ANNIE
Future Physics Opportunities

NuSTEC NDNN
Thursday: First Discussion
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See Snowmass LoIs: Physics Opportunities at ANNIE
ANNIE Detector R&D
ANNIE is studying the possibility of deploying Water-based Liquid Scintillator (WbLS) in the central fiducial volume to improve vertex resolution and also gain sensitivity to sub-Cherenkov charged hadrons at the vertex.
WbLS + Gd
Water-based Liquid Scintillator with Gadolinium

Newly developed at BNL, WbLS-Gd is now undergoing testing for scattering, absorption, stability, and ability to recirculate. Candidate for use in SANDI, as this would improve neutron efficiency near the vertex.

WbLS long arm attenuation measurement device
Multi-Target Measurements
Potential for $\text{H}_2\text{O} + \text{Ar}$ Analysis with SBND

- Proximity of ANNIE & SBND presents an opportunity for joint $\text{Ar} + \text{H}_2\text{O}$ measurements at $\sim 1$ GeV
- Nearly identical flux $\rightarrow$ high precision on ratios
- Oscillations: DUNE/HK, WbLS Theia FD + DUNE ND, ...
- Neutrino interaction physics
  - Neutron tagging in ANNIE + proton tagging in SBND
  - Modeling neutron production in LAr
- Cross section (ratio)s, generator validation, generator tuning, ...

FIG. 4 (color online). The MiniBooNE pulsed horn system. The outer conductor (gray) is transparent to show the inner conductor components running along the center (dark green and blue). The target assembly is inserted into the inner conductor from the left side. In neutrino-focusing mode, the (positive) current flows from left-to-right along the inner conductor, returning along the outer conductor. The plumbing associated with the water cooling system is also shown.

FIG. 3 (color online). Left: Neutrino event times relative to the nearest RF bucket (measured by the RWM) corrected for expected time-of-flight. Right: An oscilloscope trace showing the coincidence of the beam delivery with the horn pulse. The top trace (labeled ''2'' on the left) is a discriminated signal from the resistive wall monitor (RWM), indicating the arrival of the beam pulse. The bottom trace (labeled ''1'' on the left) is the horn pulse. The horizontal divisions are 20 ns each.

FIG. 5. Measurements of the azimuthal magnetic field within the horn. The points show the measured magnetic field, while the line shows the expected $1/R$ dependence. The black lines indicate the minimum and maximum radii of the inner conductor.

BNB $8 \text{ GeV } p$

(not to scale)
Multi-Target Measurements
Potential for $\text{H}_2\text{O} + \text{Ar}$ Analysis with SBND

Examples with a generator-level \textbf{GENIE v3.00.06 MC} and \textbf{true CC0π} selection:

Nucleon multiplicity for $\nu_\mu\text{CC0π}$

validate

LAr neutron reco per
PRD 102, 092010 (2020)

Kinematics in DUNE and HK FDs vs. ANNI/SBND

$|q^3|$ (GeV/c) vs. $q^0$ (GeV)

Energy transfer $W$ vs. $Q^2$
Timing

Precision Neutrino Beam Timing

Can precision timing resolve the \textit{time evolution of the flux} composition?

Potential \textbf{PRISM-like analysis} using time slices with higher-frequency RF

Original figure: DUNE-PRISM, P. Dunne, ICHEP2020

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{Projection of the initial (53.1 MHz, red) and final (531 MHz, blue) bunches onto the phase space variables $\phi$ and $\delta$ using the proton bunch initial conditions from 6. The simulation includes 20 neighboring 53.1 MHz rf buckets. The resulting width of the 531 MHz bunches is affected by interbucket cross-talk. The number of protons contained in each 531 MHz bunch varies from 15% to 5% of the number of protons in the initial 53.1 MHz bunch.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{The plots on the top row show the relative time-of-arrival of all neutrinos at the far detector for the zero bunch width and perfect detector timing (left) and 250 ps bunch width and 100 ps detector timing in 200 ps bins (right). Time cut ranges that produce the fluxes on the bottom row (red, magenta, indigo, blue, light blue, cyan, teal) are shown as shaded regions in the time-of-arrival plots on the top row. All plots include pile-up affects from neighboring 531 MHz bunches. The plots on the bottom row show the simulated LBNF neutrino energy distribution (outer envelope), overlaid with the fluxes corresponding to increasingly later binned time-cuts relative to the bunch arrival time. The bins are 200 ps wide in both cases. Both plots are in forward horn current mode, as reverse horn current versions look identical.}
\end{figure}

PRD 100, 032008 (2019)
250ps bunch/100ps detector