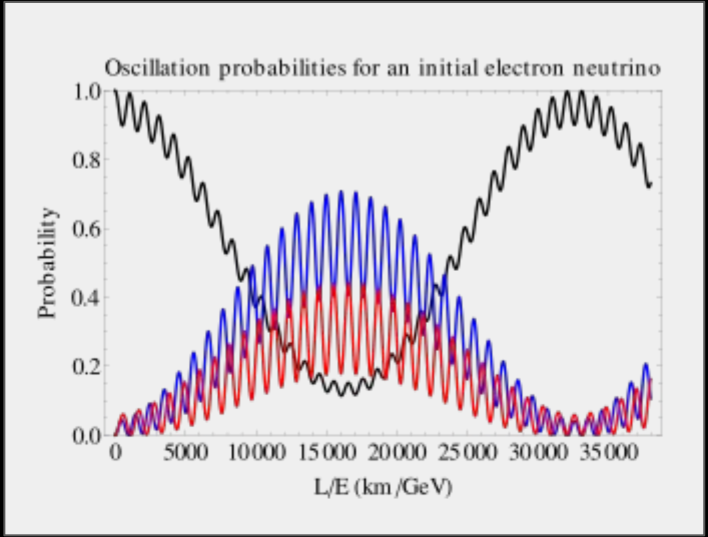
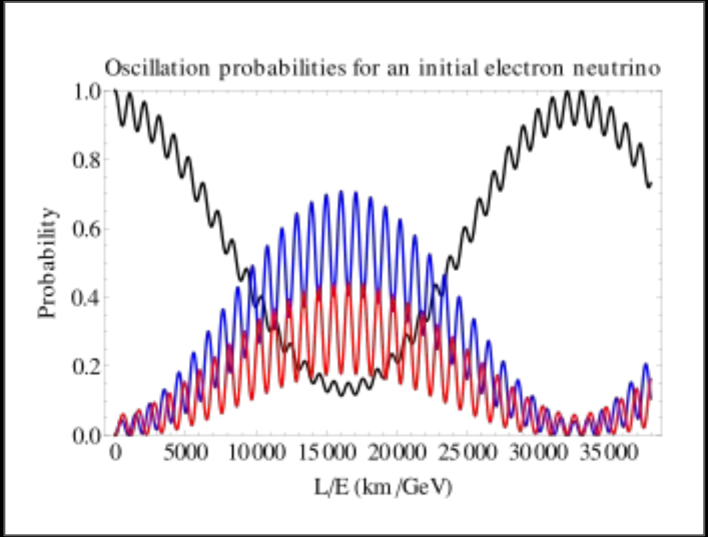
v

So you want to build a neutrino detector?

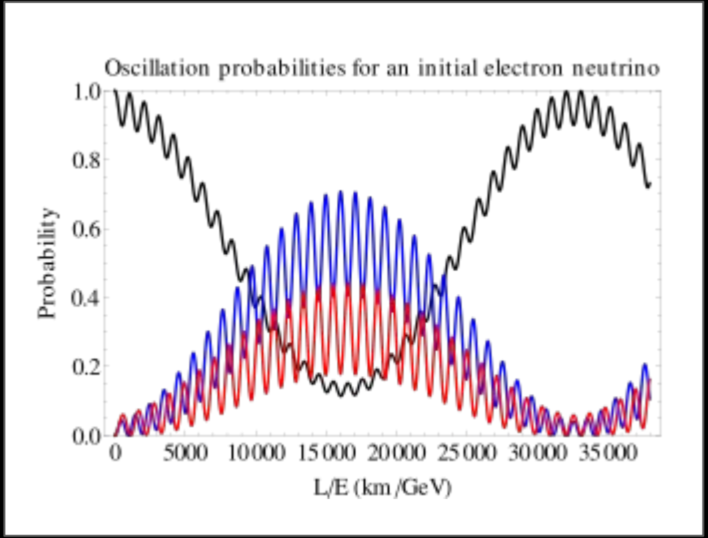
Why?


Oscillation probabilities for an initial electron neutrino
Probability
1.0
0.8
0.6
0.4
0.2
0.0
0
5000
10000
15000
20000
25000
30000
35000
L/E (km/GeV)



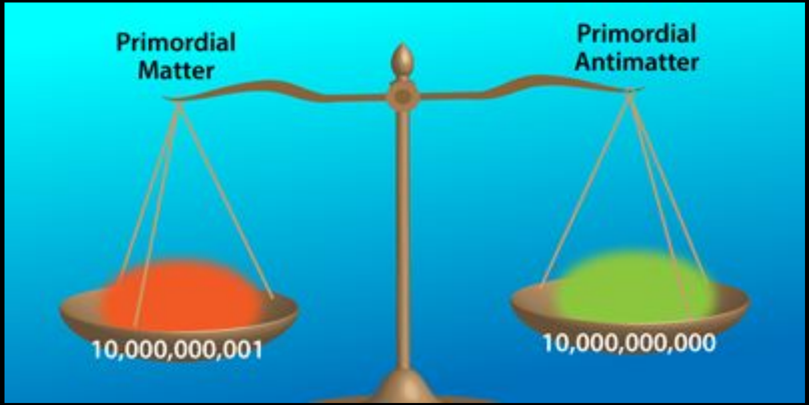
$\nu_\mu \rightarrow \nu_e$ oscillation probability:

$$P(\nu_\mu \rightarrow \nu_e) = sin^2\theta_{23} sin^2 2\theta_{13} sin^2\left(\frac{\Delta m_{31} L}{2}\right)$$
$$+cos^2\theta_{23} sin^2 2\theta_{12} sin^2\left(\frac{\Delta m_{21} L}{2}\right)$$
$$+\bar{J}cos\left(\delta_{\mathrm{CP}} - \frac{\Delta m_{31} L}{2}\right) sin\left(\frac{\Delta m_{21} L}{2}\right) sin\left(\frac{\Delta m_{31} L}{2}\right)$$



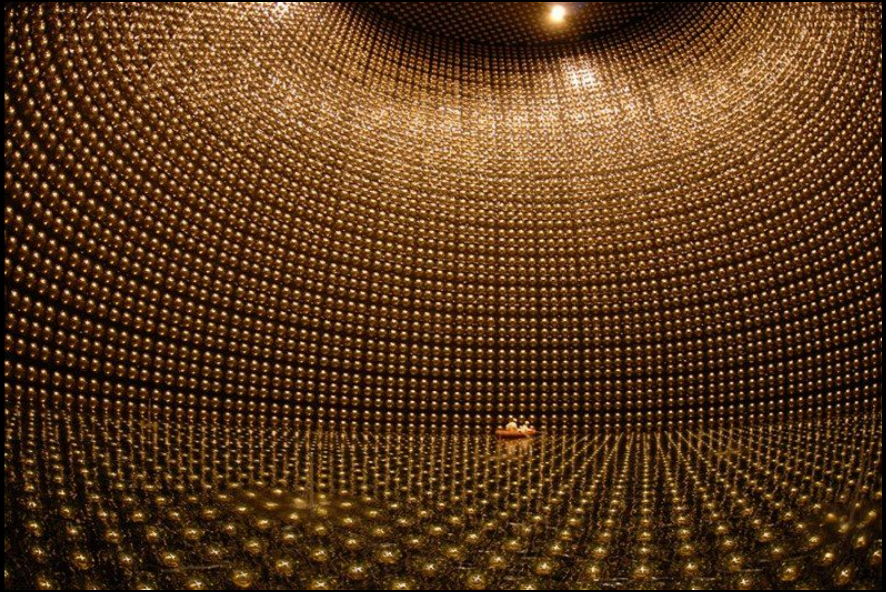
$\nu_\mu \rightarrow \nu_e$ oscillation probability:

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m_{31}L}{2}\right) + \cos^2\theta_{23}\sin^2 2\theta_{12}\sin^2\left(\frac{\Delta m_{21}L}{2}\right) + \tilde{J}\cos\left(\delta_{CP} - \frac{\Delta m_{31}L}{2}\right)\sin\left(\frac{\Delta m_{21}L}{2}\right)\sin\left(\frac{\Delta m_{31}L}{2}\right)$$

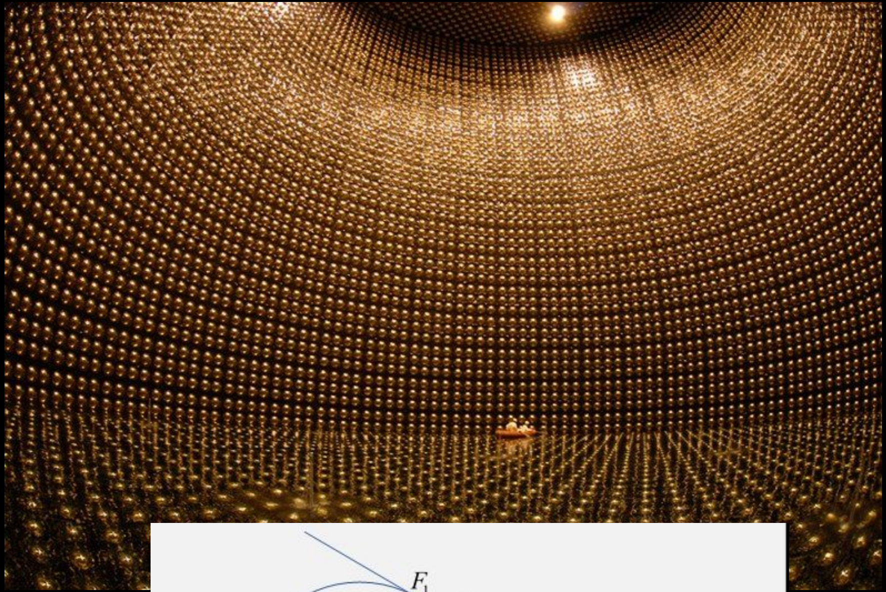


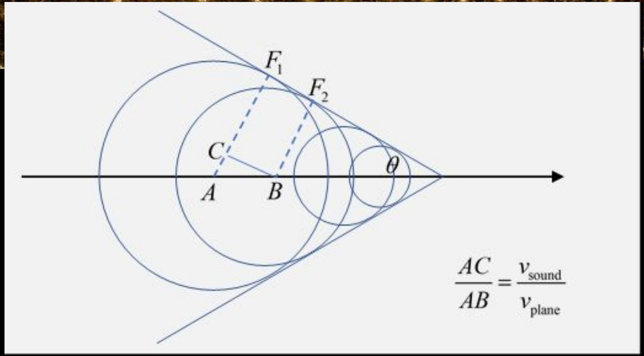
How?

1. Really big

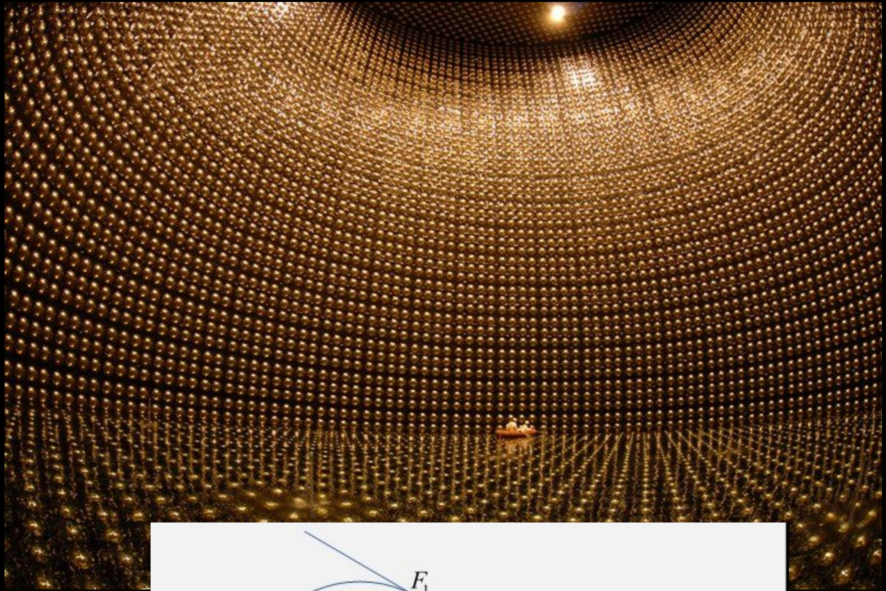


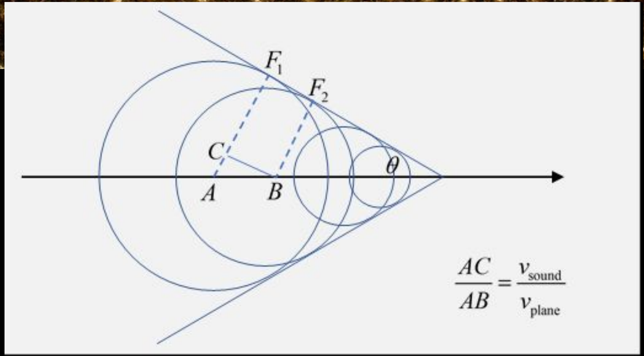
1. **Really big**
2. **Filled with water**





1. **Really big**
2. **Filled with water**
3. **Equipped with PMTs**





4. A whole bunch of neutrinos!

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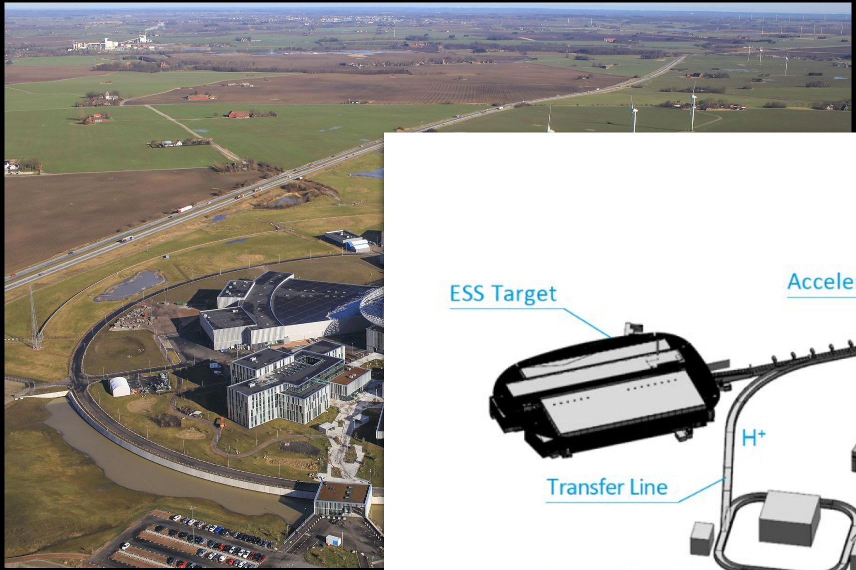
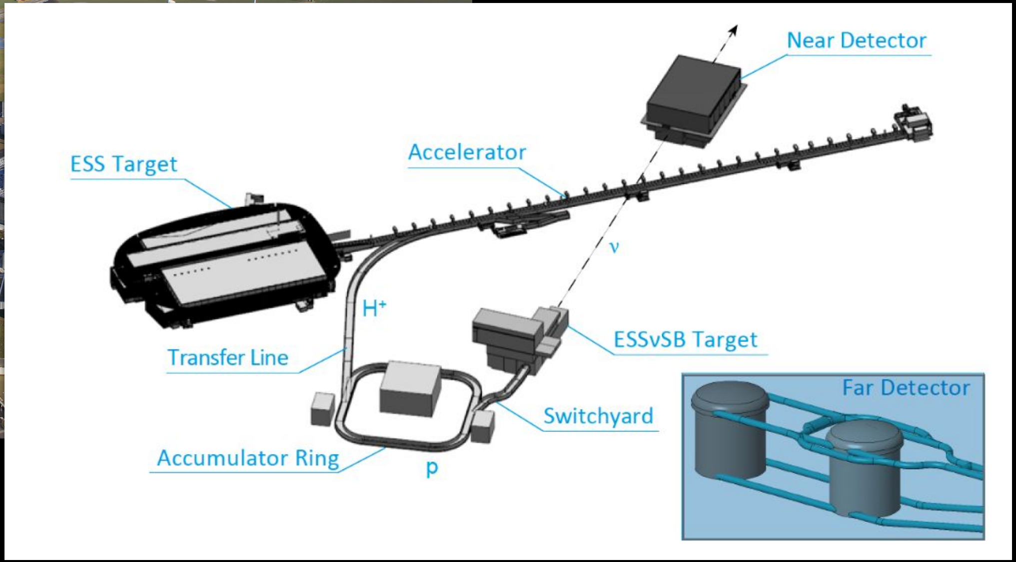
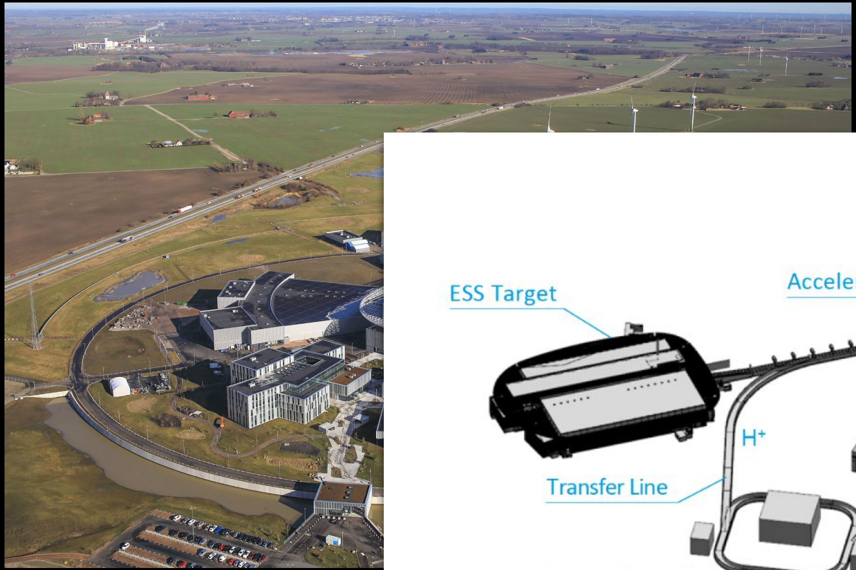
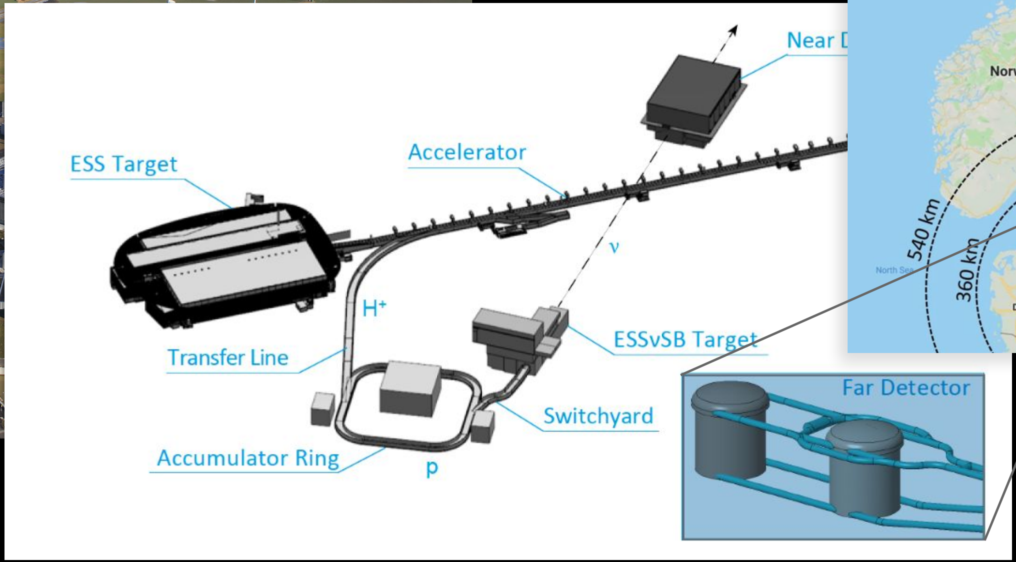
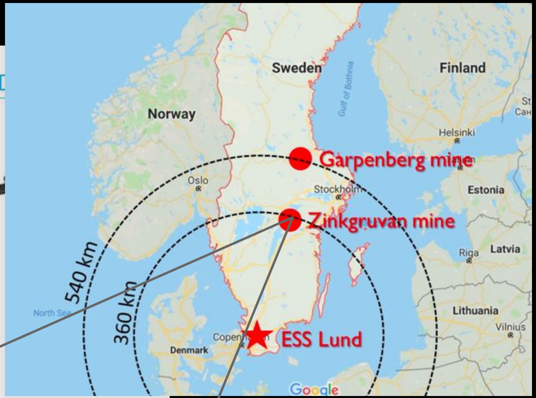




4. A whole bunch of neutrinos!

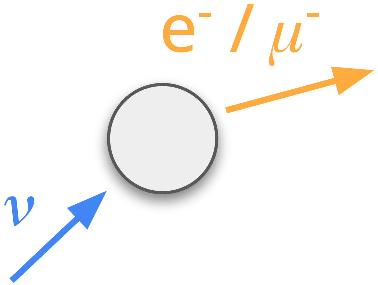


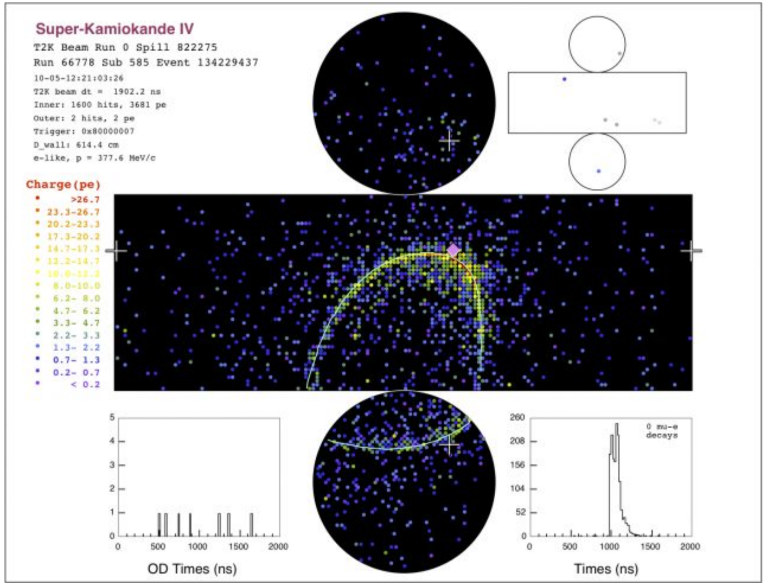




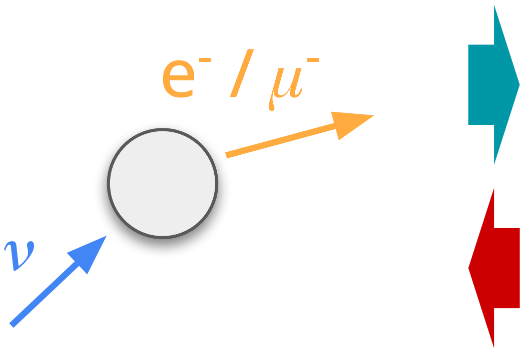
Cool! What’s it going to look like?

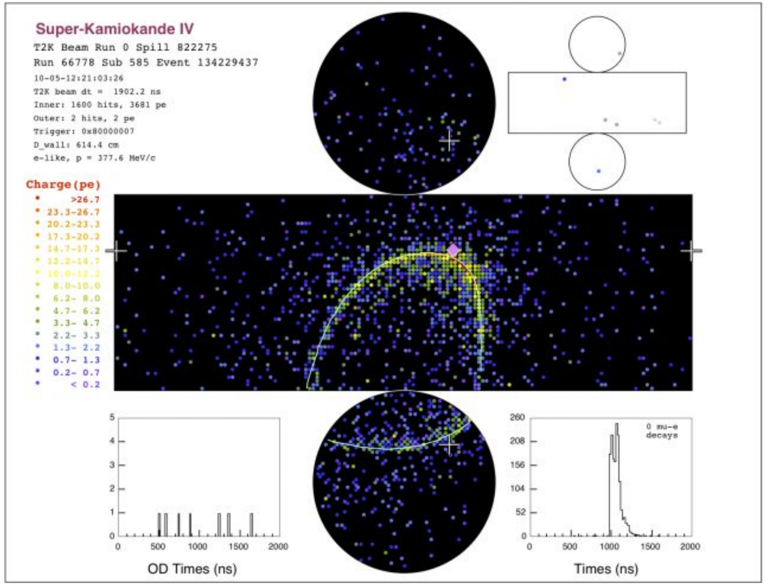
Exploring ESSνSB Detector Designs





Step 1: Simulations



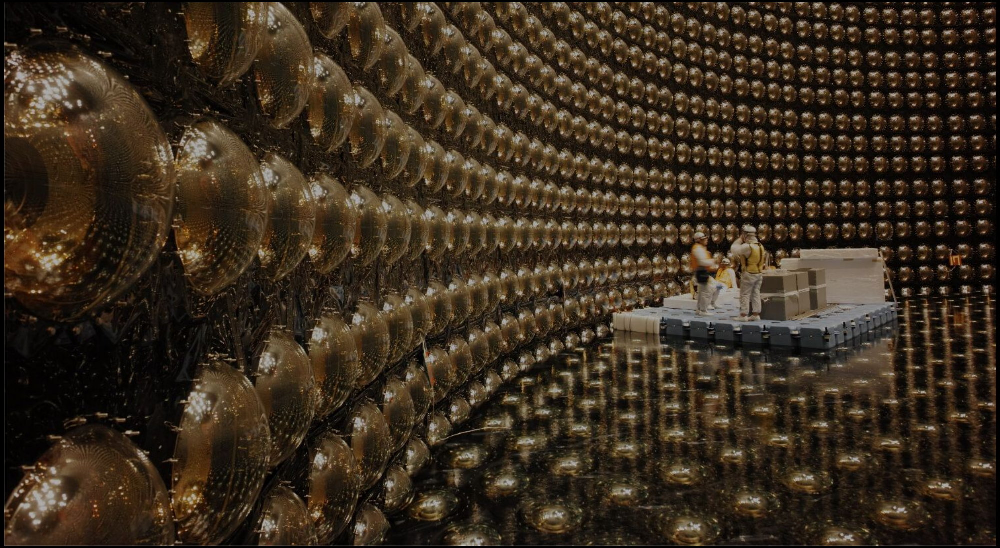


Step 1: Simulations

Step 2: Reconstruction

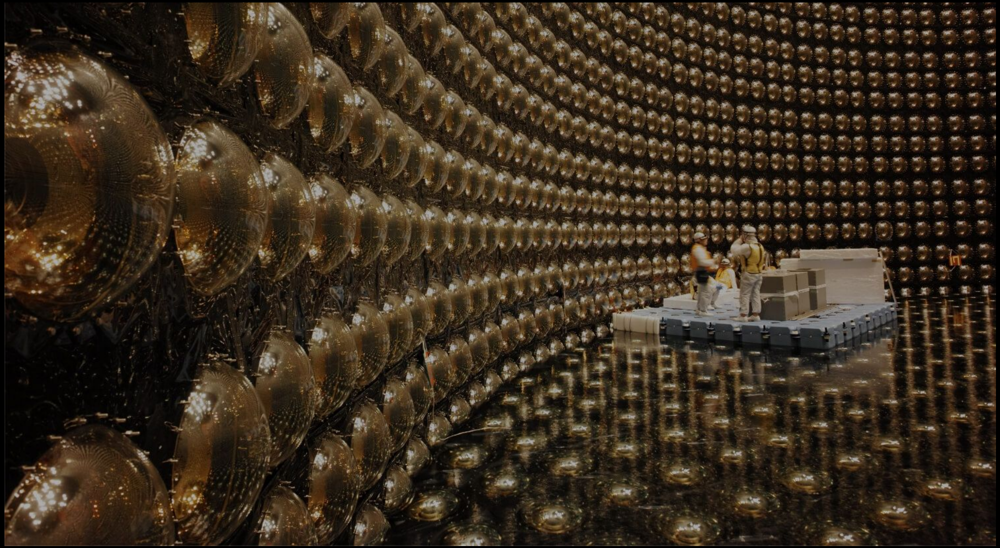
fiTQun

$$L(\boldsymbol{x}) = \prod_{j}^{unhit} P_j(unhit|\boldsymbol{x}) \prod_{i}^{hit} \{P_i(hit|\boldsymbol{x})\} f_q(q_i|\boldsymbol{x}) f_t(t_i|\boldsymbol{x})$$



fiTQun

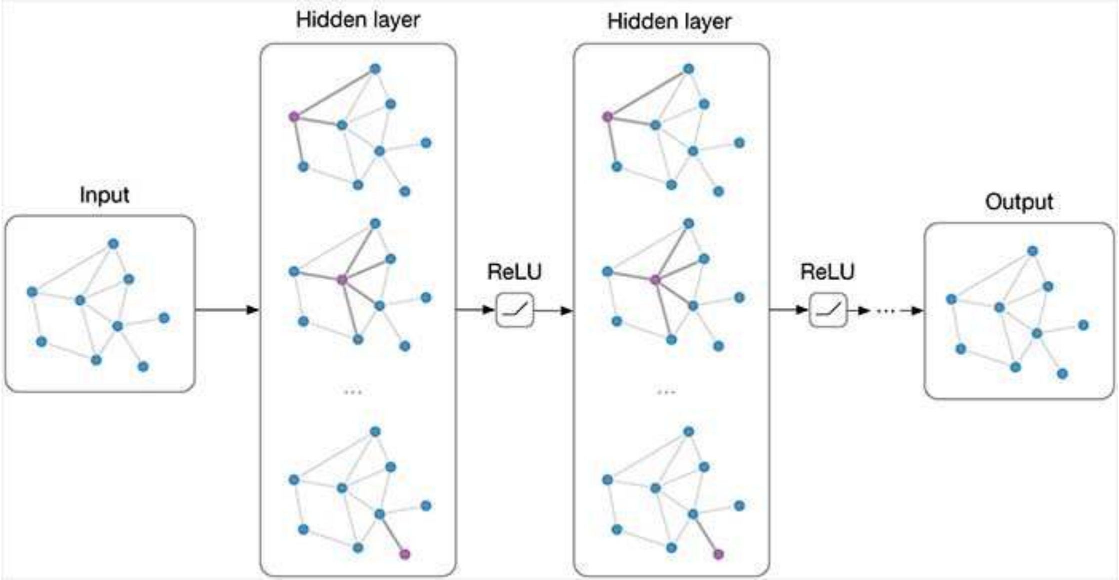
$$L(\boldsymbol{x}) = \prod_{j}^{unhit} P_j(unhit|\boldsymbol{x}) \prod_{i}^{hit} \{P_i(hit|\boldsymbol{x})\} f_q(q_i|\boldsymbol{x}) f_t(t_i|\boldsymbol{x})$$



1. Slow
2. Limited generalisation

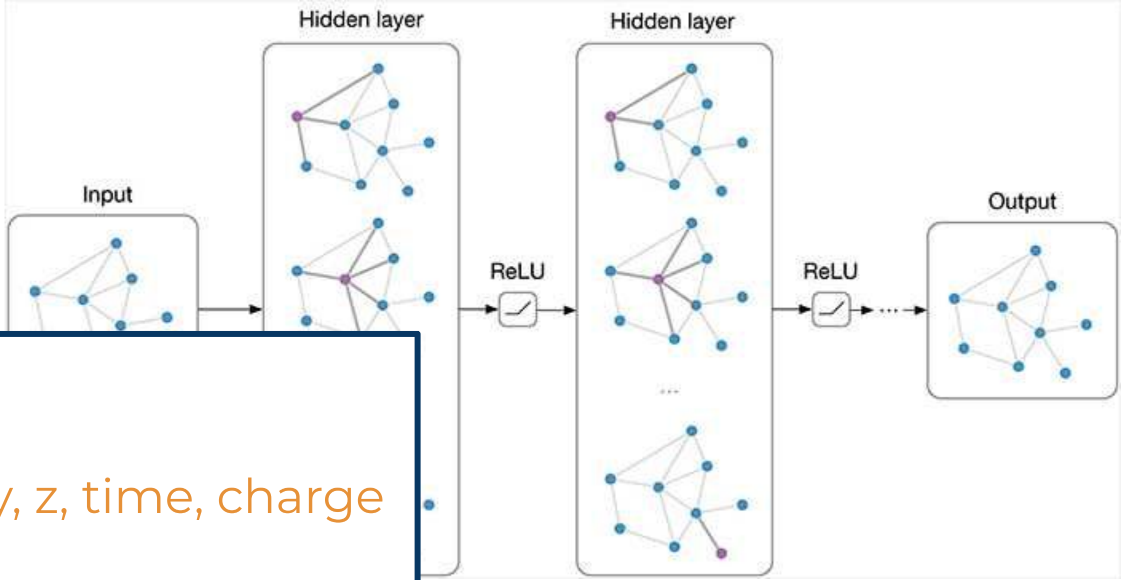
- **Machine Learning methods are fast on GPUS**

- **Machine Learning methods are fast on GPUS**
- **GNNs are useful for sparse events**



- **Machine Learning methods are fast on GPUS**

- **GNNs are useful for sparse events**

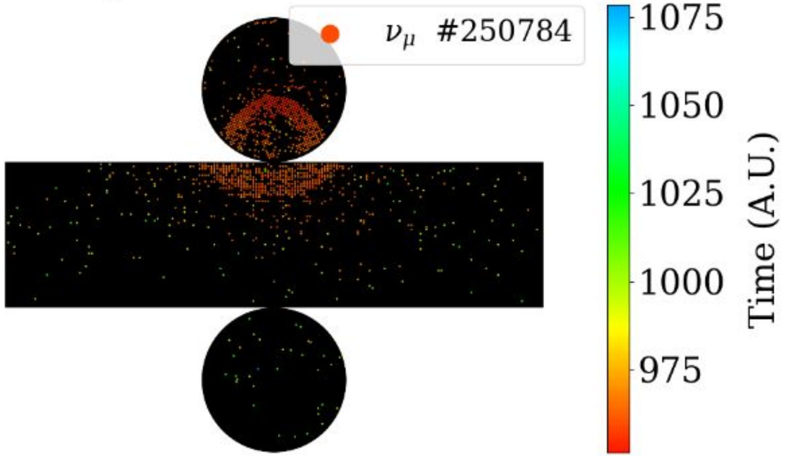


1 event = 1 graph
1 PMT hit = 1 node
Node features: x, y, z, time, charge

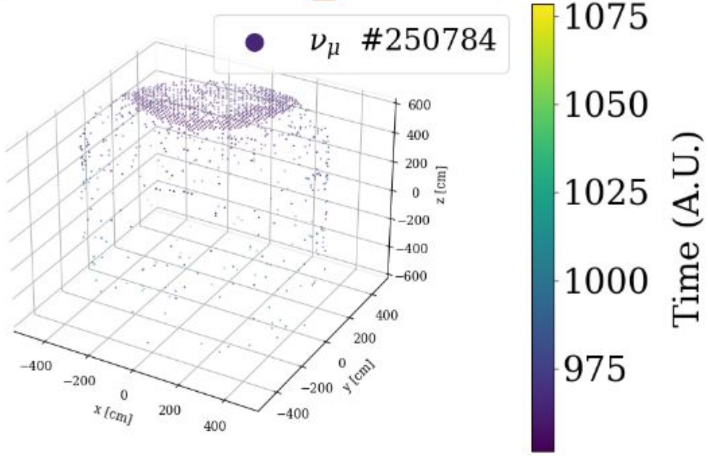
Neighbours in {x,y,z,t} connected with edges

Exploring ESSνSB Detector Designs

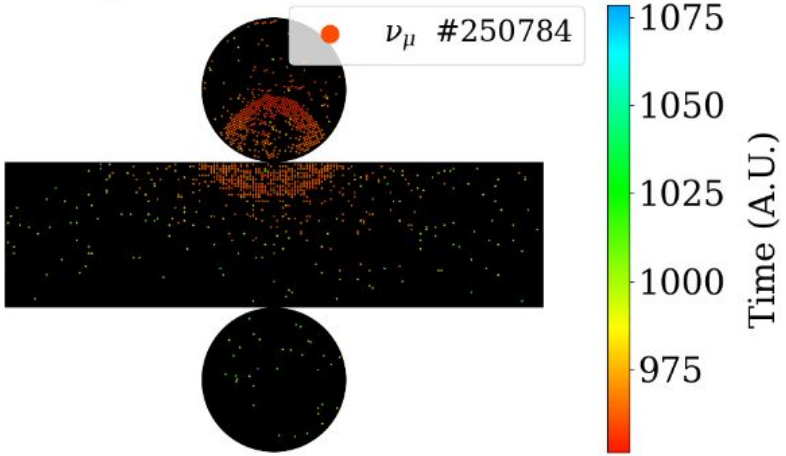
With GNNs

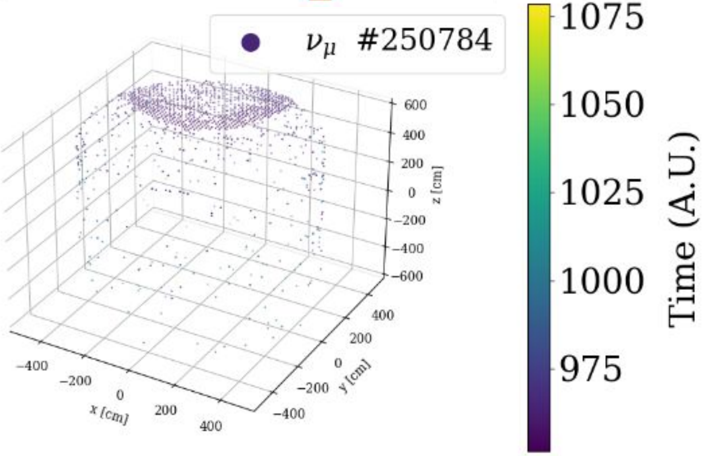


ν_μ #250784
1075
1050
1025
1000
975
Time (A.U.)



ν_μ #250784
600
400
200
0
−200
−400
−600
z [cm]
x [cm]
y [cm]
1075
1050
1025
1000
975
Time (A.U.)

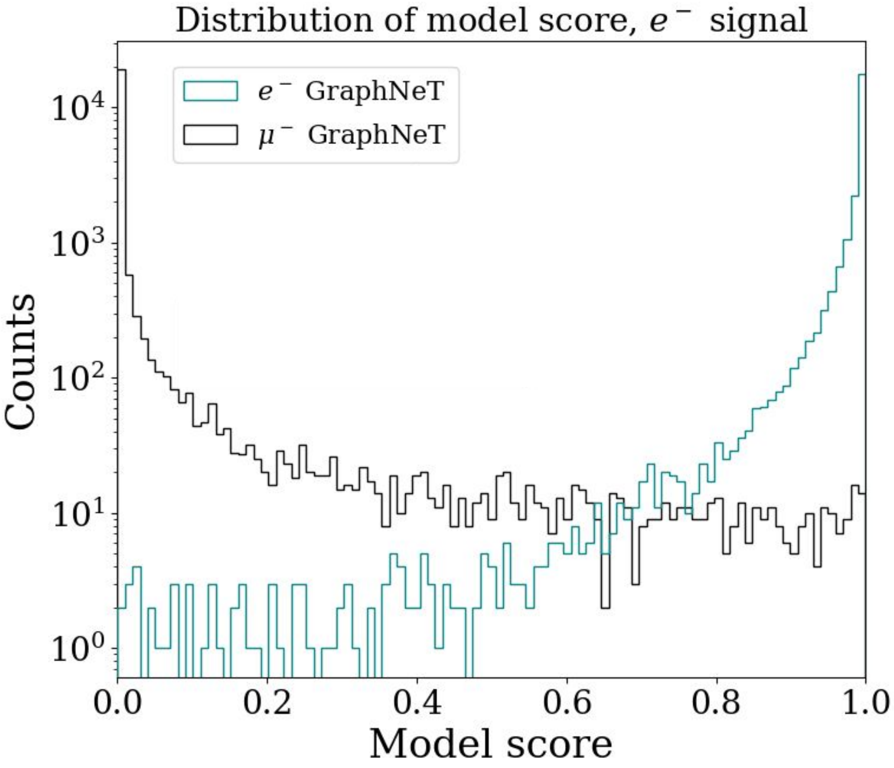


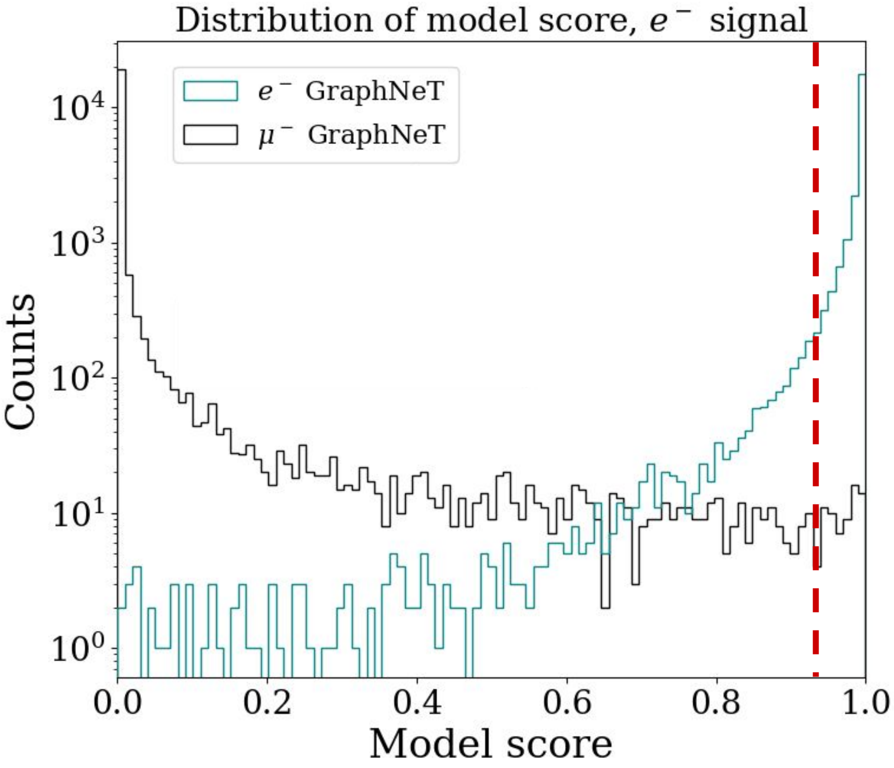


- **GNN:**
  Model score [0,1]

- **fiTQun:**
  LLH_e
  LLH_μ

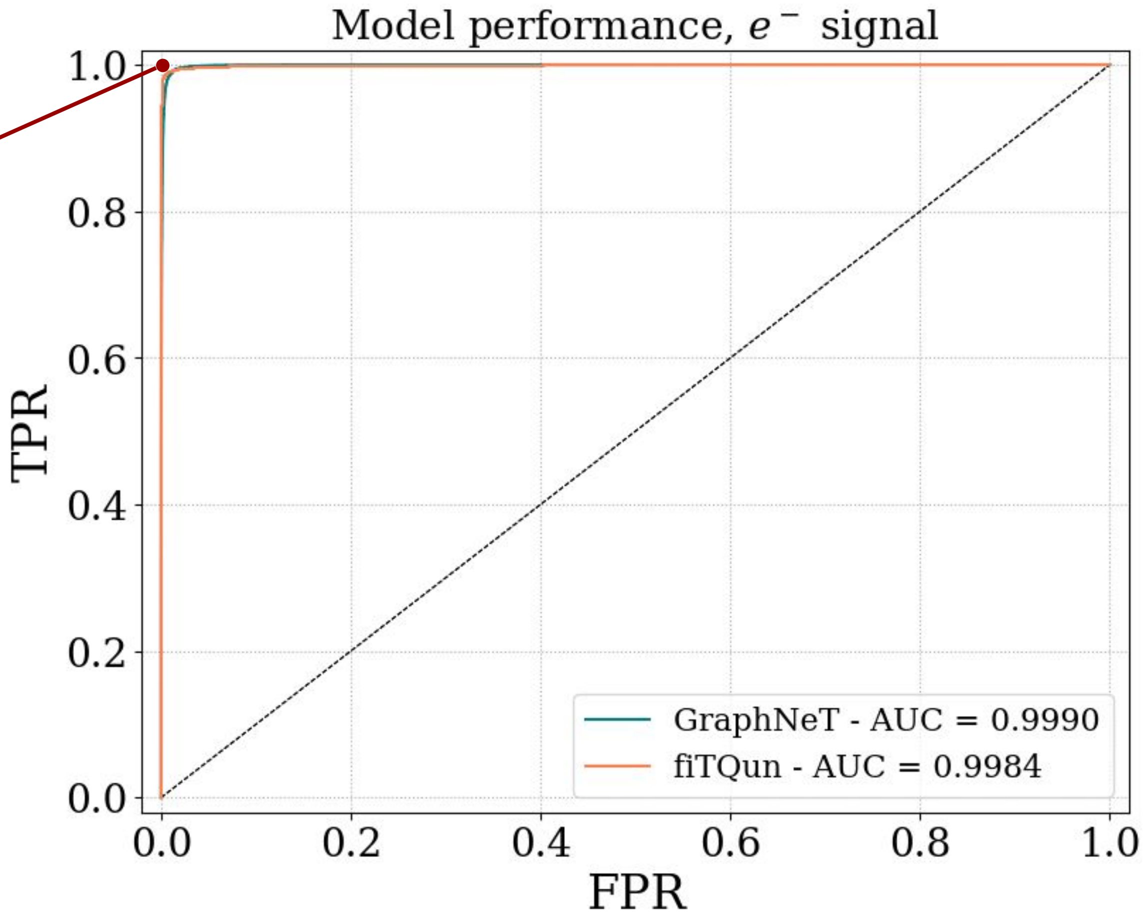
  LLH_e/LLH_μ = **"model score"**

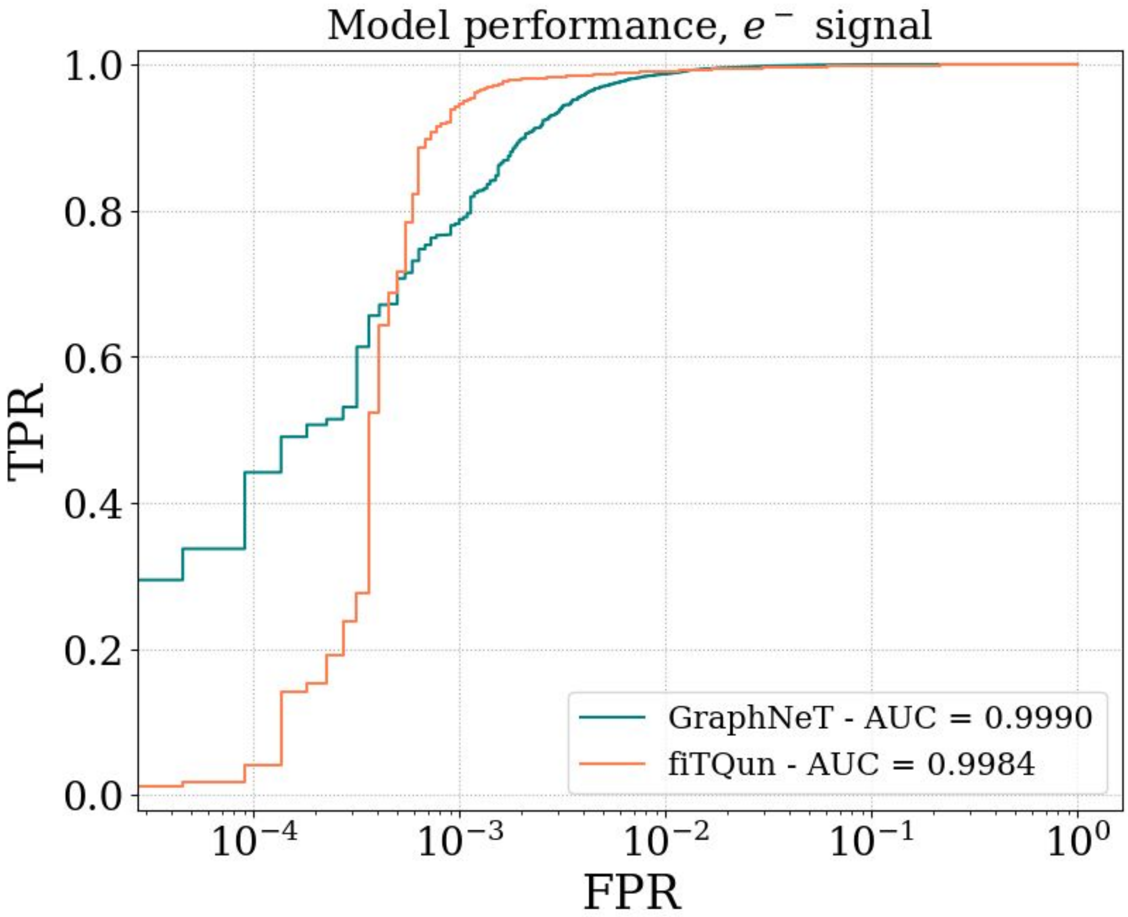

Distribution of model score, e^- signal
e^- GraphNeT
μ^- GraphNeT
Counts
10^0
10^1
10^2
10^3
10^4
0.0
0.2
0.4
0.6
0.8
1.0
Model score


Distribution of model score, e^- signal
e^- GraphNeT
μ^- GraphNeT
Counts
10^4
10^3
10^2
10^1
10^0
0.0
0.2
0.4
0.6
0.8
1.0
Model score

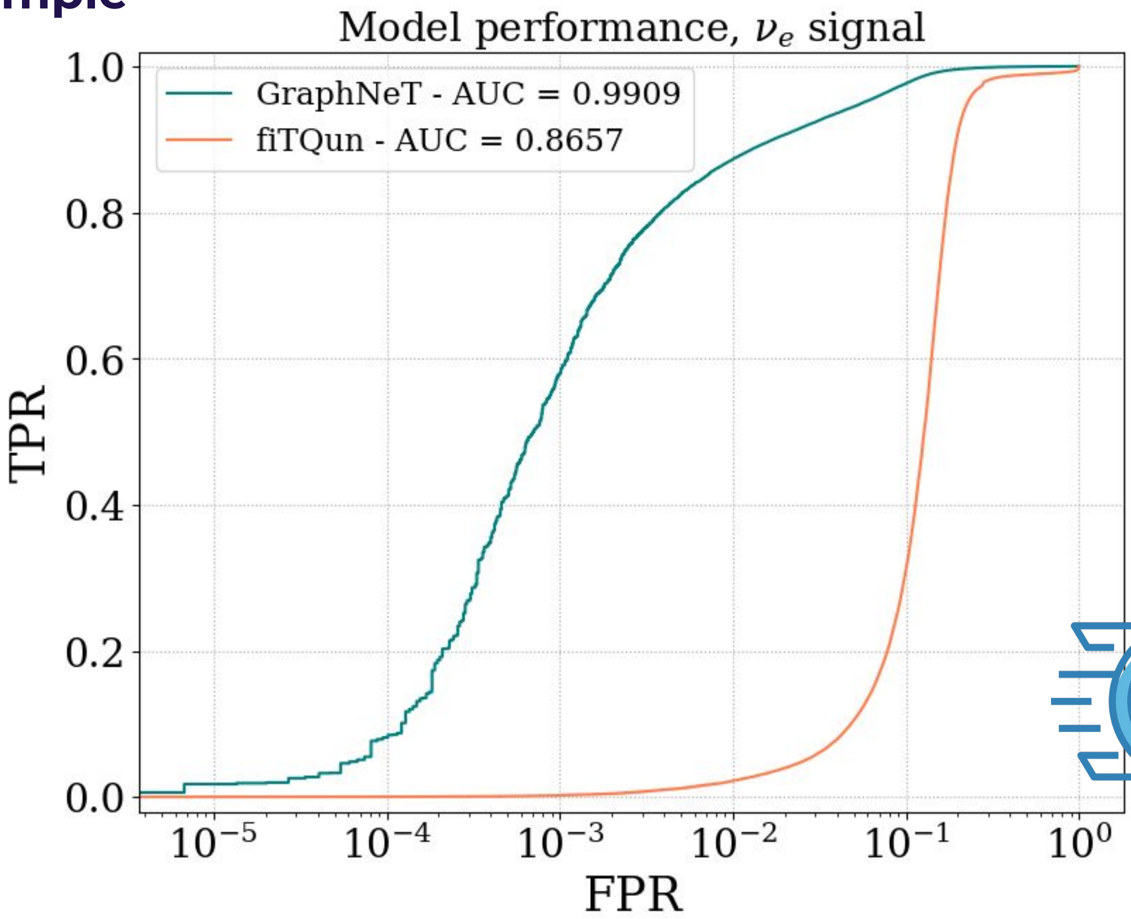
- **FPR**
- **TPR**

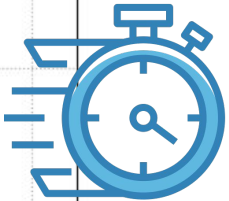
Perfect classifier




Model performance, e^- signal
1.0
0.8
0.6
0.4
0.2
0.0
TPR
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
FPR
GraphNeT - AUC = 0.9990
fiTQun - AUC = 0.9984

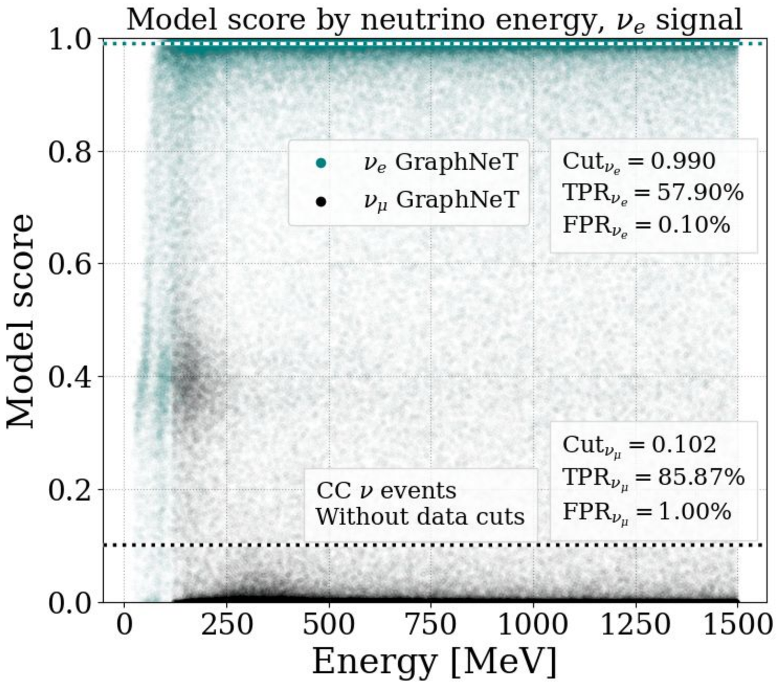
Full event sample

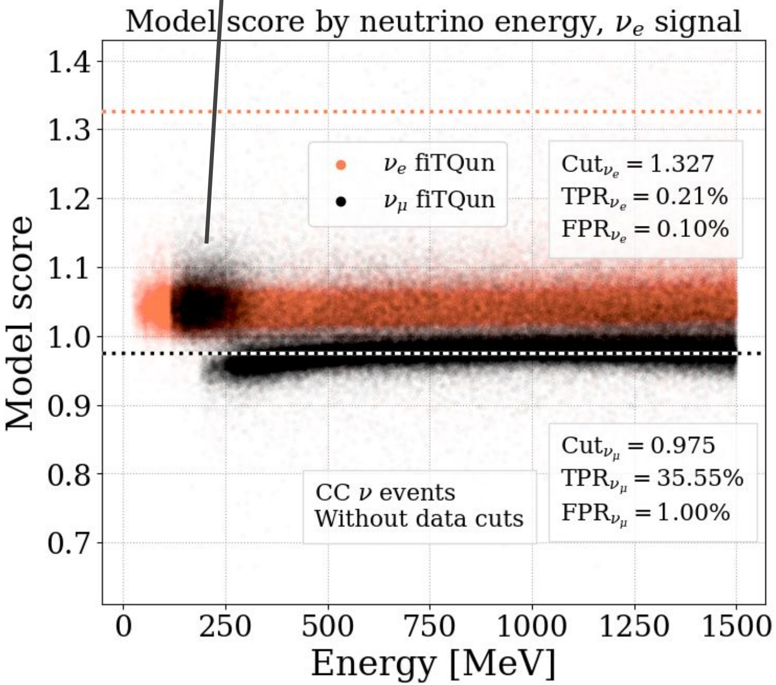




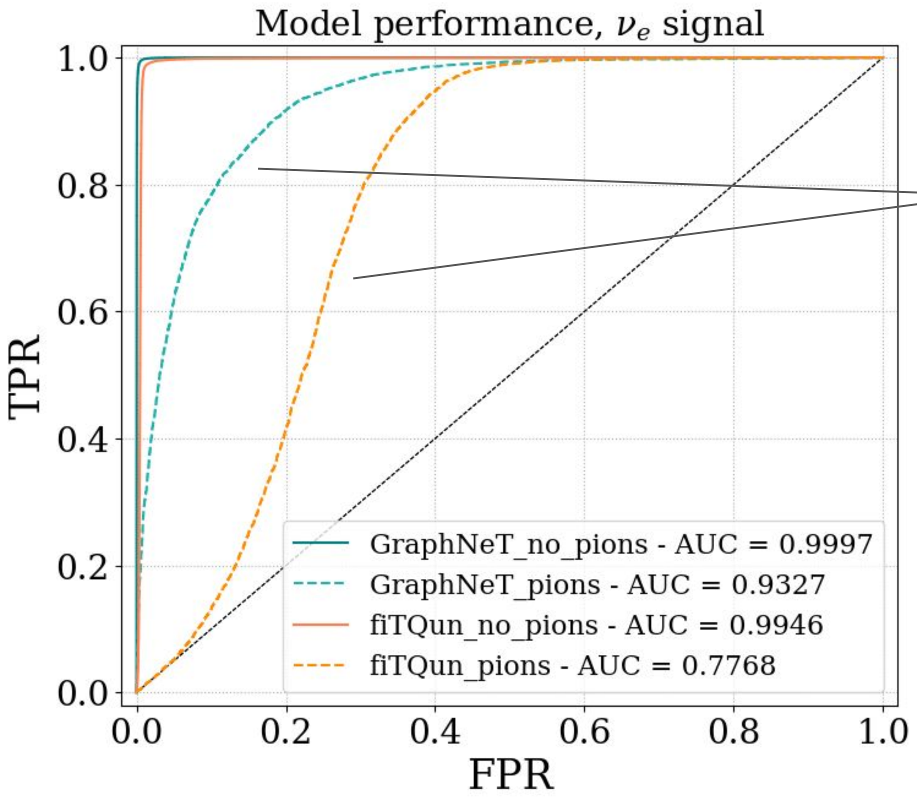
Neutrino energy distribution

Misidentified low-energy muon neutrinos





Pion production



Pions =
worse performance

- GNNs can perform well on complicated events that fiTQun cannot
- Inference is fast on GPUs once trained
- Using this increase in speed, detector geometry can be explored fast