Fermi-LAT Detection of γ-ray Pulsars above 10 GeV

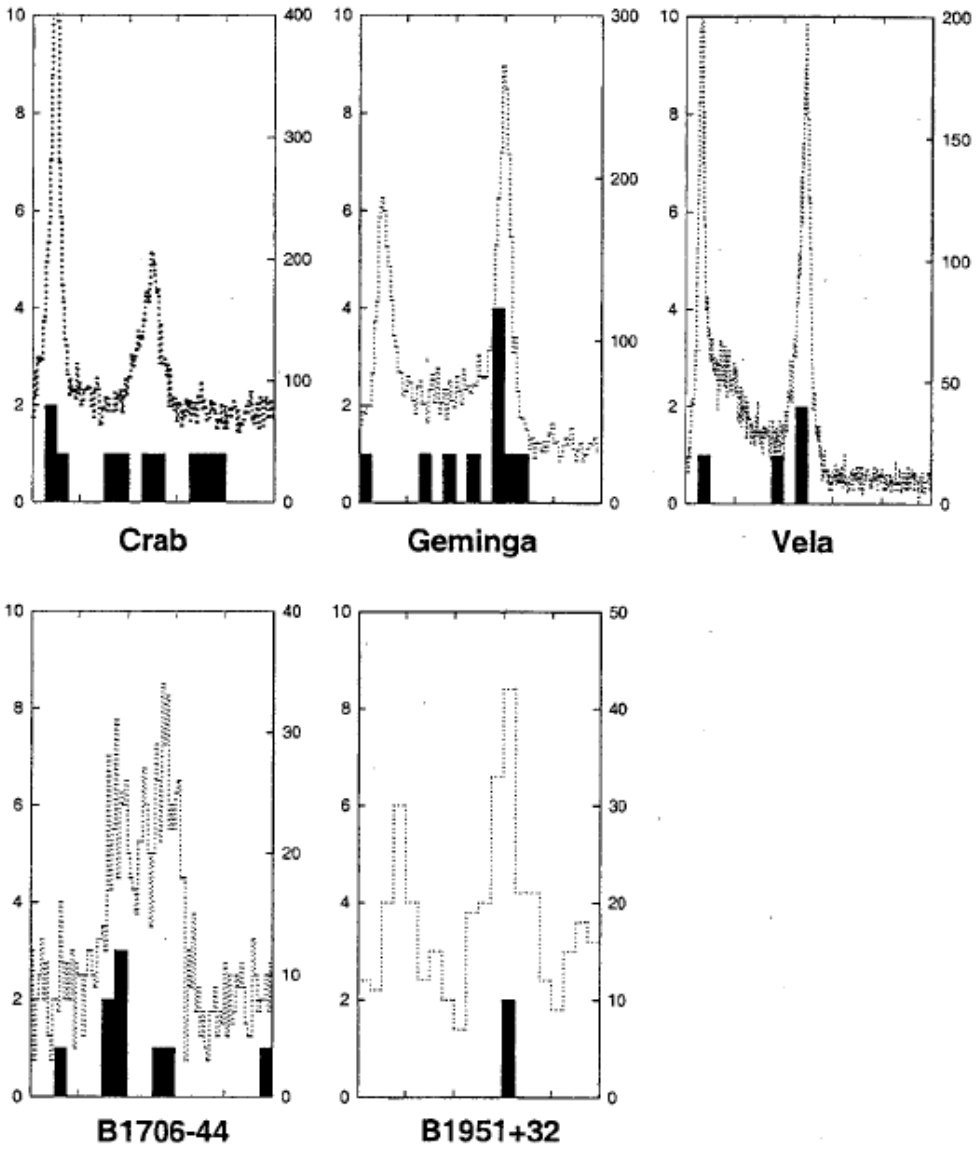
Pablo Saz Parkinson
Santa Cruz Institute For Particle Physics
pablo@scipp.ucsc.edu

on behalf of the Fermi LAT collaboration

γ **2012**
Heidelberg, 9 July 2012

Pulsars above 10 GeV: The EGRET view (1991-2000)

Thompson et al. 2004



- Total of ∼1500 photons above 10 GeV (∼1300 diffuse)
  1. Crab: 10 photons (7 in the peaks)
  2. Vela: 4 photons (4 in the peaks)
  3. Geminga: 10 photons (5 in the peaks)
  4. B1706-44: 9 photons (5 in the peaks)
  5. B1951+32: 2 photons (2 in the peaks)
  6. J0538+2817? (SNR S147): 2

Fermi LAT Catalogs[1] so far ...

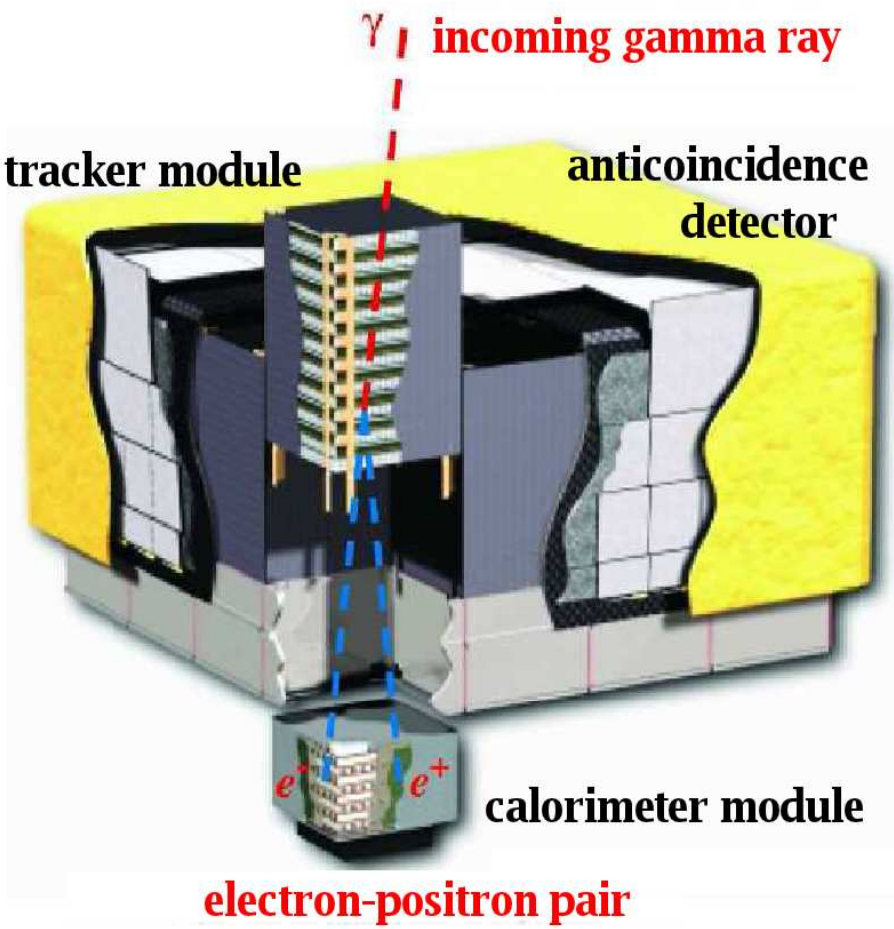


Figure: The Fermi Large Area Telescope

1. Bright Source List (Abdo et al. 2009, 0FGL)
   - 3 months of data
   - 205 ($> 10\sigma$) sources
   - 30 pulsars
   - 37 unassociated sources
2. First Pulsar Catalog (Abdo et al. 2010, 1PC)
   - 6 months of data
   - 46 pulsars
3. First Source Catalog (Abdo et al. 2010, 1FGL)
   - 11 months of data
   - 1451 ($> 4\sigma$) sources
   - 56 pulsars
   - 630 unassociated sources
4. Second Source Catalog (Nolan et al. 2012, 2FGL)
   - 24 months of data
   - 1873 ($> 4\sigma$) sources
   - 83 pulsars
   - 575 unassociated sources

[1] Not all of these are considered catalogs ... and these are not all the LAT catalogs.

Fermi LAT Catalogs in the works

... and highly relevant to this talk.

1. Hard Sources Catalog (1FHL)
   - 36 months of data
   - energies above 10 GeV
   - See talk by David Paneque
2. Second Pulsar Catalog (2PC)
   - 36 months of data
   - 117 γ-ray pulsars
   - See presentation by Ozlem Celik

Figure: Happy 4th Birthday Fermi!

LAT γ-ray pulsar associations in 1FHL

25 sources in the 1FHL Catalog are associated (not necessarily identified) with LAT γ-ray pulsars:

- 5 EGRET pulsars
- 7 Young (non-recycled) radio-selected γ-ray pulsars
- 10 Young (non-recycled) γ-selected pulsars
- 3 Millisecond γ-ray pulsars

Search for emission above 10 GeV in the SED

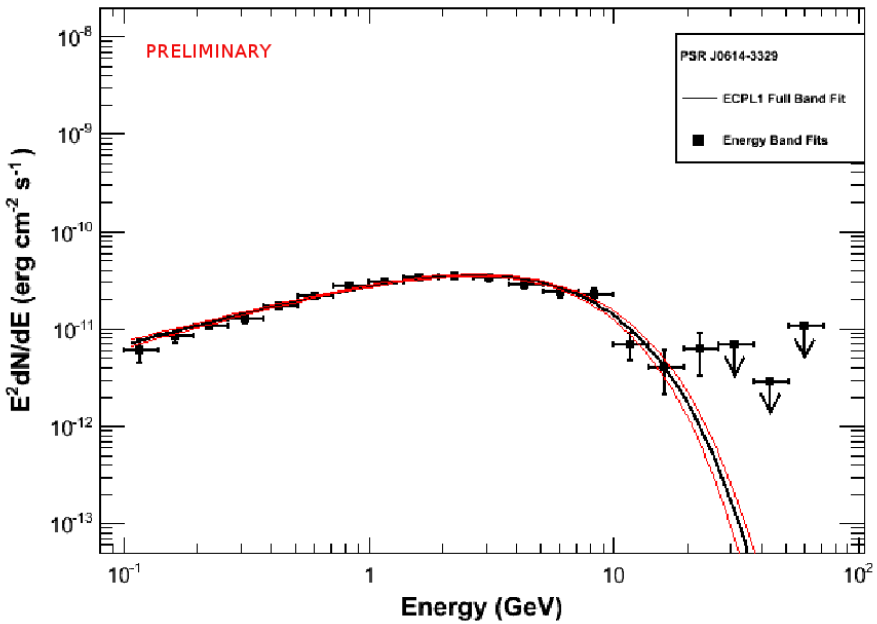


Figure: 2PC SED for PSR J0614–3329, showing a typical simple exponential cutoff spectrum, with emission nevertheless extending above 10 GeV.

- Spectrally-selected 2PC pulsars not in Hard Source List (See presentation by O. Celik)
  1. J0633+0632
  2. J1509–5850
  3. J1747–2958
  4. J1838–0537
  5. J1954+2836
  6. J2017+0603
  7. J2021+4026
  8. J2238+5903
  9. J2302+4442

Generation of light curves (histograms)

1. Use same 3-year data set as 2PC and 1FHL
2. Use latest timing models from 2PC
3. Use latest spectral models from 2PC
4. Low energy templates generated with weights in 0.3–10 GeV range
5. High energy light curves generated with no weights for energies $>$10 GeV
6. ROI radii for high-energy events: 0.6° for Front events and 1.2° for Back events ($\sim$r95%)

Pulsars clearly detected above 10 GeV

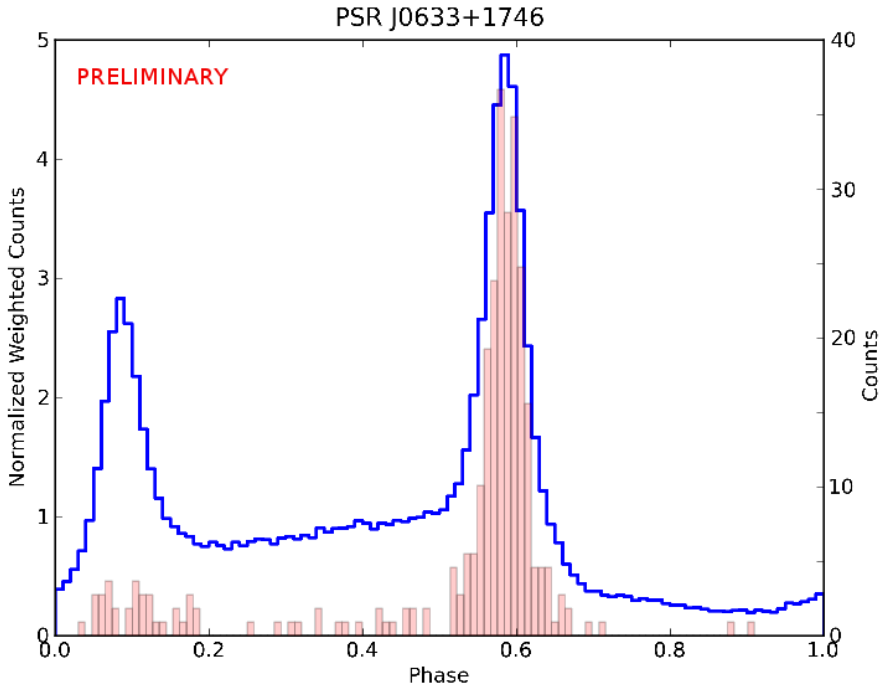


Figure: Geminga normalized weighted light curve (100 bins) in the 0.3-10 GeV range (blue) and unweighted light curve above 10 GeV (pink).

- Firm detections above 10 GeV
  1. J0007+7303 (CTA1)
  2. J0534+2200 (Crab)
  3. J0614-3329
  4. J0633+1746 (Geminga)
  5. J0835-4510 (Vela)
  6. J1028-5819
  7. J1048-5832
  8. J1709-4429
  9. J1809-2332
  10. J2021+3651 (Dragonfly)
  11. J2032+4127

Marginal detections above 10 GeV

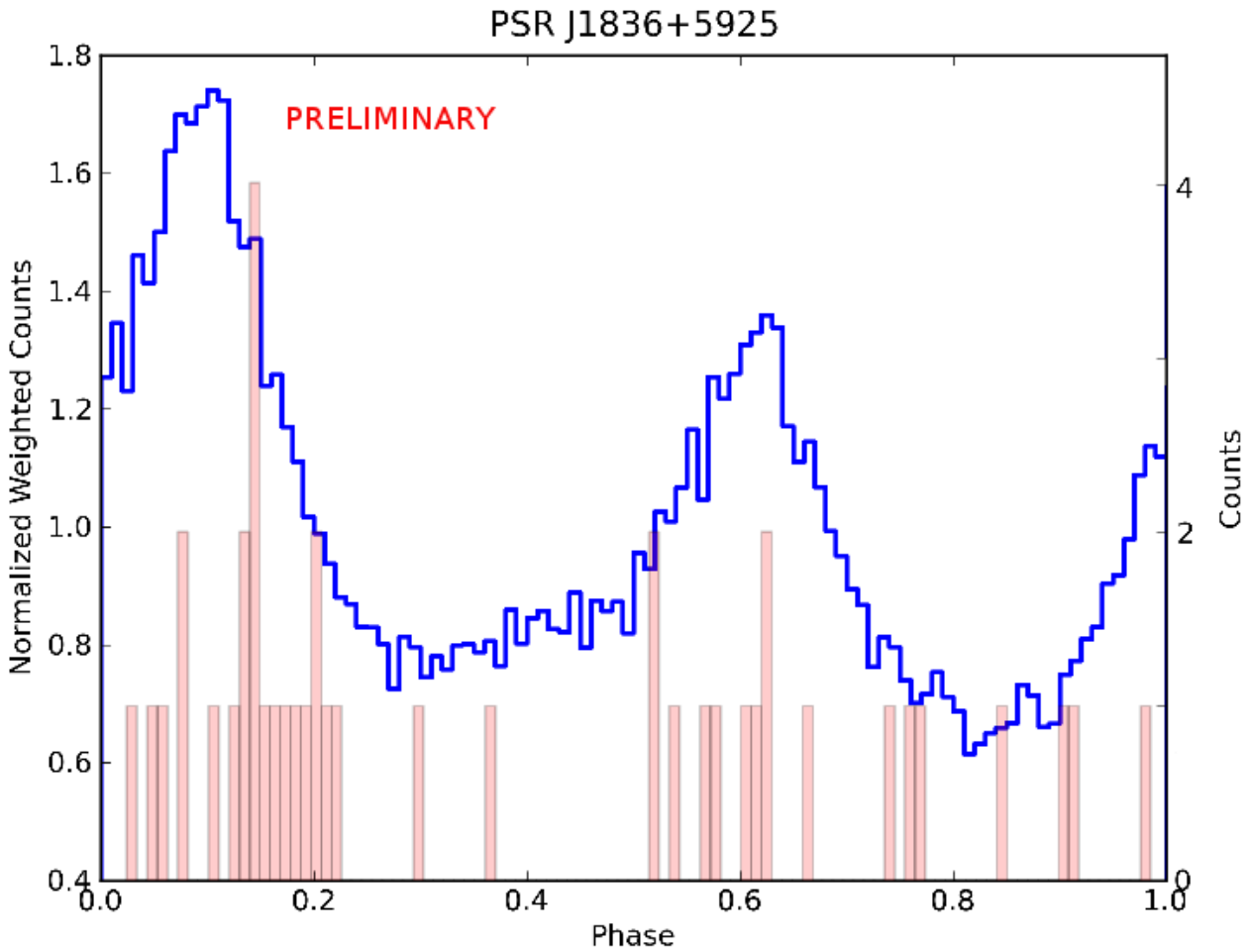
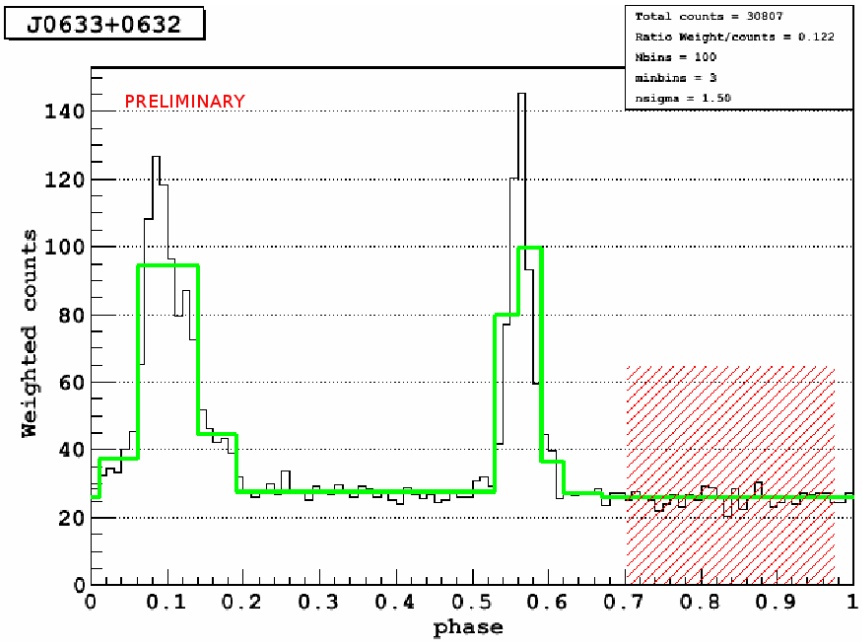


Figure: Marginal detection of pulsations from PSR J1836+5925 above 10 GeV.

Defining the off-pulse region: Bayesian Blocks



- Definition of the off-pulse region will be provided in 2PC.
- Important for PWN and SNR studies
- Bayesian Blocks (Scargle 1998) provide a good *a priori* definition of pulsed region

Figure: Definition of the off-pulse region of PSR J0633+0632 using Bayesian Blocks (green histogram).

Searching for significant pulsed emission above 10 GeV

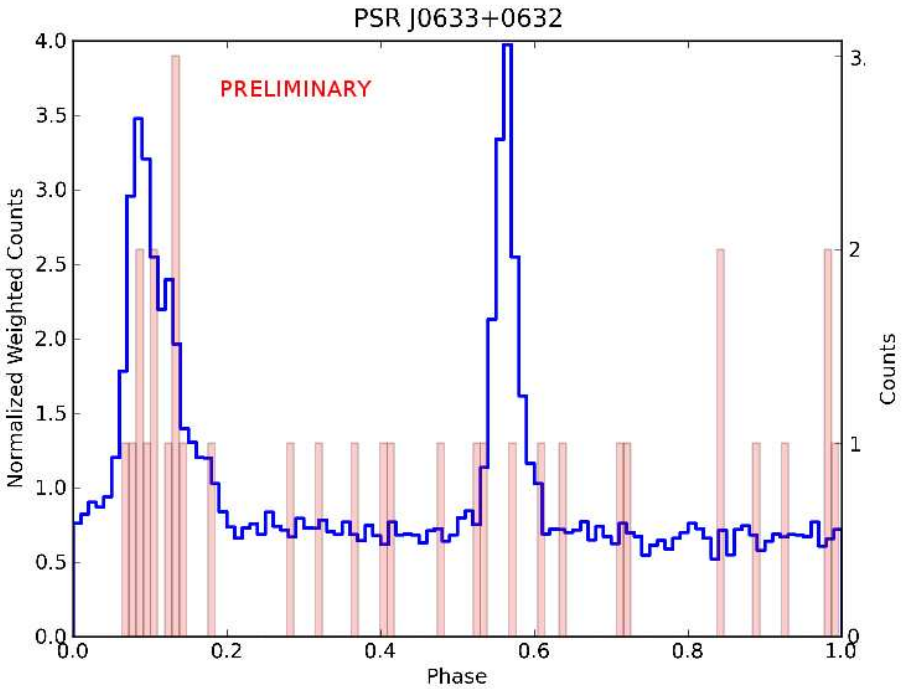


Figure: Possible detection of >10 GeV pulsations from PSR J0633+0632.

- Spectrally-selected 2PC pulsars not in Hard Source List (O. Celik)
  1. J0633+0632
  2. J1509–5850
  3. J1747–2958
  4. J1838–0537
  5. J1954+2836
  6. J2017+0603
  7. J2021+4026
  8. J2238+5903
  9. J2302+4442

LAT detections above 25 GeV

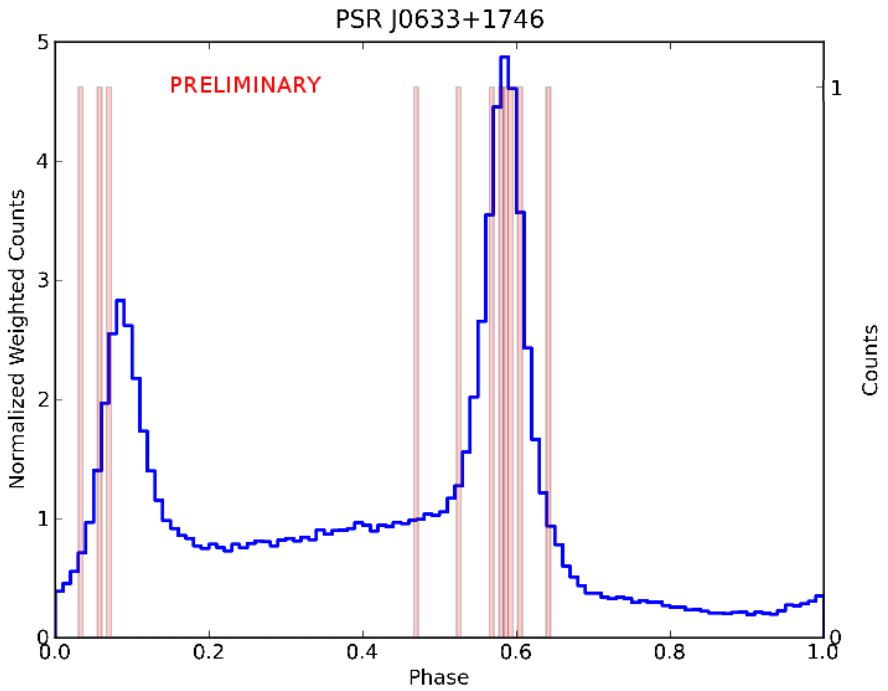


Figure: Detection of >25 GeV pulsations from Geminga.

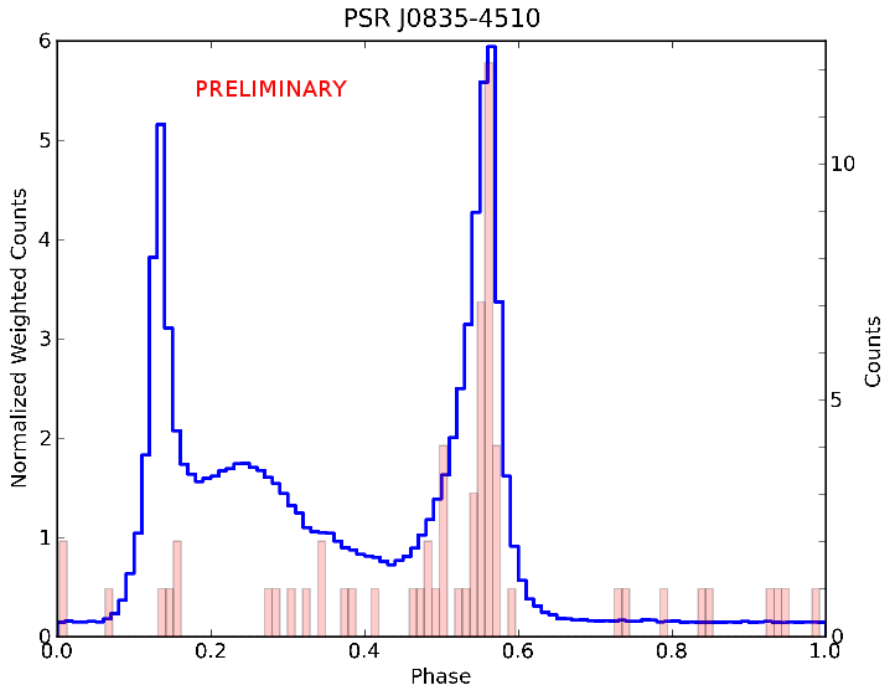


Figure: Detection of >25 GeV pulsations from Vela.

LAT γ-ray events above 50 GeV

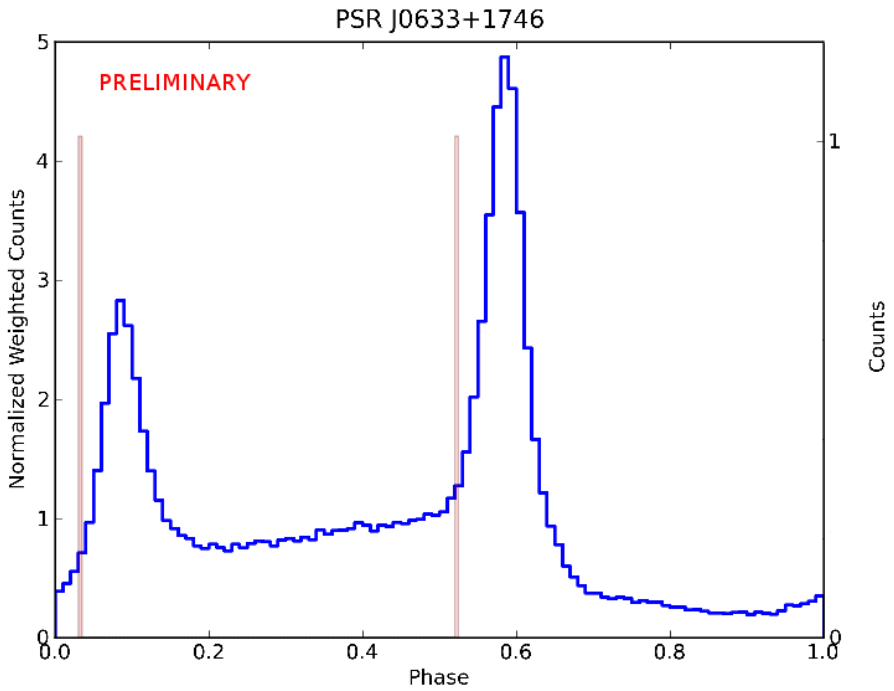


Figure: Geminga events above 50 GeV (53 and 77 GeV)

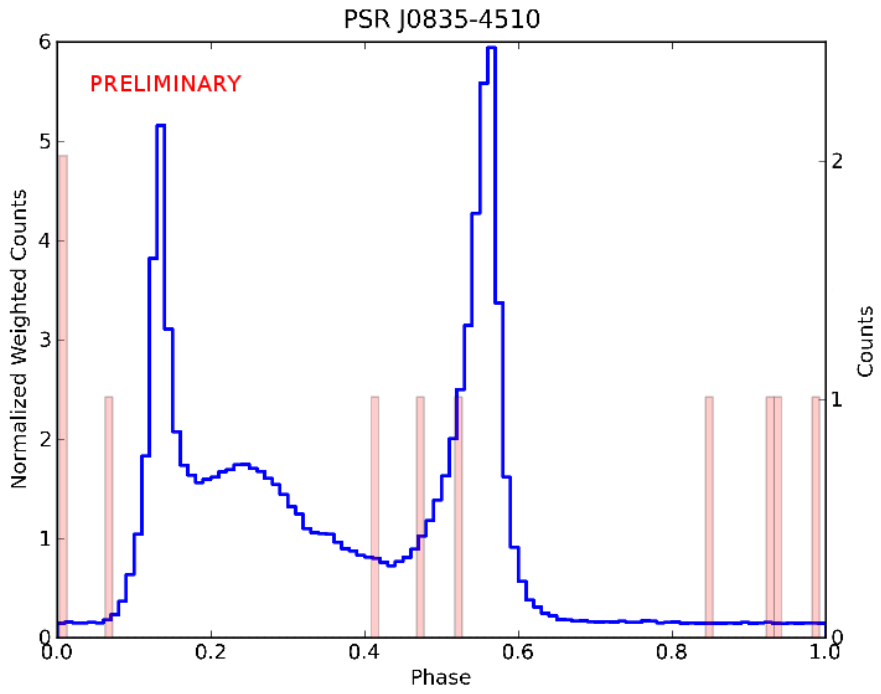


Figure: Vela events above 50 GeV (5 events above 100 GeV)

Summary and Outlook

- *Fermi* has dramatically increased the statistics in the 10-100 GeV range
- 25 sources in 1FHL Catalog (cf. Paneque) associated with LAT pulsars
- Many 2PC pulsars (cf. Celik) show >10 GeV emission in their SED
- Future γ-ray pulsars will be discovered ... but will be fainter
- Top candidates for VHE pulsations depend on many assumptions ...
- Empirically, the bright EGRET pulsars remain the best VHE candidates
- Bright radio-quiet γ-ray pulsars are also promising
- Current study uses 3 years of data ... currently ~4 years (and hopefully many more to come)
- LAT sensitivity at >10 GeV improves αt (not background limited)
- Pass 8 will increase the effective area of the LAT at higher energies
- Future TeV experiments (e.g. CTA, HAWC) will complement and extend LAT observations

Thank You!