The Abdus Salam
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United Nations
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IAEA
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2246-4

Workshop on Cosmic Rays and Cosmic Neutrinos: Looking at the Neutrino Sky

20 - 24 June 2011

IceCube studies on point sources and some studies on CR composition

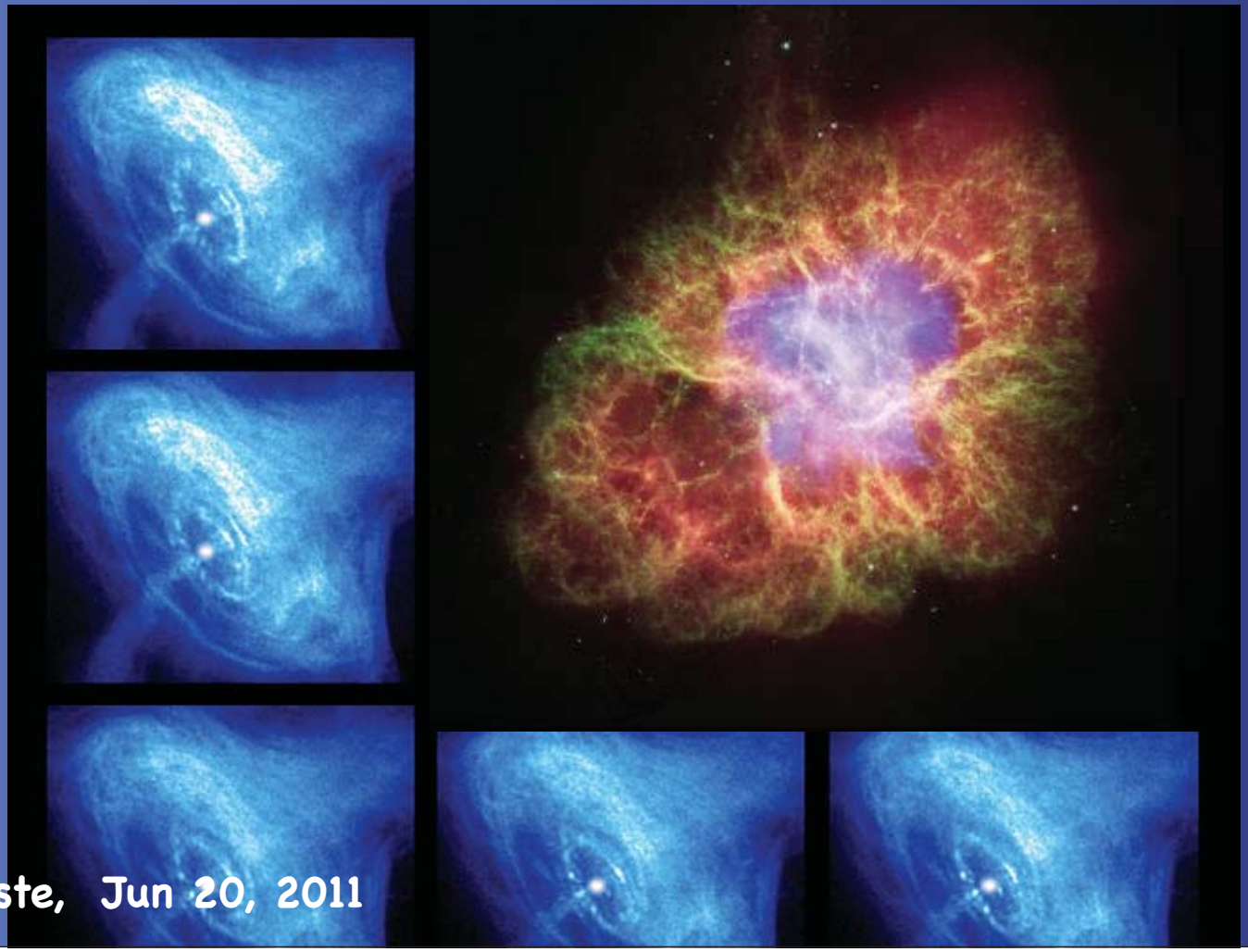
Teresa MONTARULI
University of Wisconsin
USA

Strada Costiera 11, 34151 Trieste, Italy - Tel.+39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it

IceCube Point source results and CR composition sensitivity

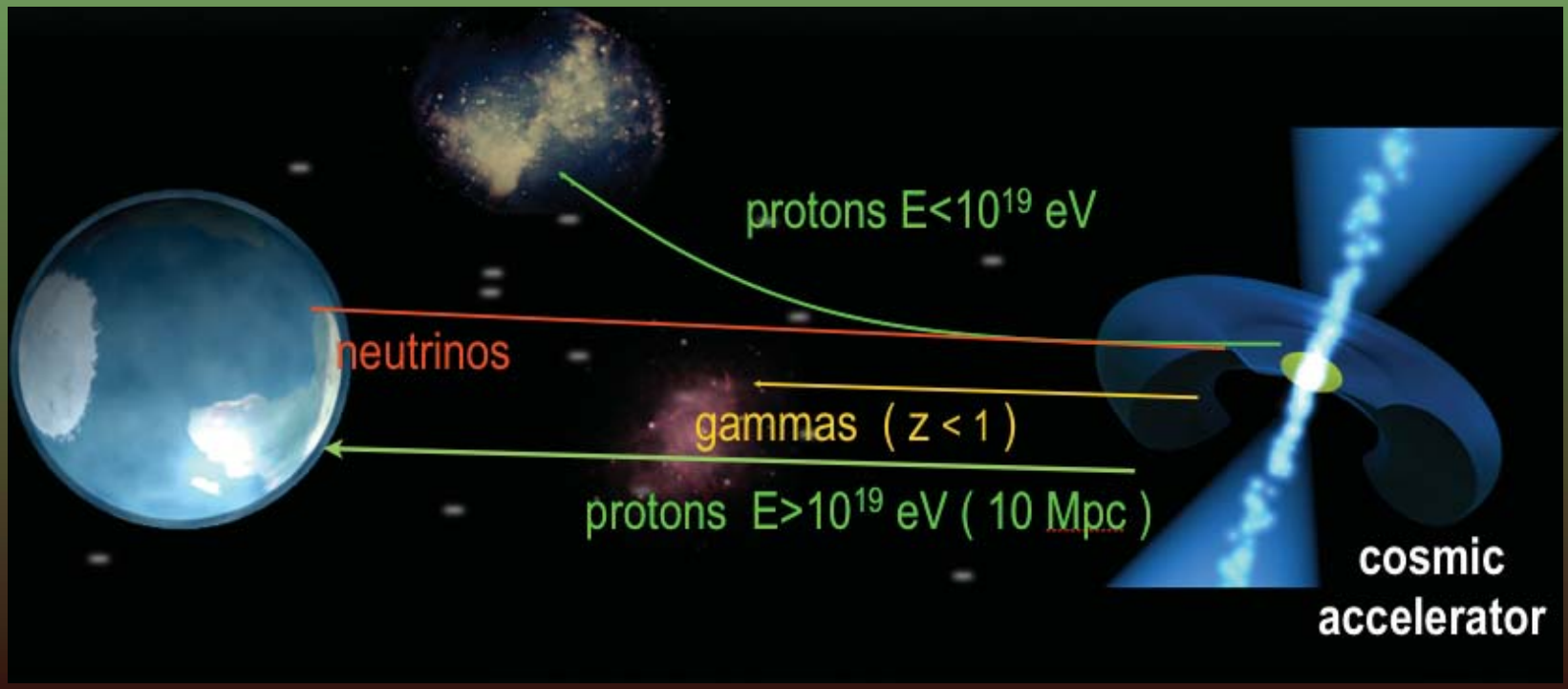
teresa.montaruli@icecube.wisc.edu
University of Wisconsin - Madison

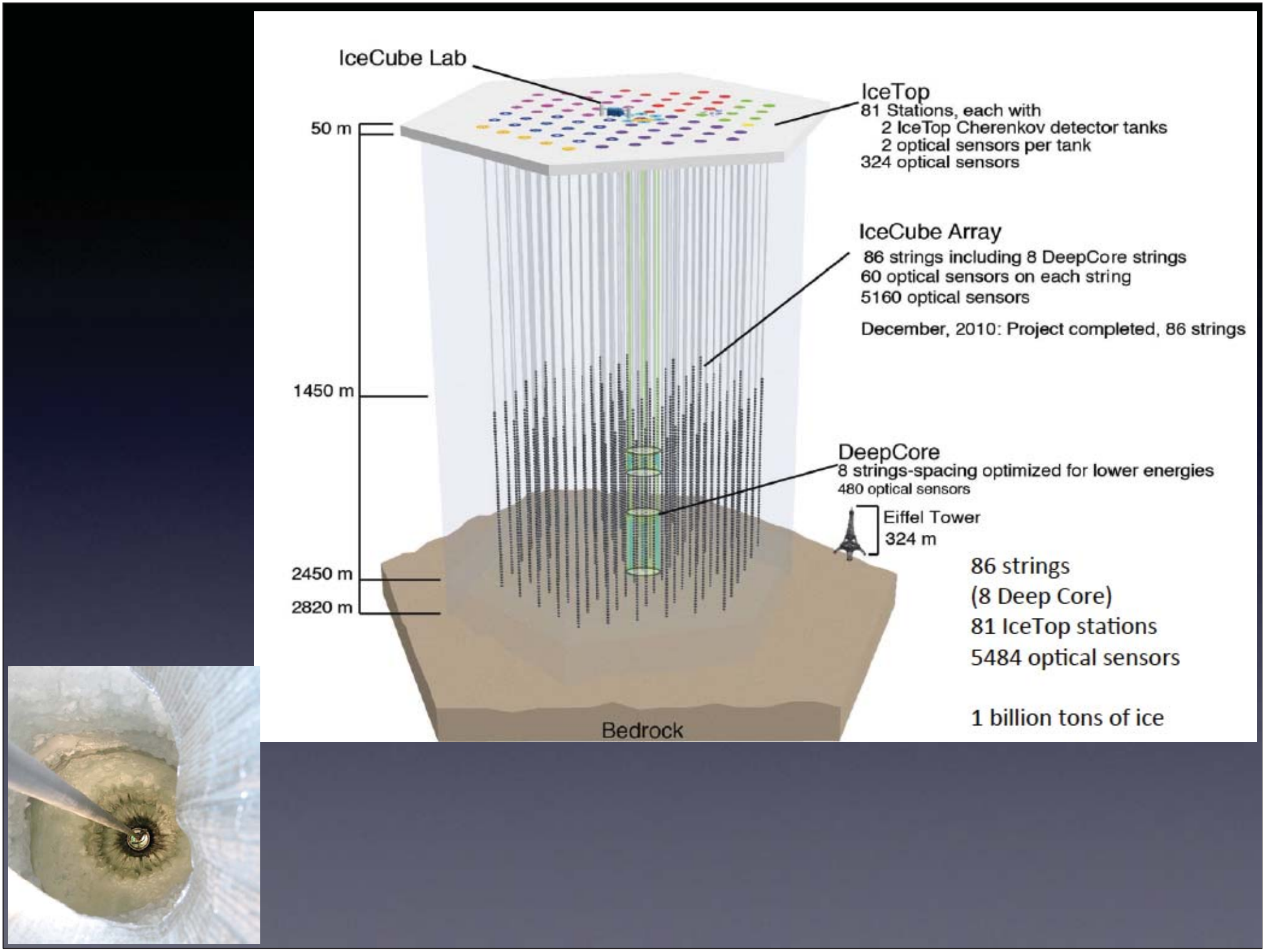
Point-Source results are presented for the IceCube Collaboration



CONTENTS

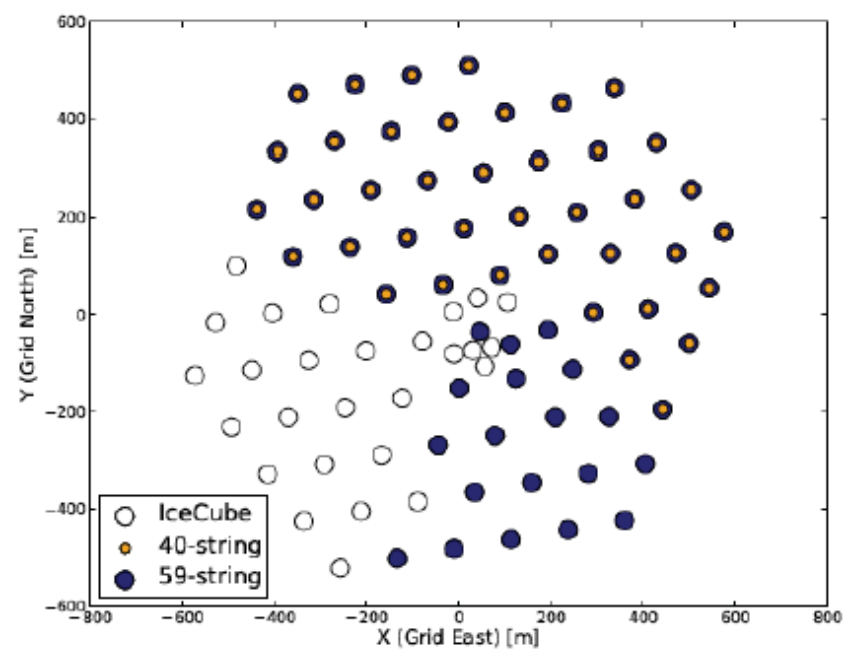
- **IceCube Pointing capabilities with muon neutrinos**
- **Likelihood analysis for steady and time dependent signals**
- **Stacking analysis**
- **Current results on extragalactic and galactic sources (no GRBs)**
- **Are IceCube muons sensitive to the knee?**




IceCube Lab
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors
50 m
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors
December, 2010: Project completed, 86 strings
1450 m
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m
2450 m
2820 m
86 strings
(8 Deep Core)
81 IceTop stations
5484 optical sensors
1 billion tons of ice
Bedrock

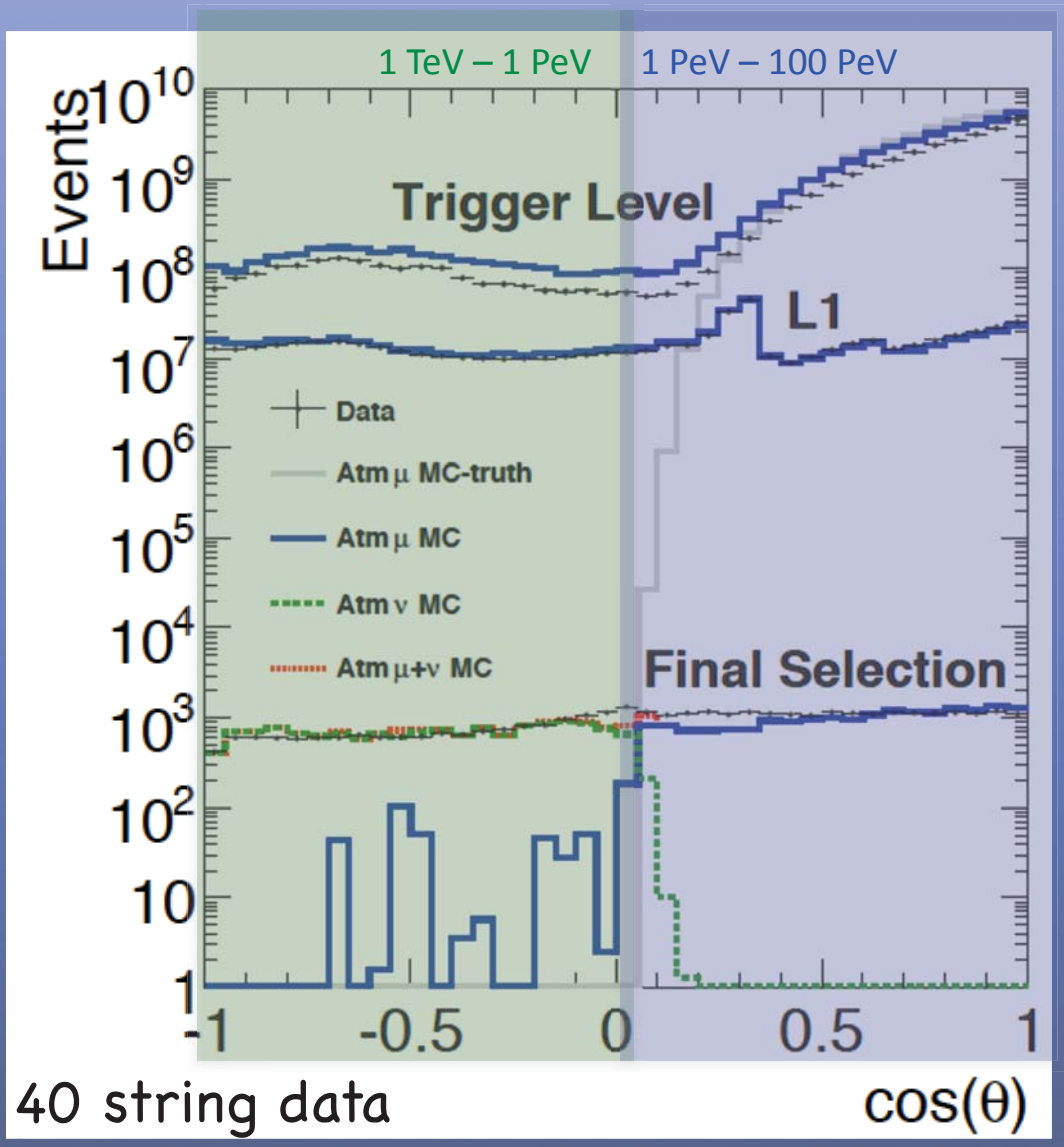
Seasons

configuration (years)	livetime (d)	trigger rate (kHz)	neutrino rate (d^{-1})
AMANDA 19 strings (2000-2006)	1387	0.1	5
9 strings (2006)	137	0.08	1.7
22 strings (2007)	275	0.6	28
40 strings (2008)	375.5	1.1	37.6
59 strings (2009)	348	1.9	124.5
79 strings (2010)	~ 365	2.3	170*
86 strings (2011)	about 1 month	2.7	190*



Data selection

Upgoing region efficiency:
(eff trigger * eff L3 * eff PS-final) = 0.79*0.76*0.27 = 16%
in 59 strings (eff PS-final = x 2 than 40 strings)

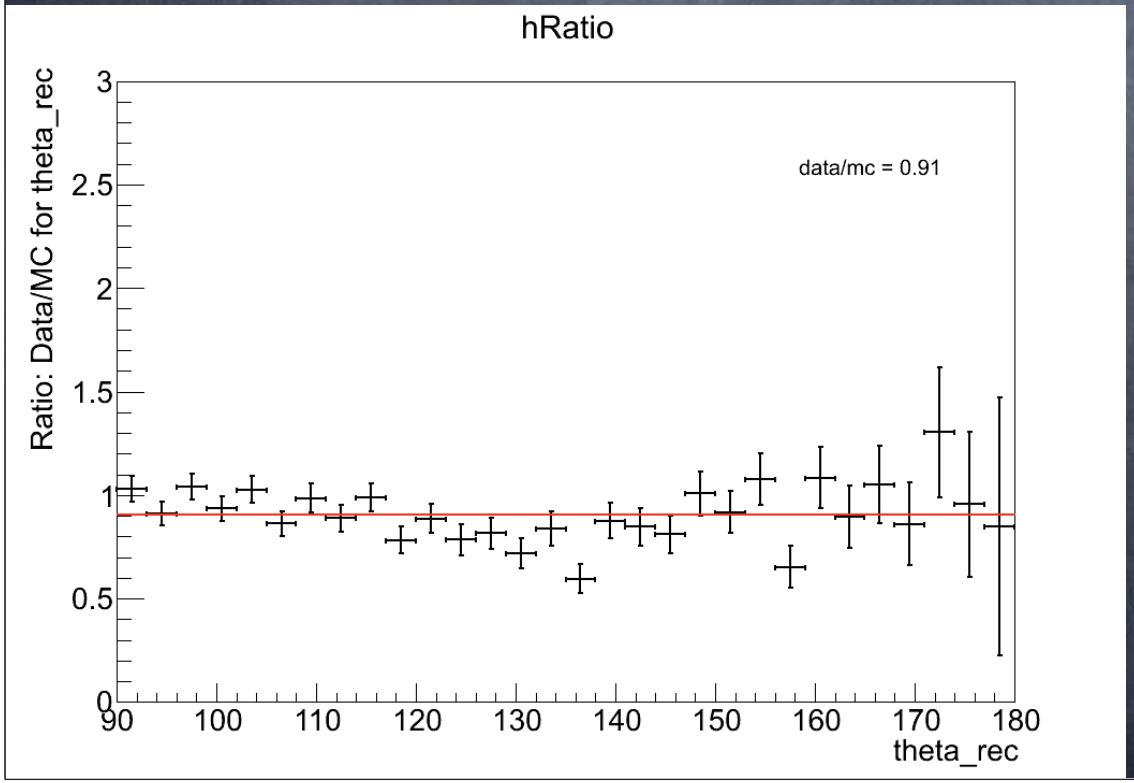


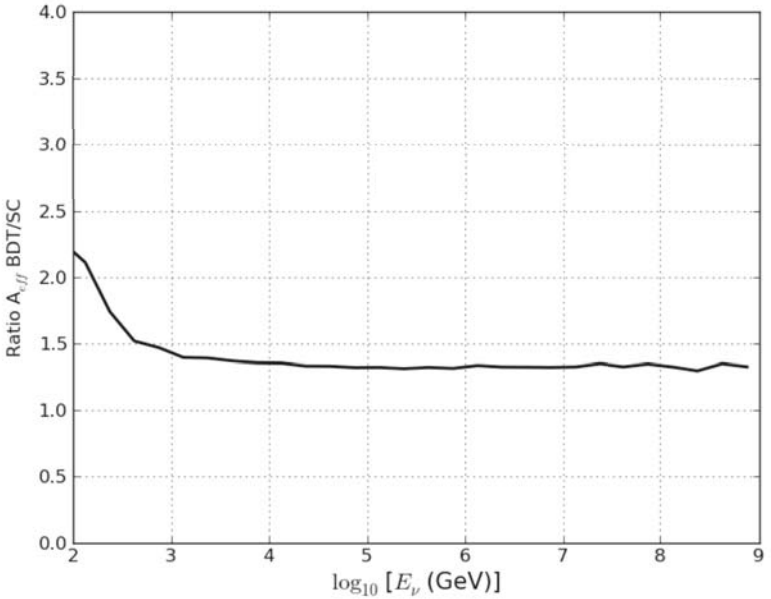
Final sample from straight cuts on variables on track quality, direct light hits, zenith of `split' events, angular resolution estimate, muon energy proxy

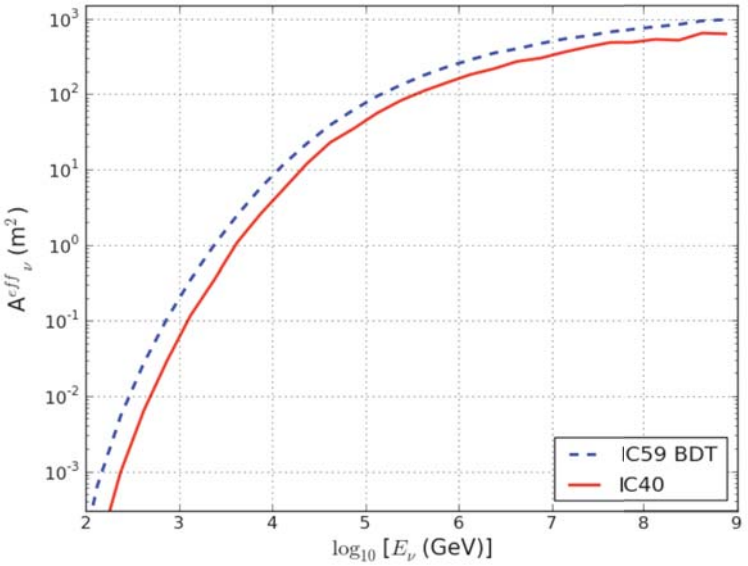
Upgoing region: final selection

- For 59 strings we improved the selection using 2 BDTs with variables with small correlation
- This enhances the efficiency by 40% and up to a factor of more than 2 at 100 GeV

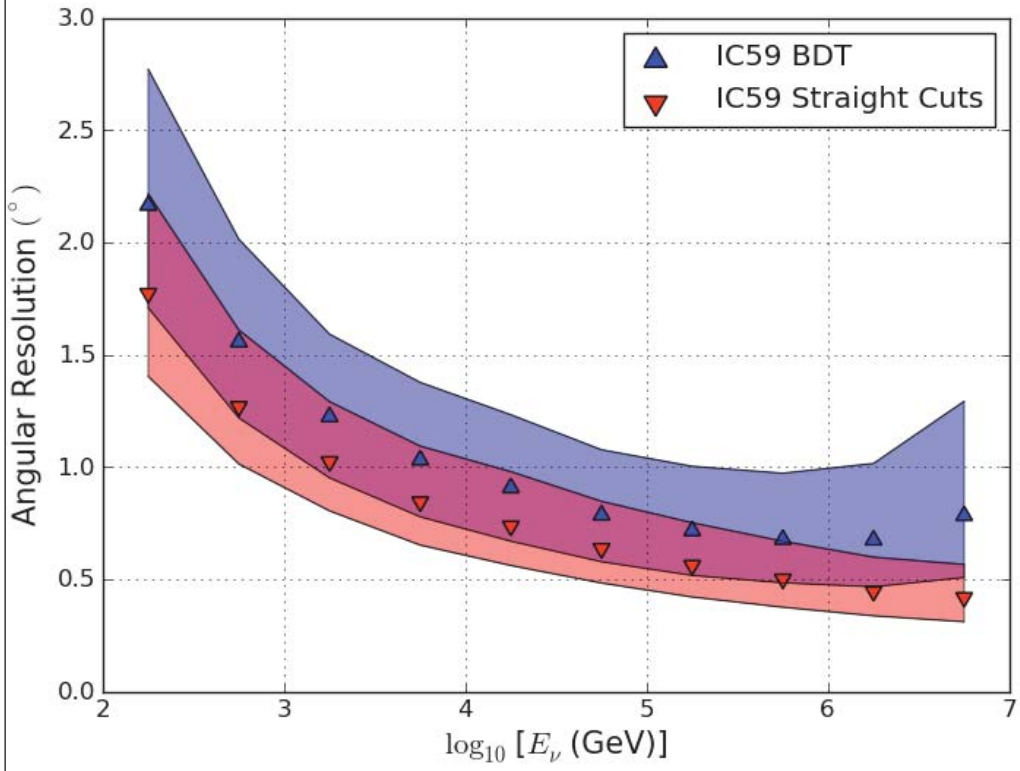
data/MC vs zenith (upgoing)

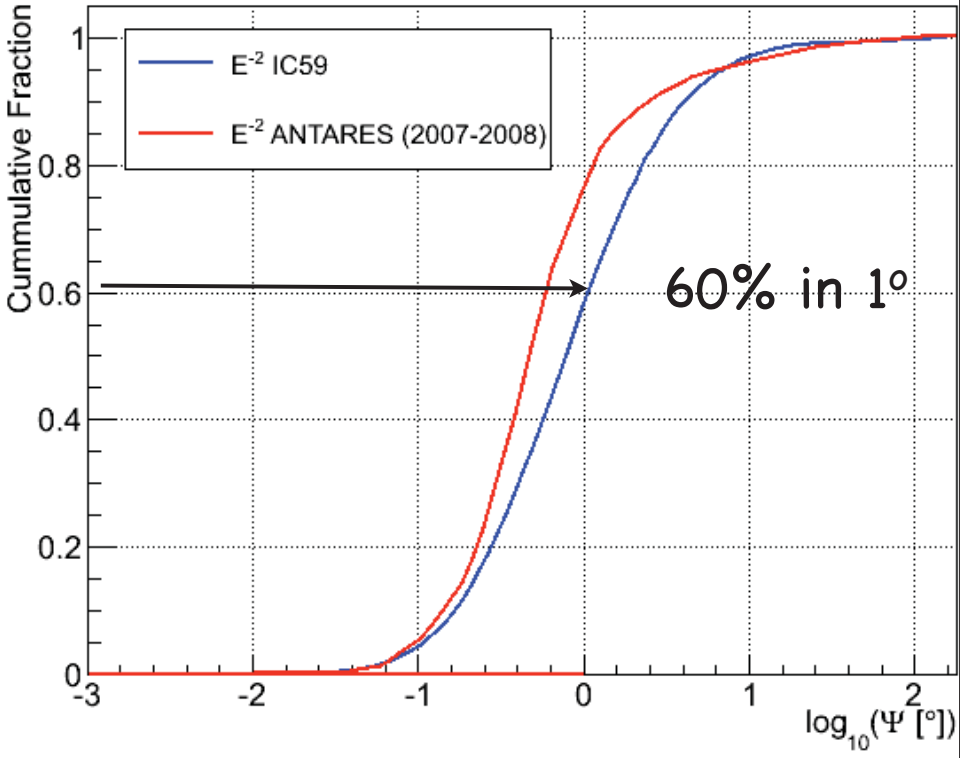




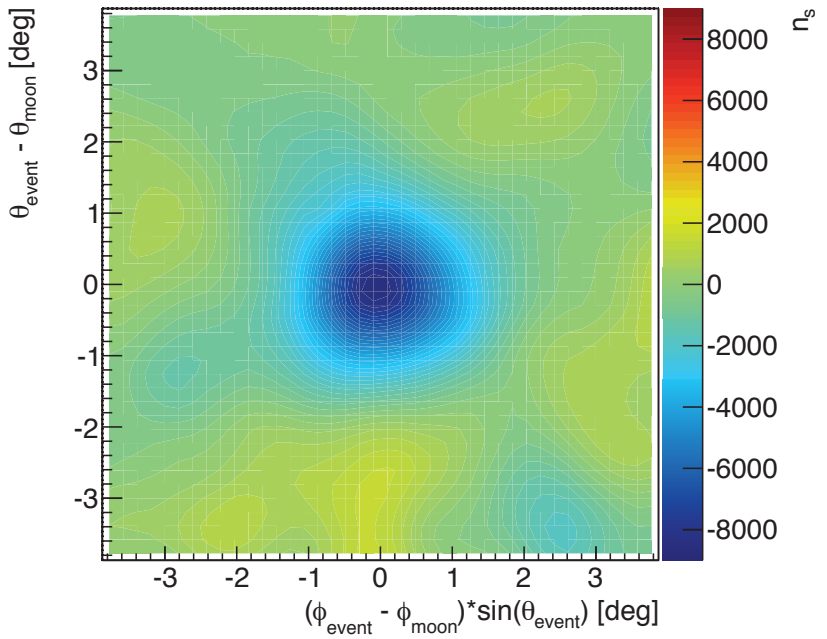


PSF in ANTARES and IceCube



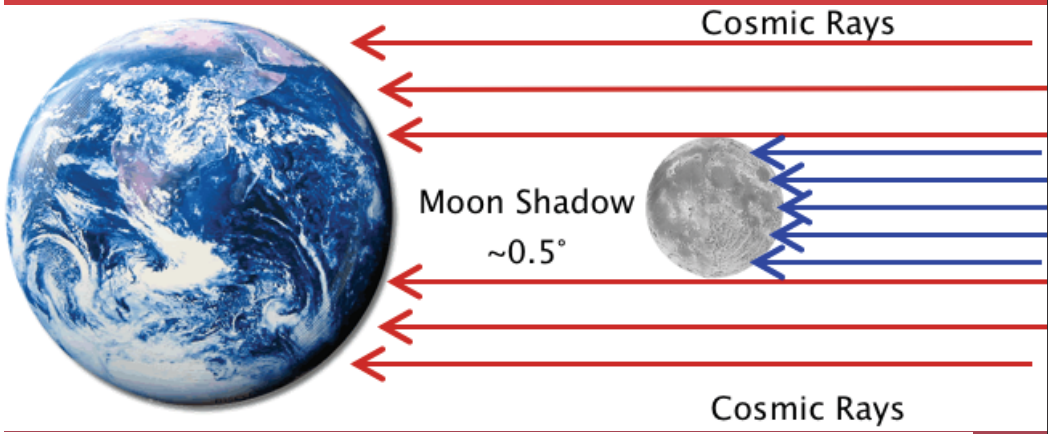


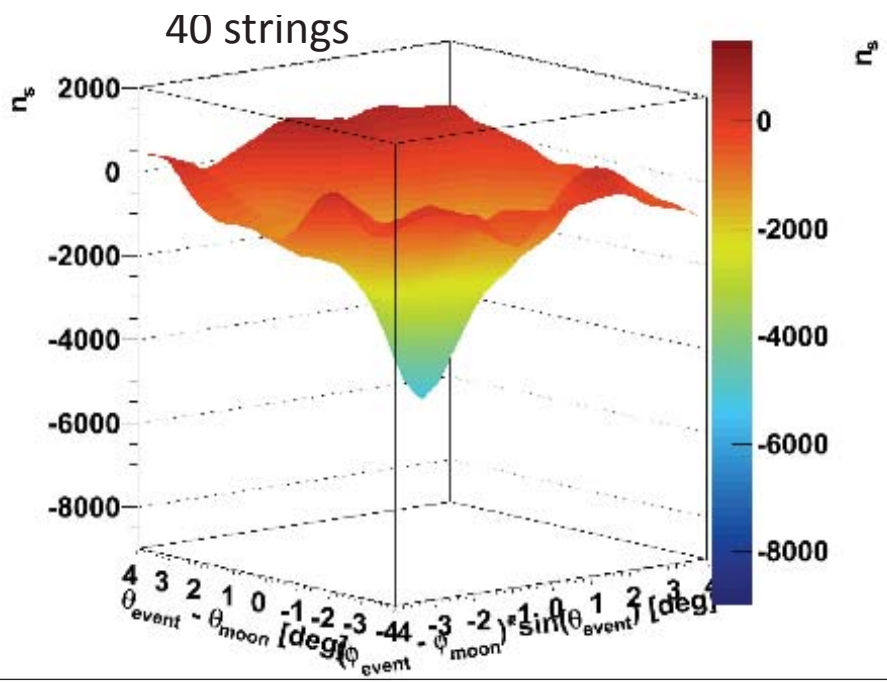
Sub-degree Pointing proved on the Moon

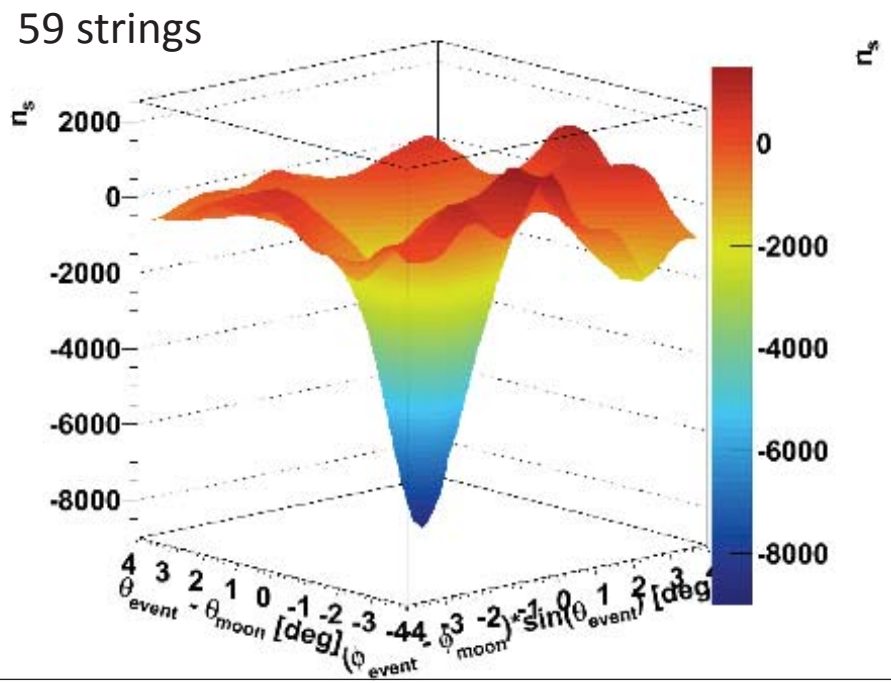


Moon shadow LH analysis (to be presented at ICRC2011): 2 analyses with fine binning and unbinned and consistent results

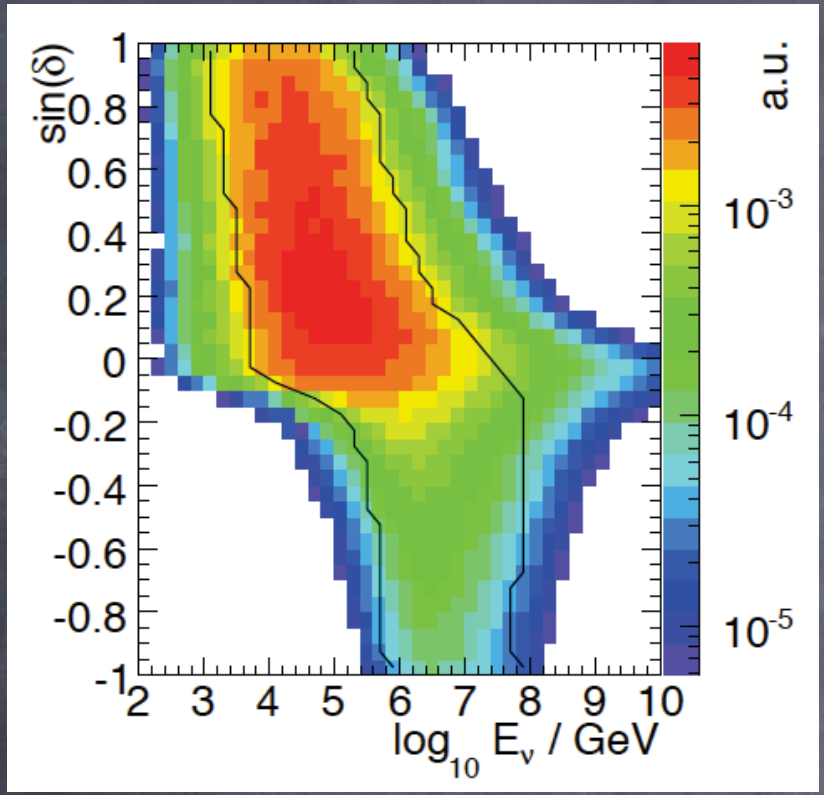
More than 12σ underfluctuation in 59-strings







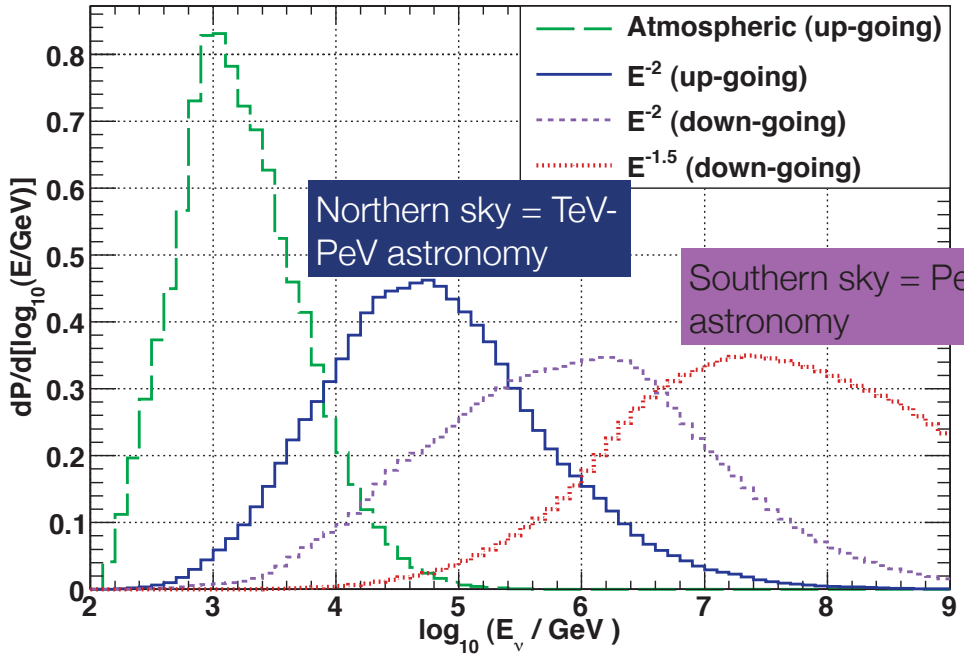
Addition of the downgoing region



black lines: E^{-2} contour from 5% to 95%

Energy proxy cut vs cos(zenith) to keep event rate constant.

Done to select the high energy tail of atmospheric muons and limit number of events to be used in the LH method



IceCube, Astrophys.J.732:18,2011

LH analysis and PDFs

$$L(\mathbf{x}_s, \gamma, n_s) = \prod P_i(|\mathbf{x}_i - \mathbf{x}_s|, E_i, \gamma, n_s)$$

likelihood function

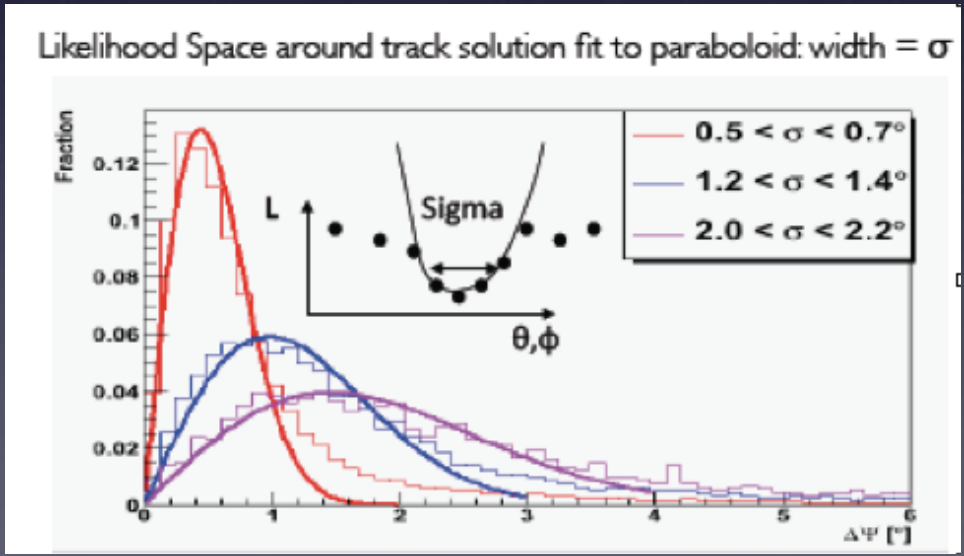
individual event probability: weight of events

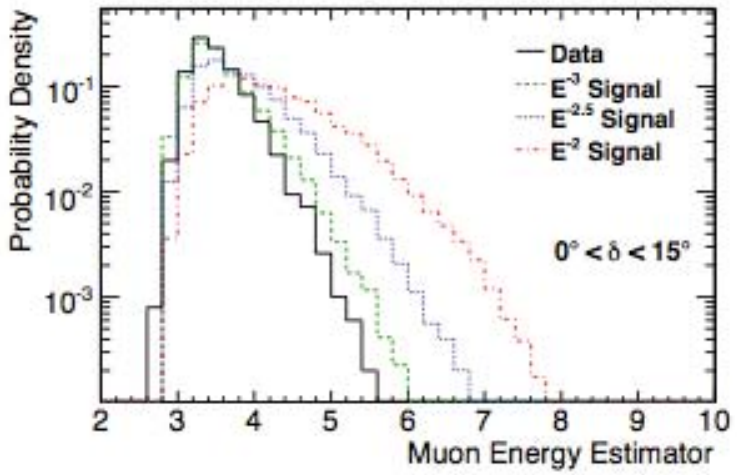
$$P_i(|\mathbf{x}_i - \mathbf{x}_s|, E_i, \gamma, n_s) = \frac{n_s}{n_{\text{tot}}} S_i(|\mathbf{x}_i - \mathbf{x}_s|, E_i, \gamma) + \left(1 - \frac{n_s}{n_{\text{tot}}}\right) B(\mathbf{x}_i, E_i)$$

background PDF from scrambled data in right ascension

$$B(\mathbf{x}_i, E_i) = P_{BkgDec}(\mathbf{x}_i)\, P_{BkgMue}(\delta_i, E_i)$$

$$S_i(|\mathbf{x}_i - \mathbf{x}_s|, E_i, \gamma) = \frac{1}{2\pi\sigma_i^2} \exp\left(-\frac{|\mathbf{x}_i - \mathbf{x}_s|^2}{2\sigma_i^2}\right) P_{SigMue}(E_i|\delta_i, \gamma)$$



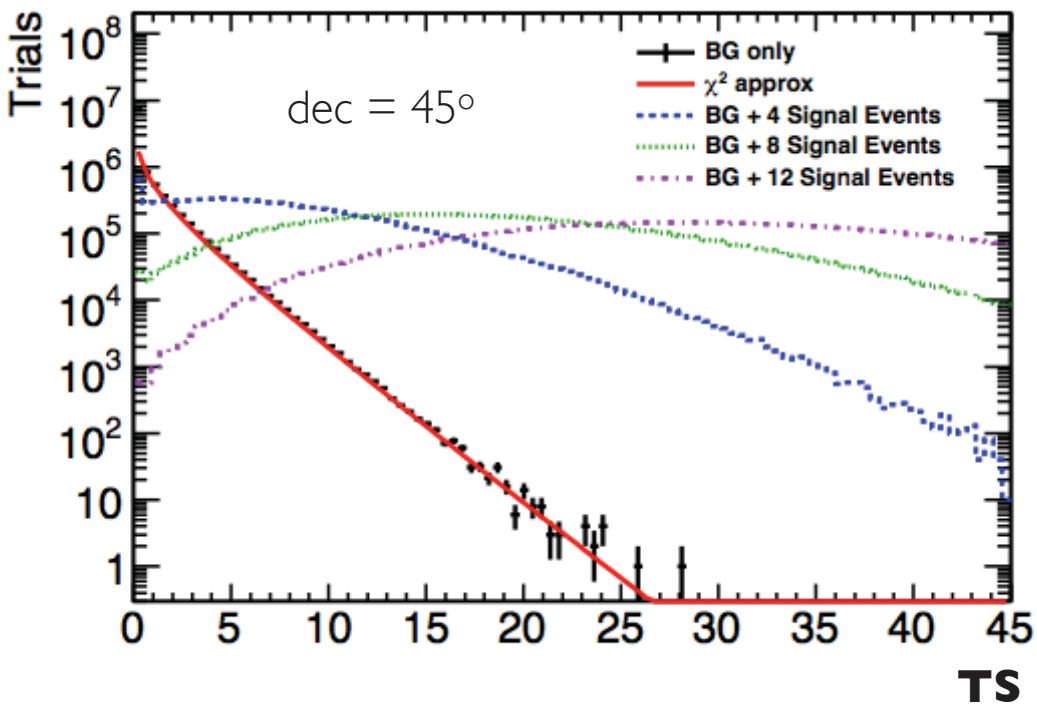


J. Braun et al. Astrop. Phys. 33 (2010) 175.; J. Braun et al. Astropart. Phys. 29 (2008) 299 and arXiv:0801.1604.

TEST STATISTICS DISCOVERY POTENTIAL

Test statistics. Fit parameters that minimize test statistics or maximize the likelihood ratio

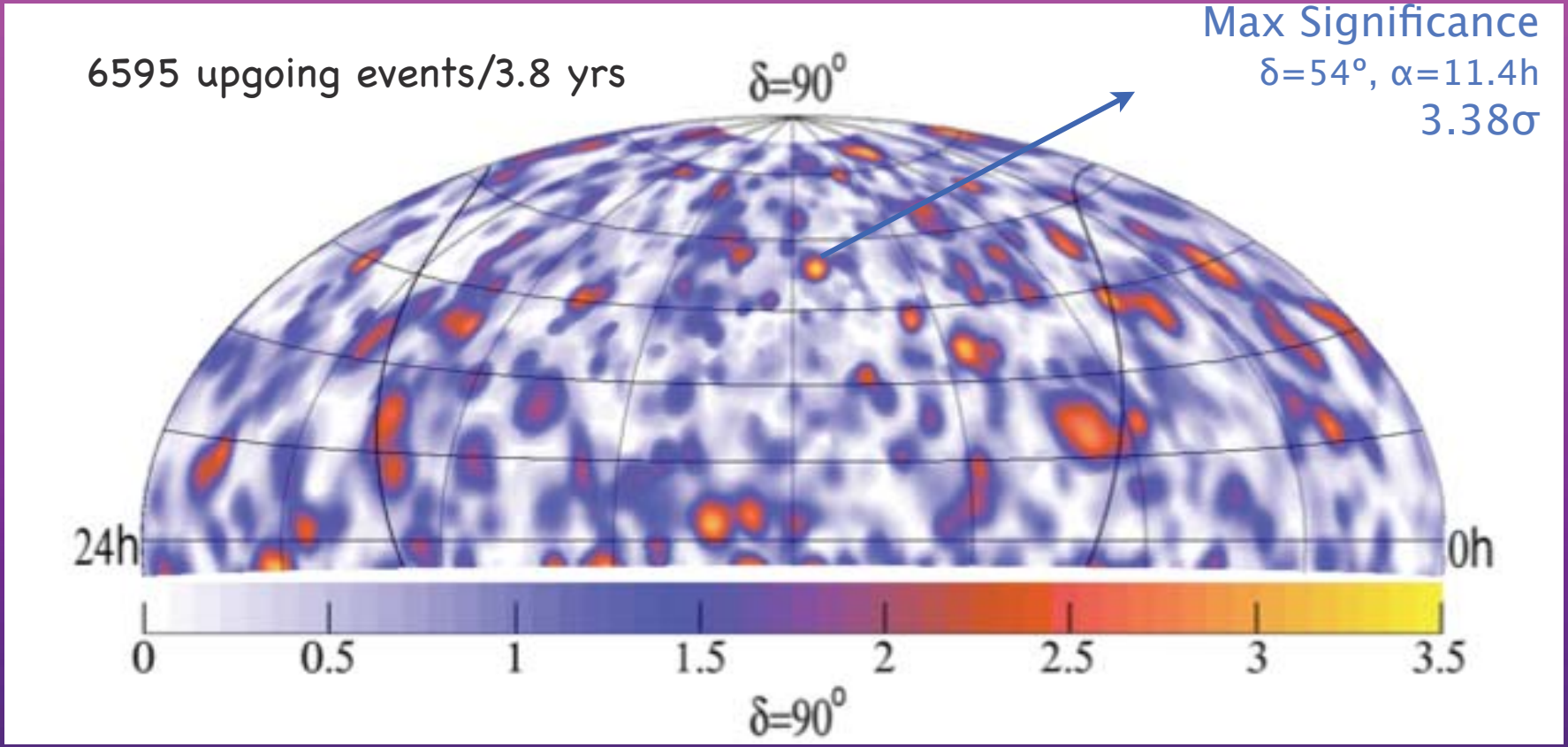
$$TS = -2\log\lambda = -2\log\left[\frac{\mathcal{L}(n_s = 0)}{\mathcal{L}(\hat{n}_s, \hat{\gamma}_s)}\right]$$



Reliable results: Blind analysis, background from data, p-values from scrambling

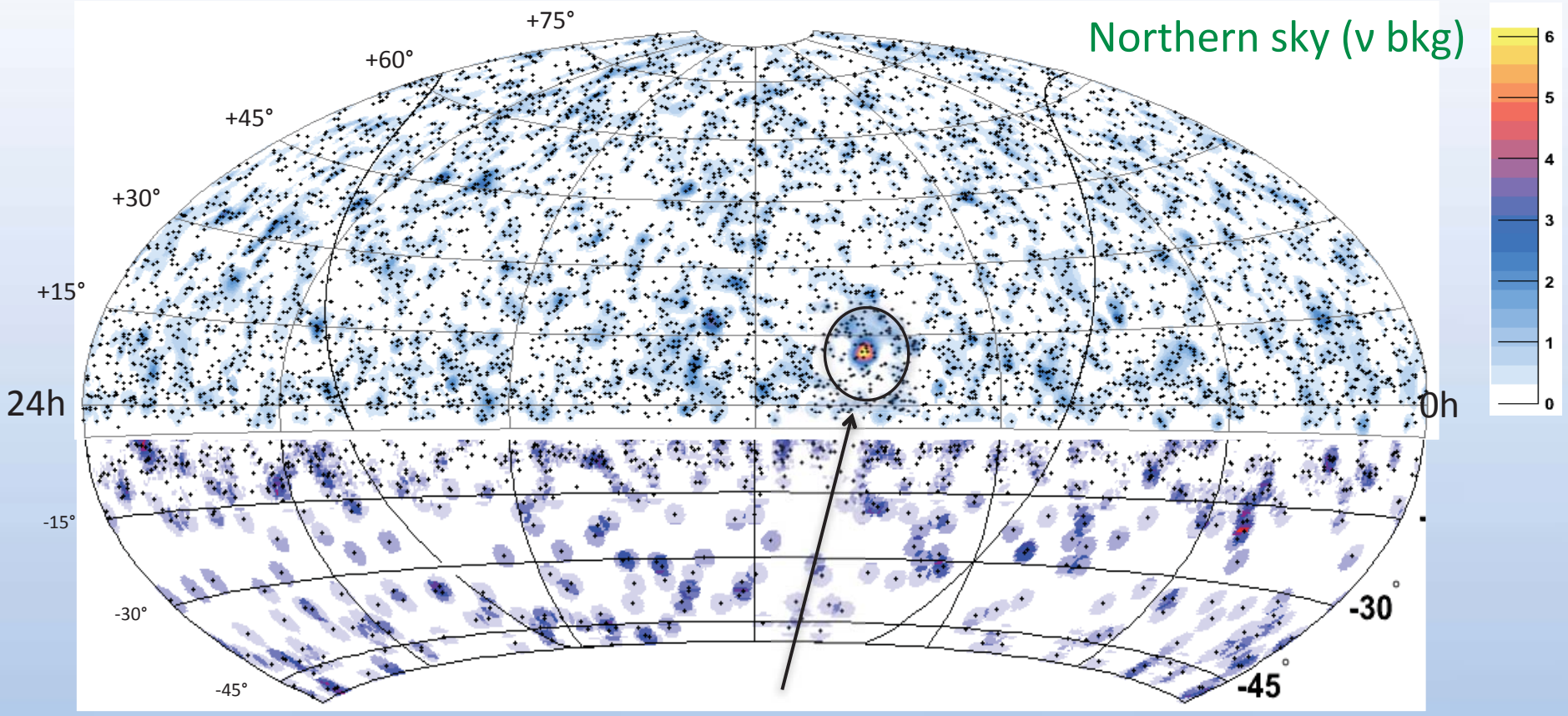
The golden channel: point-sources

From AMANDA...



Observatory data: http://www.icecube.wisc.edu/science/data

22-string all-sky results



Hottest spot found at r.a. 153.4° , dec. 11.4°

First IceCube analysis extended to -50° dec

Post-trials p-value of analysis is ~ 1.34% (2.2 sigma) ...

PRL 103, 221102 (2009)

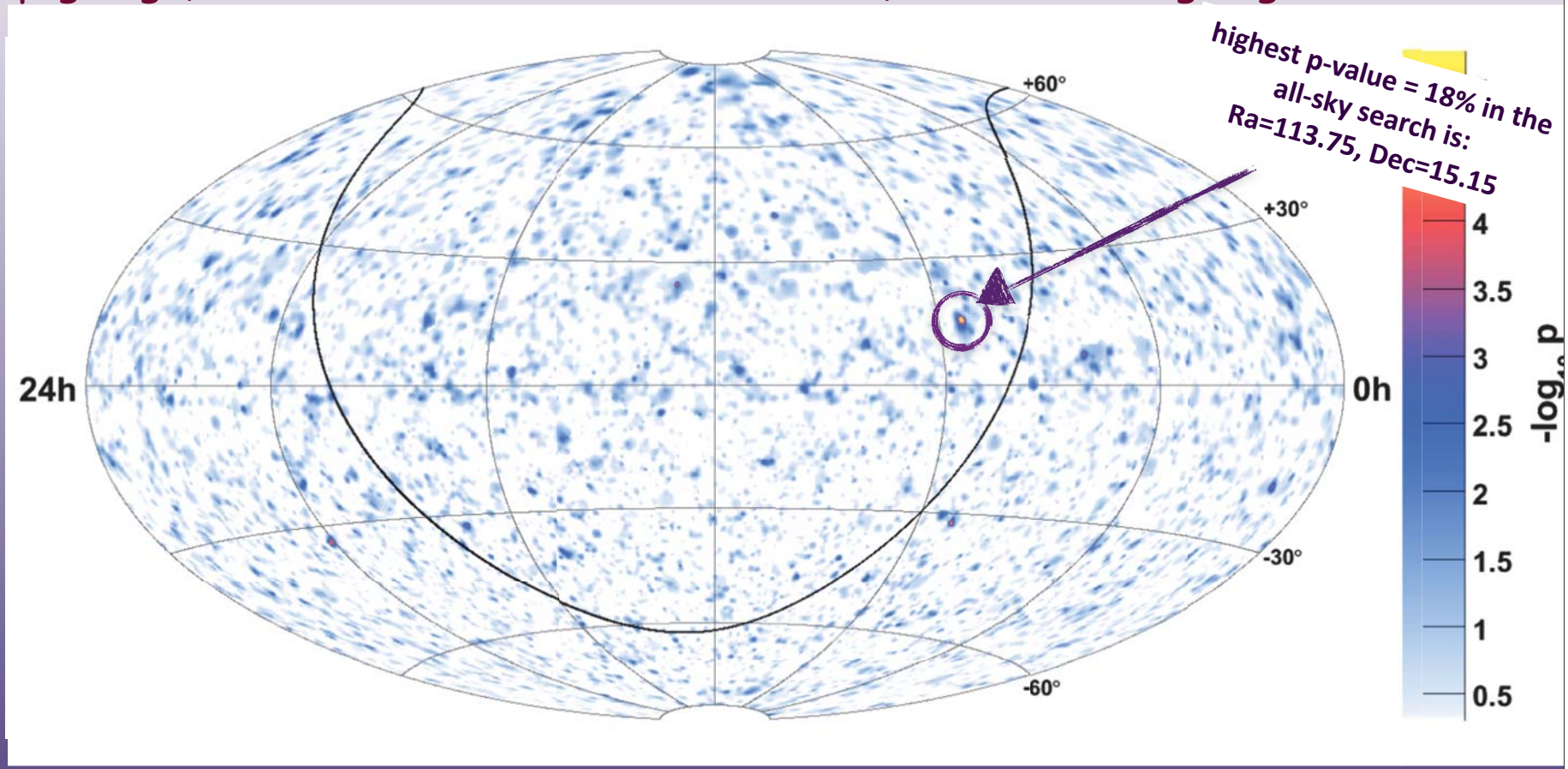
ApJL 70, 47 (2009)

…to 1/2 IceCube Map

14139 up-going (x2 from AMANDA in x3 less time), 23151 down-going in 375.5 d

Atm. neutrinos

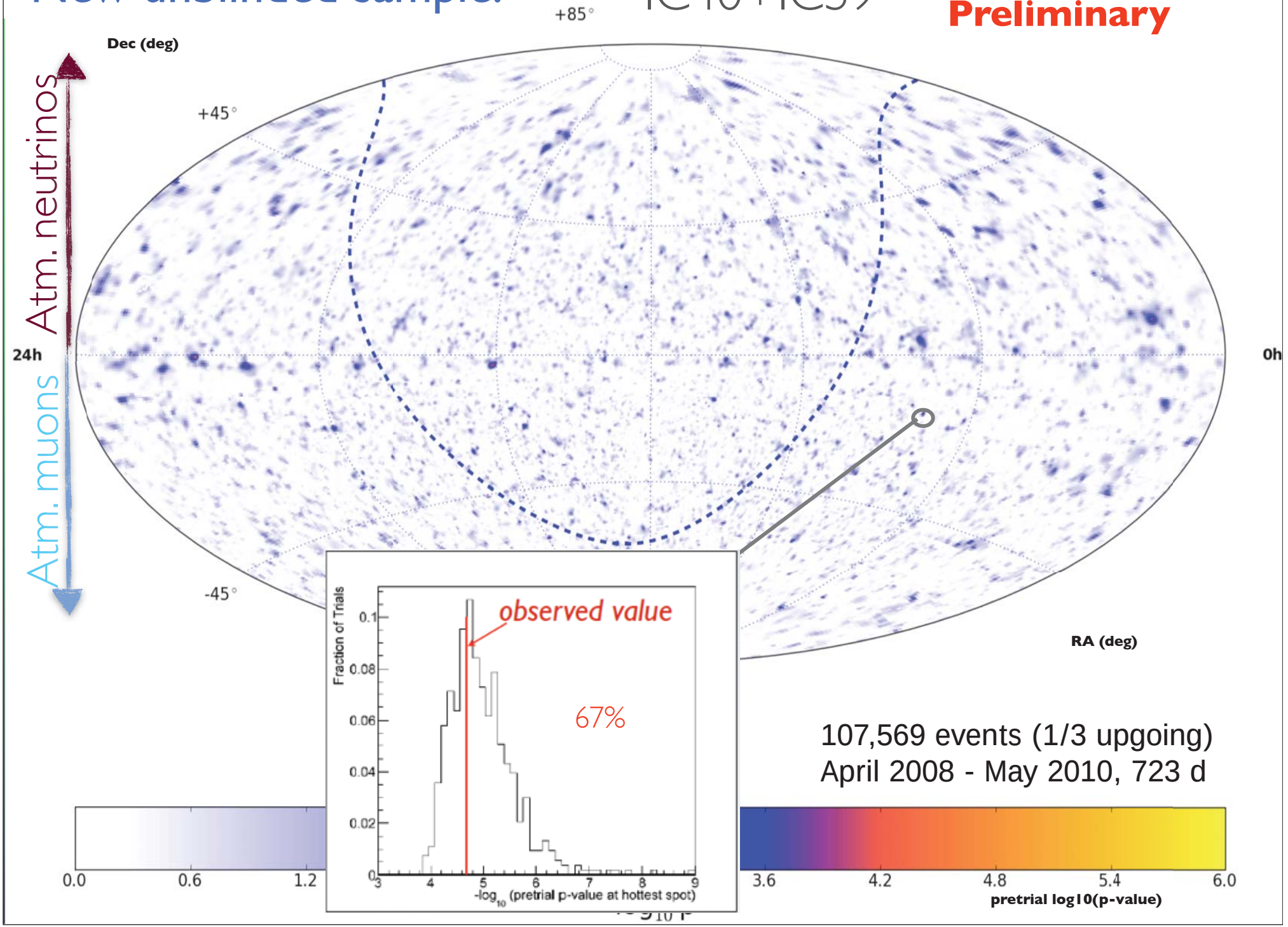
Atm. muons



IceCube, Astrophys.J.732:18,2011

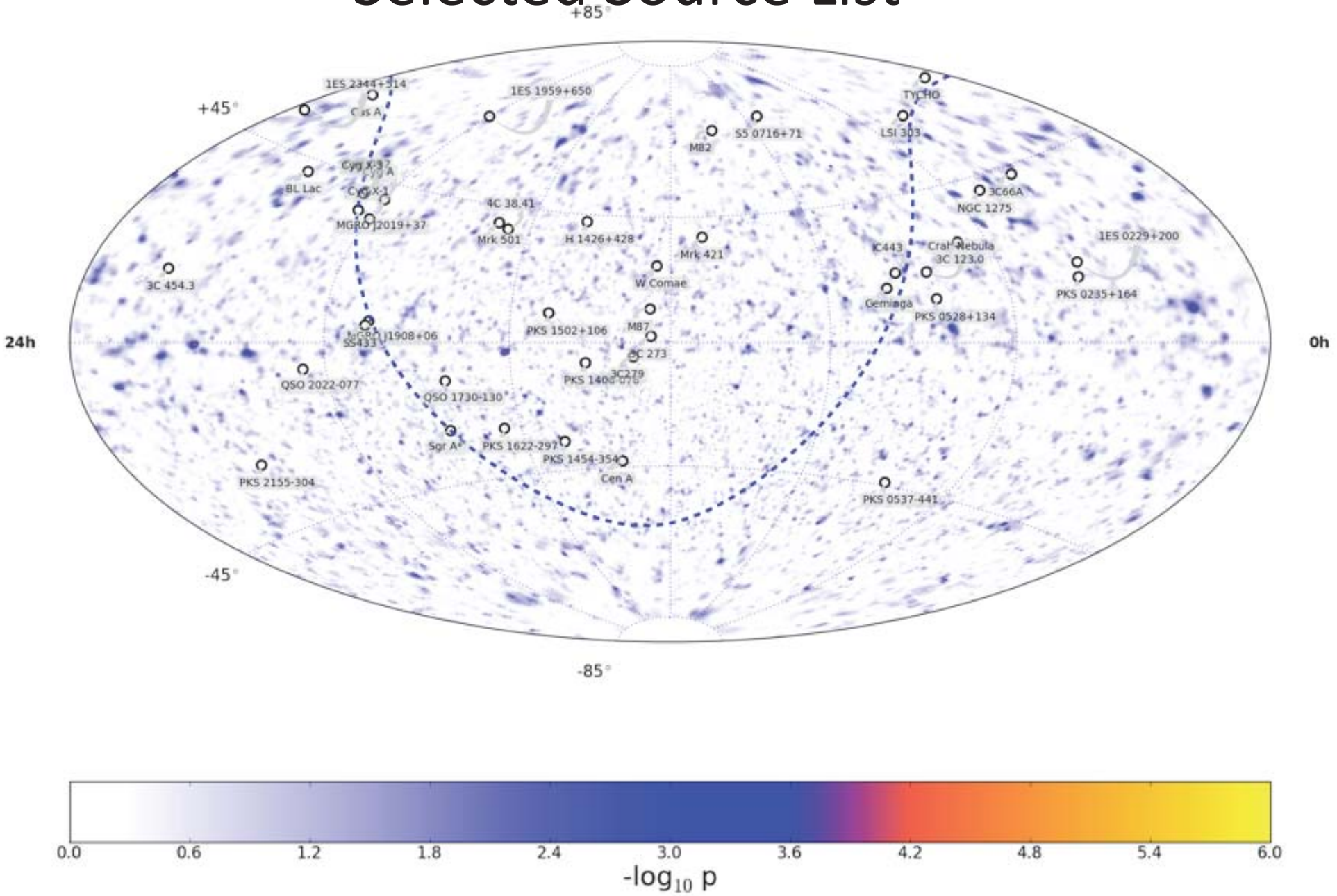
New unblinded sample: IC40+IC59

Preliminary



107,569 events (1/3 upgoing)
April 2008 - May 2010, 723 d

Selected Source List

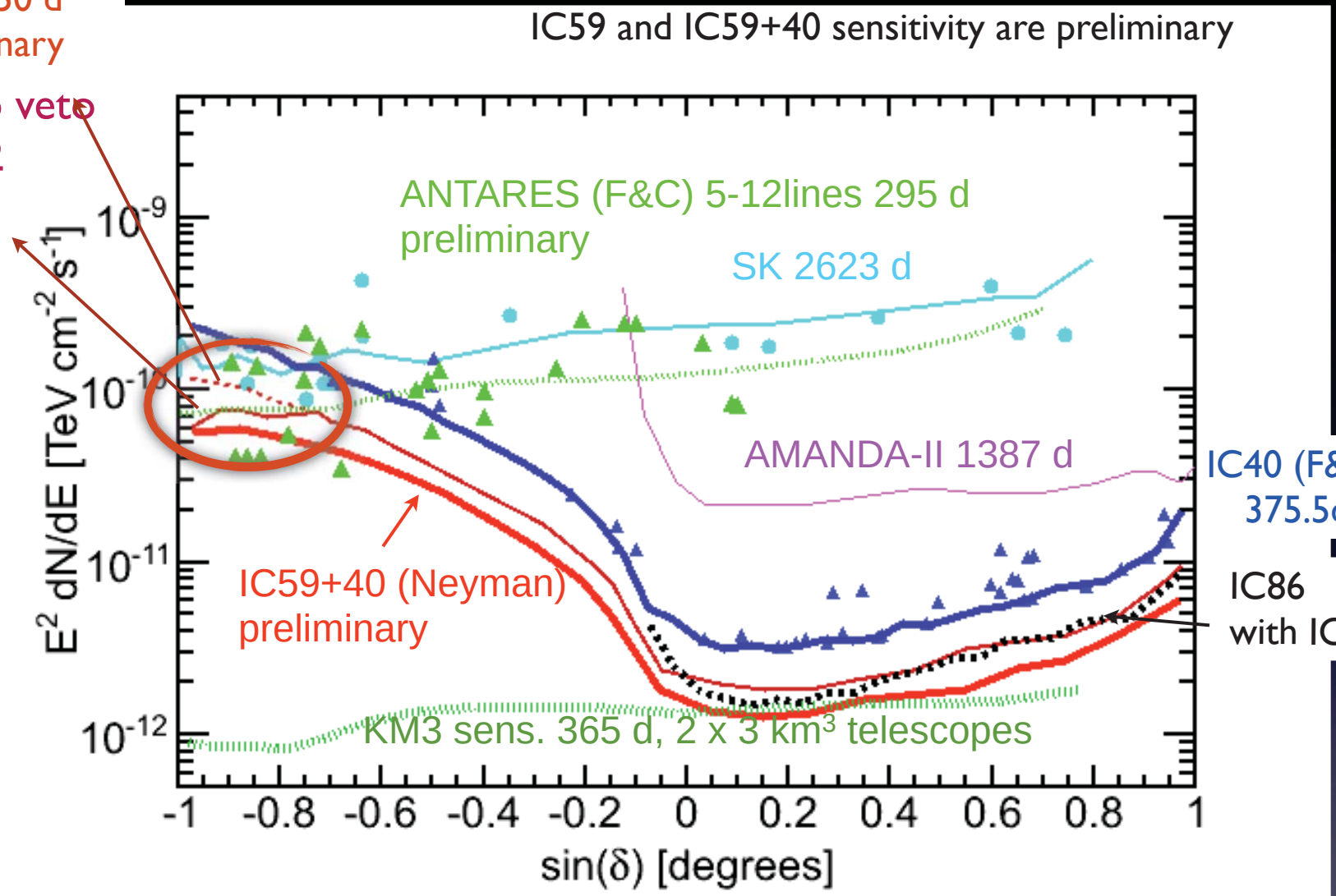


No significant fluctuation: best pre-trial p-value = 0.14 pretrial in a list of 43 sources => 95% post-trial for PKS_1454-354

E^{-2} median sensitivity and upper limits (90%cl)

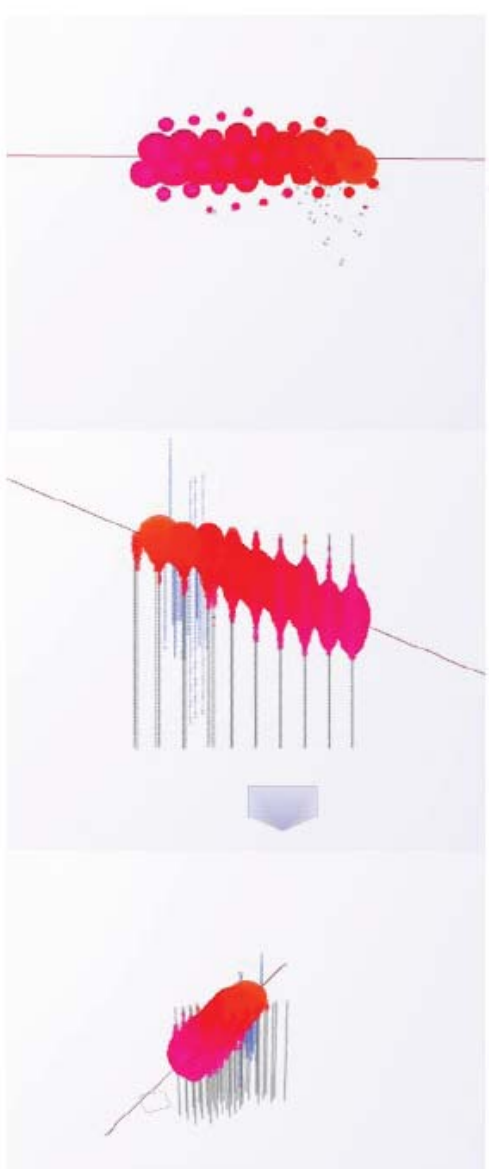
IC59 350 d
preliminary

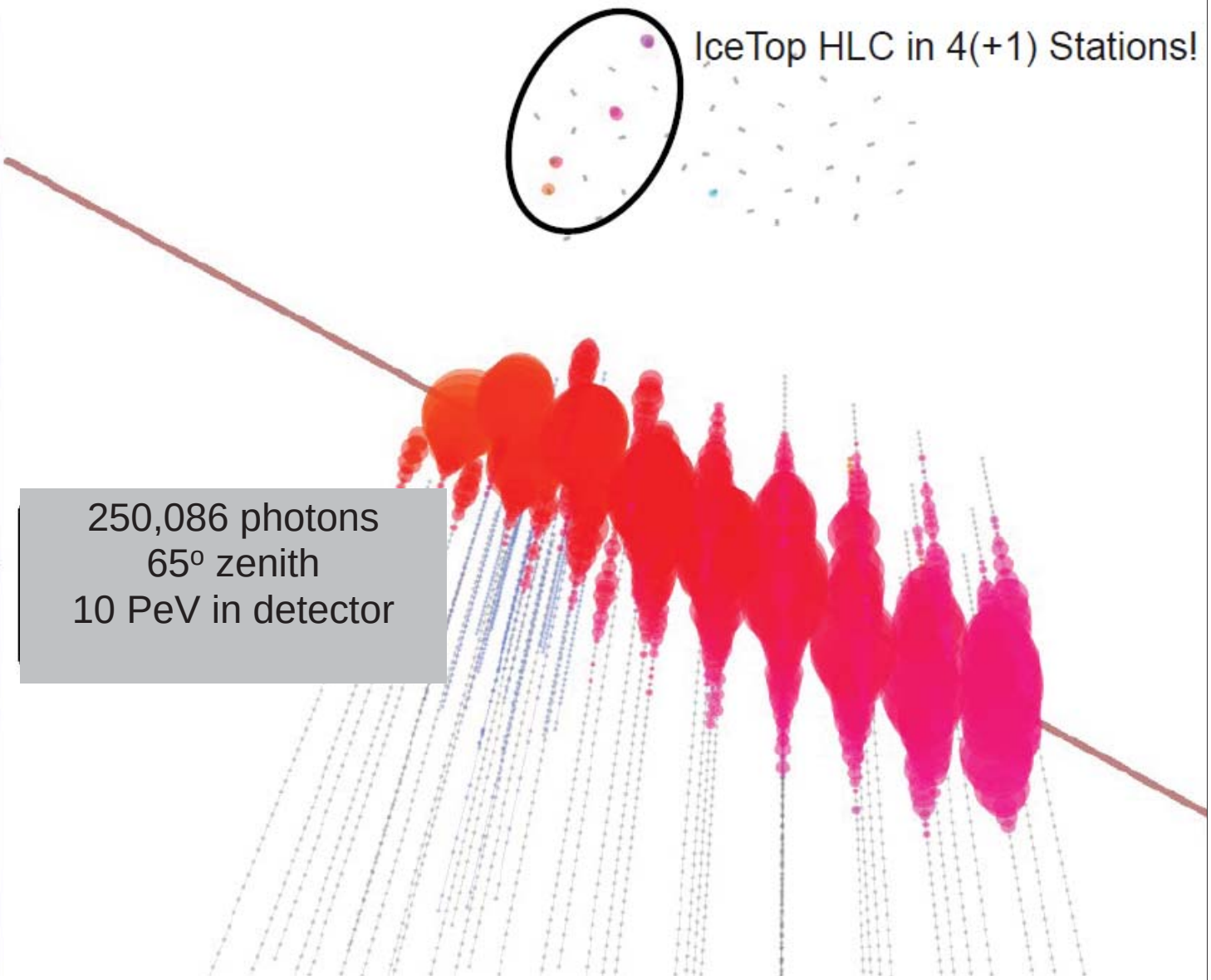
+IceTop veto
x 2



40+59 strings (x2.5 IC40) = better than preliminary estimates of full IceCube
IC40+IC59+IC79+IC86 = about factor of 5 from the blue curve (IC40)

Biggest Shower in IC40 EHE Analysis



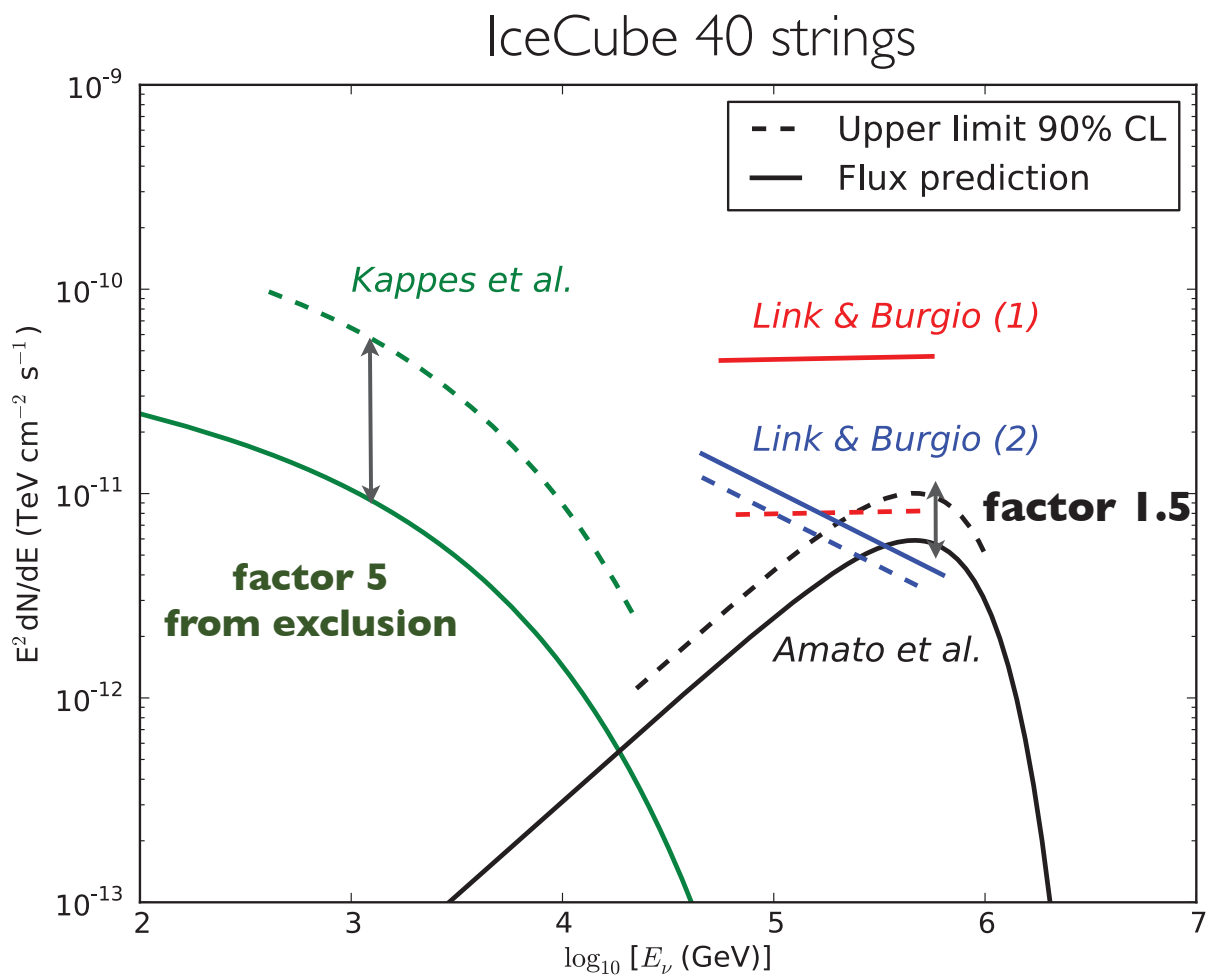


250,086 photons
65^{o} zenith
10 PeV in detector

A. Ishihara, S. Yoshida
the event is rejected by blind cuts

paper submitted to ApJ

CRAB (STEADY EMISSION)



For isotropic emission the E^{-2} limit corresponds to a nu luminosity constraint of 1×10^{35} erg s-1 ~1.7 luminosity between 0.4-40 TeV.

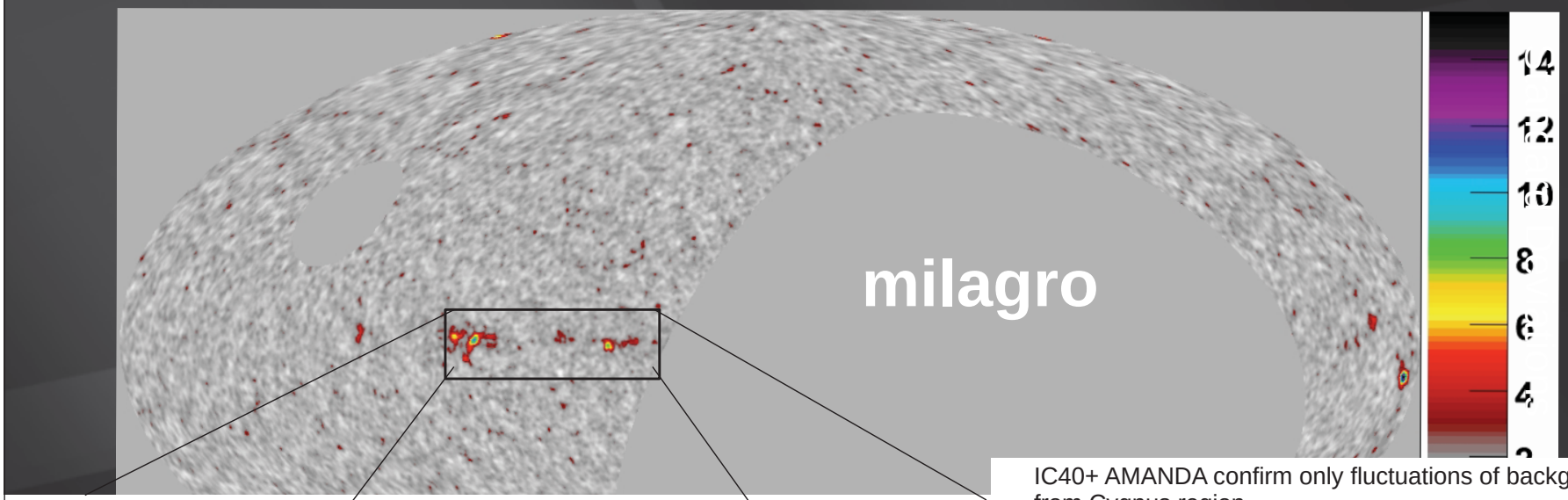
L&B 2006: ions accelerated to Δ threshold with constant E-field (1) or linearly increasing E-field (2) with height above n star surface. Most optimistic predictions rejected @> 90% cl

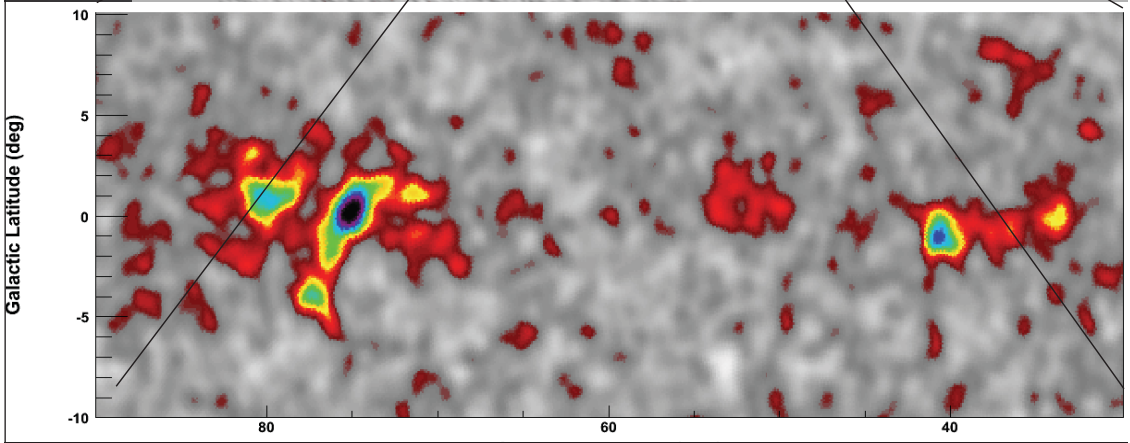
Blasi & Amato 2003: close to exclude most optimistic values of the plerion wind Lorentz factor (10^7) and of effective target density for protons.

Kappes et al, 2007: protons and fit HESS gamma spectrum

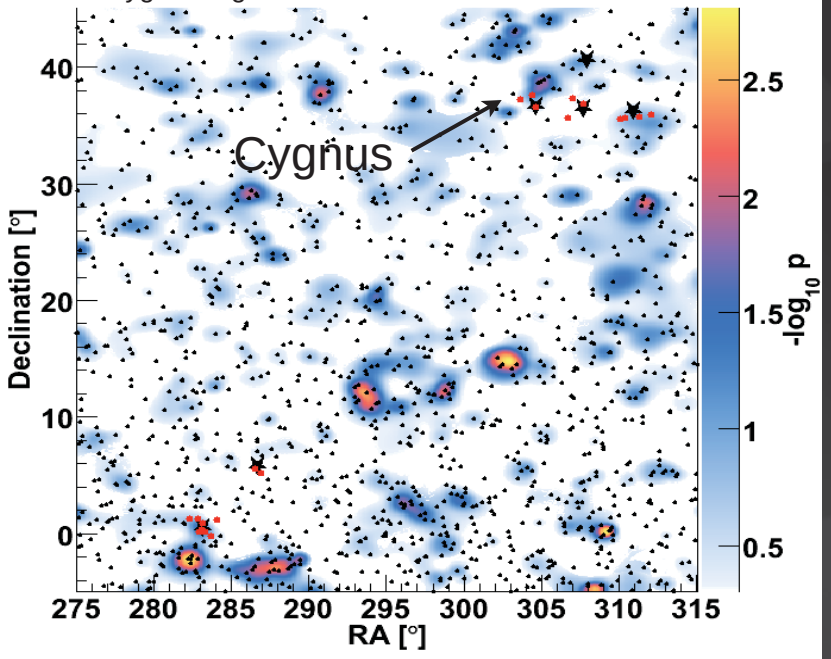
$$\frac{dN_p}{dE_p} = k_p \left(\frac{E_p}{1\,\mathrm{TeV}}\right)^{-\alpha} \exp\left(-\frac{E_p}{\epsilon_p}\right) \Rightarrow \frac{dN_{\gamma/\nu}}{dE_{\gamma/\nu}} \approx k_{\gamma/\nu} \left(\frac{E_{\gamma/\nu}}{1\,\mathrm{TeV}}\right)^{-\Gamma_{\gamma/\nu}} \exp\left(-\sqrt{\frac{E_{\gamma/\nu}}{\epsilon_{\gamma/\nu}}}\right)$$

Stacking the Milagro Pevatrons (SNR in molecular clouds)





IC40+ AMANDA confirm only fluctuations of background from Cygnus region



Catalogue	Med Sens	upper limit (90%cl)
6 Milagro SNR	2.9x prediction	7.2 x prediction

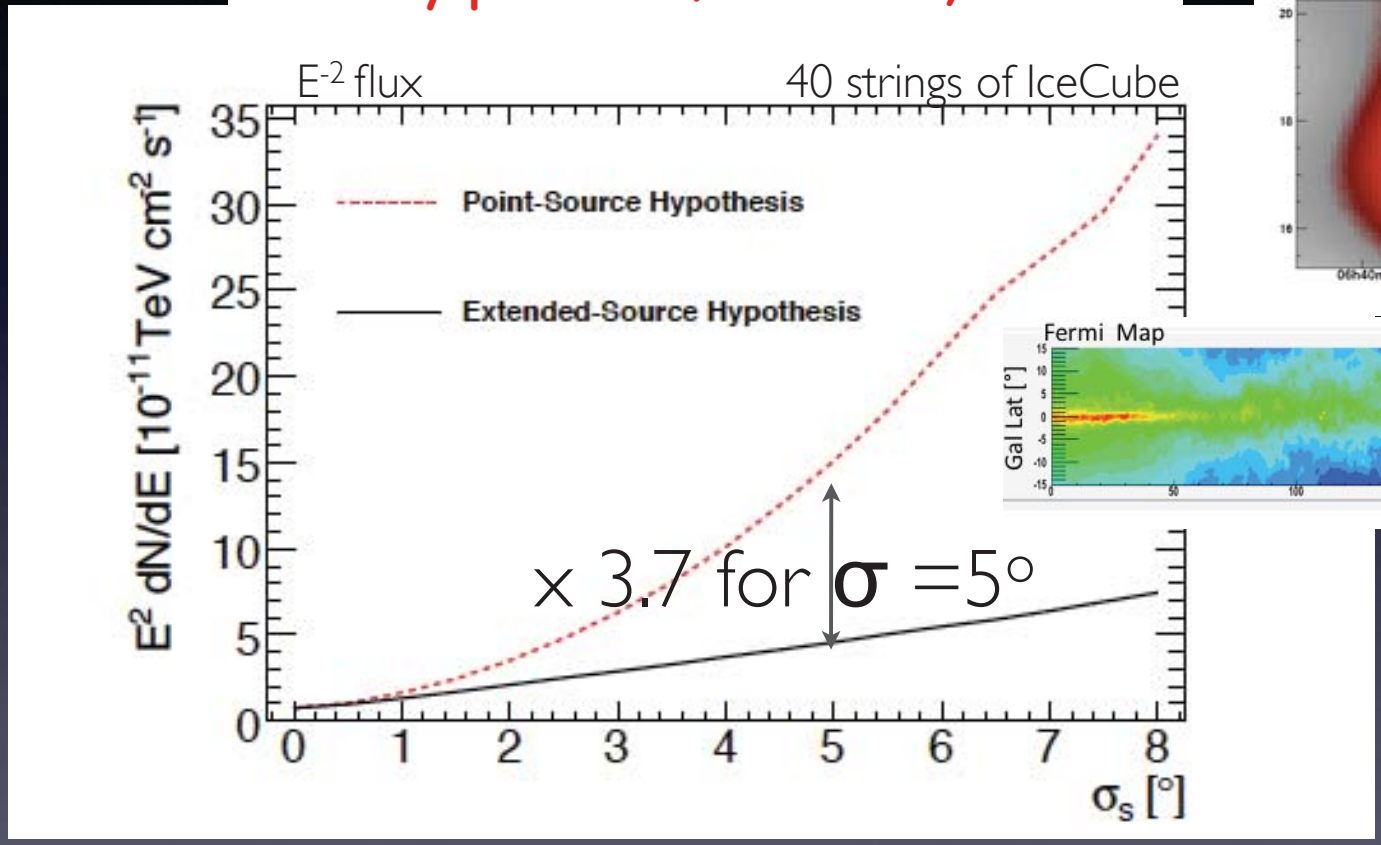
Model (Gonzalez-Garcia et al., arXiv:0902.1176): if E^{-2} cut-off at 300 TeV (10% of the knee of their CR primaries) => 5σ in 3 yr of IceCube

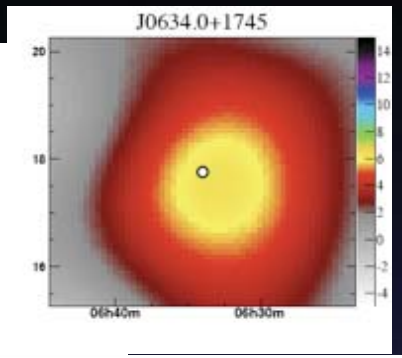
Stacking and extended sources

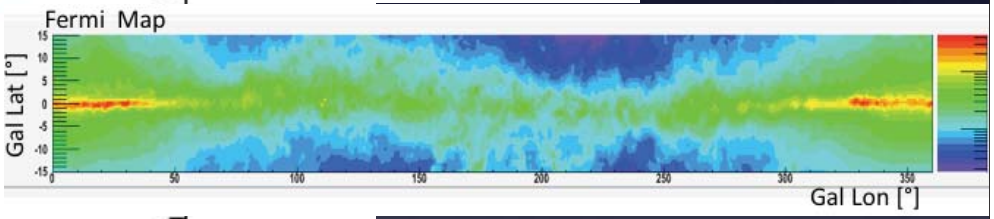
The origin of Galactic cosmic-ray ions has remained an enigma for almost a century. Although it has generally been thought that they are accelerated in the shock waves associated with powerful supernova explosions ...**we may be on the wrong track altogether in looking for isolated regions of cosmic-ray acceleration.**

(Y. Butt Nature 2009)

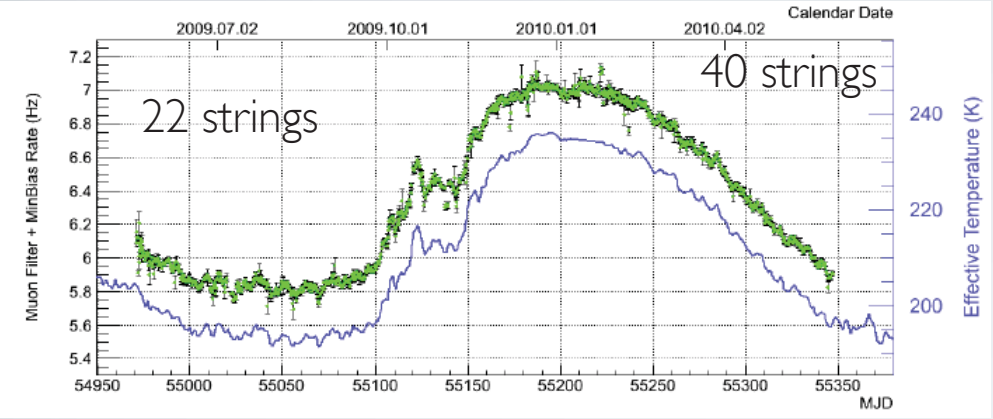
discovery potential flux at 5 σ , P = 50%





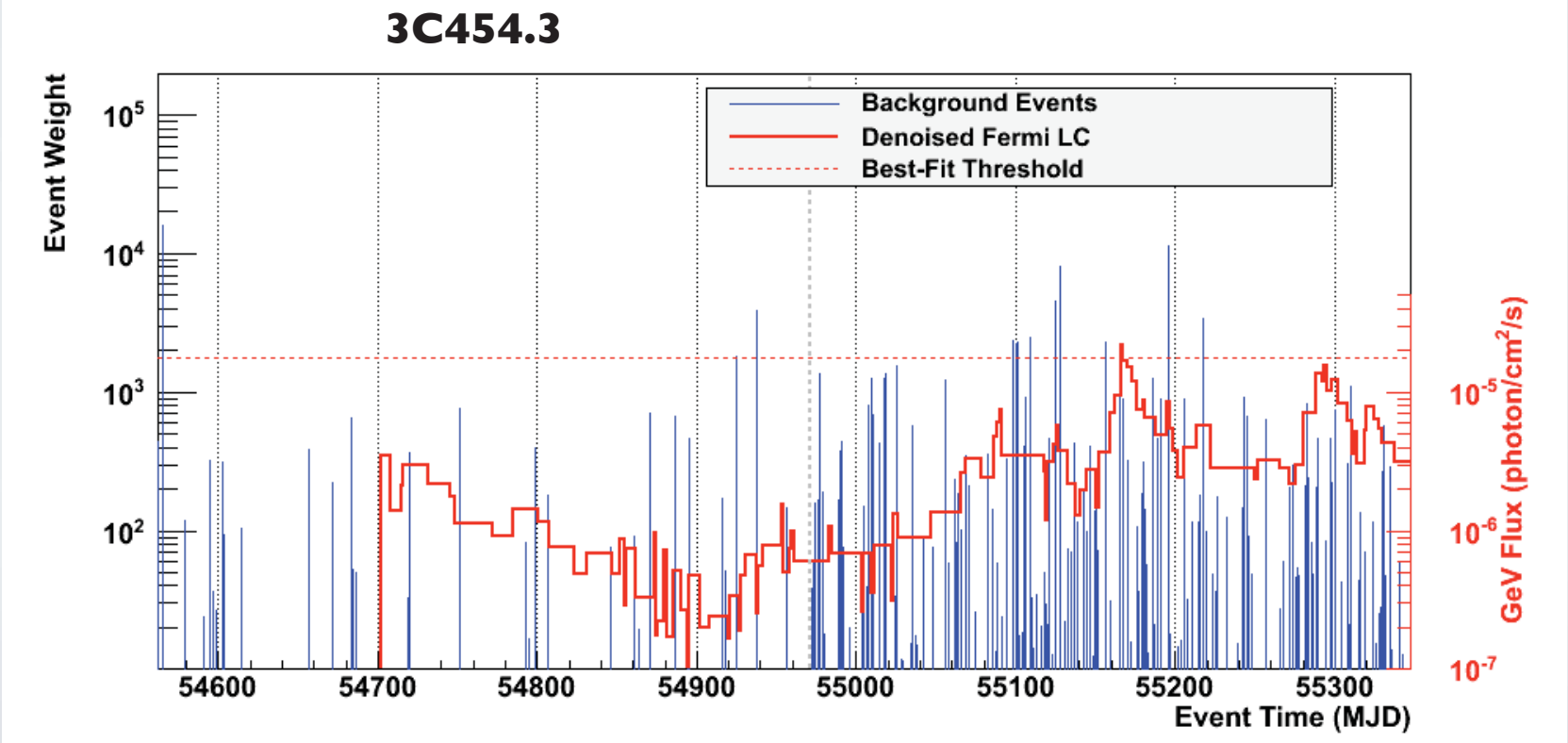


TIME DEPENDENT SEARCHES



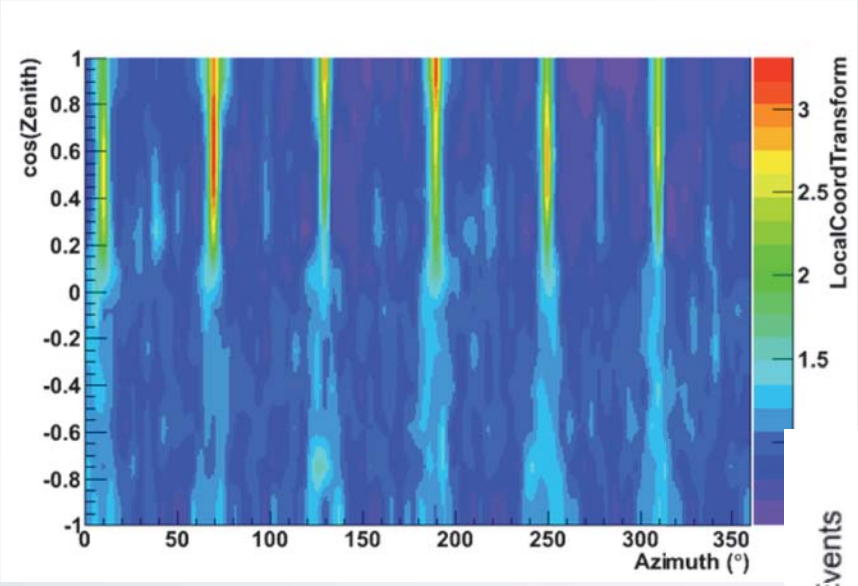
$$S_i = S_i^{space}(\mid \vec{x}_i - \vec{x}_s \mid, \sigma_i) S_i^{energy}(E_i, \theta_i, \gamma_s) S_i^{tim}$$

Time dependent PDF from other experiment lightcurves (eg. Fermi-LAT)



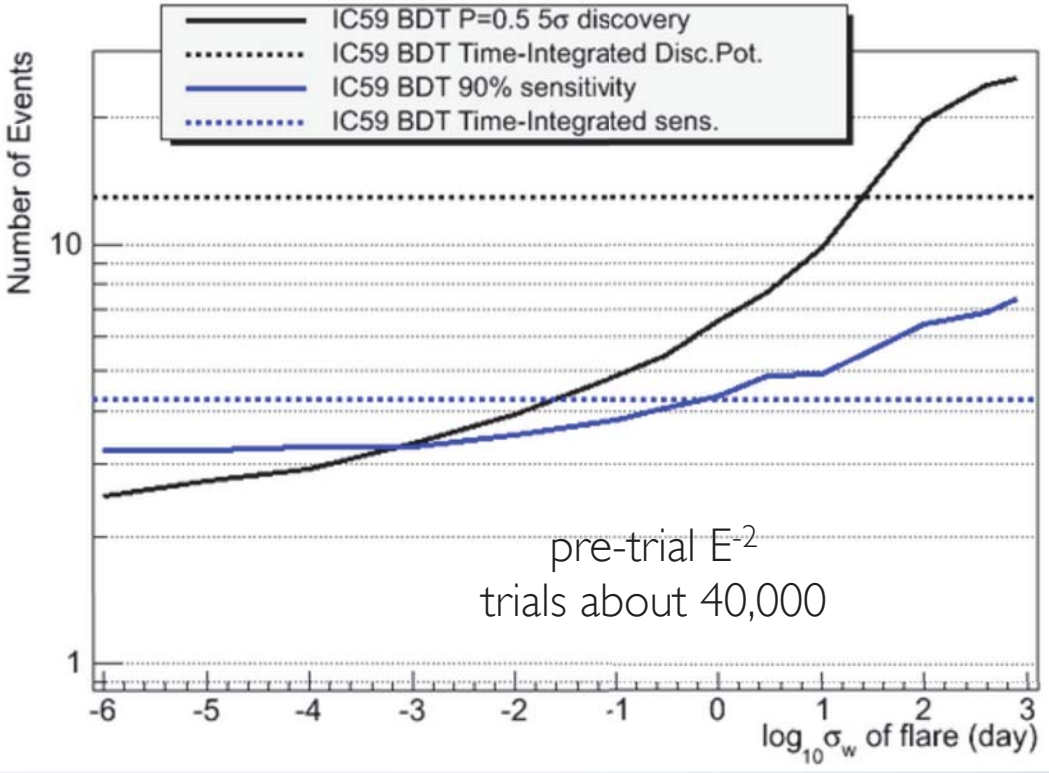
ALL SKY SCAN IN TIME-ENERGY-SPACE

$$S_i(|\mathbf{x}_i-\mathbf{x}_s|, E_i, \gamma, t_i, t_o, \sigma_w) = \frac{1}{2\pi\sigma_i^2}\exp\left(-\frac{|\mathbf{x}_i-\mathbf{x}_s|^2}{2\sigma_i^2}\right) P_{SigMue}(E_i|\delta_i,\gamma) * \frac{1}{\sqrt{2\pi}\sigma_w}\exp\left(-\frac{(t_i-t_o)^2}{2\sigma_w^2}\right)$$



For signal shorter than 1 day azimuth dependency needs to be considered

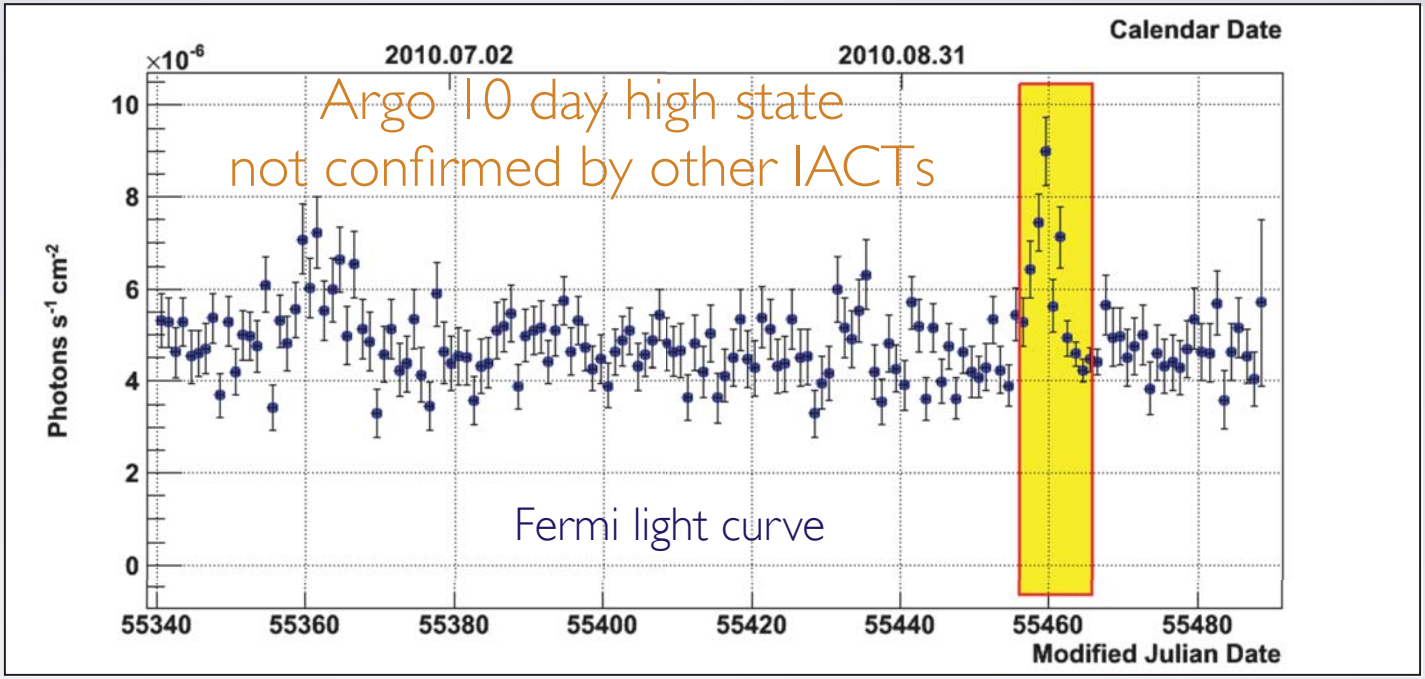
preliminary



Results at ICRC 2011

PRELIMINARY

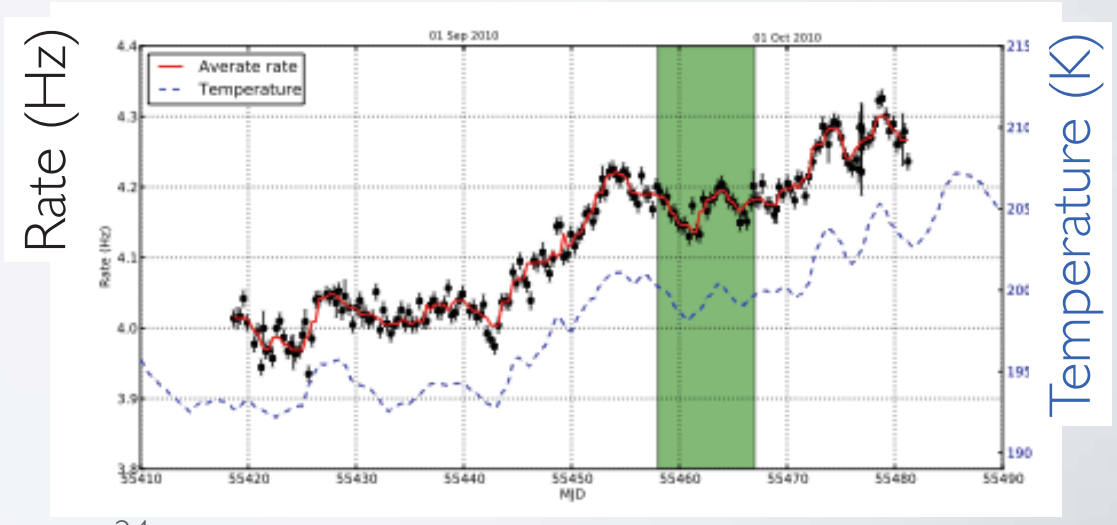
CRAB FLARE



79 string data

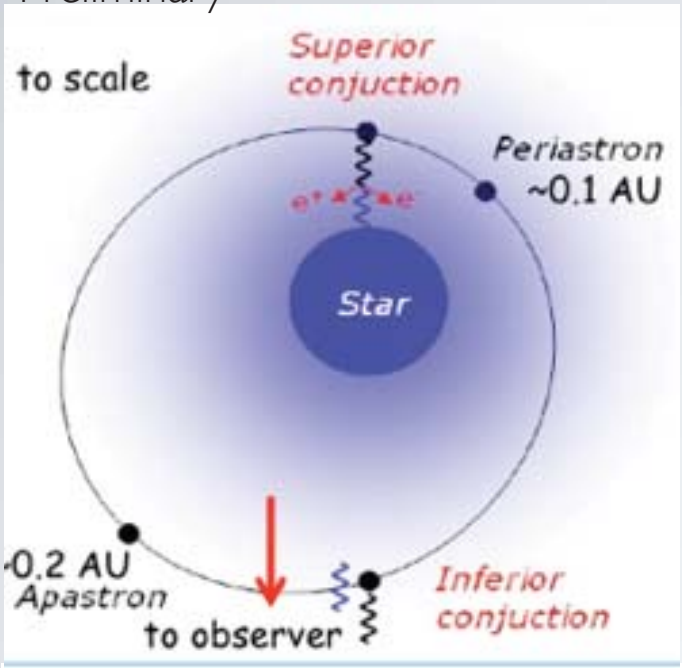
E^{-2} (1 TeV cut-off) limit corresponds to
u luminosity constraint of 1×10^{35} erg
1.5×10^{36} erg s^{-1}). This is 2-3 orders of
gnitude below the spin-down
inosity of the pulsar 5×10^{35} erg s^{-1}
GILE 0.1-10 GeV)

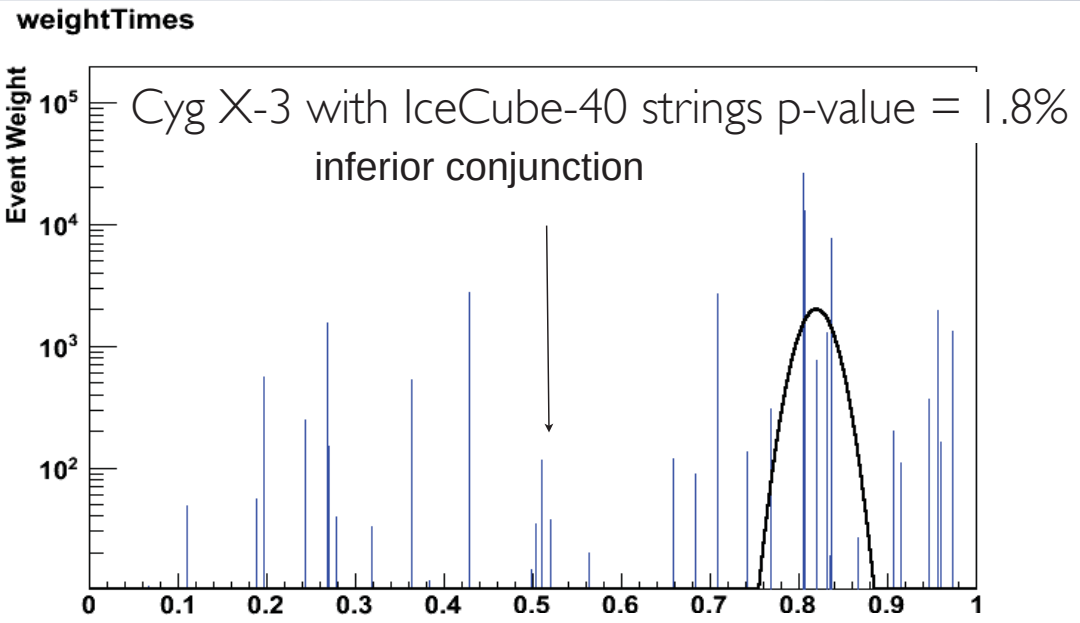
Paper submitted to ApJ



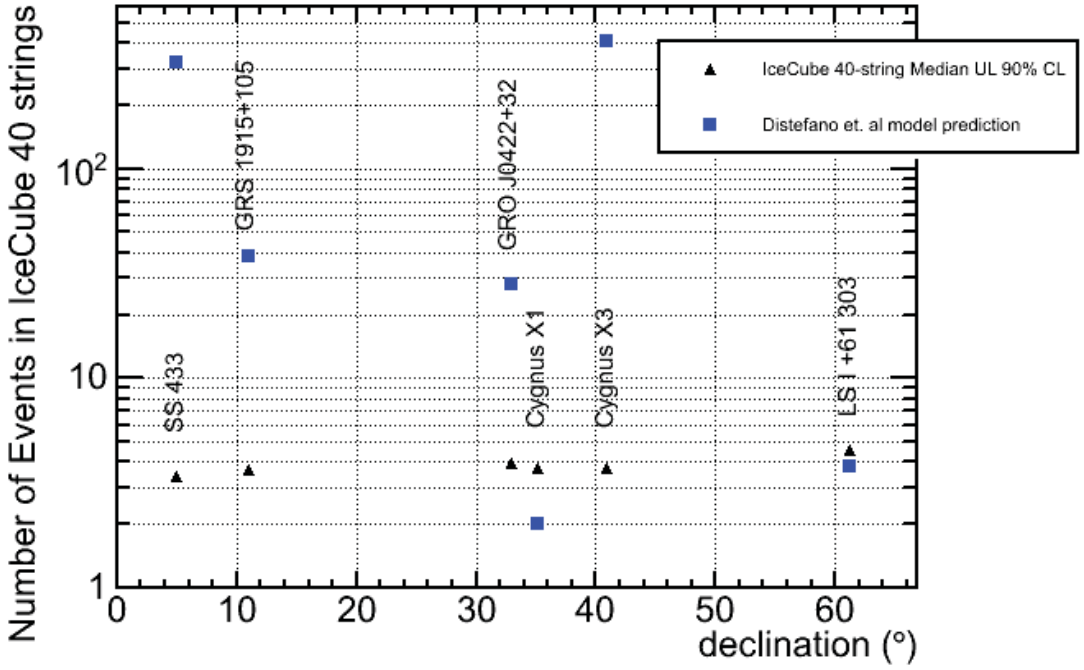
Preliminary

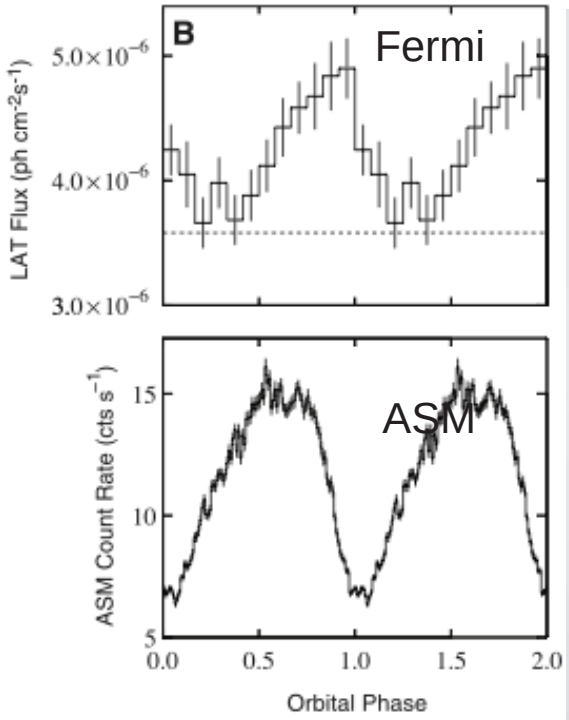
PERIODIC SYSTEMS





Neutrinos from Microquasar (Distefano et al, 2002, p-ϒ)

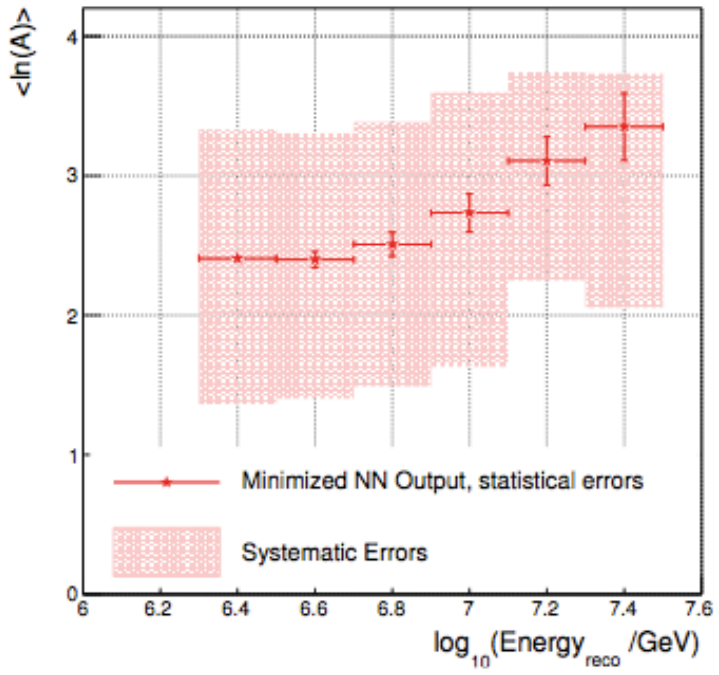




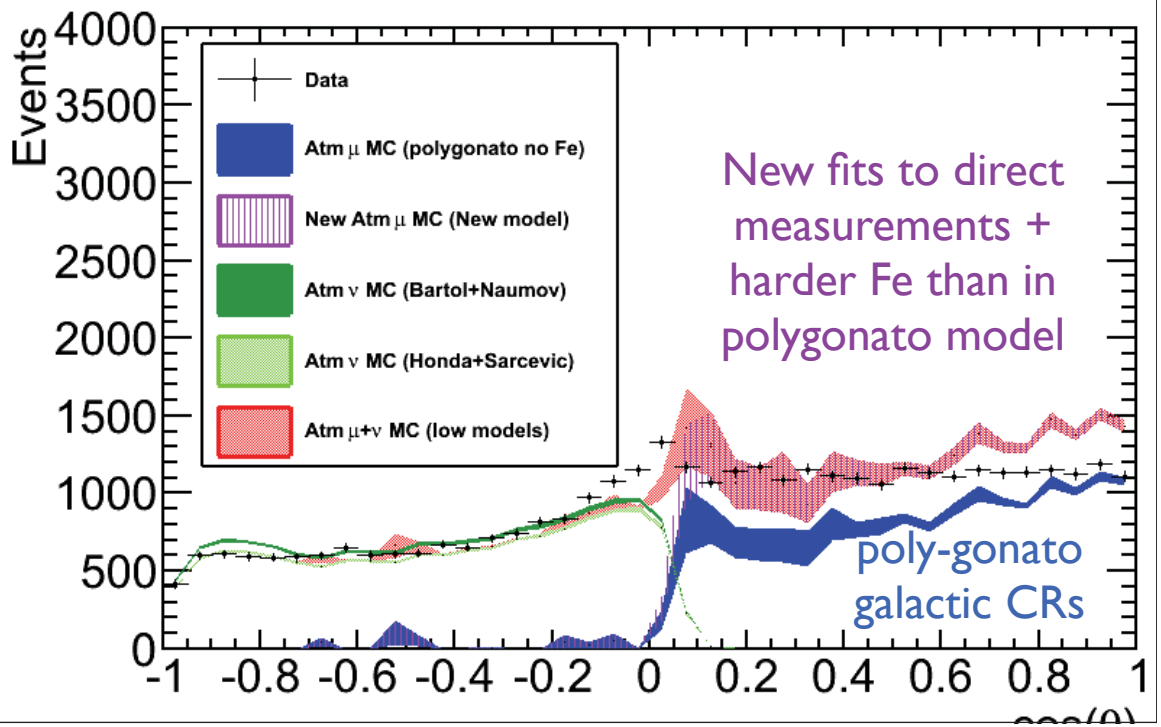
IceCube-IceTop unique capability of CR composition measurement at and above the knee

High Energy atmospheric muons and neutrinos + IceTop are sensitive to the composition in the knee region and above.

IceTop, paper in preparation
to be presented also at ICRC2011



Final PS sample 40 string zenith distribution



Overall strategy for updated CR composition model

• Fit direct measurements with broken PL to fix A and spectral index γ_2 before the knee

$$\frac{d\Phi}{dE} = \begin{cases} A \cdot \left(\frac{E}{E_0}\right)^{\gamma_1} & \text{if } E < E_b \\ A \cdot \left(\frac{E_b}{E_0}\right)^{\gamma_1-\gamma_2} \cdot \left(\frac{E}{E_0}\right)^{\gamma_2} & \text{else.} \end{cases}$$

•Use `polygonato' function

$$\frac{d\Phi}{dE} = \begin{cases} A \cdot \left(\frac{E}{E_0}\right)^{\gamma_1} & \text{if } E < E_b \\ A \cdot \left(\frac{E_b}{E_0}\right)^{\gamma_1-\gamma_2} \cdot \left(\frac{E}{E_0}\right)^{\gamma_2} \times \left[1 + \left(\frac{E}{E_Z}\right)^{\epsilon_c}\right]^{-(\Delta\gamma/\epsilon_c)} & \text{else.} \end{cases}$$

•or exponential cut-off function

$$\frac{d\Phi}{dE} = \begin{cases} A \cdot \left(\frac{E}{E_0}\right)^{\gamma_1} & \text{if } E < E_b \\ A \cdot \left(\frac{E_b}{E_0}\right)^{\gamma_1-\gamma_2} \cdot \left(\frac{E}{E_0}\right)^{\gamma_2} \times e^{-E/E_Z} & \text{else.} \end{cases}$$

• Fit proton parameters and derive Ep, $\Delta\gamma$, ε_c

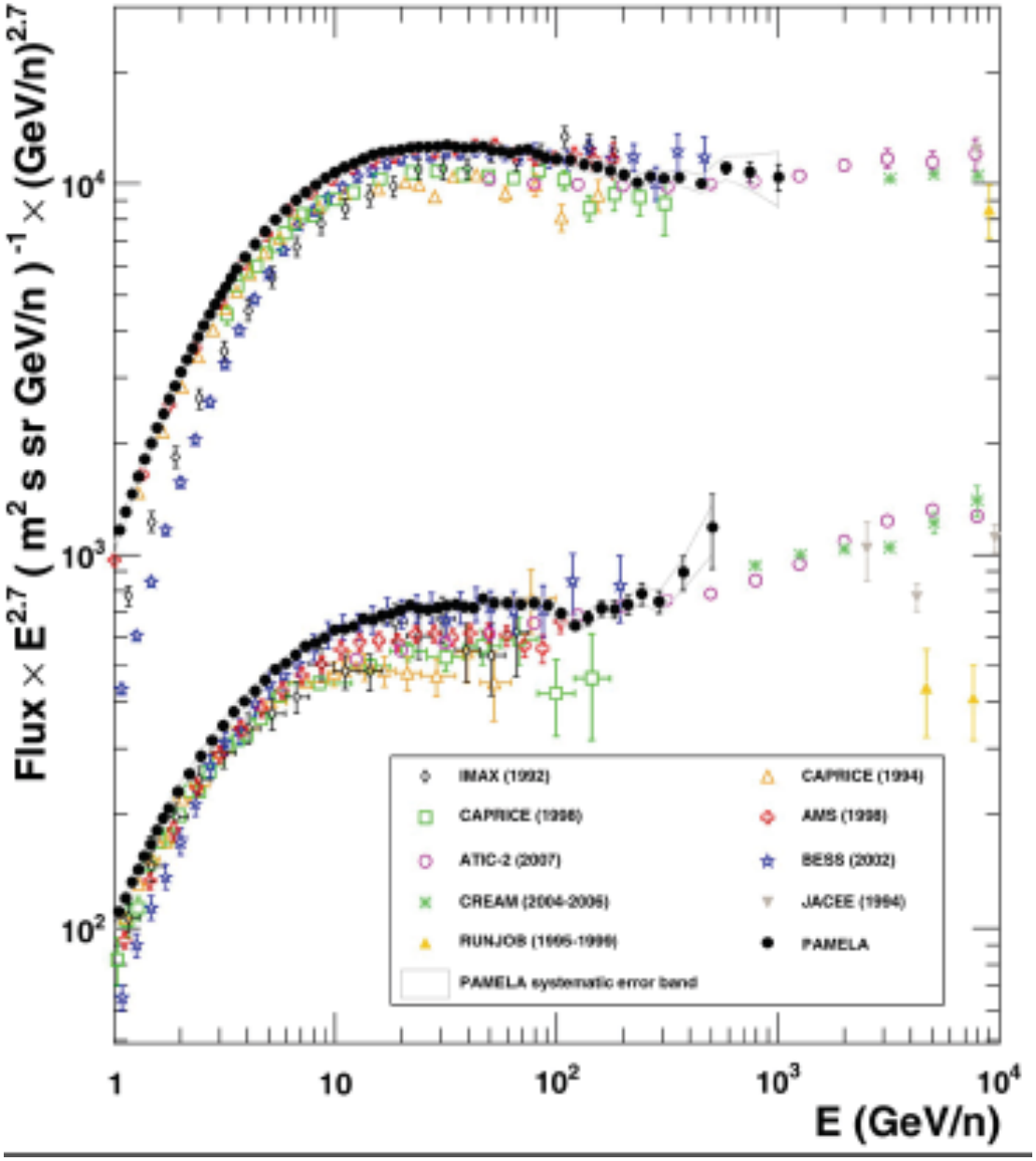
•Fit p and He using Kascade and Tibet data separating those derived with QGSJET and SIBYLL and fixing parameters: A and γ_2 inside 2σ of direct measurements error, Z dependent knee Ez = Z x Ep and same slope as proton above the knee

•Sum all components and compare to all particle spectrum

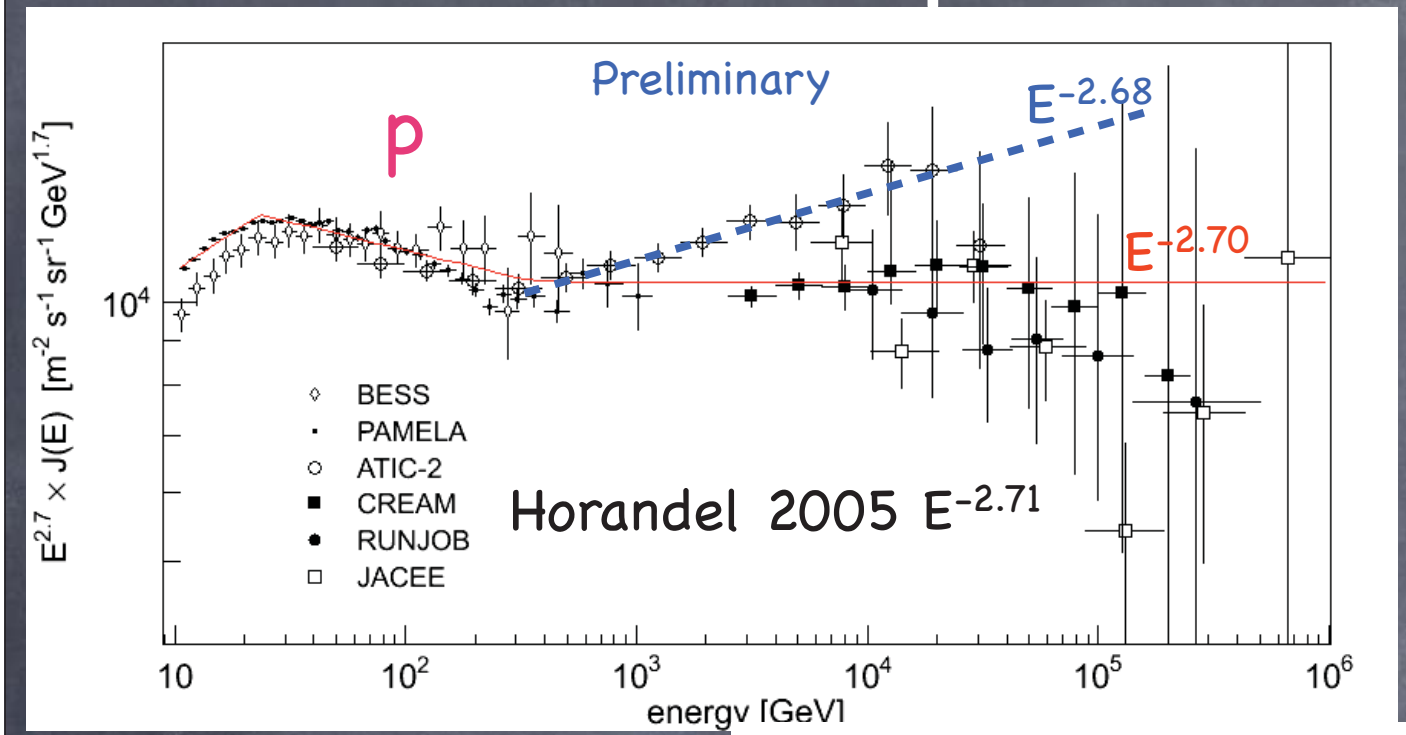
•Ad a `Superheavy' component and an EG to fill the gap to HiReS data

Direct detection data

- PAMELA Science 2011
- CREAM, ApJ 728 (2011), ApJ 714 (2010)
- ATIC, Bulletin of the Russian Academy of Sciences: Physics, 2009, Vol. 73, No. 5
- RunJob: Astrop Phys 16, 2001,
- JACEE, ApJ 502 (1998)
- BESS-TeV: Nuclear Physics B (Proc. Suppl.) 166 (2007) 62

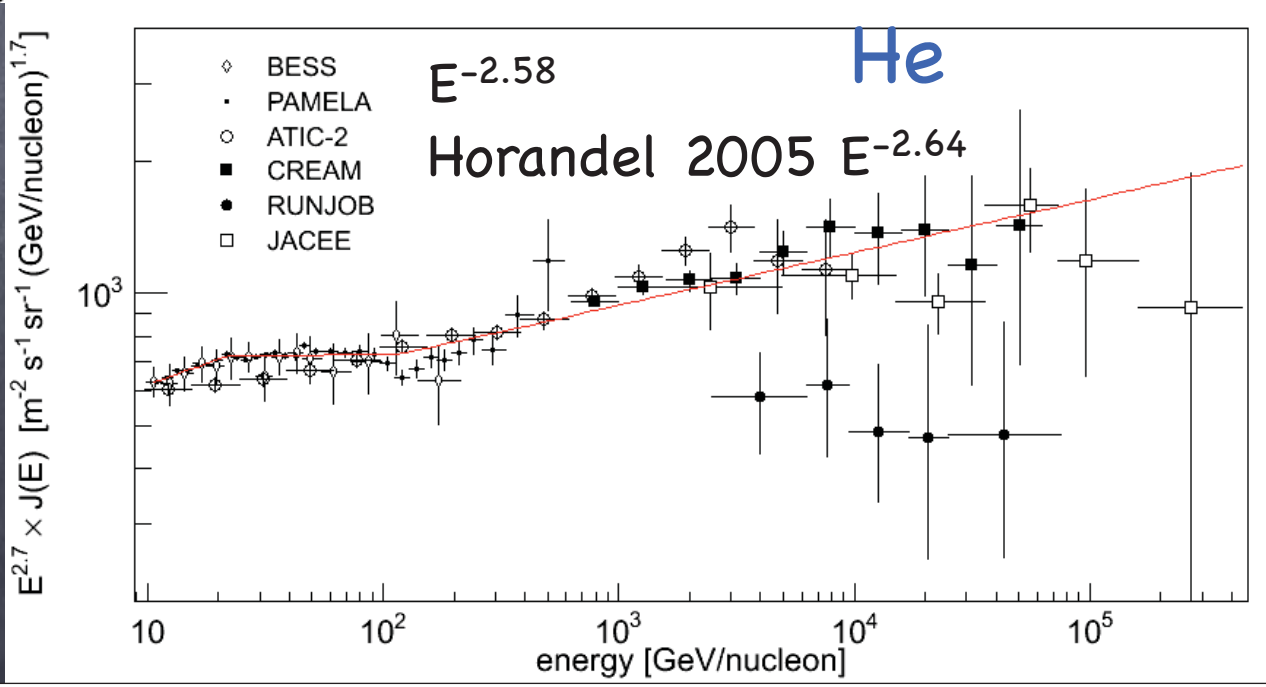


Composition



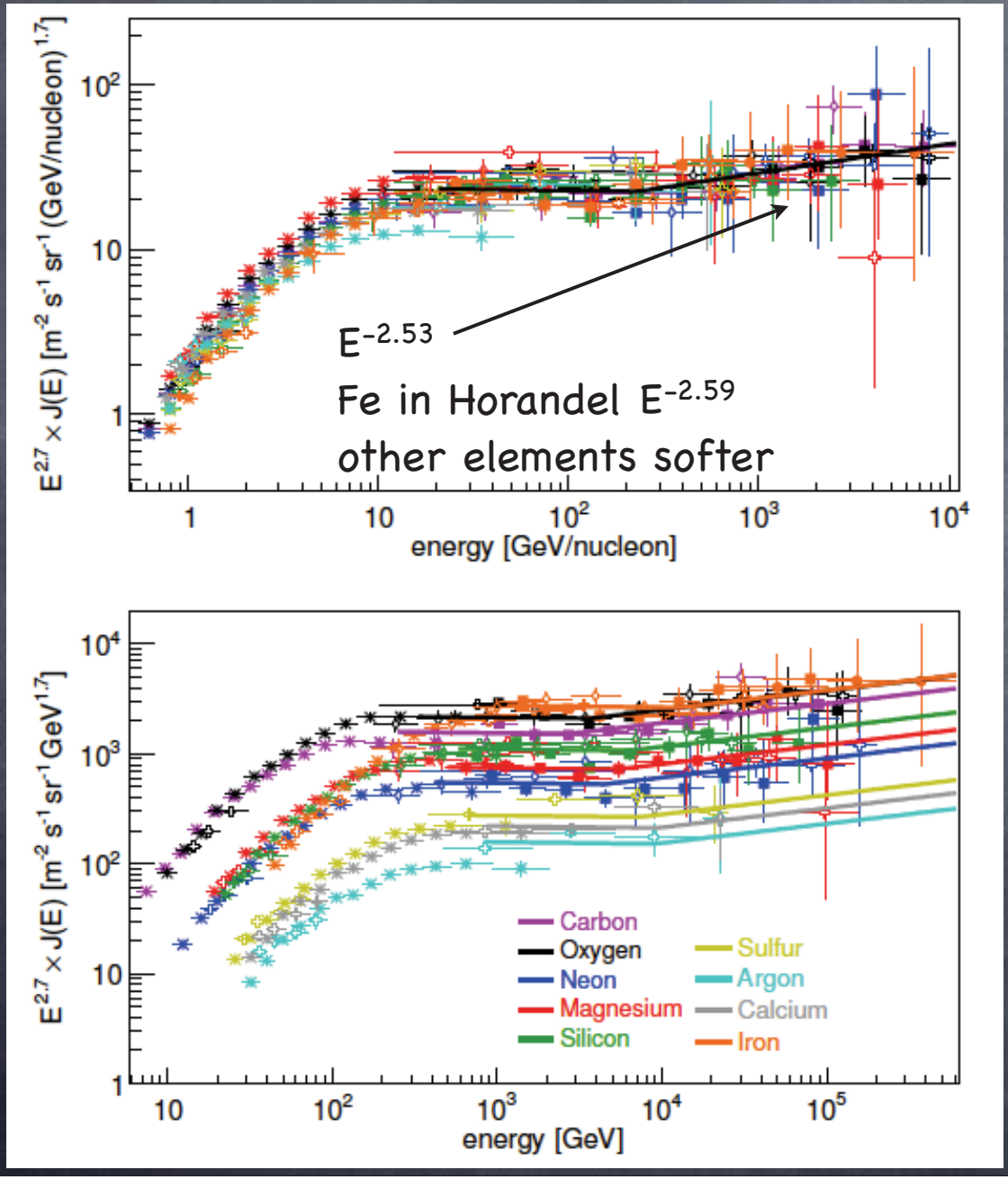
work with Segev BenZi

Fits are unstable due to small errors of Pamela and poor agreement of CREAM and ATIC



PAMELA, Science, Mar 2011
CREAM, ApJ 2010
ATIC-2 Bulletin of Russian Acc. 2009
BESS-TeV Nucl. Phys B 2007
JACEE Astrop. Phys. 2008

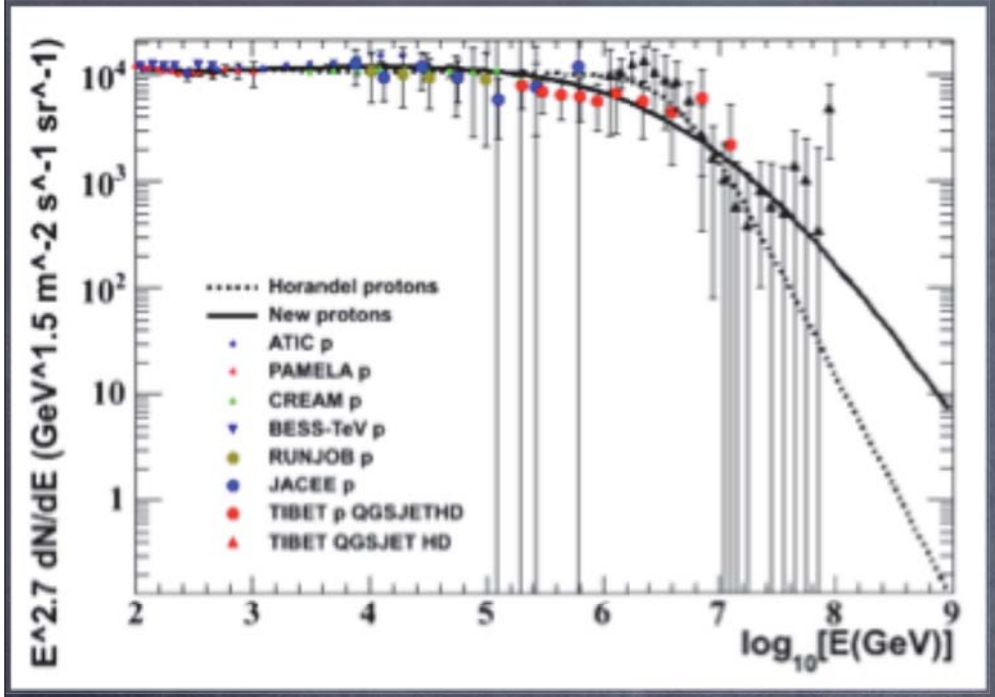
Common Fit for heavy nuclei

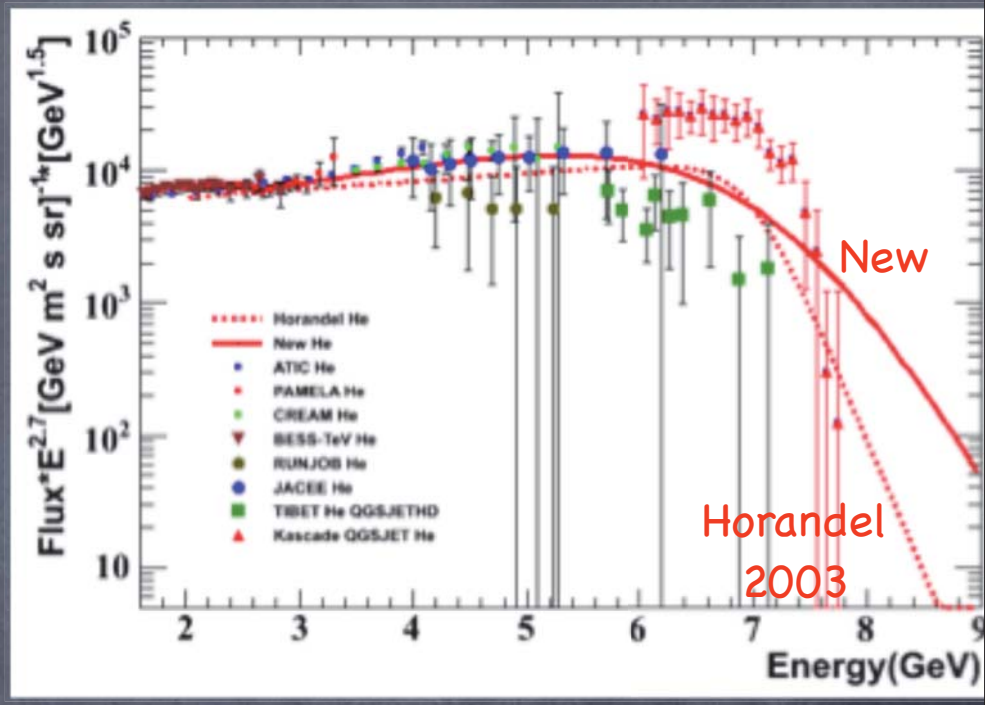


All components seem to exhibit a hardening of the spectrum at E(GeV/nucleon) ~200 GeV

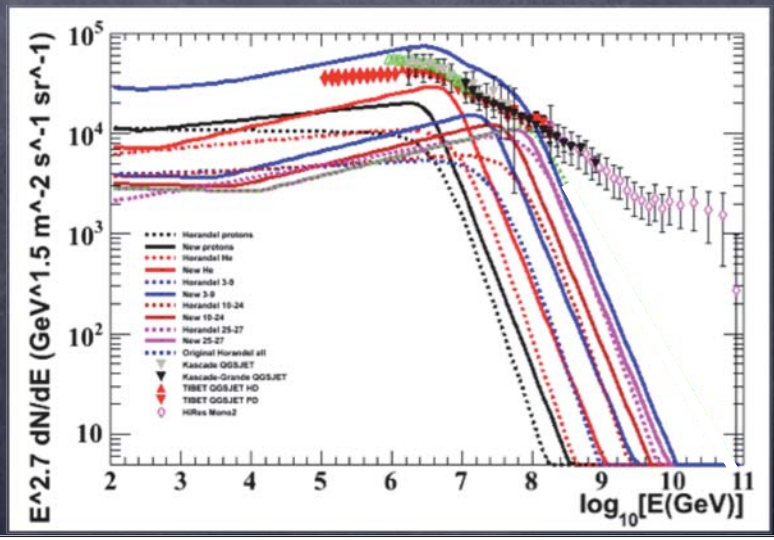
Proton and He example

(Kascade + Tibet)



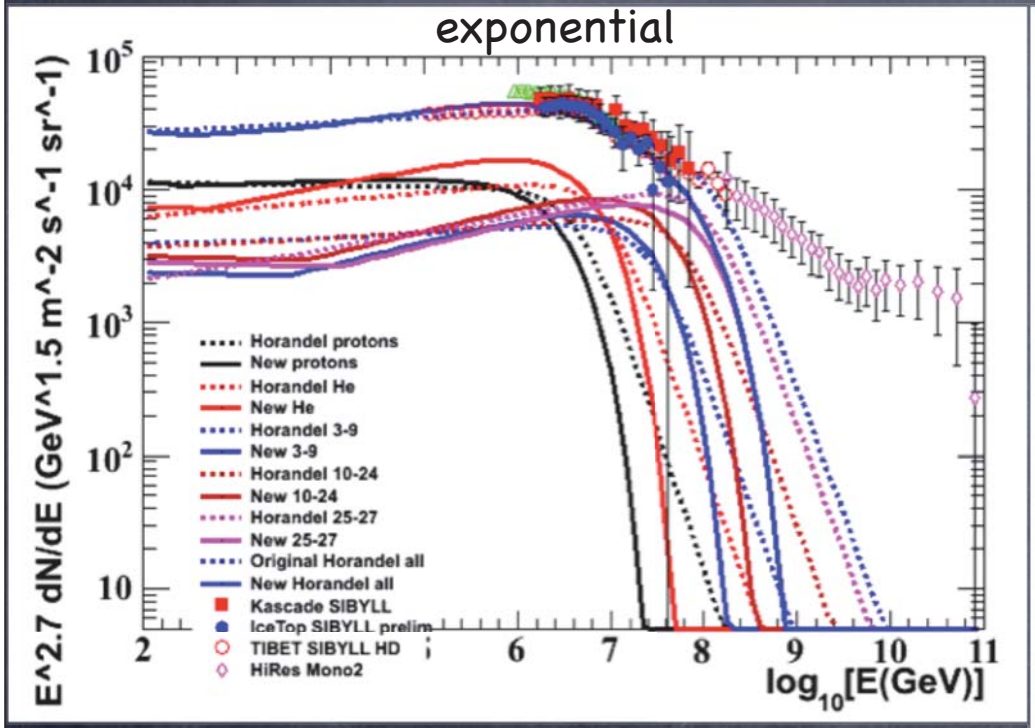


Using only KASCADE would produce a too high all particle spectrum

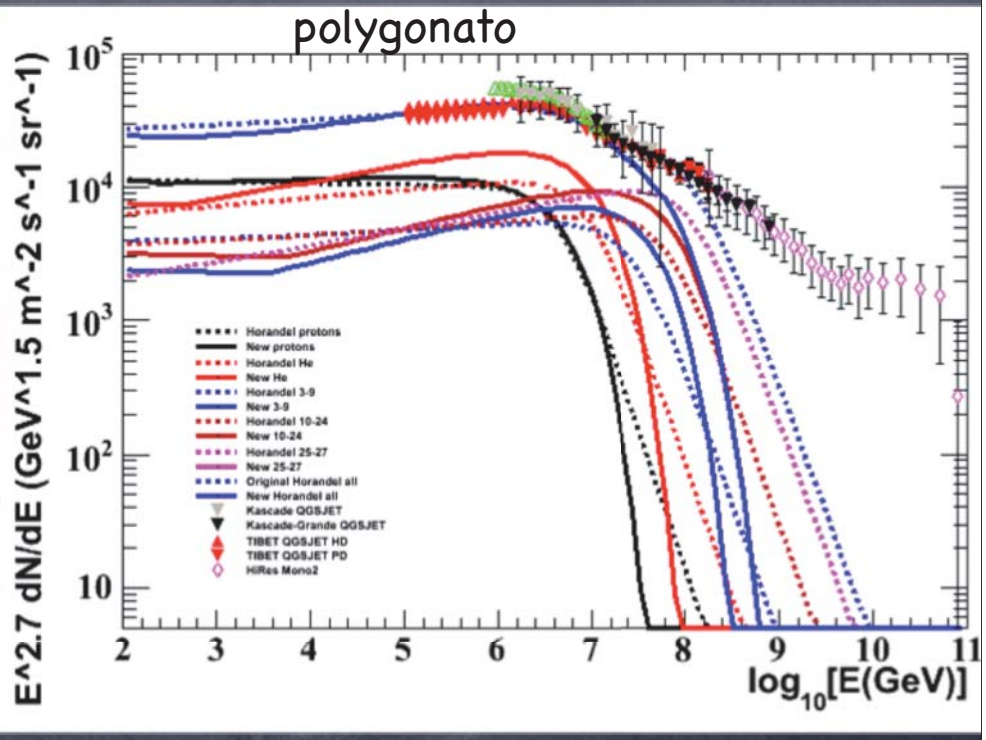


All particle result (SIBYLL)

exponential

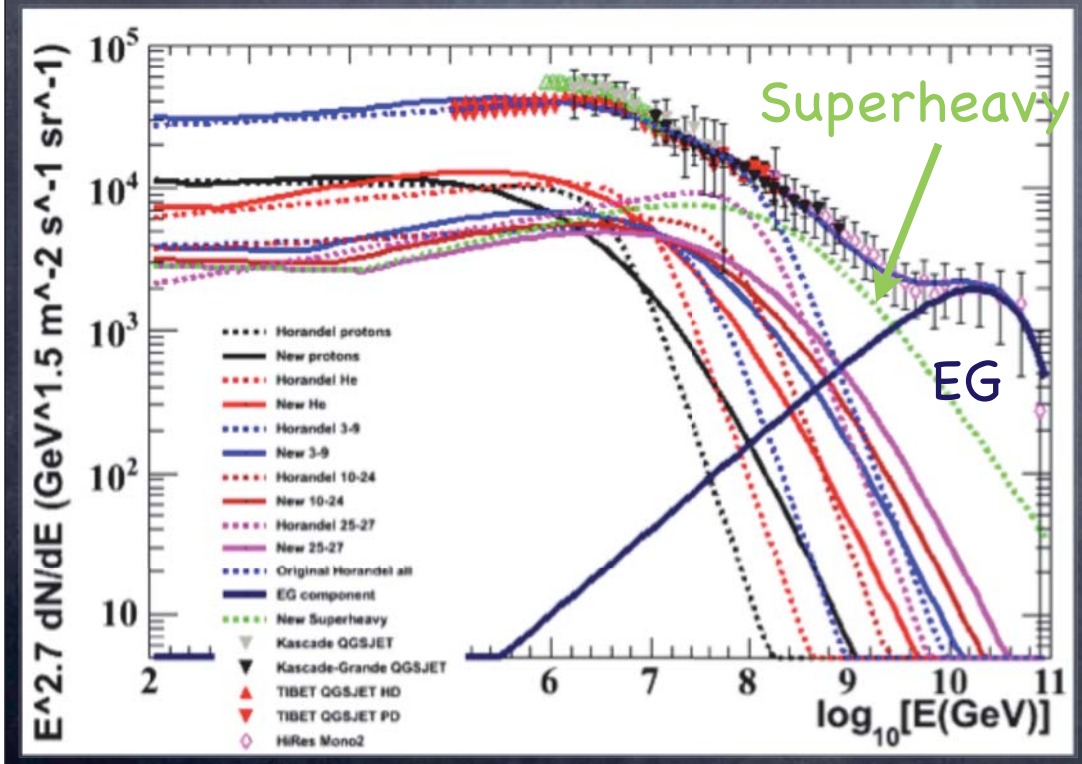


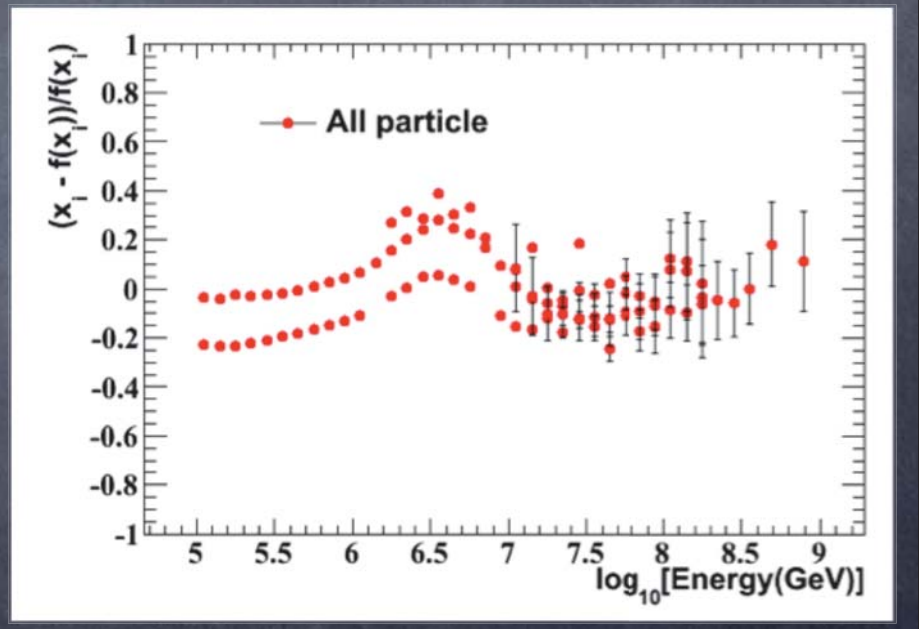
polygonato



The exponential goes so fast down above the knee that a very high knee of about 10 x 26 x Ep would be needed to fill the gap to HiReS

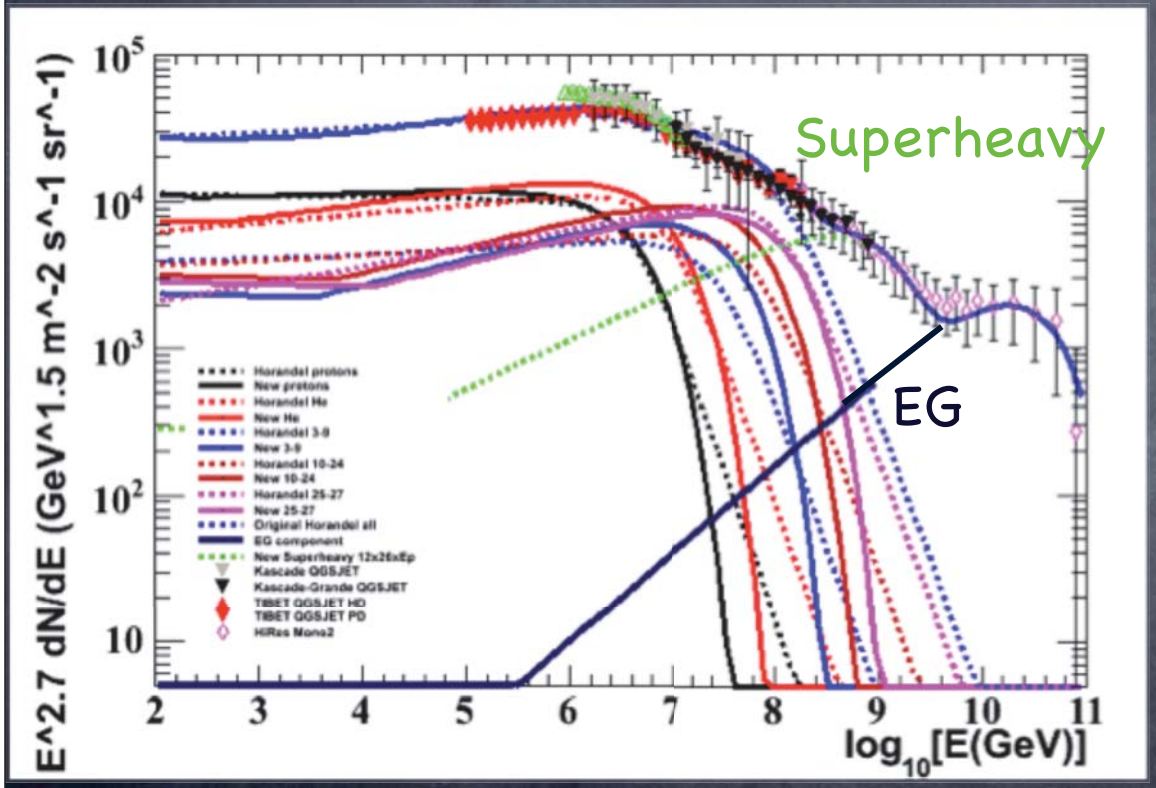
Polygonato+components

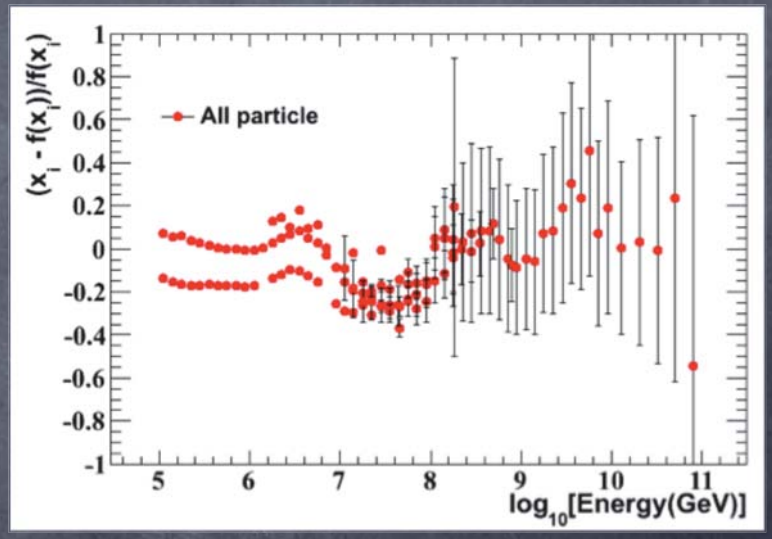




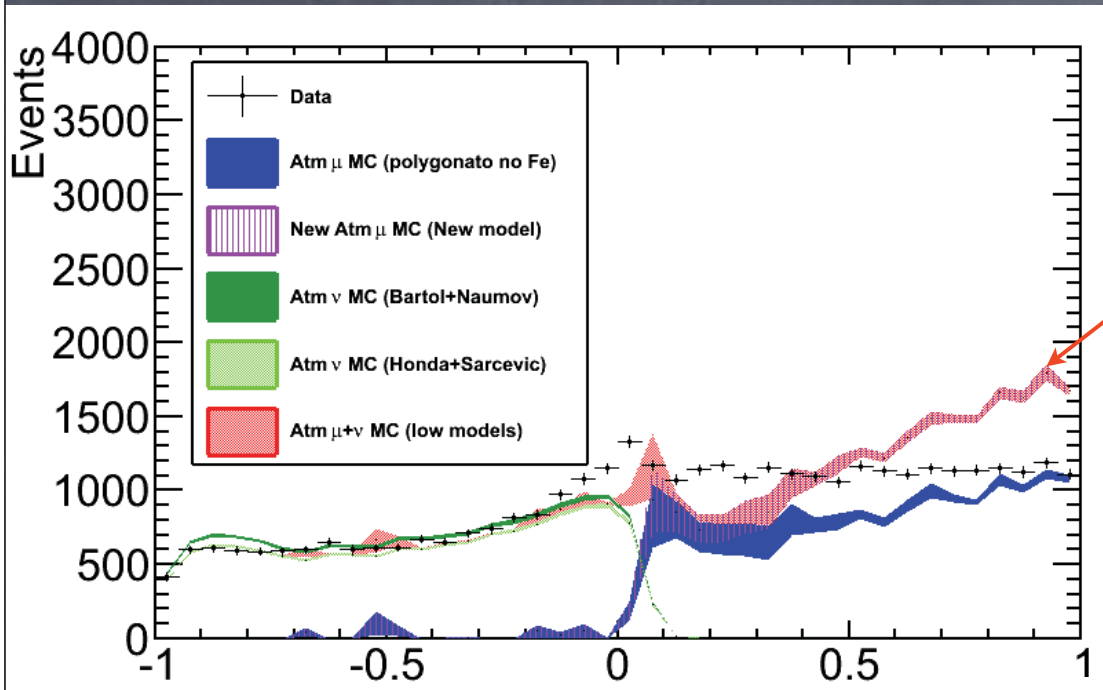
delta_proton – 0.5 and epsilon_c + 0.2

Exponential + components (QGSJET)



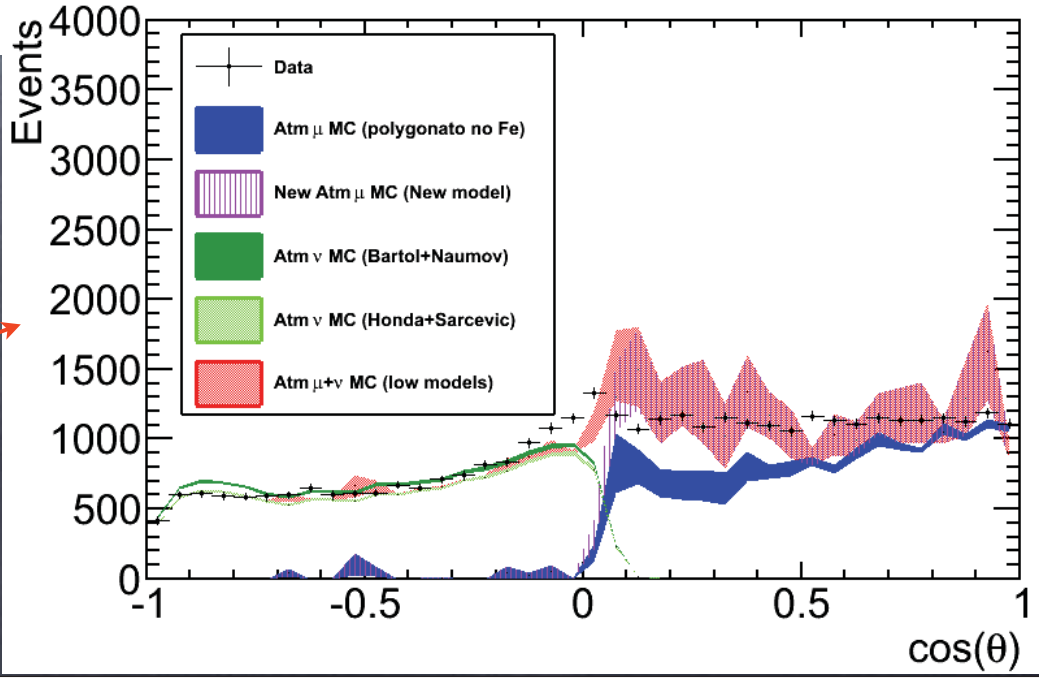


First results...(do not trust them ;)



use `Superheavy' as if they were Fe

use `Superheavy as if they were p



Conclusions

- Tools are ready for a discovery covering a wide spectrum of hypothesis
- Time dependent searches have great potential
- IceCube is sensitive to the composition at and above the knee