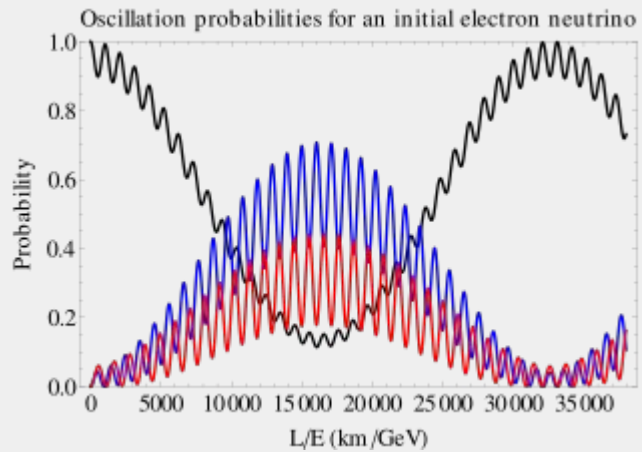
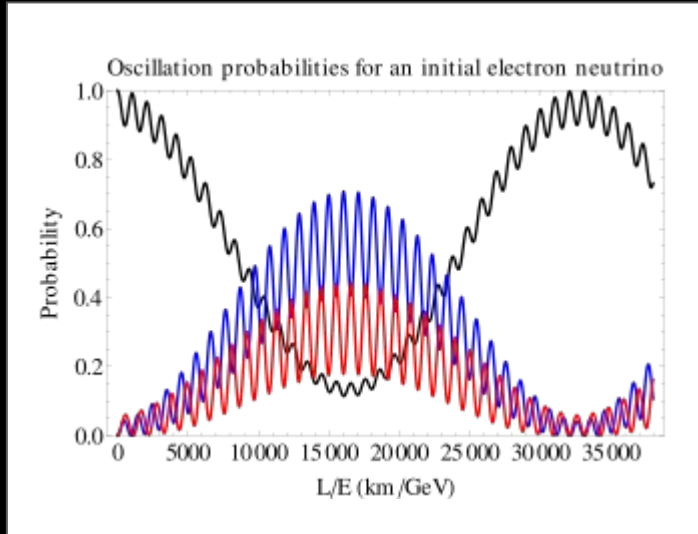


v

**So you want to build
a neutrino detector?**

Why?



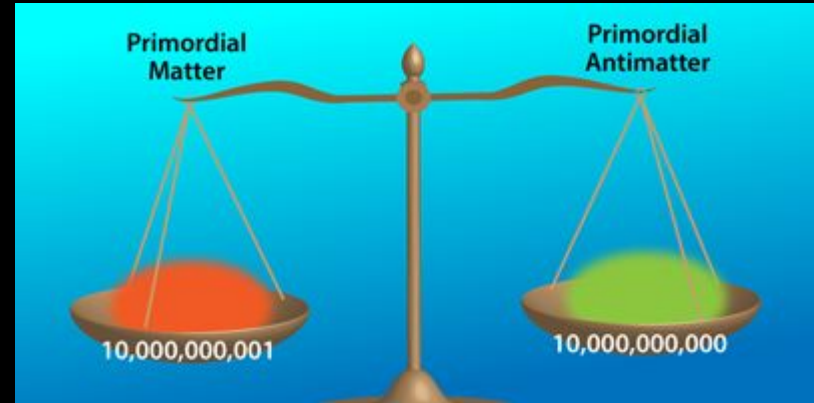
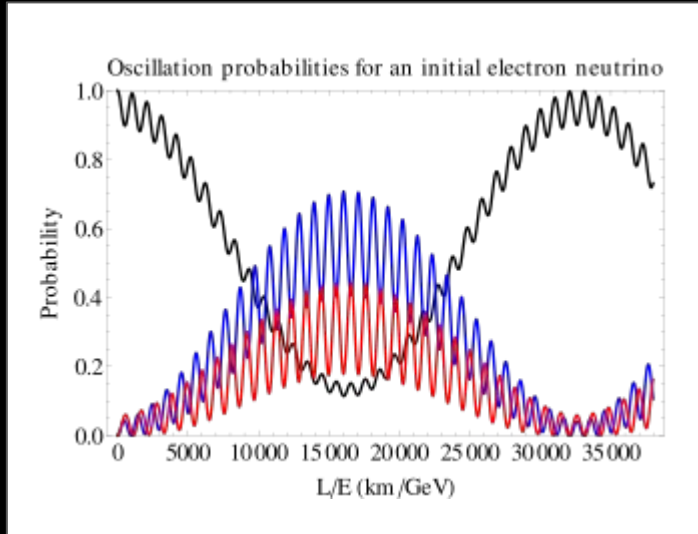


$\nu_\mu \rightarrow \nu_e$ oscillation probability:

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

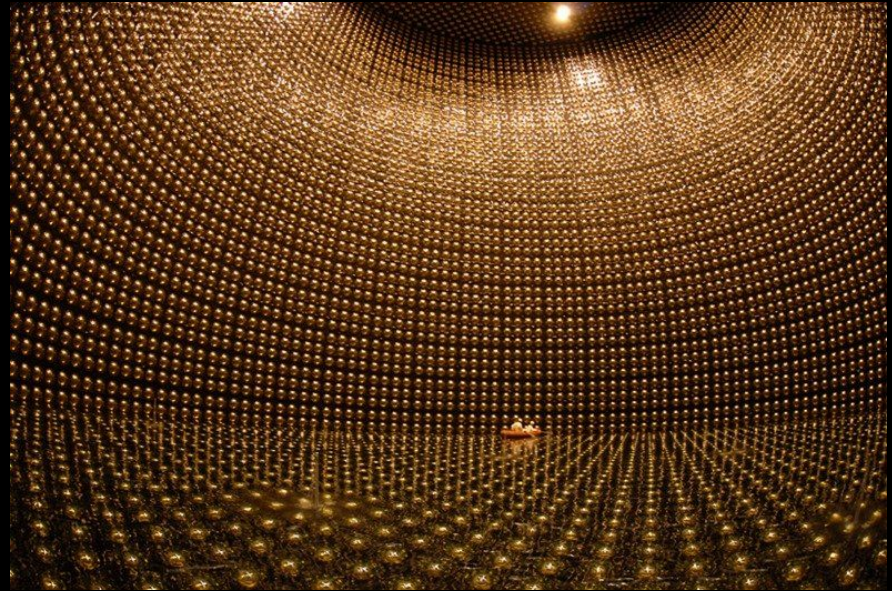
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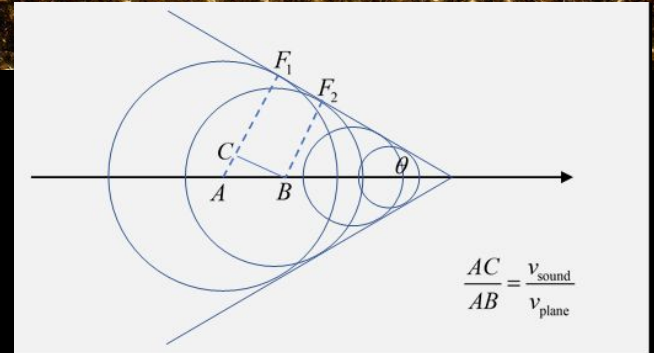
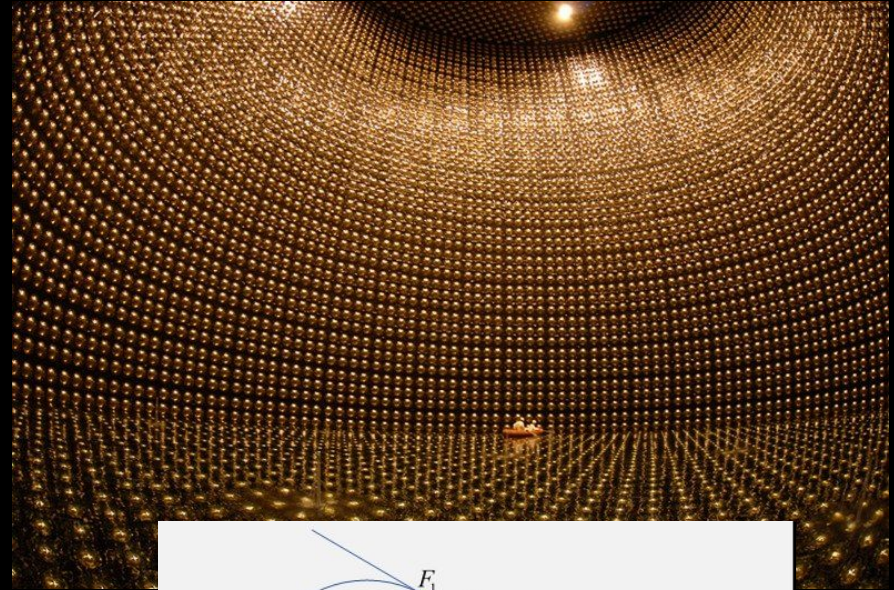


How?

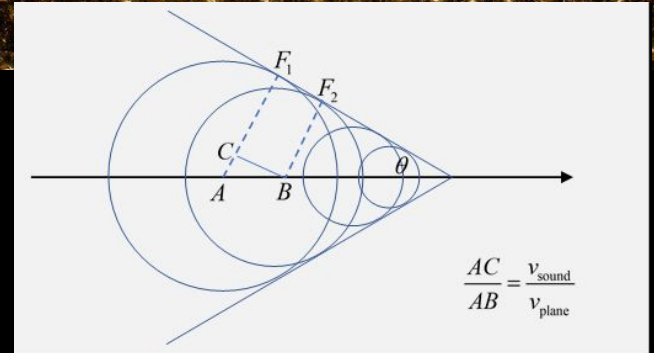
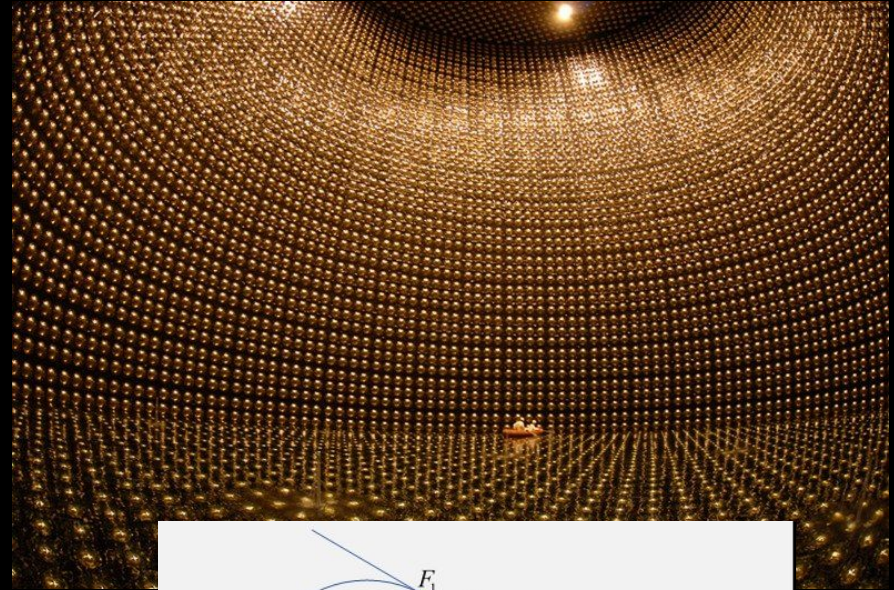
1. Really big



1. Really big
2. Filled with water



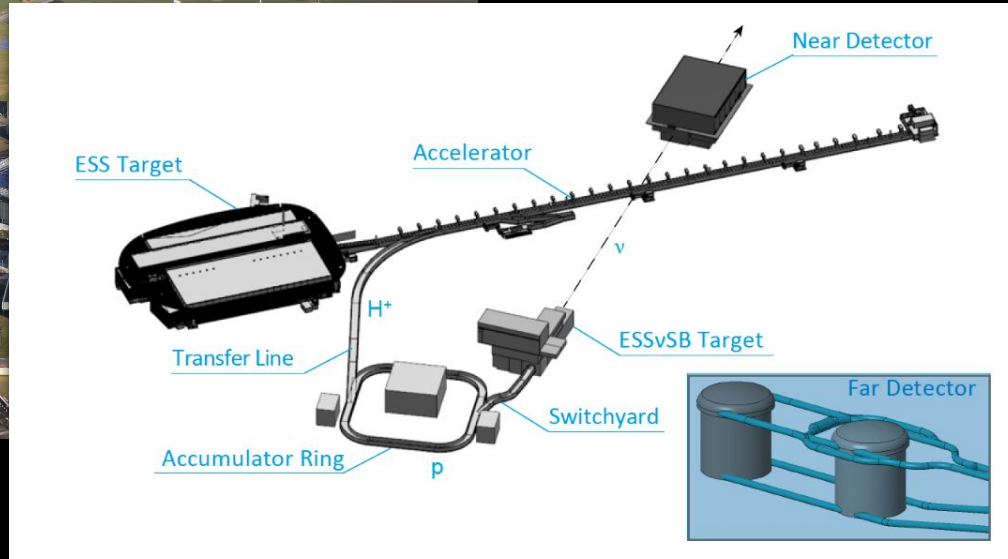
1. Really big
2. Filled with water
3. Equipped with PMTs



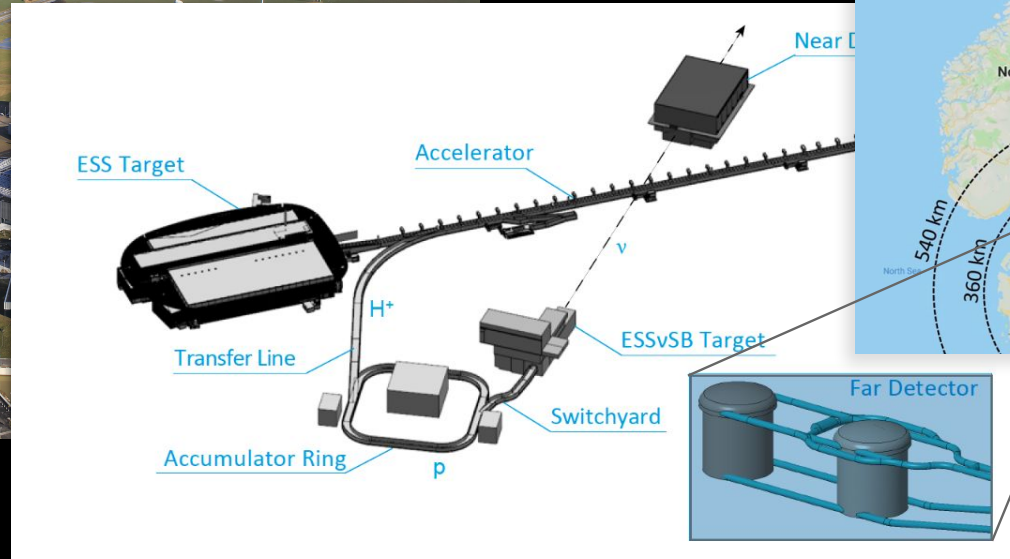
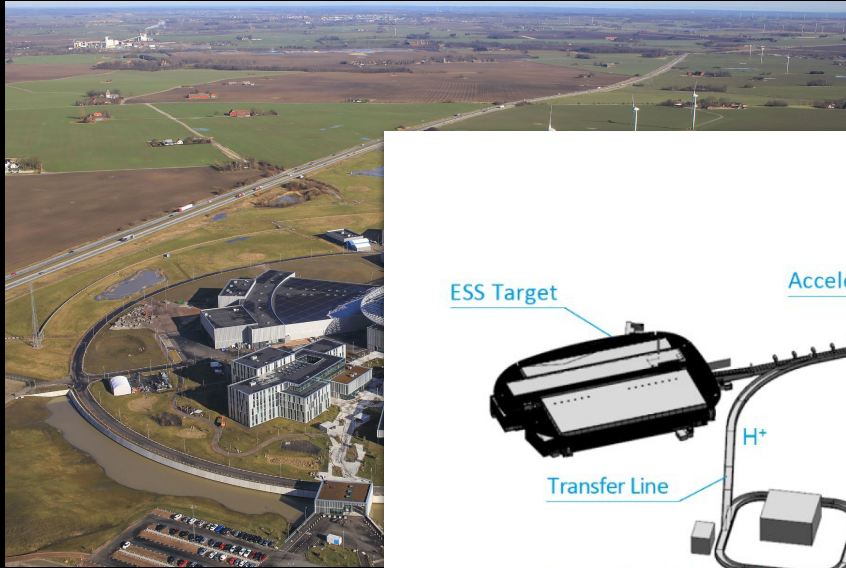
4. A whole bunch of neutrinos!



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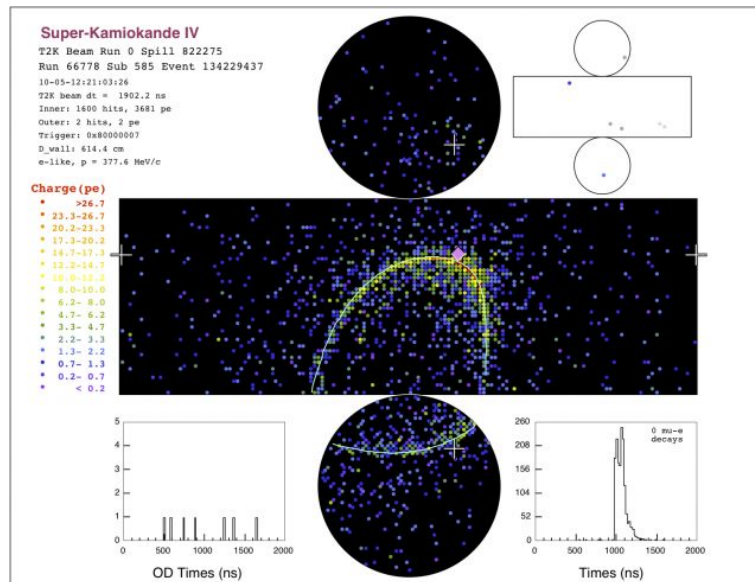
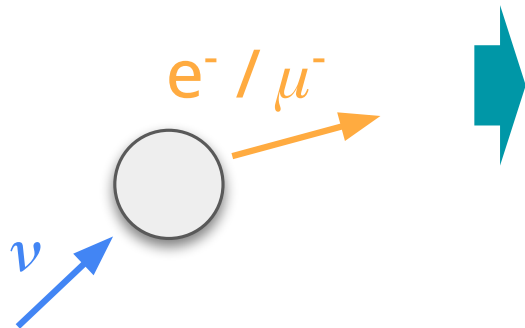
4. A whole bunch of neutrinos!



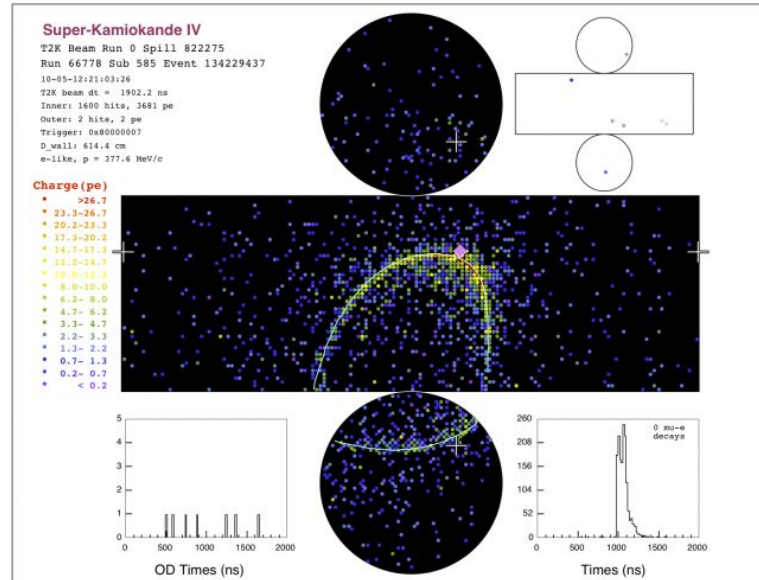
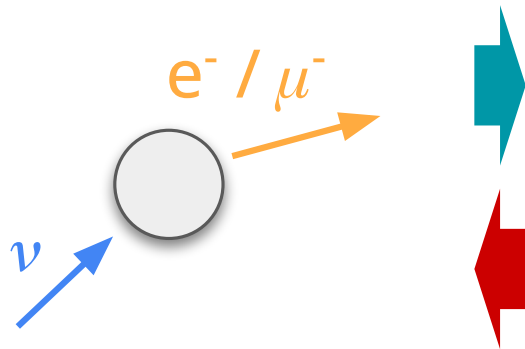
Cool! What's it going to look like?

An aerial architectural rendering of a proposed particle detector facility, identified by the text as ESSvSB. The design features a central circular structure with a blue 'ess' logo, surrounded by various buildings, parking lots, and landscaped areas. A winding river or canal flows through the site, and a major highway runs along the right side. The background shows a mix of green fields and urban development.

Exploring ESSvSB Detector Designs



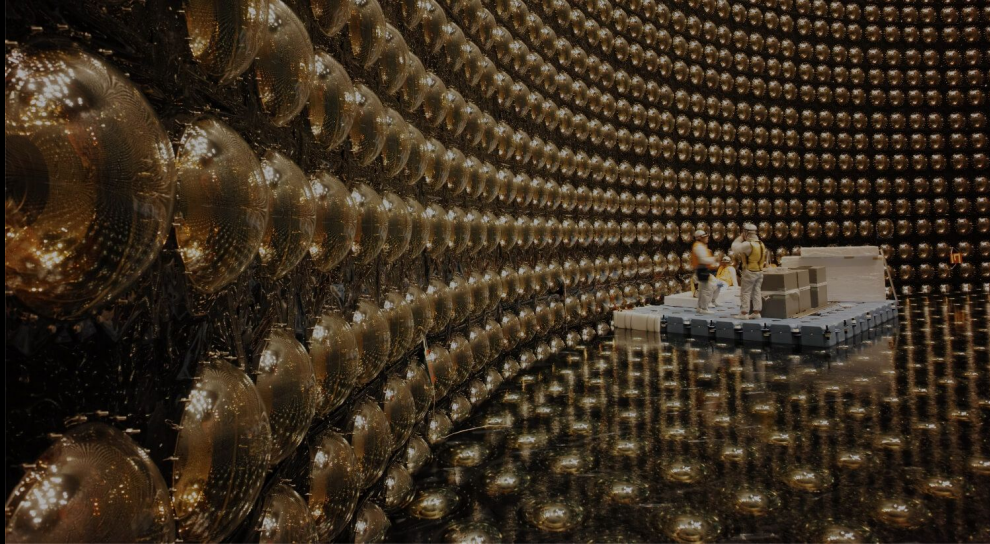
Step 1: Simulations



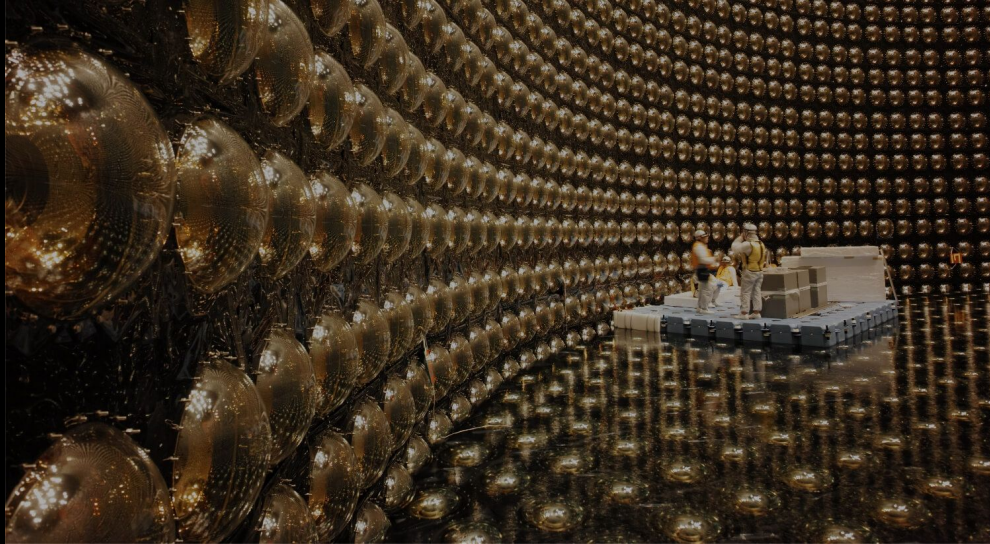
Step 1: Simulations

Step 2: Reconstruction

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



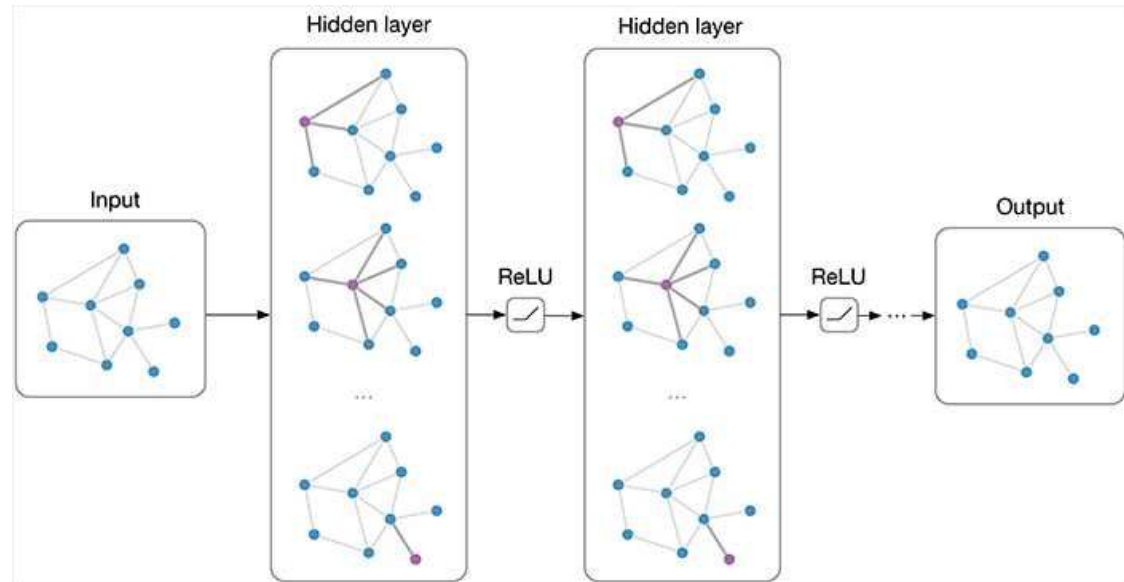
$$L(\boldsymbol{x}) = \prod_j^{unhit} P_j(unhit|\boldsymbol{x}) \prod_i^{hit} \{P_i(hit|\boldsymbol{x})\} f_q(q_i|\boldsymbol{x}) f_t(t_i|\boldsymbol{x})$$



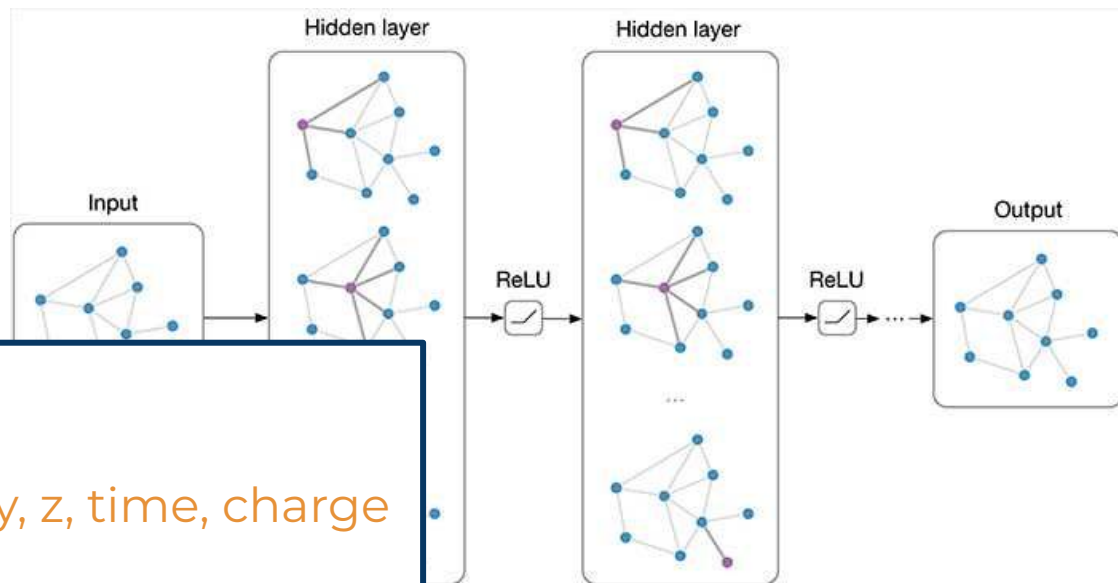
1. **Slow**
2. **Limited generalisation**

- **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

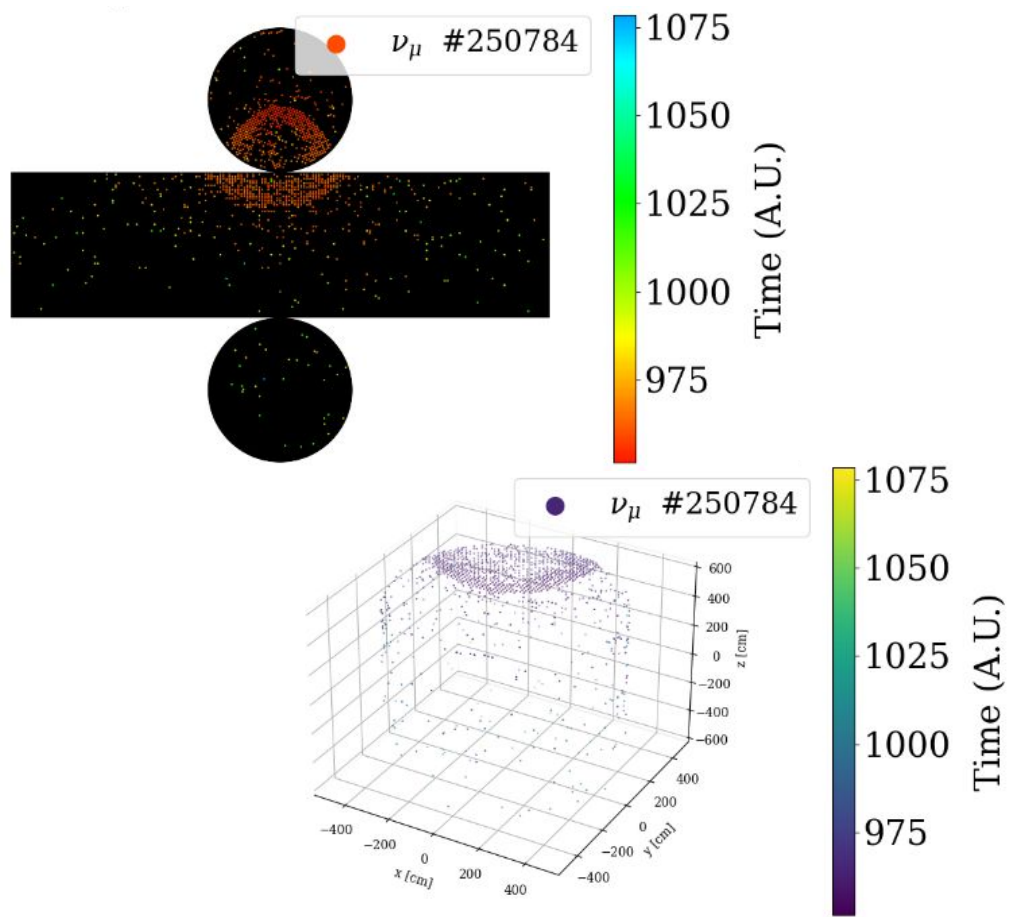
1 PMT hit = 1 node

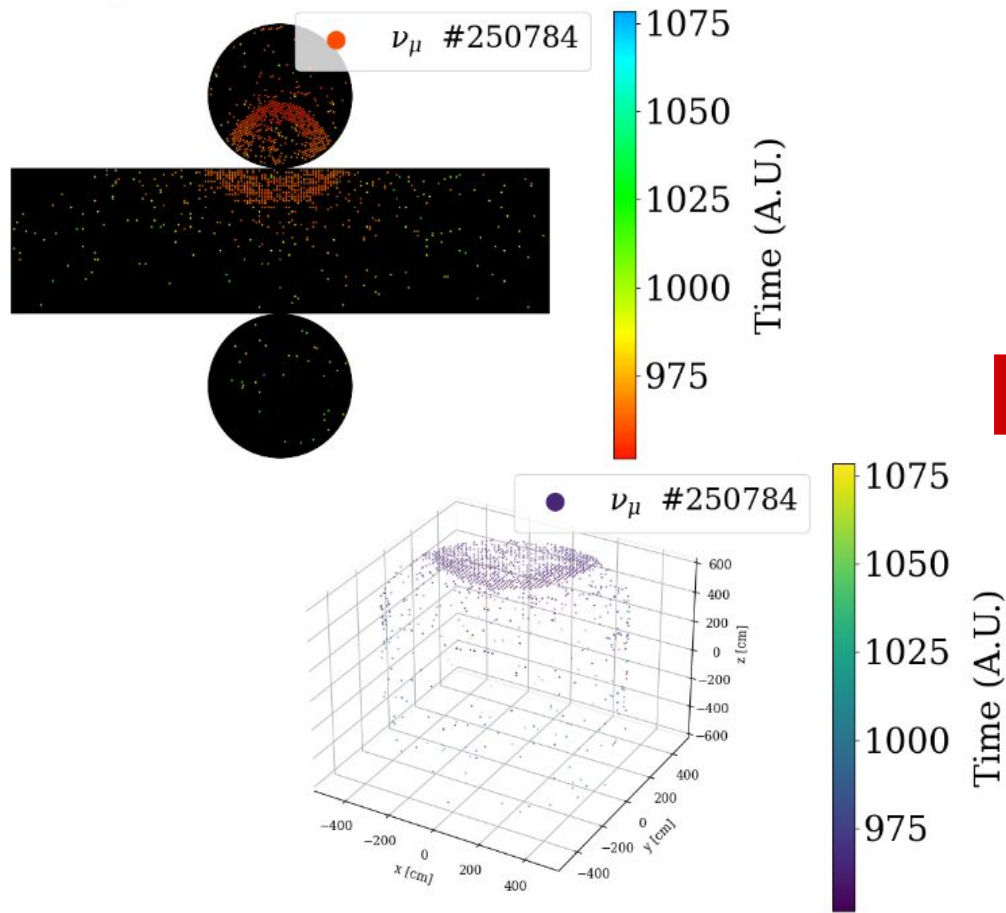
Node features: x, y, z, time, charge

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

An aerial, isometric-style rendering of a futuristic urban landscape. A winding river flows through the center, flanked by green fields and yellow agricultural plots. A multi-lane highway runs along the right side. In the foreground, there are several large, modern buildings, including a long, low structure and a circular one. In the background, a dense city skyline is visible under a clear sky. The overall scene is a blend of nature and advanced urban planning.

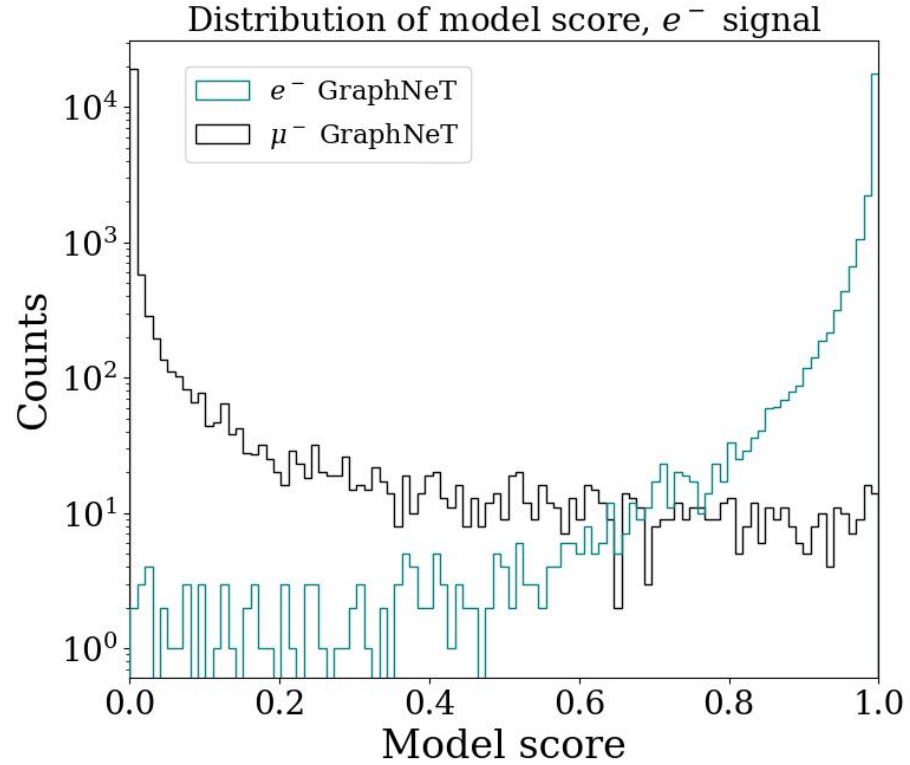
Exploring ESS_vSB Detector Designs With GNNs

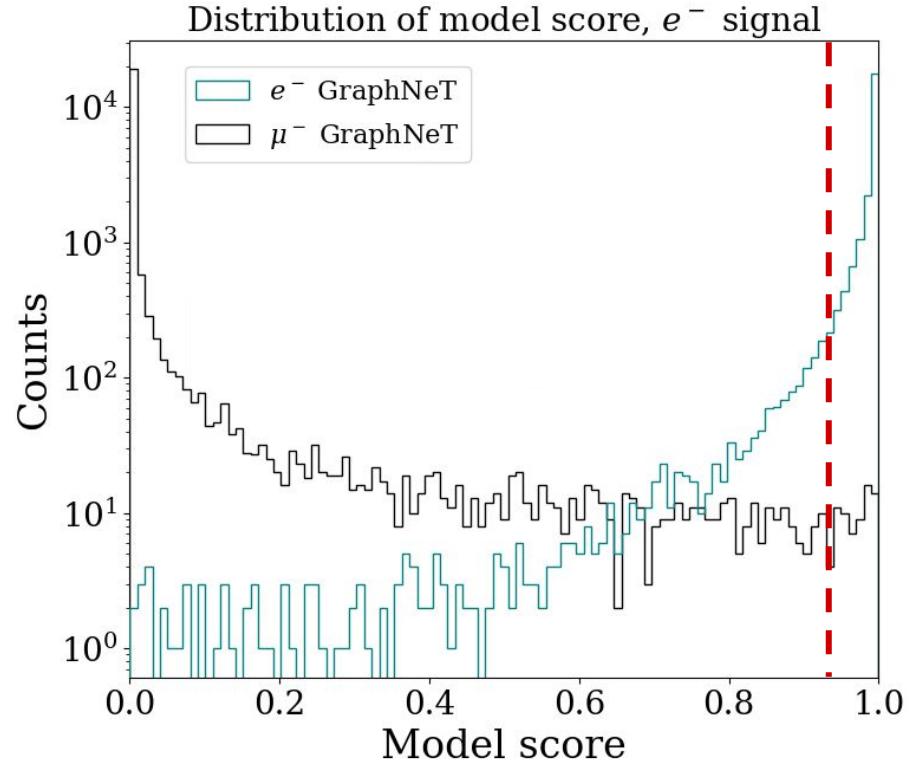




- **GNN:**
Model score $[0,1]$
- **fiTQun:**

$$\frac{\text{LLH}_e}{\text{LLH}_\mu} = \text{"model score"}$$

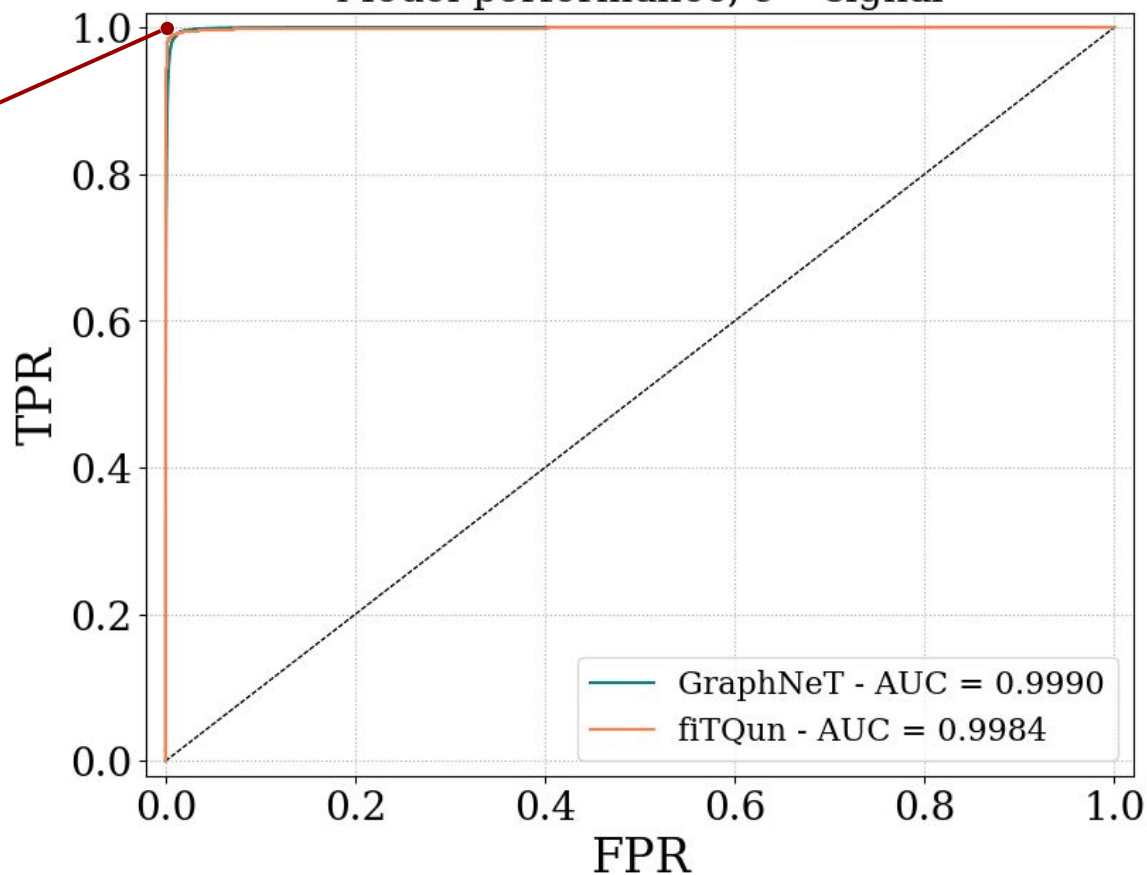


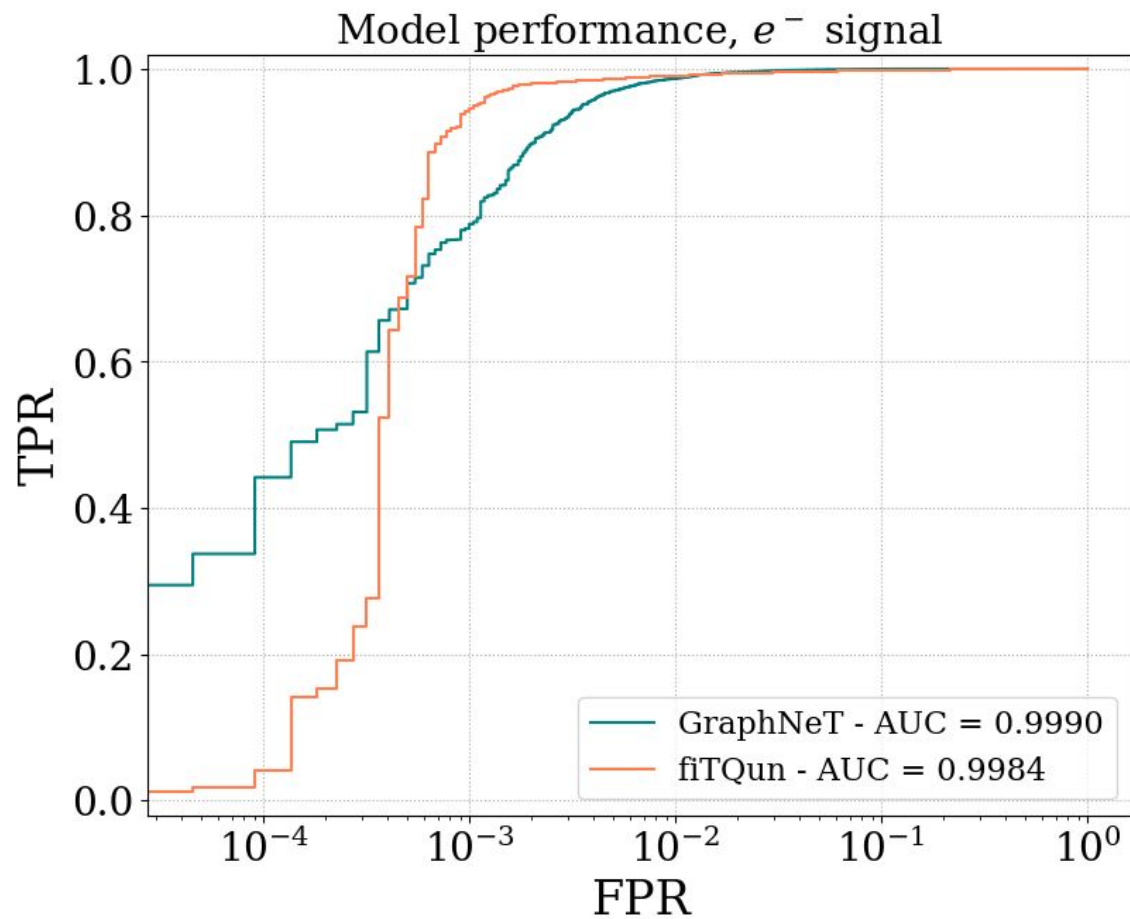


- FPR
- TPR

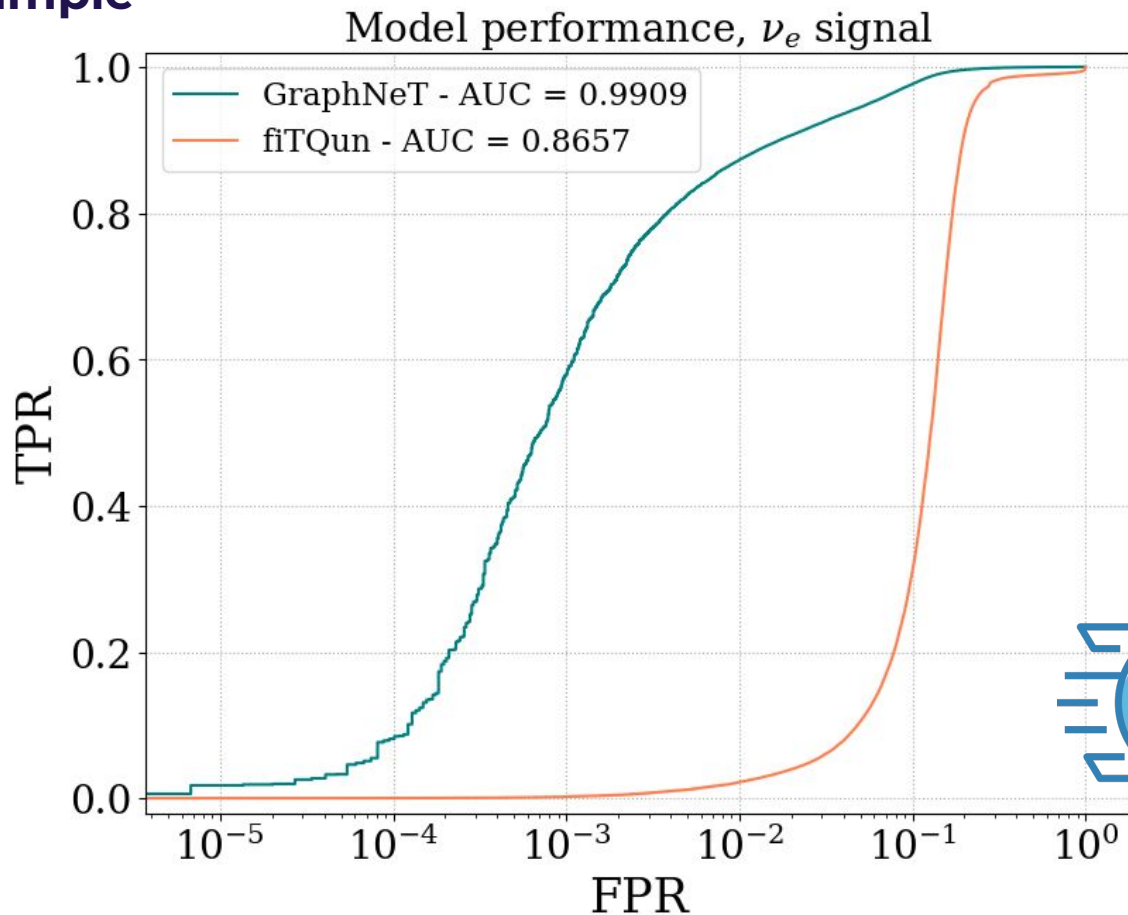
Model performance, e^- signal

**Perfect
classifier**

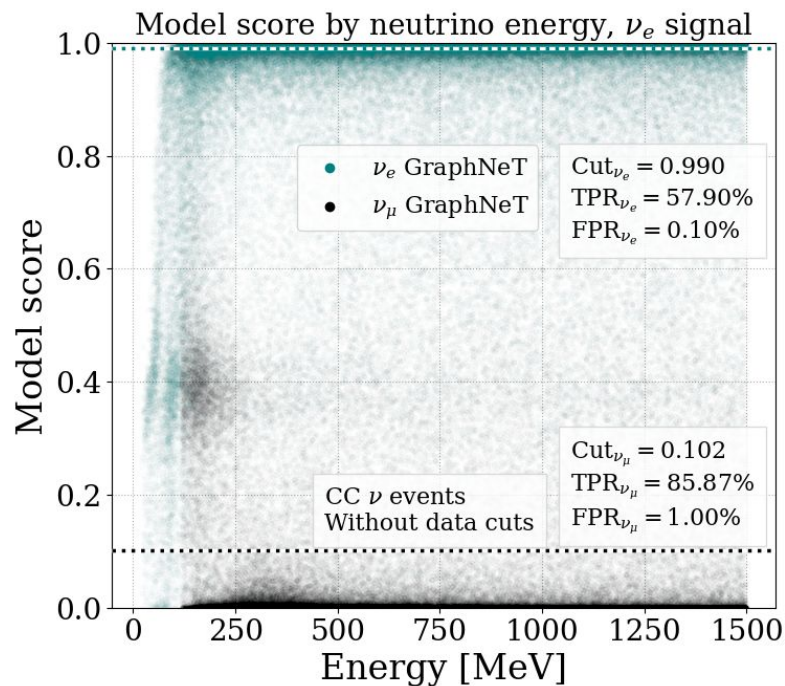




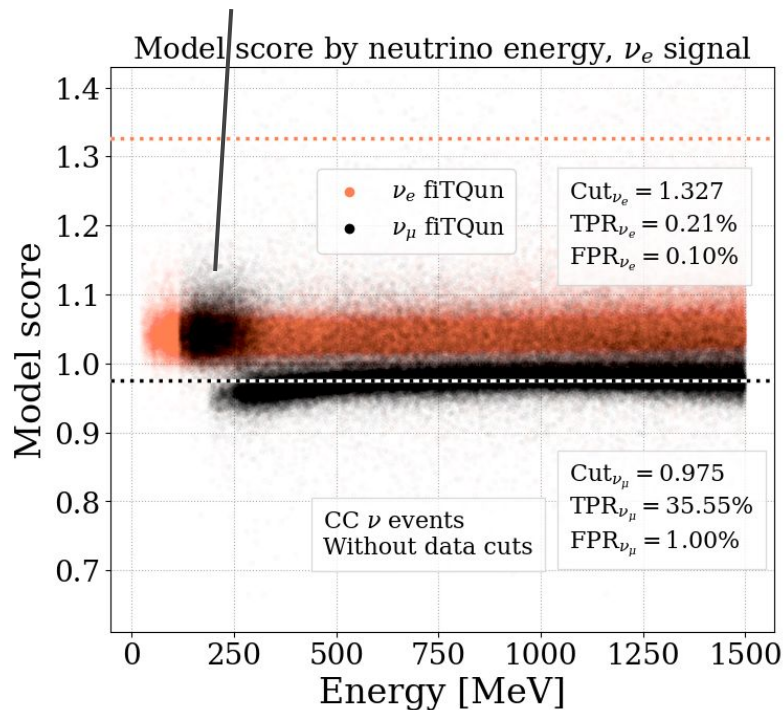
Full event sample



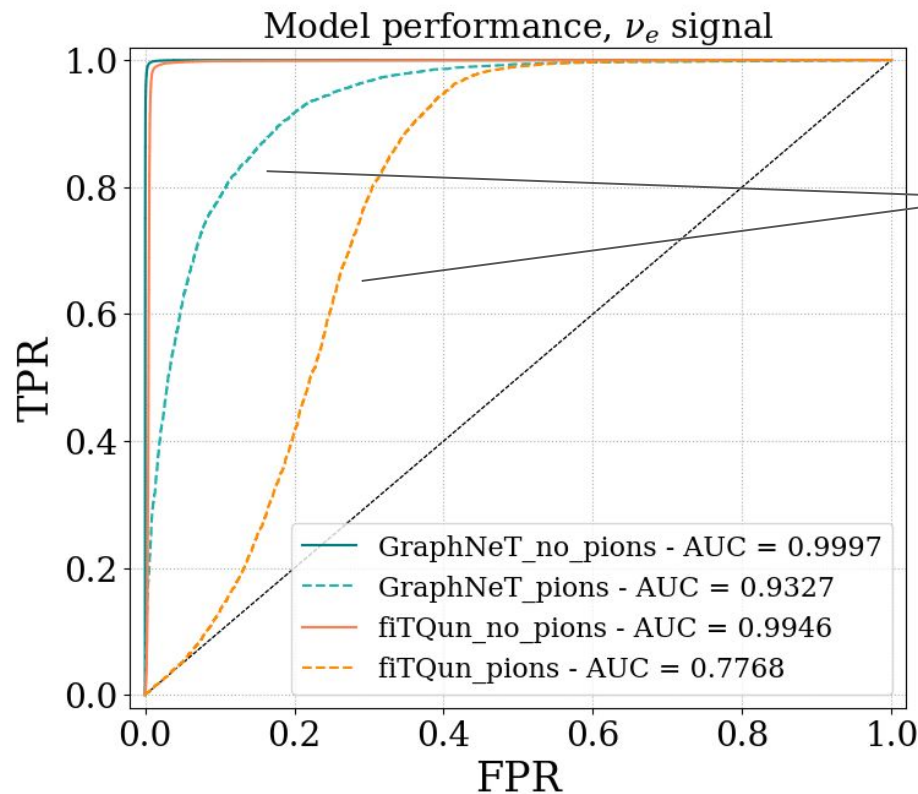
Neutrino energy distribution



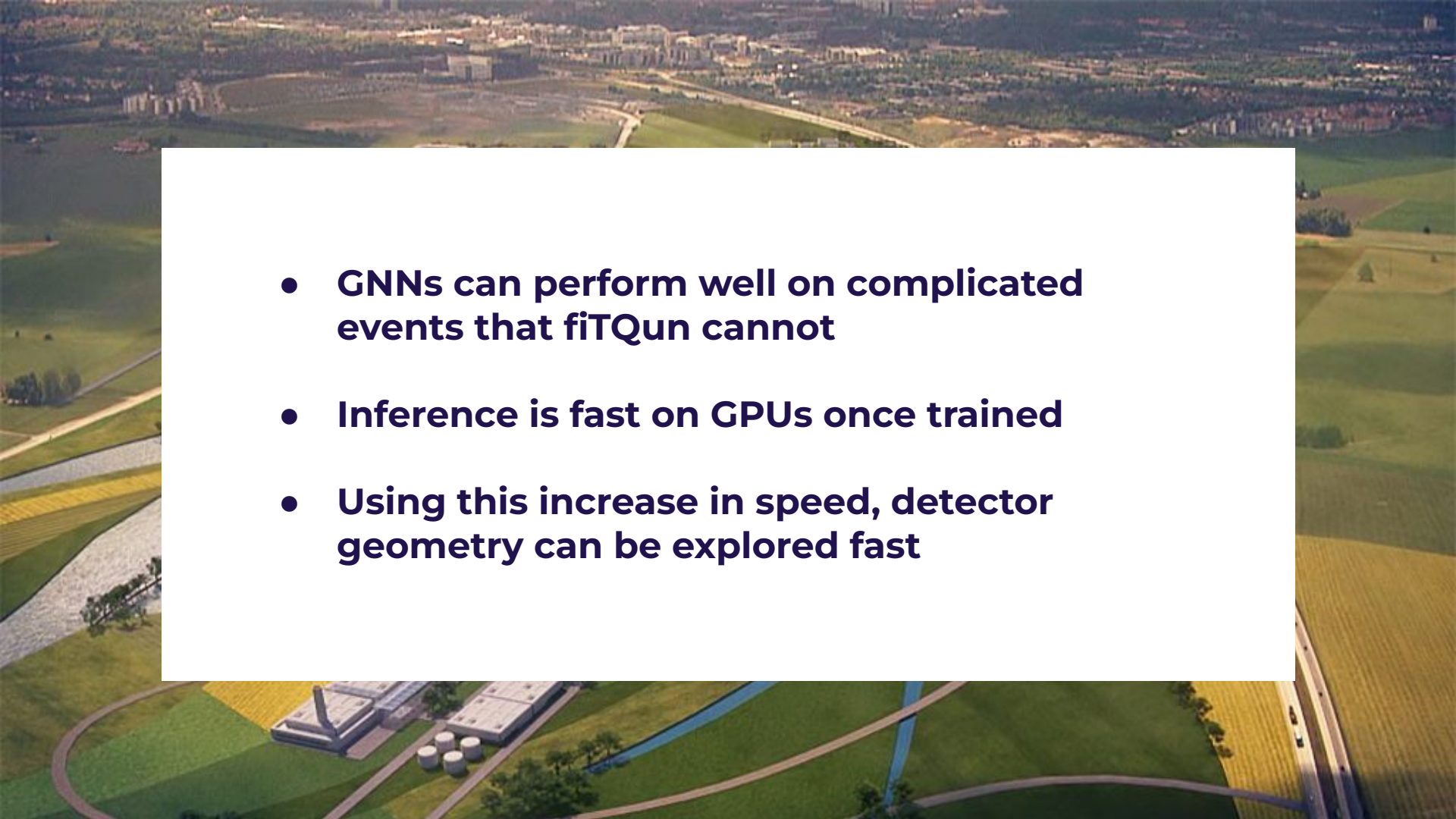
Misidentified low-energy muon neutrinos



Pion production



Pions =
worse performance

- 
- An aerial photograph of a landscape. In the foreground, there's a river flowing through green fields. A road curves through the fields. In the background, a city with various buildings and more greenery is visible under a clear sky.
- **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**