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Resultate der Neutrinoastronomie

Wolfgang Rhode, TU Dortmund

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Deutsche Gruppen in der Neutrinoastronomie

RWTH AACHEN UNIVERSITY

HUMBOLDT-UNIVERSITÄT ZU BERLIN

universitätbonn
Rheinische Friedrich-Wilhelms-Universität Bonn

RUHR UNIVERSITÄT BOCHUM
RUB

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BERGISCHE UNIVERSITÄT WUPPERTAL

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

DESY

Technische Universität München

Gefördert durch

BMBF Verbundforschung

DFG

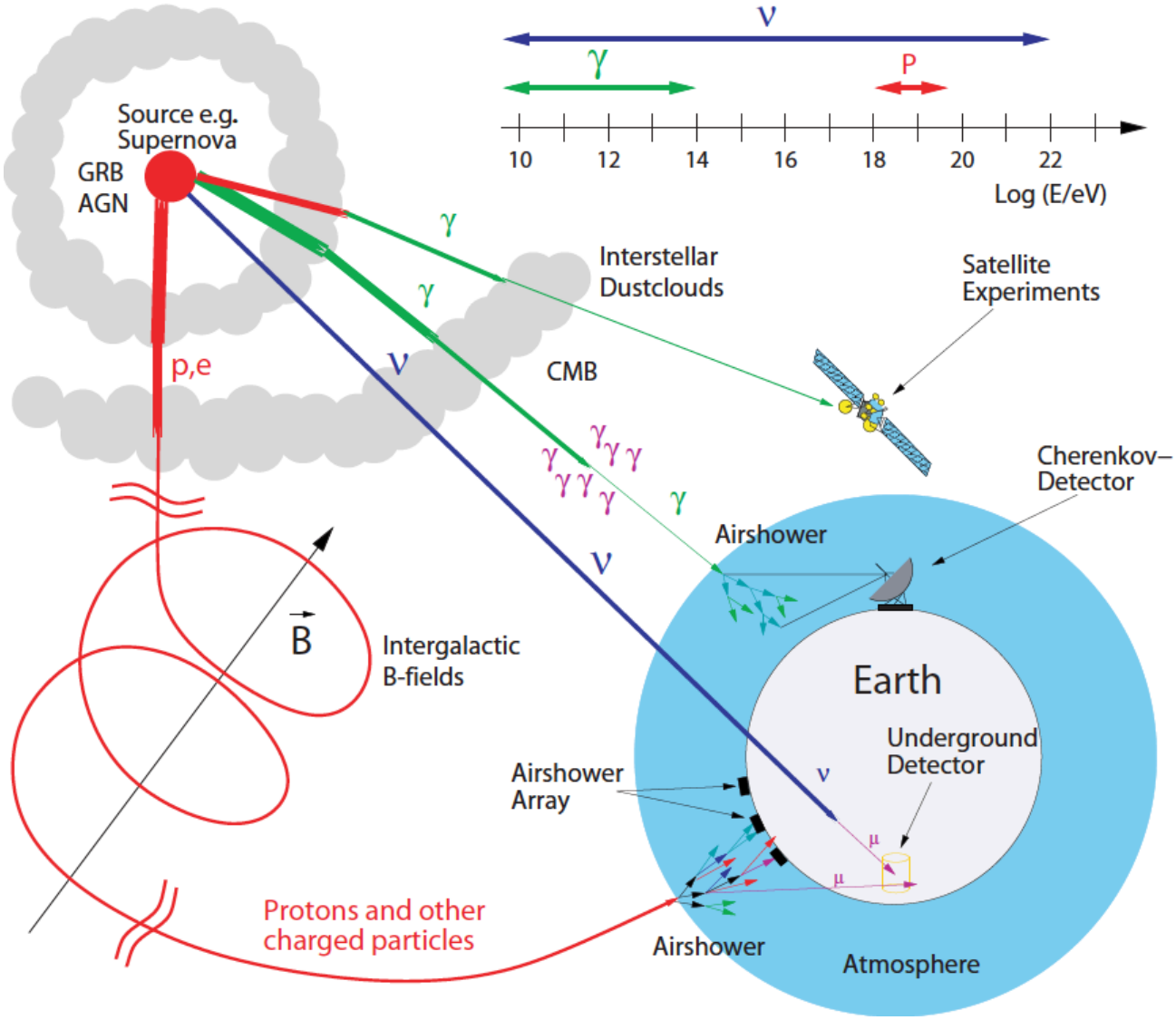
HAP - Helmhotz-Allianz Astroteilchenphysik

MERCUR

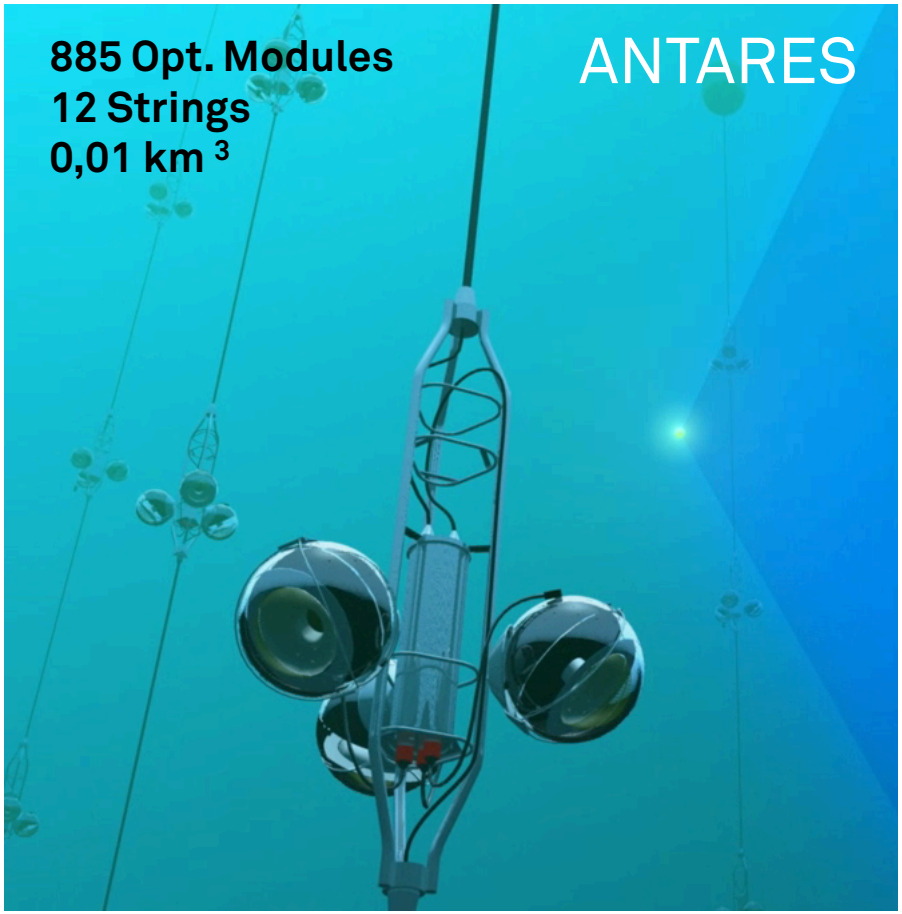
Scientific Questions

- Astronomy
  - Search for localized neutrino sources
  - Search for other high energy extra-terrestric neutrino fluxes
- Cosmic radiation
  - Energy spectrum, Chemical composition, Isotropy
- Particle Physics
  - Neutrino-Oscillations, Dark Matter, Monopoles, SUSY
  - Charm-CR, Muon-CR

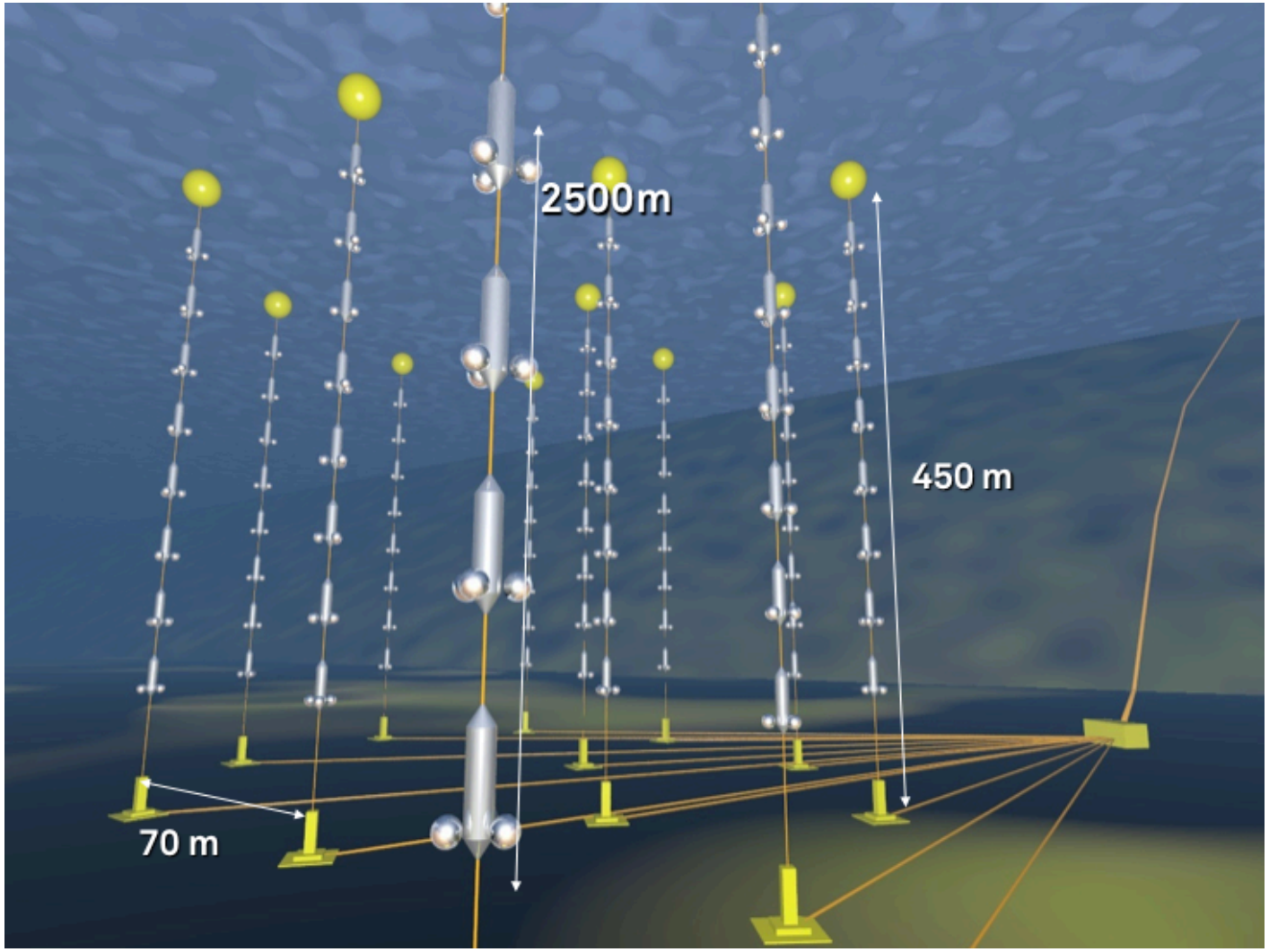
Astroparticles: Neutrino Astronomy



Detection Principle

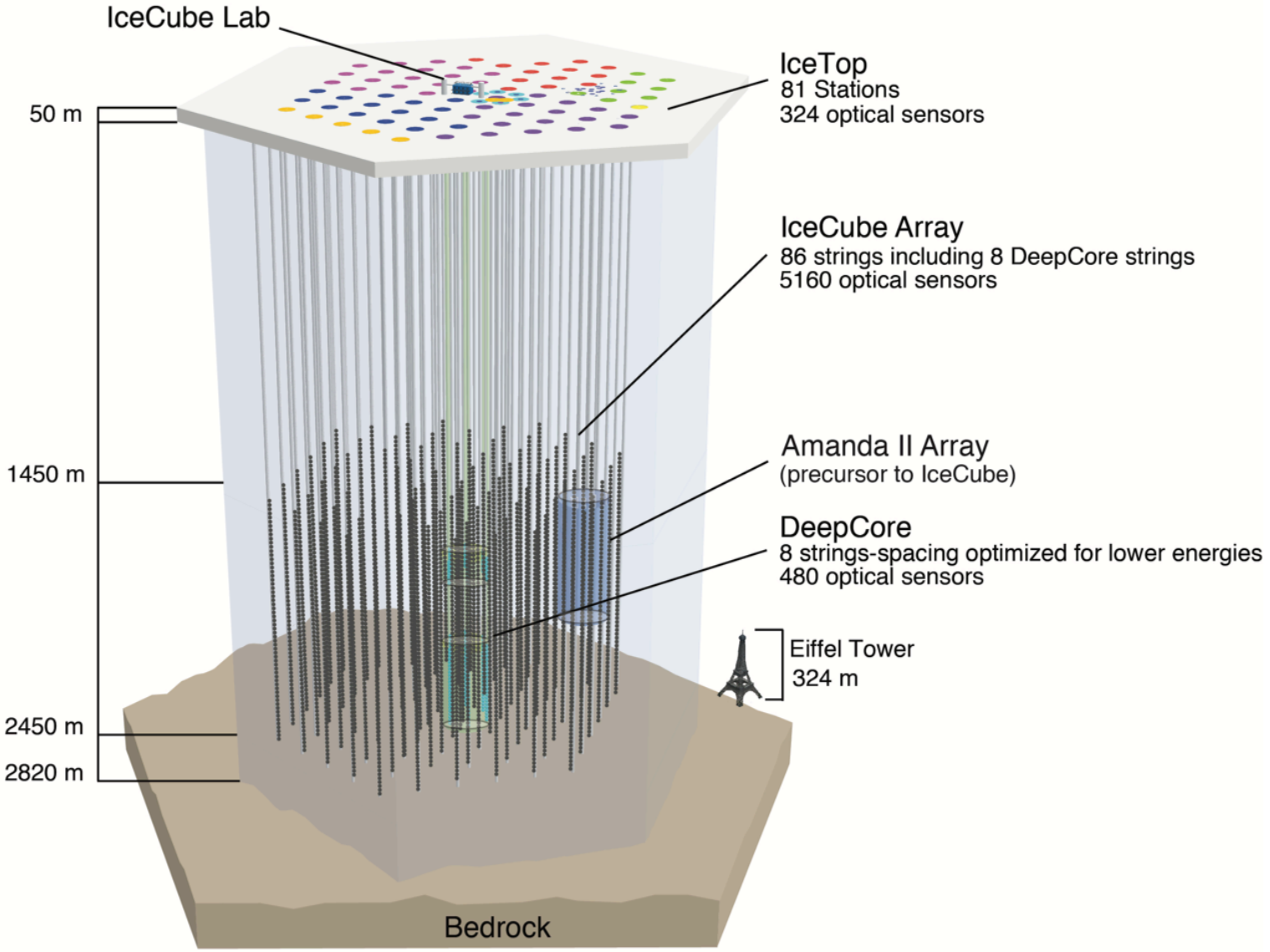


ANTARES



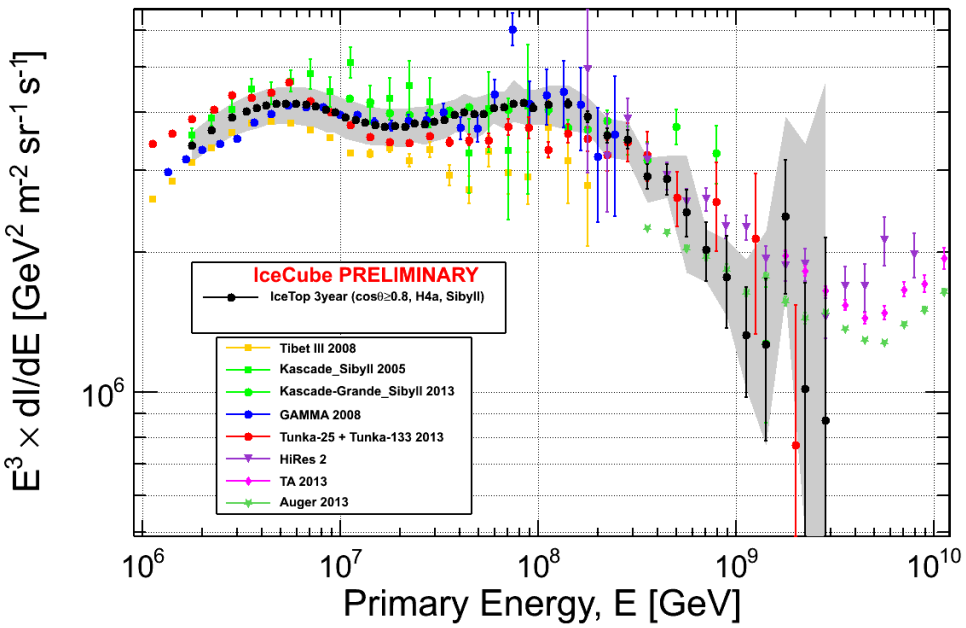
V. Bertin - CPPM - ARENA'08 @ Roma

IceCube


IceCube Lab
IceTop
81 Stations
324 optical sensors
50 m
IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors
1450 m
Amanda II Array
(precursor to IceCube)
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m
2450 m
2820 m
Bedrock

IceTop: Physics & Veto

Energy Spectrum (3 years)

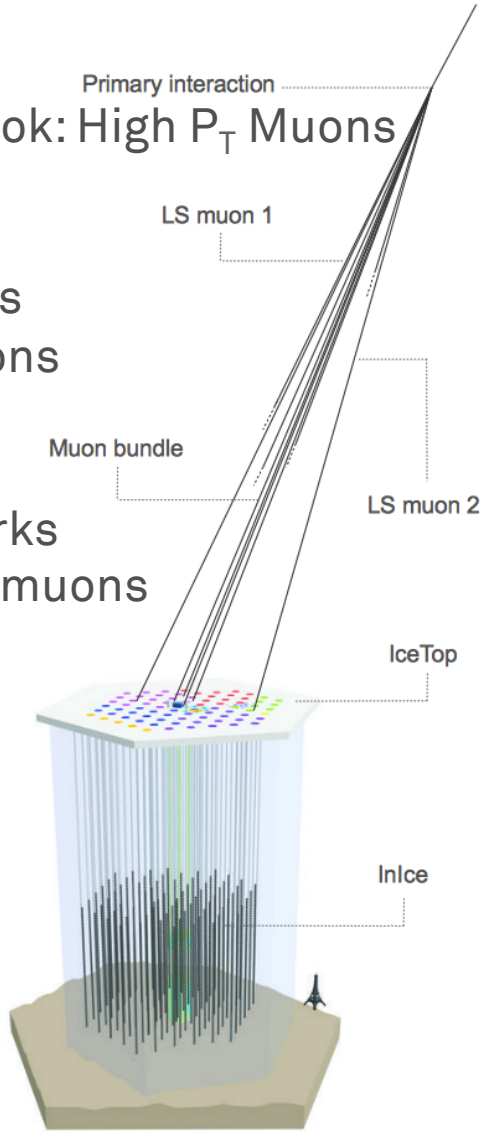


- $E_{max} > 2$ EeV
- Deviation from a single power law above the knee
- → Chemical Composition (four groups)

Outlook: High P_T Muons

high p_T Jets
→π, K muons

heavy quarks
→ prompt muons



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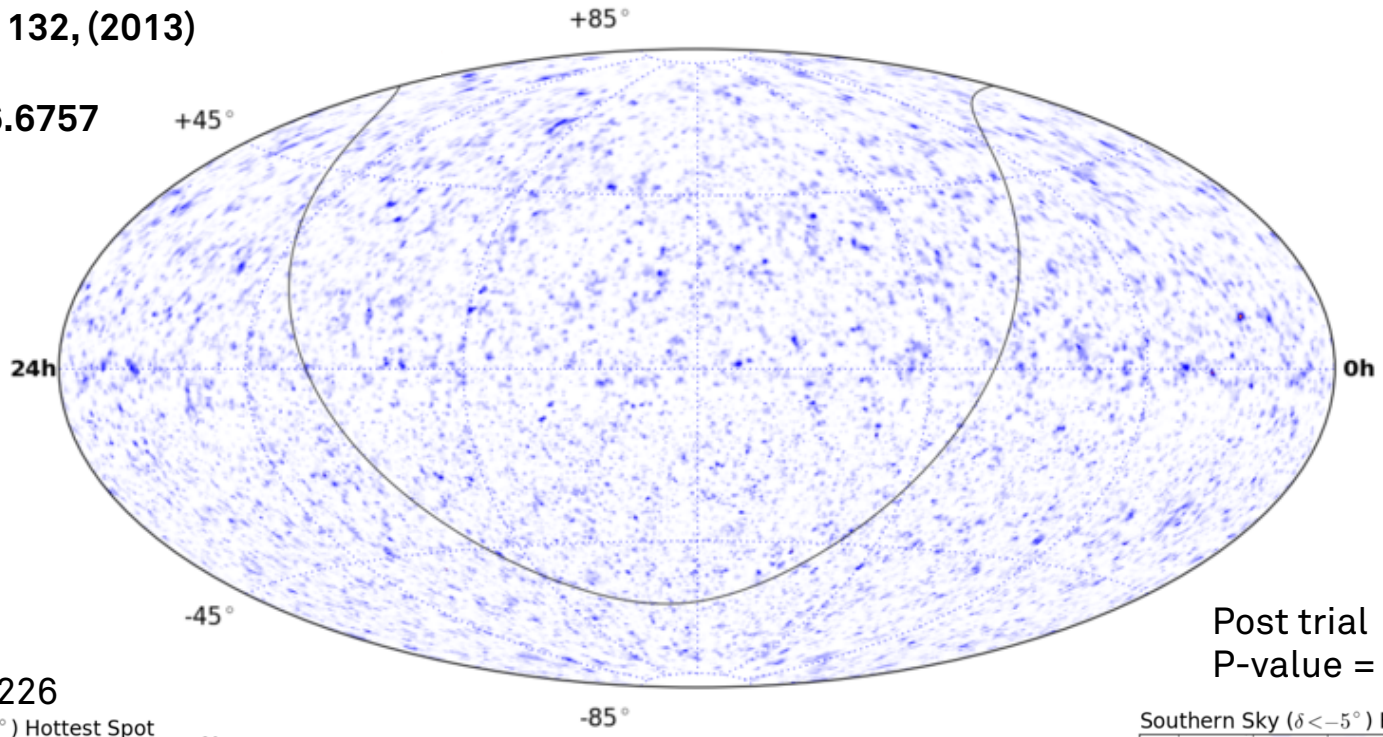
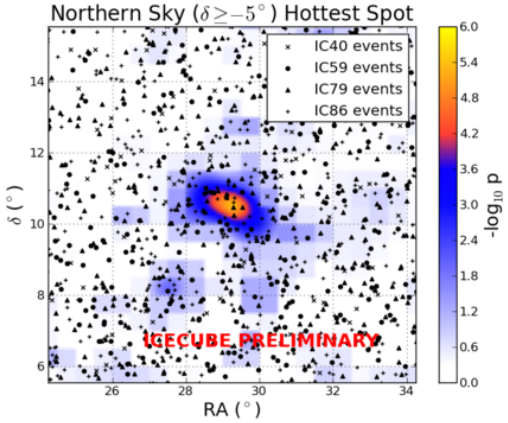
IceCube South Pole Neutrino Observatory

Point Source Analysis: IC40+IC59+IC79+IC86

IC40+IC59+IC79 =
ApJ, 779, 2, id. 132, (2013)
+IC86=
arXiv.org:1406.6757

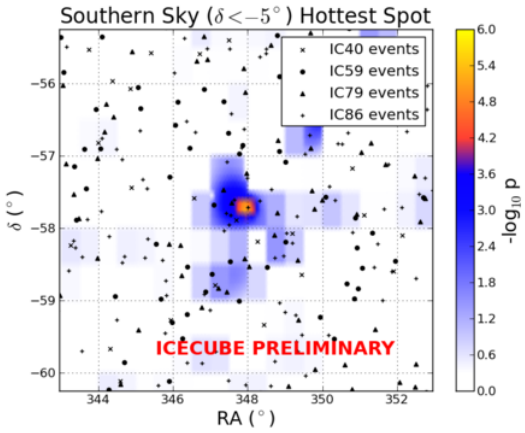


Post trial
P-value = 0.226



Source	$\Phi^{90\%}_{\nu_\mu+\bar{\nu}_\mu}$	p-value	$\hat{n}_s$
PKS 1502 +106	2.40	0.076	8.4
HESS J0632+057	2.23	0.058	15.6
IC443	1.63	0.43	2.8
Mrk 421	3.45	0.18	3.7
Mrk 501	2.84	0.34	4.8
Cyg X-3	2.35	0.43	2.4

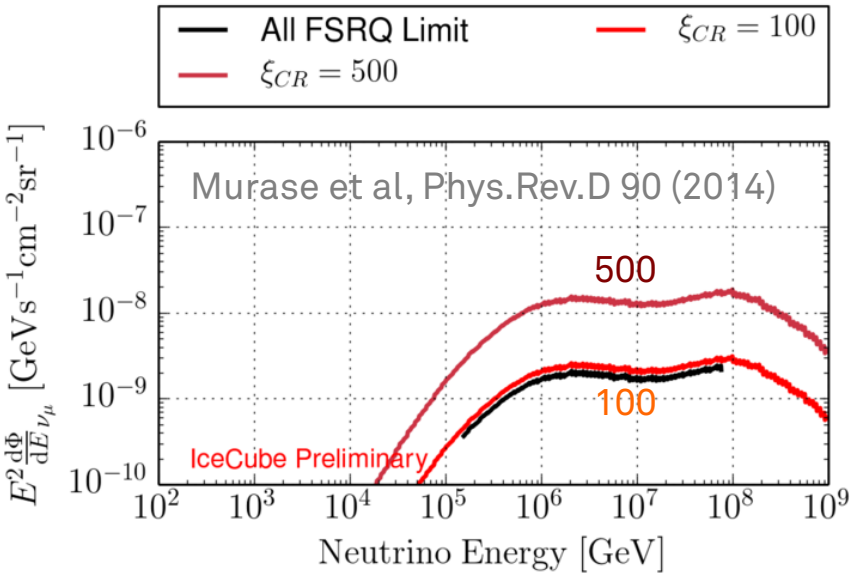
Post trial
P-value = 0.440

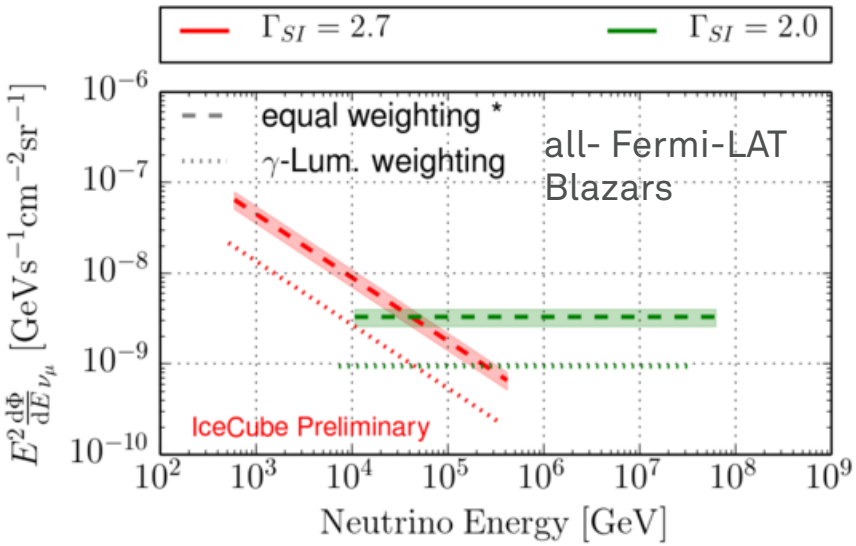


Analysis of the cumulative neutrino flux from FERMI-LAT blazar populations using 3 years of IceCube data

- Blazar classification (10% of the sky!):
  - Position of the synchrotron peak (L/M/H/SP)
  - Width of optical emission lines (BlLAC < 5A; FSRQ >5A)
- Weighting scheme:
  ① γ flux ~ν flux
  ② γ flux and ν flux not correlated

Limits obtained
FSRQ parameter space restricted





*) Band denotes central 90 % of outcomes of different realizations from the γ-Luminosity Function. This limit also holds for all (quasi-)isotropic subpopulations, independent of their gamma emission.

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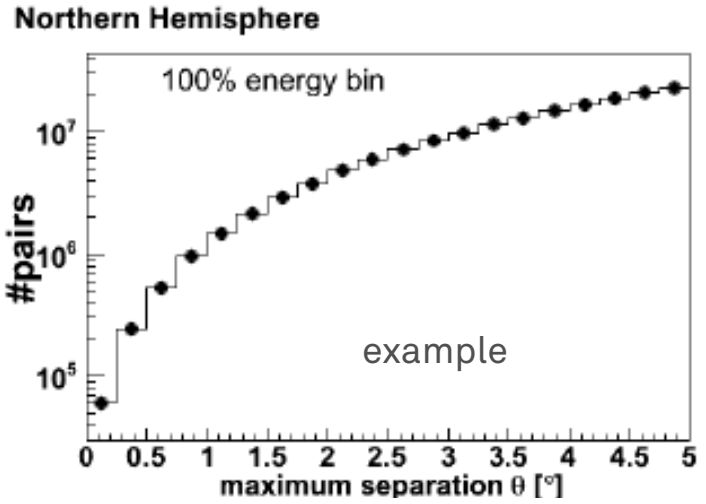
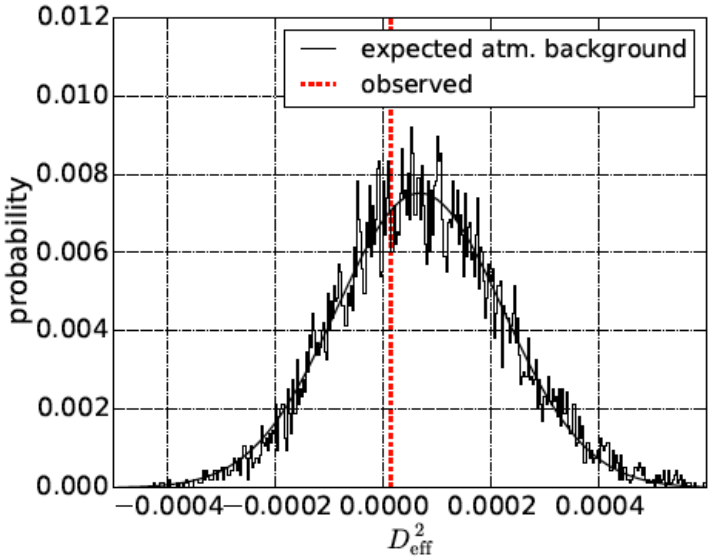
IceCube SOUTH POLE NEUTRINO OBSERVATORY

Searches for small-scale anisotropies from neutrino point sources with three years of IceCube data

- **Autocorrelation test:**
  - Results consistent with background fluctuations
- **Multipole Analysis:**
  - Agreement with background distribution
- **Limits derived e.g. for one source :**
  - O(10^{-8} GeV $cm^{-2}s^{-1}$)
- Excluded, that the emission of < 10 isotrop dist. strong sources with E^{-2} dominates the HE flux.

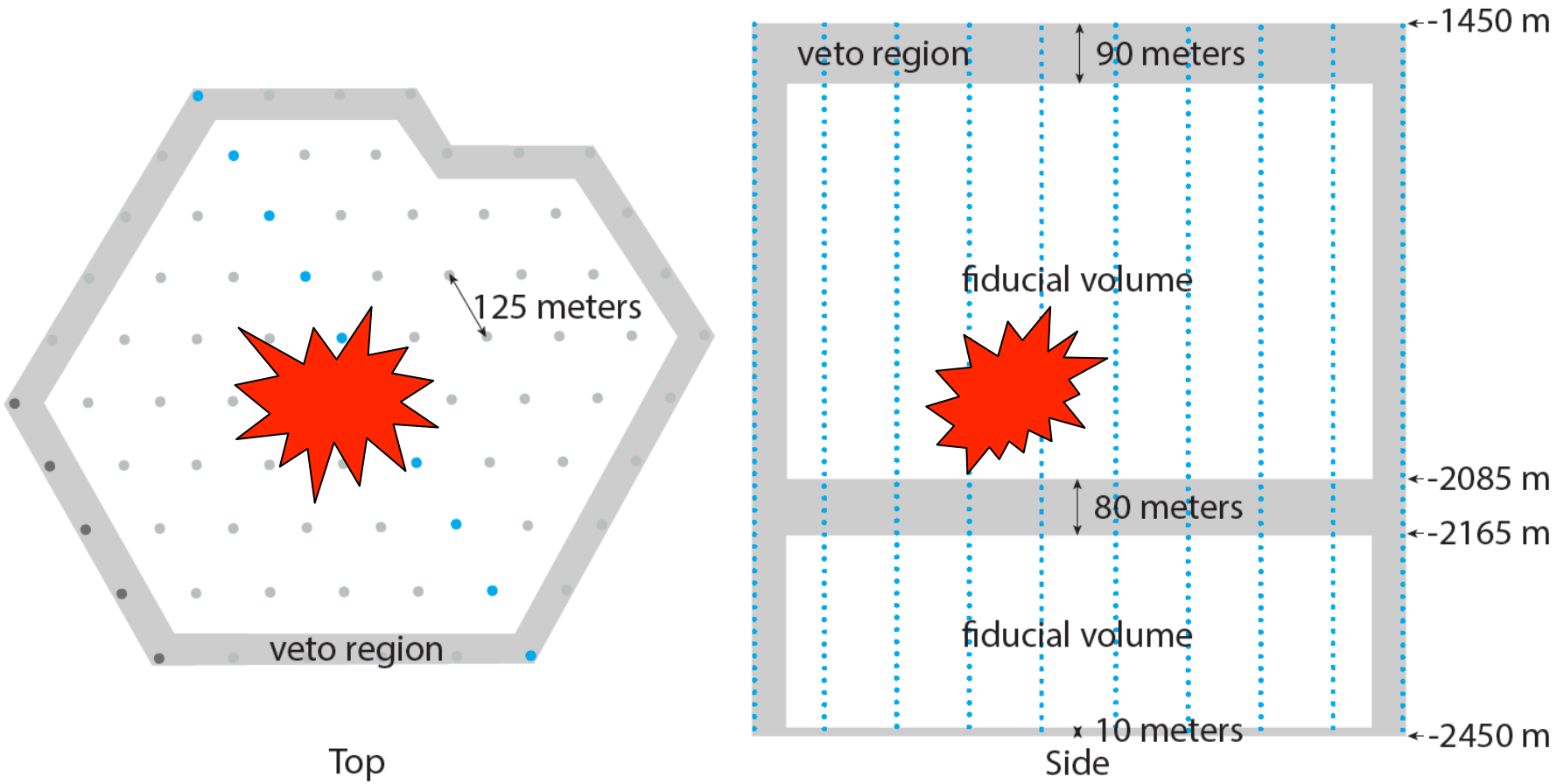




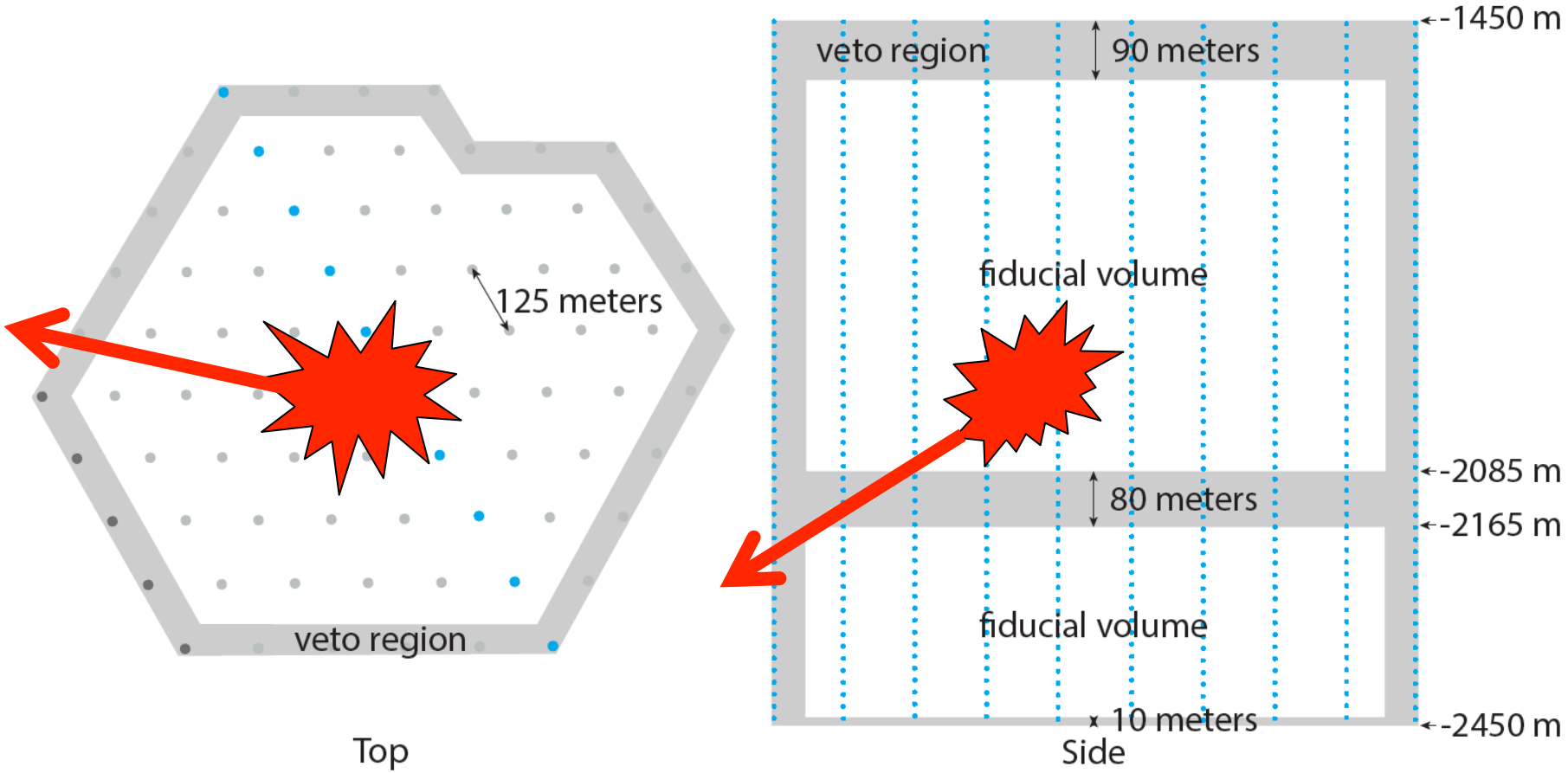
Dist. of weighted differences of Cl exp/bg-Coeff.

E. Resconi, München; C. Wiebusch, Aachen; arXiv:1408.0634

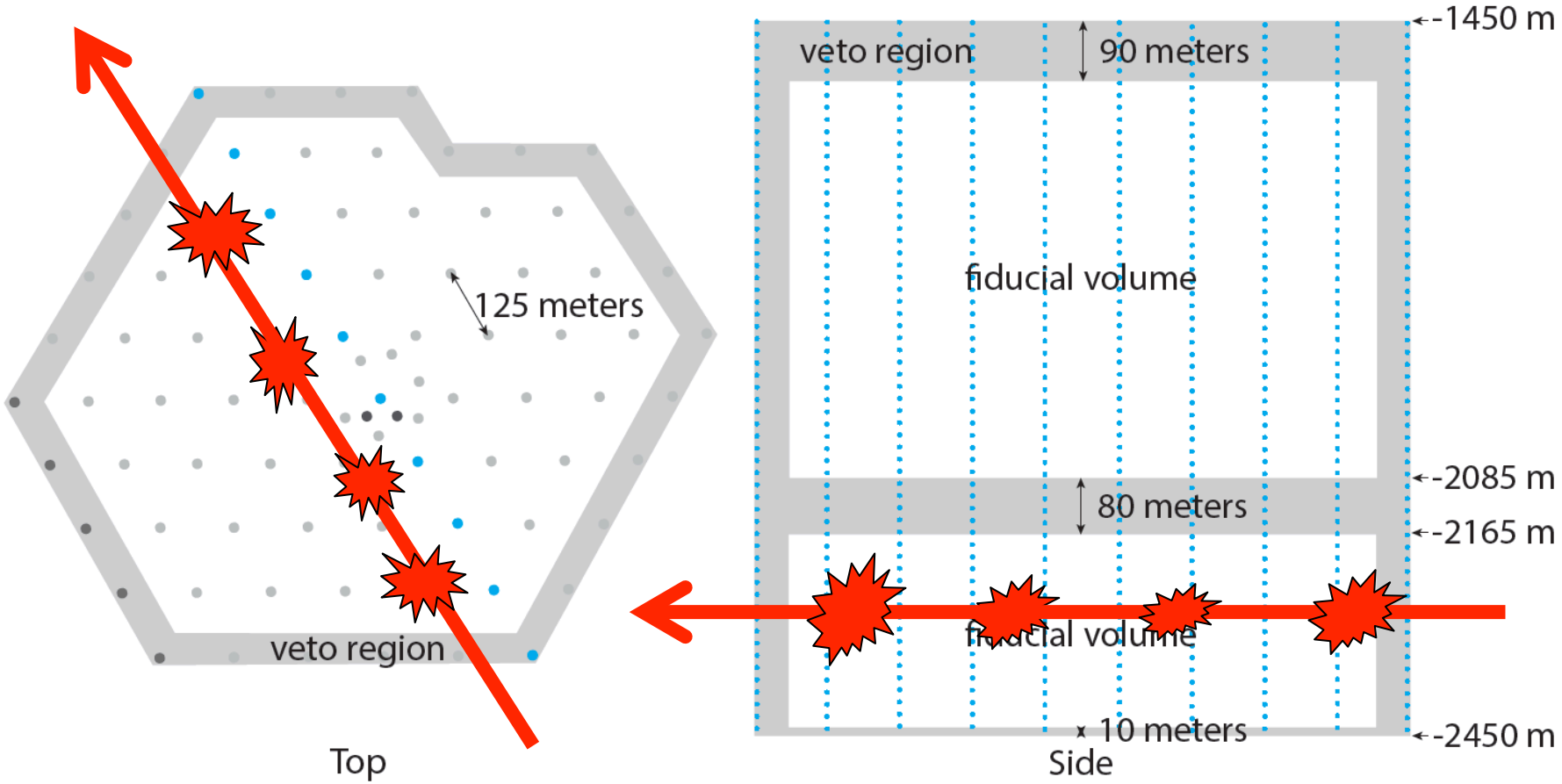
Three Signatures: 1. Cascades



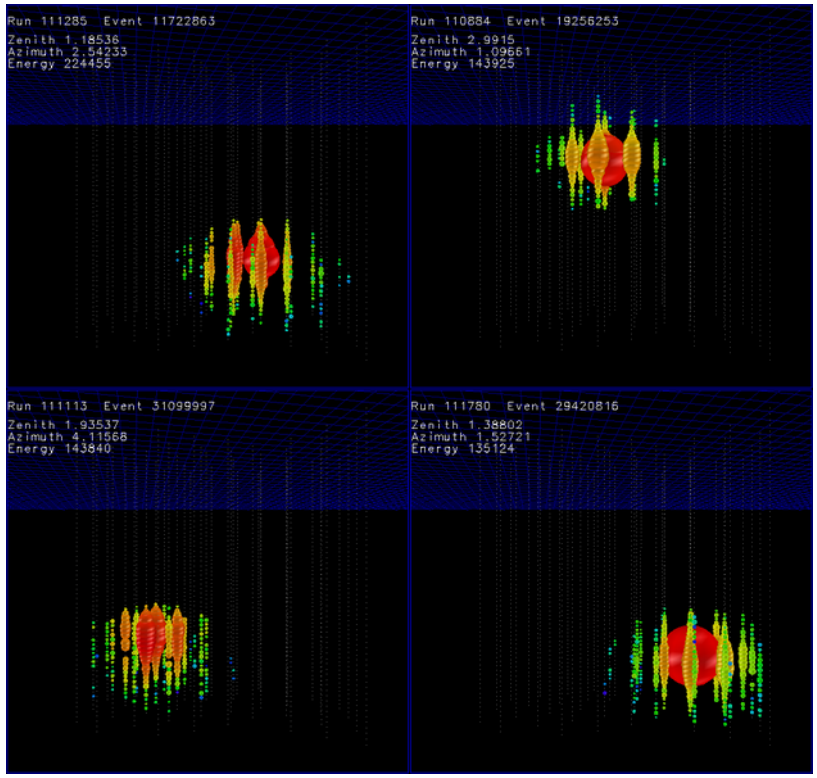
Three Signatures: 2. Starting Tracks

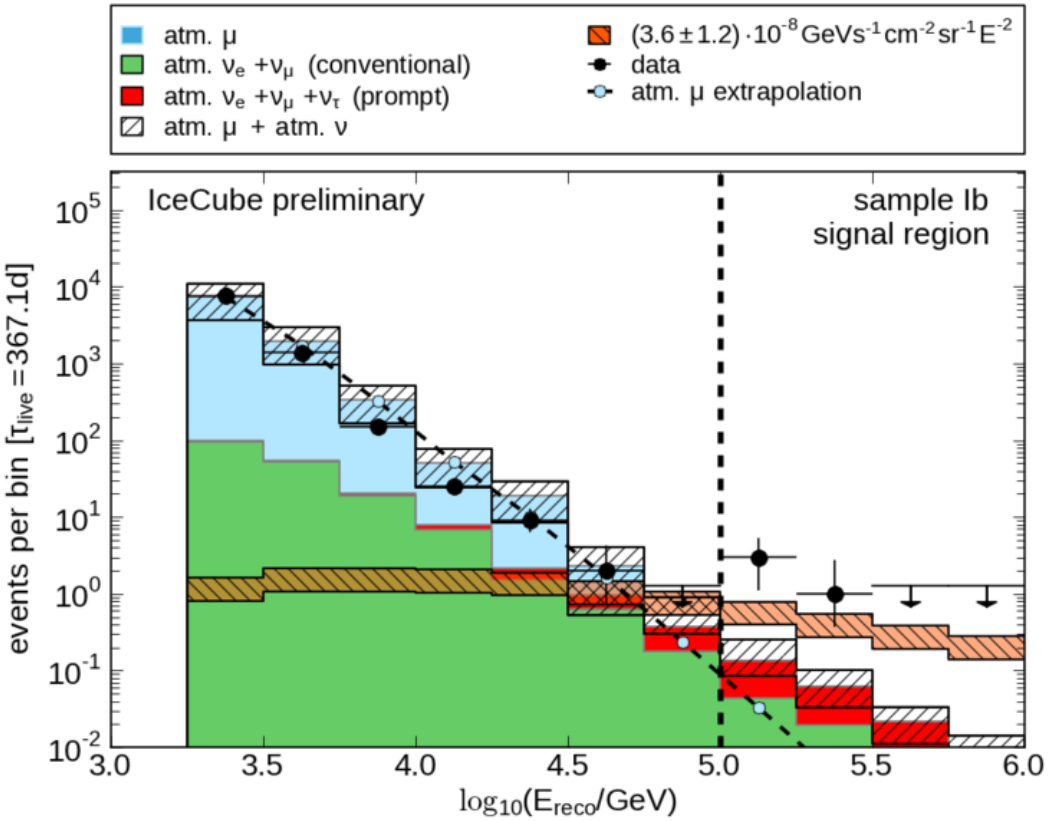


Three Signatures: 3. Throughgoing Tracks



IC40 Atmospheric Flux Cascade Analysis





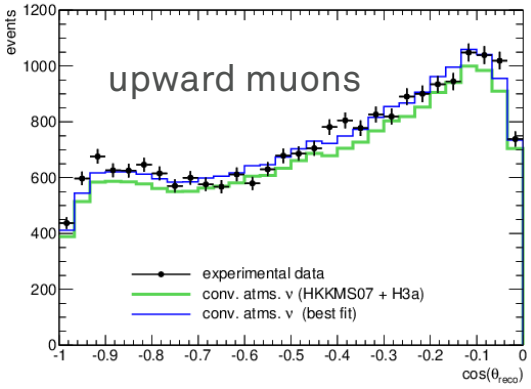
- 1+3 Cascade Events > 100 TeV
- → 2,7 σ excess

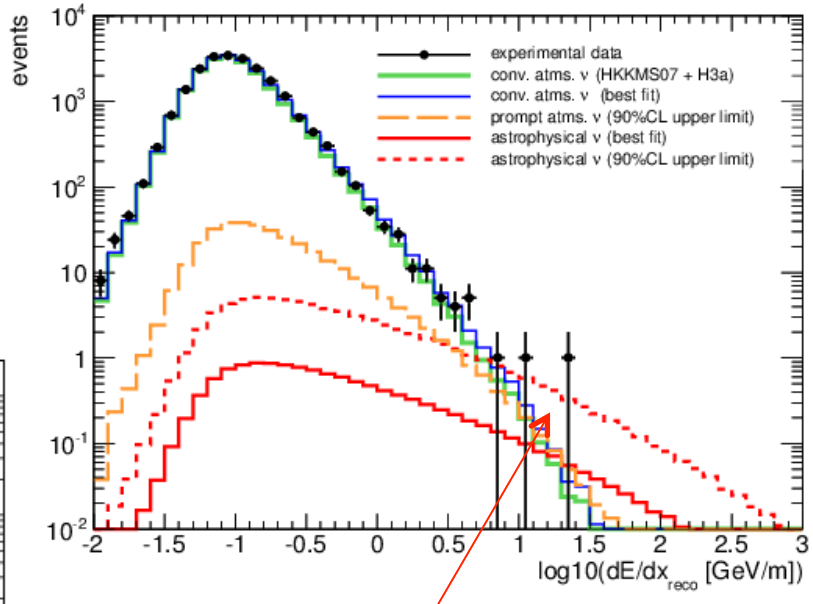
Limit 90% CL:

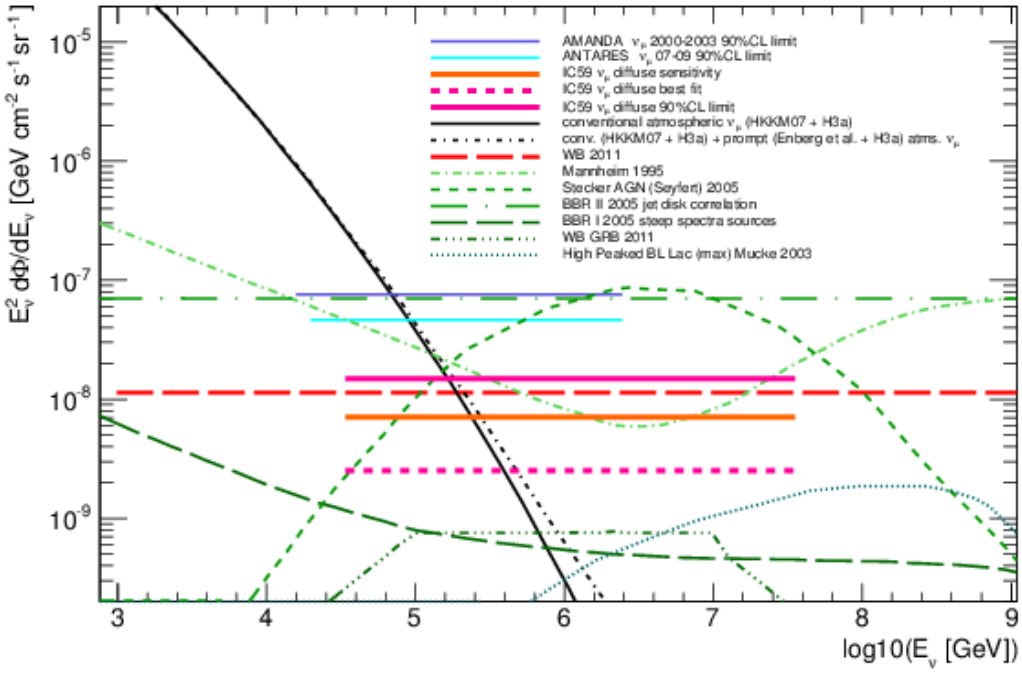
$7{,}64 * 10^{-8}\ E^2 d\Phi/dE_\mu$ [GeV cm^{-2}s^{-1}sr^{-1}]

Eike Middell, Zeuthen Phys. Rev. D 89, 102001 (2014)

IC 59: Search for a diffuse flux of astrophysical neutrinos







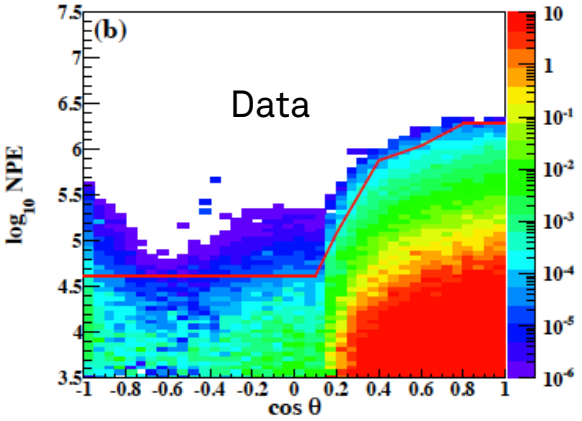
400 TeV Muon; 1.8 σ

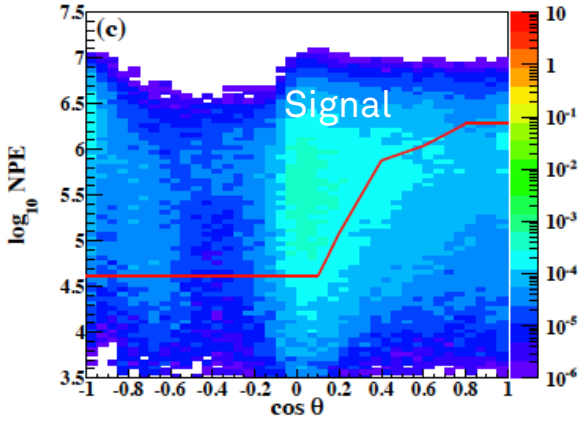
Limit 90% CL:

$1{,}44 \cdot 10^{-8}\, E^2 d\Phi/dE_\mu$ [GeV cm^{-2}s^{-1}sr-1]

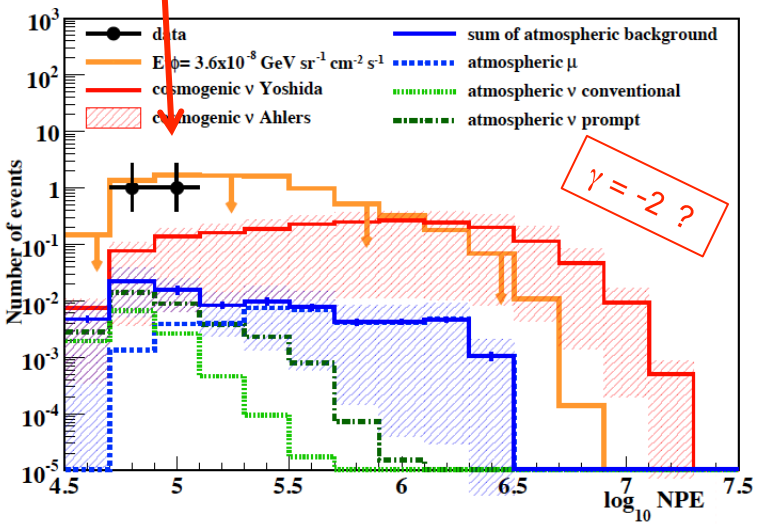
High energy cascades in IC 79 und IC 86

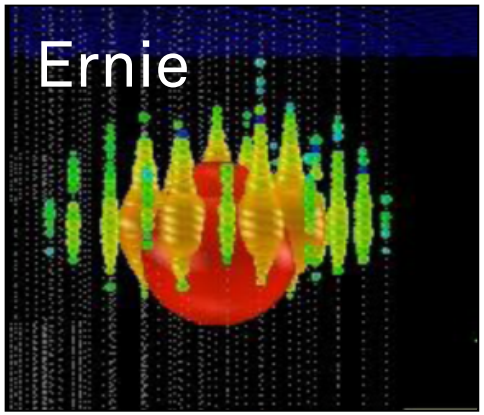
- Search for cosmogenic „contained“ >1 PeV-neutrinos in IC 79 und IC 86

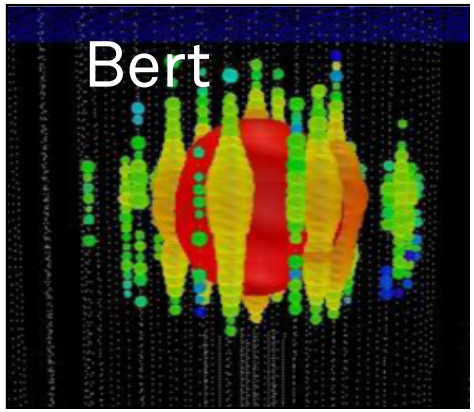




2,8 σ







Phys. Rev. Lett. 111, 021103 (2013)

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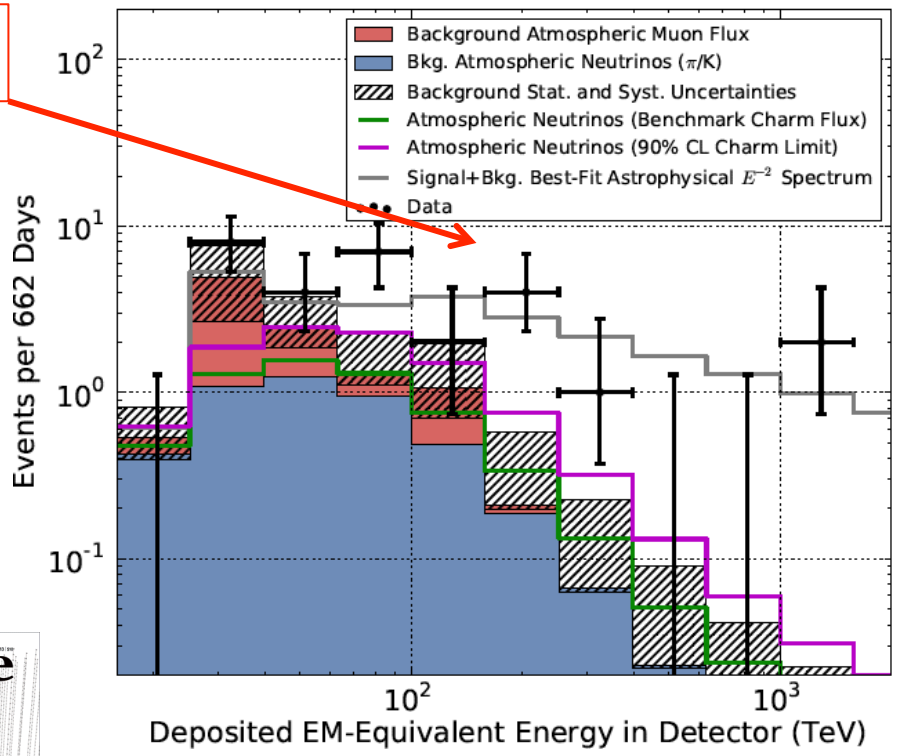
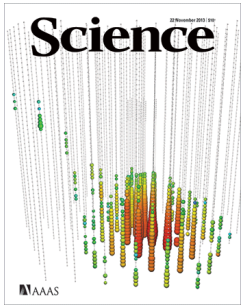
HESE: High Energy Starting Events in IC 79 und IC 86

- Search for „semi-contained“ HE-Events

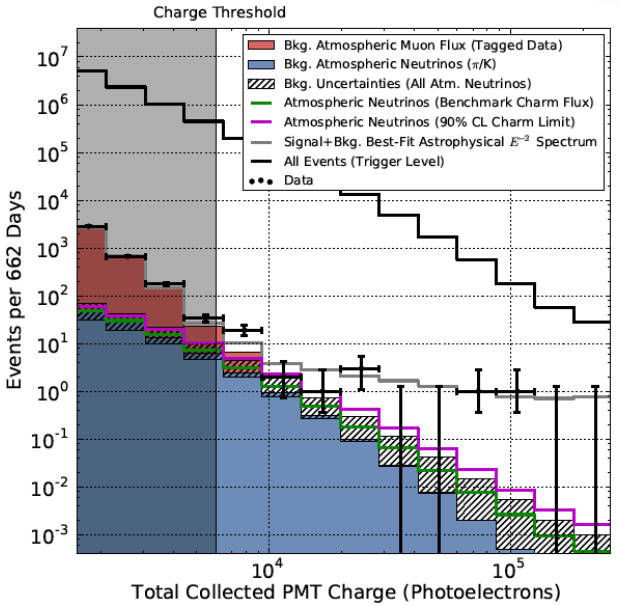
> 4 σ

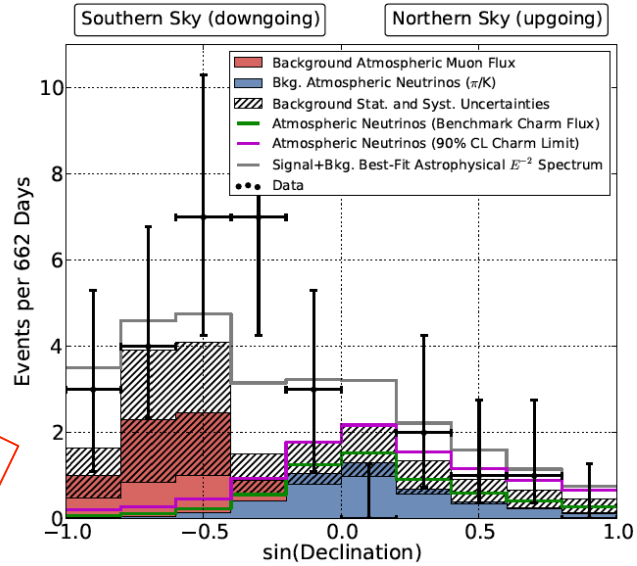




26 + 2 Events

γ = -2 ?

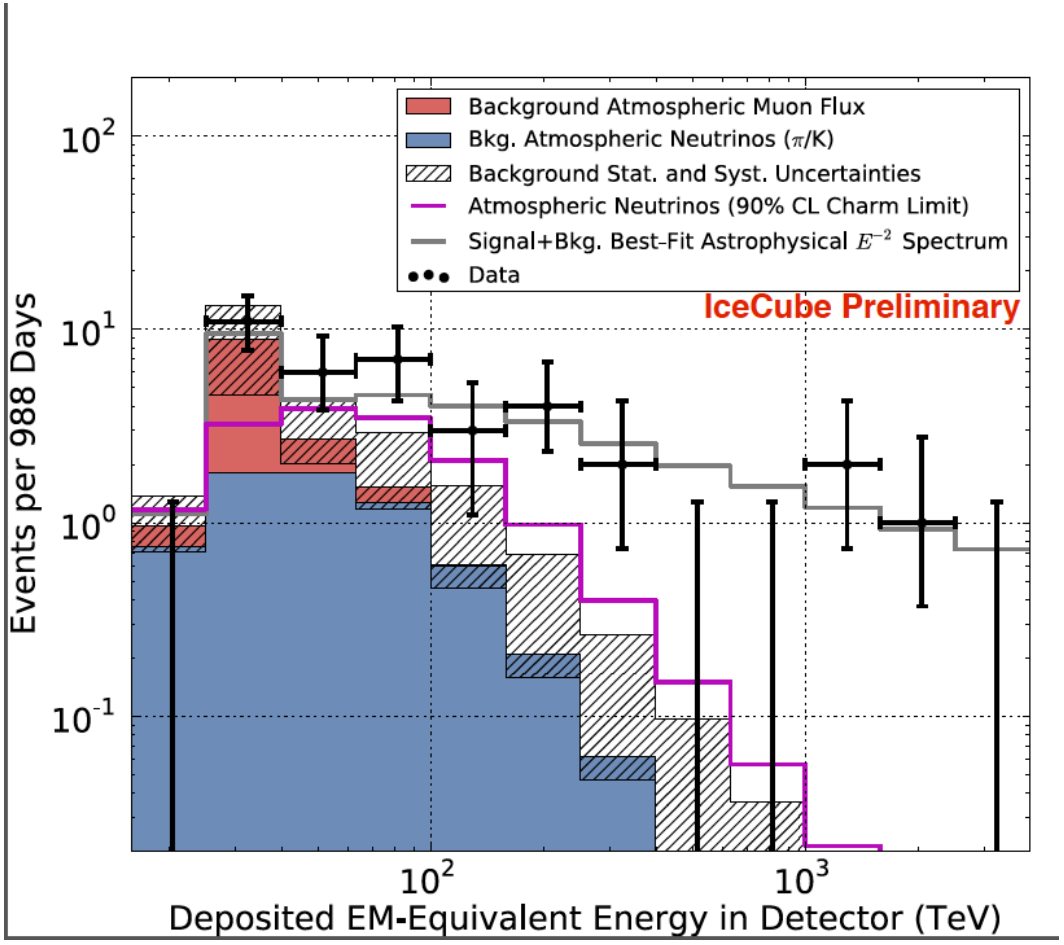




Science, 342, Is. 6161, id.1242856 (2013)

HESE: 3 years

37 Events → 5.1 σ (rumors: 4 years → 54 events...)



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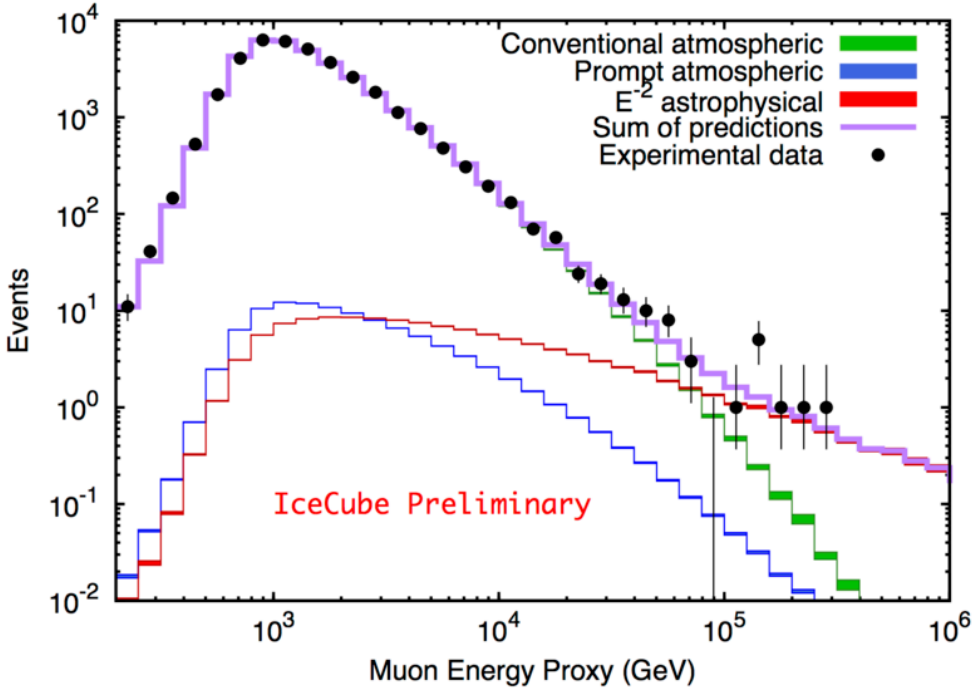
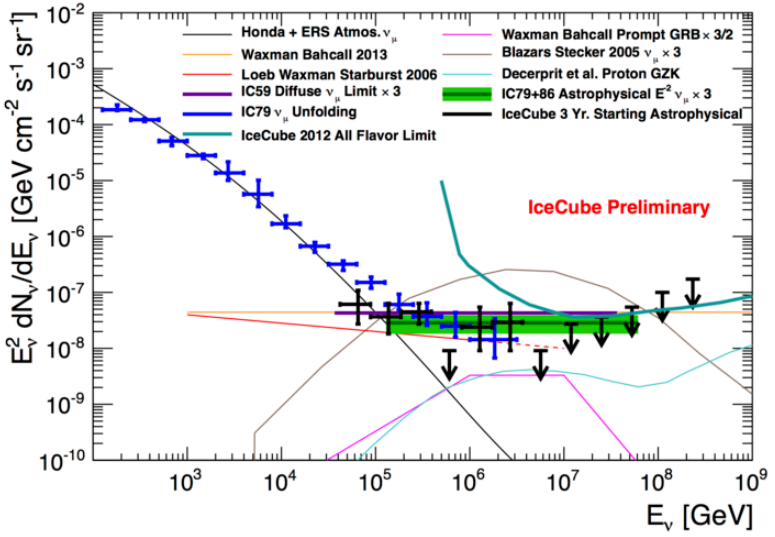
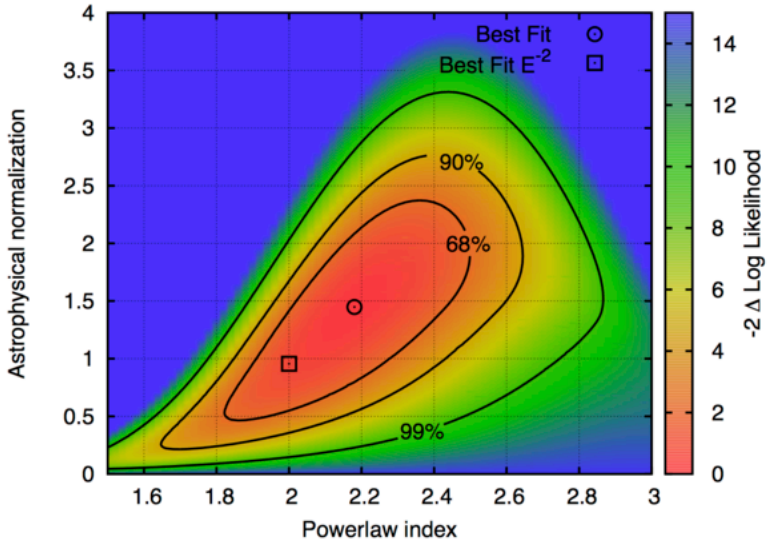
IceCube SOUTH POLE NEUTRINO OBSERVATORY

Diffuse Muon Neutrino Analysis IC79 + IC86



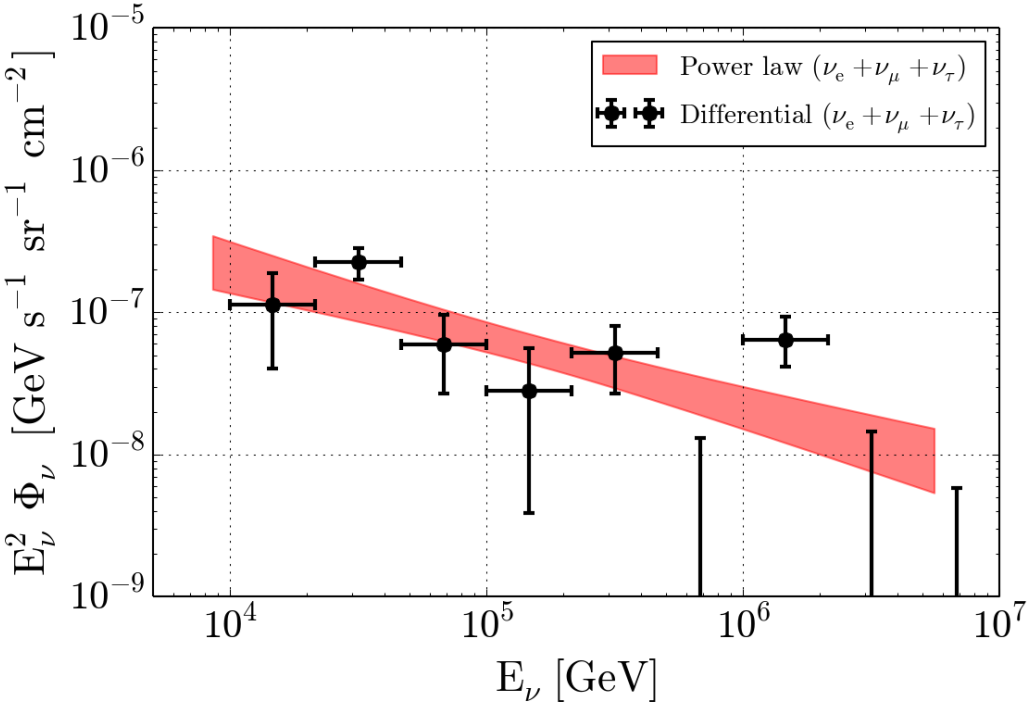


Atm. norm: **fixed**
Prompt norm: **fixed**
Astrophys. Index : **= 2.2 ± 0.2**



A Global Fit of the Results of the Diffuse Analyses

- Analyses:
  - Cascades: IC 40 + IC59 + IC79/86 (incl. Tracks)
  - Diffuse: IC 59 + IC 79/86
  - HESE
- Free Parameters:
  - conv. ν-flux: norm.
  - prompt ν-flux: norm.
  - astro. ν-flux norm + ind.
- Syst. uncertainties of the models considered



$$\Phi_{astro} = (2.29^{+0.36}_{-0.35}) * 10^{-18}\ GeV^{-1}\ s^{-1} sr^{-1} cm^{-2} * (E / 100\ TeV)^{-2.50 \pm 0.08}$$

Prompt component: fitted to zero with < 1.5 * ERS at 90% CL

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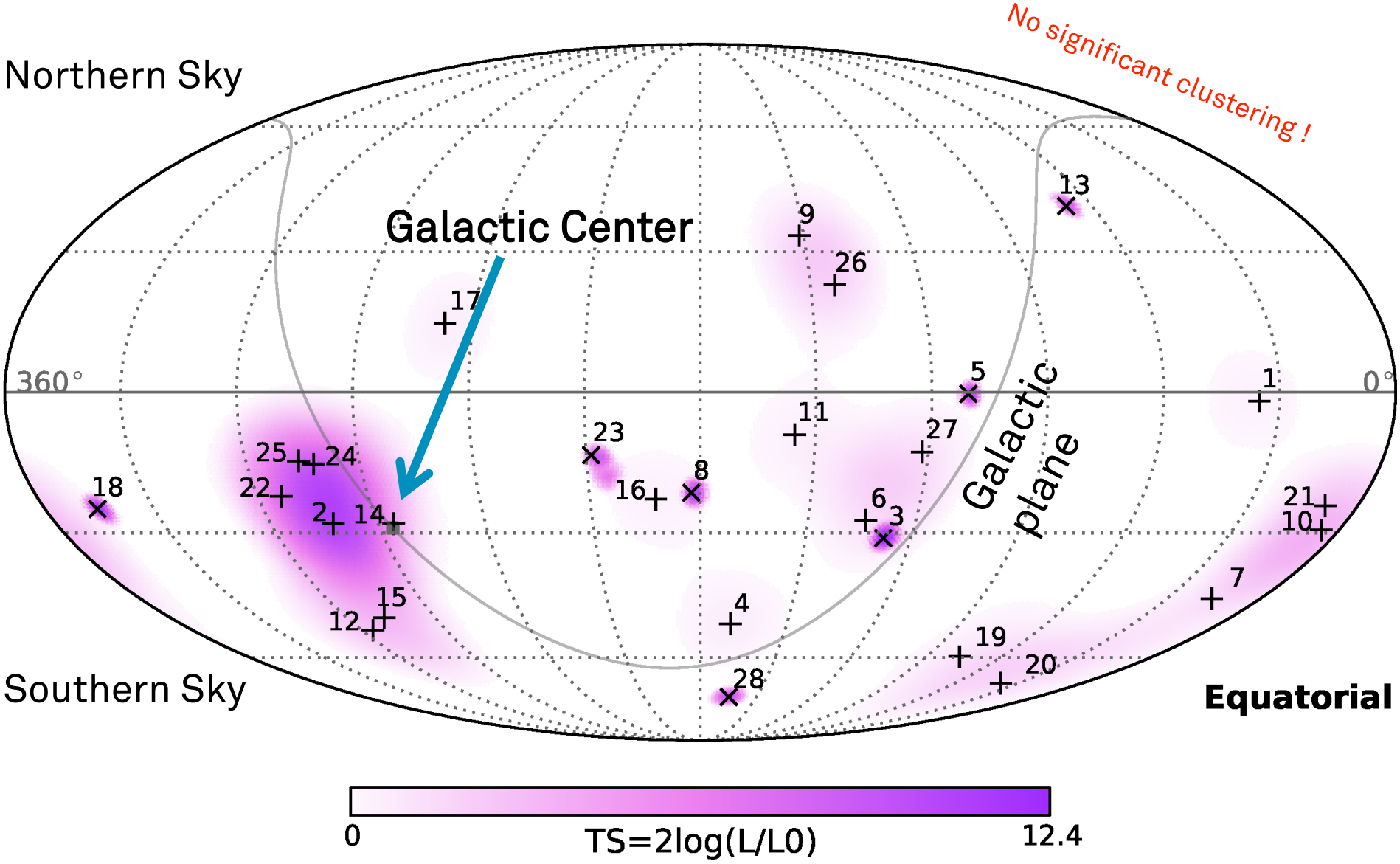
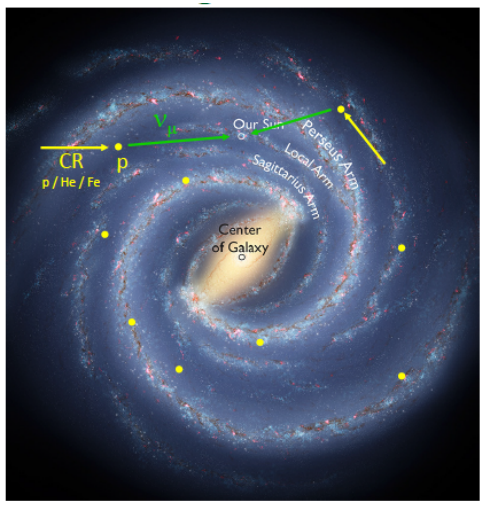
IceCube SOUTH POLE NEUTRINO OBSERVATORY

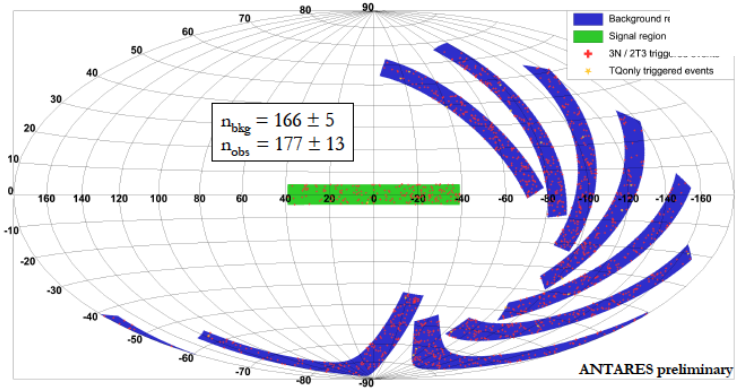
Sky Map of the 28 HE Neutrino Events

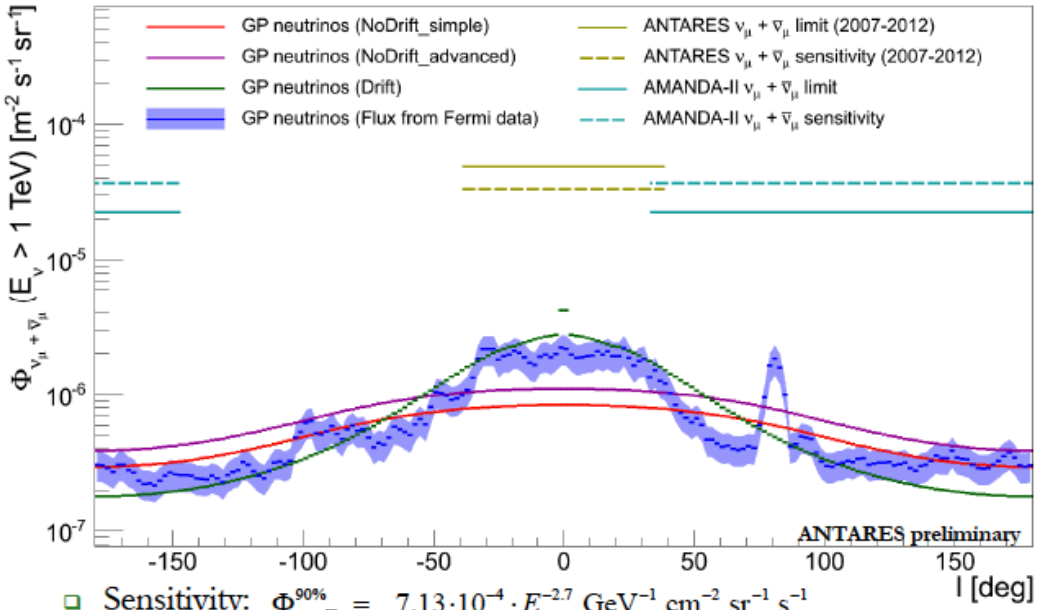


ANTARES: Neutrinos from the Galactic Plane?

ECRS 2014 - Erwin Visser







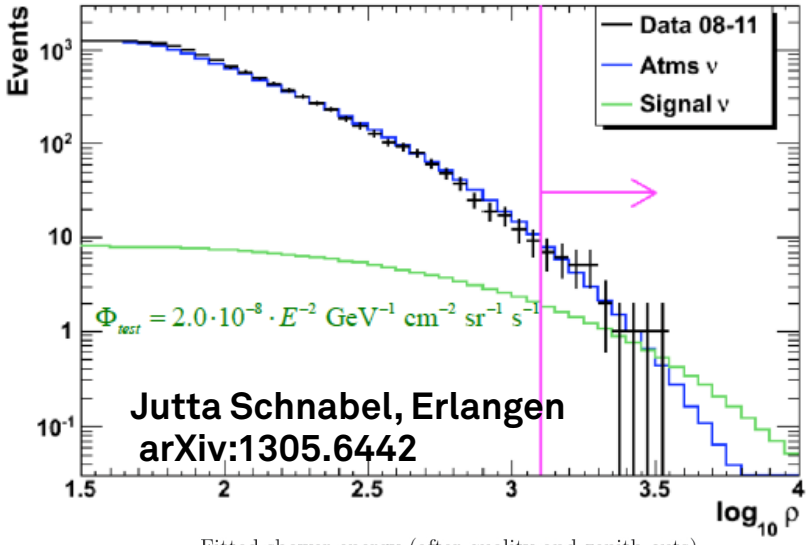
- Sensitivity: $\Phi^{90\%}_{\nu_\mu+\bar{\nu}_\mu} = 7.13 \cdot 10^{-4} \cdot E^{-2.7}$ GeV^{-1} cm^{-2} sr^{-1} s^{-1}
- Flux limit: $\Phi^{90\%}_{\nu_\mu+\bar{\nu}_\mu} = 10.18 \cdot 10^{-4} \cdot E^{-2.7}$ GeV^{-1} cm^{-2} sr^{-1} s^{-1}

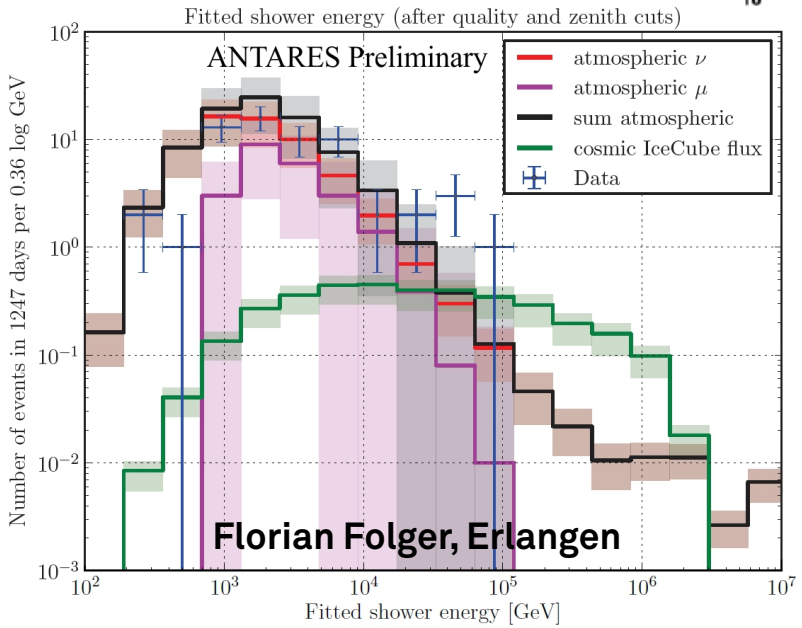
Result:

- Small Excess of 0,8 σ
- Flux Limit Calculated

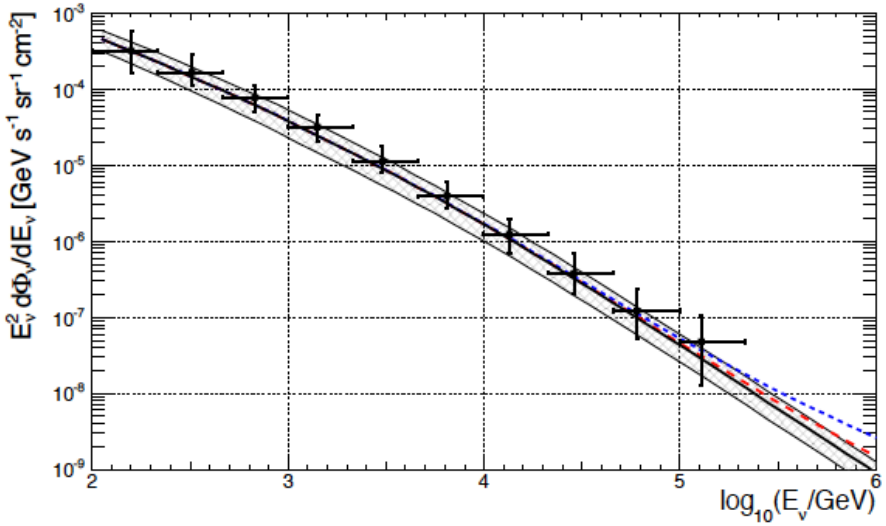
ApJL, 786, 1, id. L5, . (2014)

ANTARES: Search for Isotropic Contributions to the Atm. Flux





$$\Phi^{90\%}_{\nu_\mu+\bar{\nu}_\mu} = 4.7 \cdot 10^{-8} \cdot E^{-2} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$$
$$\Phi^{90\%}_{\nu_\mu+\bar{\nu}_\mu} = 5.1 \cdot 10^{-8} \cdot E^{-2} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$$
$$45 \text{ TeV} < E < 10 \text{ PeV}$$



EPJC, 73, id.2606 (2013)

$$\Phi^{90\%}_{\nu+\bar{\nu}} = 3.9 \cdot 10^{-8} \cdot E^{-2} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$$
$$\Phi^{90\%}_{\nu+\bar{\nu}} = 4.9 \cdot 10^{-8} \cdot E^{-2} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$$
$$23 \text{ TeV} < E < 7.8 \text{ PeV}$$

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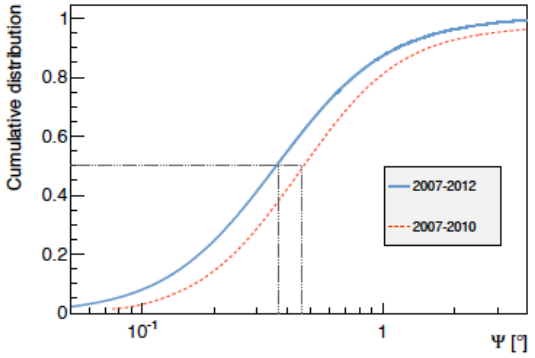
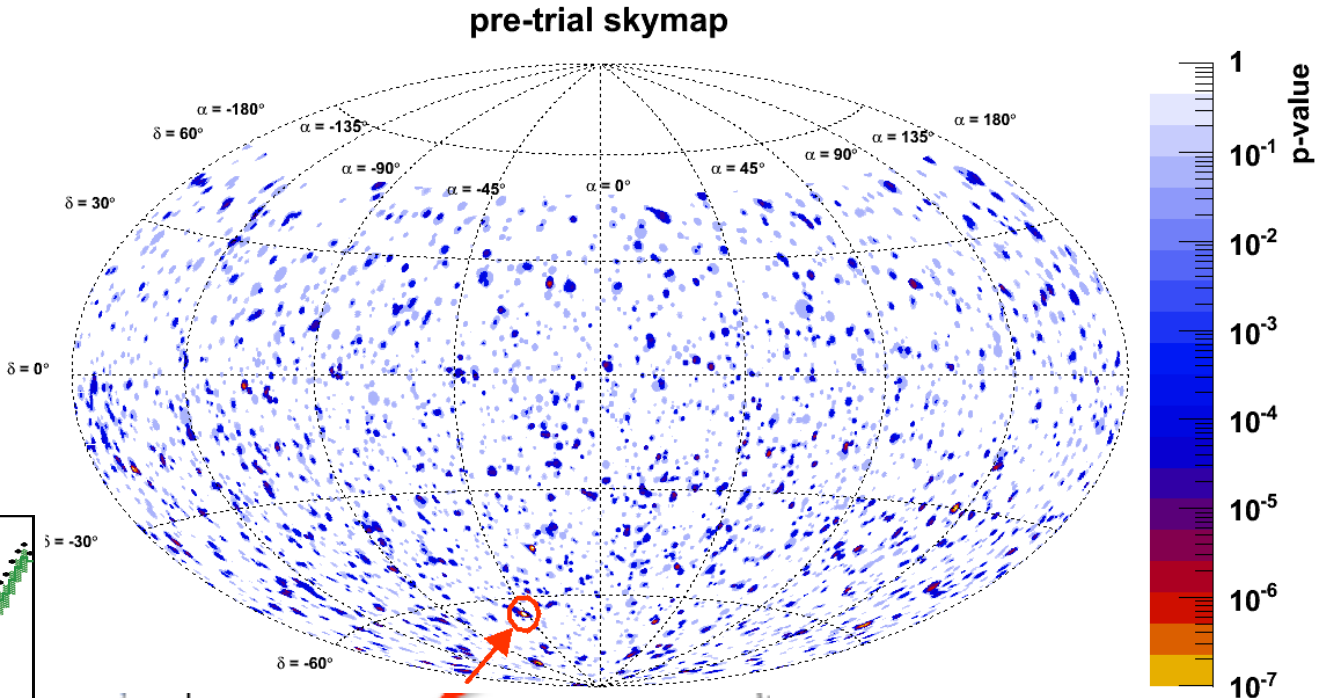
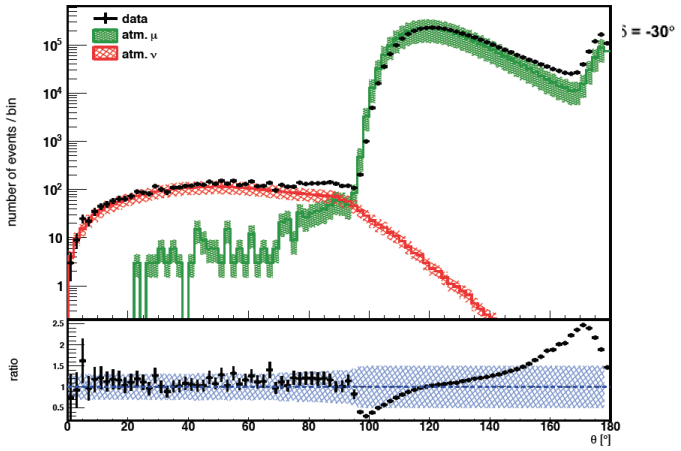
ANTARES: Search for Point Sources in Six Years of Data







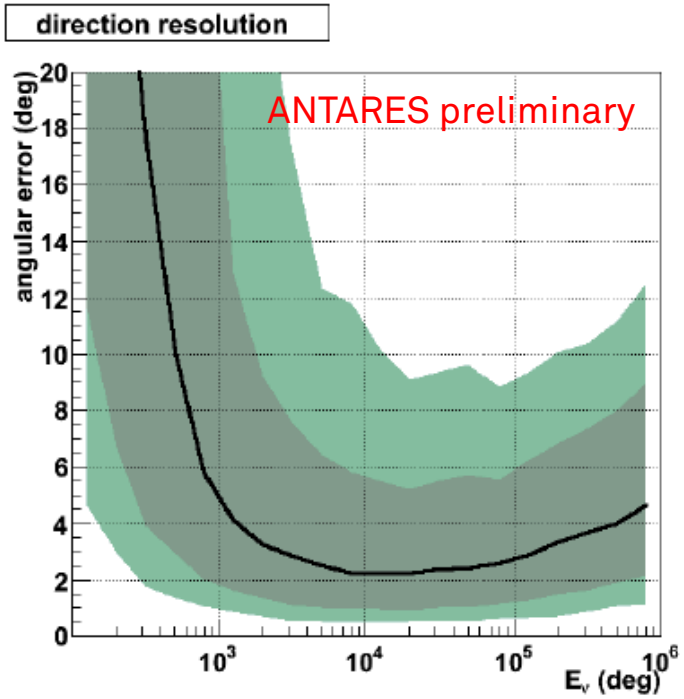
Full sky search:
Post trial p-value: 0.027
Significance: 2.2σ
RA: -46°8 DEC: -64°9
Same cluster than in the 2007-2010 analysis

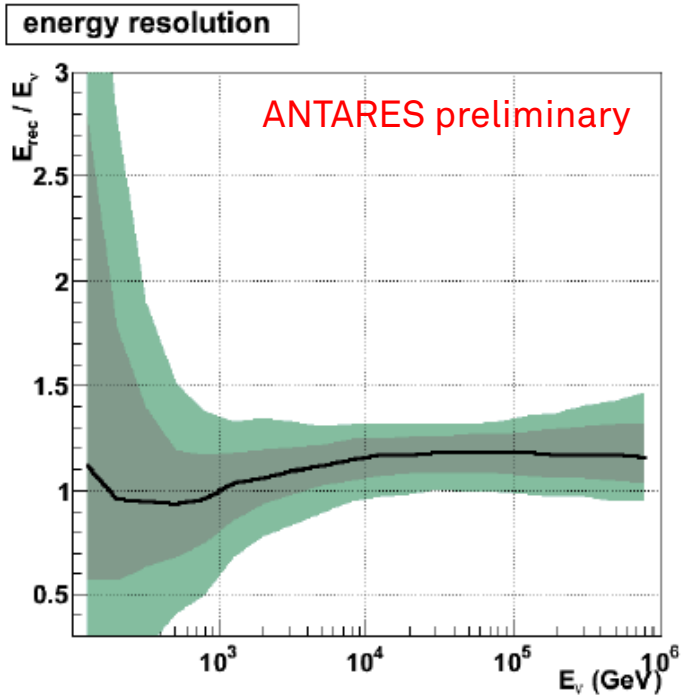
Candidate list:
Post trial p-value: 0.061
Significance: 1.9σ
RA: 98°2 DEC: 5°8
HESS J0632+057

arXiv:1402.6182

ANTARES: Outlook → Improvement of the point source analysis

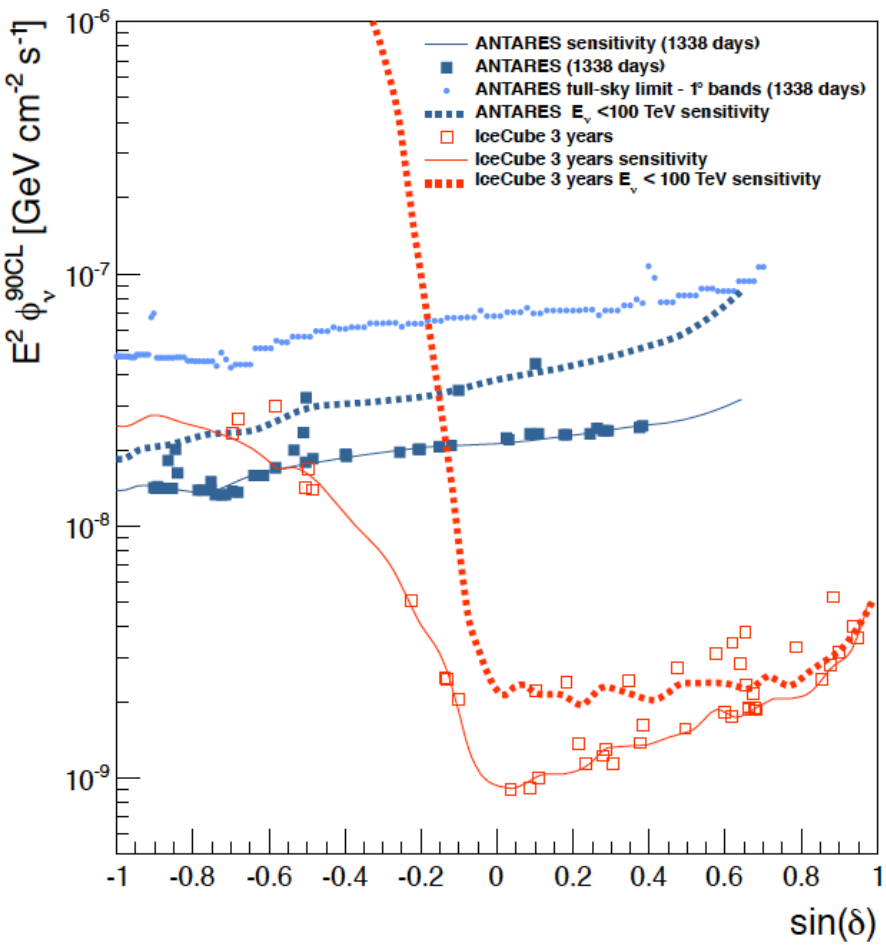
- Reconstruction of cascades:
  - Angular resolution: 6 deg at 10-50 TeV
  - Energy resolution: 0.2 - 0.3 OM
- With a newly developed method:
  - Angular resolution: 2 deg at 10 TeV
  - Energy resolution: 10%





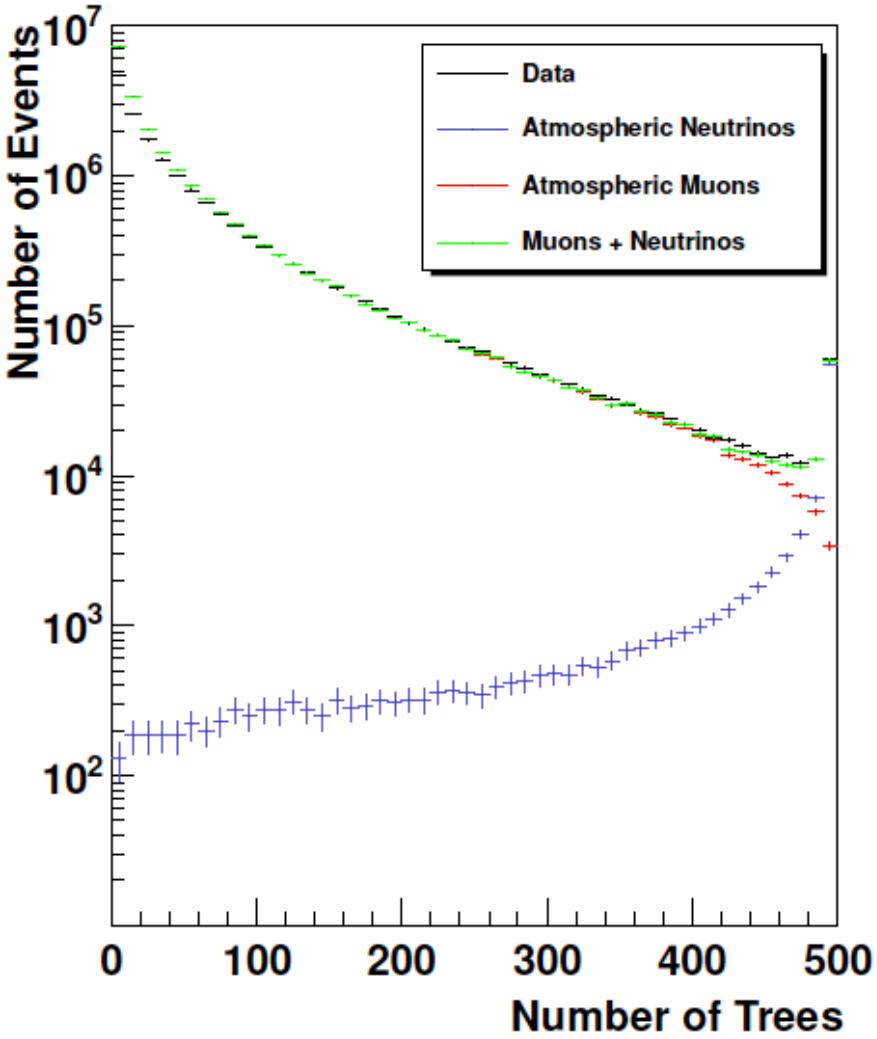
ANTARES: Combination of the point source search with IceCube

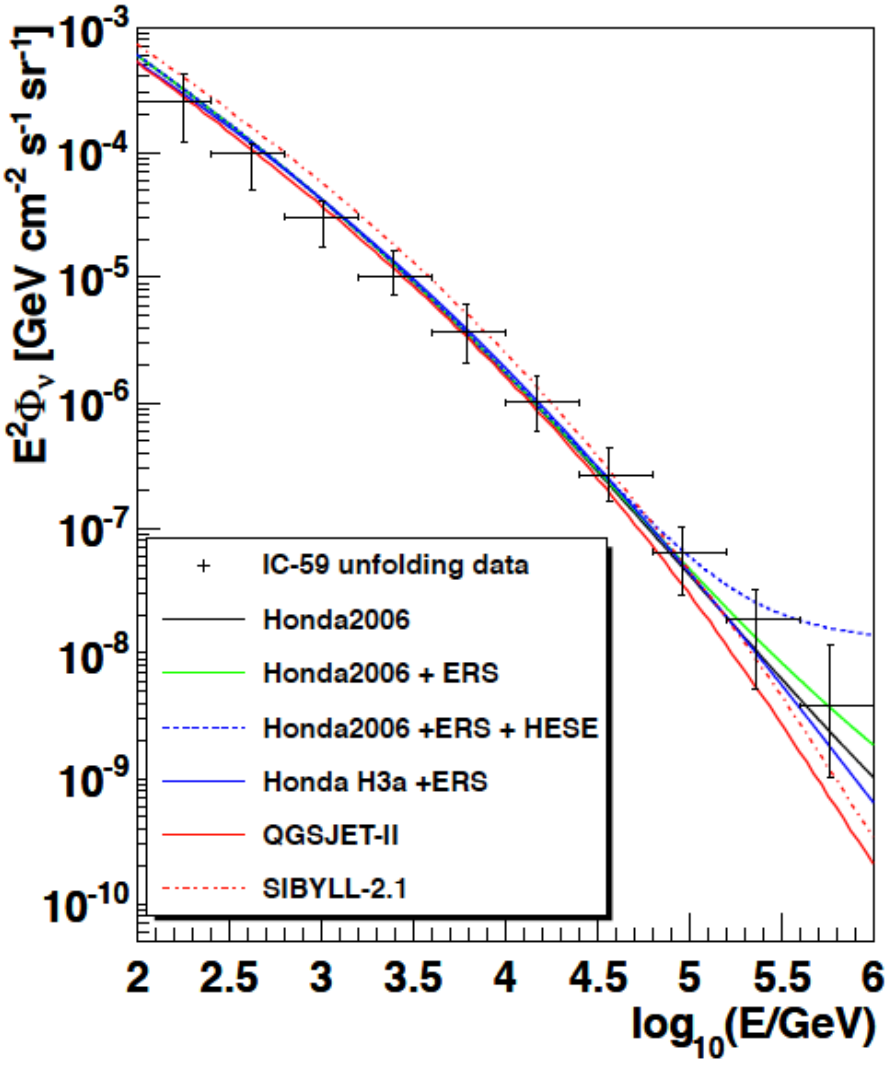
- ANTARES has the best sensitivity at the Southern sky for energies below 100 TeV
- Optimal for Galactic Sources
- No detections yet
- IceCube sensitivity at Southern sky only for cut-off at > PeV
- General: Factor 1000 sensitivity increase in 12 years
- Expect another factor 3 until 2016
- Combined analyses will help



ApJL, 786, L5 (2014)

IC 59: Unfolding of the ν_μ-Energy Spectrum,
Data Mining + Regularized Unfolding (TRUEE)



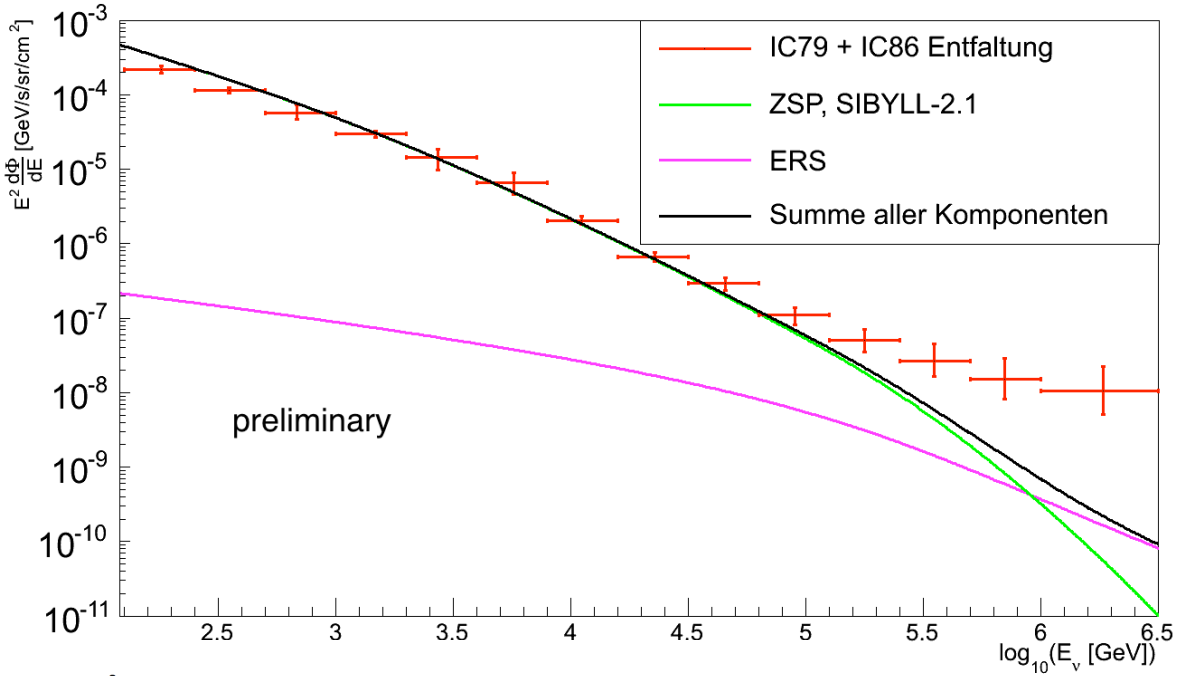


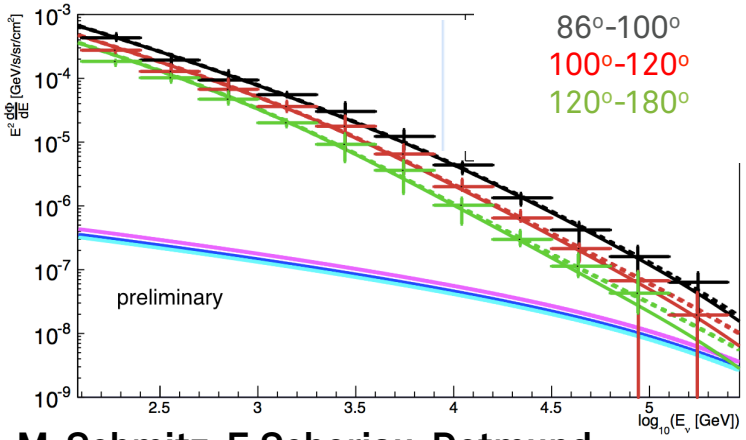
Tim Ruhe, Dortmund arxiv: 1409.4535

technische universität dortmund

IceCube SOUTH POLE NEUTRINO OBSERVATORY

IC 79 + IC 86: Unfolding of the ν_μ-Energy Spectrum,
Data Mining + Regularized Unfolding (TRUEE)

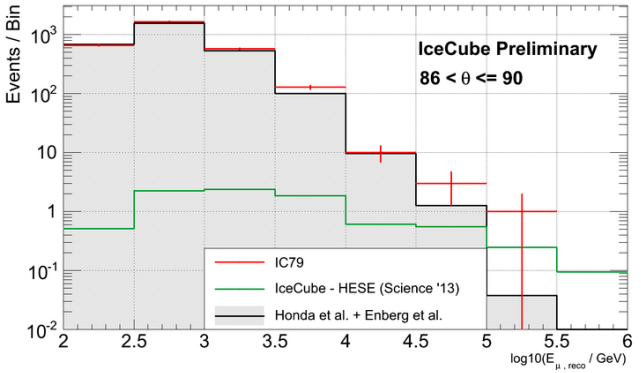


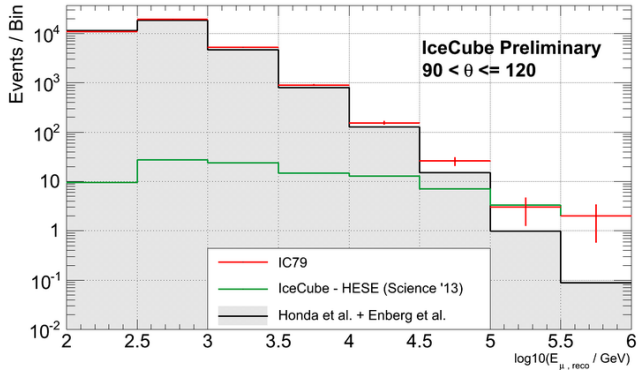


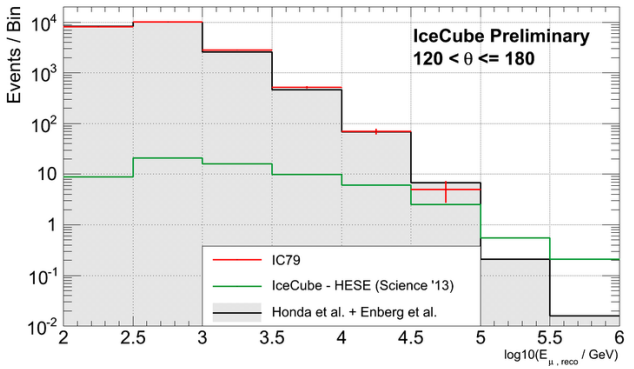
Fit:

Astro γ = 2,4±0,3

Prompt = $0{,}1^{+2{,}8}_{-0{,}1}$







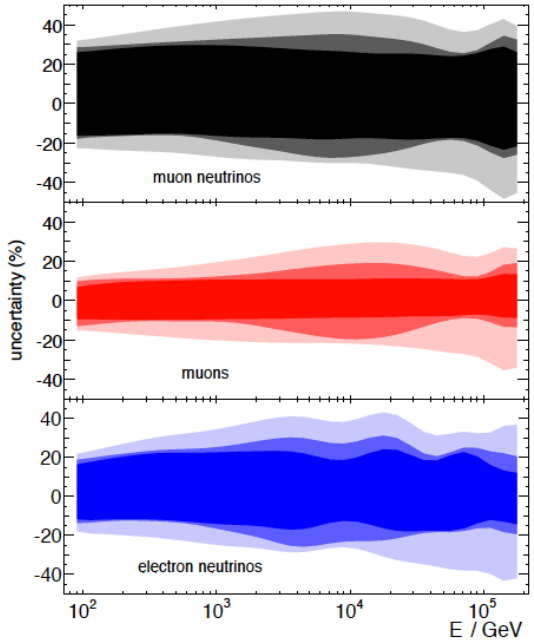
M. Schmitz, F. Scheriau, Dotmund

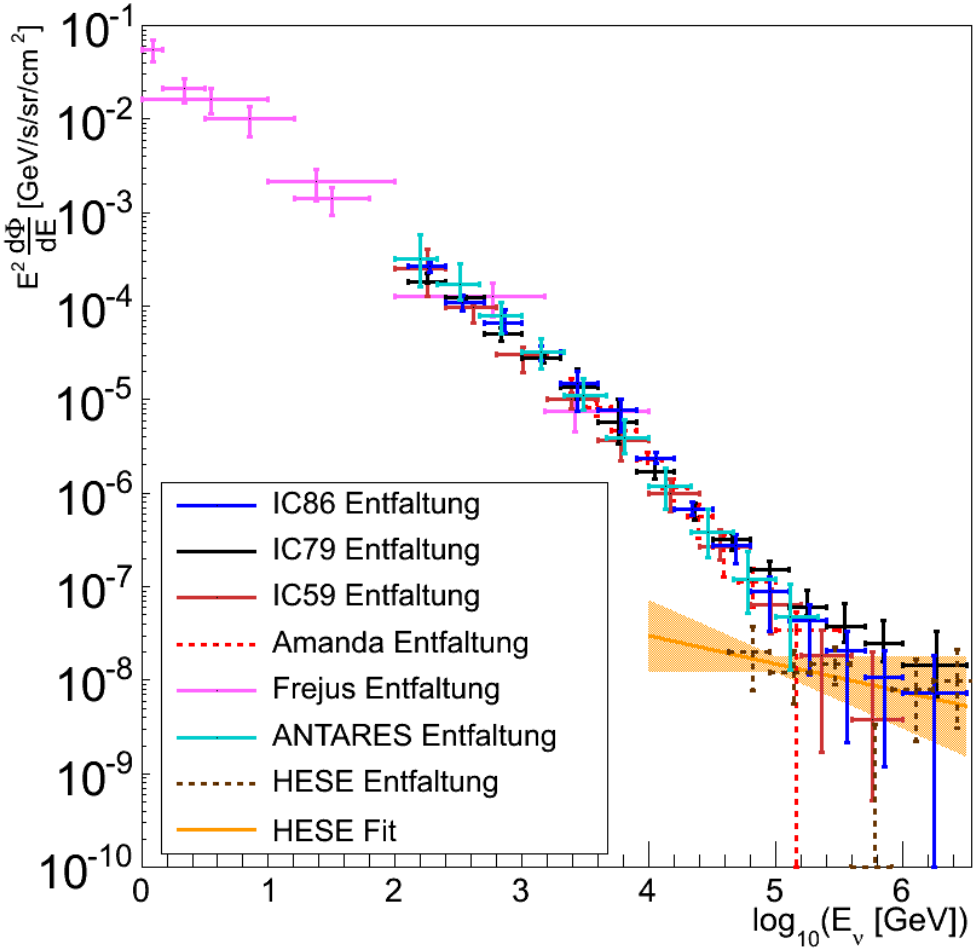
Synopsis of the ν_μ-Energy Spectra

Caveat:

- **Muon cross sections**
- **Angular comparability**

- **Primary Flux**
- **Interaction Models**





J. Tjus, Bochum

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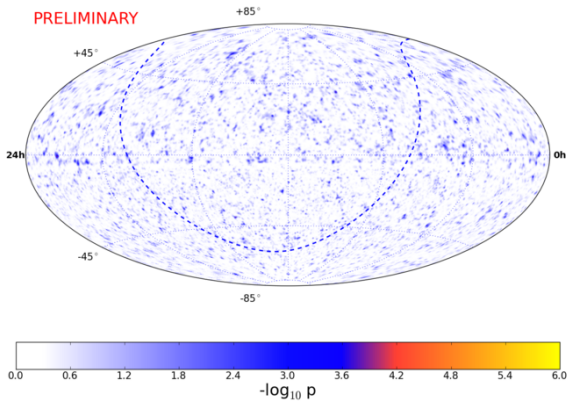
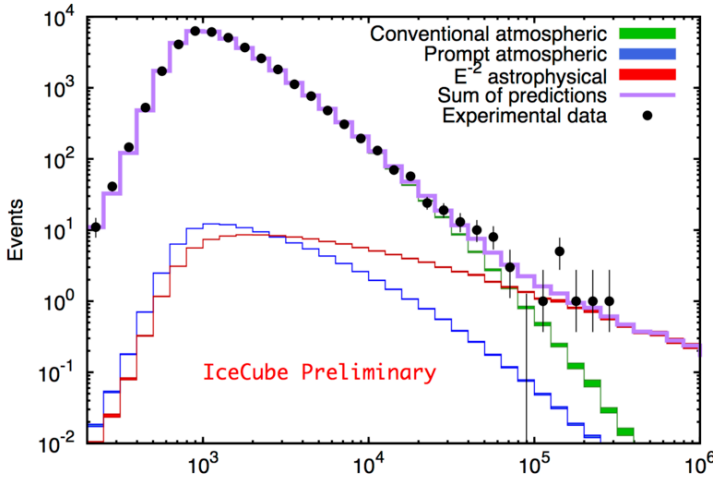
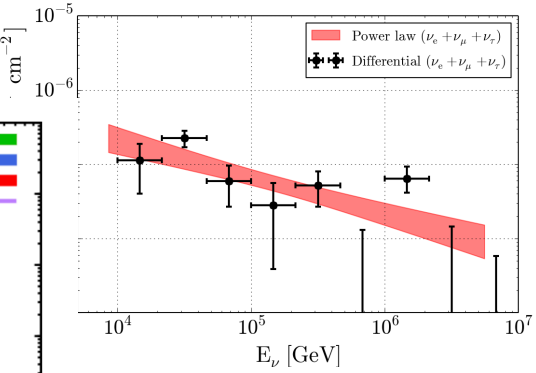
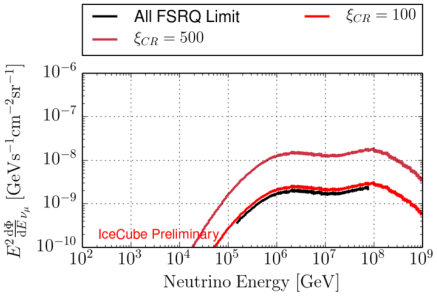
IceCube SOUTH POLE NEUTRINO OBSERVATORY

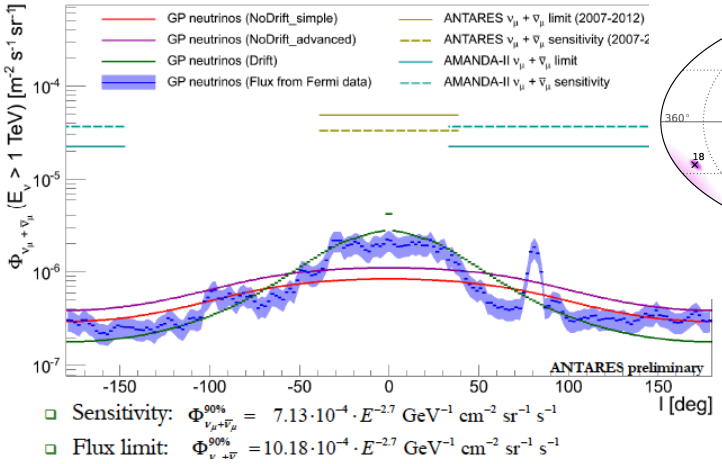
Conclusion



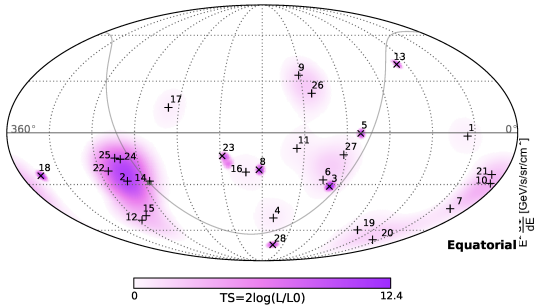


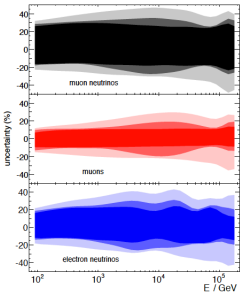


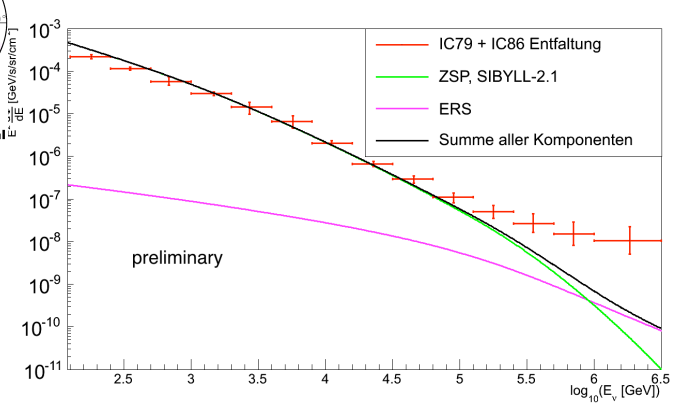


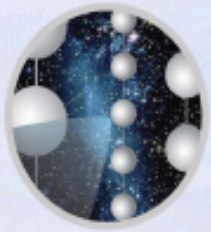


- Sensitivity: $\Phi^{90\%}_{\nu_\mu+\bar{\nu}_\mu} = 7.13\cdot10^{-4}\cdot E^{-2.7}$ GeV^{-1} cm^{-2} sr^{-1} s^{-1}
- Flux limit: $\Phi^{90\%}_{\nu+\bar{\nu}} = 10.18\cdot10^{-4}\cdot E^{-2.7}$ GeV^{-1} cm^{-2} sr^{-1} s^{-1}









The IceCube Collaboration

43 Institutions
~220 collaborators

USA
Clark Atlanta University
Georgia Institute of Technology
Lawrence Berkeley National Laboratory
Ohio State University
Pennsylvania State University
South Dakota School of Mines & Technology
Southern University and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware
University of Kansas
University of Maryland
University of Wisconsin–Madison
University of Wisconsin–River Falls
Yale University

Canada
University of Alberta–Edmonton
University of Toronto

Chiba University, Japan

Sungkyunkwan University, Korea

University of Oxford, **UK**

Belgium
Université Libre de Bruxelles
Université de Mons
Universiteit Gent
Vrije Universiteit Brussel

Niels Bohr Institutet, **Denmark**

Sweden
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Uppsala universitet

Germany
Deutsches Elektronen-Synchrotron
Friedrich-Alexander-Universität Erlangen-Nürnberg
Humboldt-Universität zu Berlin
Ruhr-Universität Bochum
RWTH Aachen
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Universität Bonn
Technische Universität Dortmund
Universität Mainz
Universität Wuppertal

Université de Genève, **Switzerland**

University of Adelaide, **Australia**

University of Canterbury, **New Zealand**

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Fonds de la Recherche Scientifique (FRS-FNRS)
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German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

The ANTARES Collaboration

24 Institutes
~150 Collaborators