Recent results from IceCube

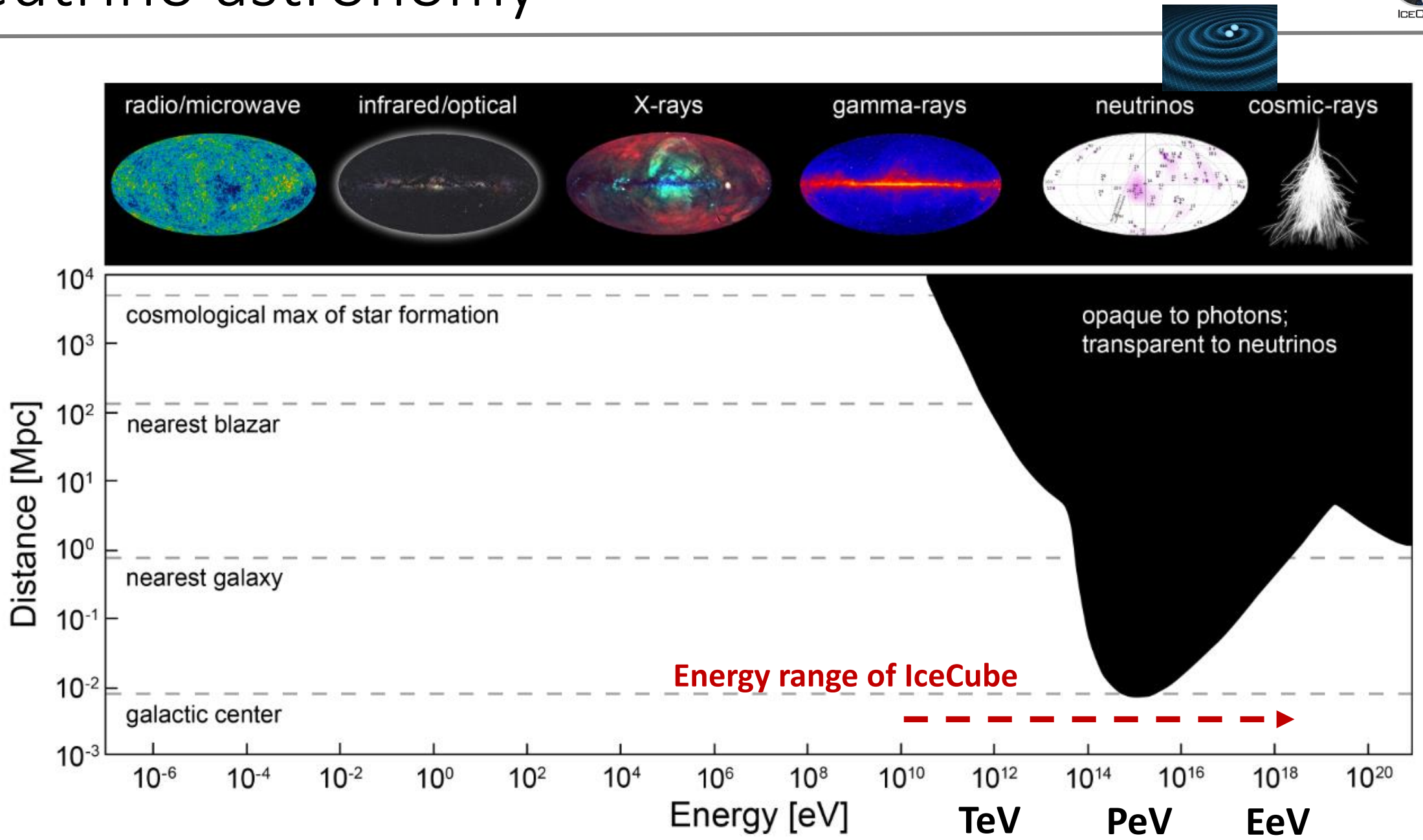
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

ICECUBE

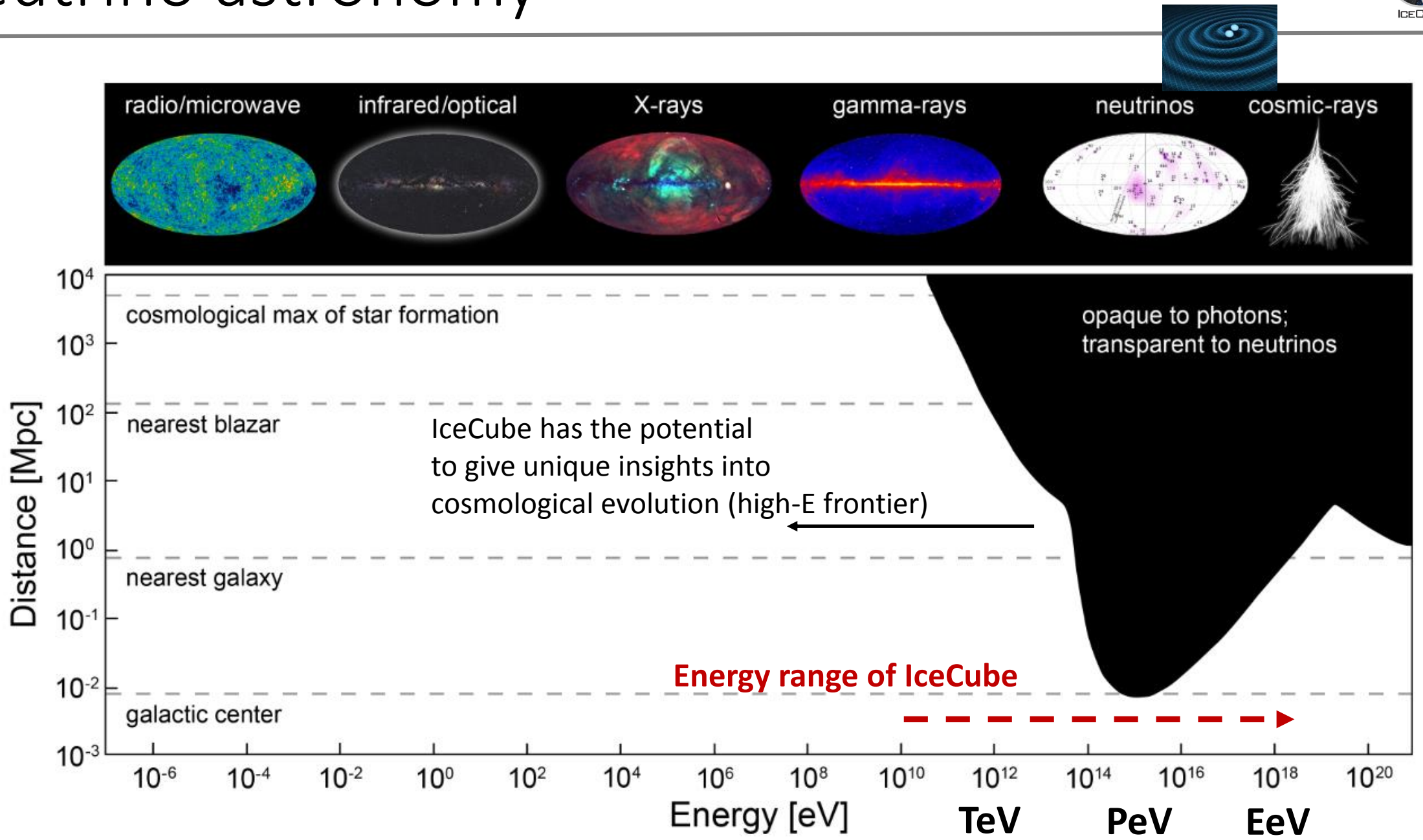
Thorsten Glüsenkamp, for the IceCube collaboration

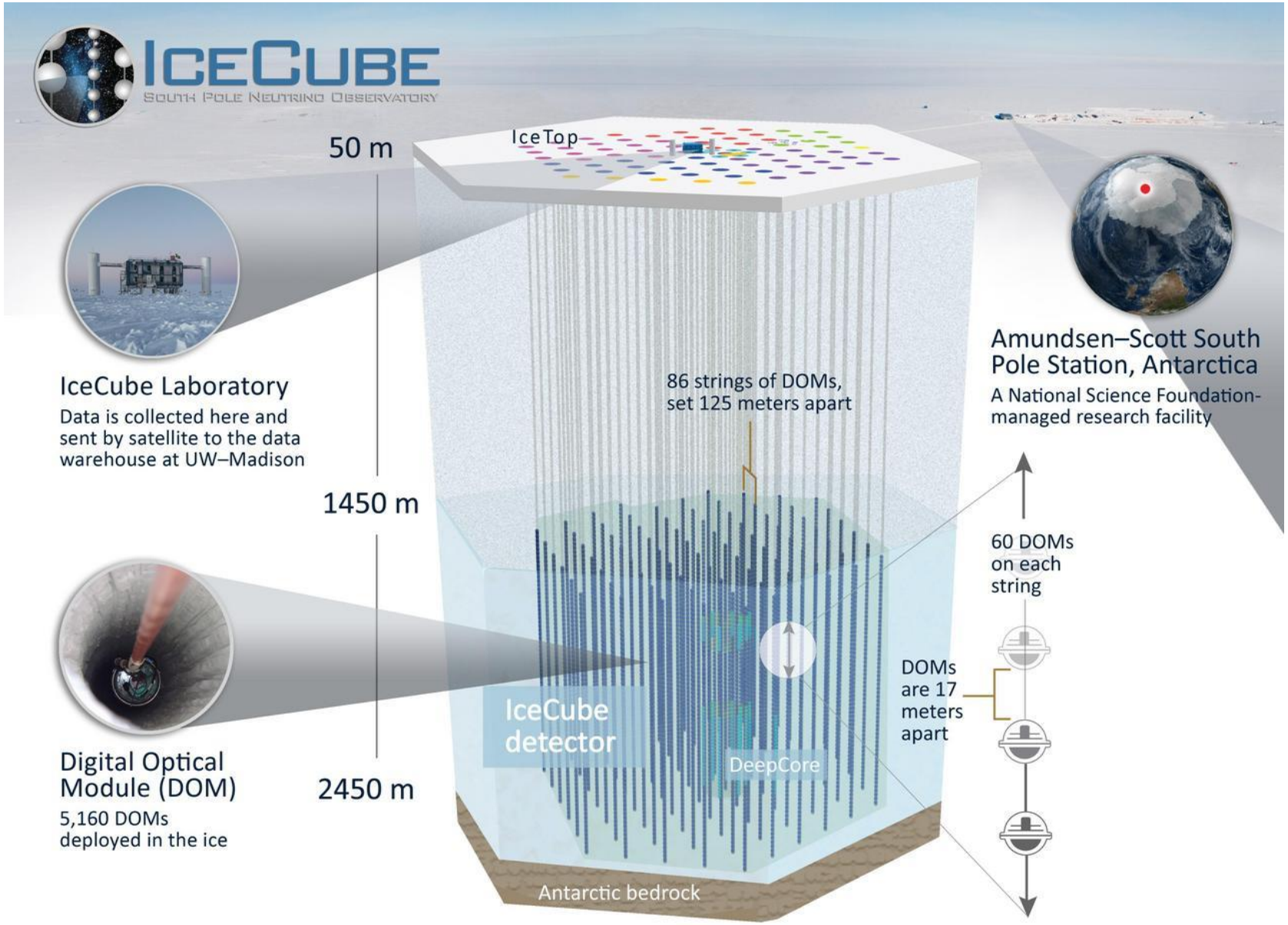
Cosmology 2018, Dubrovnik

Neutrino astronomy

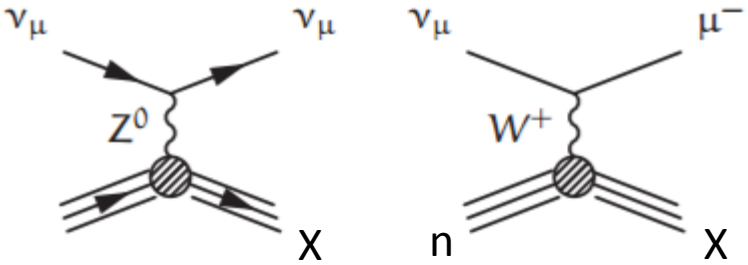


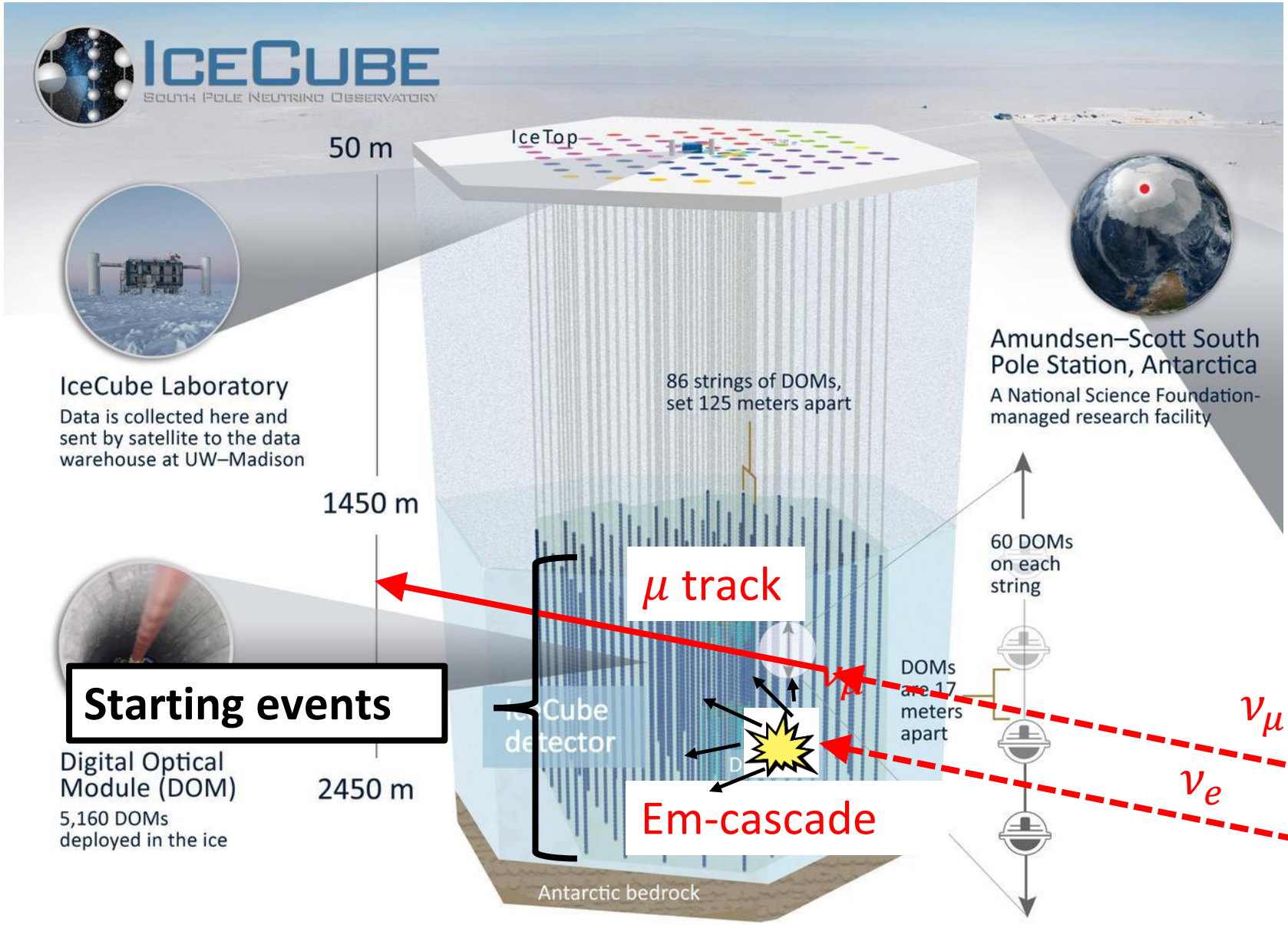
Neutrino astronomy





@ 10 GeV+: DIS – N.C. / C.C





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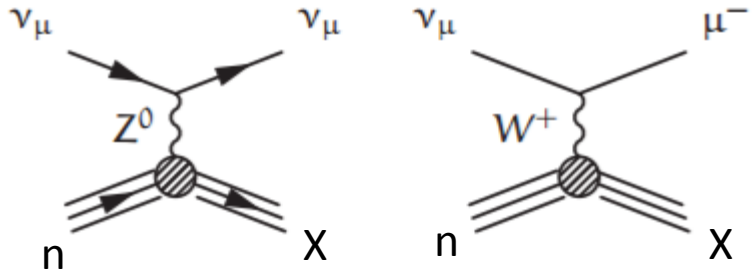

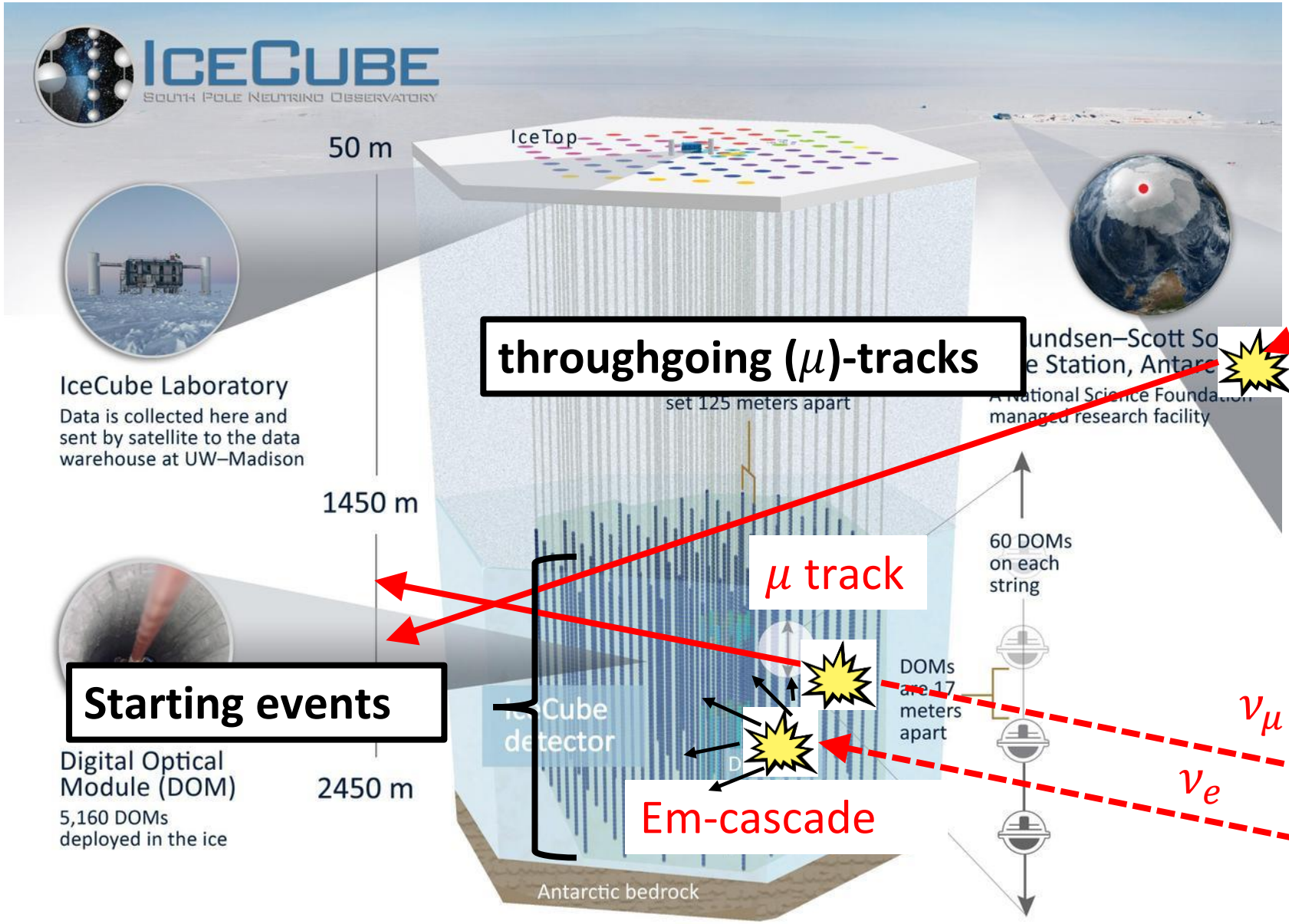

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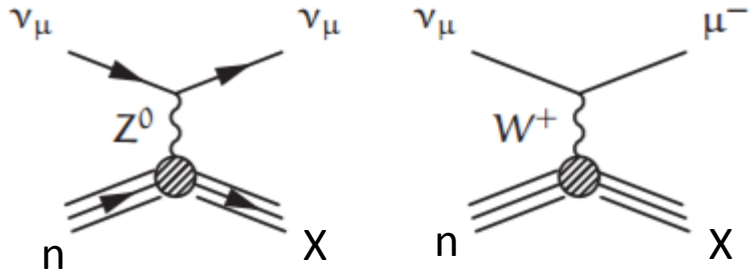
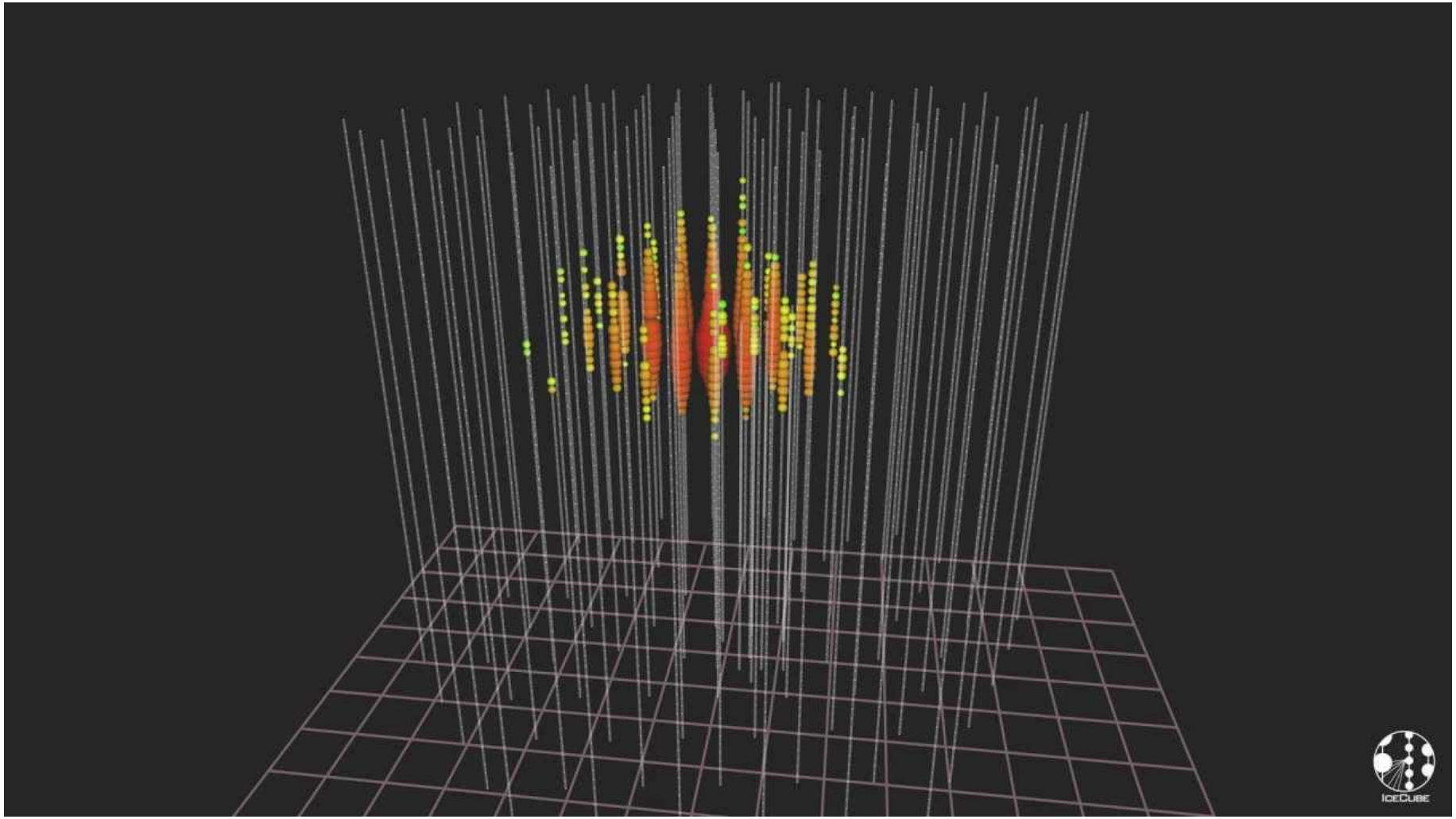
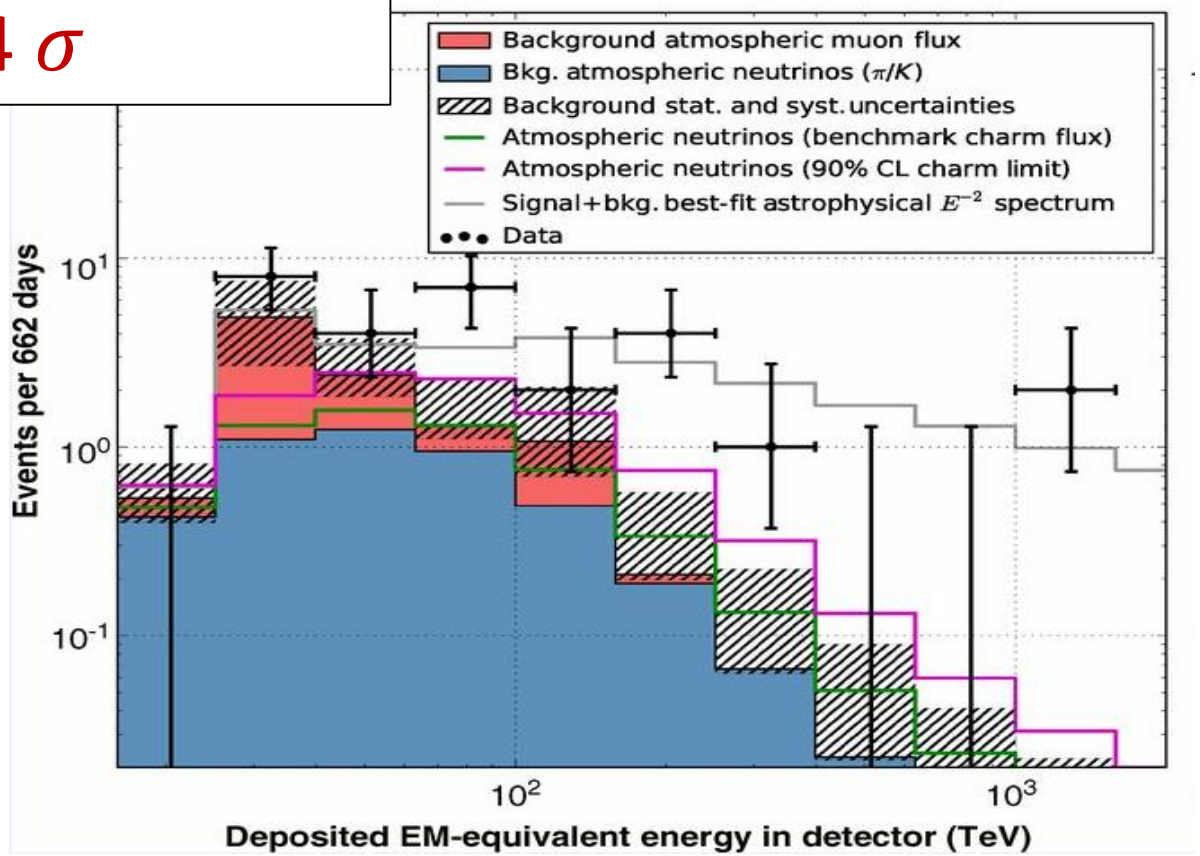


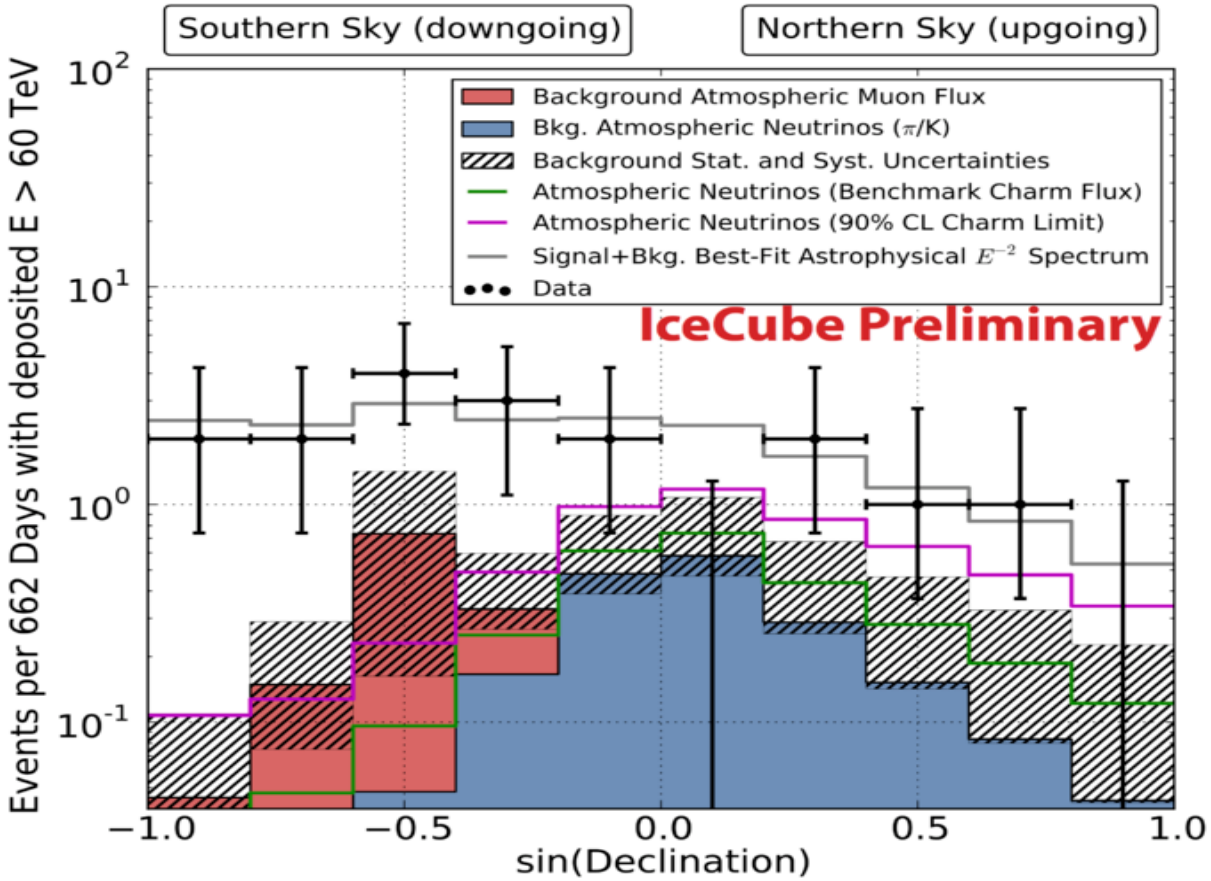
Starting events



The astrophysical flux: starting events

2010-2012:
4 σ

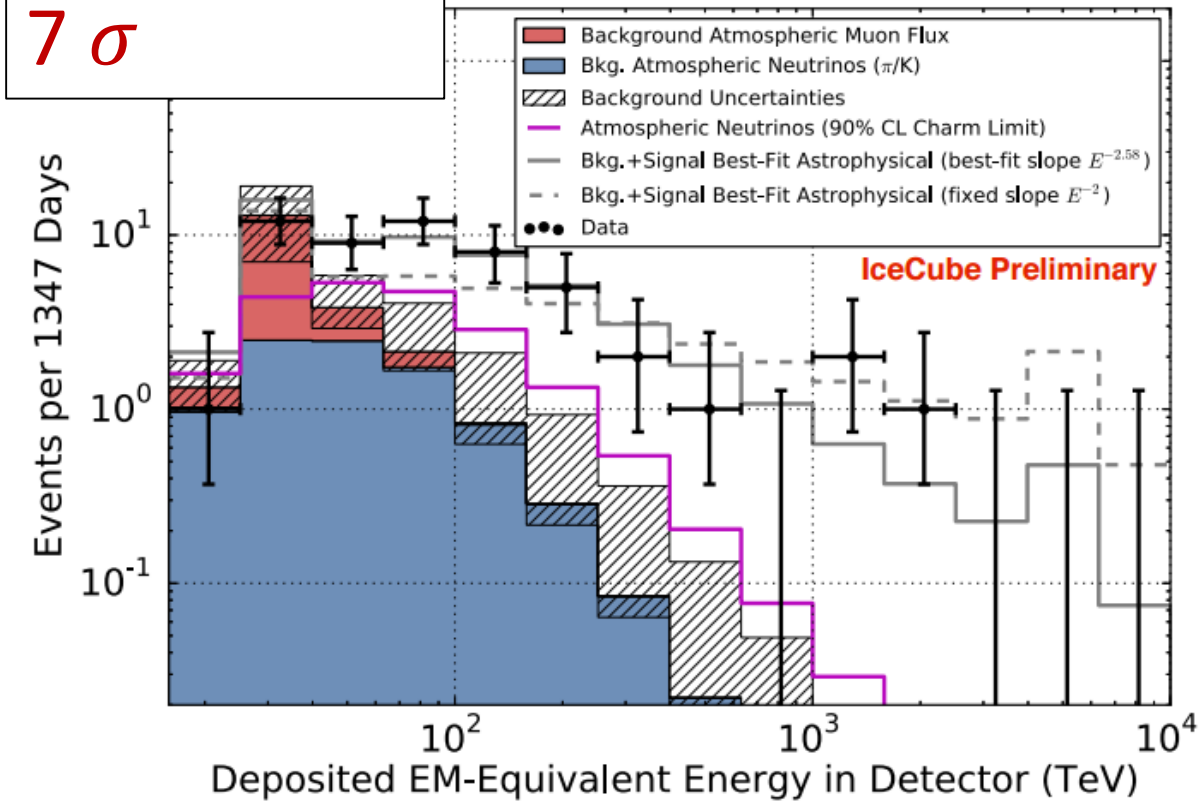


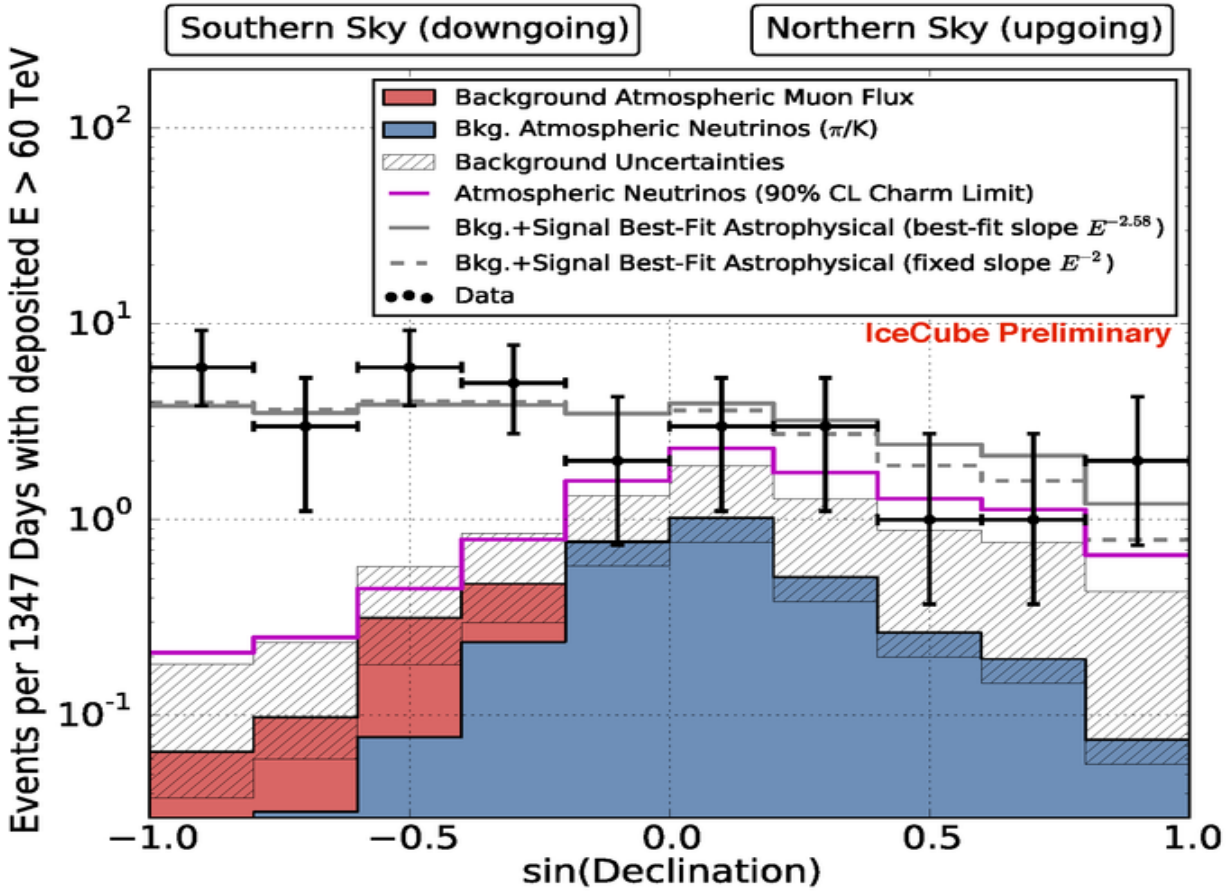


IceCube, Science, 2013

The astrophysical flux: starting events

2010-2014:
7 σ



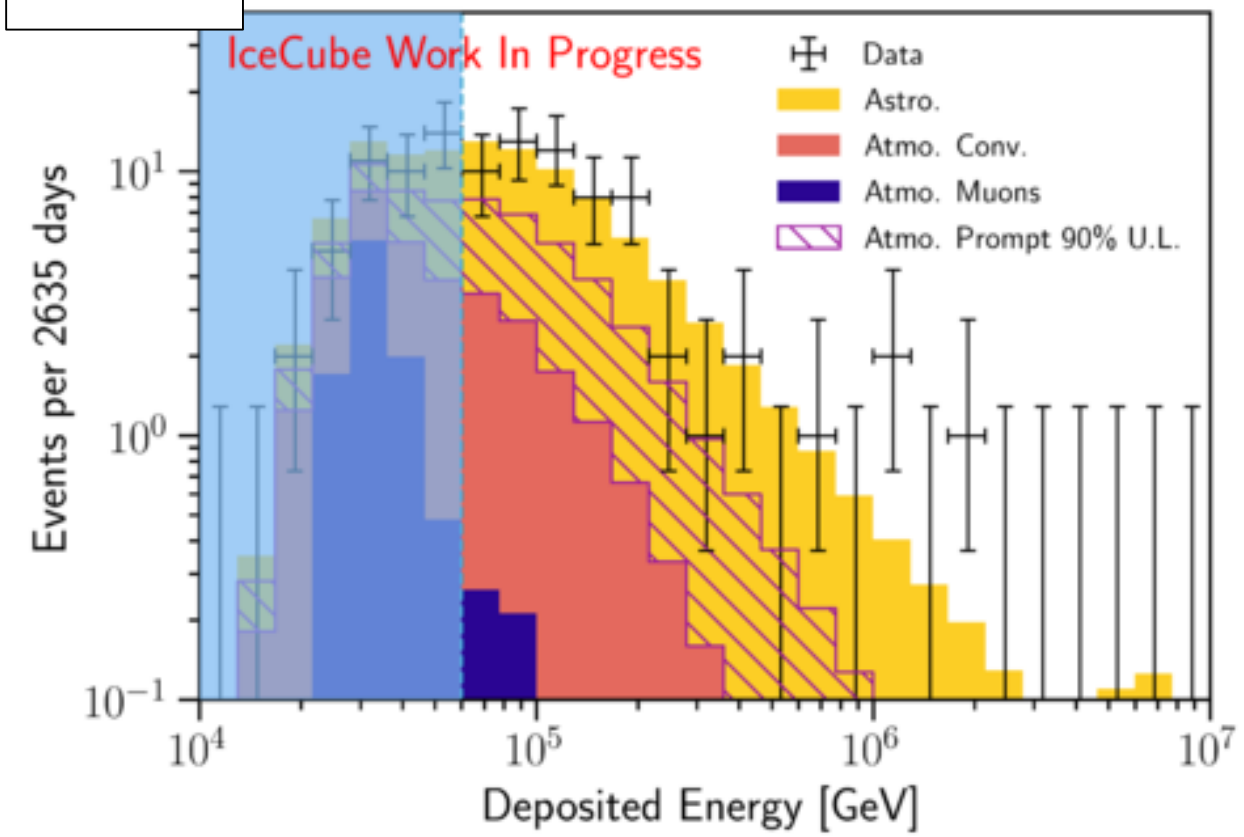


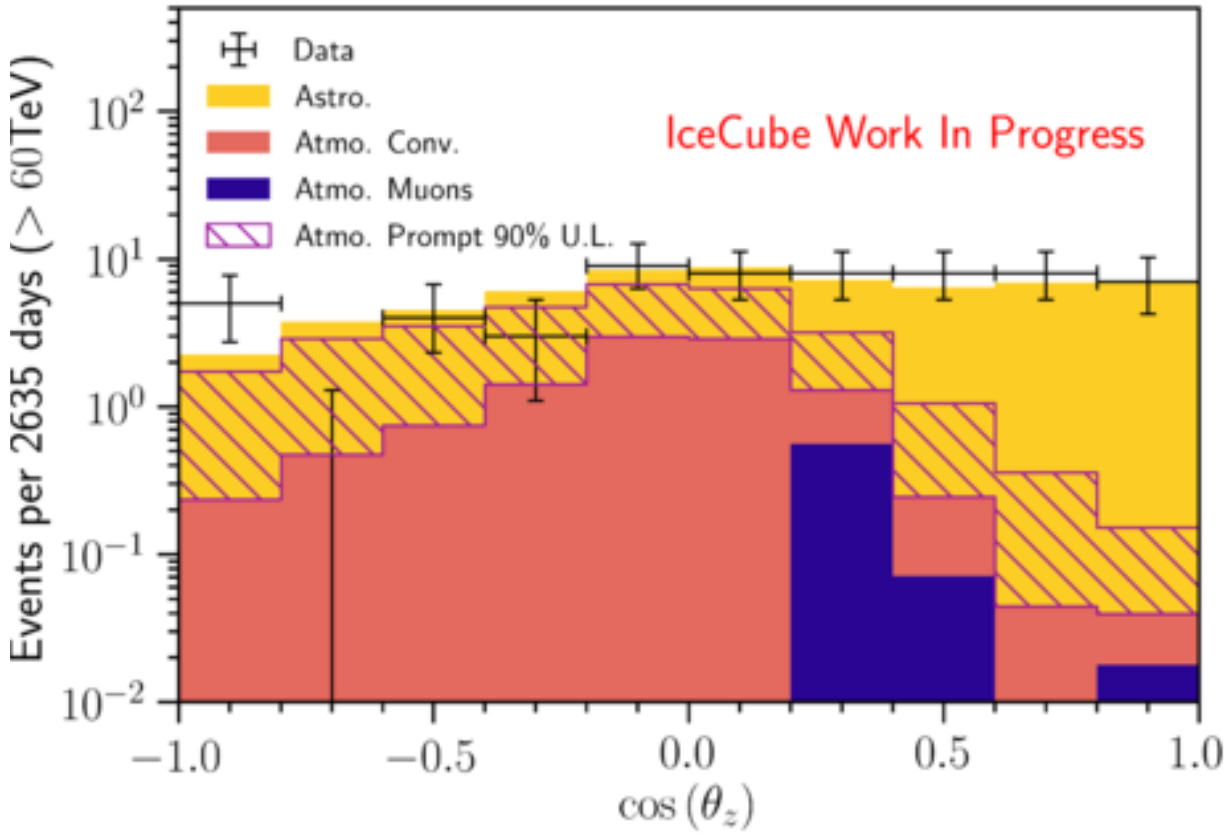
Spectral index: ~ -2.58 +/- 0.25

IceCube, ICRC, 2015

The astrophysical flux: starting events

2018:
7 σ+



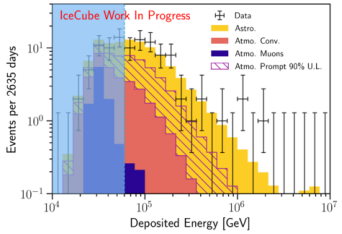


Spectral index: ~ -2.8 +/- 0.2

Work in progress

Starting events: further developments

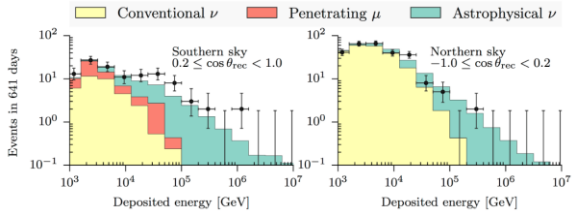
$E > 50\ TeV$



Work in progress

γ=-2.8 $\pm$0.2

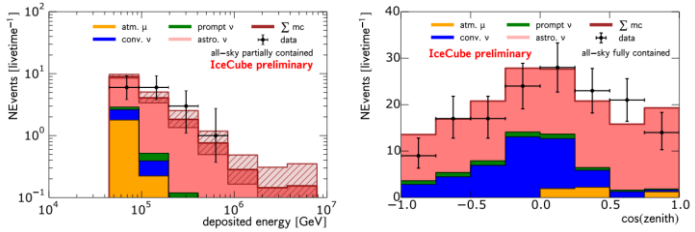
$E > 5\ TeV$



IceCube, PRD, 2015

γ=-2.5 $\pm$0.13

showers (+partially cont.)



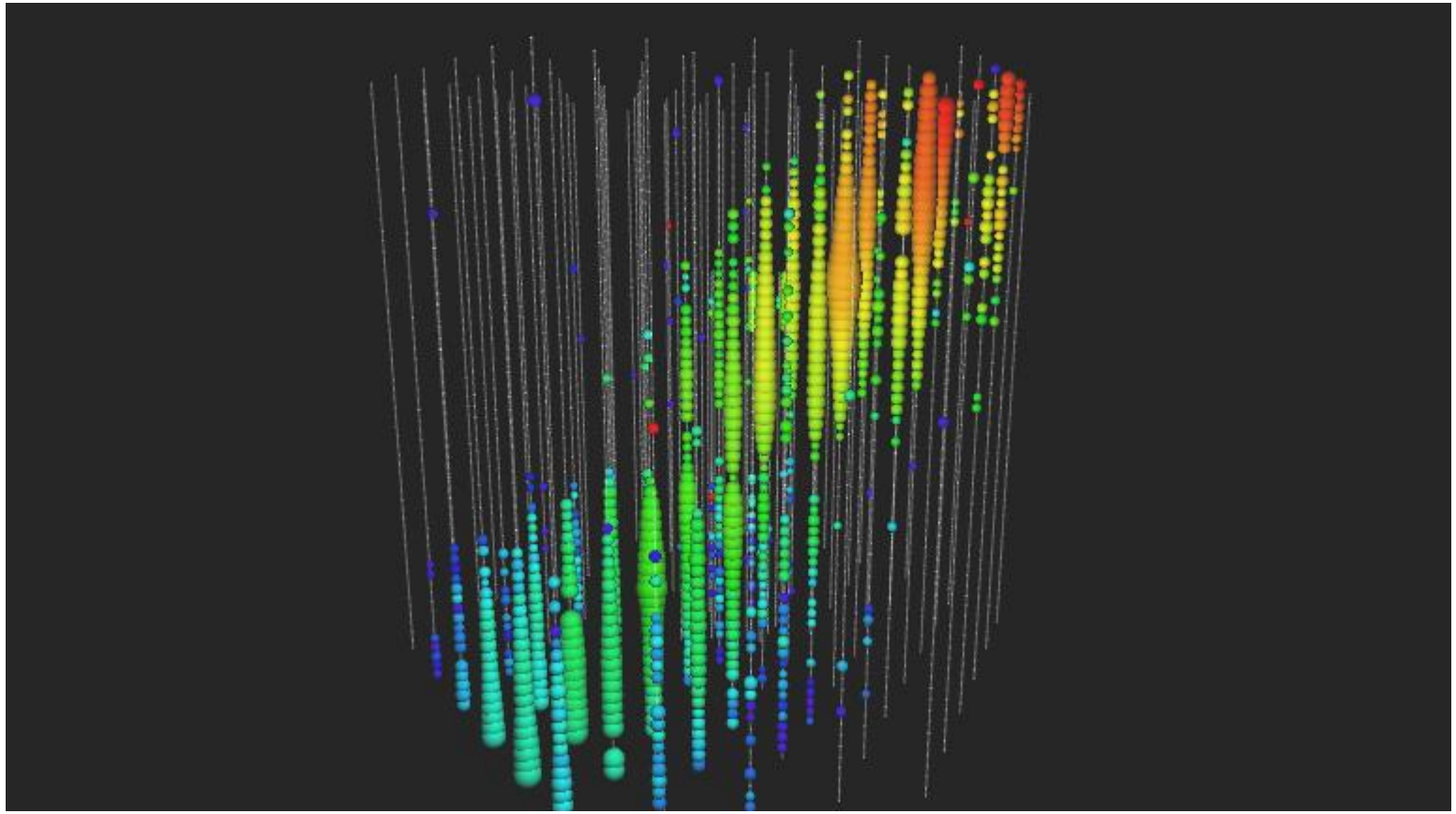
IceCube, ICRC, 2015

γ=-2.7 $\pm$0.12

Soft

Spectral index?

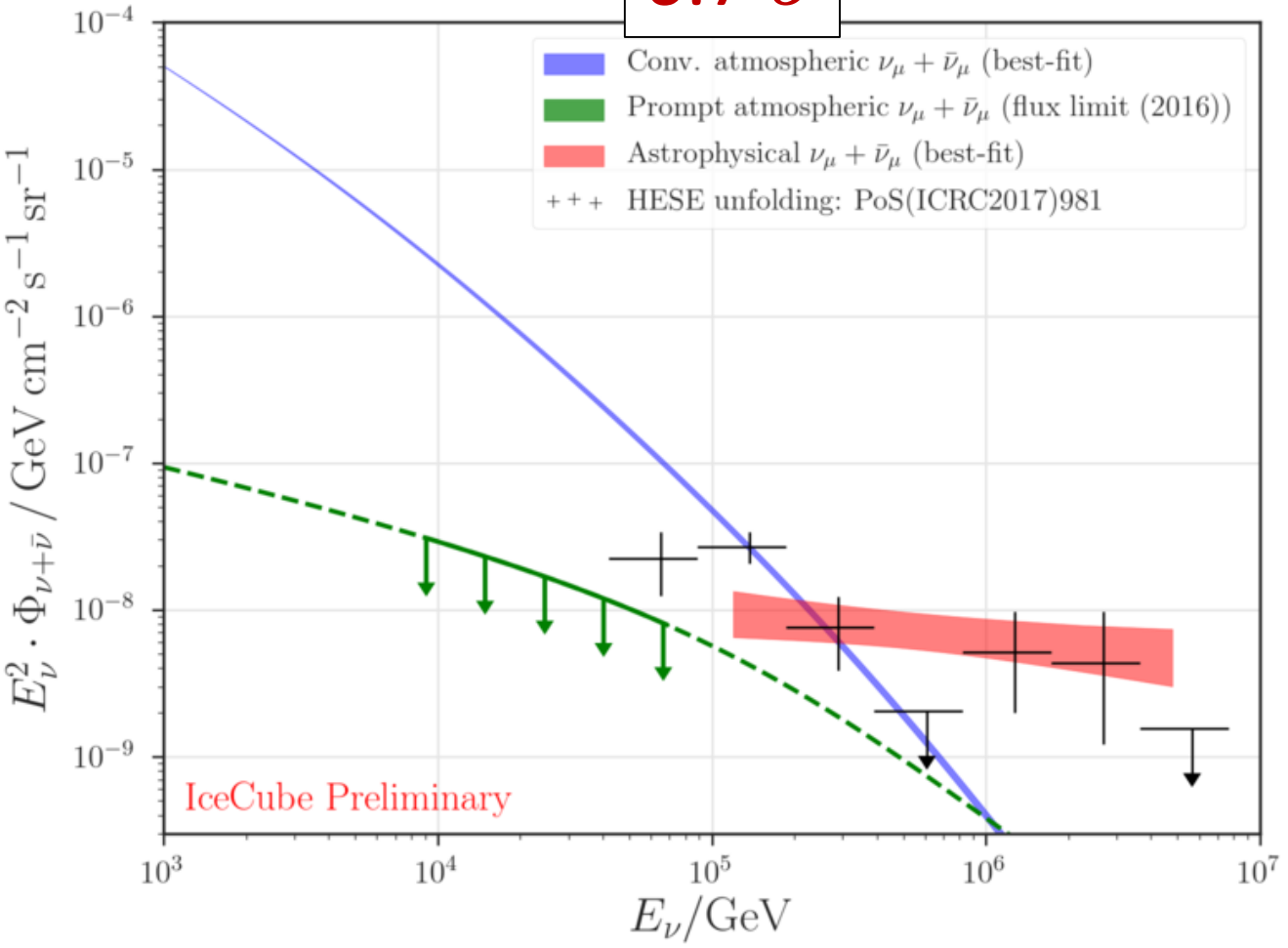
Throughgoing muons

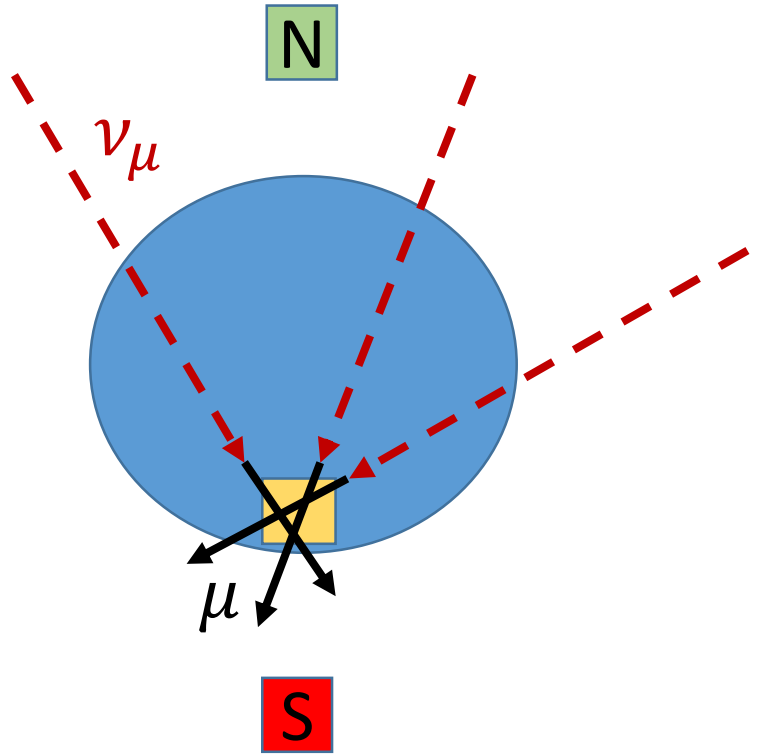


Throughgoing muons

- Complementary sample to starting events
- 8 years analyzed

6.7 σ





Throughgoing muons

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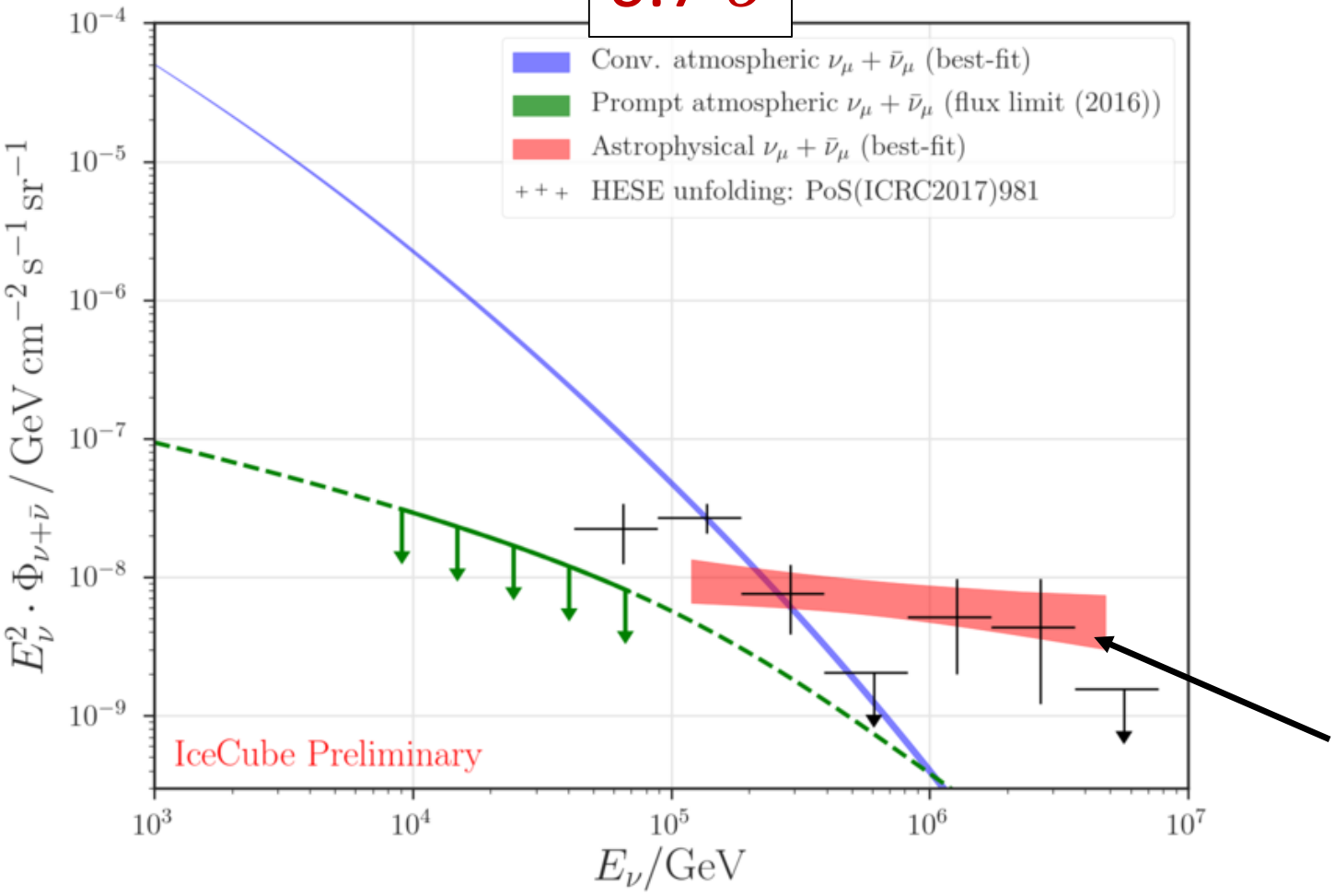
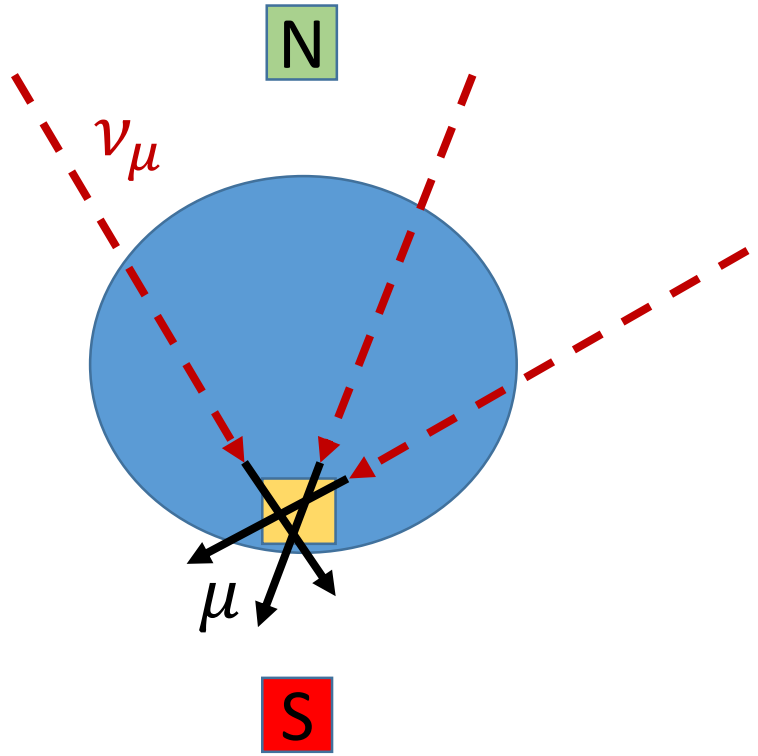
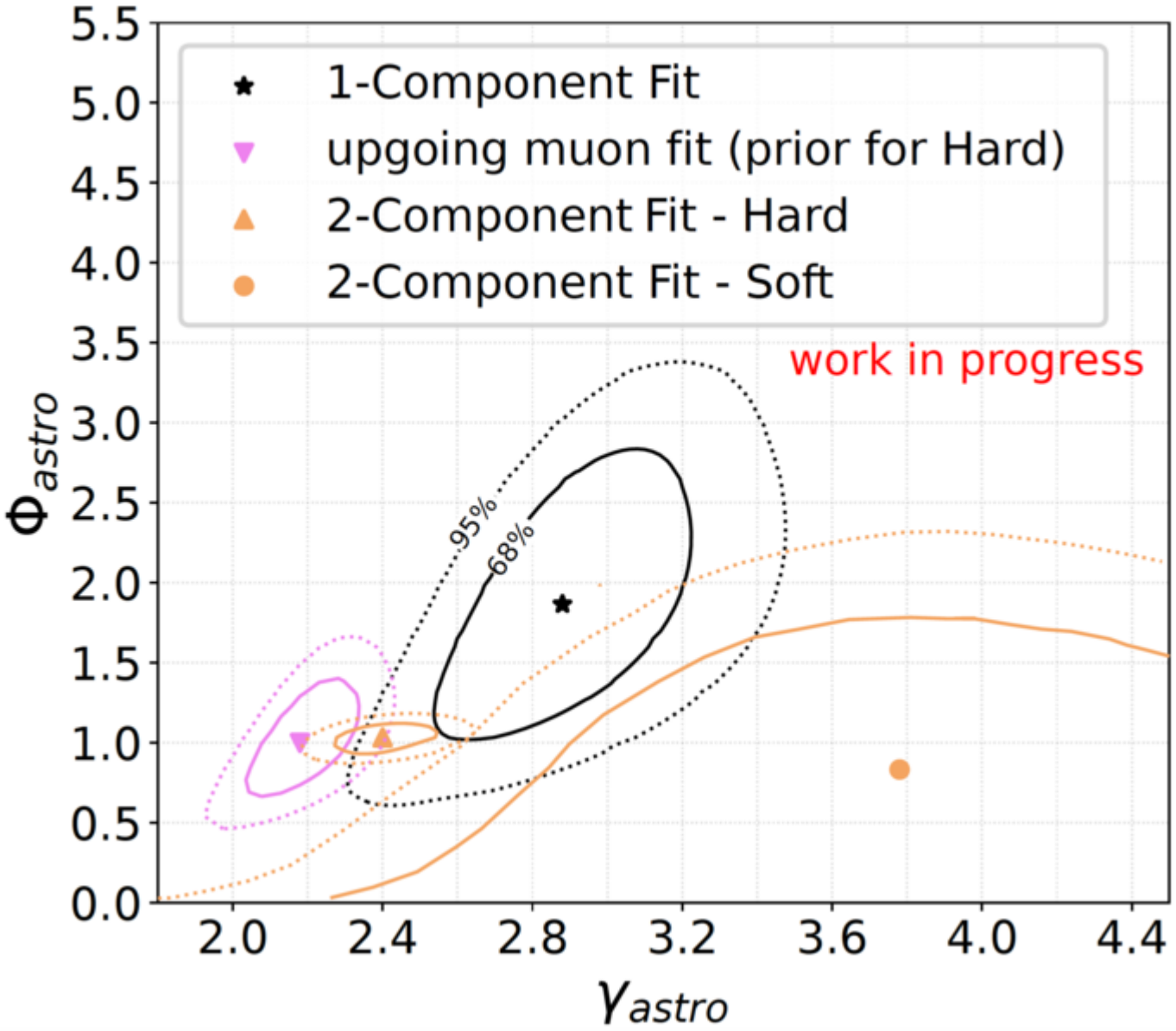




Spectral Index: -2.2 +\- 0.1
Significant harder spectrum?

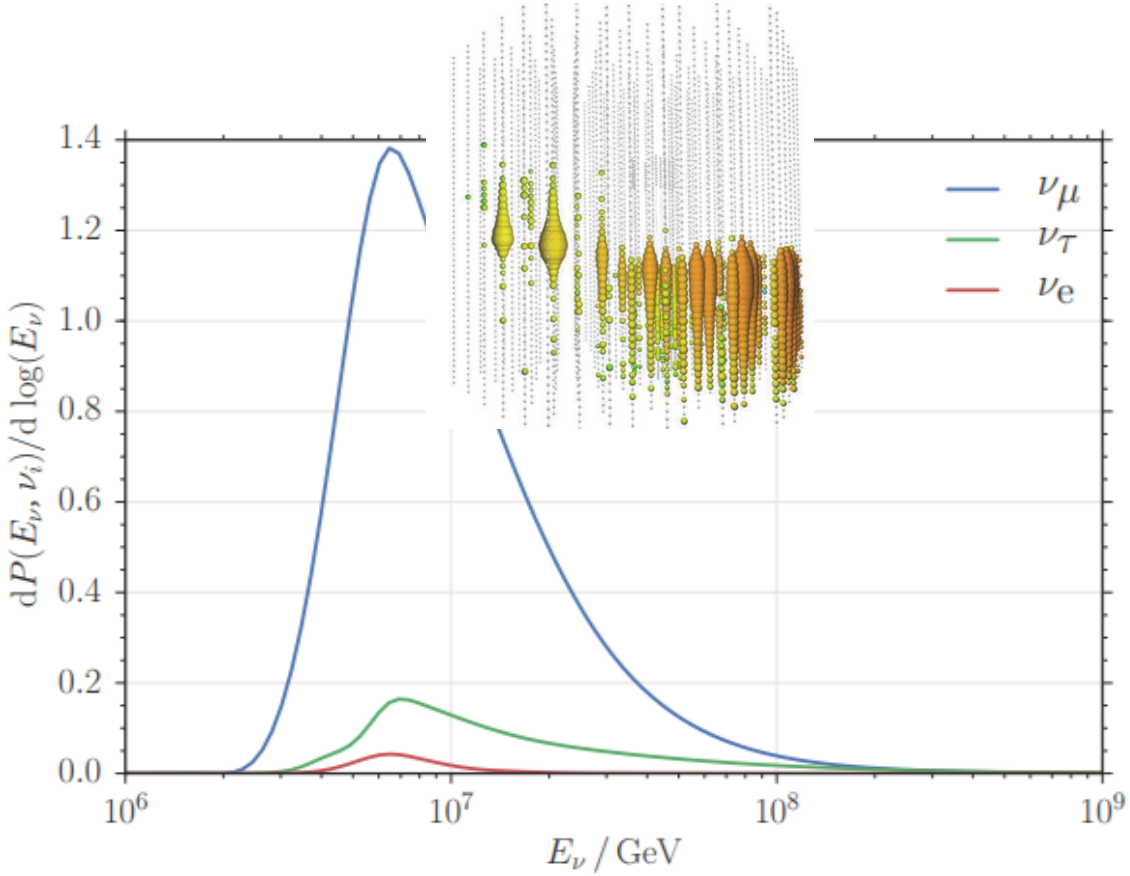
Starting+Throughgoing combination



- ~2 σ tension between samples
- Need more data (Hard/soft 2-component fit not yet significant)

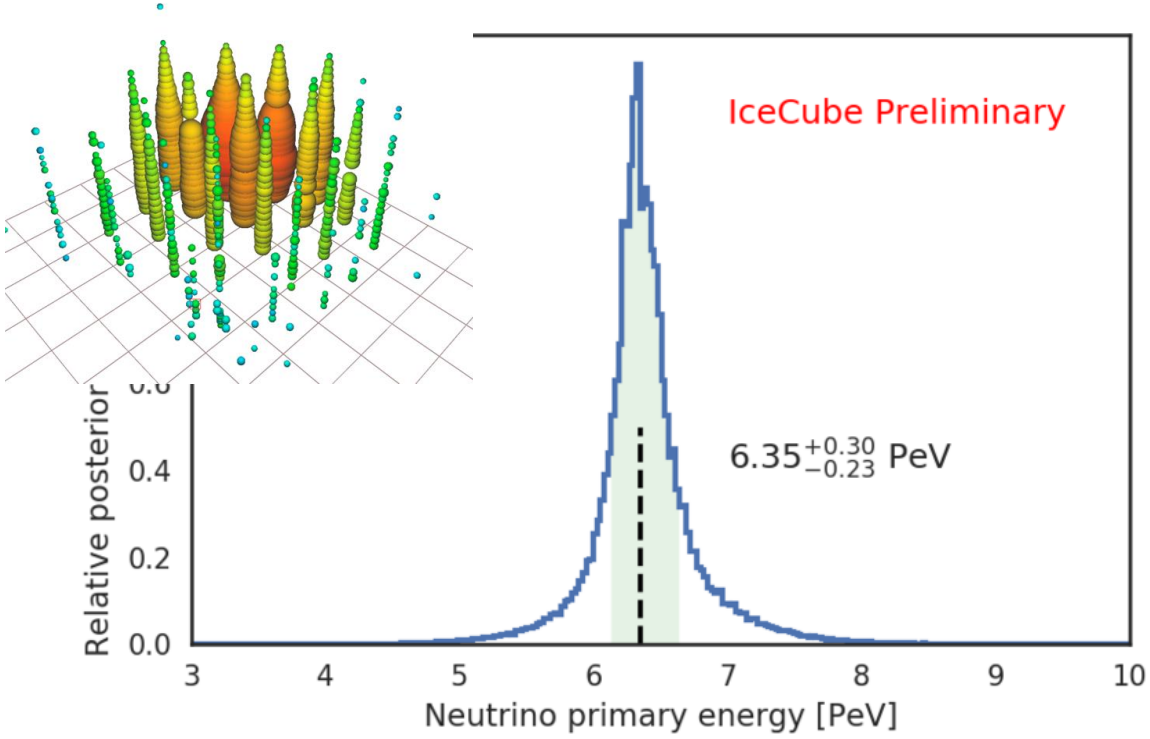
The two highest-energy neutrinos so far…

highest energy track event



Median exp E_ν : 8.5 PeV (log scale)

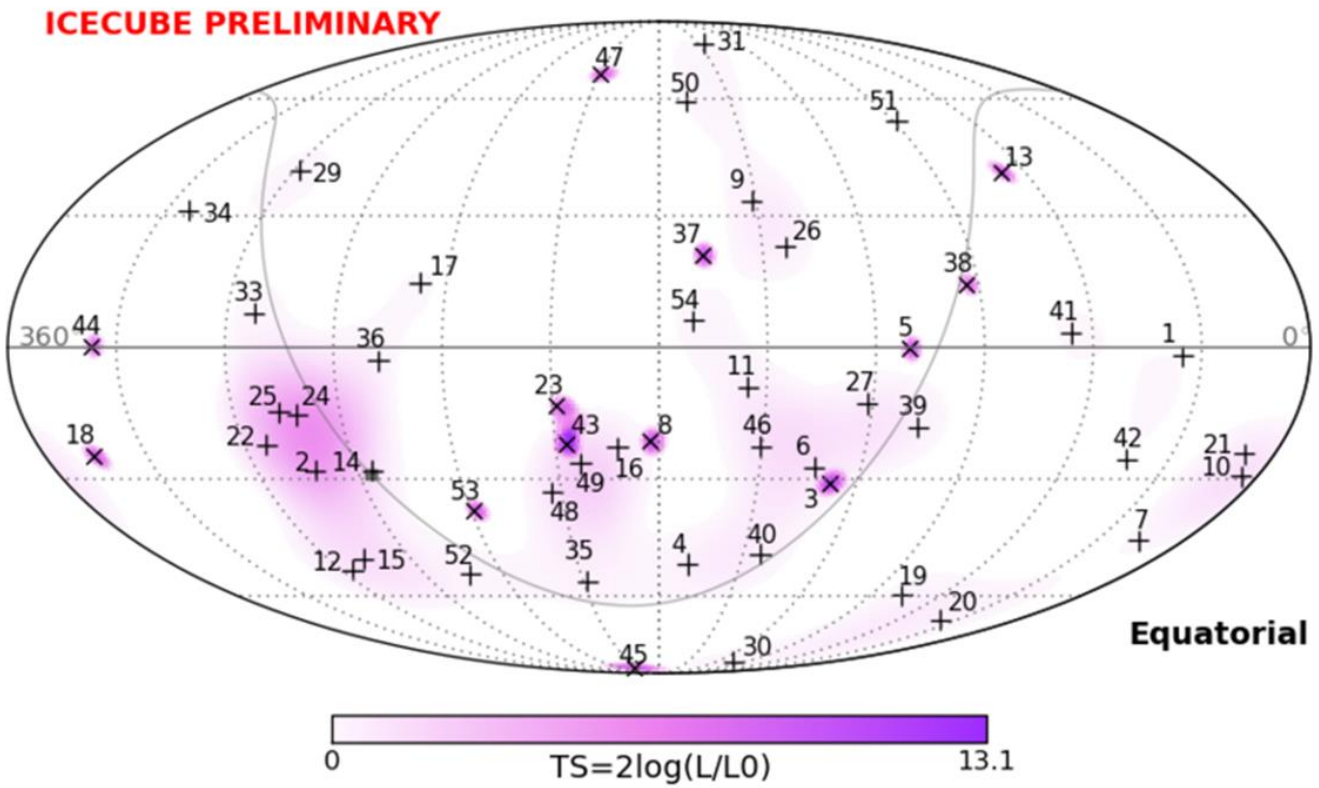
highest energy contained event



Median E_ν: 6.35 PeV (linear scale)

What is the origin of these neutrinos?

Galactic?



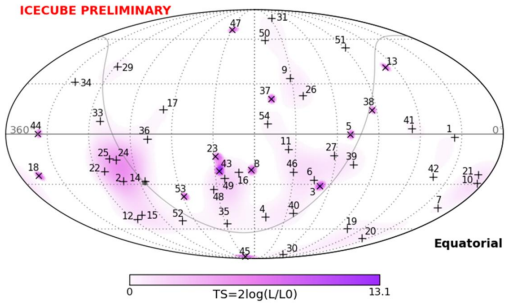
IceCube, ICRC, 2015

Starting Event sample

Galactic plane clustering p-value: 2.5 %

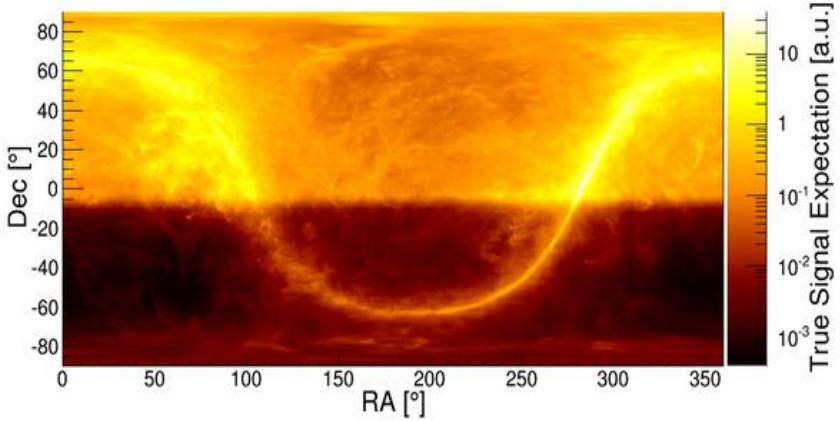
Galactic?

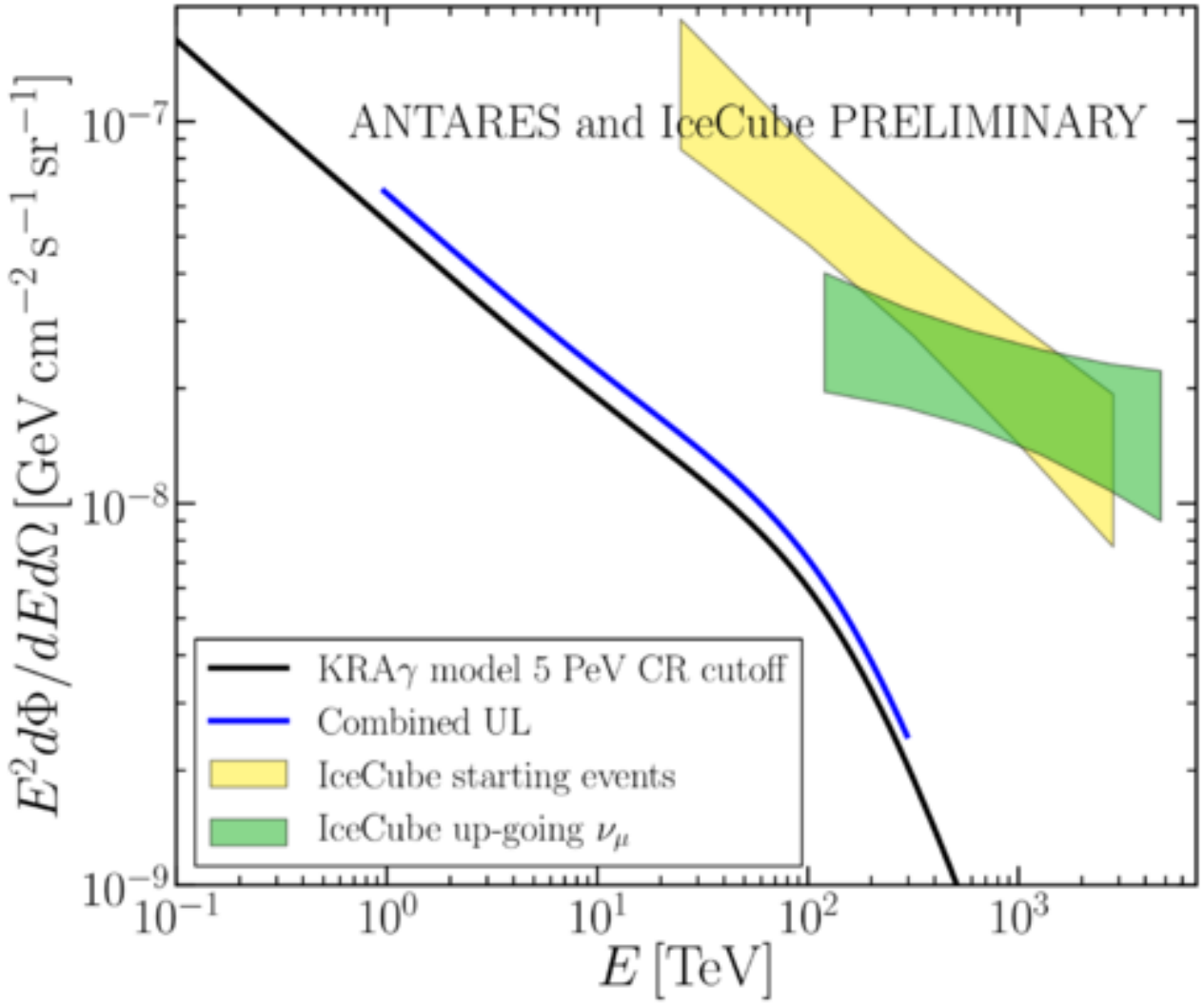
Gal. Plane scan
p-value(isotr.): 2.5 %



IceCube, ICRC, 2015

π^0 template (Fermi-LAT)



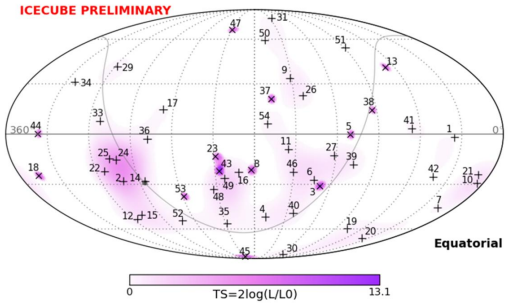


Galactic diffuse (template)
p-value (isotr.): 4.3 %

IceCube&Antares, in progress

Galactic?

Gal. Plane scan
p-value(isotr.): 2.5 %



IceCube, ICRC, 2015

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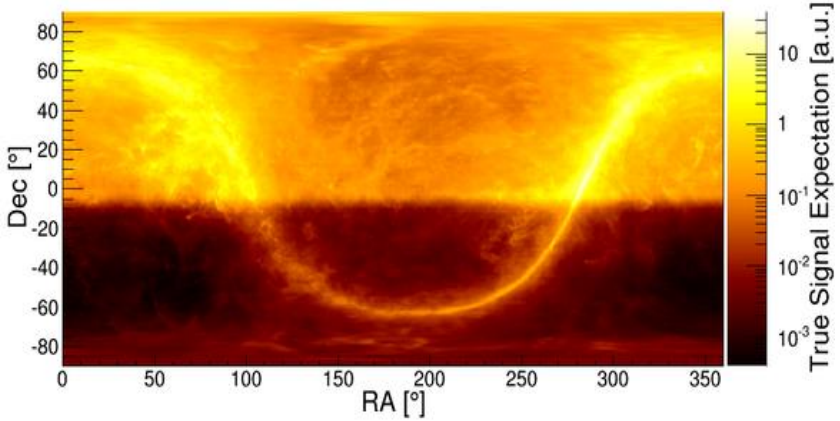
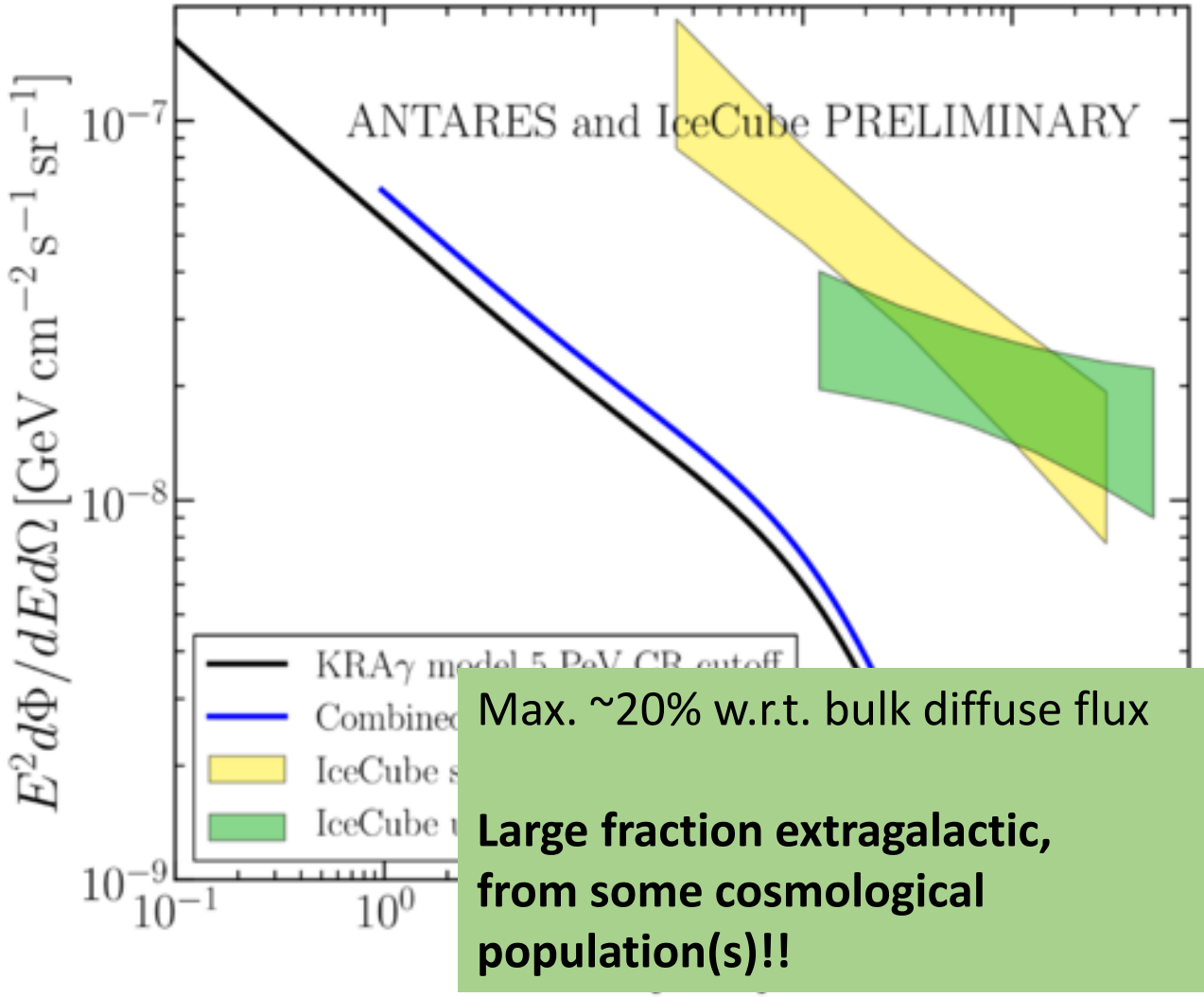




Max. ~20% w.r.t. bulk diffuse flux

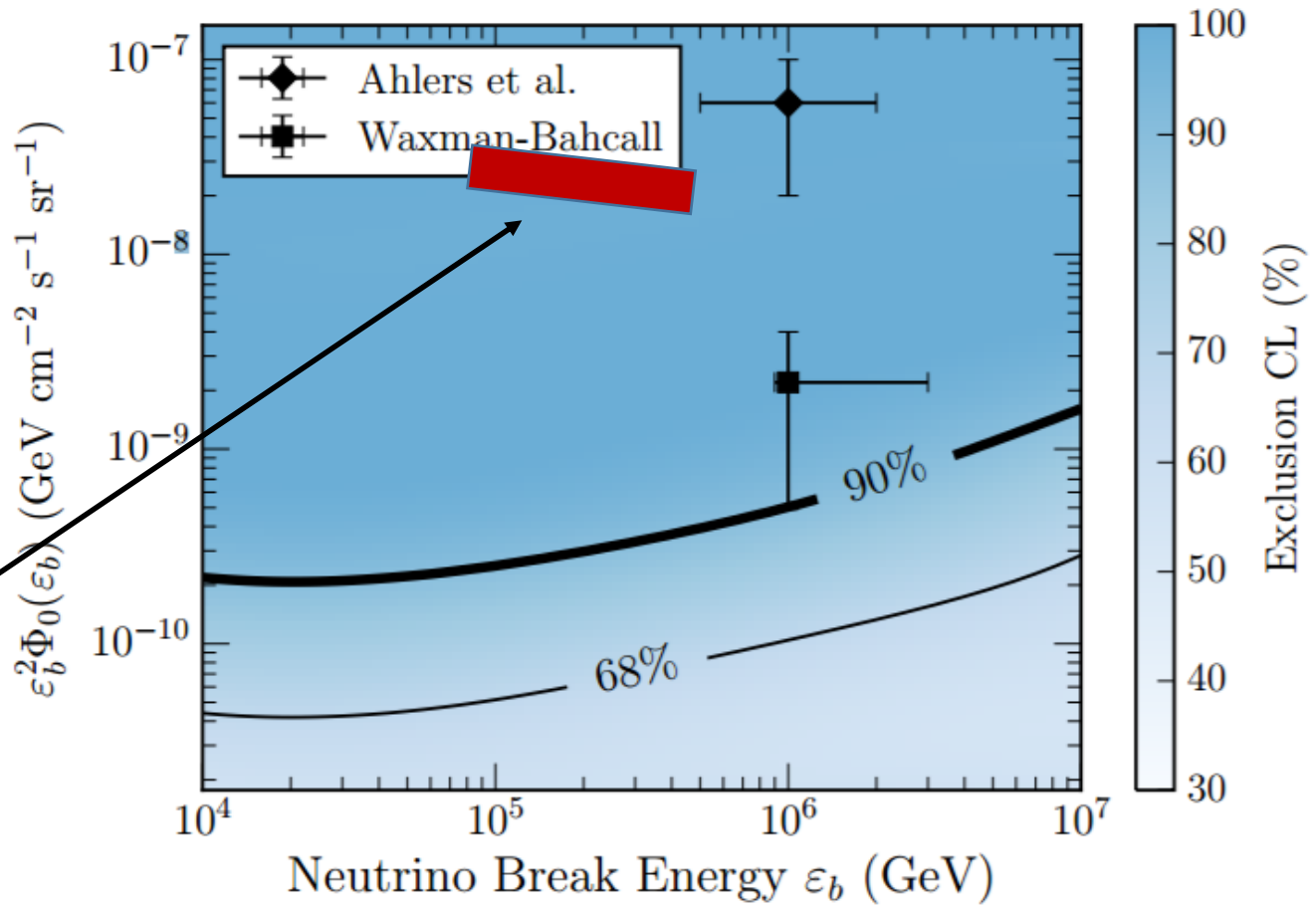
Large fraction extragalactic, from some cosmological population(s)!!

Galactic diffuse (template)
p-value (isotr.): 4.3 %

IceCube&Antares, in progress

GRBs?

- Max a few % of high-E neutrino emission from cosmological population of prompt GRBs (with similar properties as the ones we observe in satellites)



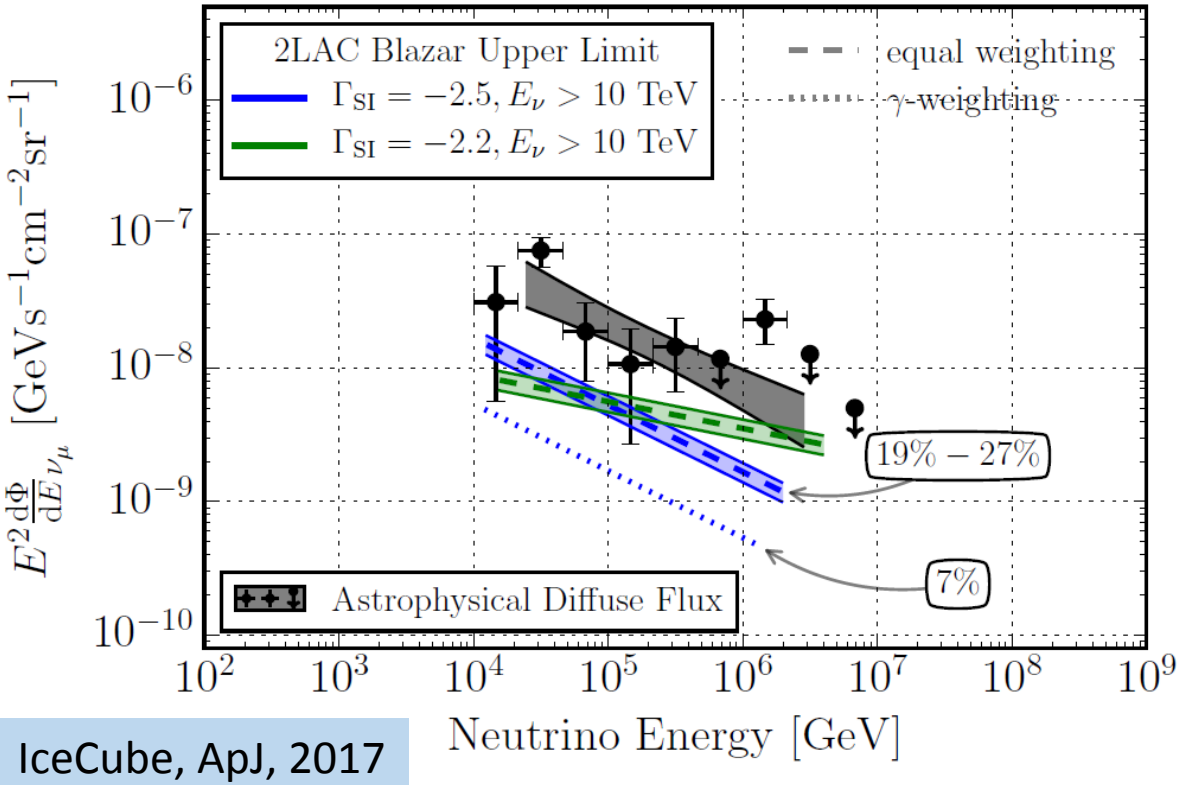
High-E neutrinos

IceCube, ApJ, 2016

AGN? Blazars?

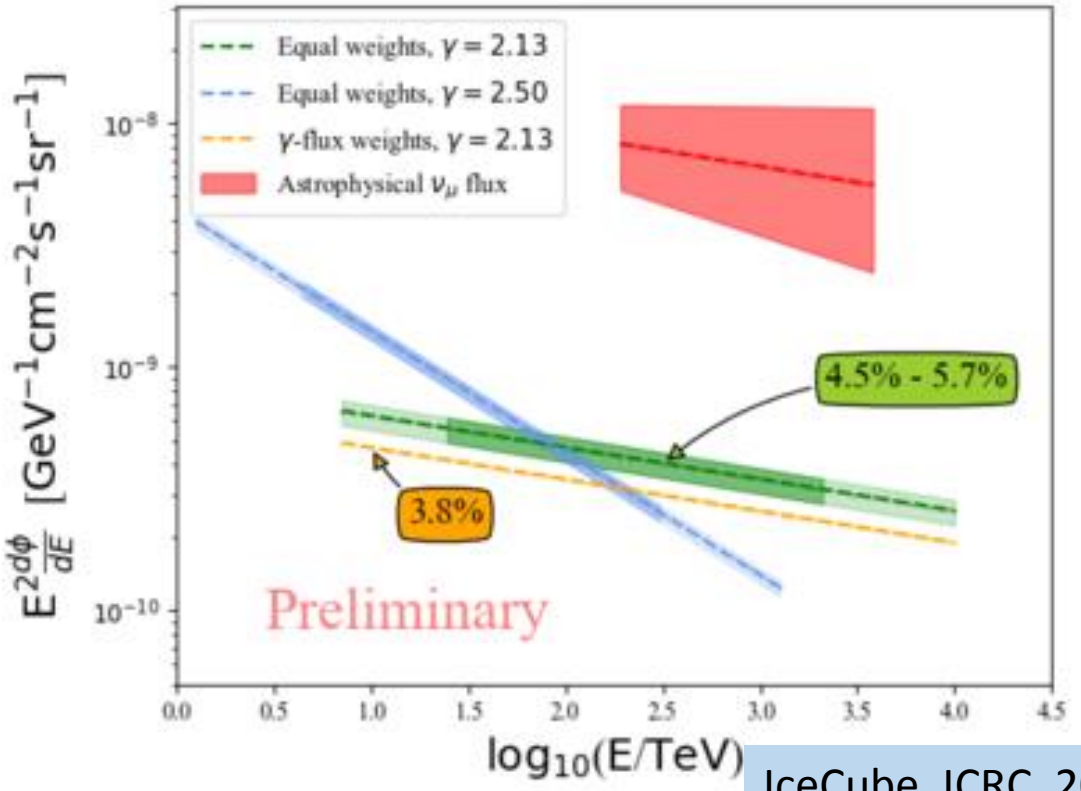
- AGN too numerous -> focus on managable sub-populations (i.e. Blazars)

2LAC catalogue (70% flux complete > 100 MeV)



IceCube, ApJ, 2017

2FHL HBLs catalogue (>50 GeV sources)



IceCube, ICRC, 2017

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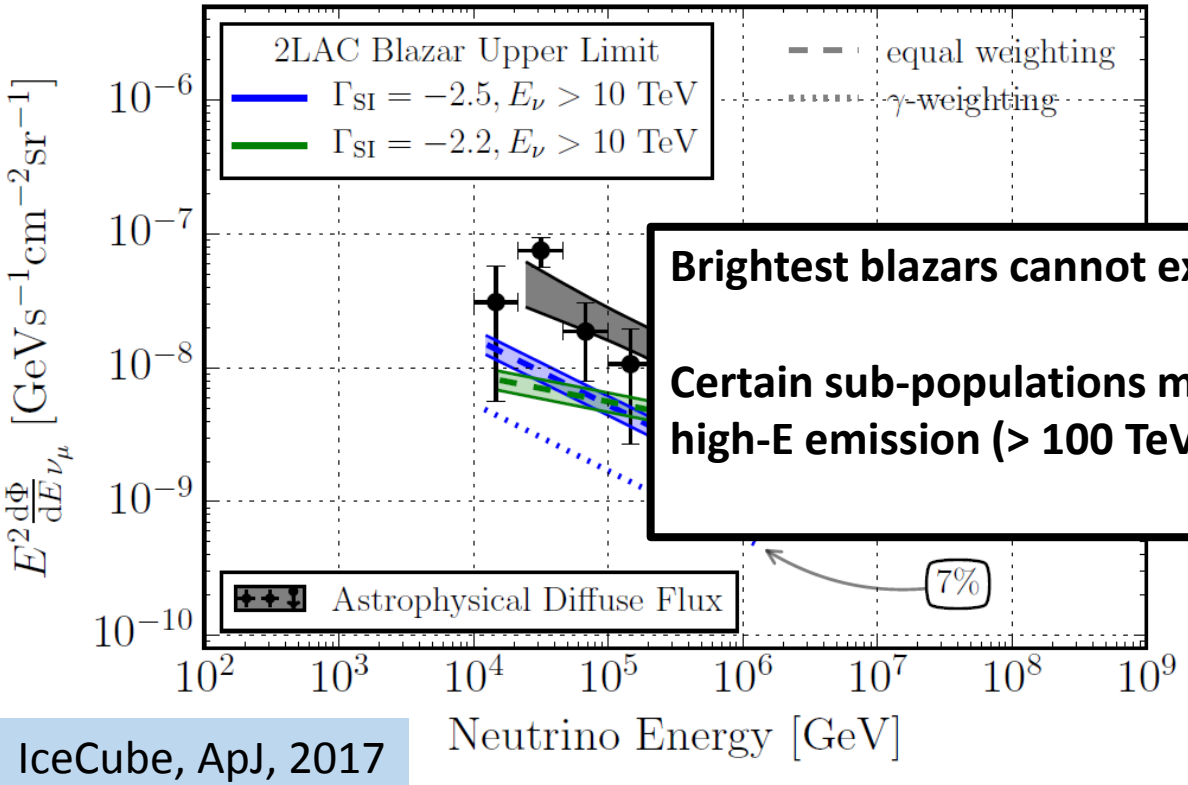

IceCube, ApJ, 2017

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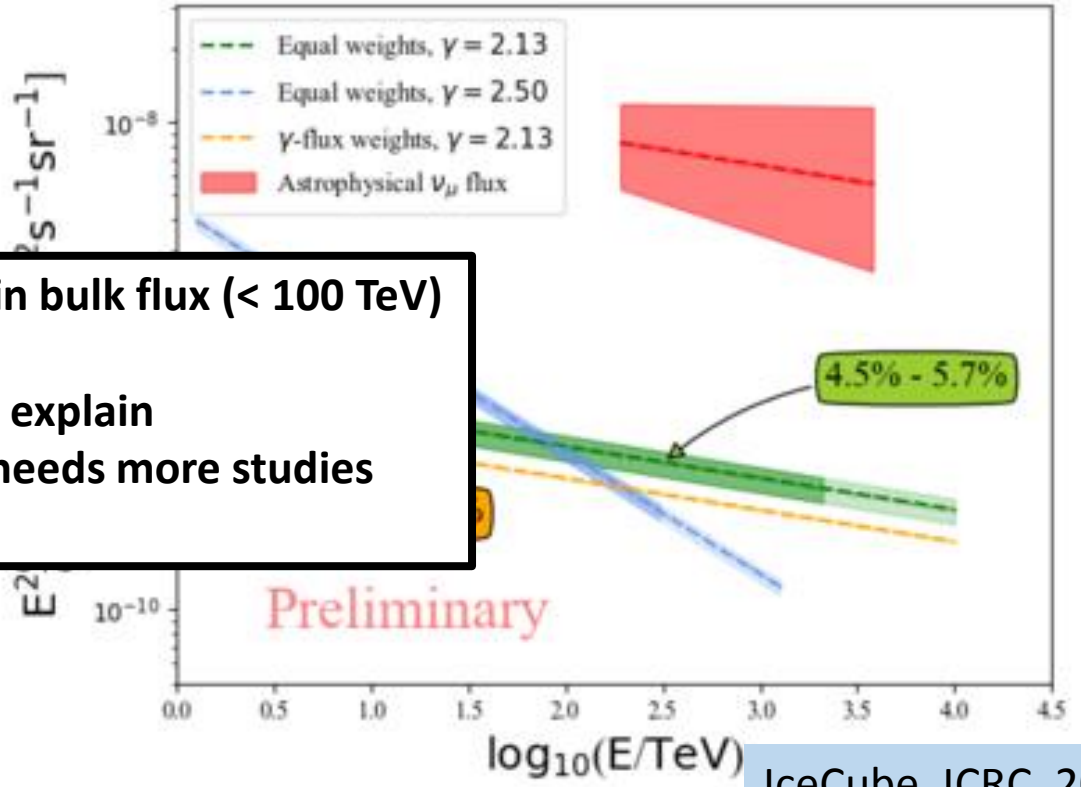


IceCube, ICRC, 2017

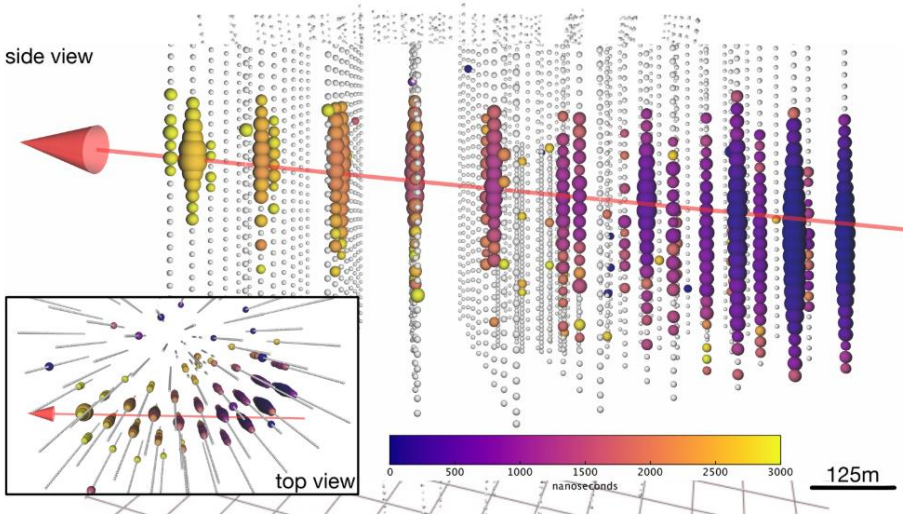
Brightest blazars cannot explain bulk flux (< 100 TeV)

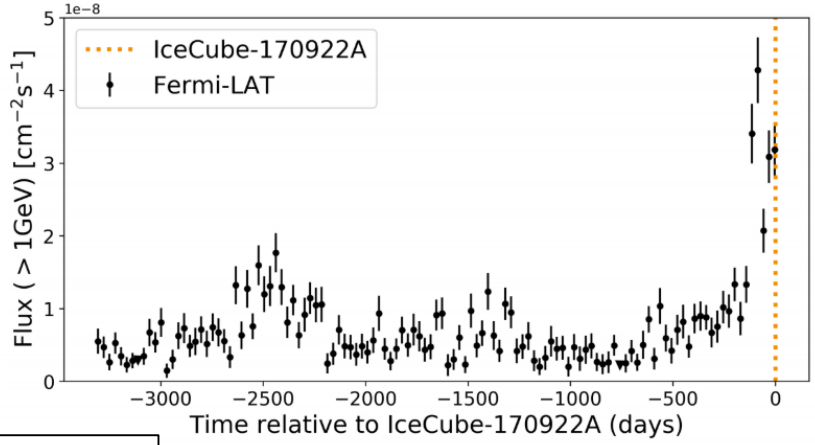
Certain sub-populations might explain high-E emission (> 100 TeV) .. needs more studies

Evidence for a first source: TXS 0506+056

- September 2017: neutrino detected (alert) in association with gamma flare

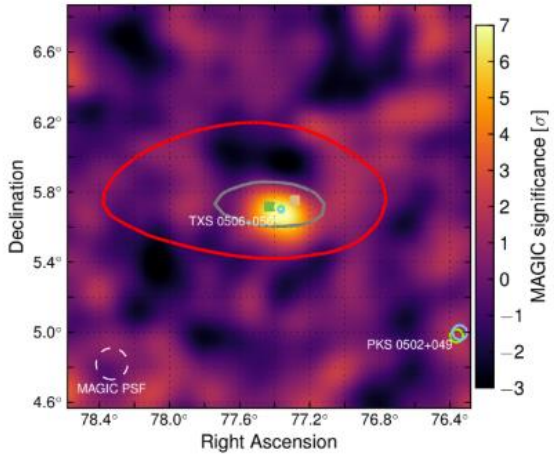
Muon neutrino alert (Sept 2017)





Fermi-LAT flare

3-σ chance



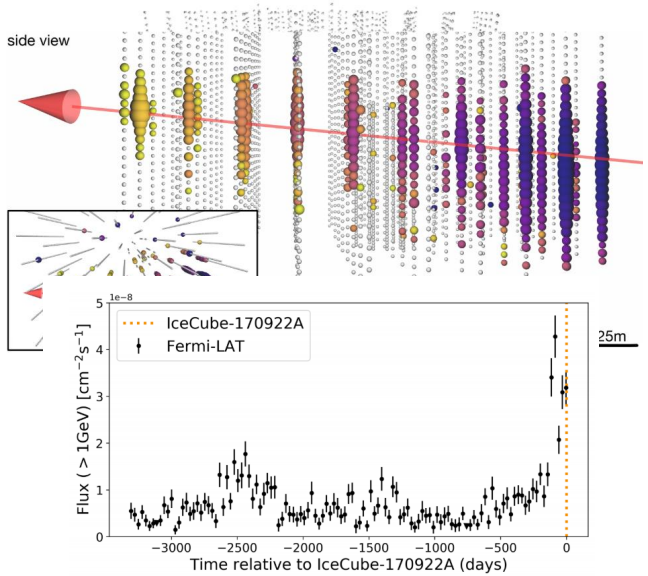
MAGIC flare

Science, 2018

Evidence for a first source: TXS 0506+056

- Check in archival neutrino data reveals independent neutrino flare

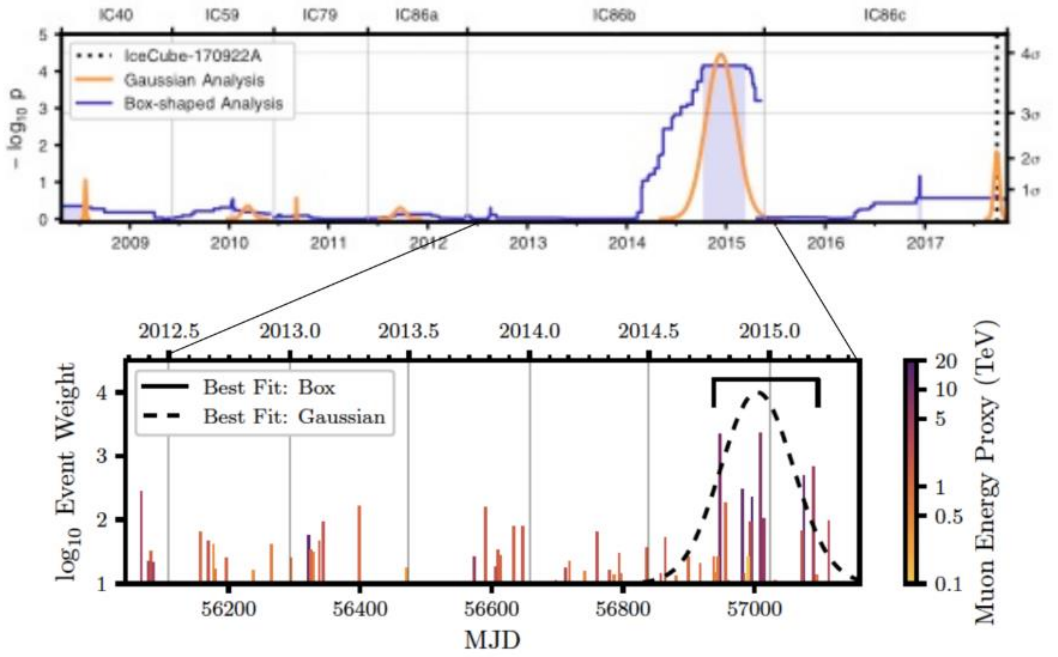
Muon neutrino alert (Sept 2017)



Science, 2018

3-σ chance

Neutrino flare in 2015, 13 +/- 5 signal events



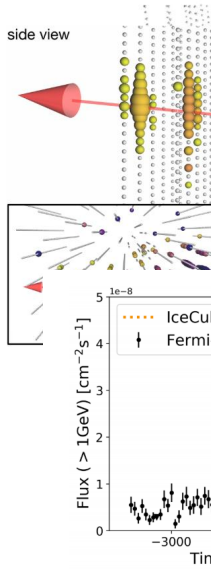
Science, 2018

Independent 3.5-σ chance

Evidence for a first source: TXS 0506+056

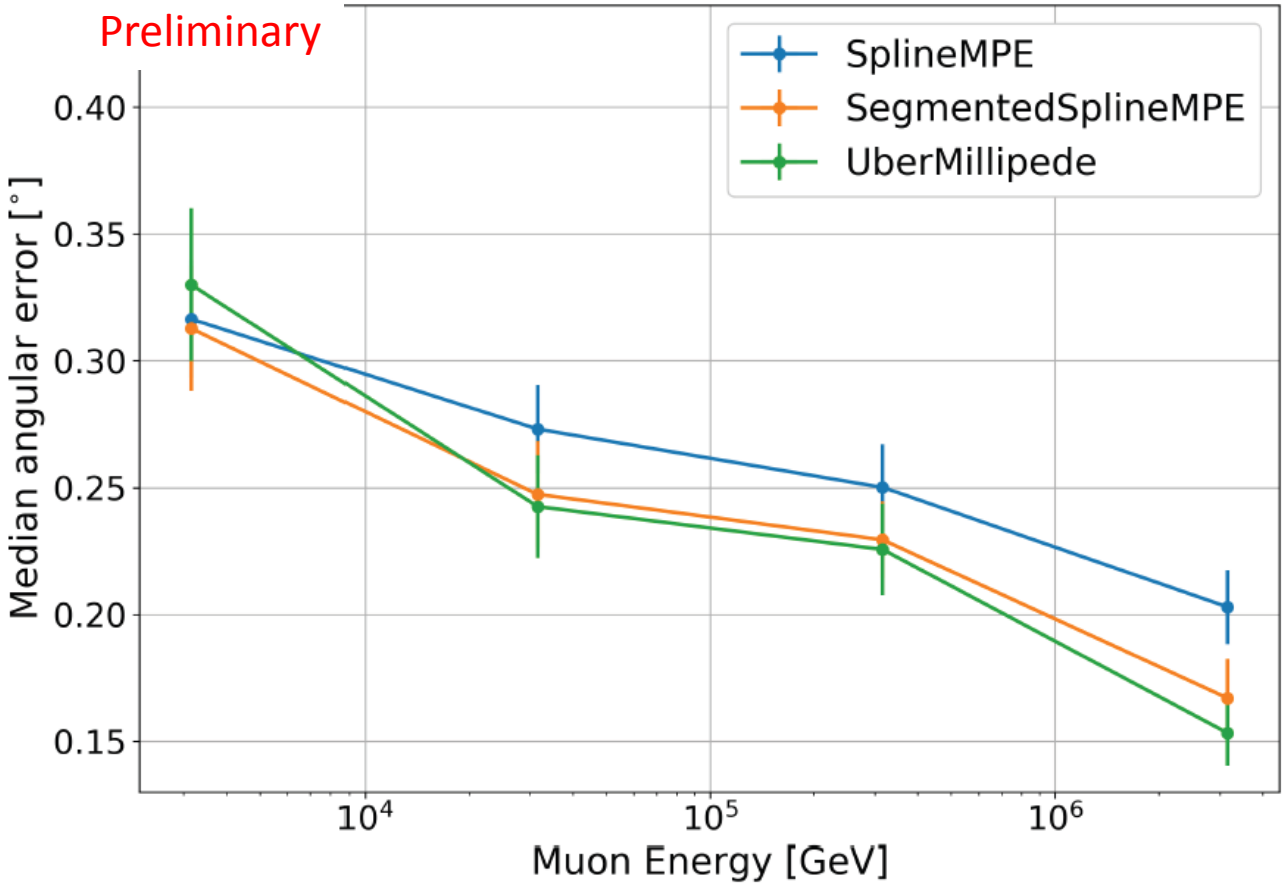
- Check in
  neutrinc

Muon neu

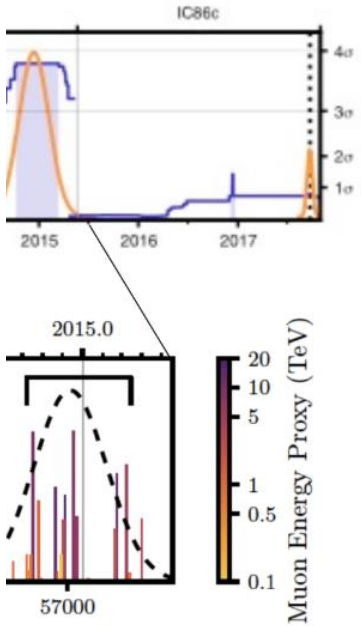


Science, 2018

Preliminary



5 signal events



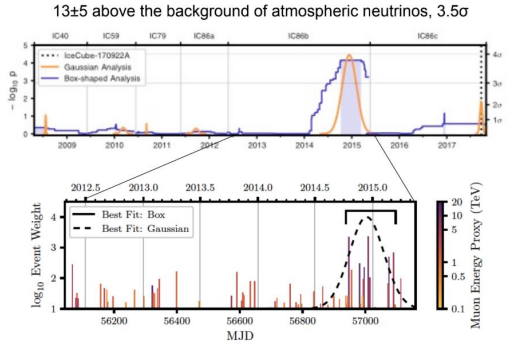
3-σ chance

New Reconstructions will eventually give older results an overhaul .. **also this one**

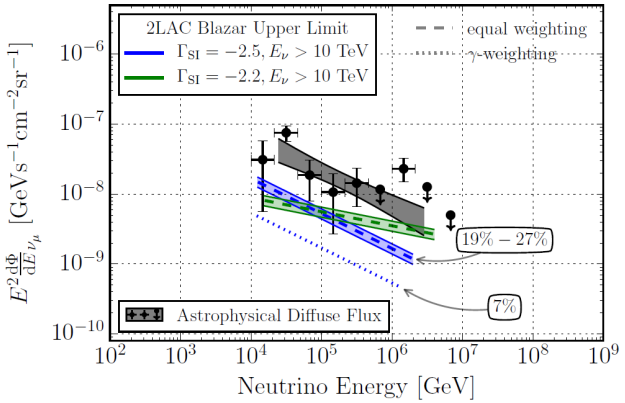
Independent 3.5-σ chance

Does not contradict blazar population results

- Averaged over 9.5 years, the neutrino flux from TXS corresponds to about 1% of the total neutrino flux
  (intrinsic neutrino luminosity 4X higher than average gamma lum.
  -> part of unusual blazar population?)



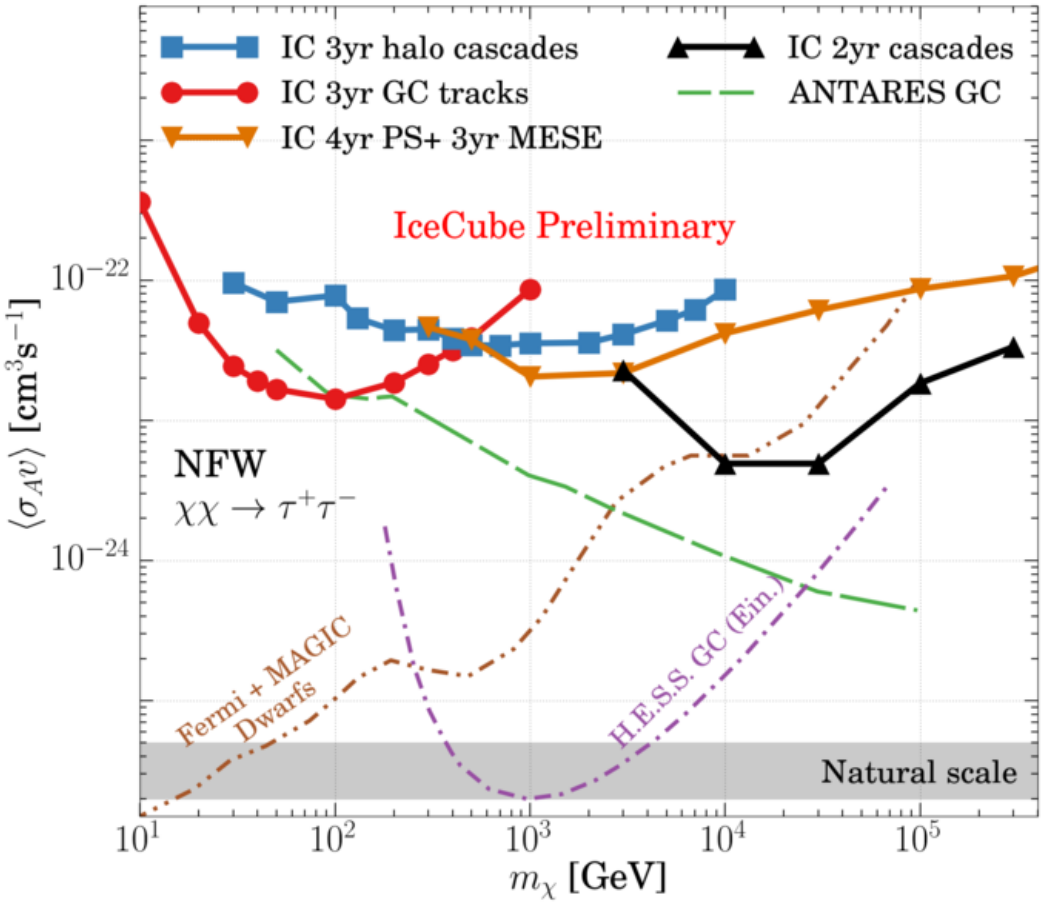
- Population result contained TXS 0506+056, but not the flare, and individual sources play a minor role in overall population PDF



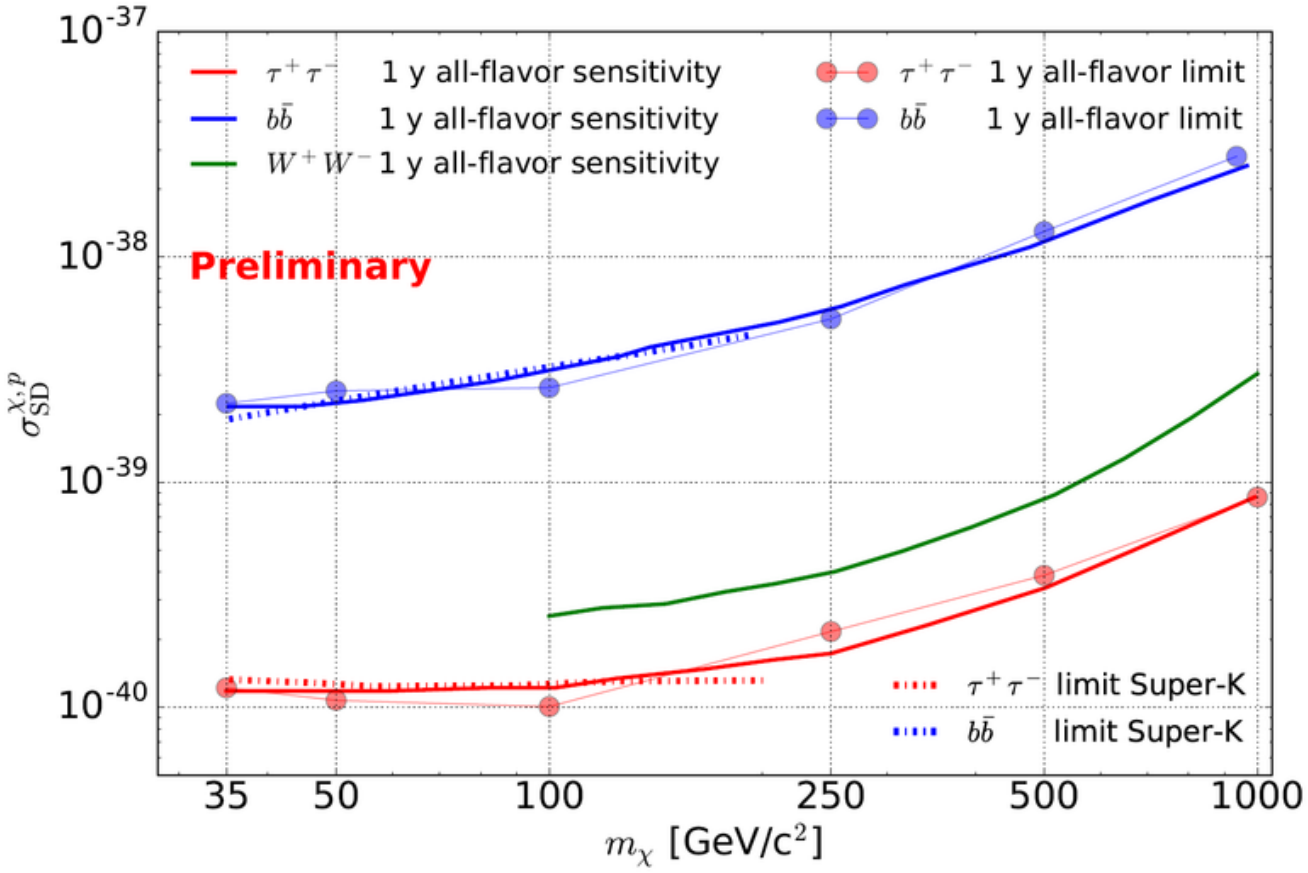
A few other selected topics…

Dark matter constraints

Halo / GC

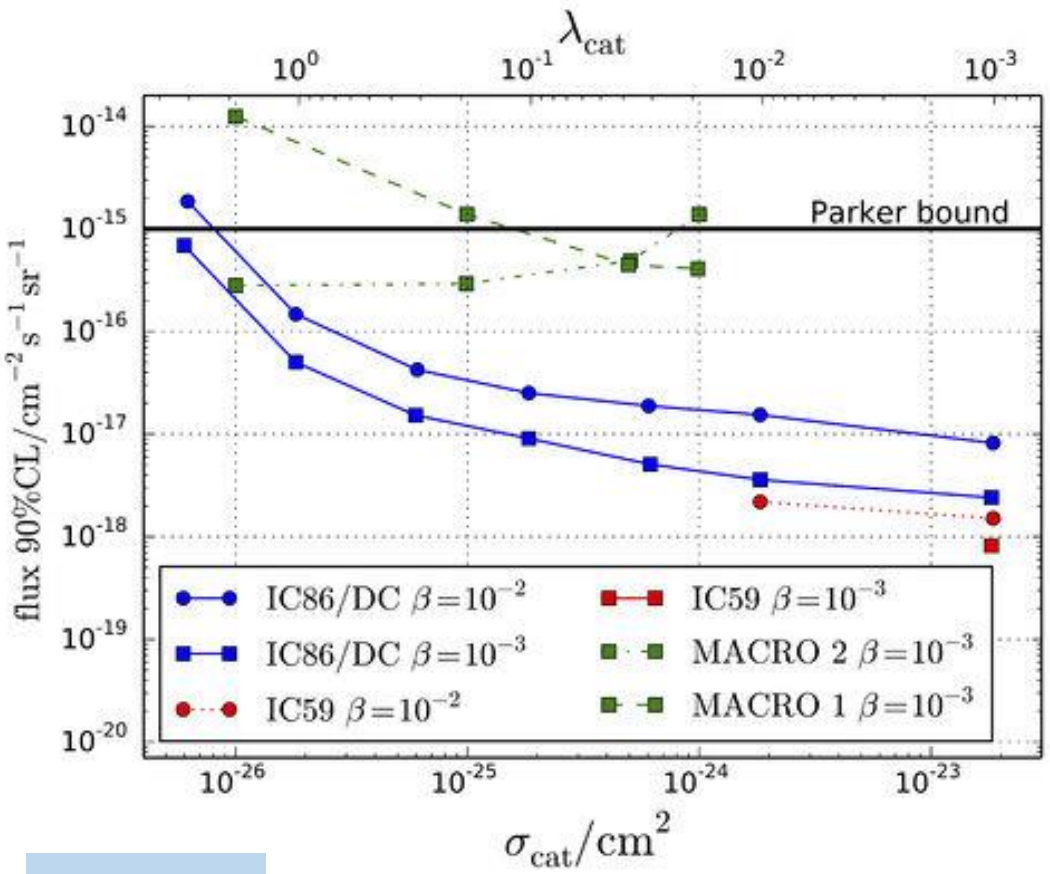


Solar



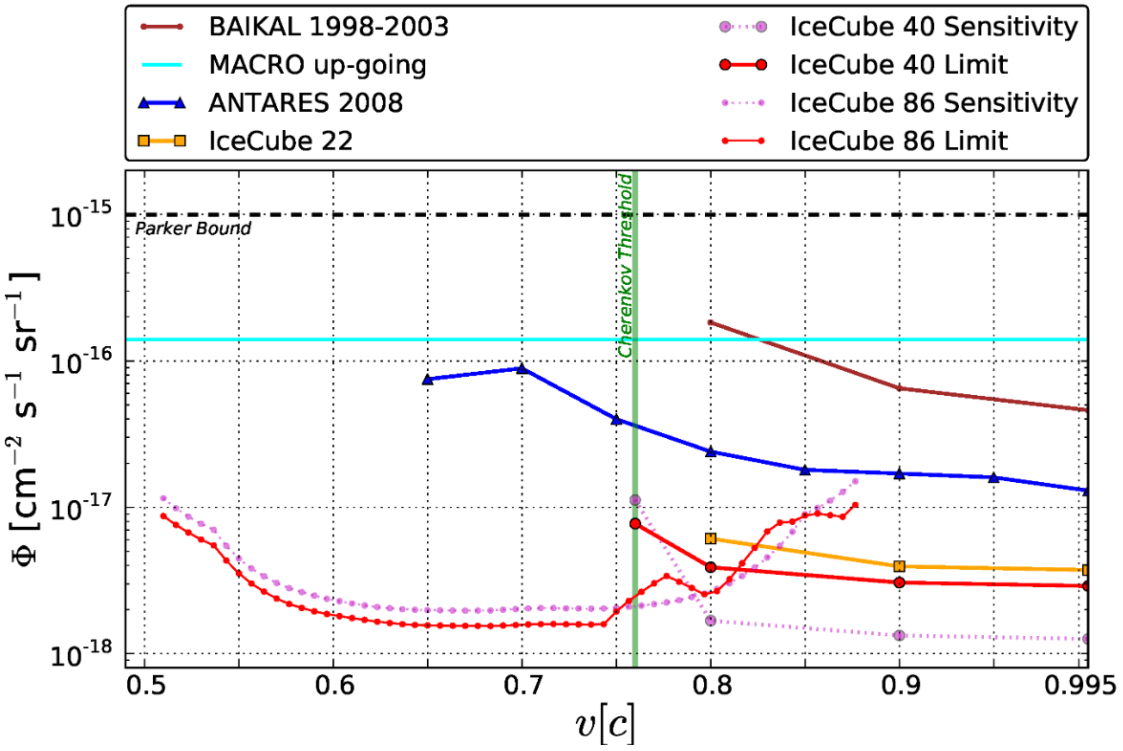
Magnetic monopoles

subrelativistic (v < 0.01 c)



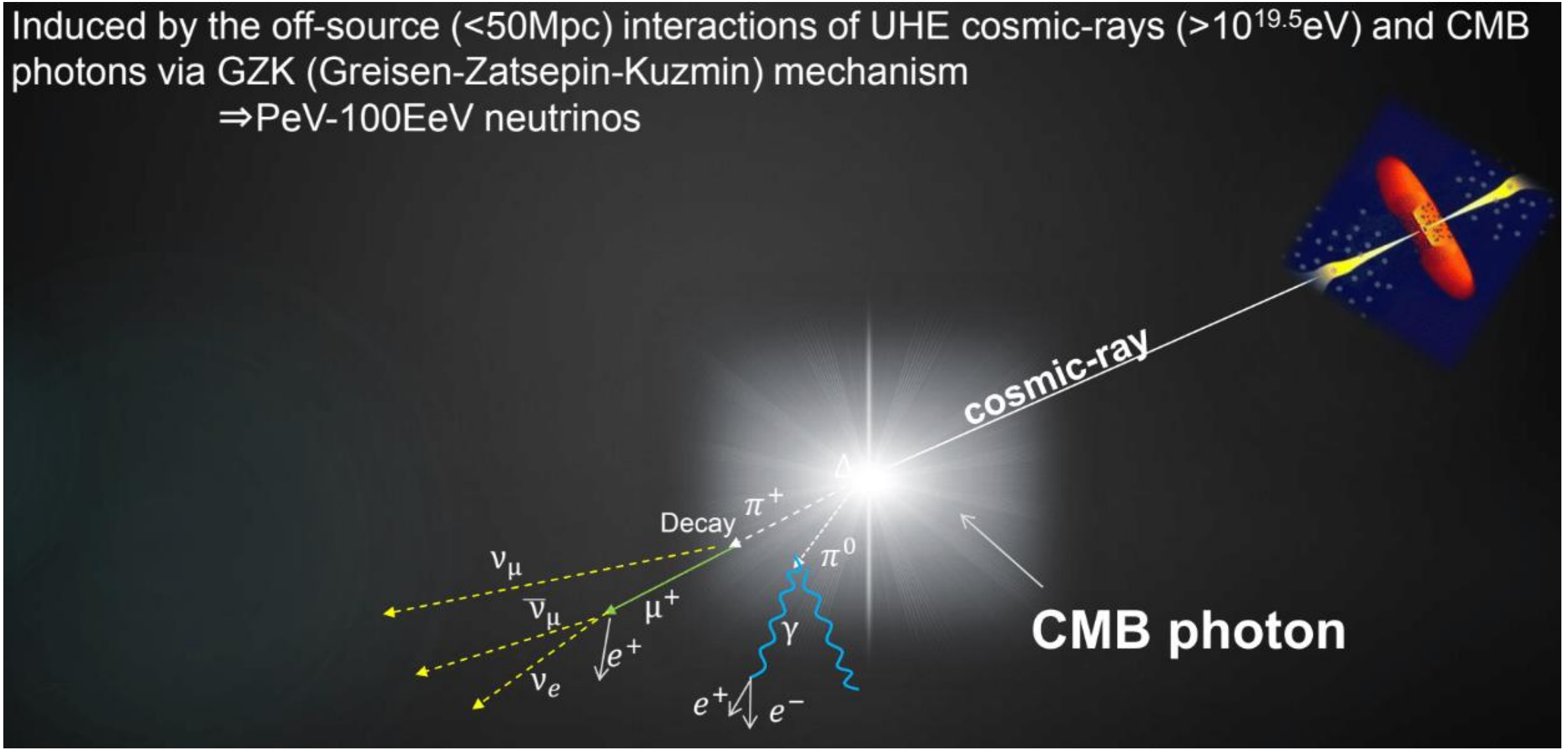
EPJ, 2014

Mildly relativistic – relativistic (> 0.5 c)



EPJ, 2015

Extremely high energies (EHE)

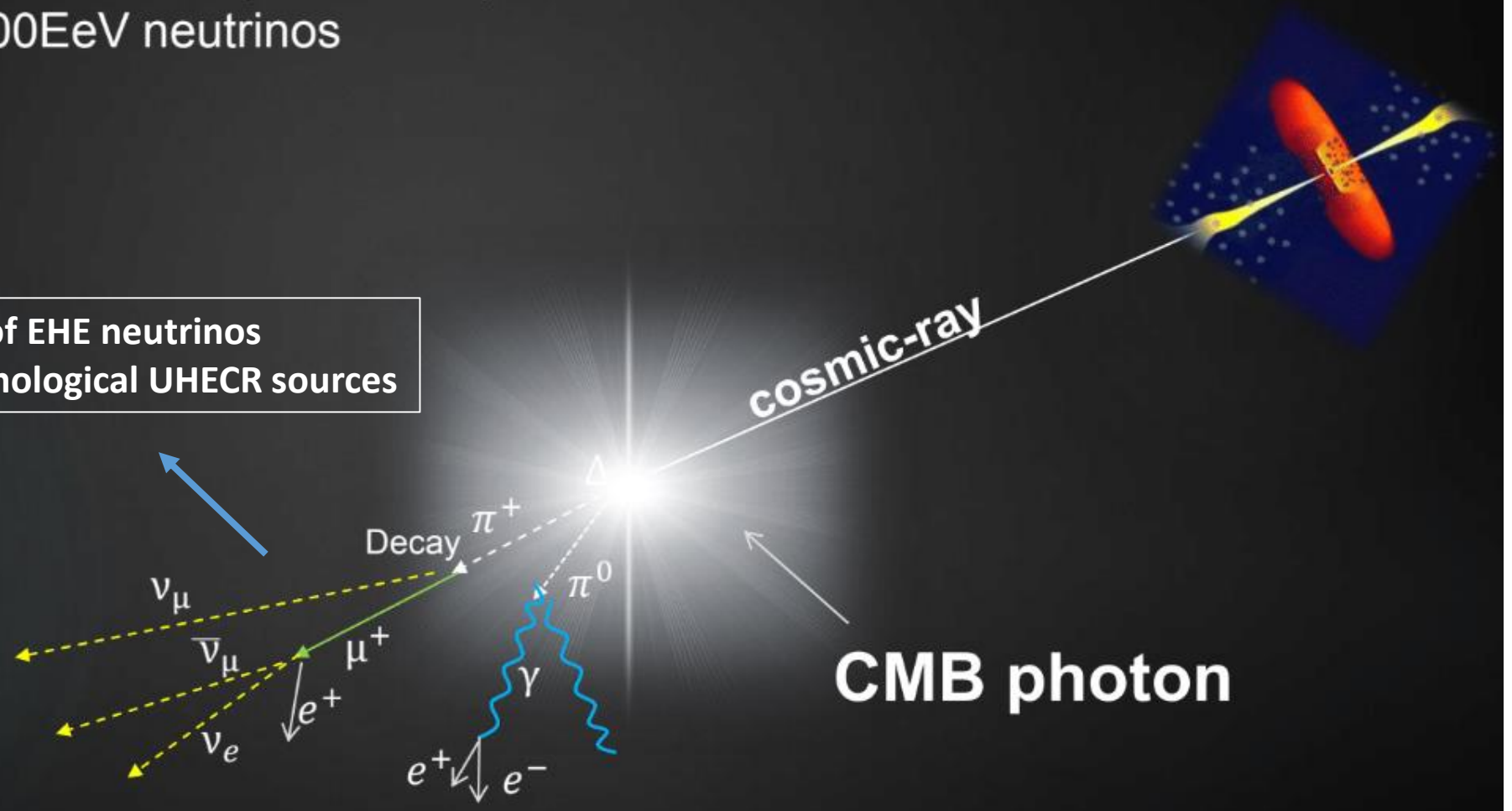


Extremely high energies (EHE)

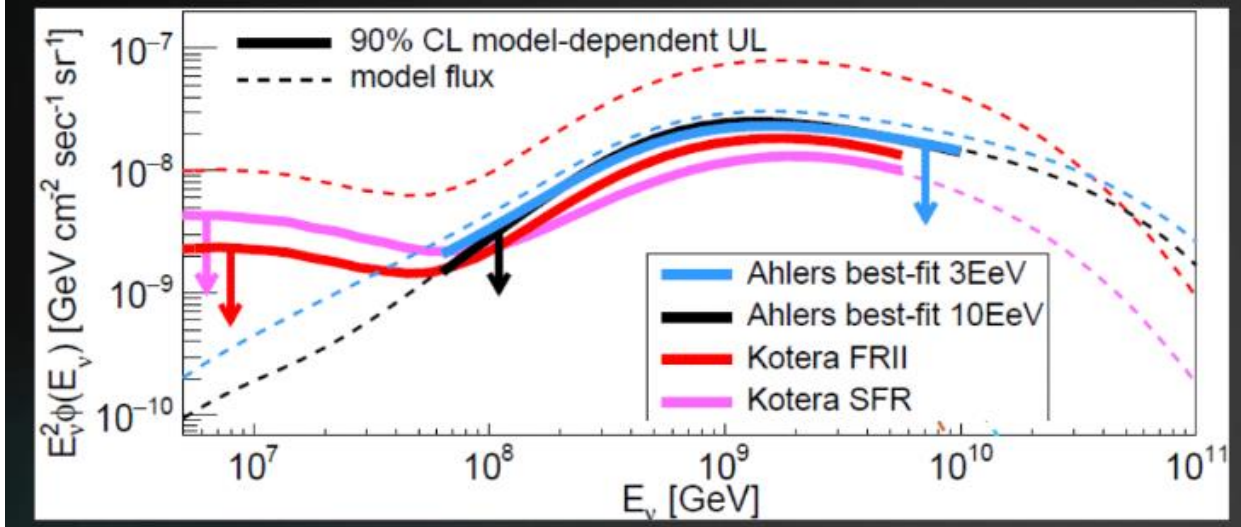
Induced by the off-source (<50Mpc) interactions of UHE cosmic-rays (>$10^{19.5}$eV) and CMB photons via GZK (Greisen-Zatsepin-Kuzmin) mechanism

⇒PeV-100EeV neutrinos

Non-observation of EHE neutrinos can constrain cosmological UHECR sources



7 – year EHE results



- Expect 3.6-4.8 events from SFR models
- UHECR sources evolve more slowly than SFR
- Or heavier/mixed composition

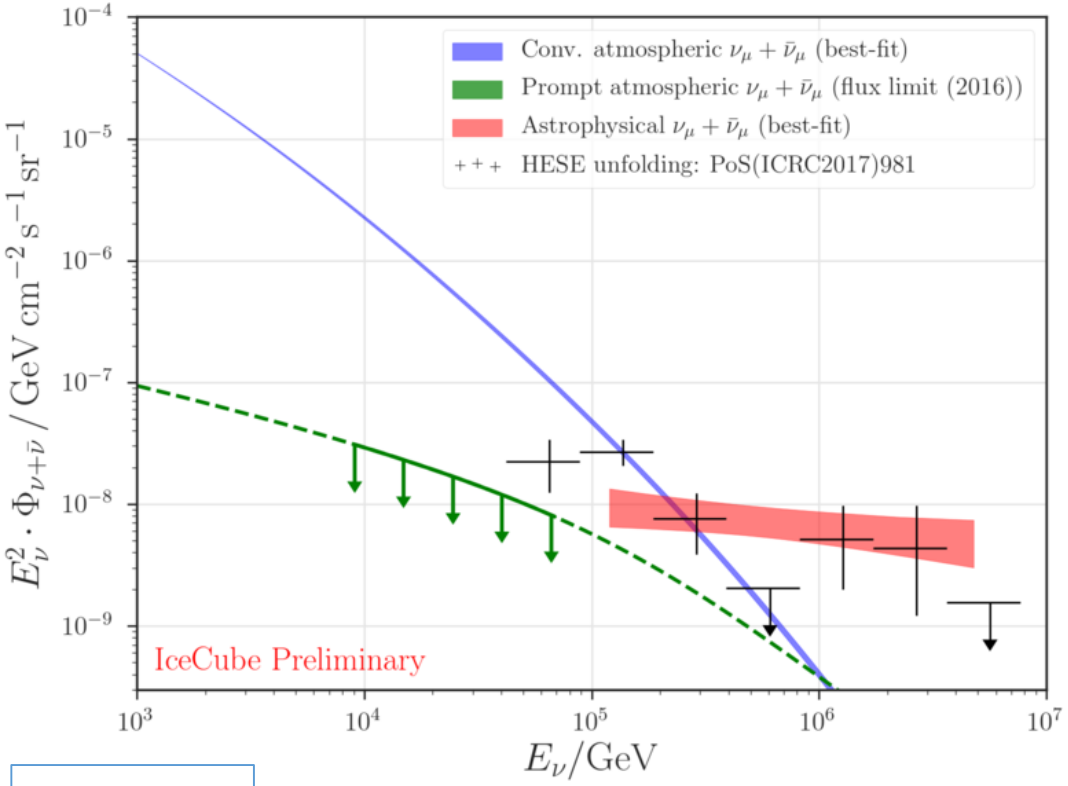
  ⇒Constraints on proton component

- Models to describe the origin of observed diffuse gamma-ray as cosmogenic from observed UHECRs constrained

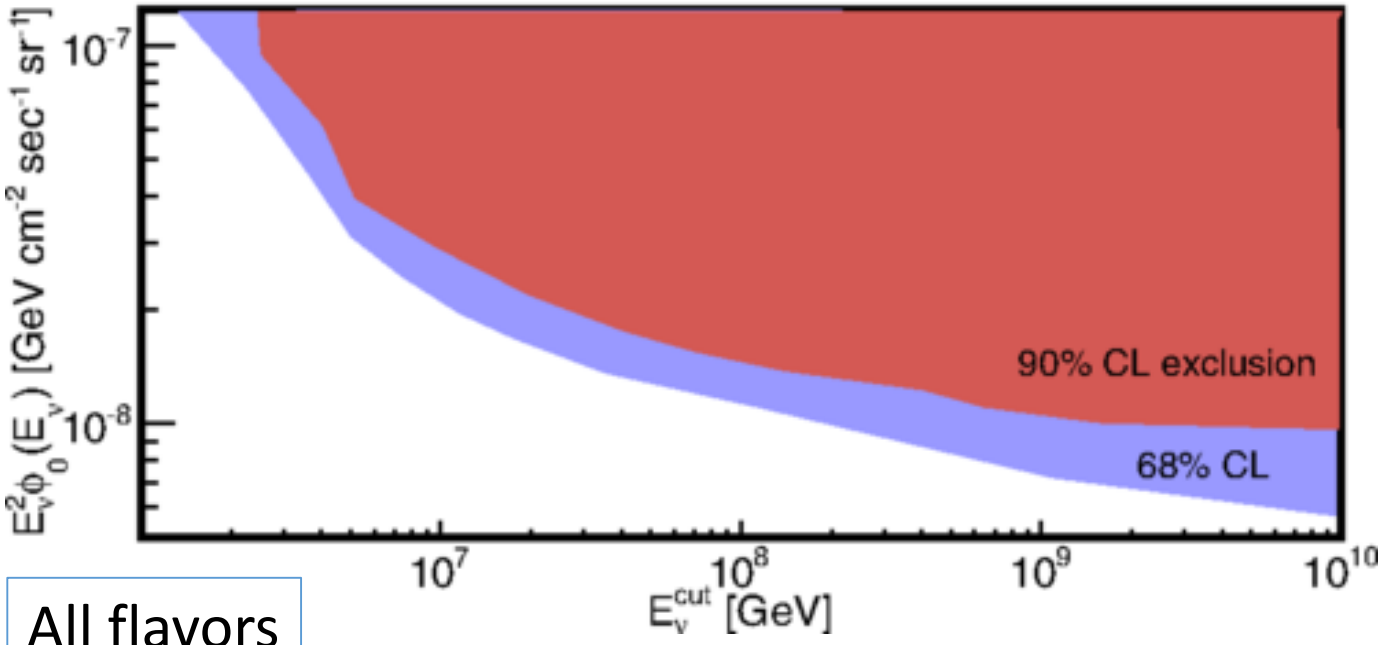
PRL, 2016

ν Model	Event rate per livetime	p-value	MRF
Kotera *et al.* SFR	$3.6^{+0.5}_{-0.8}$	$6.0^{+2.9}_{-1.0}\%$	1.04
Kotera *et al.* FRII	$14.7^{+2.2}_{-2.7}$	<0.1%	0.23
Aloisio *et al.* SFR	$4.8^{+0.7}_{-0.9}$	$3.2^{+2.8}_{-0.7}\%$	0.80
Aloisio *et al.* FRII	$24.7^{+3.6}$	<0.1%	0.15
Yoshida *et al.* $m = 4.0, z_{max} = 4.0$	$7.0^{+1.0}_{-1.0}$	$0.1^{+0.4}_{-0.1}\%$	0.43
Ahlers *et al.* best fit, 1 EeV	$2.8^{+0.4}_{-0.4}$	$13.4^{+9.2}_{-2.2}\%$	1.33
Ahlers *et al.* best fit, 3 EeV	$4.4^{+0.6}_{-0.7}$	$3.2^{+1.8}_{-1.4}\%$	0.76
Ahlers *et al.* best fit, 10 EeV	$5.3^{+0.8}_{-0.8}$	$1.1^{+2.5}_{-0.3}\%$	0.63

EHE constraints on astrophysical flux



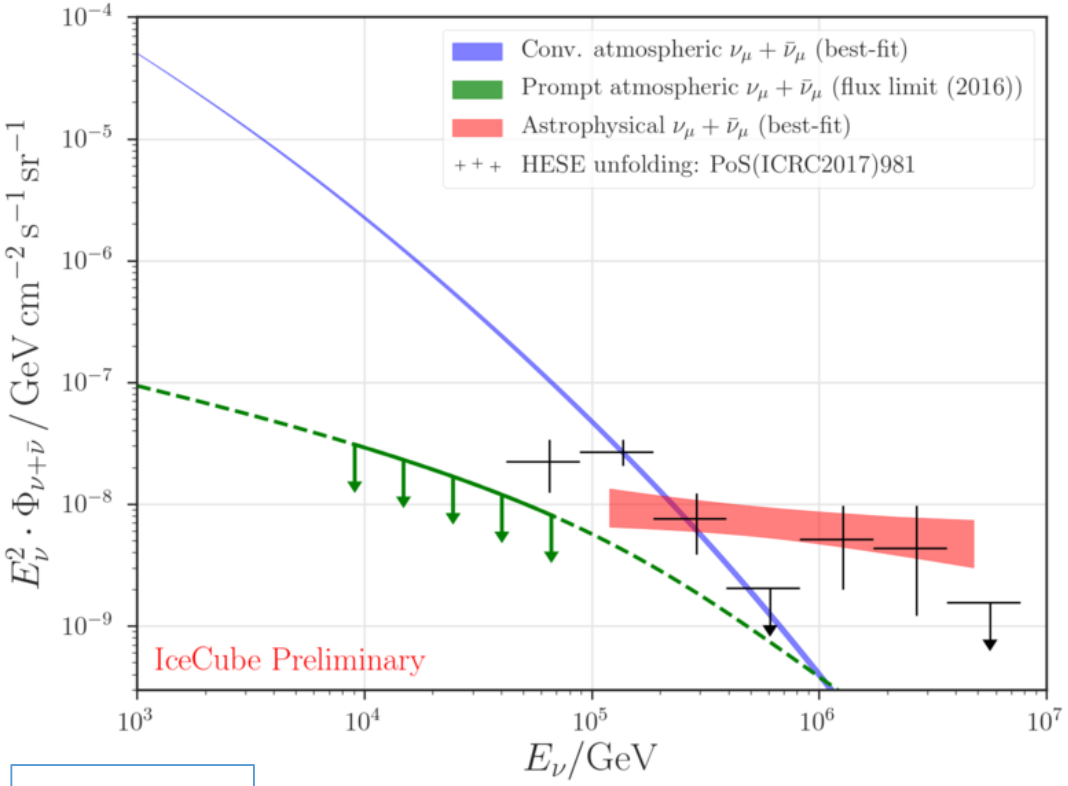
Only ν_μ



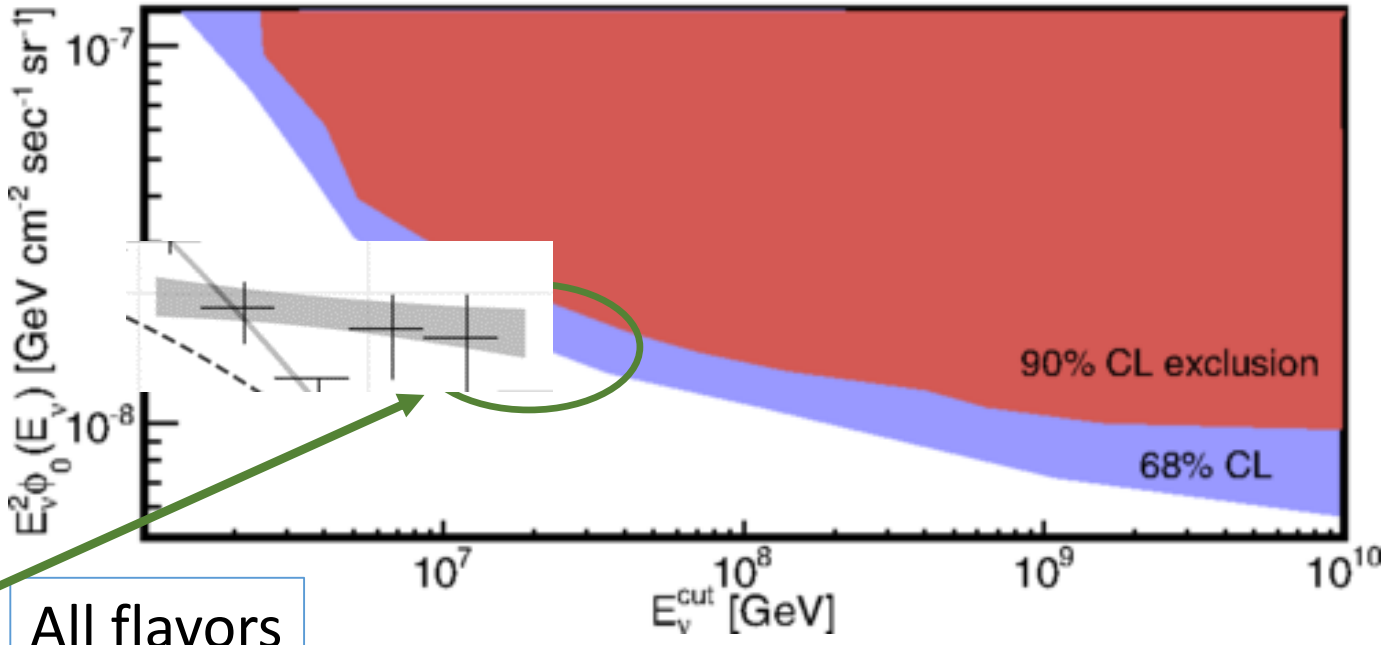
All flavors

PRL, 2016

EHE constraints on astrophysical flux



Only ν_μ



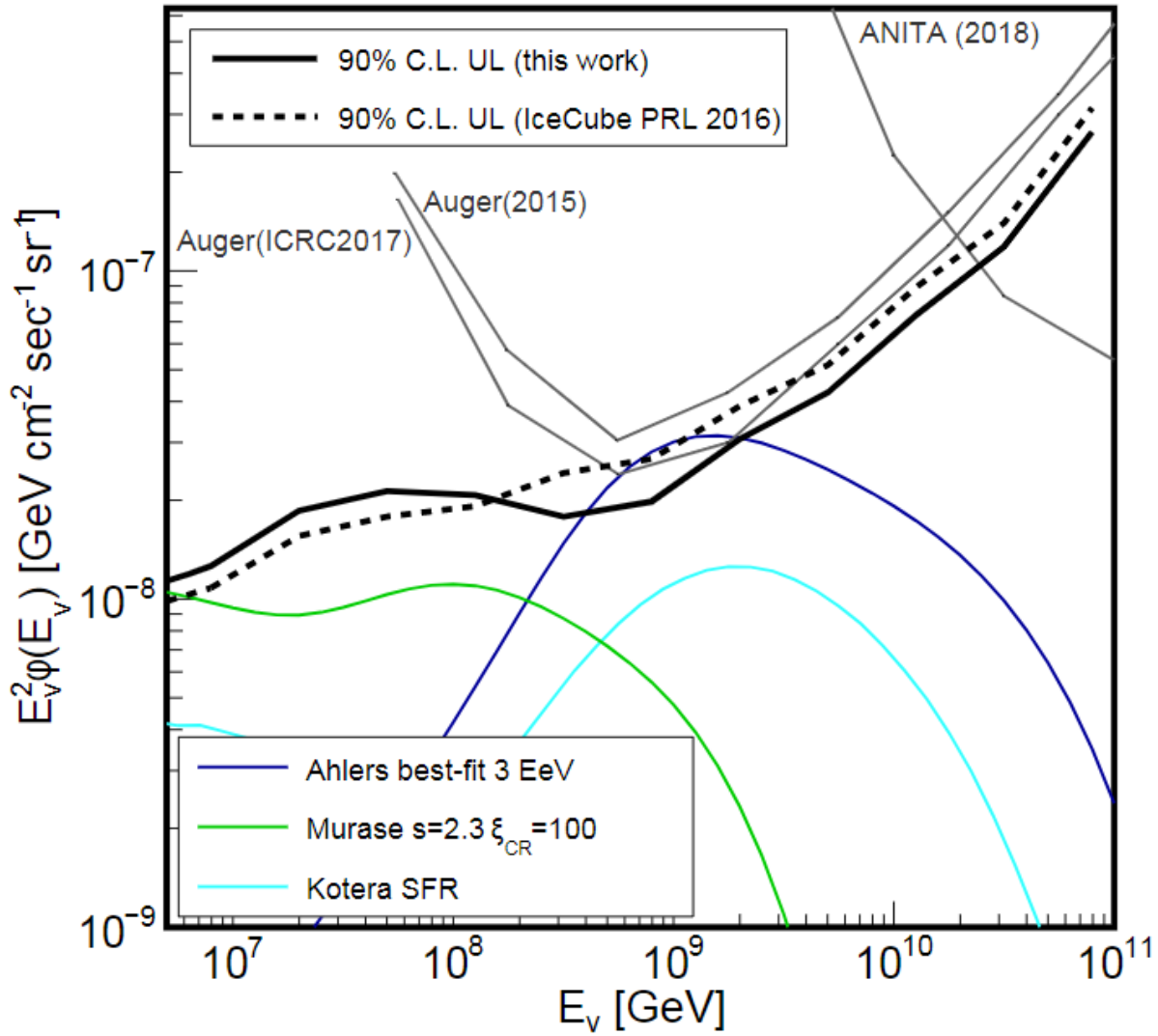
All flavors

Spectrum constrained
to be softer/to cut off

PRL, 2016

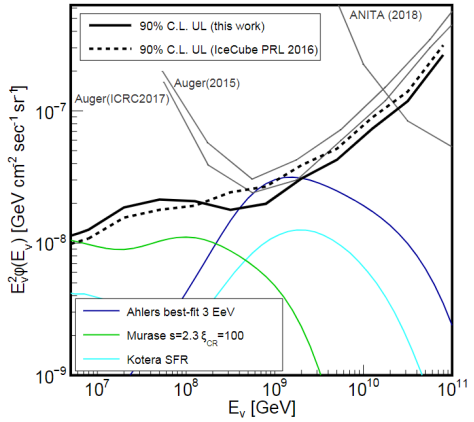
Recent 9-year EHE results

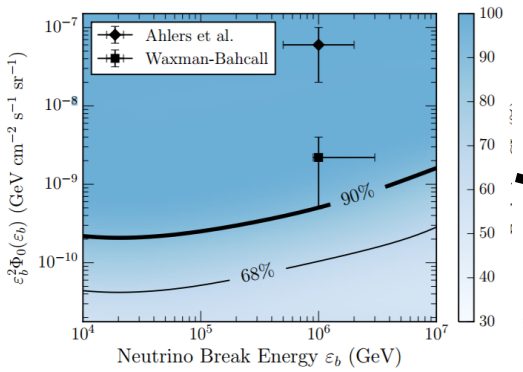
- Most sensitivite differential limit in EHE region

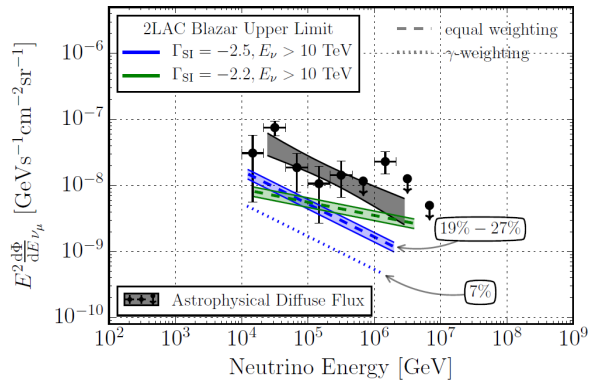


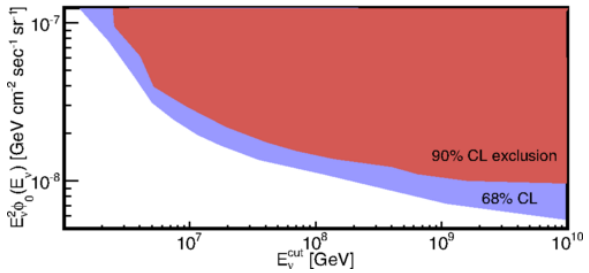
IceCube, PhysRev-D, 2018

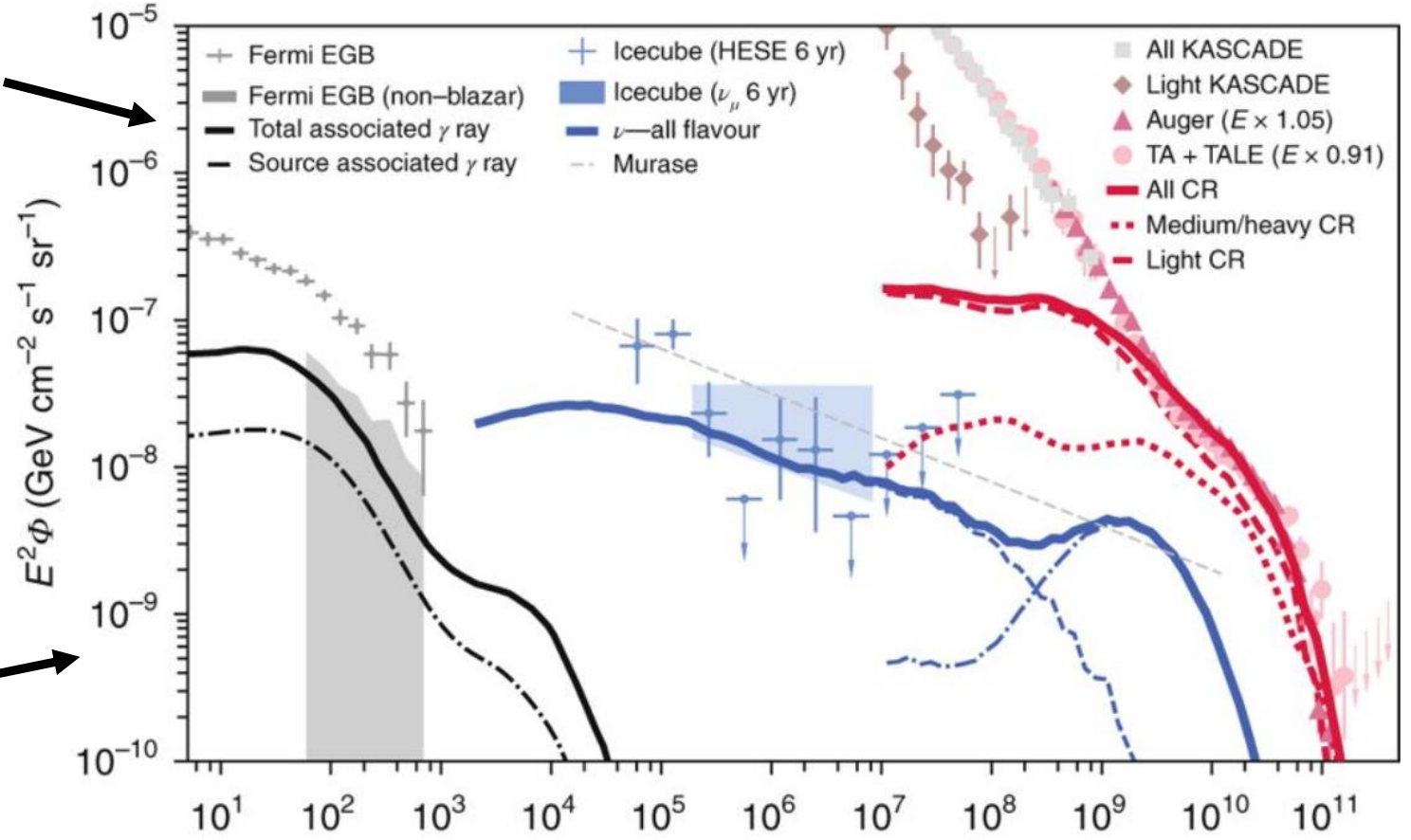
Many ingredients in overall picture











Fang/Murase, Nature, 2018

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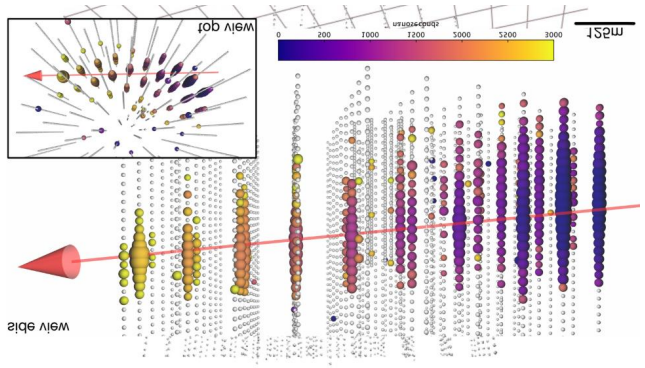
Summary

- Astrophysical neutrinos: discovery in **independent channels**
- Some tension for simple power-law (~ 2-3 σ)

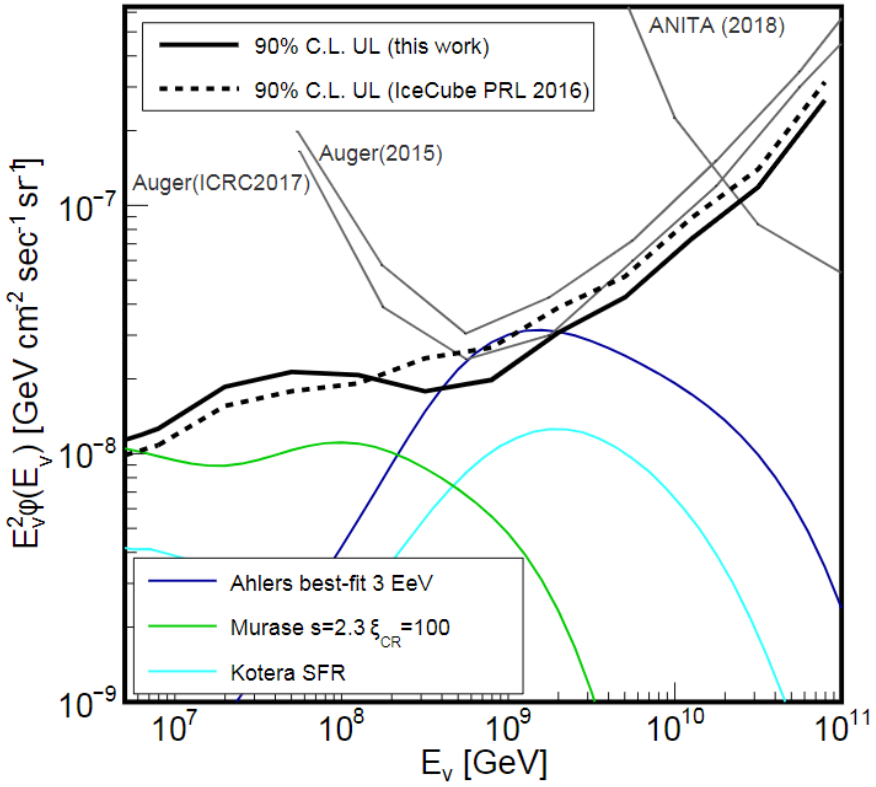
Summary

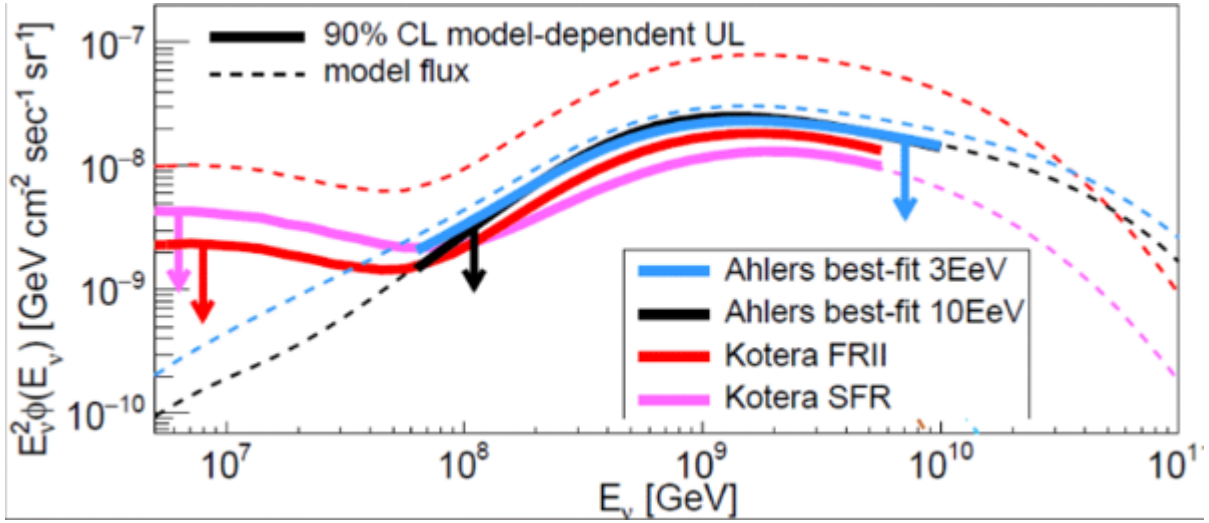
- Astrophysical neutrinos: discovery in **independent channels**
- Some tension for simple power-law (~ 2-3 σ)
- Bulk emission: prompt bright GRBs (< a few %)
  Bright gamma-ray blazars (< 27% - model independent)
  Galactic diffuse emission < ~20 %
- Evidence for neutrino emission from a neutrino-luminous blazar
  TXS 0506+056 .. Blazars are neutrino emitters to some extent



Summary

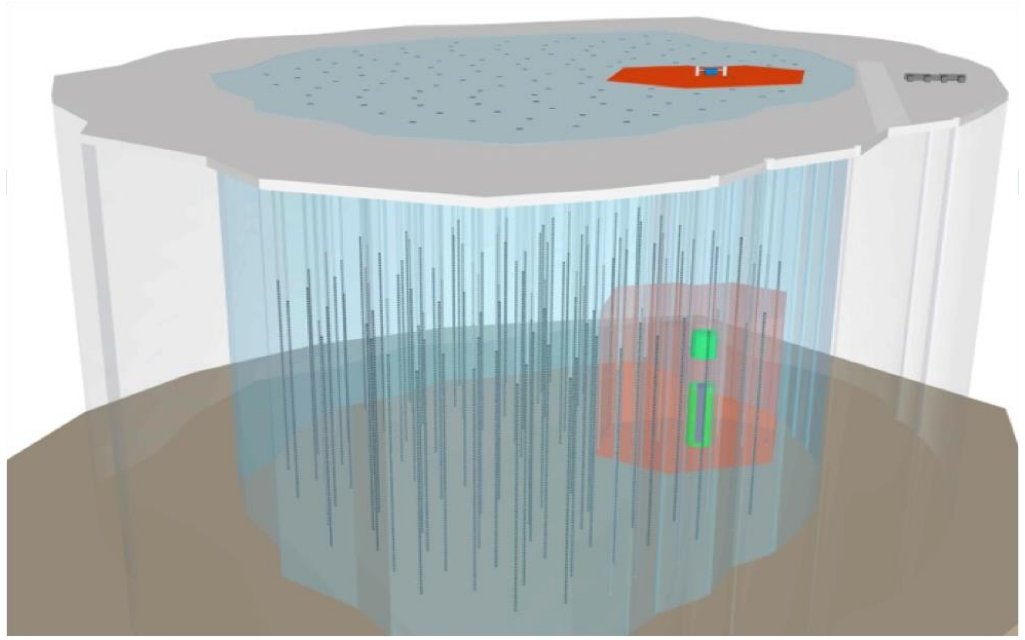
- Non-observation of cosmogenic neutrinos constrains most optimistic UHECR models (Kotera et al.)
  -> e.g. UHECR source evolution limited in case pure proton composition

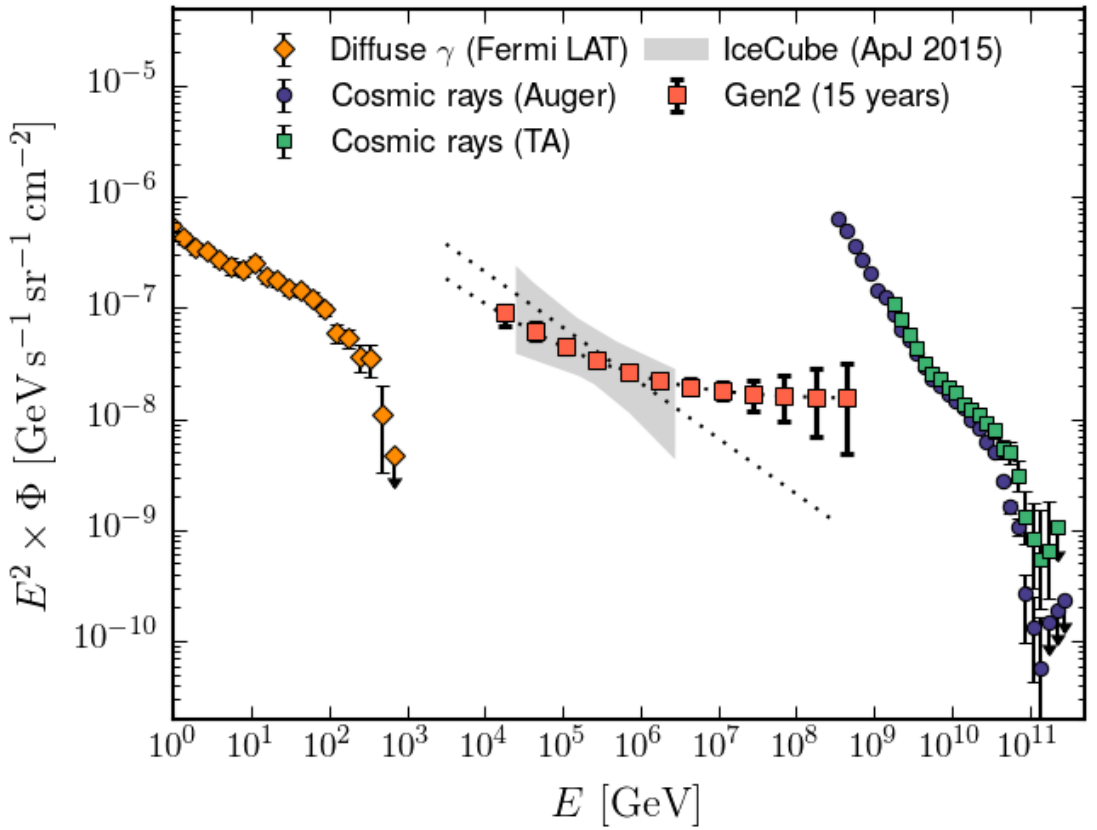




Outlook

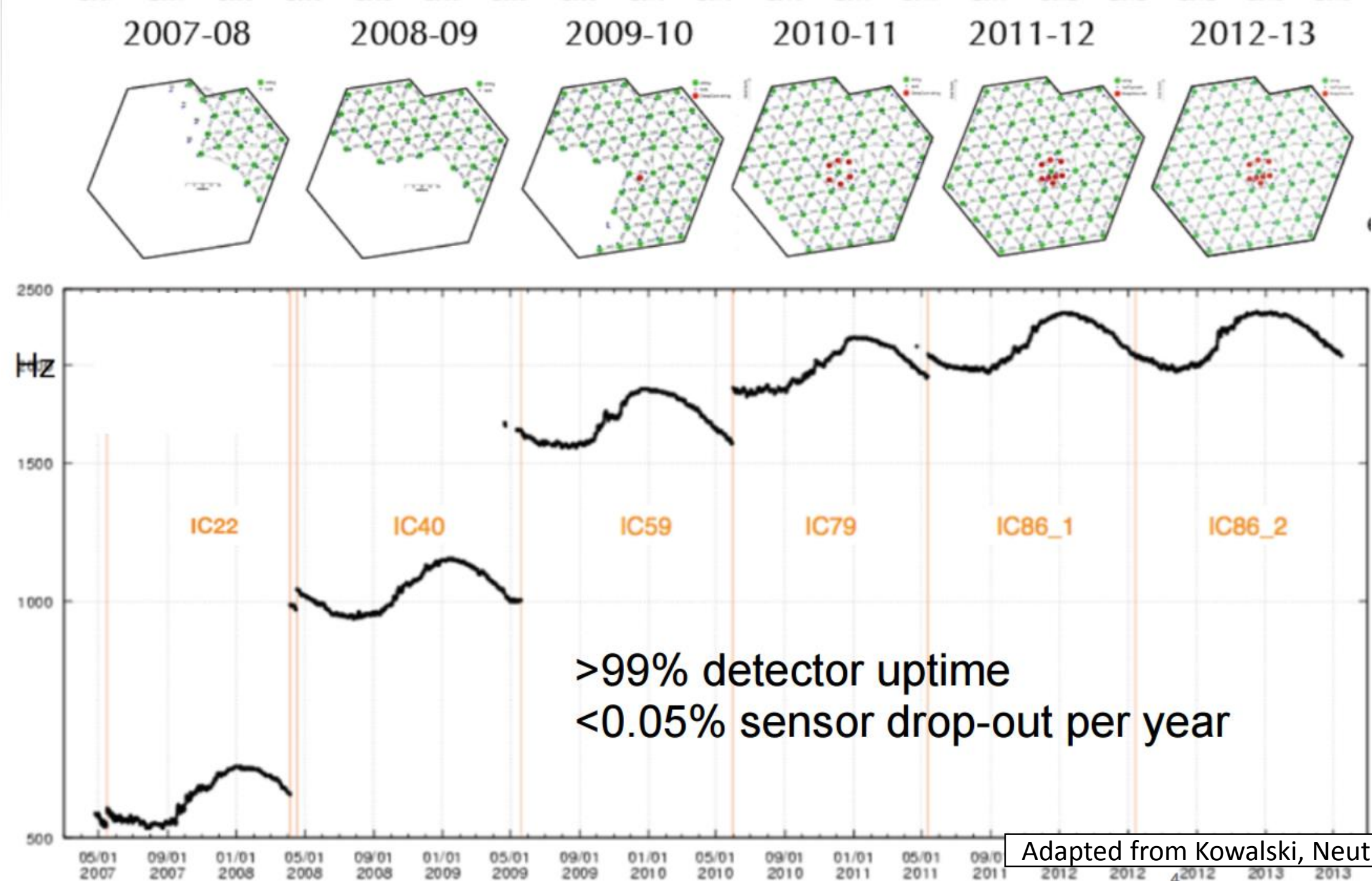
- Next gen IceCube is in planning („Gen 2“)





- Should be able to significantly improve cosmological constraints

Backup

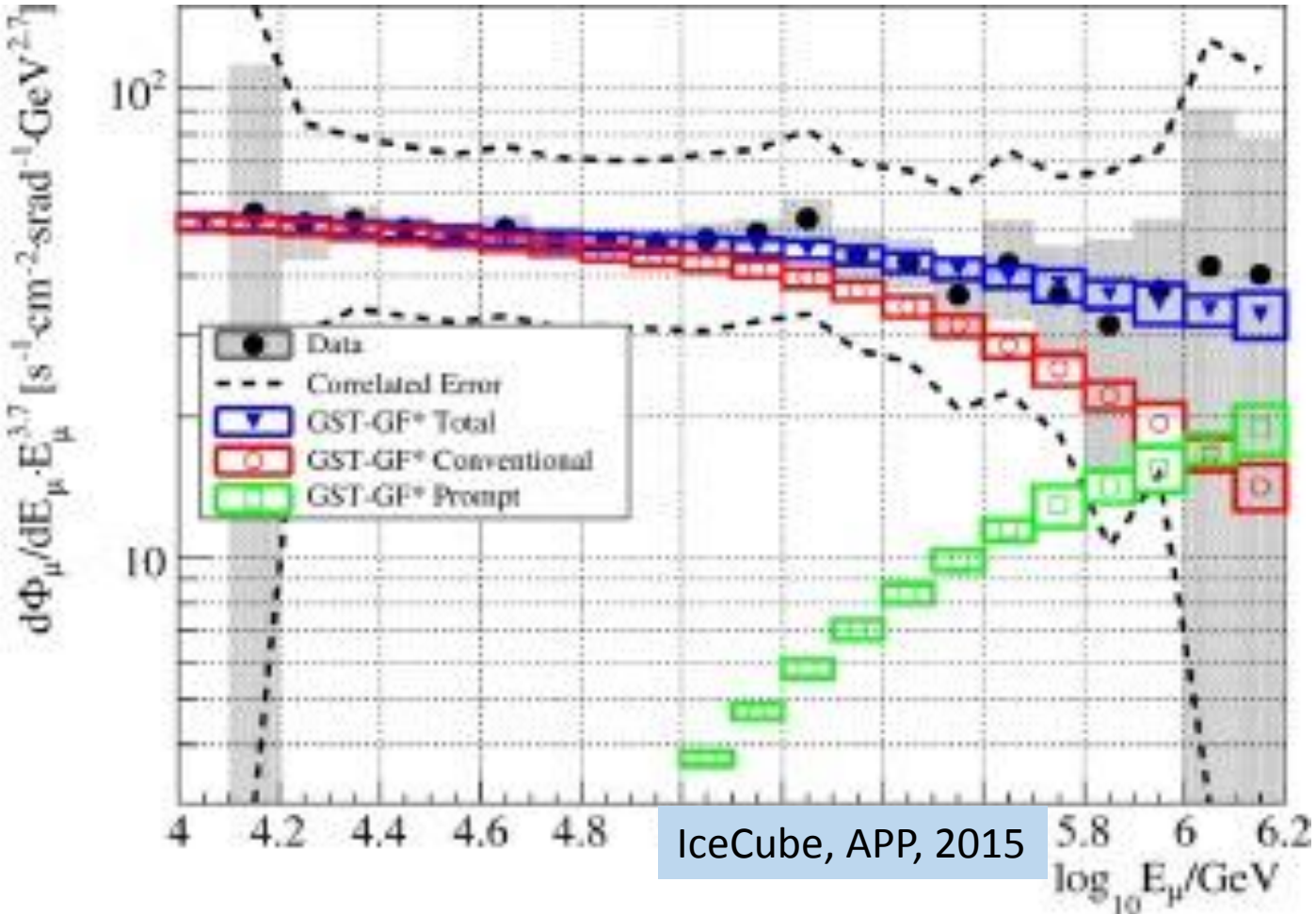


Adapted from Kowalski, Neutrino 2016

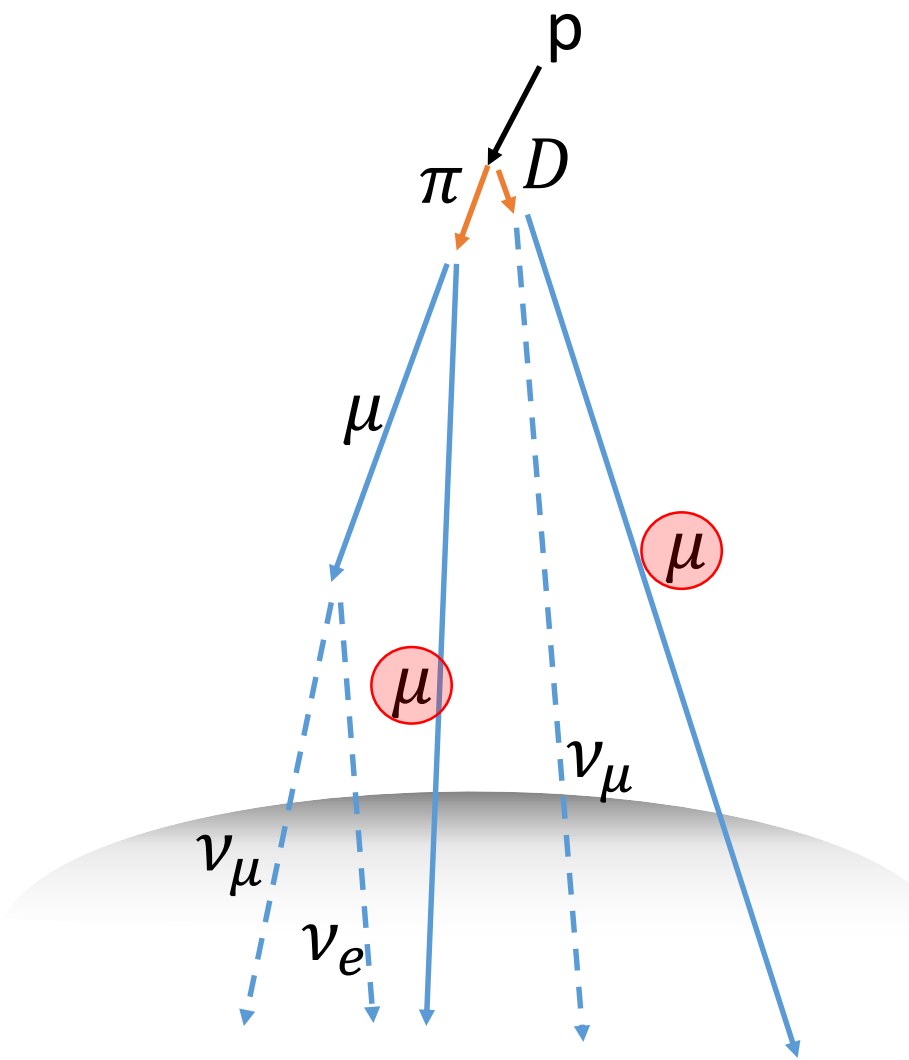
Atmospheric backgrounds

- Muons: > 2000 / s

Spectrum @ high E

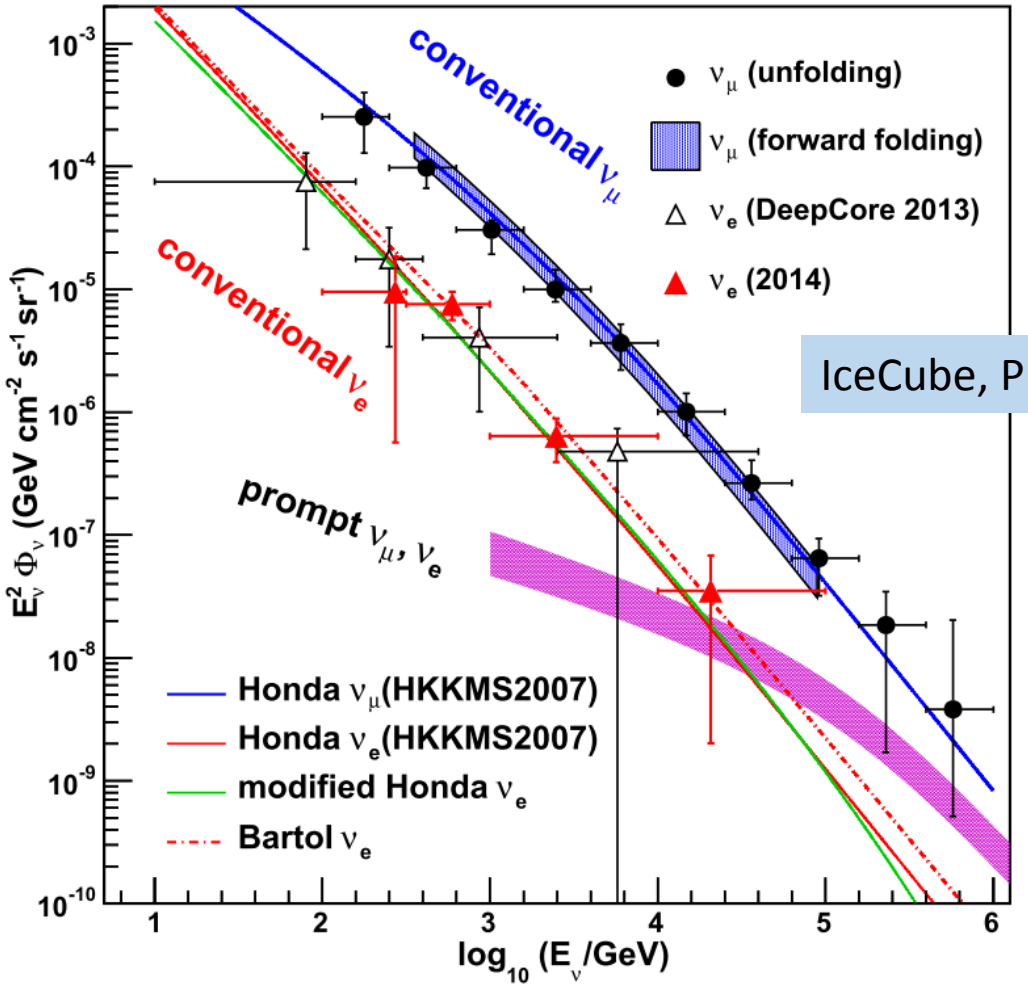


IceCube, APP, 2015

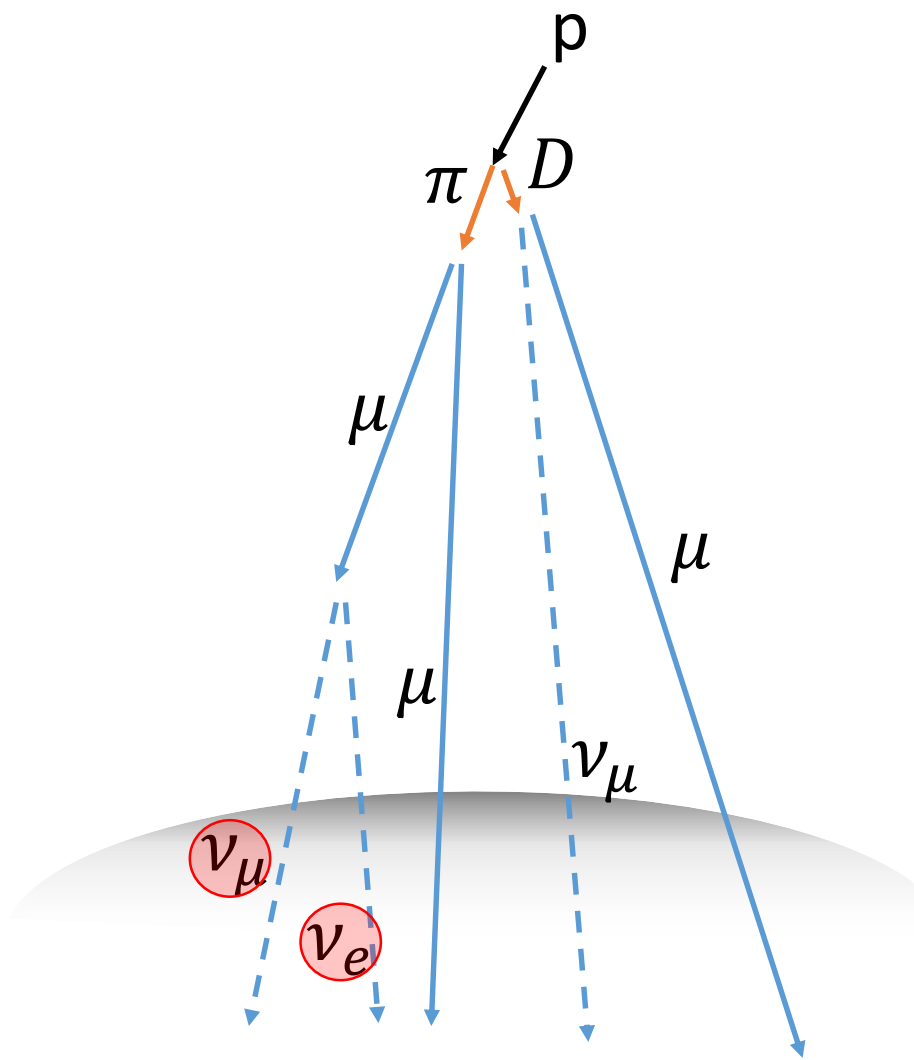


Atmospheric backgrounds

- Muons: > 2000 / s
- Neutrinos: ~ 70000 / year

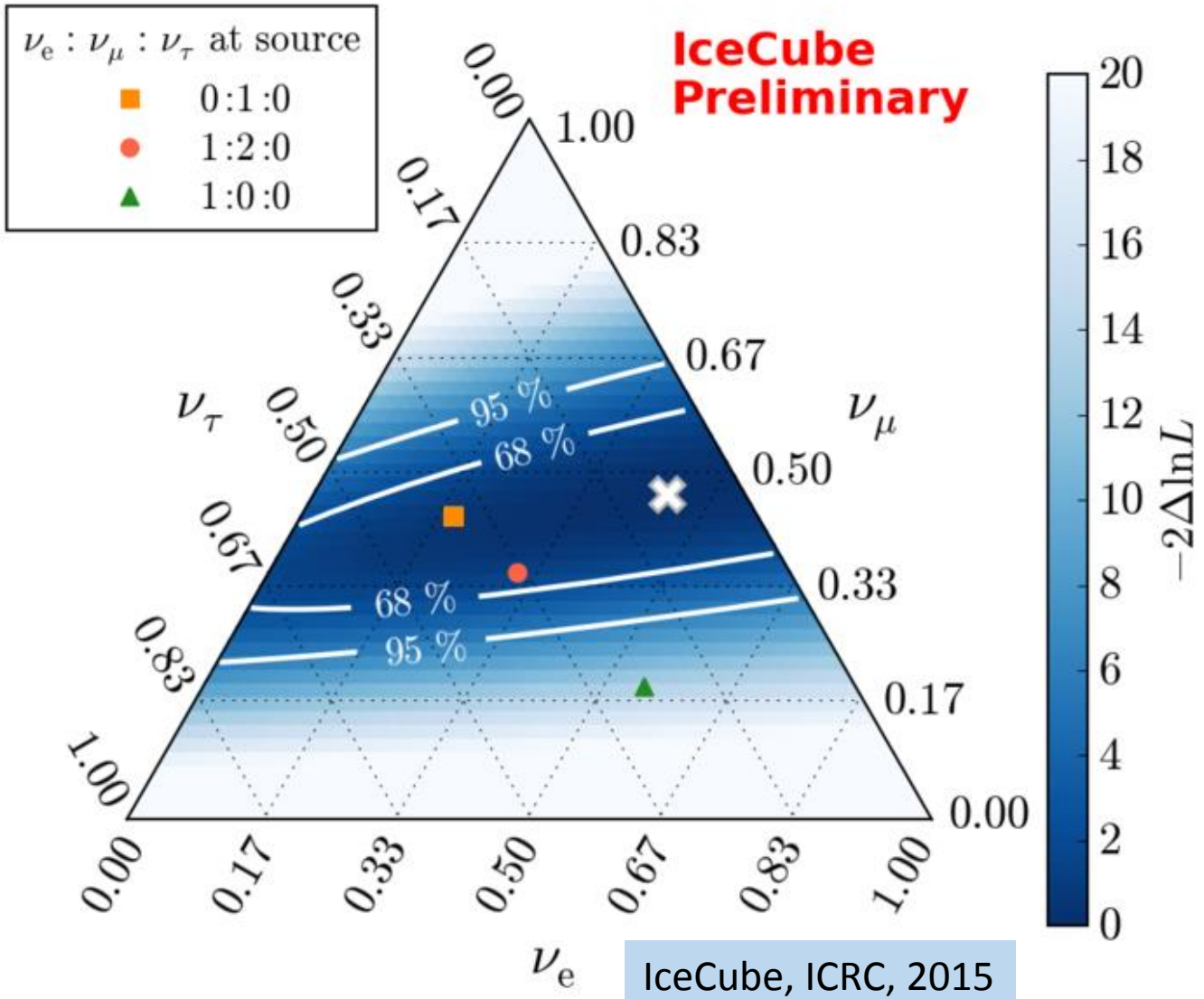


IceCube, PRD, 2015



Flavour constraints: combining channels

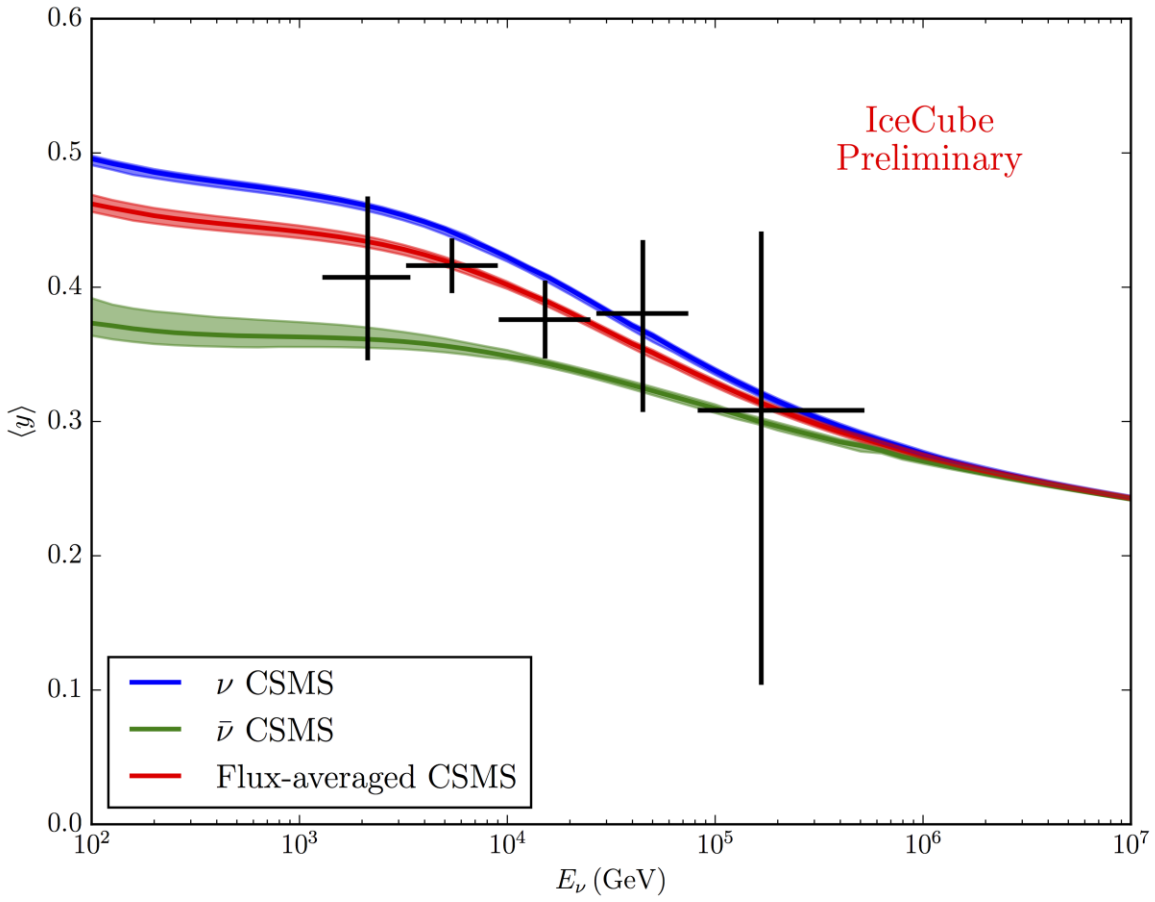
- Global fit using starting event + throughoing muons (2year)

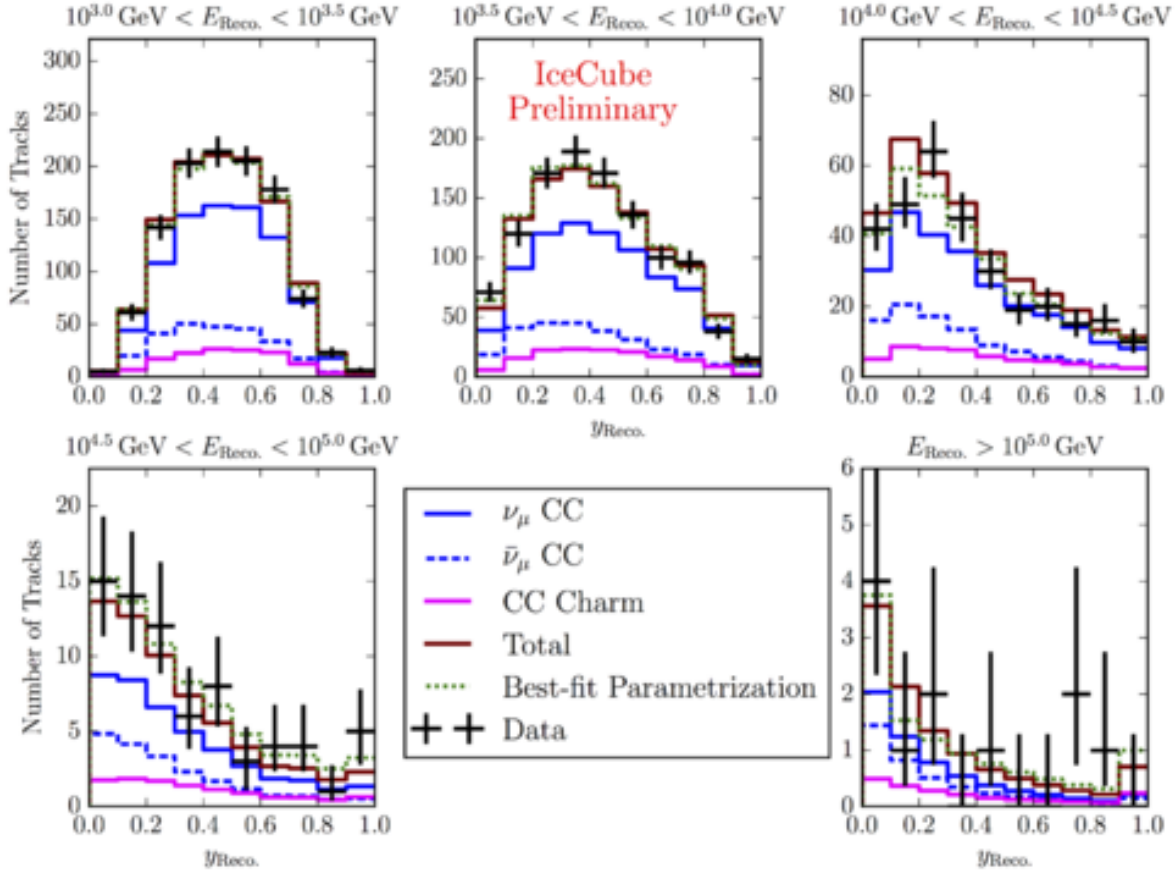


IceCube, ICRC, 2015

- Pure electron neutrinos @ sources excluded @ 3.7 σ

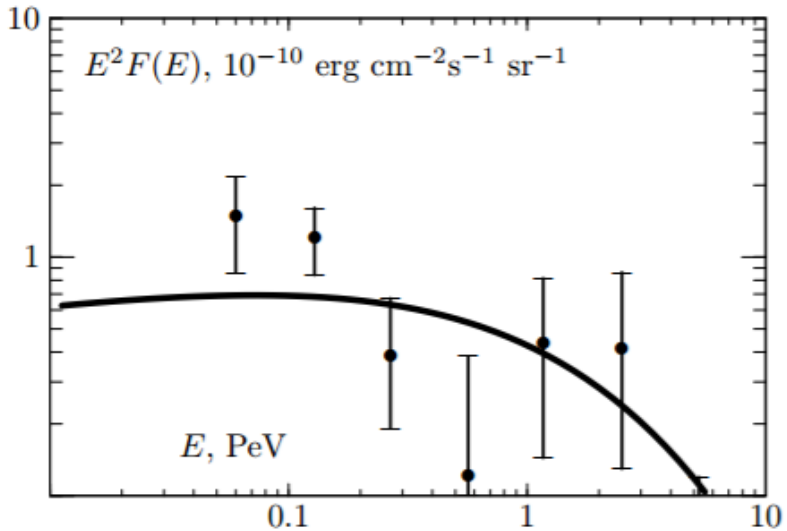
Measuring Inelasticity





Type IIn Supernova explosions

Explosion into dense wind of progenitor star
Acceleration to 10^{17} eV; ν to > PeV with cutoff
Murase et al., PR D84 (2011) 043003



Zirakashvili & Ptuskin arXiv:1510.08387
Integrated flux from all Type Iin SNR could account for high-energy part of IceCube signal with a cutoff

Zirakashvili and Ptuskin note two possible coincidences:

- SN 2005bx at z=0.03 is 1.35° from HESE #47 track
- SN 2005jq at z=0.23 is 0.3° from track event #11 in upward ν_μ sample