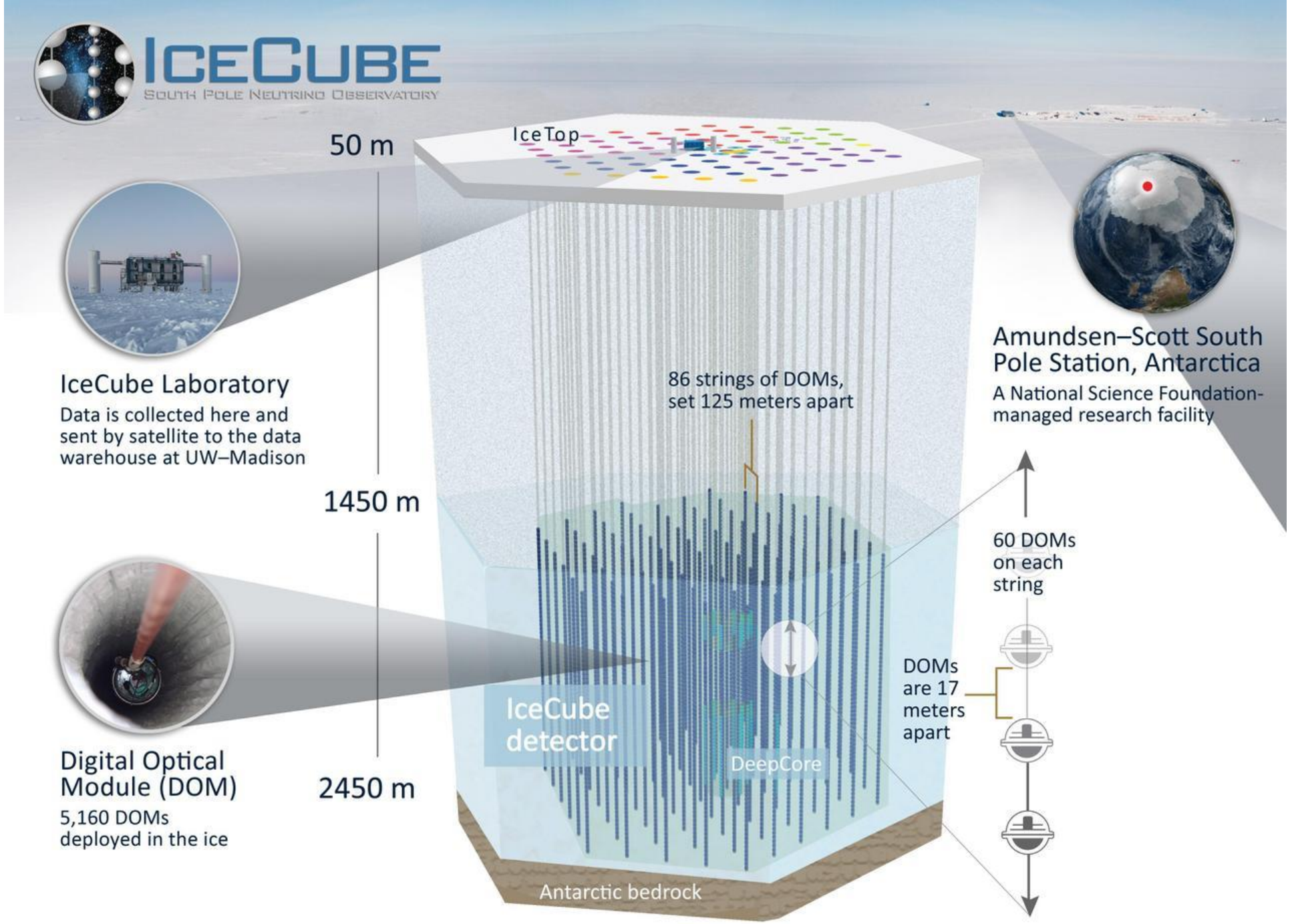
Neutrino Astronomy with IceCube

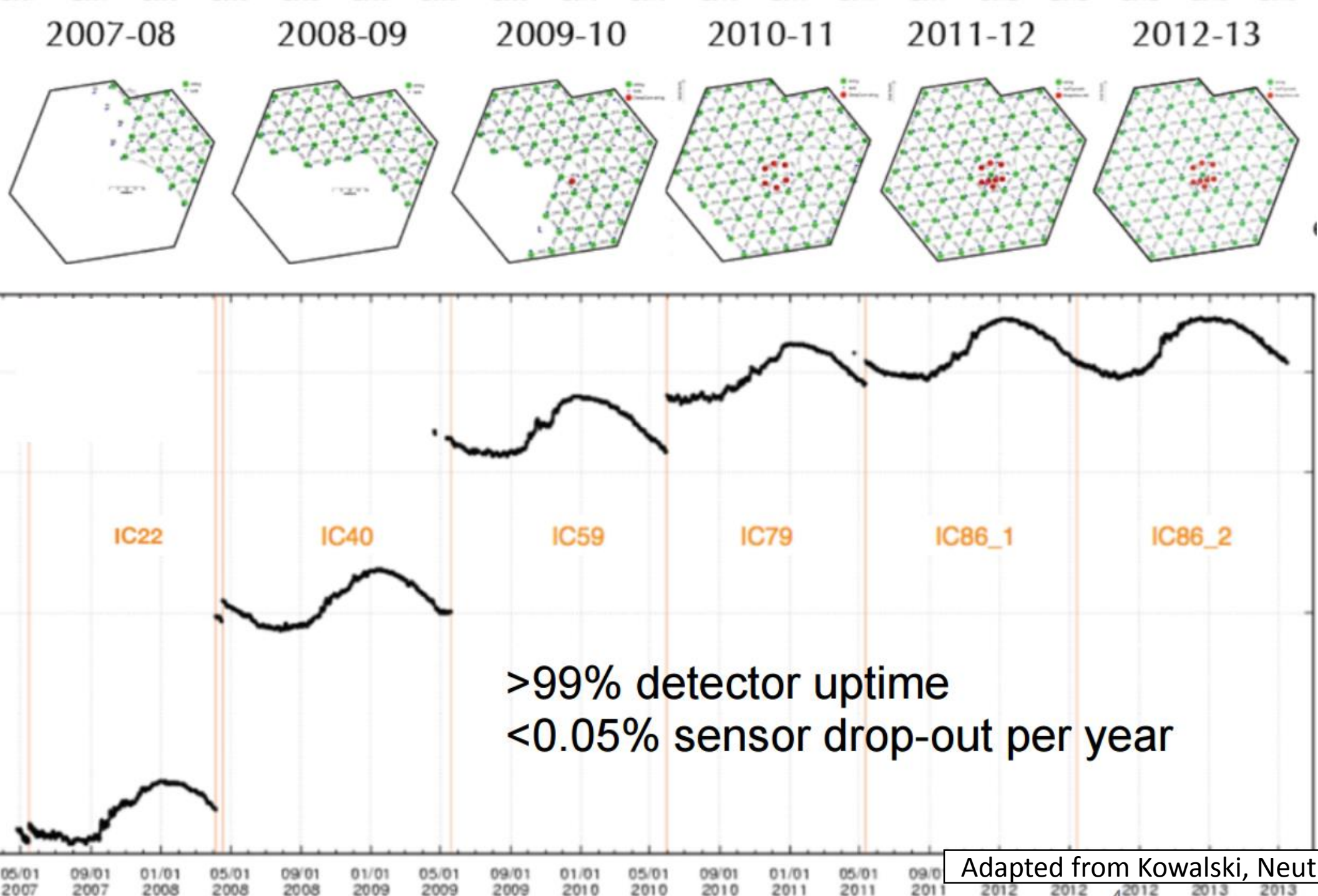
Thorsten Glüsenkamp, FAU Erlangen

SciNeGHE 2016, Pisa, Oct. 19th

ICECUBE

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG


IceCube
South Pole Neutrino Observatory
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
1450 m
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
2450 m
Antarctic bedrock

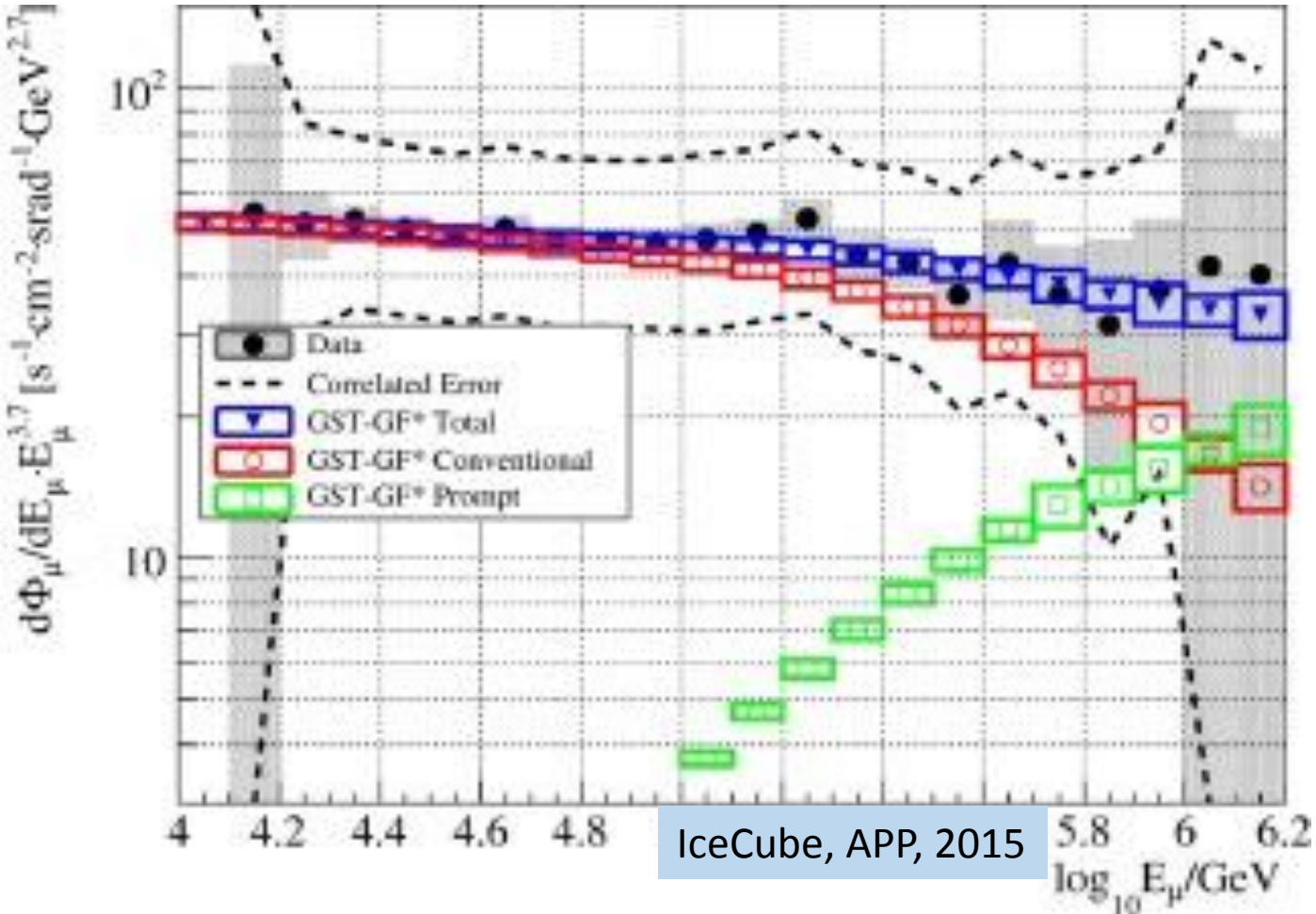


Adapted from Kowalski, Neutrino 2016

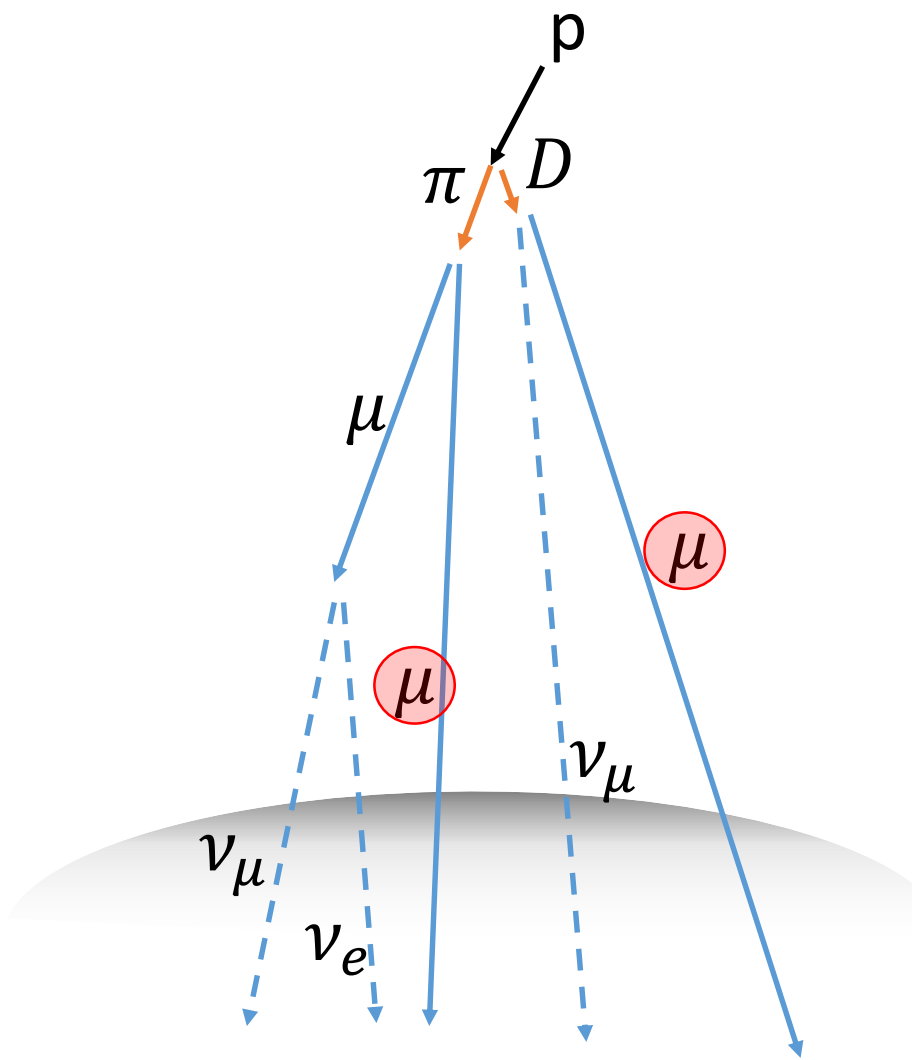
Atmospheric backgrounds

- Muons: > 2000 / s

Spectrum @ high E

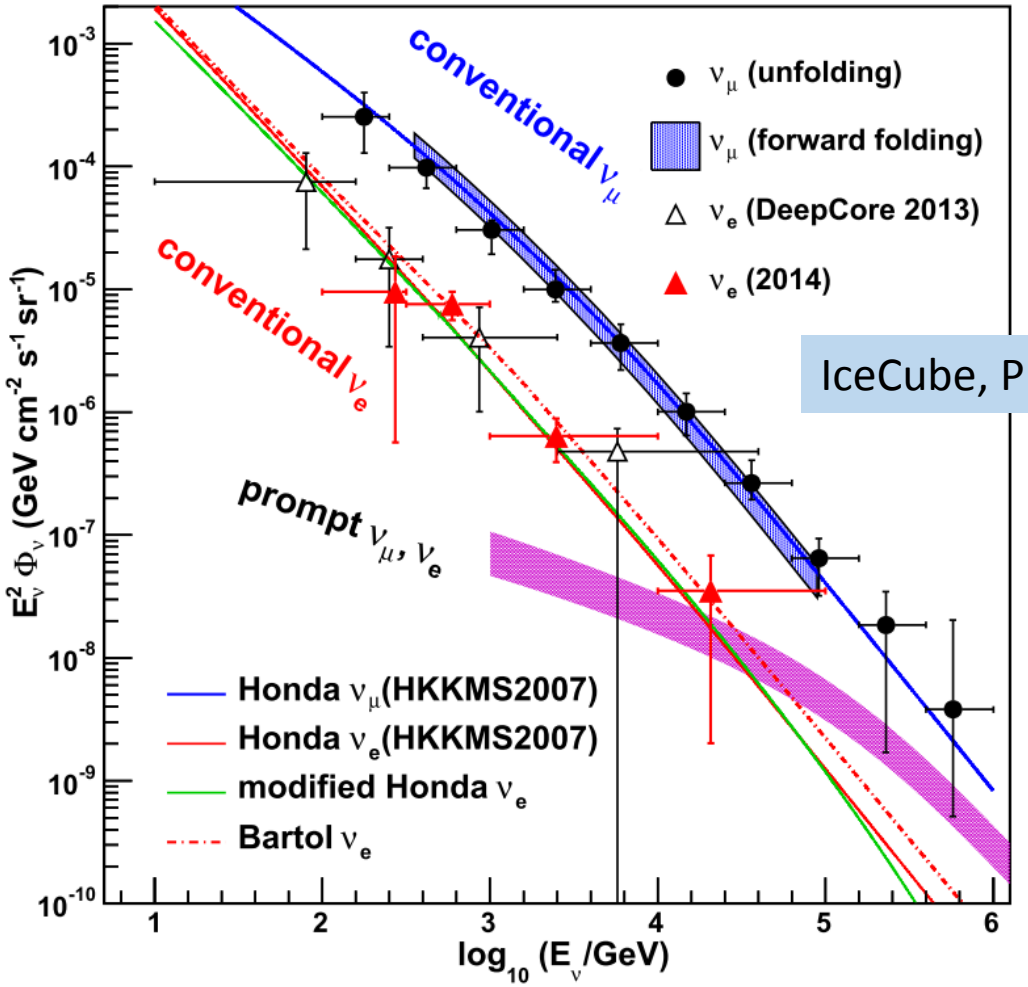


IceCube, APP, 2015

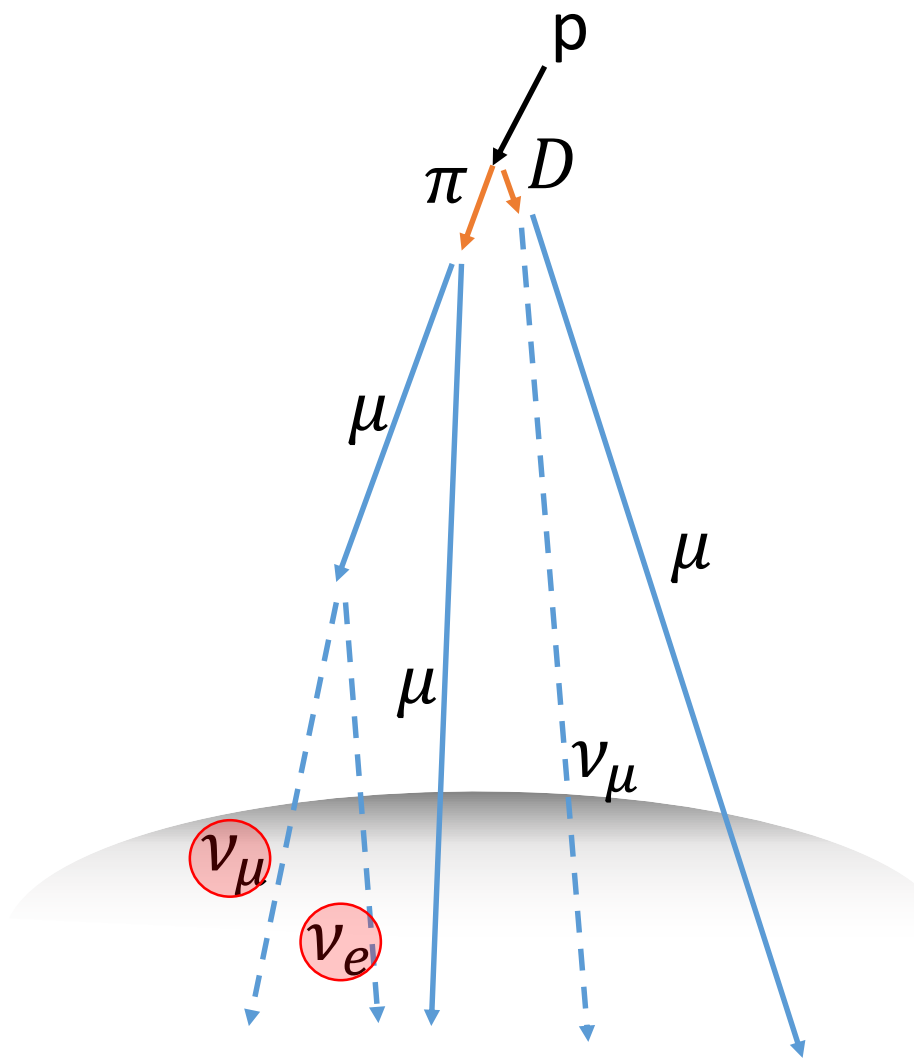


Atmospheric backgrounds

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



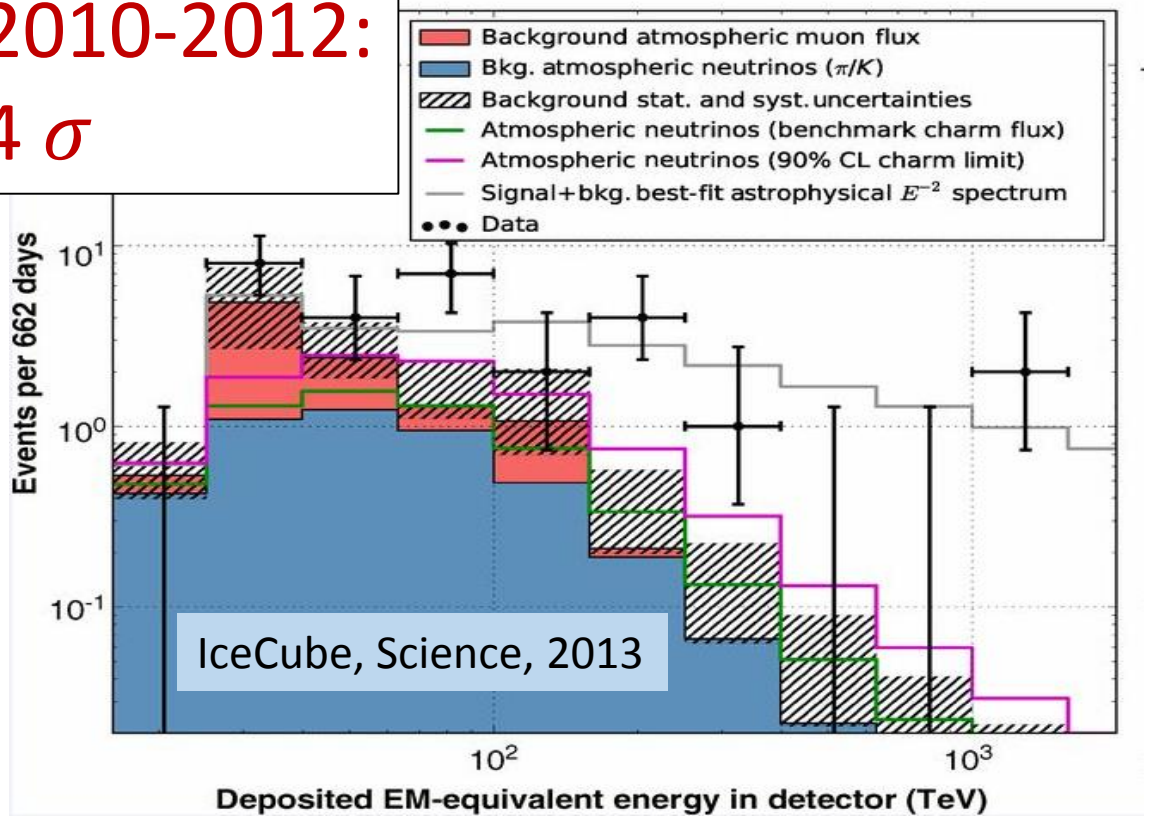
IceCube, PRD, 2015



The astrophysical flux

The astrophysical flux: starting events

2010-2012:
4 σ



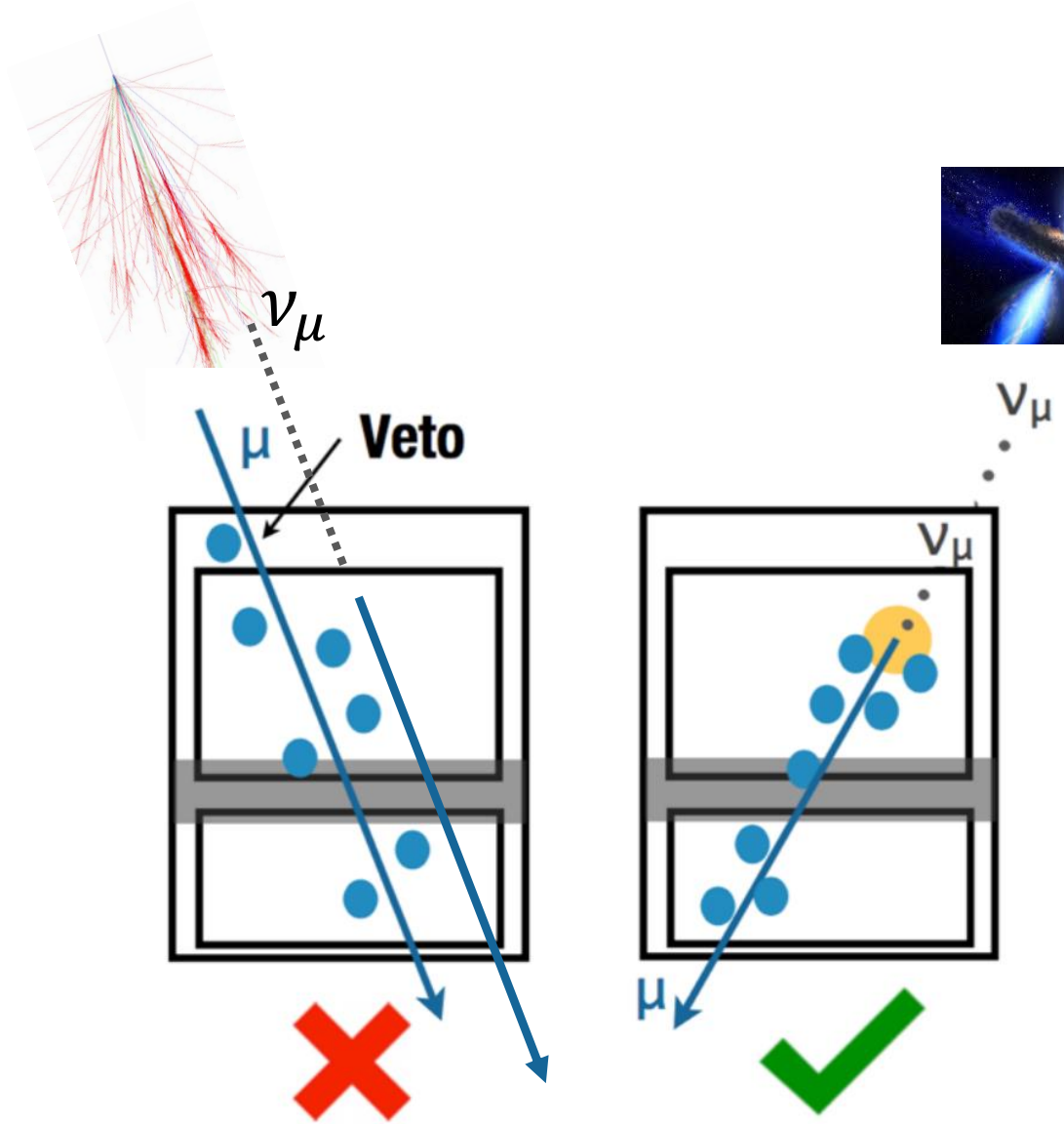


image adapted from Kowalski, Neutrino 2016

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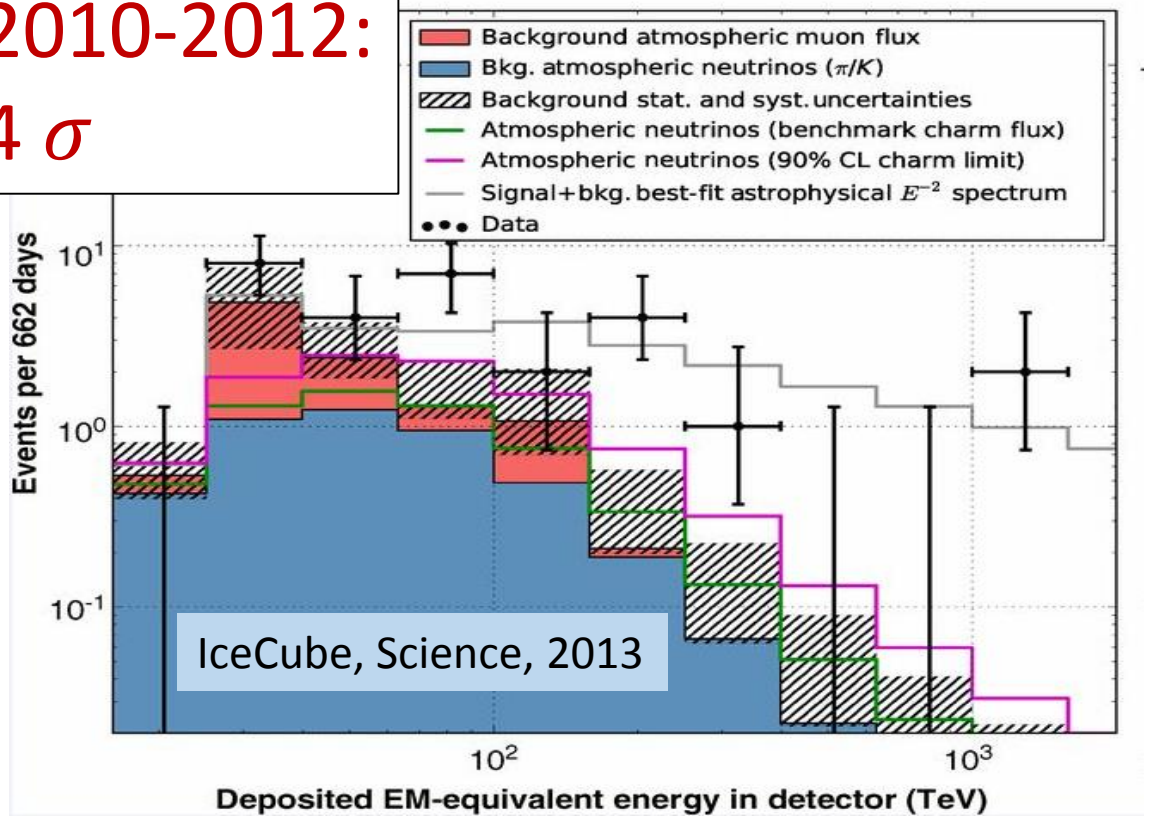
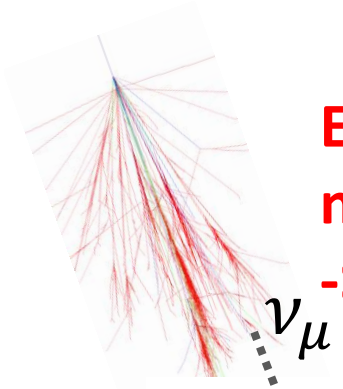
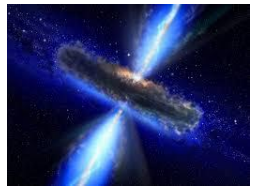
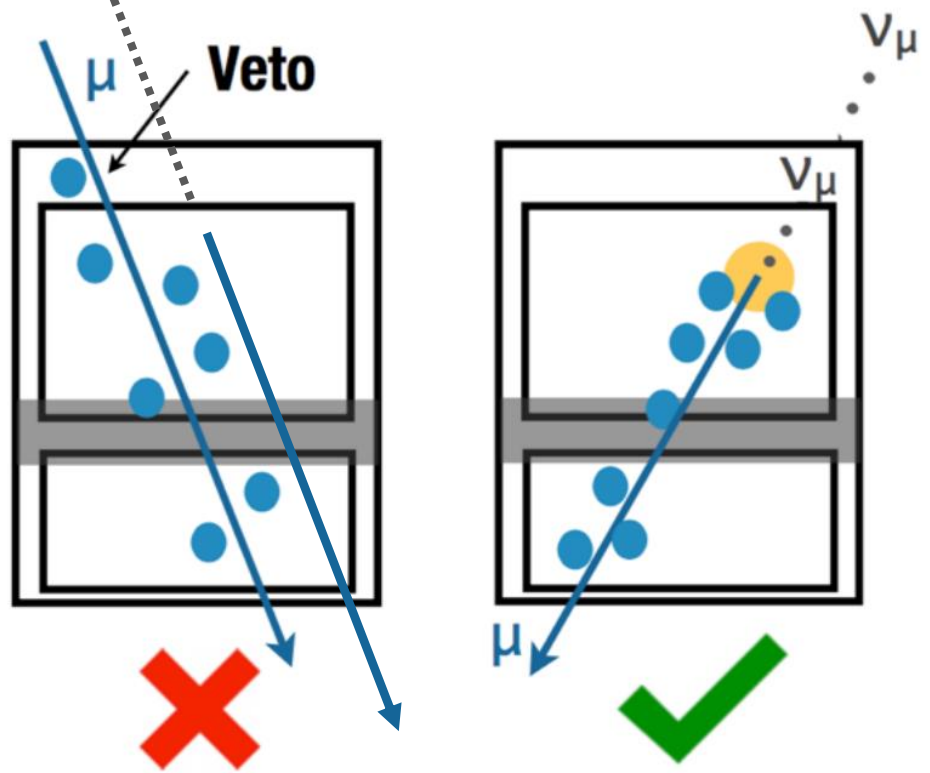




Even veto atmospheric neutrinos!!!
-> background-free





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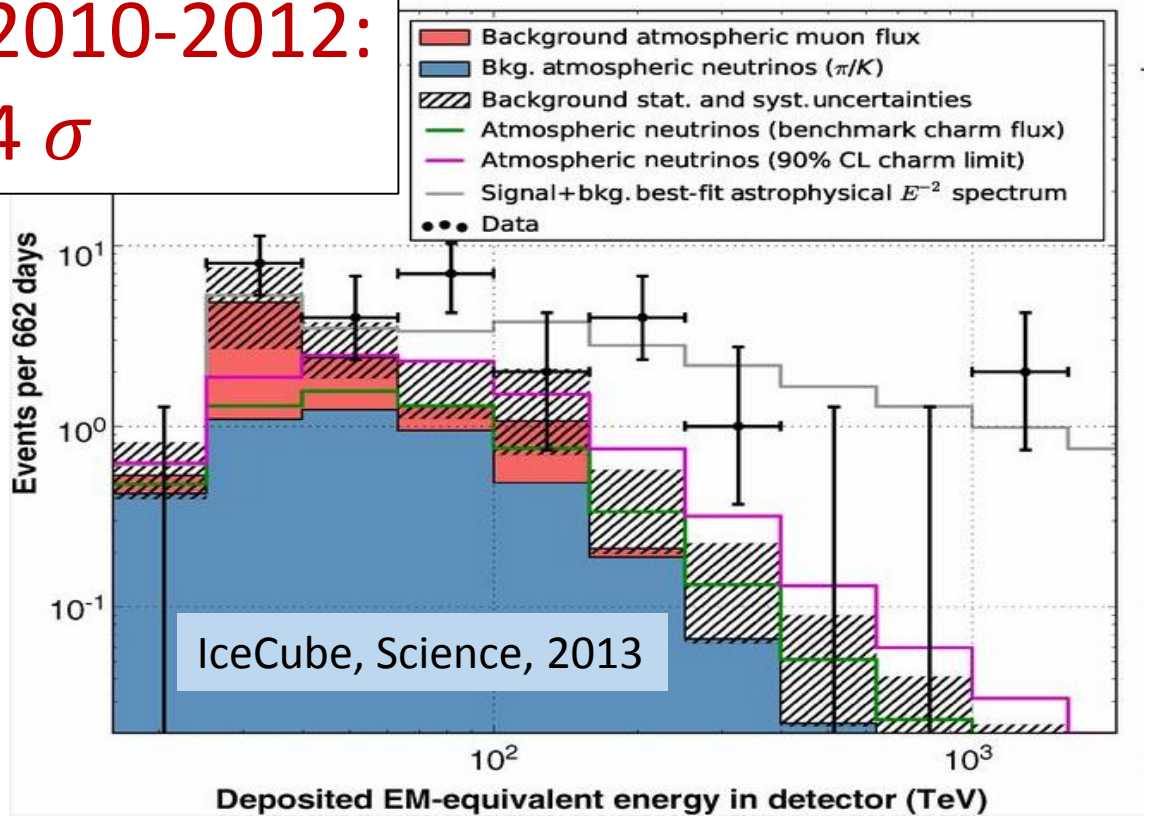
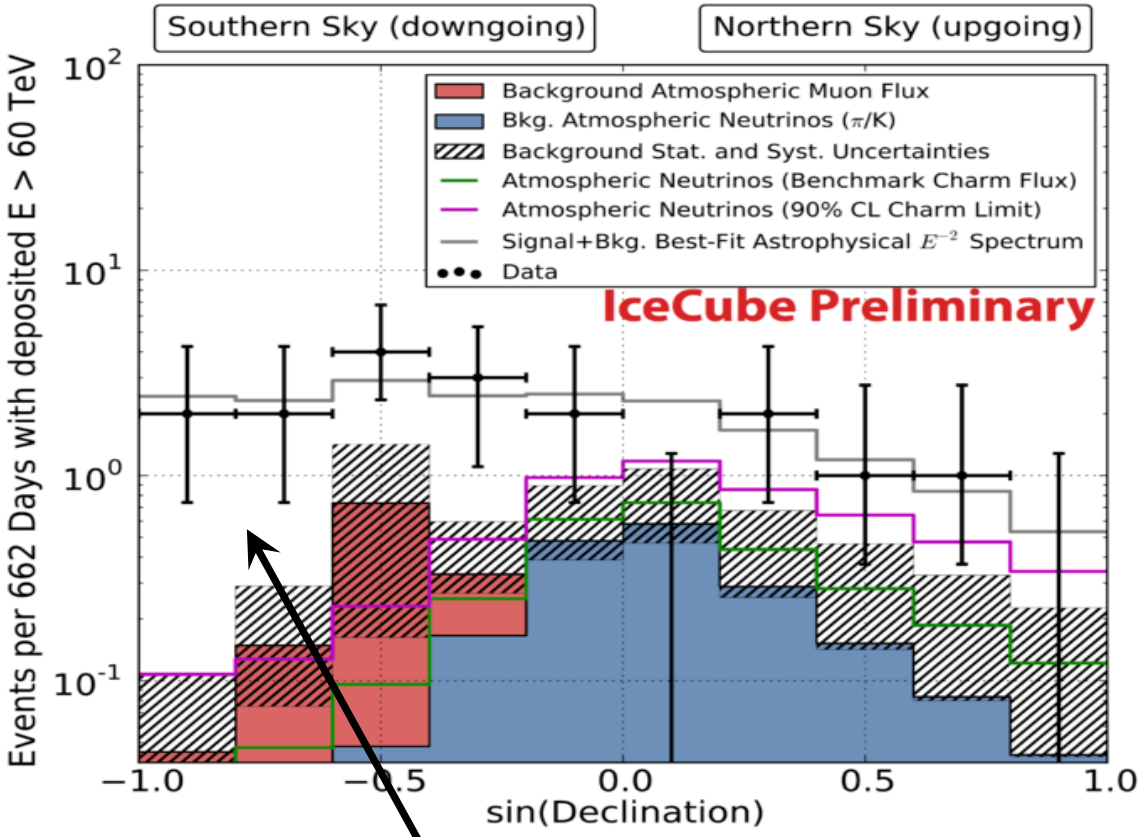
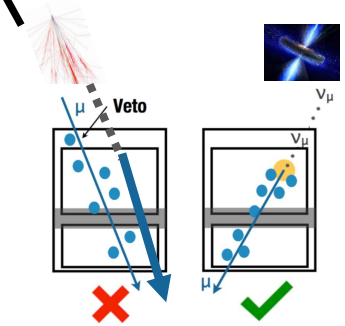




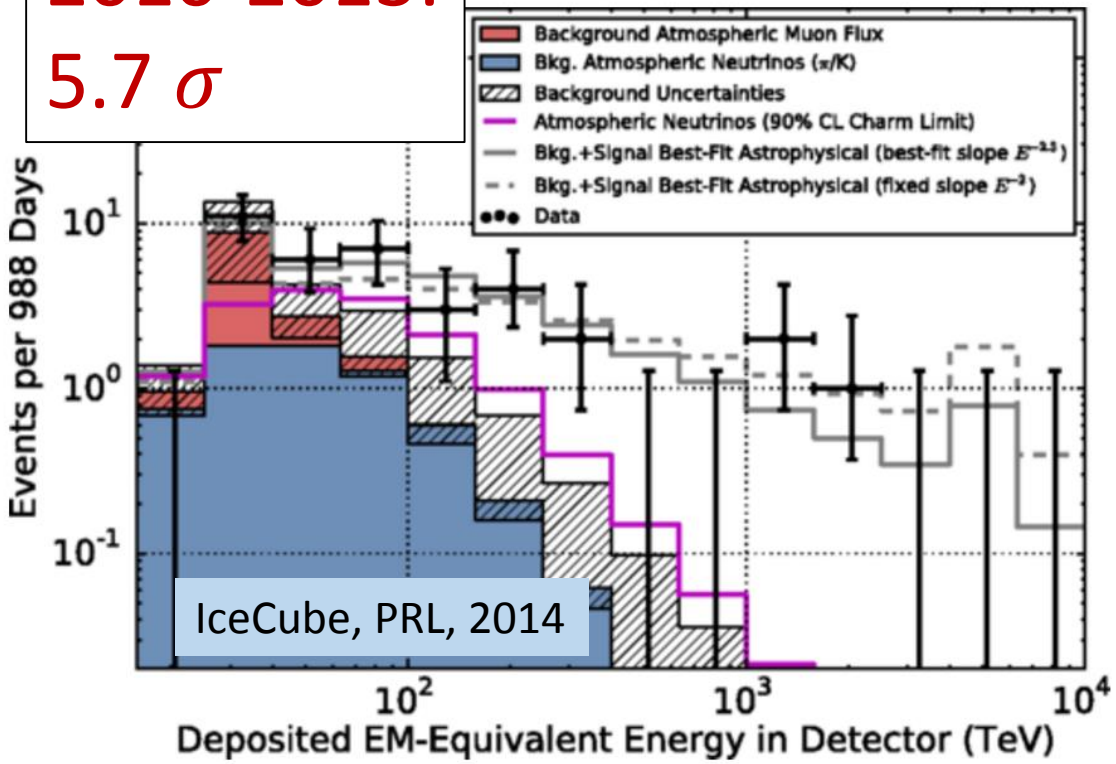


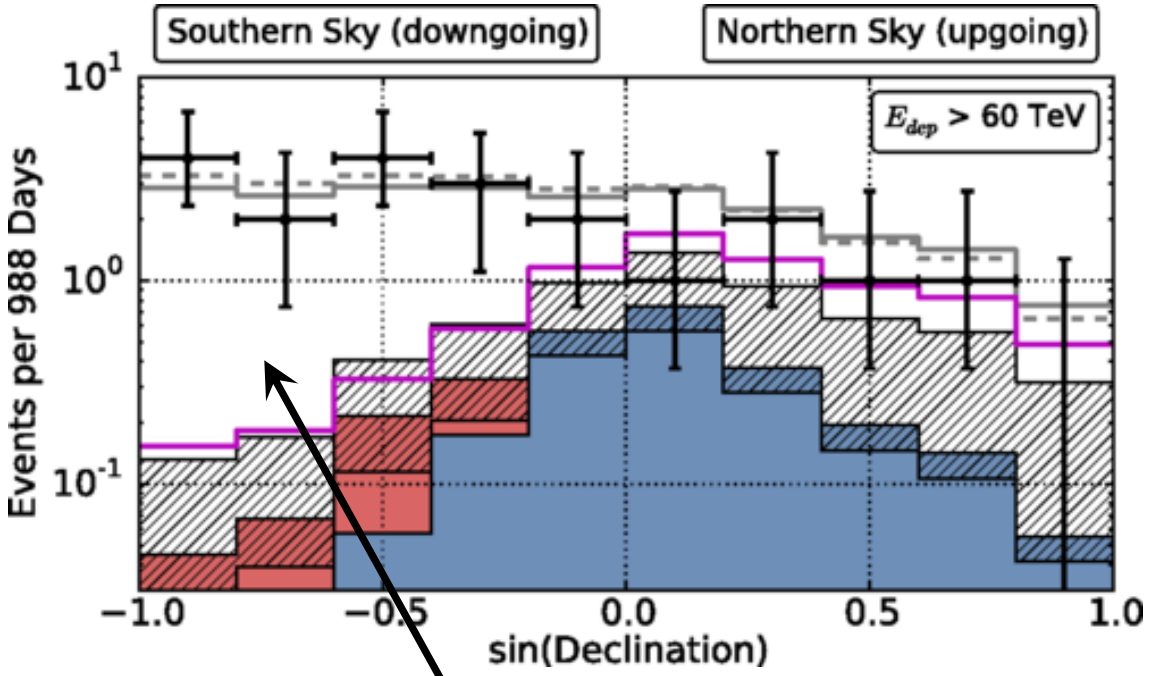
Nice features:

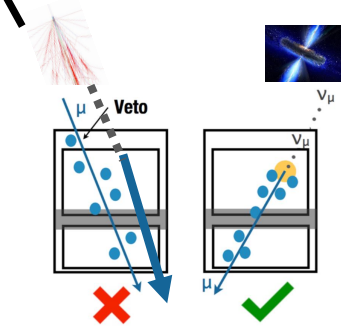
- Veto atmospheric neutrinos
- Muon background from data

The astrophysical flux: starting events

2010-2013:
5.7 σ







Nice features:

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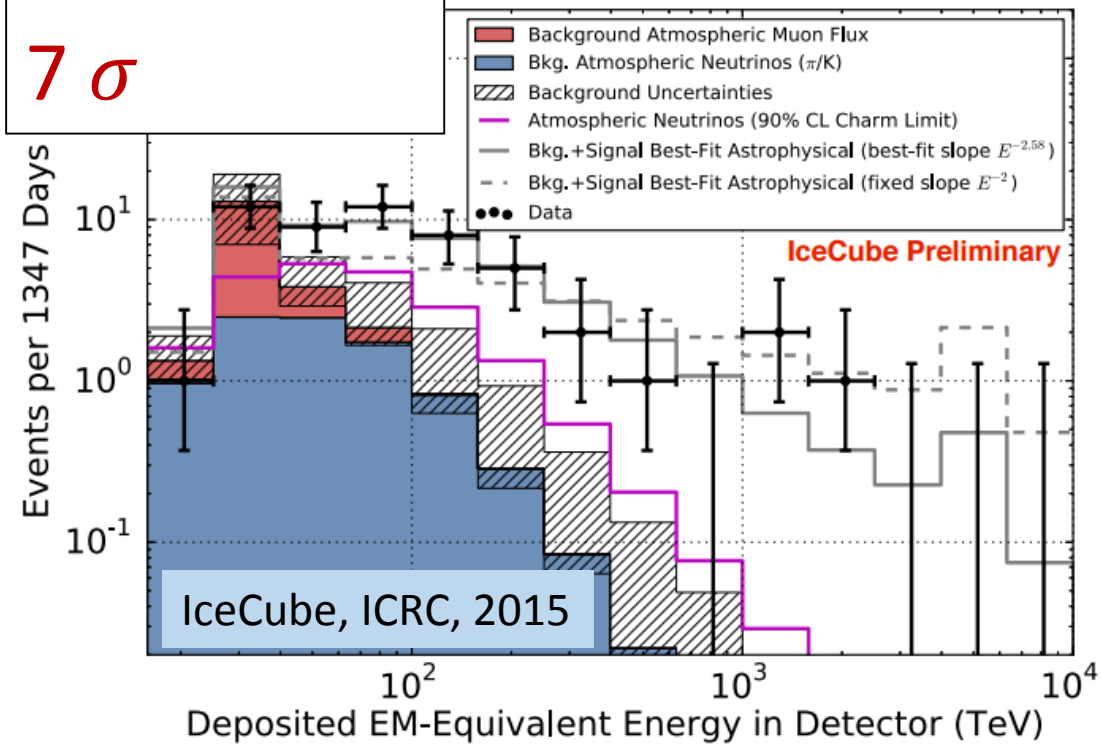
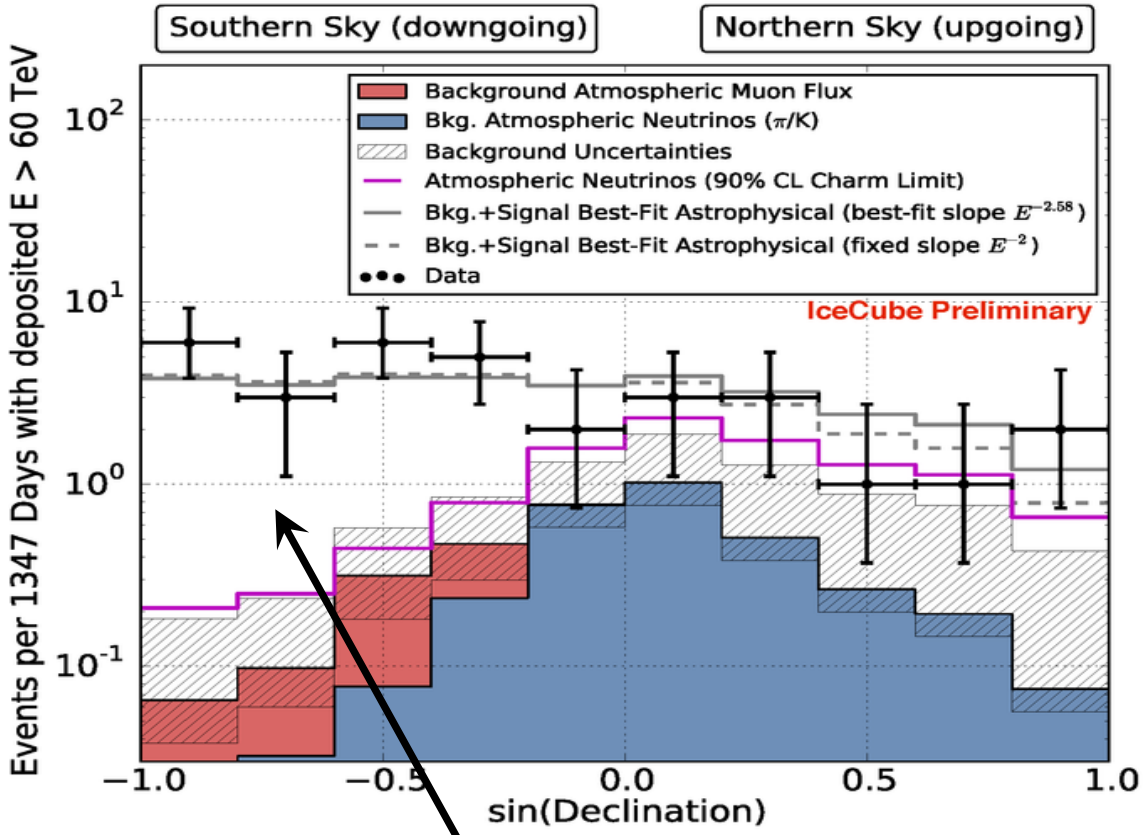
- Muon background from data

The astrophysical flux: starting events

2010-2014:
7 σ





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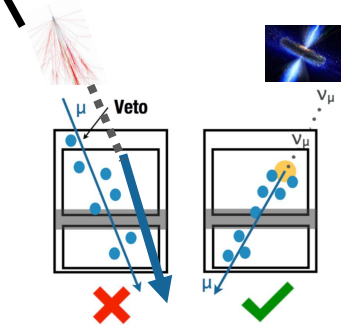
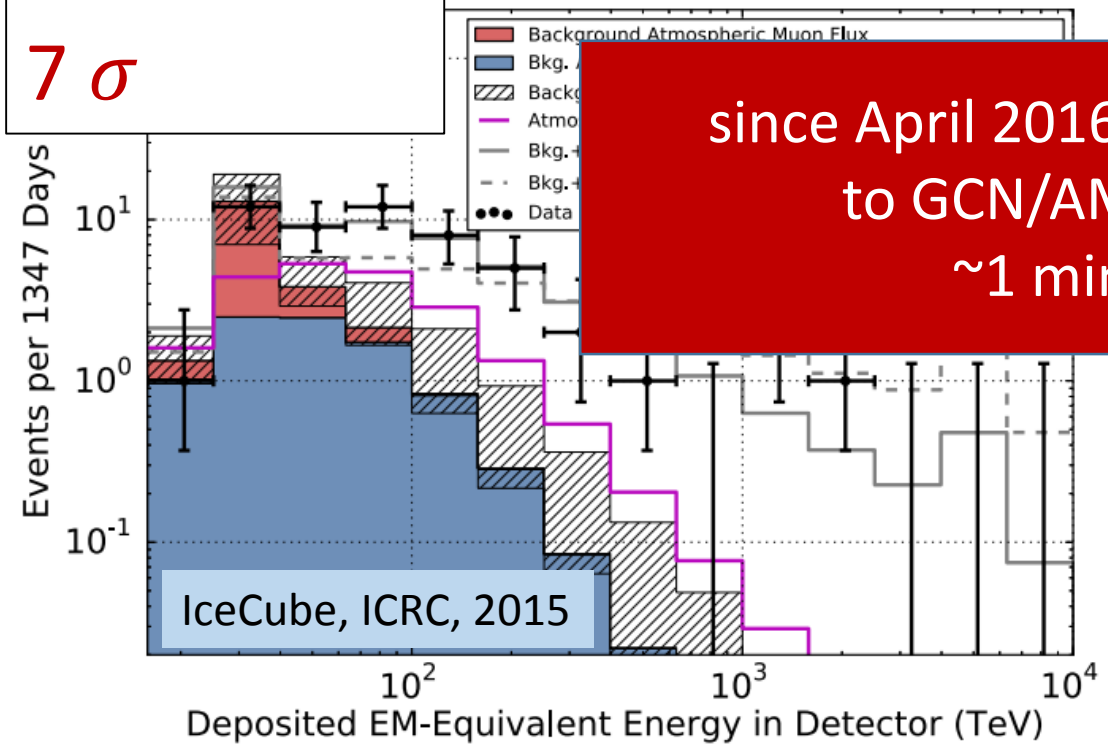
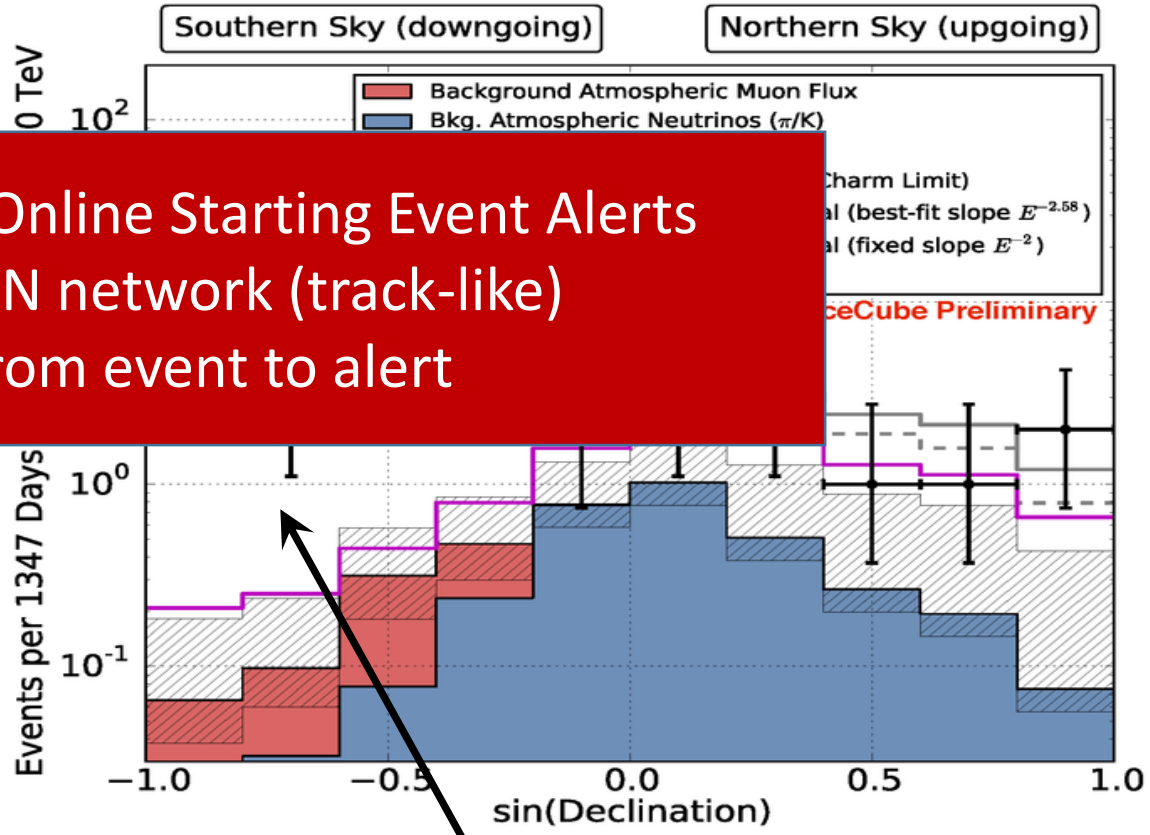


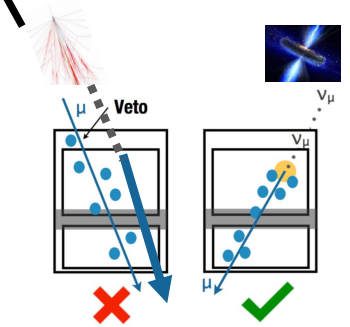
The astrophysical flux: starting events

2010-2014:
7 σ

since April 2016 : Online Starting Event Alerts
to GCN/AMON network (track-like)
~1 min from event to alert







Nice features:

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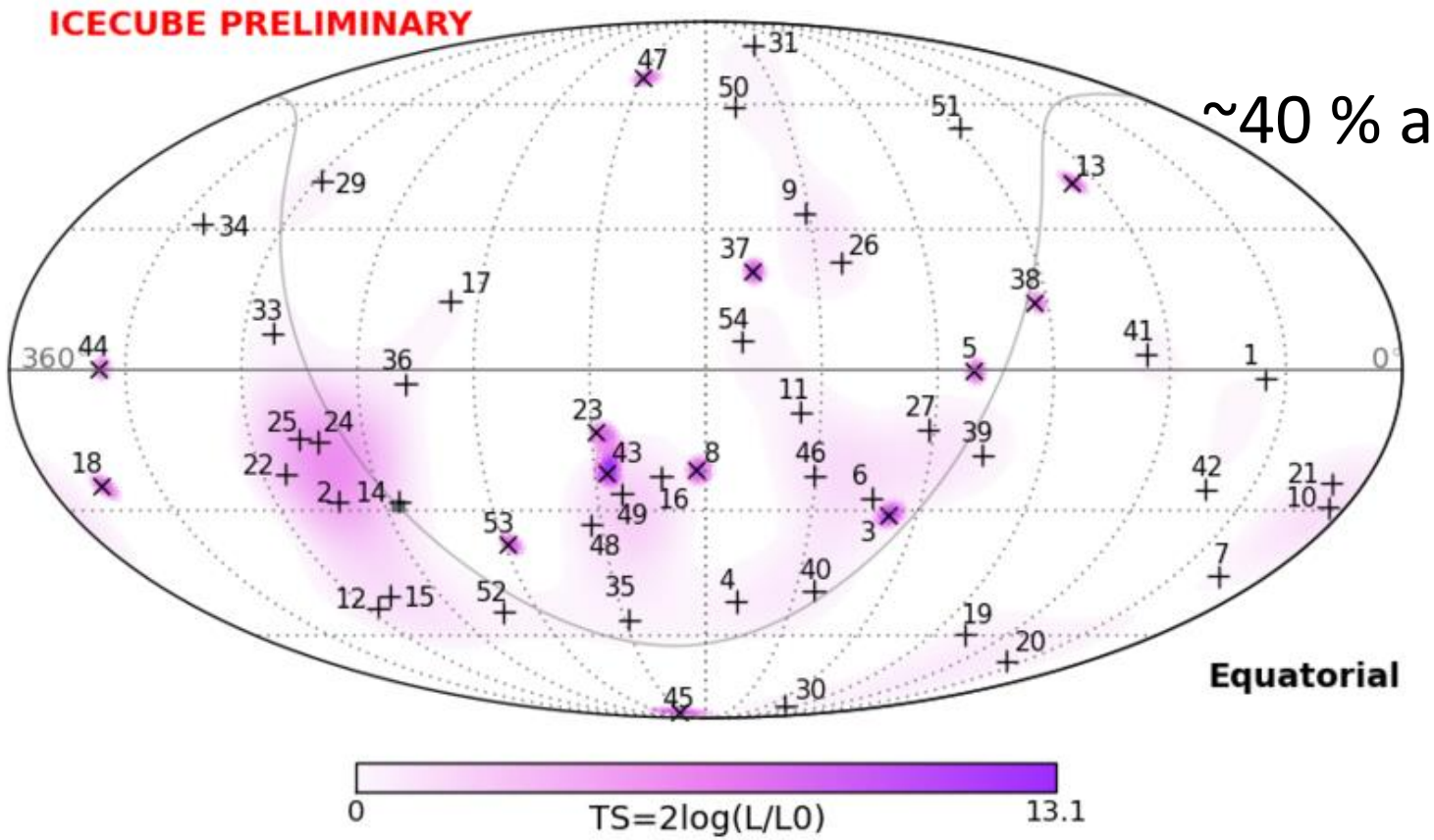
starting events: further developments

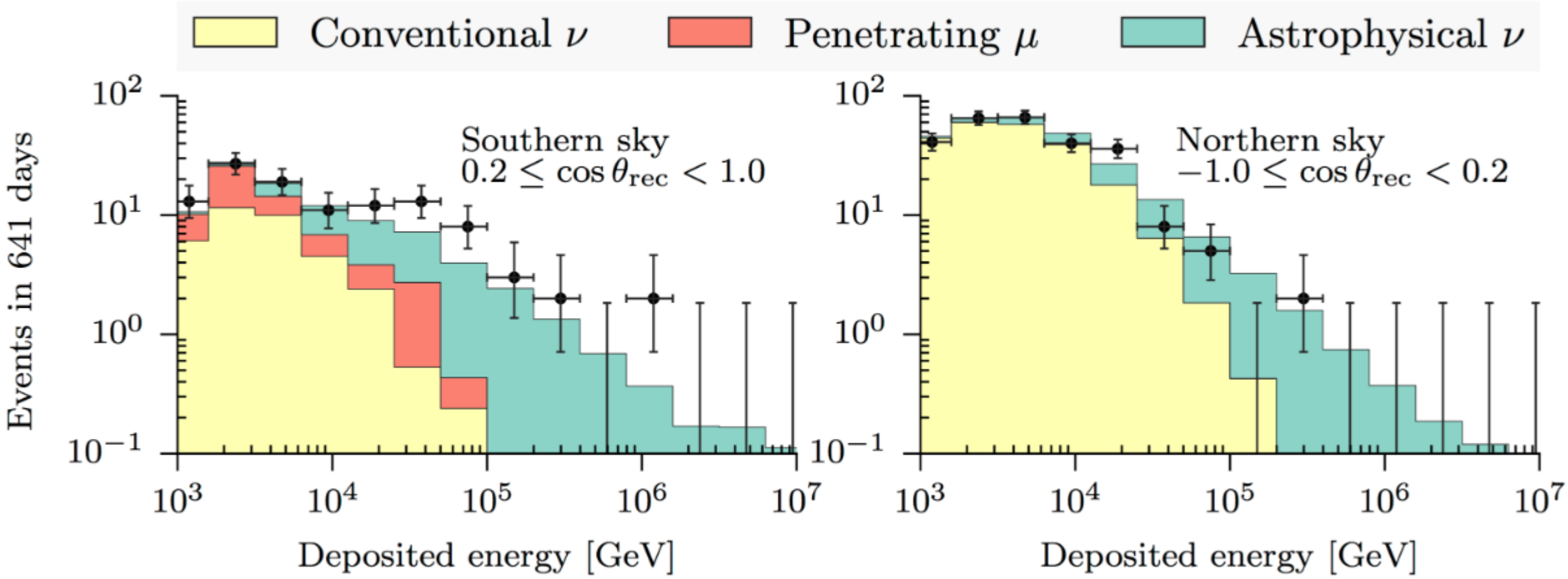
- Skymap (4 years) IceCube, ICRC, 2015
  - no galactic plane clustering (2.5% pvalue)



~40 % atmospheric events

starting events: further developments

- Skymap (4 years) IceCube, ICRC, 2015
  - no galactic plane clustering (2.5% pvalue)
- Lower E-Threshold ~ 5 TeV (refined veto/selection) IceCube, PRD, 2015



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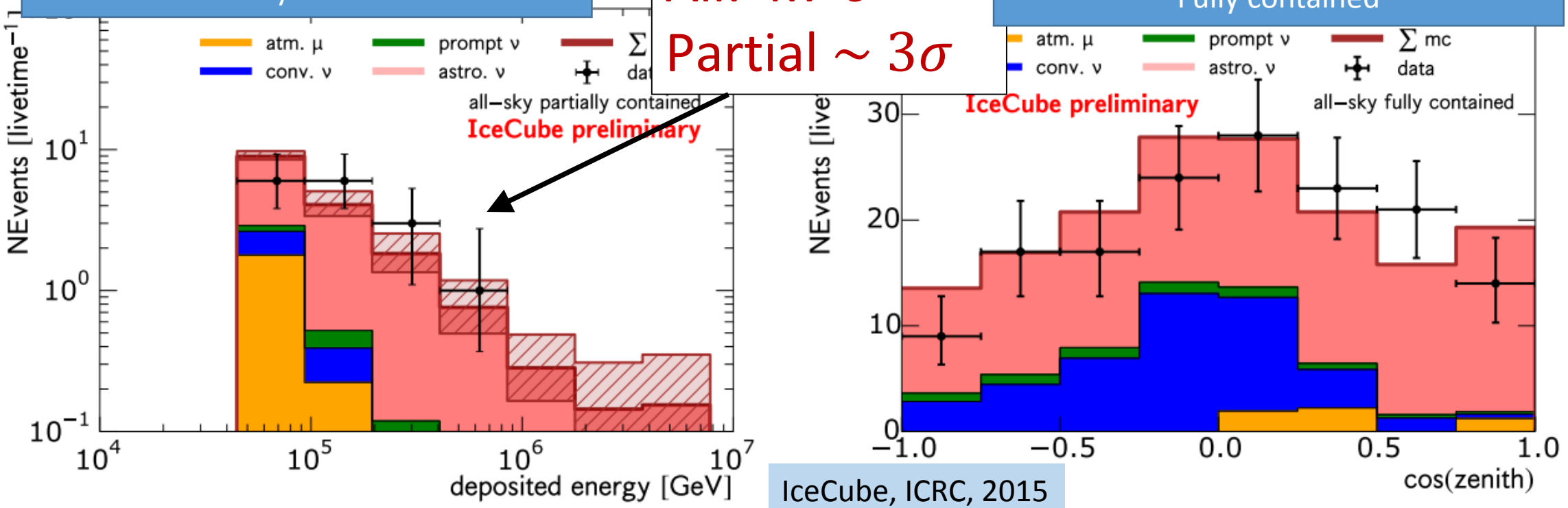
- Skymap (4 years) IceCube, ICRC, 2015
  - no galactic plane clustering (2.5% pvalue)
- Lower E-Threshold ~ 5 TeV (refined veto/selection) IceCube, PRD, 2015
- HE-contained (+ partially contained) showers

Partially contained

All: 4.7 σ

Partial ~ 3σ

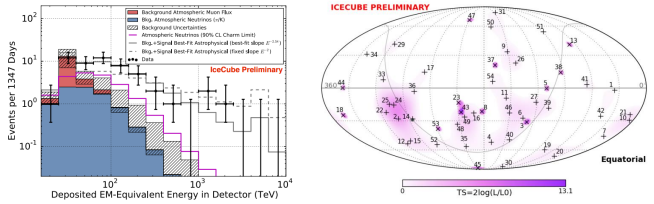
Fully contained



IceCube, ICRC, 2015

Starting events: further developments

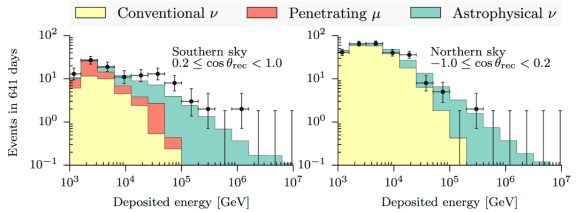
$E > 50\ TeV$



IceCube, ICRC, 2015

γ=-2.58 $\pm$0.25

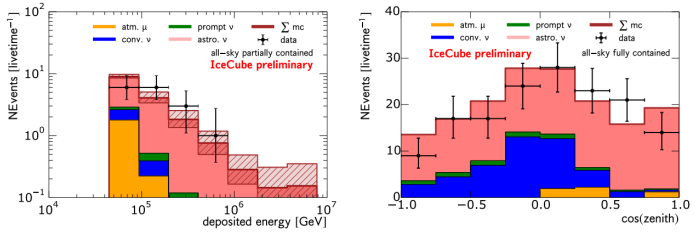
$E > 5\ TeV$



IceCube, PRD, 2015

γ=-2.5 $\pm$0.13

showers (+partially cont.)



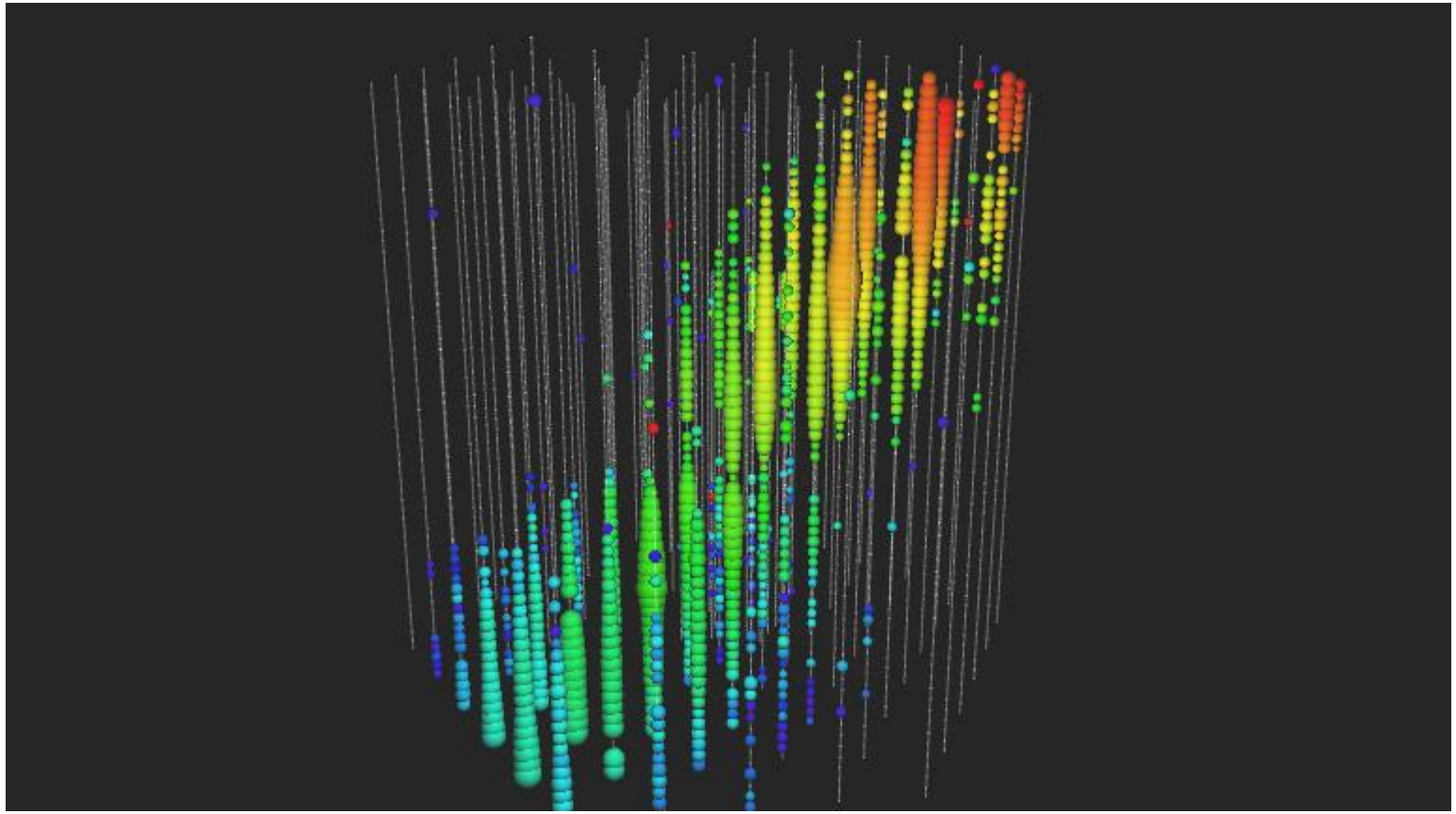
IceCube, ICRC, 2015

γ=-2.7 $\pm$0.12

Soft

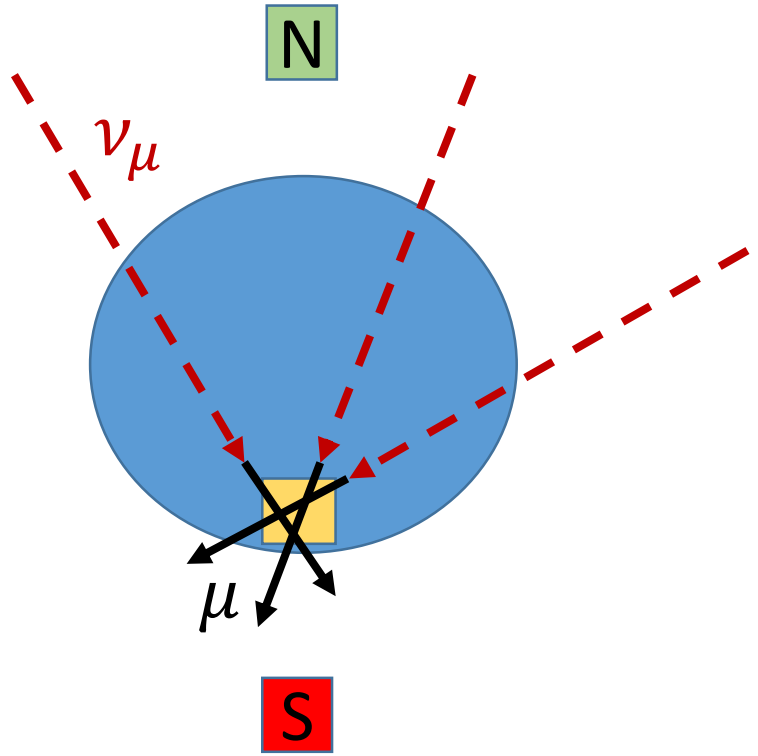
Spectral index?

The astrophysical flux: **throughgoing muons**



The astrophysical flux: **throughgoing muons**

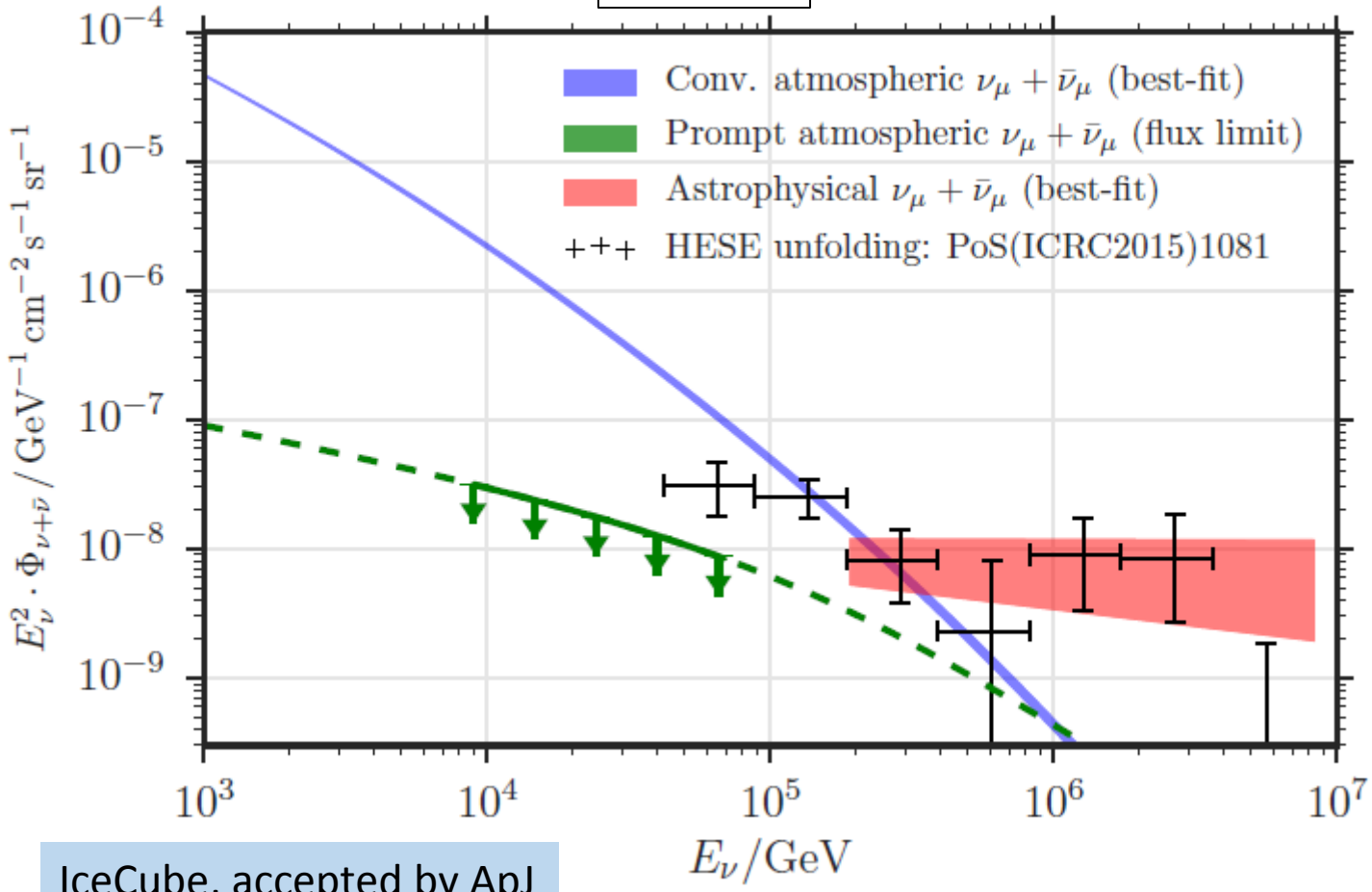
- Complementary sample to starting events



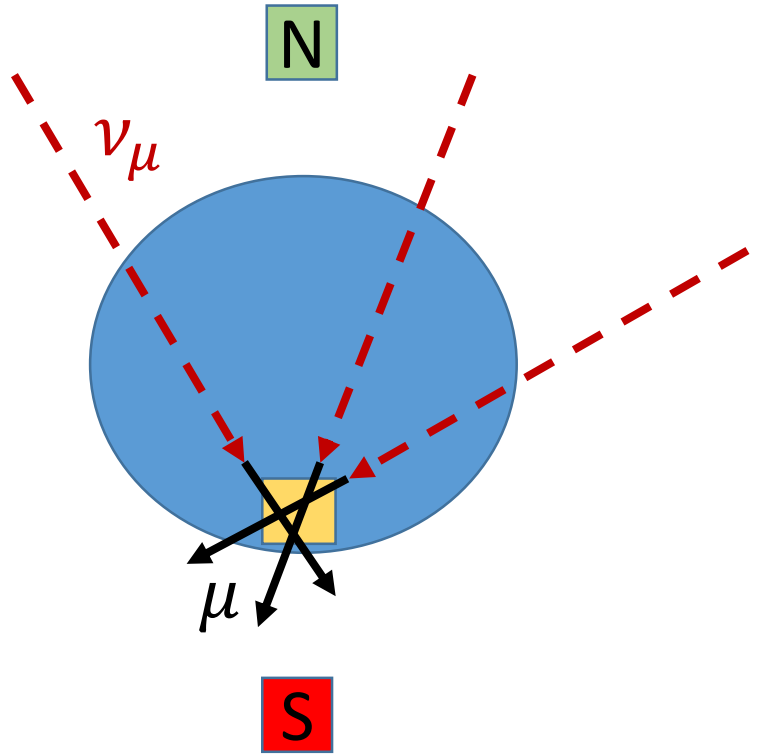
The astrophysical flux: **throughgoing muons**

- Complementary sample to starting events
- 6 years analyzed

5.6 σ



IceCube, accepted by ApJ



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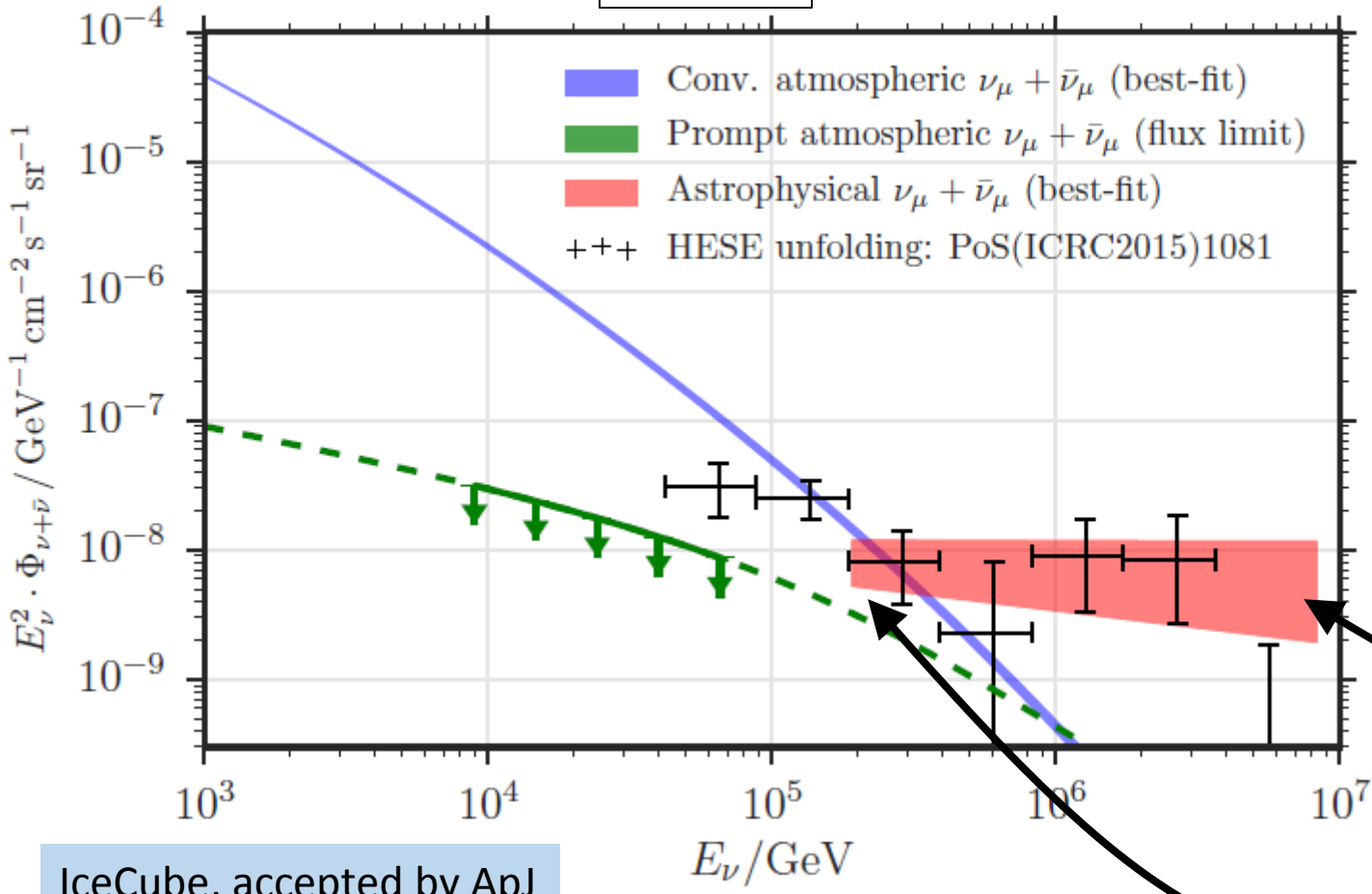

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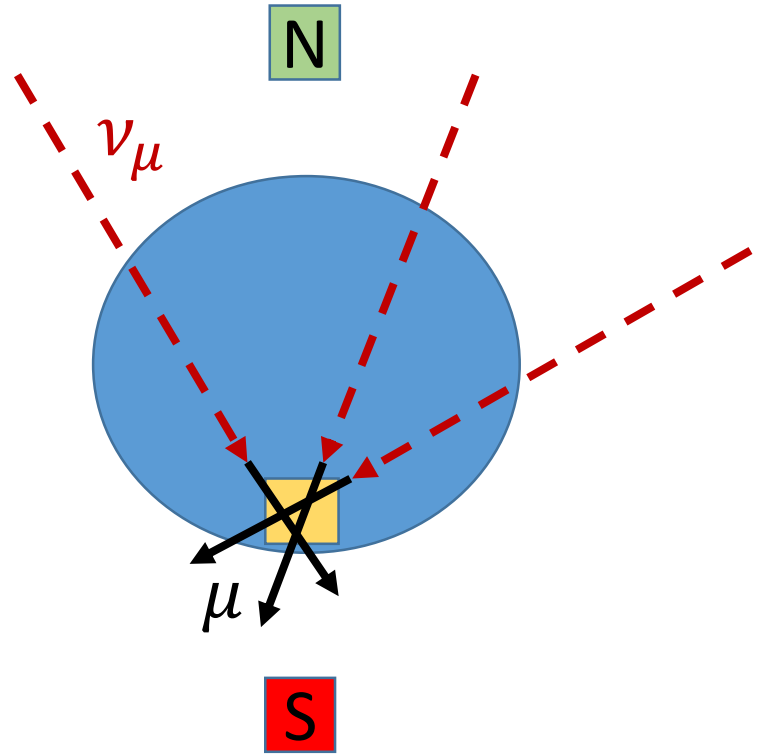


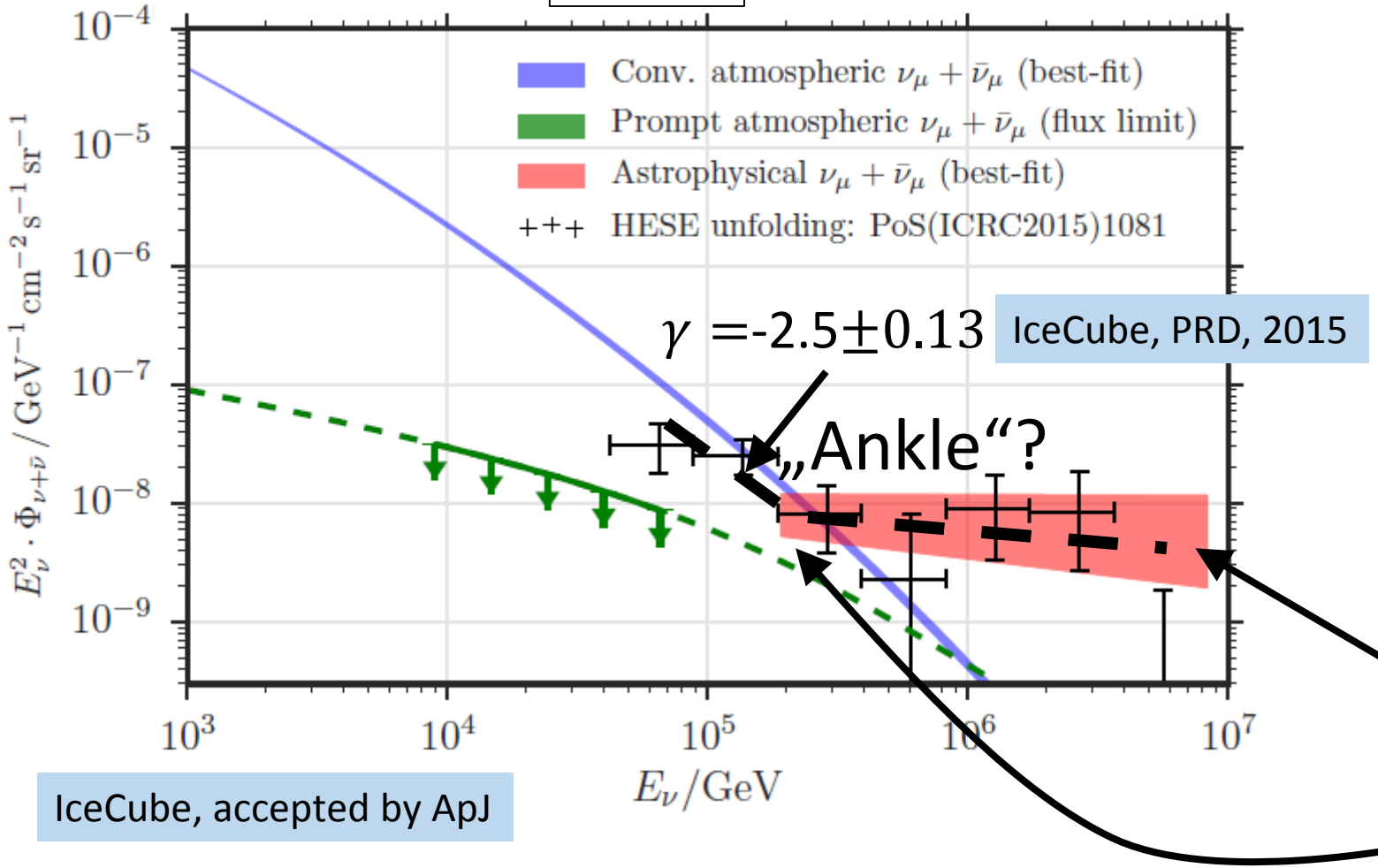
Bestfit spectral index:
γ =-2.13$\pm$0.13

Energy range > 200 TeV

The astrophysical flux: **power-law deviations?**

- Complementary sample to starting events
- 6 years analyzed

5.6 σ



γ =-2.5±0.13 IceCube, PRD, 2015

„Ankle“?

2-3 σ tension!

Bestfit spectral index:
γ =-2.13±0.13

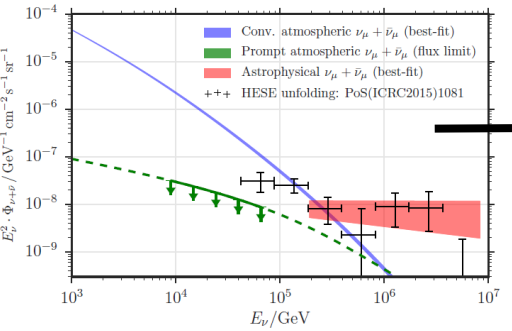
Energy range > 200 TeV

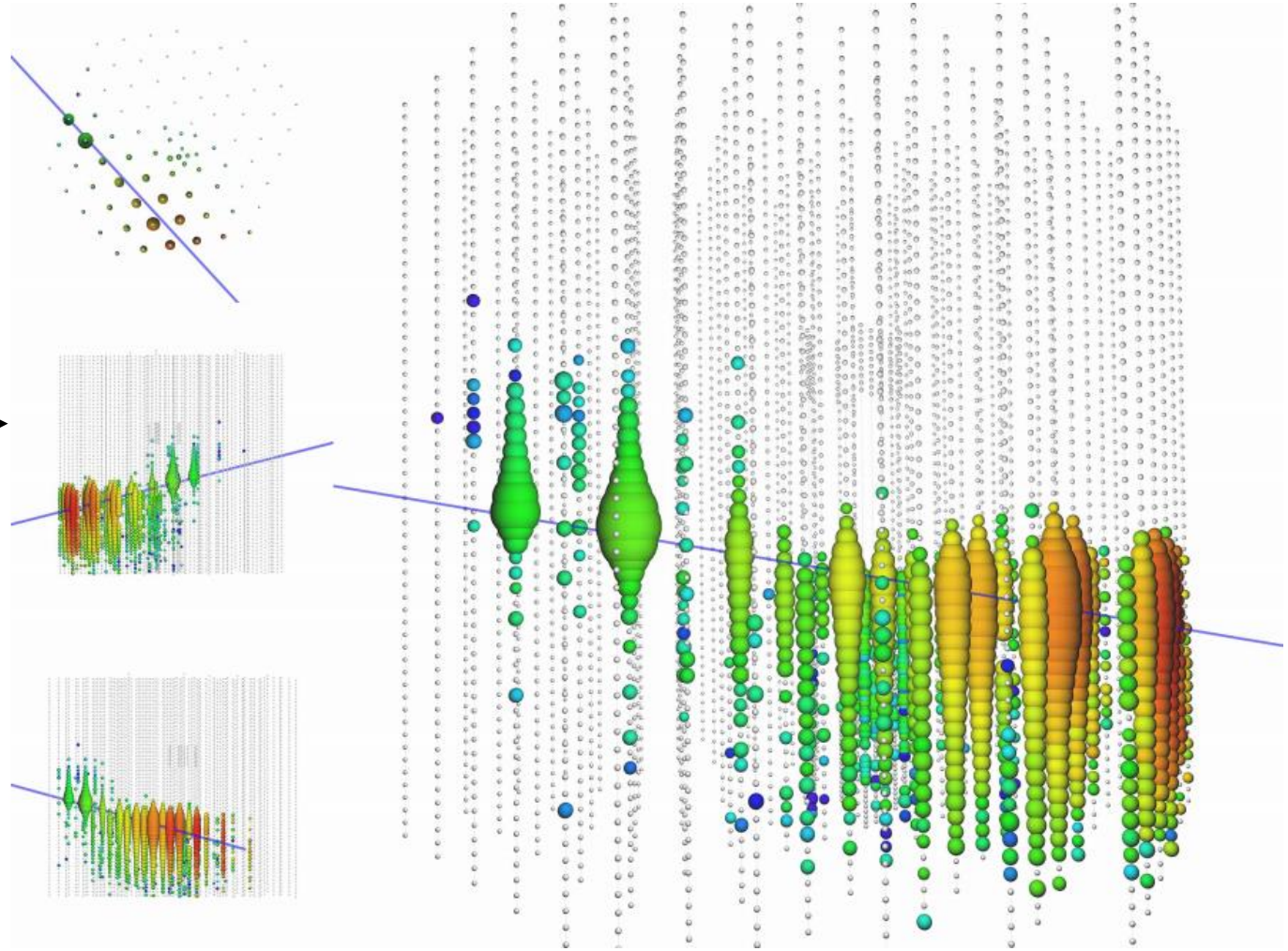
IceCube, accepted by ApJ

The highest energy neutrino ever detected

- 4.5 ± 1.2 PeV muon (ν-Energy higher!)
- Chance to be of atmospheric origin: 0.005%

Within 6-year sample





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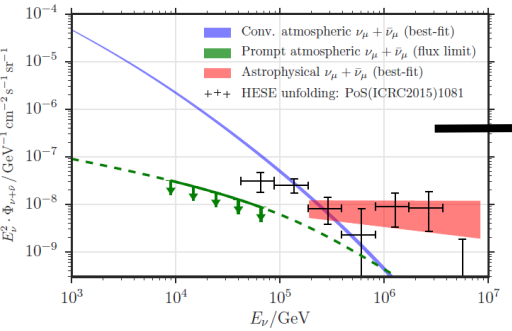
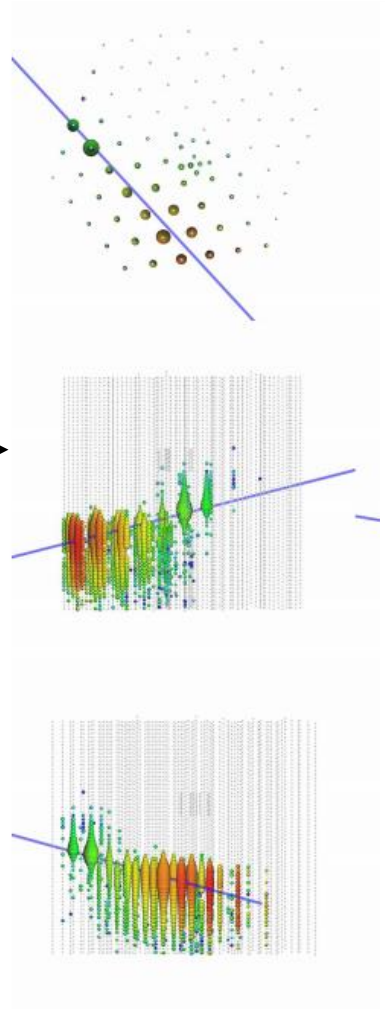
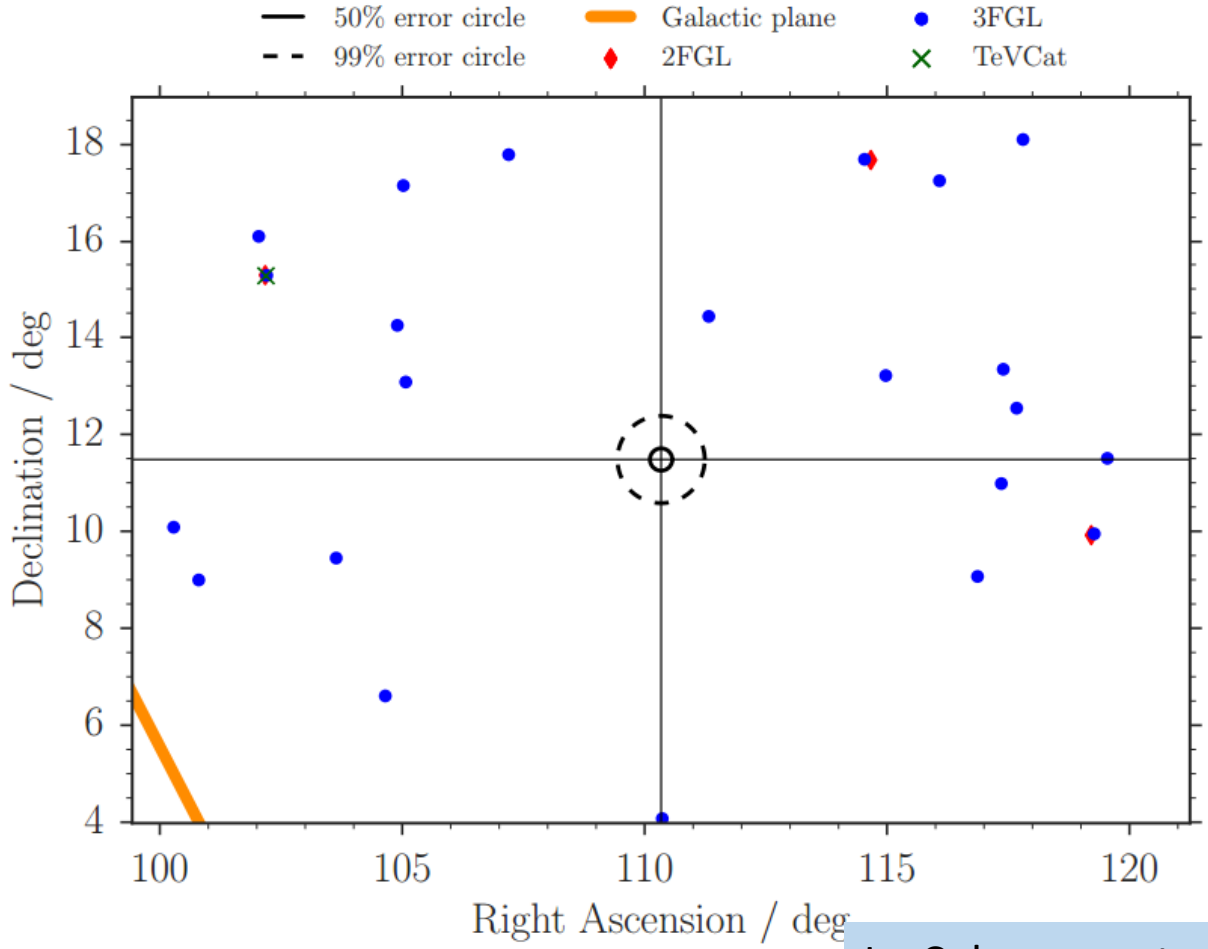


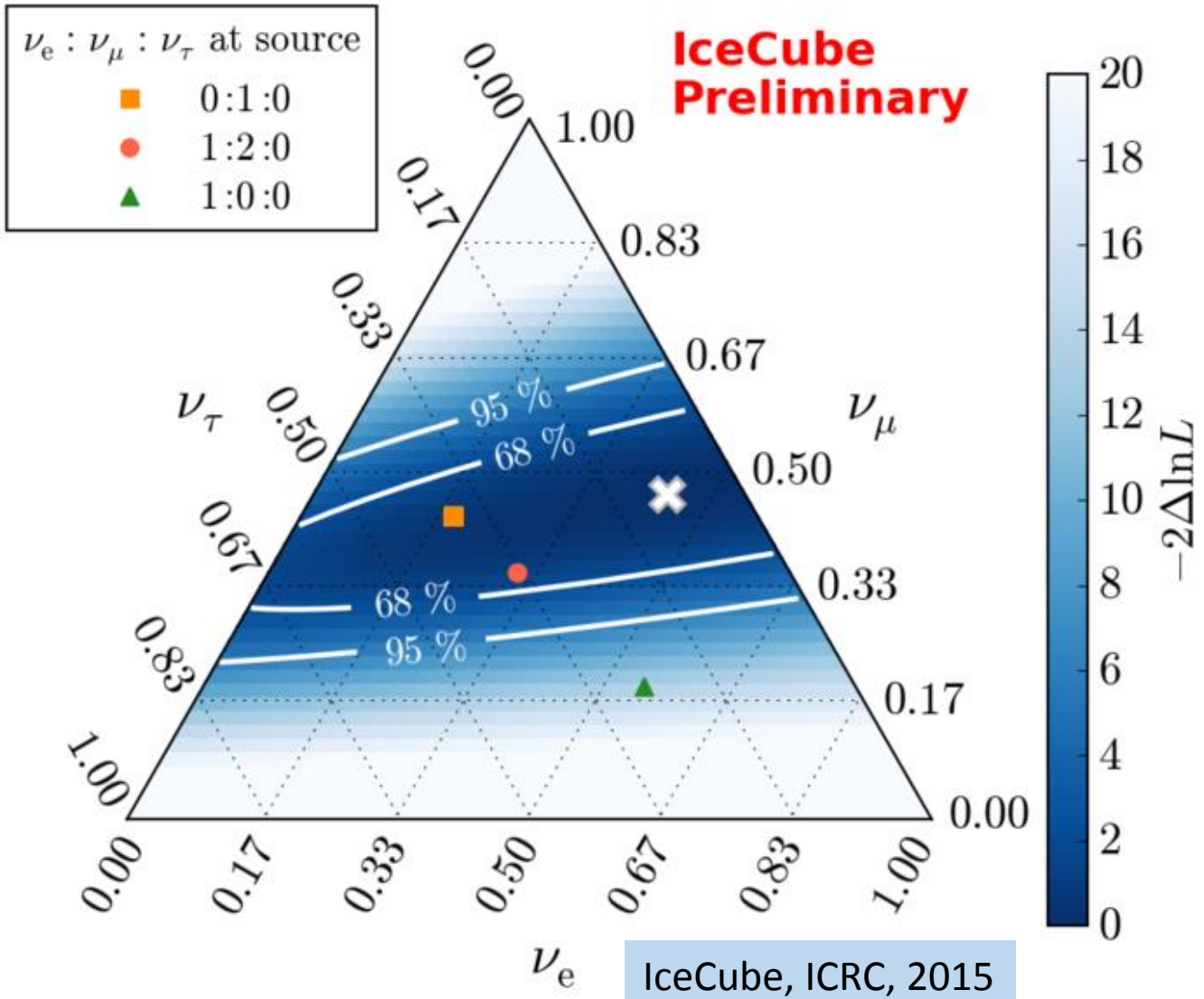




IceCube, accepted by ApJ

Flavour constraints: combining channels

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

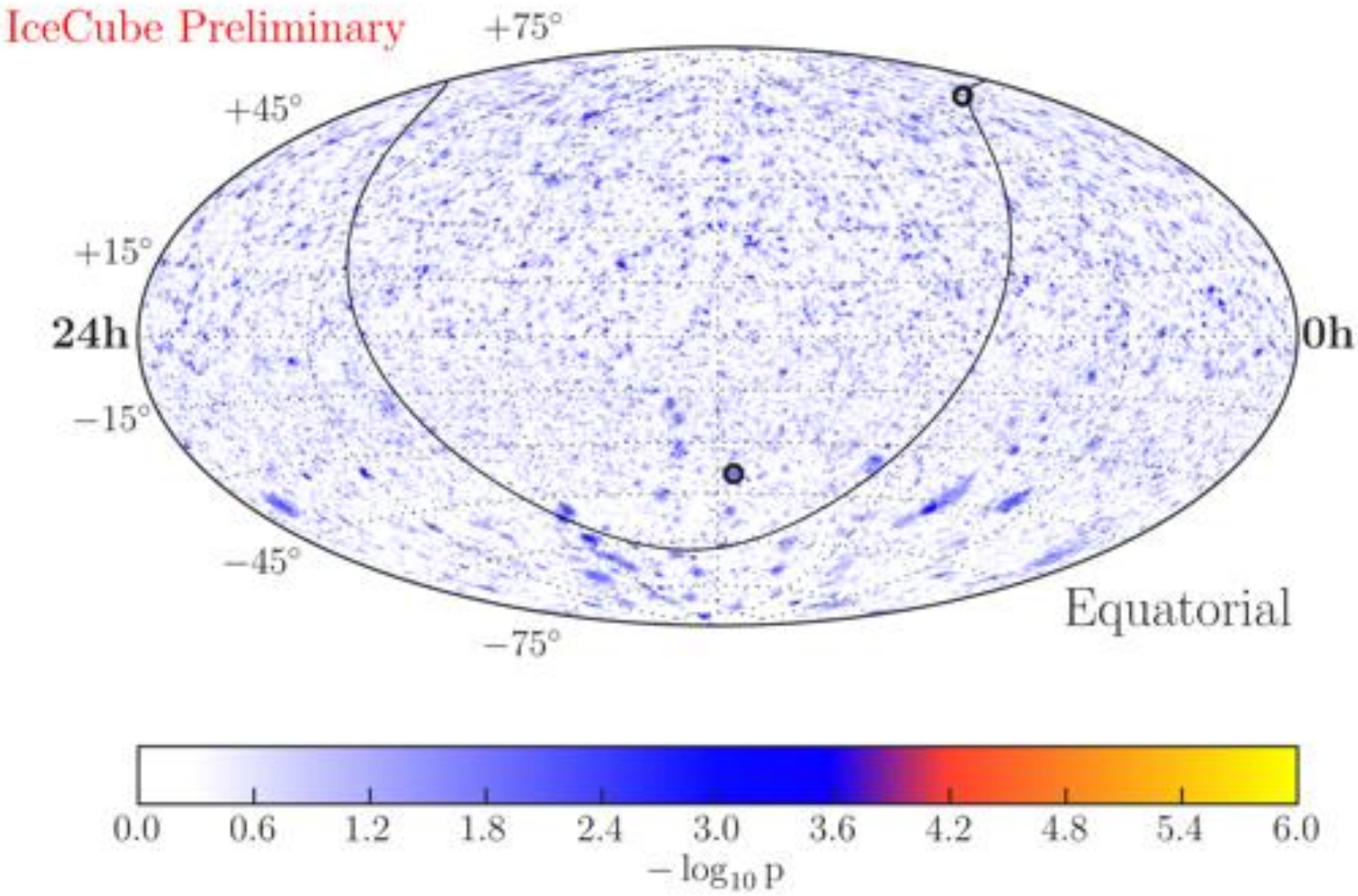


IceCube, ICRC, 2015

- Pure electron neutrinos @ sources excluded @ 3.7 σ

What are (not) the sources?

7 year point source search

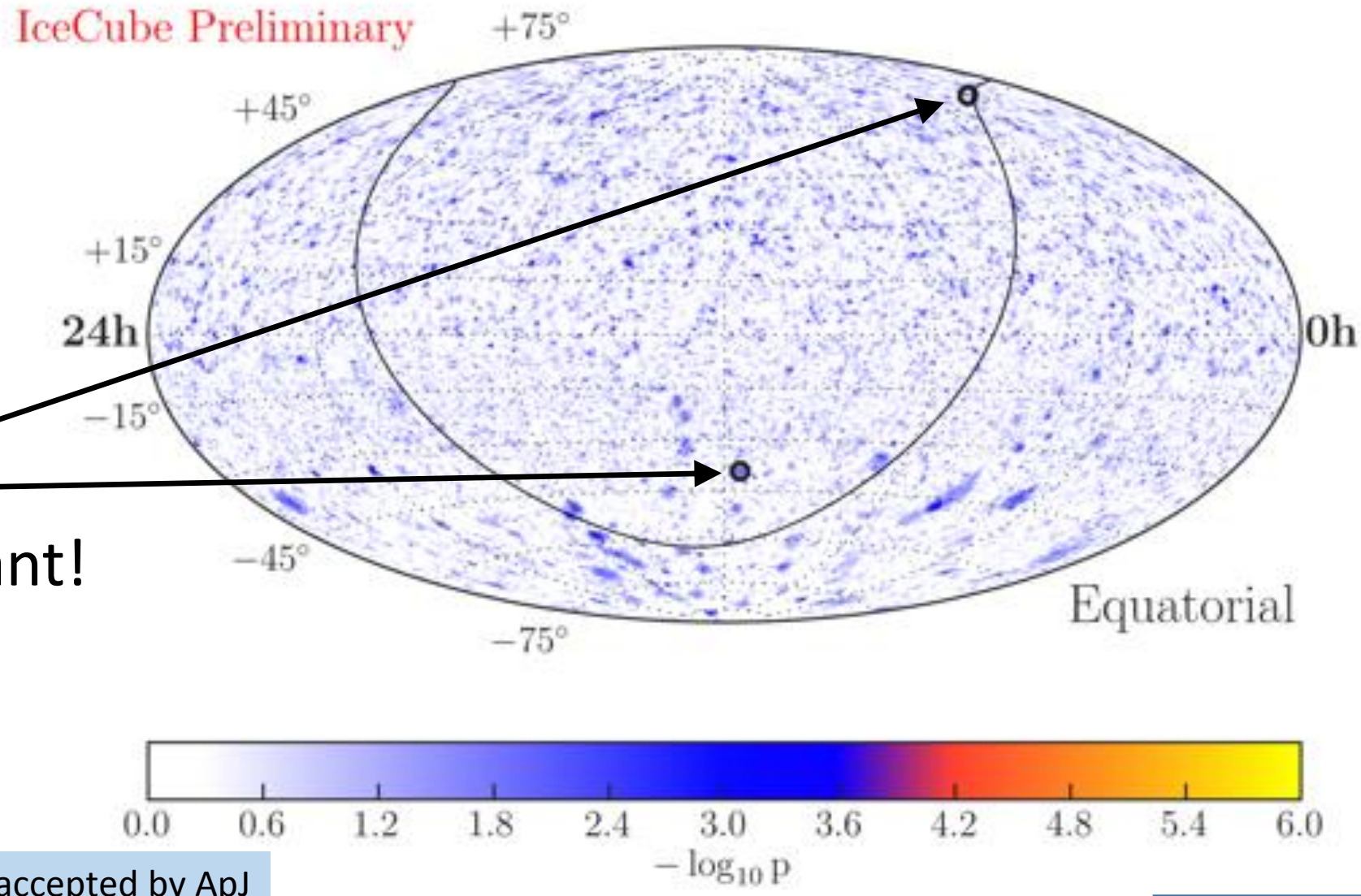


Northern sky: atm. ν

Southern sky: atm. μ

https://arxiv.org/abs/1609.04981

7 year point source search



Hottest spots not Significant!

Northern sky: atm. ν

Southern sky: atm. μ

IceCube, accepted by ApJ

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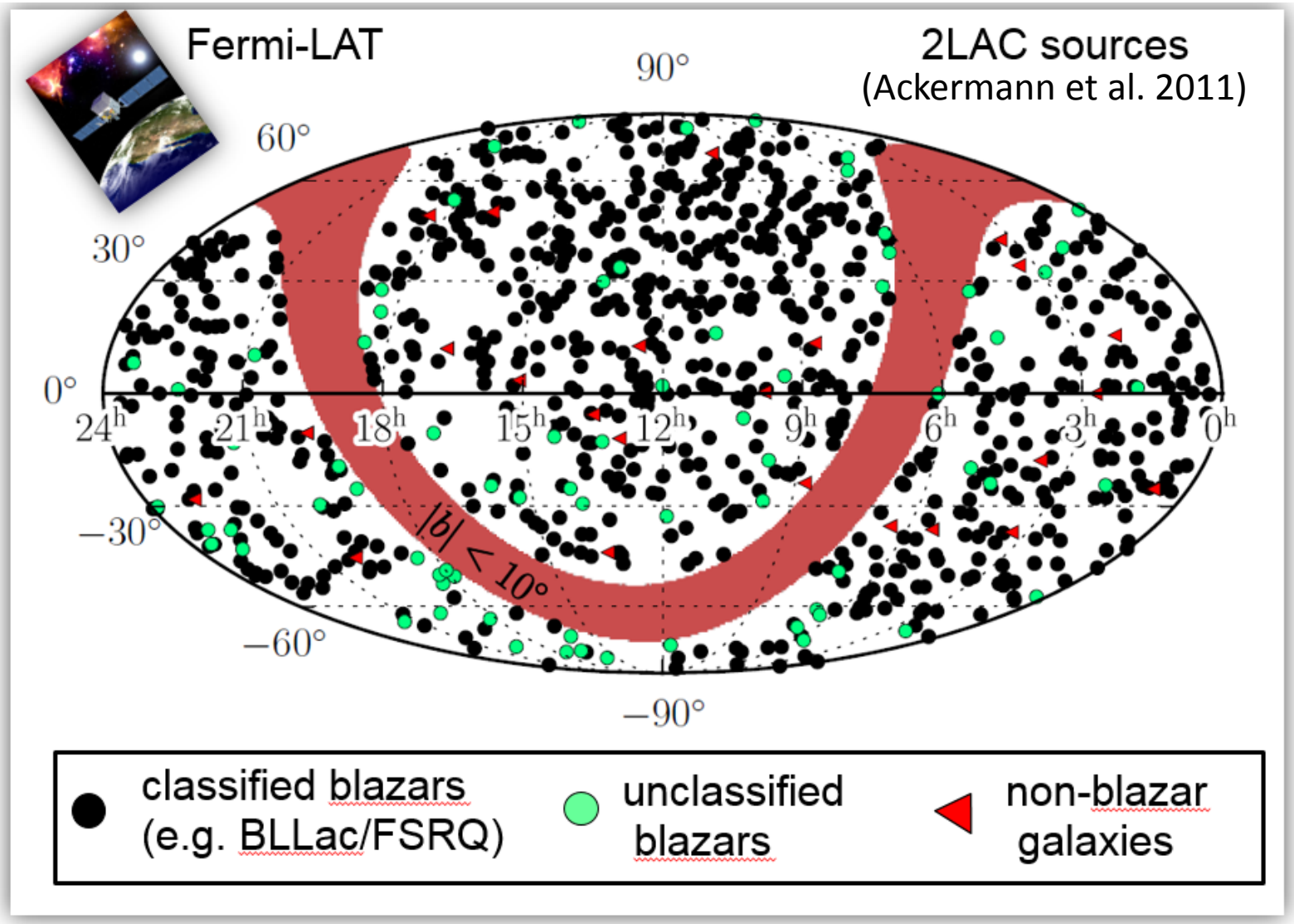
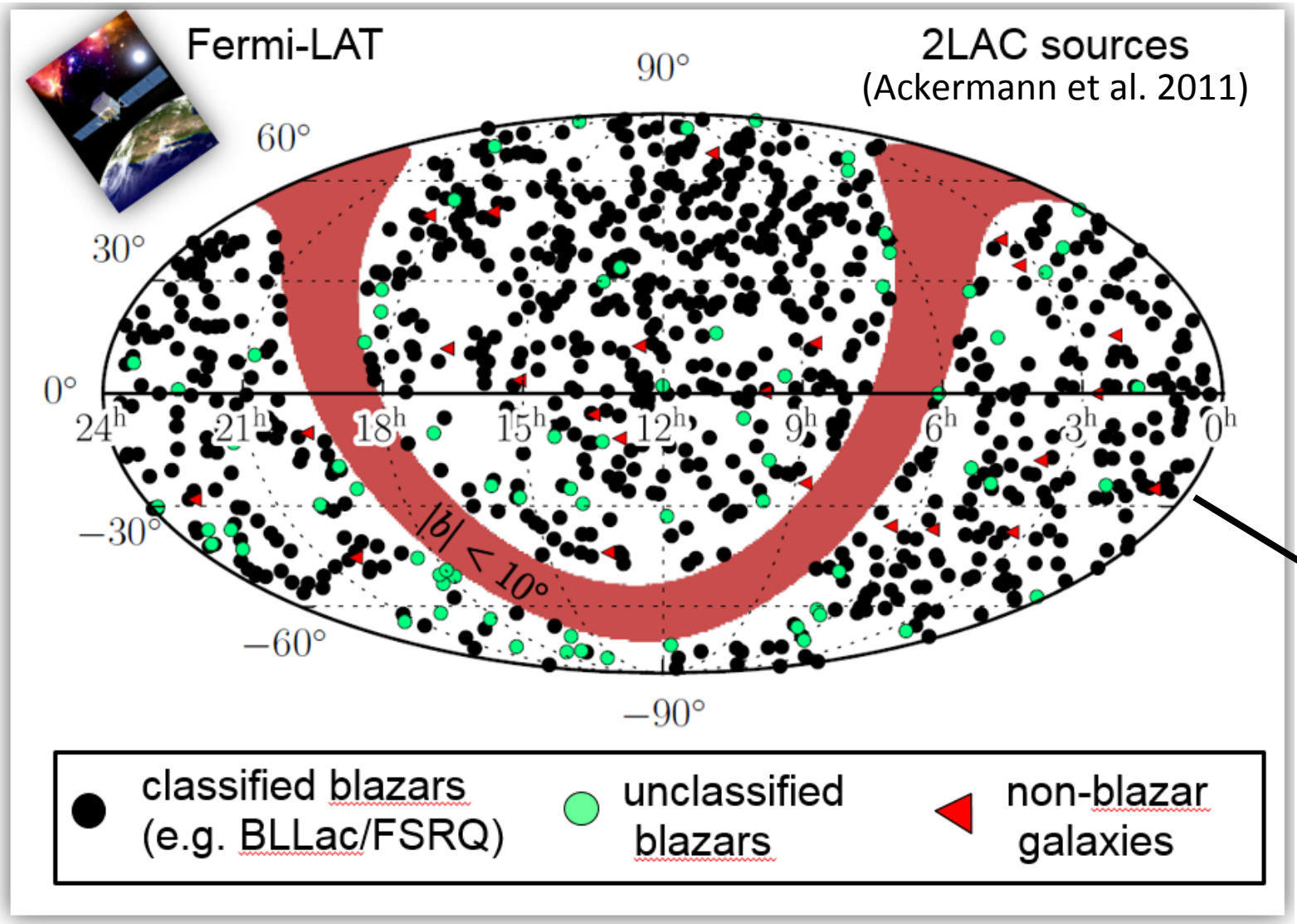
Stacking search with Fermi-LAT blazars



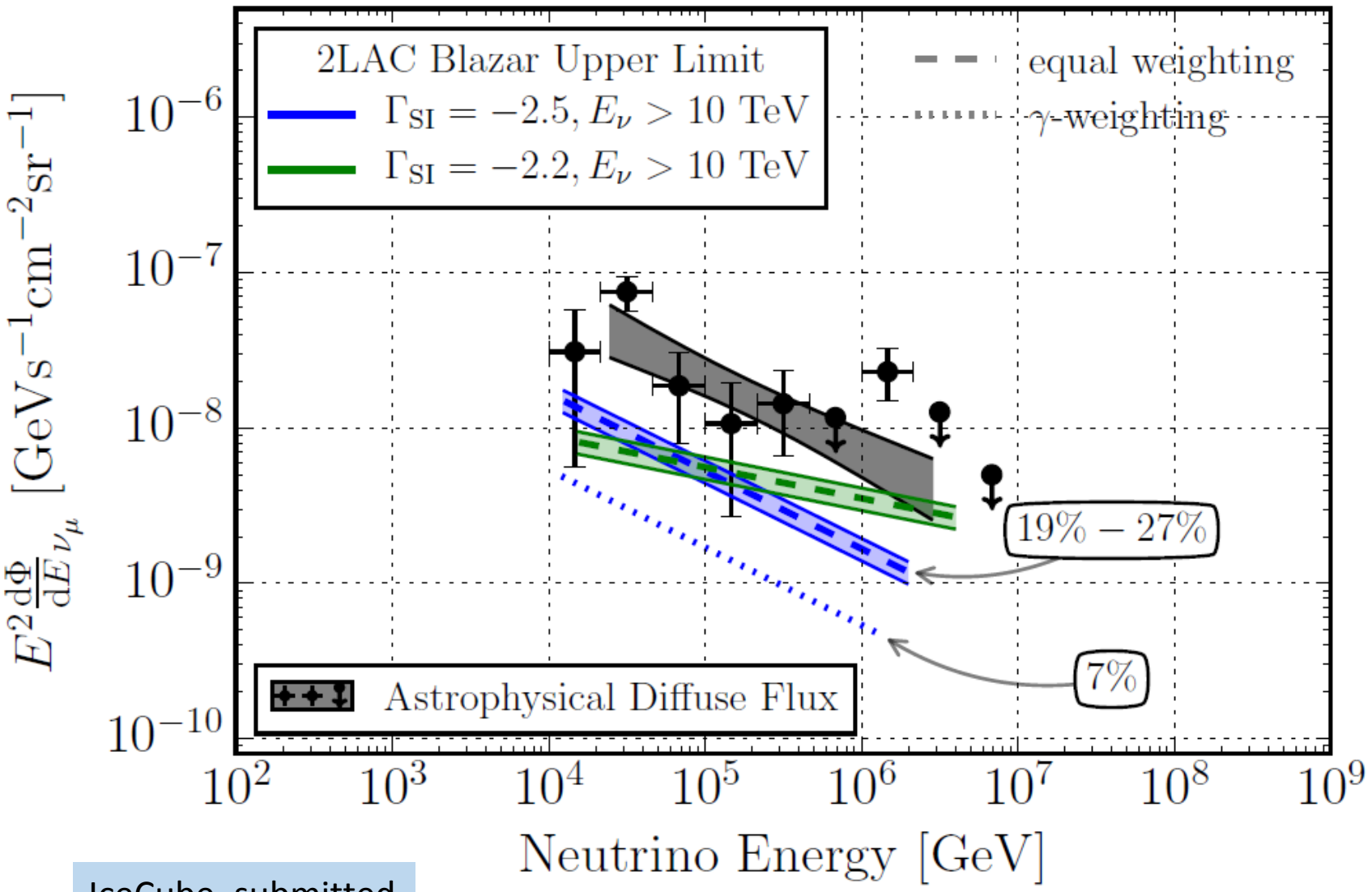
Stacking search with Fermi-LAT blazars



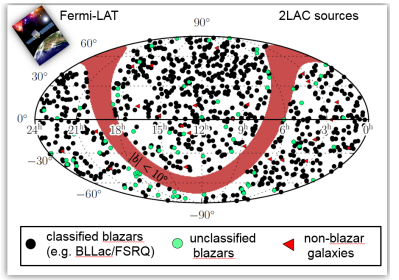
- EGB dominated by blazars
- 2LAC is 70% flux complete (Ackermann et al. 2015)

Pointing to the majority of extragal. γ-rays in the universe

Stacking search with Fermi-LAT blazars



IceCube, submitted



70% flux complete! (Ackermann et al. 2015)

- 3 years of througoing muon data (PSF < 1°)

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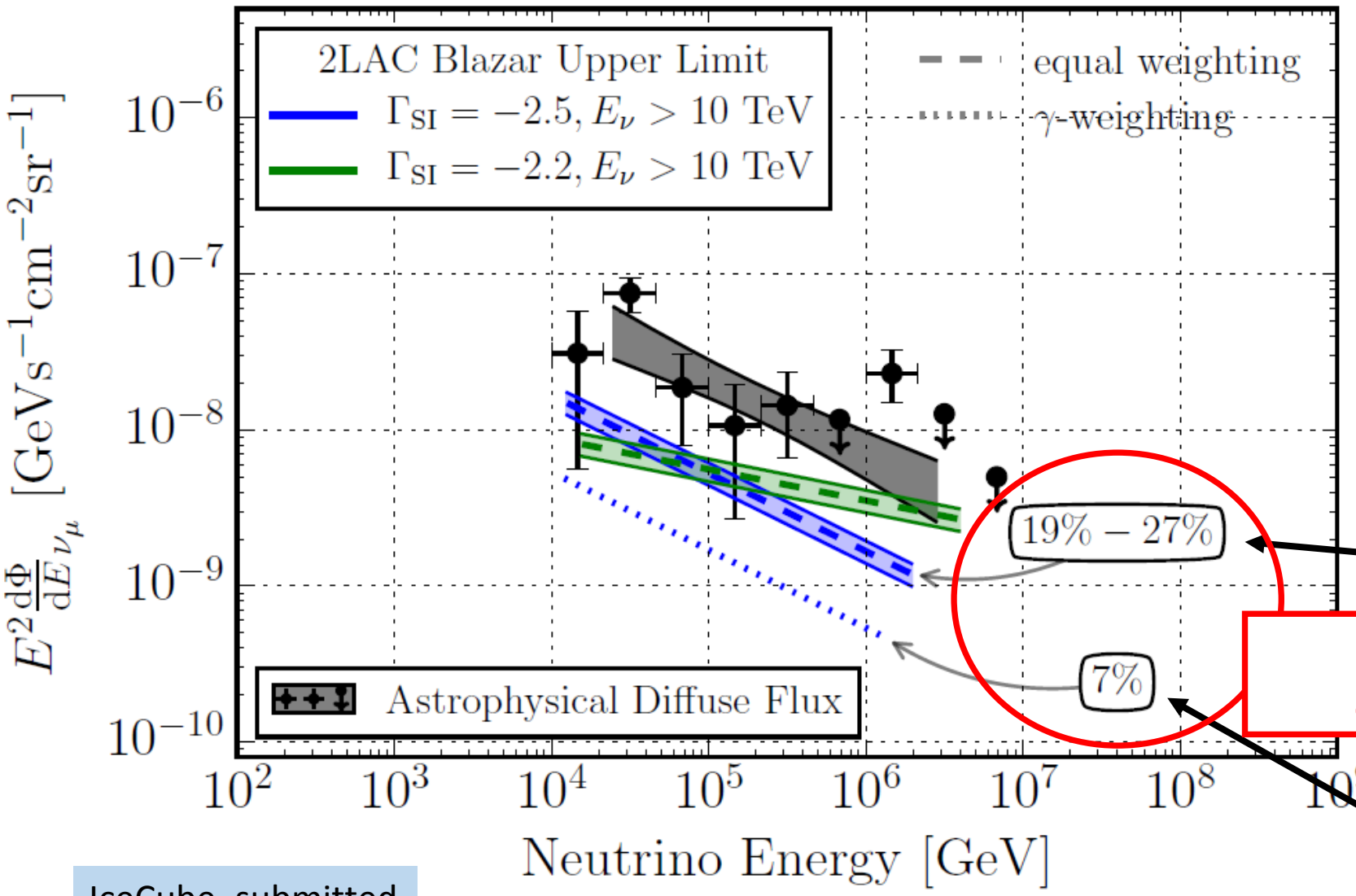

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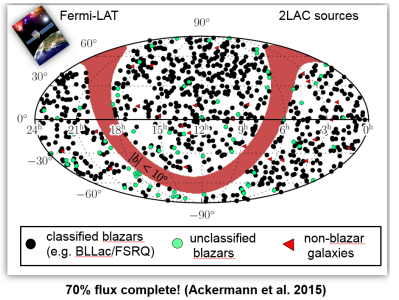


70% flux complete! (Ackermann et al. 2015)

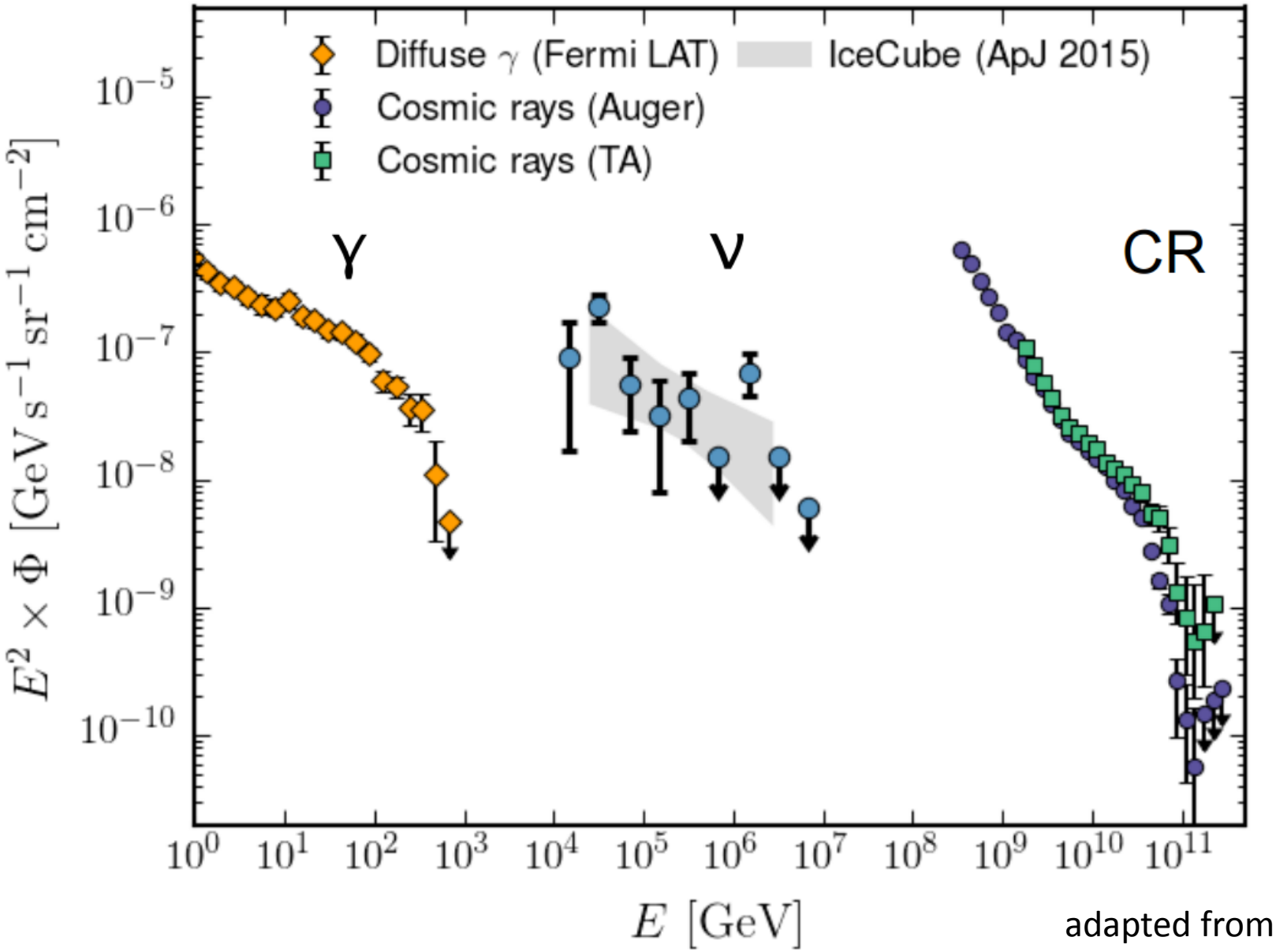
- 3 years of throughgoing muon data (PSF < 1°)

unbiased

max bulk contribution

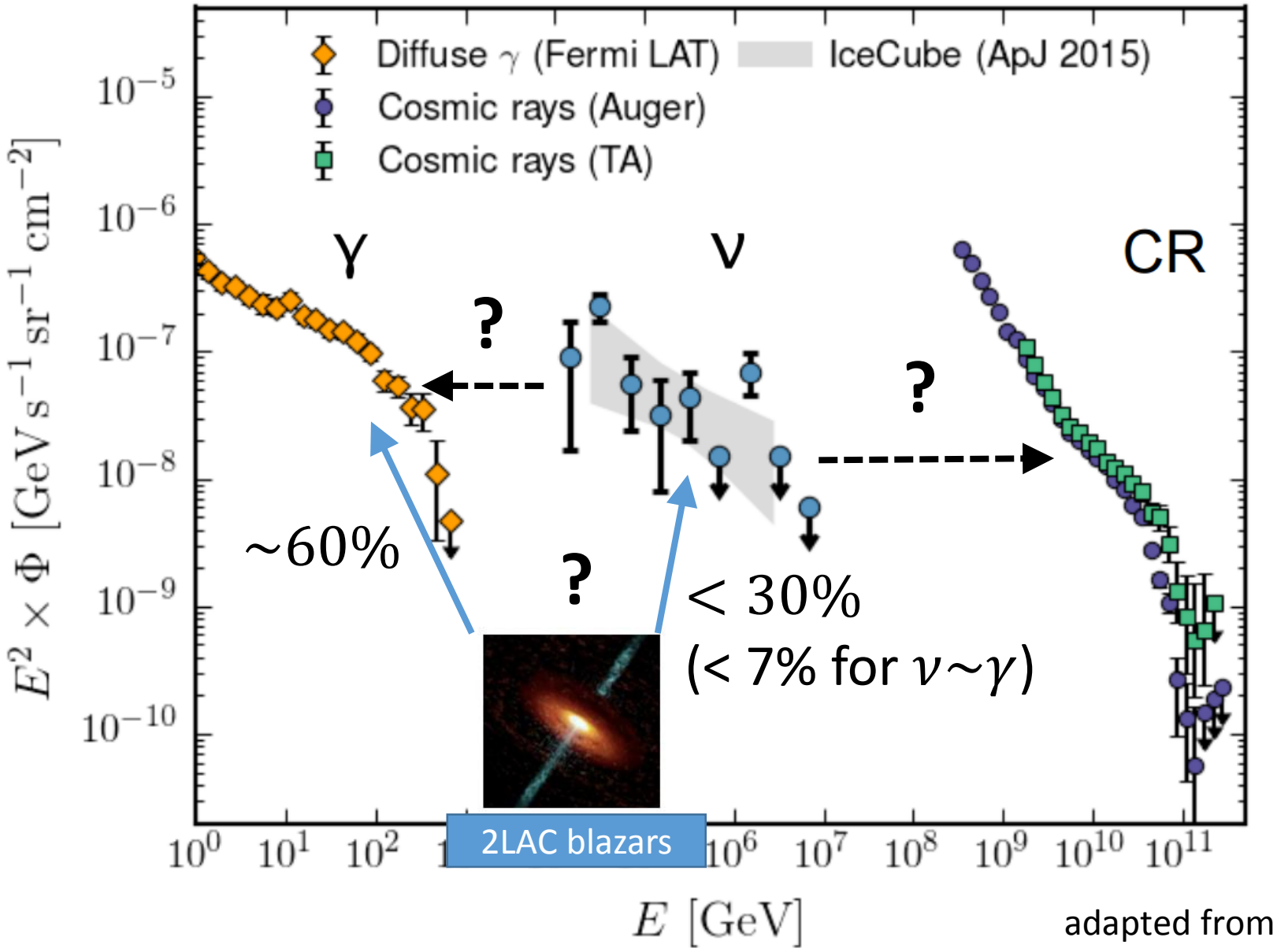
assumes $\nu \sim \gamma$

The big picture



adapted from M. Kowalski, Neutrino 2016

The big picture



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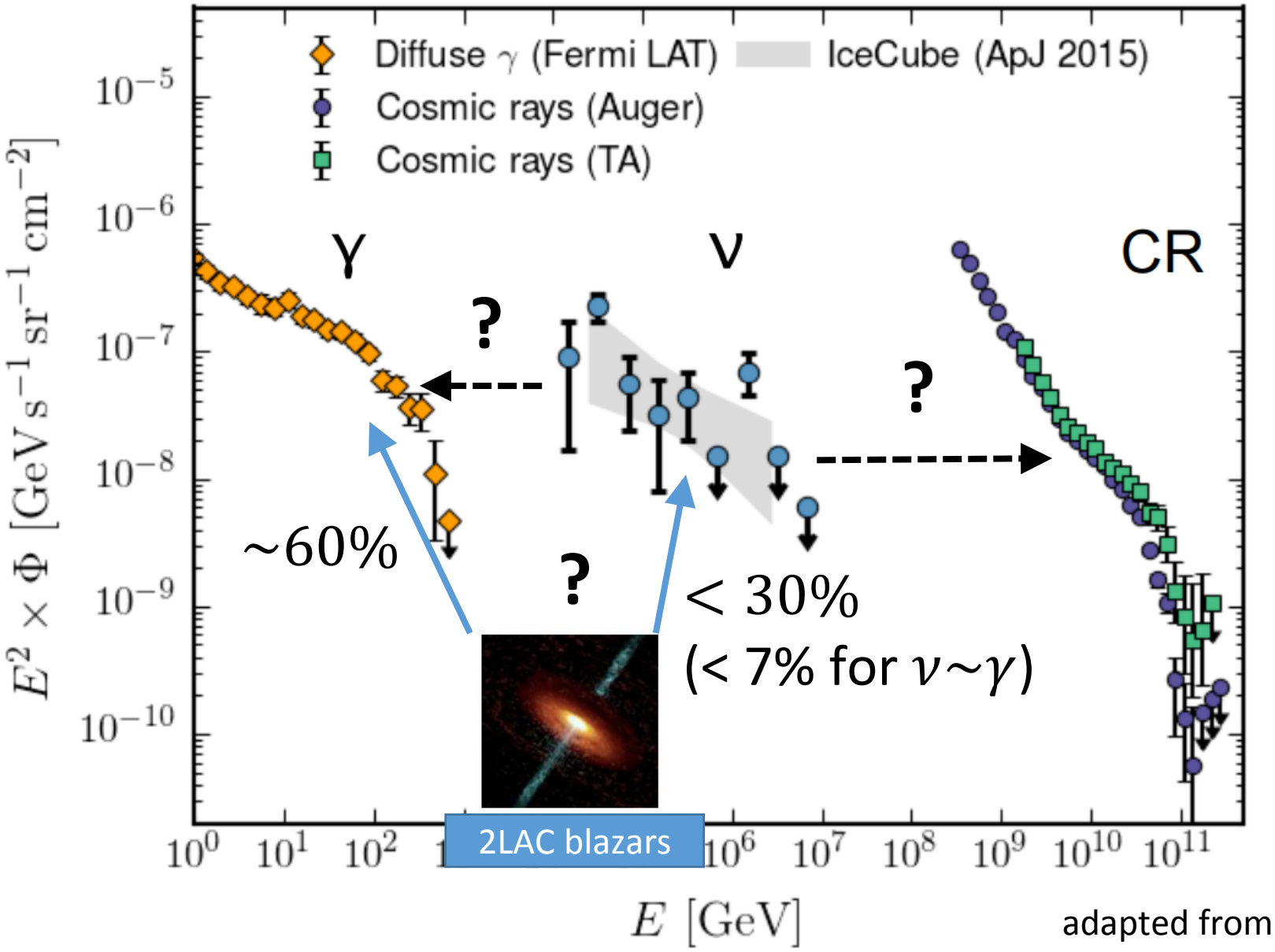

Further constraints:

- prompt GRB < 1 %

IceCube, APJL, 2015

Unconstrained:

- Choked GRBs
- Radio-Galaxies
- Supernovae
- Galactic .....

...

adapted from M. Kowalski, Neutrino 2016

Summary

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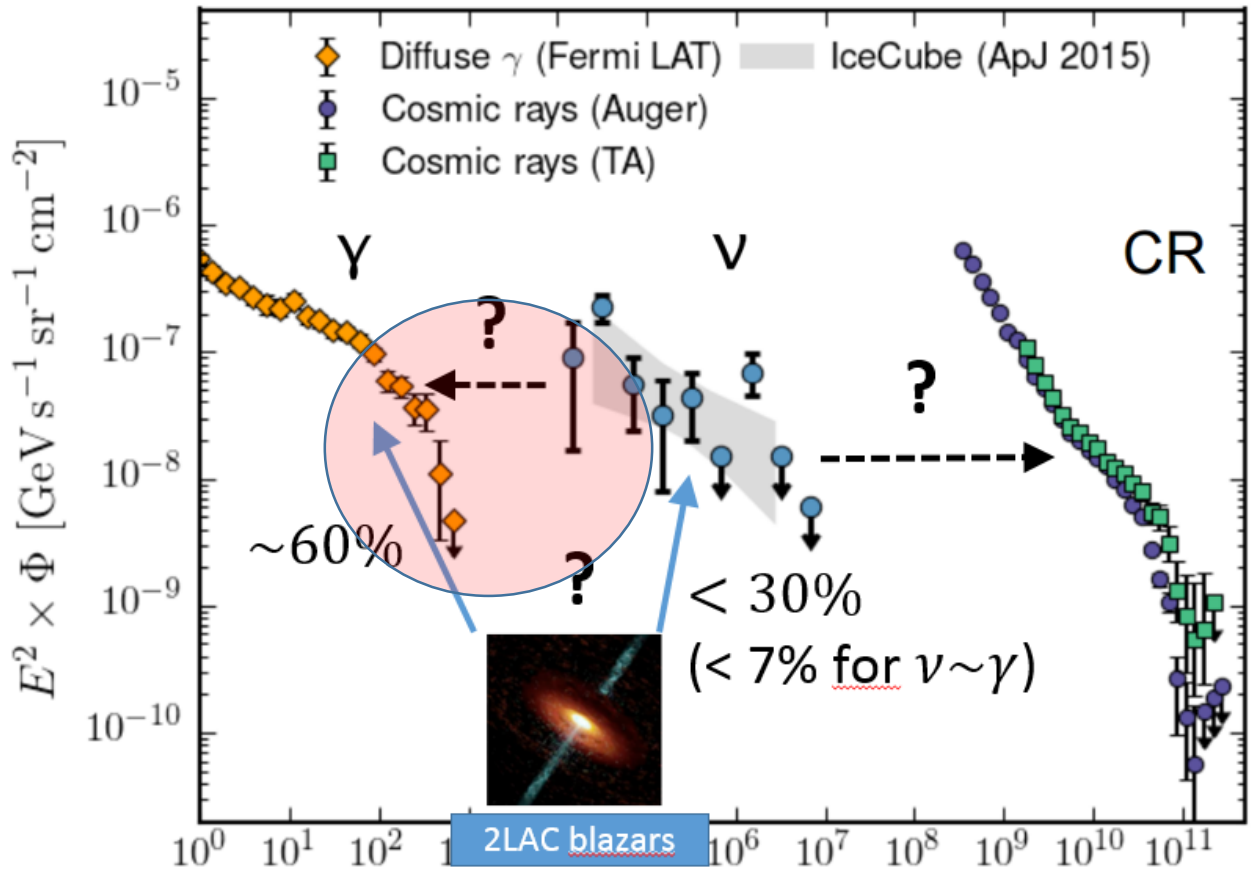
- Bulk emission: GRBs (< 1%)
  Fermi 2nd catalog blazars (< 30% - model independent)
  GeV-blazars in general (< 10% - $\nu \sim \gamma$)
- Still allowed: Radio-Galaxies, choked GRBs, Supernovae, gal. Contribution..

Summary

- E.M radiation + global modelling crucial for understanding!!



Thank you!