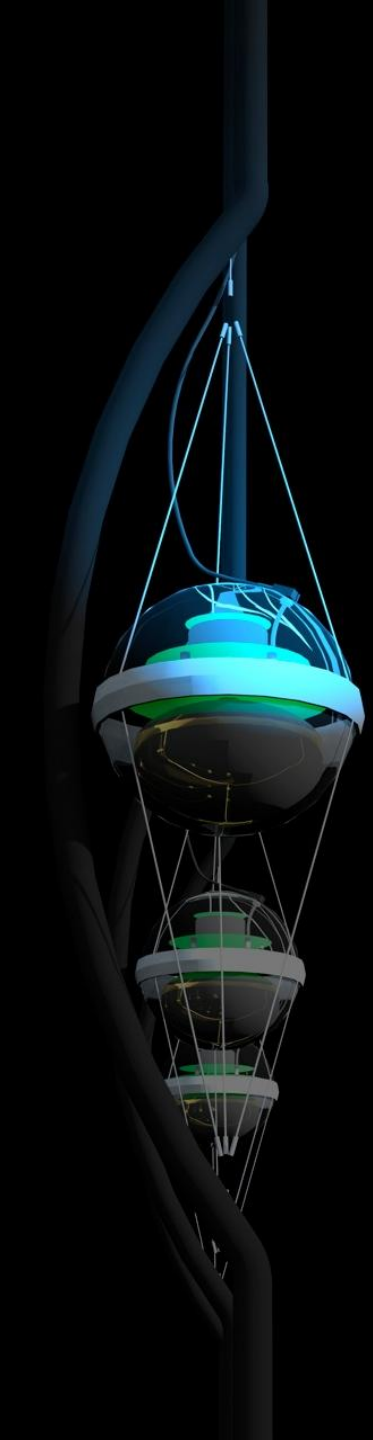
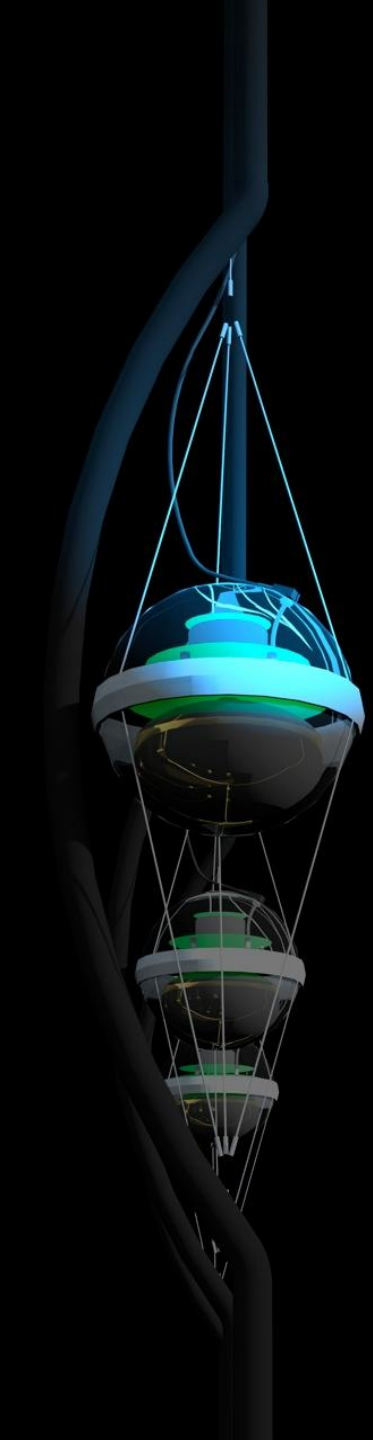


darkattack2012

- IceCube
- atmospheric and cosmic neutrinos
- the search for dark matter

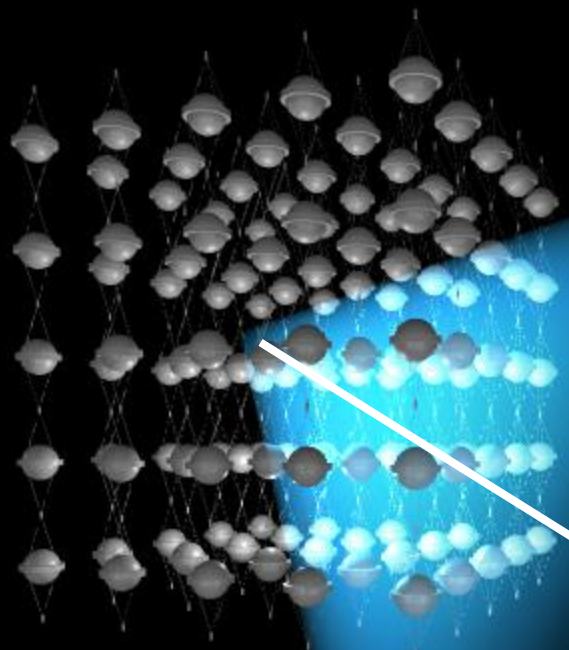
IceCube.wisc.edu



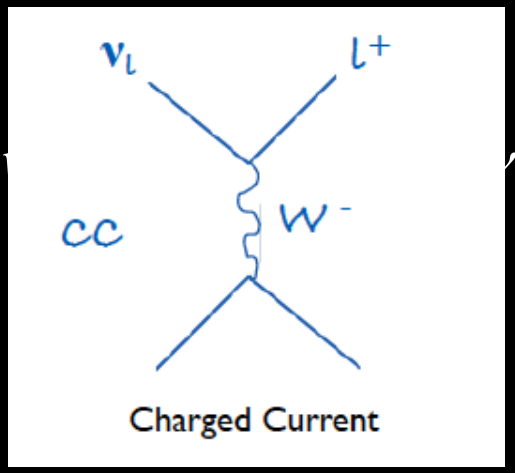
- all results with detector under construction
- soon:
  - → results from completed detector with improved software and calibration
  - → WIMP masses as low as 10 GeV
- far from the square root regime
- thanks: C. Rott and M. Danninger

IceCube.wisc.edu

- shielded and optically transparent medium



$P_{\mu\to}$



R_{μ}

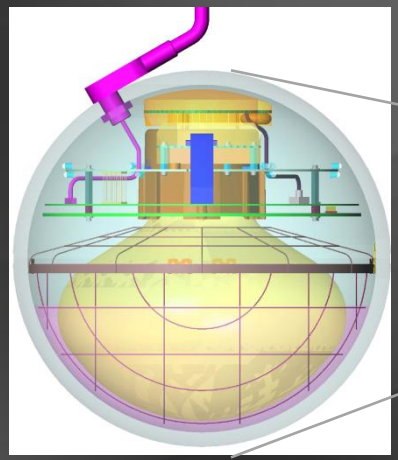
μ

ν

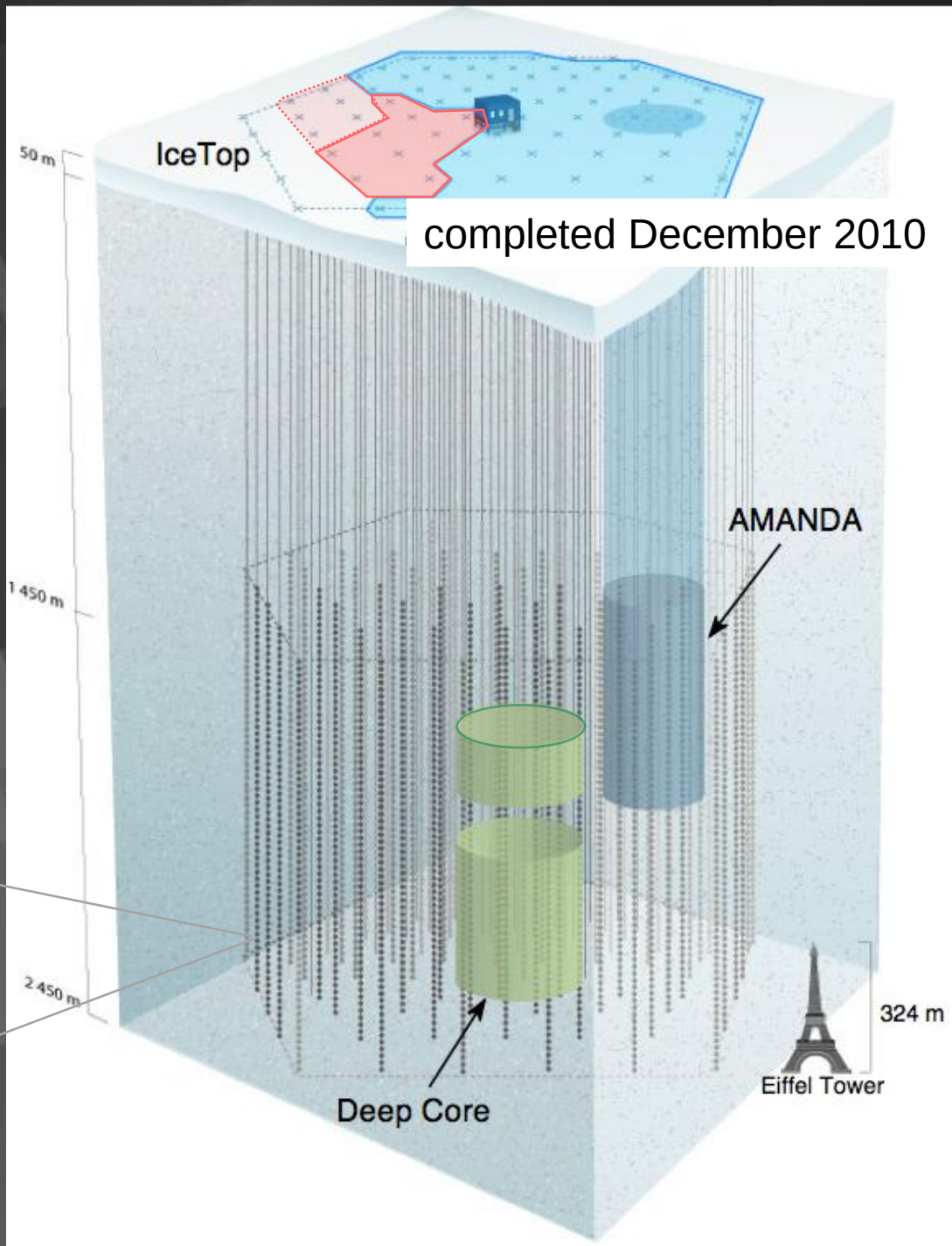
- lattice of photomultipliers

IceCube / Deep Core

- 5160 optical sensors between 1.5 ~ 2.5 km
- 10 GeV to infinity
- < 0.5 degree on-line
  < 0.2 degree off line
- < 30% energy resolution

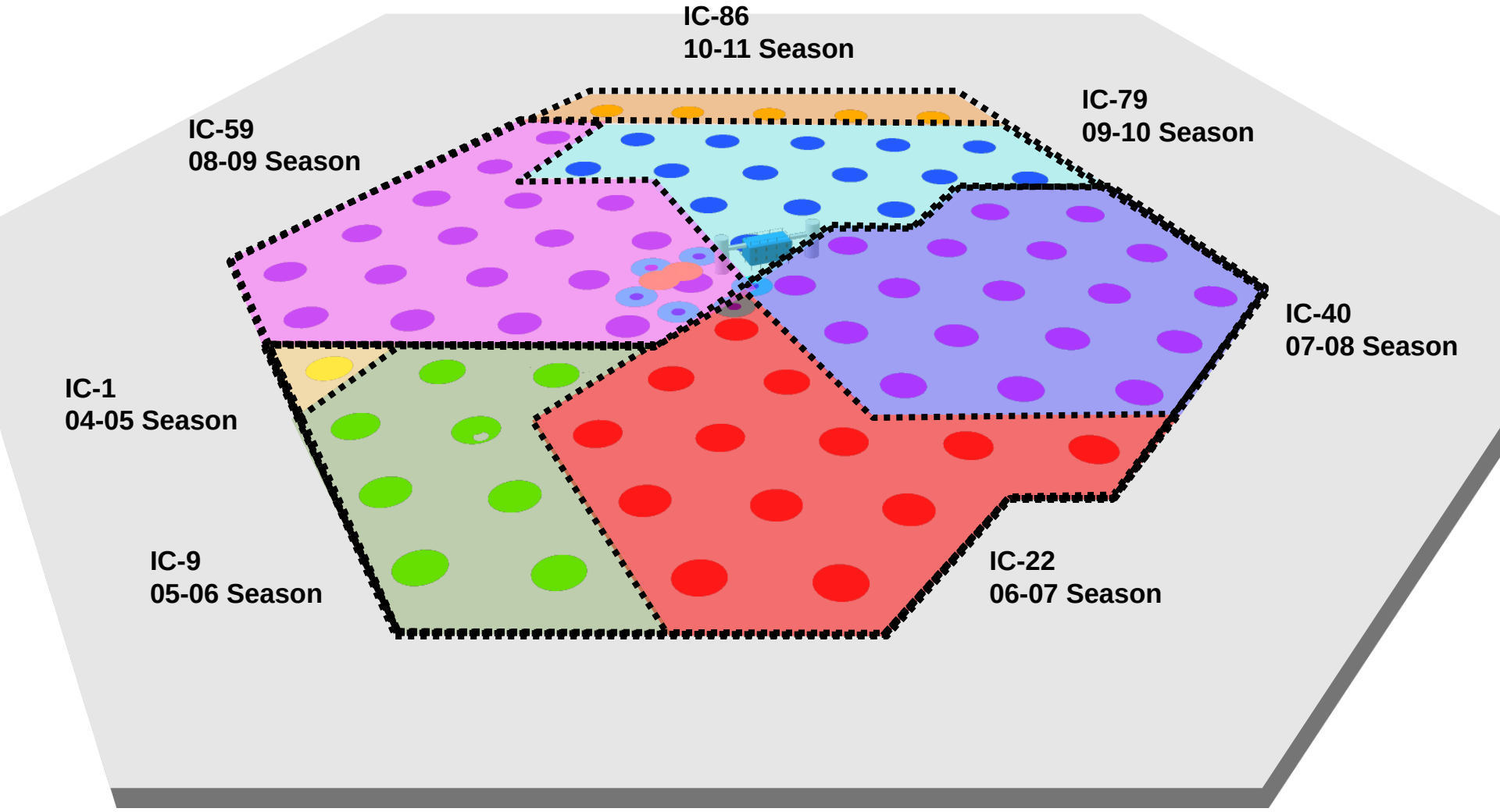


Digital Optical Module (DOM)

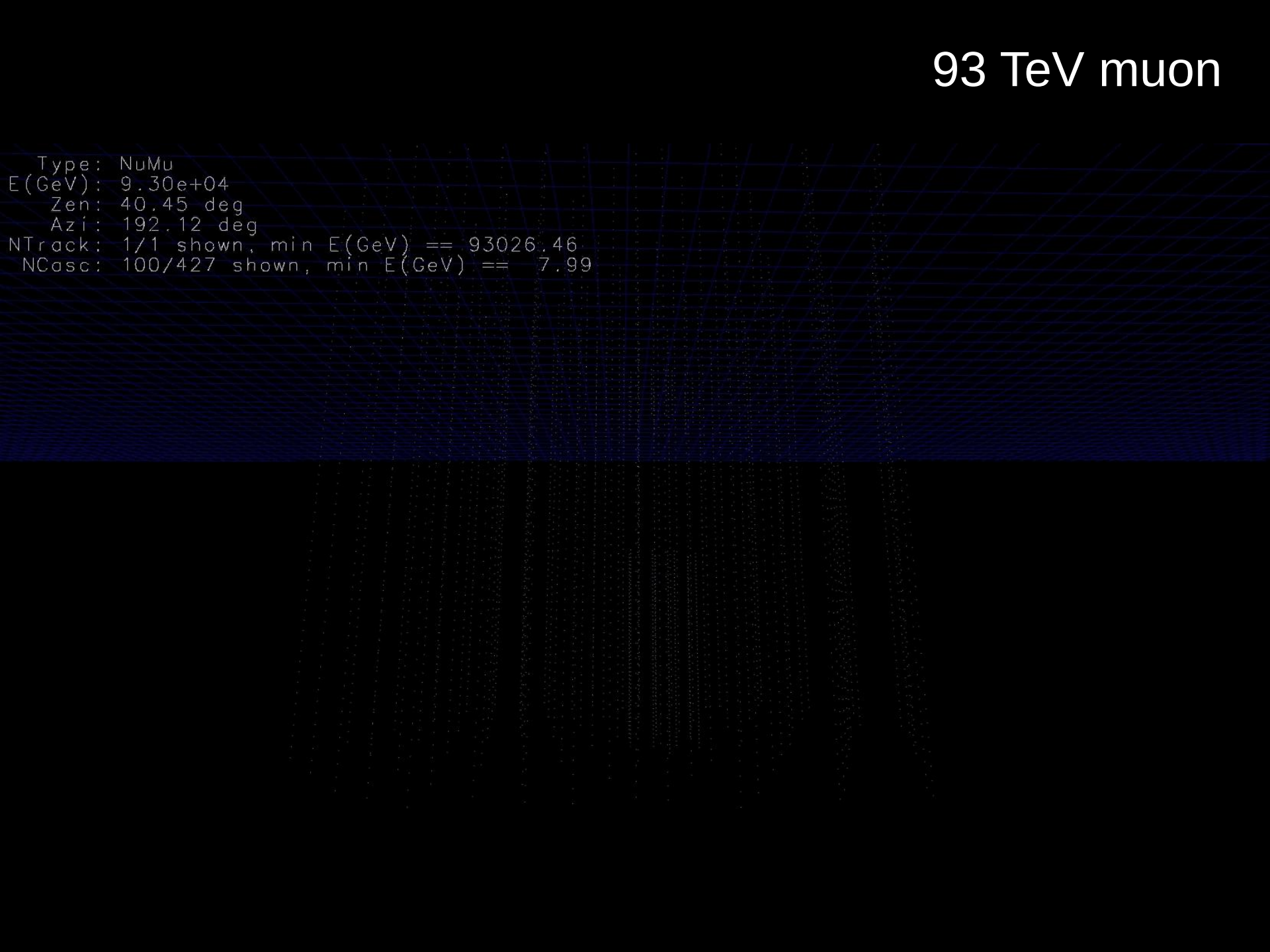


completed December 2010

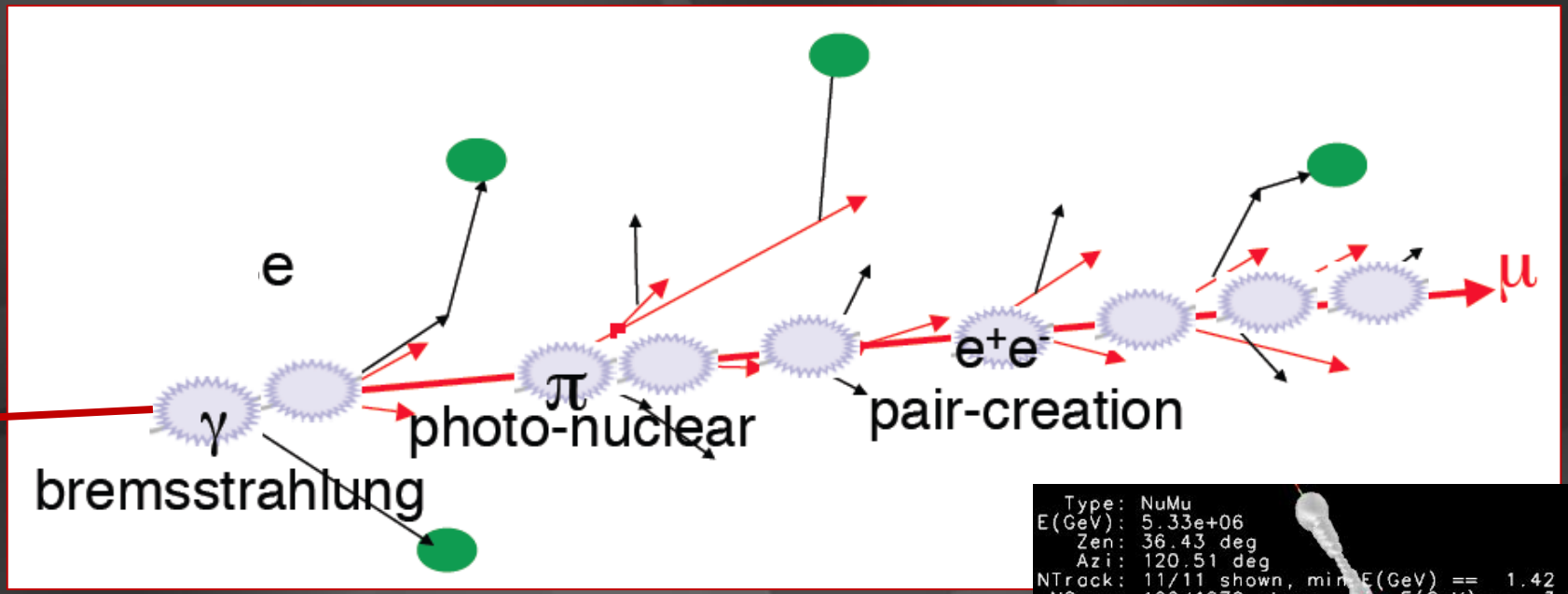
completed December 18, 2010



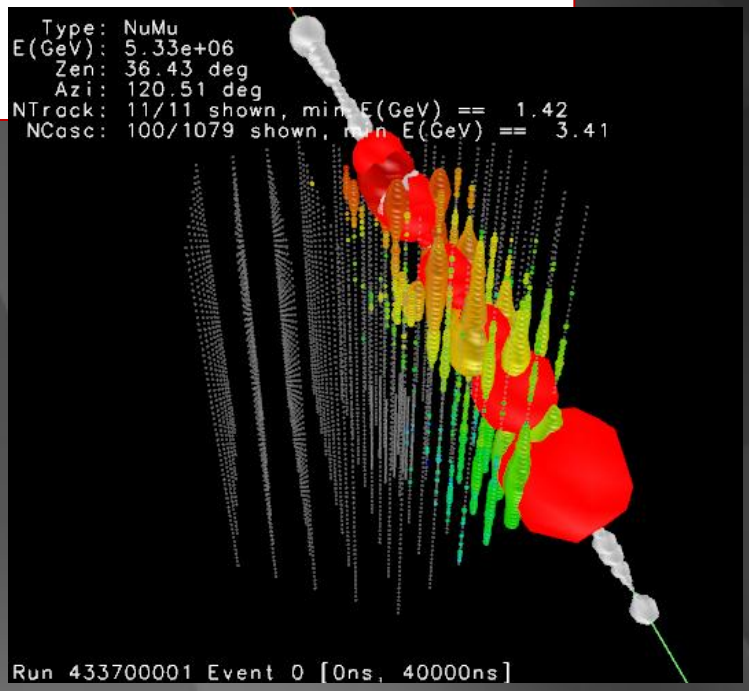
93 TeV muon


Type: NuMu
E(GeV): 9.30e+04
Zen: 40.45 deg
Azi: 192.12 deg
NTrack: 1/1 shown, min E(GeV) == 93026.46
NCasc: 100/427 shown, min E(GeV) == 7.99

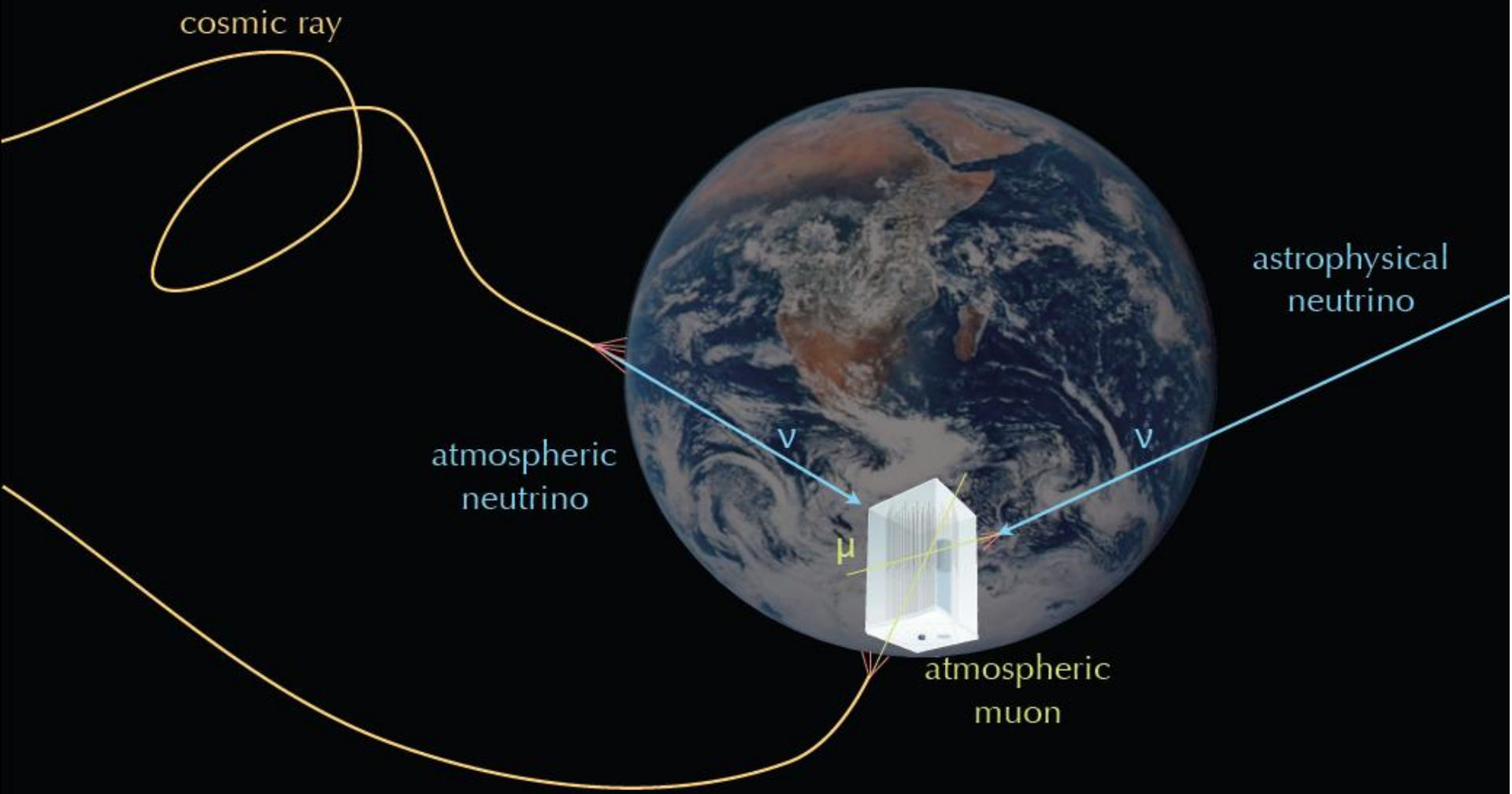
energy measurement (> 1 TeV)

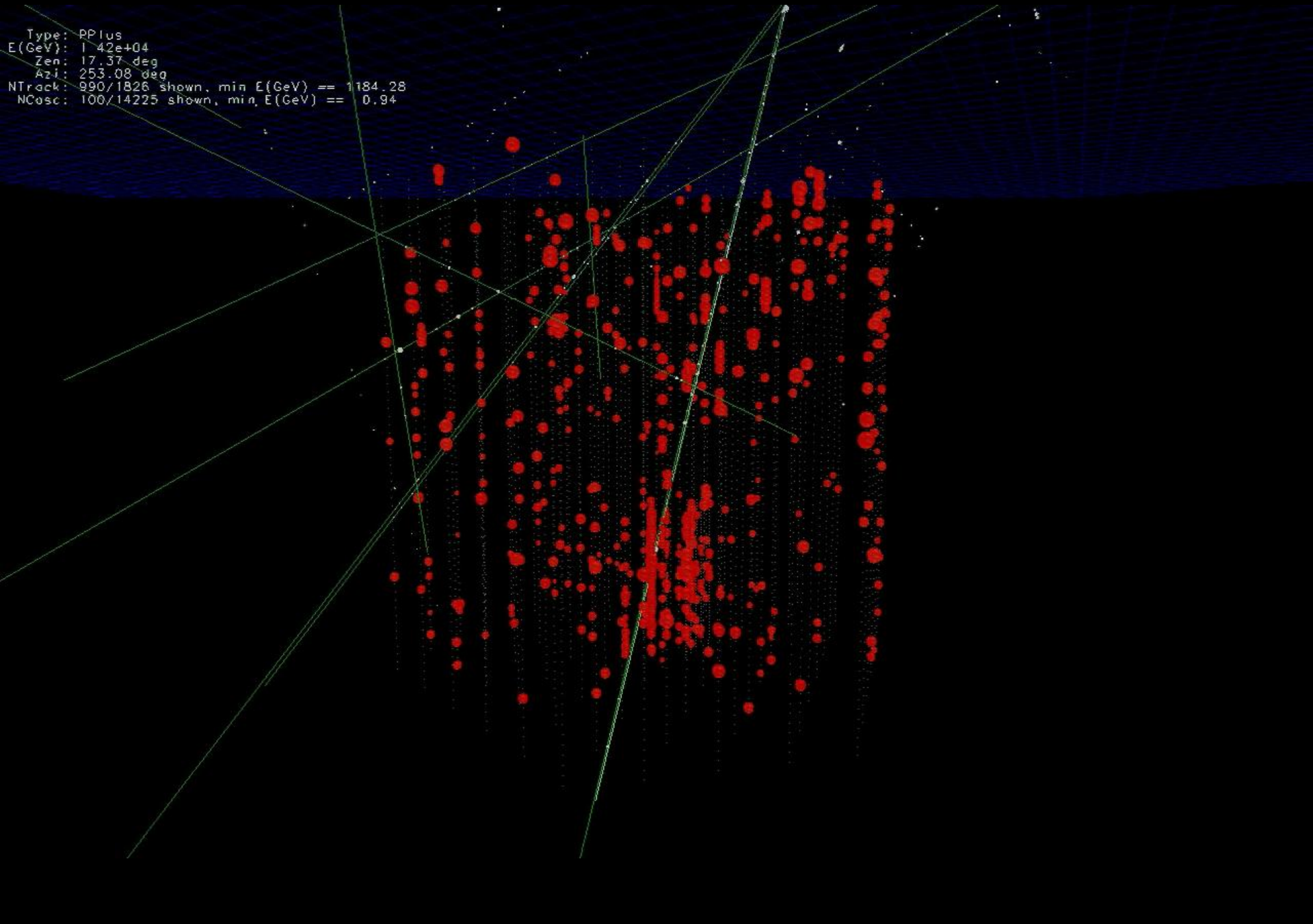


convert the amount of light emitted to measurement of the muon energy (number of optical modules, number of photons, dE/dx, …)



Signals and Backgrounds




Type: PPlus
E(GeV): 1.42e+04
Zen: 17.37 deg
Azi: 253.08 deg
NTrack: 990/1826 shown, min E(GeV) == 1184.28
NCasc: 100/14225 shown, min E(GeV) == 0.94

… you looked at 10 msec of data !

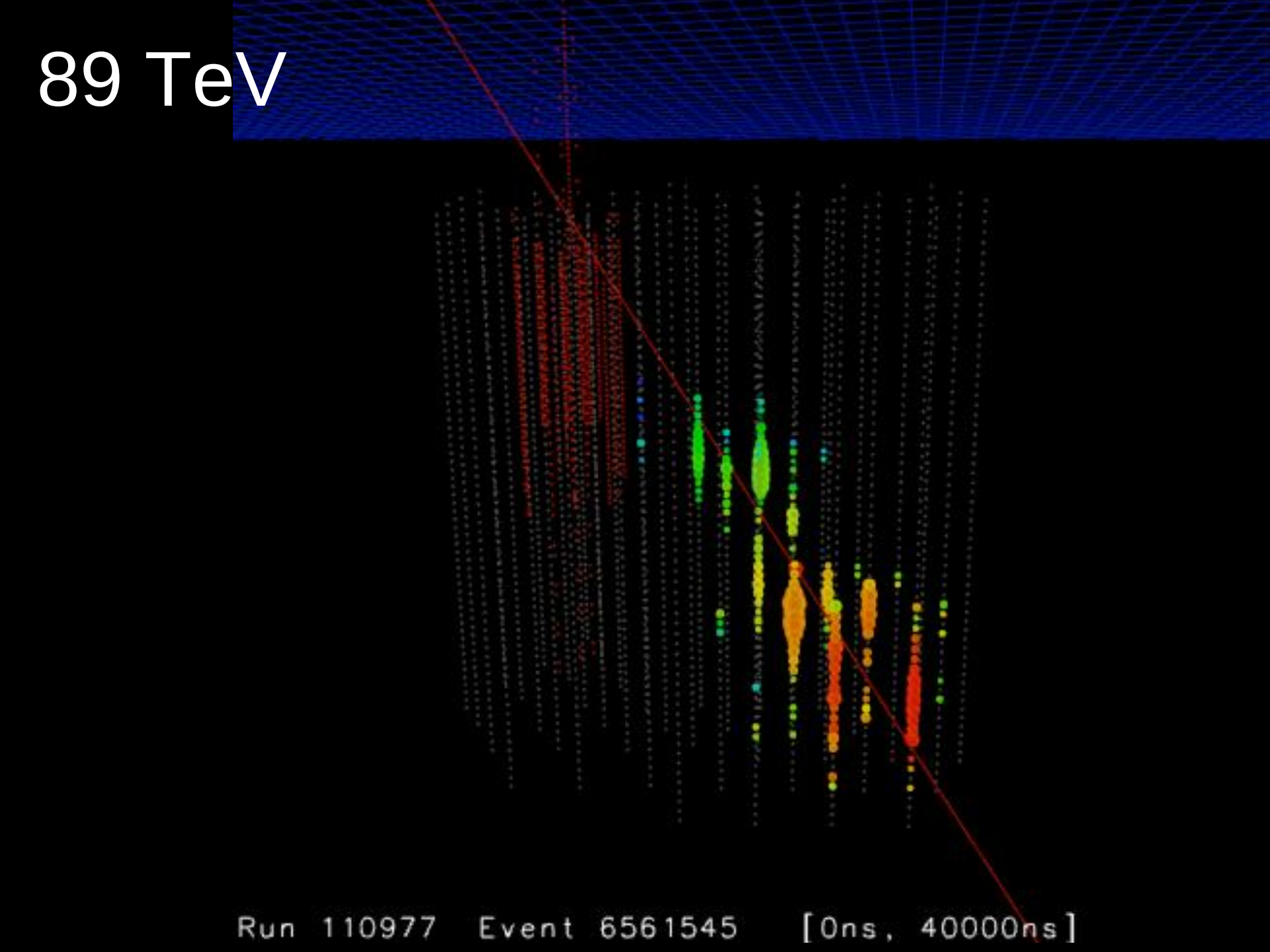
muons detected per year:

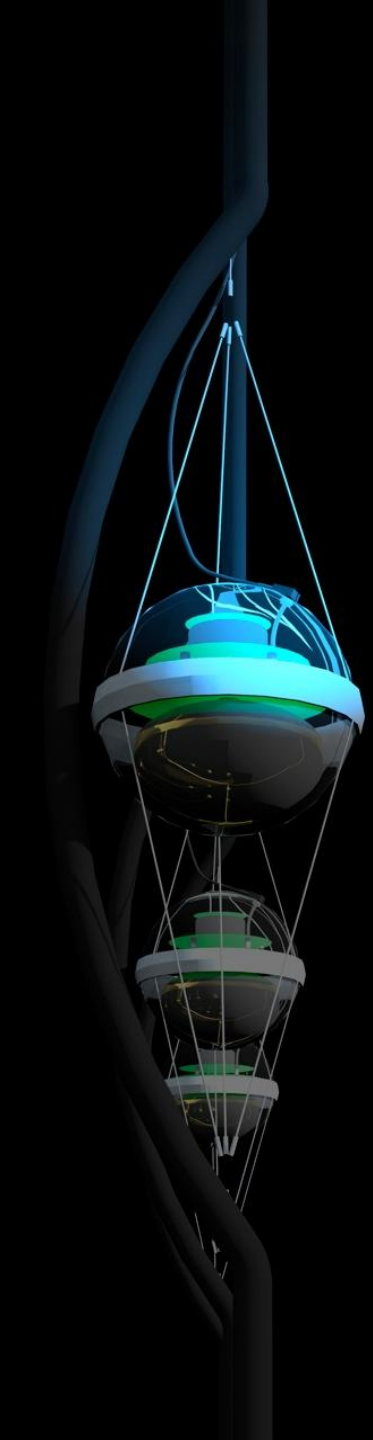
- atmospheric* μ $\sim 10^{11}$
- atmospheric** $\nu \rightarrow \mu$ $\sim 10^{5}$
- cosmic $\nu \rightarrow \mu$ ~ 10

* 3000 per second

** 1 every 6 minutes

89 TeV



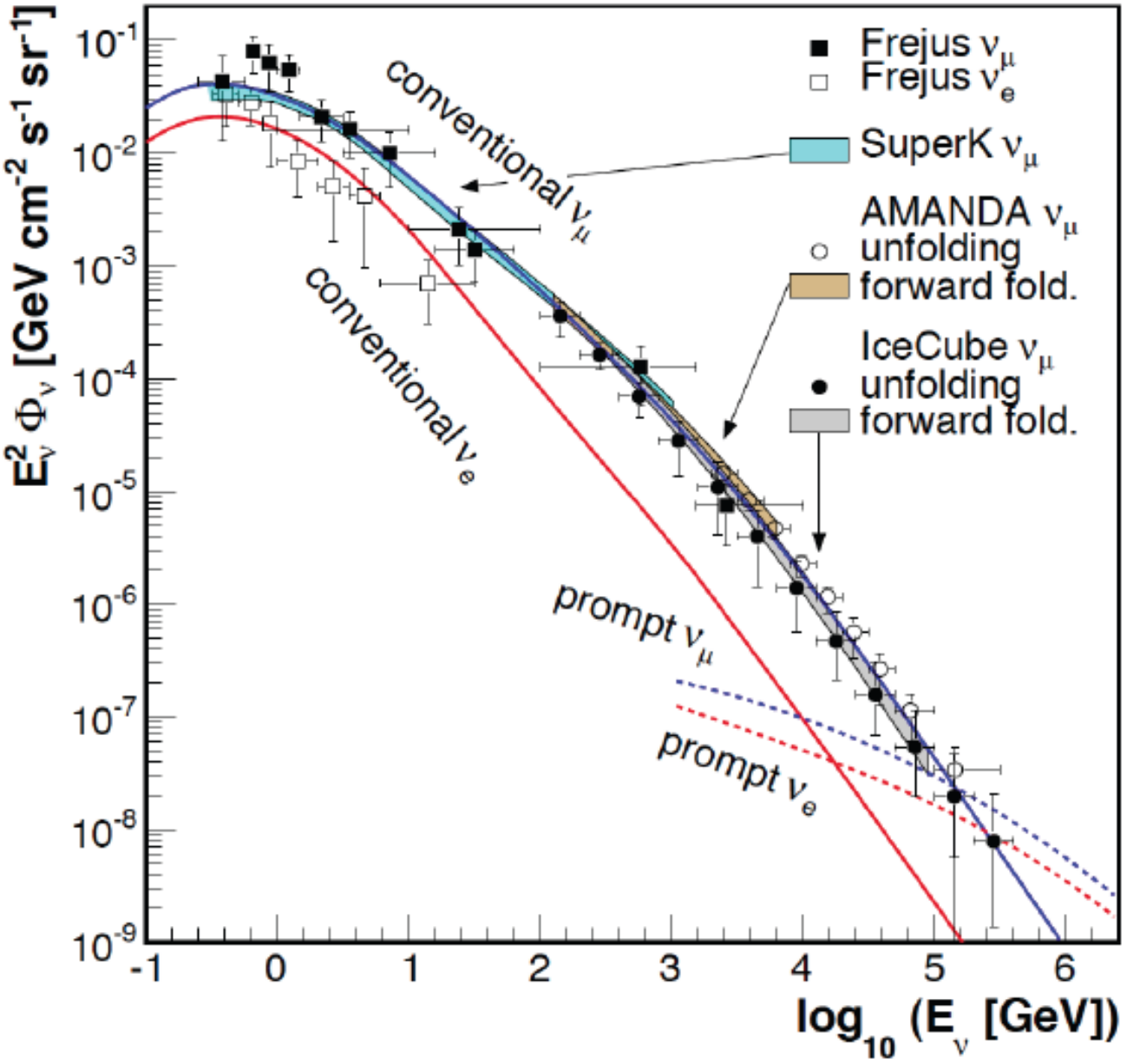


- IceCube
- atmospheric and cosmic neutrinos
- the search for dark matter

IceCube.wisc.edu

cosmic neutrinos:

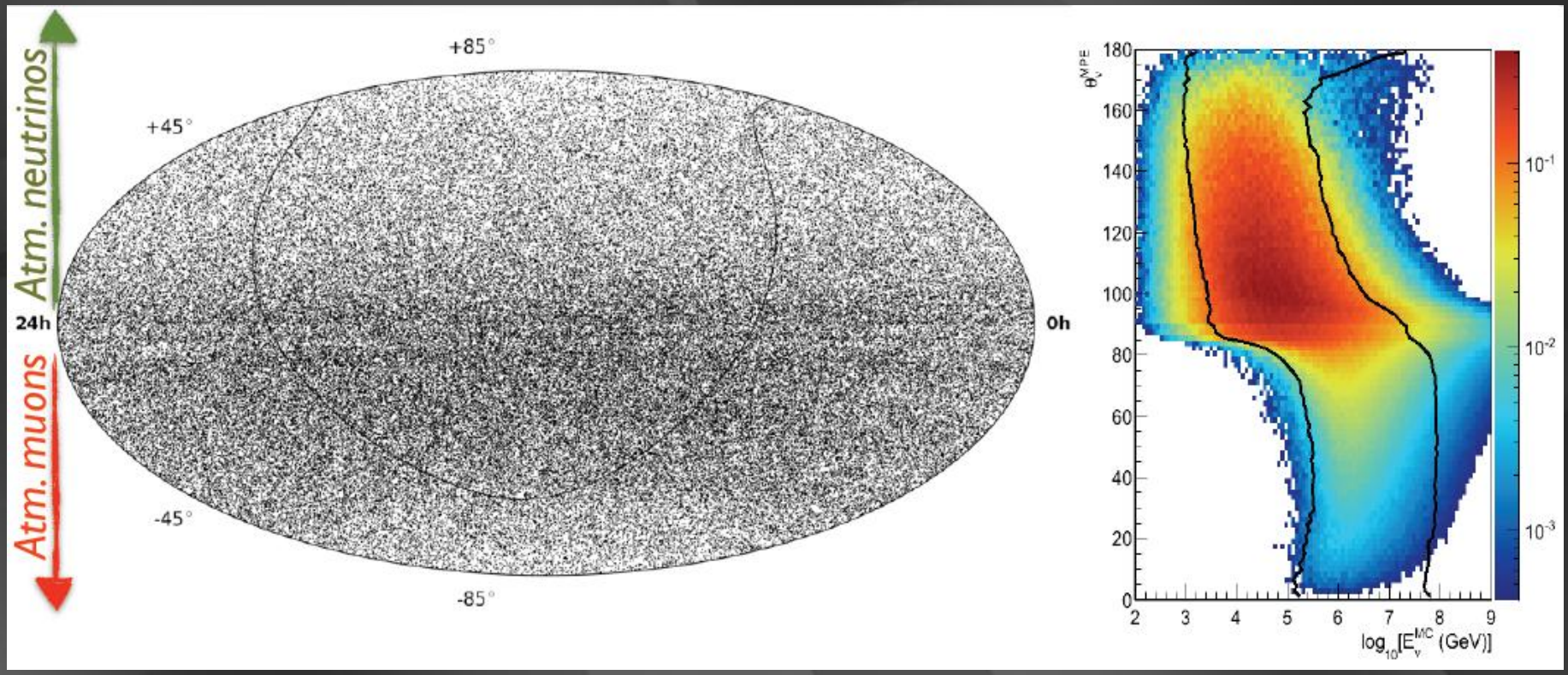
energy:
>> 100 TeV



atmospheric neutrino spectrum to >100 TeV

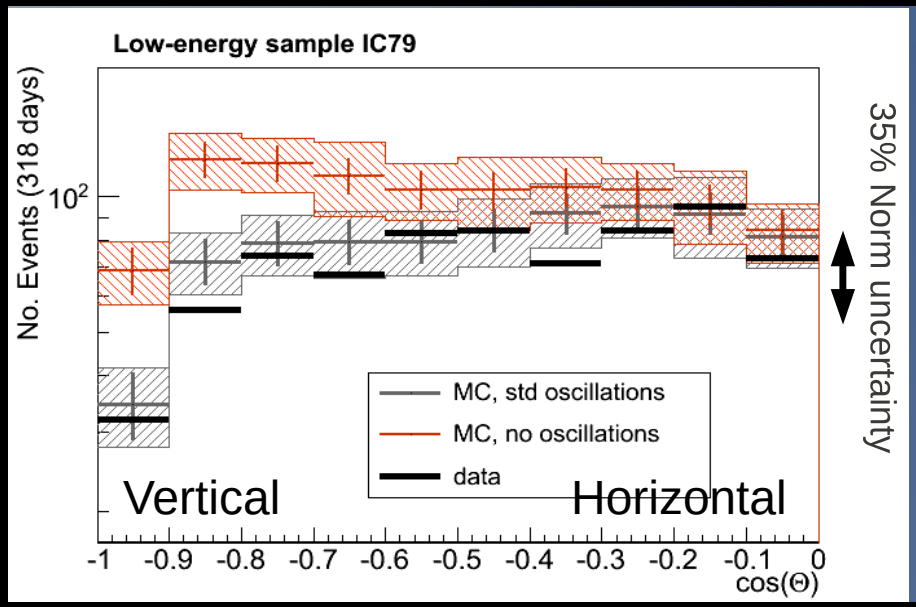
IceCube 40 + 59 strings out of 86

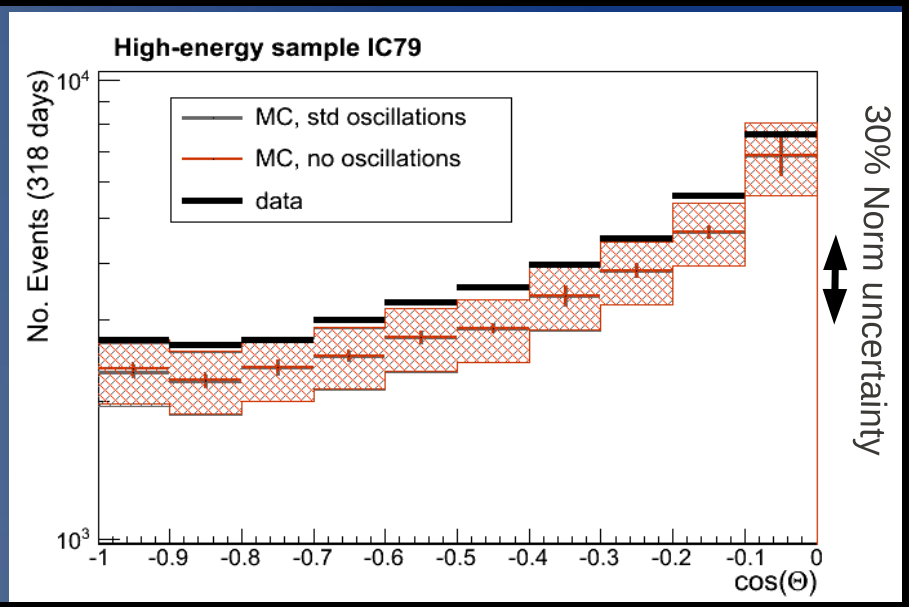
43339 neutrinos

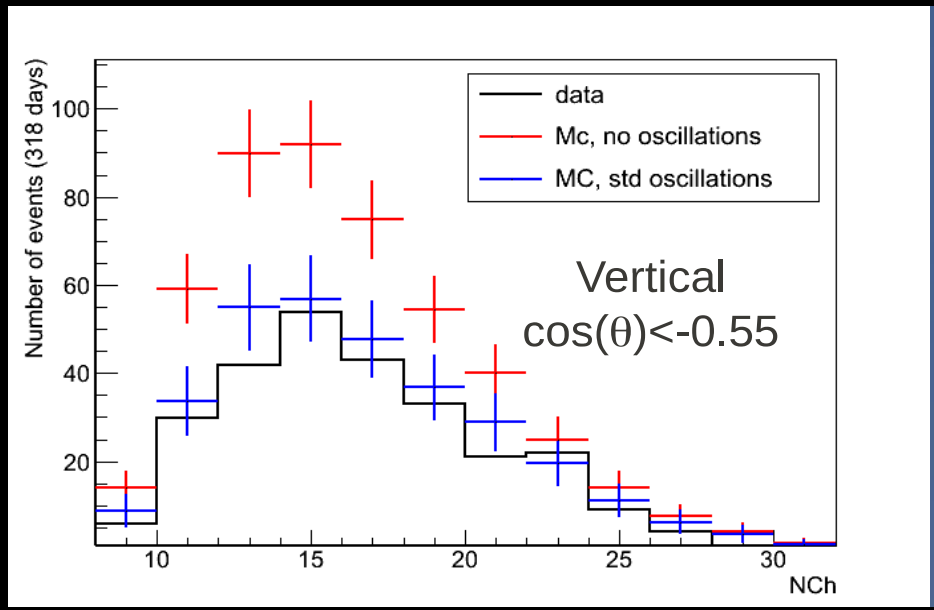


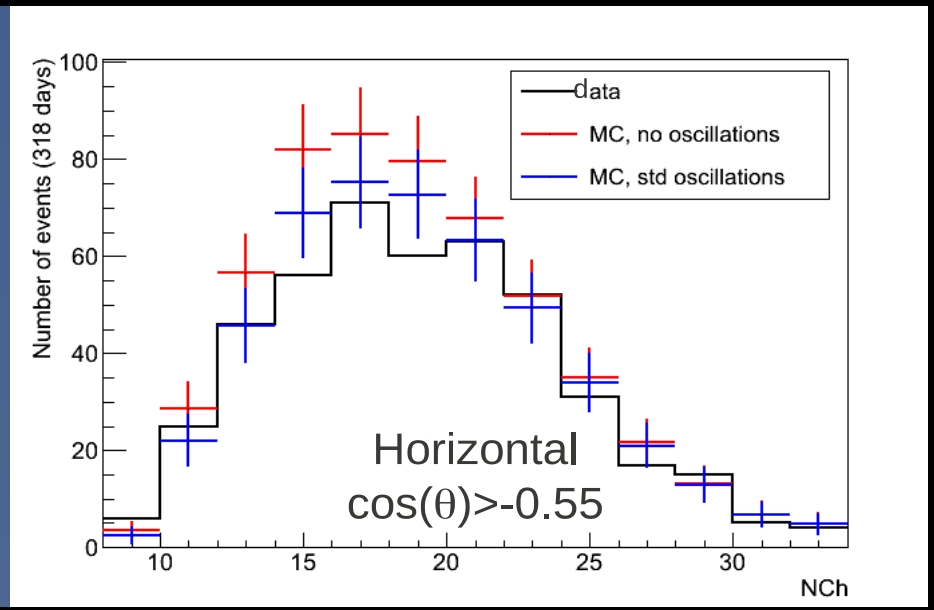
64230 muons

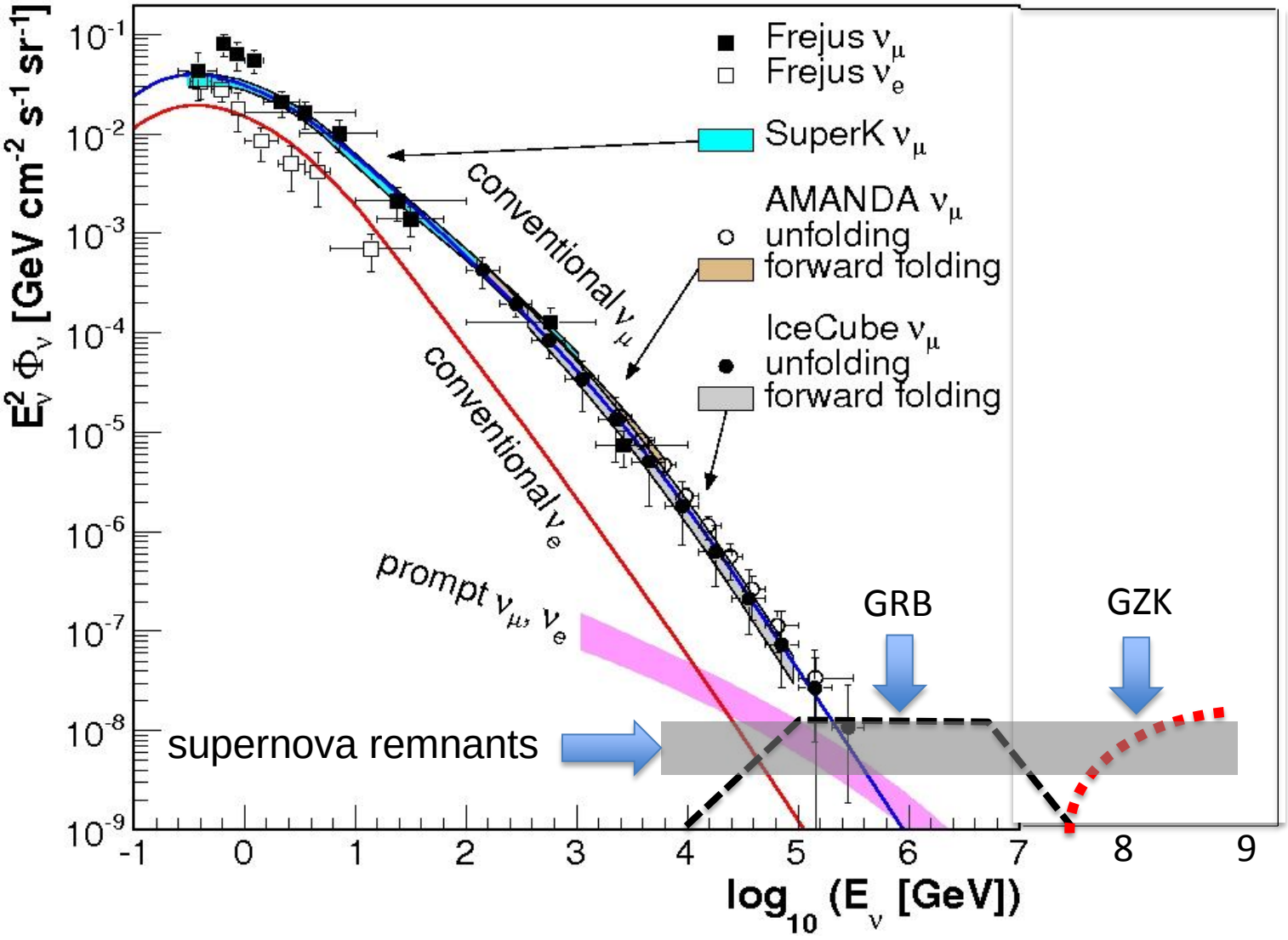
oscillations in DeepCore [5.6 sigma]

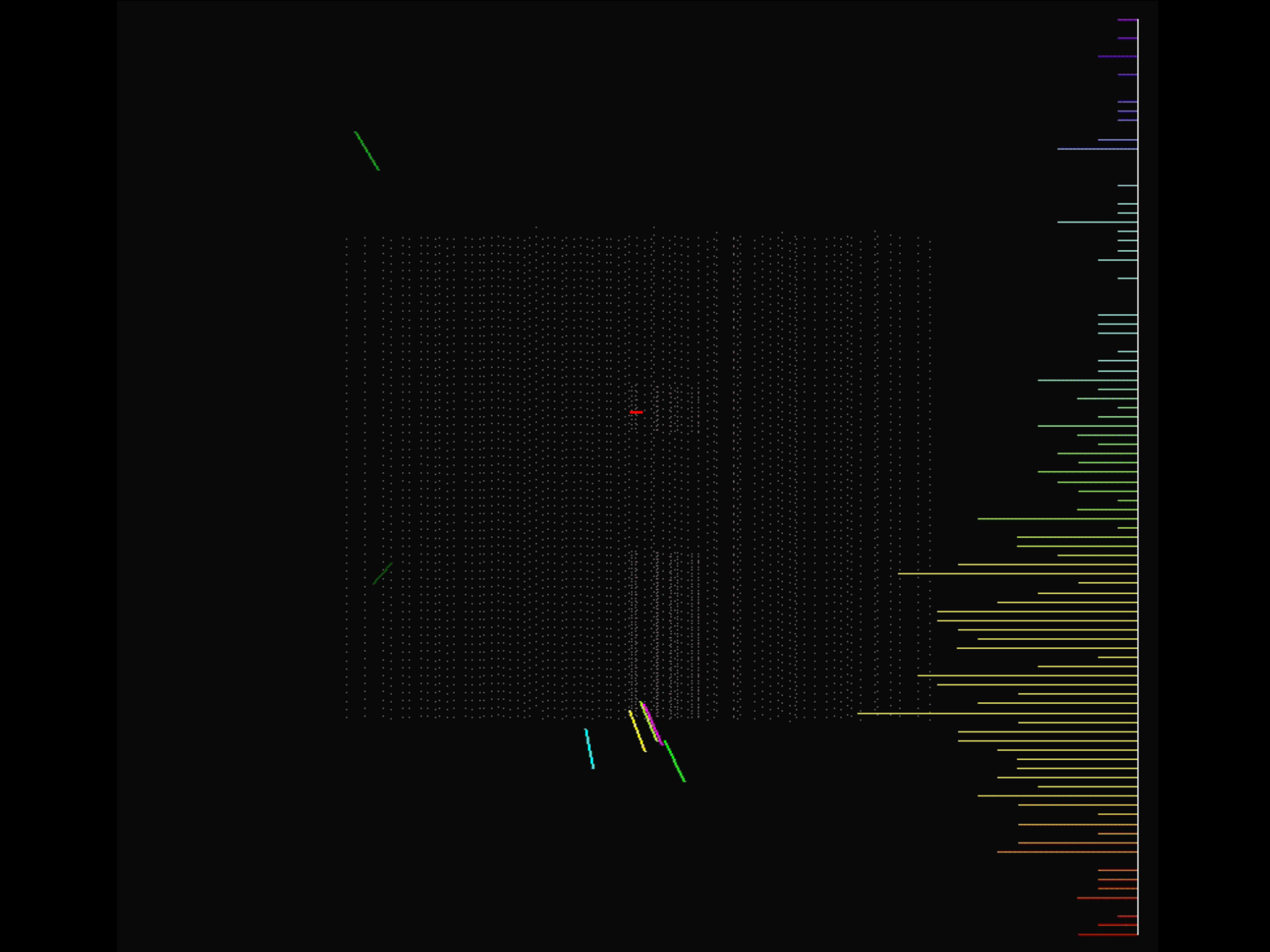


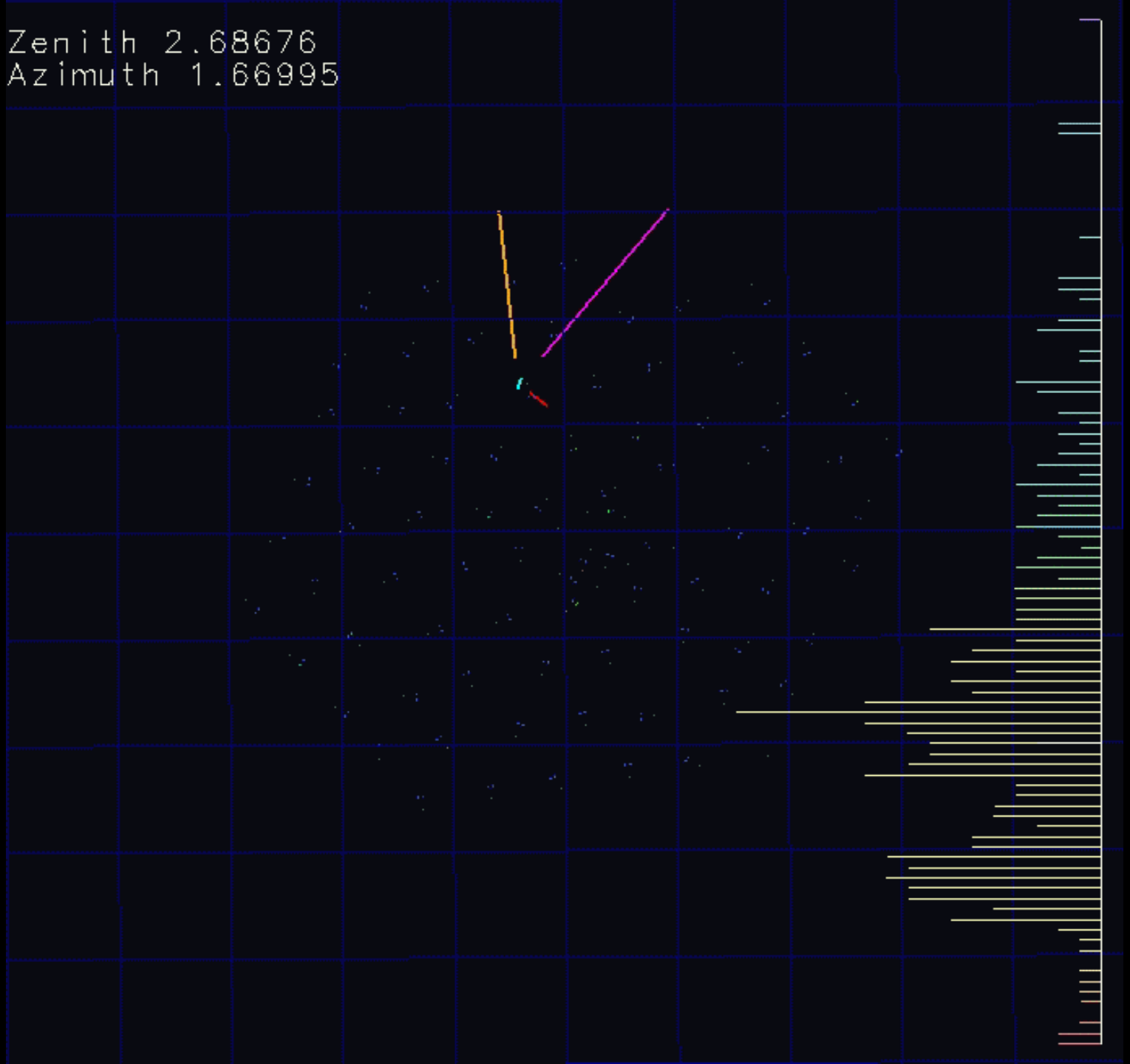




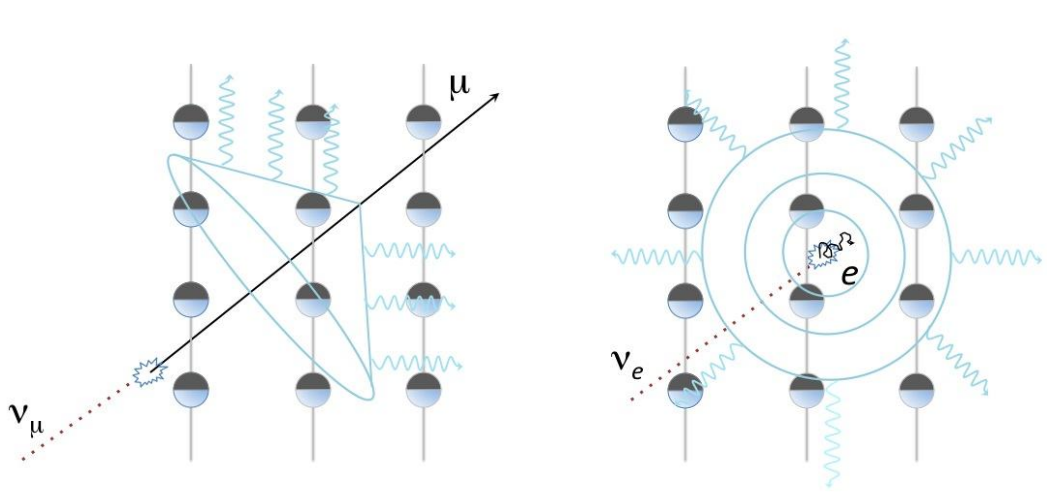


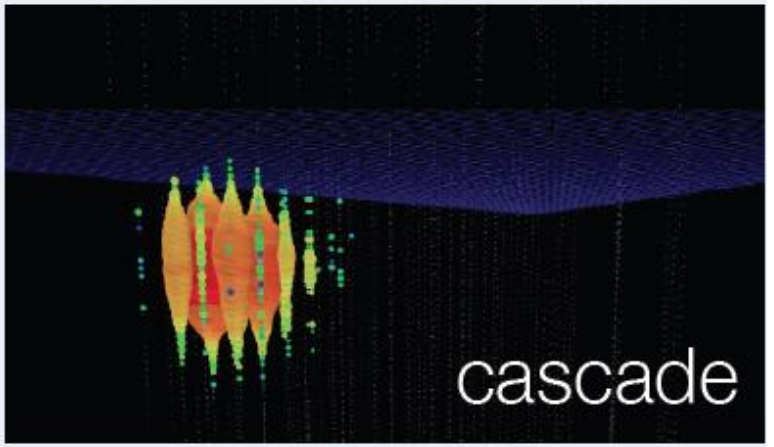

$E_\nu^2 \Phi_\nu$ [GeV cm^{-2} s^{-1} sr^{-1}]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
-1
0
1
2
3
4
5
6
7
8
9
$\log_{10}(E_\nu$ [GeV])
Frejus ν_μ
Frejus ν_e
SuperK ν_μ
AMANDA ν_μ
unfolding
forward folding
IceCube ν_μ
unfolding
forward folding
conventional ν_μ
conventional ν_e
prompt ν_μ, ν_e
GRB
GZK
supernova remnants

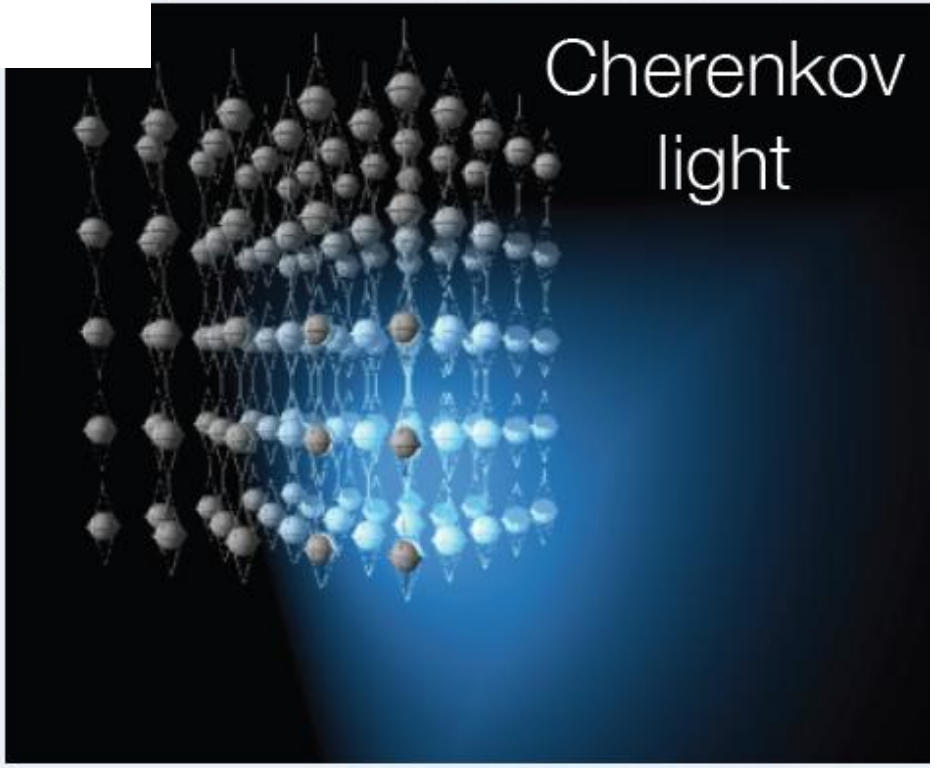


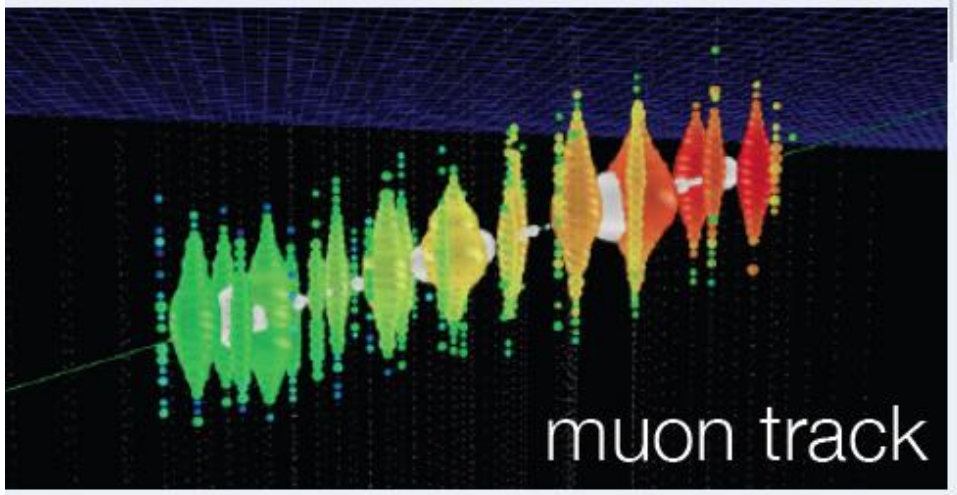

Zenith 2.68676
Azimuth 1.66995

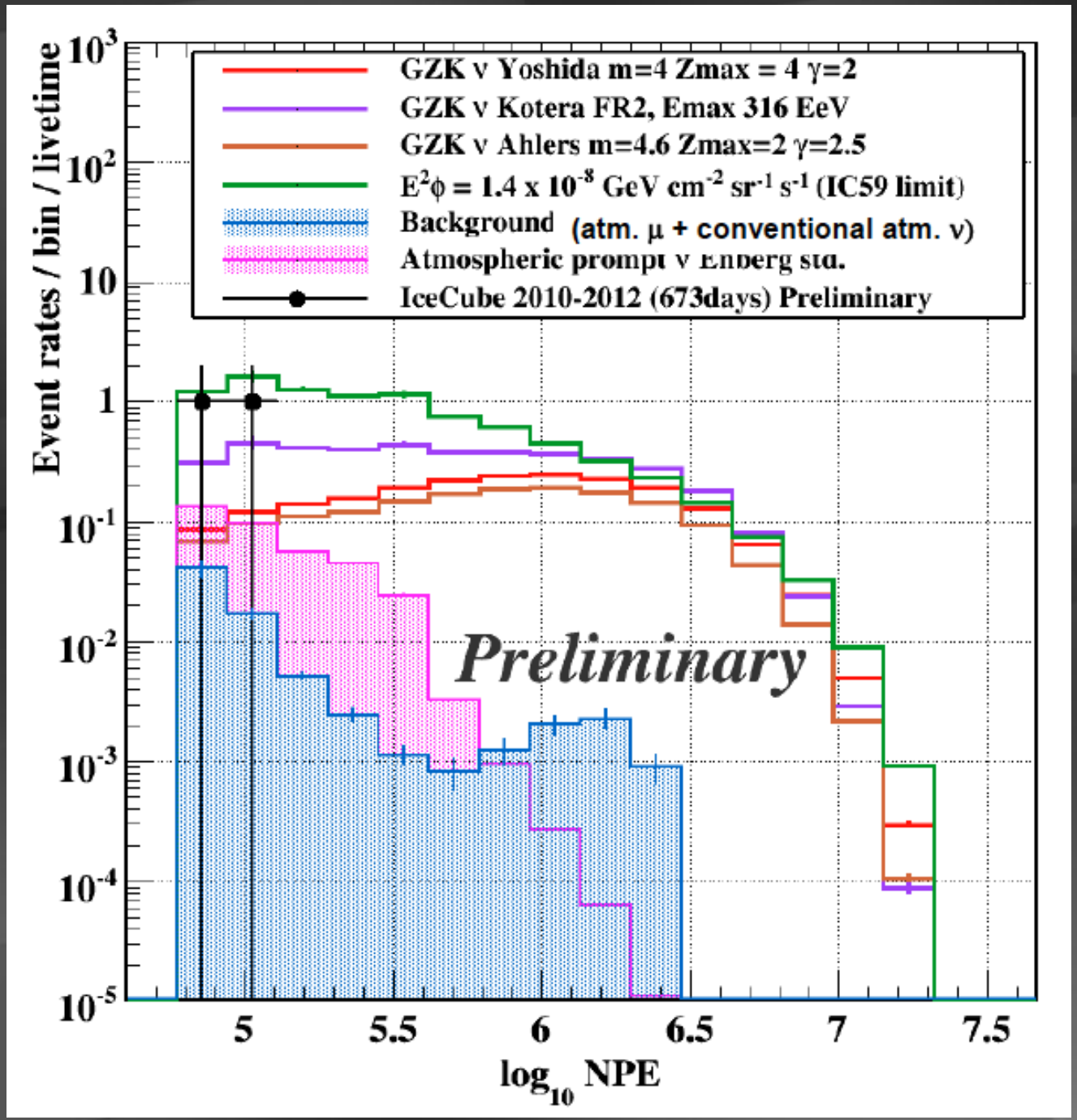
tracks and showers











- PeV energy
- cascade
- downgoing
- not atmospheric

→ flux at present level of diffuse limit

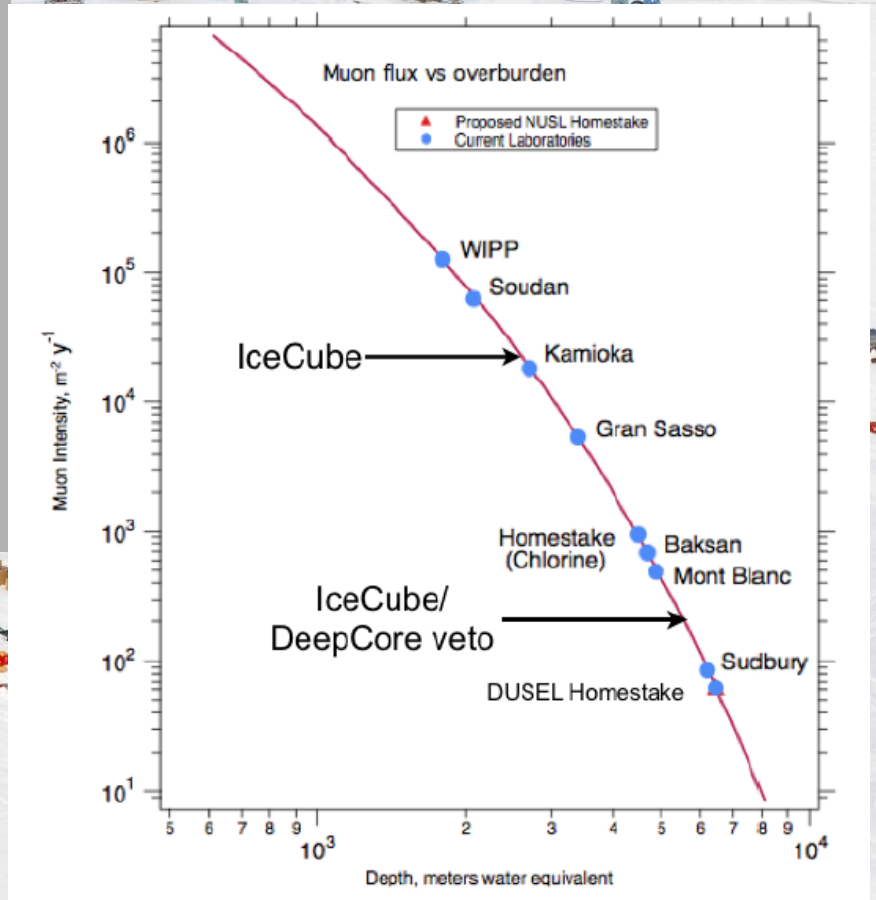
→ largest bkgd: atmospheric charm
< 0.2 events

IceCube drilling to best low background site on Earth:

→ radio-pure ice
→ no seasonal variations (temperature, humidity,…)
→ shielded from cosmic rays by IceCube veto

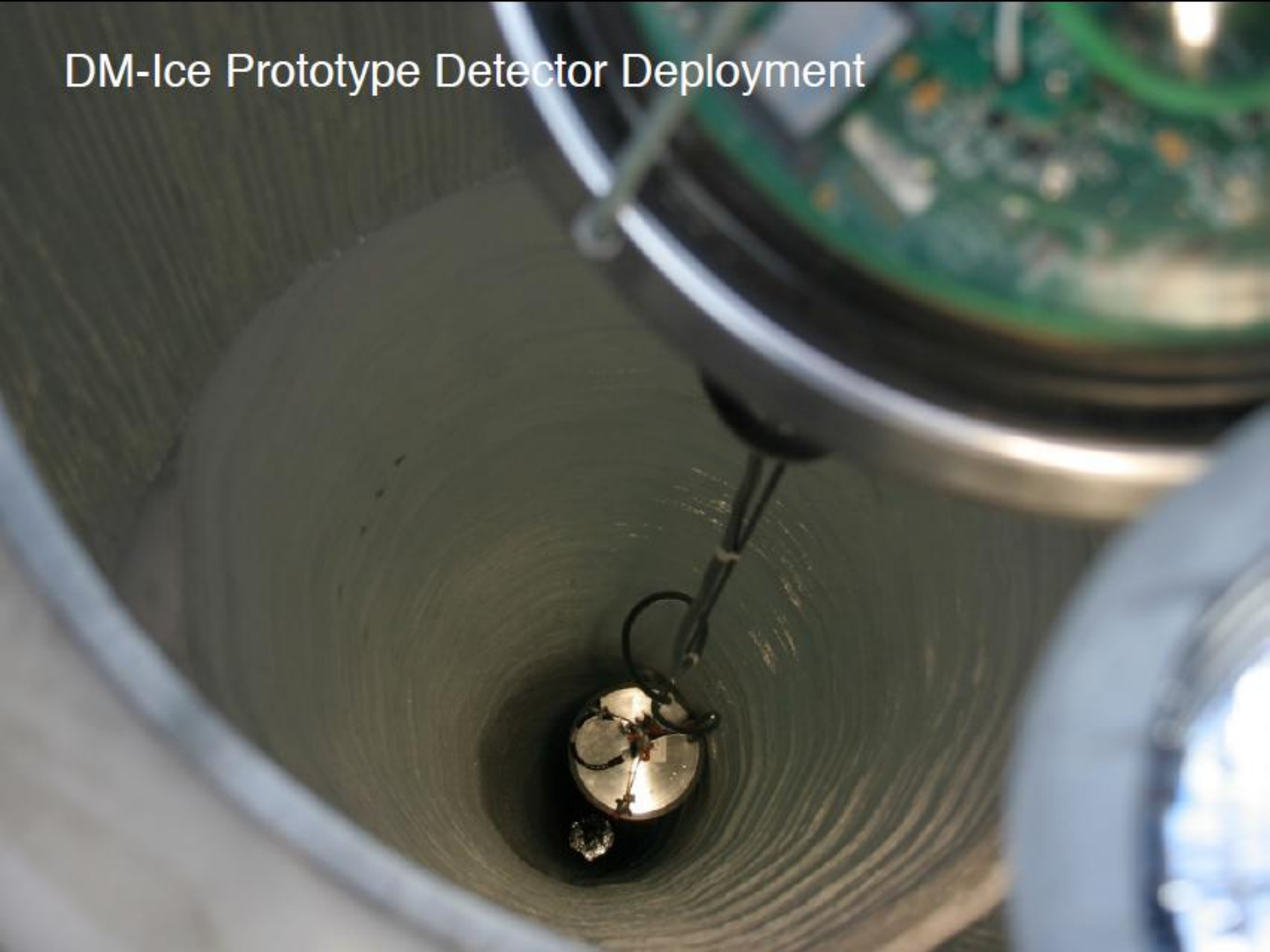
• DM-ice, DeepCore upgrades

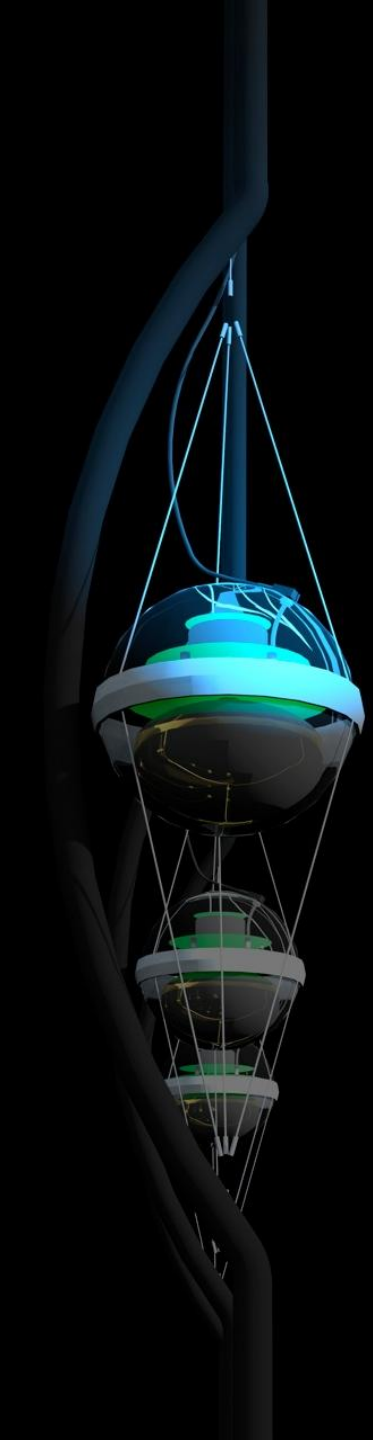
• < 700K$ per string of 60 ten inch PMTs (data to your pc)



DM-Ice Prototype Detector

DM-Ice Prototype Detector Deployment



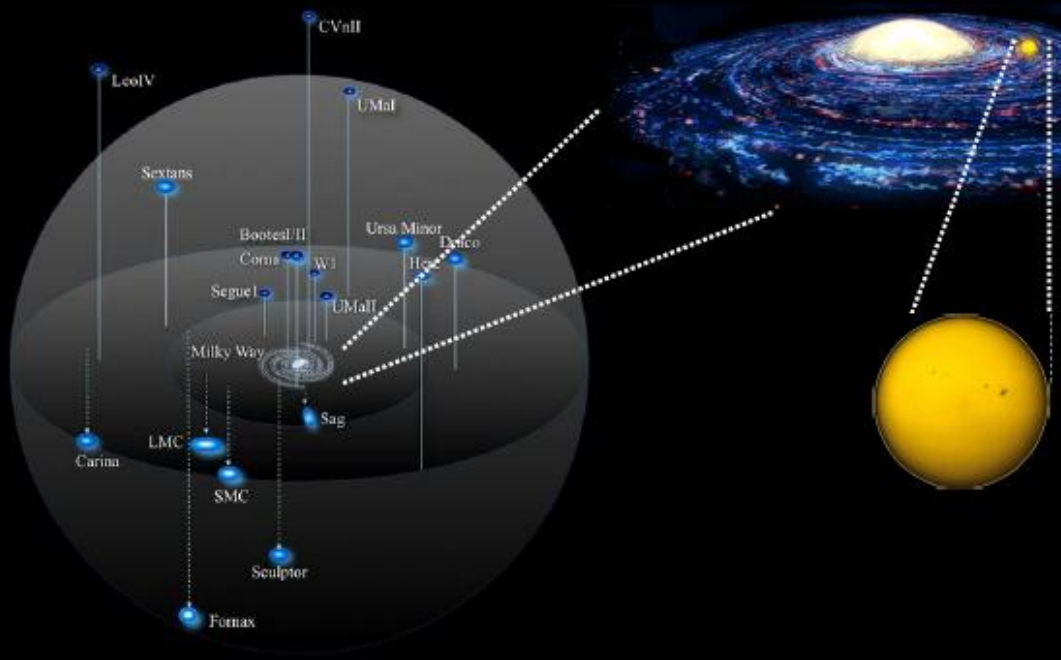


- IceCube
- atmospheric and cosmic neutrinos
- the search for dark matter

IceCube.wisc.edu

Indirect Search with IceCube

Look for potential sources that are well defined and have low or understood astrophysical backgrounds



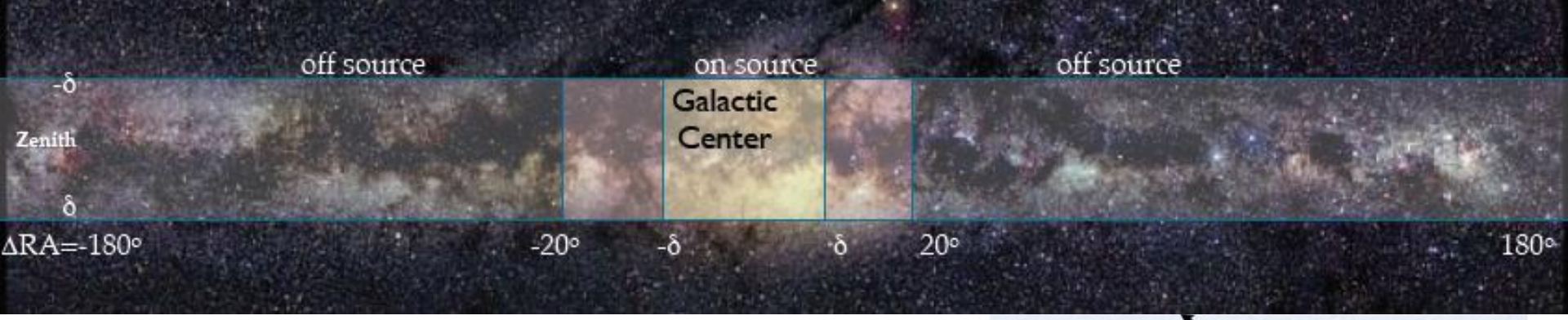
Galactic Center & Halo:
Limits from IceCube-22
Galactic Center:
Limits from IceCube-40

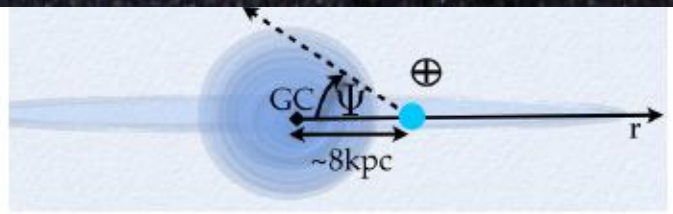
Local sources:
Sun:
Combined Limits form AMANDA, IC22, IC40+AMANDA
→ IceCube-79 final sensitivity *new

Searches beyond "standard" SUSY:
→ secluded dark matter sector *new

Earth:
Limits from AMANDA
(new analysis with IceCube-86 ongoing)

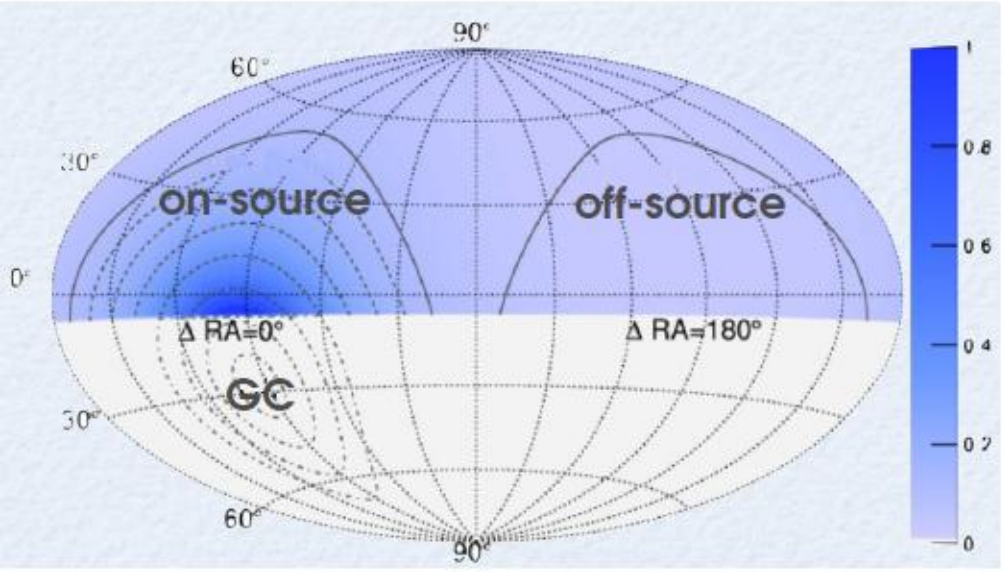
Dwarf spheroidal Galaxies:
→ IceCube-59 limits *new
Clusters of Galaxies:
→ IceCube-59 limits *new





Galactic Center:

- ✗ on-source region below the horizon
- ✗ need to veto downgoing muons.
- ✗ Use central strings of detector as fiducial volume, surrounding layers as veto.

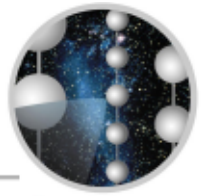


IC22 (Halo analysis – 275 days):
observed on-source: **1367** evts
observed off-source: **1389** evts
Event selection dominated by atm. **ν**

IC40 (G-Center analysis – 367 days):
observed on-source: **798842** evts
predicted from off-source: **798819** evts
Event selection dominated by atm. **μ**

Observations in both analyses were consistent with background-only expectations

Galactic & galaxy cluster limits



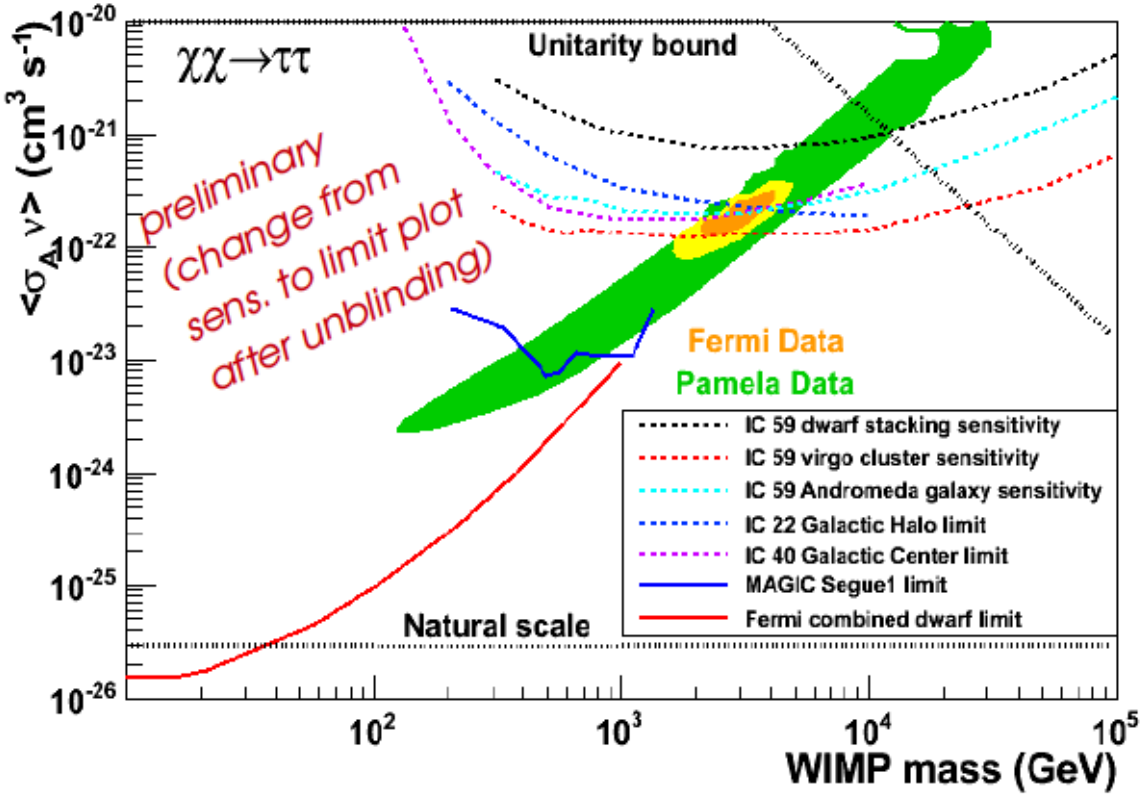
Limits computed at **90% C.L.** as function of WIMP mass and for various annihilation channels assuming branching fractions of 100%

Dwarf galaxies:

- Source stacking analysis
- Optimized size of search window
- NFW profile assumed

Galaxy clusters:

- Extended point source search
- Optimized size of search window
- Substructures taken into account

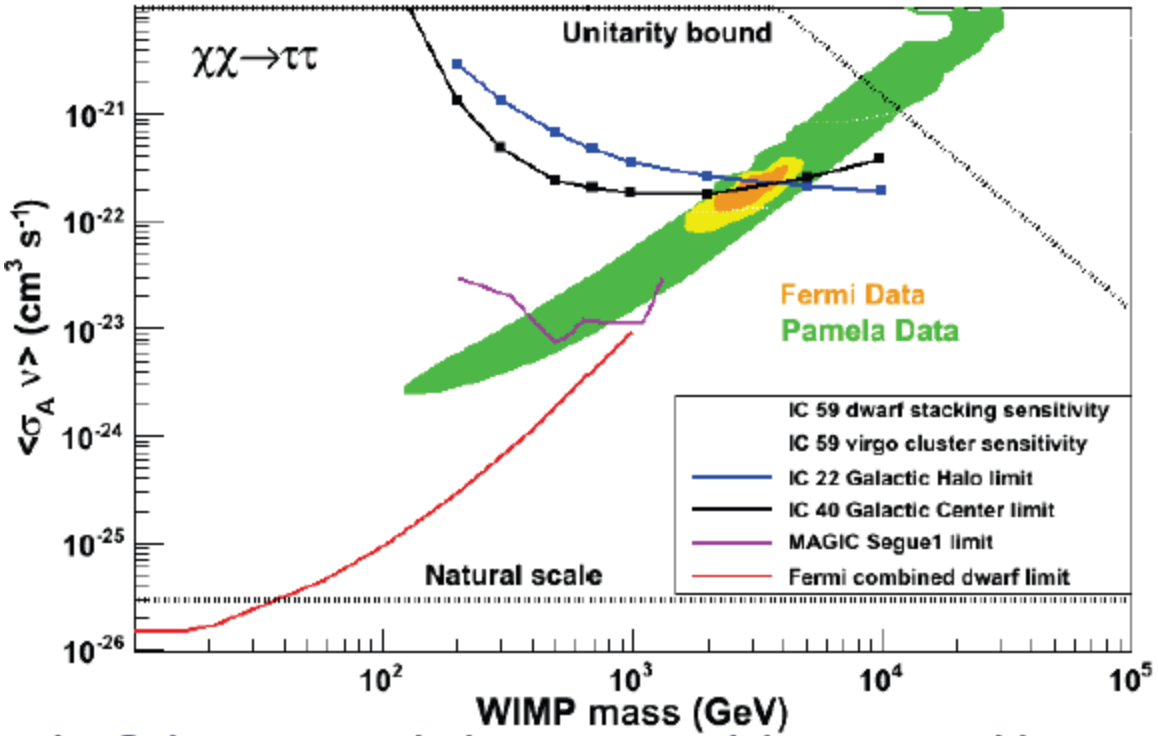


multi-wavelength approach to dark matter searches:
IceCube can test DM models motivated by PAMELA & Fermi data (e.g. Meade et al. 2008)

Milky Way / Dwarfs

Phys.Rev.D84:022004,2011

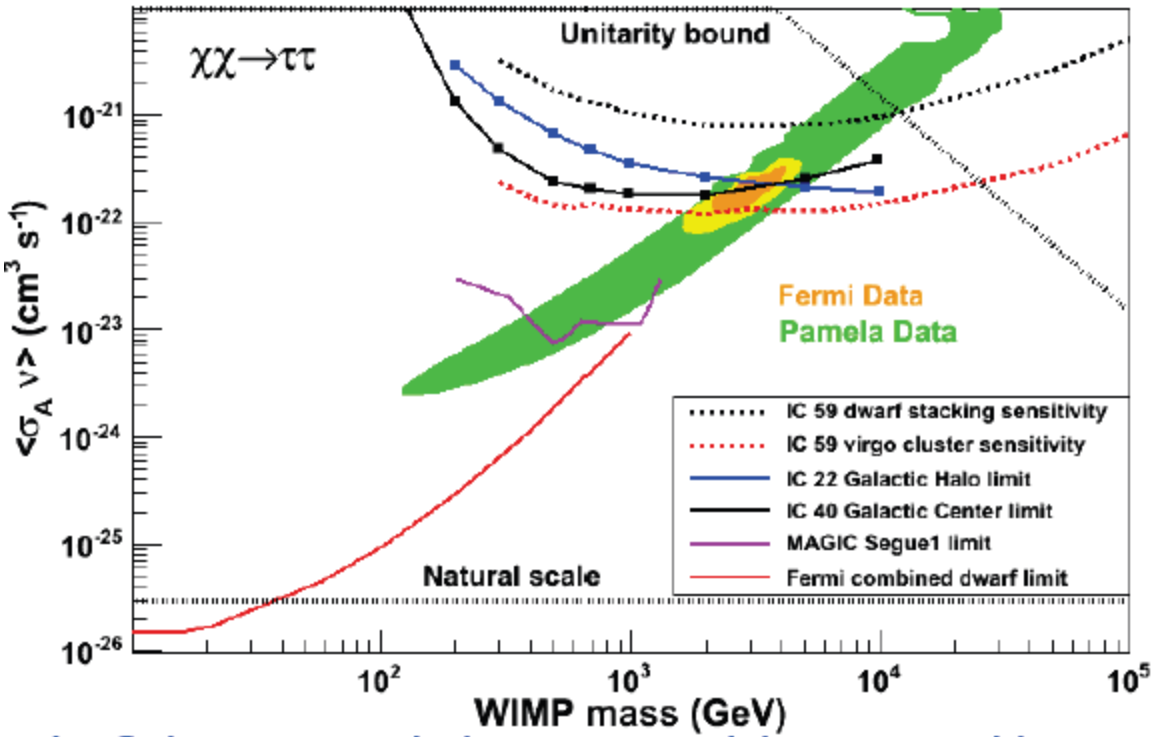
Limits computed at **90% C.L.** as function of WIMP mass and for various annihilation channels assuming branching fractions of 100% and NFW profile



IceCube can test dark matter models motivated by PAMELA and Fermi electron data (e.g. Meade et al. 2008)

Dwarfs / Clusters of Galaxies

Limits computed at **90% C.L.** as function of WIMP mass and for various annihilation channels assuming branching fractions of 100% and NFW profile



Dwarf galaxies:

- Source stacking analysis
- Optimized size of search window
- NFW profile assumed

Galaxy clusters:

- Extended source
- Optimized size of search window
- Substructures taken into account

IceCube can test dark matter models motivated by PAMELA and Fermi electron data (e.g. Meade et al. 2008)

WIMP Capture and Annihilation

1. Halo WIMPs scatter on nuclei in the Sun
2. Some lose enough energy in the scatter to be gravitationally bound
3. Scatter some more, sink to the core
4. Annihilate with each other, producing neutrinos
5. Propagate+oscillate their way to the south pole, convert into muons in the ice

$$\chi + \chi \rightarrow W + W \rightarrow \nu + \nu$$
$$b + b \rightarrow \nu + \nu$$

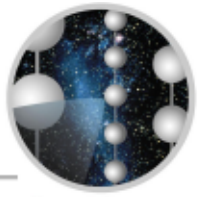
indirect dark matter detection

- indirect rates are dictated by the interaction cross section of WIMPS with hydrogen.
  → no unknown astrophysics

- in the neutrino case there is a direct connection between theory and observation and the background is understood.

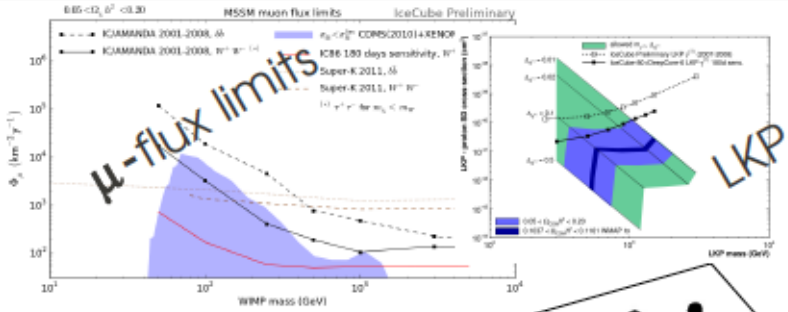
PRD 85, 042002 (2012)

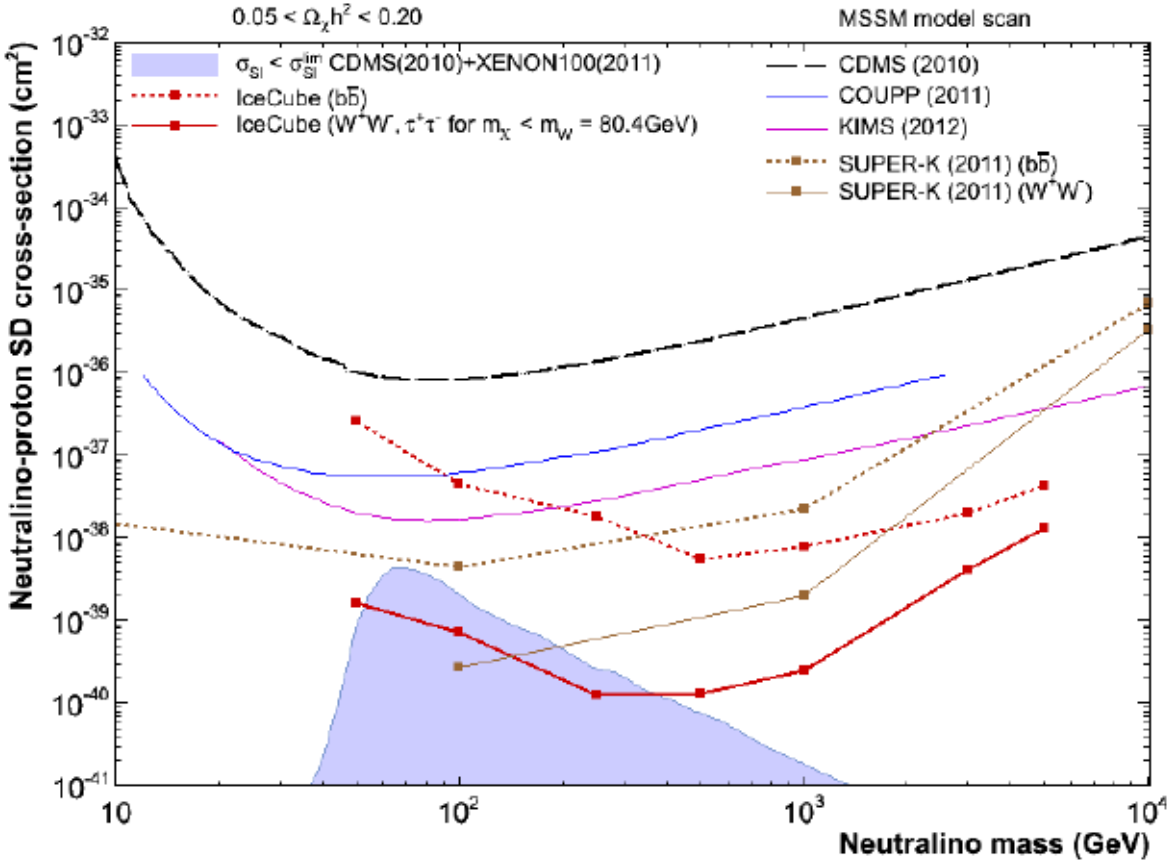
Analysis Results from the Sun

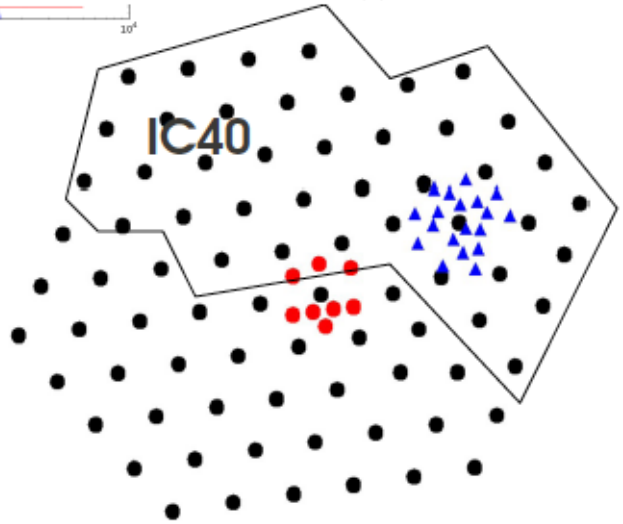


More details on limits

Abbasi et al., ***PRL*. 102**, 201302 (2009) (IC22)
Abbasi et al., ***PRD* 81,** 057101 (2010) (IC22)
Abbasi et al., ***PRD* 85**, 042002 (2012) (IC40+AMANDA)







Combined multi-year limit from AMANDA, IceCube-22 and IceCube-40+AMANDA data
Total livetime of 1065 days

IceCube 79 string analysis

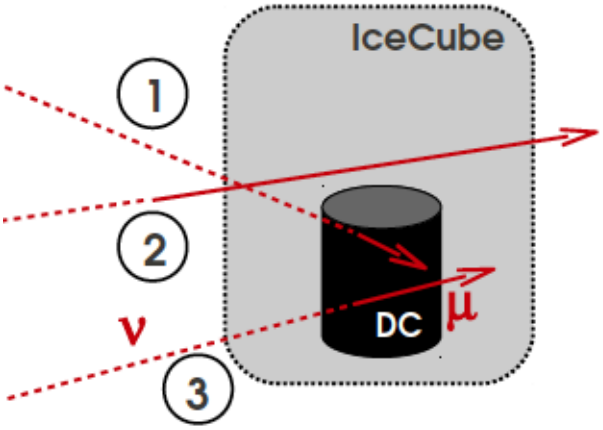
Solar WIMP analysis with 79 strings *(sensitivity)*

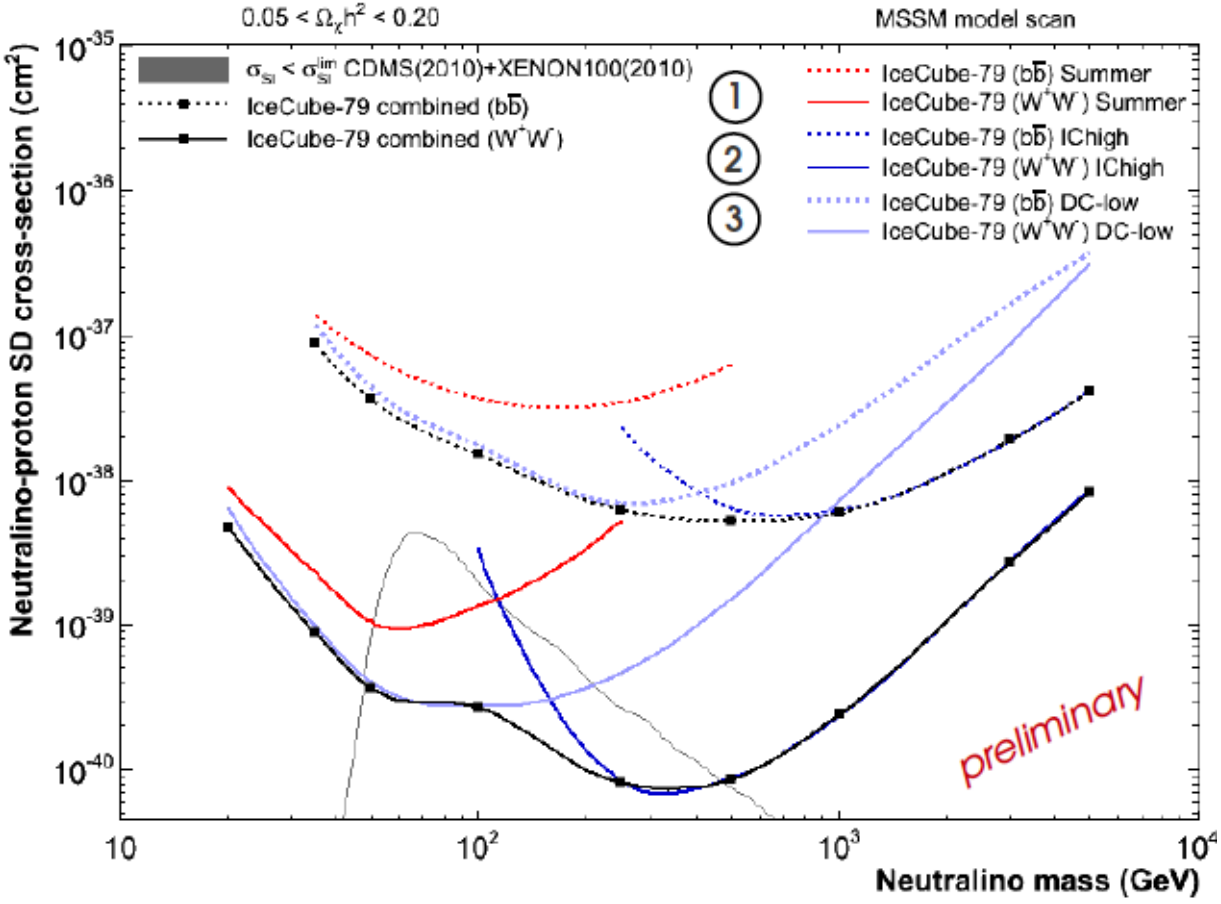
- Incl. DeepCore
- Performed separately for austral winter & summer (152d +167d livetime)
- Low energies (look for contained or partially contained events)

Analysis performed separately for;
austral summer (Sun above horizon)

&

austral winter (Sun below horizon)



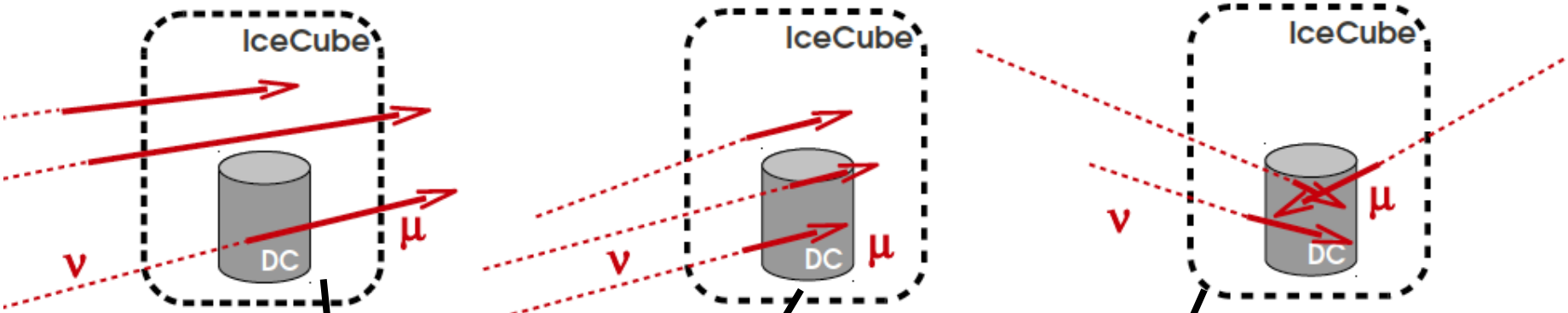


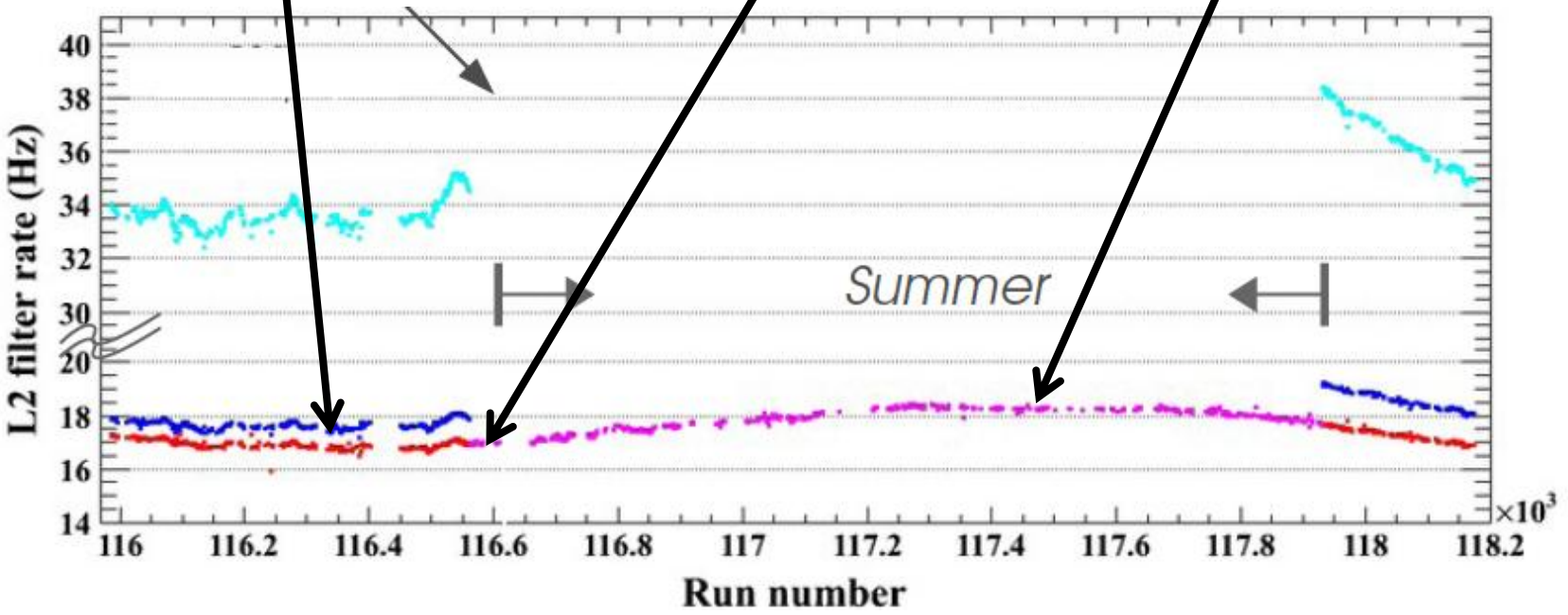
IceCube 79 data

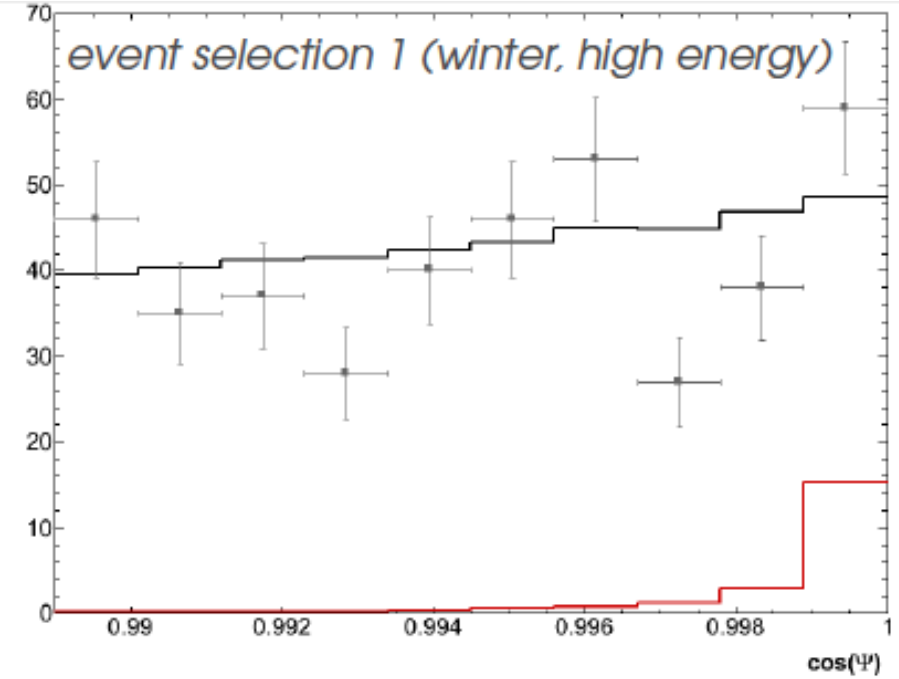
- Up-going ①
- No containment

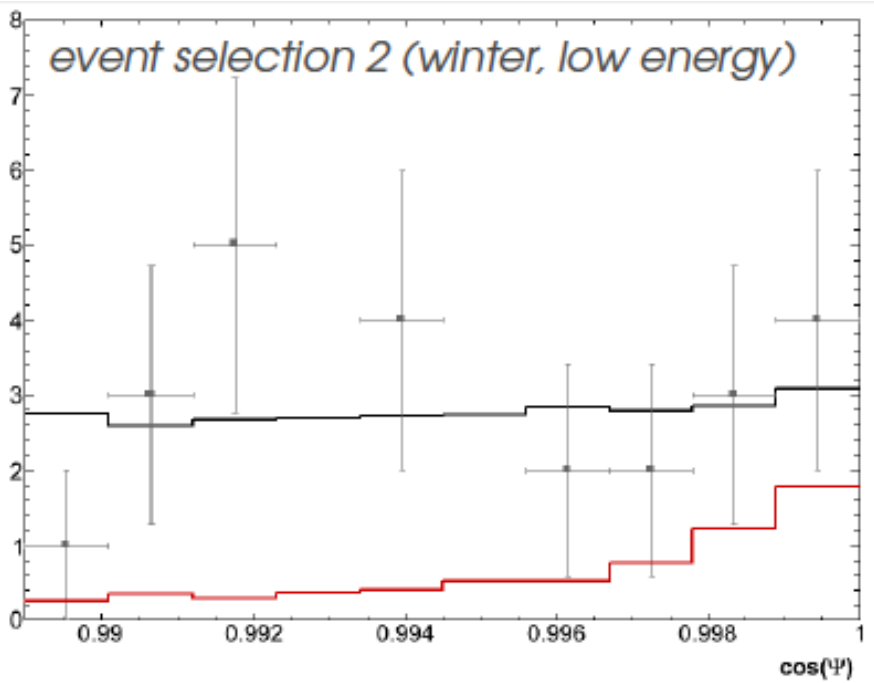
- Up-going ②
- strong containment

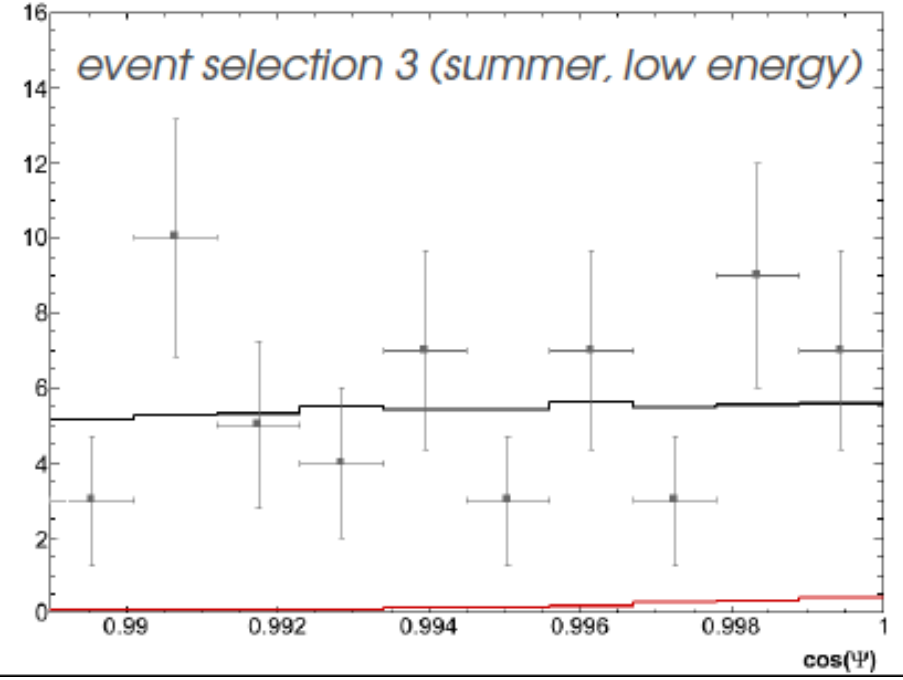
- Down-going ③
- strong containment

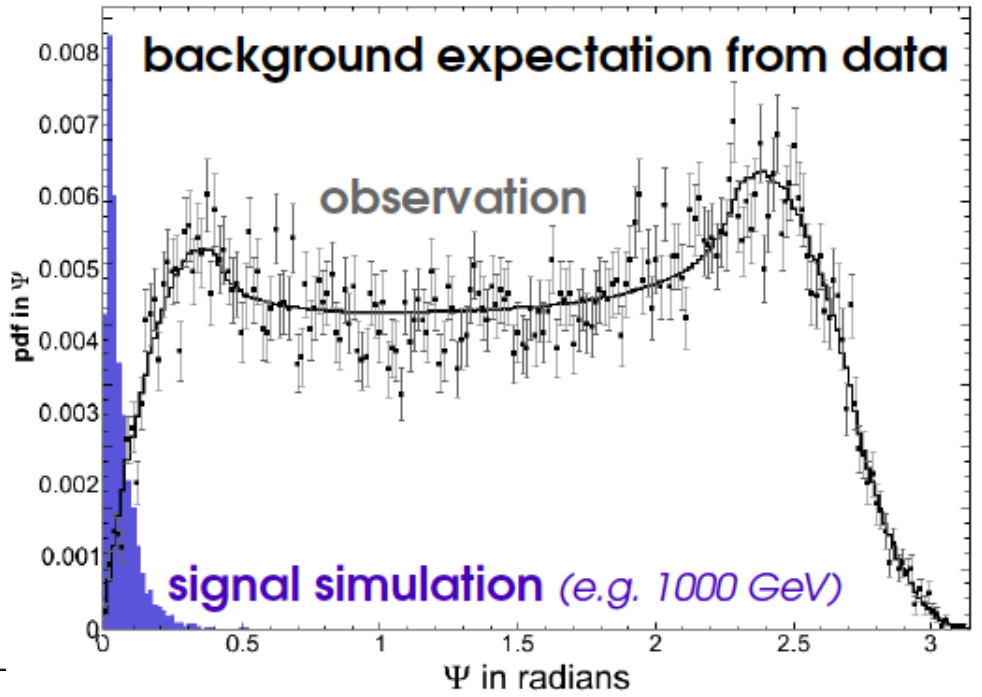




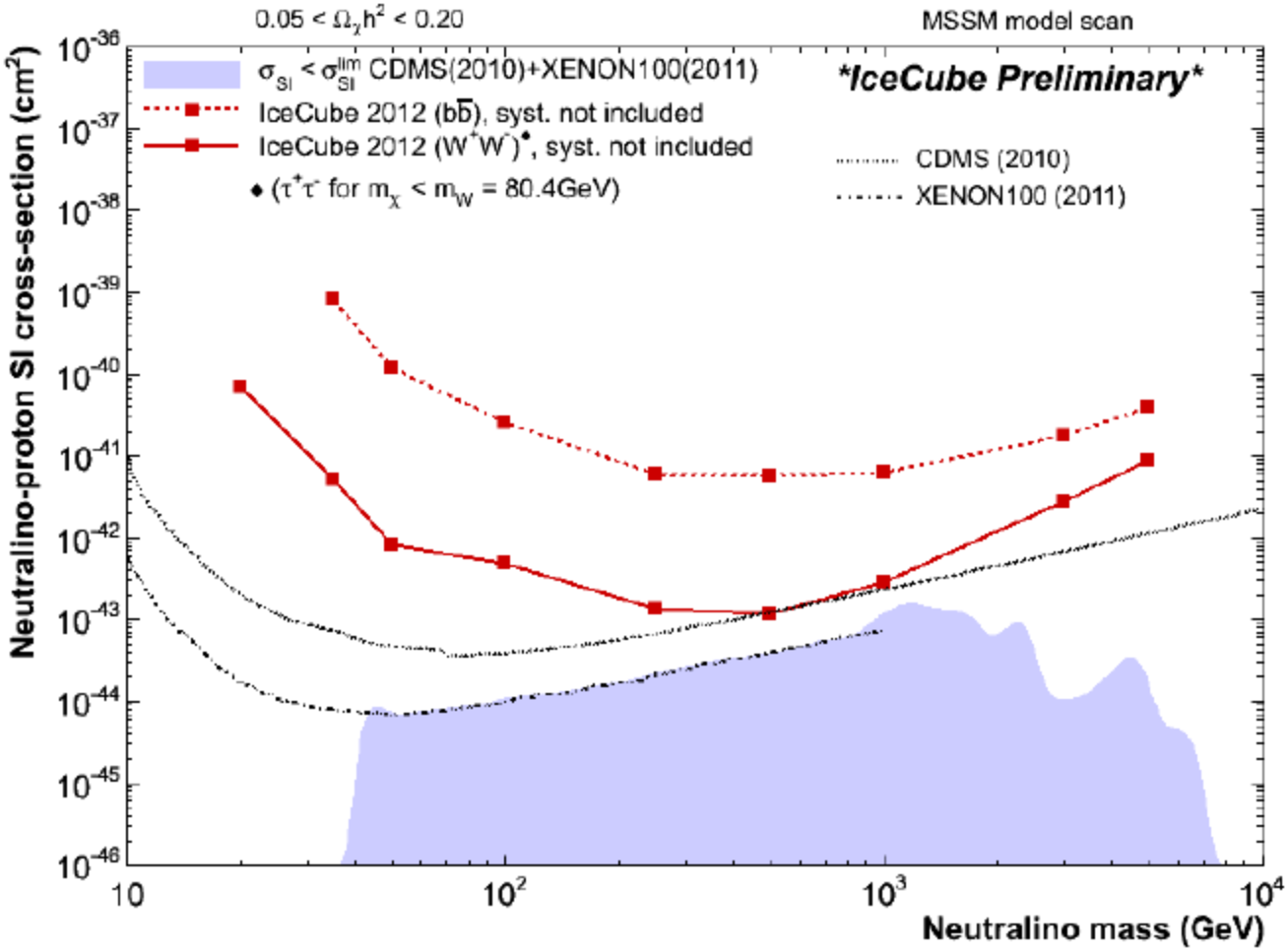

event selection 1 (winter, high energy)
cos(Ψ)


event selection 2 (winter, low energy)
cos(Ψ)


event selection 3 (summer, low energy)
cos(Ψ)


background expectation from data
observation
signal simulation (e.g. 1000 GeV)
pdf in Ψ
Ψ in radians

Unblinding results (SI-cross-section limit)



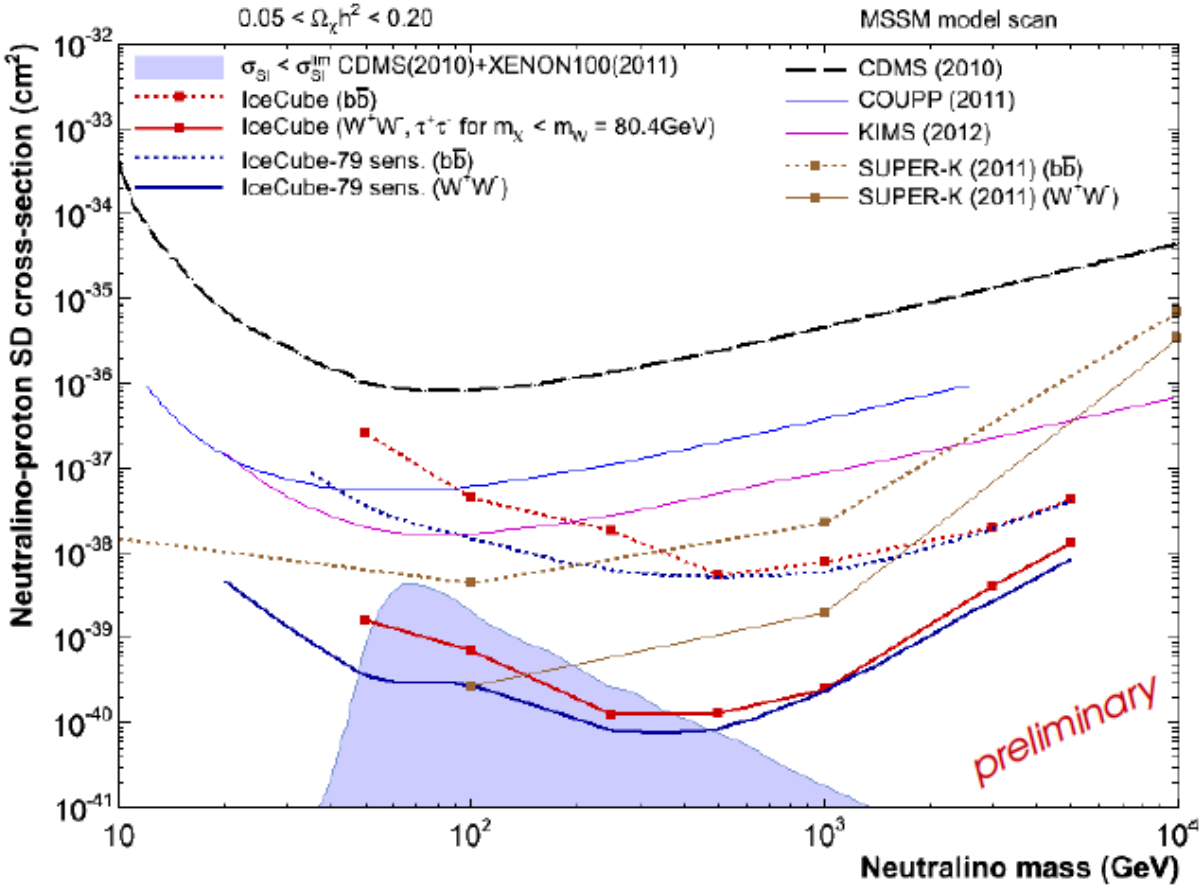
IceCube 79 string sensitivity

Sensitivity extends to WIMP masses of 20 GeV

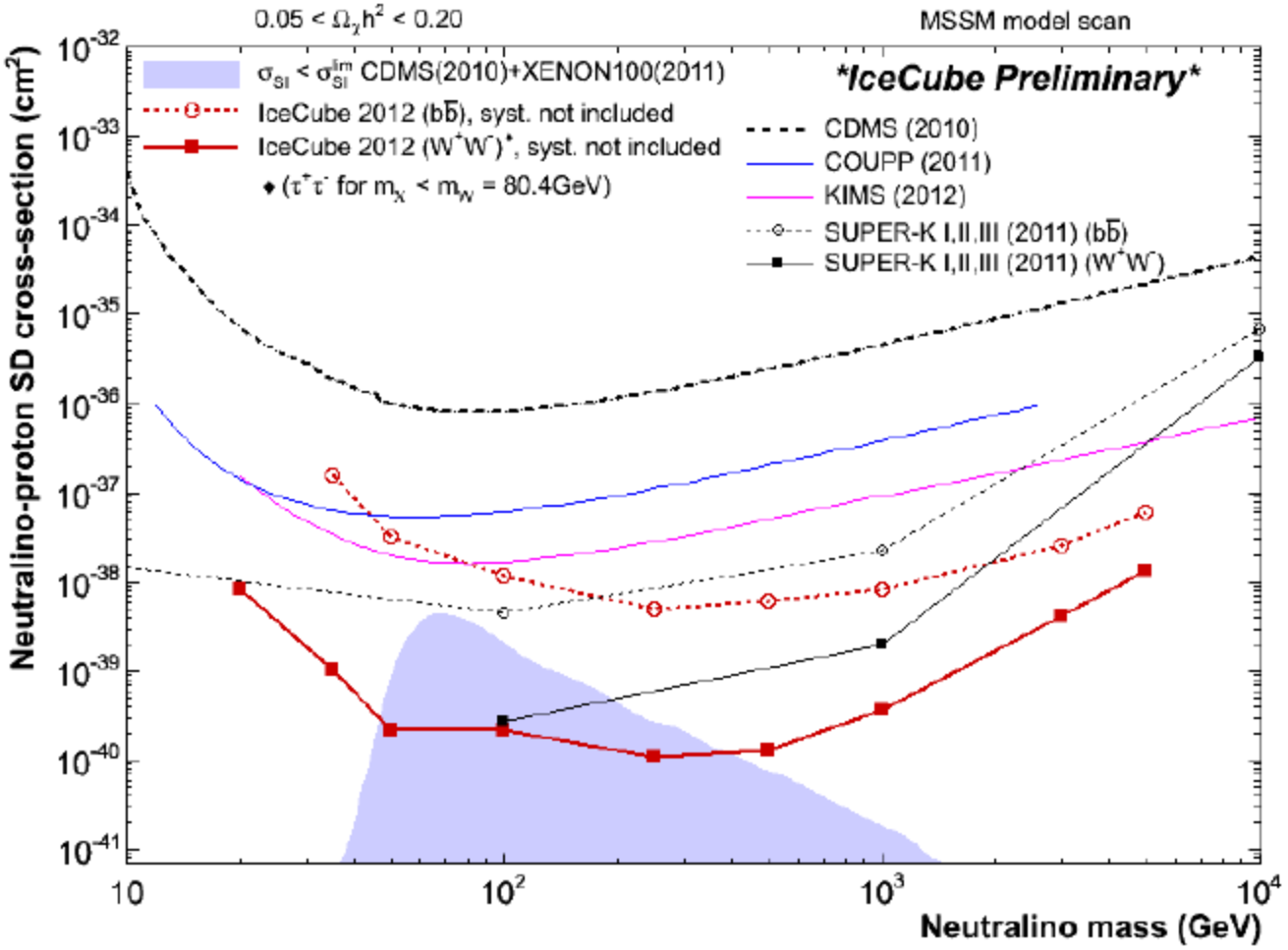
Only 1 year of data

Data unblinding soon!

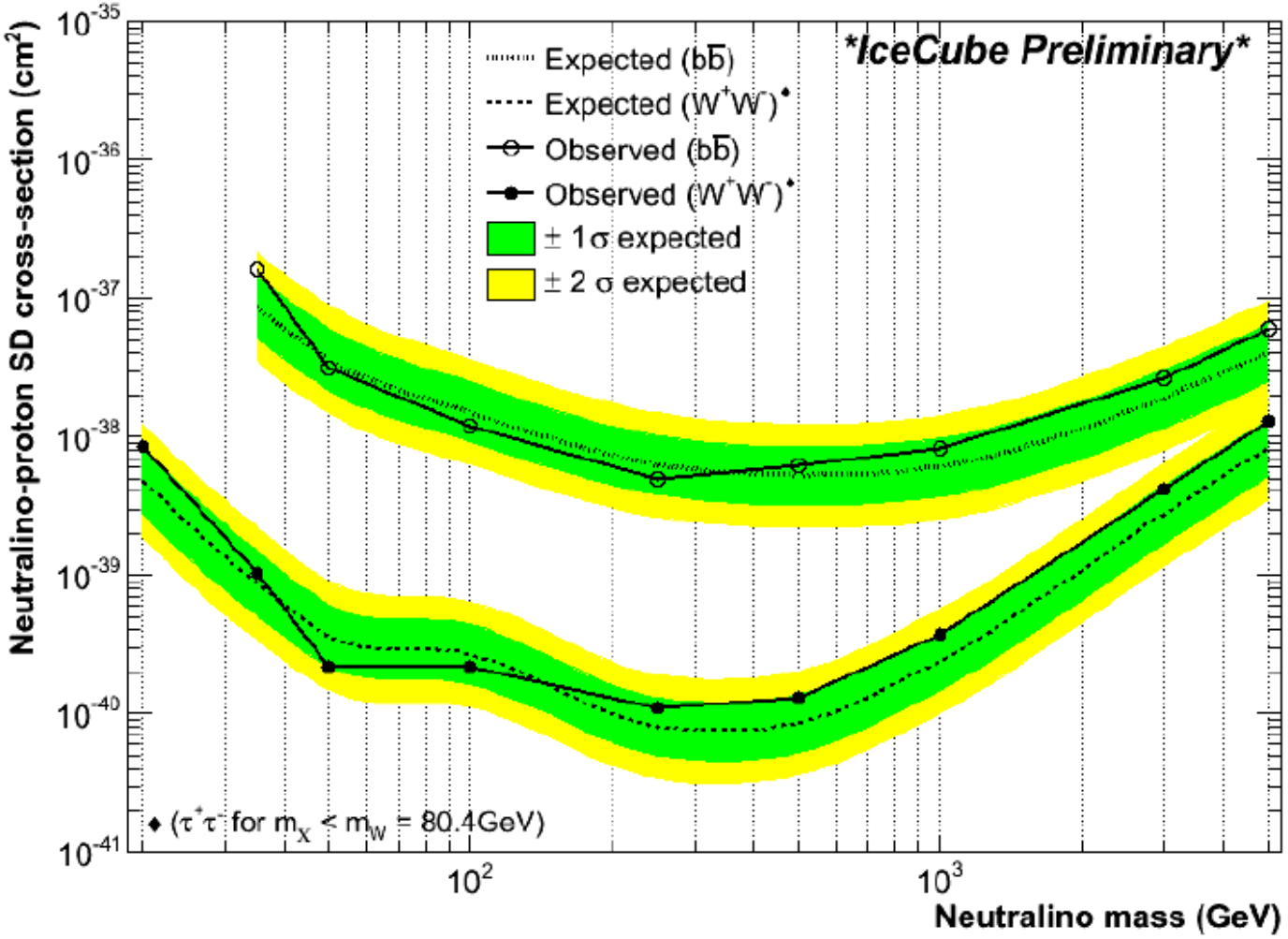
also search for UED models (not shown here)



Unblinding results (SD-cross-section limit)



Unblinding results (observed results)

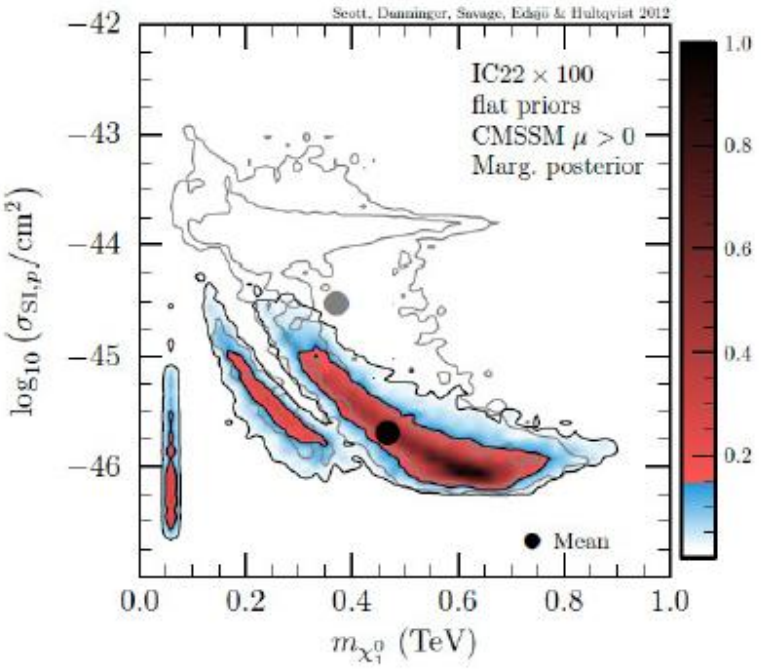


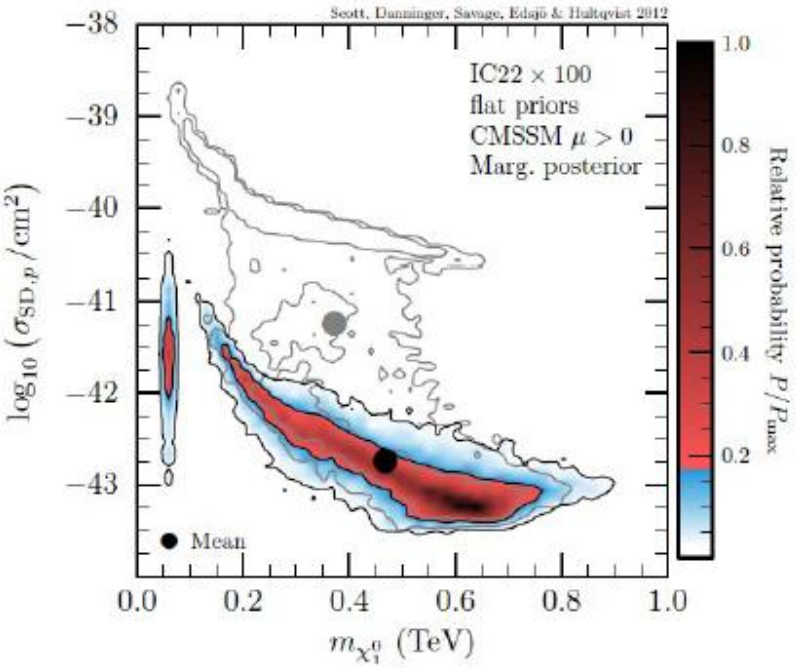
Global SUSY analysis with IceCube

More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:00001v1

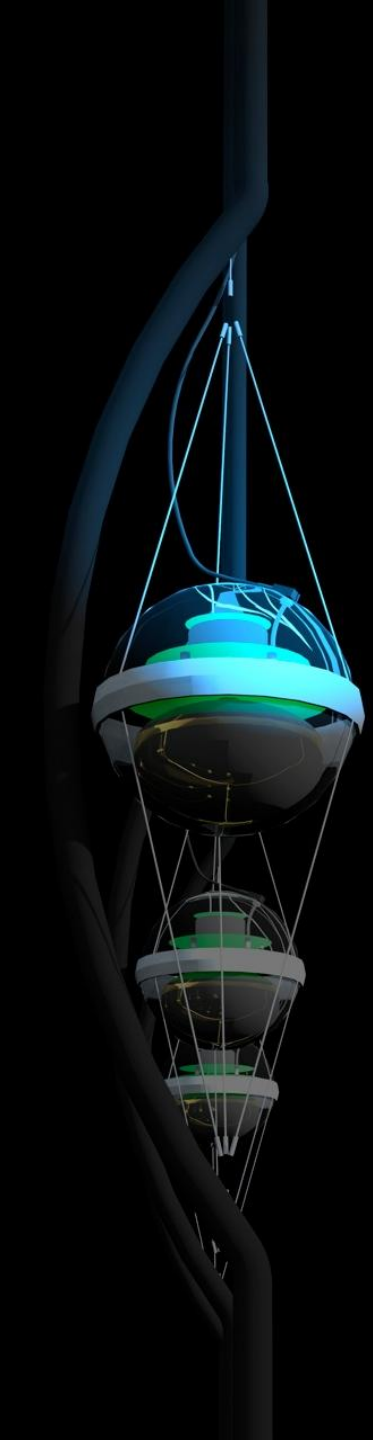
Plots will be substituted with higher quality plots

CMSSM, IceCube-22 with 100x boosted effective area
(indication for IceCube-79 and 86-string prospects)





- ✗ Contours indicate 1σ and 2σ credible regions
- ✗ Grey contours correspond to fit *without* IceCube data
- ✗ Shading+contours indicate *relative* probability only, not overall goodness of fit

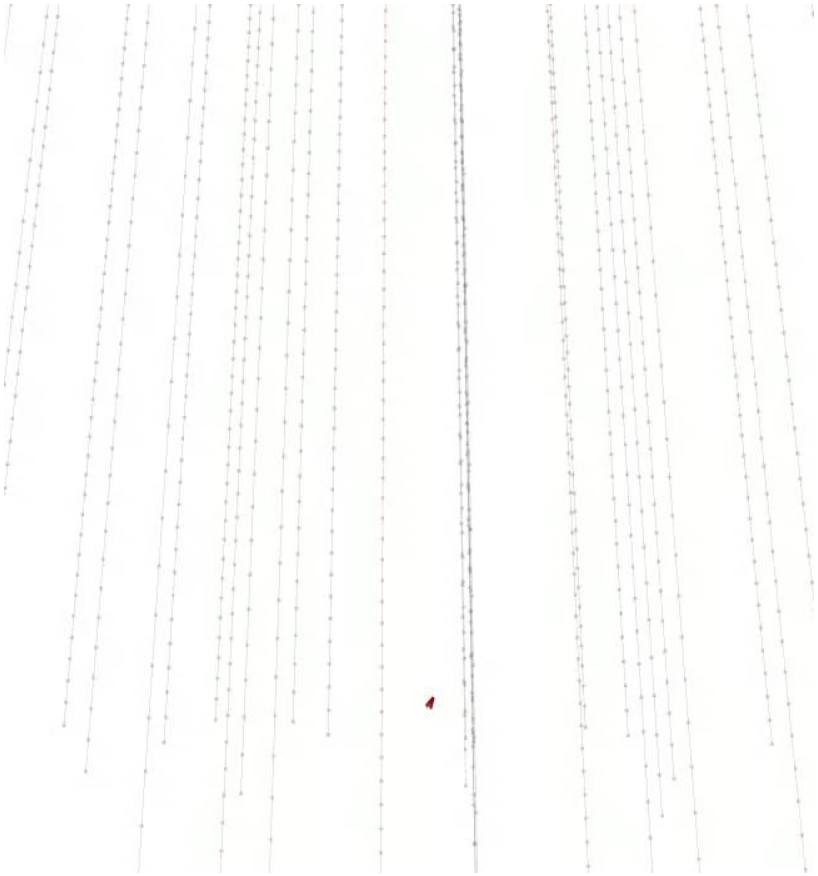


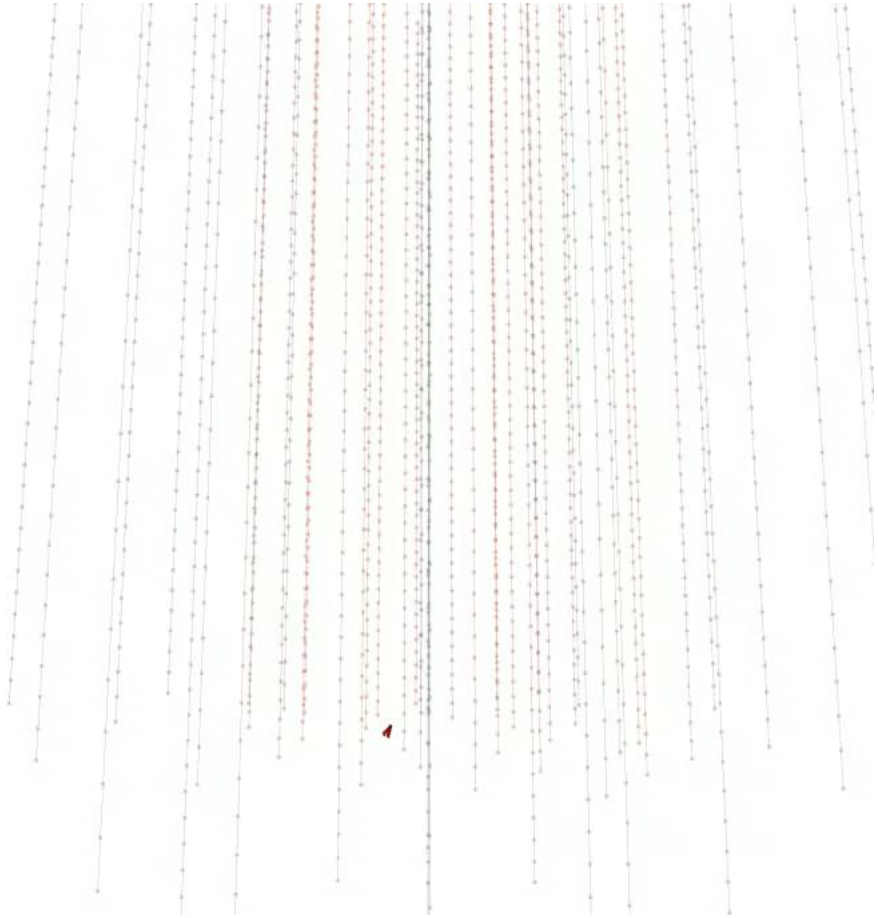
- all results with detector under construction
- soon:
  - → results from completed detector with improved software and calibration
  - → WIMP masses as low as 10 GeV
- far from the square root regime
- thanks: C. Rott and M. Danninger

IceCube.wisc.edu

DeepCore (+6 strings):11 hits

PINGU (+20 strings): 83 hits





8 GeV muon-neutrino

The IceCube Collaboration

International 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)