Lecture-cise 2:
z Expansion Reweighting in GENIE

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GENIE z-Expansion Mini-Workshop

Outline

By the end of this lecture-cise, we will have gone through:

- Turning a dipole event sample into a z-expansion sample
- Turning a z-expansion sample into another z-expansion sample with different parameters
- Creating a covariance matrix file
- Reweighting with a z-expansion covariance matrix to generate error bars

We will need to use:

- The z-expansion sample from the first lecture-cise (*gntp.1.ghep.root*, *gntp.1.gst.root*)

Reweighting: Initial

We will be using the reweighting utilities with source code in *$GENIE/src/contrib/zexp/* and *$GENIE/src/Apps/*

One of the binaries is not built when GENIE is compiled

$\Longrightarrow$ we need to explicitly build it

To build the binary, navigate to *$GENIE/src/contrib/zexp/* and do:

```
$ make grwghtzexpdirect
```

If it's missing, try looking in *$GENIE/src/contrib/zexp/* and move it to *$GENIE/bin/*

Reweighting: Initial

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$\Longrightarrow$ we need to explicitly build it

To build the binary, navigate to *$GENIE/src/contrib/zexp/* and do:

```
$ make grwghtzexpdirect
```

If they have built successfully, you should see the file *grwghtzexpdirect* in *$GENIE/bin/*

If it's missing, try looking in *$GENIE/src/contrib/zexp/* and move it to *$GENIE/bin/*

Reweighting Dipole $\longrightarrow$ z-Expansion

Dipole $\longrightarrow$ z-Expansion Reweighting

Hypothetically, given dipole sample with known m_A

If z-expansion sample is required, could generate from scratch $\implies$ costly

Use reweighting to convert from old parameter set into a new parameter set

In the case at hand, old dipole samples can be turned into z-expansion samples

Dipole → z-Expansion Reweighting

The first reweighting utility source is in *$GENIE/src/Apps/* (binary in *$GENIE/bin/*)

This is the standard GENIE reweighting tool *grwght1p* for reweighting
a single systematic parameter

Dipole → z-Expansion Reweighting

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This is the standard GENIE reweighting tool *grwght1p* for reweighting
a single systematic parameter

Included in the supplemental materials is both a raw (*gntp.ma135.ghep.root*) and converted (*gntp.ma135.gst.root*) dipole sample with $m_A = 1.35\ \mathrm{GeV}$.

We will reweight this sample to have the same z-expansion parameters as the sample from lecture-cise 1 (*gntp.1.gst.root*) and compare the two samples

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a single systematic parameter

Included in the supplemental materials is both a raw (*gntp.ma135.ghep.root*) and converted (*gntp.ma135.gst.root*) dipole sample with $m_A = 1.35\ \mathrm{GeV}$.

We will reweight this sample to have the same z-expansion parameters as the sample from lecture-cise 1 (*gntp.1.gst.root*) and compare the two samples

The options for both z-expansion and dipole are used by the reweighting utility

In *UserPhysicsOptions.xml*, search for option `QEL-Ma` and change it to 1.35

Dipole → z-Expansion Reweighting

Now that we've set the options, we can go ahead with reweighting

Use the raw event file to do the reweighting (watch for newline):

```
$ grwght1p -f gntp.ma135.ghep.root -s AxFFCCQEshape -t 3
  --min-tweak -1 --max-tweak 1 -o wght.ma135.dpl.root
```

Dipole → z-Expansion Reweighting

Now that we've set the options, we can go ahead with reweighting

Use the raw event file to do the reweighting (watch for newline):

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$ grwght1p -f gntp.ma135.ghep.root -s AxFFCCQEshape -t 3
  --min-tweak -1 --max-tweak 1 -o wght.ma135.dpl.root
```

The generated weight file is simple:

aaron@obelisk: ~/code/lgenie/GENIE/temp

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```
aaron@obelisk:~/code/lgenie/GENIE/temp$ root -l wght.2.dpl.root
root [0]
Attaching file wght.2.dpl.root as _file0...
root [1] TTree* t1 = (TTree*) _file0->Get("AxFFCCQEshape")
root [2] t1->GetListOfBranches()->ls()
OBJ: TObjArray  TObjArray       An array of objects : 0
 OBJ: TBranch   eventnum        eventnum/I : 0 at: 0x2657940
 OBJ: TBranchElement    weights weights : 0 at: 0x26674f0
 OBJ: TBranchElement    twkdials        twkdials : 0 at: 0x2699e50
root [3] TArrayF* weights
root [4] TArrayF* twkdials
root [5] t1->SetBranchAddress("weights",&weights)
(const Int_t)0
root [6] t1->SetBranchAddress("twkdials",&twkdials)
(const Int_t)0
root [7] t1->GetEntry(0)
(Int_t)36
root [8] cout <<weights.At(0)<<", " <<weights.At(1)<<", " <<weights.At(2) <<endl;
1.36941, 1, 0.630591
root [9] cout <<twkdials.At(0)<<", " <<twkdials.At(1)<<", " <<twkdials.At(2) <<endl;
-1, 0, 1
root [10]
```

Dipole → z-Expansion Reweighting

Now that we've set the options, we can go ahead with reweighting

Use the raw event file to do the reweighting (watch for newline):

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$ grwght1p -f gntp.ma135.ghep.root -s AxFFCCQEshape -t 3
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root [1] TTree* t1 = (TTree*) _file0->Get("AxFFCCQEshape")
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OBJ: TObjArray  TObjArray       An array of objects : 0
 OBJ: TBranch   eventnum        eventnum/I : 0 at: 0x2657940
 OBJ: TBranchElement    weights weights : 0 at: 0x26674f0
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-1, 0, 1
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```

Objects in file

Dipole → z-Expansion Reweighting

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  --min-tweak -1 --max-tweak 1 -o wght.ma135.dpl.root
```

The generated weight file is simple:

aaron@obelisk: ~/code/lgenie/GENIE/temp

File Edit View Search Terminal Help

```
aaron@obelisk:~/code/lgenie/GENIE/temp$ root -l wght.2.dpl.root
root [0]
Attaching file wght.2.dpl.root as _file0...
root [1] TTree* t1 = (TTree*) _file0->Get("AxFFCCQEshape")
root [2] t1->GetListOfBranches()->ls()
OBJ: TObjArray  TObjArray       An array of objects : 0
 OBJ: TBranch   eventnum        eventnum/I : 0 at: 0x2657940
 OBJ: TBranchElement    weights weights : 0 at: 0x26674f0
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root [3] TArrayF* weights
root [4] TArrayF* twkdials
root [5] t1->SetBranchAddress("weights",&weights)
(const Int_t)0
root [6] t1->SetBranchAddress("twkdials",&twkdials)
(const Int_t)0
root [7] t1->GetEntry(0)
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1.36941, 1, 0.630591
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-1, 0, 1
root [10]
```

Match index of weights and twkdials array

twkdials = 0 $\Longrightarrow$ weight = 1.0 $\Longrightarrow$ dipole

twkdials = 1 $\Longrightarrow$ z-expansion (twkdials = -1 $\Longrightarrow$ garbage)

Dipole $\rightarrow$ z-Expansion Reweighting

Let's plot with the example script from the supplemental materials:

```
$ root -l example2_1.C
```

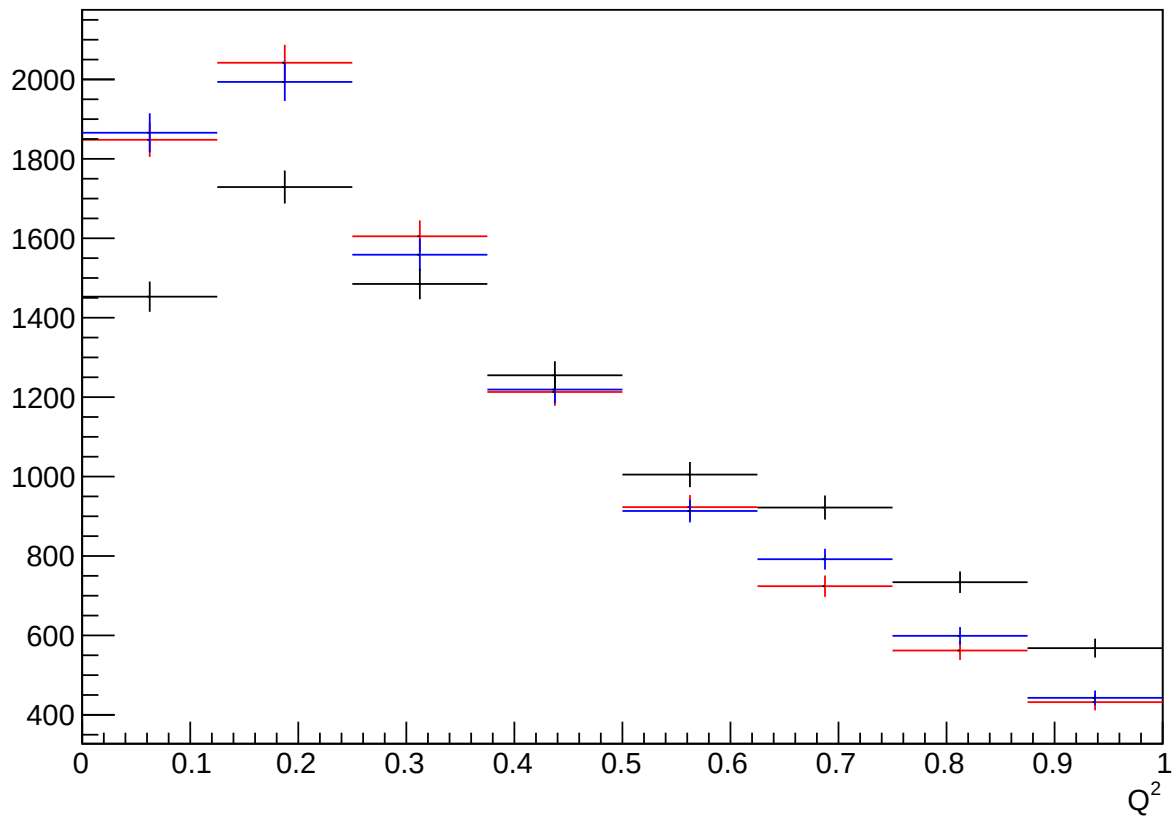
This fills histograms of Q^2 for dipole and z-expansion and plots them

Dipole → z-Expansion Reweighting

Let's plot with the example script from the supplemental materials:

```
$ root -l example2_1.C
```

This fills histograms of Q^2 for dipole and z-expansion and plots them



Black: nominal dipole; Blue: reweighted dipole; Red: z-expansion

Reweighting z-Expansion $\rightarrow$ z-Expansion

Reweighting $z \longrightarrow z$

Given z-expansion sample with known parameters

Want a sample with different parameters

Rather than running with different parameter set, reweight to new sample

Can go directly from one parameter set to another

Reweighting $z \longrightarrow z$

This uses the reweighting utility source in *$GENIE/src/contrib/zexp/*

Utility is named *grwghtzexpdirect*

We will reweight the z-expansion sample from lecture-cise 1 (*gntp.1.gst.root*)
to a new z-expansion sample and compare the two

This utility takes the starting z-expansion values from *UserPhysicsOptions.xml*
and GENIE must be configured to run in z-expansion mode
$\Longrightarrow$ these should already be set

Reweighting $z \longrightarrow z$

We should reweight to the parameter set (which we will use later):

$$\{a_1, a_2, a_3, a_4\} = \{2.38, 0.16, -6.2, 4.8\}$$

The command is (watch for newline):

```
$ grwghtzexpdirect -f gntp.1.ghep.root -v 2.38,0.16,-6.2,4.8
  -o wght.1.zexp.root
```

Reweighting $z \longrightarrow z$

We should reweight to the parameter set (which we will use later):

$$\{a_1, a_2, a_3, a_4\} = \{2.38, 0.16, -6.2, 4.8\}$$

The command is (watch for newline):

```
$ grwghtzexpdirect -f gntp.1.ghep.root -v 2.38,0.16,-6.2,4.8
  -o wght.1.zexp.root
```

aaron@obelisk: ~/code/lgenie/GENIE/temp

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```
Attaching file wght.1.zexp.root as _file0...
root [1] TTree* t1 = (TTree*) _file0->Get("ZExpCCQE")
root [2] t1->GetListOfBranches()->ls()
OBJ: TObjArray  TObjArray       An array of objects : 0
 OBJ: TBranch   eventnum        eventnum/I : 0 at: 0x19f4290
 OBJ: TBranch   weights weights/F : 0 at: 0x1a03e40
 OBJ: TBranch   norm    norm/F : 0 at: 0x1a05500
 OBJ: TBranch   param_1 param_1/F : 0 at: 0x1a05a20
 OBJ: TBranch   param_2 param_2/F : 0 at: 0x1a05f40
 OBJ: TBranch   param_3 param_3/F : 0 at: 0x1a06480
 OBJ: TBranch   param_4 param_4/F : 0 at: 0x1a069c0
root [3] float weights,param_1,param_2,param_3,param_4
root [4] t1->SetBranchAddress("weights",&weights);
root [5] t1->SetBranchAddress("param_1",&param_1);
root [6] t1->SetBranchAddress("param_2",&param_2);
root [7] t1->SetBranchAddress("param_3",&param_3);
root [8] t1->SetBranchAddress("param_4",&param_4);
root [9] t1->GetEntry(0)
(Int_t)28
root [10] cout <<weights <<endl;
1.08234
root [11] cout <<param_1<<", " <<param_2<<", " <<param_3<<", " <<param_4<<endl;
2.38, 0.16, -6.2, 4.8
root [12]
```

Reweighting $z \longrightarrow z$

We should reweight to the parameter set (which we will use later):

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The command is (watch for newline):

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root [3] float weights,param_1,param_2,param_3,param_4
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2.38, 0.16, -6.2, 4.8
root [12]
```

"/F" indicates that the variable is a float

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We should reweight to the parameter set (which we will use later):

$$\{a_1, a_2, a_3, a_4\} = \{2.38, 0.16, -6.2, 4.8\}$$

The command is (watch for newline):

```
$ grwghtzexpdirect -f gntp.1.ghep.root -v 2.38,0.16,-6.2,4.8
  -o wght.1.zexp.root
```

aaron@obelisk: ~/code/lgenie/GENIE/temp

File Edit View Search Terminal Help

```
Attaching file wght.1.zexp.root as _file0...
root [1] TTree* t1 = (TTree*) _file0->Get("ZExpCCQE")
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root [11] cout <<param_1<<", " <<param_2<<", " <<param_3<<", " <<param_4<<endl;
2.38, 0.16, -6.2, 4.8
root [12]
```

Parameters match central values which were input

Reweighting with Covariance Matrix

Reweighting with Covariance Matrix

Given a set of z-expansion parameters and a known error matrix

Want to calculate cross section errors implied by parameter errors

Method is to compute weights with several sets of random parameter values

Errors are standard deviation of histogram bins

Reweighting with Covariance Matrix

The utility is included with the other standard GENIE reweighting utility sources in *$GENIE/src/Apps/*

Unlike previous reweighting utilities, this takes a covariance matrix file as input

We will need to generate this file before going ahead with reweighting...

Creating a Covariance Matrix File

When calling the reweighting utility, we will need to supply the utility with a TMatrixD as the only object in a root file

Creating a Covariance Matrix File

When calling the reweighting utility, we will need to supply the utility with a TMatrixD as the only object in a root file

Writing a script to create the matrix is not difficult:

aaron@obelisk: ~/code/lgenie/GENIE/temp

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```
{
#include <TMatrixD.h>
  int nP = 4; // matrix size
  TFile *fMat = new TFile("tmat.out.root","recreate");

  // covariance matrix
  double tDat[nP][nP] =
    {{0.0154, 0.0, 0.0, 0.0},
     {0.0, 1.08, 0.0, 0.0},
     {0.0, 0.0, 6.54, 0.0},
     {0.0, 0.0, 0.0, 7.40} };

  // flatten matrix into 1-D array
  double tFlt[nP* nP] = {0.};
  for (int i=0;i<nP;i++) {
  for (int j=0;j<nP;j++) {
    tFlt[i*nP+j] = tDat[i][j];
  }}

  // make into TMatrixD object and write to file
  TMatrixD tMat(nP,nP);
  tMat.SetMatrixArray(tFlt);
  tMat->Write("tMat",TObject::kOverwrite);
  fMat->Close();
  exit(0);
}
```

1,1 All

This file has been provided in the supplemental materials (`$ root -l makeCovMatrix.C`)

Creating a Covariance Matrix File

When calling the reweighting utility, we will need to supply the utility with a TMatrixD as the only object in a root file

Writing a script to create the matrix is not difficult:

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  for (int i=0;i<nP;i++) {
  for (int j=0;j<nP;j++) {
    tFlt[i*nP+j] = tDat[i][j];
  }}

  // make into TMatrixD object and write to file
  TMatrixD tMat(nP,nP);
  tMat.SetMatrixArray(tFlt);
  tMat->Write("tMat",TObject::kOverwrite);
  fMat->Close();
  exit(0);
}
```

1,1 All

File name

Unphysical covariance matrix
(to be changed during exercises)

Object name in file (arbitrary)

This file has been provided in the supplemental materials
(`$ root -l makeCovMatrix.C`)

Running Covariance Reweighting

Now that we have the covariance matrix (*tmat.out.root*),
the reweighting command is (watch for newlines):

```
$ grwghtnp -f gntp.1.ghep.root -c tmat.out.root -t 10
  -s ZExpA1CCQE,ZExpA2CCQE,ZExpA3CCQE,ZExpA4CCQE
  -v 2.30,-0.6,-3.8,2.3 -o wght.1.cov.root
```

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Now that we have the covariance matrix (*tmat.out.root*),
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  -v 2.30,-0.6,-3.8,2.3 -o wght.1.cov.root
```

- This will generate 10 random z-expansion parameter sets distributed around the central values

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```

- This will generate 10 random *z*-expansion parameter sets distributed around the central values
- The first row/column of the covariance matrix corresponds to the first *z*-expansion parameter, the second row/column to the second, etc.
  (These systematics are listed in *$GENIE/src/ReWeight/GSyst.h*)

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- This will generate 10 random *z*-expansion parameter sets distributed around the central values
- The first row/column of the covariance matrix corresponds to the first *z*-expansion parameter, the second row/column to the second, etc.
  (These systematics are listed in *$GENIE/src/ReWeight/GSyst.h*)
- The utility requires the central values for the *z*-expansion parameters be given as an input (same as in *UserPhysicsOptions.xml*)

Running Covariance Reweighting

Now that we have the covariance matrix (*tmat.out.root*),
the reweighting command is (watch for newlines):

```
$ grwghtnp -f gntp.1.ghep.root -c tmat.out.root -t 10
  -s ZExpA1CCQE,ZExpA2CCQE,ZExpA3CCQE,ZExpA4CCQE
  -v 2.30,-0.6,-3.8,2.3 -o wght.1.cov.root
```

- This will generate 10 random *z*-expansion parameter sets distributed around the central values
- The first row/column of the covariance matrix corresponds to the first *z*-expansion parameter, the second row/column to the second, etc.
  (These systematics are listed in *$GENIE/src/ReWeight/GSyst.h*)
- The utility requires the central values for the *z*-expansion parameters be given as an input (same as in *UserPhysicsOptions.xml*)
- This routine will generate temporary files in the working directory which are cleaned up when the run is completed

Covariance Reweighting File

Reweighting file similar to other weight files

aaron@obelisk: ~/code/lgenie/GENIE/temp

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```
aaron@obelisk:~/code/lgenie/GENIE/temp$ root -l wght.1.cov.root
root [0]
Attaching file wght.1.cov.root as _file0...
root [1] TTree* t1 = (TTree*) _file0->Get("covrwt")
root [2] t1->GetListOfBranches()->ls()
OBJ: TObjArray  TObjArray       An array of objects : 0
 OBJ: TBranch   n_tweaks        n_tweaks/I : 0 at: 0x205e890
 OBJ: TBranch   eventnum        eventnum/I : 0 at: 0x206e420
 OBJ: TBranchElement    weights weights : 0 at: 0x206e940
 OBJ: TBranchElement    twk_ZExpA1CCQE  twk_ZExpA1CCQE : 0 at: 0x20a1550
 OBJ: TBranchElement    twk_ZExpA2CCQE  twk_ZExpA2CCQE : 0 at: 0x20a1e30
 OBJ: TBranchElement    twk_ZExpA3CCQE  twk_ZExpA3CCQE : 0 at: 0x20a2710
 OBJ: TBranchElement    twk_ZExpA4CCQE  twk_ZExpA4CCQE : 0 at: 0x20a2ff0
root [3] int n_tweaks
root [4] TArrayD* weights
root [5] TArrayD* twk_a1
root [6] t1->SetBranchAddress("n_tweaks",&n_tweaks);
root [7] t1->SetBranchAddress("weights",&weights);
root [8] t1->SetBranchAddress("twk_ZExpA1CCQE",&twk_a1);
root [9] t1->GetEntry(0);
root [10] for(int i=0;i<n_tweaks;i++){ cout<<weights.At(i)<<" "; }; cout<<endl;
1.08764 1.17014 1.02533 1.07174 1.13345 0.963058 1.16056 1.26868 1.03673 1.24304
root [11] for(int i=0;i<n_tweaks;i++){ cout<<twk_a1.At(i)<<" "; }; cout<<endl;
-0.14621 -1.37697 -0.805901 1.08218 -0.589803 0.681752 -1.94222 -1.46002 -0.180608 -0.737421
root [12]
```

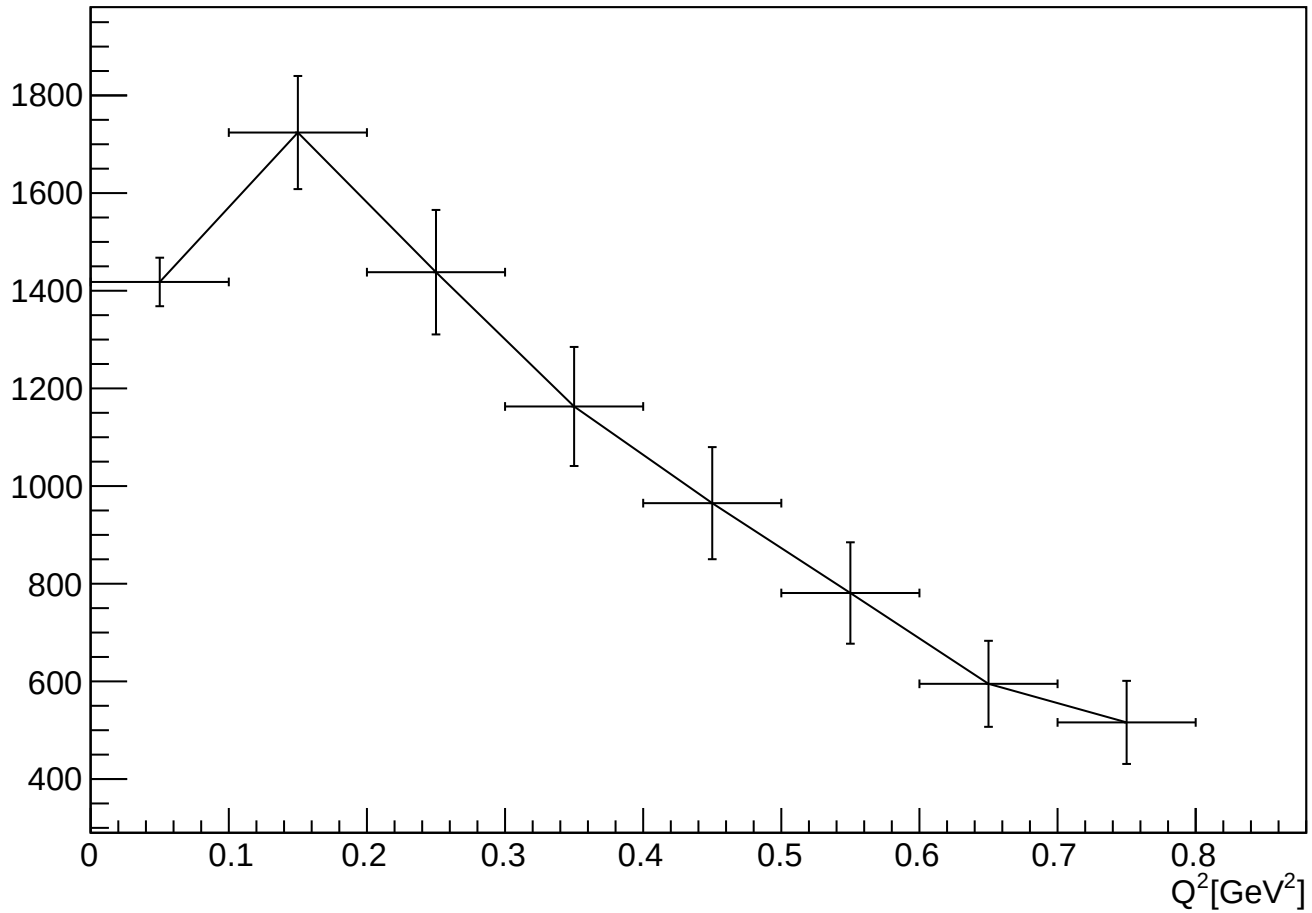
Tweaks are used to compute values for updated z-expansion parameters:

$$a_i = a_i^{\text{nom}} + (\text{tweak})\sqrt{c_{ii}^2}$$

where $c_{ii}^2 = (covariance)_{ii} \neq \sigma_{ii}^2$

Covariance Reweighting Plot

The script *example2_2.C* has been provided in the supplemental materials to plot the error bars from reweighting



Fin

This concludes GENIE z-expansion lecture 2!

You should now be able to use reweighting to quickly change parameters with the z-expansion.

Before moving on to the exercises, I suggesting backing up

- your weight file from the direct z to z reweighting (*wght.1.zexp.root*)

Exercises

Exercise 2.1

Another dipole sample has been included in the supplemental materials

- raw event file: `gntp.ma200.ghep.root`
- converted gst file: `gntp.ma200.gst.root`

For dramatic effect, this sample has an unphysical $m_A = 2.0\ \mathrm{GeV}$

Using `grwght1p`, reweight this to have the same parameters as our nominal z-expansion sample from lecture-cise 1 and plot the two samples together

- Be sure to remember to change the m_A in *UserPhysicsOptions.xml*!
- The example script *example2_1.C* can be reused to do the plotting

Exercise 2.2

Let's fill in physical values for the covariance matrix

Make a covariance matrix with the updated values:

$$\begin{pmatrix} 0.0154582 & 0.0451836 & -0.215641 & 0.20647 \\ 0.0451836 & 1.08091 & -2.38702 & 1.0386 \\ -0.215641 & -2.38702 & 6.53568 & -4.76577 \\ 0.20647 & 1.0386 & -4.76577 & 7.39832 \end{pmatrix}$$

and use that to generate a new set of covariance error bars.

Exercise 2.3

As an alternative to using the stochastic covariance matrix method in *grwghtnp*, one can use the principle axes method to approximate the error bars

The principle axes method states that for eigenvalues λ_i and eigenvectors $\vec{r}_i$ of the covariance matrix, the error on an observable O is given by

$$\delta O^2 = \sum_i \left(O(\vec{a}_0) - O(\vec{a}_0 \pm \delta\vec{a}_i)\right)^2$$

where $\vec{a}_0$ are the central value parameters and

$$\delta\vec{a}_i = \lambda_i^{\frac{1}{2}}\vec{r}_i$$

Using the principle axes method, calculate the errors on the z-expansion sample from lecture-cise 1 and compare to the covariance errors from Exercise 2.2.

The parameter sets one obtains from the eigenvalues and eigenvectors are:

- {2.38,0.16,-6.2,4.8} (from lecture)
- {2.29,-1.27,-2.8,3.4}
- {2.38,-0.79,-3.9,2.3}
- {2.31,-0.57,-3.8,2.3}