Neutrino Cross-Section Measurement in IceCube

TK, Juan Pablo Yanez, Tianlu Yuan
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4. Inelasticity
5. Glashow resonance
6. Some thoughts

Neutrino Interaction Physics in Neutrino Telescopes

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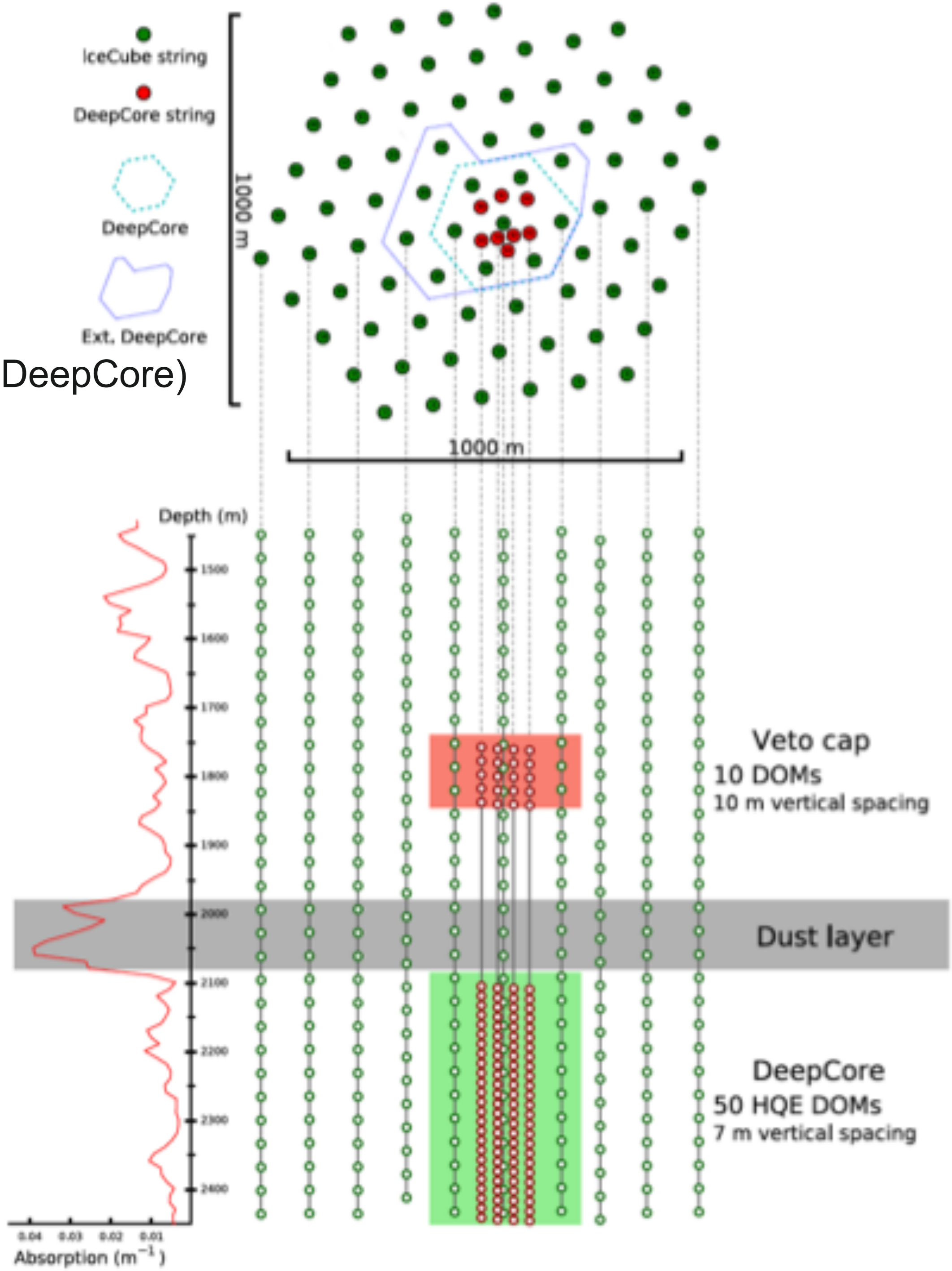
Abstract. Neutrino telescopes can observe neutrino interactions starting at GeV energies by sampling a small fraction of the Cherenkov radiation produced by charged secondary particles. These experiments instrument volumes massive enough to collect substantial samples of neutrinos up to the TeV scale as well as small samples at the PeV scale. This unique ability of neutrino telescopes has been exploited to study the properties of neutrino interactions across energies that cannot be accessed with man-made beams. Here we present the methods and results obtained by IceCube, the most mature neutrino telescope in operation, and offer a glimpse of what the future holds in this field.

Teppei Katori @teppeikatori
King's College London
NuSTEC board meeting, Dec. 6, 2021

1. Introduction



IceCube detector

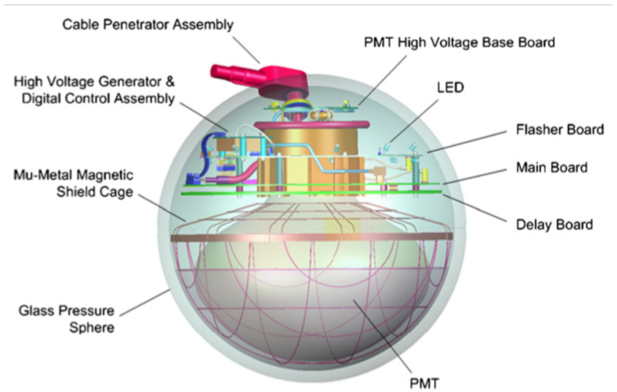
- 60 DOMs per string, ~17 m apart
- 79 strings, ~125 m apart
- 7 strings, 60 DOMs 7 m apart closer (DeepCore)

DeepCore

- Low energy (< a few 100 GeV)
- Track energy by range (ionization)

IceCube

- High energy (> 50 TeV)
- Energy by shower (radiation)



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1. Introduction

IceCube detector
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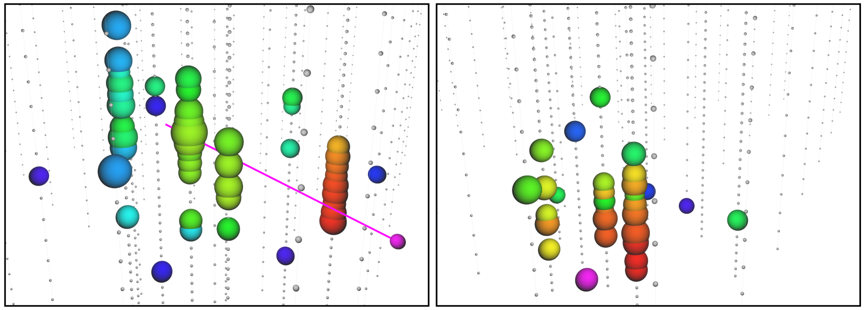
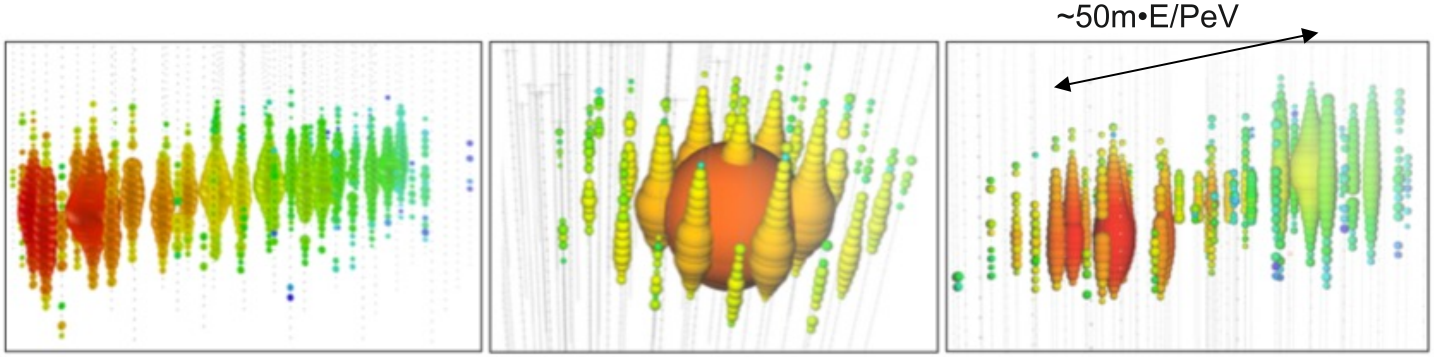
DeepCore
- Low energy (< a few 100 GeV)
- Track energy by range (ionization)
- Track vs. Cascade



IceCube
- High energy (> 50 TeV)
- Energy by shower (radiation)
- Track vs. Cascade vs. Double cascade

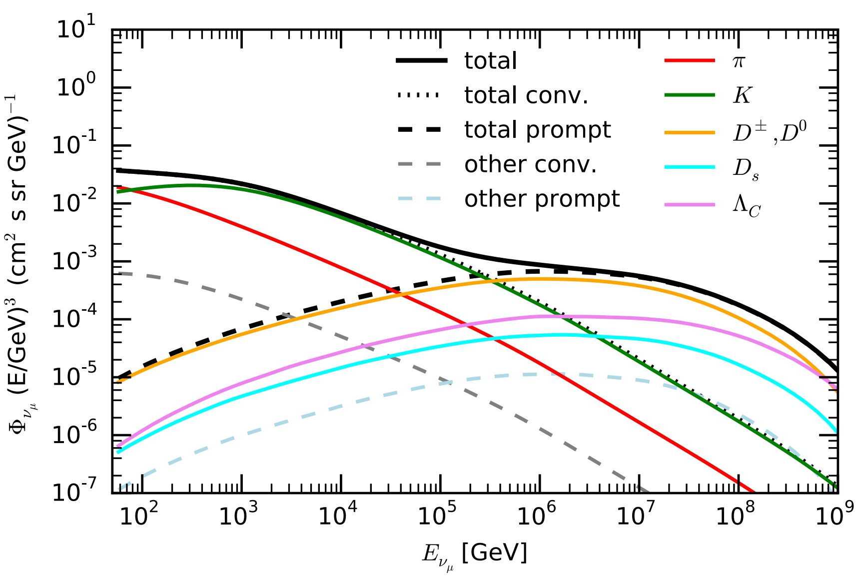
IceCube, ArXiv:2011:03561

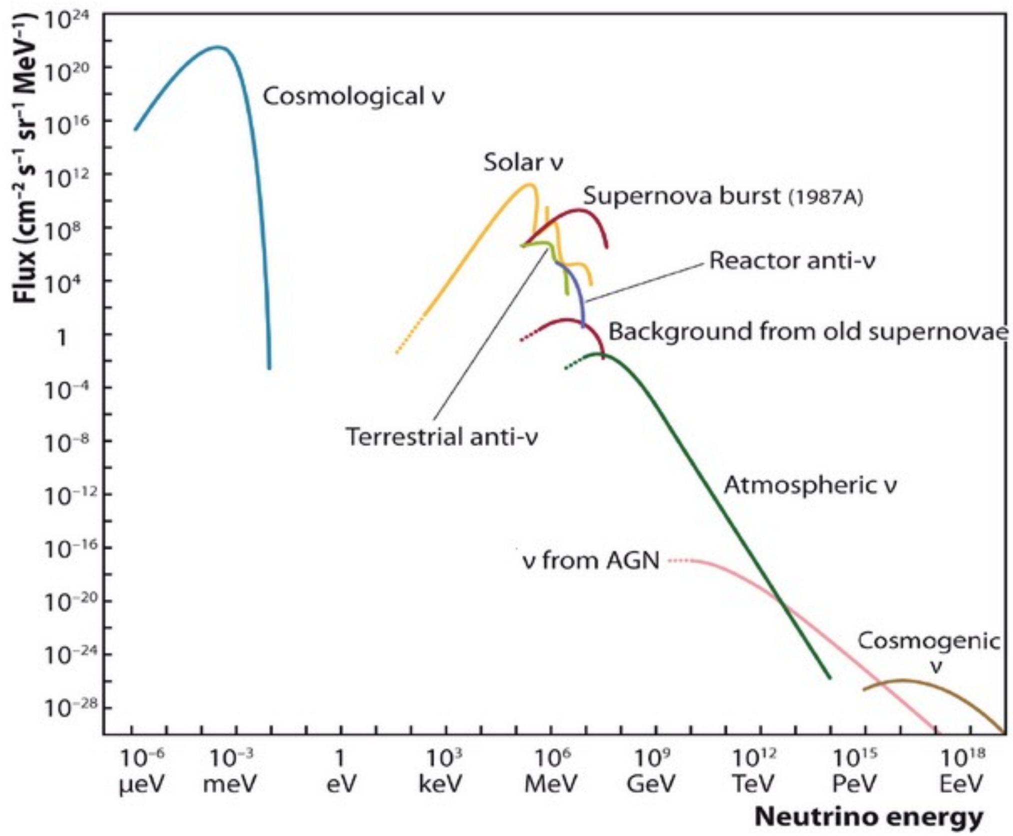


1. Introduction

Atmospheric and astrophysical neutrino flux

- Conventional atmospheric neutrinos (<50 TeV)
- Prompt atmospheric neutrinos (>50 TeV)
- High-energy astrophysical neutrinos (>50 TeV)
- Comic neutrinos (>???)

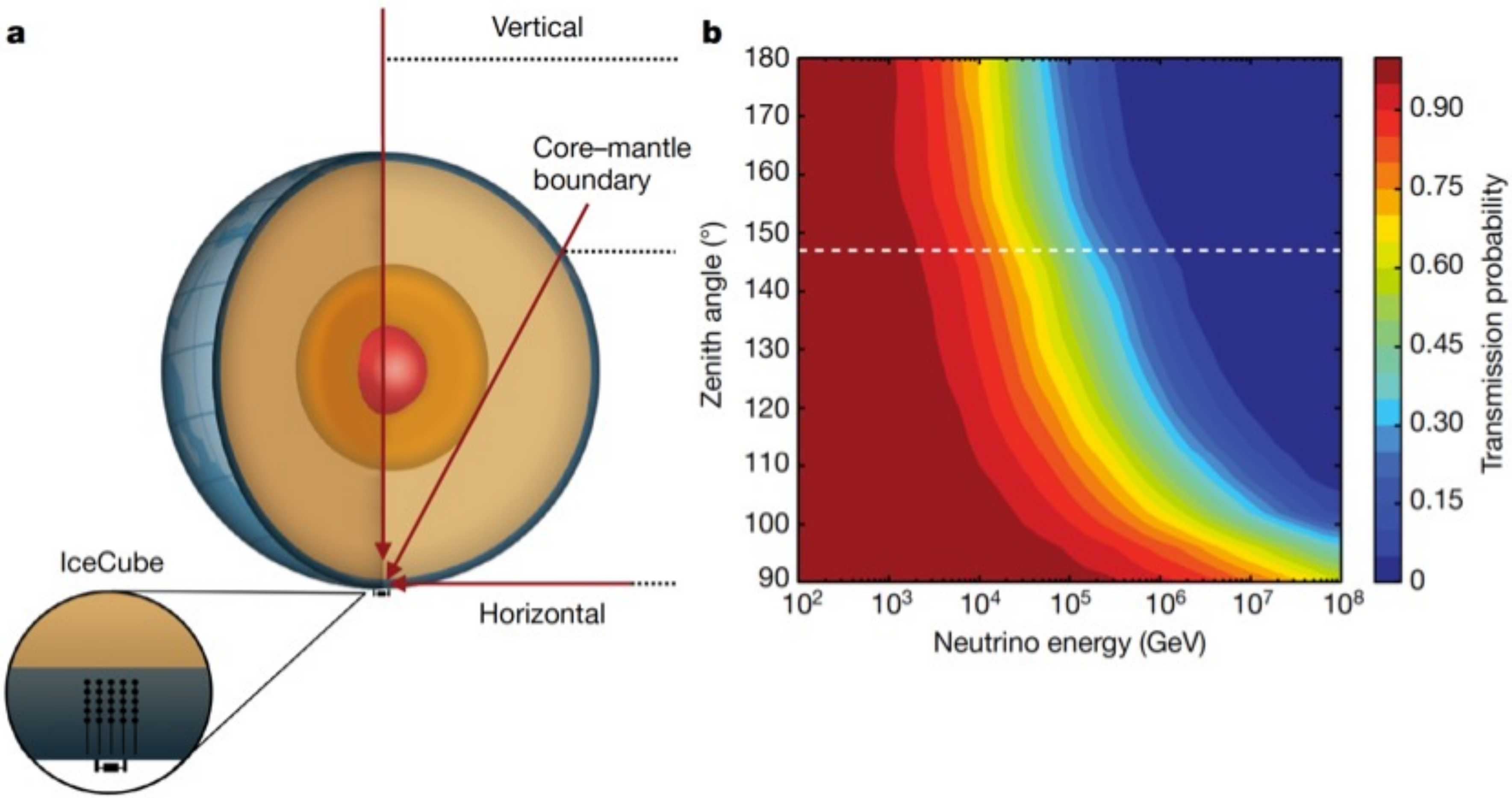




1. Introduction

Earth absorption

- Around 50 TeV, neutrinos have ~50% survival chance to penetrate the Earth diameter

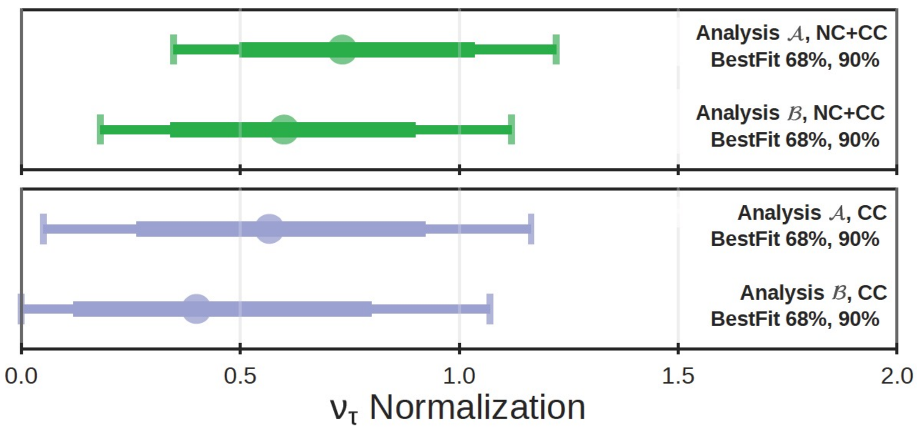


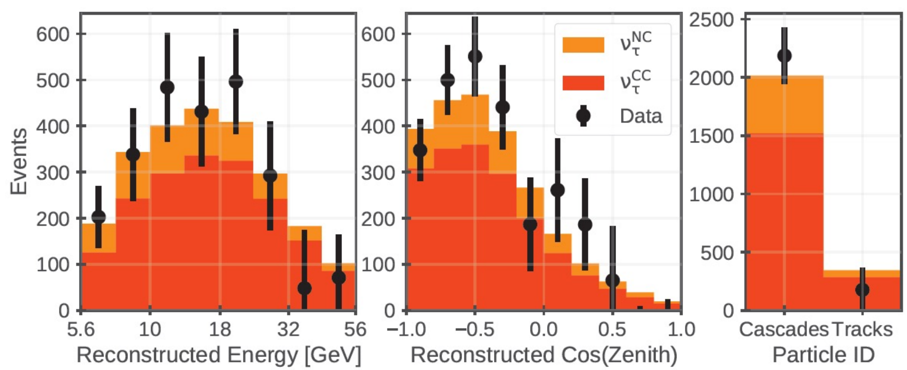
IceCube, PRD99(2019)032007

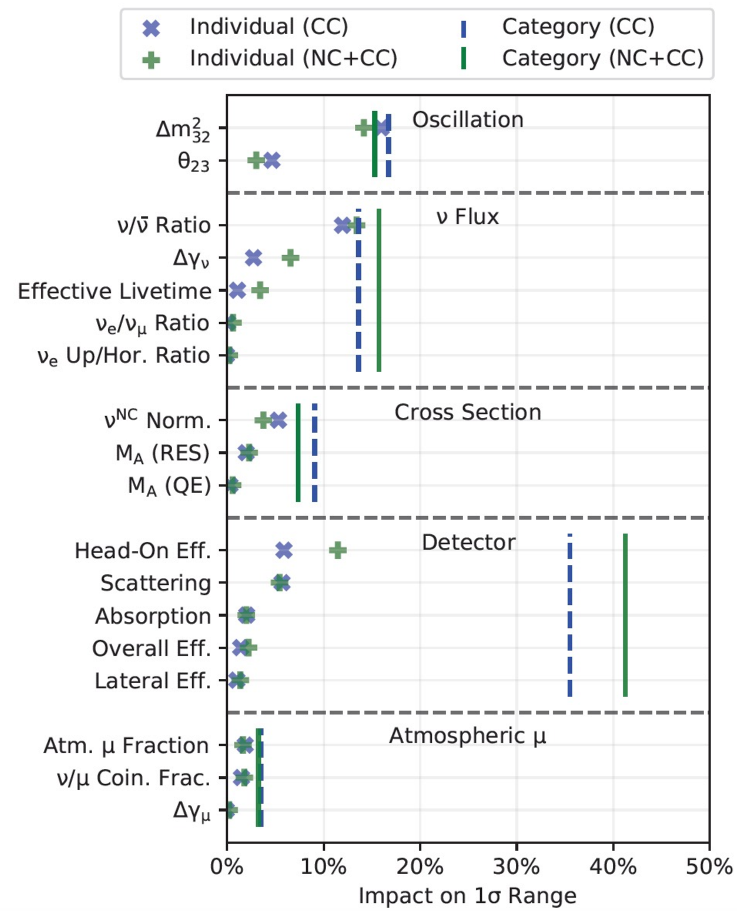
2. Low-energy cross section analysis

DeepCore analysis

- below a few 100 GeV
- ~35 GeV is the first oscillation maximum for the Earth diameter
- Similar tools (GENIE) with LBL experiments
- Similar topics (numu disappearance, tau appearance) with LBL experiment



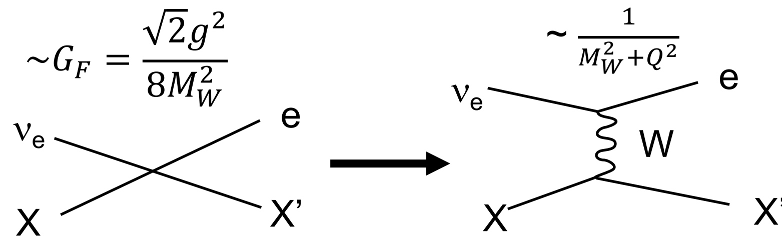




3. High-energy cross section analysis with through-going events

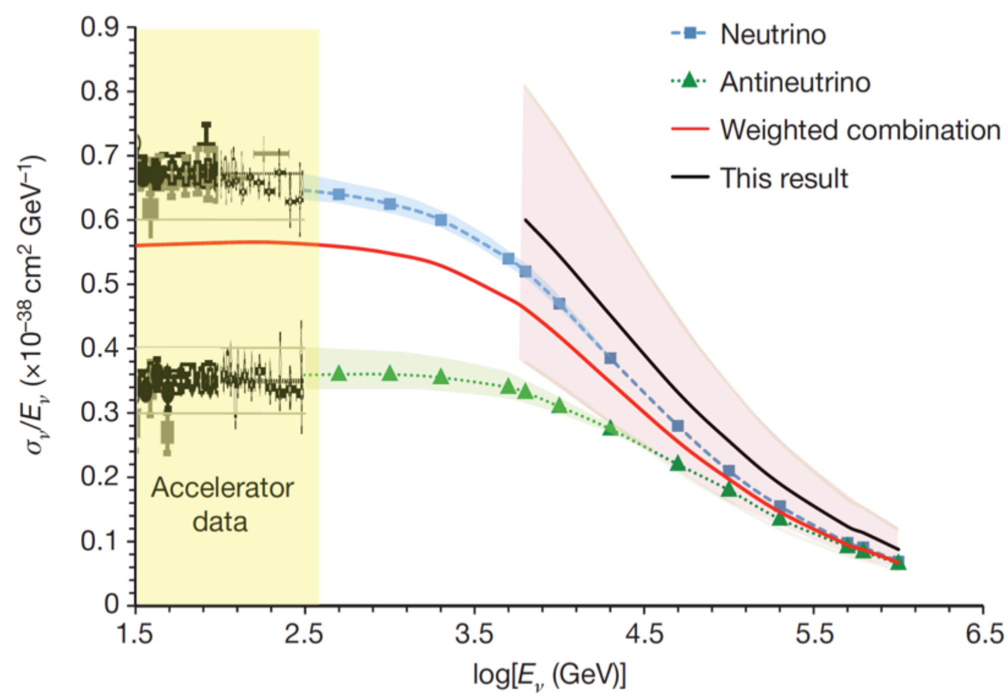
IceCube analysis

- CSMS model (iso-scalar, NLO PDF)
- Weighted averaged of numu and anti-numu
- Target, surrounding rock and ice
- analysis is based on the forward folding
- flux spectrum index ($\propto E^{-\gamma}$), γ=2.42±0.02
- DIS xs is not linear from ~10 TeV



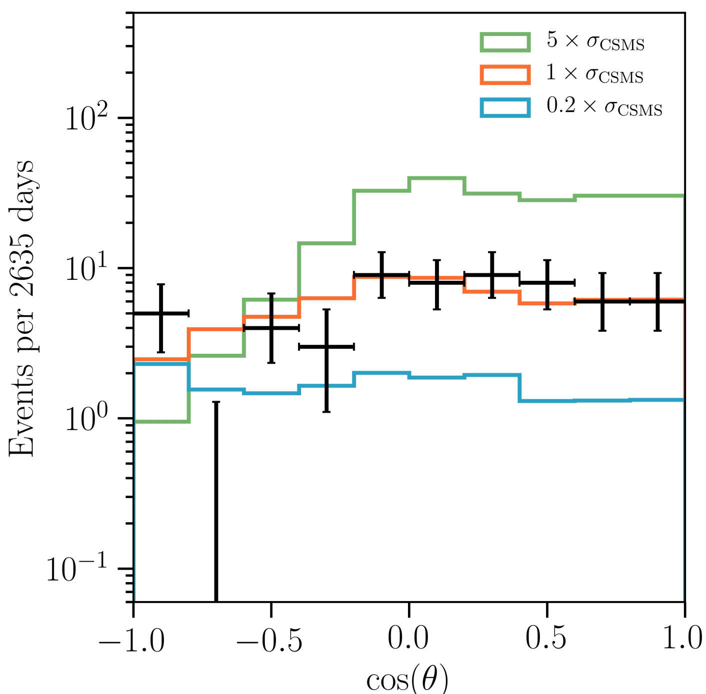
cross section | efficiency | flux | target

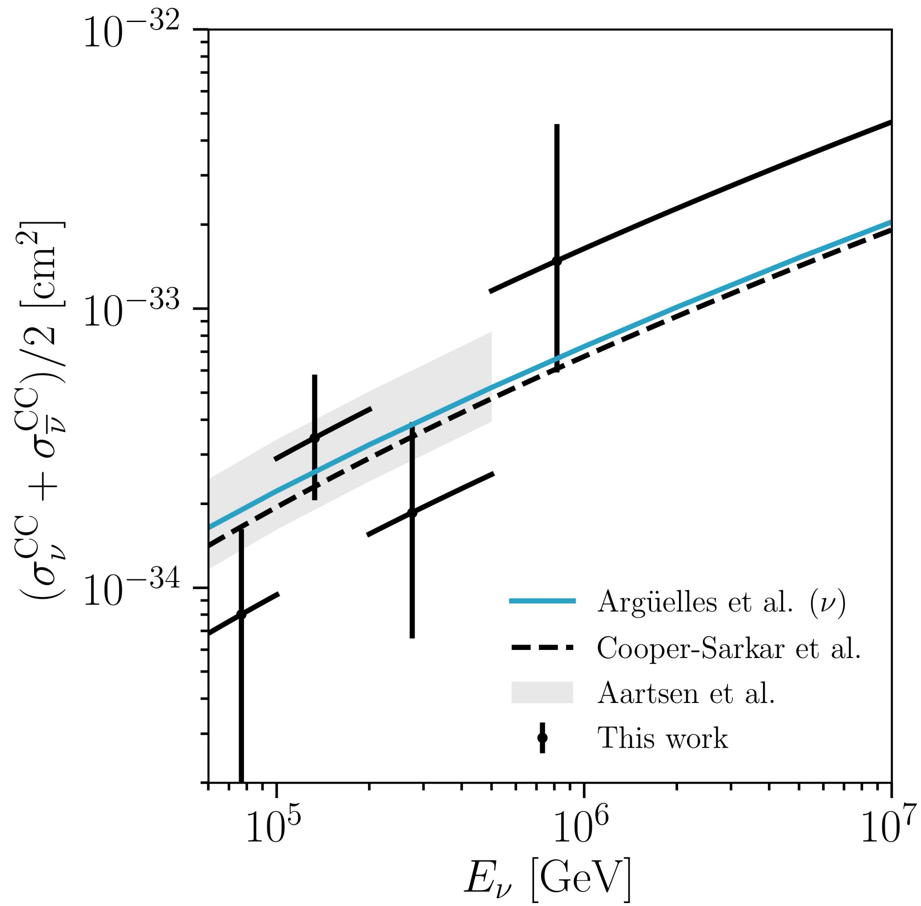
Event rate $N = \Phi \times \sigma \times T \times \varepsilon$



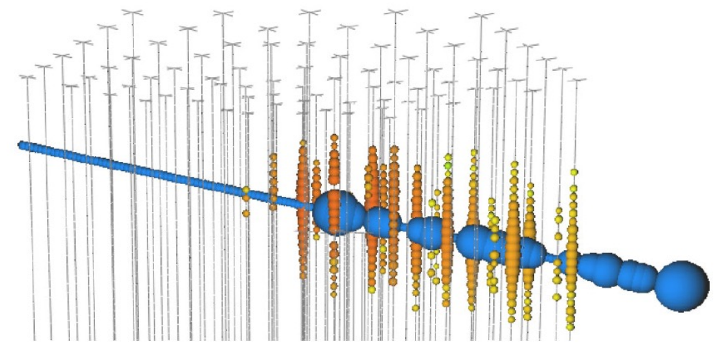
3. High-energy cross section analysis with fully-contained events

IceCube analysis
- CSMS model (iso-scalar, NLO PDF)
- Weighted averaged of nu and anti-nu, for all flavors
- Target, fiducial volume ice
- analysis is based on the forward folding
- flux spectrum index ($\propto E^{-\gamma}$), γ=2.9±0.2
- new physics model from ~ PeV



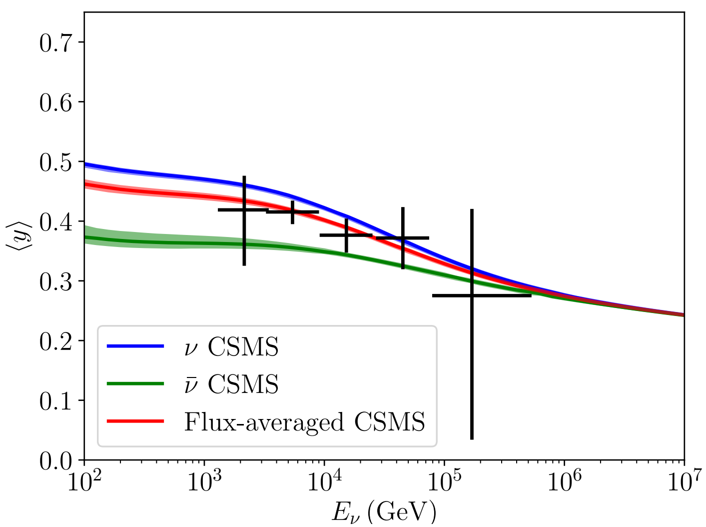


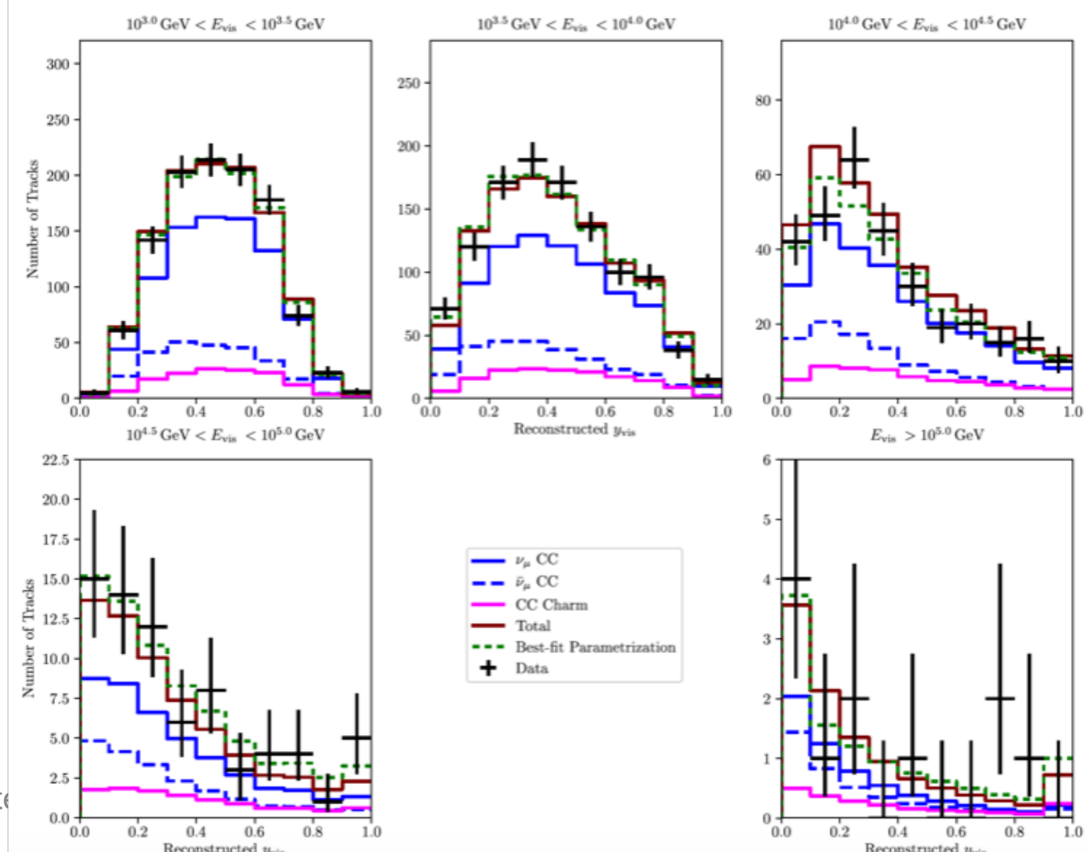
4. High-energy neutrino inelasticity



IceCube analysis

- CSMS model (iso-scalar, NLO PDF)
- Target, surrounding rock and ice
- Fit muon track and hadronic shower
- Parameterize inelasticity, $\propto(1+\varepsilon(1-y^2))y^{\lambda-1}$
- flux spectrum index ($\propto E^{-\gamma}$), γ=2.62±0.07





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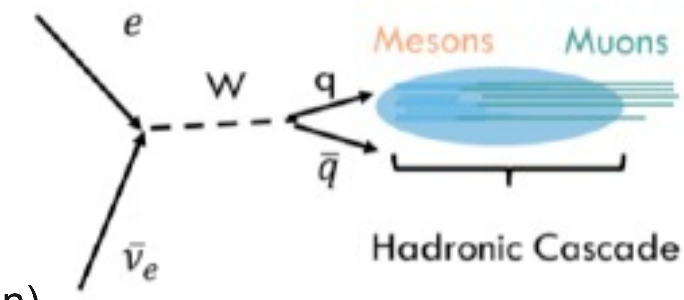
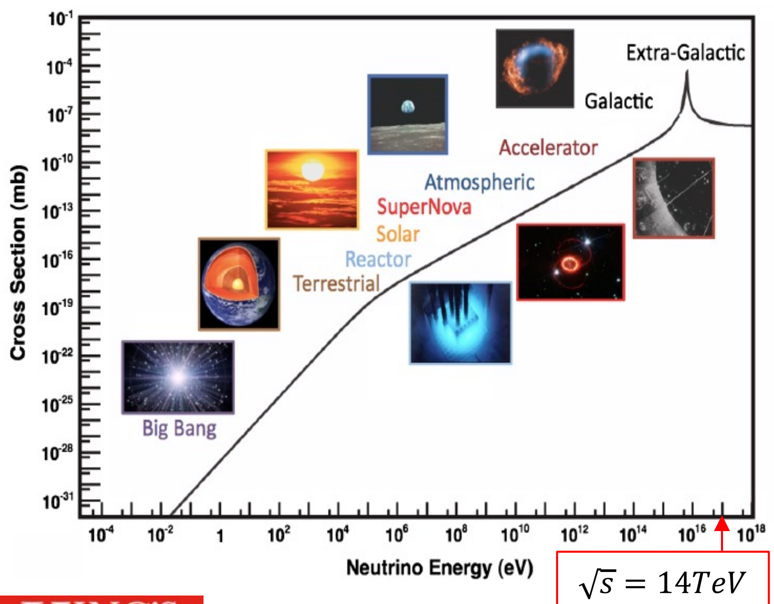
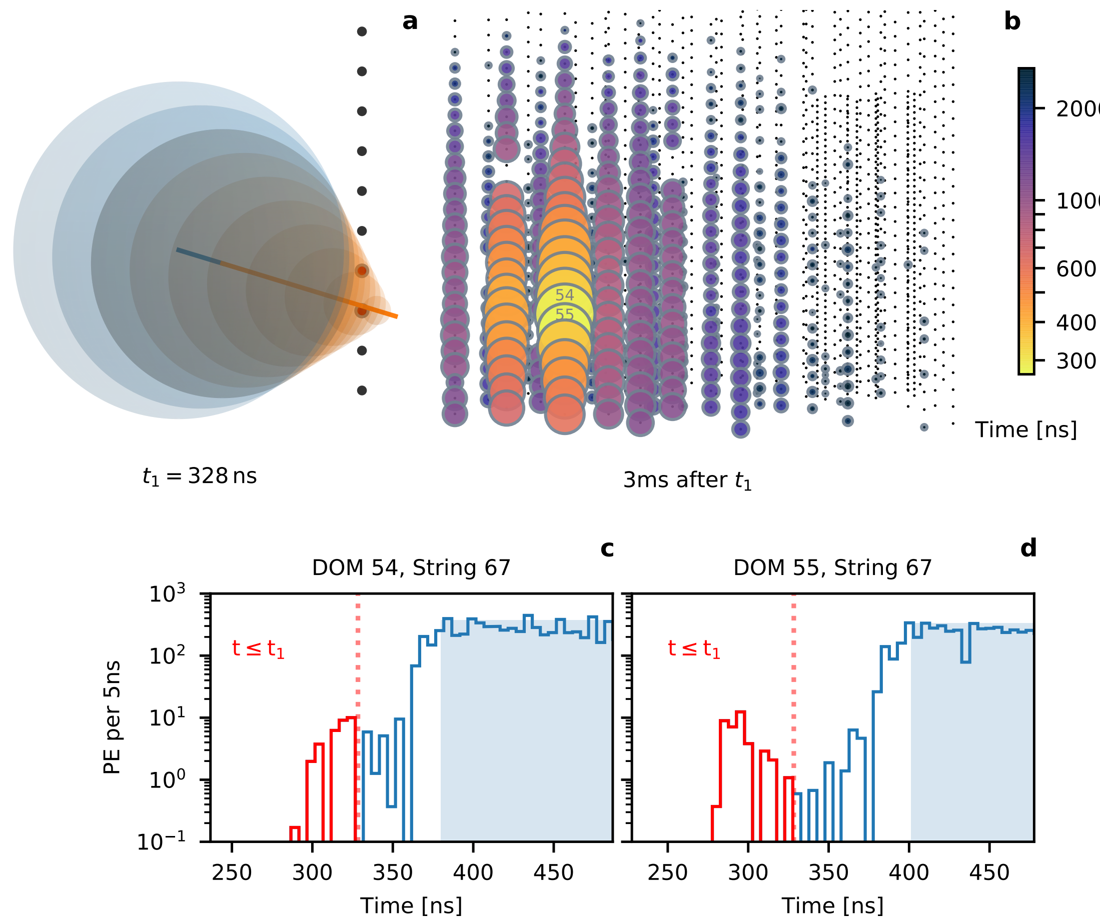
5. Glashow resonance



IceCube analysis

- Resonance on-shell W production at 6.9 PeV
- Only electron anti-nu (flavor and charge sensitive)
- Cherenkov cone front has hits faster than c (=muon)





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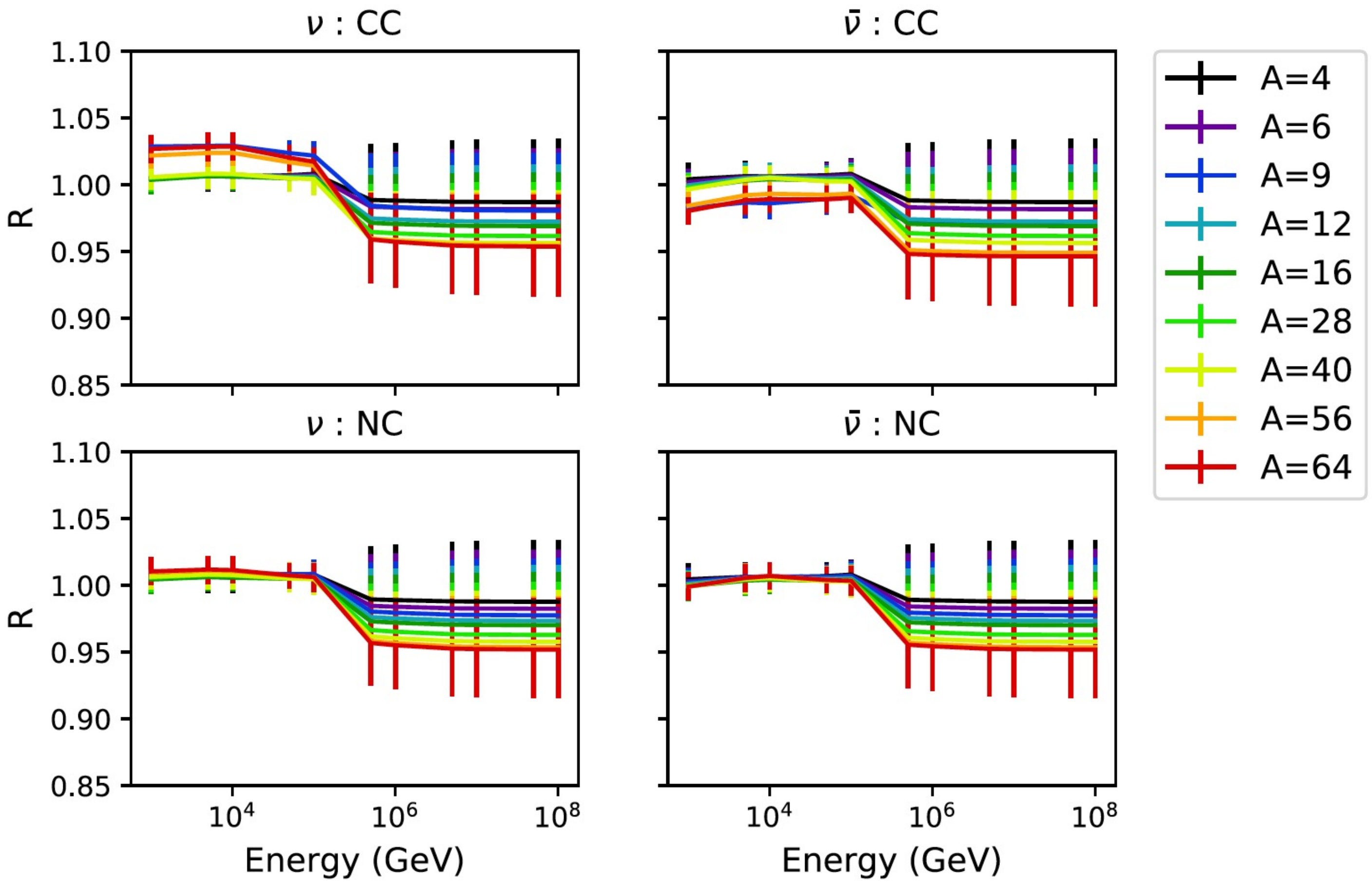
6. Nuclear effect?

Nuclear effect for high-energy neutrinos, nPDF EPPS16

- non-isoscalar effect,
- Anti-shadowing (~2%) below 500 TeV
- Shadowing (~4%) above 500 TeV
- So far not included in any analyses



6. Pion productions in astrophysical neutrinos?

$$\begin{matrix} p+p \\ p+\gamma \end{matrix} \rightarrow X + \pi \begin{cases} \pi^0 \rightarrow \gamma\gamma \\ \pi^+ \rightarrow \mu^+ + \nu_\mu \\ \mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e \\ n \rightarrow p + e^- + \bar{\nu}_e \end{cases}$$

Multi-messenger astronomy

- Astrophysical neutrino flux is predictable from gamma-ray astronomy

Cosmic neutrinos

$$p + \gamma \rightarrow \pi + p$$
$$X + \gamma \rightarrow \pi + X'$$

- From GZK cutoff (not confirmed)
- ~30EeV proton + 2.7K photon
- Race for the first detection, flux prediction (including nuclear target) is very important