MINERvA Flux Work/Strategy

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Outline

1. Basic MINERvA Strategy
2. Hadron Production
   - Etas
   - Reweighting outside the target
   - MIPP K/π ratio
3. Low-nu technique
4. Beam Fits
5. νe scattering

Foundation Hadron Production (Leo and I)

Methodology Low-nu technique (Josh Devan, Lu Ren, Donna Naples, Arie Bodek, Jeff Nelson)

Refinement Multi-beam fits (Leo)

Reinforcement νe scattering (Jaewon Park), monitors (Majo).

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What do we reweight?

Technique is to reweight interactions in neutrino anscestry.

MC=G4NUMI, FTFP-Bert, G4 version 9.2.p03

- $pC \rightarrow \pi^{\pm}X$ for $x_F < 0.5$ using NA49 @ 158 GeV.
- Also, some higher x_F using Barton @ 100 GeV.
- $pC \rightarrow K^{\pm}X$ for $x_F < 0.2$ using NA49 (G. Tinti thesis) @ 158 GeV.
- Weights applied for $12 < p_{\text{incident}} < 120\,\mathrm{GeV}$. Data cross-section scaled via Fluka. Checked $pC \rightarrow \pi^{\pm}X$ using NA61 @ 31 GeV

This was as of August 2013

New additions & Todos

New stuff

- Fixed a bug in the cross-section calculation.
- Applying weights to interactions outside the target.
- $pC \rightarrow K^{\pm}X$ for $0.2 < x_F < 0.5$ using MIPP K/π ratio.

Todos

- Transition away from model spread uncertainties where possible. Requires a code reorg.
- Deal with K_S and K_L via quark counting formula.
- Incorporation of $pC \rightarrow nX$ data from NA49, w/ Ben Messerly (Pitt).
- Will do "something" about pion incident. Have surveyed the small amount of data available.
- Neutron incident via "isospin considerations"?

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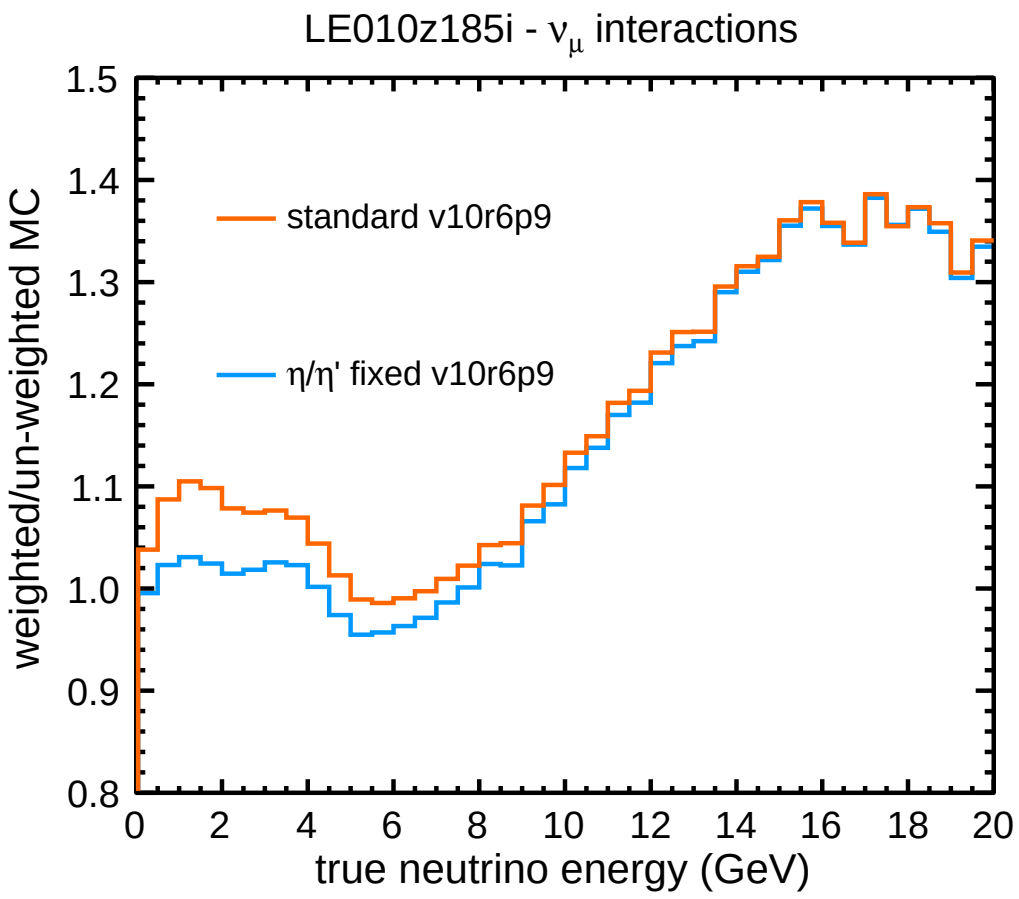
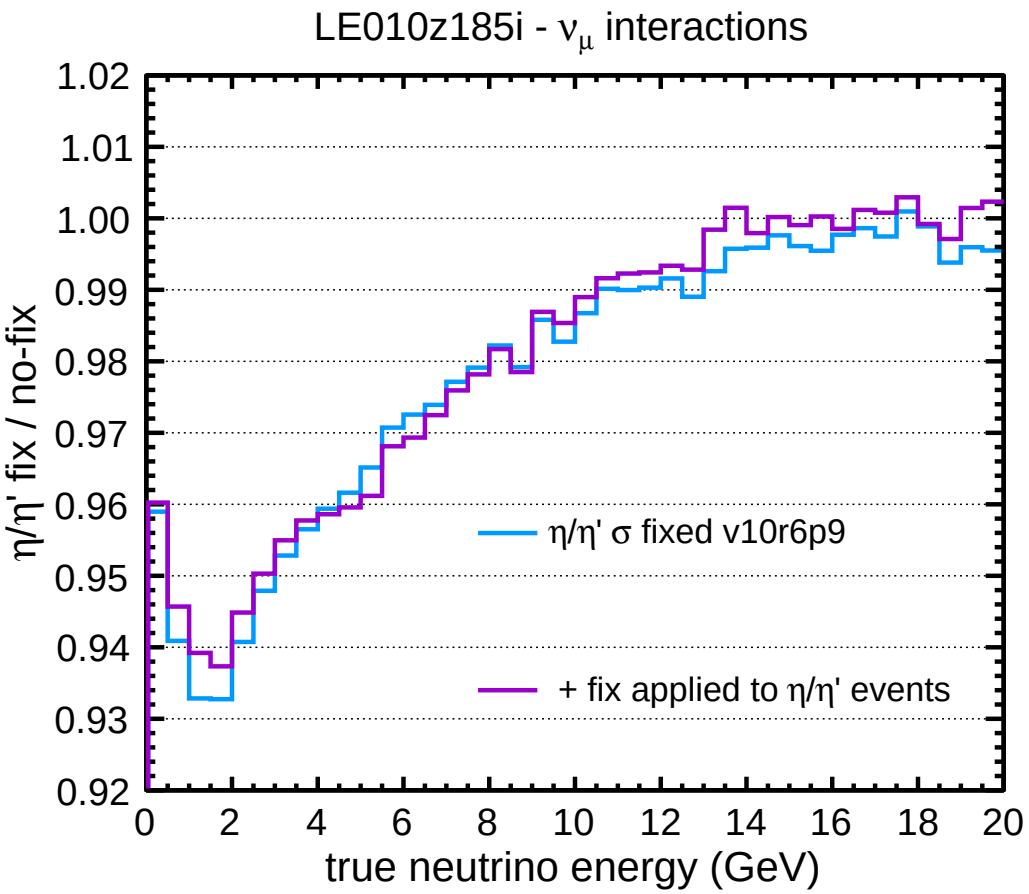
Improper etas

For a while, we were neglecting eta meson production events when calculating cross-sections and appling HP reweighting. We were expecting these to be decayed. Interesting note: a problem for NA61 too.



etas, more clearly



This fix reduces the MC prediction at all energies. The effect is most noticable in the peak, where we get as large as a 6% reduction. Now also reweighting events with an η, η' and other quickly decaying particles.

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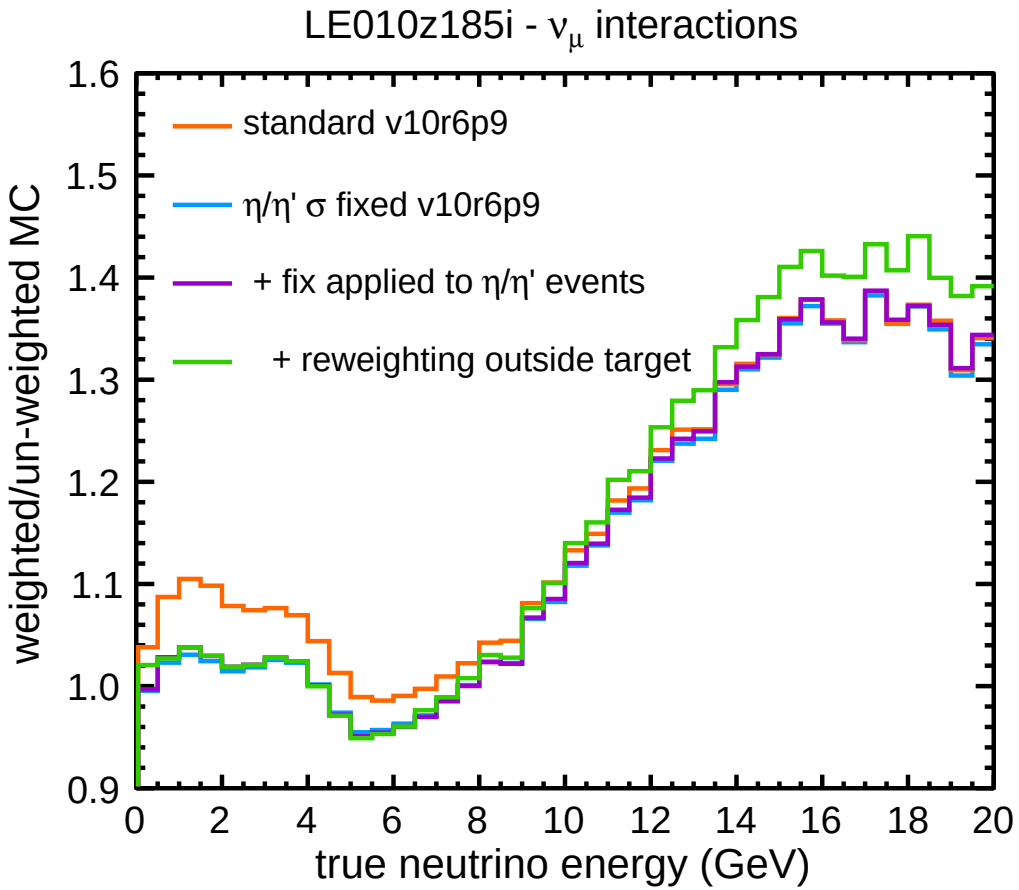
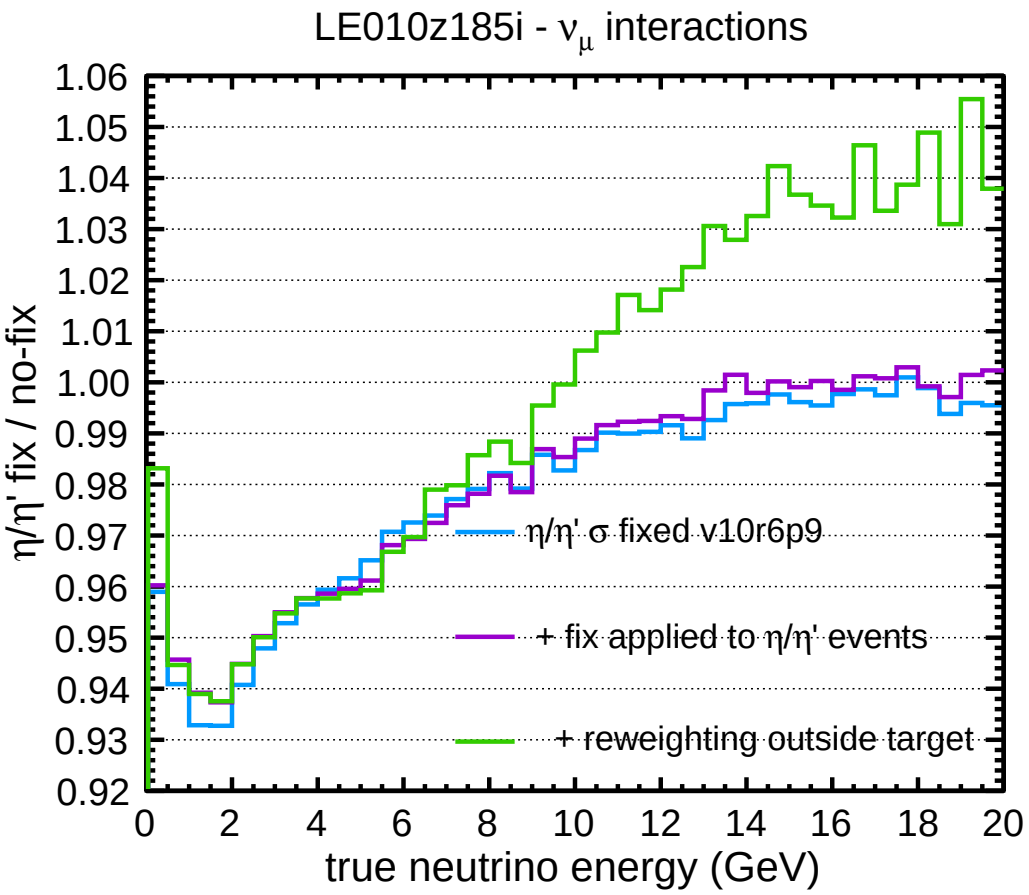
Reweighting outside the target

Now applying reweighting to interactions on other materials, treating them like carbon. Specifically, `DPIP` (Fe), `DVOL` (He), `HORN1IC`, `HORN2IC` (Al), `TARG` (Air). 99% of interactions occur in these volumes or `TGT/BudalMonitor`.



Reweighting outside the target

Result: increases the MC prediction by a few % in the high energy tail.



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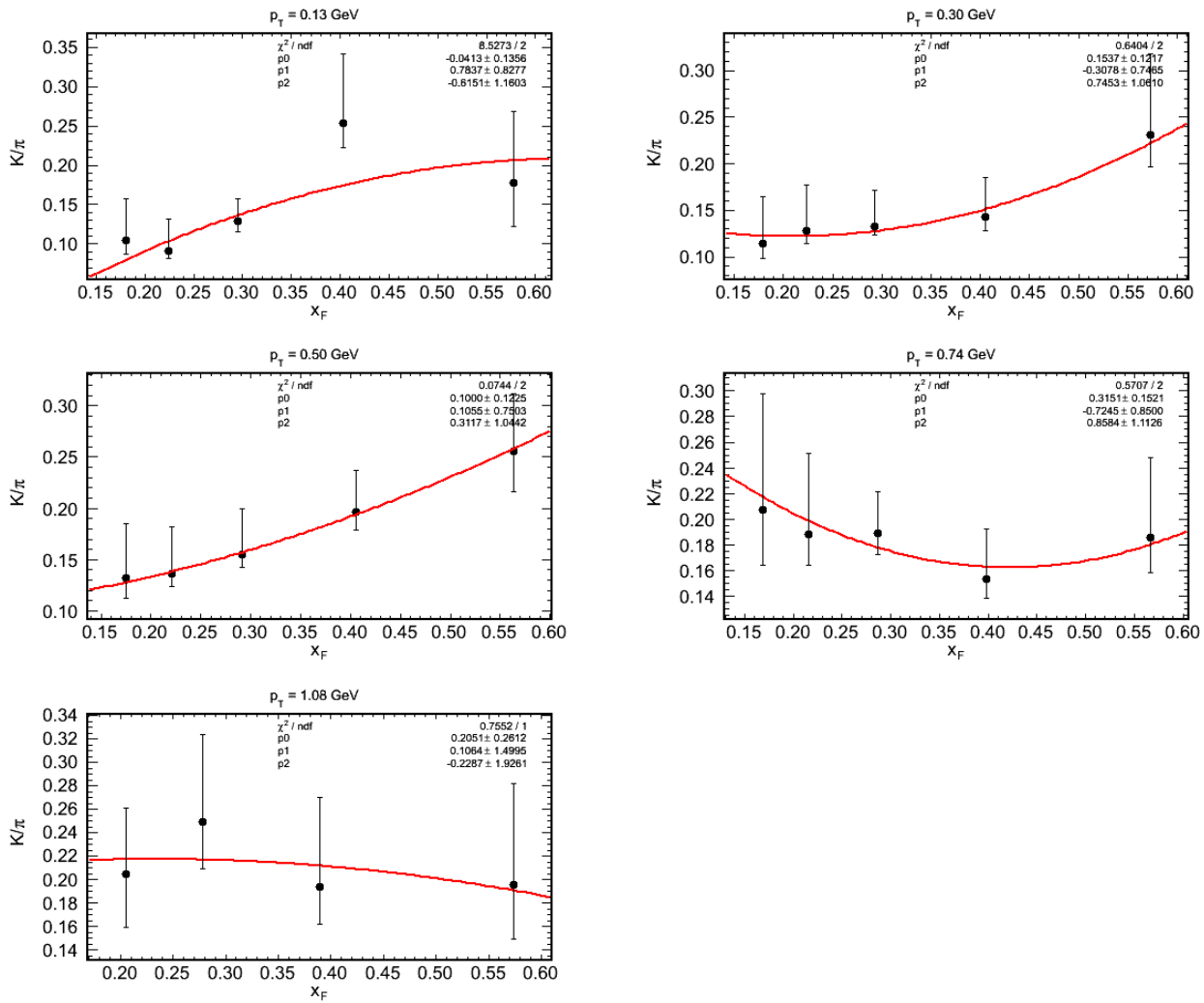
MIPP K/π data

- A. Lebedev thesis. $pC \to \pi, K$ @ 120 GeV. Thin target.
- Ratio as a function of x_F at five values of p_T
- Cover $0.2 < x_F < 0.5$.
- Parameterized by me as $A + Bx + Cx^2$. Covariance matrices saved for later.

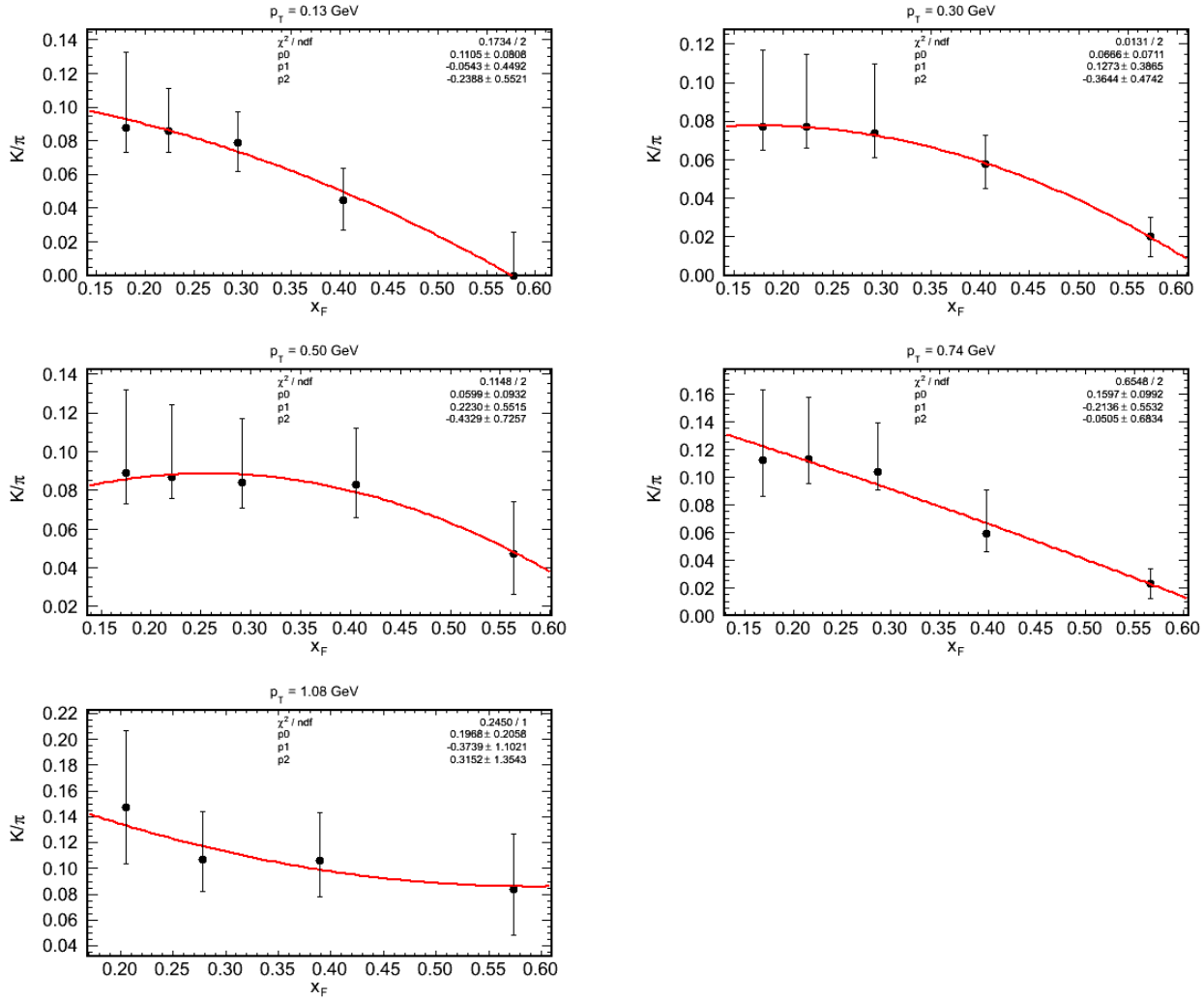
K^+/π^+ ratios

$p_T = 0.15, 0.3, 0.5, 0.75$ and $1.08\,\mathrm{GeV}$



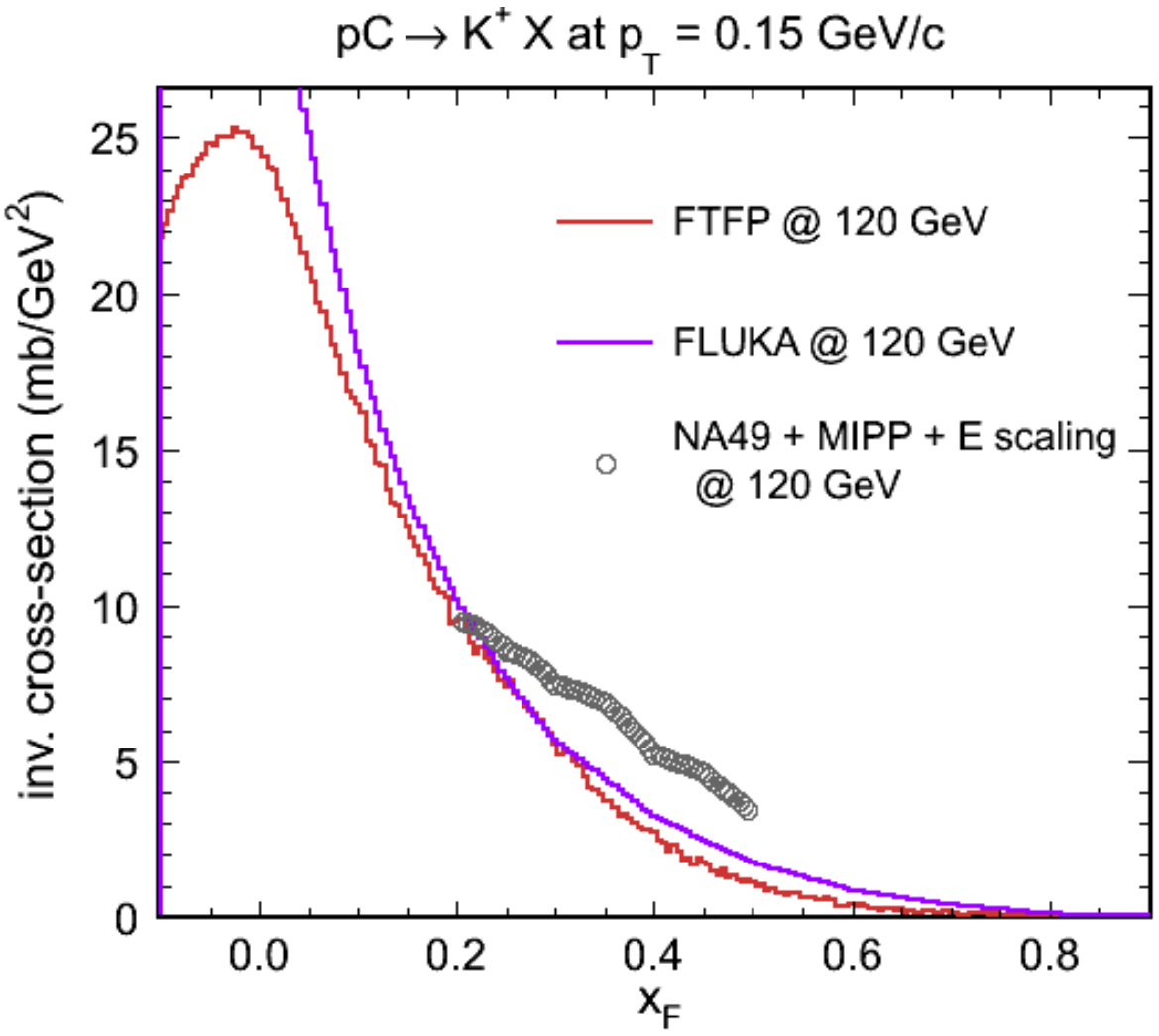
K^-/π^- ratios

$p_T = 0.15, 0.3, 0.5, 0.75$ and $1.08\,\mathrm{GeV/c}$



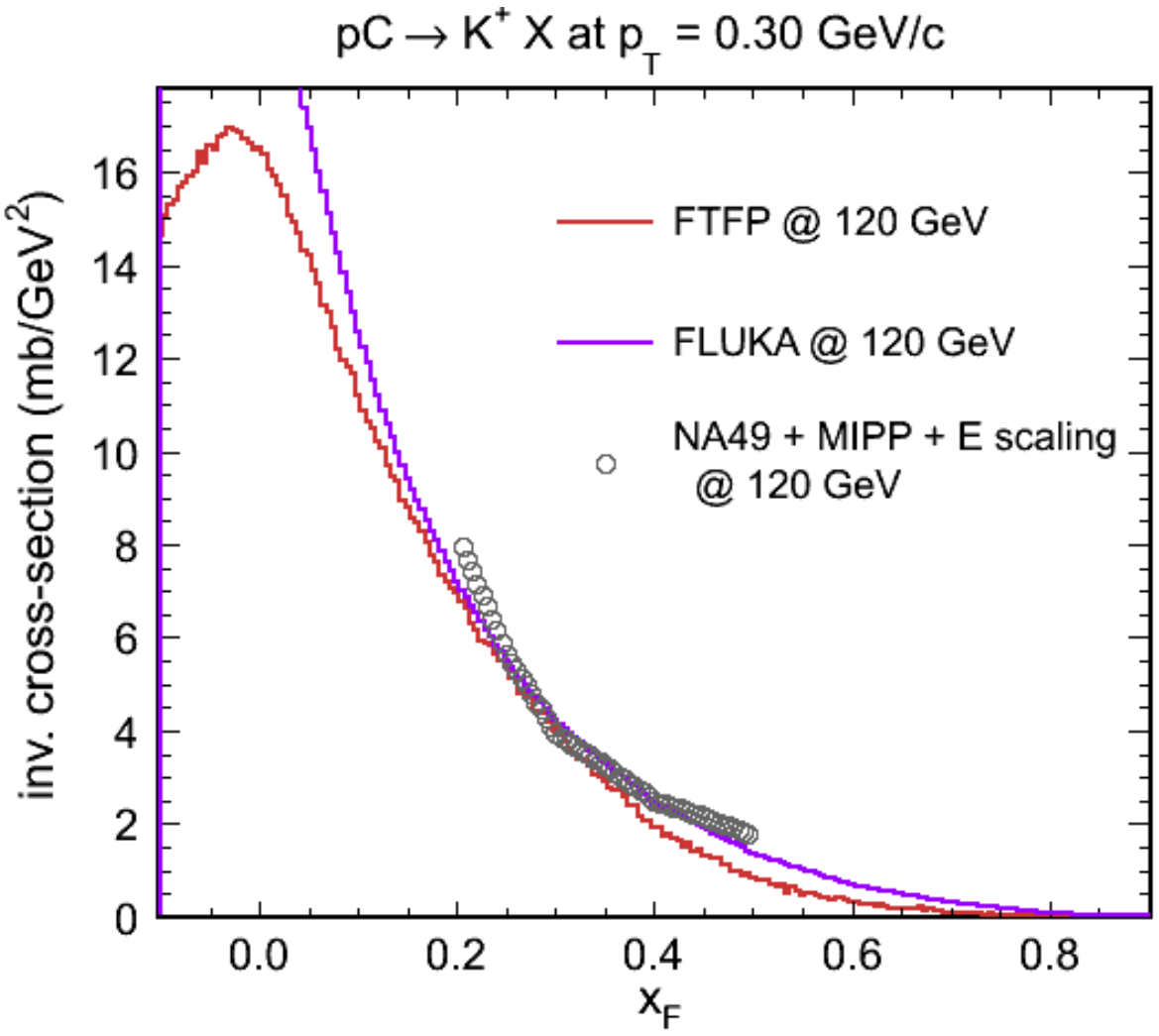
Predicted cross-section, $p_T = 0.15\,\mathrm{GeV/c}$

Predict K production cross-section using $K/\pi \times \sigma_{\mathrm{NA49}}(pC \to \pi X)$.



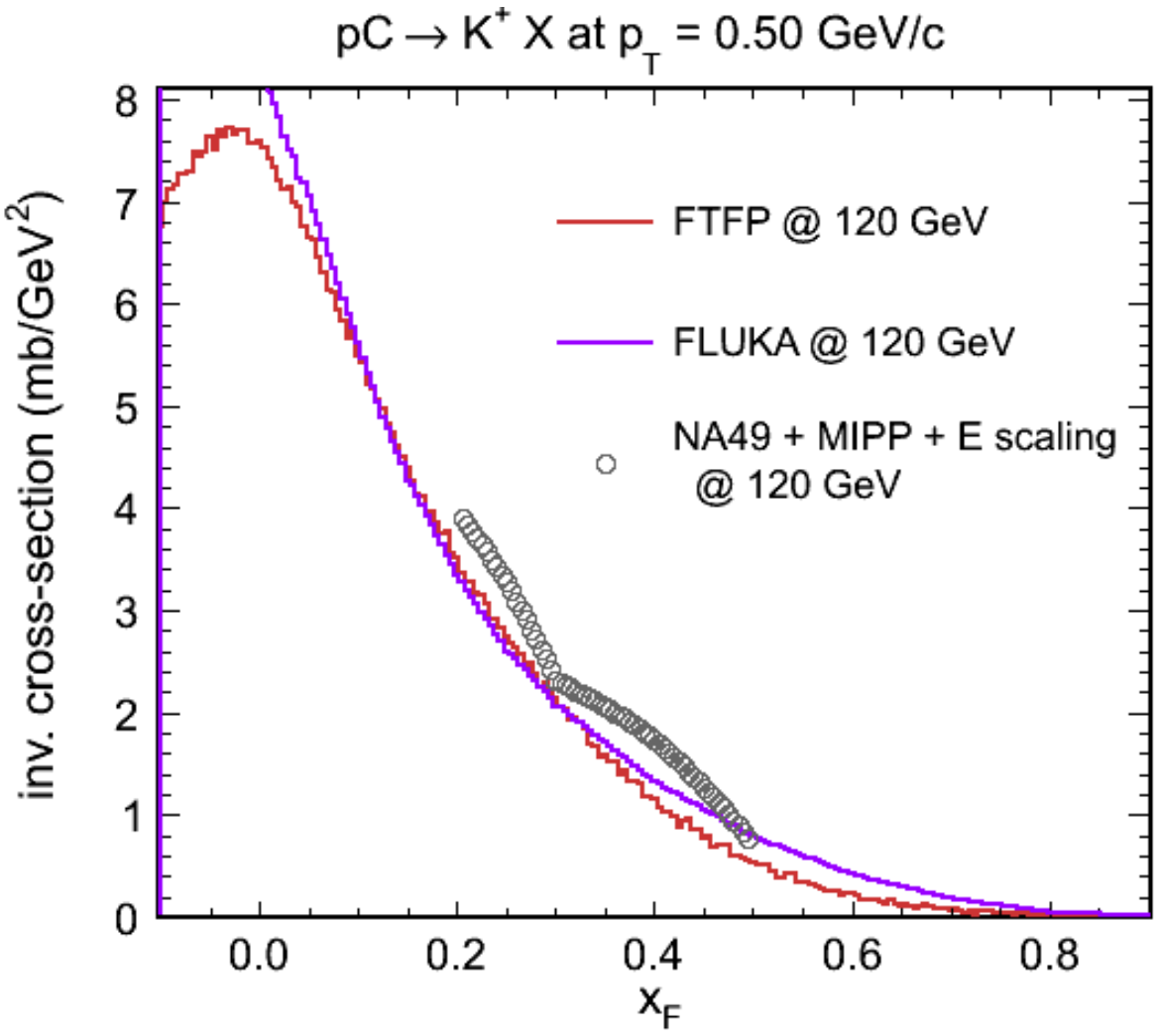
Predicted cross-section, $p_T = 0.30\,\mathrm{GeV/c}$

Predict K production cross-section using $K/\pi \times \sigma_{\mathrm{NA49}}(pC \to \pi X)$.

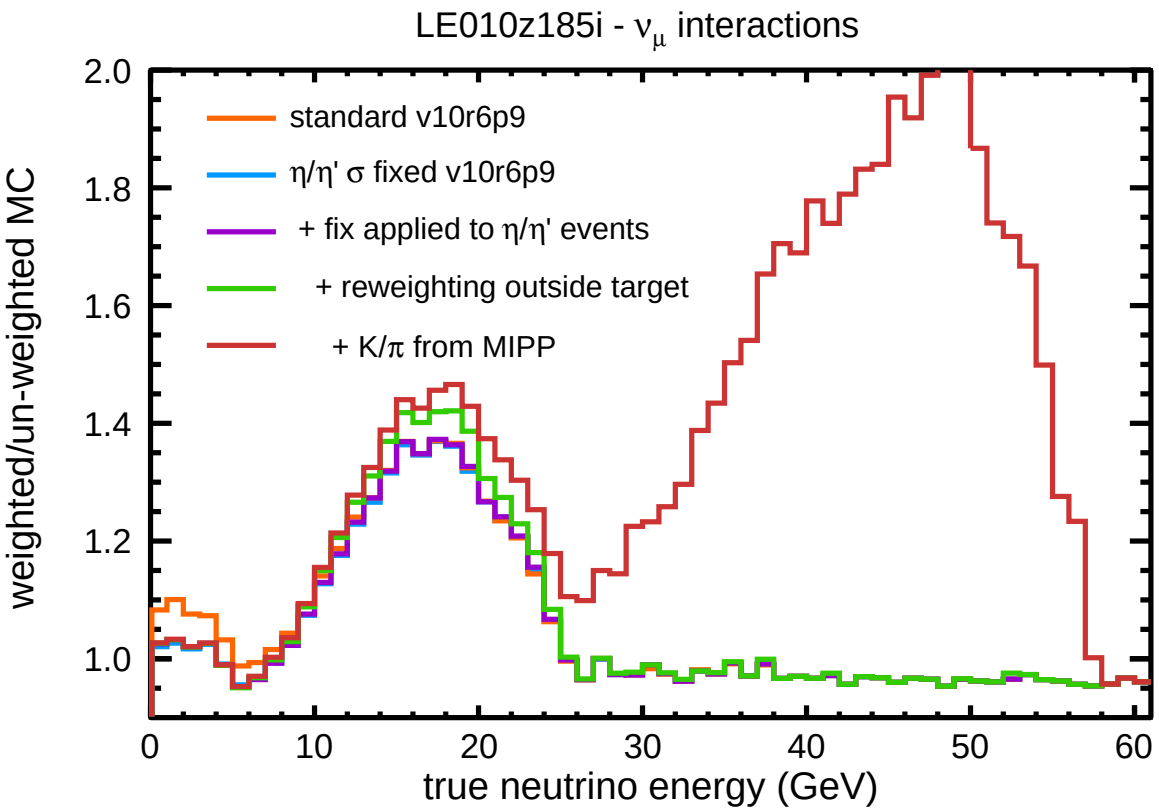


Predicted cross-section, $p_T = 0.50\,\mathrm{GeV/c}$

Predict K production cross-section using $K/\pi \times \sigma_{\mathrm{NA49}}(pC \to \pi X)$.



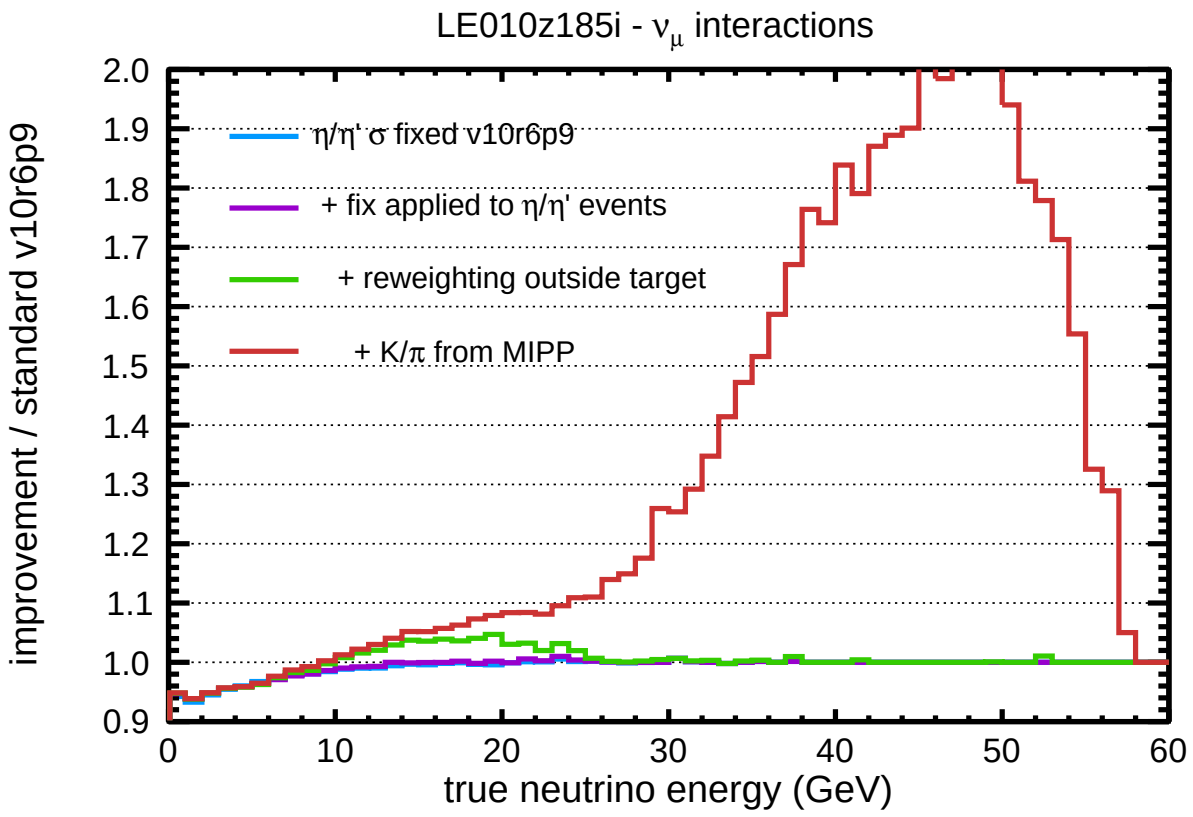
MIPP K/π : results



Dip due to pion weights cutting out, kaon weights slowly turning on.

MIPP K/π : results

The incremental effect over and above Titan (="v10r6p9" = base 2013 physics processing).



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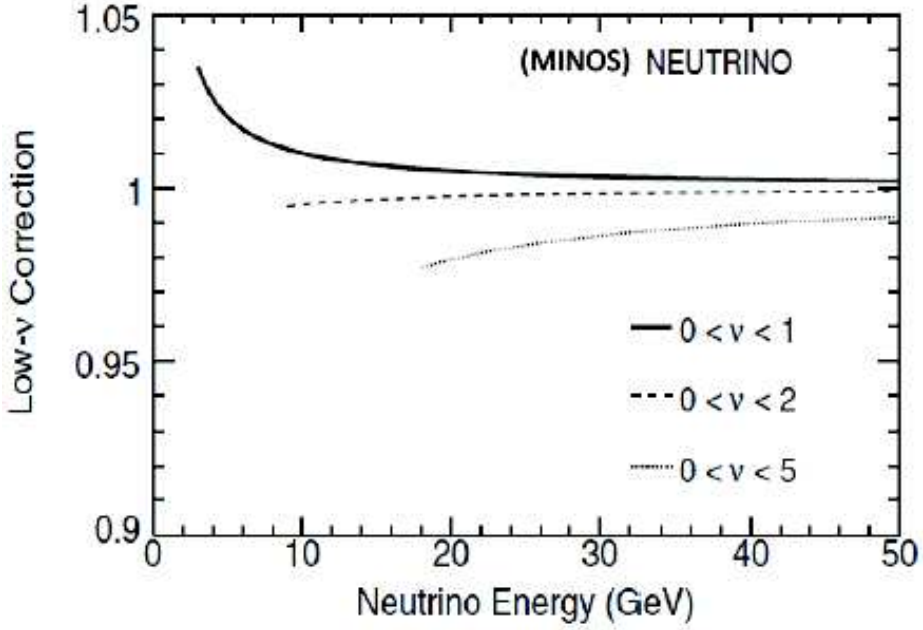
Basic Idea

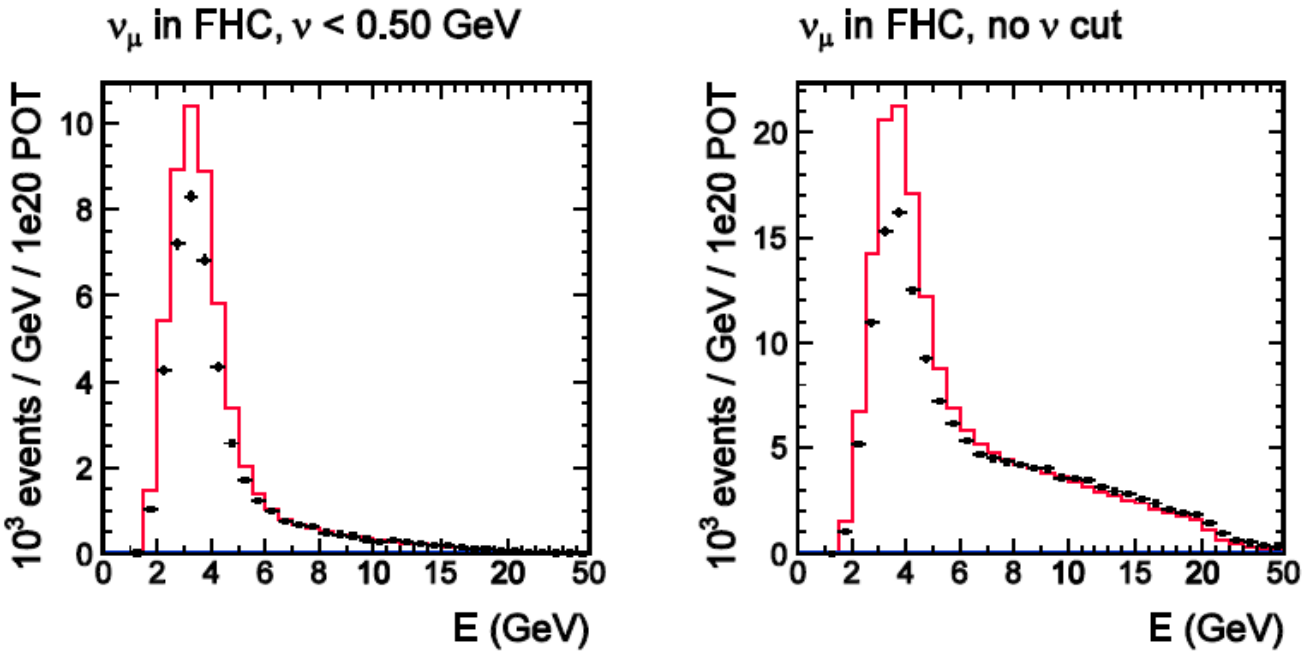
Recent articles, not original source material:
A. Bodek et al, Eur.Phys.J. C72 (2012) 1973
D. Naples et al, Phys.Rev. D81 (2010) 072002

$$\frac{d\sigma}{d\nu} = A\left(1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2}\right) \tag{1}$$



Status

- Converging on binning and ν cut ranges.



- Studying unfolding for non-beam fit, stand-alone flux extraction.
- Systematics studies (Ex., hadron energy) underway.

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Fit Technique

A reminder

- Fit adjusts $\pi^{\pm}$ and $K^{\pm}$ yields off the target as a function of x_F and p_T. Can nuisance parameters (e.g., horn focusing errors).
- Fit done after reweighting using HP data.
- Some HP constraints in fit. K/π, π^+/π^- ratios.
- Multiple beam configurations fit simultaneously:

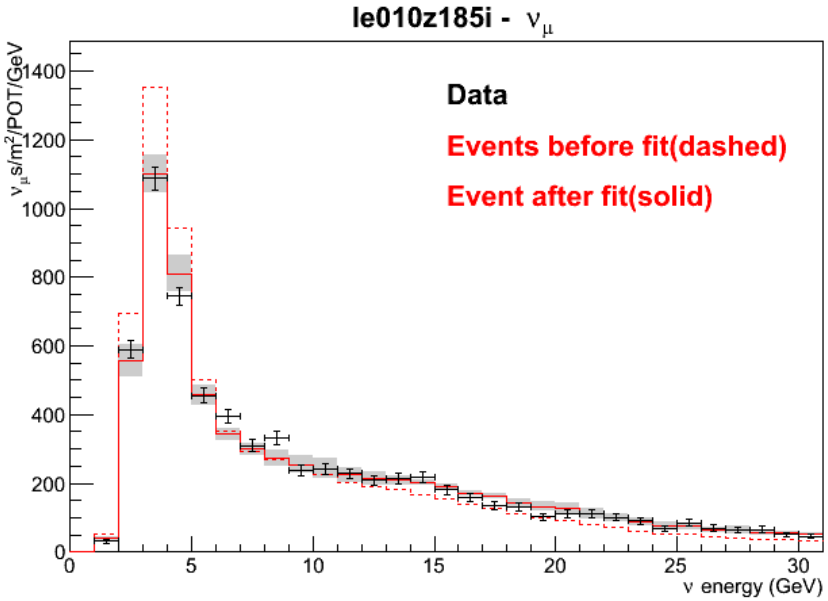
ν_μ	$\bar{\nu}_\mu$
LE010z185i	LE010z-185i
LE100z200i	LE100z-200i
LE010z000i	LE010z000i
LE250z200i	

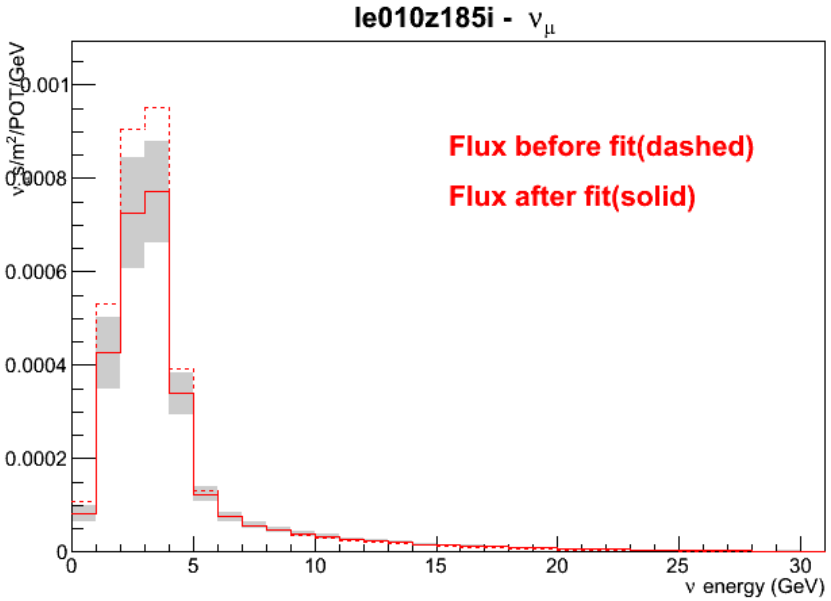
Fit Technique

- Traditionally, uses inclusive CC scattering samples.
- Extended to fit low nu samples.
- After fit, weight true MC events to predict flux. Cross-section uncertainties must be incorporated here.
- "Many universe" technique for systematic errors. Redo fits in each universe.
- Result: In principle, a predition for any beam configuration, any location, $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$. With uncertainties.

Example: CC inclusive fit

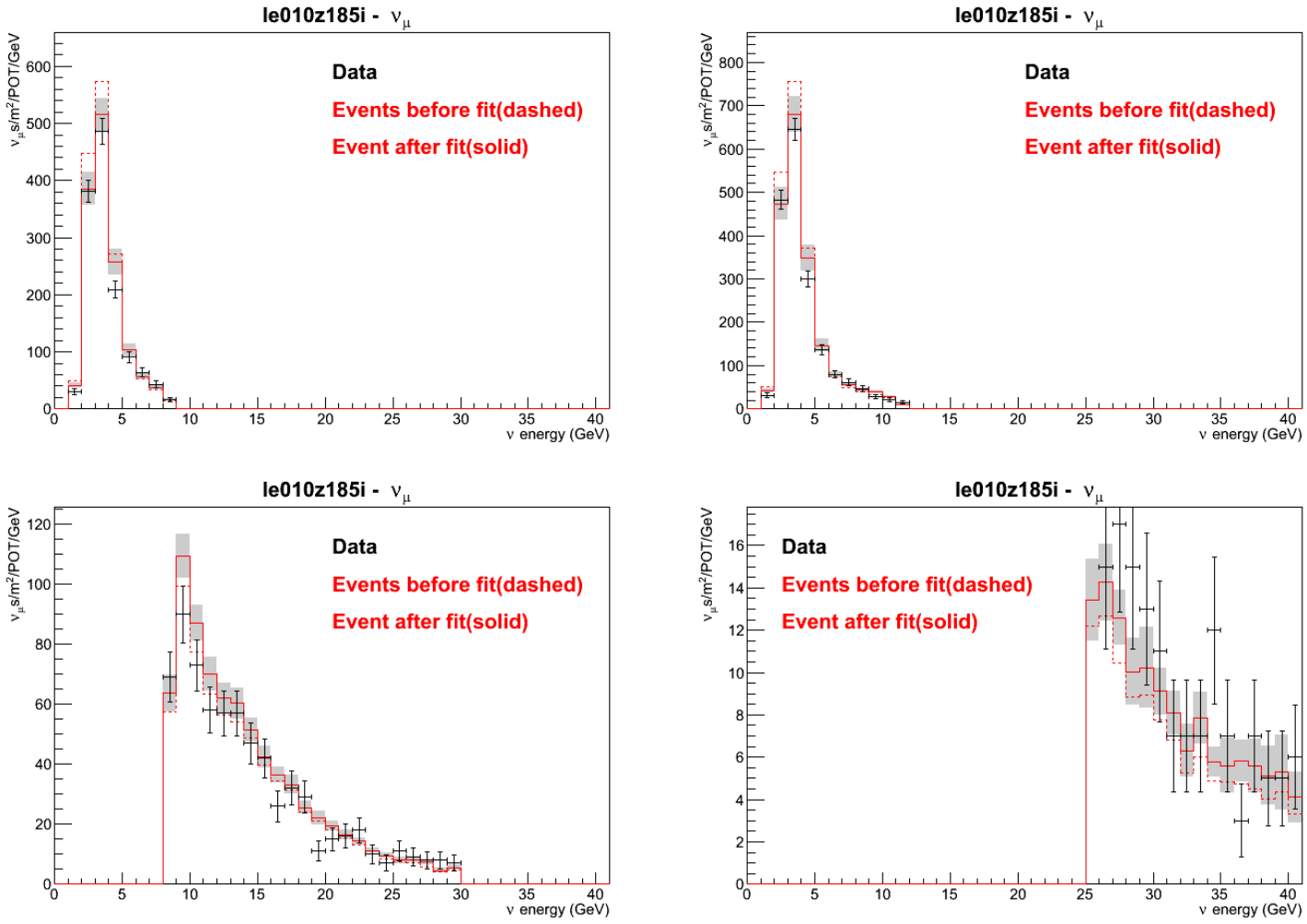
Fit to CC inclusive energy spectra





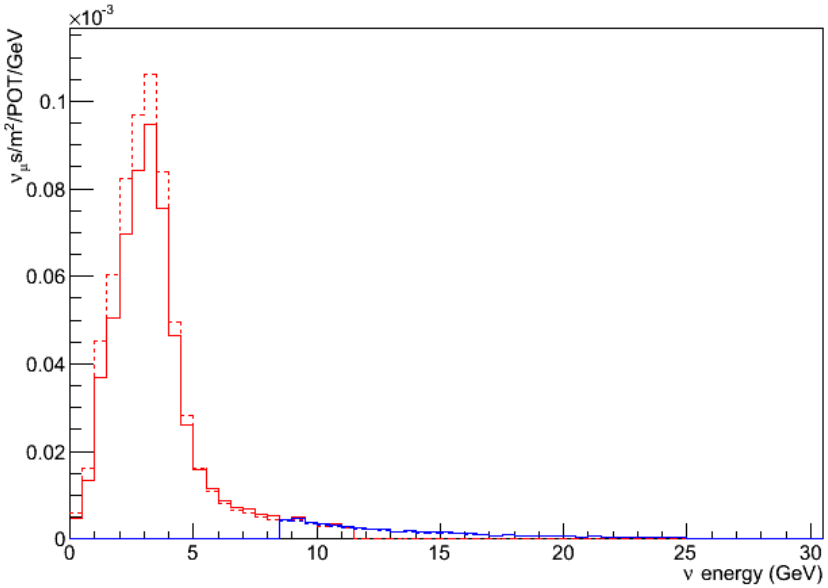
Example: low-nu fit

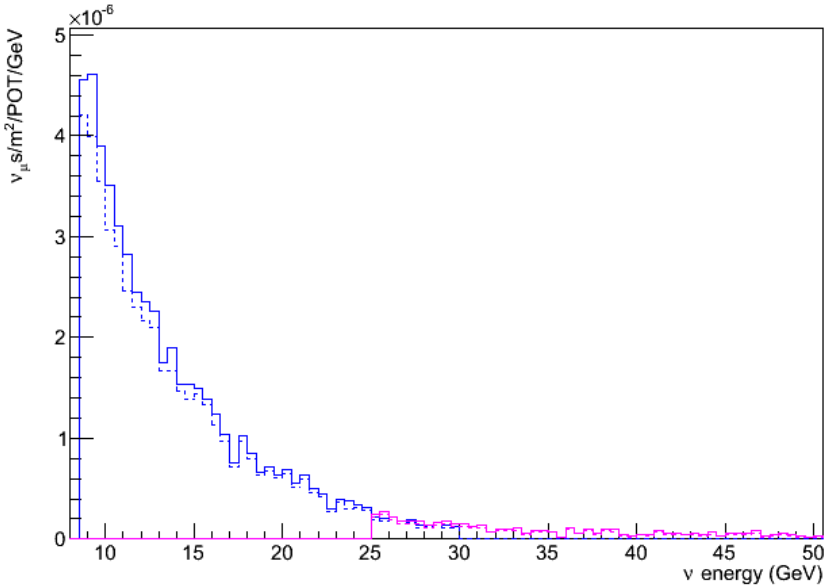
Fit to low nu energy spectra: $\nu < 0.45, 0.6, 2.0, 4.0\,\mathrm{GeV}$



Joining the low-nu slices

After the fit, the flux from each ν slice is cross-normalized. The flux is normalized in the highest energy slice so that the number of events you predict when multiplying by the well known CC cross-section agrees with what you actually observe.





Above: cross-normalization of different ν slices.

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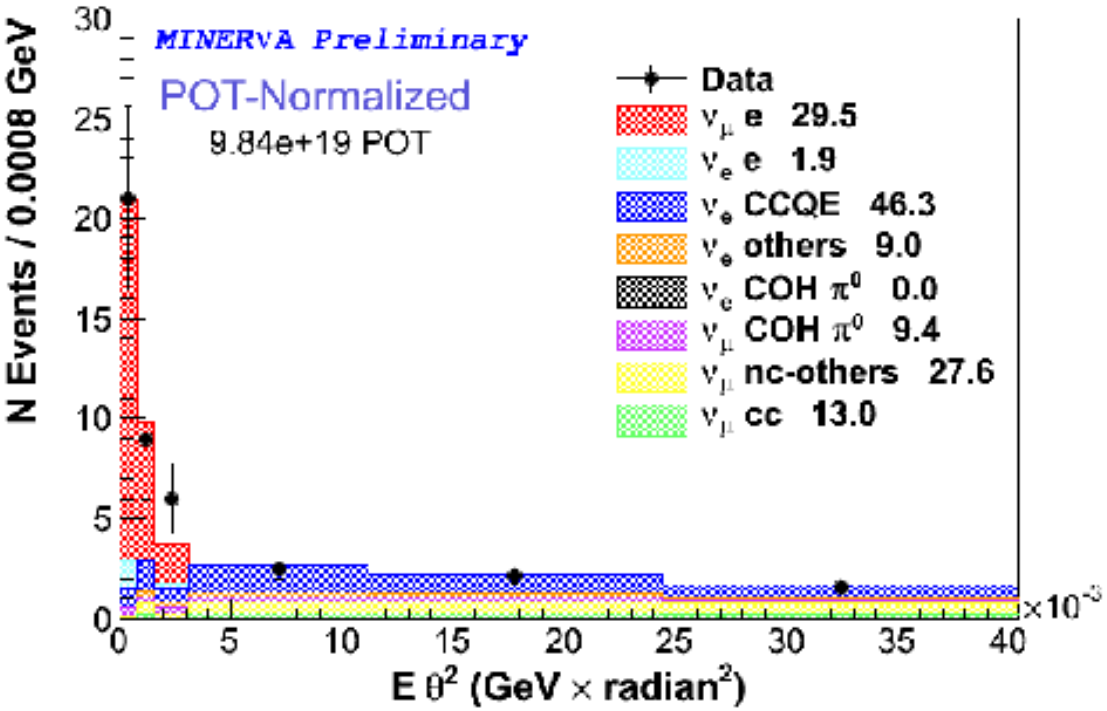
νe scattering

Precision Electroweak Process

$$\sigma(\nu e) = \frac{G_F^2 s}{\pi}\left[\left(\frac{1}{2} - \sin^2\theta_W\right) + \frac{1}{3}\sin^4\theta_W\right] \tag{2}$$

Jaewon Park Ph.D. thesis



Hope: 10% constraint in LE beam. Better in ME.

The end

Questions?
How NuMI-X can help: Geometry checks. Horn modeling.