Search for Extended Gamma-ray Halos Around Active Galactic Nuclei with VERITAS

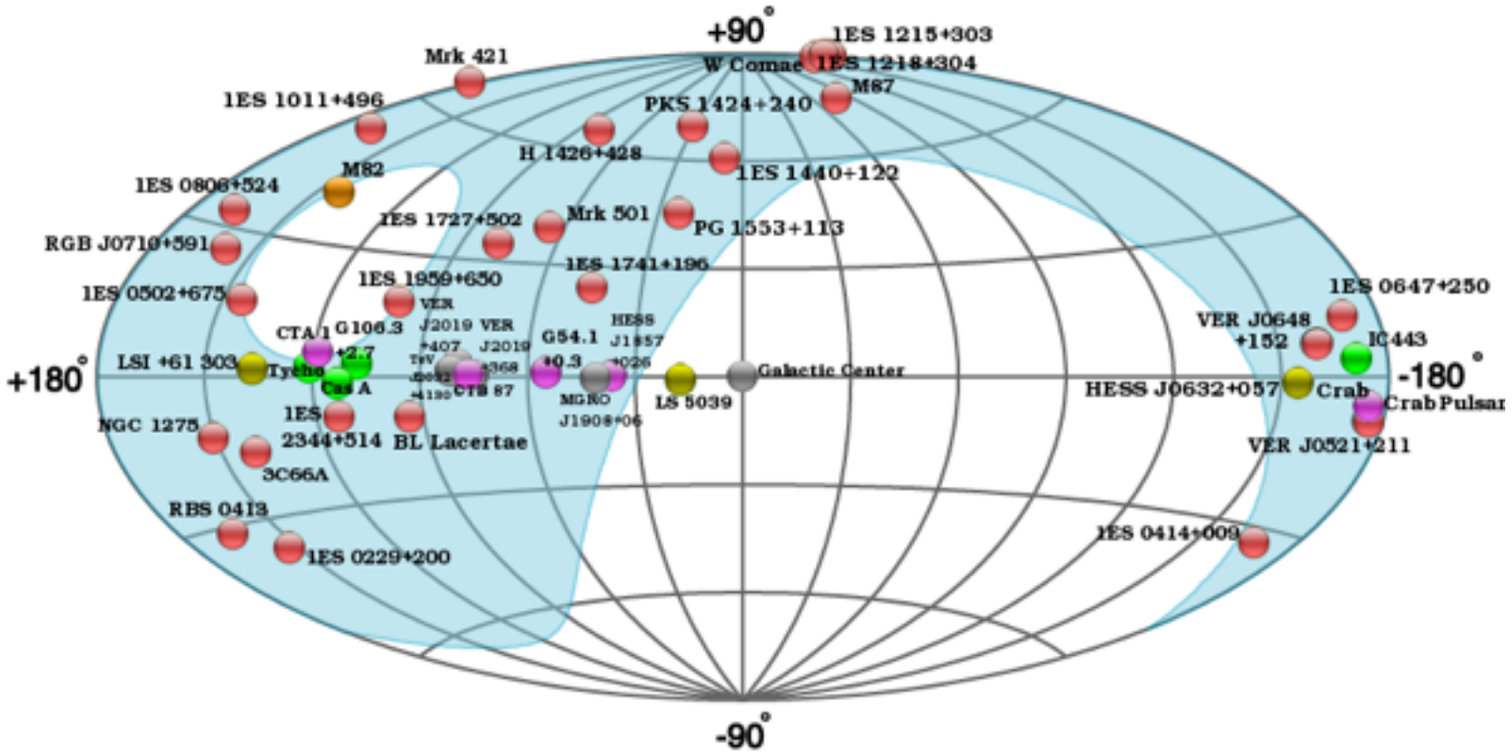
Elisa Pueschel
University College Dublin
on behalf of the VERITAS Collaboration

SciNeGHE2014
4-6 June 2014

VERITAS

- Four 12m Imaging Atmospheric Cherenkov Telescopes located in southern Arizona
- Energy range: 100 GeV to > 30 TeV
- Energy resolution: 15% at 1 TeV
- Angular resolution: 0.1° at 1 TeV
- Field of view: 3.5°
- Peak effective area: 100,000 m^2
- Point source sensitivity: 1% Crab in < 30 hr

VERITAS Science Program

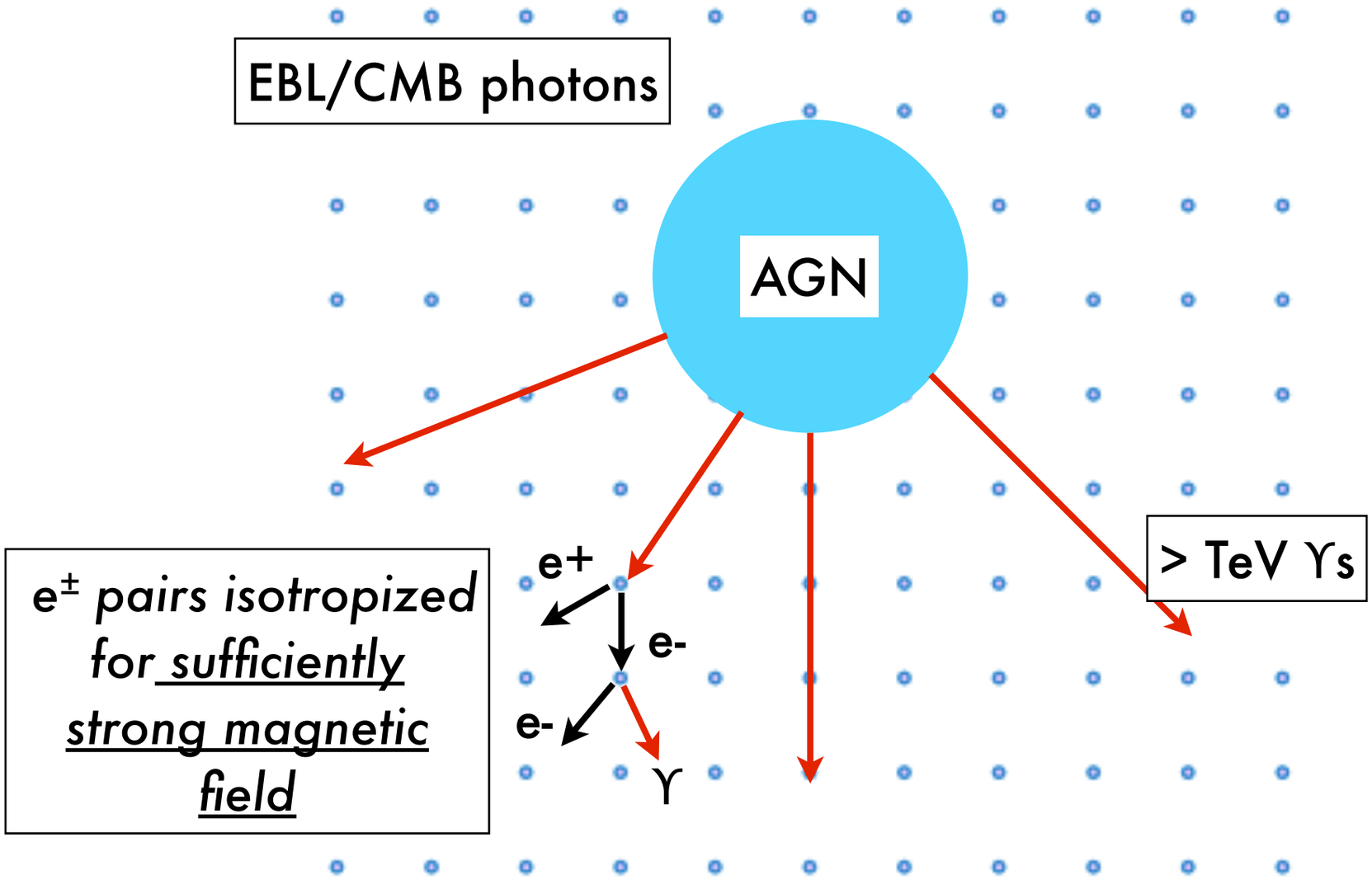


47 detected sources (>5σ)

Blazars	Galactic	Extragalactic non-Blazar	Unindentified Sources
26 detected	*PWN* *Binary* *SNR* *Pulsar*	*Starburst* *FR1*	

Plus Cosmic rays, Gamma-ray Burst follow up, extragalactic background light studies, Dark Matter, axions, Lorentz invariance…

Pair Halos Around AGN

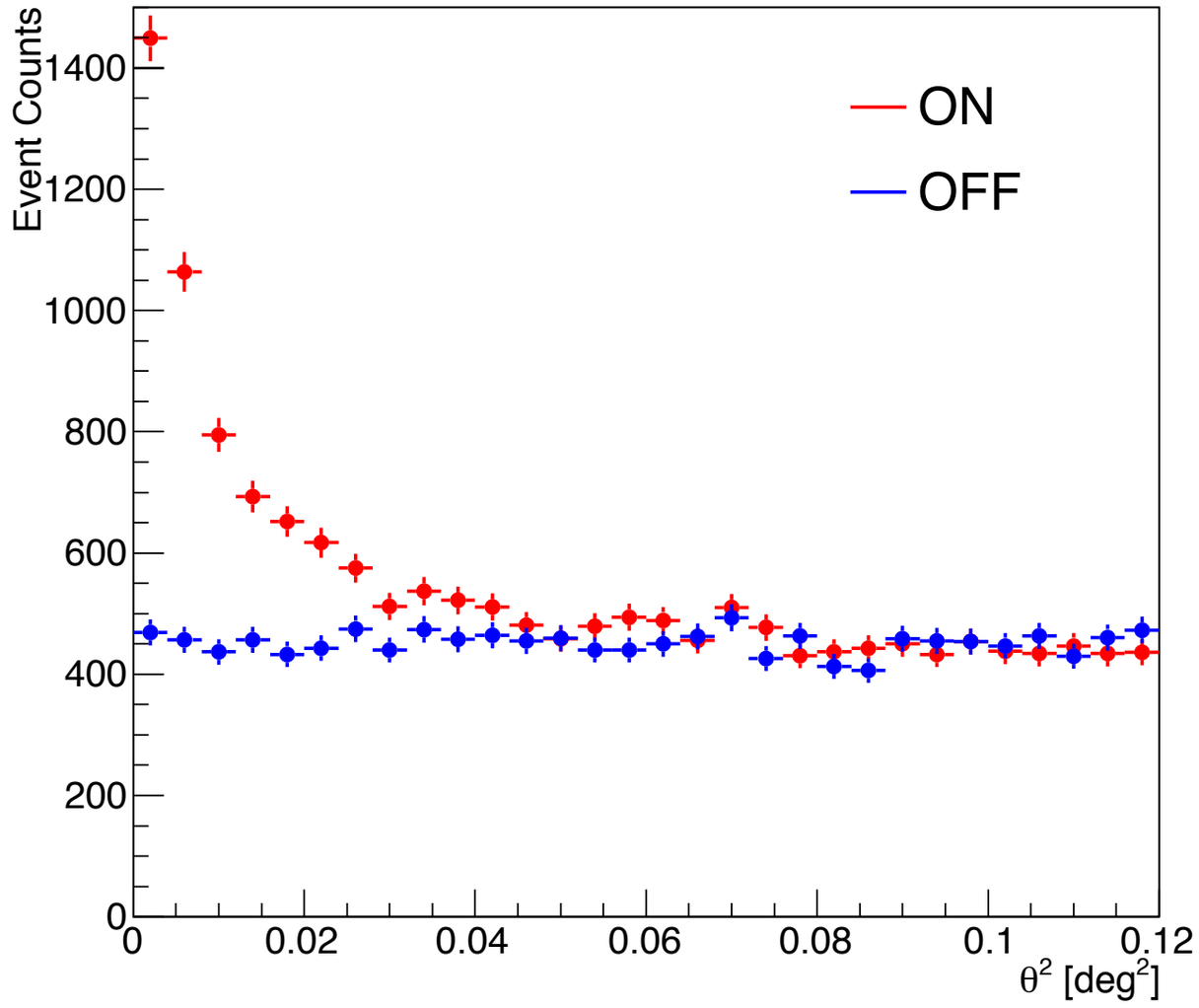


Probe of extragalactic magnetic field strength (current lower limit $B>10^{-17}$ G)

Previous results:
MAGIC using Mrk 421 & Mrk 501
HESS using 1ES 1101-232, 1ES0229+200, PKS 2155-304
Fermi-LAT stacked analysis

Angular Profile for a Point Source

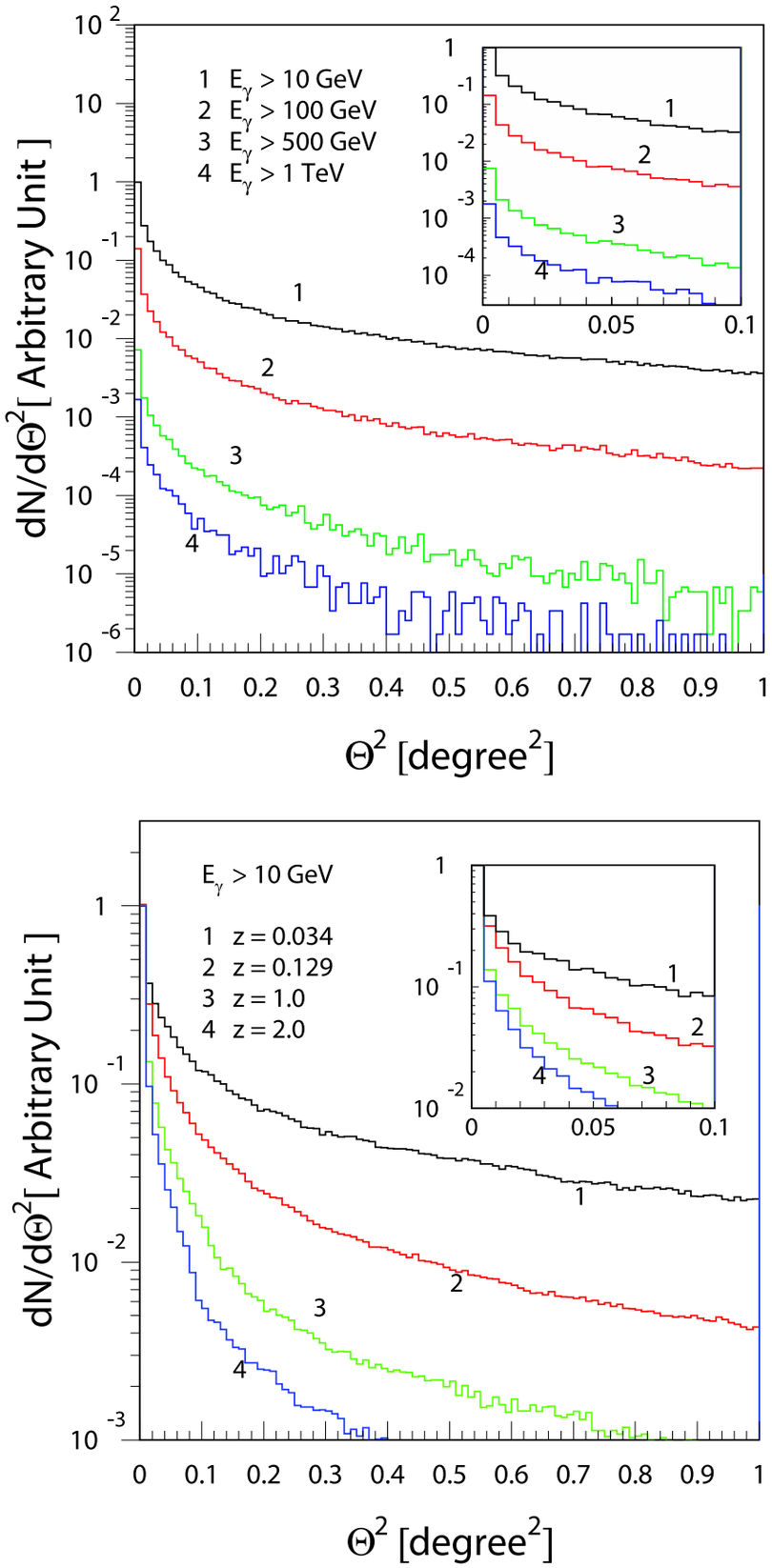
- Point source
  - Angular profile → θ^2: angular distance between shower arrival direction and source's estimated location
  - Background: flat in θ^2
  - Signal: sharp peak at $\theta^2 = 0$
- Extended emission from halo could broaden angular profile
  - Broad extended emission overlaid on point-source beamed emission



Predicted Halo Angular Profile

(Aharonian & Eungwanichaypant, 2009)

- EGMF strength B=10^{-7}-10^{-12} G → halos
  - Angular profile insensitive to exact strength
- Weaker field (B<10^{-14} G) → magnetically broadened cascade
- Predicted angular profile sensitive to
  - Energy of γs from AGN
  - Energy/spectral index of secondary γs
  - Source redshift
  - EBL model



Selected Sources

Ideal candidates based on theoretical predictions:
z = 0.1 - 0.24
Hard spectrum
Detect emission above 1 TeV

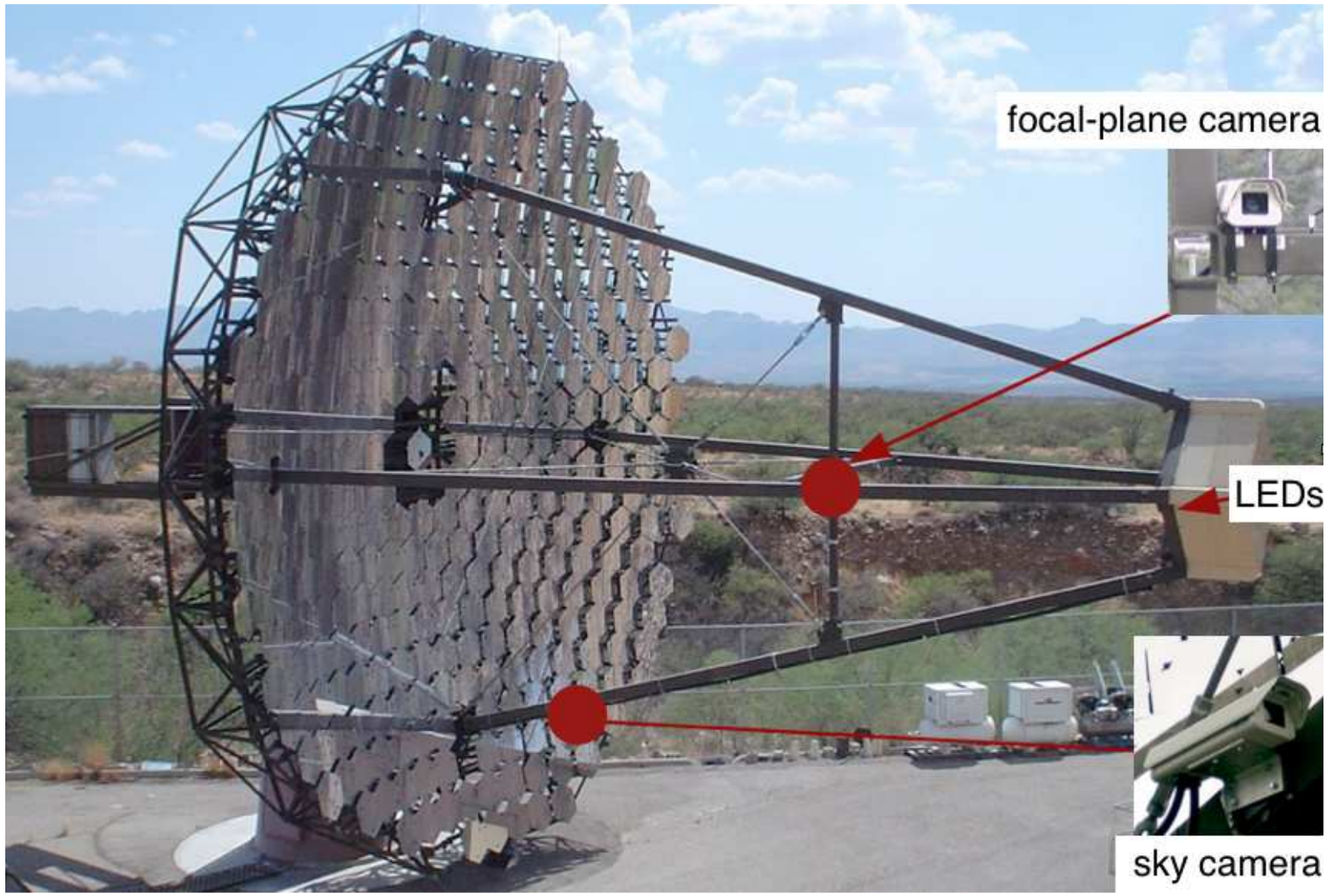
General selection criteria:
Strongly detected blazars (>10σ)
Range of redshifts
Remove flare data (1ES1959, Mrk421)

	z	Γ	Φ (CU)	σ
Mrk 421	0.031	2.2	0.3	81.6
1ES 2344+514	0.044	2.95	0.11	9.6
1ES 1959+650	0.048	-	0.64	14.4
1ES 0229+200	0.14	2.5	0.018	11.1
1ES 1218+304	0.182	-	0.08	37.8
PG 1553+113	0.5	4.5	0.034	41.4

Expect best model-dependent constraints

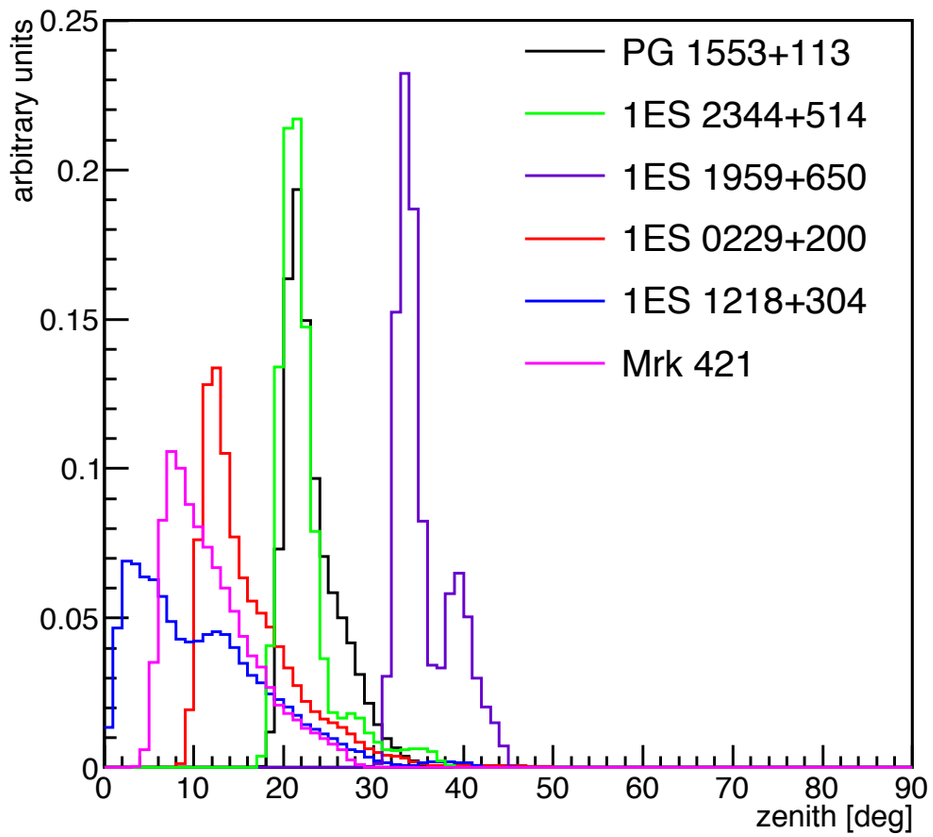
VERITAS Pointing Monitor (VPM)

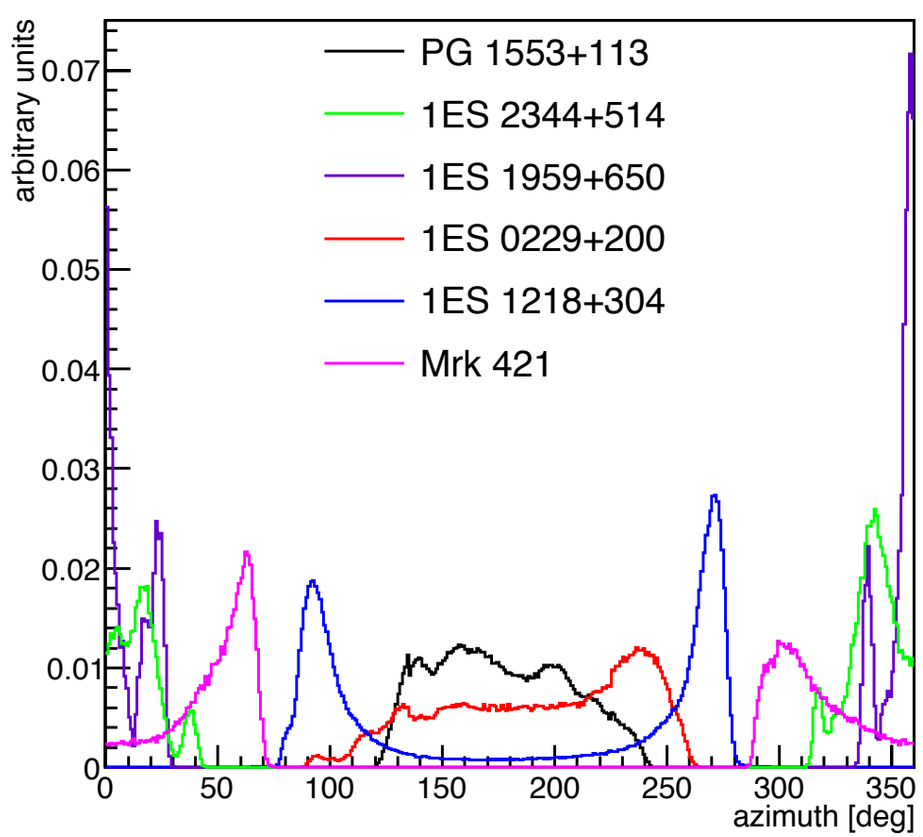
- Accurate pointing necessary for observation of extended emission
- VPM monitors telescope pointing for each observation
- Systematic uncertainty on pointing: < 50''
  - Much smaller than angular resolution



Simulation of Point Sources

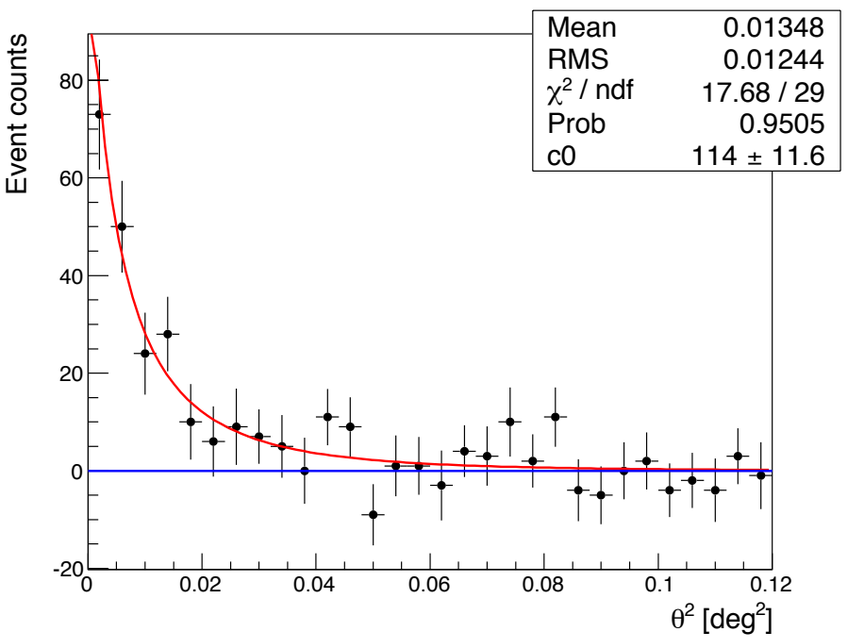
- Compare angular distribution in data against that of a point source
  - θ^2 distribution depends on zenith, azimuth, source spectral index
- Derive θ^2 distribution for each source from simulation
  - Fit with hyperbolic secant
- Fit θ^2 distribution in data with hyperbolical secant width fixed to σ_{SIM}



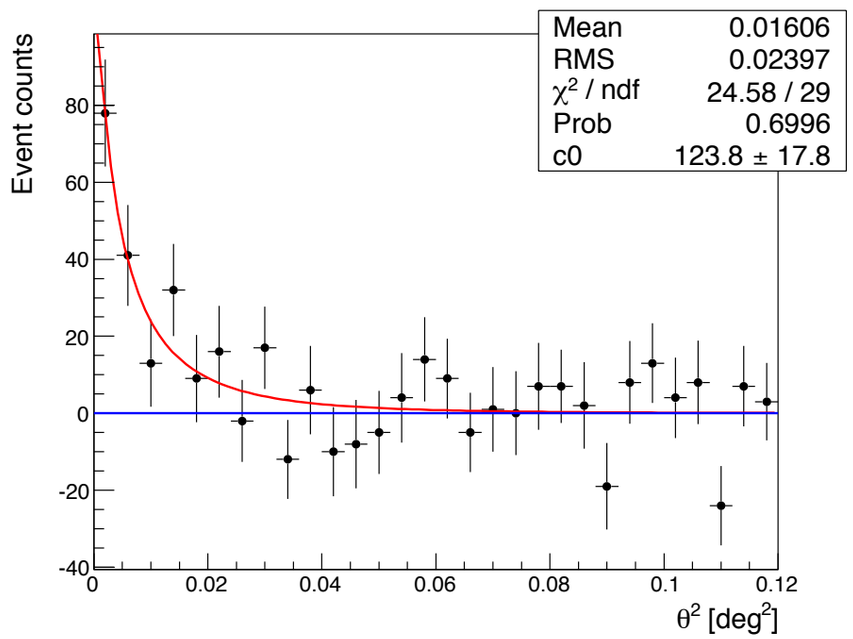


Fits with Widths Fixed to σ_{SIM}

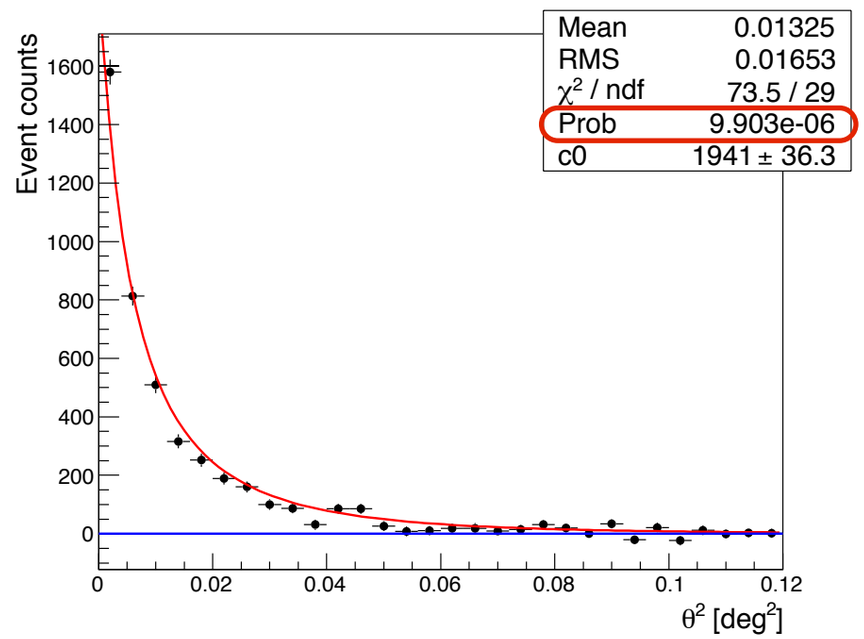
1ES 1959+650



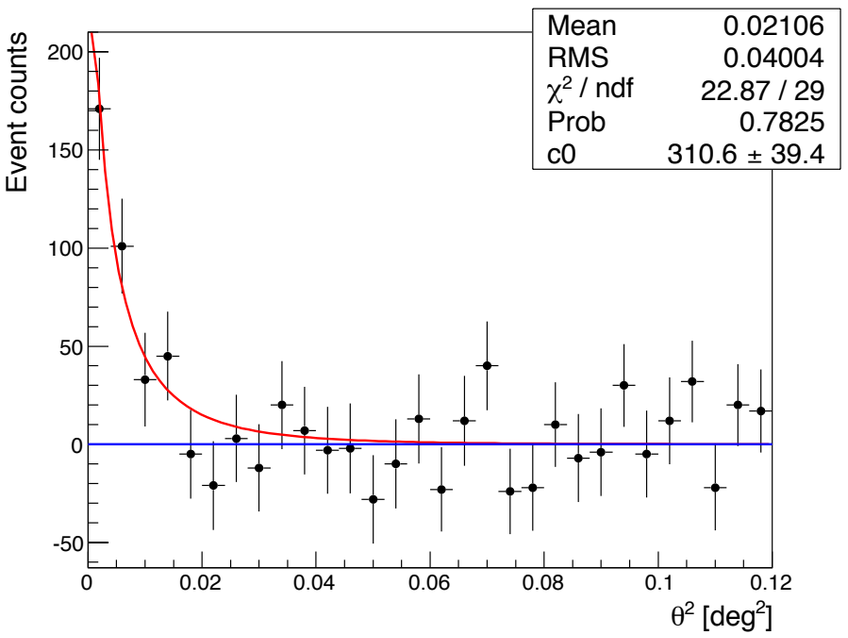
1ES 2344+514



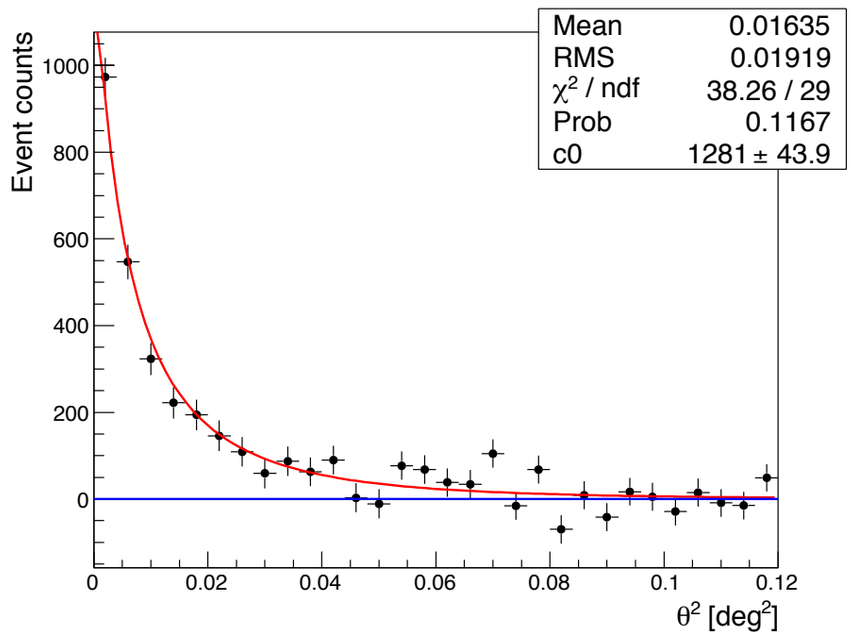
Mrk 421



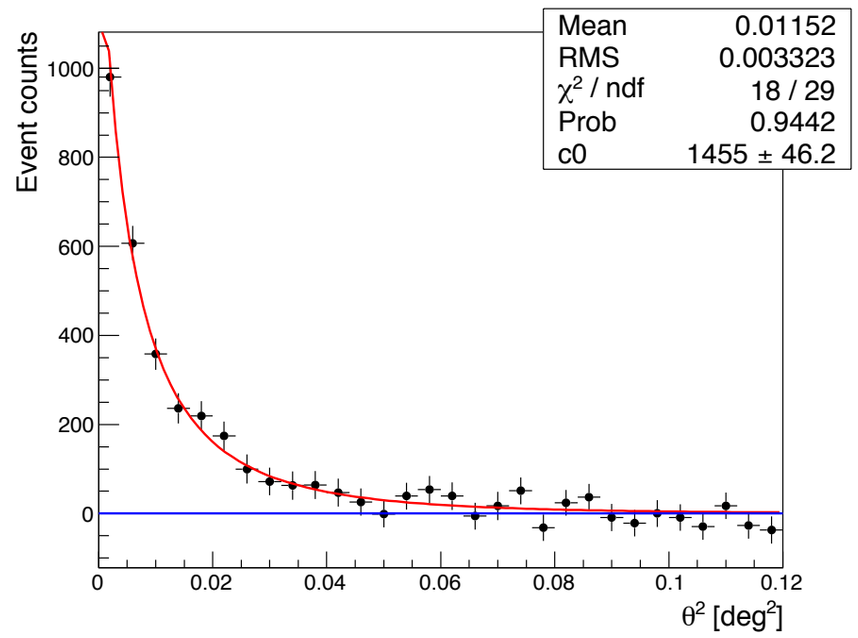
1ES 0229+200



1ES 1218+304

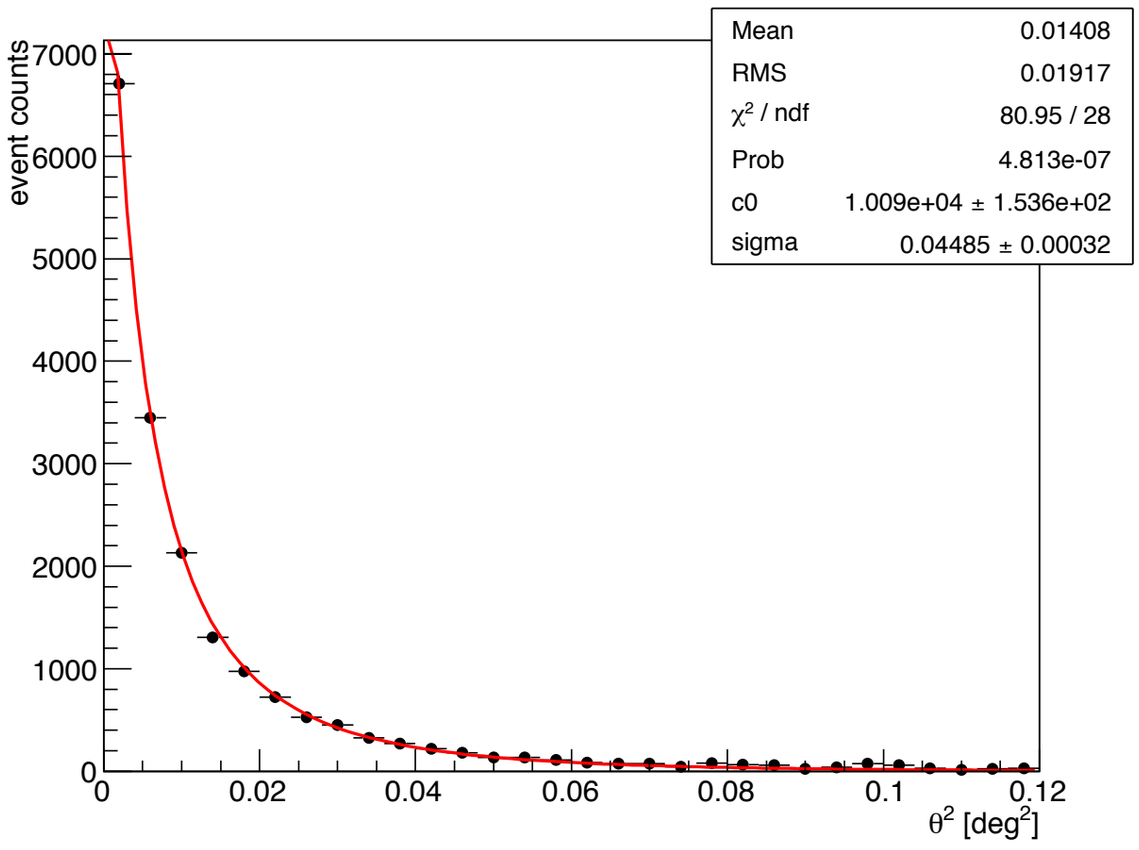


PG 1553+113

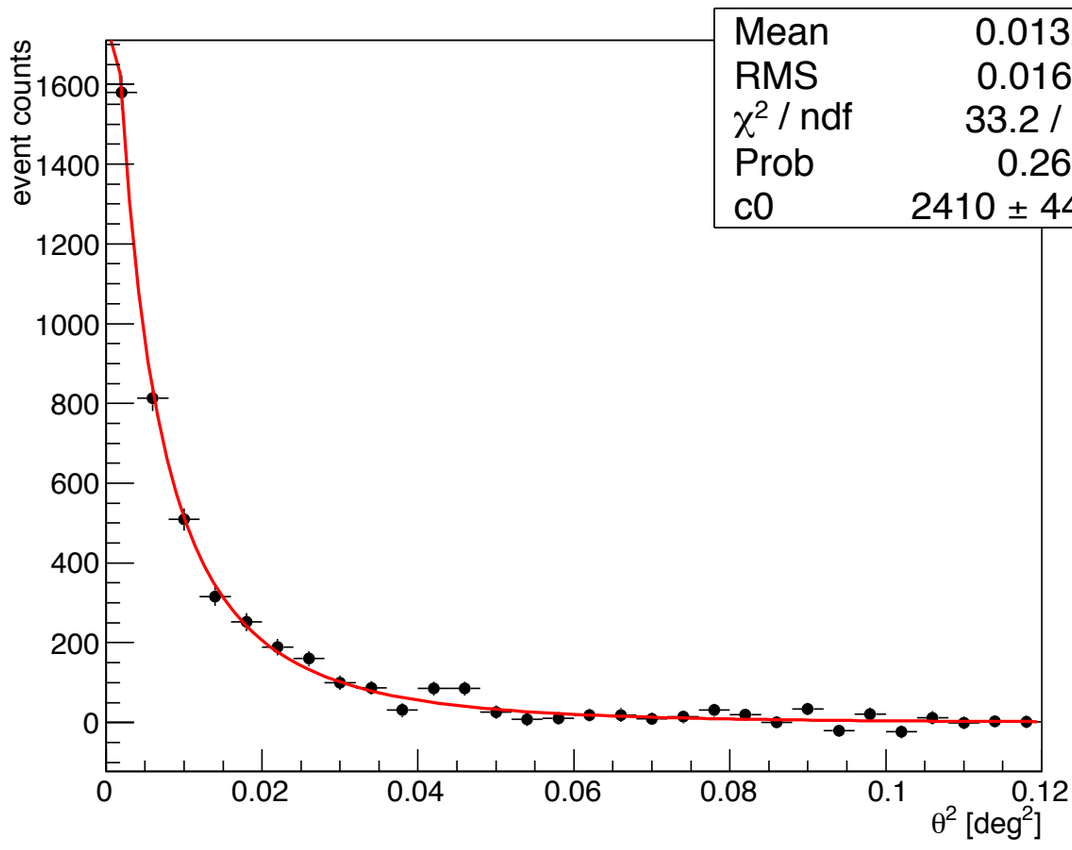


Mrk 421 with Flare Data as Point Source

April 2013 flare data



Fit non-flare data with width fixed



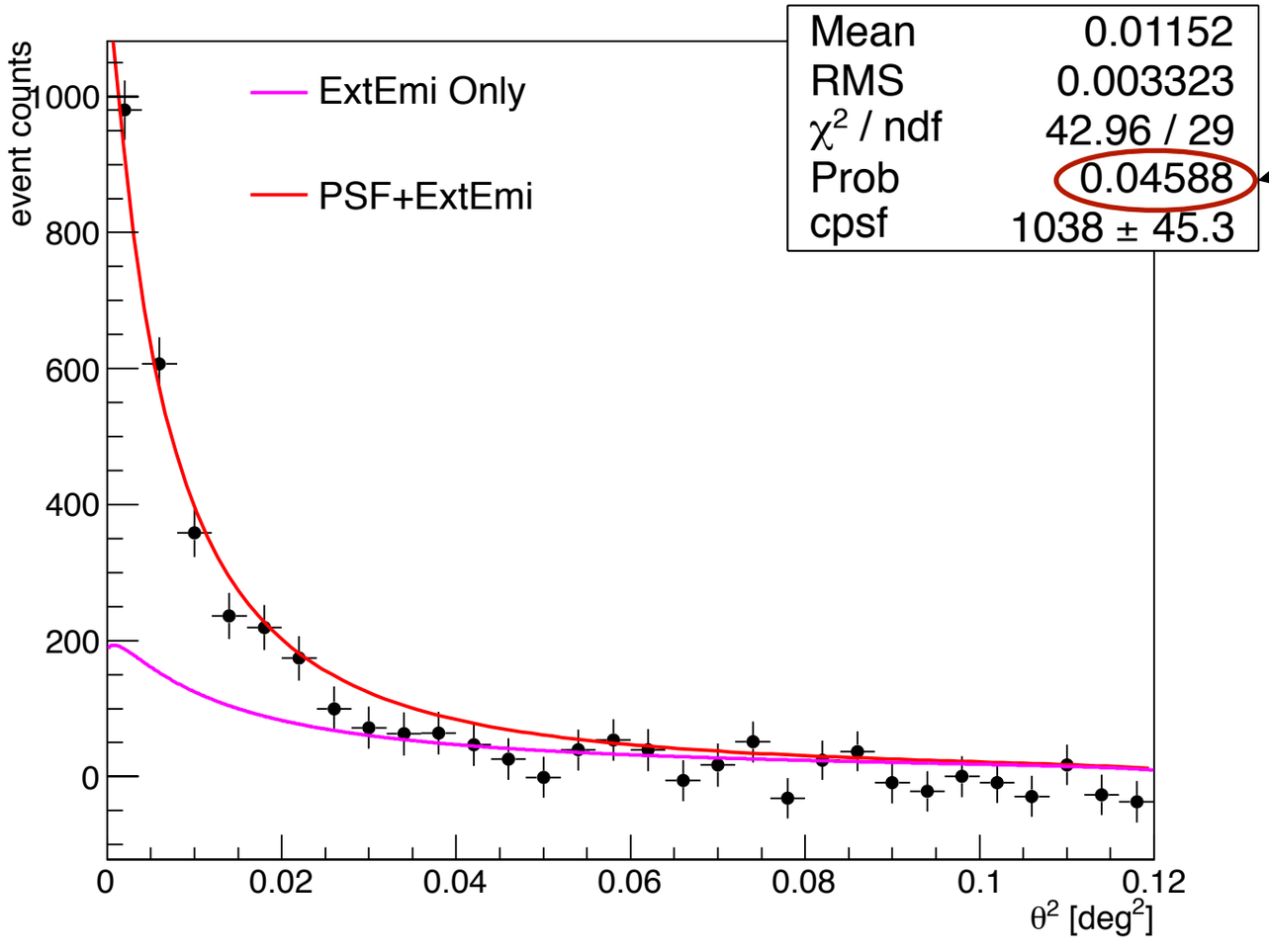
Fit with Extended Emission Model

$$\frac{dN}{d\theta} \propto \theta^{-k}$$

Predicted angular profile for pair halo

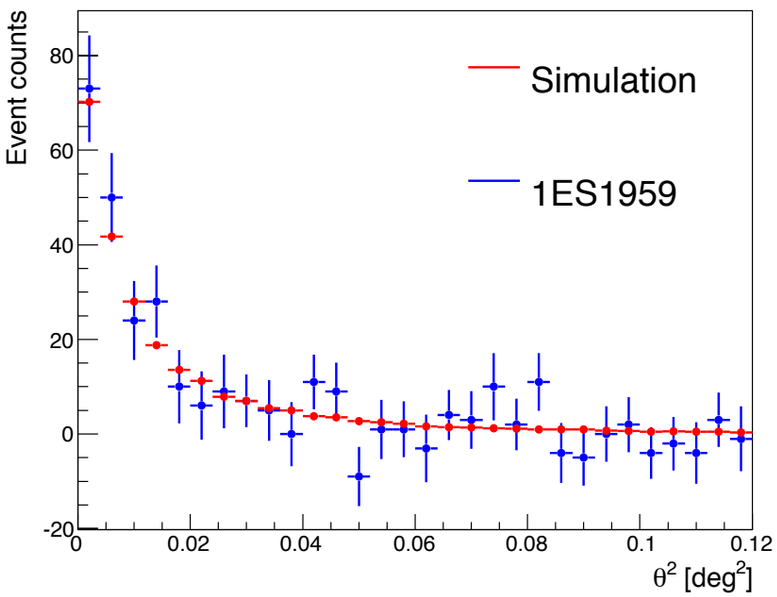
$$N(\theta^2) = N(\theta^2)_{PS} + N(\theta^2)_{EE}$$

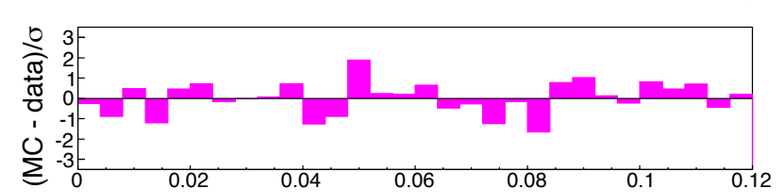
Beamed emission + Extended emission

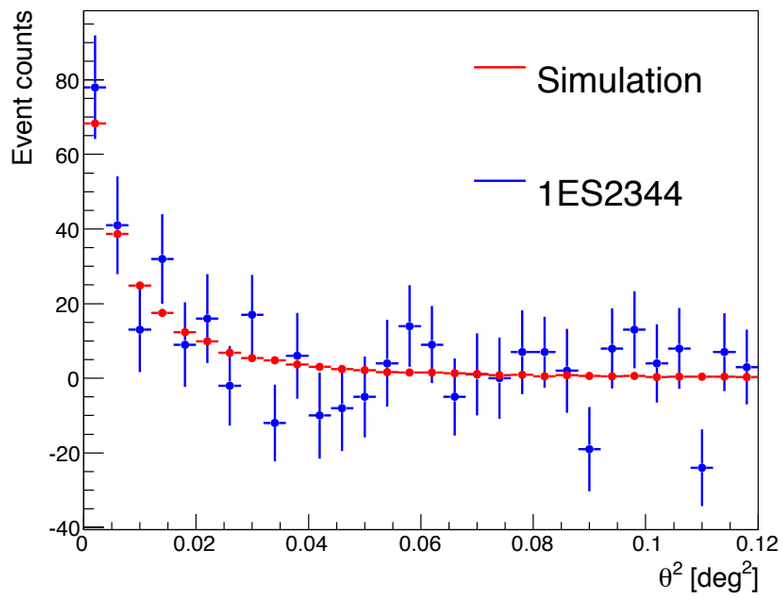


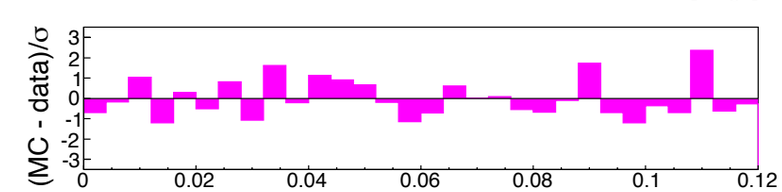
Increase extended emission component until fit no longer describes data

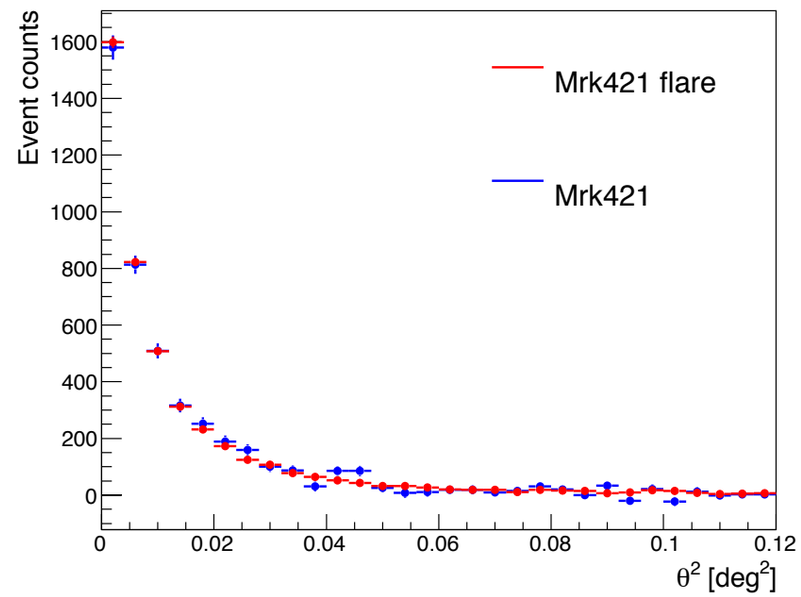
Agreement between Data and Simulation

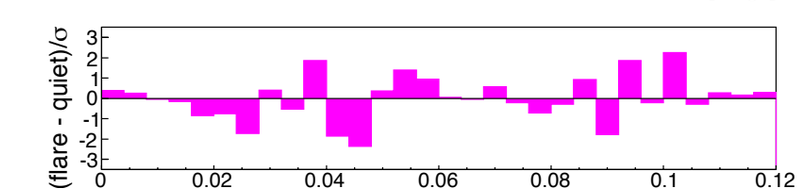


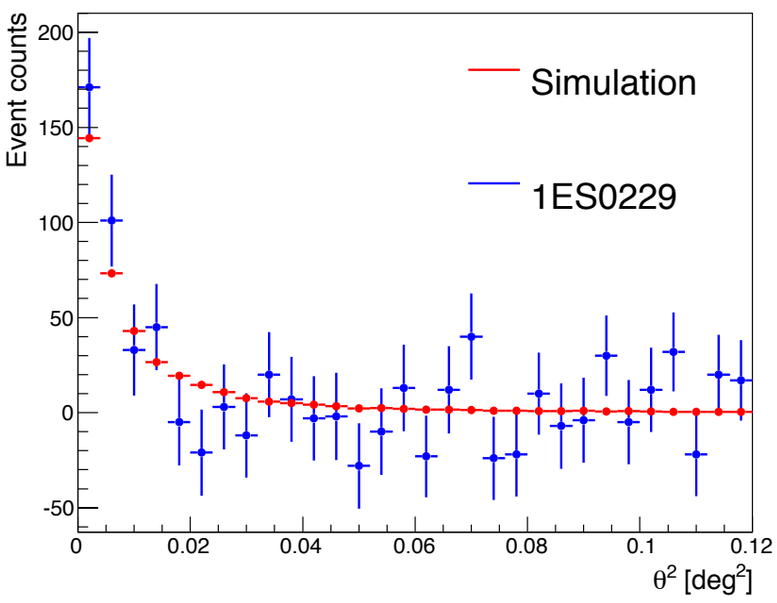


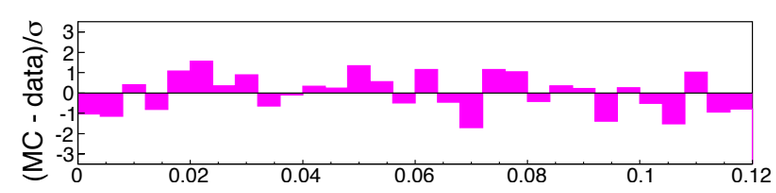


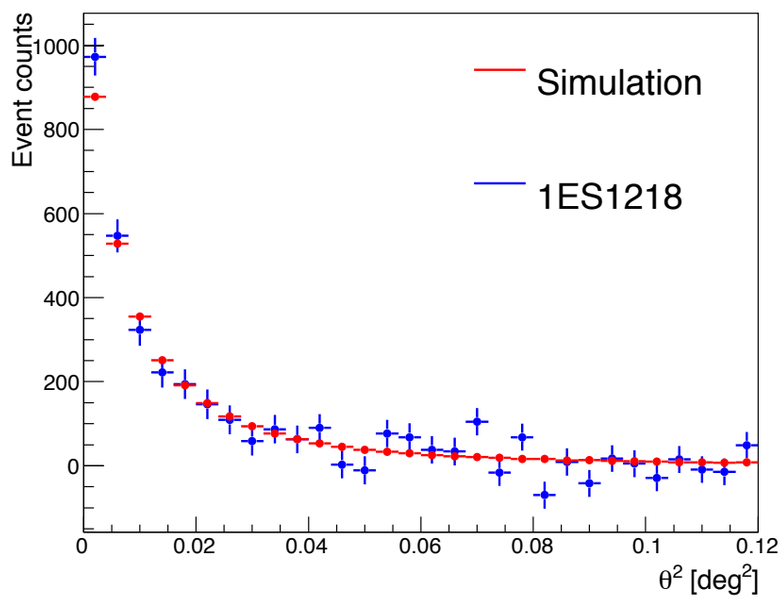


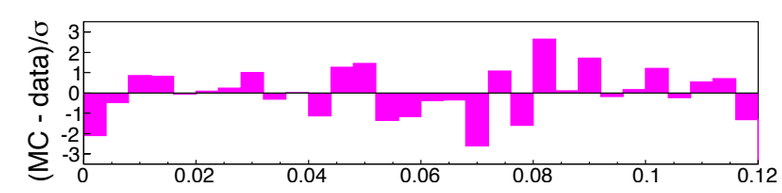


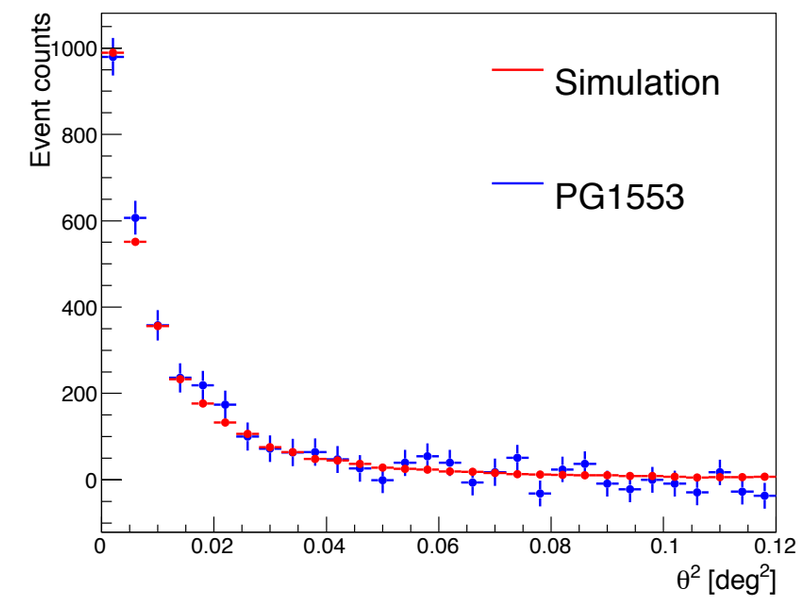


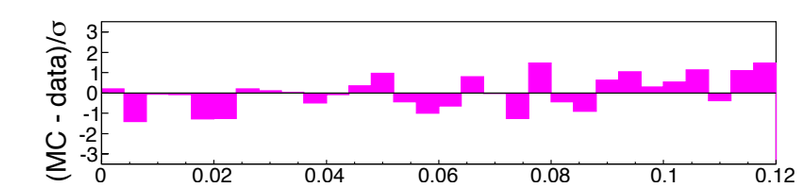








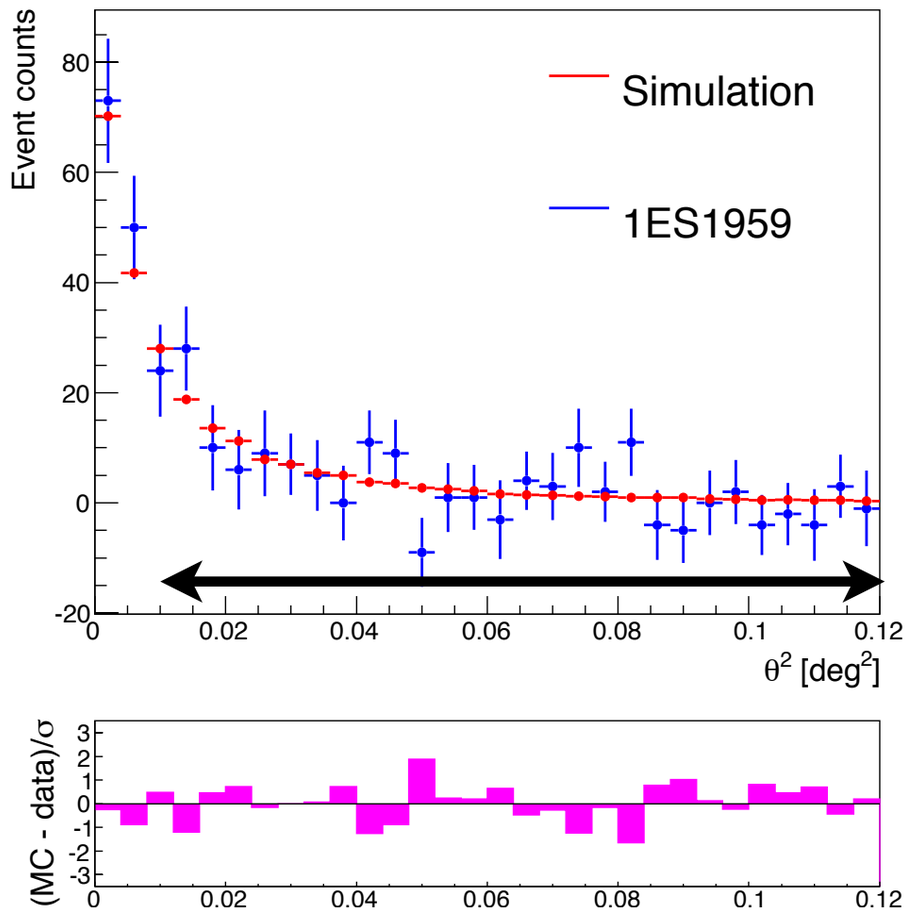




Preliminary Model-Independent Limits

$$excess = \int_{0.01}^{0.12} \theta^2_{Source} - \int_{0.01}^{0.12} \theta^2_{SIM}$$

Upper limits on extended emission calculated using method of Helene 1983



	95% CL Upper Limit (% Crab Flux)
Mrk 421	4.0%
1ES 2344+514	2.1%
1ES 1959+650	1.9%
1ES 0229+200	0.9%
1ES 1218+304	0.8%
PG 1553+113	0.8%

Conclusions

- Preliminary results on search for extended emission from pair halos
  - Examined blazars with a range of redshifts
  - Preliminary model-independent limits set
    - Plan to set model-dependent limits
- Additional sources, analysis improvements on the way
- Long-term blazar plan includes continued monitoring of these sources

Acknowledgements

Funding provided by Irish Research Council's
Government of Ireland Postdoctoral Research Fellowship