Flux Shape Measurement with ν-e Scattering in STT

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Introduction

- The goal is to measure the flux shape using ν-e events.
- There could be two methods:
  - Event by event reconstruction: $E_\nu = E_e/(1 - E_e\theta_e^2/2m)$
  - **Statistically constrain** the flux shape by fitting (this talk).
- Use (E_e, θ_e) 2D distribution in each E_ν bin as templates and fit to data.
  - E_ν: true neutrino energy.
  - E_e: reconstructed electron energy.
  - θ_e: reconstructed electron angle with respect to the line from average meson decay point in the decay pipe to the event vertex.

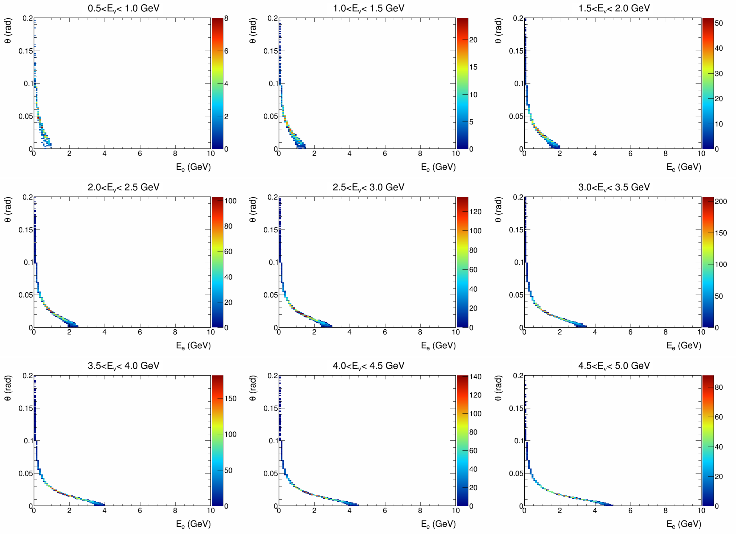
Updates

- Updated statistics using optimized beam design.
- 3 fitting methods:
  - Fit with a function of E_ν: better constraint provided we have a good functional form (see my previous talk at ND meetings).
  - Fit E_ν bin-by-bin without a function (focus of this talk).
  - Fit with empirical parametrization of hadron production (future plan).
- Systematic study.
  - Backgrounds.
  - Electron selection efficiency.
  - Electron energy and angle measurement.

Statistics and Detector Assumptions

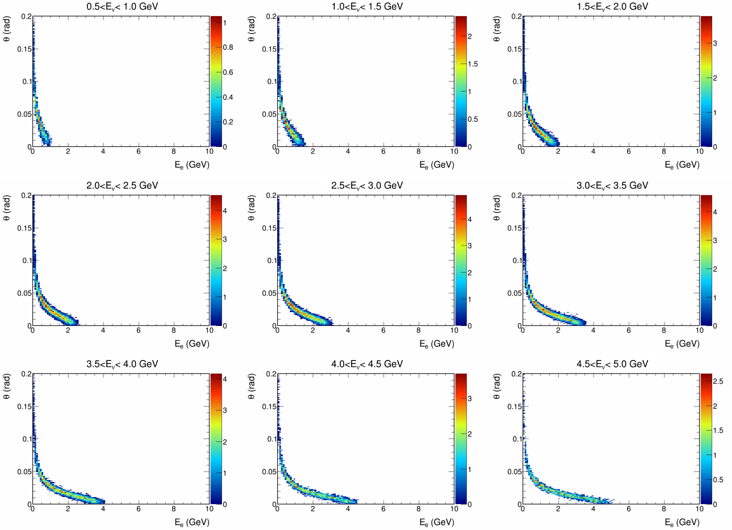
- 3-horn optimized flux at 574 m (1.07 MW, 80 GeV protons, 1.47 POT per year).
- 4850 ν-e events in STT (5 ton fiducial mass, 5 years running).
- $\sigma(E_e)/E_e = 6\%/\sqrt{E_e}$
- $E_e > 0.15$ GeV
- $\sigma(\theta_e) = 1$ mrad.

Electron Energy vs Angle: No Smearing, No ν Divergence



- With no smearing, events in each neutrino energy bin populate distinctly in the electron energy vs angle 2D space.

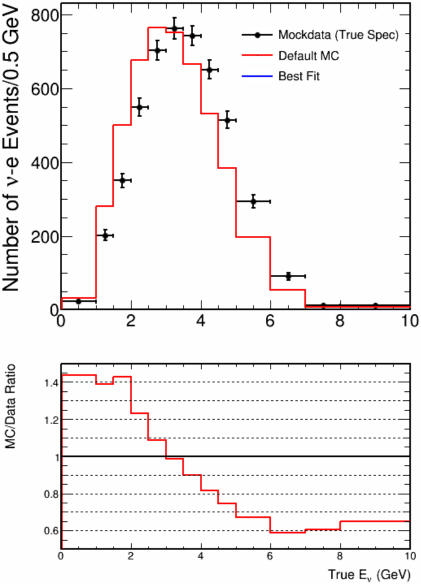
Electron Energy vs Angle: With Smearing & ν Divergence



- Detector smearing and beam divergence smears the distribution, but still see the difference between each E_ν bin.

Bin-by-Bin E_ν Fit

- 4850 mockdata events, re-weighted to make it different from default MC.
- Statistically independent MC sample with 10X statistics.
- Use Minuit to tune the number of events in each MC E_ν bin to minimize χ^2 between data and MC in electron energy and angle 2D space.
- A "smoothness" requirement by adding a χ^2 from each bin and average from adjacent bins (improving this).
- The error band is statistical fitting error (returned by Minuit).



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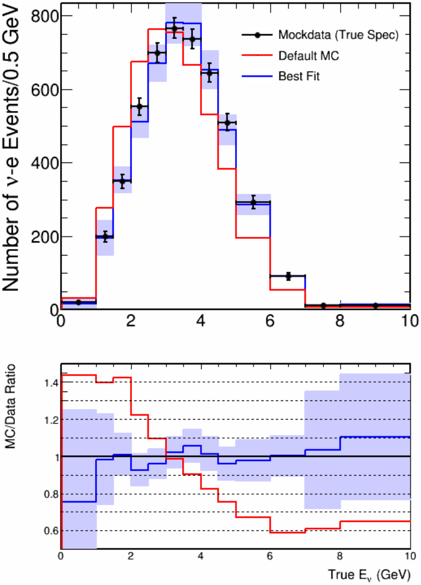
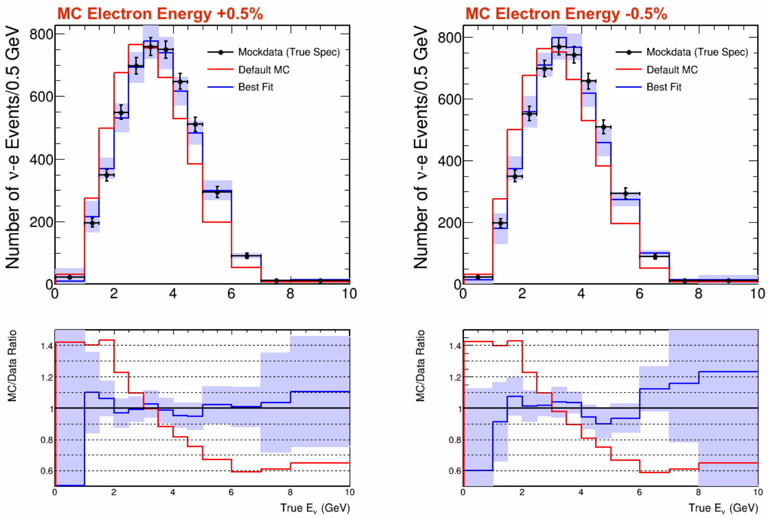


Systematic Uncertainty

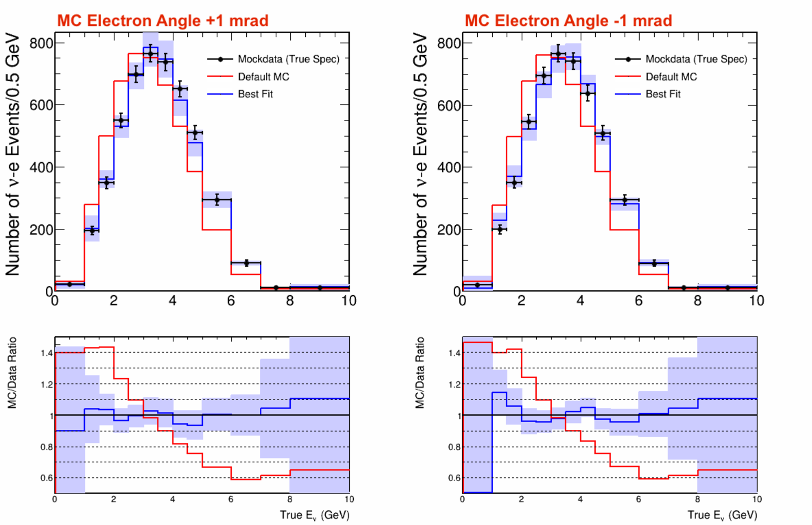
- An approximate estimation:
- Background $\sim 6\%$
  - ν_e-CC QE(4%): constrained by $e^- p$ topology. The uncertainty is $\sim$ 2-3%.
  - NC-π^0 (2%): constrained by e^+ sample, negligible uncertainty.
  - A very small contribution compared to statistical uncertainty.
- Electron selection efficiency (transition radiation): $< 0.5\%$, constrained by γ conversion sample by removing the positron track.
- The fit relies upon the relation between neutrino energy and reconstructed electron energy and angle:
  - E_e scale: $\pm 0.5\%$.
  - θ_e: ± 1 mrad.

Electron Energy Uncertainty



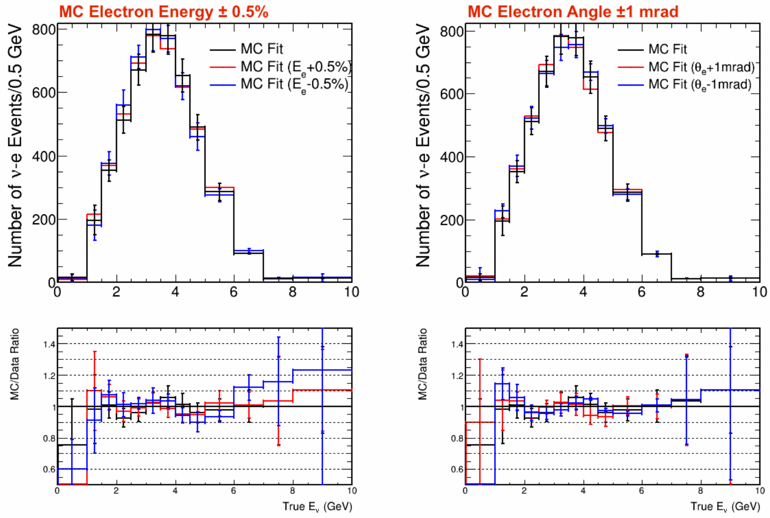
- Shift MC electron energy by $\pm 0.5\%$, repeat the fit.

Electron Angle Uncertainty



- Shift MC electron angle by ± 1 mrad, repeat the fit.

Electron Energy and Angle Uncertainty



- Effects of electron energy and angle shift are within statistical uncertainty.

Empirical Parametrization of Hadron Production

- The (x_F, p_T) of hadrons can be parametrized and constrained by ND samples:
- An example is a BMPT-type function (used by MINOS low-ν).
- Tune the hadron production parameters, re-weight ν-e events to do the fit.

BMPT-type fuction:

$$\left(E \times \frac{d^3\sigma}{dp^3}\right) = A\,(1-x_F)^{\alpha}\,(1+Bx_F)x_F^{-\beta} \times \left((1+a'(x_F)p_T + b'(x_F)p_T^2\right)e^{-a'(x_F)p_T}$$

where $a'(x_F) = a/x_F^{\gamma}$ and $b'(x_F) = a^2/2x_F^{\delta}$

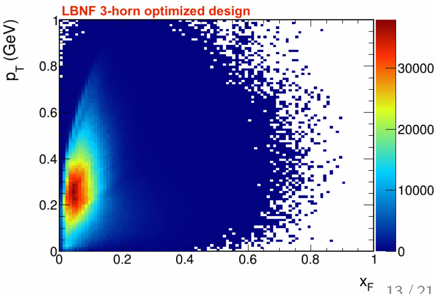
14 parameters are used: 7 for π and 7 for K

π^+/π^- ratio:

$$R\left(\pi^+/\pi^-\right) = r_0\,(1+x_F)^{r_1}$$

K^+/K^- ratio:

$$R\left(K^+/K^-\right) = r_2\,(1-x_F)^{r_3}$$

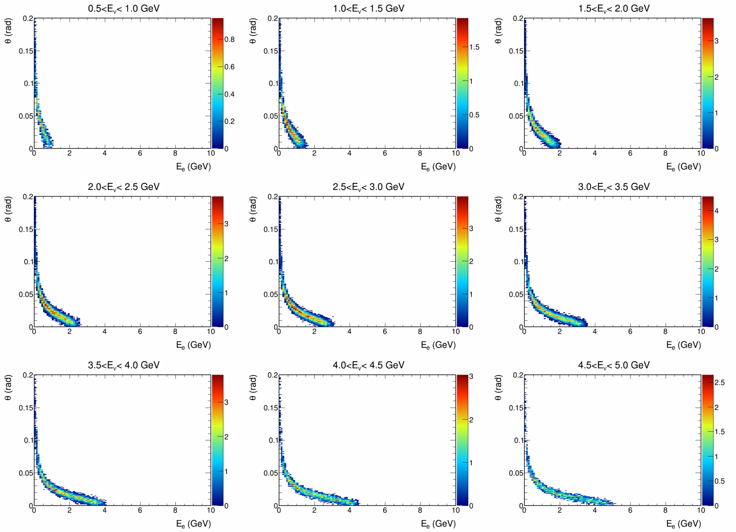


Summary

- It looks promising to use 2D template fit method to measure $\phi(E_\nu)$.
- The uncertainty would still be statistics dominant: detector mass is the most important factor.
- It might help to combine LAr and STT events to do the fit:
  - LAr provides lots of statistics.
  - STT reduces systematics.
- A function fit (of E_ν or hadron production) can also improve the fit.

Back up slides

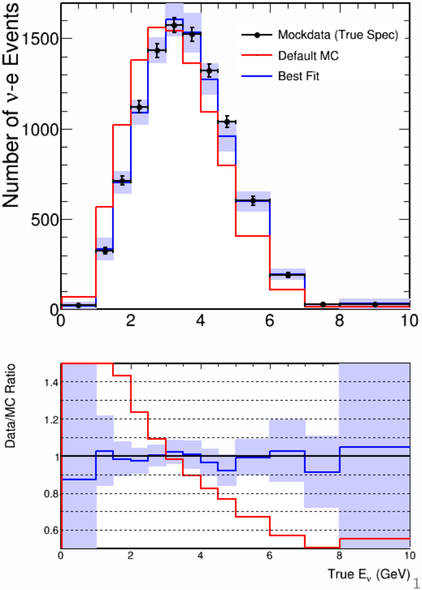
Electron Energy vs Angle: Smeared, With ν Divergence



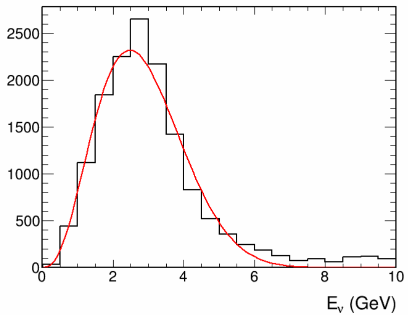
- Beam divergence further smears the distribution with previous θ_e definition (to the detector z).

Bin-by-Bin E_ν Fit

- 7500 mockdata events, re-weighted to make it different from default MC.
- Statistically independent MC sample with 10X statistics.
- Use Minuit to tune the number of events in each MC E_ν bin to minimize χ^2 between data and MC in electron energy and angle 2D space.
- A "smoothness" requirement by adding a χ^2 from each bin and average from adjacent bins (improving this).
- The error band is statistical fitting error (returned by Minuit).



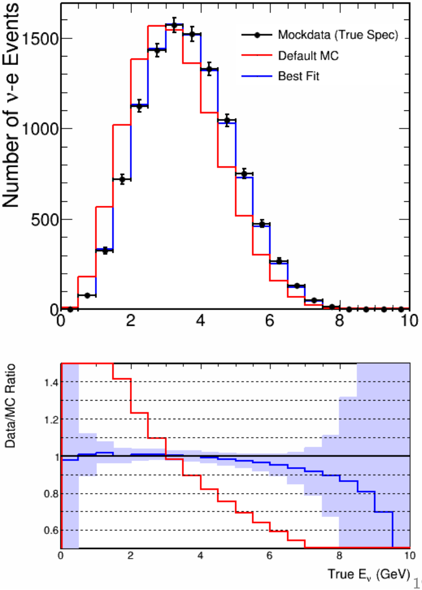
E_ν Parametrization



- Flux is a continuous/smooth function of E_ν.
- We use a simple fictional form: $f(E_\nu) = aE_\nu^b(c - E_\nu)^d$ where a, b... are free parameters. (slightly different from the one used at collaboration meeting, where c was a constant)
- Not a perfect fit, but a good start point to demonstrate this method.
- Reweight E_ν spectrum to the function. (assume the E_ν spectrum can be perfectly described by the function.)

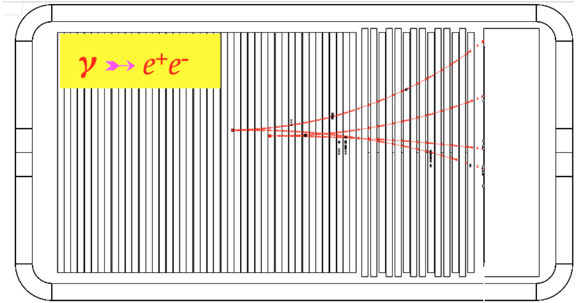
E_ν Fit With Function

- **Assume there is a smooth function that fits the E_ν spectrum perfectly**.
- Use: $f(E_\nu) = aE_\nu^b(c - E_\nu)^d$ where a, b... are free parameters.
- Re-weight the MC to the function.
- Create mockdata (7.5k, independent from MC) by slightly change the parameters and reweight event by event.
- A quite good fit: the error is a few percent in the peak region.
- The error band is statistical fitting error (returned by Minuit).

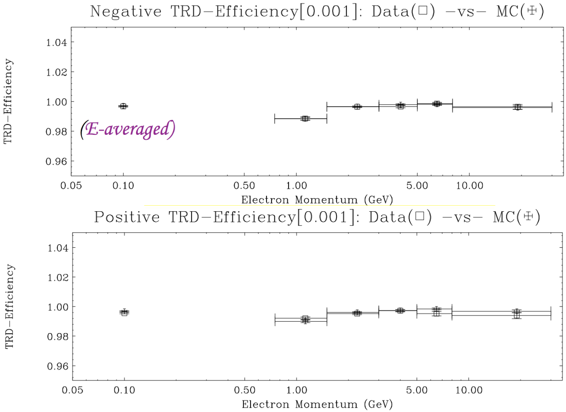


in situ TR Electron Selection Efficiency Constraint

- Select $\gamma \to e^+e^-$ conversion
  - Separated from event vertex ($>$ 1cm)
  - Opending angle in X-Z plan $<$ 5mrad.
  - $M_{ee} < 30\text{MeV}$
- $\sim 10^7$ photon conversion with purity $> 99\%$
- Check TR and ECAL cuts on the e^+/e^- in data and MC.



in situ Electron Selection Efficiency Constraint (NOMAD)



- NOMAD Data/MC difference in efficiency $< 1\%$.