The IceCube Neutrino Observatory

Markus Ackermann
Physics Research Committee meeting
DESY, Hamburg, 25.10.2011

Overview

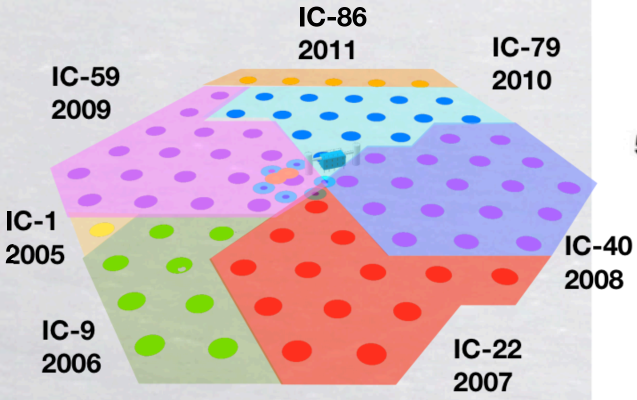
- The IceCube detector
- Scientific results
- Future developments

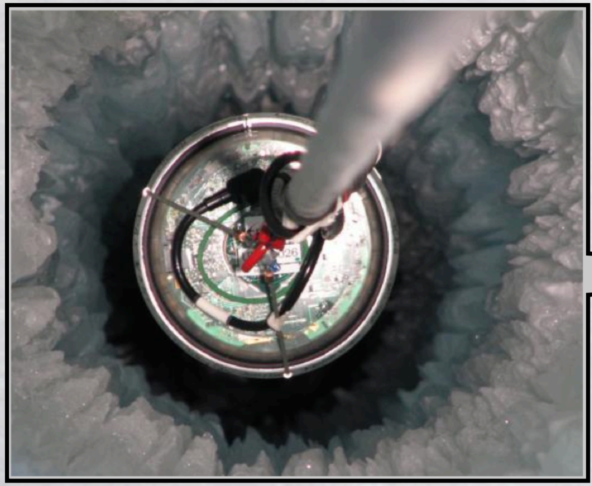
The IceCube collaboration

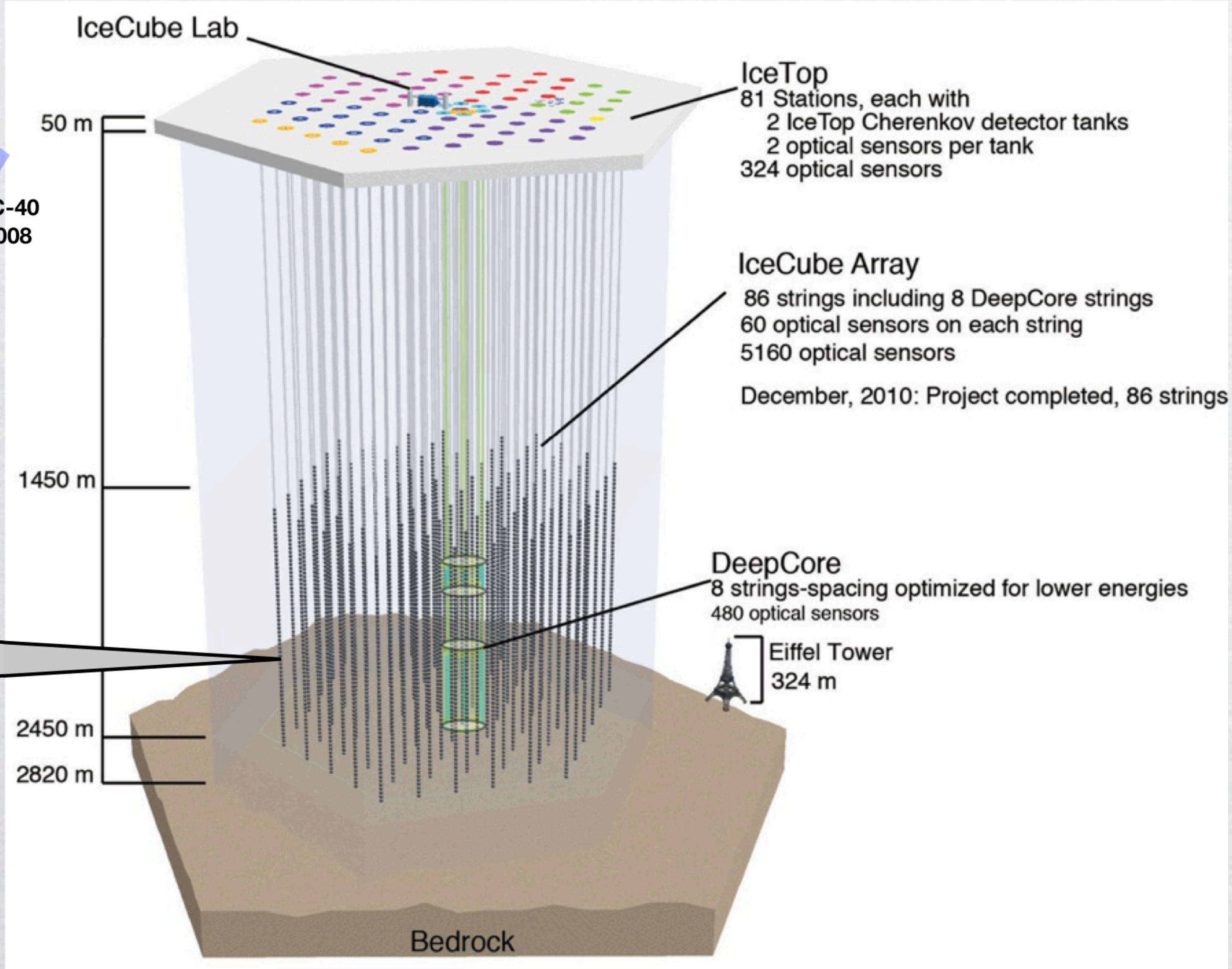
Internationl Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
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 IceCube Neutrino Observatory

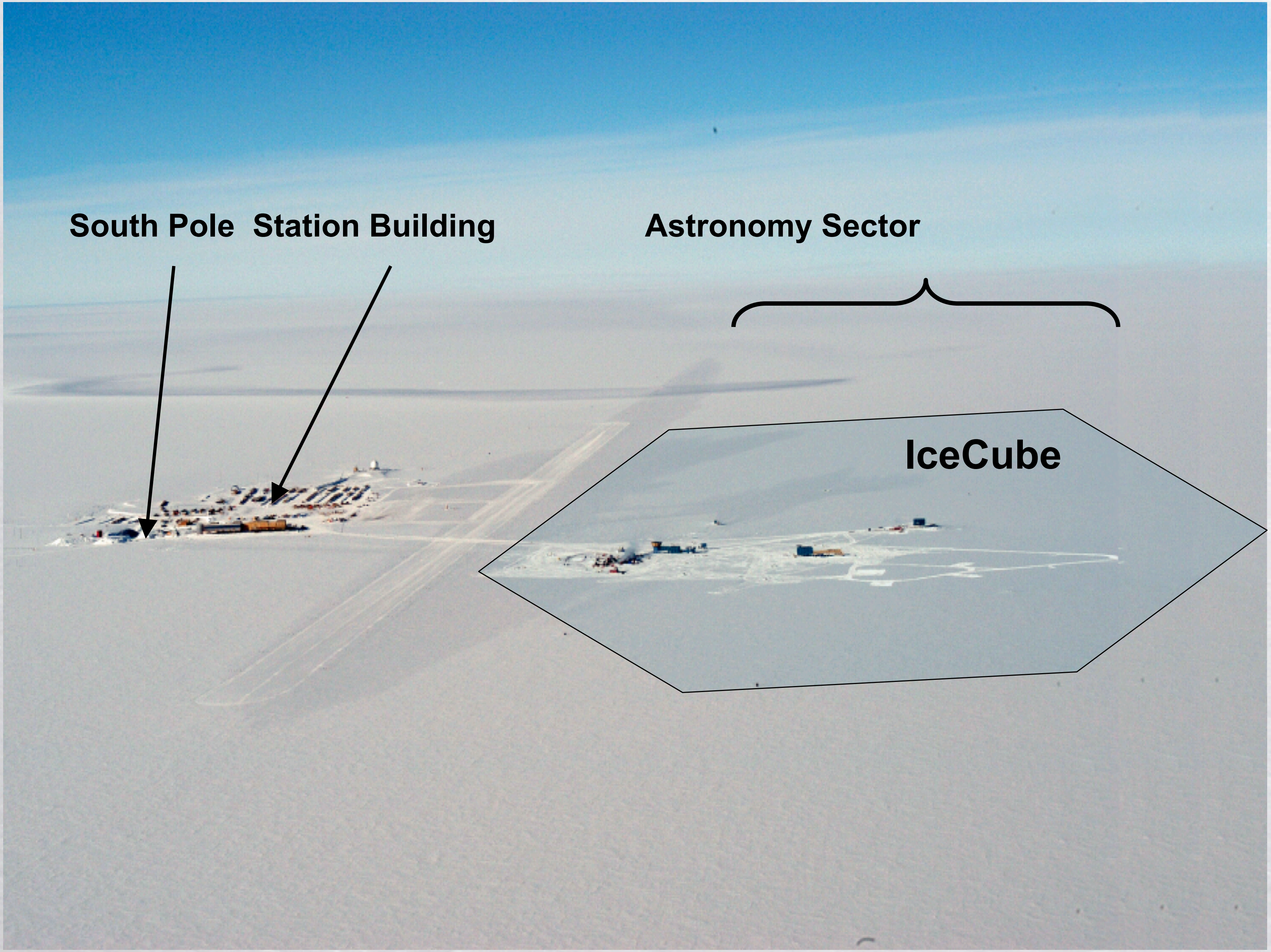






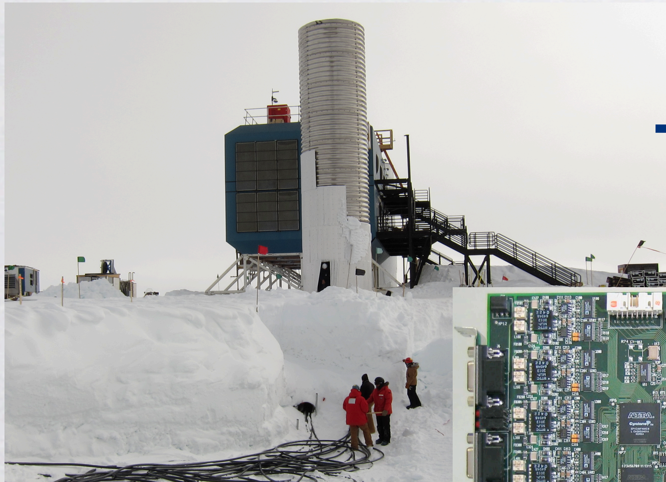
- Completed in December 2010 after 6 years of construction.
- Operational for science in different sub-detector configurations during construction phase (IC-22, IC-40, IC-59, IC-79)

IceCube & South Pole Station

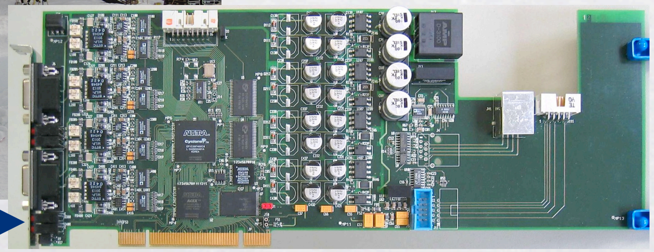


IceCube detector elements

IceCube
Laboratory
DAQ
Online filtering
Transfer
Storage



South Pole link to TDRSS satellite network

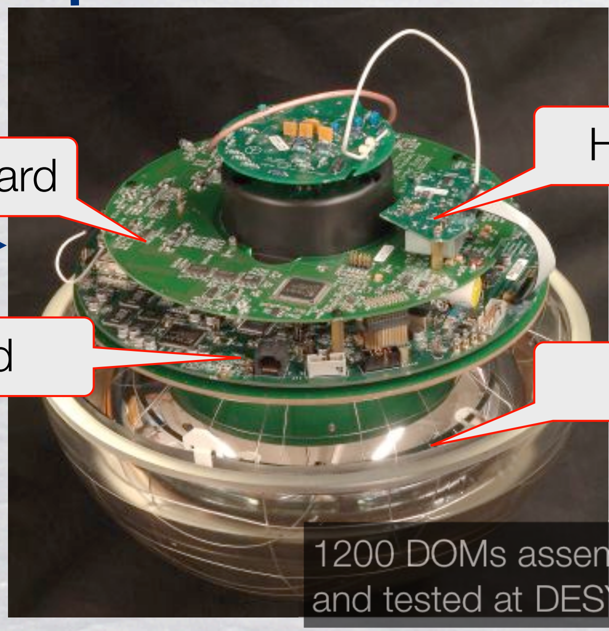


DOM receiver card

Designed and built at DESY

Digital optical module (DOM)

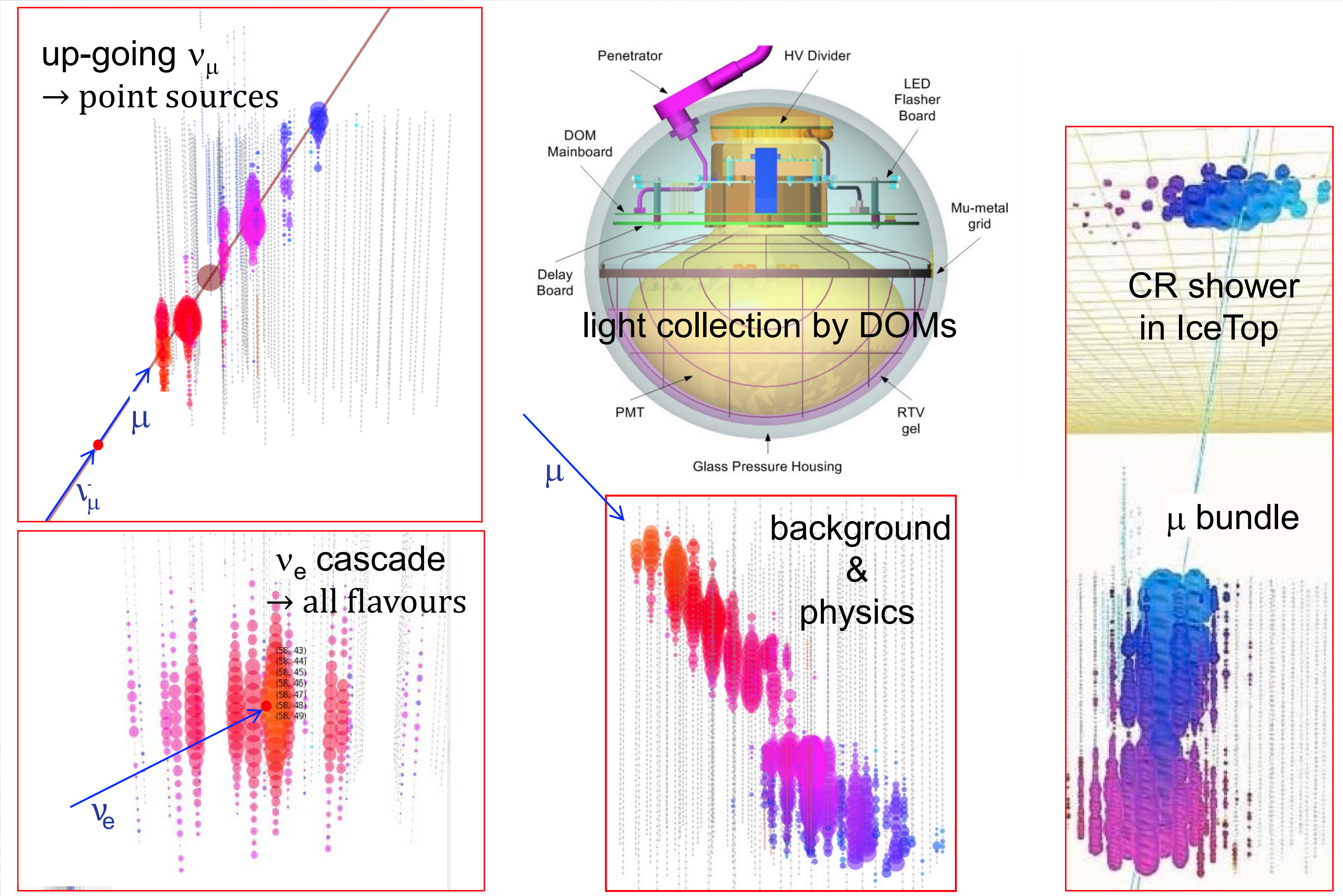
InIce Array
86 strings
60 DOMs per string



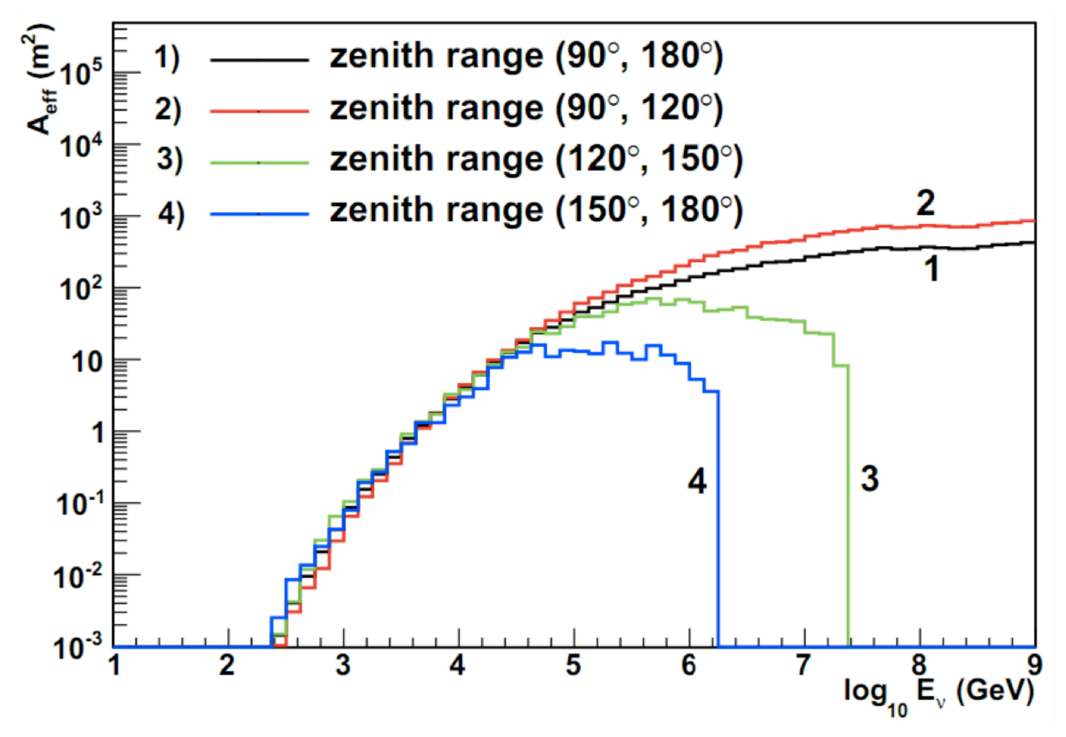
1200 DOMs assembled and tested at DESY

IceTop Array
81 stations
2 tanks per station
2 DOMs per tank

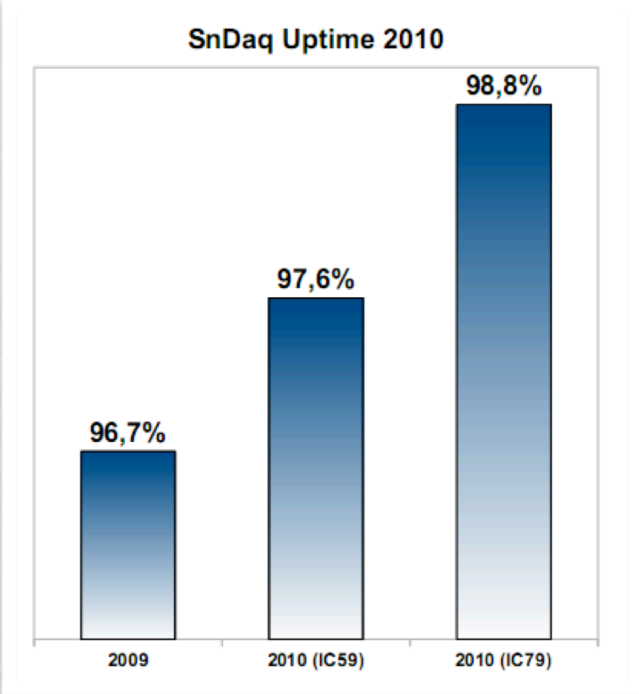
Particle signatures in IceCube



IceCube performance



IC-40 muon neutrino effective area



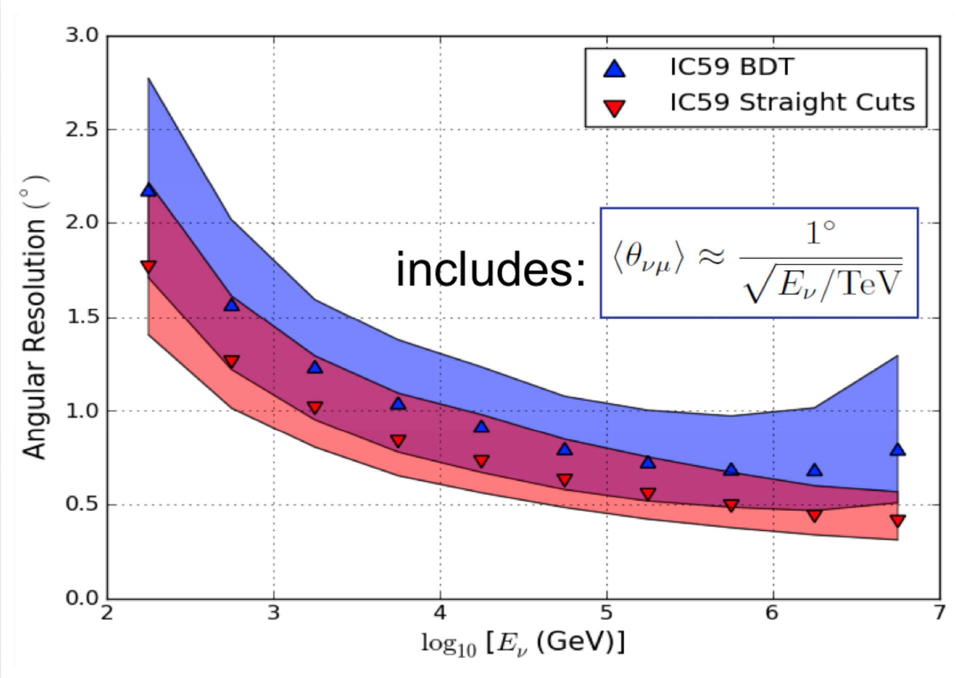
Effective area

- Earth opaque for E_ν >> 100 TeV
- Dependent on analysis (event selection)

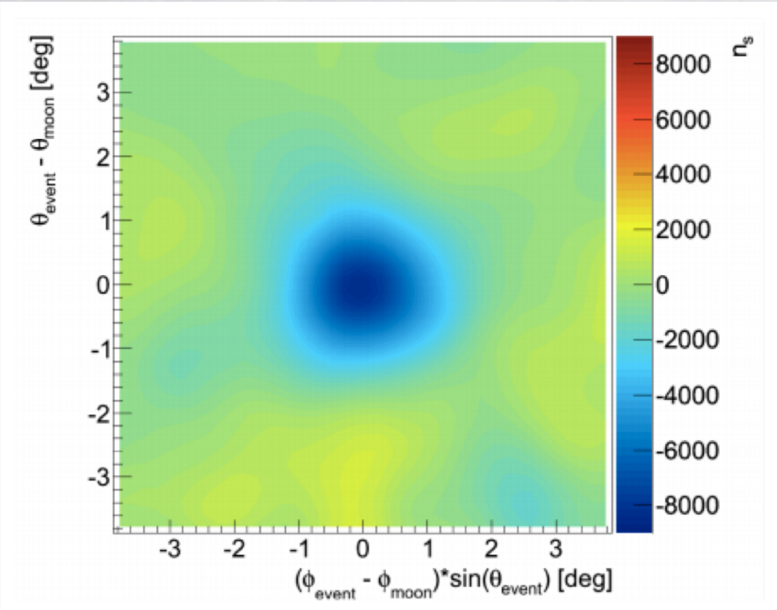
Detector uptime

- General detector uptime: 98.5% (99% goal)
- Supernova alert system uptime: 98.8% (99% goal)
- “Clean” uptime: 93.1% (95% goal)

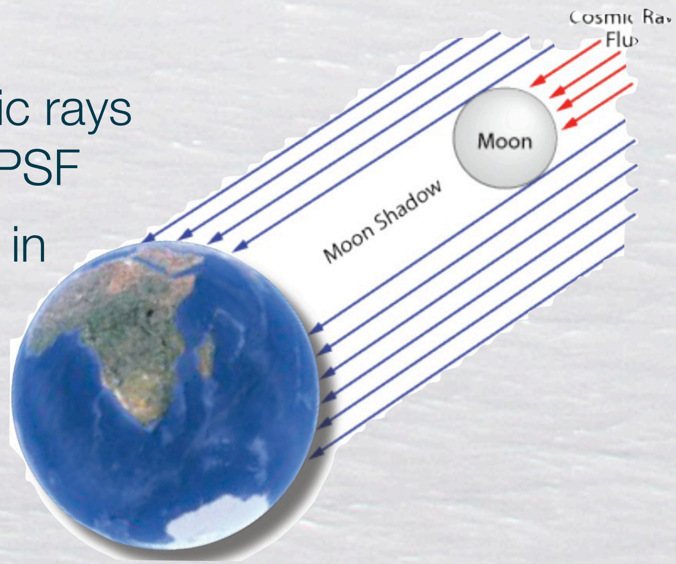
Ice Cube performance - Point Spread Function



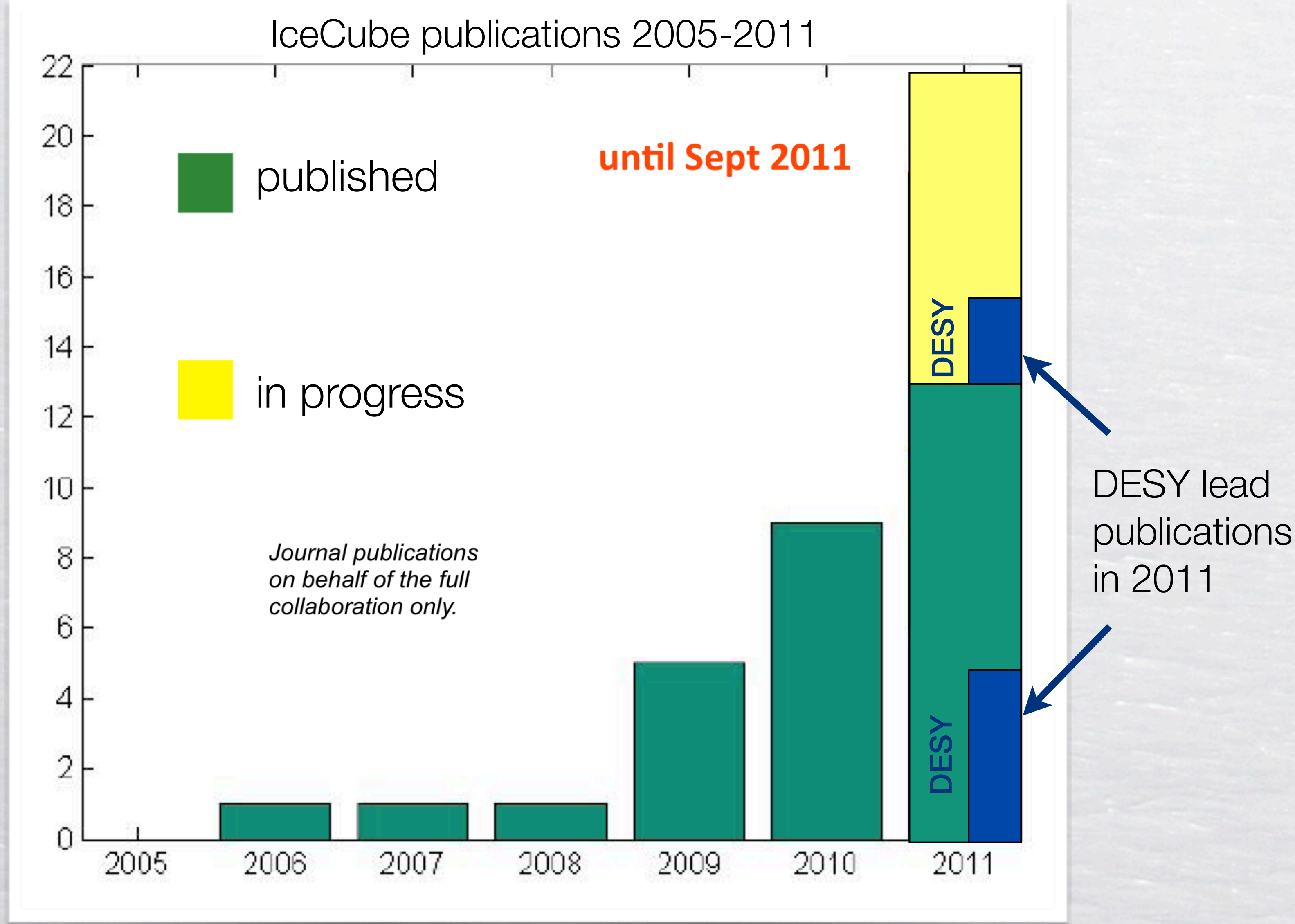
- PSF for events used in the IC-59 point source analysis
- Better than 1 deg above E_ν = 1 TeV
- dependent on event selection



- Use shadowing of cosmic rays by the moon to confirm PSF
- Moon shadow observed in IC-40 / IC-59 data
- Significance: 13 σ

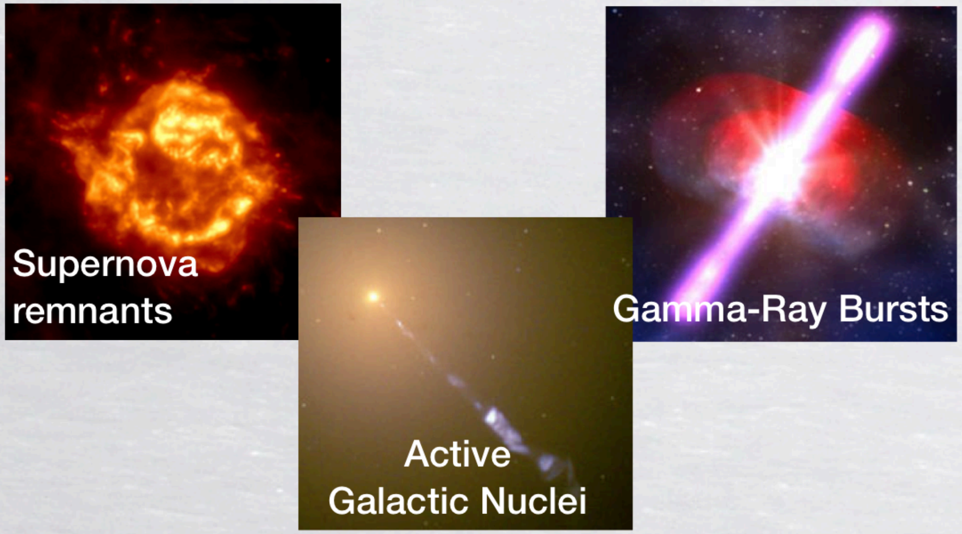


IceCube performance - Science output

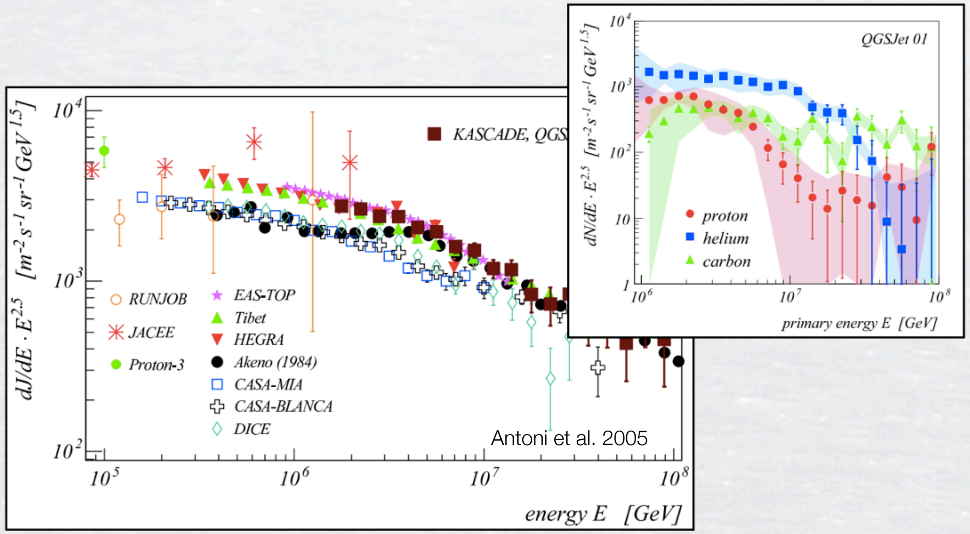


- 30 papers published using construction phase data
- Analysis results from partial detector configurations (IC-22, IC-40, IC-59, IC-79)

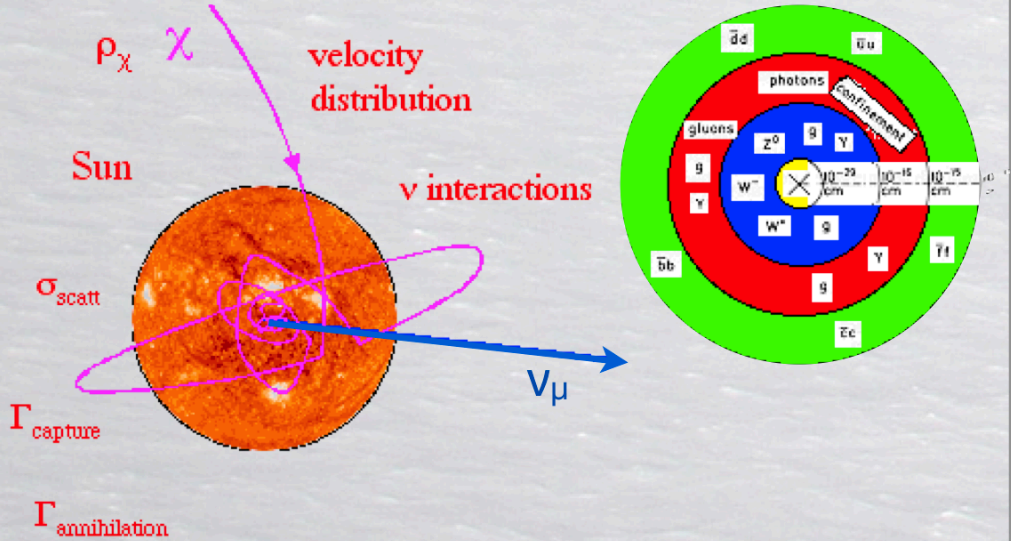
IceCube science topics



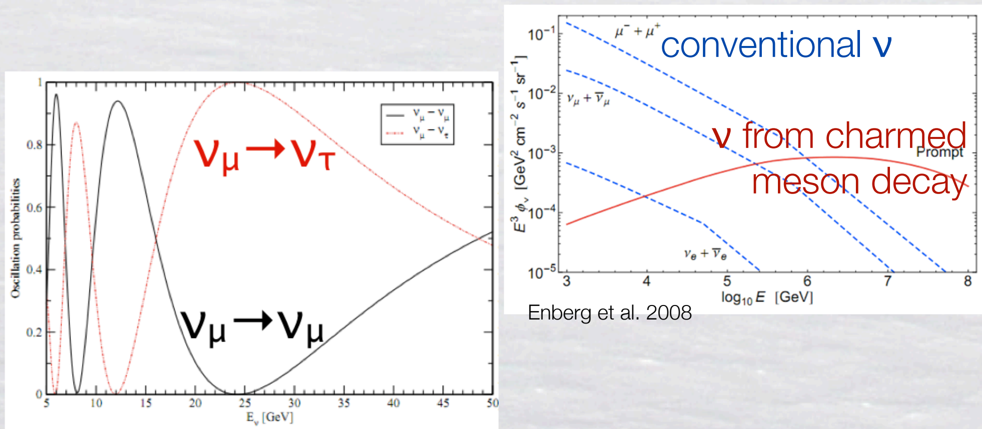
Neutrino astrophysics



Properties of cosmic rays



Dark matter & exotic particles



Neutrino properties & particle physics

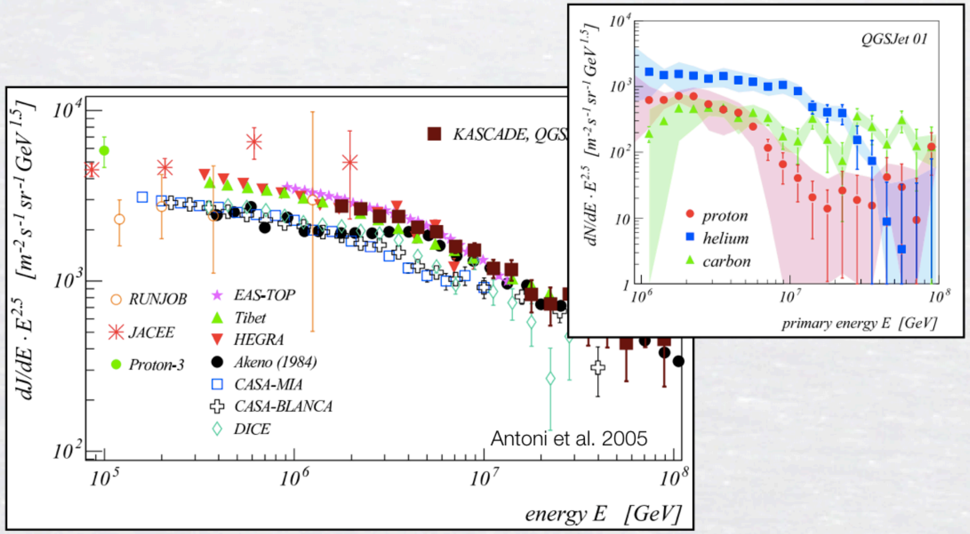
IceCube science topics

High-energy neutrinos....

- probe the acceleration of nuclei
- can identify the sources of cosmic rays
- are not attenuated over cosmological distances

Search for...

- Point sources of neutrinos
- Transients (GRBs, AGN flares, Supernovas)
- Diffuse astrophysical flux



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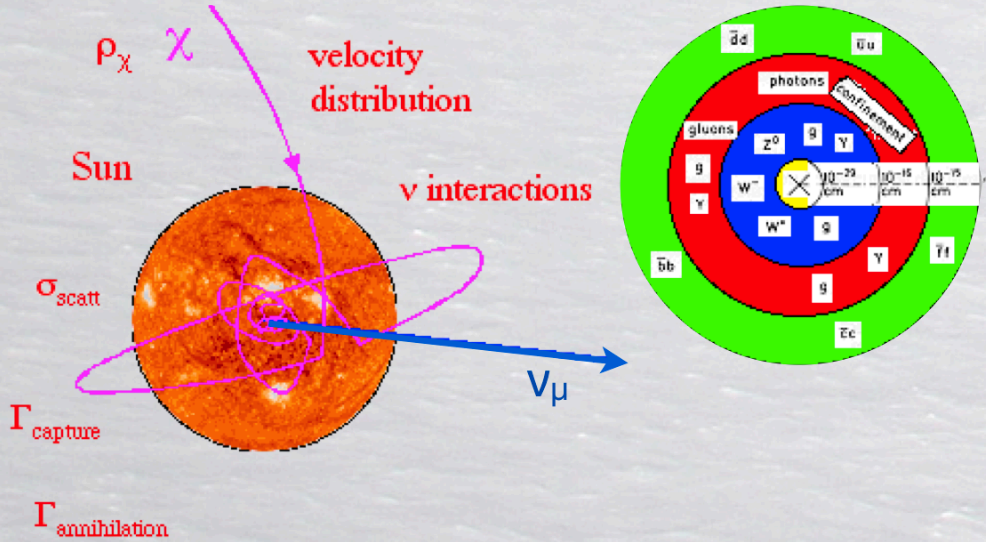

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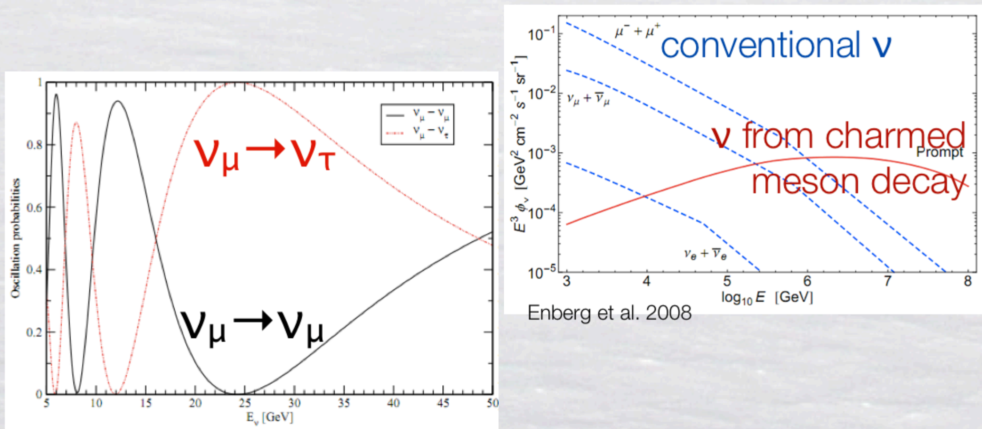

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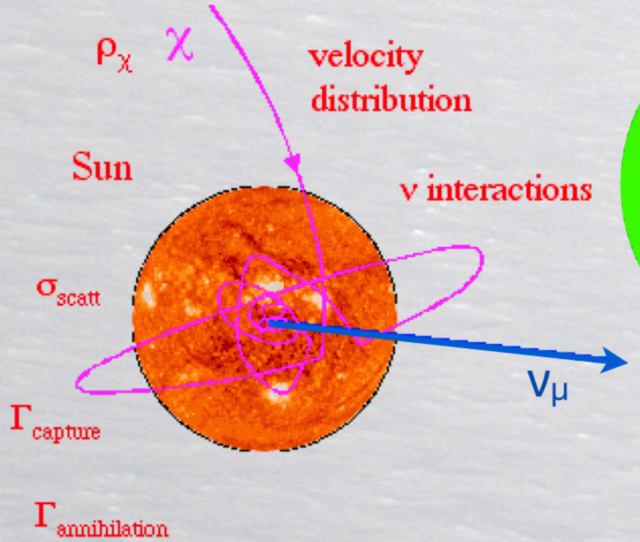
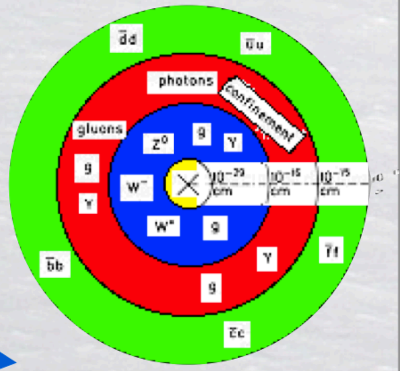
- Measurement of the CR spectrum in the “knee” region (10^{16} eV - 10^{18}eV)
- Constraints on the CR composition
- Measurement of CR anisotropy

Antoni et al. 2005

Properties of cosmic rays





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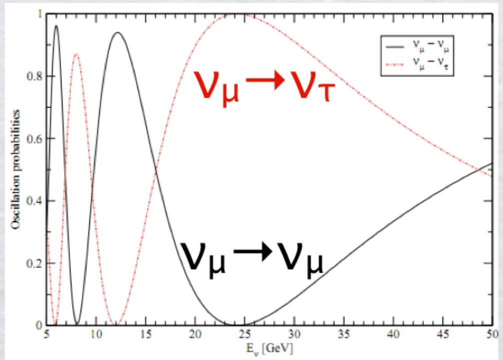

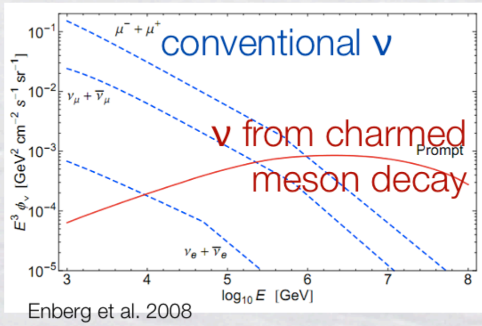

Enberg et al. 2008

Neutrino properties & particle physics

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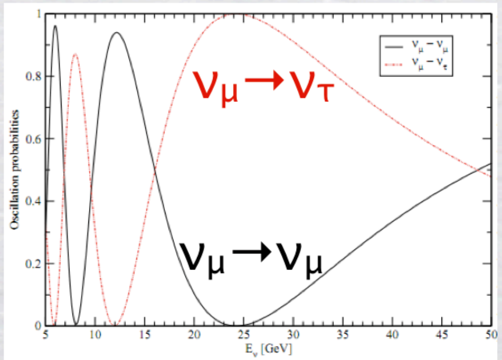
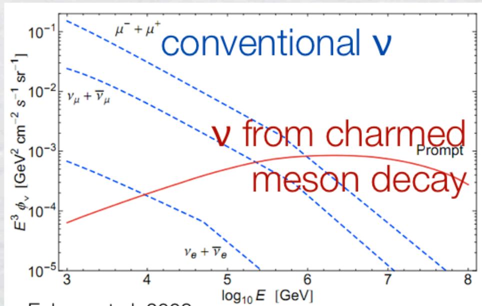
- Search for magnetic monopoles
- Signatures of sterile neutrinos

Dark matter & exotic particles





Enberg et al. 2008

Neutrino properties & particle physics

IceCube science topics

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Neutrino properties & particle physics

- Neutrino oscillation parameters
- Charm production in atmosphere
- High-energy cross-sections

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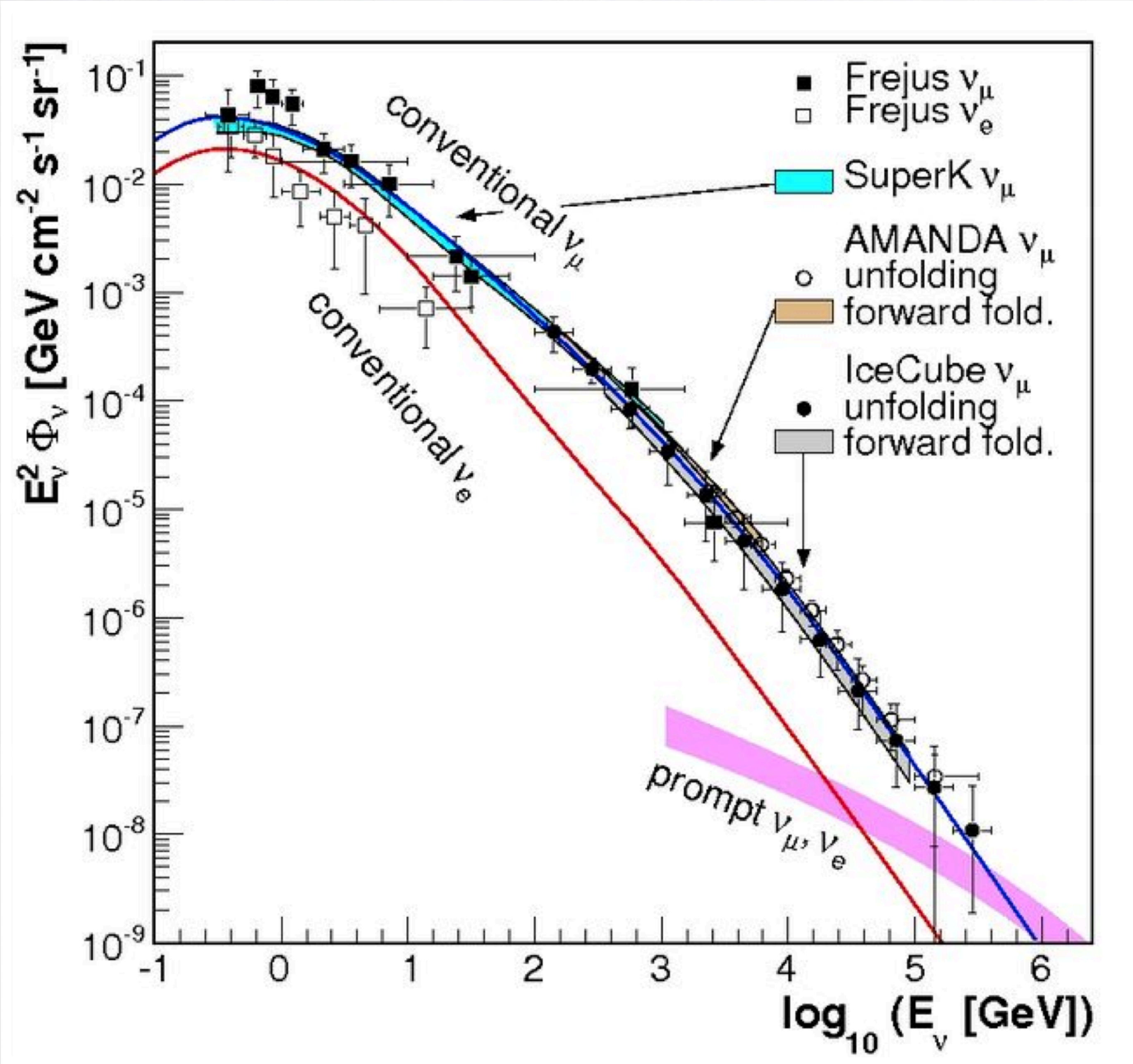
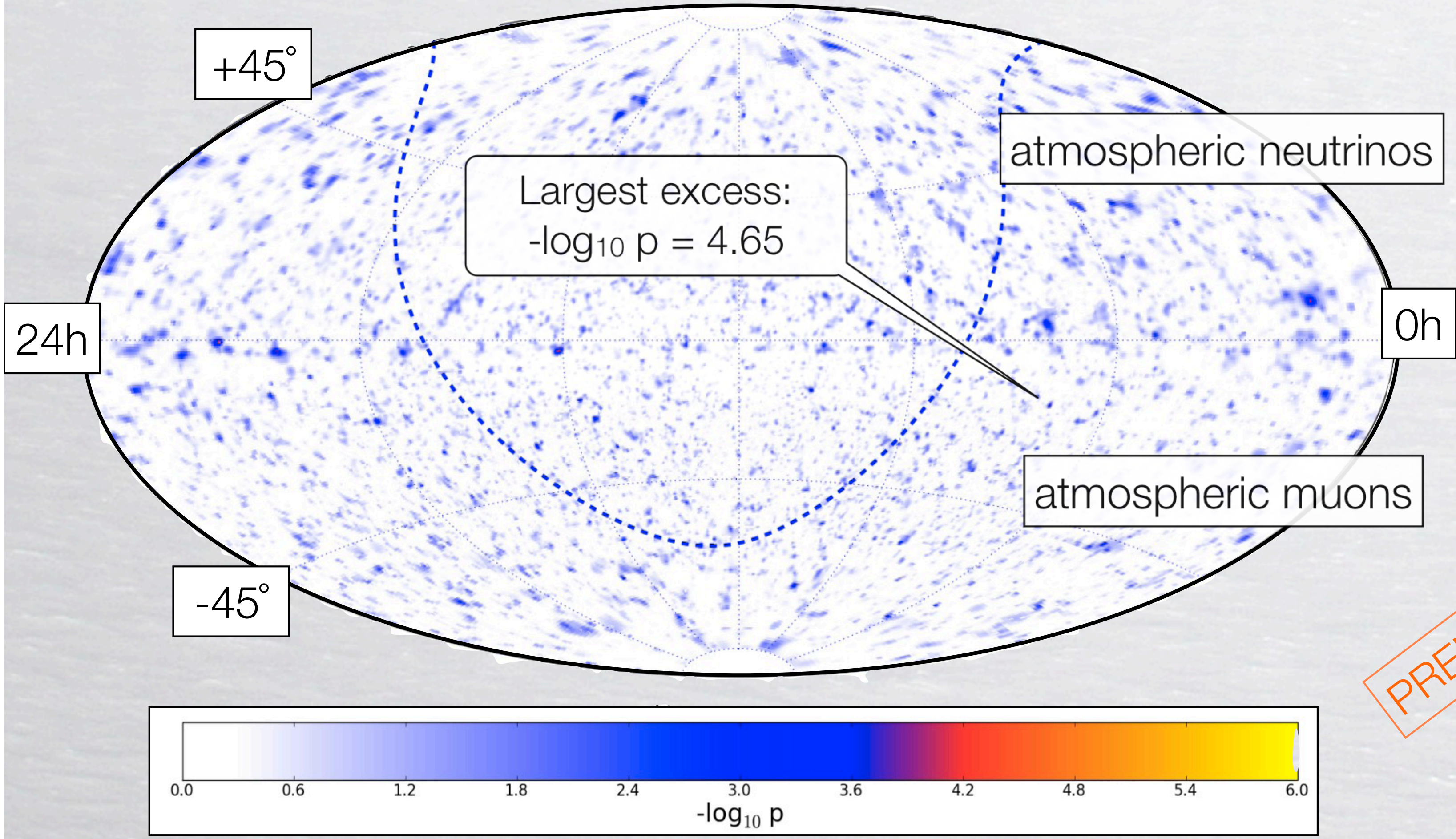
Neutrino properties & particle physics

Atmospheric muon neutrino spectrum



- IC-40 analysis extends measurement of atmospheric neutrino spectrum up to 400 TeV
- Compatible with predictions of atmospheric neutrino fluxes (Honda et al. 2006, Barr et al. 2004)
- Close to energy range of significant contributions from prompt neutrinos

Search for point sources of neutrinos



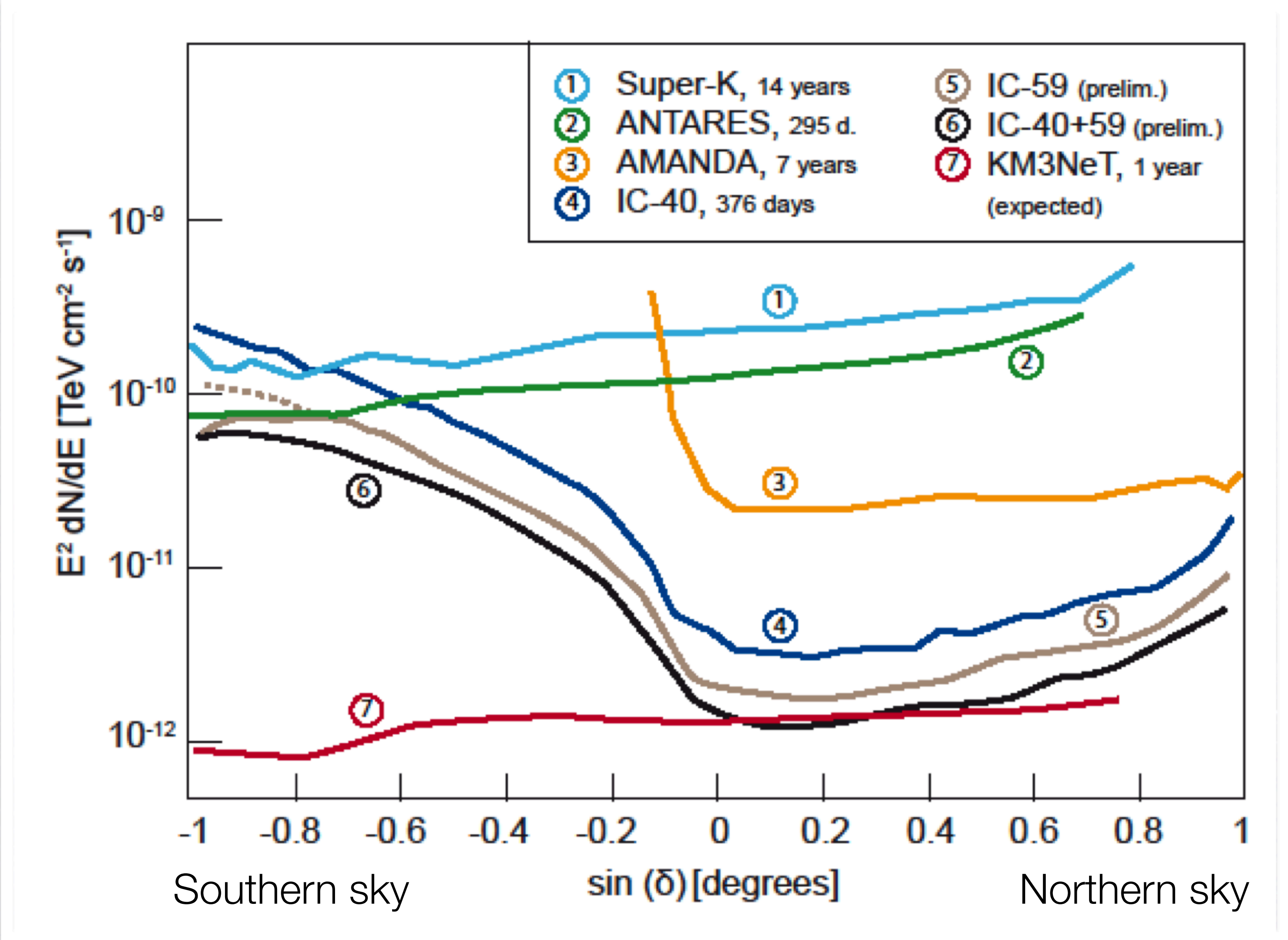
Probability to observe largest excess on randomized maps: **67 %**

PRELIMINARY

Excess significance map IC40+IC59

43339 up-going + 64230 down-going events
723 days of livetime

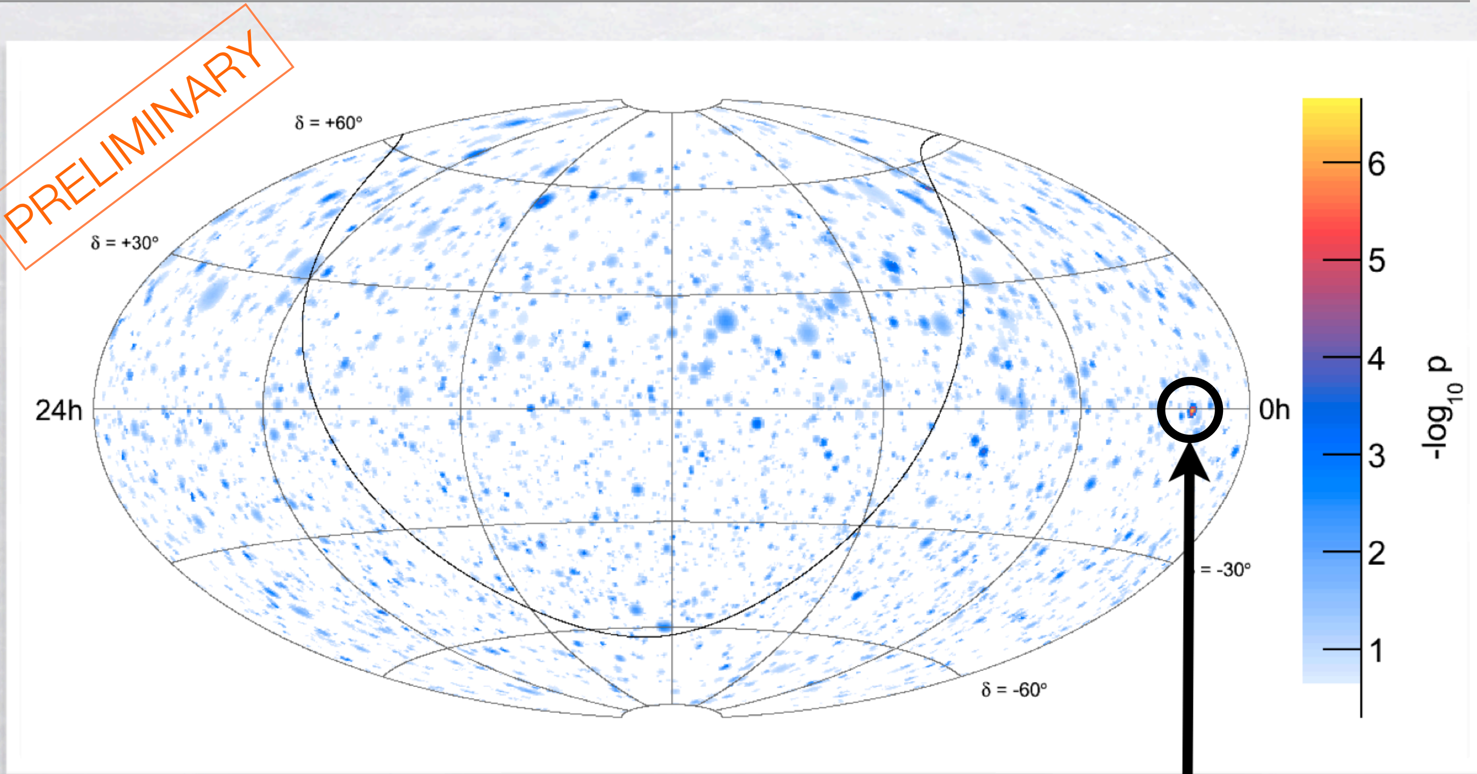
Flux upper limits for point sources of neutrinos

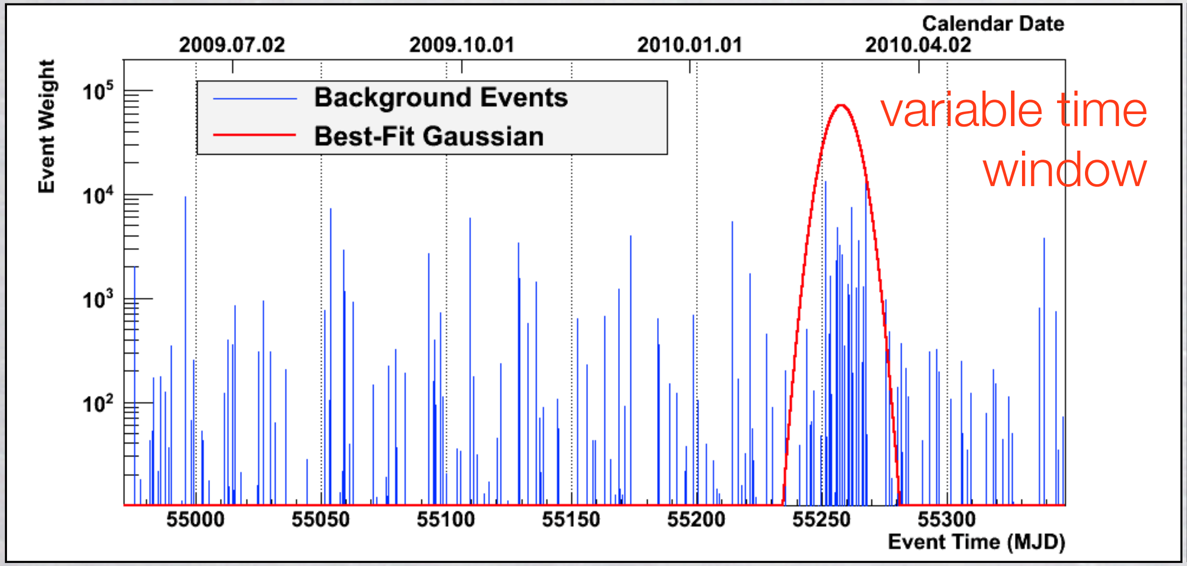


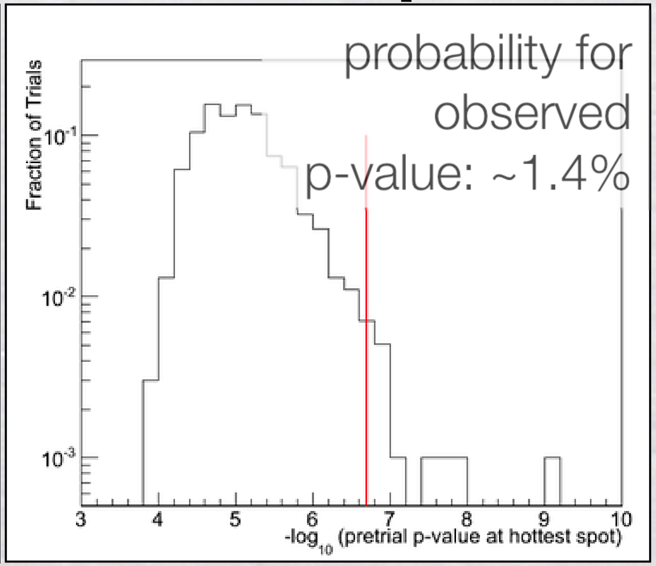
- Factor 1000 improvement in 12 years for neutrino point source searches

Search for transients - Flares

- Search for excess of events in variable time window with IC40+IC59 data
- no known counterpart in the region of the fluctuation
- Searches for correlations with known gamma-ray flares with negative results



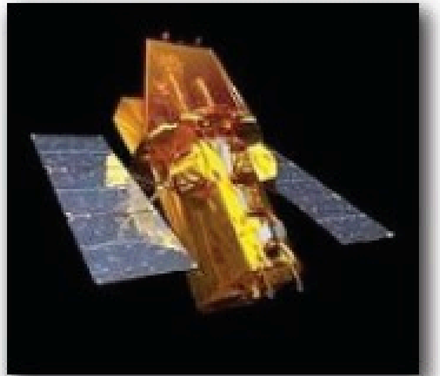




Search for transients - Online alert system

- **Trigger other instruments** (IACTs, X-ray satellites, optical telescopes . . .)

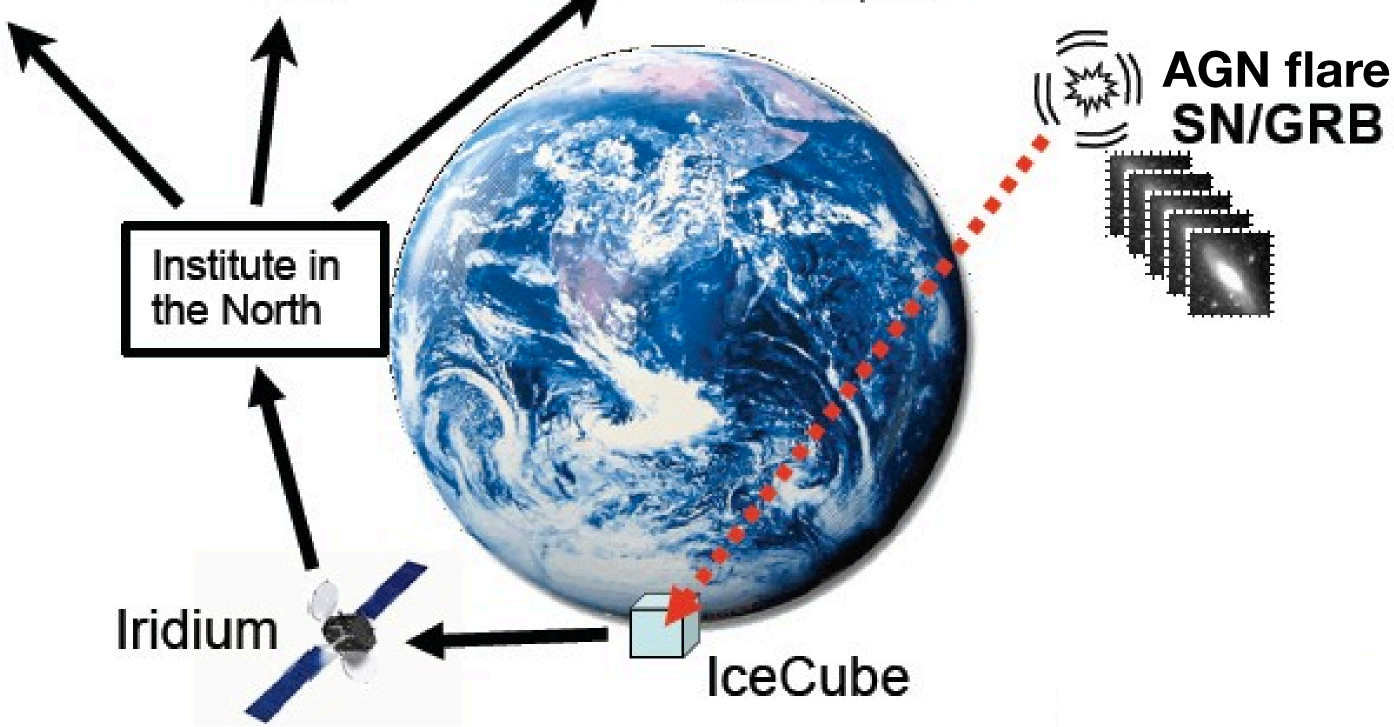
MAGIC
online alert system for
Cherenkov telescopes
developed at DESY



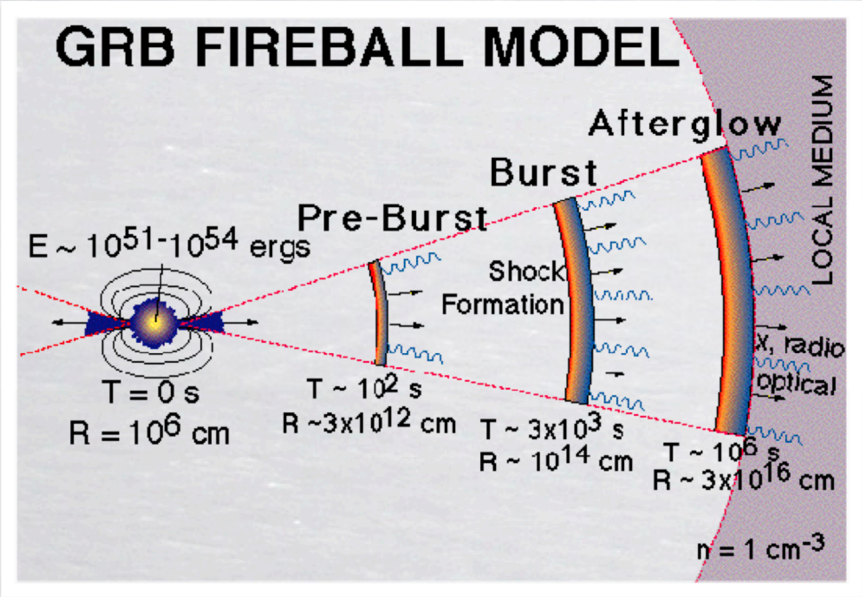
Swift

ROTSE, PTF

- **Multiplet trigger:**
  (example optical)
  - angular window 4°
  - time window 100 s
  - Delay < 5 min

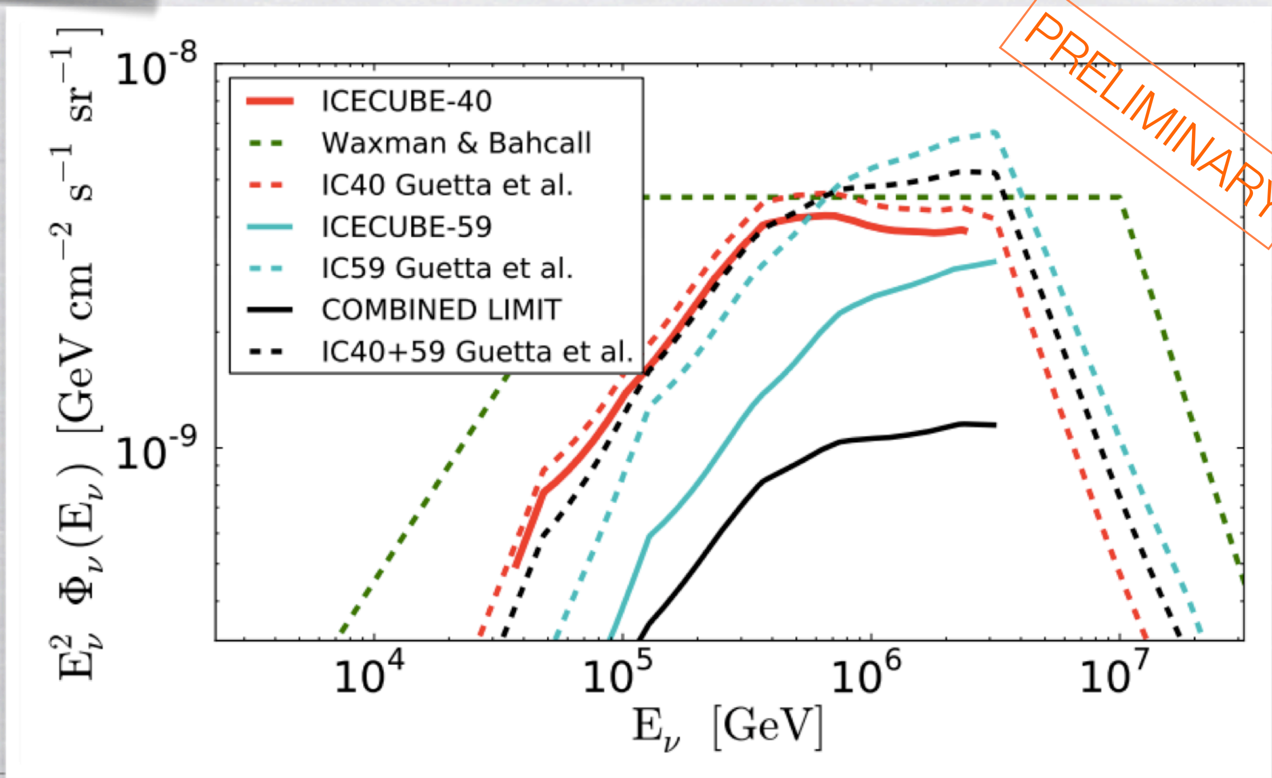


Search for transients - Gamma ray bursts



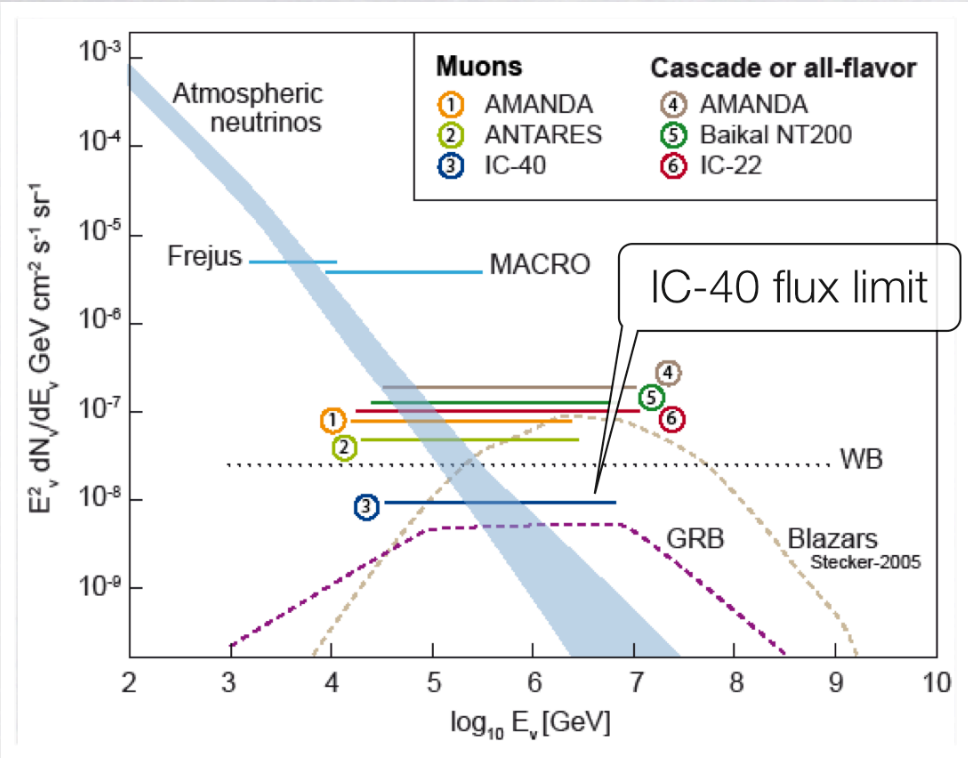
- 105 (IC-59) + 117 (IC-40) bursts analyzed
- 0 events observed

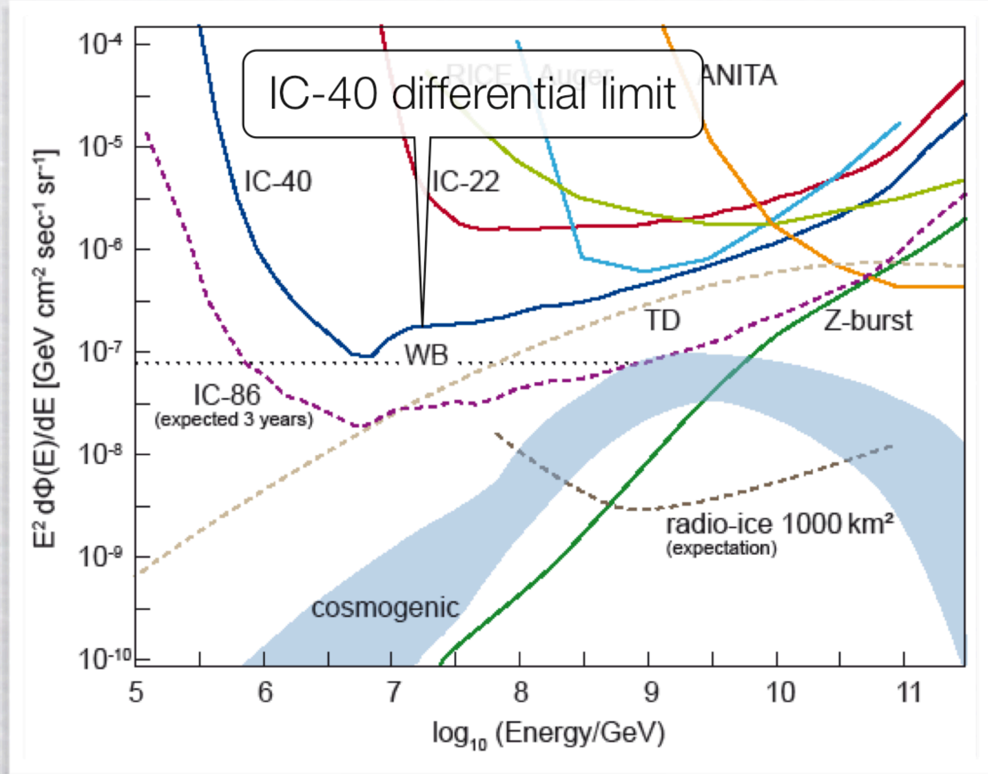
- IceCube limits exclude a wide range of models in which GRBs are responsible for the bulk of the UHECR production



Searches for the cosmic diffuse neutrino background

- 3 different search strategies
  - Excess of high-energy up-going ν_μ over atmospheric background
  - All-flavor search for very high-energy bright events
  - All-flavor search for contained neutrino-induced EM/hadronic cascades (next slide)
- IC-59 sensitivity factor 4 below Waxman-Bahcall upper bound on flux from transparent sources
- IC-40 flux limit on very-high-energy events close to predictions of GZK neutrinos





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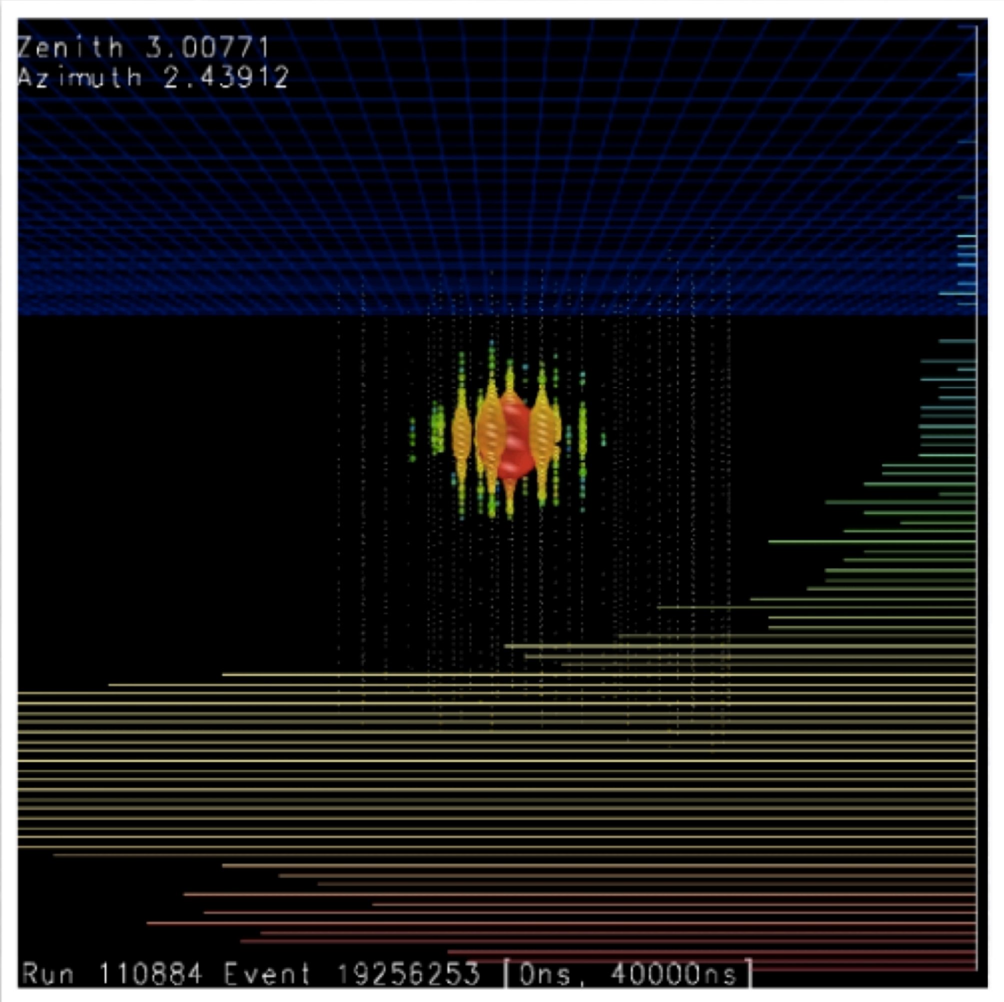
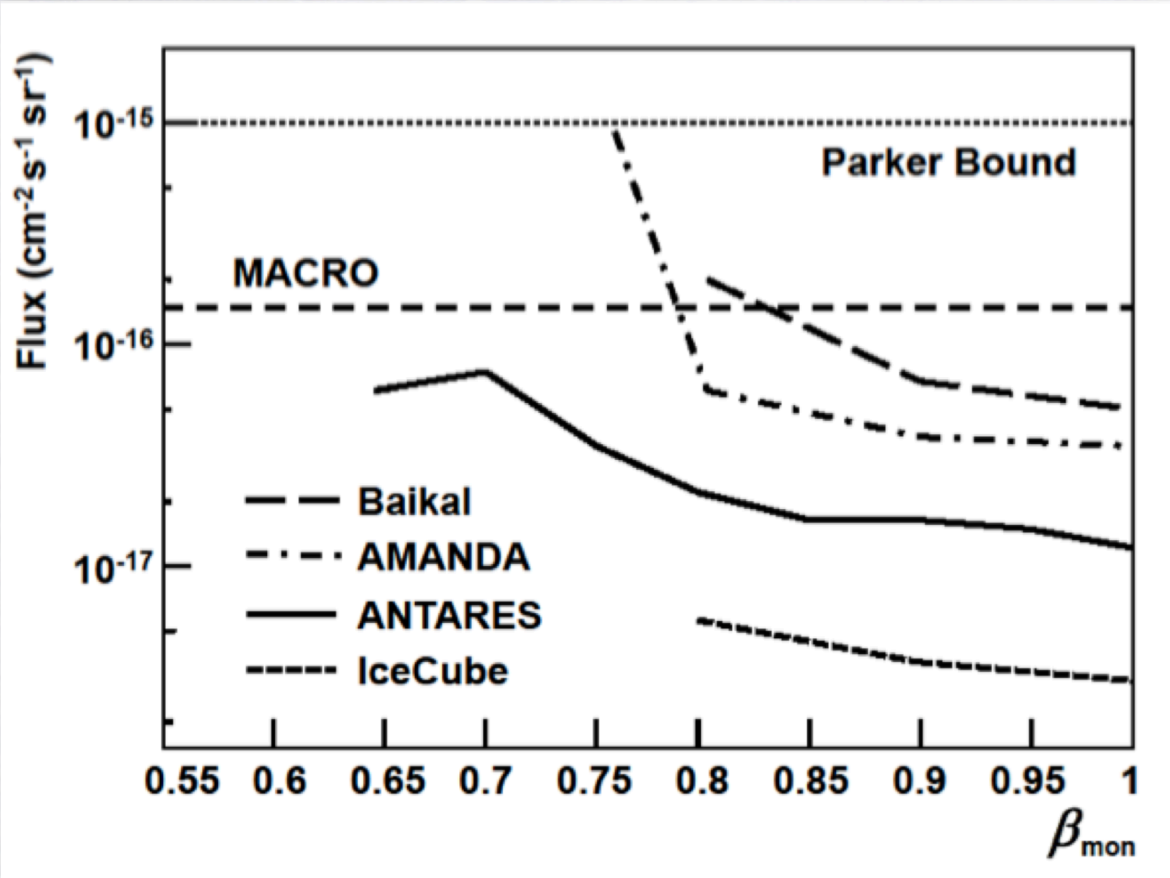
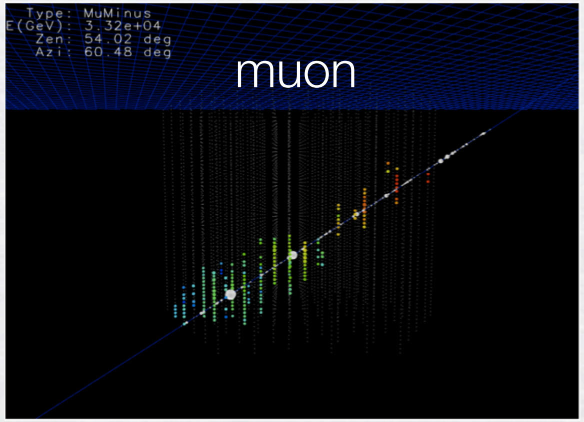


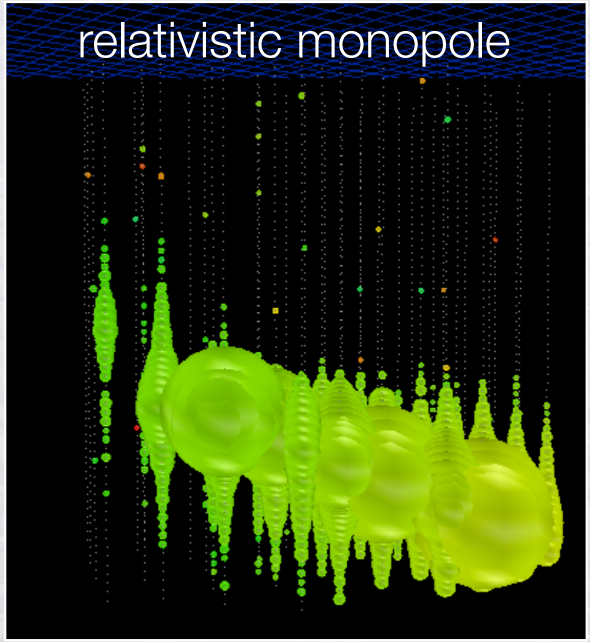
- Searches for contained neutrino-induced cascades
- Smaller effective volume offset by good energy resolution
- ...but systematics of background estimate from high-energy CR-induced muons are challenging.
- Searches for neutrino-induced cascades with IC-40 find high-quality candidates with energies between 27 TeV and 175 TeV
- Additional Monte Carlo studies are necessary to derive flux limits from these measurements.

Searches for exotic particles

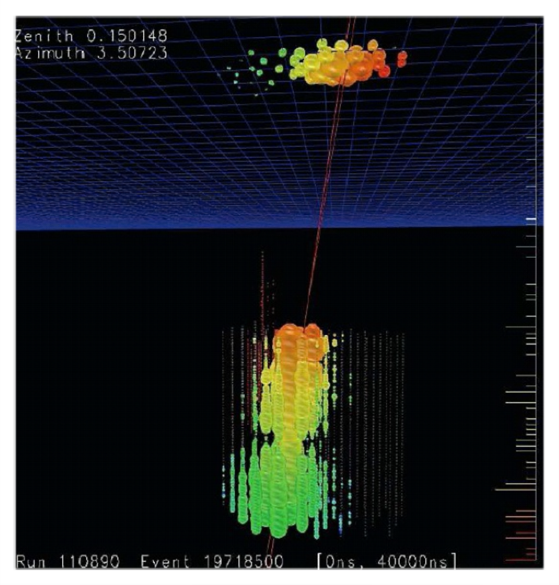
- Limits from IceCube on monopoles with $\beta > 0.8$ more than factor 100 below fundamental (Parker-) bound
- In the future: Slow monopoles with $\beta \sim 10^{-3}$
- Long event duration challenging for IceCube DAQ
- New slow monopole trigger will be installed in 2012



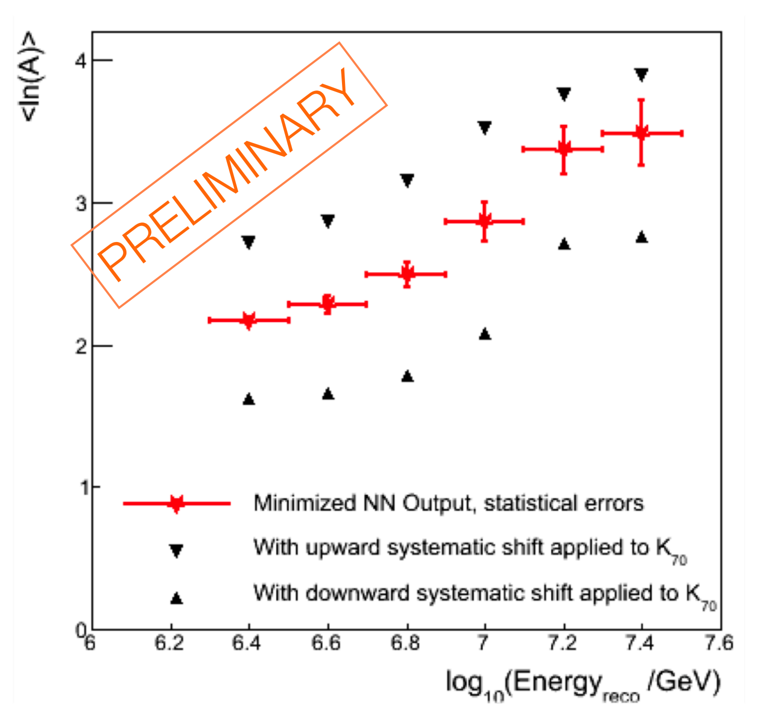


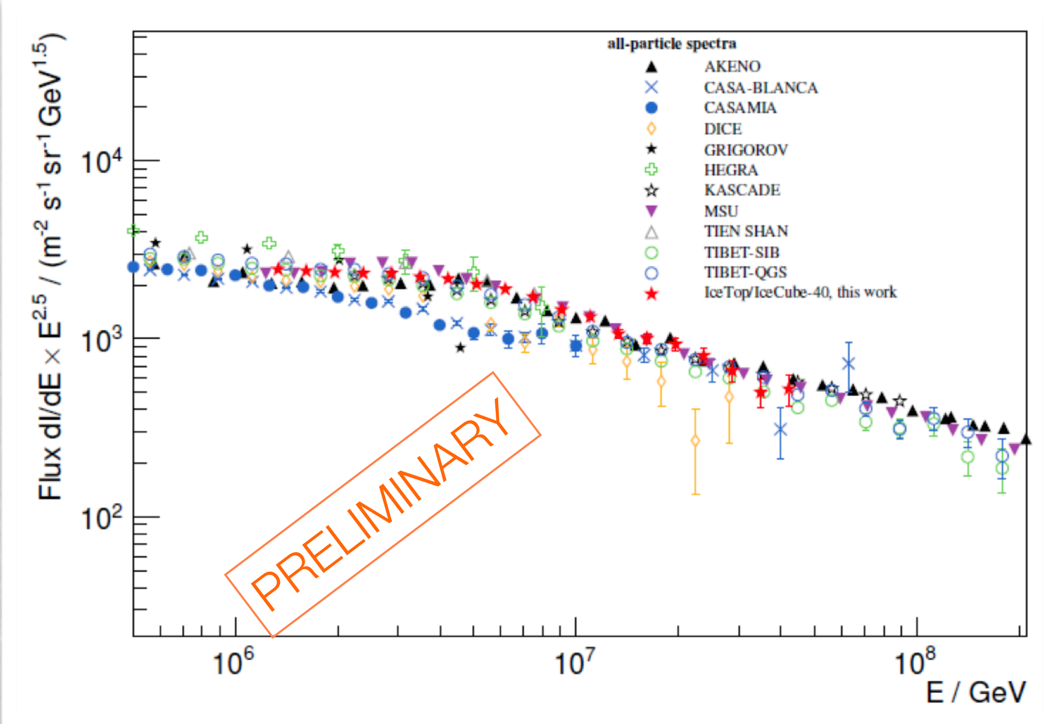


Cosmic-ray spectrum and composition

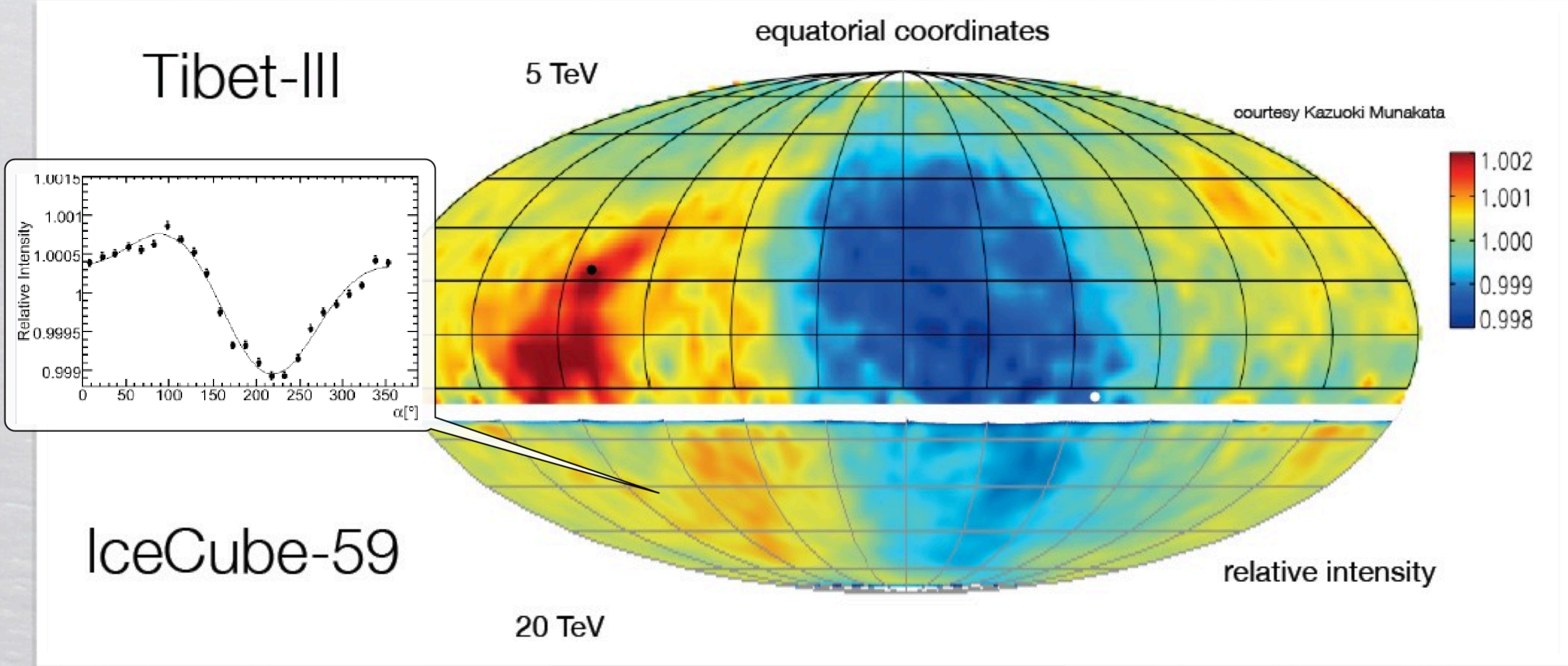


- IceTop/InIce coincident events are complementary composition sensitive signatures
- High energy muons in IceCube come from first interactions
- First analysis of CR spectrum and composition with coincident events based on IC-40 data





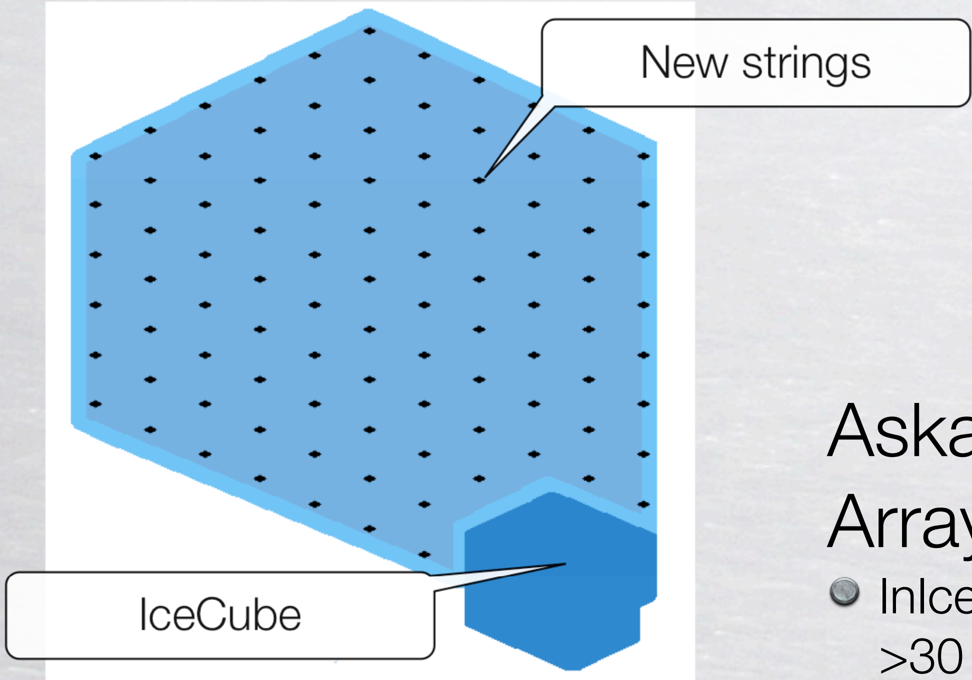
Cosmic-ray anisotropy



- First observation of cosmic-ray anisotropy on the southern hemisphere
- Origin unknown
  - Compton-Getting effect ? (problems with dipole orientation)
  - heliospheric origin ?
  - nearby pulsars ?
  - interstellar magnetic fields ?

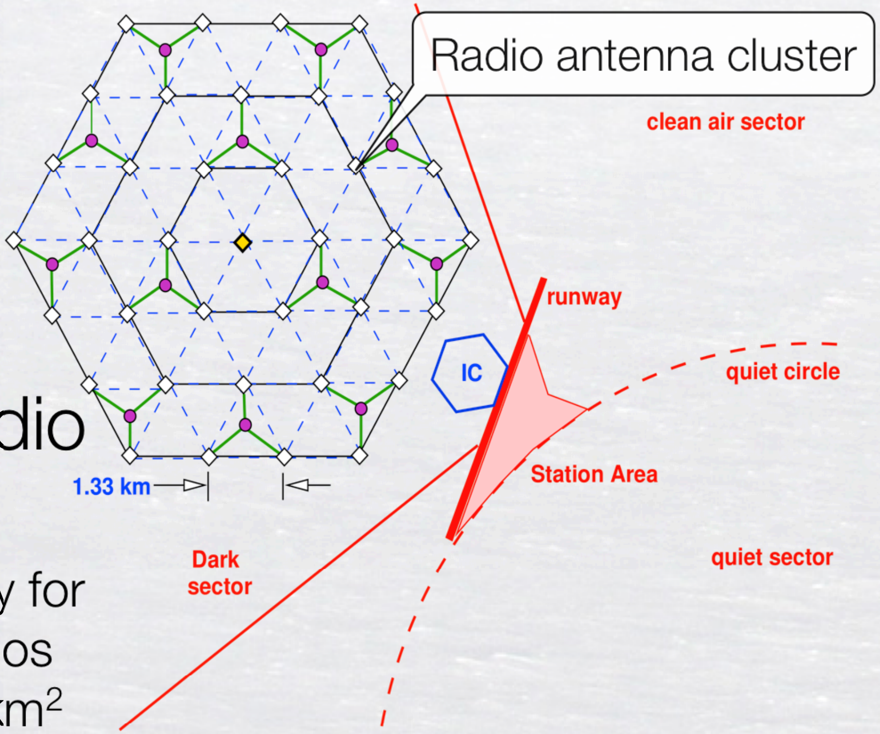
Beyond IceCube - Plans for future instrumentation

IceCube++, ARA, PINGU



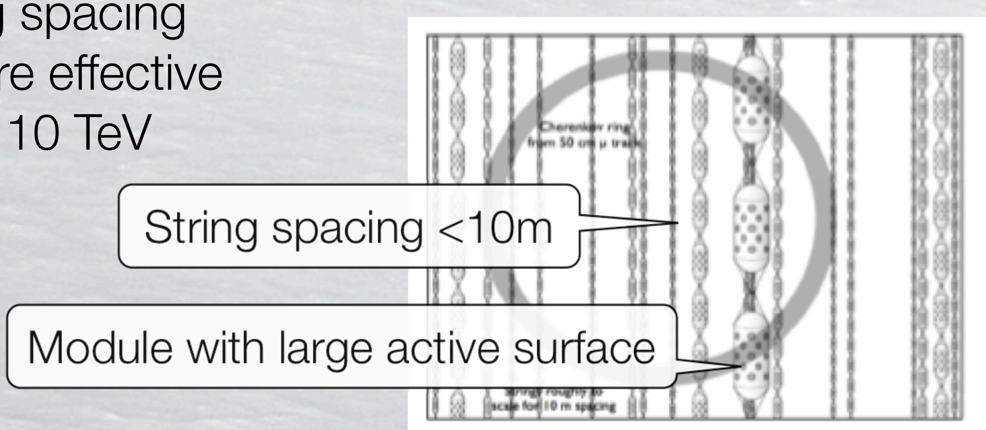
IceCube ++

- IceCube extension with larger string spacing
- 4 times more effective area above 10 TeV



Askarian Radio Array (ARA)

- InIce Radio array for >30 PeV neutrinos
- several tens of km^2 surface area



PINGU

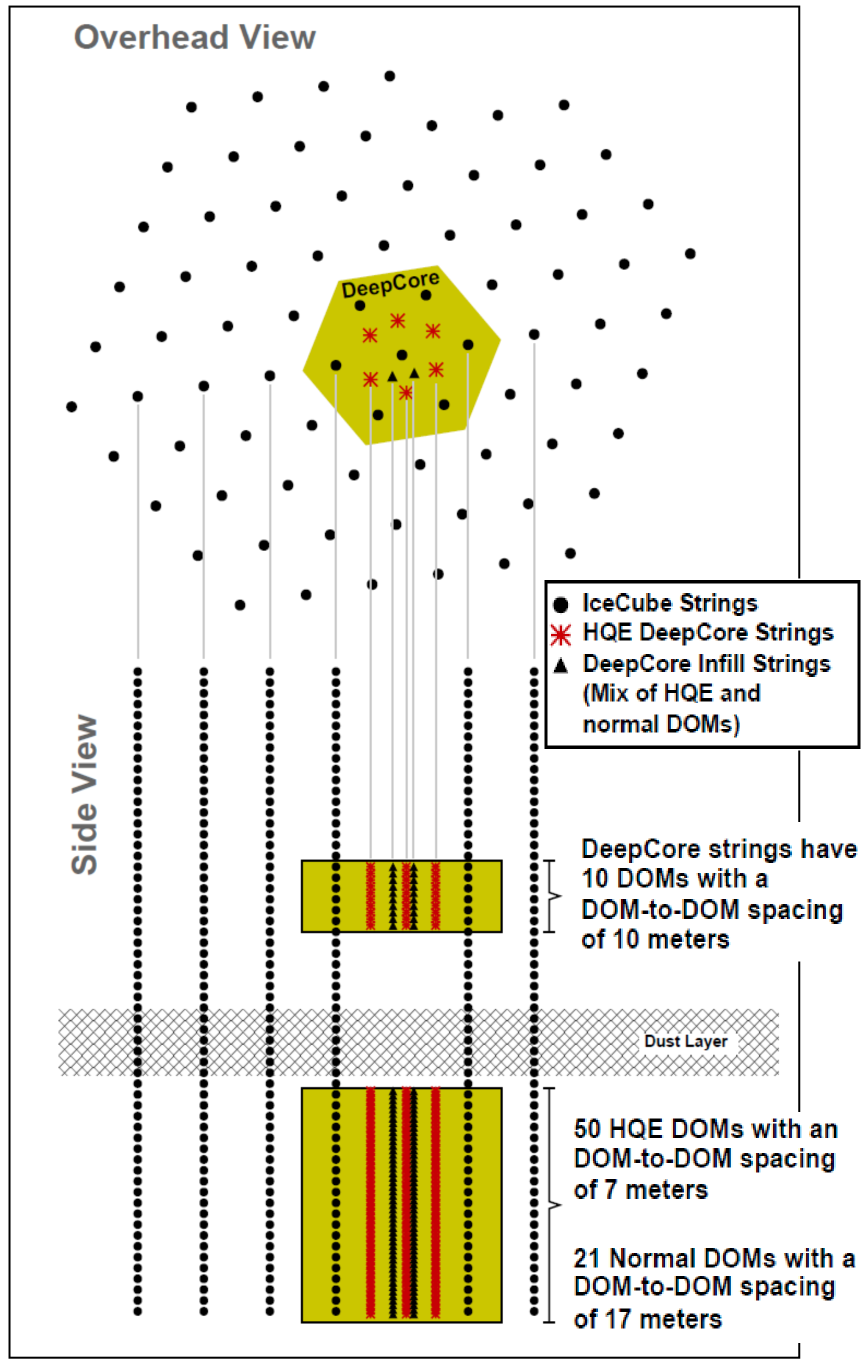
- High-density array inside IceCube
- <10 GeV neutrino oscillation
- SN neutrinos beyond the Milky Way
- Proton decay (?)

Summary

- IceCube construction successfully completed in 2011.
- Performance of the IceCube detector is as expected or better.
- Quickly growing number of physics results using the in-construction IceCube detector data.
- Measurement of atmospheric neutrino flux to > 400 TeV.
- Searches for neutrino point sources set only limits so far.
- Not seeing neutrinos from GRBs excludes a wide range of models in which GRBs produce the bulk of the CRs.
- Competitive searches for WIMP annihilation and magnetic monopoles.
- New measurements of the CR spectrum and composition, first measurement of the CR anisotropy in the Southern hemisphere

Backup slides

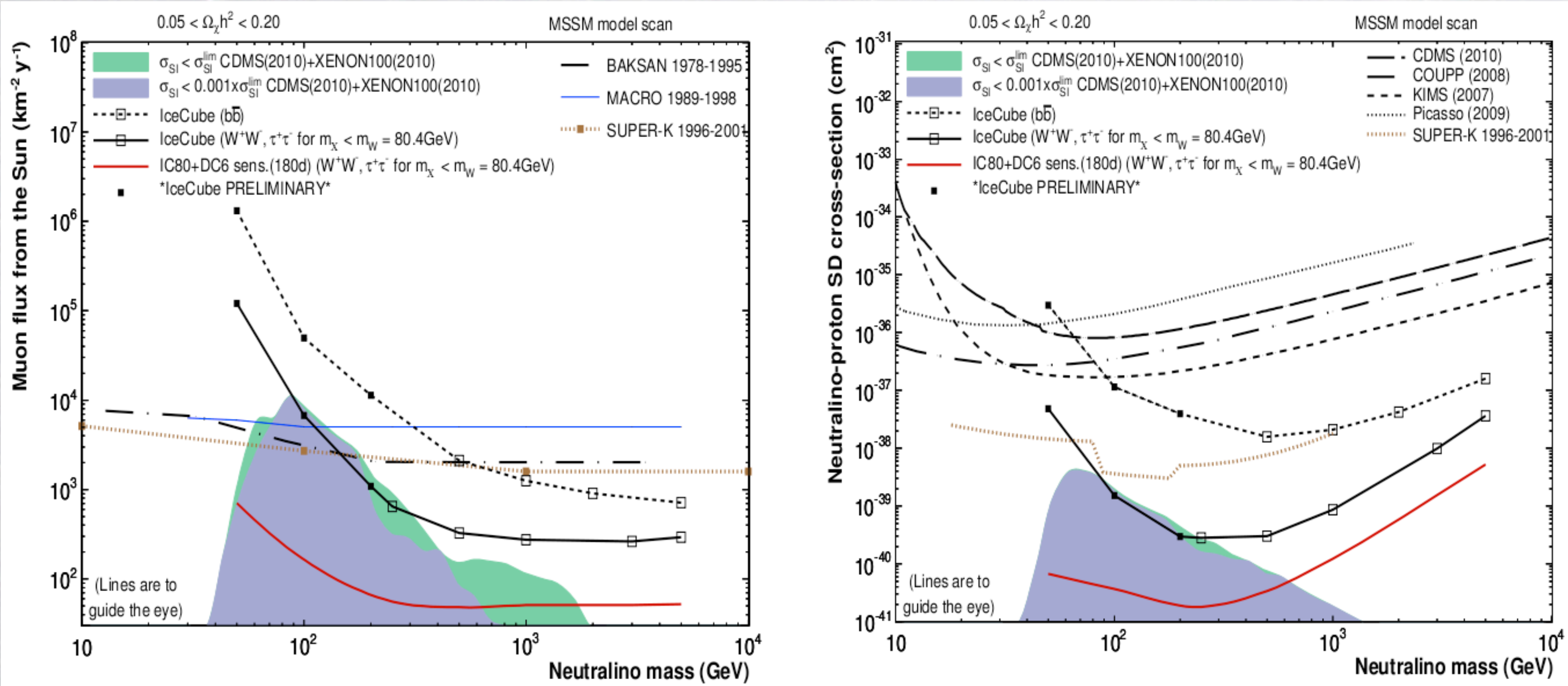
IceCube detector elements - Deep Core



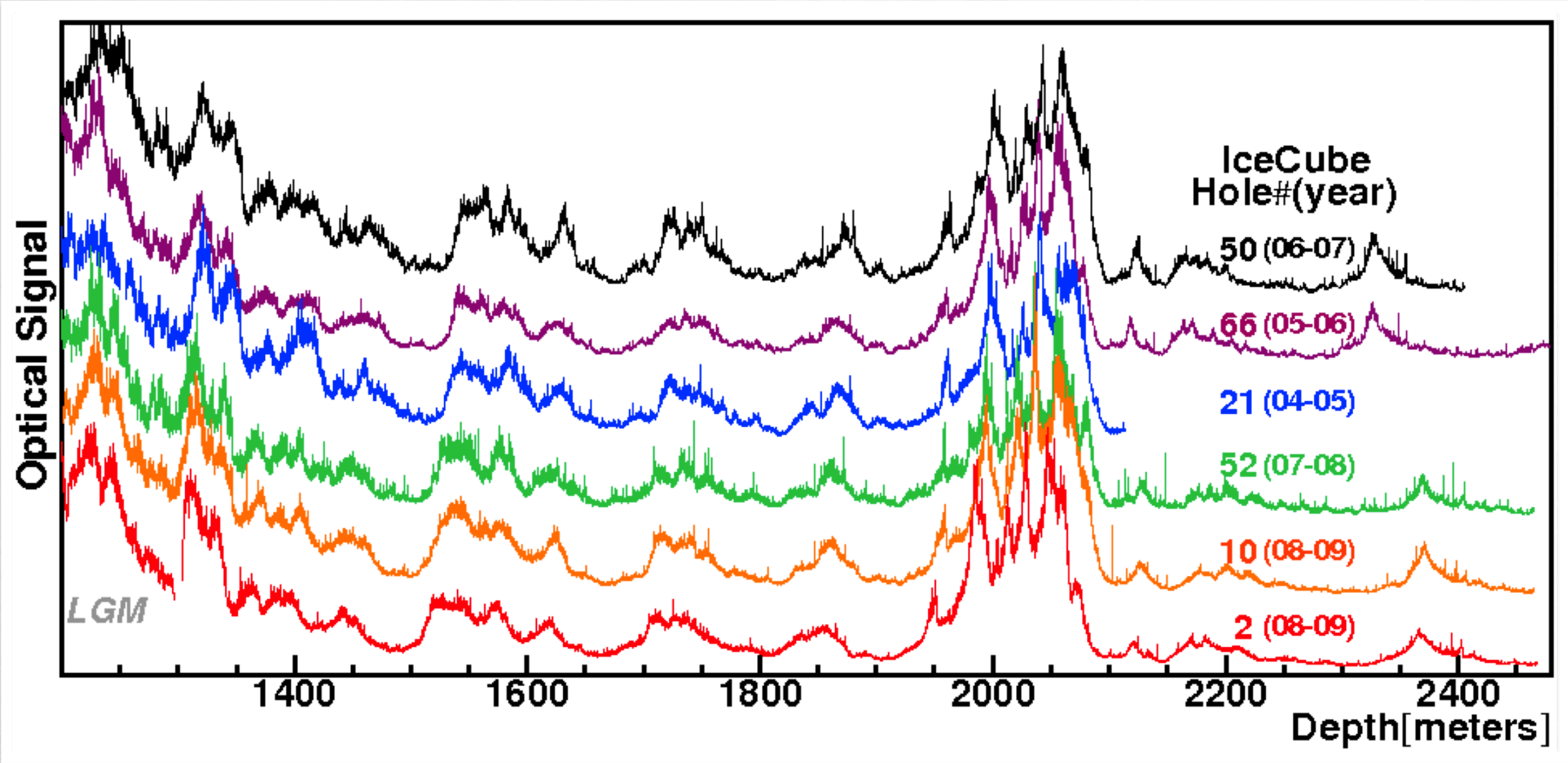
- Deep Core extension
  - 6 strings with 50 HQE DOMs placed between regular IceCube strings
  - 2 additional strings from IceCube corner (mix of HQE/normal DOMs)
  - 10m/7m spacing instead of 17m spacing
  - 50 DOMs inside the cleanest ice layers
- Enhancement of IceCube effective are for E_ν < 100 GeV
- Deep Core science
  - neutrino oscillation studies
  - low-mass WIMPs
  - SN/GRB physics

Searches for (WIMP) dark matter

- Limits from AMANDA + IC-22 + IC-40 sun observations (below horizon only)
- Conversion from muon flux limits to neutralino-proton cross-section is model dependent
  - cosmological parameters: relic density, velocity distribution, annihilation cross-section
  - neutralino decay channels
- Very competitive limits of IceCube on the spin-dependent χ/p cross-section



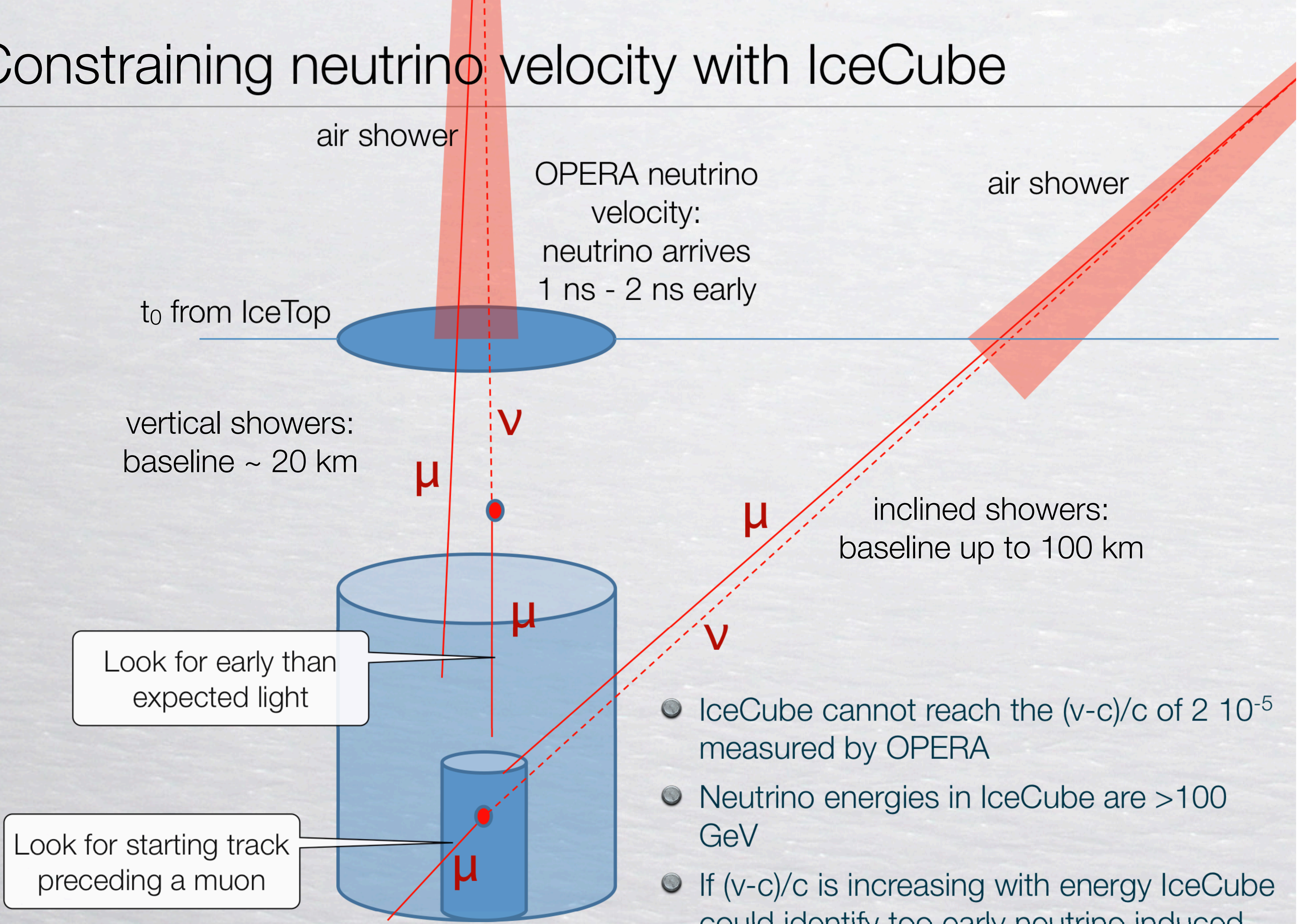
Properties of the South Pole Ice



Measurements of dust concentration in the South Pole ice during deployment.

- Depth dependent absorption and scattering in ice due to variable dust deposits
- Modeling of ice properties based on
  - Dust concentration measurements during deployment
  - In-situ light sources (56880 LEDs, 2 calibrated high-intensity light sources)

Constraining neutrino velocity with IceCube



- IceCube cannot reach the (v-c)/c of 2 10^{-5} measured by OPERA
- Neutrino energies in IceCube are >100 GeV
- If (v-c)/c is increasing with energy IceCube could identify too early neutrino induced muons