Electrons for Neutrinos Simulation

03/07/2019

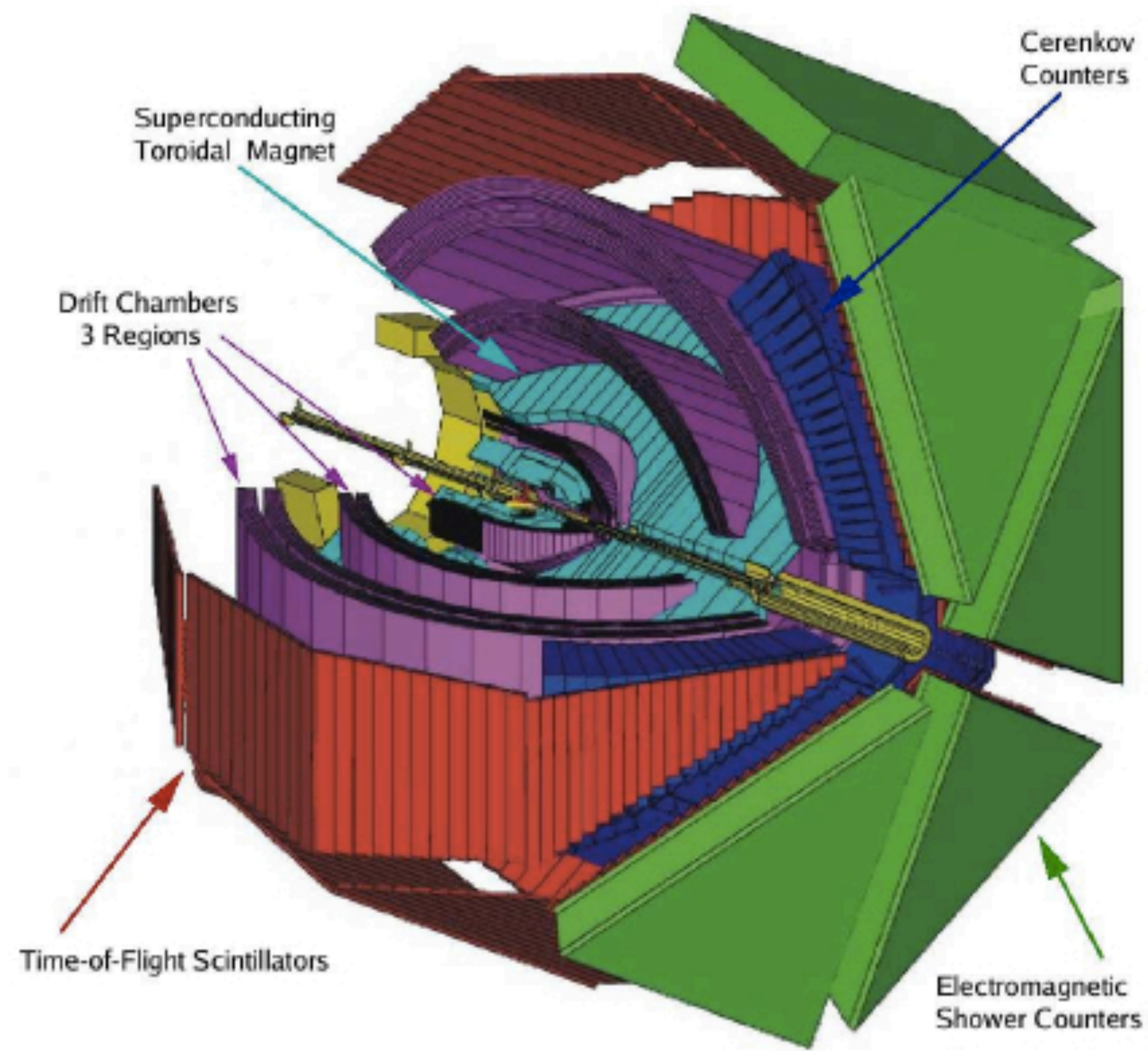
CLAS Collaboration Meeting

Afroditi Papadopoulou, Adi Ashkenazi (MIT)

e4V: Playing the Neutrino game

Analysing electron data from CLAS as if it was ‘neutrino data’

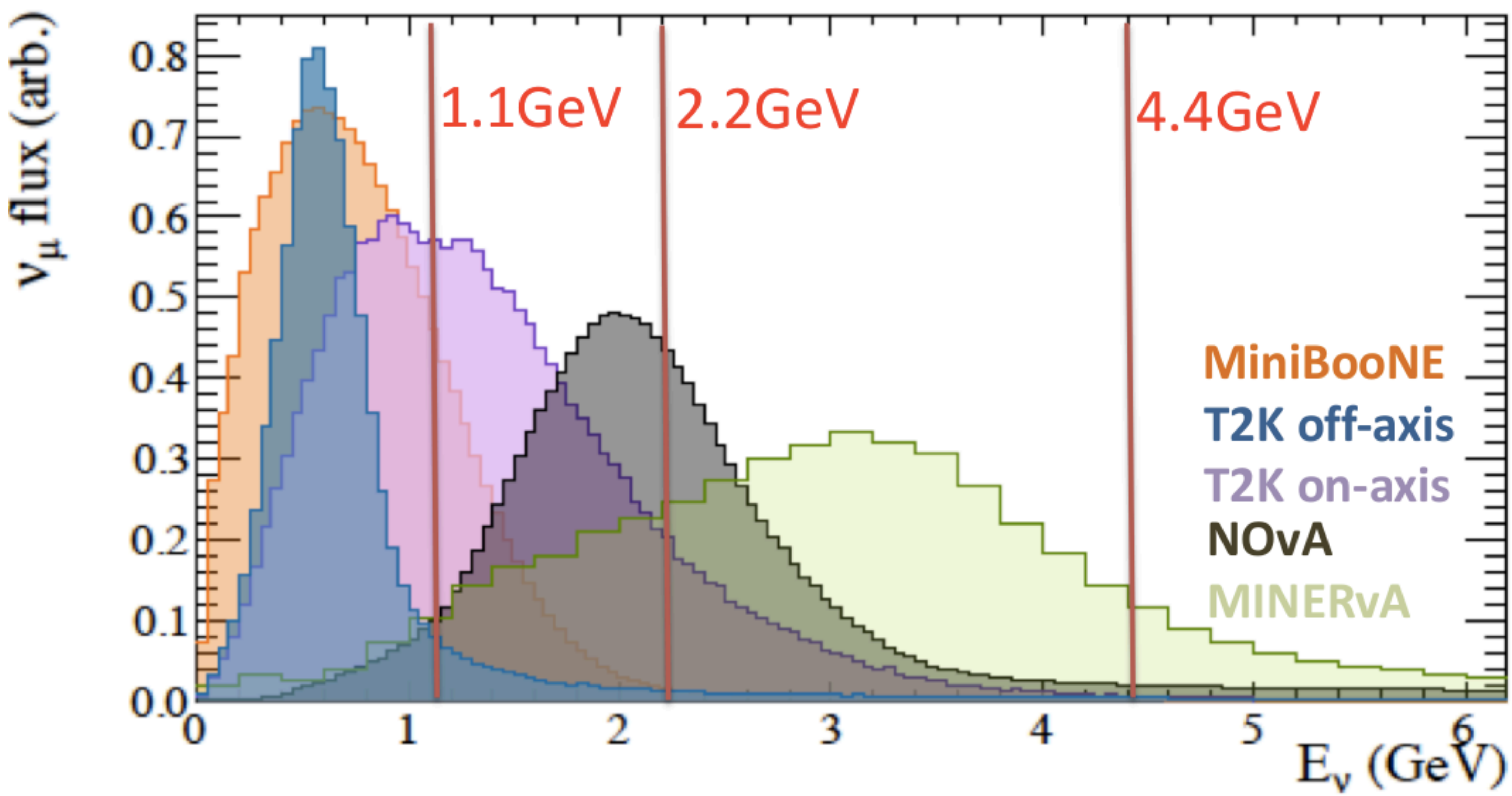
- Select a specific interaction
- Scale the electron data using the inverse Mott cross section
- Test the energy reconstruction method and compare to the incoming electron energy
- Compare to event generators



CLAS A(e,e'p) Data

Targets: ^{4}He, ^{12}C, ^{56}Fe, ^{208}Pb

Energies: 1.1, 2.2, 4,4 GeV



νA Interaction Modelling

Neutrino event generators are used to simulate a νA interaction

Among those:

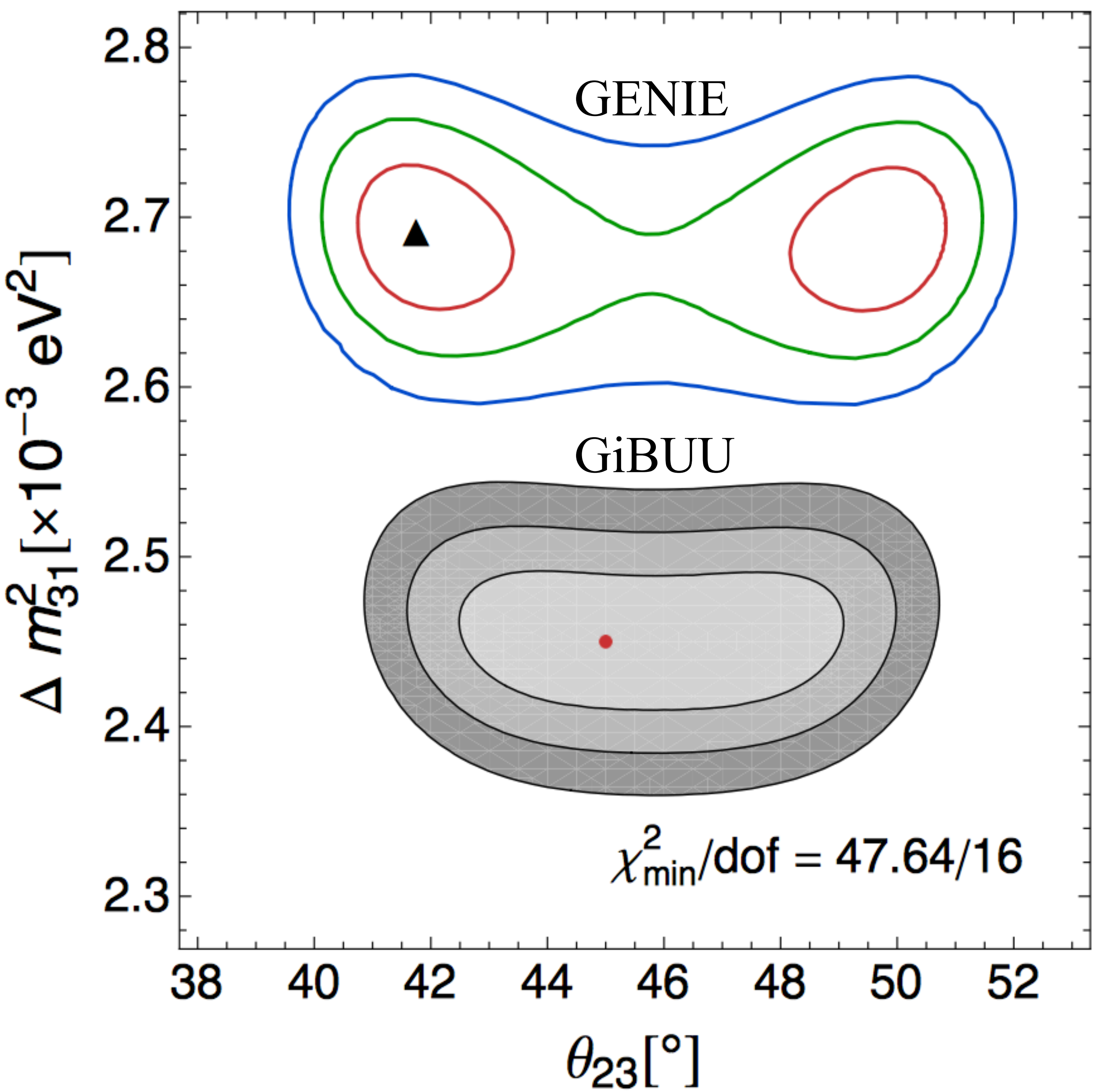
Genie

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

and many more

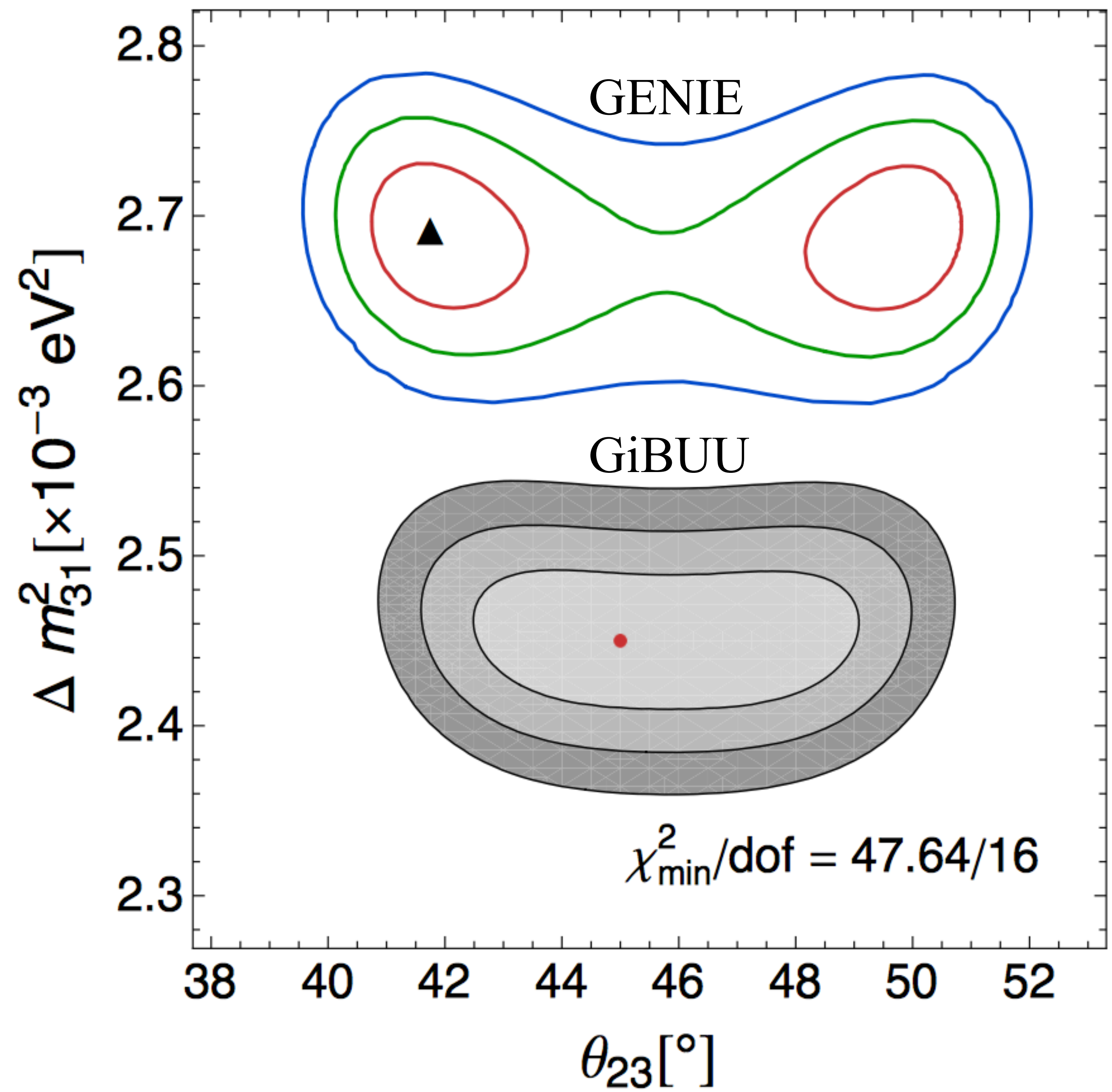
Nuclear uncertainties are significant



Phys. Rev. D 89, 073015 (2014)

Nuclear uncertainties are significant

Could lead to wrong extraction of the mixing parameters due to incomplete modelling of the nuclear physics involved.



Phys. Rev. D 89, 073015 (2014)

Neutrino generators -Simulation

E_ν Reco Requires Interaction Modeling

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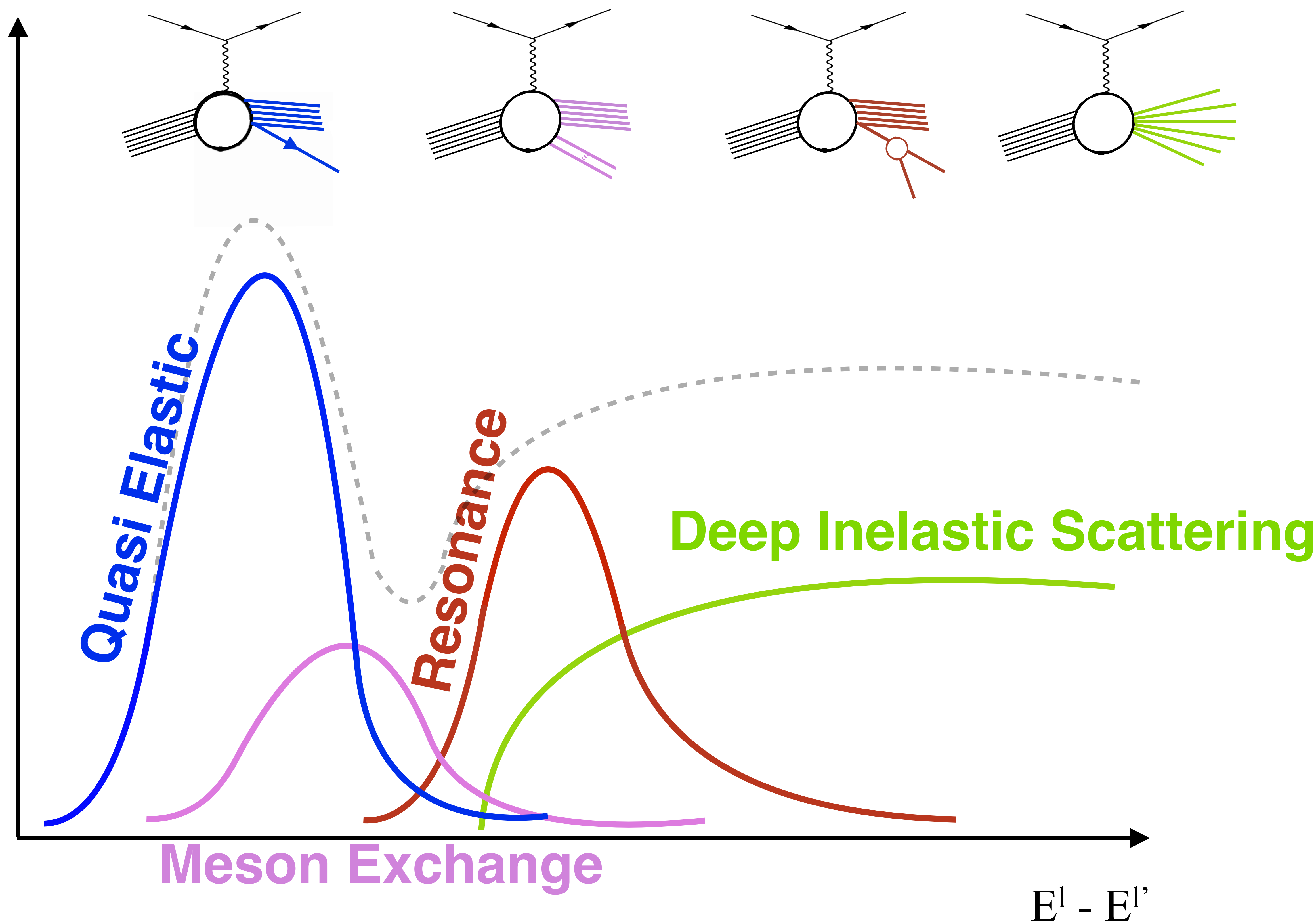
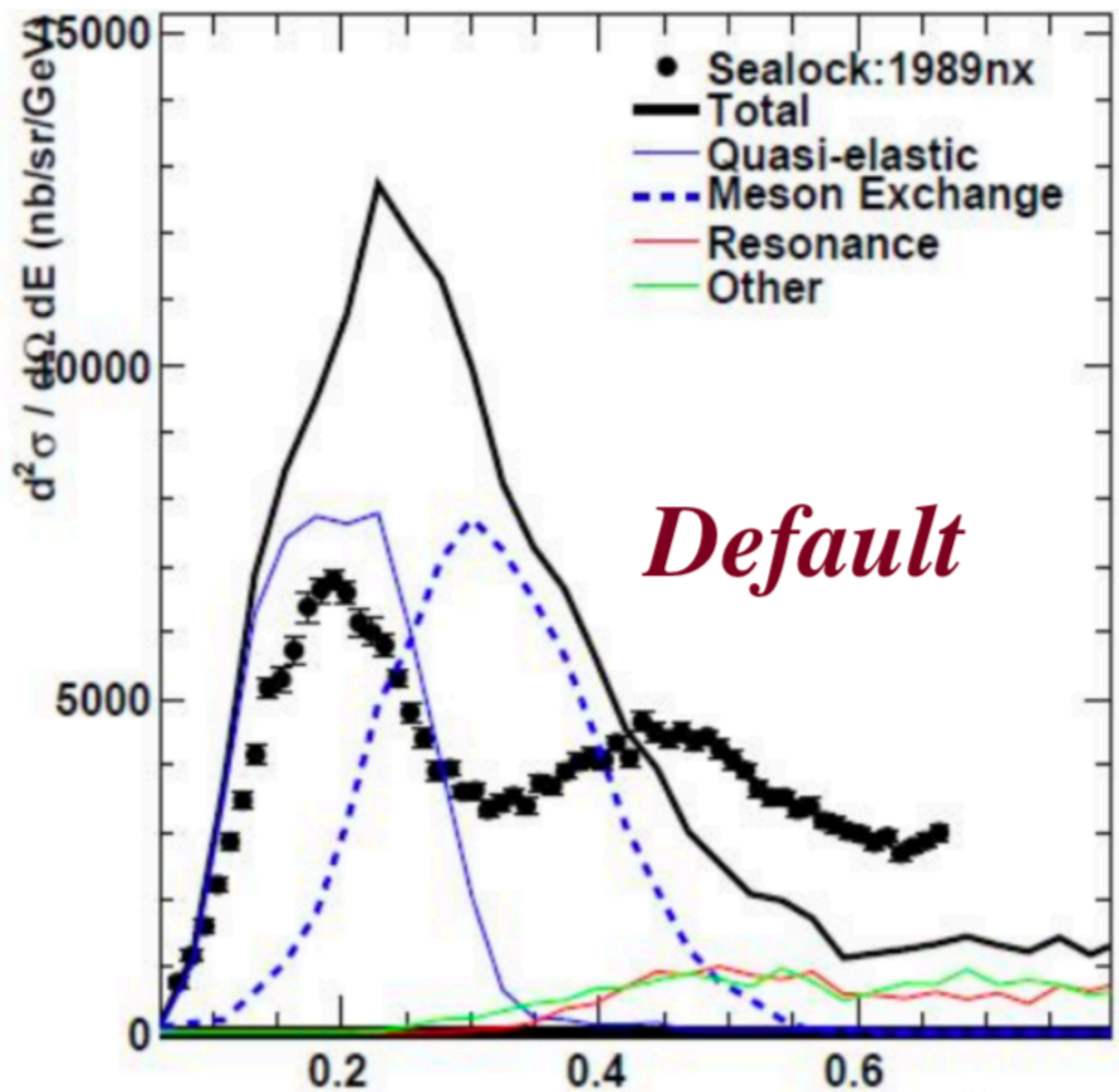
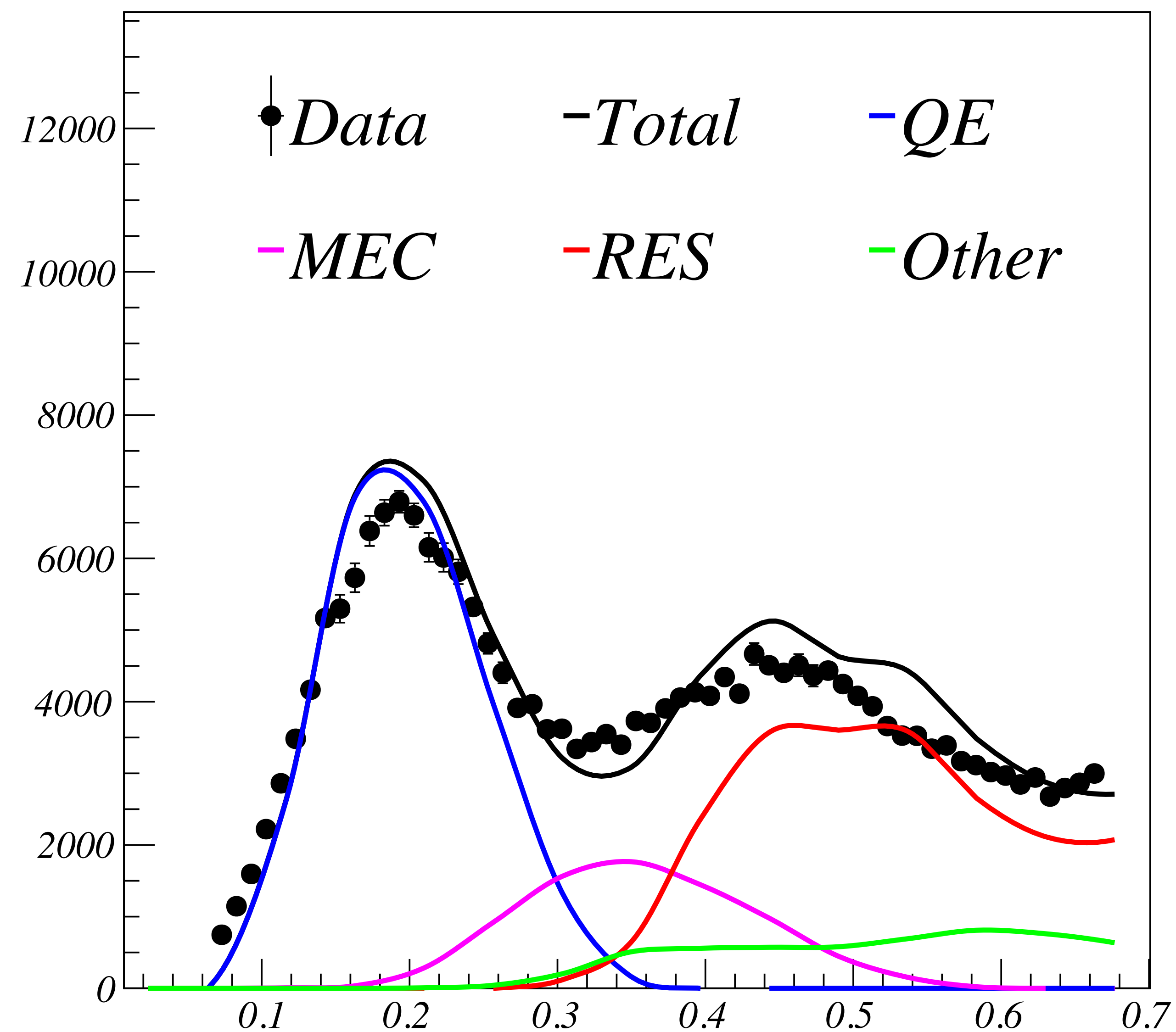


Testing neutrino generators with inclusive electron scattering data

12C(e,e') E = 0.961 GeV $\theta = 37.5^{\circ}$



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



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

GENIE Simulation

Nuclear model	Local fermi gas model
QE	Lewellyn Smith for neutrino
	Rosenbluth CS for electrons
MEC	Empirical Dytman model
Resonances	Berger Sehgal
FSI	hA (data driven) + variations

GENIE is calculating each contribution separately and then summing them up

GENIE simulation will also require radiative corrections

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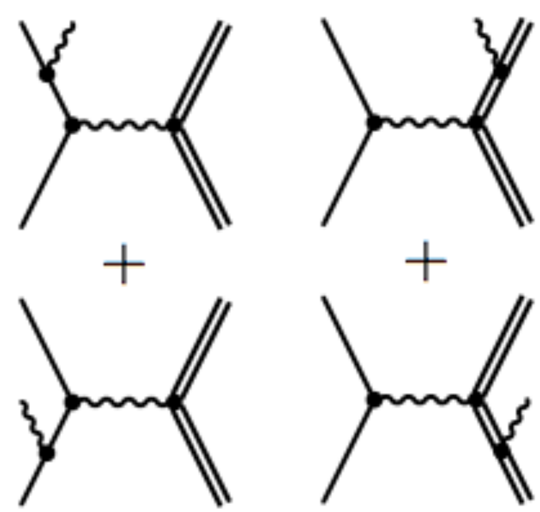
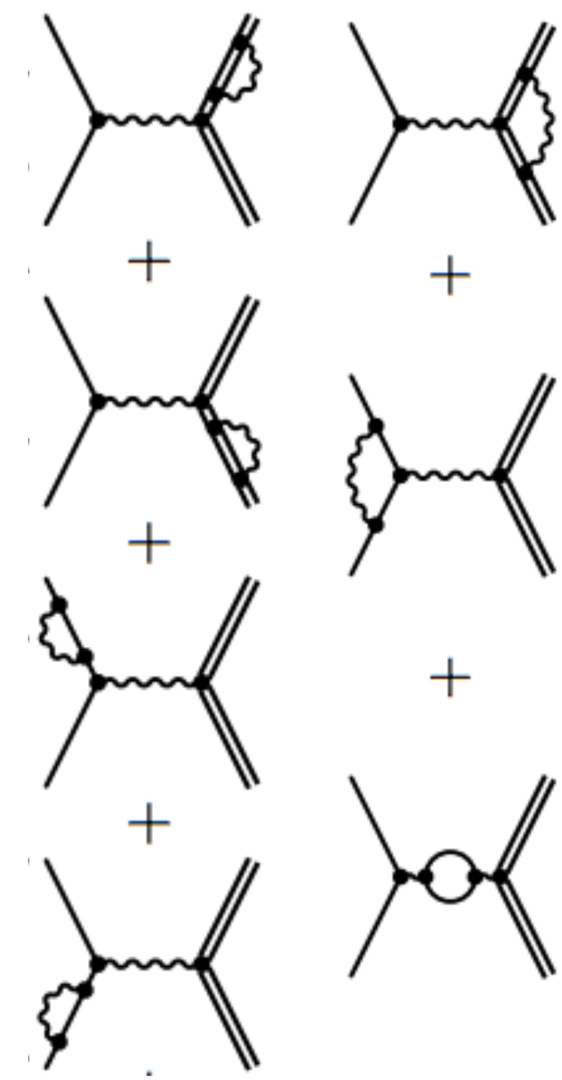
GENIE simulation will also require radiative corrections

Radiative Effects in GENIE

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





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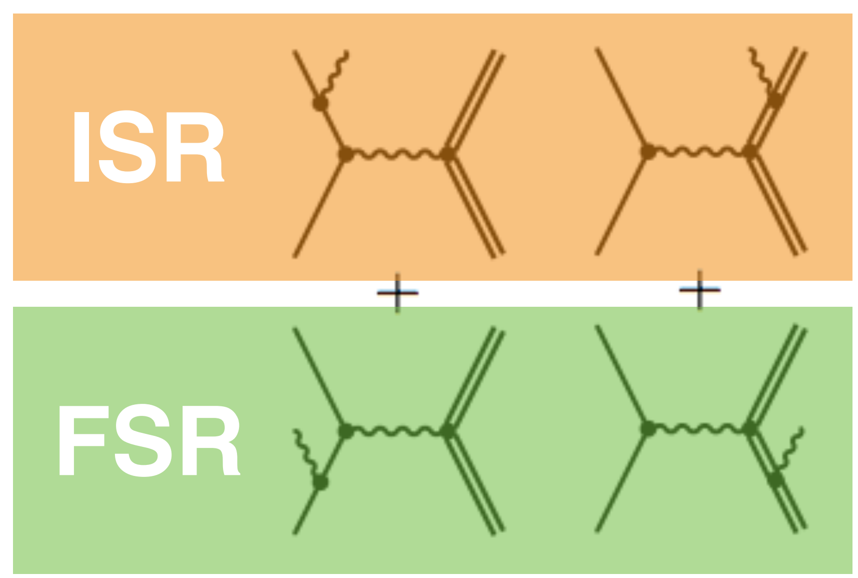
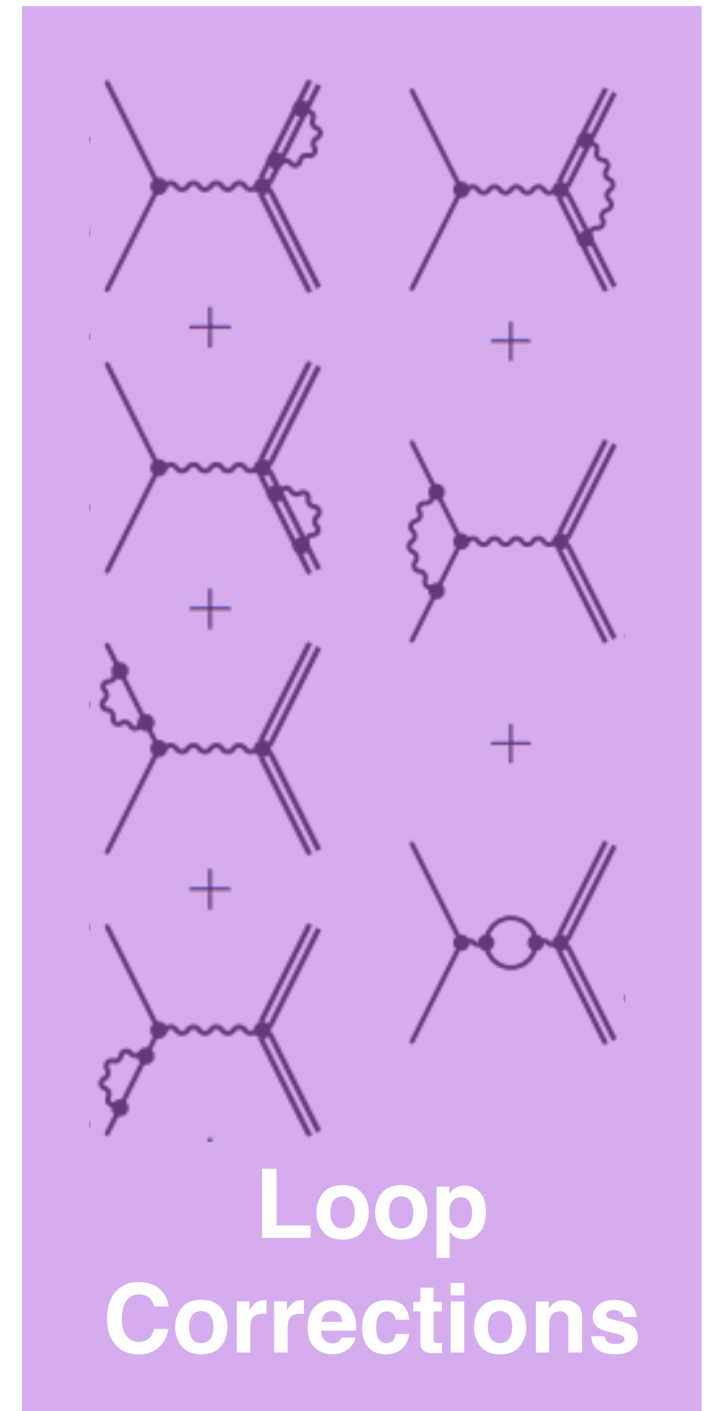
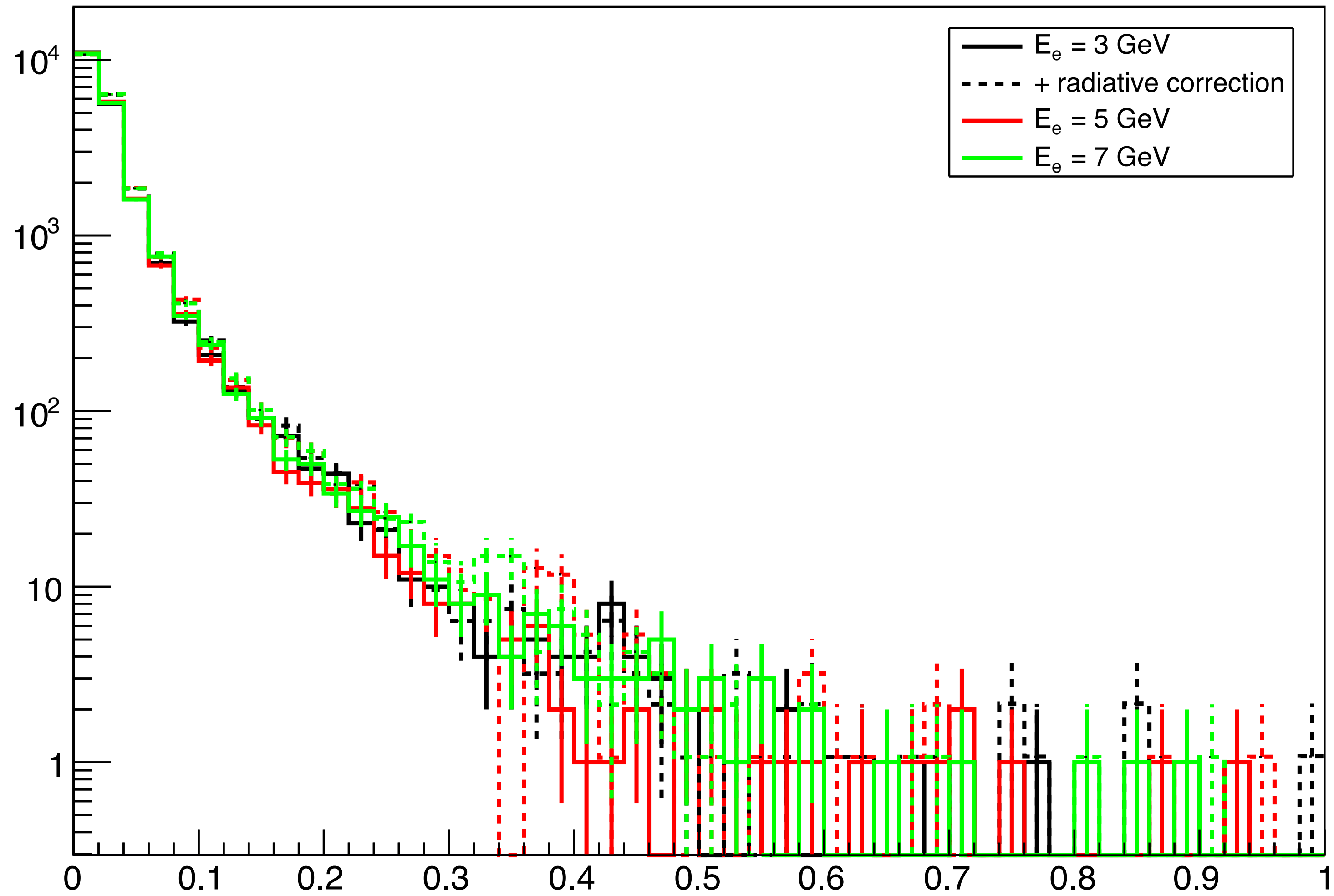




Radiative Effects in GENIE

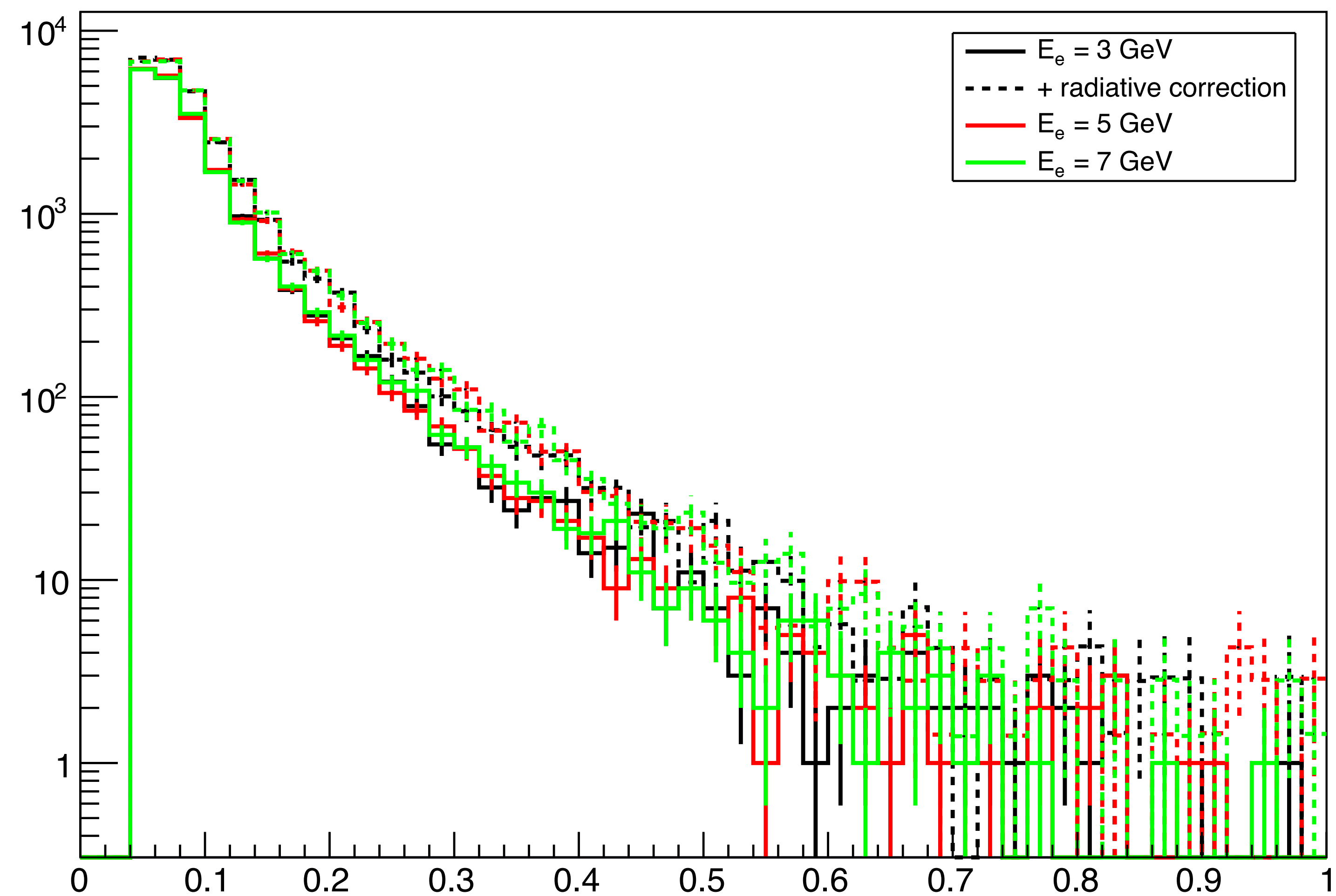
p(e,e’)



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

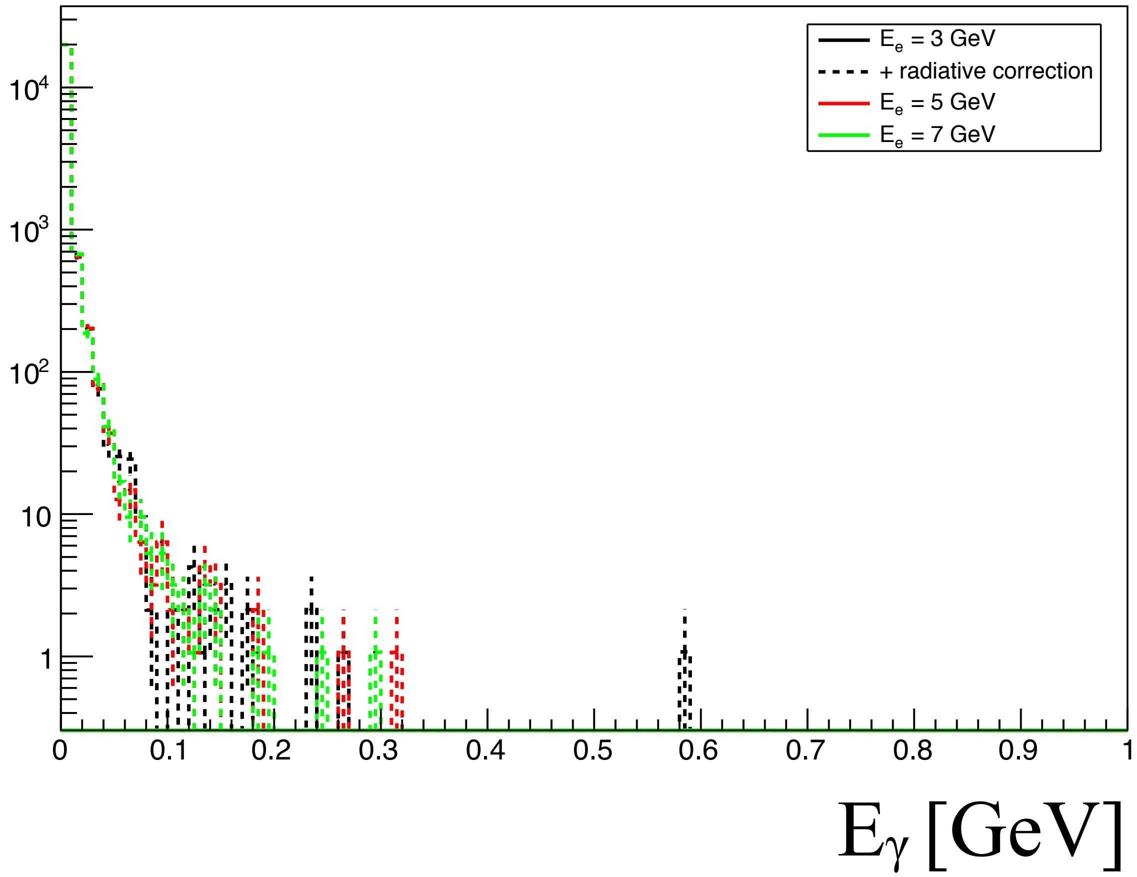
Radiative Effects in GENIE

$^{12}C(e,e')$

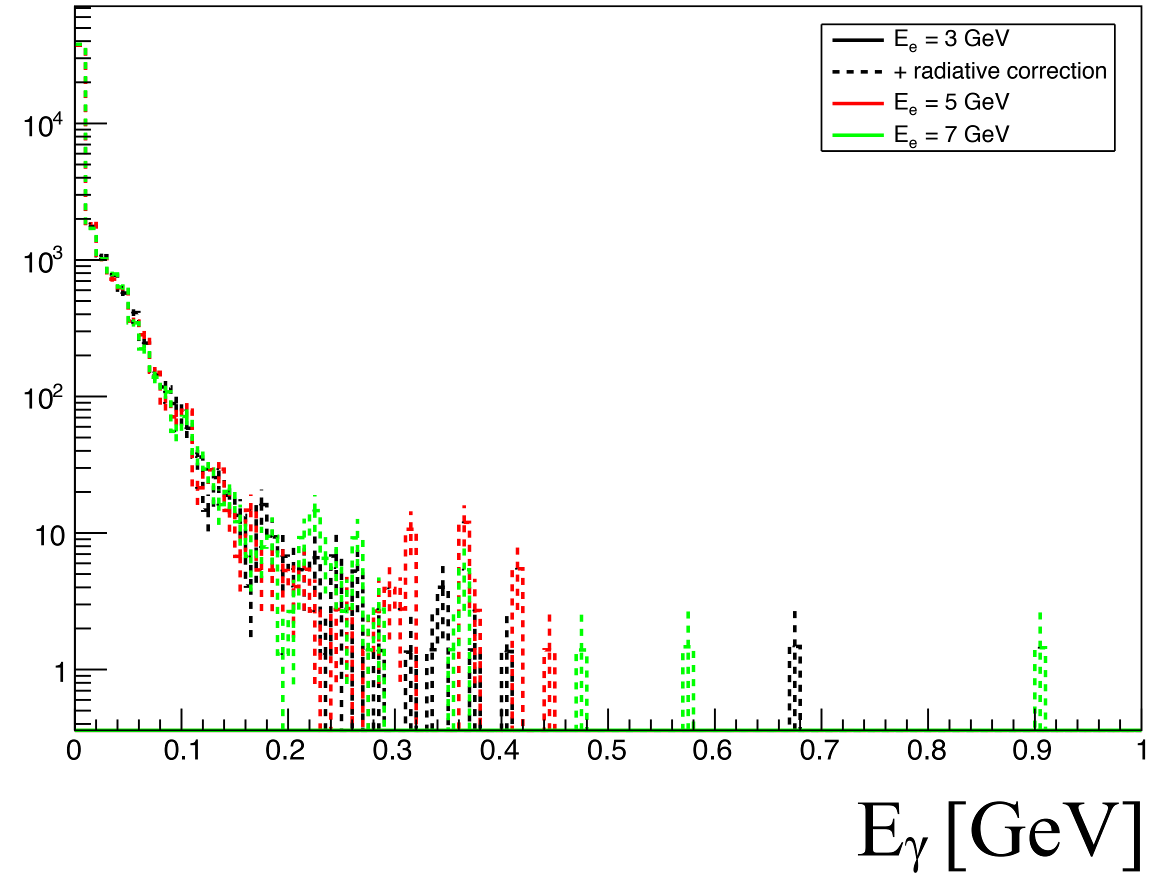


E^1 - $E^{1'}$ [GeV]

Radiative Effects in GENIE

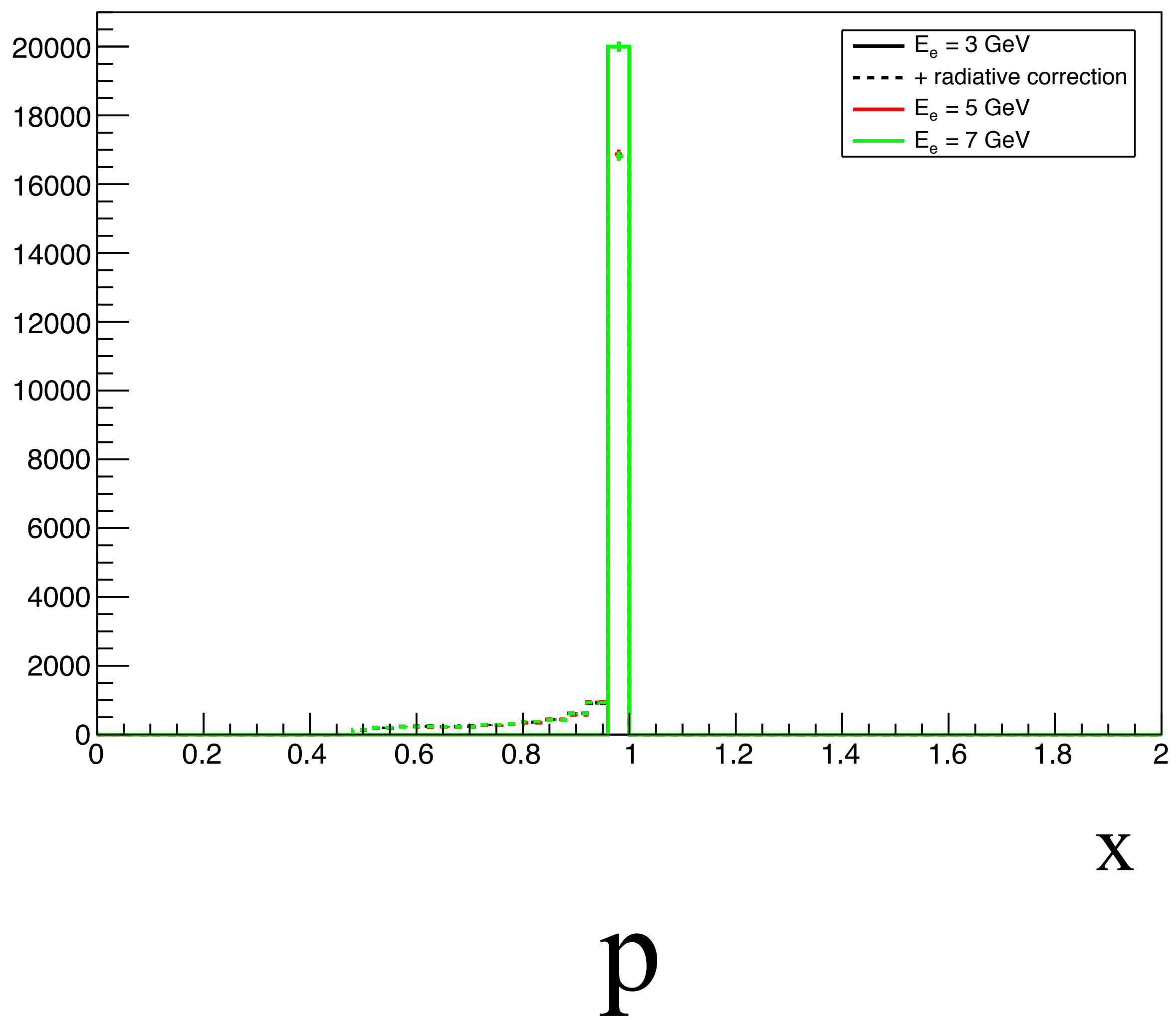


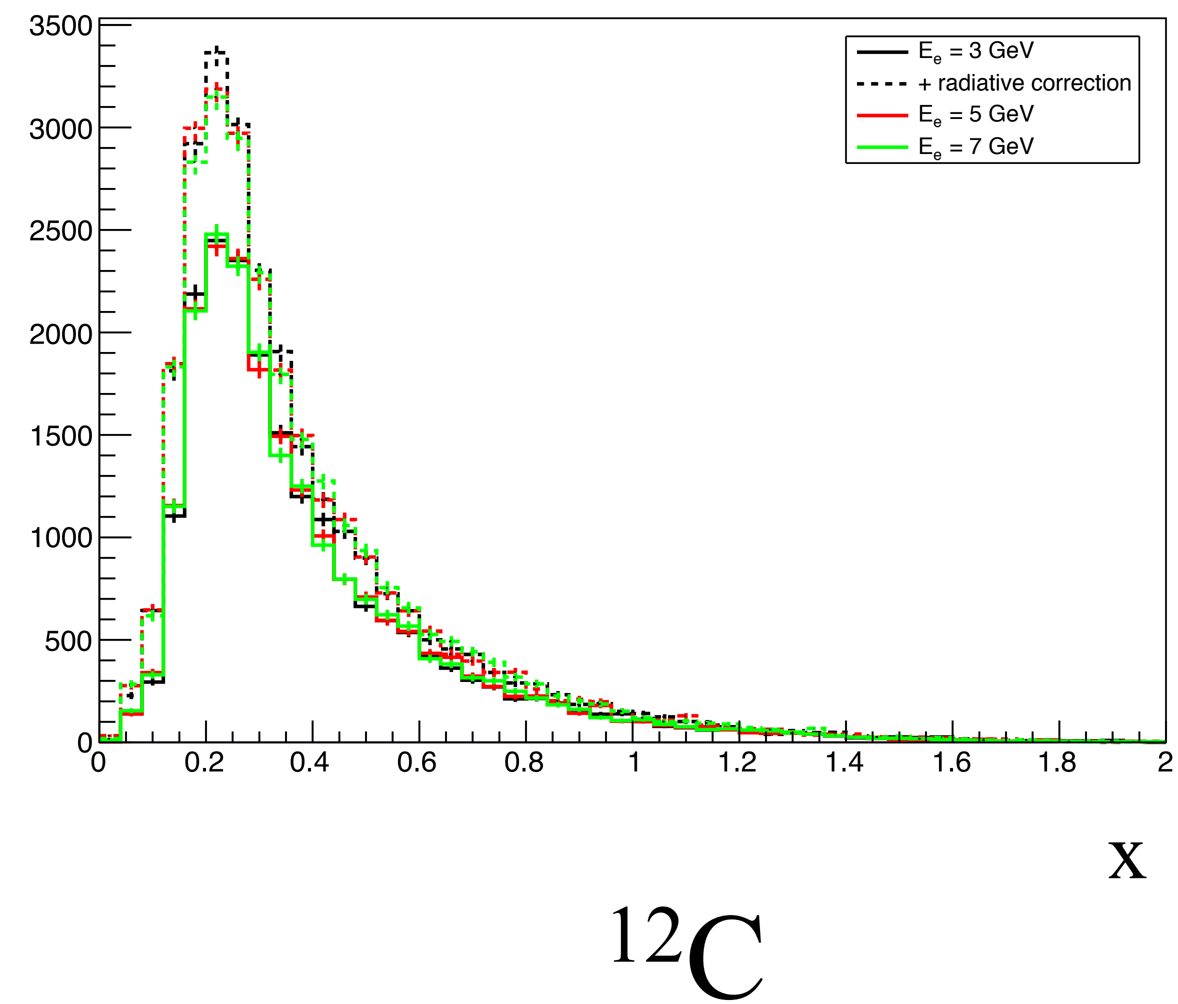
p



^{12}C

Radiative Effects in GENIE

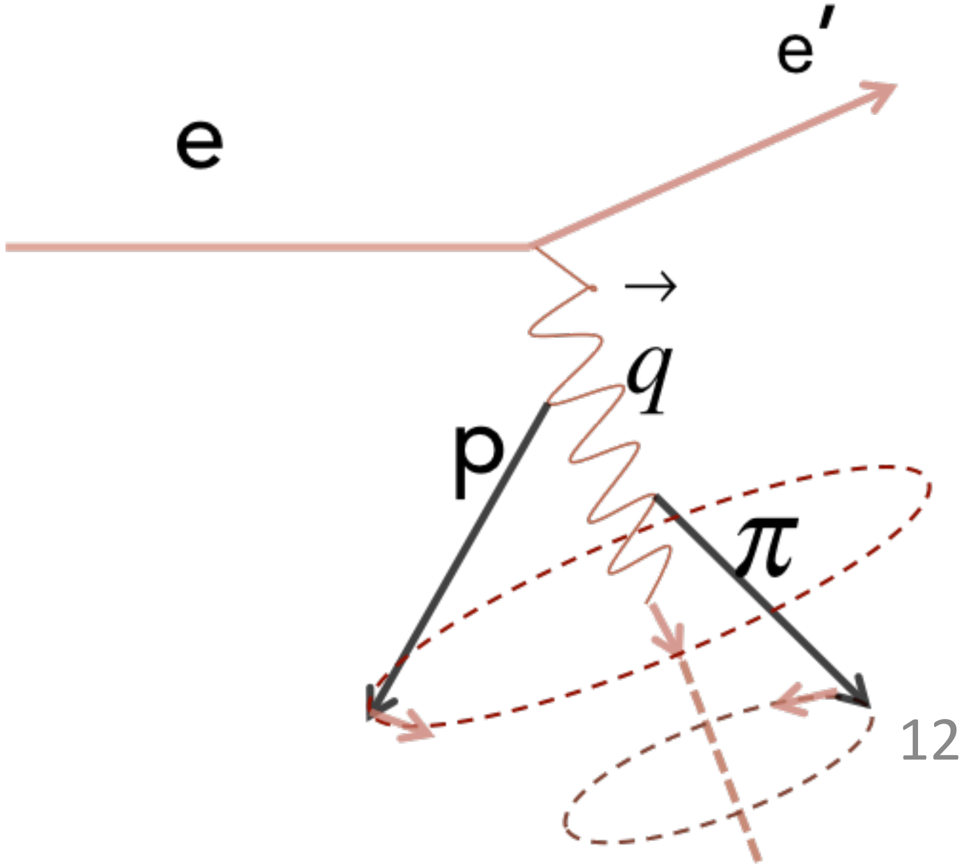




Detector simulation

Final state particles from GENIE simulation are passing through:

- CLAS efficiency maps
- Energy smearing 0.3% for e, 1% for p
- Data driven background subtraction

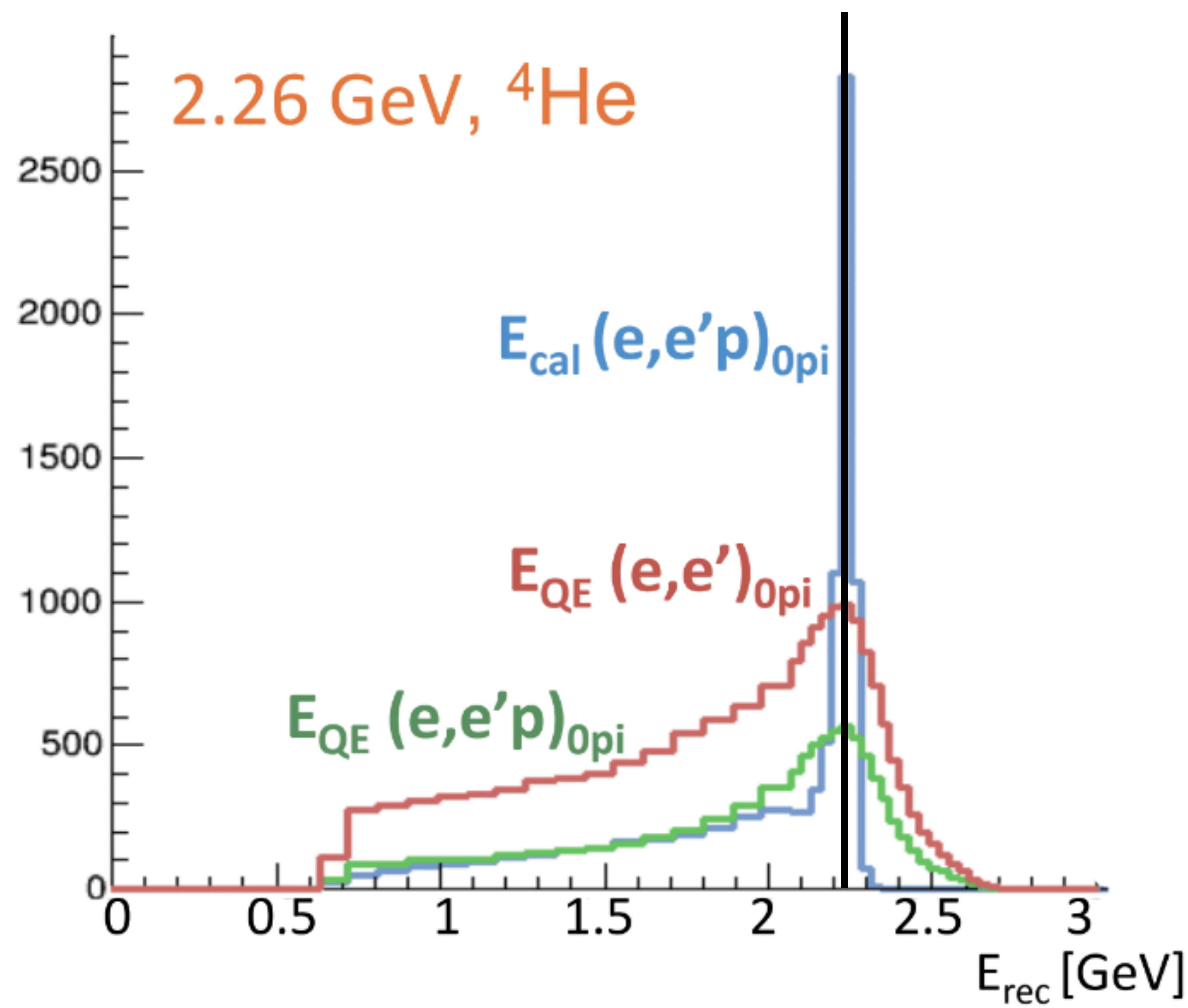


12

Data to Simulation Comparison

Testing the incoming energy reconstruction

The neutrino event generators should be able to reproduce these energy spectrum



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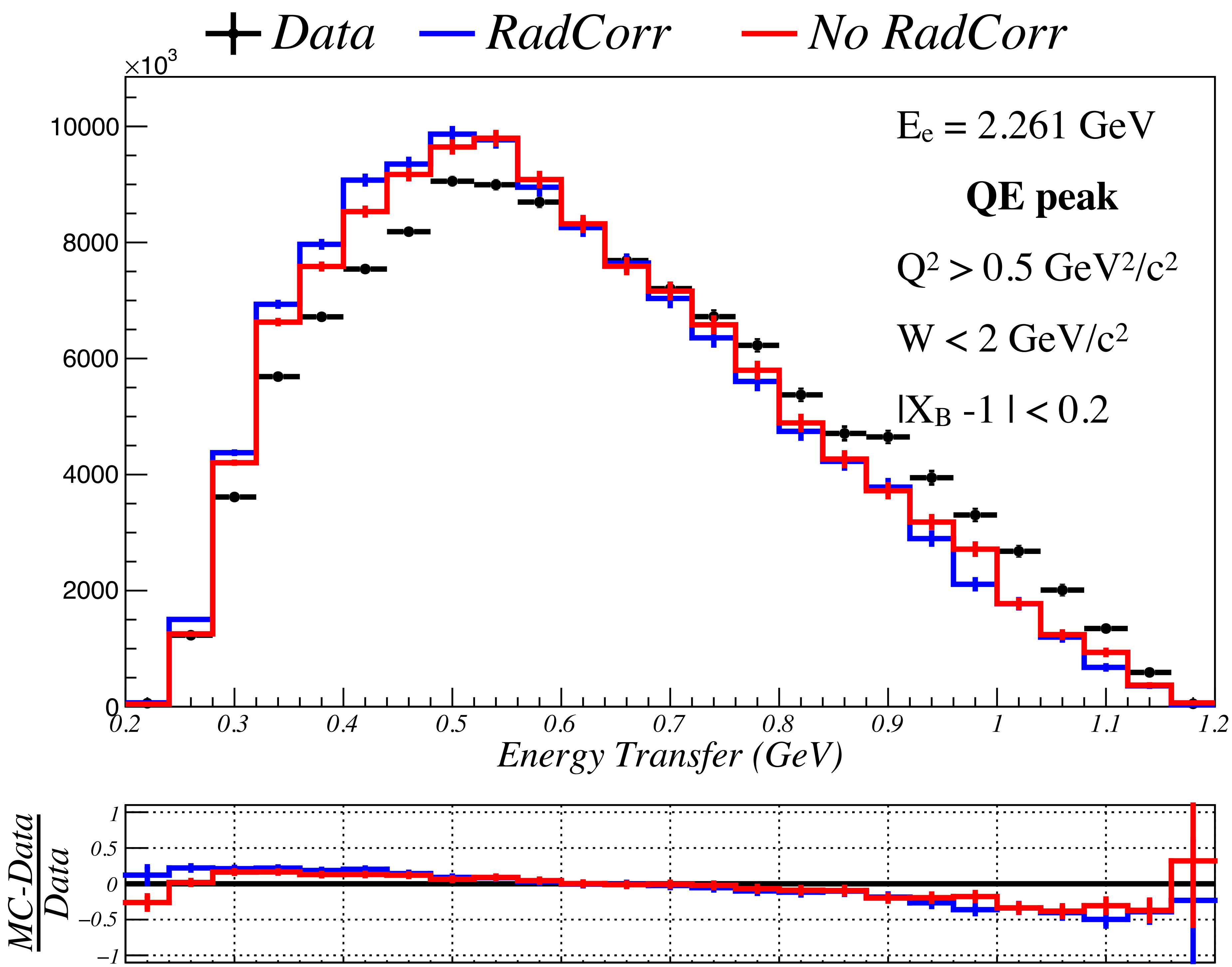

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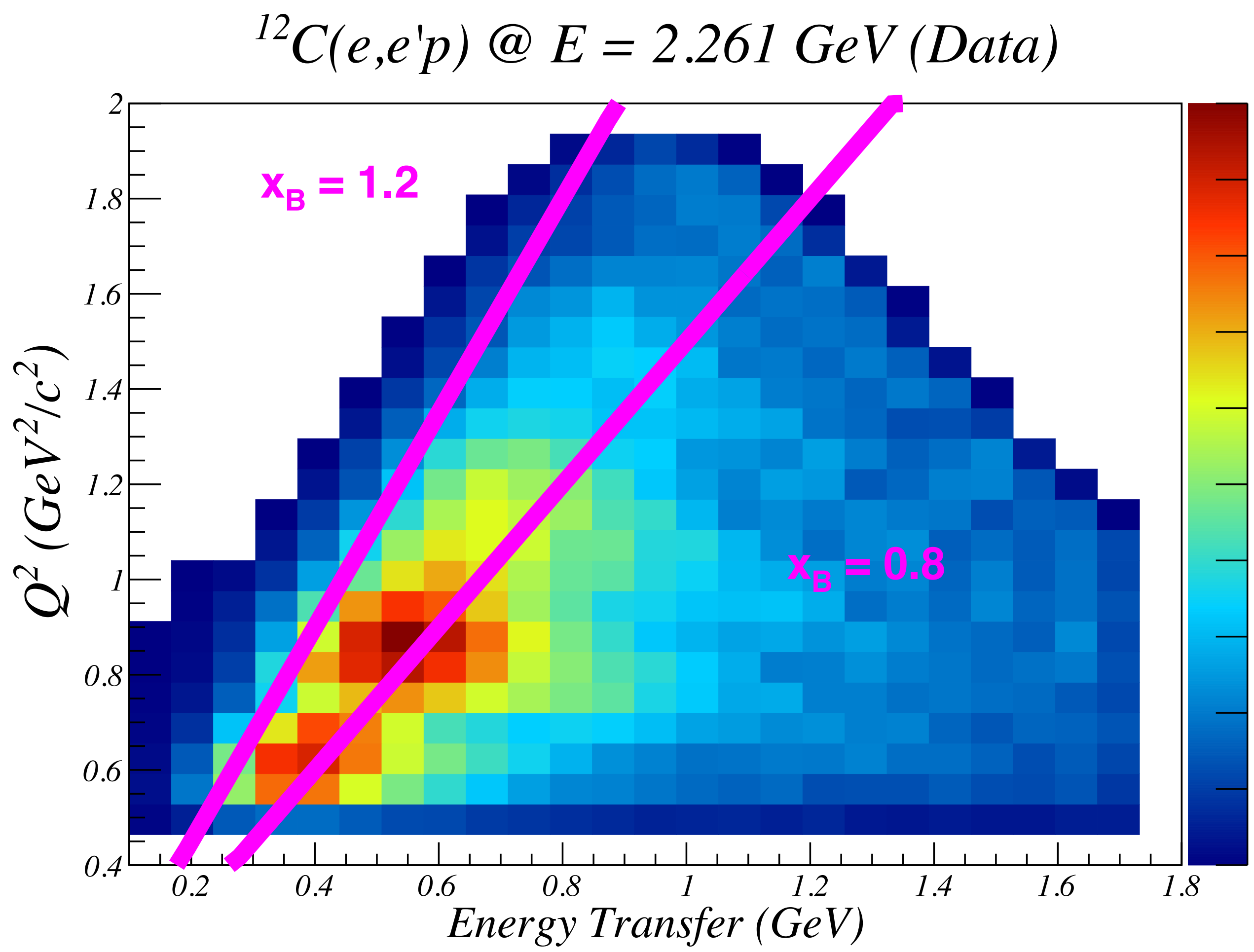

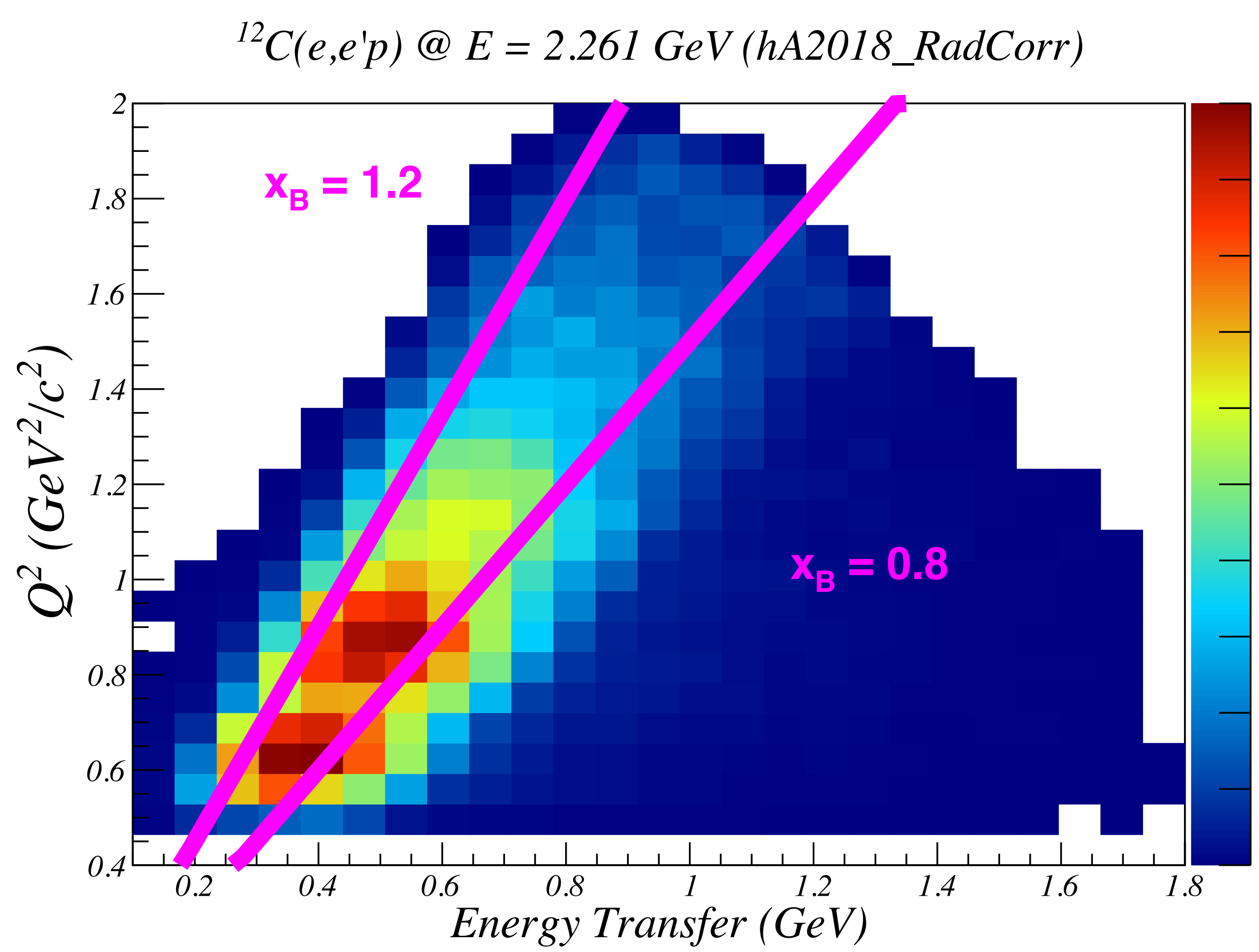

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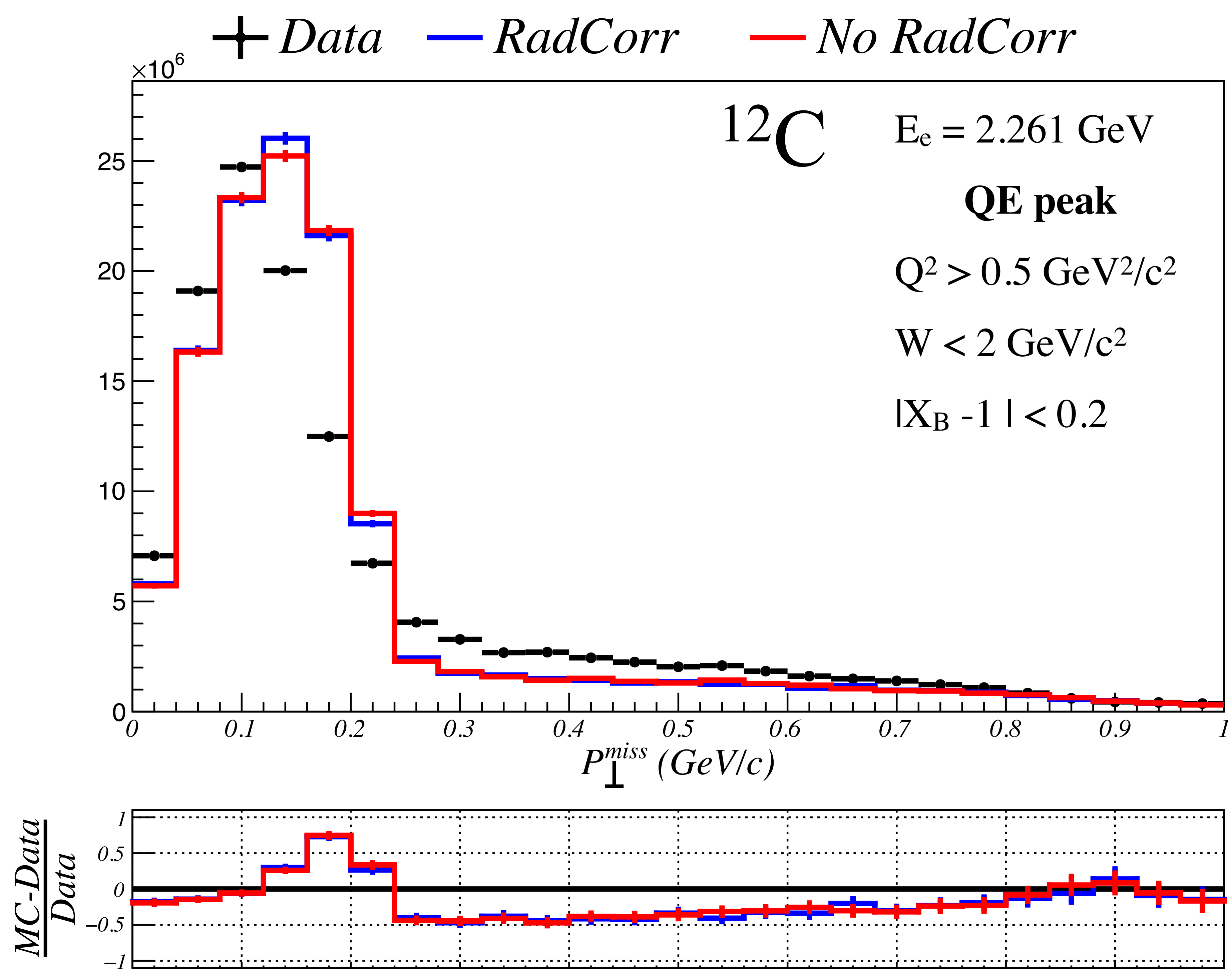

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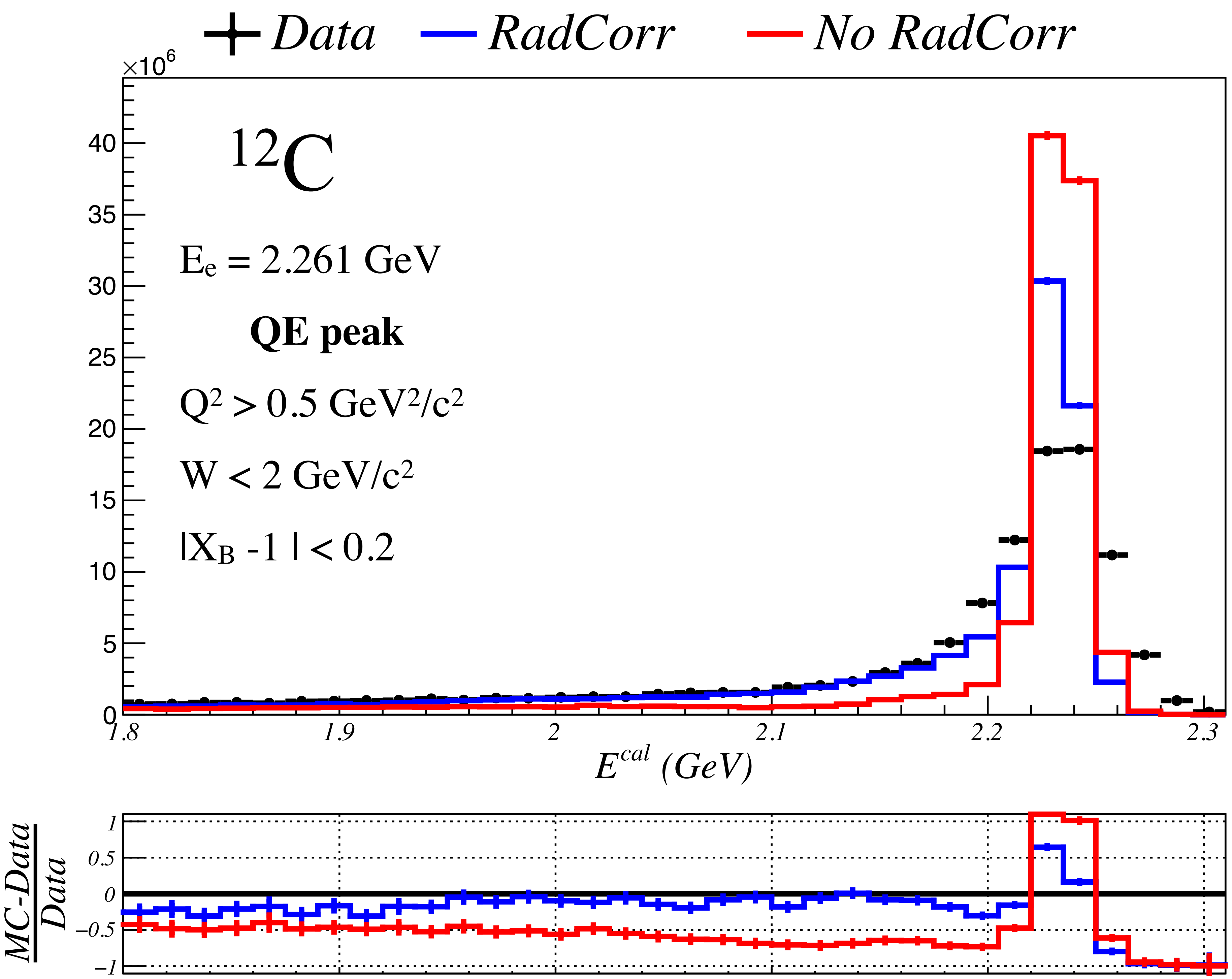

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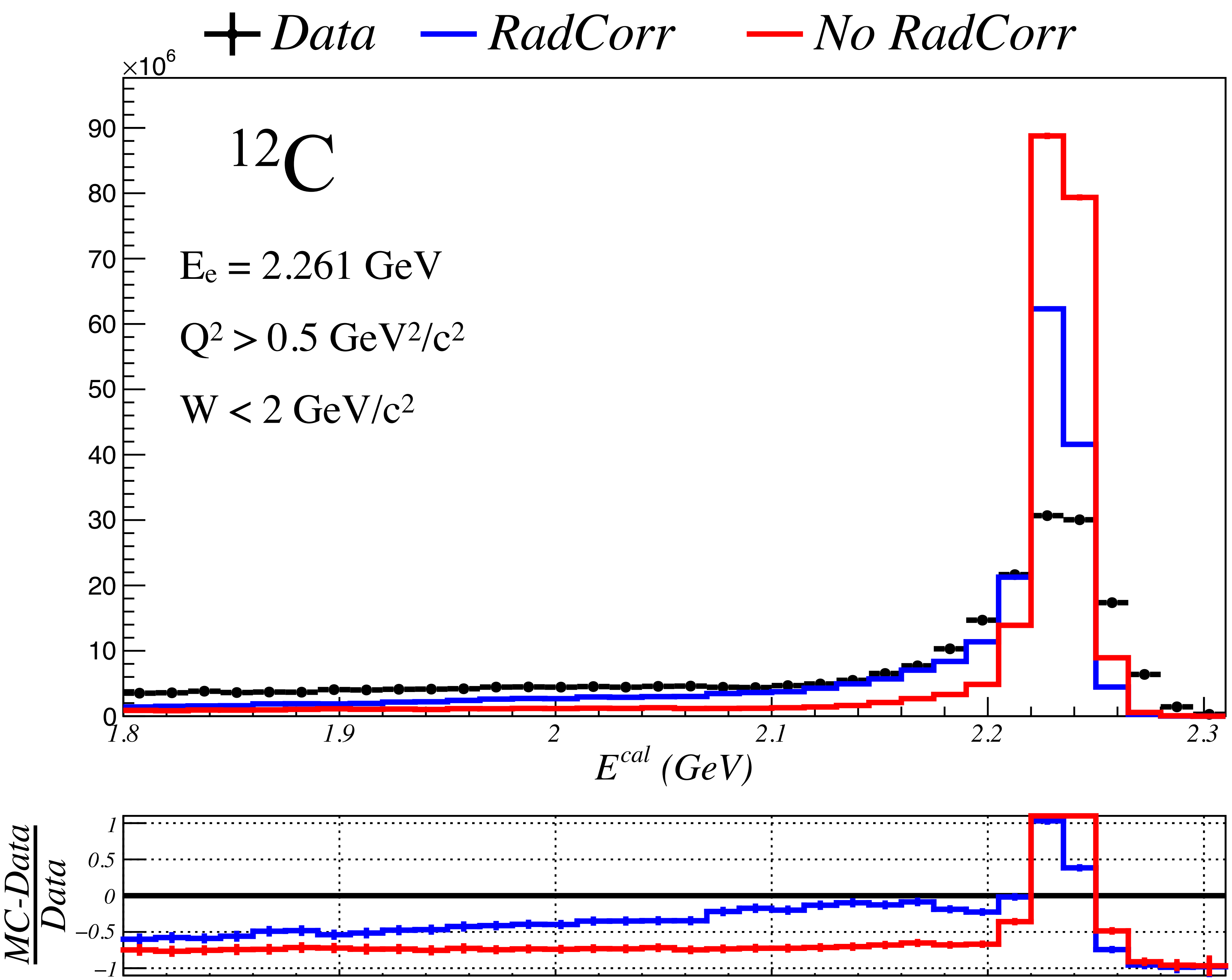

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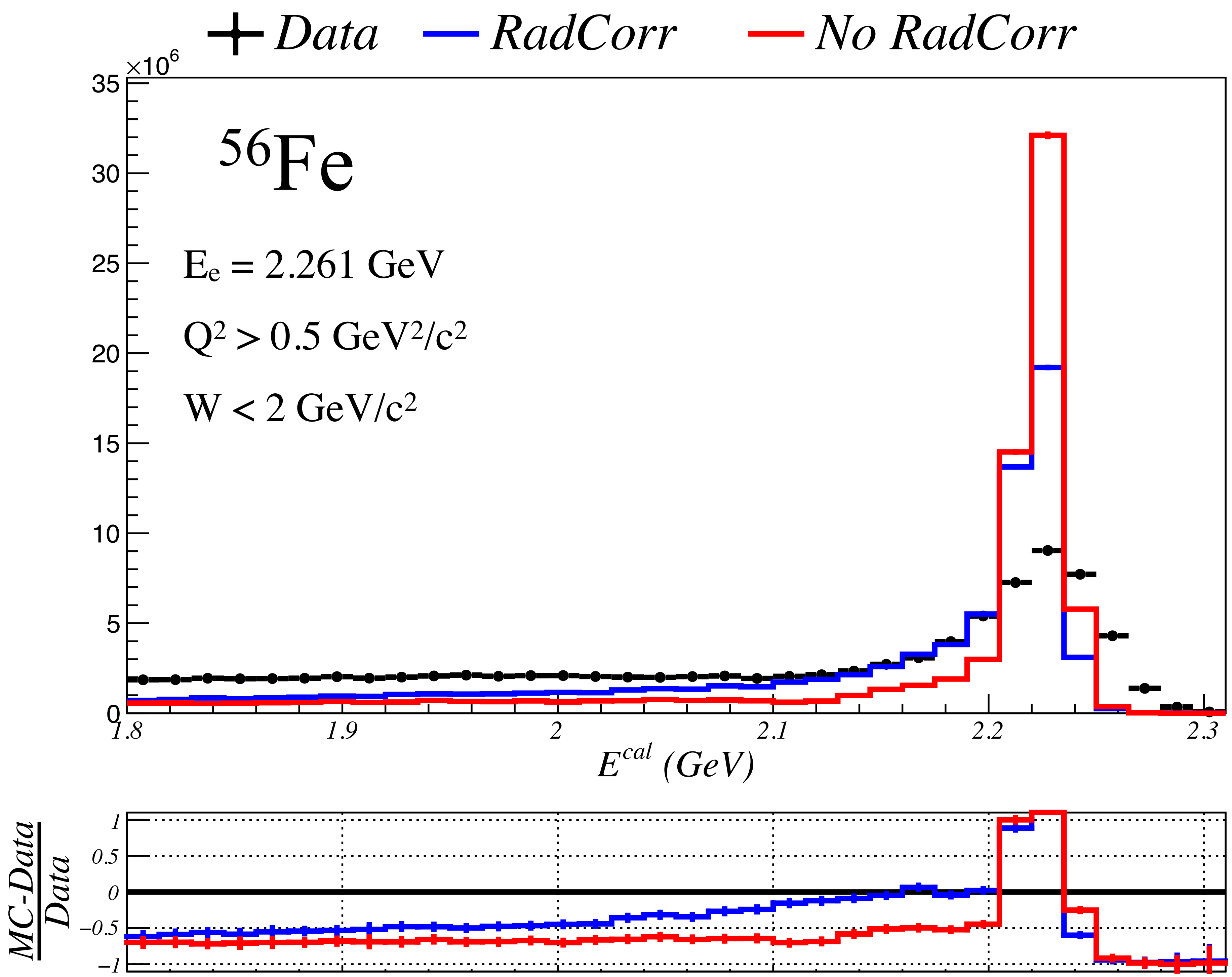


Summary

A wide phase space electron scattering data is used to test the methods for incoming energy reconstruction and improve νA interaction modelling.

Electron scattering data is currently being used as a quality proof of any new model and an important tool to find bugs.

Disagreement between data and event generators were shown.

For QE-like events both leptonic and hadronic reconstructed energies have bad resolution, mostly for heavier nuclei and high missing transverse momentum

Following the data analysis we will add photon background subtraction

Looking forward to:

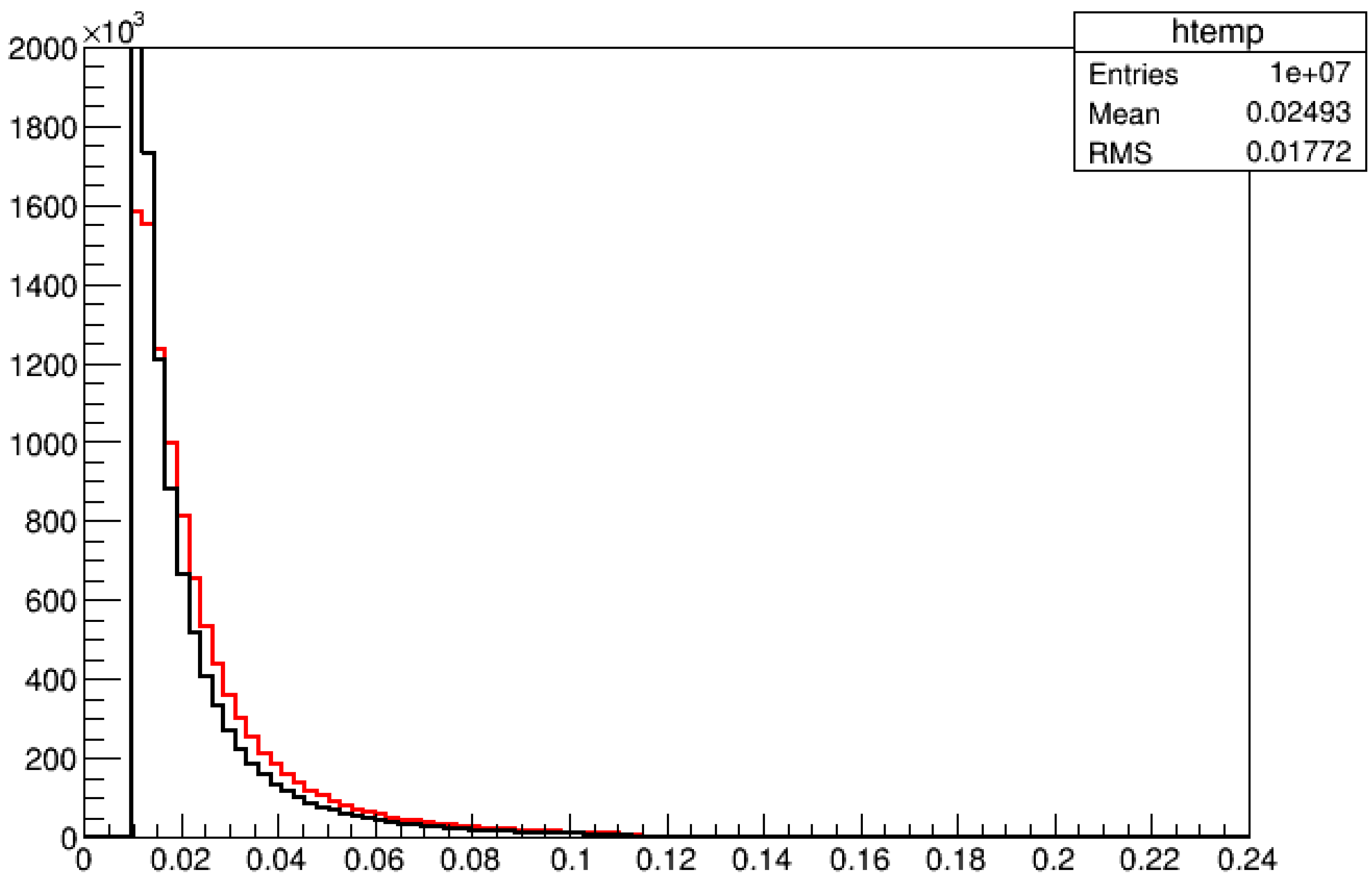
- Finalise the simulation and validate the radiative correction with ep data
- Obtain new data with more relevant nuclei, energies and processes.

Backup

Radiative Effects in GENIE

Expected validation from ep data - in the coming week

E = 0.292 GeV



E^{l}-$E^{l'}$

Radiative Effects in GENIE

Expected validation from ep data - for validation

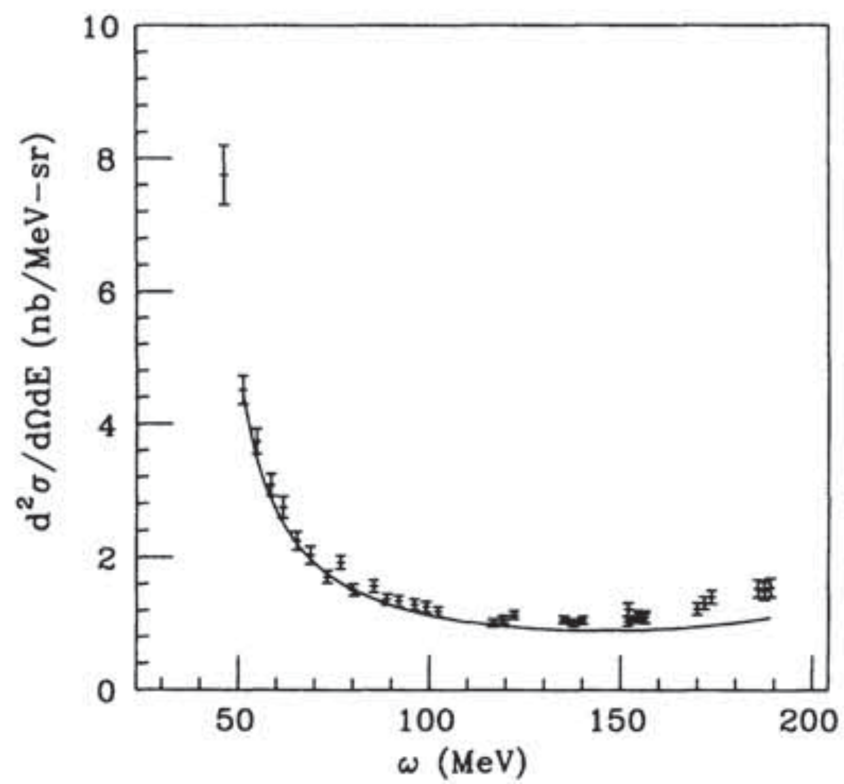
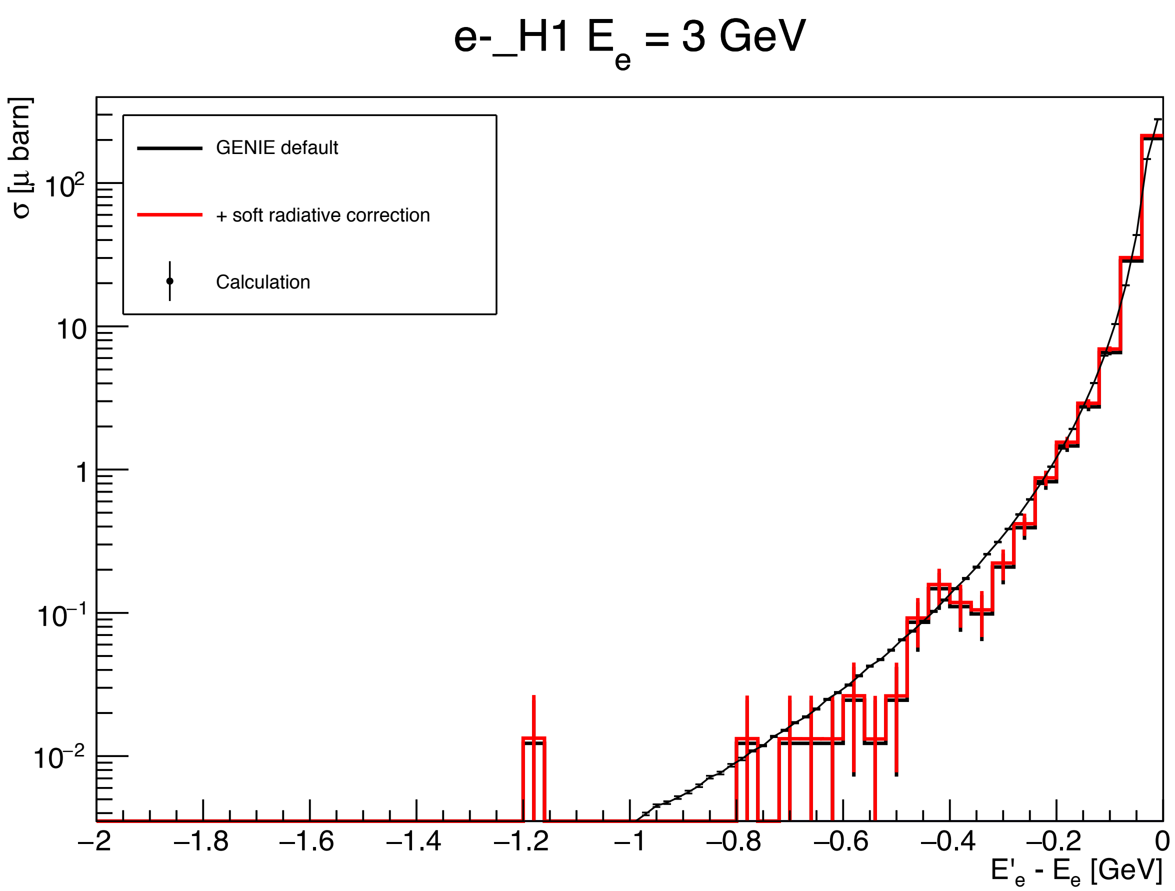
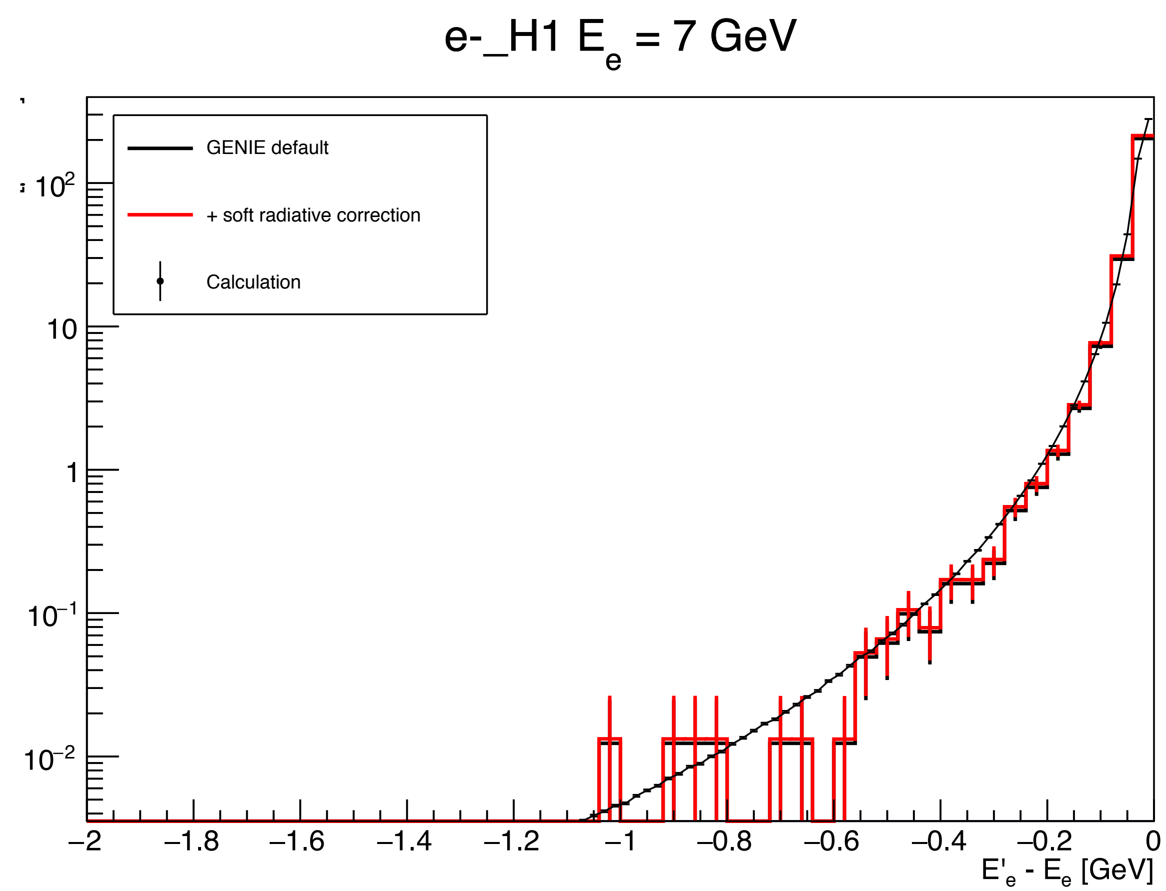


FIG. 6. A series of measurements of the ^1H cross section is shown. In the region below the pion-production threshold only the radiative tail of the elastic peak contributes. The solid line shows the predicted radiative tail found from the formalism of Mo and Tsai (Ref. 21) and a parametrization of previous ^1H elastic scattering cross sections (Ref. 23). The agreement is found to be good, indicating that the radiative properties of the target are well understood and that no unexpected background exists.

Radiative Effects in GENIE

Comparison to calculation - validation





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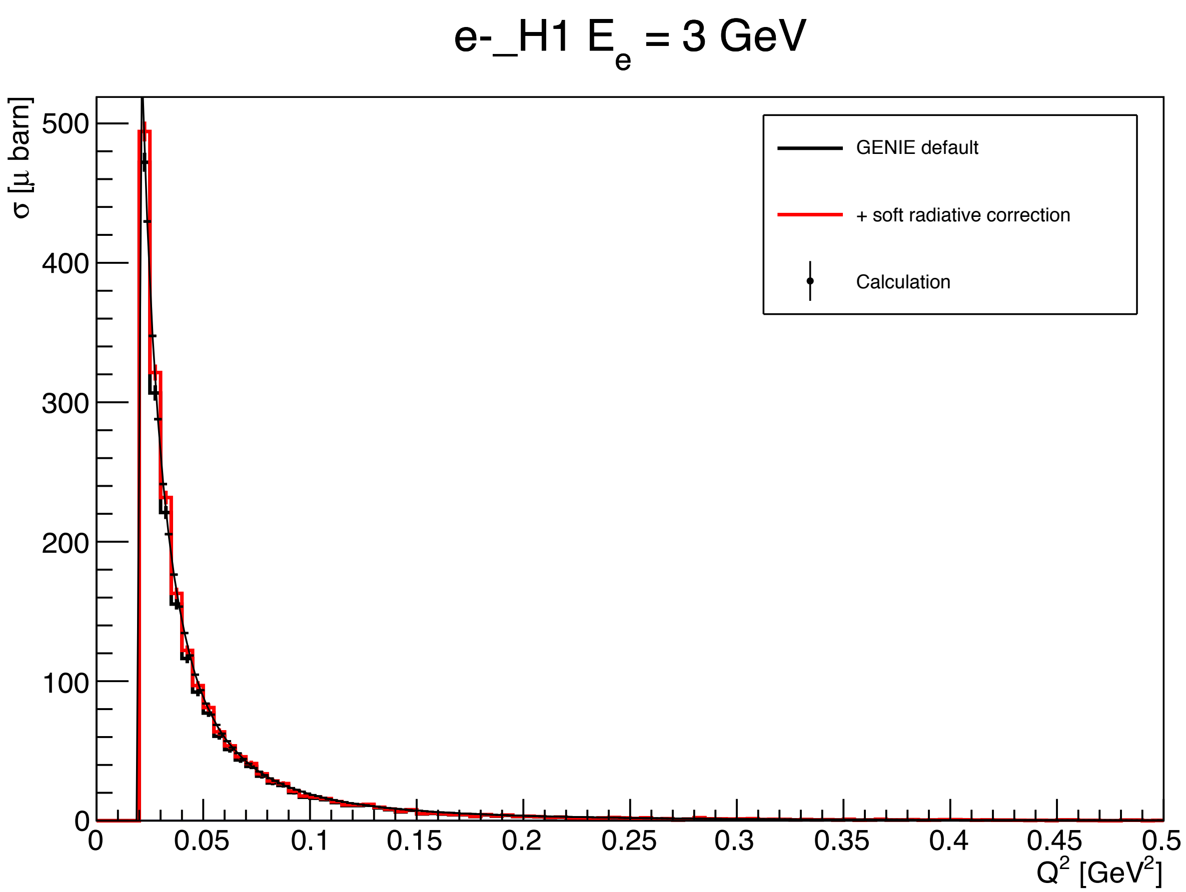

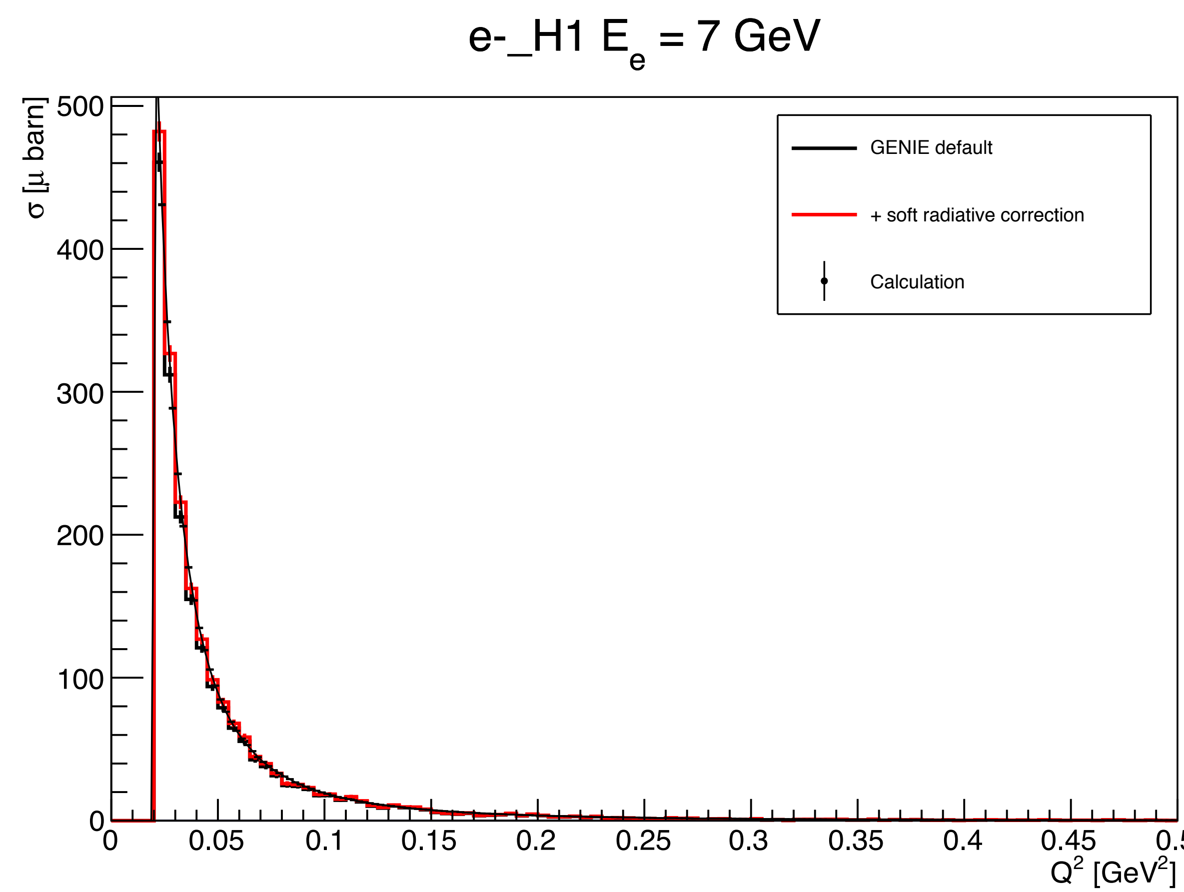

Radiative Effects in GENIE

Expected validation from ep data - in the coming week

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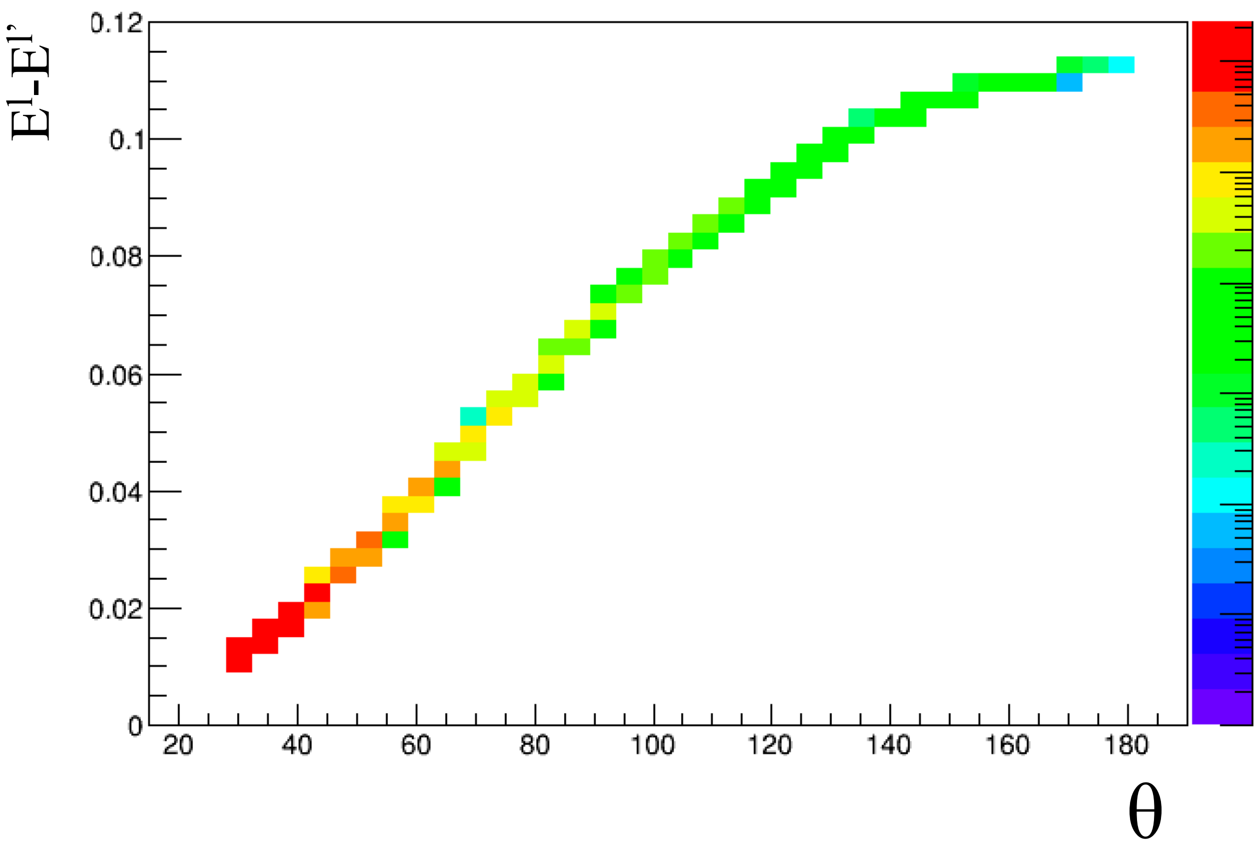
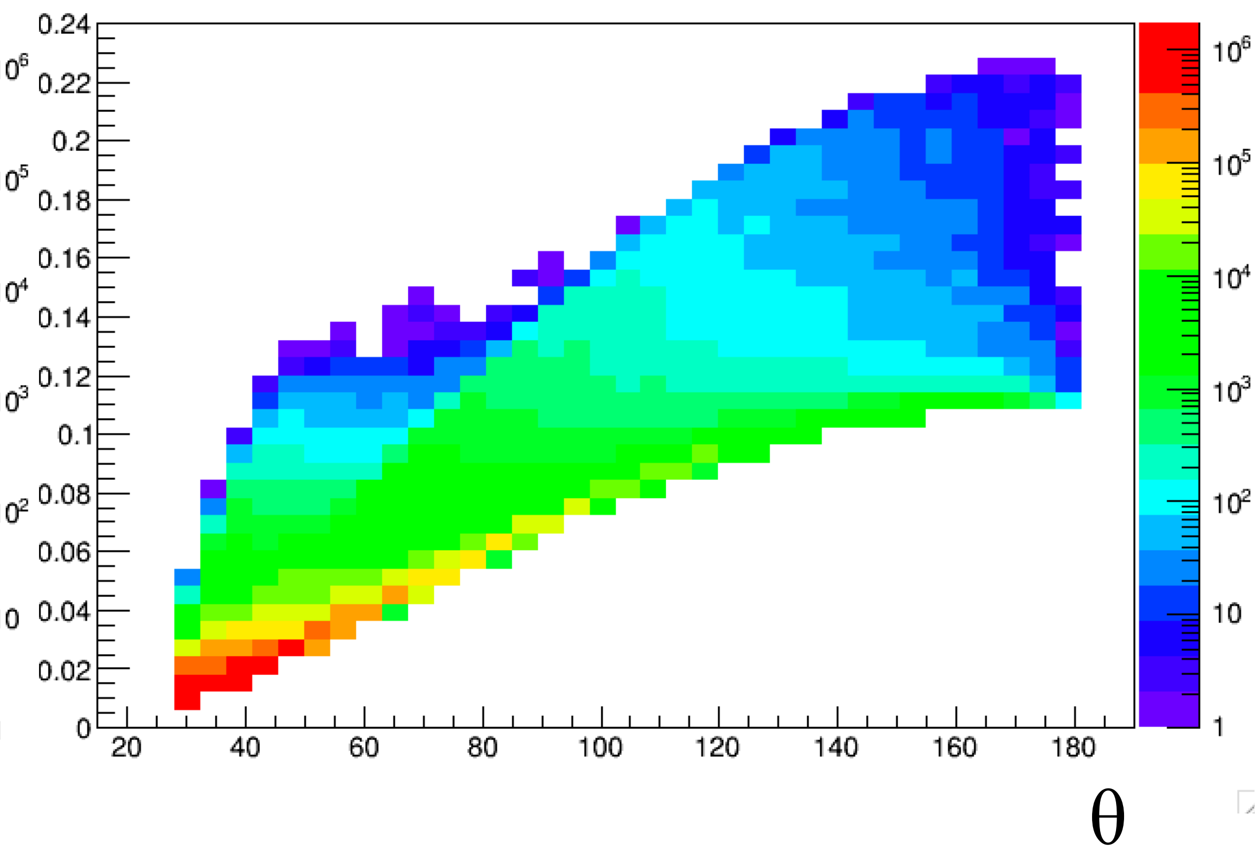
GENIE Default



w. Radiative correction



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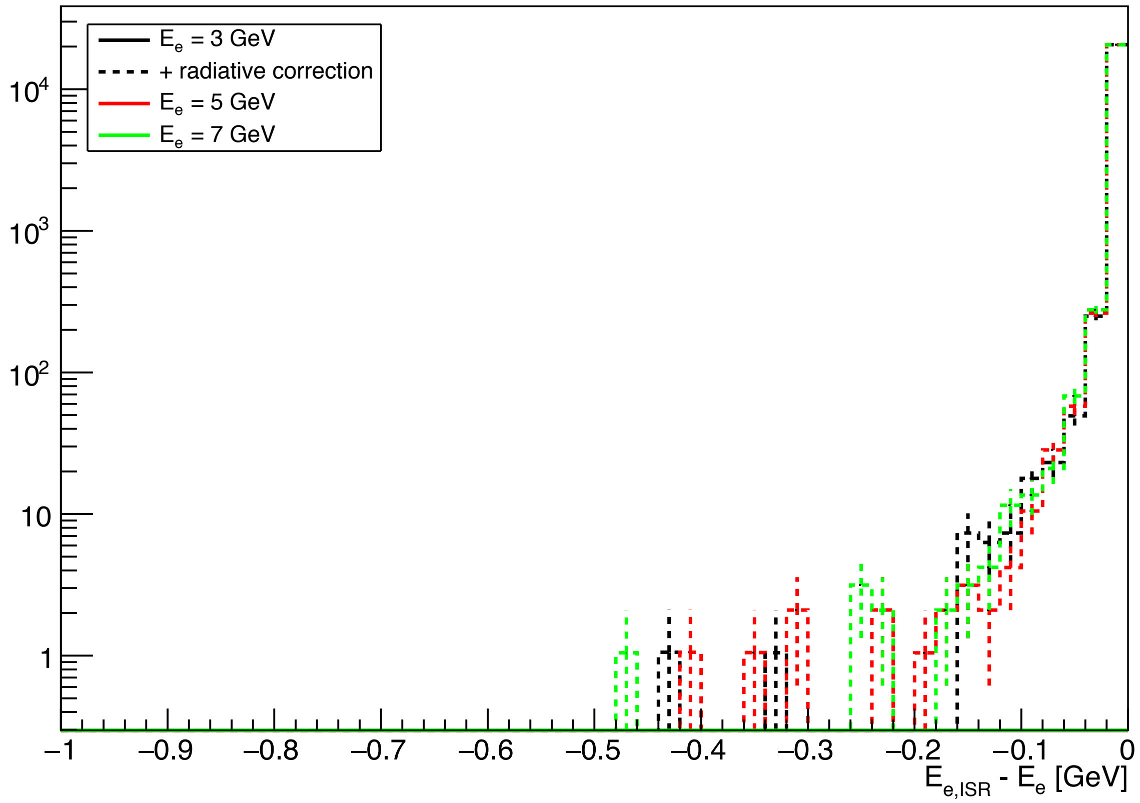

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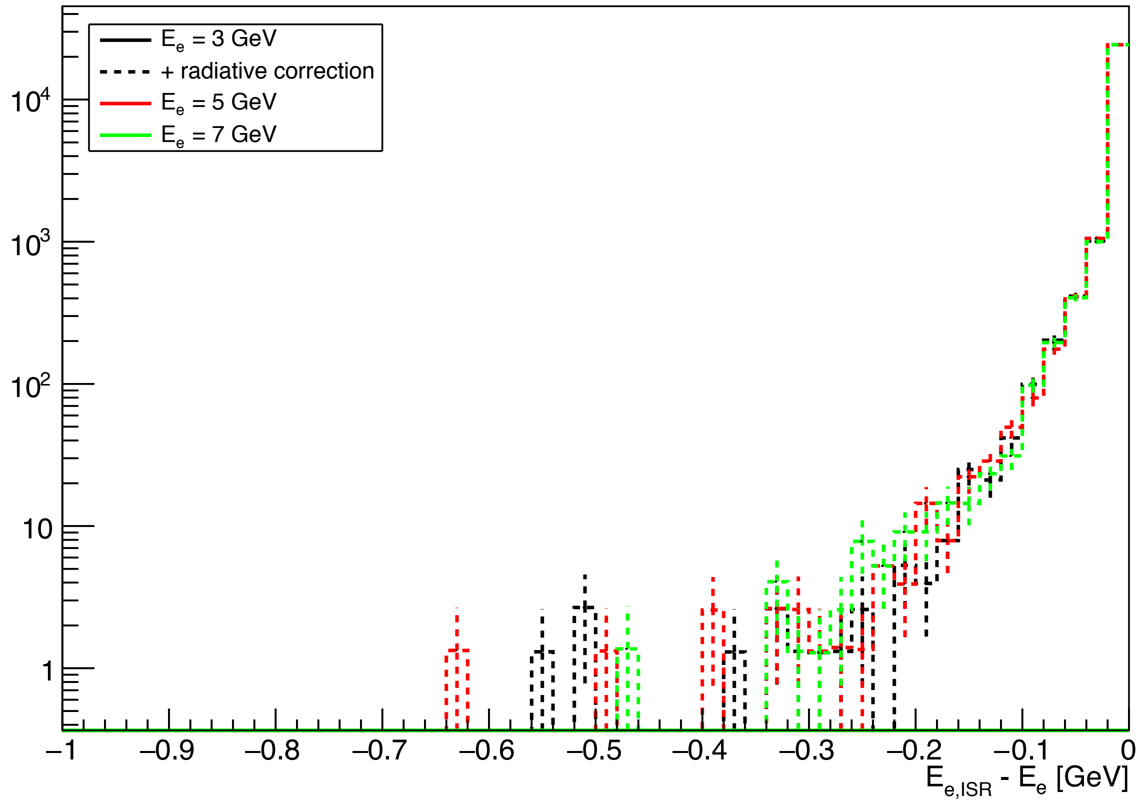
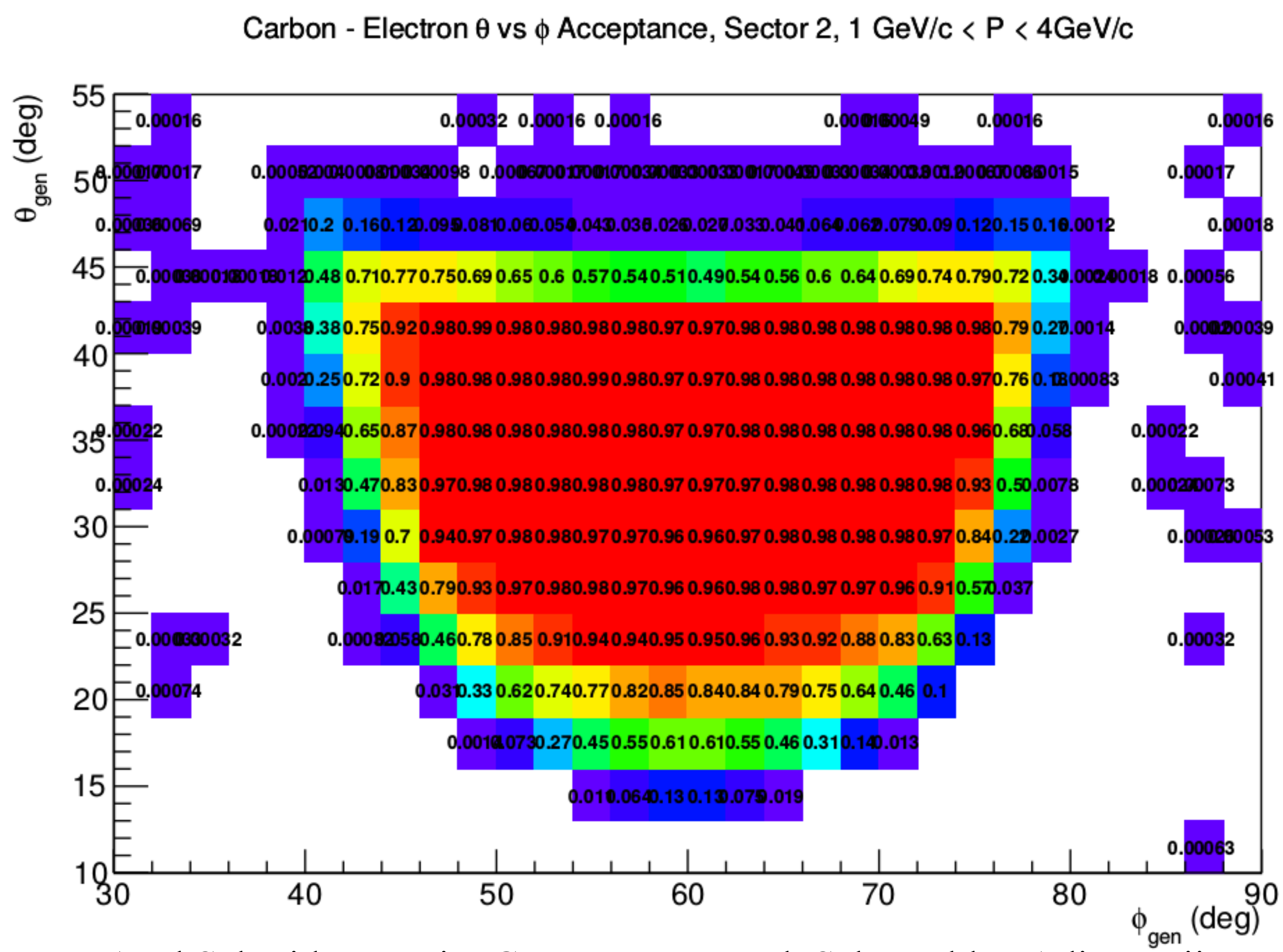


^{12}C

CLAS: Acceptance maps availble

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

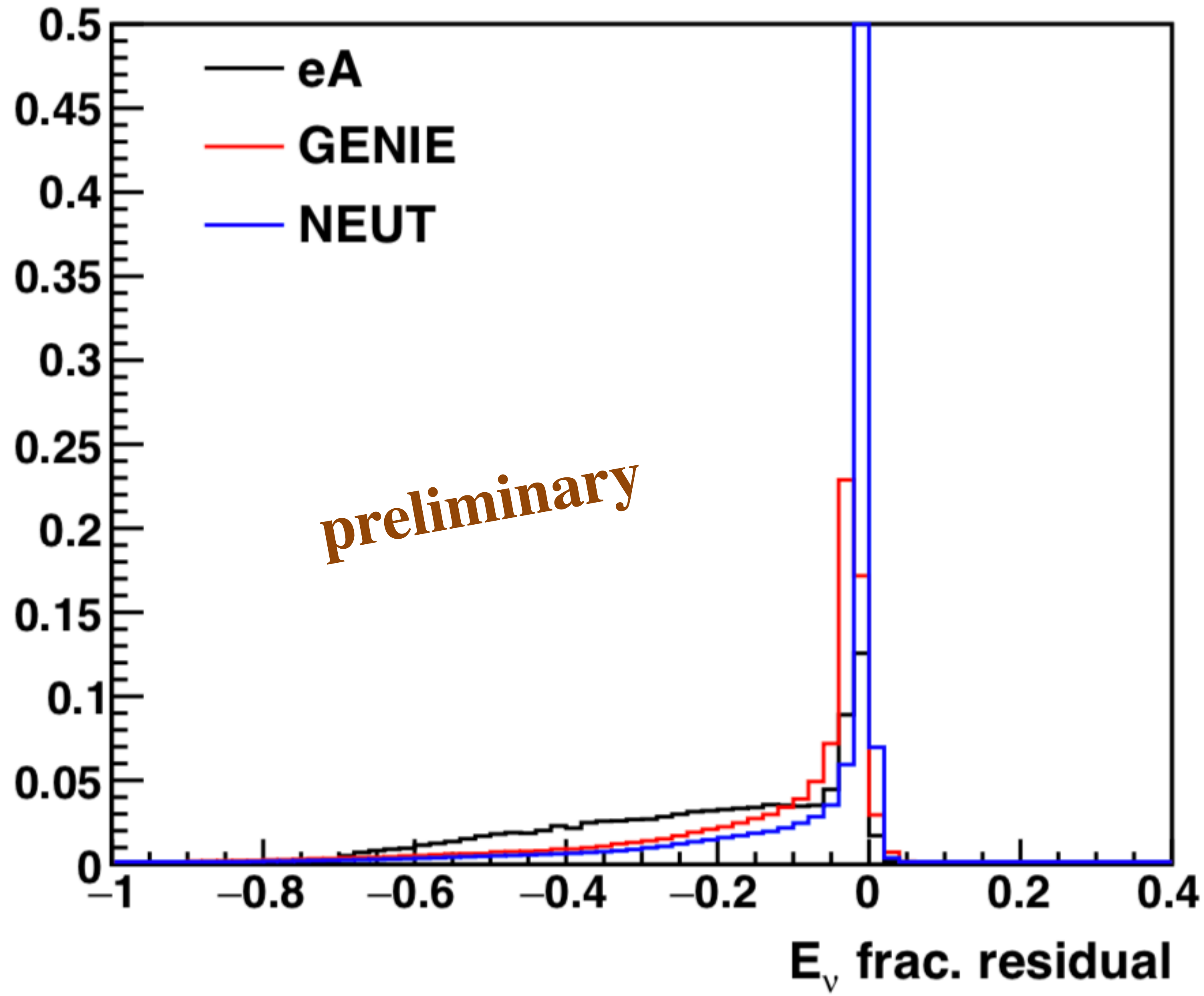
- Target
- Particle type
- Particle momentum



Axel Schmidt, Reynier Cruz Torres, Barak Schmookler, Adin Hrnjic

Potential implication on DUNE analysis

The expected energy at DUNE far detector as reconstructed using the energy feed down from A(e,e'p) data and simulation



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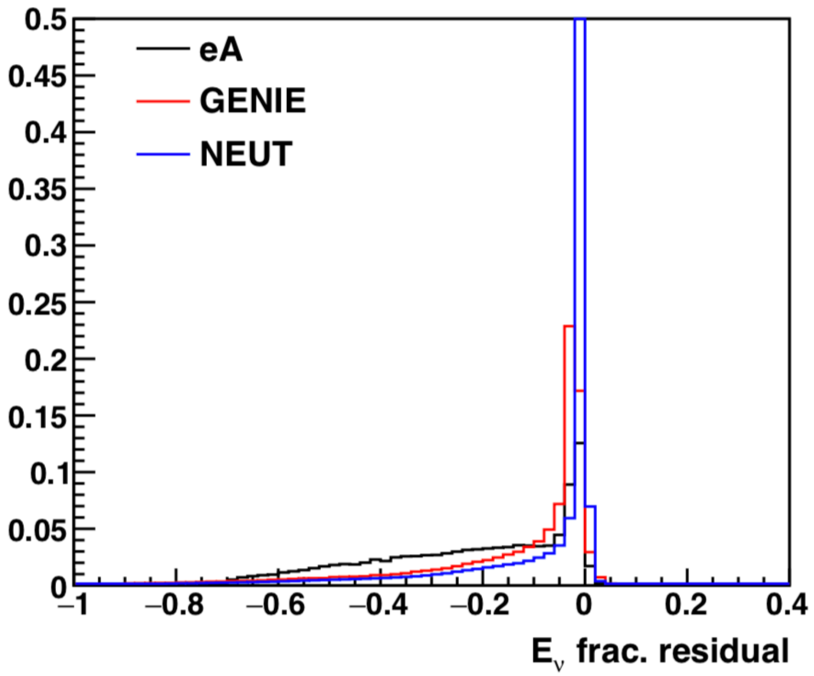
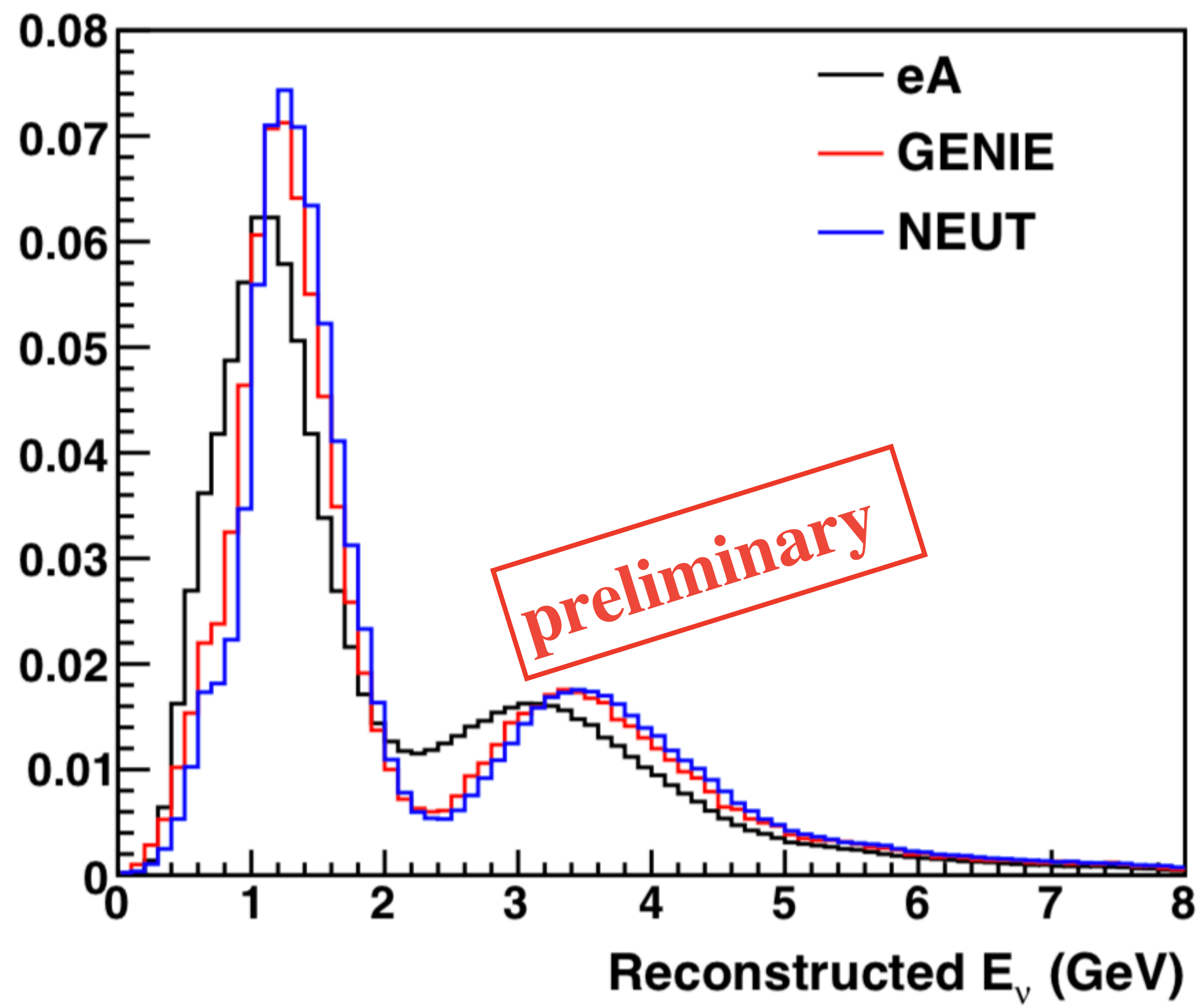


→



Un-modelled nuclear effects can be mistakingly considered as oscillation effects

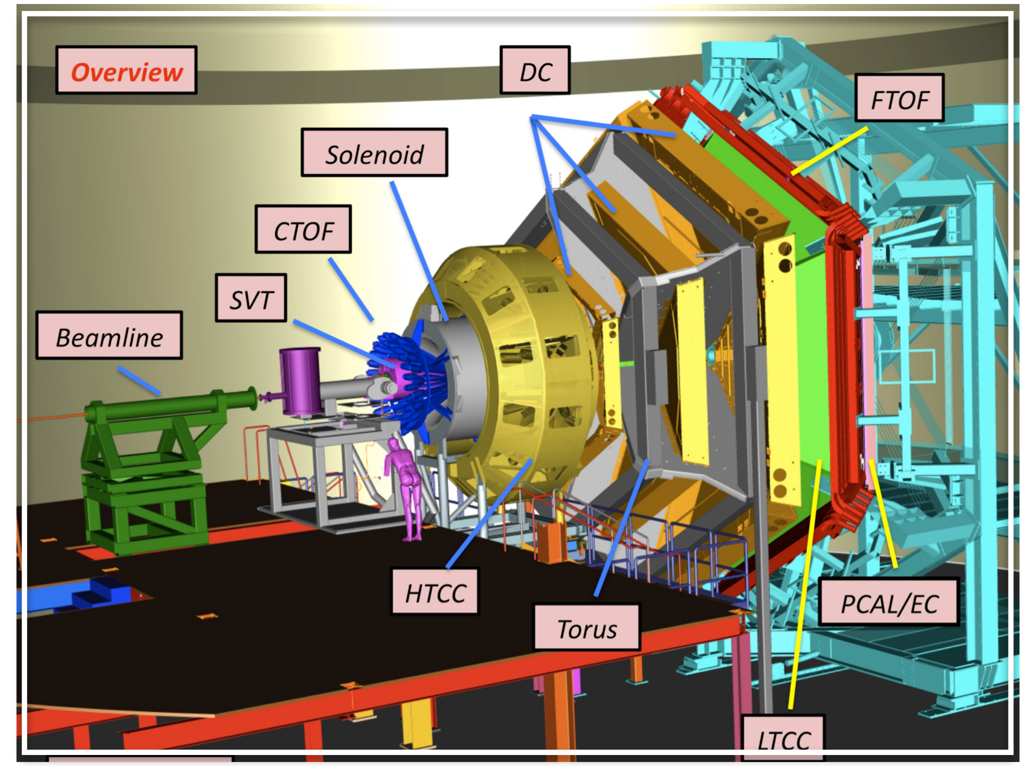
Future Plans -Approved run for CLAS12

Ten times more luminosity

Keeping the low threshold 300 MeV/c

Targets: ^{2}D, ^{4}He, ^{12}C, ^{16}O, ^{40}Ar, ^{120}Sn

Incoming 1 - 7 GeV relevant for DUNE incoming flux



Overwhelming support from:

Fermilab

Hyper-Kamiokande

DUNE

MINERvA

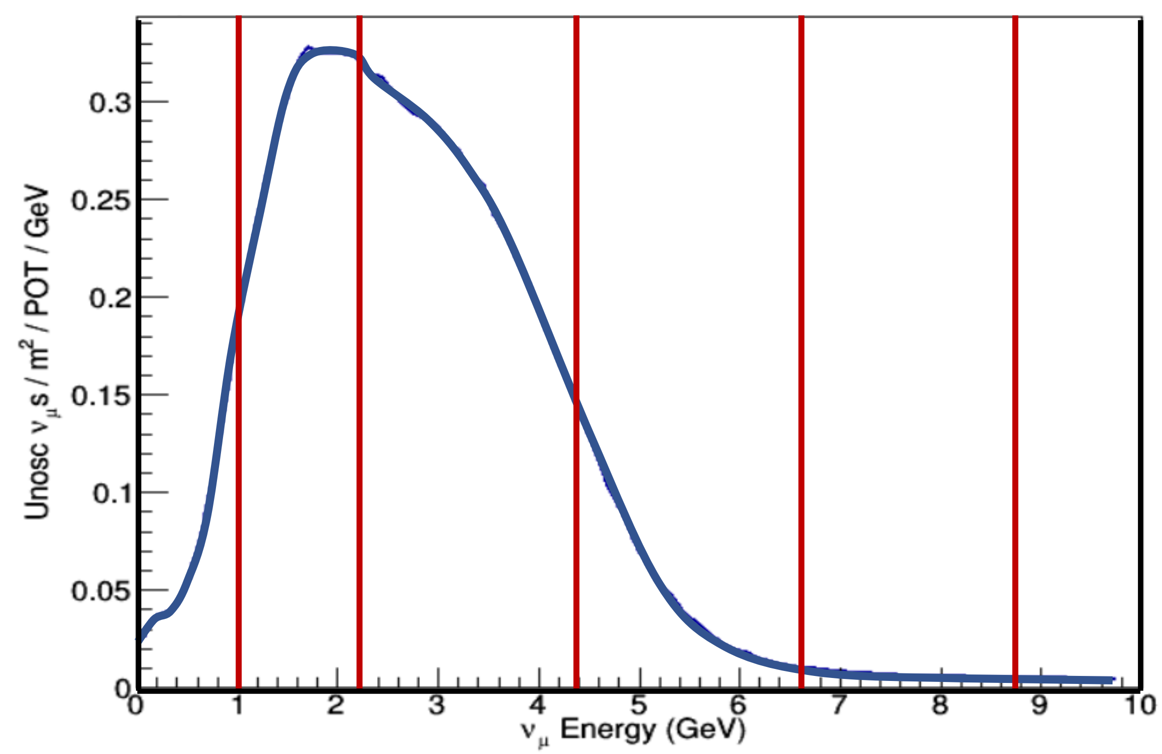
ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

NOvA

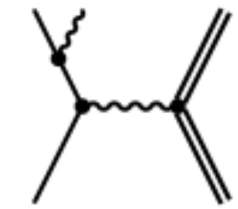
T2K

μBooNE

GiBUU The Giessen Boltzmann-Uehling-Uhlenbeck Project



Radiative Effects in GENIE



Initial State Radiation

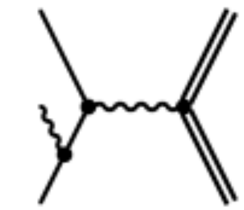
For the ISR, relevant only for the electron scattering case.

Energy and momentum are omitted from the initial state probe .

note:
- not recording the probe energy before radiating a photon.
- not recording the emitted photon.
- Q2 will also change with the new probe energy.

GENIE notes:
the change was done in:
- The initial state probe in InitialState using SetProbeE(energy)
- The particle at slot 0 in GHepRecord

Radiative Effects in GENIE



Final State Radiation

Final state radiation should be applicable for both electron and neutrino mode.

The final state electron was decayed, and a final state photon was added.

GENIE notes:
- The decayed electron is still recorded with a status of 3 (decayed state)
- The probe's daughters are changed for the new final state lepton.

Radiative Effects in GENIE

Cross Section

Due to the radiative correction the cross section for a given interaction is changed.

We've added a weight to each event which is dependent on the initial and final state kinematic variables.

note: for the incoming neutrino case the weight will of course be different.

Radiative Correction

The radiated photon should have a maximal limit.
In many models this limit is dependent on the final state kinematics.

Previously we’ve used:

- The lepton momentum, but for large Eγ the approximation is not valid
- 10% or 30% of the lepton momentum, but we were sensitive to that cut off

Nowadays,
We have to apply a final state dependent cut off for the energy loss
Energy difference in the process E - E’ (Peskin)

Radiative Effects in GENIE

Introducing a new class
currently implemented in a private branch:

src/EVGModules/RadiativeCorrector.C
src/EVGModules/RadiativeCorrector.h

The module is being called twice:

```
<param_set name=“QEL-EM-radcorr">
  <param type="string" name="VldContext"> </param>
  <param type="int"    name="NModules">  16                                                </param>
  <param type="alg"    name="Module-0">     genie::InitialStateAppender/Default                </param>
  <param type="alg"    name="Module-1">     genie::VertexGenerator/Default                     </param>
  <param type="alg"    name="Module-2">     genie::FermiMover/Default                          </param>
  <param type="alg"    name="Module-3">     genie::QELKinematicsGenerator/EM-Default           </param>
  <param type="alg"    name="Module-4">     genie::QELPrimaryLeptonGenerator/Default           </param>
  <param type="alg"    name="Module-5">     genie::RadiativeCorrector/ISR                      </param>   Emitting ISR photon
  <param type="alg"    name="Module-6">     genie::QELKinematicsGenerator/EM-Default           </param>
  <param type="alg"    name="Module-7">     genie::QELPrimaryLeptonGenerator/Default           </param>
  <param type="alg"    name="Module-8">     genie::QELHadronicSystemGenerator/Default          </param>
  <param type="alg"    name="Module-9">     genie::PauliBlocker/Default                        </param>
  <param type="alg"    name="Module-10">    genie::UnstableParticleDecayer/BeforeHadronTransport </param>
  <param type="alg"    name="Module-11">    genie::NucDeExcitationSim/Default                  </param>
  <param type="alg"    name="Module-12">    genie::HadronTransporter/Default                   </param>
  <param type="alg"    name="Module-13">    genie::NucBindEnergyAggregator/Default             </param>
  <param type="alg"    name="Module-14">    genie::UnstableParticleDecayer/AfterHadronTransport </param>
  <param type="alg"    name="Module-15">    genie::RadiativeCorrector/FSR                      </param>   Emitting FSR photon
                                                                                                         + applying weight
  <param type="alg"    name="ILstGen">   genie::QELInteractionListGenerator/EM-Default         </param>
</param_set>
```

Radiative Effects in GENIE

Models:

1. Mo & Tsai as recommended by Vanderhagen
2. Full calculation as will be done by Dr. Doreen Wackeroth and Daniel Crowe from the University at Buffalo, coordinated by Minerba Beatancourt
3. Any other model

Vanderhagen approach

Theory

Based on PHYSICAL REVIEW C, VOLUME 62, 025501 VanderHagen The energy loss, ΔE , can be sampled using the distribution:

$$I_{int}(E, \Delta E, a) = \frac{a}{\Delta E}(\frac{\Delta E}{E})^{a}$$

where E is the incoming electron energy:

$$a = \frac{\alpha_{EM}}{\pi}[ln(\frac{Q^2}{m^2}) - 1]$$

An event cross section should be weighted by:

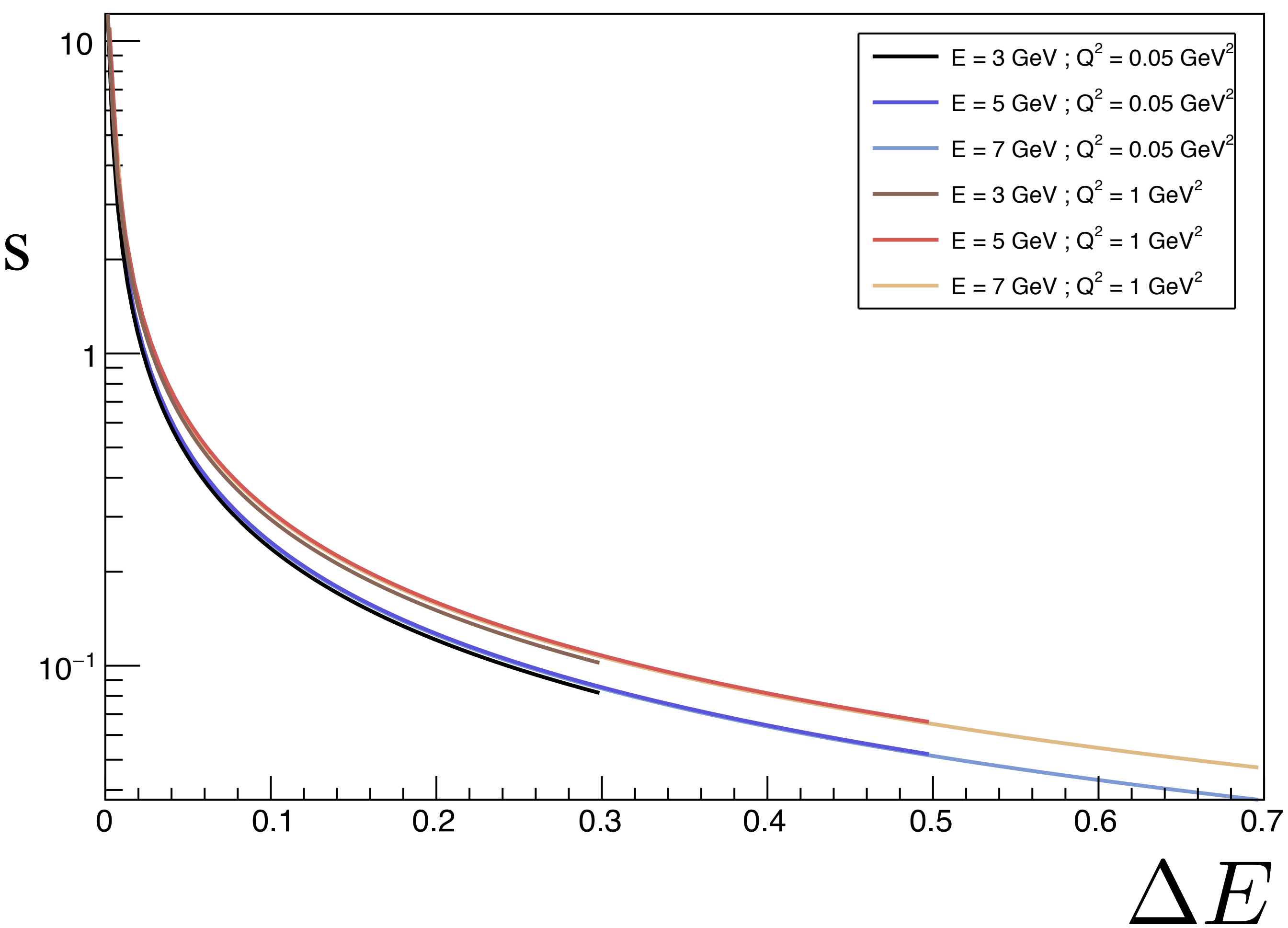
$$\left(\frac{d\sigma}{d\Omega'_e}\right)_{VIRTUAL\gamma} + \left(\frac{d\sigma}{d\Omega'_e}\right)_{REAL\,SOFT\gamma} = \left(\frac{d\sigma}{d\Omega'_e}\right)_{BORN}(1+\delta_{vac}+\delta_{vertex}+\delta_R),$$

$$\delta_{vac}+\delta_{vertex}+\delta_R = \frac{\alpha_{em}}{\pi}\left\{\ln\left(\frac{(\Delta E_s)^2}{E_e E'_e}\right)\left[\ln\left(\frac{Q^2}{m^2}\right)-1\right] + \frac{13}{6}\ln\left(\frac{Q^2}{m^2}\right) - \frac{28}{9} - \frac{1}{2}\ln^2\left(\frac{E_e}{E'_e}\right) - \frac{\pi^2}{6} + Sp\left(\cos^2\frac{\theta_e}{2}\right)\right\}$$

Radiative Effects

Theory

$\propto P(\Delta E)$
Probability
for Energy Loss



Radiative Effects in GENIE

Current Status

Incubator Projects

[Currently in incubation] - [Graduated from incubation] - [Retired from incubation]

Incubator projects are in-house development activities or community development efforts led by the GENIE WG Coordinators and overseen by the GENIE board. An incubator project is the **unique route for any physics or software development into any of the GENIE suite products** (Generator, Comparisons, Tuning).

This page serves the purpose of informing the community for the scope and breadth of the GENIE development programme. Community members that have a wish to contribute to GENIE and identify the need for a new project are strongly encouraged to contact the GENIE WG Coordinators who, upon fully defining the scope and specification, can launch new incubator projects.

Currently in incubation: 23 projects

Project: ***radiative_effects_for_electron_scattering***
Description: Adding radiative effects to electron scattering processes in GENIE.
Developers: Adi Ashkenazi (MIT)
Reporting: NPWG
Target release: GENIE/Generator v3.0.0
Documentation: internal wiki

Project: ***electron_scattering_form_factors***
Description: Update Form Factors (FFs) for electron scattering processes in GENIE, and enable future similar updates
Developers: Adi Ashkenazi (MIT)
Reporting: NPWG
Target release: GENIE/Generator v3.0.0
Documentation: internal wiki

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