Maintaining unified models for neutrino and electron scattering in **generators**

ECT*
EUROPEAN CENTRE FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS

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Outline

- Review relevant generators
- Unified models - review methods
- Comparison to data
  - Challenges
- Unified models
  - Requirements
  - Propagating results to expireiments

The working group lively discussion can be seen here

Generators

Calculate the cross section for ν and e in one chosen model.

In the past, had some separate models and codes for ν and e

(QE Rosenbluth for e wrt to Llewellyn Smith for ν)

Until recently calculates cross section for ν and scaling it to e.

Possible to read different hadronic tensors for e, not yet used.

Recent developments will allow reading the different hadronic tensors in a joint QE MEC environment.

Did not yet report electron mode but has shown interest

Generators

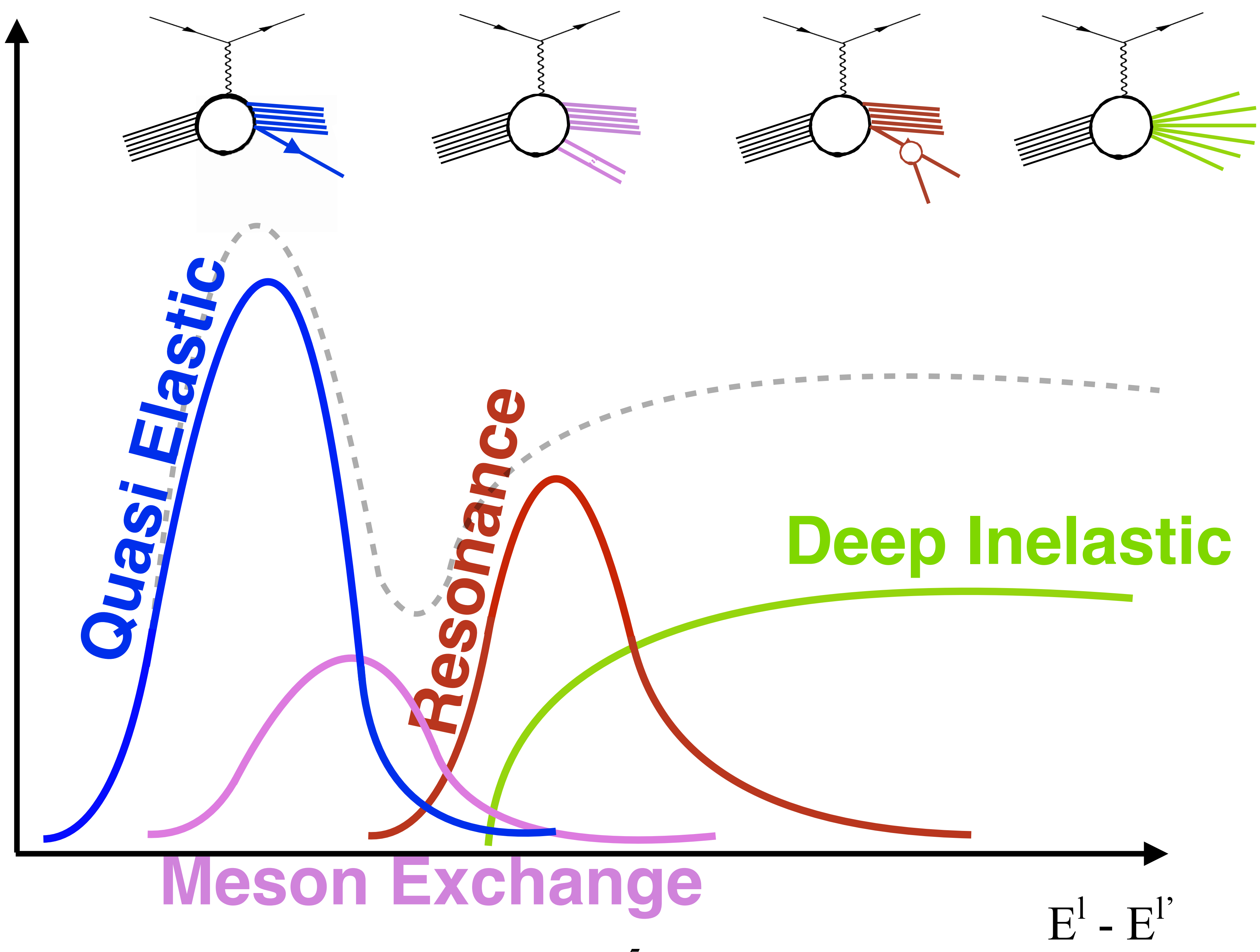
Single calculation

Allows various model sets (referred to as tunes)

Each model has it free parameters which can be tuned

The frameworks allows comparison and reweighting of one tune to the other

Generators - Processes



Generators - Electron mode database

	Model Name	ν	ε	Detailed Electron Mode Implementation
Quasi Elastic				
Meson Exchange				
Resonance				
Deep Inelastic Scattering				

Generators - Electron mode database

	Model Name	ν	ε	Detailed Electron Mode Implementation
Quasi Elastic		+	✓	
Meson Exchange		+	?	
Resonance		+	?	
Deep Inelastic Scattering		+	✓	

Generators - Electron mode database

GiBUU

	Model Name	v	e	Detailed electron mode implementation
COherent				
Quasi **E**lastic	QE[1]	+	+	The electron σ is calculated using the formfactor BBA2003 parametrization. For the neutrino cross section, the vector form factors are extracted from the electrons ones based on CVC, the axial form factor is using the dipole form with the axial vector constant, gA, taken from β decay, and Q2 dependence tuned to neutrino data.
Meson **E**x**C**hange	SuSA	+	+	?
	Empirical	+	+	The cross section for electrons is obtained from a data analysis by Bosted and Christy, and the neutrino one is then extracted based on the relations between the e and v structure functions used by the Lyon group[2]
RESonance	Phenomenological FF	+	+	For the e σ calculation, the helicity amplitudes are determined in the MAID analysis[3] For σv , the vector form factors, C_{6V} C_{5V} C_{4V} , are extracted from the electrons ones based on the CVC. $C_{5A}(0)$ is obtained by fitting the available pion production data on an elementary target. C_{3V} is taking the modified dipole form. C_{3A} is set to zero. C_{6A} can be related to C_{5A} by PCAC. C_{5A} parametrization is given in Leitner et al..
Deep **I**nelastic **S**cattering	[4]	+	?	1. lepton interacts with a nucleon, modeled by Pythia (nucleon is treated as free or bound + Fermi motion, Pauli blocking). 2. (pre-)hadrons are propagated through the surrounding nuclear medium according to the BUU transport description. This is exactly the same for e and v all other hadron-induced reactions on nuclei.

Genie

	Model Name	v	e	Detailed electron mode implementation
COherent	Ahrens	+	-	
	Coherent pion	+	-	
Quasi **E**lastic	Rosenbluth	-	+	Stand alone code only for electrons
	Llewellyn Smith	+	+	Calculating for v, if probe is electron modify coupling constants (release candidate for v3.2)
	SUSA	+	+	SDo: Works for nu and e in the same code using hadron tensor table framework (although of course the nu and e tensors are different). Inclusive model implementation.
	Nieves dipole	+	-	
	Nieves z exp	+	-	
Meson **E**x**C**hange	Empirical Dytman model	+	+	Calculating for v, if probe is electron modify coupling constants.
	Nieves	+	-	
	SUSA	+	+	SDo: Works for nu and e in the same code using hadron tensor table framework (although of course the nu and e tensors are different). Inclusive model implementation. Can predict the different contributions from different initial state pairs for e and for nu.
RESonance	Rein Sehgal	+	+	Calculating for v, if probe is electron modify coupling constants
	Berger Sehgal	+	+	Calculating for v, if probe is electron modify coupling constants
Deep **I**nelastic **S**cattering	Bodek-Yang			

Unified models - methods

Separate calculation / Scaling approach

Zeroing out the axial-vector contribution to the cross section and modifying the coupling constants and if needed also the used form factors

Right now this is the method being used in GENIE and GiBUU

During this week we intend to:

- Dive into the code and report the cases in which the exact same code is not used for both modes
- Suggest what can be done to ensure the consistency is kept in subsequent evolutions of the code

Unified models - method

Hadronic tensors approach

Currently each model supplies different tables for ν and e.

Challenges: hard to reweight, alter the model if need-be, estimate errors

Hadron tensors implicitly integrate over the momenta of outgoing particles, don't have final state

We need to make sure:

- Using the equivalent tables for both e and ν modes.
- Using the same model for (same ground state) QE & 2p2h tensor.

In cases where the form factors can be decoupled, such as the MEC standalone case, it will be optimal to give just one table supply the relevant form factors conventions for both e and ν side, to allow scaling one to the other.

Comparing to data

So far comparison to inclusive data

GiBUU has also compared to photo-nuclear, inclusive and meson production.

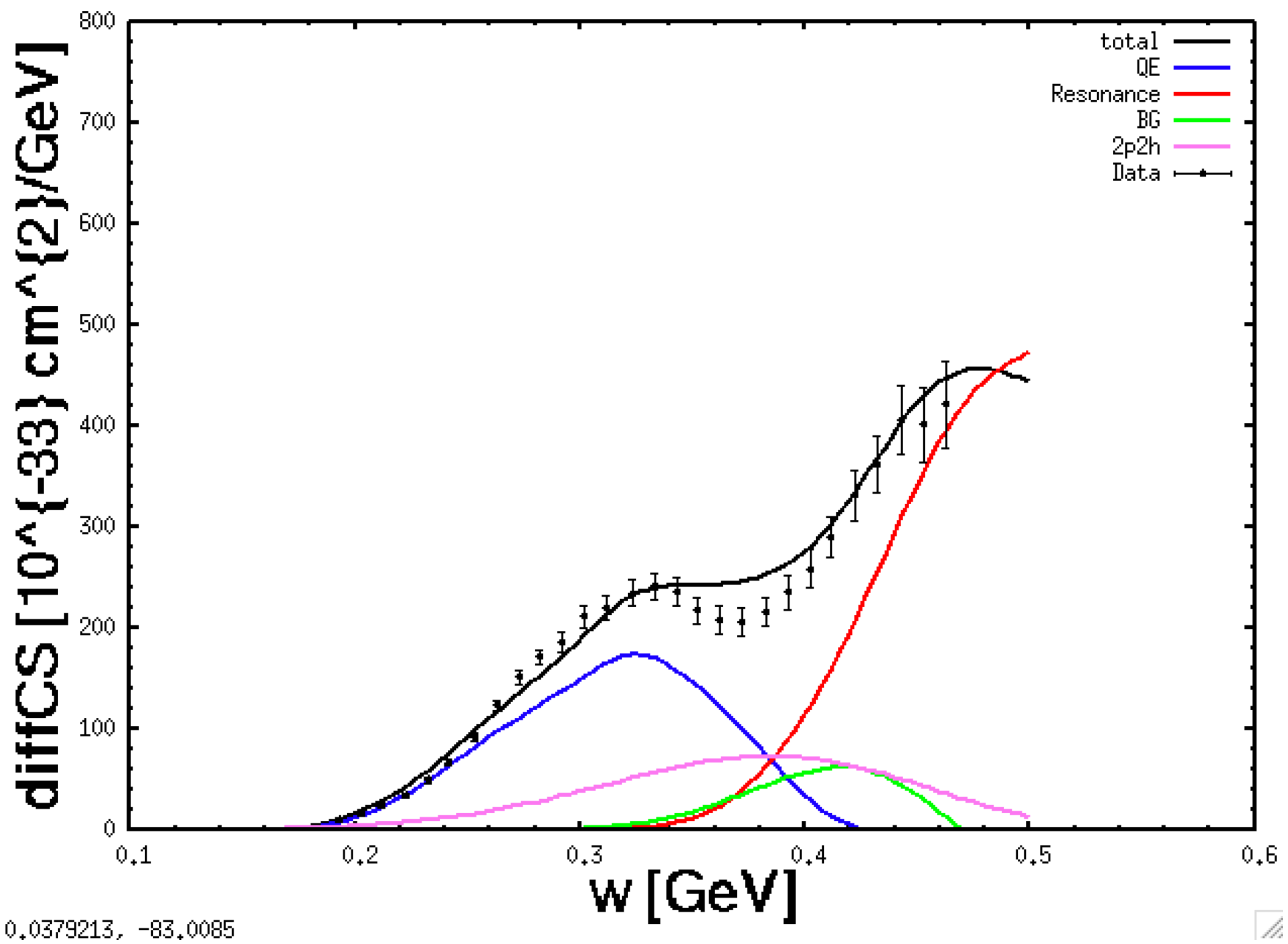
Pion-nucleon data can also be used.

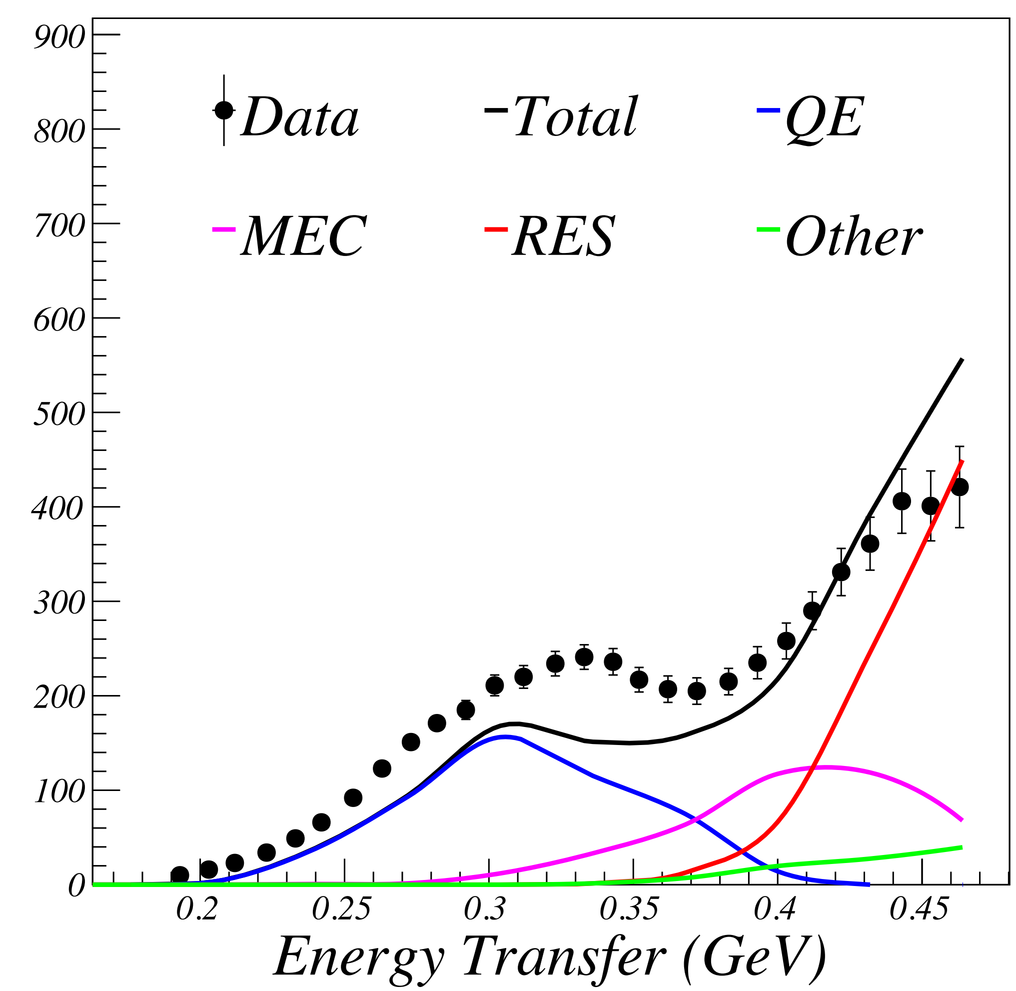
For MEC model in order to investigate the dip region this is enough.

For the rest of the models especially since some generators are not accounting for interference between the processes exclusive data can be vital.

Comparing to data - Inclusive A(e,e')

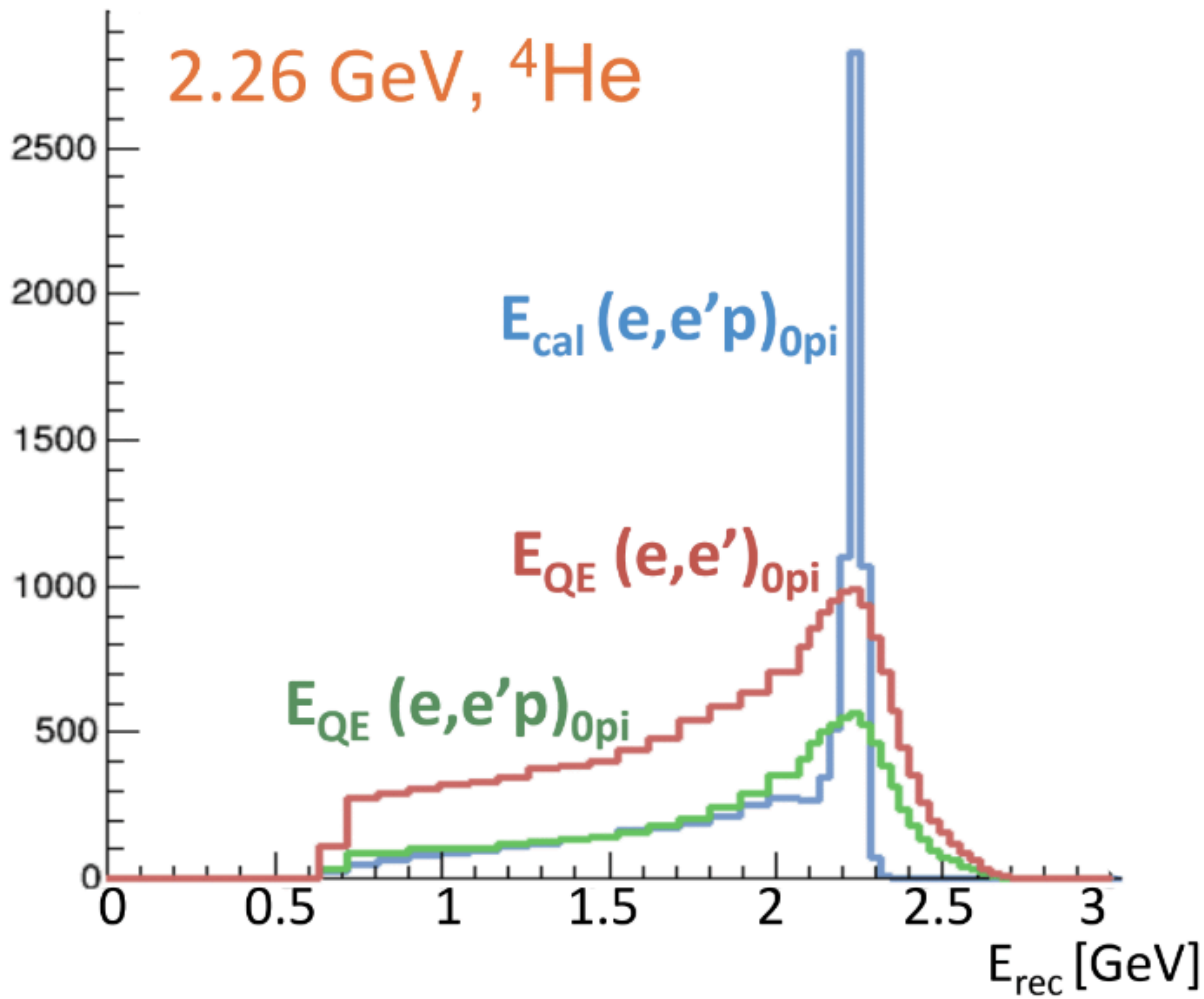
^{12}C @$E = 0.56$ GeV & $\theta = 145^o$





Comparing to data - A(e,e'p)

See Or Hen's talk



Comparing to data - Challenges

Comparing to data - Acceptance

Future experiments should publish un-corrected (as measured) data with detailed acceptance and resolution maps, and their error estimation.

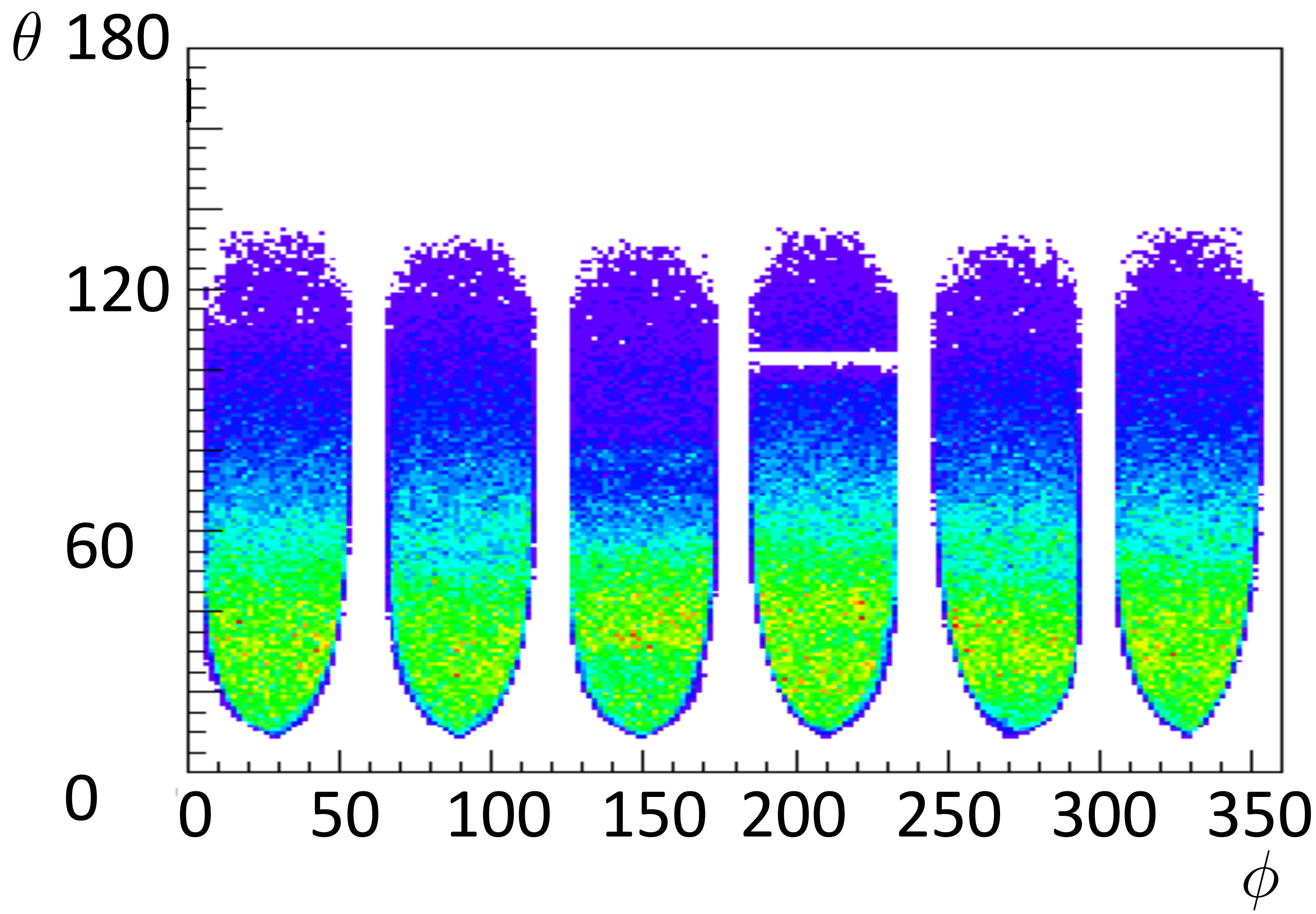
Preferably present data without unfolding

In case unfolding has been made, the relevant covariance matrices should be given.

Comparing to data - Acceptance

Example from CLAS has a different efficiency, which we will publish as acceptance maps for public use for each:

- Target
- Particle type
- Particle momentum



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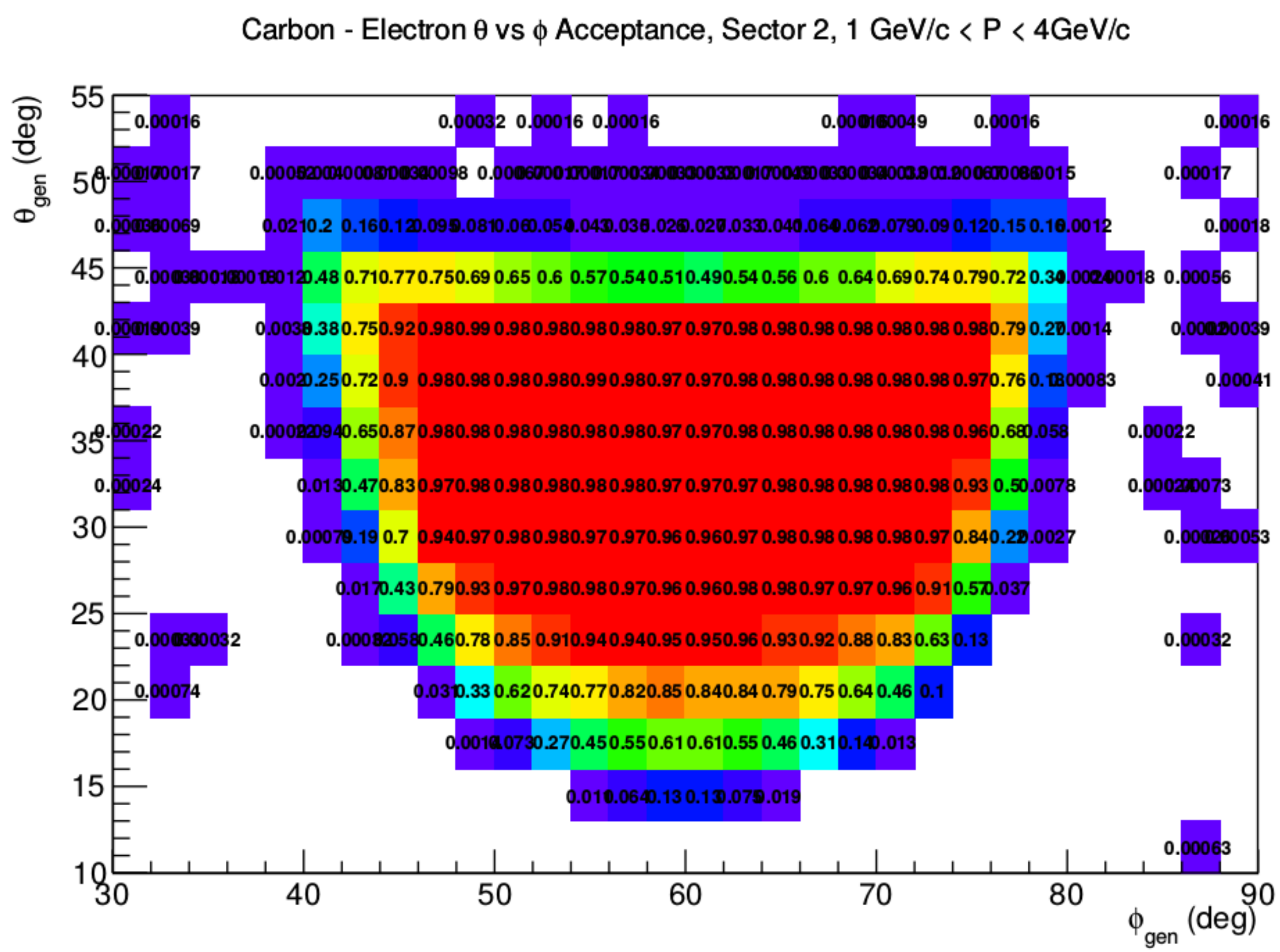
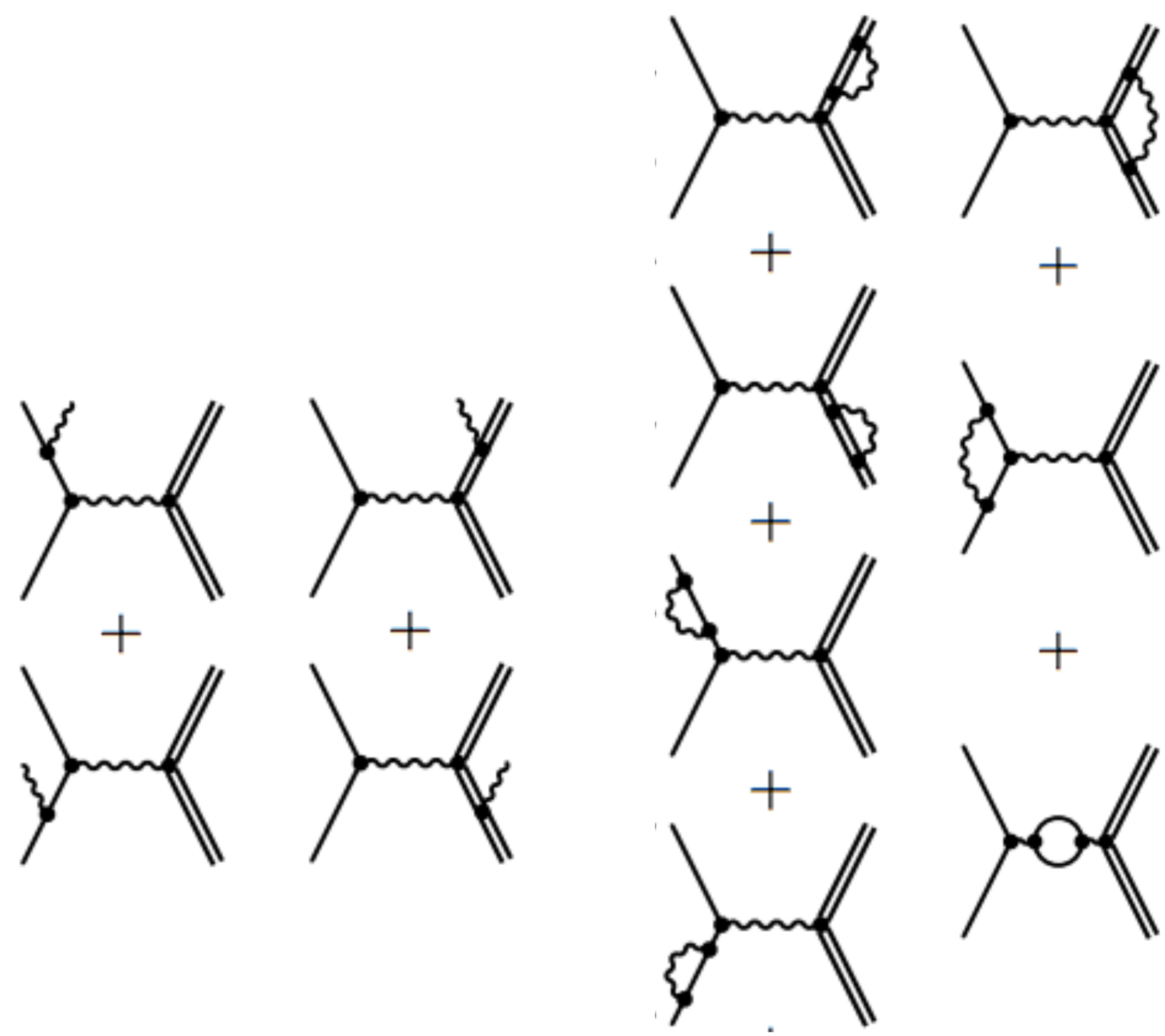


Comparing to data - Radiative correction

When comparing simulated prediction to electron scattering data, one should account for all radiative correction

The final state radiation should be applicable also to the neutrino mode



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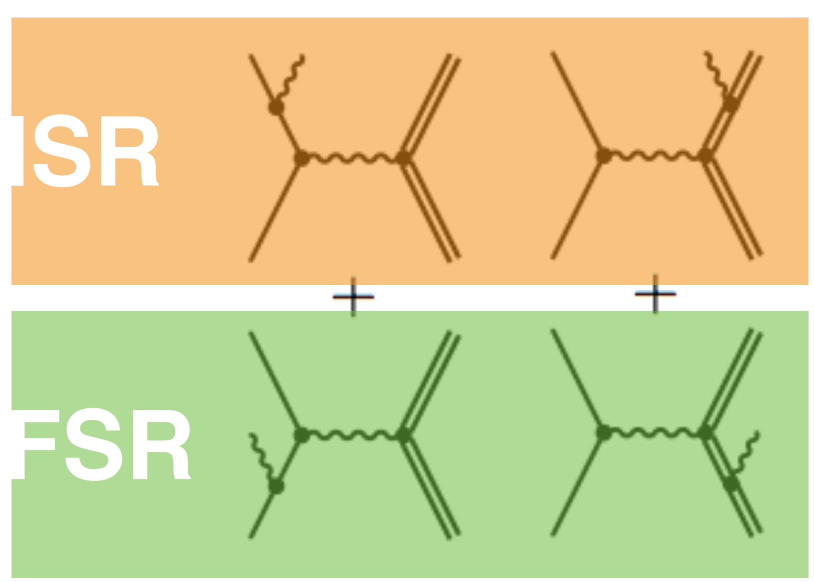
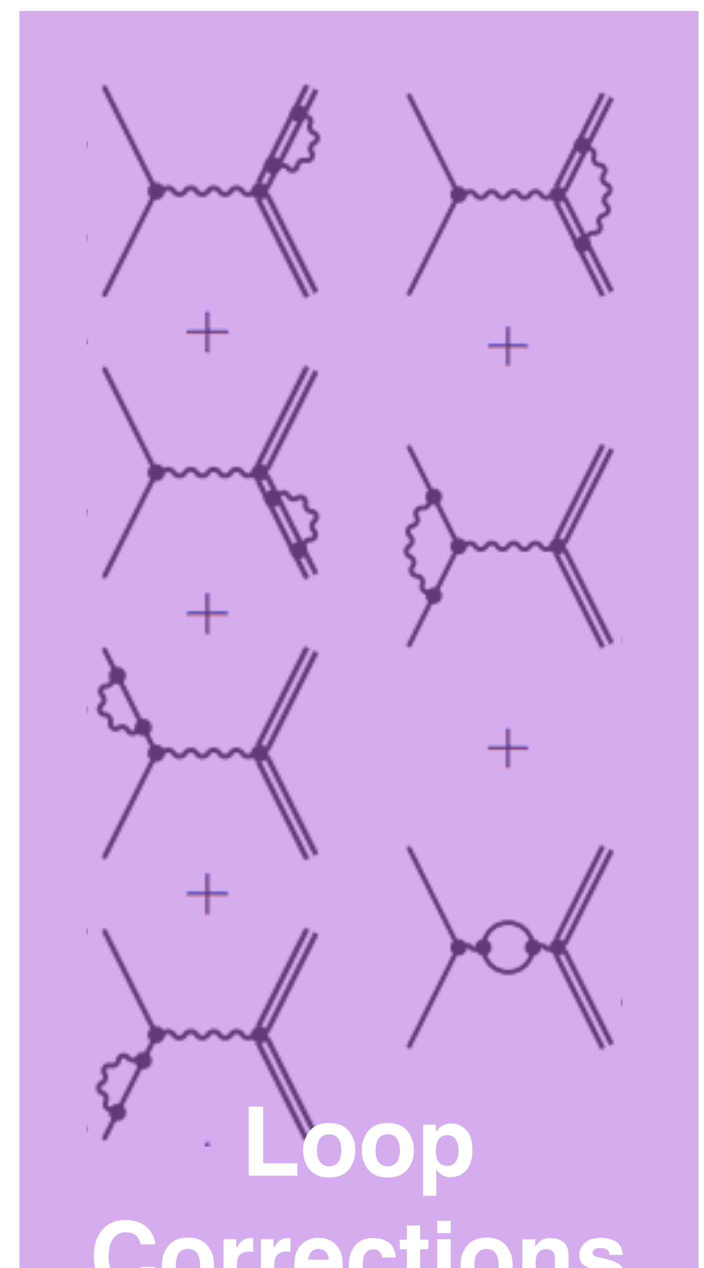
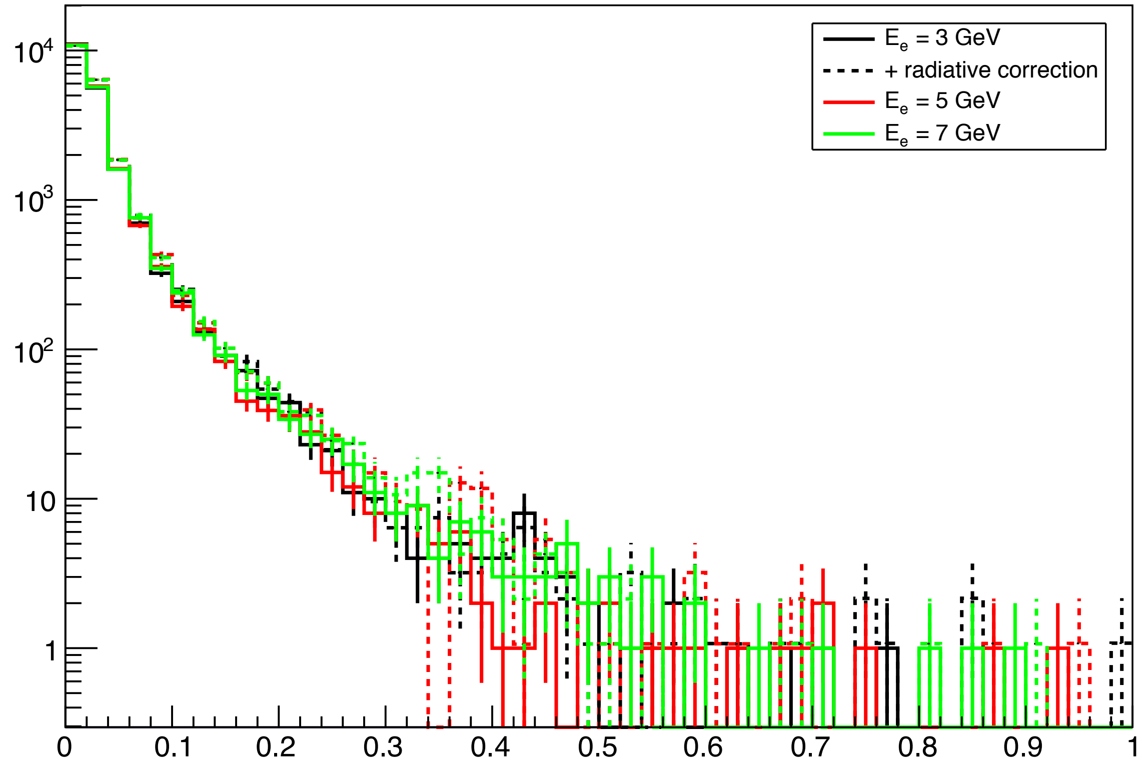




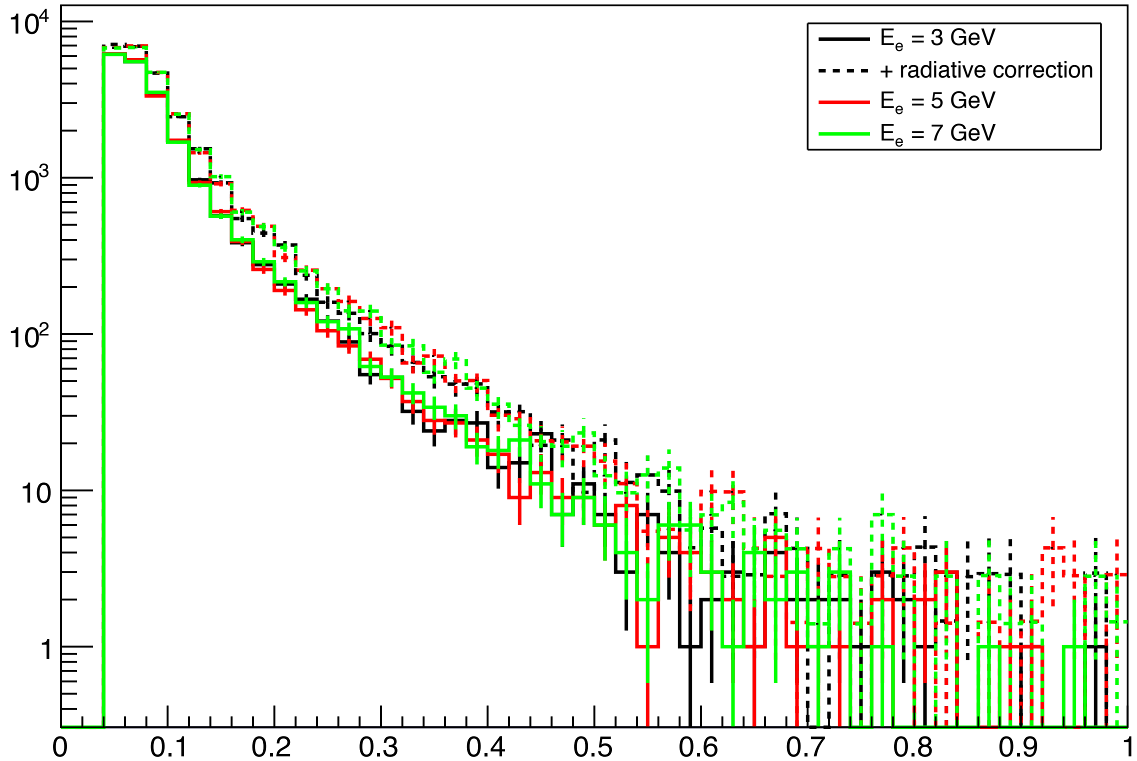
Comparing to data - Radiative correction

p(e,e')



$E^l - E^{l'}$ [GeV]

^{12}C(e,e')



$E^l - E^{l'}$ [GeV]

Comparing to data - Radiative correction

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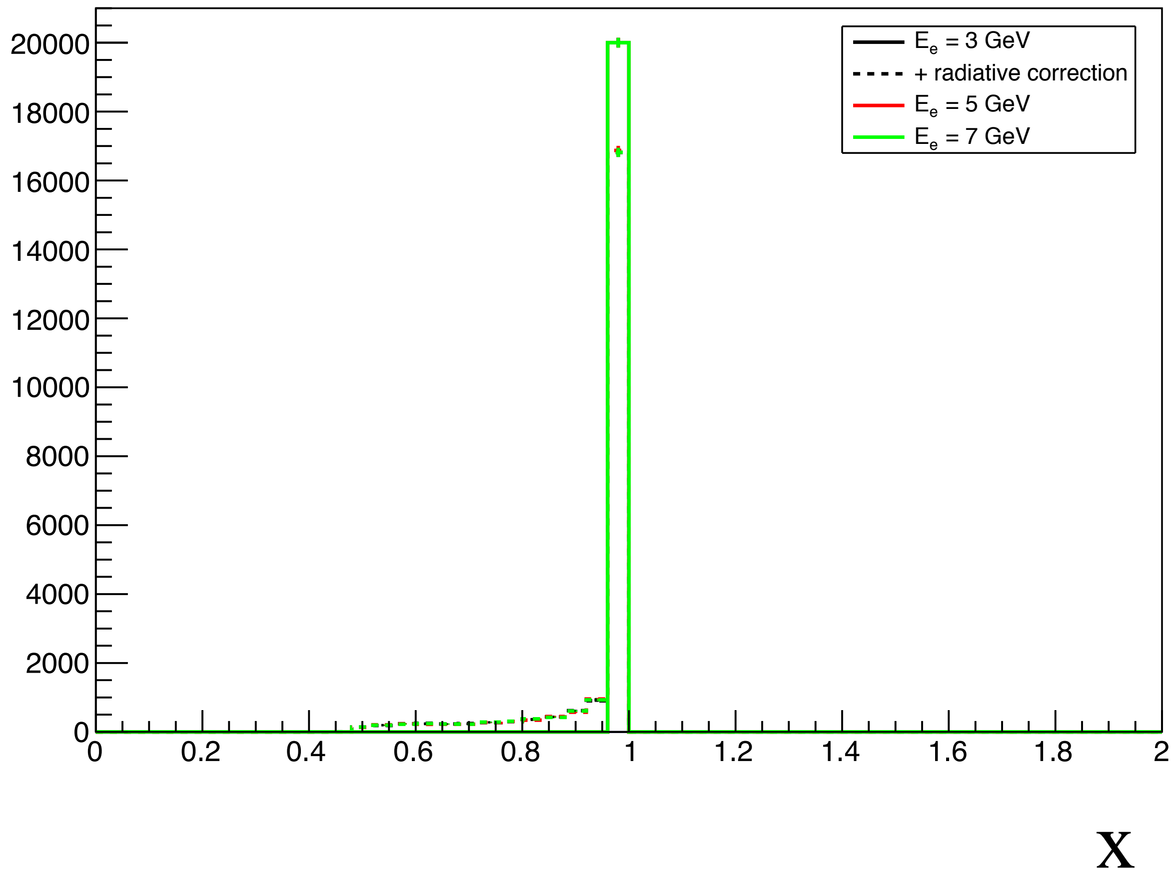

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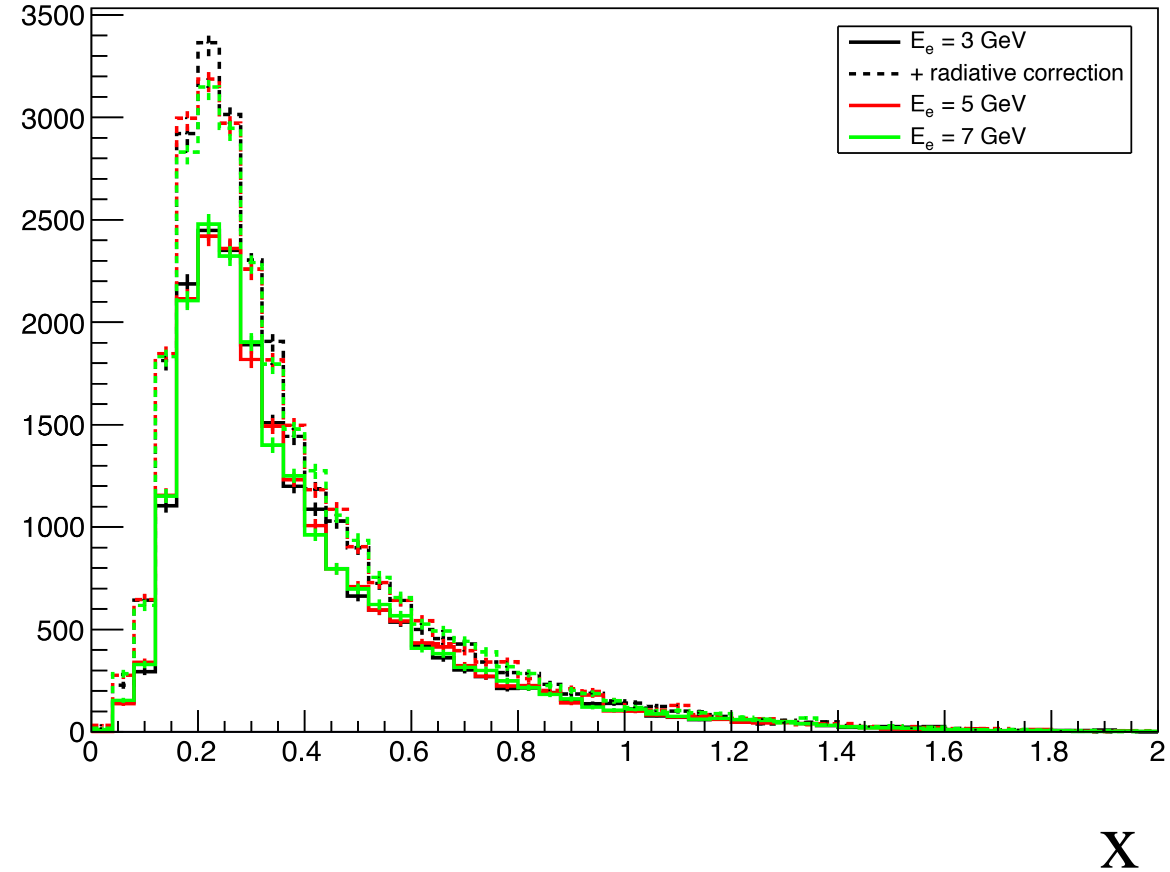
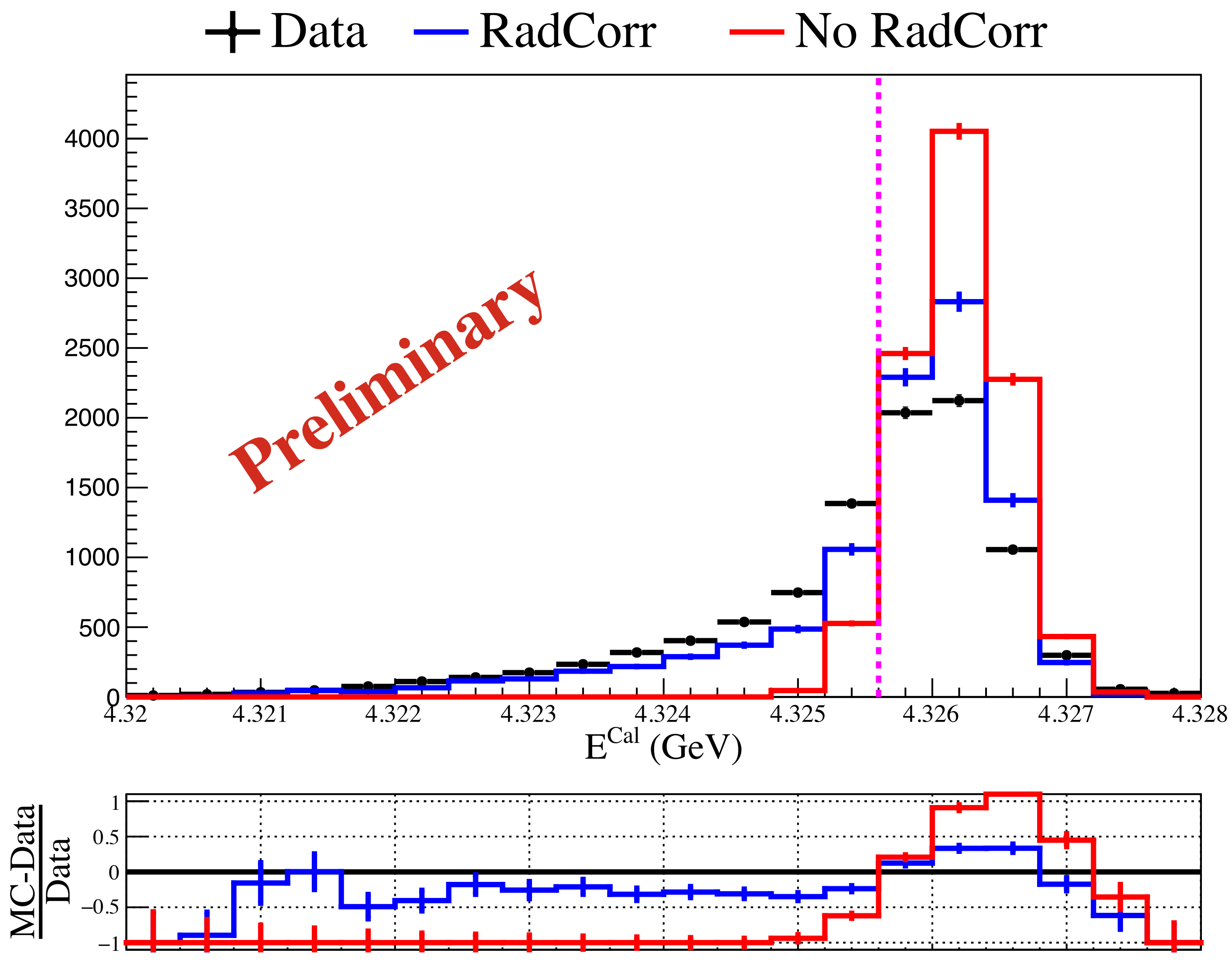


Comparing to data - Radiative correction

A suggested implementation into GENIE.

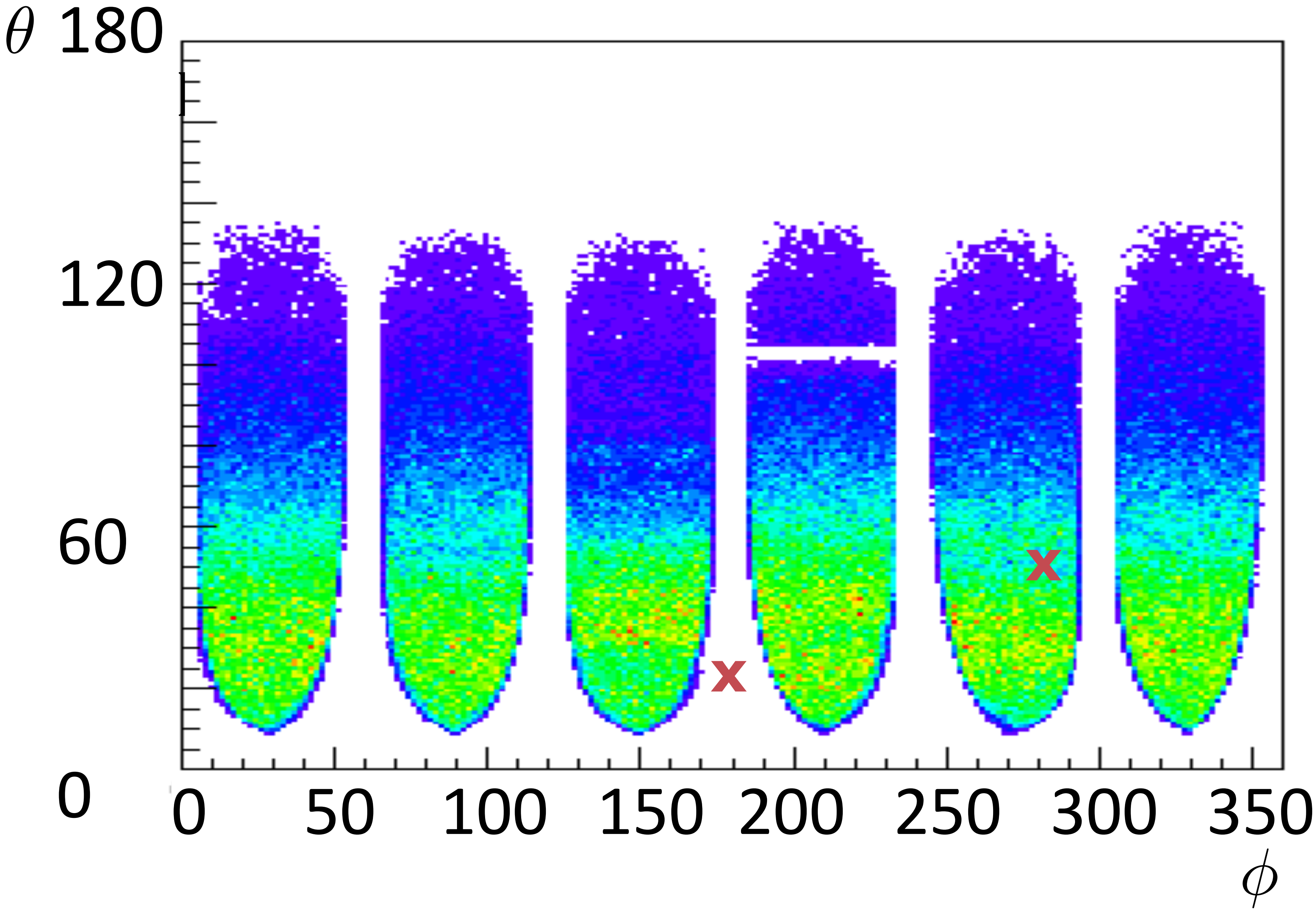
Preliminary validation of this implementation using electron proton scattering from JLAB



Comparing to data - Background

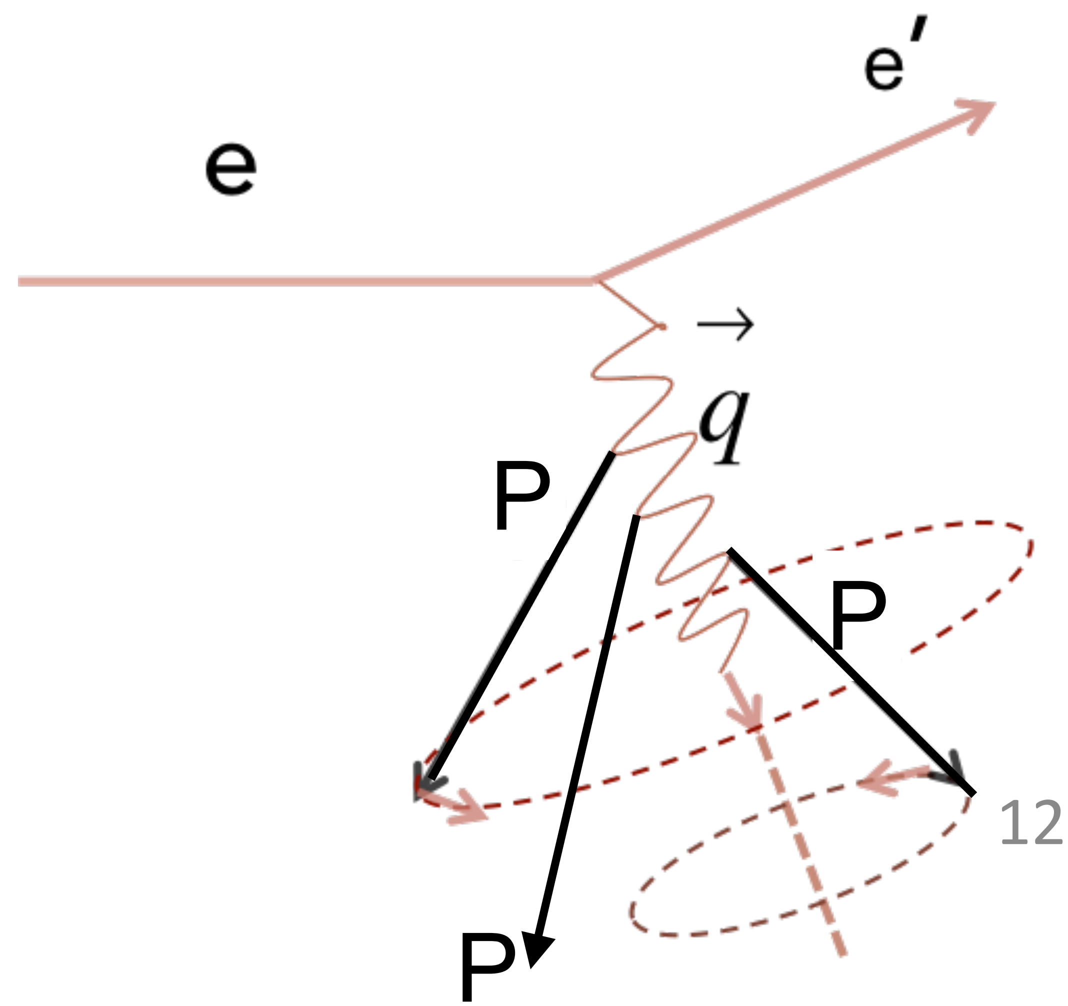
Different interaction lead to multi-hadron final states

Gaps can make them loop like QE-like events with outgoing 1μ1p



Comparing to data - Background

- Using events with two hadrons,
- Rotating p,π around q and determine π detection efficiency
- Subtract contribution to QE-like



Same for final states with more than 2 hadrons

Comparing to data - kinematic range

When using electron scattering data one should make sure the kinematic range that is relevant to neutrino is the one being tested.

Divide by the Mott cross section ratio

Unified models - Requirements

Define a core set of observables (electrons & neutrinos) that any model, tuned or not, have to reproduce to be considered valid for use in neutrino data analysis

Comparison to inclusive data is sufficient for estimating the leptonic energy

For the calorimetric energy estimation:

Nuclear mass (A)

Beam-energy (E)

Transparency ratios for nucleons

During this week's discussion we would like to define this set and what it means to have a good comparison.

Unified models - Output to experiment

In this week's discussion we would also like to define the best way to propagate the results to the experiments.

Each generator can supply the model set which was validated using electron scattering data.

Giving the tension between datasets, should these be given as alternative tunes?

Can the generator have electron comparison tools?

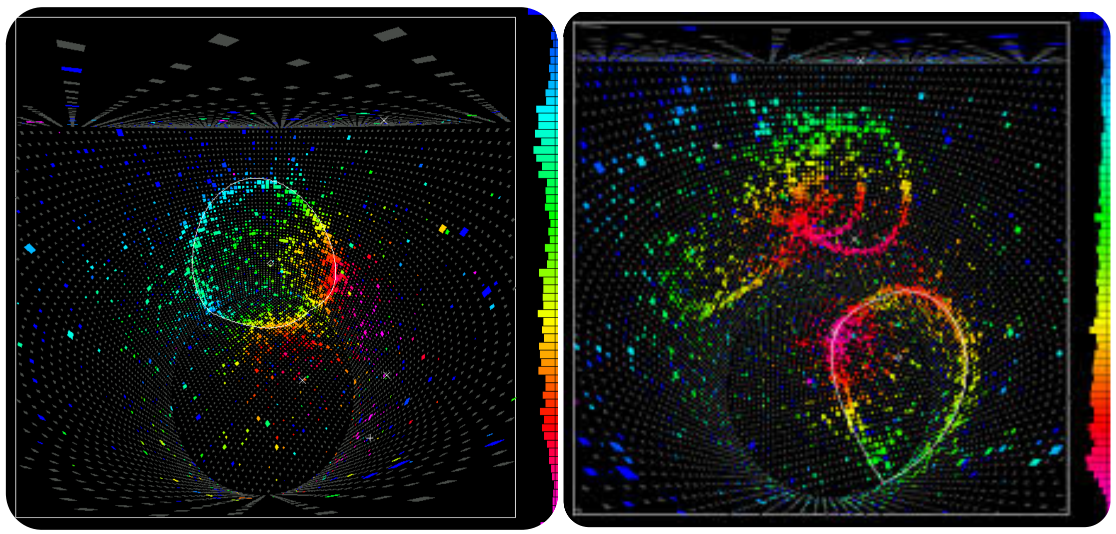
Summary

Join us for the live discussion here and on Wednesday afternoon to:

- Define the set of observables a model needs to reproduce to be considered valid for use in neutrino data analysis
- Define he way tuned prediction are propagated to experiments
- Review the existing electron mode for various models and generator
- Suggest what can be done to ensure the consistency is kept in subsequent evolutions of the code

Thank you for your attention

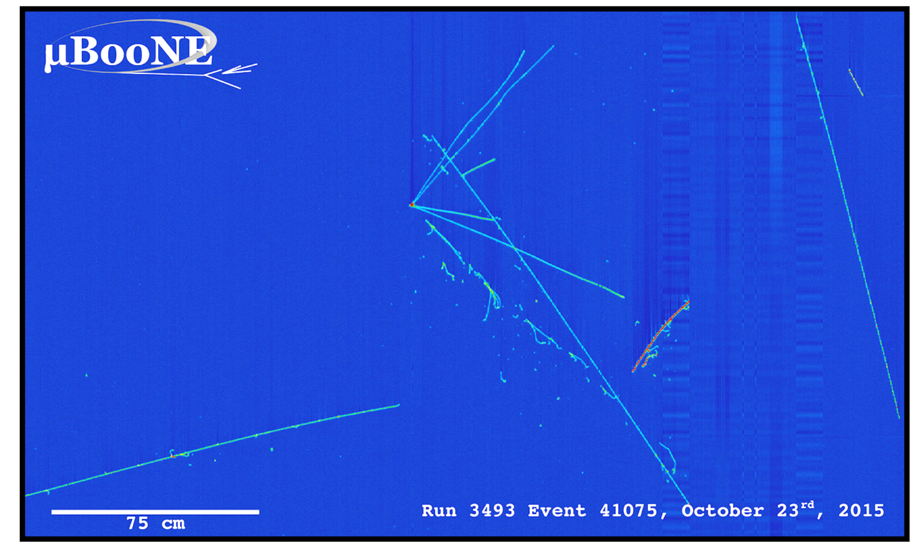
Incoming neutrino Energy Reconstruction



Cherenkov detectors:

Assuming QE interaction

Using solely the final state lepton



Tracking detectors:

Need good hadronic reconstruction

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

$$E_{\text{cal}} = E_l + E_p^{\text{kin}} + \epsilon$$

ϵ is the nucleon separation energy ~ 20 MeV

Comparing to data

^{12}C @ $E = 0.56$ GeV & $\theta = 60^o$