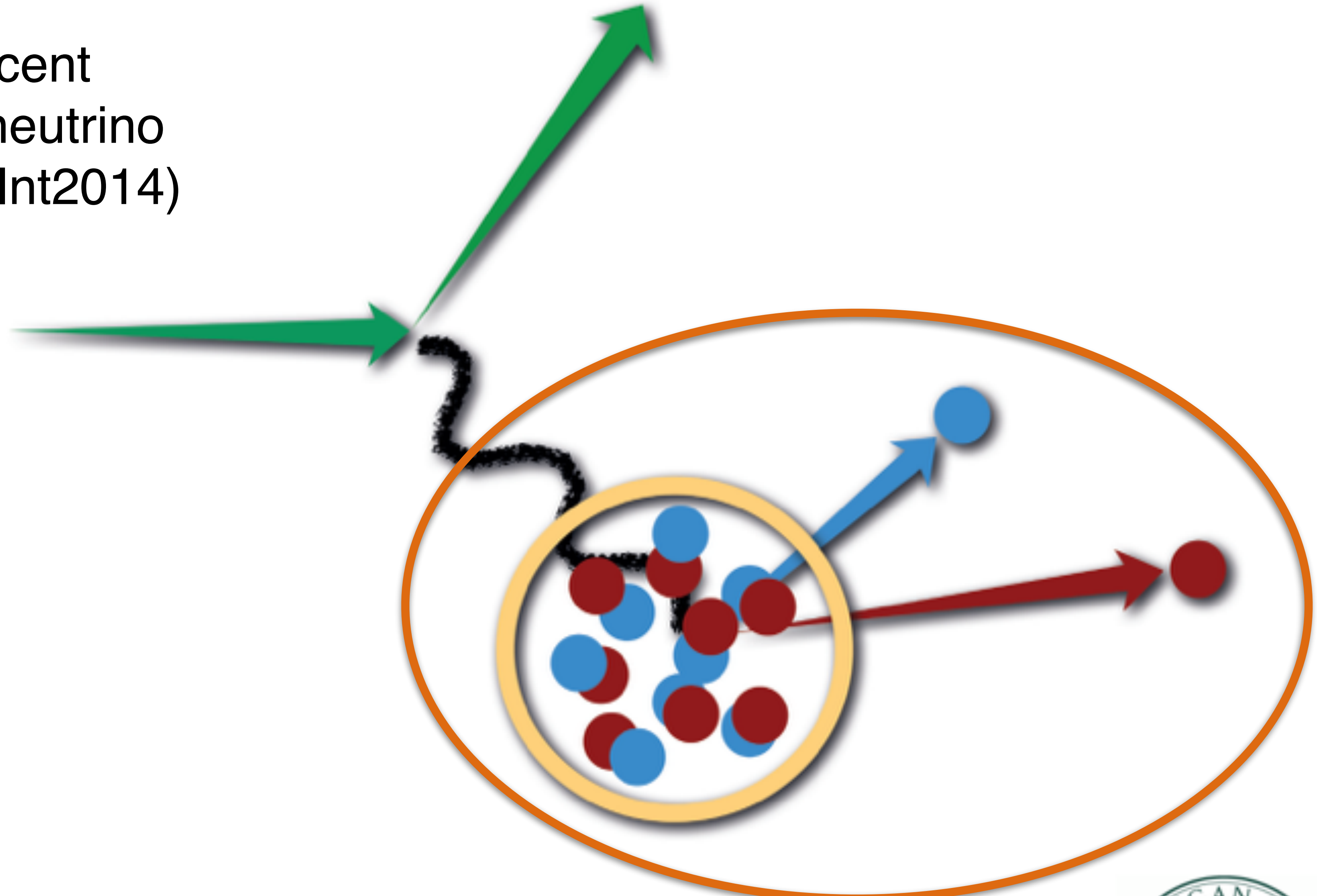
Testing neutrino physics with electron scattering

what can we use?

Image from recent workshop on neutrino scattering (NuInt2014)



Kendall Mahn
Michigan State University

The problem(s)

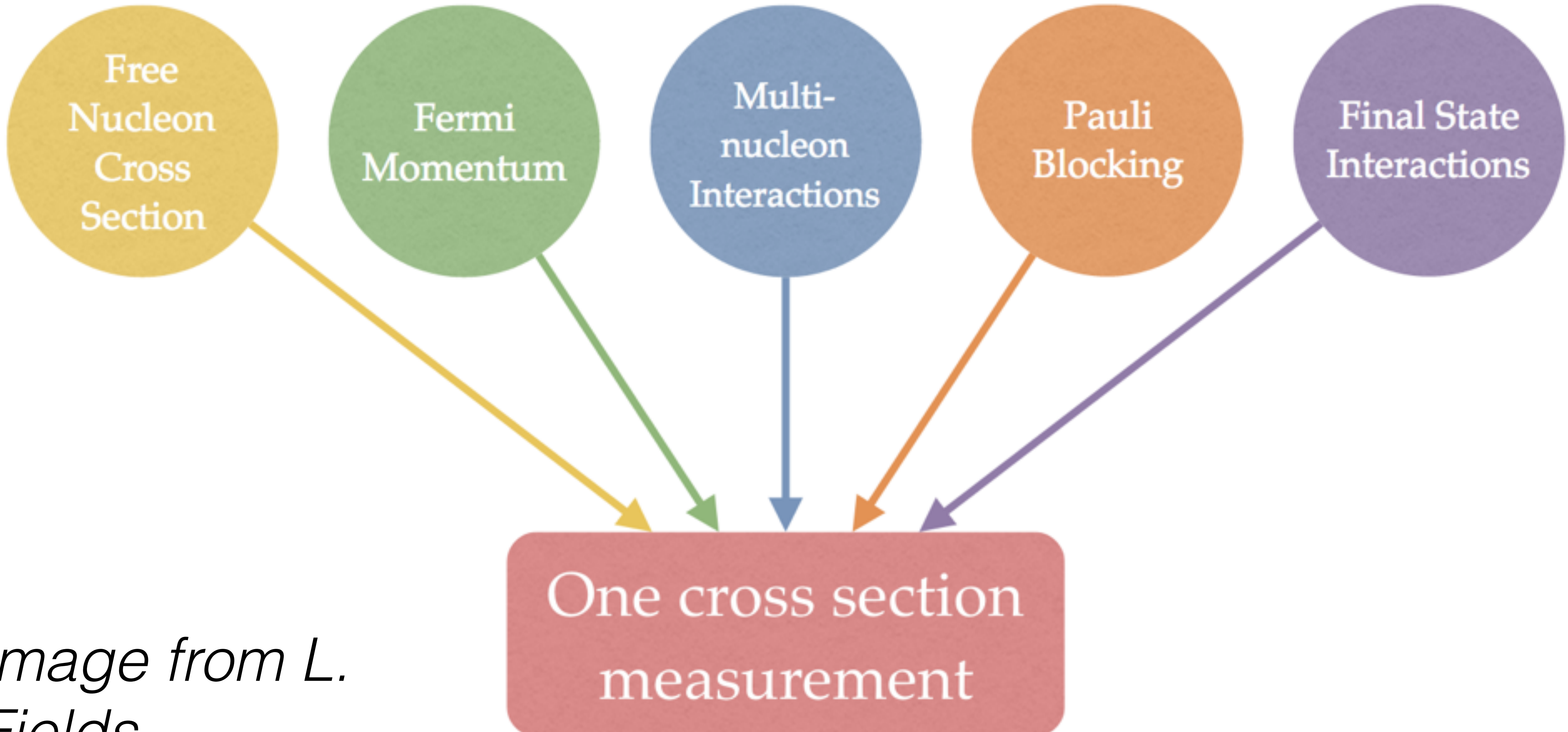


Image from L. Fields

- Measurements are sensitive to multiple physics effects on signal and background processes

- Lack of reliable hadronic state models (backups)

It takes a village

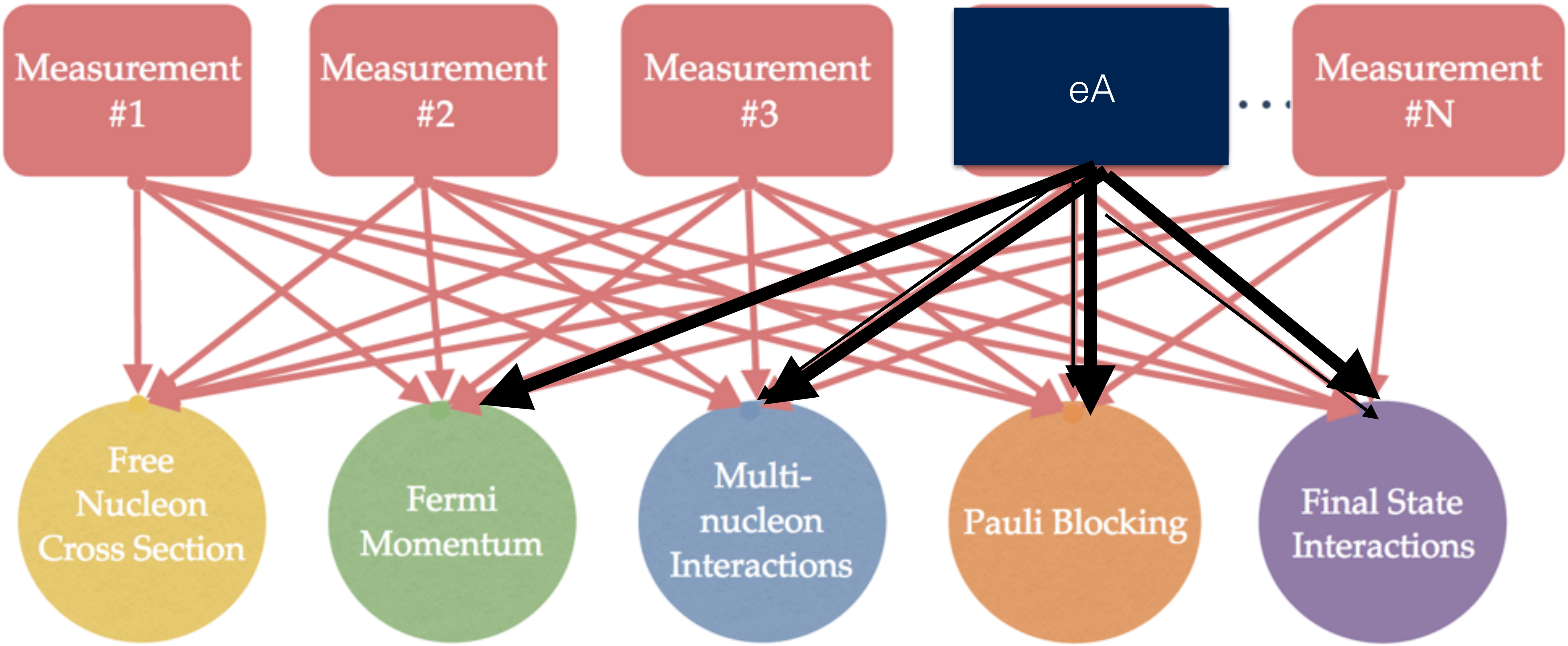


Image from L. Fields

- Electron scattering data is sensitive to initial, final nuclear state

- Same detector, range of targets, known energies

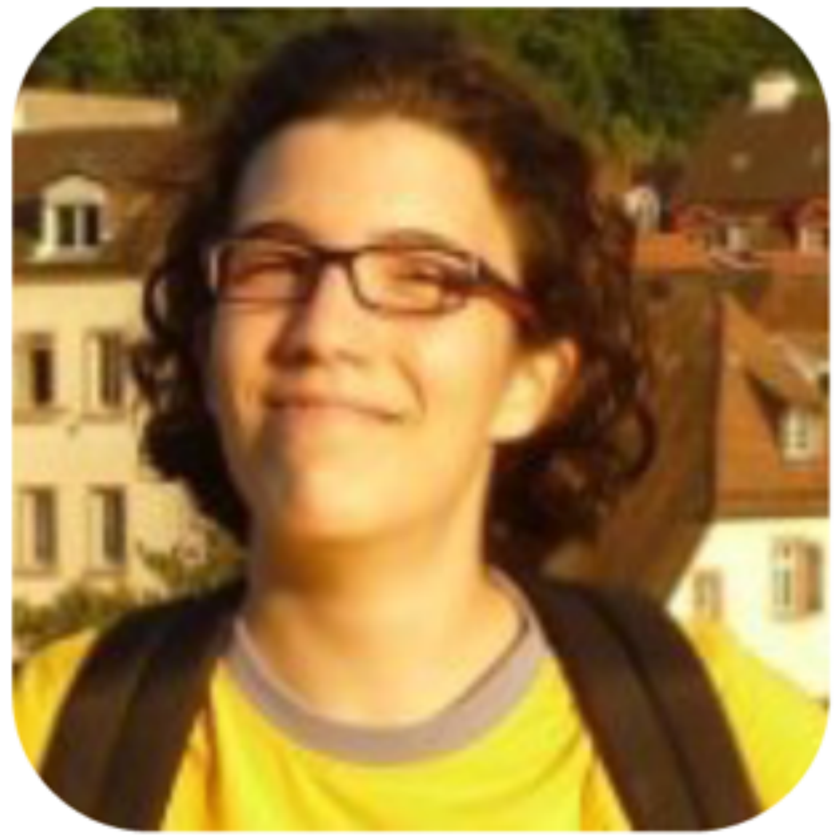
“Data Mining” of JLab

Electron scattering data analysis using data not considered in original proposals

*The following is **preliminary***

The group

Mariana Khachatryan (ODU)



Afroditi Papadopoulou (MIT)

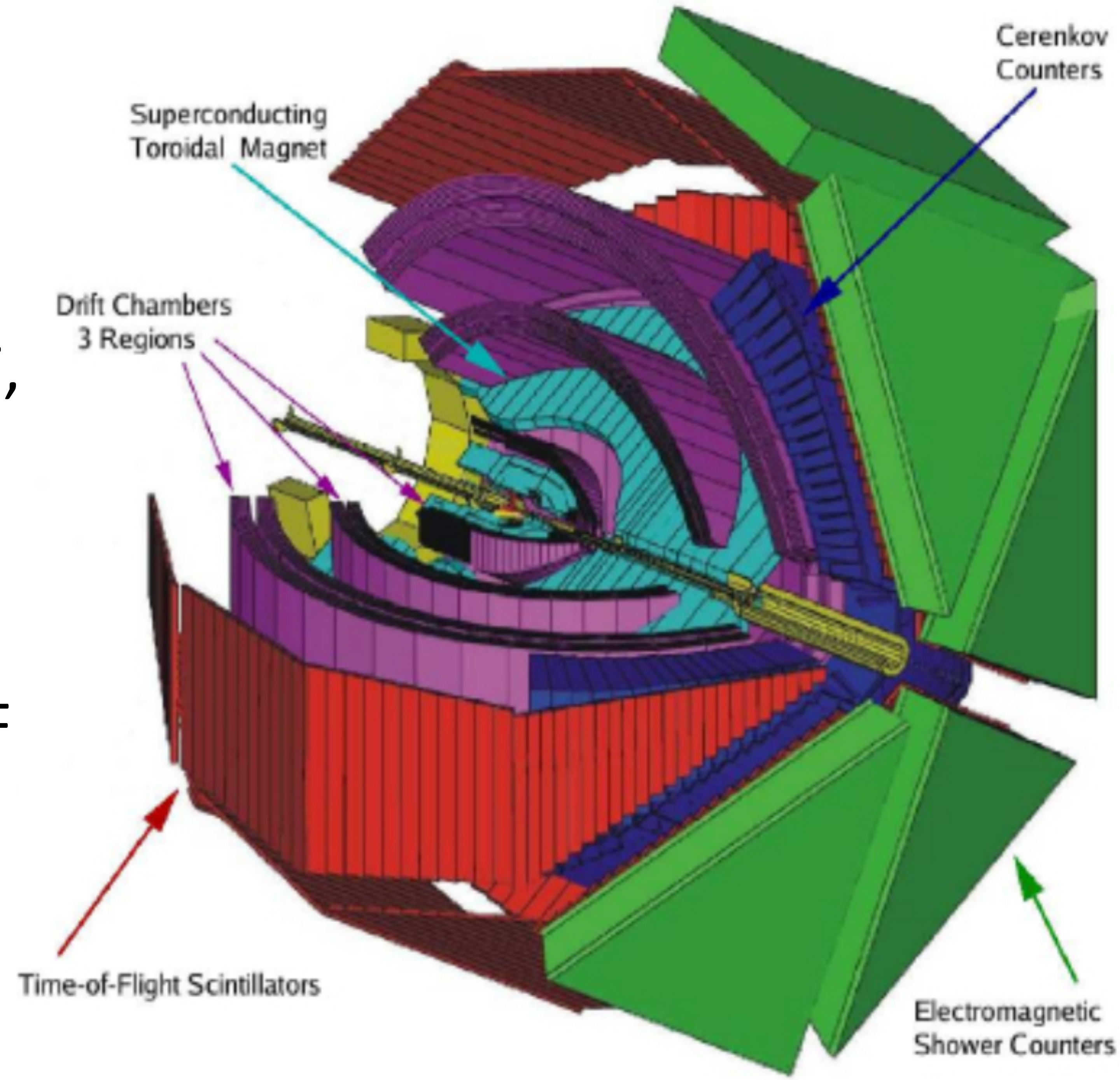
Adi Ashkenazi (TAU -> MIT)

Larry Weinstein (ODU),
Or Hen, Adrian Silva (MIT)
Kendall Mahn (MSU)

Steve Dytman (Pittsburgh)
Eli Piasetzky, Erez Cohen (TAU)
Minerba Betancourt (FNAL)

CLAS detector: *like a neutrino experiment*

- 1 - 5 GeV electron beam,
- (almost) 4π acceptance,
- Charged particles (8^o-143^o): Toroidal field + tracking, TOF, Cerenkov, and EM Calorimeter,
- Neutral particles: EM Calorimeter (8^o-75^o) and TOF (8^o-143^o).
- Low detection threshold (~300MeV/c),
- <u>OPEN TRIGGER !</u>



Goal: test neutrino energy reconstruction

QE-based and calorimetric

Method:

- Select clean e,e’,p data (no pions, no multiple protons)
- Weight by (known) Mott cross section (eA/nuA)
- Analyze as if neutrino data
- Compare to “true energy” (from known beam)
- Compare to generator (GENIE) predictions

CLAS E2 Data sets

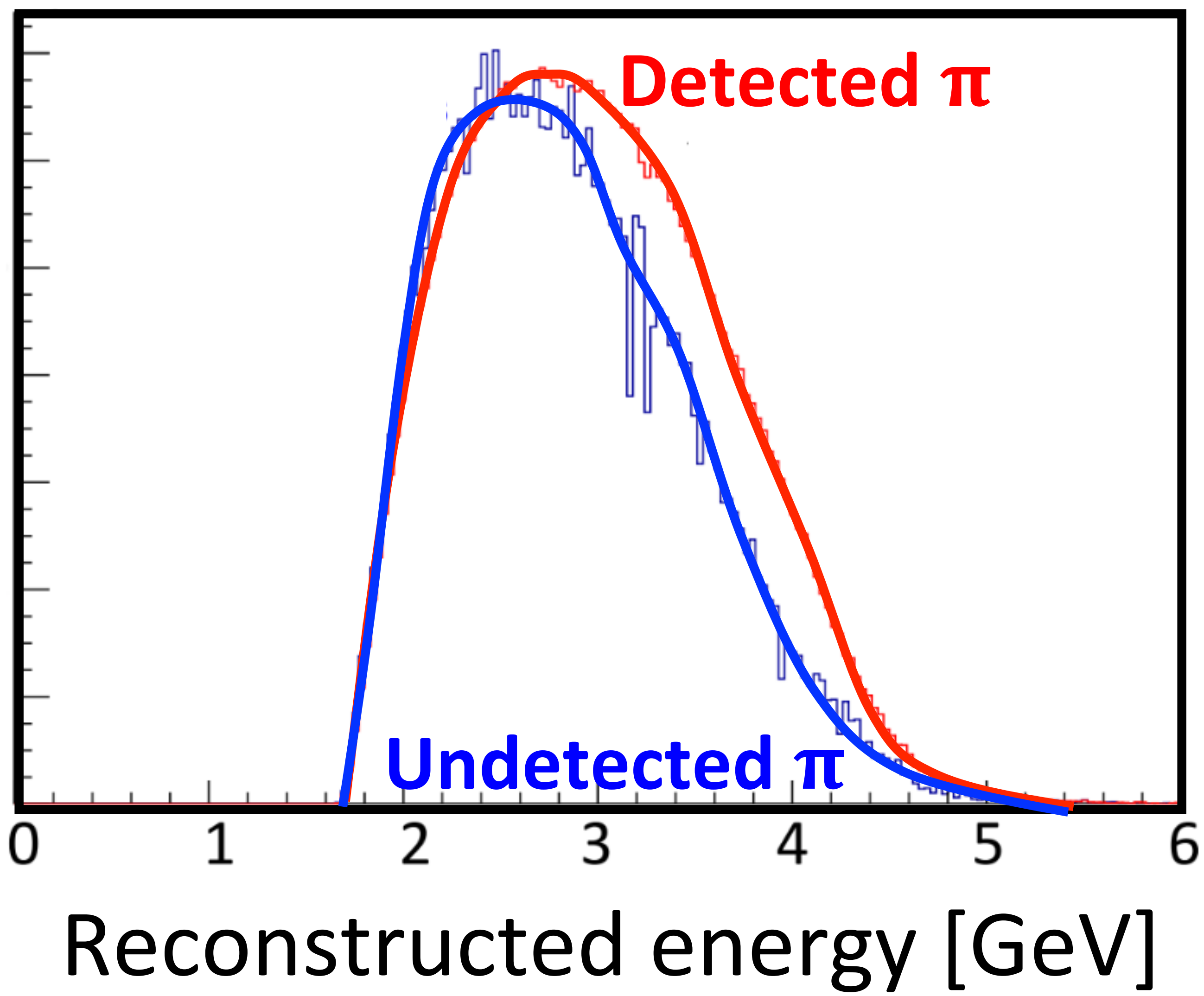
Target	Beam Energy, GeV (# Triggers x $10^{allot!}$)		
	1.161	2.261	4.461
^{3}He	141	217	186
^{4}He	-	333	445
^{12}C	62	238	310
^{56}Fe	-	23	30
CH_2	10	35	21
Empty Cell	19	69	33

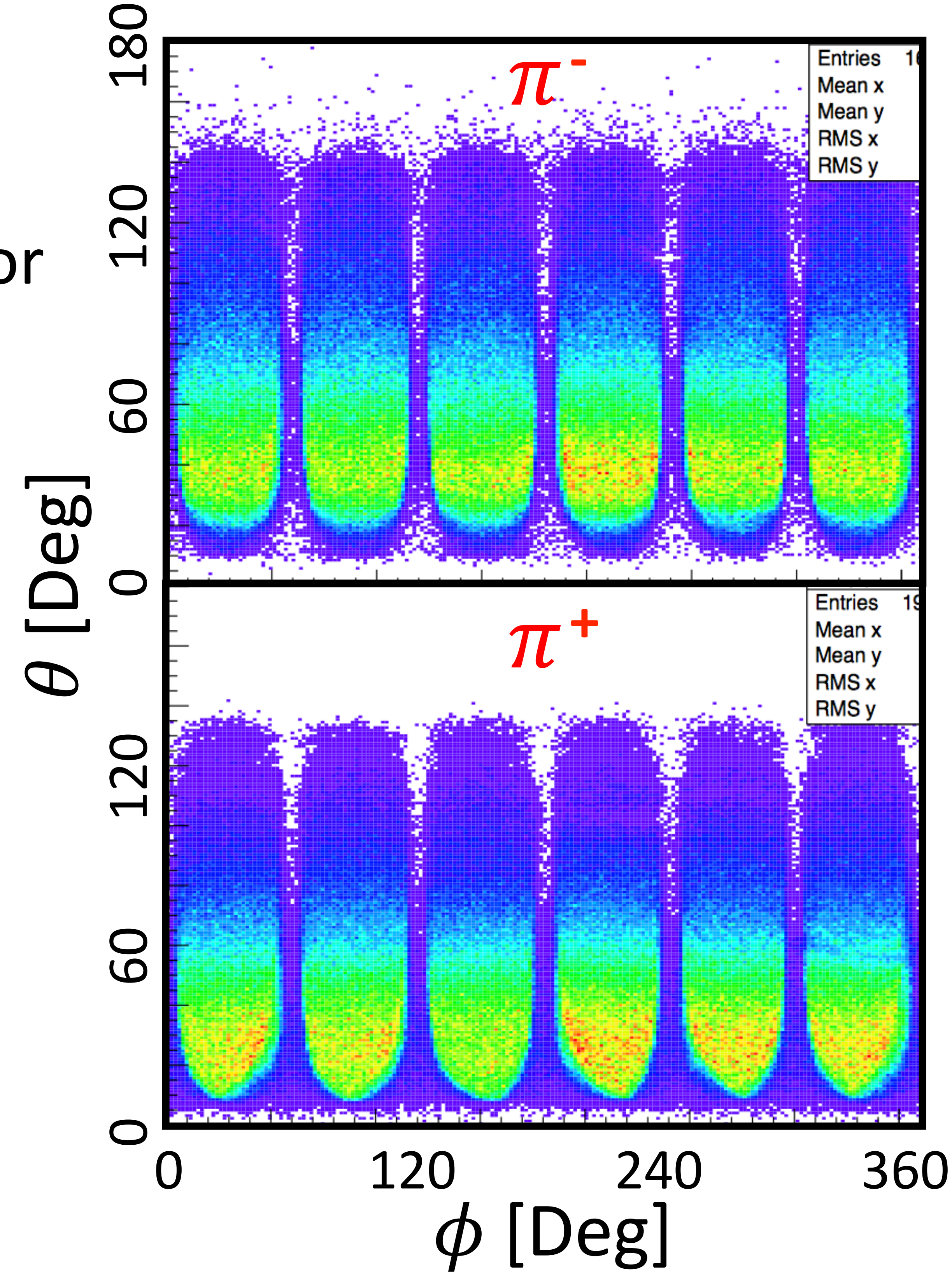
+ CLAS EG2 Experiment: 5 GeV on d, ^{12}C, ^{27}Al, ^{56}Fe, ^{208}Pb

Selecting events with no pions

<u>One sentence summary:</u>

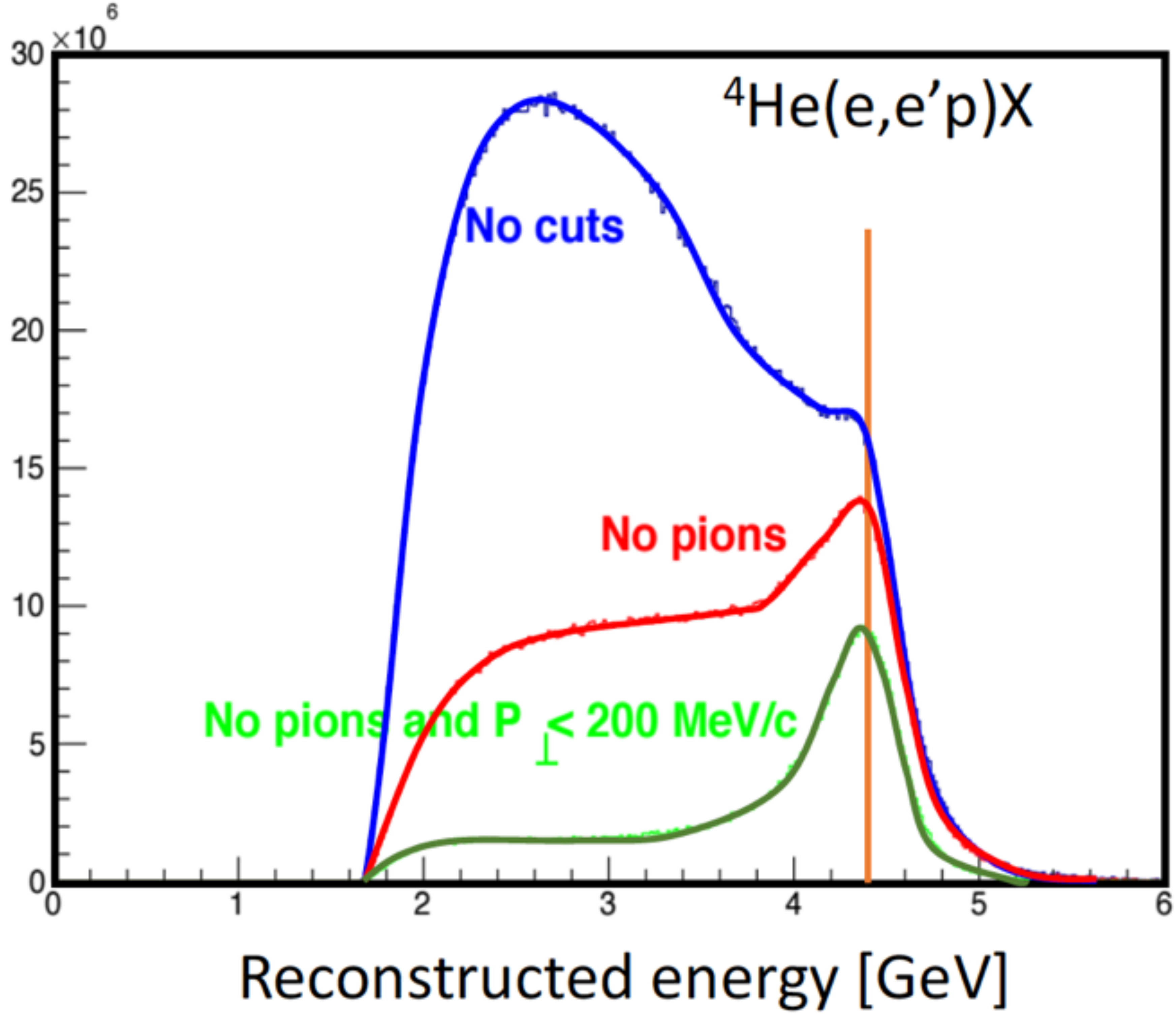
- Smooth over ϕ gaps,
- Use π+/π- ratios to correct for acceptance hole @ small θ.





$$E_\nu = \frac{2(M-\varepsilon_n)E_1 + M^2 - (M-\varepsilon)^2 - m_l^2}{2\left(M - \varepsilon - E_1 + |k_1| cos(\theta)\right)}$$

QE-based



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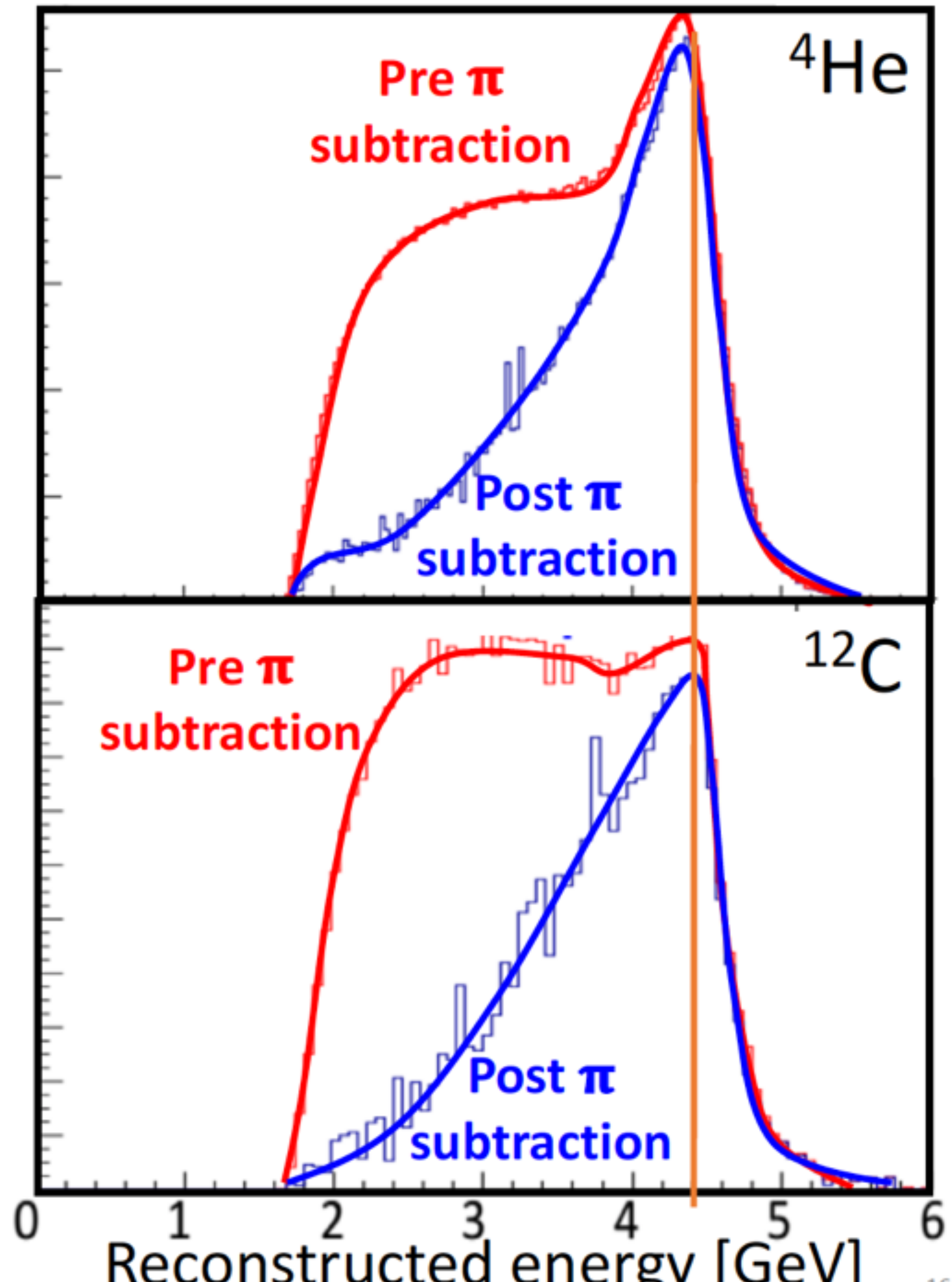
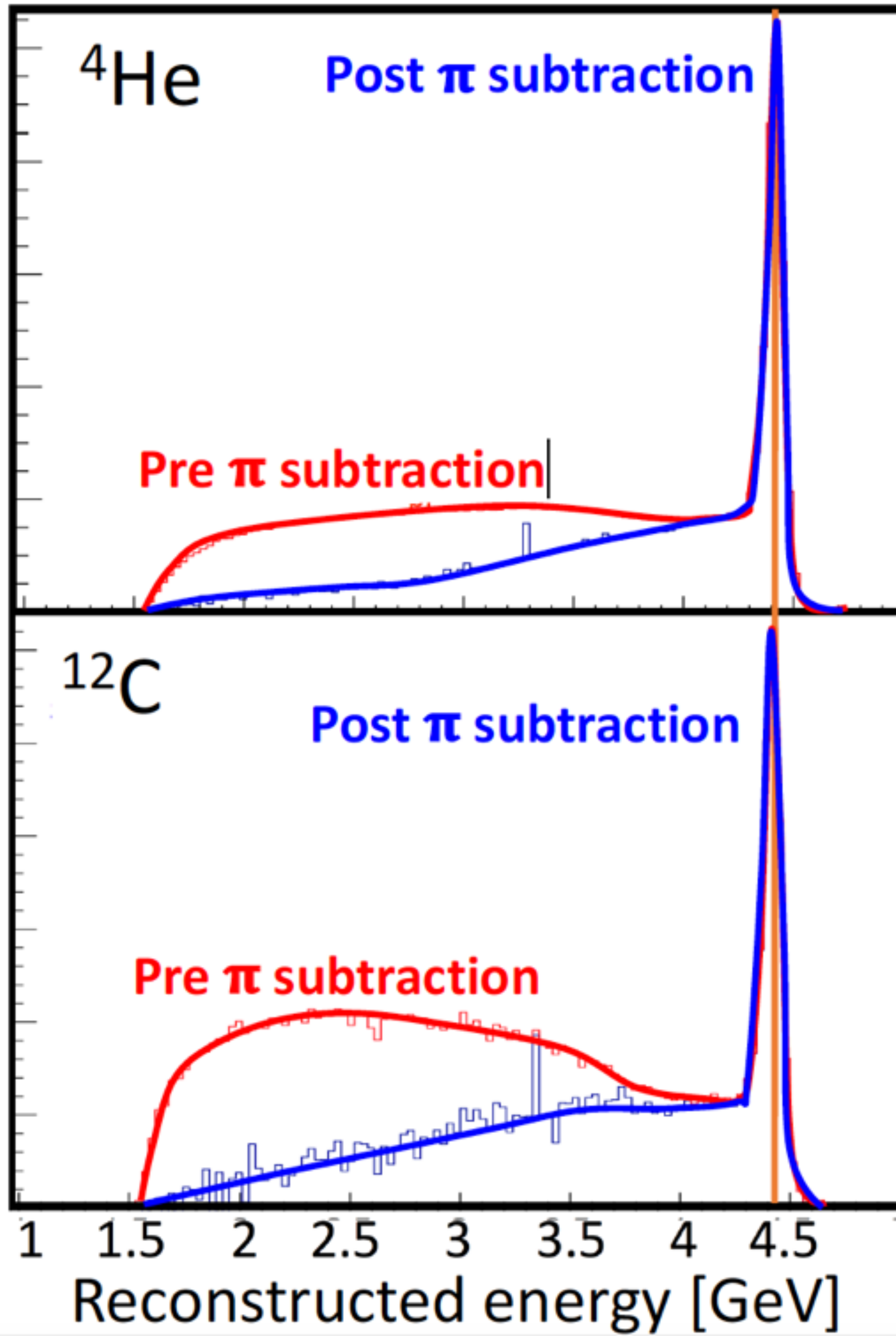
Significant smearing relative to beam energy



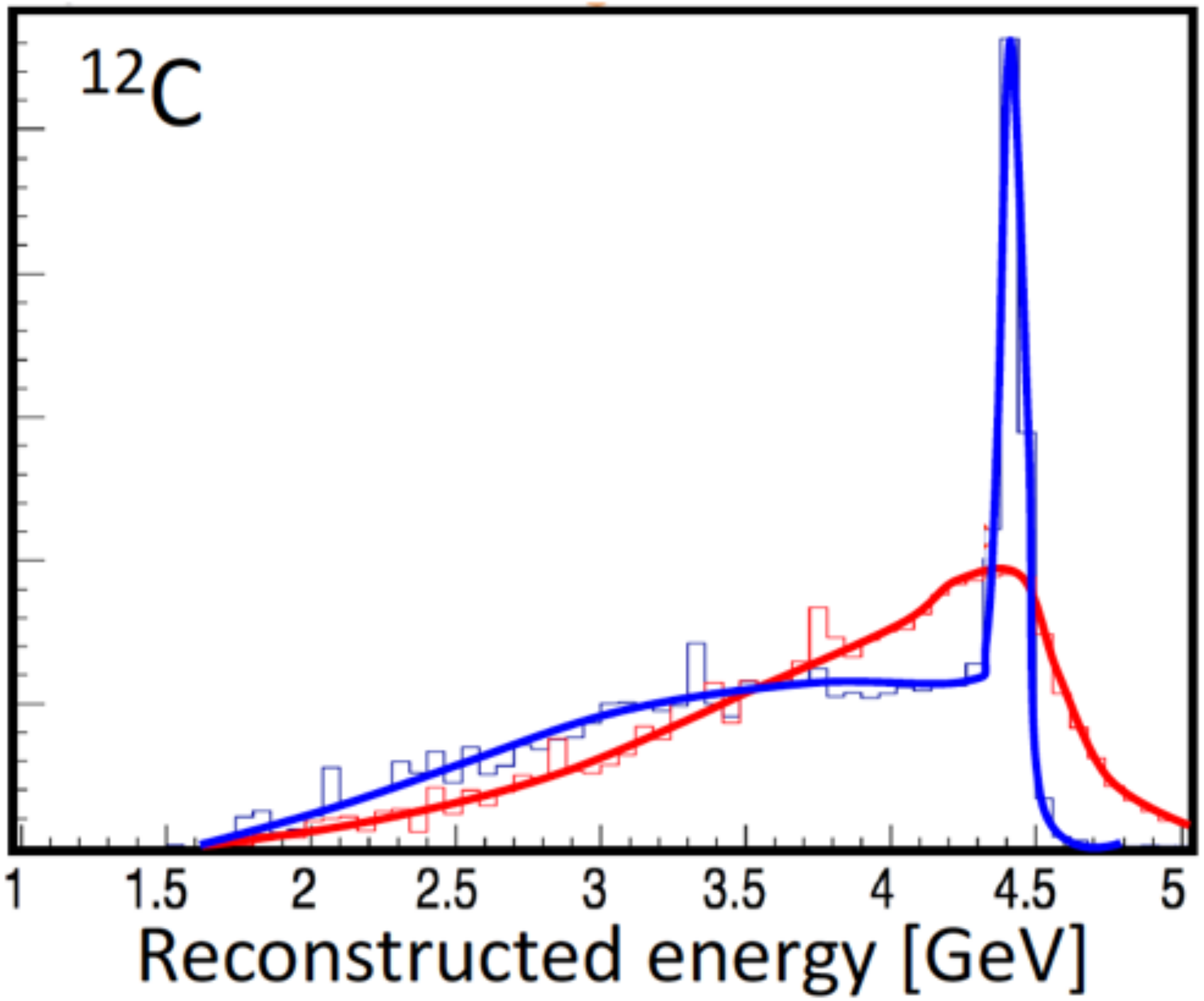
$$E_\nu = E_l + E_p^{kin}$$

Calorimetric

- Peaked, but still feed down



QE vs. Calorimetric



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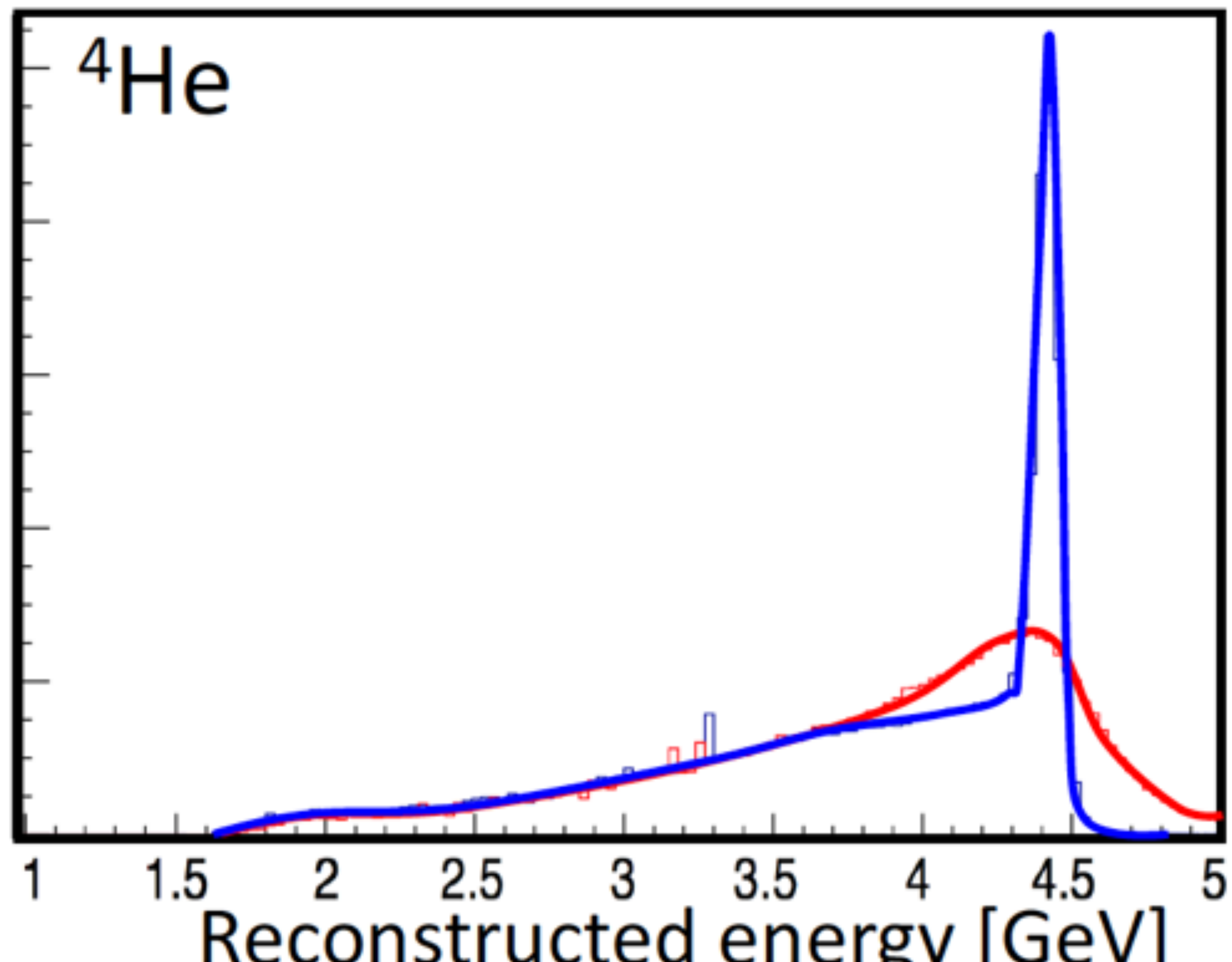

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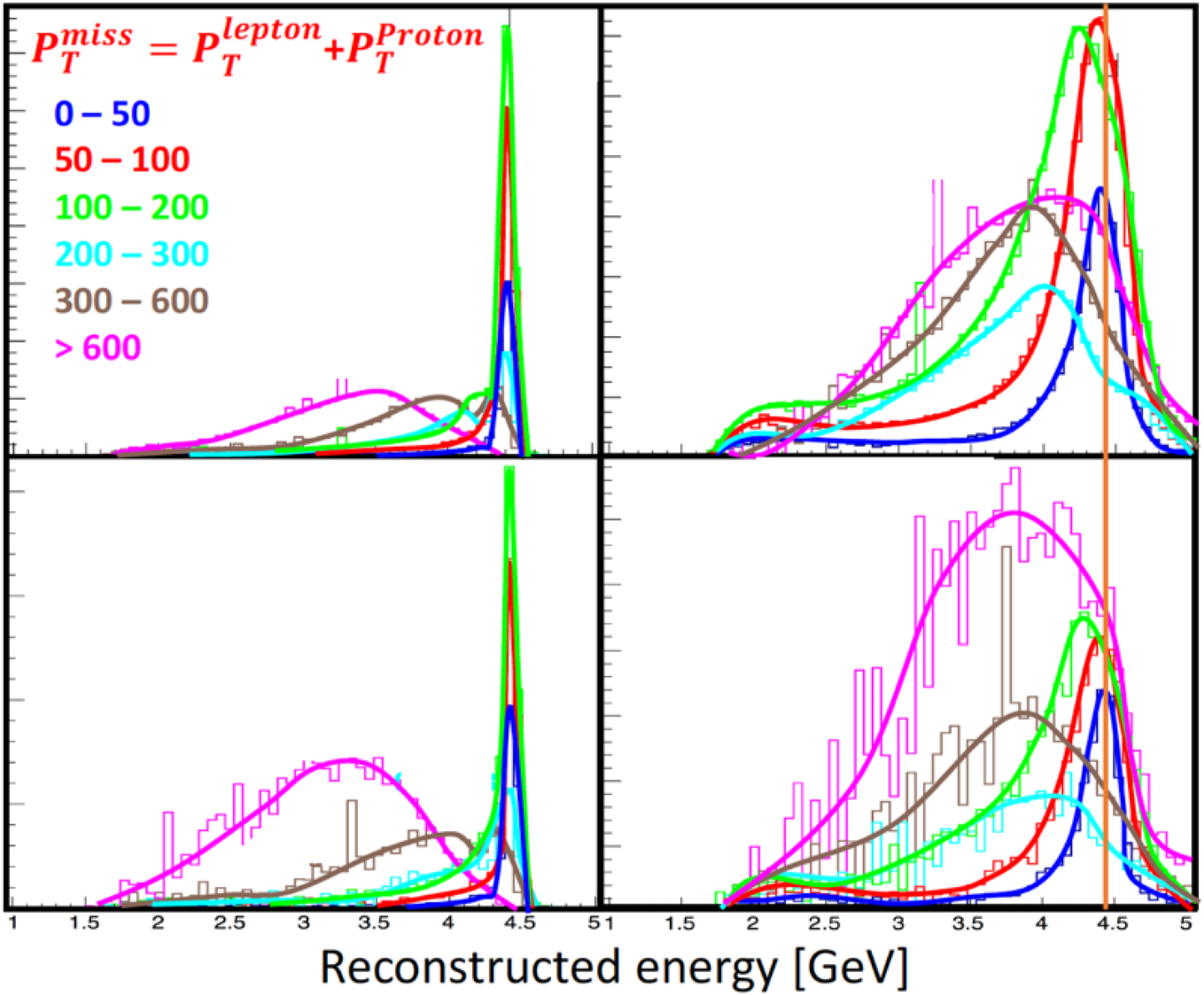
Missing pT: separate true QE in eA



New proposal to JLab

Targets:

^{4}He, ^{12}C, ^{16}O, ^{40}Ar, ^{208}Pb

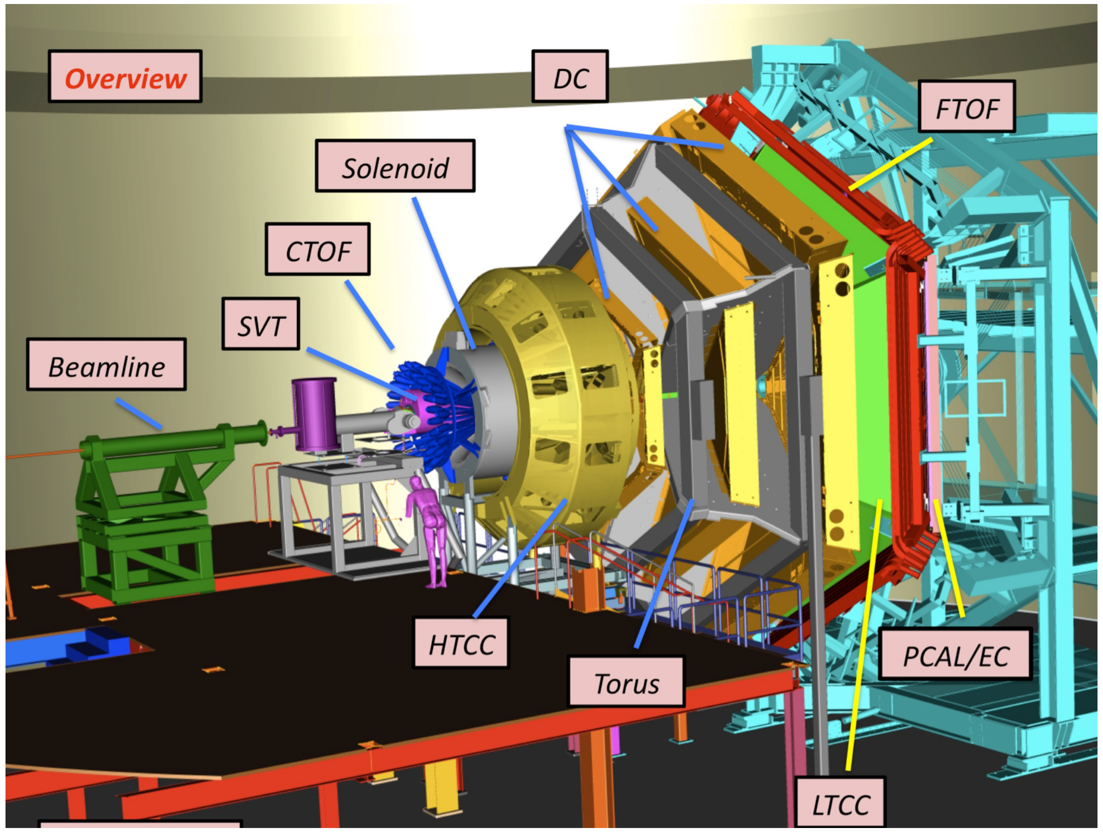
Beam Energies:

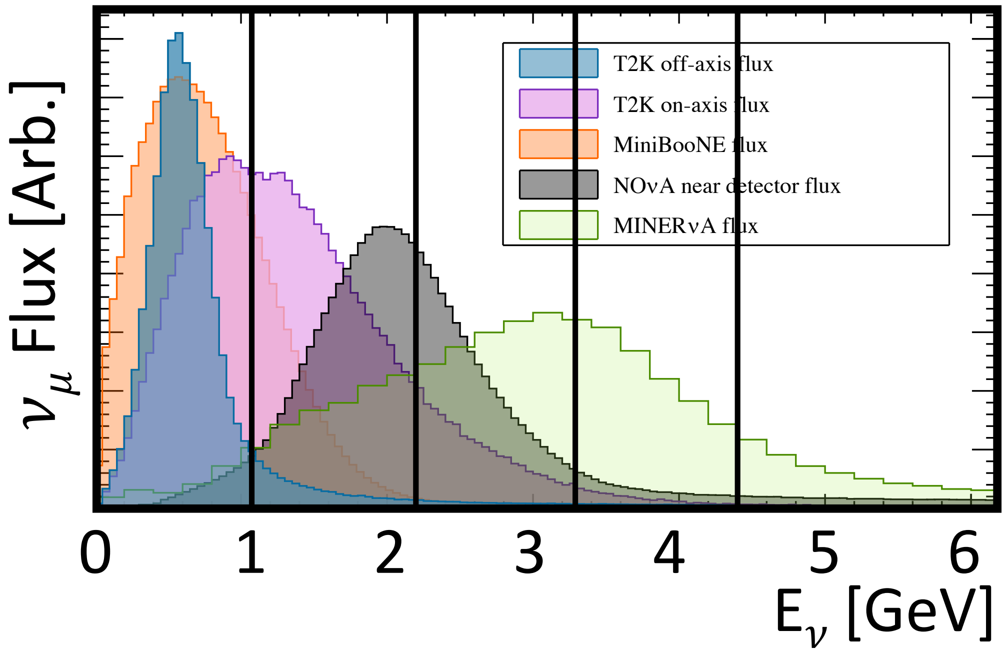
1.1, 2.2, (3.3), 4.4, 6.6 GeV

CLAS12 Spectrometer:

- Luminosity: x10 higher than CLAS6 !
- Charged Particles: 5° – 120°
- Neutrons: 5° – 120° + 160° – 170°
- Threshold: ~300 MeV/c

=> High stat. semi-inclusive and exclusive data sets on multiple targets at multiple energies.





Unique hadronic models test!

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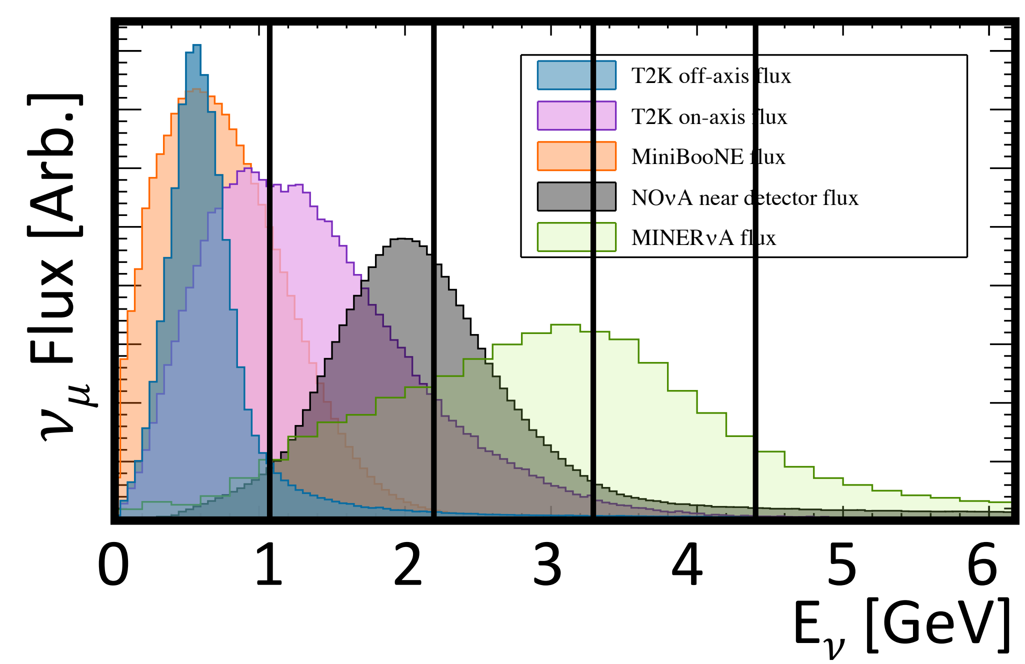
Support letters from DUNE?



Unique hadronic models test!

Summary

- Electron scattering data is a unique and valuable window in conjunction with planned near detectors
- First CLAS data mining show separation of QE/reasonable energy estimation, but require a proton in the final state.
    - Does this hold up for neutrino *spectrum*?
- Next steps: overhaul to to GENIE eA interface, comparisons to generators of semi-inclusive p, π data
- New data sets on Ar for range of energies of interest to DUNE proposal to JLab
    - semi-inclusive **neutron** data

Where do we want to go?

- Quantify what will be crucial for oscillation experiments
  - NuSTEC white paper
  - Role of neutrons (**ANNIE**, CAPTAIN)
  - New techniques: NuPRISM, transversely
- Field needs to confront methodology issues raised at TENSIONS2016 and NuInt workshop series
  - Tensions between measurements, hidden model dependance? physics? efficiency problems?

Brave new world and much physics to be done!

Backup slides

State of the Nu-tion workshop

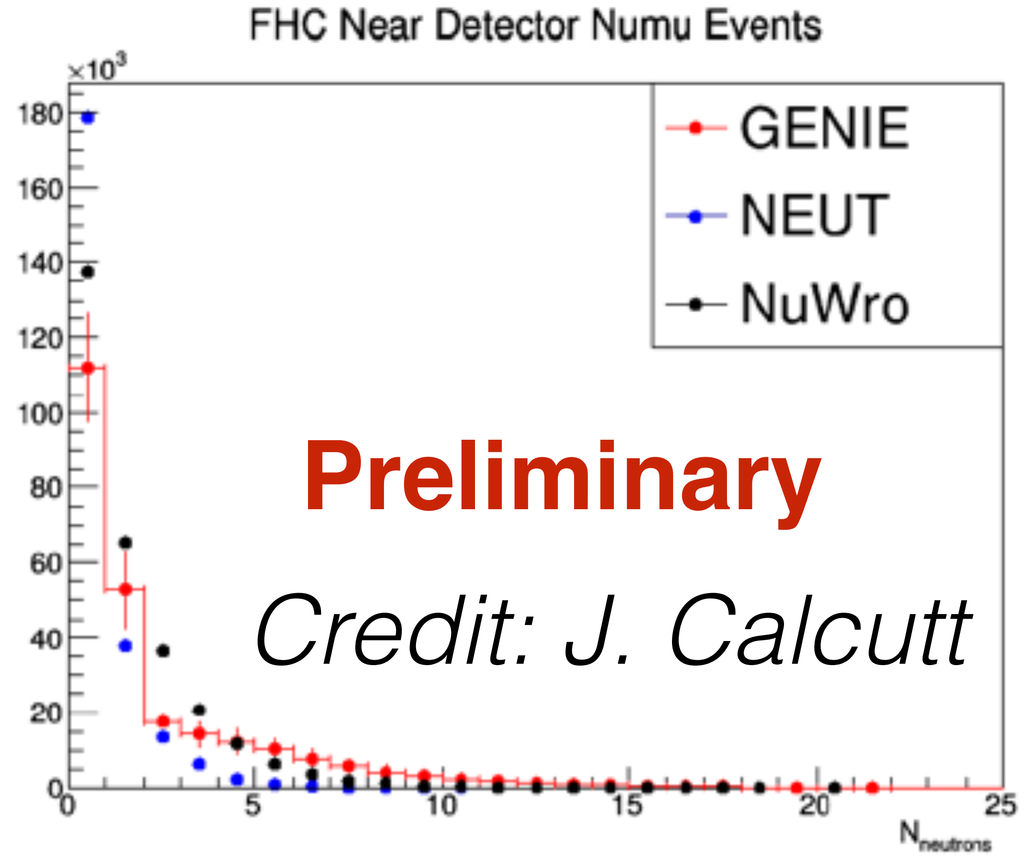
- Major issues in cross section measurements, how do we tackle them?
- Discussion based workshop in Toronto, Canada, before NuInt2017 (June 23-24)
- https://nuint2017.physics.utoronto.ca/state-of-the-nu-tion-premeeting/announcement

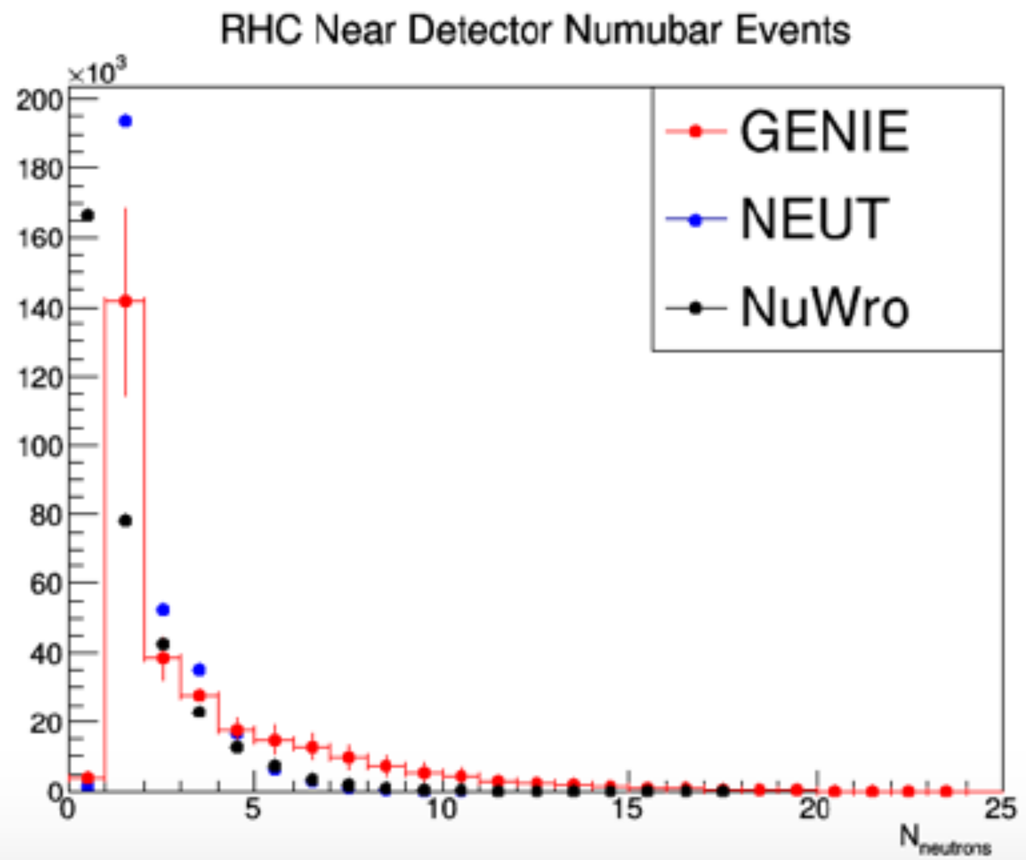
ν-A measurement problems…

Methods and Techniques

Brainstorm solutions!

Another pitfall: Role of neutrons

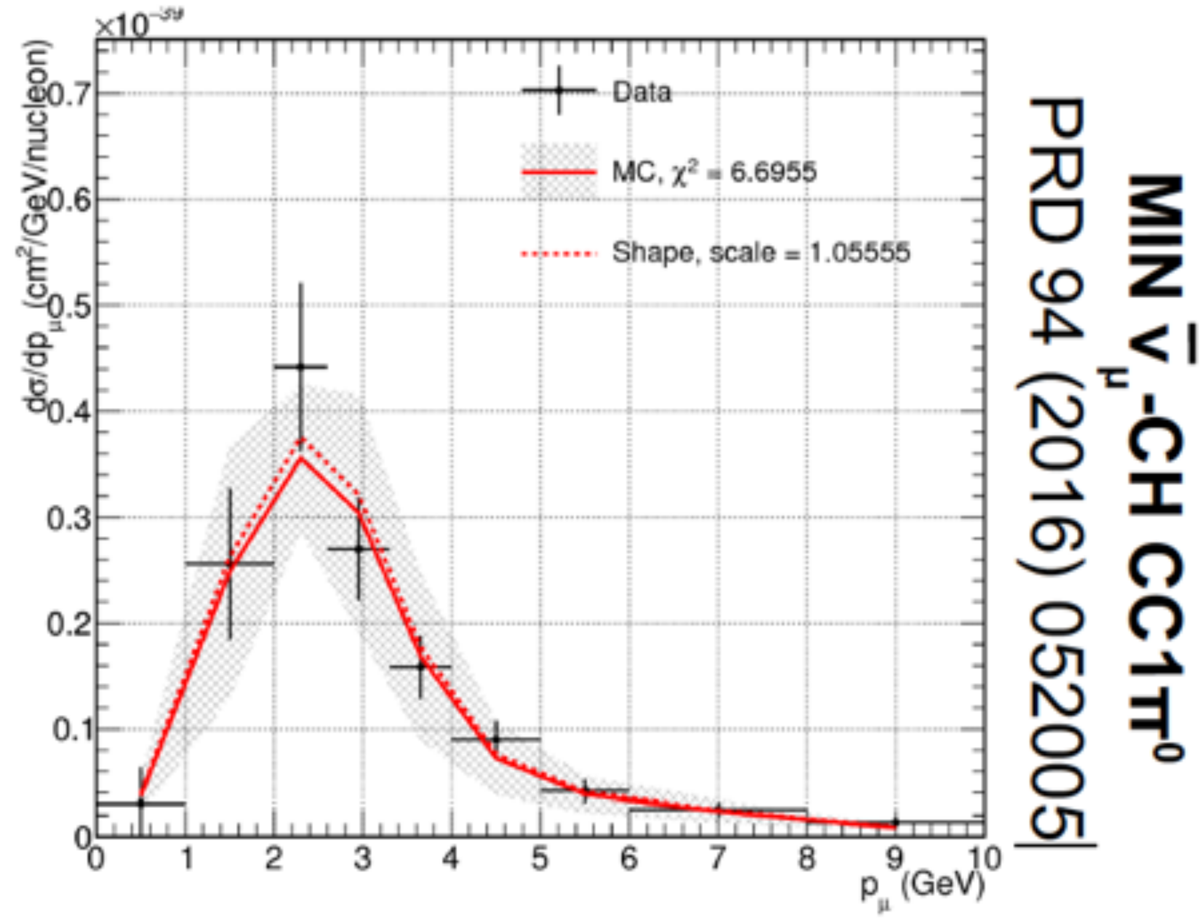


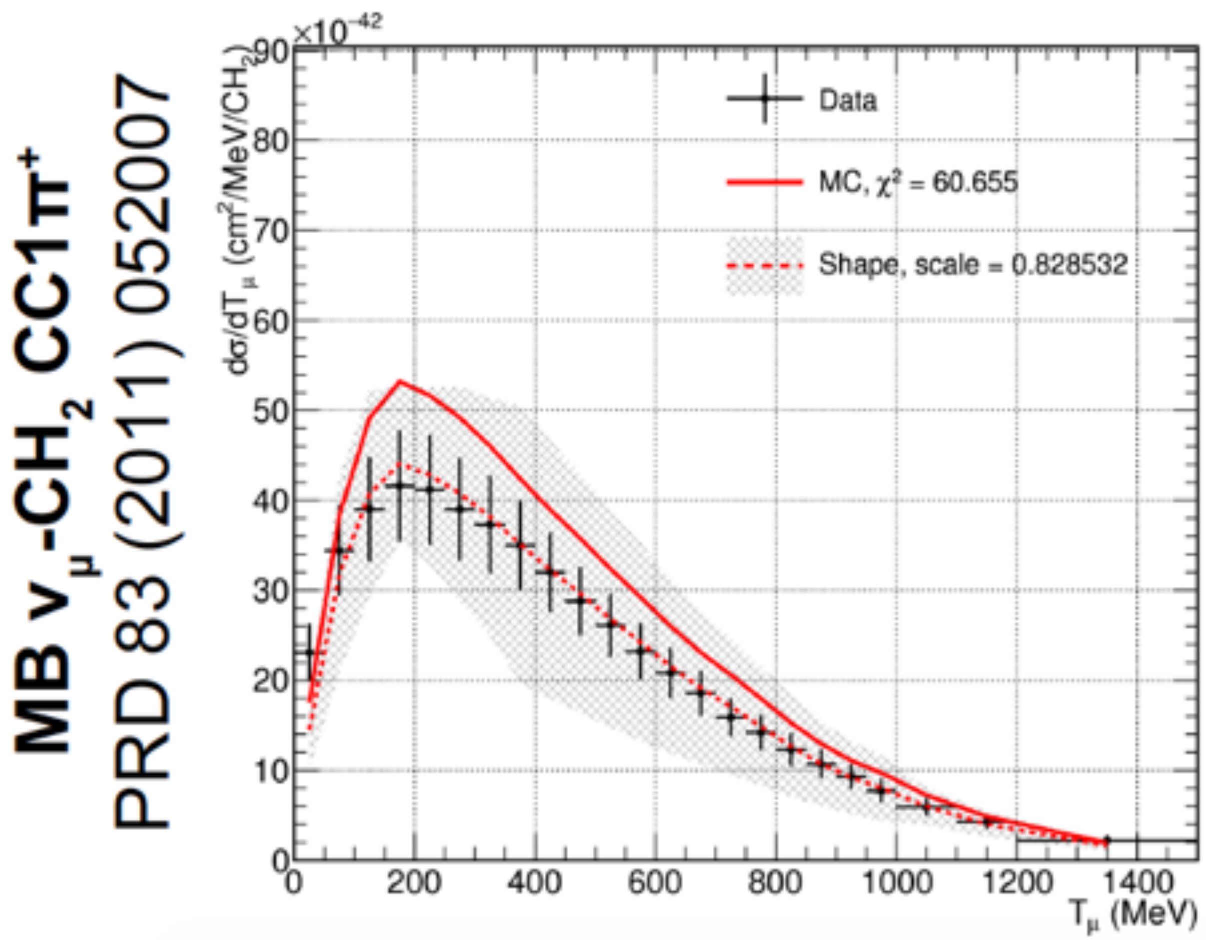


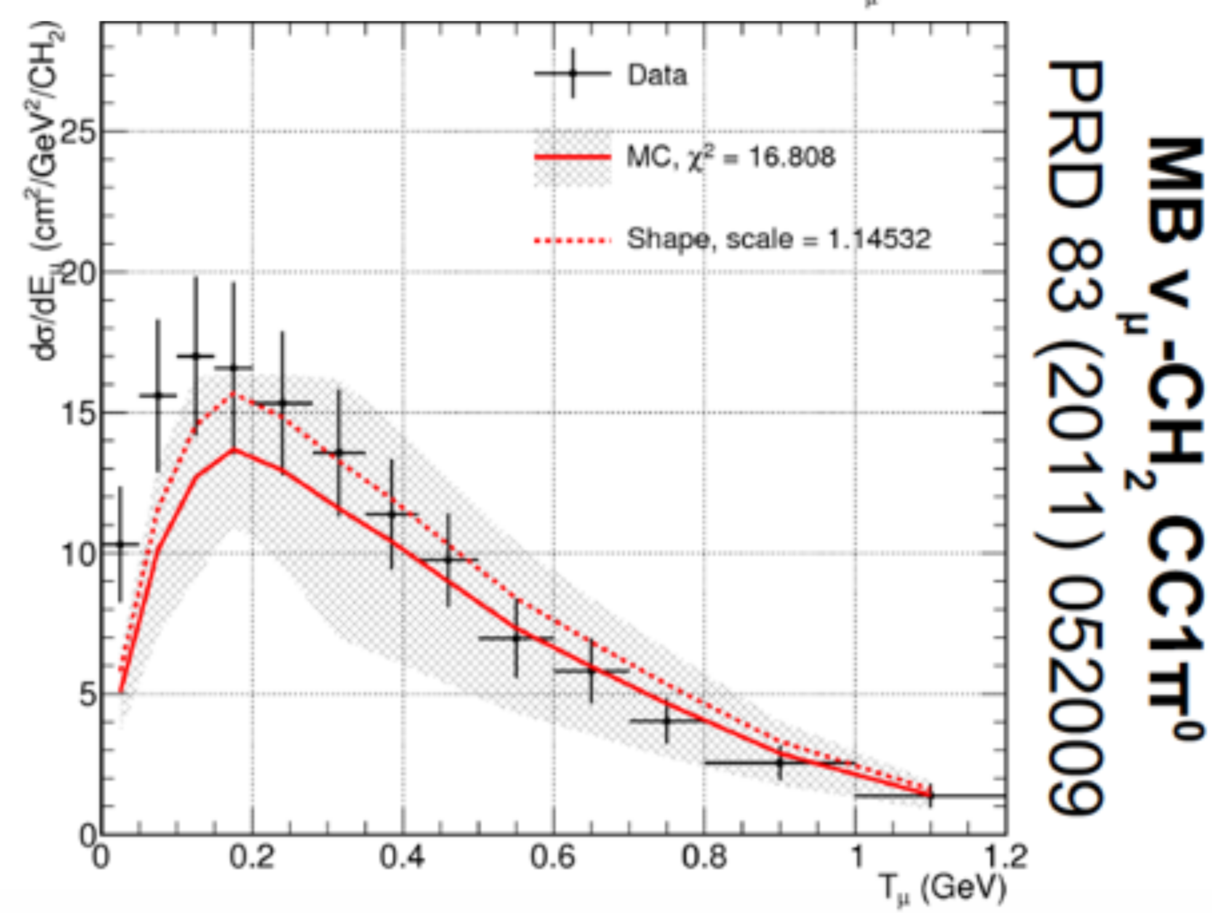
- For CC0π events on DUNE, signifiant fraction of energy carried away by neutrons
- Significant model spread
- Theory: need semi-inclusive prediction of neutrons
- Experiment: Need validation of those models. **Crucial role of experiments like ANNIE**

Single Pion Production Puzzles

- **Reasonable agreement in outgoing muon spectrum**
- Terrible agreement in outgoing pion spectrum
- Model development essential







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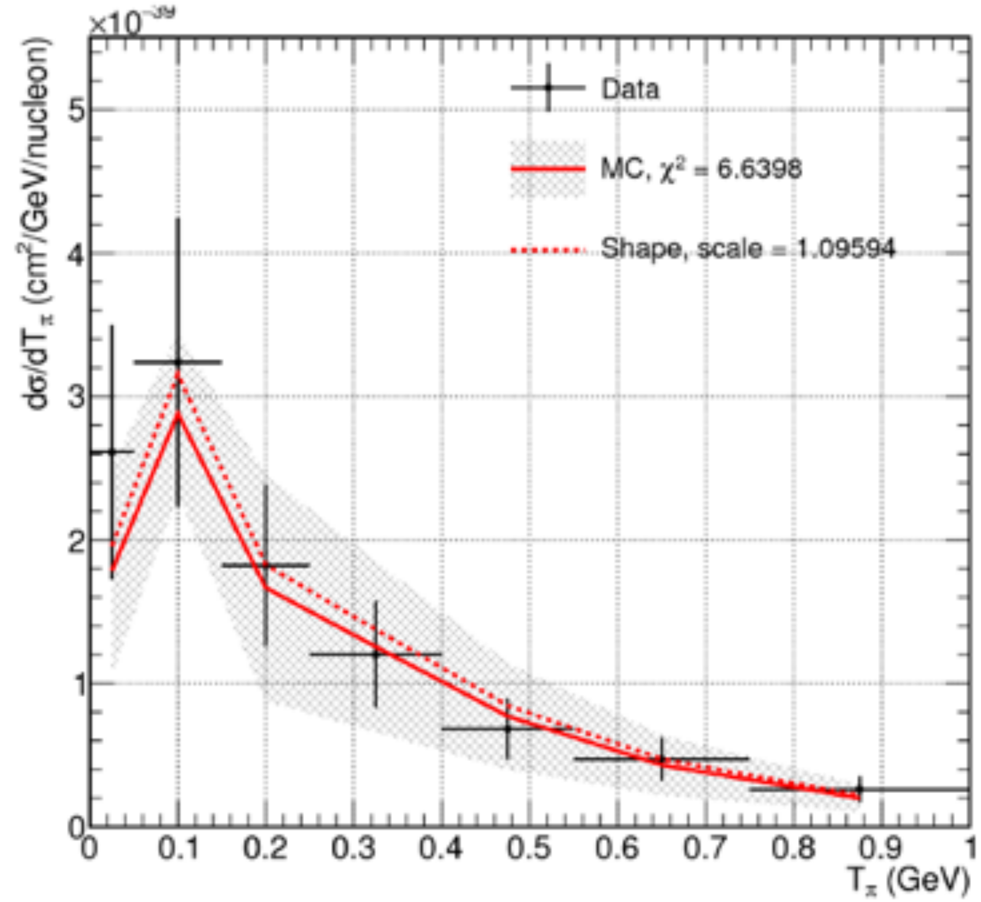
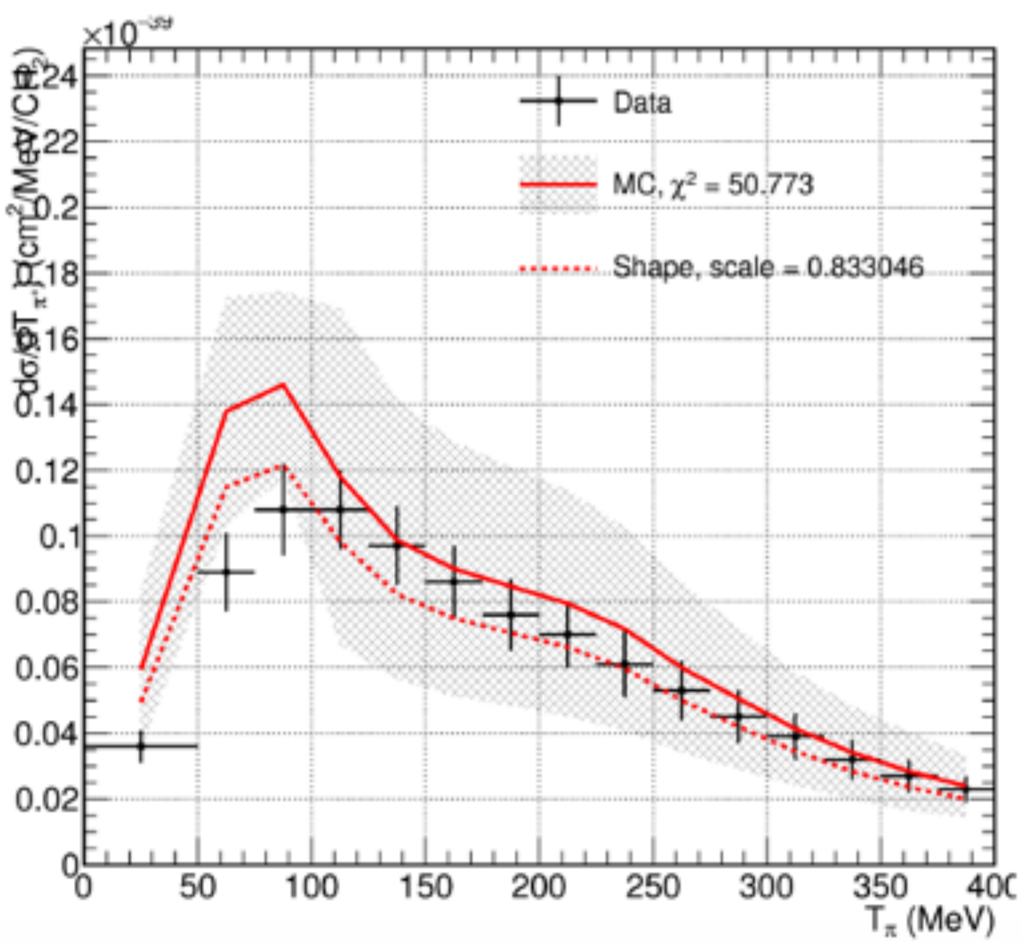
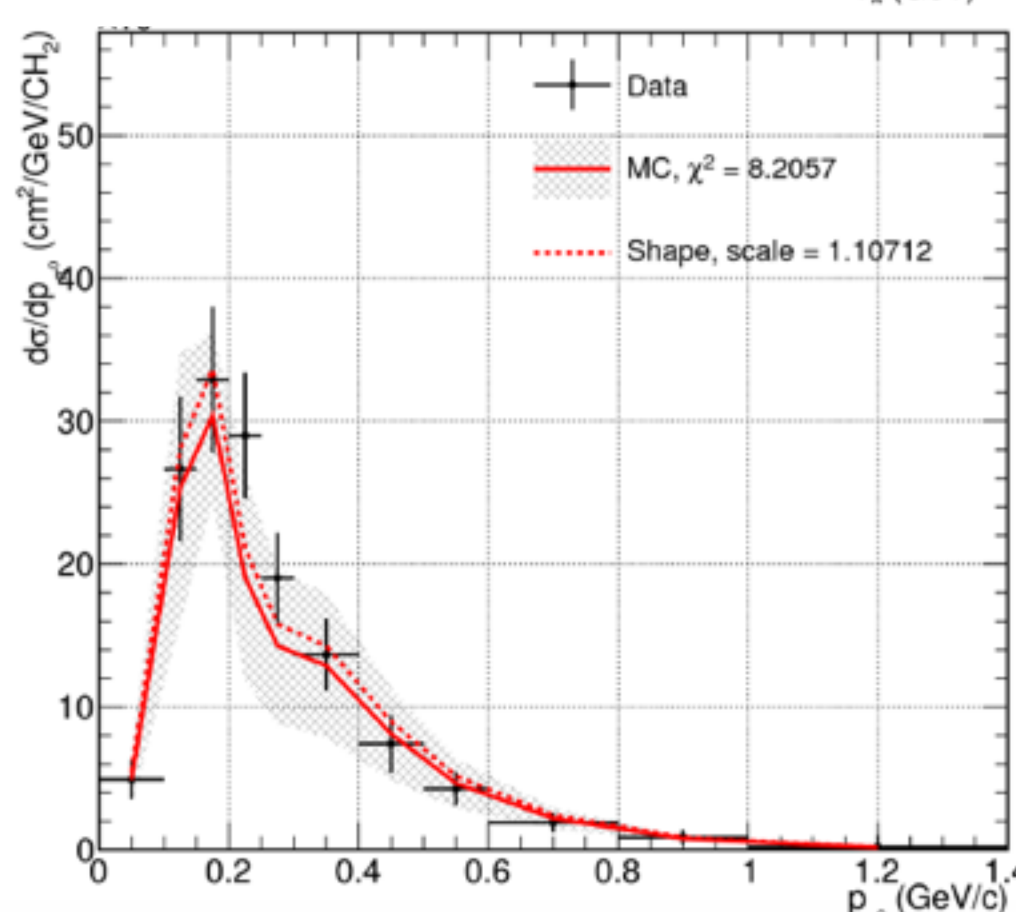


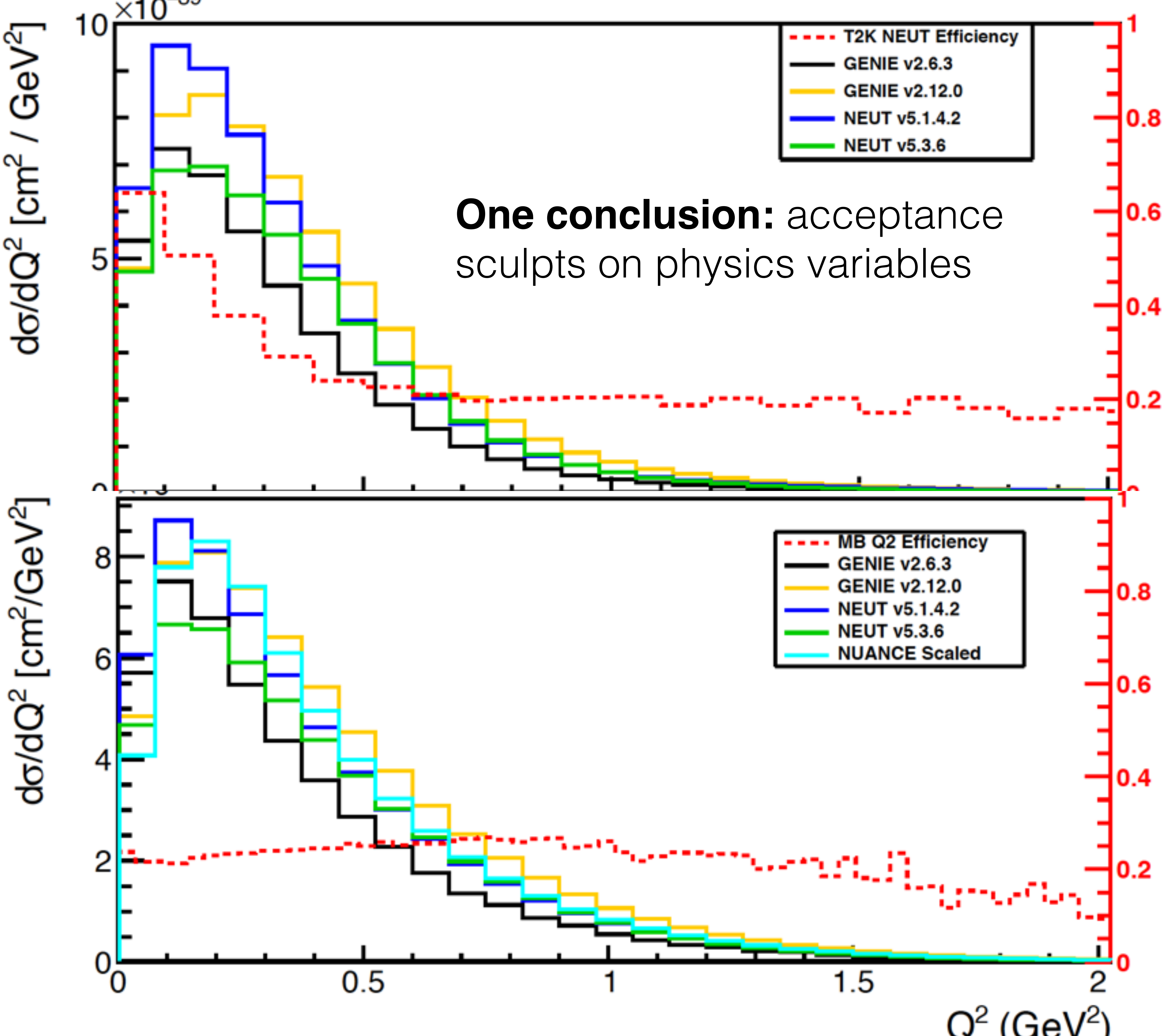
MIN $\bar{\nu}_\mu$-CH CC1π^0
PRD 94 (2016) 052005



MB ν_μ-CH_2 CC1π^+
PRD 83 (2011) 052007



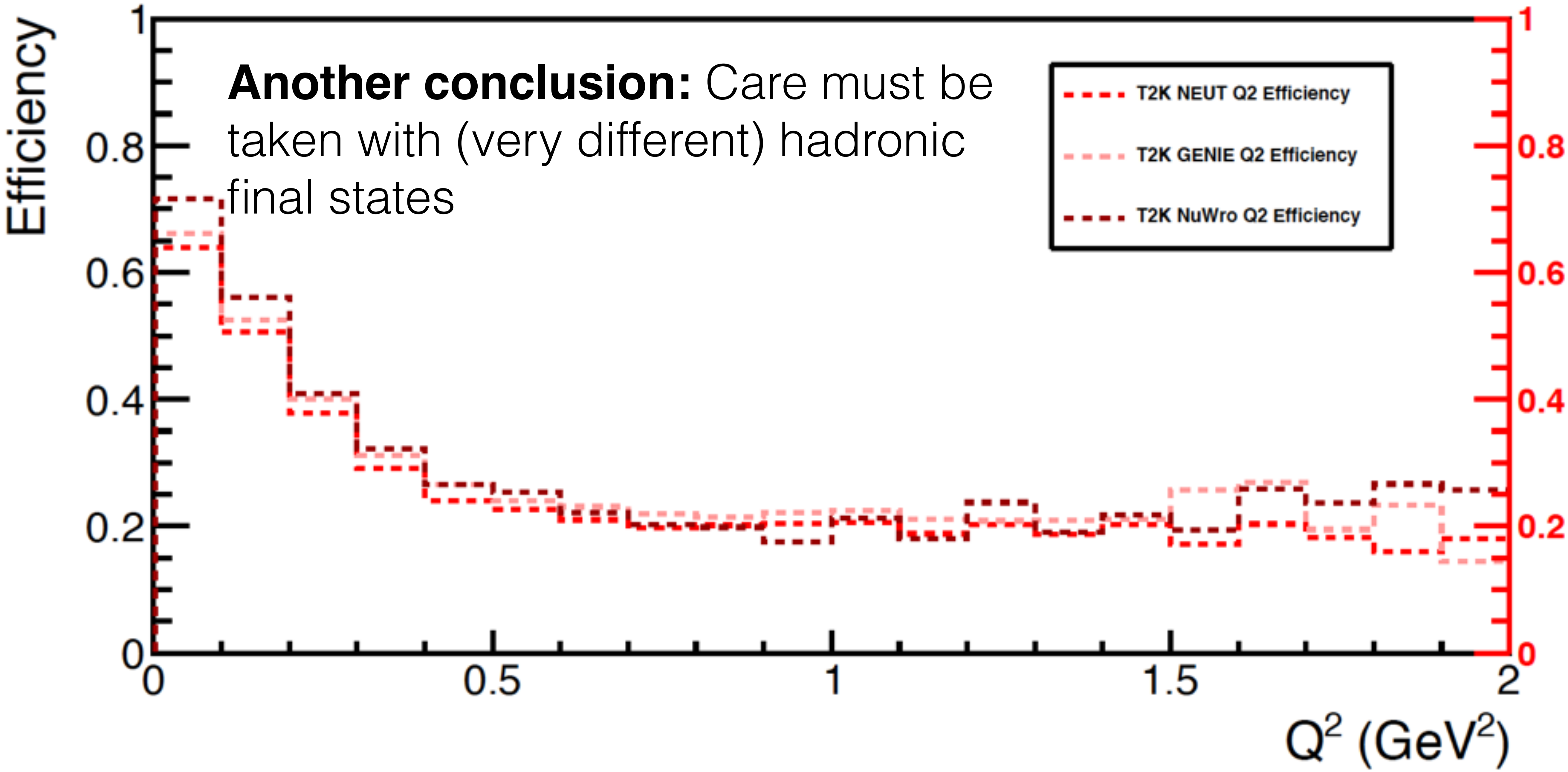
MB ν_μ-CH_2 CC1π^0
PRD 83 (2011) 052009



One conclusion: acceptance sculpts on physics variables

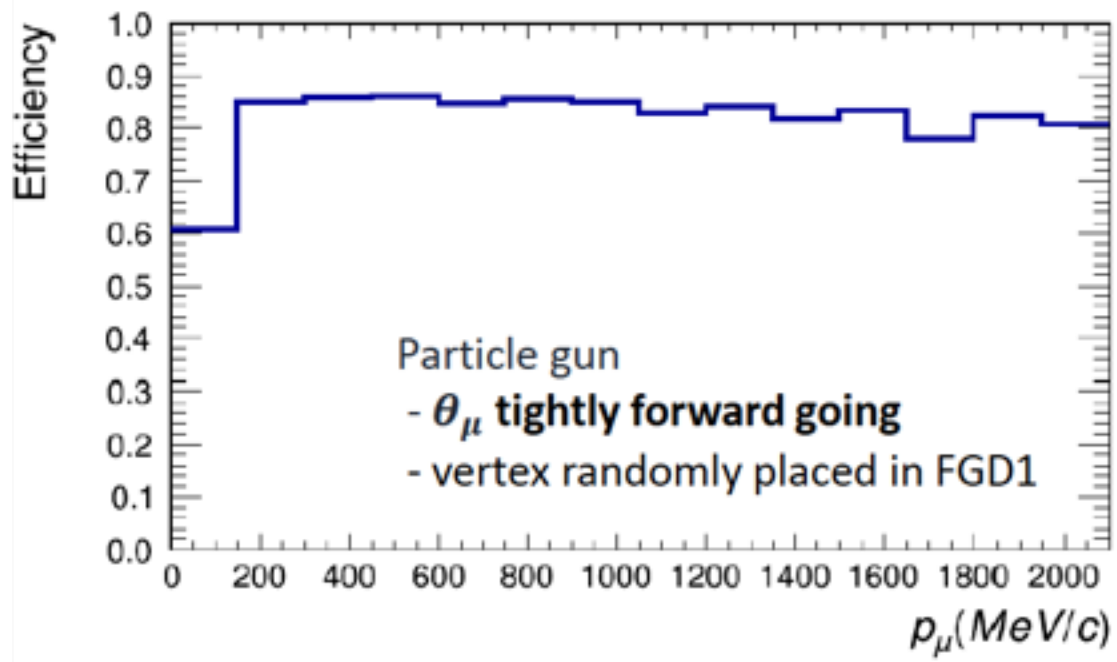
Efficiency on T2K with three models

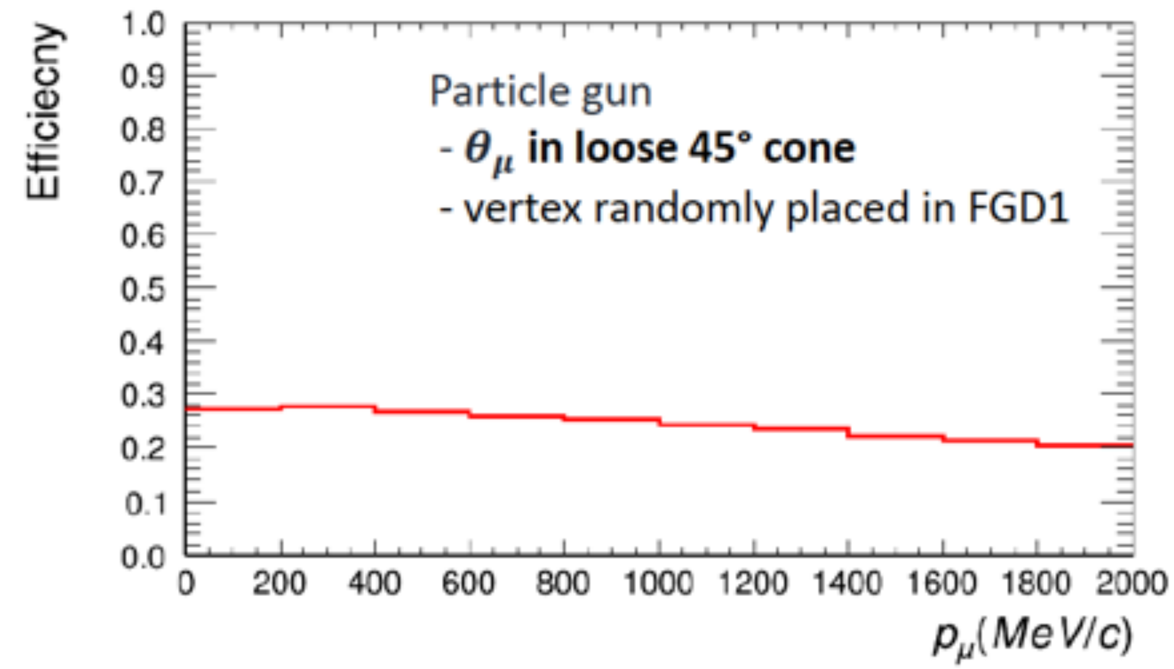
Another conclusion: Care must be taken with (very different) hadronic final states



Model dependence? Efficiency Calculation

- **Example 1** – want to measure p_μ for single muons using TPC.
  - The efficiency is very dependent on the underlying θ_μ distribution.
  - The underlying θ_μ distribution depends on the neutrino scattering model





- **Solution** – Build efficiency in bins of p_μ, θ_μ
  – Restrict p_μ, θ_μ phase space to regions of high (flat) ϵ

- Problem becomes more complicated with multiple particles

Credit: S. Dolan, T2K-XSEC workshop and State of Nu-tion speaker