“And for those of us still waiting for our big break, let us pray.”

Explore High Energy Universe

with IceCube ν observation

Extreme Astrophysics

Chiba University

Shigeru Yoshida

2009/9/5

千葉大学
Chiba University

Science of ν astrophysics

- Origin of cosmic rays
- Hadronic vs. leptonic signatures

Detector size

Supernovae

Oscillations

Dark matter (neutralinos)

Astrophysical neutrinos

GZK, Topological Defects

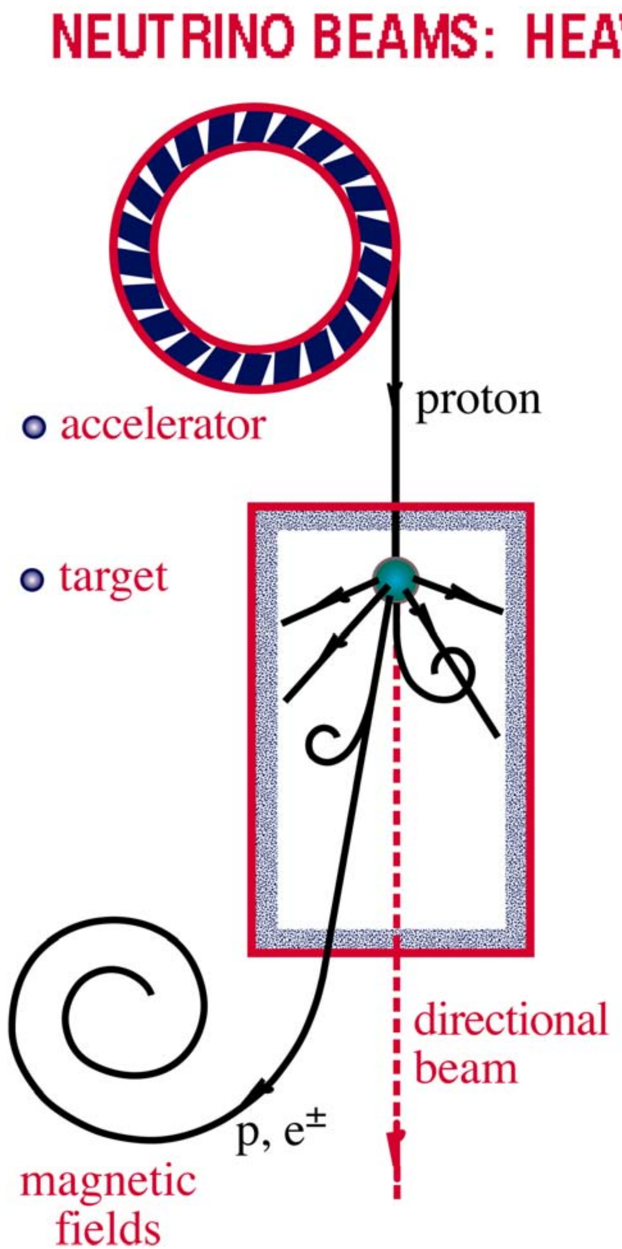
MeV GeV TeV PeV EeV

Limitation at low energies:
-Short muon range
-Low light yield
-^{40}K (in water)

Detector density

Limitation at high energies:
Fast decreasing fluxes E^{-2}, E^{-3}

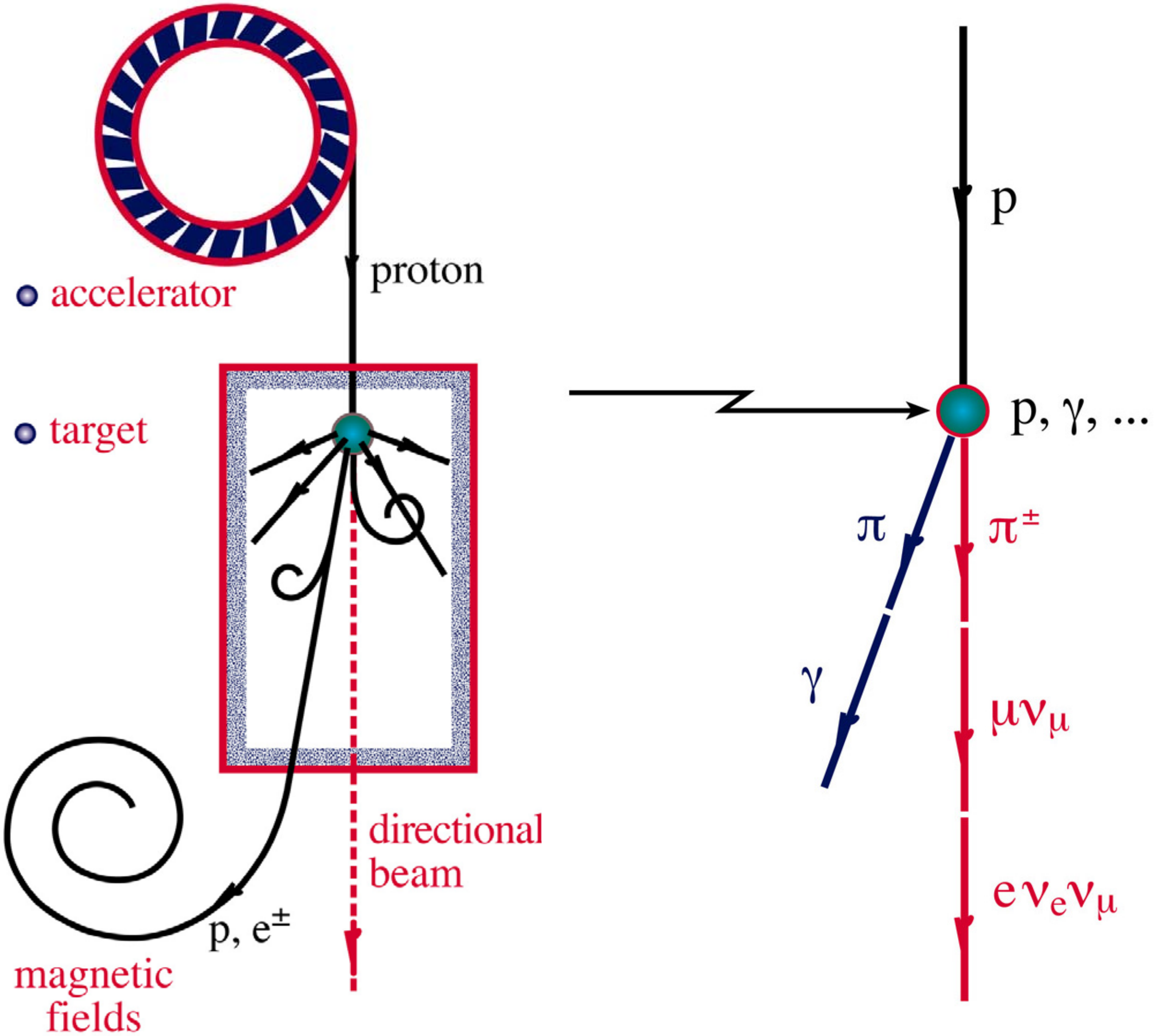
Other physics: monopoles, etc...



black hole

radiation
enveloping
black hole

NEUTRINO BEAMS: HEAVEN & EARTH



Connections to γ and CR

$p\,\gamma \longrightarrow (p,n)\ \pi$

$\pi \rightarrow 2\gamma \rightarrow$ **Fermi observations !!**

$\pi \rightarrow \mu\,\nu$

$\mu \rightarrow e\,\nu\,\nu$

Cosmic Ray observations!

Cosmic Ray and Neutrino Sources

Candidate sources (accelerators):

Cosmic ray related:

– SN remnants

– Active Galactic Nuclei

– Gamma Ray Bursts

Other:

– Dark Matter

– Exotics

Guaranteed sources (known targets):

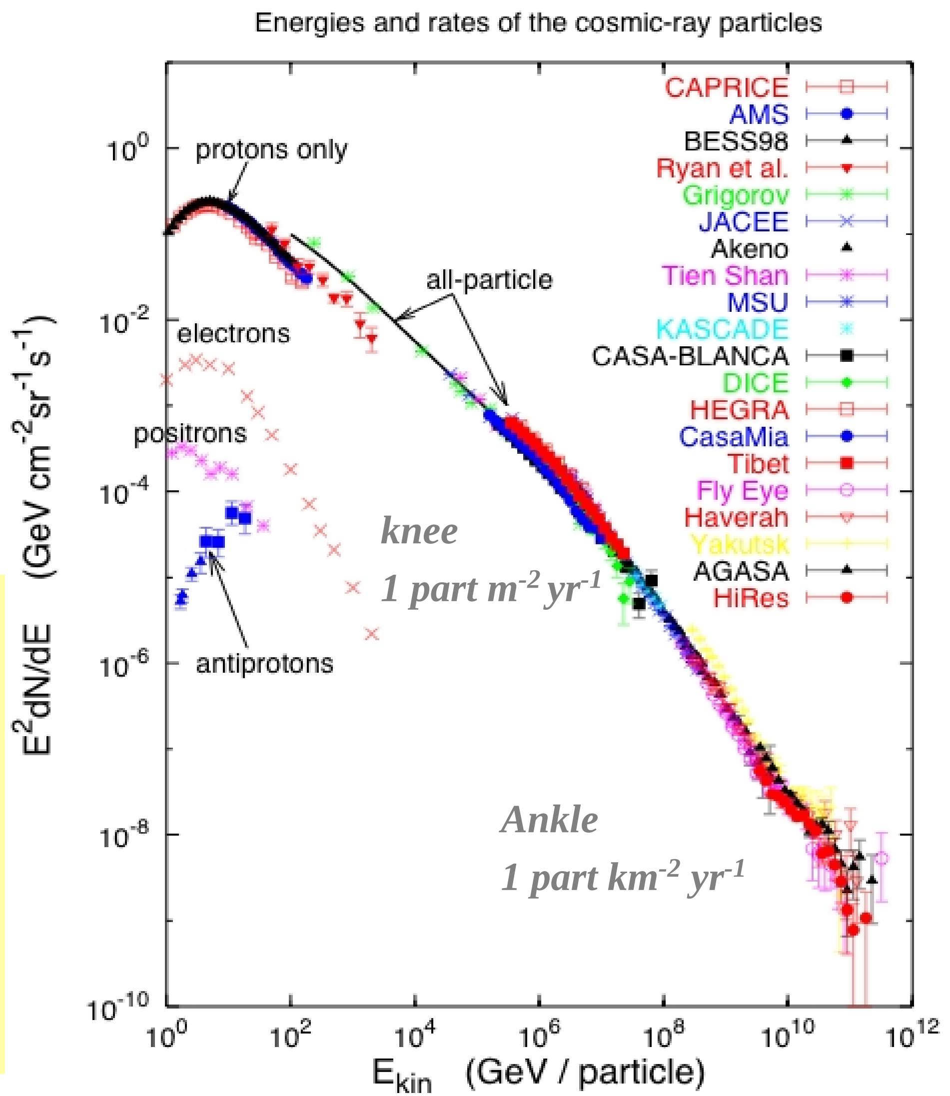
• Atmospheric neutrinos (from π and K decay)

• Galactic plane: CR interacting with ISM, concentrated on the disk

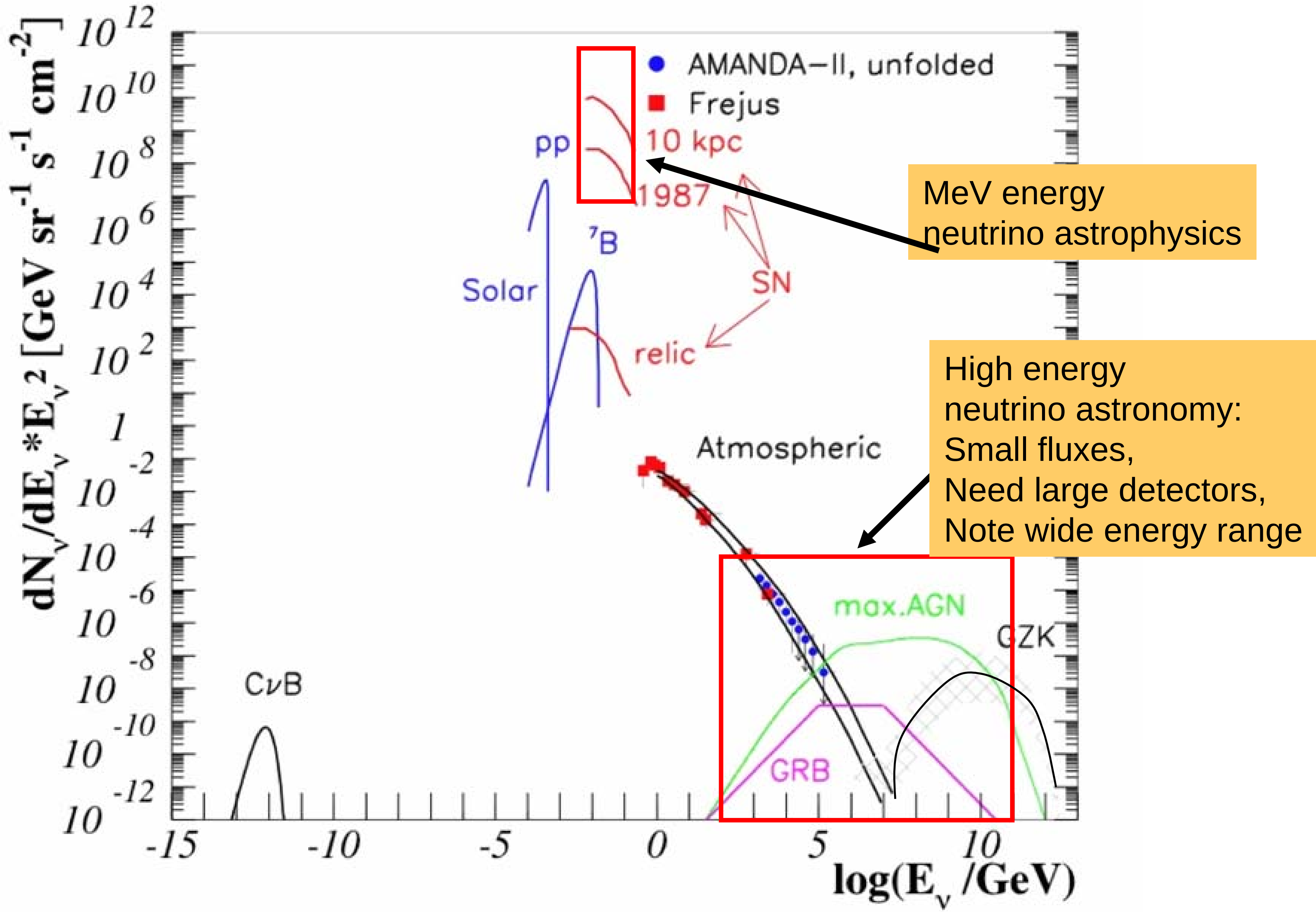
• GZK (cosmogenic neutrinos)

$$p\,\gamma \rightarrow \Delta^{+} \rightarrow n\,\pi^{+}\ (p\,\pi^{0})$$

Cosmic rays



Neutrino Fluxes Overview



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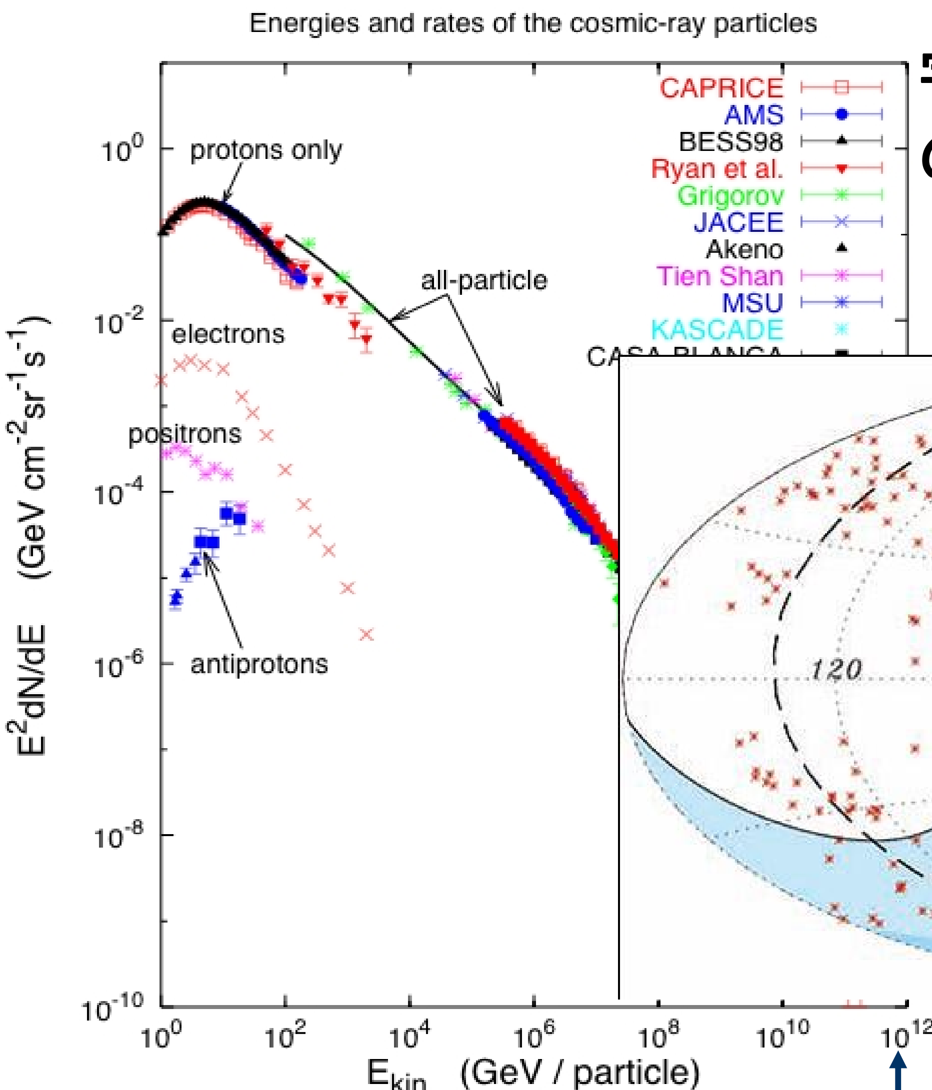
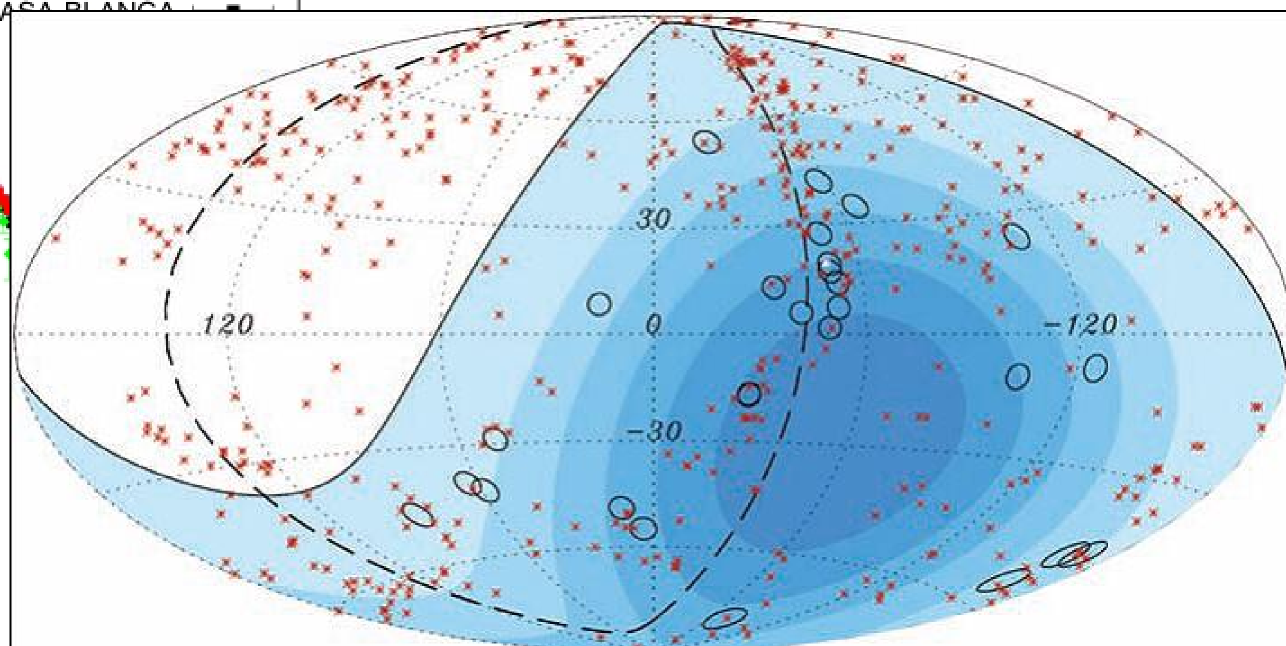
Extremely-high Energy Universe



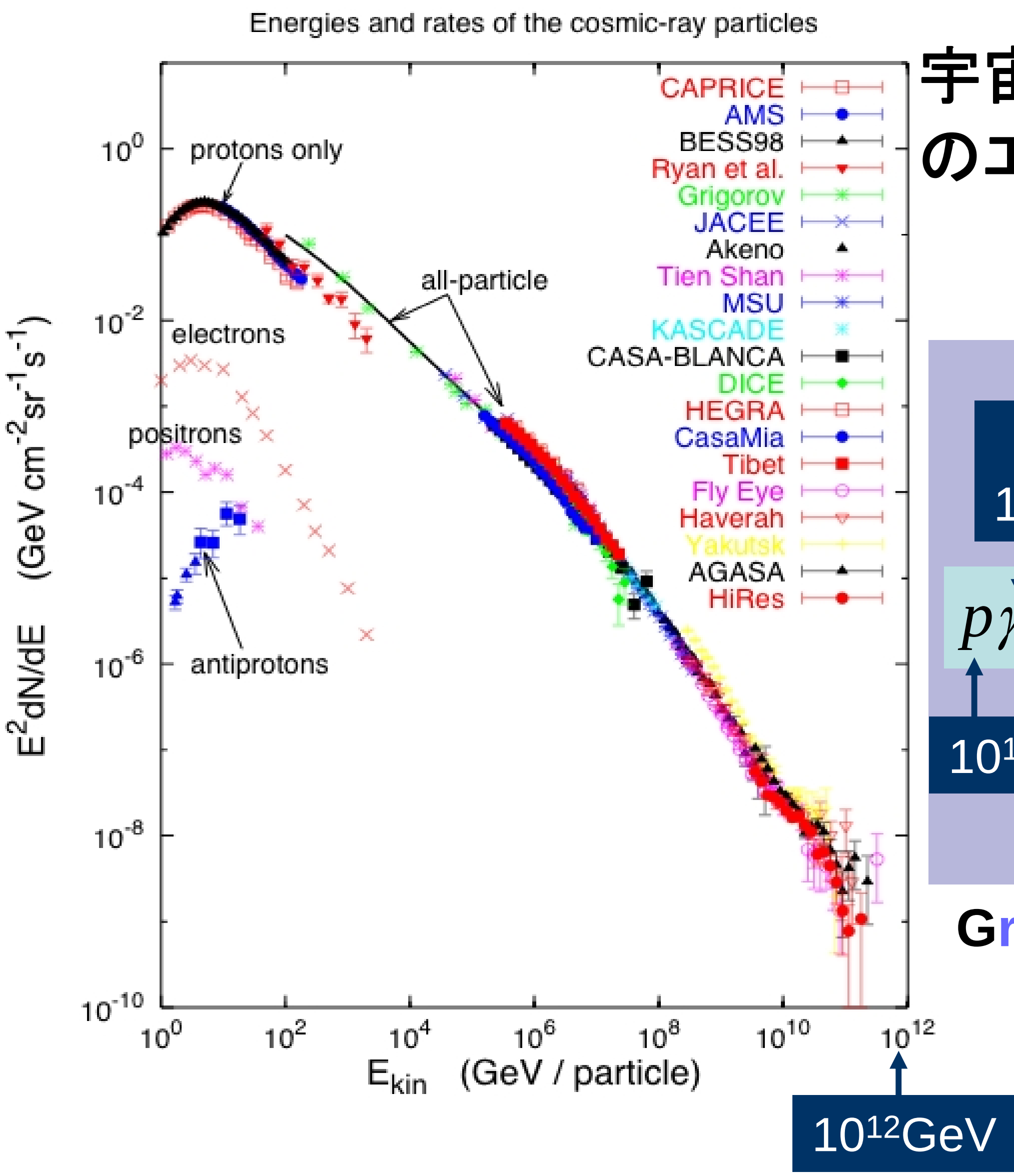
10^{12}GeV

宇宙が産み出す(素)粒子
のエネルギーには上限があるのか？

Sky @ E = 5×10^{10} GeV



Extremely-high Energy Universe



宇宙が産み出す(素)粒子
のエネルギーには上限があるのか？

CMB
10^{-12}GeV

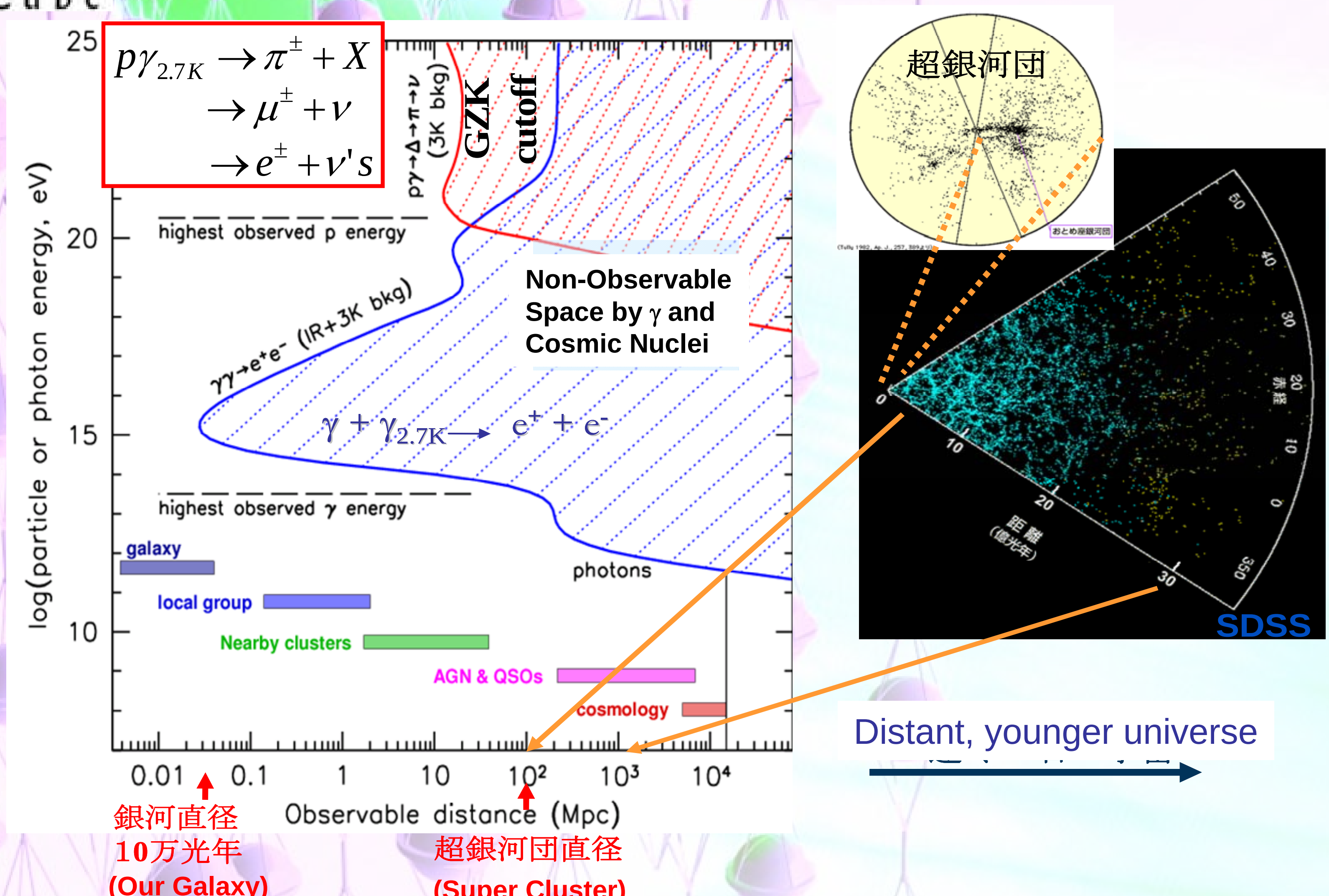
$$p\gamma_{2.7K} \rightarrow \pi^{\pm} \rightarrow \mu^{\pm} + \nu \rightarrow e^{\pm} + \nu' s$$

10^{11}GeV

“GZK” ν

Greisen – **Z**atsepin – **K**uzmin Effect

Why GZK ν ?



$p\gamma_{2.7K} \rightarrow \pi^{\pm} + X$
$\rightarrow \mu^{\pm} + \nu$
$\rightarrow e^{\pm} + \nu's$
pγ→Δ→π→ν (3K bkg)
GZK cutoff
highest observed p energy
γγ→e⁺e⁻ (IR+3K bkg)
Non-Observable Space by γ and Cosmic Nuclei
γ + γ2.7K⟶ e⁺ + e⁻
highest observed γ energy
galaxy
local group
Nearby clusters
AGN & QSOs
cosmology
photons
log(particle or photon energy, eV)
Observable distance (Mpc)
銀河直径
10万光年
(Our Galaxy)
超銀河団直径
(Super Cluster)
超銀河団
SDSS
距離 (億光年)
赤経
Distant, younger universe

High-Energy Neutrino Astrophysics

様々な領域の
クロスオーバー

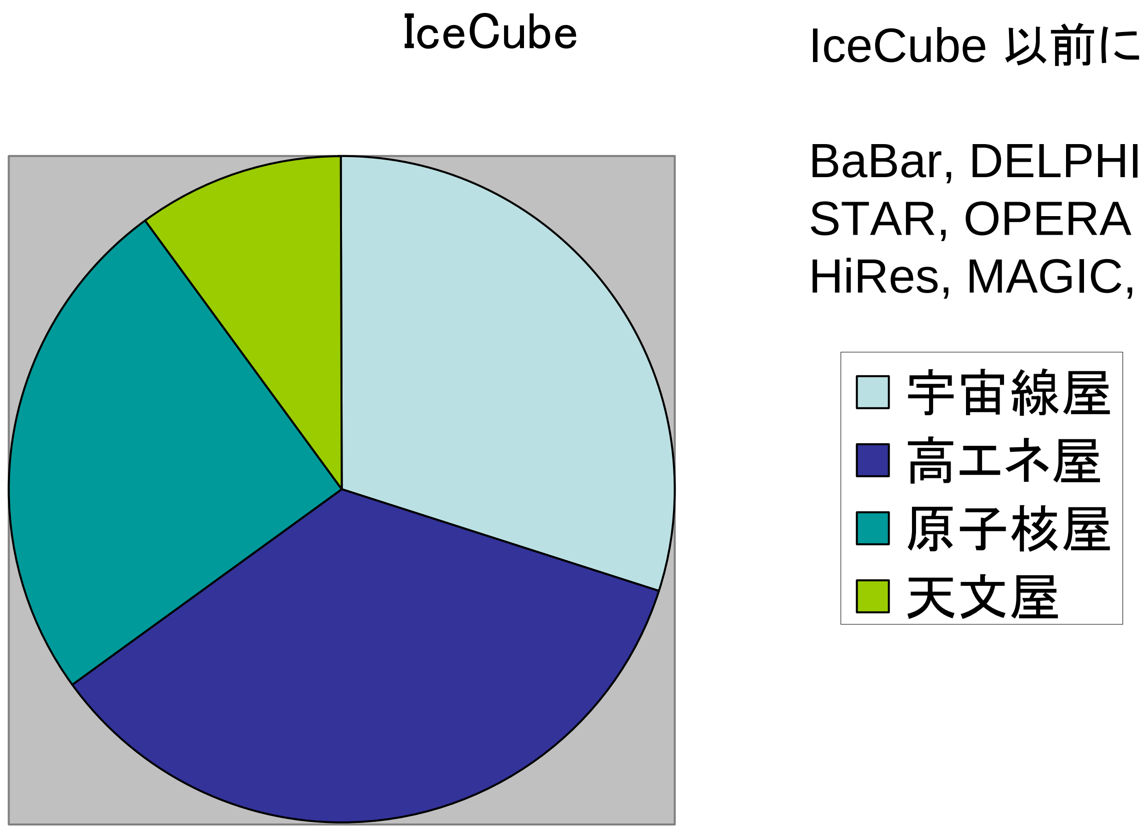
Particle Astrophysics
- 宇宙線の起源
- エネルギー収支
- 深宇宙探査

ν

非加速器物理
- 暗黒物質
- 相対論的モノポール
- ニュートリノ核子相互作用

“新”物理現象探索
- ローレンツ不変性の破れ
- ブラックホール蒸発

やっている人間もクロスオーバー



IceCube 以前に従事したプロジェクト

BaBar, DELPHI, SSC, SNO
STAR, OPERA
HiRes, MAGIC,….,

IceCube status

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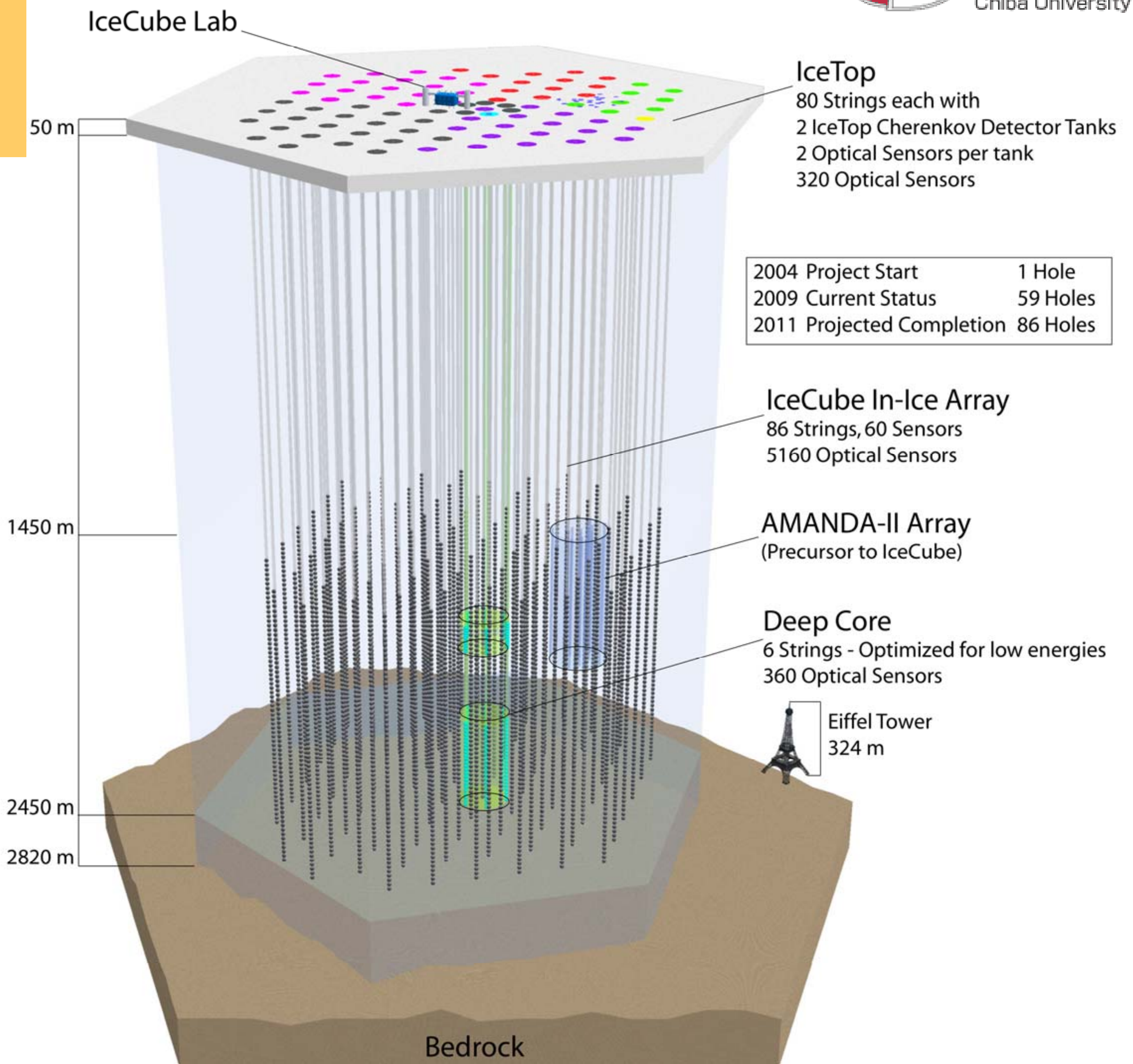
Chiba University

- Total of 59 strings and 118 IceTop tanks → over two thirds complete!
- Completion with 86 strings: January 2011
- Detector is taking data during construction phase.



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IceCube

IceTop

Air shower detector

80 pairs of ice

Cherenkov tanks

Threshold ~ 300 TeV

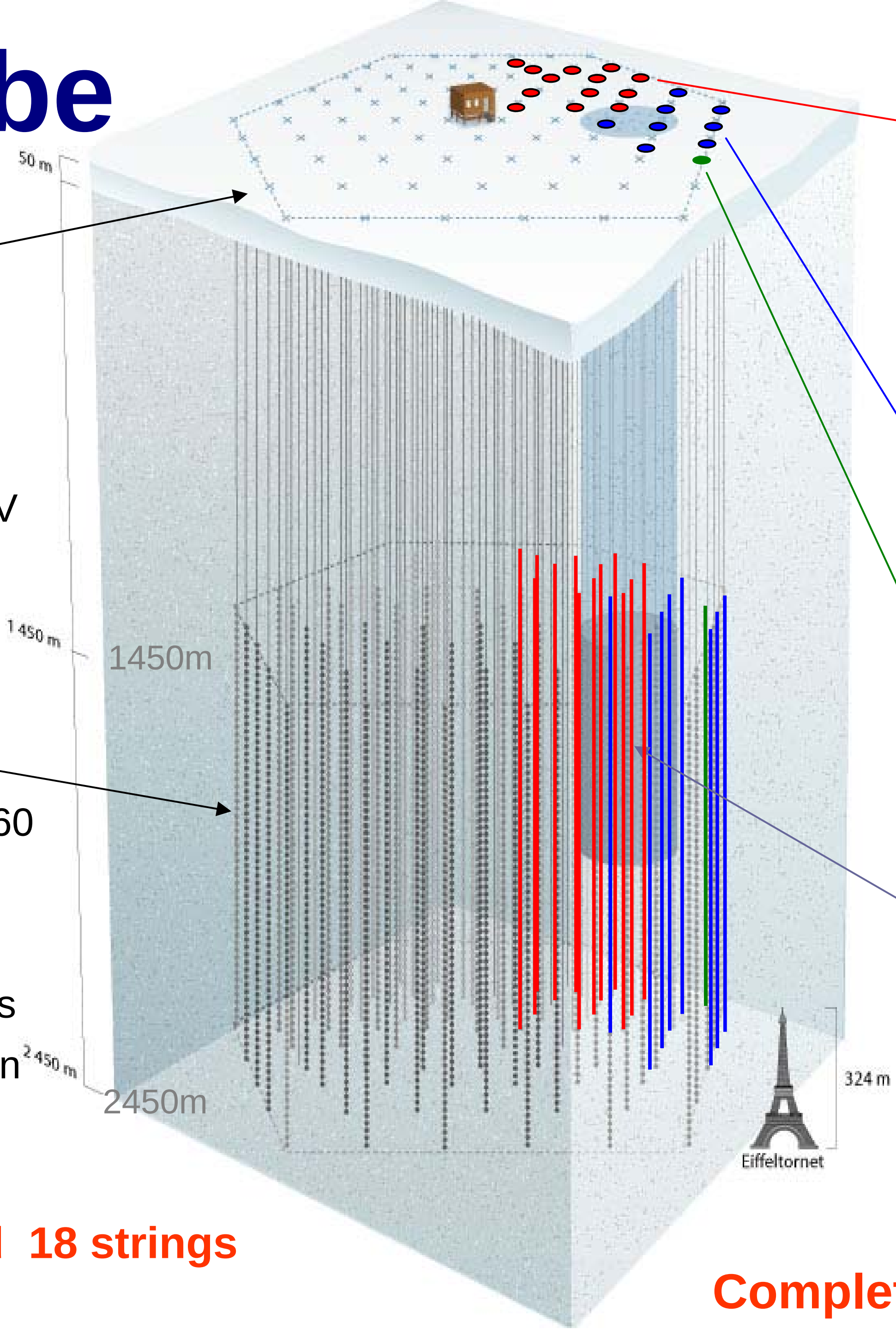
InIce

Planned 80 strings of 60

optical modules each

17 m between modules

125 m string separation



2006-2007:

13 strings deployed

2007 configuration

- 22 strings
- 52 surface tanks

2005-2006: 8 strings

2004-2005 : 1 string

AMANDA-II

19 strings

677 modules

AMANDA now operating as part of IceCube

2007/08: added 18 strings

Completion by 2011.

The IceCube Collaboration

IceCube

千葉大学
Chiba University

USA:
Bartol Research Institute, Delaware
University of California, Berkeley
University of California, Irvine
Pennsylvania State University
Clark-Atlanta University
Ohio State University
Georgia Tech
University of Maryland
University of Alabama, Tuscaloosa
University of Wisconsin-Madison
University of Wisconsin-River Falls
Lawrence Berkeley National Lab.
University of Kansas
Southern University and A&M College, Baton Rouge
University of Alaska, Anchorage

Sweden:
Uppsala Universitet
Stockholm Universitet

UK:
Oxford University

Netherlands:
Utrecht University

Switzerland:
EPFL

Germany:
DESY-Zeuthen
Universität Mainz
Universität Dortmund
Universität Wuppertal
Humboldt Universität
MPI Heidelberg
RWTH Aachen

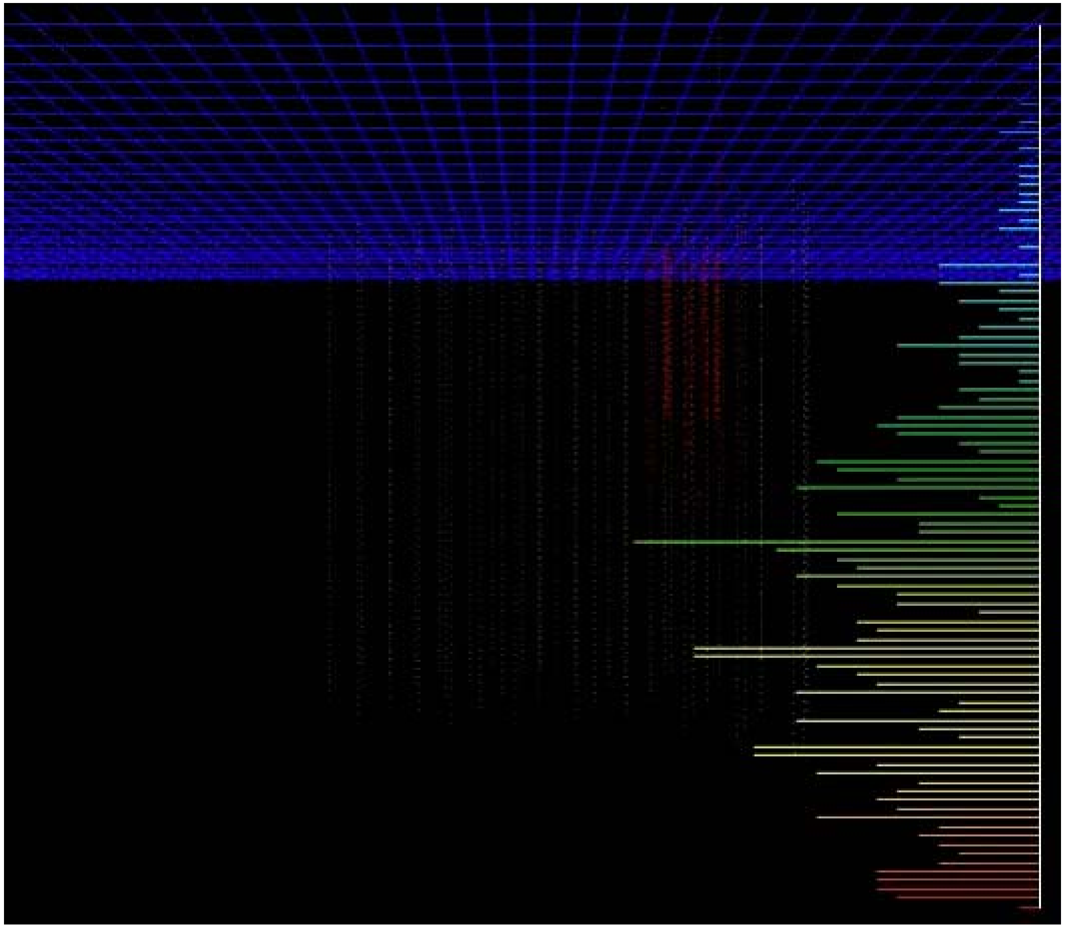
Belgium:
Université Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons-Hainaut

Japan:
Chiba University

New Zealand:
University of Canterbury

33 institutions, ~250 members
http://icecube.wisc.edu

Our Events



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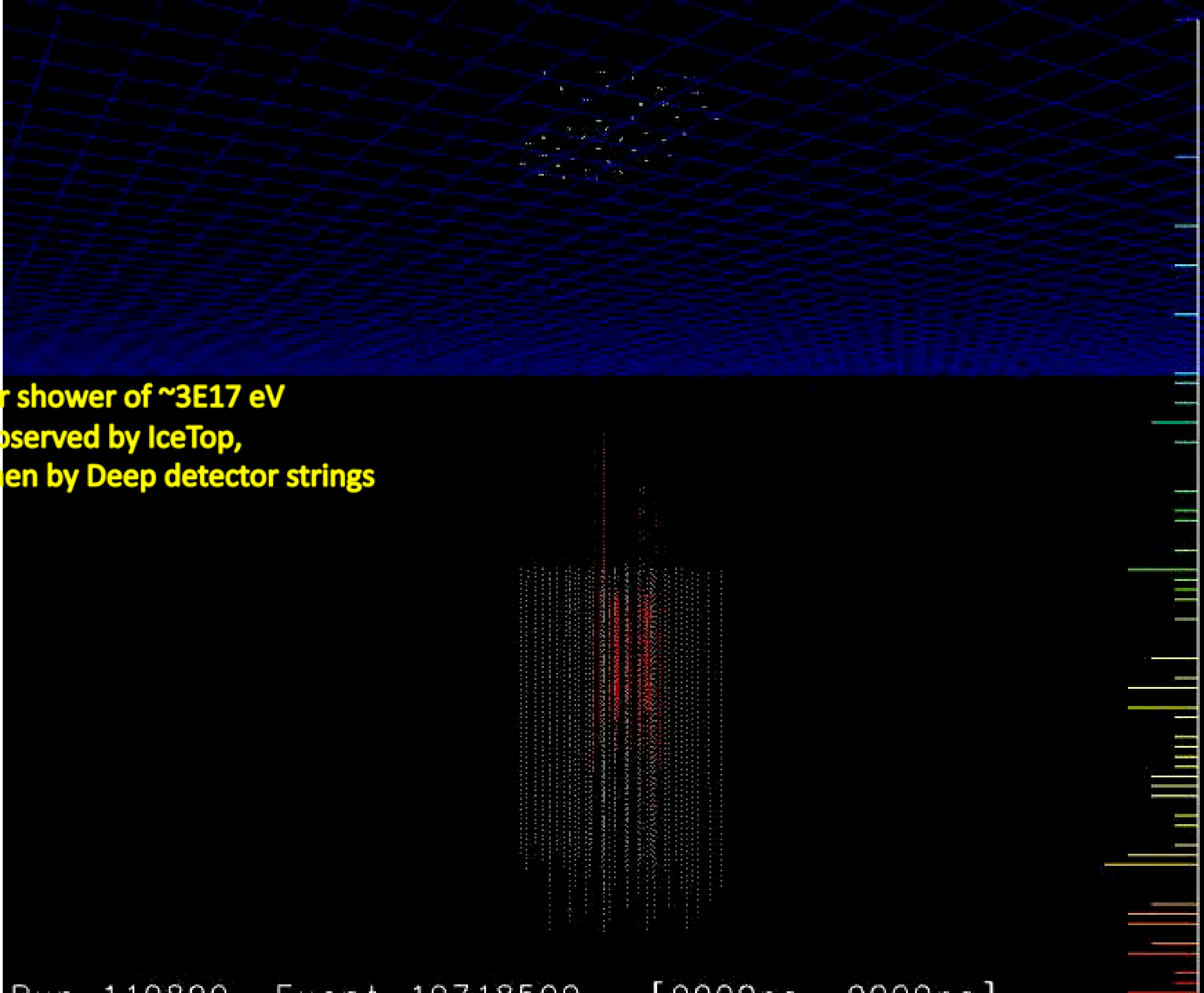
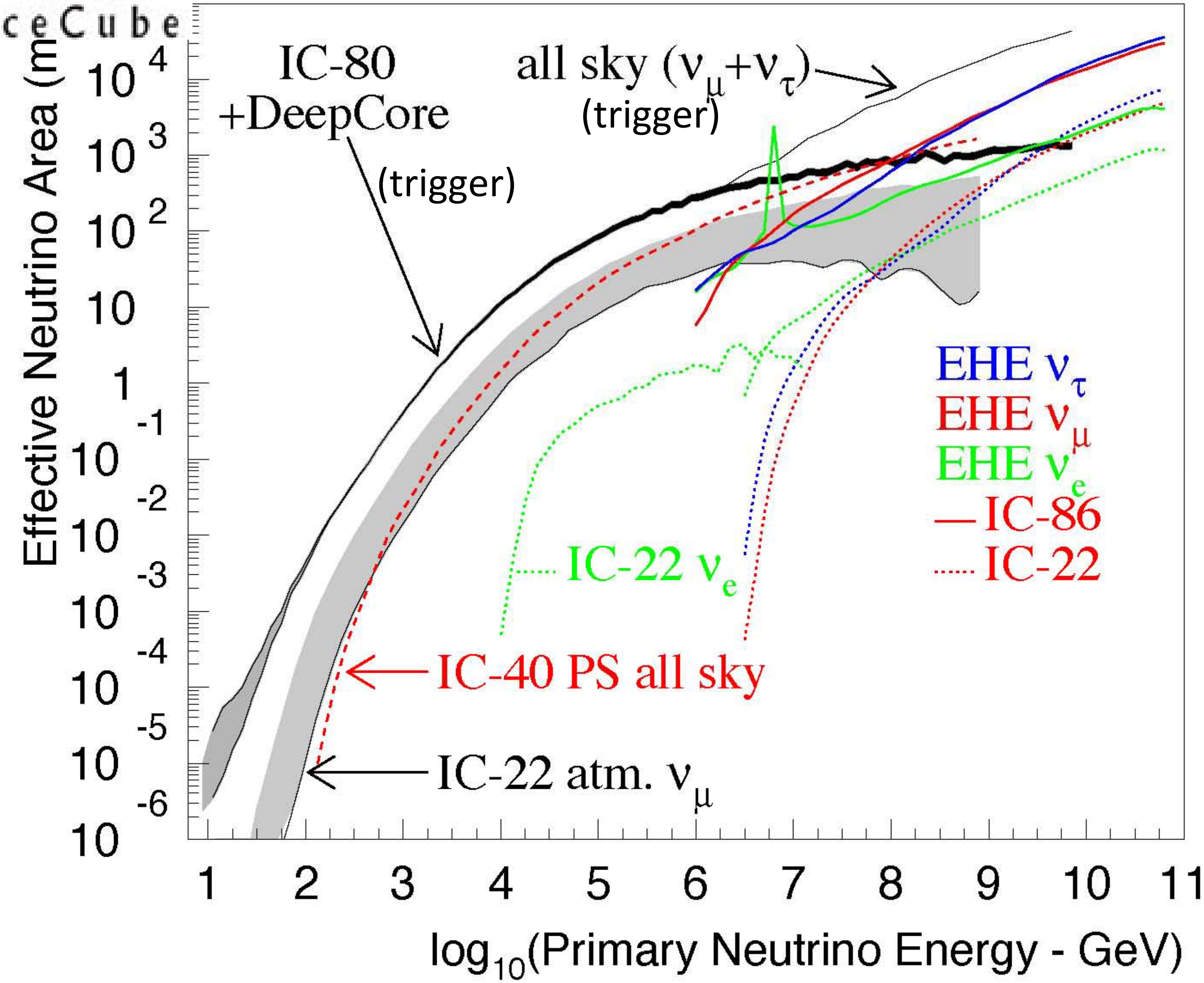


Air shower of ~3E17 eV
Observed by IceTop,
Then by Deep detector strings

Neutrino Effective Areas



Area at 100 TeV (1TeV)
AMANDA-II: 3m^2 (0.005)
IceCube 86: 100m^2 (0.3)

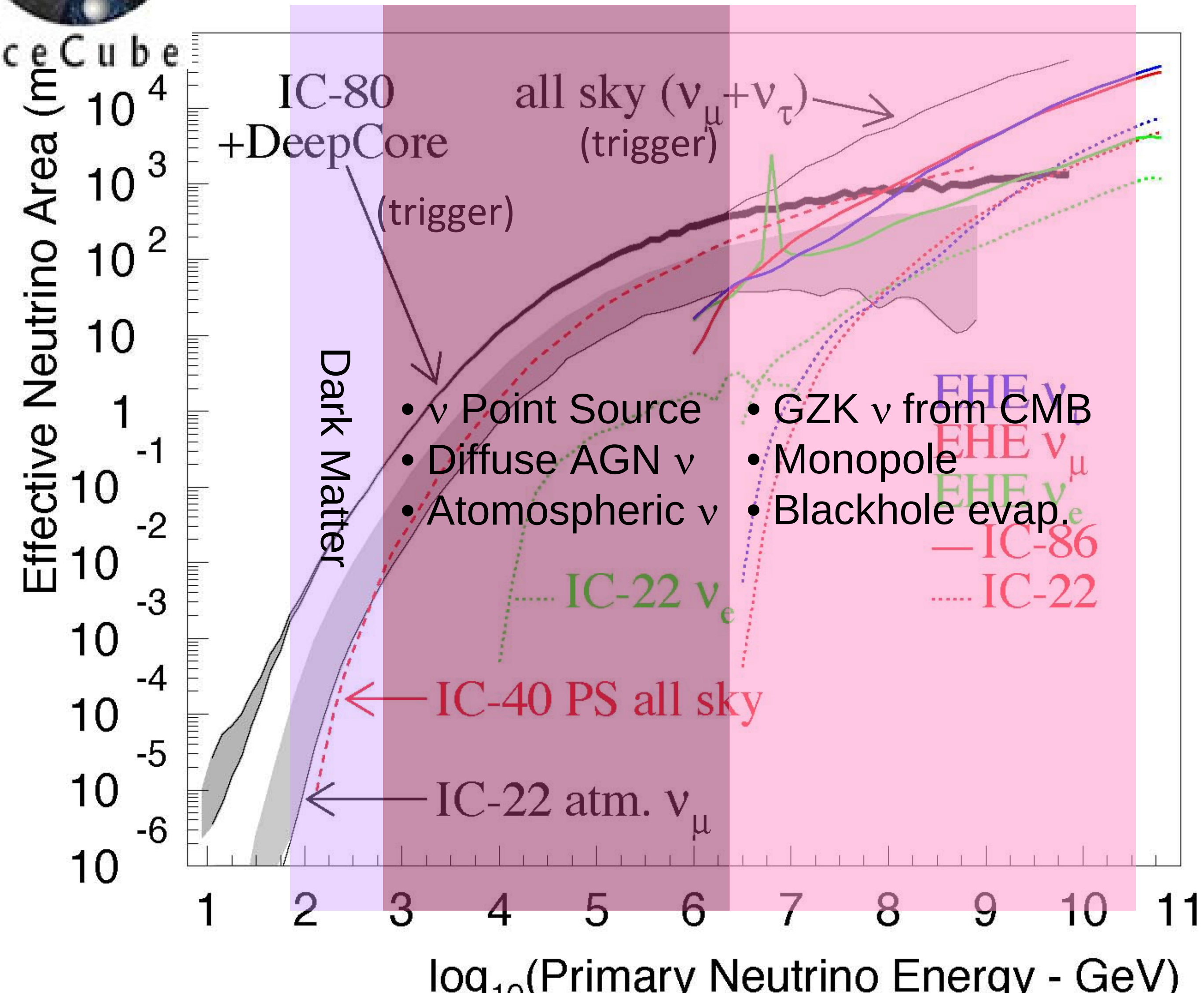
Deep Core lowers threshold from 100 GeV to 10 GeV.

Effective area for ν_μ

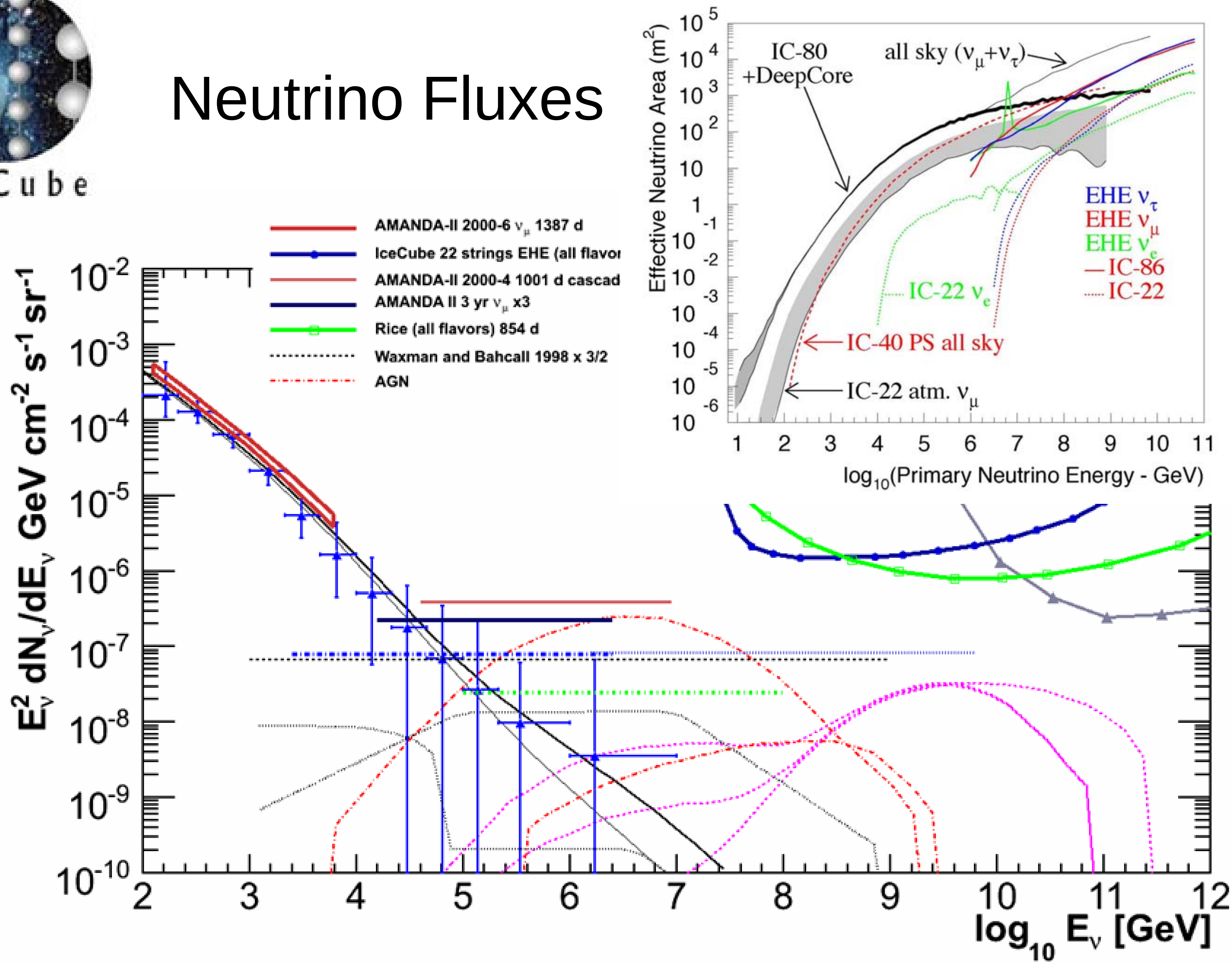
Strong rise with energy:

- $\sigma \propto E_\nu$
- Increase of muon range with energy up to PeV

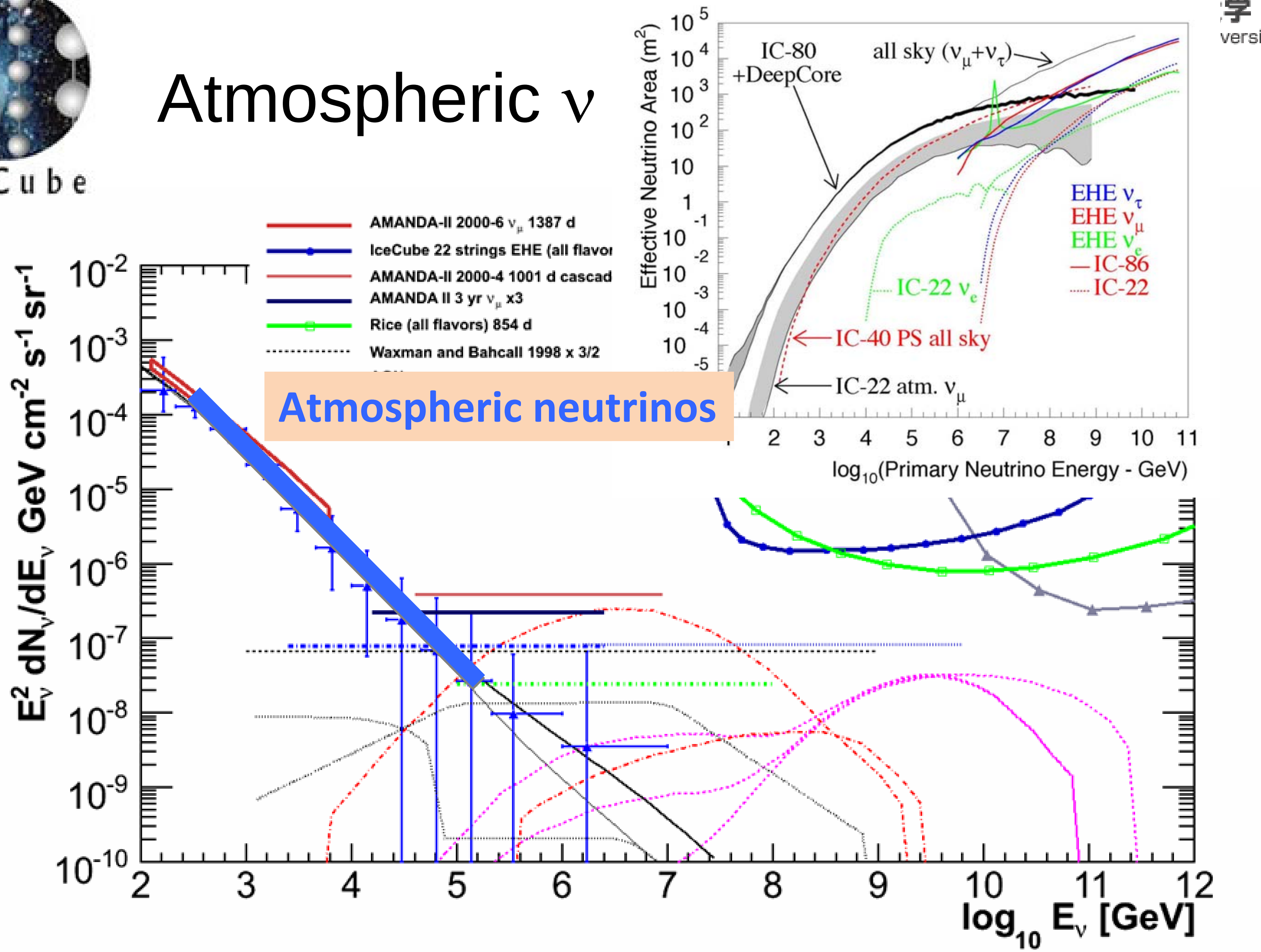
Neutrino Effective Areas



Neutrino Fluxes

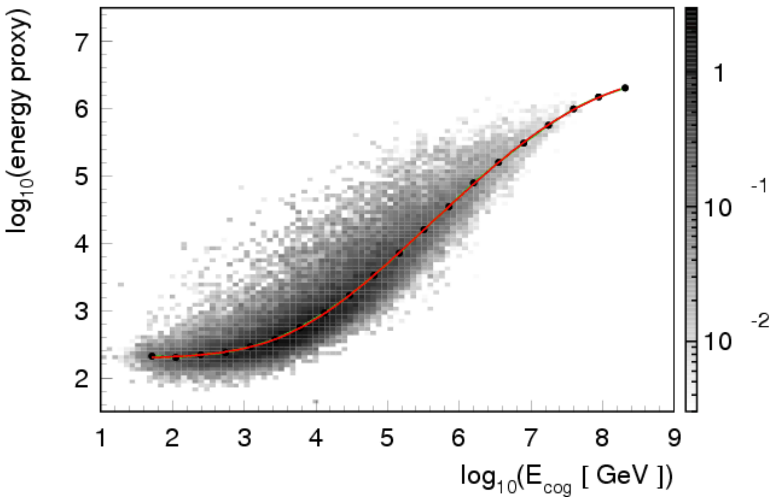


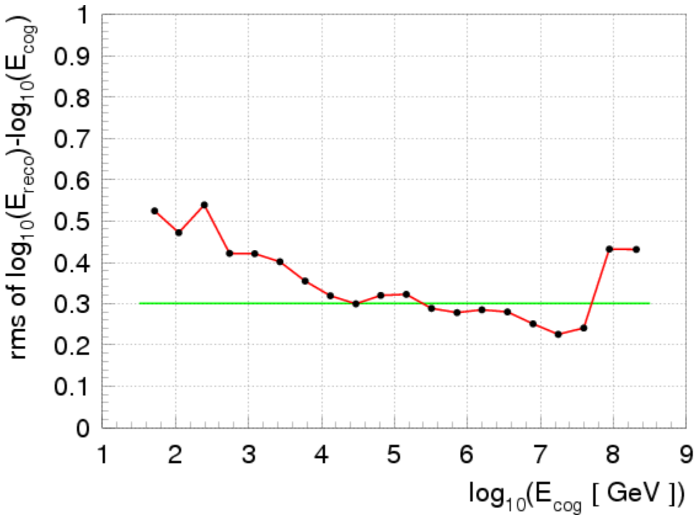
Atmospheric ν

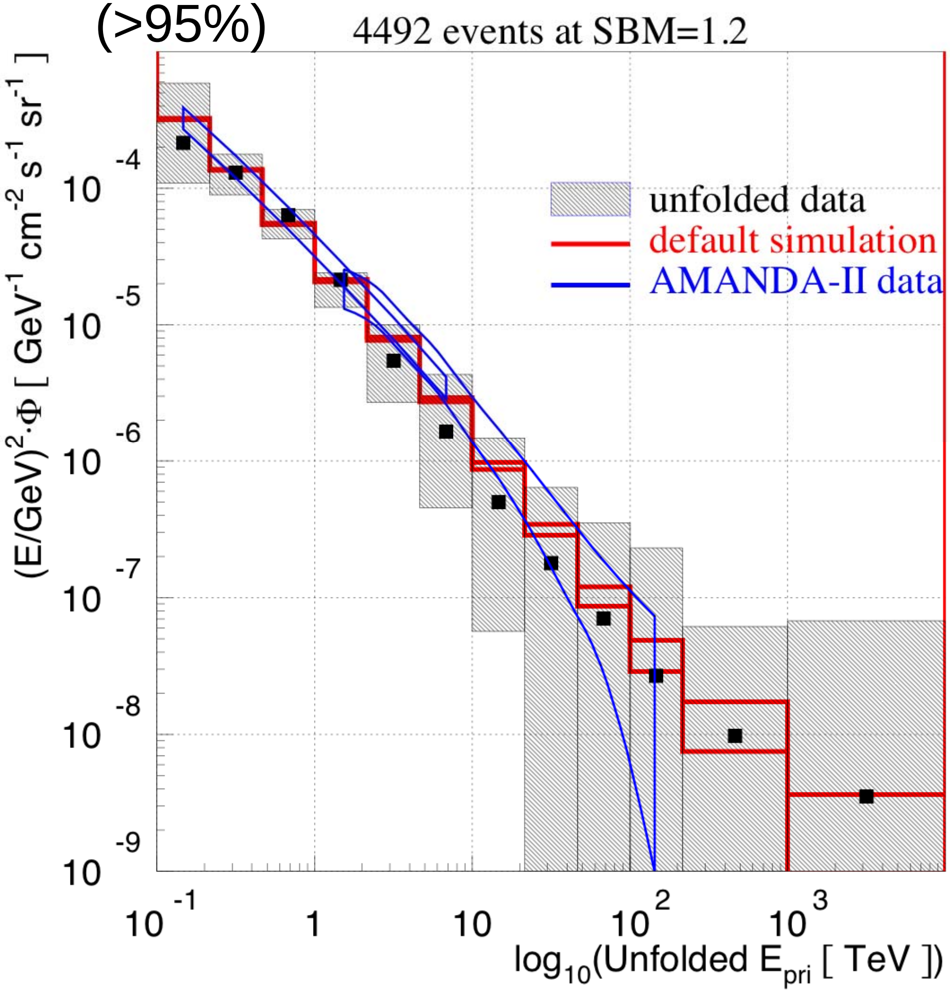


Atmospheric ν

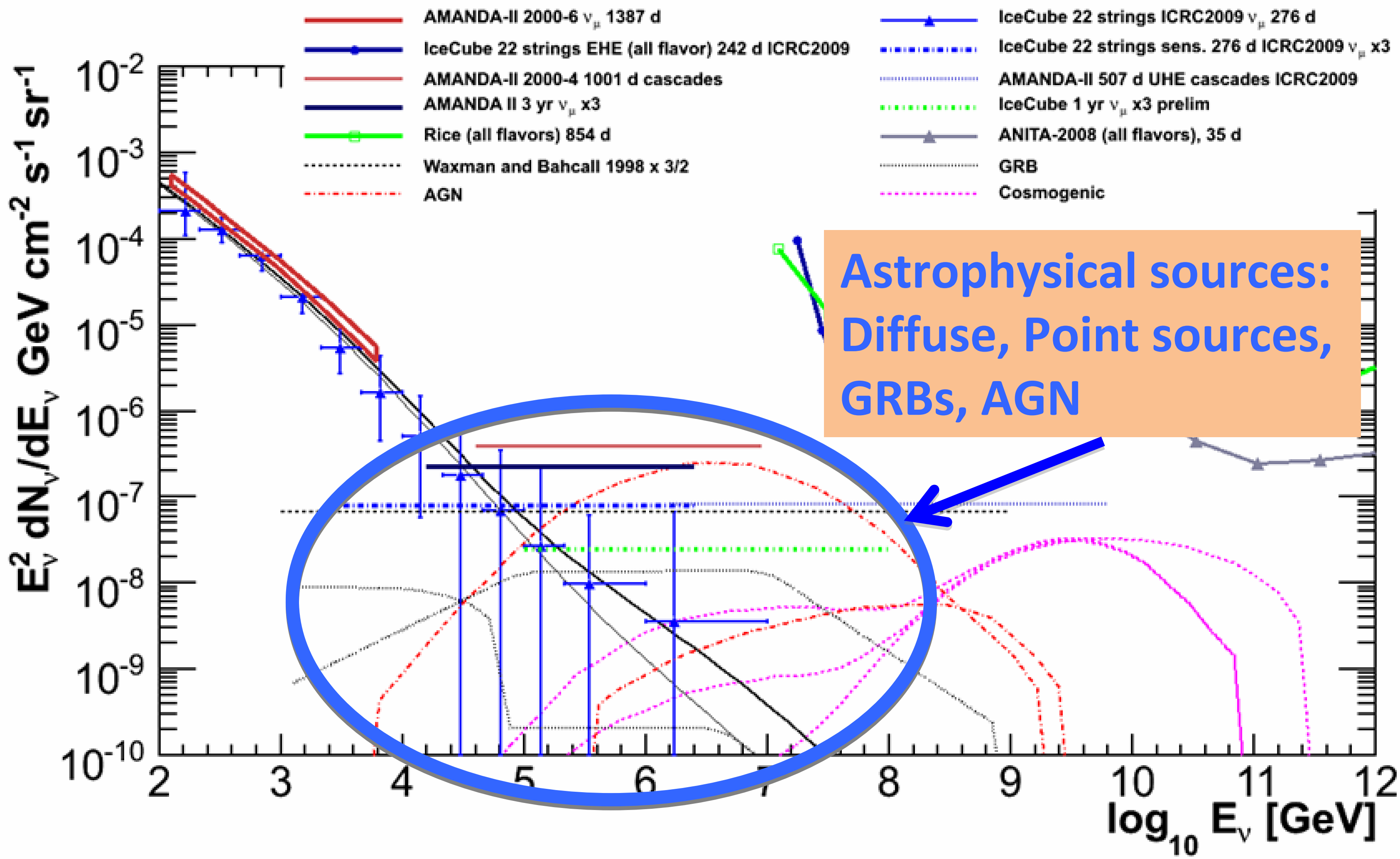
- IceCube 22 string analysis
- 4492 neutrino events at high purity (>95%)



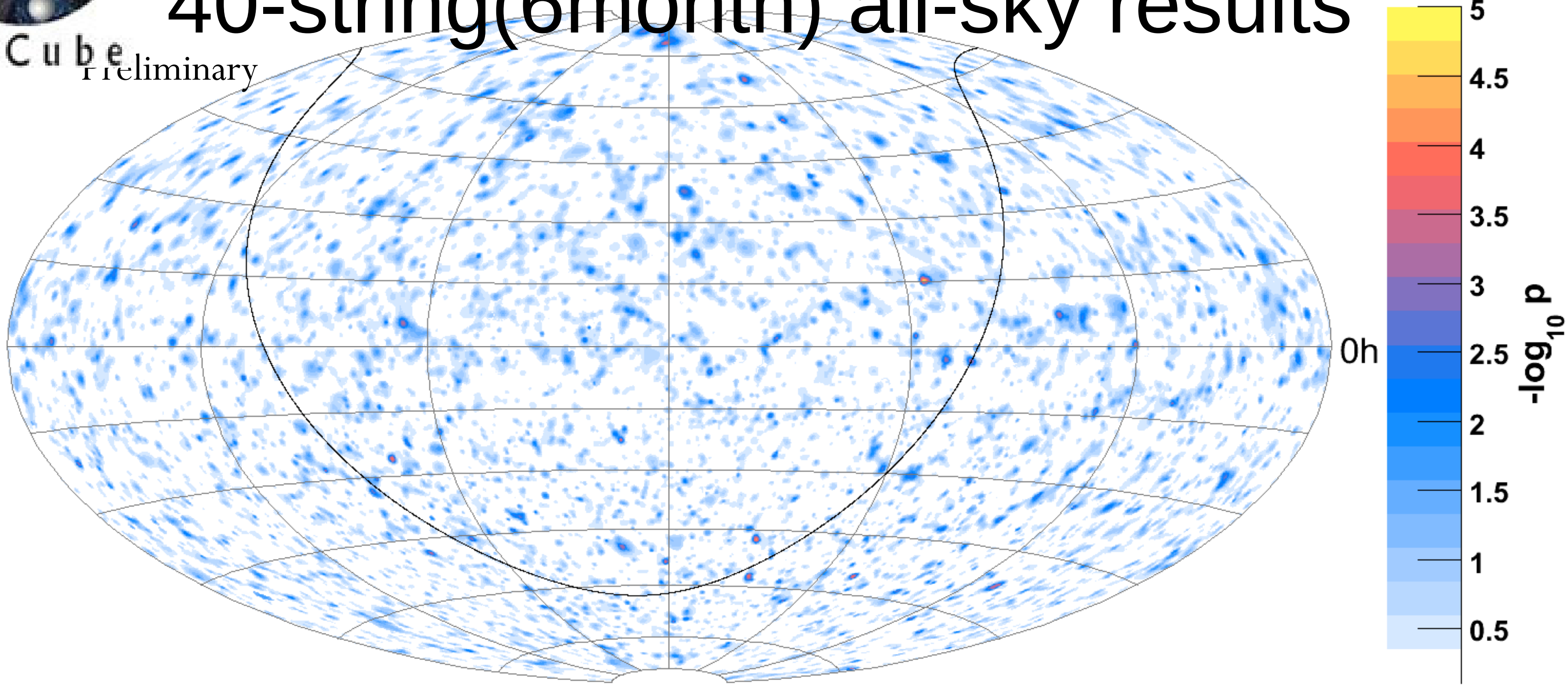




Very High Energy (TeV-PeV) ν



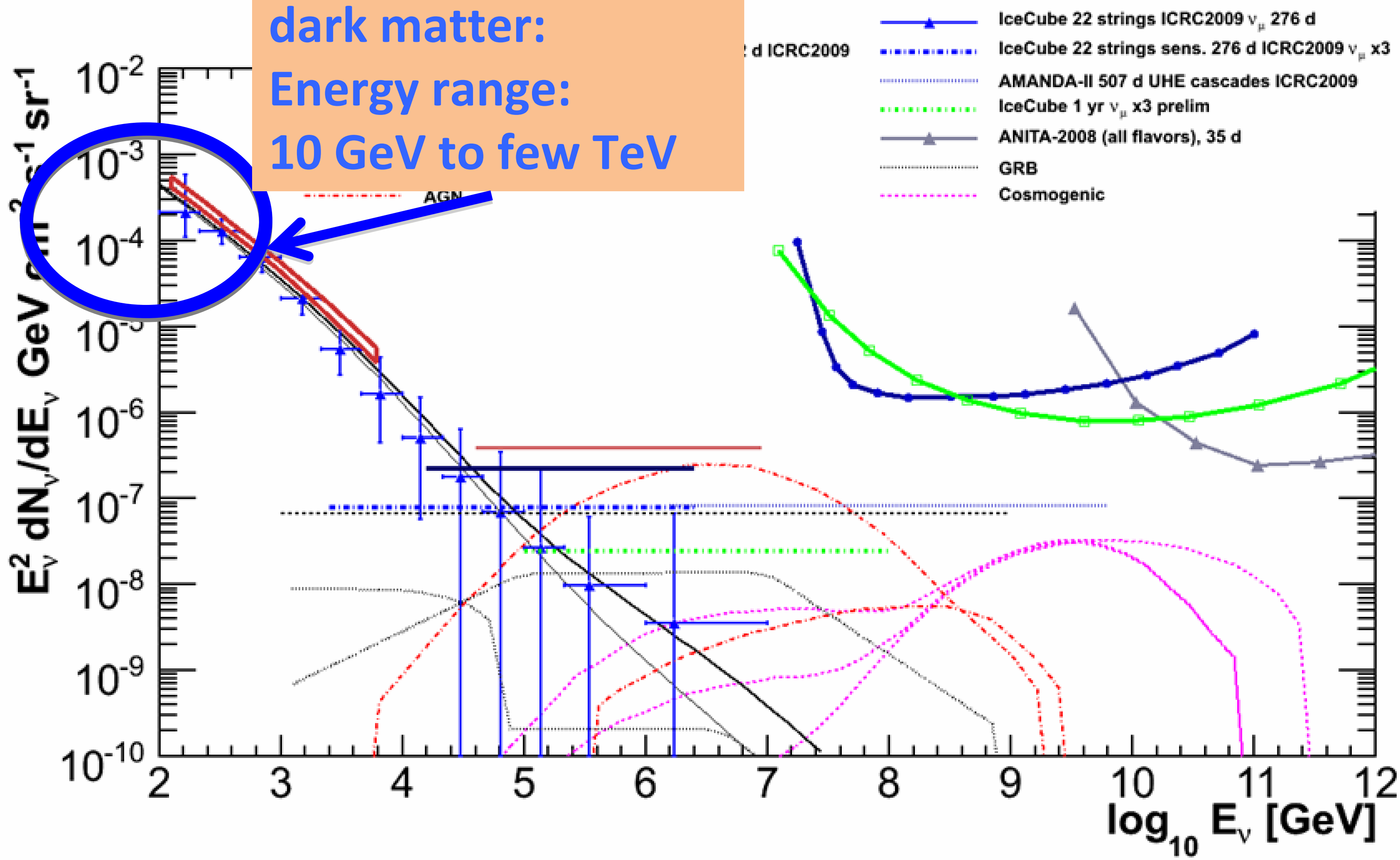
Search for point sources - 40-string(6month) all-sky results



175.5 days livetime,
17777 events:
    6796 up-going,
    10981 down-going

Dark Matter

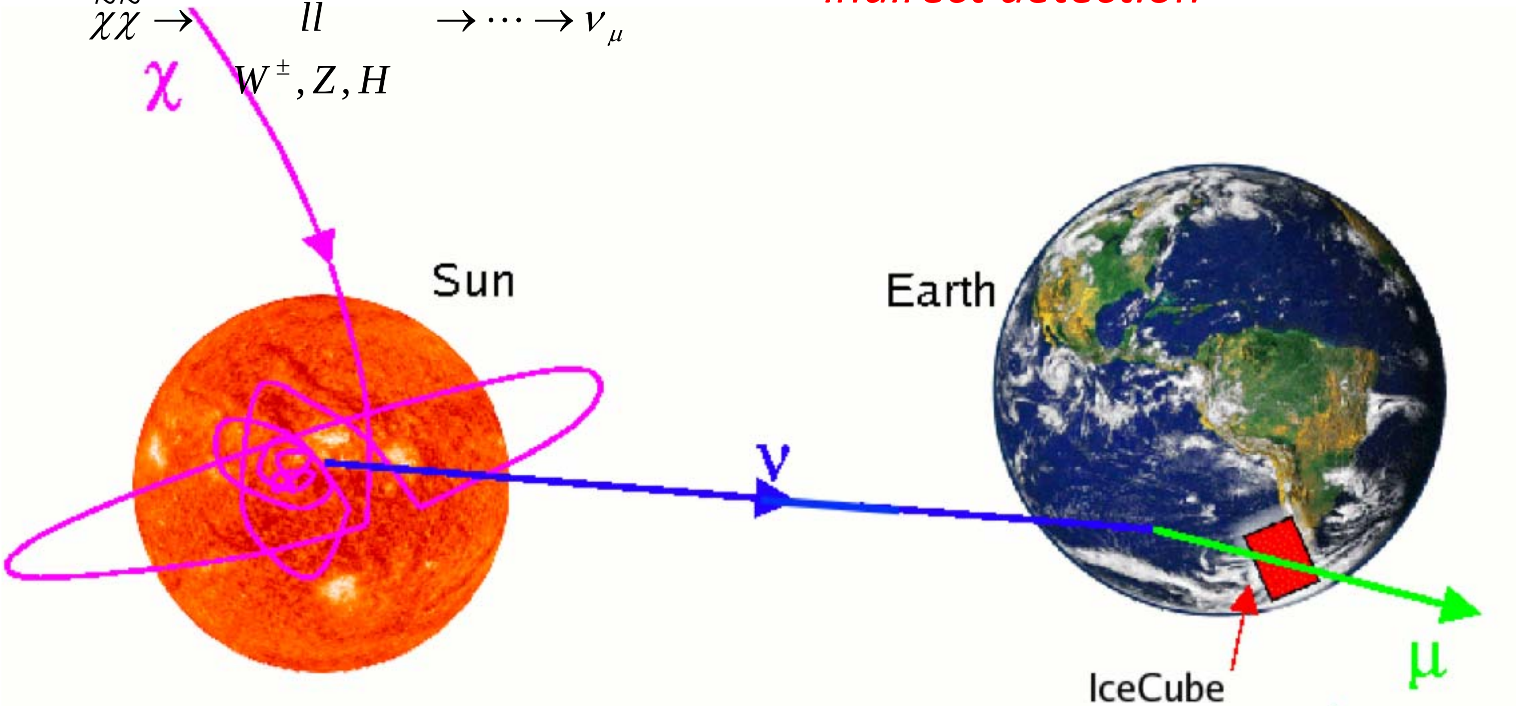
Search for indirect dark matter:
Energy range:
10 GeV to few TeV



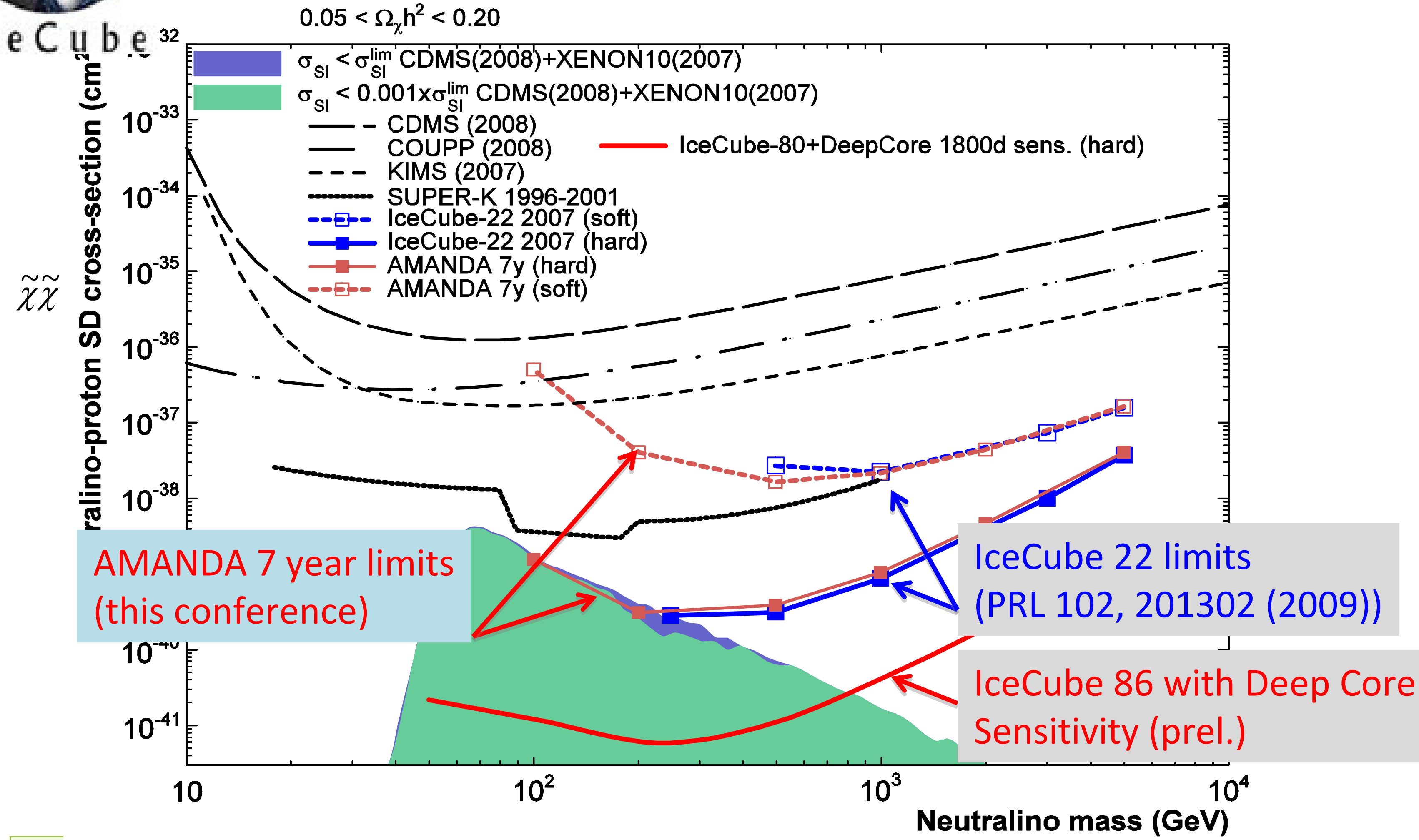
Search for dark matter, example: WIMPs in sun → neutrino flux at Earth

- *annihilating in the gravity well of the Sun*
- *indirect detection*

$$\tilde{\chi}\tilde{\chi} \to \begin{matrix} q\bar{q} \\ l\bar{l} \\ W^{\pm}, Z, H \end{matrix} \to \cdots \to \nu_{\mu}$$



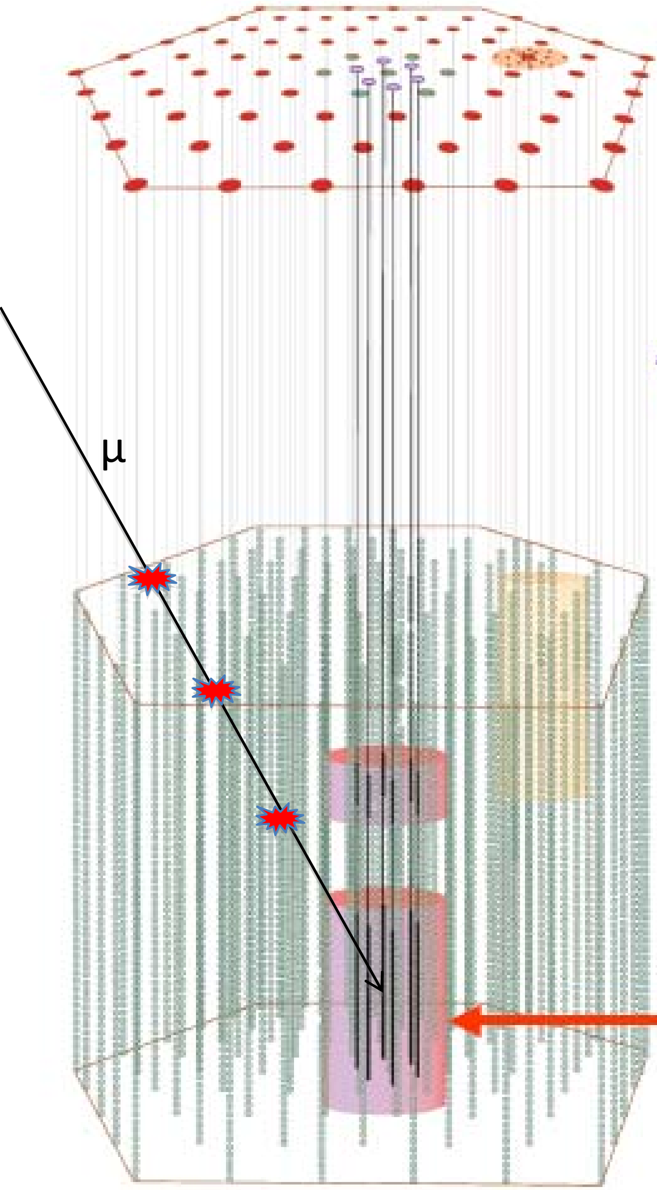
Dark Matter search:
neutrinos from WIMP annihilation in the sun



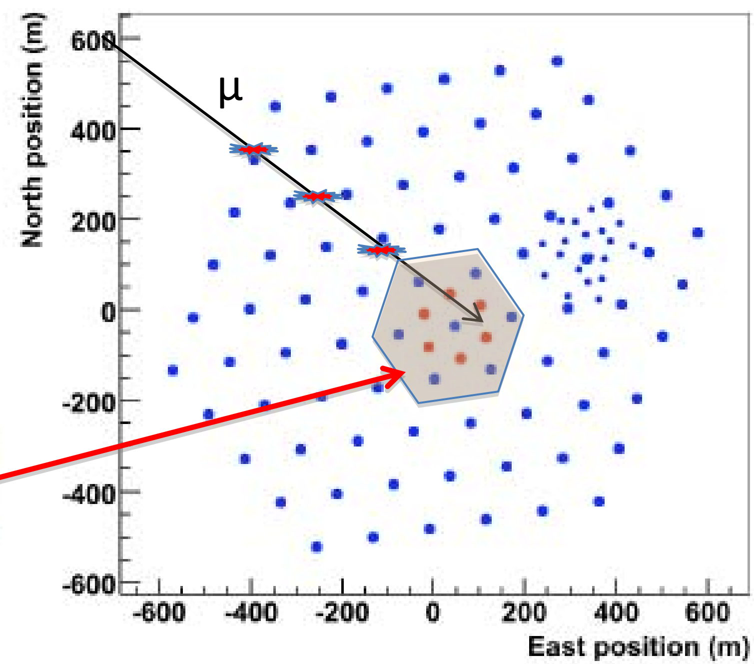
→ Deep core enhancement under construction will greatly enhance sensitivity.

IceCube Deep Core

→Add 6 strings at small spacing, all high quantum efficiency PMT
→Lower energy threshold:
Open window between 10 and 100 GeV
→ High background rejection using surrounding IceCube strings as Veto: $\phi(\mu) / \phi(\nu_{\rm atm}) \simeq 10^6$



Deep core

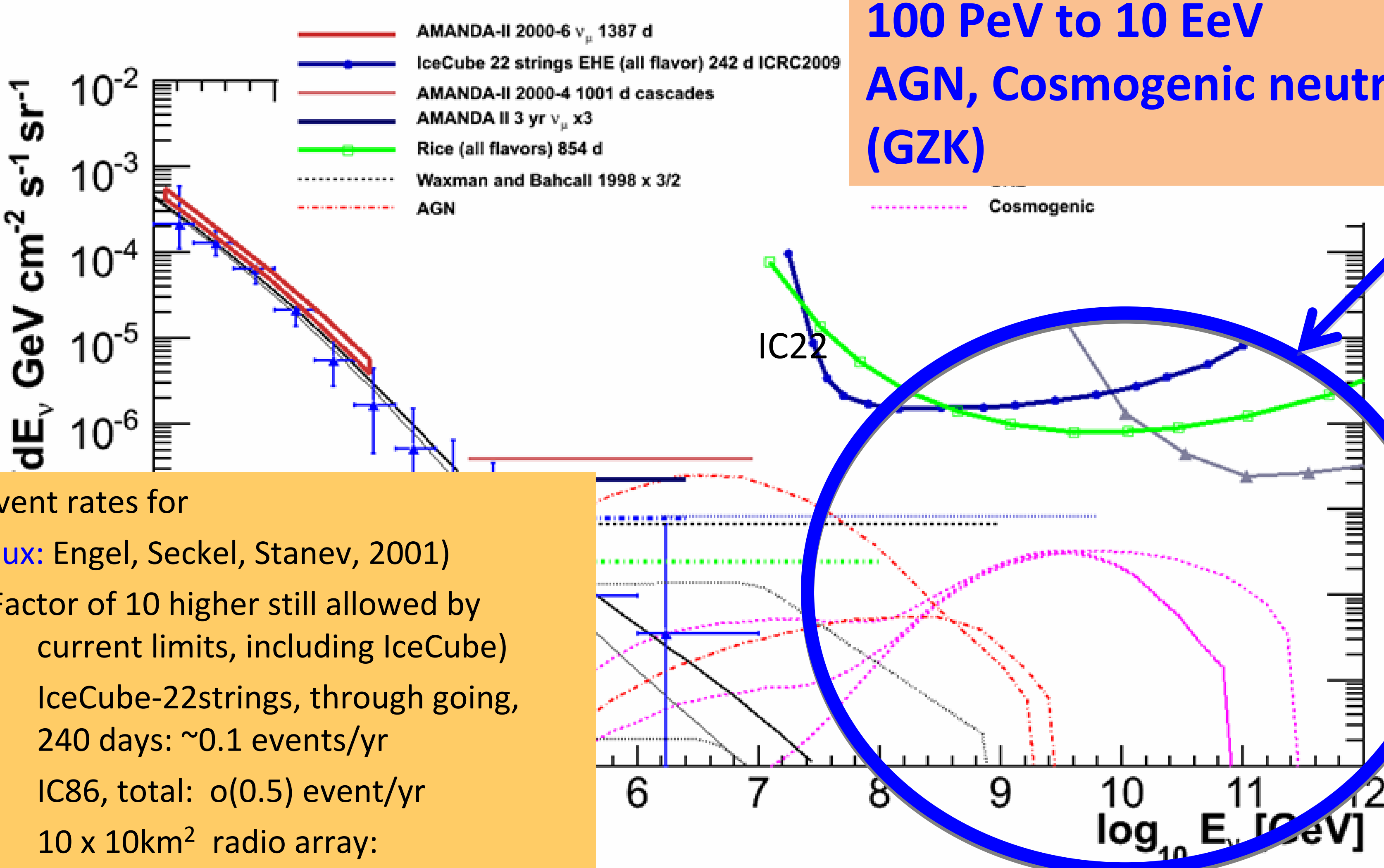


side view

top view

EHE (EeV and higher)

Astrophysical sources:
100 PeV to 10 EeV
AGN, Cosmogenic neutrinos (GZK)



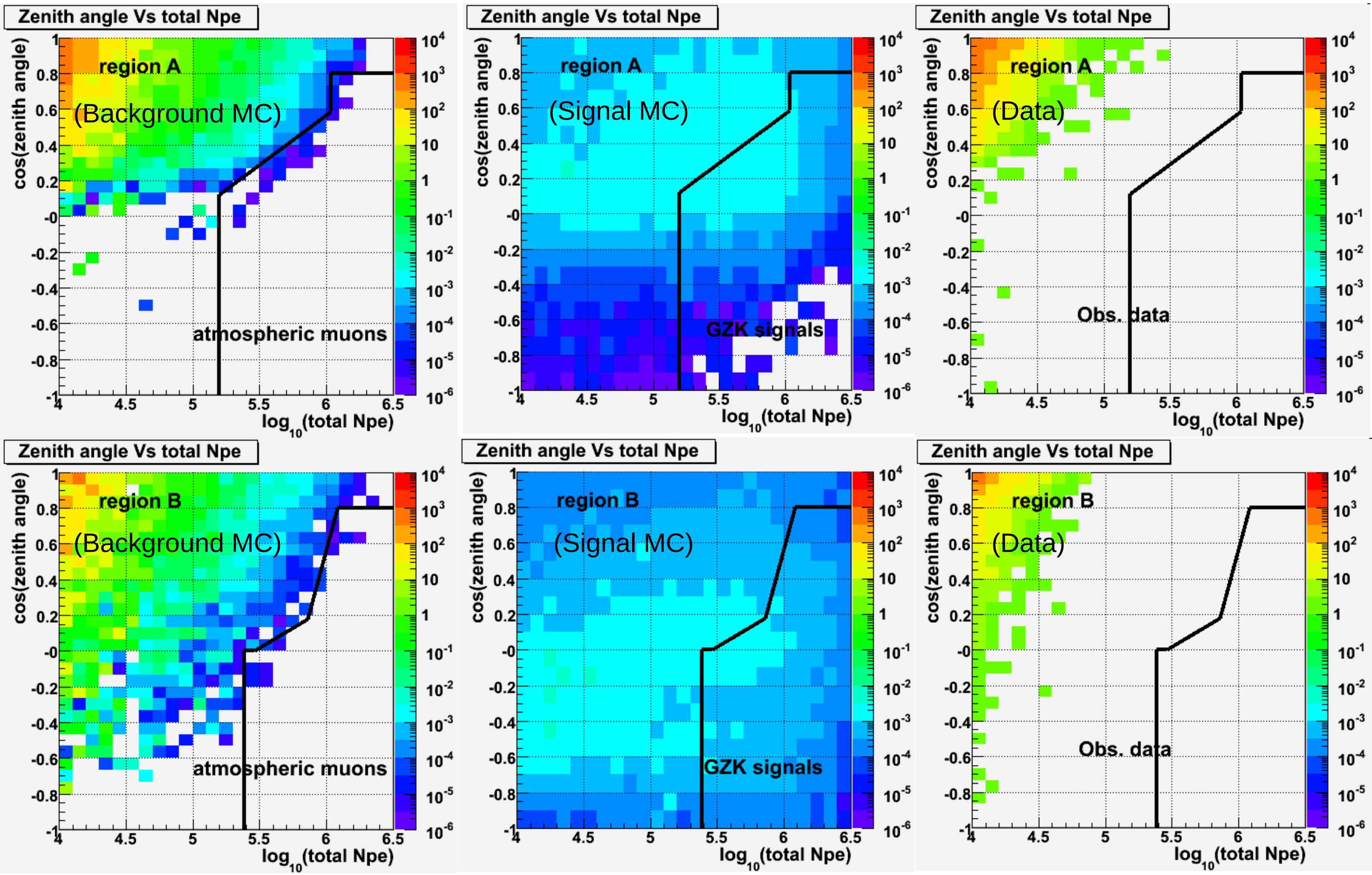
Event rates for

Flux: Engel, Seckel, Stanev, 2001)

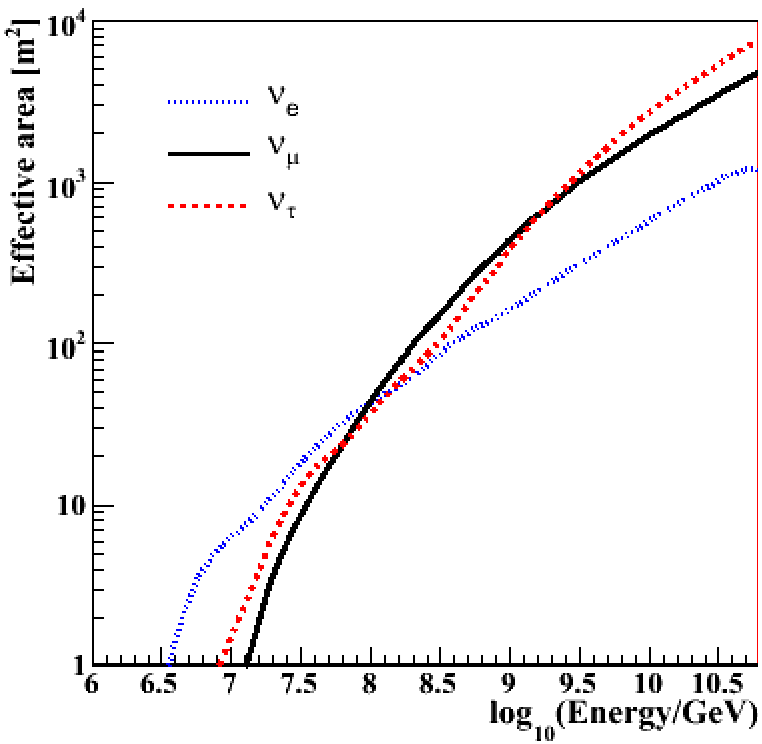
(Factor of 10 higher still allowed by current limits, including IceCube)

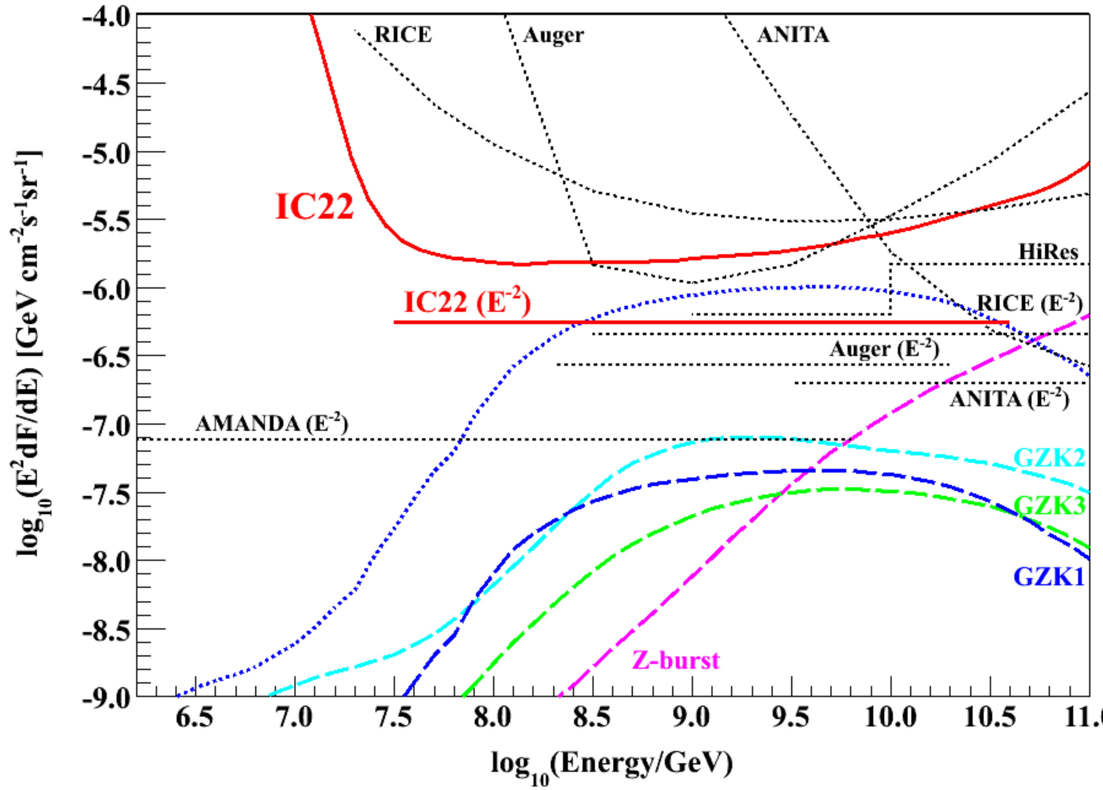
- IceCube-22strings, through going, 240 days: ~0.1 events/yr
- IC86, total: o(0.5) event/yr
- 10 x 10km^2 radio array: o(10) events/yr

region A: -250 < CoGZ < -50 m and CoGZ > 50 m
region B: CoGZ < -250 m and -50 < CoGZ < 50m



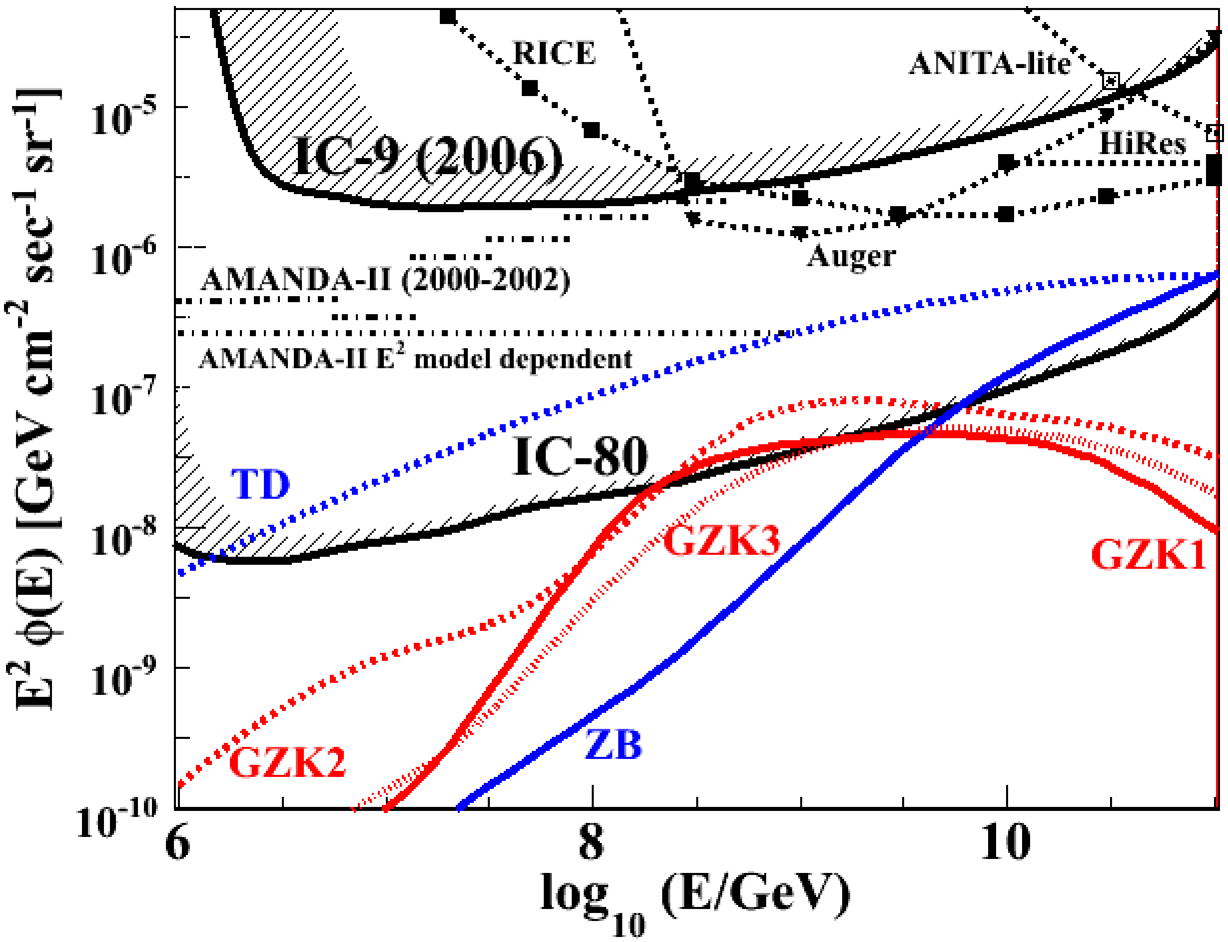
Extremely-High Energy ν limits
with 241 days observation in 2007



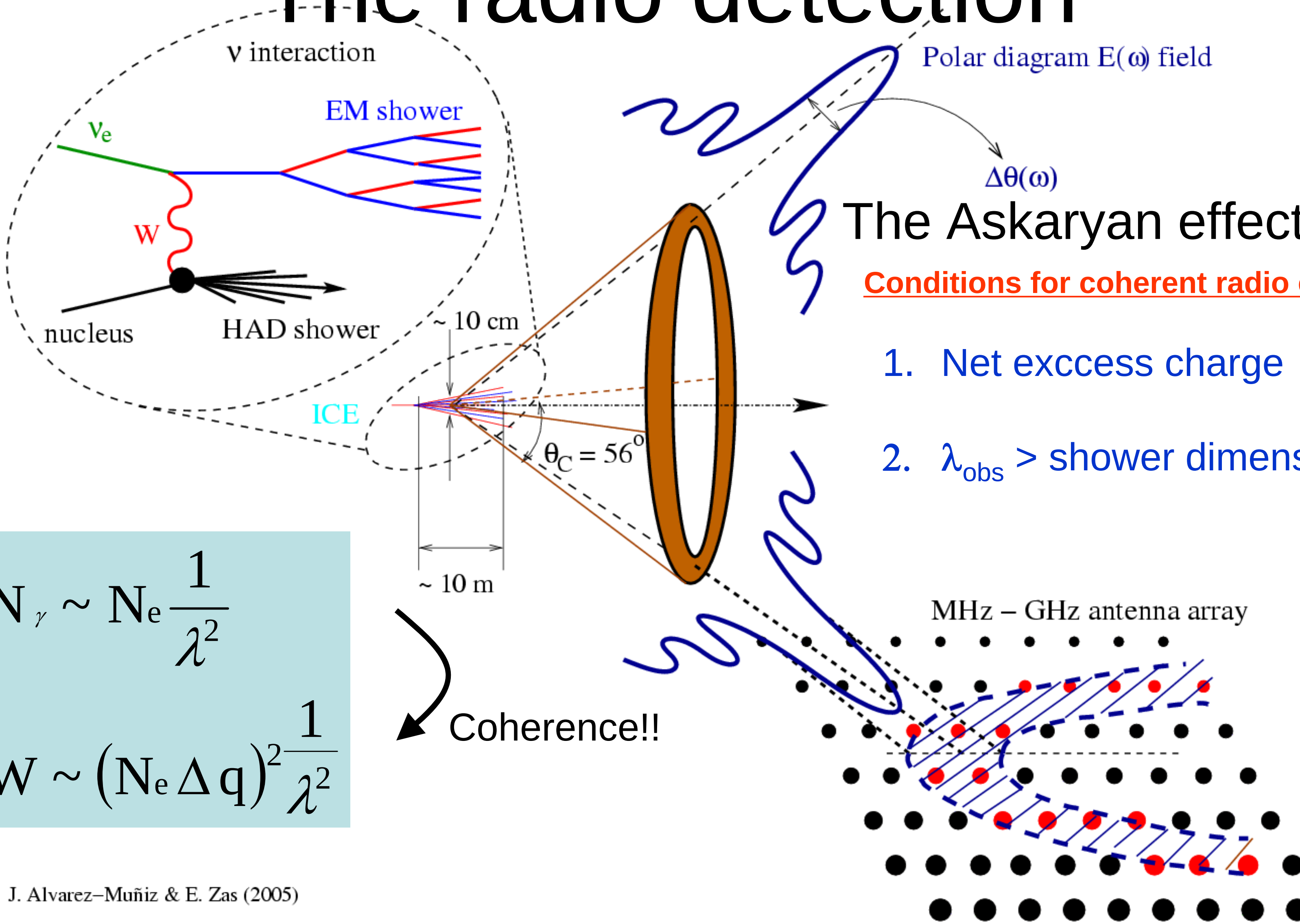


We will have more observation time with more than twice bigger volume
Stats will be increased by x5 before 2011

Extremely-High Energy ν limits
with 5 year full IceCube



The radio detection



J. Alvarez–Muñiz & E. Zas (2005)

The Askaryan effect

Conditions for coherent radio emission

1. Net exccess charge
2. λ_{obs} > shower dimensions

$$N_\gamma \sim N_e \frac{1}{\lambda^2}$$

$$W \sim (N_e \Delta q)^2 \frac{1}{\lambda^2}$$

Coherence!!

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Calibration of the Askaryan effect

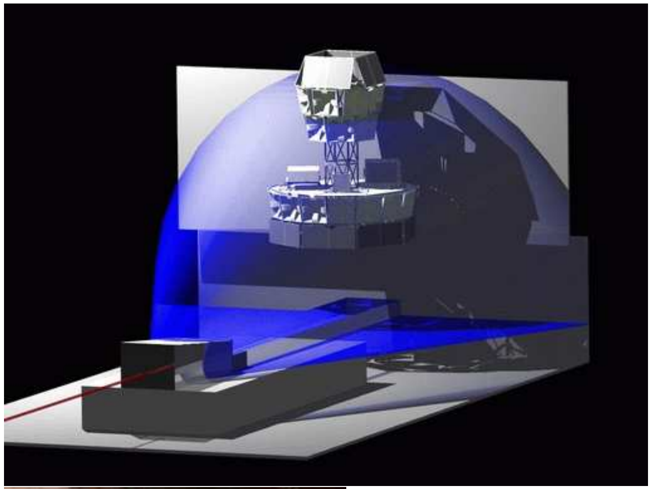
@SLAC 10^9 x 28.5 GeV e

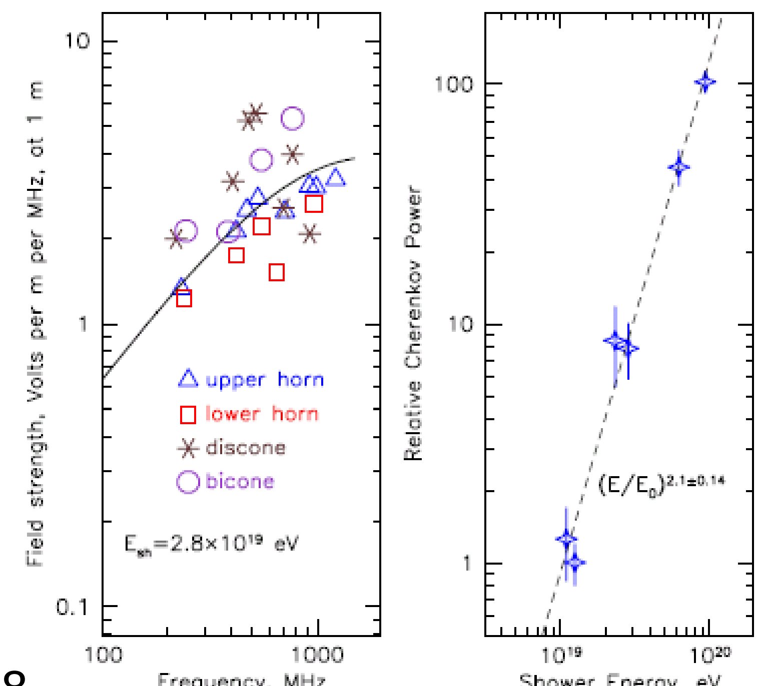
↓

2×10^{10} e^+e^- in the target ice

↓

Anita instruments





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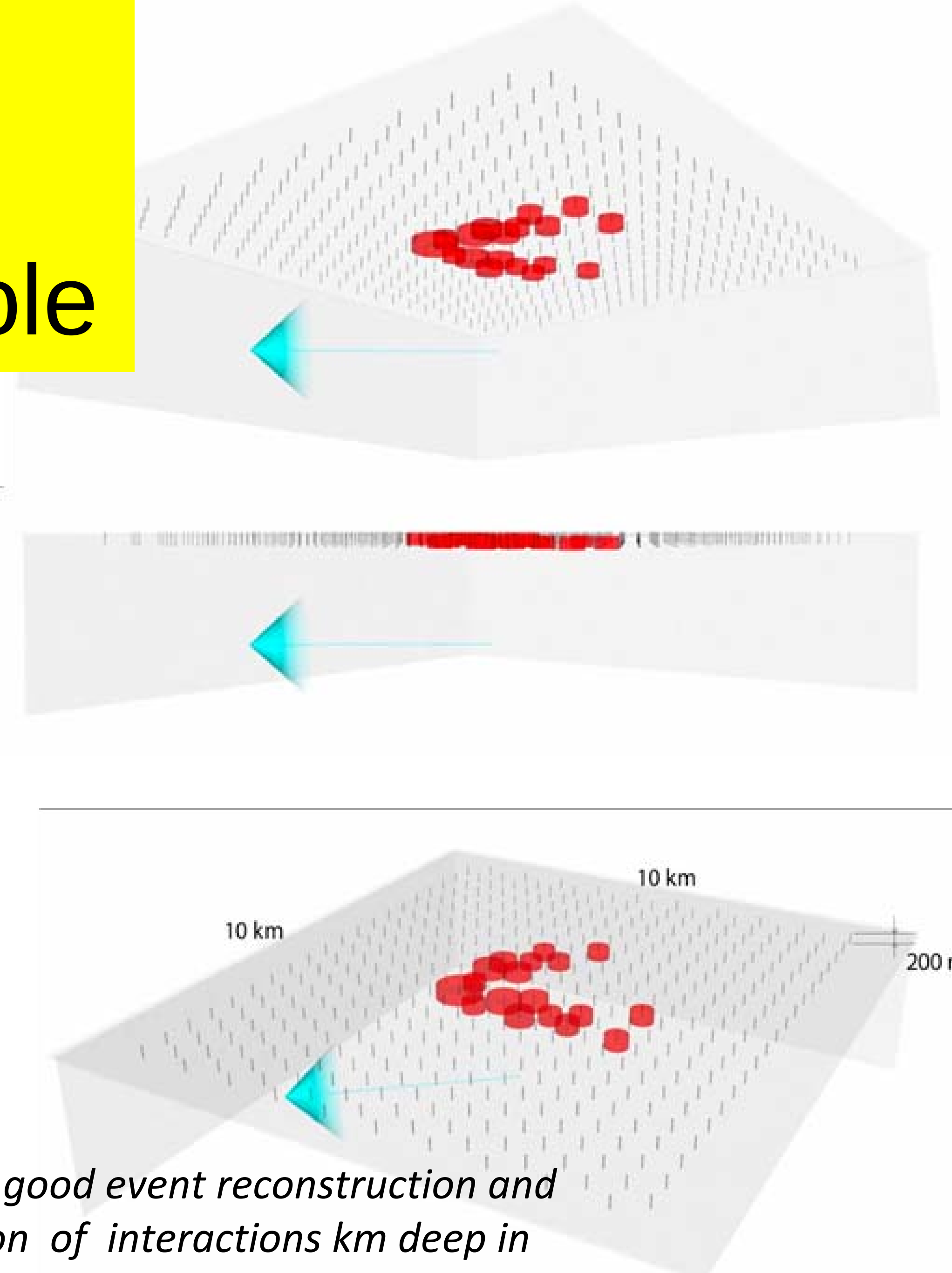
Gorham et al hep-ex/0611008

Askaryan radio array at the South Pole

- Large Radio array of short strings,
- Depth: 200m
- Spacing: ~0.5 to 1km
- Coverage: $100km^2$
- Low cost (shallow holes, antennas)
- Large enough to reliably detect GZK neutrino flux:

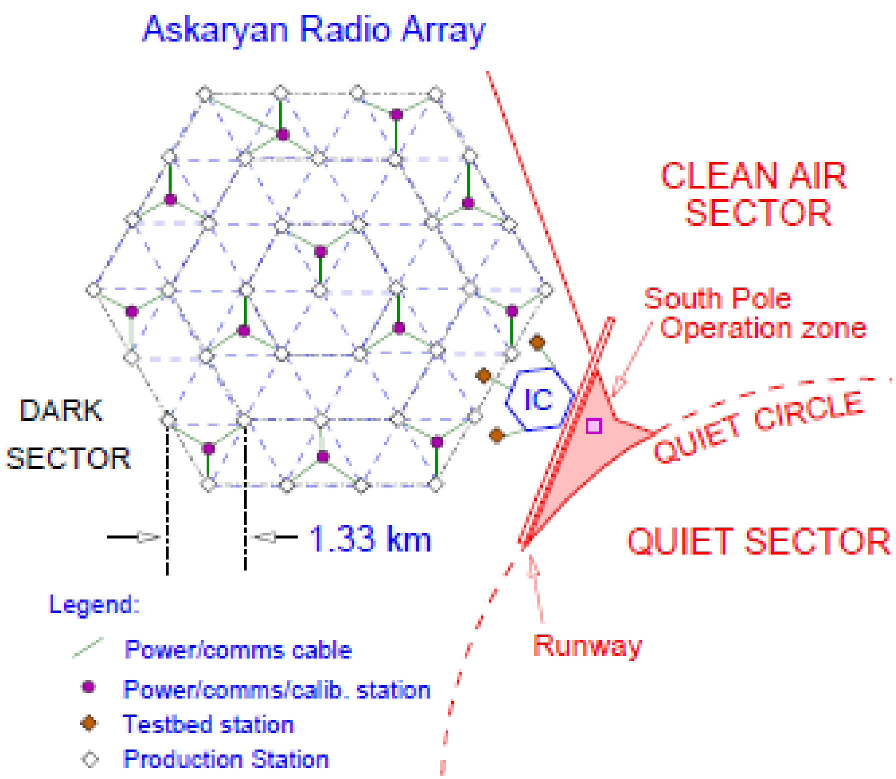
  > $250km^3$ viewed target volume
- O(10) events per year

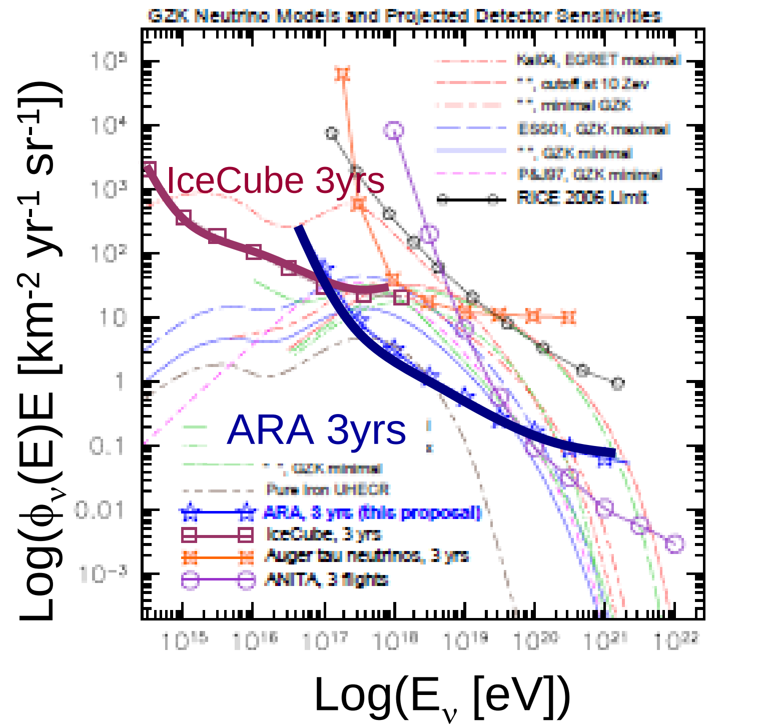


3 D observation for good event reconstruction and background rejection of interactions km deep in the ice sheet.

Askaryan Radio Array
IceCube Extension

Construction starts at 2011 - Science 2014-





Explore Particle Physics

ν Flux measurement

$$\mathrm{Rate} = \mathrm{V}\,\Omega\,\mathrm{T} \otimes N_A \sigma \otimes \phi(\mathrm{E}_\nu)\exp(-N_A \sigma\, \mathrm{X})$$

Detector+ Geometry

Interaction

Unknown FLUX

Absorption

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Explore Particle Physics

ν Cross Section measurement !!

$$\mathrm{Rate} = \mathrm{V}\,\Omega\,\mathrm{T} \otimes N_A \sigma \otimes \phi(\mathrm{E}_\nu)\exp(-N_A \sigma\,\mathrm{X})$$

Detector+ Geometry

Interaction

GZK ν FLUX

Absorption

Kusenko, Weiler PRL. 2002

Downgoing events / Upgoing events

Tyler, Olinto, Sigl PRD. 2001

$$\sigma_{CC}(\mathrm{E} \geq 10^9\ \mathrm{GeV}) \leq\sim 10^{-29}\ \mathrm{cm}^2$$

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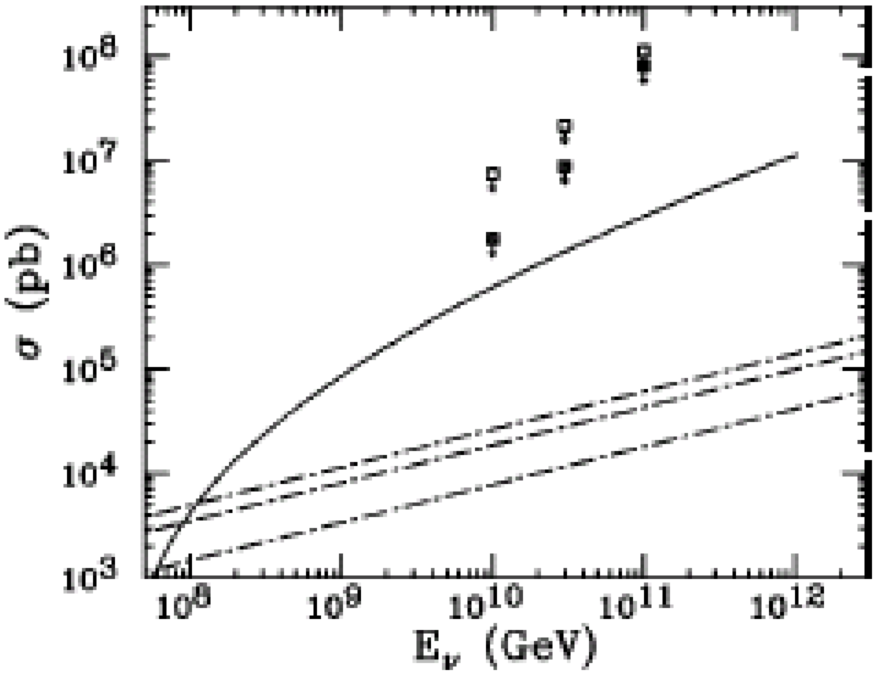
Explore Extra Dimensio

Tyler, Olinto, Sigl PRD. 2001

$$\sigma \approx 10^{-28}\left(\frac{M_{4+n}}{1\,\mathrm{TeV}}\right)^{-4}\left(\frac{E_\nu}{10^{10}\,\mathrm{GeV}}\right)\mathrm{cm}^2$$

Anchordoqui, Feng et al PRD. 2002

Based on AGASA/Fly's Eye limits

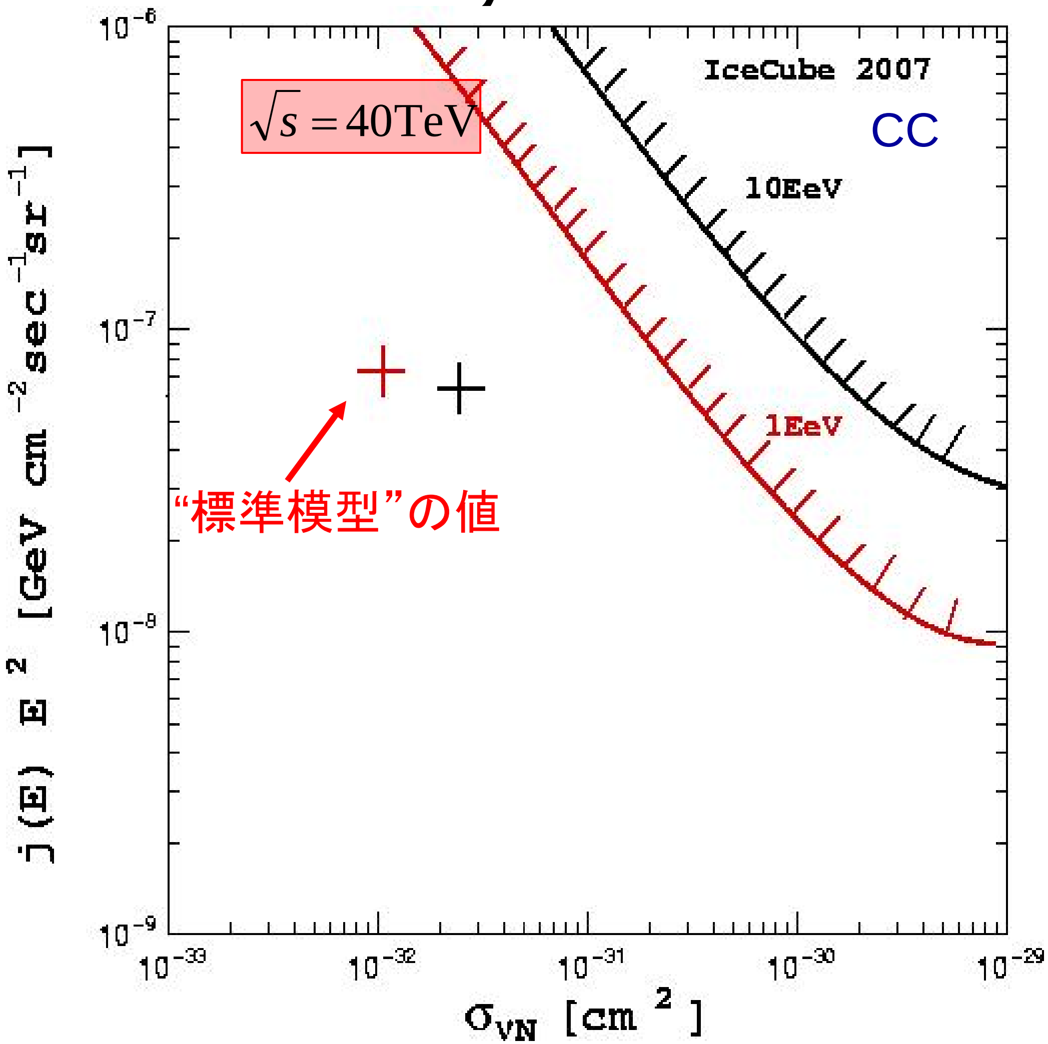


Model Independent limits

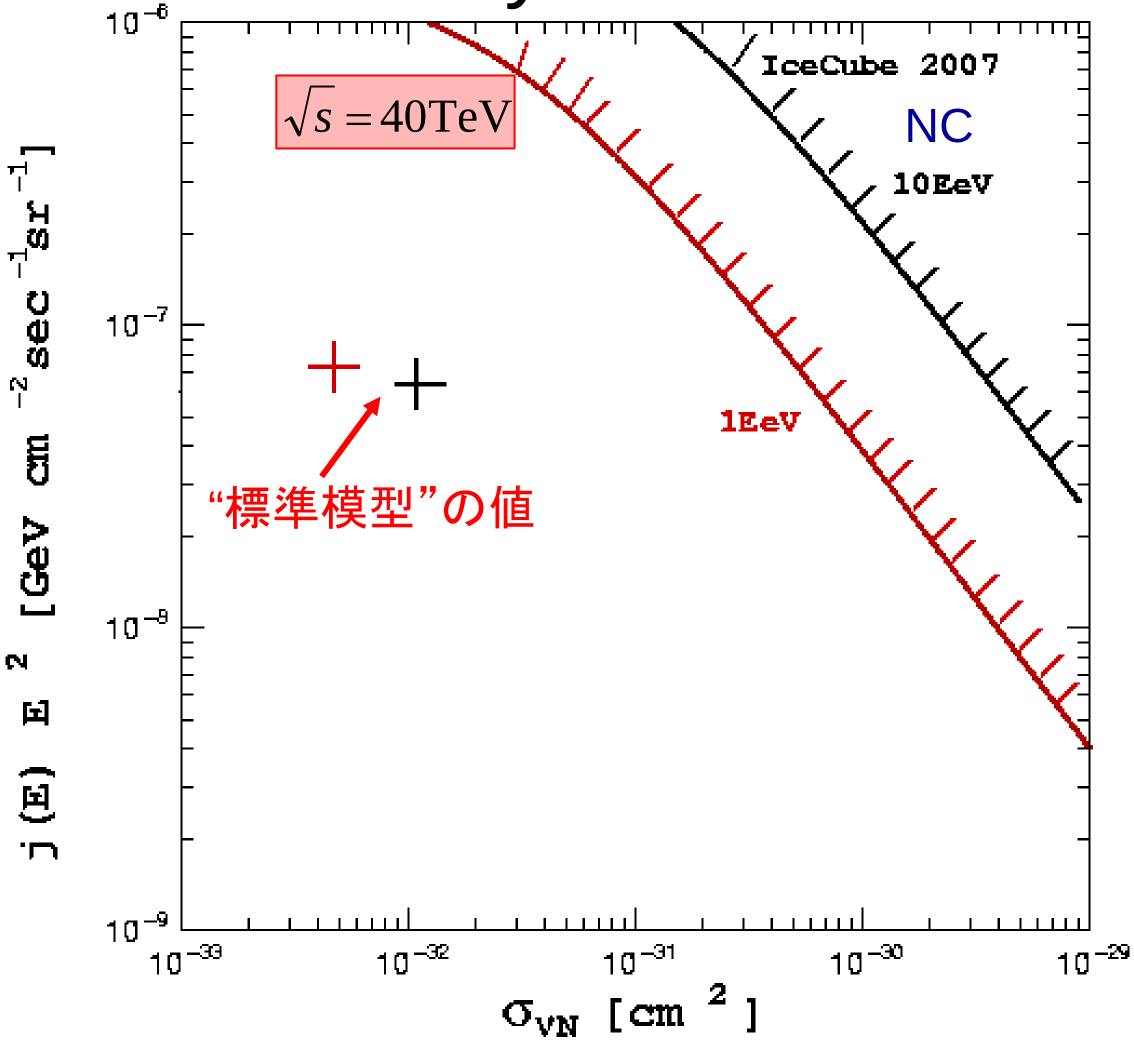
BH production limit

SM CC/NC σ

νN cross section bound with 241 days observation in 2007



νN cross section bound with 241 days observation in 2007



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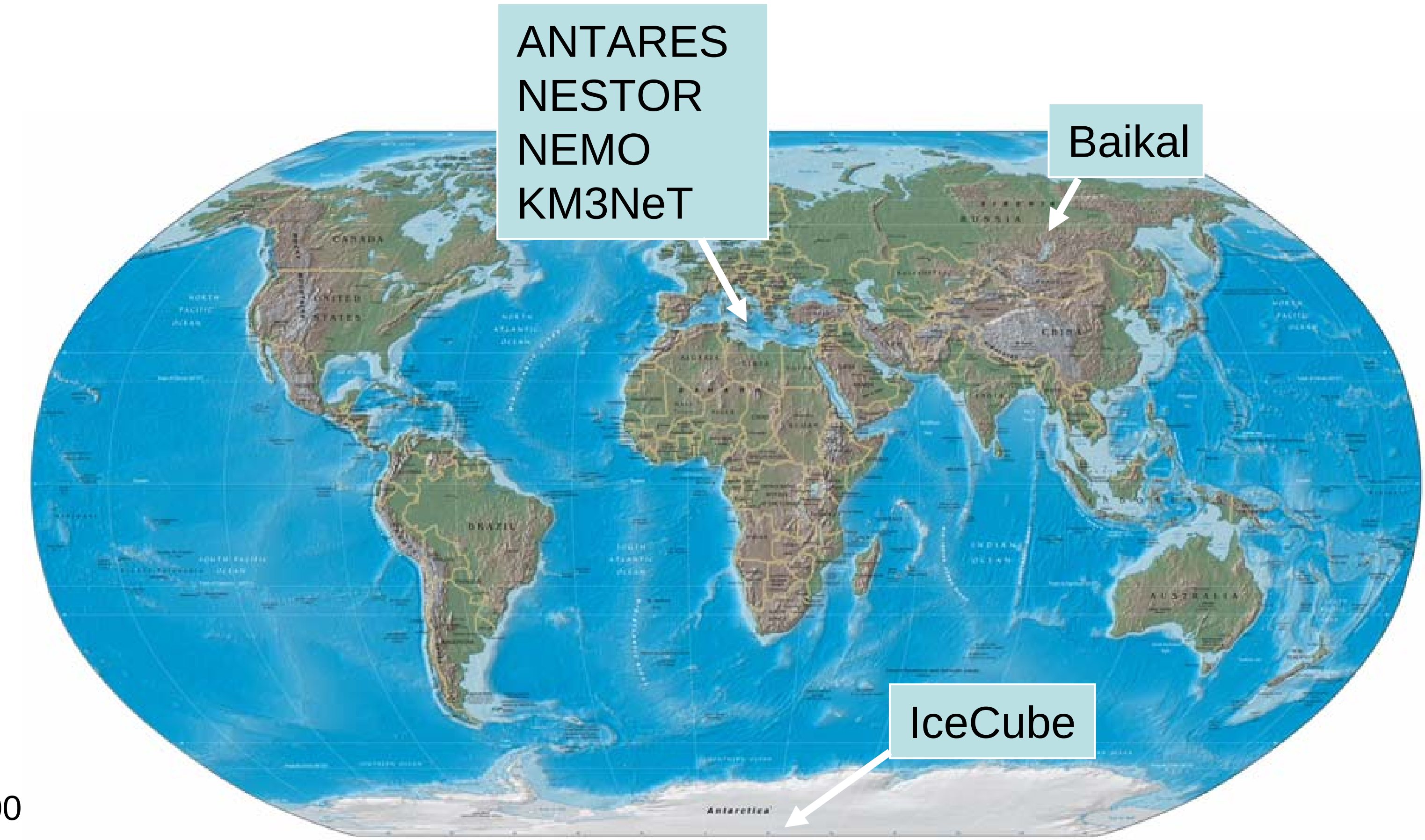
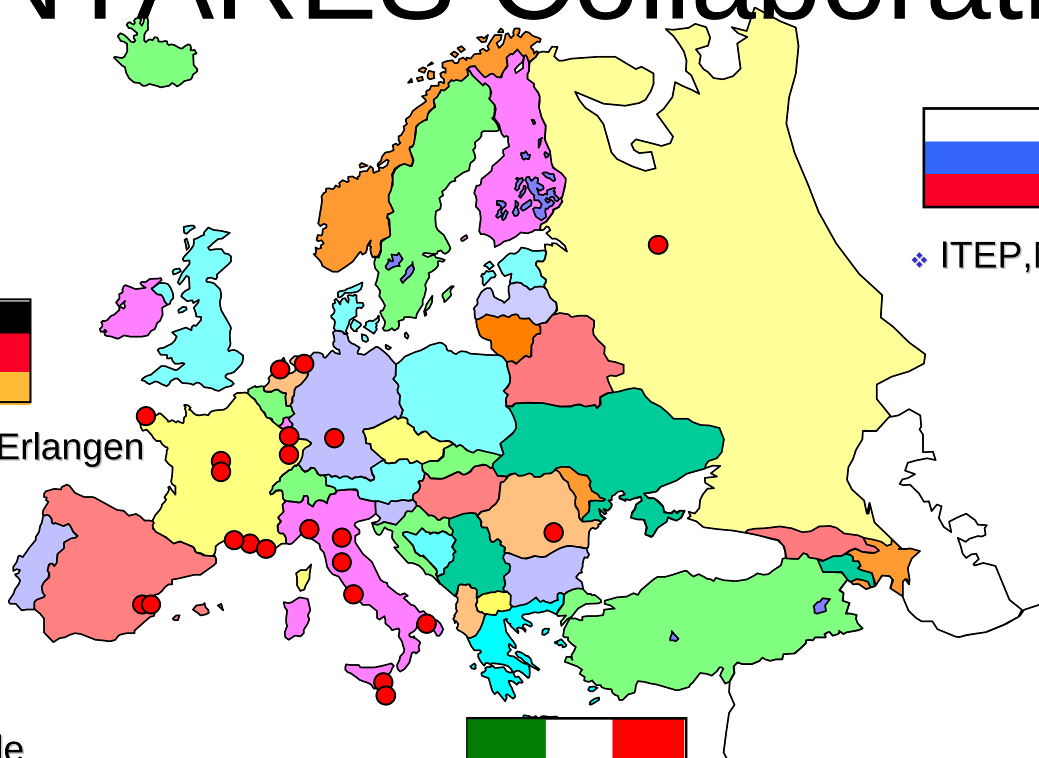
Neutrino Telescopes

- Several projects are working/planned, both in ice and ocean and lakes.



The ANTARES Collaboration



- NIKHEF, Amsterdam
- KVI Groningen
- NIOZ Texel

- University of Erlangen

- IFIC, Valencia
- UPV, Valencia

- CPPM, Marseille
- DSM/IRFU/CEA, Saclay
- APC Paris
- IPHC (IReS), Strasbourg
- Univ. de H.-A., Mulhouse
- IFREMER, Toulon/Brest
- C.O.M. Marseille
- LAM, Marseille
- GeoAzur Villefranche

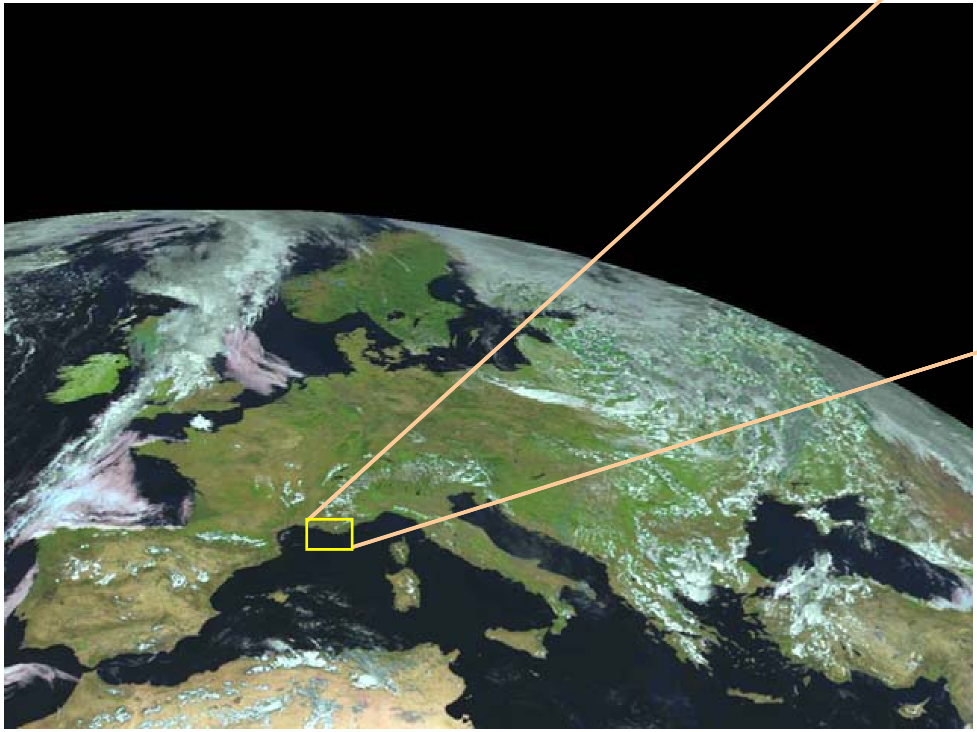
- ITEP,Moscow

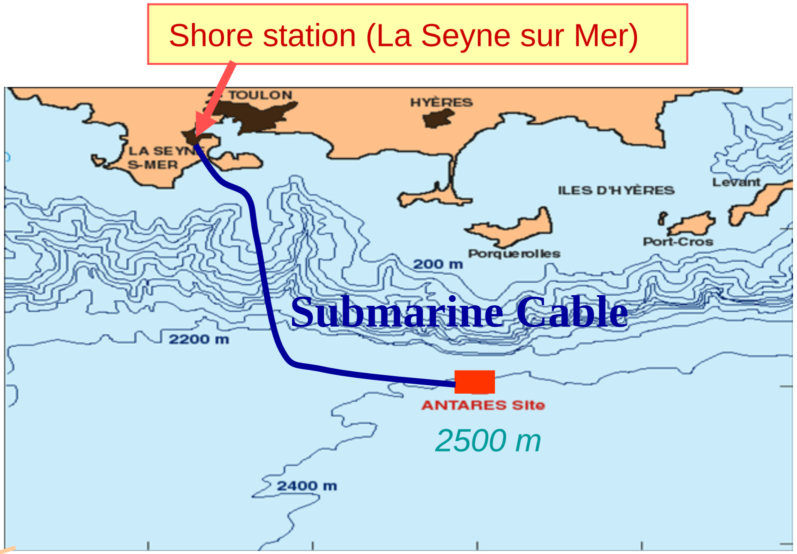
- ISS, Bucarest

- University/INFN of Bari
- University/INFN of Bologna
- University/INFN of Catania
- LNS – Catania
- University/INFN of Pisa
- University/INFN of Rome
- University/INFN of Genova

Location

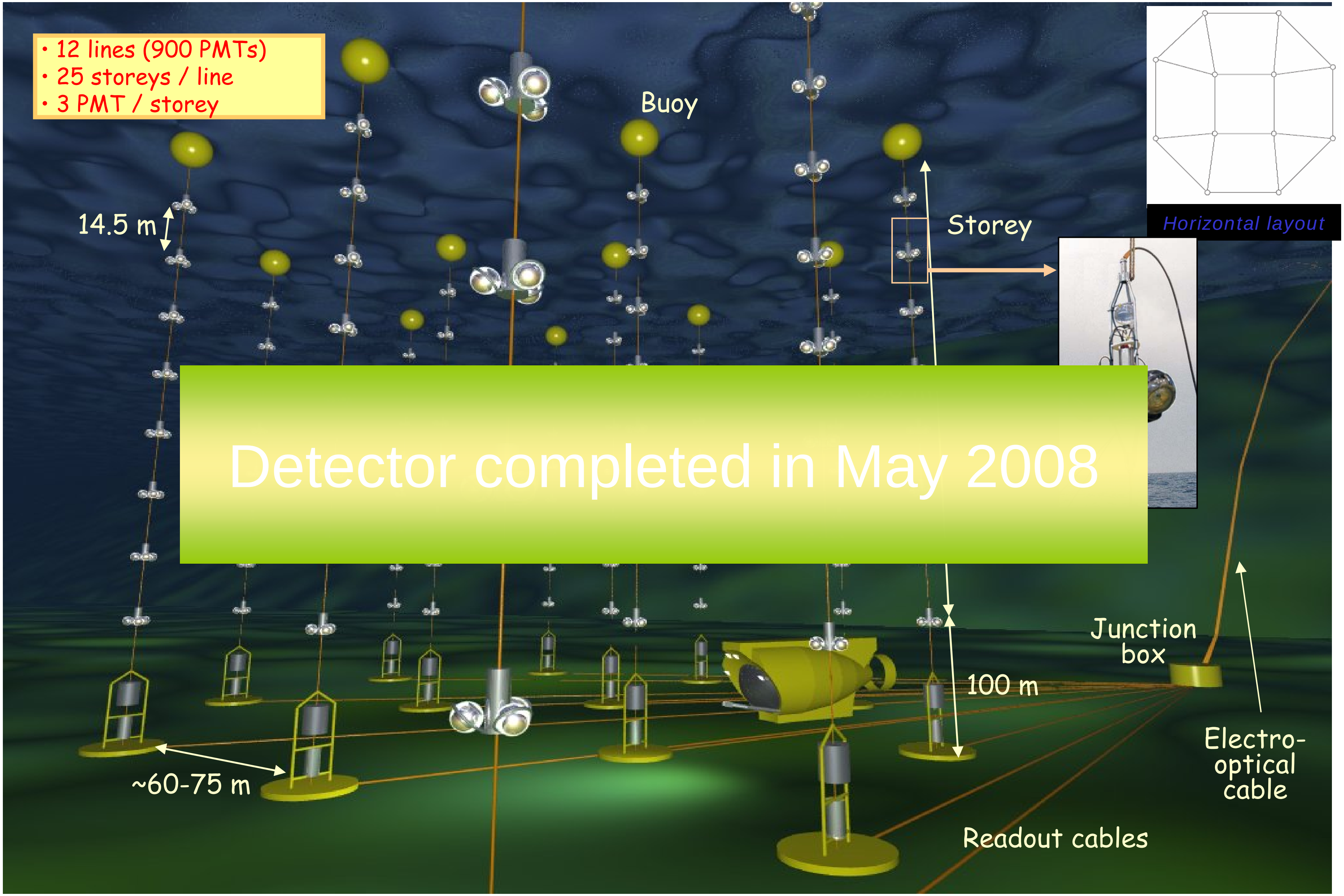
- *The detector will be located in the Mediterranean Sea (42º50’N, 6º10’E) at 2500 m depth, off the coast of Toulon (France).*
- *This location benefits from IFREMER infrastructures.*





- The ANTARES detector will observe 3.5π sr (0.6π sr overlap with AMANDA/IceCube).
- The Galactic Centre is observable 67% of the day.

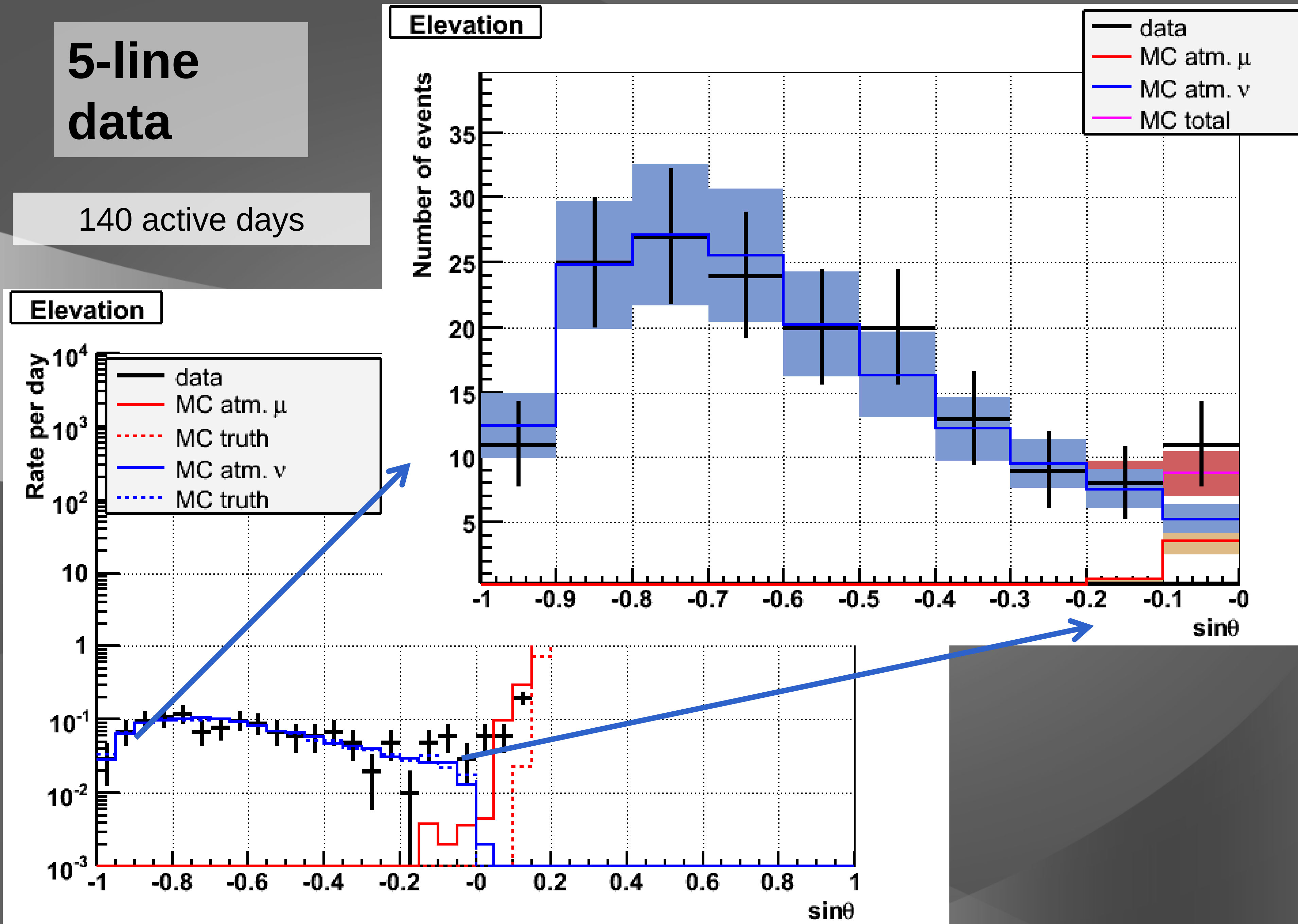
The ANTARES detector



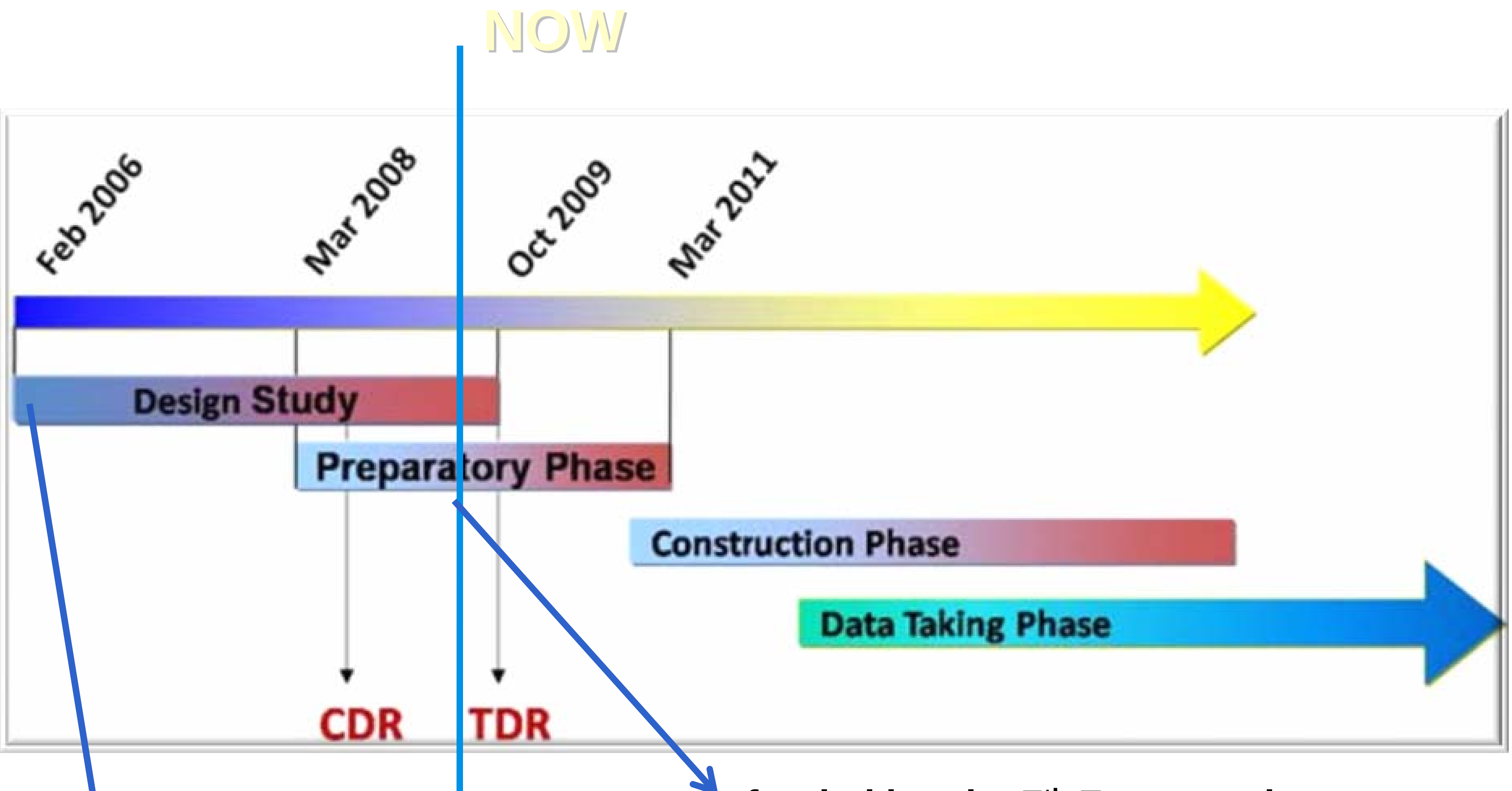
Detector completed in May 2008

5-line data

140 active days



KM3NeT project timeline



funded by the 6th Framework Programme

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