Report of neutrino point source activities in Zeuthen

D. Gora/R. Franke

1) Introduction

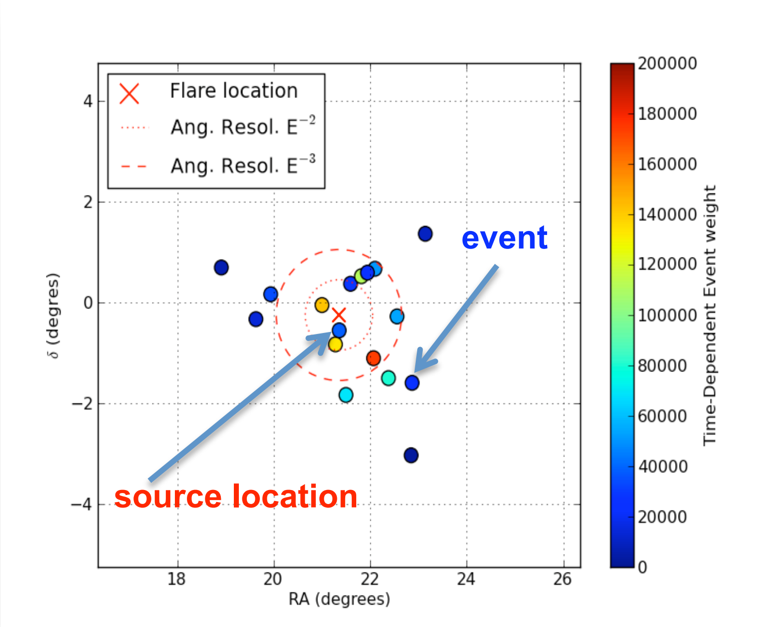
2) Short description of the method :
   --unbinned maximum likelihood

3) Results:
   -- IC79 Crab Online analysis
   -- UHECR correlation analysis with IC22/IC40
   -- IC 40 time-clustering analysis
   -- IC59/IC79 multi-flare search

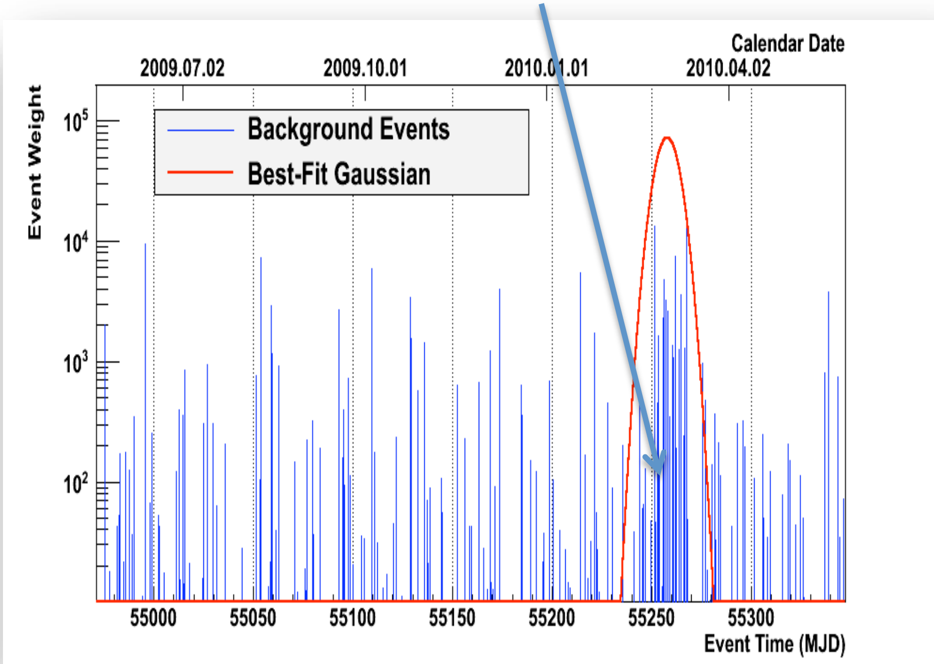
4) Neutrino Triggered Target of Oportunity (IC79)

5) Summary

Basic concept of neutrino point source search



Compact cluster of events in time



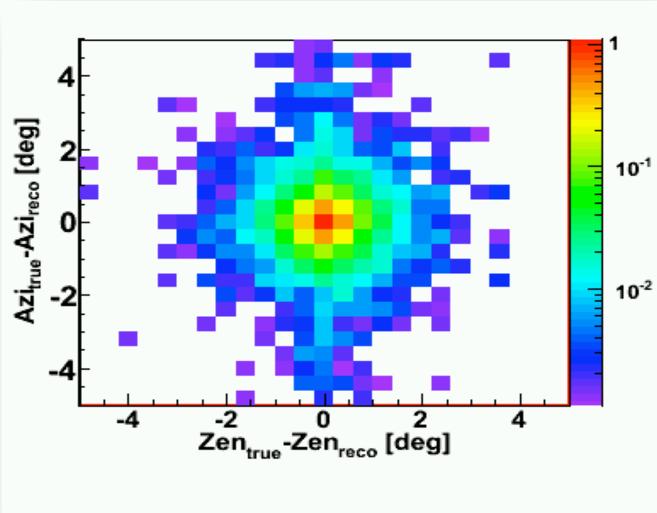
Finding neutrino point source in the sky requires locating of events from a particular direction over the background of atmospheric neutrinos and muons. The signal events might present additional features: different energy spectrum or time structure.

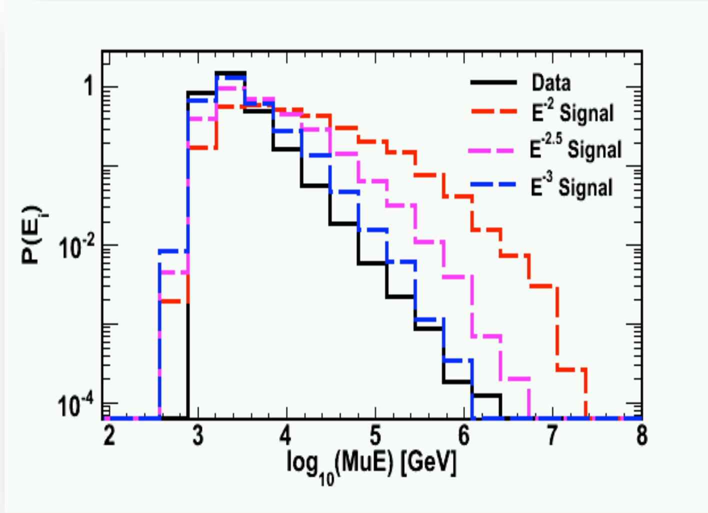
Physics motivation:

-- Question of hadronic accelaration in cosmic accelerators hard to answer with photon data alone.

-- Simultaneous TeV-photon and neutrino data can increase the chanceto discover the first astrophysical neutrino or shed light on accelaration mechanism

Method: an unbinned maximum likelihood



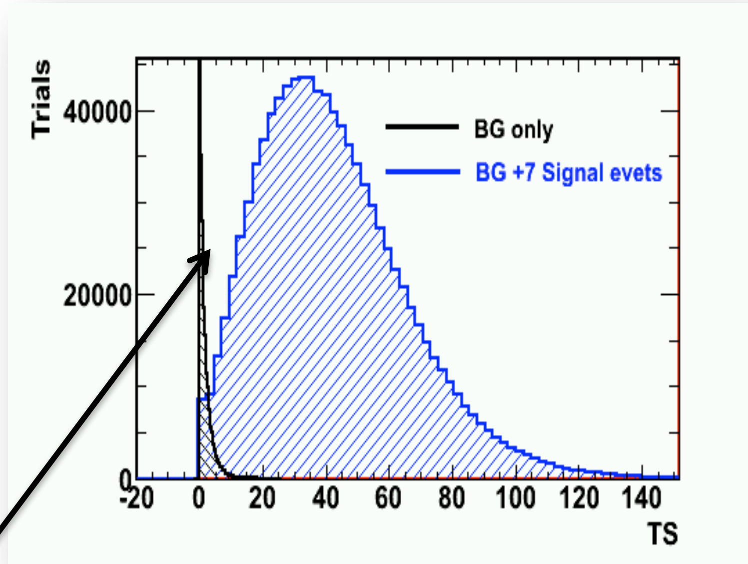


$$\mathcal{L}(\mathbf{n_s},\gamma) = \prod_{\mathbf{i=1}}^{\mathbf{N}} \left[\frac{\mathbf{n_s}}{\mathbf{N}} \mathcal{S}_\mathbf{i} + (\mathbf{1} - \frac{\mathbf{n_s}}{\mathbf{N}}) \mathcal{B}_\mathbf{i} \right]$$

$$\mathcal{S}_i = P^{space}(|x_i - x_s|, \sigma_i) \times P^{energy}(E_i|\gamma) \times P^{time}(\Delta t_j)$$

$$\mathcal{B}_\mathbf{i} = \frac{\mathbf{1}}{\mathbf{d\Omega}} \times \mathbf{P_i(E_i)} \times \mathbf{P^{time}}(\theta, \phi, \mathbf{t_i})$$

$$\mathbf{TS} = -\mathbf{2}\log(\lambda) = -\mathbf{2}\log \frac{\mathcal{L}(\mathbf{n_s} = \mathbf{0})}{\mathcal{L}(\mathbf{n_s^f}, \gamma^\mathbf{f})}$$

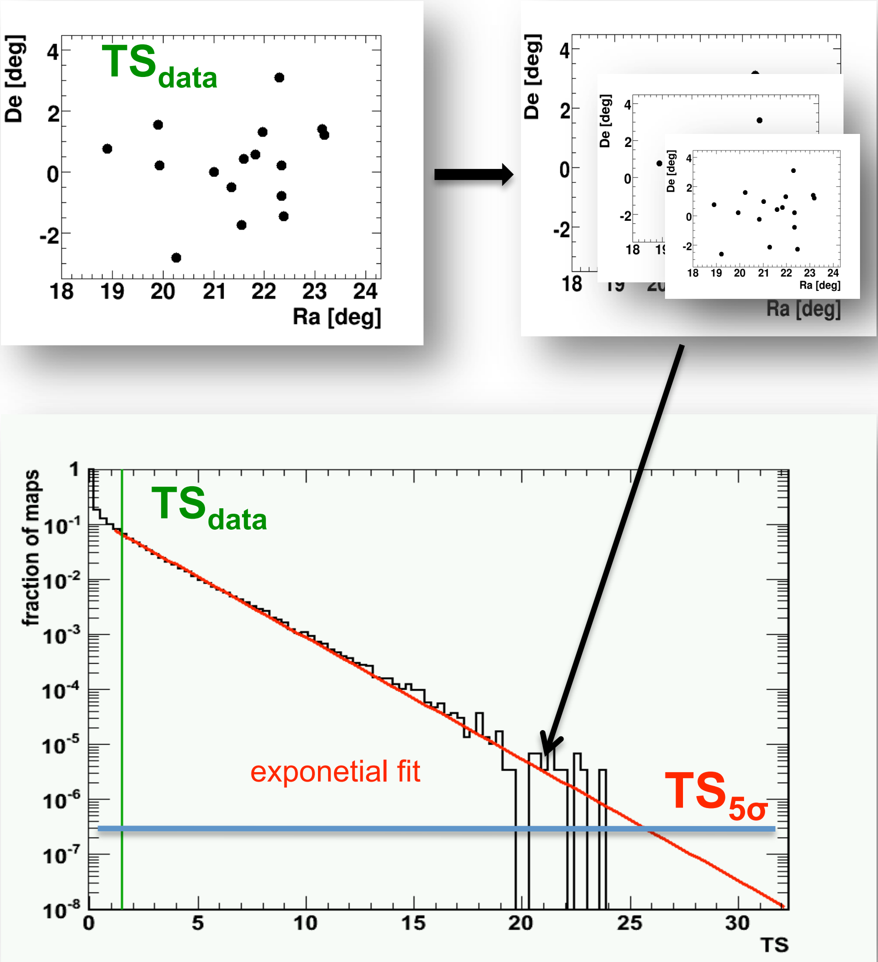


TS distribution for no signal events in data sample

Generation of scrambled data sets

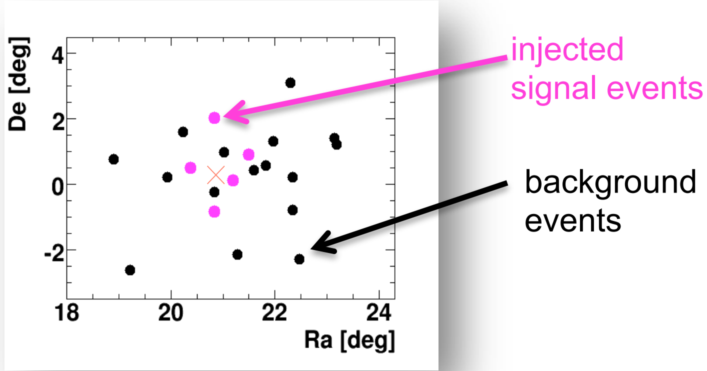
Background simulations

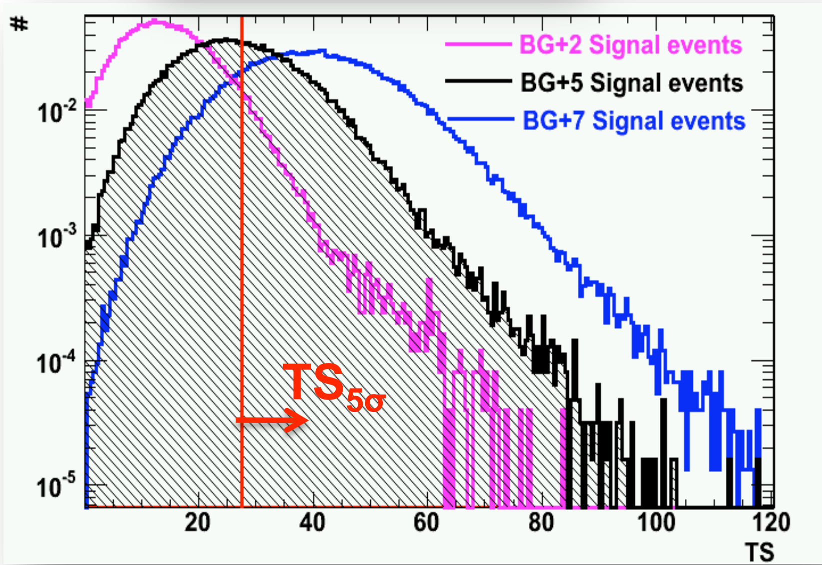
Data distribution *Scrambled data sets*



RESULT: the 5 sigma threshold, TS$_{5\sigma}$ from fit
p-value as the fraction of events
above TS$_{data}$

Signal events injected on the top of the backgroud events

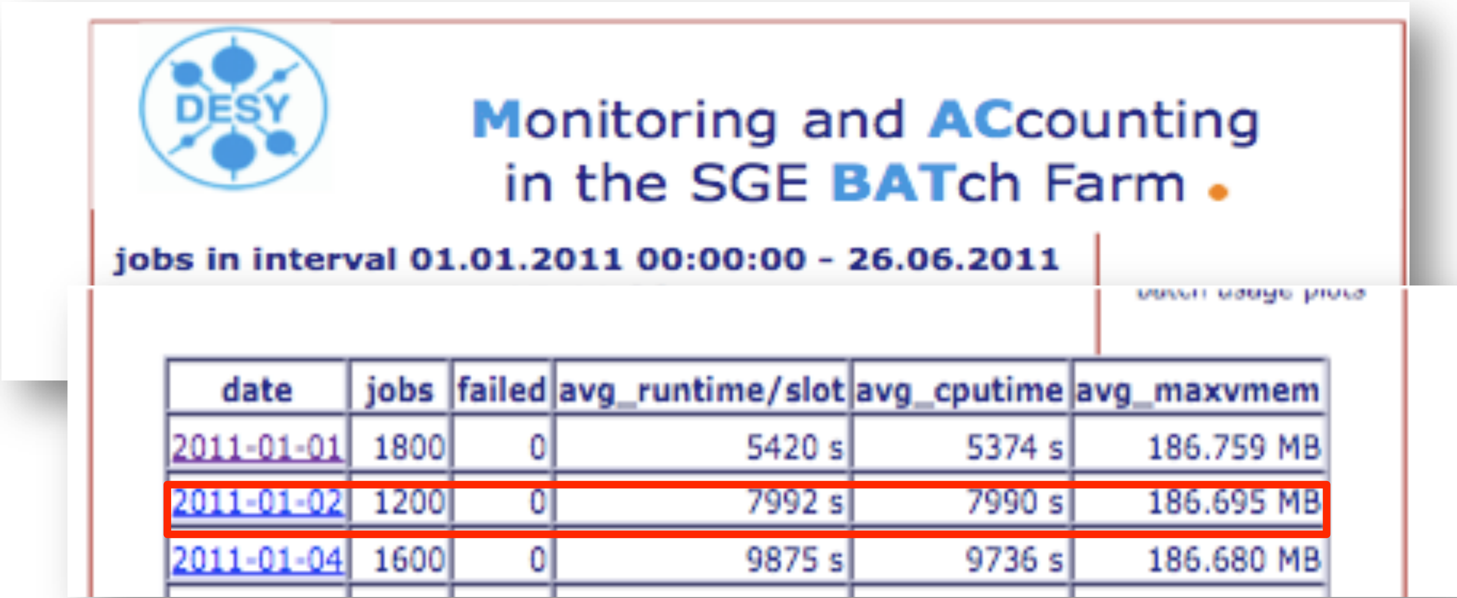




RESULT: the number of events needed
for 5sigma discovery

Jobs properties

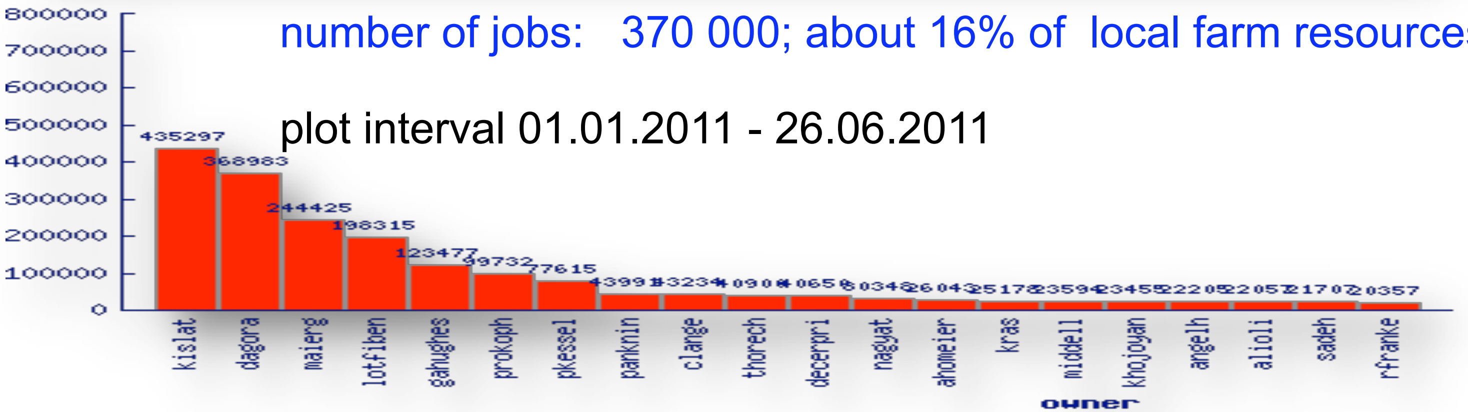
from DESY Zeuthen farm-monitoring page



Monitoring and ACcounting in the SGE BATch Farm

jobs in interval 01.01.2011 00:00:00 - 26.06.2011

date	jobs	failed	avg_runtime/slot	avg_cputime	avg_maxvmem
2011-01-01	1800	0	5420 s	5374 s	186.759 MB
2011-01-02	1200	0	7992 s	7990 s	186.695 MB
2011-01-04	1600	0	9875 s	9736 s	186.680 MB



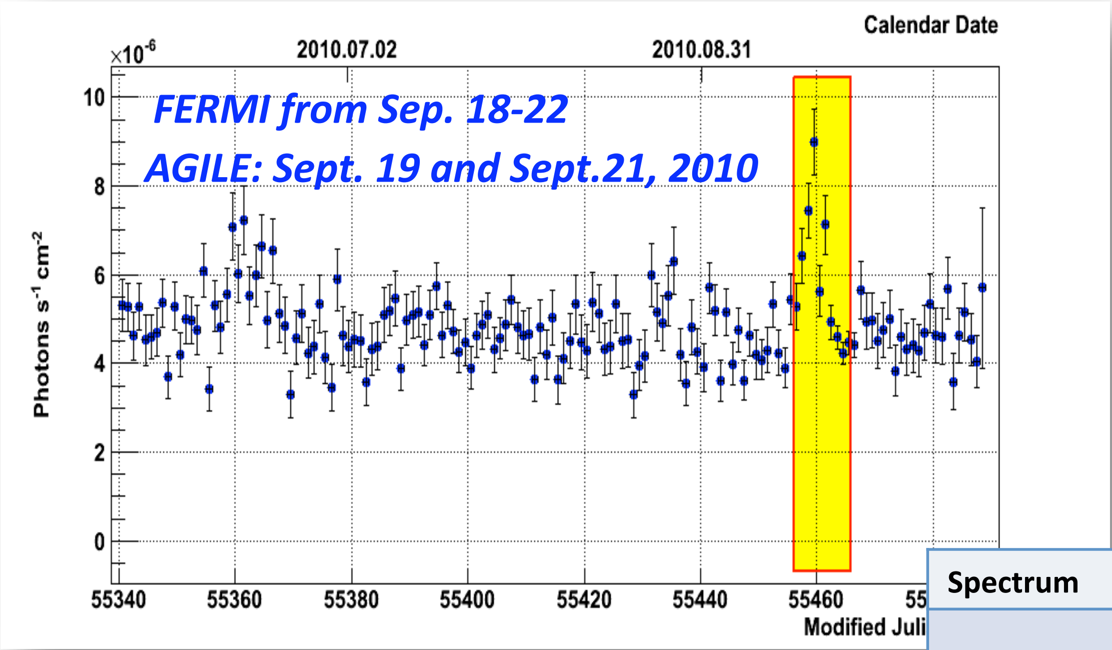
number of jobs: 370 000; about 16% of local farm resources (CPU time)

plot interval 01.01.2011 - 26.06.2011

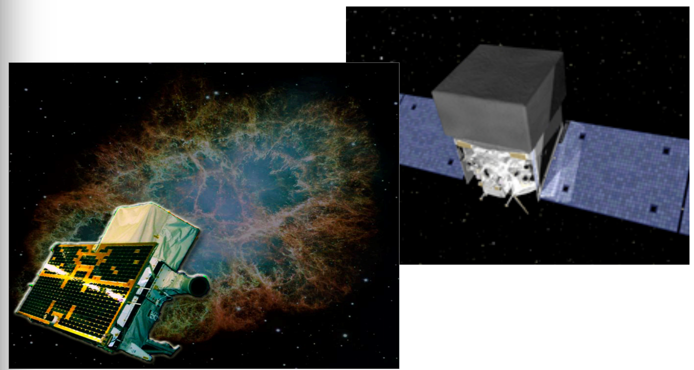
In principle single job is not time (cpu) or memory consuming, but the huge number of data sets are needed to simulate and analyzed in order to calculate 5 sigma threshold and the discovery potential.

IC79 Crab flare online analysis

For astrophysical sources which manifest large time variations in electromagnetic radiation, the signal-to-noise ratio can be increased by testing smaller time window around the flare.



A flare from Crab has been reported in the GeV region from Fermi and AGILE



Cross-check with Madison results

IceCube Collaboration, arXiv:1106.3484

(Madison/This work) in %

Spectrum	This work		Madison	
	P=0.5 5σ Disc		P=0.5 5σ Disc.	
	#Ev	Flux N.	#Ev	Flux (GeV/cm²/s)
E^{-2}	5.26	1.30E-7	5.04	1.26E-7 (97%)
$E^{-2.5}$	6.76	2.32E-5	6.22	2.13E-5 (92%)
E^{-3}	8.08	1.84E-3	7.53	1.72E-3 (94%)

Directional correlations between UHECRs and neutrinos observed with IceCube data

Directional correlations between UHECRs … (method)

Unbinned correlation method based on **likelihood maximisation:**

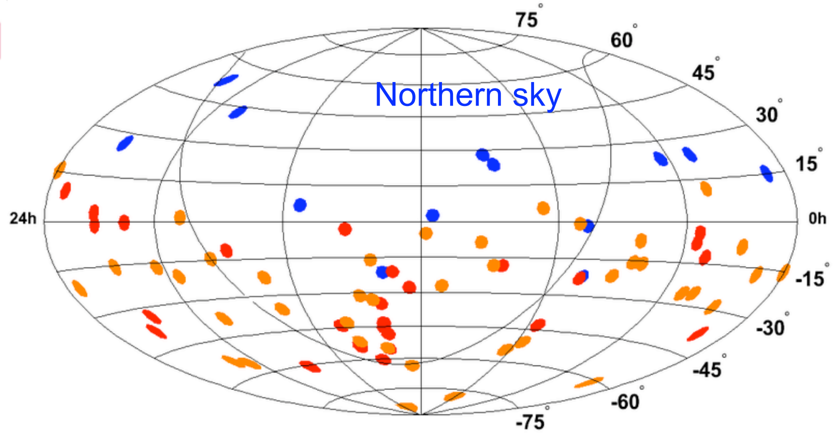
$$L(\{\mathbf{x}_u\},\gamma,n_s) = \prod_i \left(\frac{n_s}{n_{\mathrm{tot}}} \sum_{j=1}^{M} R(j,\gamma) S_i^j(\mathbf{x}_i, E_i, \gamma) / \sum_{k=1}^{M} R(k,\gamma) + \left(1 - \frac{n_s}{n_{\mathrm{tot}}}\right) B(\mathbf{x}_i, E_i) \right)$$

- Sum over UHECR directions
- Relative weights due to IceCube declination dependence
- Source p.d.f. Depending on position and energy
- Background p.d.f. obtained from data

Based on the stacking principle, **one total number of signal neutrinos and one common spectral index are fitted.**

IceCube data for 22/40-strings
Auger and HiRes published events with energy above 57EeV

Orange – 42 events PAO 2010
Red- 27 events from PAO 2007
Blue -13 events from HiRes



R. Lauer for IceCube Collaboration, Astrophys. Space Sci. Trans., 7, 201–205, 2011; R. Lauer PhD thesis.

UHECR correlations analysis with IC22:

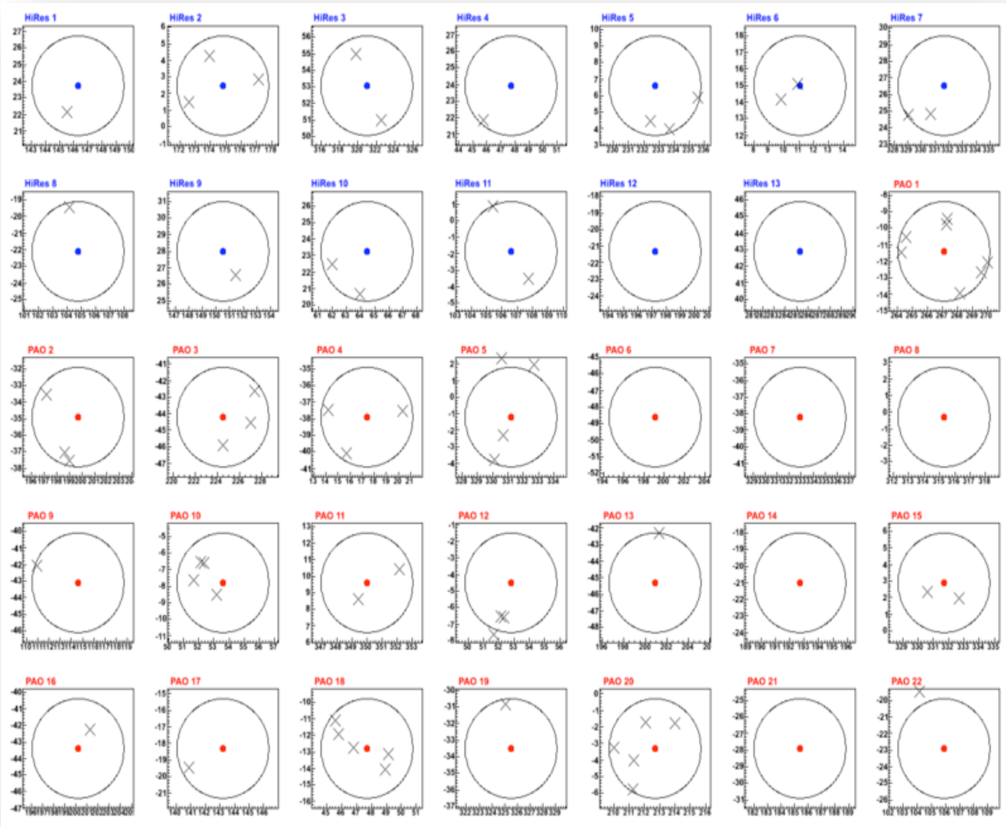
Auger:
27 events above 57 EeV

HiRes:
13 stereo events above 56 EeV

Tolal IceCube events count
in 35 bins (3^{o} radius) **60**

Mean expectation from
scrambled maps: **43.7**

Excess probability: **0.98%**
(2.33 σ)



This excess is compatible with background fluctuations

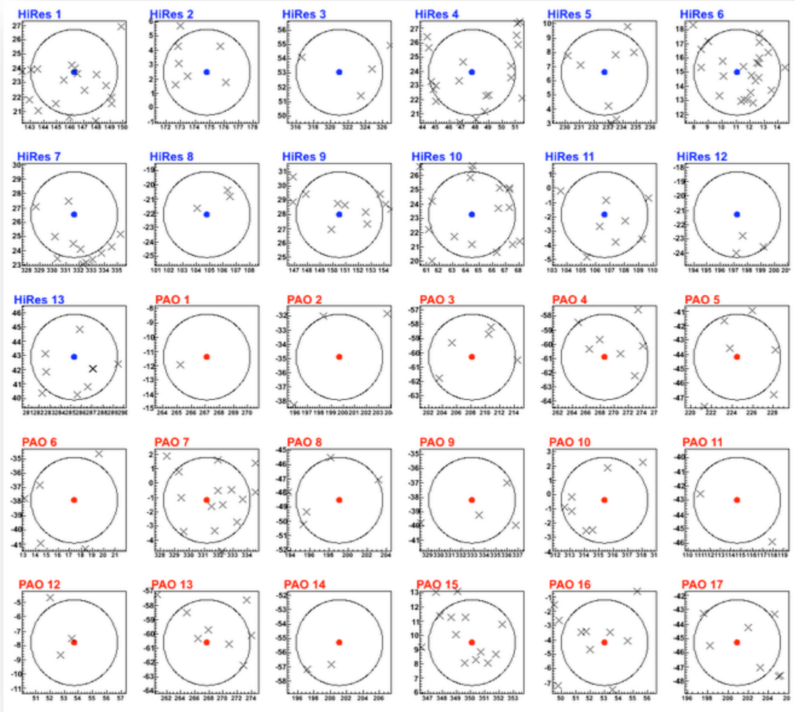
Approximate neutrino flux limit per source: **0.9 x 10-8 GeV cm-2 s-1**

Update: UHECR correlation analysis with IC40

Stacking of 82 UHECR directions from HiRes and PAO

TS: 0.0
nsig: 0.0
p-value: 1.0

However, one applies the single source unbinned likelihood method to the coordinates of HiRes 6, one obtains:



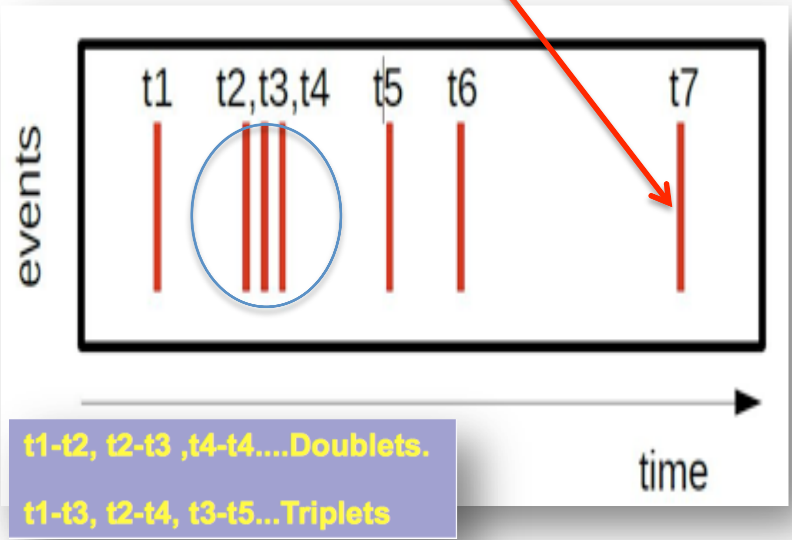
TS: **5.47**
nsig: **20.7** [best fit number of signals]
Spectral index: **-2.6** [best fit source spectral index]
p-value: **0.0249** [a-posteriori and not accounting for any trials]
sigma: **1.96** [one-sided convention, a-posteriori and not accounting for any trials]

This work was motivation for a present ps-wg analysis: UHCR correlation analysis by N.Kurahashi

Time-dependent searches for flares of neutrinos (in order to increase the signal-to-noise ratio)

Time-Clustering Algorithm

signal–like event have $S_i/B_i>1$



1) *Choose signal-like events by sorting using $S_i/B_i>1$*

(2) *Define ΔT by trying all multiplets (ΔT<30days)*

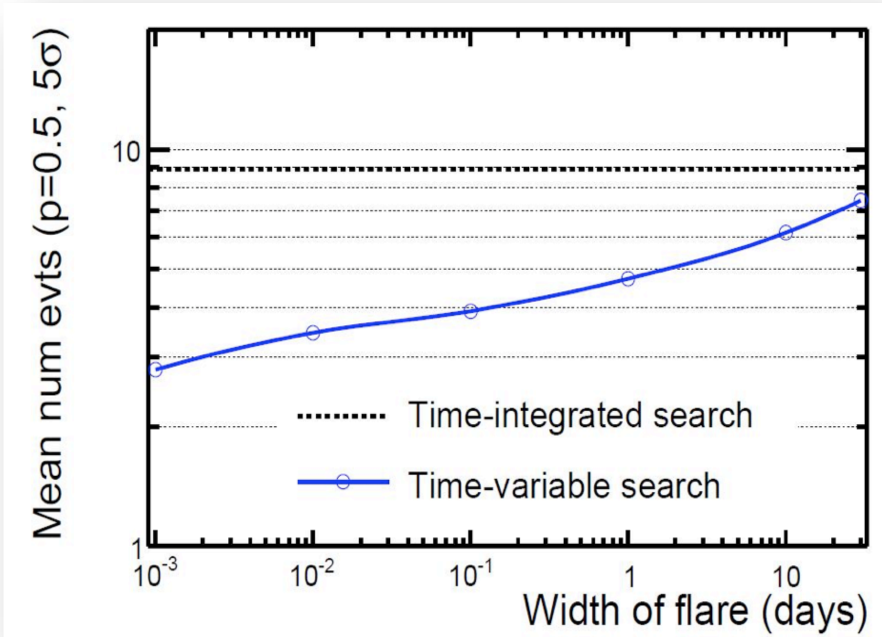
(3) *For each ΔT calculate a Test Statistic (TS)*

(4) *Choose greatest TS (i.e select most significant cluster of events)*

$$\mathcal{S}_i = P^{space}(|x_i - x_s|, \sigma_i) \times P^{energy}(E_i|\gamma)$$

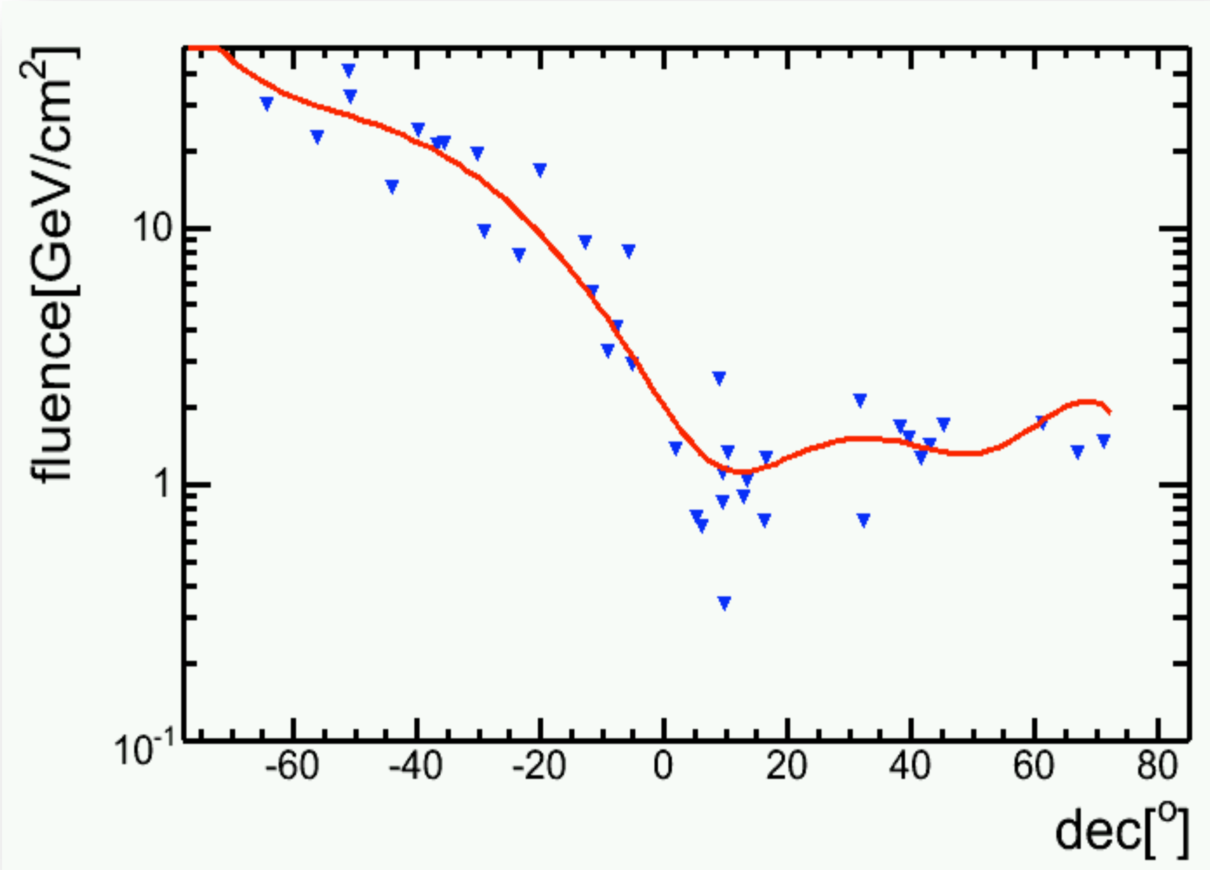
$$\mathcal{B}_i = \frac{1}{d\Omega} \times P_i(E_i)$$

Jose Bazo PhD thesis, results with the IceCube 40-strings configuration and for point source at dec=16 deg, ra=343 deg.



Results: IC40 untriggered neutrino flare search

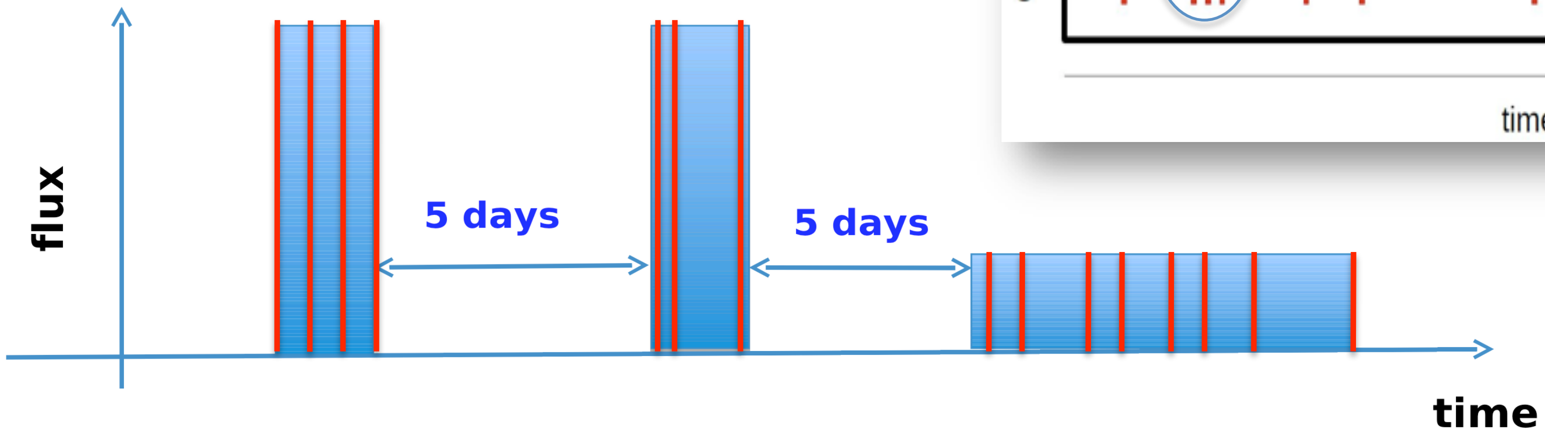
for 40 astrophysical bright variable sources candidates (18 south, 22 north) from Fermi catalog.

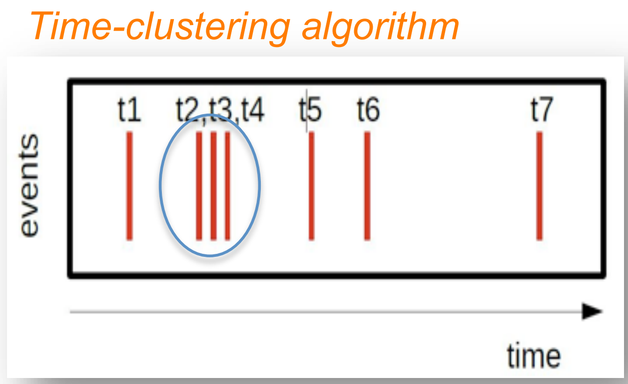


No significant deviation from the background only hypothesis is found, *so upper limits are calculated. The maximum significance found, was **p-value=0.07 (1.4 sigma)** for **0FGL J0643.2+0858**. The post-trial p-value is calculated to be 94.5%. The corresponding best time cluster was 14.3 days*. (IceCube Collaboration, **arXiv:1104.0075**)

Multi-flare method
extention of the time-clustering algorithm

Motivation



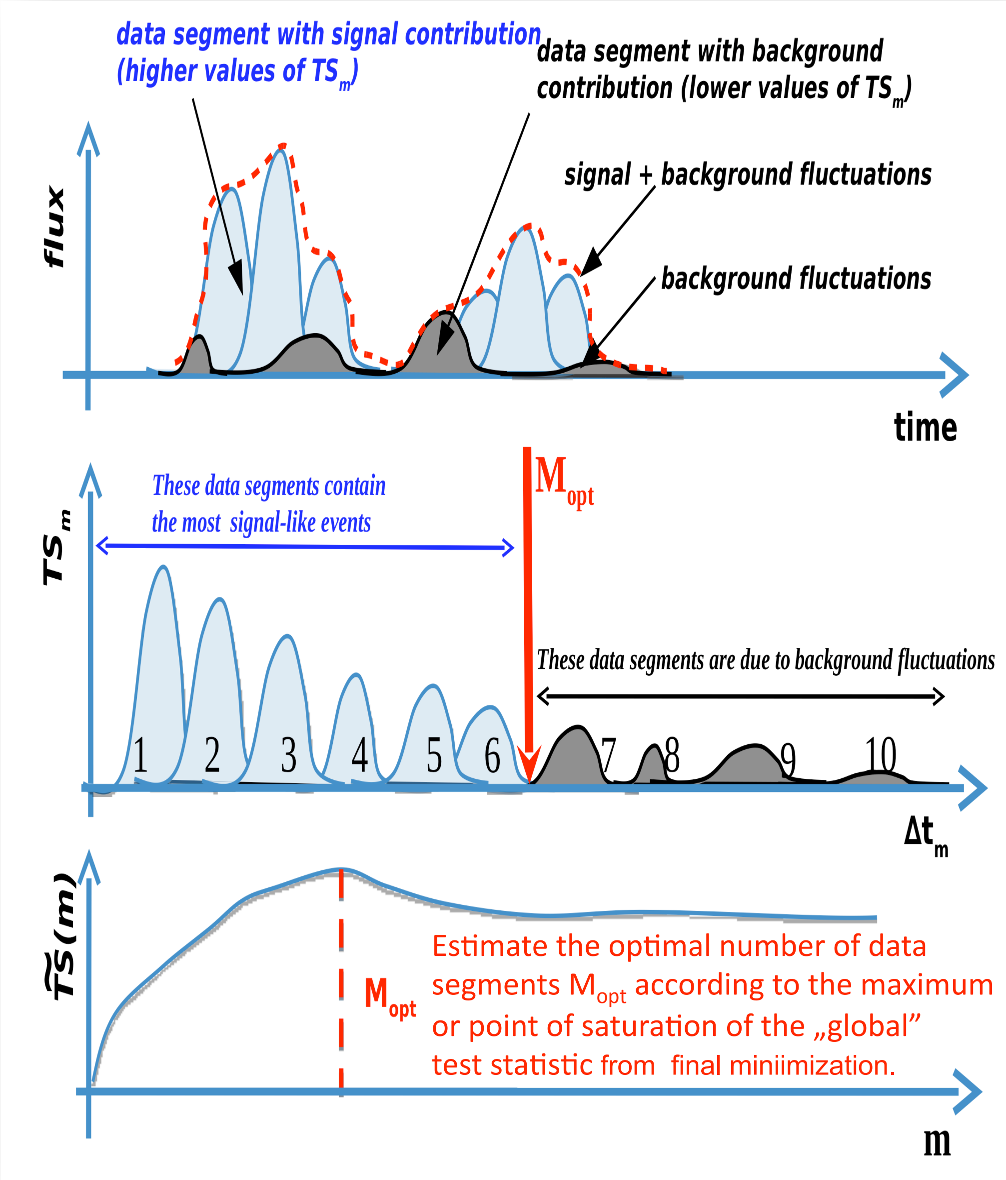


Such case of a few "weak" flares cannot be discovered at a 5σ level by the standard point search algorithm. This is because standard algorithms only search for a maximum which corresponds to the one most significant flare *(one cluster of events compact in time).*

The multi-flare method use a unified algorithm which can find single and multi-flares i.e. signal events from all individual flares/sub-flares will be considered and not only from the most significant one.

Method

(the time-clustering algorithm with an unbinned likelihood method*)



1) Extract all consecutive doublets of all signal-like events (S_i/B_i>1) over the entire data period (doublet define a time window Δt_m to be tested)

2) For each time window Δt_m perform a maximization of standard likelihood:

$$\mathcal{L}(n_s,\gamma)|_{\Delta t_m} = \prod_{i=1}^{N}\left[\frac{n_s}{N}\mathcal{S}_i + \left(1-\frac{n_s}{N}\right)\mathcal{B}_i\right]$$

3) Sort time windows Δt_m according to the test statistic:

$$TS_m|_{\Delta t_m} = -2\log\left[\frac{\Delta T_{Data}}{\Delta t_m}\times\frac{\mathcal{L}(\tilde{x}_s, n_s=0)}{\mathcal{L}(\hat{n}_s,\hat{\gamma}_s)}\right]$$

4) Replace the single-source term in likelihood function by signal sub-term over m data segments

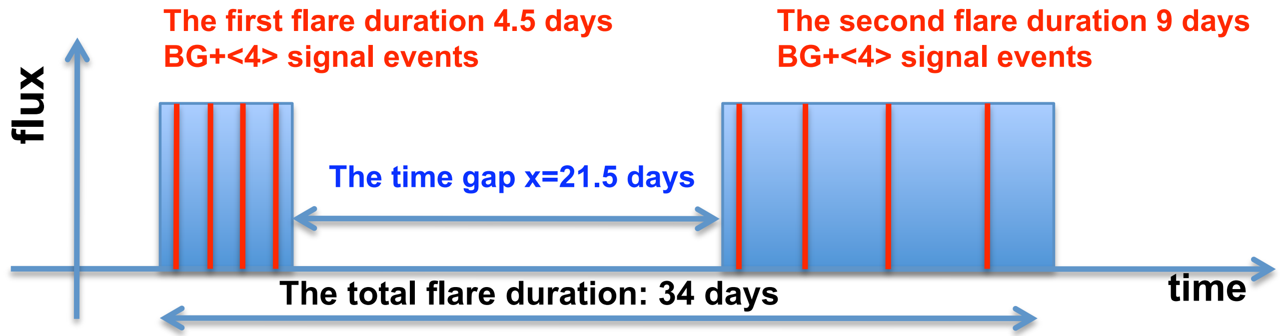
$$S_i \rightarrow S_i^{tot}(m) = \frac{\sum_{j=1}^{m} W(j)\times\mathcal{S}_{i,j}(|\tilde{x}_i-\tilde{x}_s|, E_i, \gamma, \Delta t_m)}{\sum_{j=1}^{m} W(j)}$$

5) For a given configuration of m data segments calculate the „global" test statistic:

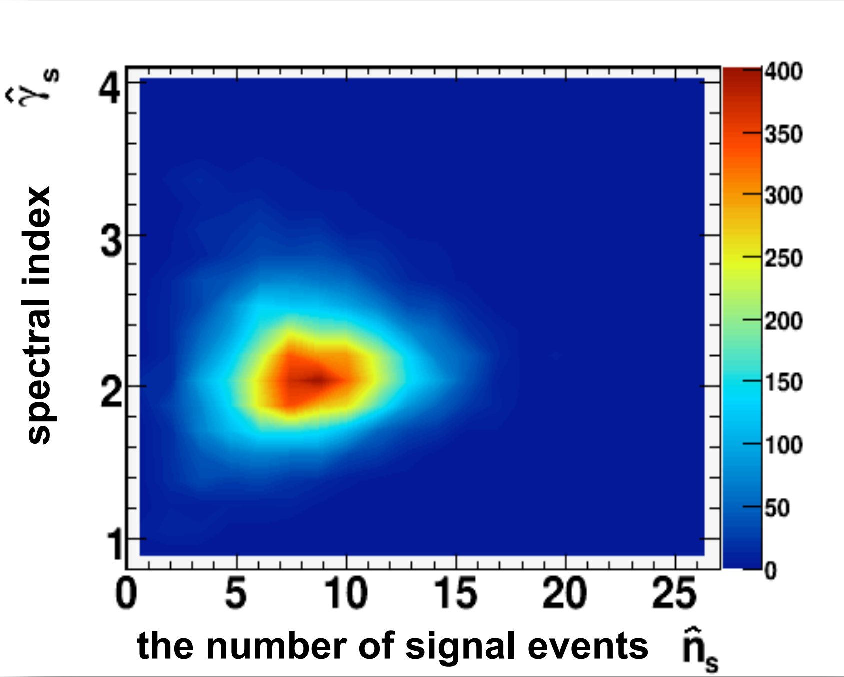
$$\widetilde{TS}(m) = -2\log\left[\frac{\tilde{\mathcal{L}}(\tilde{x}_s, n_s=0)}{\tilde{\mathcal{L}}(\tilde{x}_s,\hat{n}_s,\hat{\gamma}_s, m)}\right]$$

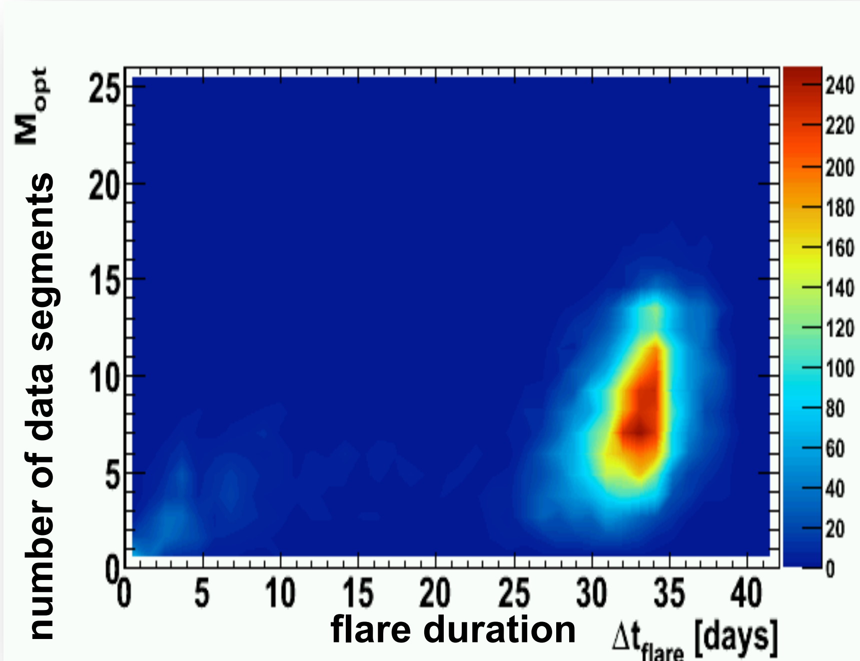
*D. Gora, E. Bernardini and A. Cruz, arXiv:1103.2644

Application of the method to two flares



Injected signal events equally distributed among two flares. The total flare duration 34 days

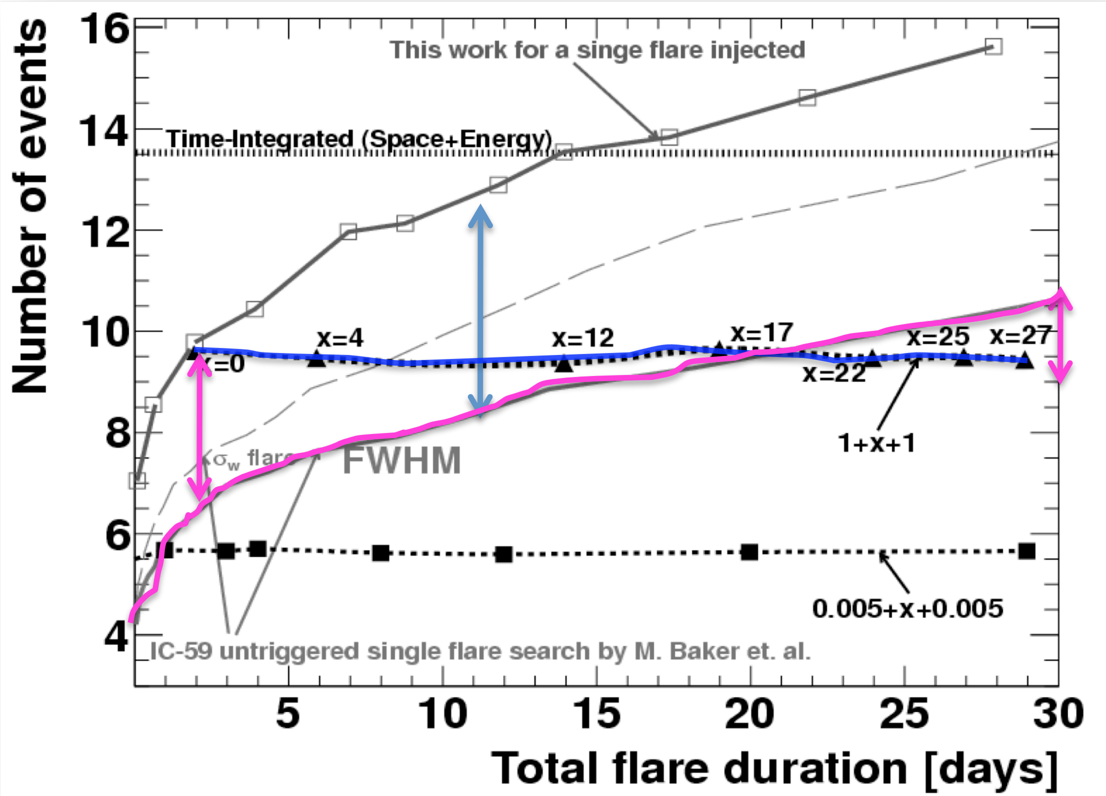




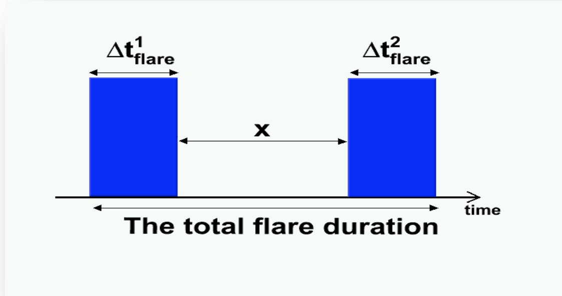
In this case, signal events are not form one cluster of events in time, but the method can recover the most important parameters. The proposed algorithm looks for all signals events but does not matter how these signal events are distributed in time.

Method performance

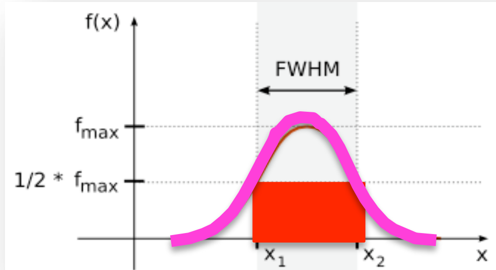
(IC59, 376 days data period, source at declination 22 deg)

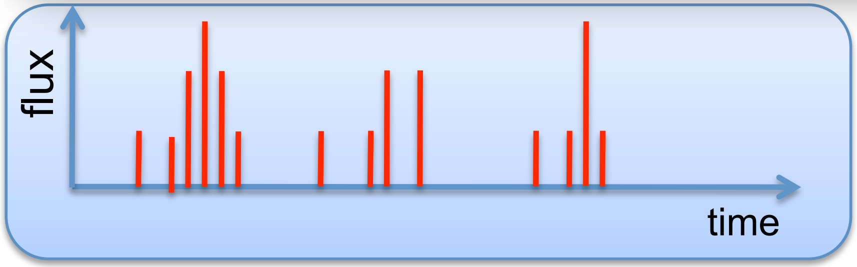


horizontal dashed lines: double flare searches



Solid lines: single flare search



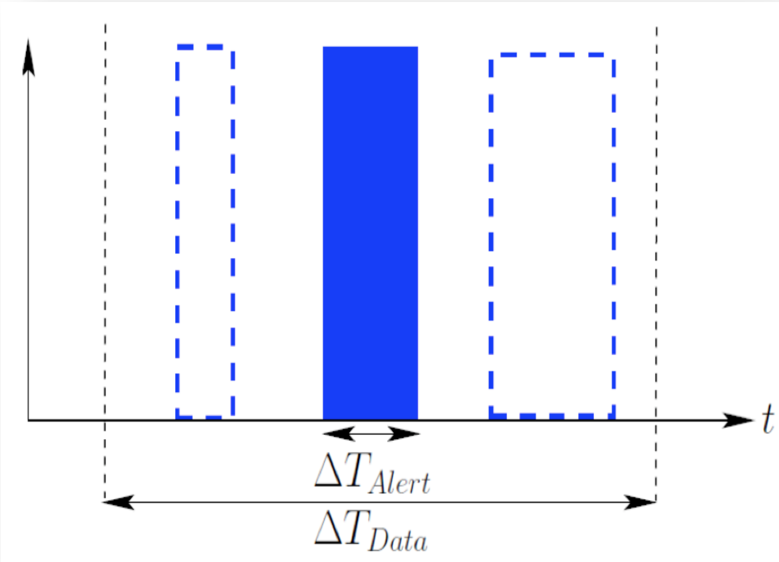


For same cases the method is better than a time-integrated search and the standard point search algorithm.

IC-59: Source List/choosing the time window

Advantage of the method:
the flare shape is result of an application of the method not it's input like for the standard point search algorithm.

We applied the method to 23 selected sources, which manifest the large variations in emitted electromagnetic emissions.



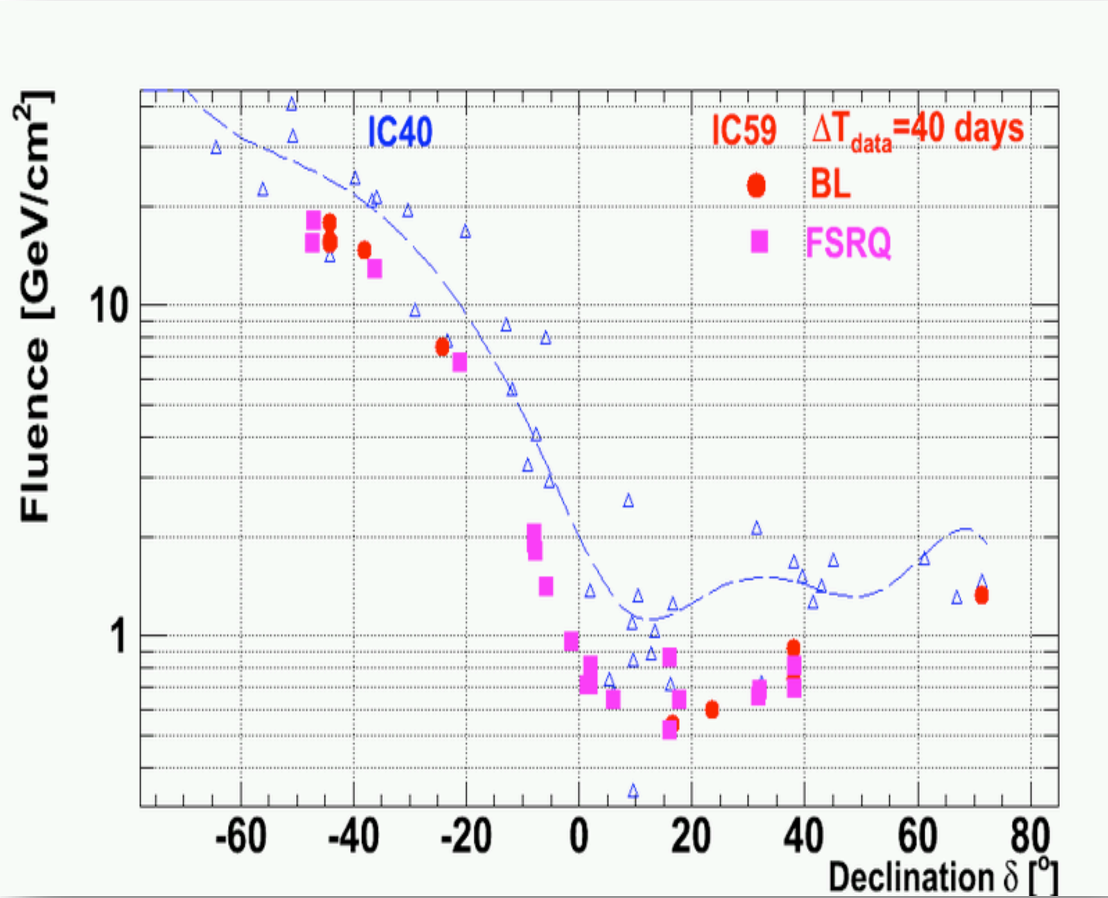
Selection of sources based on Fermi LAT data (photon flux, spectral index, variability index)

BL-Lacs: Flux (1-100 GeV) > 1e-9 ph cm^-2s^-1
and spectral index < 2.3
and variability index > 23.21

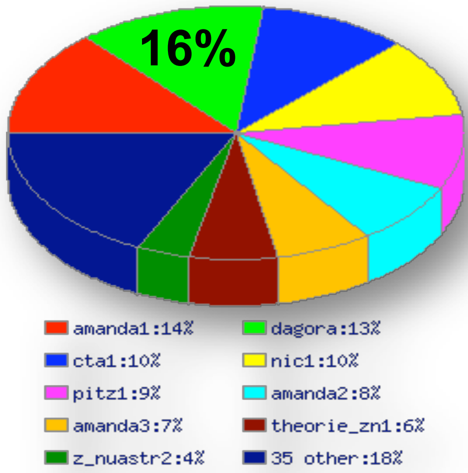
FSRQs: Flux (0.1-1 GeV) > 7e-8 ph cm^-2s^-1
and the variability index > 23.21

For the multi-flare analysis we "only need a first guess" of the flare(s)-time/duration
In this way we are allowing to find a possible time lag in the photon-neutrino emission…

Results: IC59 and multiflare analysis

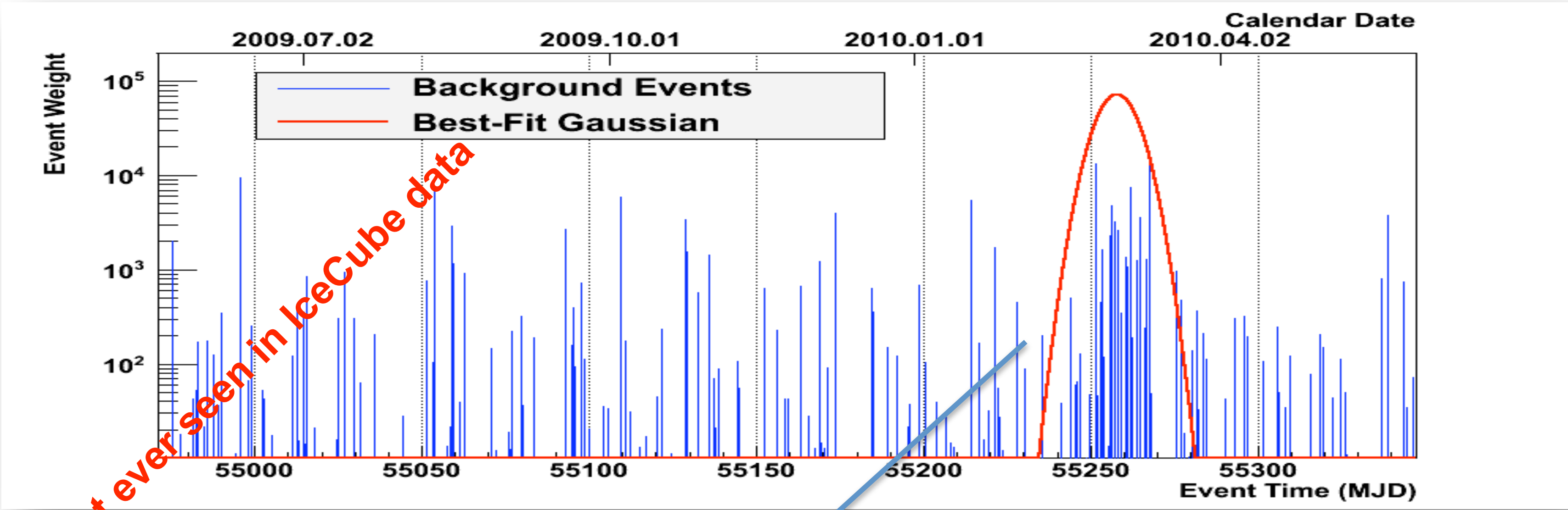


DESY Zeuthen local farm
CPU time in June

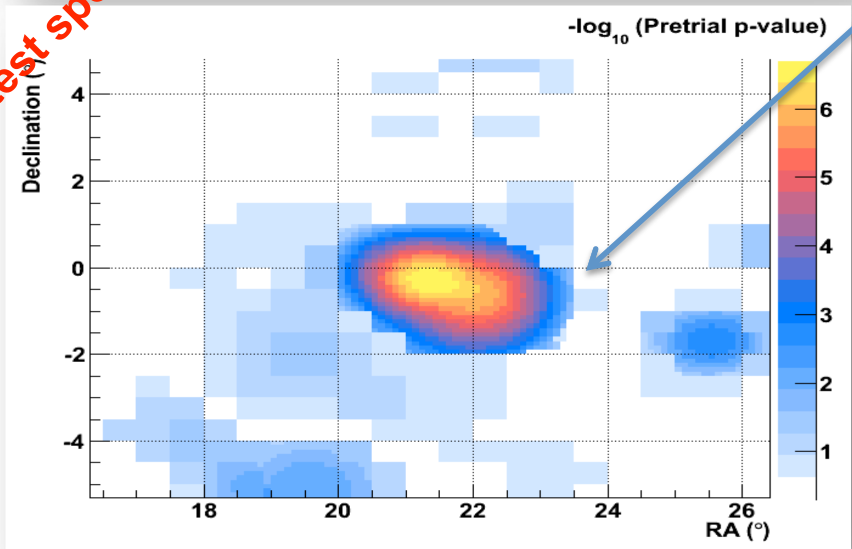


No significant deviation from the background only hypothesis is found.
The maximum significance found, without correcting for the trials for ***3C 454.3 p-value=0.08 (1.4 sigma)****. The corresponding best time cluster was 28.67 days.*
(IceCube ICRC-2011 contribution)

Results: untriggered all-sky flare search (IC59) (Mike Baker et al.)



The hottest spot ever seen in IceCube data



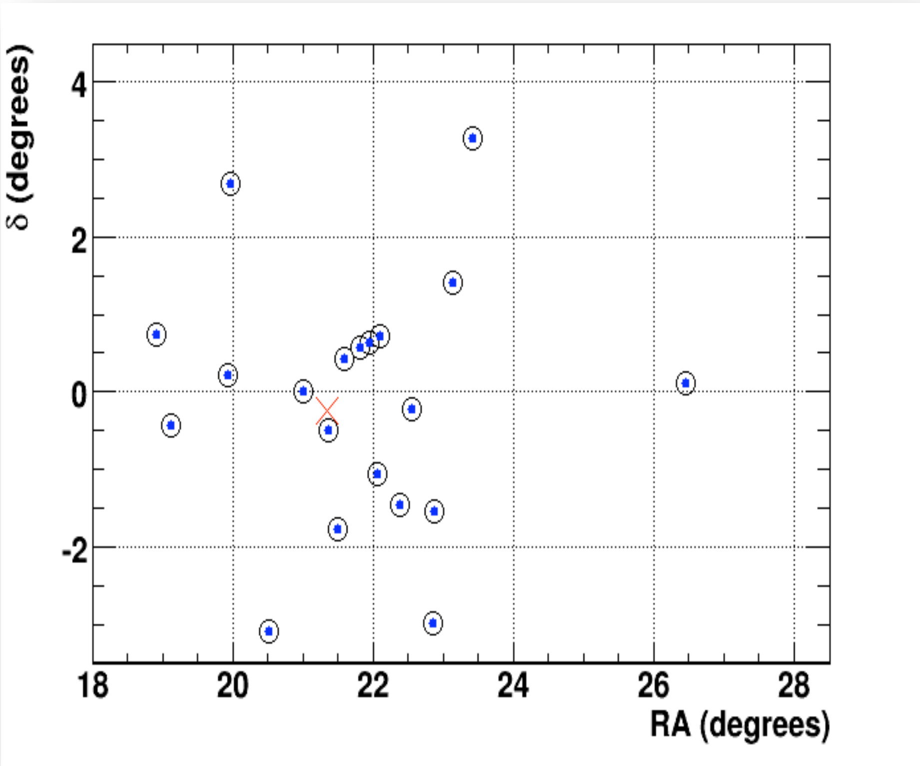
The strongest flare was found to be from location:

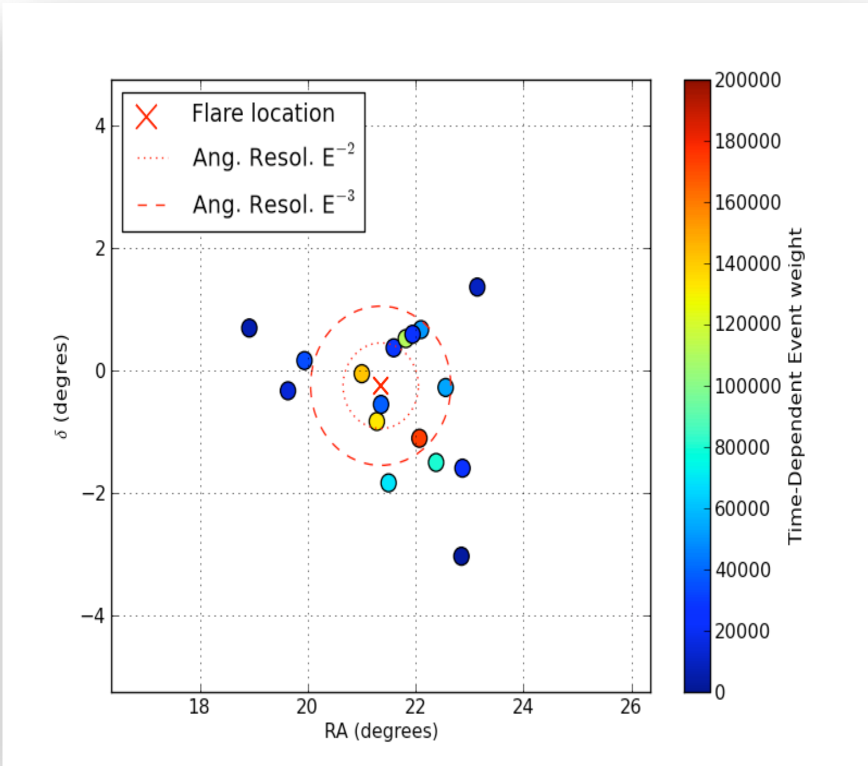
ra=21.35 deg, dec=-0.25 deg

Gaussian flare with:
Mean: MJD =55259
Sigma: 5.5. days (FWHM=13 days)

n_sig=14.5, gamma_s=3.95
-log10(pre trial p-value)=6.6 (4.7 sigma)
-postrial p-value=1.2 %

Application of the multiple flare method for direction of the hottest-spot





$$\hat{n}_s = 13.8, \hat{\gamma}_s = 3.95, \Delta t_{flare} = 23.5 days$$

Almost all significant events (19-1) found by M. Baker et al. are also seen by the multi-flare method. In order to increase the performance of the method for single flare search ***consecutive quadruplets*** *are used.*
This configuration has ***p-value=0.00034*** *(one-sided sigma: 3.4).*

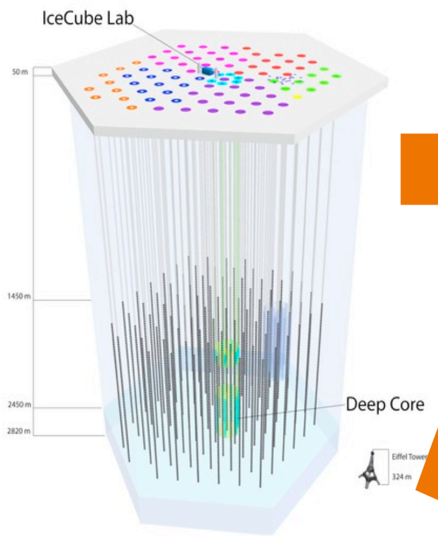
IceCube-Magic Neutrino Triggered Target of Oportunity (NToO)

Schematics

Small FOV and duty cycle for existing IACTs. Need neutrino trigger to increase availability of simulataneous neutrino/TeV photon data

- Send alerts for neutrino multiplets with a pre-defined significance threshold to MAGIC for a selection of sources

Neutrino Telescope



Data

Online neutrino event selection & Flare search at the South Pole

Alert

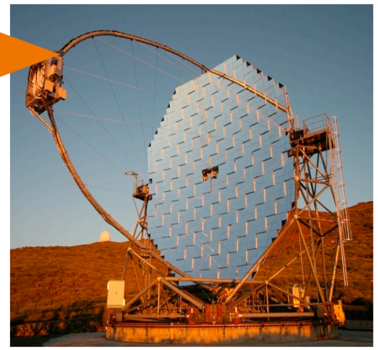
Data

Uptime

Online stability monitoring

Imaging Atmospheric Cherenkov Technique

Cherenkov Telescope



Possible inclusion of other experiments!

High-Energy Gamma-Ray Follow-Up Program

Online processing
at the South Pole (IC79)

Trigger: ~2000 Hz

↓

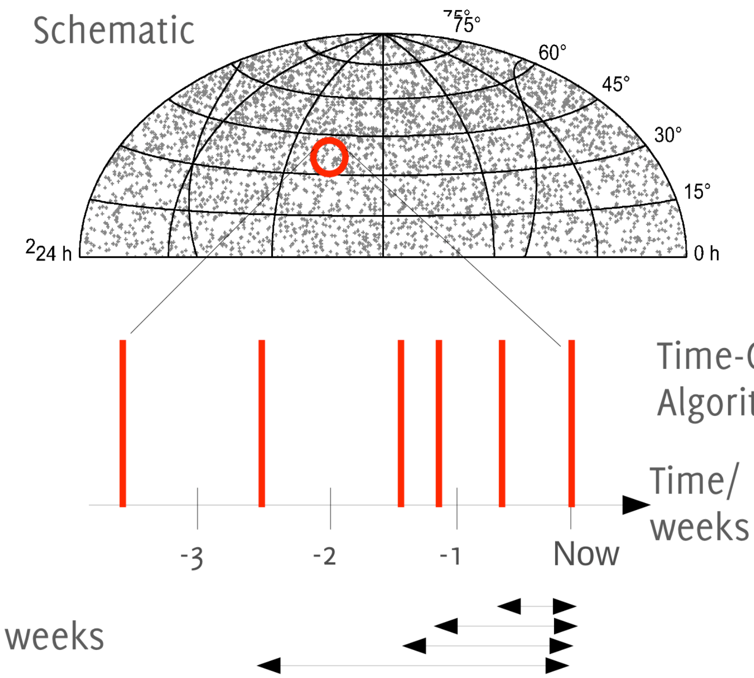
Level 1 Filter: ~35 Hz
Single iterations SPE Fit

↓

Level 2 Filter: ~4 Hz
Multi-iteration SPE fit,
MPE fit, CramerRao

↓

Neutrino selection:
~1.1 mHz



Time-Clustering Algorithm

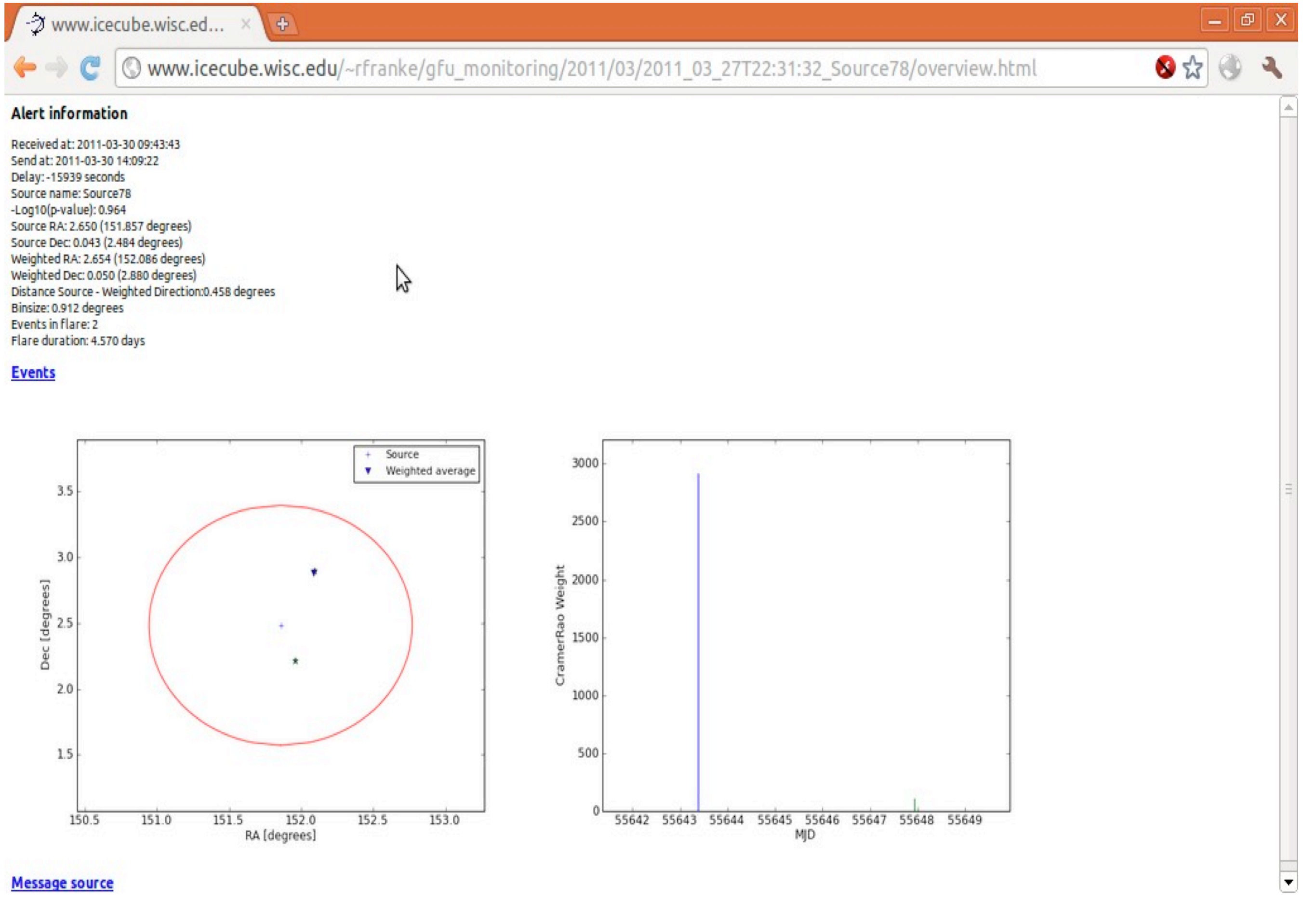
Time-scale for cluster search:
seconds to ~3 weeks

Detector stability monitoring + Significance of current neutrino cluster → Alert

Right now: Send alerts for 0.5 sigma clusters

Monitoring Web Page

To monitor/test the stability of the event selection and significance calculation, alerts (aprox. 4/ day) are generated for each source based on a bigger on-source bin with much weaker event selection cuts and a lower alert threshold. 2000 monitoring sources are added to the list.

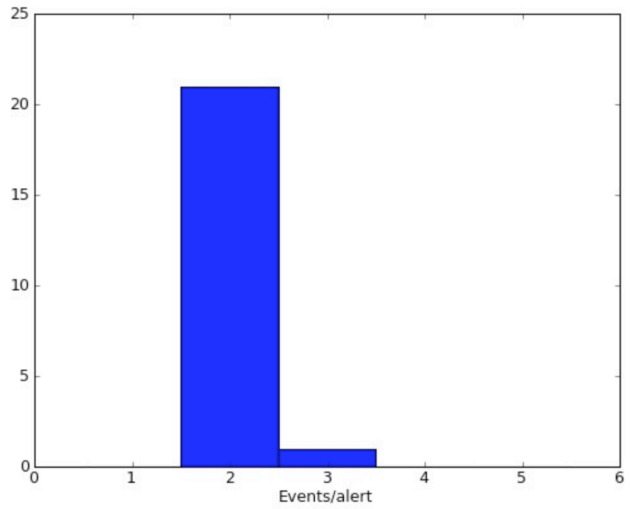


- Individual alert information
- Statistical info on all alerts
- Access to info from stability monitoring
- Alerts from physics sources blinded

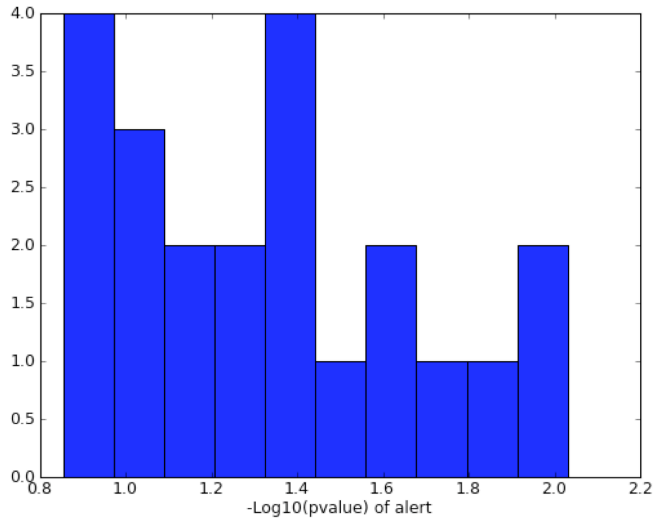
Work in progress at: http://www.icecube.wisc.edu/~rfranke/gfu_monitoring/

Monitoring Web Page

Global information about all alerts



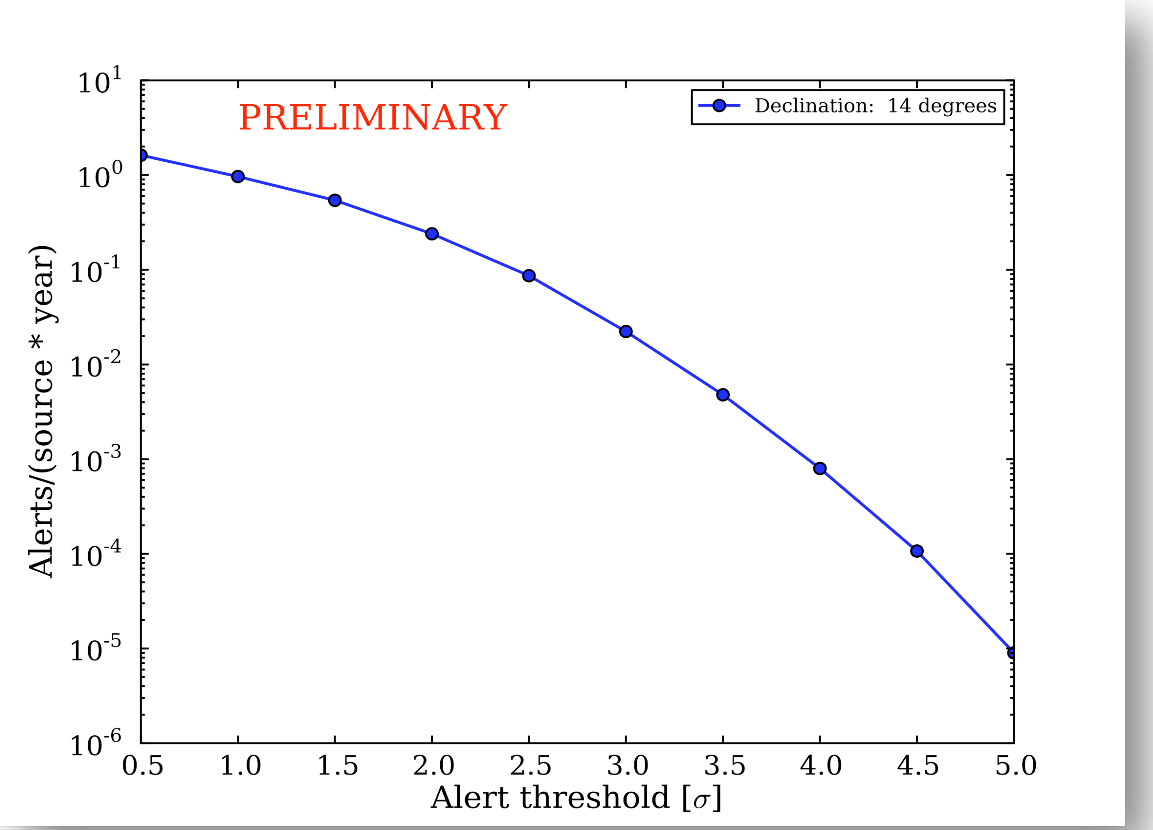
Number of events in alert



Distribution of alert p-values

Add more of these plots (e.g. length of the alerts, angular distance distribution to the source)

Expected number of accidental background alerts



Expected number of accidental background alerts per year for a source at a declination of 14 ◦ as a function of the alert threshold expressed in units of standard deviations corresponding to a one-sided p-value.

NToO Status Overview

- Permission to send (low-significance) alerts to MAGIC granted by analysis call
- Running online since March 2011, not yet forwarding alerts
- Web page to monitor alert system finished, displayed information blind
- Interface to MAGIC in preparation!
- Online detector stability monitoring usable as a service for the collaboration

Summary and Conclusion

1) Several point source analysis have been done during the last year using resources of DESY Zeuthen Computer Center.
   Results of these simulations published as the IceCube collaboration papers.

2) NToO ready to start sending alerts to Magic !!!