Analyses in IceCube

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IceCube Summer School 2025
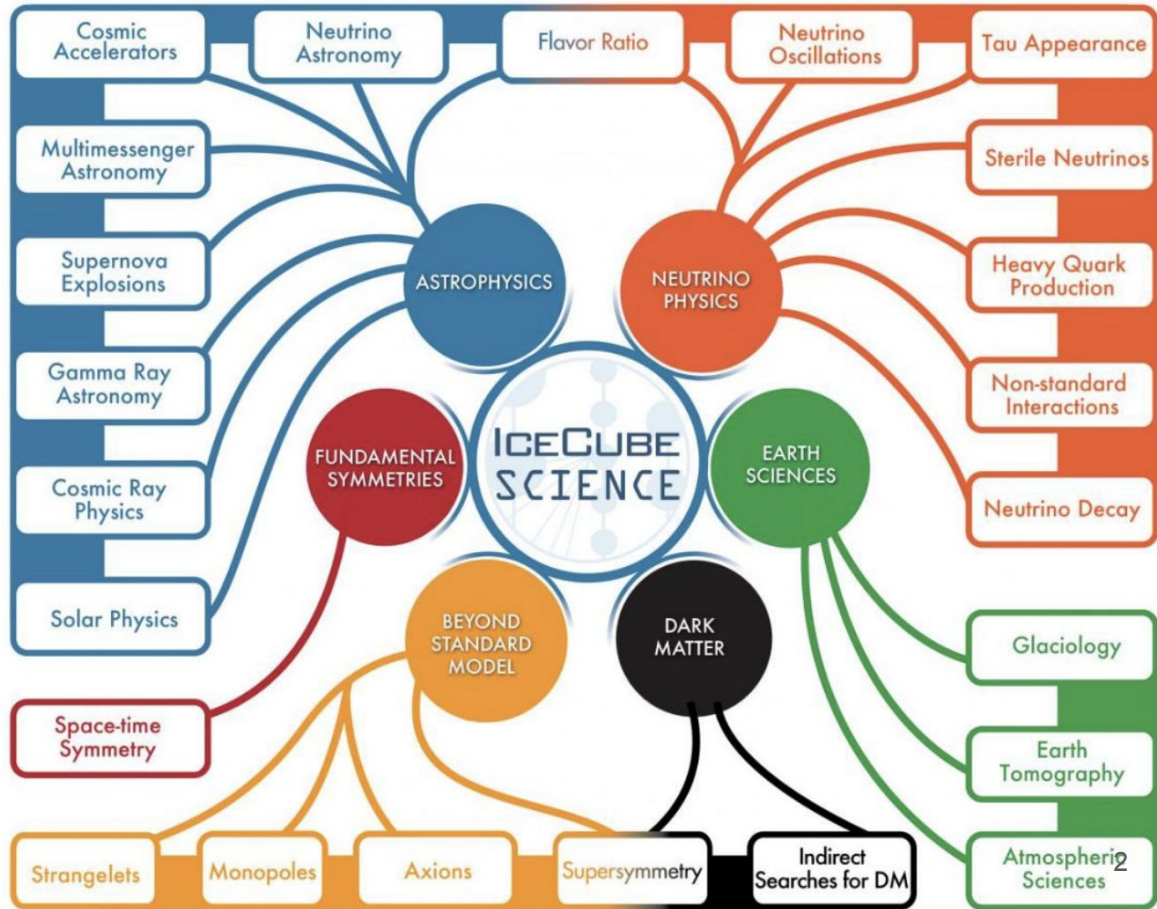
Science in IceCube

Organized by Working Groups (WG)

Each WG group covers one large physics goal

- Usually with some overlap

You will interact with your WG the most (in weekly or biweekly calls)

- Expert feedback
- Interaction with similar analyses

Details are discussed with subgroup of experts until it is ready for the next step

Working groups

Analysis		
Oscillations	(calls)	(mail)
Cosmic rays	(calls)	(mail)
Diffuse/Atmospheric ν	(calls)	(mail)
Low Energy Astrophysics	(calls)	(mail)
Beyond the Standard Model	(calls)	(mail)
Neutrino Sources	(calls)	(mail)

Technical Working Groups		
Reconstruction	(calls)	(mail)
Realtime	(calls)	(mail)
Calibration	(calls)	(mail)
Software	(calls)	(mail)

Detector & Simulation	
Simulation	(mail)
Simulation Production	

R&D projects		
IceCube-Gen2		
Acoustic	(calls)	(mail)
AURA		
RASTA	(calls)	(mail)
PINGU		
Proton Decay		
Simulation		
IceCube Extensions		(mail)
IceAct	(calls)	

| Legacy working groups		
Neutrino Oscillations	(calls)	(mail)
Low-energy ν	(calls)	(mail)
Extreme energies	(calls)	(mail)
Tau & Composites	(calls)	(mail)
Exotic particles	(calls)	(mail)
WIMPs/Dark Matter	(calls)	(mail)
Transients	(calls)	(mail)
Point sources	(calls)	(mail)
Cascades/Taus	(calls)	(mail)
Muons	(calls)	(mail)
Verification		(mail)
Supernova	(calls)	(mail)

Each WG has

- A wiki page
  - Summaries of current & past analyses
  - Dedicated calls page where regular calls are coordinated
- Usually 2 WG leads and a technical lead

3

WG summaries and
some existing analyses in each WG

Neutrino Sources WG

● Main goal: to pinpoint the sources of astrophysical neutrinos

● Check for "hot spot" (clusters of neutrinos)

● Can have clusters in both time and space

● Analyses are testing new hypotheses for correlating IceCube's neutrino data with possible sources

● WG has several tools to do these searches (Skylab, csky, FIRESONG, etc.)
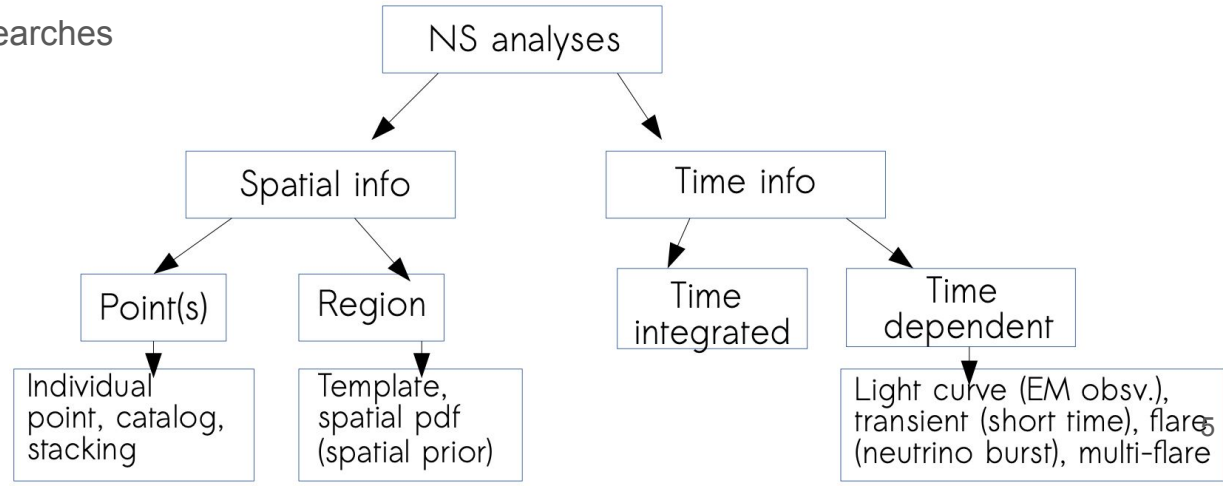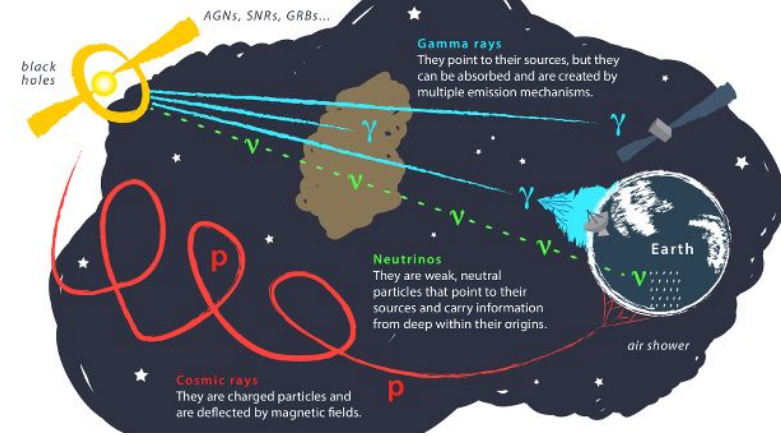
Neutrino Sources Analyses

All-sky scan

- Look for hotspots in the sky
- 10-yr time integrated analysis
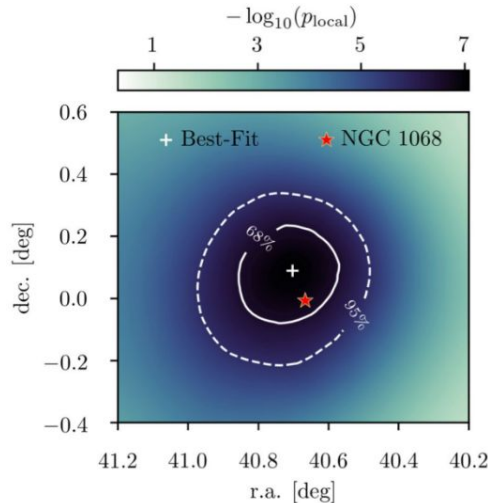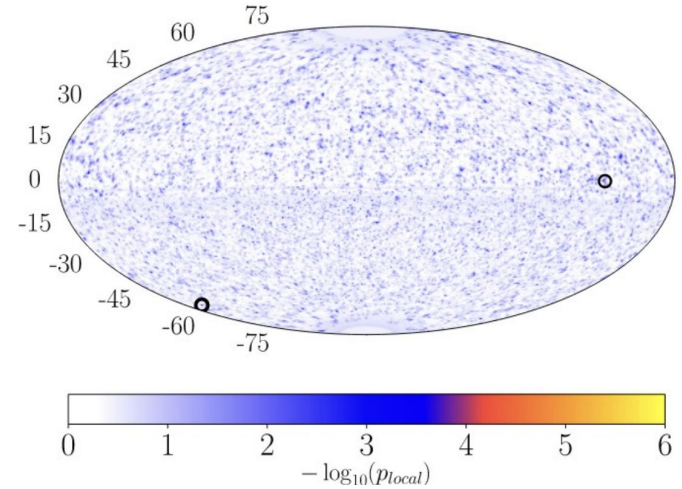
NGC 1068

Spatial excess around NGC 1068

Evidence for Neutrino... NGC 1068, https://arxiv.org/abs/2211.09972
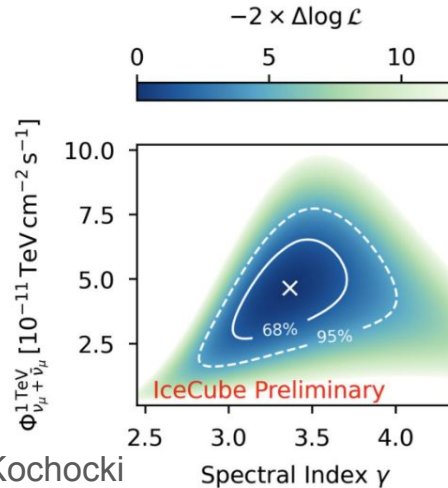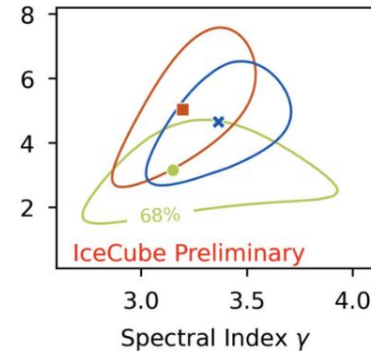
Shape and intensity of neutrino energy spectrum

Recent 'Improved PS-Tracks' analysis result

Credit: Alina Kochocki

Neutrino Sources Analyses

Observation of high-energy neutrinos from the Galactic plane

- A diffuse galactic neutrino emission is expected from cosmic-ray interactions on gas within the galaxy
- Galactic point sources may also contribute to this excess:
  - X-ray binaries
  - Supernova remnants
  - Pulsar wind nebulae
  - Dense, gaseous regions
  - Magnetars…

Credit: Alina Kochocki

https://arxiv.org/pdf/2307.04427
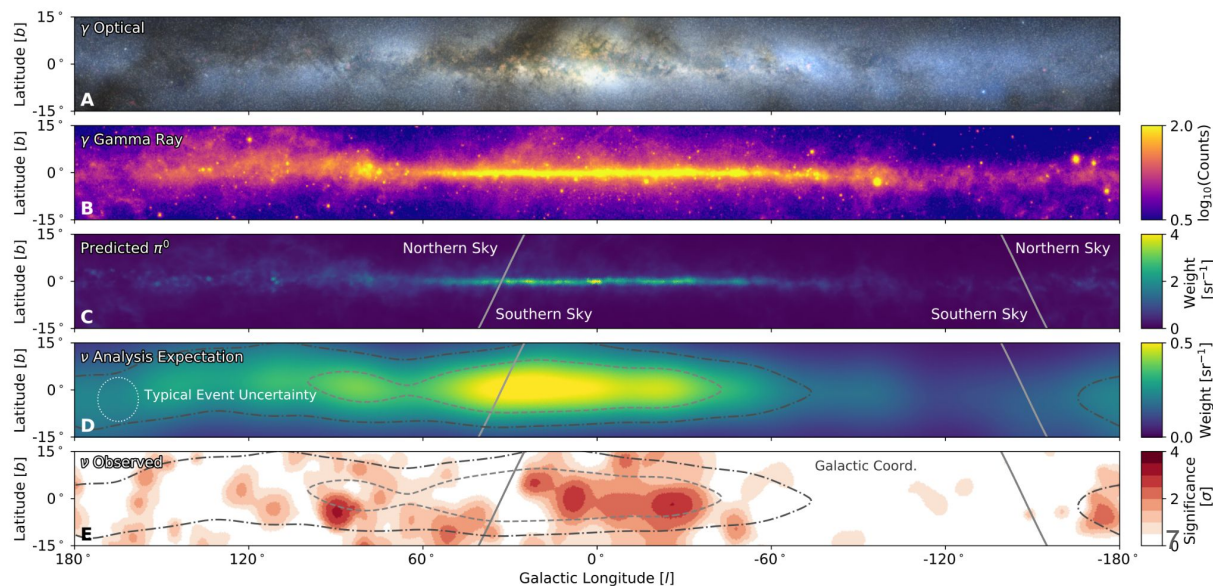
Realtime WG

- Technical WG, works closely with nu-sources WG

- Builds tools for rapid identification of neutrino sources

- Sends alerts to the astro community

- Also receives alerts from the astro community and quickly searches for neutrinos in coincidence

- Analyses are presented in the nu-sources WG

Three main strategies:

Alert generation, broadcasting and curation

Follow-up of external triggers

Self-triggers
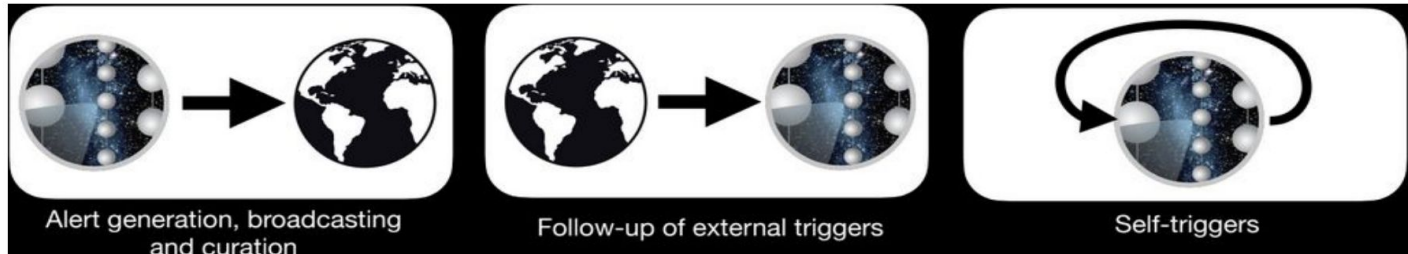
Realtime Analyses

TXS Follow-up

- Alert from IceCube followed up by several observatories
- Magic found a correlated flare of gamma rays, Fermi detects a flaring blazar: TXS 0506+056

IceCube Alerts 2011 - 2020

Skymap of all neutrino alerts
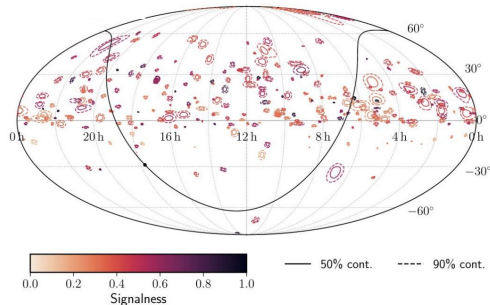
Follow-up detections of IC170922 based on public telegrams

IceCube — September 22
Swift — September 26
Fermi, ASAS-SN — September 28
SALT, Kapteyn — October 7
MAGIC — October 4
Liverpool, AGILE — September 29
Kanata, NuSTAR — October 12
VLA — October 17
Subaru — October 25
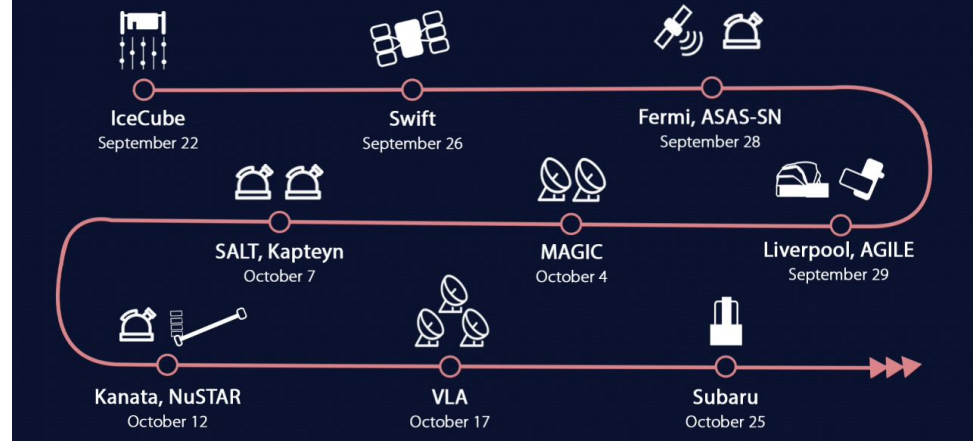
Diffuse WG

- Works on the diffuse (from all directions) flux of neutrinos observed on Earth
- Tries to measure the atmospheric and astrophysical spectrum of neutrinos in the energy range of TeV to EeV
- Also several particle-physics measurements such as
  - Cross-sections
  - nu/nu_bar ratio
  - Inelasticity
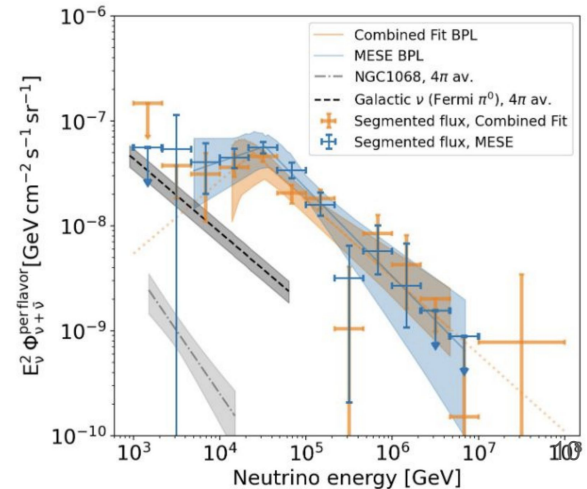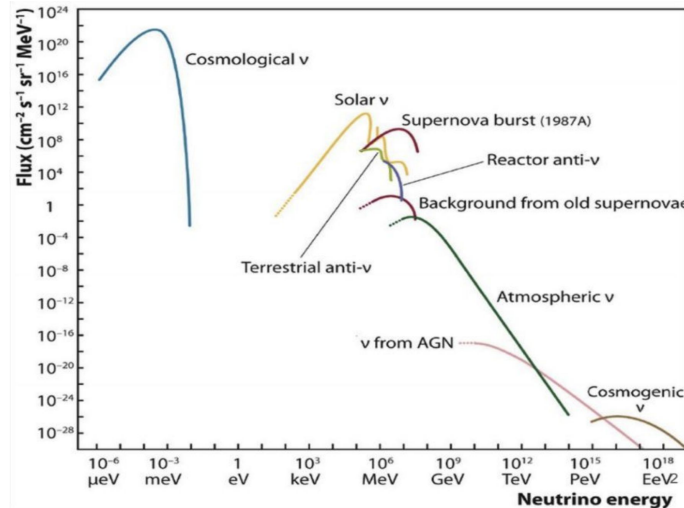
Diffuse Analyses

Diffuse Astrophysical Neutrino Flux
- Flux measurement ([9.5 Year Northern Track](#))
- Astrophysical Neutrino Flavor Ratio ([Above 35 TeV in IceCube](#))

Atmospheric Neutrinos
- Measurement of atmospheric neutrino flux
- Seasonal Variations (Also Cosmic Ray WG)

Cosmogenic Neutrino Flux
- [Limit on Extremely-High-Energy Neutrino Flux](#)

Particle Physics
- [Glashow Resonance](#) $\bar{\nu}_e + e^- \rightarrow W^- \rightarrow X$
- [Inelasticity](#): Ratio of hadronic cascade to total neutrino energy
- [Cross-Section](#): Neutrino-nucleon interaction cross-section measurement

Diffuse Analyses Technical Side

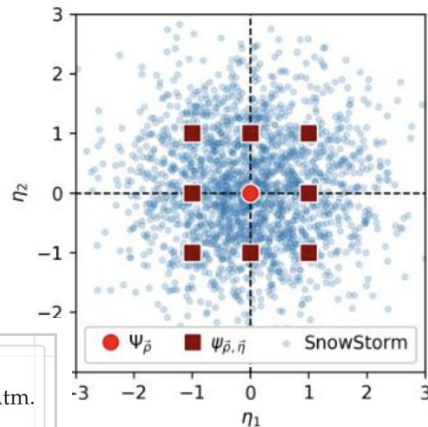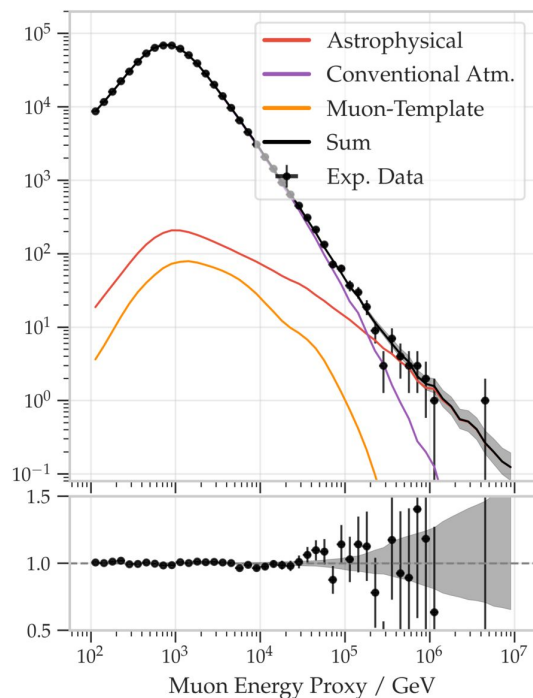**Heavily relies on simulation**

Your observed data needs to (to a certain degree) match your expectation from simulation

More rigorous treatment of systematics

Snowstorm MC: Continuously varied detector systematics rather than discrete

Solid understanding of backgrounds

Atmospheric neutrinos/muons

Cosmic Ray WG

- Focuses on analyses with cosmic-ray air showers
- When cosmic rays hit Earth's atmosphere, a particle air shower is created
- Uses IceTop (cherenkov tanks) + in-ice detectors
- Works on CR energy spectrum, CR composition, CR anisotropy, sun+moon shadow, seasonal variations (of atmospheric neutrinos)
- Uses MCEq, CORSIKA, FLUKA and GEANT4
- Also deals with surface enhancements (Surface array WG) with scintillators, radio, and IceACT

primary cosmic ray

hadrons

electromagnetic component

surface

GeV muons

2835 m.a.s.l

TeV muons

1450 m

in-ice

2450 m
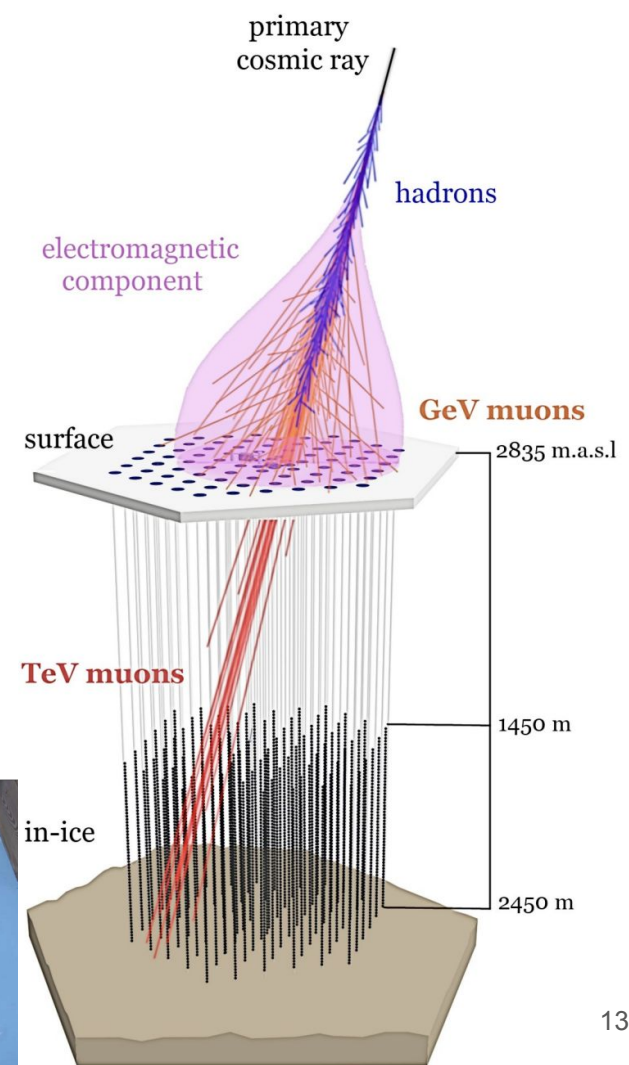
Cosmic Ray Analyses

Seasonal variations

Summer → warm → less dense → pions decay

Winter → colder → more dense → pions interact
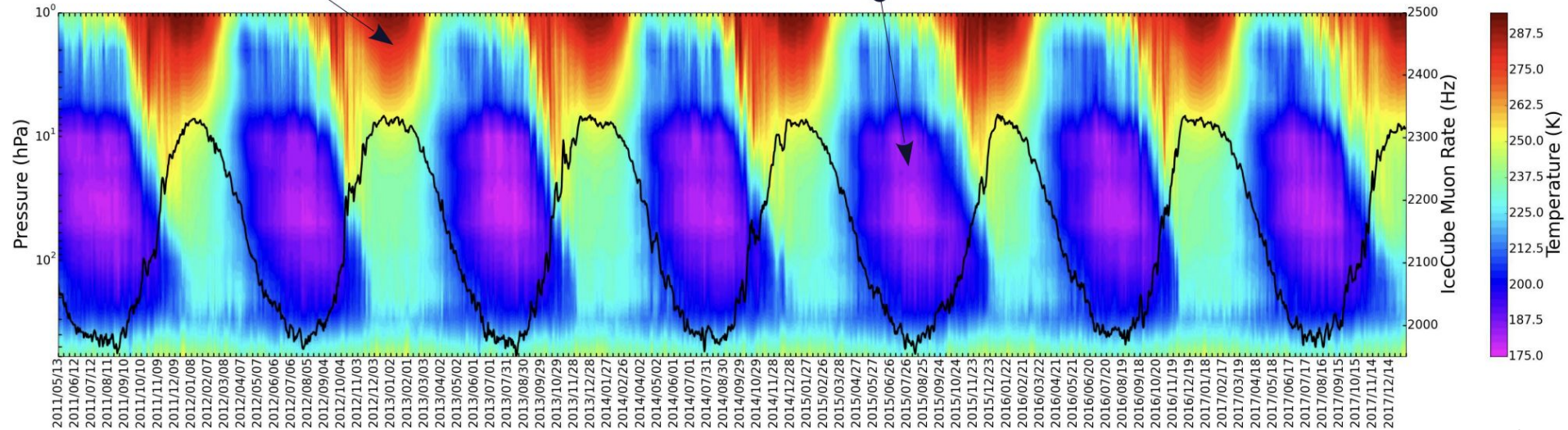
Cosmic Ray + Diffuse Analysis (IceTop as veto)

IceTop activity used to differentiate downgoing

Atmospheric events (w/ IceTop hits)

Astrophysical events (w/o IceTop hits)   Y. Lyu, PoS-ICRC2021-1137

Event 134701/49508272-0
Time 2020-11-15 16:01:42 UT
Duration 33434.4 ns

Event 134327/10548129-0
Time 2020-07-28 08:17:51 UT
Duration 896965.5 ns

IceTop Inefficiency from Data, 2-hits veto

$\log_{10}$(Muon Energy Proxy) [GeV]

Distance to Center of IceTop [m]

15
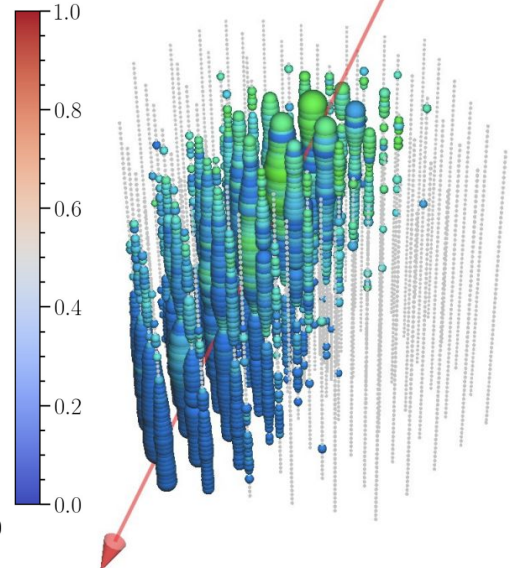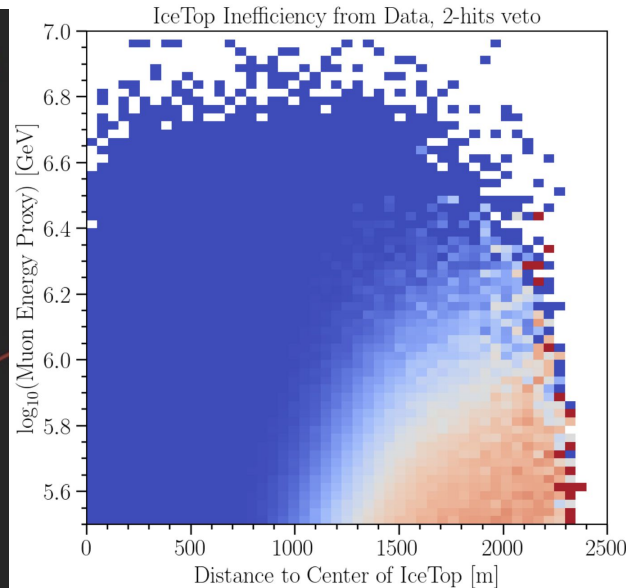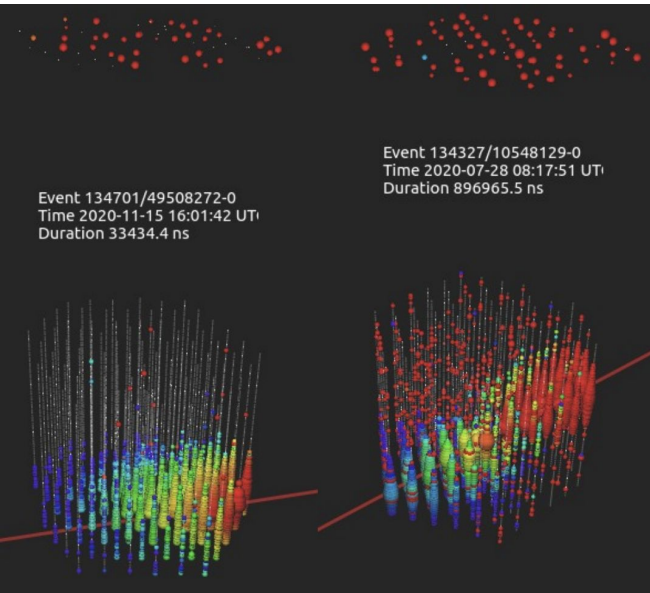
BSM WG

- Focuses on new physics that could be out there (The 3-flavor model of neutrino oscillations is widely accepted, but what if that is not the whole story?)
- Interactions with new physics can cause distortions in the spectrum and flavor of both astrophysical and atmospheric neutrinos

xkcd
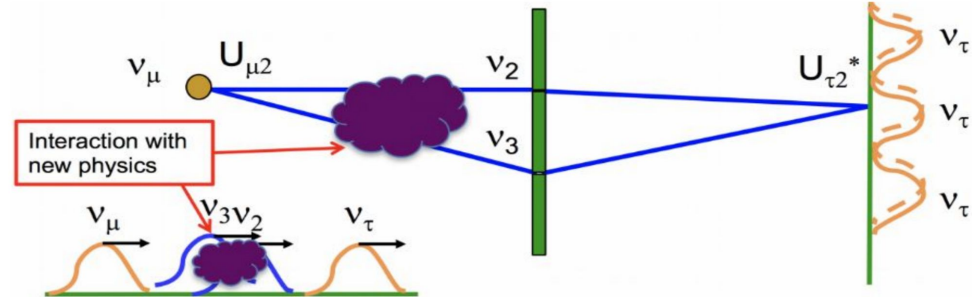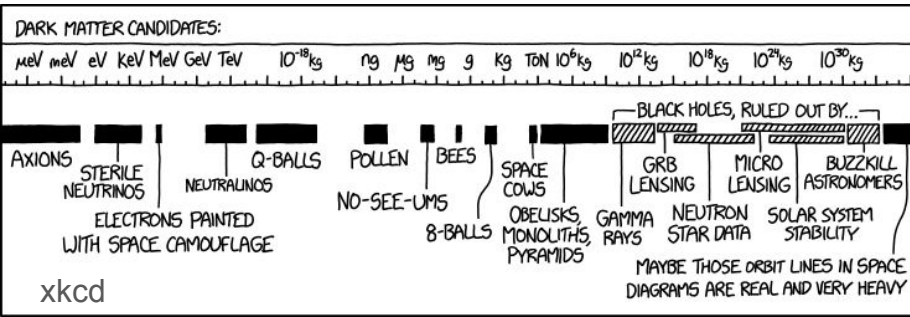
BSM Analyses

Sterile-neutrinos (w/ decay): Do we see a signal consistent with that from a 4th neutrino flavor? Using MEOWS

Magnetic monopoles: Is there evidence for slow non-relativistic monopoles?

Diffuse DM: could part of the diffuse spectrum be due to DM?

Solar/Earth DM: Do we see an excess of neutrinos from the Sun/center of the Earth that could be from DM?

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

Exotics
Q-balls
Monopoles
Anomalous charged particles
...

Neutrinos
Sterile Neutrinos
Oscillations
Flavor ratio
Trident Production
...

Dark Matter
Earth WIMPs
Galactic Center
Solar Dark Matter
...
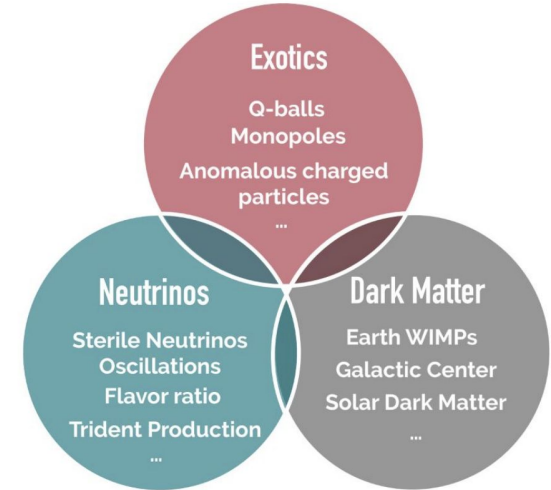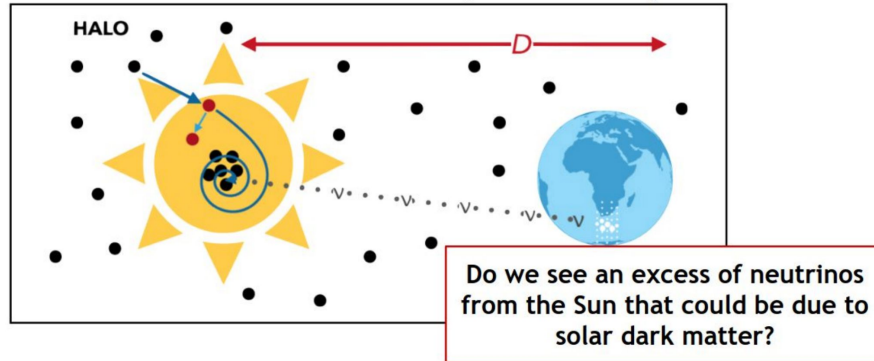
BSM Analyses

Flavor composition of high-energy astrophys
effects of neutrino decay

Source flavor compositions

Various decay scenarios

Oscillations WG

Oscillation probabilities for an initial electron neutrino
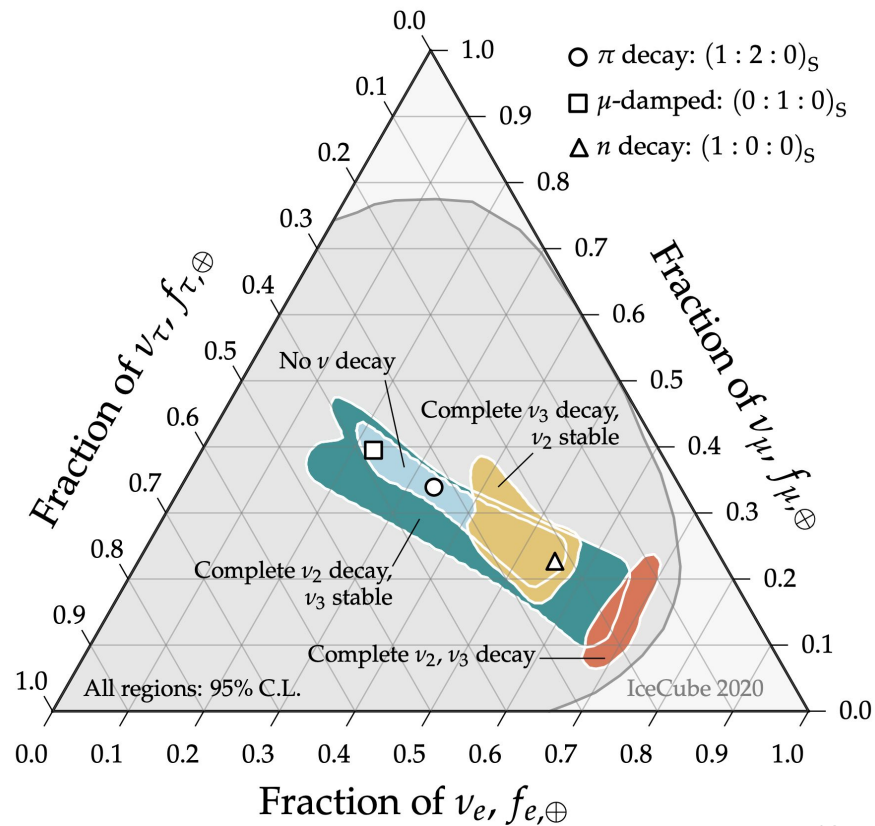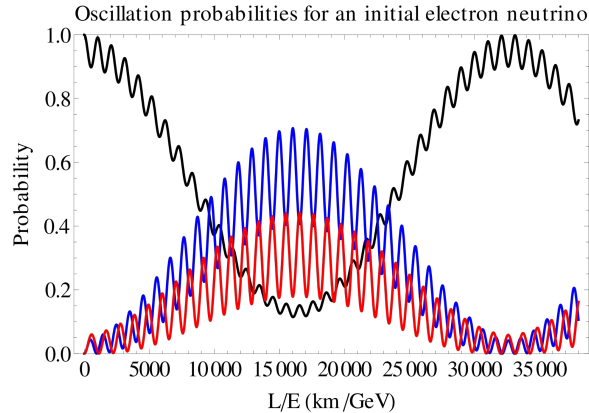
- Focus on neutrinos changing flavor as they Cross the Earth
- Oscillation probability

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

- Oscillation parameters, tau neutrino appearance, neutrino mass ordering, non-standard interactions, sterile neutrinos

Oscillation Analyses

OscNext: Data selection using DeepCore
- Two samples: "high-stats" sample and "verification" sample (subset of golden events)
- Analysis using OscNext:
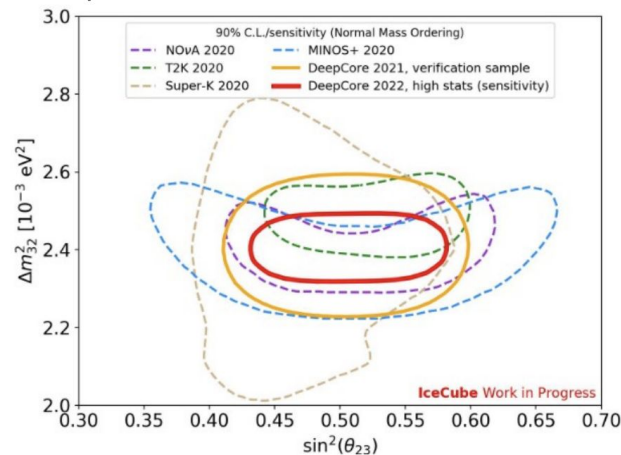 - NuMu disappearance, NuTau appearance
  - Non standard neutrino interactions (NSI)
  - Neutrino mass ordering

MEOWS
- Sterile neutrino search
- NSI analysis
- Earth density profile
- Galactic Plane flavor ratio

FLERCNN
- New reconstruction tool (fast) for low energies

Low Energy WG

Searches for **MeV neutrinos** from supernovae & other transients:

- Sensitivity to astrophysics and fundamental neutrino physics.
- Multi-messenger warnings as part of the SNEWS network.
- Lots of modeling tools (SNEWPY, ASTERIA, SNOwGLoBES, sntools, …)

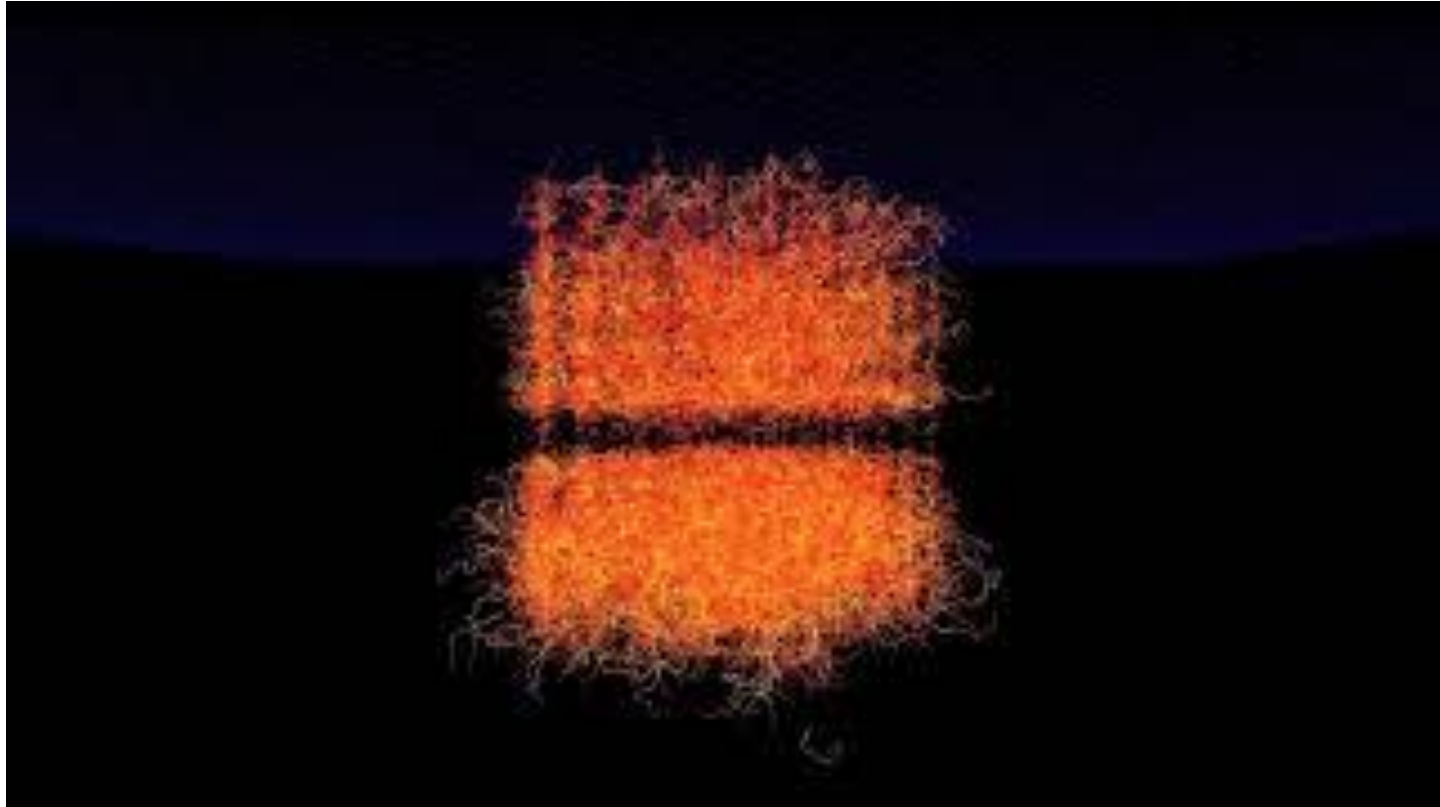Constraining **GeV neutrino emission** from energetic transients:

- Sensitivity to a huge range of astrophysical neutrino production mechanisms.
- Background reduction challenge: interesting task in computer vision!

Significant overlap with **Neutrino Sources** & **BSM** Working Groups.

Credit: Segev BenZvi

Low energy events

Not your typical neutrino event

Technical WGs

Calibration WG

- Deals with calibration of the detector
- Ice properties with LED flashers, using muon tracks, Sweden camera studies
- DOM efficiency, IceTop calibration

Reconstruction WG

- Many of the recos are machine learning/deep learning based

Software WG

- IceTray, detector response, other simulation tools

Physics analyses depend heavily on these technical WGs

Where everything comes together

- **Analysis Call** on Thursdays at 9:00 am CST (~1 hour)
  - Most nearly-finished analyses are presented to the whole collaboration here
- High-level description of the analyses
- Good for learning about other analyses in IceCube
- Also sometimes have WG summaries
- Collaboration-wide announcements, discussions and decisions happen here

https://wiki.icecube.wisc.edu/index.php/Analysis_calls_2025

How to Do Your Own Analysis in IceCube

How to publish an IceCube paper
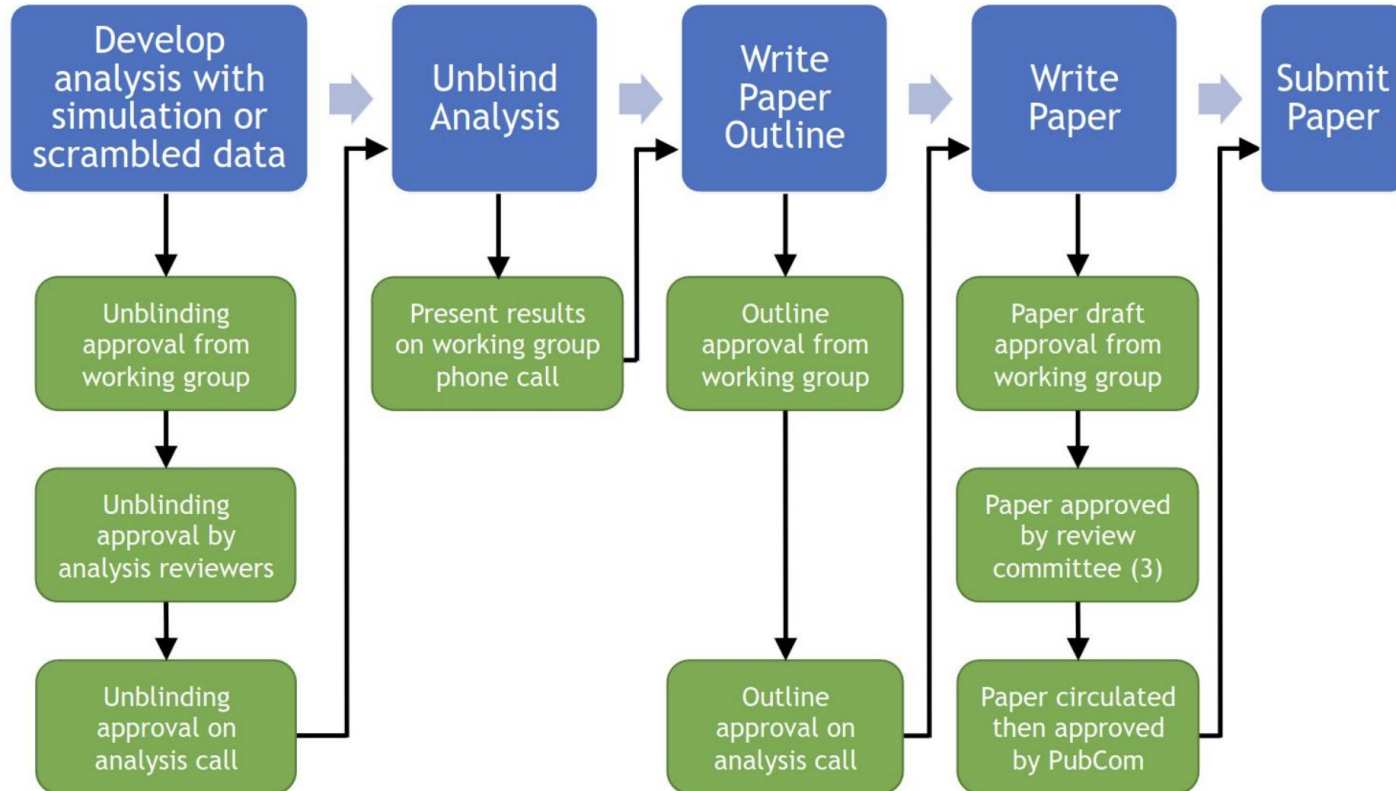
How to present at an international conference

- Presentations (talks/posters) are given on behalf of the IceCube collaboration.
- **You MUST obtain permission from the speakers committee to make an IceCube presentation at an international conference.**
- You do not need speakers committee approval to give:
  - a presentation at a national physics/astronomy/similar meeting (e.g. APS, Deutsche Physikalische Gesellschaft), a school, a colloquium or a seminar
  - an overview presentation that discuss more than one experiment and uses only published IceCube results

After the permission

- An abstract must be circulated
- The presentation must be available for review
  - If your presentation includes new material, follow the procedures for obtaining permission

More details: https://wiki.icecube.wisc.edu/index.php/Speakers_Committee

Thank you for your attention
Questions?