Constraining $\nu(\bar{\nu})$ Interactions in LAr

R. Petti

University of South Carolina, Columbia SC, USA

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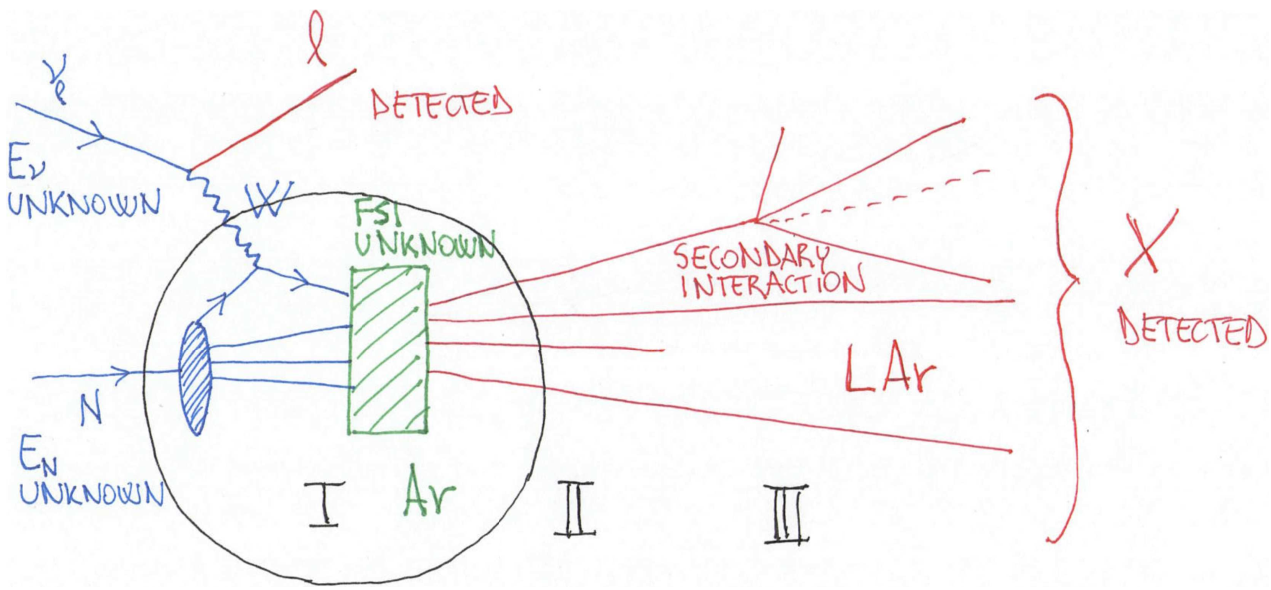
UNDERSTANDING CC INTERACTIONS IN LAr



- **I** *Nuclear smearing from target Ar nucleus:* *Ar target + "solid" H target in STT*
- **II** *Hadron multiplicities from $\nu(\bar{\nu})$-Ar:* *Ar target + low density STT in B field*
- **III** *Secondary interactions in LAr (transport):* *LAr + low density STT in B field*

$\Longrightarrow$ *GRAIN+STT can disentangle and constrain different effects offering a calibration tool for both ND-LAr and FD*

SECONDARY INTERACTIONS IN LAr (III)

- *Acceptance variation vs. vertex z in LAr* controlled by interacting/stopping hadrons
  $\Longrightarrow$ *Hadrons exiting from sides of GRAIN small fraction ($\sim$ 6% of $\pi^{\pm}$) of total*

- *Excellent vertex resolution for CC events with ≥ 1 reconstructed hadrons in STT.*

- *Determine mean free path τ from analysis of reconstructed $\pi^{\pm}, p$ vs. z in LAr:*

$$N_{\pi}^{\rm rec}(\Delta z) \;=\; N_0 \exp\left(-\Delta z/\tau\right)$$

  with Δz thickness of LAr crossed along z axis.

- *Constraining secondary interactions in GRAIN+STT:*
  - *Exploit thickness of GRAIN and unique combination of LAr followed by low-density STT;*
  - *Small number of reconstructed secondary $\pi^{\pm}, p$ in STT roughly proportional to interaction rate*
  - *Separation of secondary interactions from primary particles emerging from $\nu(\bar{\nu})$-Ar interactions.*

HADRON MULTIPLICITIES FROM $\nu(\bar{\nu})$-Ar (II)

- *Excellent π/p identification in STT+ECAL allows high purity selection of $\pi^{\pm}, p$ multiplicities (neglect tiny $K^{\pm}$ fraction).*

- *Measured mean free path τ in LAr can be used to correct reconstructed multiplicities:*

$$\begin{aligned} N^0_{2\pi} &= N_{2\pi} \exp\left(2\Delta z/\tau\right) \\ N^0_{1\pi} &= N_{1\pi} \exp\left(\Delta z/\tau\right) - N^0_{2\pi} \exp\left(\Delta z/\tau\right) \left[1 - \exp\left(-2\Delta z/\tau\right)\right] \\ N^0_{0\pi} &= N_{0\pi} - \left[1 - \exp\left(-\Delta z/\tau\right)\right] \left[N^0_{1\pi} + N^0_{2\pi} - N^0_{2\pi} \exp\left(-\Delta z/\tau\right)\right] \end{aligned}$$

with only $\leq 2\pi$ for illustration and similar relations can be written for p topologies.

- *Data-driven diagonalization of migration matrix among different $\pi^{\pm}, p$ topologies:*
  - *Final state multiplicities emerging from $\nu(\bar{\nu})$-Ar interactions can be determined using the downstream LAr fiducial volume close to STT with $\Delta z \ll \tau$;*
  - *Small number of reconstructed secondary $\pi^{\pm}, p$ can be reduced using backward track extrapolation;*
  - *Excellent momentum and angular resolution in STT limits smearing effects on kinematics.*

CONSTRAINING NUCLEAR SMEARING IN Ar (I)

$$N_X(E_{rec}) = \int_{E_\nu} dE_\nu \boxed{\Phi(E_\nu)} P_{osc}(E_\nu) \boxed{\sigma_X(E_\nu)} \boxed{R_{phys}(E_\nu, E_{vis})} \boxed{R_{det}(E_{vis}, E_{rec})}$$

$\Phi(E_\nu) \rightarrow$ **~1% in H** $\sigma_X(E_\nu) \rightarrow \boldsymbol{F_i(Q^2)}$ $R_{phys}(E_\nu, E_{vis}) \rightarrow \boldsymbol{R_{phys} \equiv I}$ $R_{det}(E_{vis}, E_{rec}) \rightarrow \boldsymbol{K_0, \Lambda, \gamma}$

✦ *Compare interactions on H in STT and on Ar in GRAIN for $\Delta z \ll \tau$:*

- *Constraining the nuclear smearing if acceptance R_{det} similar for Ar and H;*
- *Calibration of the (anti)neutrino energy scale.*

✦ *Providing necessary redundancy against MC/model & unexpected discrepancies:*

- *Ar detectors alone (even ideal) cannot resolve nuclear smearing & related systematics;*
- *PRISM alone sensitive to (beam) model & tuning to resolve off-axis discrepancies.*

$\Longrightarrow$ *Synergy between PRISM and Hydrogen measurements in STT to resolve systematics from beam modeling & nuclear smearing*