Variability of VHE γ–ray sources

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Method

- presence of source in a given region:
  on–off method (Li&Ma, ApJ 272 (1983) 317)

Binomial significance

$$S_{\mathrm{Bi}} = \frac{N_{\mathrm{on}} - \alpha N_{\mathrm{off}}}{\sqrt{\alpha \left(N_{\mathrm{on}} + N_{\mathrm{off}} \right)}}$$

- hypothesis: $\mu_{\mathrm{on}} = \alpha \mu_{\mathrm{off}}$, $\mu_{\mathrm{S}} = 0$

← normally distributed

↓

Li–Ma significance

$$S_{\mathrm{LM}} = s\sqrt{2} \left\{ N_{\mathrm{on}} \ln \left[\frac{1+\alpha}{\alpha} \frac{N_{\mathrm{on}}}{N_{\mathrm{on}} + N_{\mathrm{off}}} \right] + N_{\mathrm{off}} \ln \left[(1+\alpha) \frac{N_{\mathrm{off}}}{N_{\mathrm{on}} + N_{\mathrm{off}}} \right] \right\}^{\frac{1}{2}}$$

Method

- presence of source in a given region:
  on–off method (Li&Ma, ApJ 272 (1983) 317)
- modification: test of constant intensity
  source parameter β

Citing Articles: 451
(from All Databases)

For: ANALYSIS-METHODS FOR RESULTS IN GAMMA-RAY ASTRONOMY

Binomial significance

$$S_{\mathrm{Bi}} = \frac{N_{\mathrm{on}} - \beta\alpha N_{\mathrm{off}}}{\sqrt{\beta\alpha\left(N_{\mathrm{on}} + N_{\mathrm{off}}\right)}}$$

← normally distributed
↓

- hypothesis:

$\mu_{\mathrm{on}} = \beta\alpha\mu_{\mathrm{off}}$

~~$\mu_S = 0$~~

$\mu_S = (\beta - 1)\,\alpha\mu_{\mathrm{off}}$

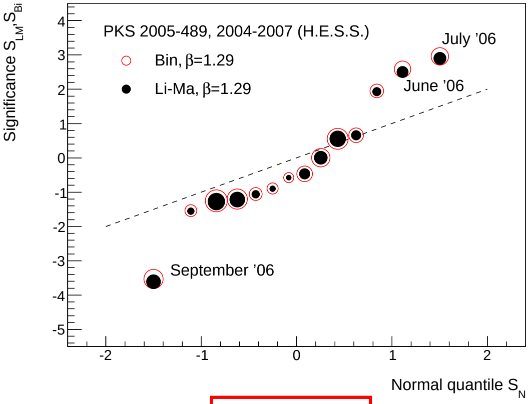
Li–Ma significance

$$S_{\mathrm{LM}} = s\sqrt{2}\left\{N_{\mathrm{on}} \ln\left[\frac{1+\beta\alpha}{\beta\alpha}\frac{N_{\mathrm{on}}}{N_{\mathrm{on}} + N_{\mathrm{off}}}\right] + N_{\mathrm{off}} \ln\left[(1+\beta\alpha)\frac{N_{\mathrm{off}}}{N_{\mathrm{on}} + N_{\mathrm{off}}}\right]\right\}^{\frac{1}{2}}$$

Nosek et al., ICRC 2013, **arXiv:1309.6476**

Applications: PKS 2005–489

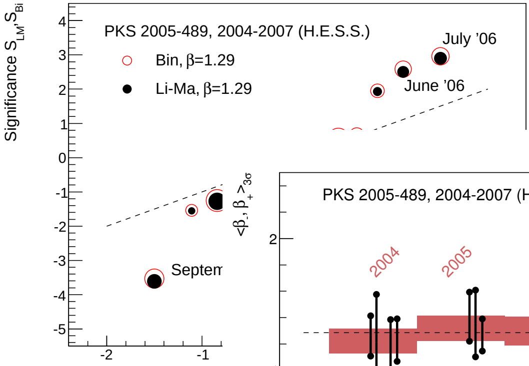
- **F.Acero et al. (H.E.S.S. Collaboration), A&A 511 (2010) A52**



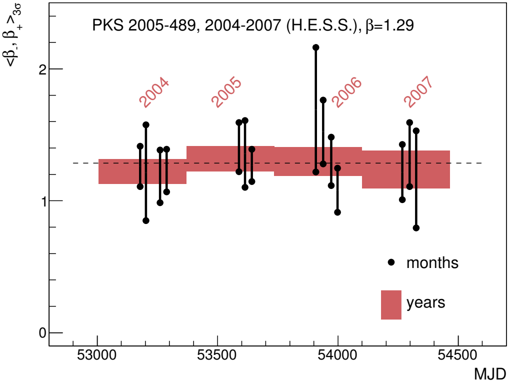
Dark Period	MJD First	MJD Last	Time [hrs]	On	Off	α	Excess	Sig [σ]	$I(>400\ \mathrm{GeV})^a$ [$10^{-12}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$]	Crab[b] %	χ^2 (NDF[c])	$P(\chi^2)^c$
06/2004	53171	53185	8.1	678	5877	0.0919	138	5.4	2.64 ± 0.50	3.0	7.2 (10)	0.71
07/2004	53199	53205	1.5	105	985	0.0909	15	1.5	1.06 ± 1.18	1.2	1.4 (1)	0.75
09/2004	53255	53268	5.6	342	3171	0.0916	52	2.8	1.89 ± 0.78	2.1	2.1 (5)	0.84
10/2004	53285	53292	9.0	569	5065	0.0916	105	4.5	2.58 ± 0.62	2.9	1.5 (4)	0.83
07/2005	53582	53595	9.4	573	4504	0.0908	164	7.3	3.56 ± 0.67	4.0	9.2 (9)	0.42

Applications: PKS 2005–489

- **F.Acero et al. (H.E.S.S. Collaboration), A&A 511 (2010) A52**



Dark Period	MJD First	MJD Last	Time [hrs]
06/2004	53171	53185	8.1
07/2004	53199	53205	1.5
09/2004	53255	53268	5.6
10/2004	53285	53292	9.0
07/2005	53582	53595	9.4

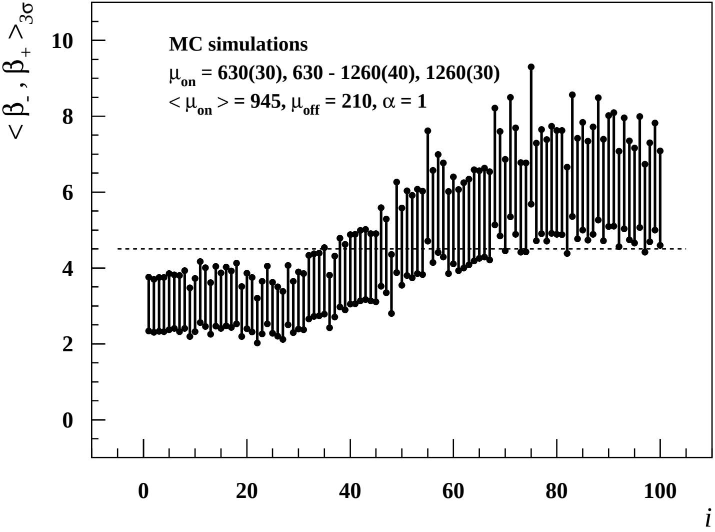


Thank you!

Back–up

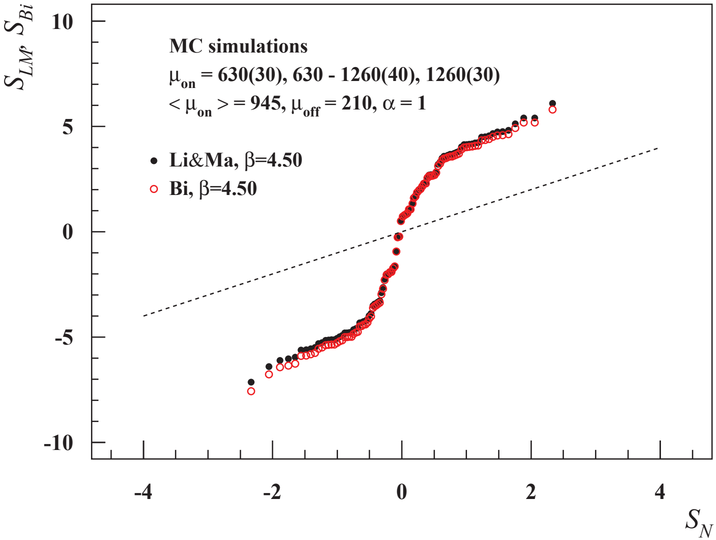
MC example

- evolution of the source intensity $|S_{\mathrm{LM}}(\beta)| < 3$

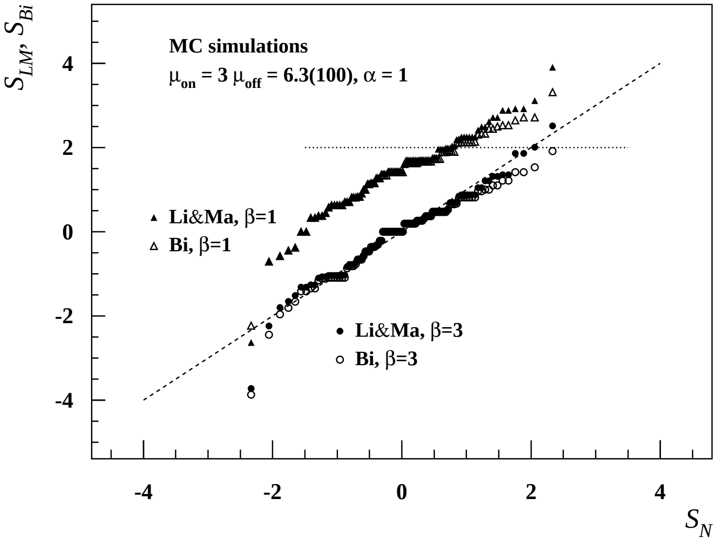


MC example

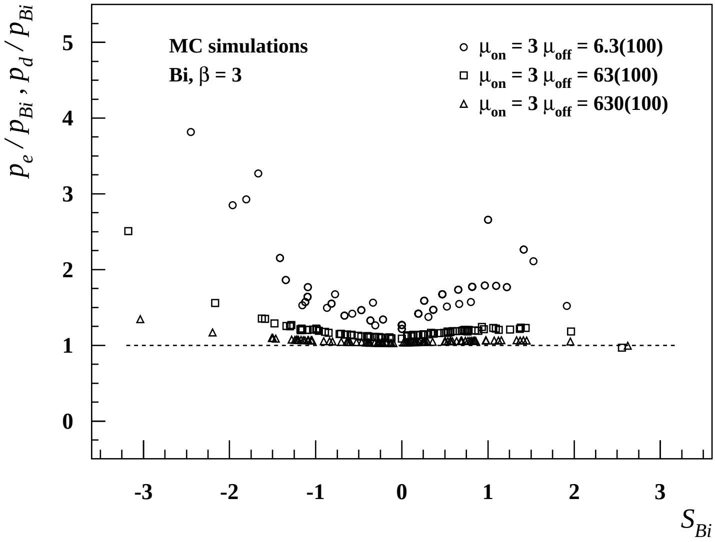
- quantile–quantile plots



Hypotheses tests

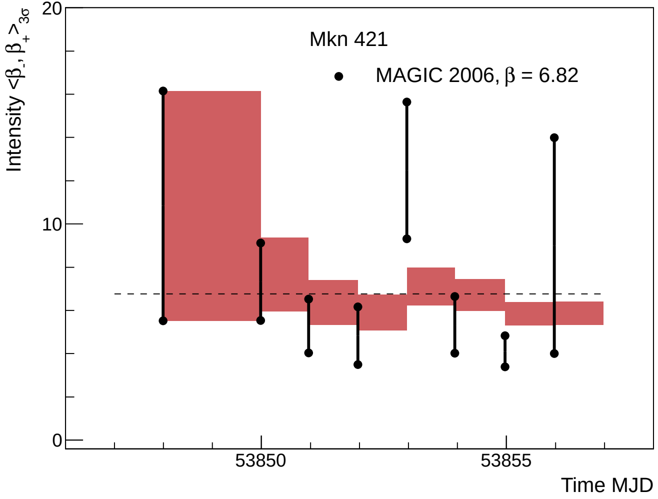


Asymptotic properties



Mkn 421

- **J.Aleksić et al. (MAGIC Collaboration), A&A 519 (2010) A32**



Other sources

Epoch	N_{on}	N_{off}	α	N_s	S^0_{LM}	S^0_{Bi}	S_{LM}	S_{Bi}	p_e or p_d	$\langle\beta_-,\beta_+\rangle_{3\sigma}$
PSR B1259-63/LS 2883 (HESS Collaboration 2013), $\beta = 4.08$										
Pre–flare	44	133	0.0760	34	7.4	9.2	0.4	0.4	0.38	$\langle 2.5, 7.2\rangle$
Flare	68	232	0.0760	50	8.5	10.4	-0.5	-0.5	0.34	$\langle 2.5, 5.7\rangle$
PG 1553+113 (Aharonian et al. 2008), $\beta = 1.16$										
04/2005	1210	8154	0.1250	191	5.5	5.6	0.8	0.8	0.23	$\langle 1.1, 1.3\rangle$
08/2005	491	3462	0.1250	58	2.5	2.6	-0.5	-0.5	0.33	$\langle 1.0, 1.3\rangle$
04/2006	1811	12742	0.1250	218	5.0	5.1	-0.8	-0.8	0.22	$\langle 1.1, 1.2\rangle$
07/2006	2236	15341	0.1250	318	6.7	6.8	0.2	0.2	0.41	$\langle 1.1, 1.2\rangle$
B2 1215+30 (Aliu et al. 2013b), $\beta = 1.39$										
2008–09	304	2288	0.1243	20	1.1	1.1	-4.4	-4.3	$5.1\ 10^{-6}$	$\langle 0.9, 1.3\rangle$
2011	472	2325	0.1161	202	10.4	11.2	4.4	4.6	$5.1\ 10^{-6}$	$\langle 1.5, 2.0\rangle$
2012	443	898	0.1177	37	3.2	3.4	-0.3	-0.3	0.40	$\langle 1.0, 1.8\rangle$
1ES 0229+200 (Aharonian et al. 2007; Aliu et al. 2014)[a] , $\beta = 1.20$										
2005	246	2238	0.0916	41	2.7	2.7	-0.0	-0.0	0.52	$\langle 1.0, 1.5\rangle$
2006	1344	12304	0.0914	220	6.1	6.2	-0.1	-0.1	0.46	$\langle 1.1, 1.3\rangle$
2009–10	1054	7601	0.0909	363	12.2	12.9	7.1	7.3	$7.8\ 10^{-13}$	$\langle 1.4, 1.7\rangle$
2010–11	614	5862	0.0909	81	3.3	3.3	-1.0	-1.0	0.17	$\langle 1.0, 1.3\rangle$
2011–12	249	2241	0.0909	45	2.9	3.0	0.3	0.3	0.40	$\langle 1.0, 1.5\rangle$

1ES 0229+200 data

Table 1. The MJD of the first and last night of HESS observations of 1ES 0229+200, the live time of the observations, the number of on- and off-source events measured, the on/off normalization (α), the excess, and the significance of the excess are given. In addition, the integral flux above 580 GeV (assuming $\Gamma = 2.50$), and the corresponding percentage of the Crab Nebula flux above 580 GeV are shown. The χ^2, degrees of freedom (NDF), and χ^2 probability, $P(\chi^2)$, for a fit of a constant to the flux binned by dark period within each year, or yearly within the total, are also given.

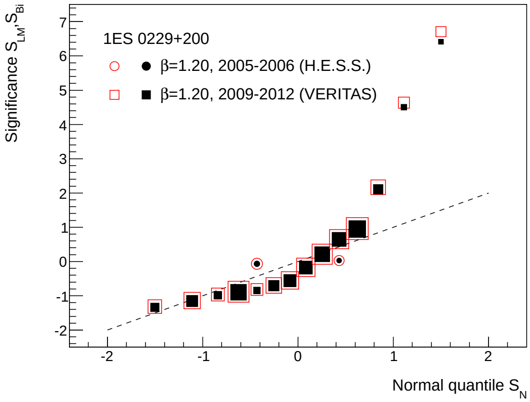
Epoch	MJD First	MJD Last	Time [h]	On	Off	α	Excess	Sig [σ]	I(>580 GeV) [10^{-13} cm^{-2} s^{-1}]	Crab %	χ^2, NDF	P(χ^2)
2005	53614	53649	6.8	246	2238	0.09160	41	2.7	$6.8\pm3.1_{stat}\pm1.4_{syst}$	1.3	1.6 , 1	0.21
2006	53967	54088	35.0	1344	12304	0.09136	220	6.1	$10.0\pm1.7_{stat}\pm2.0_{syst}$	1.9	1.5 , 3	0.68
Total	53614	54088	41.8	1590	14542	0.09140	261	6.6	$9.4\pm1.5_{stat}\pm1.9_{syst}$	1.8	0.8 , 1	0.37

Table 1: The VERITAS 1ES 0229+200 observation details. α (the ratio of the area $\times$ livetime of the *on* source and *off* source regions) is 1/11. The integral flux is calculated assuming an overall spectral index of 2.59. Upper limits at the 99% confidence level using the Rolke method (Rolke & López 2001) are presented when the significance is less than two standard deviations. The horizontal lines delineate the results for the full time period, the data divided by season, and the data divided by observing period (dictated by the lunar cycle and indicated by 'P. 1' through 'P. 5' in each season).

Period	Dates [MJD]	Live Time [minutes]	*On* [events]	*Off* [events]	Significance [σ]	Flux (> 300 GeV) [10^{-9} m^{-2} s^{-1}]	UL (> 300 GeV) [10^{-9} m^{-2} s^{-1}]
2009-2012	55118 - 55951	3260	1917	15704	11.7	$23.3 \pm 2.8_{stat} \pm 5.8_{sys}$	N/A
2009-2010	55118 - 55212	1674	1054	7601	12.2	$30.3 \pm3.9_{stat} \pm 7.6_{sys}$	N/A
2010-2011	55476 - 55587	1079	614	5862	3.3	$18.7 \pm5.1_{stat} \pm 5.7_{sys}$	N/A
2011-2012	55828 - 55951	507	249	2241	2.9	$9.9 \pm6.4_{stat} \pm 2.5_{sys}$	N/A
2009-2010 P. 1	55118 - 55131	715	484	3210	9.7	$41.8 \pm6.4_{stat} \pm 10.5_{sys}$	N/A
2009-2010 P. 2	55144 - 55159	844	524	3880	8.1	$24.2 \pm5.4_{stat} \pm 6.1_{sys}$	N/A
2009-2010 P. 3	55183 - 55183	24	10	120	-0.3	$1 \pm26_{stat} \pm 1_{sys}$	100
2009-2010 P. 4	55200 - 55212	91	36	391	0.1	$3 \pm10_{stat} \pm 1_{sys}$	51
2010-2011 P. 1	55476 - 55482	319	187	1900	1.0	$15 \pm9_{stat} \pm 4_{sys}$	41
2010-2011 P. 2	55501 - 55513	162	121	901	3.8	$39 \pm14_{stat} \pm 10_{sys}$	N/A
2010-2011 P. 3	55526 - 55538	127	69	692	0.7	$1 \pm14_{stat} \pm 1_{sys}$	60
2010-2011 P. 4	55555 - 55570	297	147	1490	1.0	$15 \pm10_{stat} \pm 4_{sys}$	40
2010-2011 P. 5	55583 - 55587	174	90	879	1.1	$26 \pm13_{stat} \pm 7_{sys}$	54
2011-2012 P. 1	55828 - 55840	101	46	434	1.0	$13 \pm14_{stat} \pm 3_{sys}$	66
2011-2012 P. 2	55855 - 55861	111	55	460	1.9	$15 \pm14_{stat} \pm 4_{sys}$	78
2011-2012 P. 3	55886 - 55895	119	68	608	1.6	$13 \pm14_{stat} \pm 3_{sys}$	77
2011-2012 P. 4	55916 - 55922	103	41	435	0.2	$-6 \pm13_{stat} \pm 2_{sys}$	51
2011-2012 P. 5	55940 - 55951	73	39	304	1.9	$16 \pm18_{stat} \pm 4_{sys}$	100

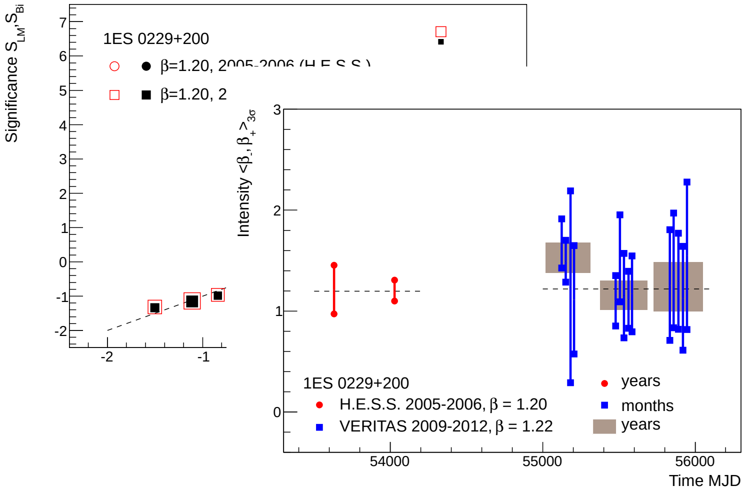
Applications: 1ES 0229+200

- **F.Aharonian et al. (H.E.S.S. Collaboration), A&A 475 (2007) L9**
- **E.Aliu et al. (VERITAS Collaboration), ApJ 782 (2014) 13**



Applications: 1ES 0229+200

- **F.Aharonian et al. (H.E.S.S. Collaboration), A&A 475 (2007) L9**
- **E.Aliu et al. (VERITAS Collaboration), ApJ 782 (2014) 13**

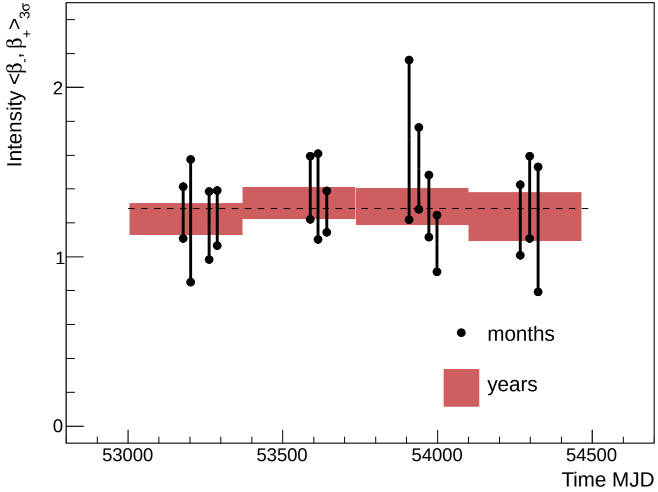


PKS 2005–489 data

Table 1. Results from long-term HESS observations of PKS 2005−489.

Dark Period	MJD First	MJD Last	Time [hrs]	On	Off	α	Excess	Sig [σ]	I(>400 GeV)[a] [10^{-12} cm^{-2} s^{-1}]	Crab[b] %	χ^2 (NDF[c])	P(χ^2)[c]
06/2004	53171	53185	8.1	678	5877	0.0919	138	5.4	2.64 ± 0.50	3.0	7.2 (10)	0.71
07/2004	53199	53205	1.5	105	985	0.0909	15	1.5	1.06 ± 1.18	1.2	1.4 (1)	0.75
09/2004	53255	53268	5.6	342	3171	0.0916	52	2.8	1.89 ± 0.78	2.1	2.1 (5)	0.84
10/2004	53285	53292	9.0	569	5065	0.0916	105	4.5	2.58 ± 0.62	2.9	1.5 (4)	0.83
07/2005	53582	53595	9.4	573	4504	0.0908	164	7.3	3.56 ± 0.67	4.0	9.2 (9)	0.42
08/2005	53609	53618	5.1	286	2159	0.0989	73	4.5	2.86 ± 0.93	3.2	4.6 (4)	0.33
09/2005	53639	53646	18.1	1072	9125	0.0928	225	7.1	2.93 ± 0.46	3.3	13.1 (6)	0.041
06/2006	53908	53909	1.3	127	824	0.0938	50	4.9	4.72 ± 1.32	5.3	0.0 (1)	0.97
07/2006	53938	53940	4.4	397	2927	0.0901	133	7.3	4.33 ± 0.70	4.8	1.3 (2)	0.52
08/2006	53967	53977	8.4	500	4261	0.0913	111	5.1	2.74 ± 0.57	3.1	15.1 (7)	0.035
09/2006	53995	54002	7.4	405	4116	0.0920	26	1.3	1.31 ± 0.58	1.5	6.0 (5)	0.30
06/2007	54264	54270	5.3	333	3006	0.0924	55	3.1	1.02 ± 0.60	1.1	1.9 (6)	0.93
07/2007	54291	54304	4.4	309	2412	0.0964	76	4.5	2.51 ± 0.70	2.8	15.2 (8)	0.056
08/2007	54321	54329	1.8	93	849	0.0977	10	1.0	0.52 ± 0.92	0.6	2.9 (3)	0.41
09/2007	54345	54345	0.5	11	114	0.1000	0	−0.1	< 6.60[d]	<7.4	–	–
2004	53171	53292	24.2	1694	15098	0.0917	310	7.7	2.37 ± 0.33	2.6	2.0 (3)	0.57
2005	53582	53646	32.6	1931	15785	0.0930	462	11.0	3.09 ± 0.35	3.5	0.6 (2)	0.73
2006	53908	54002	21.5	1429	12128	0.0914	320	8.8	2.84 ± 0.34	3.2	13.5 (3)	0.0037
2007	54264	54345	12.0	746	6381	0.0947	141	5.3	1.50 ± 0.40	1.7	3.8 (3)	0.28
Total	53171	54345	90.3	5800	49392	0.0924	1233	16.7	2.57 ± 0.18	2.9	10.2 (3)	0.016

PKS 2005–489



Intensity <β-, β+>3σ
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Time MJD
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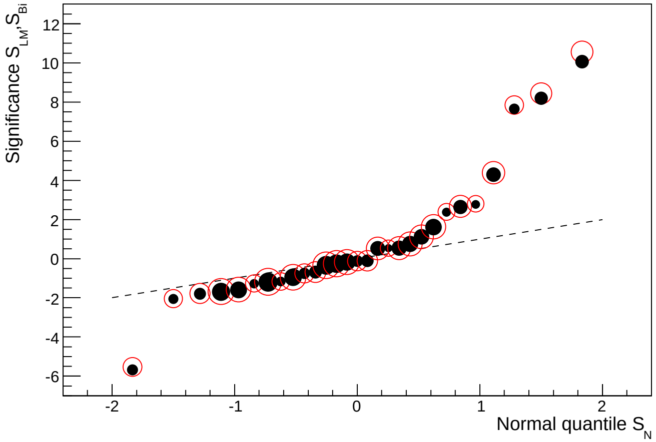
PKS 2155–304



Significance S_{LM},S_{Bi}
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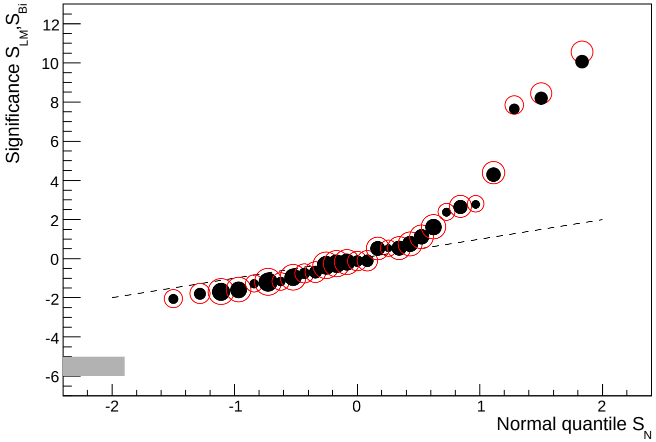
PKS 2155–304



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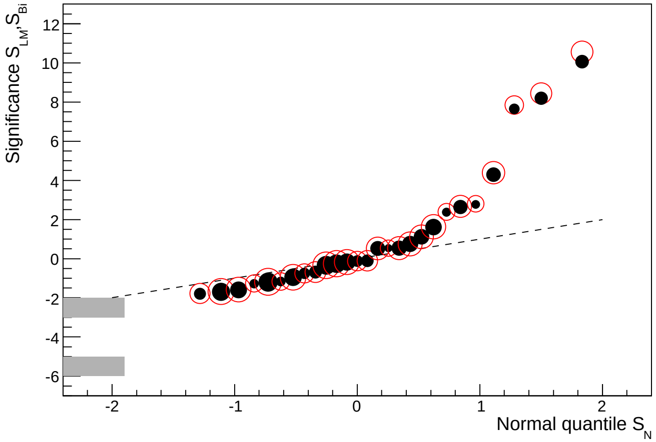

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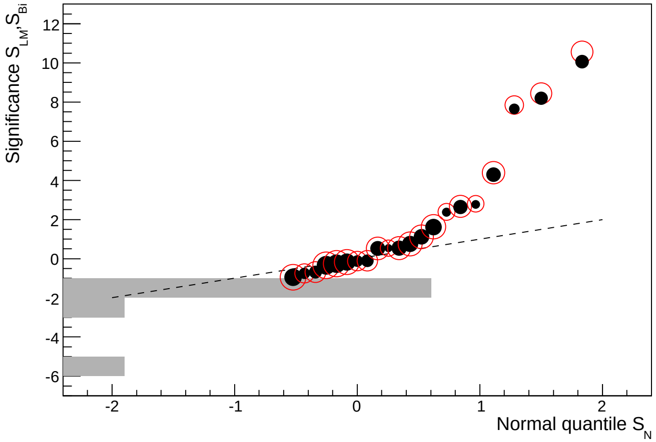

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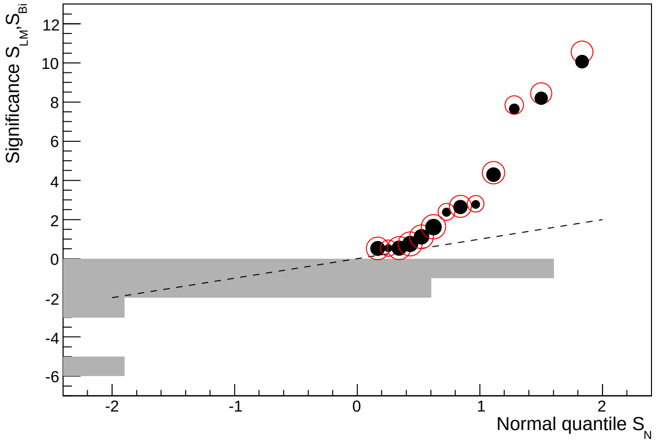

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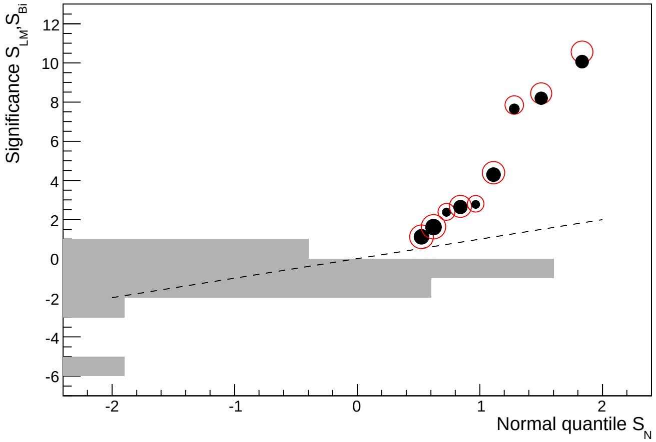

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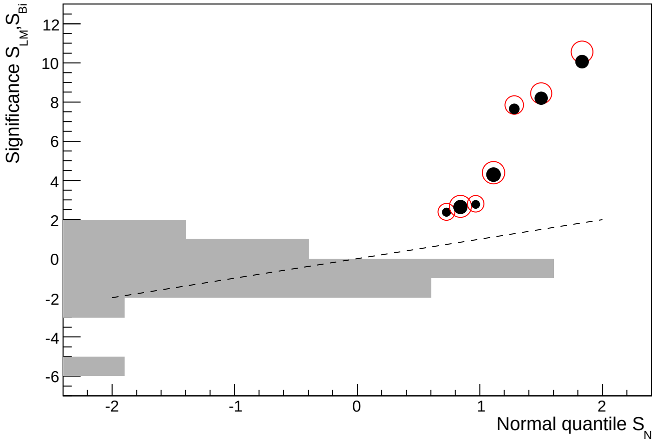
Significance S_{LM},S_{Bi}
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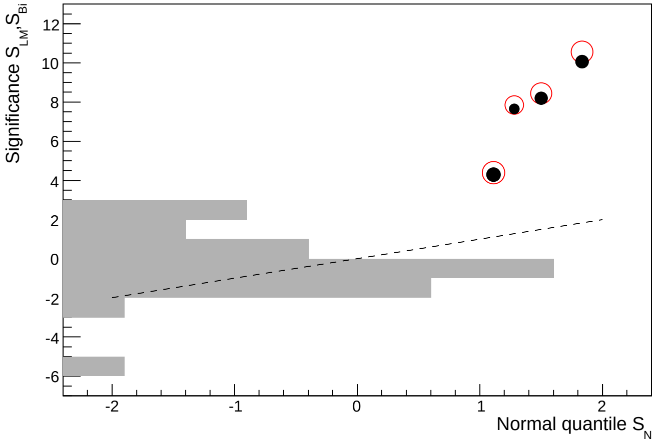

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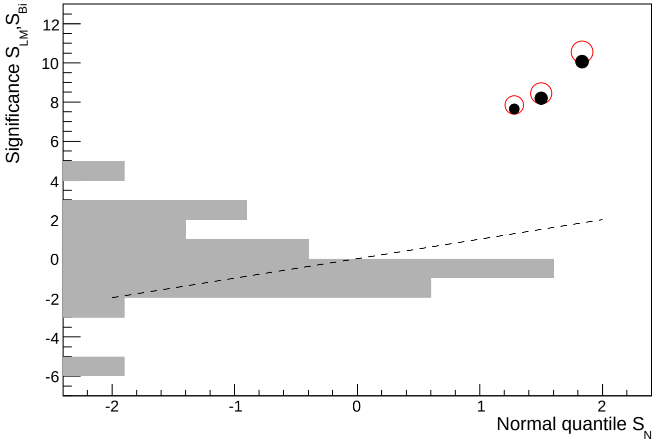

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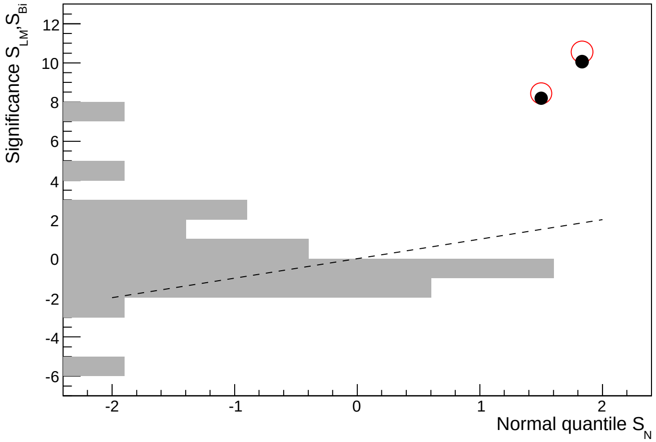

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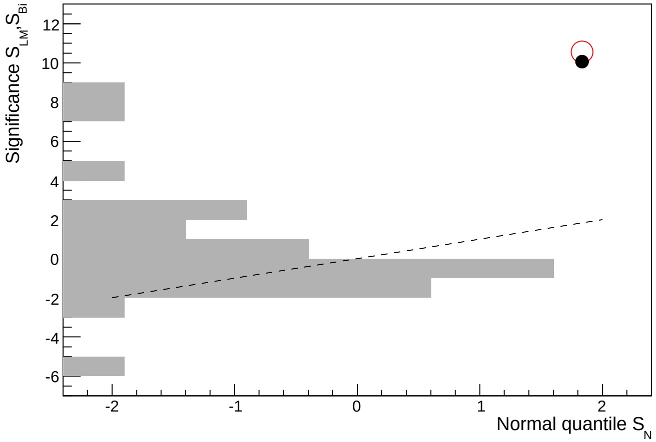
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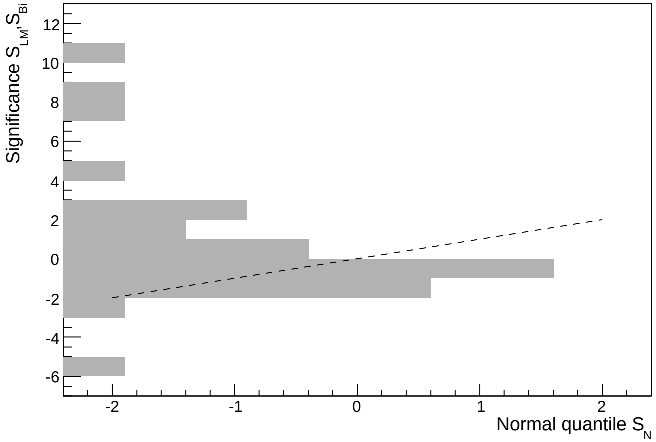
Normal quantile S_N

PKS 2155–304



Significance S_{LM},S_{Bi}
12
10
8
6
4
2
0
-2
-4
-6
-2
-1
0
1
2
Normal quantile S_N

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