

MINERvA ($\bar{\nu}$) ν -CC0 π i Results

Daniel Ruterbories

NuInt 2017

June 29th, 2016

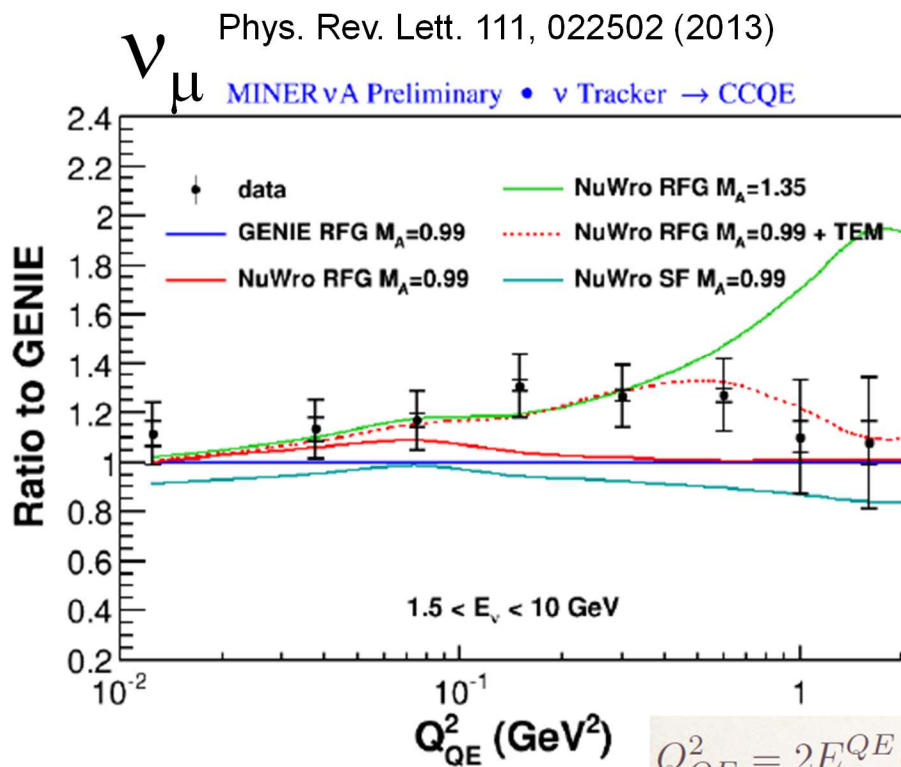


Objectives

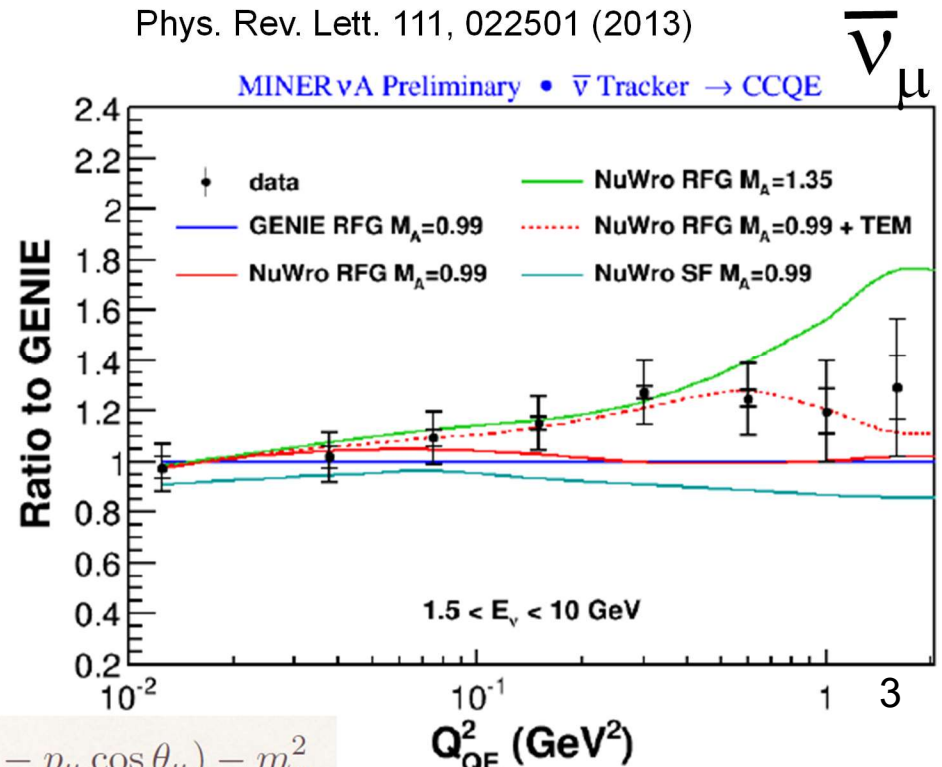
- What has changed since 2013
 - New event selection
 - New background constraint method
 - New models
- Double Differential Cross Sections
- Q^2 distribution
- Models
- Vertex energy distributions

To Start

- Original MINERvA CCQE measurements indicated our data preferred 2p2h-like effects



$$Q_{QE}^2 = 2E_\nu^{QE}(E_\mu - p_\mu \cos \theta_\mu) - m_\mu^2$$



- What can the next generation say?

Our underlying model set has changed

- GENIE 2.6.2 → GENIE 2.8.4[1]
- Latest flux [2]
- Additional models and CV tweaks
 - Sourced from **outside** MINERvA
 - Non-resonant pion production rate reduced[3]
 - Add in Valencia 2p2h[4]
 - Add in Valencia RPA[5]
 - Sourced from **MINERvA data**
 - Low recoil fit enhancing 2p2h effect in q_0, q_3 space
 - Smaller $q_0 q_3$ space and restricted E_ν than the neutrino result shown today
- See Rik Gran's talk Monday

[1] Nucl.Instrum.Meth.A614 (2010) 87-104

[2] Phys. Rev. D 94, 092005 (2016)

[3] Phys. Rev. D 90, 112017 (2014)

[4] PRC 70, 055503 (2004); PRC 83, 045501 (2011)

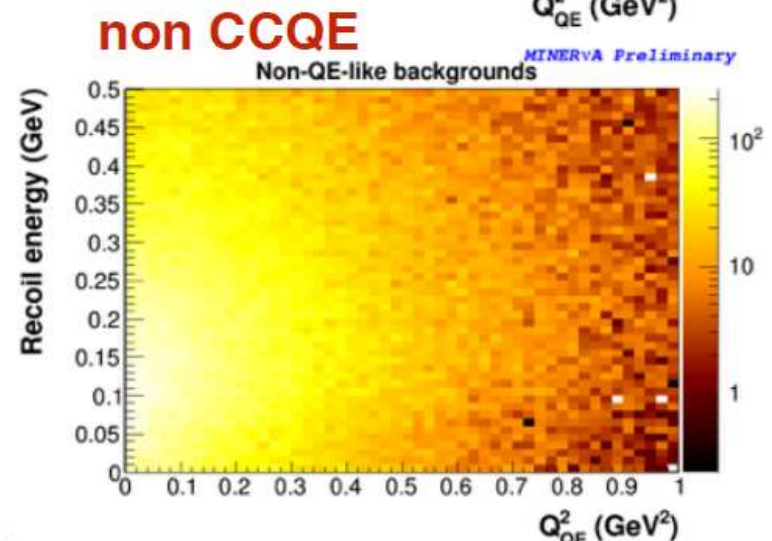
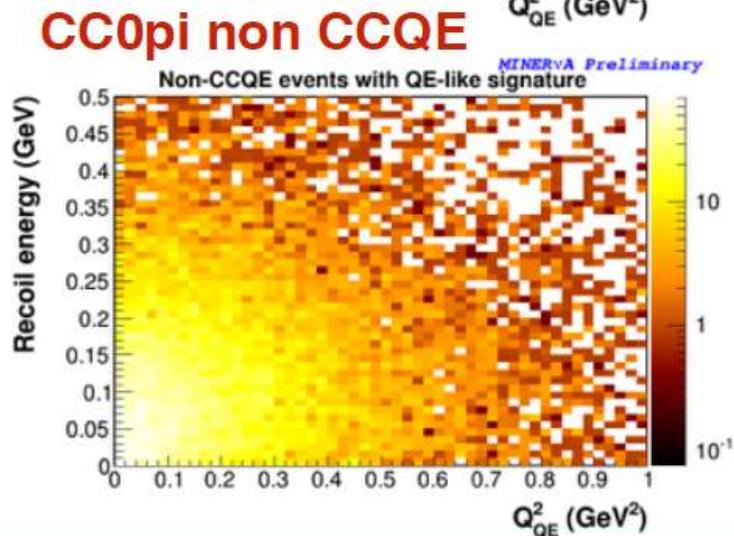
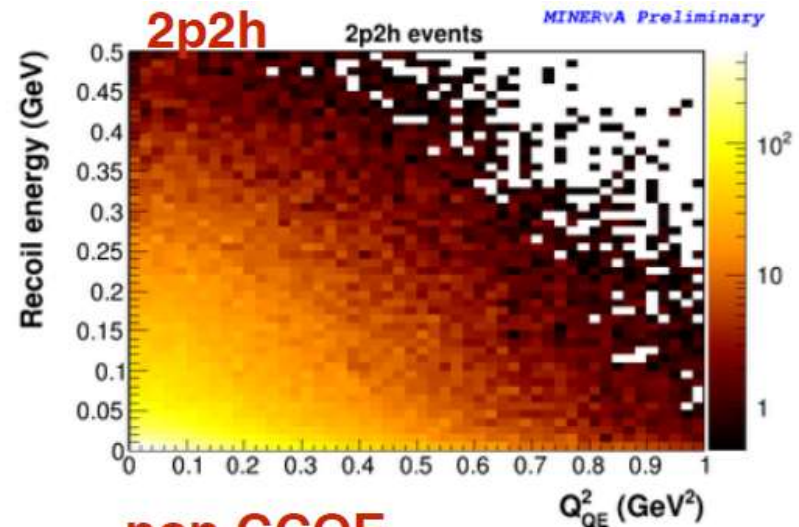
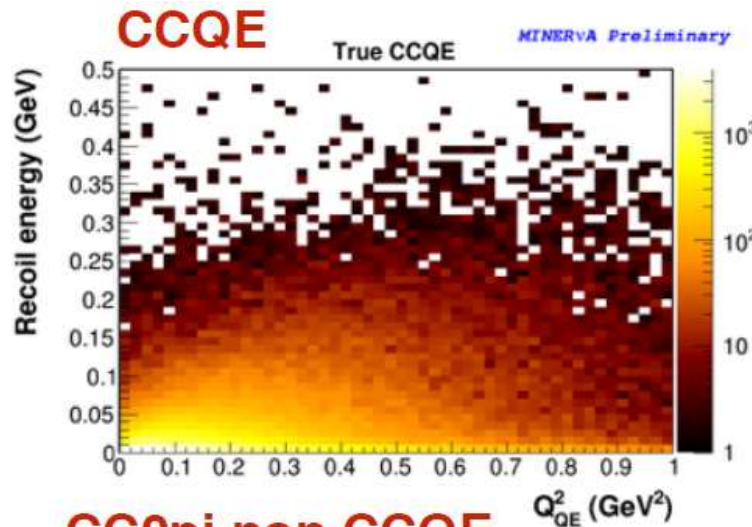
[5] PRC 70, 055503 (2004); PRD 88, 113007 (2013)

[6] Phys. Rev. Lett. 116, 071802 (2016)

What else changed?

- QE-like signal means the recoil cut can be sensitive to the underlying model

C. Patrick JETP Seminar June 17, 2016

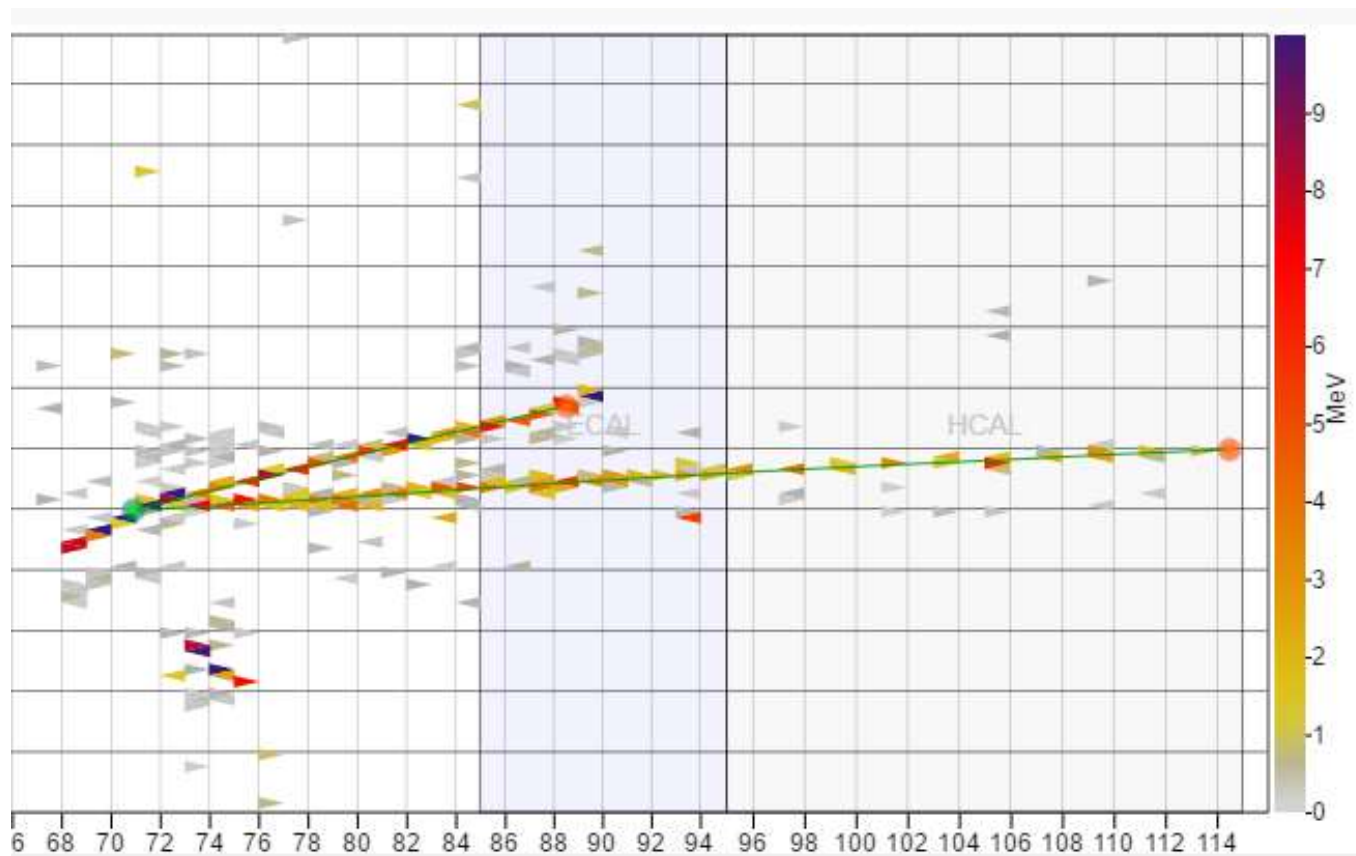


What else changed

- Two avenues to attack this dependence
 - Analysis selection and background constraint modifications
 - Better understanding of underlying sensitivity to the model outputs
- Anti-neutrino result benefits from the latter
 - Not many other handles in reconstruction
 - Future neutron tagging benefits
- Neutrino benefits from both (focus here)

What does MINERvA say about quasi-elastic processes?

- **Previous Strategy** – Use summed hadronic energy
- Selection based on cutting out high recoil events
constrain background using the hadronic recoil energy

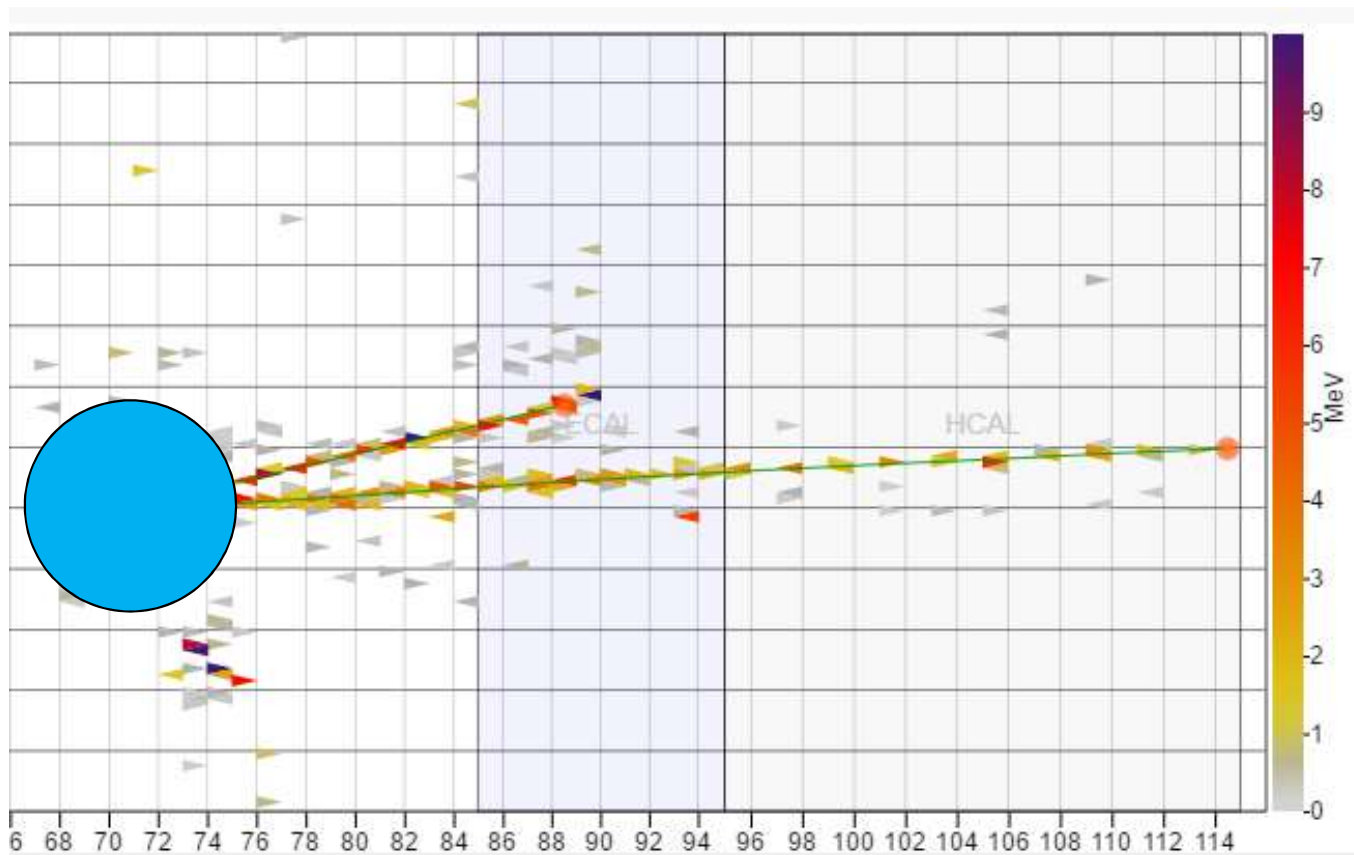


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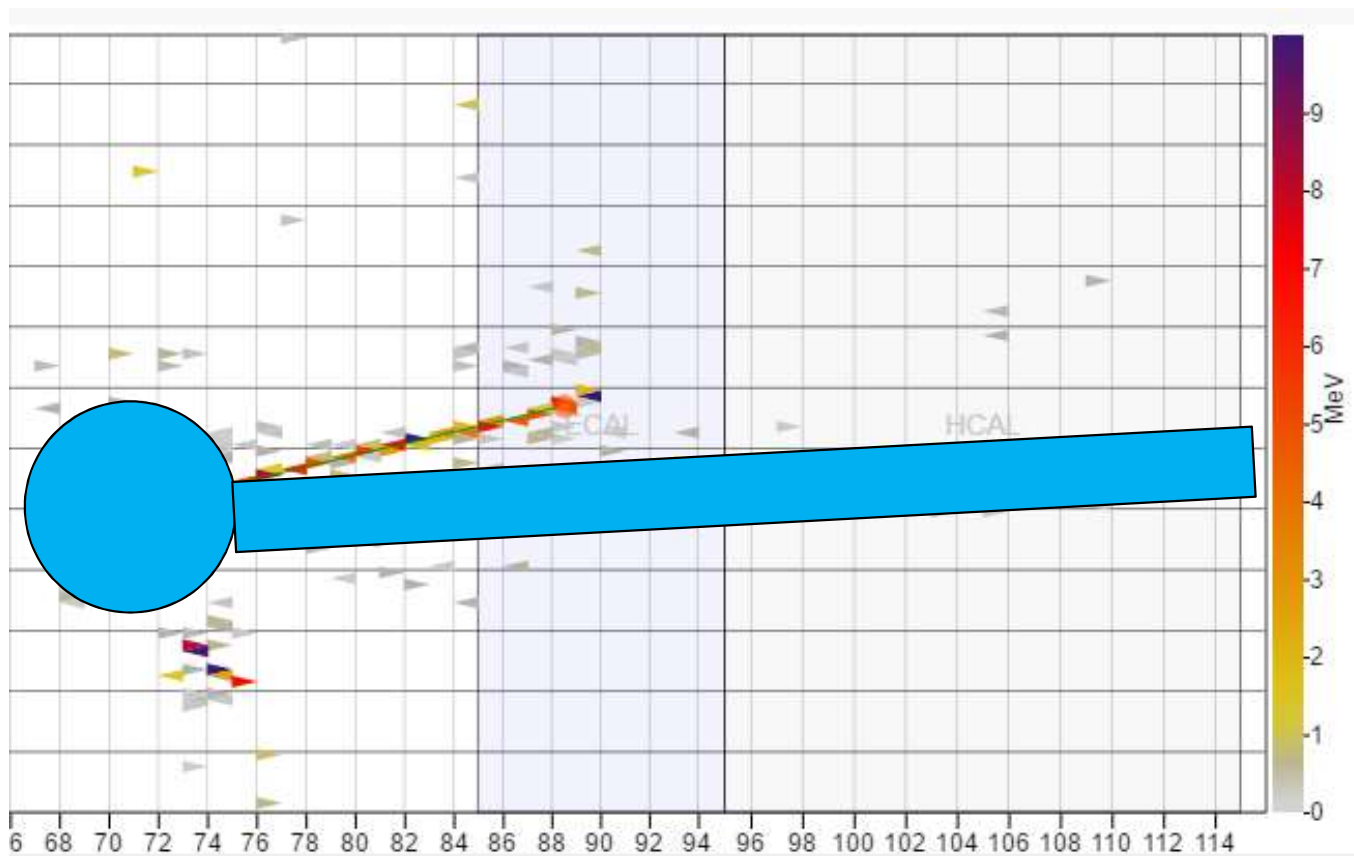


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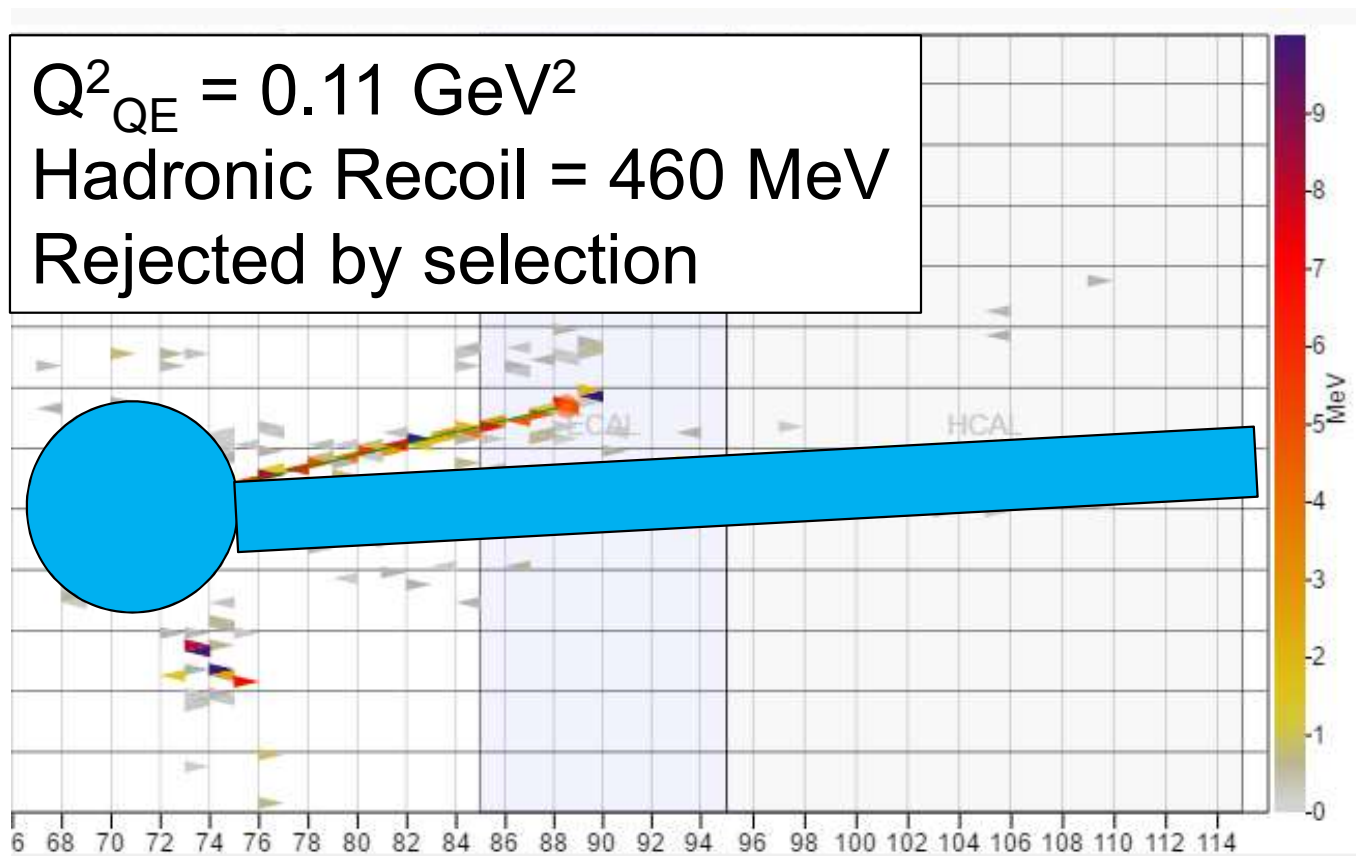
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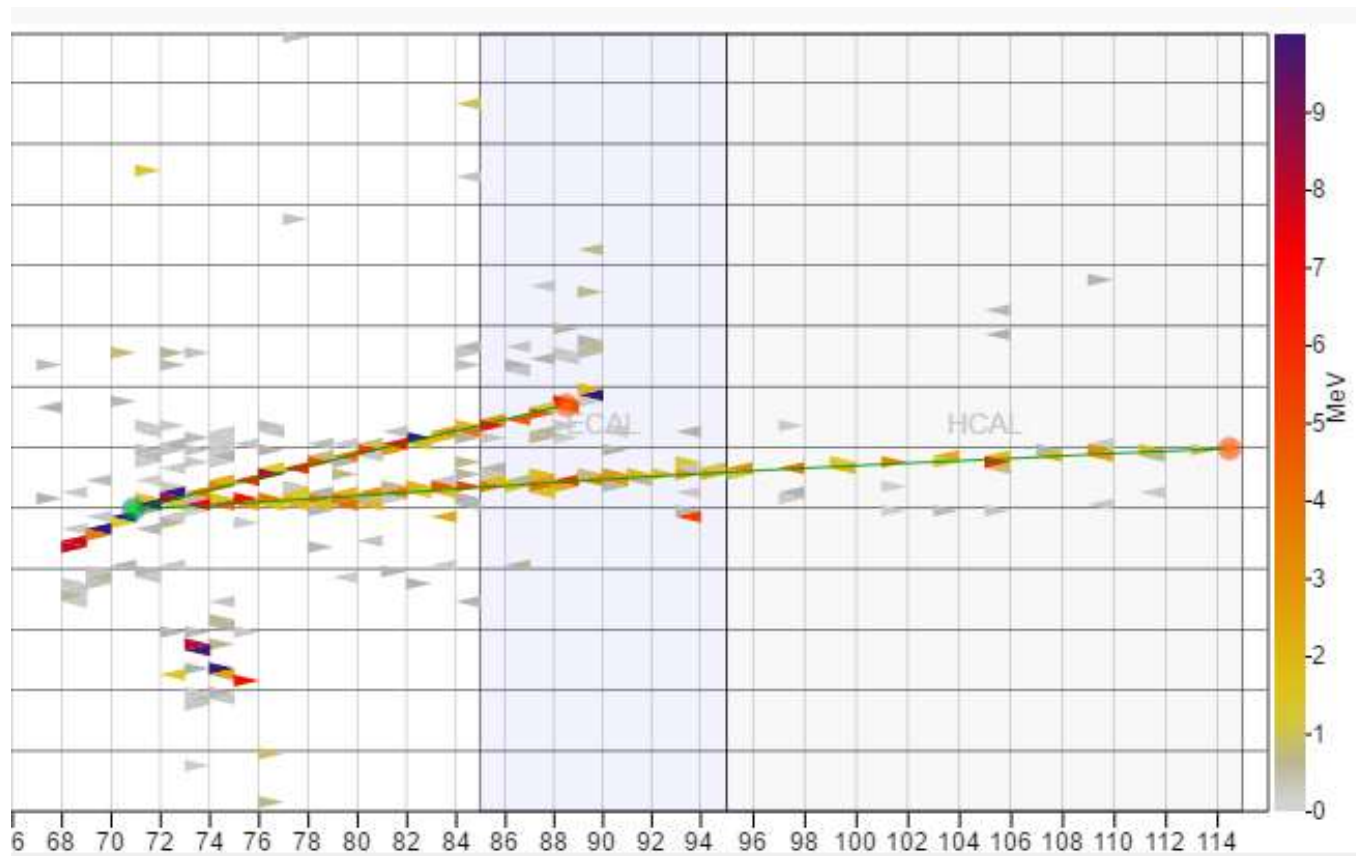
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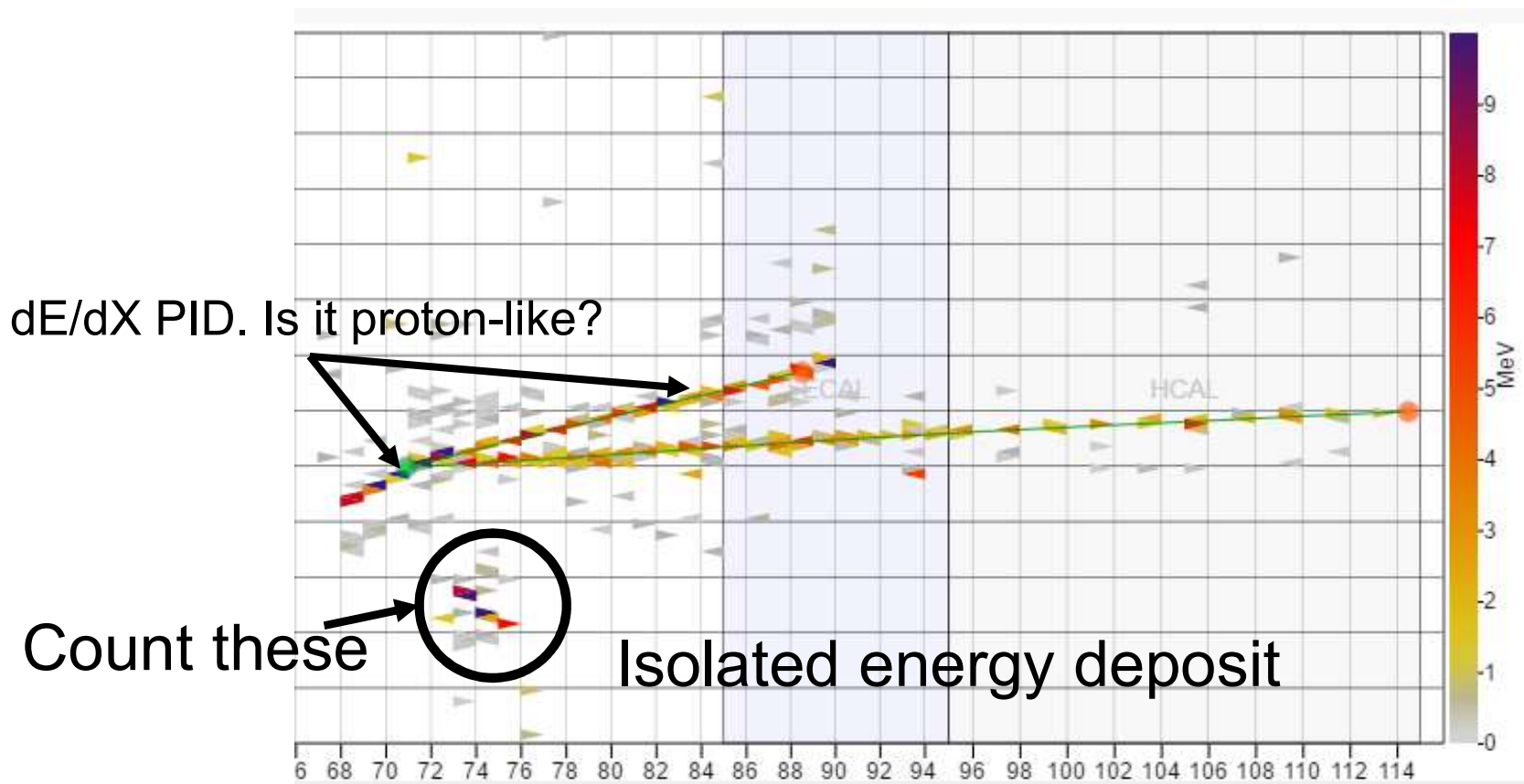
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- **New Strategy** –Track pions and protons
- Select events based on particle identification
- Constrain pion background using side band fits



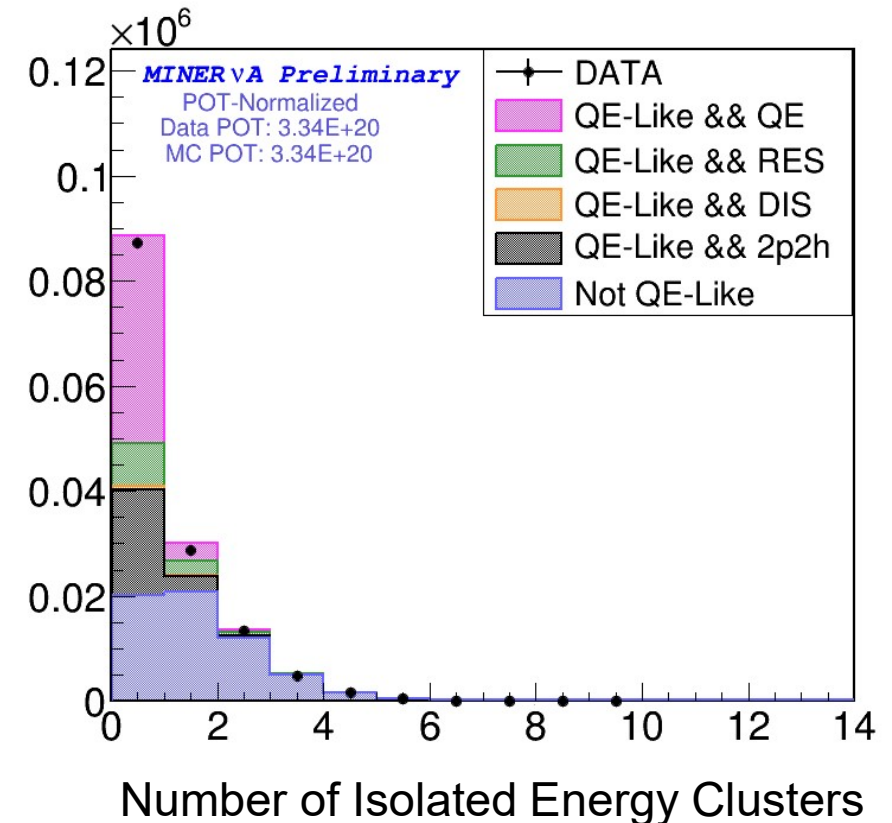
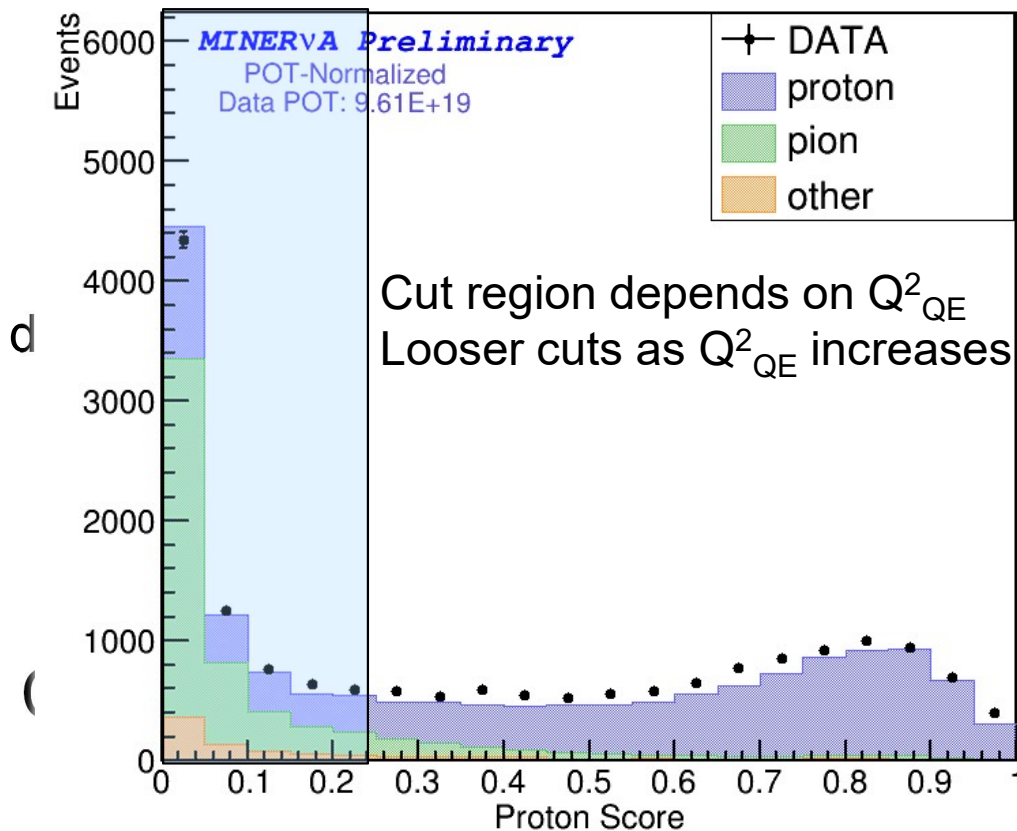
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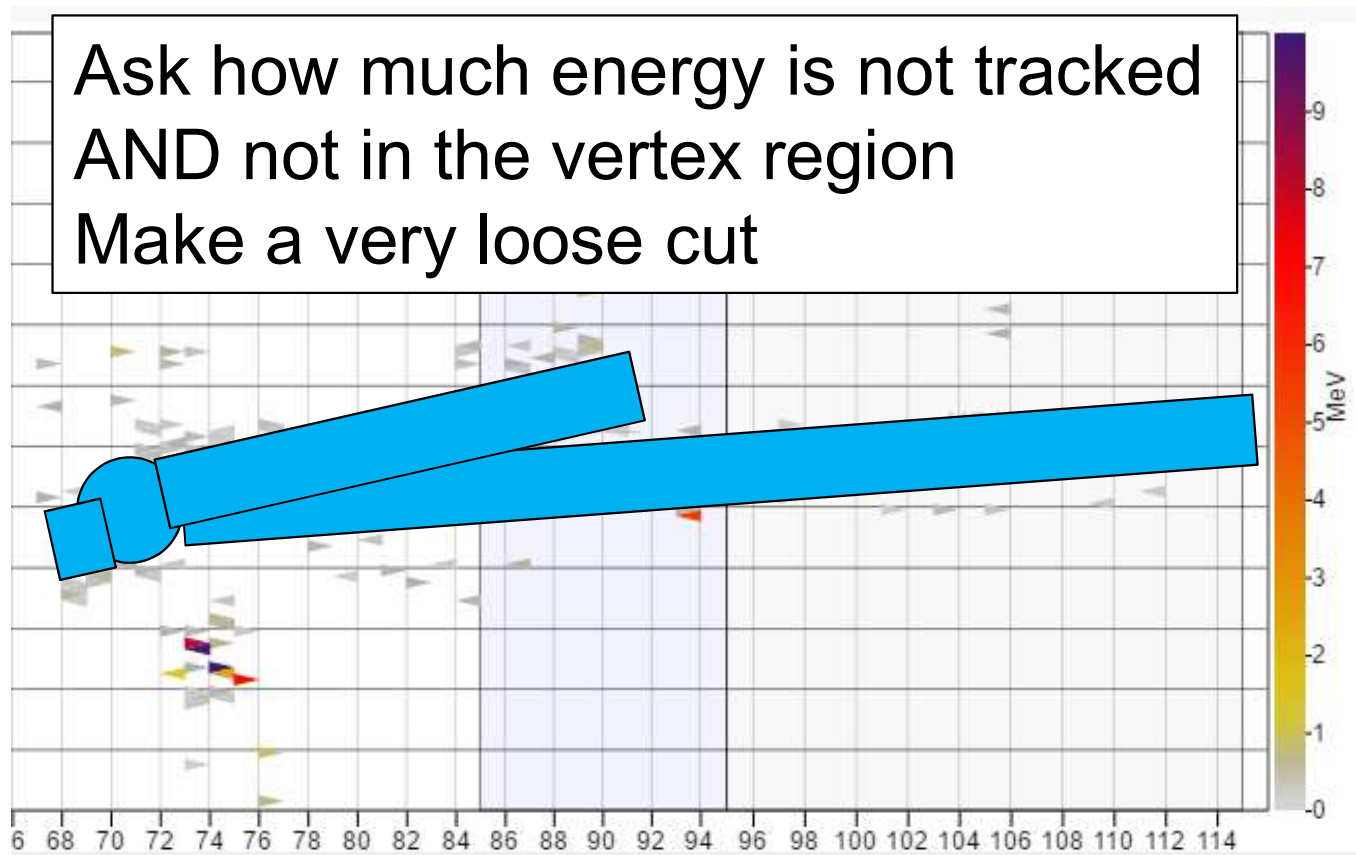
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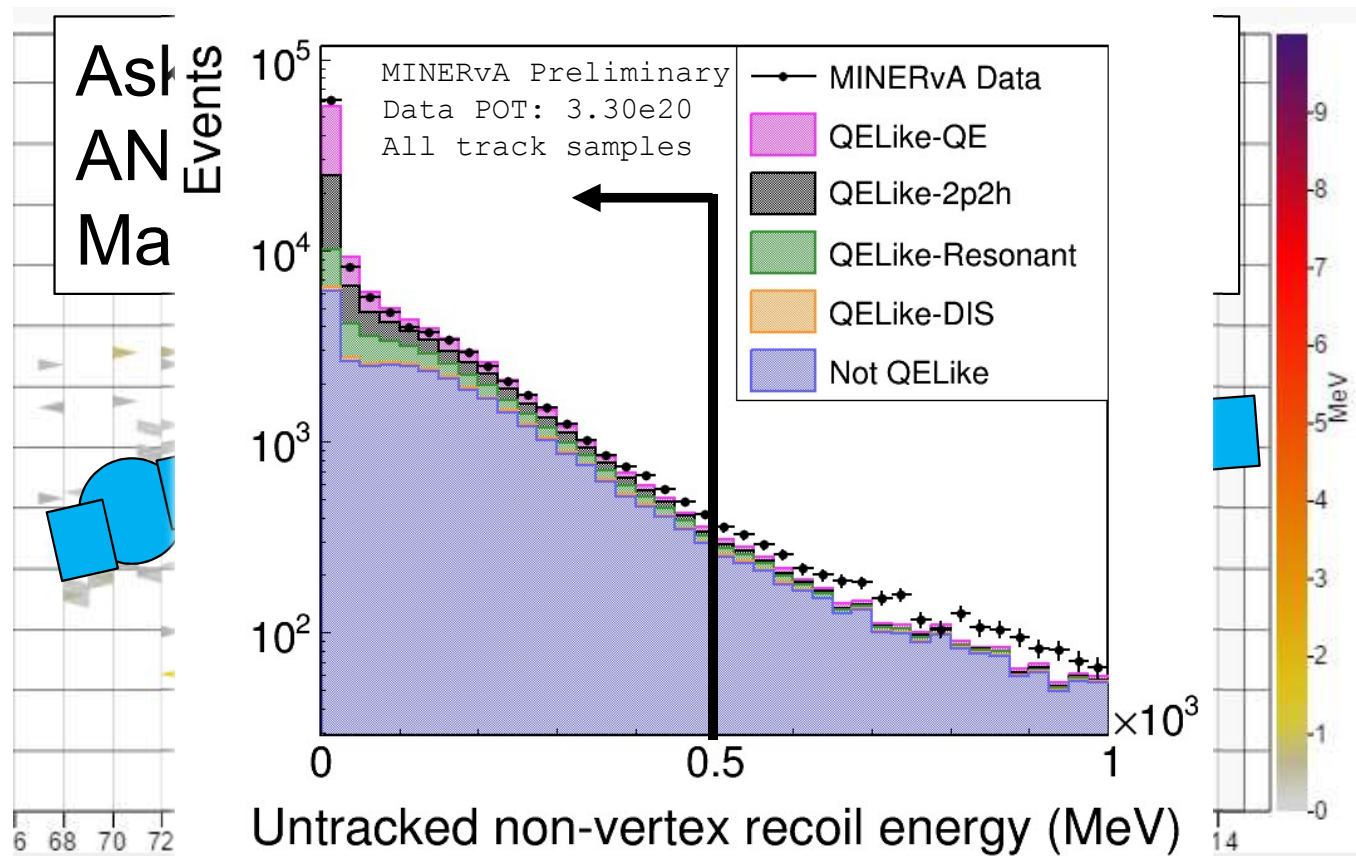
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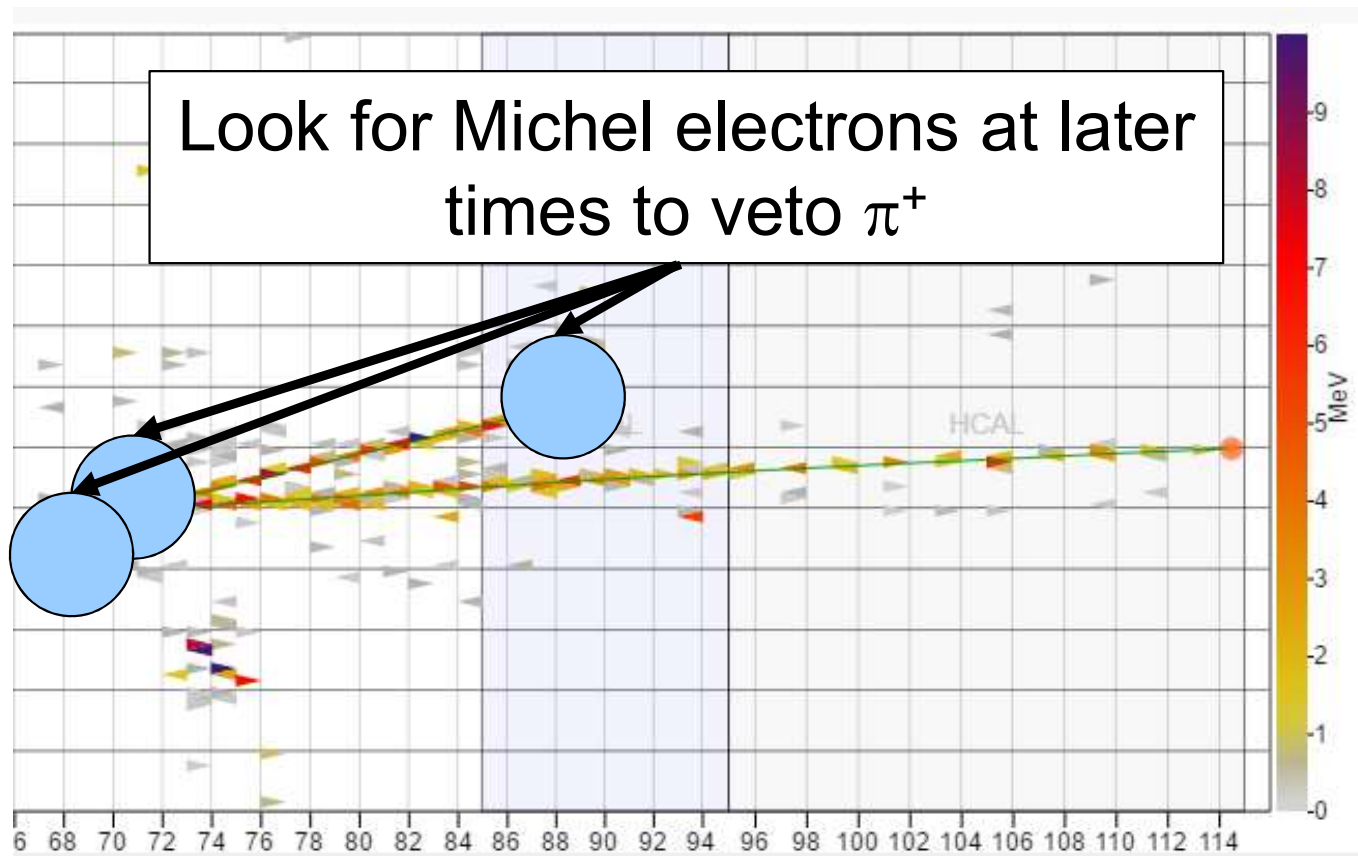
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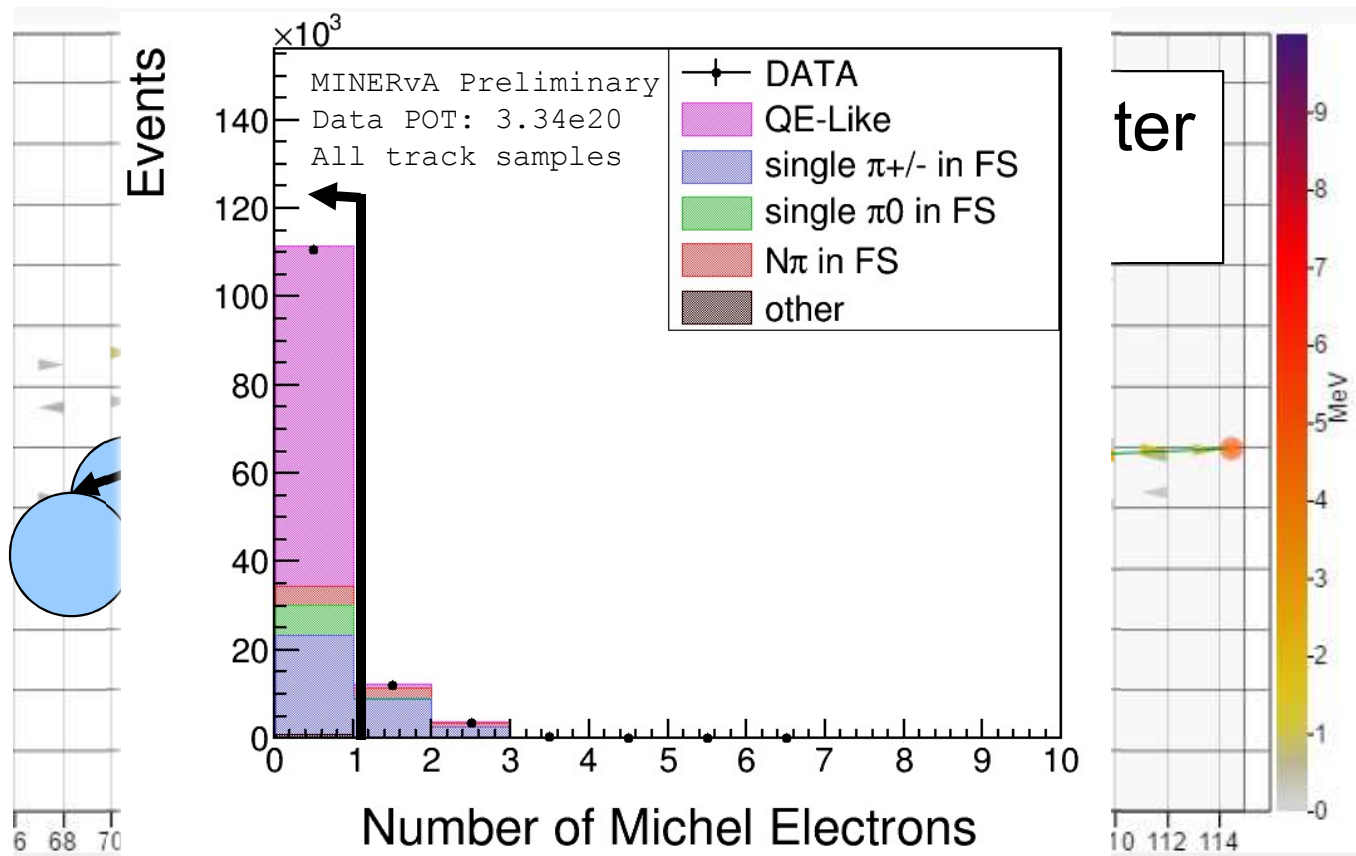
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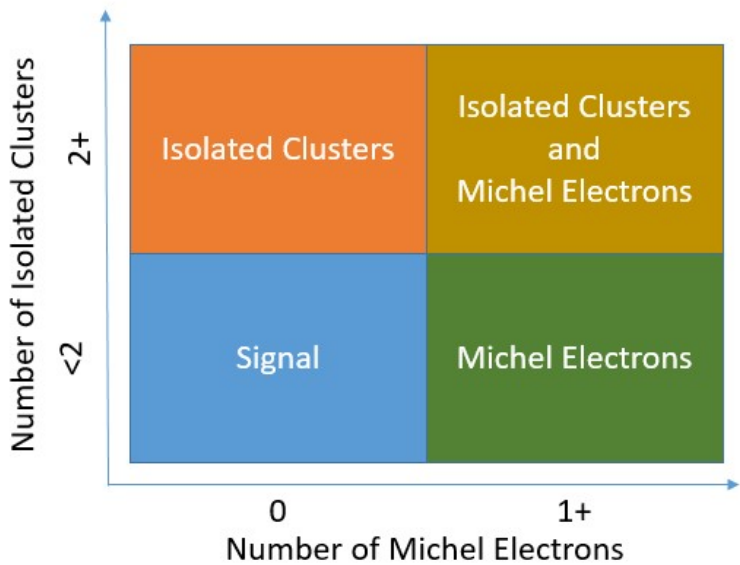
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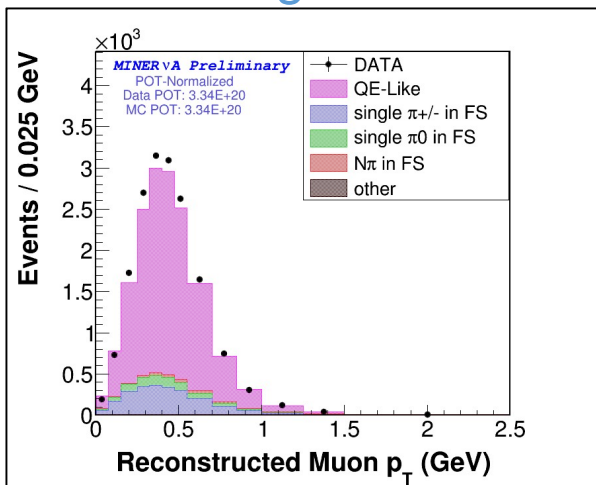


Background Constraint

Treats 1-track and >1-track samples separately.



Signal



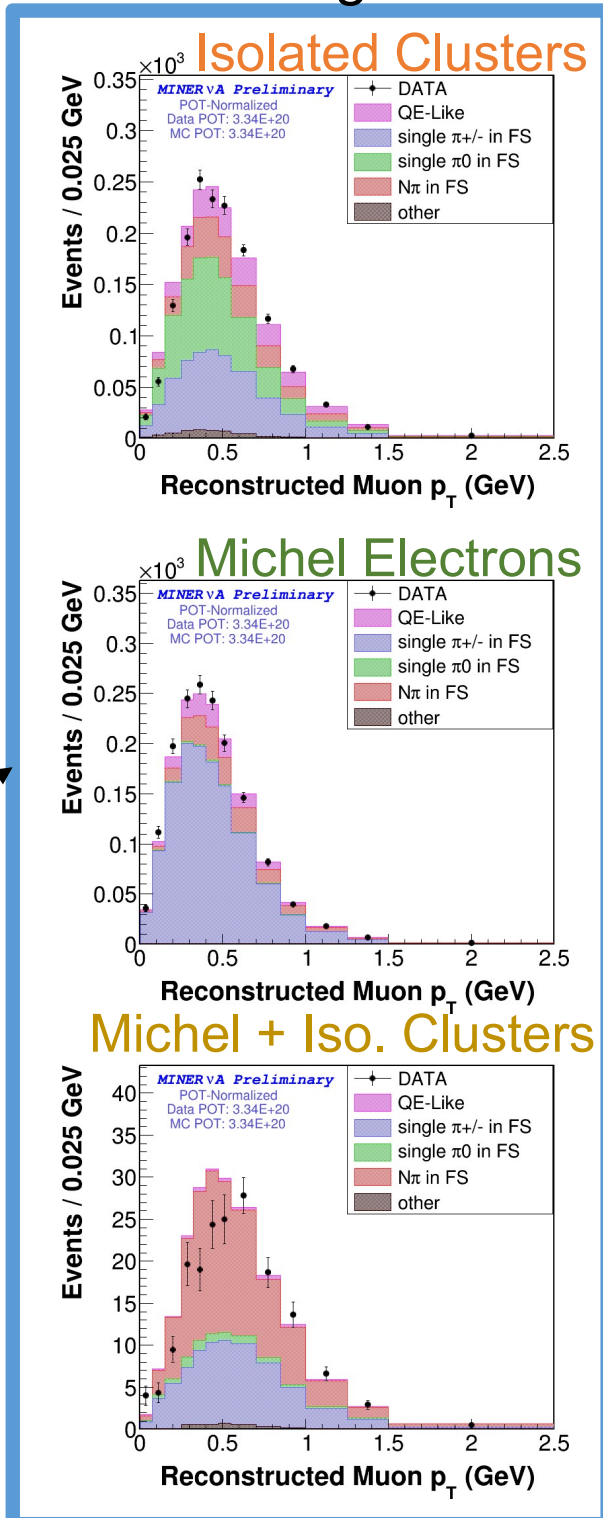
Scaling Factors as Function of p_T :

$\pi^{+/-}$

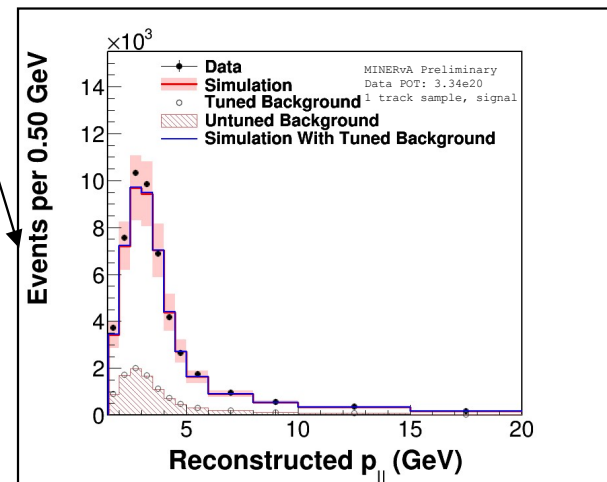
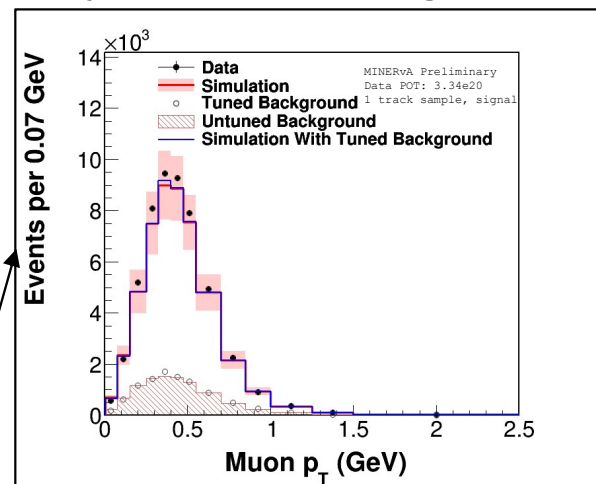
π^0

$N\pi$

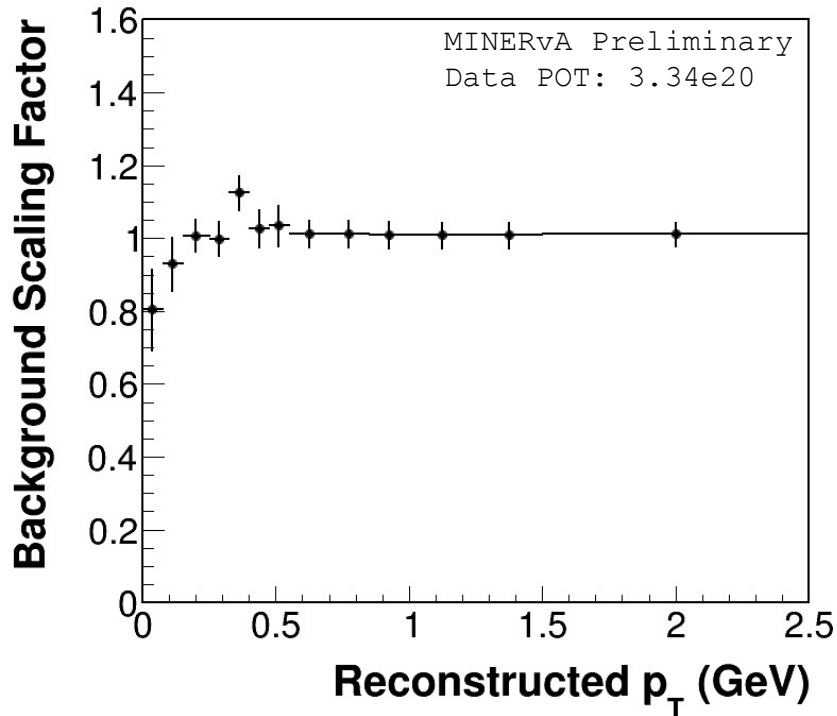
Fit 3 scaling factors



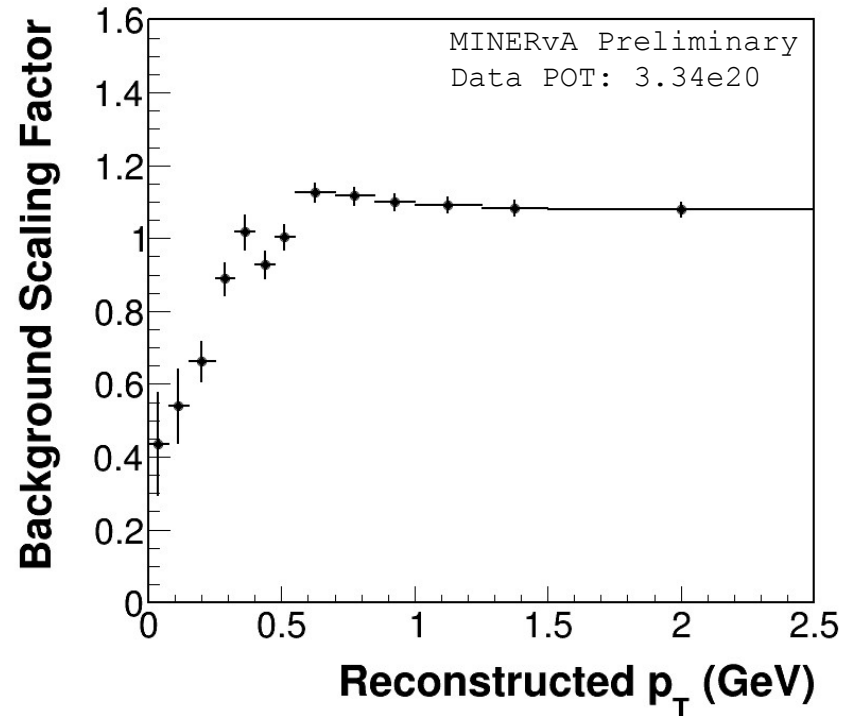
Apply to the background



Overall scale factors



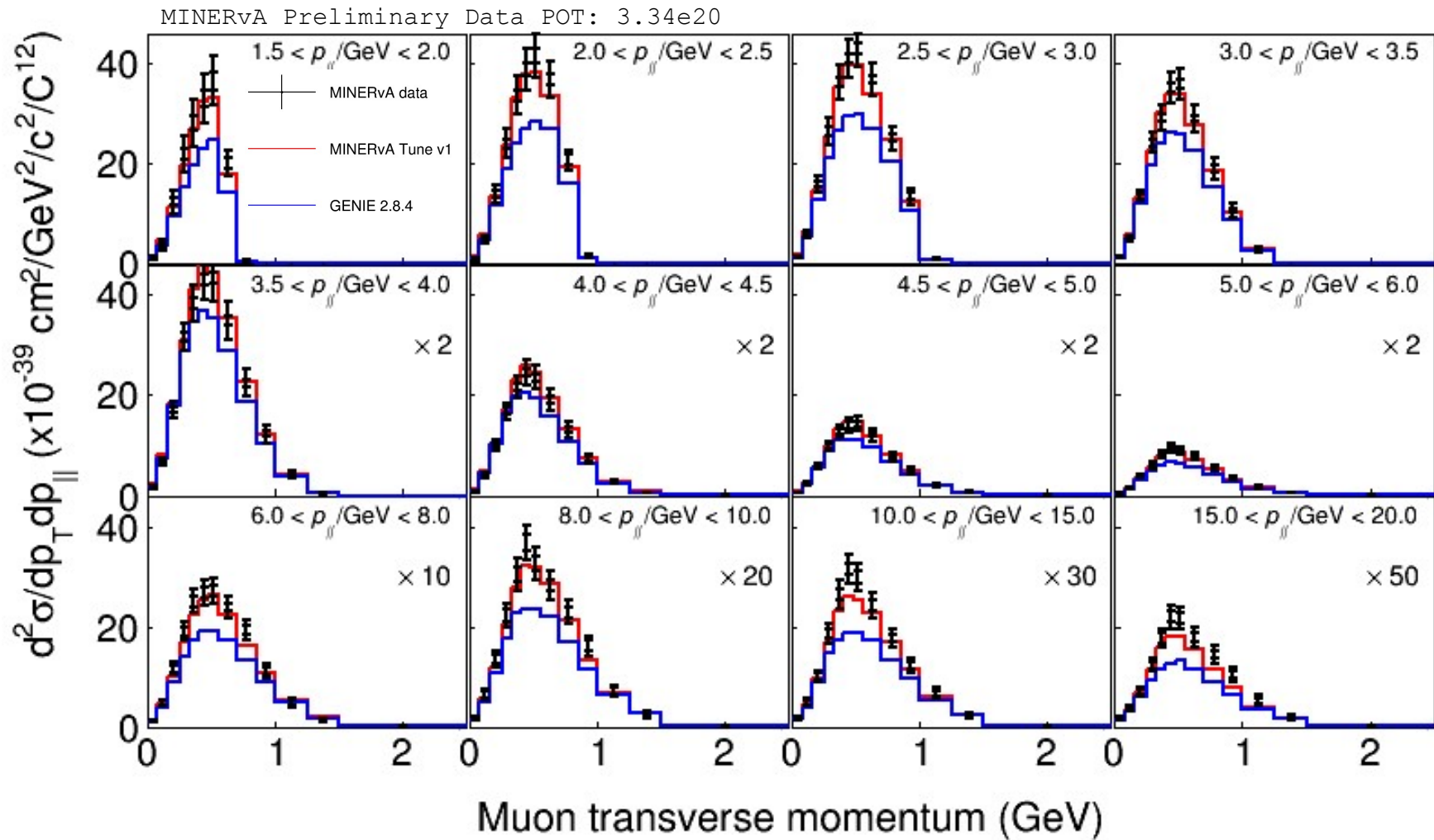
1-track



>1-track

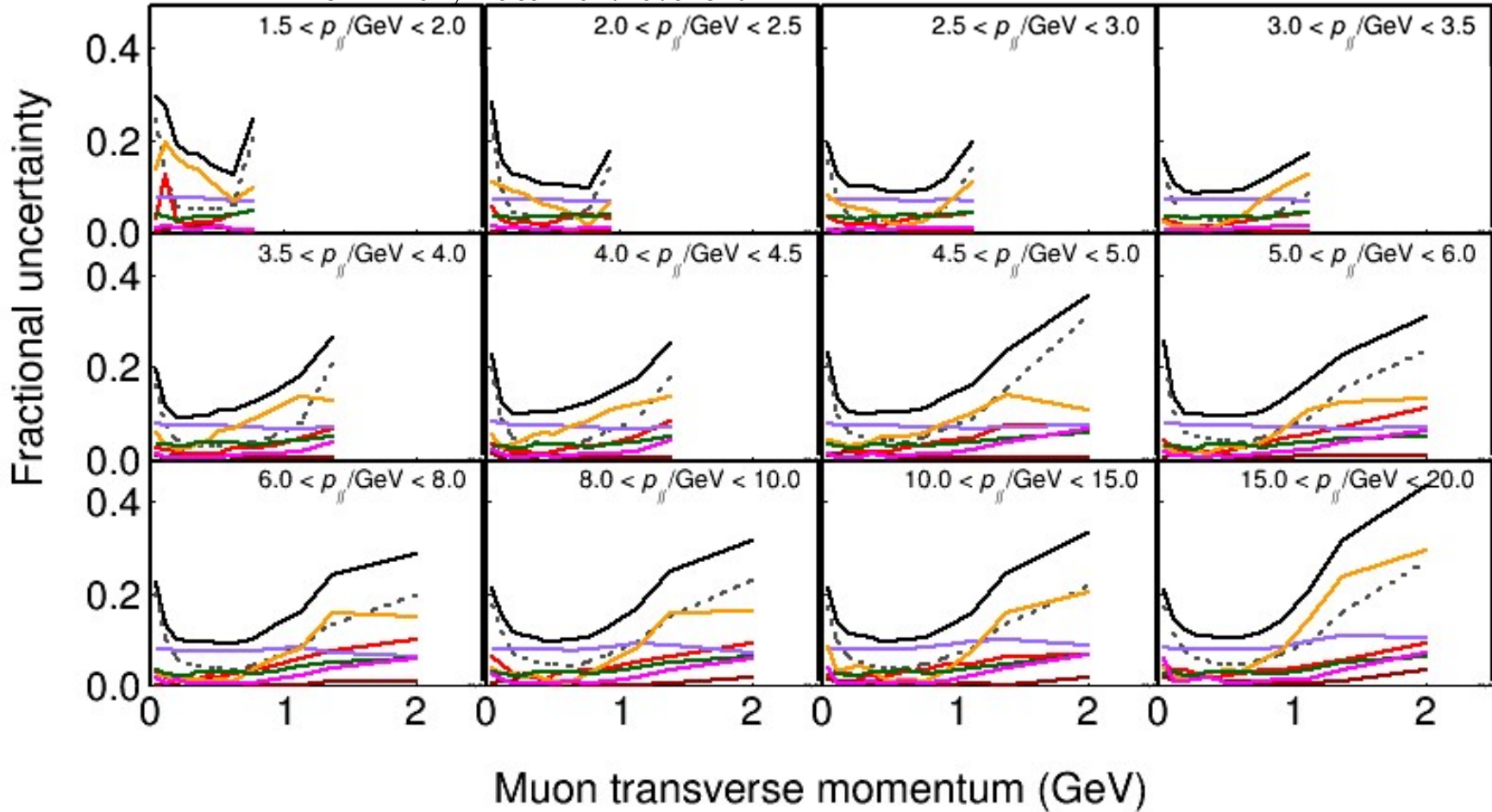
- Surprisingly, this analysis is sensitive to **low Q^2 resonant pion** processes which populate the **low p_T** regions
 - Seen in pion results, both low recoil analyses

ν -Result

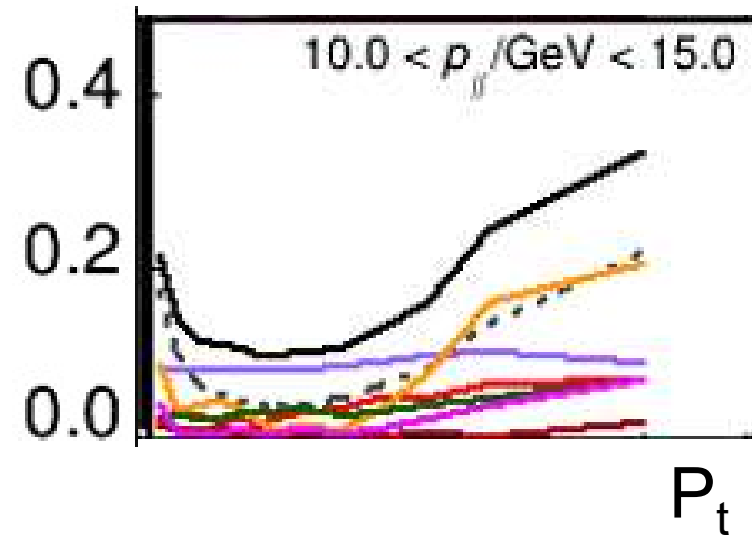
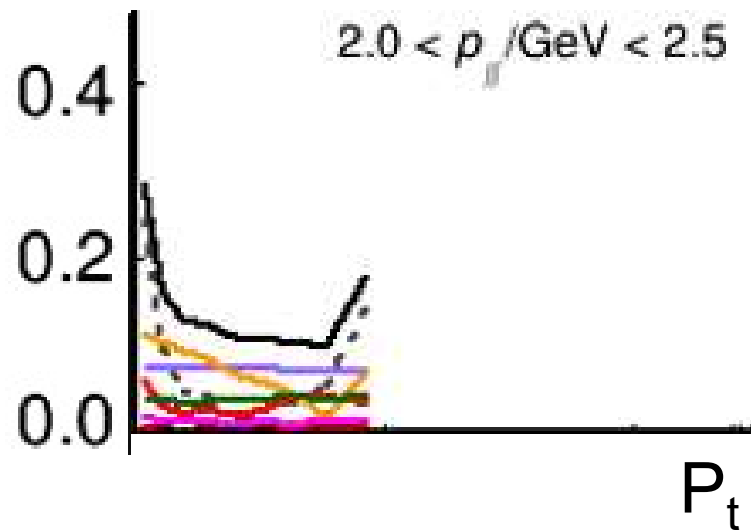


Systematics - ν

MINERvA Preliminary Data POT: 3.34e20



Systematics ν



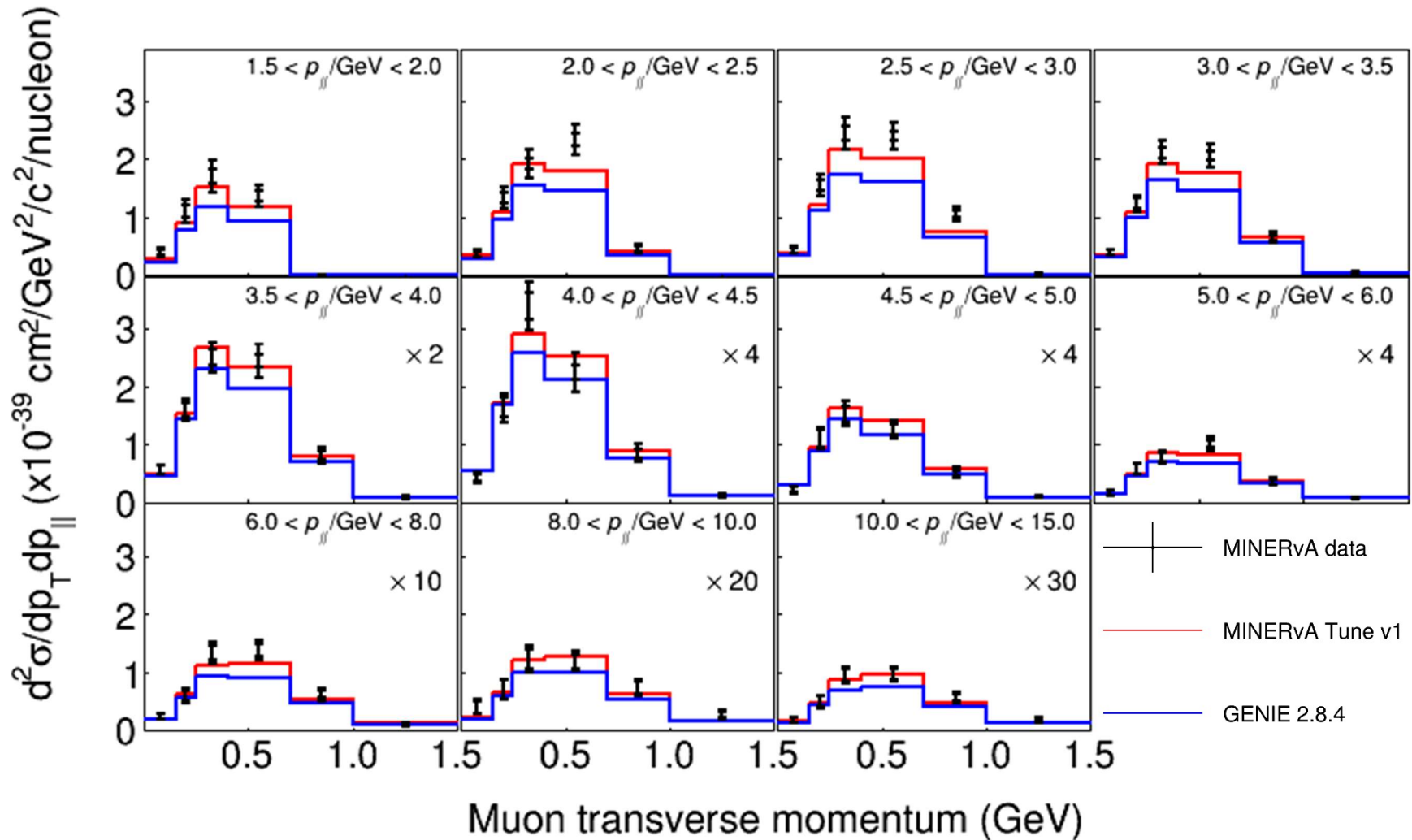
Mostly **flux** or **muon reconstruction** uncertainties

Some increase to the few% level for **FSI**, **interaction models** at P_t extrema

But those are regions of statistics dominated uncertainties \rightarrow NOvA Era Dataset!

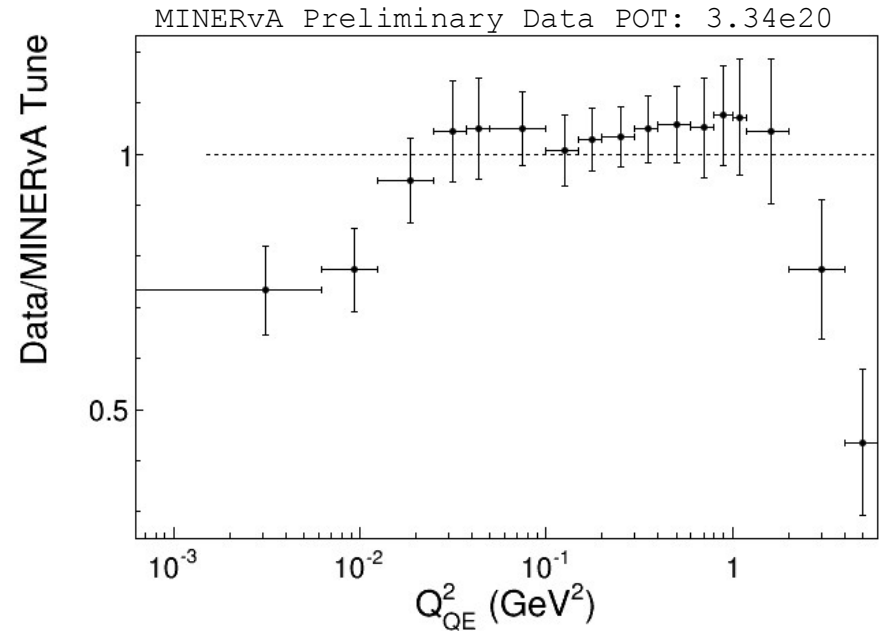
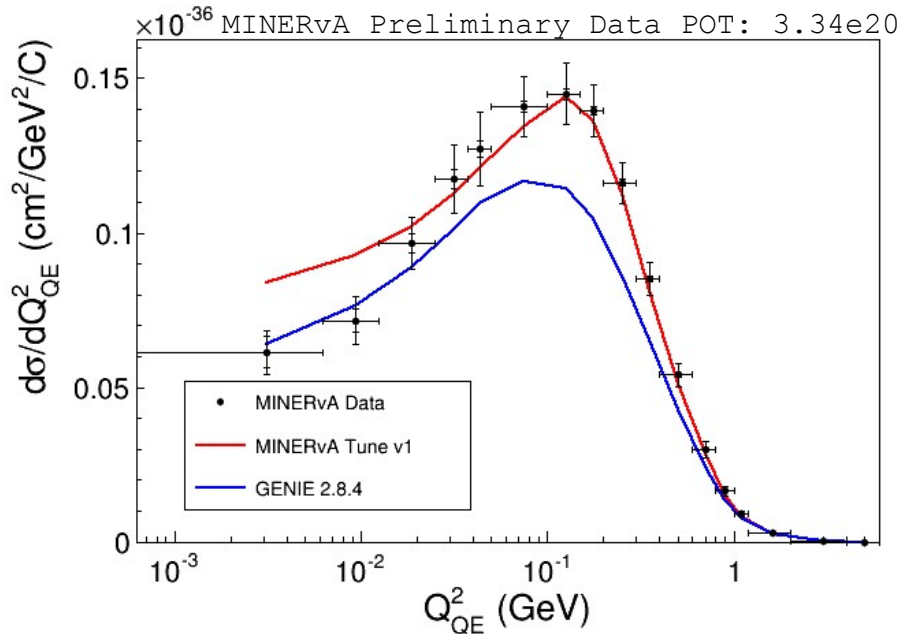


$\bar{\nu}$ result



Neutrino $q_0 q_3$ fit improves the prediction here too!

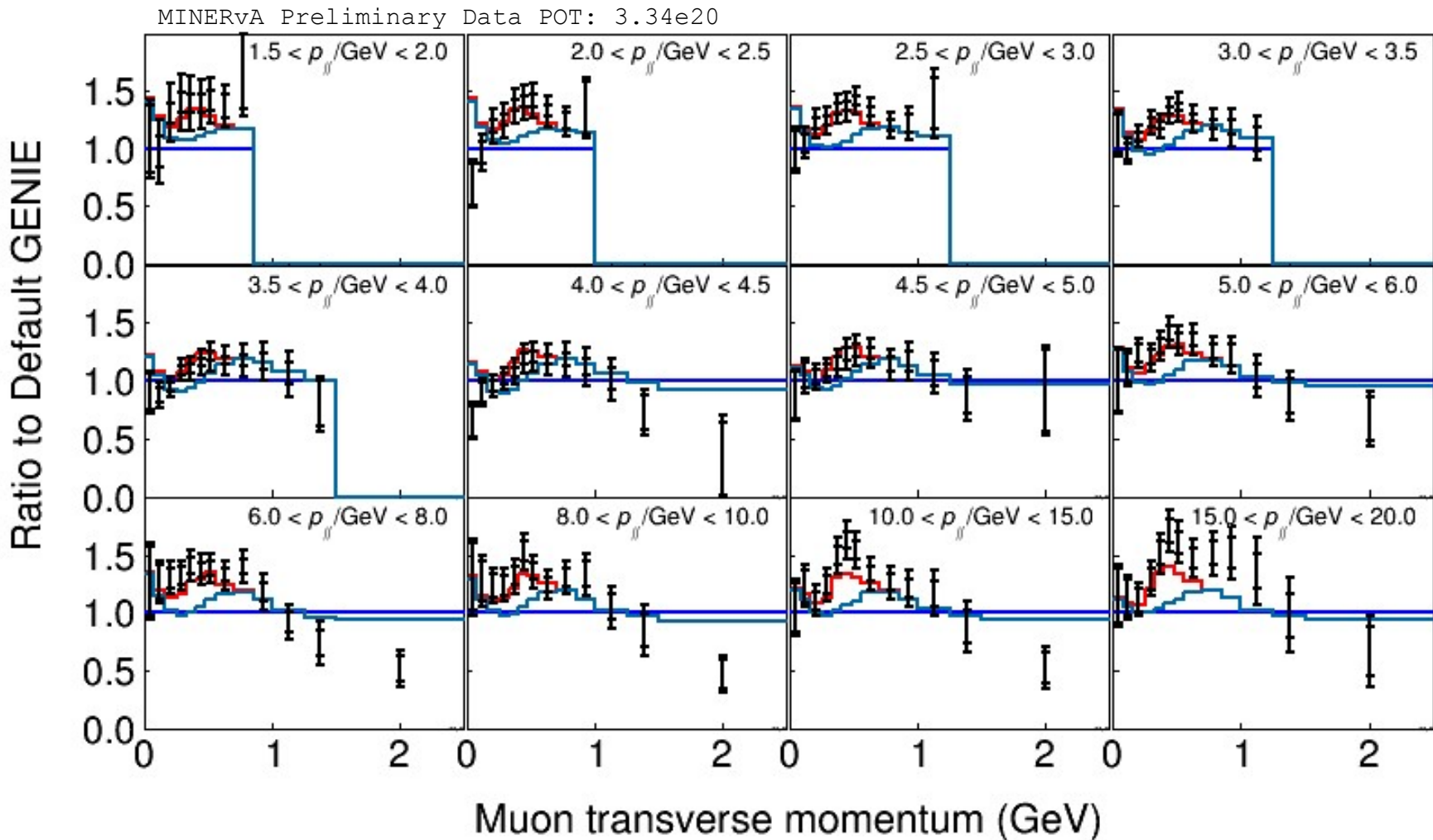
$$Q^2_{QE}$$



- Low Q^2 is a region of phase space where the fraction of events has an increased population of resonant pion qe-like events.
- High Q^2 is a region where we are pushing the extent of the dipole approximation

Models - neutrino

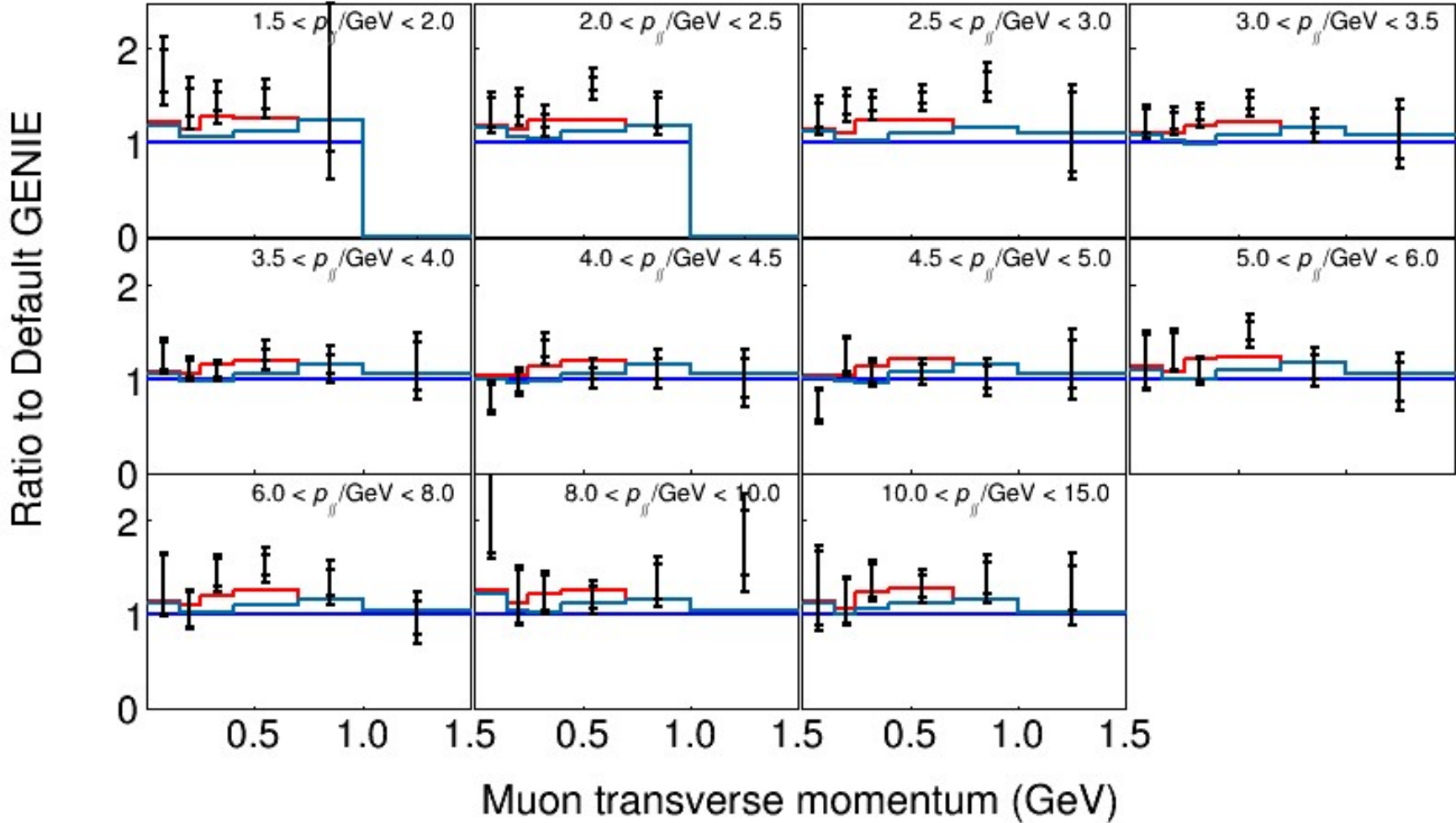
- MINERvA data
- MINERvA Tune v1
- GENIE 2.8.4
- RPA+2p2h



This shows the regions of phase space where the simulation needs more strength

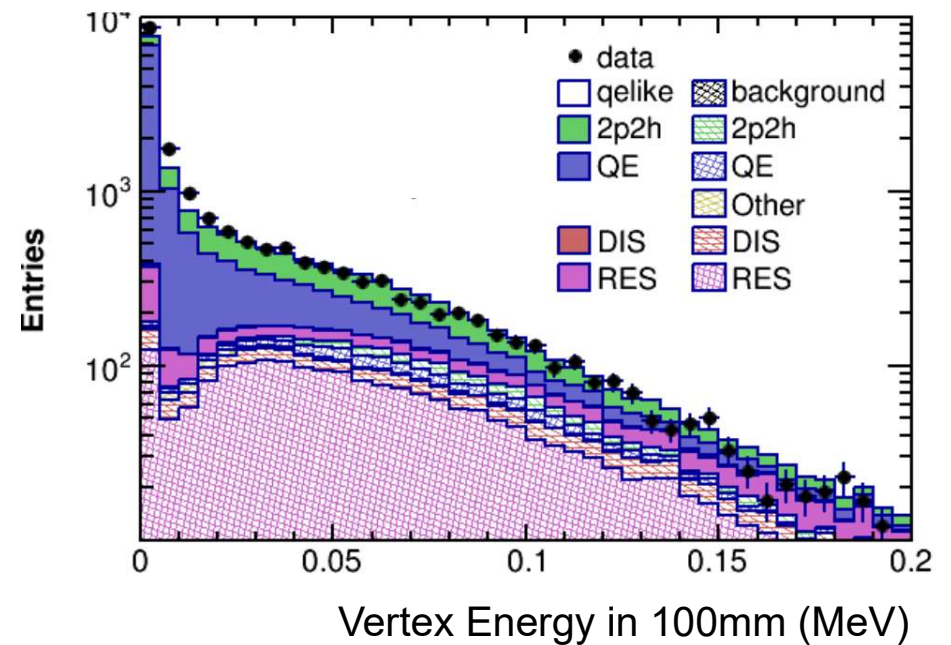
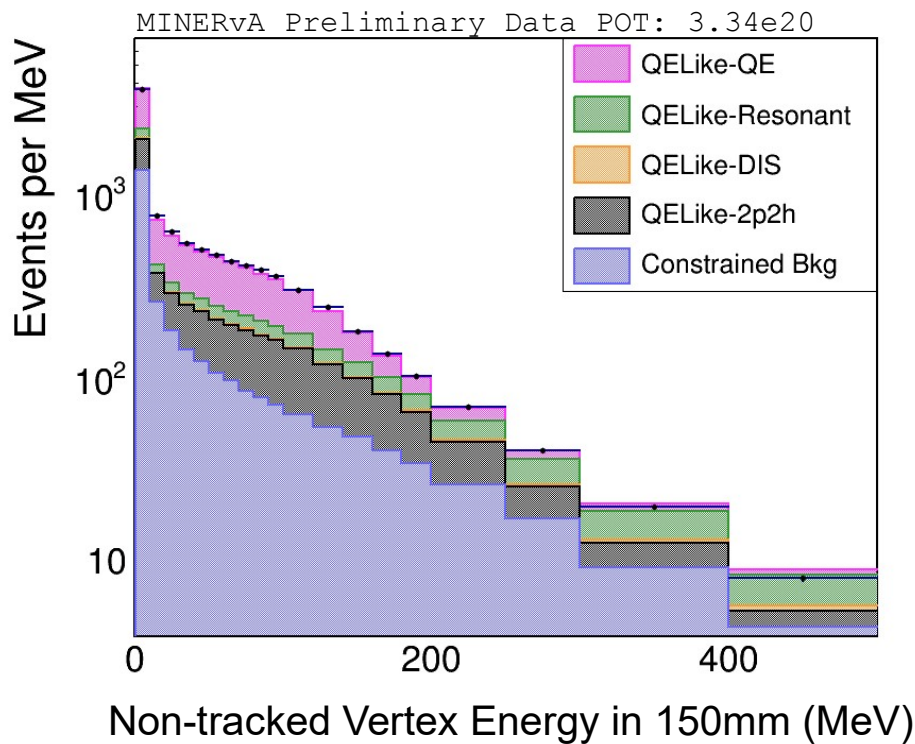
Models – anti-neutrino

- MINERvA data
- MINERvA Tune v1
- GENIE 2.8.4
- RPA+2p2h



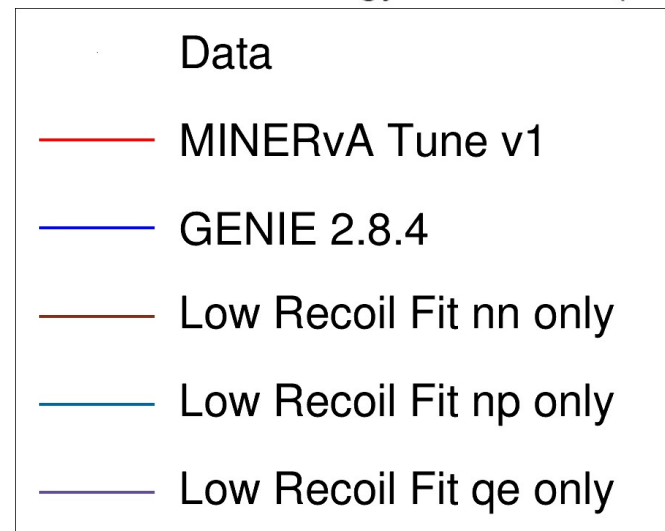
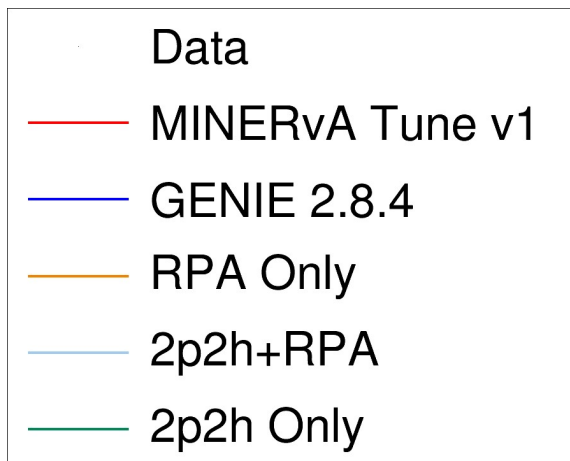
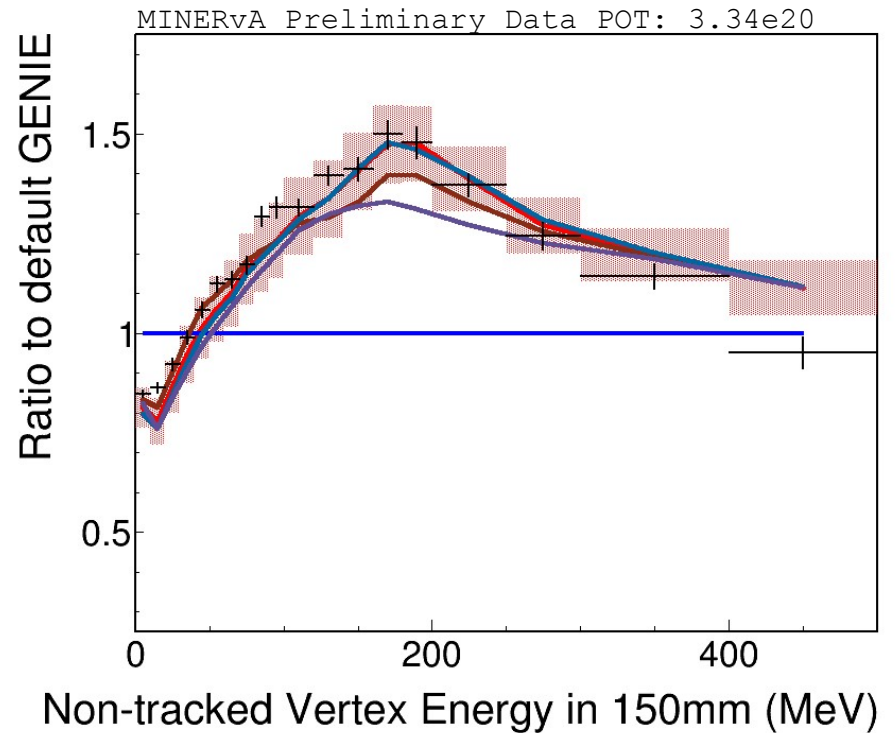
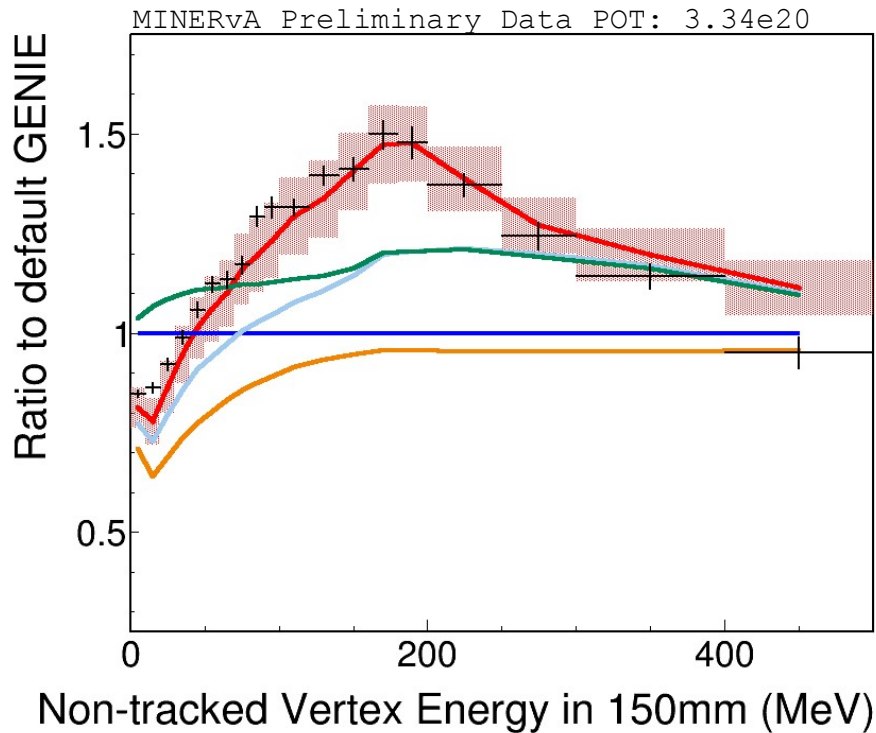
Vertex Energy

A different picture than in 2013!

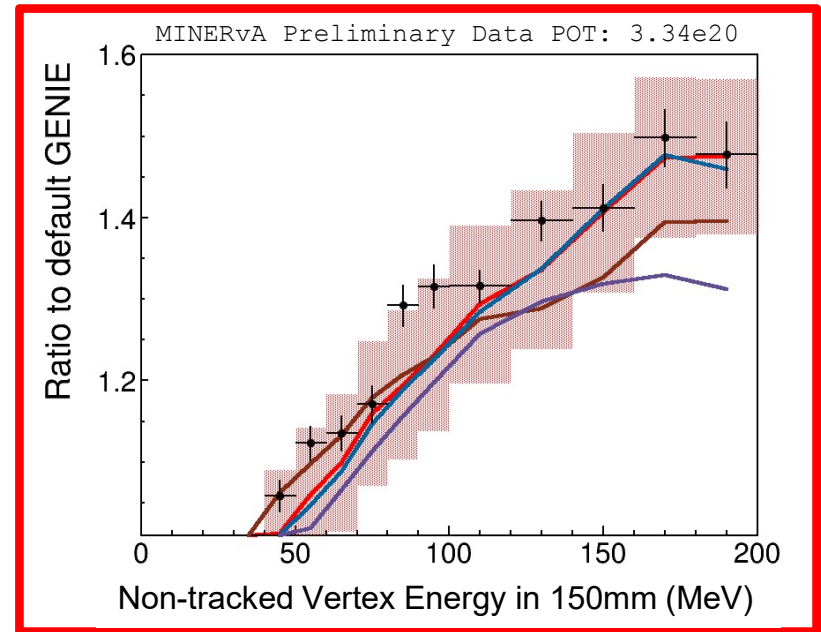
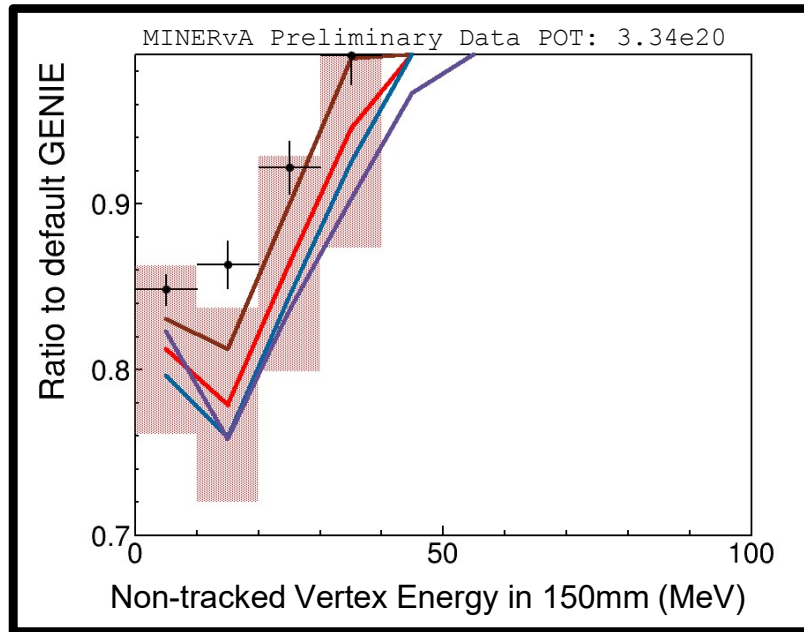


Note: Because of improved selection and reconstruction the vertex energy definition changed

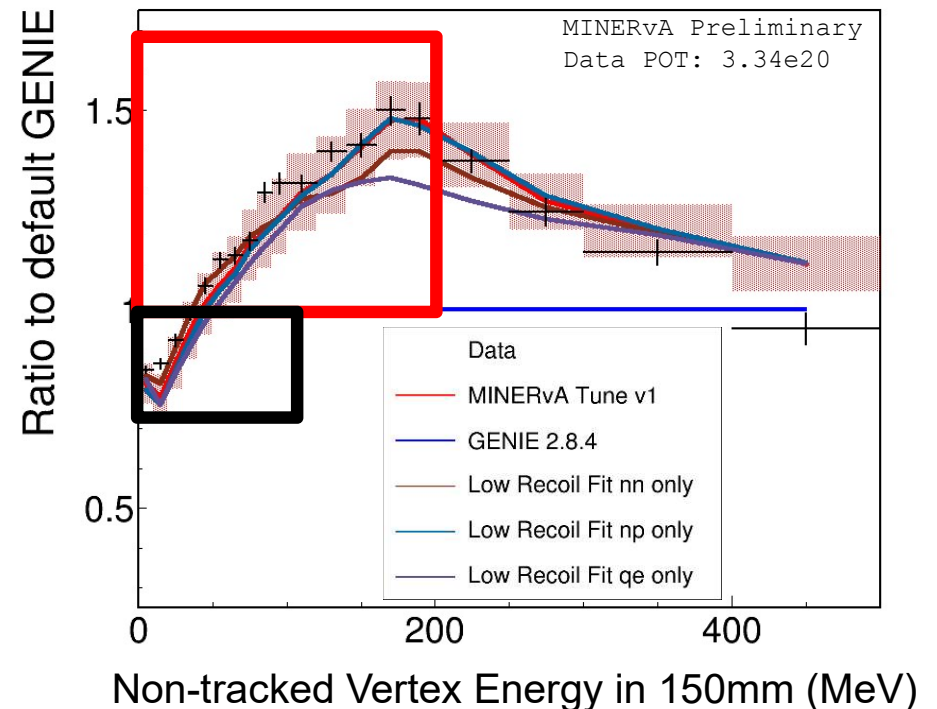
What Do The Models Say?



What Do The Models Say?



- Seems prefer more **nn pairs** at low energy
- Seems to prefer more **np pairs** at higher energy
- **QE only** doesn't seem to do as well overall



χ^2 Reporting

- MINERvA compares to various models, and reports χ^2 compared to the data
- Recently been discussing the effect of highly correlated data and calculation of the χ^2
 - Can lead to χ^2 which don't follow what your eye says has to be right
- Known as “Peelle’s Pertinent Puzzle” to nuclear physicists
 - International evaluation of neutron cross-section standards”, IAEA 2007
 - “Box-Cox transformation for resolving the Peelle’s Pertinent Puzzle in curve fitting”, Oh and Seo 2004
- Cross section typically have at least one highly correlated scaling uncertainty - Flux

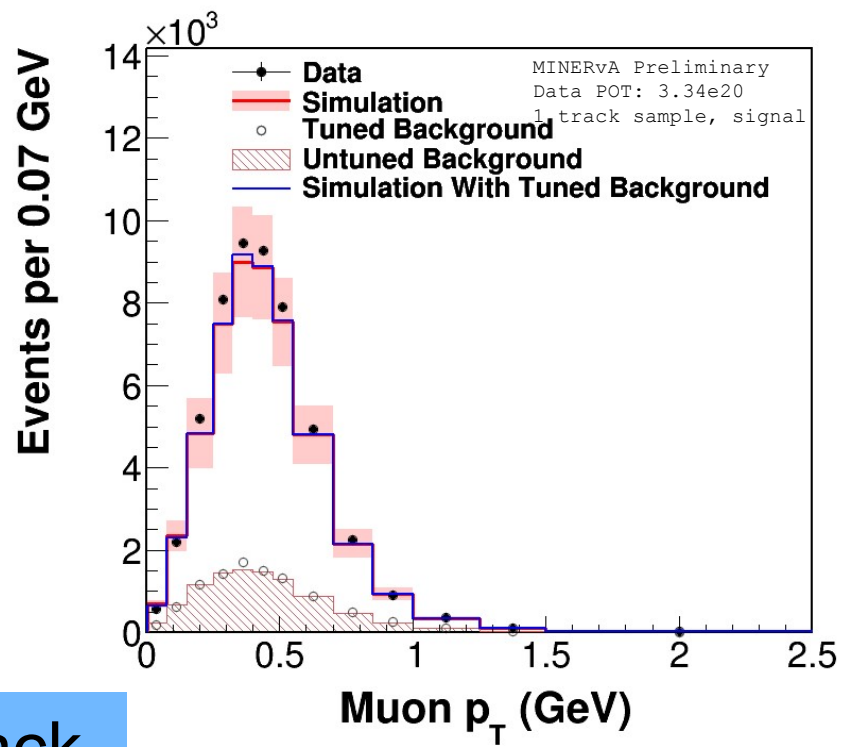
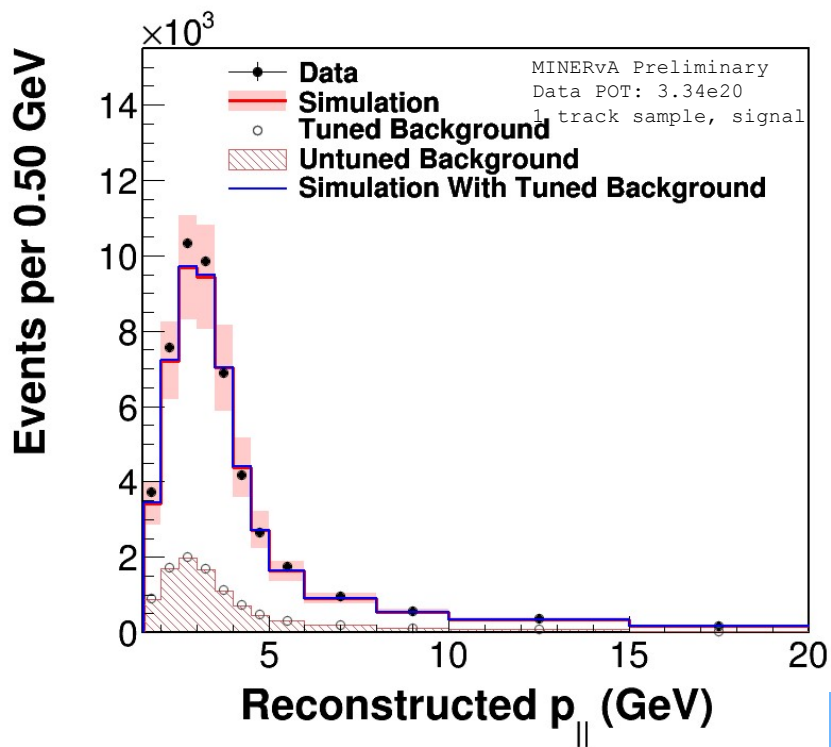
Conclusions

- MINERvA has updated both the $(\bar{\nu})\nu$ CCQE-like analyses incorporating new models and modifications to the underlying simulation
- Both analyses provide a rich set of measurements including lepton (2D) and lepton derived quantities (Q^2 and E_ν)
- Rich information about the vertex region
- MINERvA has a prescription which targets the data excess in the “dip” region as well as systematic variations to explore variations in how much energy is deposited in the detector
- Our growing NOvA era dataset provides expanded kinematic reach and increased statistics – This will be interesting!

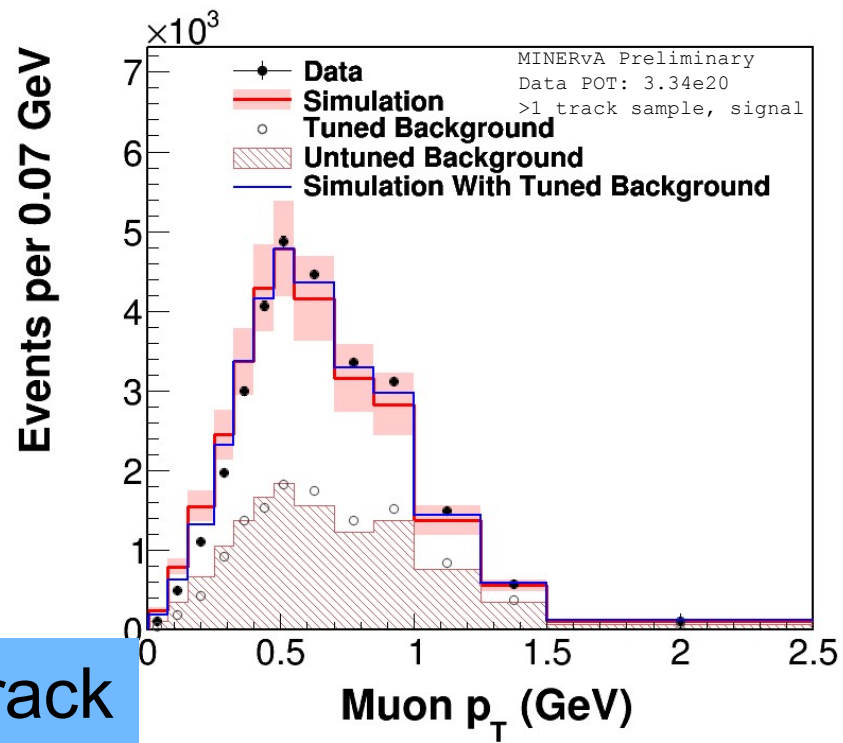
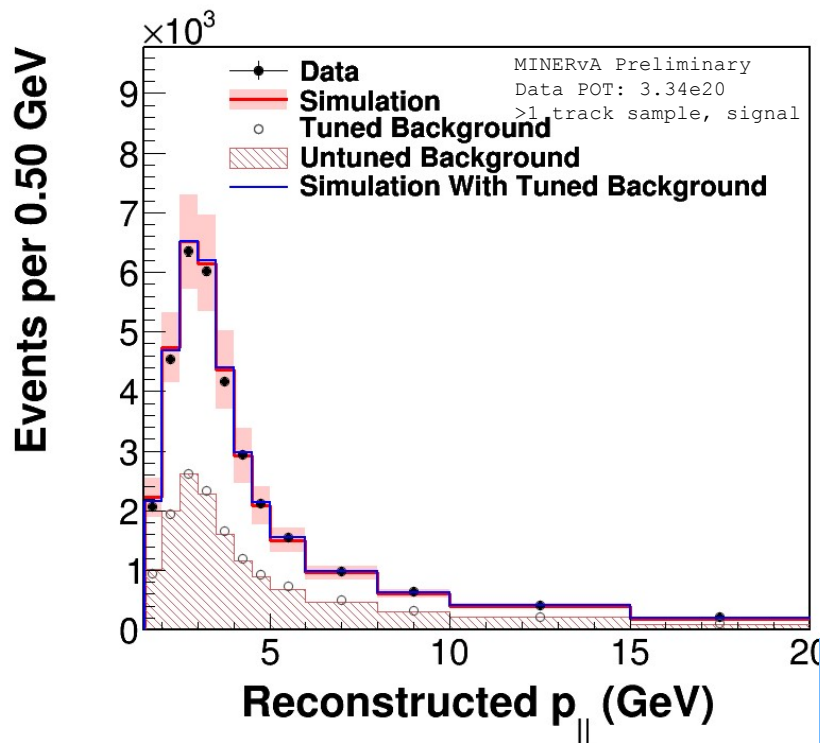
Thank you!



Backup

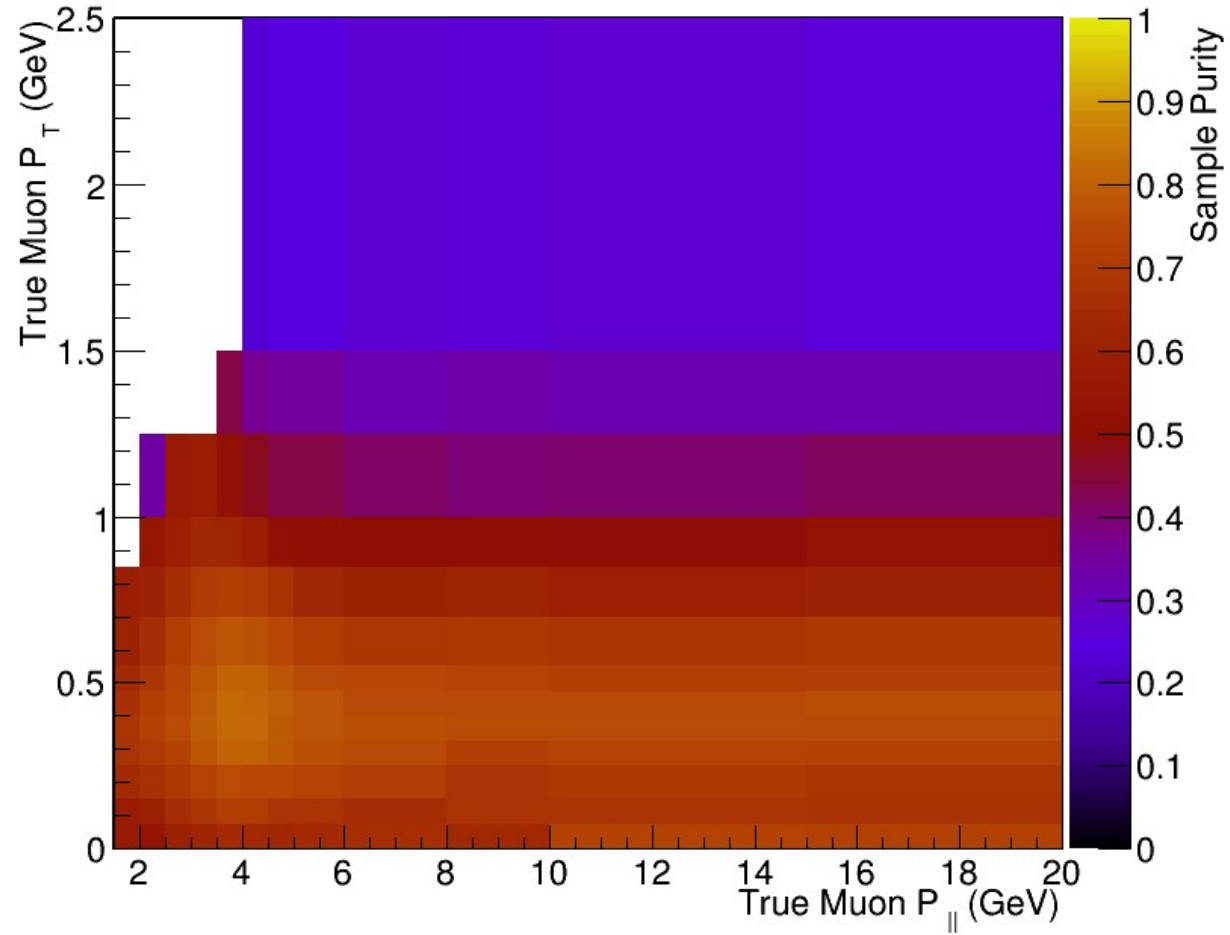


1-track

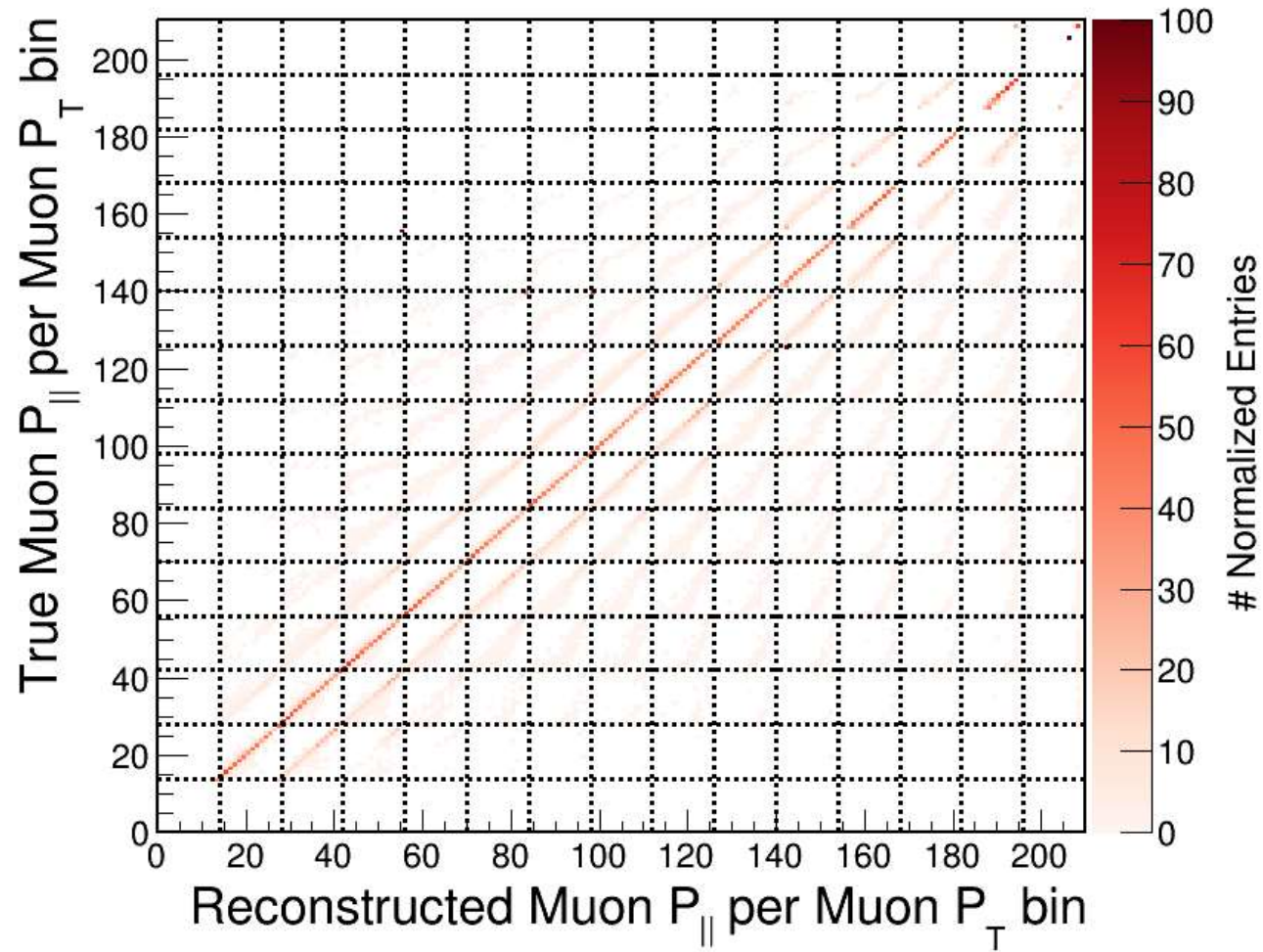


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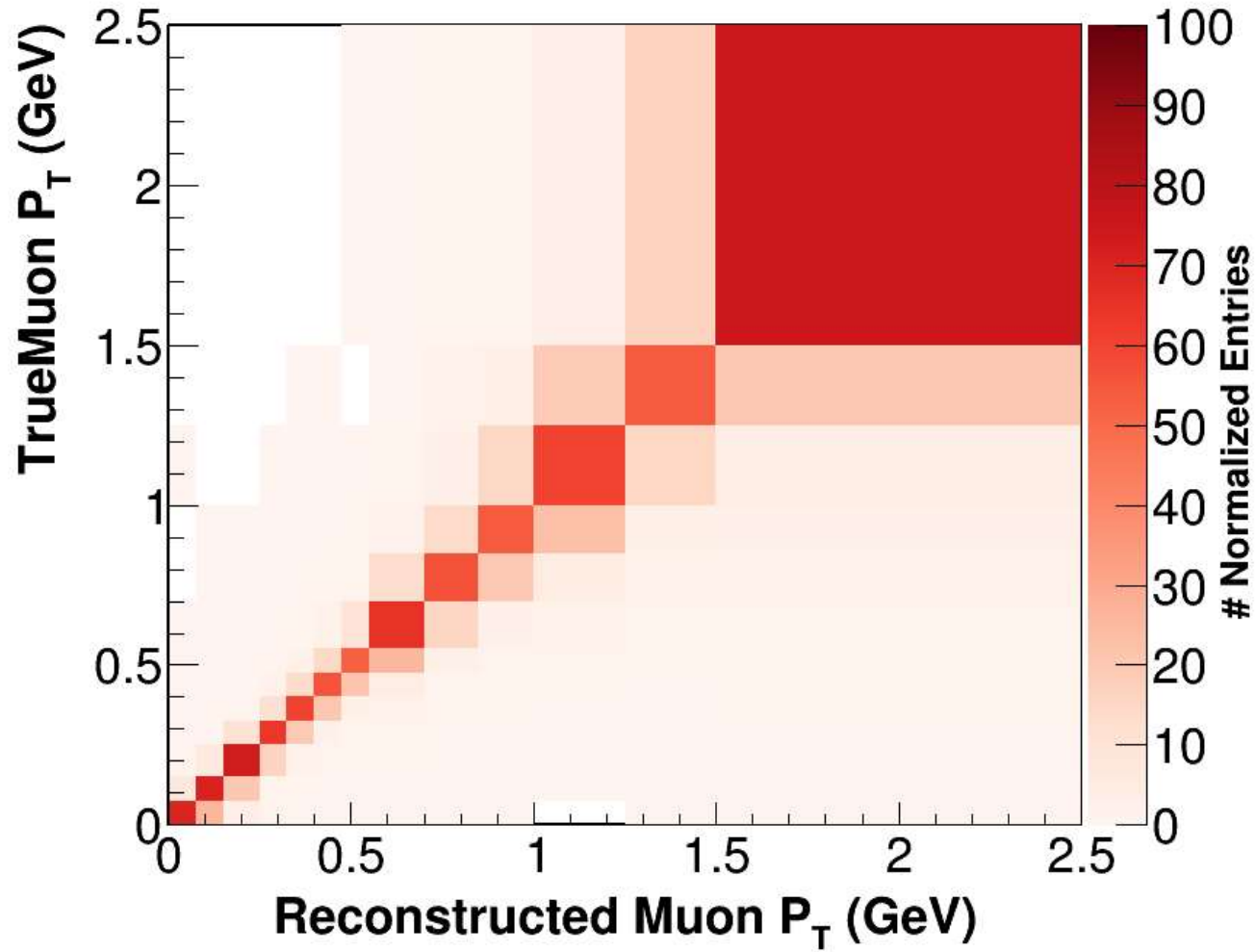
Purity



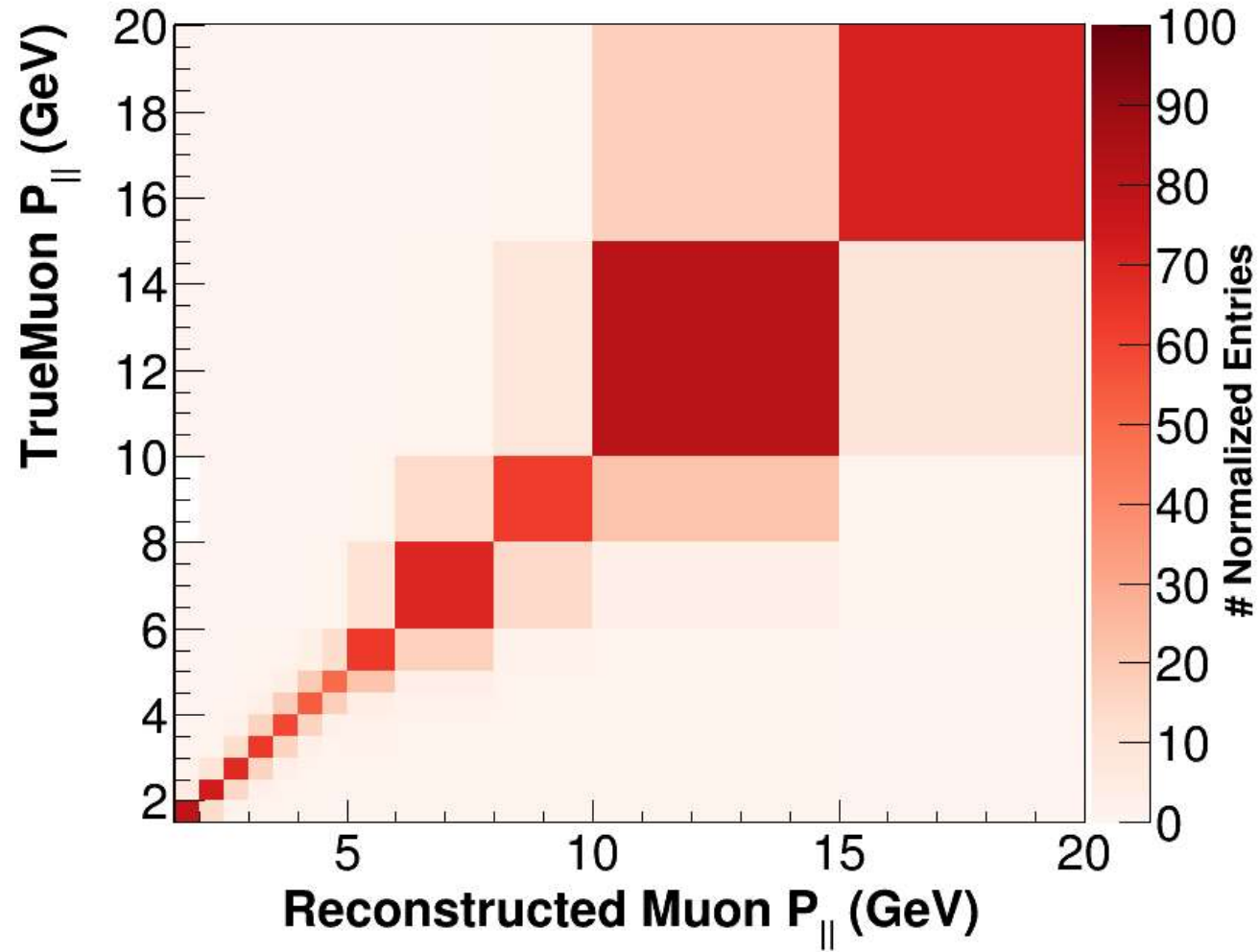
PtP ||



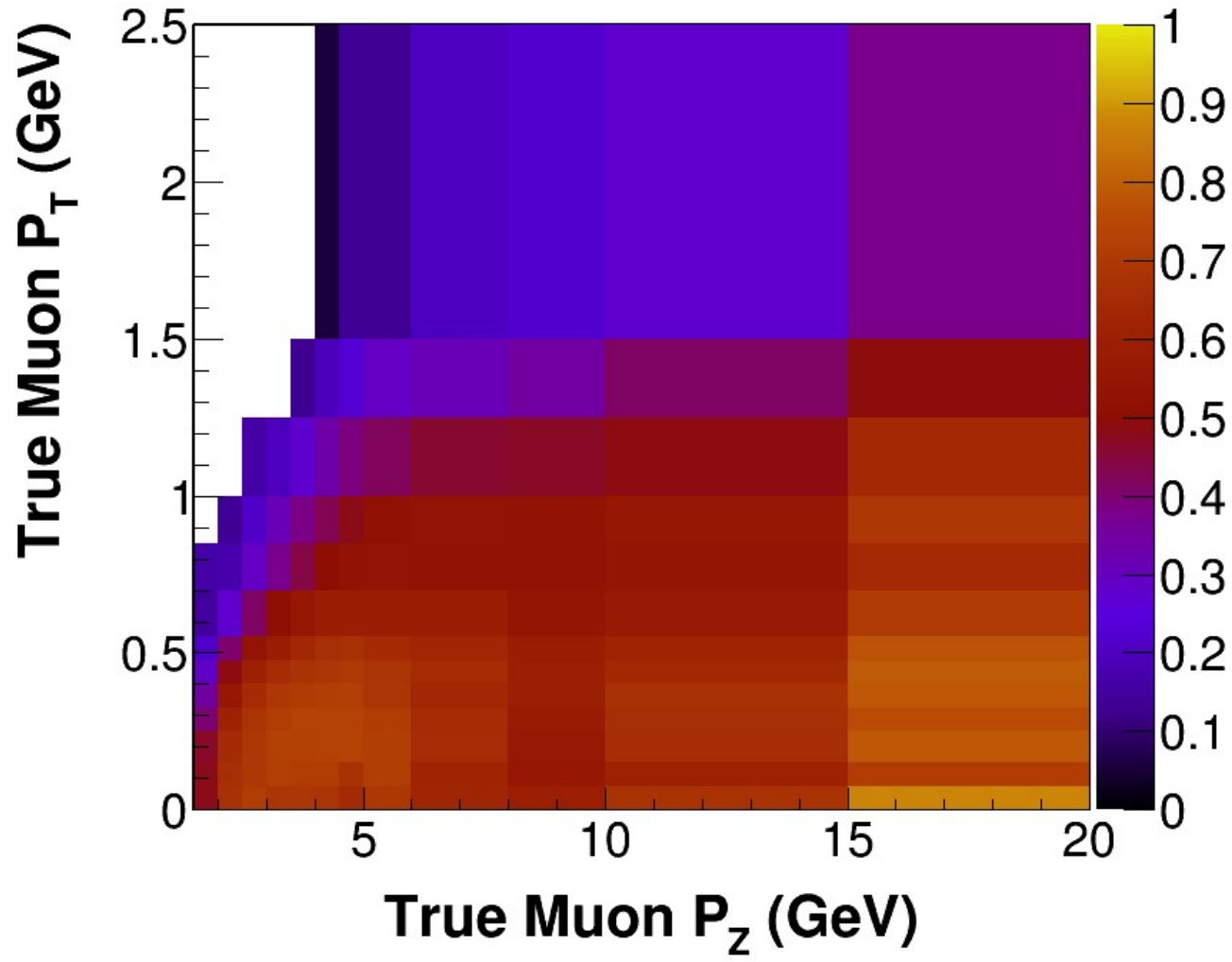
Pt



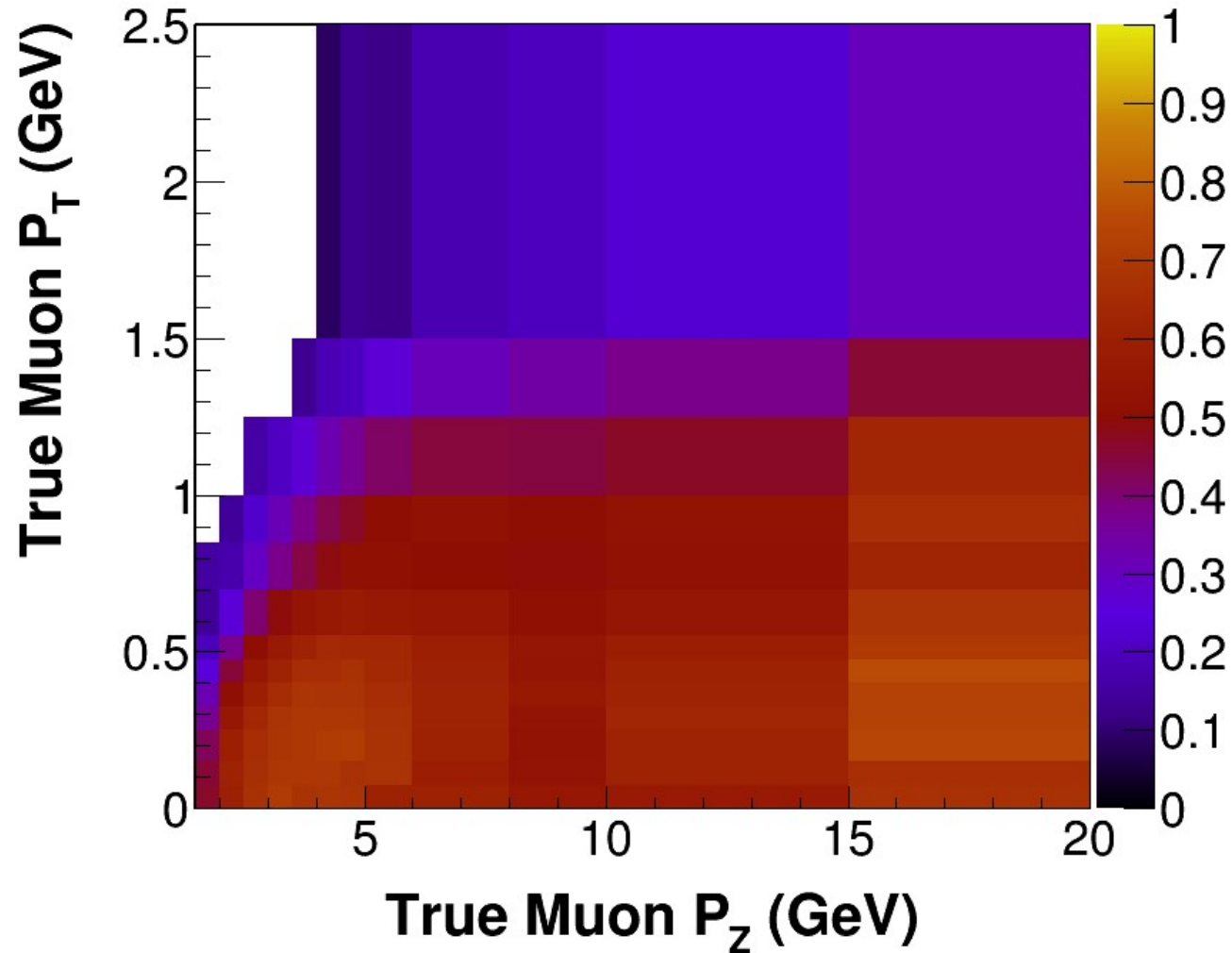
$P_{||}$



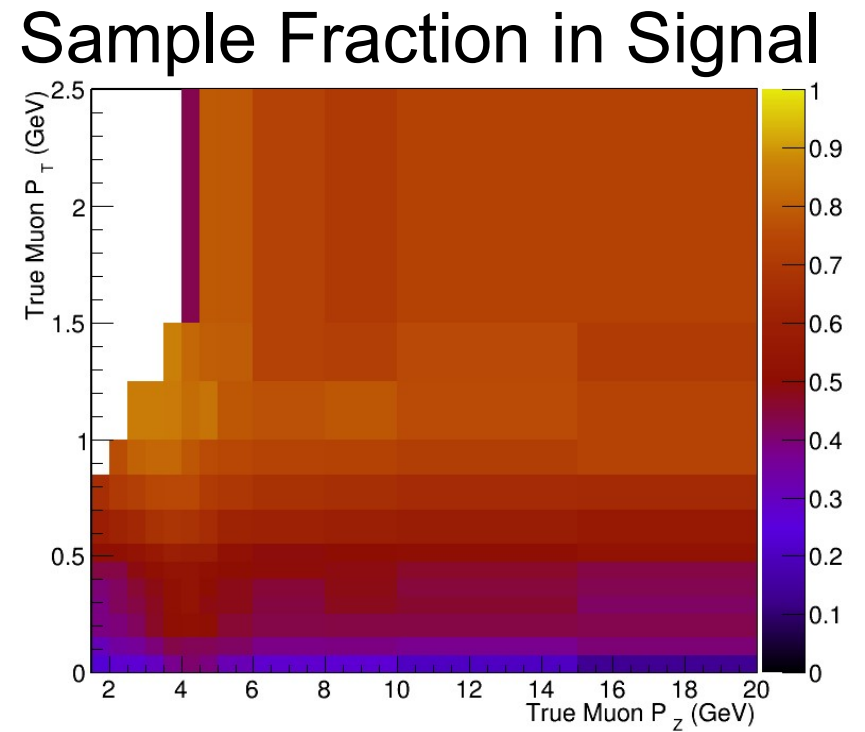
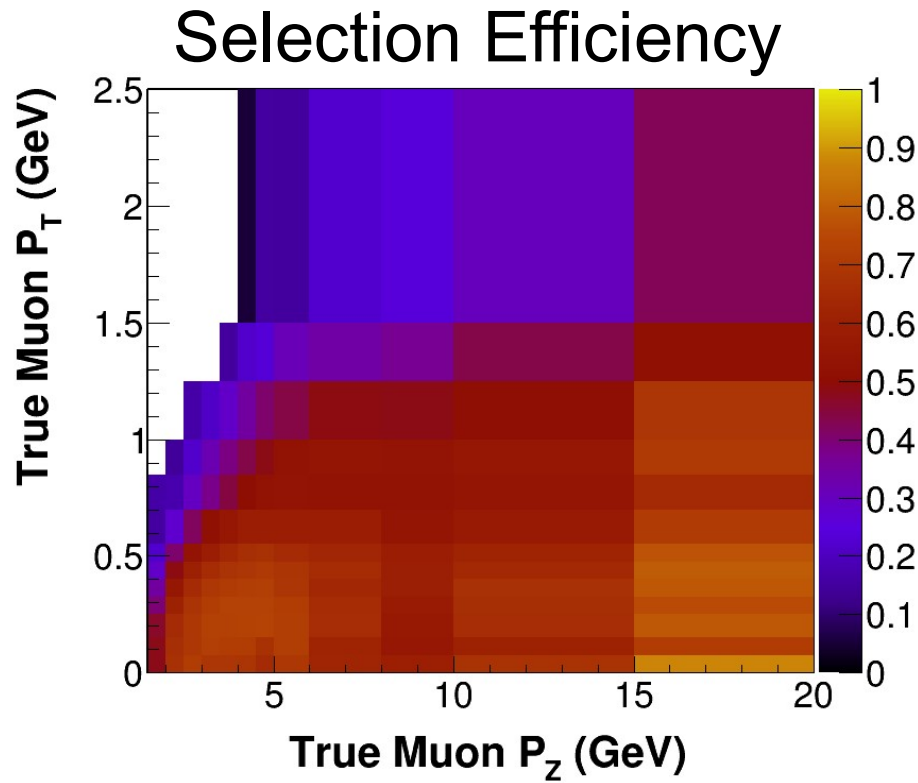
True QE Efficiency



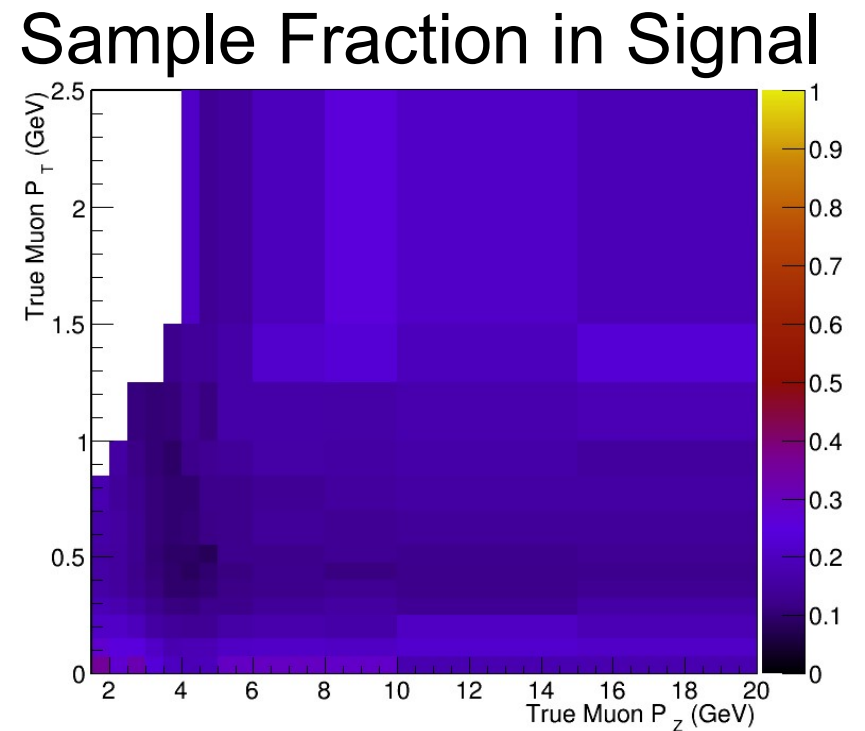
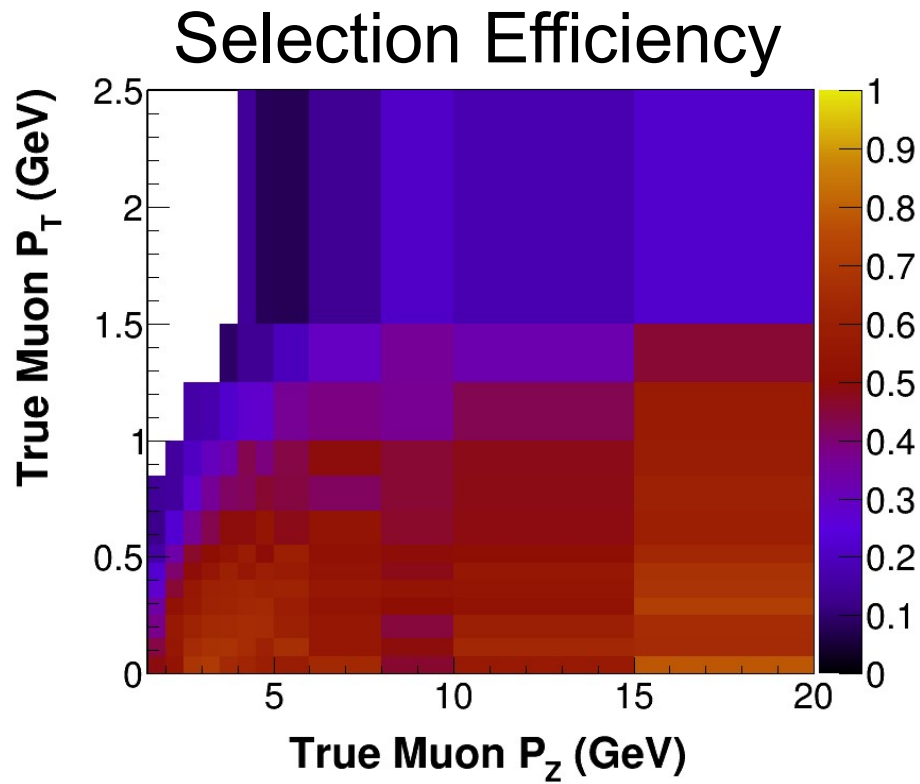
Overall $CC0\pi$ Efficiency



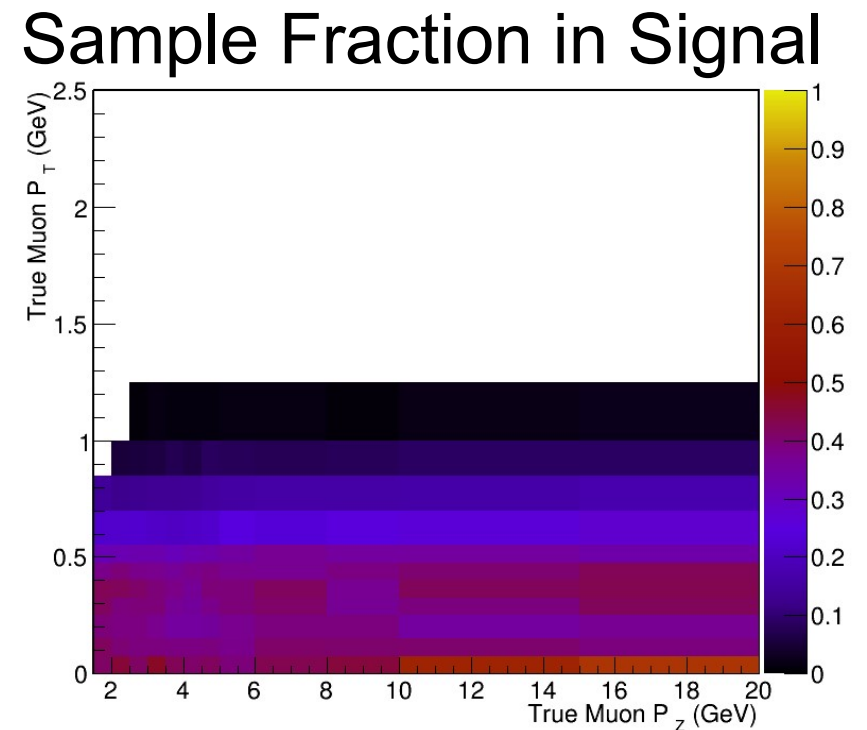
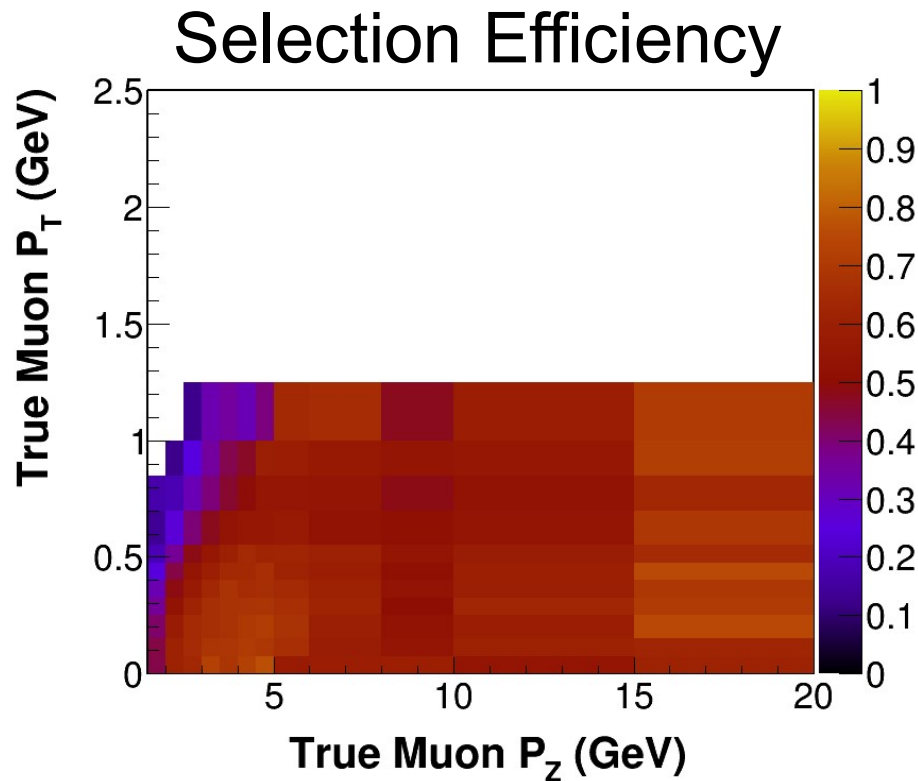
True QE AND $CC0\pi$



True Resonant AND $CC0\pi$



True 2p2h AND CC0 π



The underlying model has a q_3 cut off of 1.2 GeV