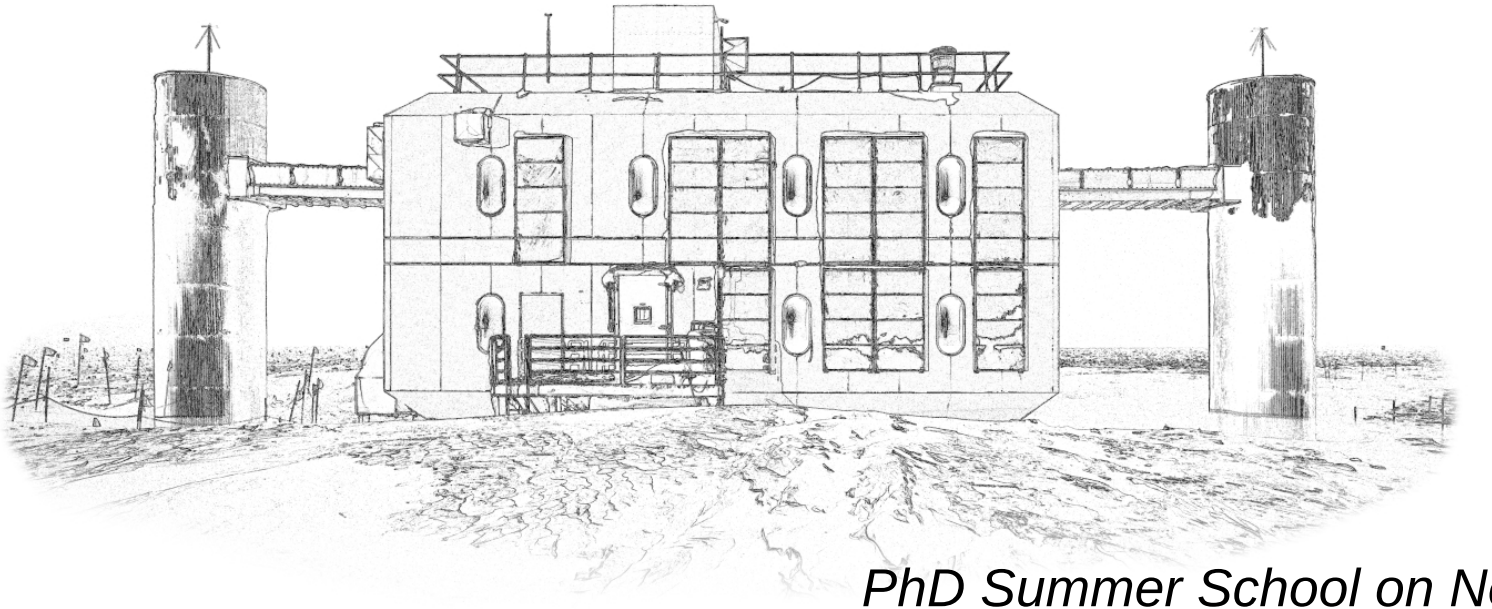
Inelasticity reconstruction and ν/ν̄ separation for the IceCube Upgrade detector



PhD Summer School on Neutrinos: Here, There & Everywhere

Marc Jacquart

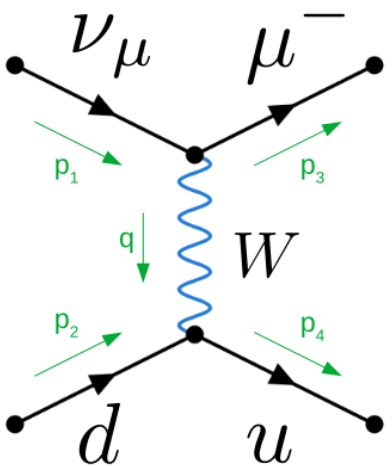
8 July 2025

IceCube Neutrino Observatory

University of Copenhagen

Inelasticity

$$y := \frac{p_2 \cdot q}{p_2 \cdot p_1} \overset{\text{L.I.}}{=} \frac{E_\nu - E_\mu}{E_\nu}$$

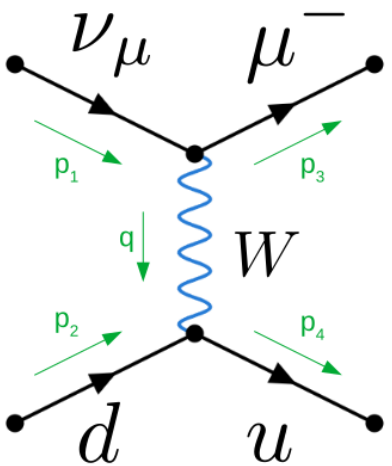


ν_μ(CC), DIS

Inelasticity

$$y := \frac{p_2 \cdot q}{p_2 \cdot p_1} \overset{\text{L.I.}}{=} \frac{E_\nu - E_\mu}{E_\nu}$$

Frame: nucleon at rest

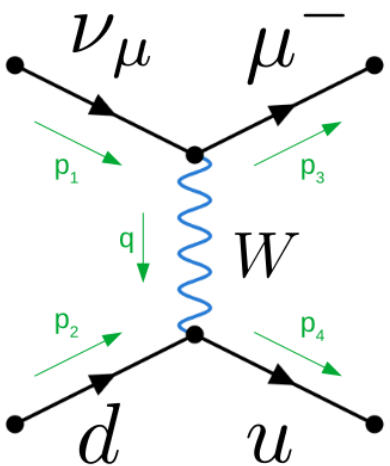


ν_μ(CC), DIS

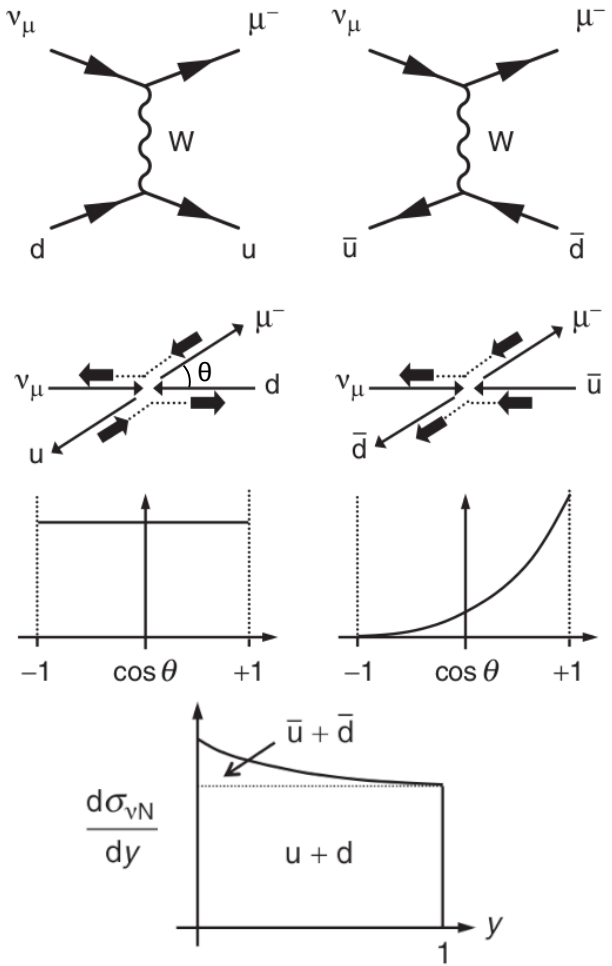
Inelasticity

$$y := \frac{p_2 \cdot q}{p_2 \cdot p_1} \overset{\text{L.I.}}{=} \frac{E_\nu - E_\mu}{E_\nu}$$

Frame: nucleon at rest



ν_μ(CC), DIS

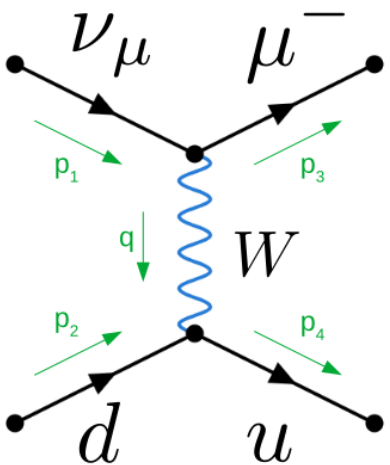


M. Thomson. Modern Particle Physics, ch.12

Inelasticity

$$y := \frac{p_2 \cdot q}{p_2 \cdot p_1} \overset{\text{L.I.}}{=} \frac{E_\nu - E_\mu}{E_\nu}$$

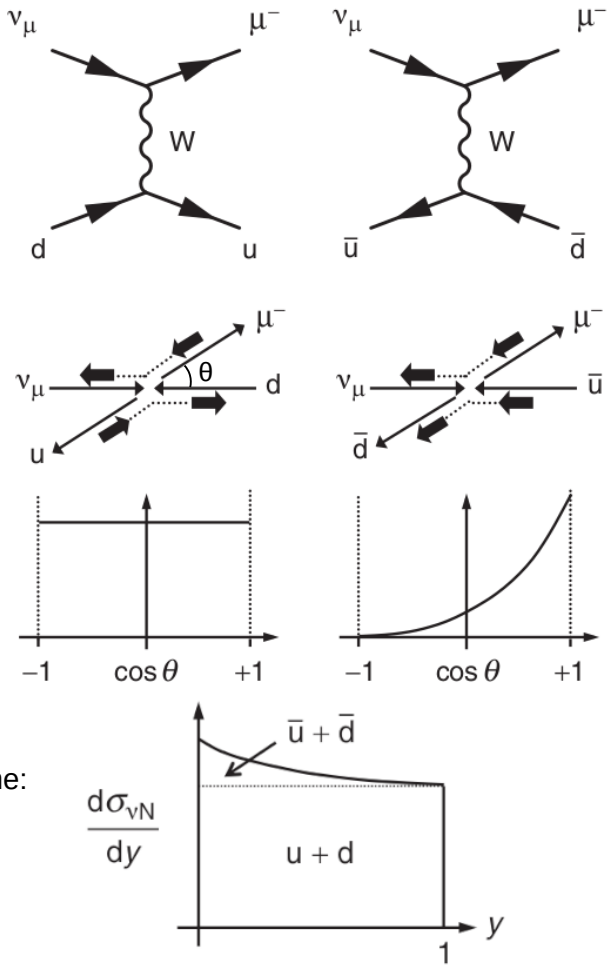
Frame: nucleon at rest



ν_μ(CC), DIS

Center of mass frame:

$$y = \frac{1 - \cos\theta}{2}$$

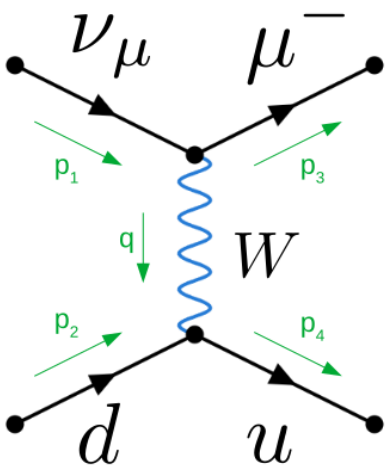


M. Thomson. Modern Particle Physics, ch.12

Inelasticity

$$y := \frac{p_2 \cdot q}{p_2 \cdot p_1} \overset{\text{L.I.}}{=} \frac{E_\nu - E_\mu}{E_\nu}$$

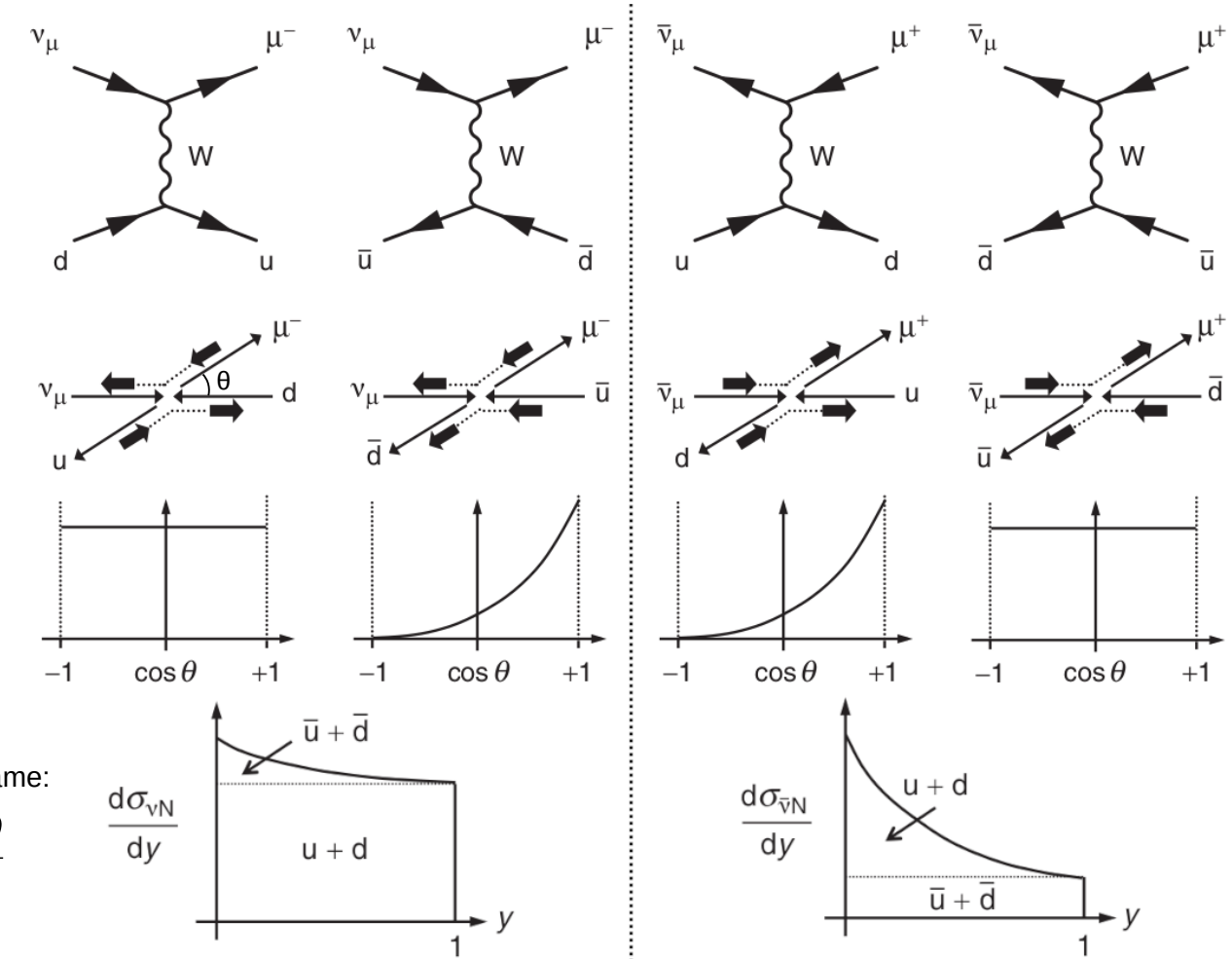
Frame: nucleon at rest



ν_μ(CC), DIS

Center of mass frame:

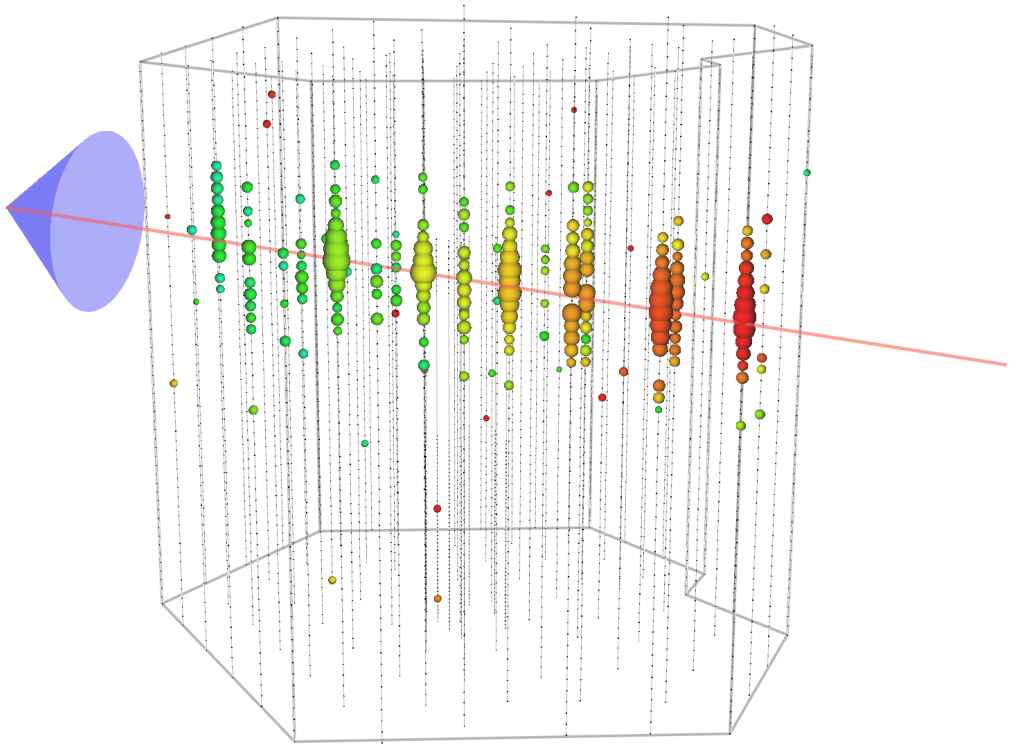
$$y = \frac{1 - \cos\theta}{2}$$



M. Thomson. Modern Particle Physics, ch.12

Separating hadronic cascade from muon track

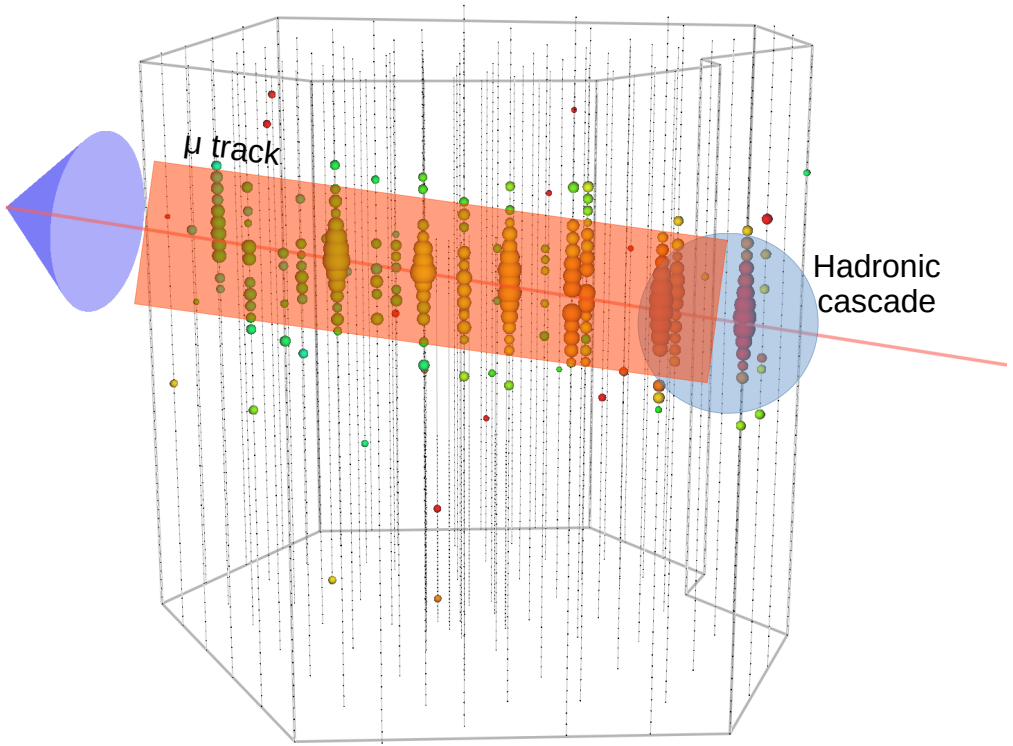
~200TeV



IceCube-240327A

Separating hadronic cascade from muon track

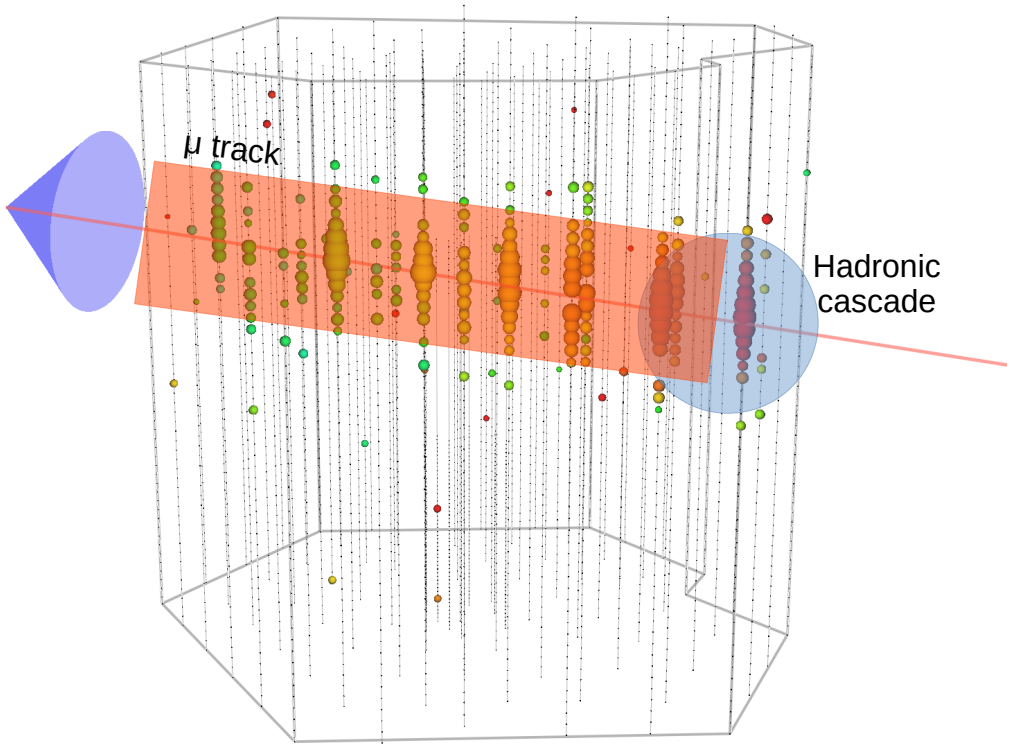
~200TeV



IceCube-240327A

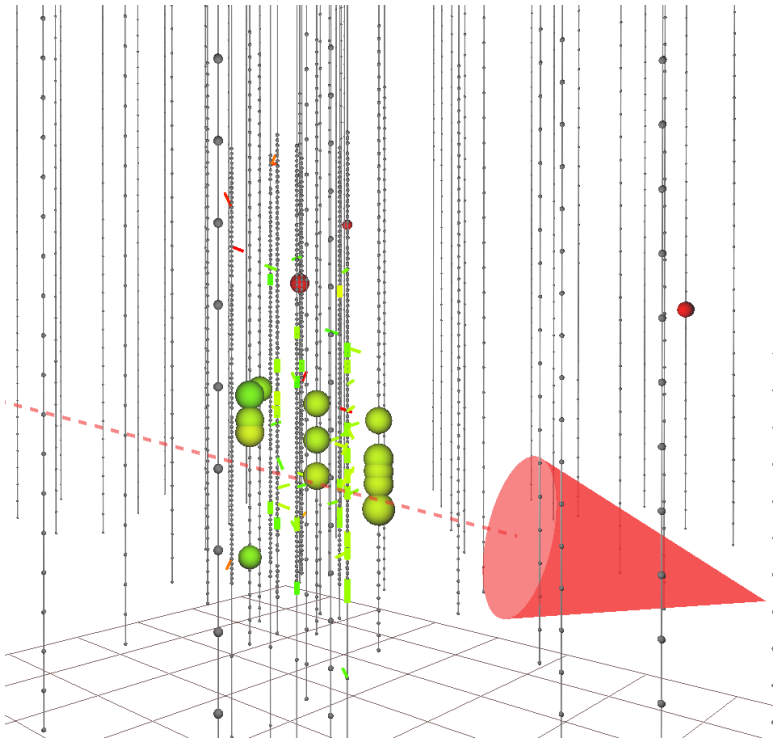
Separating hadronic cascade from muon track

~200TeV

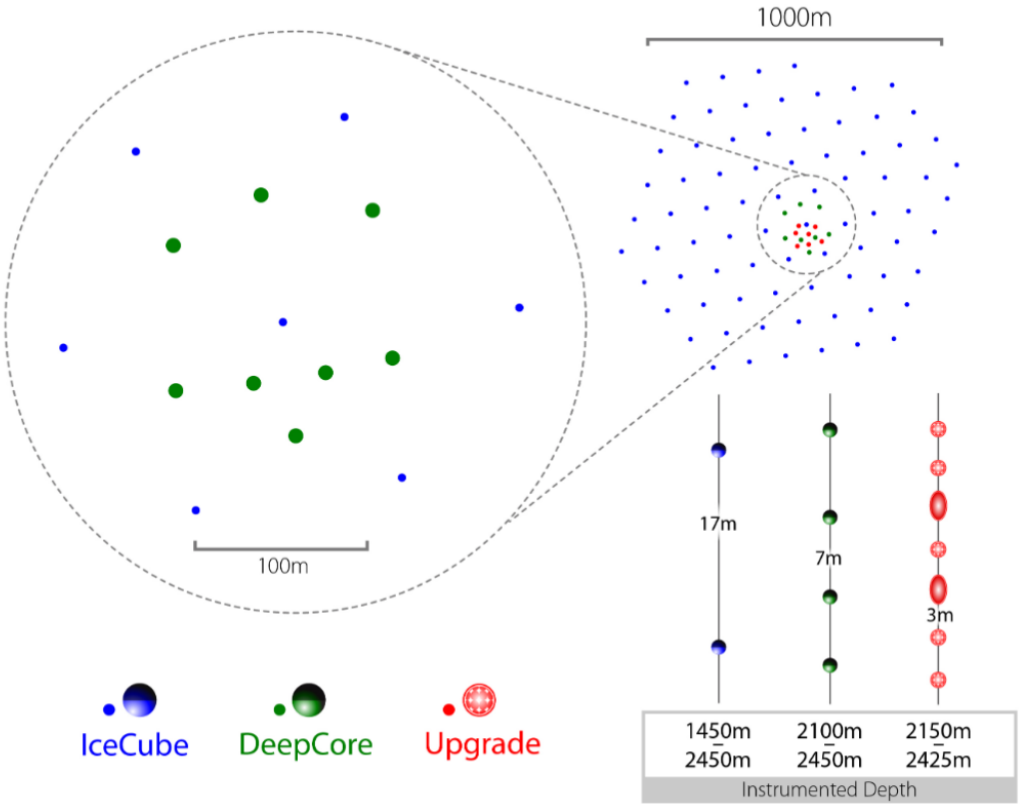


IceCube-240327A

19 GeV, y=0.6



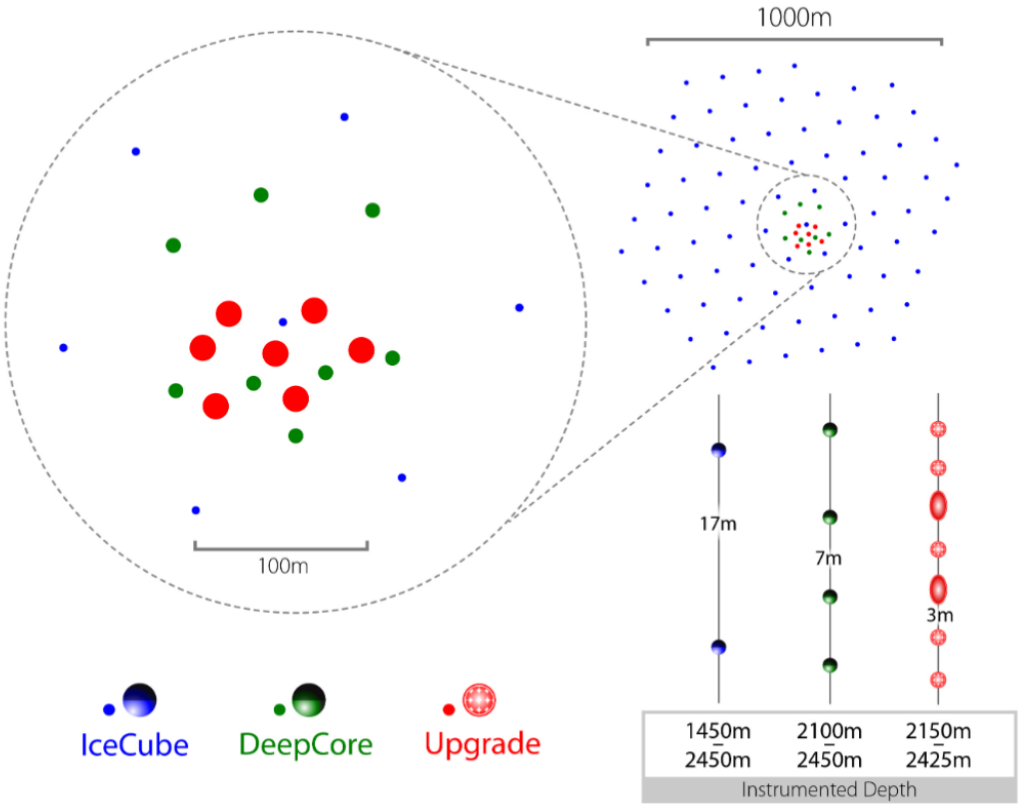
IceCube Upgrade



arXiv:1908.09441

IceCube Upgrade

- 7 additionnal strings

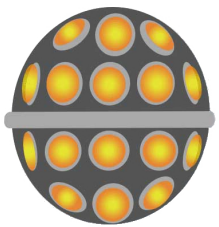


arXiv:1908.09441

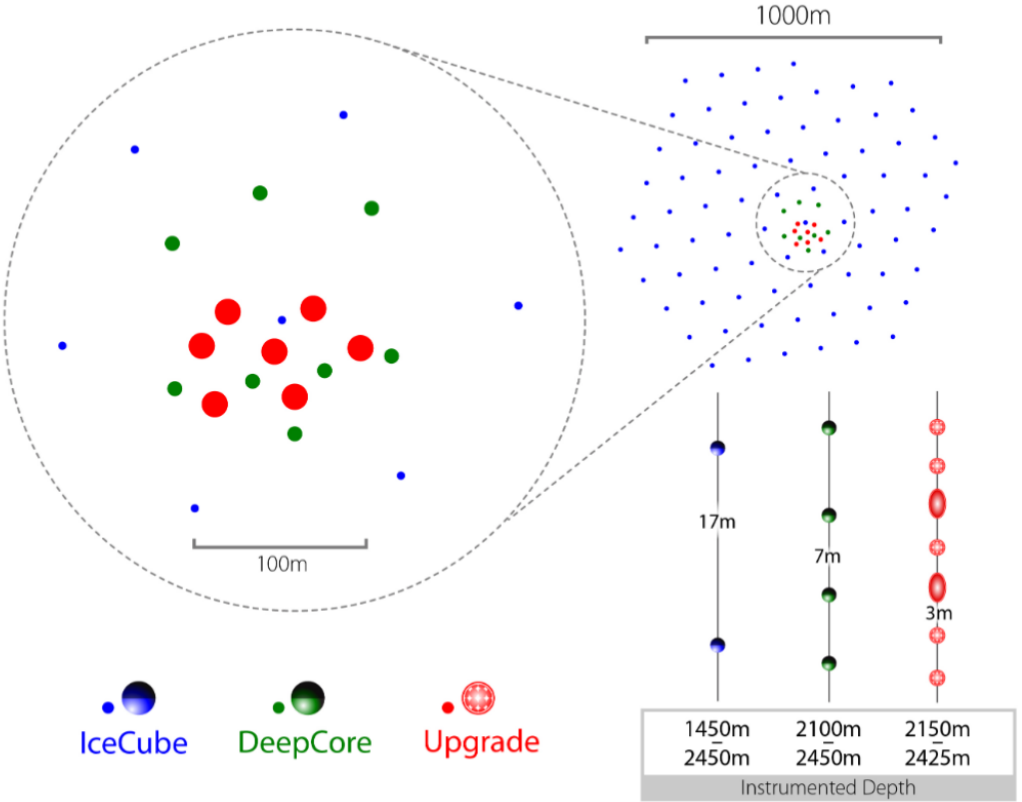
IceCube Upgrade

- 7 additionnal strings
- Multi-directional PMTs

D-Egg
2 x 8" PMT
300 sensors



mDOM
24 x 3" PMT
430 sensors

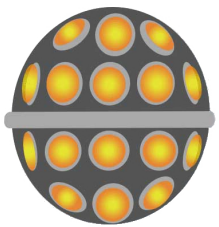


arXiv:1908.09441

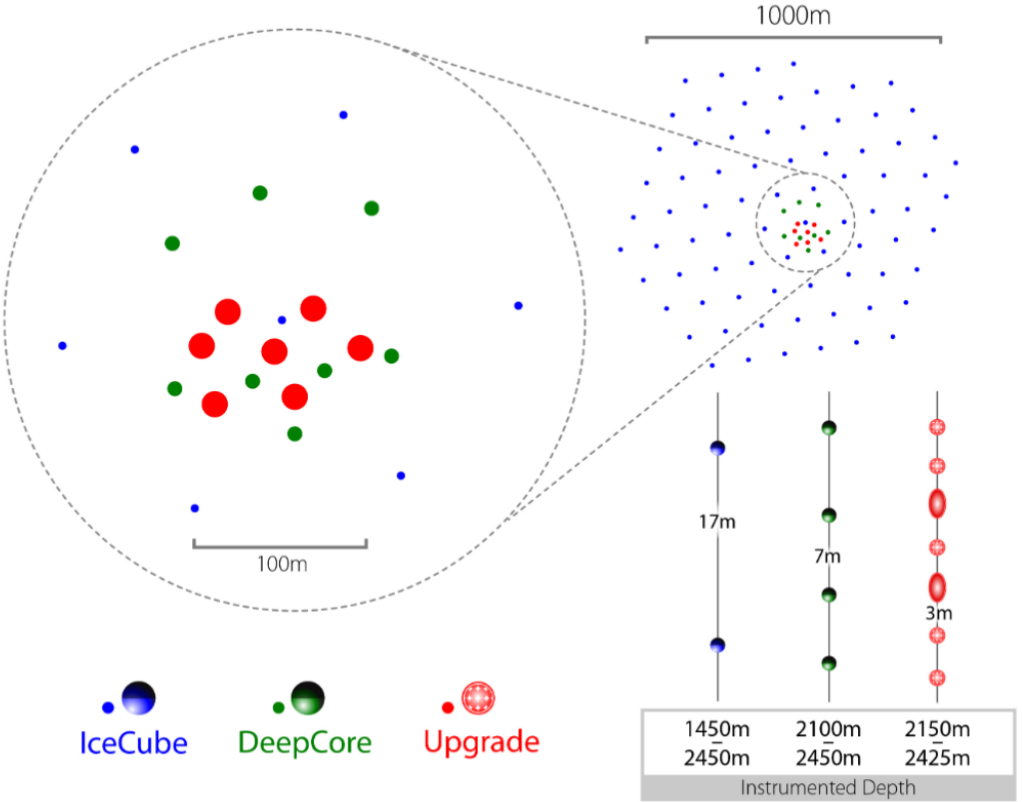
IceCube Upgrade

- 7 additionnal strings
- Multi-directional PMTs
- Deployment in 6 months

D-Egg
2 x 8" PMT
300 sensors



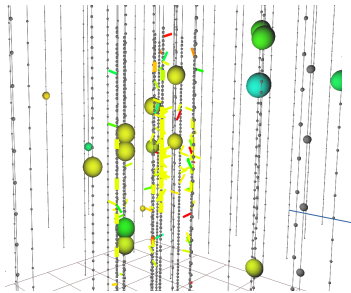
mDOM
24 x 3" PMT
430 sensors

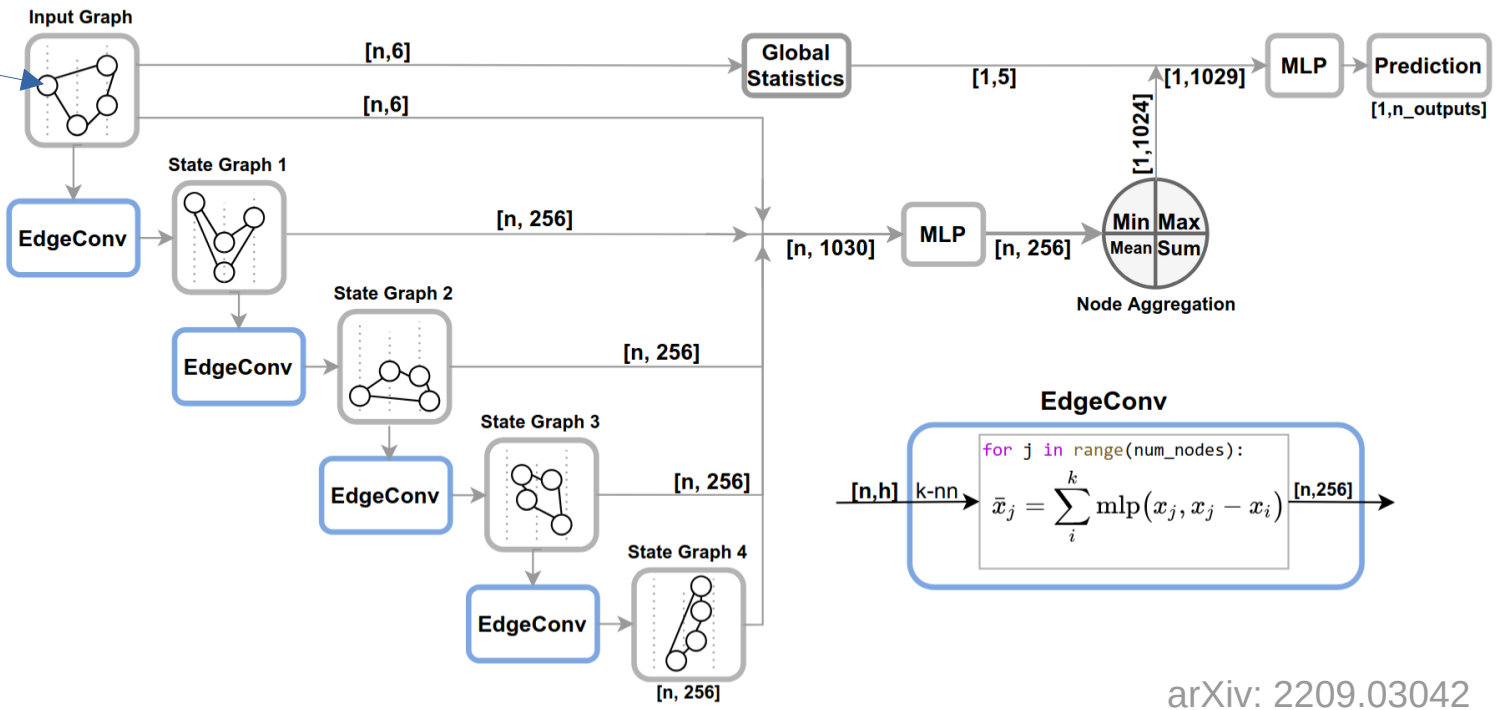


arXiv:1908.09441

DynEdge Model

GraphNeT
Deep Learning for Neutrino Telescopes



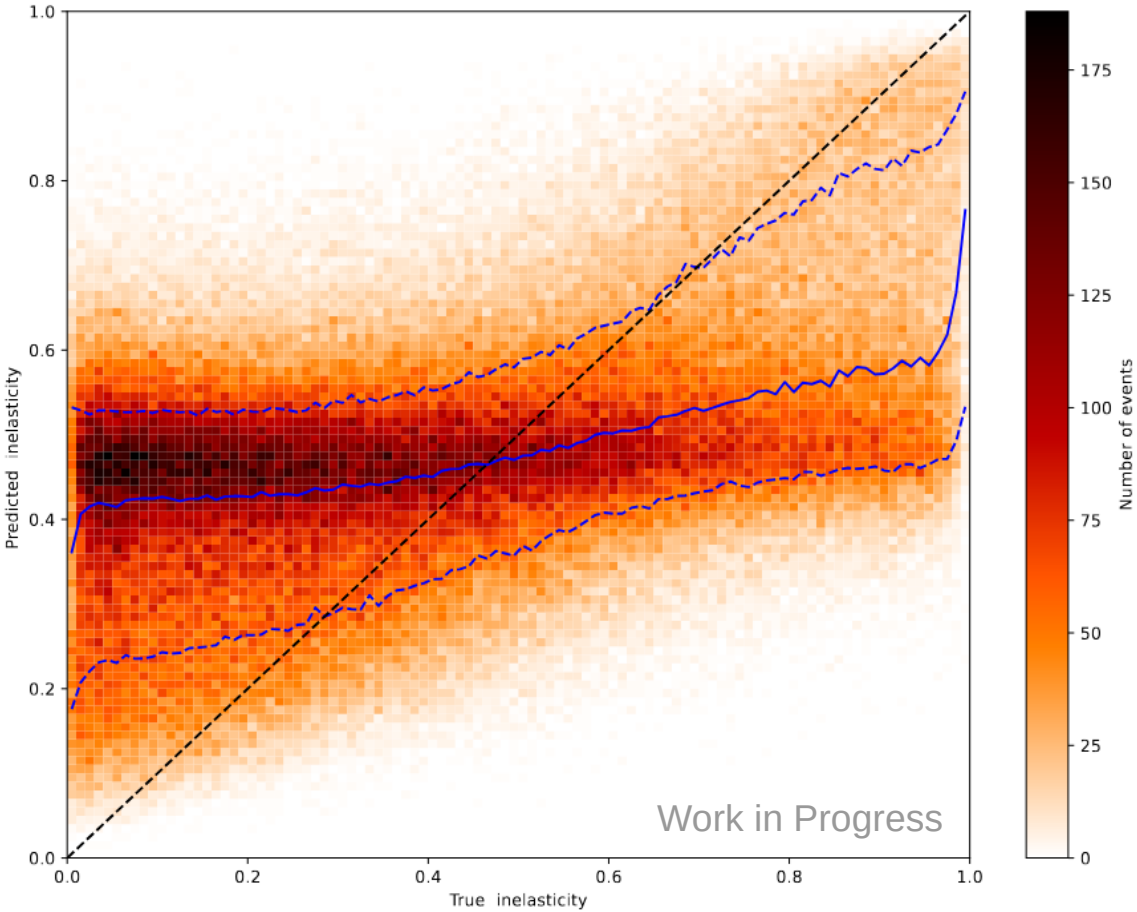


arXiv: 2209.03042

Reconstruction results

- E=[1, 500] GeV, ɣ=-2.5
- No information: y=0.5
- Uncertainty prediction:

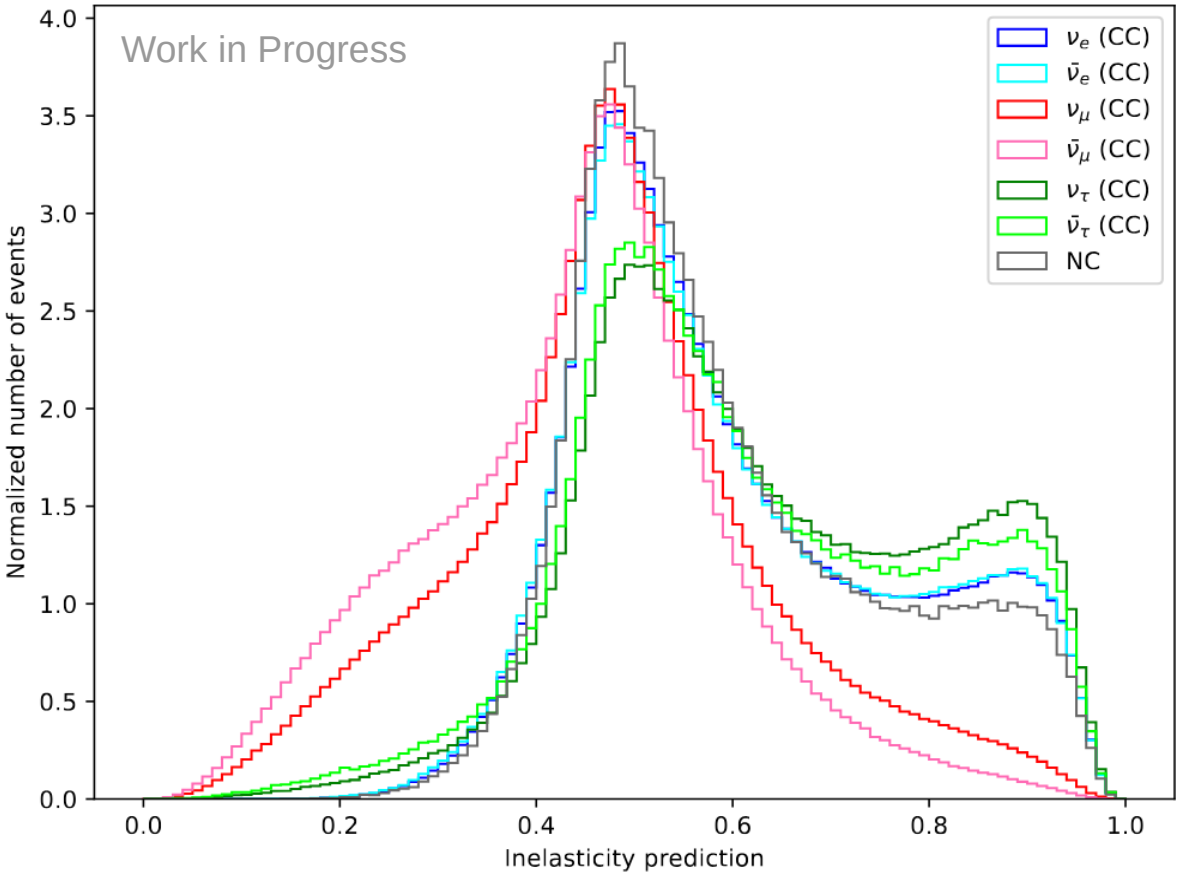
  performance vs statistics



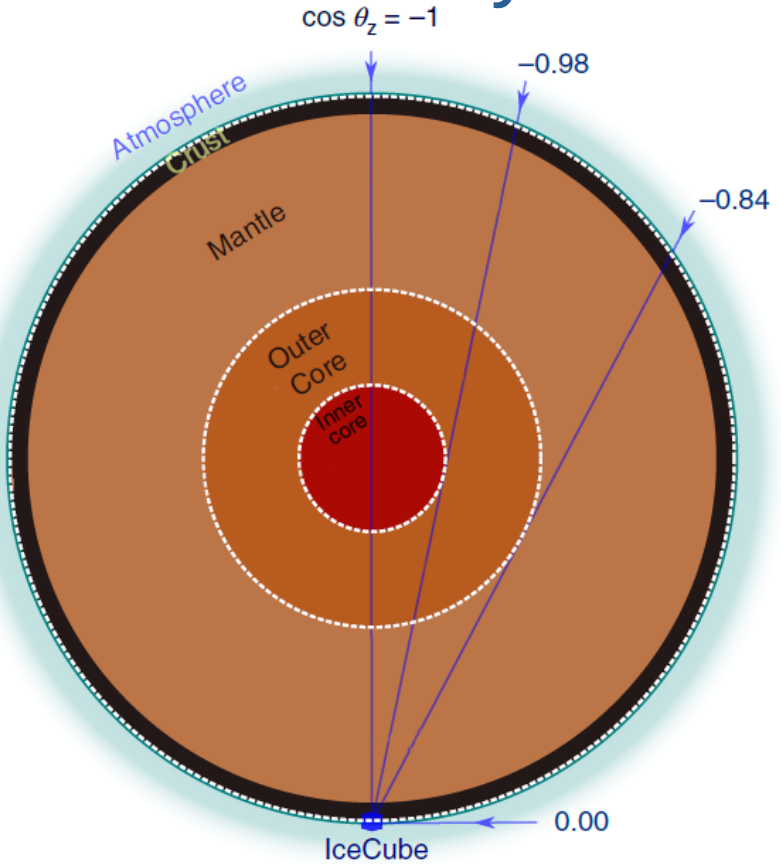
Applying the model to other interaction types

Observe expected features:

- ν_τ (83%), ν_e, NC: expect y≈1
- $m_\tau \approx 1.7$GeV: low E_ν suppression
- 17% τ leptonic decay → μ



NMO sensitivity enhancement



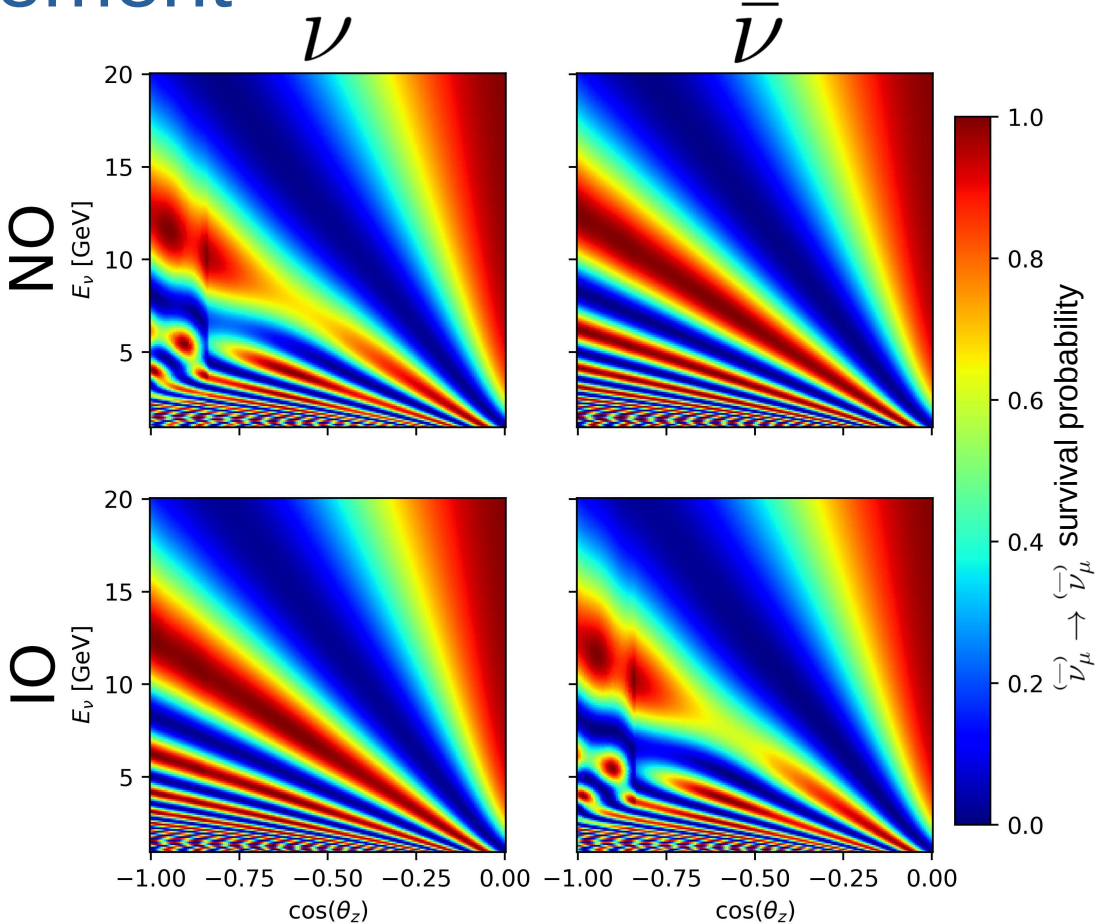


Image: doi.org/10.1038/s41567-018-0319-1

Summary

- Inelasticity measurement allows statistical $\nu/\bar{\nu}$ separation
- Inelasticity reconstructed with a graph neural network
- Future work: IceCube Upgrade NMO sensitivity