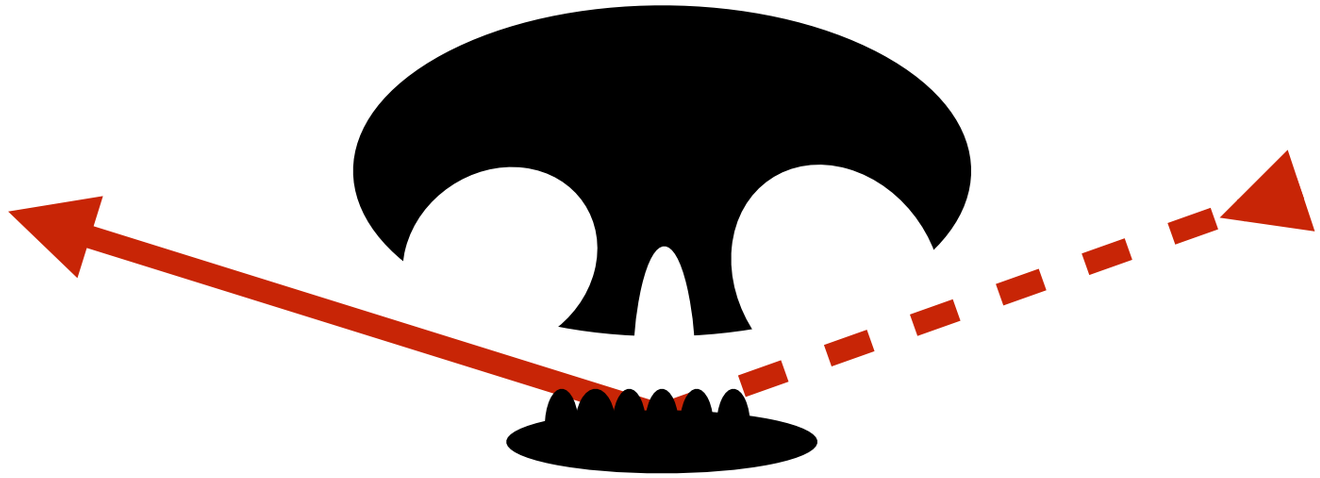

Pirate

Single Pion Production Cross Section Measurements with the **Pirate** Experiment

SLAC Summer Institute
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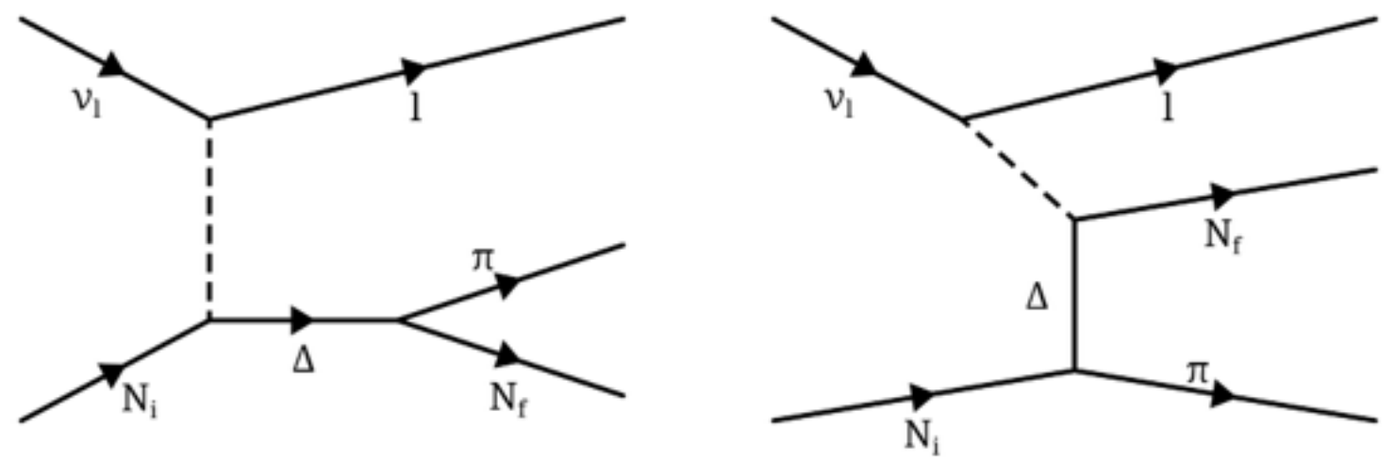
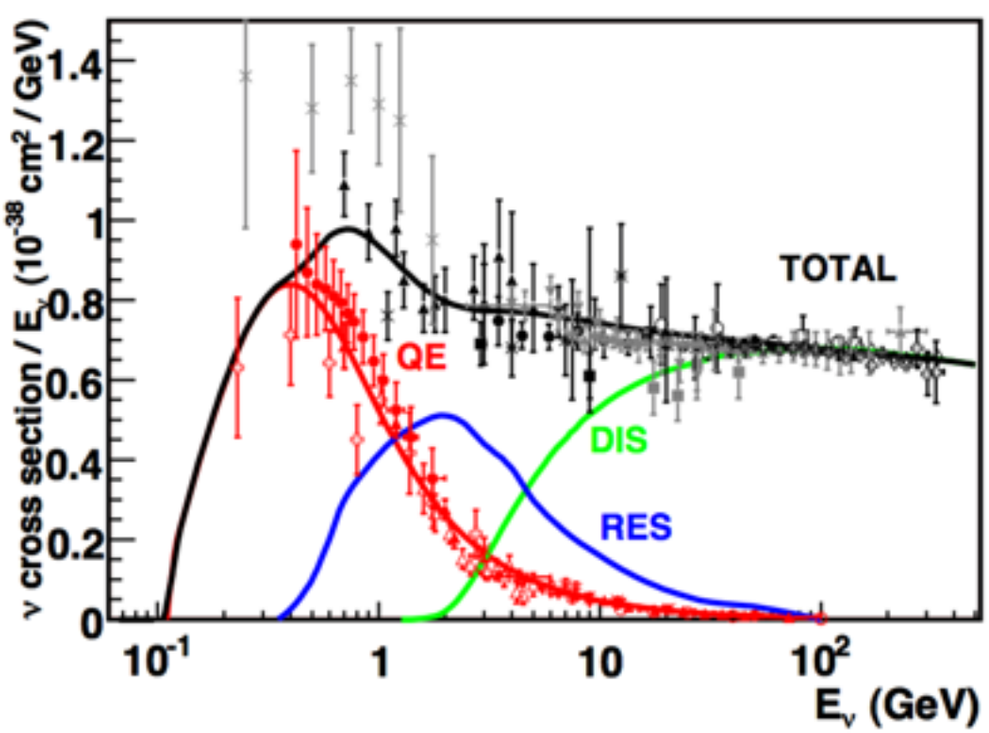
Statement of Problem

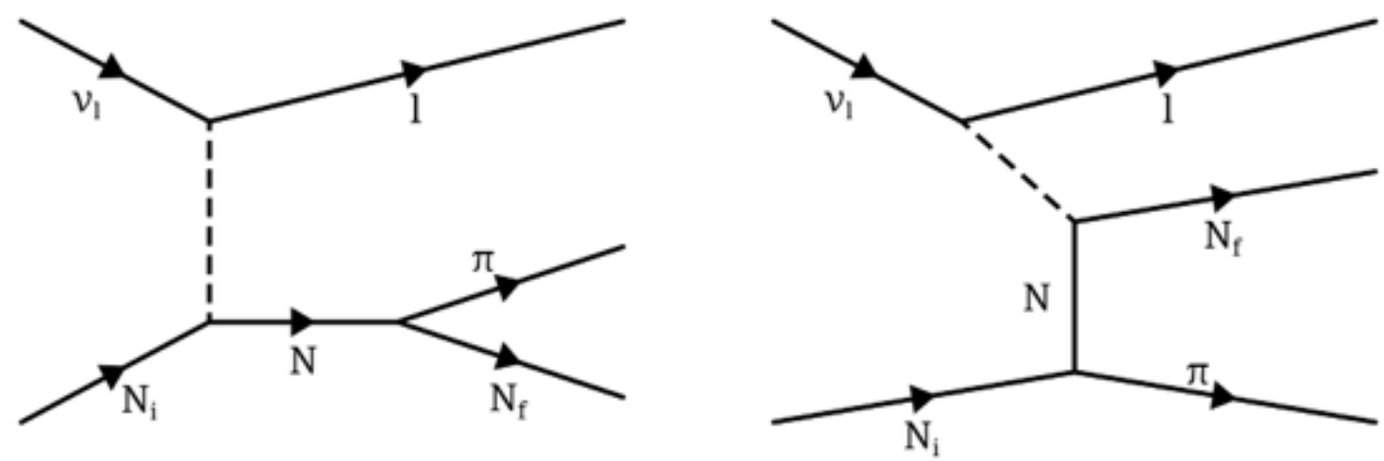
Design a neutrino cross section experiment in which a subtraction technique (for example, measurements on D_2O and H_2O, or C and a hydro-carbon molecule) is used to measure the **total CC single pion production cross section on free nucleons** at ~5 GeV to within 5% statistical uncertainties. What are the implications of this accomplishment to the neutrino oscillation program?

Pion Production Mechanisms

Resonances within the nucleus can create single pions in the final state, as well as processes such as coherent pion production.

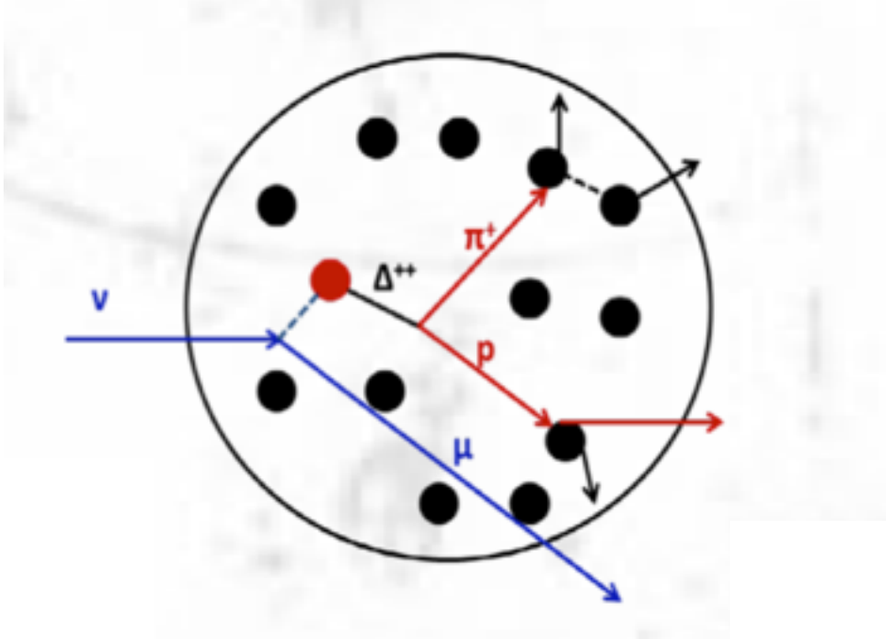






Resonant Cross section at **5 GeV** Neutrino Energy is ~ 1.5 E-38 cm^2

Why do oscillation experiments care?



$E_{\nu} = E_{lepton} + E_{hadronic}$

$E_{visible\ hadronic\ energy} = E_{hadronic} - E_{hadronic\ trapped\ in\ nucleus}$

$E_{hadronic\ trapped\ in\ nucleus}$ is <u>not</u> measured -> E_{ν} is mis-reconstructed!!

Measuring the pion production cross section on single nucleons informs generators in understanding the amount of hadronic energy trapped in large nuclei.

Often this takes something that is not truly Quasi-Elastic, and makes it look Quasi-Elastic, because the pion didn't escape.

Why do oscillation experiments care?

Oscillation physics depends heavily on E_ν reconstruction.

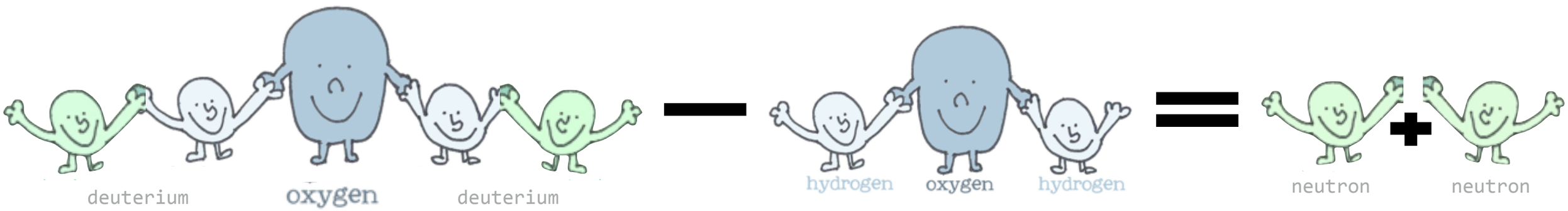
Free Nucleon Pion Production ~FSI-free π production

Final State Interactions affect the reconstruction of neutrino energy and are not calculable from first principles.

They need to be measured to be understood!

For example, in the Theta 23 measurement from T2K in 2014, Nuclear Effects were the dominant systematic at 5%. AirXIV 1403.1532v3

The Subtraction Technique



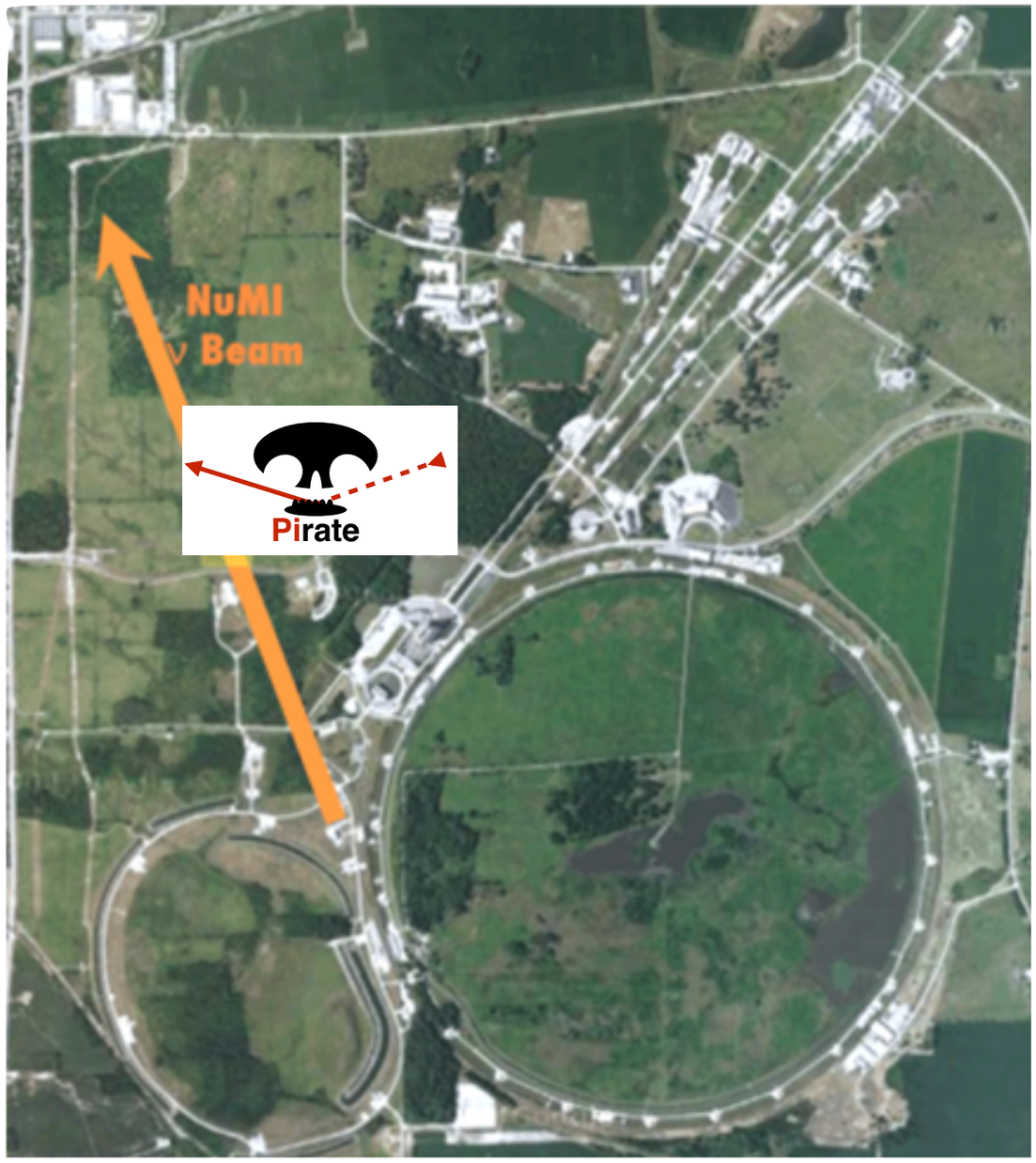
Subtraction (D_2O - H_2O) gives π spectrum for free nucleon

Additionally, D_2O & H_2O cross sections are valuable for many experiments.

π absorption due to Final State Interactions can be studied by looking at the difference between heavy nuclei and free nucleon cross sections.

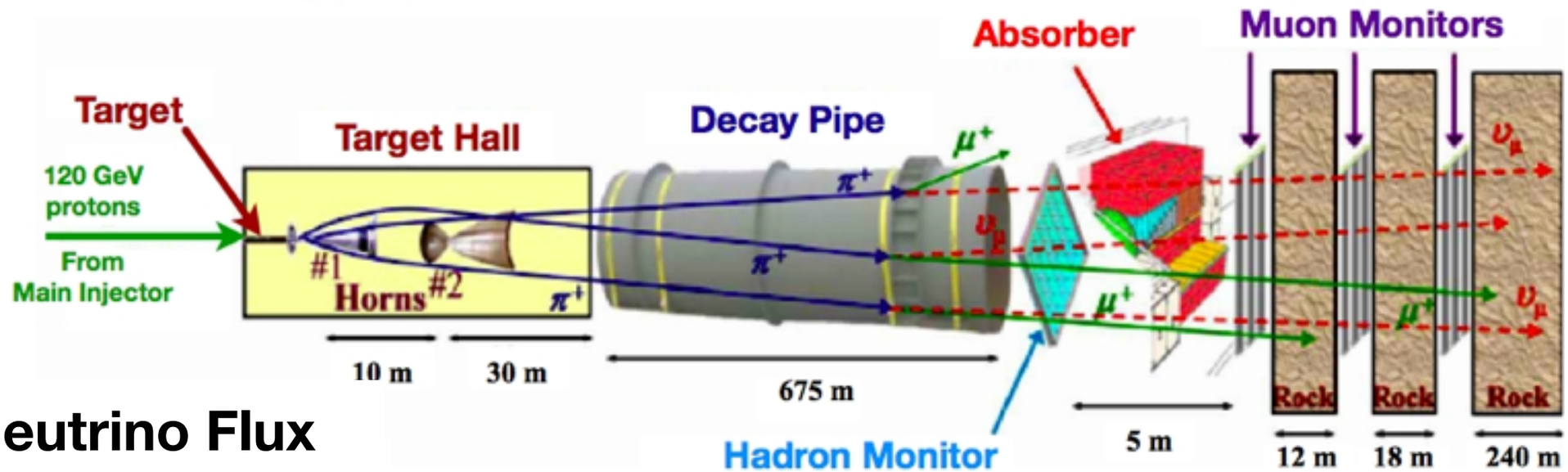
Measurements of Final State Interactions can be used to tune MC and account for mis-reconstruction. Reduce errors in oscillation analysis

Where would we sail?

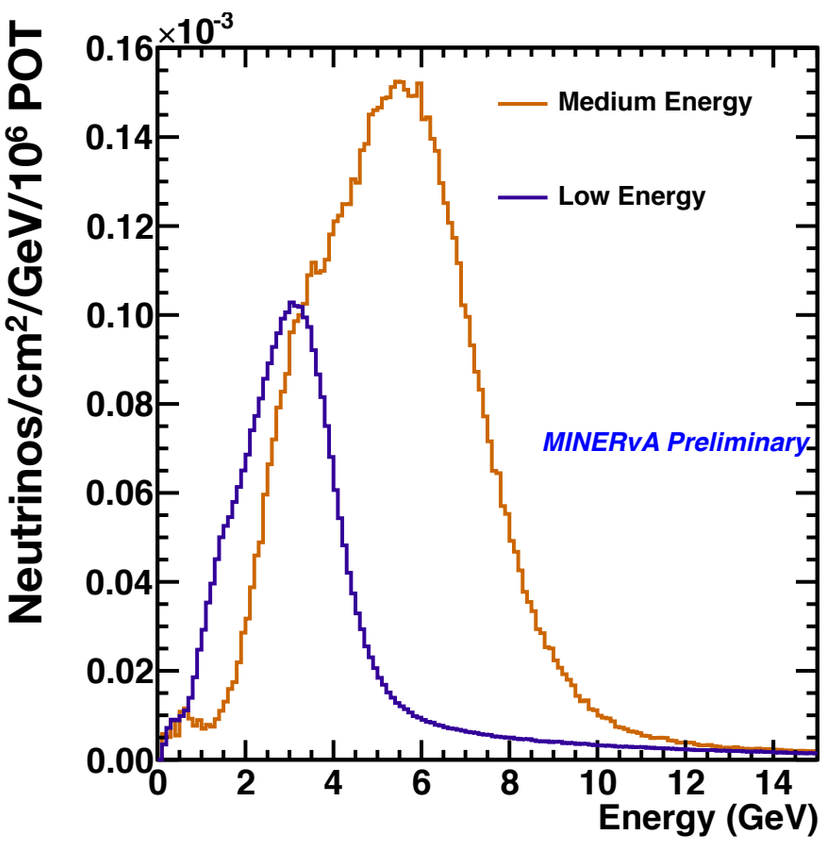


Fermilab

NuMI Beam line

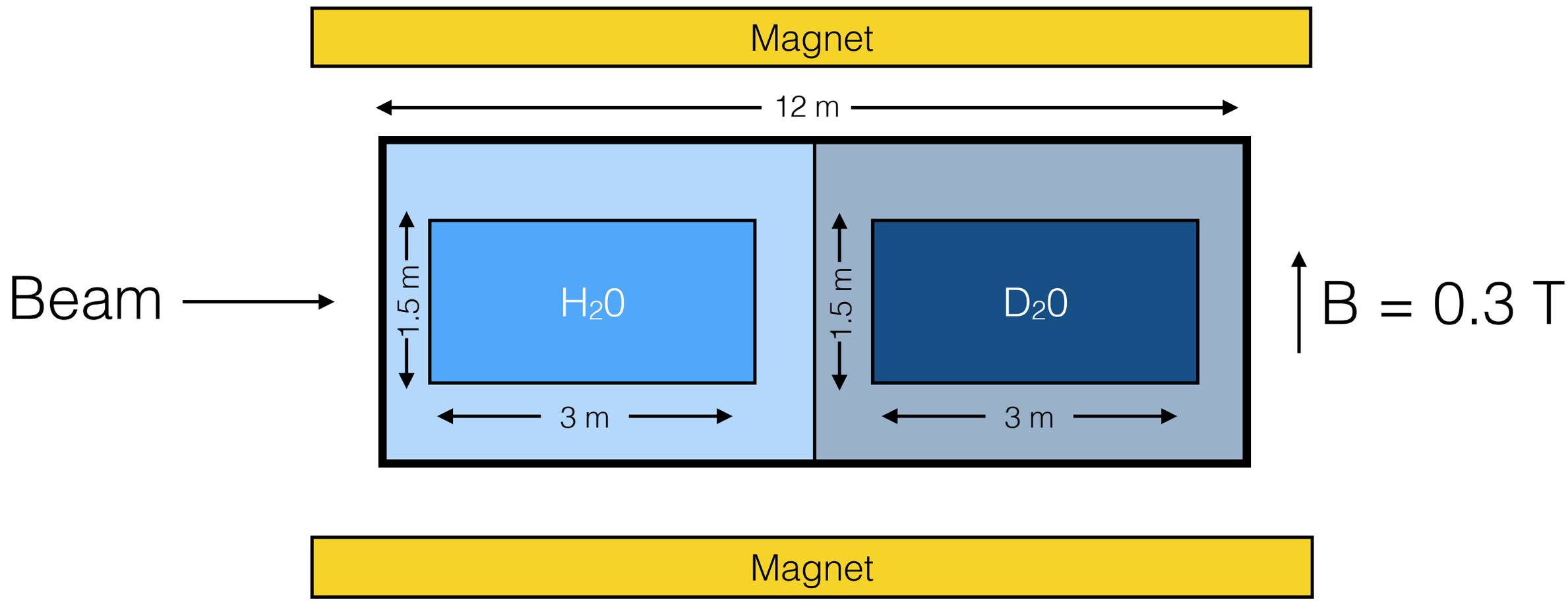


MINERvA Neutrino Flux



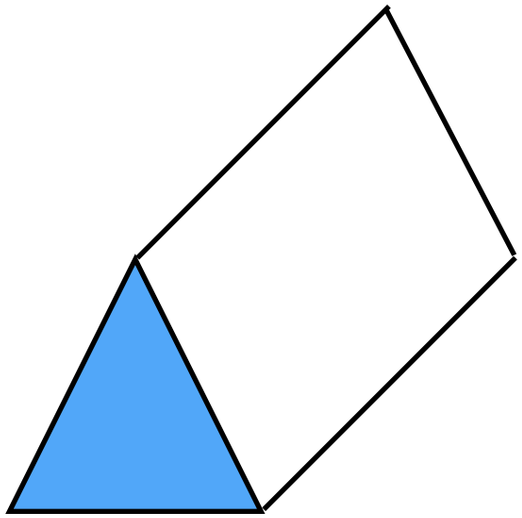
We based our flux on the NuMI beam line in it's current configuration at **5 GeV** neutrino energy.
~ 3E-9 1/(cm^2 POT)

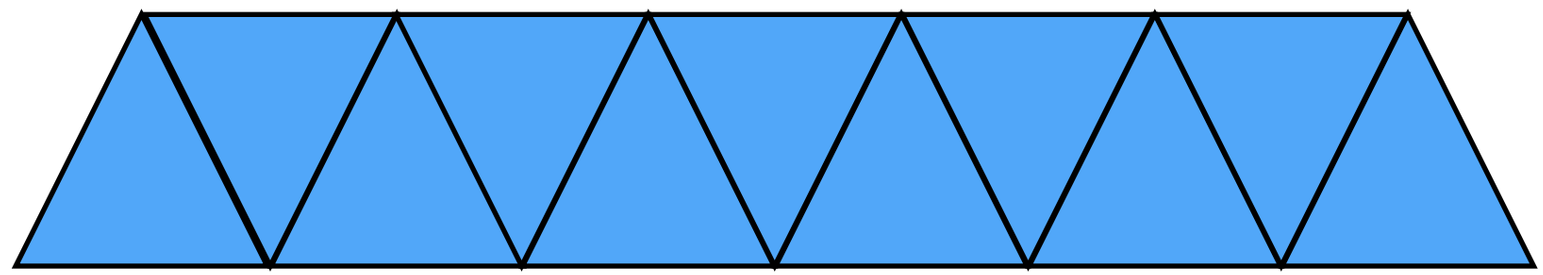
Pirate Detector



Side View

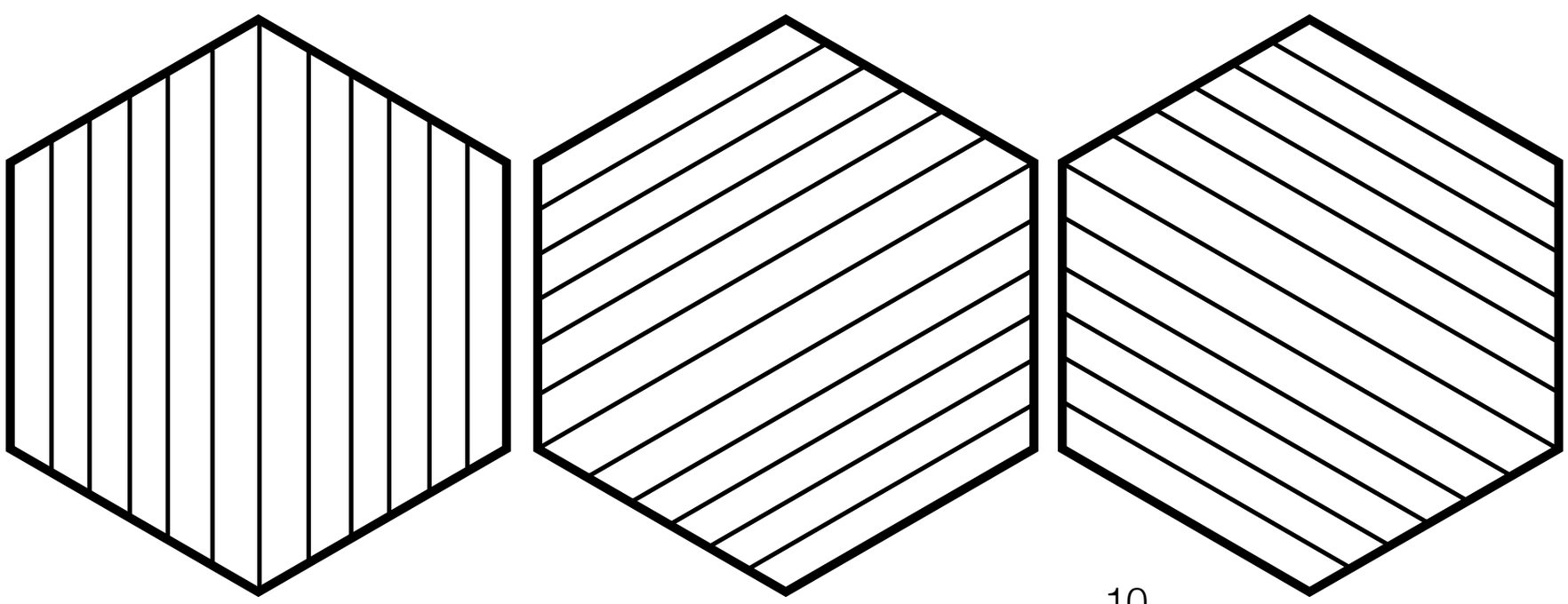
Pirate Detector





1 cm

Three views, stacked to give 3D reconstruction capabilities



A single SiPM would be placed one end, and a light tight two way pressure flange would be placed on the other so that we can fill the detector slowly and have equal pressure in each cell.

Detector Capability

- 3D printing of this detector would allow for the light tight plastic walls of the cells to be as thin as possible. No structural support is required, since the detector is suspended in the material.

- The finely segmented structure of the tracking detector could offer sub cm precision in reconstruction.

- By applying a 0.3 T magnetic field, we would be able to bend particles from 50 MeV pions to 5 GeV muons in a way that would allow for charge and momentum measurements.

How long would it take?

- At Fermilab in the NuMI beam line, a year in the current beam line yields around 6E20 POT.
- Two years of data taking would give us a 5% statistical uncertainty on our pion production cross section on free nucleons.

$$$$$$

- We wouldn’t have to construct a beam line, so costs can be kept down.

Item	Cost
SiPMs	22.6 M
Heavy Water (re-sellable)	3.6 M
Beam Time	105 M
Detector	10k
Magnet (recycled)	50k
Total	~131.3 M

Conclusions

- As neutrino oscillations enter a precision era, nuclear effects are becoming crucial to precise energy reconstruction.
- Measuring production cross sections on “free” nucleons gives us a handle on nuclear absorption of final state particles.
- This will improve energy reconstruction for oscillation experiments.
- Nuclear models will be a dominant systematic uncertainty for precision oscillation experiments, so this is the frontier to improve!