Results from IceCube

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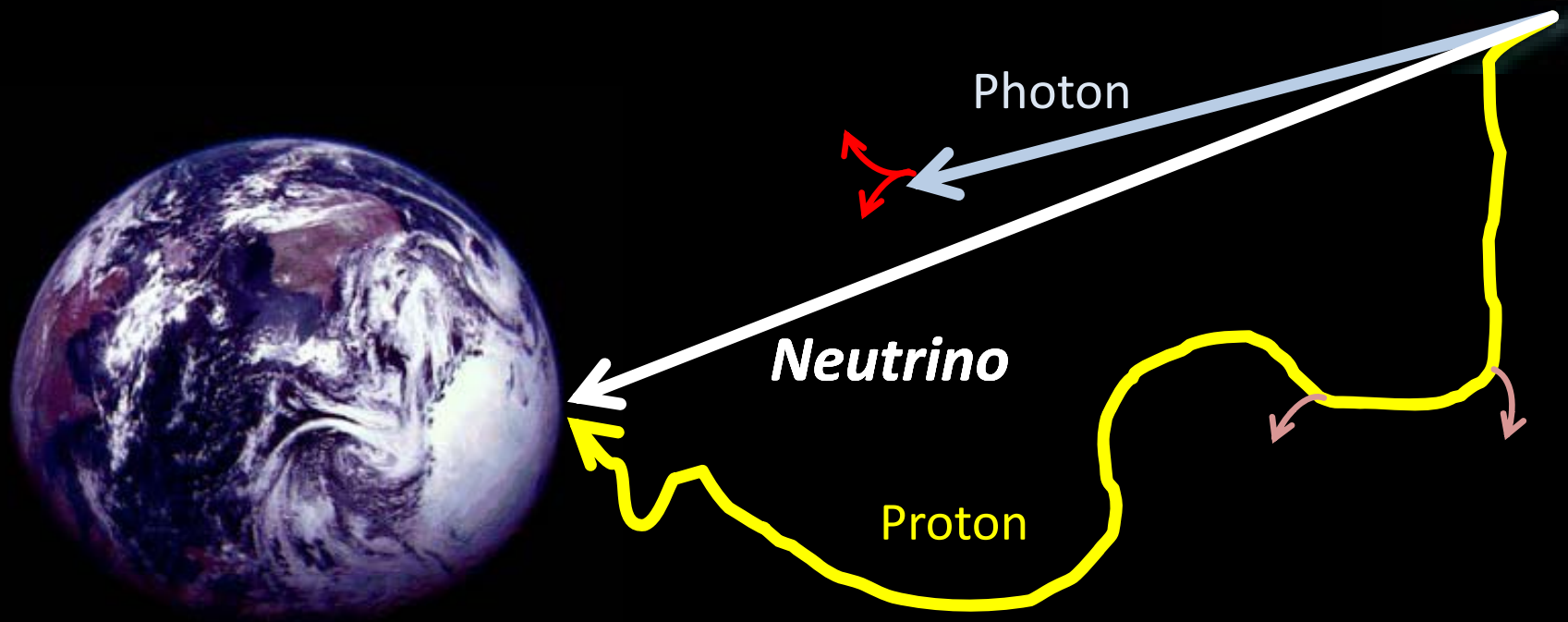
RWTH Aachen

Workshop Astroteilchenphysik in Deutschland
DESY Zeuthen, 20. September 2012

GEFÖRDERT VOM

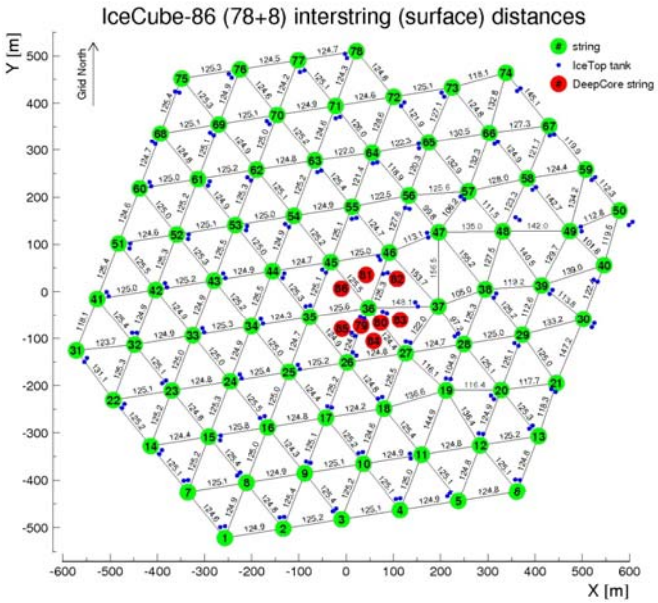
Neutrinos as messenger particles from the Universe



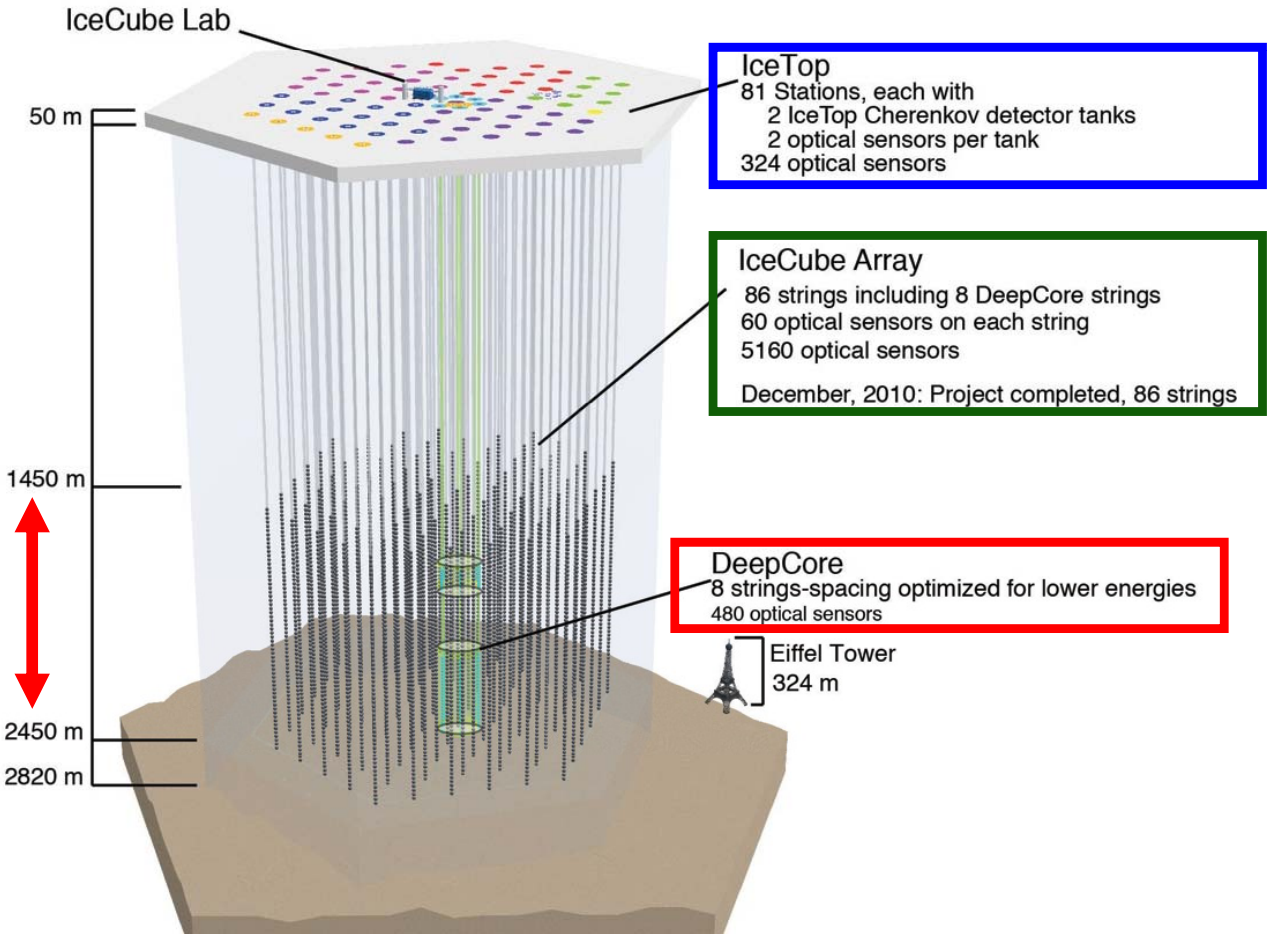
Neutrinos are ideal messenger particles: neutral stable unabsorbed
Measurement: Direction, Energy, Time

- Unambiguous tracers of hadronic sources
- Need large detectors on the km^3 scale

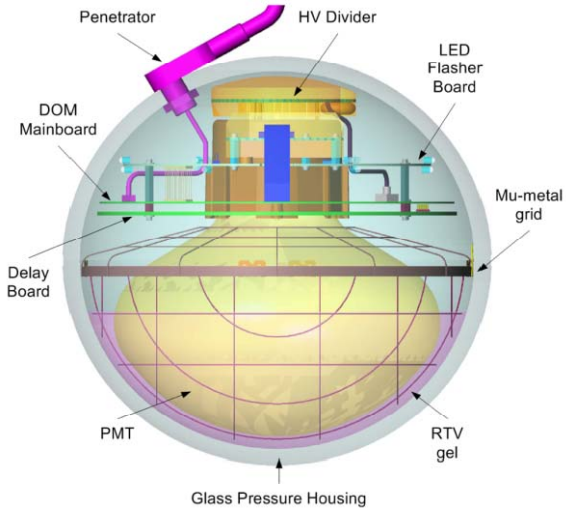
The IceCube Neutrino Observatory



Completed in December 2010



Digital Optical Module (DOM) 10” PMT & local DAQ



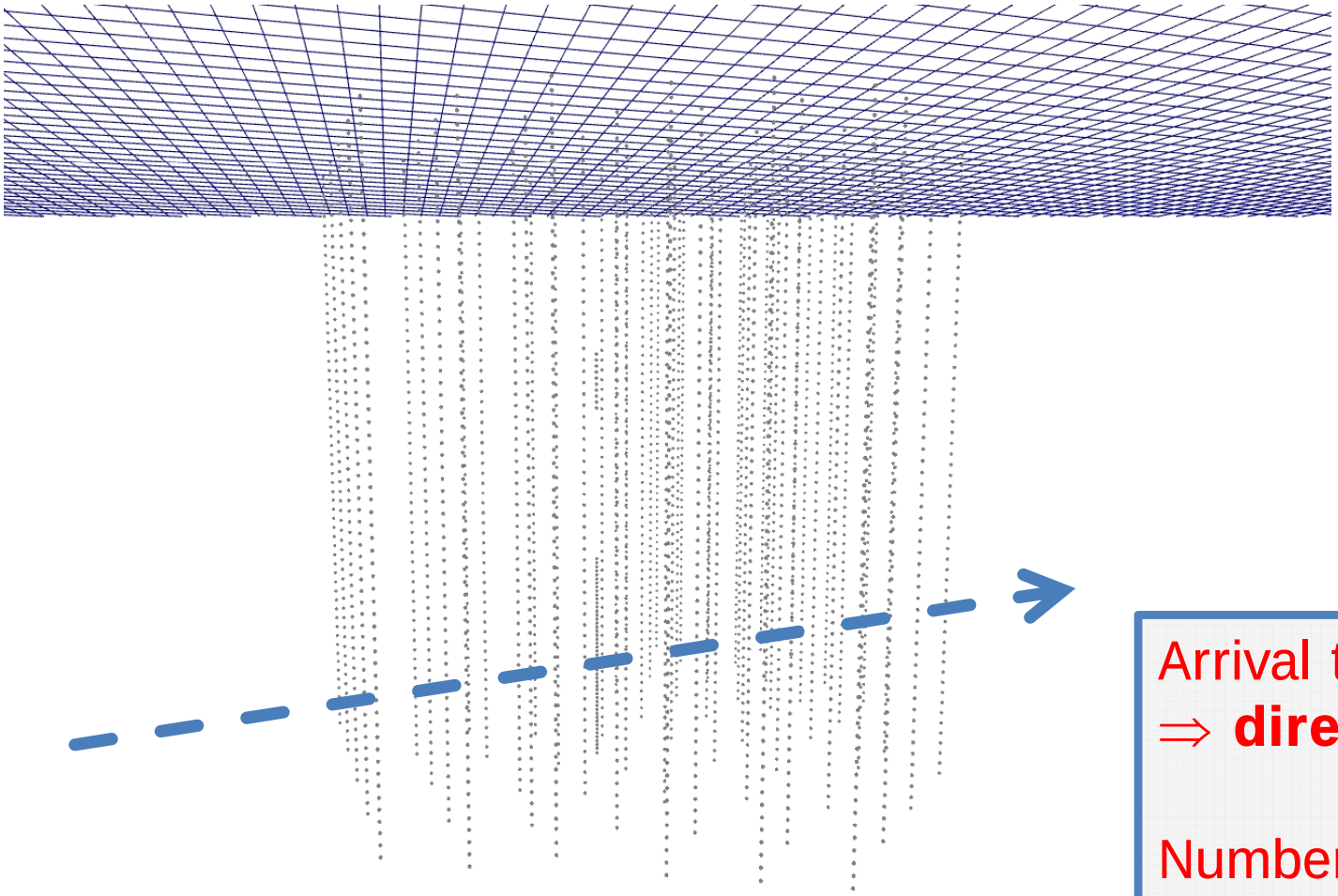
http://icecube.wisc.edu

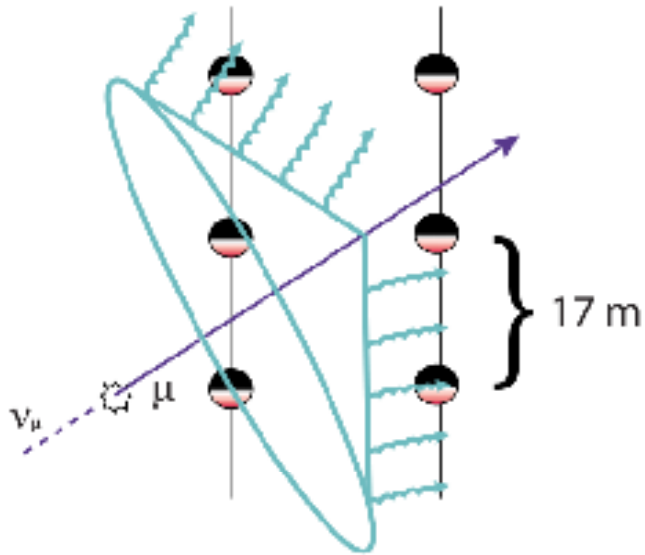
IceCube: 39 institutions 11 countries ~260 scientist

Germany: 9 institutions, ~80 authors (30%)

German groups cover the full science spectrum and with leadership in several fields

Detection Principles





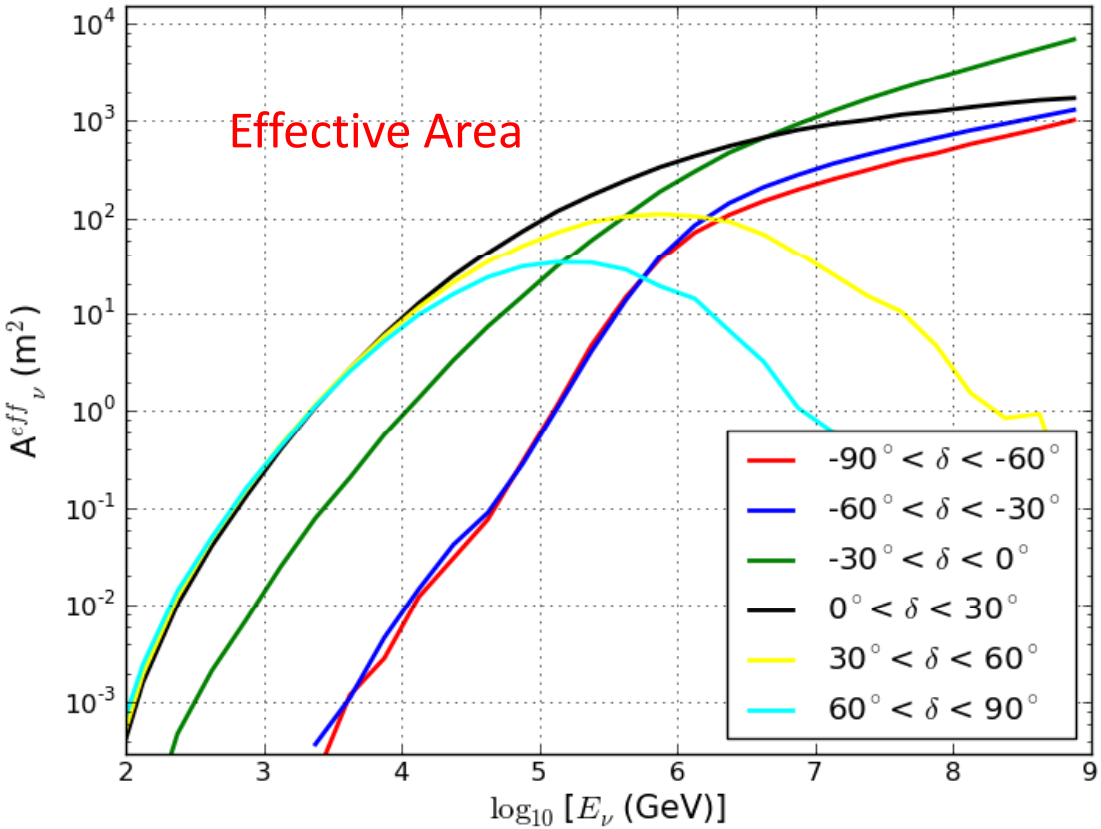
Arrival time of photons
⇒ **direction & geometry**

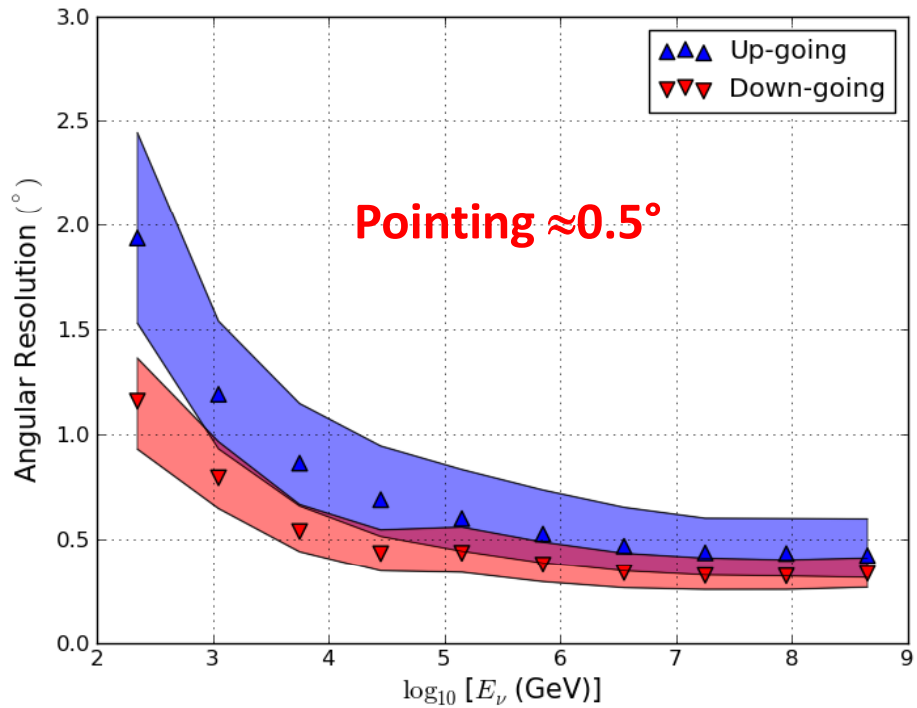
Number of registered photons
⇒ **energy**

Zeitskala

Highest energy event (~200TeV) from Diffuse ν_μ Analysis IC59

Detector performance

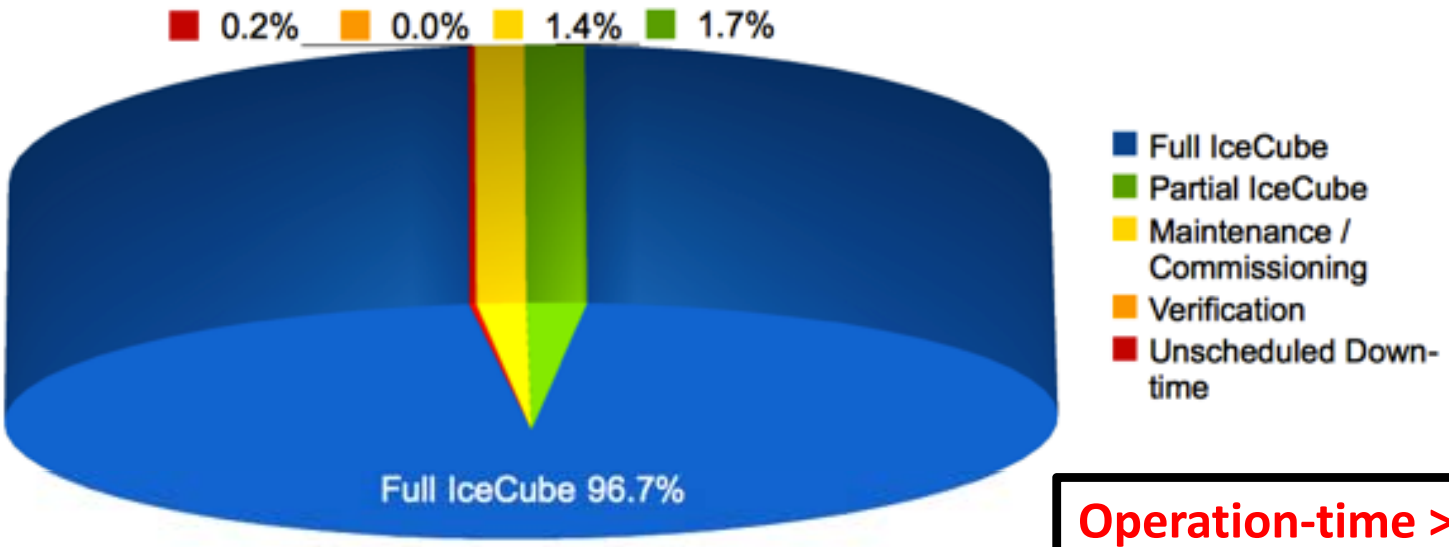




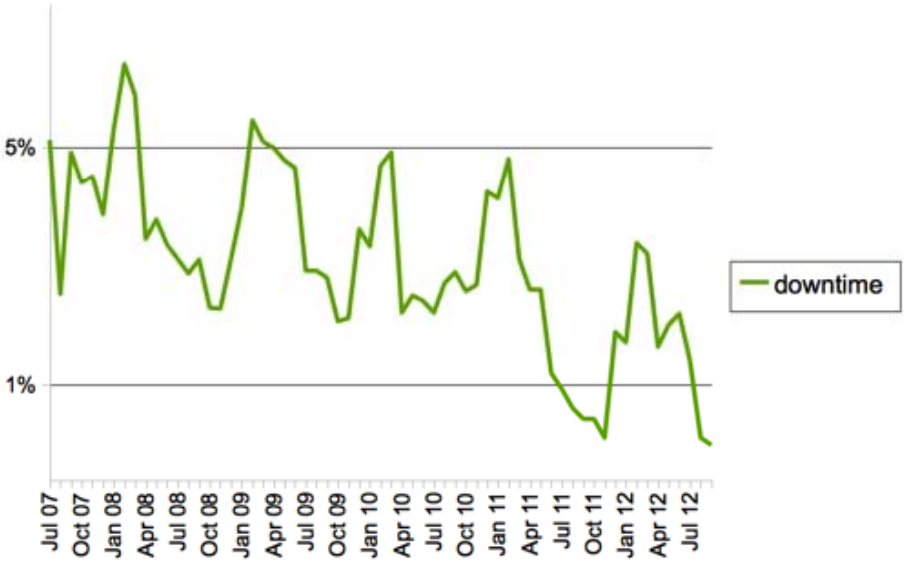
$$\mathrm{Rate}(E,\vec{\Omega}) = A_{\mathrm{eff}}(E,\vec{\Omega}) \cdot \Phi_{\nu}(E,\vec{\Omega})$$

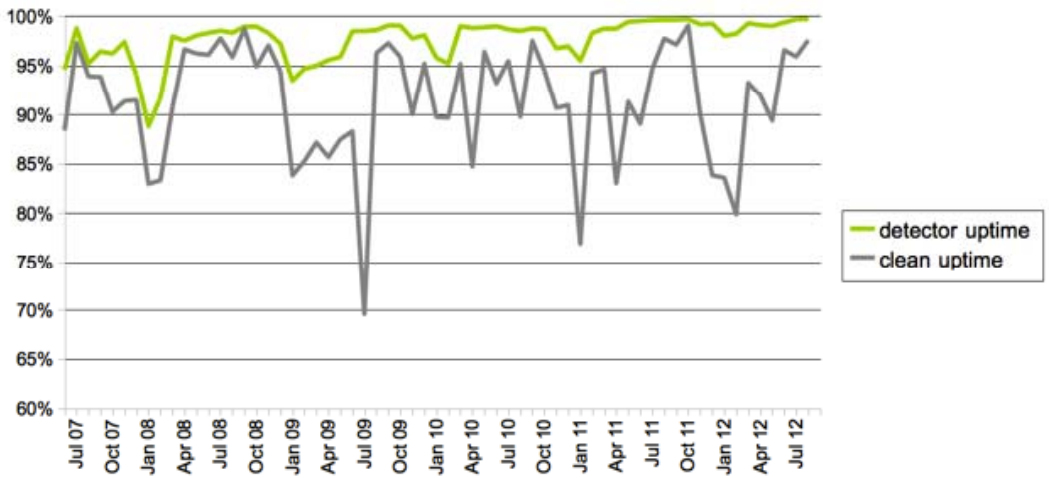
A_{eff} includes neutrino cross-section, absorption in Earth and detection efficiency

Detector Performance

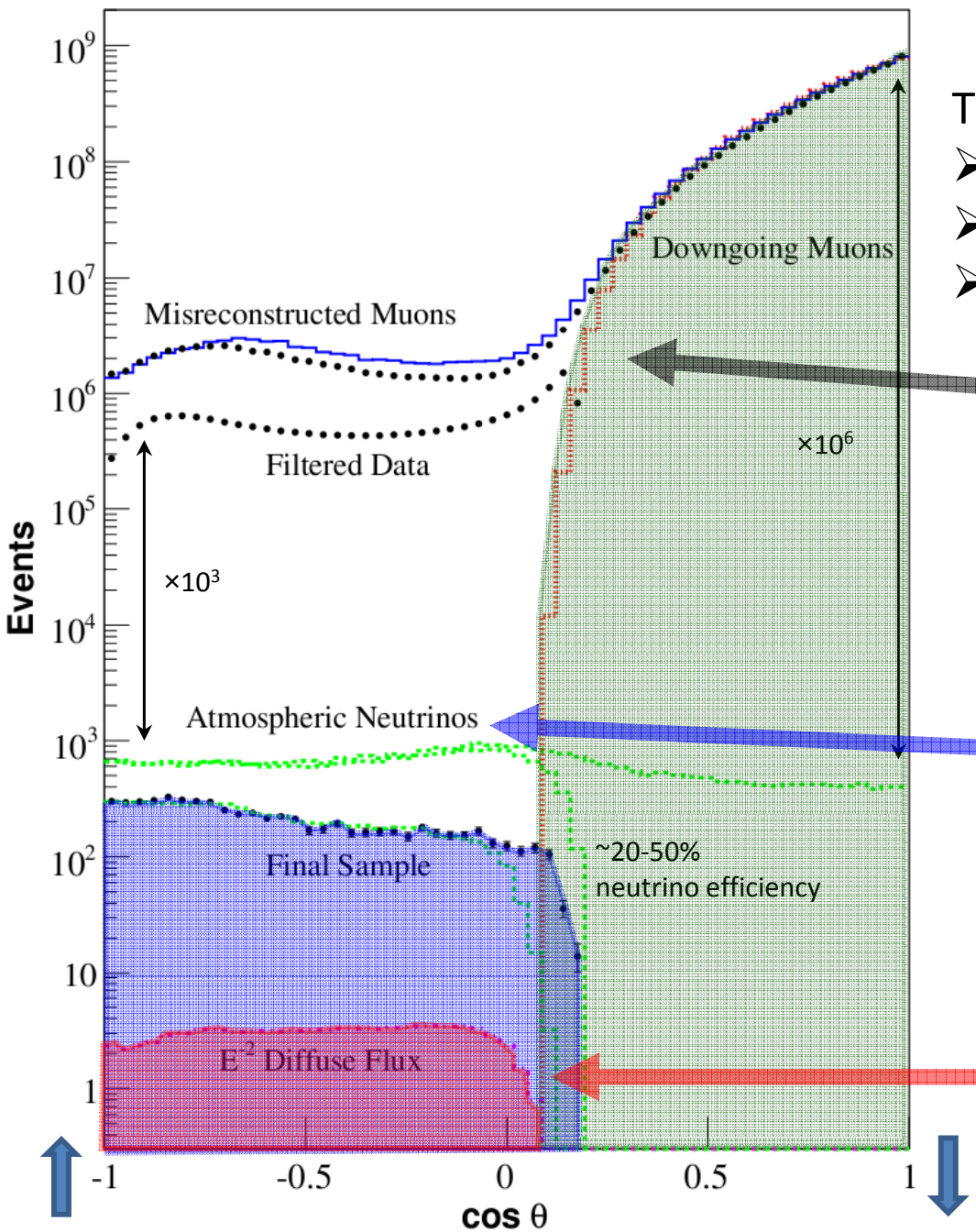


Operation-time > 99.8 %
Physics data > 96.7%





Data Selection



Trigger rates:

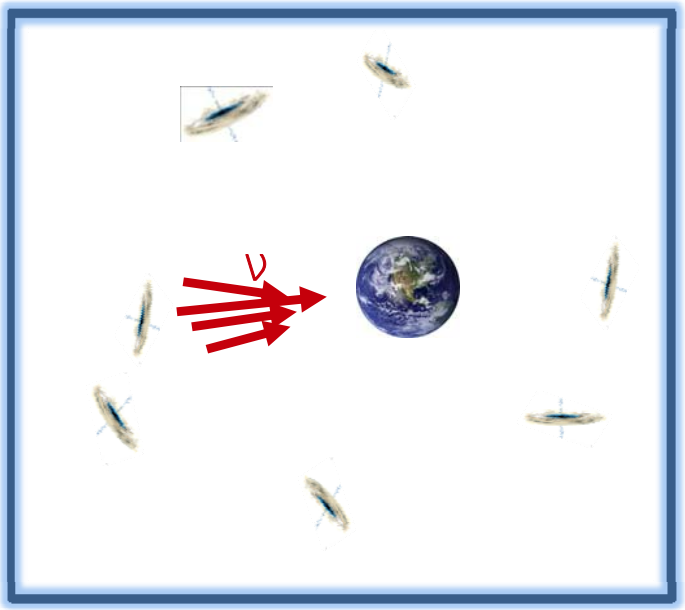
- Atm.Muons: ~2100 Hz,
- 200 atm ν_μ /day (IceCube >100 GeV)
- 500 atm ν_μ /day (DeepCore >10GeV)

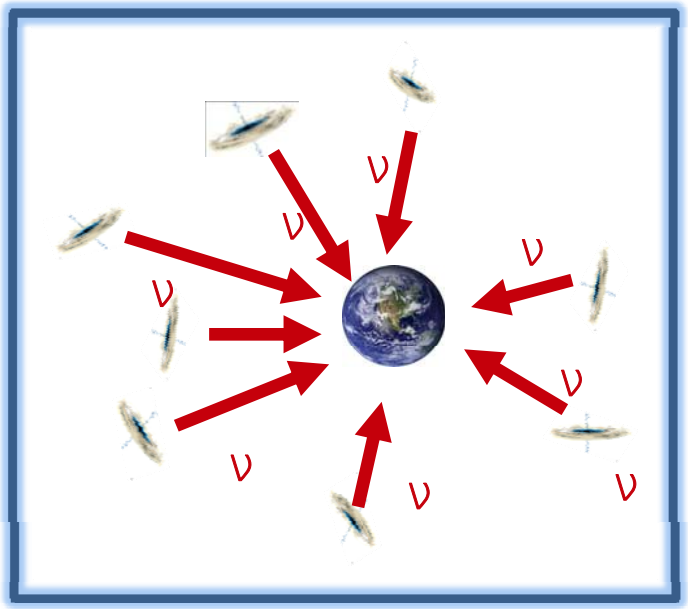
atmospheric muons

atmospheric neutrinos

extra-terrestrial neutrinos

Point source search versus Diffuse search





Single source flux

$$\phi_1(E \mid L, z) = \frac{\varepsilon_\nu \cdot L \cdot E^{-\gamma}}{4\pi d_L(z)^2 \cdot (z+1)^{\gamma-1}}$$

Cummulative flux from all sources

$$\phi_{diffuse}(E) = \int \phi_1(E \mid L, z) \frac{d^2 n(L, z)}{dz dL} dz dL d\Omega$$

Luminosity density function know for astrophysical -> Integration easy

Conclusions

- Diffuse searches are more promising for abundant extra-galactic objects like AGN
- Exception: (transient) rare, bright distant sources like GRB
- Exception: Galactic point sources
- A detailed look reveals more exceptions from this simplified argumentation

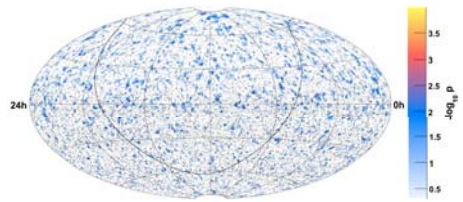
Argument worked out by Marek Kowalski (2006), see also Paolo Lipari ,arXiv:astro-ph/0605535v1

Science Results

1. Diffuse Searches
   1. Diffuse search for high energy muon neutrinos (new)
   2. Diffuse search for cascade events (newer)
   3. Extremely high energy events (new)
   4. first observation of atmosperic ν_e
2. Point sources
   1. GRB fireball model (WB) seriously challenged
   2. IC–40+59+79 point source result (newer)
3. Cosmic rays
   1. Spectrum, composition (⇒ talk by A.Haungs)
   2. Anisotropy of cosmic ray (new)
   3. R&D Radio (⇒ talk by J.Rautenberg)
4. Particle Physics
   1. Dark matter (⇒ talk by C.Rott)
   2. Atmospheric neutrino oscillations (new)
   3. Magnetic Monopoles (newer)

Last ATP Meeting (Feb 2010)

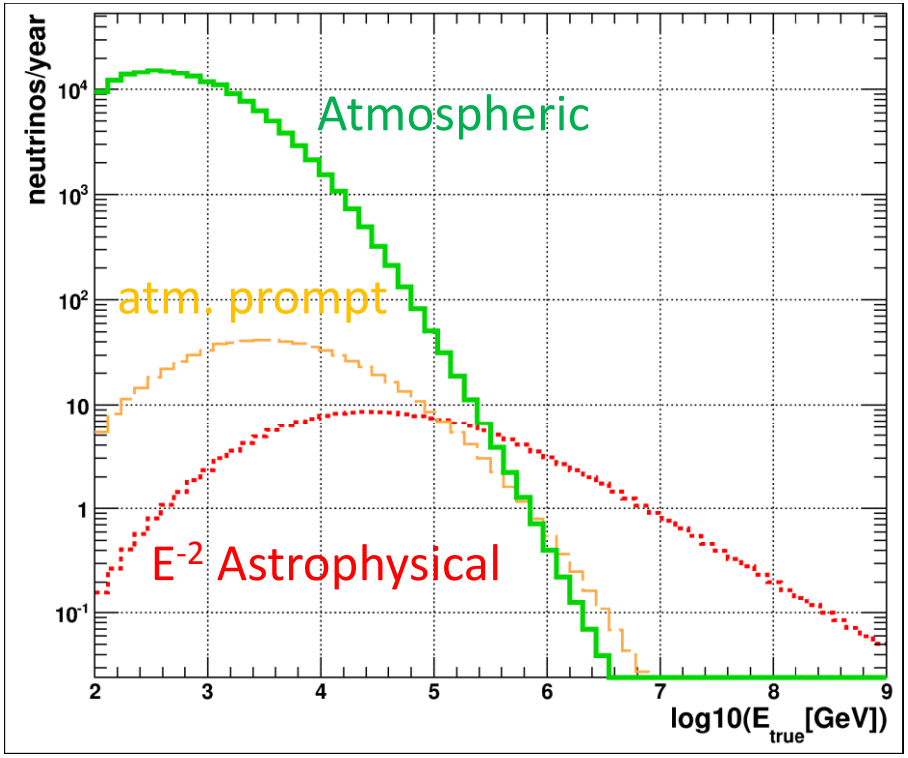
- No Diffuse analysis yet
- No point source signal with IC 22, initial IC-40 analysis



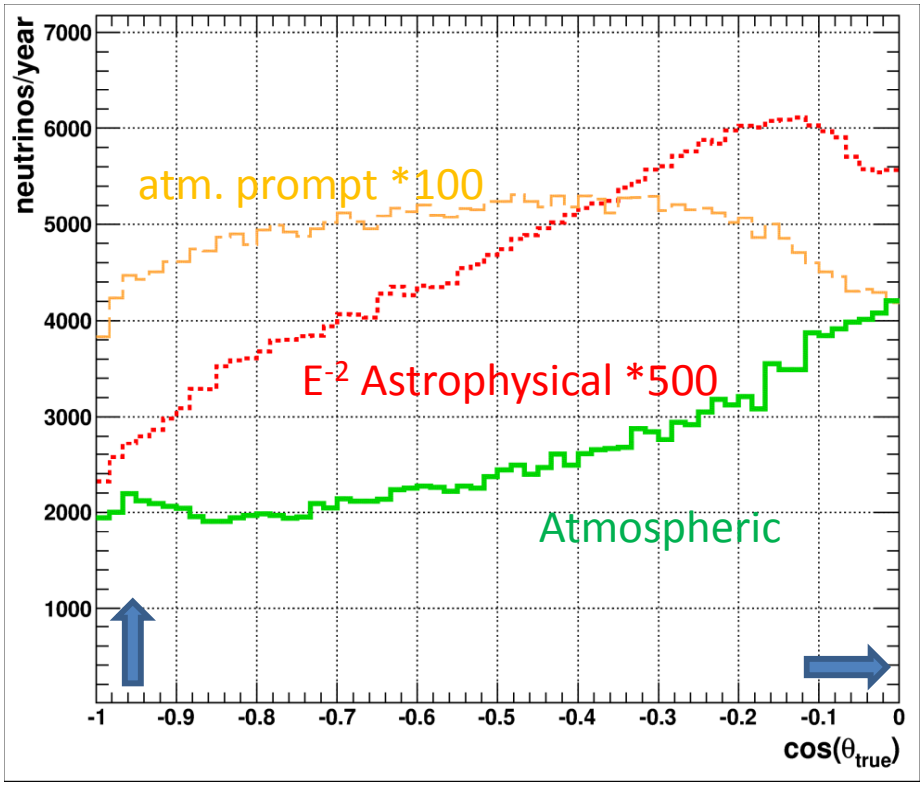
Seach for diffuse fluxes of ν_μ

Signature: **energy** and **angular** distribution

energy



angular distribution

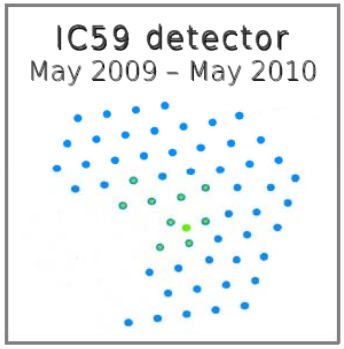


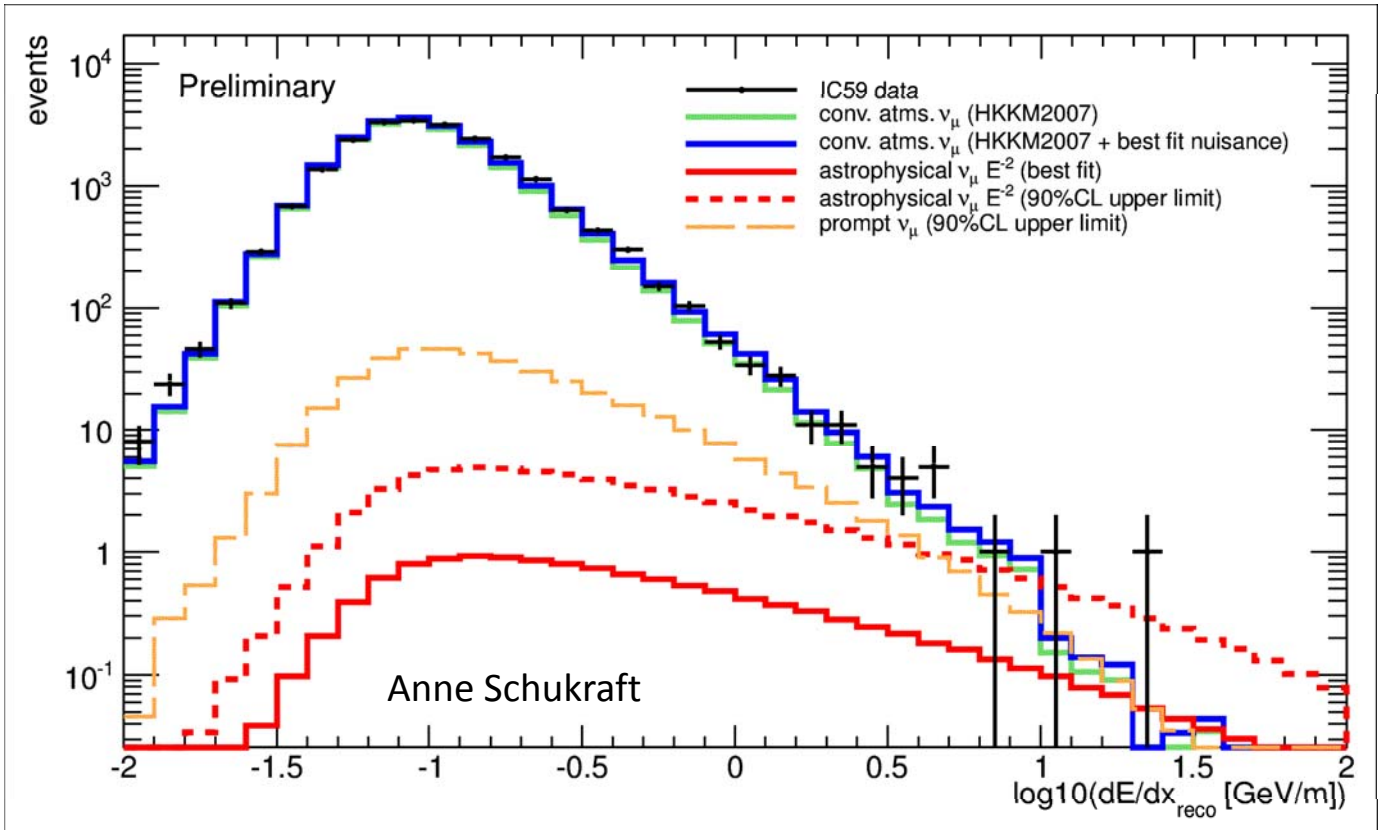
Global fit of both distributions allows to improve the sensitivity by 30% and to constrain systematic uncertainties included as nuisance paramenters in the fit

Systematic uncertainties:

- Detector: DOM sensitivity, Ice properties
- Model Atm. flux norm., spectr. index, π/K ratio,…

Final fit result of diffuse ν_μ in IC-59





Final sample:

- 21943 ν_μ events
- 99.85% purity

Less than

- < 150 prompt atm ν_μ
- < 40 astrophysical ν_μ
- < 30 atm μ background

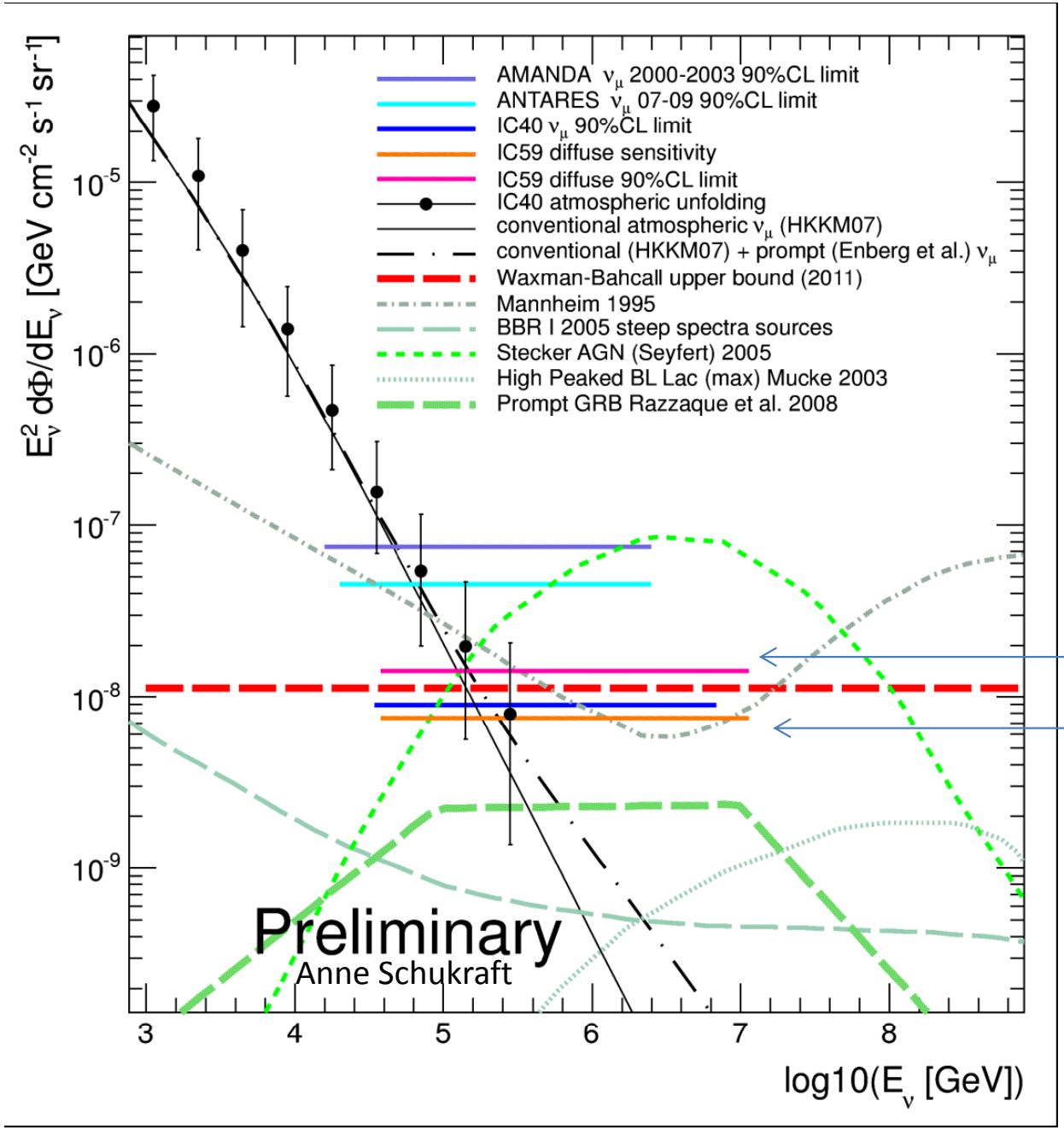
Best fit

- nuisance parameters in reasonable range
- No prompt component
- Astrophysical E^{-2} flux: $E^2\phi = 0.3 * 10^{-8}$ $GeV^{-1}cm^{-2}s^{-1}sr^{-1}$
  1.8 σ excess at high energy … not significant

Astrophysical ν_μ:
$E^2\phi \leq 1.4 * 10^{-8}$ $GeV^{-1}cm^{-2}s^{-1}sr^{-1}$
Prompt ν_μ:
$\phi \leq 2.3 *$ Enberg et al.
(with H3a CR model)

See poster @ this meeting

Upper limit at the Waxman-Bahcall bound



Sensitivity of IC-59 is a factor 2.5 better than IC-40 but limit is worse because of upward fluctuation

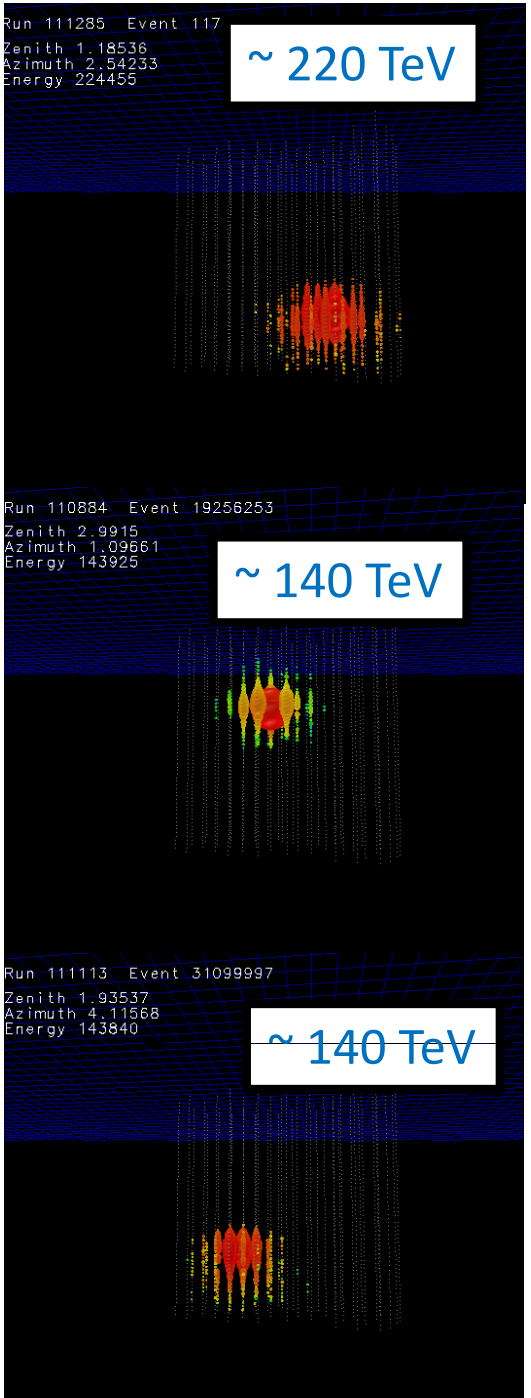
Upper limit

Sensitivity

See poster @ this meeting

Main contributions: RWTH Aachen

Diffuse: Contained Cascade-like events

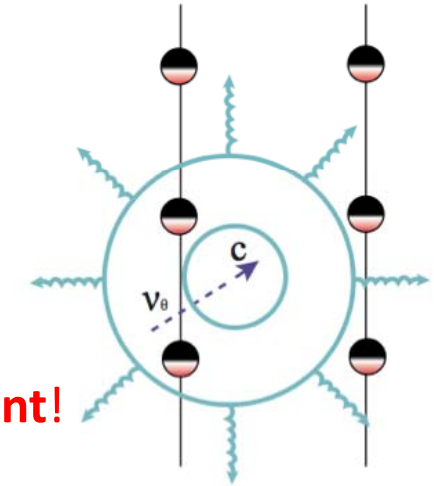


High energy (>100TeV)

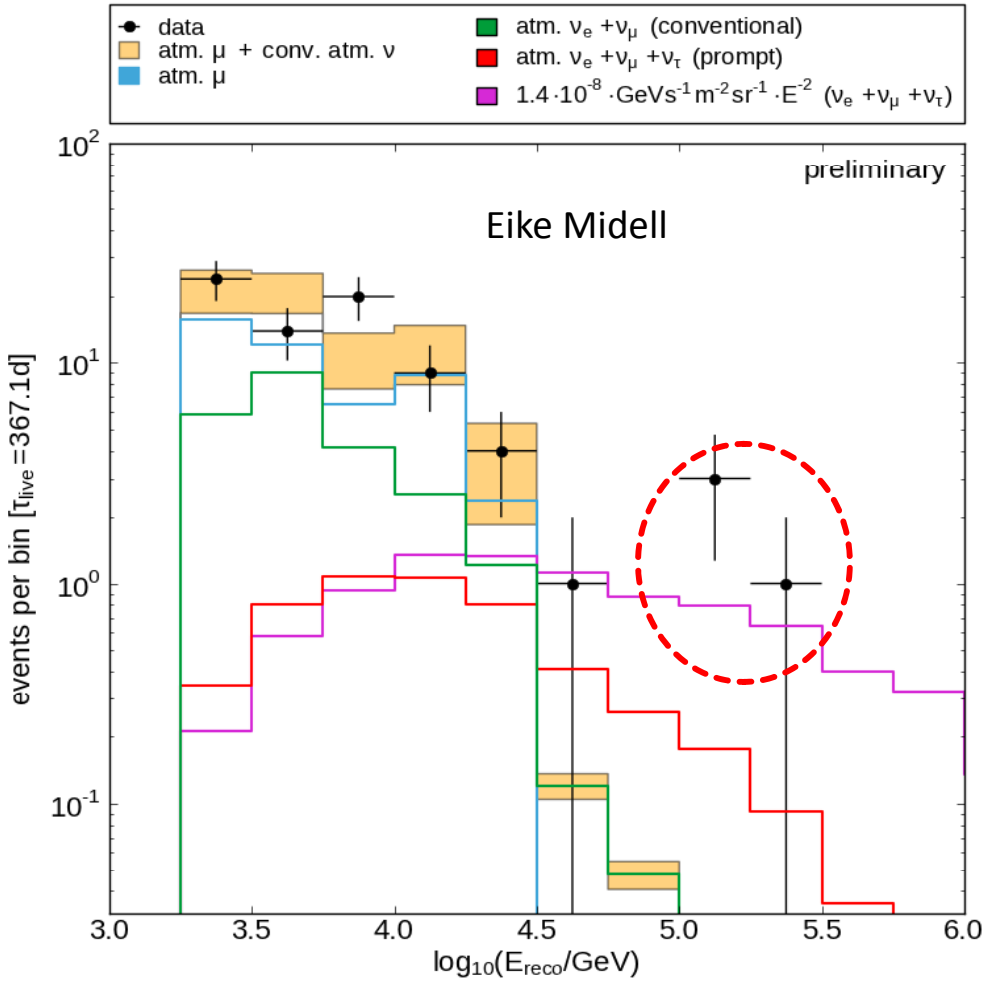
3 events observed, (+1 burn sample)

Preliminary BG expectation: 0.3

⇒ 1.6 sigma excess (incl. uncert.) **Not significant**!



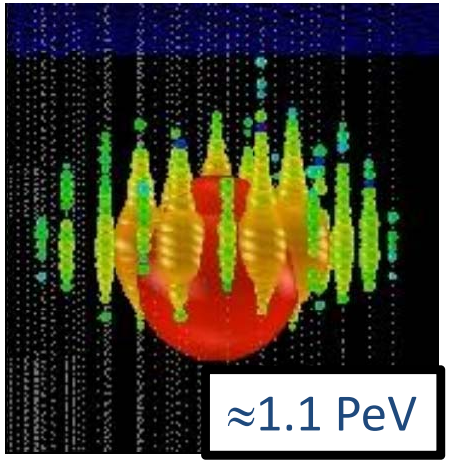
Zeitskala

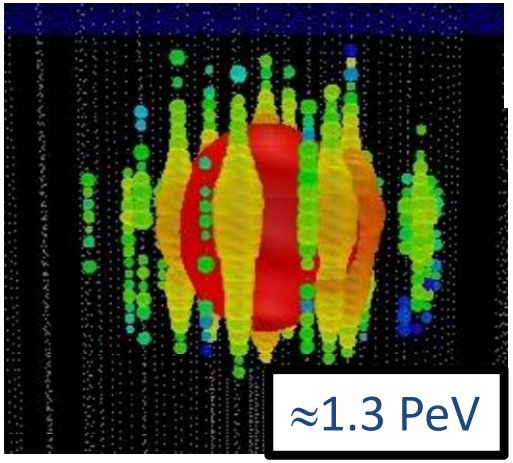


⇒ Energy

Main contributions: Uni Bonn, DESY Zeuthen

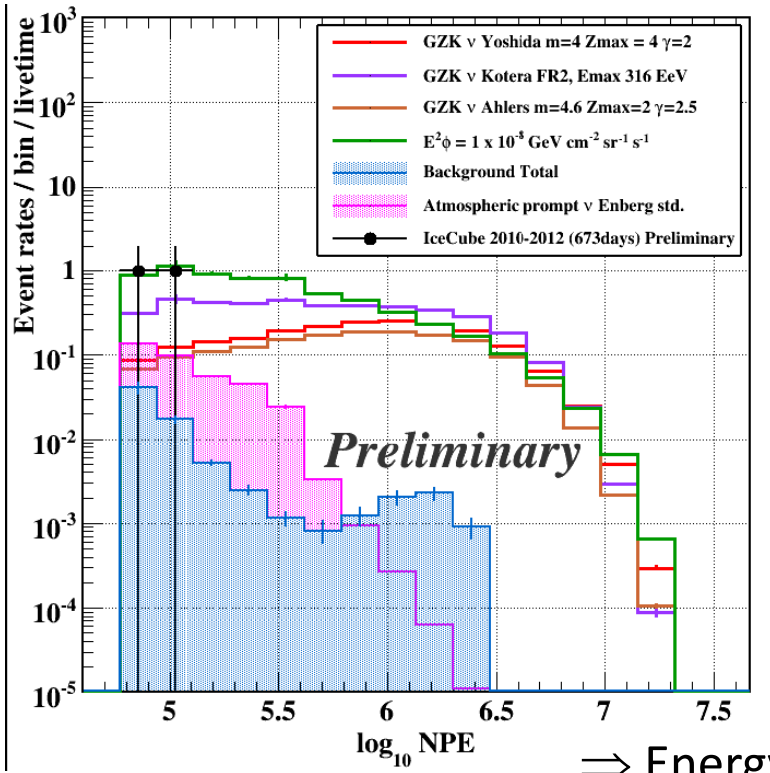
Extreme high energy analysis in IceCube-86





Zeitskala

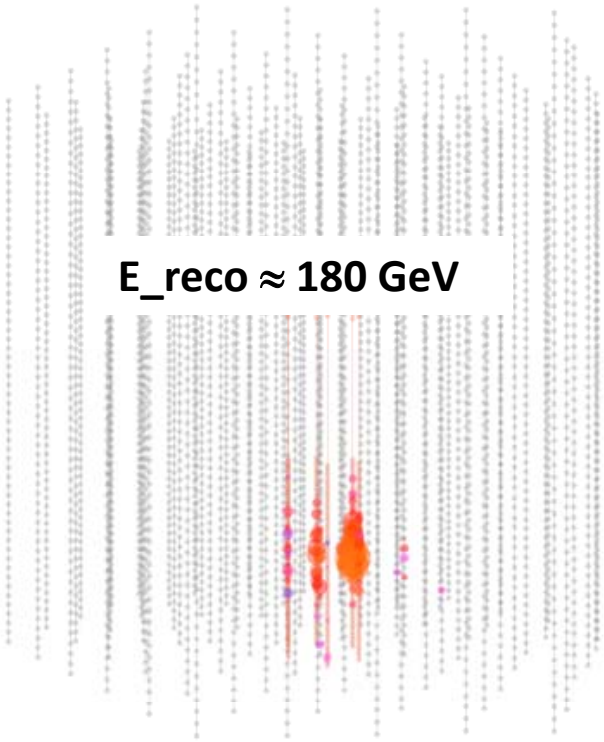
Data	2
Expected event numbers:	
Atms. Background (conv. ν + μ)	0.06
Prompt atms. ν (Enberg et al. + knee)	0.13
Prompt (IC59 upper limit)	0.30
Astrophysical (IC59 best fit) 0.3×10^{-8} GeV cm^{-2} s^{-1} sr^{-1}	1.7
Astrophysical (IC59 limit) 1.4×10^{-8} GeV cm^{-2} s^{-1} sr^{-1}	9.1
GZK (various models)	0 – 4

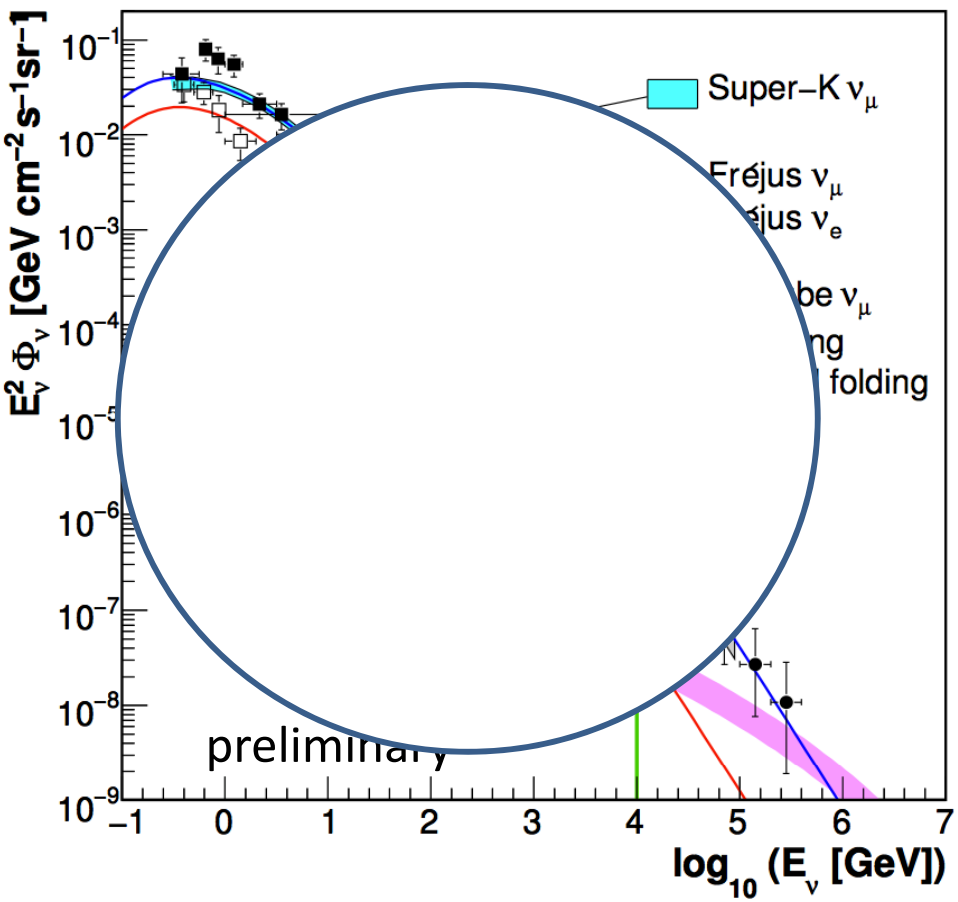


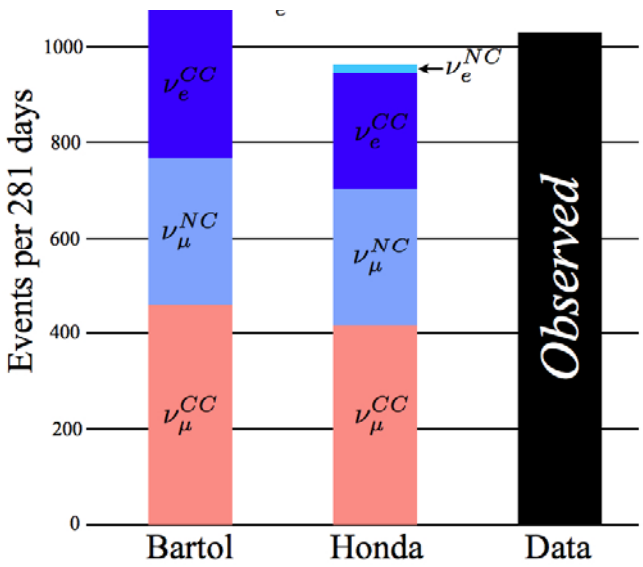
⇒ Energy

- PeV-events detected at the low-energy threshold of the IC86 EHE analysis!
- Not significant: 2.9σ (conv.) 2.1σ (incl. prompt)
- Consistent with IC-59 diffuse astrophysical fits
- ..... Investigations ongoing

First observation of low energy cascades with DeepCore



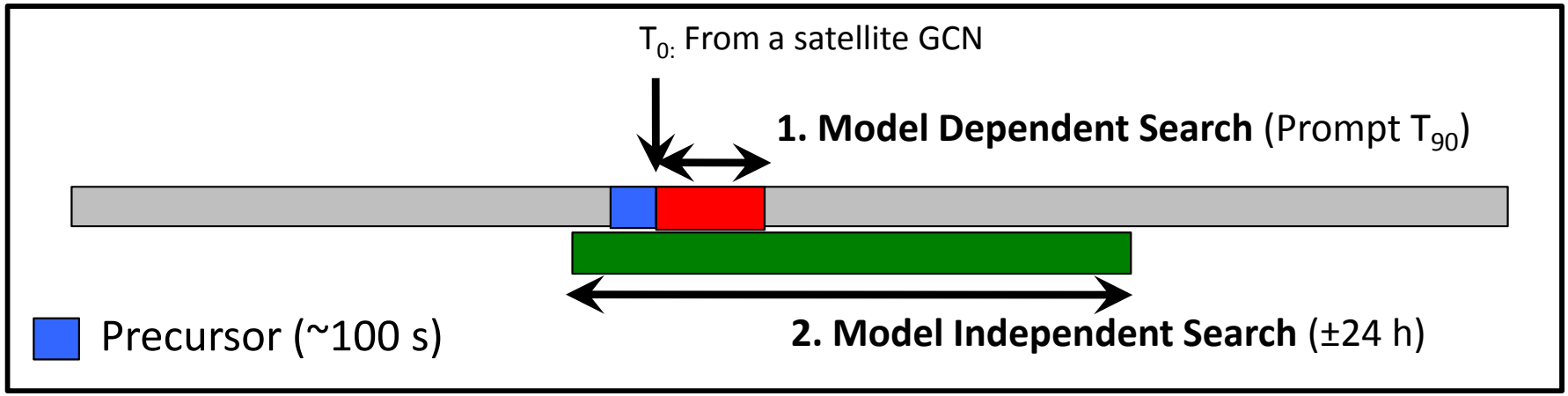




⇒ **First (statistical) detection of ν_e Cascades**

⇒ **Demonstration of IceCube veto concept**

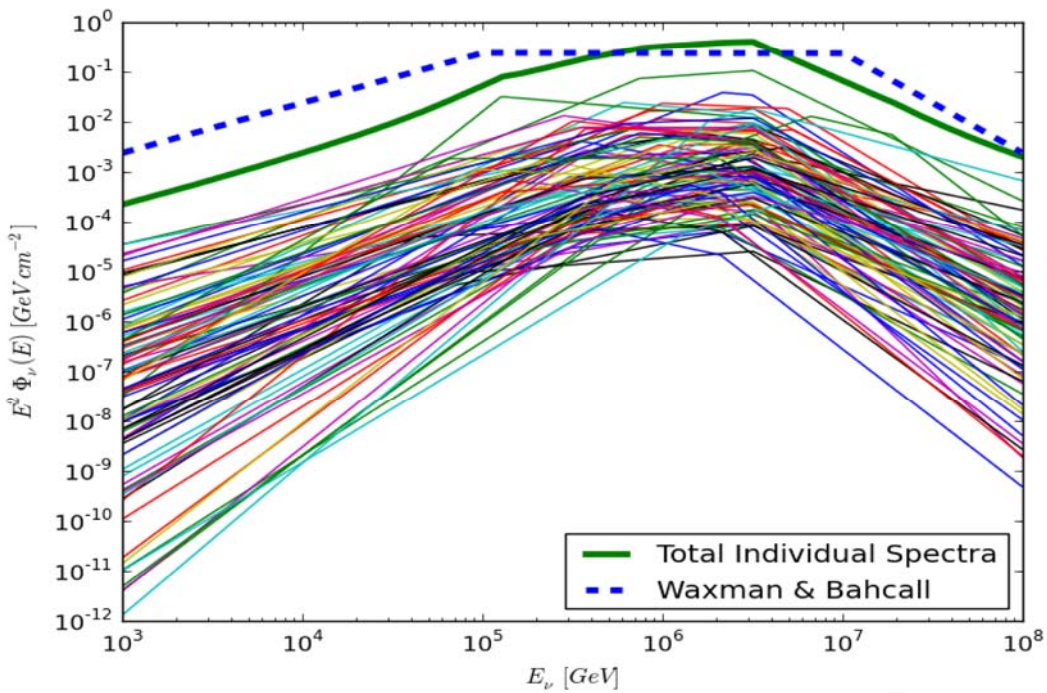
Search for Neutrinos from Gamma Ray Bursts



1. Model-dependent search
   - Time window derived from Gamma T90
   - Energy spectrum and flux expectation from individual Burst's observational data
2. Model independent search
   - Likelihood analysis with variable Time window (10s - 24h)
   - no specific spectrum assumed

GRB search catalog from GCN satellite information (z.B. Fermi GBM, SWIFT ….)

Sum of Individual Spectra (Analysis 1.)



⇒ Energy

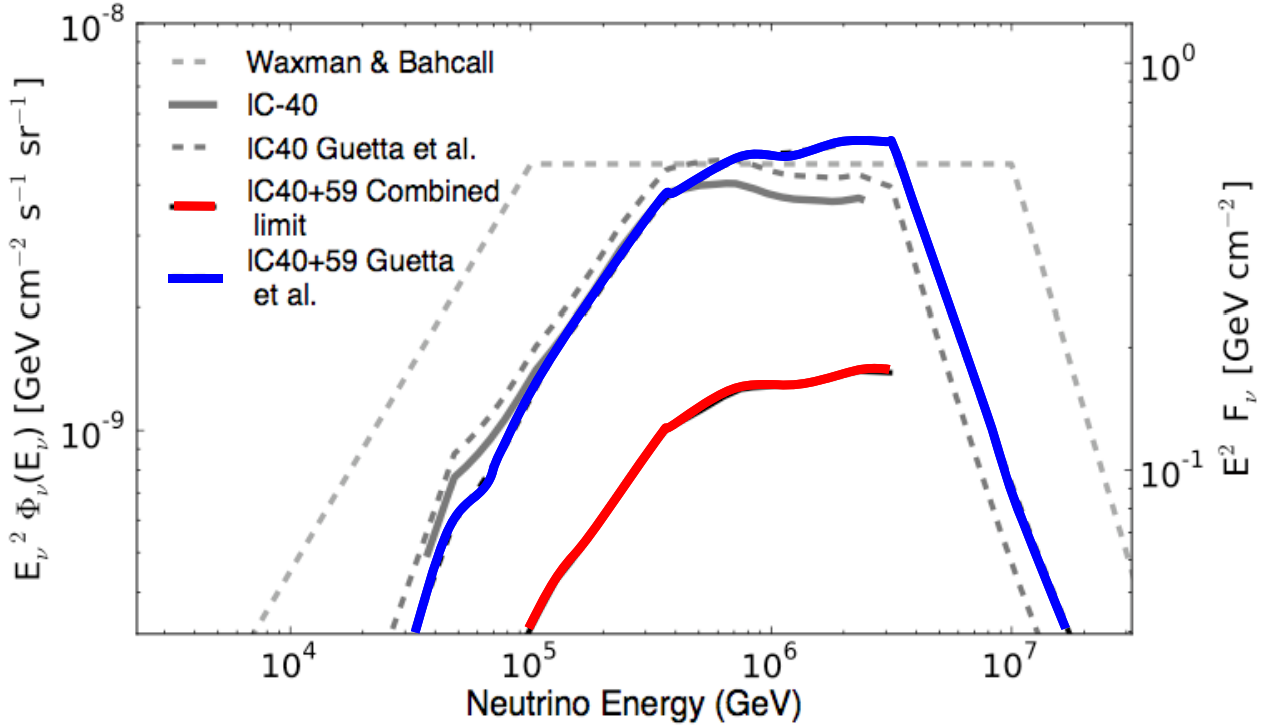
No neutrino in coincidence with GRB

2008-9 (40-string) data:
117 GRBs in northern sky

2009-10 (59-string) data:
98 GRBs in northern sky
another 85 GRBs in southern sky
also analyzed

Observed 0 events

Model prediction:
8.4 events (Guetta et al.
excluded at > 3 σ
(upper limit ≈ 2.3 events)



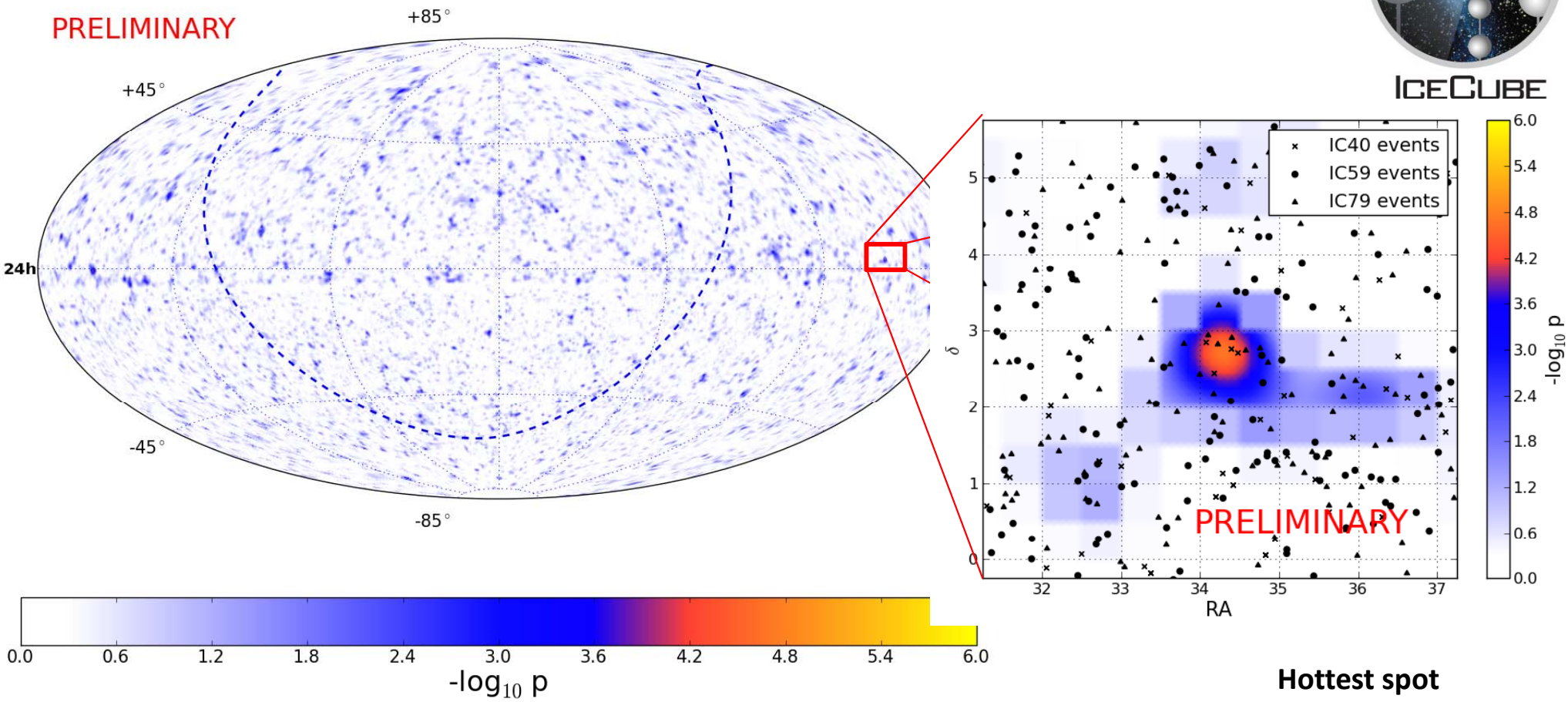
⇒ fireball model of GRB as sources of UHECR are seriously challenged

Nature, Vol. 484, 351 (2012)

-> talk by Julia Tjus

Important contributions: RUB Bochum & HU Berlin

Point source results IC-40+59+79



Hottest spot
-log10(p) = 4.707
Ra: 34.25
Dec: 2.75
Ns: 23.07
Gamma: 2.35
p-value ~60%
(post trial)

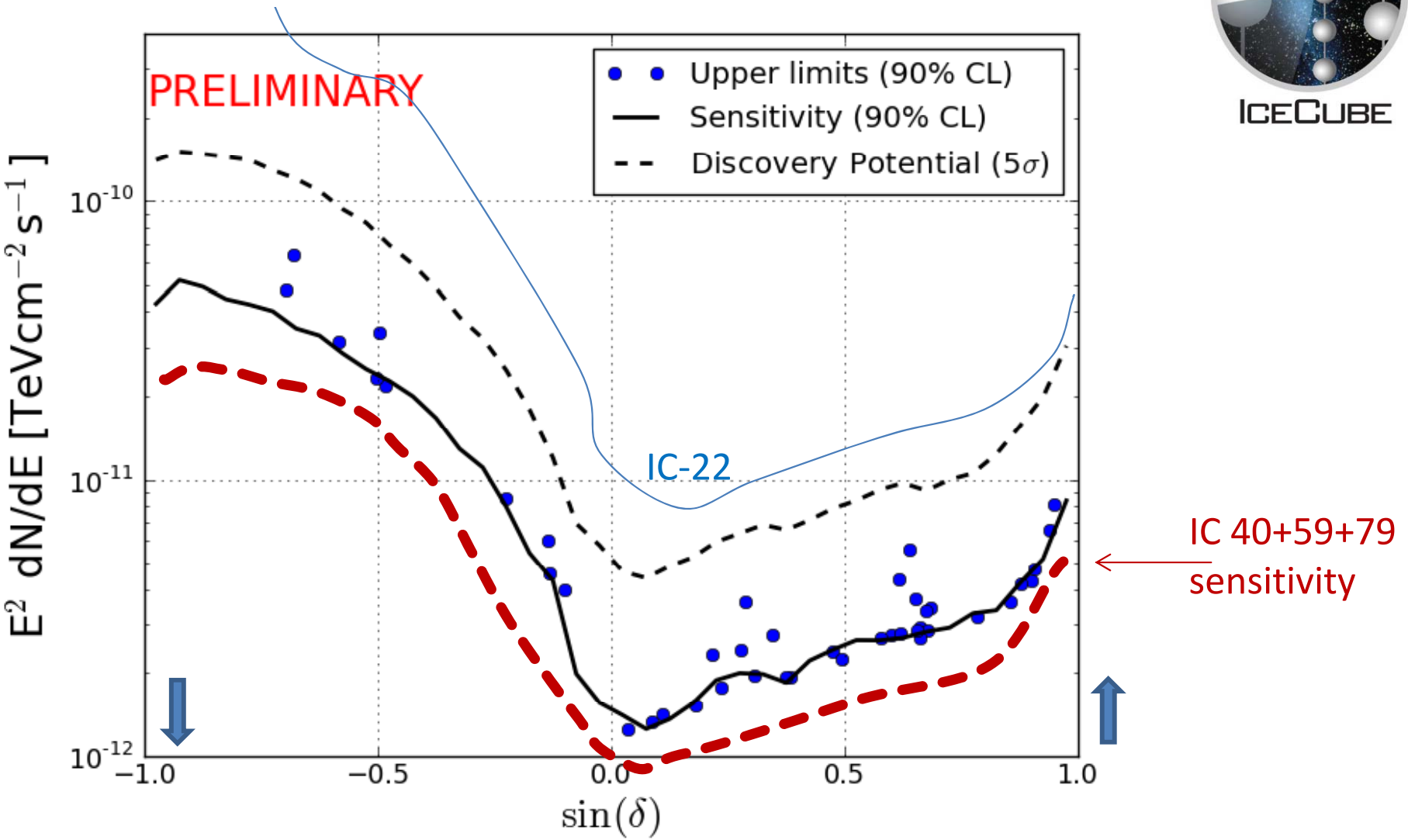
Unblinded 2 weeks ago

Total events: 108317 (upgoing) + 146018 (downgoing)

Livetime: 316 days (IC79) + 348 days (IC59) + 375 days (IC40) >1000 days

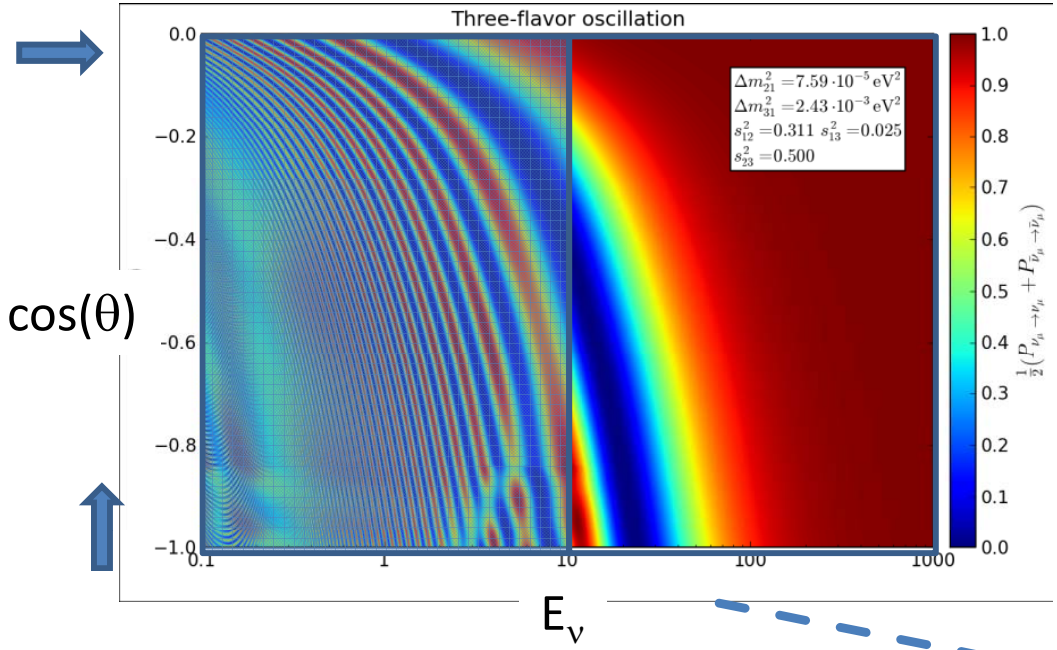
- *First analysis: no significant excess*
- *No spot with increasing significance with time*

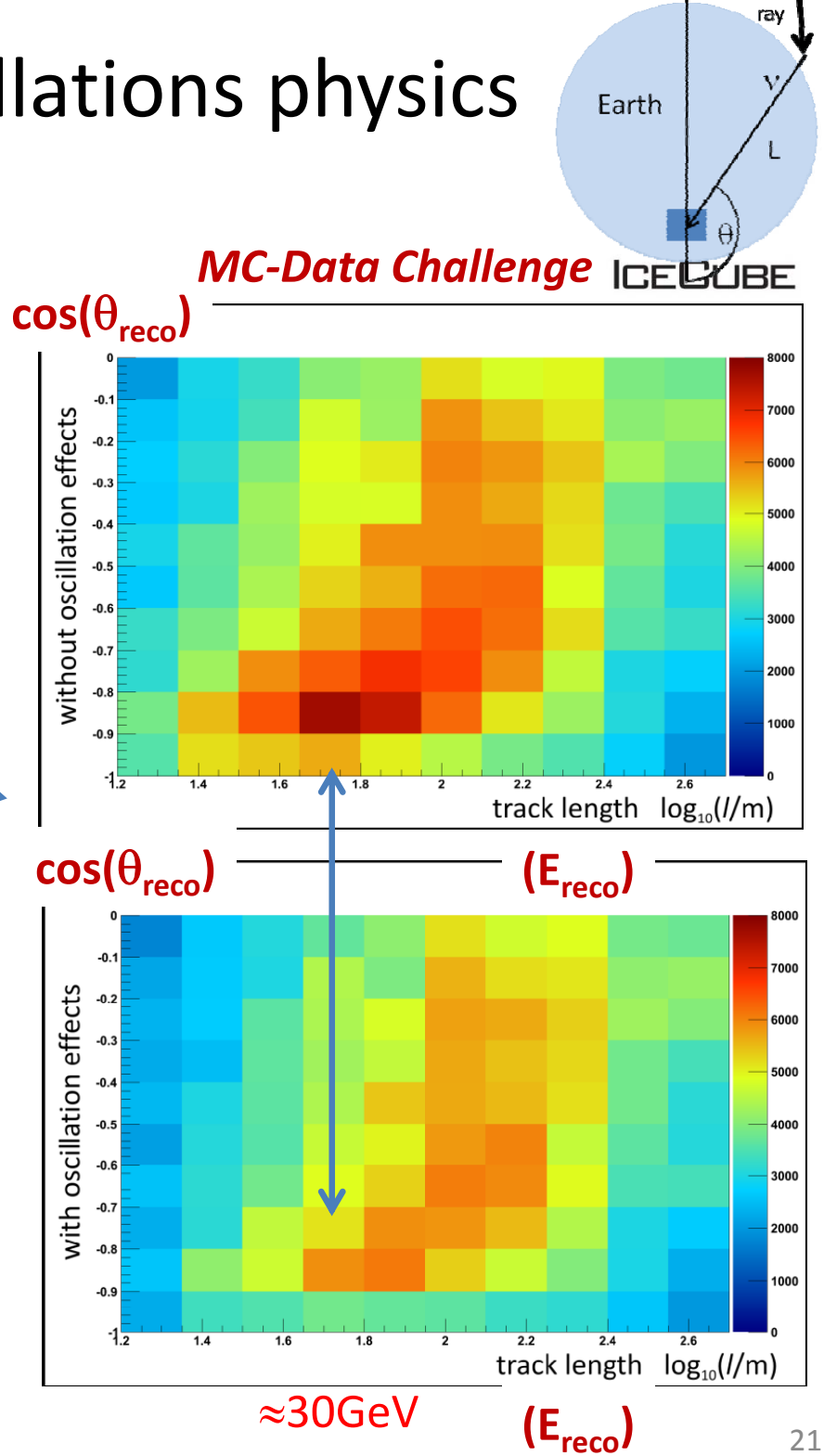
Point source result galactic sources (IC-40+59)



- About 1 order of magnitude improvement w.r. to IC22,
- IC40+IC59 achives the full IC86 sensistivity
- strong improvement in Southern hemisphere

Measurement of neutrino oscillations physics





Analysis principle:

Compare measured zenith-energy distribution with expectation

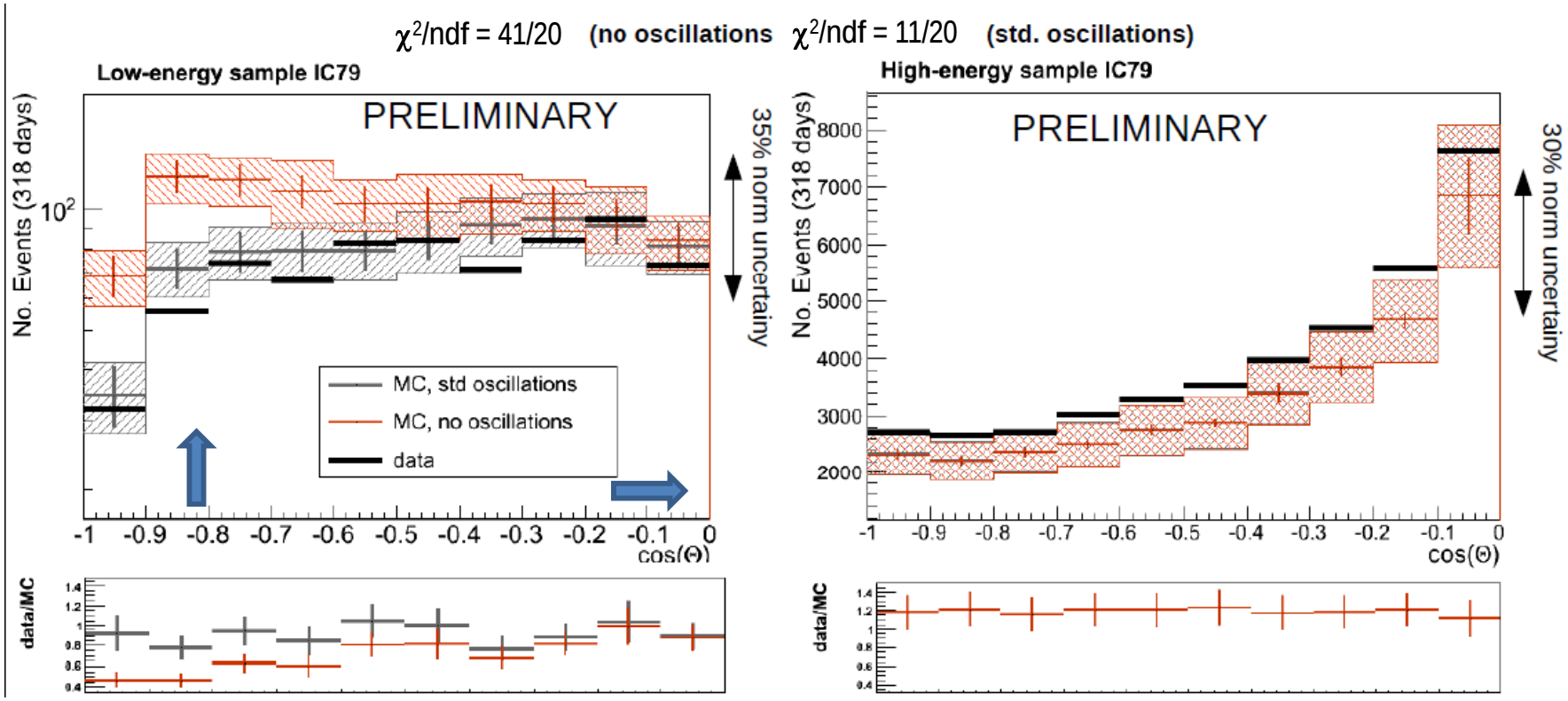
Global fit including systematic uncertainties

- high energy >100GeV (no oscillation effects)
- low energy <100GeV (with oscillation effects)

See posters @ this meeting

See Pingu/Orca talk by A.Kappes

Obervation of atmopheric neutrino oscillations



Initial analysis of zenith distributions:

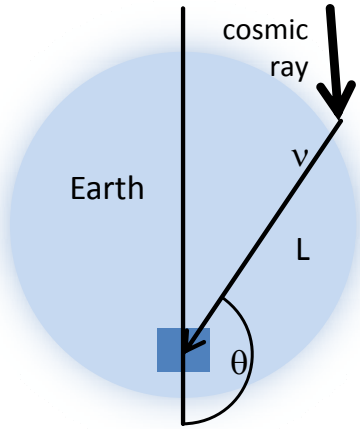
No oscillation case ruled out by 5.8σ

In work:

⇒ detailed parameter estimation and 2-dim fits

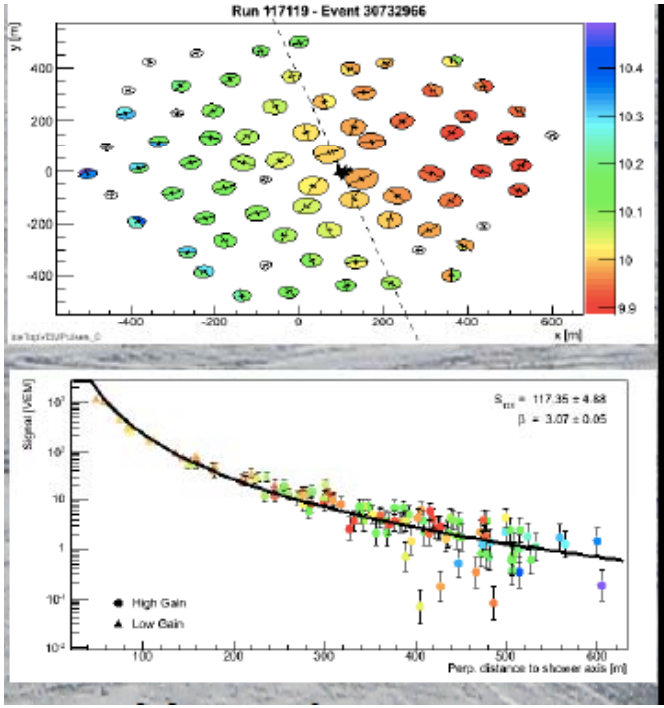
next steps:

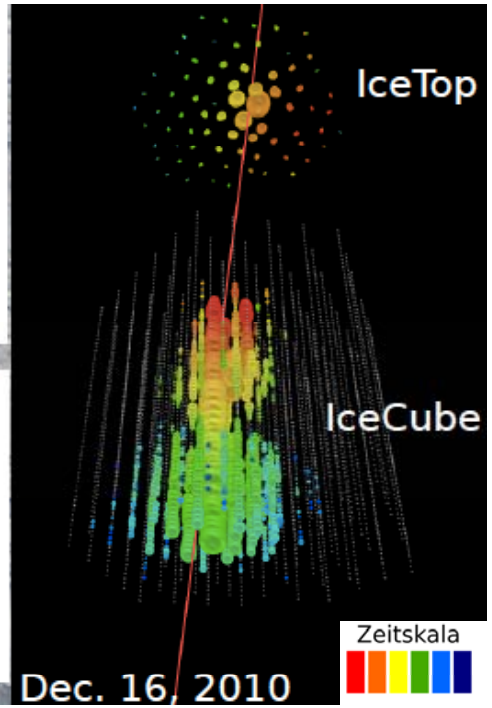
- Competitive or better estimation of Δm_{31} and ϑ_{23}
- appearance of ν_τ (exp. 30k/a triggered)
- lower energy threshold (PINGU) -> Talk by A.Kappes

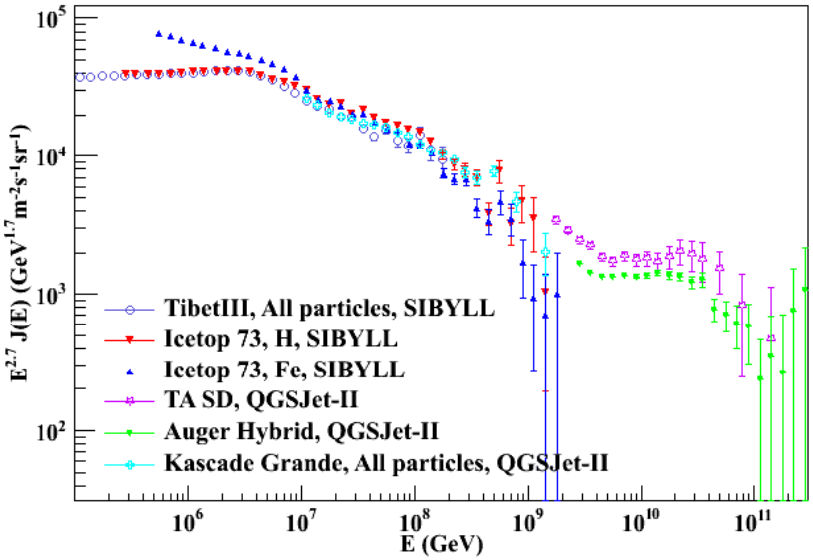


Main contributions: RWTH Aachen, TU München, DESY Zeuthen

Cosmic Ray Physics with the IceCube Observatory







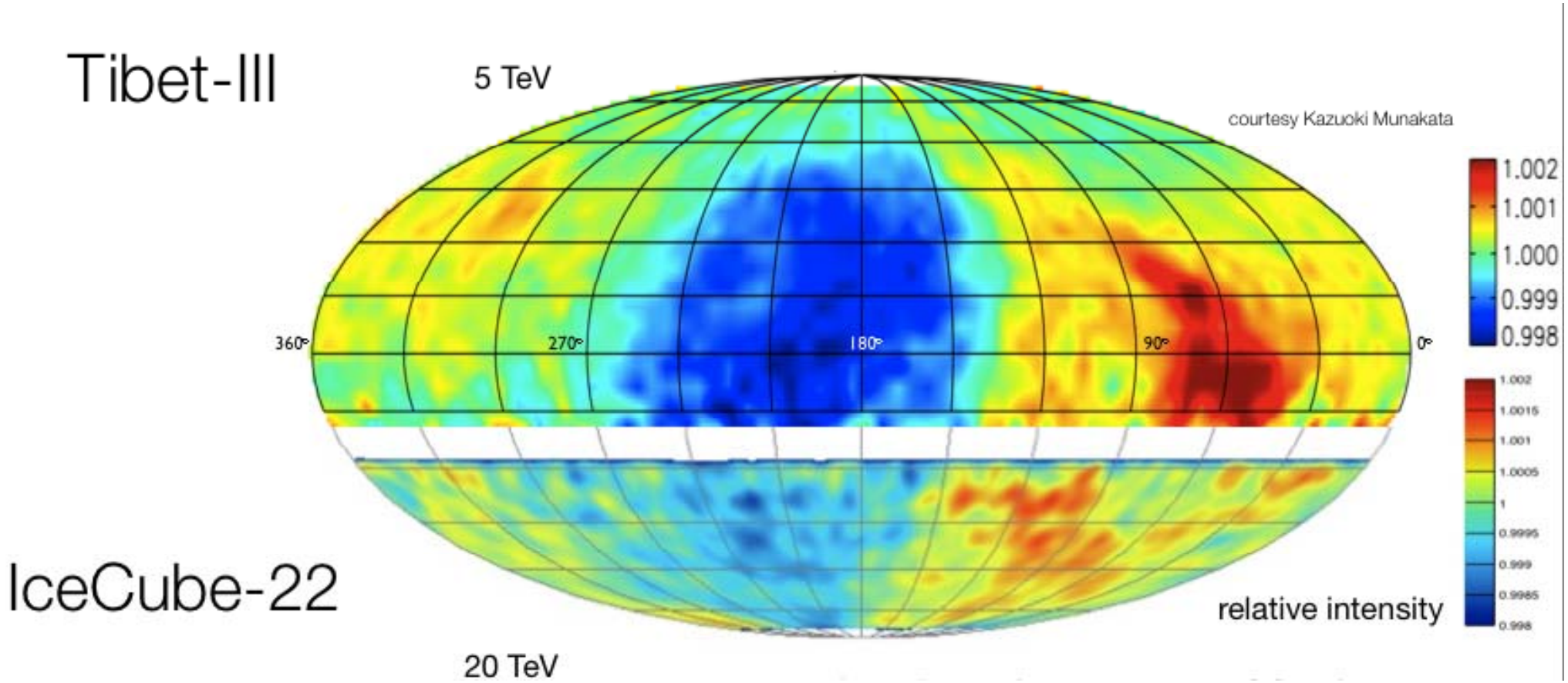
IceCube has been succesfully converted to a 4π Cosmic Ray Observatory

- Cosmic ray spectrum, arXiv:1202.3039 [astro-ph.HE]
- Initial composition results, arXiv:1207.3455 [astro-ph.HE]
- First steps toward radio detection of air showers (RASTA)
- Precision measurement of the cosmic ray anisotropy

⇒ See talk by Andreas Haungs on Cosmic rays und Julian Rautenberg on Radio detection

Important contributions: HU Berlin, BU Wuppertal

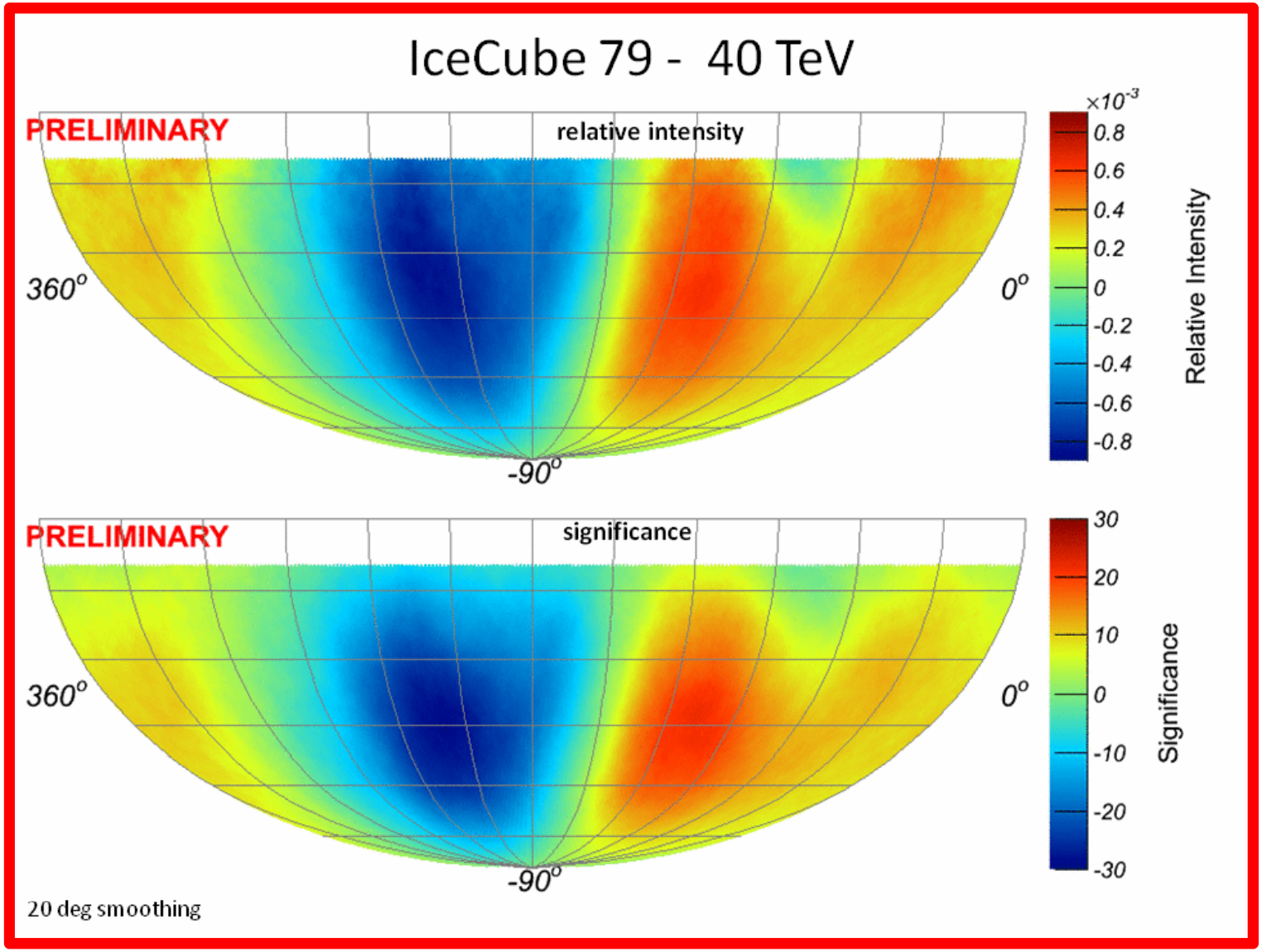
Anisotropy on the 10^{-3} level consistent with northern hemisphere observations



$4 \cdot 10^9$ events <E>≈20TeV

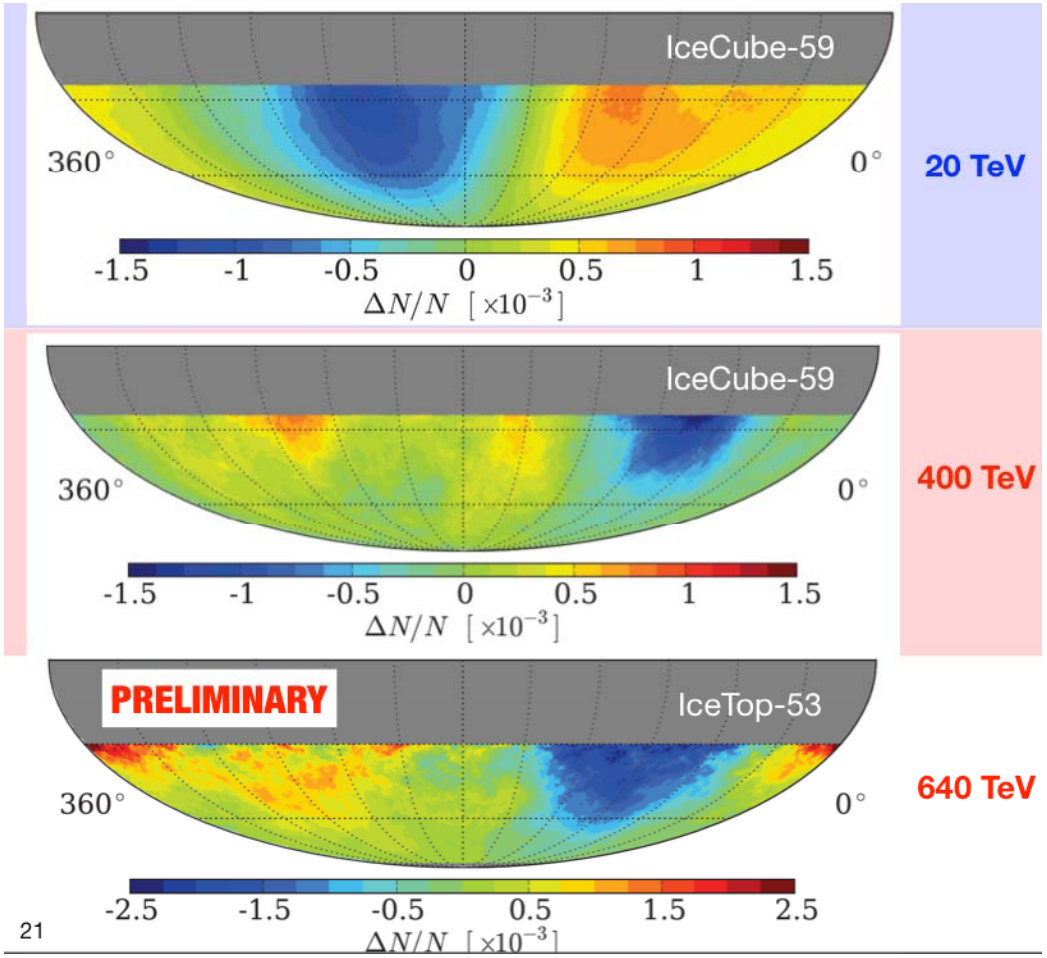
- Good match with northern hemisphere observations
- no compton-getting like dipole
- IceCube is an ideal detector for this: Flat overburden, high statistics, precisely known exposure

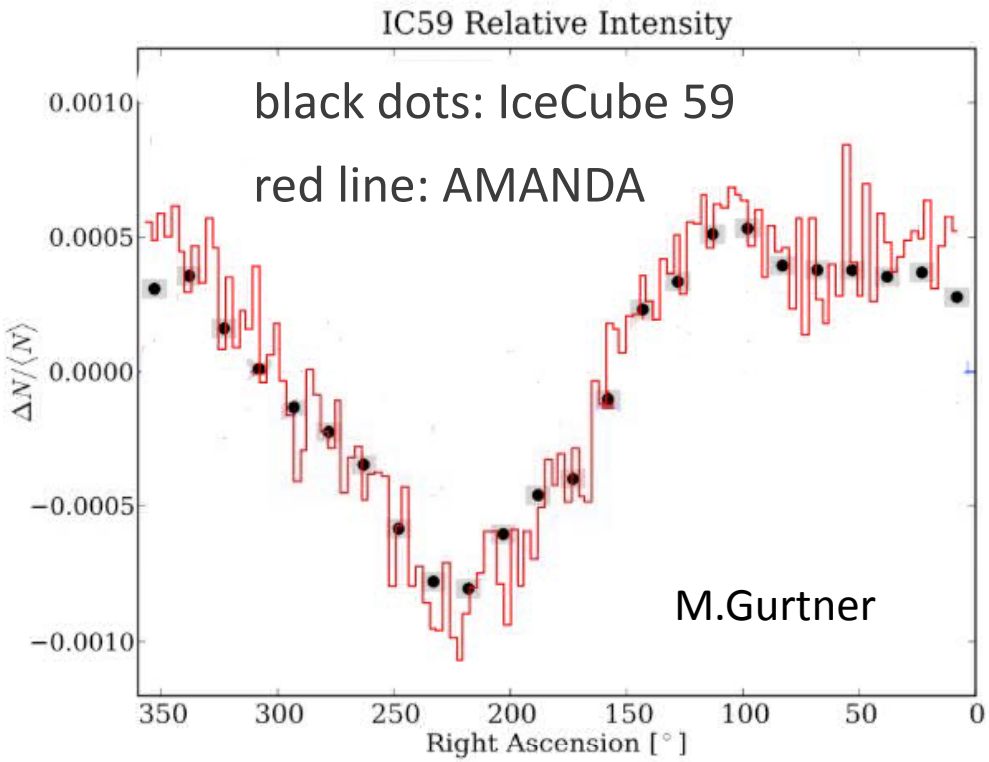
Anisotropy is energy dependent (40TeV-10PeV)



- Anisotropy changes with higher energy
- Strength seems to increase at high energy
- Probing and challenging CR ray source and propagation models

Observed Anisotropy is confirmed by IceTop and AMANDA

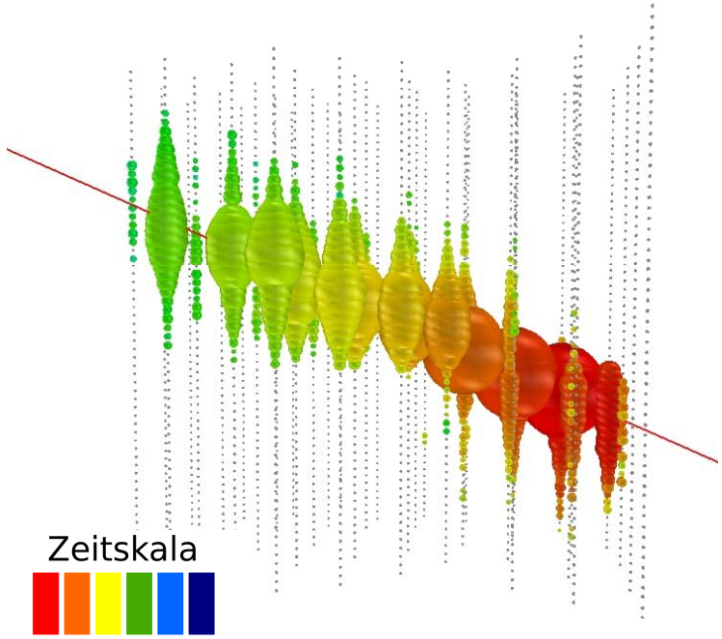




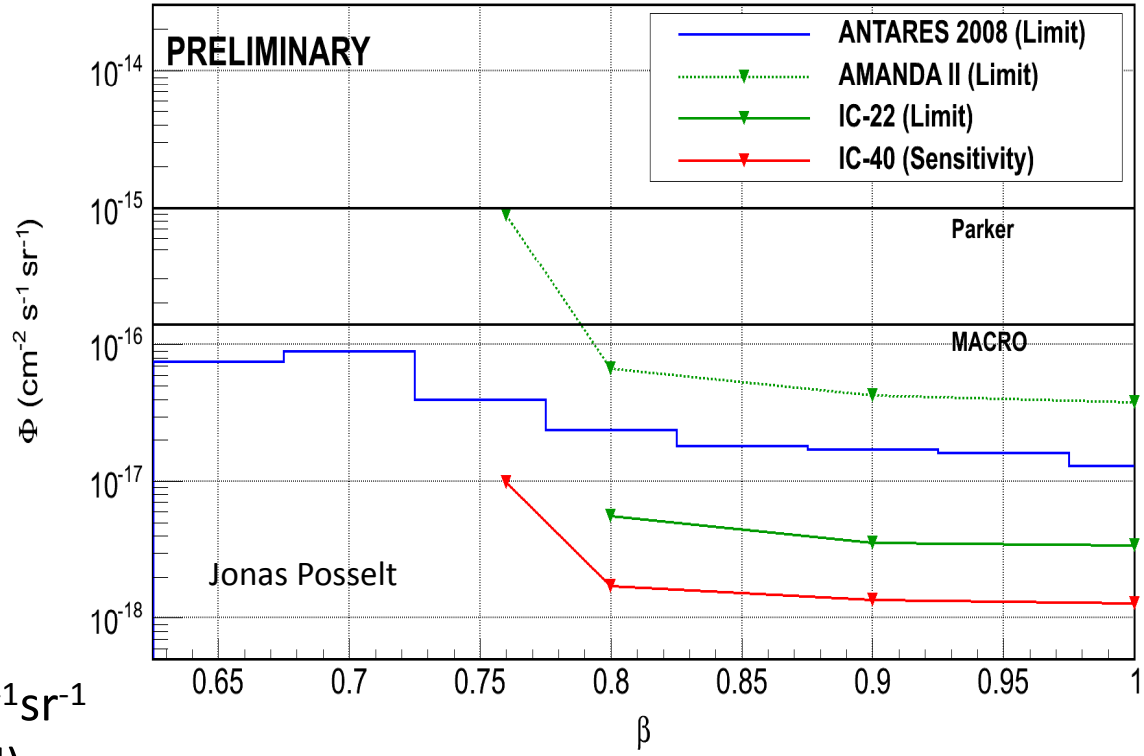
- IceTop confirms high energy anisotropy with > 5 sigma
- AMANDA confirms low energy anisotropy (result stable > 1decade)

Important contributions: BU Wuppertal

Exotic physics: relativistic magnetic monopoles



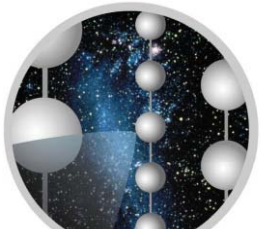
$$\frac{dN_{ph}}{dx} \propto \left(\frac{gn}{e}\right)^2 \propto 8300 \text{ muon}$$



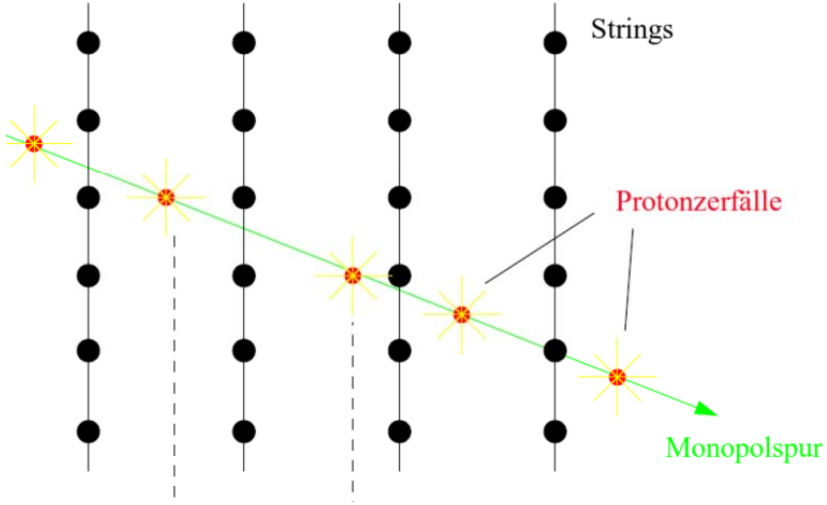
search for very bright events

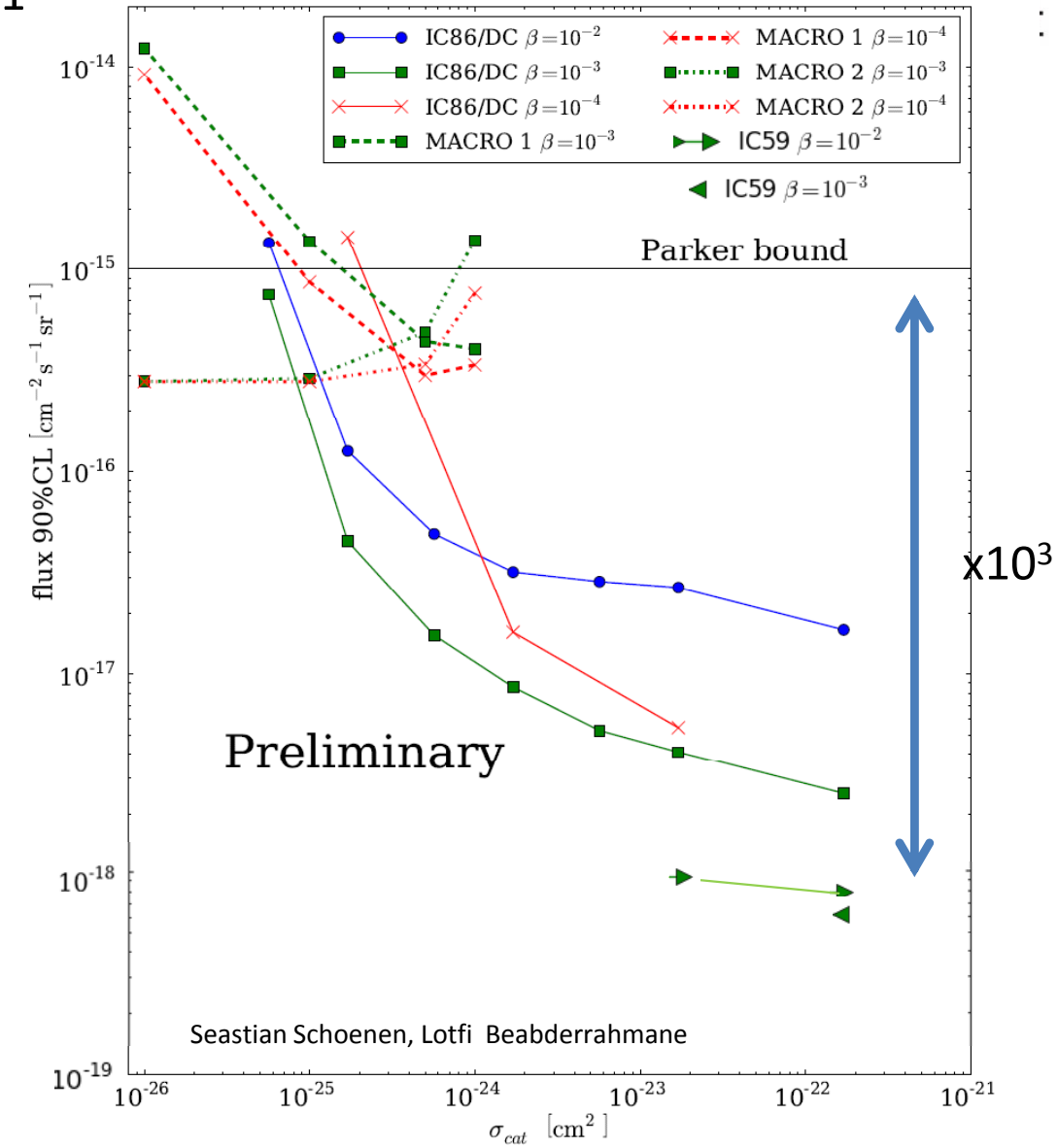
- IC-40 unblinding within 2 weeks
- sensitivity approaching $\phi \approx 10^{-18} cm^{-2} s^{-1} sr^{-1}$ (3 order of mag. below Parker bound)

First Results from slow magnetic monopole searches



Search for slow monopoles by subseqent proton decays (Rubakov-Callan effect)
New SlowParticleTrigger operating since 2011





Brightness

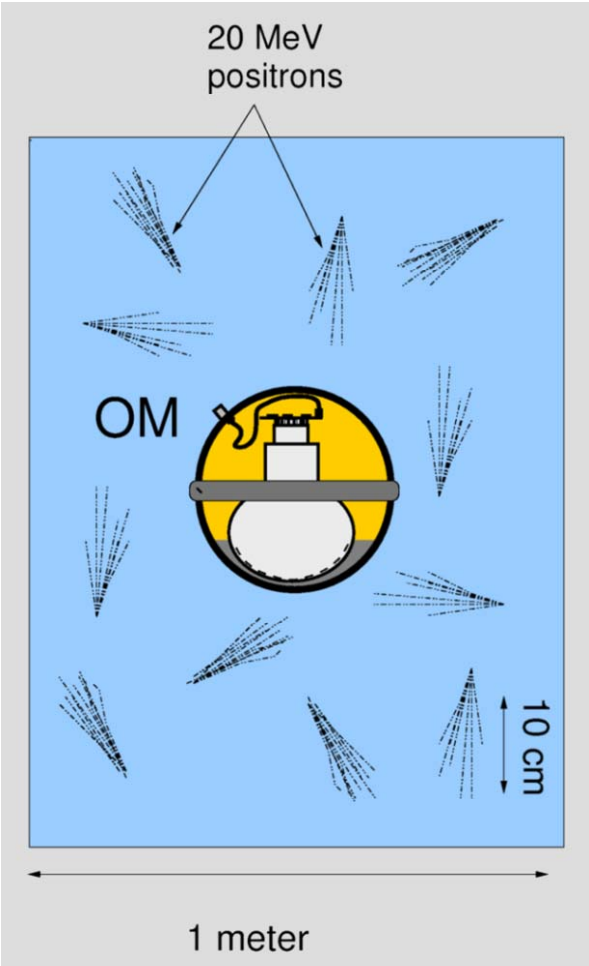
Two Analyses

1. Search for long duration events in IC-59
   typical λ_{cat}~1mm
   $\Rightarrow N_{obs} = 1$ (<BG>=1.1)
2. Analysis of 2011/12 DeepCore SLOP Data
   typical λ_{cat}~10m-1mm
   $\Rightarrow N_{obs} = 1$ (<BG>=0.46)

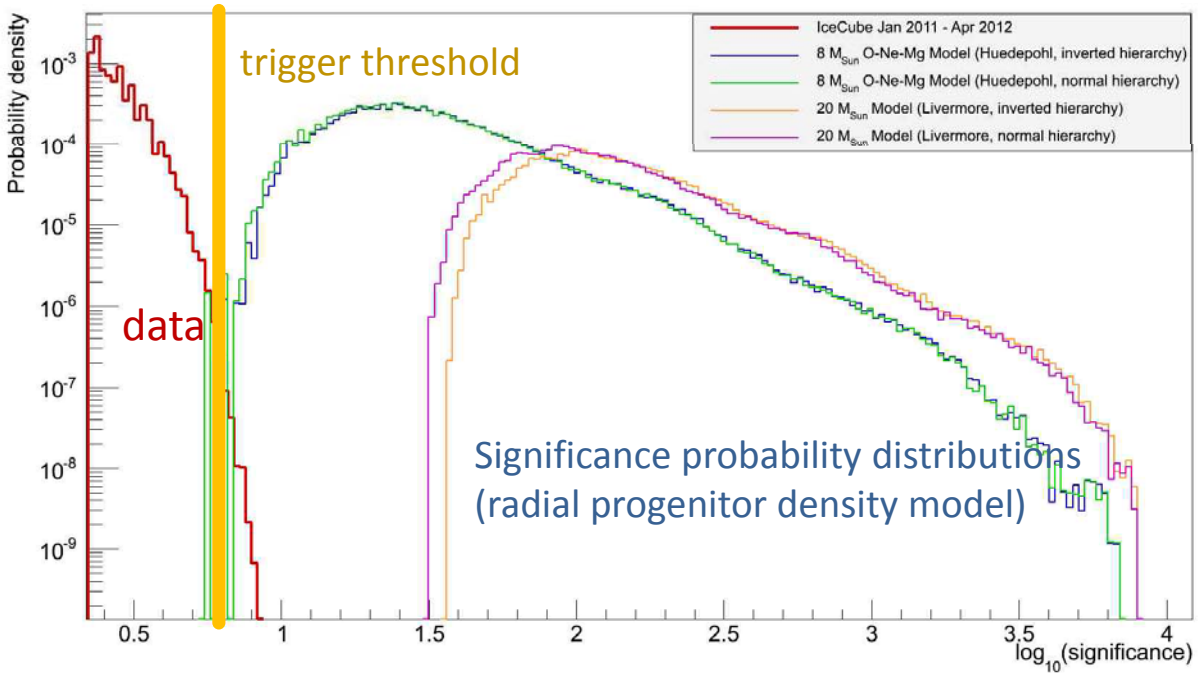
Flux limits @ 10^{-18}cm^{-2}s^{-1}sr^{-1}

Contribution by RWTH Aachen & DESY Zeuthen

Supernova detection



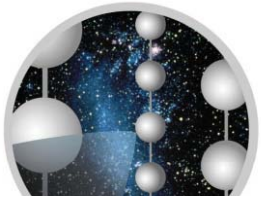
Large Rate of MeV neutrino interactions in the Gton volume leads to a collective increase of single count rates

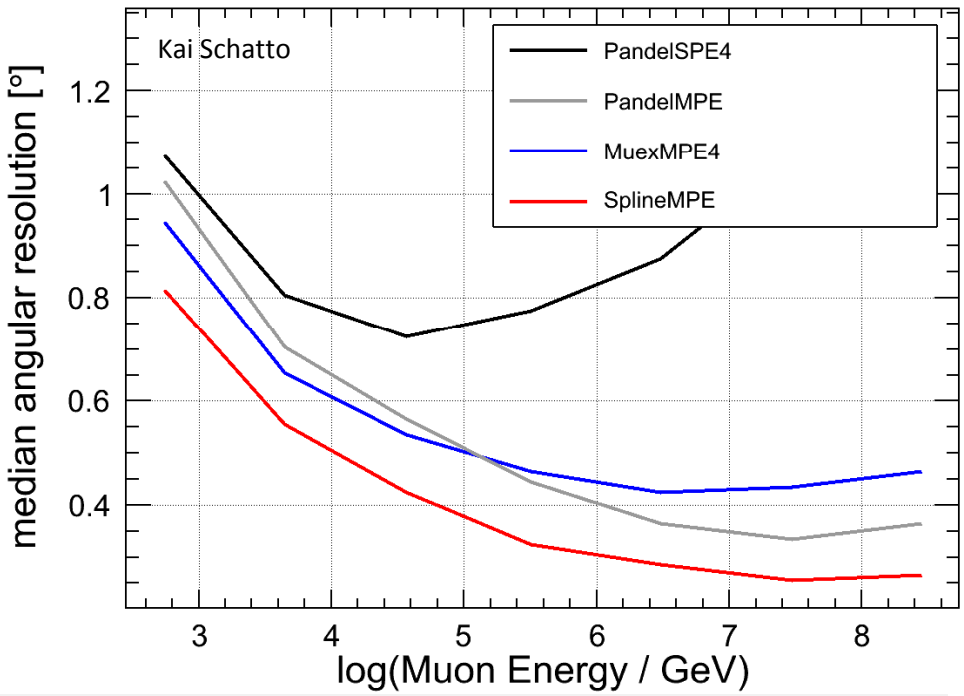


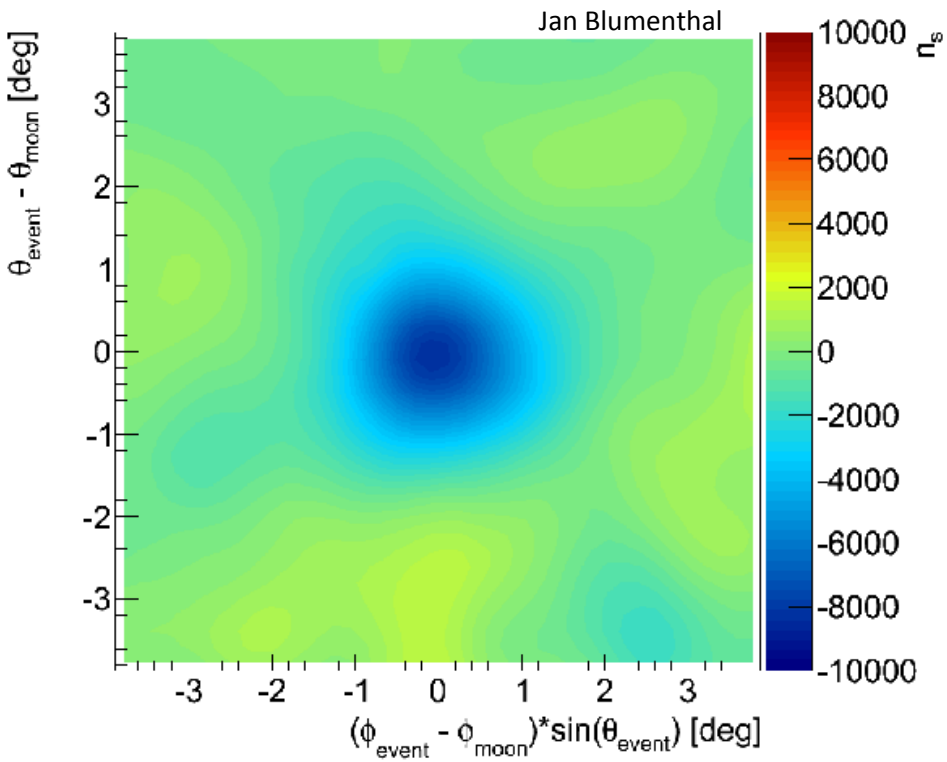
- very stable data, small seasonal effect
- > 98% uptime
- > 99 % of supernovae in our galaxy covered, even from light progenitors

Main contributions: University Mainz

Innovation made in Germany



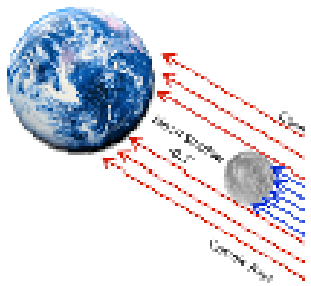




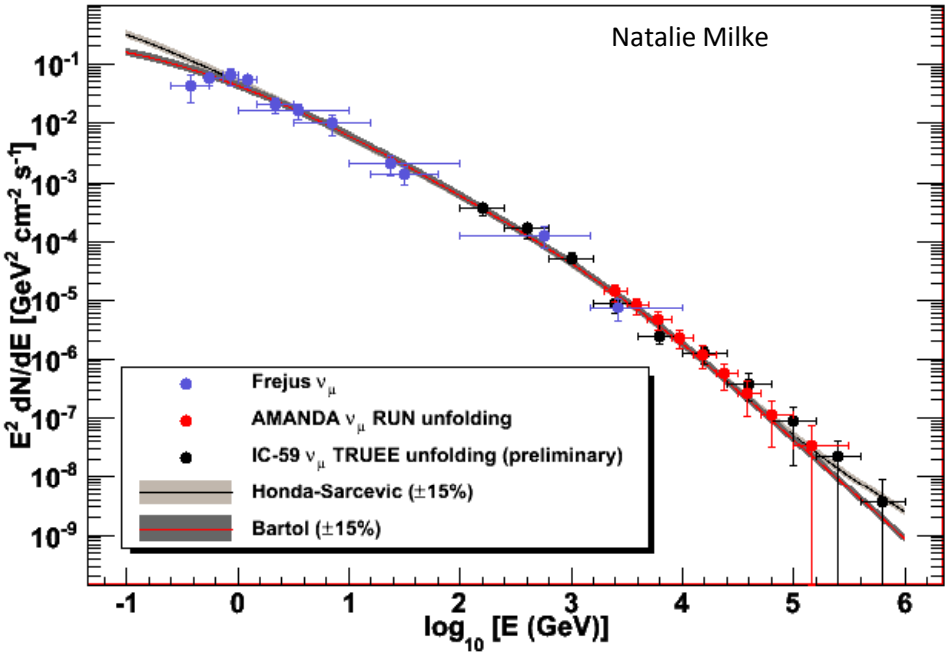
Precise modelling of ice layers substantially improves angular resolution
→ reach < 0.3° at high energies

Many R&D projects in Germany:
SPATS/Acoustic neutrino detection
RASTA: radio detection of air showers Rautenberg
DeepCore / Pingu -> Alexander Kappes

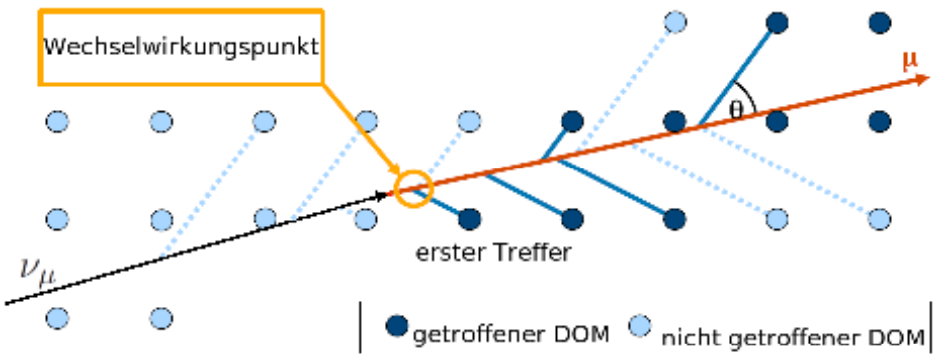
Point source analysis of the moon shadow in cosmic ray muons
⇒ Detected ~~source~~/sink wit 14 σ
⇒Pointing accurate to 0.1°
⇒Assumed point spread function correct



Innovations made in Germany part 2

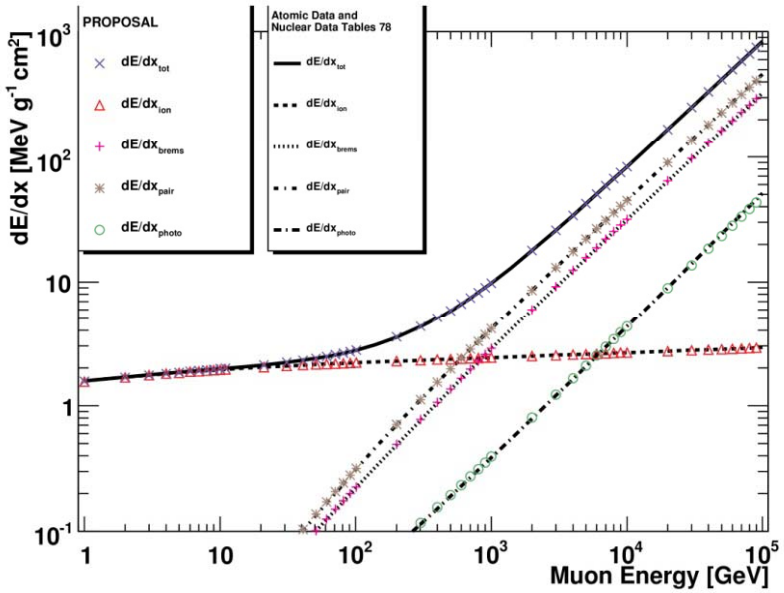


Spectral unfolding with **TRUEE**
(**T**ime dependent **R**egularized **U**nfolding for **E**conomics and **E**ngineering



Reconstruction of finite tracks

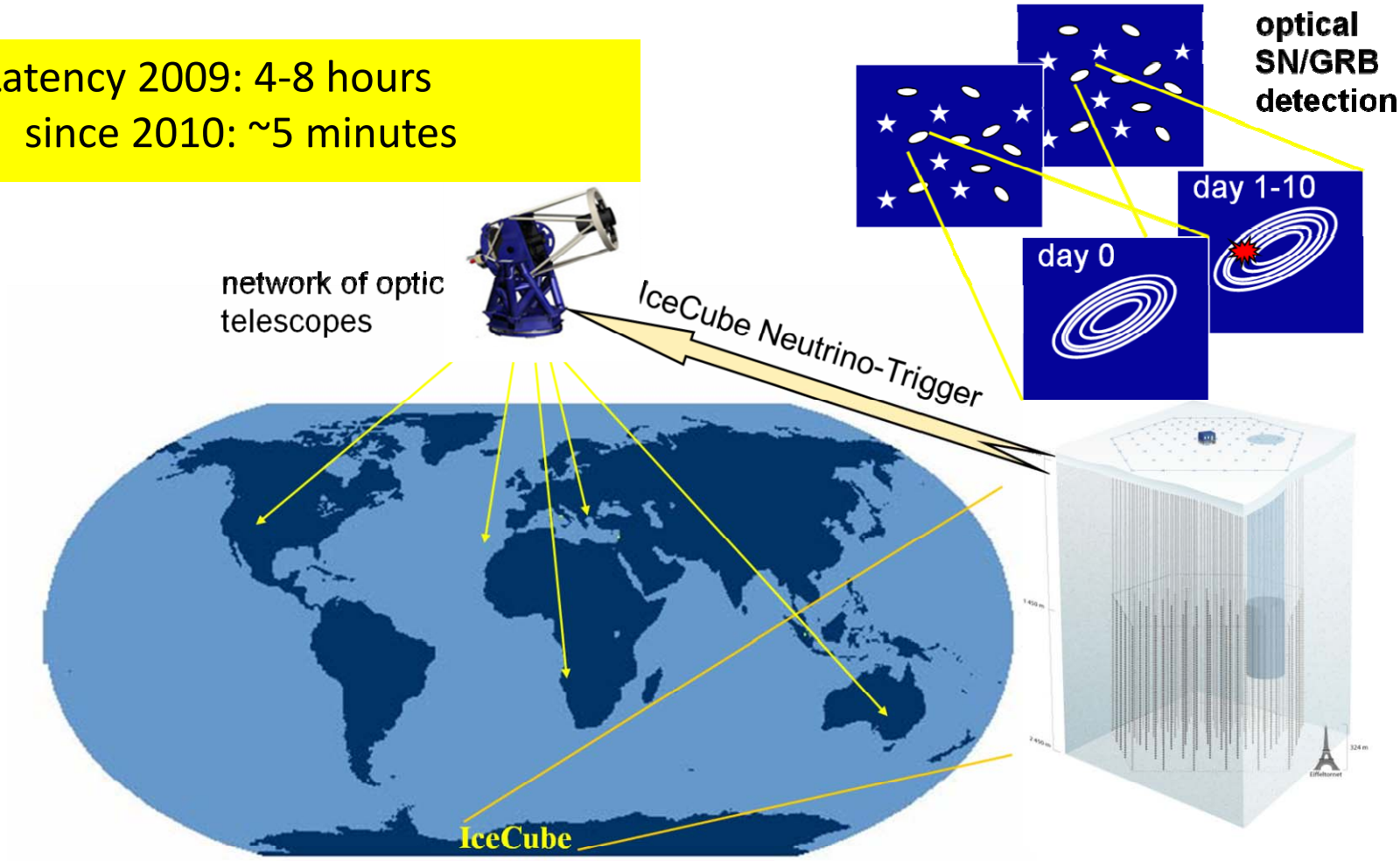
PROPOSAL: **PR**opagator with **O**ptimal **P**recision and **O**ptimized **S**peed for **A**ll **L**eptons, Successor of MMC (**M**uon **M**onte **C**arlo) written in C++



Innovations made in Germany part 3

- Optical & X-ray Follow up (Bonn)

Latency 2009: 4-8 hours
since 2010: ~5 minutes



- TeV Blazars Target of opportunity (DESY)
- Supernova early warning: participation in SNEWS (Mainz)

Summary & Conclusions

- IceCube construction is completed.
  Data-taking with >98% efficiency
- Multi-pupose Experiment with important new results
  - Diffuse searches: high energy excess in several analyses (not significant)
  - First observation of atmospheric electron neutrinos
  - Observation of atmospheric neutrino oscillations
  - Point source searches: GRB models have to be revised
  - IC-40+59+79: No (galactic) point sources yet
  - Cosmic ray: Precision measurement of anisotropy
  - Magnetic monopoles: >1 order improved limit (Macro)
- Significant contributions by German groups
- More exciting results still to come (soon)

German Institutions

Arbeitsbereiche	AA	BO	BN	DESY	DO	HU	MZ	TU	WU	EN
Punktquellen und transiente Phänomene	x		x	x		x		x		
Quellen dunkler Materie	x						x		x	
nicht lokalisierte ν_μ-Strahlung	x				x					
ν_e's & neutrale Ströme			x	x						
kosmische Strahlung & atm.ν's, μ's	x	x		x		x	x	x	x	
Supernova Suche							x			
Suche nach exotische Teilchen	x			x					x	
neue Technologien: RASTA	x		x						x	
neue Technologien: Akustik	x								x	
neue Technologien: PINGU			x				x	x		x
Rekonstruktions- & Simulations-verfahren	x		x			x	x			
DAQ,Trigger, Filter, Monitoring	x		x			x	x	x		
Simulations- & Datenmanagement	x	x		x	x			x	x	
Phänomenologie		x			x					

Analysis coordinators:
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Workgroup coordinators:
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Exotics: K.Helbing
Cascades: *M.Kowalski*
Supernova: L.Köpke
Cosmic Ray :*T. Waldenmeier*
Reconstruction: D.Boersma
RASTA: S.Böser
Acoustic neutrino detection: K.Laihem & T.Karg

Run Coordination: S.Böser
Excecutive board:
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Publication board:
H.Kolanoski, J.Tjus, A. Kappes , E. Resconi
Speakers board: K. Helbing & E. Resconi

- ~20 publications/a,
- ~30 conference talks/a
- ~ 5-10 PhD theses/a,
- ~20-30 Diplom/Master theses/a,
- ~20-30 Bachelor theses/a