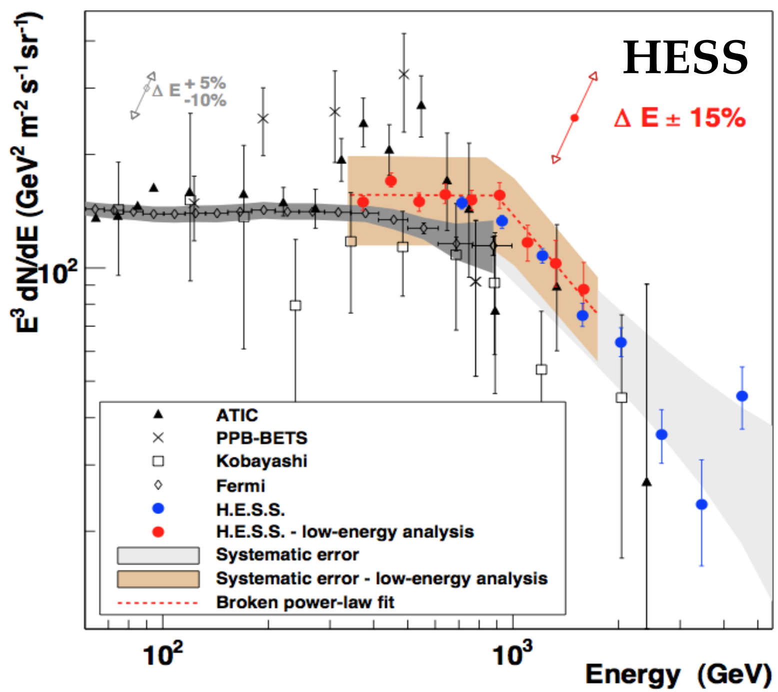
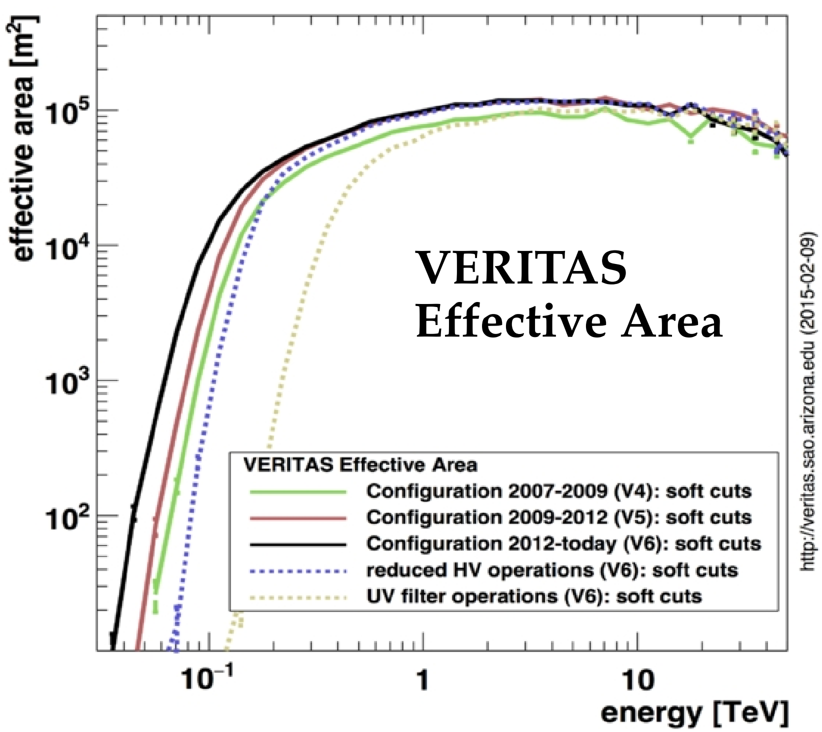
Measurement of a Cosmic-ray Electron Spectrum with VERITAS

David Staszak,
for the VERITAS Collaboration

THE UNIVERSITY OF CHICAGO

Cosmic-Ray Electrons and Positrons at TeV Energies





- Electrons are a unique probe of our local Galaxy - they lose energy very quickly via IC and synchrotron processes during propagation

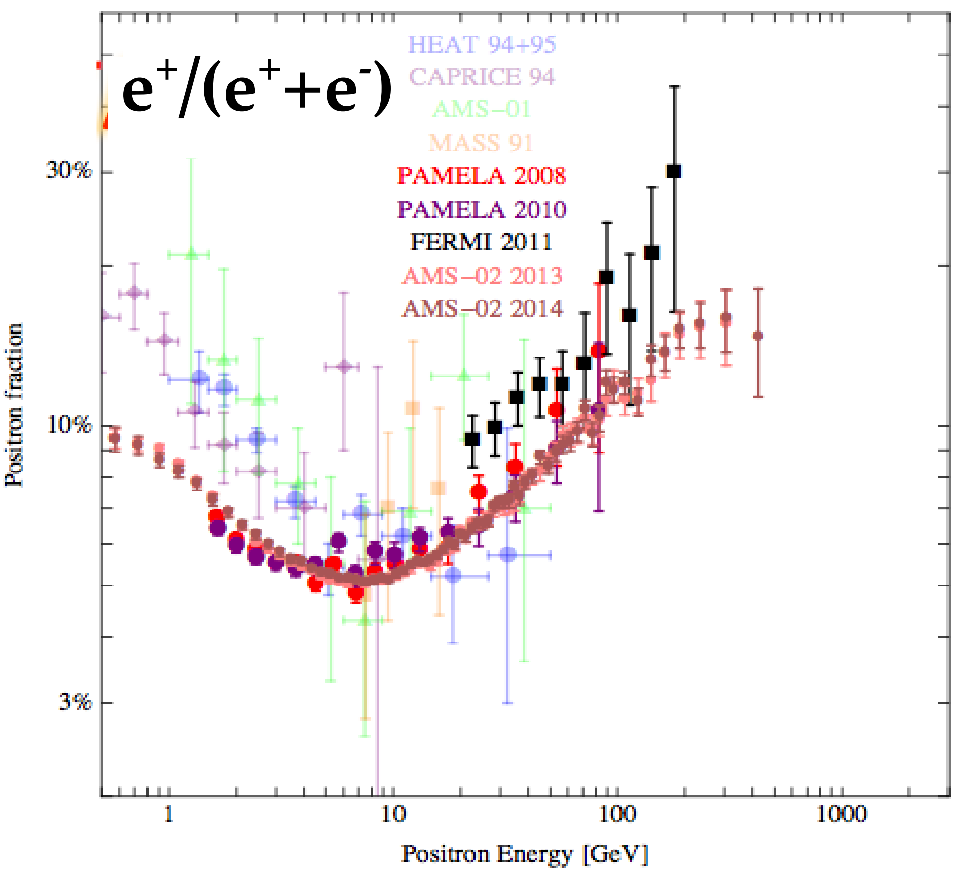
- Prior to HESS, all measurements of CR electrons came from satellites and balloon measurements

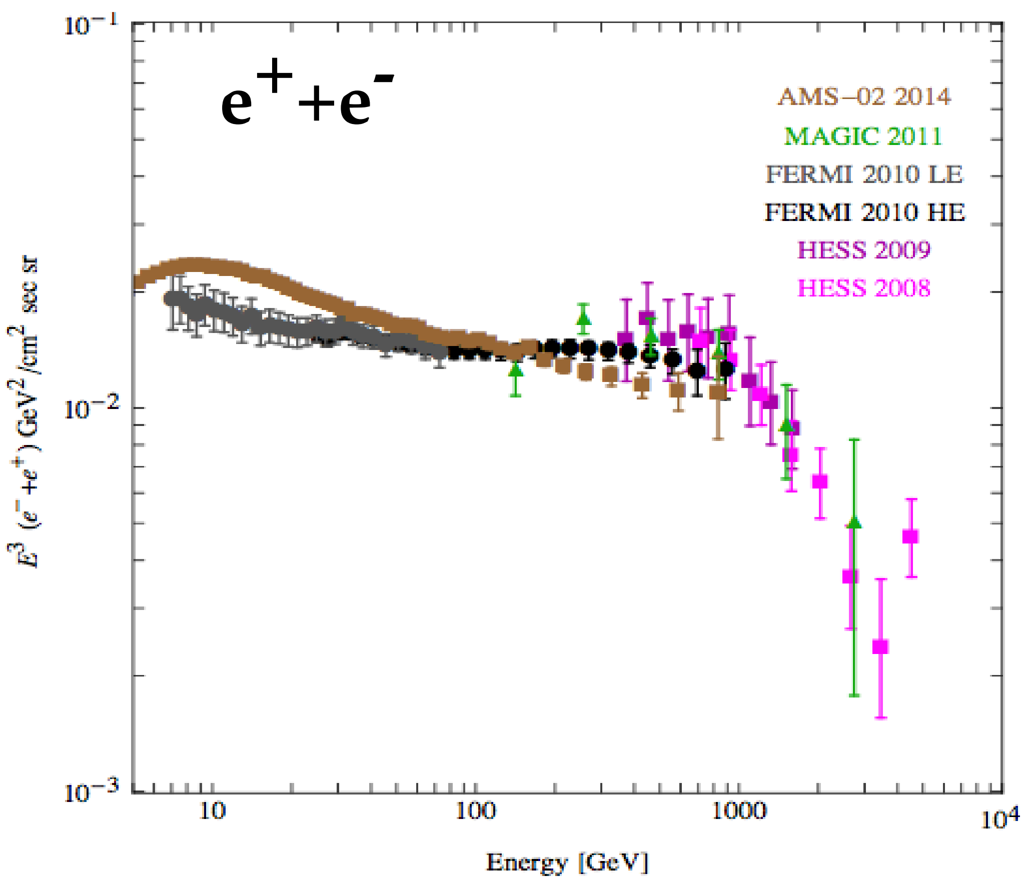
- Ground-based electron measurements can extend spectra out to higher energies:
  + much higher effective area (by 5 orders of magnitude ~ 10^5 m^2)
  - large systematics:
    * atmospheric fluctuations/models
    * hadronic interaction models
  - high background rates

Cosmic-Ray Electrons and Positrons

The current results point to the existence of a positron rich excess that could be explained in several ways:

- Cosmic ray diffusion/interaction models are wrong (or need to be better pinned down)
- Local emitter that produces positrons, like a nearby pulsar or SNR
- Positron production by particle dark matter





From Marco Cirelli, ICRC 2015

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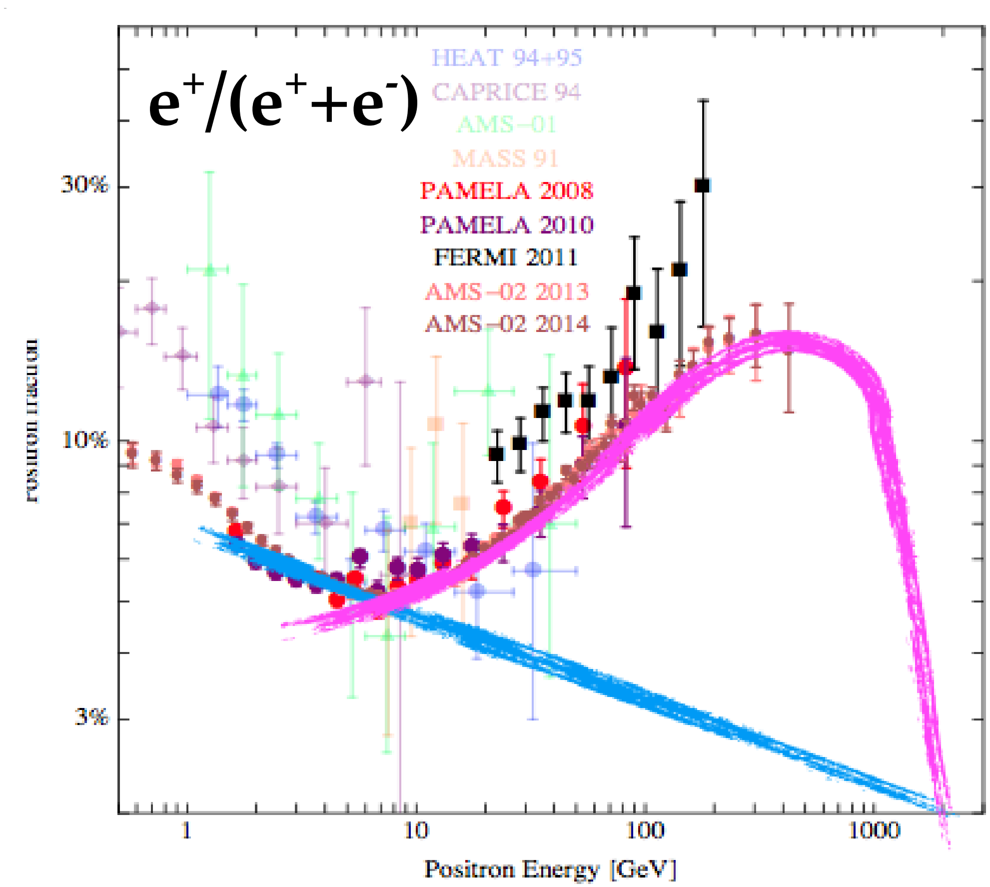

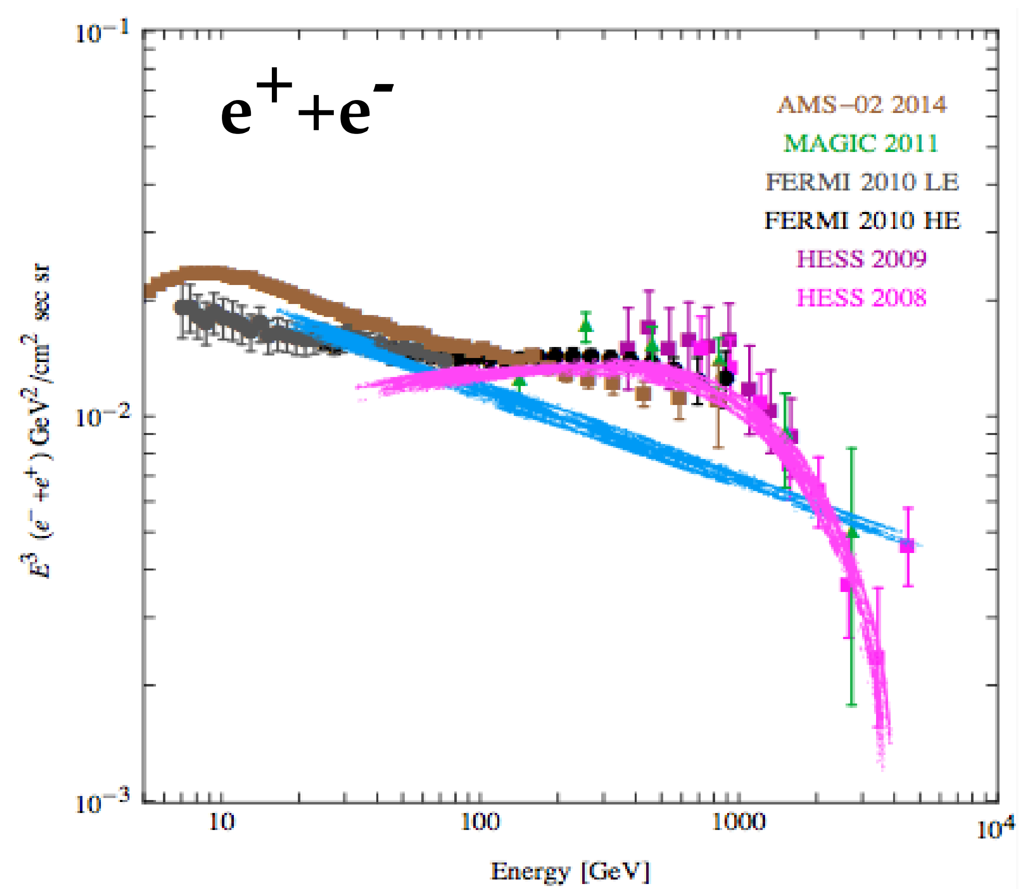

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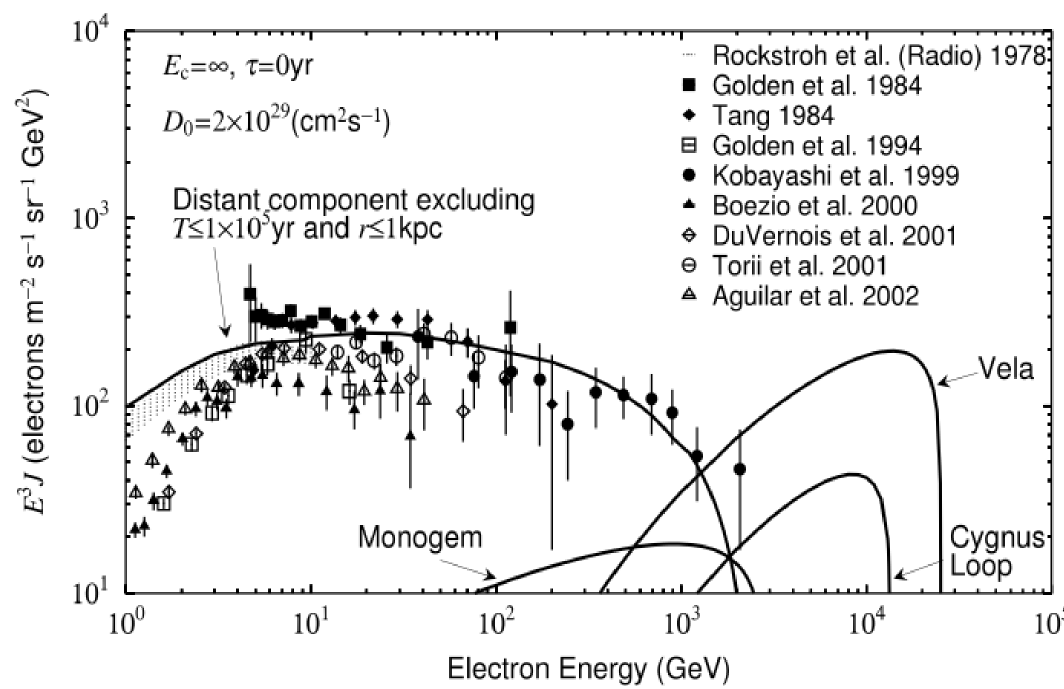
The signature of a single (or few) source of TeV CREs is predicted to show up 1-10 TeV

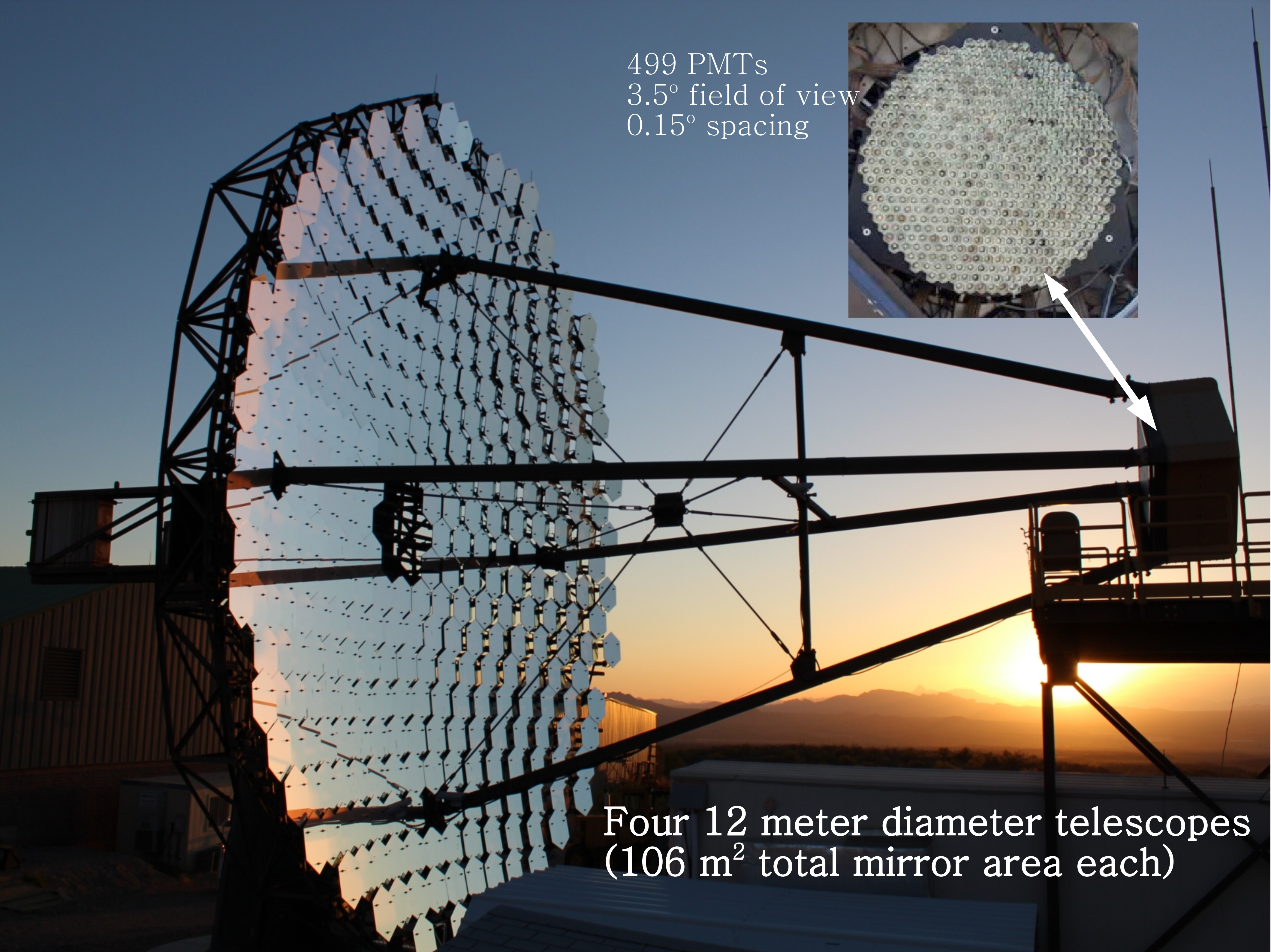
→ Additional measurements needed of both the positron fraction + all electron spectra in this energy range

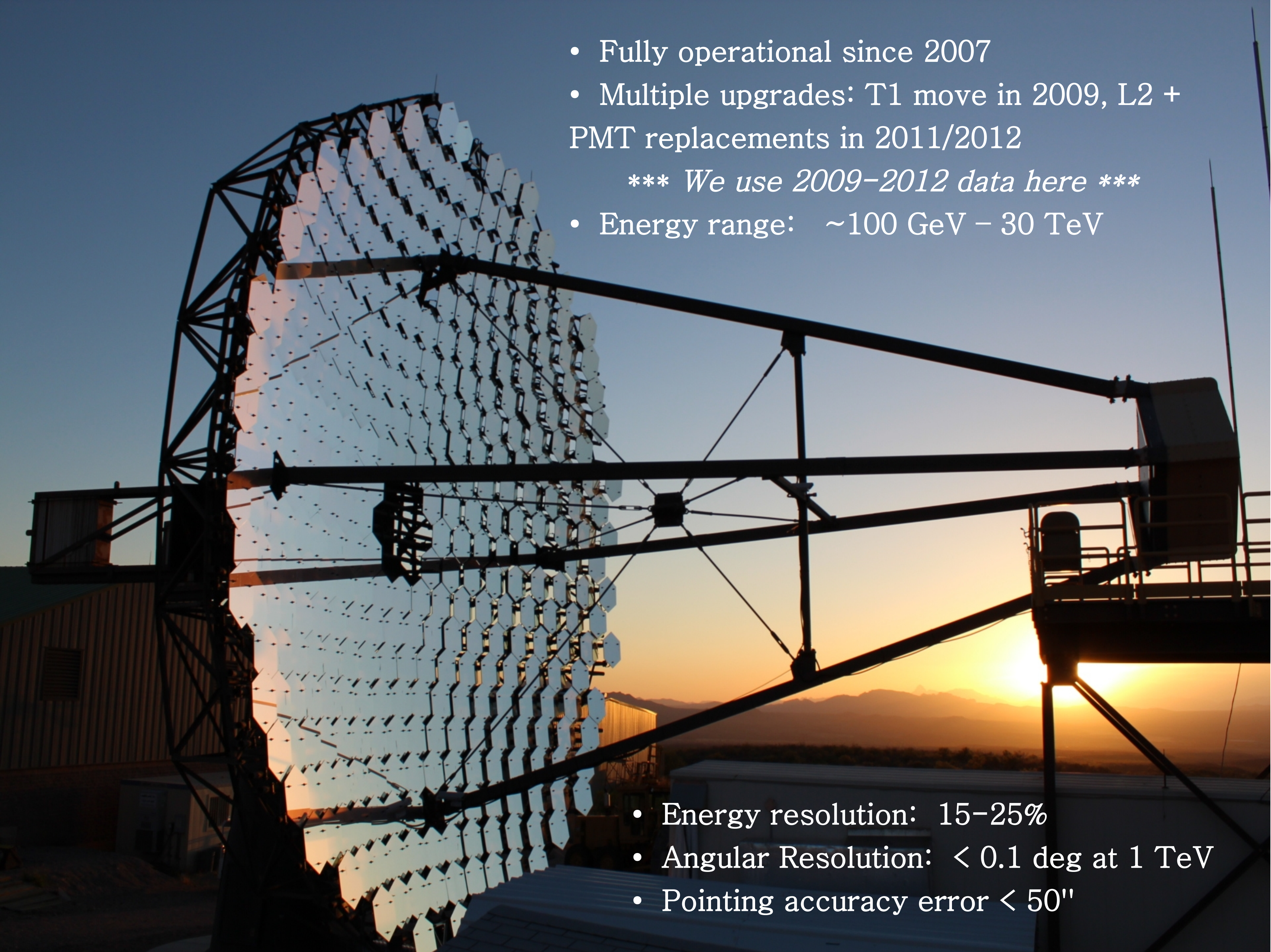
SNR	Distance (kpc)	Age (yr)
SN 185	0.95	1.8×10^3
S147	0.80	4.6×10^3
HB 21	0.80	1.9×10^4
G65.3+5.7	0.80	2.0×10^4
Cygnus Loop	0.44	2.0×10^4
Vela	0.30	1.1×10^4
Monogem	0.30	8.6×10^4
Loop1	0.17	2.0×10^5
Geminga	0.4	3.4×10^5

$e^+ + e^-$

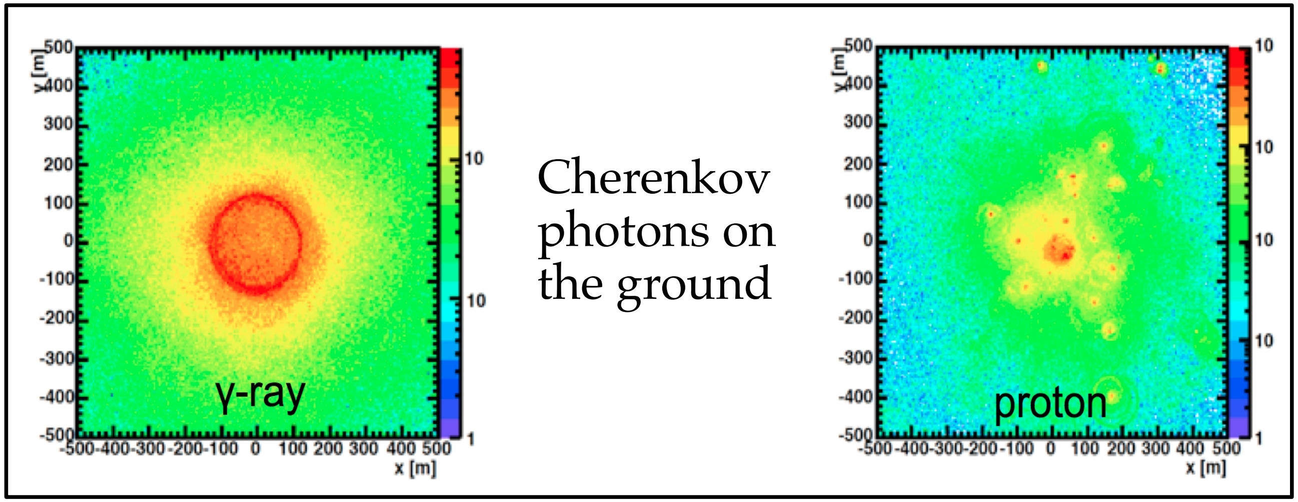


Kobayashi, et al. ApJ 2004


499 PMTs
3.5° field of view
0.15° spacing
Four 12 meter diameter telescopes
(106 m² total mirror area each)


• Fully operational since 2007
• Multiple upgrades: T1 move in 2009, L2 + PMT replacements in 2011/2012
*** We use 2009-2012 data here ***
• Energy range: ~100 GeV – 30 TeV
• Energy resolution: 15-25%
• Angular Resolution: < 0.1 deg at 1 TeV
• Pointing accuracy error < 50''

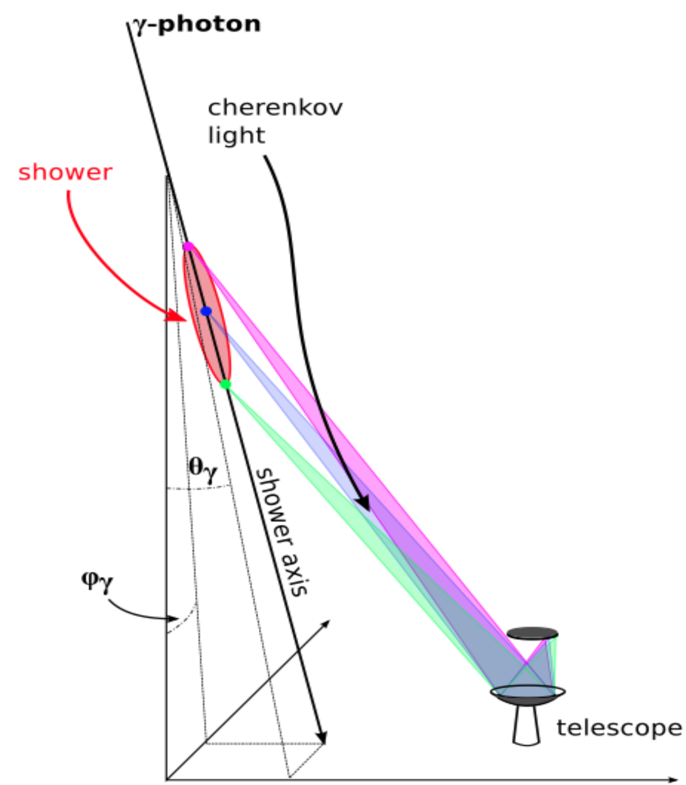
Electrons, Gammas, Protons at VERITAS



- Hadronic showers are much less uniform than EM showers

- Electrons and gammas showers imaged at VERITAS are very similar → γ s become a background, avoid by data selection (extragalactic pointings, exclude regions around any γ -ray candidate)

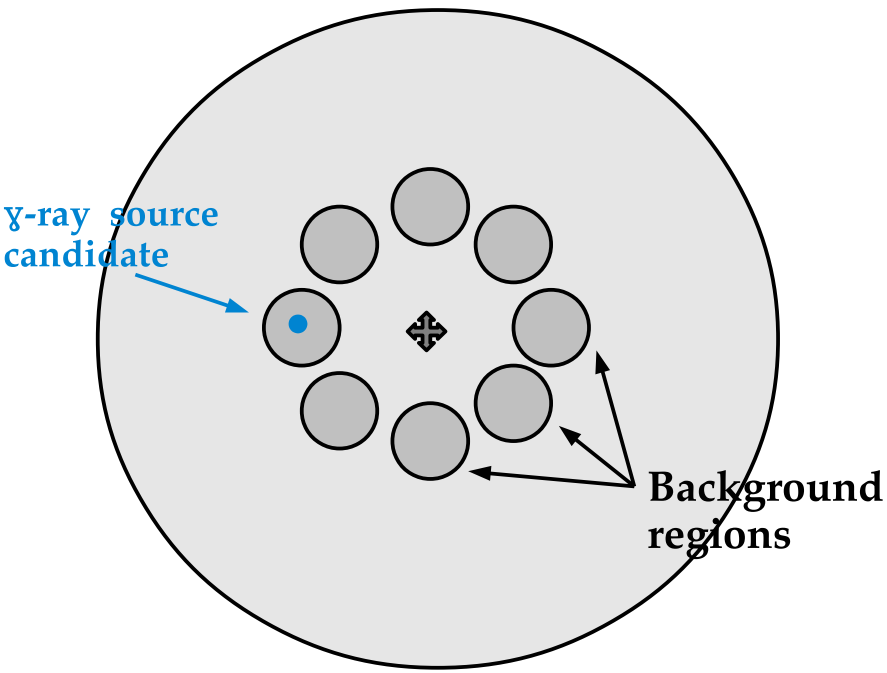
- Statistically, electrons and gammas have a ~1/2 radiation length difference of first interaction (pair production), this is one of the only differences



Sketch by Christian Skole

Electron Analysis Method

Standard analysis



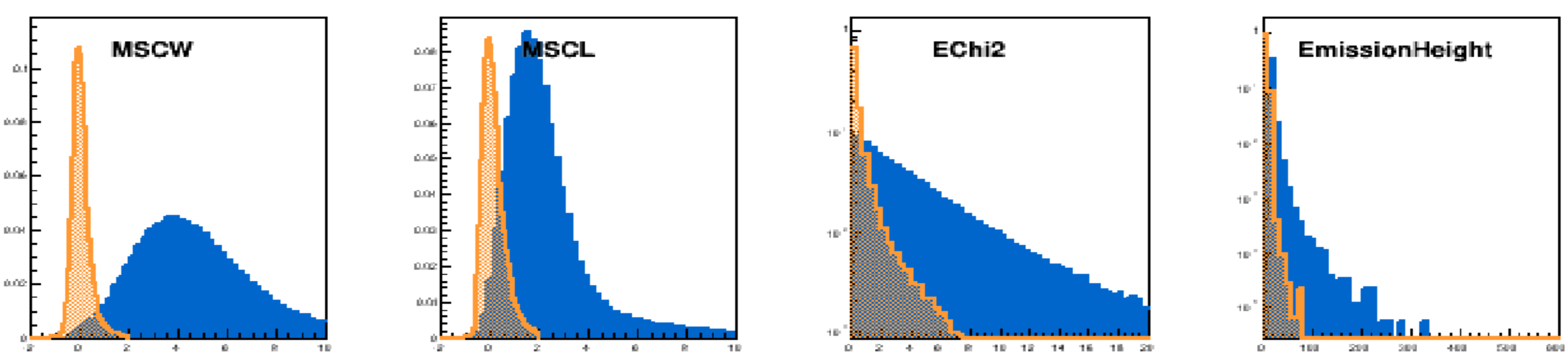
- In the standard analysis method at VERITAS, the background is sampled and subtracted from within the field of view (background including CR electrons, gamma-like hadron events, etc.)

- One of the most discriminating cuts we have is the direction cut

- In an electron analysis these advantages are lost, electrons are a diffuse/isotropic source

- Solution: analyze the full field of view using a machine learning algorithm

Input image and energy reconstruction variables into boosted decision trees

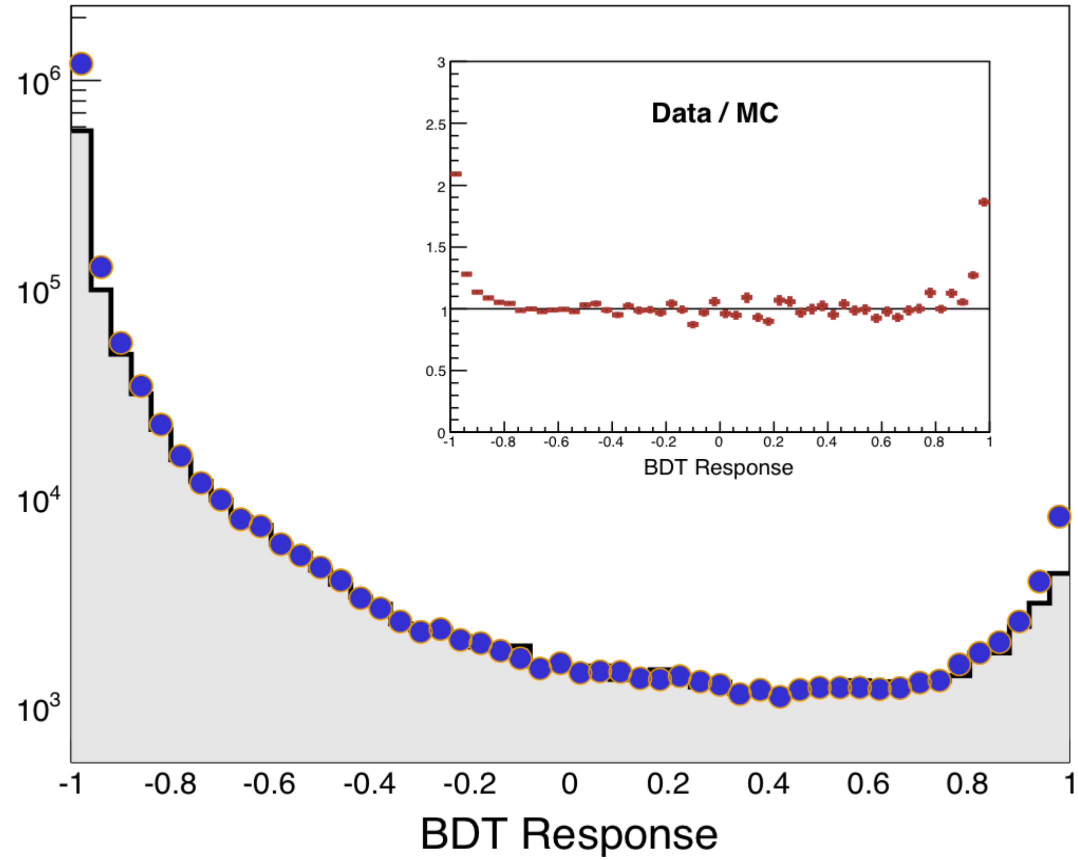


Solid blue – proton MC or data, shaded orange – electron MC

Data Selection & Hadronic Model

- Extragalactic fields + remove any candidate gamma-ray sources, stars

- Stringent cuts to the data
  - Require 4 telescope images
  - Inner 1 degree of VERITAS field of view
  - Pristine weather conditions, no moonlight data
  - Reconstructed core radius <200m



- **296 hours of data remains**, sampling much of the celestial sphere visible to VERITAS

- BDTs determine for each event a 'BDT Response', 1.0: signal-like, -1.0: background-like

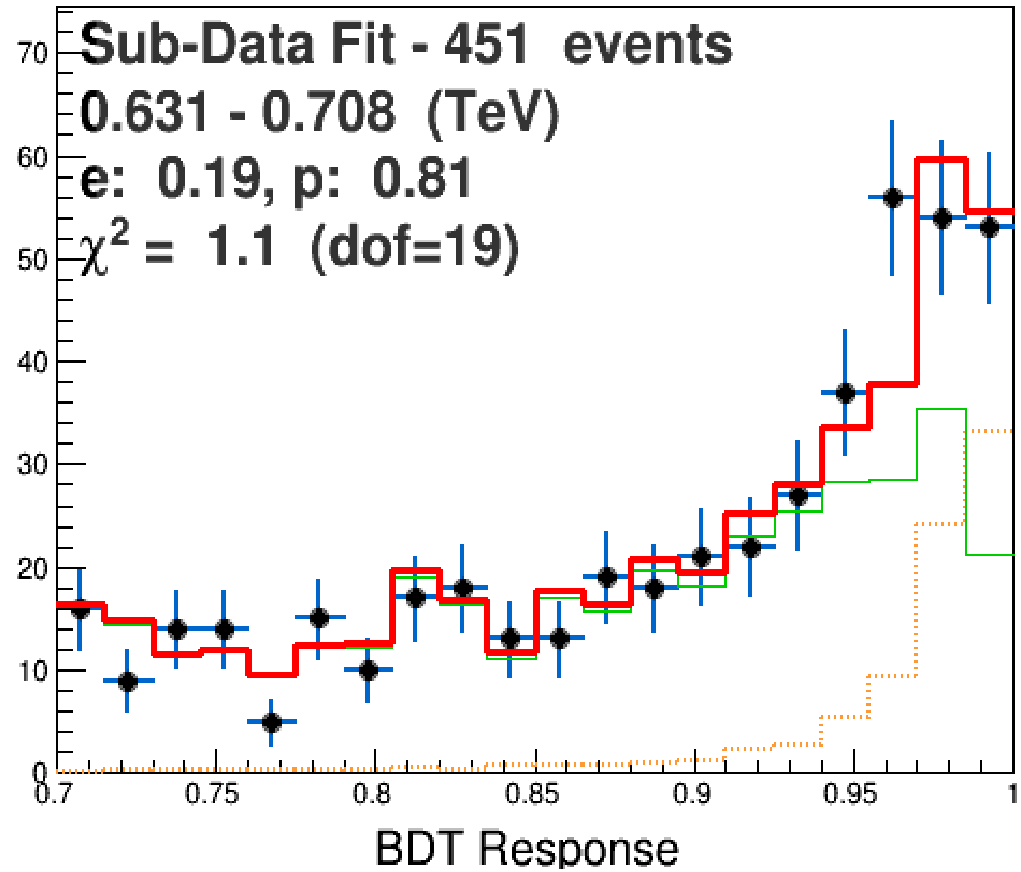
- Comparison of this data and proton MC yields good agreement except at the limits of the BDT response distribution (QGSJetII + URQMD).

Fitting Method: *Extract nElectrons & nProtons in a given energy bin*

- Binned likelihood fit of the data: Fit the relative contributions of proton MC and electron MC distributions to the total (fraction of e/p floats)

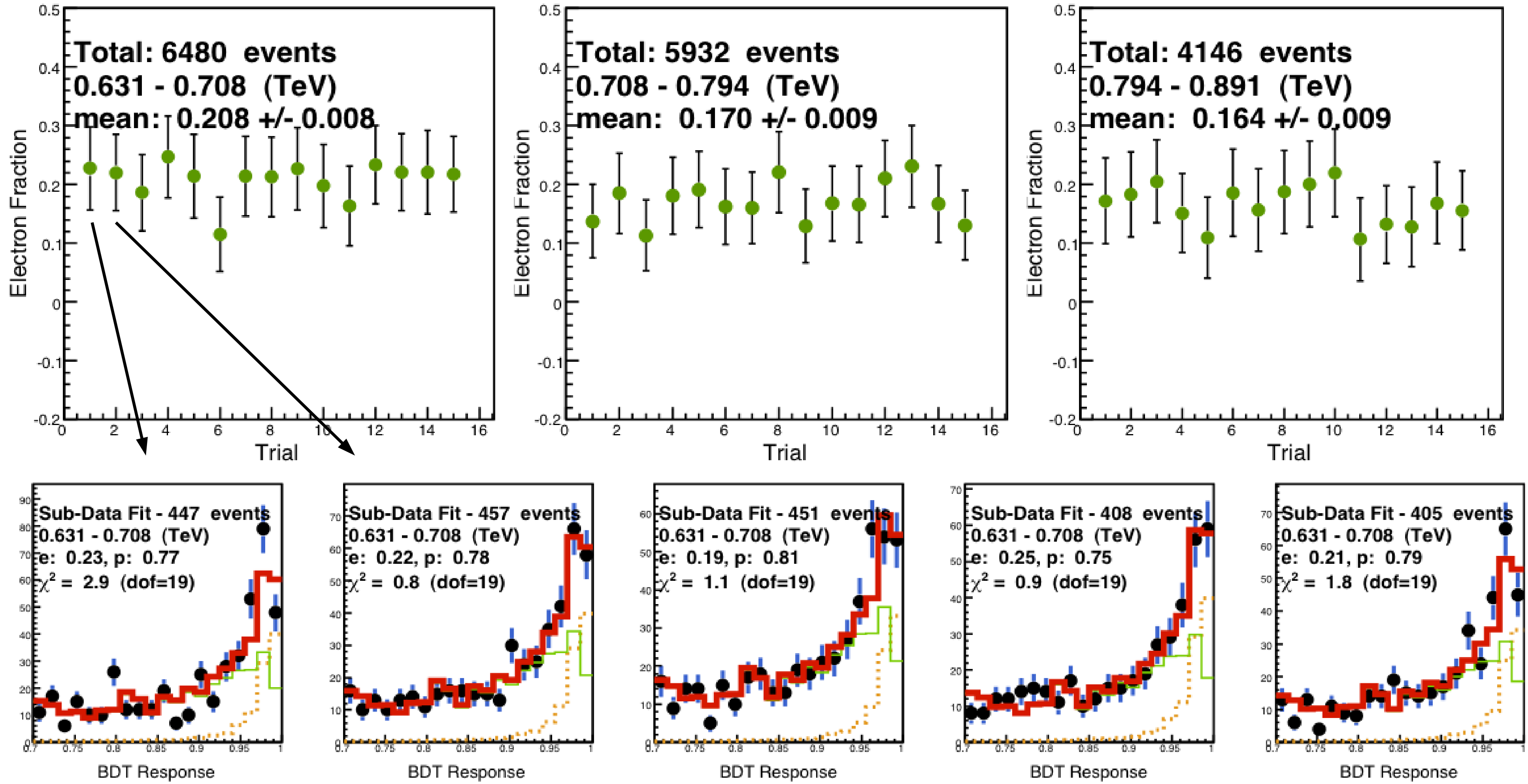
- Note the truncated x-axis, this is in effect an analysis cut to focus on the electron dominated region

- We can neglect contributions of helium and higher-Z elements to first order (sufficiently discriminated by the BDTs)



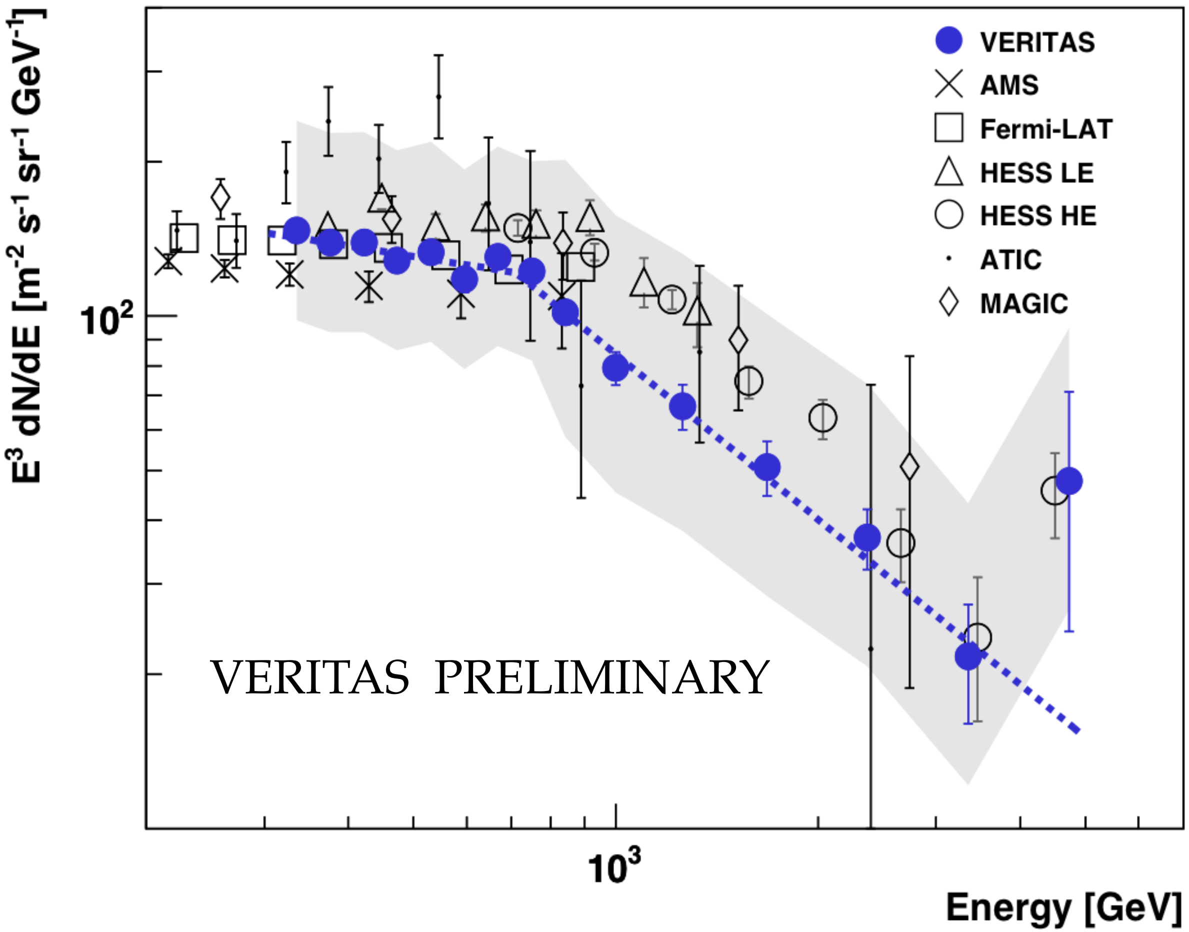
- Red is the Fit, Orange is Gamma MC, Green is Proton MC

Bin-by-bin Fitting: *Perform fits for each energy bin to extract number of electrons, form a spectrum*



Divide data in a given bin up into several trials (experiments) to estimate the statistical uncertainty on electron fraction in the data – mean value and the error on that mean

VERITAS CRE Spectrum



- VERITAS measurement covers ~300 GeV to ~5 TeV
- Best fit yields a $-3.2 \pm 0.1_{STAT}$ ($-4.1 \pm 0.1_{STAT}$) spectral index below (above) the energy cutoff at 710 ± 40 GeV
- Systematical uncertainty is dominated by the ~20% uncertainty on the VERITAS absolute energy scale

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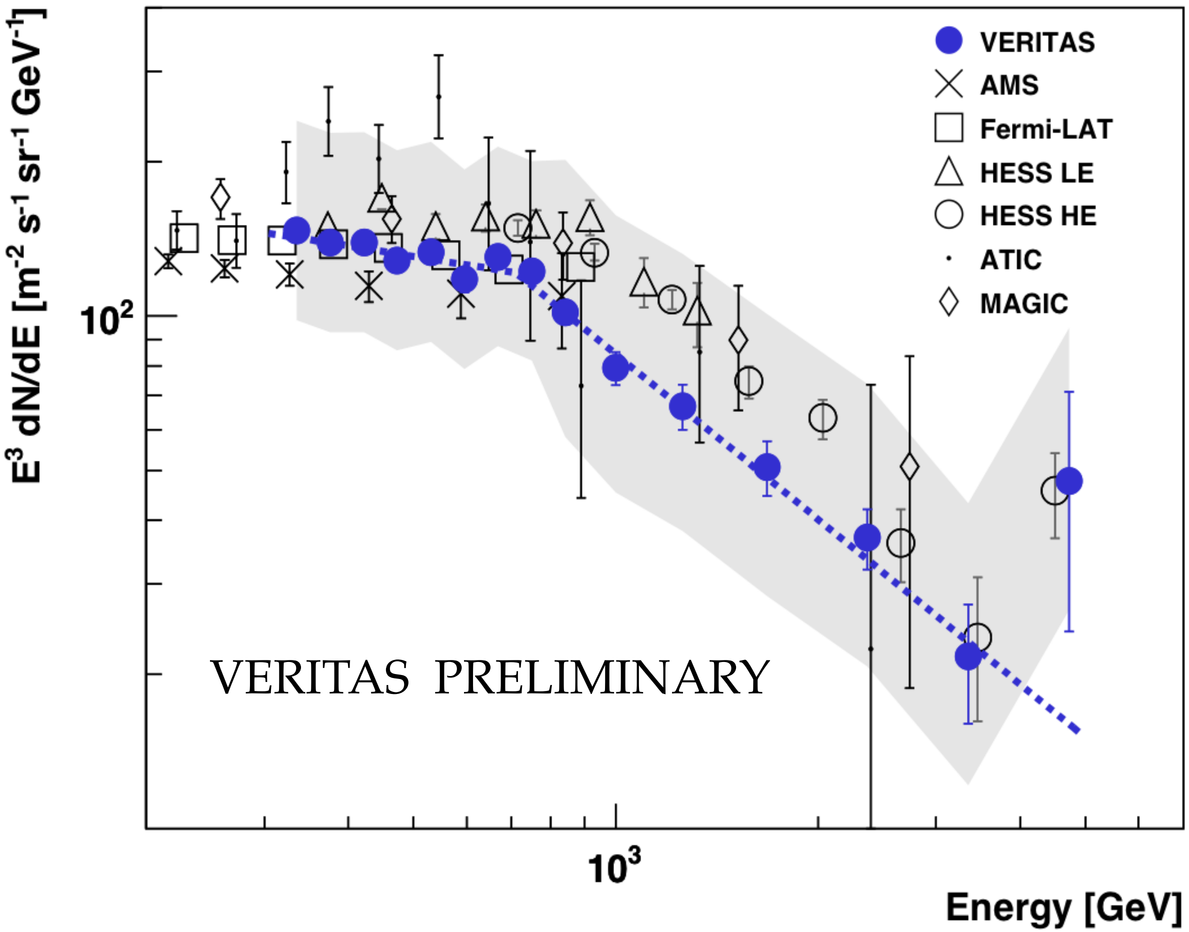

Additional Cross-checks investigated:

- CRE spectrum using SIBYLL proton event generator is within systematical uncertainties

- CRE spectrum without BDTs (simply using existing machinery to fit the distributions of most discriminating variable) agrees within systematical uncertainties

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Conclusions:

- The VERITAS CRE spectrum qualitatively agrees with prior satellite- and ground-based measurements within systematical uncertainty

- Second high statistics measurement of a cutoff in the all-electron spectrum just below ~1 TeV

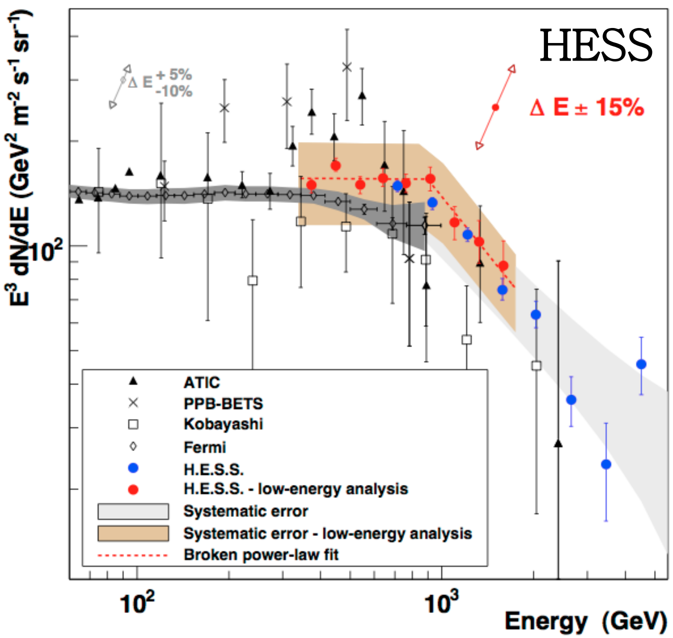
- Provides further evidence of at least one local high energy CRE emitter

- Can't rule out significant contamination from gamma-rays due to the similar nature of electron and gamma showers

- For the future – more data on disk so we will continue to push towards higher energies

Backups…

Cosmic Ray Electrons/Positrons



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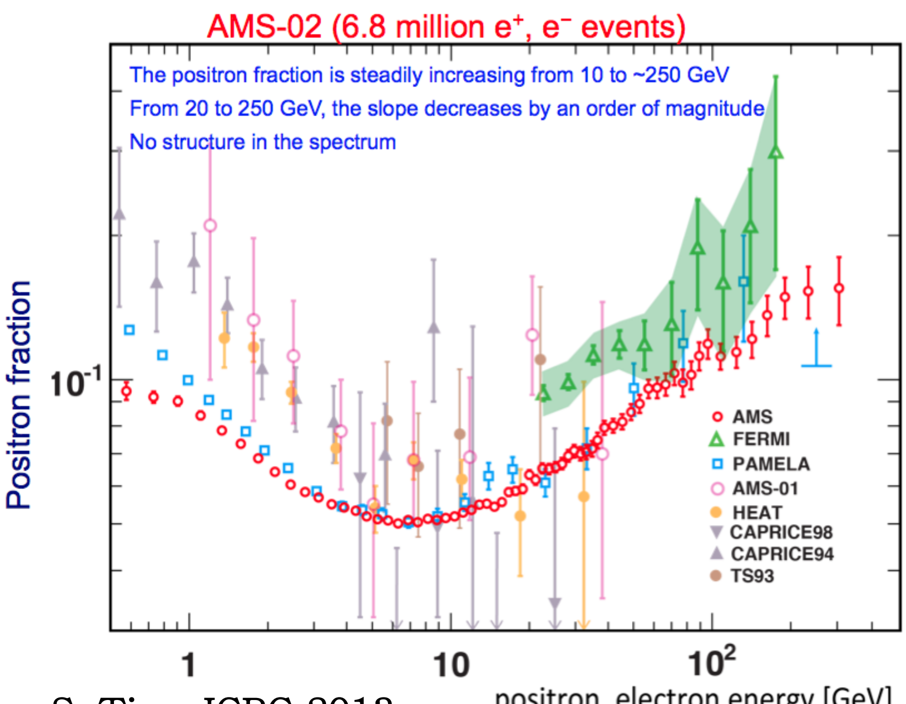
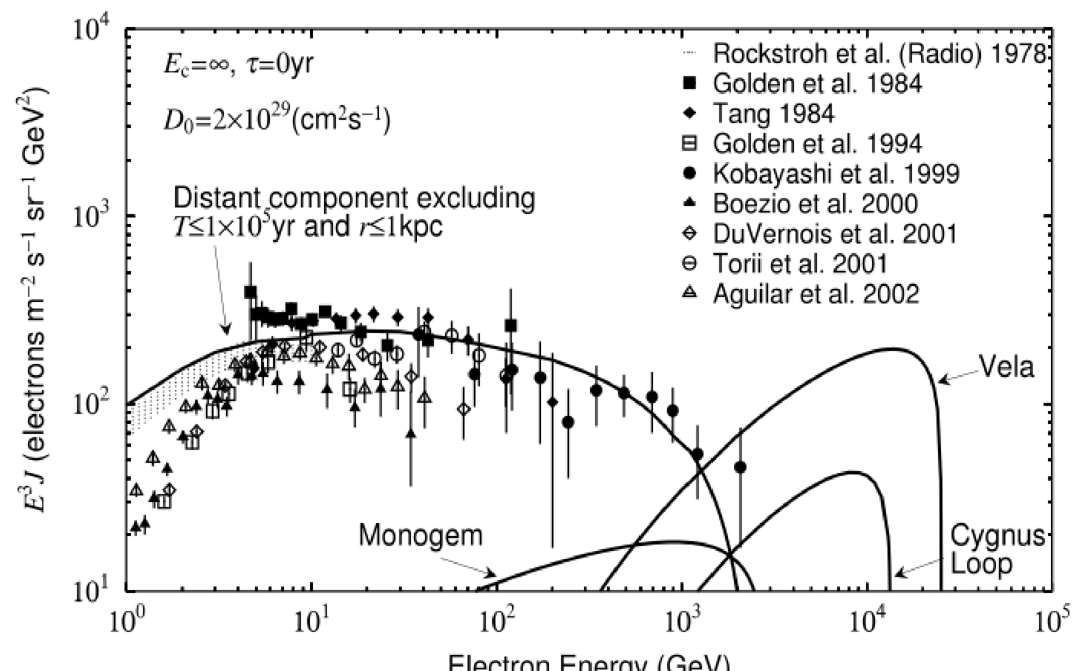


S. Ting, ICRC 2013

D. Staszak, 2016 ICHEP



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