

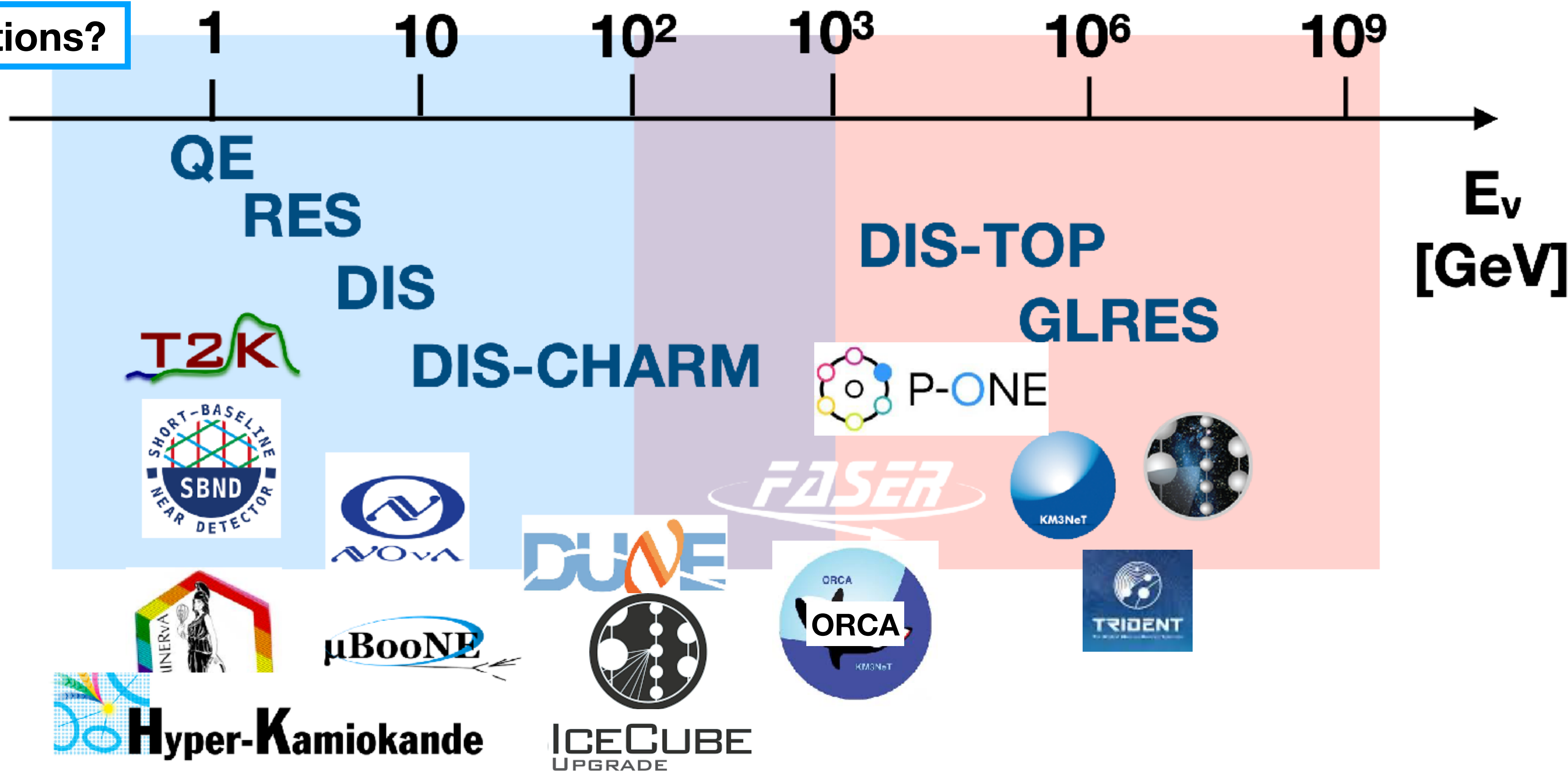


Measurement of the Neutrino-Nucleon Cross Section Across Four Decades in Energy with IceCube

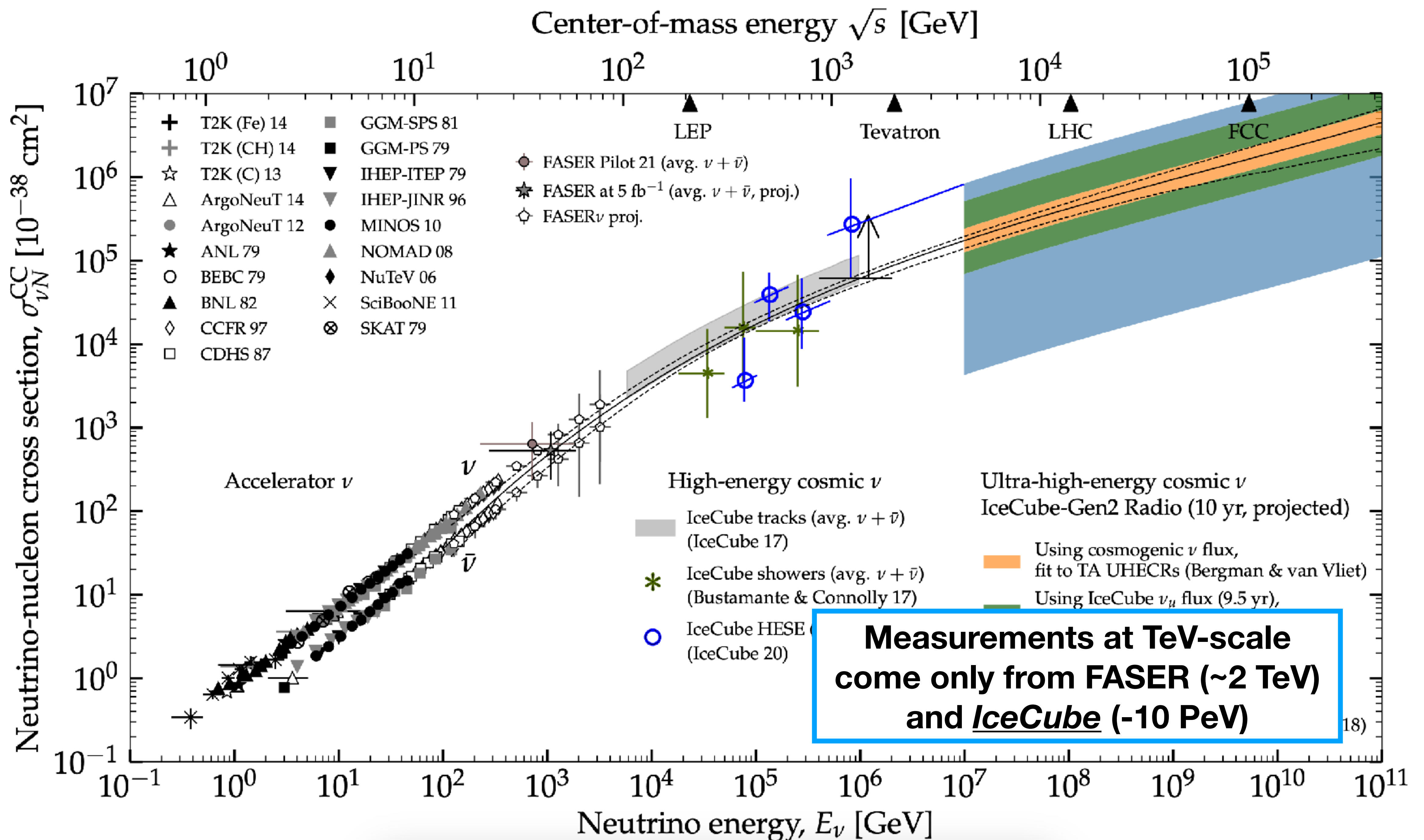
Colton Hill for the IceCube Collaboration



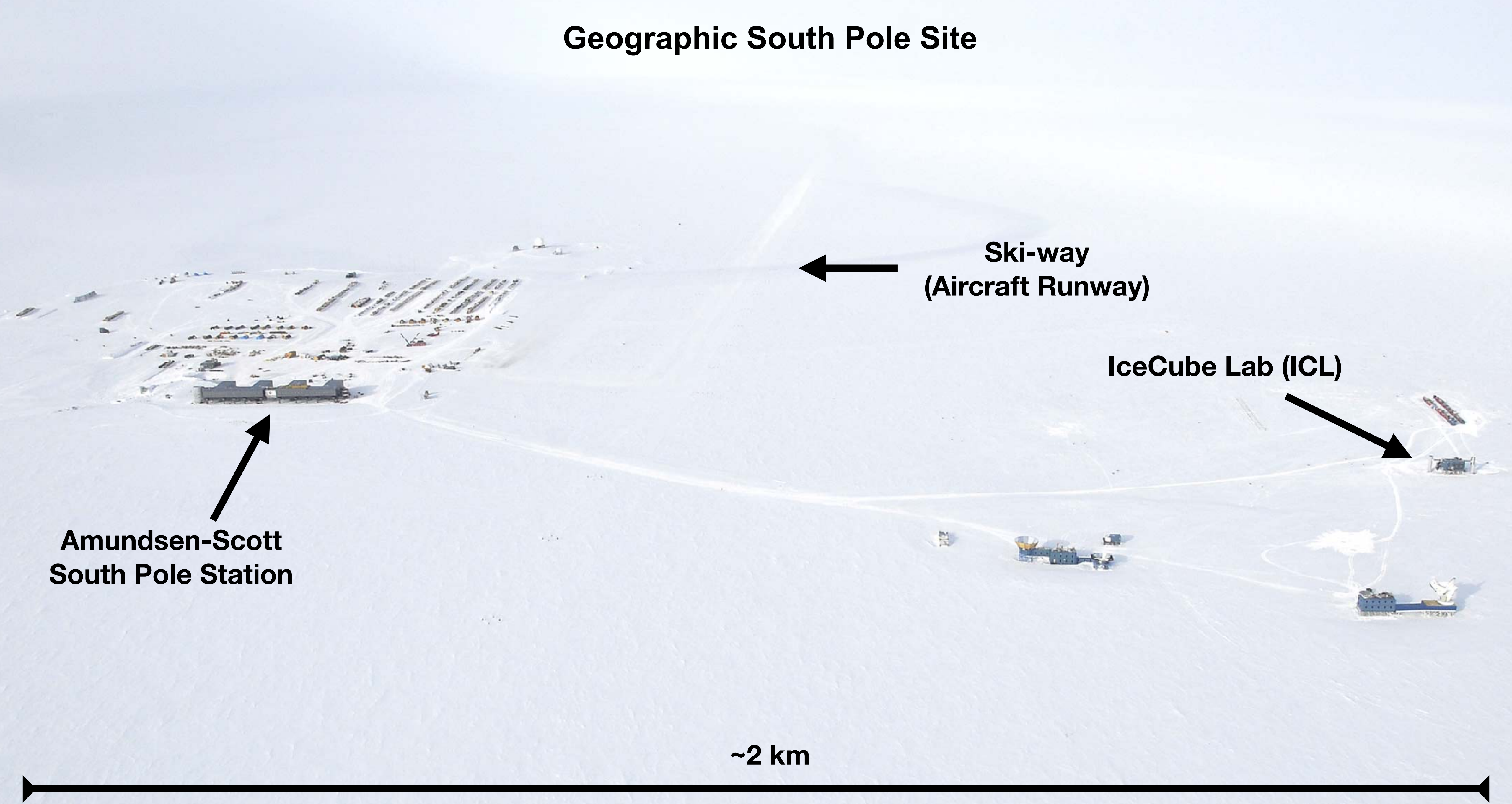
Why Cross Sections?



Cross section (σ) informs:
Event rates
Interaction features (final state particles, inelasticity)
Often source of systematic uncertainty.



Geographic South Pole Site

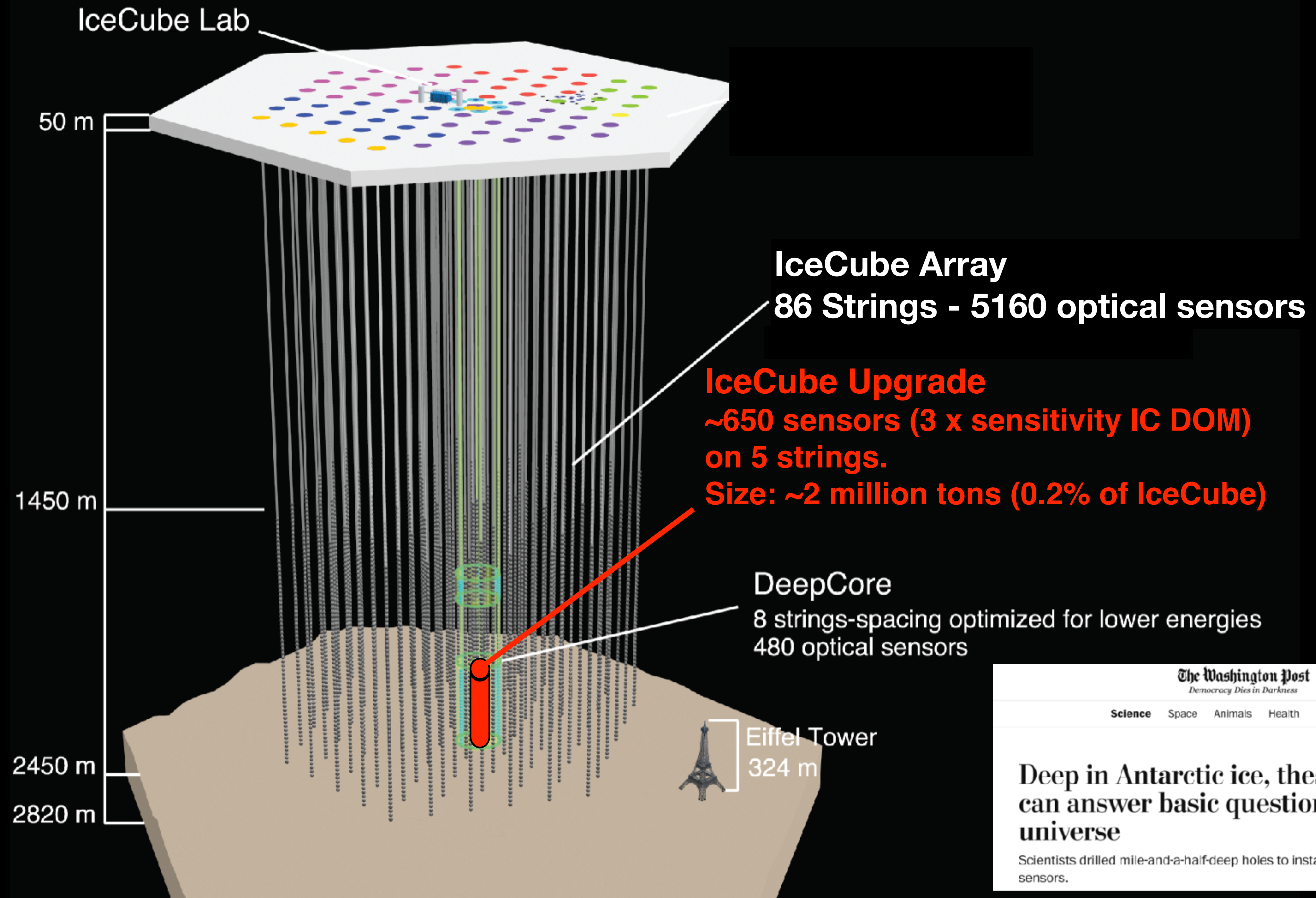


**Amundsen-Scott
South Pole Station**

**Ski-way
(Aircraft Runway)**

IceCube Lab (ICL)

~2 km



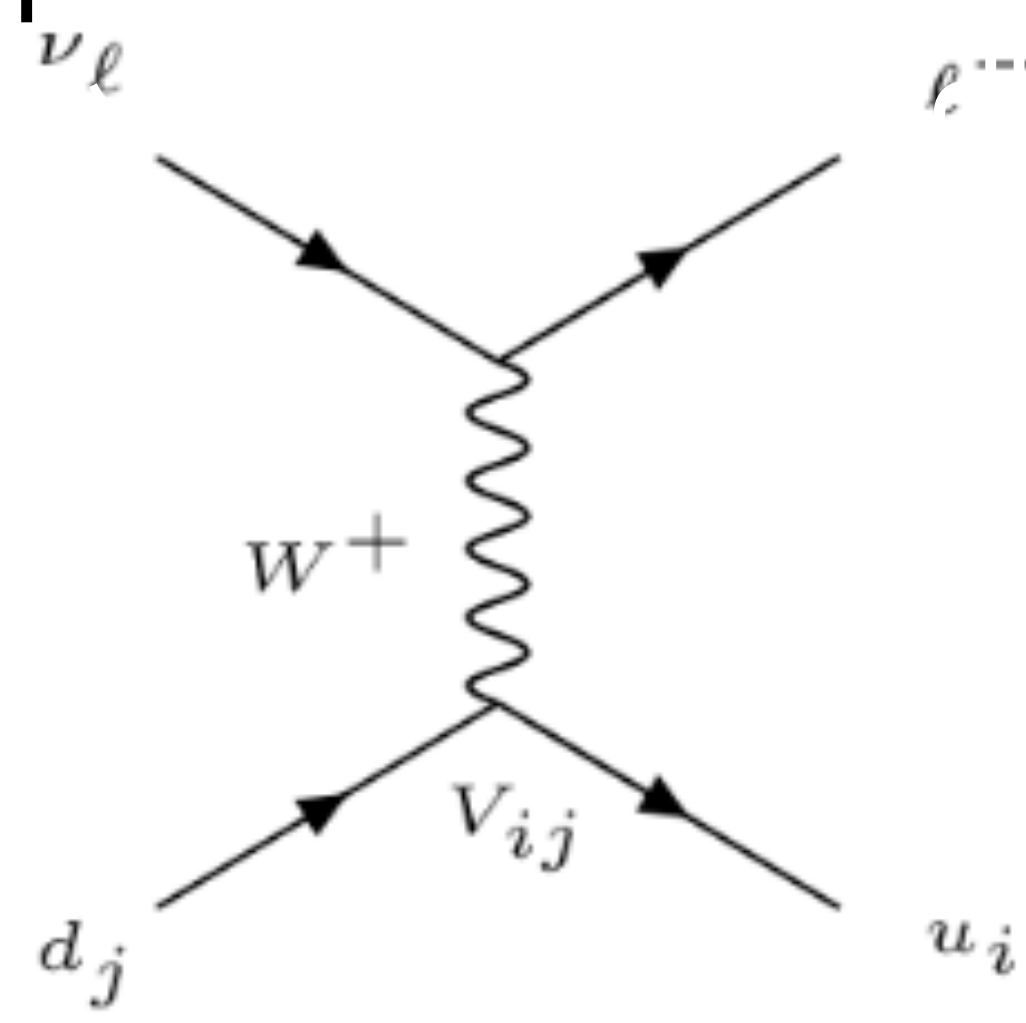
The Washington Post
Democracy Dies in Darkness

Science Space Animals Health Environment

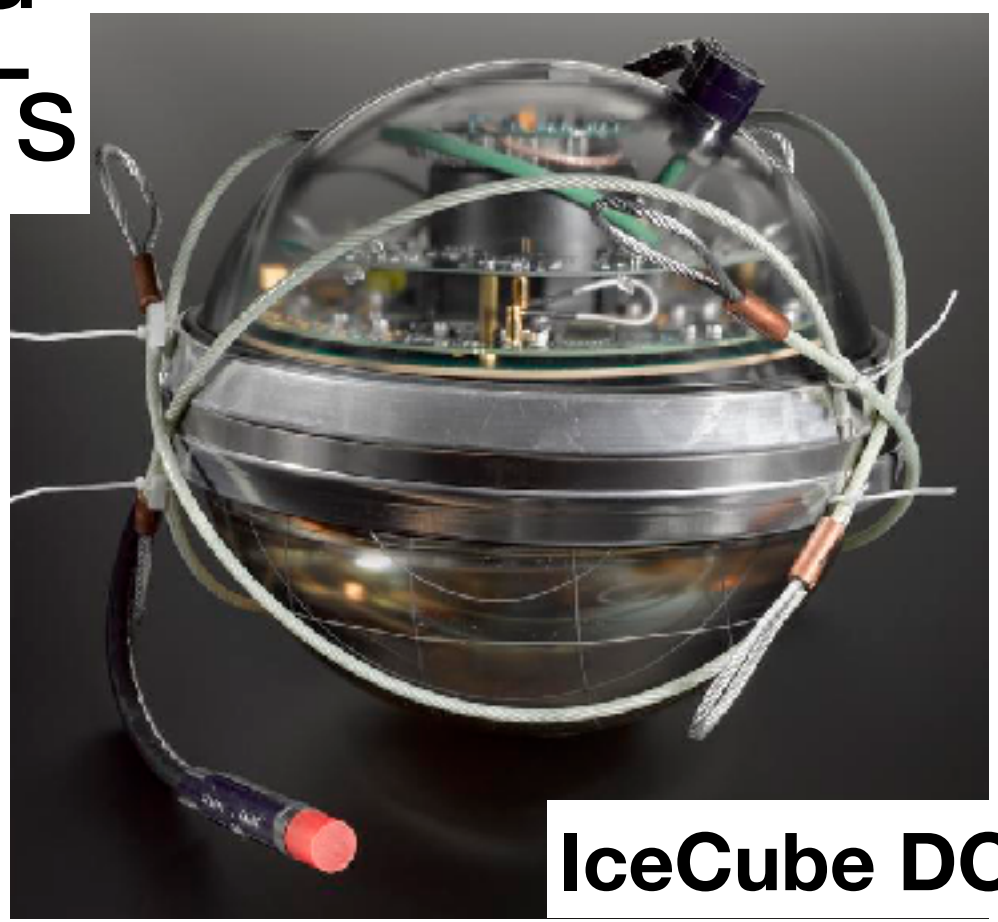
Deep in Antarctic ice, these particles can answer basic questions about the universe

Scientists drilled mile-and-a-half-deep holes to install hundreds of new sensors.

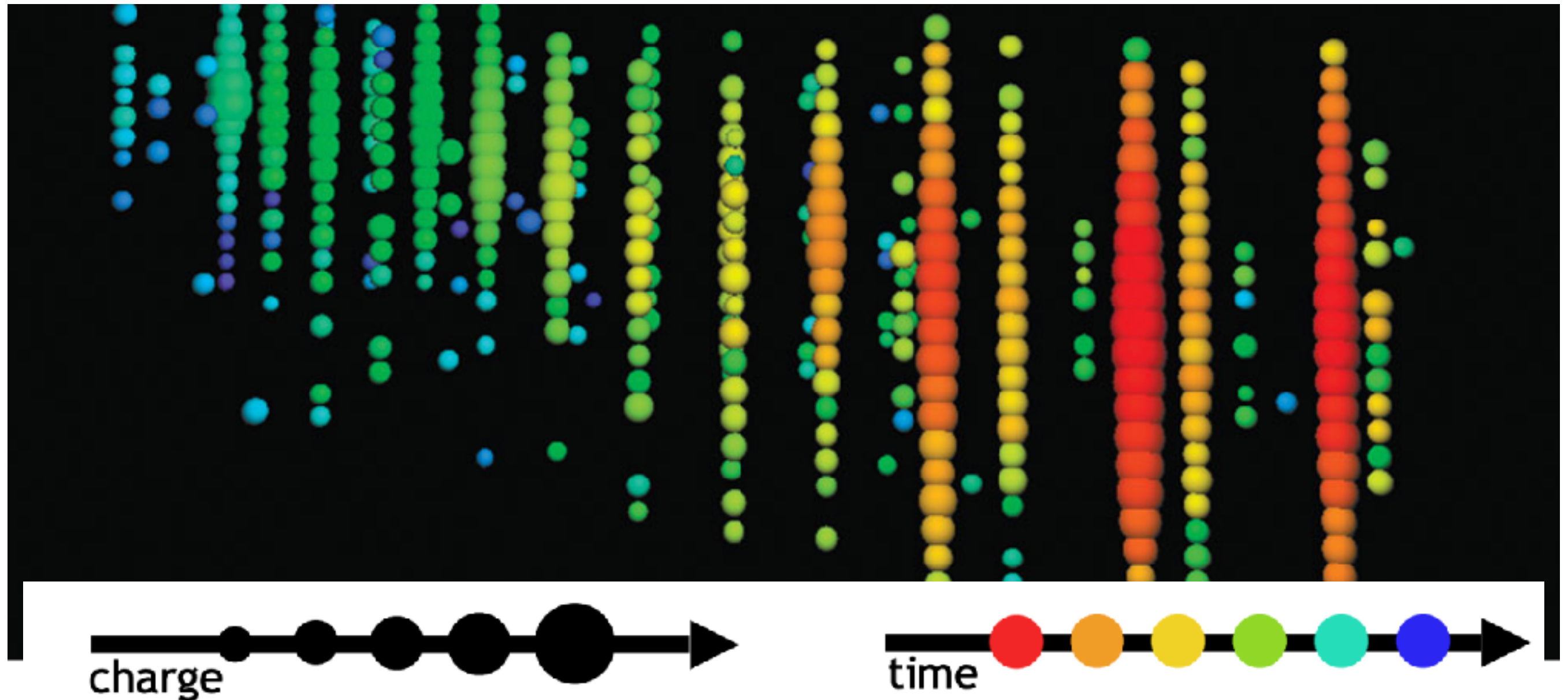
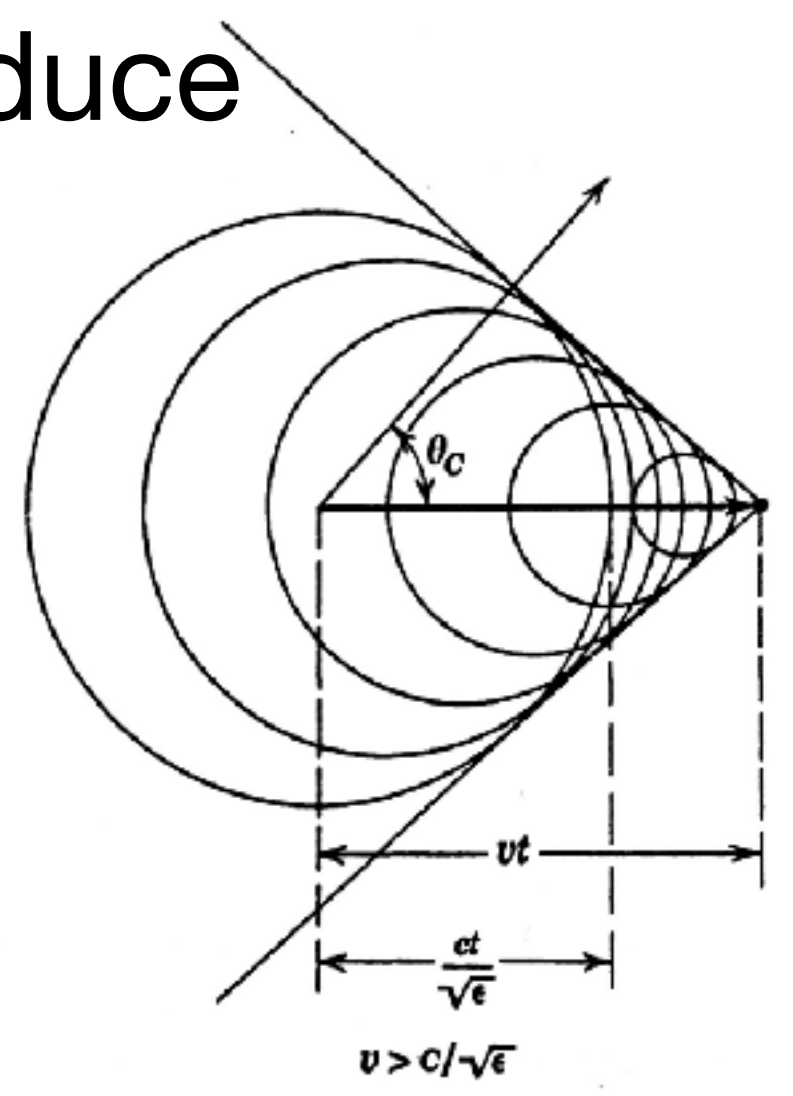
The products of neutrino interactions produce relativistic charged particles



Which we can read out with 5160 PMTs

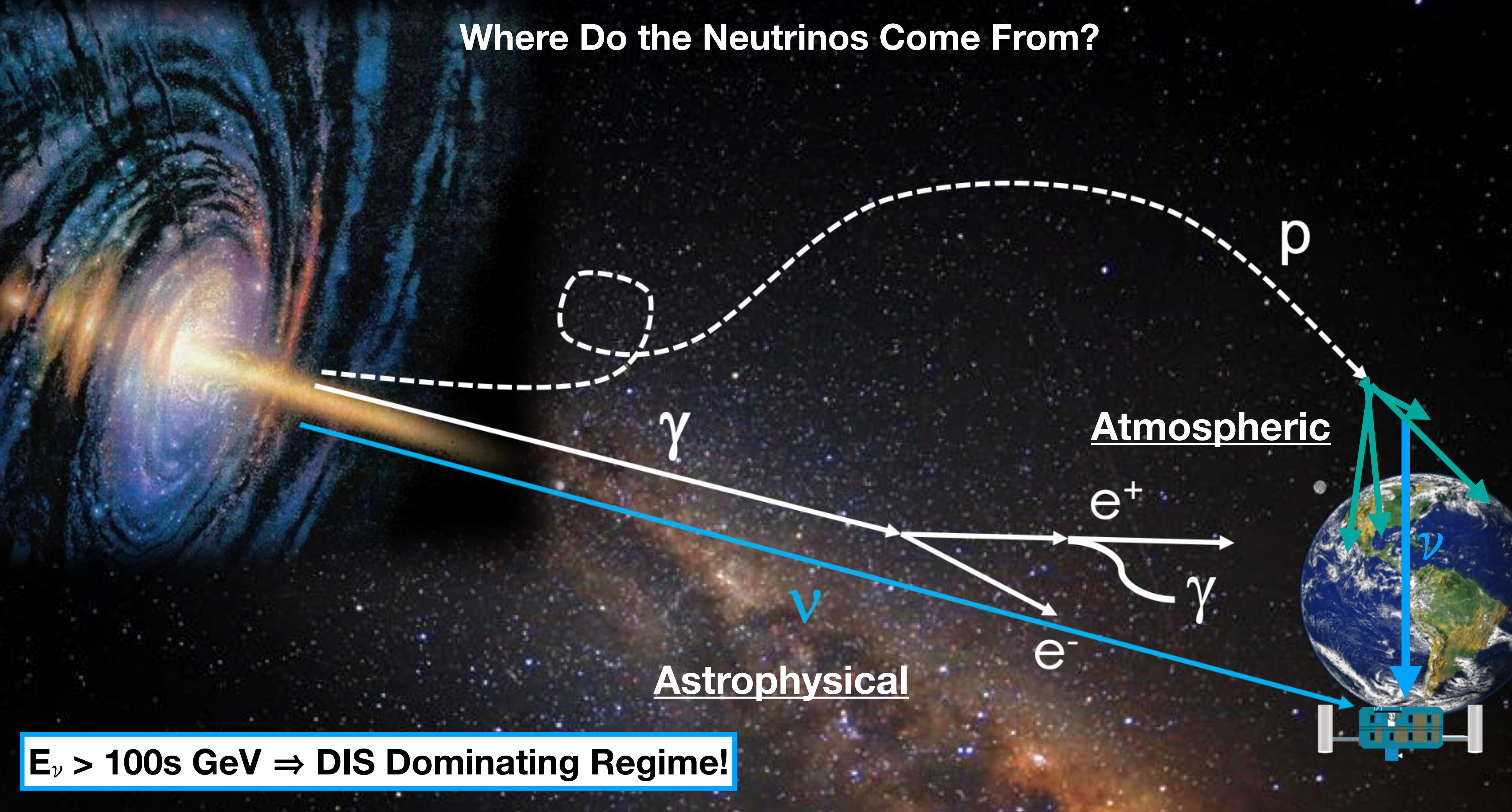


When these particles travel faster than the speed of light in ice, they produce Cherenkov Radiation



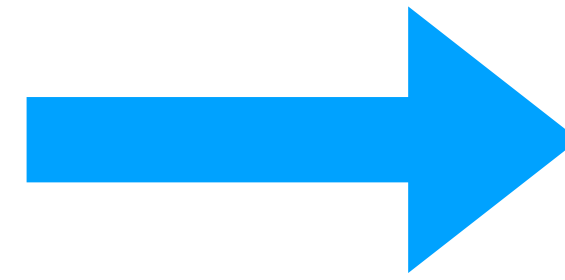
Reconstruct the neutrino direction & energy.

Where Do the Neutrinos Come From?



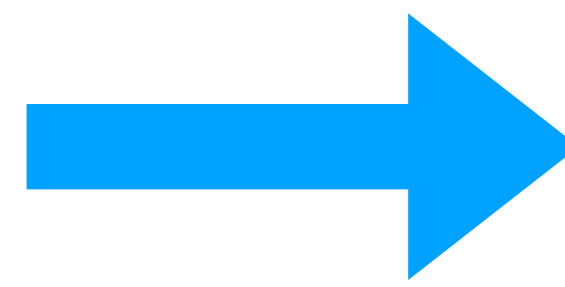
$E_\nu > 100\text{s GeV} \Rightarrow$ DIS Dominating Regime!

Common challenge in cross section measurements - what is the flux?

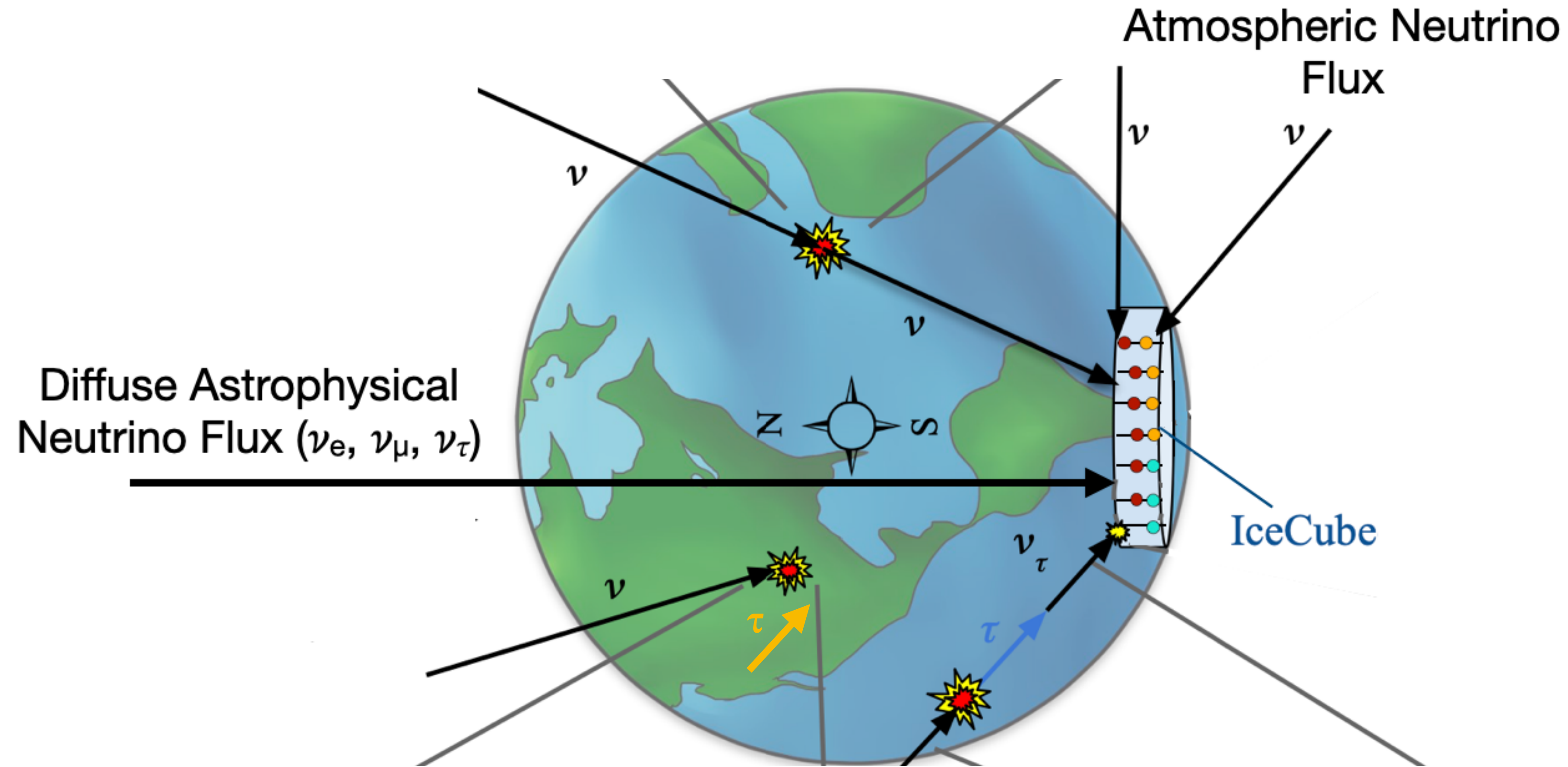


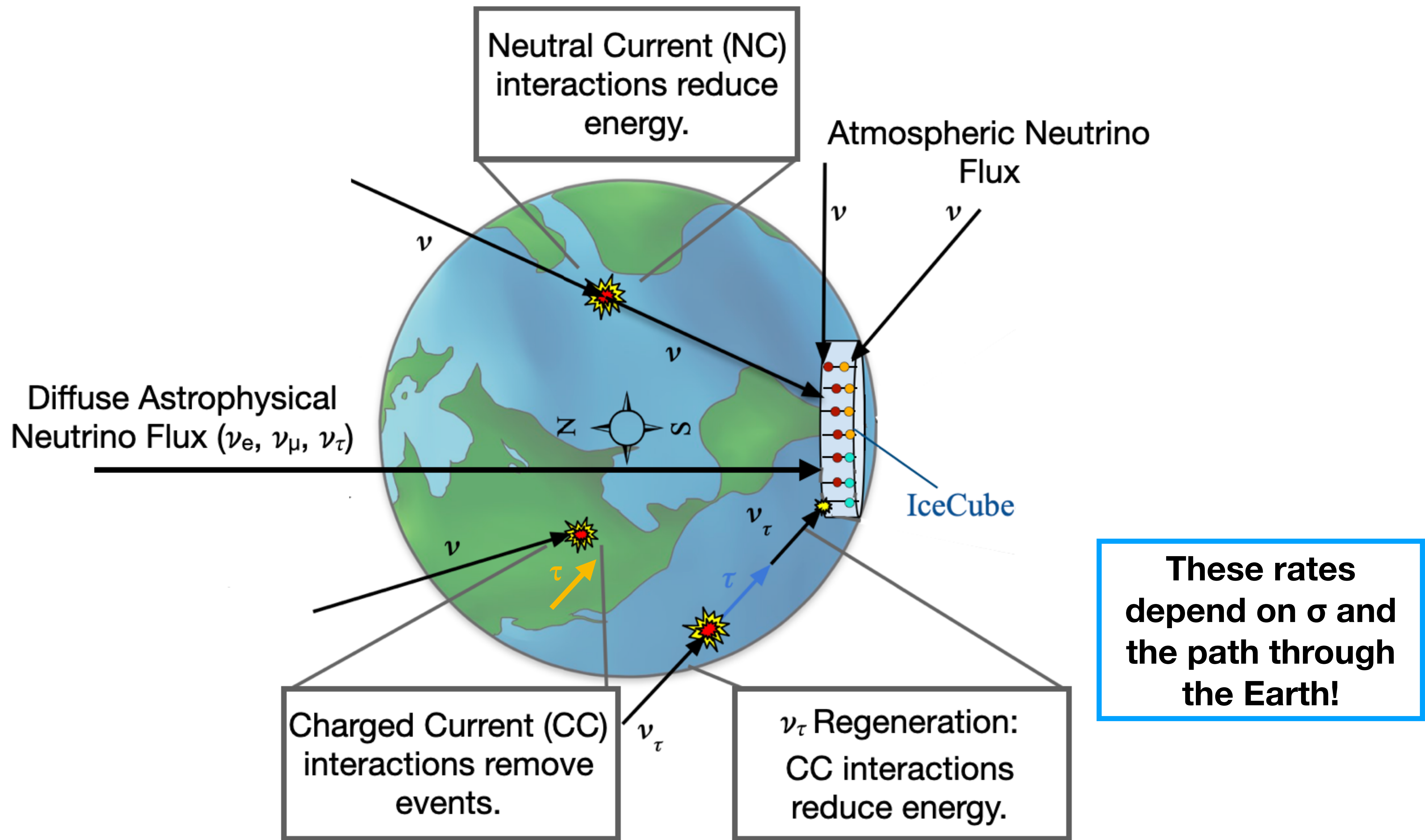
How can we decouple the flux uncertainties from σ ?

Common challenge in cross section measurements - what is the flux?



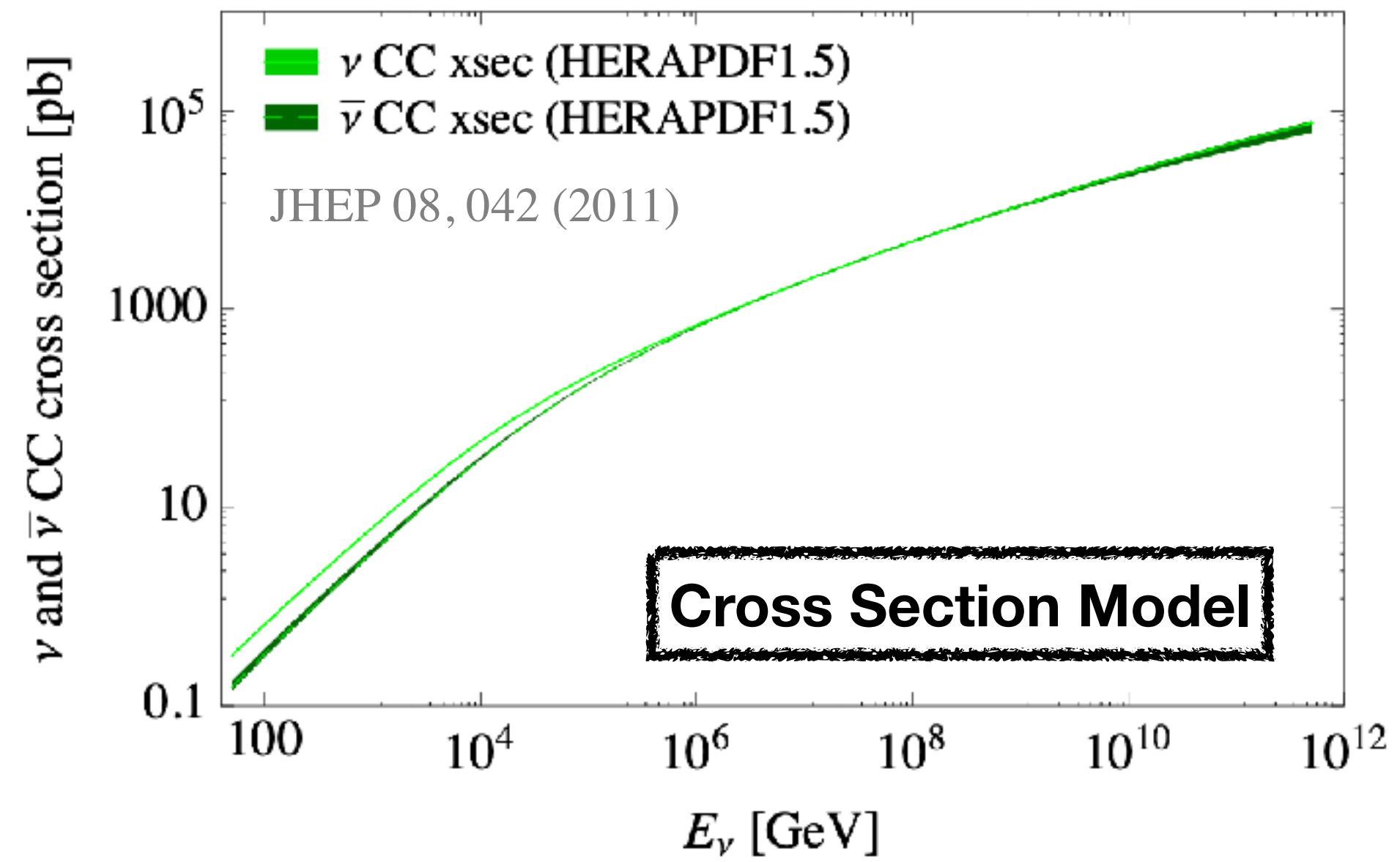
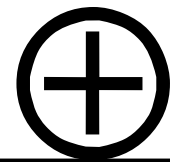
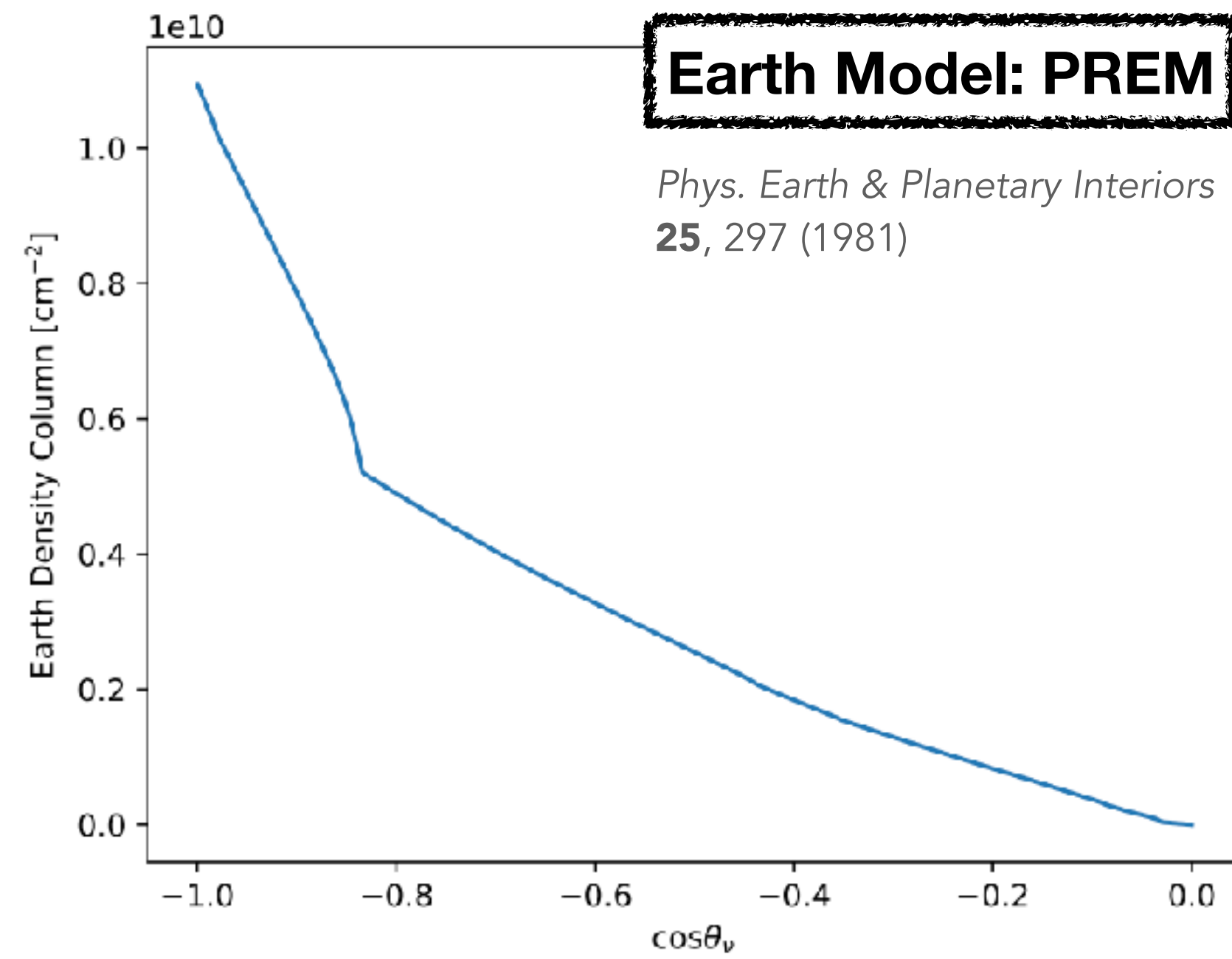
How can we decouple the flux uncertainties from σ ?





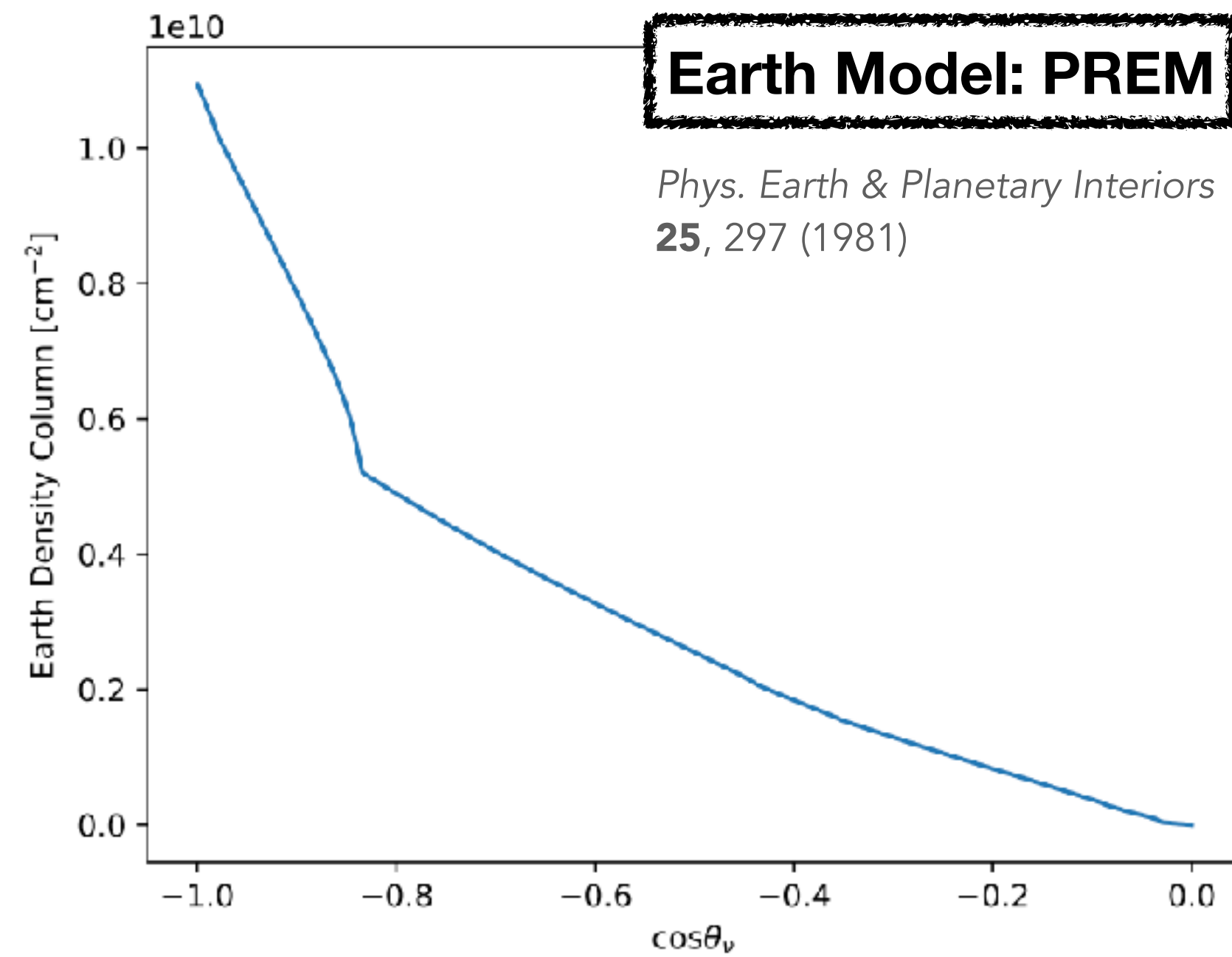
Earth Model: PREM

Phys. Earth & Planetary Interiors
25, 297 (1981)

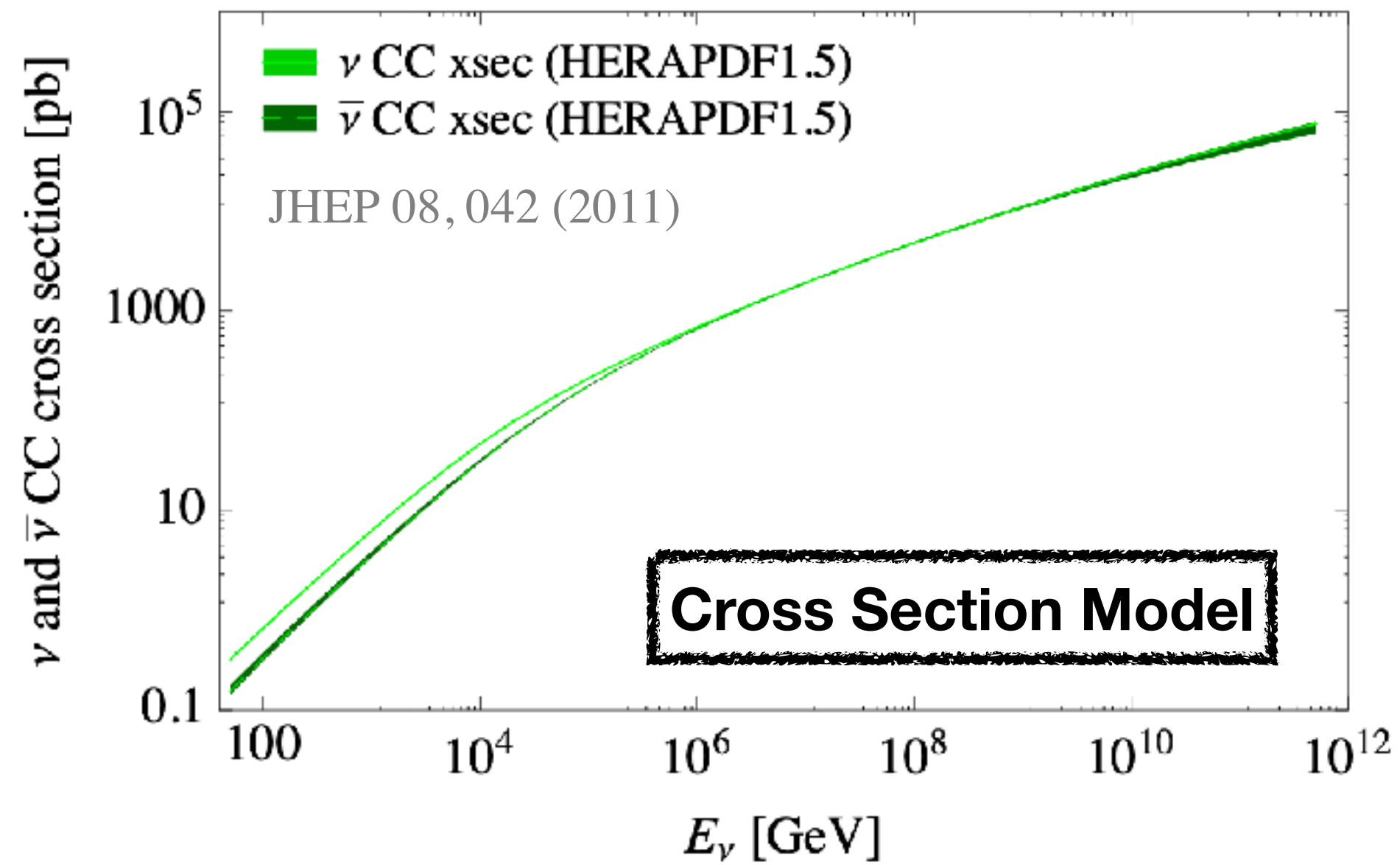


Earth Model: PREM

Phys. Earth & Planetary Interiors
25, 297 (1981)

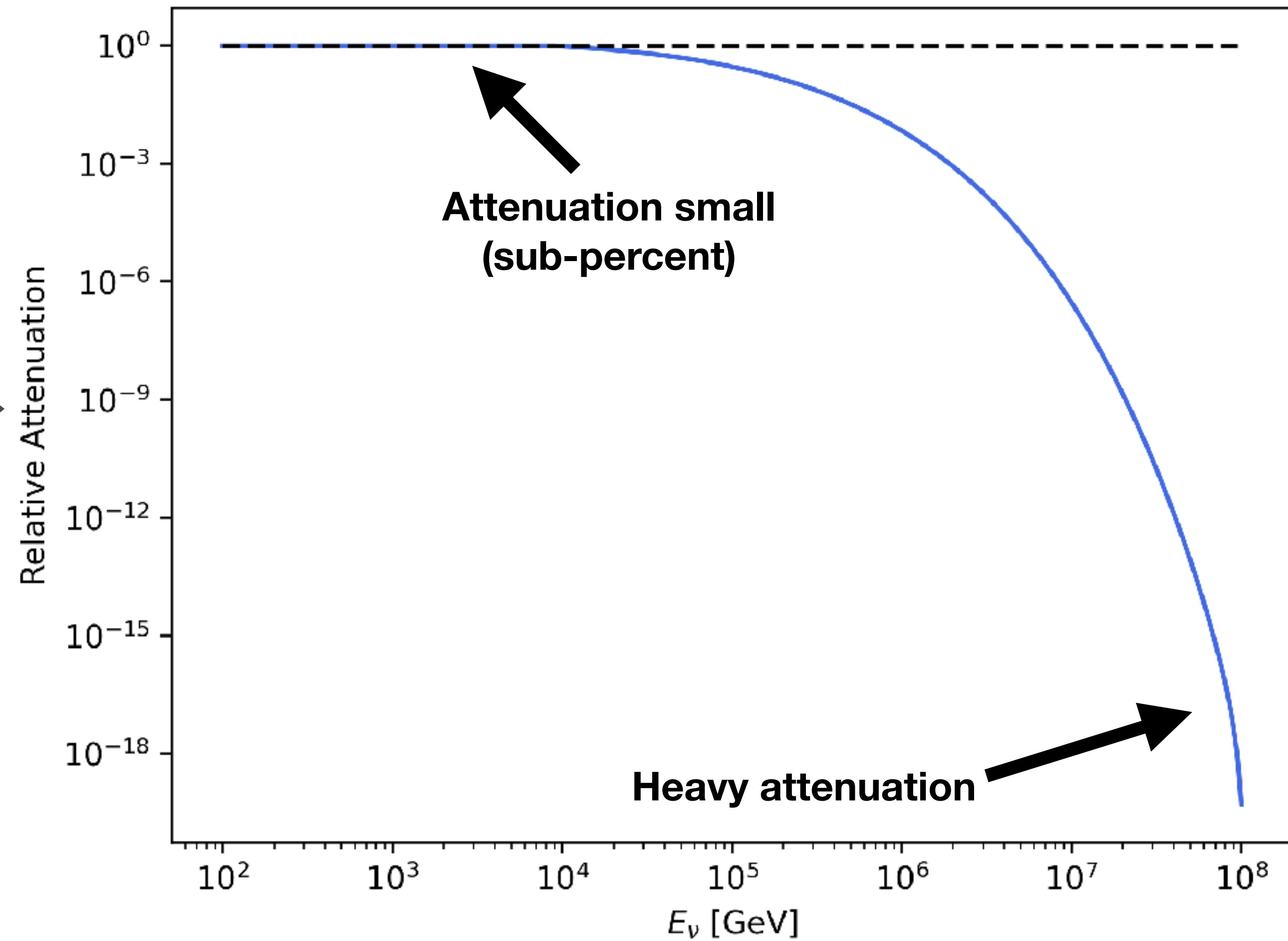


$\oplus$



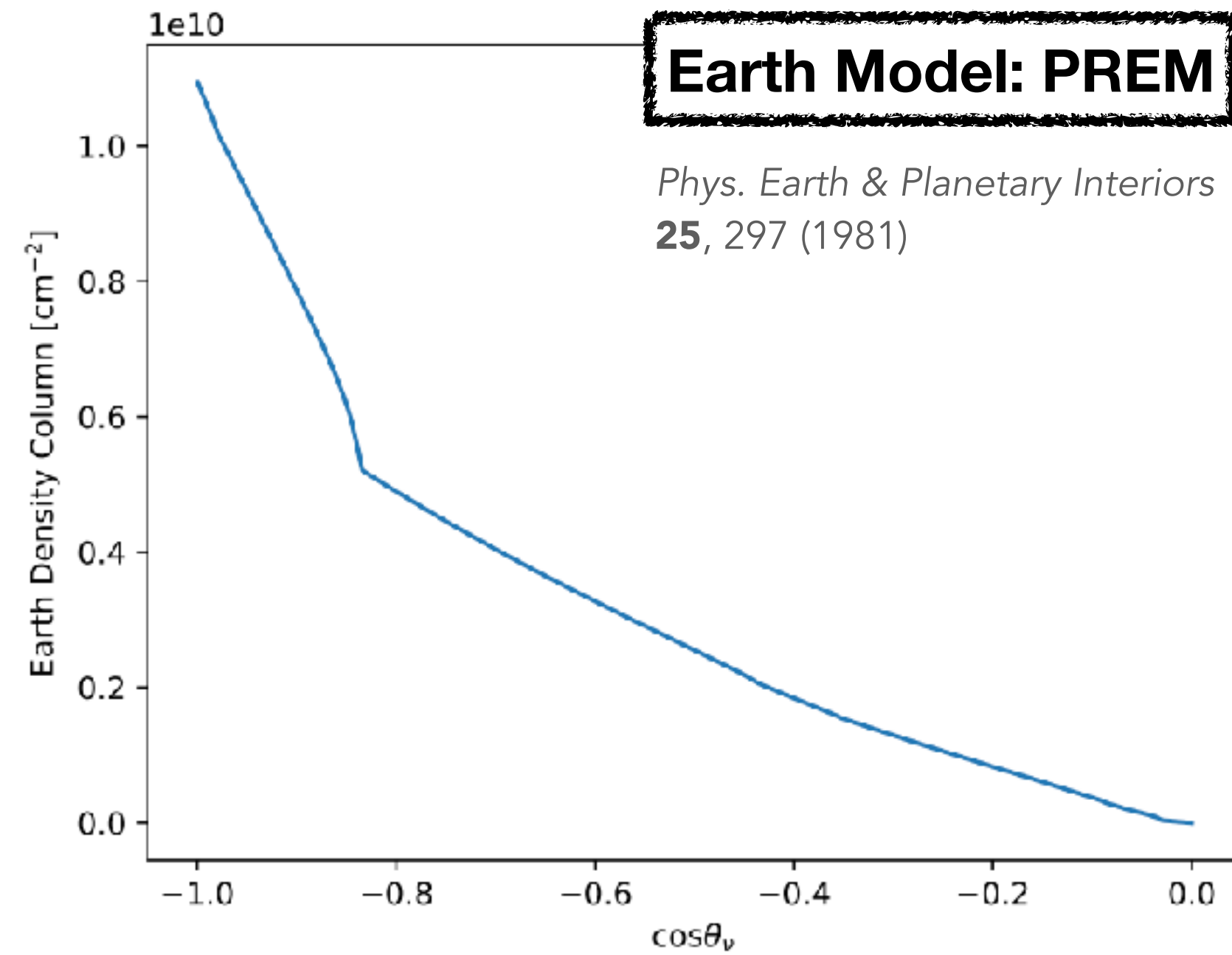
1D Slice in $\cos(\Theta_\nu)$

ν_μ , $\cos\Theta=-1.0$, up-going

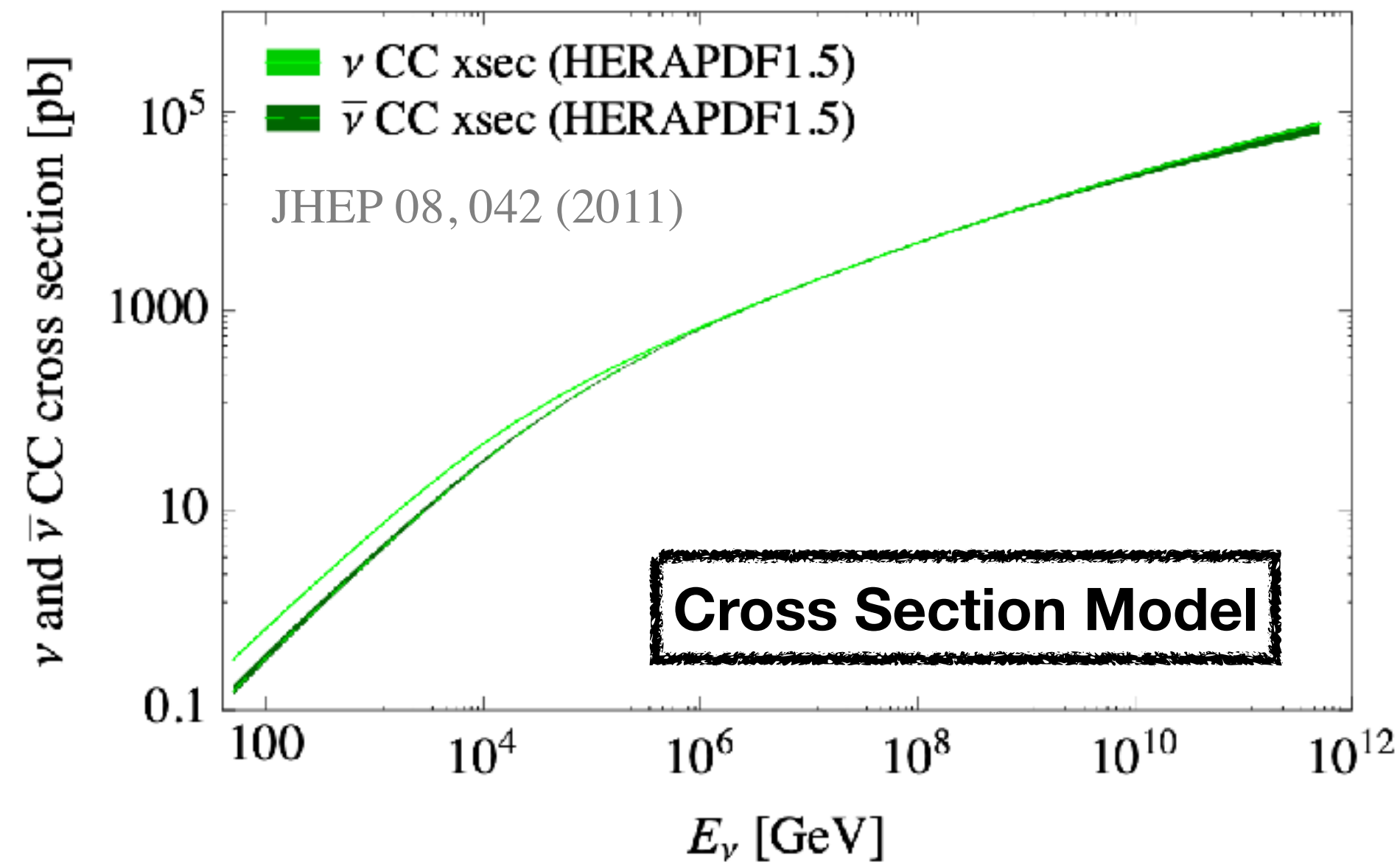


Earth Model: PREM

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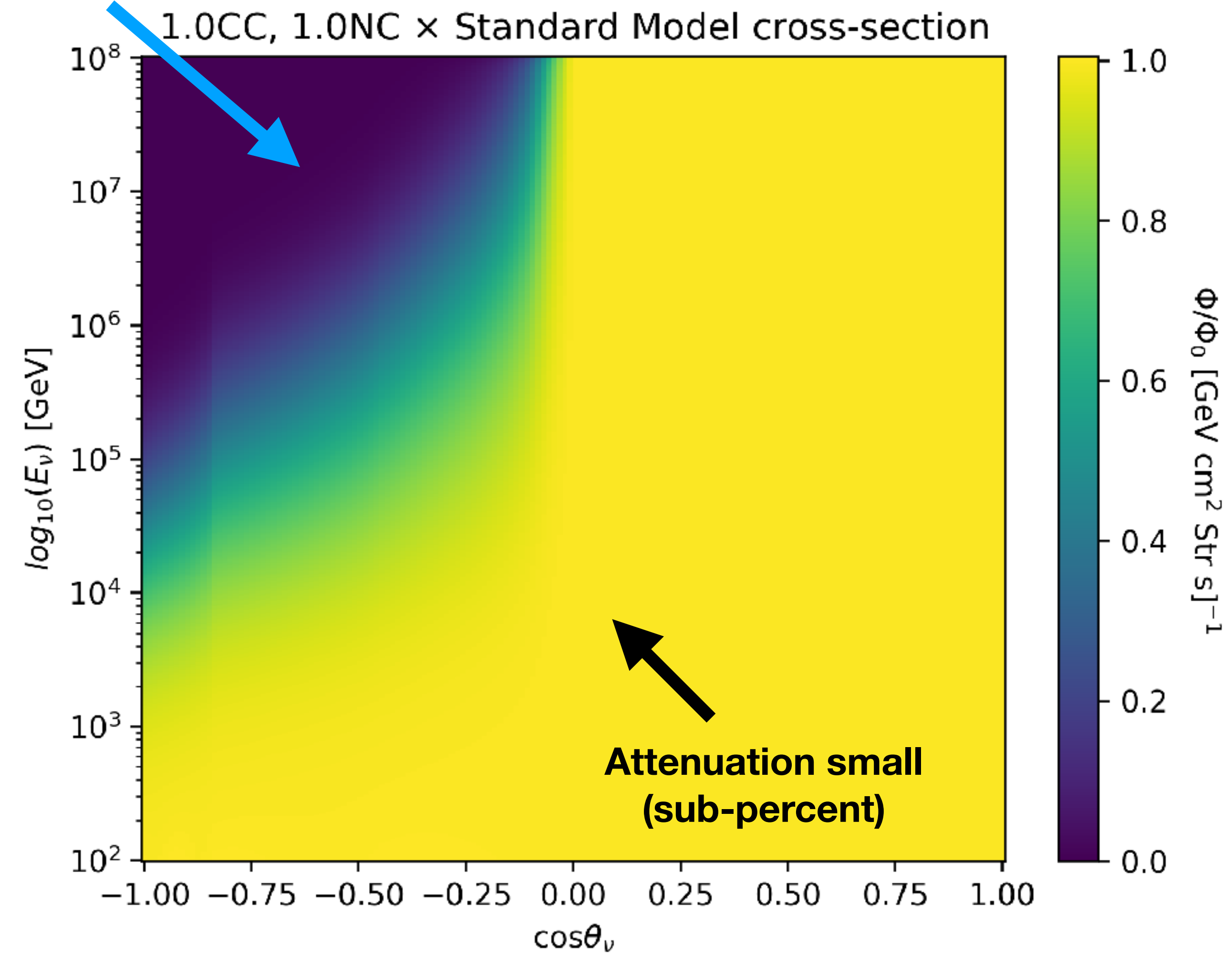


$\oplus$



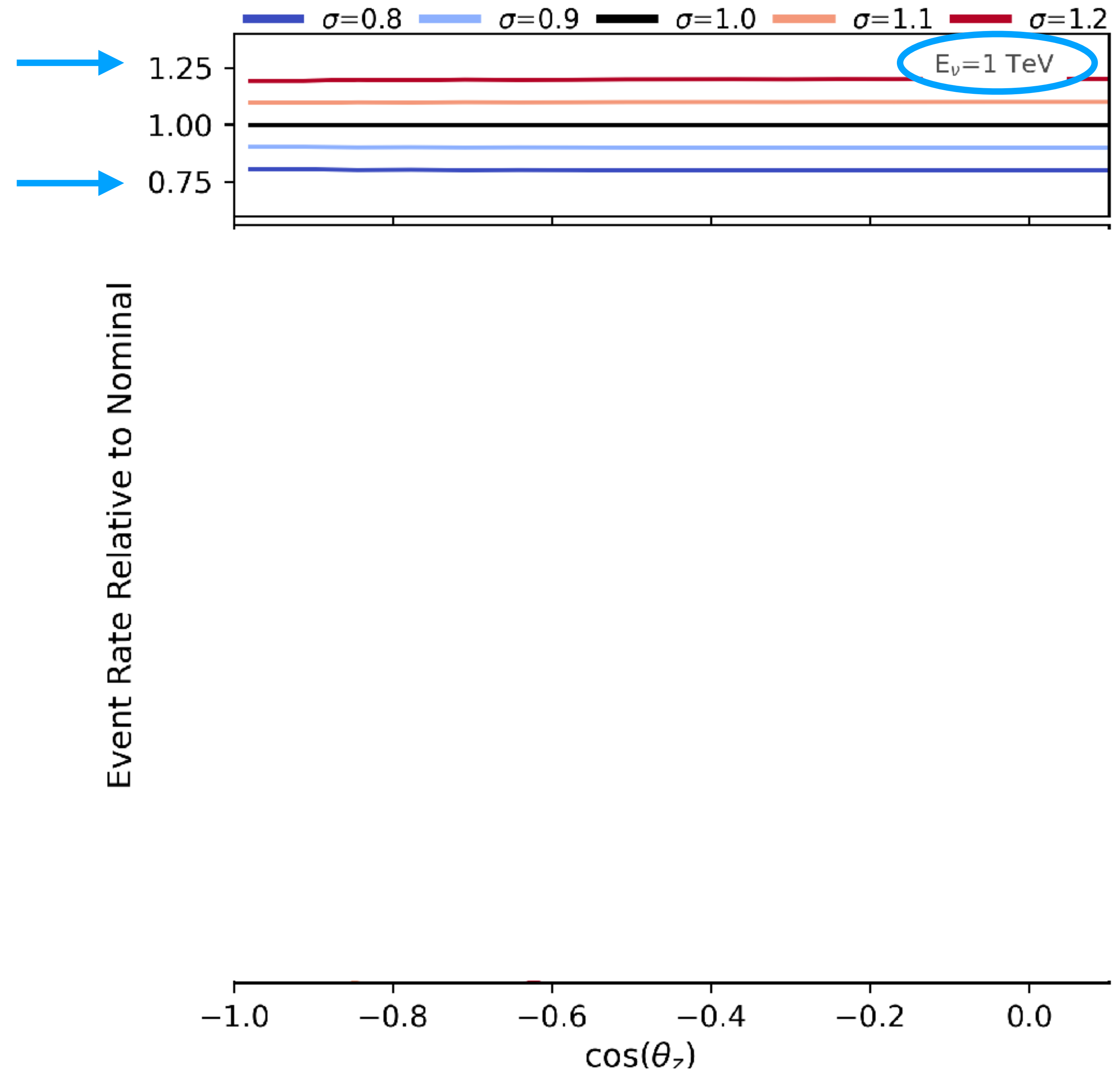
2D in E_ν & $\cos(\Theta_\nu)$

Heavy attenuation



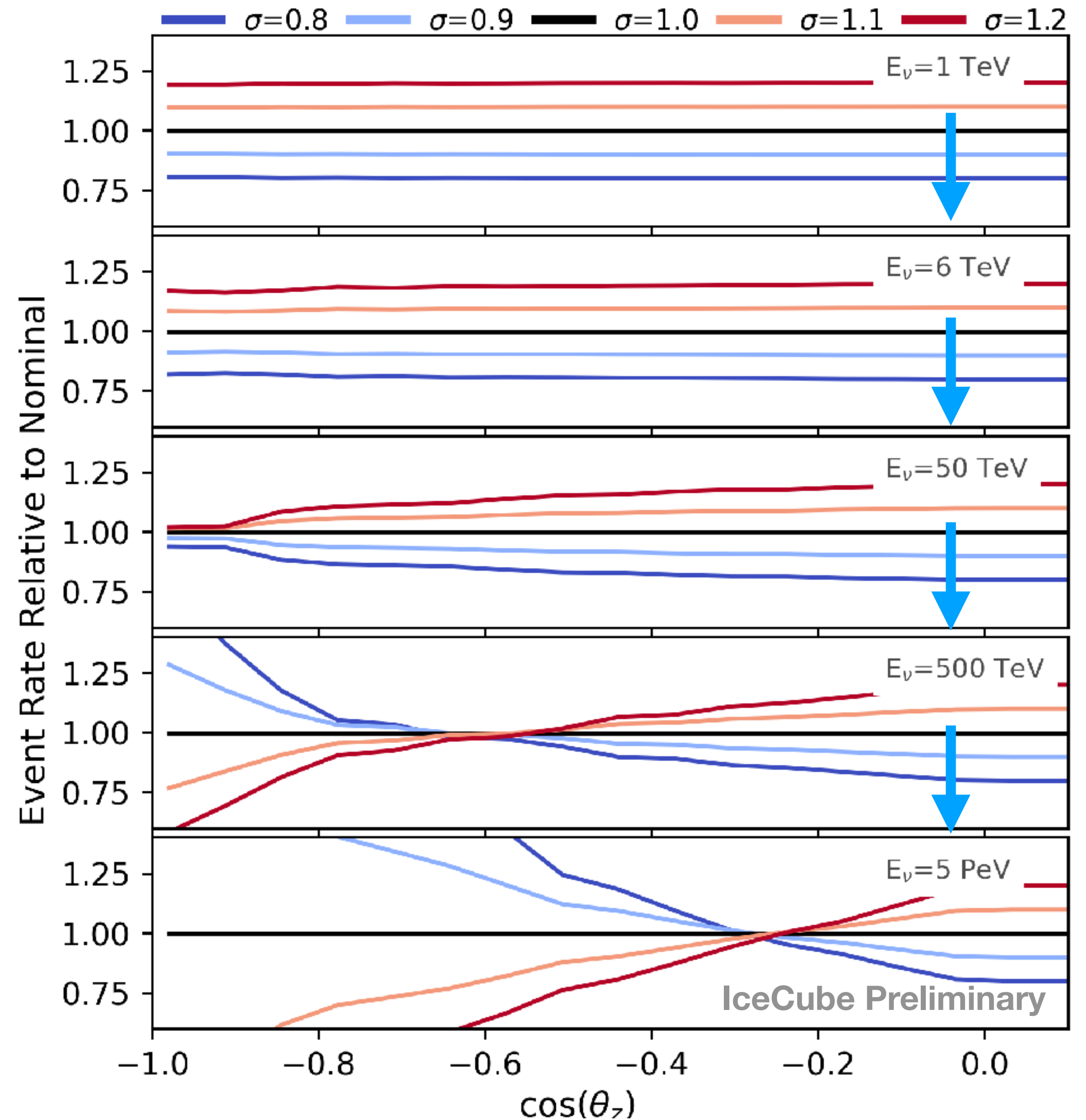
Cross section also determines interactions with the detector.

Combining attenuation and interaction terms, the event rate is a function of E , Θ , and σ .

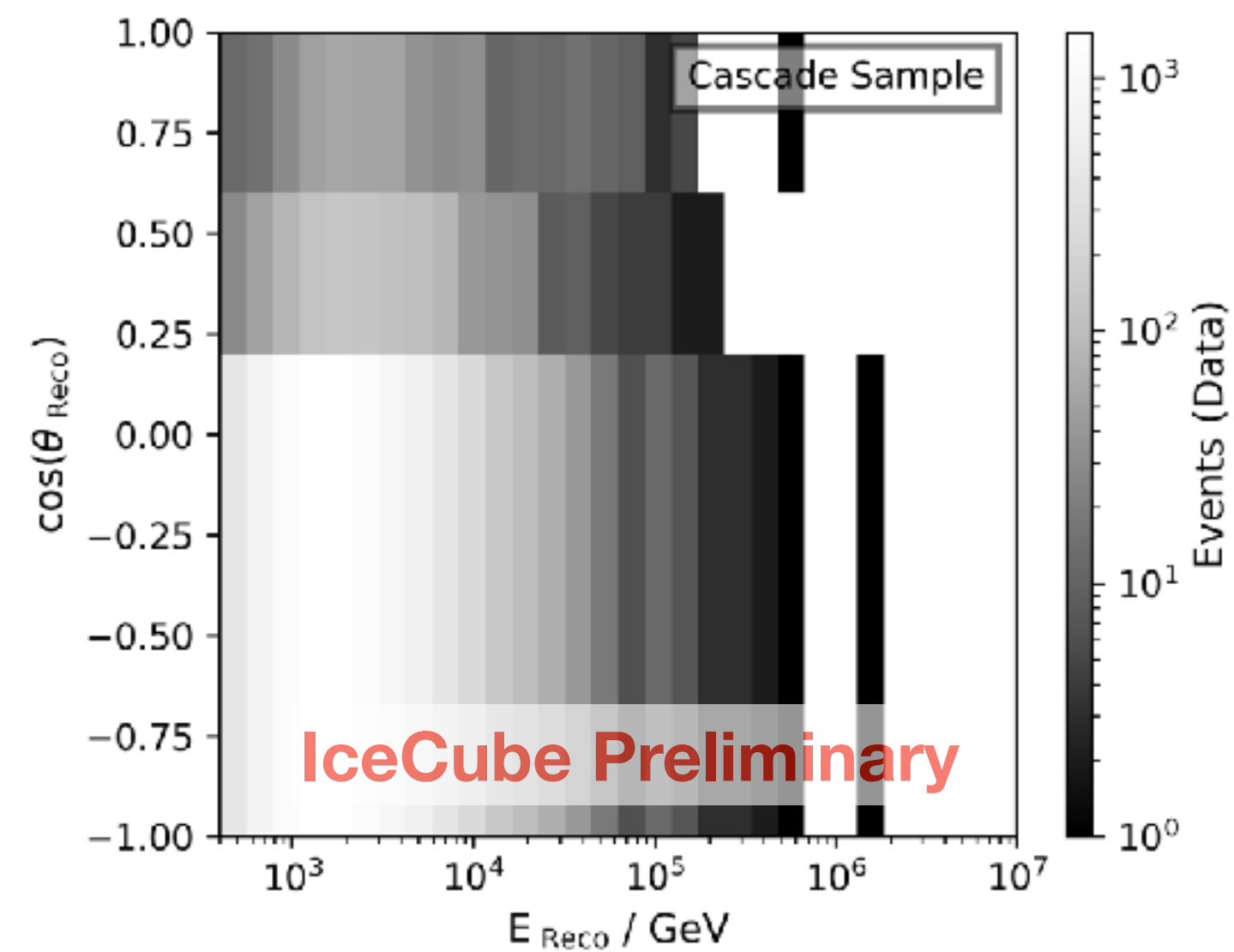
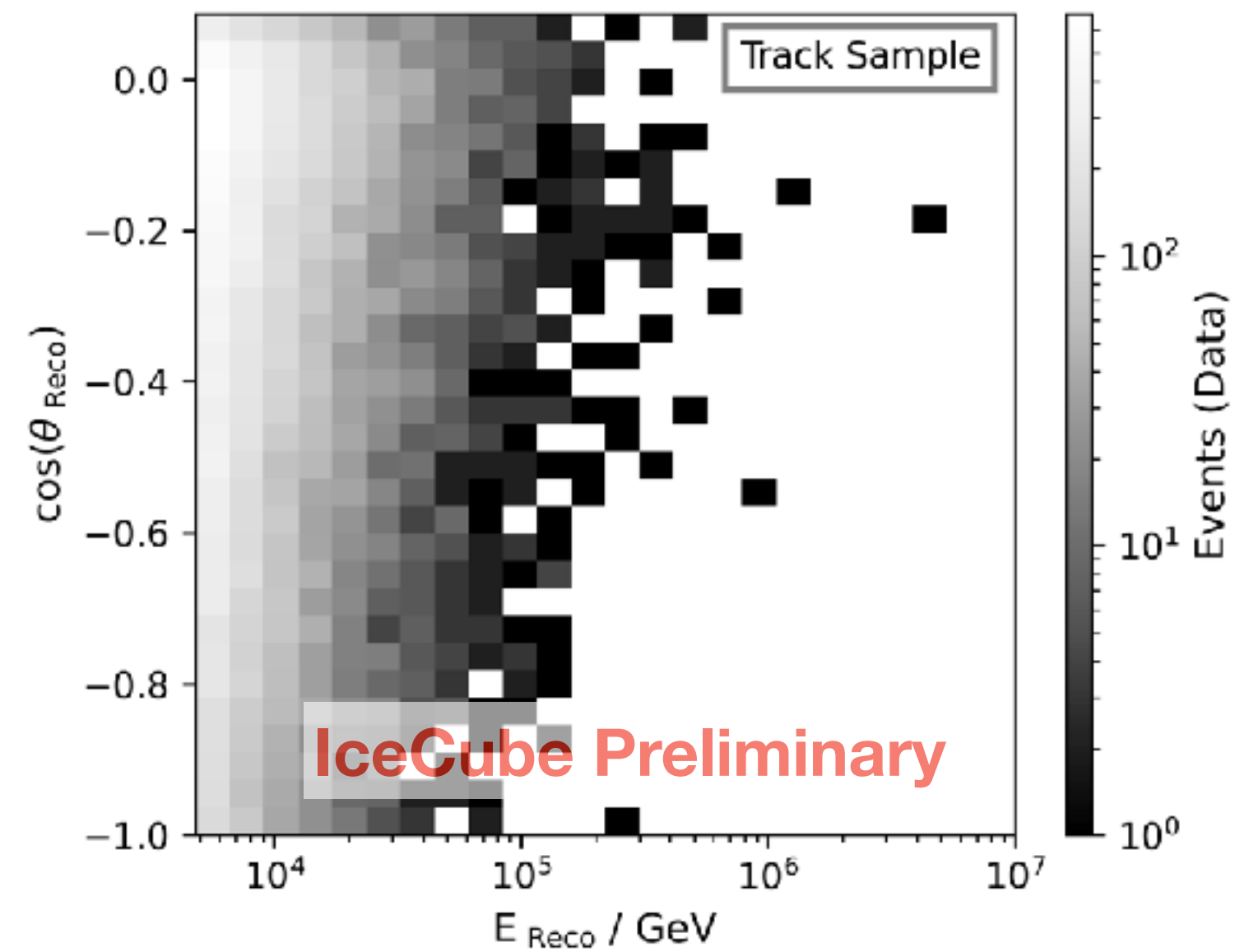


Cross section also determines interactions with the detector.

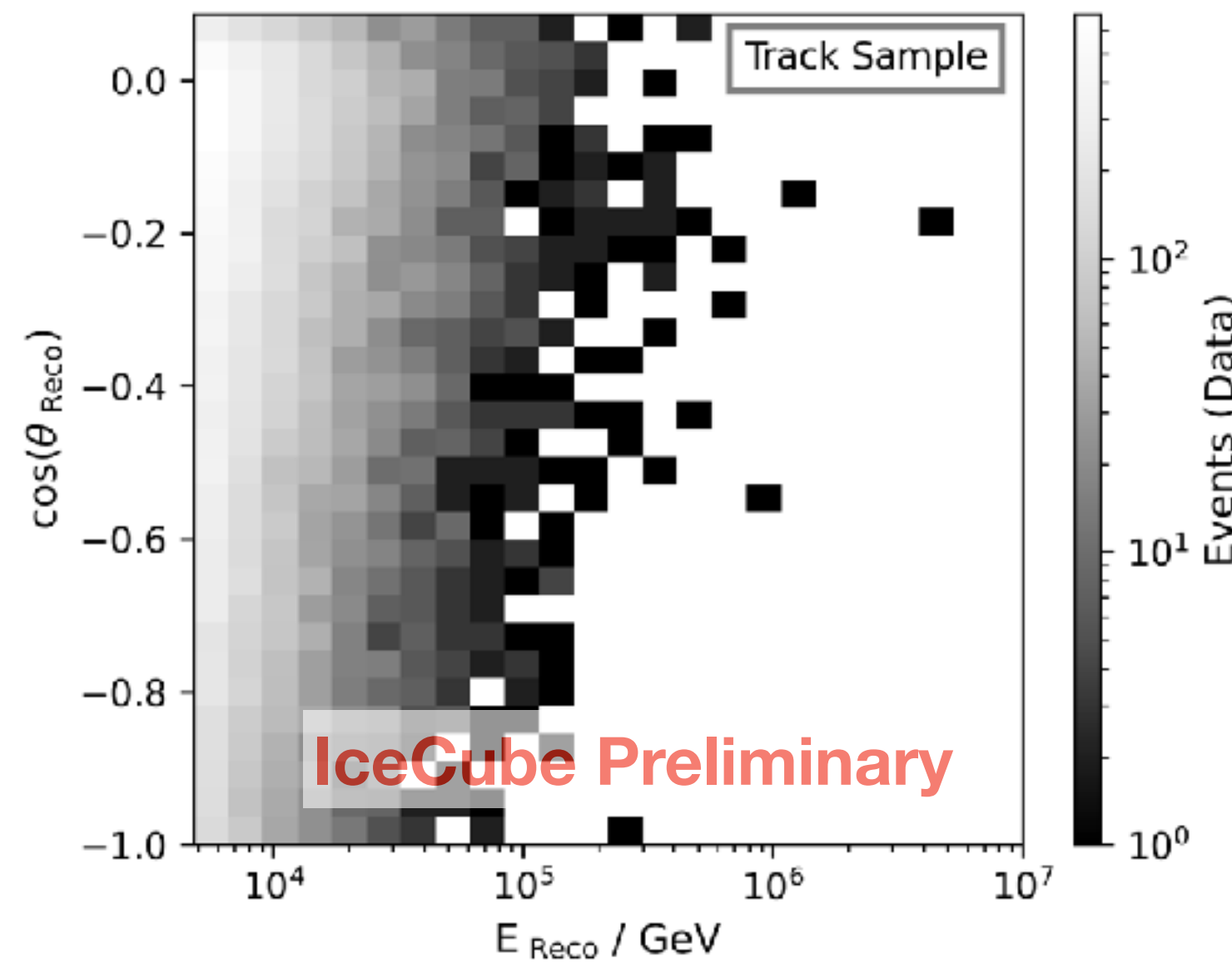
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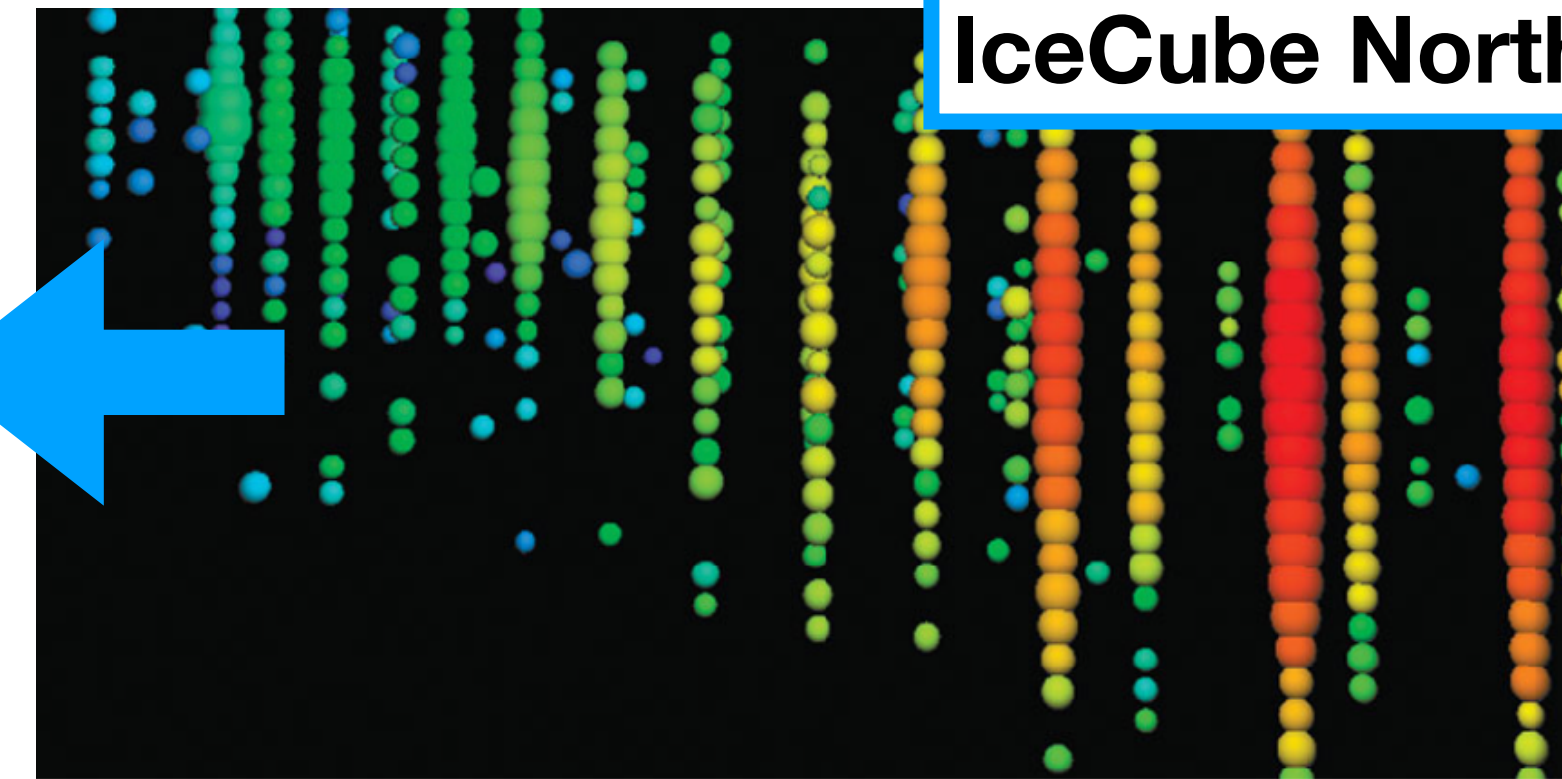
- Construct binned forward-folding likelihood
- Data binned in E_{reco} and $\cos(\Theta_{\text{reco}})$



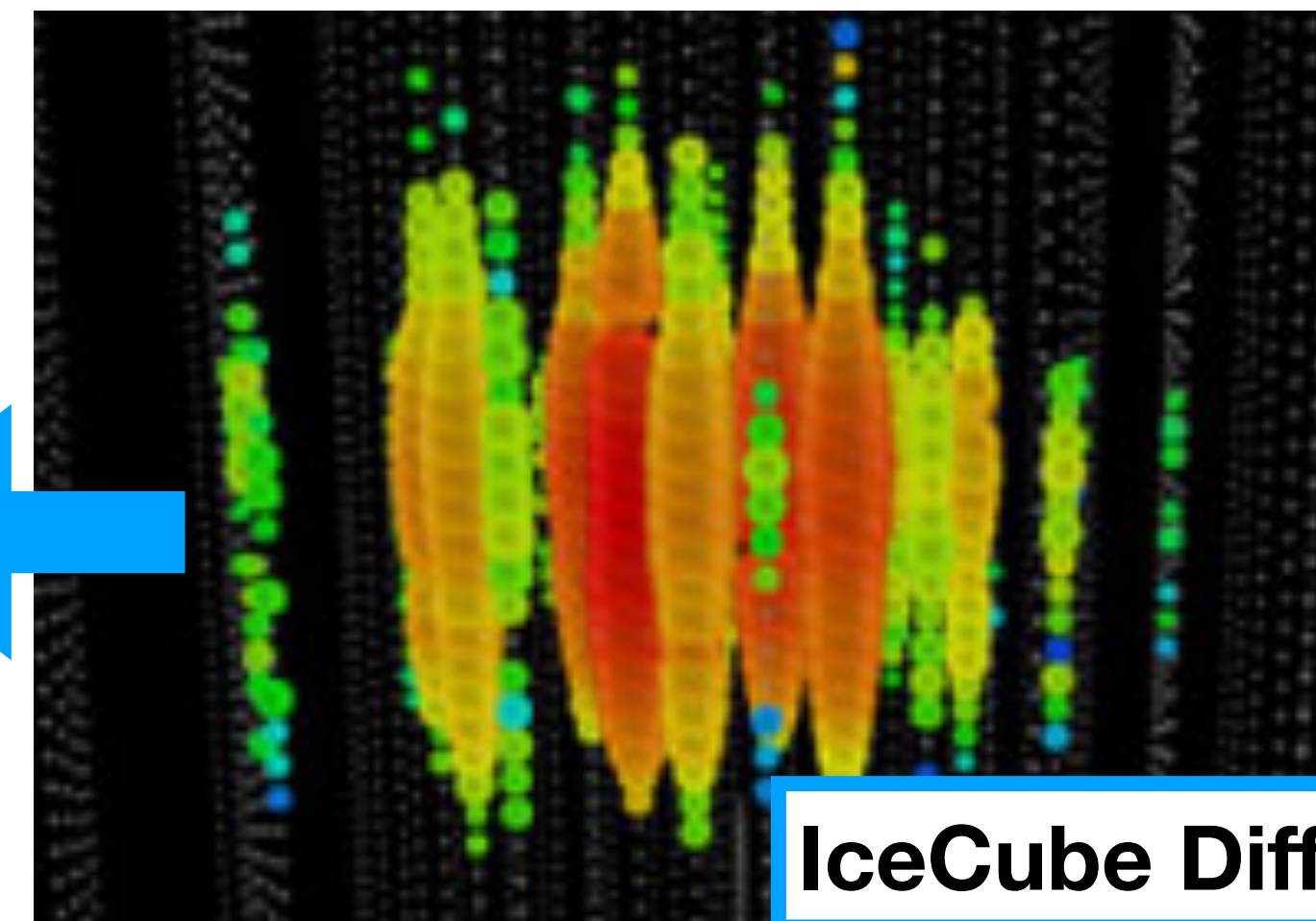
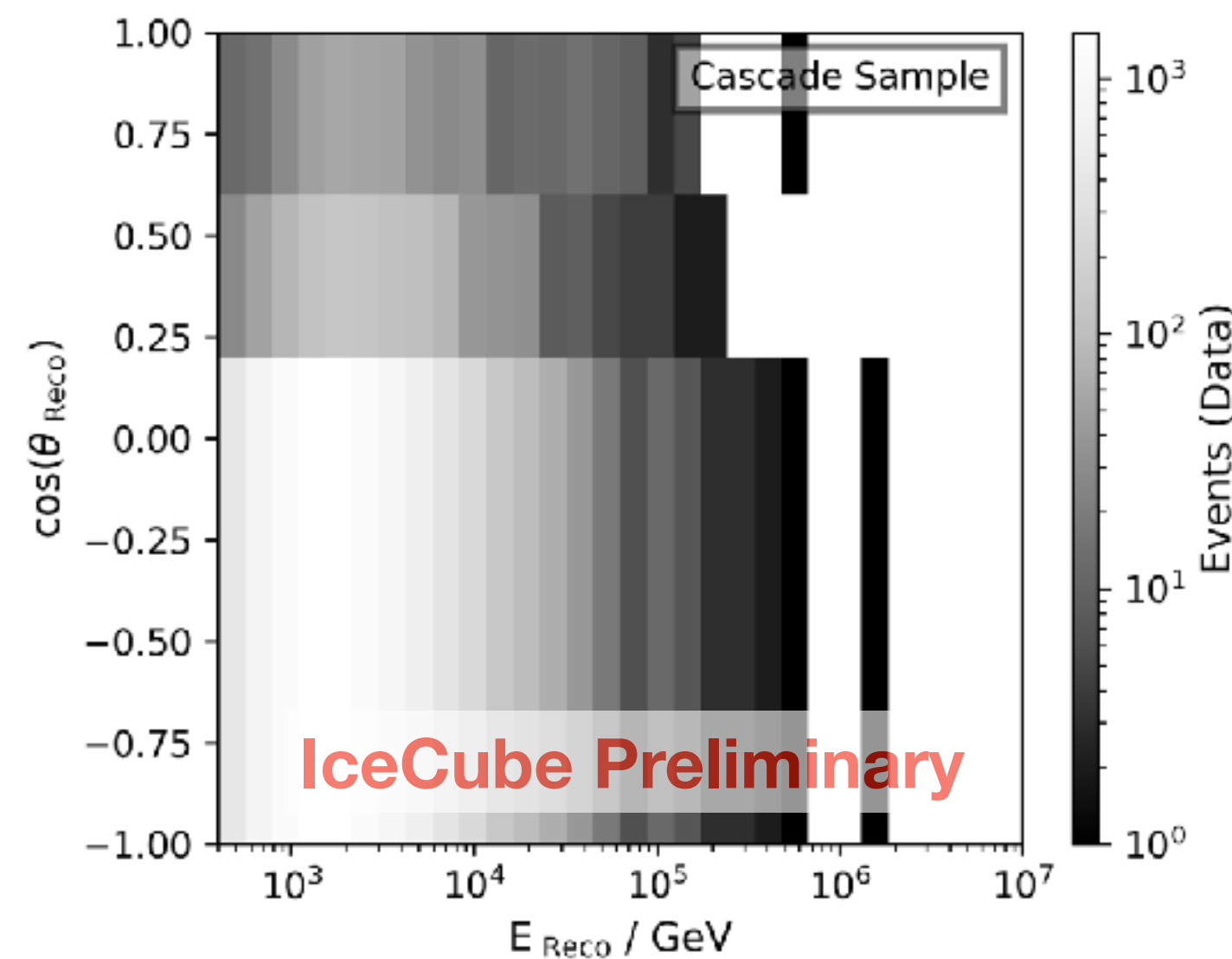
- Construct binned forward-folding likelihood
- Data binned in E_{reco} and $\cos(\Theta_{\text{reco}})$



IceCube Northern Tracks Sample

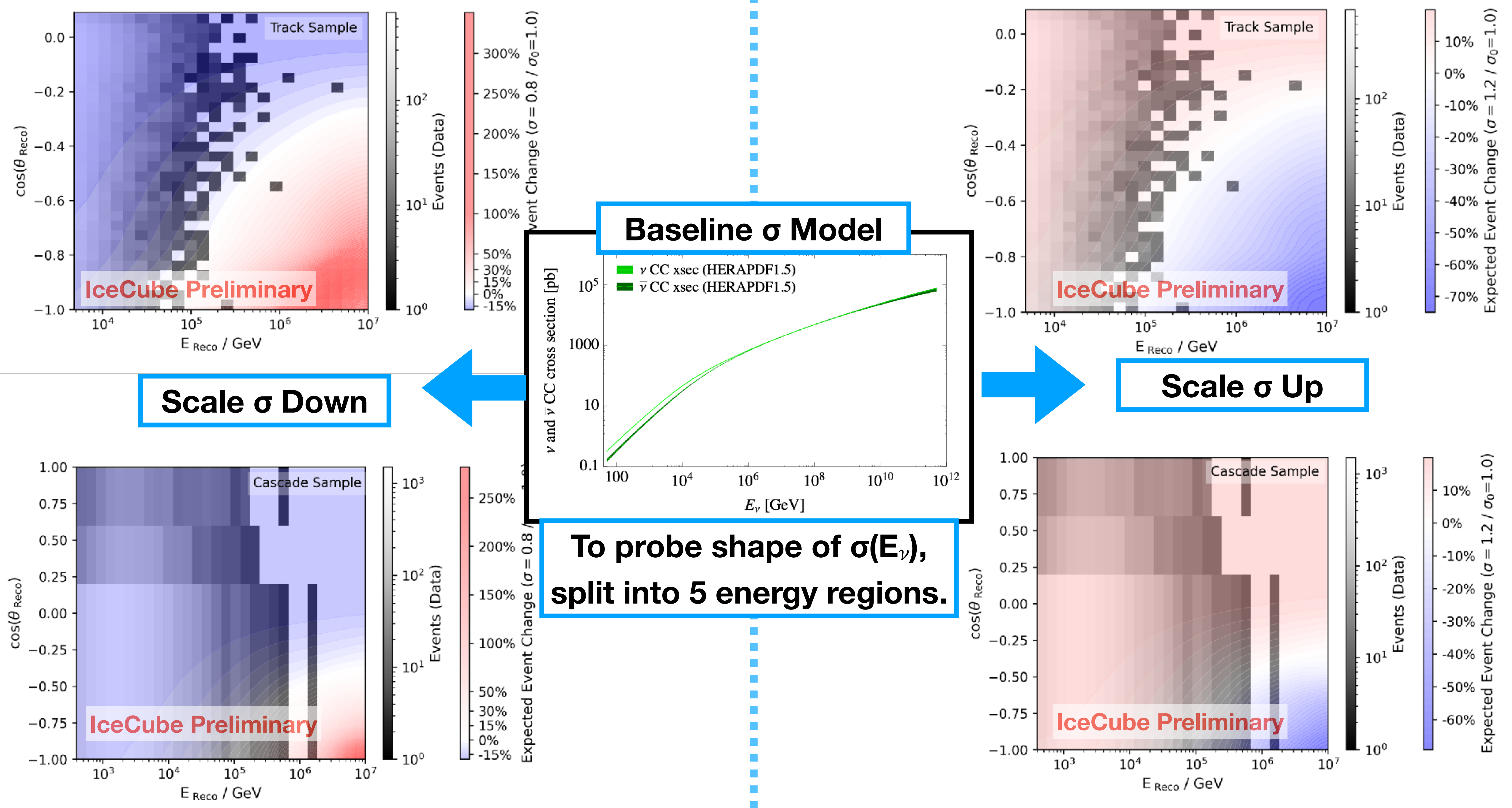


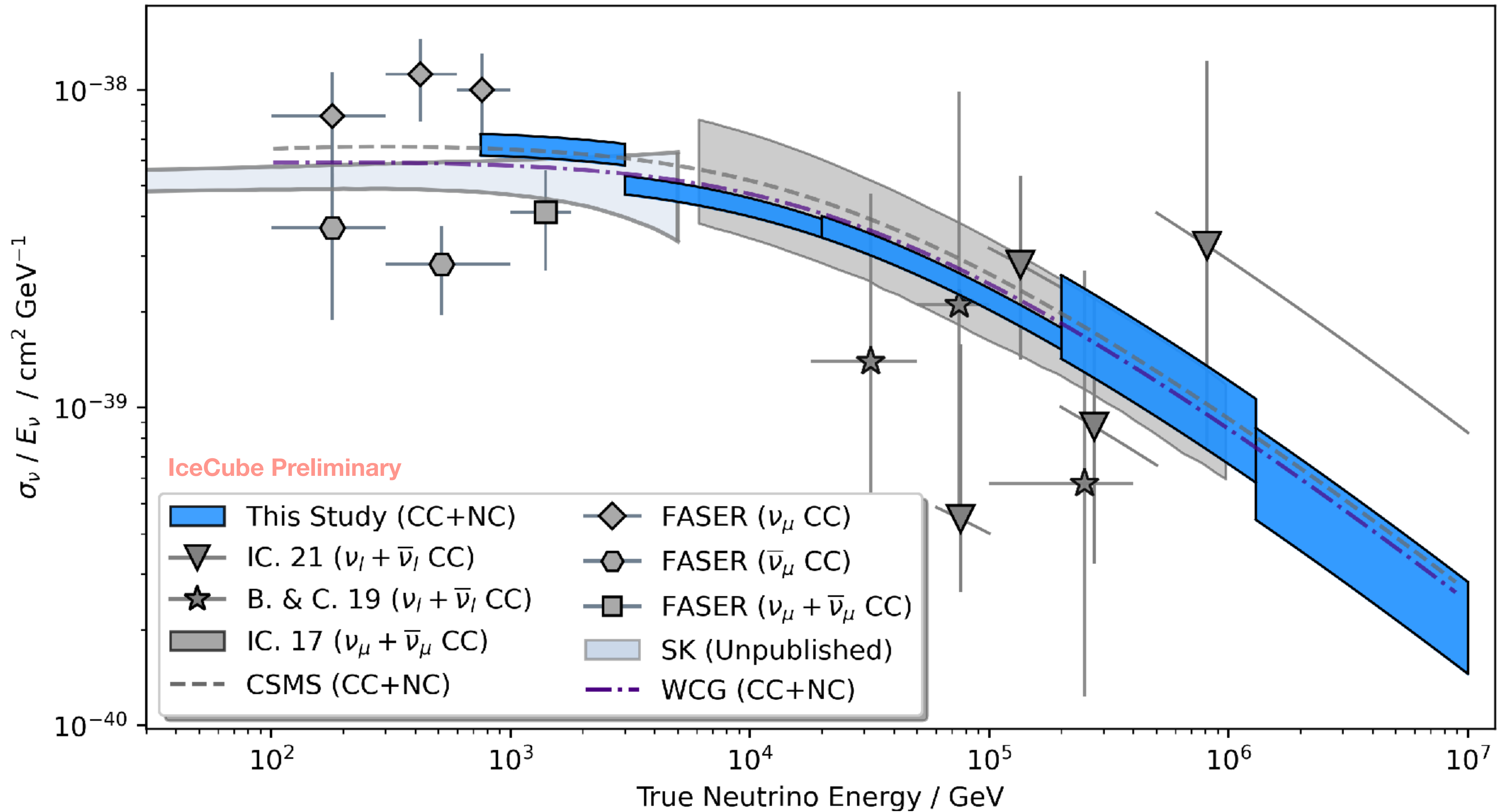
Combine two event classes to maximise info.

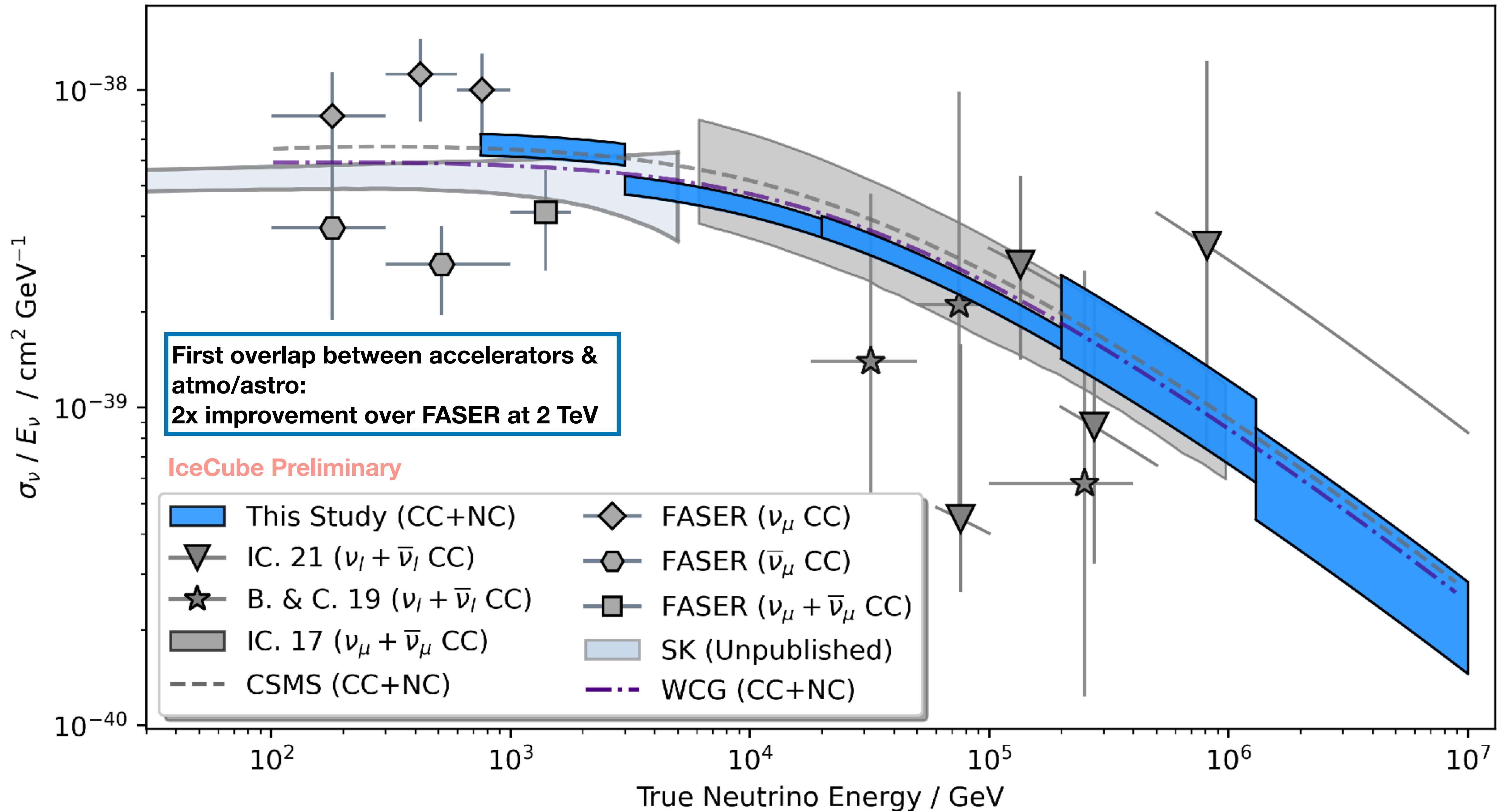


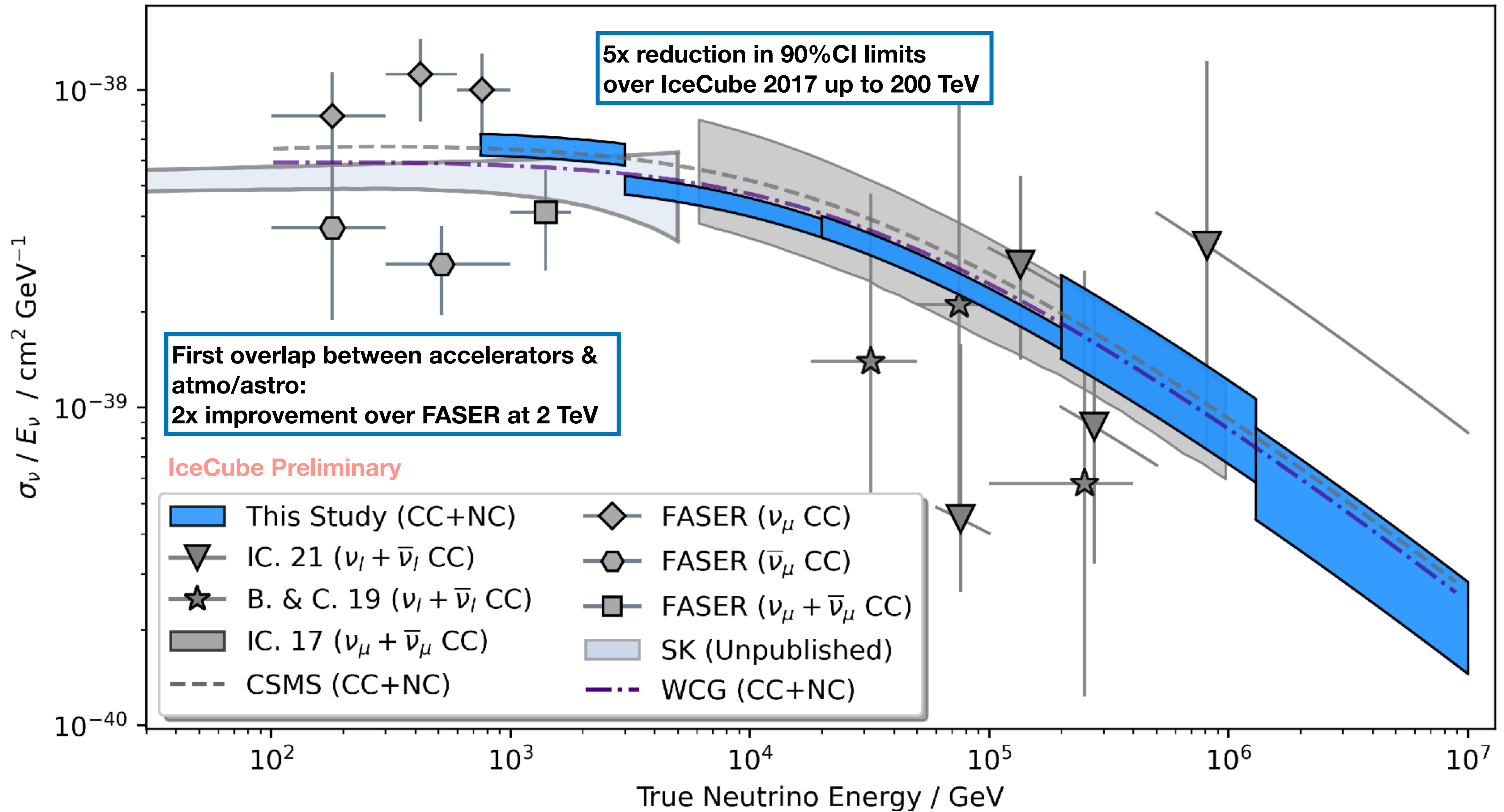
IceCube Diffuse Cascades Sample

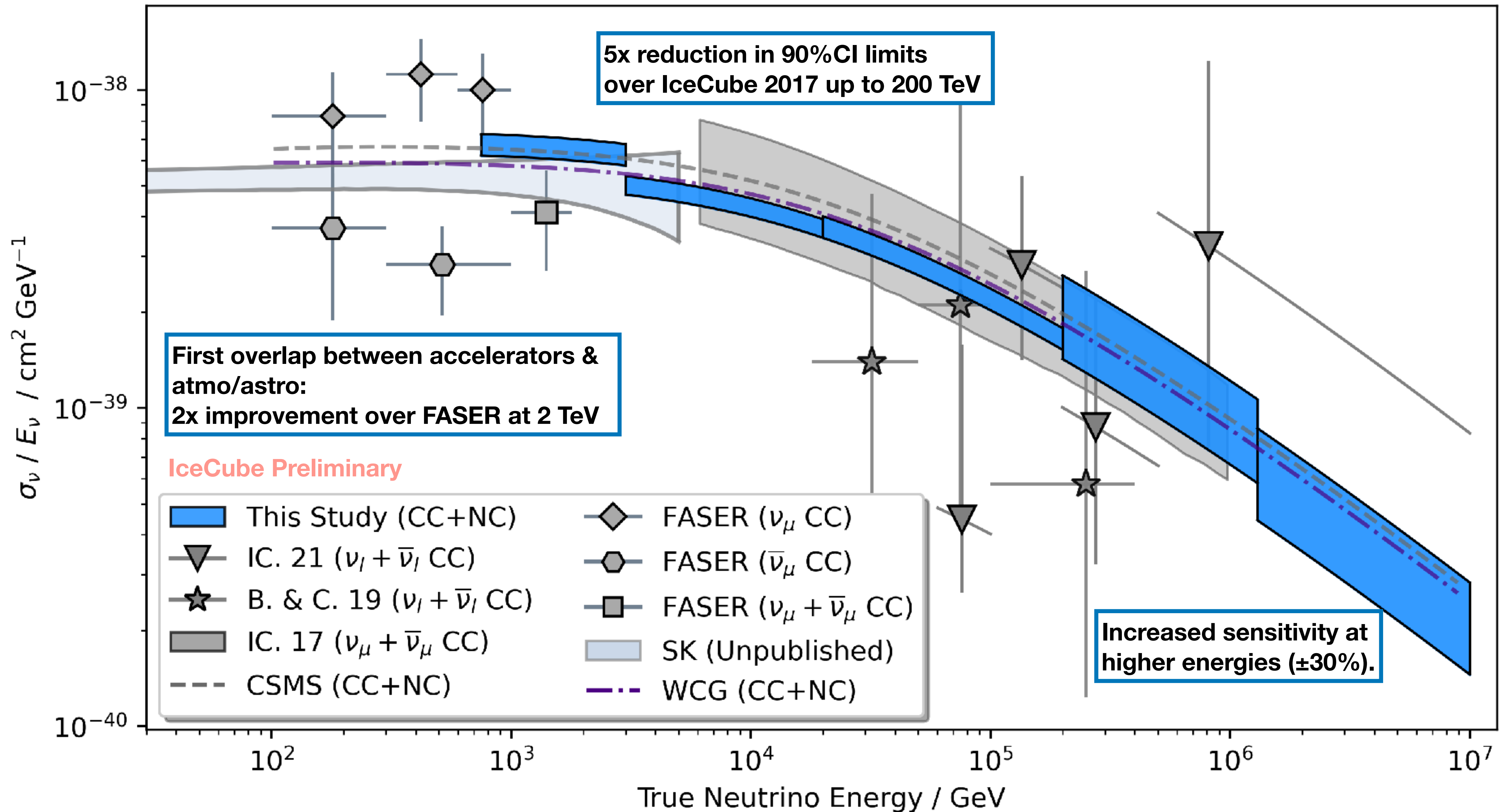












Take-Aways

- Next-generation IceCube cross section analysis (~10 years more data).
- Extend the lower bound of previous IceCube cross section measurements: fill-in the energy gap between Accelerators and Atmospheric/Astrophysical neutrino experiments.
- Bringing the precision cross section era up to higher energies (200 TeV, sub-10% uncertainty).
- Setting leading constraints up to 10 PeV, while including modern IceCube systematic uncertainties.
- Future measurements look to probe agreement between cross section calculations and underlying Standard Model physics (nuclear effects, choice of PDFs).

- Backup

Fluxes and Nuisance Parameters

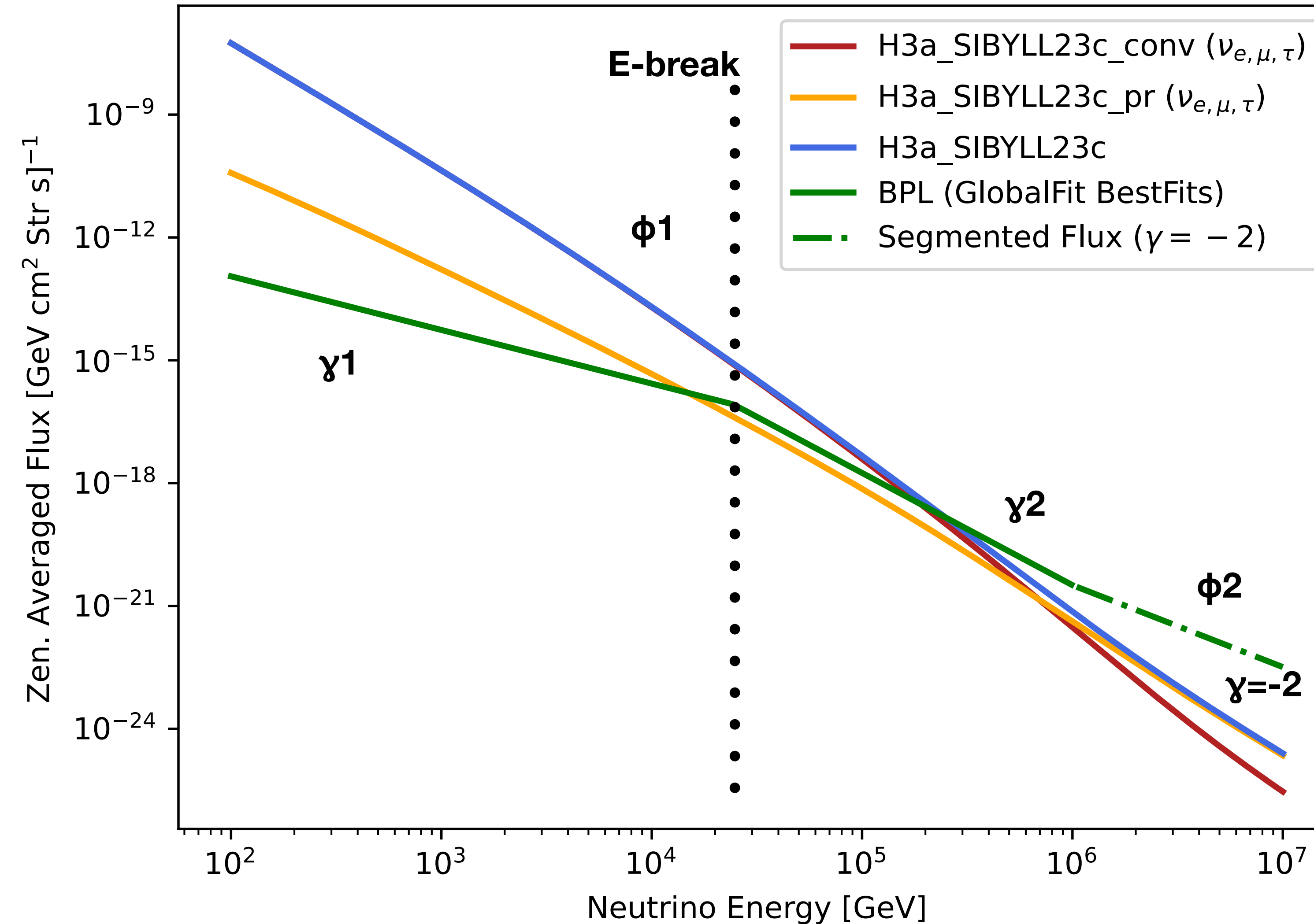
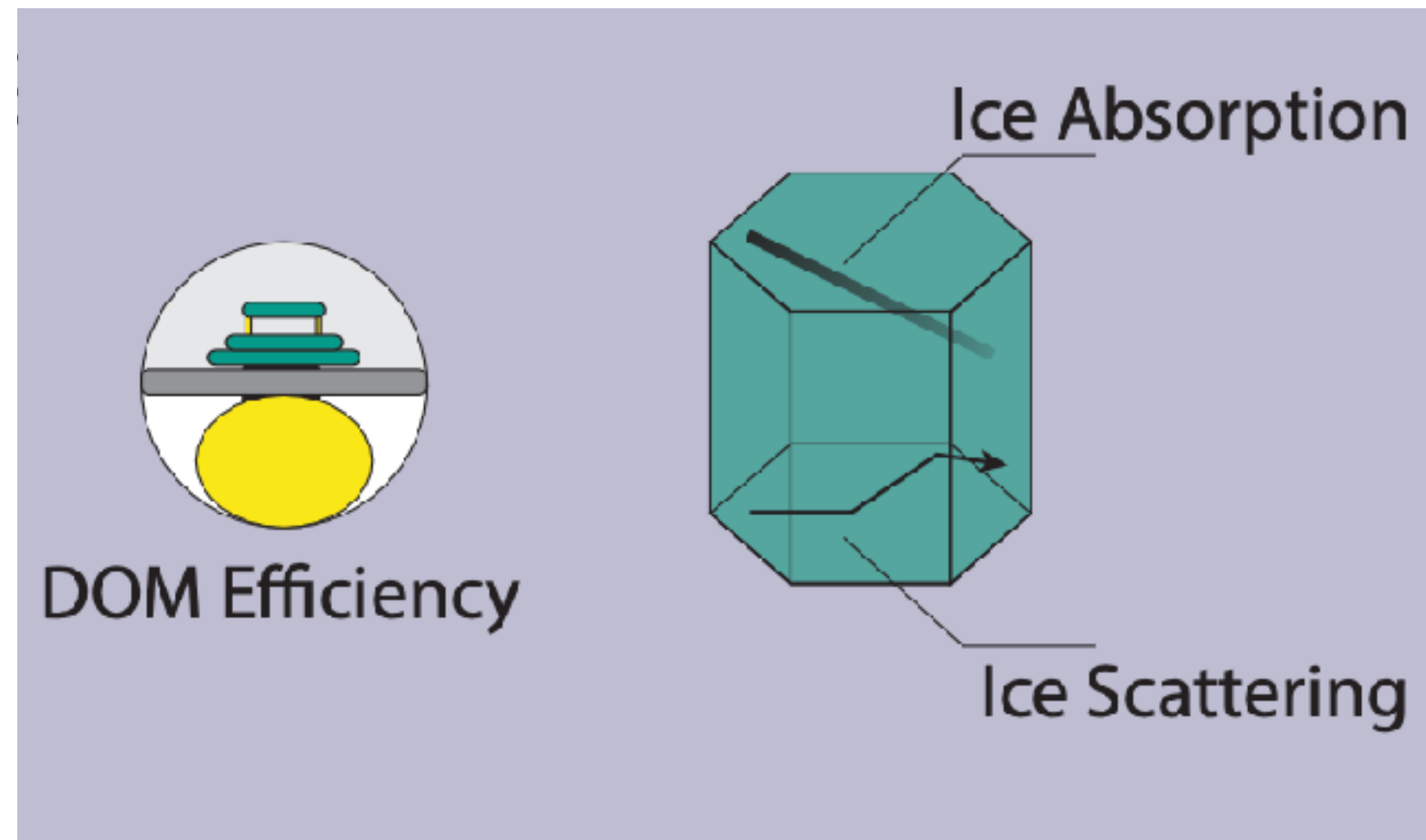
Nuisance Parameter Type

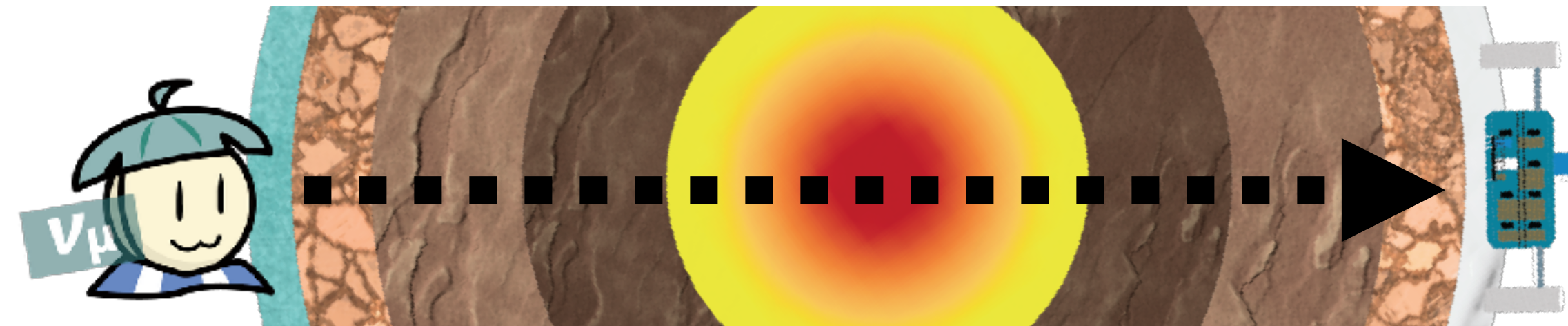
Atmospheric (Shape, Norm)

Astrophysical (BPL Shape, Norm)

EHE ($E_\nu > 10^6$ GeV)

Detector (DOMs, Ice)

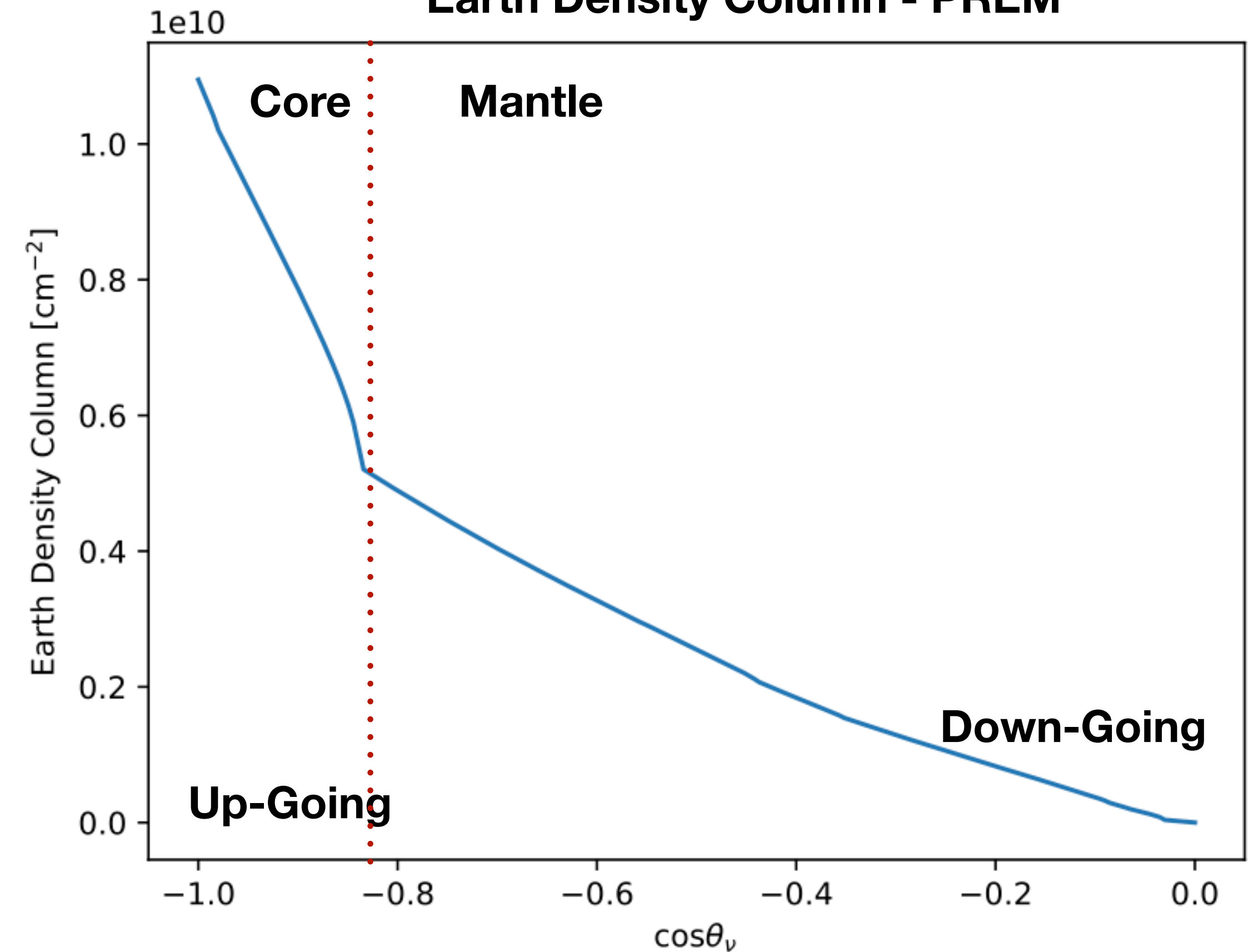
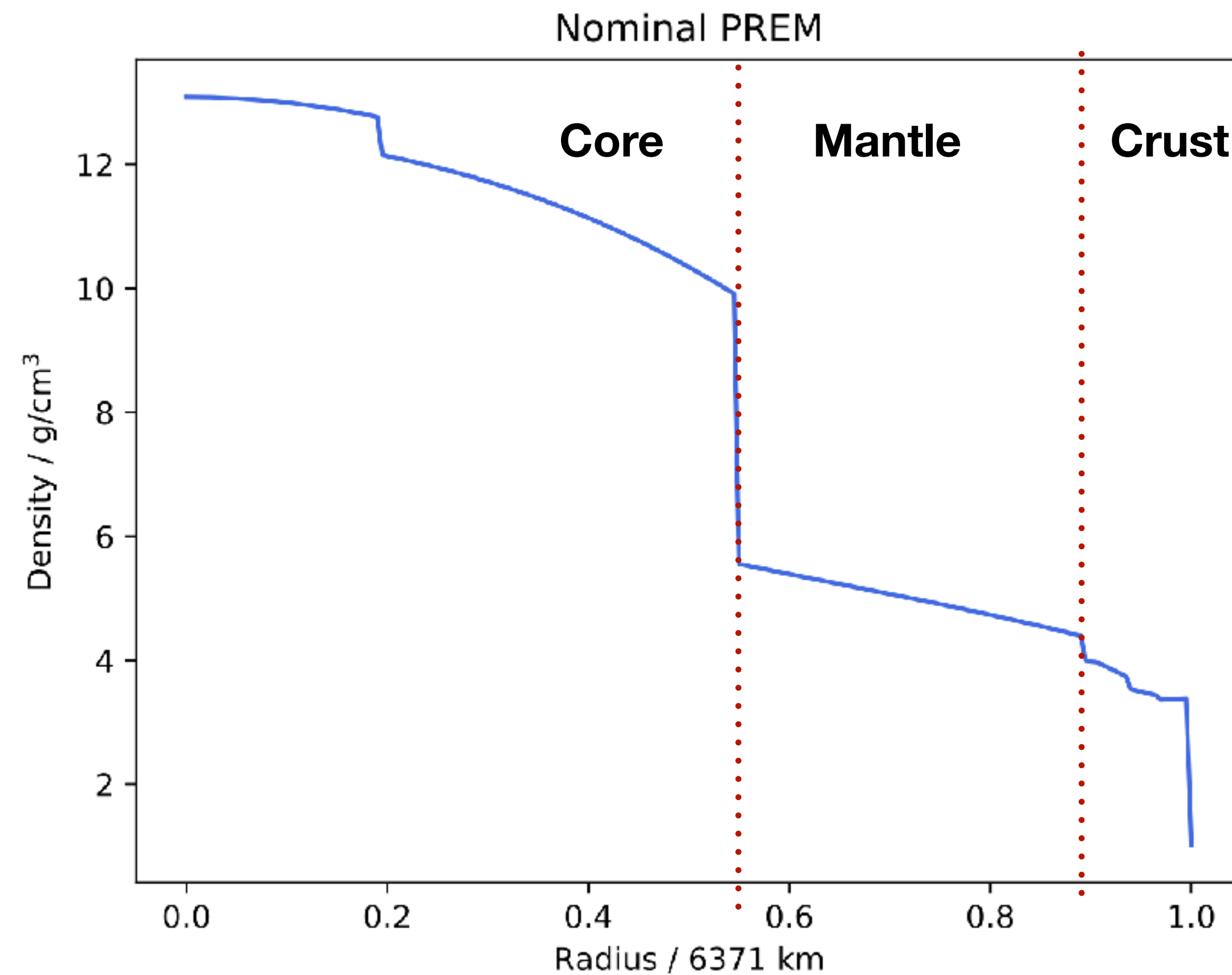




Element	Crust	Mantle	Core	$N - Z$					
^{16}O	46.8	44.23	5.40	0	^{28}Si	30.8	21.0	-	0
^{23}Na	2.9	0.27	-	2	^{32}S	3.0	-	8.43	0
^{24}Mg	1.3	22.8	-	0	^{40}Ca	-	2.53	-	0
^{27}Al	8.0	2.53	-	1	^{56}Fe	3.5	6.26	81.79	4
					^{59}Ni	-	0.2	6.70	3

arXiv:2001.03677v2

Earth Density Column - PREM



In "IceCube Coordinates": neutrino cosine zenith