Analyses in IceCube

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*Content borrowed from previous year's talks + other talks of collaborators

Outline

- Working Groups in IceCube

- Existing Analyses in IceCube

- How to Do Your Own Analysis in IceCube

Working Groups in IceCube

Working Groups

What is a working group (WG)?
- Several studies are done within IceCube
- Analysis-based, technical, planning, ..
- For convenience divide into topical subgroups called "working groups"
- Majority of the details are discussed in these working groups
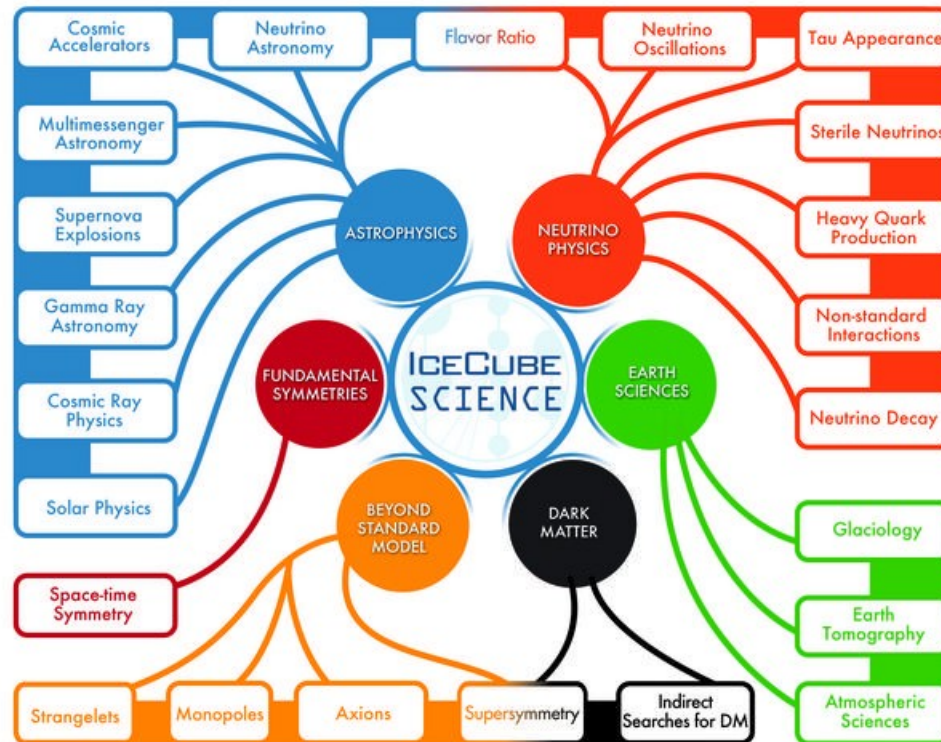
Working Groups

Working groups

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

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

Detector & Simulation	
Simulation	(mail)
Simulation Production	

R&D projects		
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)

Link to all working groups available here:
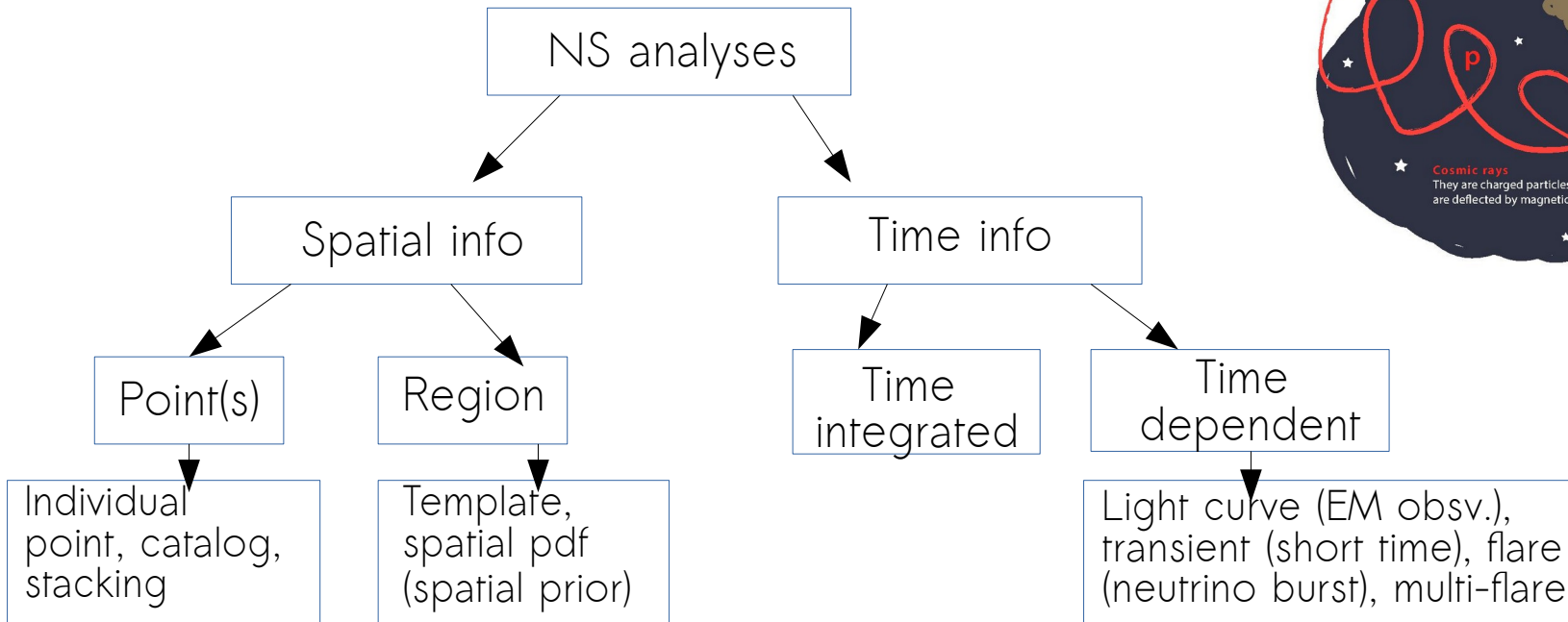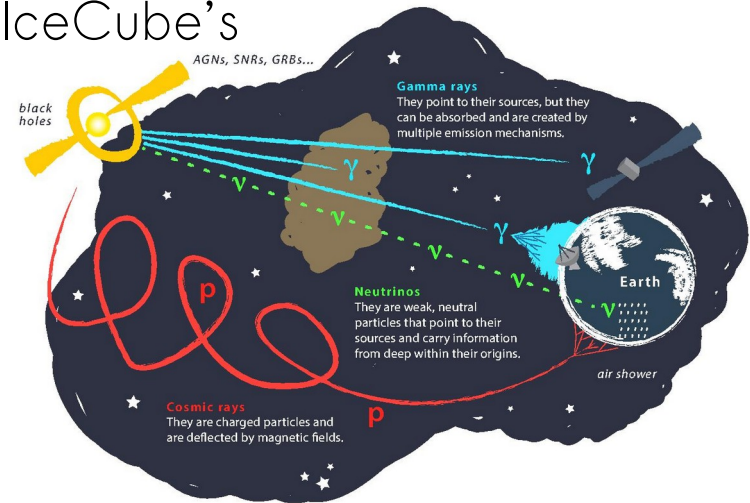https://wiki.icecube.wisc.edu/index.php/Main_Page

Existing Analyses in IceCube

Selected analyses in each working group[*]

*Due to limited time, I will not cover everything. Apologies if I missed out your favourite analysis!

Neutrino Sources Working Group

- Main goal: to find the sources of astrophysical neutrinos
- Check for "hot spot" (clusters of neutrinos)
- Can have clusters in both time and space
- Analyses testing new hypotheses for correlating IceCube's neutrino data with possible sources
- WG has several tools to do these searches


```
                        NS analyses
                       /           \
               Spatial info      Time info
                /       \         /        \
          Point(s)    Region   Time        Time
                               integrated   dependent
```

| Individual point, catalog, stacking | Template, spatial pdf (spatial prior) | | Light curve (EM obsv.), transient (short time), flare (neutrino burst), multi-flare |

Neutrino Sources Analyses

All-sky scan

- Look for hotspots in the sky
- 10-yr time integrated anaysis

Hotspot near
NGC 1068
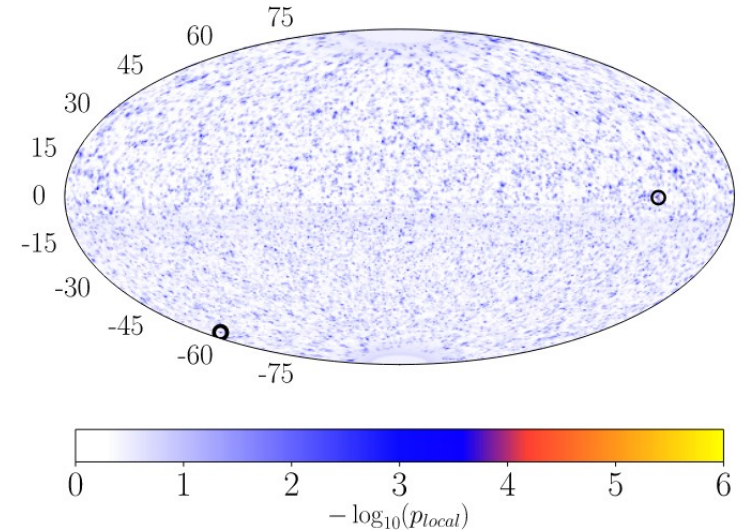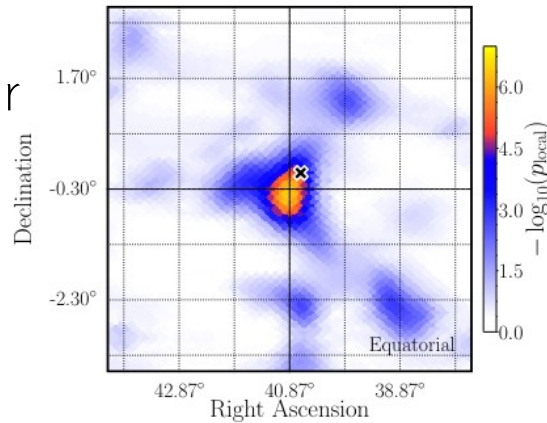
Galactic Plane

- Template analysis using

  DNN cascades– paper submitted

- Using tracks (ESTES) – under progress
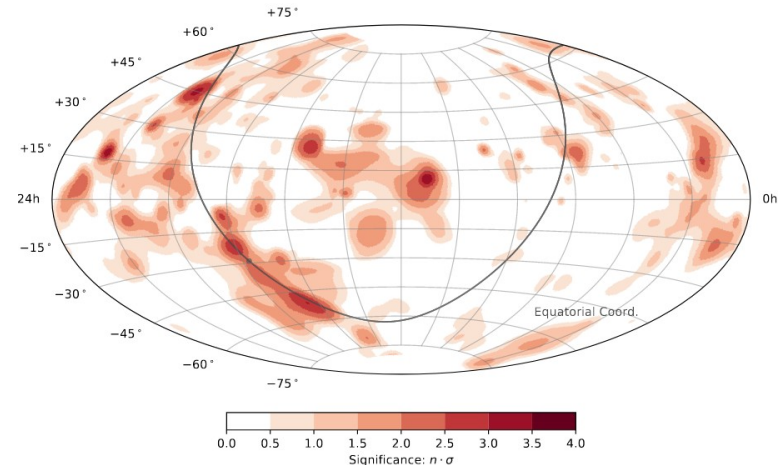
Realtime

- Technical WG, works closely with nu-sources wg
- Rapid identification of sources
- Sends alerts to astro community
- Also receives alerts from astro community and quickly searches for neutrinos in coincidence
- Three main strategies

Alert generation, broadcasting and curation | Follow-up of external triggers | Self-triggers
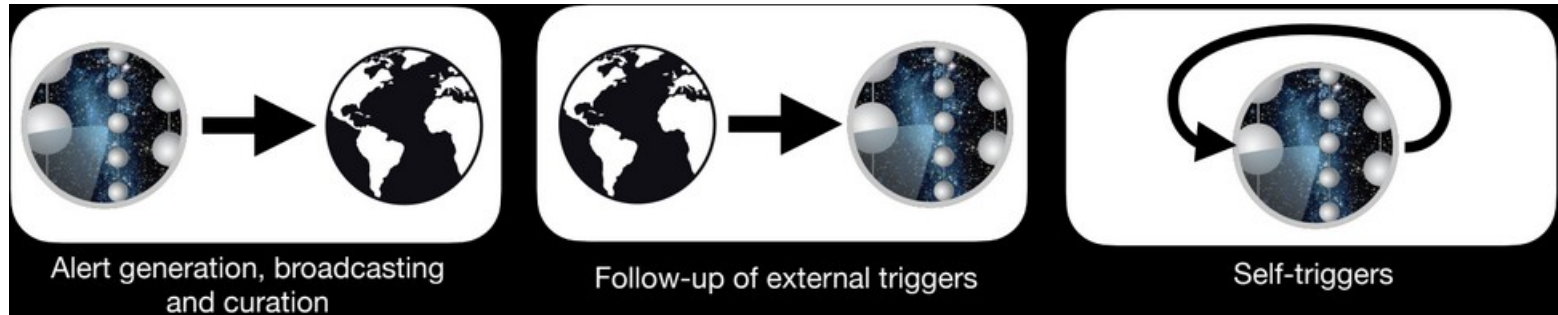
Realtime Analyses

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
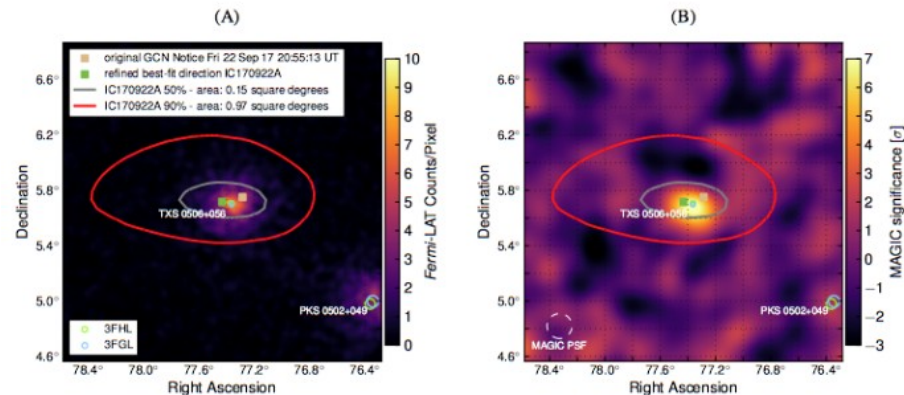
GW Follow-up

- Gravitational Wave events followed up in realtime
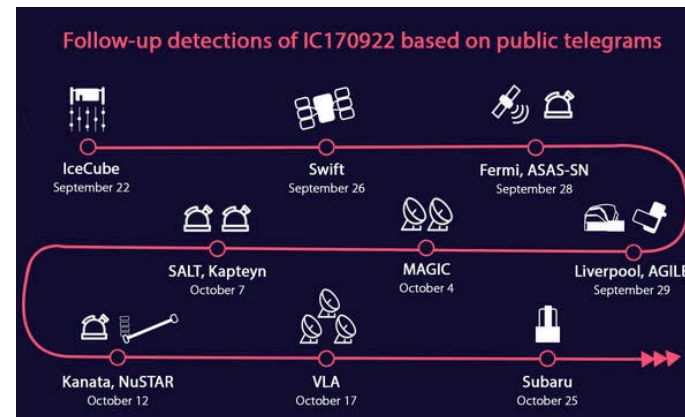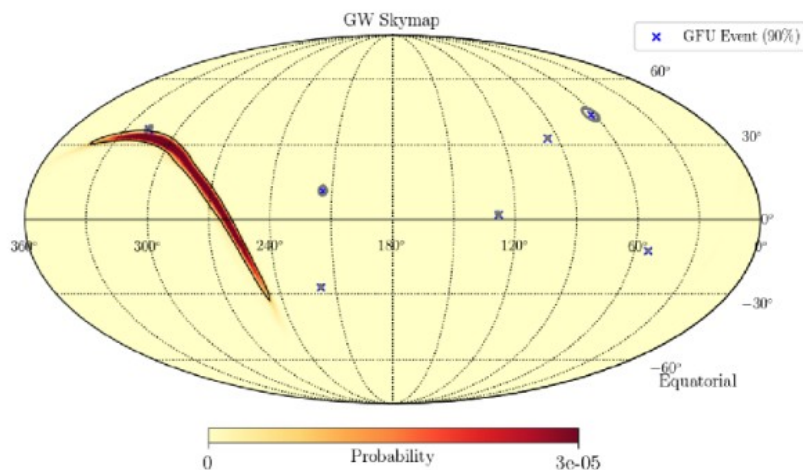
Diffuse WG

- Works on the diffuse (from all directions) flux of neutrinos observed on Earth

- Tries to measure the atmospheric and astrophysical spectrum of neutrinos

- Also deals with several particle-physics measurements
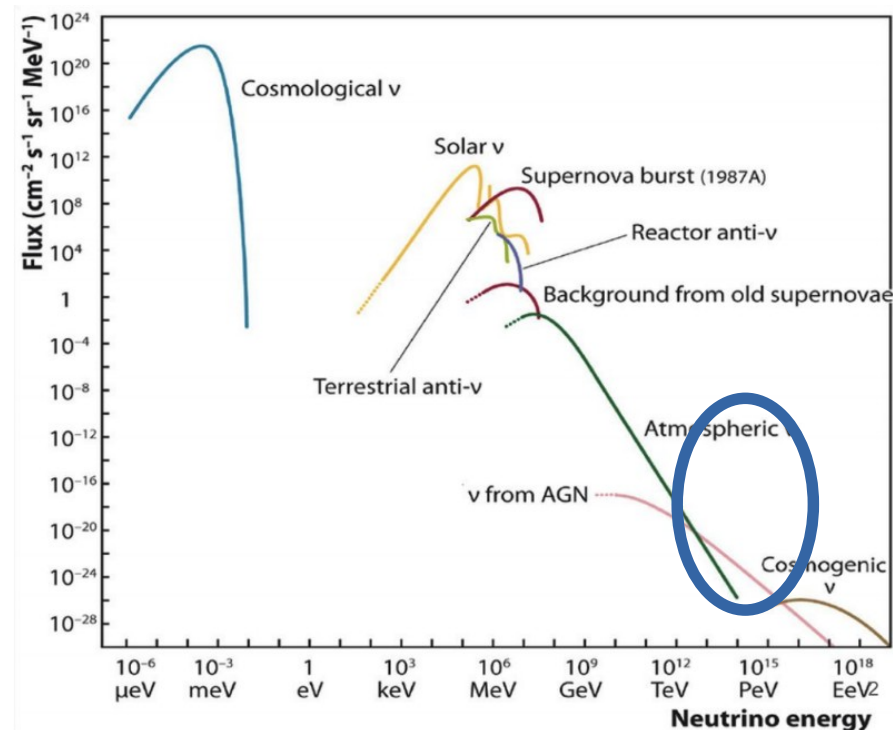
Diffuse Analyses
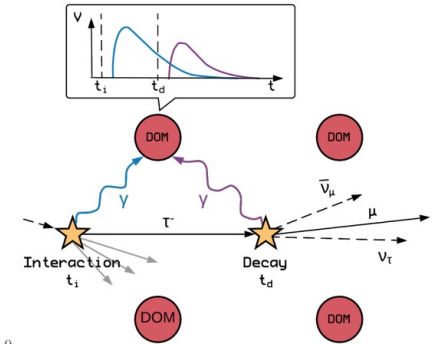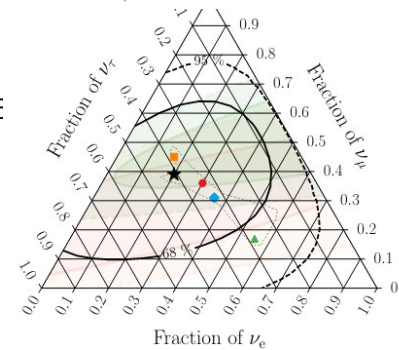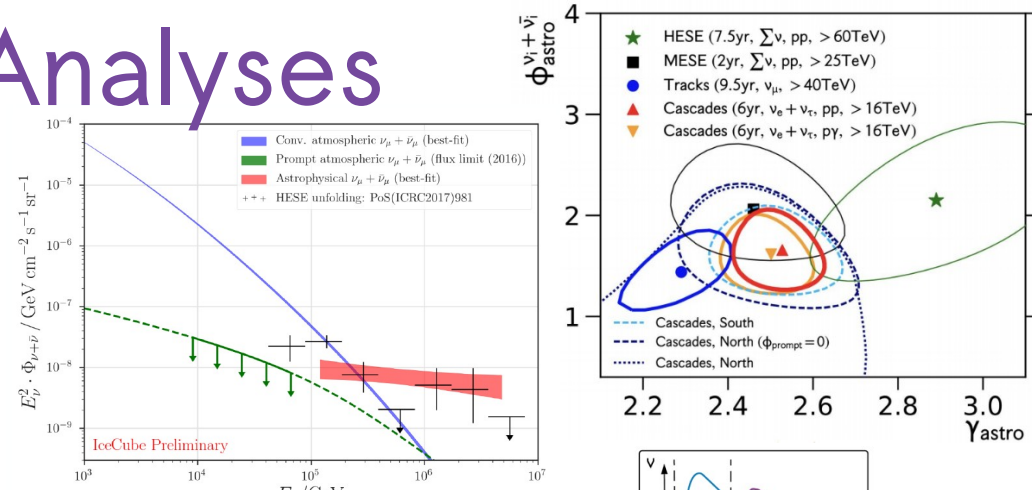
Astrophysical flux

- HESE: High energy starting events (>100 TeV)

- MESE: Medium energy (>1 TeV)

- Northern Tracks/Diffuse NuMu: Through-going tracks sample, Diffuse cascades

- ESTES: Enhanced Starting Track Event Selection

- PEPE: Partially contained events

- Identification of tau neutrinos (double pulse, double cascade)

- Flavour ratio of astophysical neutrinos (expectation: 1:1:1)

- Upcoming "GlobalFit": combining measurements

Particle physics

- Inelasticity measurements-the ratio of hadronic cascade energy to total neutrino energy in ν_μ CC interactions

- Neutrino-nucleon cross section measurements

- Glashow resonance @ 6.3 PeV $\quad \bar{\nu}_e + e^- \to W^- \to X$

Atmospheric nu

- Seasonal variations (also CR-WG), measuring earth's core density

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Oscillations WG

Oscillation probabilities for an initial electron neutrino
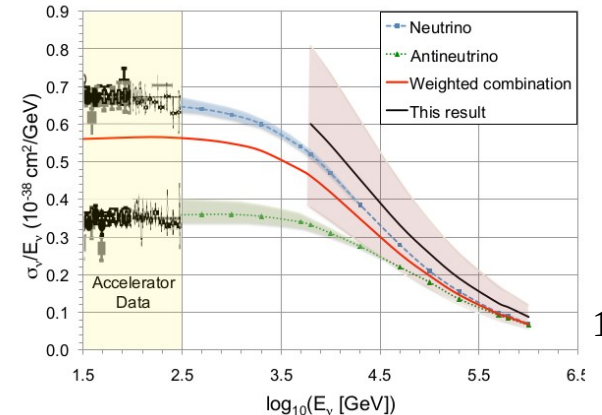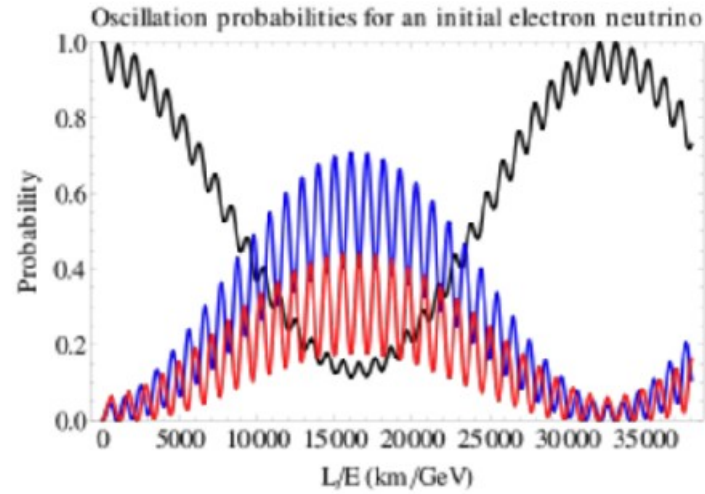
- Focus on analyses where neutrinos change flavour as they cross the Earth
- Oscillation probability

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

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

Oscillations Analyses

OscNext: new selection using DeepCore

- Two samples: "high-stats" sample and "verification" sample

  (subset of golden events)

  - NuMu disappearance

  - NuTau appearance

  - Non standard neutrino interactions (NSI)
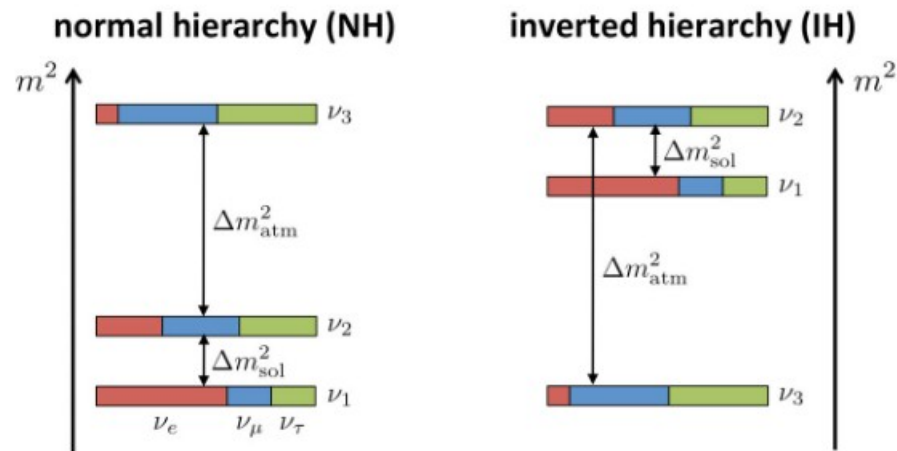
  - Neutrino mass ordering
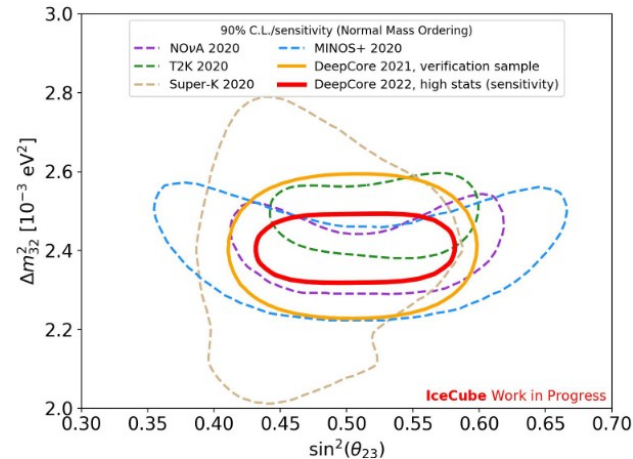
  MEOWS

- Dataset for sterile neutrino search

  FLERCNN

- New reco tool (fast) for low energies

Cosmic Rays WG

- WG focuses on analyses with air showers (shower of particles as cosmic rays intercat with the atmosphere)

- Uses IceTop + in-ice detectors

- Works on CR energy spectrum, composition, anisotropy, sun+moon shadow, seasonal variations

- Also deals with surface enhancements (Surface array WG) with scintillators, radio, and IceACT
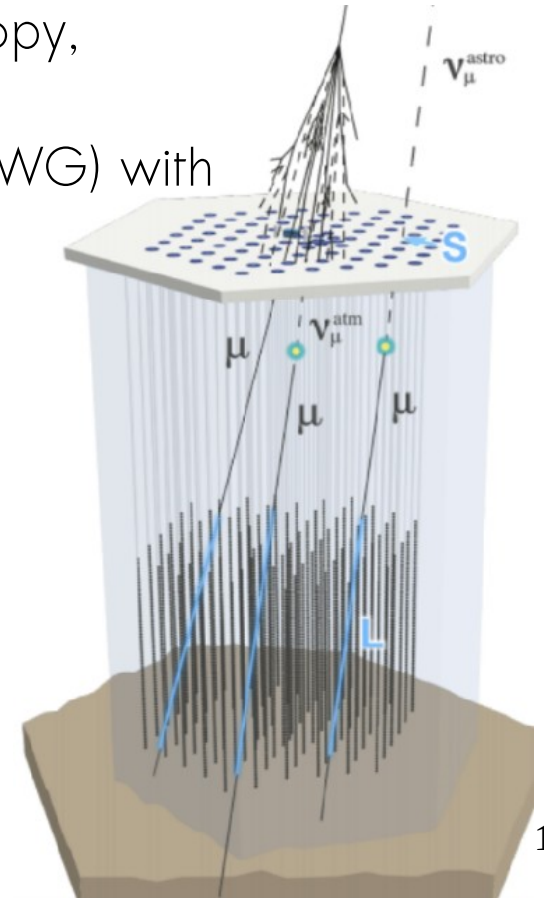
Cosmic Ray Analyses

Spectrum and composition

- Both low-energy and medium energy spectra

- Composition (how light-proton like- or how heavy-iron like- are the observations) studied with both IceTop and in-ice muons

- Density of GeV muons in IceTop

- Upcoming analyses: Machine learning methods for composition, muon multiplicity, low energy extension, gamma-hadron separation
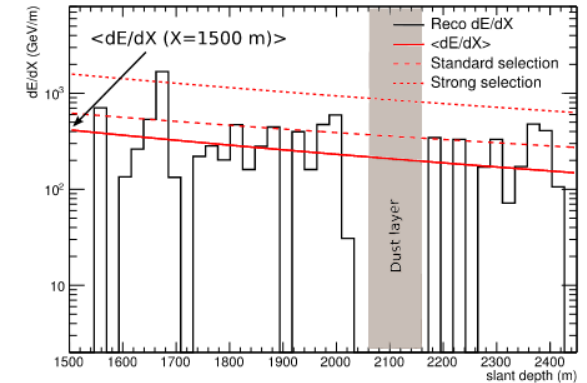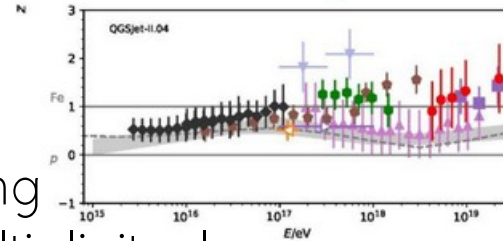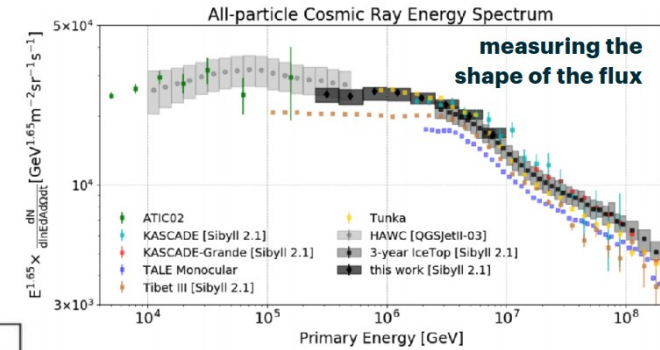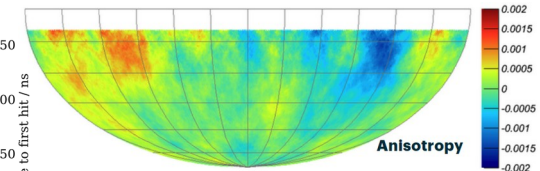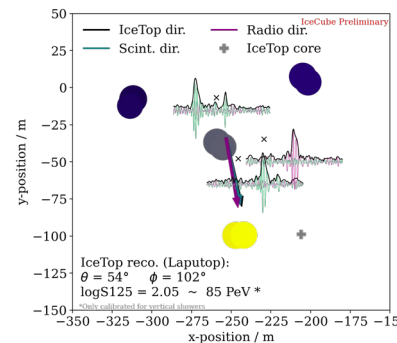
Anisotropy

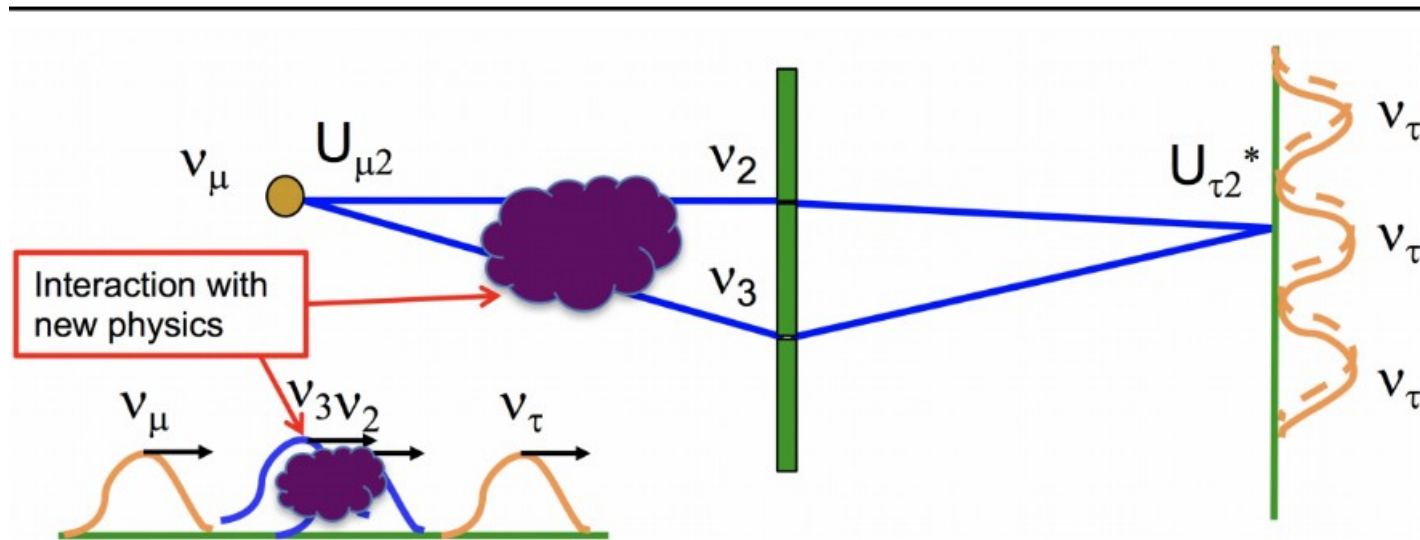- Small and large scale structures in the sky

Surface upgrade

- Air shower reconstructions and cross-calibrations of prototype stations

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Beyond Standard Model WG

- WG focuses on new physics that could be out there
- Interactions with new physics can cause distortions in the spectrum and flavor of both

BSM Analyses

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

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

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

- Diffuse DM: could part of the diffuse spectrum be due to DM?
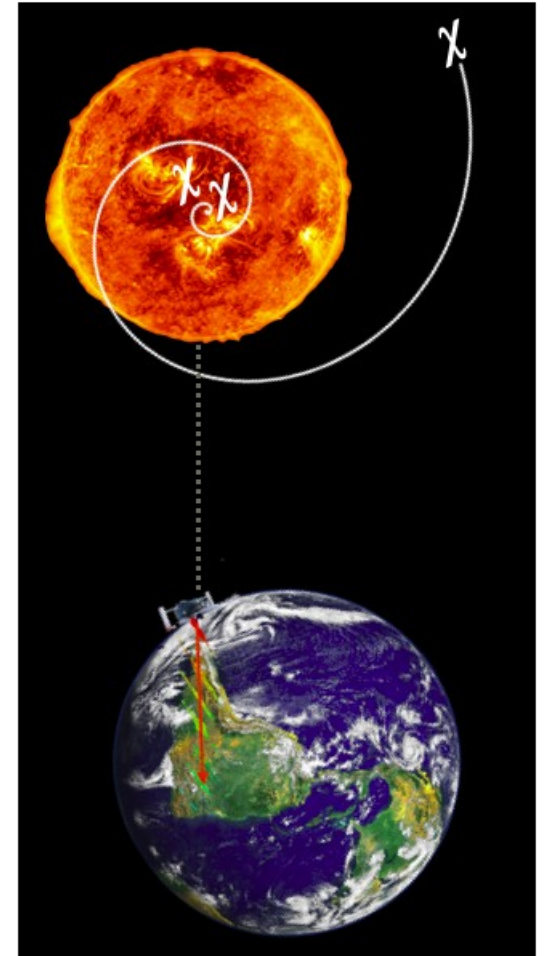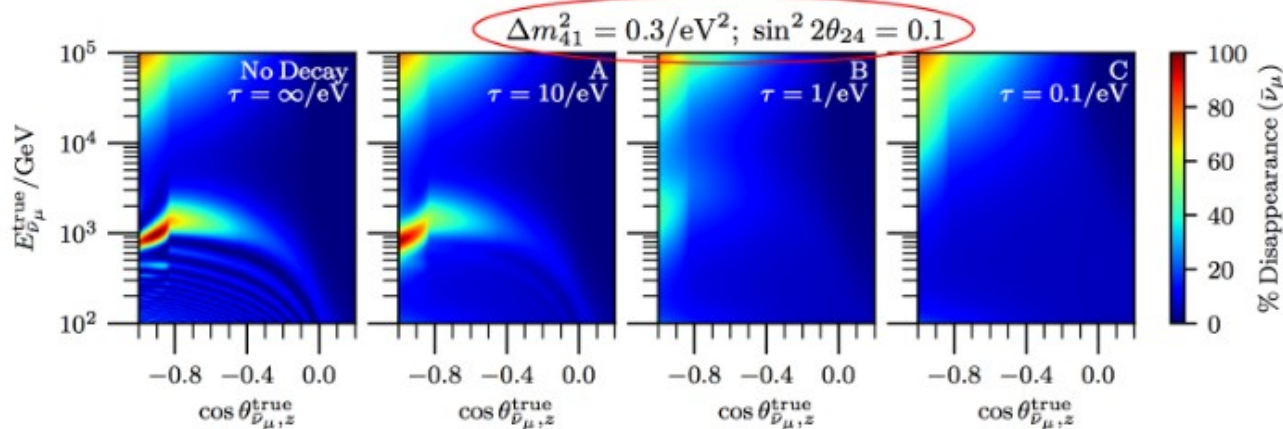
Supernova WG
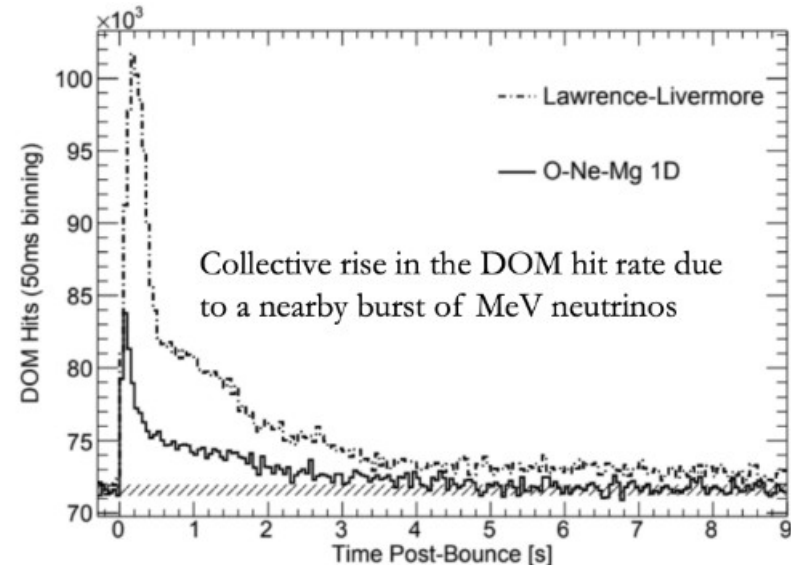
- Supernova neutrinos are at a very low energy compared to what IceCube normally sees.
- Therefore in a supernova, we would expect an overall rise in the "noise" rate of the detector, rather than identifying many individual events
- SN WG does online and offline SN analyses
- Conducts "fire drills" to test response
- ELOWEN analyses for GeV neutrinos: solar flare and GW
- Realtime alert within SNEWS

Supernova Early Warning System

SNEWS

Collective rise in the DOM hit rate due to a nearby burst of MeV neutrinos

- - - Lawrence-Livermore
— O-Ne-Mg 1D

DOM Hits (50ms binning) vs Time Post-Bounce [s]

Other 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

- Physics analyses depend heavily on the calibration and reconstruction wg's

Where everything comes together

- **Analysis Call on Thursdays at 9:00 am CST**

- Most nearly-finished analyses withing the whole collaboration are presented here

- Collaboration-wide discussions and decisions happen here

- Good for learning about other analyses in IceCube

- Also sometimes have WG summaries

https://wiki.icecube.wisc.edu/index.php/Analysis_calls_2022

How to Do Your Own Analysis in IceCube

How to publish an IceCube paper