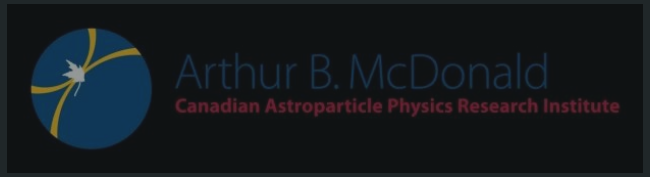

CASST 2021

Cascade Reconstruction in P-ONE

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Supervisors:
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Dr. Thomas McElroy
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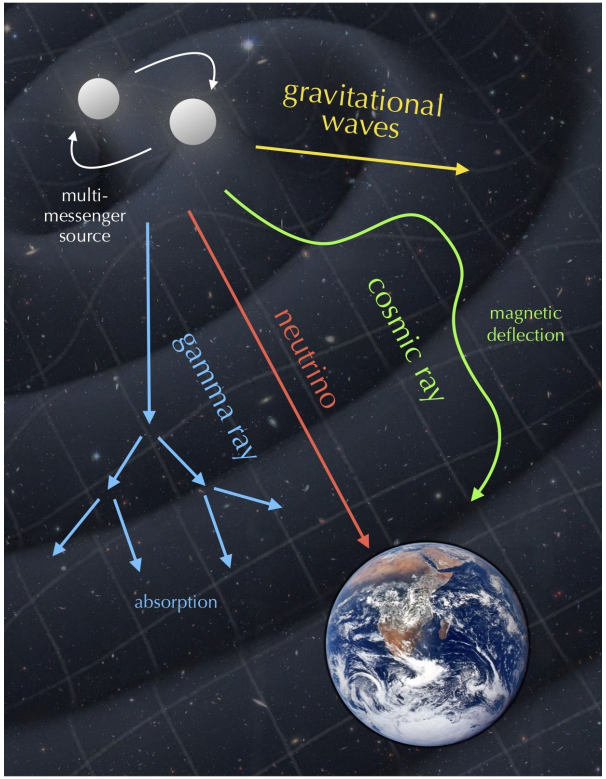
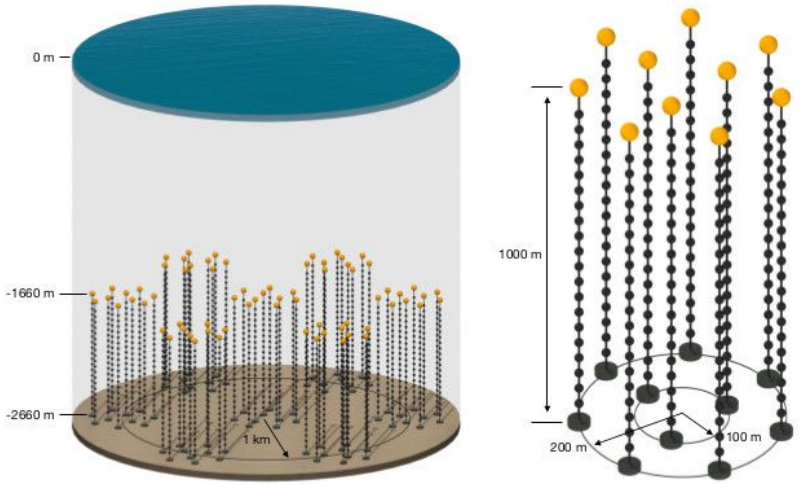
AIM: TO UNDERSTAND ASTROPHYSICAL NEUTRINOS

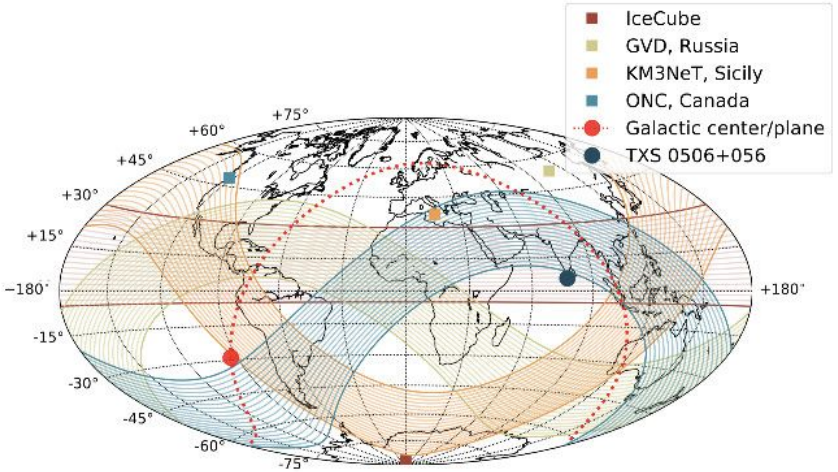
- First reported by IceCube in 2013, between energies 10 TeV - 2 PeV
- Hardly interact with matter -- detection is hard, but excellent cosmic messengers.
- More than 1000 x energy of neutrinos in particle accelerators.
- Probe previously unexplored regions of universe; understand physics beyond “Standard Model”



INTRODUCTION TO THE P-ONE EXPERIMENT

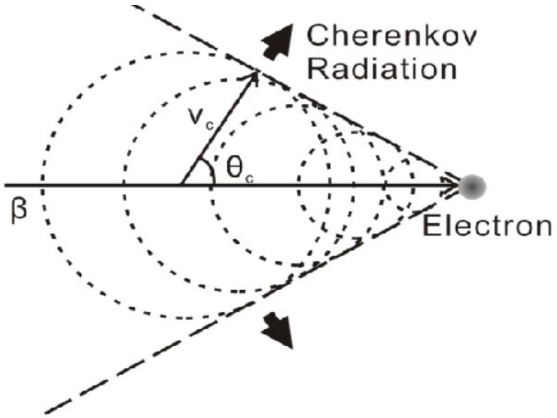


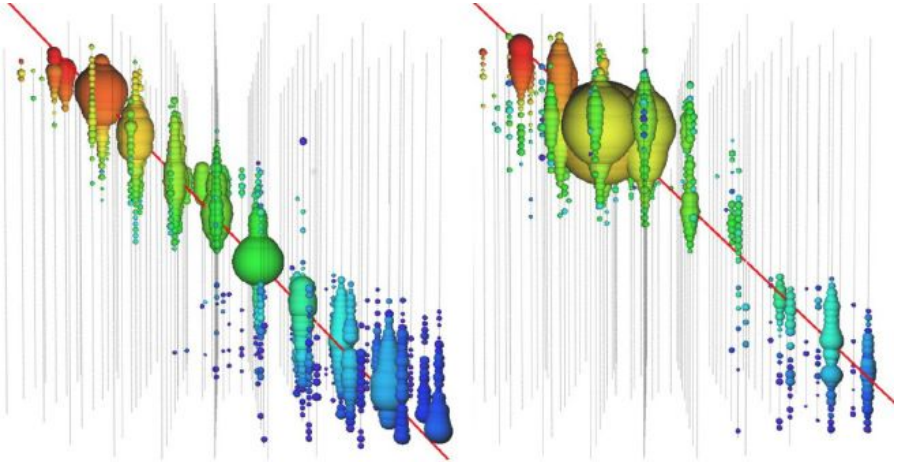
- P-1: 10 strings, 20 DOMs/string
- P-2: 70 strings, 20 DOMs/string



P-ONE + other neutrino telescopes
= single distributed detector
= increased sky coverage

P-ONE: THE INNER WORKINGS

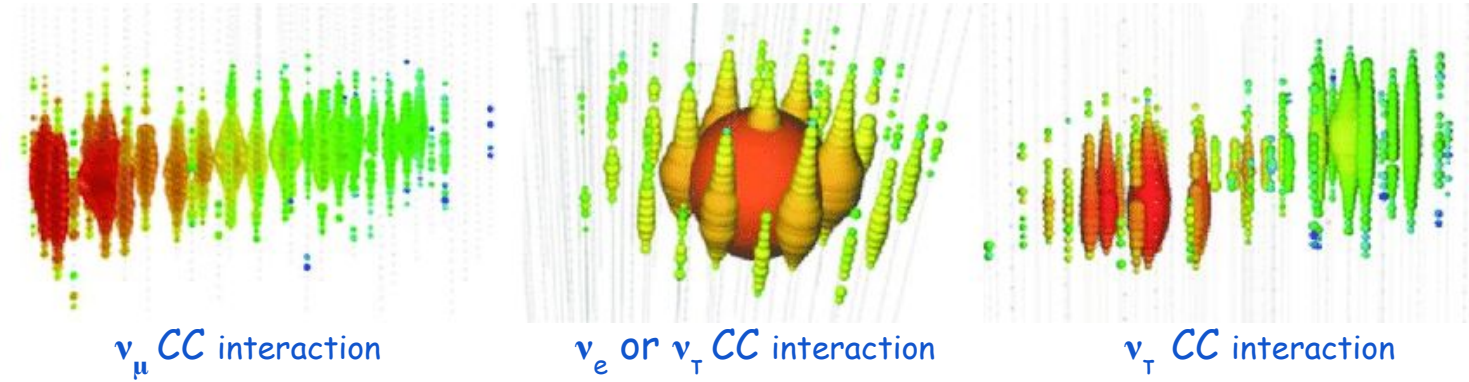




- Neutrino interacts with detector, producing secondary particles.
- **Cherenkov** radiation emitted by propagating secondary particles, when $c/n < v < c$.
- Light pulses detected by DOMs, which relay data about charge collected, pulse times, etc.
- Data to be used for particle direction/energy reconstruction and event topology classification

PROBLEM 1: CASCADE RECONSTRUCTION

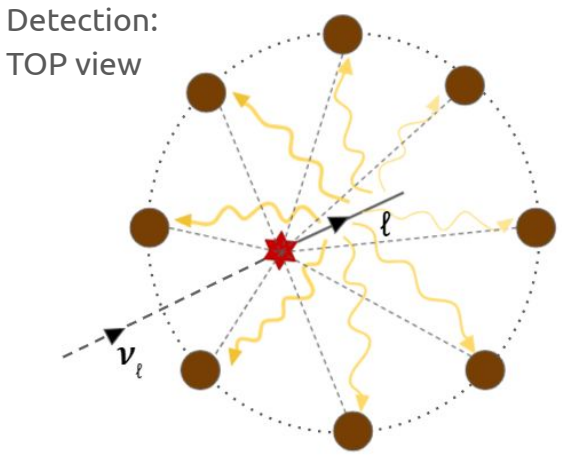
- **3** flavors of neutrinos: e, μ and τ types. Correspondingly, create electron, muon or tau leptons in a CC/NC interaction.
- These **3** leptons emit **Cherenkov** radiation in different patterns.
- 2 different signatures: **track-like** (muons) & **cascade-like** (electrons and taus).



Q: Design a "cascade-fitter"which -- for cascade-like events -- can precisely reconstruct the arrival direction of a neutrino and the coordinates of the interaction vertex.

PROBLEM 1: CASCADE RECONSTRUCTION

VERTEX RECONSTRUCTION: (Real data collection would begin after 2023. Meanwhile, we simulate data.)



Assumed isotropy of Cherenkov radiation emission

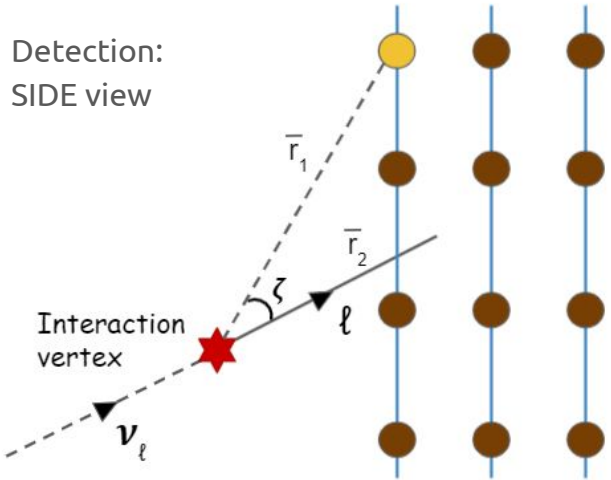
- First guess: **weighted average** of Cherenkov photons collected by the DOMs.

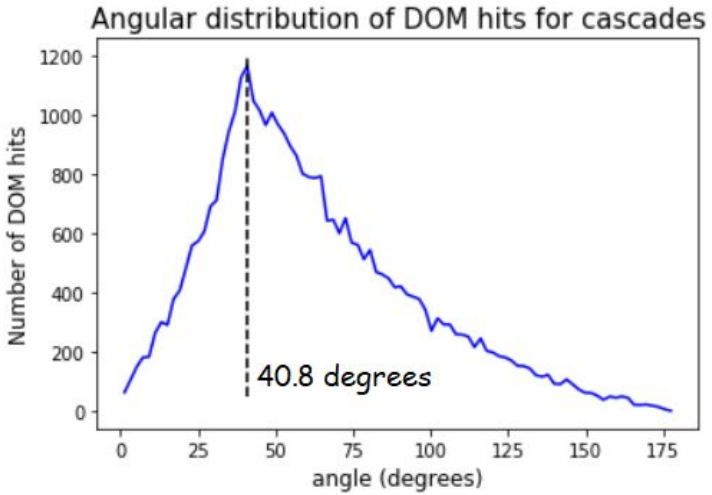
$$v_i = \frac{\sum_{k=1}^{n}(\text{Charge collected by } k^{th} \text{ DOM} \times i^{th} \text{ coordinate of } k^{th} \text{ DOM})}{\text{Total charge collected by all DOMs}}$$

$$i = \{x, y, z\}$$

PROBLEM 1: CASCADE RECONSTRUCTION

VERTEX RECONSTRUCTION: (Real data collection would begin after 2023. Meanwhile, we simulate data.)





High boosted particles emit Cherenkov radiation within well-defined cone of angle ζ:

$$\cos\zeta = \frac{1}{n\,\beta}$$

- Cherenkov angle for ultrarelativistic particles in water (n=1.33) is **41.4^0**.
- Most photons emitted near this angle

PROBLEM 1: CASCADE RECONSTRUCTION

VERTEX RECONSTRUCTION:

Think of a function that captures **deviation** from isotropy: $f(\zeta|k,A) = \frac{A}{2}\frac{k}{\sinh k}e^{k\cos\zeta}\sin\zeta$

PROBLEM 1: CASCADE RECONSTRUCTION

VERTEX RECONSTRUCTION:

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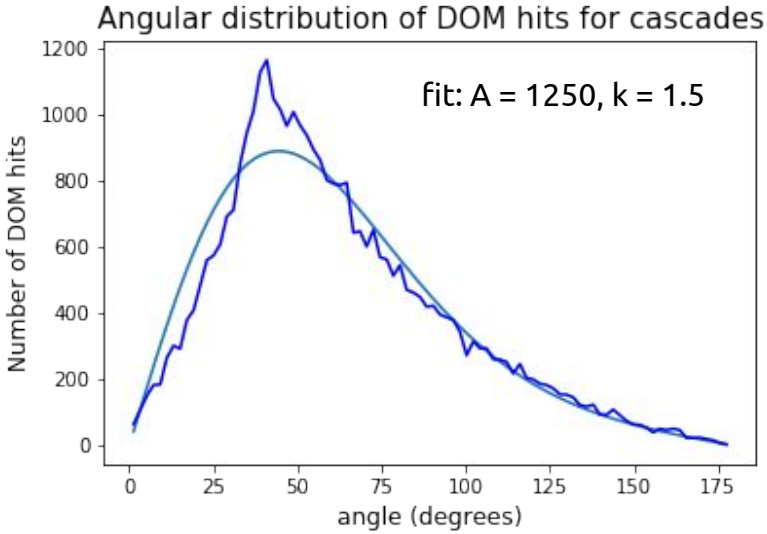

PROBLEM 1: CASCADE RECONSTRUCTION

VERTEX RECONSTRUCTION:

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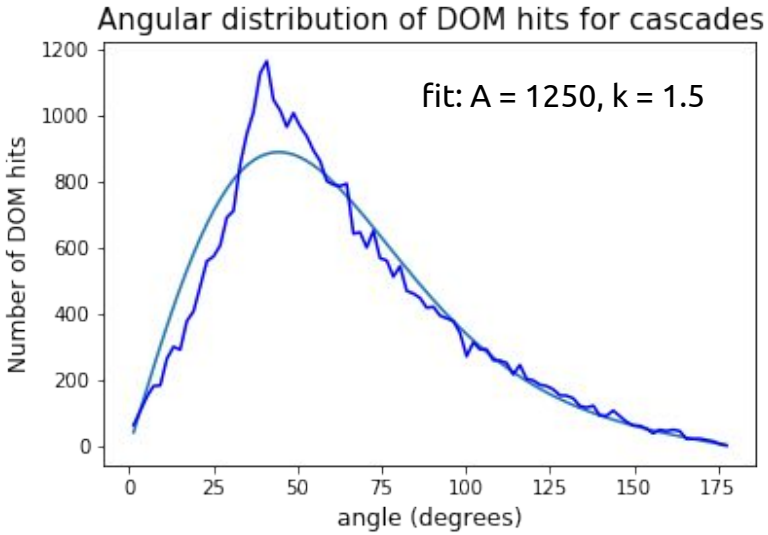
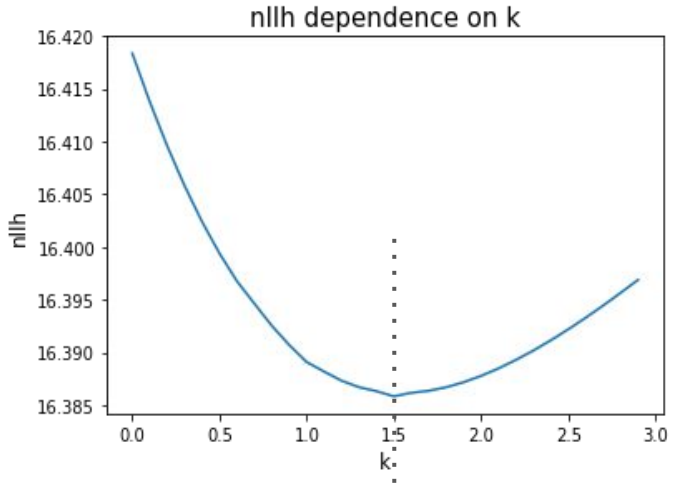


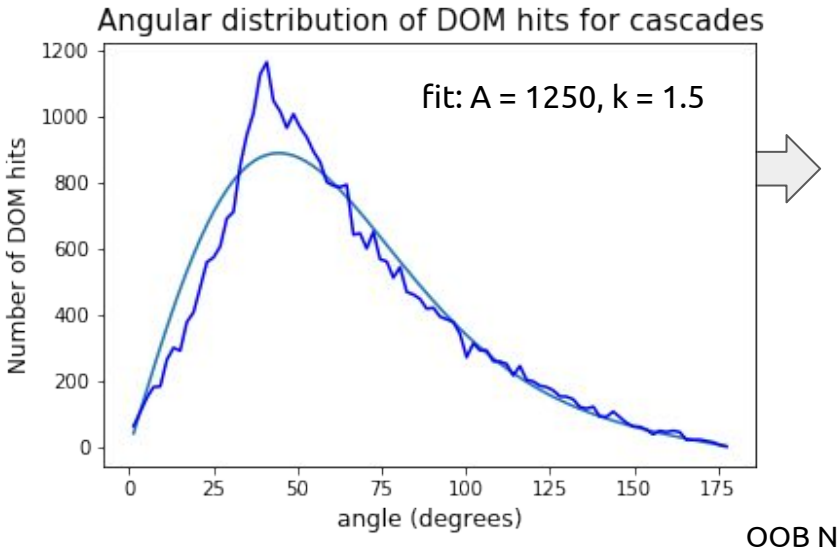
Check: For what k is NLL minimum - with truth values of the other params?

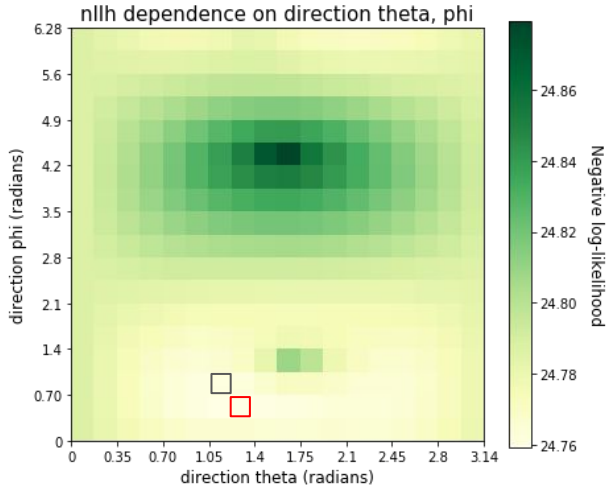


PROBLEM 1: CASCADE RECONSTRUCTION

VERTEX RECONSTRUCTION + ARRIVAL DIRECTION:

Think of a function that captures **deviation** from isotropy: $f(\zeta|k,A) = \frac{A}{2}\frac{k}{\sinh k} e^{k\cos\zeta}\sin\zeta$

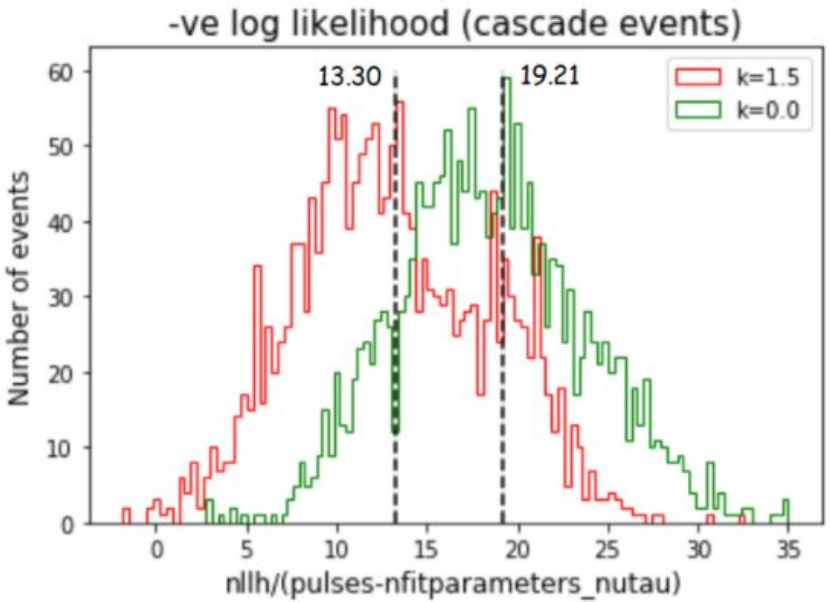




OOB NLLH for arrival direction of ν with fitted anisotropy function

PROBLEM 1: CASCADE RECONSTRUCTION

SUMMARY OF IMPROVEMENTS:

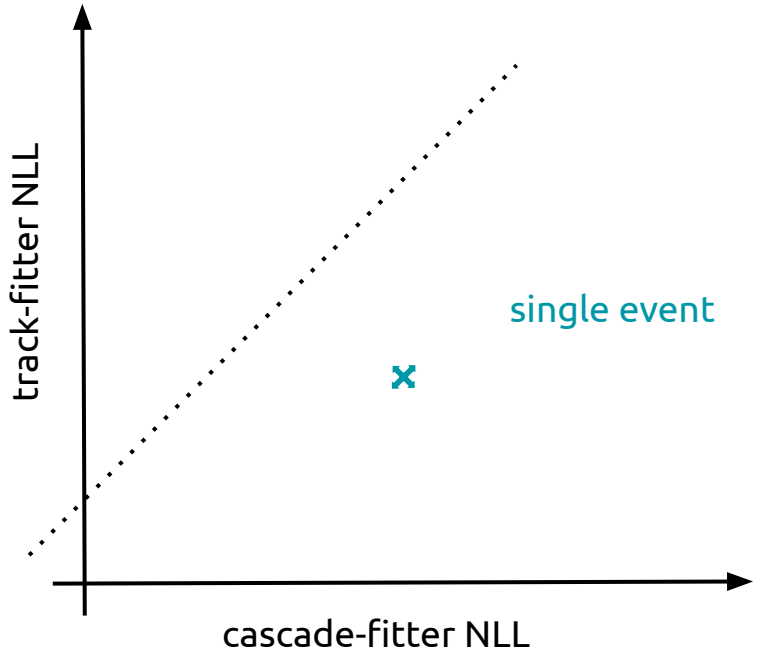


- Peak of the likelihood curve shifts towards the left for anisotropic case, a 6-orders of magnitude improvement in likelihood over existing isotropic benchmark
- Indicates the data is **better represented** much better by adding and fine-tuning anisotropy
- Improvement in resolution of vertex reconstruction + accuracy in neutrino arrival direction

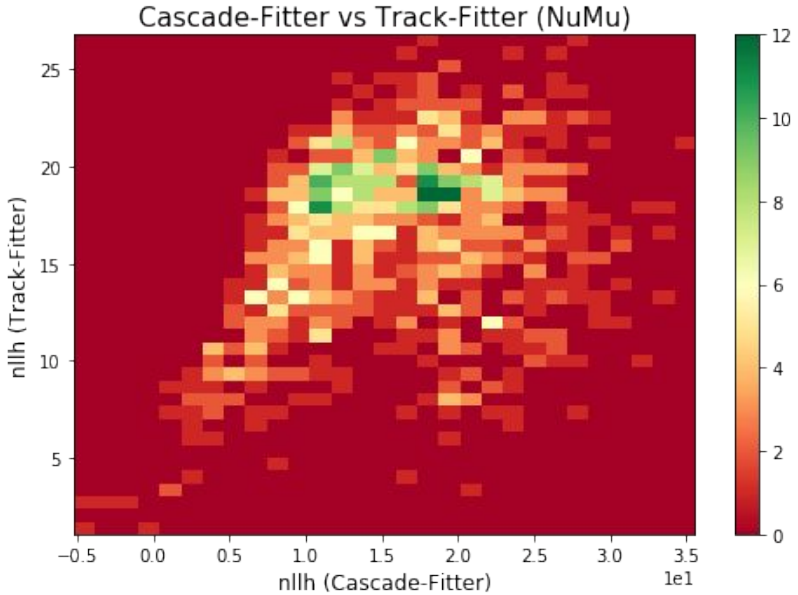
PROBLEM 2: EVENT DISCRIMINATOR

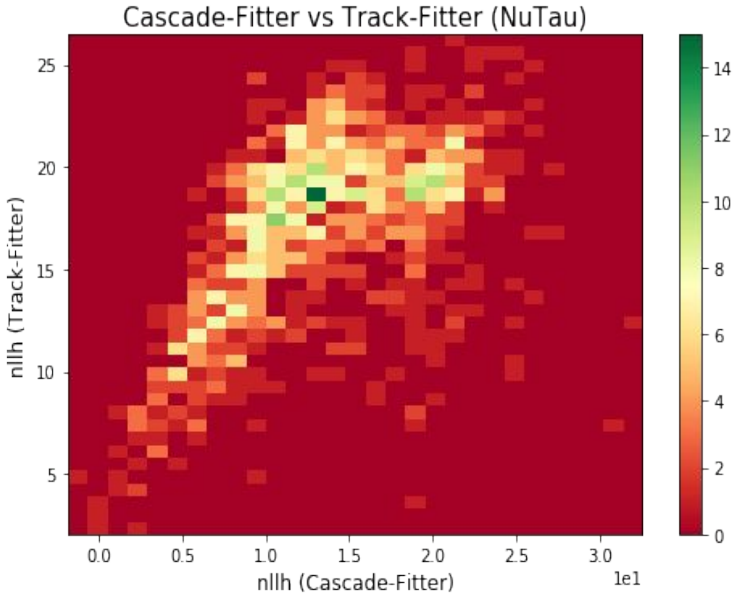
OUTLINE OF LOGIC:

- Discriminator distinguishes between the two topologies, event by event
- Decision based on whether event is **more likely** (using NLL) to be a cascade (e, τ) or a track (μ)
- Discriminator is a **decision boundary** inside this 2D histogram.



PROBLEM 2: EVENT DISCRIMINATOR





- Unfortunately, not much difference in the population distributions (ideally two separate blobs)
- Further improvements must be made in cascade/track fitter algorithms for better discrimination
- Presumably also use Machine Learning (Support Vector Machines)

THANK YOU!

QUESTIONS?