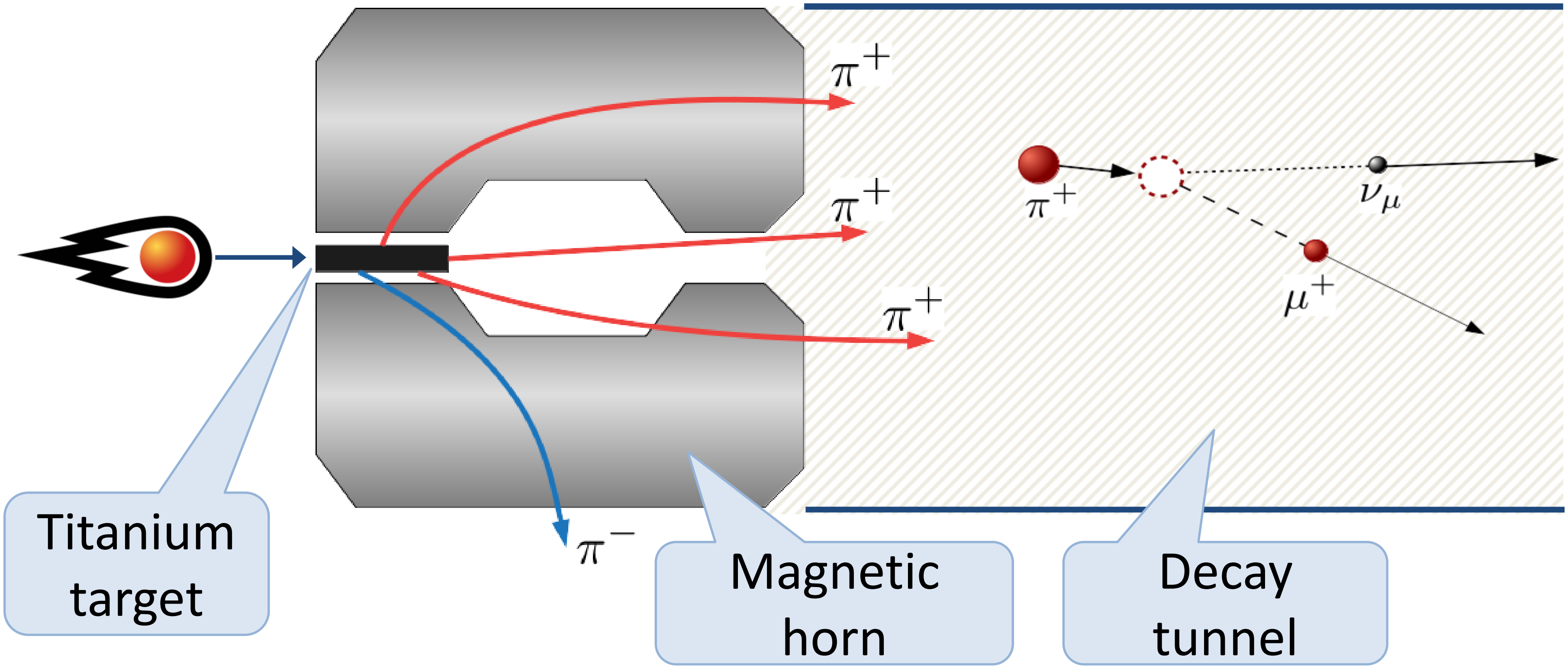
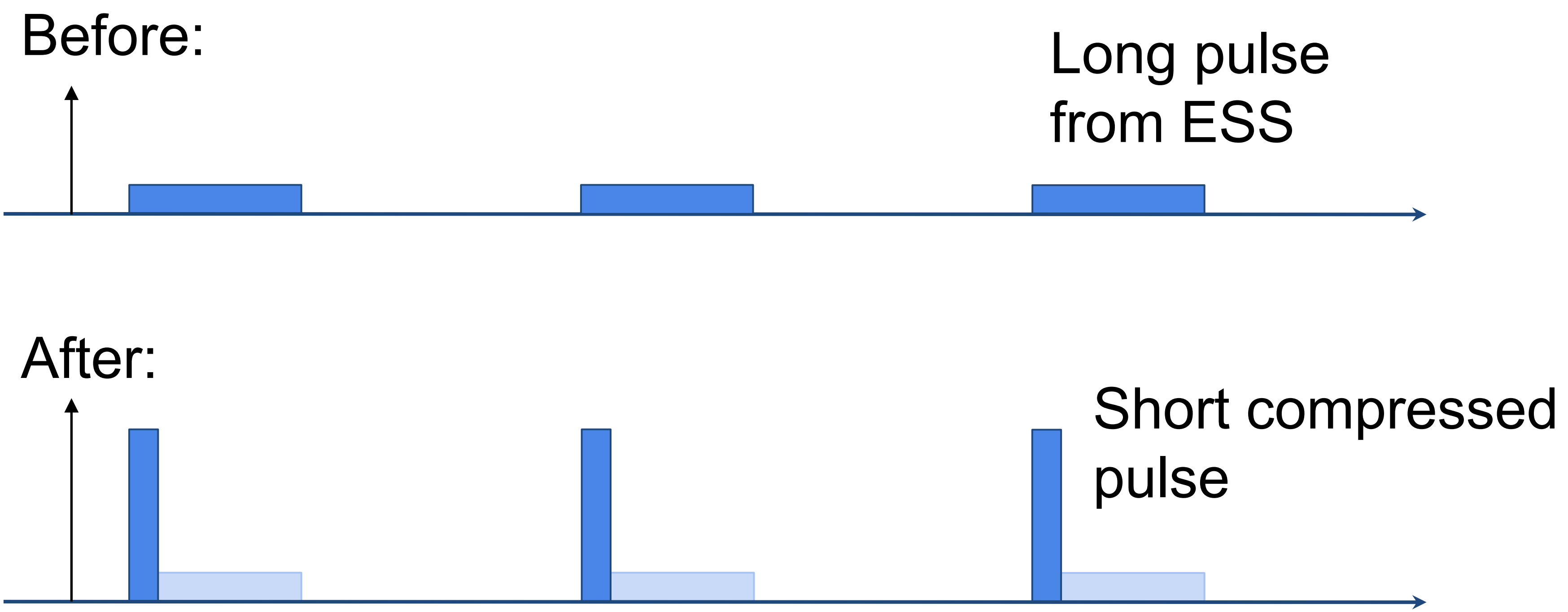
How to select neutrinos or antineutrinos



- A pulsed magnetic horn selects the pion polarity:
  - $\pi^+ \to \nu_\mu$ (beam of muon neutrinos)
  - $\pi^- \to \bar{\nu}_\mu$ (beam of muon antineutrinos)

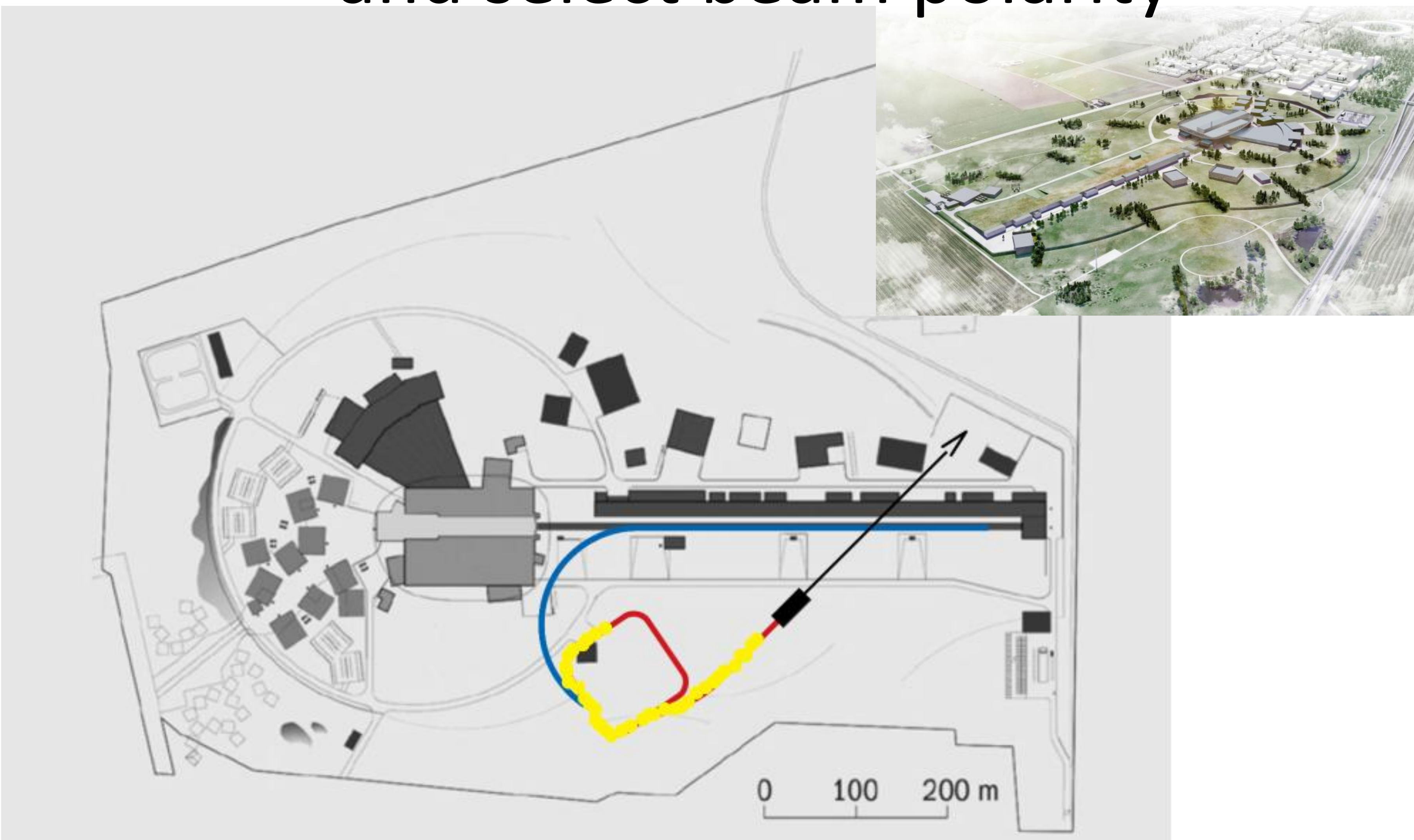
Caveat: Magnetic horn can only take short pulse



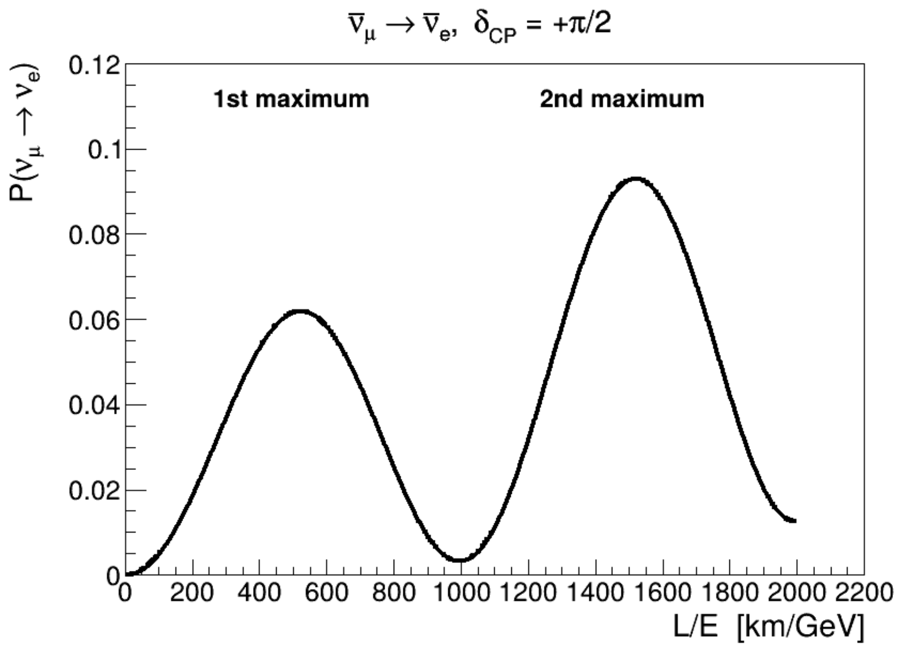
- We need to compress the proton pulse from the ESS using a storage ring

Use ESS to fill the storage ring

Shoot storage ring beam on target and select beam polarity



Now we need to measure the beam at the 2nd maximum



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- That means we need a flight length, L, of approximately 400 km

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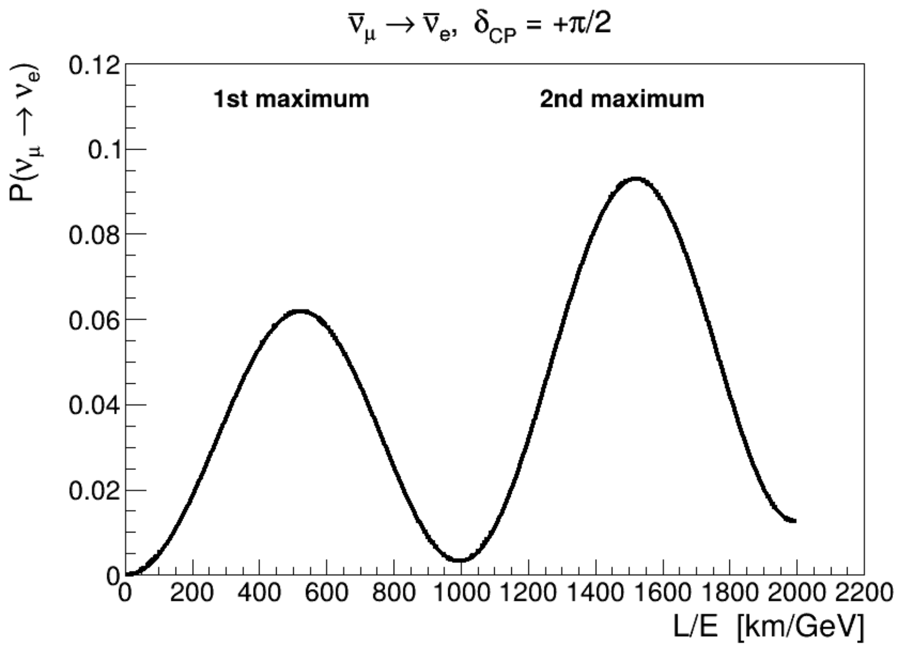

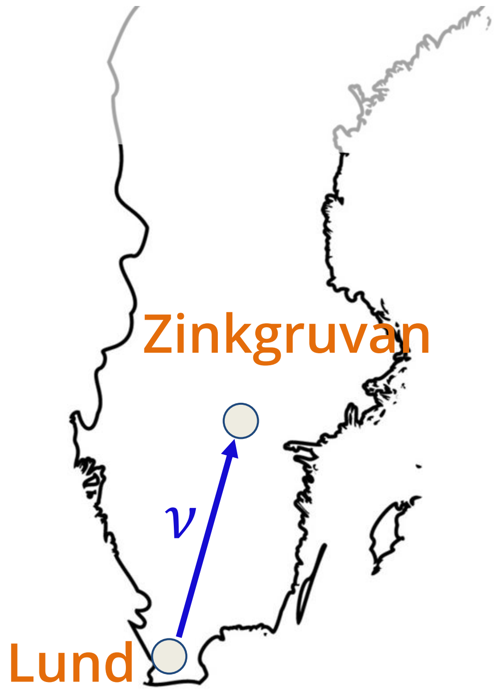

- ESS defines the neutrino beam energy, E
- That means we need a flight length, L, of approximately 400 km
  - We can use the Zinkgruvan mine which is 360 km away!

How do we detect the neutrinos?

- Neutrinos are notoriously hard to detect
  - About 100 trillion (100.000.000.000.000) neutrinos pass through your body every second.
    - Still one would have to wait about 100 years for a neutrino to interact in a detector the size of a person.

$\rightarrow$ We need a massive detector with a weight of approximately 1 Mton (1.000.000.000 kg)

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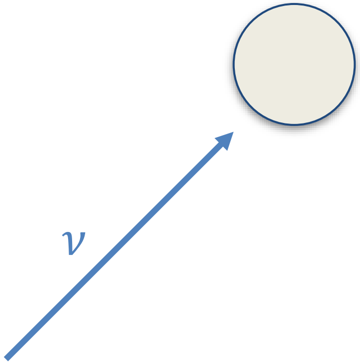
$\rightarrow$ We need a massive detector with a weigh of approximately 1 Mton (1.000.000.000 kg)

- We need to make it transparent so we can easily instrument it $\rightarrow$ use a huge water tank!
- We need to operate the experiment for a long time!
  - Approximately 10 years

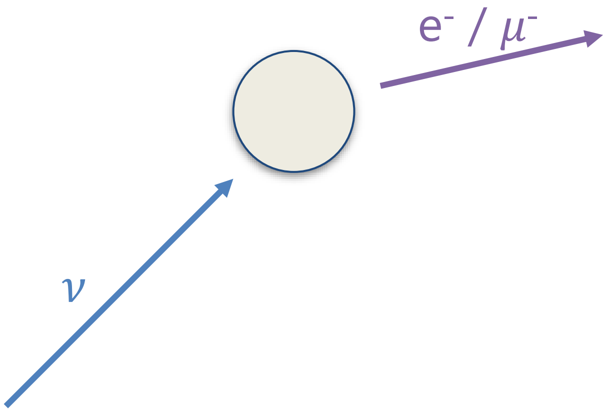
What happens when a neutrino “finally” hits an atom?



What happens when a neutrino "finally" hits an atom?

A new particle is produced!

Typically, **an electron** or it's heavier cousin **the muon** (depends on neutrino flavor)



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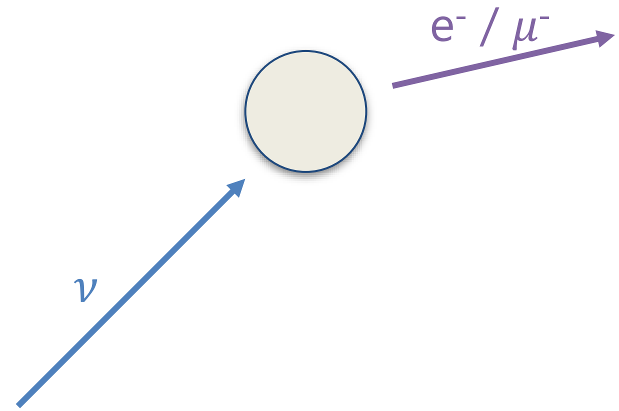

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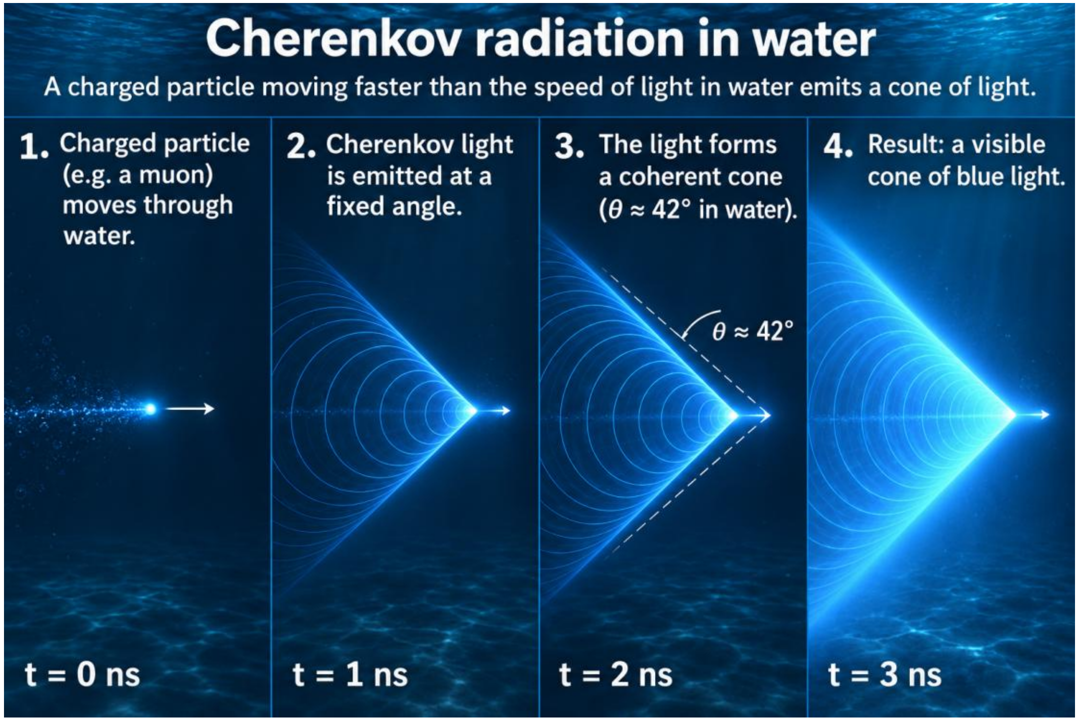
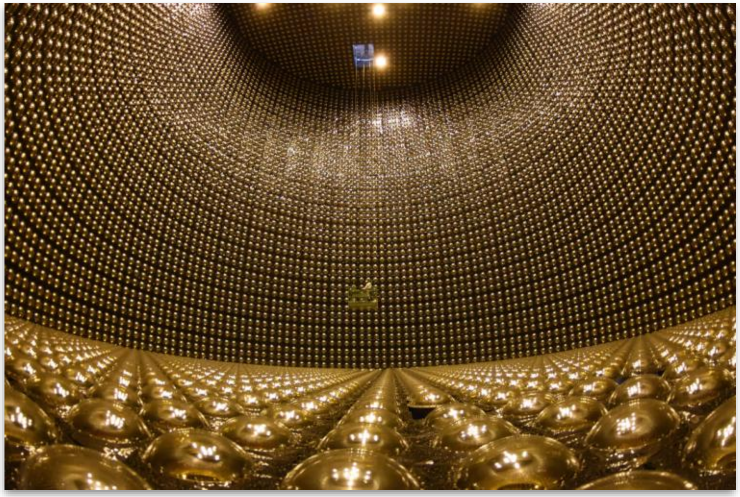
Because it has **electric charge** and a lot of **energy** it can create a shockwave in the water!

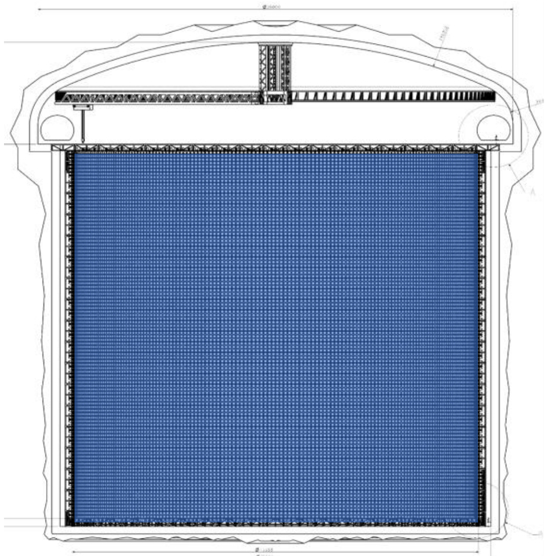


We collect the light with photomultiplier tubes!

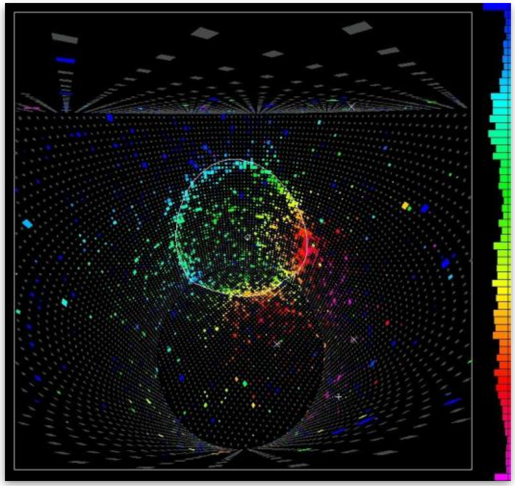
The walls of the detector are covered with **Photomultiplier Tubes**: digital cameras that can enhance very small signals



Superkamiokande, Japan

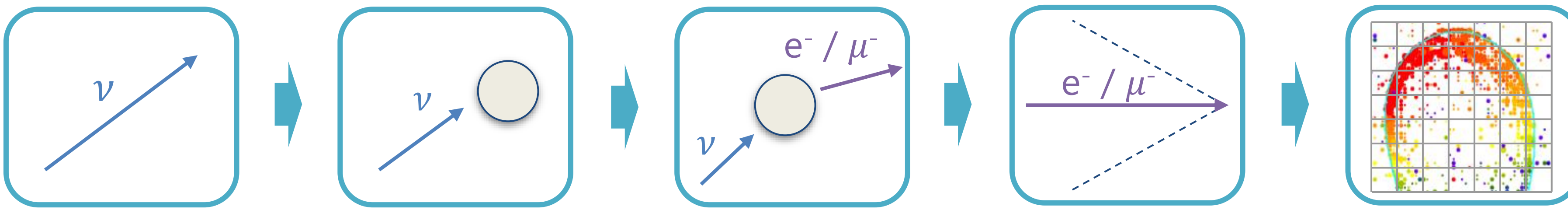


Signal



How do we extract informatoion about the neutrino from the ring?

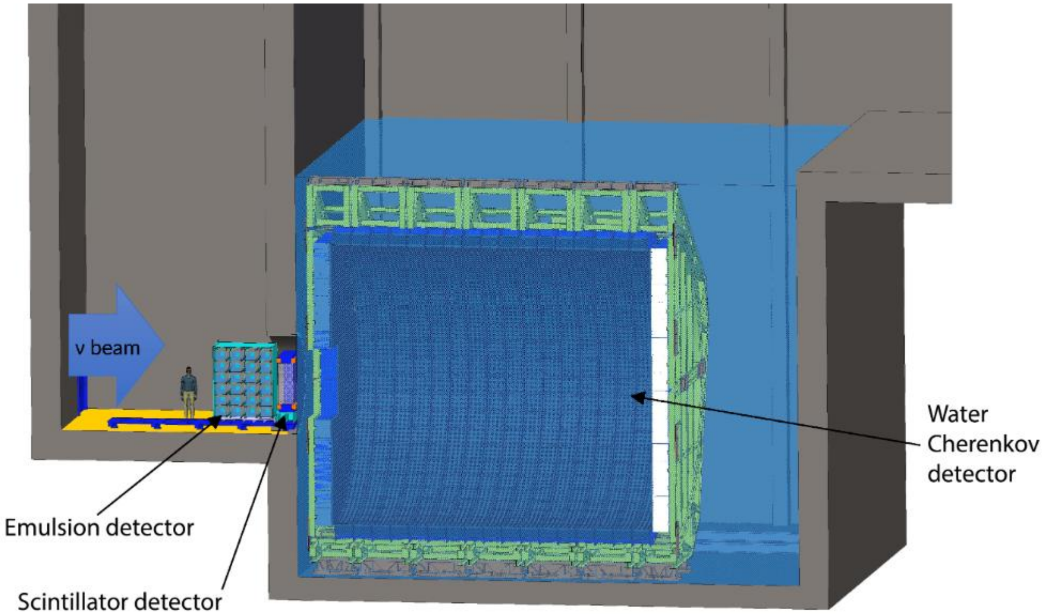
Physical processes

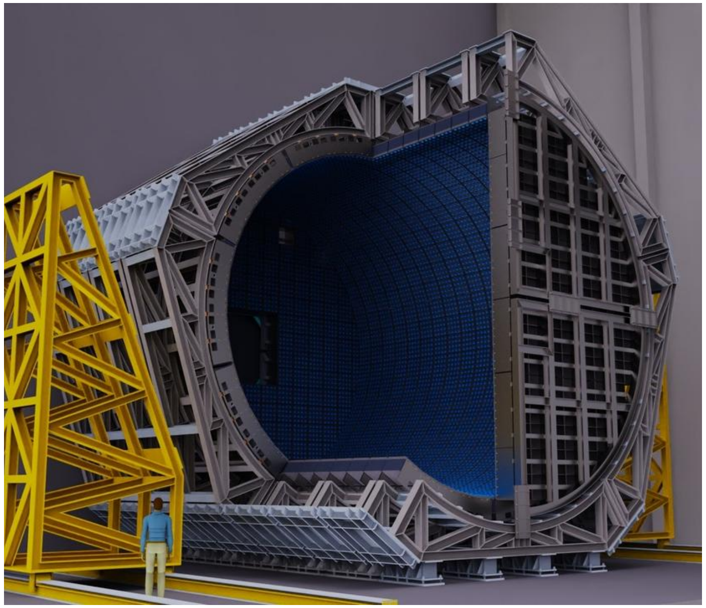


Neutrino | Atom hit | Charged particle | Cherenkov light | Detector signal

Reconstruction: Takes the procress backwards

Focus on the Near Detector (which I work on) from here

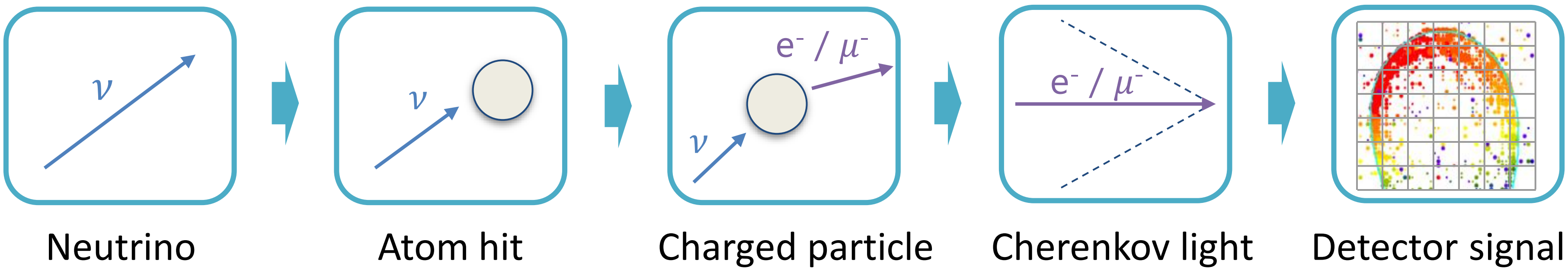




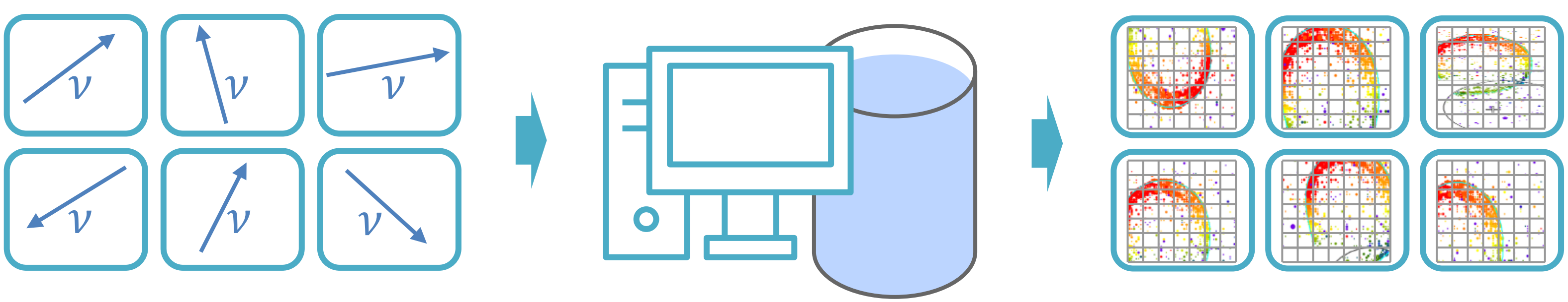
- The goal of the near detector (in Lund) is to measure the neutrino beam before it has oscillated
- In particular to measure contamination of electron neutrinos

For now, we simulate the expected performance

Physical processes



Simulated processes should be as close as possible to the physical processes



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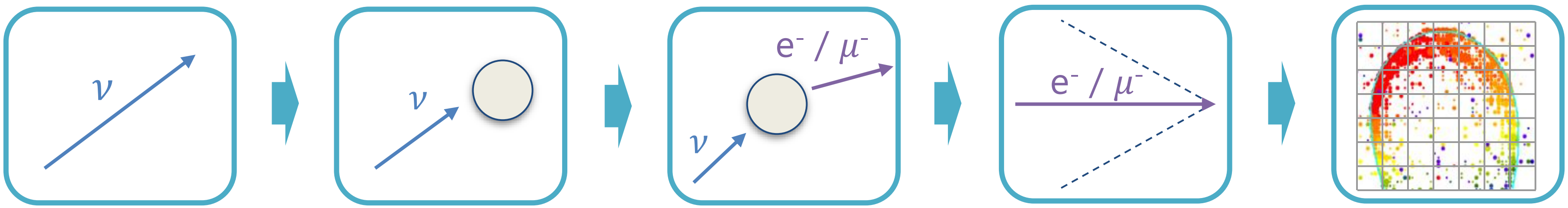
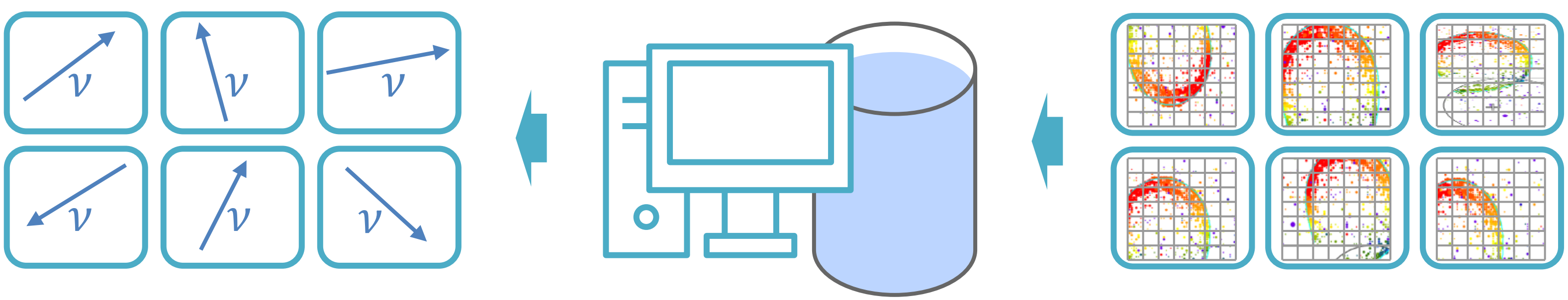
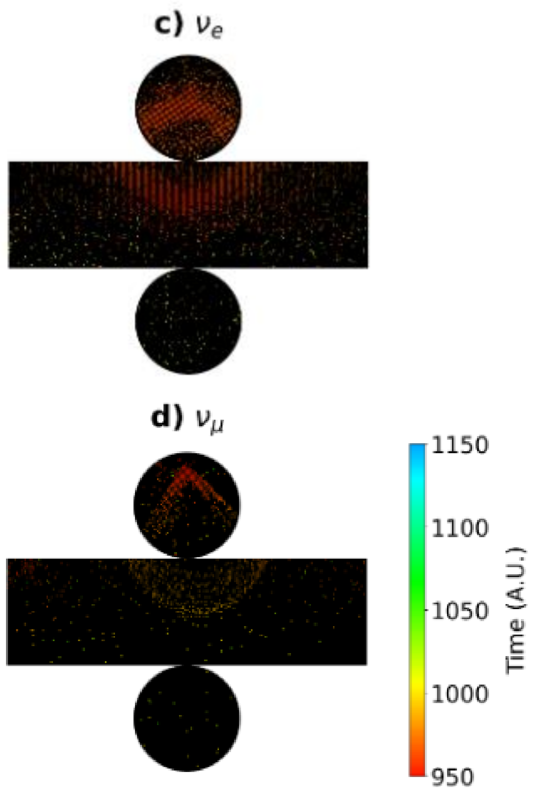


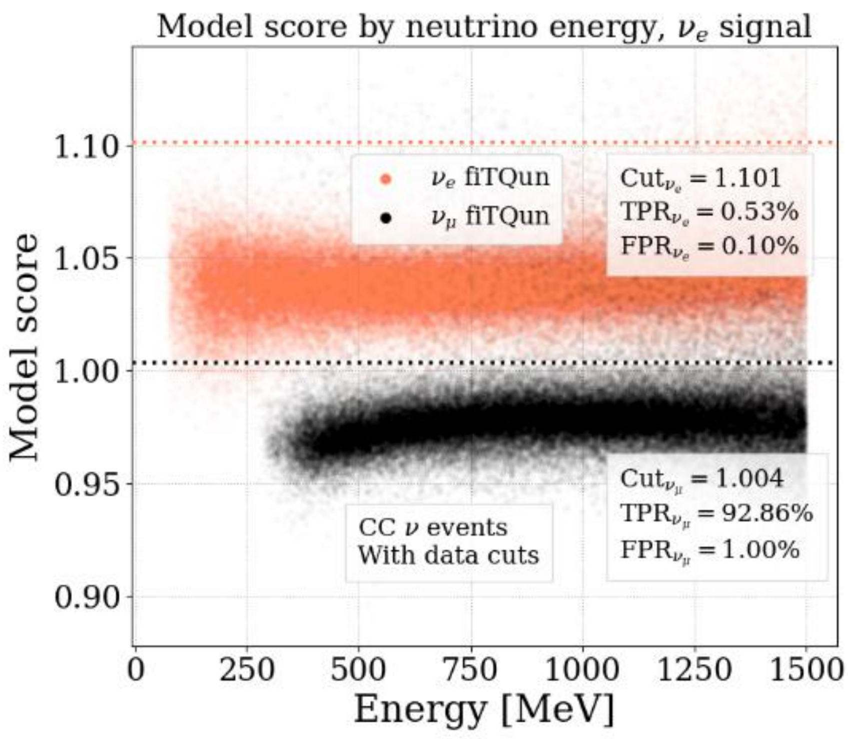
Neutrino | Atom hit | Charged particle | Cherenkov light | Detector signal

Study how well the reconstruction algorithm works



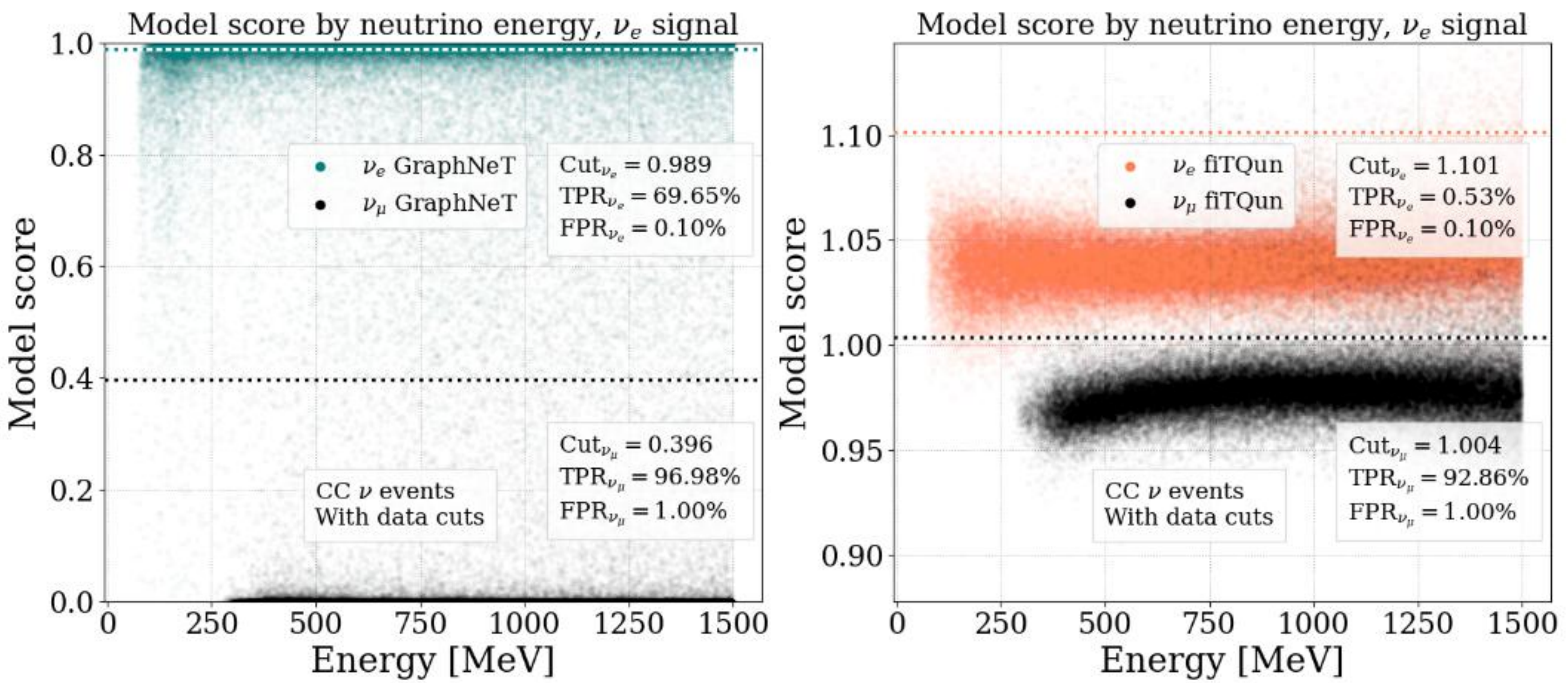
Example with traditional reconstruction methods





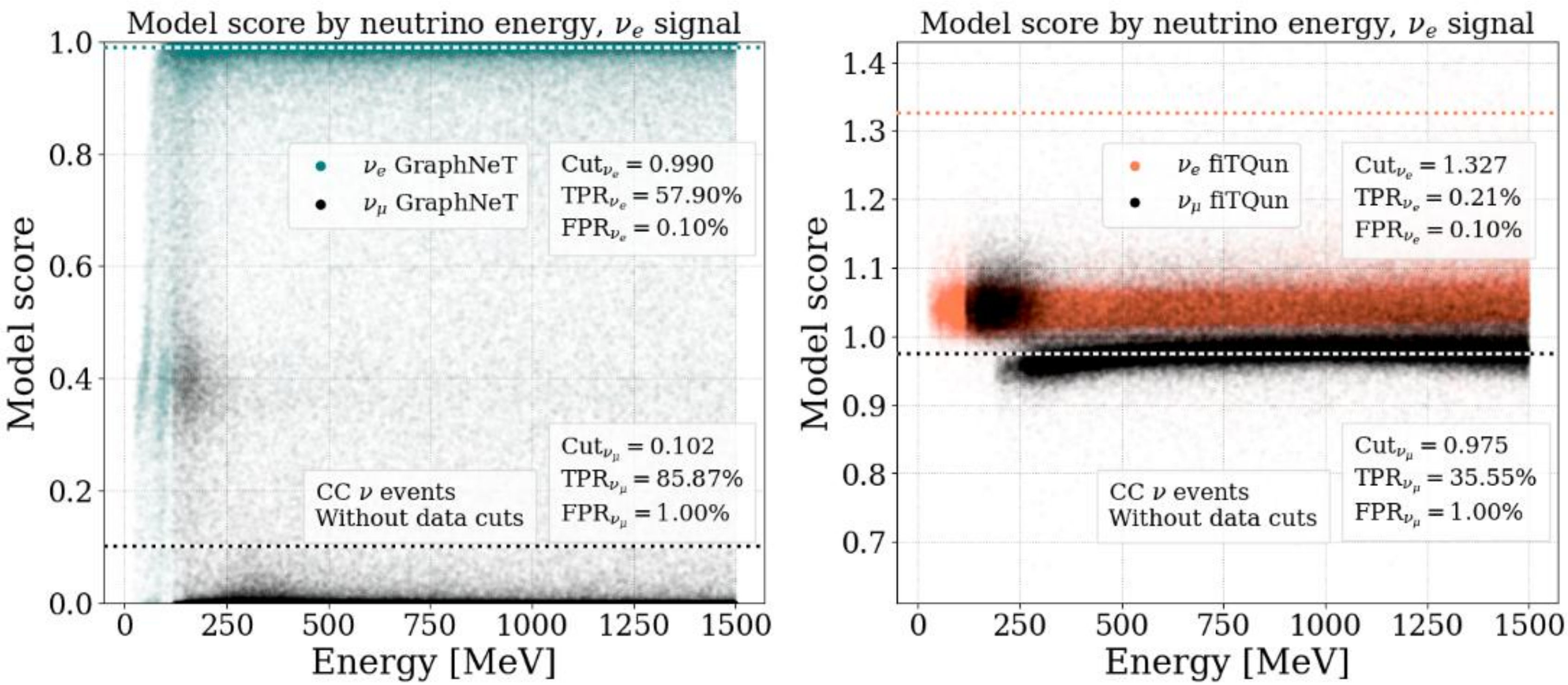
- We first study the performance using existing tools from Superkamiokande
  - We can achieve the required separation!

Example with Machine Learning algorithms (AI / GNNs)



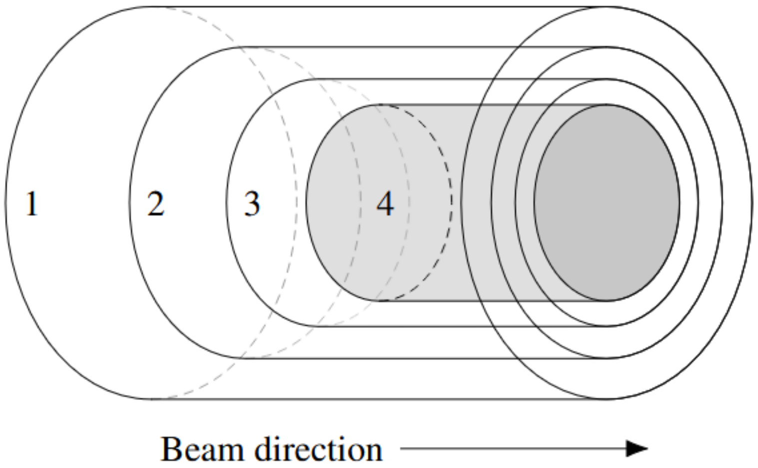
- We do slightly better with Machine Learning
  - In particular for more complicated event topologies

The real kicker with Machine Learning (ML) is that it easy



- With traditional methods we had to do a lot of cleaning up to get the good performance
  - Machine learning also learns to clean up!

ML is therefore a very flexible tool for optimizing the detector!



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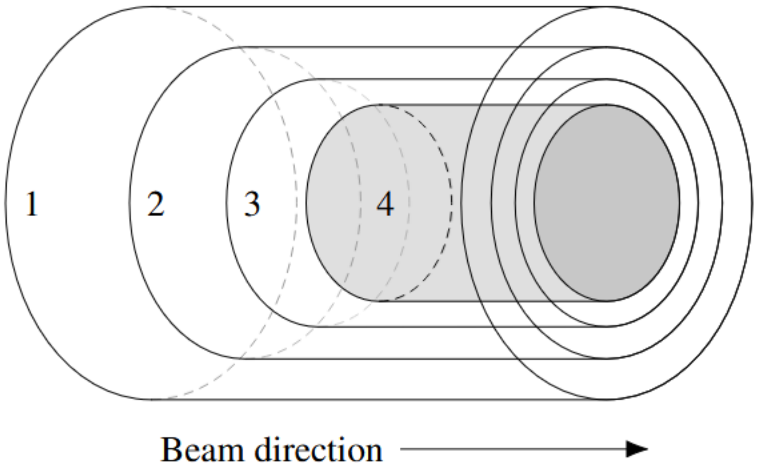
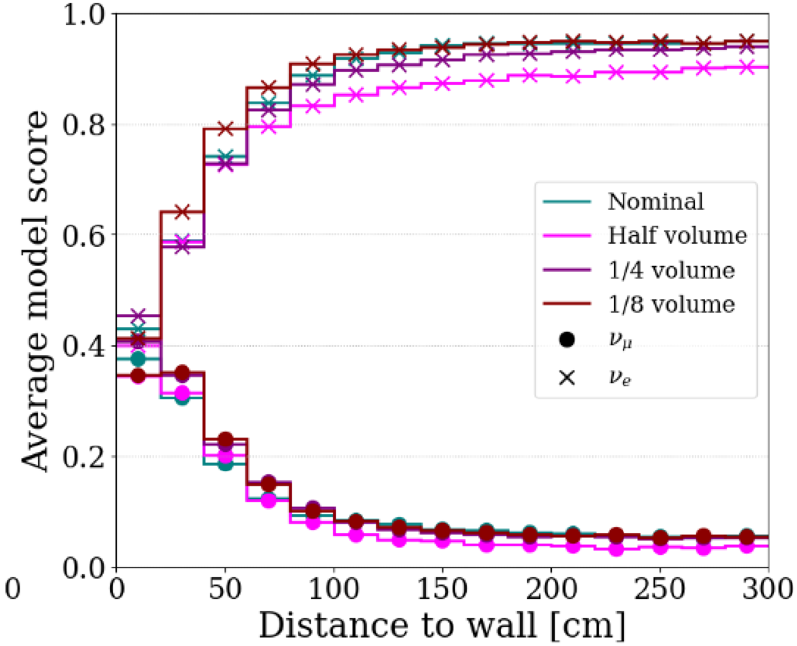
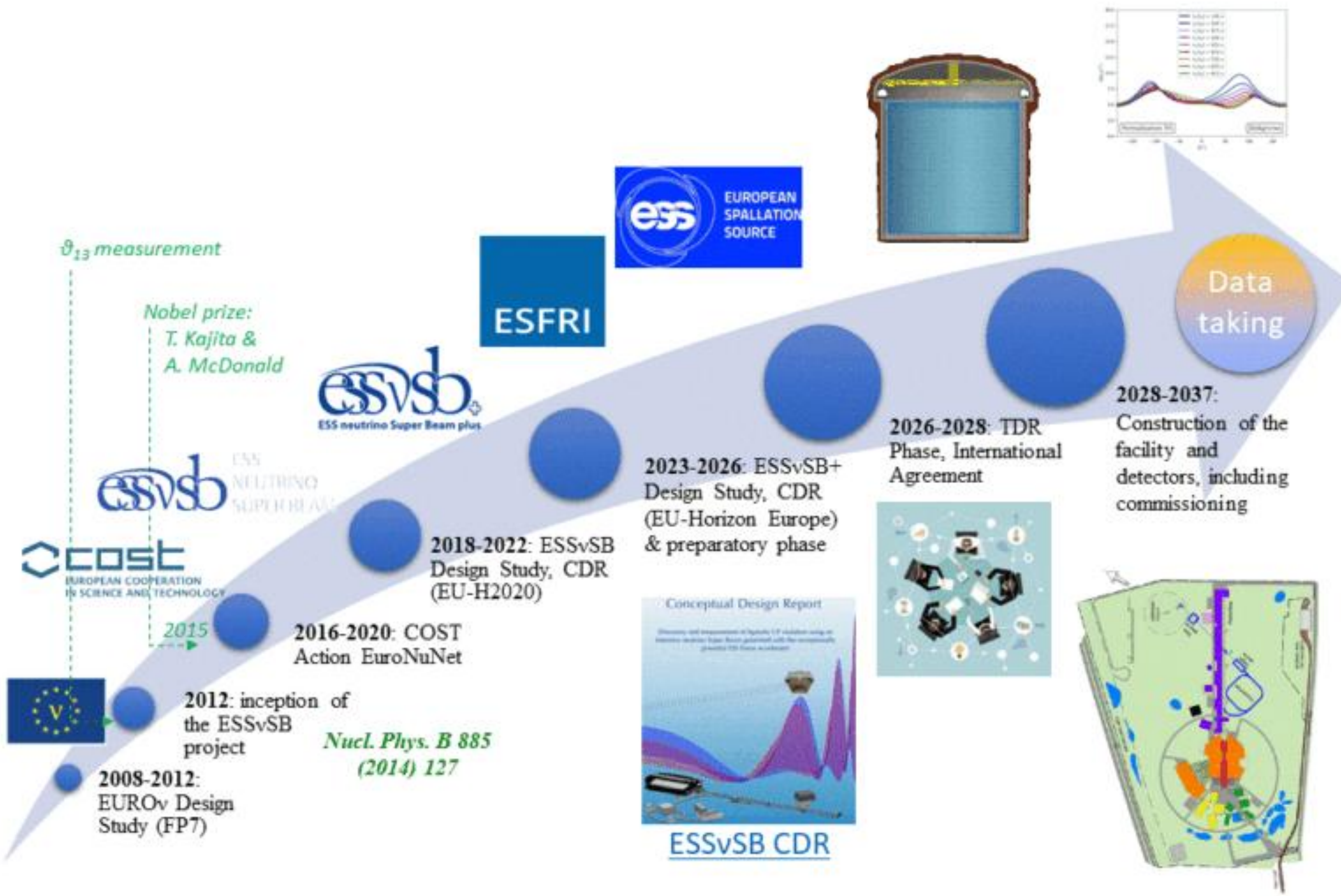




- We can have a much smaller detector!
- ML reconstruction vetos neutrinos that produces leptons with a short flight path to the wall!
- Many other optimizations can be explored

The road to the final experiment!



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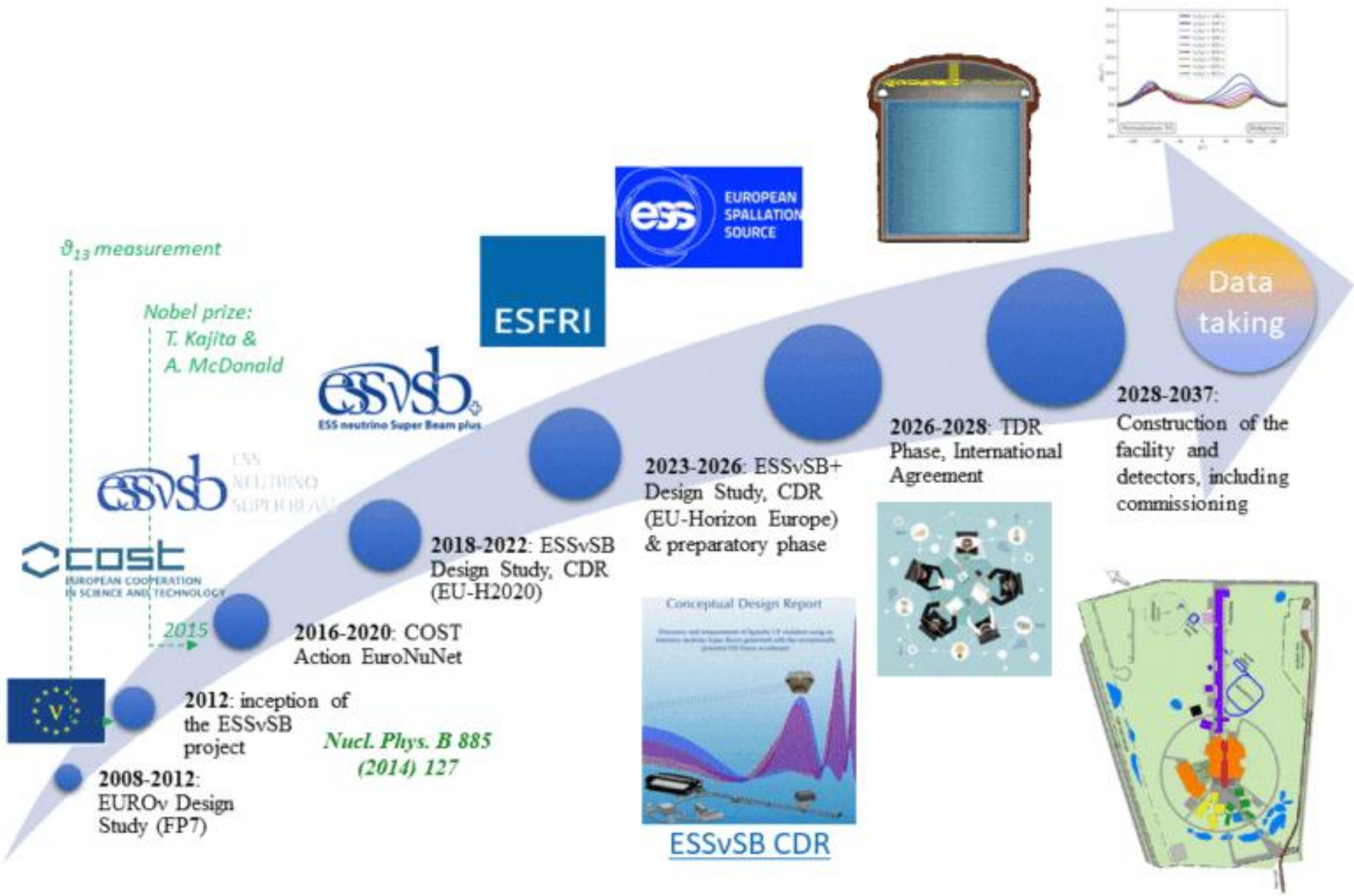

Thank You!