NuSTEC and DUNE Preparations

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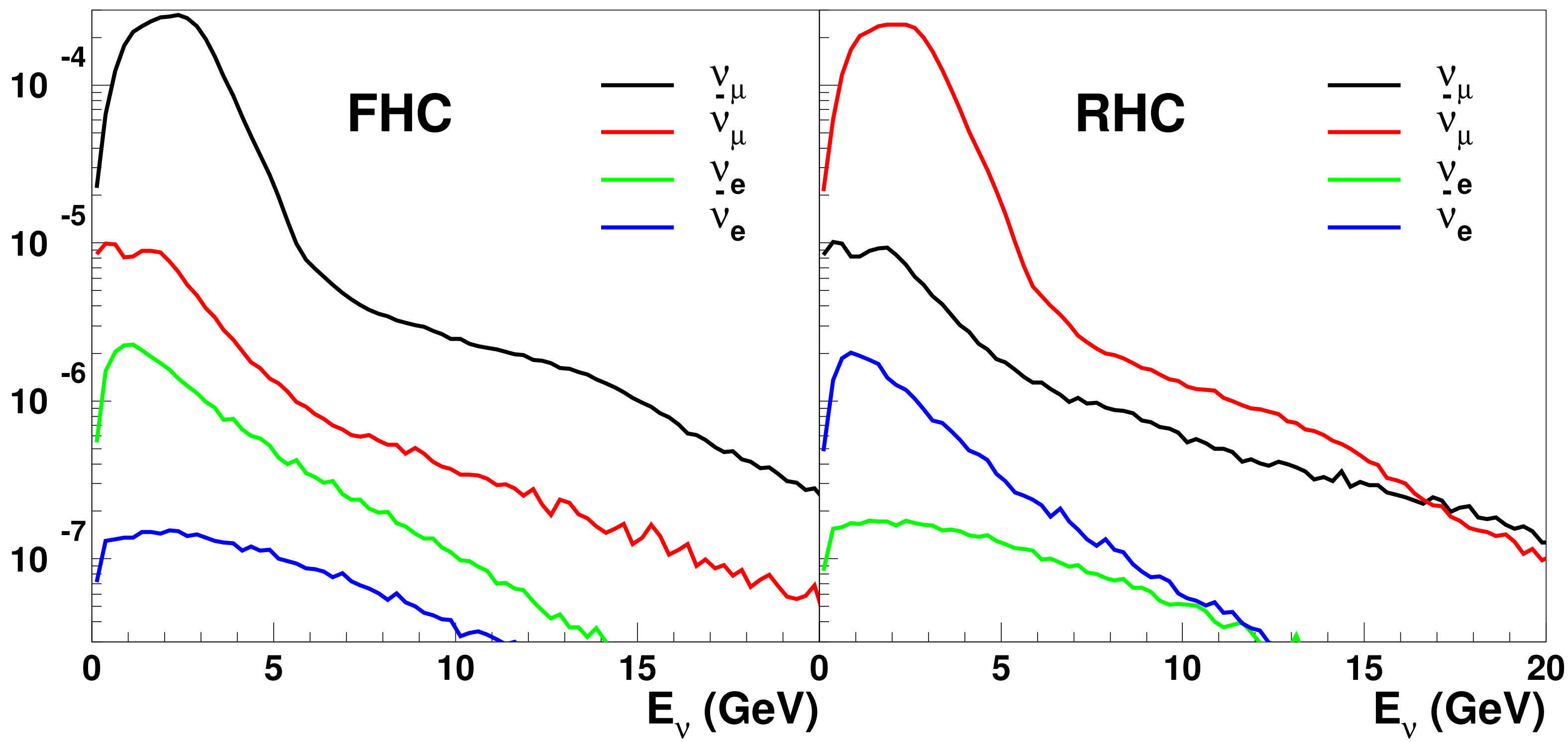
INTERACTIONS IN DUNE

✦ *In DUNE about 25% Quasi-elastic, 42% Resonances and 33% DIS*

- *Wide energy spectrum* $\Longrightarrow$ *NOT a simple counting experiment;*
- *Covers intermediate transition region, where QE, RES, and DIS have comparable weights;*
- *Need to understand all the QE, RES, DIS processes on* ^{40}*Ar and their interplay at the boundary of the corresponding kinematic regions.*

$\Longrightarrow$ *Substantial uncertainties on* $\nu(\bar{\nu})$*-nucleus interactions*



- *Events of exclusive process* X *(signal & bkgnd) in both ND* ($P_{\rm osc} \sim 1$) *and FD:*

$$N_{\rm X}(E_{\rm rec}) = \int_{E_\nu} dE_\nu \; \Phi(E_\nu) \; P_{\rm osc}(E_\nu) \; \sigma_{\rm X}(E_\nu) \; R_{\rm phys}(E_{\rm rec}, E_\nu) \; R_{\rm det}(E_{\rm rec}, E_\nu)$$

$R_{\rm phys}$ *describes the physics smearing (e.g. final state interactions)*
$R_{\rm det}$ *describes the detector smearing (e.g. readout, pile-up)*

- *The ND complex provides in-situ constraints on* $\Phi, \sigma_{\rm X}, R_{\rm phys}, R_{\rm det}$, *to be extrapolated at the FD location (FD/ND ratio)*

  $\Longrightarrow$ *Uncertainties at FD must be* $<$ *than FD statistics:* $\sim$ *1,000* ν_e *CC, 10,000* ν_μ *CC*

- *Uncertainties on modeling (anti)neutrino interactions directly affect the measurement of* $\Phi, \sigma_{\rm X}, R_{\rm phys}$ *and only indirectly* $R_{\rm det}$ *(acceptances, efficiencies)*

MEASUREMENTS IN DUNE ND

- *In DUNE considering a highly capable ND complex with hybrid design including a non-magnetized LAr detector followed by a multi-purpose low-density tracker (MPT).*

- *Number of events/ton for the inclusive CC interactions of the various flavors expected in ND with the nominal 1.07 MW beam (80 GeV, 1.47 $\times 10^{21}$ pot/year):*

Interaction type	Evt/ton (5y FHC)	Evt/ton (5y RHC)
ν_μ CC	7,352,430	508,172
$\bar{\nu}_\mu$ CC	150,076	2,270,050
ν_e CC	90,137	25,273
$\bar{\nu}_e$ CC	9,270	25,124

- *Fiducial masses under consideration ~ 25 tons for LAr and $\sim$ a few tons for MPT imply large event statistics in ND for all interaction types*

  $\Longrightarrow$ *Limiting factor in ND measurements from modeling of $\nu(\bar{\nu})$-nucleus interactions*

✦ $\boxed{\Phi(E_\nu)}$ *flux measurements of all flavors* $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$

- *Relative* ν_μ *flux vs.* E_ν *from the* $\nu < 0.25$ *GeV CC sample.*
  Need to understand low-ν *region (QE and RES) to quantify model uncertainties on flux correction factor and event selection (*ν *cut)*
- $\bar{\nu}_\mu/\nu_\mu$ *vs.* E_ν *from coherent* $\pi^\pm$ *production.*
  Need to quantify theoretical uncertainties on cross-sections for different A *targets*

✦ $\boxed{\sigma_{\rm X}(E_\nu)}$ *for* $\nu(\bar{\nu})$ *exclusive processes on Ar target*

- *Most critical regions resonance production & transition region from SIS to DIS*
- *Quantify effects of non-perturbative power corrections from HT and TMC in* $\nu(\bar{\nu})$*-nucleon scattering*
- *Understand interplay of LT and HT nuclear effects and differences with respect to* e, μ *scattering*
- *Study applicability of quark-hadron duality to* $\nu(\bar{\nu})$ *scattering vs. isospin of target*

✦ $\boxed{R_{\rm phys}(E_{\rm rec}, E_\nu)}$ *requires multiple nuclear targets*

- *Need to understand the effect of the nuclear smearing from FSI in order to unfold the response function from measurements (e.g. neutron production, multi-nucleon production, low-threshold particles, etc.)*
- *Need to refine hadronization models to understand signal & backgrounds, especially in the SIS/DIS transition region.*

RICH SHORT BASELINE PHYSICS

✦ PRECISION MEASUREMENTS:

- *Measurement of* $\sin^2\theta_W$ *and electroweak physics;*
- *Measurement of strange sea contribution to the nucleon spin* Δs*;*
- *Precision tests of isospin symmetry;*
- *Precision tests of the structure of the weak current: PCAC, CVC;*
- *Adler sum rule;*
- *Studies of QCD and hadron structure of nucleons and nuclei;*
- *Strange sea and charm production;*
- *Measurement of Nuclear effects in neutrino interactions;*
- *Precision measurements of cross-sections and particle production; etc. .....*

Deep synergy with the LBL oscillation program: same requirements and mutual feedback

✦ SEARCHES FOR NEW PHYSICS:

- *Search for weakly interacting massive particles (e.g.* ν*MSM sterile neutrinos);*
- *Search for high* Δm^2 *neutrino oscillations (e.g. LSND, MiniBooNE)*
- *Search for light (sub-GeV) Dark Matter; etc. .....*

$\Longrightarrow$ *A generational advance in the study of fundamental interactions / structure of matter requiring a new level of theoretical accuracy*