2x2 Chicago Meeting

February 20, 2024

Angela White and Elise Hinkle

Agenda

1. Paper Update
2. General Analysis Update
3. n-LAr XS Systematics Update

General 2x2 Analysis Outlook

Current “First Analysis” topics:

1.) Charged track multiplicity
2.) $\overline{\nu}_{\mu}$-Ar CC mesonless cross section
3.) n-Ar cross section/neutron production in $\overline{\nu}_{\mu}$-Ar interactions

Other analyses currently in development:

1.) CC π^0 production in ν-Ar interactions
2.) Strangeness production ($K^{\pm}$ + X, Λ + X) in ν-Ar interactions

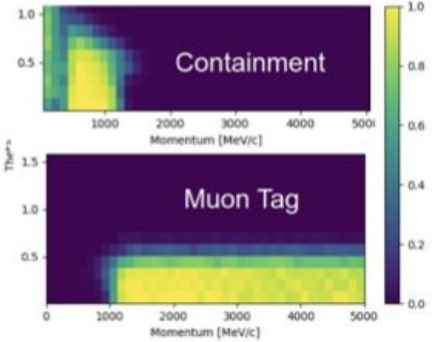
Additional Analysis Topics: Cross Sections

Previous proposals and studies presented by Callum Wilkinson at January 2023 ND Prototypes Analysis Workshop

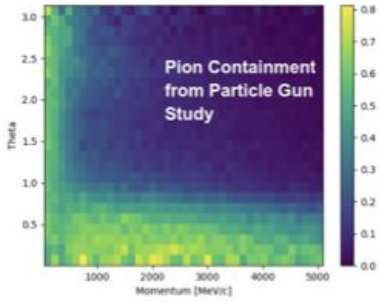
C. Wilkinson

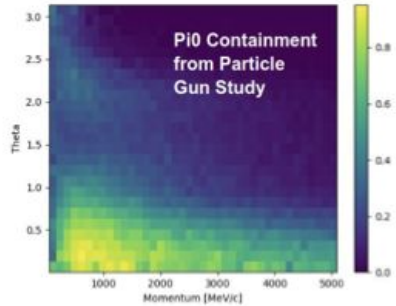
What measurements are viable?

- Downstream muons (E_μ >1.2 GeV) can only be tagged
  - No momentum measurements
  - STV variables not accessible
  - E_ν proxies inaccessible – shouldn't try to measure those anyway…



- Limited hadronic containment in 2x2-only, more in 2x2+MINERvA
- Shower containment poor in 2x2 only – but can be tagged





Figures from Stephen Greenberg

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C. Wilkinson

What measurements are viable?

From Stephen's studies:

Total Number of CC Events Expected Per Year

	0 $\pi^{\pm}$	1 $\pi^{\pm}$	2 $\pi^{\pm}$	3+ $\pi^{\pm}$
0 π^0	2.01e+05	1.64e+05	9.31e+04	6.65e+04
1 π^0	8.22e+04	9.63e+04	5.42e+04	5.36e+04
2 π^0	3.11e+04	2.88e+04	2.3e+04	2.49e+04
3+ π^0	1.05e+04	1.32e+04	9.72e+03	1.19e+04

Number of 2x2 Only CC Contained Events Expected Per Year

~~2023~~

	0 $\pi^{\pm}$	1 $\pi^{\pm}$	2 $\pi^{\pm}$	3+ $\pi^{\pm}$
0 π^0	1.4e+05	4.81e+04	1.4e+04	4.41e+03
1 π^0	7.30e+03	3.32e+03	1.27e+03	5.21e+02
2 π^0	3.42e+02	2.02e+02	1.18e+02	6.72e+01
3+ π^0	5.6e+00	1.68e+01	5.6e+00	0.e+00

Number of CC Contained Events Expected Per Year

~~2024~~
~~2???~~

	0 $\pi^{\pm}$	1 $\pi^{\pm}$	2 $\pi^{\pm}$	3+ $\pi^{\pm}$
0 π^0	1.53e+05	8.04e+04	3.26e+04	1.56e+04
1 π^0	2.83e+04	2.8e+04	1.09e+04	7.59e+03
2 π^0	6.58e+03	4.96e+03	3.04e+03	2.25e+03
3+ π^0	1.32e+03	1.22e+03	7.39e+02	5.94e+02

Mostly escape the 2x2

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My potentially biased ordered list of topics

Scientific interest™

- **CC $2\pi^+$**: unmeasured since 80s, in the "transition region"
- **NC $1\pi^+$**: muon background at FD
- **CC $1\pi^+$**: huge fraction of DUNE events, unknown at high-W
- **Electron neutrino → anything**: basically unmeasured
- **NC π^0 measurements**: electron background at FD
- **Kaon production**: some interest as an unusual channel
- **CC π^0 measurements**: $\pi^0/\pi^\pm$ ratio give FSI info
- **NC $2\pi^\pm$**: never measured, will break RES model
- **RHC CC0π**: SBND may not measure this, muon tag only
- **NC-elastic scattering**: some ability to measure "Δs"
- **FHC CC0π**: SBND will measure this extremely well

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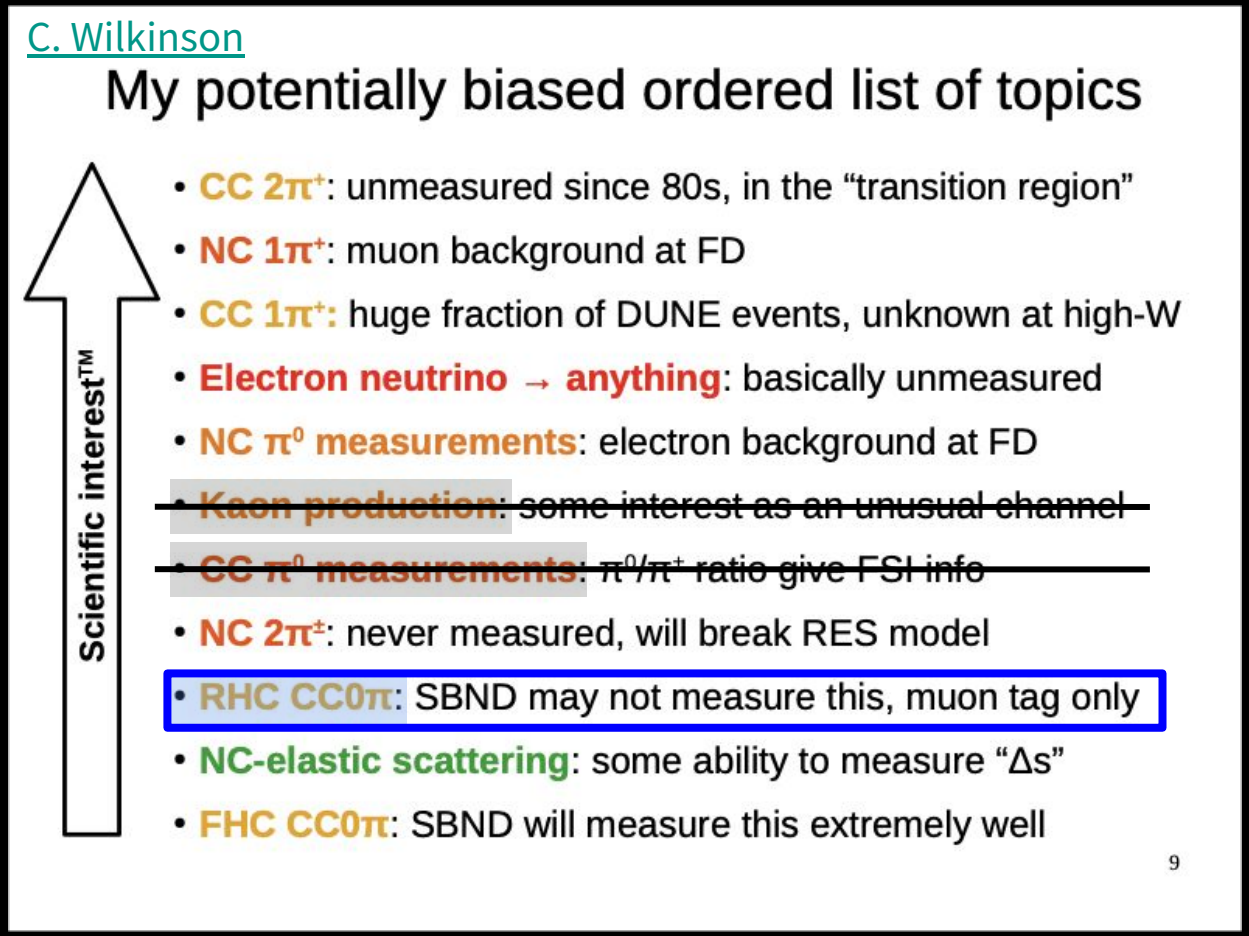

Additional Analysis Topics: Cross Sections

Additional interesting options from Callum's list:

1.) **CC $1\pi^+$, CC $2\pi^+$**
   - **Main difficulties:** particle PID, containment (?), TPC-TPC matching
2.) **NC $1\pi^+$, NC $2\pi^+$**
   - **Main difficulties:** particle PID, containment (?), TPC-TPC matching
3.) **NC π^0**
   - **Main difficulties:** shower containment and reconstruction, statistics
4.) **Electron neutrino cross sections**
   - **Main difficulties:** shower containment and reconstruction, statistics
5.) **NC-elastic scattering**
   - **Main difficulties:** proton detection threshold

Additional Analysis Topics: Cross Sections

Can also extend analysis to differential cross sections:

- **Pros:** developing analysis techniques; potentially contribute to improving cross section models for neutrino generators
- **Cons:** muon momentum difficult and/or impossible to measure; can't currently make FSI dials in generators using kinematic variables

Possible differential variables include:

- Proton (pion) multiplicity
- Muon angle w.r.t. beam
- Leading proton (pion) momentum
- Angle between leading proton (pion) and sub-leading proton (pion)

n-LAr Inelastic XS

Preliminary Analysis: neutron KE spectrum in LAr

- Just counting/reconstruction (like a Michel e- spectrum)
- Relies on:
    - Neutron time of flight
    - Distance between neutrino vertex and neutron inelastic scatter.
- Systematics on next slide

Next Step: XS

- **“**quantify the flux by measuring the attenuation of neutron interactions as a function of distance from the neutrino vertex”
- **Major Systematics:**
  1. vertex resolution
  2. p+ blip identification

Final XS given as **flux-averaged energy** in **time-of-flight bins**

n-LAr Inelastic KE Spectrum Systematics

Expected leading systematics:

1. **Neutron elastic scatters:** The primary neutron scatters before interacting and producing a proton.
2. **Hadron interactions:** A charged pion scatters to produce a neutron which in turn produces a proton which would fake our signal
3. **Near-synchronous:** Neutrino interactions occurring nearly simultaneously within the fiducial volume can lead to signal overlap, causing topology-based signal distortion.
4. **Dirt activity:** Proton is produced through outside particle and you have a true neutrino interaction inside the fiducial volume
5. **Time drift between modules:** Can calibrate out, but need O(ns) measurement

n-LAr Inelastic XS

- Quantify the impact of the gaps between modules on this analysis
- And the steel in the detector frame(?) or is it mostly G10?

To Do:

Influence on dead regions on analyses

Are there any topologies that are particularly good with native 3D reco

2x2 Paper Update

Link to Overleaf Draft:
https://www.overleaf.com/8458358216drvhjgctvqpr#7b24bd

Status:

- General Structure Forming

To Do:

- email Callum and James at LBNL, plan for **2 complimentary papers**
  - **1st** is 2x2 first events: simple, released immediately (we lead)
  - **2nd** is detailed technical paper with more complex analysis (they lead)

Additional Analysis Topics: Cross Sections

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C. Wilkinson

Rare channels

- My Scientific interest™ ranking was entirely biased towards oscillation physics… but that's not the full story!
- Also potential to measure rare particle production, which may be interesting as a specific background for a BSM search, or as a potential calibration sample
- For reference, MicroBooNE's recent paper on hyperon production (with 5 events), arXiv:2212.07888
- According to GENIE (with NuMI ME and ^{40}Ar):
  - 2.9% contain a neutral kaon
  - 3.9% contain a charged kaon
  - 4.0% contain a strange baryon
  - 0.6% contain a charmed meson
  - 0.4% contain a charmed baryon
- **Lots of challenges**, but could be worth further investigation!

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2x2 & MINERvA

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- Correlated measurements between ^{40}Ar and C_8H_8 could be very useful for DUNE: SAND, using existing measurements
- Some challenges:
  - Getting correlated throws of the flux might be difficult
  - Utility may be somewhat analysis technique dependent
  - MINERvA and 2x2 acceptance is rather different…
- But, worth thinking about as we put more thought into analyses

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Additional thoughts: we're not on MINERvA, which makes pursuing this analysis more difficult and probably not worth it