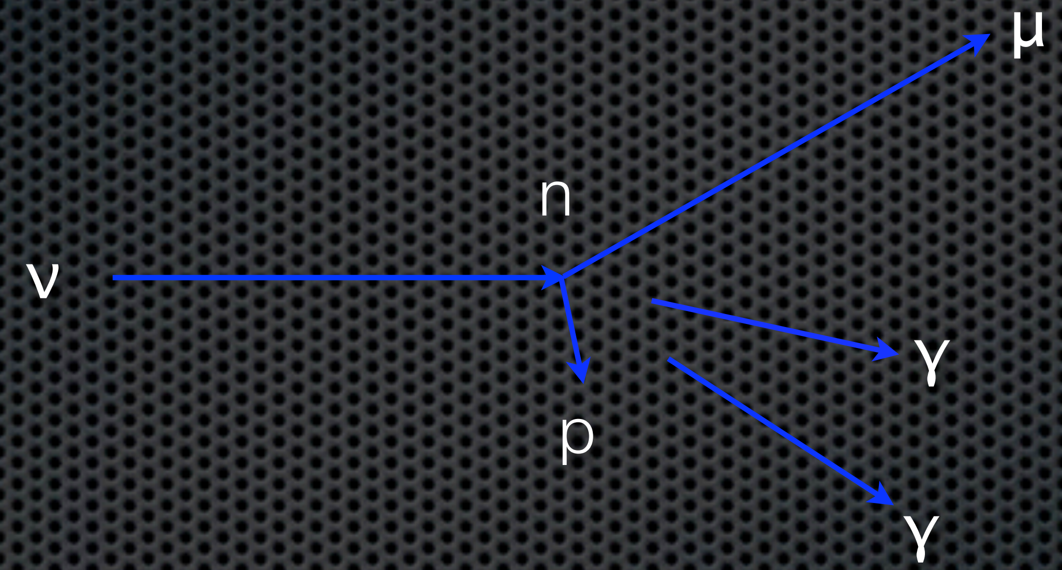
CCπ^0 cross-sections



Robert Nelson

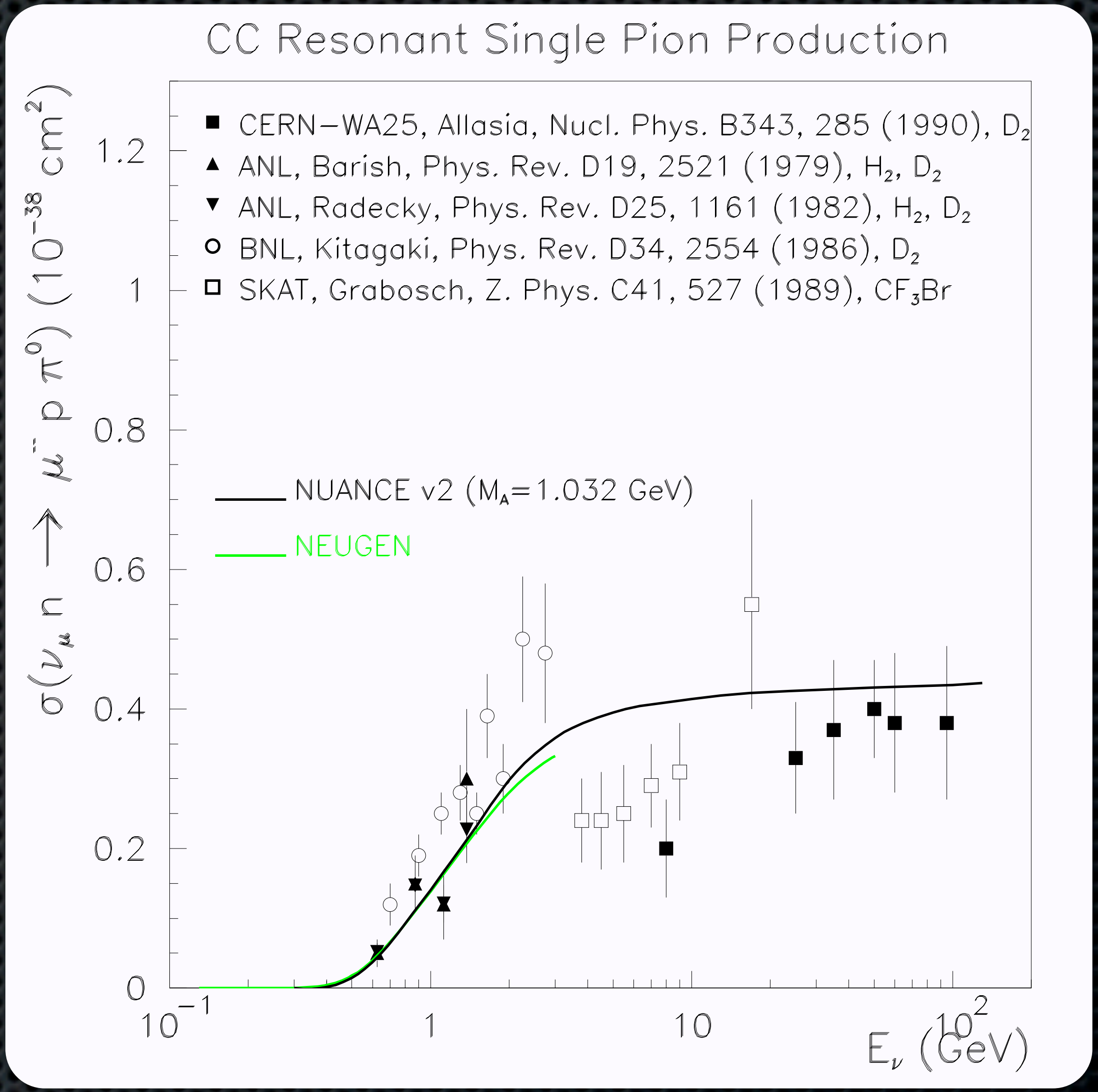
2009.9.18

MiniBooNE collaboration meeting

Outline

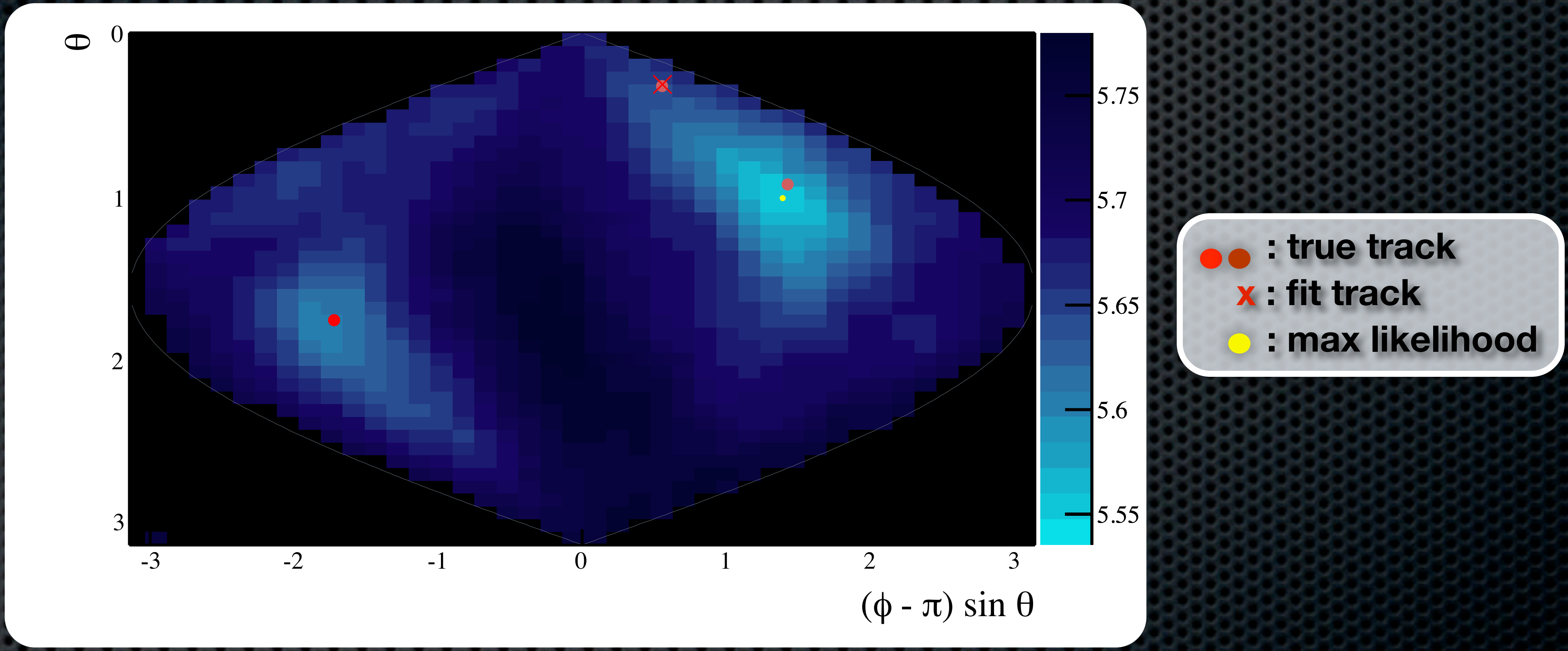
- Reconstruction
- Observable modes
- Cuts
- Cross-section
  - Rates
  - Backgrounds
  - Unfolding
  - Flux
  - Efficiency
- Conclusions

Previous measurements



Reconstructing CCπ^0 events

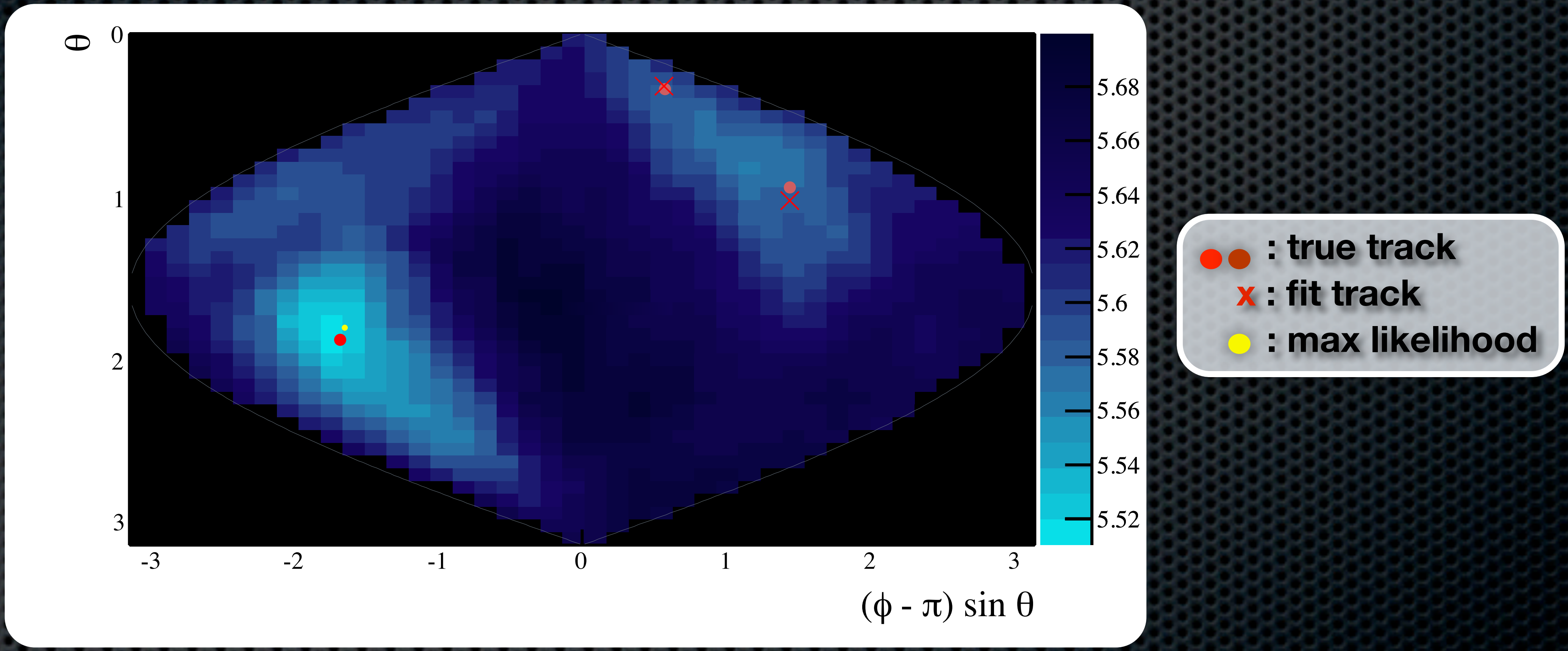
- Fixing the one-track muon fit in the three-track likelihood function, we scan (in solid angle) for a second track.



- The one track fit found one of the photons in this event.
- The scan found the second photon.
- After this scan, both tracks are allowed to float in a two-track fit.

Reconstructing CCπ^0 events

- Both tracks are fixed in the three-track likelihood function. A third track is scanned for in all directions of solid angle.

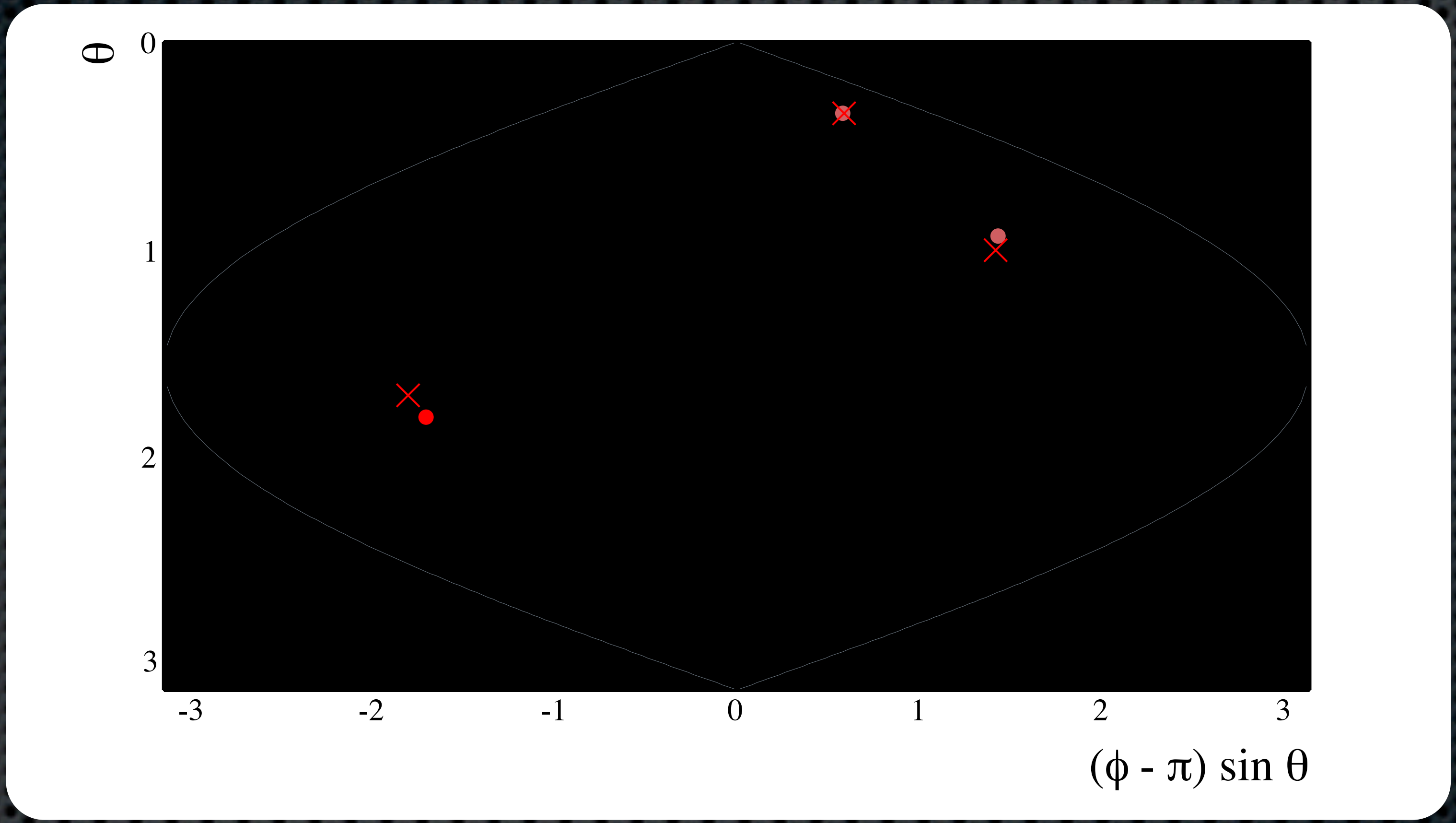


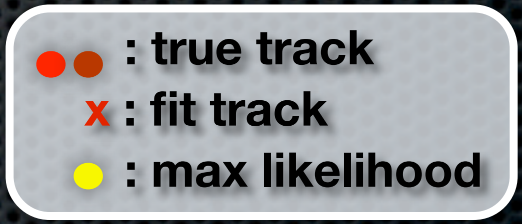
- The two-track fit dimmed likelihood around the second photon, and brightened the likelihood around the muon.

- The scan found the muon in this event.

Reconstructing $CC\pi^0$ events

- All three tracks are allowed to float, though no particle ID assumptions are made prior to this stage.

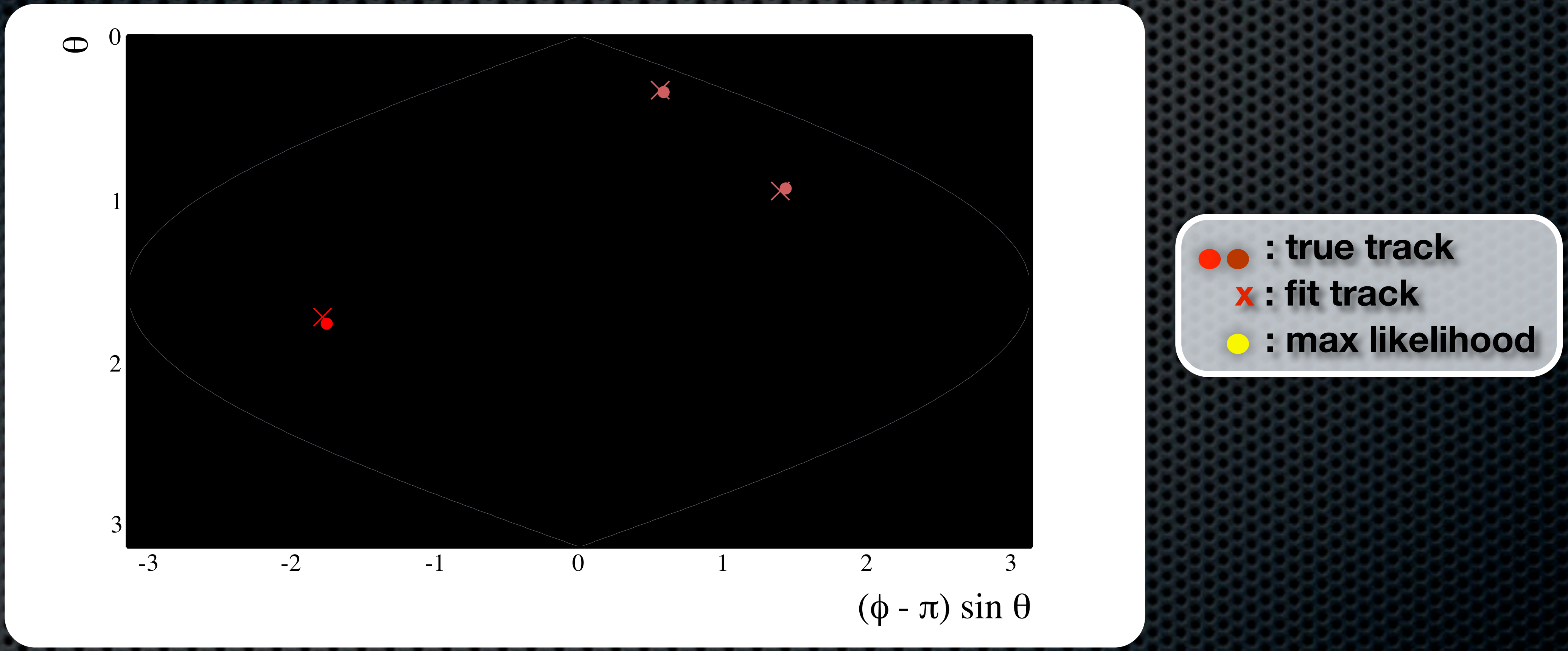




- The three-track fit has found the directions to all three particles (μ,γ,γ) in this event.
- For all three possible particle configurations, additional three-track fits are performed.

Reconstructing CCπ^0 events

- For all three possible particle configurations, additional three-track fits are performed. Swapping out two of the tracks for photons.



- Particle ID is performed by combining the fit likelihood and the direction to the michel vs the assumed muon in the fit as an additional likelihood.

- The three-track fit has identified all three particles (μ,γ,γ) in this event.

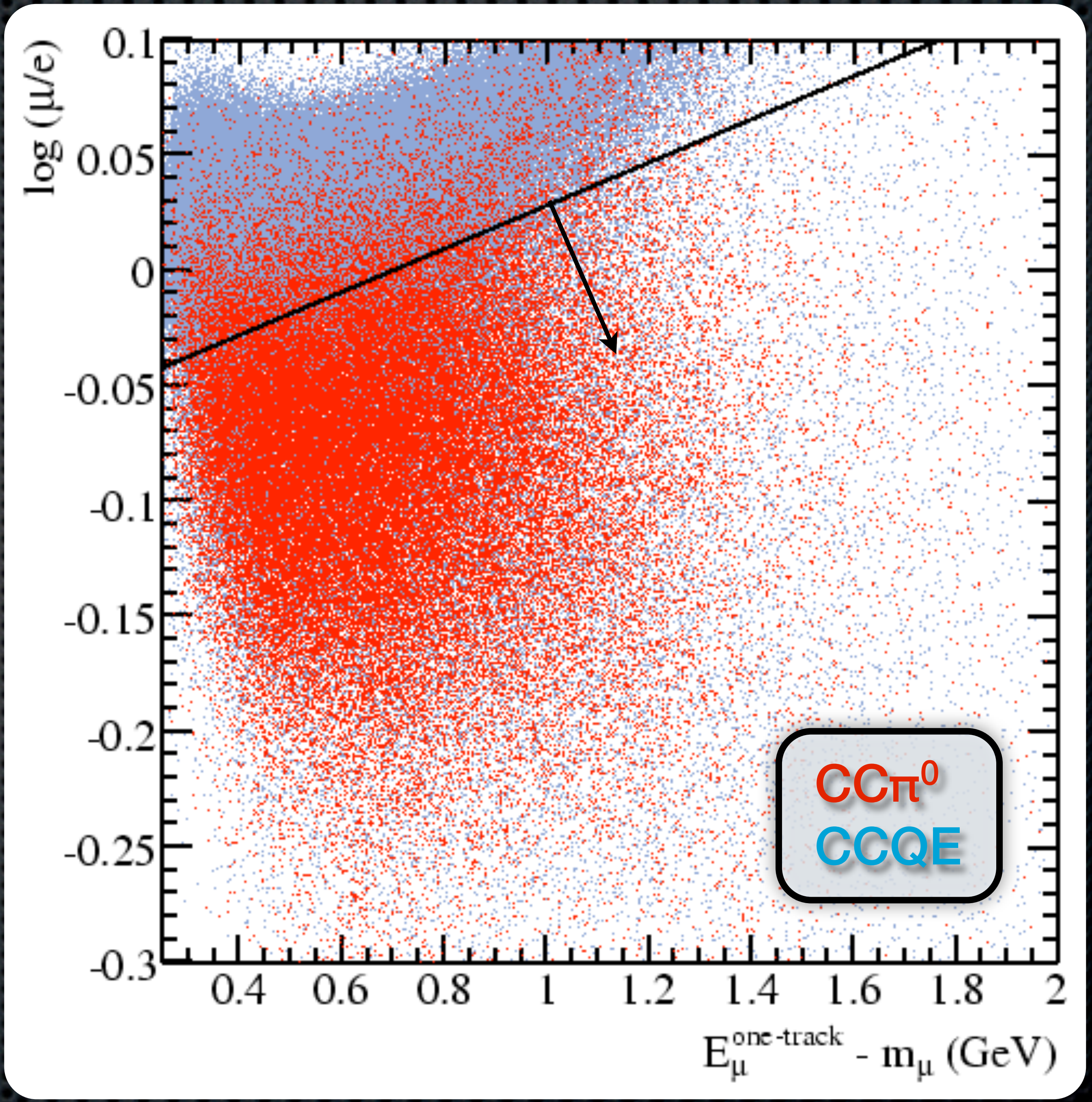
Observable modes (after FSI)

- **CCπ^0: One and only one μ^-, and π^0 from the target nucleus with no other mesons from a ν_μ interaction.**

- CCπ^+: One and only one μ^-, and π^+ from the target nucleus with no other mesons from a ν_μ interaction.
- CCQE: One and only one μ^- from the target nucleus with no mesons from a ν_μ interaction.
- CCmulti-π: One and only one μ^-, and more than one π from the target nucleus with no other mesons from a ν_μ interaction.
- CCπ^-: One and only one μ, and π^- from the target nucleus with no other mesons.
- NCmulti-π: A ν and more than one π from the target nucleus with no other mesons.
- NCπ^0: A ν and π^0 from the target nucleus with no other mesons.
- NCπ^+: A ν and π^+ from the target nucleus with no other mesons.
- DIS: Channels 91 and 92 and NOT any of the above.

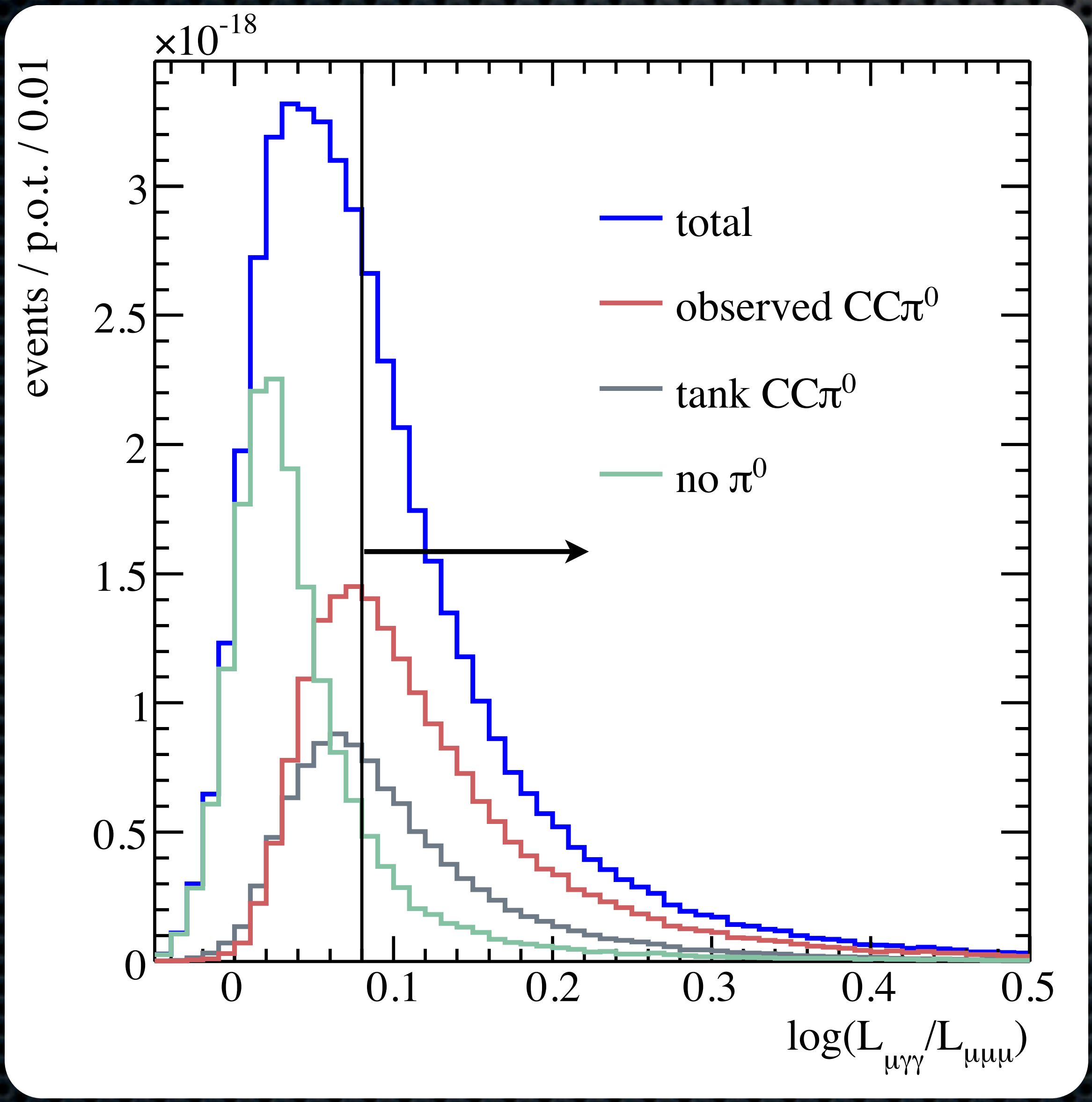
Pre-fit cuts

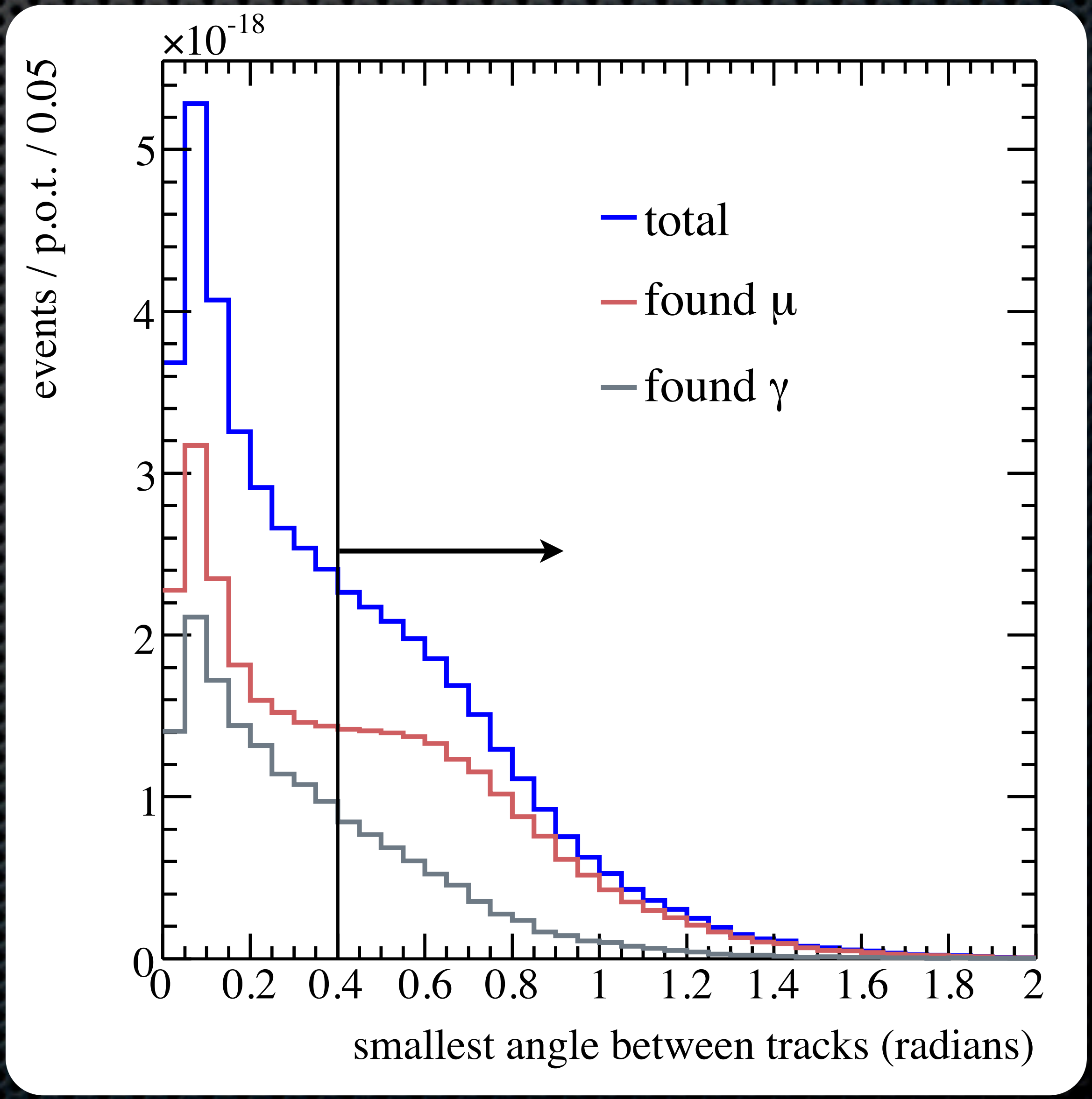
- 2 subevents.
- Tank hits > 200 (1st subevent)
  Tank hits < 200 (2nd subevent)
  Veto hits < 6 (both subevents)
- We need to reduce the two-subevent sample down to something more manageable before the fitter is run.
- A one-track likelihood ratio cut vs one-track energy reduces CCQE events by 98% while keeping 86% of $CC\pi^0$ events.



Post-fit cuts

- A fit likelihood after particle ID vs the fit before particle ID cut removes most of the events without π^0 anywhere in the event.
- Cutting on the smallest angle between tracks removes mis-reconstructions.
- Lastly, a cut on: $75 \text{ MeV}/c^2 < m_{\gamma\gamma} < 200 \text{ MeV}/c^2$.





Measuring the cross-section

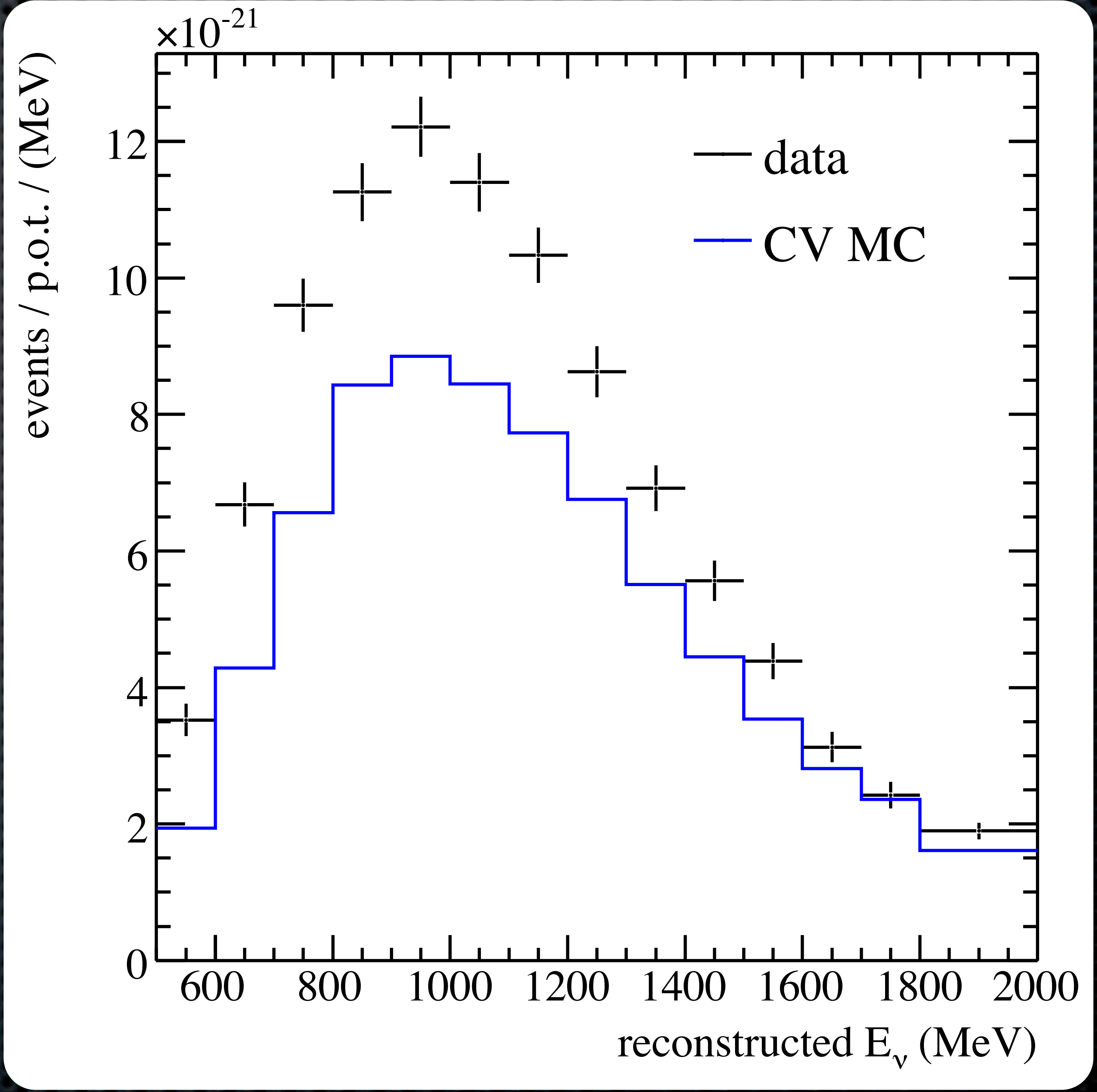
$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij}\left(N_j - B_j\right)}{\varepsilon_i \, \Phi_i \, N_{targs}}$$

- The MC sample is the may07_2 CV with a total of $43\text{x}10^{20}$ p.o.t.
  The data has $6.3\text{x}10^{20}$ p.o.t.
- $N_{targs} = 1.5\text{x}10^{32}$ nucleons.
  - Neutrons in $CH_{2.06}$ within a radius of 550 cm.
- After all cuts, there are ~7100 events in data before background subtractions.

Rate after cuts

$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij} \left(N_j - B_j\right)}{\varepsilon_i \, \Phi_i \, N_{targs}}$$

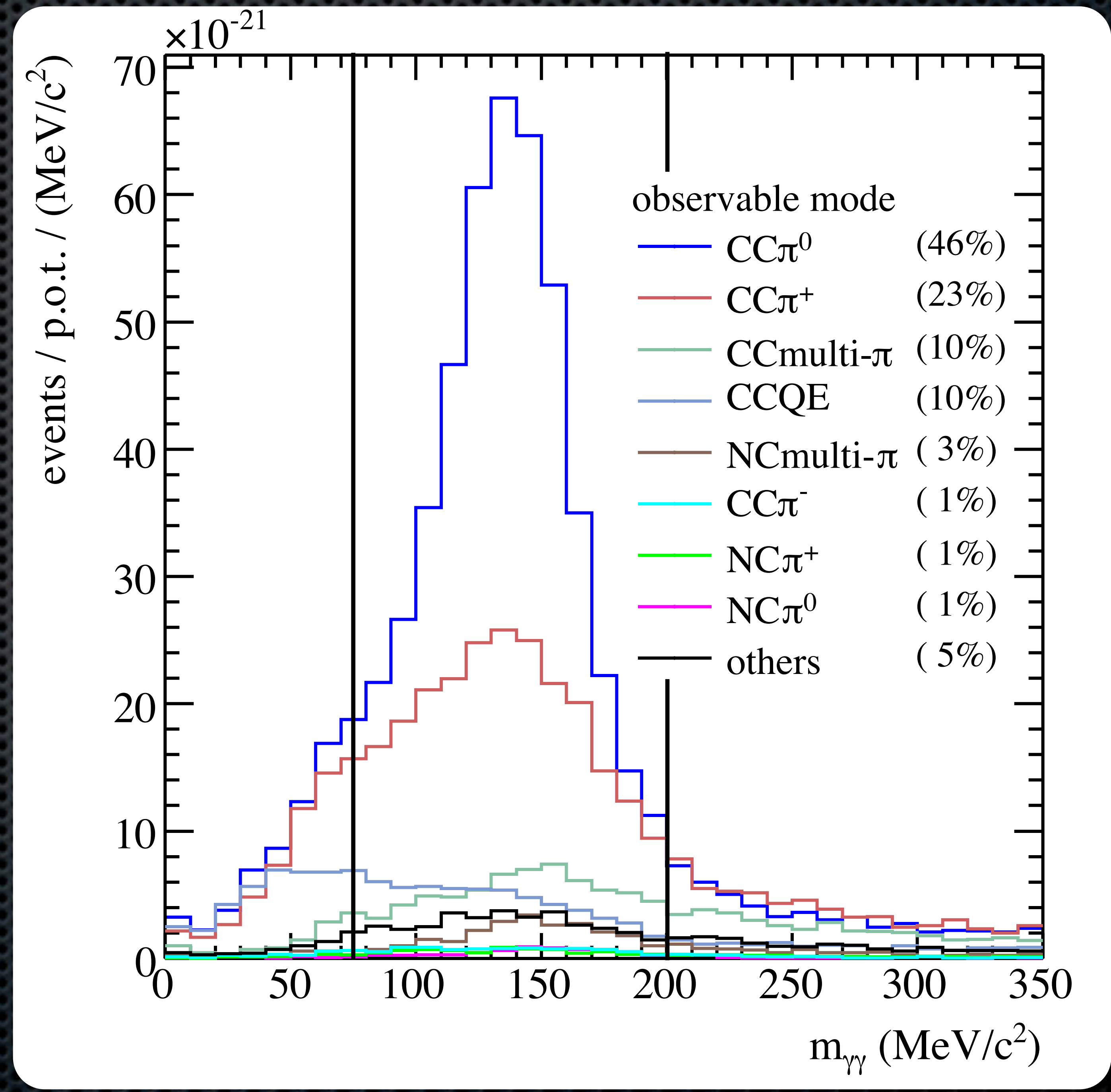
- Data and MC show clear differences in shape.
- Overall normalization difference of 1.3.



Backgrounds

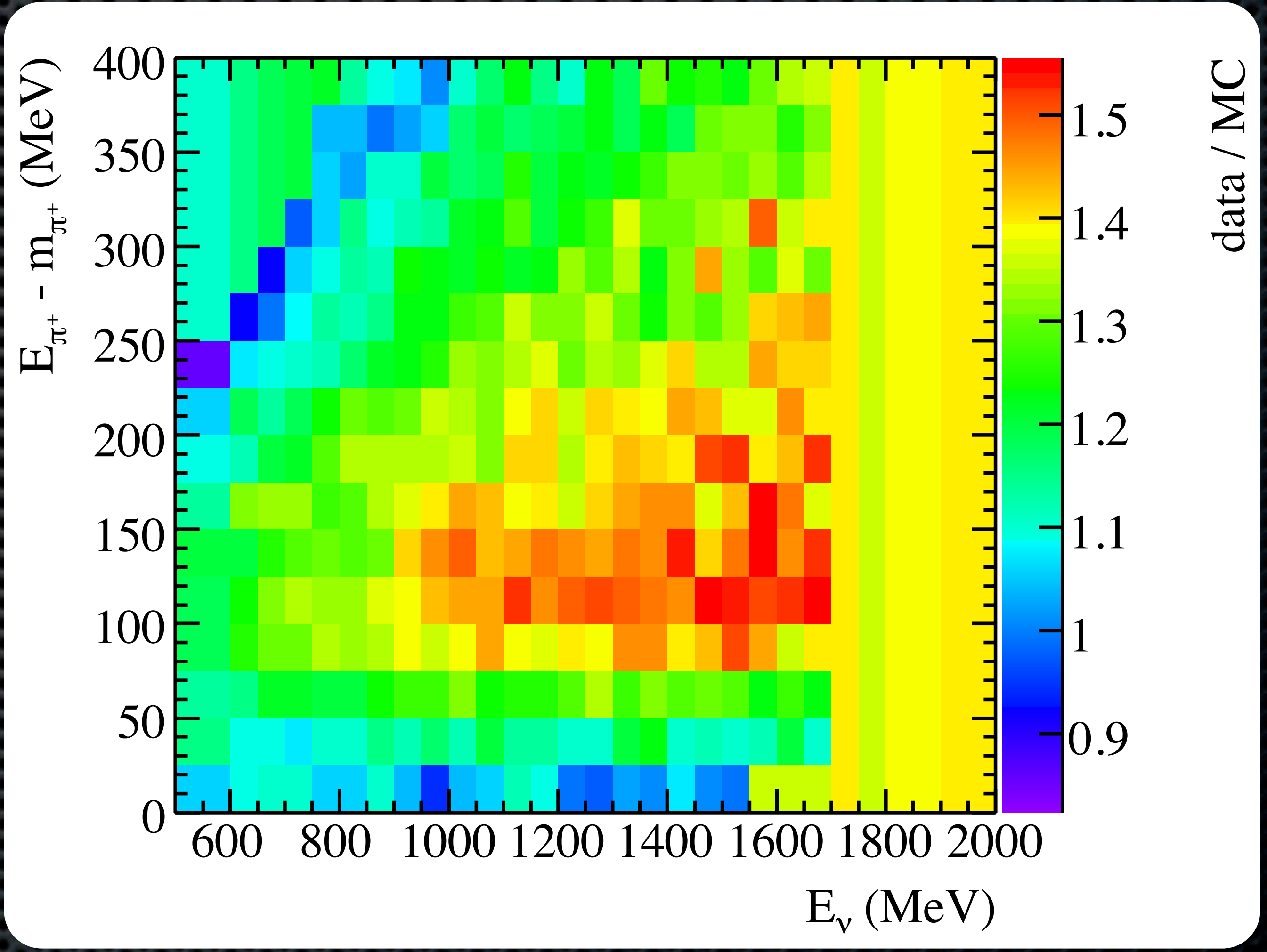
$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij}\left(N_j - B_j\right)}{\varepsilon_i \Phi_i N_{targs}}$$

- Ideally one would want to constrain as many backgrounds as possible by our own data.
- We do that for $CC\pi^+$ (next slide).
- We could do that for CCQE (and will).
- Everything else is a little up in the air:
  - We might try looking at many subevent data to make this constraint.
- These are worrisome because we do not have good constraints, and that the total backgrounds are about ~50% of the sample.



$CC\pi^+$ re-weighting

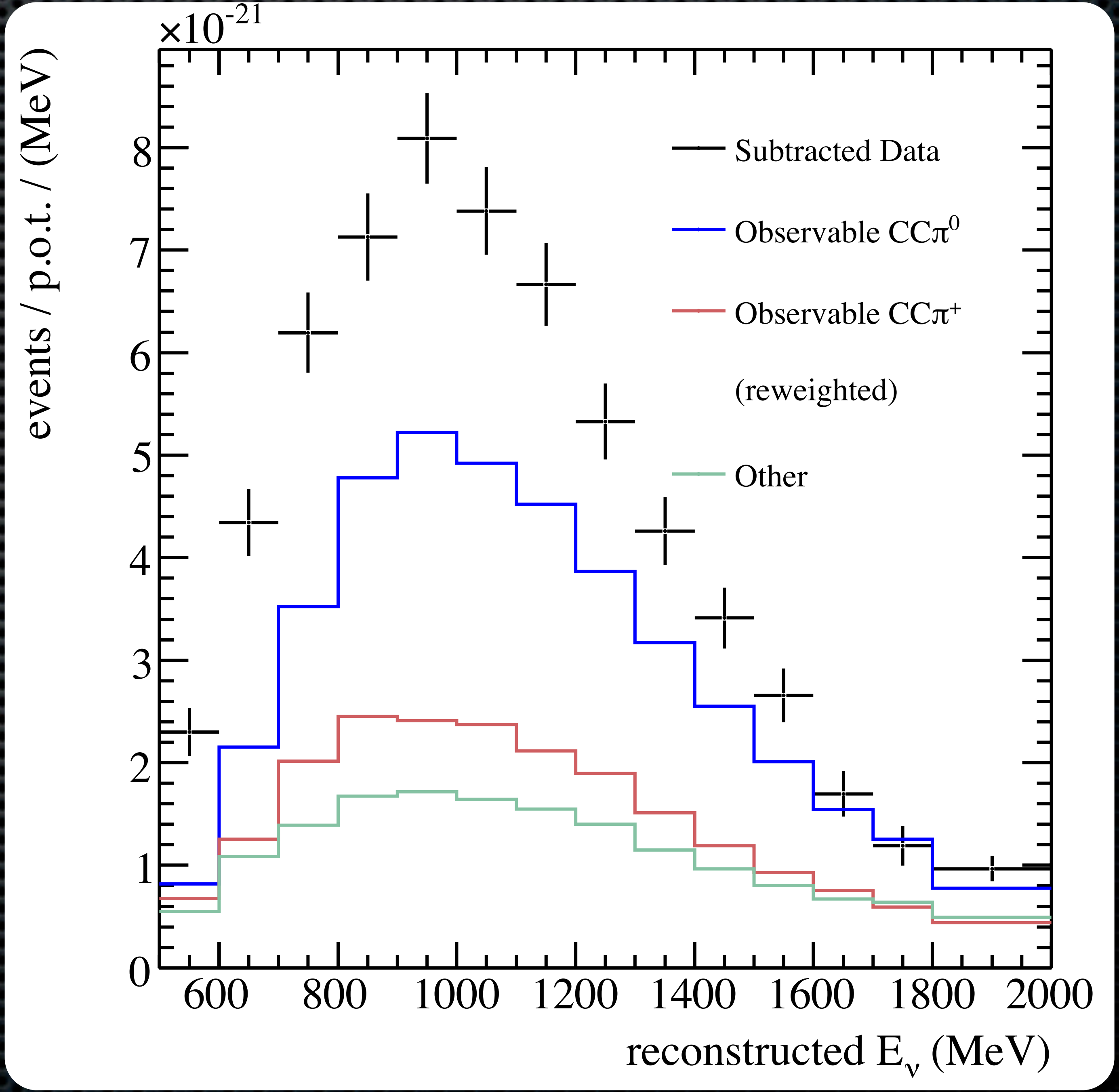
- The scheme to re-weight these events involves two of Mike's cross-section measurements:
  - $\sigma(E_\nu)$, $d\sigma(E_\nu)/dKE_\pi$
- The ratio of Data/MC defines the re-weighting and is a function of KE_π and E_ν.
- Any place that the differential cross-section left unreported values is filled in with the integrated cross-section.
- This re-weighting is applied to all observable $CC\pi^+$ events that make it into this sample.



Background subtraction

$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij} \left(N_j - B_j\right)}{\varepsilon_i \, \Phi_i \, N_{targs}}$$

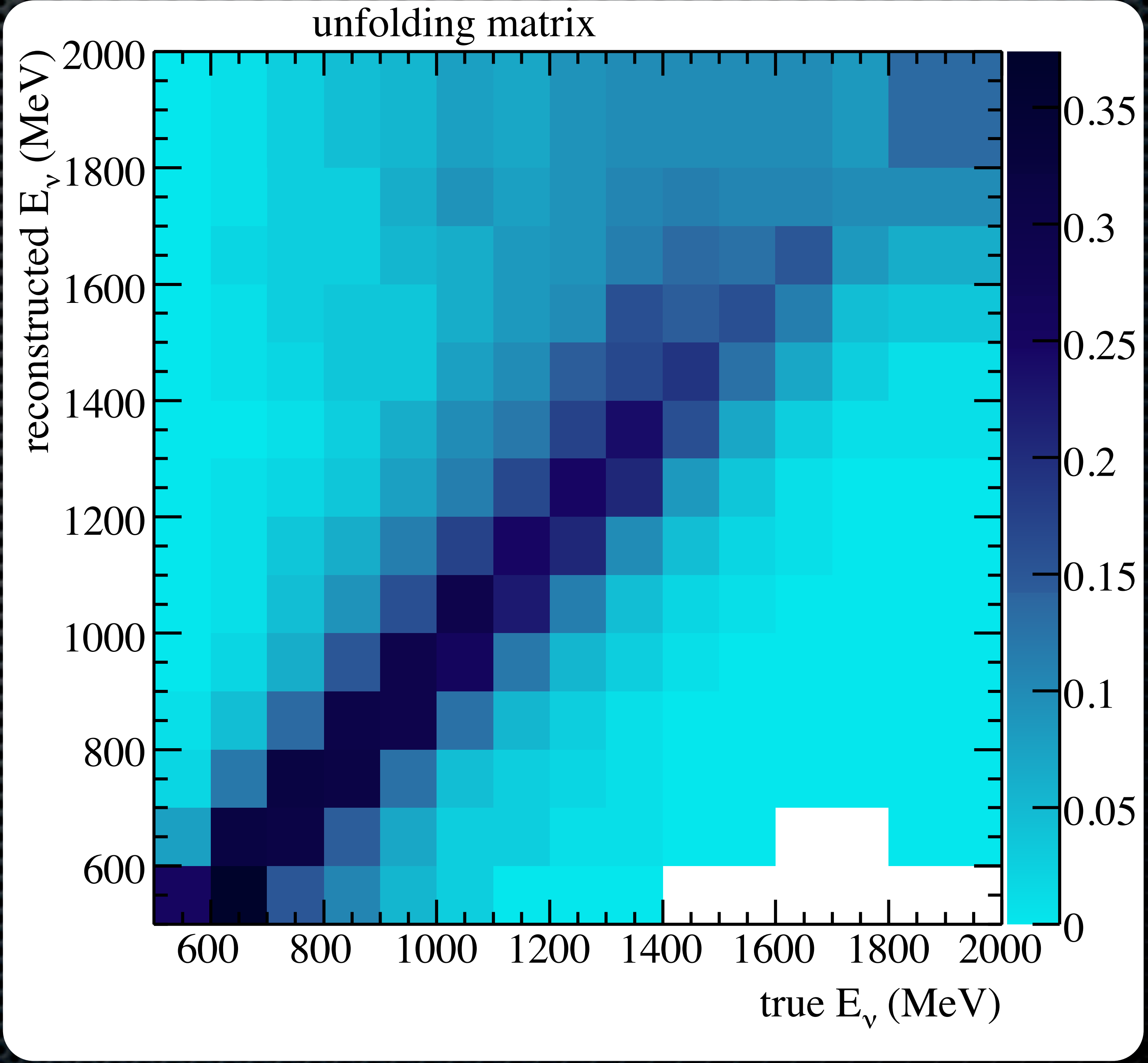
- CCπ⁺ events were re-weighted.
- The CV MC is “trusted” for everything else.



E_ν unfolding matrix

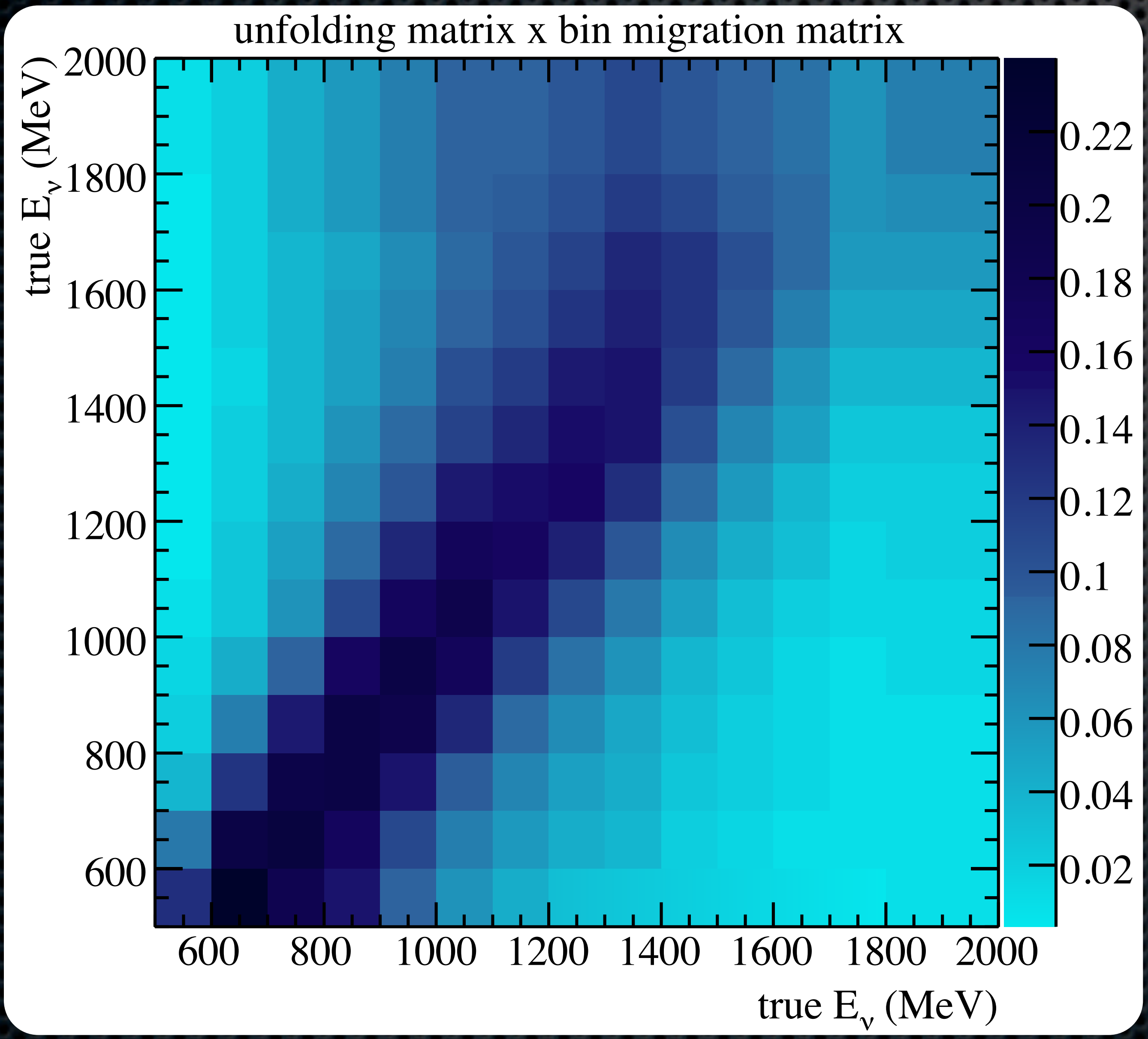
$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij} \left(N_j - B_j\right)}{\varepsilon_i \, \Phi_i \, N_{targs}}$$

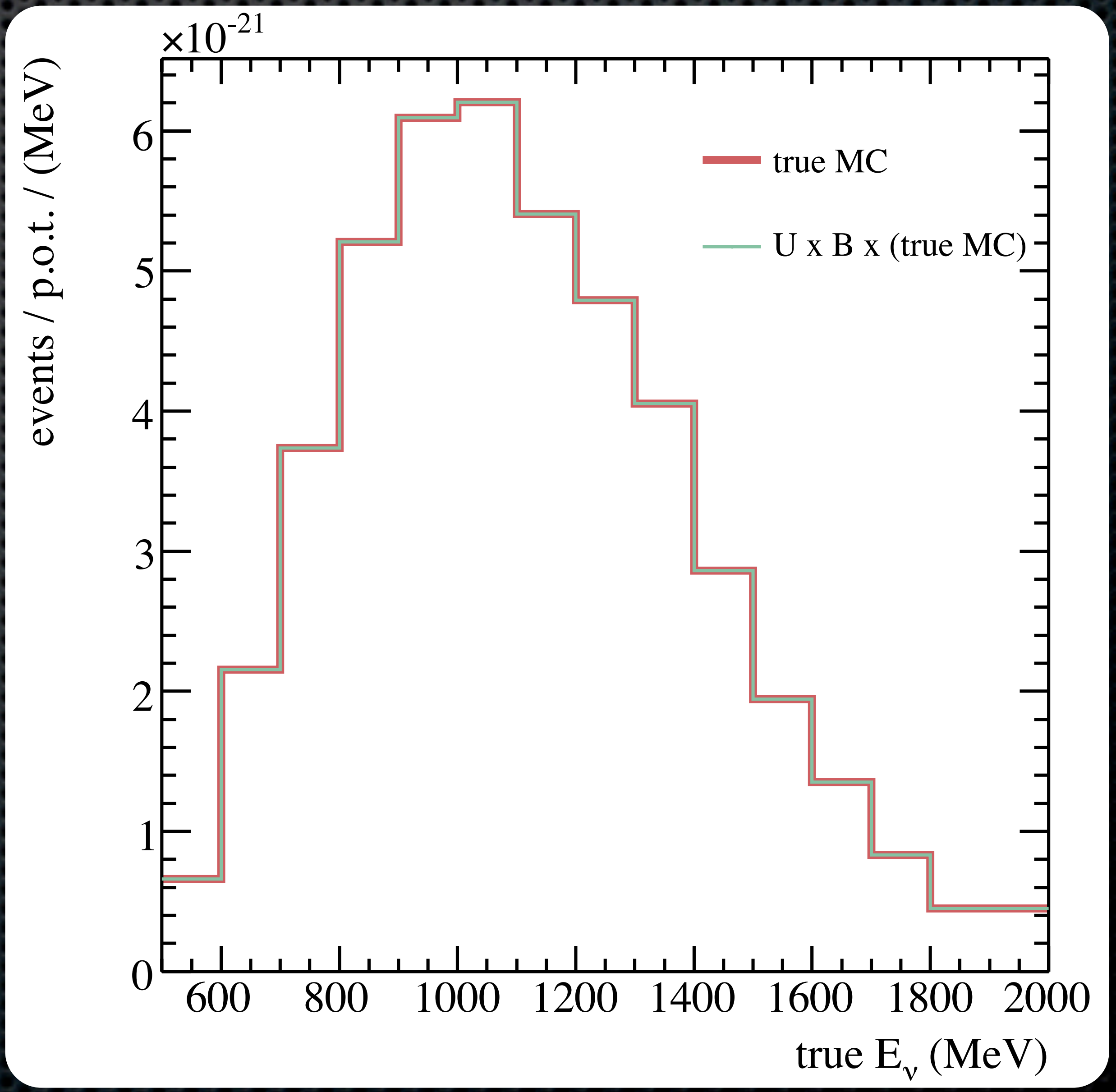
- Unfolding is performed *a la* Ryan's/Steve L.'s/Bayesian method.
  - Known to contain bias.
  - Avoids the issues associated with matrix inversion with low statistics.
- Fortunately, the matrix is mostly diagonal.
- Evaluating the bias is a goal of this analysis.



Unfolding test

- The true MC vector should be an eigenvector of the unfolding matrix times the bin migration matrix.
- The unfolding satisfies this tautology test.

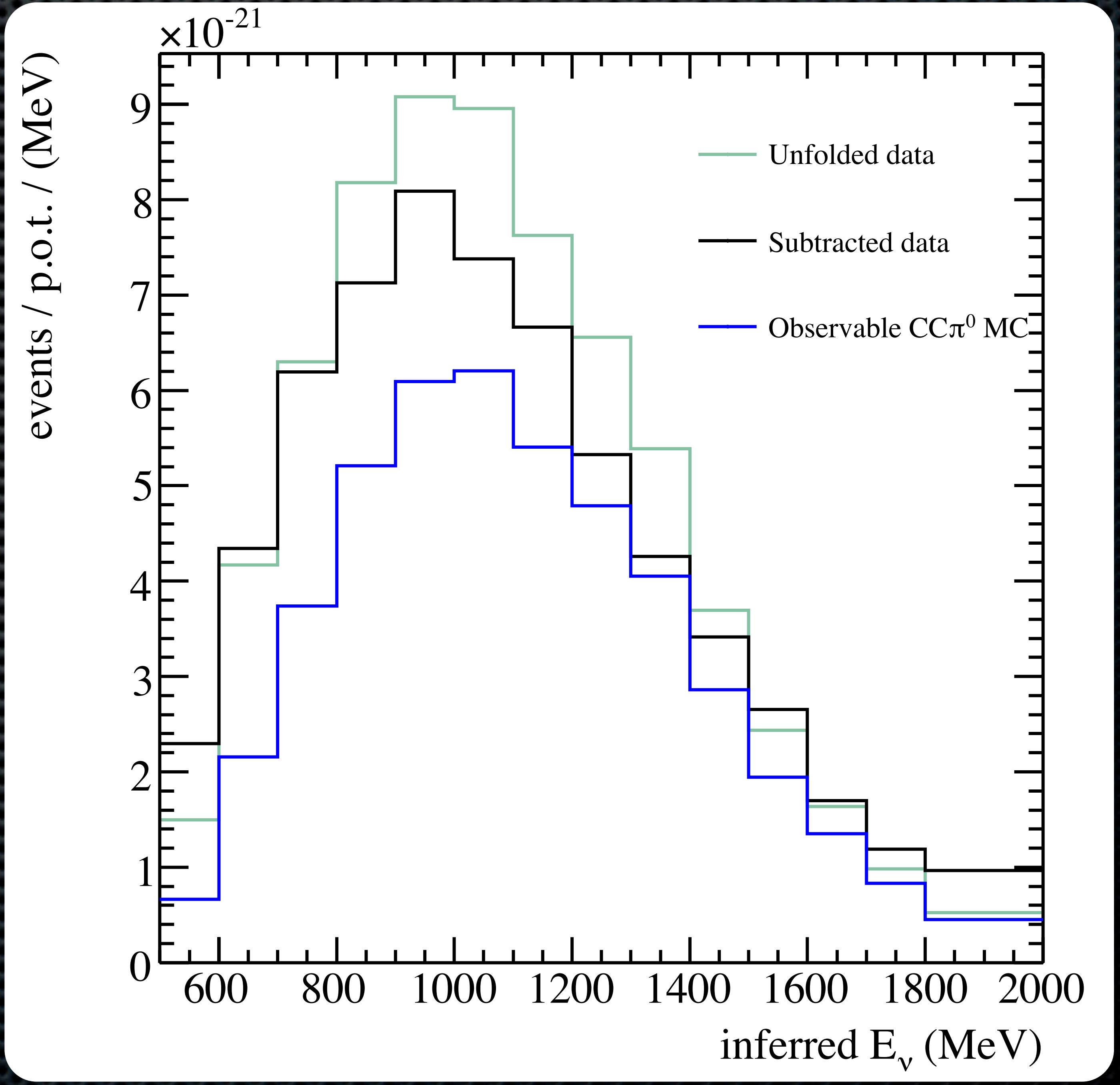




Unfolded data

$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij}\left(N_j - B_j\right)}{\varepsilon_i \, \Phi_i \, N_{targs}}$$

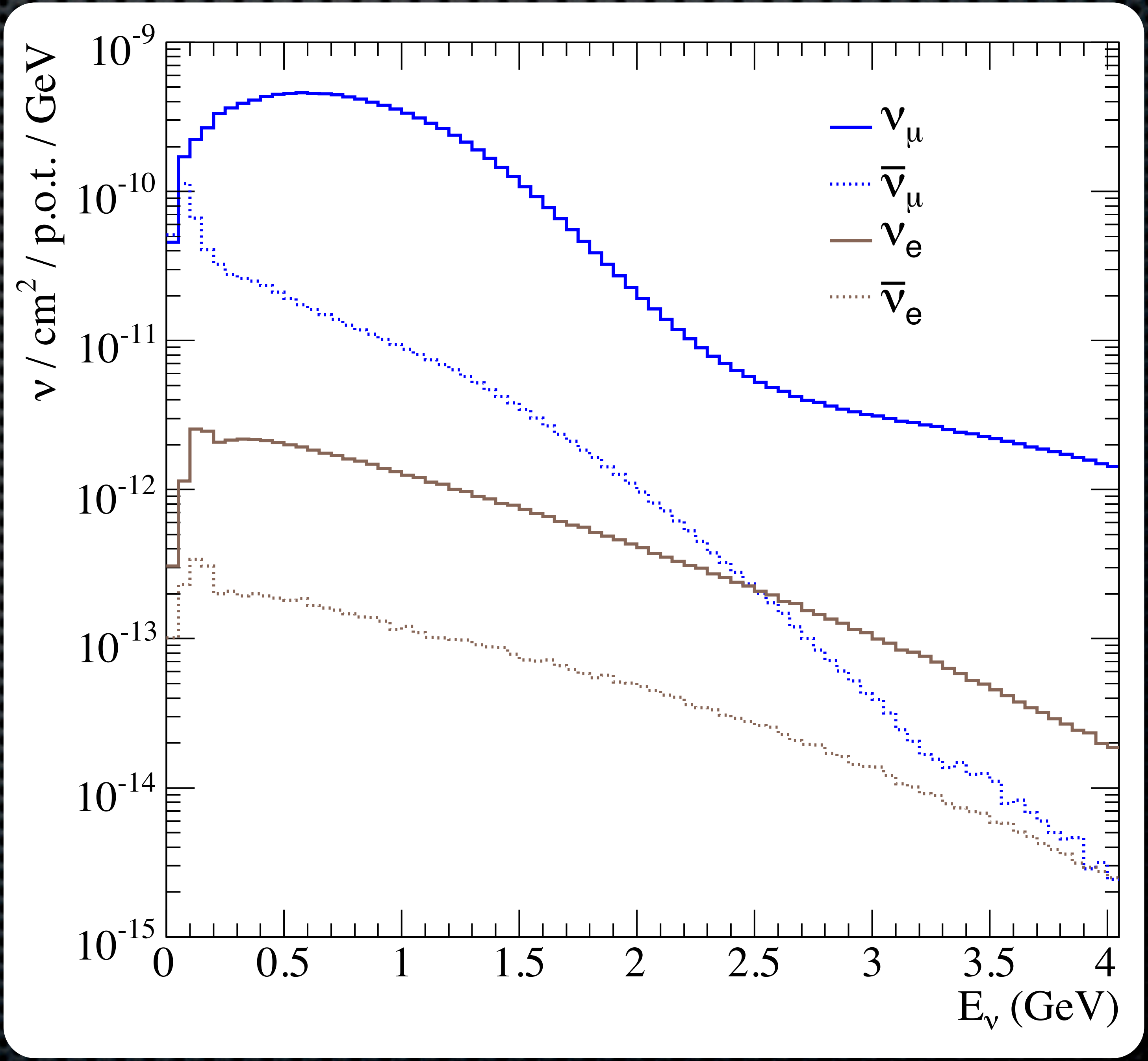
- The effect of unfolding the data causes the distribution to soften.
- There is a worry that we are biased by the CV MC.
  - This still needs to be quantified.



ν_μ flux

$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij}\left(N_j - B_j\right)}{\varepsilon_i \Phi_i N_{targs}}$$

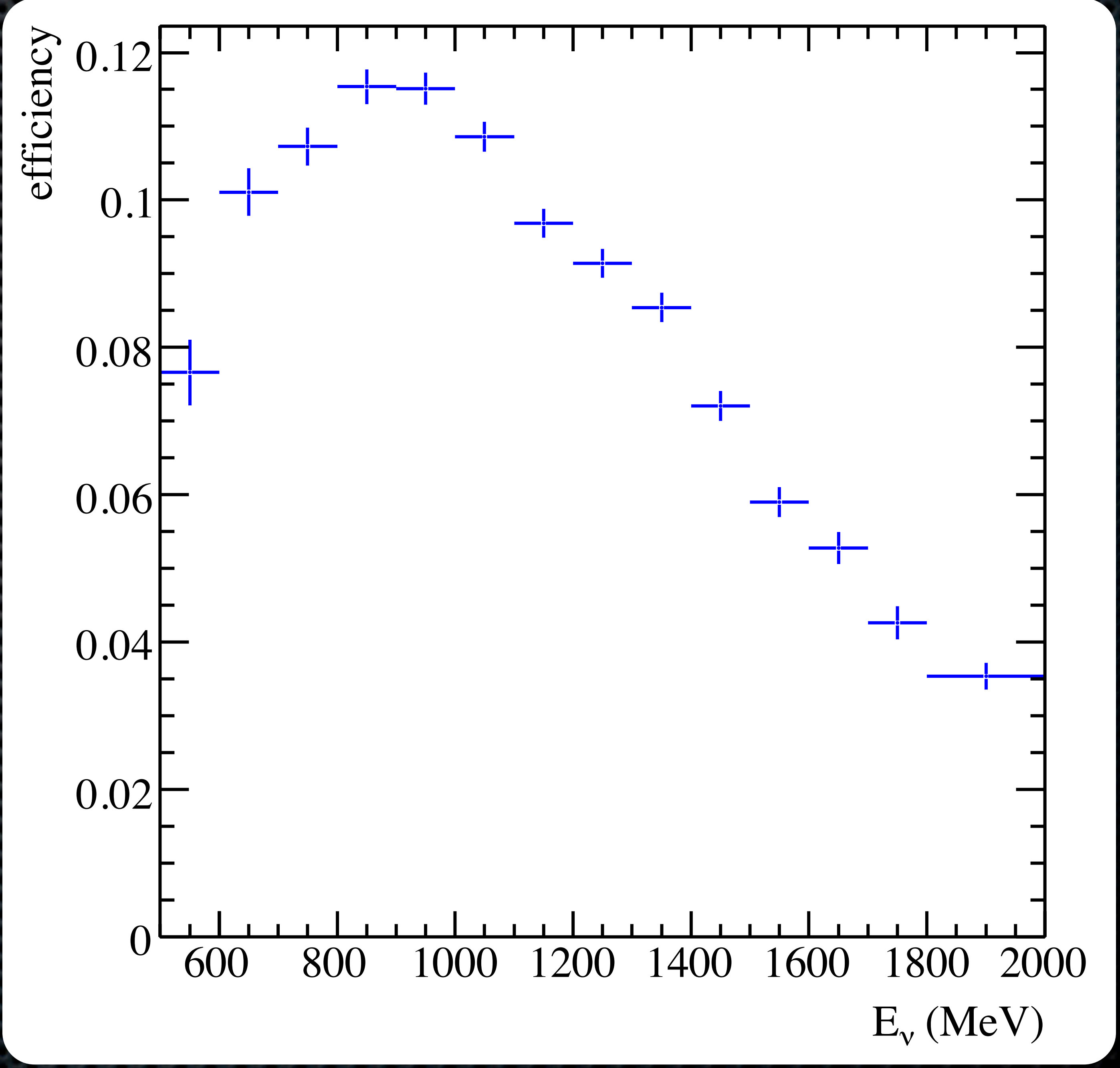
- The only relevant portions of the flux for this measurement are between 500-2000 MeV.
- This region is dominated heavily by ν_μ from π^+ decay in flight in the secondary beam.



Efficiency

$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij}\left(N_j - B_j\right)}{\varepsilon_i \Phi_i N_{targs}}$$

- This is the total efficiency.
- 60% of the events are lost immediately to the 2 subevent, and Tank/Veto hits cuts.
- Low energy events are lost by reconstruction.
- High energy events are lost by an exiting muon.



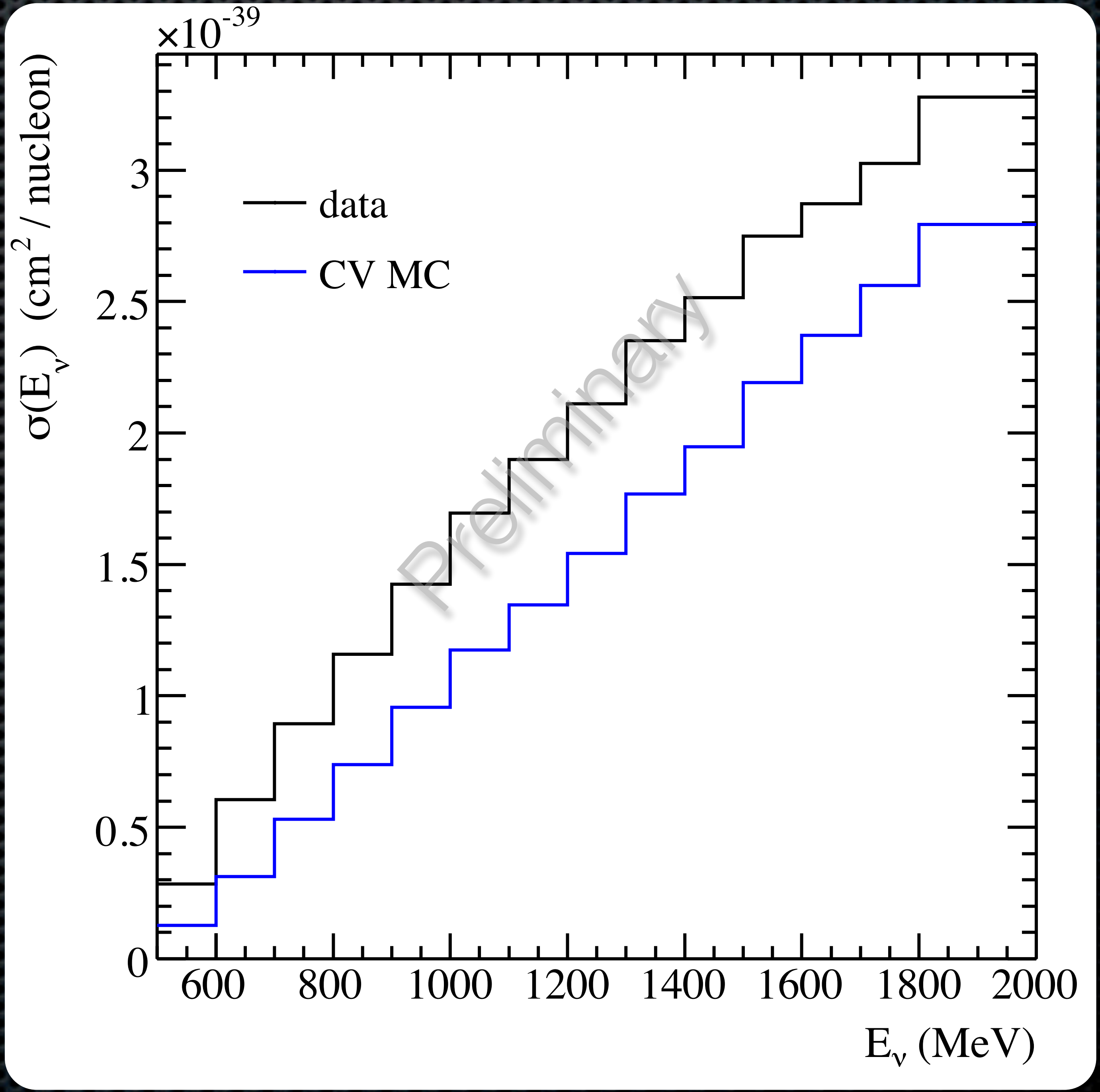
Putting it all together……

(cue orchestra)

σ(E_ν) without errors

$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij}\left(N_j - B_j\right)}{\varepsilon_i \, \Phi_i \, N_{targs}}$$

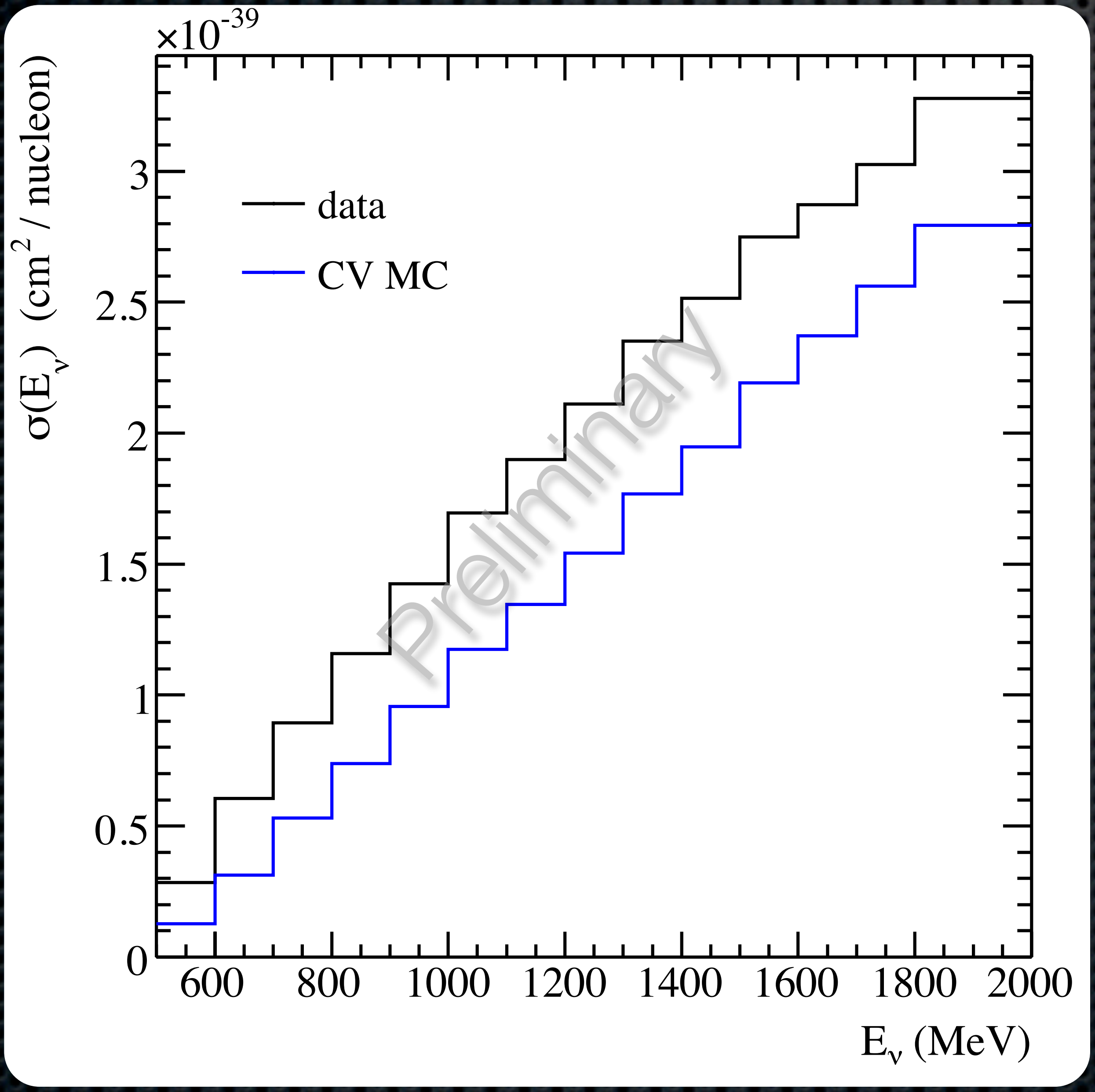
- This is preliminary with a capital "P."
- Before any serious conclusions can be made we need to evaluate the errors.
- This proves that the method for cross-section extraction works for this mode.

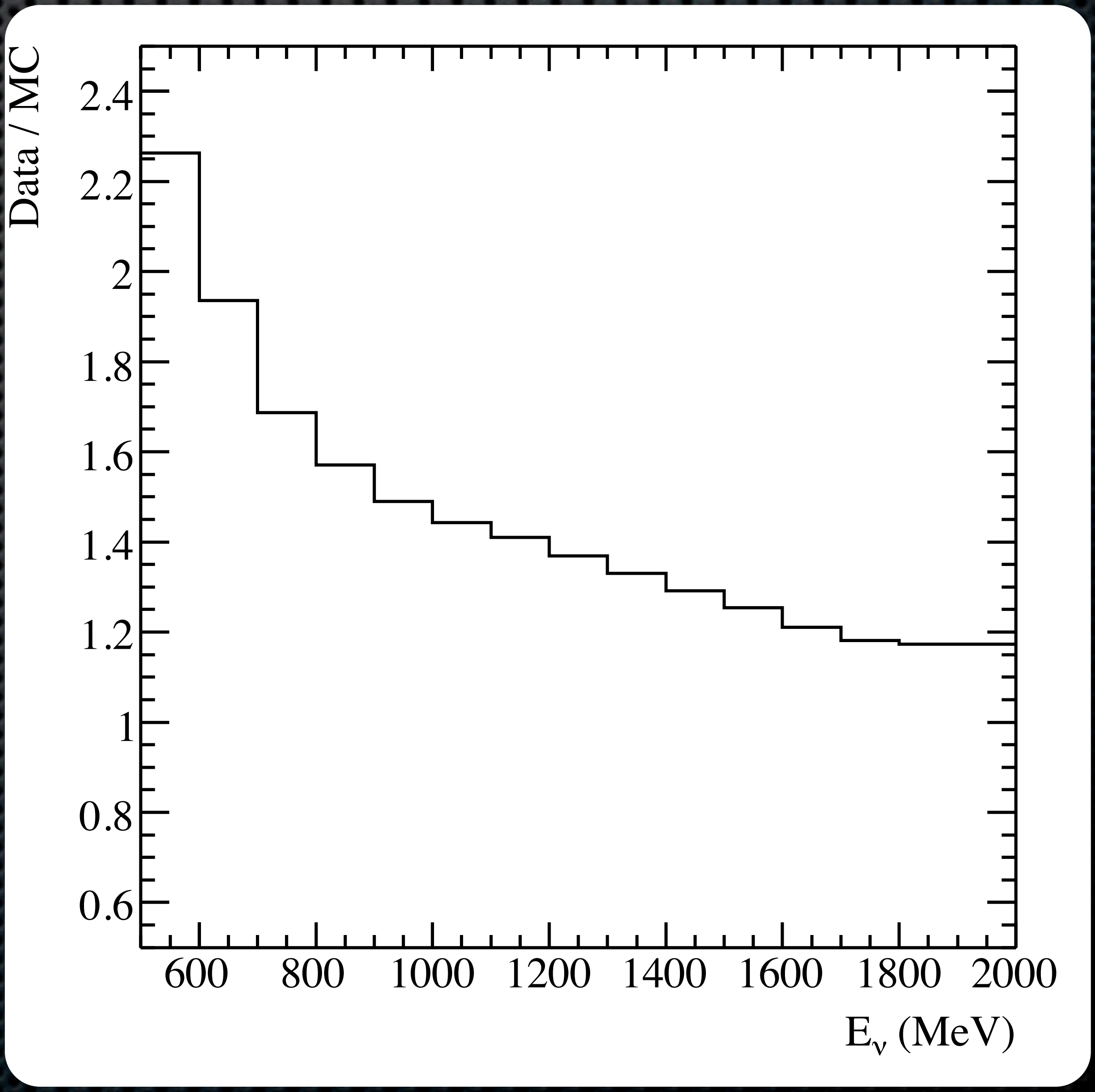


σ(E_ν) without errors

- Don't make too much of this until the background subtraction is a little more sensible.

$$\sigma(E_\nu)_i = \frac{\sum_j^{bins} U_{ij}\left(N_j - B_j\right)}{\varepsilon_i \Phi_i N_{targs}}$$





Remaining work

- Finish reconstruction technote.
- Fake data studies (in progress).
- Unfolding bias (in progress).
- Systematic errors:
  - These can be evaluated now that all the code is in place.
  - The fitter has been run on all the multisims.
- Evaluate charge-exchange/absorption uncertainties.
- Measure differential cross-sections (if feasible)
- Write paper/thesis.

Conclusion

- After all this time, I finally think I've proven that we can make this measurement.
- Besides cleaning up some of the details we're most of the way there.
- I'm cautiously optimistic; depending on the errors.