

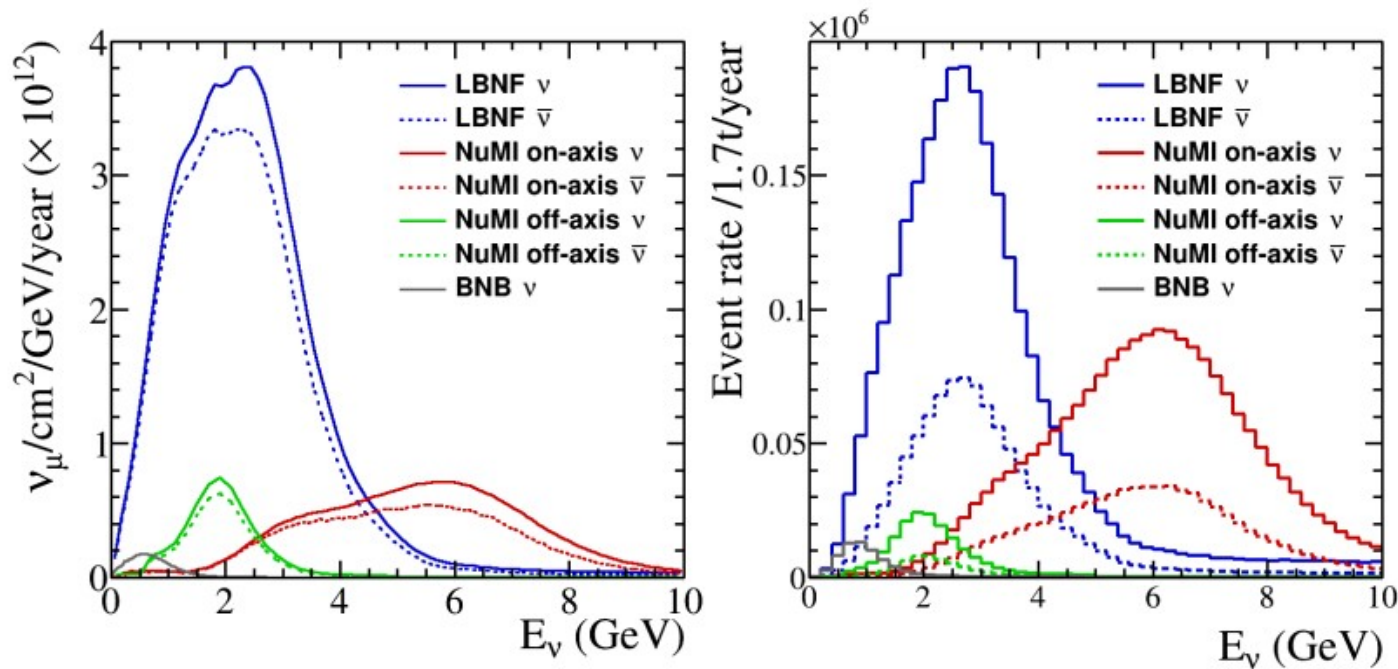
2x2 physics reach: cross sections

Callum Wilkinson
LBNL

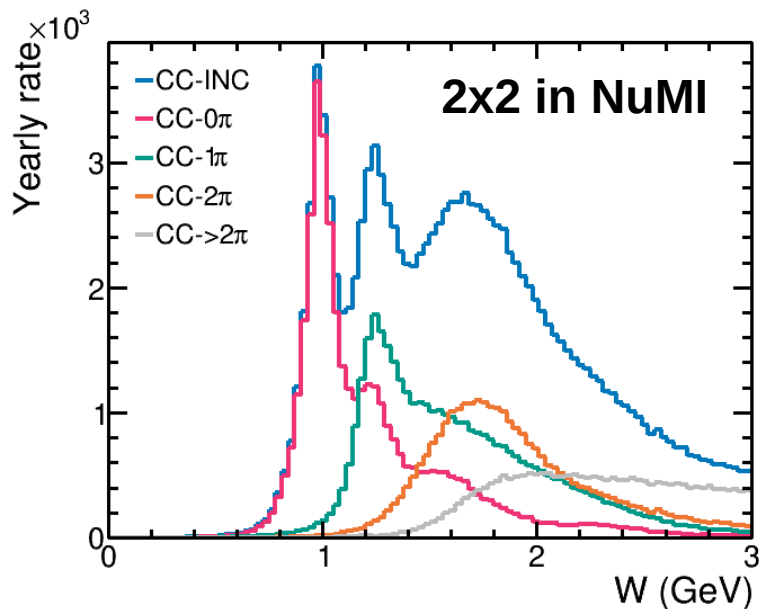
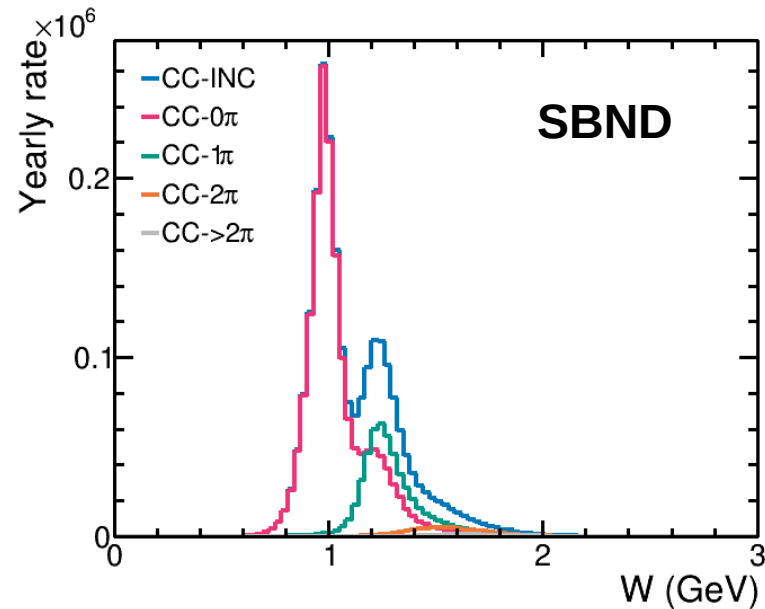
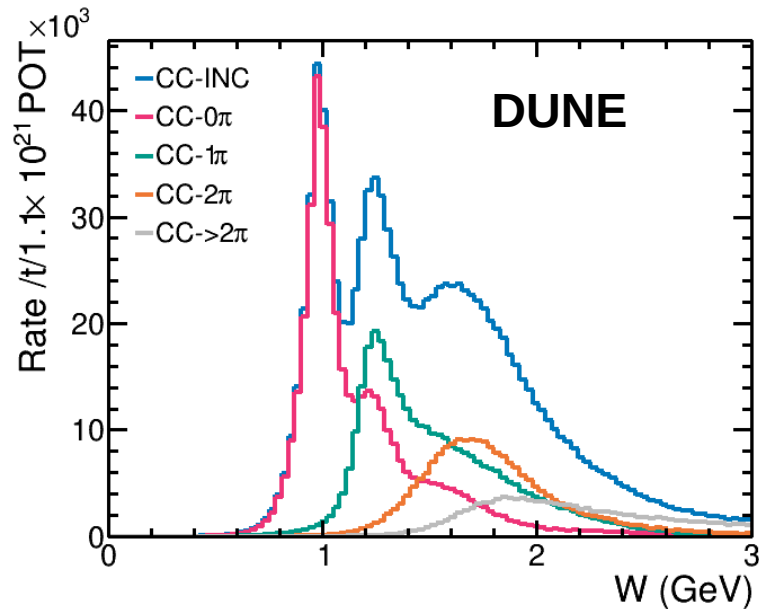


Physics context

The 2x2 accesses higher energies than other pre-DUNE LAr experiments



Physics context

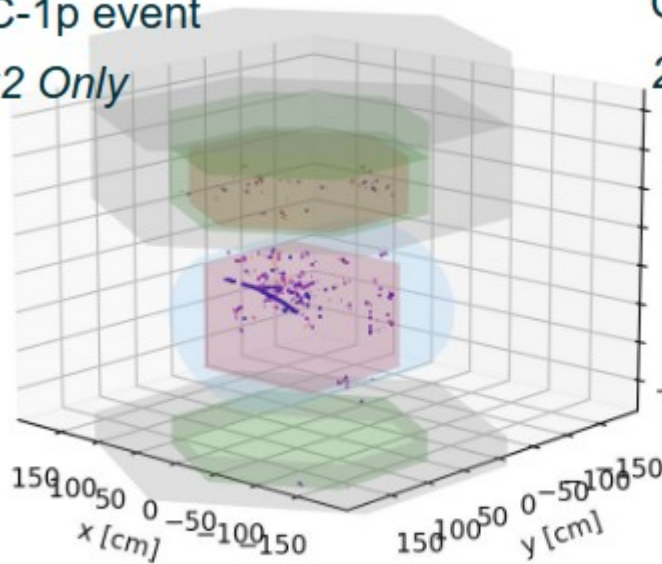


- DUNE covers a much broader kinematic range than SBND
- NuMI allows the 2x2 to access higher W and q_0 events – cover the DUNE range
- RHC even more striking as SBND may not run in it...

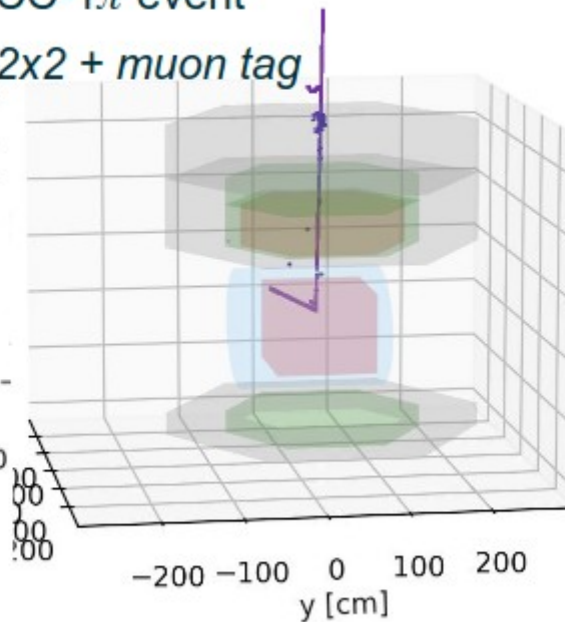
What measurements are viable?

Reconstruction complexity

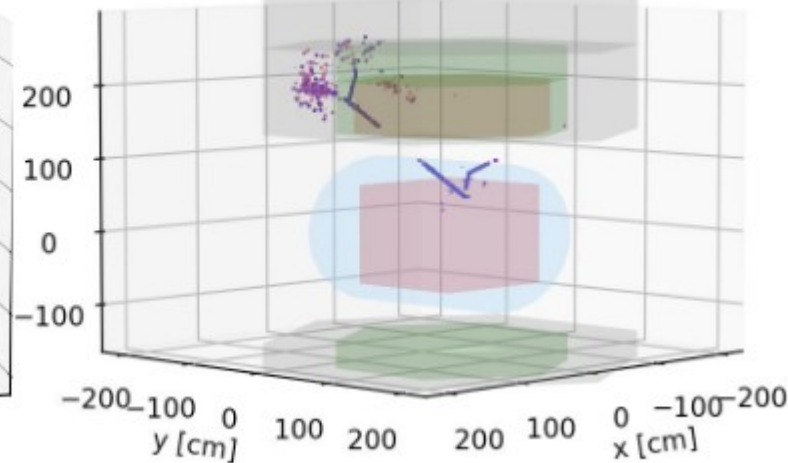
NC-1 π event
2x2 Only



CC-1 π event
2x2 + muon tag



NC-1 π event
2x2 + Minerva



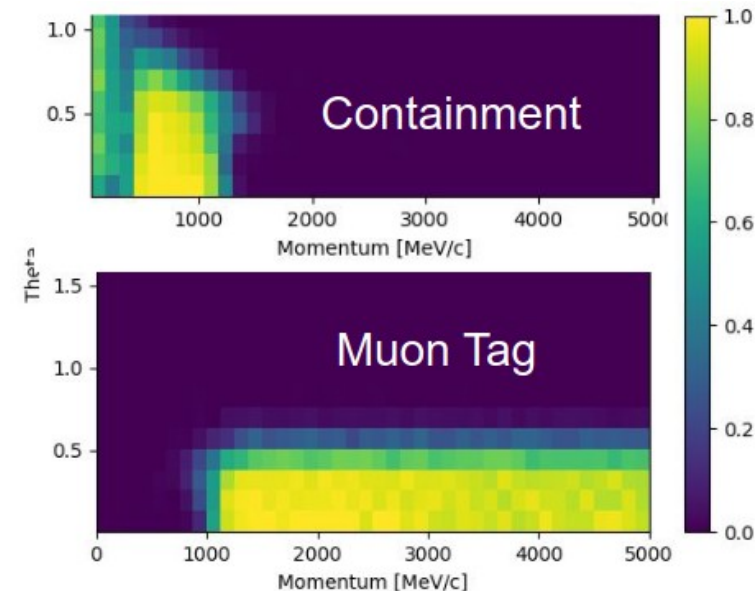
Stephen Greenberg | BERKELEY LAB

14

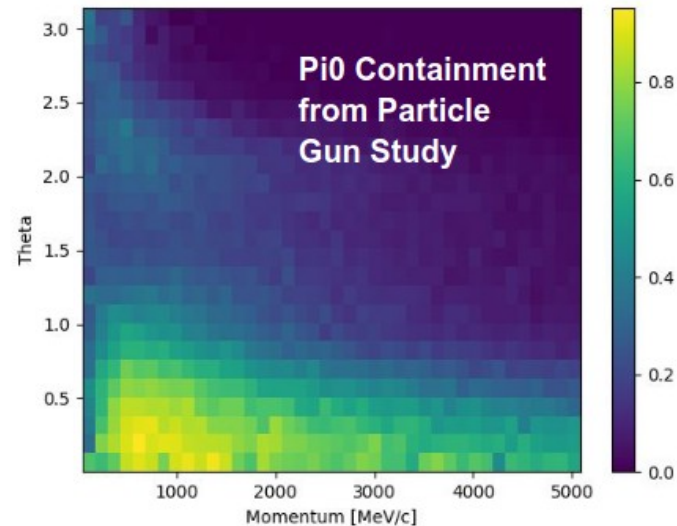
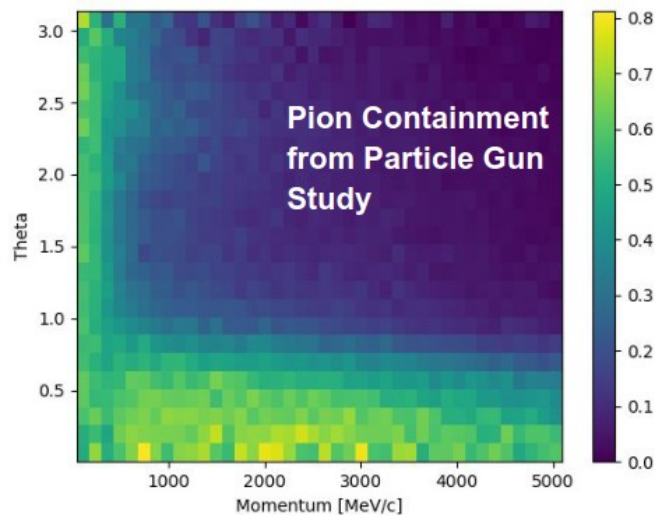
- These examples from Stephen's talk at the last CM give some concrete (cherry-picked) examples
- Possible to guesstimate accessible samples using basic simulation tools, without reconstruction

What measurements are viable?

- Downstream muons ($E_\mu > 1.2$ 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**

Timeline considerations

Analysis targets naturally vary based on the level of software maturity:

- (1) No “fully featured” reconstruction package available
- (2) 2x2 only reco in a good state
- (3) Basic 2x2 → MINERvA matching possible, 2x2 reco in a good state, MINERvA with limited calibration
- (4) Multiple track matching 2x2 → MINERvA possible, with good MINERvA calibration
- (5) 2x2+MINERvA function well together, reconstruction of showers *across detectors* possible

Timeline considerations

Analysis targets naturally vary based on the level of software maturity:

~Now (1) No “fully featured” reconstruction package available

Mid-2023 (2) 2x2 only reco in a good state

Late 2023 (3) Basic 2x2 → MINERvA matching possible, 2x2 reco in a good state, MINERvA with limited calibration

2024 (4) Multiple track matching 2x2 → MINERvA possible, with good MINERvA calibration

???? (5) 2x2+MINERvA function well together, reconstruction of showers *across detectors* possible

Trade-off between viability and physics impact

What measurements are viable?

From Stephen's studies:

Total Number of CC Events Expected Per Year

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

Number of 2x2 Only CC Contained Events Expected Per Year

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

2023

Number of CC Contained Events Expected Per Year

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

2024

????

Mostly escape the 2x2

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 \rightarrow anything**: basically unmeasured
- **NC π^0 measurements**: electron background at FD
- **Kaon production**: some interest as an unusual channel
- **CC π^0 measurements**: π^0/π^\pm ratio give FSI info
- **NC $2\pi^\pm$** : never measured, will break RES model
- **RHC CC 0π** : SBND may not measure this, muon tag only
- **NC-elastic scattering**: some ability to measure “ Δ s”
- **FHC CC 0π** : SBND will measure this extremely well

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!

2x2 & MINERvA

- As has been discussed before, the 2x2 samples the same NuMI ME flux as MINERvA did previously... perhaps an opportunity?
- 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

How can I investigate the viability of XYZ?

https://github.com/wilkinson-nu/2x2_truth_studies

Instructions on how to:

- Obtain/build/run software containers
- Make/get premade 2x2 files up to edep-sim level
- Visualize geometry/ use edep-sim event display
- Write a simple analysis script to calculate acceptances, using GENIE pass through/ G4 truth/ G4 energy deposits