DUNE NEAR DETECTOR REQUIREMENTS AND STAGING

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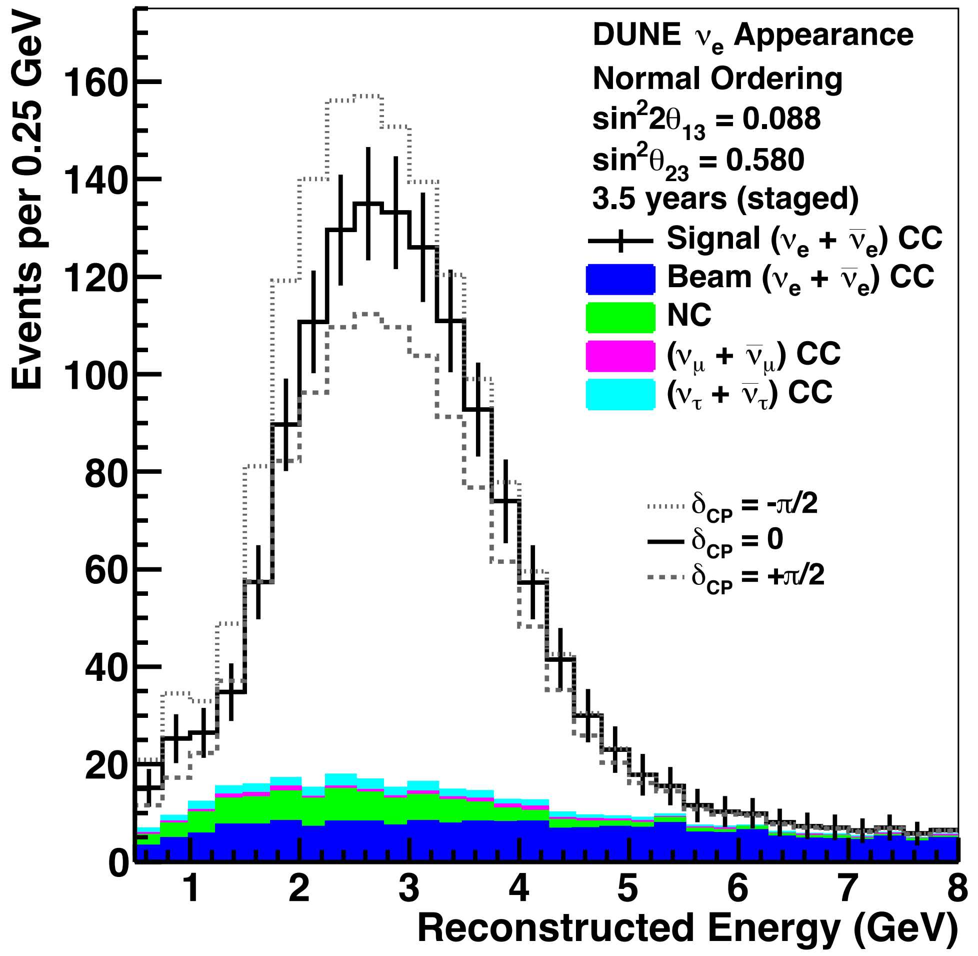
OVERARCHING REQUIREMENTS

O0 Predict the neutrino spectrum at the FD (Far Detector): The Near Detector (ND) must measure neutrino events as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy event spectra from the ND to the FD.		
O0.1	**Measure interactions on argon**	Measure neutrino interactions on argon to reduce uncertainties due to nuclear modeling, determine the neutrino flavor, and measure the full kinematic range of the interactions that will be seen at the FD.
O0.2	**Measure the neutrino energy**	Reconstruct the neutrino energy in CC events and control for any biases in energy scale or resolution, keeping them small enough to achieve the required CP coverage and transfer them to the FD.
O0.3	**Constrain the cross section model**	Measure neutrino cross-sections in order to constrain the cross-section model used in the oscillation analysis including potential mismodeling that causes incorrect FD predictions.
O0.4	**Measure neutrino flux**	Measure neutrino fluxes as a function of flavor and neutrino energy to enable neutrino cross-section measurements to be made and constraint the beam model
O0.5	**Obtain data with different neutrino fluxes**	Measure neutrino interactions in different beam fluxes (especially with different mean energies) to disentangle flux and cross-sections, verify the beam model, and guard against systematic uncertainties.
O0.6	**Monitor the neutrino beam**	Monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to changes in the beam on short timescales.

OVERARCHING REQUIREMENTS



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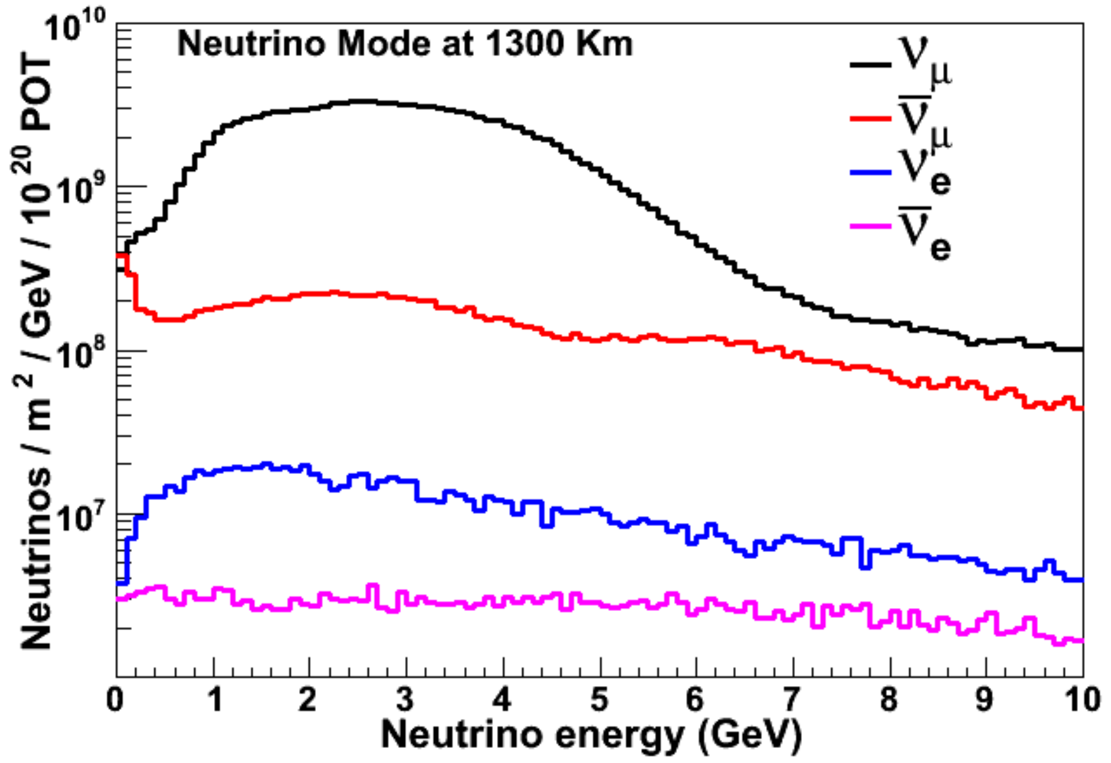
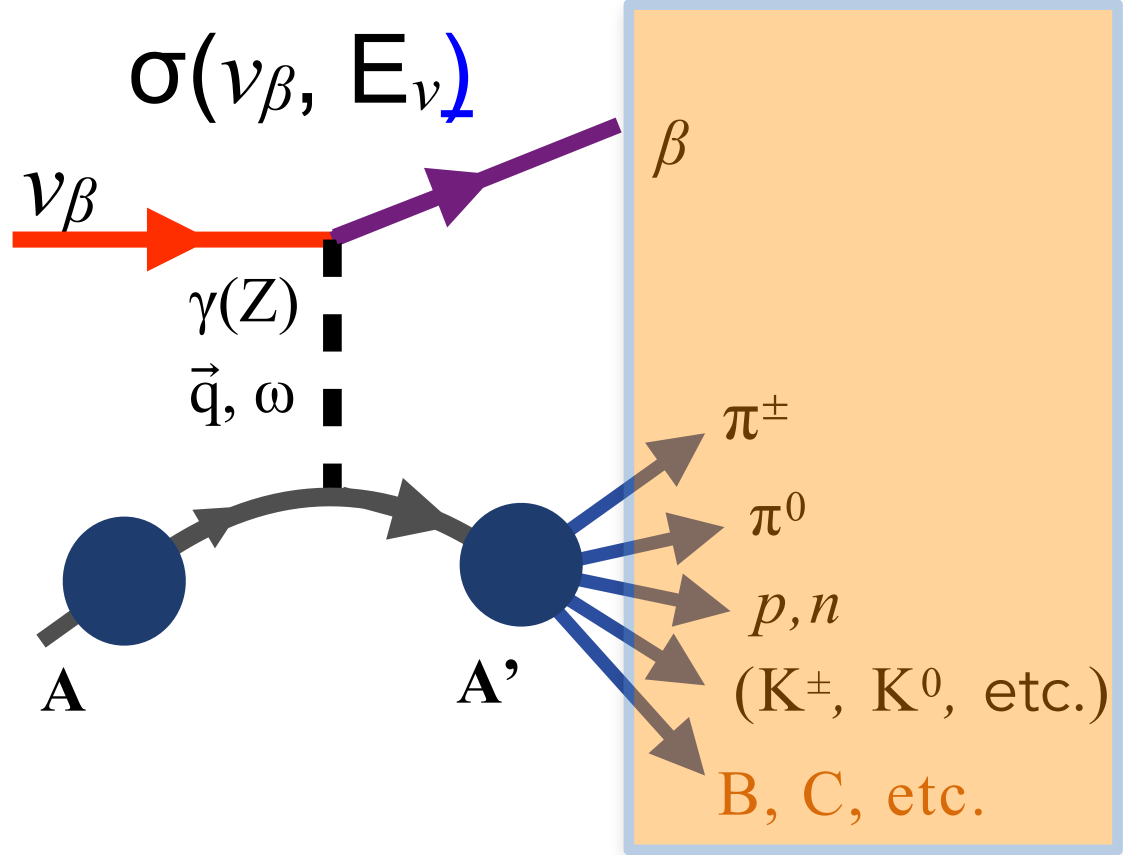
$\Phi(\nu_\alpha, E_\nu)$



$P(\nu_\alpha \rightarrow \nu_\beta)$

$\sigma(\nu_\beta, E_\nu)$



$R(\nu_\beta, E_{REC}, E_\nu)$

Intrinsic:
- Particle propagation
- Ionization/drift
- Recombination
- Secondary interactions

Particular
- Acceptance
- Rate/pileup
- Readout

O1: Measure interactions on Ar
O2: Measure EREC

O0: Predict the far detector event spectrum

$$N_{FAR}(\nu_\alpha \rightarrow \nu_\beta, E_{rec}) = \int dE_\nu \, P(\nu_\alpha \rightarrow \nu_\beta, E_\nu; L) \times \Phi(\nu_\alpha, E_\nu) \times \sigma(\nu_\beta, E_\nu) \times R(\nu_\beta, E_{rec}, E_\nu) \times V \times n$$

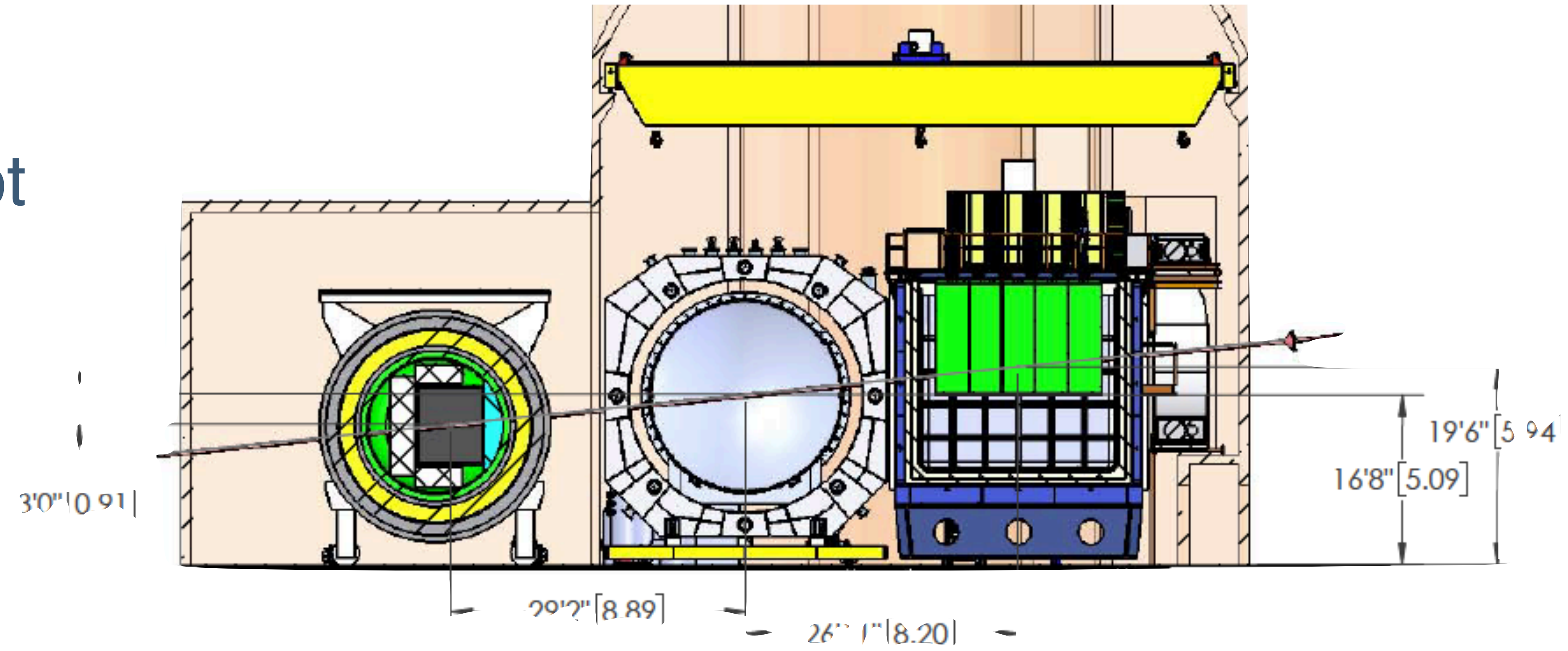
O4: Measure the flux
O6: Monitor the beam

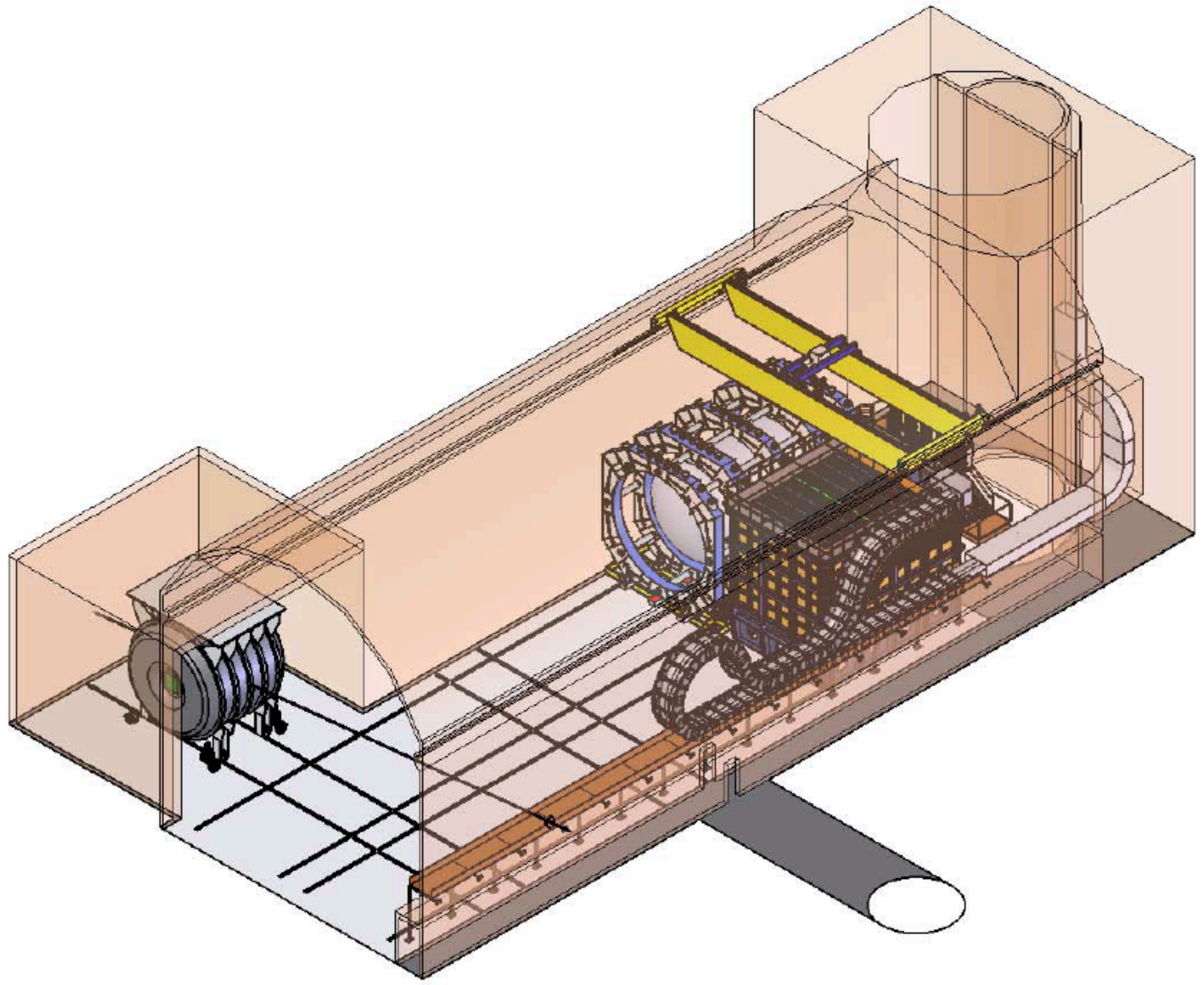
O3: Constrain the cross section model

O5: obtain data with different fluxes

NEAR DETECTOR REFERENCE DESIGN

- LAr:
  - Array of 7x 5 LArTPC modules based on the “ArgonCube” concept
  - Optimized for high rate environment
- Multi-Purpose Detector (MPD)
  - Magnetized system with
    - High Pressure gas Ar TPC (HPgTPC)
    - Electromagnetic calorimetry based on CALICE concept
    - Muon system
- DUNE-PRISM: movement of LAr + MPD up to ~30 m off-axis
- System for on-Axis Neutrino Detection (SAND)
  - Magnetized detector using KLOE SC magnet and ECAL
  - Remains on-axis for beam monitoring when LAr+MPD are off-axis for PRISM



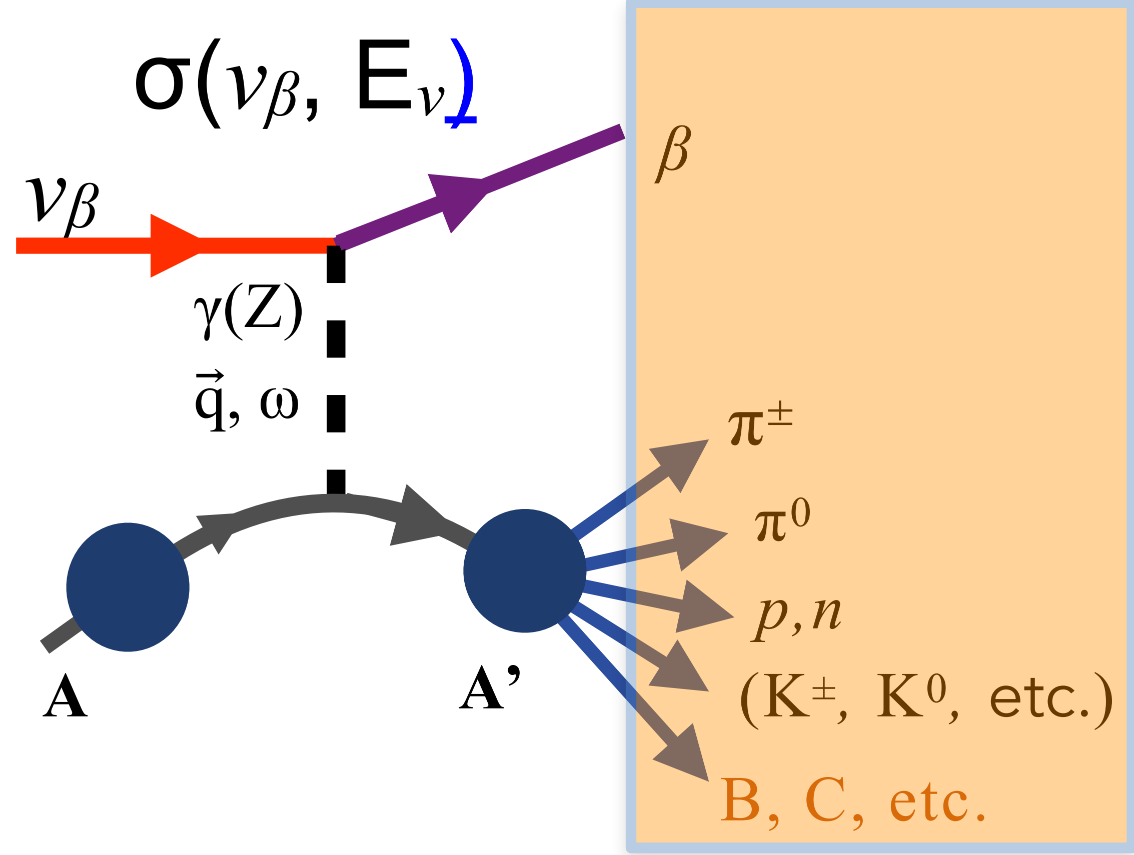


STRATEGY

O1-3:

- LArTPC to measure σ x R directly
- GAr (MPD) to measure σ with minimal acceptance, secondary interactions, etc. in order to disentangle and verify the modelling.

$\sigma(\nu_\beta, E_\nu)$



$R(\nu_\beta, E_{REC}, E_\nu)$

Intrinsic:

- Particle propagation
- Ionization/drift
- Recombination
- Secondary interactions

Particular

- Acceptance
- Rate/Pileup
- Readout

O1: Measure interactions on Ar

O2: Measure E_ν

O0: Predict the far detector event spectrum

$$N_{FAR}(\nu_\alpha \to \nu_\beta, E_{rec}) = \int dE_\nu \, P(\nu_\alpha \to \nu_\beta, E_\nu; L) \times \Phi(\nu_\alpha, E_\nu) \times \sigma(\nu_\beta, E_\nu) \times R(\nu_\beta, E_{rec}, E_\nu) \times V \times n$$

O4: Measure the flux

O6: Monitor the beam

O3: Constrain the cross section model

O5: obtain data with different fluxes

O4: ν-e scattering (LAr)

O6: on-axis beam monitoring with spectrum (SAND)

O5: PRISM to test E_ν dependence of model

FROM DECEMBER MEETING

Recommendations:

- DUNE should study how well "temporary minimal detectors" that are being considered if staging is required would actually work—for example, using the KLOE magnet+ECAL without inner detectors as a beam monitor, or using a magnetized muon spectrometer instead of an MPD. For this latter option, DUNE should quantify the design requirements for the muon spectrometer. LBNC acknowledges that the MPD provides several attractive features lacking from a minimal design, and notes that the SAND detector could be considered first in case staging is required.

- We will report on progress on understanding the requirements and whether these "temporary minimal detectors" fulfill the requirements for:

- On-axis beam monitoring
- Downstream muon spectrometer for LAr

BEAM MONITORING

- While rate-only/profile measurements have sufficed at other experiments (e.g. T2K) believe that spectral information is important both practically and scientifically for DUNE
- Initial study:
  - Compare monitoring with muon spectrum vs. 4 detectors situated (0,1,2,3) m off axis shows
  - significance for representative variations in beam line is greater with muon spectrum information.

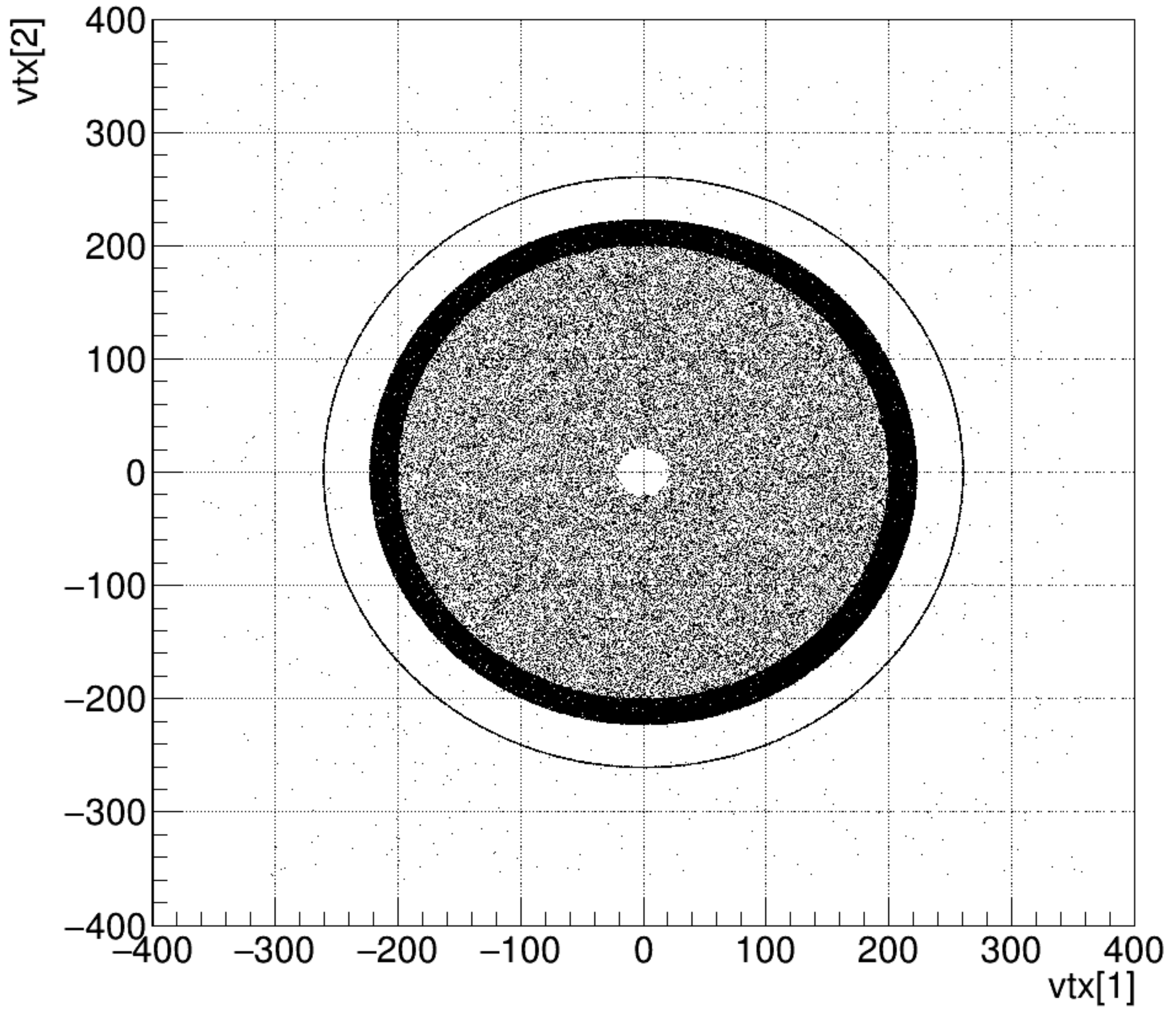
PRELIMINARY

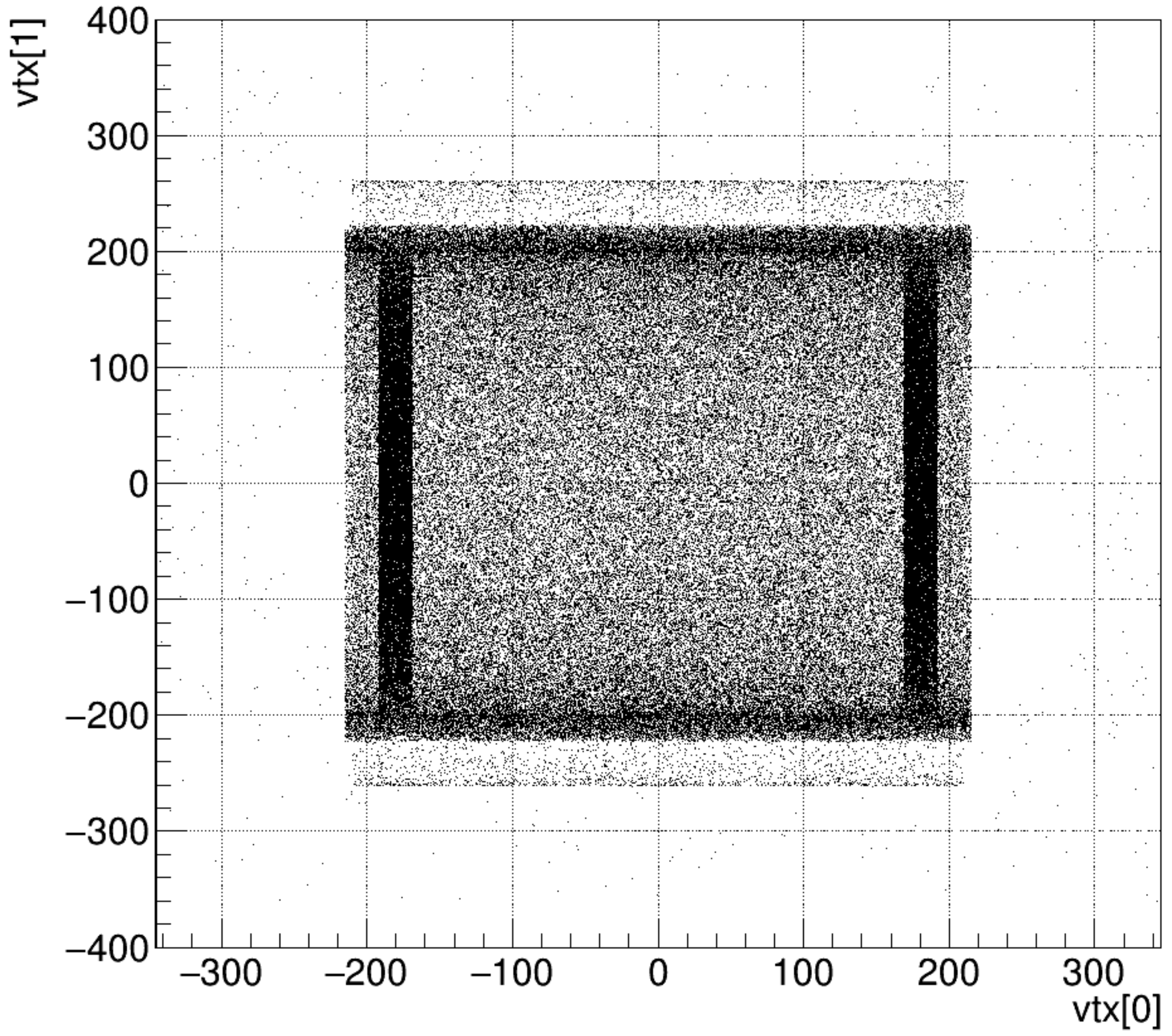
G. Yang

	Parameter description		Significance, $\sqrt{\chi^2}$	
Beam parameter	Nominal	Changed	Rate-only monitor	SAND
proton target density	1.71 g/cm^3	1.74 g/cm^3	1.9	7.8
proton beam width	2.7 mm	2.8 mm	3.0	6.7
proton beam offset x	N/A	-0.45 mm	0.7	19.9
proton beam $\theta\phi$	N/A	0.07 mrad θ and 1.5707 ϕ	0.2	12.5
horn 1 along x	N/A	0.5 mm	1.9	8.8
horn 1 along y	N/A	0.5 mm	0.7	12.8
horn 2 along x	N/A	0.5 mm	0.2	9.9
horn 2 along y	N/A	0.5 mm	0.4	6.3

- Muon momentum measurements are essential to effective beam monitoring at DUNE/LBNF

KLOE MAGNET/ECAL ONLY MONITORING





- Events generated with “empty” KLOE magnet with calorimeter only
- Consider only muon hits with 4.4 x 4.4 cm^2 voxelization in YZ plane to approximate KLOE ECAL response

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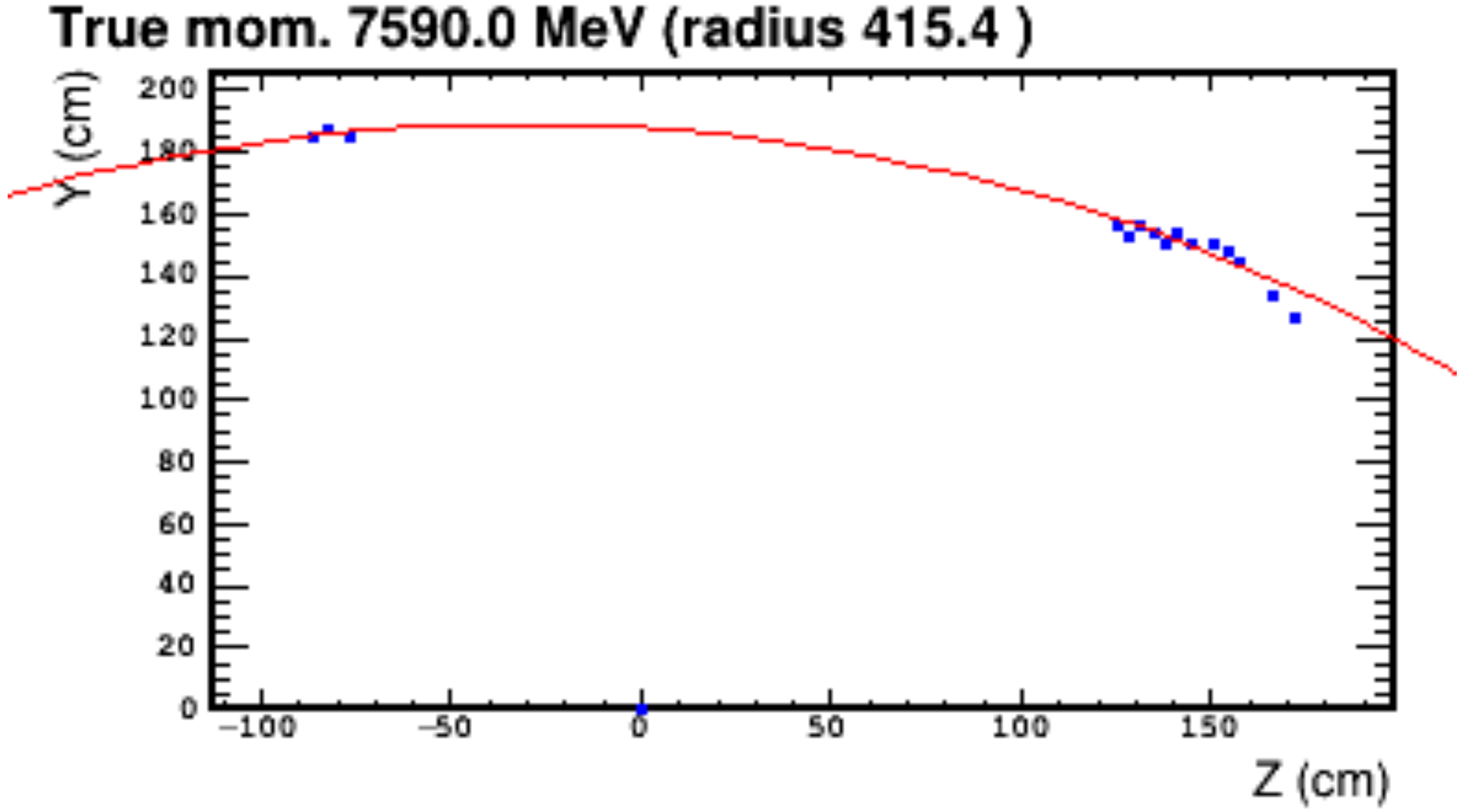


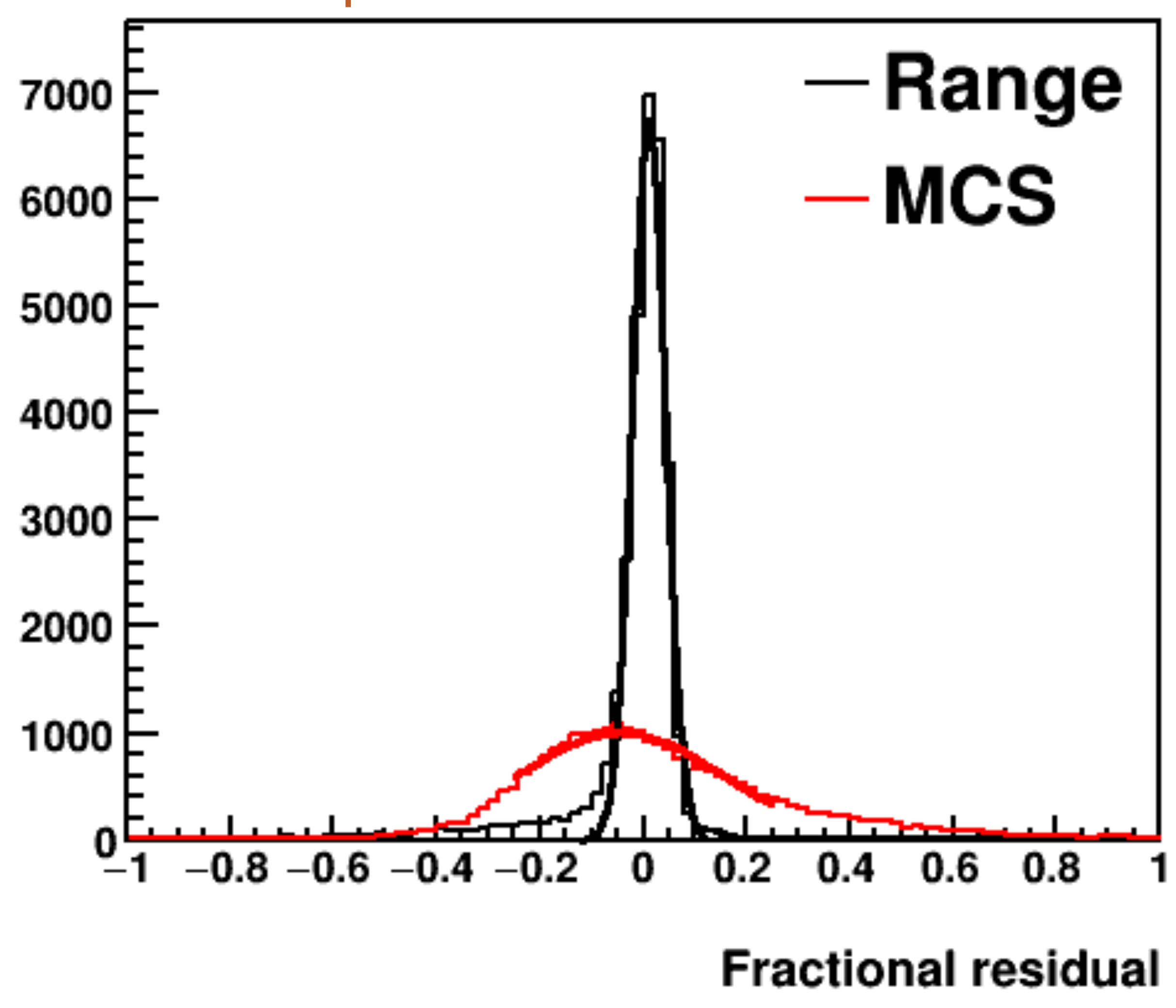
- Measure curvature measurements using circular fit
- Study still in progress. . . .

MUON SPECTROMETER REQUIREMENTS

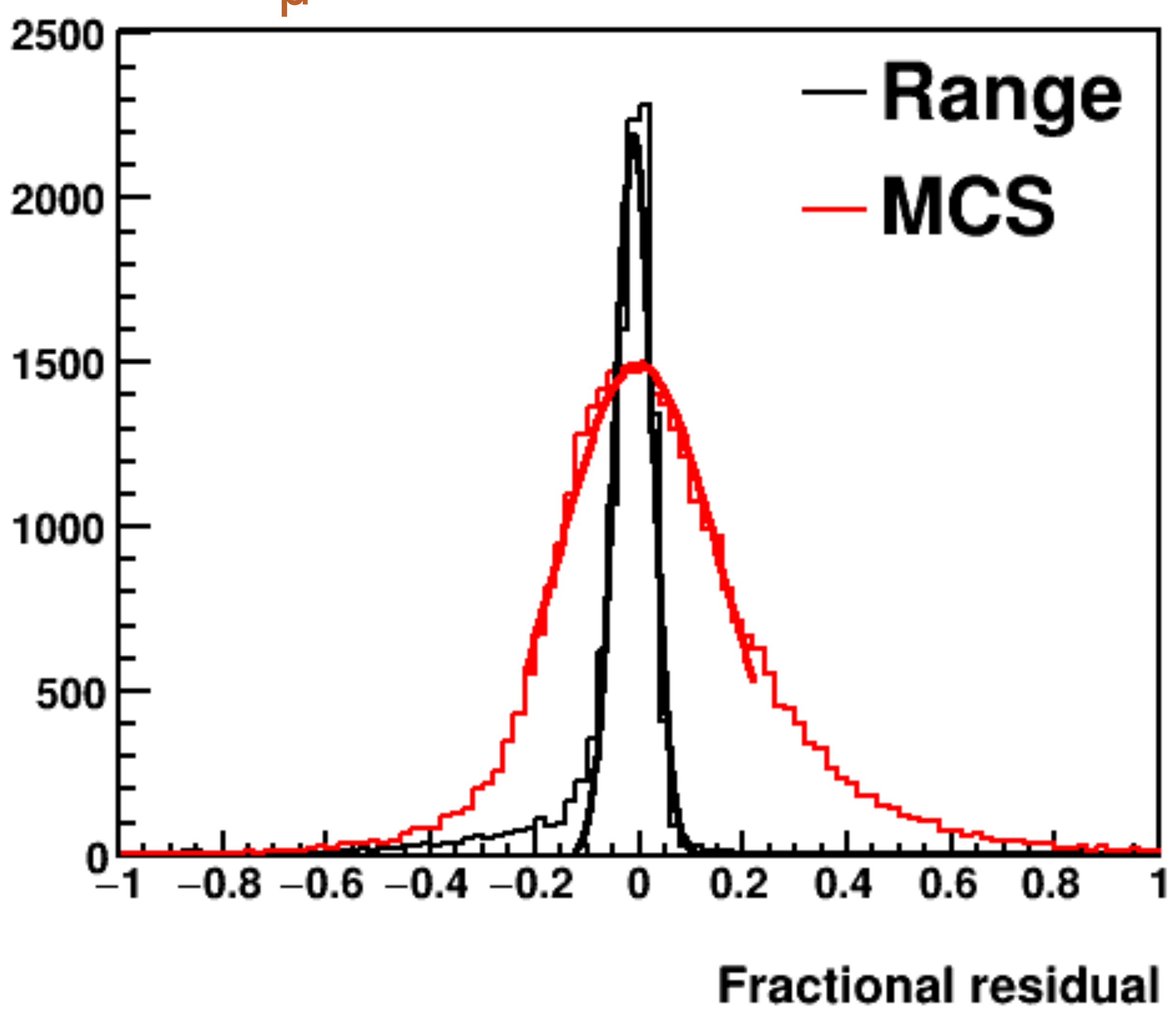
C. Marshall

- Recall overarching requirements:
  - O0: Predict the event rate at the far detector, O1: Measure the neutrino energy
- ND LAr is primary means by which near observations are translated to far predictions
  - However, many muons will not be stopped in LAr and must be measured in a spectrometer
  - Muons analyzed in spectrometer must measure momentum at least as well as by range in LAr at FD
  - These requirements must also be satisfied by MPD in its muon spectrometer role

P_μ = 1.0-1.5 GeV/c



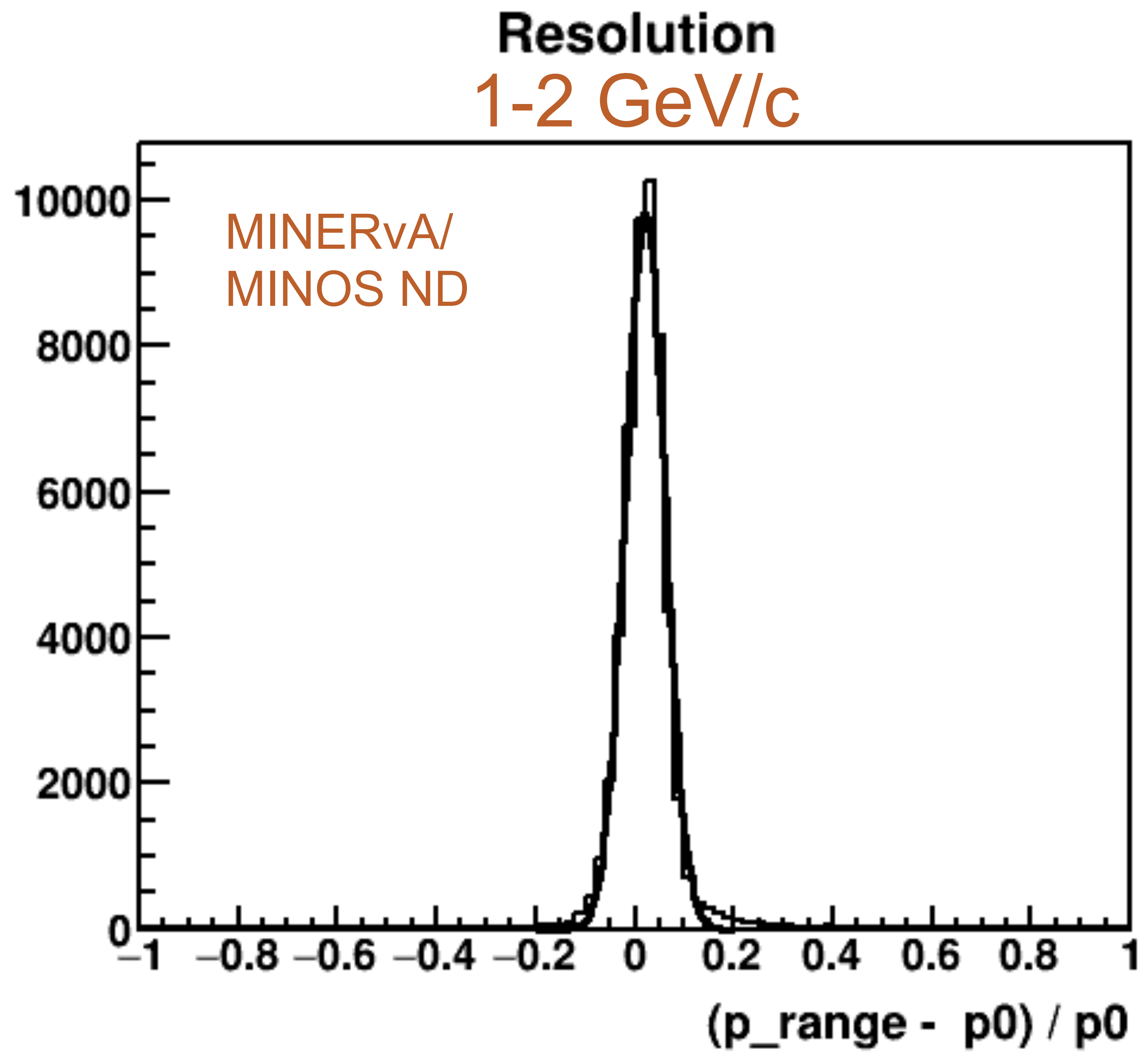
P_μ = 2.0-2.5 GeV/c

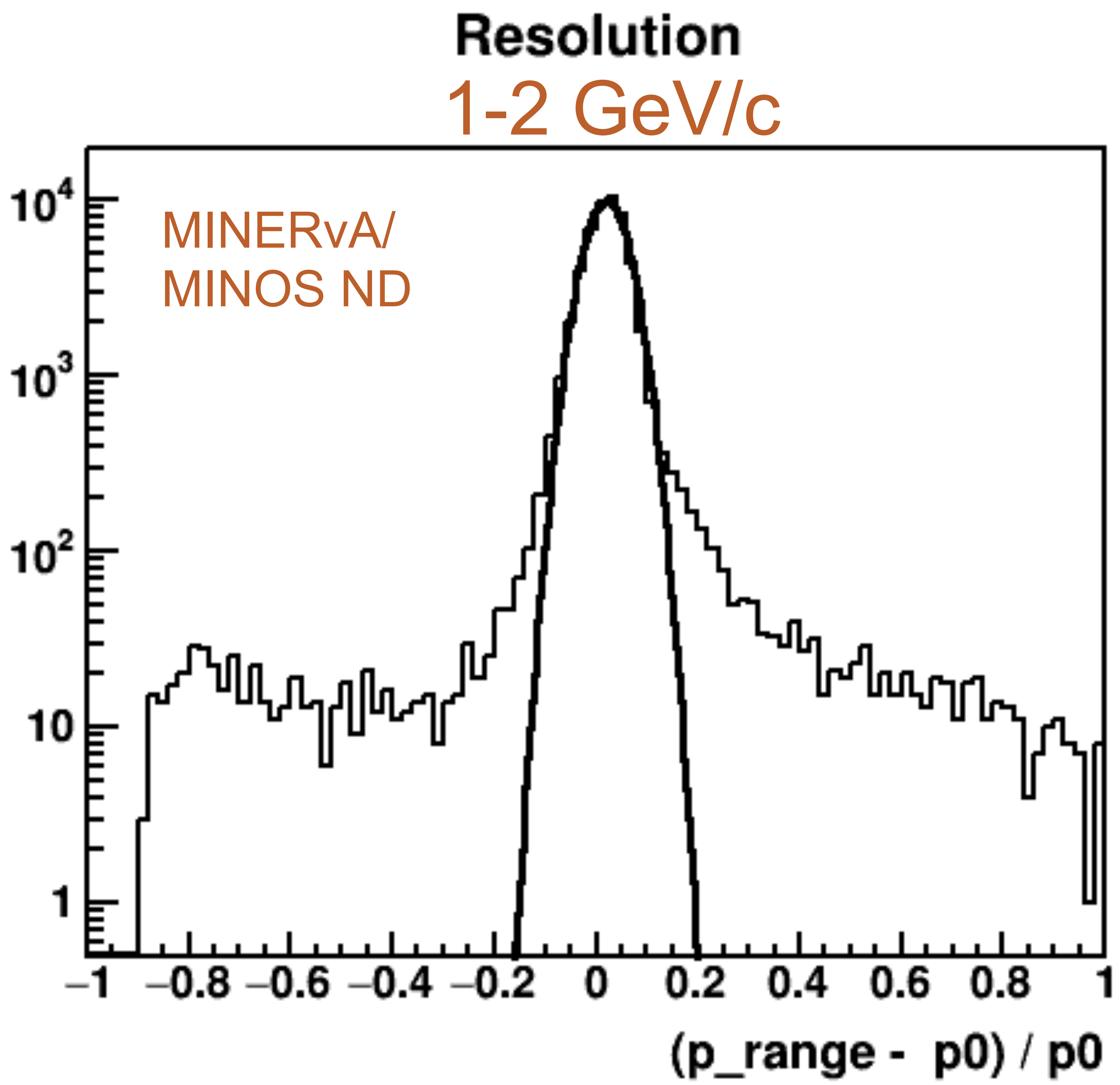


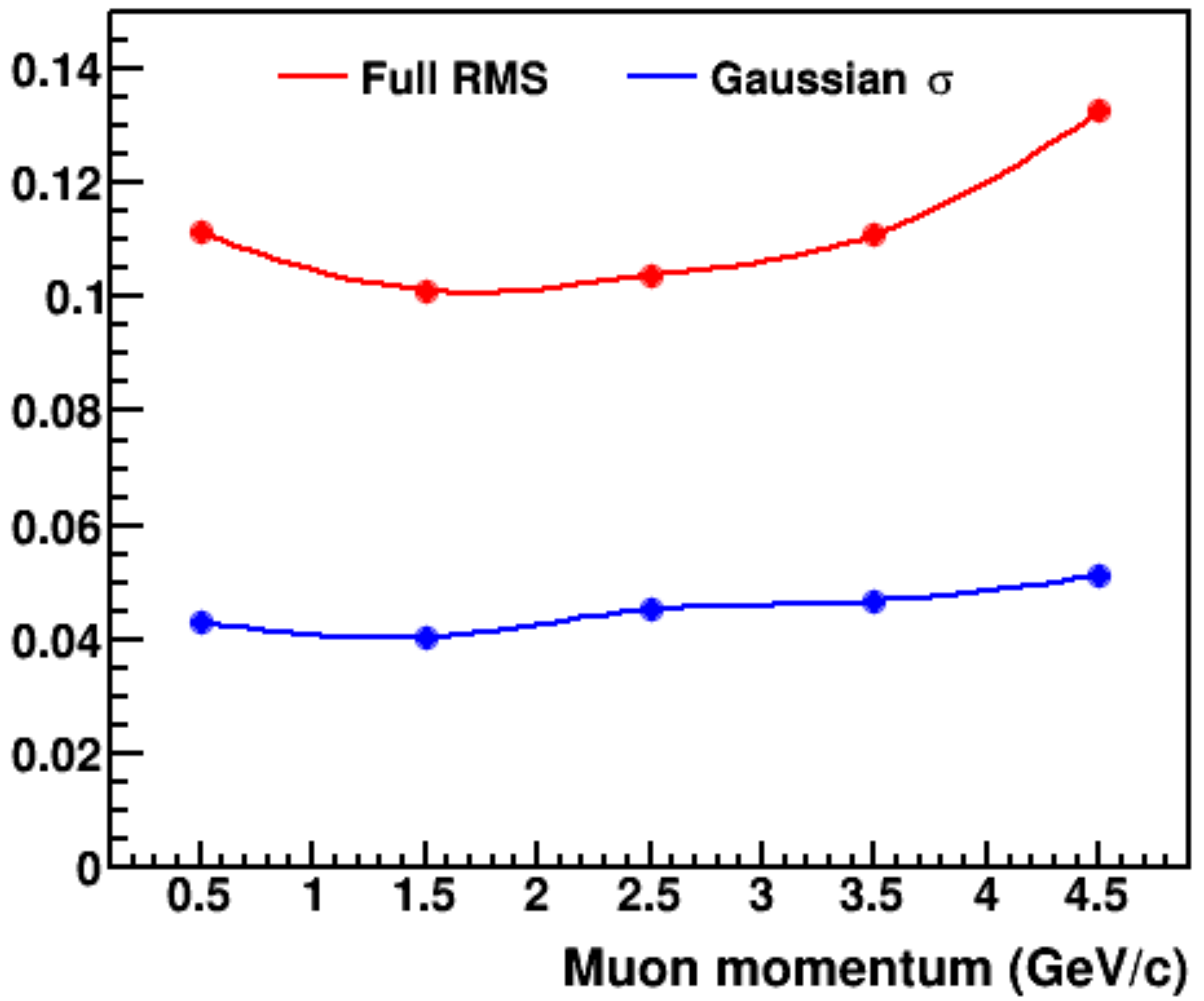
- "Core" resolution is ~4%
- RMS, including tail, is ~10%

MINOS ND SPECTROMETER

- 2.5 cm steel + 1 cm scintillator stack   T. Le, C. Marshall
- MINERvA simulation of MINOS near detector demonstrates that this configuration achieves ~4% core resolution, 10% RMS similar to what is achieved in LAr with range.
- Sign selection requirements are under investigation







REQUIREMENTS

NAME	LABEL	PRIMARY TEXT	VALUE	GOAL	RATIONALE	VALIDATION	NOTES	REFERENCE REQUIREMENTS	REFERENCE	NOTES
Descriptive name of specification		Text of requirement/ specification	Specification Value (Number + units)	Number plus unit	What drives/supports this requirement			Related requirements within this table	Relevant documentation	

- Follow template from far detector and construct a hierarchy

~Design agnostic

- Overarching:
  - Basic statements of what the ND must achieve. These have already been stated
- Measurements:
  - Key measurements that must be performed by the ND to fulfill the overarching requirements
  - e.g. flux measurement, beam monitoring . . . .

Design specific

- Capabilities:
  - Detector performance criteria required to perform measurements
  - e.g. acceptance, resolution, statistics, dynamic range (e.g. for PRISM), etc.
- Technical
  - Specifications (dimensions, mass, etc.) necessary to deliver capabilities
  - e.g. LAr: module dimensions, inactive material, pixel pitch, HV

A FEW NOTES:

- While the “top” layer of requirements should be design agnostic, the far detector is a major factor in the ND design.
  - The ND should perform measurements that specifically address the systematics of the FD
  - The choice of LArTPC as the far detector is a fundamental consideration in the ND design
  - This specifically motivates a LArTPC component in the near detector
    - And supporting measurements and systems that allow us to understand and verify the systematics for LArTPC
- Large LArTPCs face particular challenges in a high rate environment
  - Much of the ND design is motivated by the requirement of operating a LArTPC in high rate environment
- This may motivate some modifications in the overarching requirements.

CAPABILITIES

- The ND must make measurements on LAr with performance comparable to and transferable to the far detector for a representative sample of interactions on argon
  - For these interactions:
    - Detection methods should be as similar as possible to the far detector to relate and cancel detector systematic errors
    - Outgoing hadrons must be contained
    - Performance in efficiency, particle identification, resolution should be comparable to or exceed the far detector.
    - Muon resolution should be comparable to or exceed that of the far detector
    - There must be adequate statistics of $\nu_\mu/\bar{\nu}_\mu$ CC interactions which are the primary channel for study
- ND must make flux measurements via neutrino-elastic scattering
  - The ND must be able to identify these events with sufficient efficiency, purity, and statistics such that the expected statistical uncertainty in a run should be comparable to the expected systematic uncertainty of ~2%

CAPABILITIES

- The near detector must mitigate systematic errors arising from detector modeling at the far detector and the corresponding ND LAr measurements, and inform gaps in ND/FD LAr.
  - Efficiently detect particles through detection thresholds in the far detector
  - Perform detailed hadronic final state measurements which fully recover the multiplicity, identify, kinematics of the outgoing mesons for a representative sample, and protons well below the detection threshold in LAr
  - Detect, sign select, and momentum analyze outgoing hadrons to verify secondary interaction modeling
  - Detect, sign select, and momentum analyze outgoing e/μ to tag neutrino flavor
  - Verify acceptance modeling of the ND LAr measurements due to the low acceptance arising from size constraints.
- Beam Monitoring:
  - The ND must be able to detect spectral distortions in the on-axis beam corresponding to ~1 σ shifts in the beam parameters on the time scale of 1 week
- DUNE-PRISM:
  - The flux variations available to DUNE should access the full range of neutrino energies of interest for the analysis of neutrino oscillations, to the extent possible.

CONCLUSIONS:

- Based on the recommendations from the December LBNC meeting:
  - Beam monitor with a KLOE-only (magnet+ECAL) is under investigation
    - We believe that muon spectral information is a critical element of beam monitoring
    - Any option for beam monitoring should have sufficient capability to this end
  - Requirements for a temporary muon spectrometer are under investigation:
    - Performance standard is the far detector, e.g. muon momentum by range in LAr
    - Initial finding: MINOS-like Fe(2.5 cm)/Scintillator(1 cm) stack performs comparably to LAr μ-range
    - Sign selection requirements under investigation
- Overall Requirements are still under study
  - The CDR will provide a snapshot while work continues to complete these requirements