Theory Meets Experiment Seminar
15/05/2020

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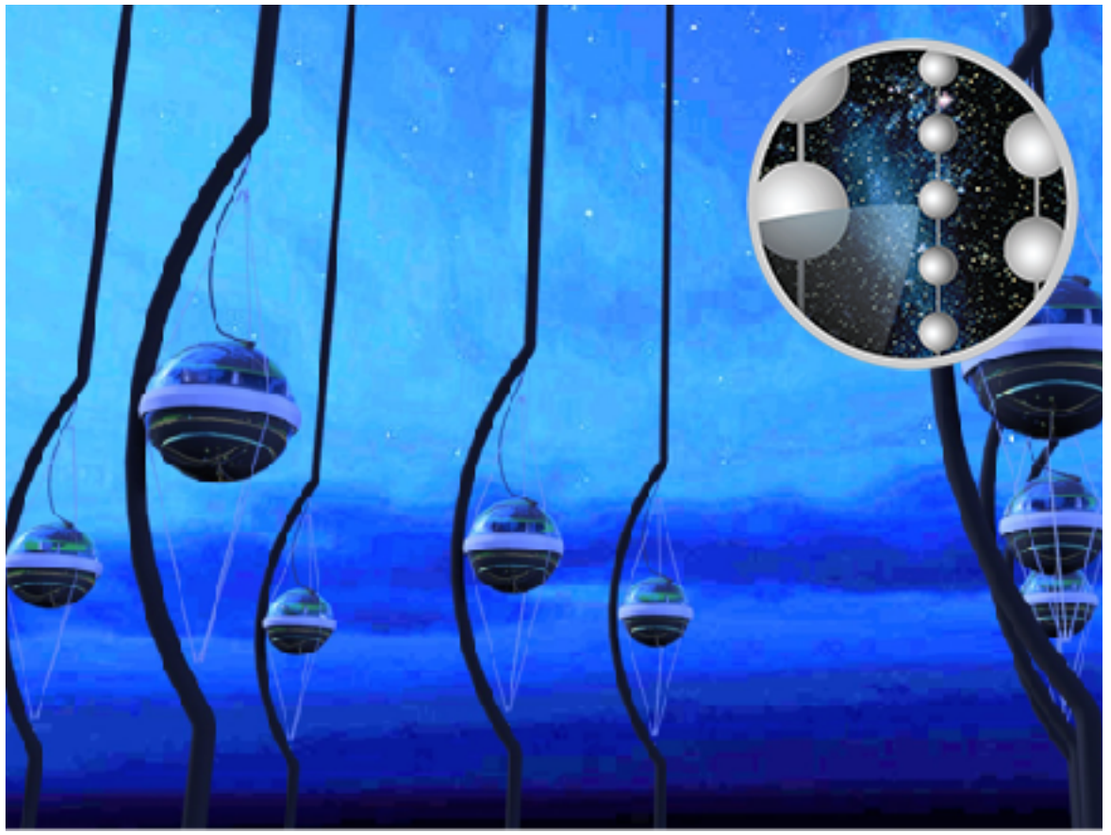
KM3NeT

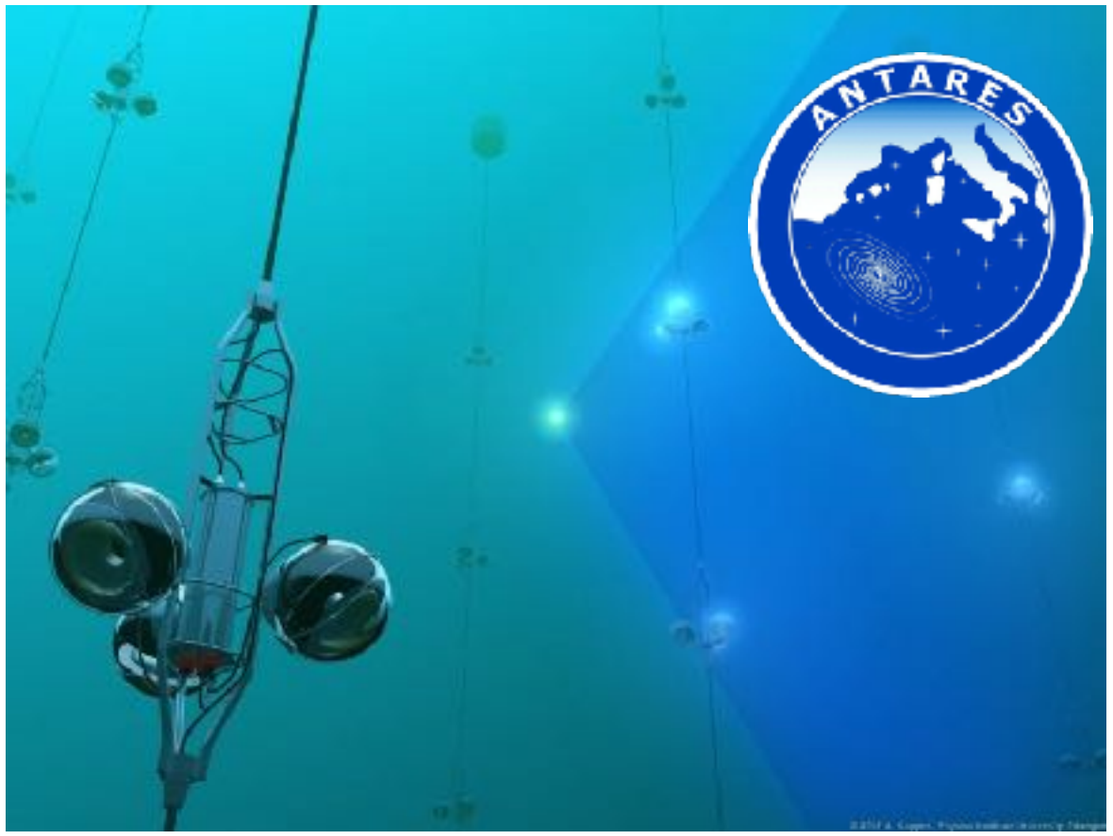
Nikhef

What is a neutrino telescope?

- Neutrinos are very difficult to catch
  - To get a few interactions:
    - Enormous volumes.
    - Intense flux.

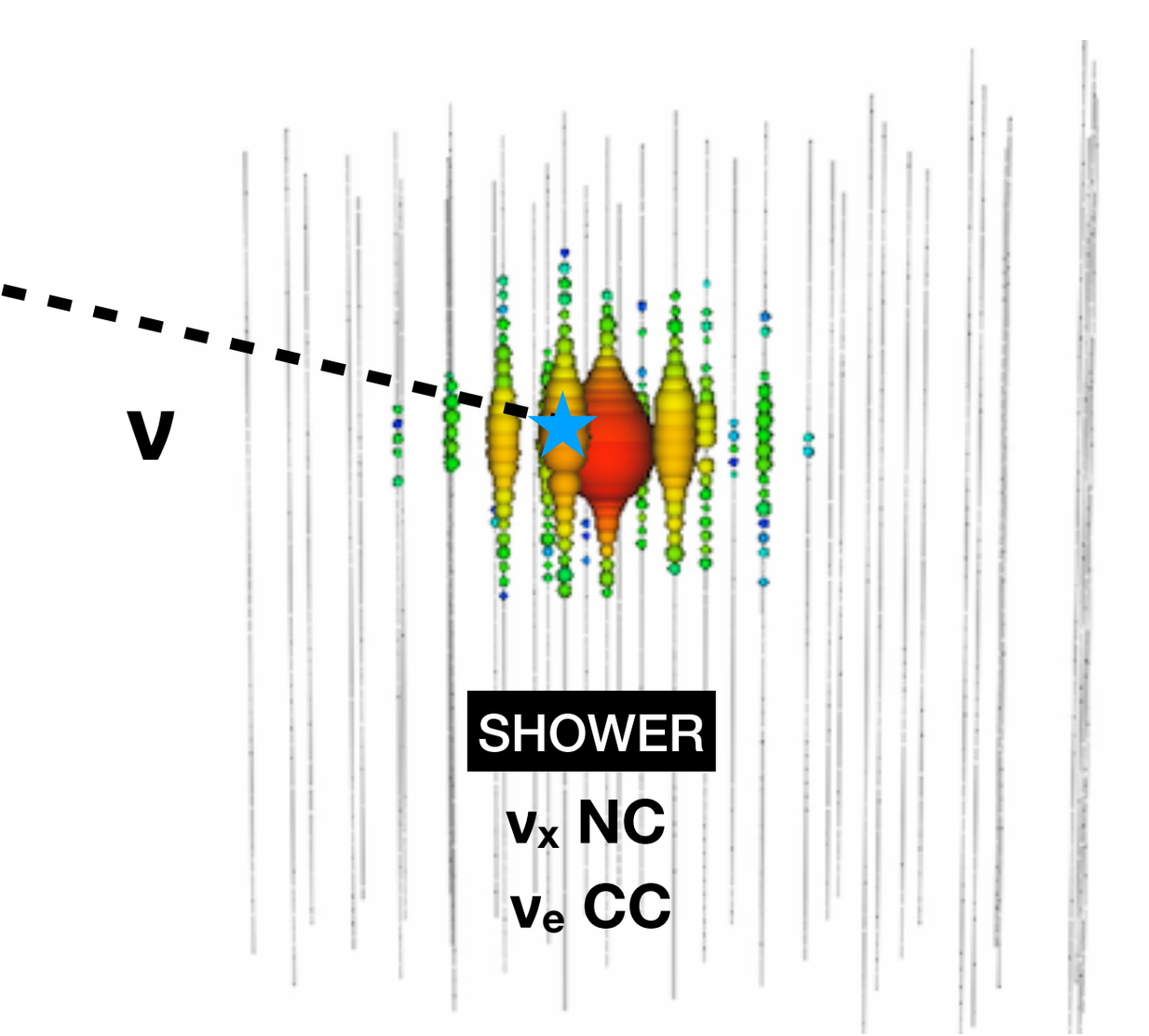


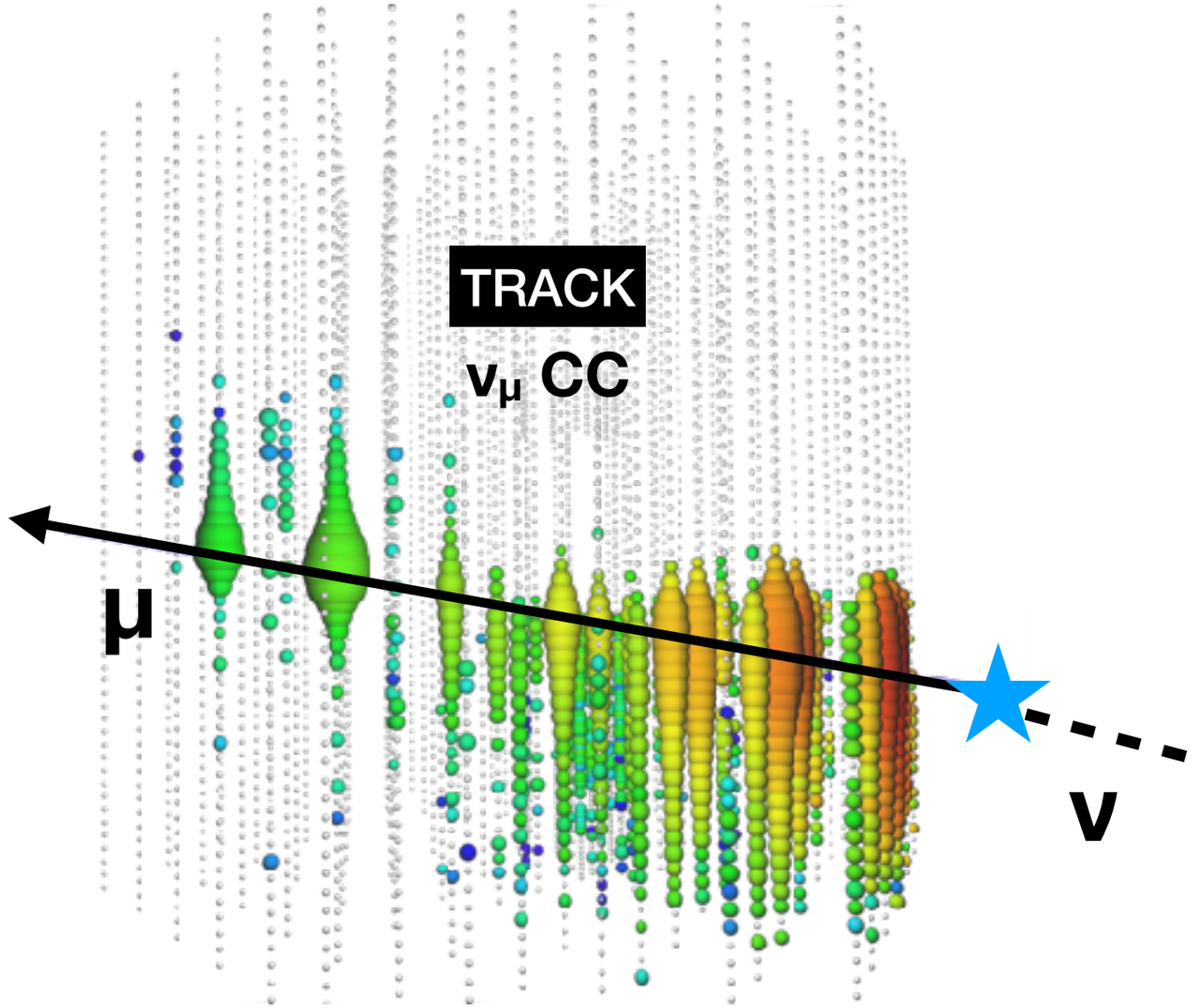
- Underwater Cerenkov detectors
  - Solid performance
  - For more than a decade, IceCube and ANTARES have been taking data.
  - Valuable for astroparticle physics.
  - …but also for particle physics!



How does it work?

- Energetic particles crossing the water produce Cerenkov light.
  - Photons collected with photon multipliers (PMTs).
  - Light pattern allows us to inferred the energy and direction of incoming particles.

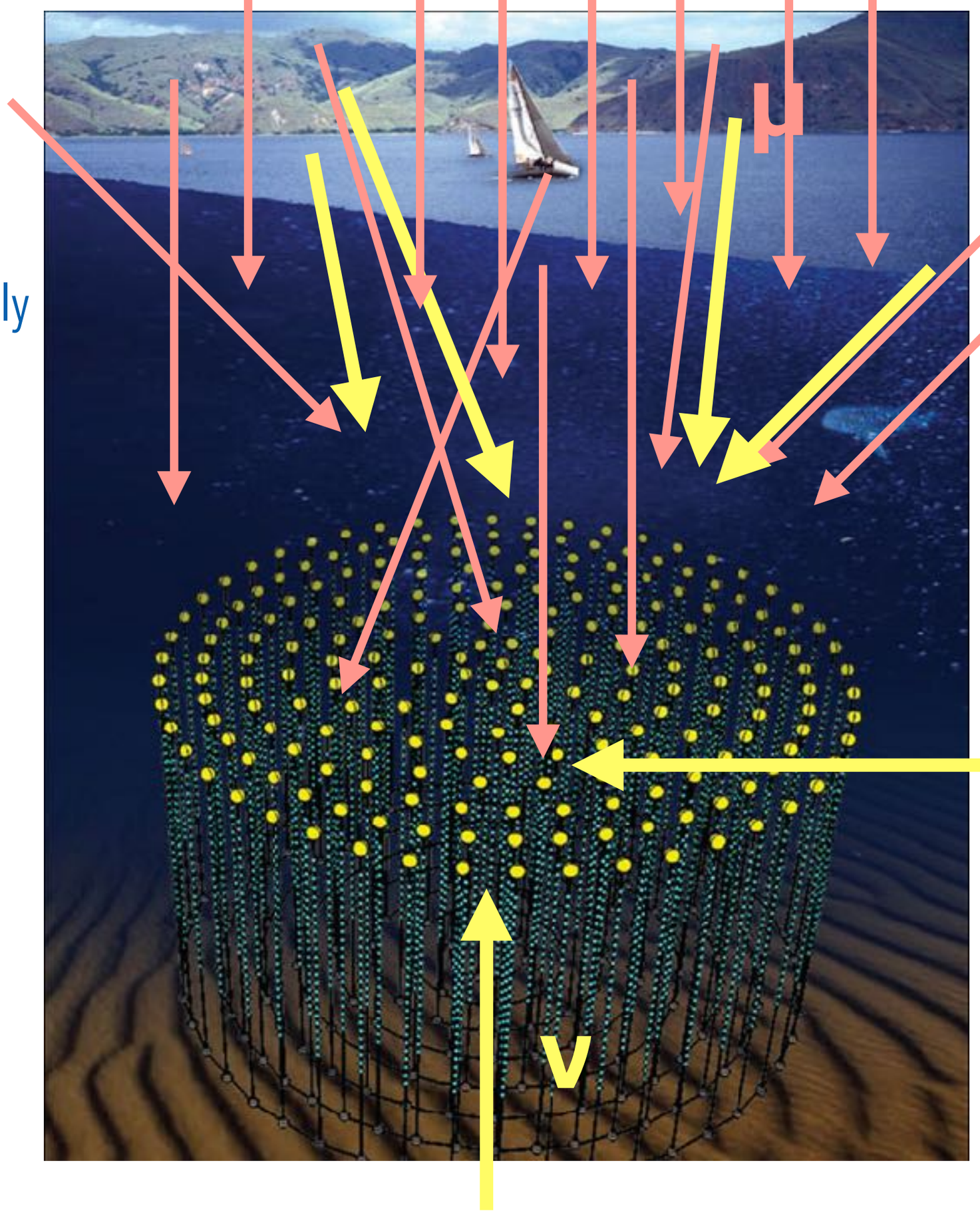




Why underwater?

- Atmospheric muons are constantly bombarding the detector.
  - The deeper you go, the less muons you have.

- Golden channels:
  - TRACK coming horizontal.
  - TRACK coming from bottom.
  - Contained SHOWER.



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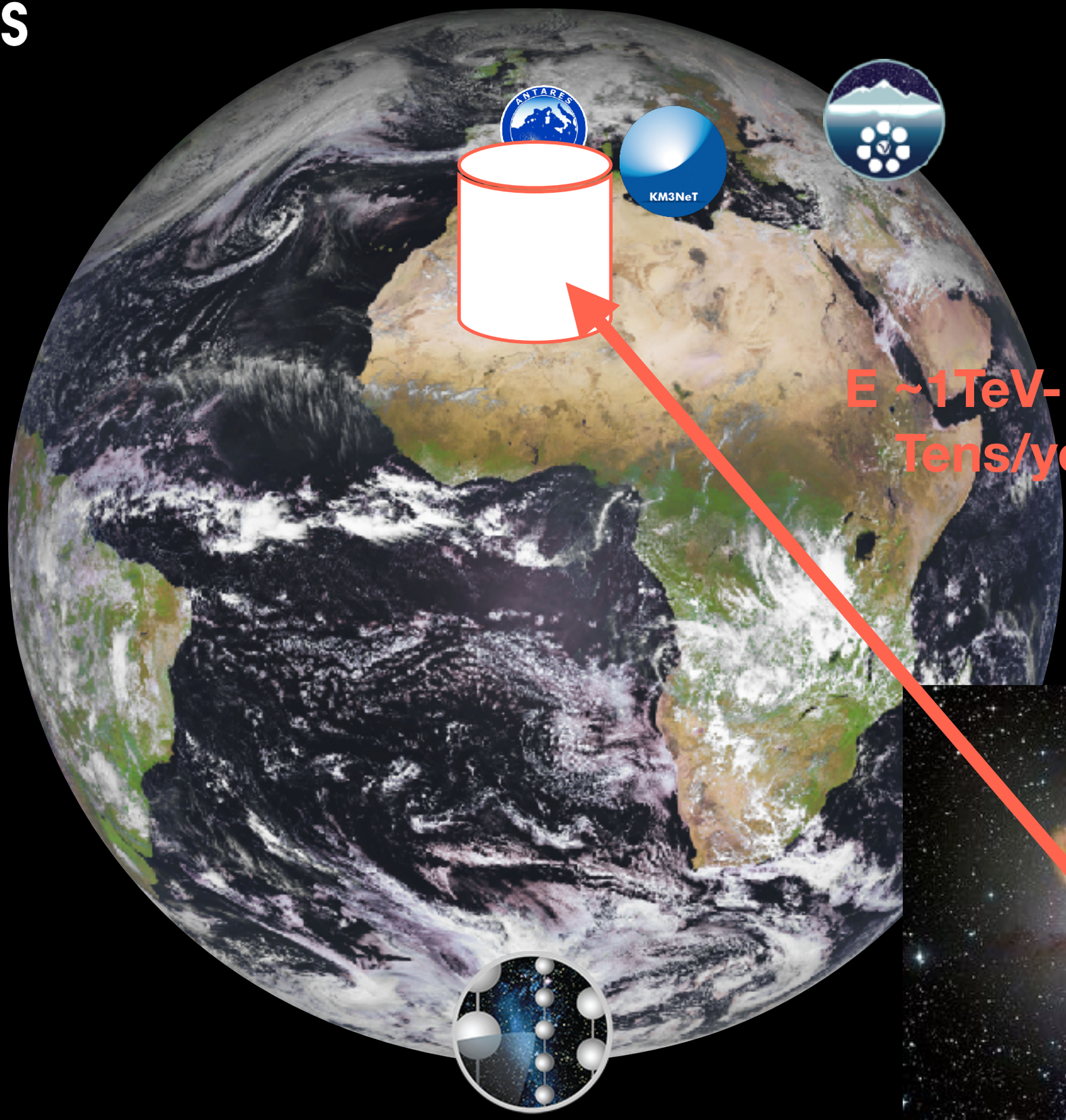
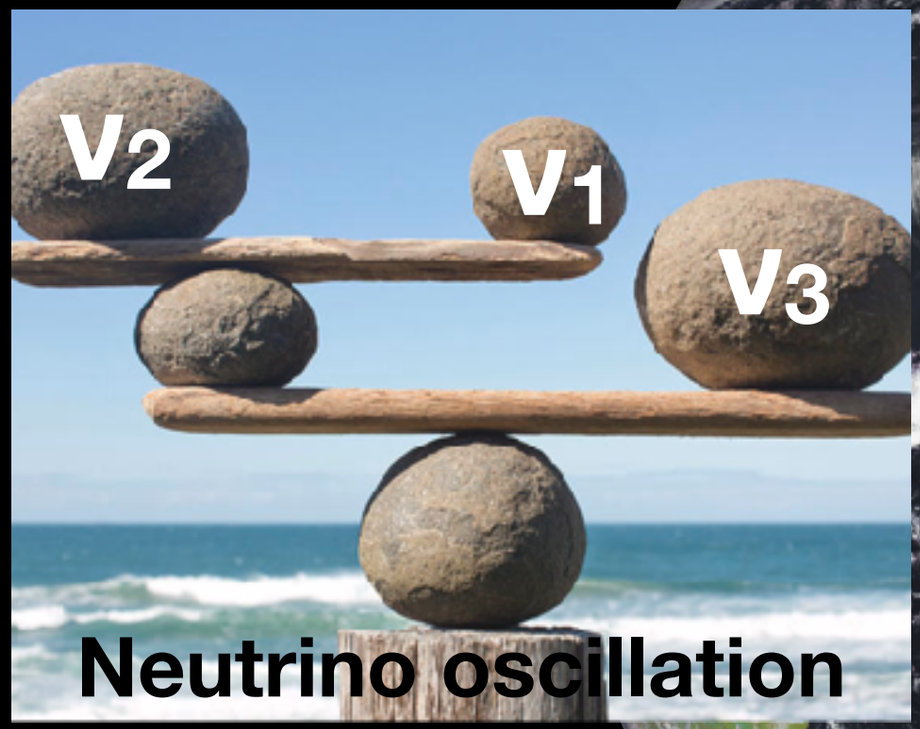


What physics can we do?



Neutrino oscillation

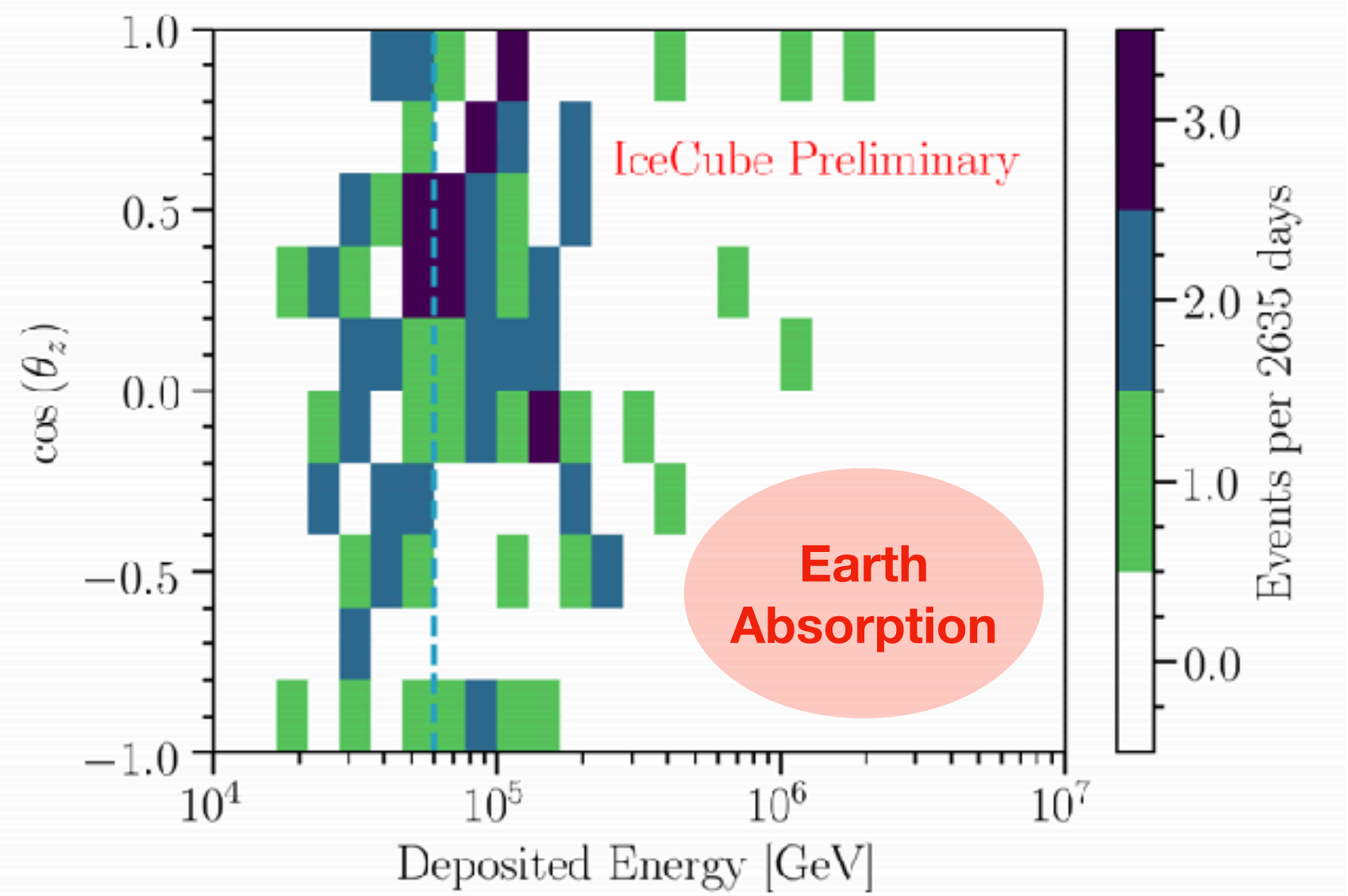
E ~1TeV-1EeV
Tens/year

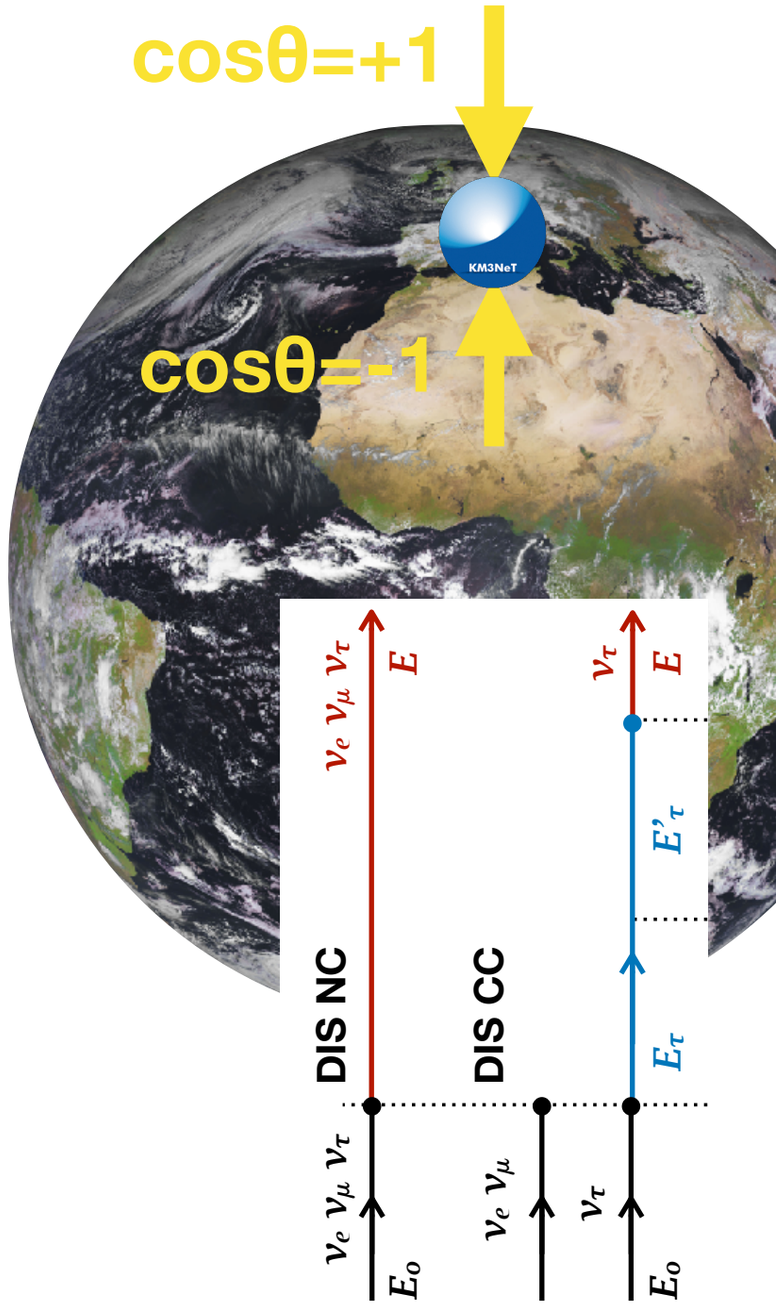
E ~1GeV-100GeV
Millions/year

How does cross section affect?

$$N(E,\cos\theta) = \phi_{source}(E,\cos\theta) \otimes e^{N_A \rho_L^{earth}(\cos\theta)\sigma(E)} \otimes N_A V_{det} \rho \sigma(E)$$

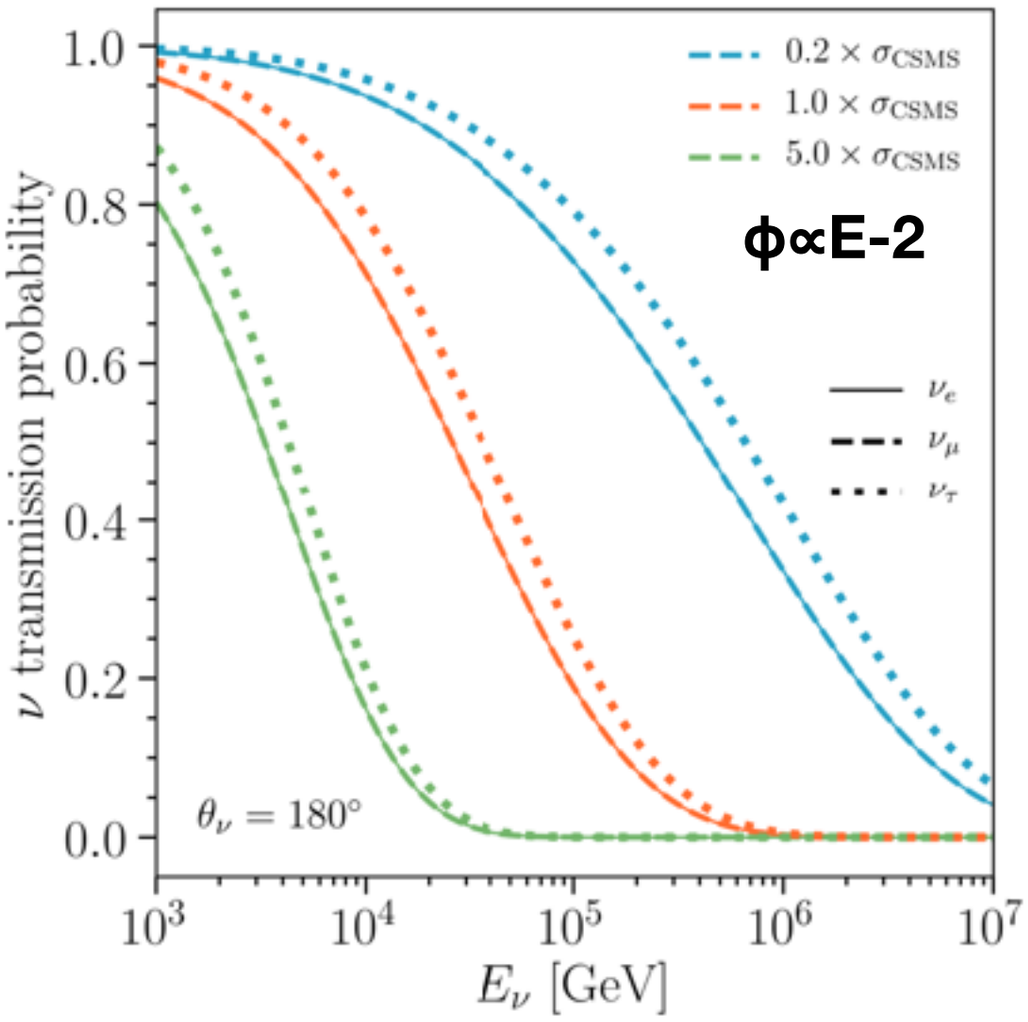
- Contained showers in IceCube:
  - 60 events in 7.5 years (E_{dep}>60TeV).

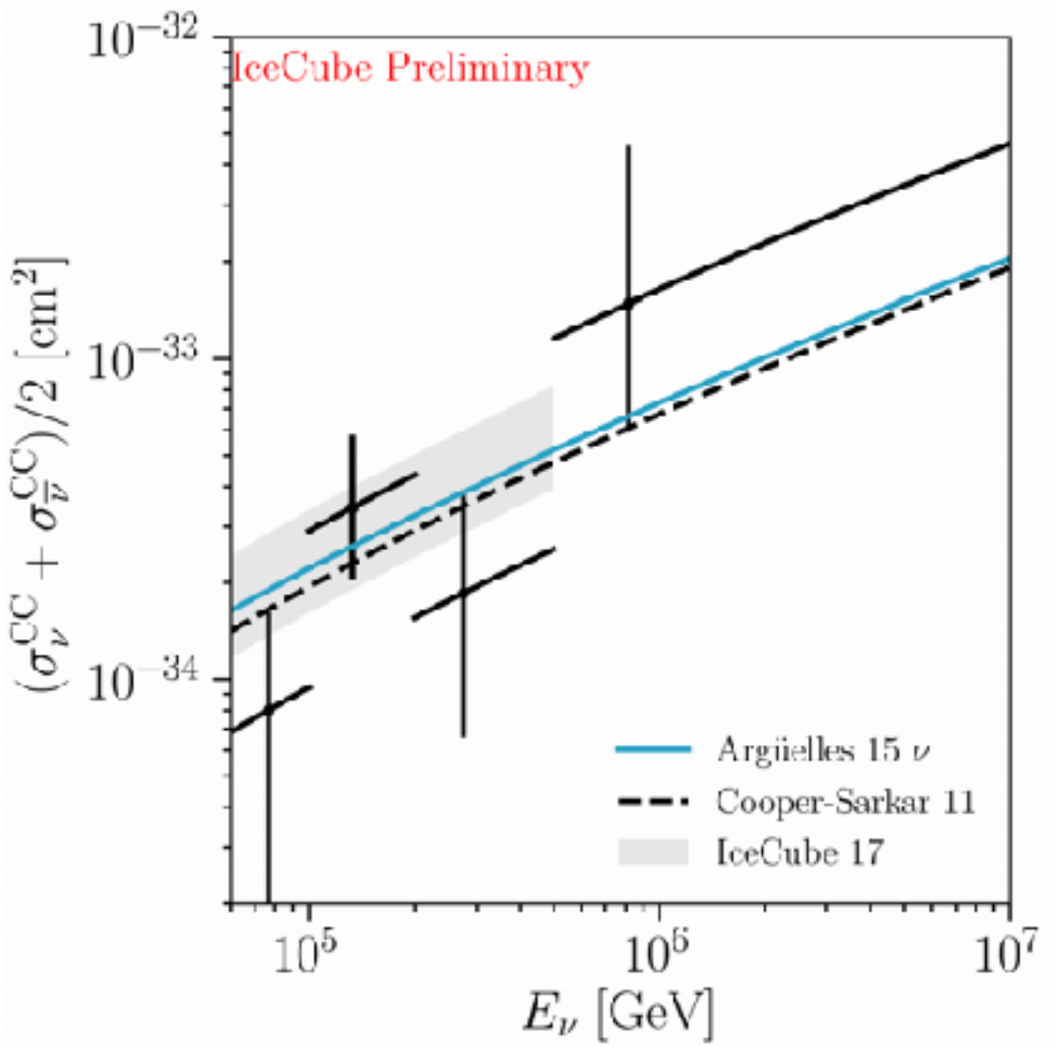




Can cross section be measured?

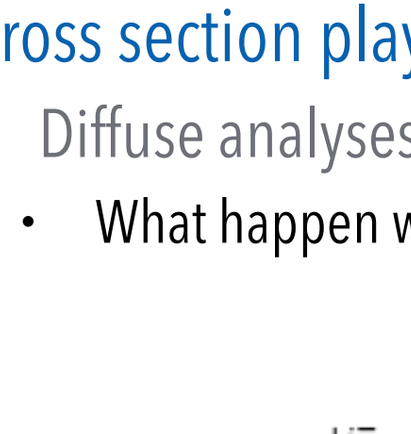
- Assuming you know well the Earth density:
  - Fit overall normalization of the CC cross section (assuming CC/NC is fixed).

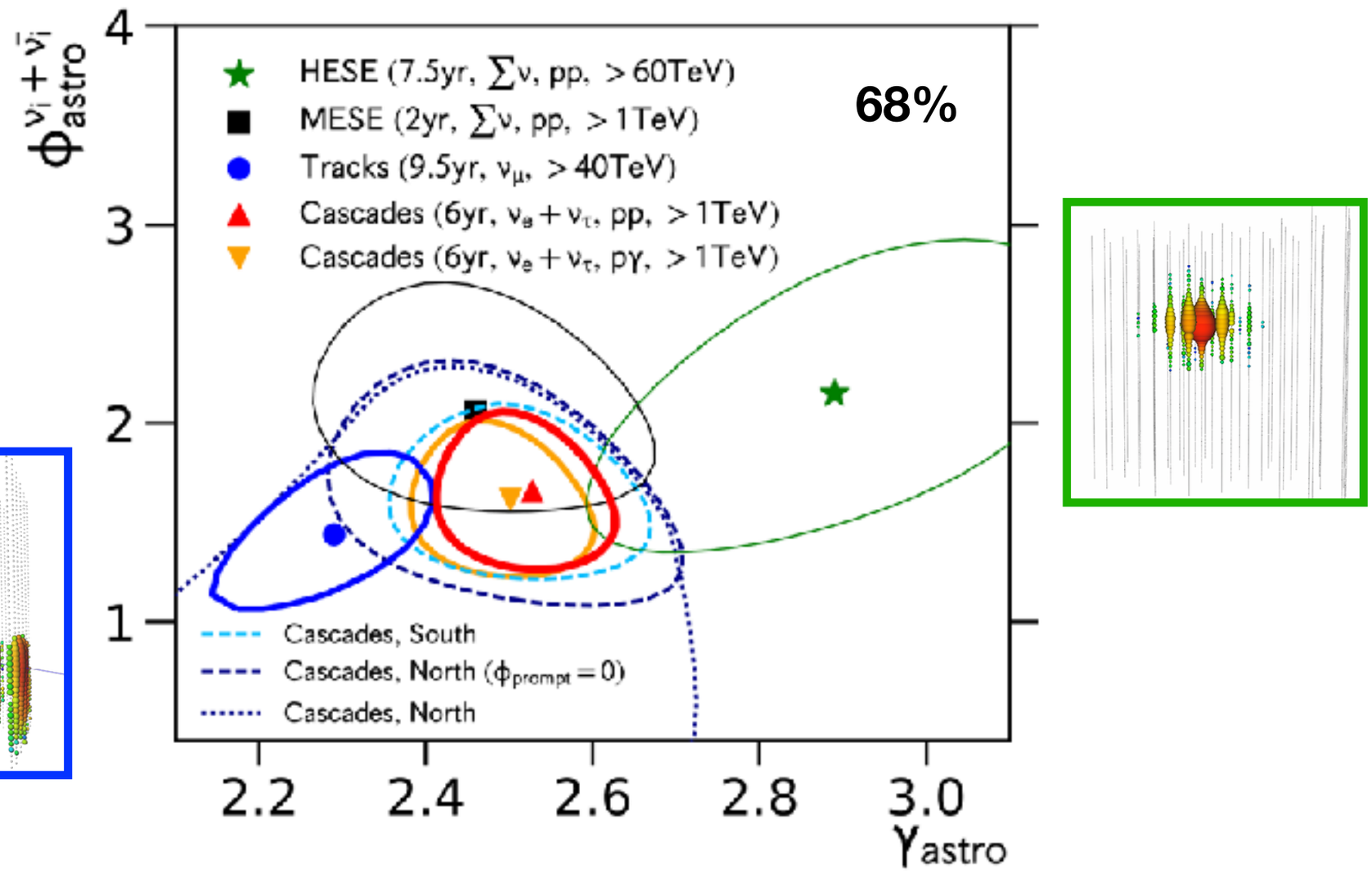




Implications:

- Cross section plays a key role in many studies:
  - Diffuse analyses.
    - What happen with HESE and Tracks?





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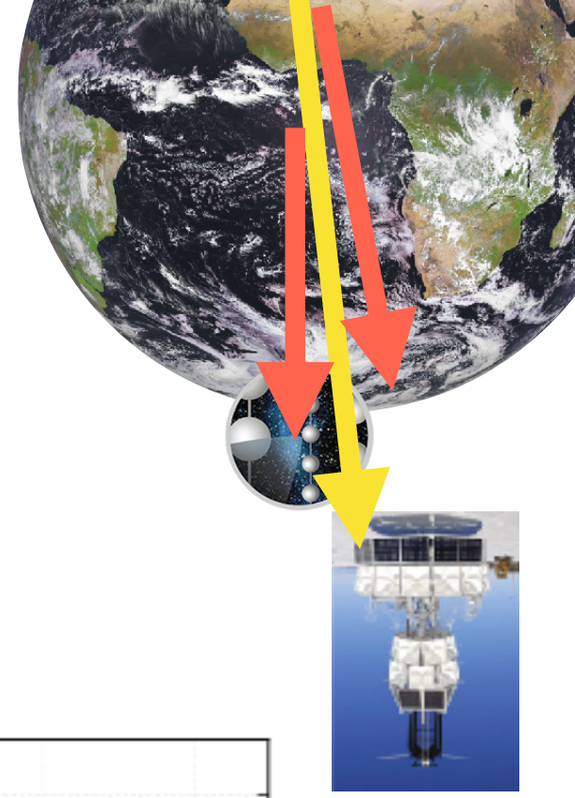
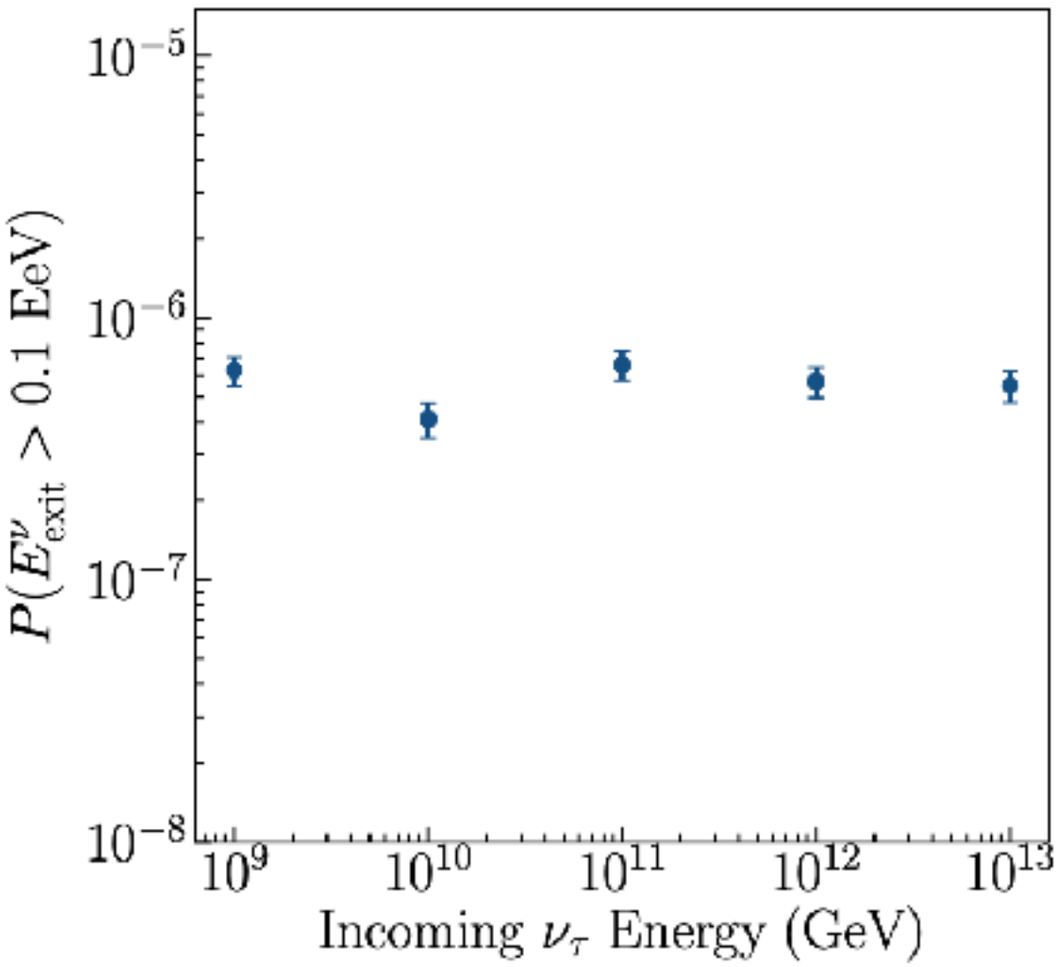
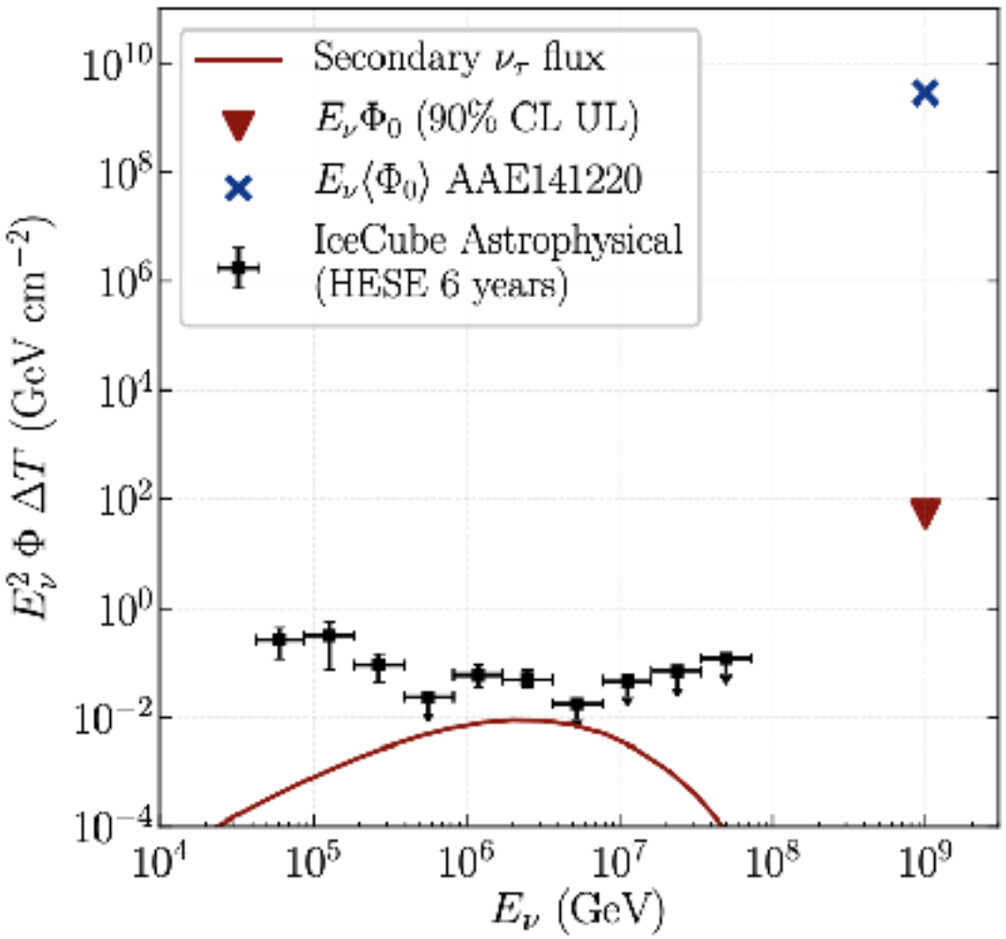


- Cross section plays a key role in many studies:
  - ANITA event (up-going nutau with E~0.5*10⁹GeV).
    - IceCube should have seen the secondary flux.





Our goal:

- Statistic still main limiting factor.
  - KM3NeT, Baykal and IceCube-Gen2 will reduce this uncertainty.

- So far, simplistic approach for cross section treatment.
  - Model
    - CMS-2011: SF(NLO) x PDF(HERAPDF15NLO)
  - Uncertainty:
    - Overall normalisation (sometimes?).

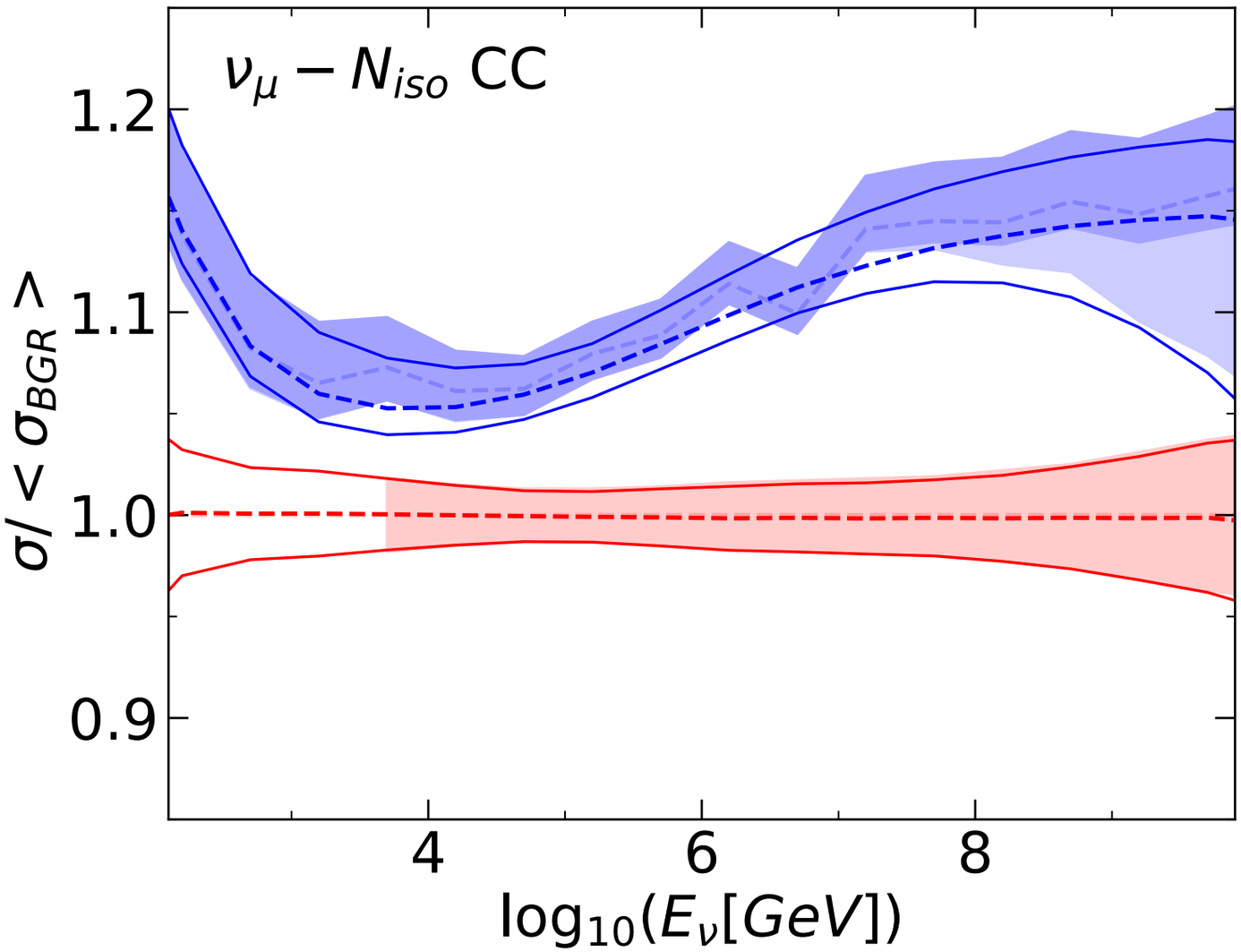
- Aim to understand better the impact of cross sections: **GENIE*-HEDIS**
  - New models
    - BGR-2018: SF(NLO) x PDF(NNPDF31_LHCb)
  - Uncertainties:
    - PDF (both in normalisation and differential cross section).
    - Nuclear effects.
    - Sub-leading processes (Rhorry, PRD2019).

https://github.com/pochoarus/GENIE-HEDIS

***GENIE is widely used in long baseline experiments to simulate neutrino interactions**

Results:

- Most relevant messages:
  - ~10% difference depending on cross section model.



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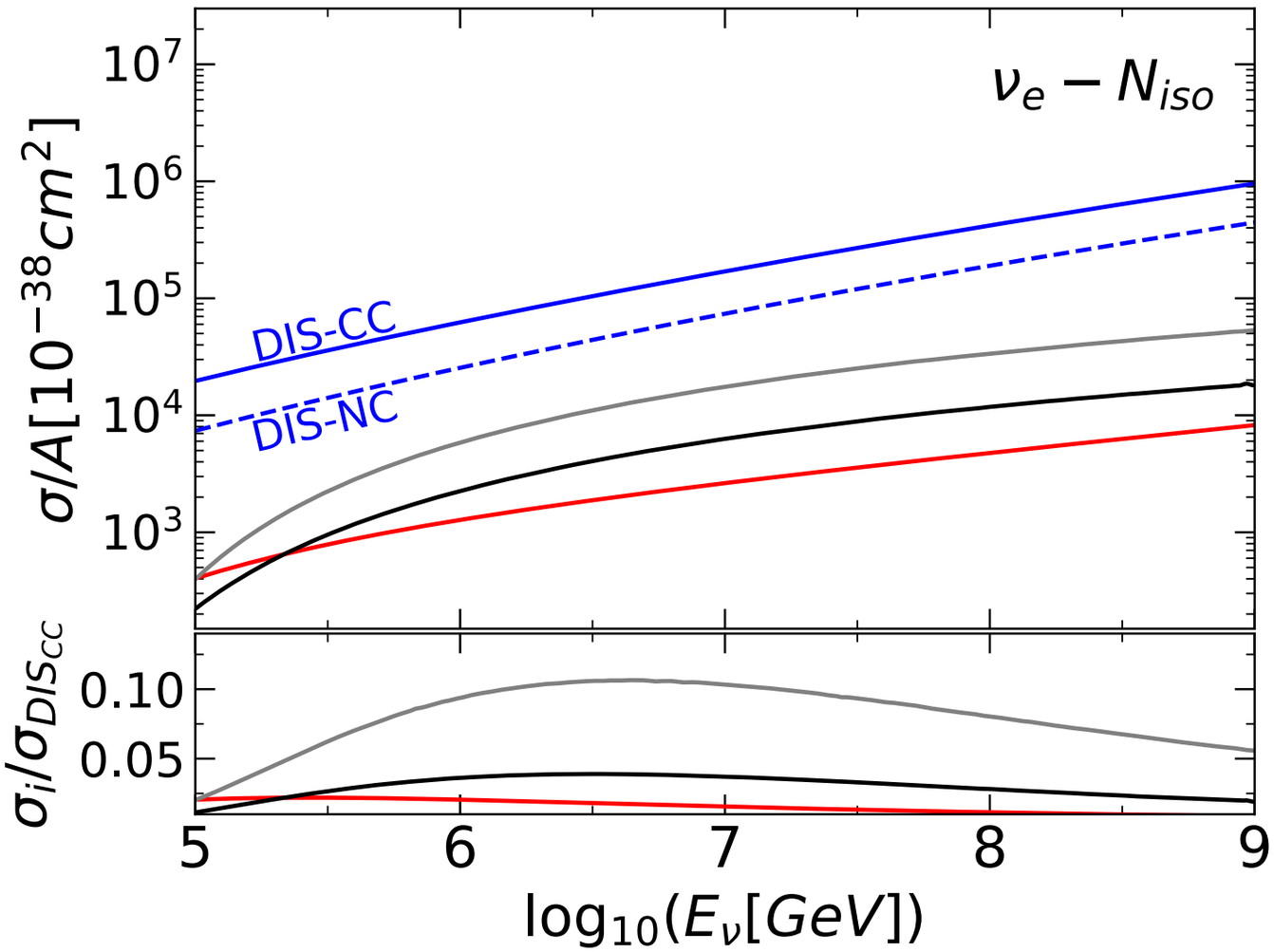
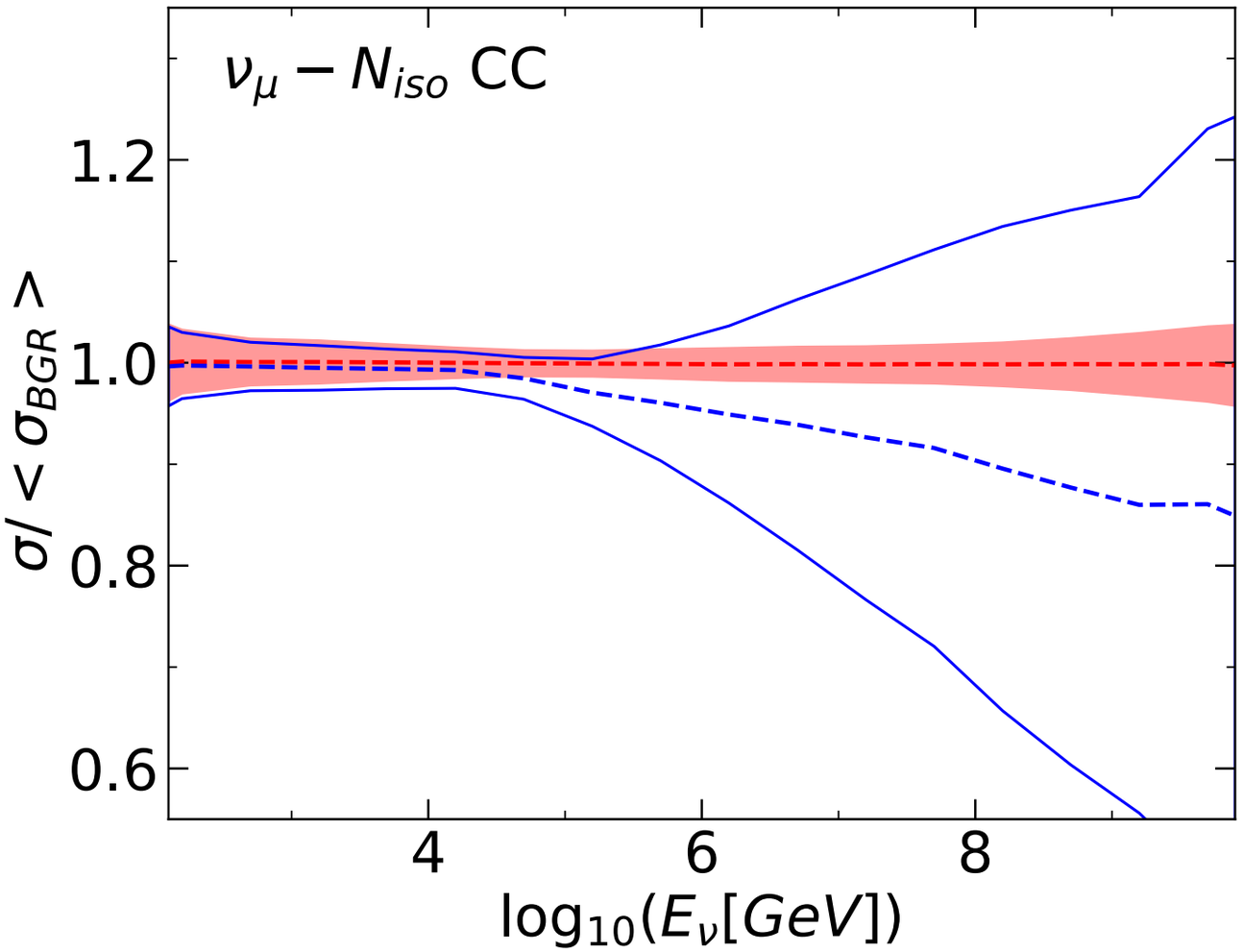
  - 5-10% enhancement due to sub-leading processes.



Results:

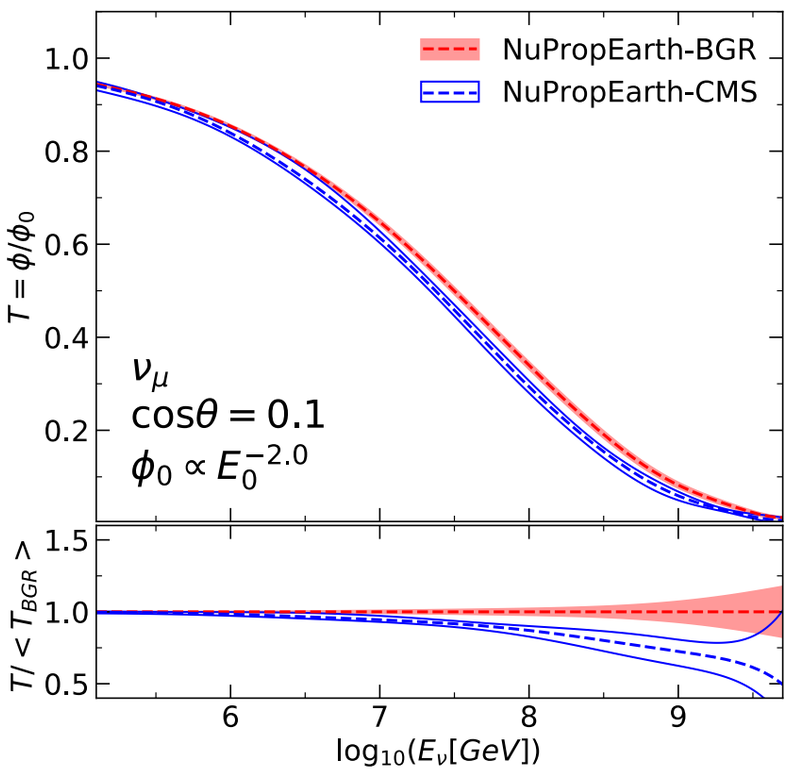
- Most relevant messages:
  - ~10% difference depending on cross section model.
  - 5-10% enhancement due to sub-leading processes.
  - 5(20)% uncertainty due to nucleon (nuclei) PDFs.



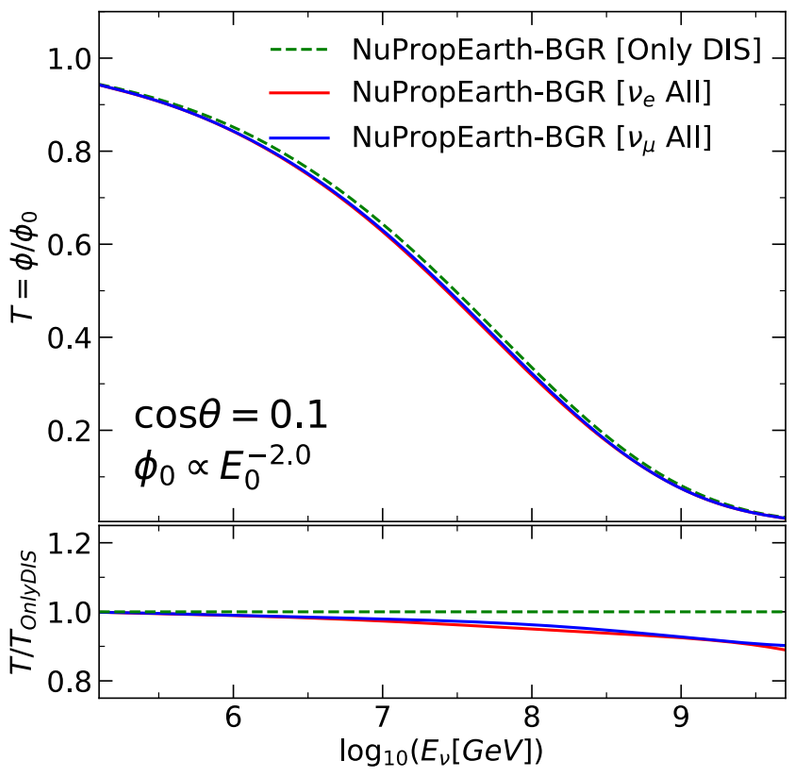
https://github.com/pochoarus/NuPropEarth

- Open source software to propagate neutrinos through Earth.
  - Used to understand cross section effects in Earth absorption.

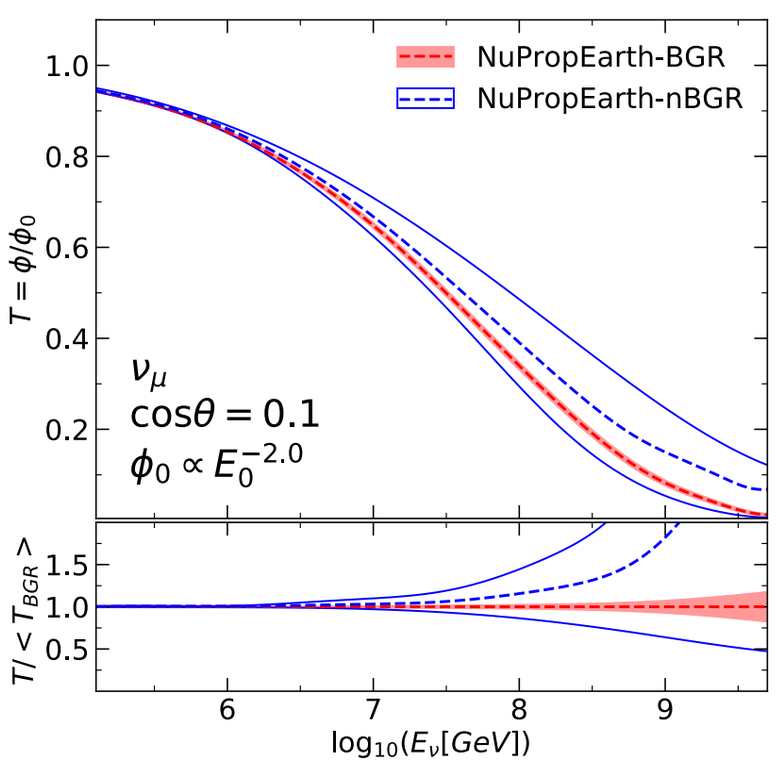
DIS Models



Sub-leading



Nuclear effects



Conclusions:

- Neutrino telescopes are opening a new era to study the universe.
- Test SM with these experiments -> precise predictions.
- The most detailed study of cross section implications has been done at NIKHEF.
  - State of the art DIS model.
  - Effect of sub-leading channels.
  - Consistent study of PDFs uncertainties.
- Future:
  - What about hadrons?
    - Hadronization is extremely simplistic (parton model). Help!!!
    - How do we propagate heavy hadrons?