e4ν NuSTEC Tutorial

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For the e4ν collaboration

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Objective

Goal: Allow independent theory predictions to apply the e4ν signal definition

and to make these results easily comparable to the published ones

Main results correspond to truth-level cross section predictions

One requires detector acceptance effects

Tutorial Overview

Dedicated github branches

- e4ν truth level predictions
- e4ν particle multiplicities

Prerequisite: ROOT 6

Expected input file in GENIE gst root format

e4ν Truth Level Prediction Code

```
# pulling the e4ν_truth code
git clone  https://github.com/adishka/e4nu.git e4v_truth
cd e4v_truth
git checkout e4v_truth
make clean; make

# running the code
 ./genie_analysis C12 1161
```

- Specify the target (56Fe, C12, 4He)
- The beam energy (1161, 2261 or 4461)

```
# changing path to input file in line 301 of genie_analysis.h
# don't forget to
# make clean;make
```

e4ν Signal Definition In README File

```
1) Min Q2 threshold
        a) Q2 > 0.1 GeV^2/c^2 @ 1.1 GeV
        b) Q2 > 0.4 GeV^2/c^2 @ 2.2 GeV
        a) Q2 > 0.8 GeV^2/c^2 @ 4.4 GeV

2) Min outgoing electron momentum
        a) Pe > 0.40 GeV/c @ 1.1 GeV
        b) Pe > 0.55 GeV/c @ 2.2 GeV
        c) Pe > 1.10 GeV/c @ 4.4 GeV

3) Min electron angle
        a) theta_e > 17 + 7 / Pe @ 1.1 GeV [deg]
        b) theta_e > 16 + 10.5 / Pe @ 2.2 GeV [deg]
        c) theta_e > 13.5 + 15 / Pe @ 1.1 GeV [deg]

4) Invariant mass W < 2 GeV^{2}/c^{2}

5) 1 proton above threshold Pp > 0.3 GeV/c & theta_p > 12 deg

6) 0 charged pions above threshold Ppi > 0.15 GeV/c

7) Min pi+ angle > 12 deg

8) Min pi- angle
        a) theta_pi- > 17 + 4 / Ppi- @ 1.1 GeV [deg]
        b) theta_pi- > 25 + 7 / Ppi- @ 2.2/4.4 GeV [deg] for Ppi- < 0.35 GeV/c
           theta_pi- > 16 + 10 / Ppi- @ 2.2/4.4 GeV [deg] for Ppi- > 0.35 GeV/c


9) 0 photons above threshold Pgamma > 0.3 GeV/c
```

From Events To Cross Sections

```
void UniversalE4vFunction(TH1D* h, TString DataSetLabel, TString nucleus, TString E, TString name) {

    // Scale by GENIE cross section/total number of events
    AbsoluteXSecScaling(h,DataSetLabel,nucleus,E);

    // e4v binning
    ApplyRebinning(h,E,name);

    // Bin width division
    ReweightPlots(h);

    // Relevant X-range ranges
    ApplyRange(h,E,name);

}
```

Provided that new theory model is implemented in GENIE,
two elements needed to obtain cross sections

```
// SuSav2 GENIE spline xsec // 10^{-38} cm^2

static std::map<std::pair<TString,TString>,double> SuSav2GenieXSec =
{
        { std::make_pair("4He", "2_261"), 8.30934e+07 }, // Q2 > 0.4
        { std::make_pair("4He", "4_461"), 3.01721e+07 }, // Q2 > 0.8
        { std::make_pair("12C", "1_161"), 1.28967e+09 }, // Q2 > 0.1
        { std::make_pair("12C", "2_261"), 2.1024e+08 }, // Q2 > 0.4
        { std::make_pair("12C", "4_461"), 8.36795e+07 }, // Q2 > 0.8
        { std::make_pair("56Fe", "2_261"), 9.66272e+08 }, // Q2 > 0.4
        { std::make_pair("56Fe", "4_461"), 3.84607e+08 } // Q2 > 0.8
};
```

Cross section obtained by GENIE

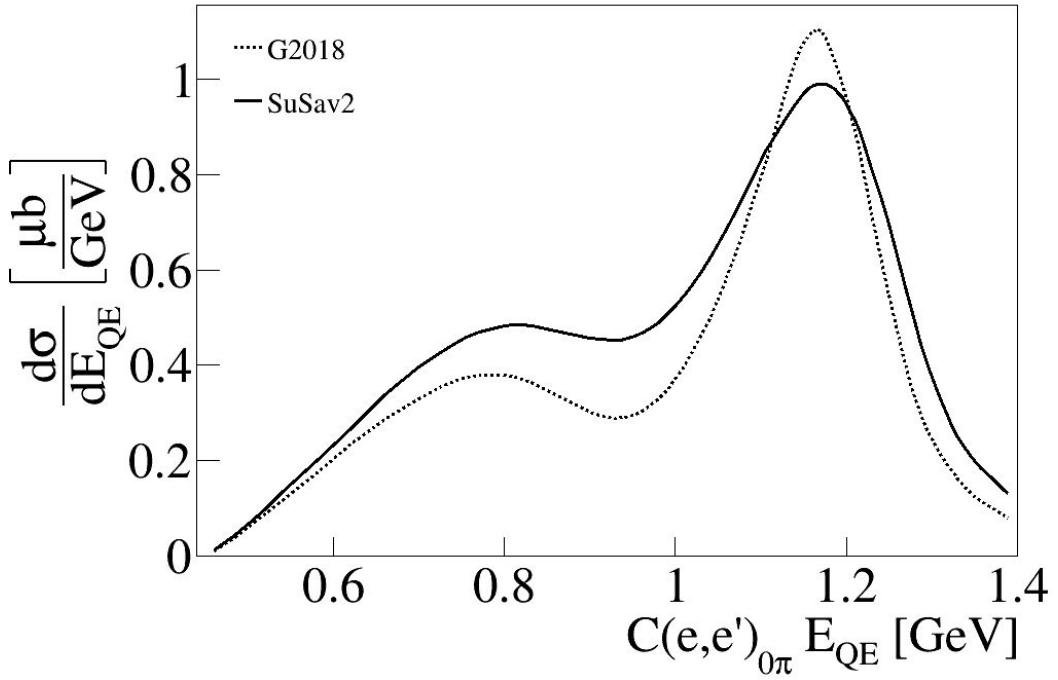
```
// No Rad SuSav2 GENIE number events

static std::map<std::pair<TString,TString>,double> NoRadSuSav2NumberEvents =
{
        { std::make_pair("4He", "2_261"),  20000000 }, // Q2 > 0.4
        { std::make_pair("4He", "4_461"),  17700000 }, // Q2 > 0.8
        { std::make_pair("12C", "1_161"),  19800000 }, // Q2 > 0.1
        { std::make_pair("12C", "2_261"),  174600000 }, // Q2 > 0.4
        { std::make_pair("12C", "4_461"),  164300000 }, // Q2 > 0.8
        { std::make_pair("56Fe", "2_261"), 167000000 }, // Q2 > 0.4
        { std::make_pair("56Fe", "4_461"), 190600000 } // Q2 > 0.8
};
```

Total number of events produced

e4ν Cross Sections

cd PlottingCode
root -l PlotGenieAbsXSec.cpp

Demo #1

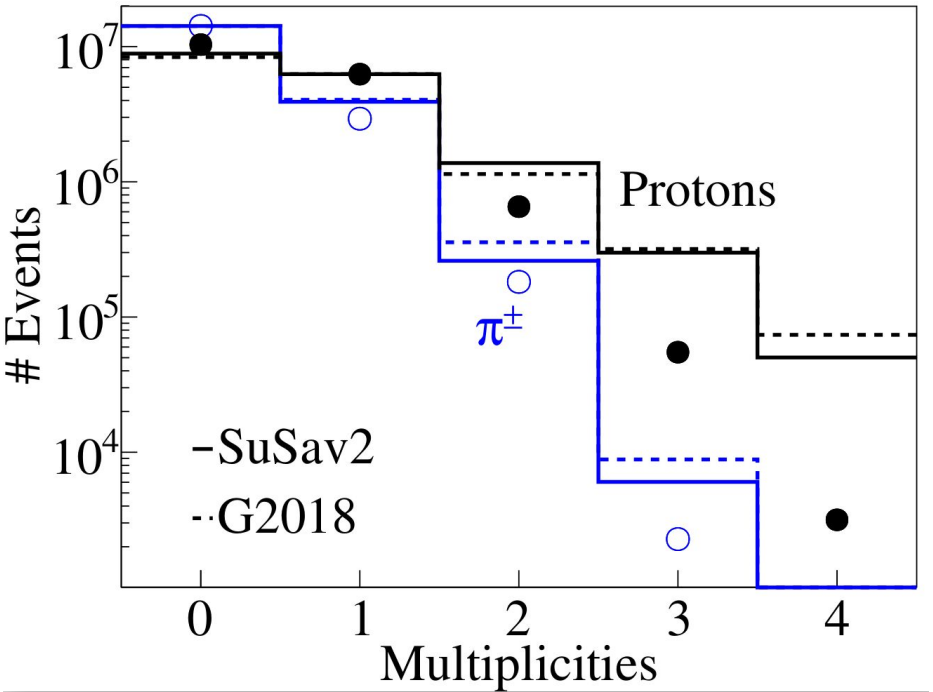


e4ν Particle Multiplicities

CLAS Fiducial Cuts & Acceptance Maps Release

```
# pulling the e4ν_multiplicity code
git clone  https://github.com/adishka/e4nu.git e4v_multiplicity
cd e4v_multiplicity
git checkout e4v_multiplicity
make clean; make

# run the code
 ./genie_analysis C12 1161
```

- Specify the target (56Fe, C12, 4He)
- The beam energy (1161, 2261 or 4461)

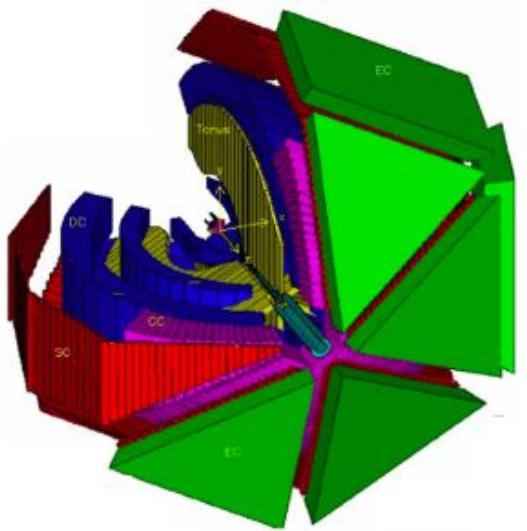


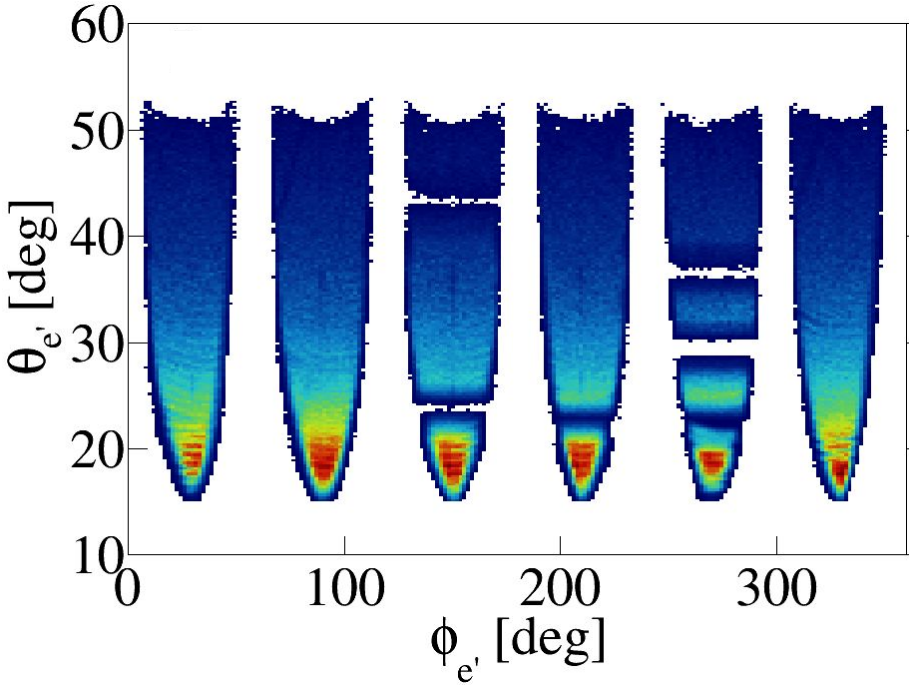
CLAS Fiducial Cuts

Relevant code located in Fiducial.{C,h}. Dependence on momentum / θ & φ angles

Relevant functions

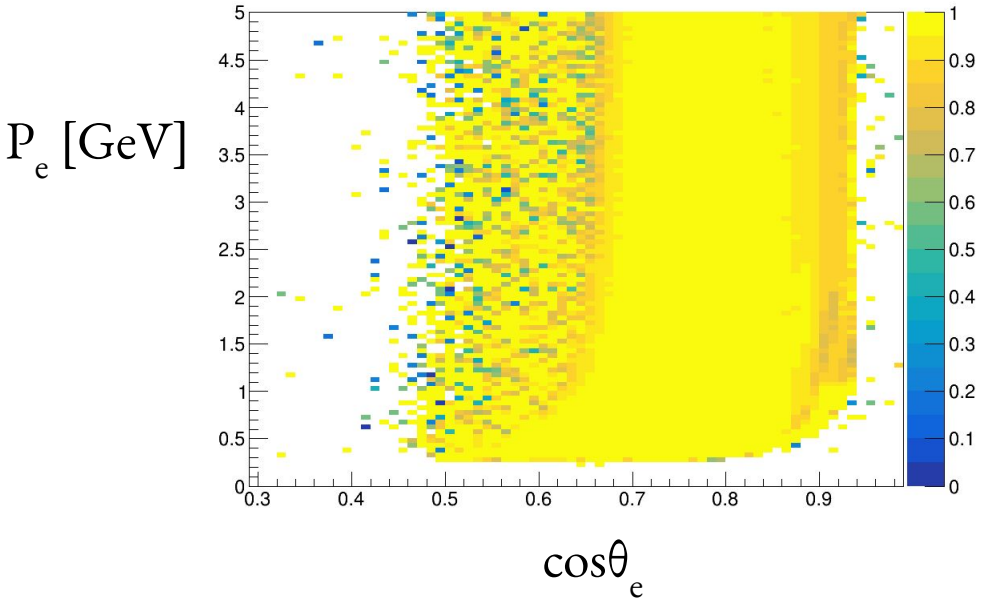
- p: PFiducialCut
- e: EFiducialCut
- γ/π: Pi_phot_fid_united

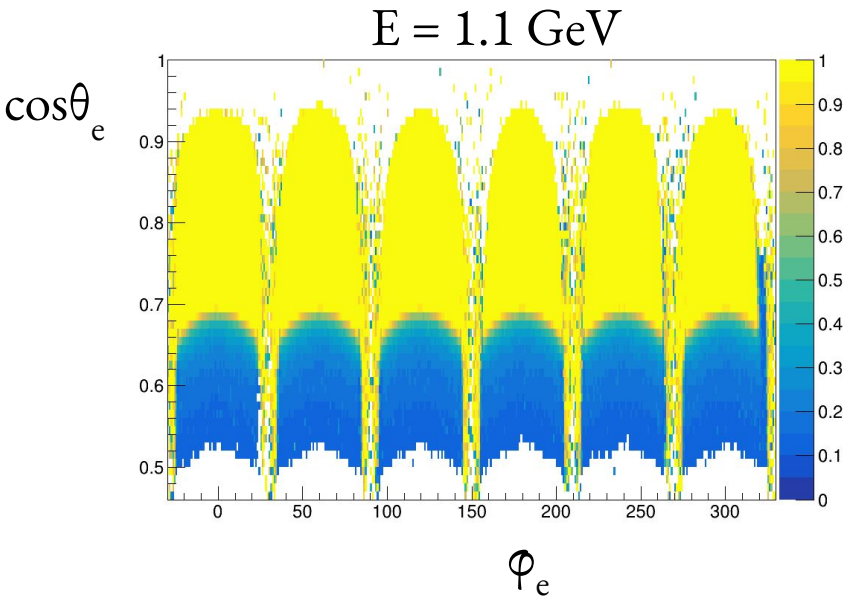




Acceptance Maps

Lines 434-469 in genie_analysis.C control the acceptance_c function
Depending on momentum & directionality, we assign an extra MC weight to account for detector acceptance effects





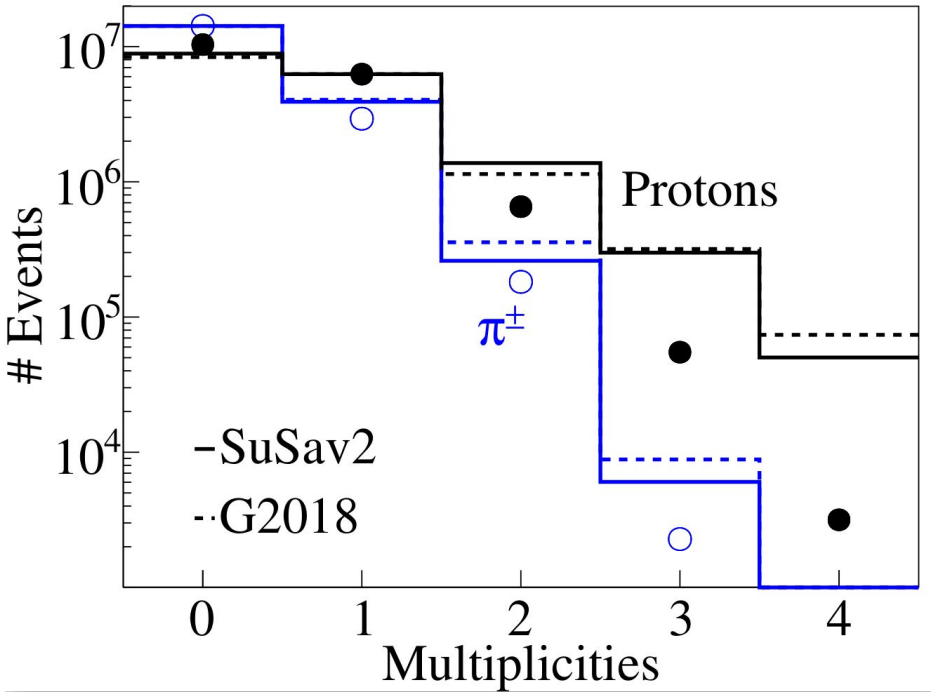
e4ν Multiplicities

cd Results_C
root -l 12C_2_261_Multiplicities.C

Demo #2

MC proton multi-1 channel multiplicity normalized to data

MC charged pion multi-0 channel multiplicity normalized to data



Data Release & Code Available Online

e4ν Electrons for Neutrinos Collaboration

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Leveraging electron scattering data to improve neutrino interaction modeling

The extraction of mixing parameters in accelerator-based neutrino oscillation measurement relays on detailed understanding of neutrino-nucleus interactions and the reconstruction of incident neutrino energy. With improved detection technologies and neutrino production beams, nuclear interaction uncertainties are becoming a leading and limiting systematic for the analysis of neutrino oscillation measurements.

Building on the large similarity of electron- and neutrino-nucleus interactions, the electrons-for-neutrino collaboration is leading a set of precision electron-nucleus interaction measurements at various beam energies and target nuclei to test, constrain, and validate models of neutrino-nucleus interactions.

We welcome all collaborators to join our e4nu effort.

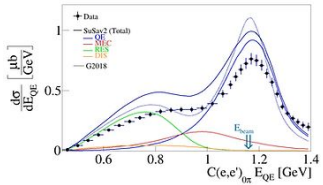
Feel free to contact us with any questions!

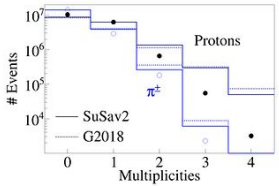
If you are interested in reproducing our results, please see links and brief discussion below

Some basic requirements include:

1. A build of `CERN ROOT`
2. Access to the e4nu Software from `GitHub`

To reproduce our plots, see the `Results_C/` folder within the `github`, and you can run each of these within a `ROOT` session to produce the plots; you can also directly view the bin contents of each plot. Here are a few examples:





Easily Reproducible e4ν Results

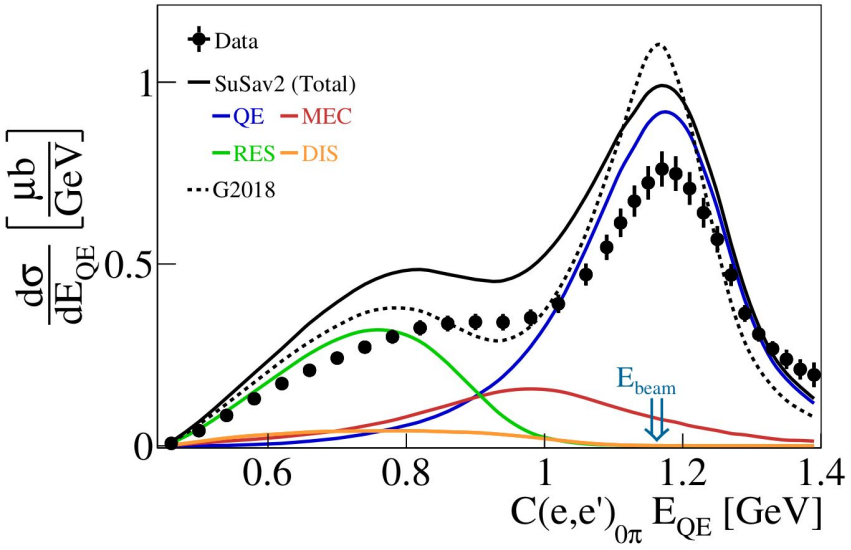
master ▾ e4nu / Results_C /

afropapp13 Feb 14 2022: 1) adding C files

..

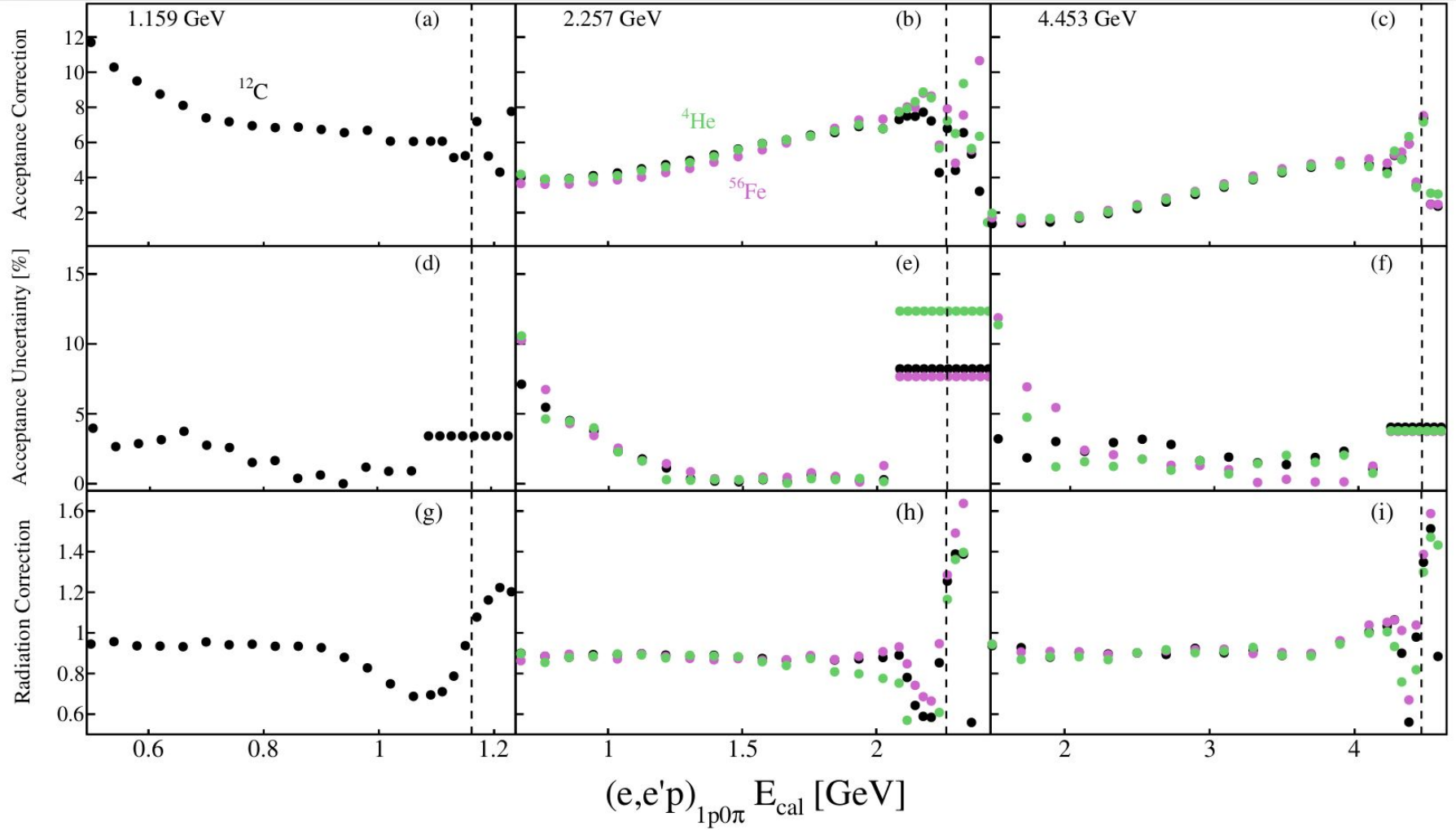
- 12C_1_161_EQE.C
- 12C_2_261_ECalInPTSlices_NoxBCut.C
- 12C_2_261_Multiplicities.C
- 12C_2_261_PT.C
- 12C_ECal_Feeddown.C
- 12C_EQE_Feeddown.C
- 56Fe_ECal_Feeddown.C
- 56Fe_EQE_Feeddown.C
- Correction_Panel.C
- DataXSec_Inclusive_Validation.C
- DeltaAlphaT_Panel.C
- DeltaPT_Panel.C
- DeltaPhiT.C
- ECal_Panel.C
- Fluxes.C
- SubtractionEffect.C

cd e4nu/Results_C
root -l 12C_1_161_EQE.C



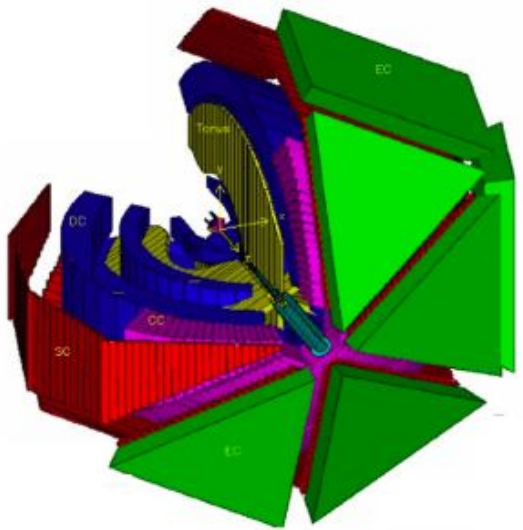
Demo #3

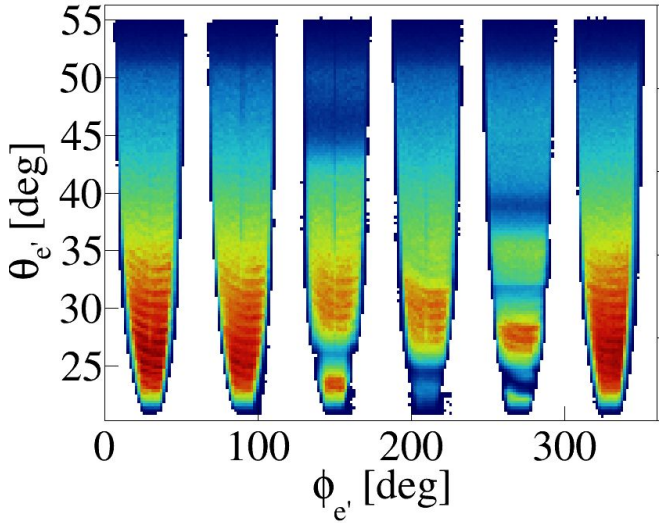
Backup Slides


1.159 GeV
(a)
2.257 GeV
(b)
4.453 GeV
(c)
^{12}C
^{4}He
^{56}Fe
(d)
(e)
(f)
(g)
(h)
(i)
Acceptance Correction
Acceptance Uncertainty [%]
Radiation Correction
$(e,e'p)_{1p0\pi}$ E_{cal} [GeV]

e4ν Unfolding

- Use GENIE gst simulation files
- Correct simulated reconstructed 1p0π spectra (detector acceptance & resolution, radiation) to true 1p0π spectra (no acceptance, resolution or radiation effects)





* UniversalE4vFunction performs the unfolding & calls relevant constants