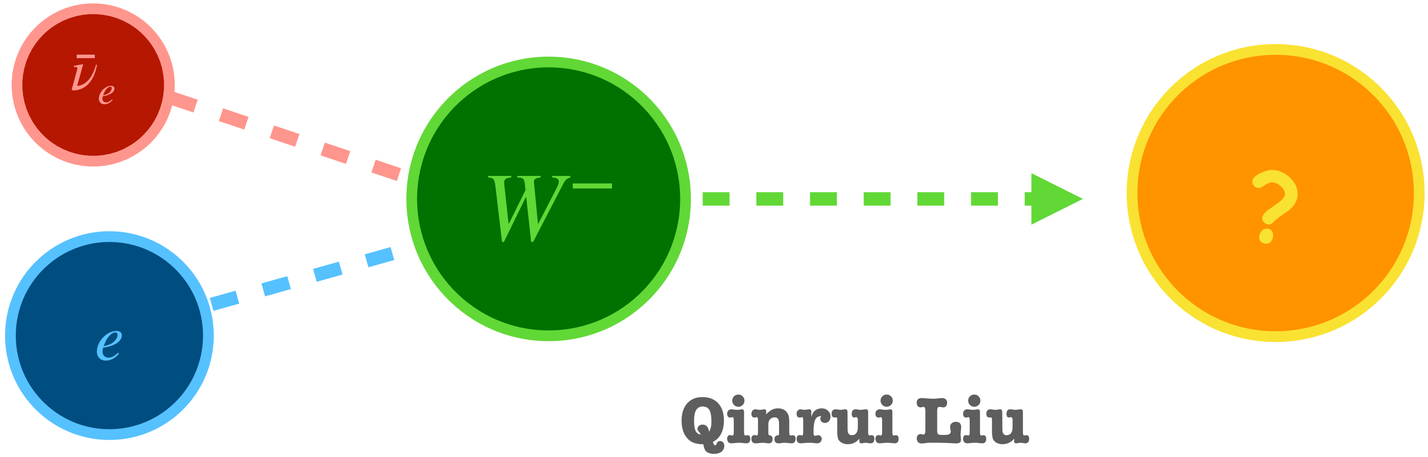
Hunting for Glashow Resonance with PeV Neutrino Telescopes



Qinrui Liu

University of Wisconsin-Madison

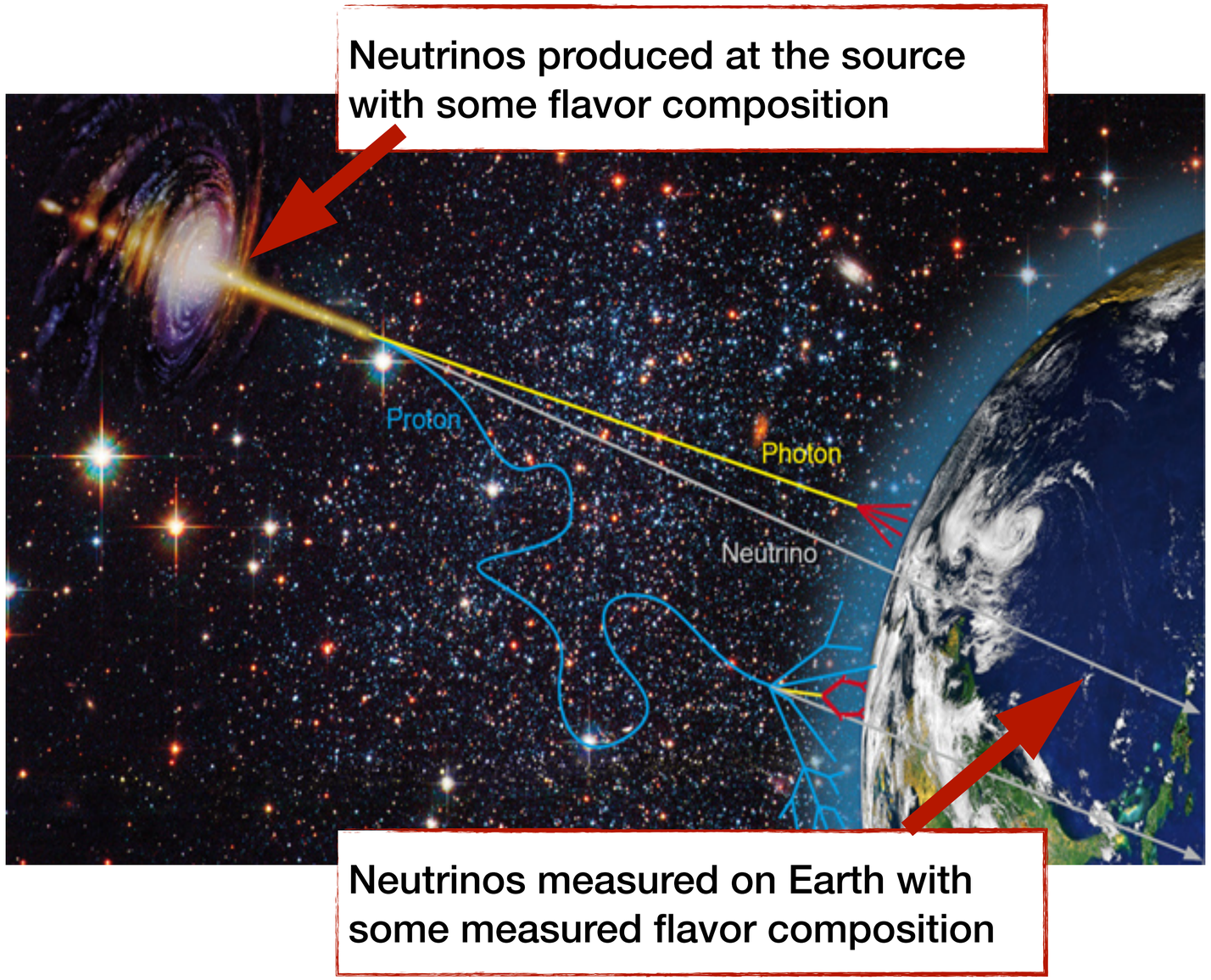
XIX International Workshop on Neutrino Telescopes
Feb 22nd, 2021

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

with Guo-yuan Huang
JCAP 03 (2020) 005 [1912.02976]

WIPAC
WISCONSIN ICECUBE PARTICLE ASTROPHYSICS CENTER

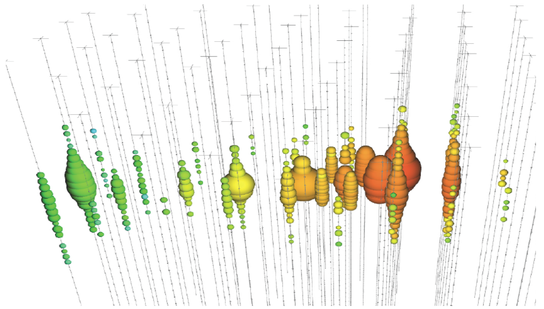
Neutrino Flavors

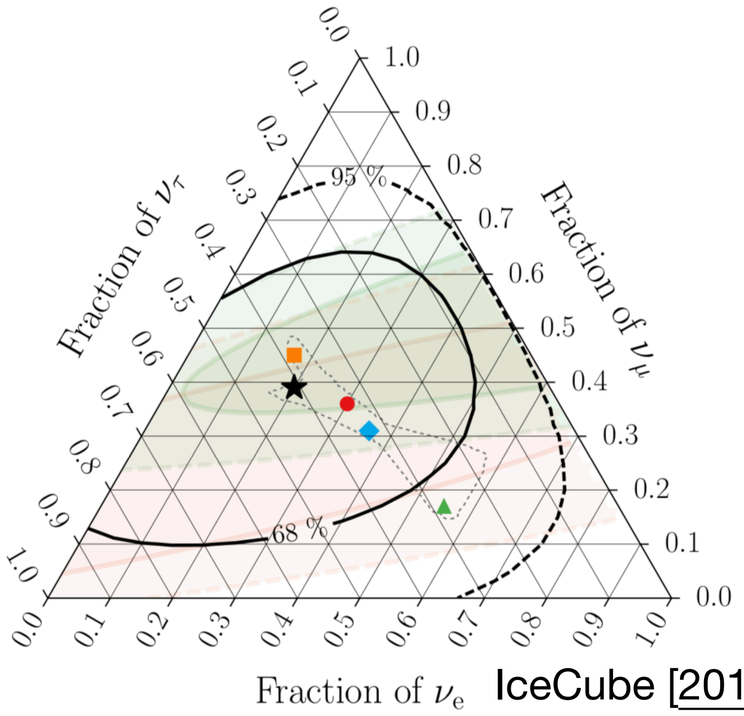


- High-energy astrophysical neutrinos arrive on Earth with a flavor composition.
- The production mechanism and propagation effect affects the flavor composition.
- Measuring the flavor composition of high-energy astrophysical neutrinos on Earth is important to pin down the physics.

Neutrino Flavor Measurement in Experiments

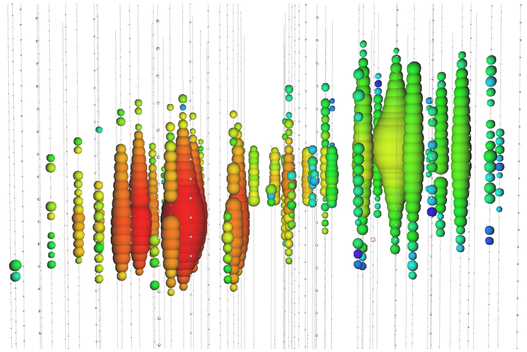
Track ~ CC ν_μ



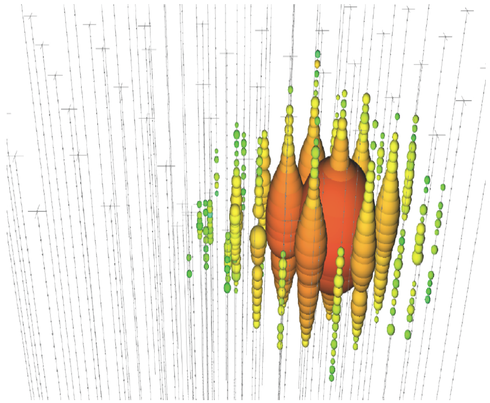


IceCube [2011.03561]

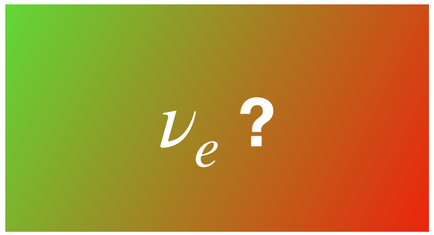
"Double-Bang" ~ CC ν_τ



Cascade ~ NC all flavor / CC ν_e



- Challenging to distinguish flavors
- Blind to neutrino and anti-neutrinos



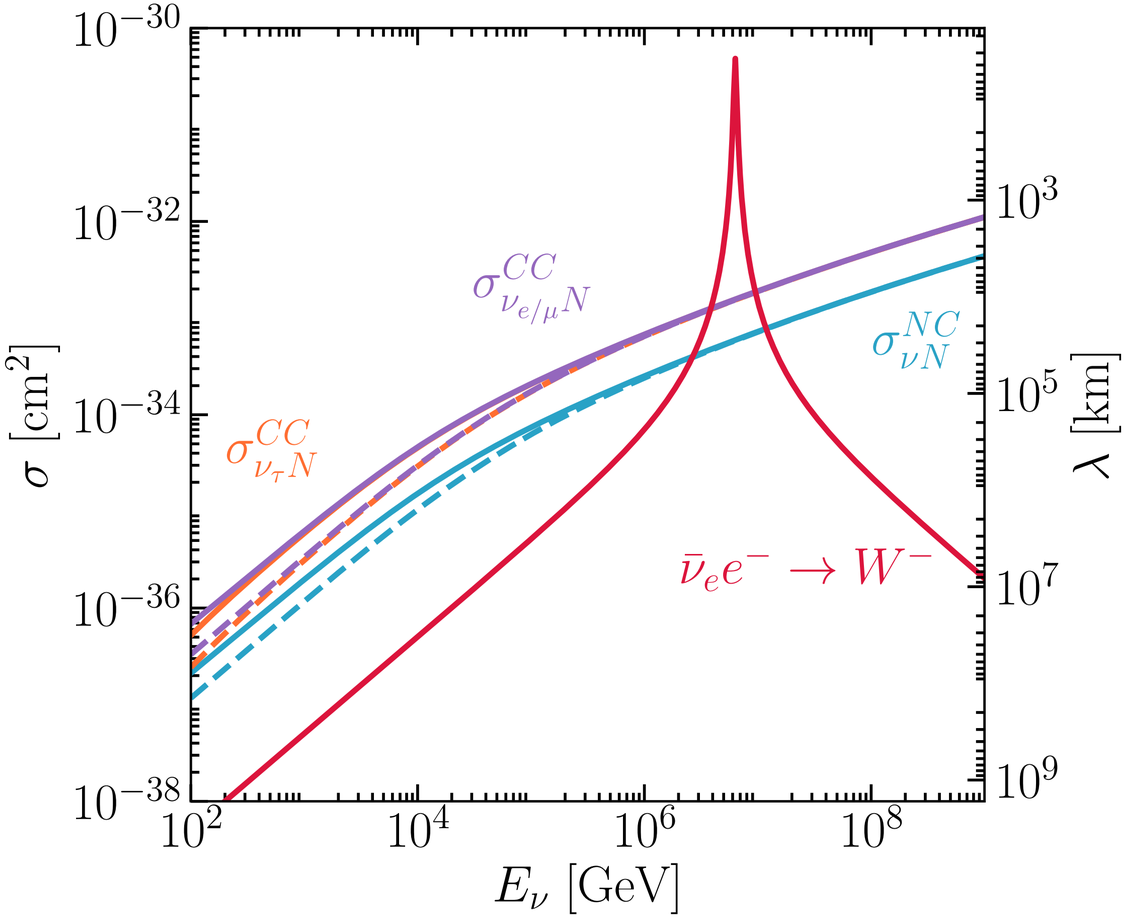
$\bar{\nu}_e$ Glashow Resonance

$\bar{\nu}_e$ can be disentangled with resonant interactions

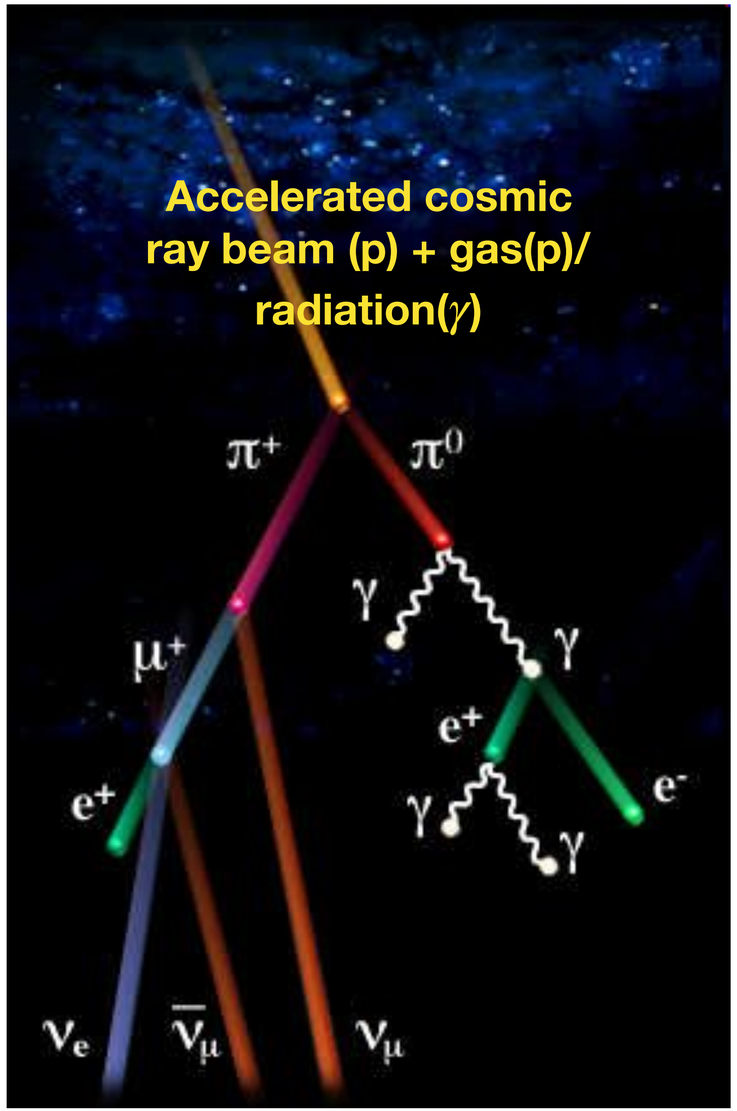
$$\bar{\nu}_e + e^- \rightarrow W^- \rightarrow X$$

6.3 PeV 511 KeV 80.38 GeV

S. Glashow *Phys.Rev.* 118 (1960) 316-317



$\bar{\nu}_e$ Glashow Resonance



Typical source flavor scenarios + standard mixing

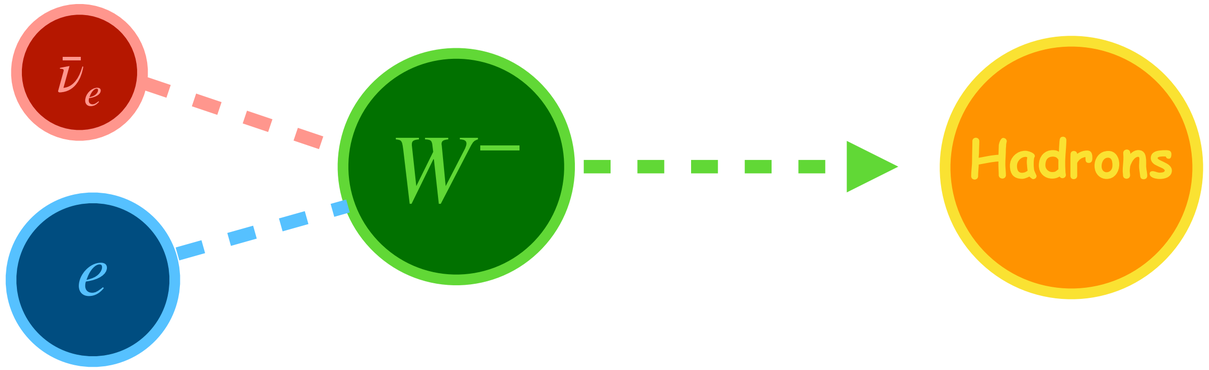
Source → Earth

$$(f_{\nu_e}, f_{\bar{\nu}_e}, f_{\nu_\mu}, f_{\bar{\nu}_\mu}, f_{\nu_\tau}, f_{\bar{\nu}_\tau})_S \rightarrow (f_{\nu_e}, f_{\bar{\nu}_e}, f_{\nu_\mu}, f_{\bar{\nu}_\mu}, f_{\nu_\tau}, f_{\bar{\nu}_\tau})_\oplus$$

		$\bar{\nu}_e$ fraction
• $pp \rightarrow \pi^\pm$	(1,1,2,2,0,0) → (1,1,1.1,1.1,1,1)	~16%
• pp μ damped	(1,1,2,2,0,0) → (1,1,2,2,1.8,1.8)	~10%
• $p\gamma \rightarrow \pi^+$	(1,0,1,1,0,0) → (3.6,1,3,2,3,1.8)	~7%
• $p\gamma$ μ damped	(0,0,1,0,0,0) → (1,0,2,0,1.8,0)	~0%
• Neutron decay	(0,1,0,0,0,0) → (0,1,0,0.4,0,0.4)	~56%

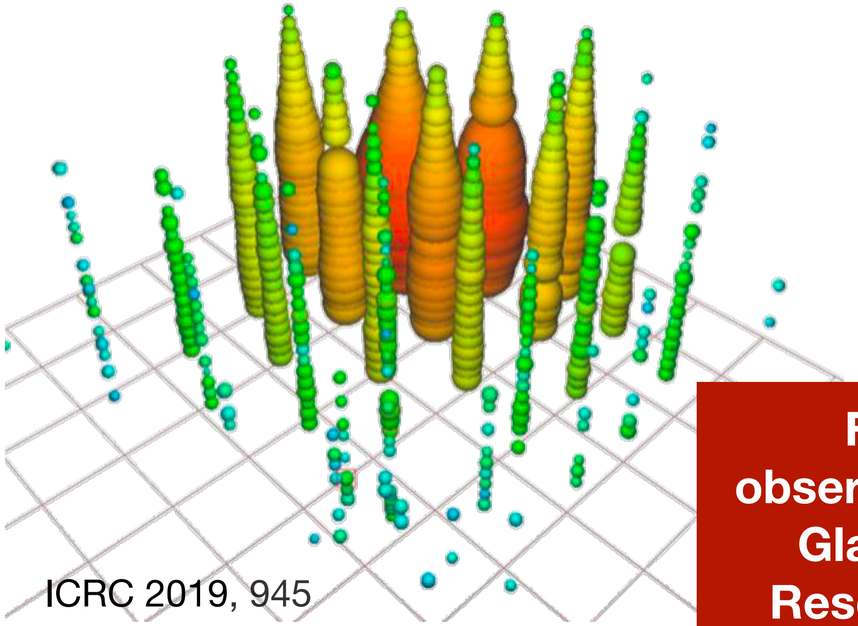
$\bar{\nu}_e$ fraction can be used to differentiate the production mechanism in the source and explore new physics.

Detection of Glashow Resonance



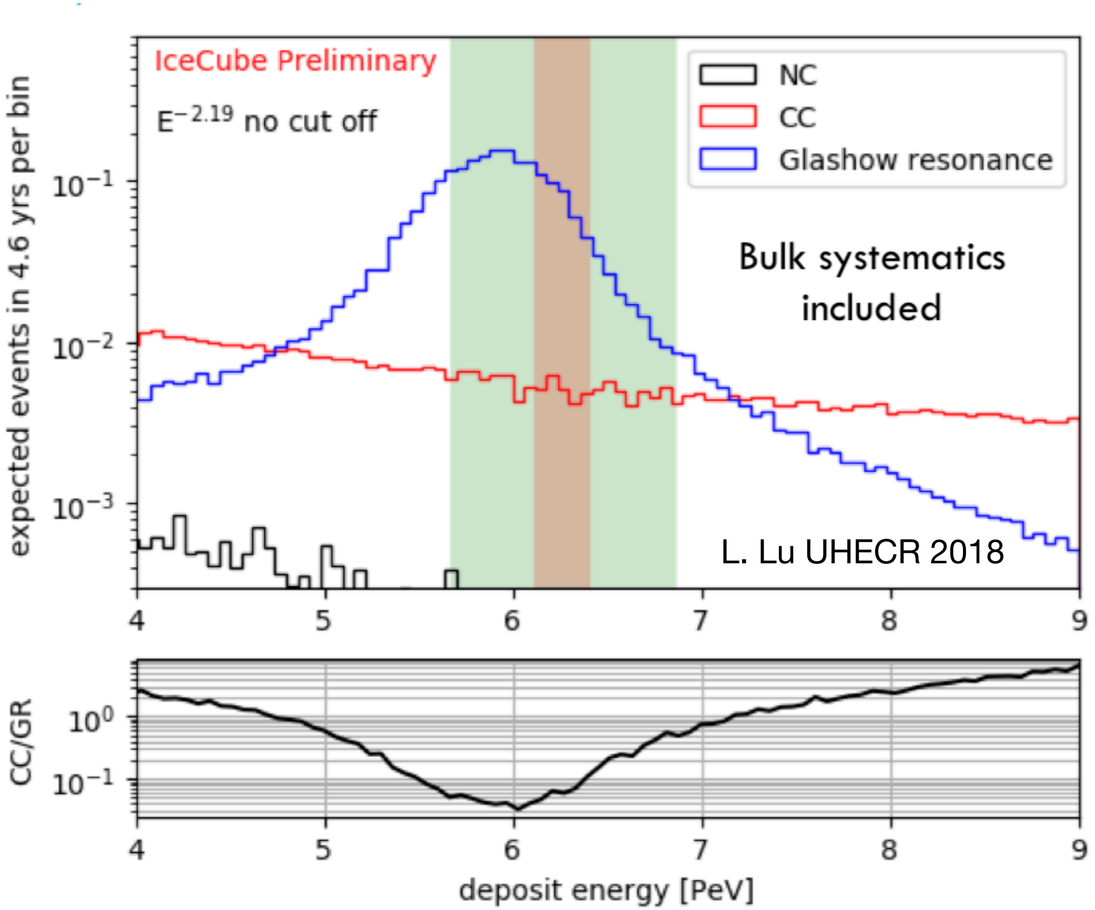
BR ~67 %

Hadronic shower is the "golden" detection channel

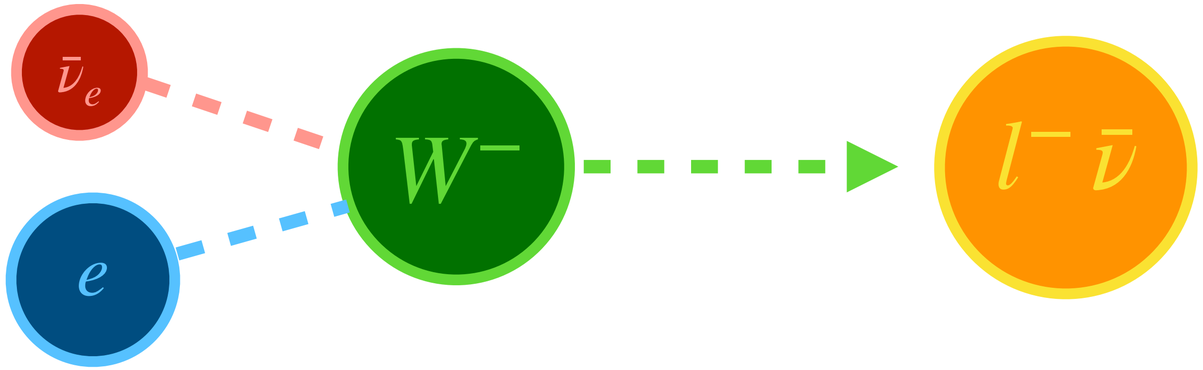


First observation of Glashow Resonance

Cascade in IceCube



More Resonant Events in IceCube?



BR ~11 % for each flavor

Alternative channel

Cascades:

- Large branching ratio
- Good Energy resolution $\sim 15\,\%$
- Interaction vertex in the detector
- Angular resolution ~ 10 degree

μ Track:

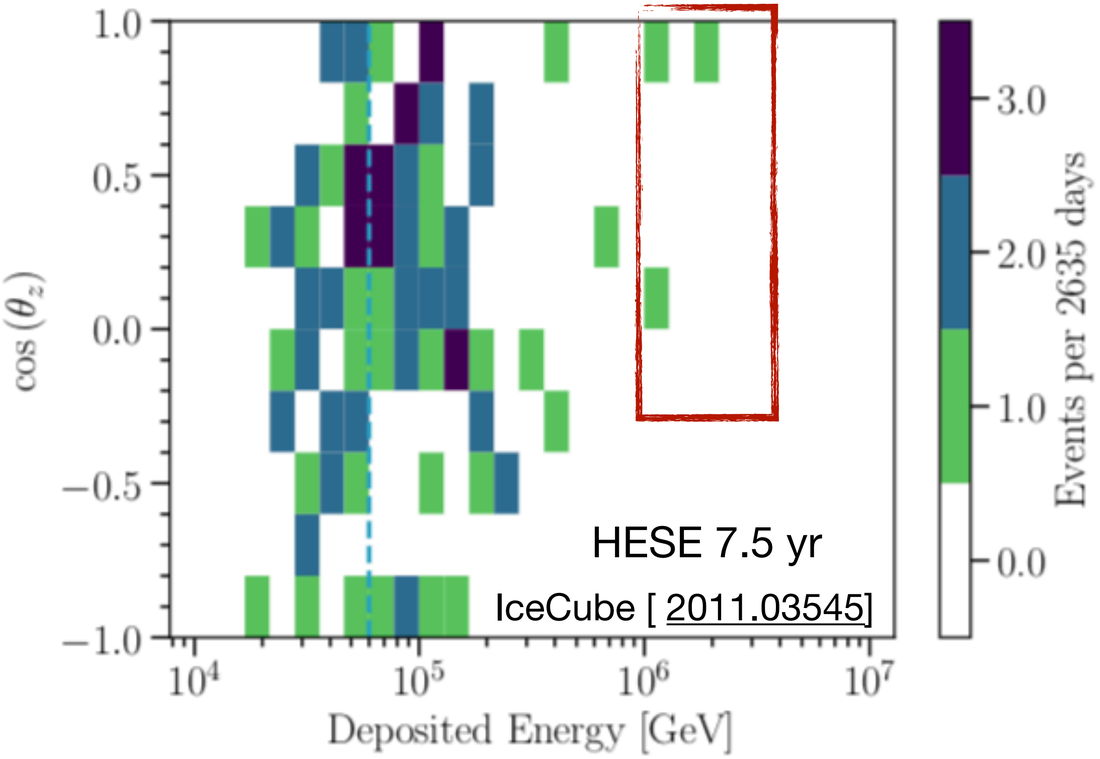
- Smaller branching ratio
- Energy resolution $\sim 200\,\%$
- vertex can be ~km away from detector
- Good angular resolution < 0.5 degree

PeV events in IceCube

- High-energy starting events (HESE)

3 cascades with deposited energies in PeV: 1.04 PeV, 1.14 PeV, 2 PeV.

Unlikely to be Glashow resonance



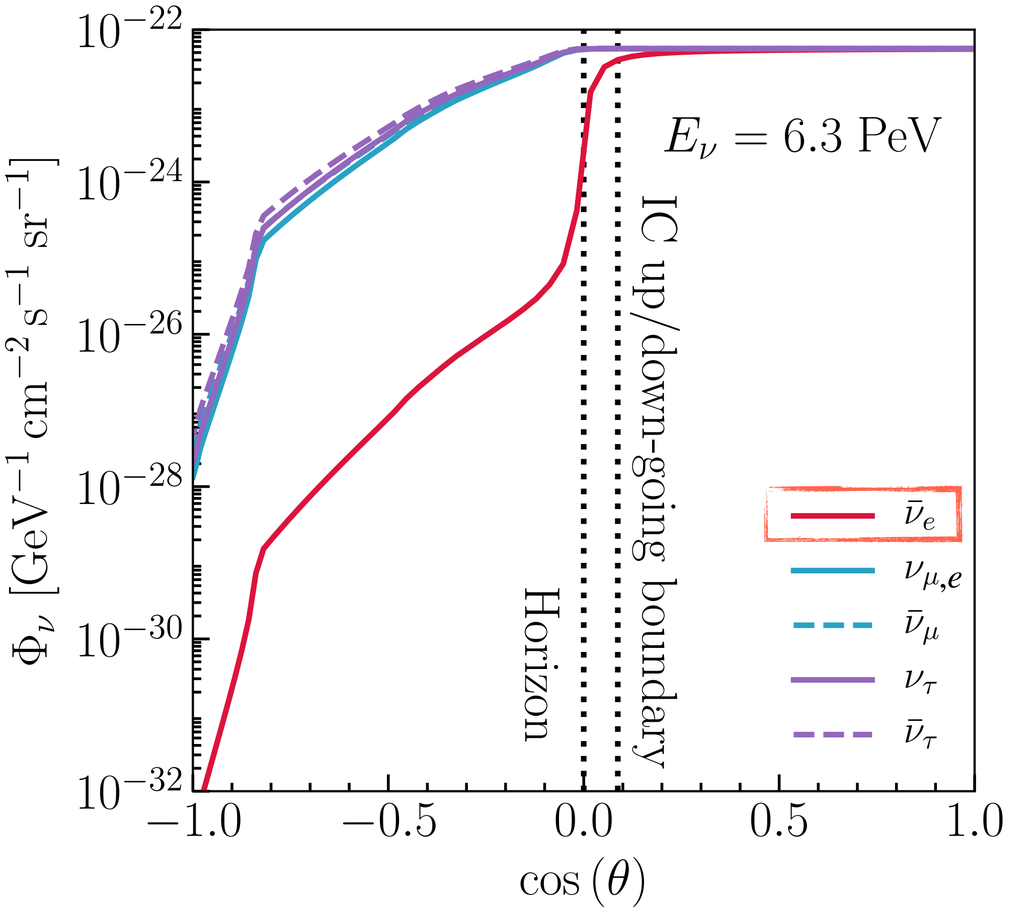
- Through-going muon events (TGM)

2 tracks with reconstructed muon energies in PeV: 4.5 PeV 1.2 PeV.

Uncertainties in energy reconstruction

Is there any resonant event in TGM?

Neutrino Flux in Earth



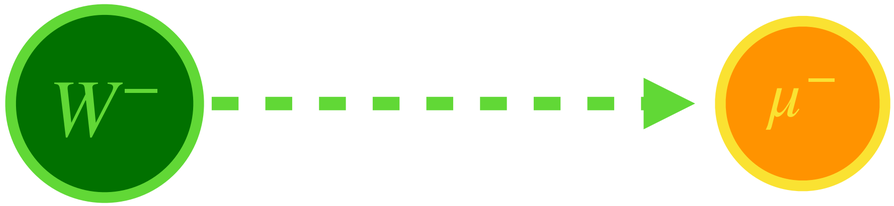
Neutrino flux when 1km away from the detector

- Mean free paths at 6.3 PeV:

$$\lambda^{GR}_{\bar{\nu}_e e} \simeq 30 \text{ km};\ \cos\theta \sim 0.04,$$
$$\lambda^{CC}_{\nu N} \simeq 4 \times 10^3 \text{ km};\ \cos\theta \sim -0.35.$$

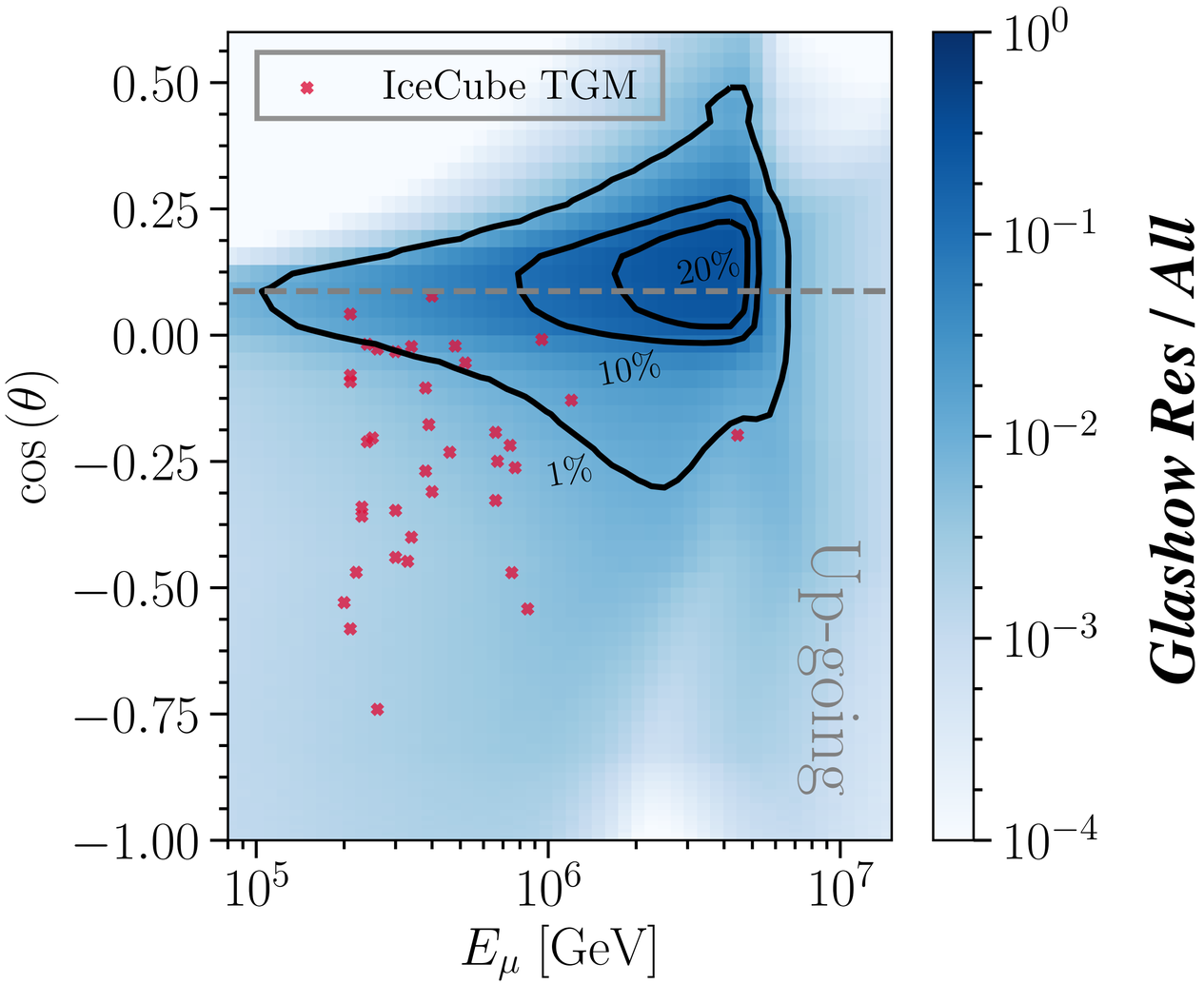
- Enhanced cross sections -> large absorption below horizon, undetectable.
- Southern Sky suffer from large amount of atmospheric muons.
- Signals are expected to appear around horizon.

TGM in IceCube



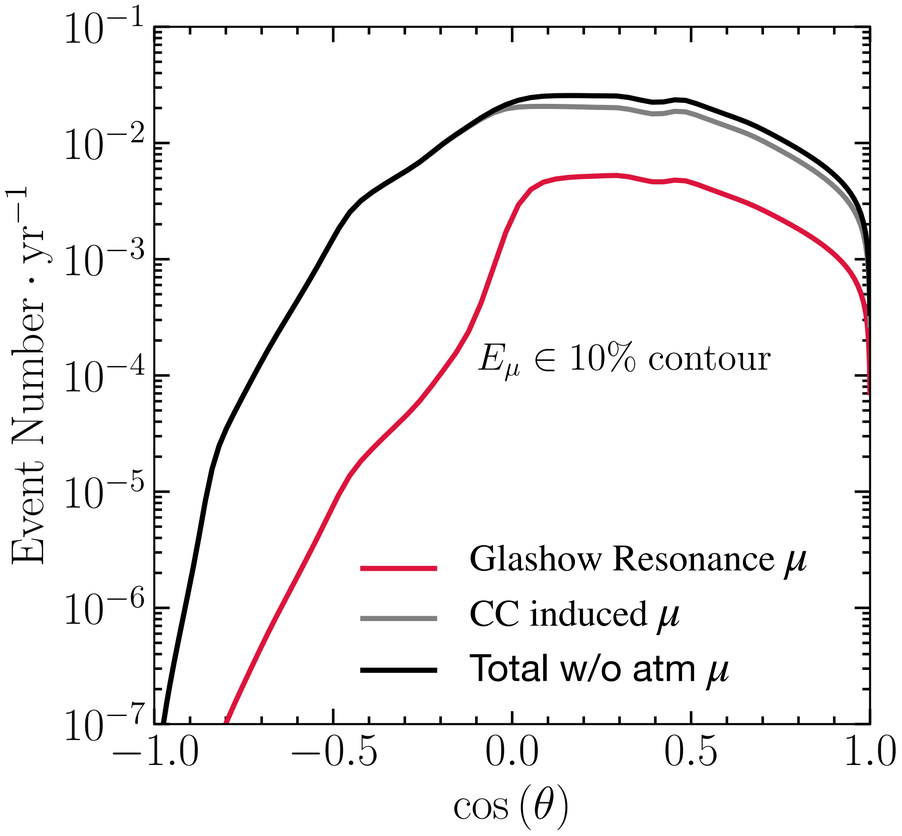
- Excess expected in area near horizon.
- No high-energy TGM event in 10% excess contour.
- PeV TGM events are unlikely to be $\bar{\nu}_e$ resonant events.

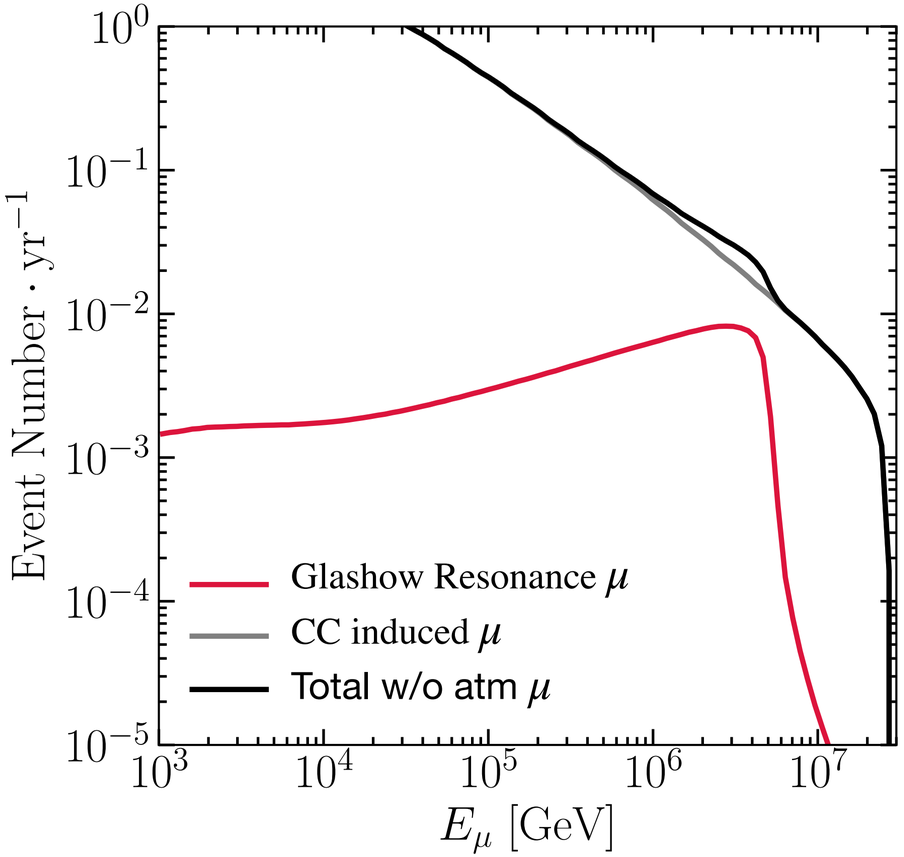
Background: CC induced μ + atmospheric μ



× TGM events in Northern Sky with reconstructed energy > 200 TeV

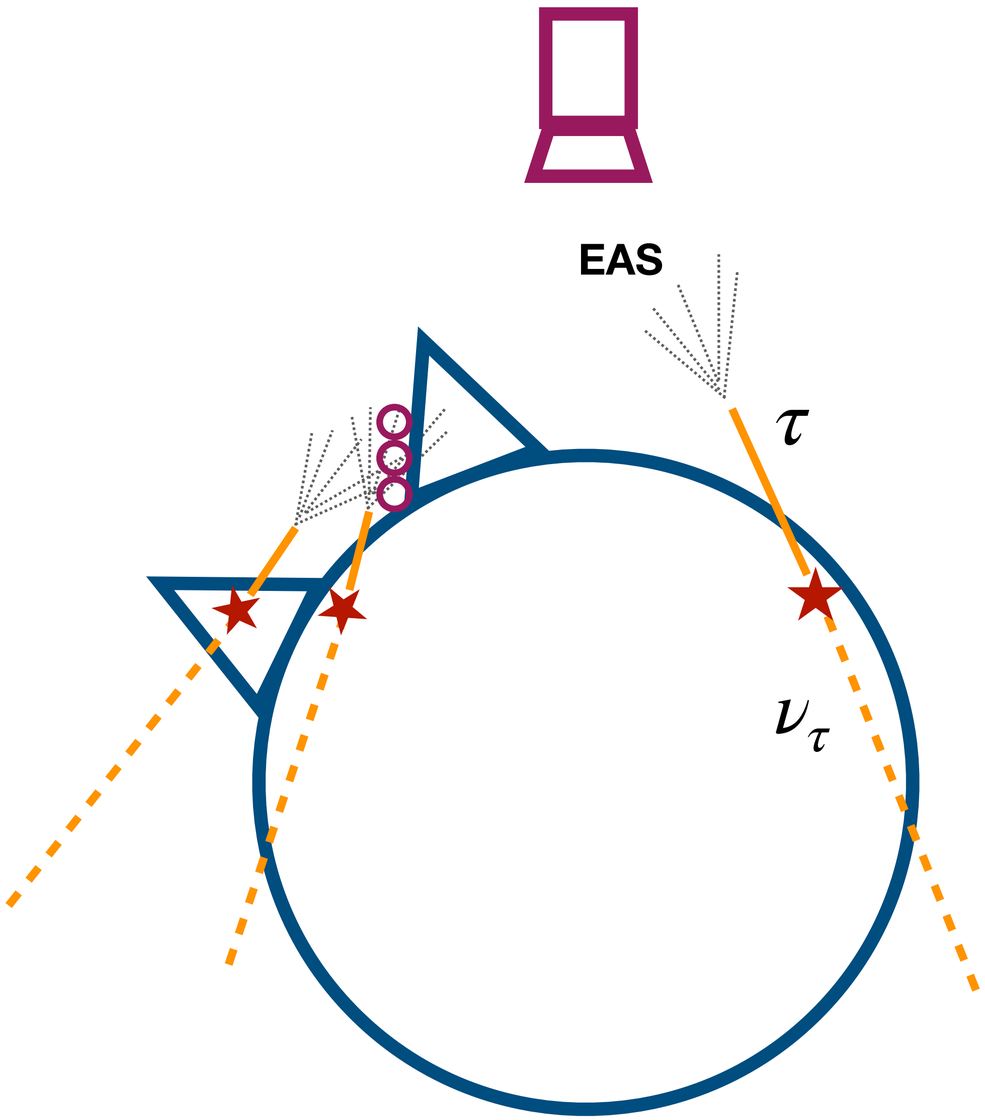
TGM from Glashow Resonance





- ~0.28 events within 10% contour in 10 yrs with TGM spectrum. ~3 events in total .
- A factor of ~4 increase in **IceCube-Gen2**. ~ 1 event within 10% contour is expected in 10 yrs.
- Similar conclusion can be drawn in other underground detectors.
  e.g. **ANTARES, Baikal-GVD, KM3NeT, P-ONE**.

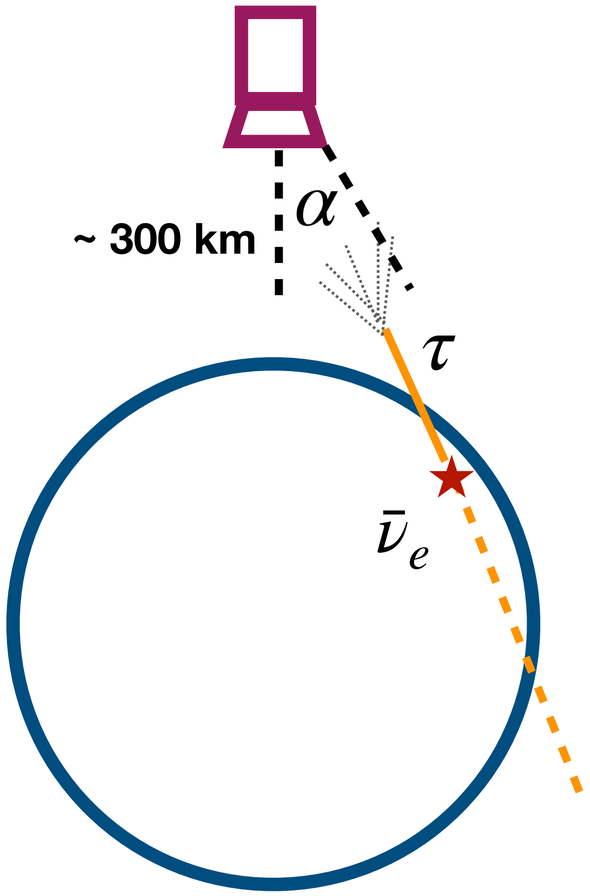
Detection in Next-generation Telescopes?



- Another possibility: τ channel, EAS detectors.
- Large attenuation in Earth. Observe neutrinos with smaller interacting lengths.
  - Detecting Earth-skimming neutrinos near horizon.
  - Detecting Mountain-penetrating neutrinos with a mountain as a target.
- Radio detectors are sensitive energies beyond PeV, e.g. GRAND, PUEO…
  Cherenkov/fluorescence detectors are preferred.

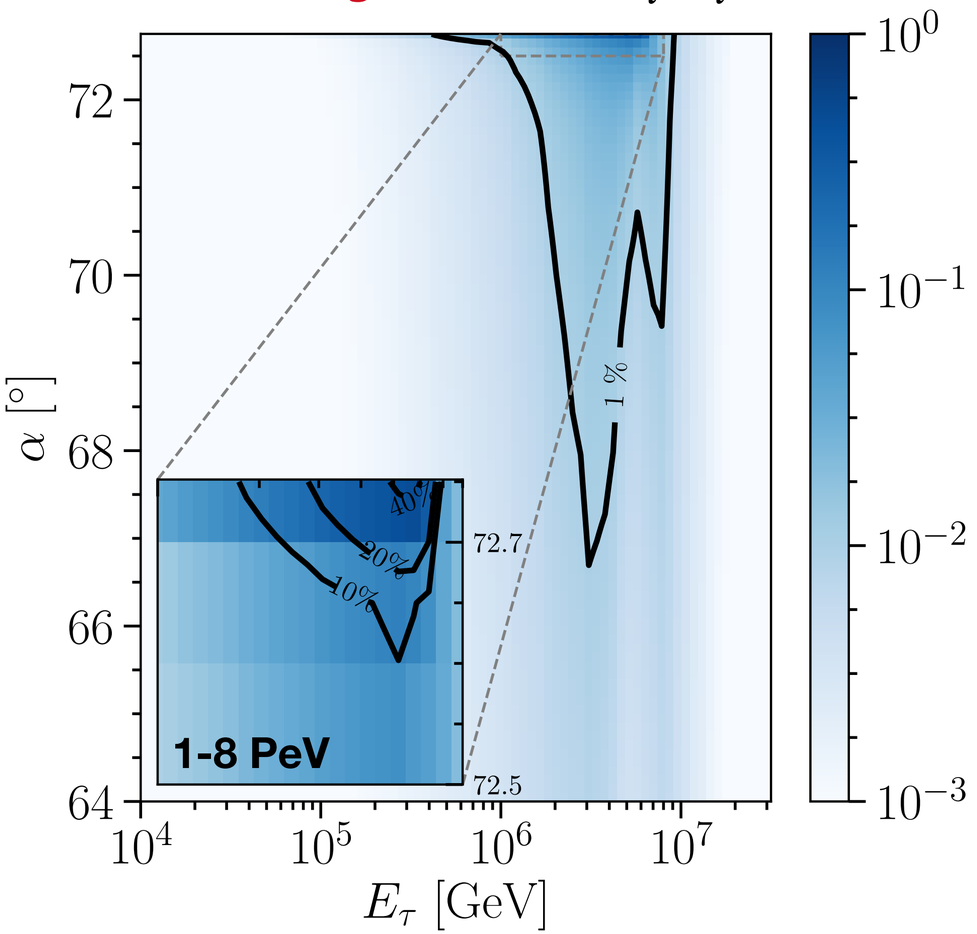
Earth-skimming Neutrinos

Elevated telescopes on mountaintops/ balloons/satellites



e.g. **Ashra NTA, CHANT, BEACON, Trinity, POEMMA**

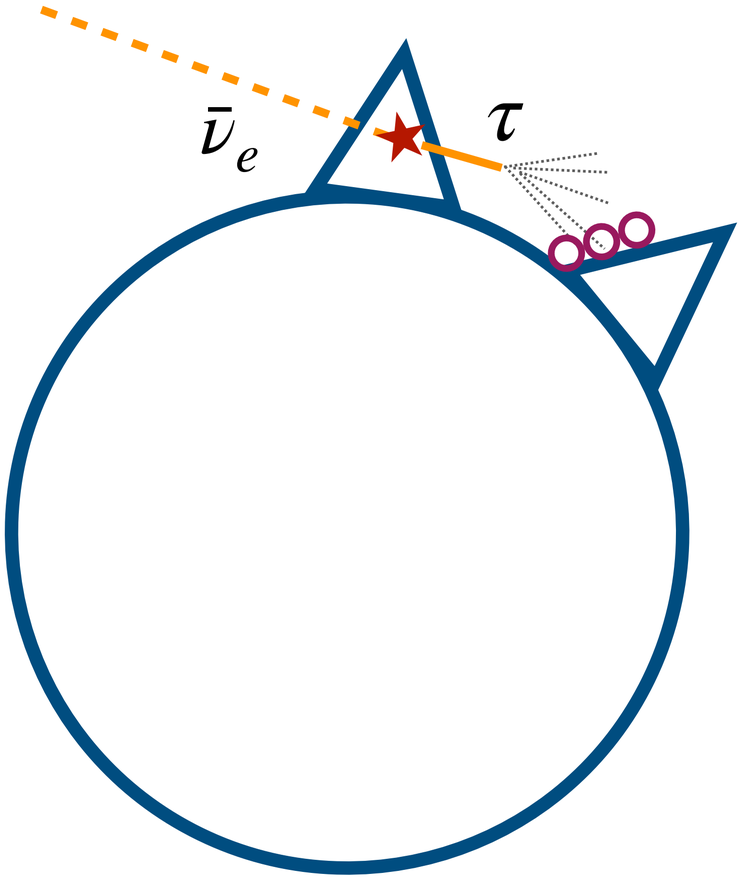
Background: CC $\nu_\tau/\bar{\nu}_\tau$

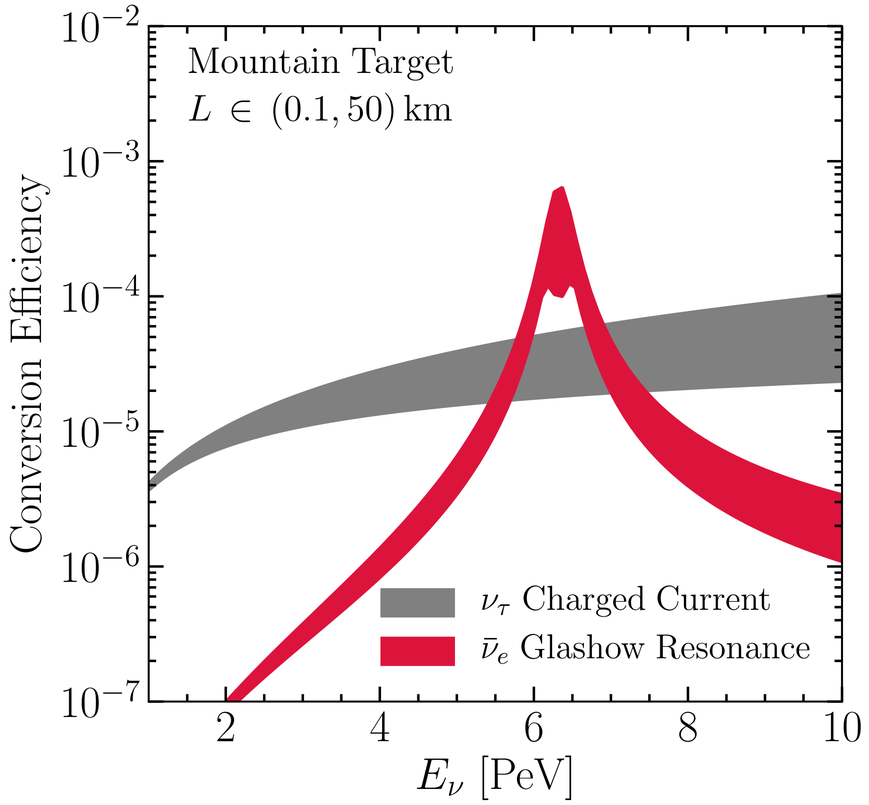


- Excess in very narrow area near horizon
- ~0.24 events within 10% contour in 10 yrs with TGM spectrum.

Mountain-Penetrating Neutrinos

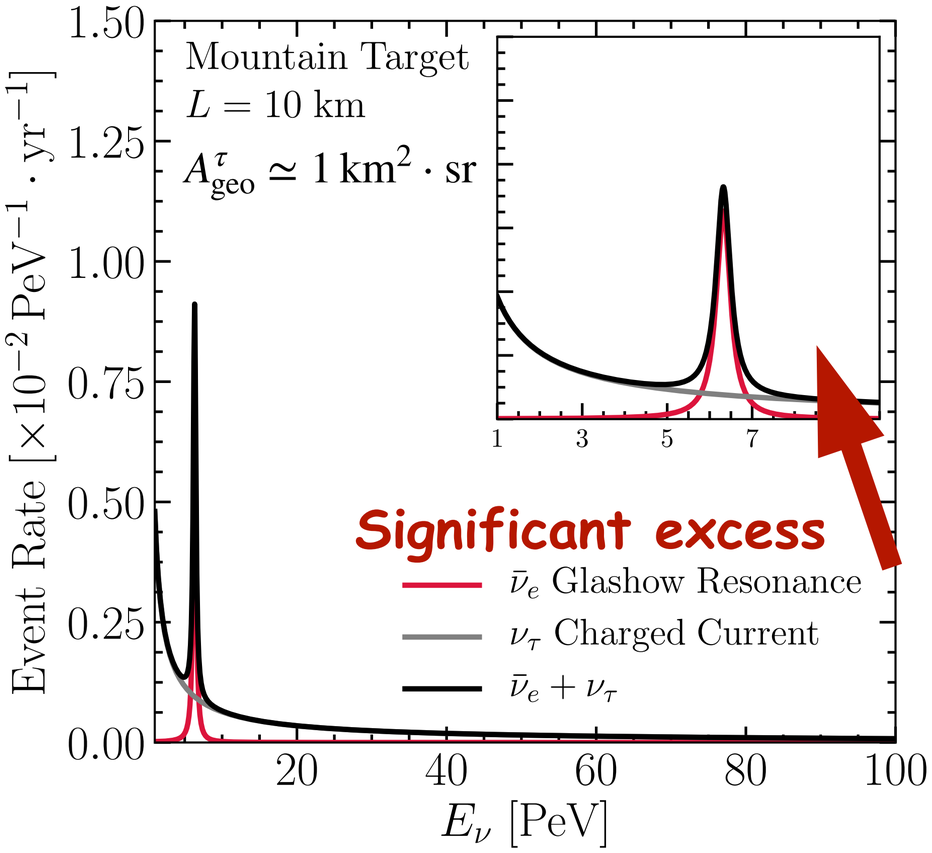
- Using Earth as the target always suffers shrink of detection volume.
- Resolvable if interaction length are satisfactory -> a mountain acts as the target.

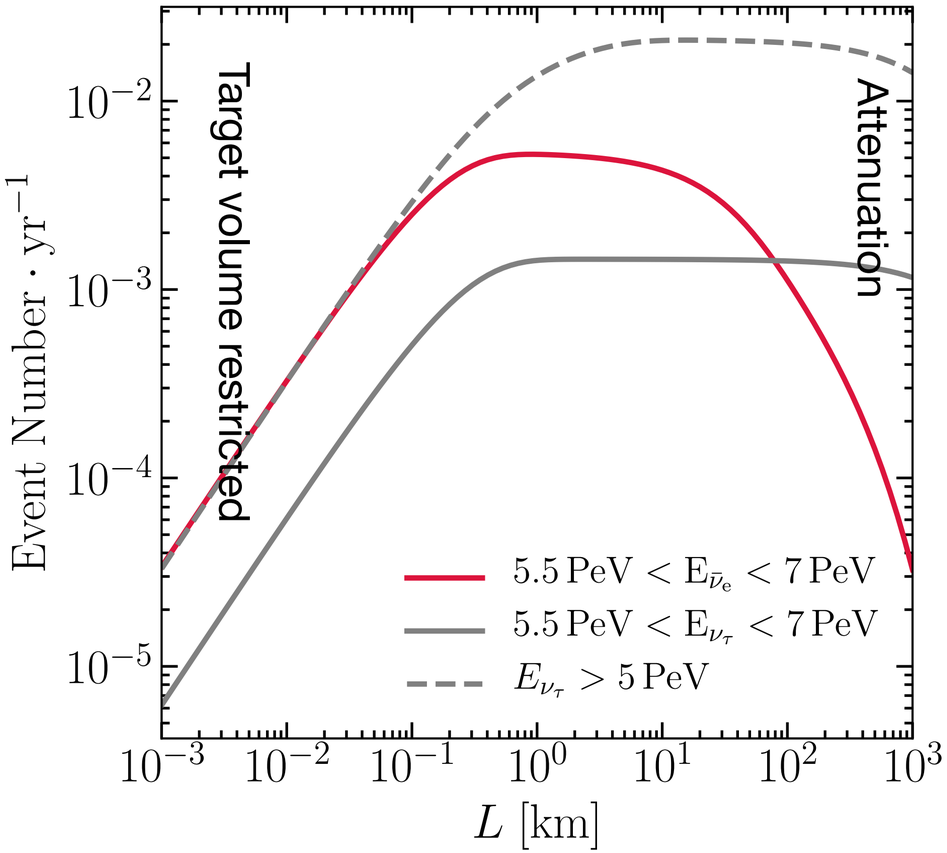




e.g. **Ashra NTA, TAMBO**

Mountain-Penetrating Neutrinos





- Array of Cherenkov detectors can enlarge the geometric aperture, $A^{\tau}_{\rm geo} \simeq 60\,{\rm km}^2 \cdot {\rm sr}$ → ~0.3 events per year with TGM spectrum.

promising

- More detailed simulation is needed.

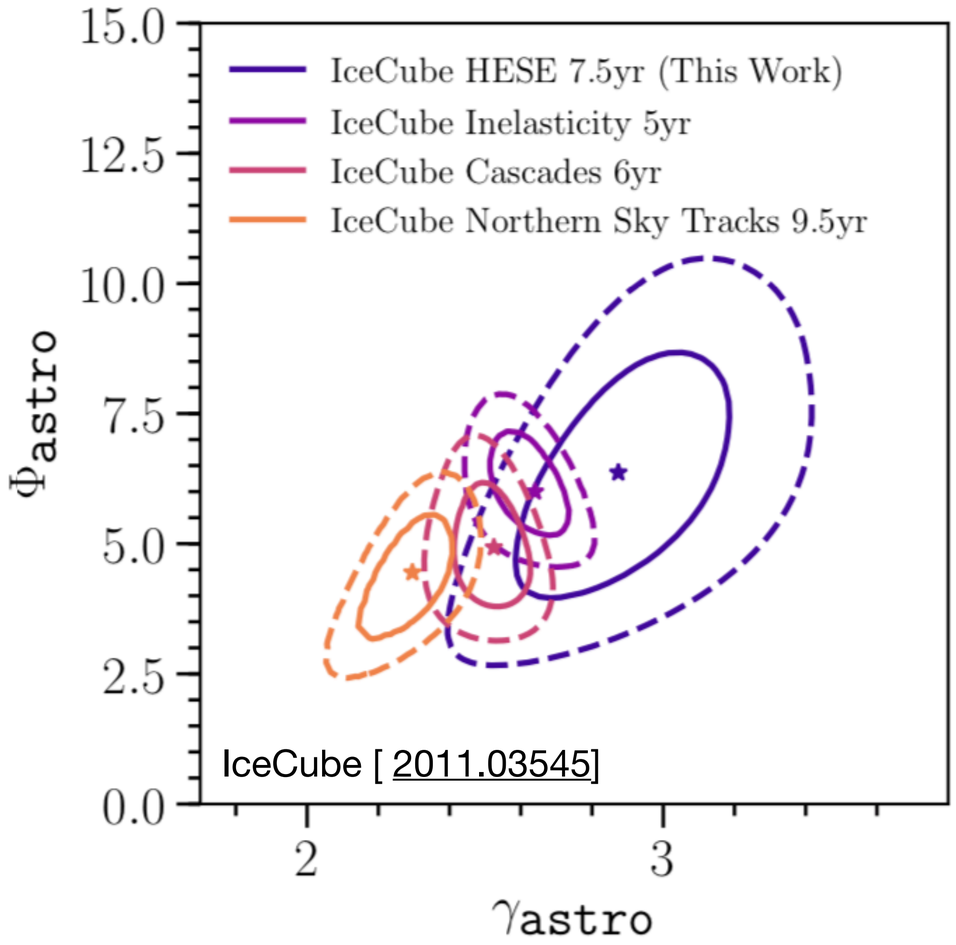
Summary

- The composition of flavors embeds important information of neutrino production and propagation.
- Glashow resonance provides possibility to disentangle $\bar{\nu}_e$ from the total neutrino flux experimentally.
- For TGM in IceCube, a 20% excess induced by Glashow resonance is expected near horizon. Searching for cascades is still the best window.
- For detection of Earth-skimming neutrinos, a similar conclusion holds to TGM in IceCube.
- Detection of mountain-penetrating neutrinos is potentially sensitive to the Glashow resonance signature.

Backup Slides

HE Astrophysical Neutrino Flux

$$\frac{d\phi}{dE} = \Phi_{astro} \times \left(\frac{E_\nu}{100\,\mathrm{TeV}} \right)^{-\gamma_{astro}} \cdot 10^{-18}\ \mathrm{GeV}^{-1}\mathrm{cm}^{-1}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$



TGM (Northern Sky Track 9.5 yr) [ICRC2019, 1017]

$$\gamma_{astro} = 2.28^{+0.08}_{-0.09}$$

HESE 7.5 yr IceCube [2011.03545]

$$\gamma_{astro} = 2.87^{+0.20}_{-0.19}$$