Physics Analyses in IceCube

Kayla Leonard

Outline

1. Summary of Existing Analyses in IceCube
2. How To Create your own Analysis in IceCube

IceCube Working Groups

Analysis Working Groups:

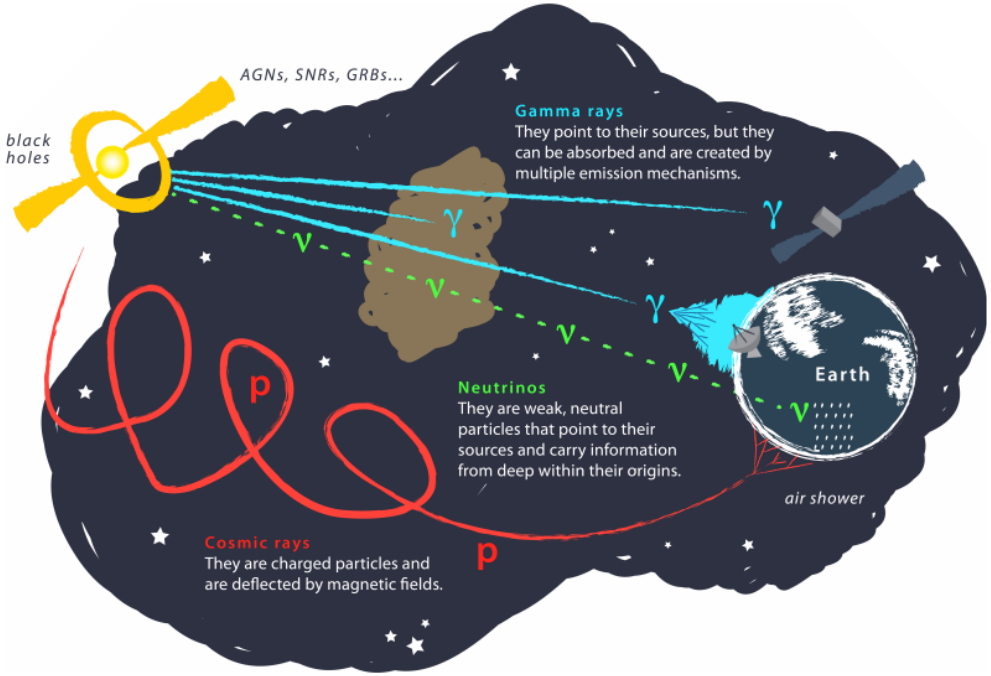
- Neutrino Sources
- Diffuse
- Oscillations
- BSM
- Cosmic Rays
- Supernova

Technical Working Groups:

- Reconstruction & Systematics
- Calibration
- Simulation
- Software
- Realtime / ROC

Neutrino Sources Working Group

- High Energy Neutrinos are produced in intense comic accelerators in our Universe.
- The Neutrino Sources Working Group tests various theories to see if there are “hot spots” or clusters of neutrinos
- Clusters can be in both space and time



Neutrino Sources Analyses

	Spatial prior	Time integrated	Time dependent
Skymap	None	• 10 yr time integrated (all-sky scan)	• All-sky single flare fit
Singe source search	Single point	• TXS archival • Anita archival • Hydrangea archival	• TXS follow-up • Anita follow-up • Hydrangea follow-up
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Template	Region of sky	• Galactic Plane	• Non-poissonian template fit • Gravitational Wave

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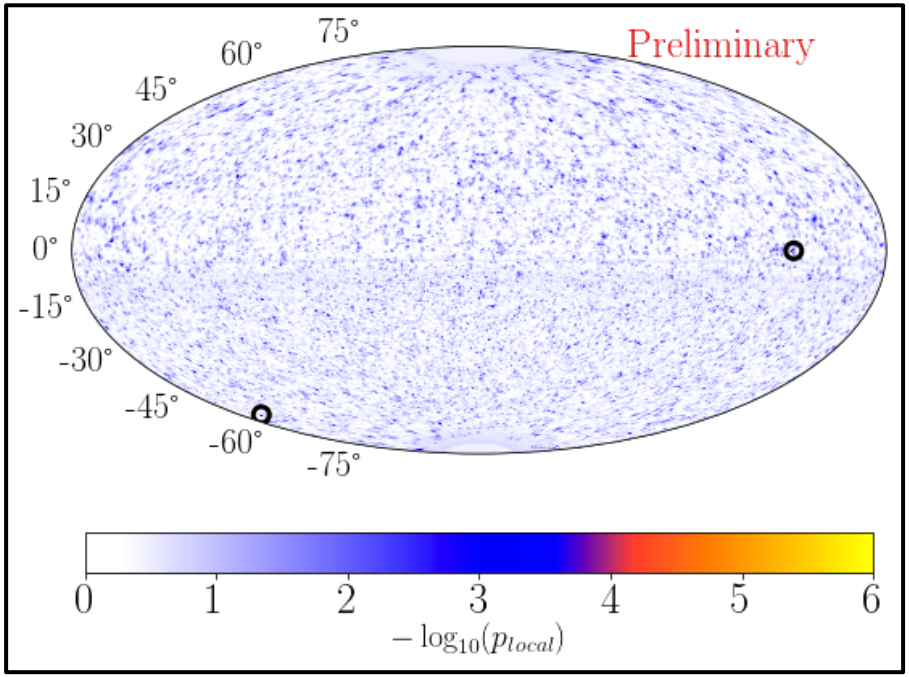
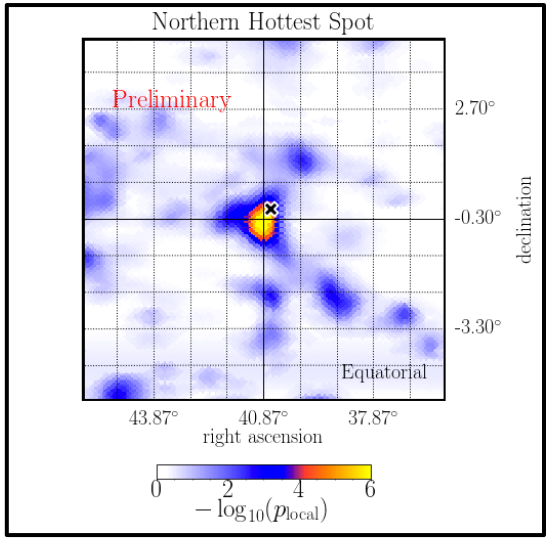
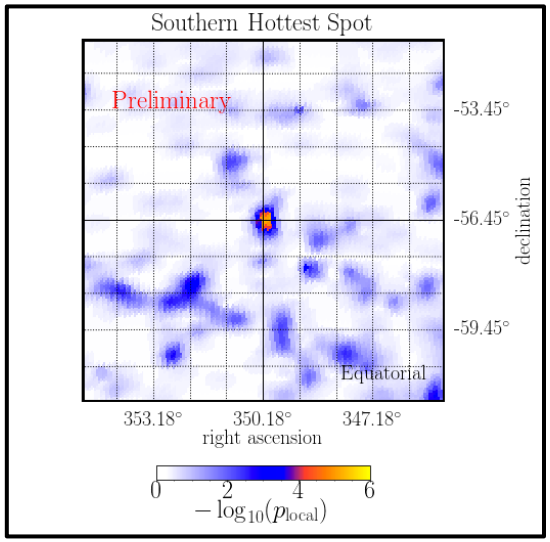
All-sky scan

- Look for any hotspot on sky







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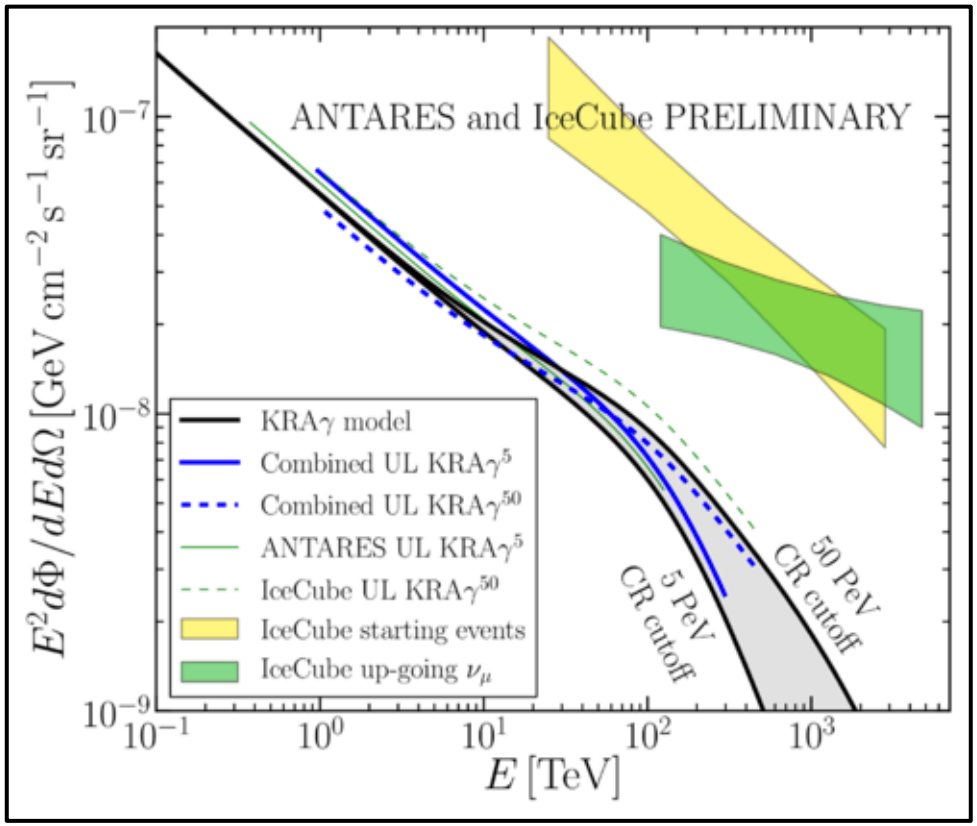
Galactic Plane Template

- Use neutrinos in galactic plane region to test KRA-gamma model



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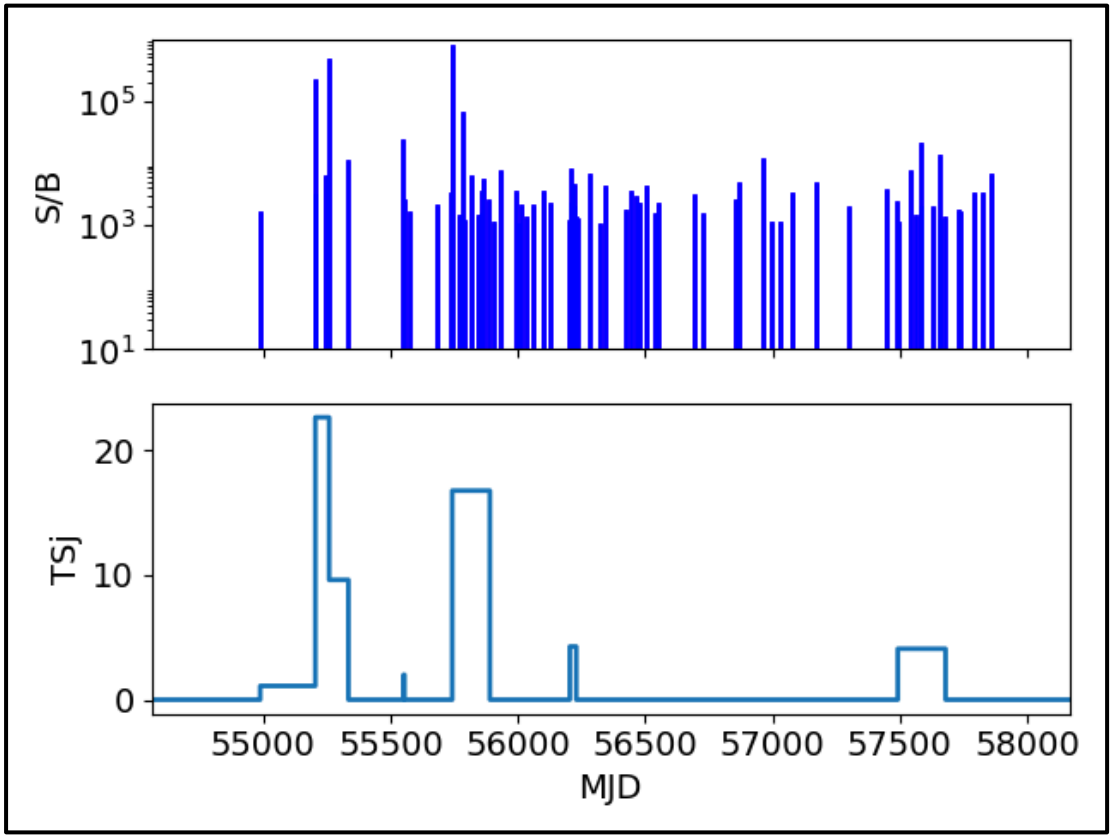
Multi-flare Blazar Stacking

- Look for clustering in *time* of events in a blazar catalog



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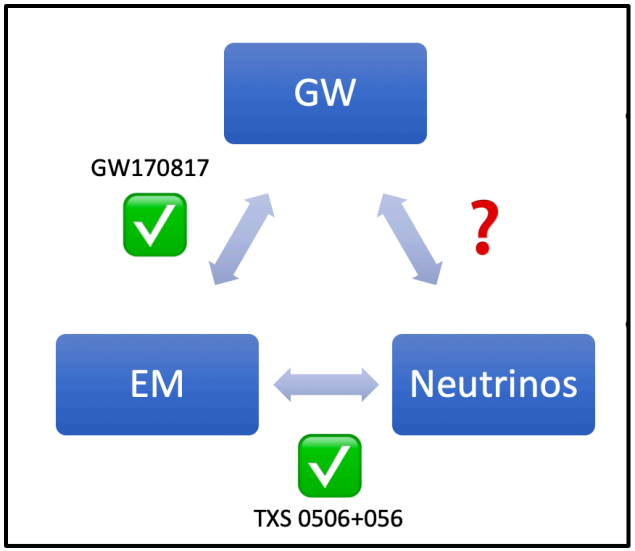

Realtime

- Alert: We see a high energy neutrino that we want other telescopes to follow up
- Follow-up: Source is a single point that telescopes alerted us to
- GW follow-up: Source is an extended contour from LIGO gravitational wave

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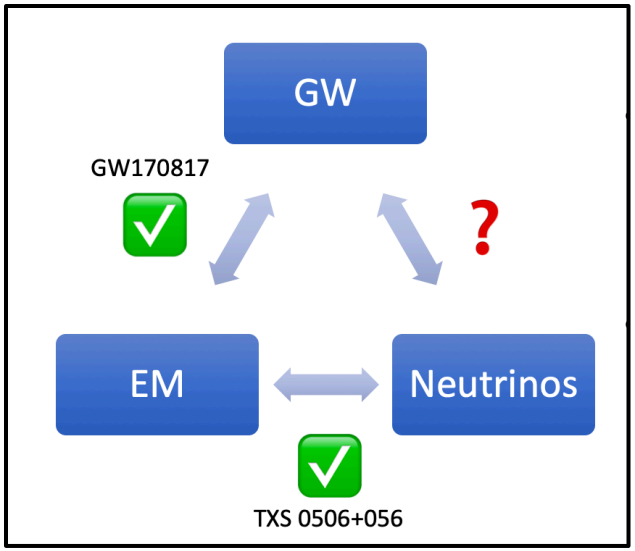

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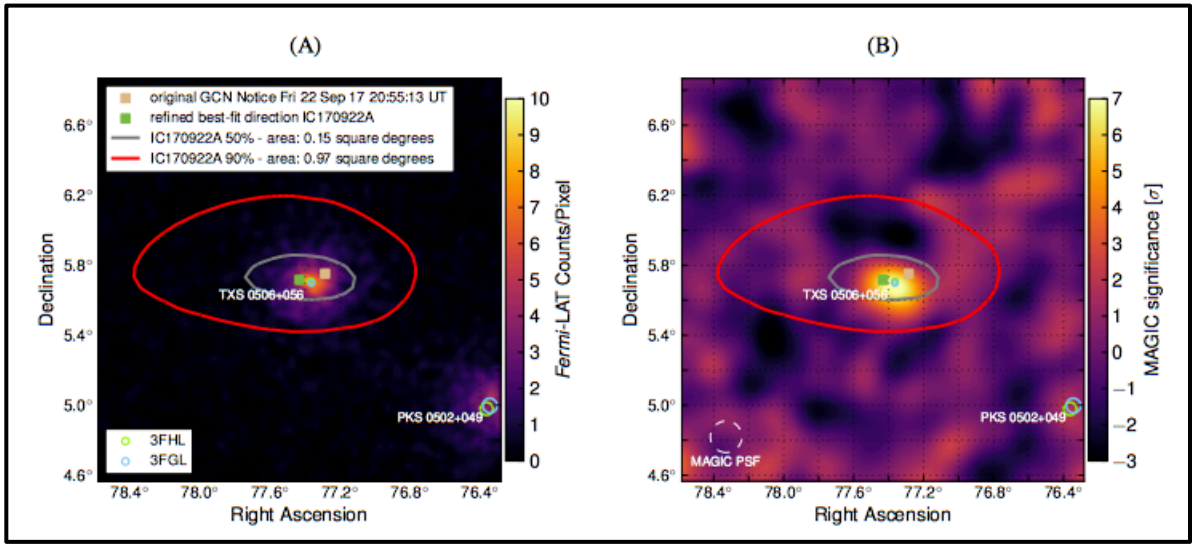

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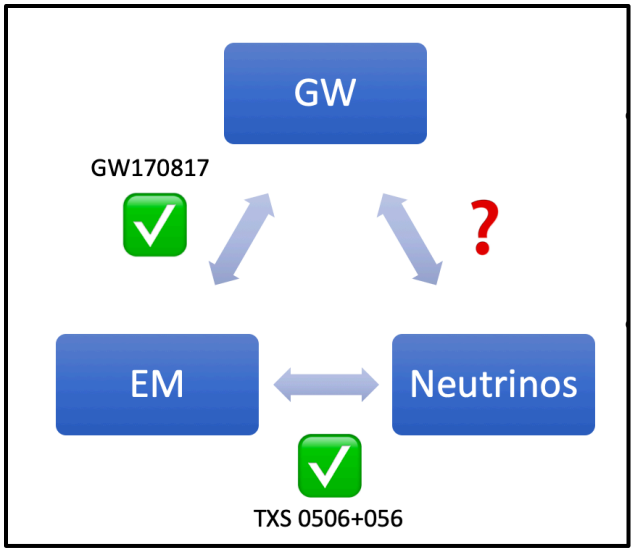

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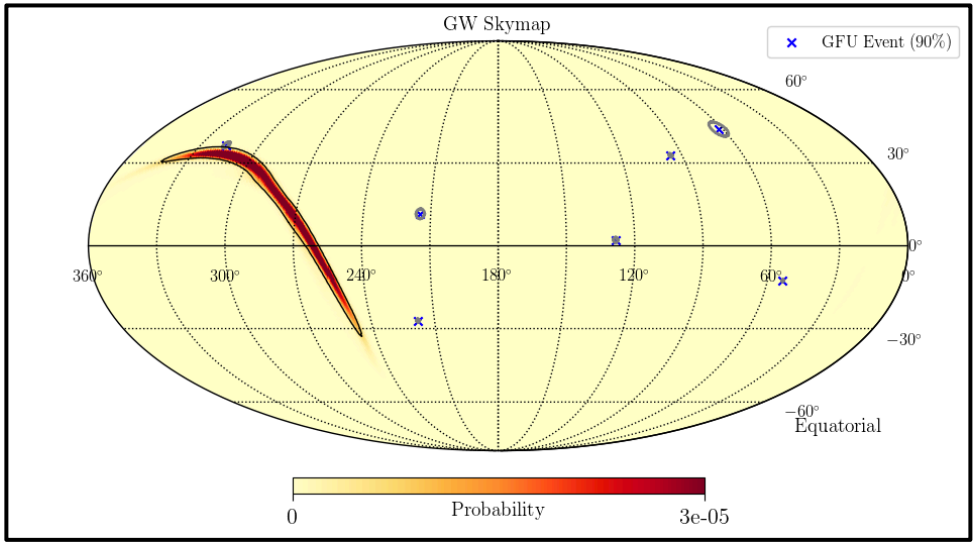
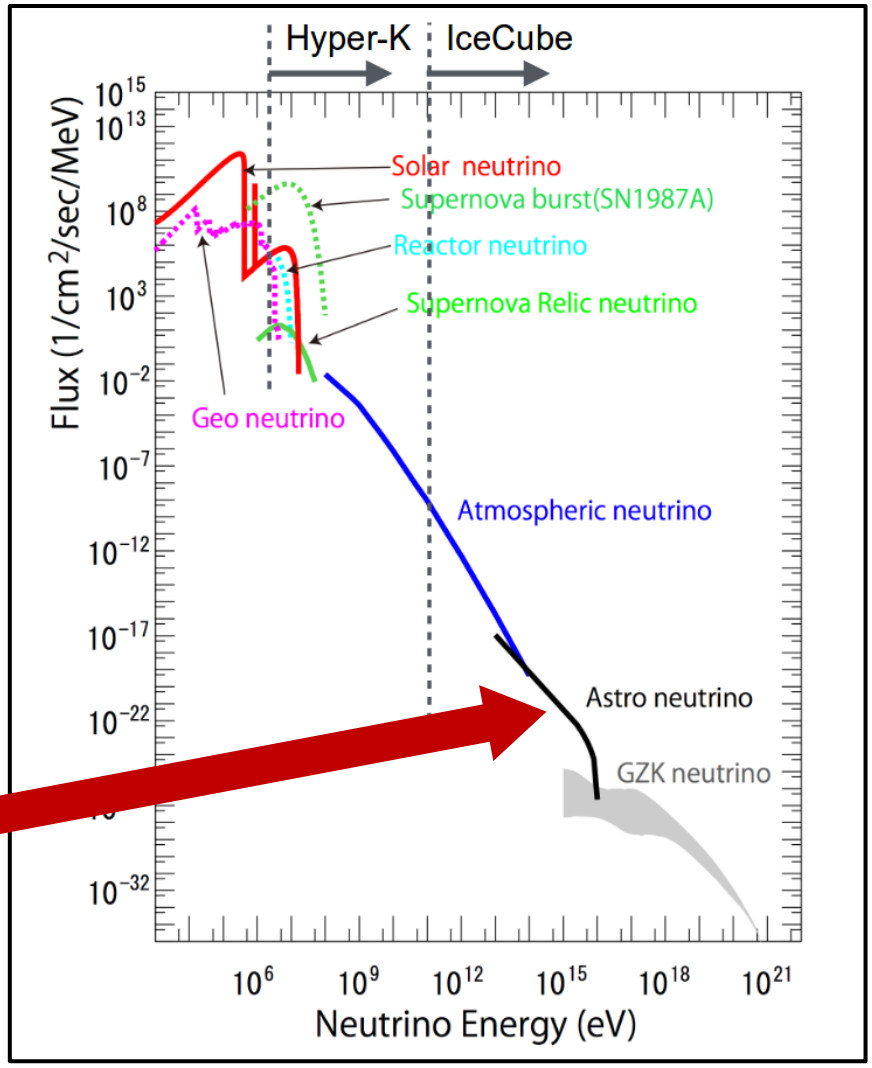


Diffuse Working Group

- Neutrinos are produced all around the Universe.
- It appears as an isotropic flux here at Earth.
- The Diffuse Working Group tries to measure the Diffuse Astrophysical Neutrino spectrum.



Diffuse Analyses

- Astrophysical Diffuse Spectrum
- Flavor ratio
- Tau neutrino identification

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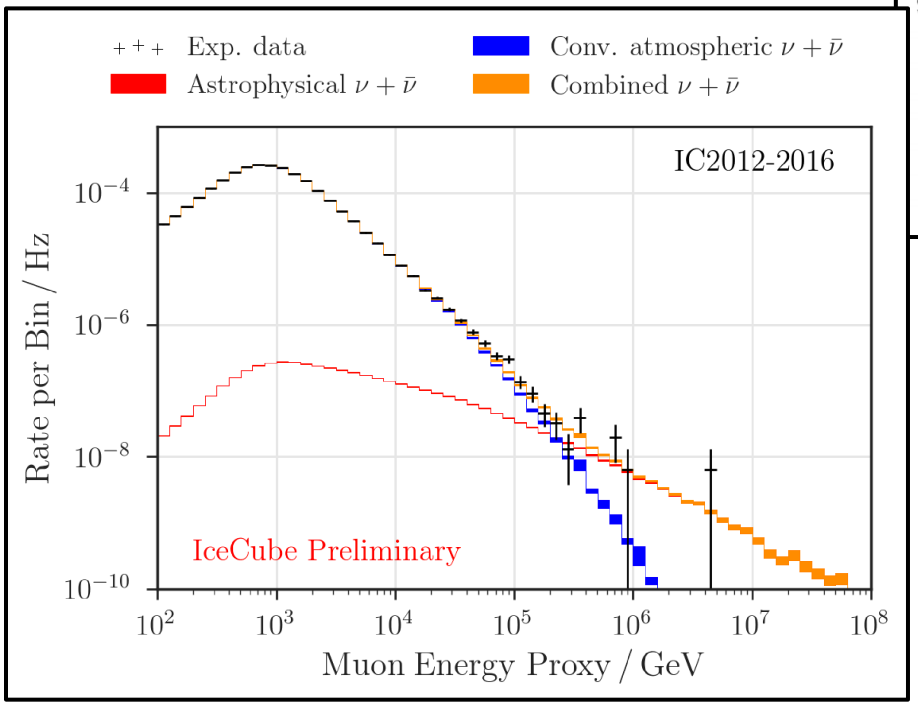
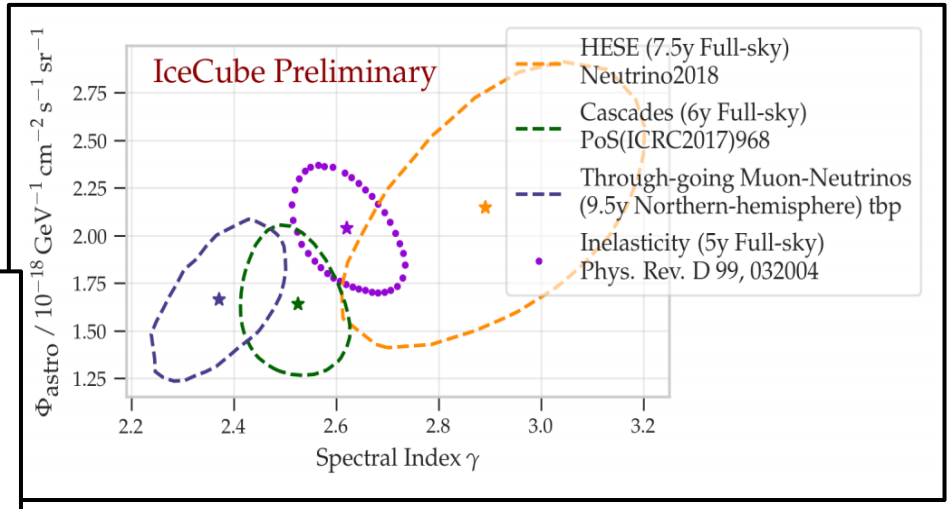


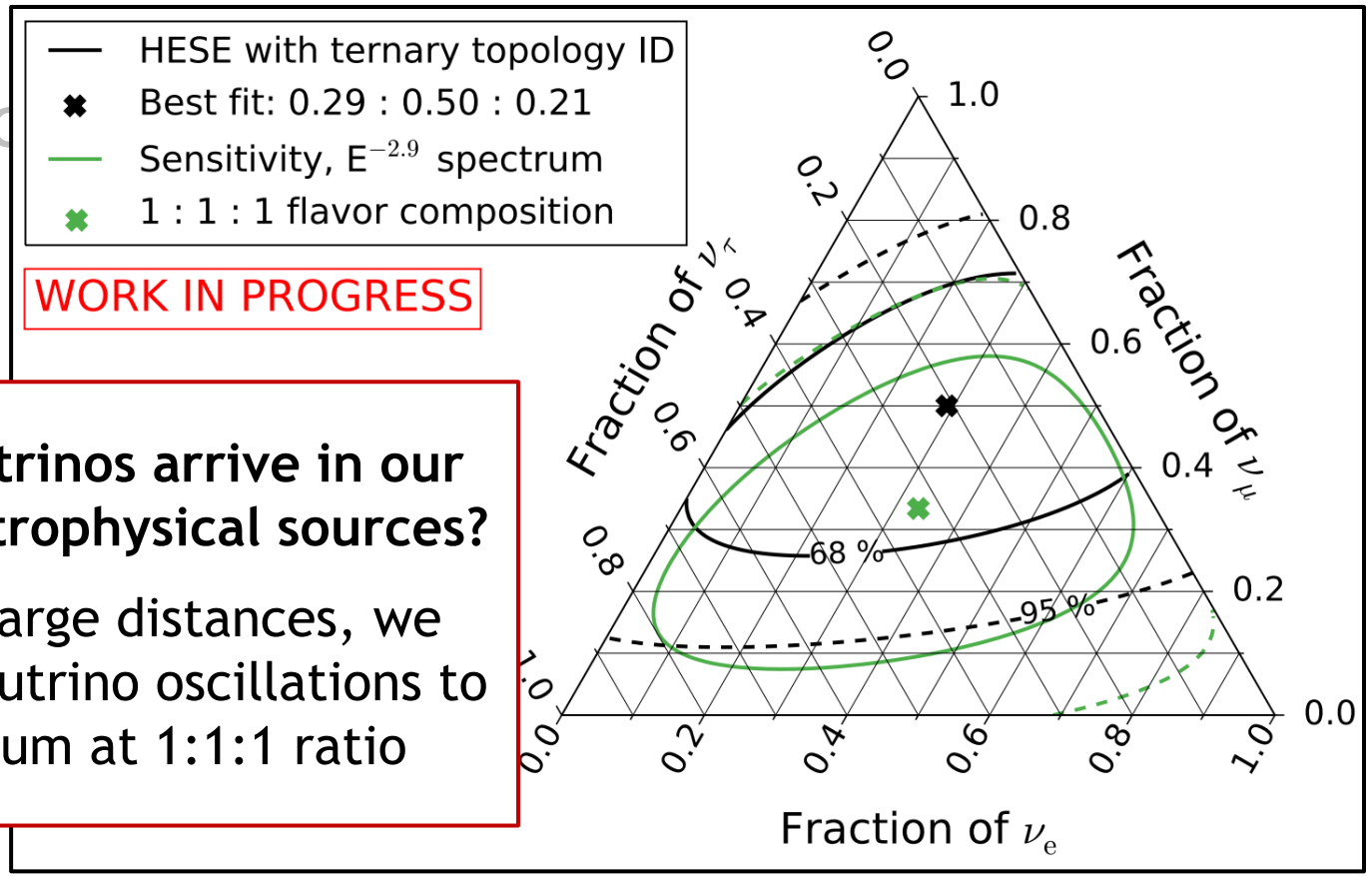


What is the spectrum of diffuse astrophysical neutrinos?

$$N = \phi * (E/E_0)^{-\gamma}$$

Diffuse Analyses

- Astrophysical Diffuse Spectrum
- Flavor ratio
- Tau identific



What flavor neutrinos arrive in our detector from astrophysical sources?

Over very very large distances, we may expect all neutrino oscillations to reach equilibrium at 1:1:1 ratio

Diffuse Analyses

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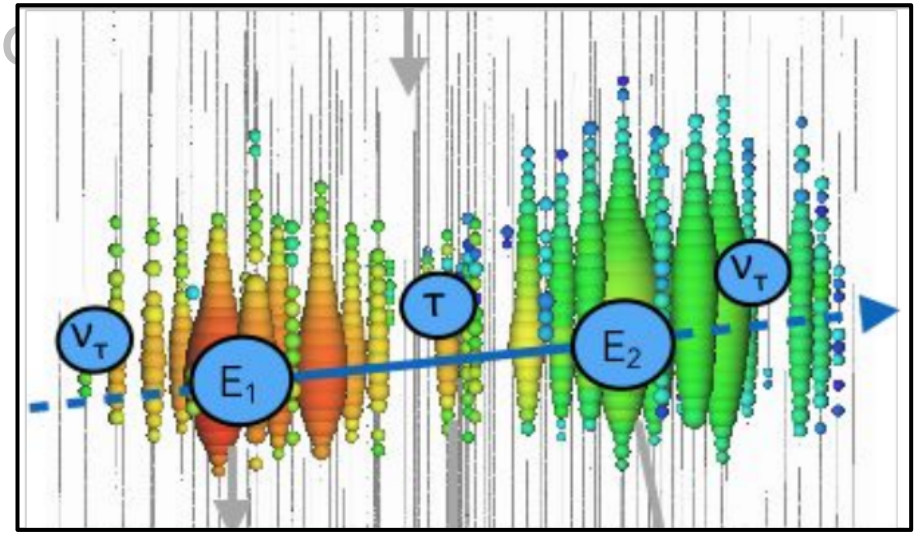
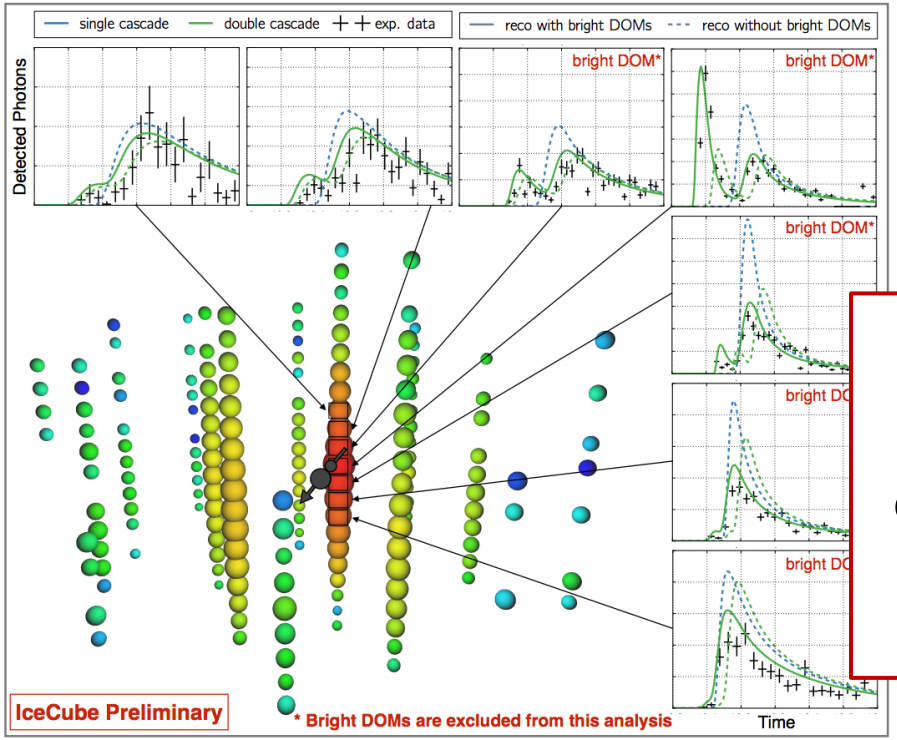
- Flavor ratio
- Tau identification





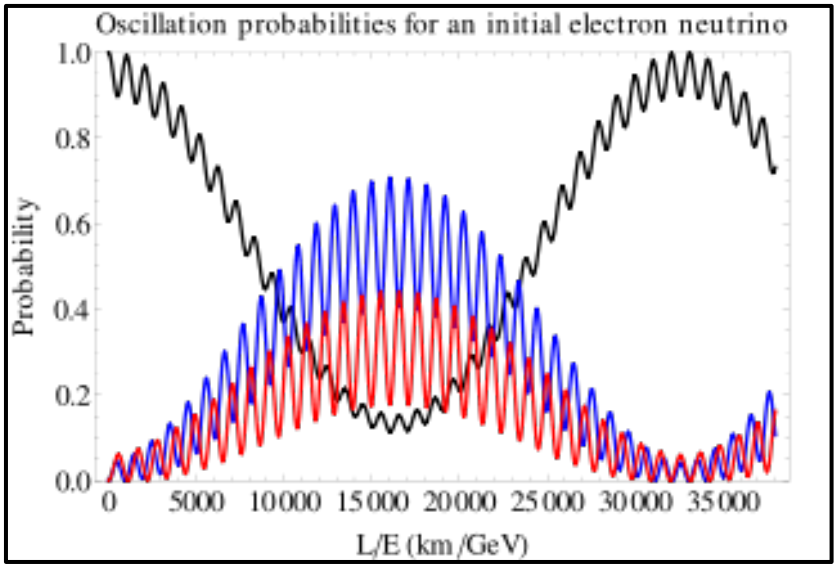
Tau particles decay quickly. If they are created and decay within the detector can we see both cascades?

Length of Track = 50 m per PeV * Energy

Oscillations Working Group

- If we know the what flavor a it was created as, we can calculate the probability of it being measured as a certain flavor at another point in time.
- Probability of starting as one flavor and measured as different flavor:

$$P_{\alpha\to\beta,\alpha\neq\beta} = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$



- N(ν_μ detected) = P($\nu_\tau \rightarrow \nu_\mu$) * N($\nu_\tau$ created)

Oscillation Analyses

- Atmospheric oscillation parameters
- Tau neutrino appearance
- Neutrino mass ordering
- Non-standard interactions
- Sterile neutrinos

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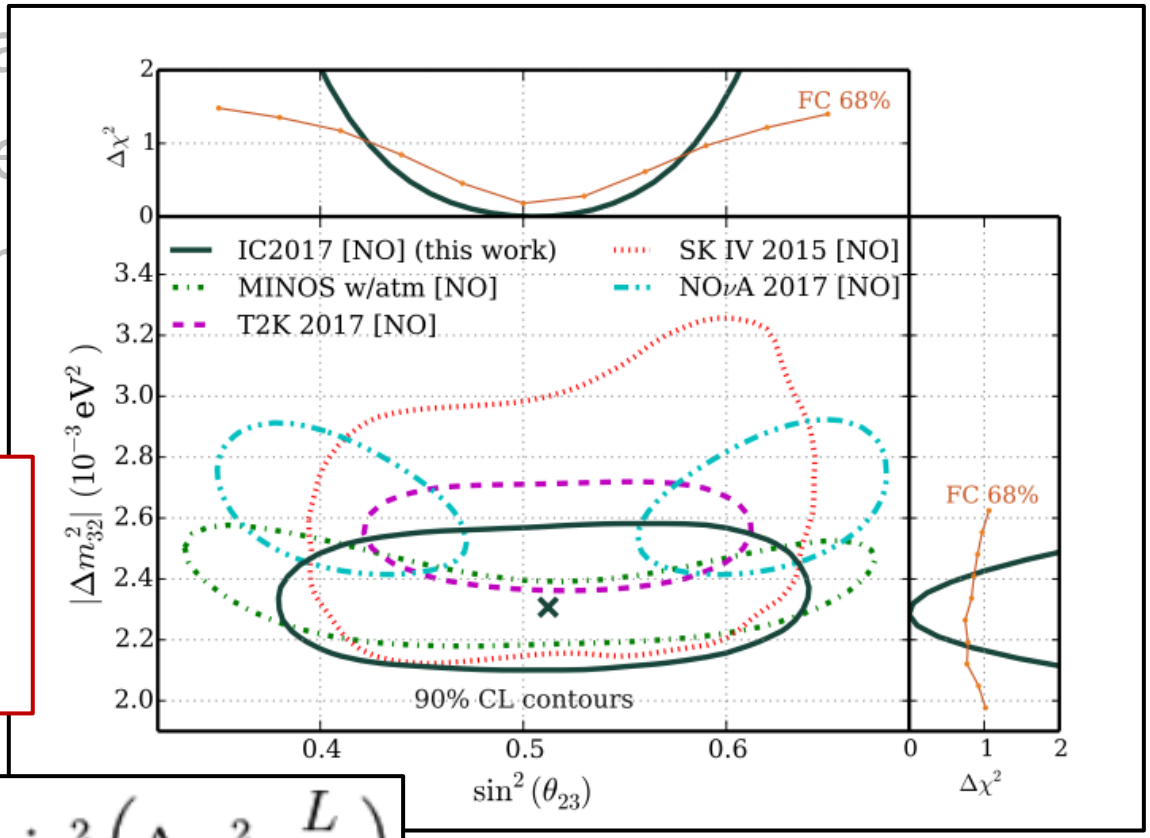
What are the parameters that describe neutrino oscillations?



$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2 2\theta_{23} \sin^2\left(\Delta m^2_{31} \frac{L}{4E}\right)$$

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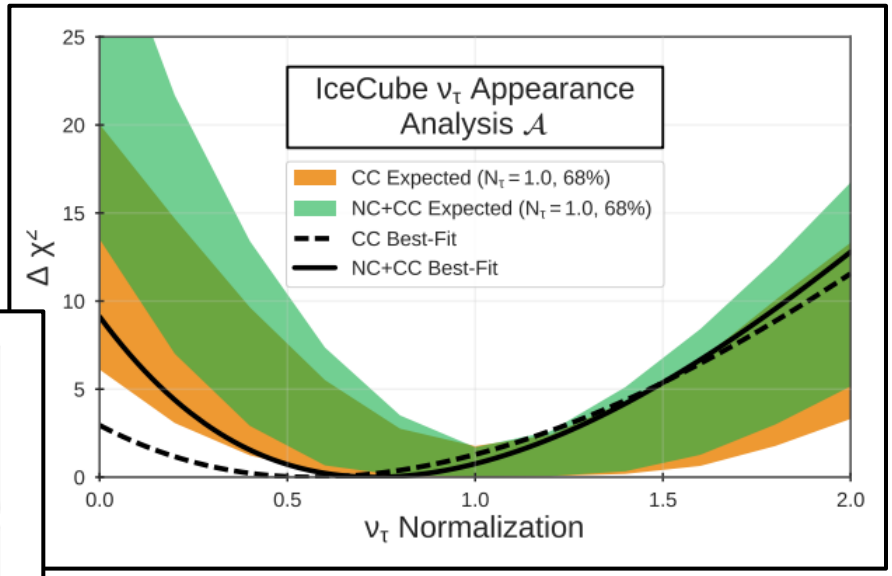

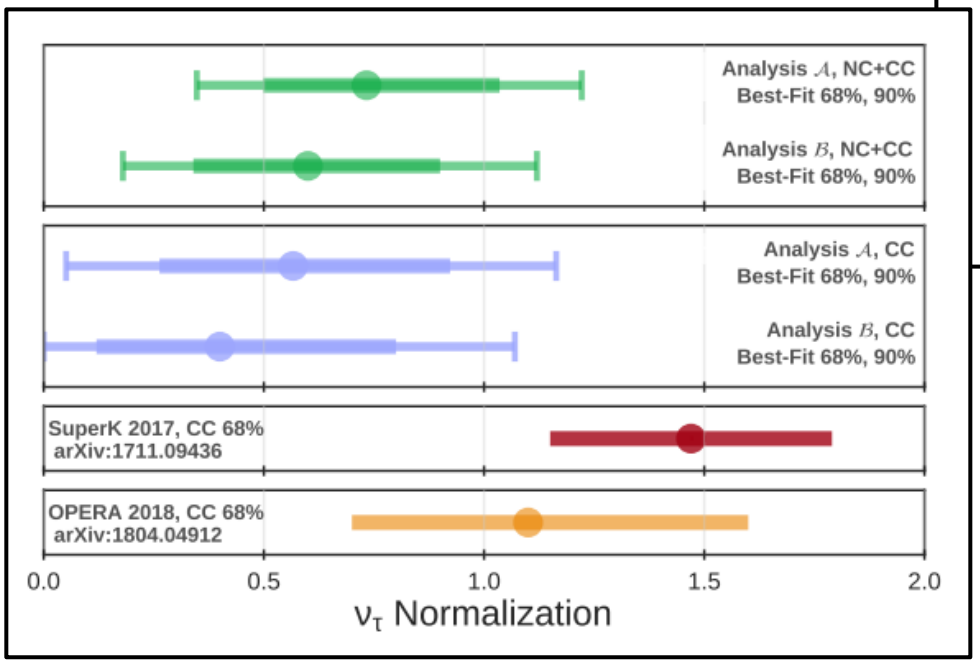

Do we see the number of tau neutrinos that we expect given the 3-flavor model?

Oscillation Analyses

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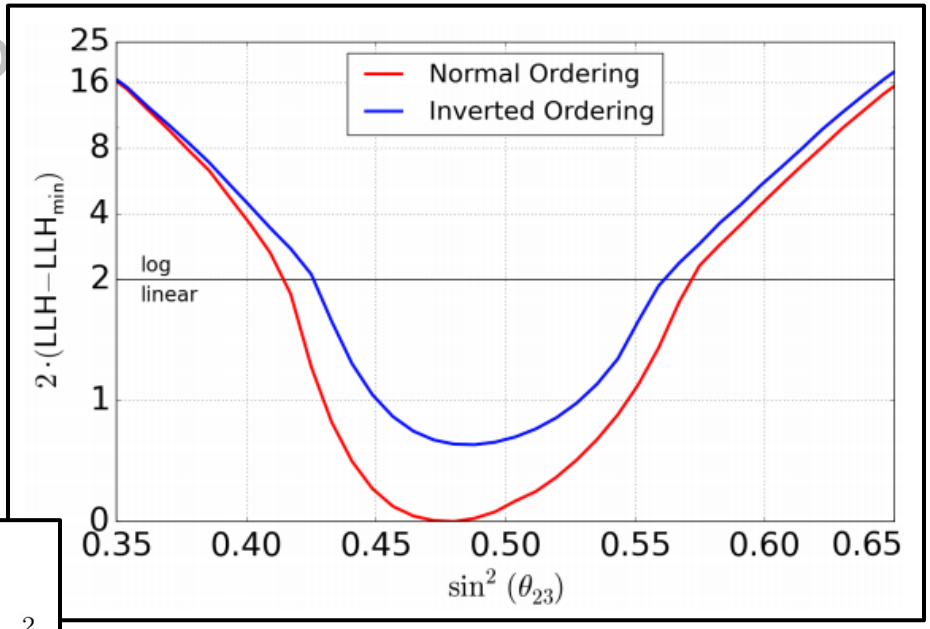
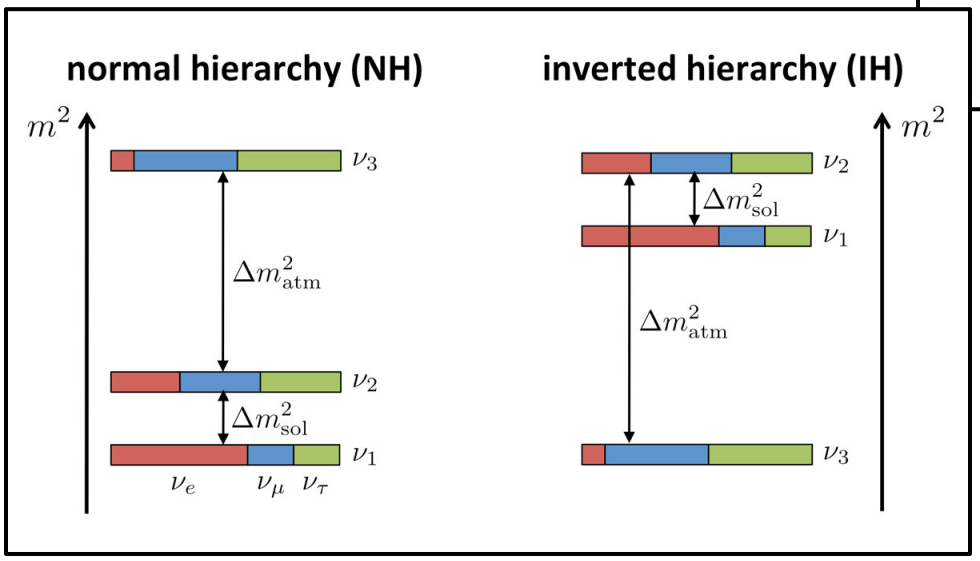
- Sterile neutrinos





Which neutrino state is the heaviest?

Oscillation Analyses

- Atmospheric oscillation parameters
- Tau neutrino appearance
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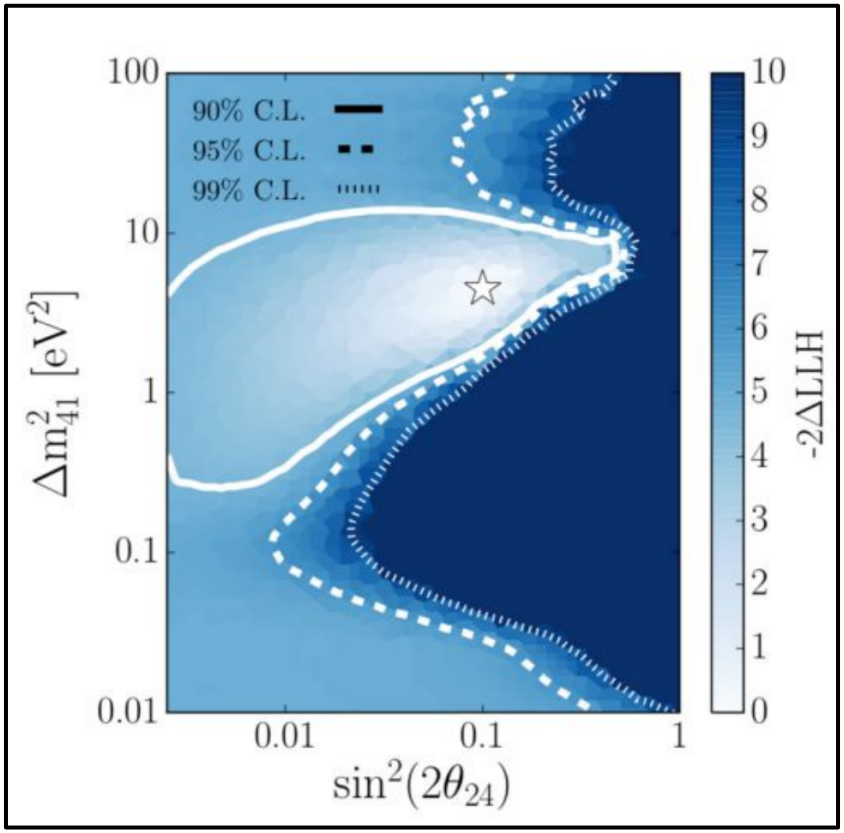
- Sterile neutrinos

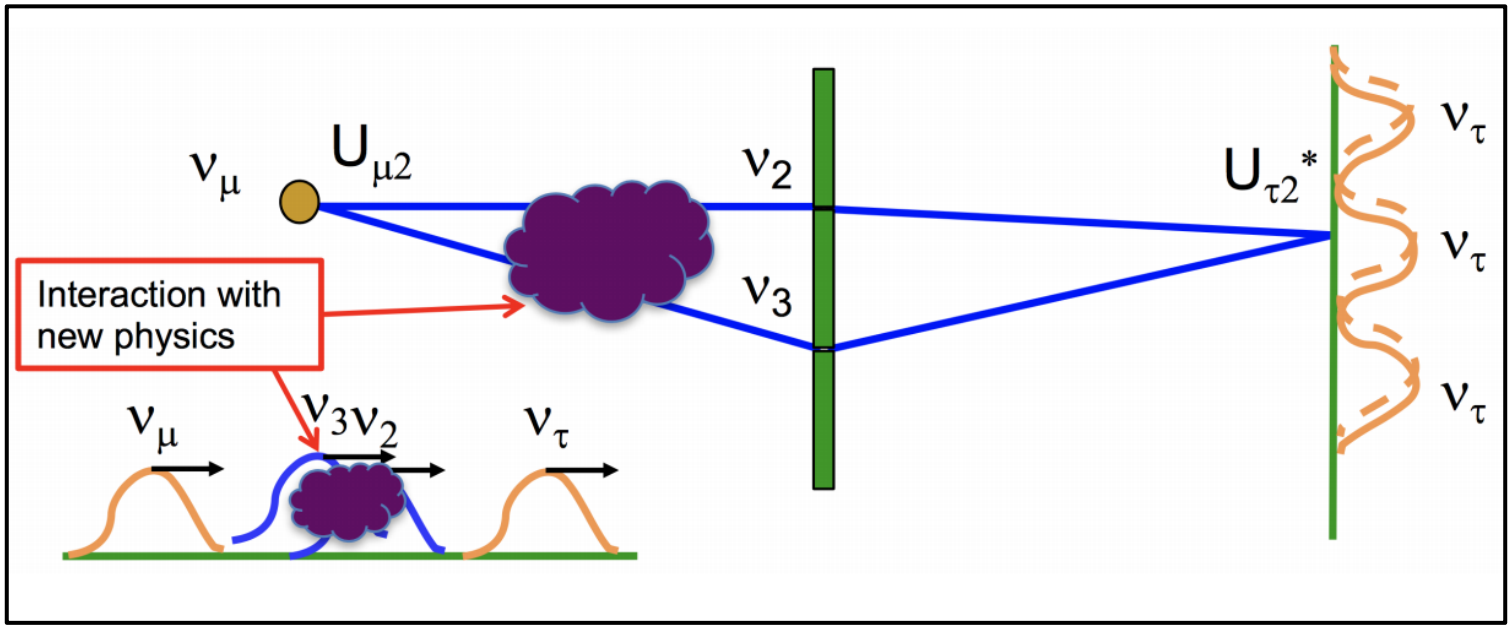
Do we see evidence for a 4th neutrino state and what would it's oscillation parameters be?



MEOWS analysis best fit point at ~1 eV

Beyond the Standard Model (BSM)

- The Standard Model with the 3-Flavor Model of Neutrino Oscillations is widely accepted as correct.
- What if there's some other new physics out there?



BSM Analyses

- Diffuse Dark Matter
- Dark Matter from the Galactic center
- Dark Matter from the Sun
- Magnetic Monopoles
- Sterile Neutrino Decay

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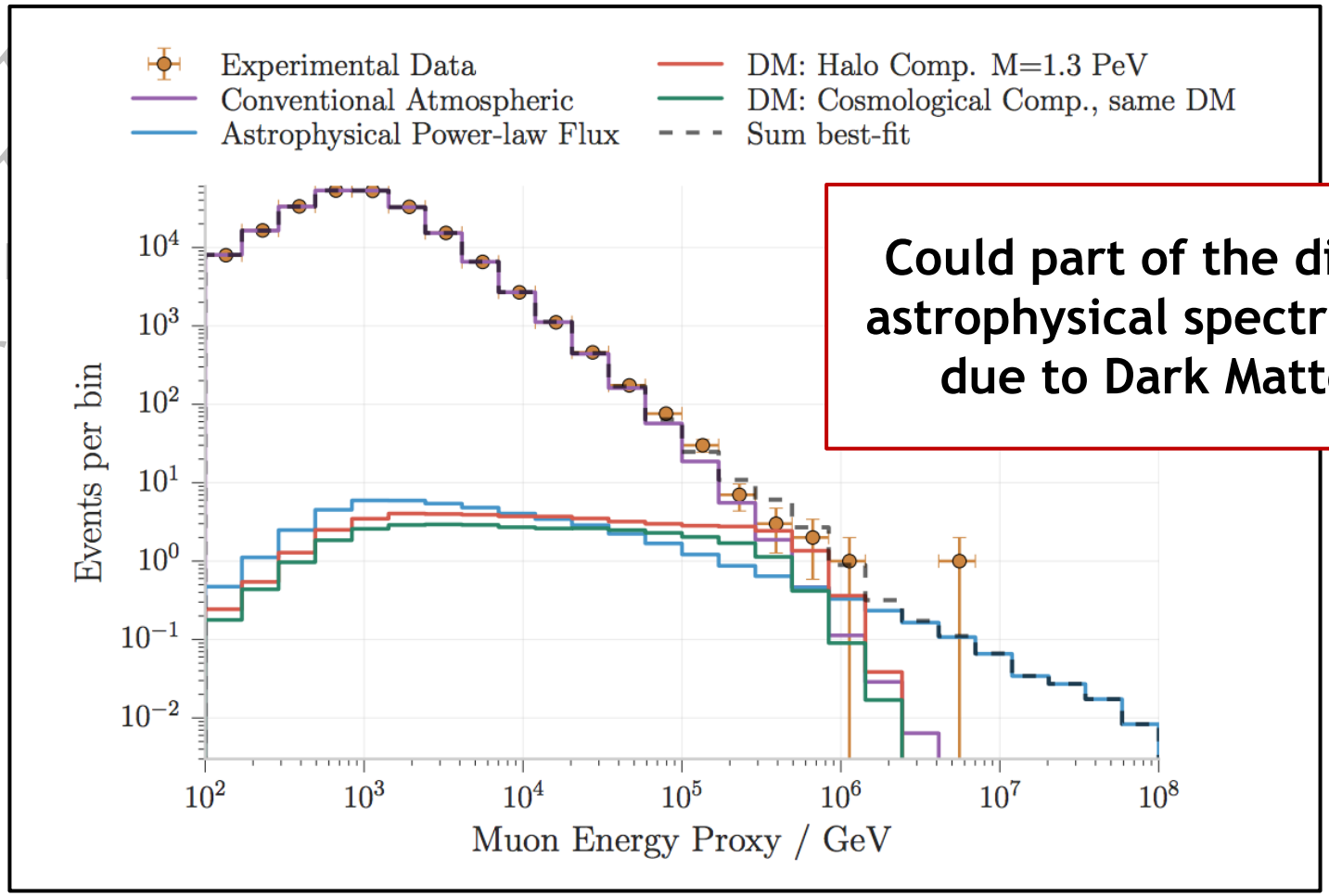

Could part of the diffuse astrophysical spectrum be due to Dark Matter?

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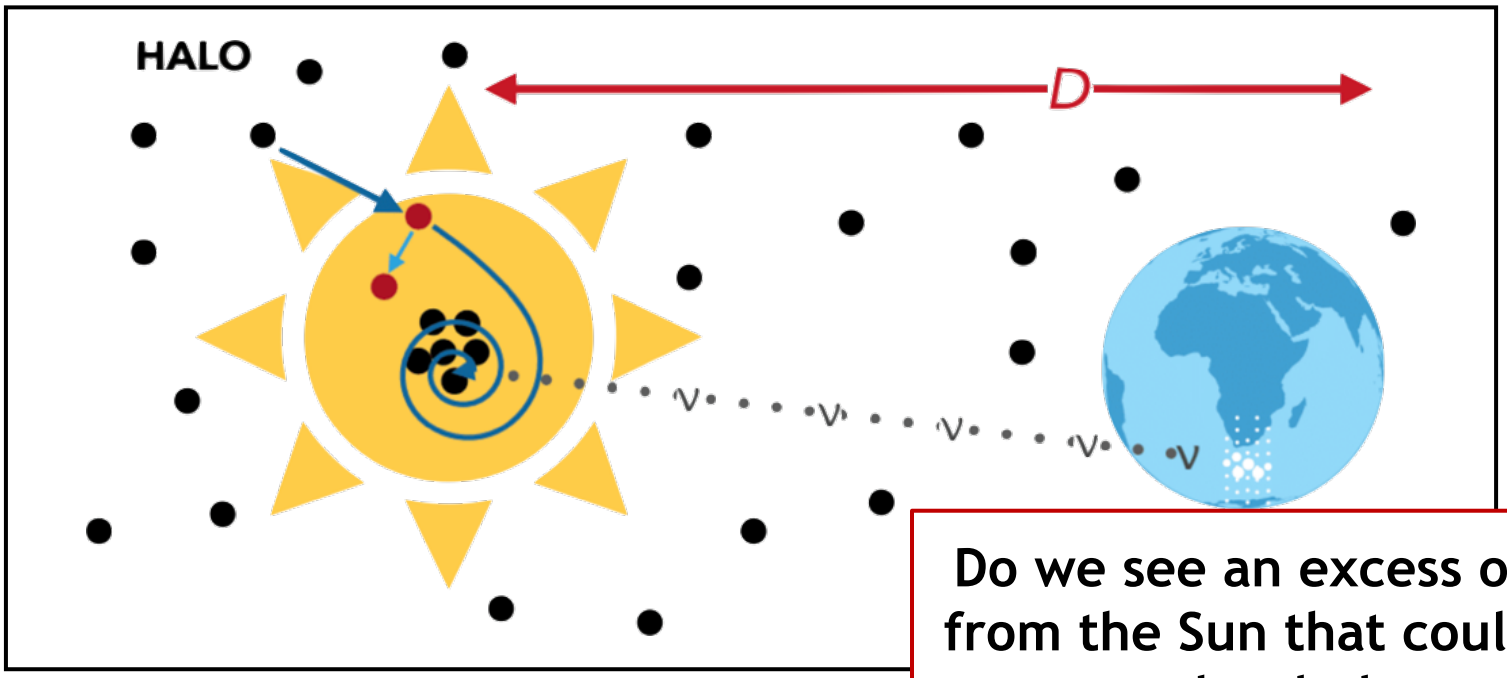
- Dark Matter from the Sun (Solar WIMP)



Do we see an excess of neutrinos from the Sun that could be due to solar dark matter?

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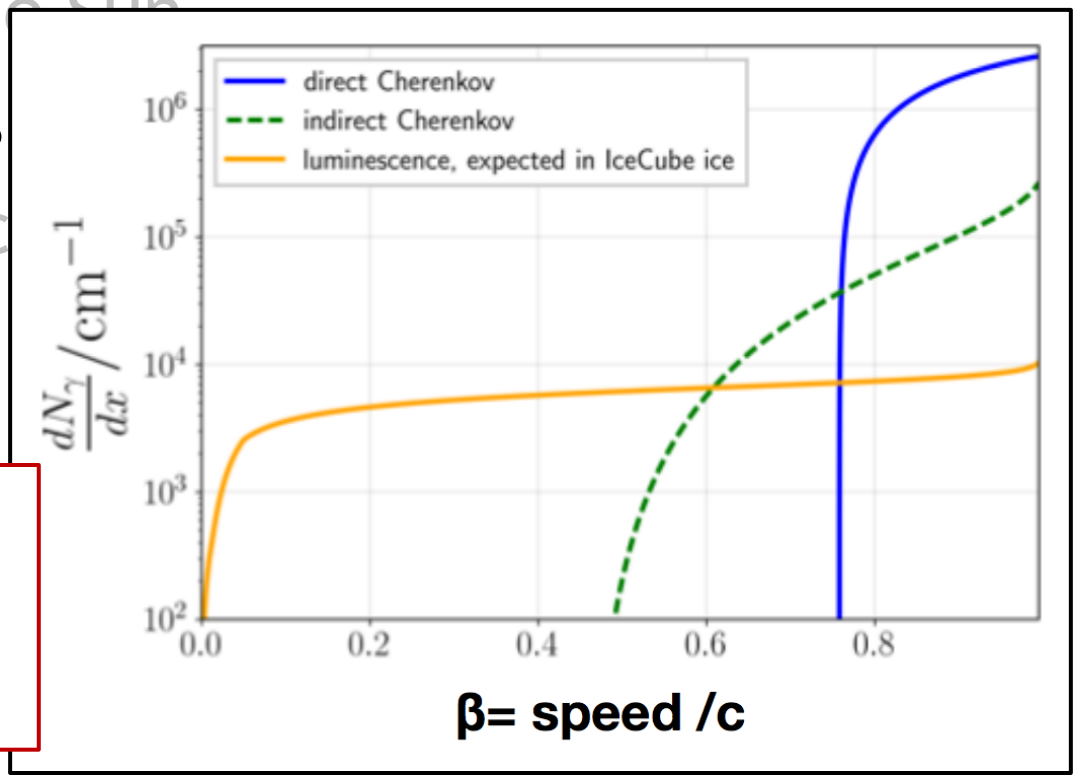

Is there evidence for slow non-relativistic monopoles in the detector?

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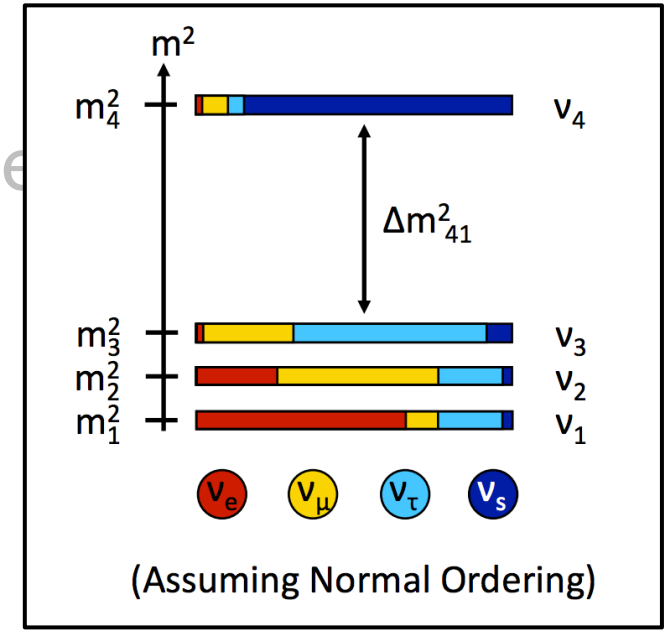
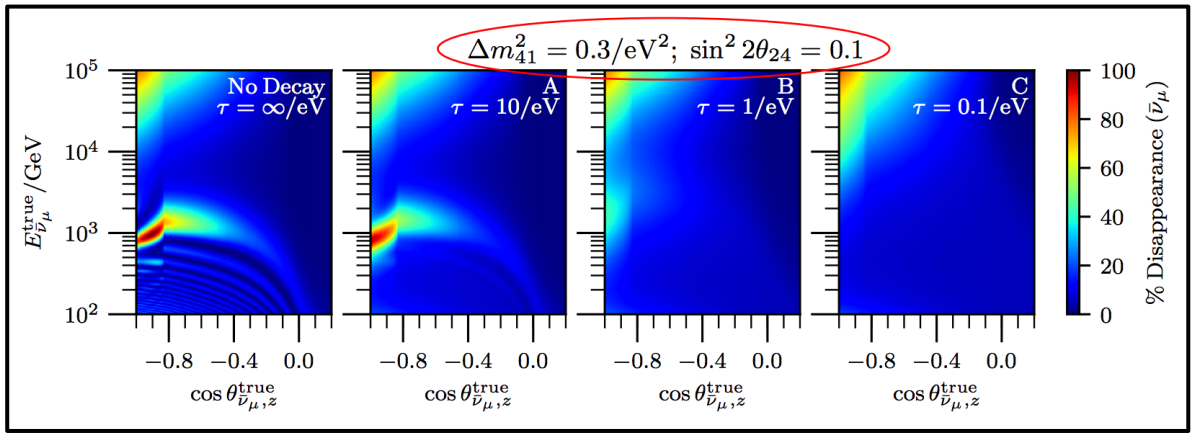
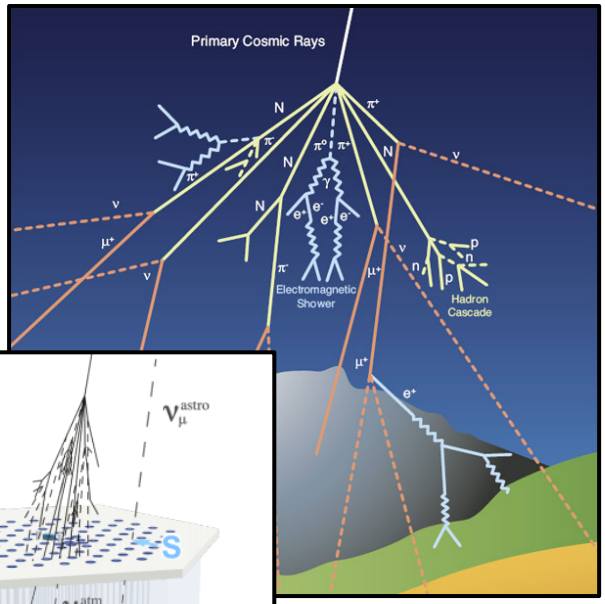


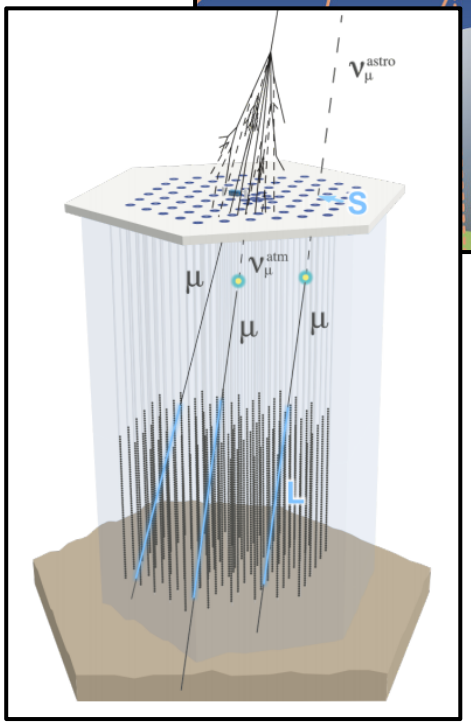


Do we see an excess or deficit of neutrinos that could be due to decaying sterile neutrinos?

Cosmic Ray Working Group

- When cosmic rays hit Earth's upper atmosphere, they produce showers of pions, kaons, muons, neutrinos, etc.
- There is a detector situated on top of IceCube called IceTop that is designed to look for these air showers.



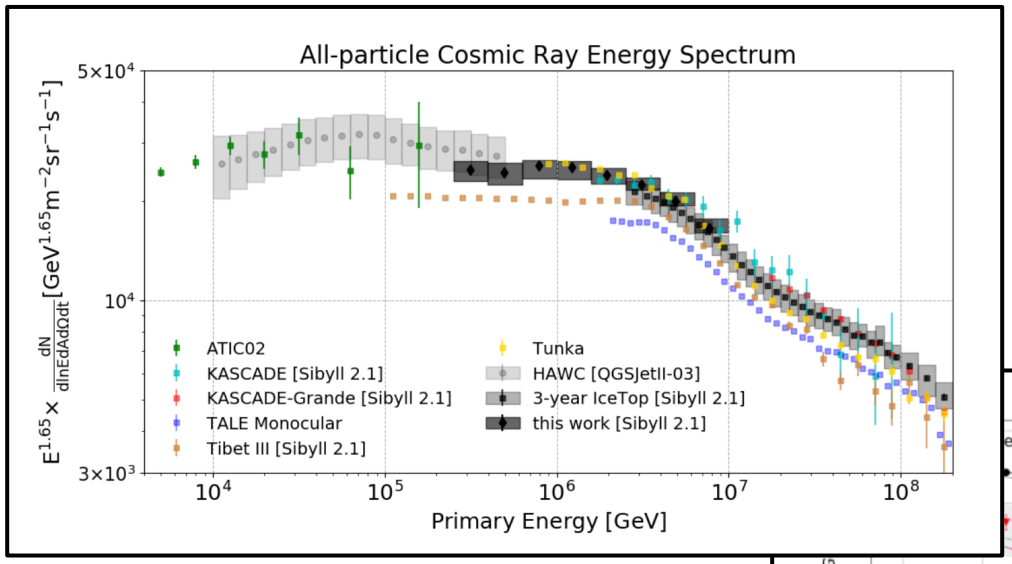


Cosmic Rays

- Cosmic ray spectrum & composition
- Cosmic ray anisotropy
- Sun/moon shadow
- Seasonal variations

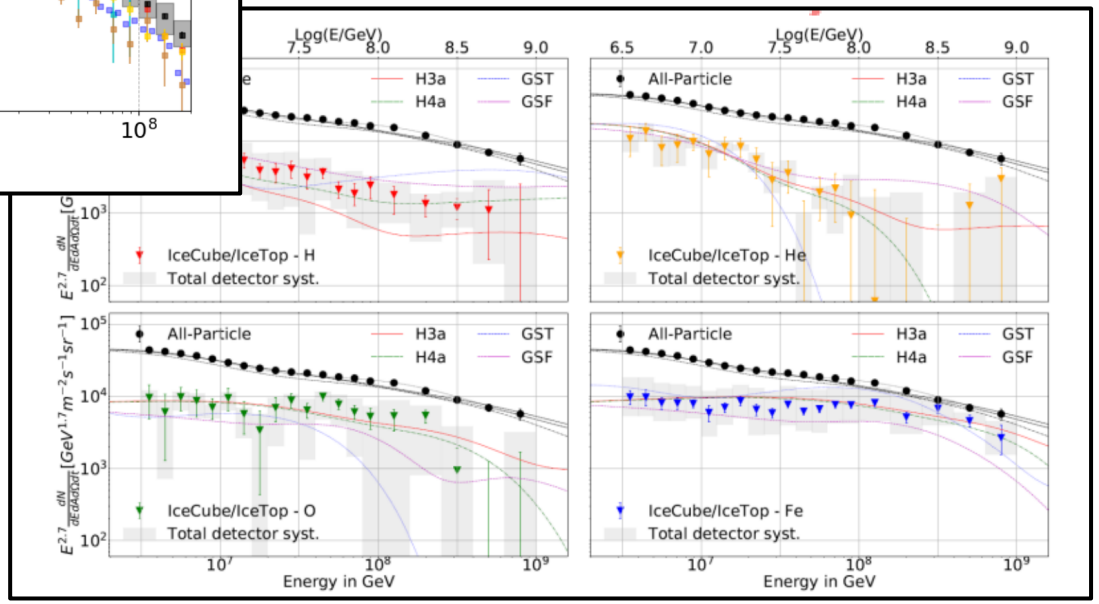
Cosmic Rays

- Cosmic ray spectrum & composition



Measuring Shape

Fraction of H, He, O, Fe in CR Spectrum



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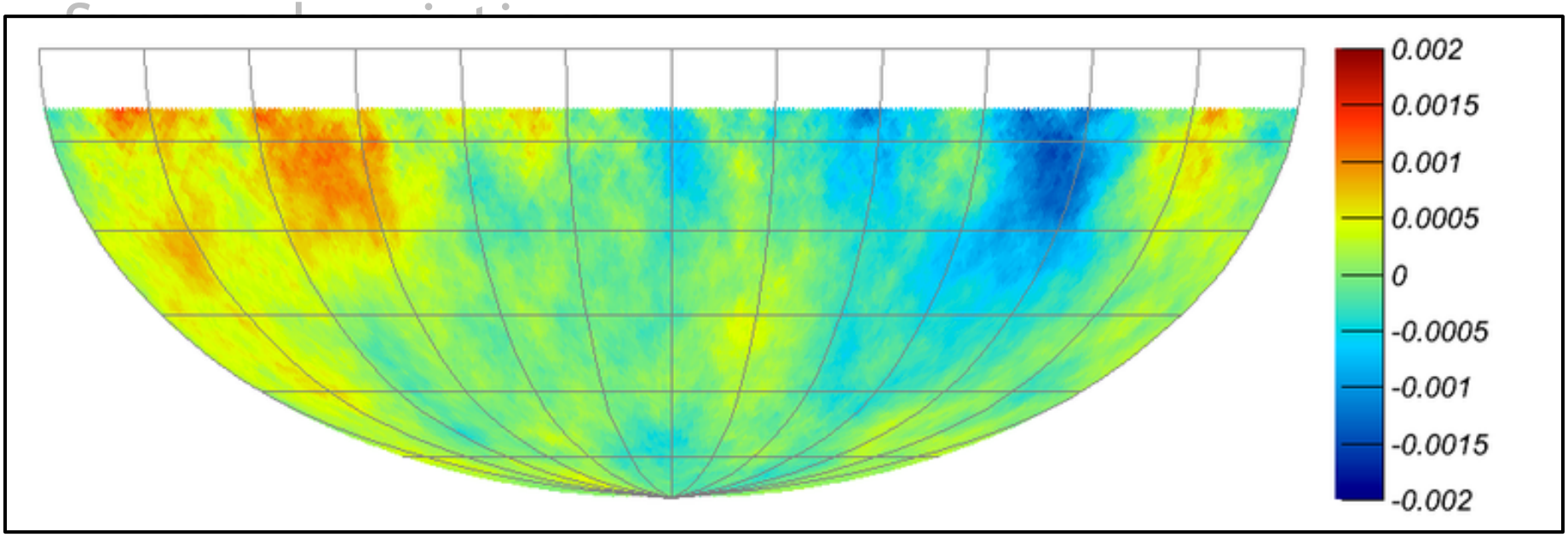

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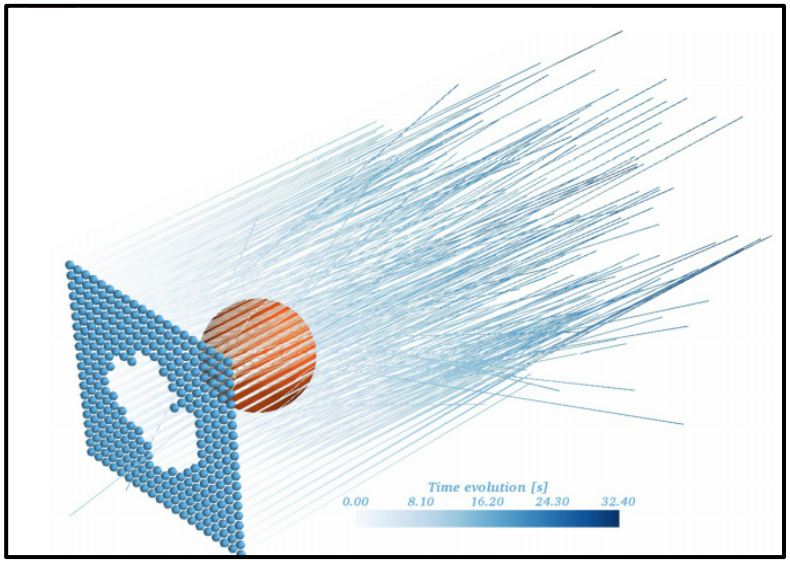

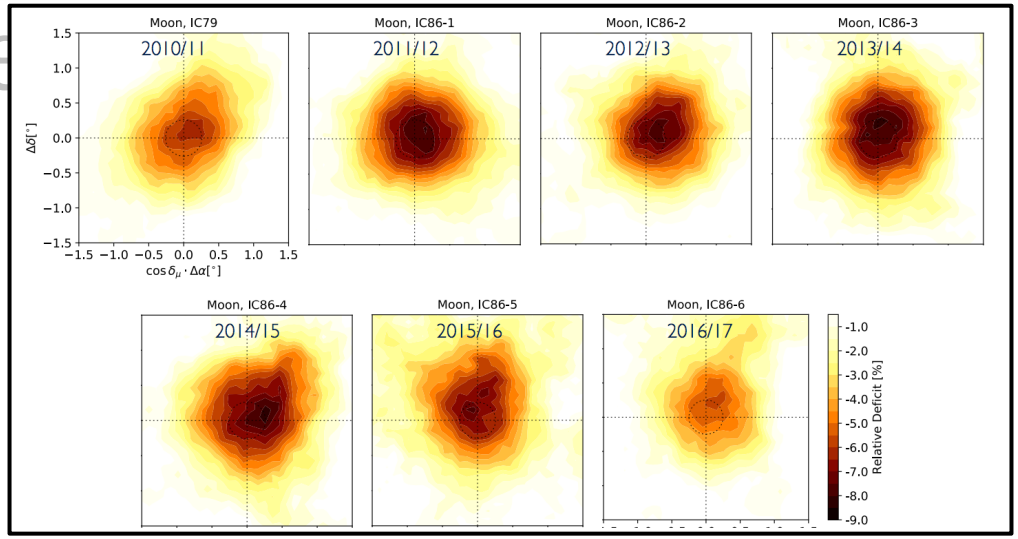

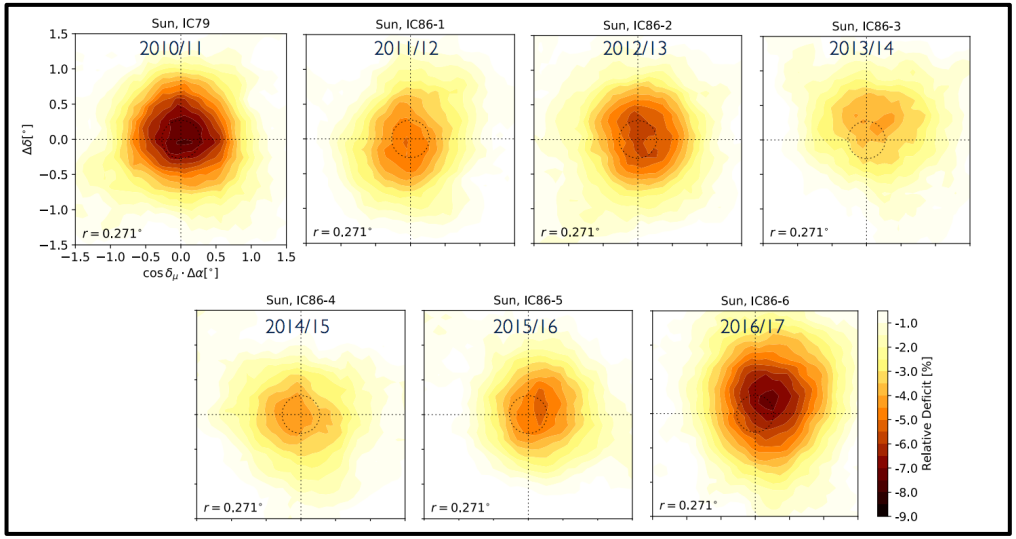

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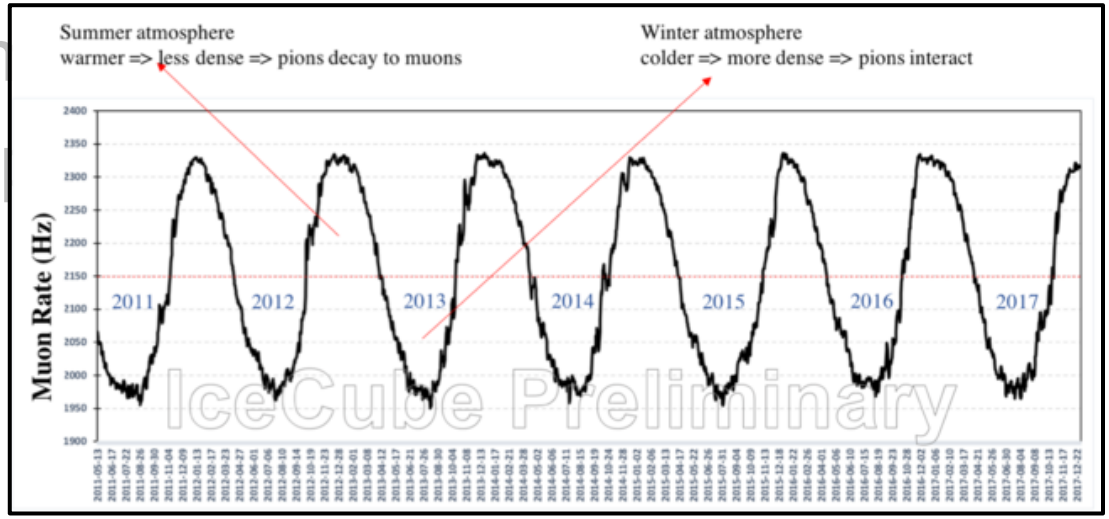
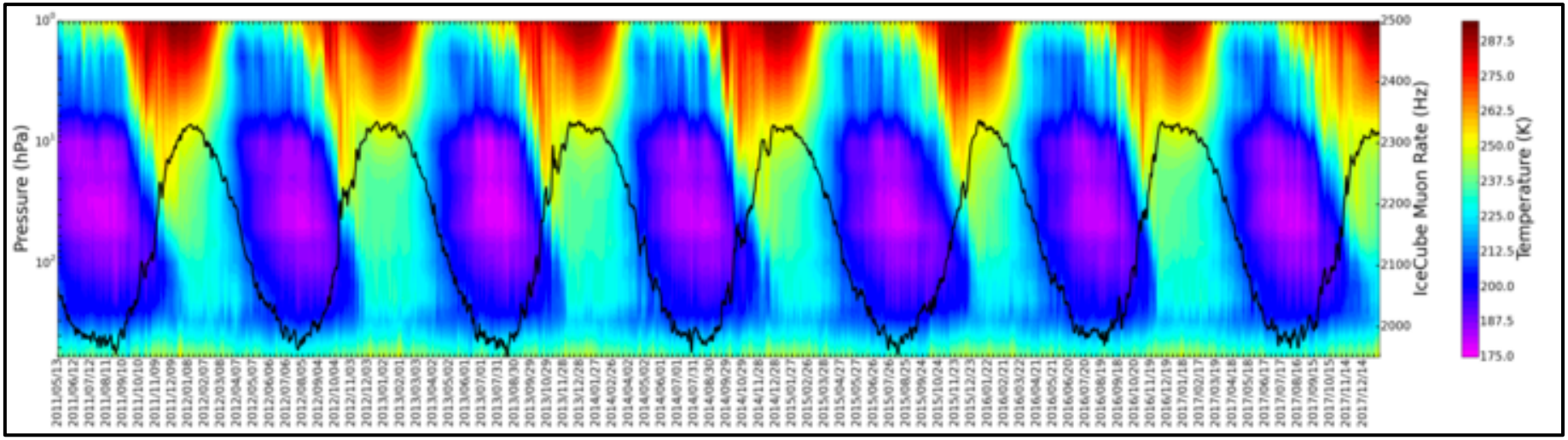
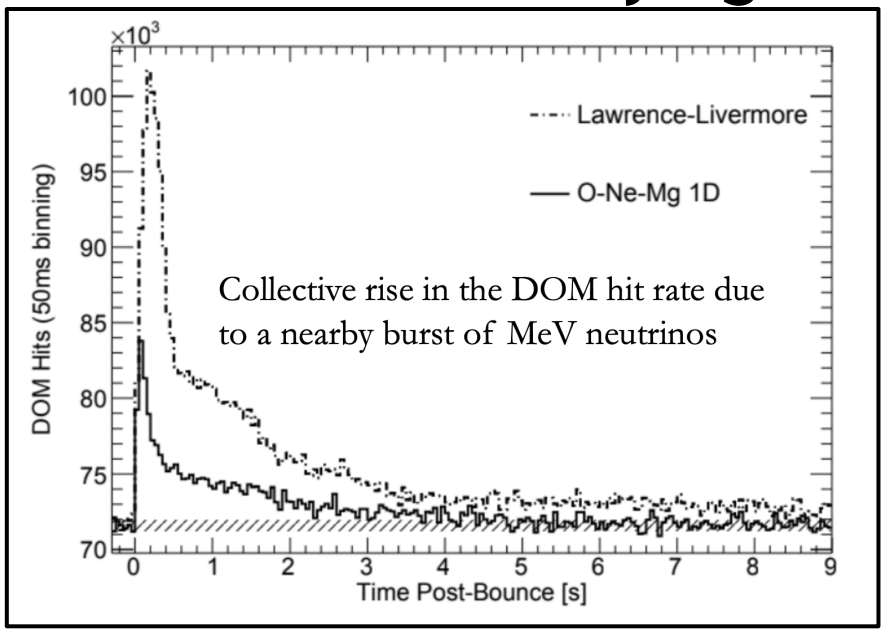




Supernova Working Group

- Supernova neutrinos are at a very low energy compared to what IceCube normally sees.
- Therefore in a supernova, we would expect an overall rise in the “noise” rate of the detector, rather than identifying many individual events



Supernova Early Warning System

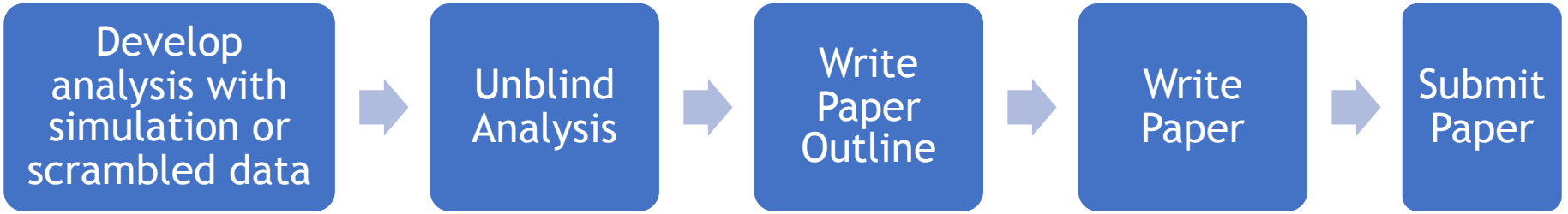
Outline

1. Summary of Existing Analyses in IceCube
2. How To Create your own Analysis in IceCube

Pipeline

How to Publish an IceCube Paper in 27 Steps:

https://docushare.icecube.wisc.edu/dsweb/Get/Document-85146/



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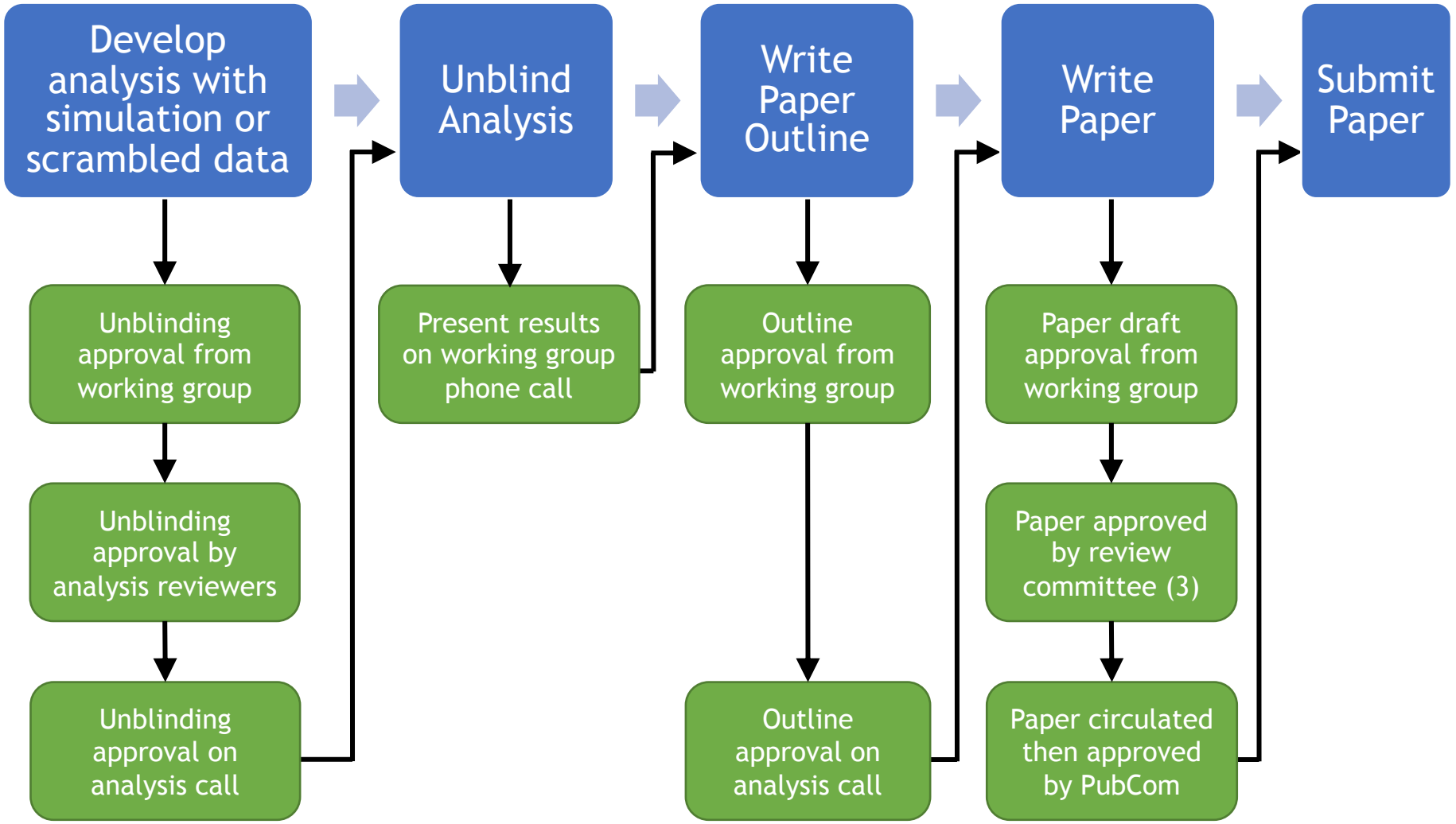

Thanks! Questions?