ND reconstruction from long-baseline perspective

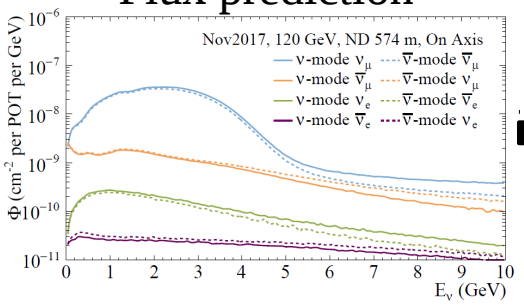
Chris Marshall
Lawrence Berkeley National Laboratory
24 July, 2019

Outline

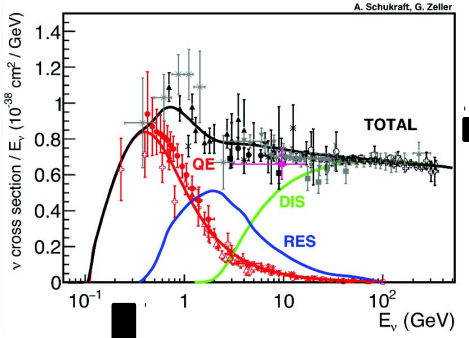
- LBL analysis overview & role of ND
- Current status, goals for ND TDR
- ND reconstruction uncertainties in LBL analysis
- Near-far cancellations

DUNE long-baseline oscillation analysis

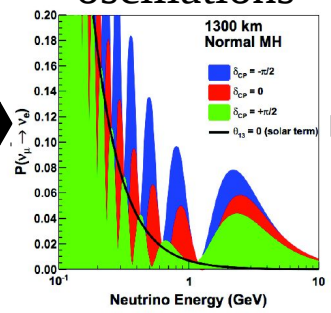
Flux prediction



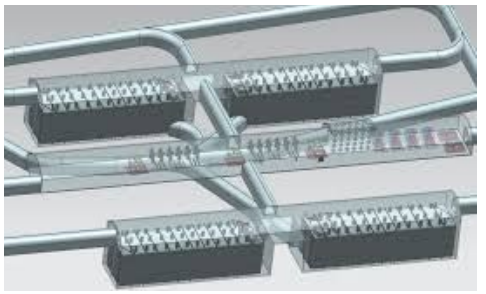
ν interaction model



oscillations



FD simulation



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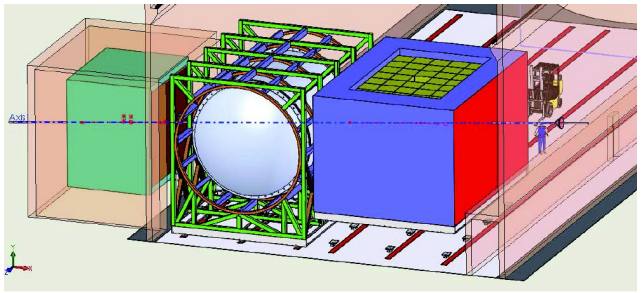
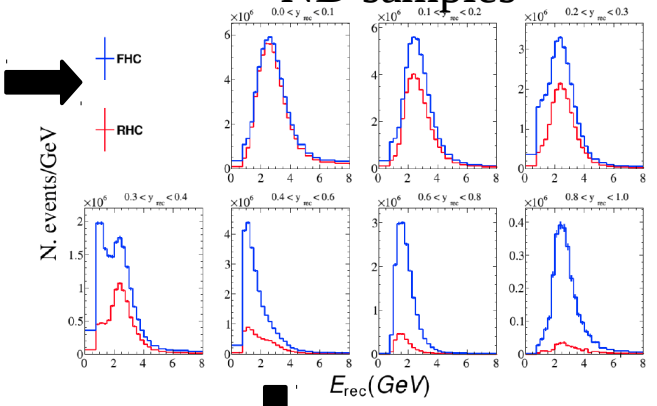


ND samples



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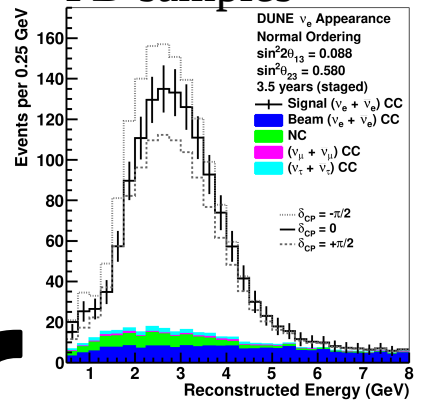
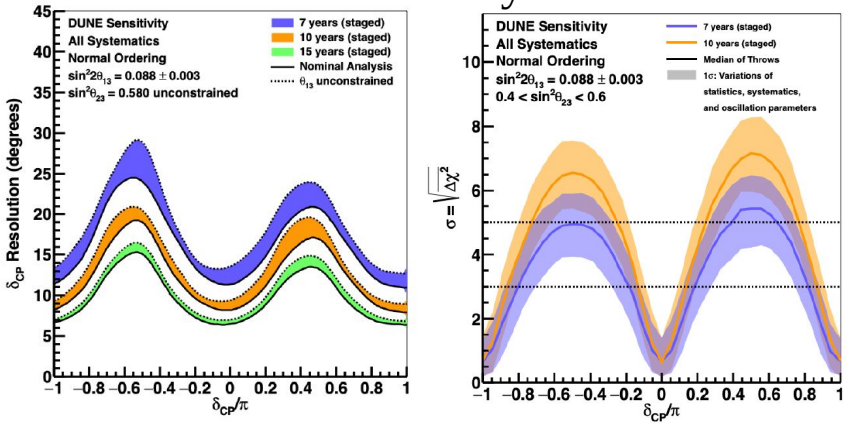
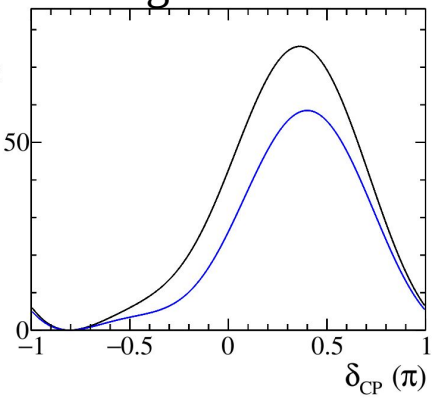


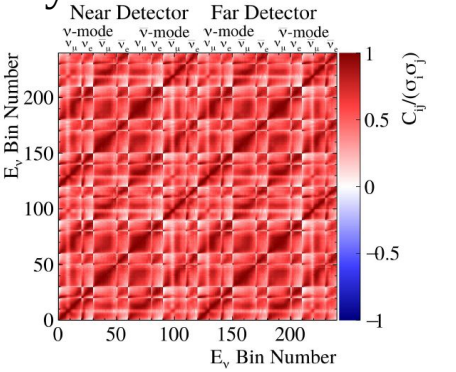
Oscillation sensitivity results



Fitting framework



Systematic uncertainties



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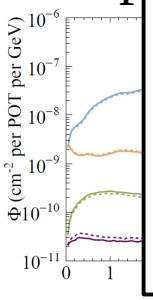
DUNE long-baseline oscillation analysis

Many ND samples will go directly into oscillation fits:
LAr CC events, ν+e → ν+e, exclusive final states,
Gas TPC, 3DST events, etc.



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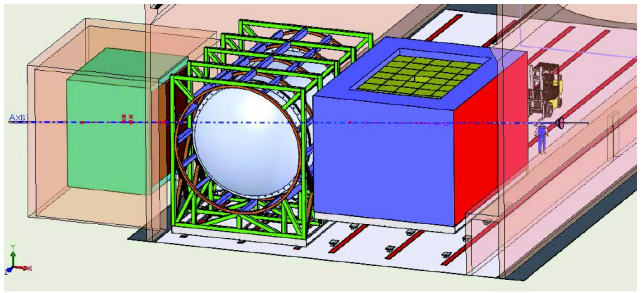
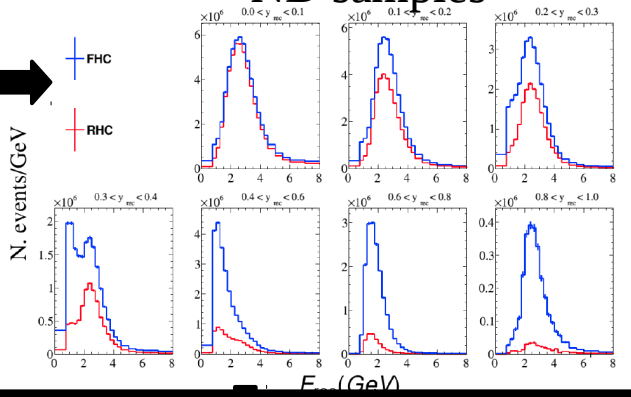


ND samples



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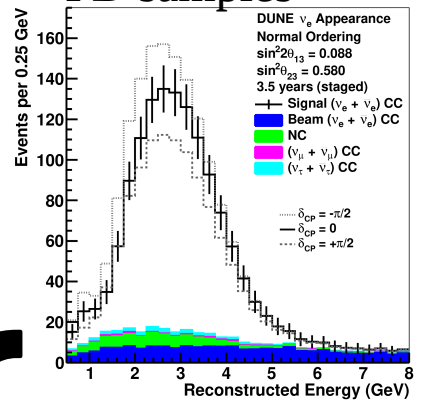

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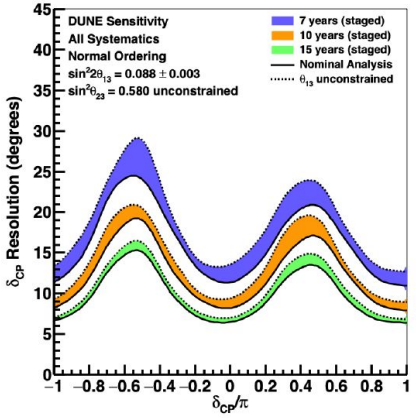

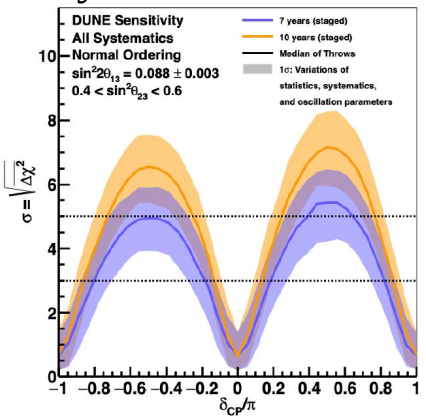

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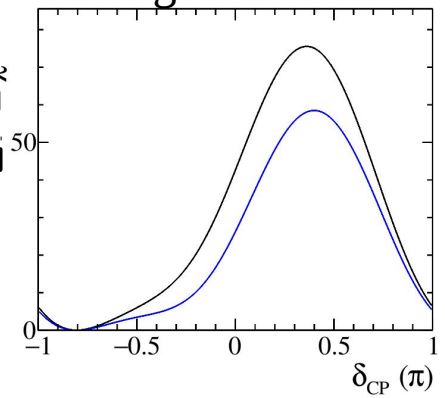

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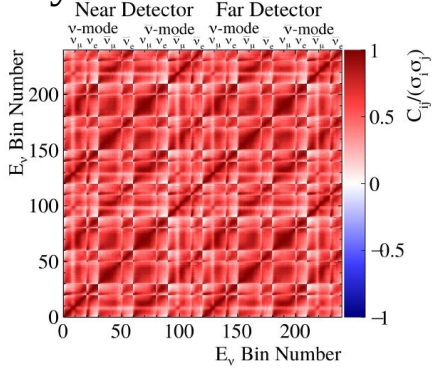

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DUNE long-baseline oscillation analysis

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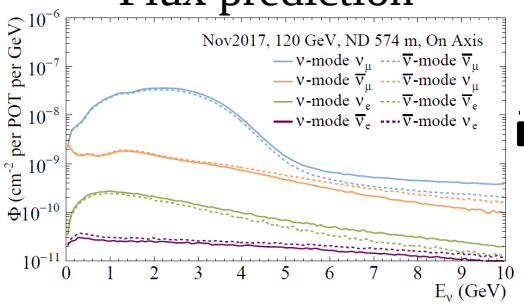

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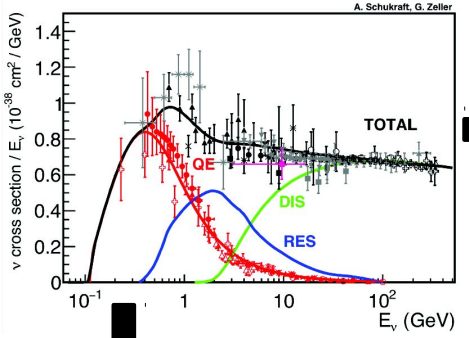

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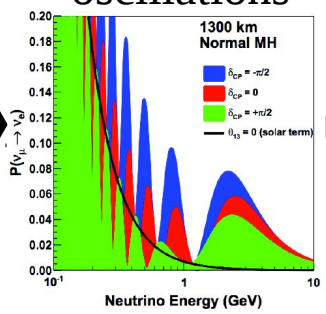

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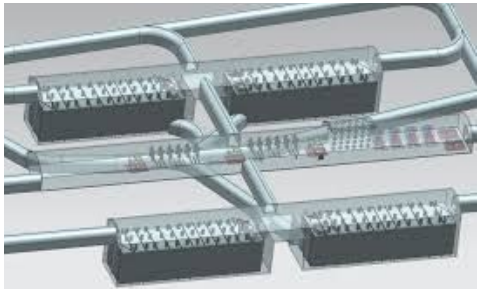
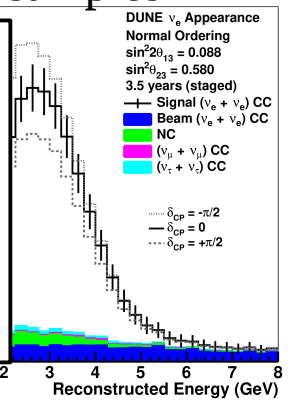


ND simulation

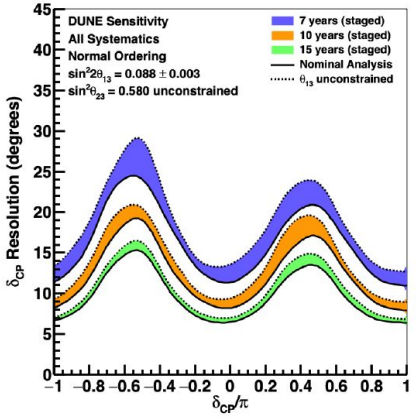
ND samples

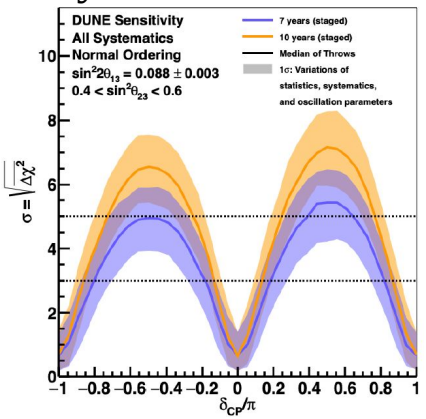
FD samples



Critical to have realistic systematic uncertainties for every sample included – we cannot add ND data to fits without associated systematics

Oscillation sensitivity results





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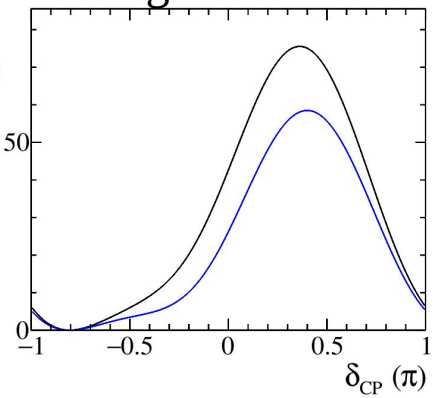

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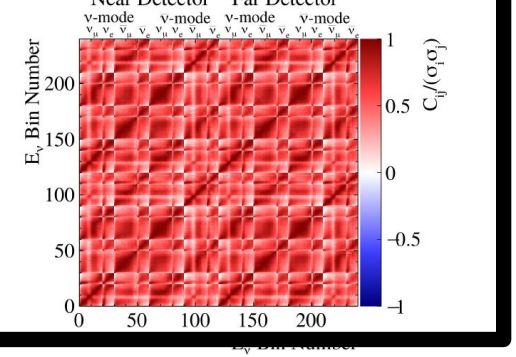

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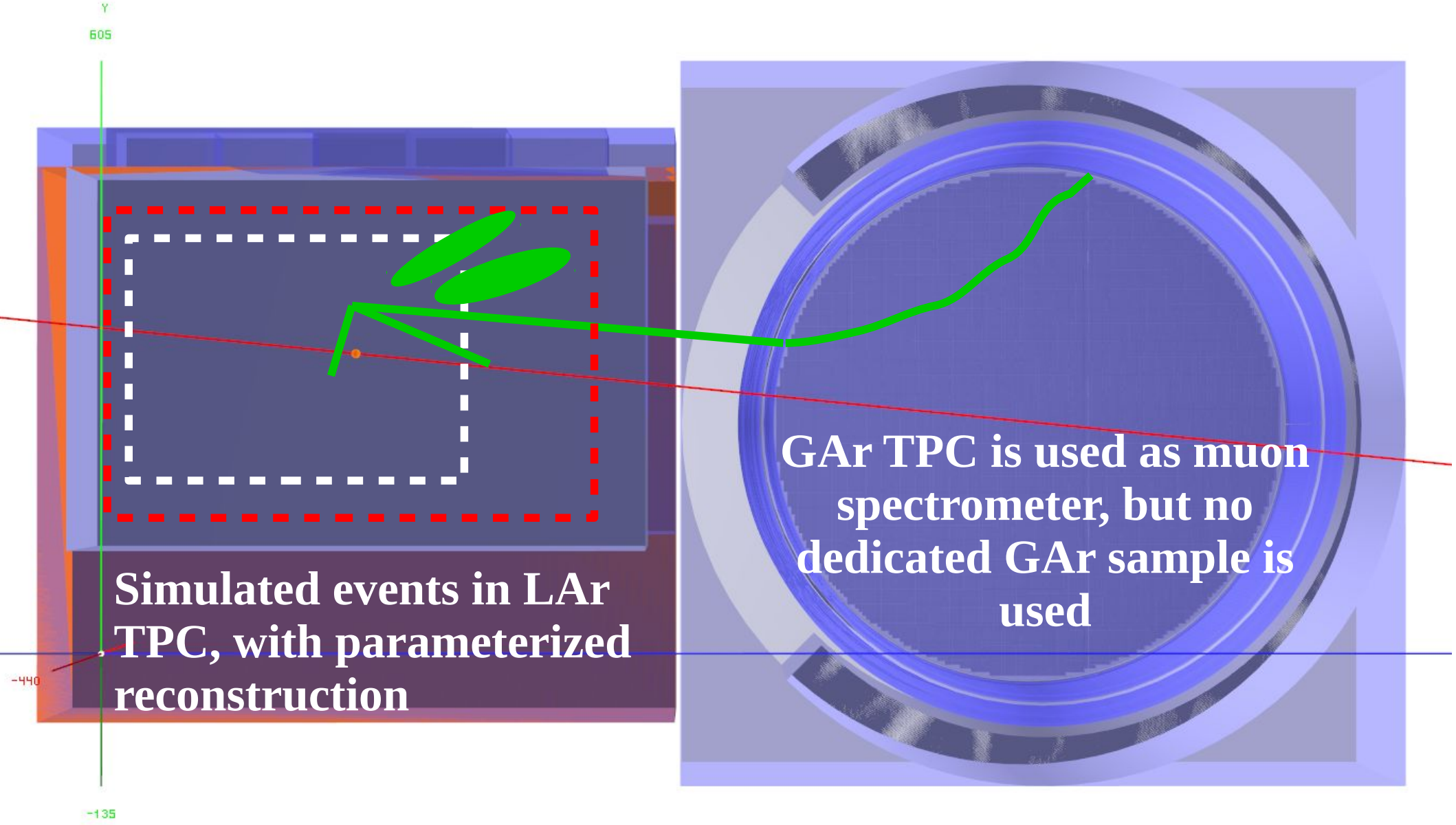
Current status of ND in LBL



Current status of ND in LBL

- For CDR, this level of study is sufficient
- Most urgent priority is building on existing work to demonstrate the physics case for each ND component, and demonstrate that ND as designed is sufficient for LBL measurements
- For TDR, we want to replace existing ND with full simulation + reconstruction

Role of ND in LBL analysis

$$P(\nu_\mu \to \nu_e) = \frac{\Phi_{\nu_e}(E_\nu, L)}{\Phi_{\nu_\mu}(E_\nu, 0)}$$

$$N_{\nu_e}^{far}(E_{reco}) = \int \Phi_{\nu_e}(E_\nu, L) \times \sigma_{\nu_e}(E_\nu) \times \epsilon^{far}(E_\nu) \times \mathbf{D}_{\nu_e}^{far}(E_\nu \to E_{reco}) dE_\nu$$

- Oscillation probabilities depend on fluxes at source & far detector
- But far detector observable (event rate vs. reconstructed neutrino energy) also depends on cross sections, energy smearing, acceptance

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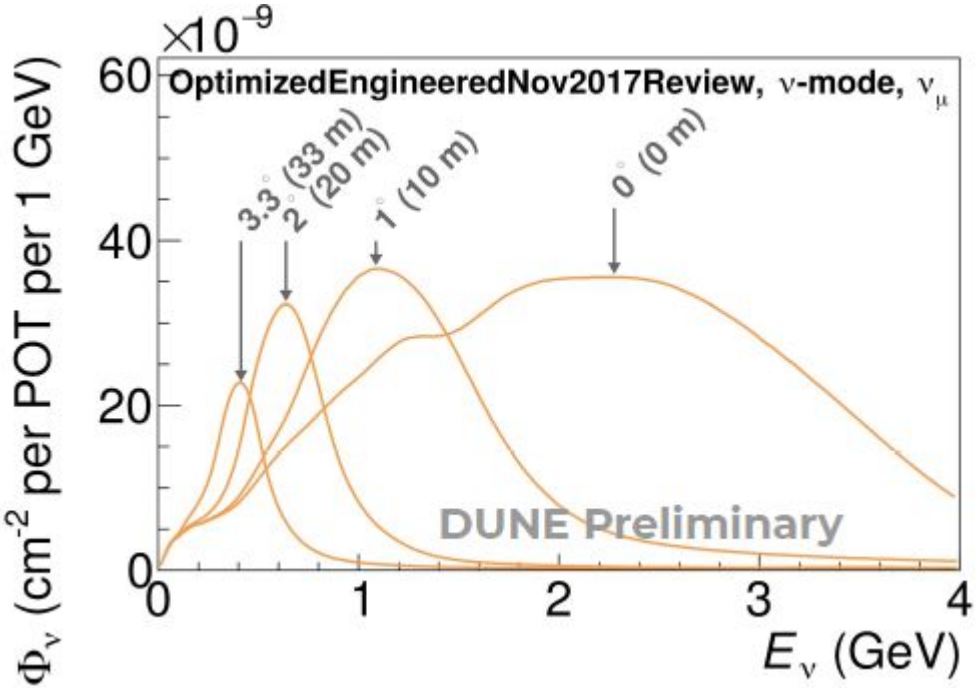
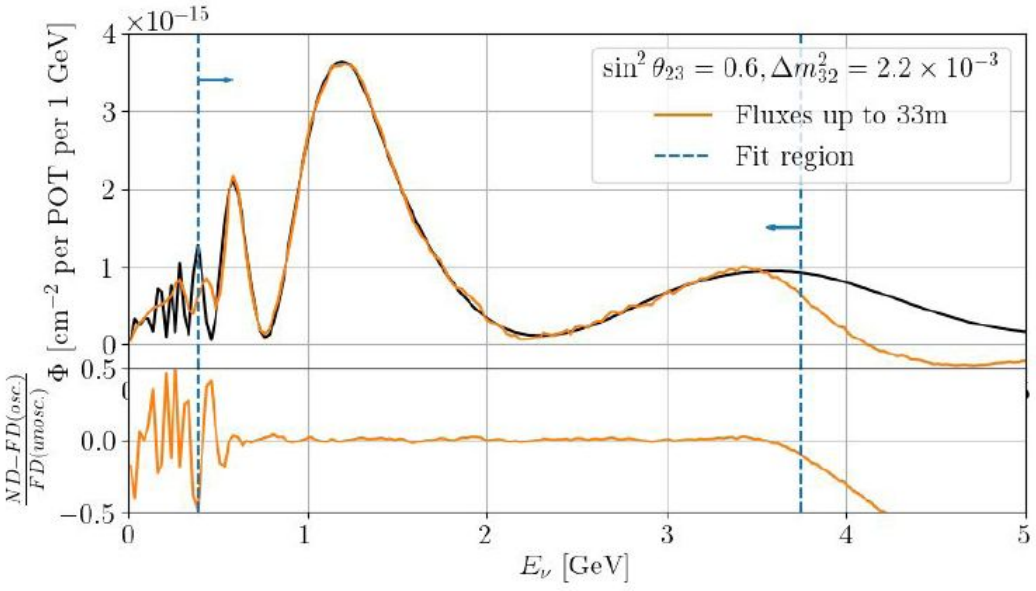
$$N_{\nu_\mu}^{near}(E_{reco}) = \int \Phi_{\nu_\mu}(E_\nu, 0) \times \sigma_{\nu_\mu}(E_\nu) \times \epsilon^{near}(E_\nu) \times \mathbf{D}_{\nu_\mu}^{near}(E_\nu \to E_{reco}) dE_\nu$$

- Near detector must measure flux, ν-Ar CC cross sections to high precision
- Must cover the full interaction phase space accessible at the far detector (i.e. all of it, 4π)
- LAr only: Make $\mathbf{D}(E_\nu \to E_{reco})$ as similar as possible to FD

DUNE-PRISM reco requirements





- Any differences between Eν → Ereco in ND and FD will need to be corrected with models
- There may be some cases where we don't want “as good as possible” in ND, we want “as close to FD as possible”
- This only applies to LAr, and it will be impossible to make it exactly the same

My personal goals for ND TDR long-baseline analysis

- Full sim+reco with up-to-date ND geometry, including samples from all ND components
  - LAr ν_μ inclusive CC
    - Maybe: 0π, 1π, 2π+ ?
  - LAr ν+e → ν+e
  - GAr ν_μ exclusive states: CC0π, 1π, with 4π muon measurement
  - 3DST sample T.B.D.
  - PRISM end-to-end analysis
- Reconstruction doesn't have to be perfect, but systematic uncertainties must be included (energy response, acceptance, etc.)

Integration requirements

- Definitely need LAr → MPD integration for muon tracking
- HPgTPC → Calorimeter integration probably required for gas TPC samples
- But samples are added as independent `CAFAna::Experiments`, so LAr, GAr, 3DST measurements can be separate

Energy uncertainties

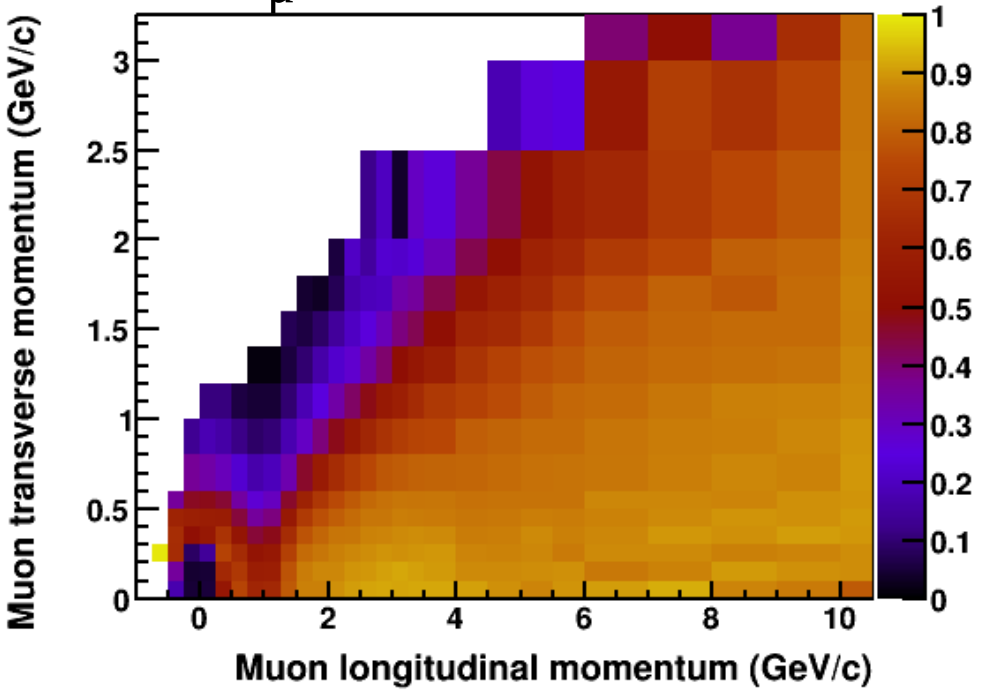
$$E'_{rec} = E_{rec} \times (p_0 \oplus p_1 \sqrt{E_{rec}} \oplus \frac{p_2}{\sqrt{E_{rec}}})$$

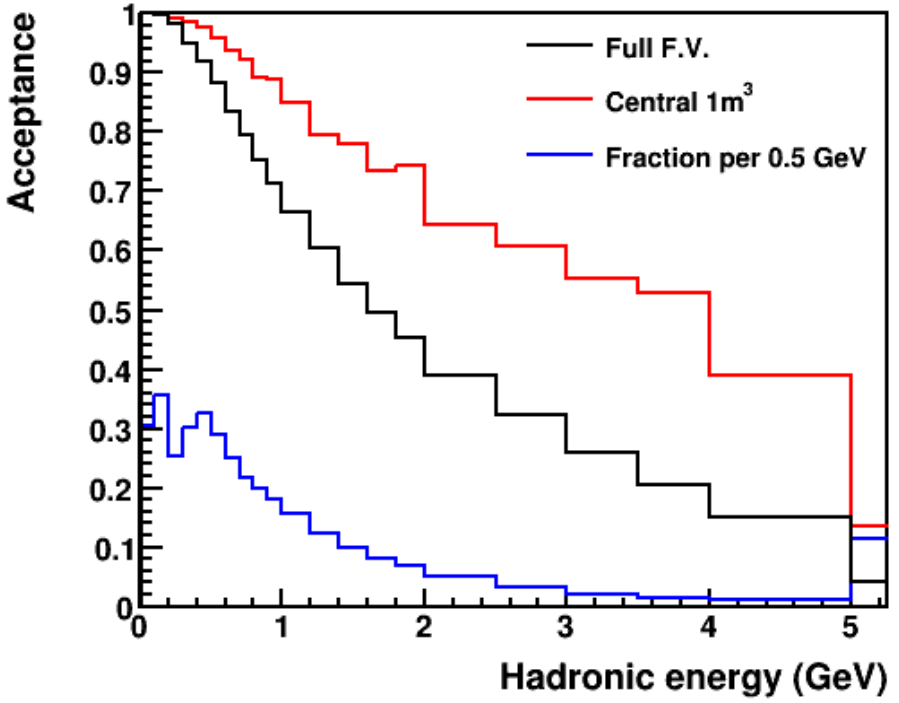
Particle	p_0	p_1	p_2
all (except muons)	2%	1%	2%
μ (range)	2%	2%	2%
μ (curvature)	1%	1%	1%
p, $\pi^{\pm}$	5%	5%	5%
e, γ, π^0	2.5%	2.5%	2.5%
n	20%	30%	30%

- Present: energy scale and energy resolution uncertainties are applied to each particle species
- No correlations between ND & FD are assumed
- Based roughly on achieved constraints by existing experiments, test beam results

LAr ND event acceptance

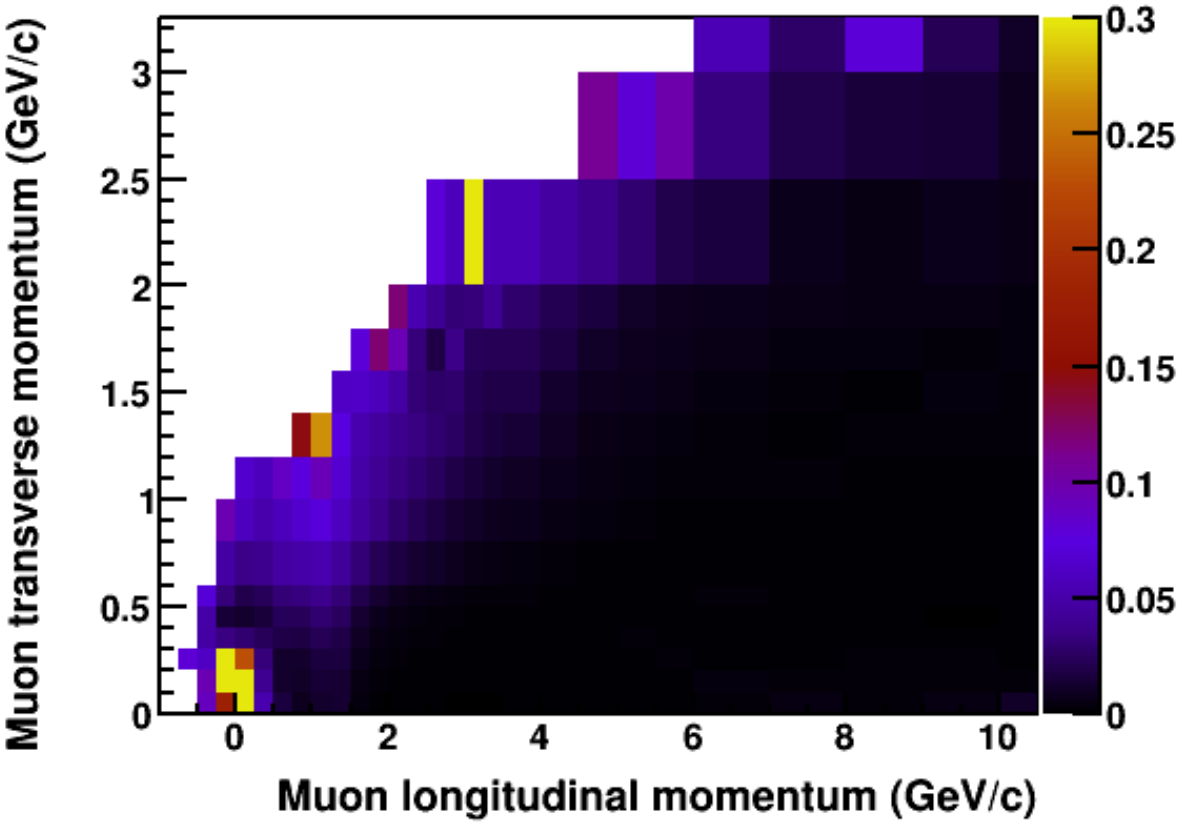
ν_μ CC acceptance





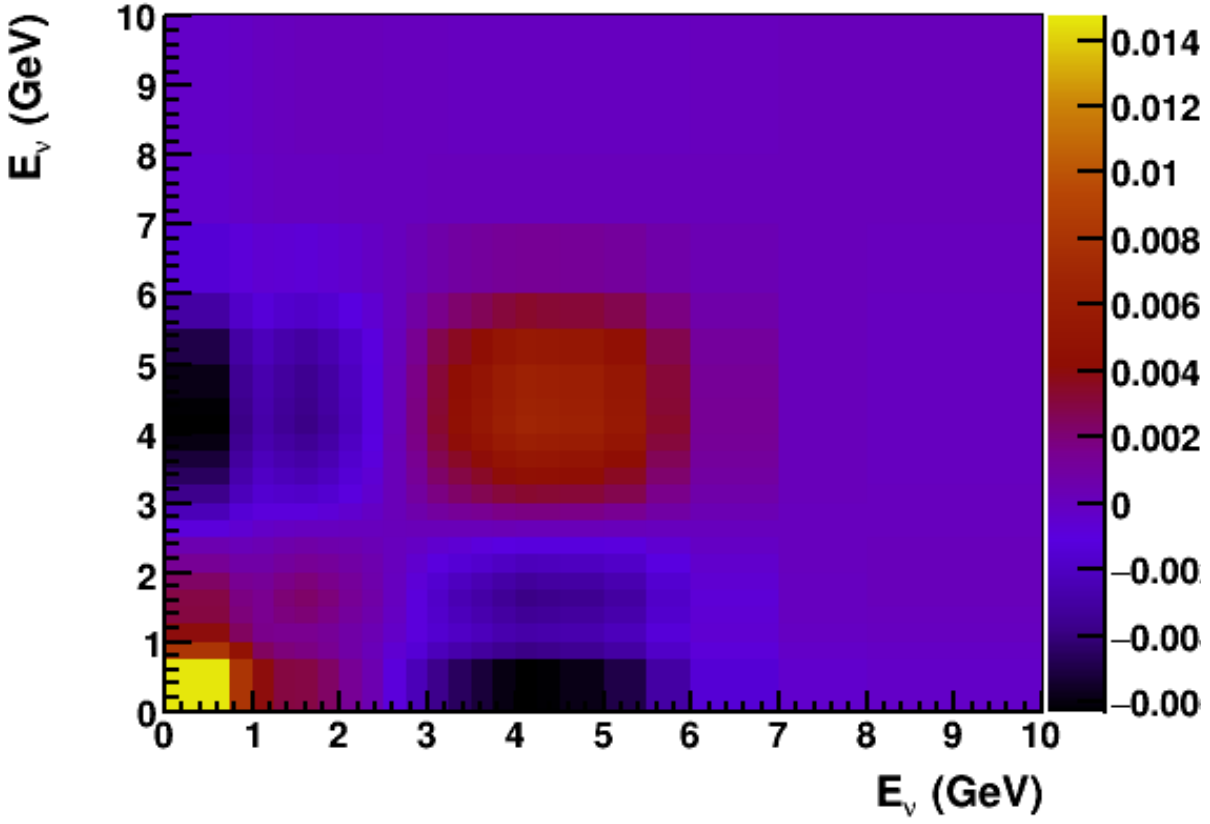
- Left: CC acceptance vs. muon kinematics
- Right: Acceptance vs. hadronic energy – events with exiting hadrons are rejected, hence the lower efficiency at very high energy

ND CC ν_μ acceptance fractional uncertainty



- CC events are rejected when
  - Muon is reconstructed as $\pi^{\pm}$ (low energy)
  - Muon exits sides
  - Muon exits downstream but does not enter gas TPC
- Acceptance is sensitive to detector modeling in phase space where muon acceptance is rapidly changing
- Uncertainty is evaluated as a function of muon momentum in transverse and neutrino direction (equivalently, energy and angle)

ND uncertainty implementation in covariance matrix

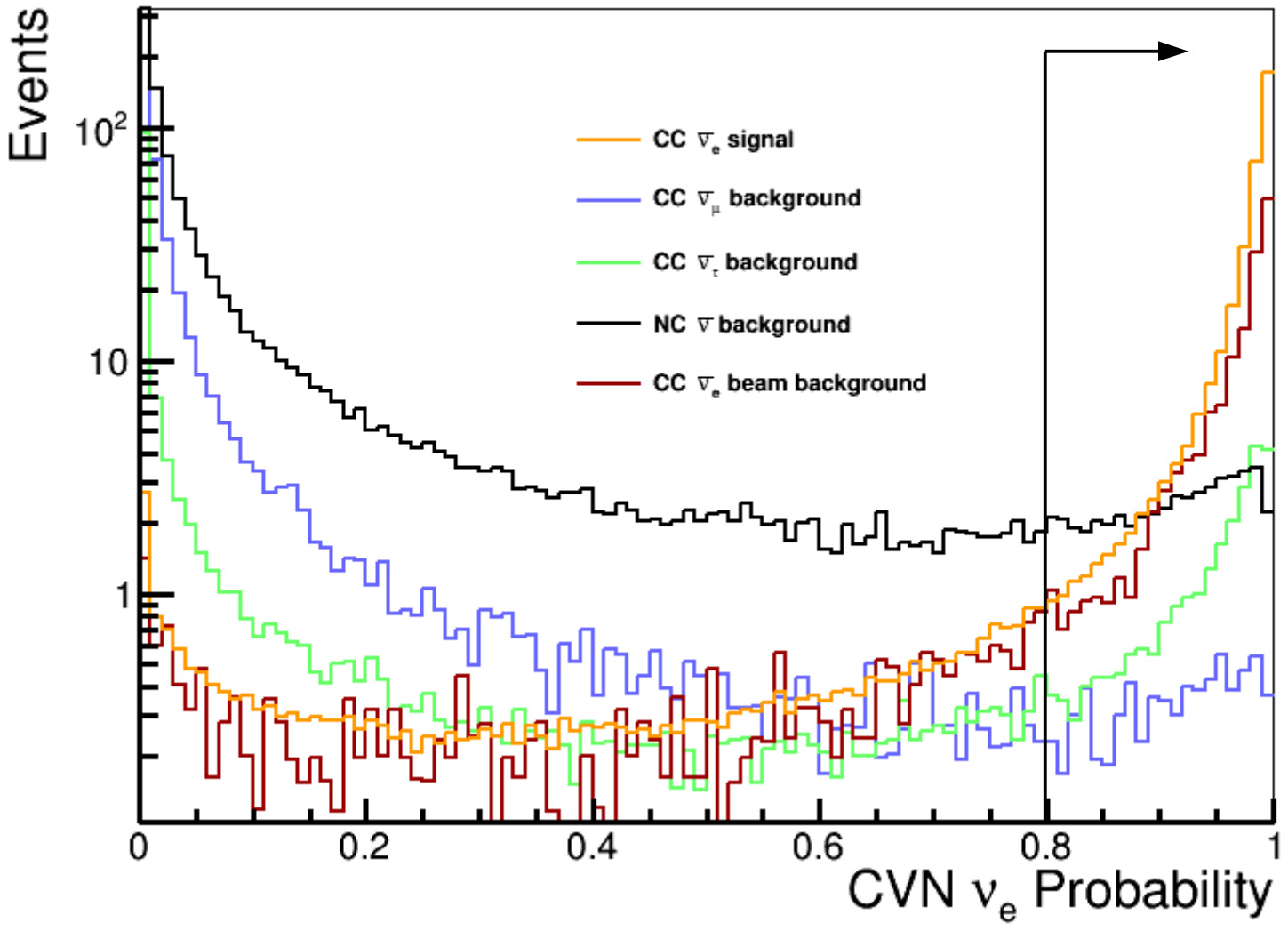


- Construct a covariance matrix in (E_ν, y) from the ND uncertainties with many universes approach
- Equivalent to including nuisance parameters in fit, but prevents these parameters from being further constrained by the ND data

Near-Far cancellations

- Existing LBL analysis assumes zero near-far correlation in detector uncertainties
- Calibration-driven uncertainties (absolute energy scale) are not expected to be correlated
- Particle response (what is the visible energy of a 400 MeV π^+ in LAr?) **should** partially cancel
- Implementation: nuisance parameters that affect FD energy, and are allowed to be constrained by ND data

Backgrounds



- NC is dominant background, most is single π^0
- Also $\tau \rightarrow e$, and smaller contribution from μ CC

Summary