LIV WORKSHOP PARIS 2017

SEARCHING FOR LIV WITH VERITAS

Tony T.Y. Lin on behalf of VERITAS collaboration

*Image credit Dr. John Quinn

McGill

OUTLINE

- Introduction to VERITAS
- Highlights from recent results
- LIV studies in VERITAS

VERY ENERGETIC RADIATION IMAGING TELESCOPE ARRAY SYSTEM

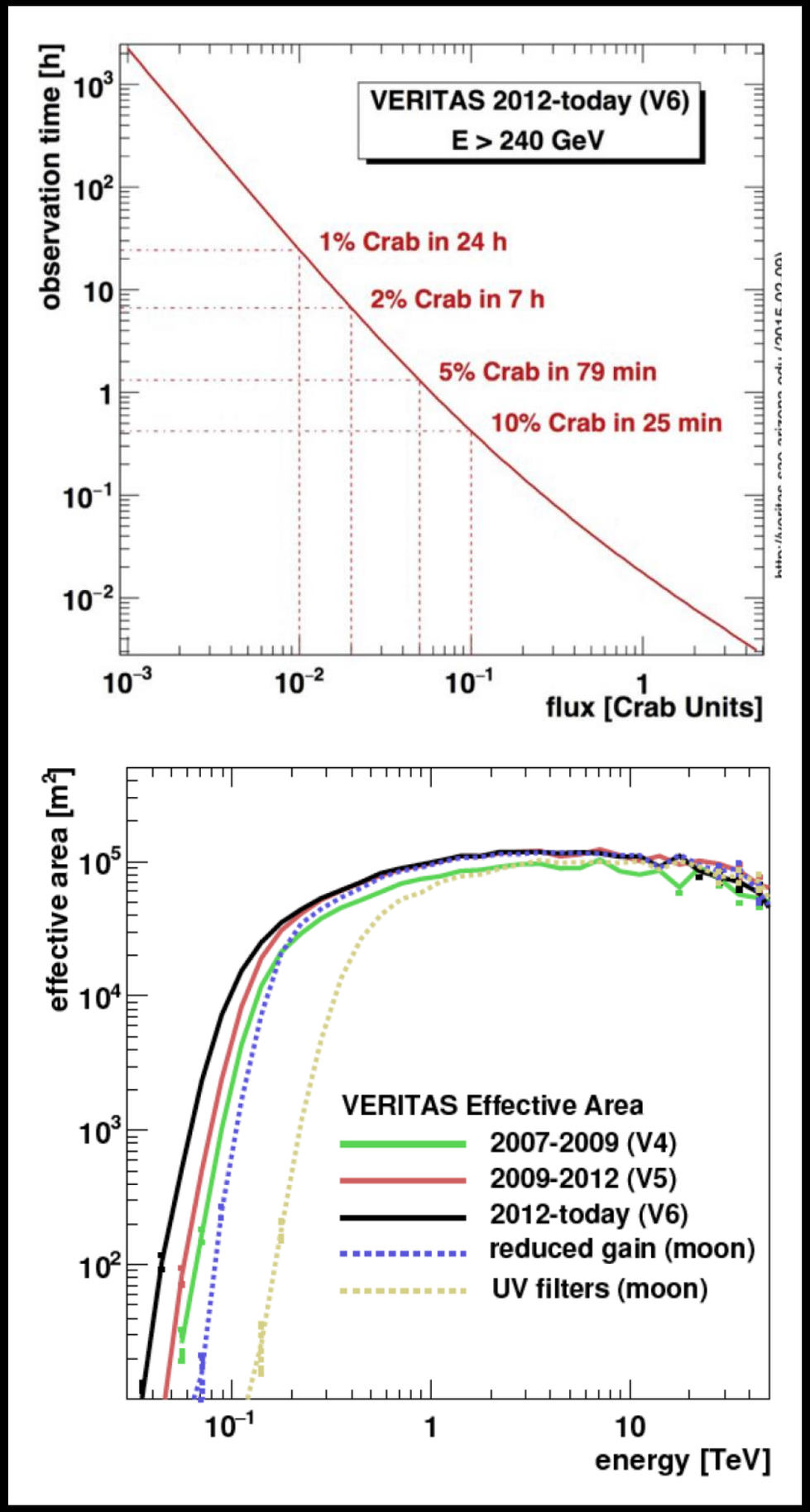
- Located at south of Tucson, Arizona, USA
- Full operation since 2007.
- Collaboration of ~100 scientist from ~ 20 institutions from 4 countries.
- 4 X 12 m Davies-Cotton type telescopes.
- Camera composed of 499 PMTs.

VERITAS UPGRADES

- Move of T1 in Summer 2009
  - Optimal array configuration with increased sensitivity
- Telescope-Level trigger upgrade in Fall 2011
  - Moved to FPGA based trigger system
  - Narrower coincidence window
- Camera upgrade in Summer 2012
  - Higher QE PMTs
  - Lower energy threshold.

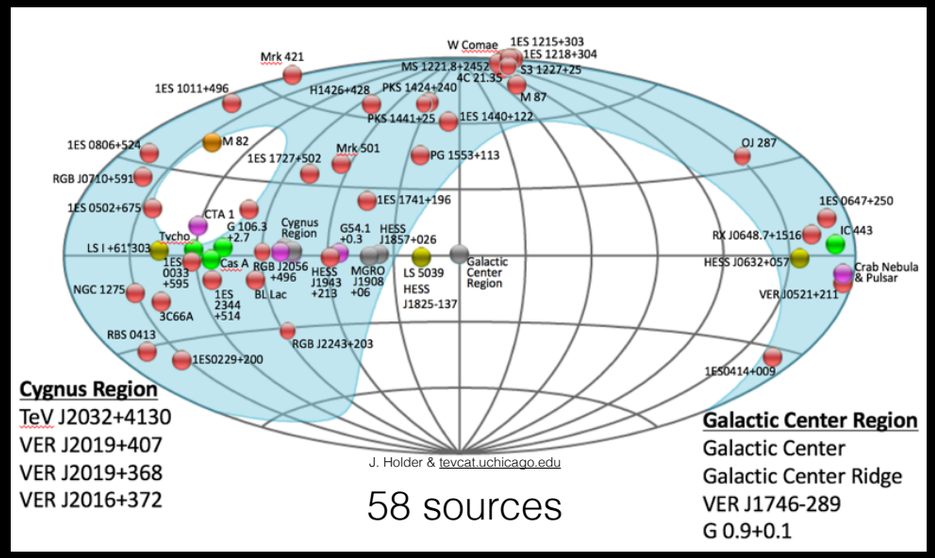
PERFORMANCE

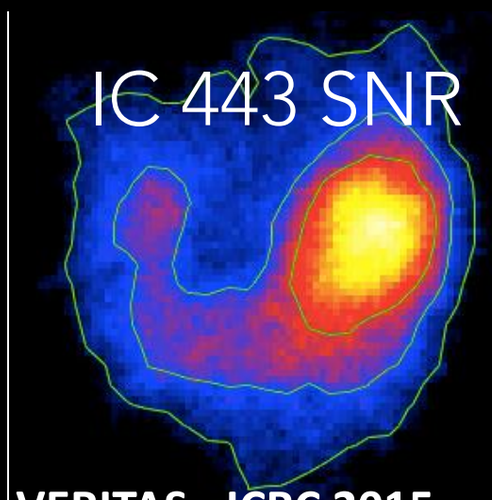
- Energy Range: 85 GeV to 30 TeV
- Energy Resolution: 15~25%
- Angular Resolution 0.08 deg @ 1 TeV
- Sensitivity 1% Crab in 25 hr
- Systematic Errors:
  - Flux ~20% Index ~0.1
- Bright moonlight programs using reduced HV or moon filter adding extra 300 hr per year of observation.



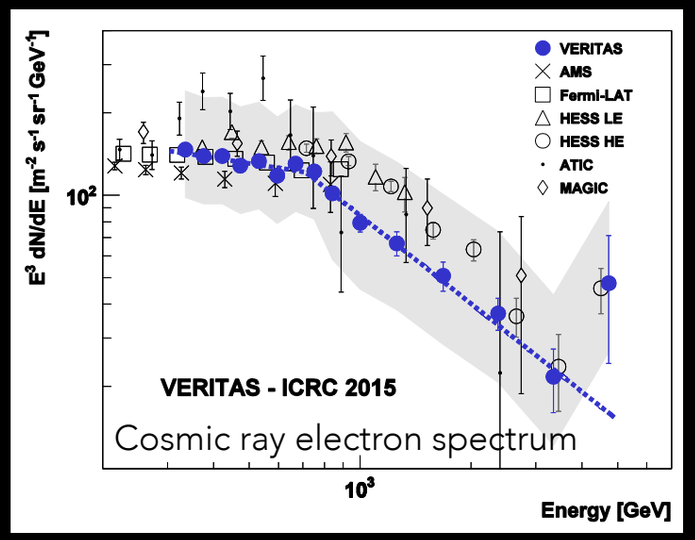
SCIENCE PROGRAMS

- Extra galactic science
  - Active Galactic Nuclei (mostly Blazar)
  - Extragalactic background light (EBL), intergalactic magnetic field (IGMF)
- Galactic science
  - Galatic centre
  - CR acceleration: SNR, PWN
  - Pulsar
  - Binaries
- Dark Matter and astro-particle physics
  - Dark Matter: Galactic centre, dwarf galaxies
  - Direct measurement of cosmic rays.
  - Cosmic ray electrons
  - Primordial black hole searches
- Follow up programs
  - GRBs
  - ICECUBE, LIGO, HAWK



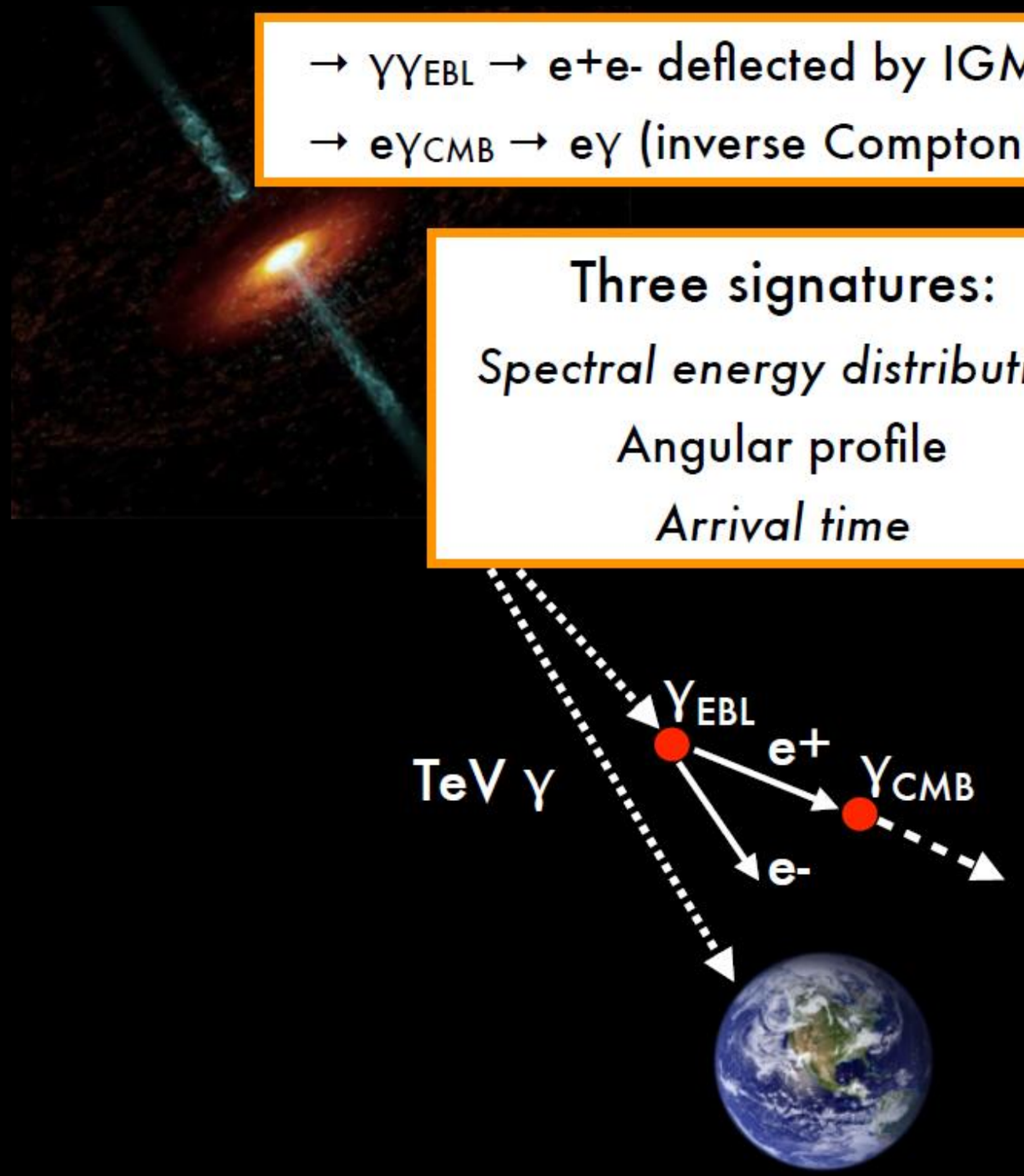


VERITAS - ICRC 2015
3, 6, 9 σ contours



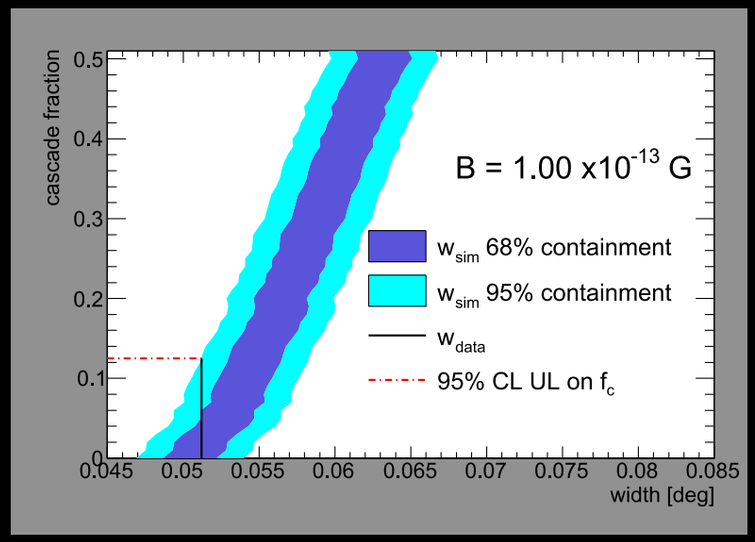
HIGHLIGHT FROM RECENT RESULTS — INTER-GALACTIC MAGNETIC FIELD CONSTRAINTS

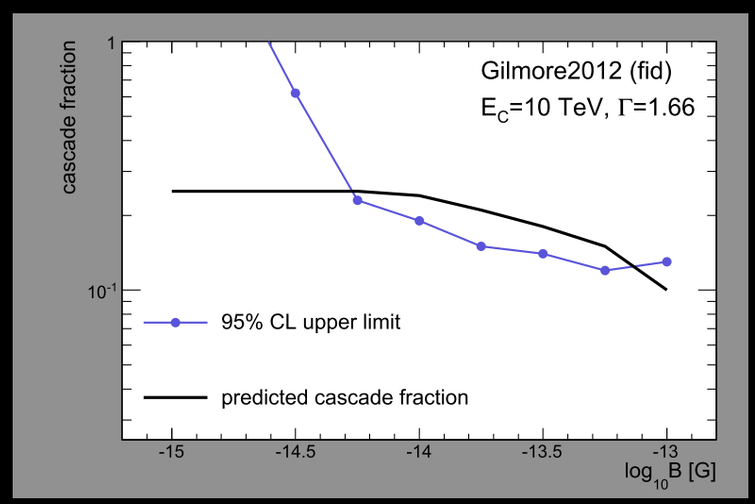
- Inter-galactic magnetic field (IGMF):
  - Very week magnetic field: 10^{-19} -10^{-9} G
  - Affects large-scale structure formation
  - Potential primordial origin —> early universe cosmology
- IGMF imprint on high-energy γ-ray
  - γ-ray pair produce with EBL
  - e^+e^- deflected by IGMF
  - A broadened angular profile from extra galactic point sources (B > 10^{-16} G).

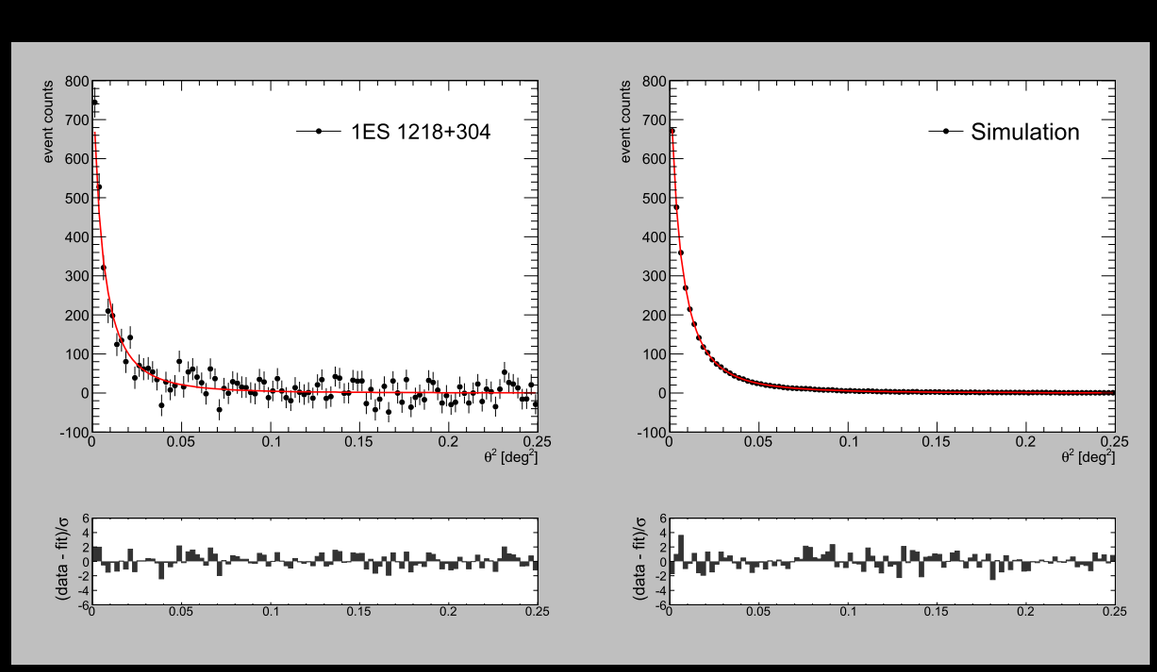


HIGHLIGHT FROM RECENT RESULTS — INTER-GALACTIC MAGNETIC FIELD CONSTRAINTS

- Seven blazars studied for evidence of angular extension due to IGMF.
- Fit simulation and observation with hyperbolic secant function.
- Total Emission = (1 -fc)* primary emission + fc*cascade emission
- Halo test for 1ES1218+304 used to constrain IGMF around 10^{-14} G.



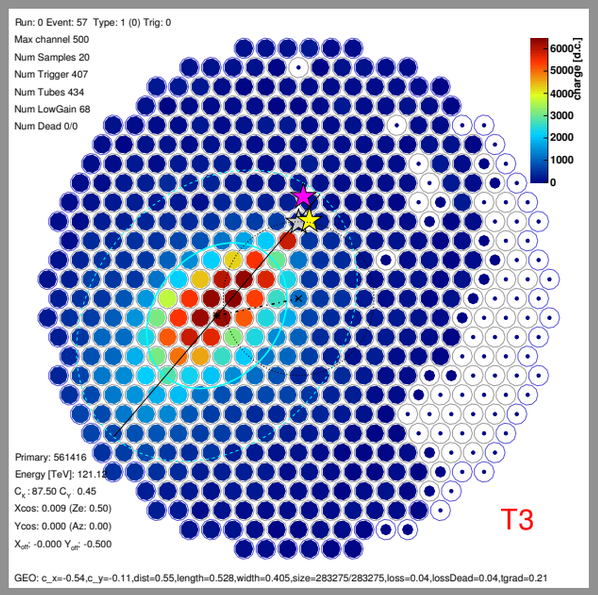




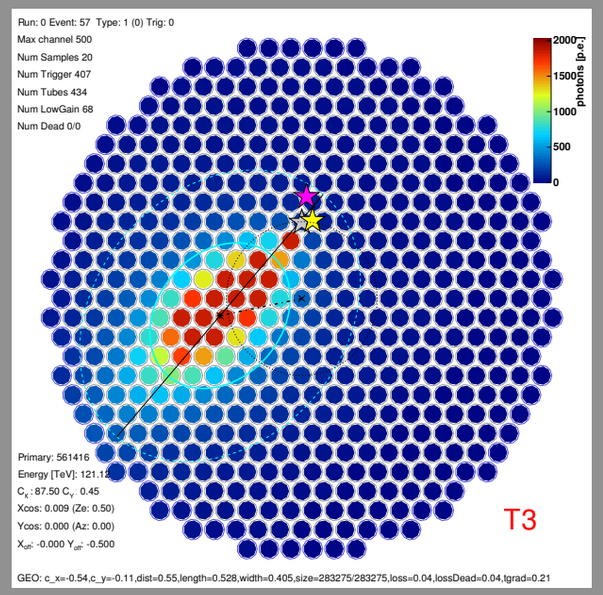
ApJ **835**, 288 (2017)

HIGHLIGHT FROM RECENT RESULTS — COSMIC RAY IRON SPECTRUM

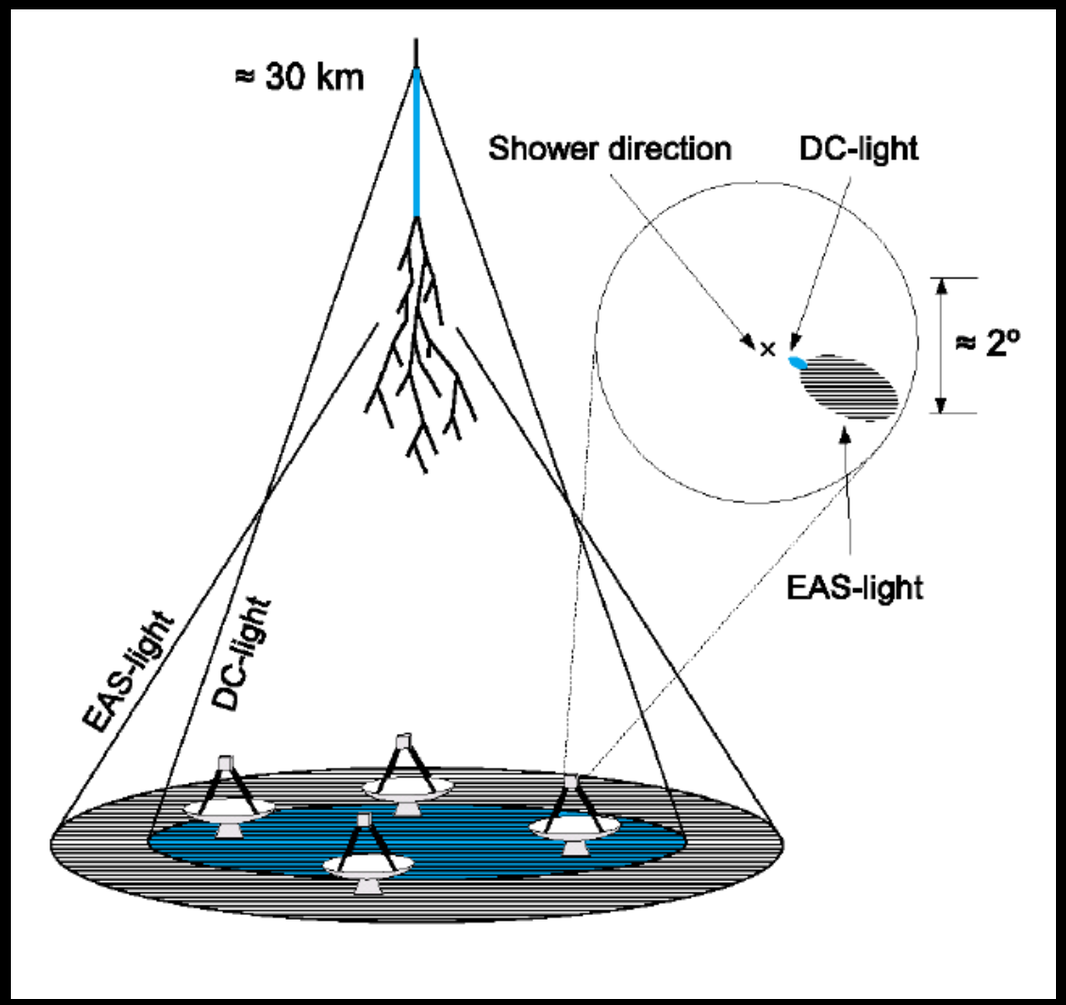
- Direct Cherenkov light technique
  - Cherenkov light from primary particle — very concentrated.
  - Intensity scale with Z^2
  - Can use to identify heavy nuclei
- Template method used to identify DC showers.
  - Better sensitivity for high energy events.
- Result feed into Random Forest for event classification.



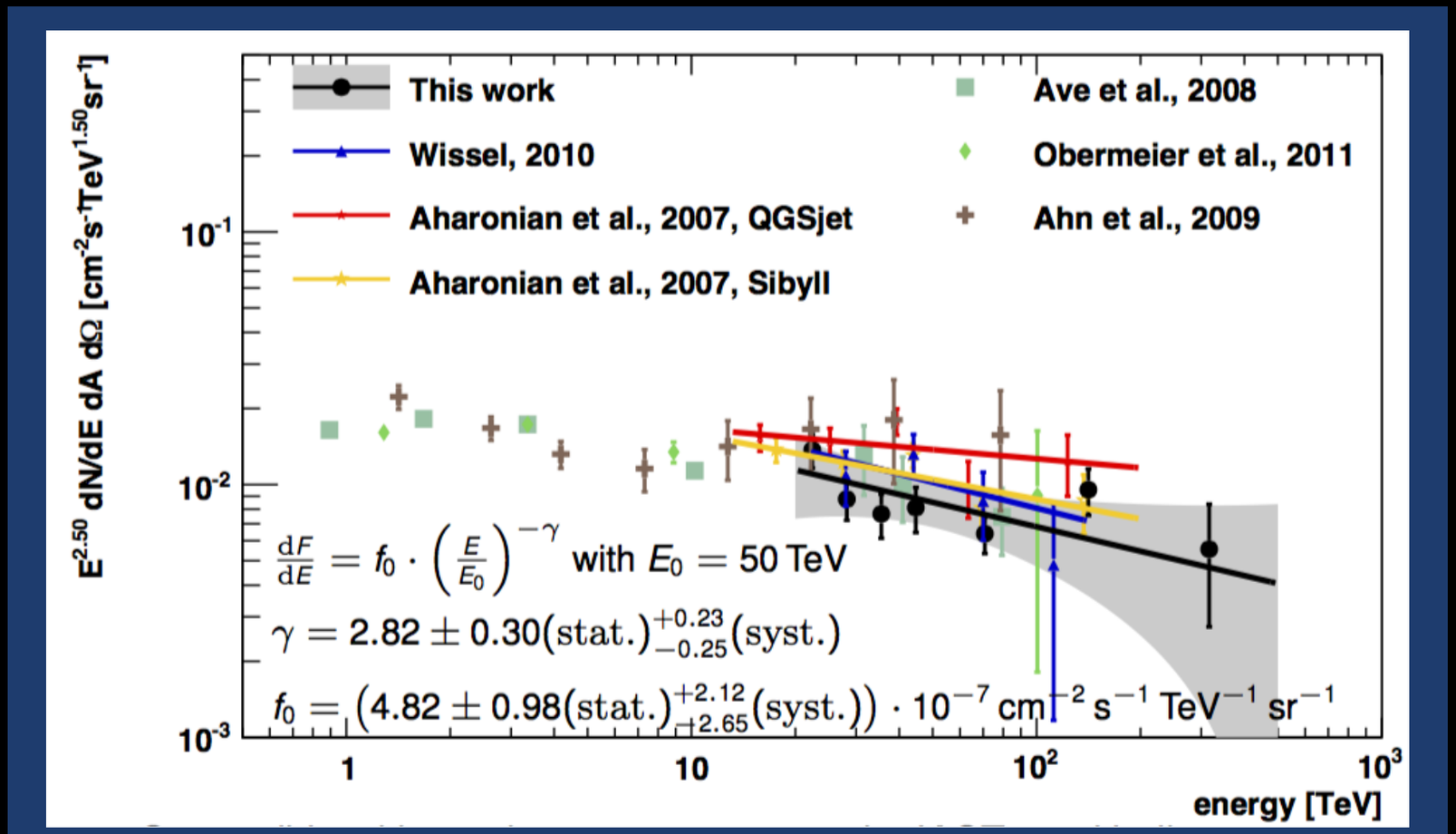
(a) Integrated charge per pixel.



(b) Best-fit image template.



HIGHLIGHT FROM RECENT RESULTS — COSMIC RAY IRON SPECTRUM

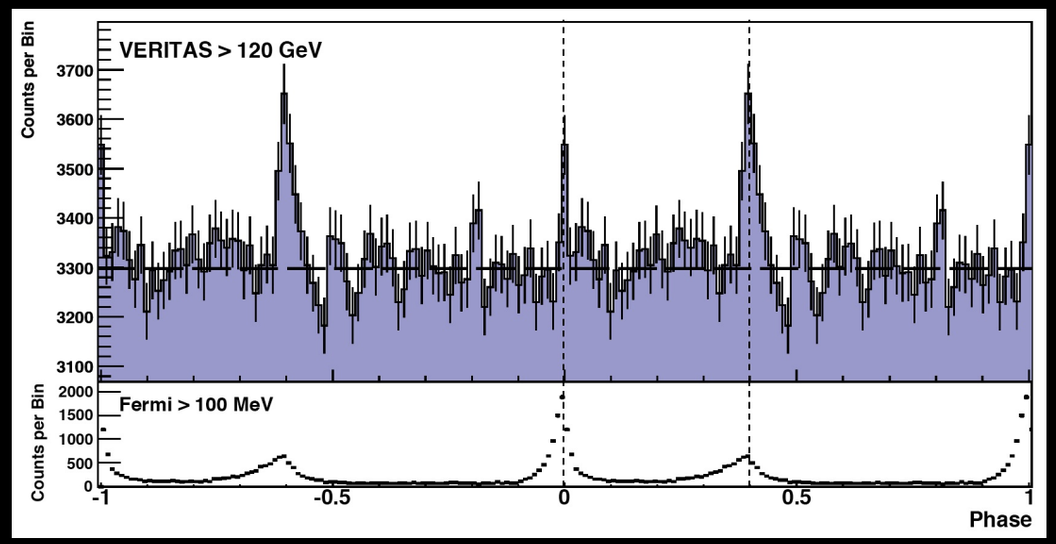


- Measurement consistent with other experiment (IACTs, balloons)
- Extend spectrum up to 500 TeV.

LIV STUDIES IN VERITAS

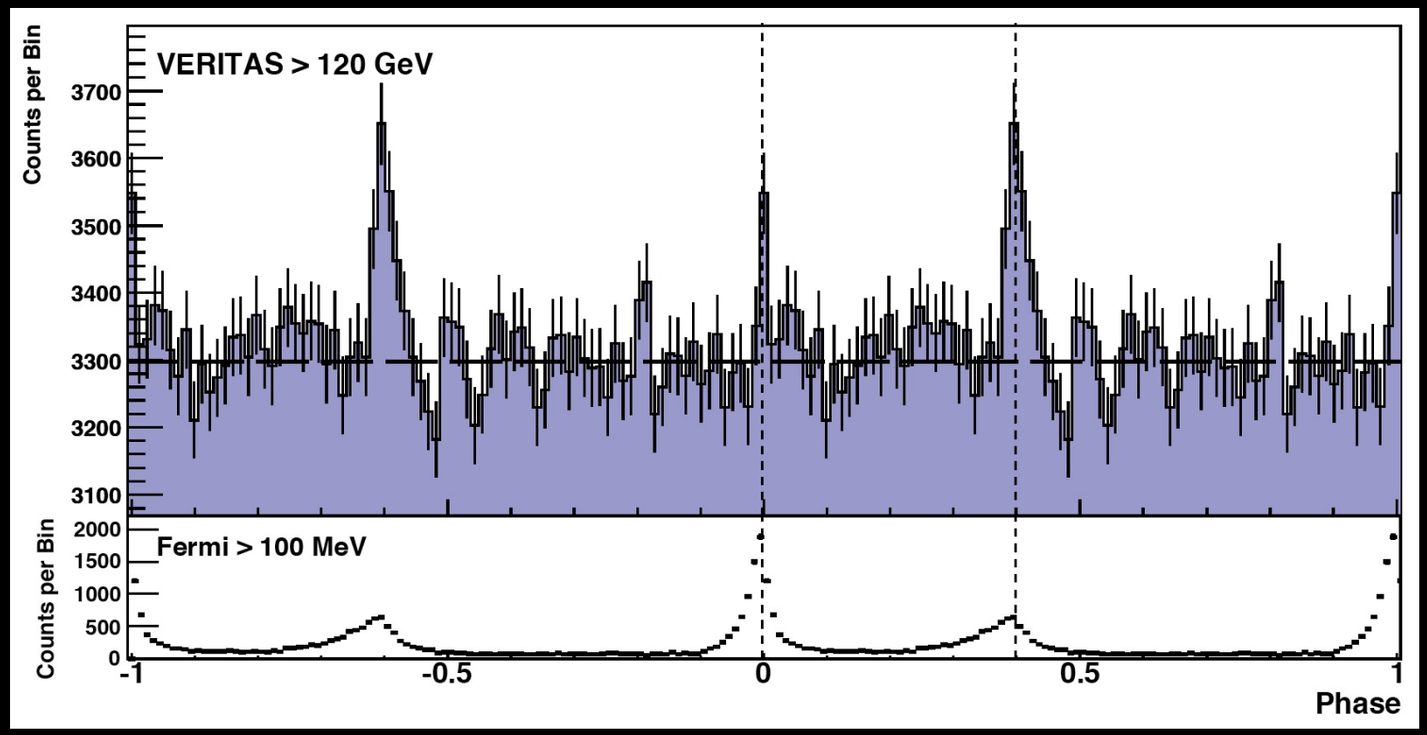
CRAB PULSAR

- Pulsing at mili-second time scale; compensating for lack of distance.
- Pros:
  - Statistics can be accumulated overtime.
    - Intrinsic effect can be distinguished
- Challenges:
  - Large background (PWN emission + hadronic showers).
- VERITAS has accumulated ~ 300 hr of quality data on the Crab.



CRAB PULSAR: DIRECT COMPARISON WITH FERMI

- Directly compare with Fermi phaseogram to look for peak shift.
- The 95% confidence upper limit on the timing differences of the peaks is calculated to be less than 100 μs.
- Translate to QG energy scale limit of 3X 10^{17}GeV at 95% confidence level for linear case.

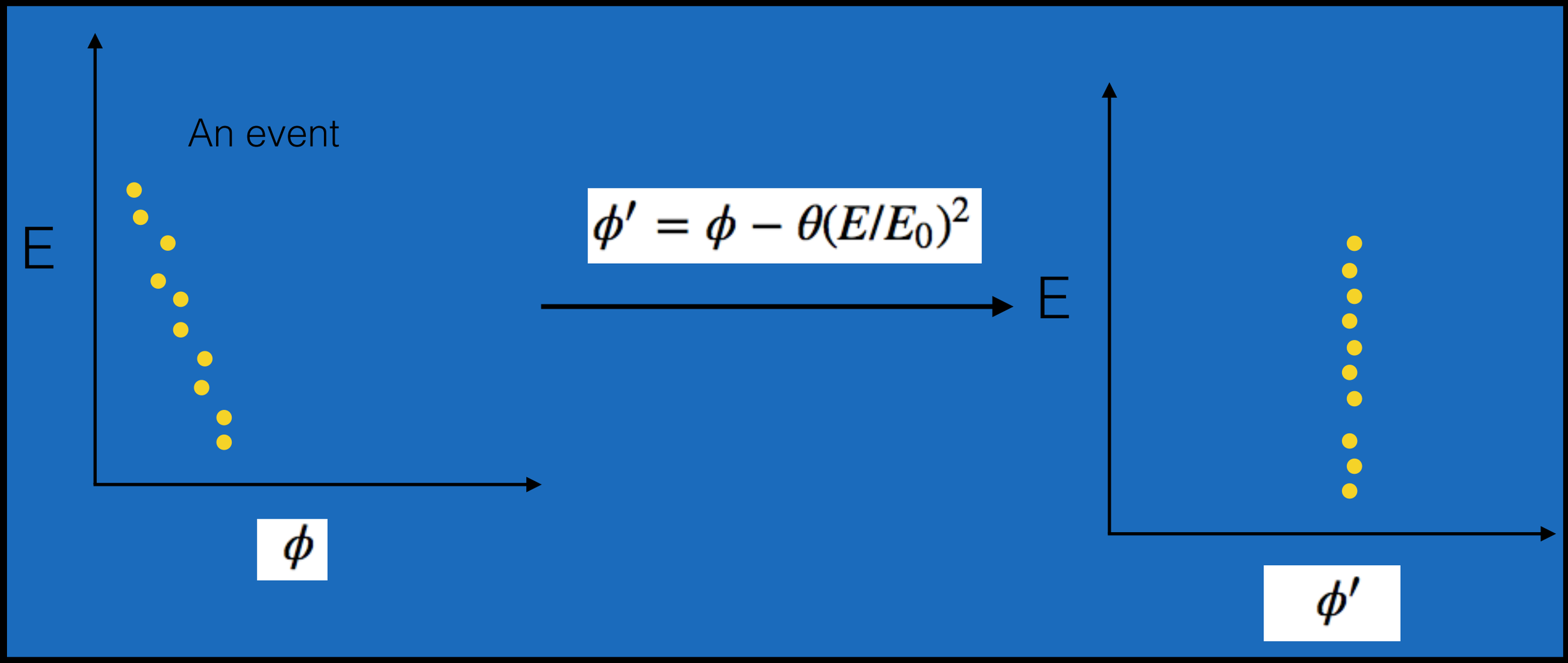


$$E_{QG1} > \frac{d\Delta E}{c_0 \Delta t_{95\%}} = \frac{2\text{kpc} * 120\text{GeV}}{3 \times 10^8 \text{m/s} * 100\mu\text{s}} \sim 3 \times 10^{17}\text{GeV} \quad (4)$$

arXiv:1307.8382v1

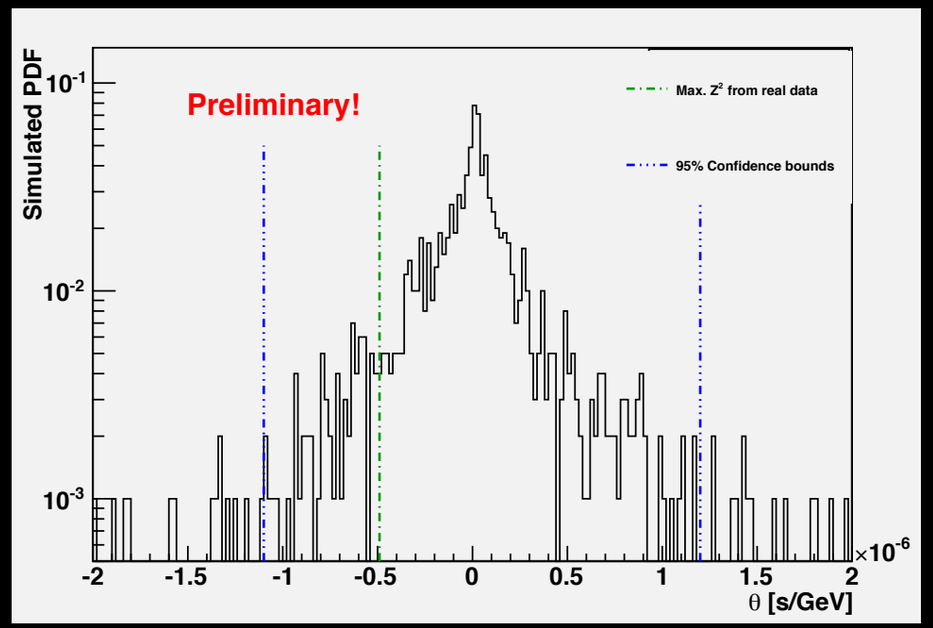
DISPERSION CANCELLATION (DISCAN)

- LIV broadens the pulse shape and make the pulse profile less “sharp”
- Adjust QG energy scale to maximize a “sharpness” metric (Z^2 Test) : $Z_m^2 = \frac{2}{N}\sum_{j=1}^{m}[(\sum_{i=1}^{N}\sin(2\pi\phi_i j))^2 + (\sum_{i=1}^{N}\cos(2\pi\phi_i j))^2]$

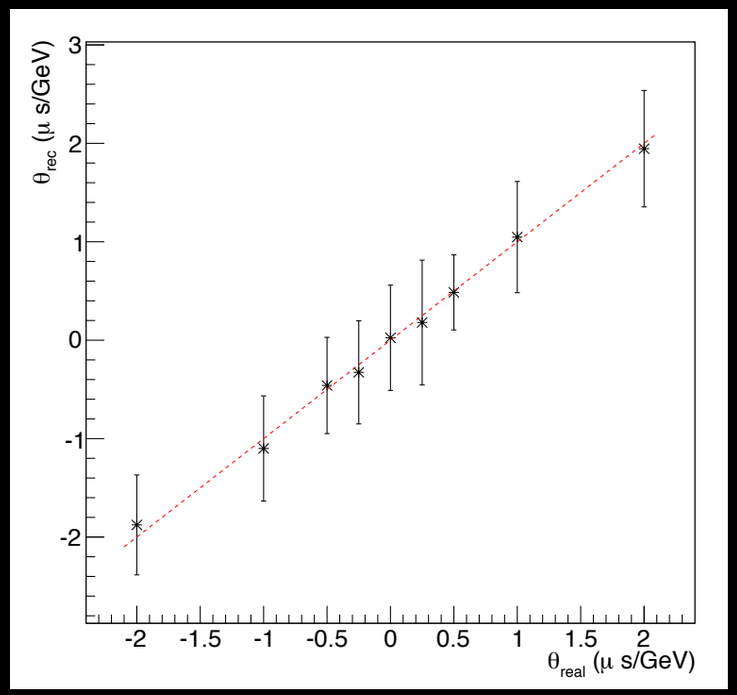


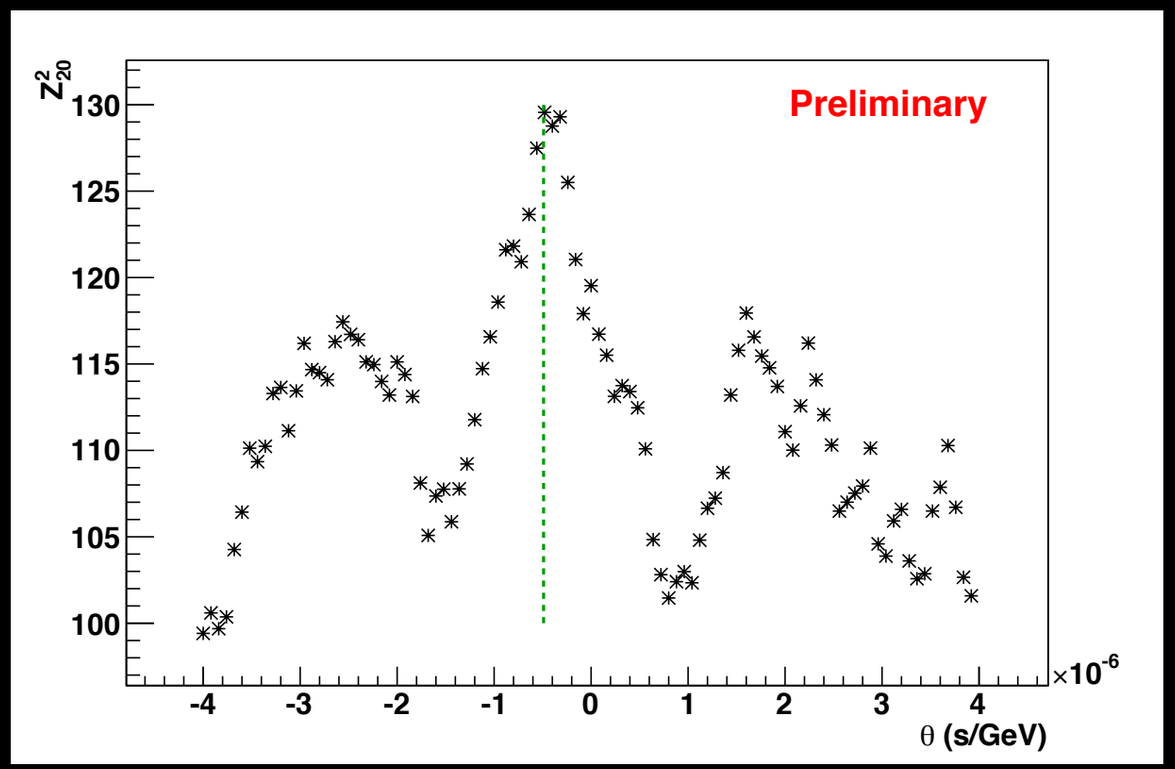
CRAB PULSAR USING DIS-CAN

- Un-binned analysis.
- Use all photons and independent of the pulse shape.
- Extract limits from simulations.
- Sub-luminal linear limit :
  - 1.9X 10^{17}GeV



- Super-luminal linear limit:
  - 1.7X 10^{17}GeV





arXiv:1307.8382v1

IN PROGRESS—
CRAB PULSAR USING MAXIMUM LIKELIHOOD

ENERGY RECONSTRUCTION RESPONSE

EMISSION TIME PROFILE

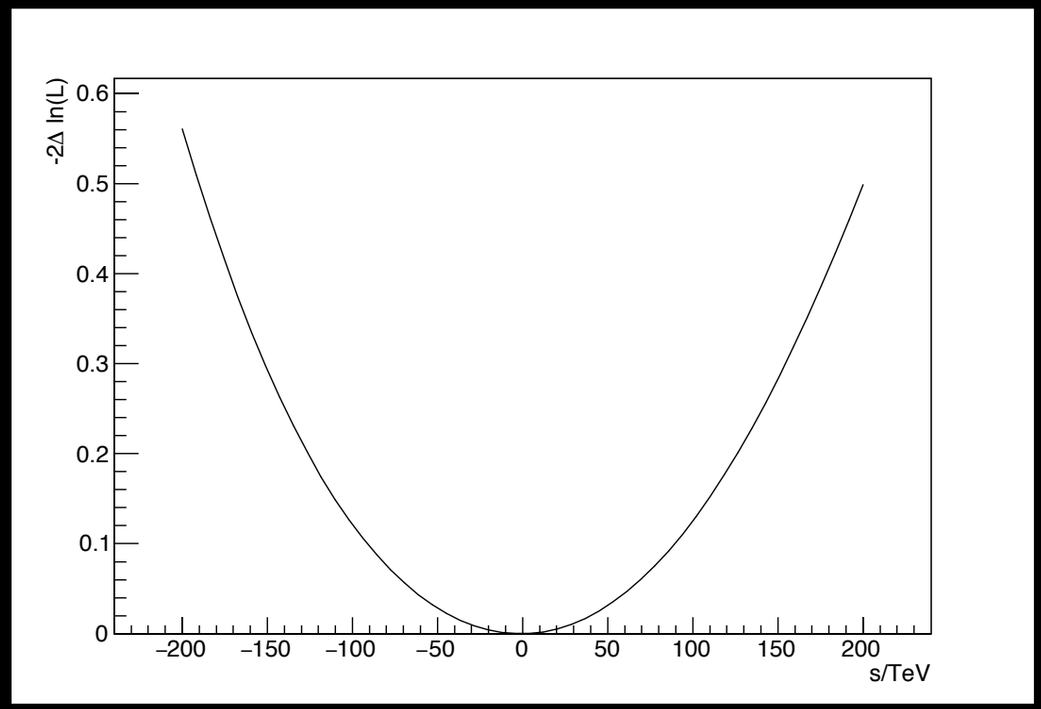
$$\frac{dP}{dEdt} = N \int_0^\infty \Gamma(E_s) C(E_s,t) G(E - E_s, \sigma_E(E_s)) F_s(t - D(E_s, E_{QGn}, z)) dE_s$$

CORRECTION FOR LIV

EMISSION SPECTRUM

DETECTOR ACCEPTANCE

- Use low energy events to build temporal profile.
- Add data from 2014 to 2017 (additional 100 hr of data).
- Combine with AGN limits from HESS and MAGIC.



SUMMARY & PROSPECT

- VERITAS continues to run smoothly and maintains sensitivity.
- Diverse scientific program
  - 70% Observing plan dedicated to long-term planning
  - 30% Observing time open to new proposal.
- On LIV front, VERITAS wasn’t as lucky in catching fast flares in the past; but we have Crab observation and more data are being accumulated.
- Other type of potential sources of interest:
  - GRB
  - Fast Radio Burst (FRB)

Thank You!

FAST RADIO BURST

- Mili-second duration burst of high dispersion measure (likely of extragalactic origin) .
- First discovered in 2007 in archived data in 2001 at Parks Radio Telescope.
- FRB121102 : repeating FRB with ~ 11 hr of VERITAS observation (~6 hrs of simultaneous observation with Arecibo).
- No steady VHE emission detected.
- Pulsed VHE search under way.
- VERITAS can also search for optical bursts.