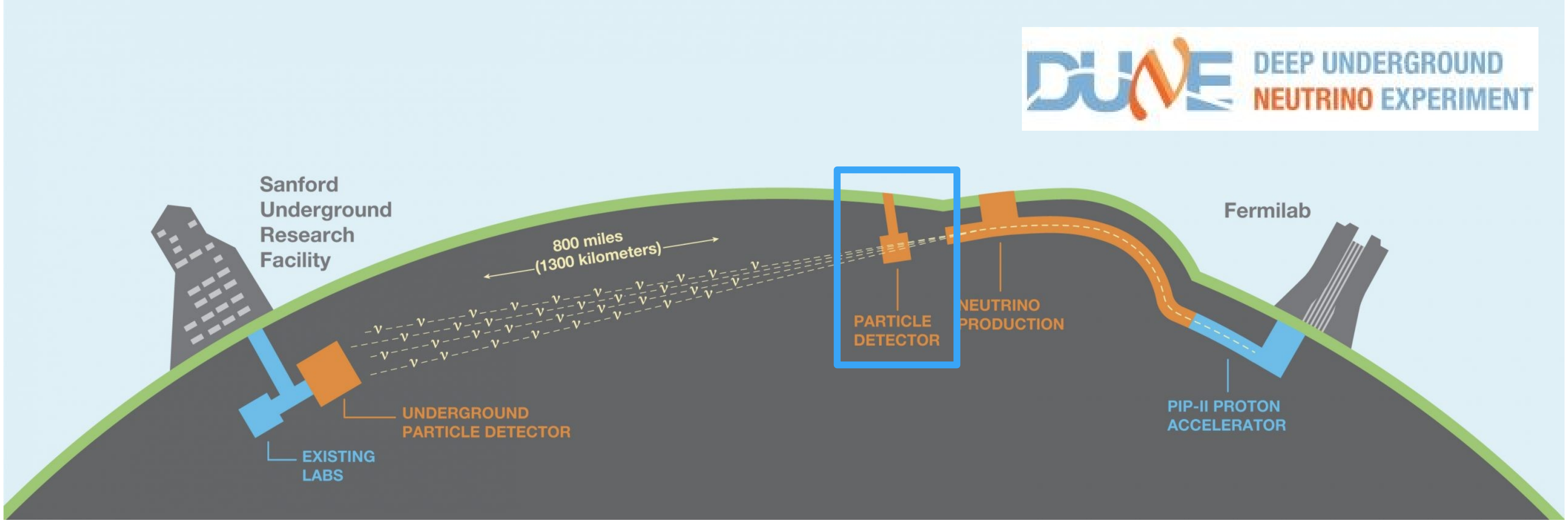


The DUNE Near Detector

Daniel Cherdack, University of Houston

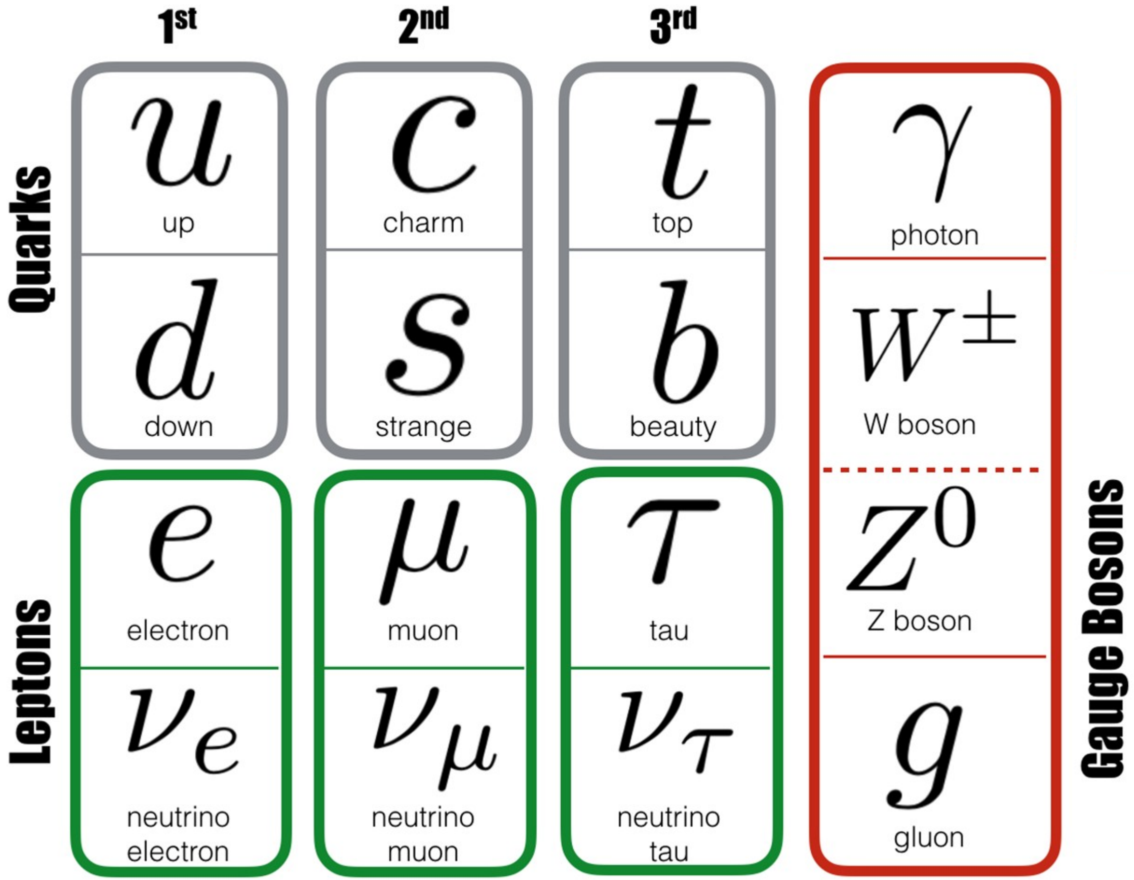
on behalf of the **DUNE Collaboration**

Lake Louise Winter Institute

Thursday June 20th, 2019

UNIVERSITY of HOUSTON

Mixing Between Weak Flavor and Mass Eigenstates



- For most interactions the incoming and outgoing particles are the same flavor
  - Gravitational
  - Electromagnetic
  - Strong
- For Weak interactions the incoming and outgoing particles are weak isospin pairs
- Differences between Weak Flavor and Mass eigenstates also allow for apparent mixing between isospin pair families
- This mixing is described by the:
  - CKM Matrix (quarks)
  - PMNS Matrix (leptons)

The Mixing Matrices

The CKM Matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_J = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_M$$

The PMNS Matrix

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

- For most interactions the incoming and outgoing particles are the same flavor
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The Mixing Matrices: Relative Element Sizes

Quarks

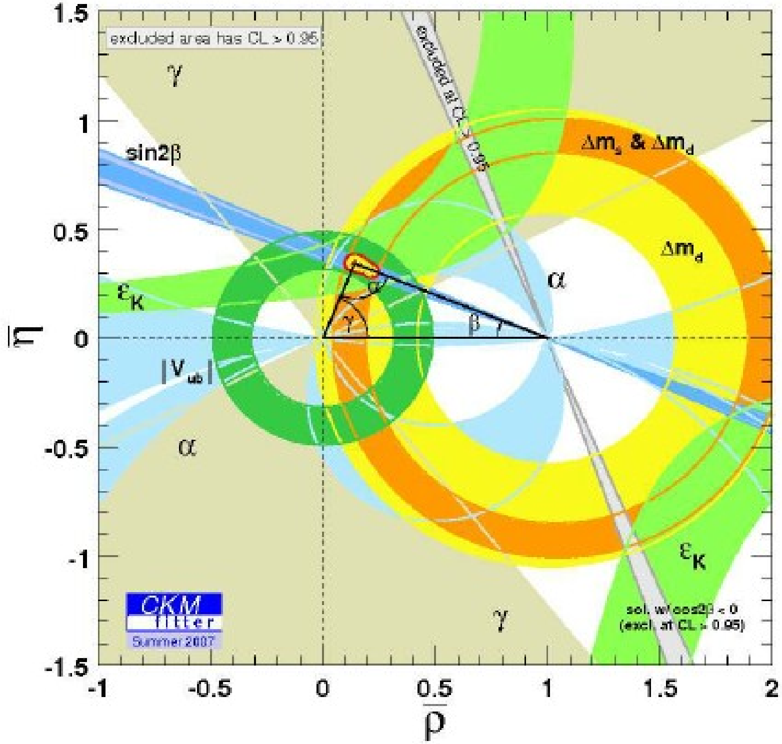
V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

Leptons

U_{e1}	U_{e2}	U_{e3}
$U_{\mu1}$	$U_{\mu2}$	$U_{\mu3}$
$U_{\tau1}$	$U_{\tau2}$	$U_{\tau3}$

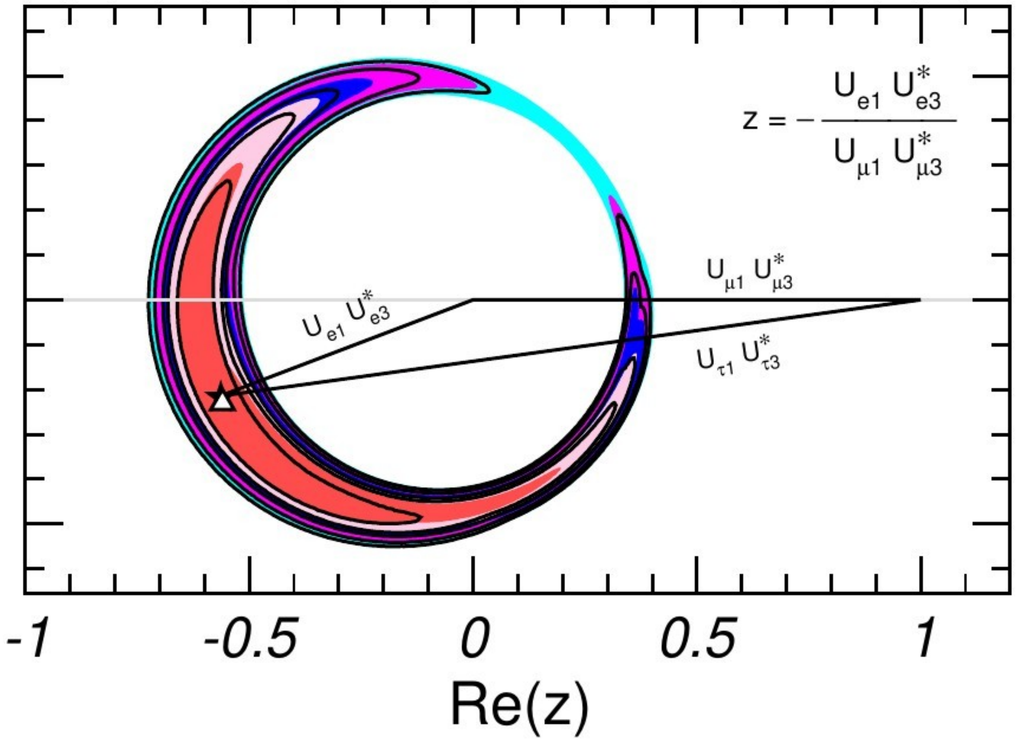
The Mixing Matrices: Unitarity

Quarks

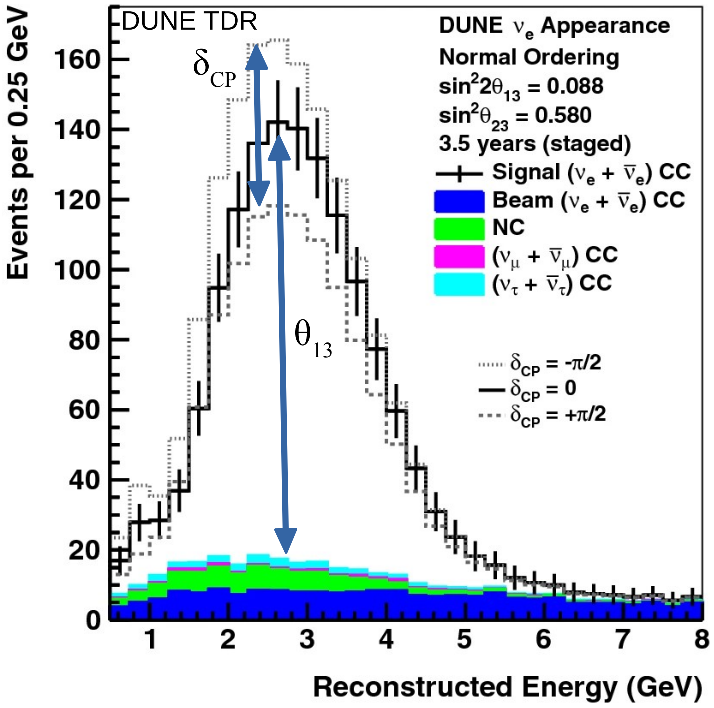


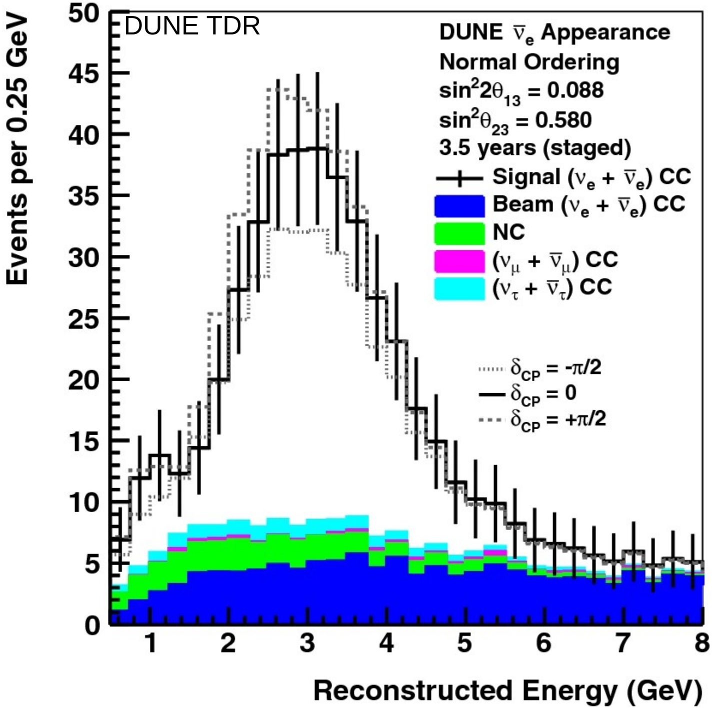
Leptons

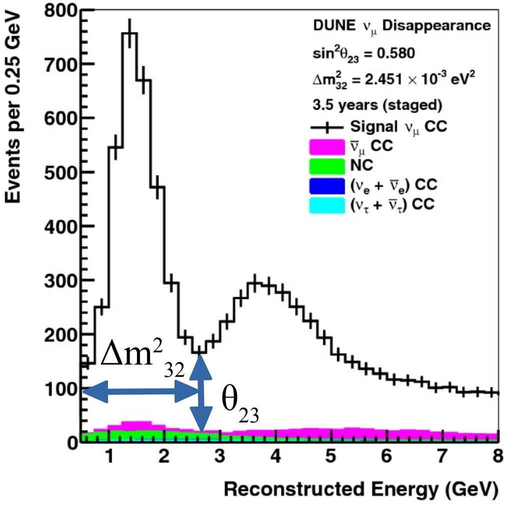
NuFit5.0



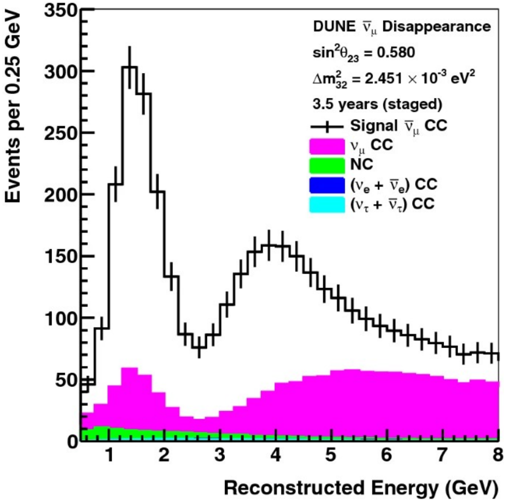
Predicting the Neutrino Event Rate







DUNE TDR



$$N_{pred}(E_\nu^{reco}) = \Phi(E_\nu^{true})\, \sigma(E_\nu^{true})\, P(\alpha \rightarrow \beta, E_\nu^{true})\, \epsilon(E_\nu^{reco})\, S(E_\nu^{true}, E_\nu^{reco})$$

Predicting the Neutrino Event Rate

$$N_{pred}(E_\nu^{reco}) = \Phi(E_\nu^{true})\ \sigma(E_\nu^{true})\ P(\alpha \to \beta, E_\nu^{true})\ \epsilon(E_\nu^{reco})\ S(E_\nu^{true}, E_\nu^{reco})$$

What we measure:

- $N_{pred}(E_\nu^{reco})$ = Expected number of events

Measure with a near detector:

- $\Phi(E_\nu^{true})$ = Neutrino flux
- $\sigma(E_\nu^{true})$ = Interaction cross sections

Physics of interest:

- $P(\alpha \to \beta, E_\nu^{true})$ = Oscillation probability

Detector Effects:

- $\epsilon(E_\nu^{true})$ = Selection efficiency
- $S(E_\nu^{true}, E_\nu^{reco})$ = Smearing matrix

Predicting the Neutrino Event Rate

$$N_{pred}\left(E_\nu^{reco}\right) = \Phi\left(E_\nu^{true}\right)\,\sigma\left(E_\nu^{true}\right)\,P\left(\alpha\rightarrow\beta, E_\nu^{true}\right)\,\epsilon\left(E_\nu^{reco}\right)\,S\left(E_\nu^{true}, E_\nu^{reco}\right)$$

$$N_{pred}\left(E_\nu^{reco}\right)$$

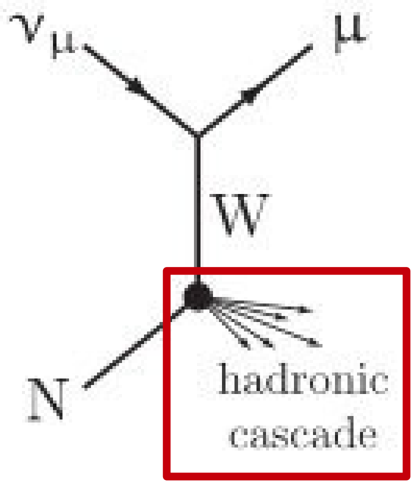
Measure with a near detector

$$\Phi\left(E_\nu^{true}\right)$$
$$\sigma\left(E_\nu^{true}\right)$$

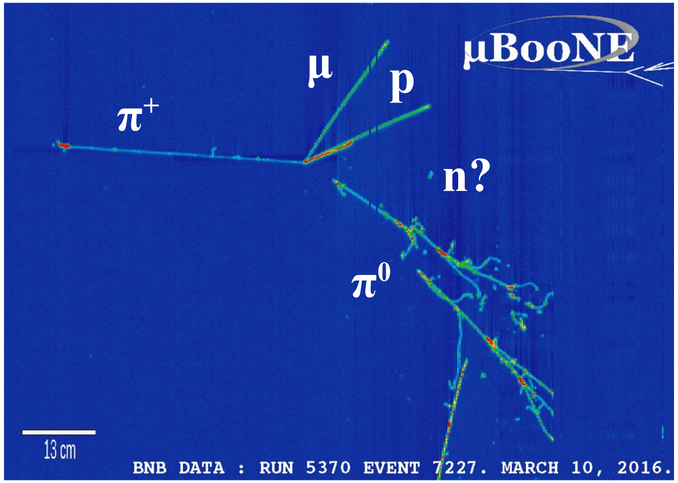
$$P\left(\alpha\rightarrow\beta, E_\nu^{true}\right)$$

Highly Dependent on Hadronic System

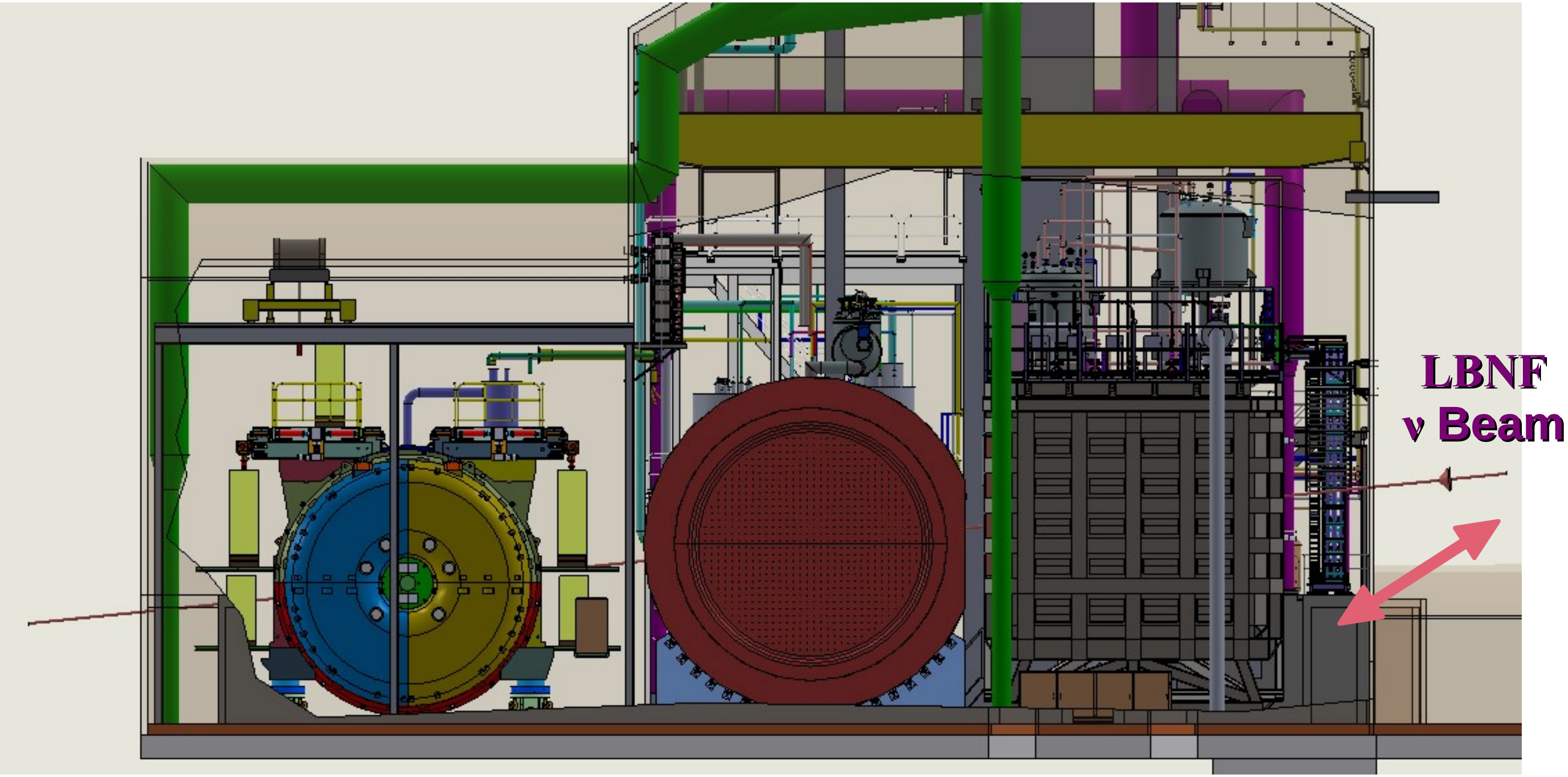
$$\epsilon\left(E_\nu^{true}\right)$$
$$S\left(E_\nu^{true}, E_\nu^{reco}\right)$$

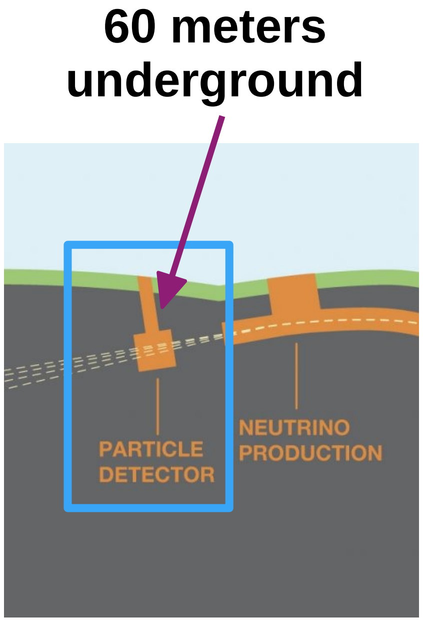


QCD!



The DUNE ND Complex (CDR Reference Design)





SAND
System for On-Axis Neutrino Detection

ND-GAr
Magnetized Gaseous Argon TPC

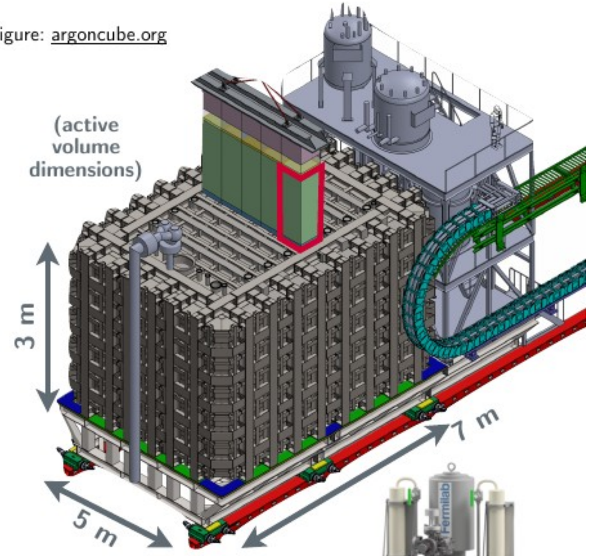
ND-LAr
Modular Liquid Argon TPC

PRISM
30m Off-Axis Mobility for LAr + Spectrometer

ND-LAr Modular TPC (ArgonCube)

- Design
  - Same liquid argon target as the DUNE FD
  - Modular design: 35 1×1×3 m^3 modules with two TPCs per module (50 cm drift)
  - Charge readout: LArPix pixel readout for direct-to-3D charge information
  - Light readout: High (~40%) detector coverage with ns-scale timing and cm-scale position
- Physics
  - High-statistics ν interactions in LAr TPC
  - ~30M accepted ν_μ CC events/year (FHC / ν mode, 1.2 MW beam)
  - Constrain flux via ν+e elastic scattering and "low-ν" method
  - Precise constraints on event rates (flux × cross sections) in LAr

Figure: argoncube.org



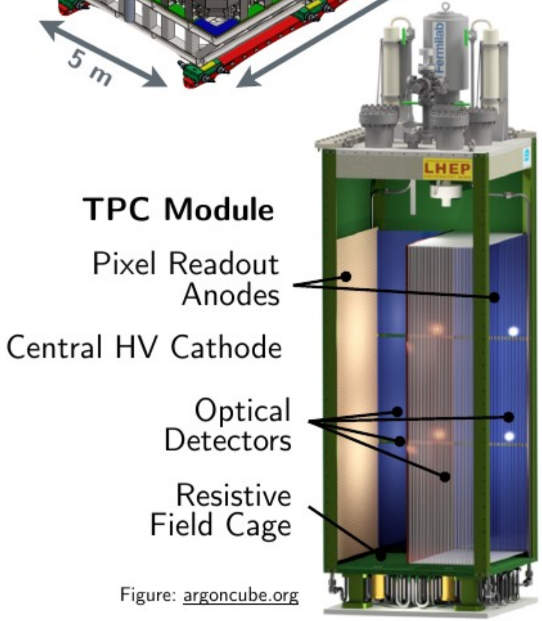
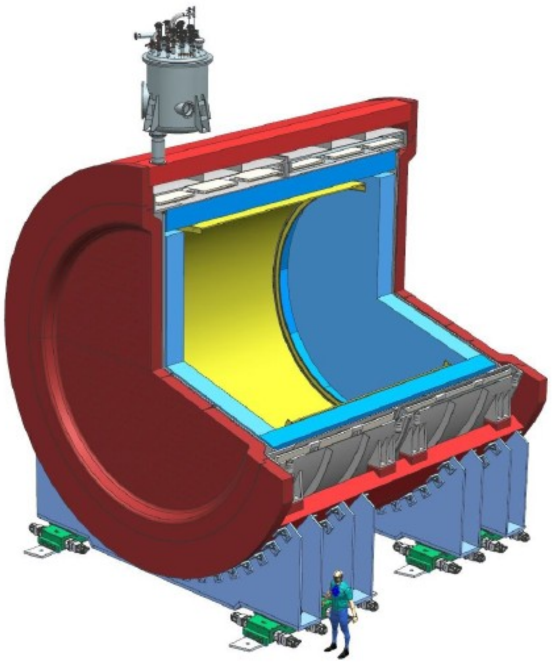
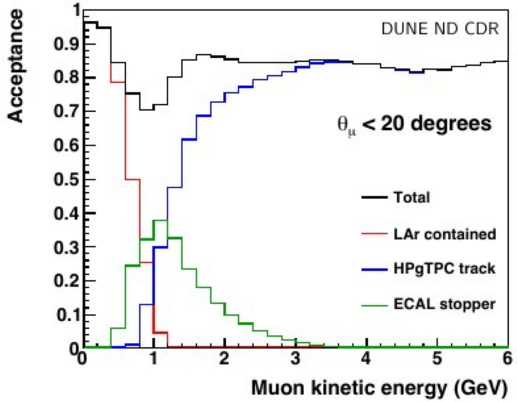


Figure: argoncube.org

ND-GAr Magnatized TPC

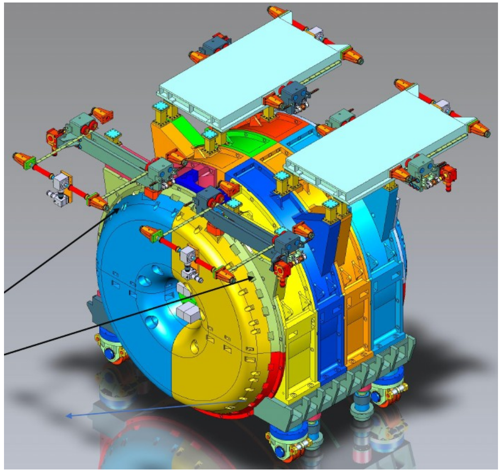
- Design
  - Same Ar target at the DUNE FD (and ND-LAr)
  - High-pressure (10 bar)
  - TPC surrounded by EM calorimeter and superconducting magnet
  - May need to wait for Phase II; Temporary Muon Spectrometer (TMS) until then (magnetized planes of Fe & scintillator)
- Physics
  - Spectrometer for tracks that exit ND-LAr: track sign and momentum (TMS can still do this)
  - ν-Ar interactions with low thresholds: better understand the hadronic system details
  - Excellent particle ID: study details of exclusive final states
  - Fine tuning of cross section systematic errors



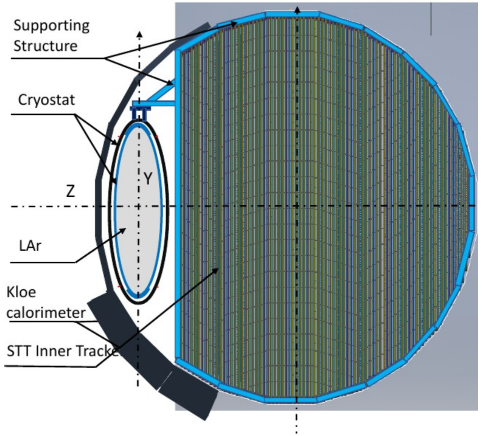


SAND: System for On-Axis Neutrino Detection

SAND Consortium

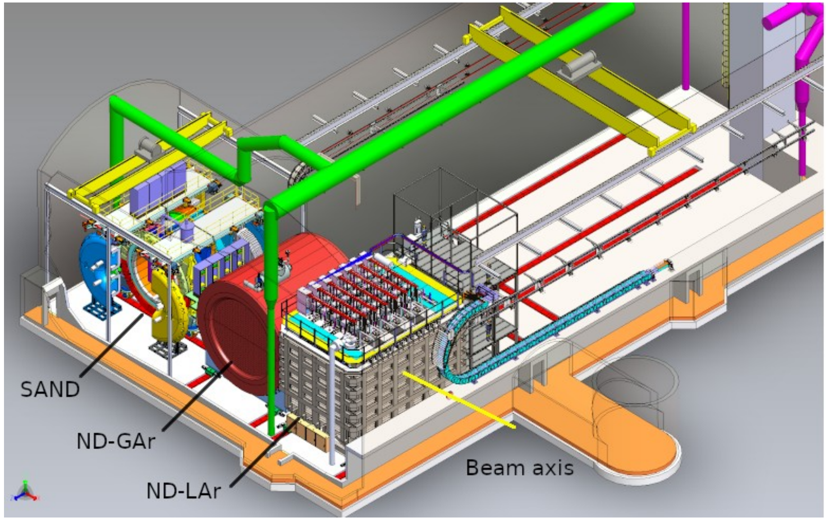


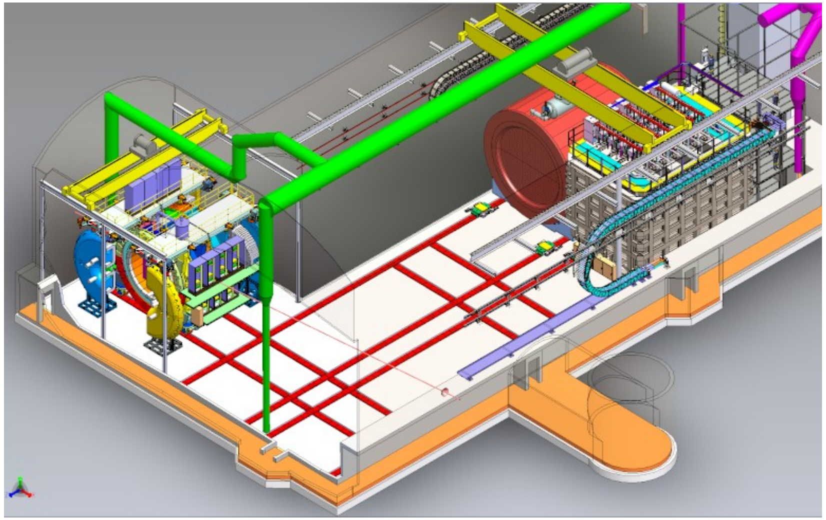
- Design
  - Fixed on-axis position
  - LAr TPC Target + STT + Ecal + solenoid magnet
  - Ecal and Magnet repurposed from KLOE Experiment
- Physics
  - Continuous monitoring of the on-axis flux: able to provide detailed flux stability measurements on a ~weekly basis
  - STT provides CH and C targets for comparison with world cross section data (mostly CH) and H cross sections via subtraction
  - Ar events provide ND-LAr cross check



PRISM

- Design
  - System for moving the LAr TPC + tracker up to 30 m transverse to the beam direction
  - Enables scan of beam at multiple off-axis positions
- Physics
  - Beam energy spectrum changes with off-axis position
  - Peak energy is reduced; peak width narrows
  - Use statistical subtraction to measure cross sections in a narrow incoming neutrino energy range
  - Better control of hadronic physics with constrained incoming neutrino energy
  - Direct use of ND data in oscillation analysis: shifts cross section uncertainties to flux uncertainties





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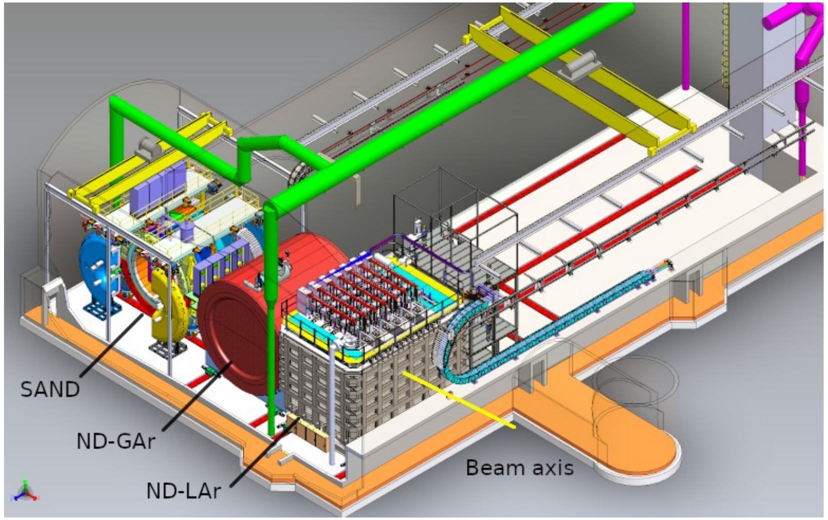
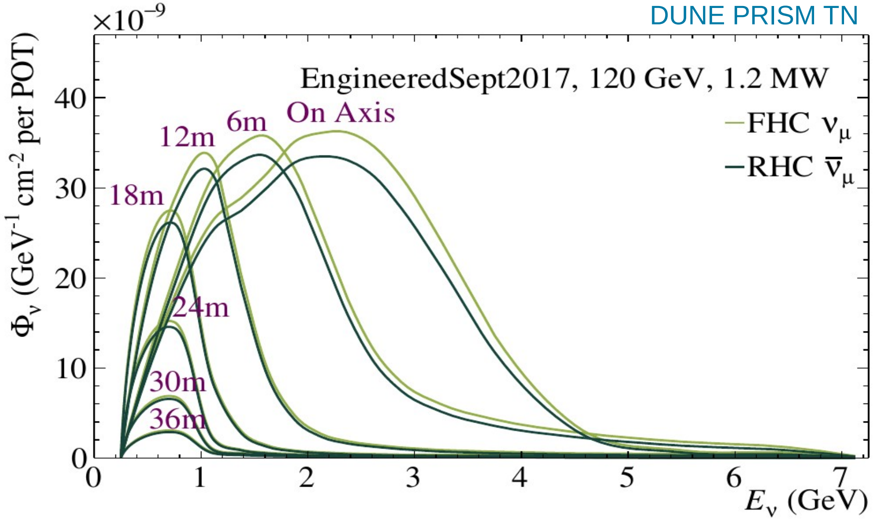
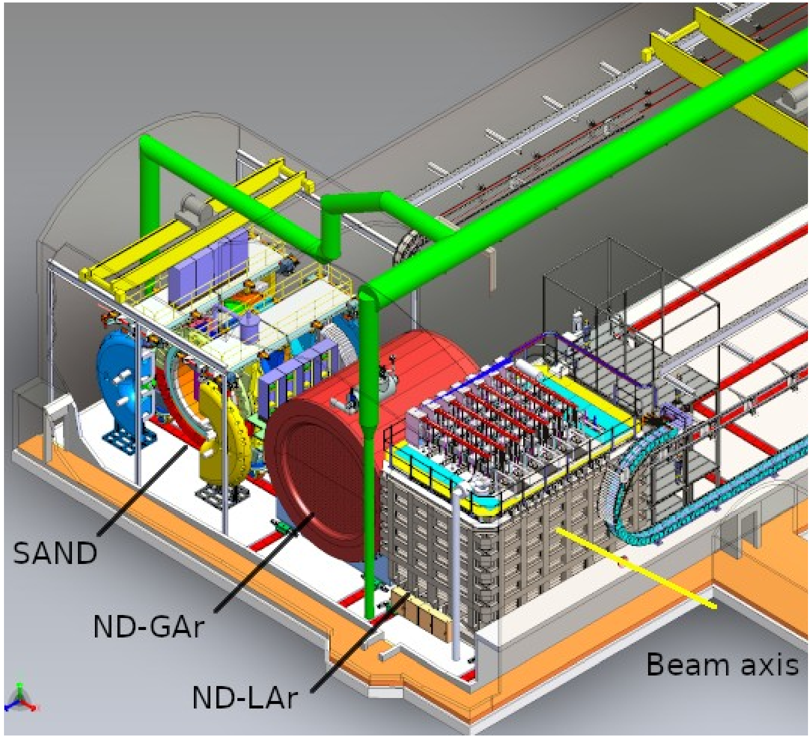




DUNE ND Complex Summary

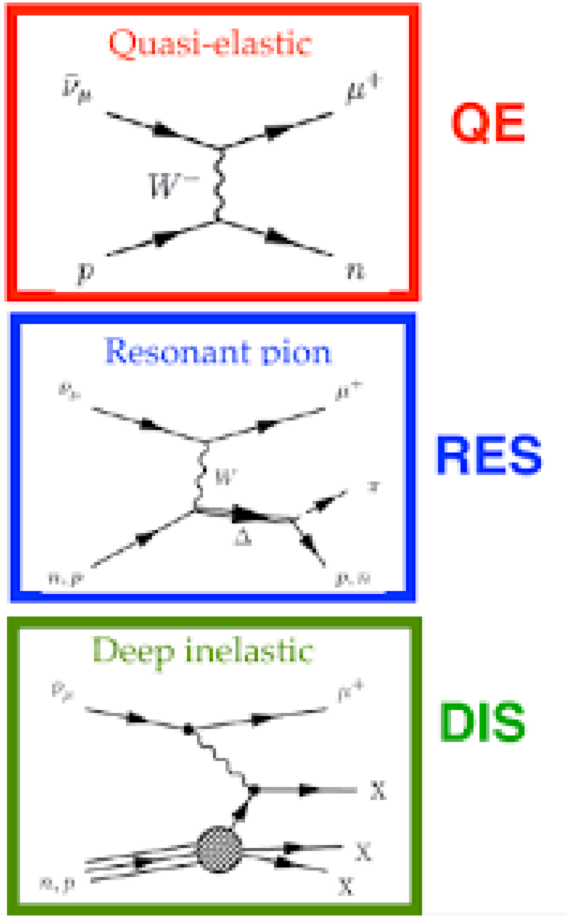
- Multi-detector design
- Liquid Argon TPC
  - Similar technology to the FD
  - Design changes to handle high rates
- Downstream Spectrometer
  - Measures momentum and charge of exiting tracks
  - Will eventually be a GAr TPC able to measure hadronic shower details
- On-axis beam monitor
  - Ensure stable beam operations
  - Contribute physics measurements and crosschecks
- Off-axis measurements from PRISM
  - Enables statistical constraints of incoming neutrino energy
  - Paradigm shifting oscillation measurement technique

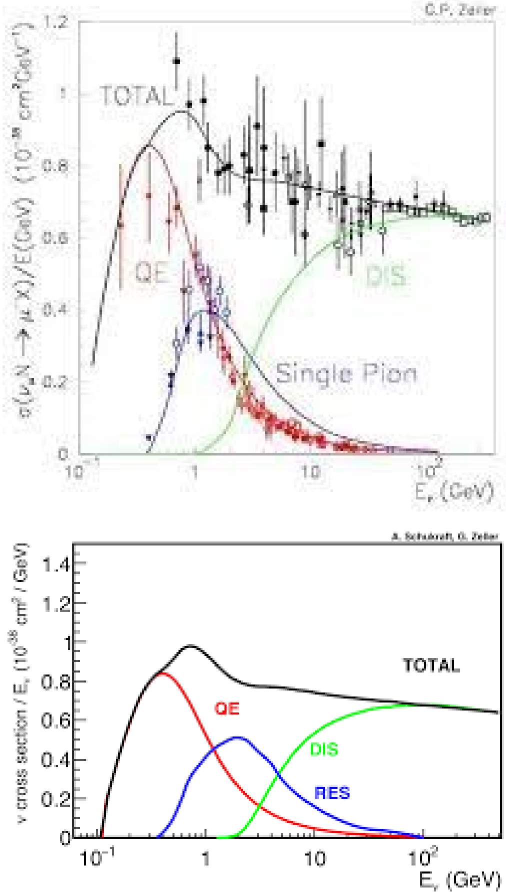


Thank You

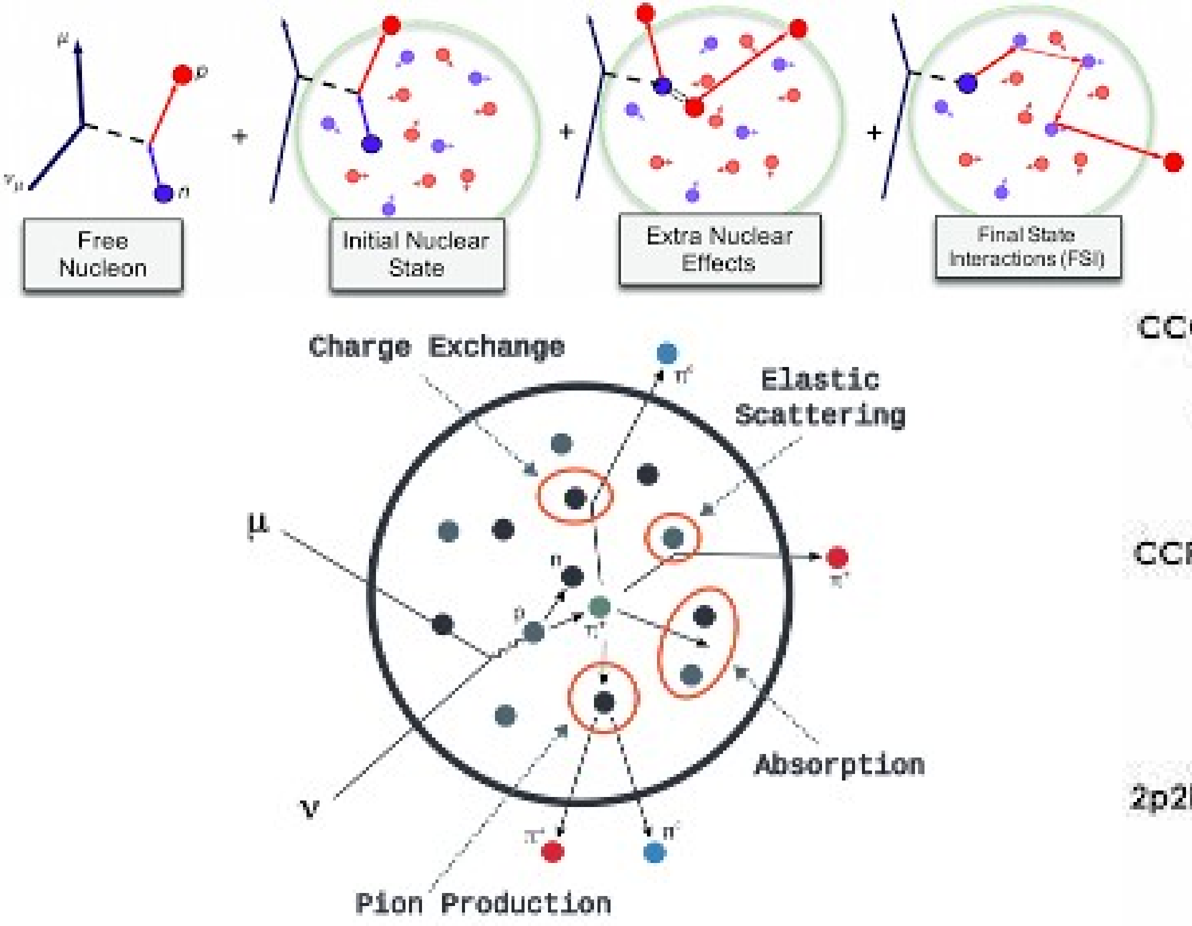
Questions?

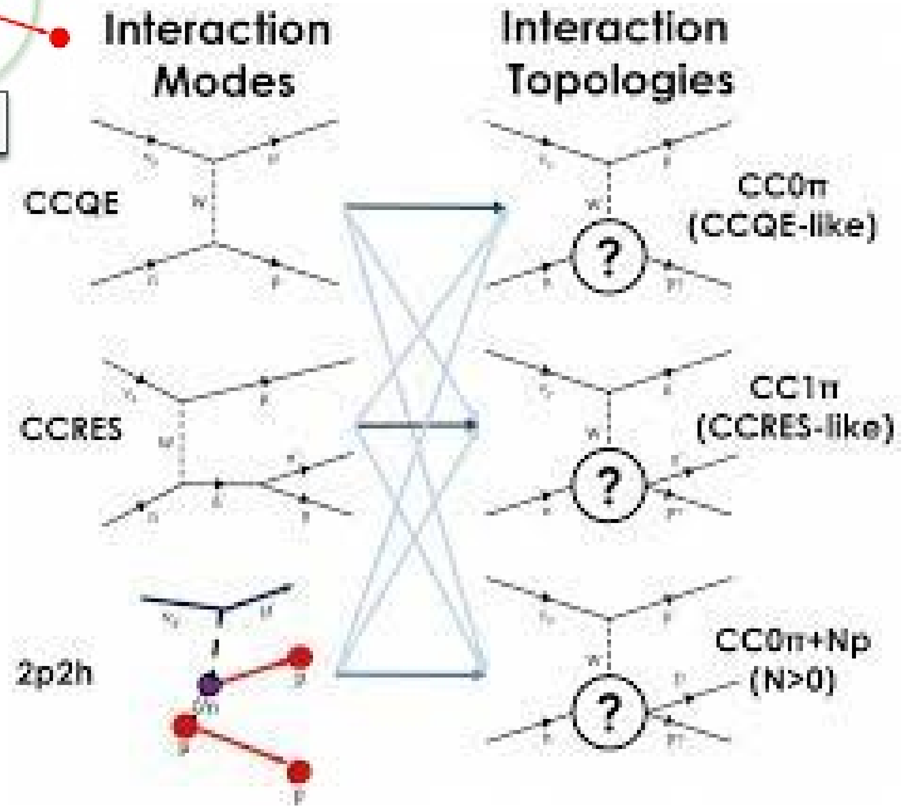
Understanding ν Cross Sections



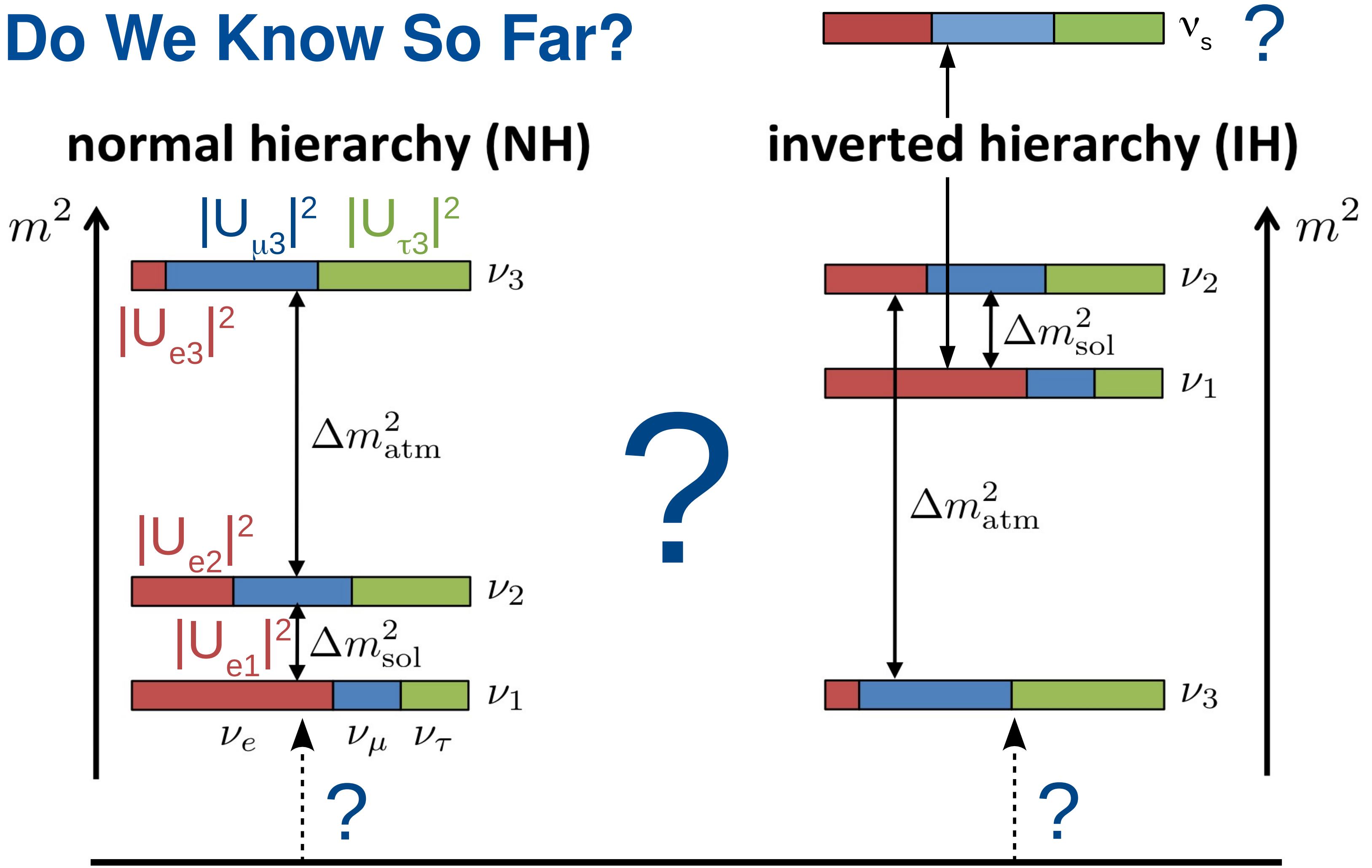


Understanding ν Cross Sections





What Do We Know So Far?



DUNE ND R&D

ND-LAr

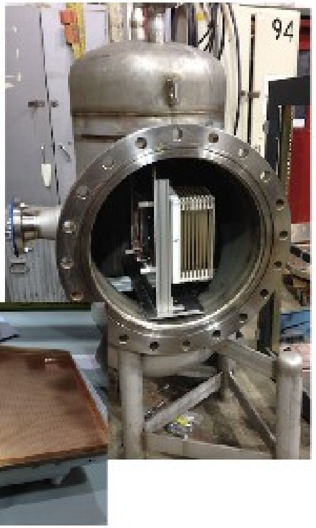
- Tested ~70% scale module
- 2×2 ν beam test @ FNAL
- Full-scale tests to follow

Module-0 @ Bern

ND-GAr

- R&D gas TPCs @ FNAL (IROC) and RHUL (OROC)
- Gas, HV tests underway in dedicated HPgTPCs

HPgTPC @ FNAL



ALICE IROC

SAND

- 3DST beam tests @ CERN
- US-Japan joint prototyping efforts underway

US-Japan prototypes

CERN tests

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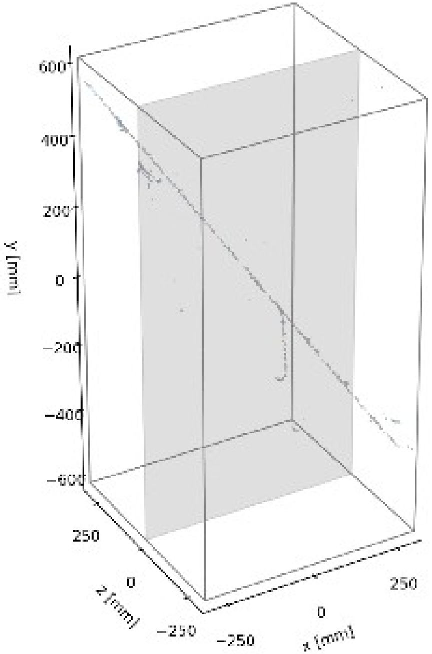

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