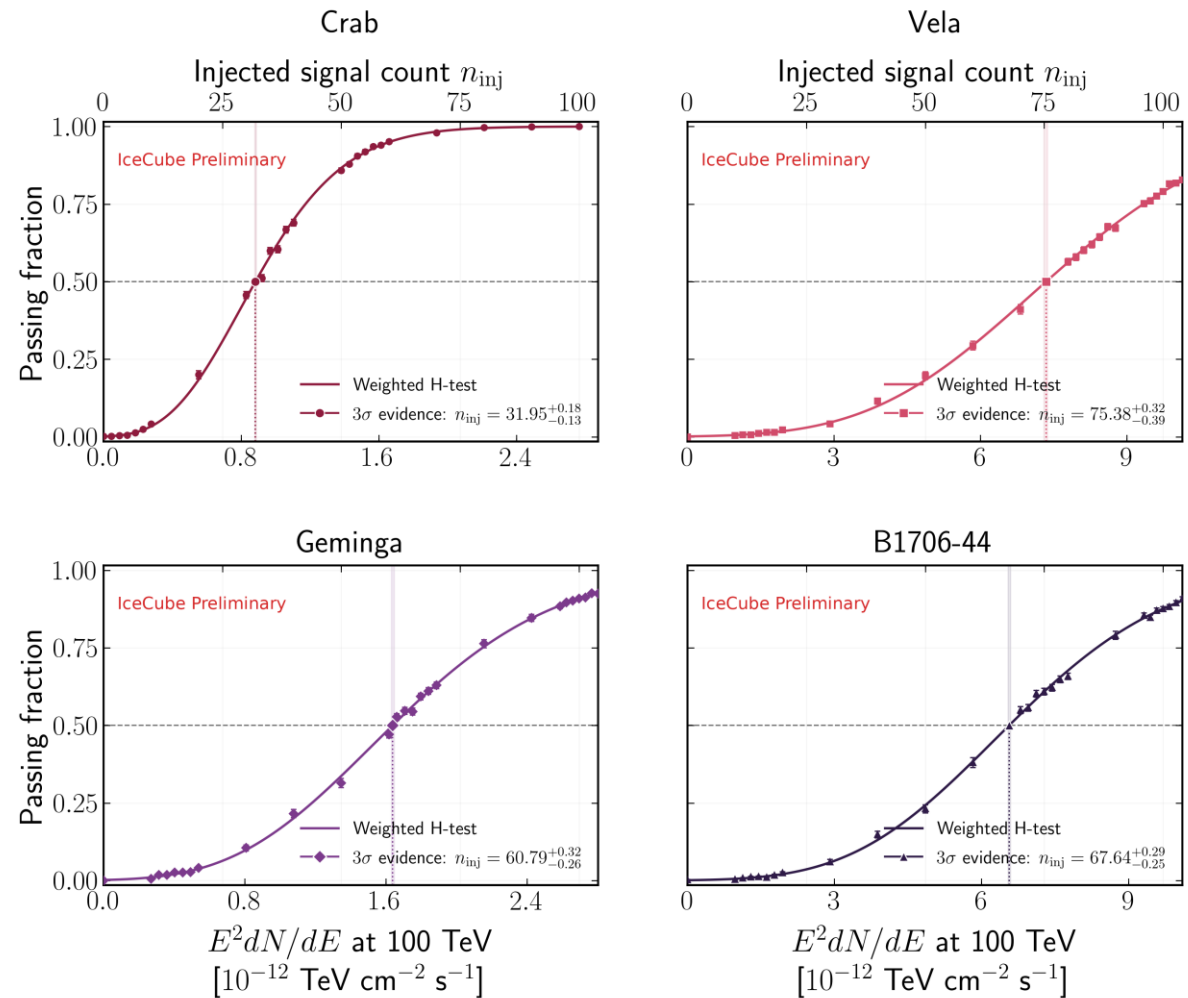
Template 3σ Evidence Potential

GeV minimum-subtracted template and injection



Weighted H-test 3σ Evidence Potential

GeV minimum-subtracted injection



Source	Point-source sensitivity	Duty cycle 100% sensitivity	Sensitivity ratio	Point-source evidence	Duty cycle 100% evidence	Evidence ratio
Crab	7.76	7.62	0.982	12.49	12.48	0.999
Vela	8.04	7.29	0.906	12.54	12.87	1.026
Geminga	6.98	7.26	1.041	12.21	11.32	0.927
PSR B1706–44	7.47	7.42	0.993	12.80	12.36	0.965

