Observations of 53 Active Galactic Nuclei with the HEGRA Cherenkov Telescopes

Overview

- the HEGRA Cherenkov Telescopes
- HEGRA observations
- data analysis
- results
- conclusion / outlook

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The HEGRA Experiment

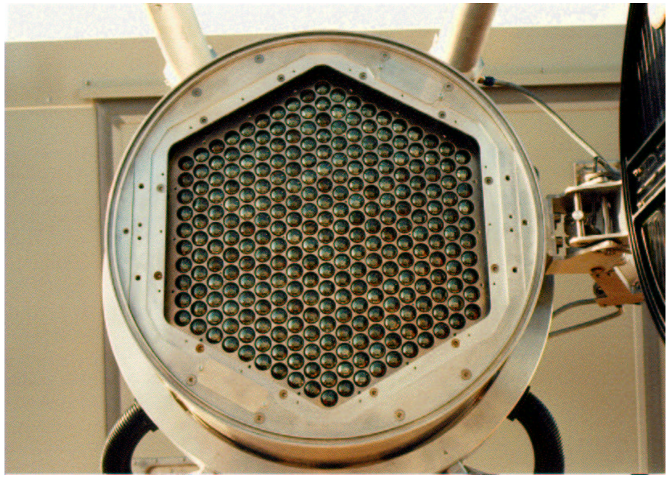
Location:

- Observatorio del Roque de los Muchachos, La Palma
- 2200 m above sea level
- TeV γ-Astronomy with 6 CTs

The Cherenkov telescope system:

- Stereoscopic system of 5 Telescopes
- energy threshold $\geq$ 500 GeV
- angular resolution $\leq$0.1 deg
- energy resolution 10-20 %

CT2, waiting for the night



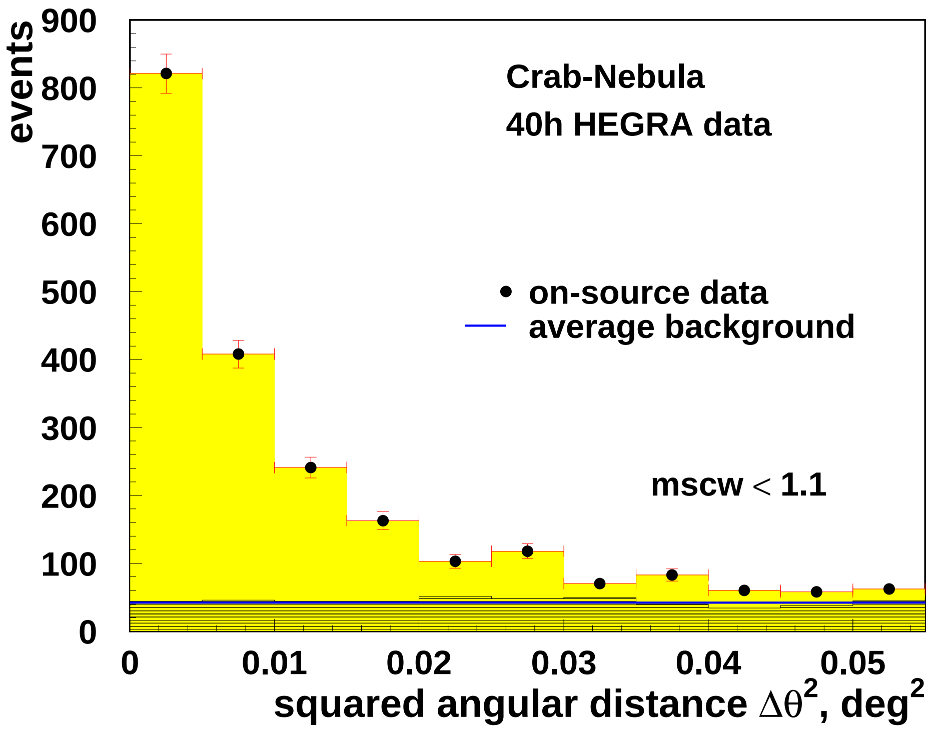
stereoscopic reconstruction

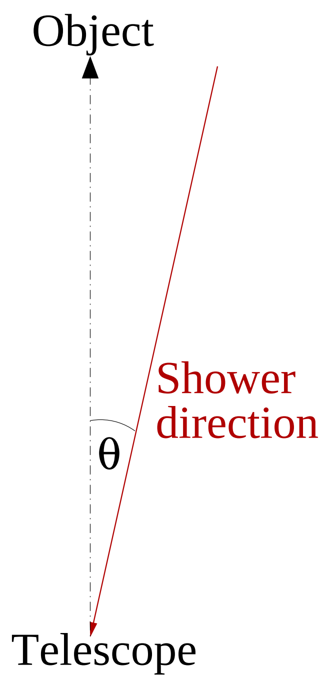
event-by-event reconstruction:

- complete geometrical reconstruction of the shower
  - primary particle direction θ
  - shower core impact position

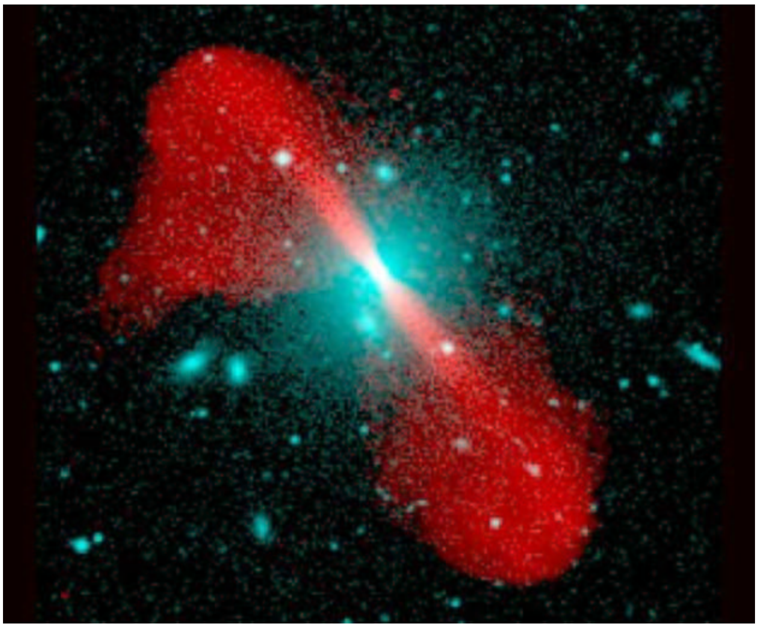
cuts:

- mscw: mean scaled <u>width</u> of images (γ-hadron separation)
- shower core distance
- squared angular distance $\Delta\theta^2$:





HEGRA AGN observations



AGN characteristics:

- black hole ($>10^6 M_\odot$)
- relativistic plasma jets

$\Rightarrow$ TeV γ–rays (Sy, IC)

- highly variable
- few TeV detections

data set:

- 1996 - 2002
- prominent sources Mkn-421, Mkn-501 excluded
- 1100 hours of data taking ($\approx$ 1 HEGRA-year)

data selection:

- runs with trigger rate $< 80\%$ of expected rate excluded
- runs with technical problems excluded
- 877 hours clean data remaining

HEGRA AGN sample

Object name	redshift z	Objectype	time [h]	Object name	redshift z	Object type	time [h]
MG0509+0541	—	BL-Lac	15.8	1ES1118+424	0.124	BL-Lac	2.0
1H0646+250	—	BL-Lac	4.1	1ES0145+13.8	0.125	BL-Lac	3.2
M82	0.00067	G	43.8	EXO0706.1+5913	0.125	BL-Lac	34.0
NGC0315	0.016	G	14.6	**H1426+428**	0.129	BL-Lac	92.3
NGC1275	0.018	Sey1	87.6	3C197.1	0.130	RadGal	15.4
1h1720+117	0.018	BL-Lac	5.3	1ES1212+078	0.136	BL-Lac	2.4
H1722+119	0.018	BL-Lac	5.1	1ES0806+524	0.138	BL-Lac	1.0
QSOB2201+044	0.028	Sey1	17.8	1ES0229+200	0.139	BL-Lac	5.0
VZw331	0.029	BL-Lac	4.1	BL1114(RBS958)	0.139	BL-Lac	3.8
NGC1054	0.032	G	57.9	1ES1255+244	0.140	BL-Lac	3.5
3C120	0.033	Sey1	25.4	MS1019.0+5139	0.141	BL-Lac	17.5
NGC4151	0.033	Sey1	7.0	1ES0323+022	0.147	BL-Lac	14.3
UGC01651	0.037	RadGal	14.3	OQ530	0.151	BL-Lac	9.4
UGC03927	0.041	G	6.3	3C273	0.158	Blazar	12.2
1ES2344+514	0.044	BL-Lac	6.8	1ES1440+122	0.162	BL-Lac	13.1
Mkn0180	0.046	BL-Lac	9.8	HB890829+046	0.180	BL-Lac	18.0
1ES1959+650	0.047	BL-Lac	86.8	1ES1218+304	0.182	BL-Lac	3.9
3C371	0.051	BL-Lac	5.4	1ES0347-121	0.185	BL-Lac	1.9
4C+37.11	0.055	Sey	6.7	1ES0927+500	0.186	BL-Lac	13.3
IZw187	0.055	BL-Lac	16.0	MS0317.0+1834	0.190	BL-Lac	2.7
QSOB1727+502	0.055	BL-Lac	0.6	QSOB2254+074	0.190	BL-Lac	16.3
3C192	0.059	RadGal	2.9	1ES1011+496	0.200	BL-Lac	2.0
1ES2321+419	0.059	BL-Lac	22.3	1ES0120+340	0.272	BL-Lac	18.9
4C+31.04	0.060	RadGal	3.0	1H0414+009	0.287	BL-Lac	4.5
BLLacertae	0.069	BL-Lac	26.7	1AXGJ072157+7120	0.300	BL-Lac	1.7
1ES1741+196	0.083	BL-Lac	10.2	3C066A	0.444	BL-Lac	1.3
4C+01.13	0.084	QSO	7.7				$\Sigma = 877$

data analysis

à priori data handling:

- image selection:
  - $\leq$ 15 defective pixels per camera
  - size (amplitude)$>$ 40 p.e.
  - images rejected if too close to camera border
- event selection:
  - $N_{tel} \geq 3$
  - shower core distance 200m, 300m, 400m
- final cuts:
  - mscw ≤ 1.1
  - $\Delta\theta^2$ optimized separately for different zenith angle, telescope multiplicity and technical setup intervals

analysis:

- DC significance (Li and Ma)
- burst significance (Kolmogorov test, Prahl test)
- upper limit on integral flux from Crab-Nebula calibration

data analysis: some formulae

generalized Li and Ma significance for observations with different alpha-factors α_i:

$$\mathbf{S} = \sqrt{2} \times \left[\sum_i \mathbf{Non}_i \mathbf{ln} \left(\frac{\sum_i \mathbf{Non}_i}{\sum_i \frac{\alpha_i}{1+\alpha_i} (\mathbf{Non}_i + \mathbf{Noff}_i)} \right) + \sum_i \mathbf{Noff}_i \mathbf{ln} \left(\frac{\sum_i \mathbf{Noff}_i}{\sum_i \frac{1}{1+\alpha_i} (\mathbf{Non}_i + \mathbf{Noff}_i)} \right) \right]^{1/2}$$

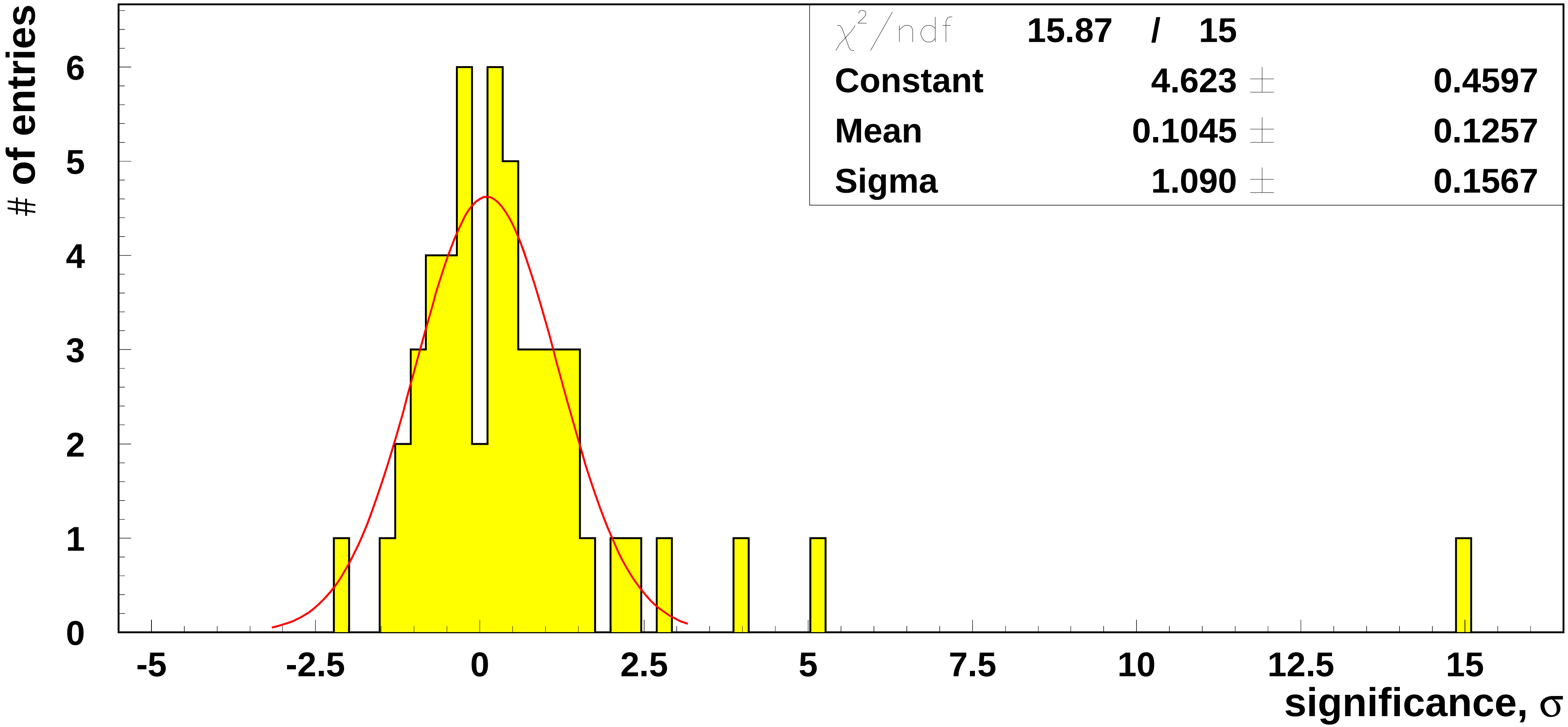
Upper limit calculation for large data sets $\rightarrow$ Crab-Flux depends on zenith angle and technical setup:

$$UL = \sum_{i,j} \frac{N_{i,j}^{max}}{t_{i,j} \times gph_{i,j}}$$

(following Helene, O., 1983)

i, j	zenith angle and technical setup bins
$t_{i,j}$	observation time in bin i, j
$gph_{i,j}$	γ-rays per hour from Crab in bin i, j
$N_{i,j}^{max}$	max. # of events compatible with 0-hypothesis

results (I): significances



detections:

object	significance DC	bursting? in HEGRA data
1ES 1959+650	15 σ	yes
H 1426+428	5.0 σ	no

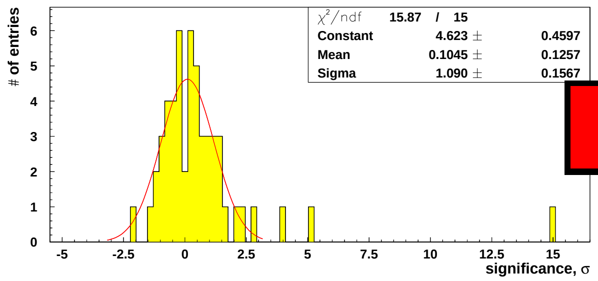
candidates:

object	significance DC	bursting? in HEGRA data
1ES 2344+514	3.9 σ	no
(BL 1114)	(2.9 σ)	no

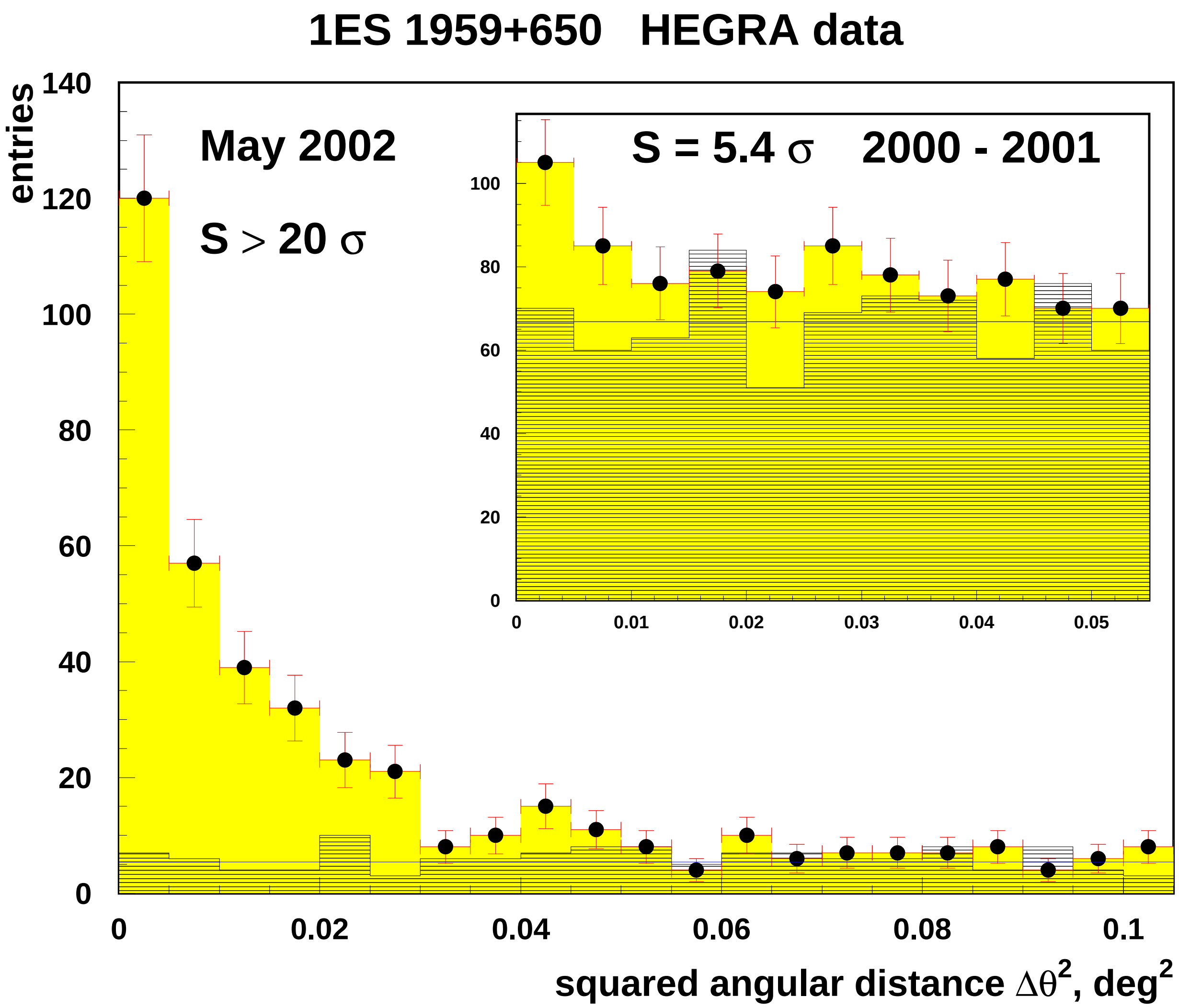
results (II): 99% CL upper limits (010- 0.3 Crab)

object	E_{thr} [TeV]	upper limit [Crab Units]	upper limit [$10^{-12}\gamma cm^{-2}s^{-1}$]
MG0509+05410.8		0.064	1.5
1H0646+250.7		0.058	1.9
M82	10060.5		
NGC03057		0.048	1.5
NGC12757		0.0065	
1h1720+117	0.7	0.120	3.7
H1722+1097		0.140	3.9
QSOB2201+044	0.8	0.047	1.1
VZw3310.7		0.099	2.9
NGC1054	0.7	0.0055	
3C120.8 0.0310.8			
NGC41510.7		0.060	2.0
UGC016510.7		0.061	2.0
UGC03927	1.0.064		1.1
1ES2344+514	0.8	0.048	1.1
Mkn0180	1060920.7		
1ES1959+650	1.4	—	—
3C371	106110.8		
4C+37.110.7		0.048	1.5
IZw187	0.8	0.059	1.4
QSOB1727+5020.8		0.260	6.1
3C1920.8		0.140	3.5
1ES2321+4097		0.037	1.0
4C+31.04	06069		2.4
BLLacertae	0.8	0.061	1.4
1ES1741+1968		0.061	1.5
4C+01.1609110			2.3

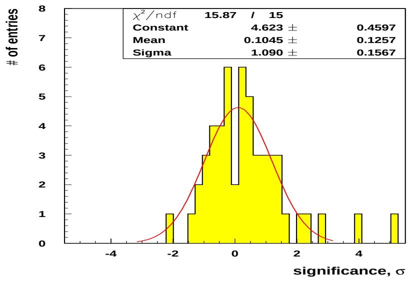
object	E_{thr} [TeV]	upper limit [Crab Units]	upper limit [$10^{-12}\gamma cm^{-2}s^{-1}$]
1ES1118+424	0.8	0.230	5.3
1ES0145+13.8	0.7	0.0260.7	
EXO0706.1+5913	1.0.0460.7		
H1426+428	0.7	—	—
3C197.10.8		0.037	0.9
1ES1212+078	0.8	0.120	3.0
1ES0806+524	1.0.120		2.0
1ES0229+200.7		0.060	1.8
BL1114(RBS958)	0.7	0.190	5.8
1ES1255+244	09087		1.8
MS1019.0+51098		0.053	1.3
1ES0323+0220.90320.7			
OQ530	1.10.098		1.5
3C273	1.10.082		1.1
1ES1440+1220.8		0.061	1.6
HB890829+0469099			
1ES1218+304	0.7	0.081	2.5
1ES0347-121	106330		2.7
1ES0927+500.8		0.047	1.1
MS0317.0+1834	0.7	0.070	2.3
QSOB2254+074	0.7	0.036	1.0
1ES1011+496110			2.3
1ES0120+340.7		0.033	1.0
1H0414+009078			1.7
1AXGJ072157+7120	1.7	0.240	1.7
3C066A	0.7	0.110	3.4



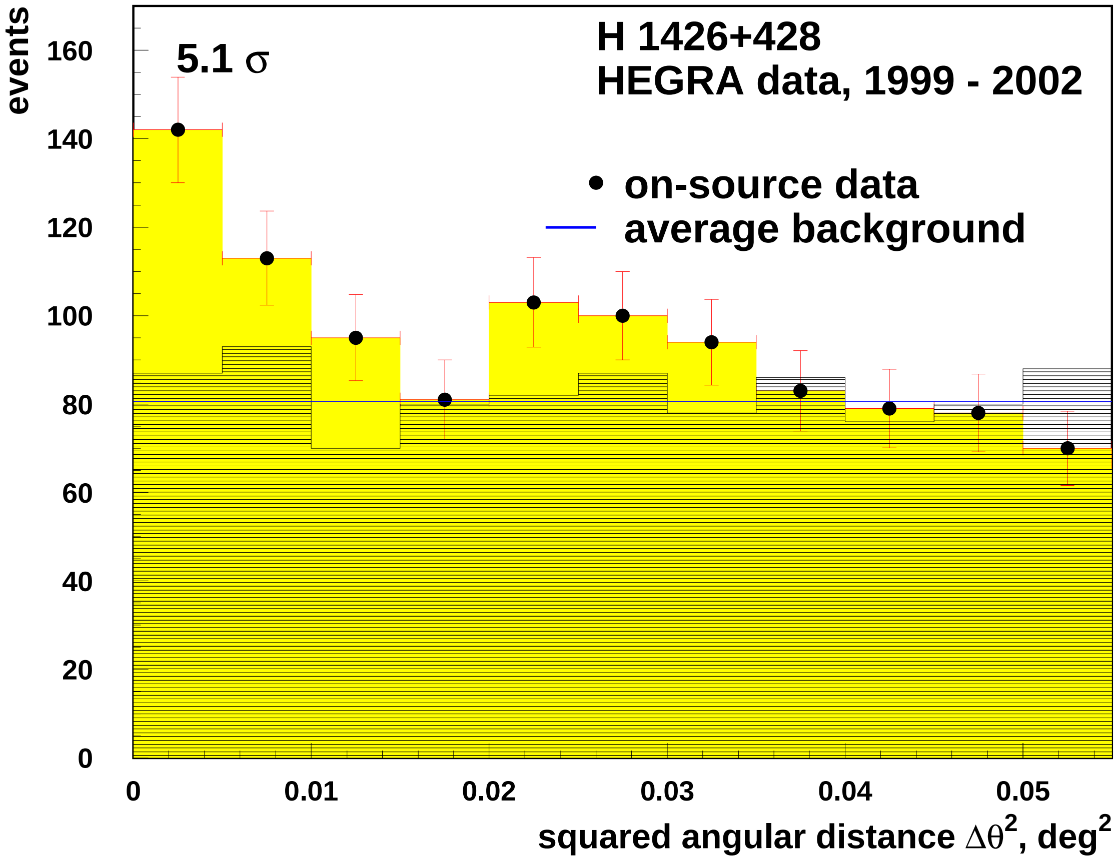
1ES1959+650 z = 0.047



- first claim: 7 Telescope Array (ICRC 1999, 3.9 σ)
- HEGRA confirmation 2001 (ICRC 2001, HEAD meeting 2002)
- huge flare 1.5 months ago
- 4th BL-Lac type γ-ray emitter in northern hemisphere



H 1426+428 $z = 0.129$



- HEGRA results

	1999-2000	2002	all(1999-2002)
significance	5.8	4.8	5.1

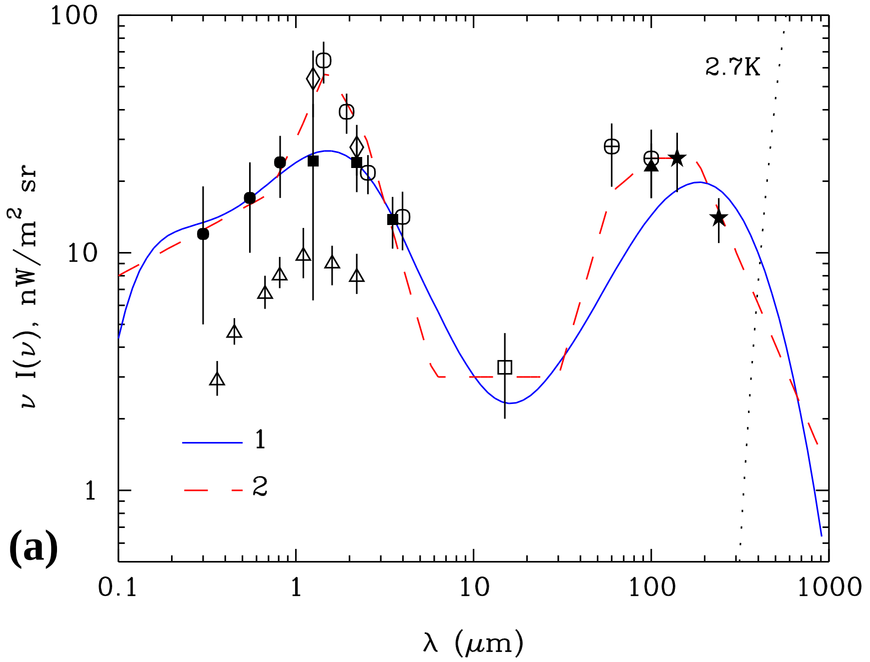
- well established TeV γ-ray source
  - Whipple (GAMMA 2001)
  - HEGRA (ICRC 2001)
  - CAT ($> 4\ \sigma$, ICRC 2001)

H 1426+428 $z = 0.129$ spectrum

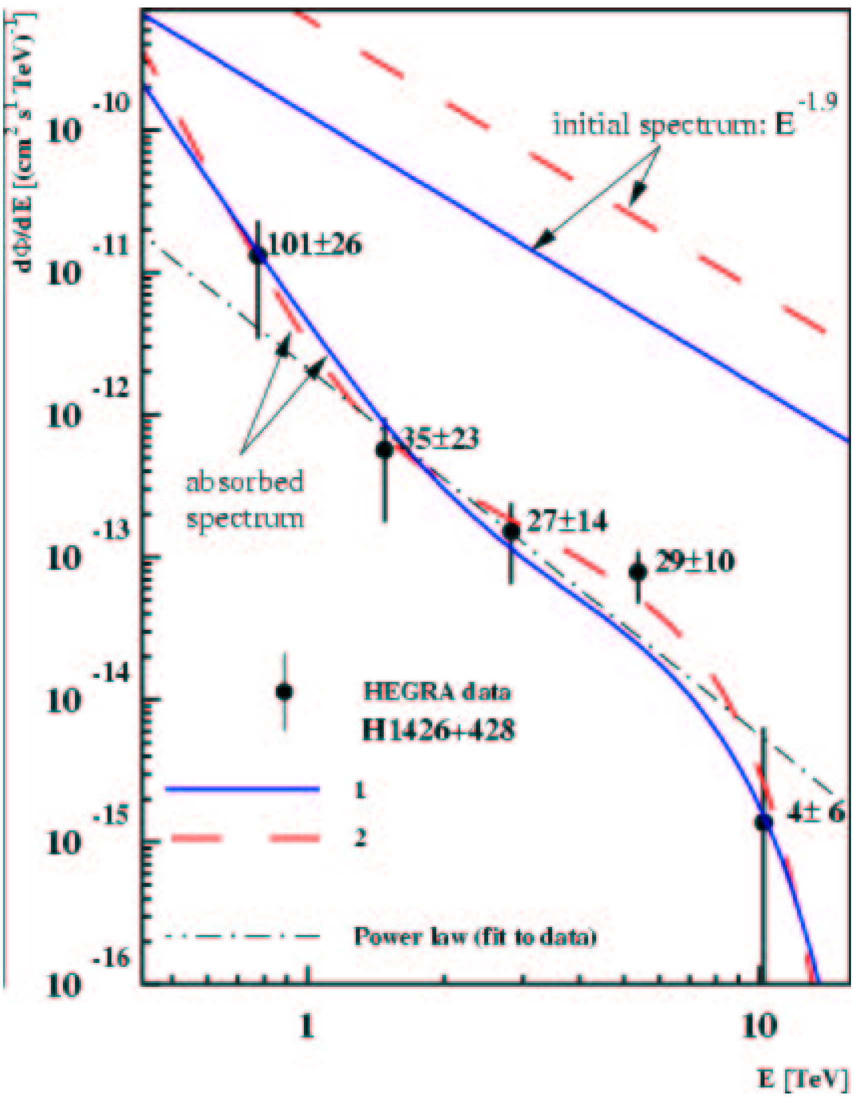
most distant TeV γ-ray source

- highest intrinsic flux
- IR absorption

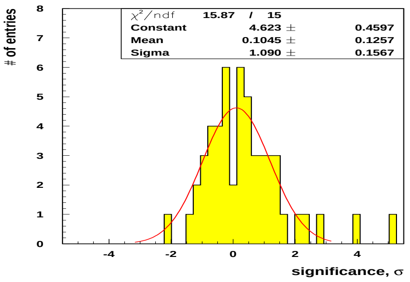
  $\gamma_{\mathbf{TeV}}\gamma_{\mathbf{IR}} \longrightarrow \mathbf{e}^+\mathbf{e}^-$



⇒ possible detection of IR signature in measured spectrum:

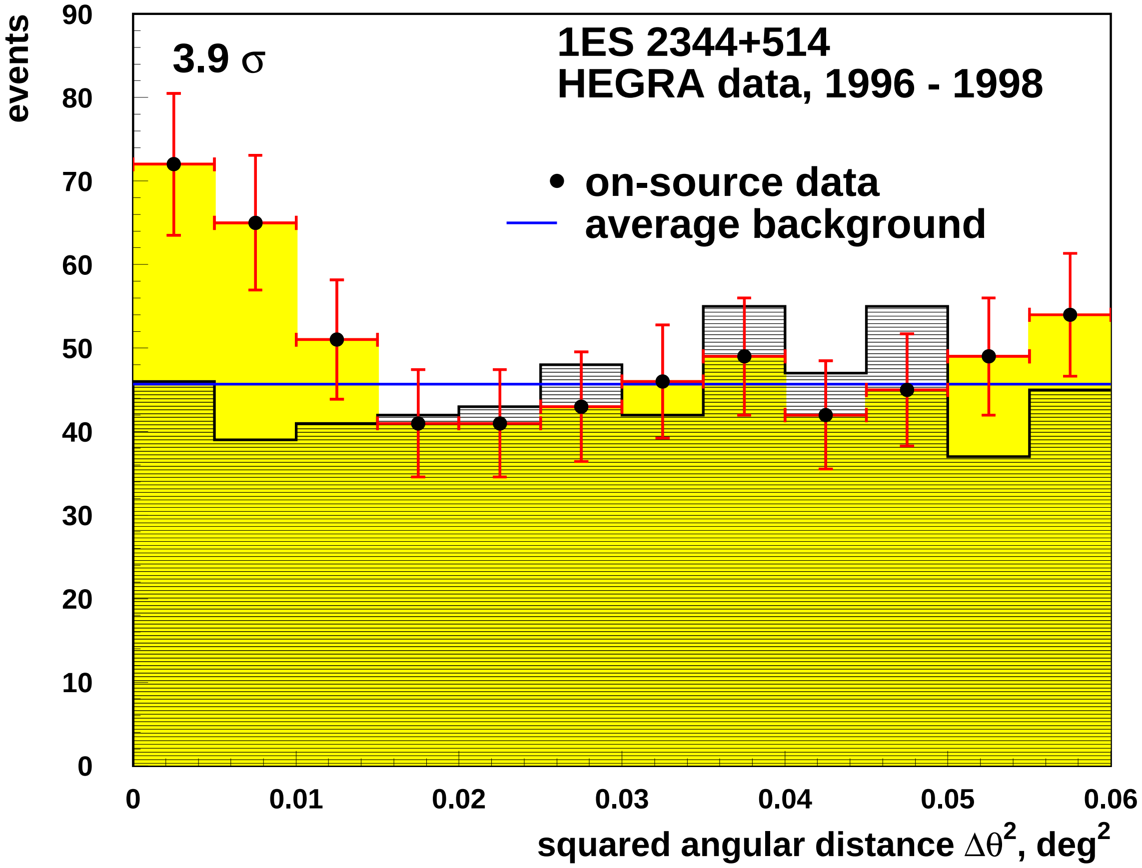


- IR absorbed spectrum matches observations
- pure power law not excluded
- A&A 384, L23 (2002)
- poster OG14P by N. Götting



1ES 2344+514 z = 0.044

- extreme synchrotron blazar
- first claim by Whipple (1998, one night flare with a 6 σ excess)



- S = 3.9 σ
- flux(E>0.8TeV) $< 1.1 \times 10^{-12} \gamma \mathbf{cm^{-2} s^{-1}}$
- no evidence for burst like behavior in HEGRA data

conclusion

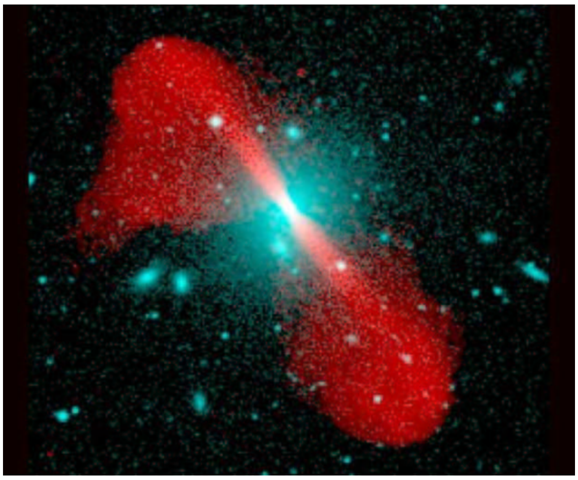
- HEGRA sample of 53 AGN analyzed (1100 hours of data)
- 2 detections:

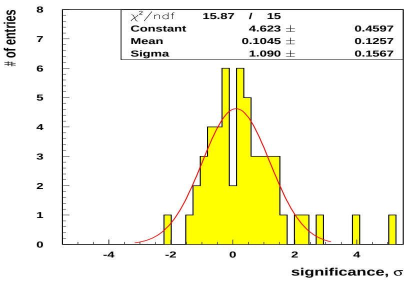
1ES 1959+650	$> 15\ \sigma$	strong flare in May 2002
H 1426+428	$> 5\ \sigma$	

- 1 candidate:

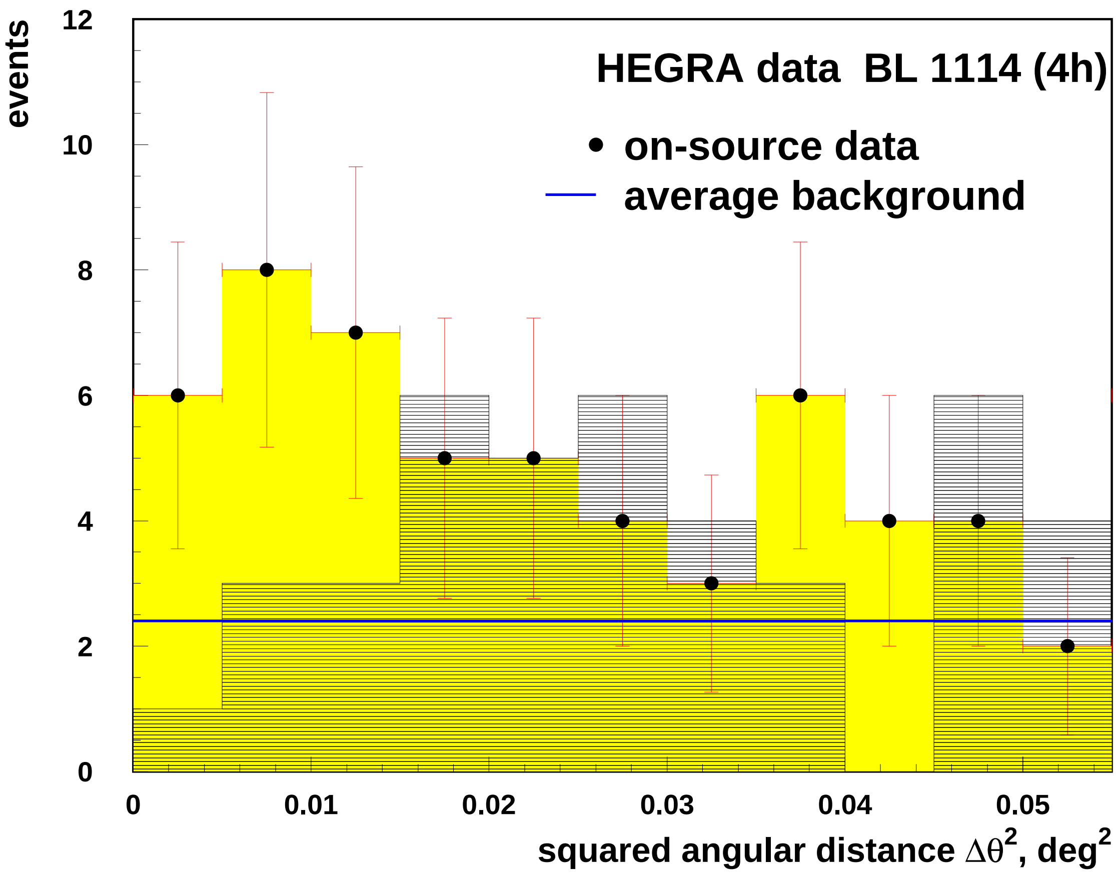
  1ES 2344+514 $3.9\ \sigma$

- interesting results in the last HEGRA months
  - number of detections of γ-rays from BL-Lacs is growing
  - possible constraint on IR background measurement
- still 2 months to go ...

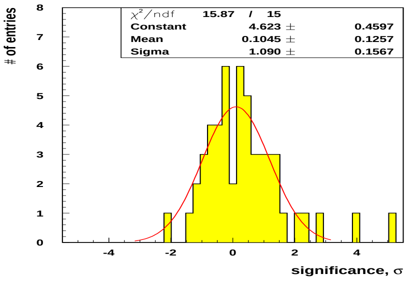




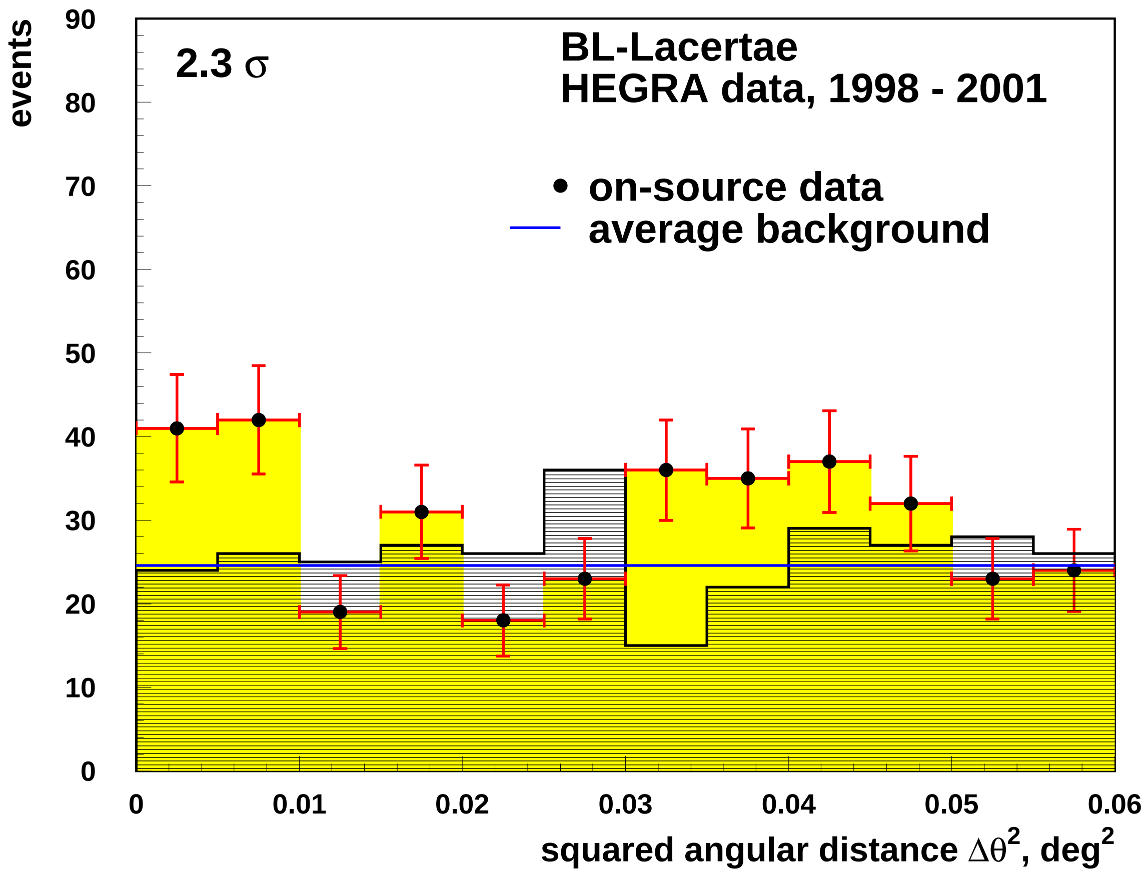
BL 1114 $z = 0.139$



- extreme synchrotron blazar
- 4 hours observation time, April 1999
- 2.9 σ
- Flux(E>0.7TeV) $< 5.8 \times 10^{-12} \gamma \mathbf{cm^{-2} s^{-1}}$
- low statistics !

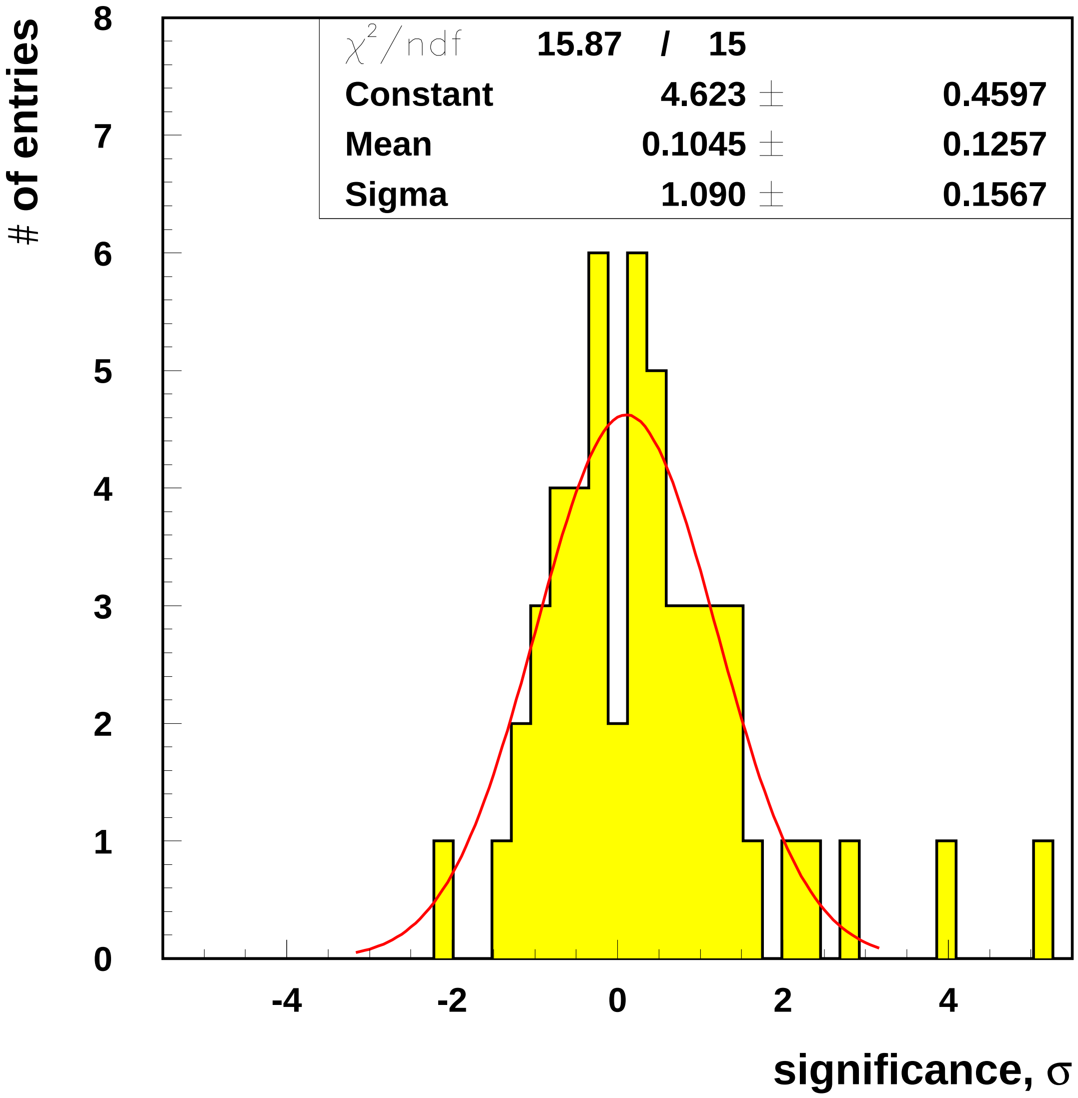


BL-Lac z = 0.069



- 27 hours observation time (1998 - 2001)
- 2.3 σ
- UL(E>0.8TeV) = $1.4 \times 10^{-12} \gamma cm^{-2} s^{-1}$
- HEGRA CT1 results: UL(E>1.0TeV) = $2.0 \times 10^{-12} \gamma cm^{-2} s^{-1}$

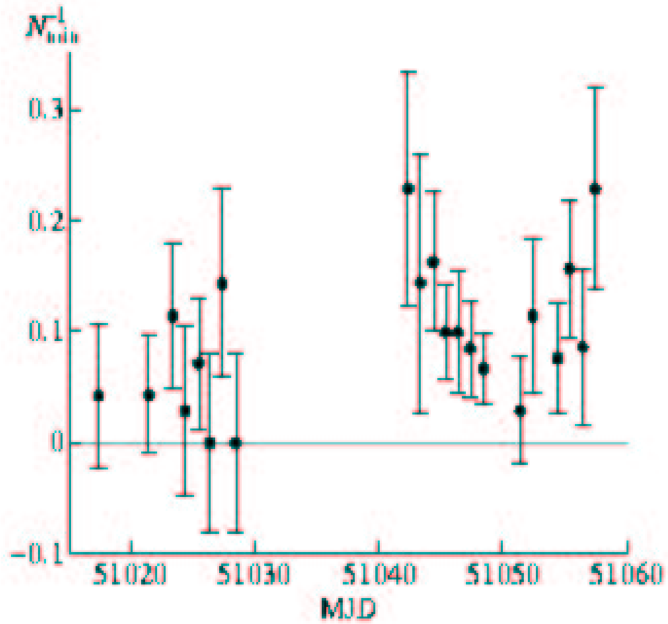
results (I): significances

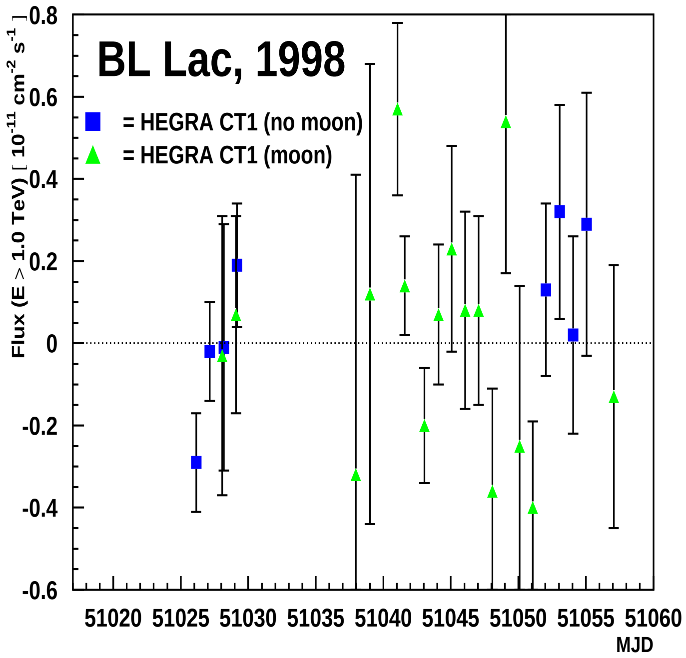


detections and candidates:

object	DC-significance	burst-like behavior in HEGRA data
1ES 1959+650	$> 15\ \sigma$	yes
H 1426+428	$>5.0\ \sigma$	no
1ES 2344+514	3.9 σ	no
(BL 1114)	(2.9 σ)	(no)

INVESTIGATION OF THE 1998 'HIGH STATE'



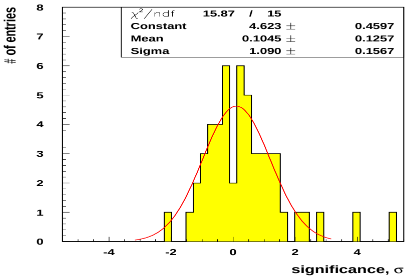


Neshpor et al. 2000: 7.2σ, $F(E > 1.0\mathrm{TeV}) = (2.1 \pm 0.4) \cdot \frac{10^{-11}}{\mathrm{s\ cm}^2}$

CT1:

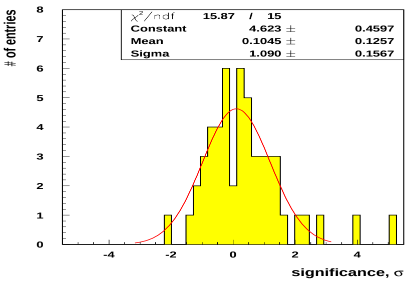
0.1σ, $F(E > 1.0\mathrm{TeV}) = (-0.01 \pm 0.06) \cdot \frac{10^{-11}}{\mathrm{s\ cm}^2}$, 14.9 h

0.0σ, $F(E > 1.0\mathrm{TeV}) = (0.03 \pm 0.06) \cdot \frac{10^{-11}}{\mathrm{s\ cm}^2}$, 30.2 h

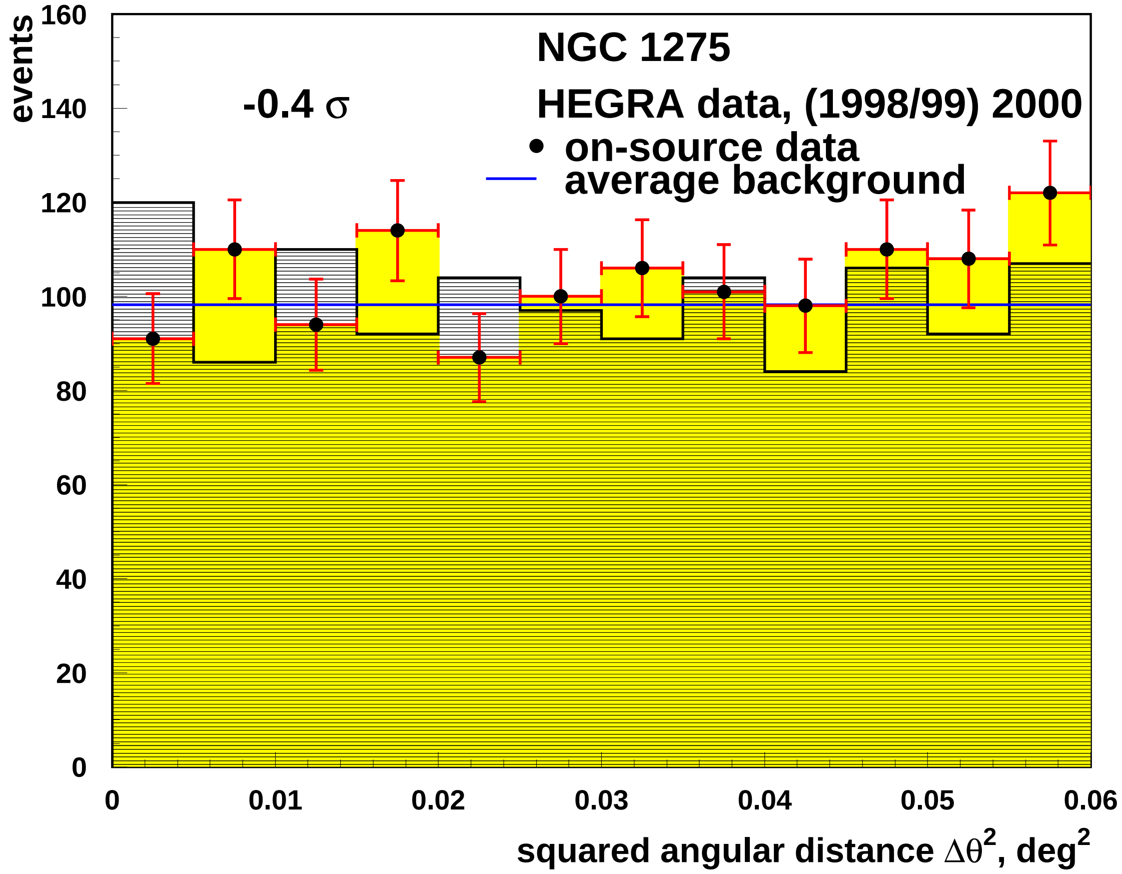


3C 66a $z = 0.444$

- 1.2 hours observation time, 1997
- -0.4 σ
- Flux(E>0.7TeV) $< 3.4 \times 10^{-12} \gamma \mathbf{cm^{-2} s^{-1}}$
- very low statistics !



NGC 1275 z = 0.018



- 90 hours observation time, 1998 – 2000
- -0.4 σ
- Flux(E>0.7TeV) $< 0.5 \times 10^{-12} \gamma \mathrm{cm}^{-2} \mathrm{s}^{-1}$