Neutrino Oscillation and Long Baseline Experiments

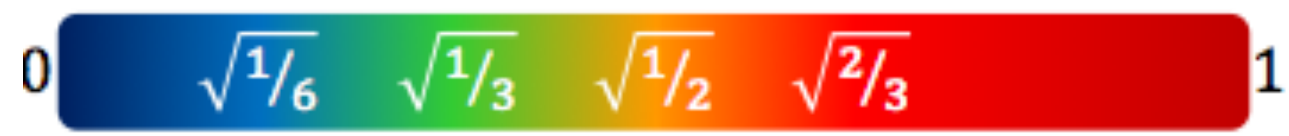
Why Neutrinos?

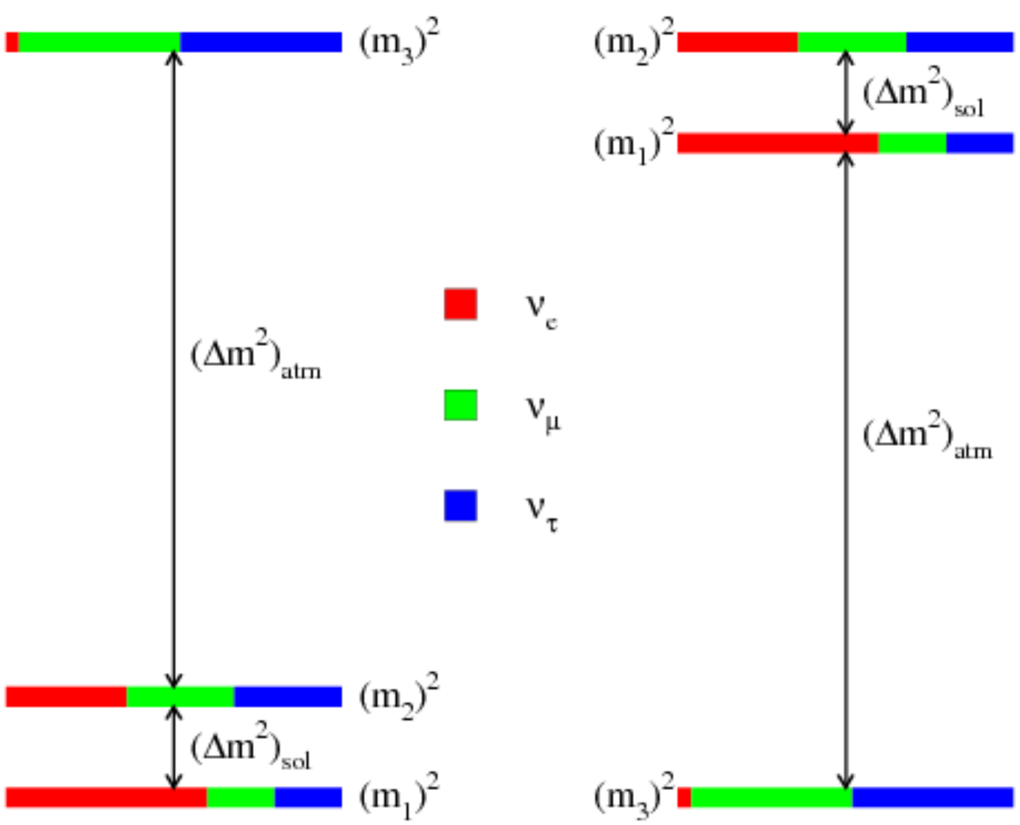
- Neutrino mass is a big piece of evidence of beyond-the-Standard-Model physics
- There are still many open questions about neutrino mass
  - Where does it come from? How does it relate to the Standard Model?
  - What does it mean for the early universe? Is it part of the matter-antimatter asymmetry puzzle?
- We need a full understanding of neutrino behavior to address these questions

Neutrino Mixing

Neutrinos have two sets of eigenstates: mass (propagation) and flavor (detection)

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$





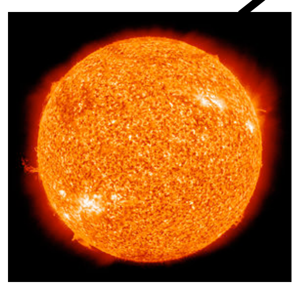
Normal Hierarchy Inverted Hierarchy

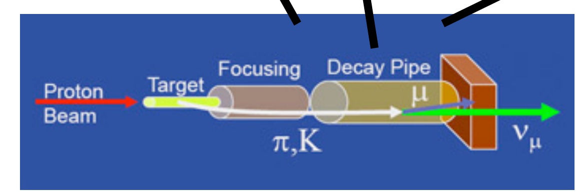
PMNS mixing matrix tells us how mass and flavor eigenstates are related

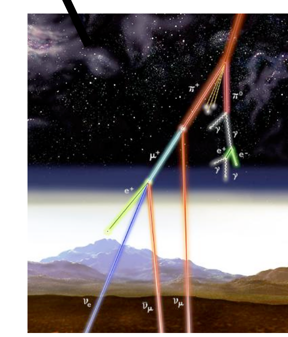
Neutrino Oscillation

$c_{ij}=\cos\theta_{ij}$ $s_{ij}=\sin\theta_{ij}$

$$\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}$$







Detection also depends on the mass splittings: $\sin^2\left(\frac{\Delta m^2 L}{E}\right)$ $\Delta m^2 = m_i^2 - m_j^2$

$\theta_{23}=47.1\pm1.6°$

$\theta_{12}=33.6\pm0.85°$

$\theta_{13}=8.49\pm0.14°$

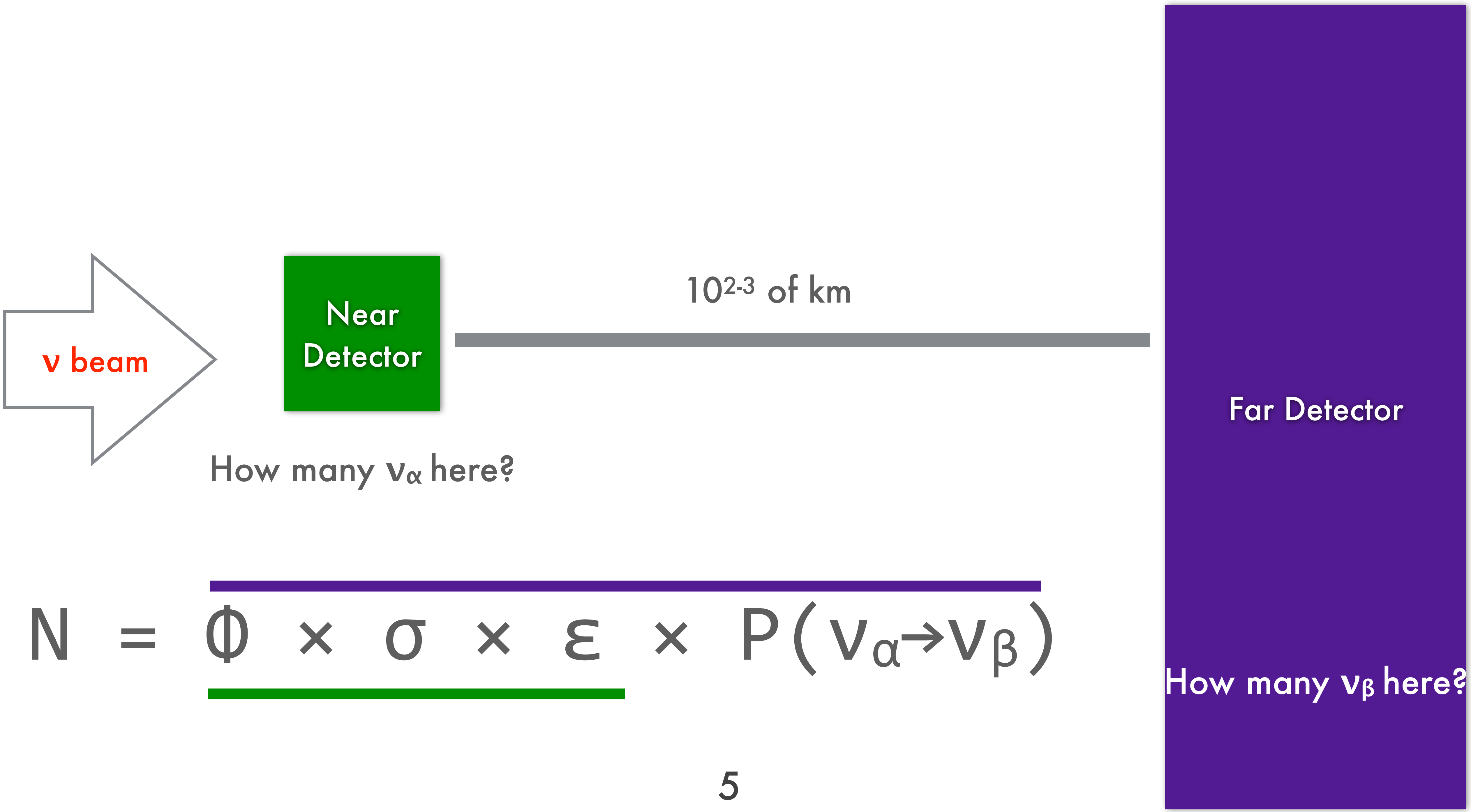
$\Delta m^2_{21} = 7.53\pm0.18\times10^{-5}\ \mathrm{eV}^2$

$|\Delta m^2_{32}| = 2.55\pm0.04\times10^{-3}\ \mathrm{eV}^2$

$\delta_{CP} = (1.37\pm0.18)\ \pi$

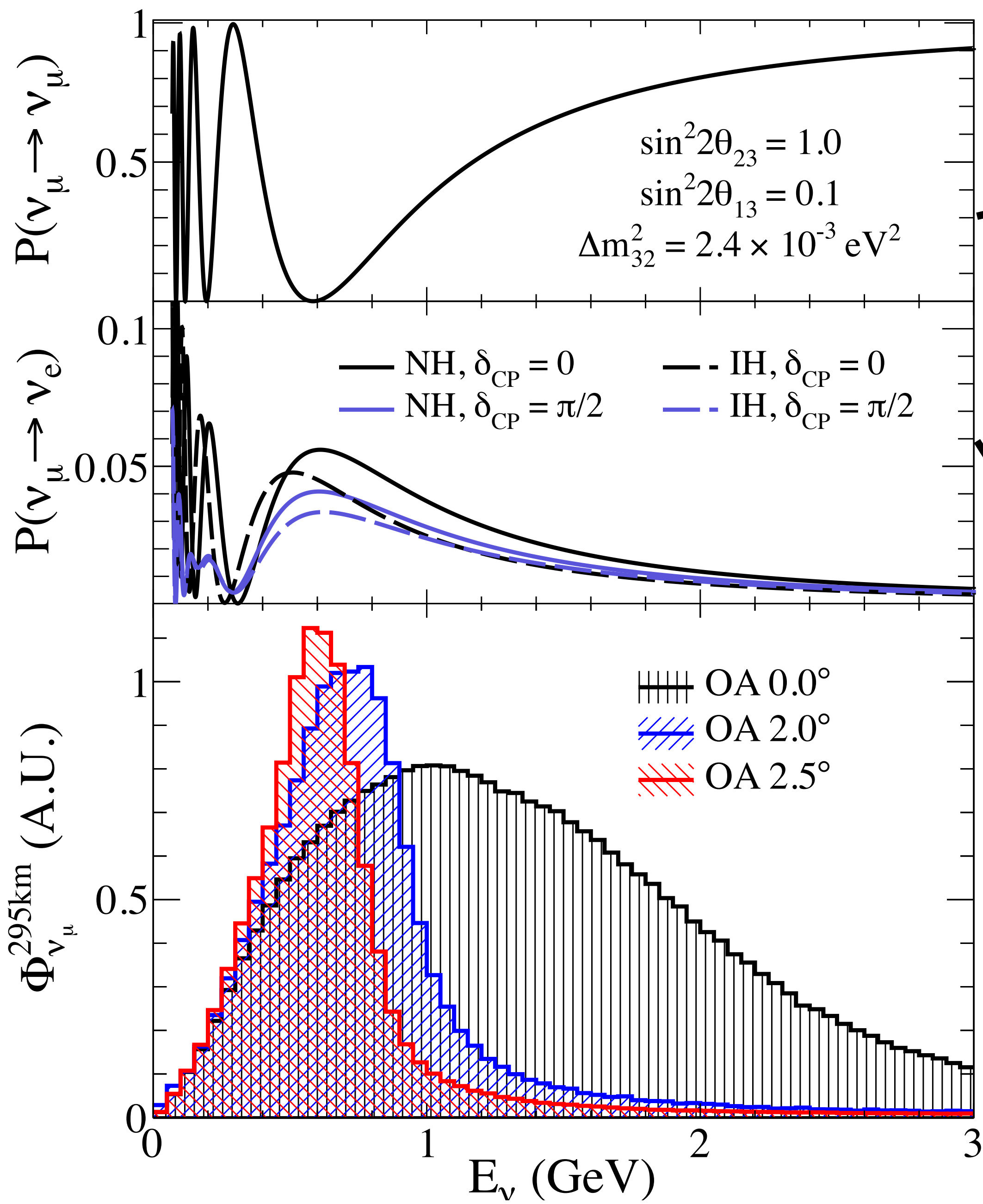
PDG 2020

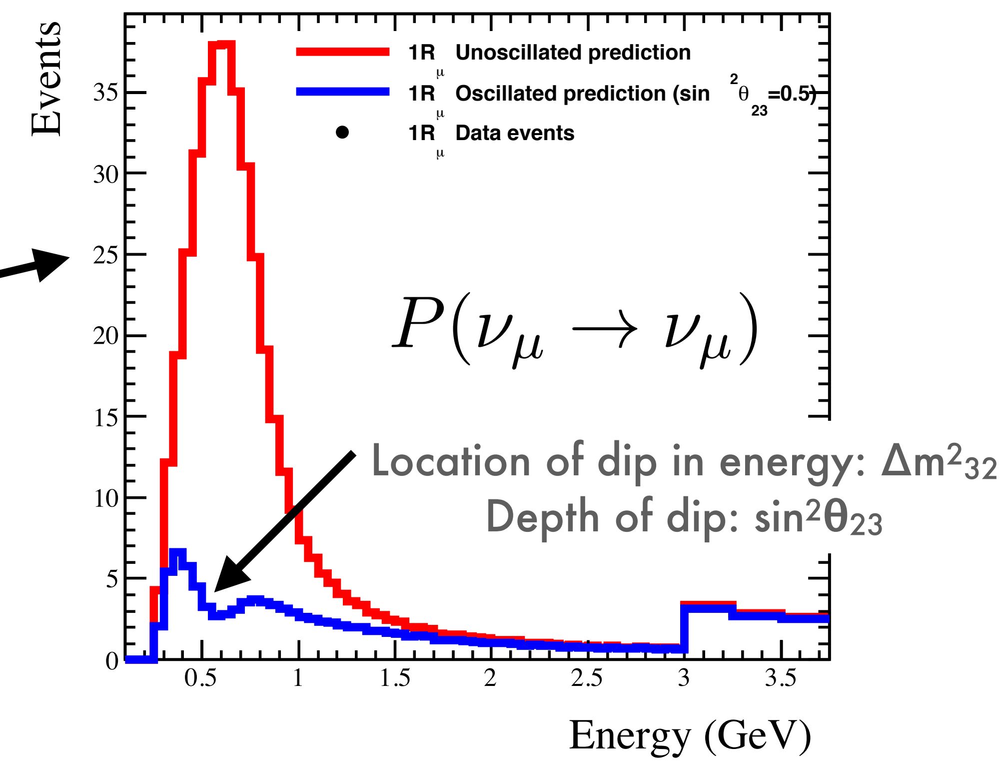
Oscillation Experiments in a Nutshell

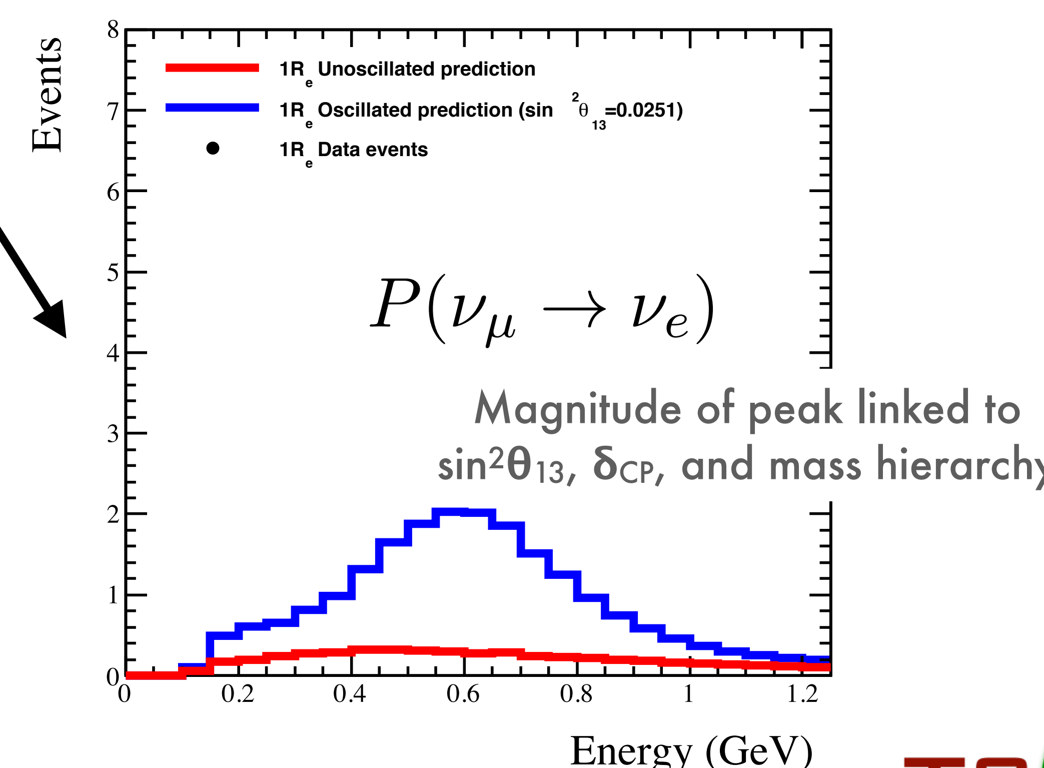


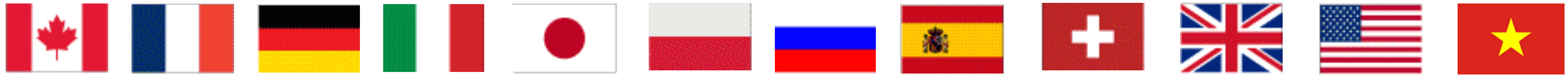
$$N = \underline{\Phi \times \sigma \times \varepsilon} \times P(\nu_\alpha \rightarrow \nu_\beta)$$

Long Baseline Neutrino Oscillation

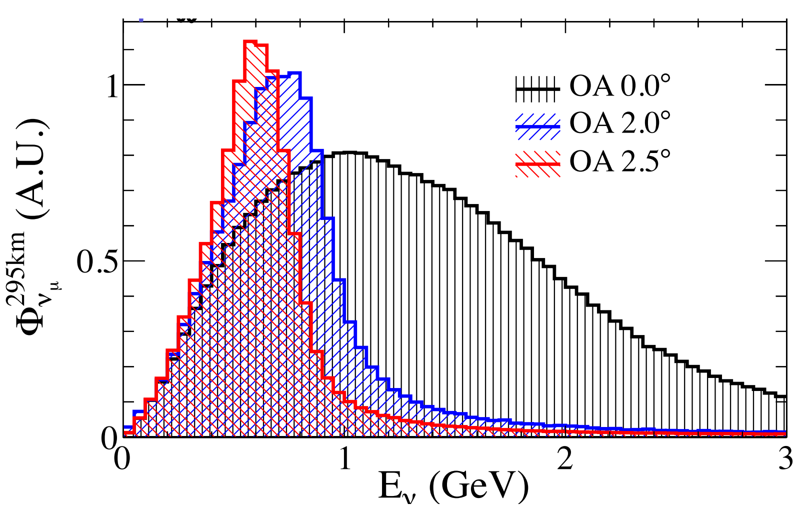


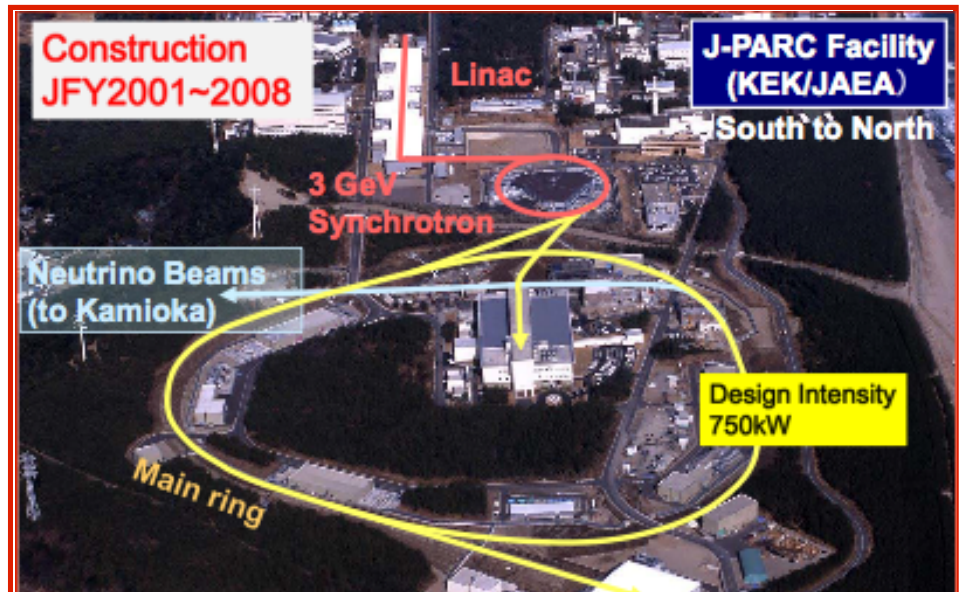




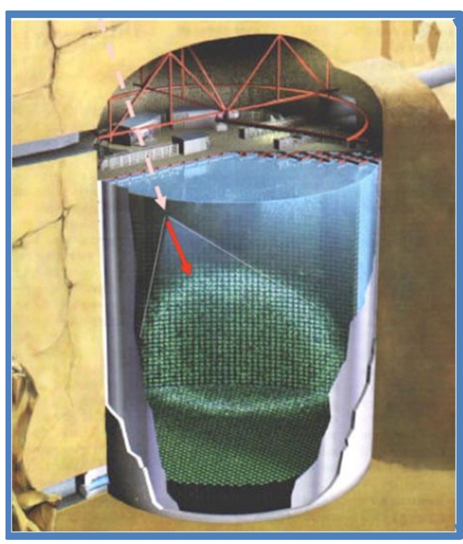


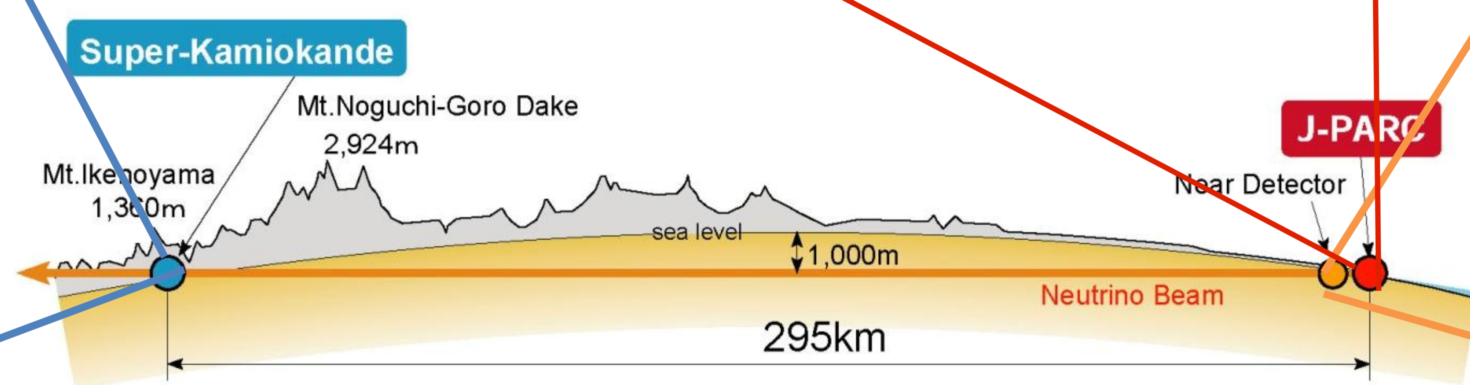
T2K

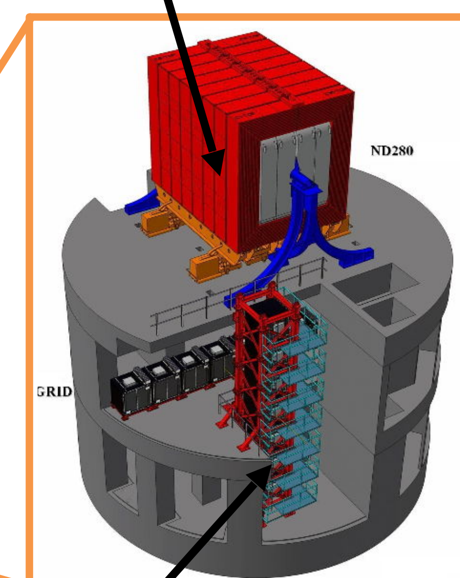




ND280

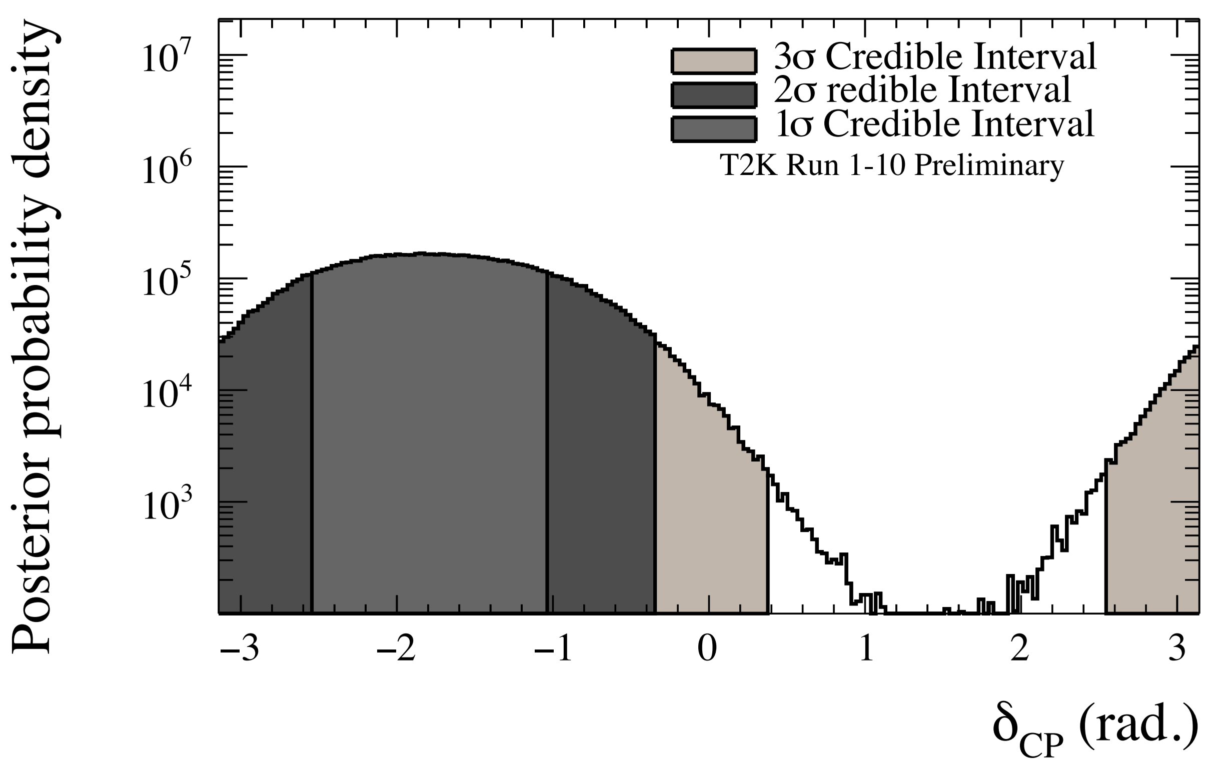






INGRID

Current World Status



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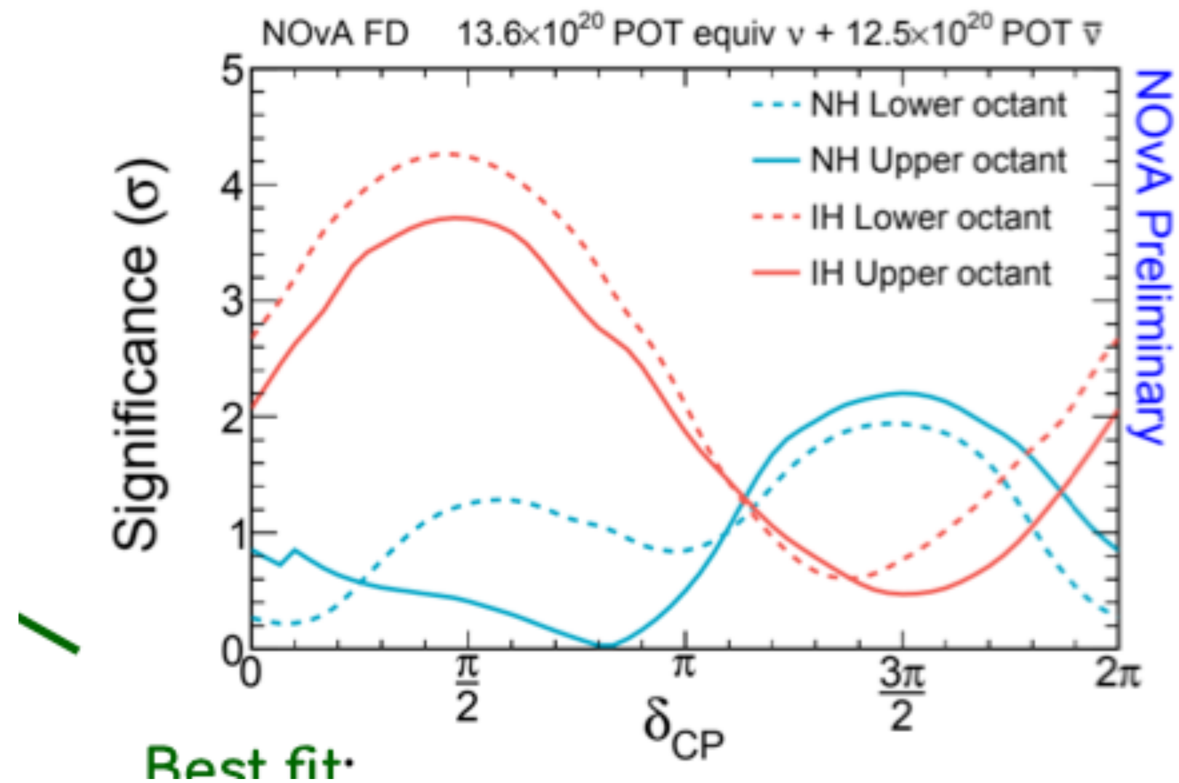
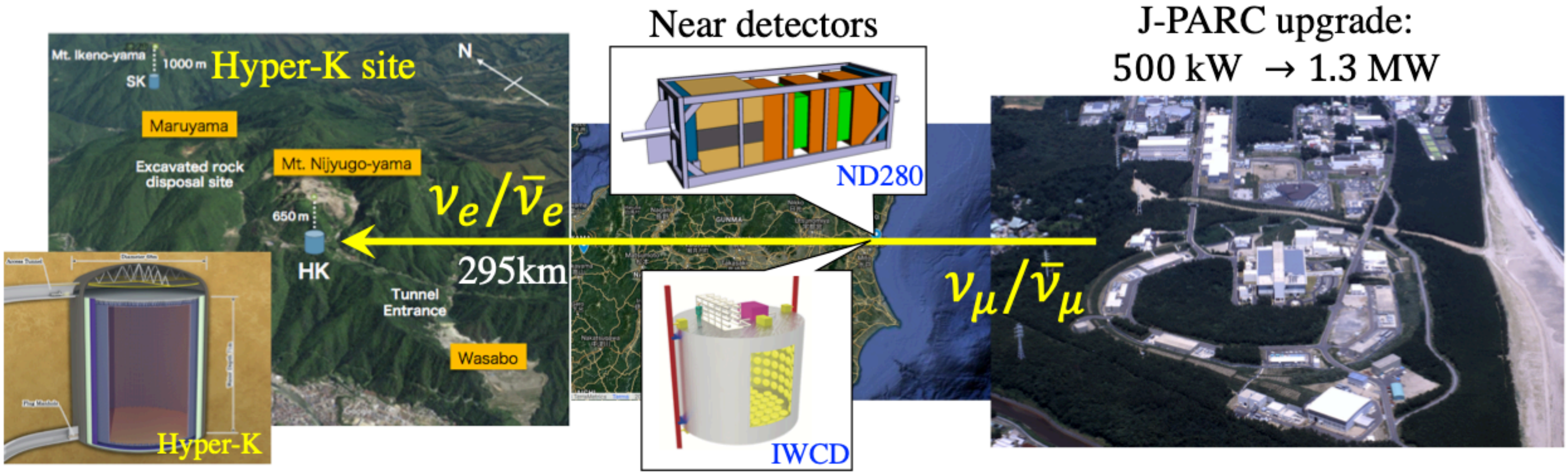


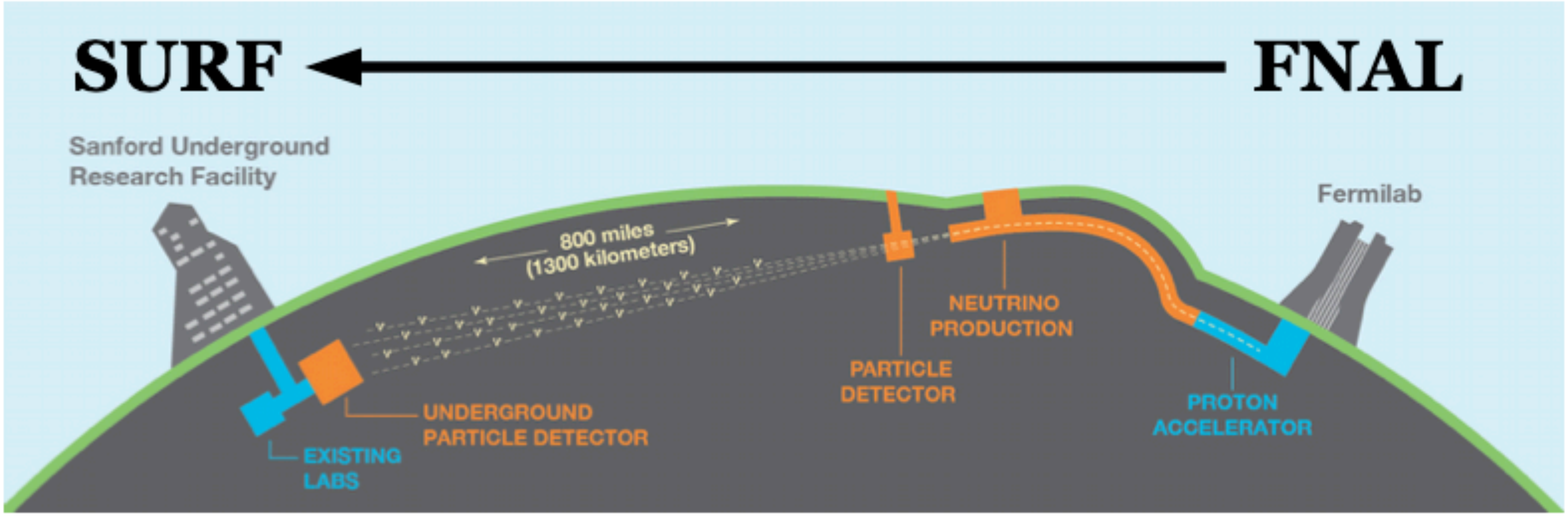
NOvA

Hyper Kamiokande

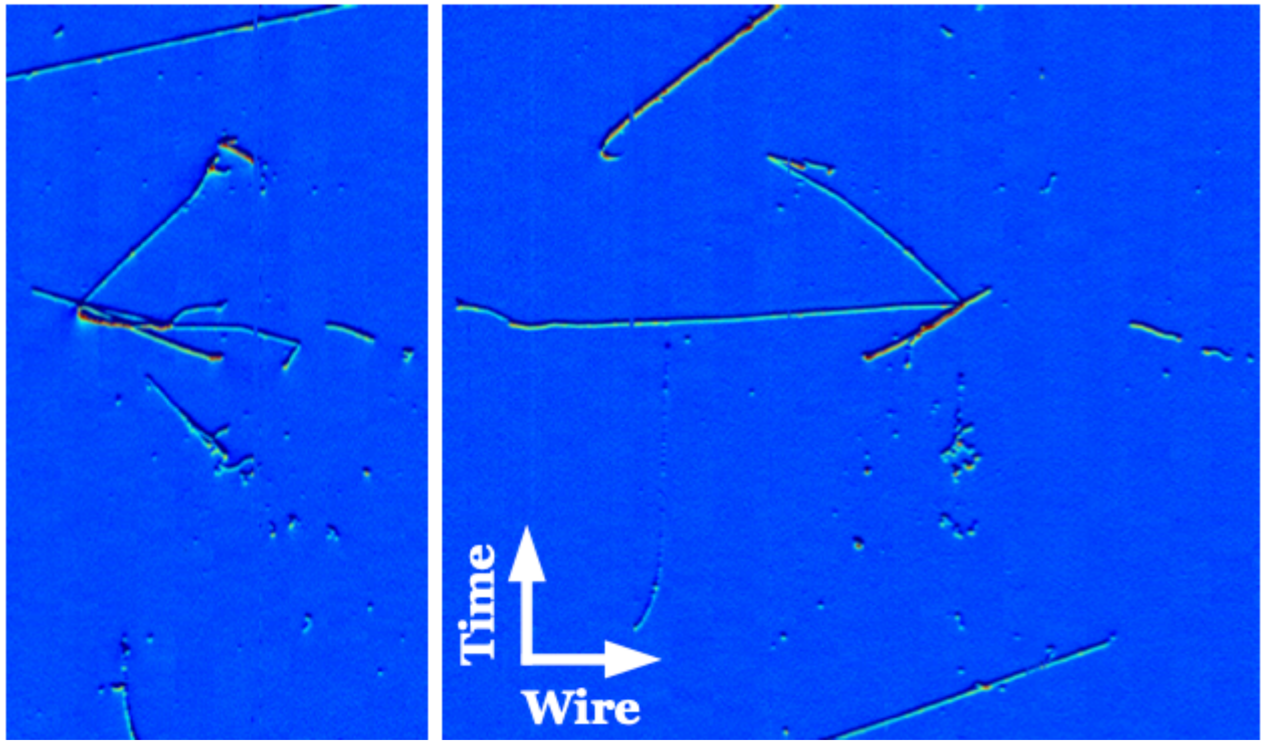


- Increase mass of far detector by 8x
- Increase beam power
- Increase near detector sensitivity

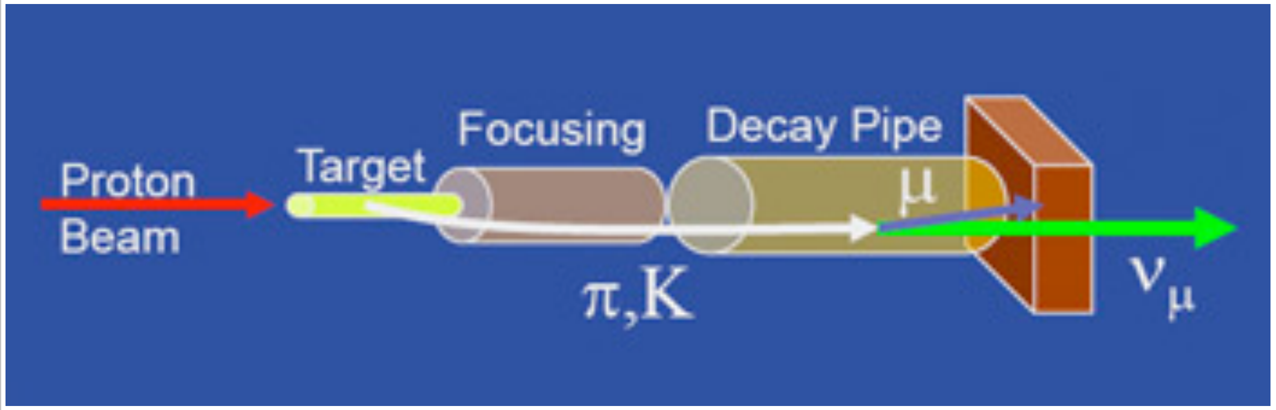
DUNE

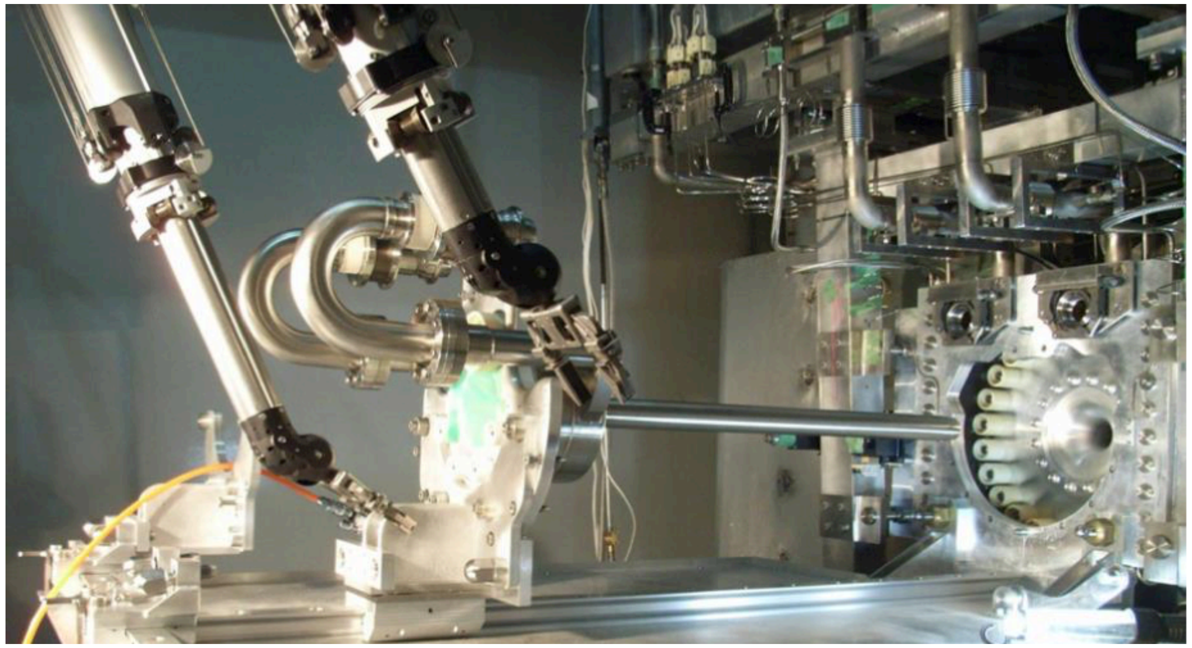


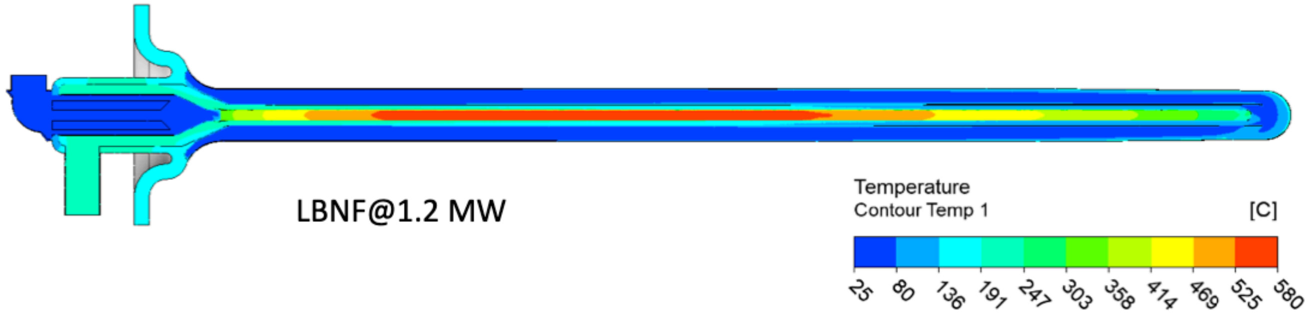
- New LAr technology allows for highly detailed event reconstruction
- Very long baseline useful for MH determination
- Very high beam power



What We Do: Beamlines



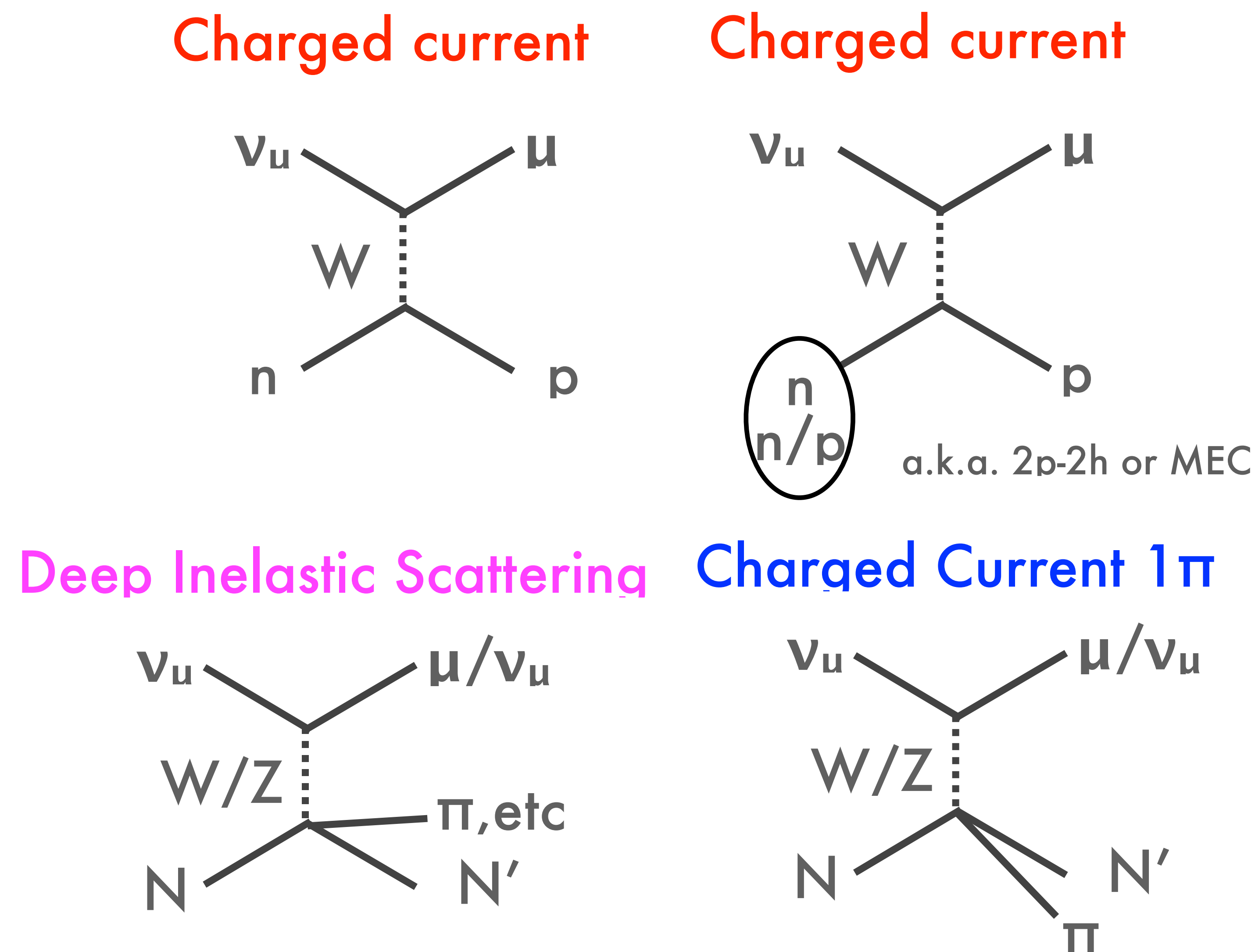


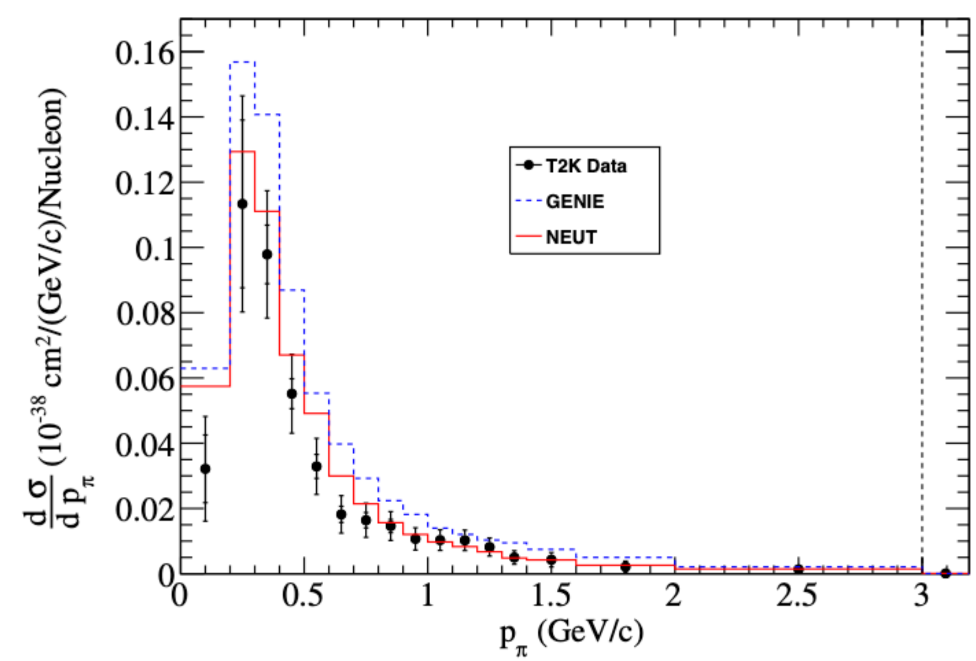


- Long history of building targets for neutrino beam lines
- Building DUNE target
- Developing upgrades for proton beam power

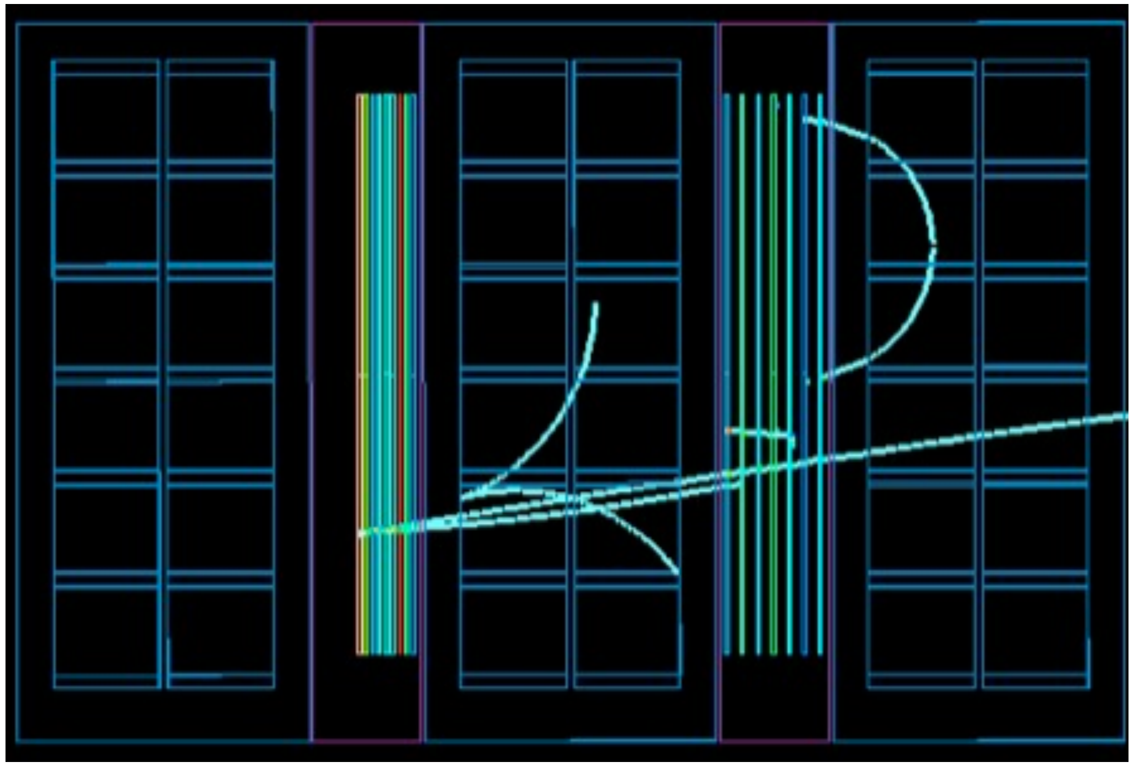
What We Do: Neutrino Interactions

- RAL leads and maintains one of the main simulation tools for neutrino interactions, called GENIE
- Link between theory and experimental communities
- Cross section uncertainties are the main source of oscillation systematic uncertainties





What We Do: DAQ

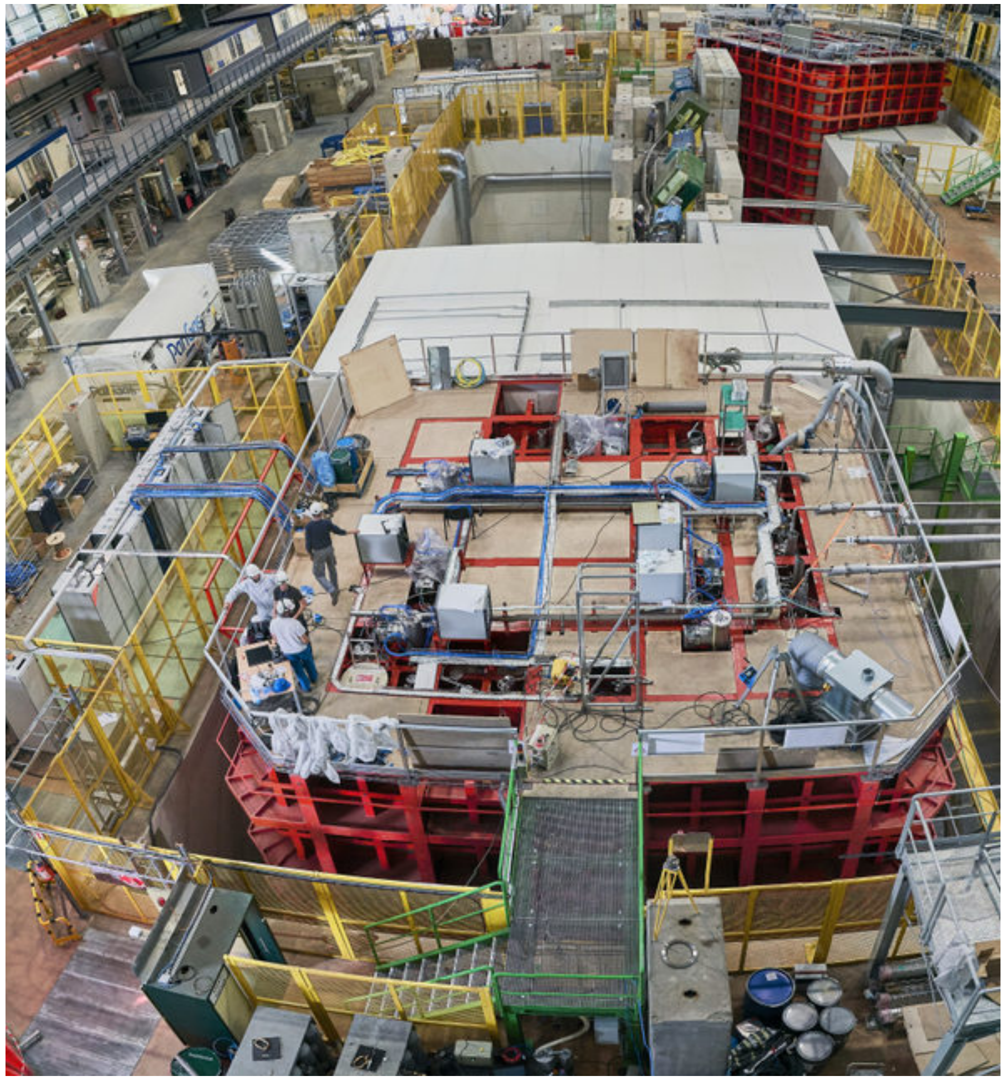


- The Data AcQuisition system is the brain of any detector: what data to take
- RAL has built & support the T2K DAQ
- Developing new methods and systems for both HK and DUNE

Project 1: DUNE


Alessandro Thea Asher Kaboth

- Project is focused on ProtoDUNE & other prototypes operating from 2022
- Develop control systems and monitoring for DAQ
- Analyze and interpret data from test beams
- Hands-on work at CERN and/or SLAC



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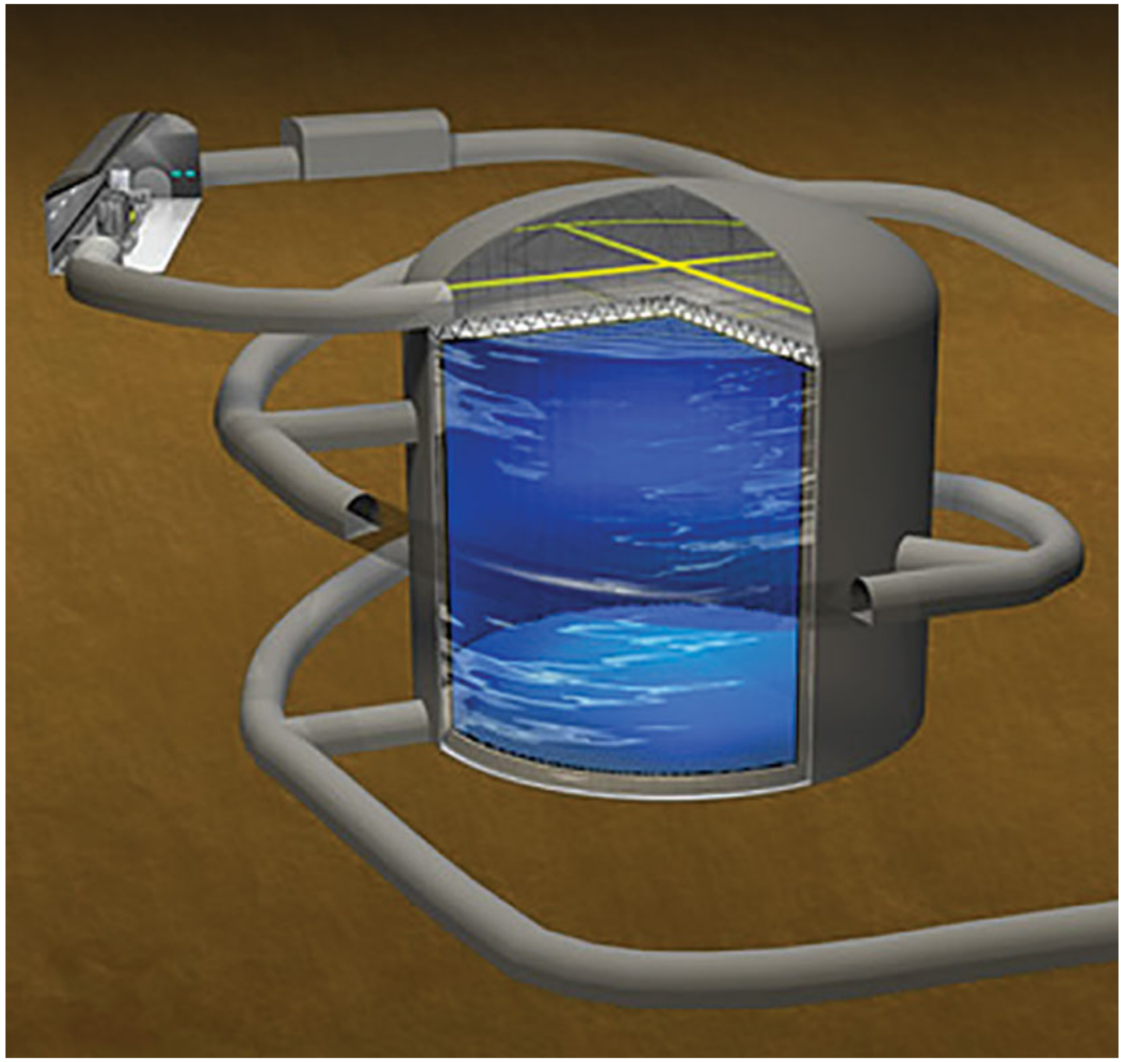
Project 2: HK



- Options open based on student interest
- Can work on the design and development of the HyperK OD (outer detector)
  - simulations and analysis
  - hardware work in the lab (e.g. PMT measurements)
- Work on SuperNova triggering and analysis

Both Projects

- First year at partner universities (RHUL and KCL) where students will take University of London lecture series
- Located at RAL for the remainder of the PhD
- Opportunity for LTA at experimental sites: J-PARC, CERN, FNAL

Conclusions

- Neutrino physics is an exciting front in BSM physics
- RAL has a huge hand in current and future long baseline experiments
- Exciting opportunities at RAL