



2/18/2

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The Challenge

$$N(E_{rec}, L) \propto \int \Phi(E, L) \sigma(E) f_\sigma(E, E_{rec}) dE$$

Measurement

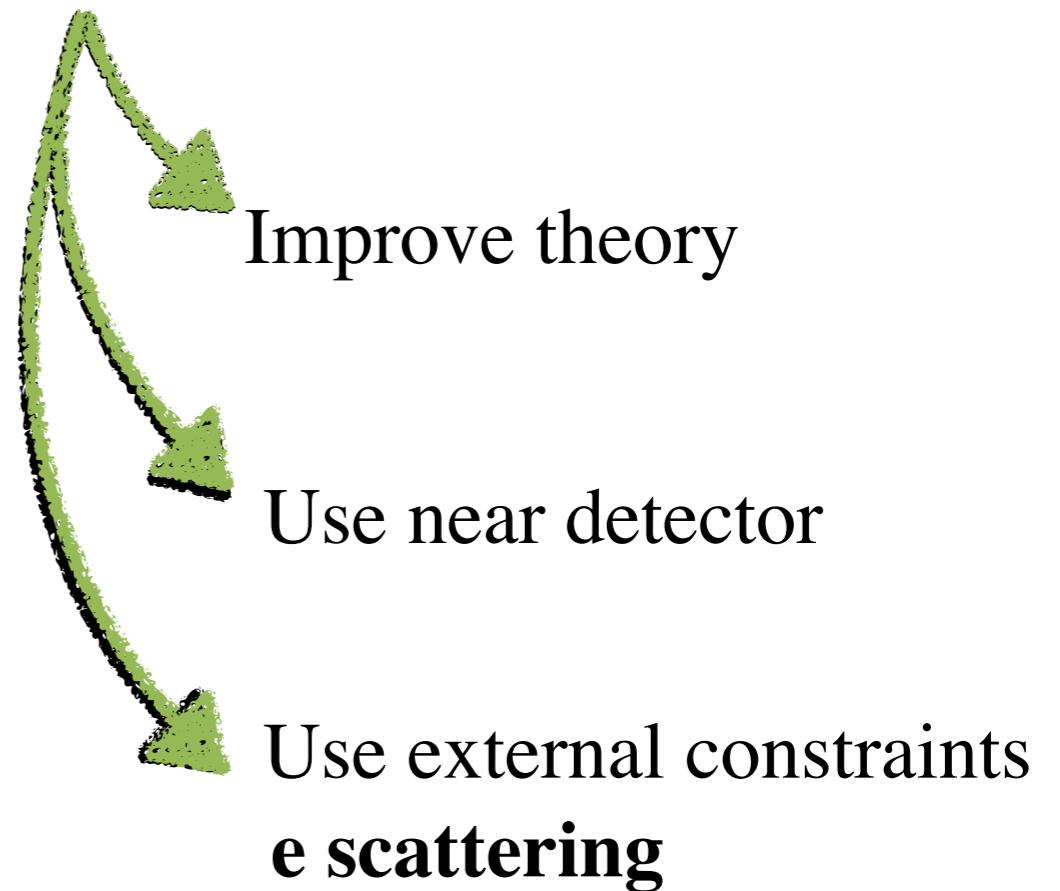
Incoming true flux Modelling input

The Challenge

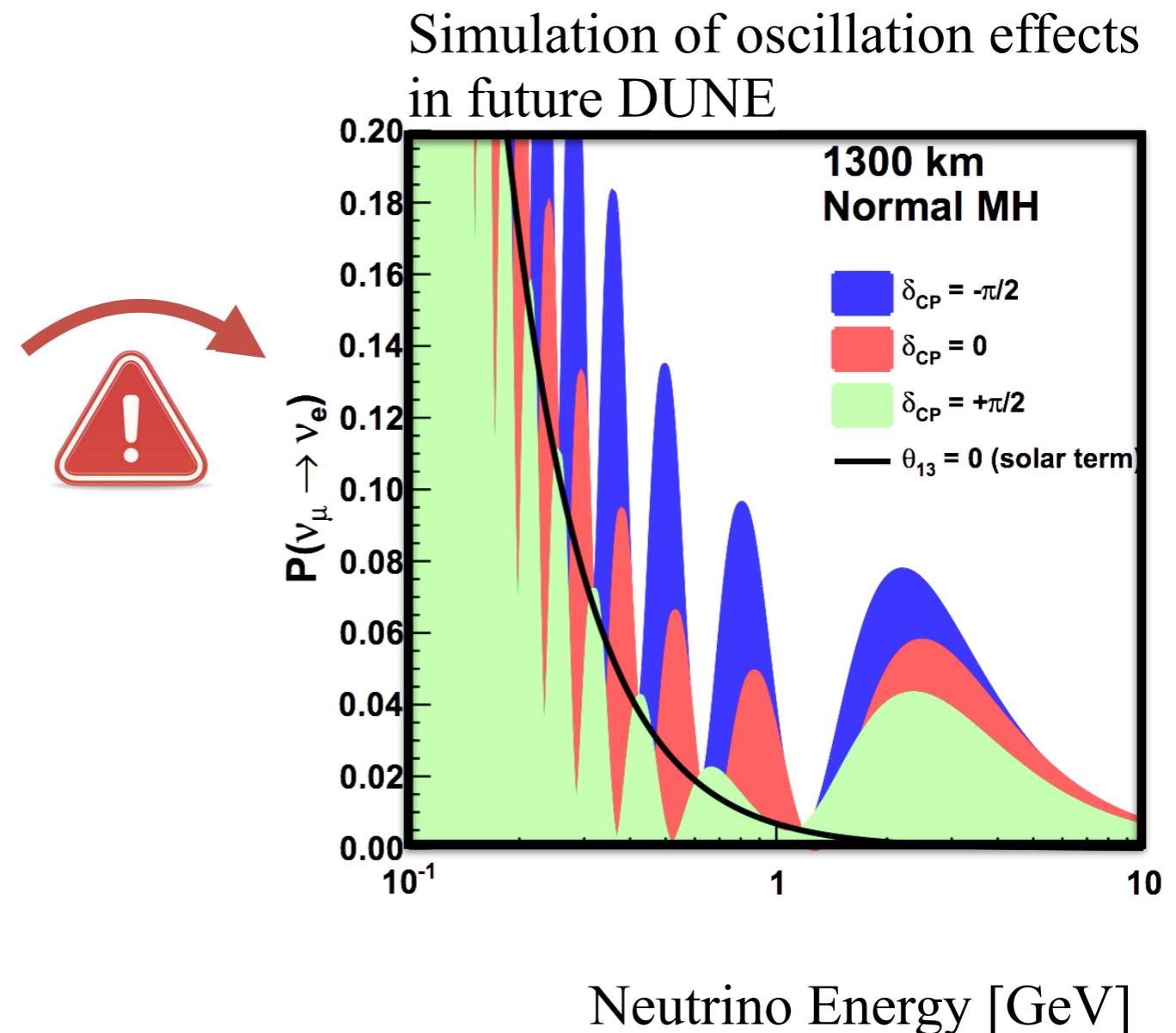
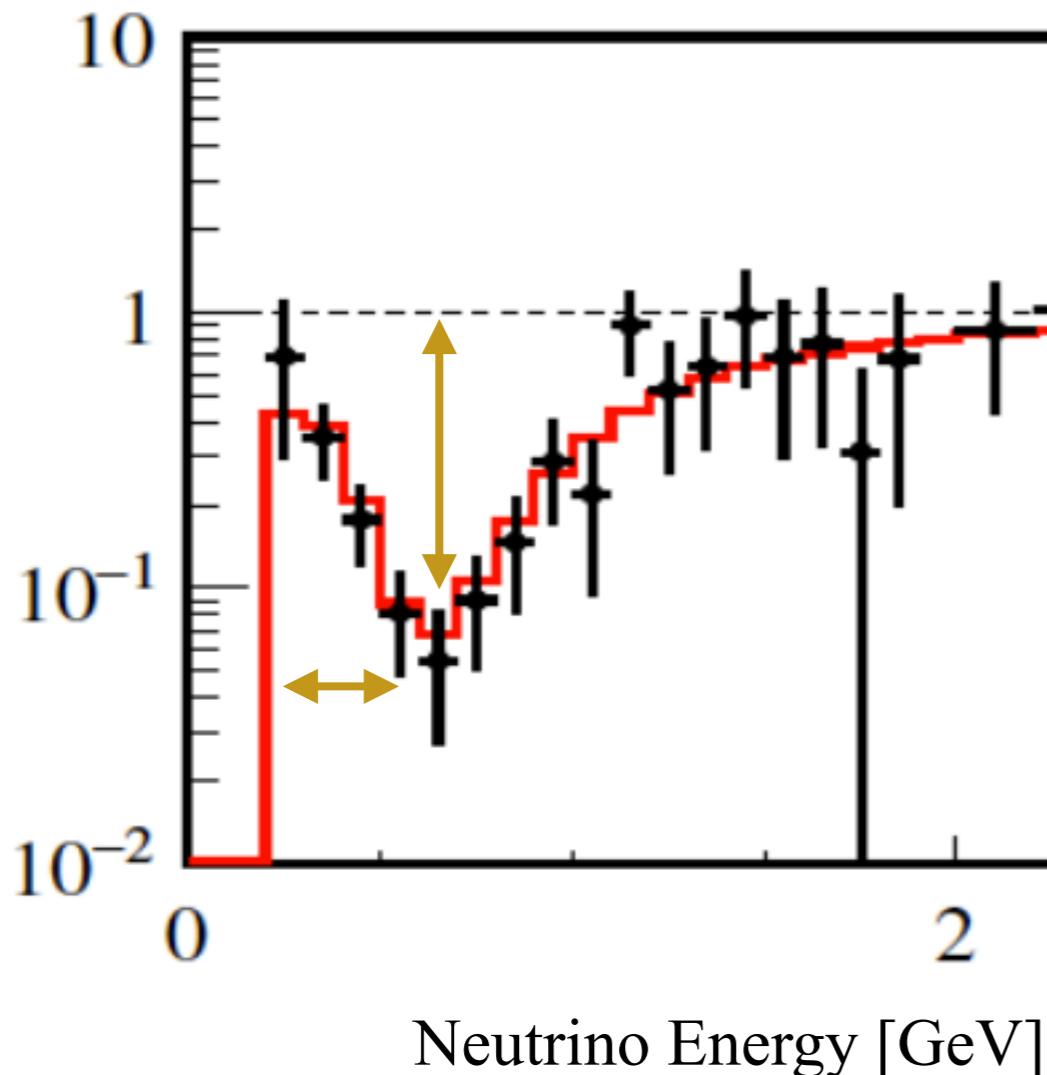
$$N(E_{rec}, L) \propto \int \Phi(E, L) \sigma(E) f_\sigma(E, E_{rec}) dE$$

Measurement

Incoming true flux Modelling input



Next generation - High Precision Challenge





- Electrons and Neutrinos have:
 - Similar interactions
 - Same nuclear effects

Electron beam have known energy

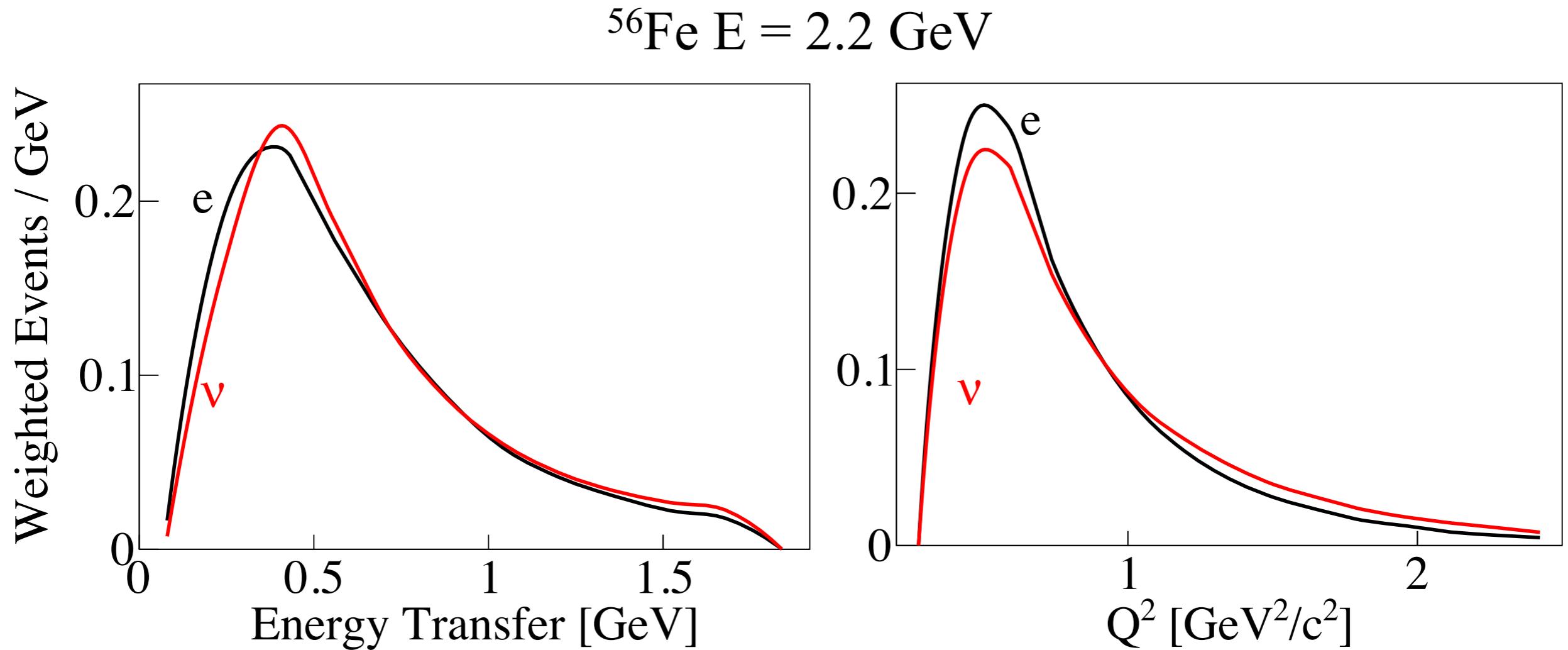
-
- Electrons and Neutrinos have:
 - Similar interactions
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Electron beam have known energy

Before we start:

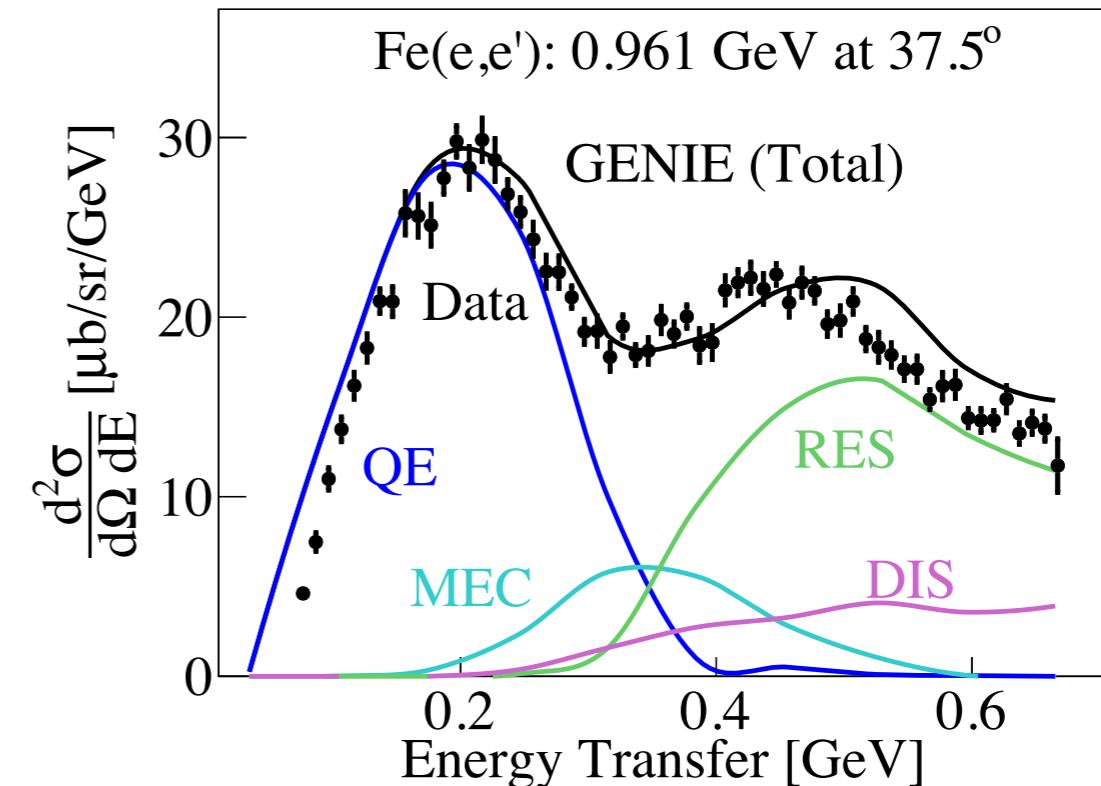
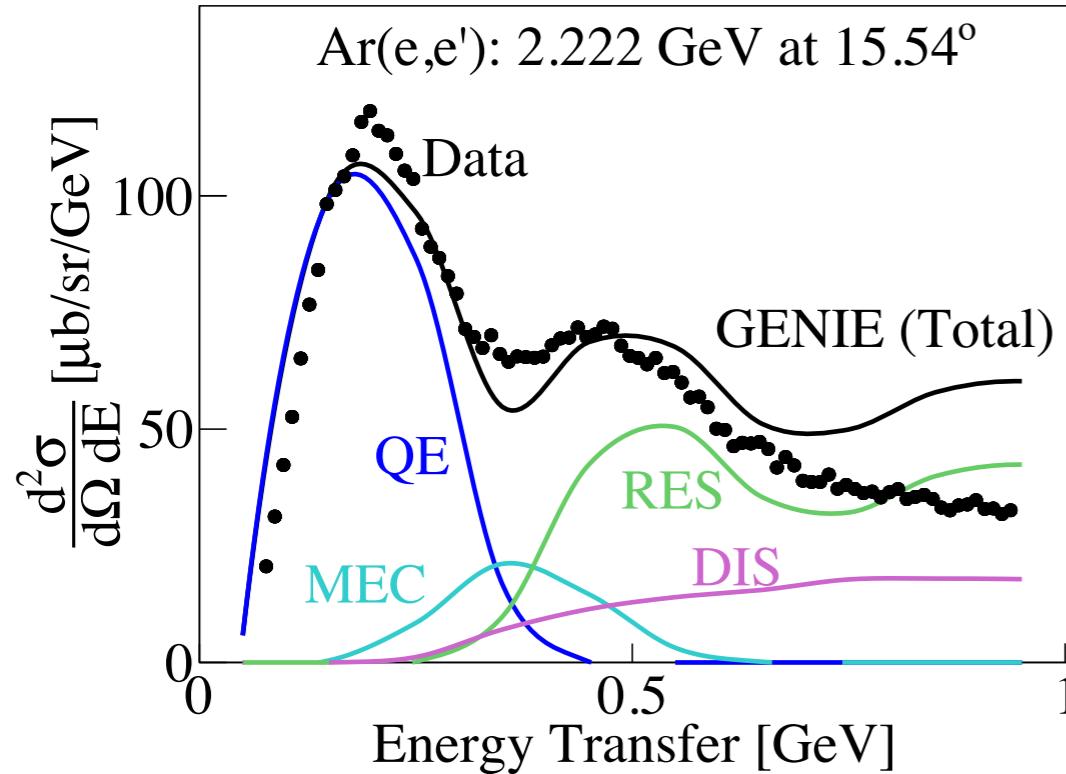
- Compare electron and neutrino mode
- Check Inclusive distributions
- Account for differences such as radiative effects

electron vs. neutrino mode in 1p0 π channel

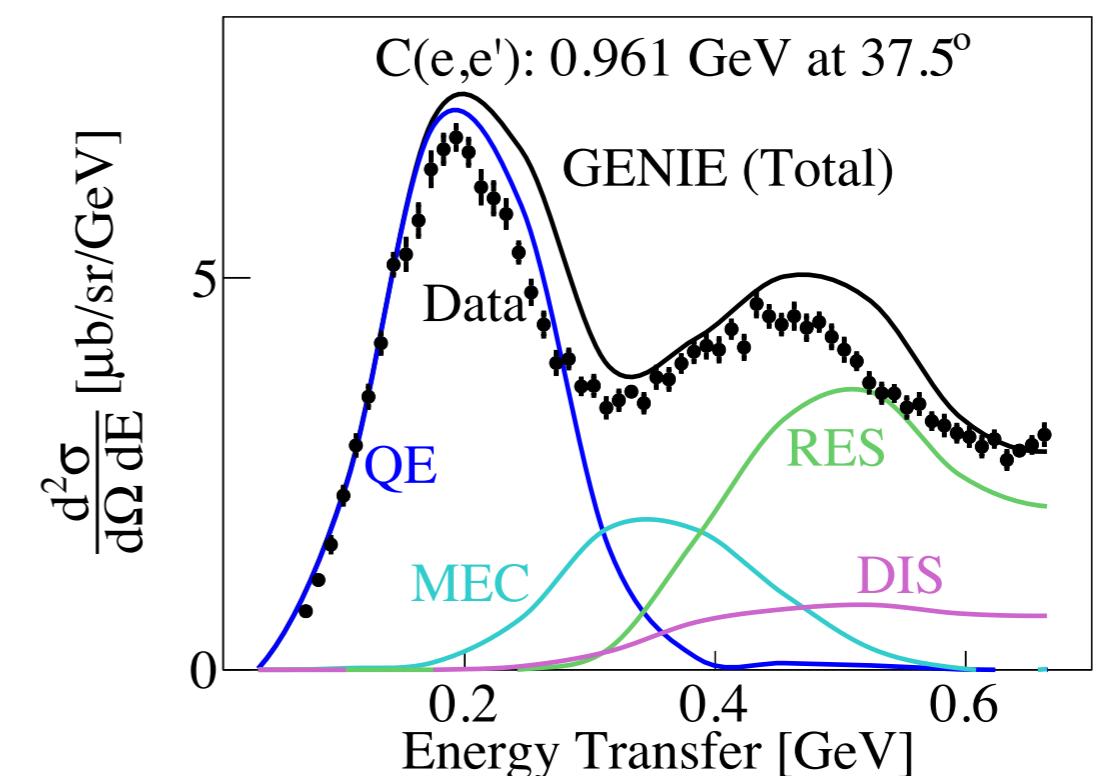


Genie v3.0.6 tune G18_10a_02_11a Electron were weighted by $1/Q^4$
For more details see backup slides

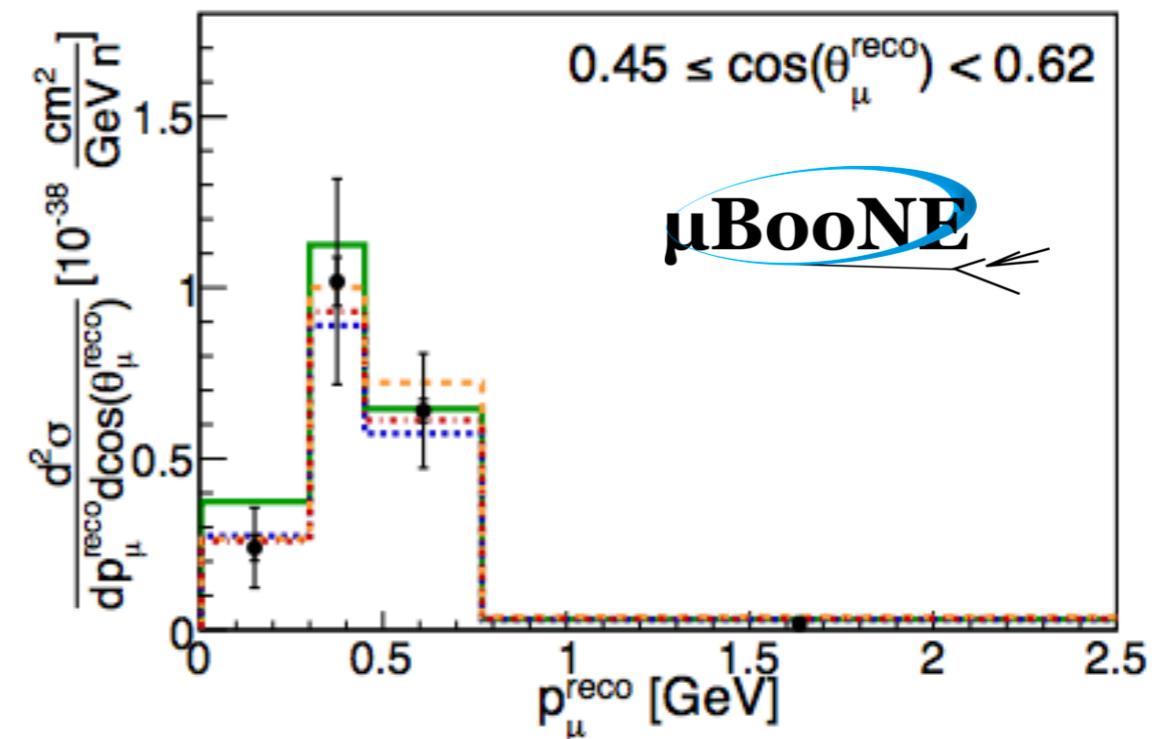
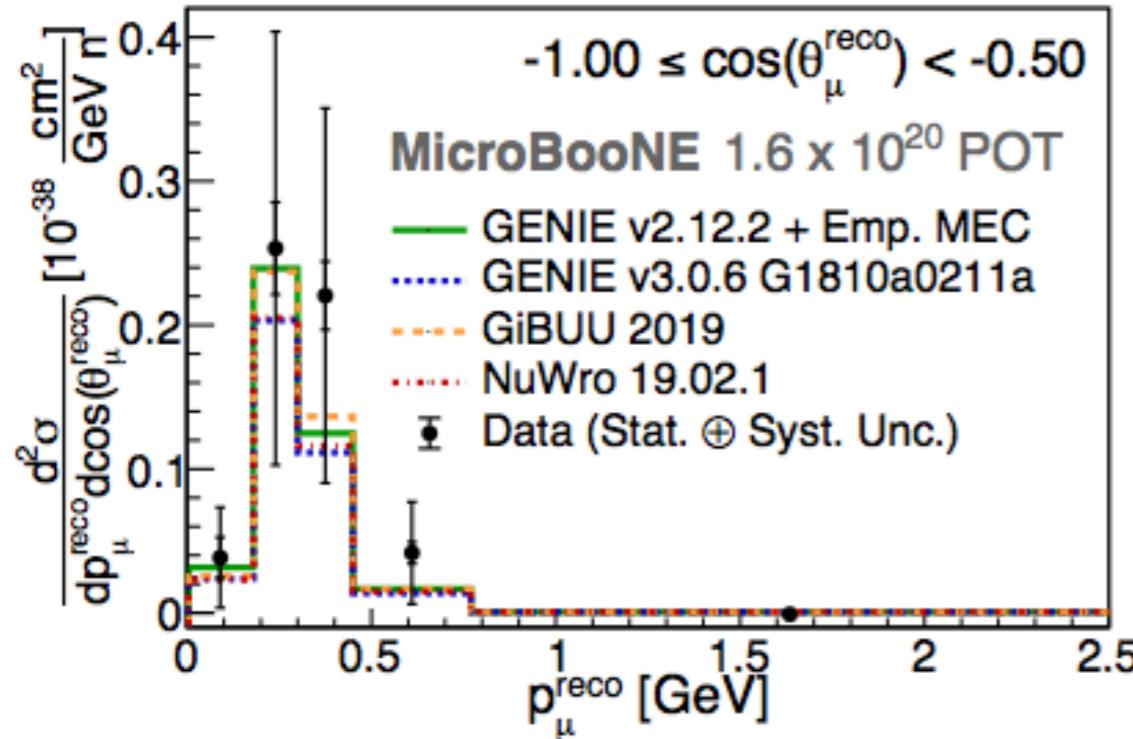
GENIE reproduced e inclusive data



Genie
— v3.0.6 tune G18_10a_02_11a
For more details see backup slides



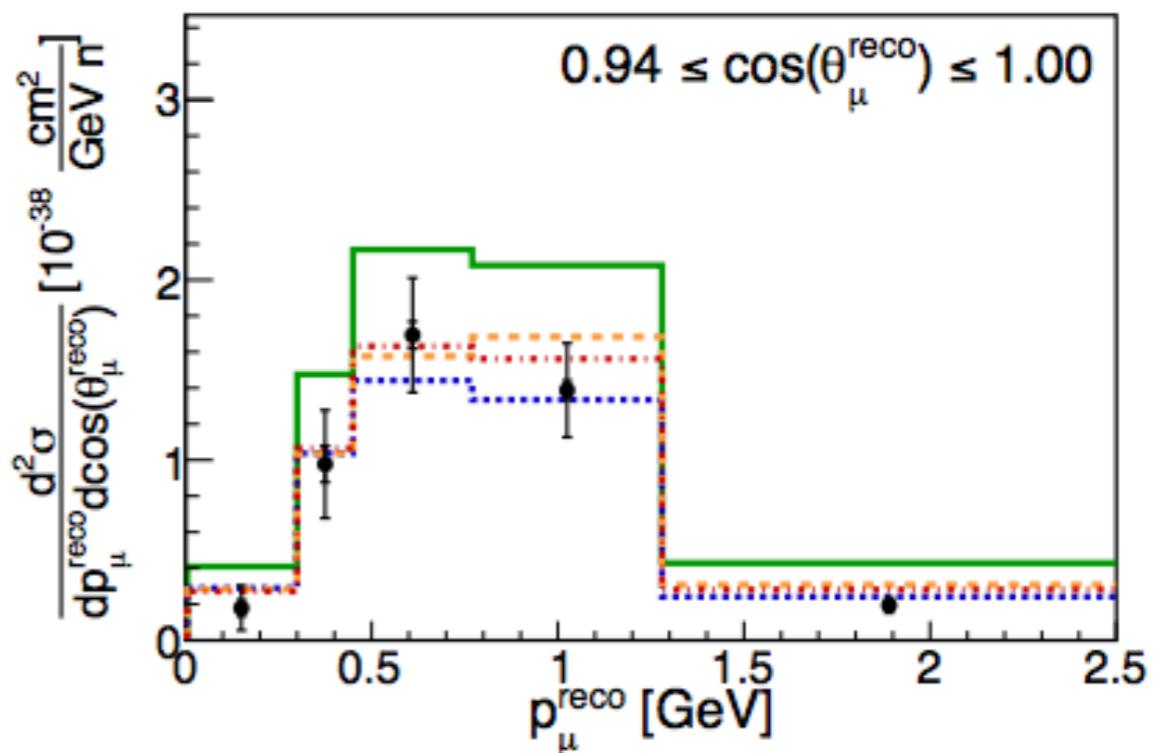
GENIE reproduced ν inclusive data



Genie

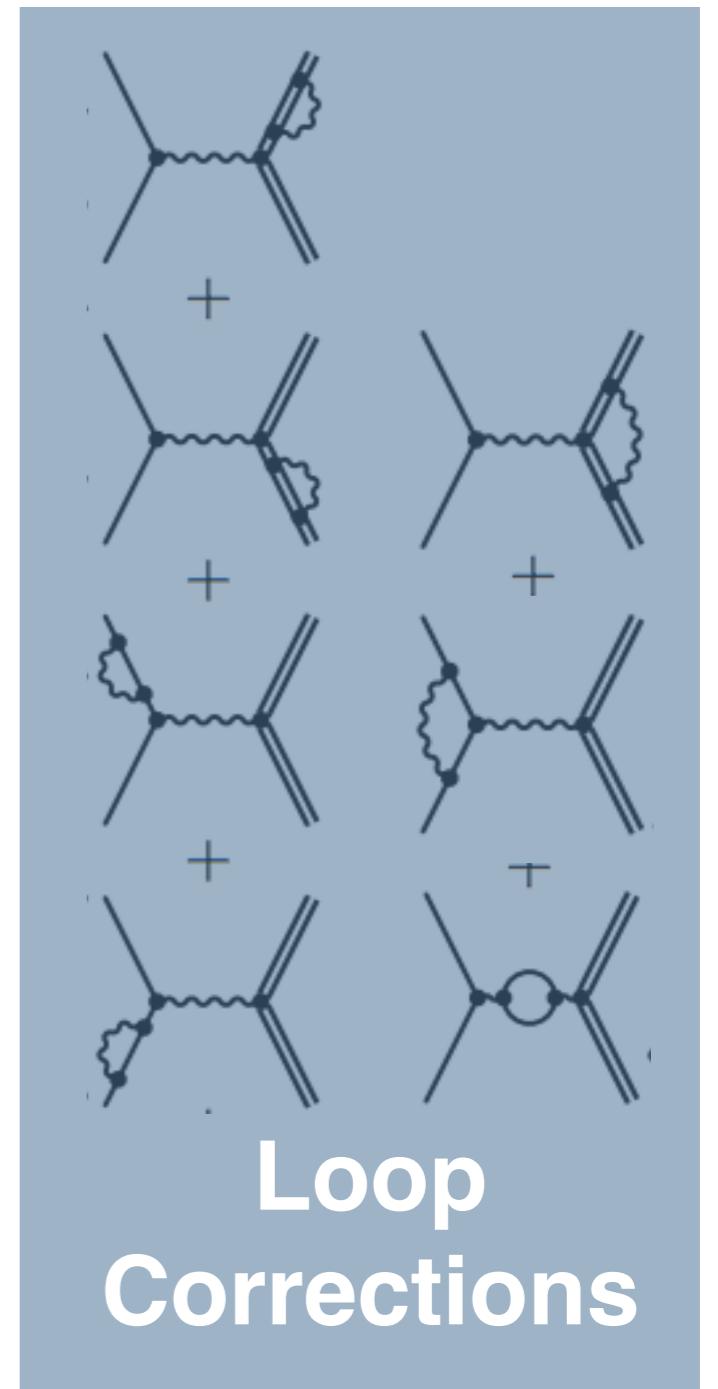
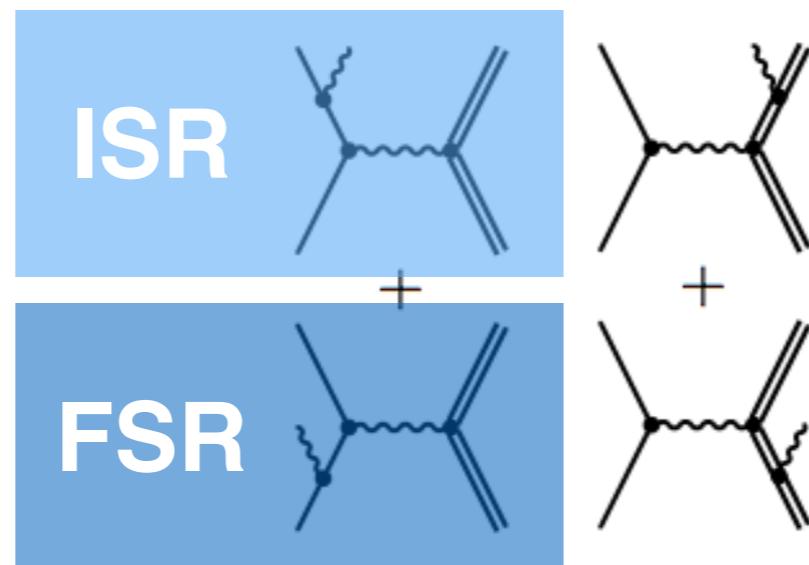
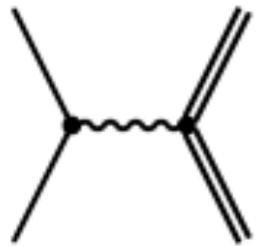
.... v3.0.6 tune G18_10a_02_11a

For more details see backup slides



Radiative Effects

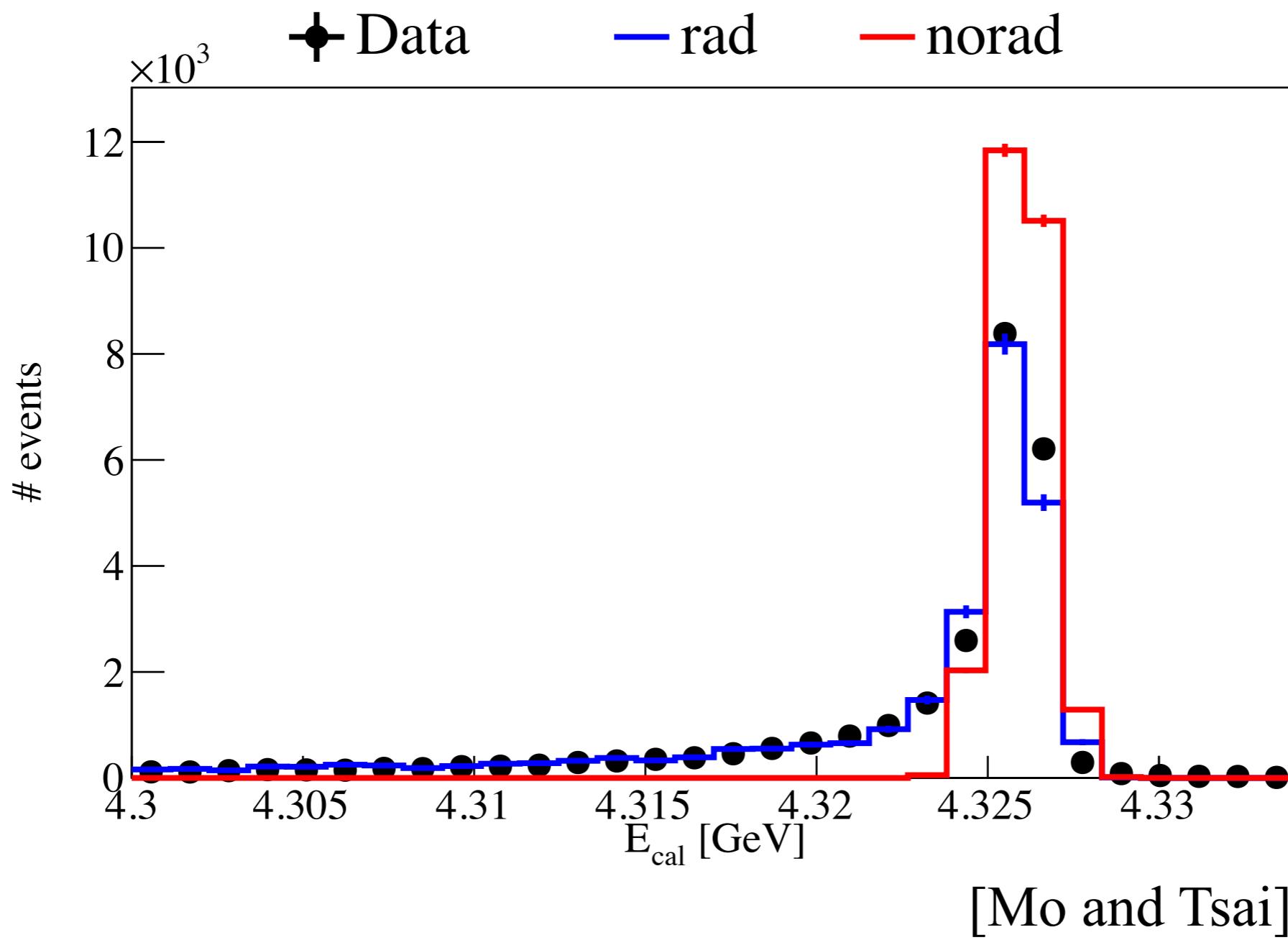
A first implementation of the radiative corrections to GENIE to account for the following processes:



Simplistic implementation based on Mo & Tsai
for ep interactions

Adding radiative effects

$^1\text{H}(\text{e},\text{e}'\text{p})$ $E = 4.325 \text{ GeV}$





e4V: Playing the Neutrino game

Let's analyse electron data as if it was ‘Neutrino data’

- Select a specific interaction: Quasi Elastic
 - 1 proton above 300 MeV/c
 - no additional hadrons above threshold:
 $P_{\pi^{+/-}} > 150 \text{ MeV}/c$
 - $P_{\pi^0} > 500 \text{ MeV}/c$
- Scale the electron data
- Compare to event generators

CLAS Detector

Electron beam with energies up to 6 GeV

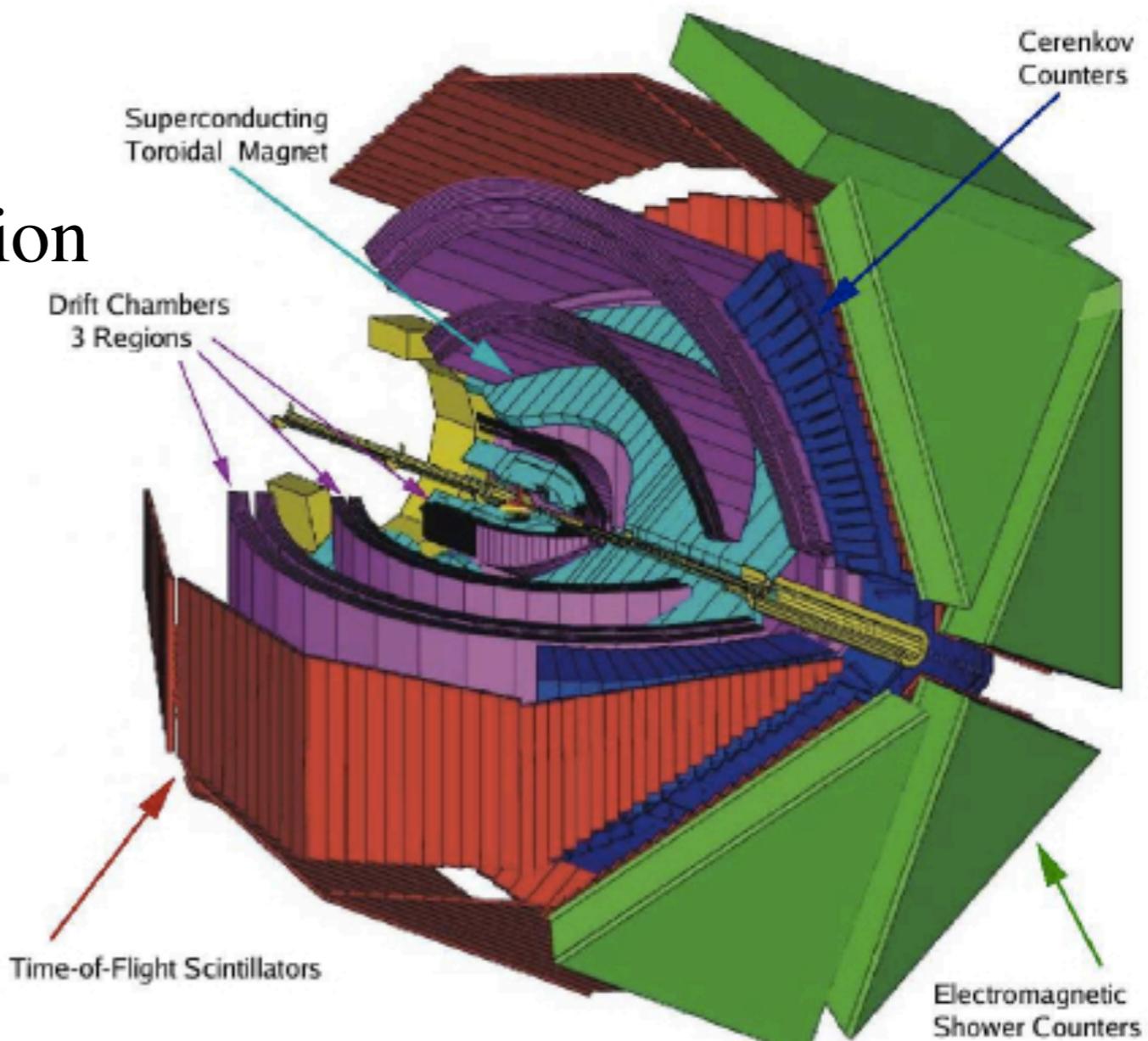
Large ($\sim 4\pi$) acceptance

Charged particles above detection
threshold:

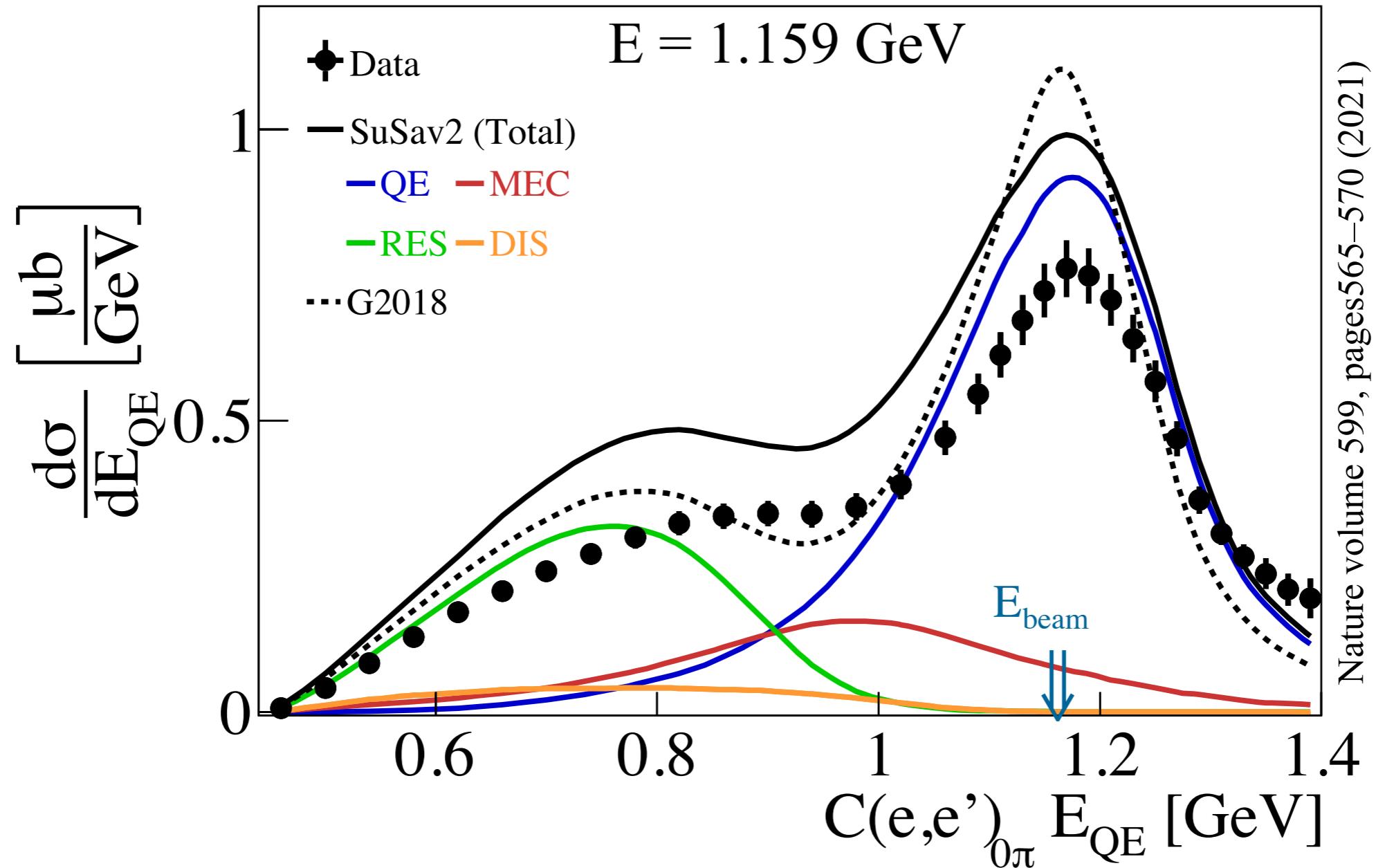
$P_p > 300 \text{ MeV}/c$

$P_{\pi^{+/-}} > 150 \text{ MeV}/c$

Open Trigger



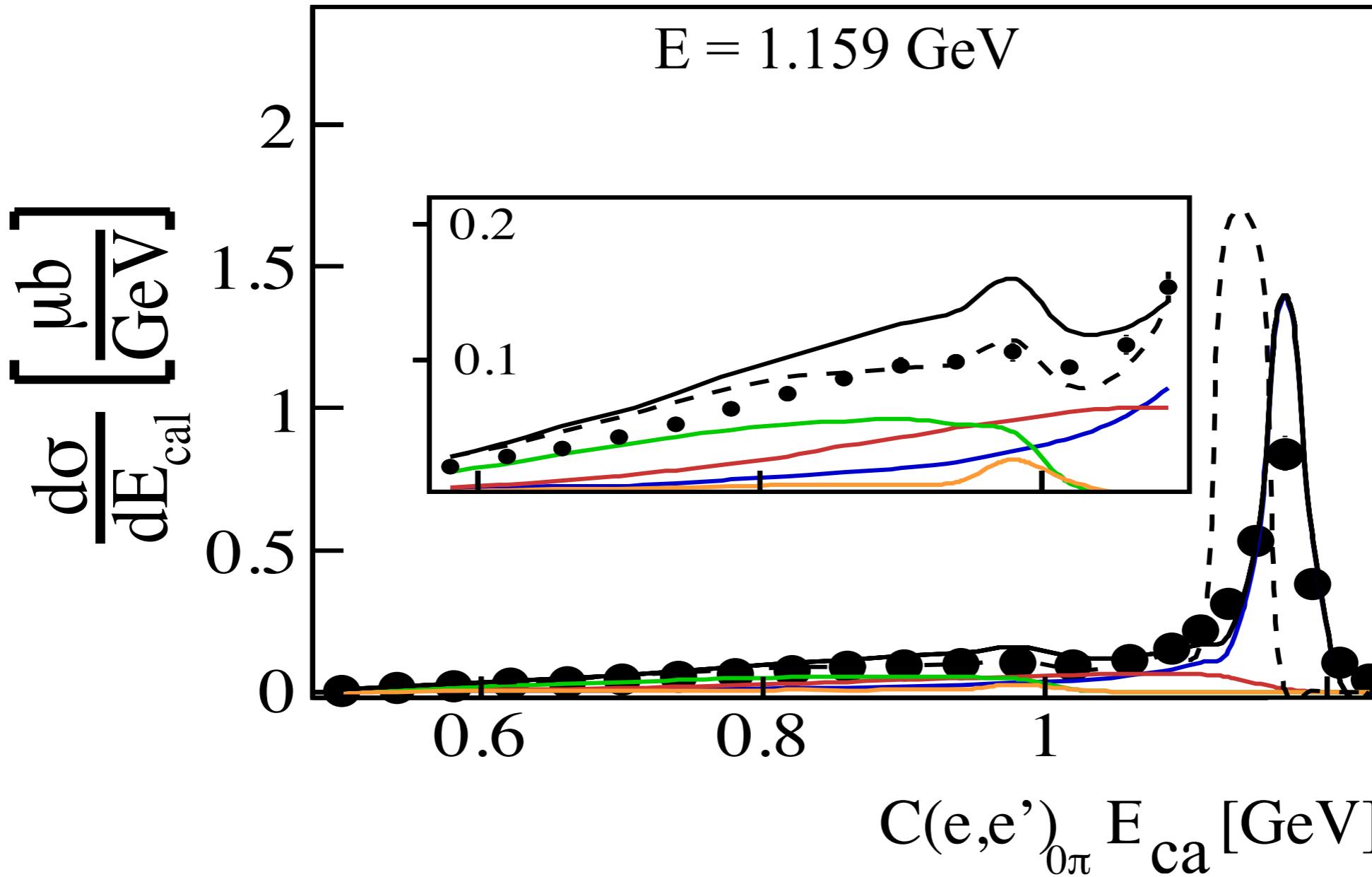
Disagreements between Data and MC



$$E_{QE} = \frac{2M\epsilon + 2ME_l - m_l^2}{2(M - E_l + |k_l| \cos \theta_l)}$$

Based on final state
lepton only

Disagreements between Data and MC



Nature volume 599, pages 565–570 (2021)

$$E_{\text{cal}} = E_l + E_p^{\text{kin}} + \epsilon \quad \text{Useful in tracking detectors}$$

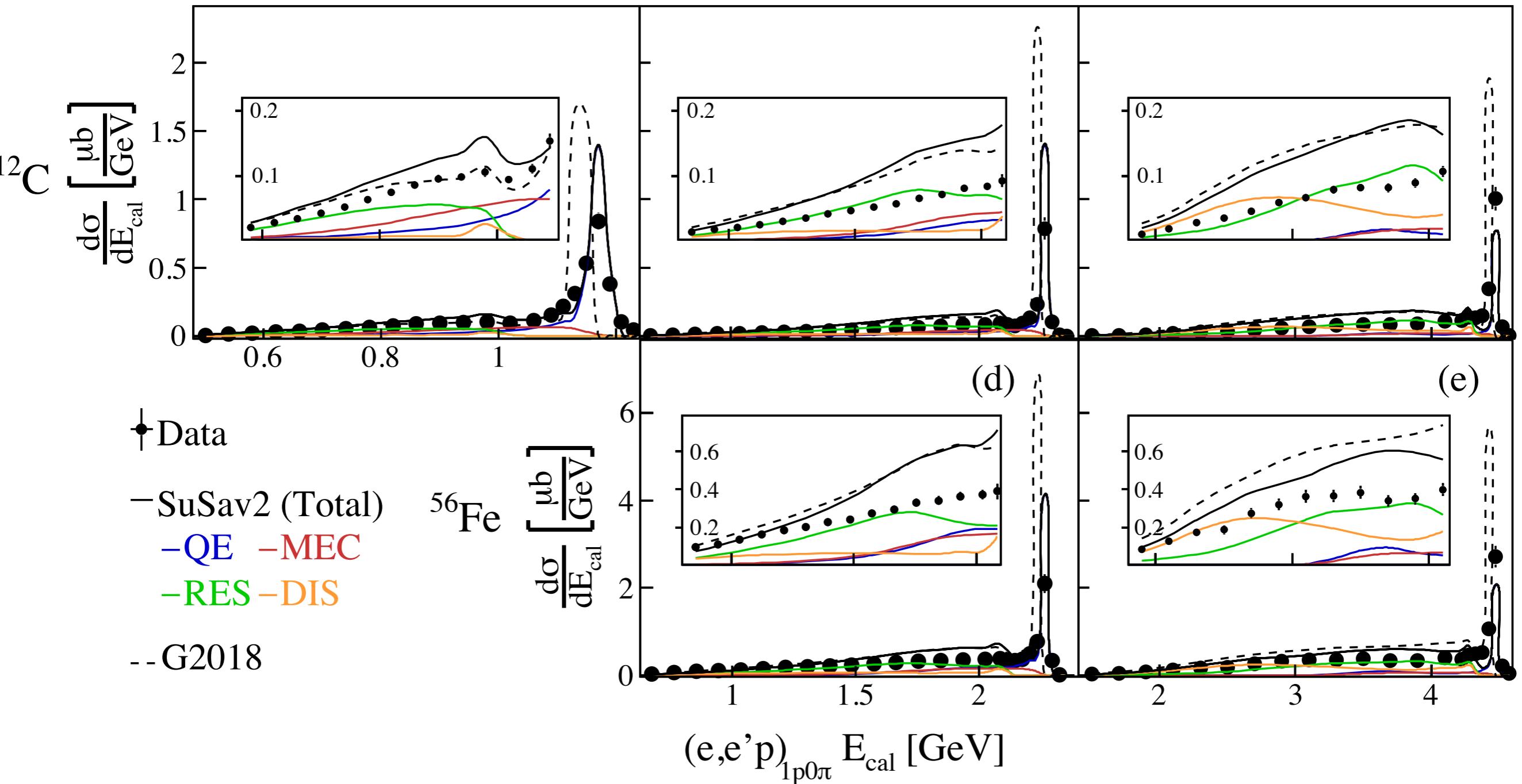
[1p0 π]

Disagreements between Data and MC

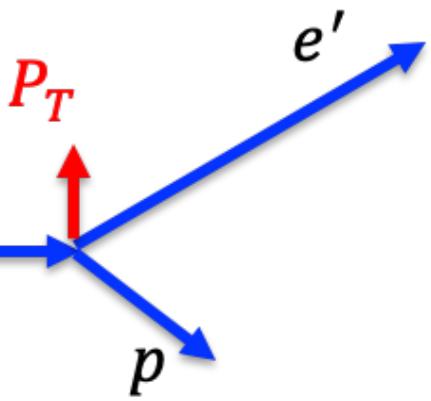
1.159 GeV

2.257 GeV

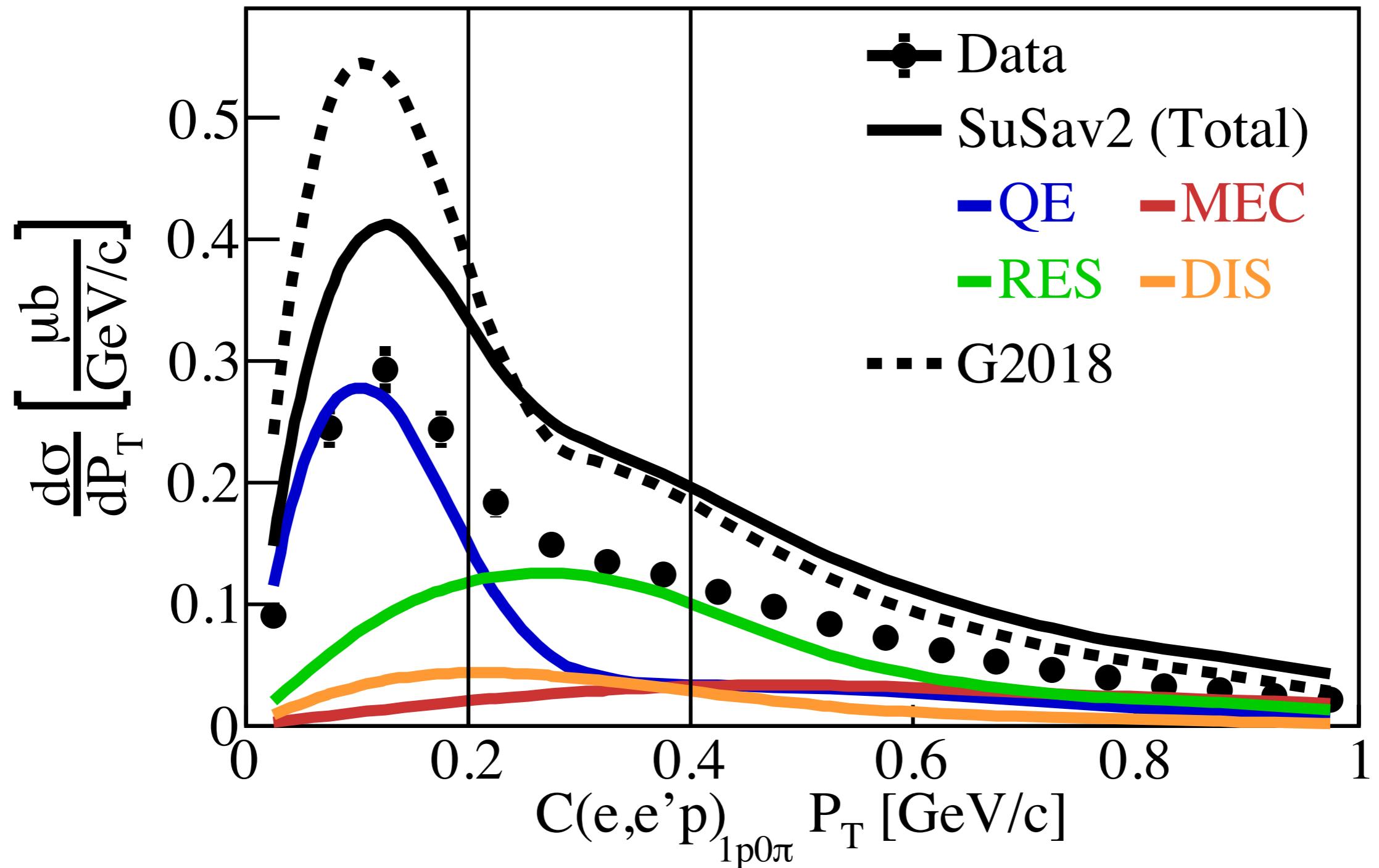
4.453 GeV



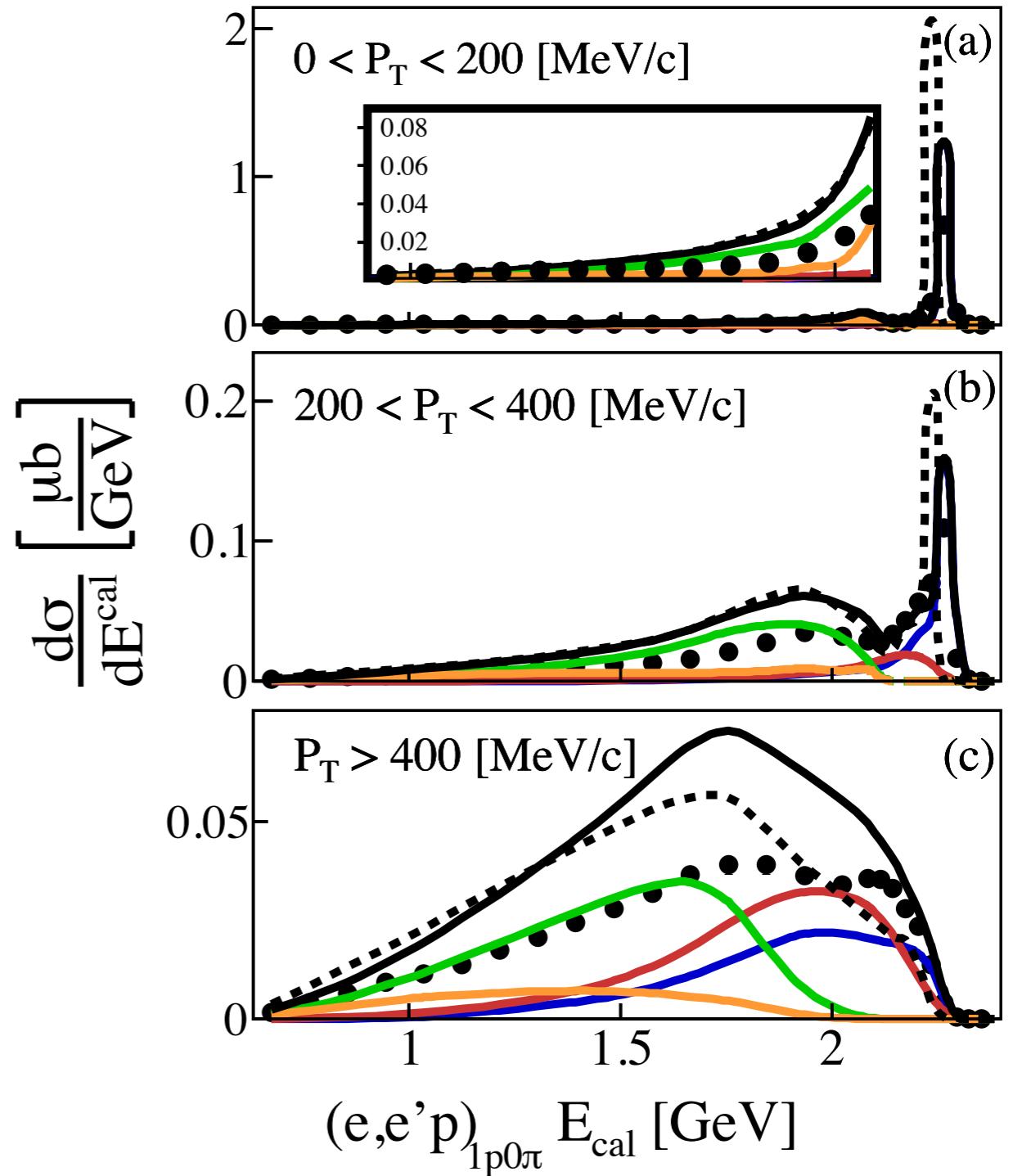
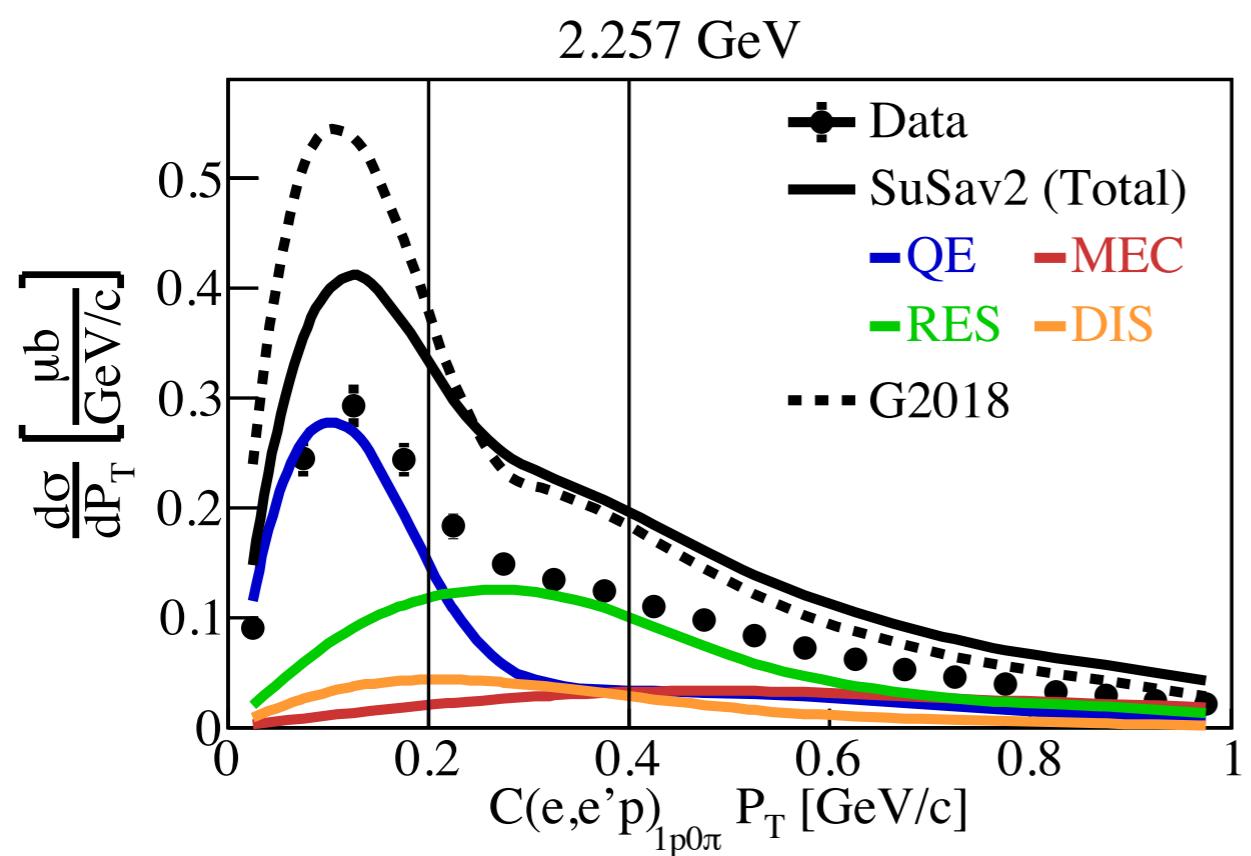
MC vs. (e,e'p) Data: $\vec{P}_T = \vec{P}_T^{e'} + \vec{P}_T^p$



2.257 GeV

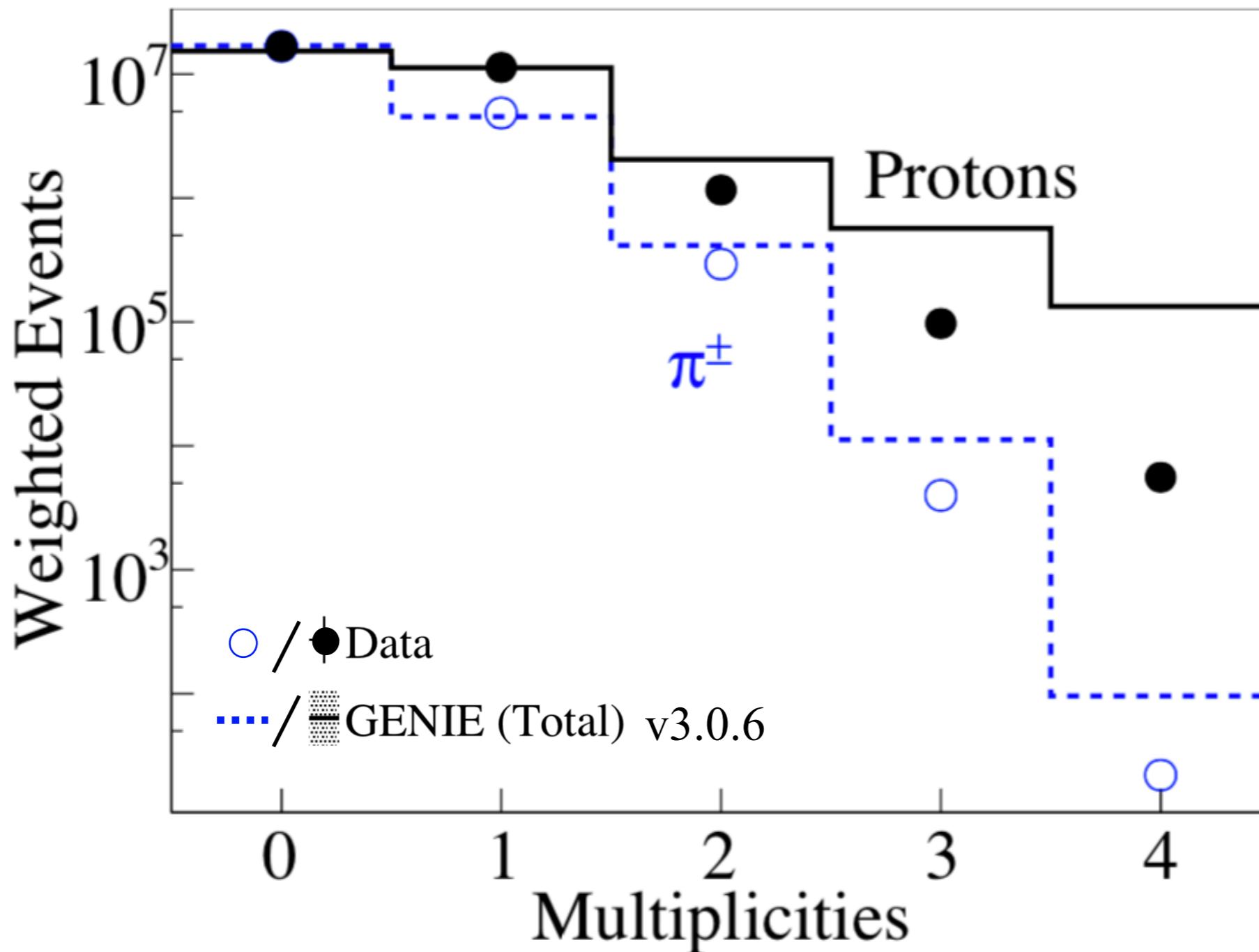


MC vs. (e,e'p) Data: $\vec{P}_T = \vec{P}_T^{e'} + \vec{P}_T^p$



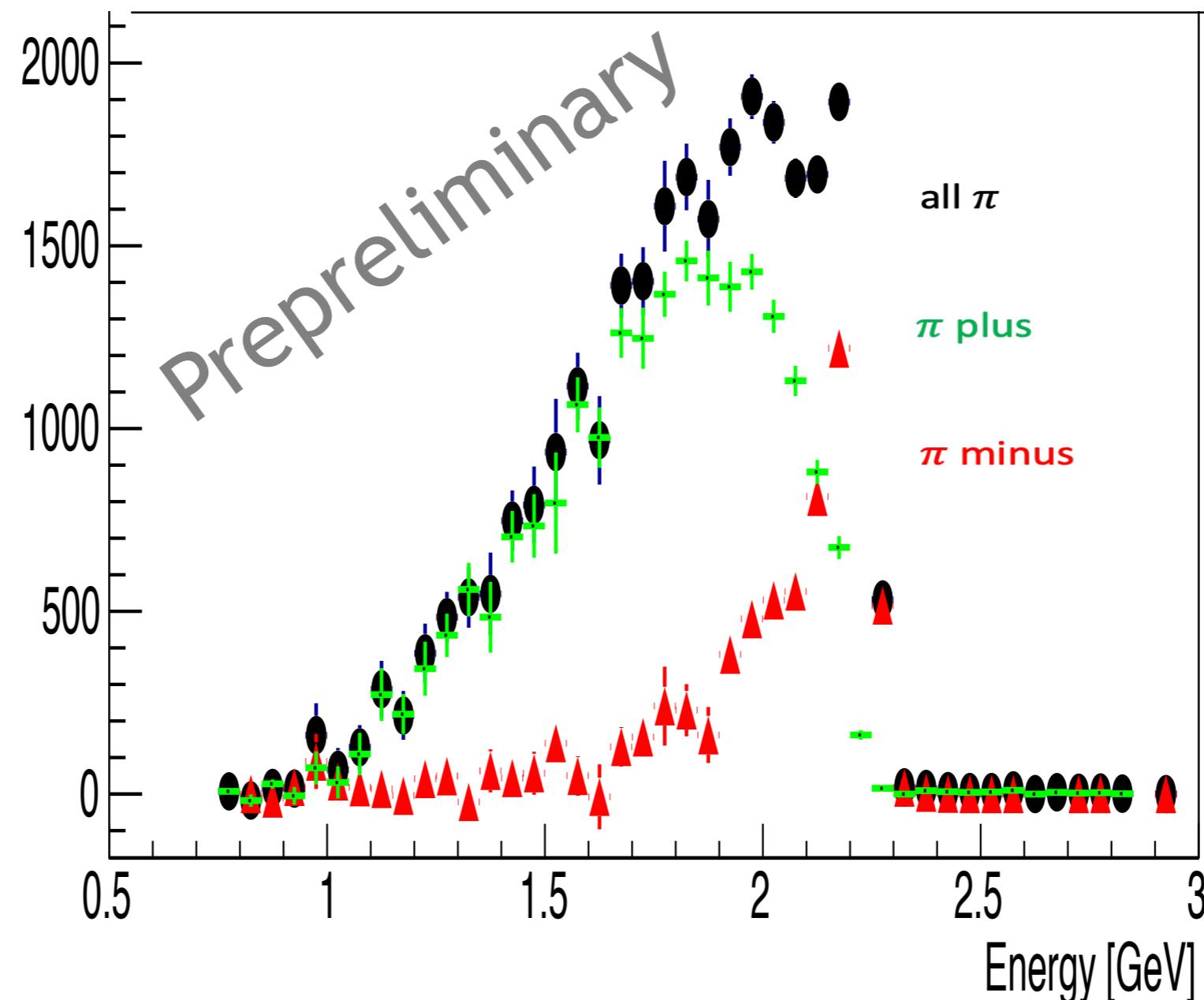
Multiplicities

$E = 2.257 \text{ GeV}$ ^{12}C



Coming up next - $1p1\pi$ and more channels

2.257 GeV



$$\text{Calorimetric energy: } E = E'_e + E_\pi + T_p$$

Data taking completed with CLAS12

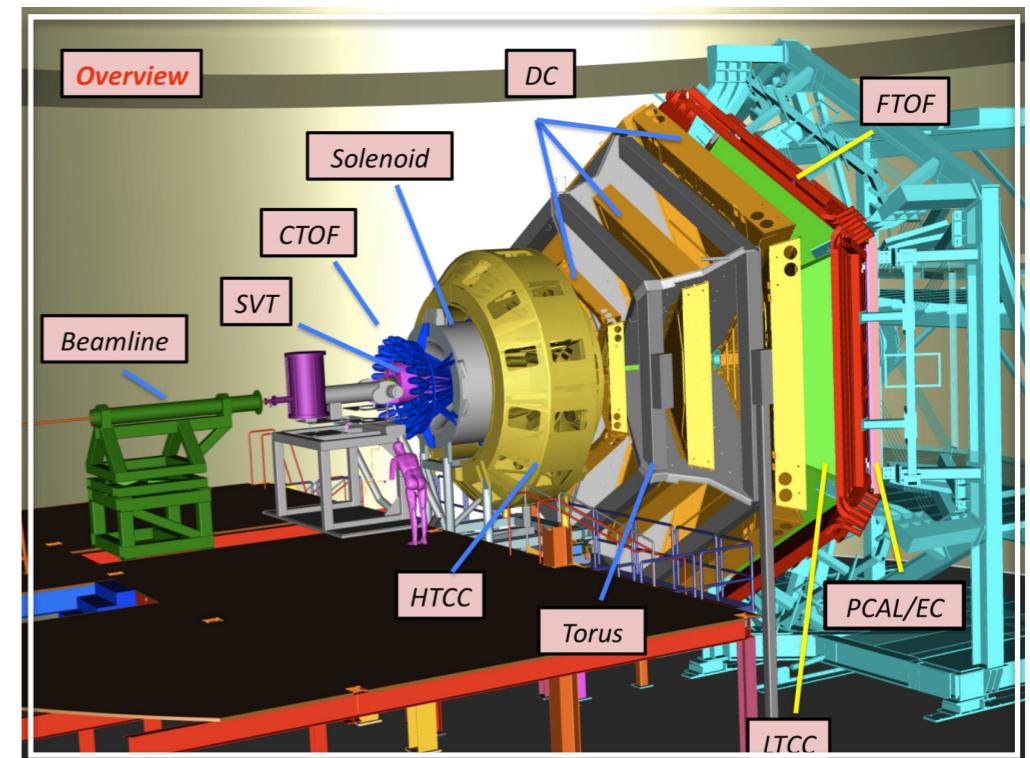
Acceptance down to 5° $Q^2 > 0.04 \text{ GeV}^2$

x10 luminosity [10³⁵ cm⁻²s⁻¹]

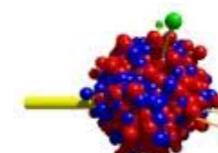
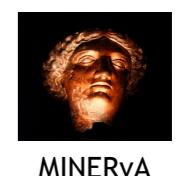
Keep low thresholds

Targets: ²D, ⁴He, ¹²C, ¹⁶O, ⁴⁰Ar, ⁴⁰Ca

2, 4, 6 GeV (relevant for DUNE)



Overwhelming support from:



GiBUU
The Giessen Boltzmann-Uehling-Uhlenbeck Project



Complementary efforts

Collaborations	Kinematics	Targets	Scattering
E12-14-012 (JLab) (Data collected: 2017) 	$E_e = 2.222 \text{ GeV}$ $\theta_e = 15.5, 17.5,$ $20.0, 21.5$ $\theta_p = -39.0, -44.0,$ $-44.5, -47.0$ -50.0	Ar, Ti Al, C	(e, e') $(e, e'p)$
e4nu/CLAS (JLab) (Data collected: 1999, 2022) 	$E_e = 1, 2, 4, 6 \text{ GeV}$ $\theta_e > 5$	H, D, He, C, Ar, ^{40}Ca , ^{48}Ca , Fe, Sn	(e, e') e, p, n, π, γ in the final state
LDMX (SLAC) 	$E_e = 4.0 \text{ GeV}$ $\theta_e < 40$		(e, e') e, p, n, π in the final state
A1 (MAMI) 	$E_e = 1.6 \text{ GeV}$	H, D, He C, O, Al Ca, Ar, Xe	(e, e') 2 additional charged particles
eALBA (Planned) 	$E_e = 500 \text{ MeV}$ - few GeV	C, CH Be, Ca	(e, e')

Table 5: Current and planned electron scattering experiments.

Taken from the Electron Scattering white paper draft

Thank you for your attention
