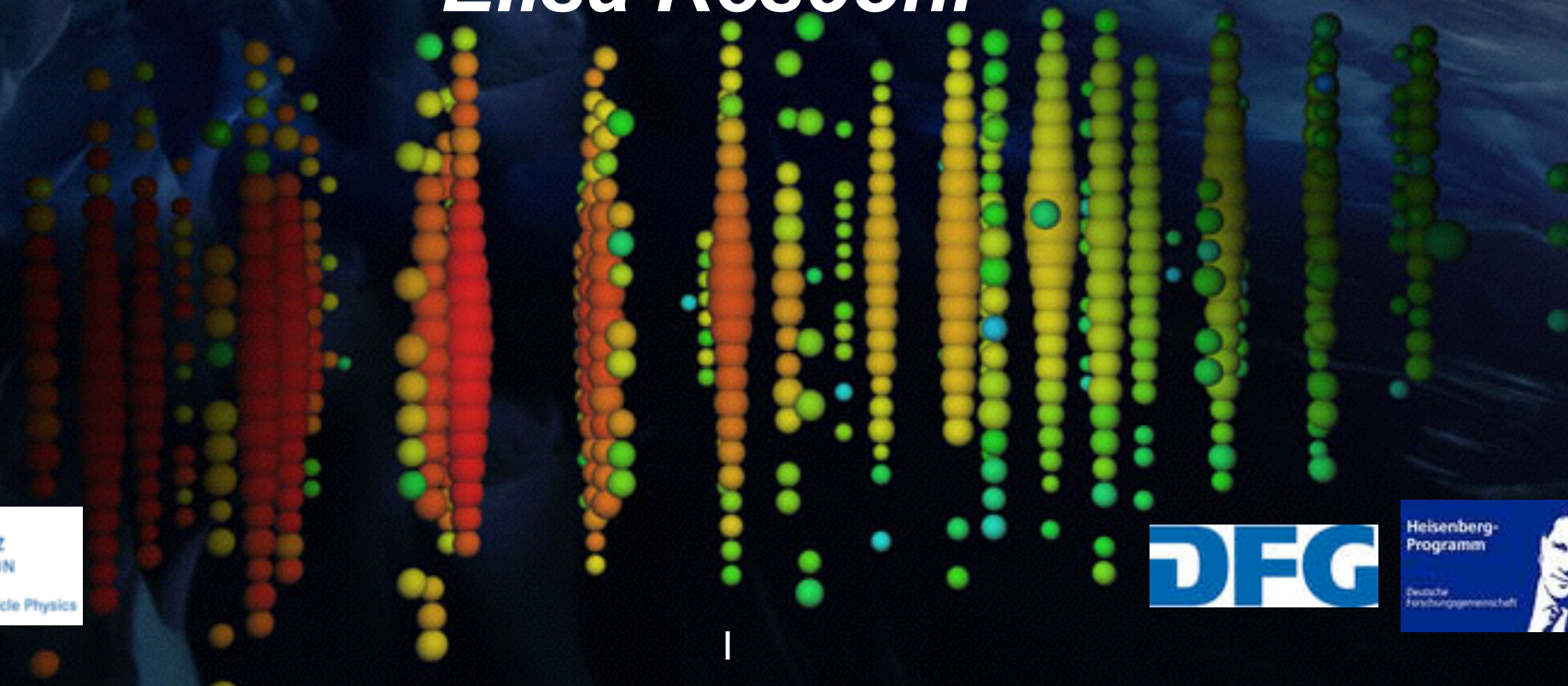


Cosmic Neutrinos @ IceCube Neutrino Observatory

Elisa Resconi



In this talk

- ➔ Why astronomy with neutrinos?
- ➔ The South Pole Neutrino Observatory IceCube
 - ➔ High-energy cosmic neutrinos
 - ➔ BL Lac scenario
- ➔ IceCube-Gen2 ... no time for that

The idea

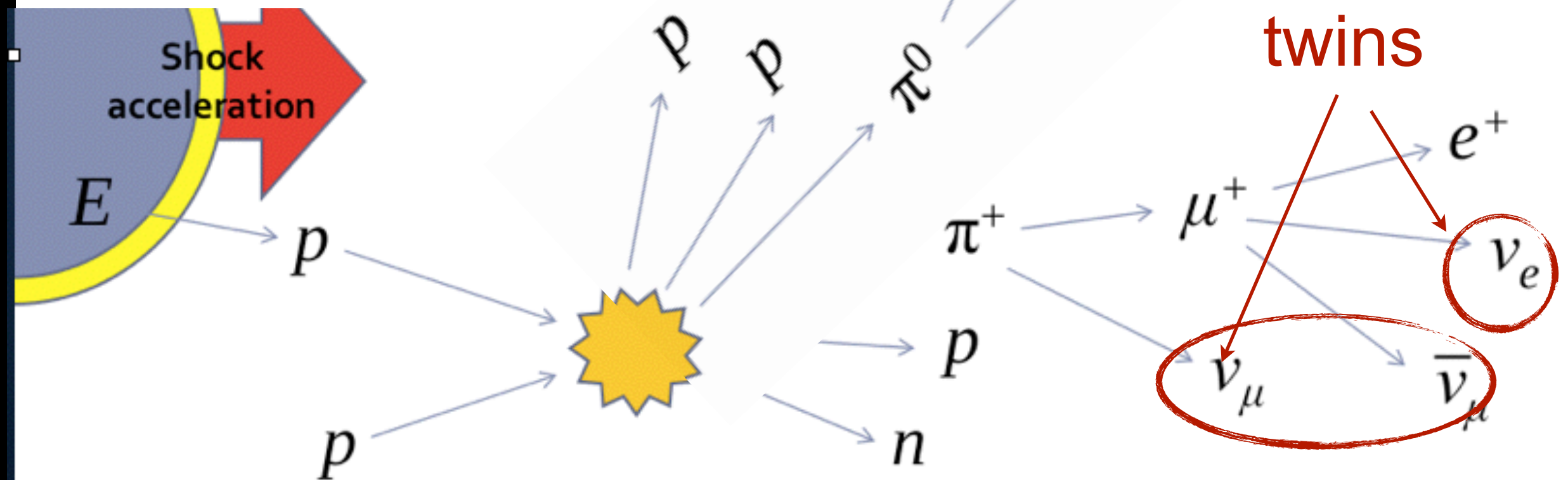
K. Greisen, “Cosmic ray showers,” Ann. Rev. Nucl. Part. Sci. 10 (1960) 63–108.

F. Reines, “Neutrino interactions,” Ann. Rev. Nucl. Part. Sci. 10 (1960) 1–26.

M.A. Markov, “On high energy neutrino physics,” Proc. Int. Conference on High Energy Physics at Rochester (1960) 578–581.

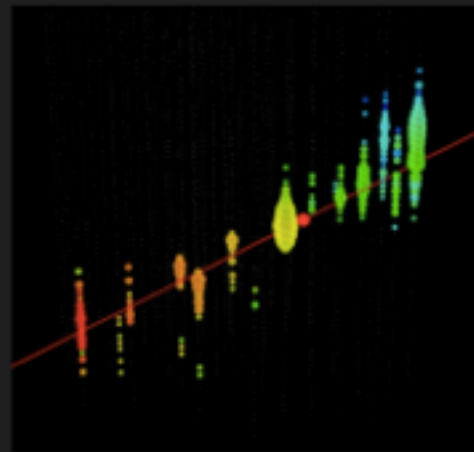
- 1960, Greisen, Reines and Markov: use large volume of clear water to detect cosmic neutrinos
- Reines: interest in the possibility of detecting cosmic neutrinos *„stems from the weak interaction of neutrinos with matter, which means that they propagate essentially unchanged in direction and energy from their point of origin [..] and so carry information which may be unique in character.”*
- Greisen: use a large volume of water in a mine
- Markov: use the deep ocean or water in a lake to study atmospheric neutrinos.

The physics scenario pp or p-gamma connection with cosmic-rays



modified from <http://www.astro.wisc.edu/~gvance/index.html>

CC Muon Neutrino

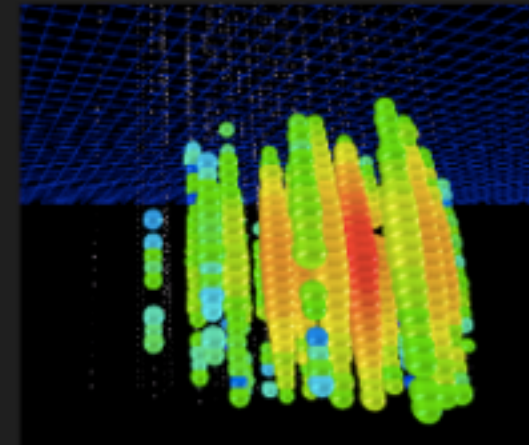


$$\nu_{\mu} + N \rightarrow \mu + X$$

track (data)

factor of ≈ 2 energy resolution
< 1° angular resolution at high
energies

Neutral Current / Electron Neutrino



$$\nu_e + N \rightarrow e + X$$

$$\nu_x + N \rightarrow \nu_x + X$$

cascade (data)

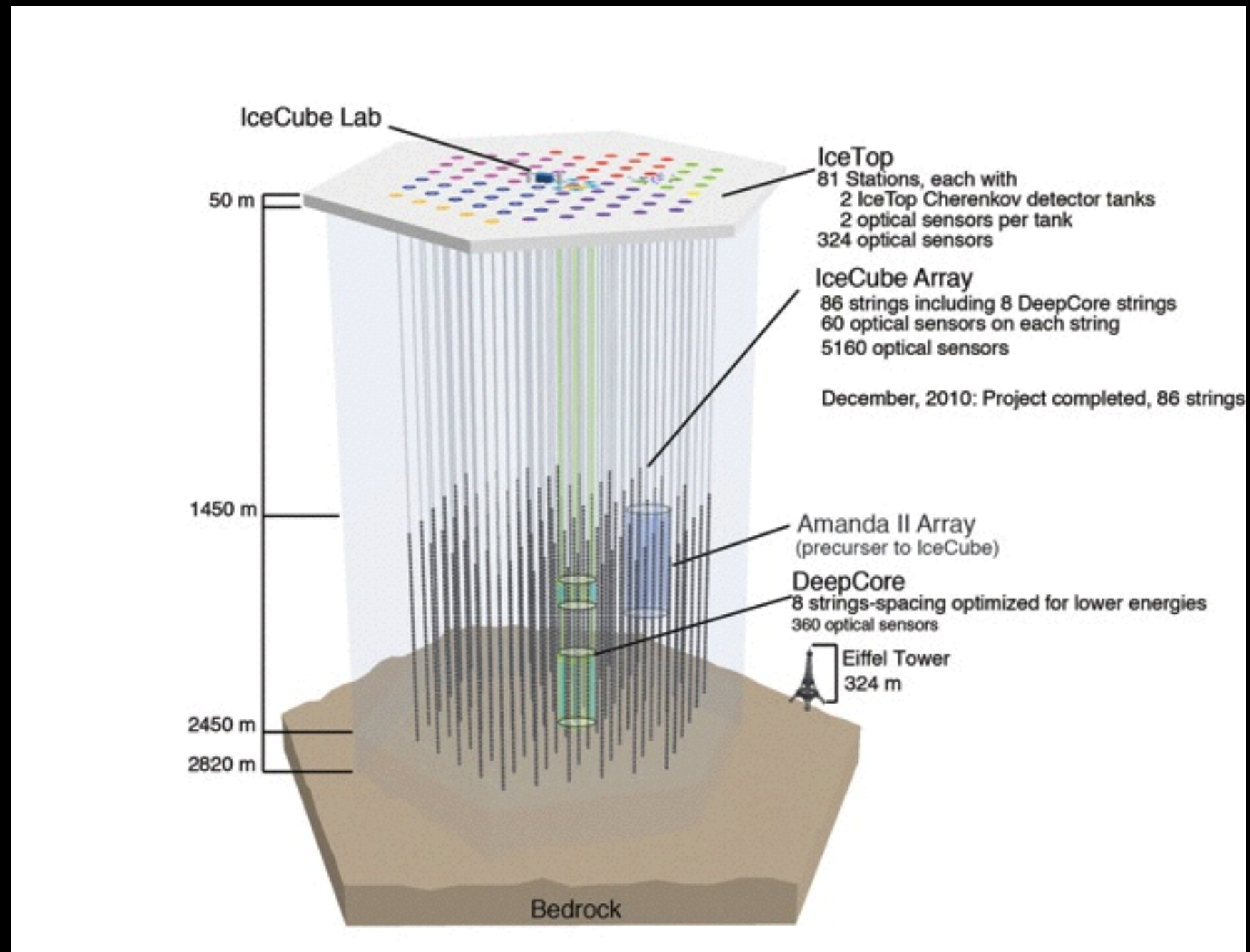
$\approx \pm 15\%$ deposited energy resolution
 $\approx 10^{\circ}$ angular resolution (in IceCube)
(at energies $\gtrsim 100$ TeV)

IceCube @ South Pole

F. Halzen and J. G. Learned, “High-energy neutrino detection **in deep polar ice**,” Proc. 5th Int. Symp. on Very High Energy Cosmic-Ray Interactions, Lodz, Poland (1988) .

- AMANDA (2000-2006)
- IceCube (completed in 2010)
i.e. IceTop, “in-ice”,
DeepCore

Extension at lower
energies (~ 100 GeV -
 ~ 10 GeV): DeepCore



IceCube: constructed in 7 seasons

IceCube-1/IceCube-9

IceCube-22

IceCube-40

IceCube-59

IceCube-79

IceCube-86 (1st year), IceCube-86 (2nd year)

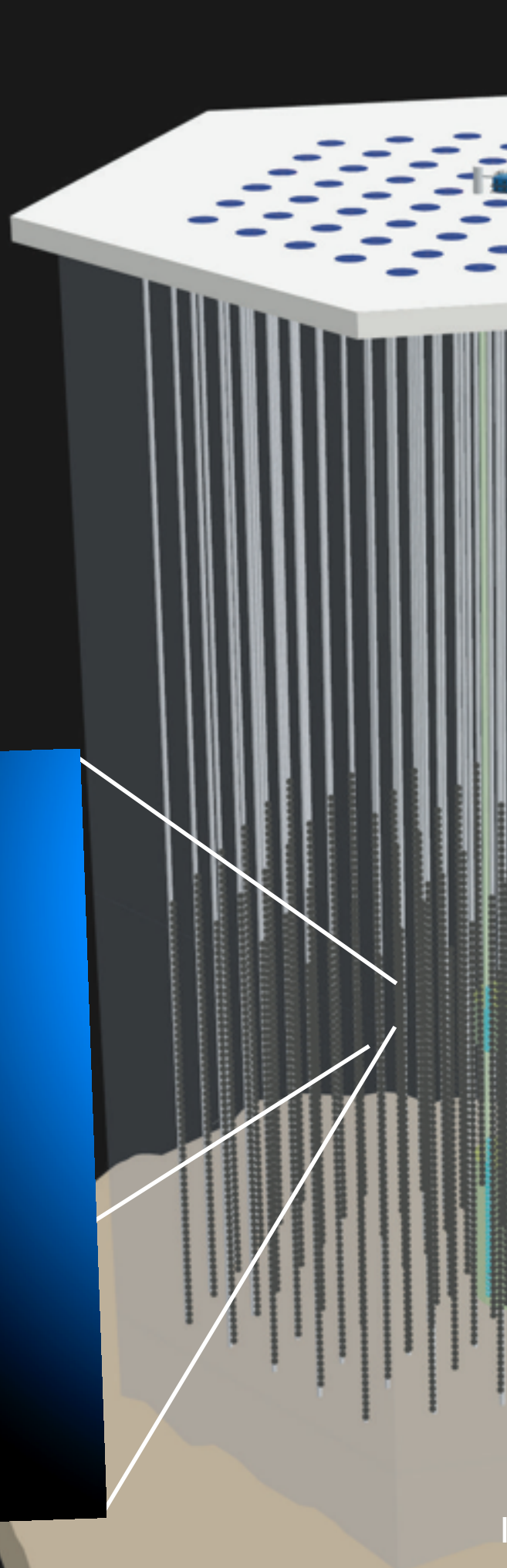
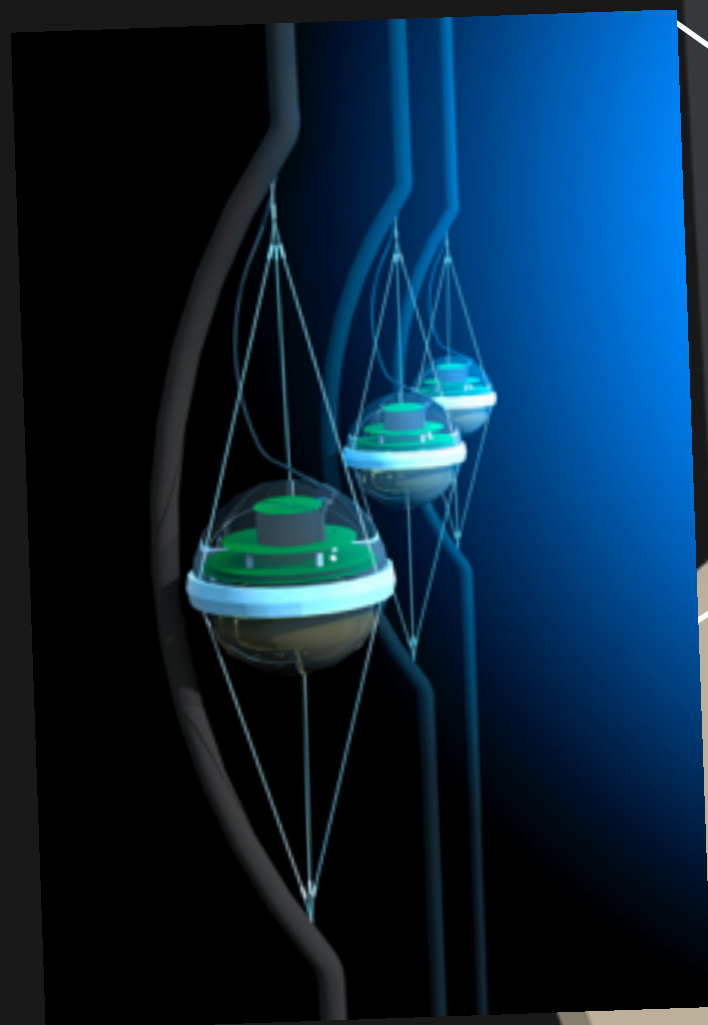
1 km

IceCube Array



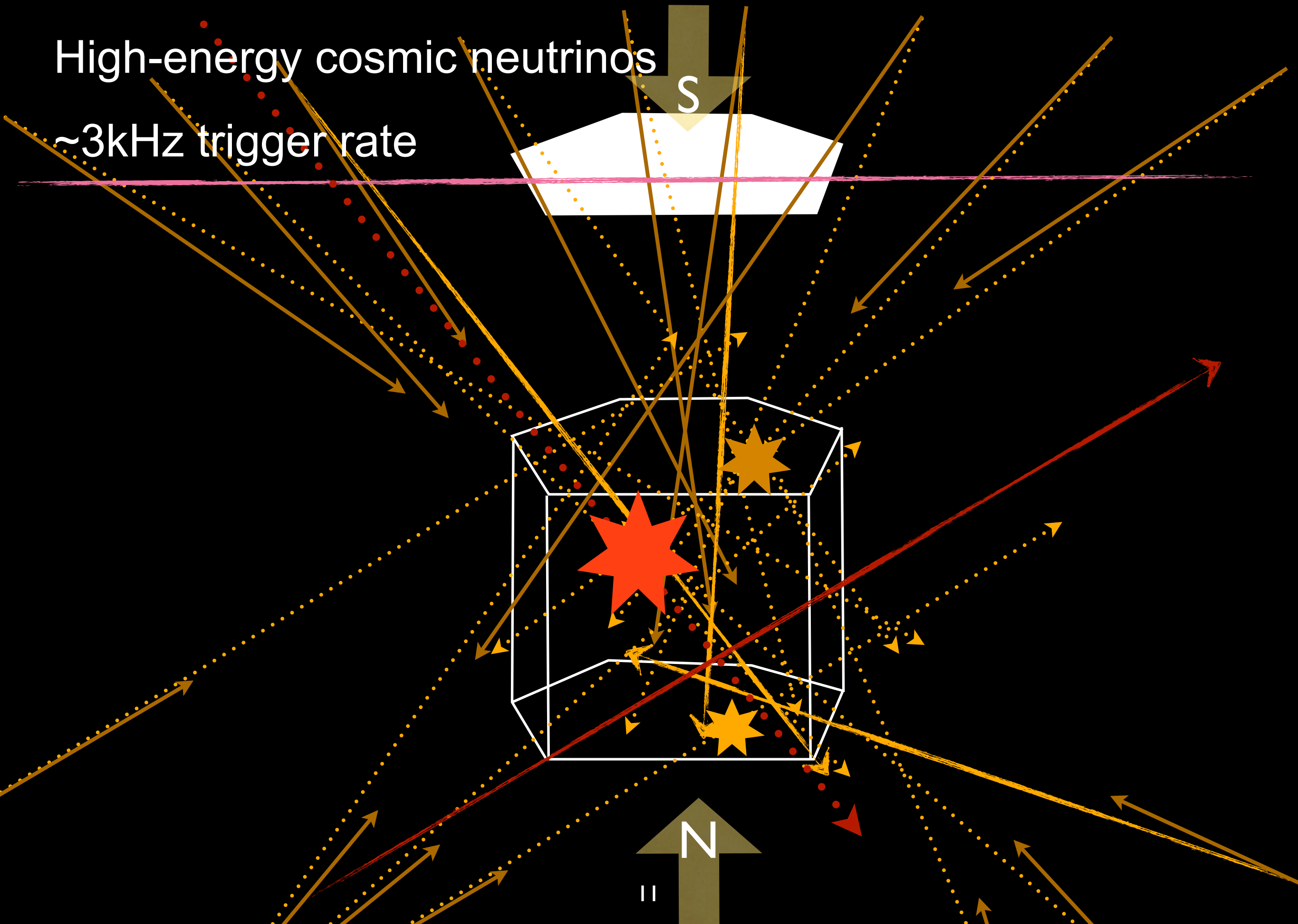
December 2010





High-energy cosmic neutrinos

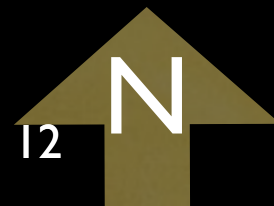
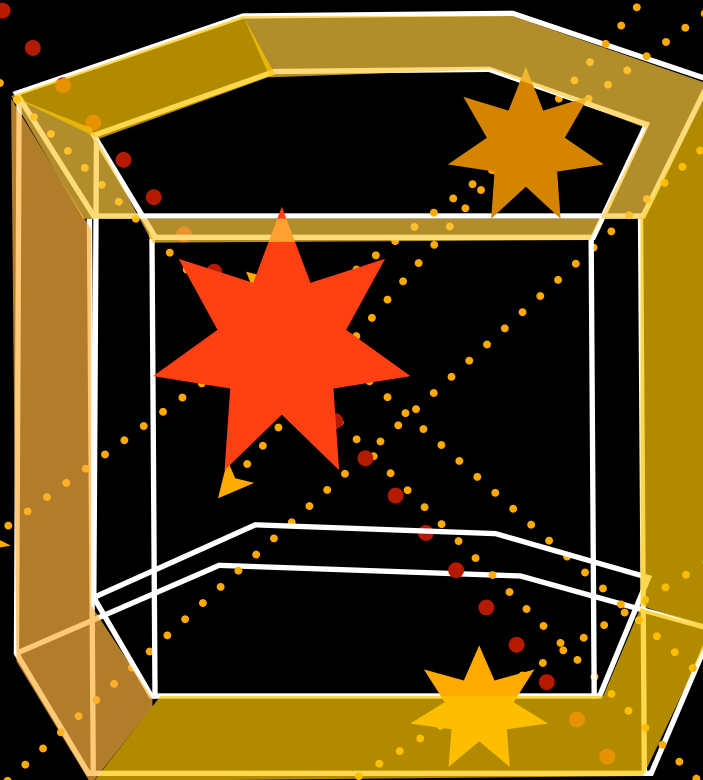
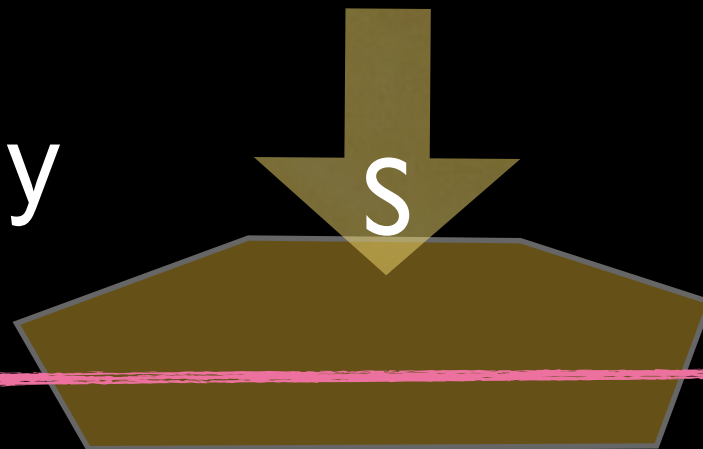
~3kHz trigger rate



Containment strategy

Cascade-like
favored

VETO

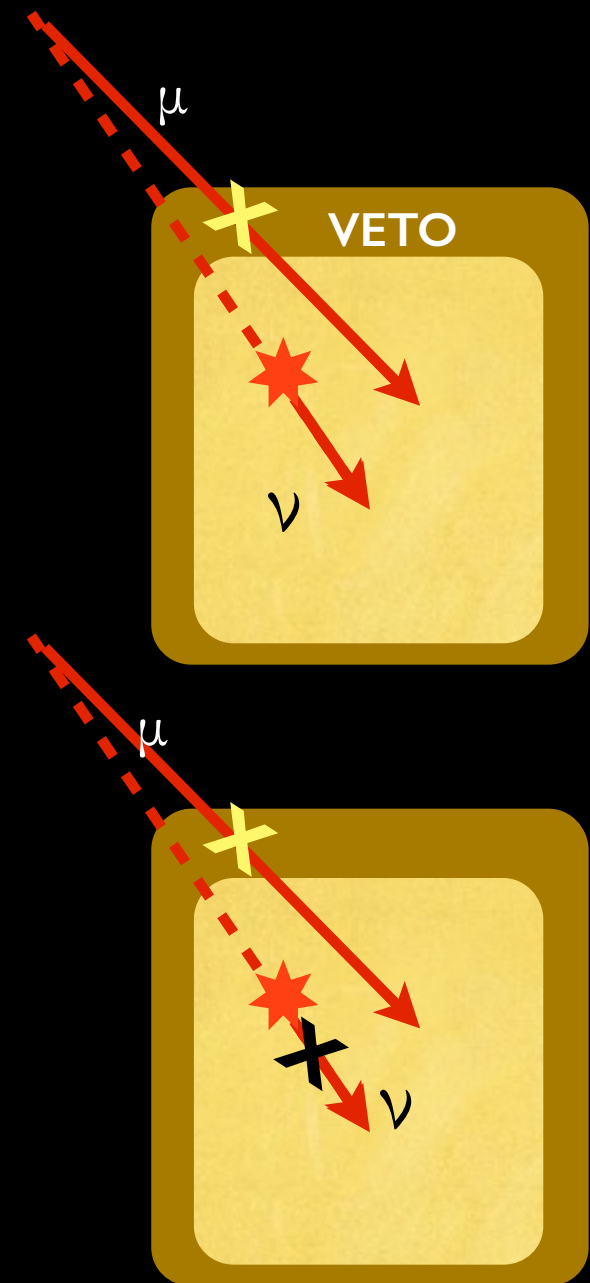
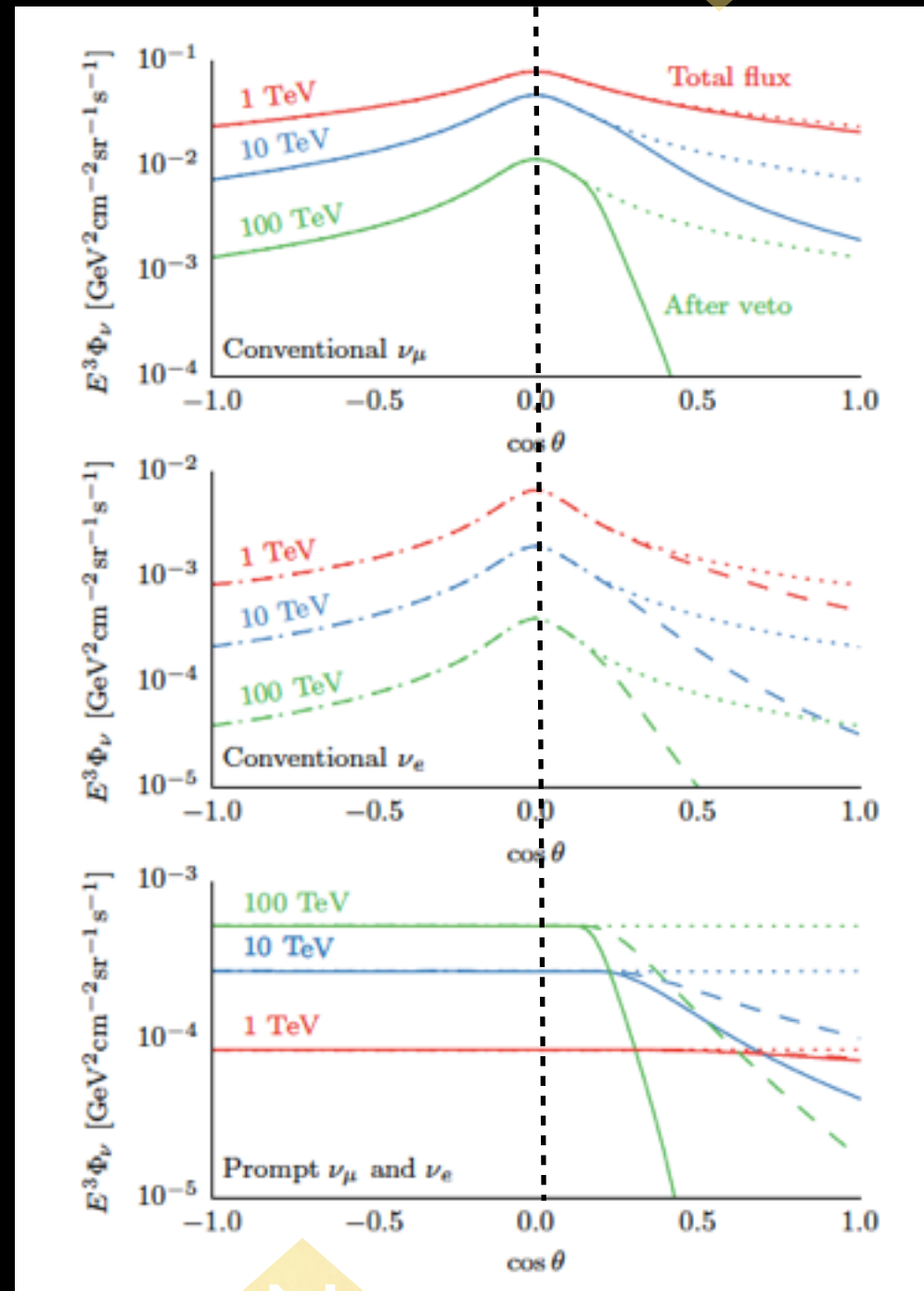


Atmospheric Neutrinos VETO



[S. Schönert, T. K. Gaisser, E. R.,
O. Schulz, PRD 79 (2009), 10.1103]

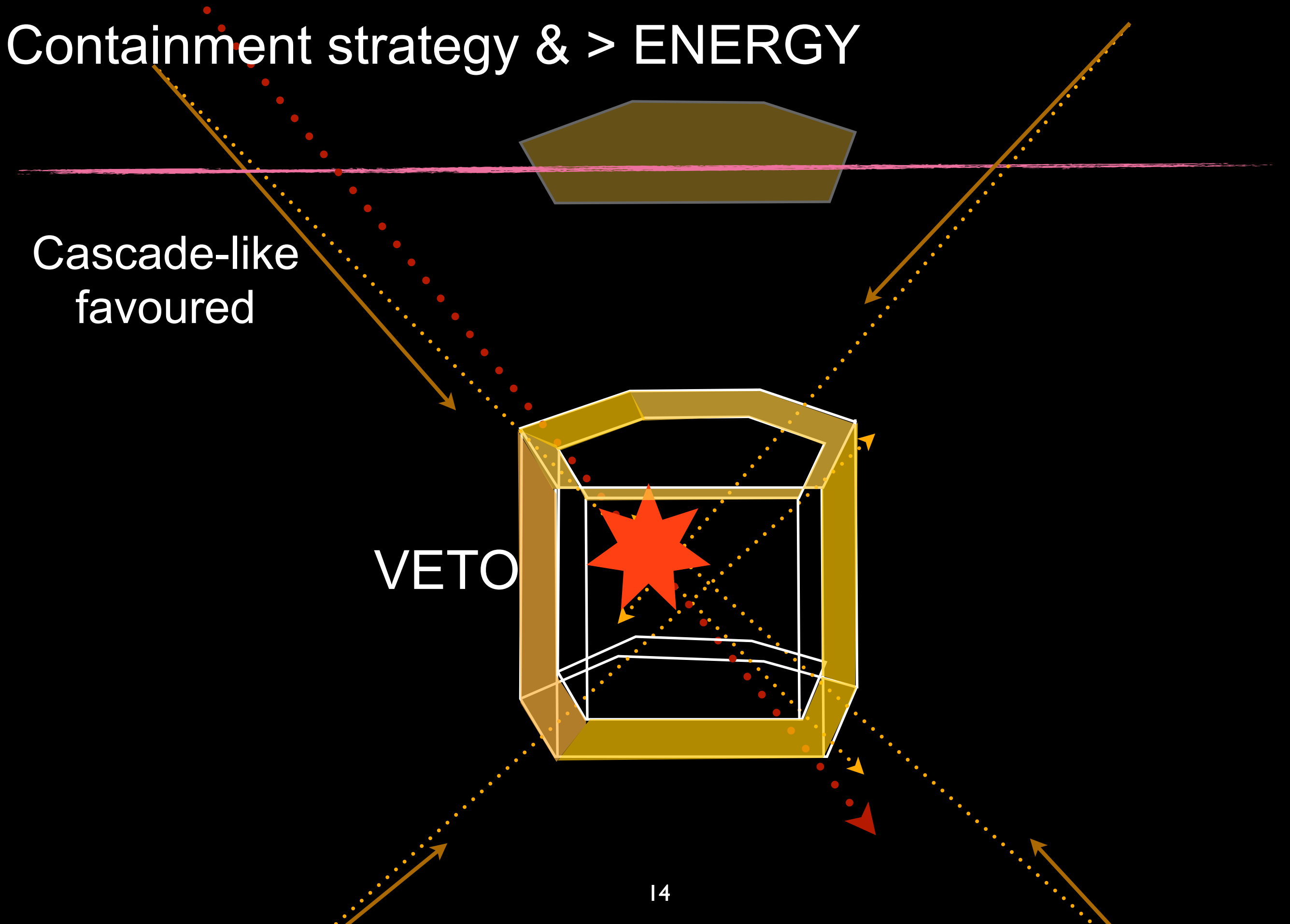
[T. K. Gaisser, K. Jero, A. Karle, and
J. van Santen, Phys. Rev. D90 no. 2,
(2014) 023009, arXiv:1405.0525]



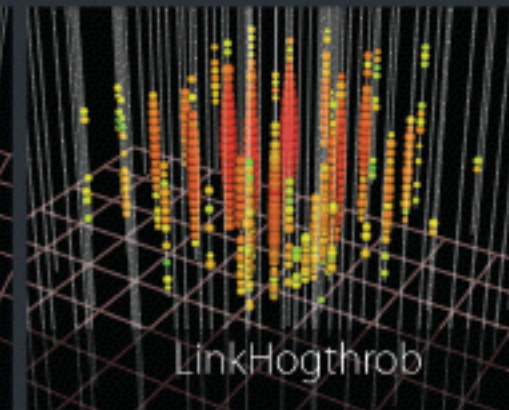
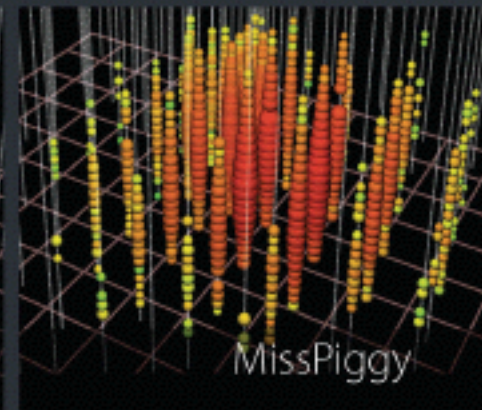
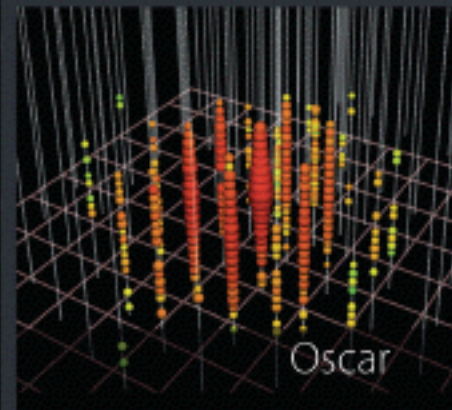
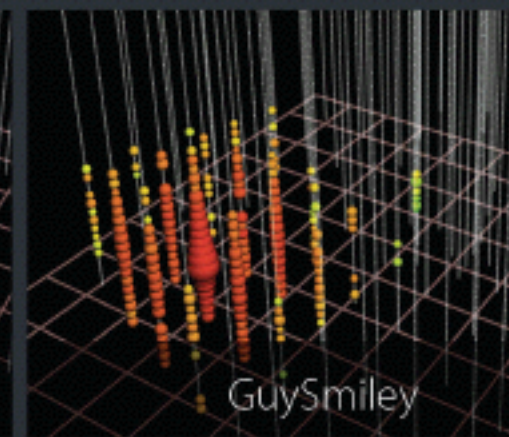
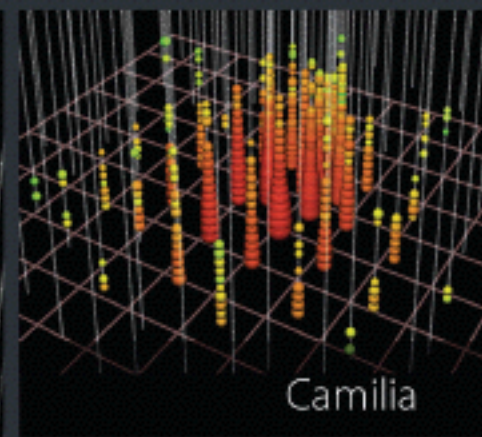
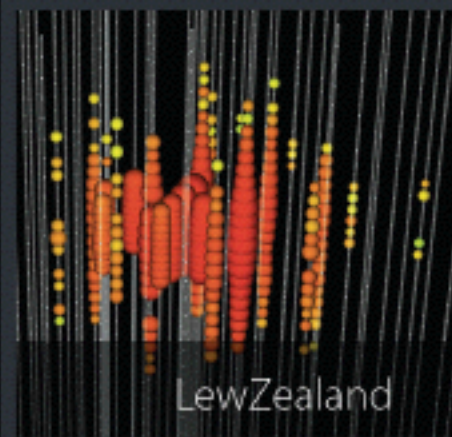
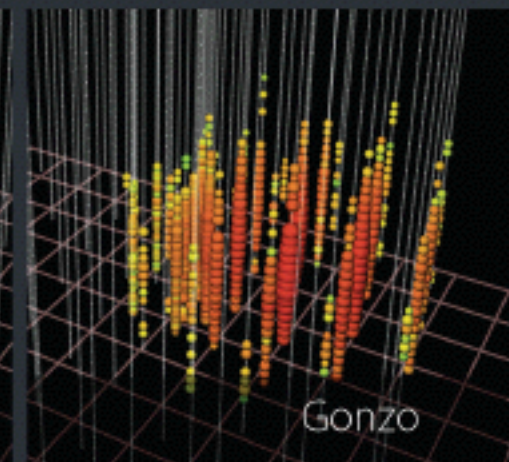
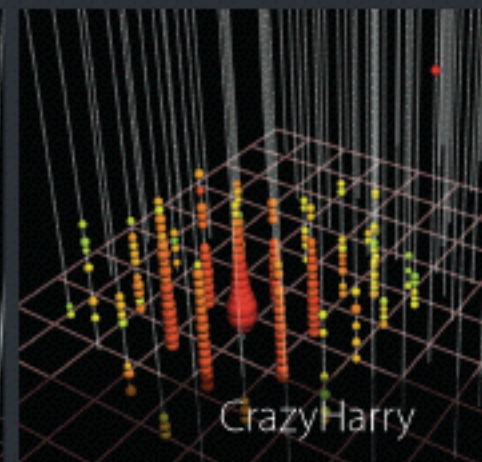
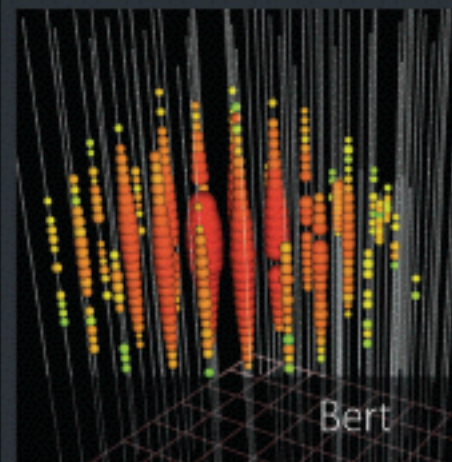
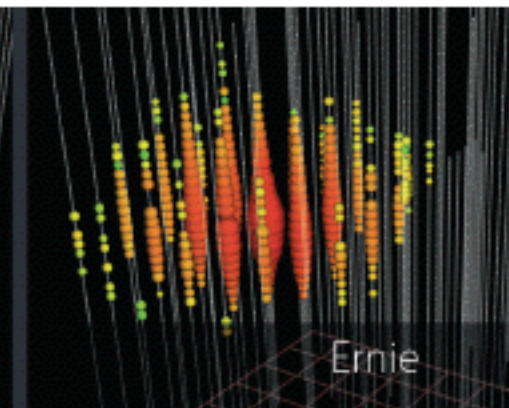
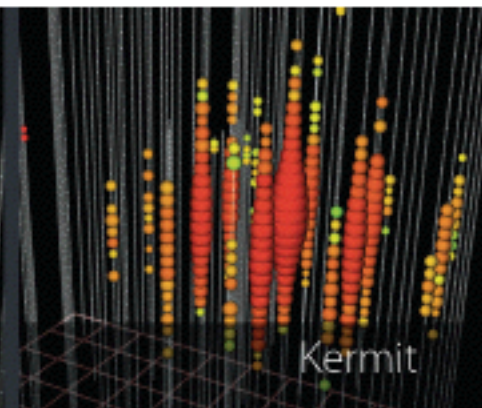
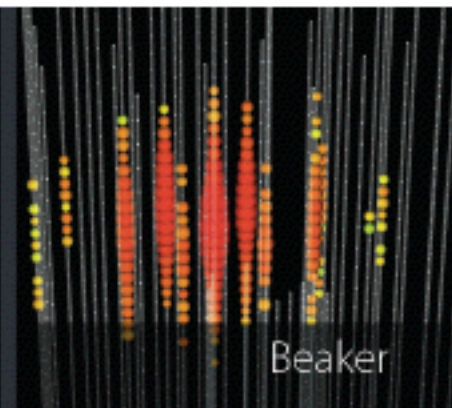
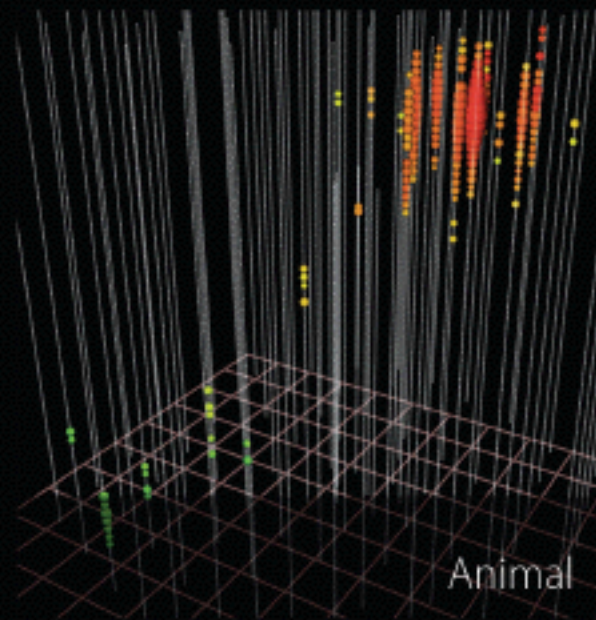
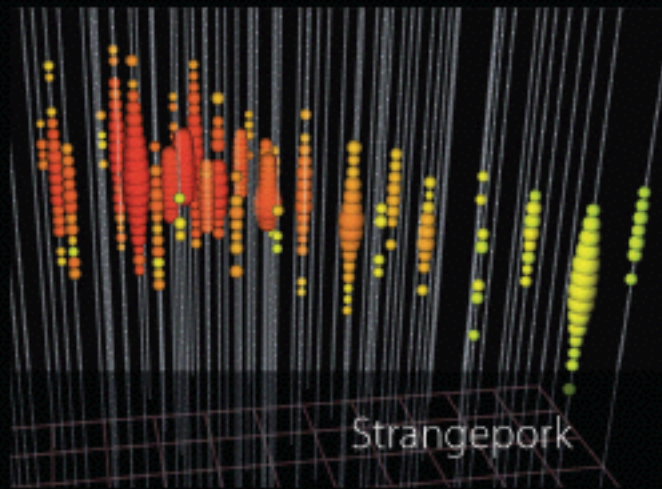
Containment strategy & $> \text{ENERGY}$

Cascade-like
favoured

VETO



~~37~~ 28 High Energy Events 54 Events

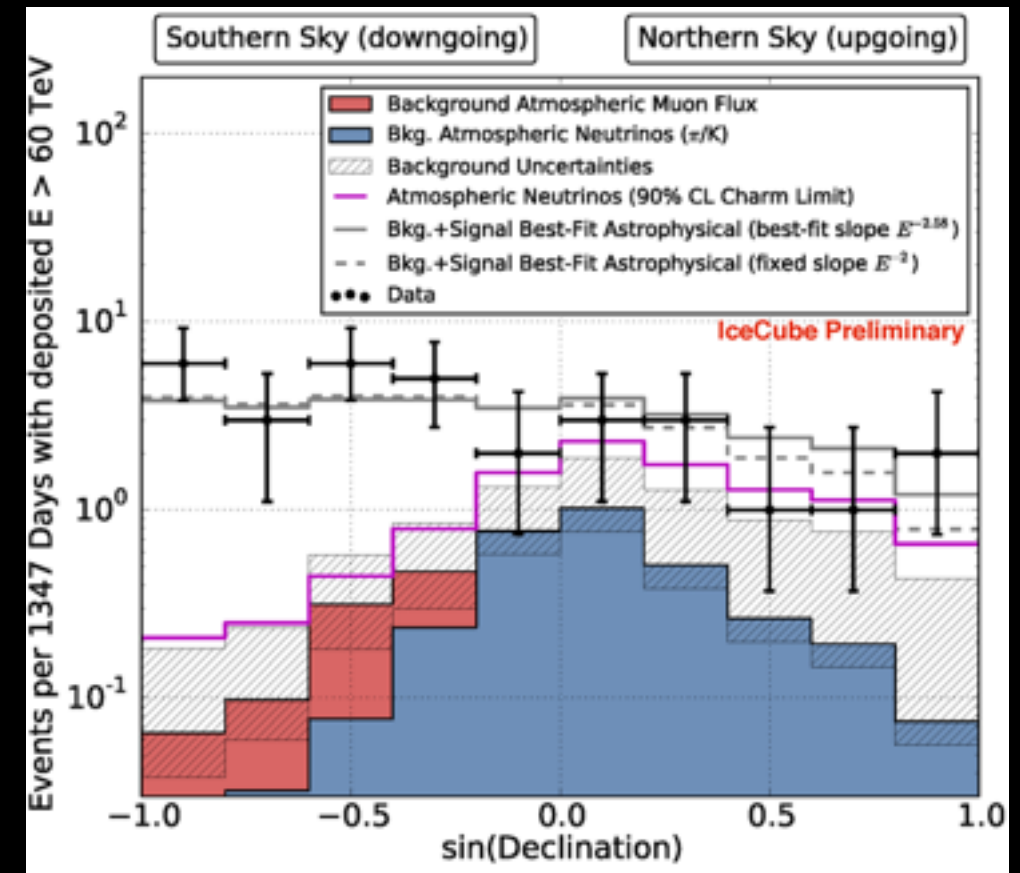
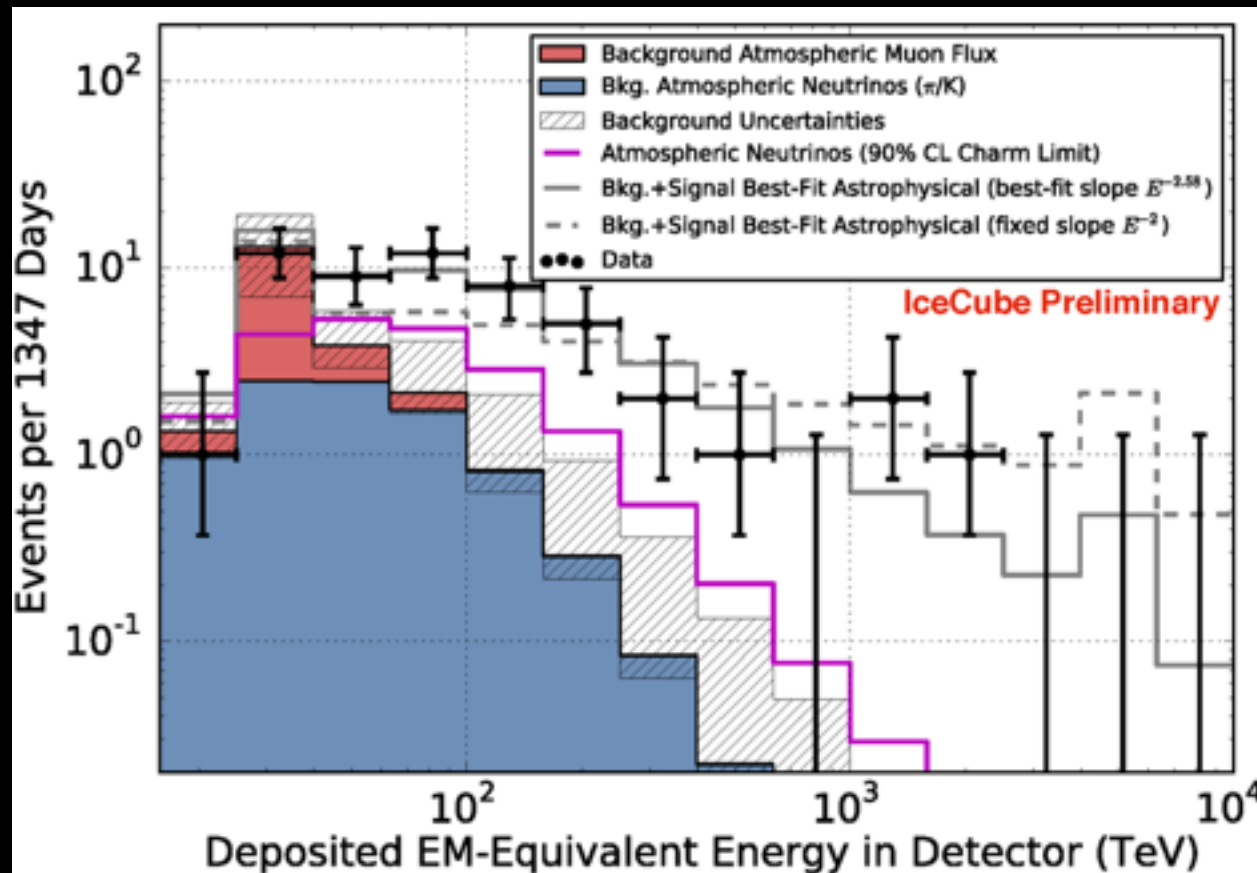


HE Cosmic Neutrinos from IceCube: 4 years

Best fit assuming E^{-2} (not a very good fit anymore):

$0.84 \pm 0.3 \cdot 10^{-8} E^{-2} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. Best fit spectral index: $E^{-2.58}$

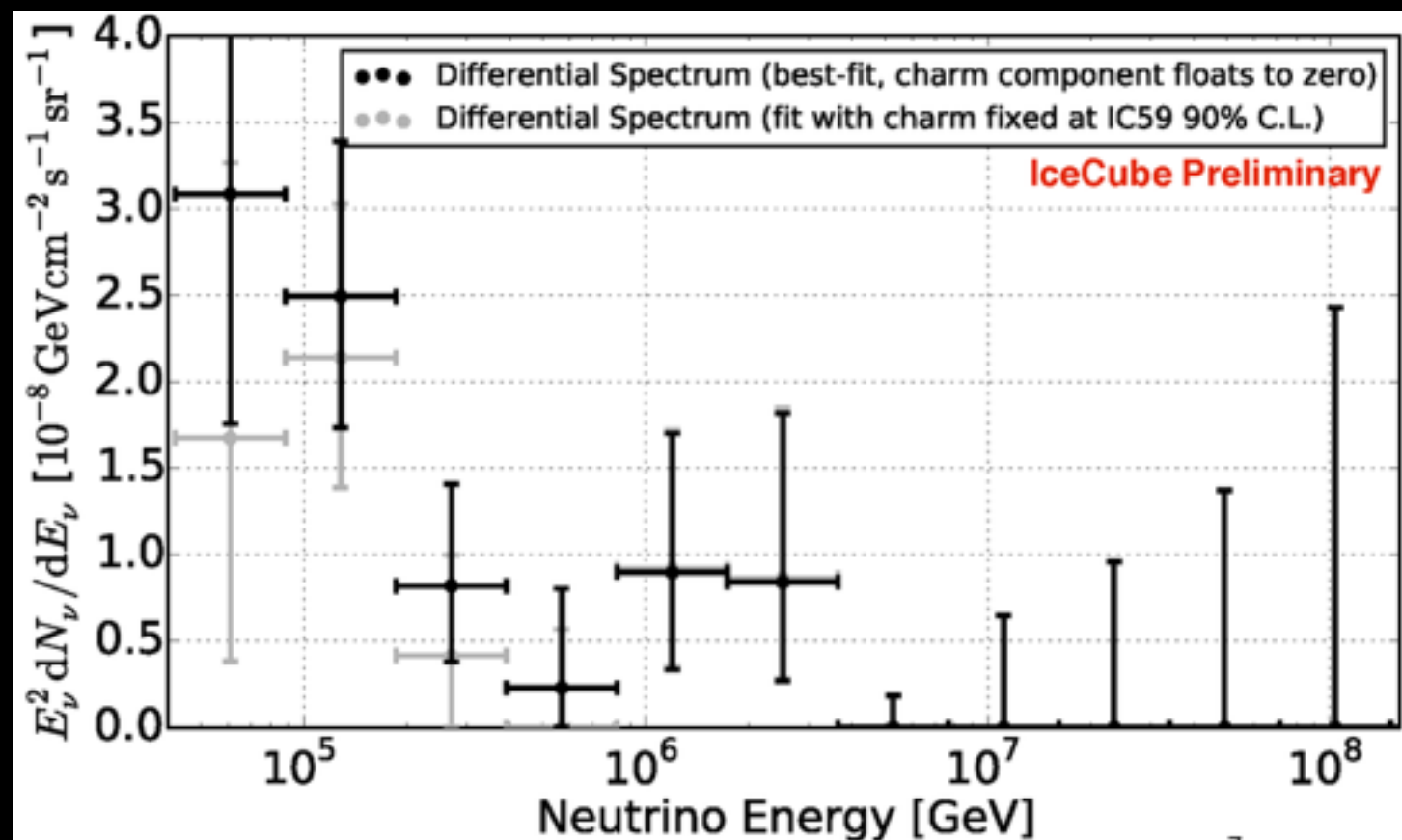
> 5 SIGMA



[The IceCube Collaboration, 2014, PRL]

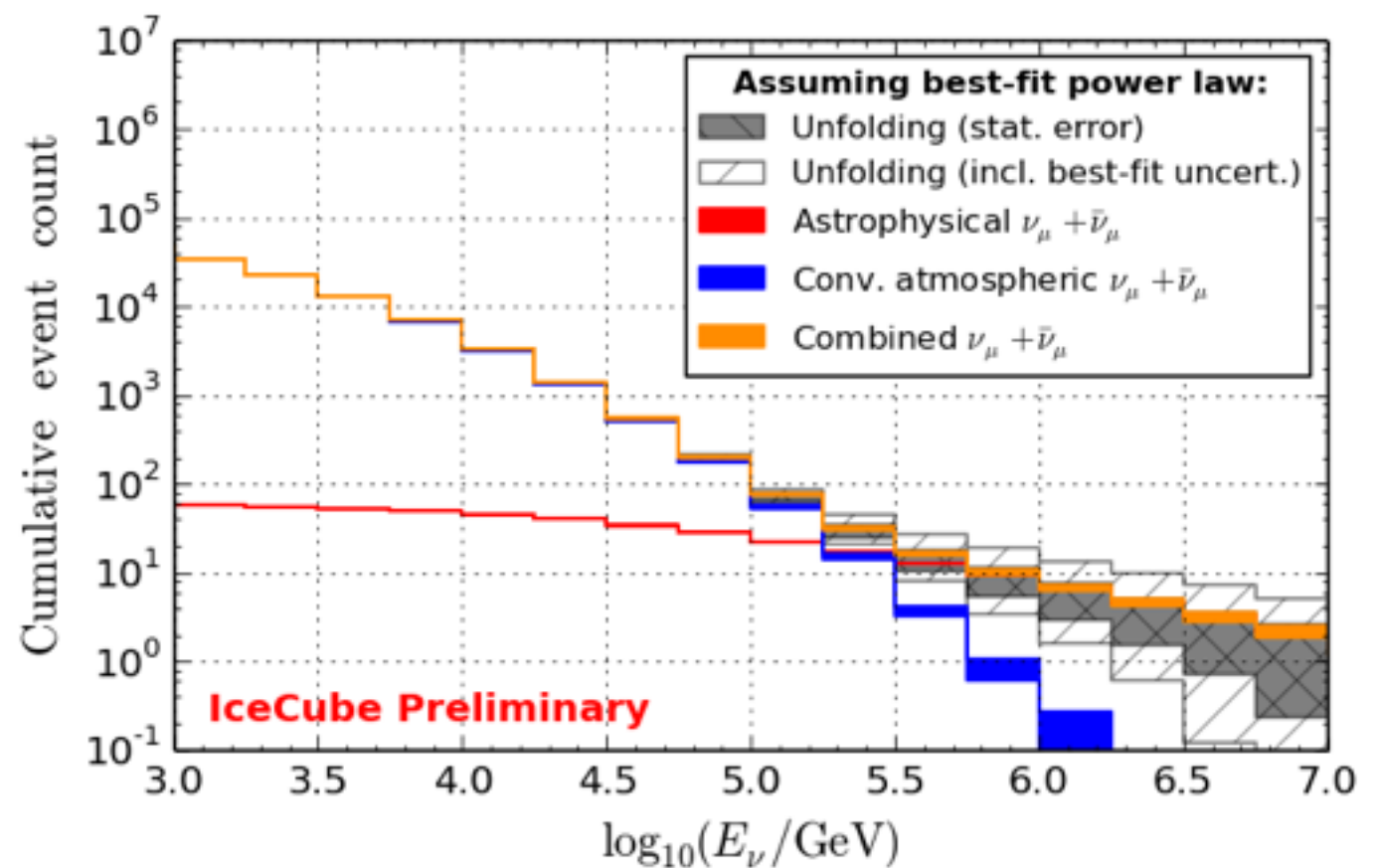
[The IceCube Collaboration, 2013, Science]

Spectral fit, starting event analysis

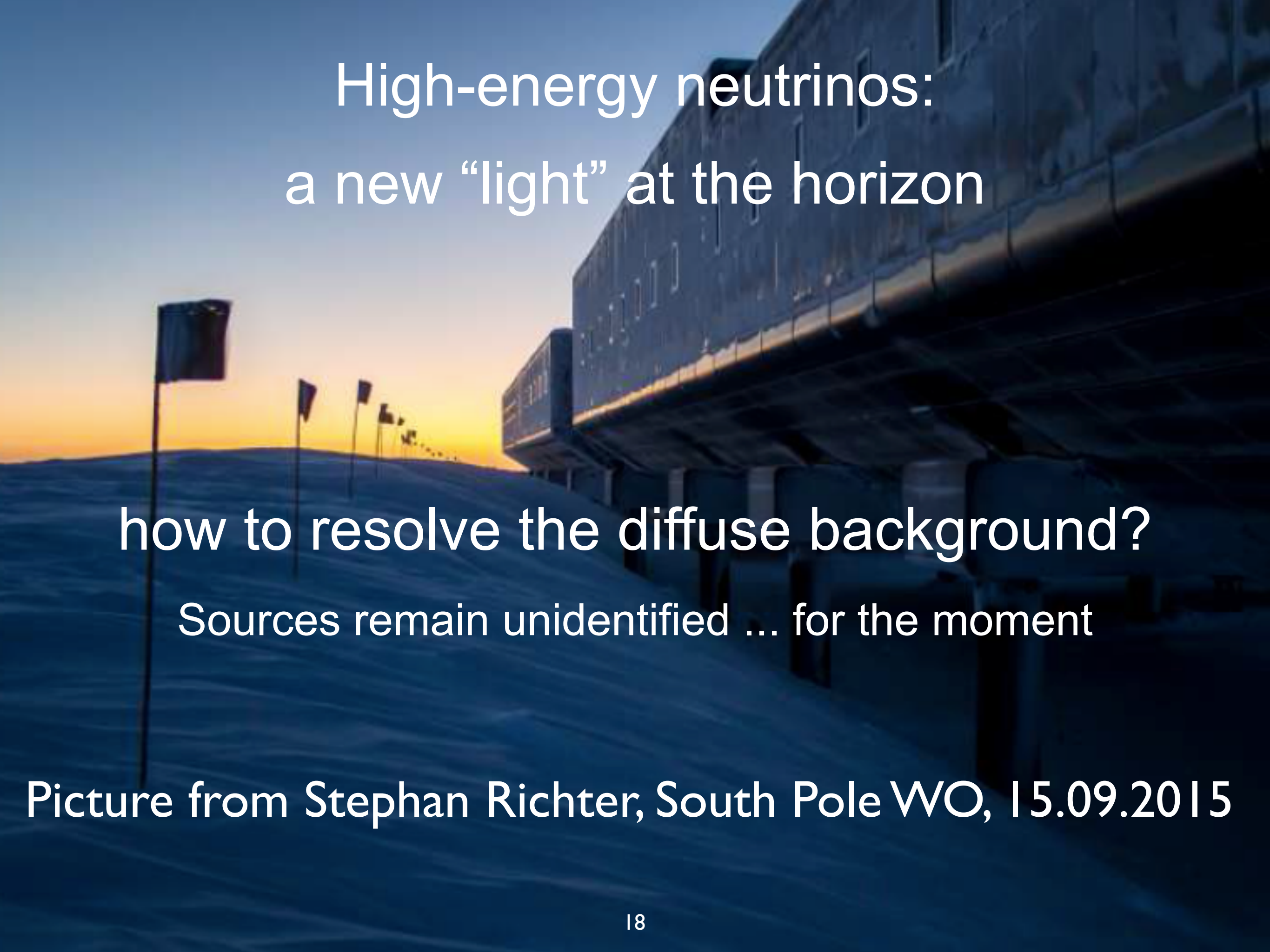


Spectral fit,
through-going event analysis

Independent channels



[The IceCube Collaboration, 2015, PRL]

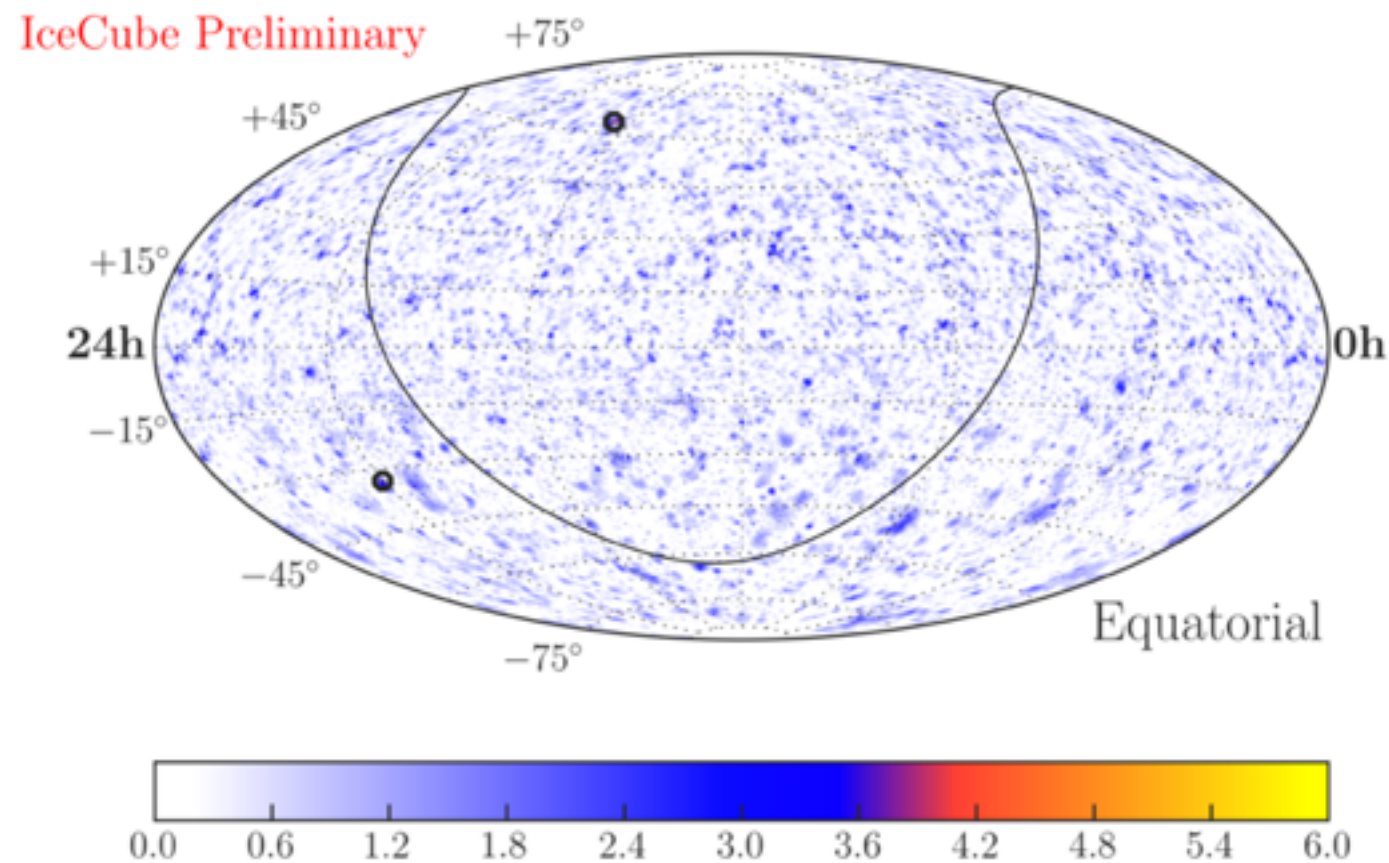


High-energy neutrinos: a new “light” at the horizon

how to resolve the diffuse background?

Sources remain unidentified ... for the moment

Picture from Stephan Richter, South Pole WFO, 15.09.2015



Likelihood search based on:

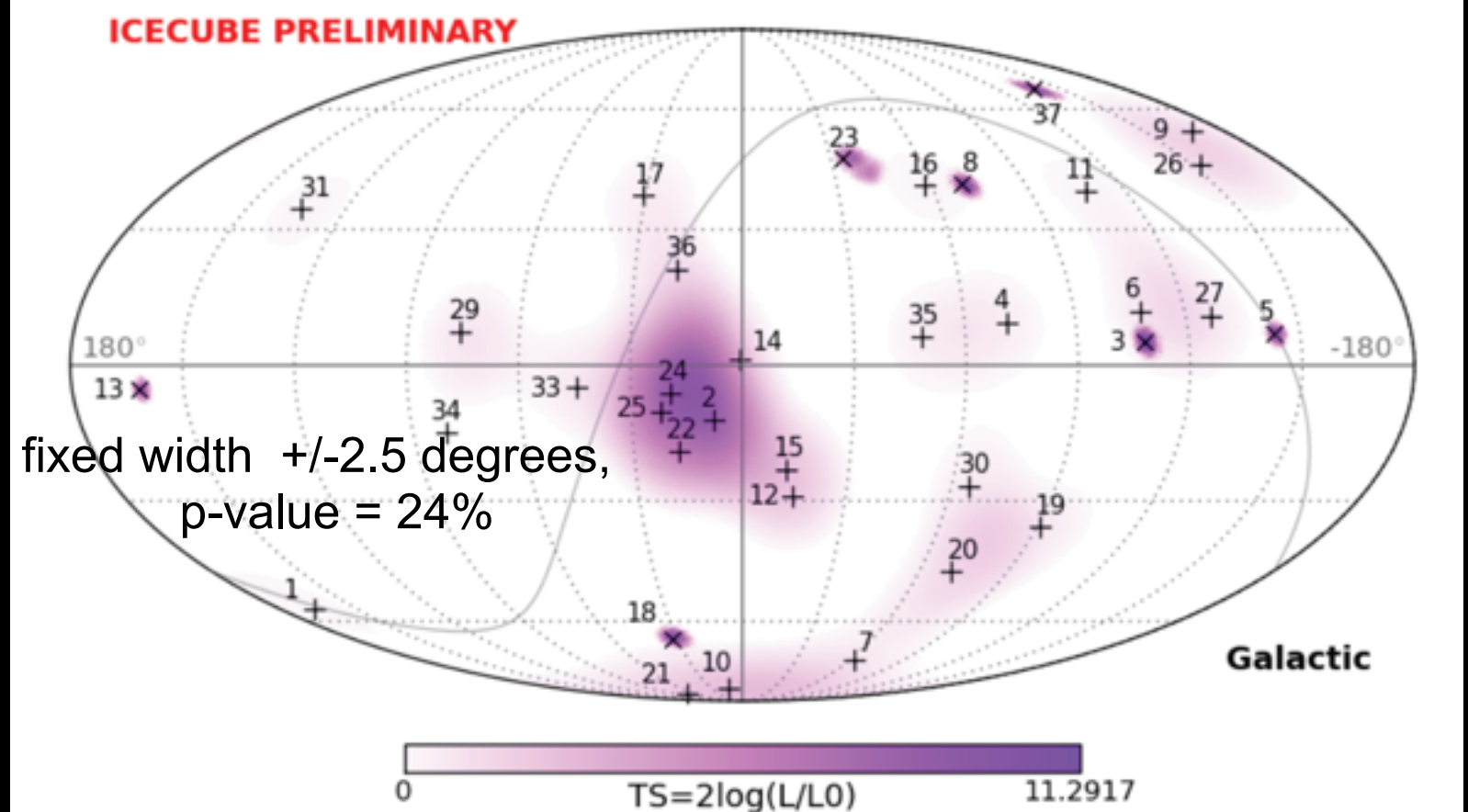
- Full pdf of the track events
- Energy weight
- Time optimized

Likelihood search based on:

- Full pdf of the starting cascades
- No energy weight
- Time optimized

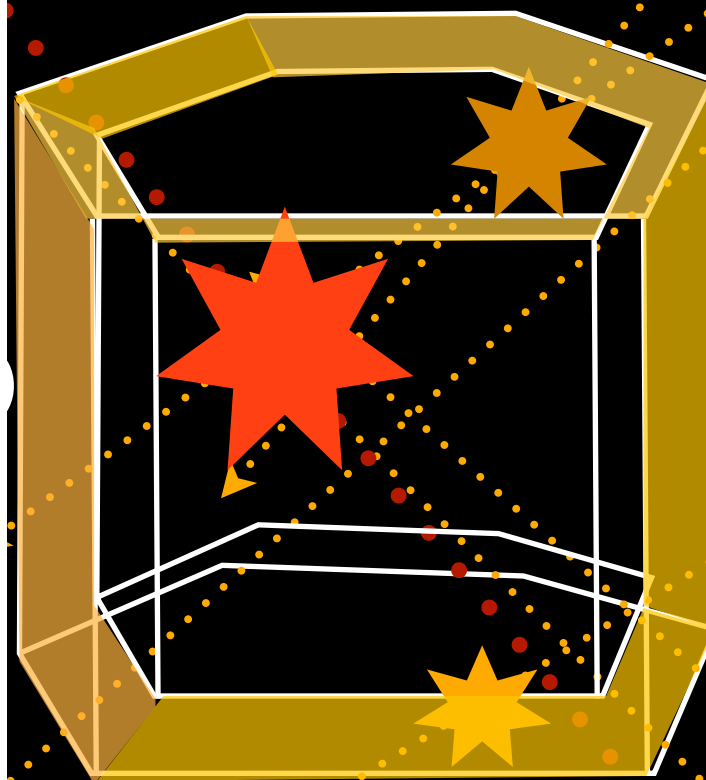
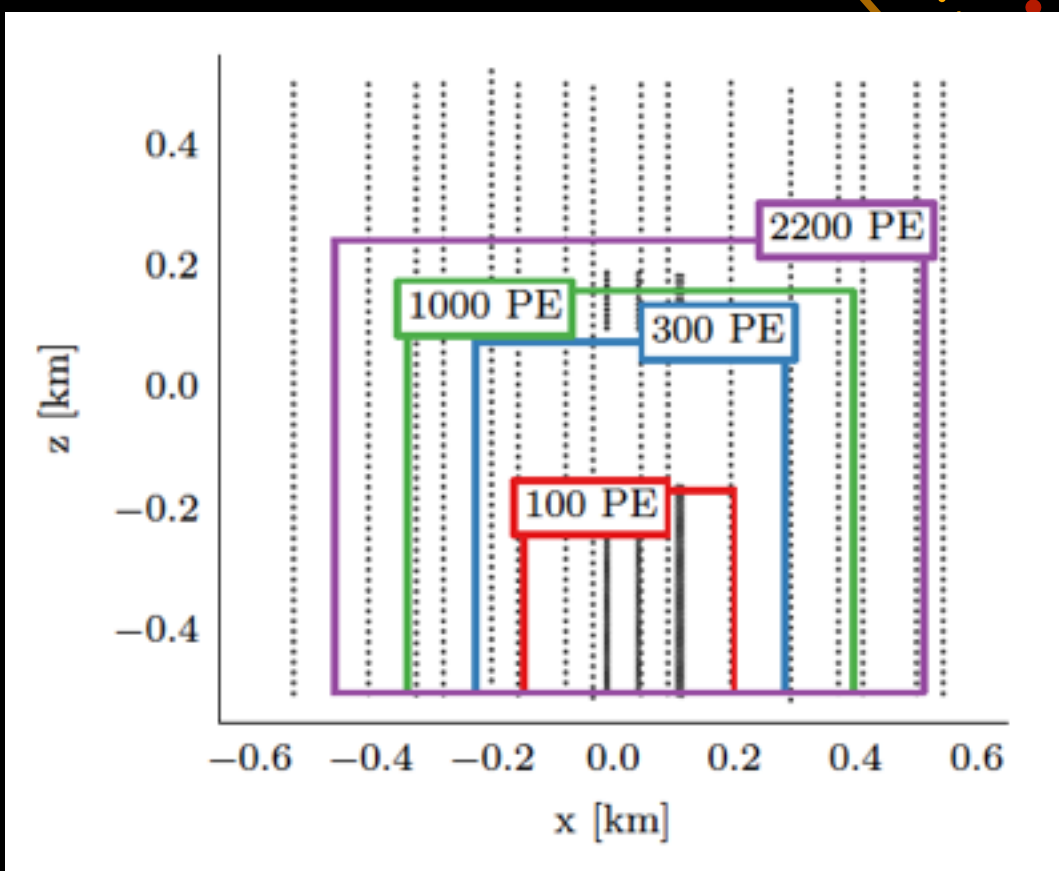
S. Coenders et al, ICRC'15

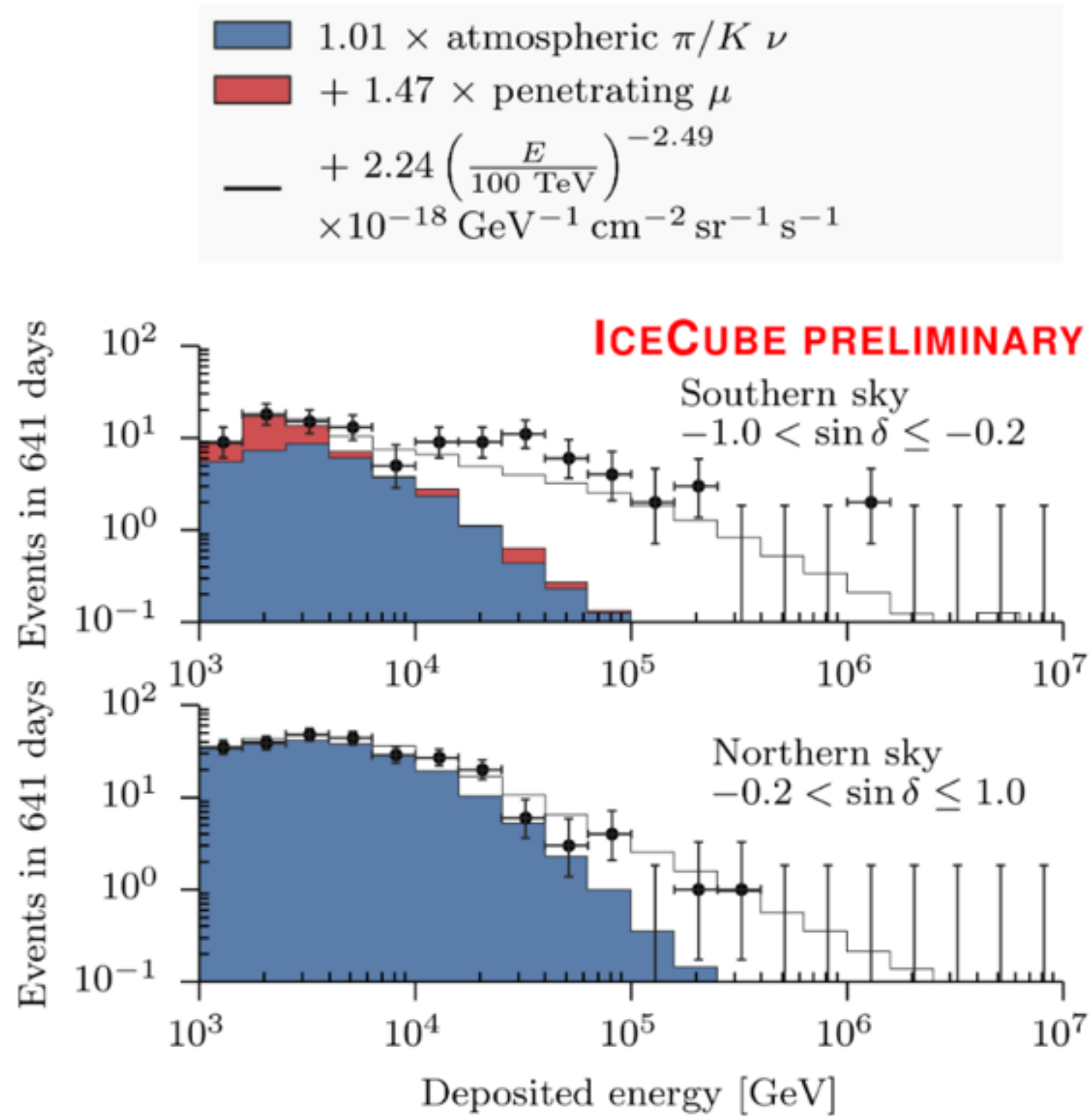
no significant cluster
diffuse regime



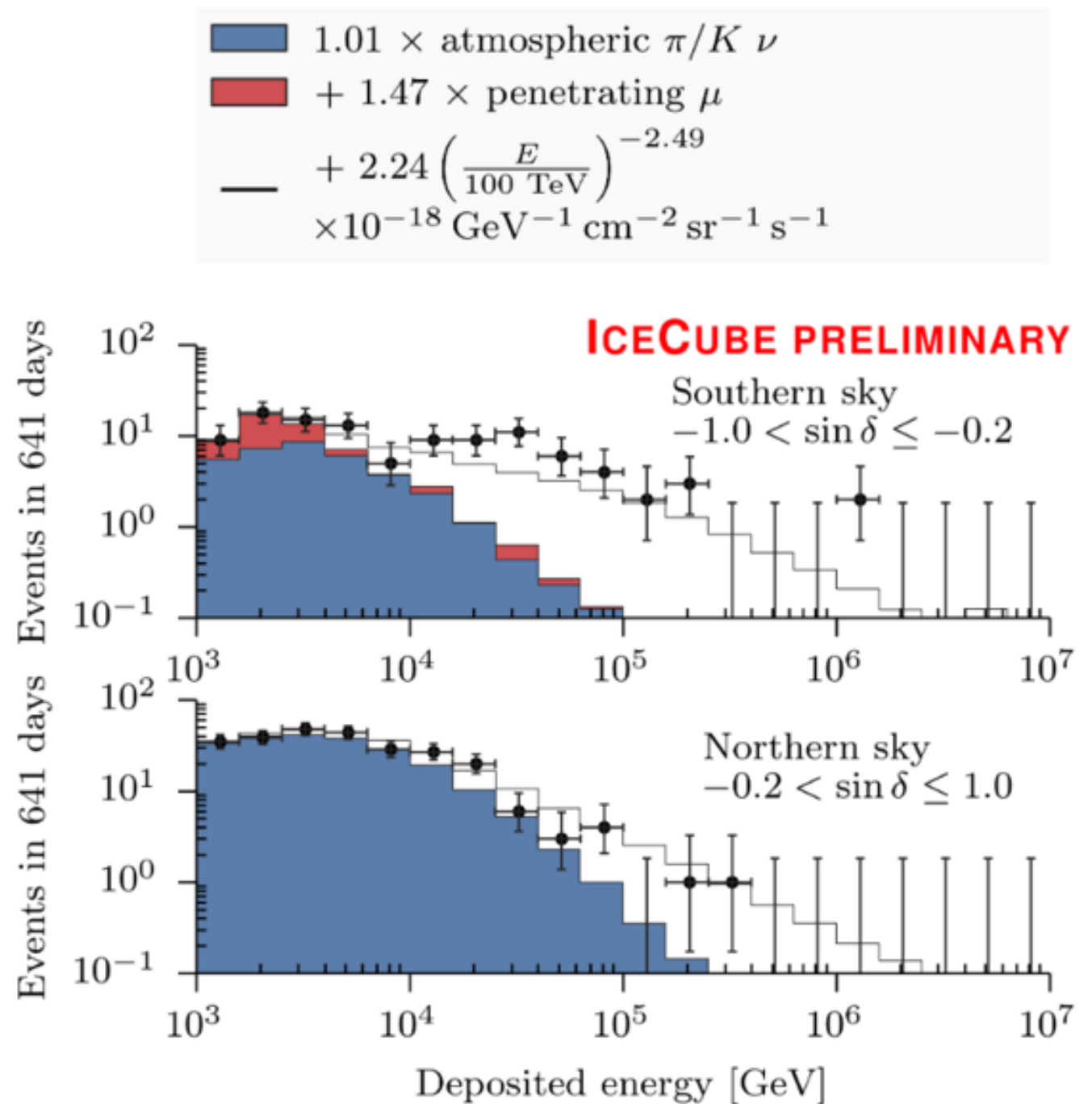
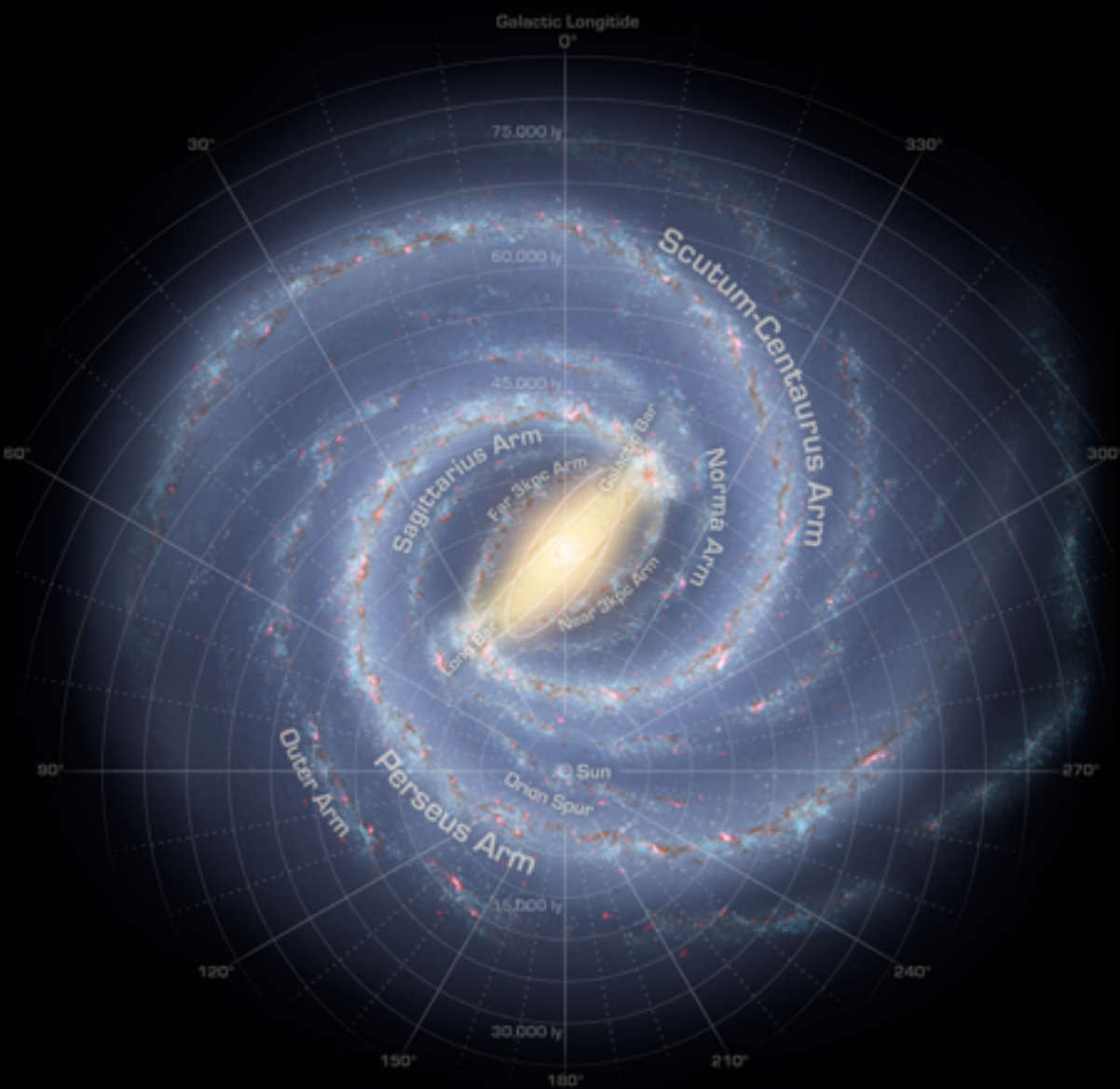
Containment strategy: extension to lower energy

[IceCube, Phys. Rev. D 91, 022001]





My favourite scenario No.1



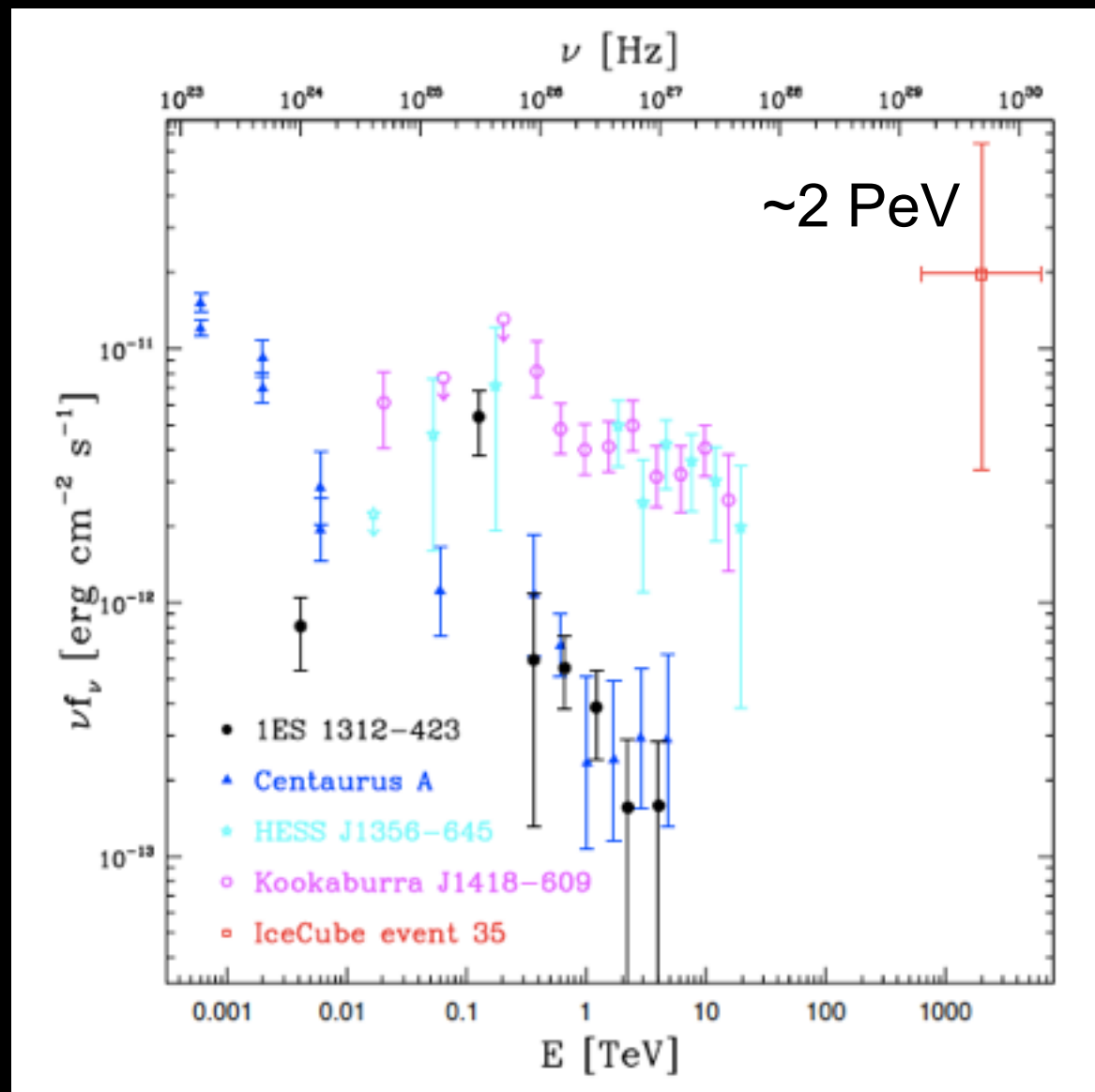
[IceCube, Phys. Rev. D 91, 022001]

My favourite scenario No.2

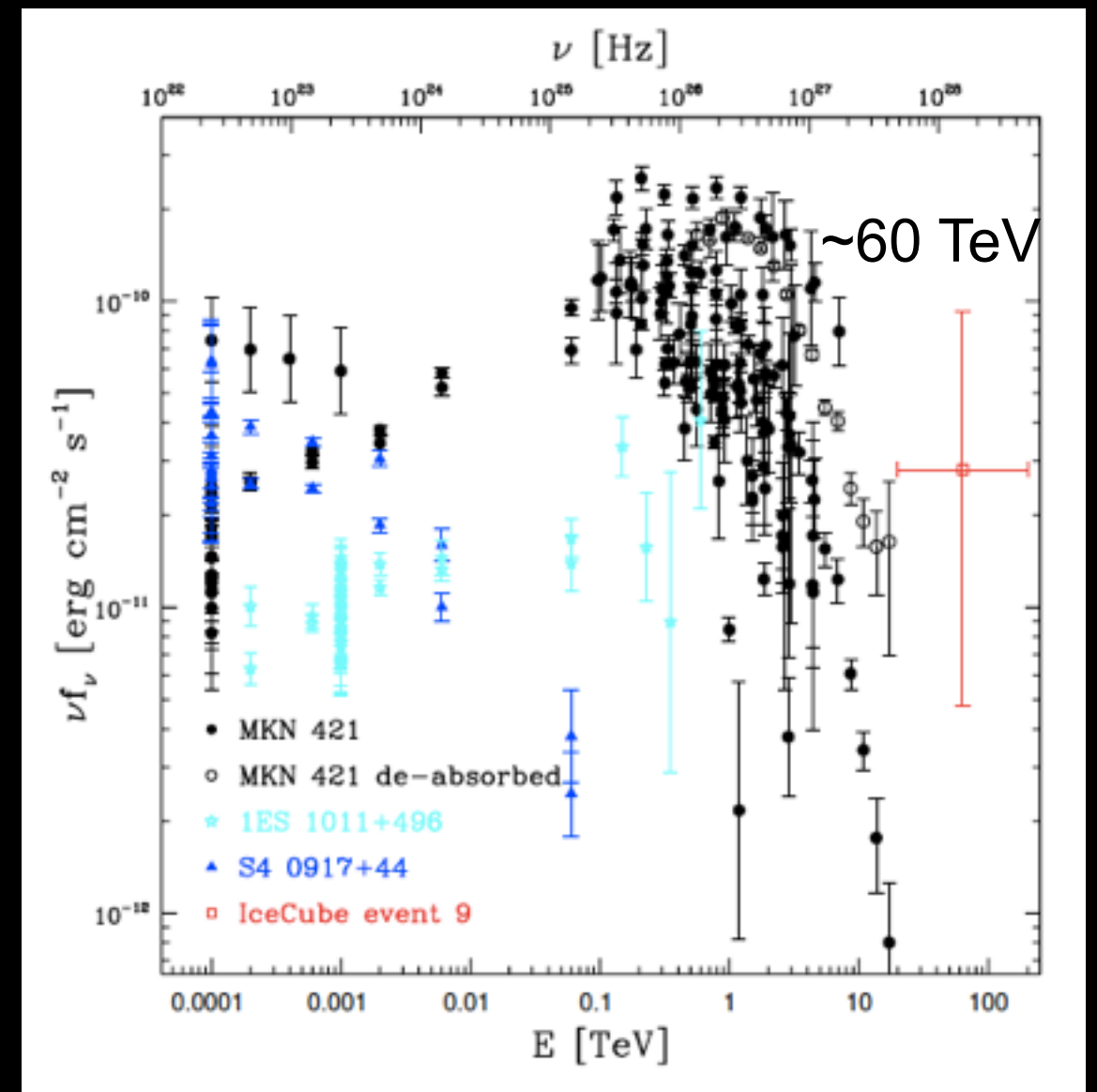
assuming gamma-neutrino connection

[P. Padovani and E.R., MNRAS 2014]

how many can be “connected”? **hybrid-SED**



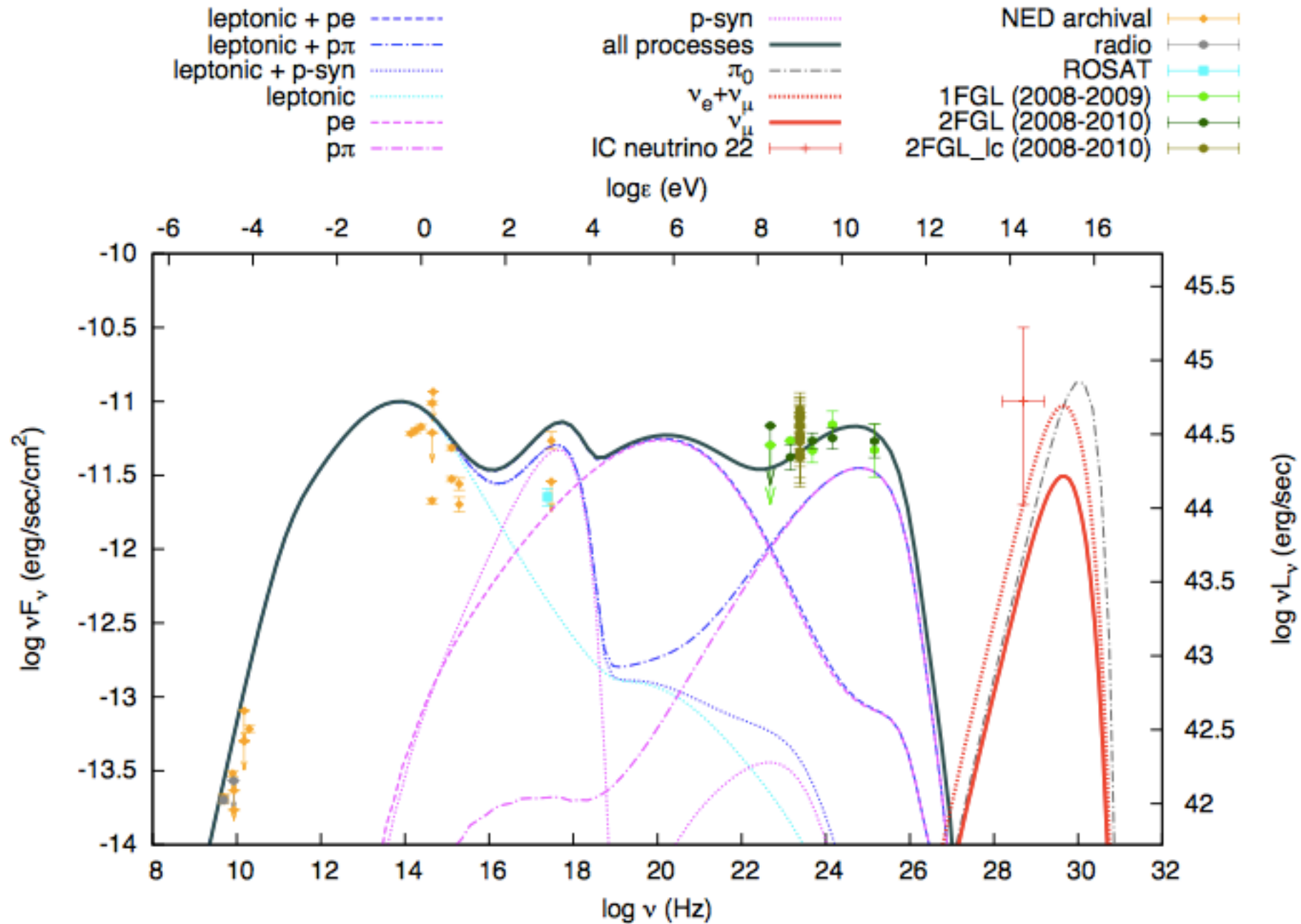
No plausible counterparts



Two plausible counterparts

What about models?

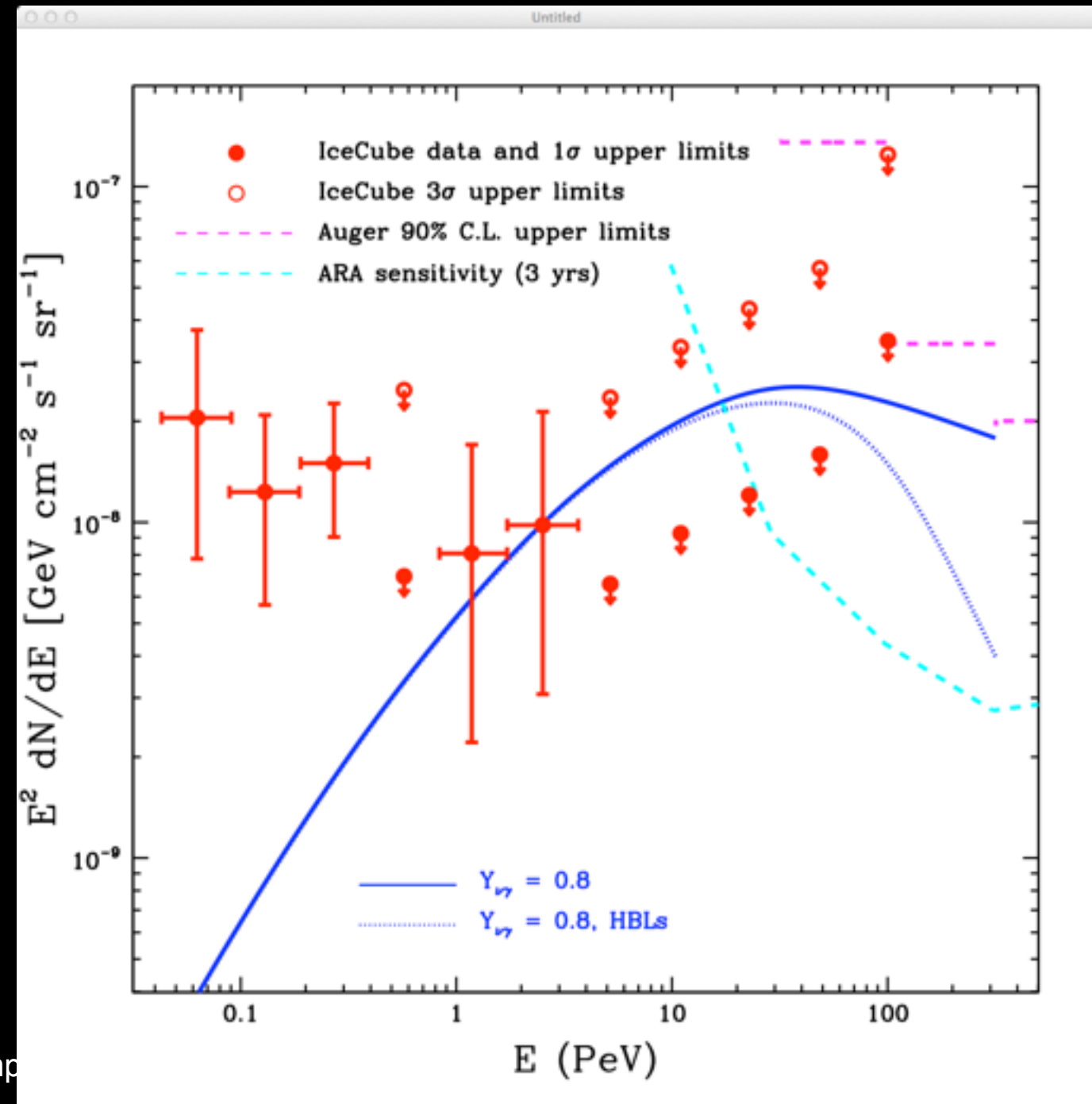
M. Petropoulou, S. Dimitrakoudis, P. Padovani, A. Mastichiadis, E. R., MNRAS 2015



Diffuse neutrino background from BL Lacs

P. Padovani, M. Petropoulou, P. Giommi, E. R.
arXiv:1506.09135, accepted for publication in MNRAS

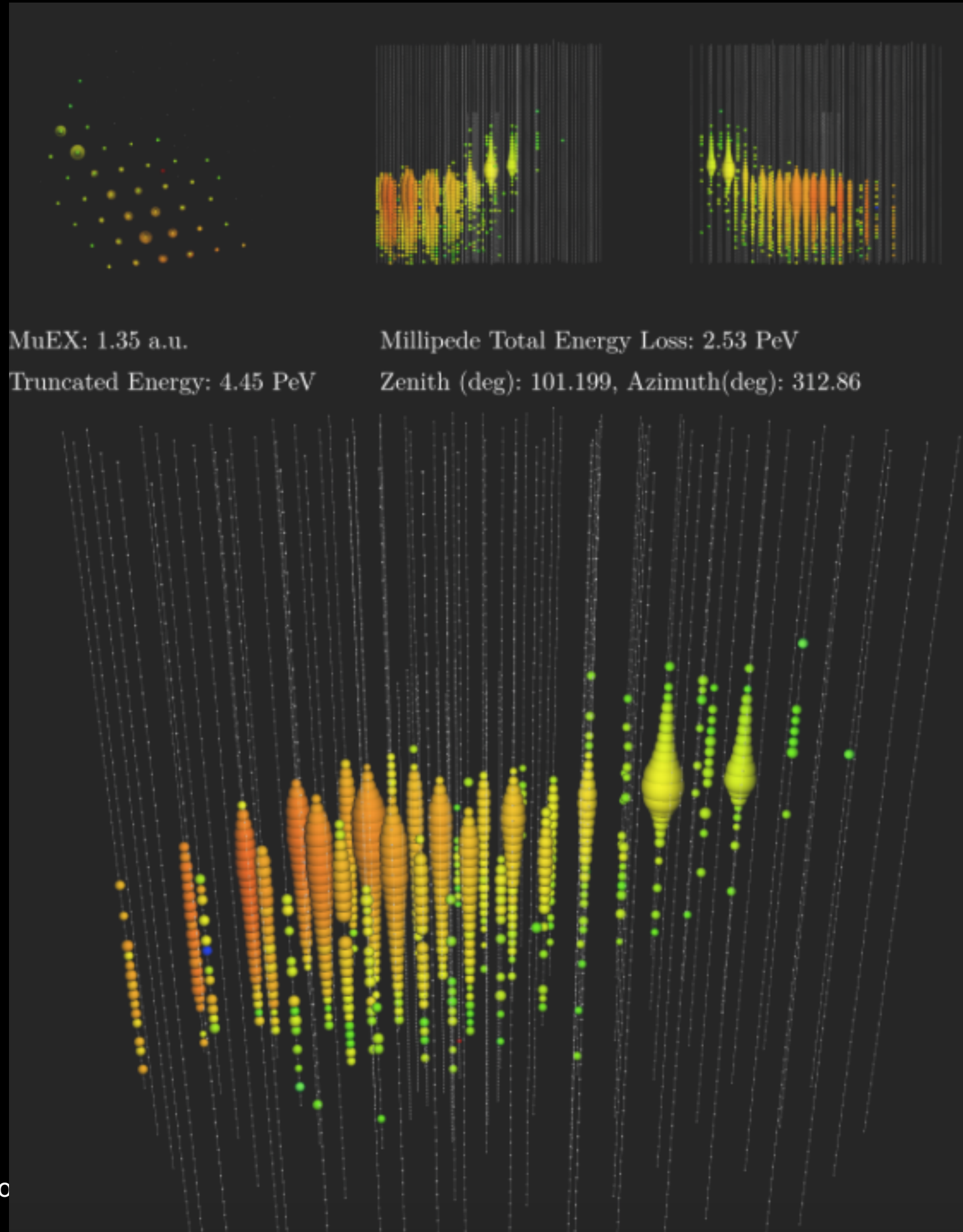
good explanation at high
energy but need of
something else for lower
energy



ATel #7856

We observed a muon neutrino event with an energy of multiple PeV originating from a neutrino interaction in the vicinity of the IceCube detector. IceCube is a cubic-kilometer neutrino detector installed in the ice at the geographic South Pole mostly sensitive to neutrinos in the TeV-PeV energy range. The event is the highest-energy event in a search for a diffuse flux of astrophysical muon neutrinos using IceCube data recorded between May 2009 and May 2015. It was detected on June 11th 2014 (56819.204437 MJD) and deposited a total energy of 2.6 ± 0.3 PeV within the instrumented volume of IceCube, which is also a lower bound on the muon and neutrino energy. The reconstructed direction of the event (J2000.0) is R.A.: 110.34 deg and Decl.: 11.48 deg. For simulated events with the same topology, 99% of them are reconstructed better than 1 deg. The directional reconstruction uncertainty is smaller than 1 deg. The probability of this event being of atmospheric origin is less than 0.01%.

E. Resconi - XLV Internatio



The most probable scenario

Neutrino point source + diffuse + dark matter (?)

IceCube is “just” at the sensitivity level of a new landscape

To resolve the neutrino background we need

IceCube-Gen2

Picture from Stephan Richter, South Pole WOI, 15.09.2015

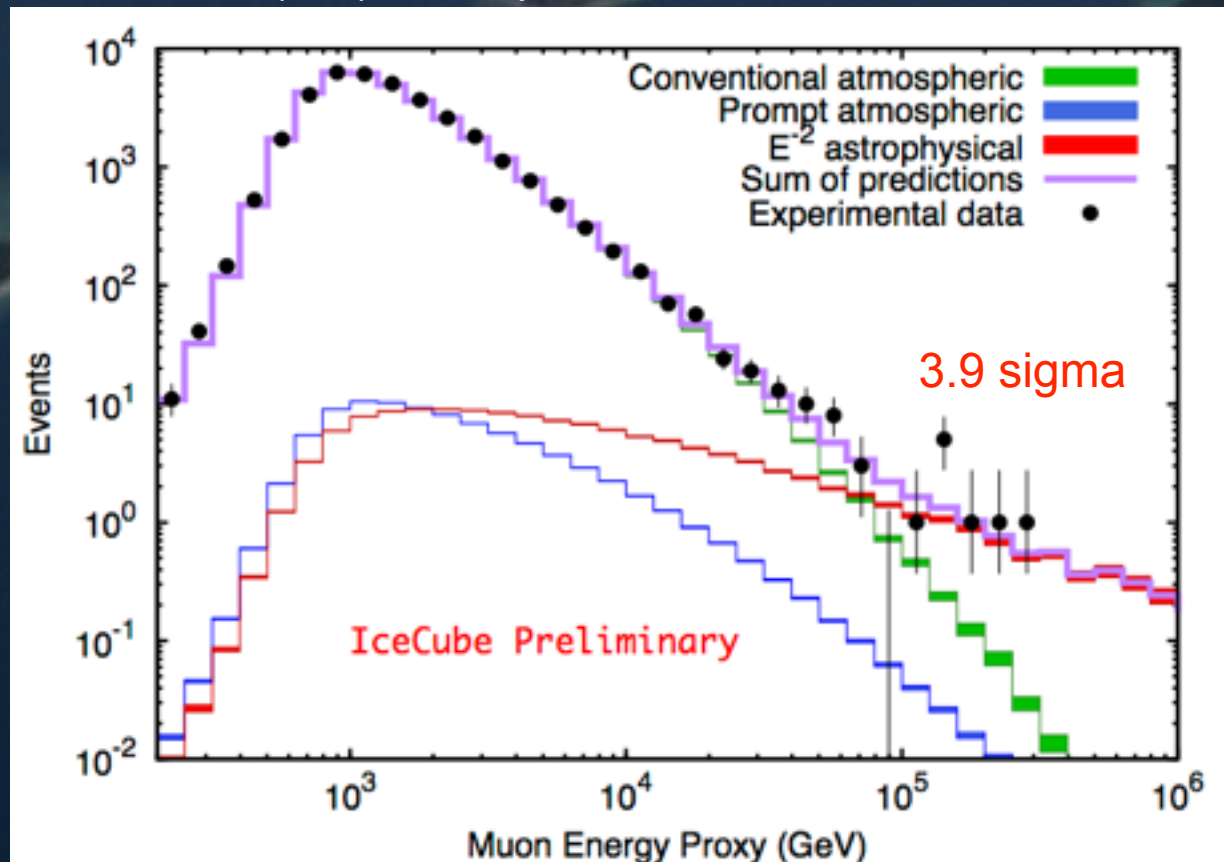
Picture from Erik Beiser, South Pole WO, 06.10.2015



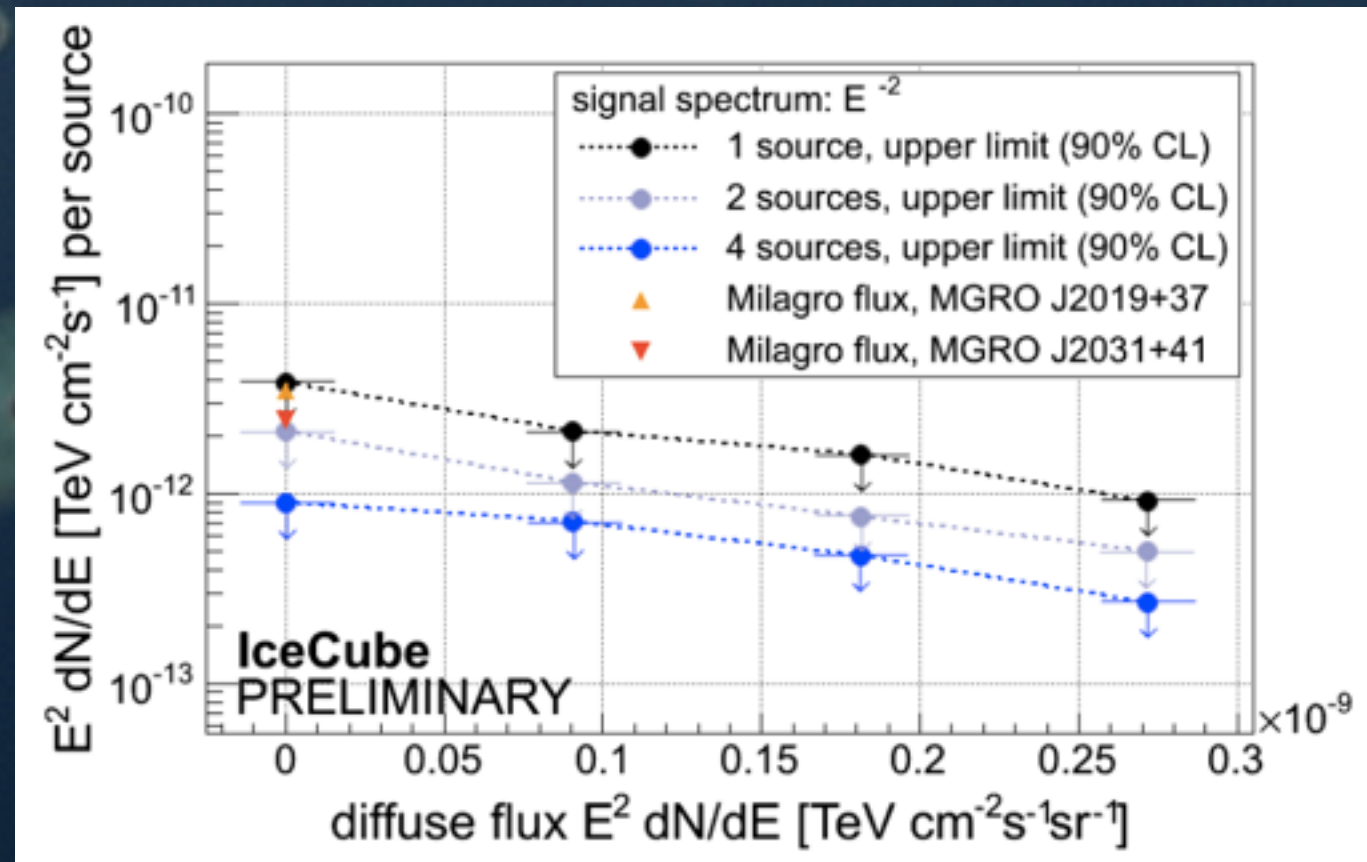
The galley prepared for Oktoberfest.

Track-like events identified via down-ward rejection strategy

$O(10^5)$ atmospheric neutrinos $> \text{TeV}$



[Chris Weaver for IceCube, APS 2014]



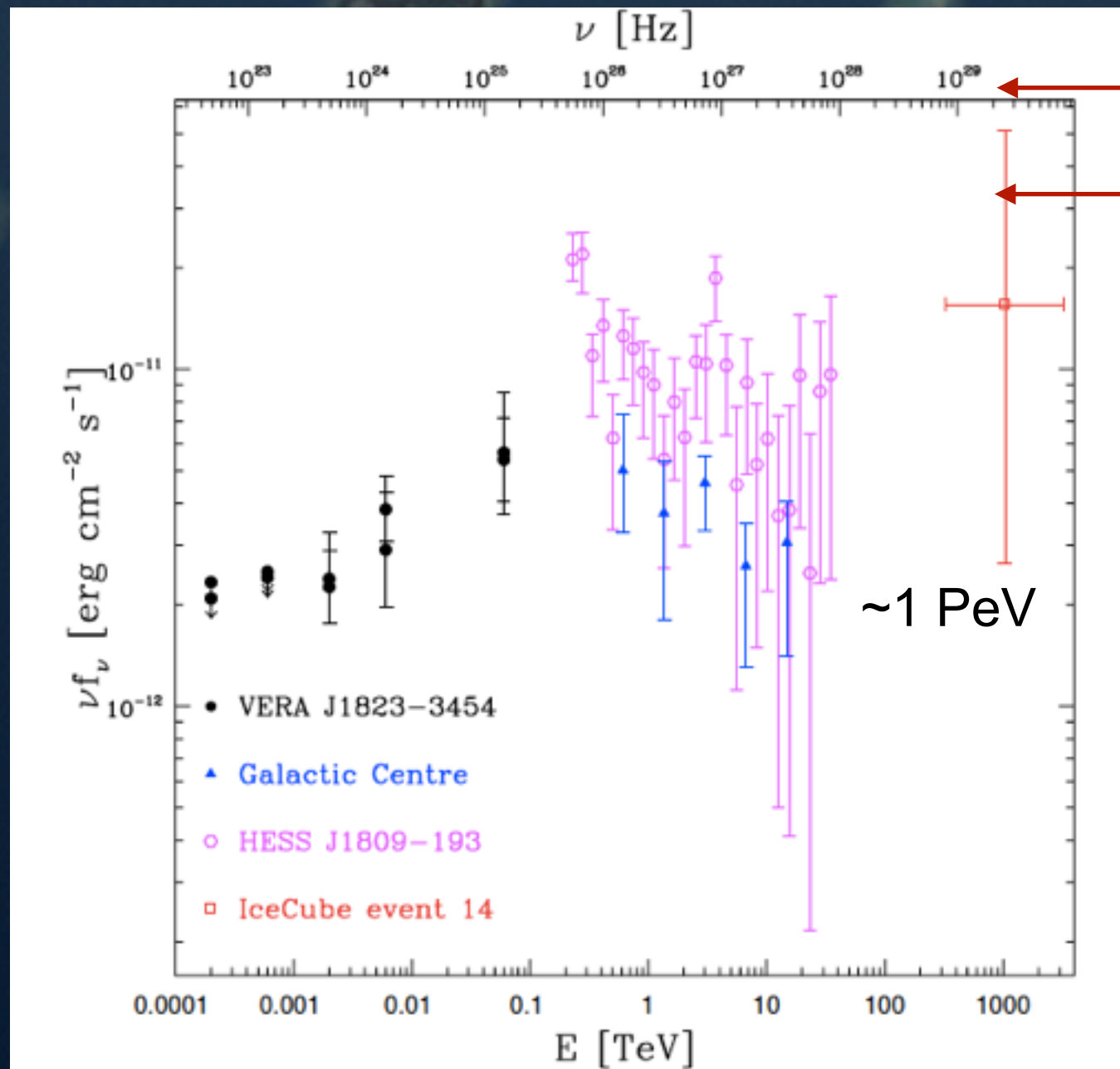
[Anna Berhard for IceCube, TevPa, 2014]

point source searches are less sensitivity
with respect to diffuse

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What about the PeV event from the Galactic Center?

[P. Padovani and E.R., MNRAS 2014]



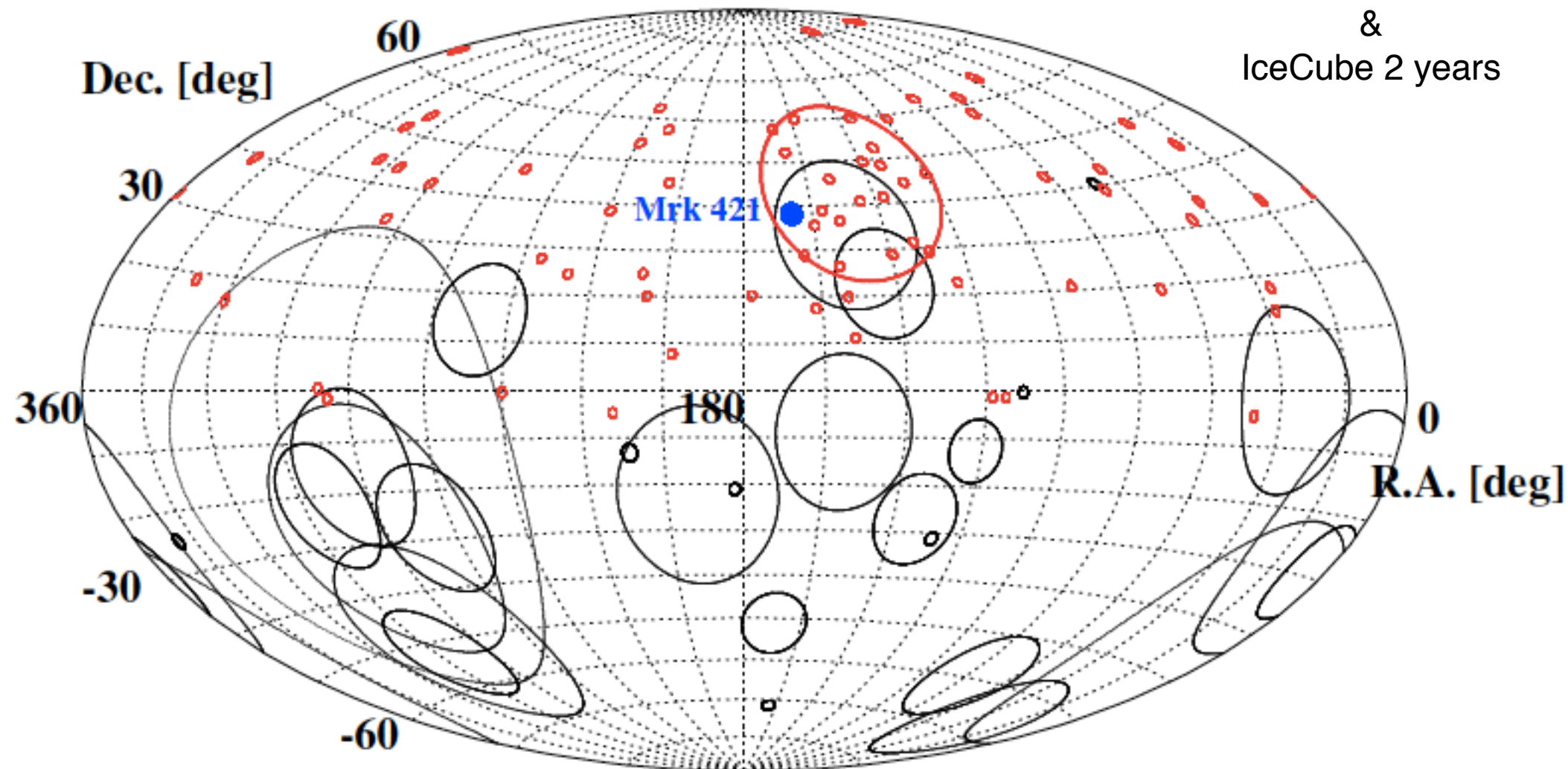
Antares 6 years upper limit
[The Antares Coll., ArXiv:1402.6182]

IceCube 4 years upper limit
[The IceCube Coll., ArXiv:1406.6757]

About MKN 421

[Ke Fang et al., arXiv:1404.6237]

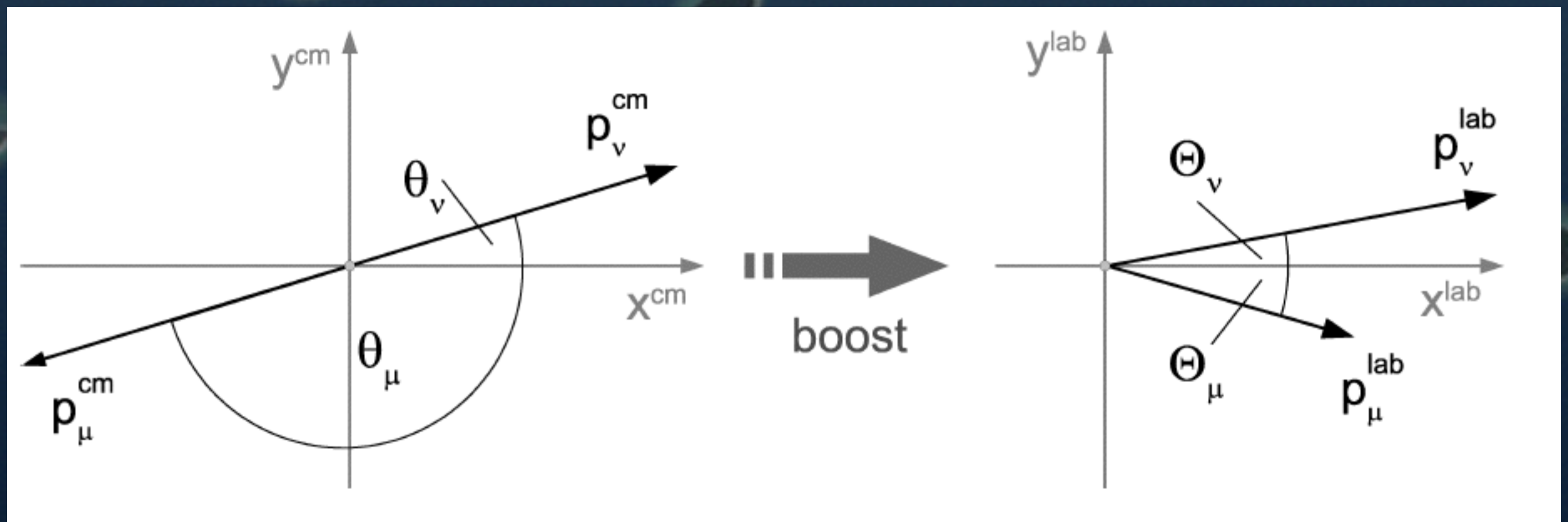
Telescope Array 5-year events
&
IceCube 2 years



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Atmospheric Neutrinos VETO

[S. Schönert, T. K. Gaisser, E. R., O. Schulz, PRD 79 (2009), 10.1103]



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What about the PeV event from the Galactic Center?

[P. Padovani and E.R., MNRAS 2014]

how many can be “connected”? hybrid-SED

IceCube ID	Counterpart(s)	Class	Catalogue(s)
9	MKN 421	BL Lac (HSP)	TeVCat/WHSP
	1ES 1011+496	BL Lac (HSP)	TeVCat/WHSP
10	H 2356–309	BL Lac (HSP)	TeVCat/WHSP
14	HESS J1809–193	PWN	TeVCat
17	PG 1553+113	BL Lac (HSP)	TeVCat/WHSP
19	1RXS J054357.3–553206	BL Lac (HSP)	WHSP
20	SUMSS J014347–584550	BL Lac (HSP)	WHSP
22	1H 1914–194	BL Lac (HSP)	WHSP
27	PMN J0816–1311	BL Lac (HSP)	WHSP
33	MGRO J1908+06	PWN	TeVCat

but 1FHL not included due to a too large gap

IF not strong neutrino point sources

diffuse
astrophysical
background

[I. Tamborra et al., arXiv:1404.1189]
[A. Taylor et al., PhRvD, 89, 2014, 103003]

....

decaying dark
matter

[V. Barger and W.Y. Keung, arXiv:1305.6907]
[A. Esmaili and P.D. Serpico, arXiv:1308.1105]

....

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