Lecture-cise 1: Running z Expansion in GENIE

Aaron Meyer

asmeyer2012@uchicago.edu

University of Chicago/Fermilab
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GENIE z-Expansion Mini-Workshop

Outline

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

- Configuring z-expansion to run
- Changing z-expansion parameters
- Creating and handling z-expansion splines
- Running GENIE with z-expansion

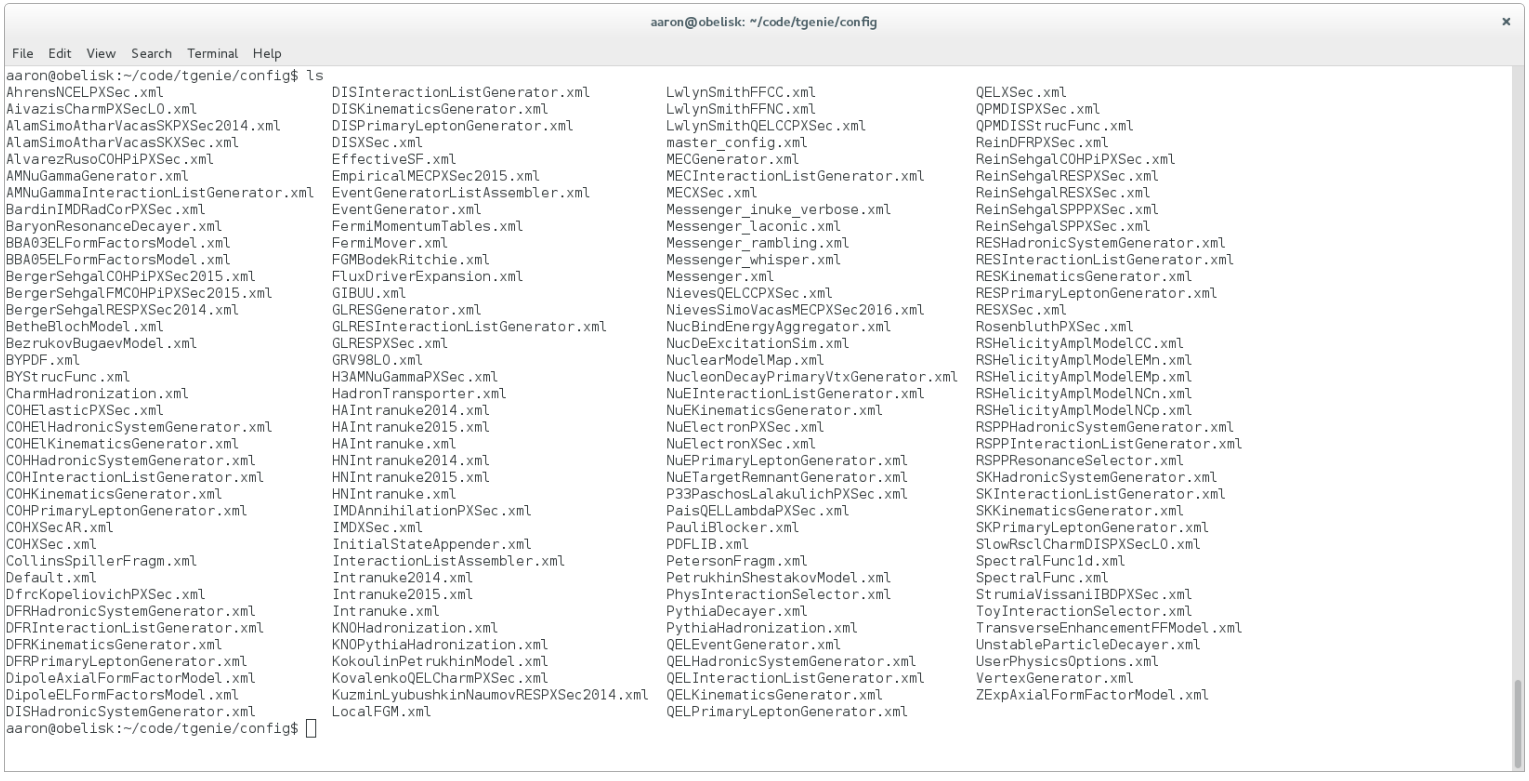
Pay special attention to:

- The switches in *UserPhysicsOptions.xml* - two of them!
- The spline generation - without new CCQE splines, you'll still be running in the old model!

Configuring GENIE for z-Expansion

Configuring *z*-Expansion

The configuration files are in *$GENIE/config*



Configuring *z*-Expansion

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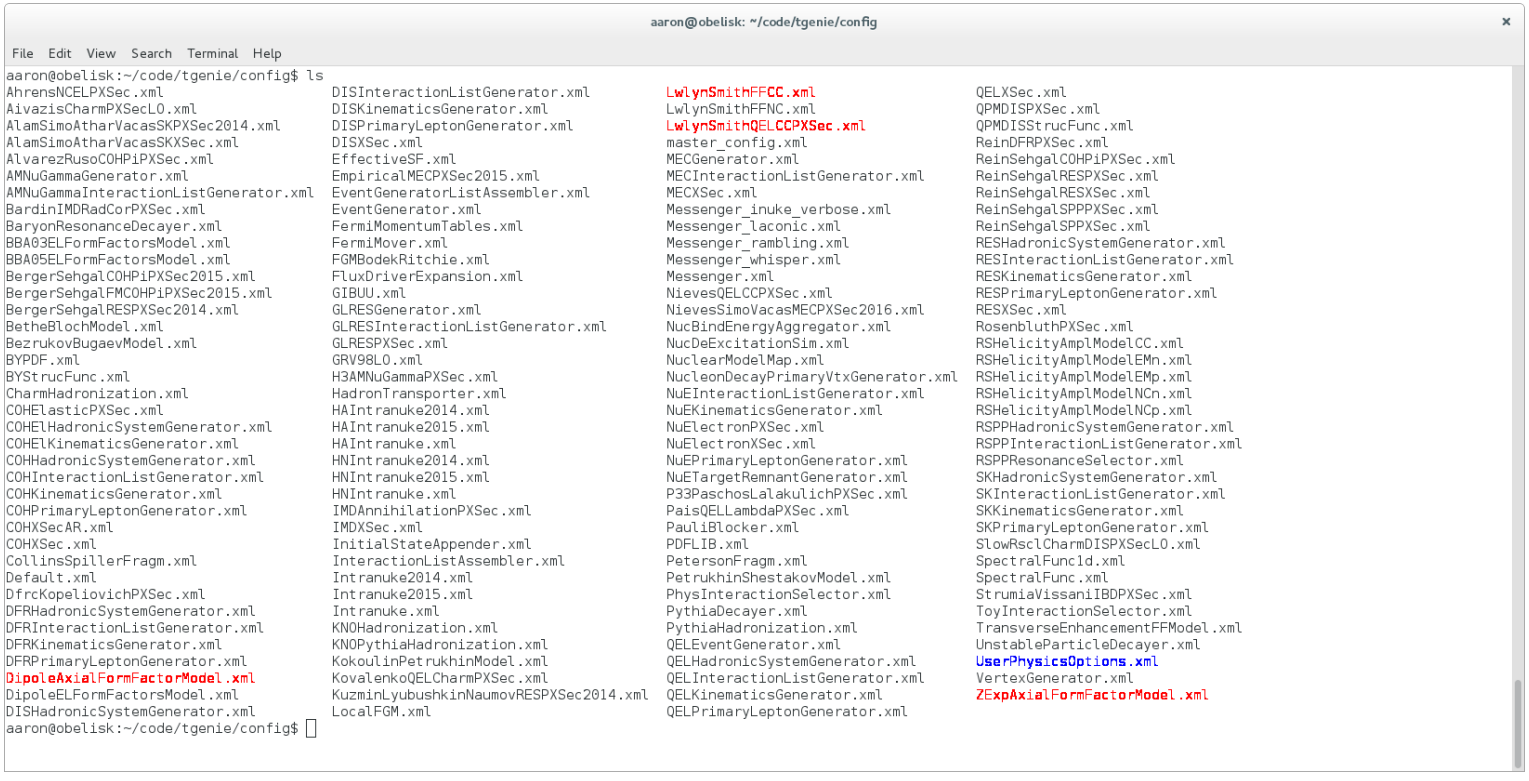

- Only a few are used by *z*-expansion & axial form factor
- Only one is important for general usage: *UserPhysicsOptions.xml*

Configuring *z*-Expansion

In *$GENIE/config/UserPhysicsOptions.xml*:

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

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```
<!--
  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
  Specify which cross section model is to be used by each GENIE event generation thread.
  The parameter name is build as: "XSecModel@[name of thread]"
  -->
<!-- New Nieves QE model   -->
<!--
  <param type="alg" name="XSecModel@genie::EventGenerator/QEL-CC">        genie::NievesQELCCPXSec/Default     </param>
  -->
  <param type="alg" name="XSecModel@genie::EventGenerator/QEL-CC">        genie::LwlynSmithQELCCPXSec/ZExp        </param>
  <param type="alg" name="XSecModel@genie::EventGenerator/QEL-NC">        genie::AhrensNCELPXSec/Default          </param>
  <param type="alg" name="XSecModel@genie::EventGenerator/QEL-EM">        genie::RosenbluthPXSec/Default          </param>
```

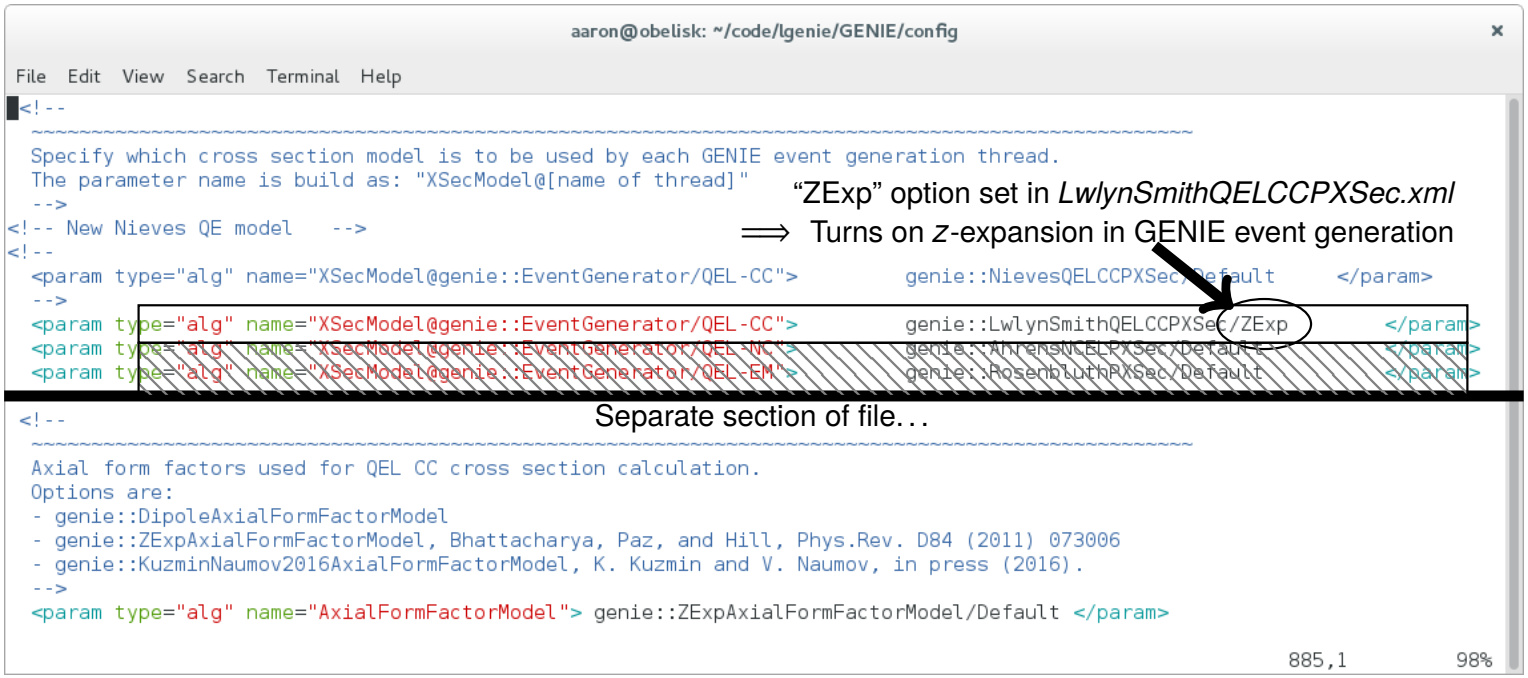
Separate section of file. . .

```
 <!--
  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
  Axial form factors used for QEL CC cross section calculation.
  Options are:
  - genie::DipoleAxialFormFactorModel
  - genie::ZExpAxialFormFactorModel, Bhattacharya, Paz, and Hill, Phys.Rev. D84 (2011) 073006
  - genie::KuzminNaumov2016AxialFormFactorModel, K. Kuzmin and V. Naumov, in press (2016).
  -->
  <param type="alg" name="AxialFormFactorModel"> genie::ZExpAxialFormFactorModel/Default </param>

                                                                                     885,1         98%
```

Configuring z-Expansion

In *$GENIE/config/UserPhysicsOptions.xml*:

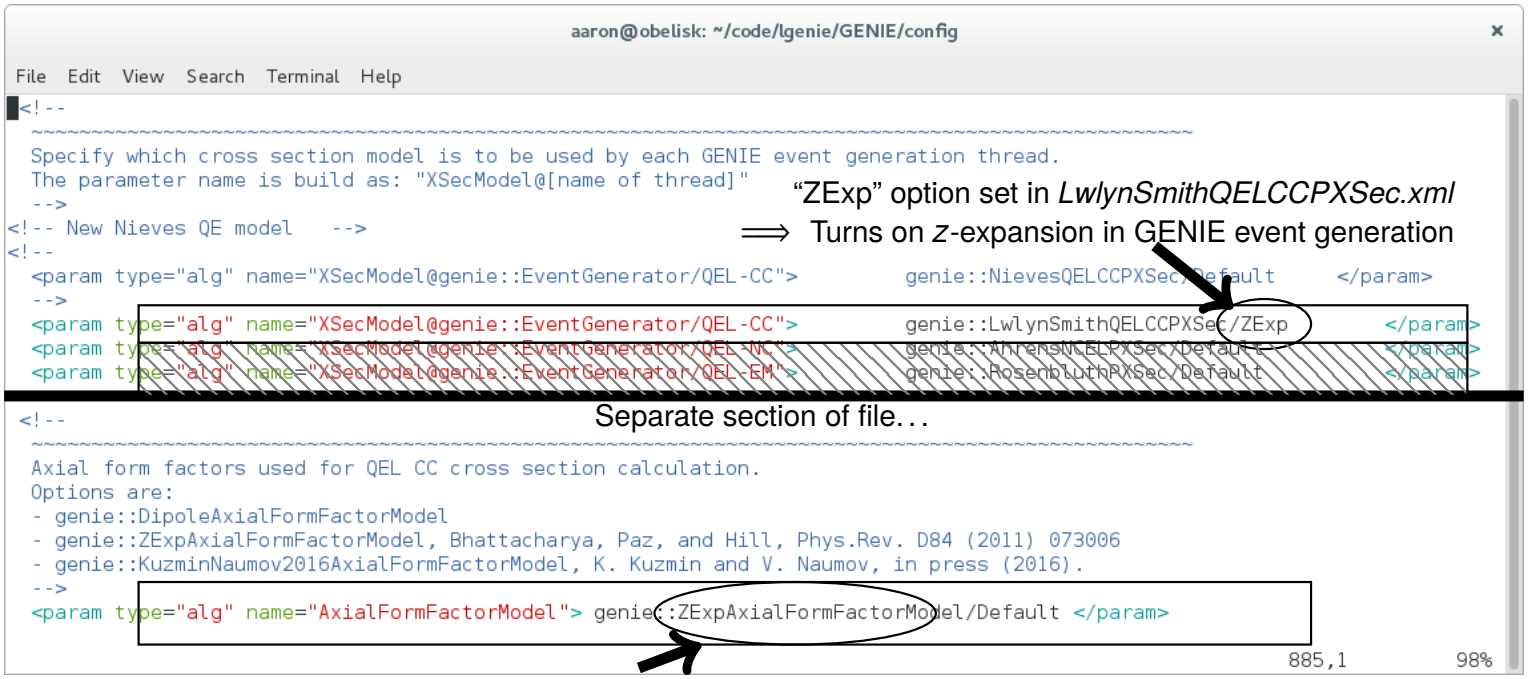


"ZExp" option set in *LwlynSmithQELCCPXSec.xml*

$\Longrightarrow$ Turns on z-expansion in GENIE event generation

Configuring z-Expansion

In *$GENIE/config/UserPhysicsOptions.xml*:



"ZExp" option set in *LwlynSmithQELCCPXSec.xml*

$\Longrightarrow$ Turns on z-expansion in GENIE event generation

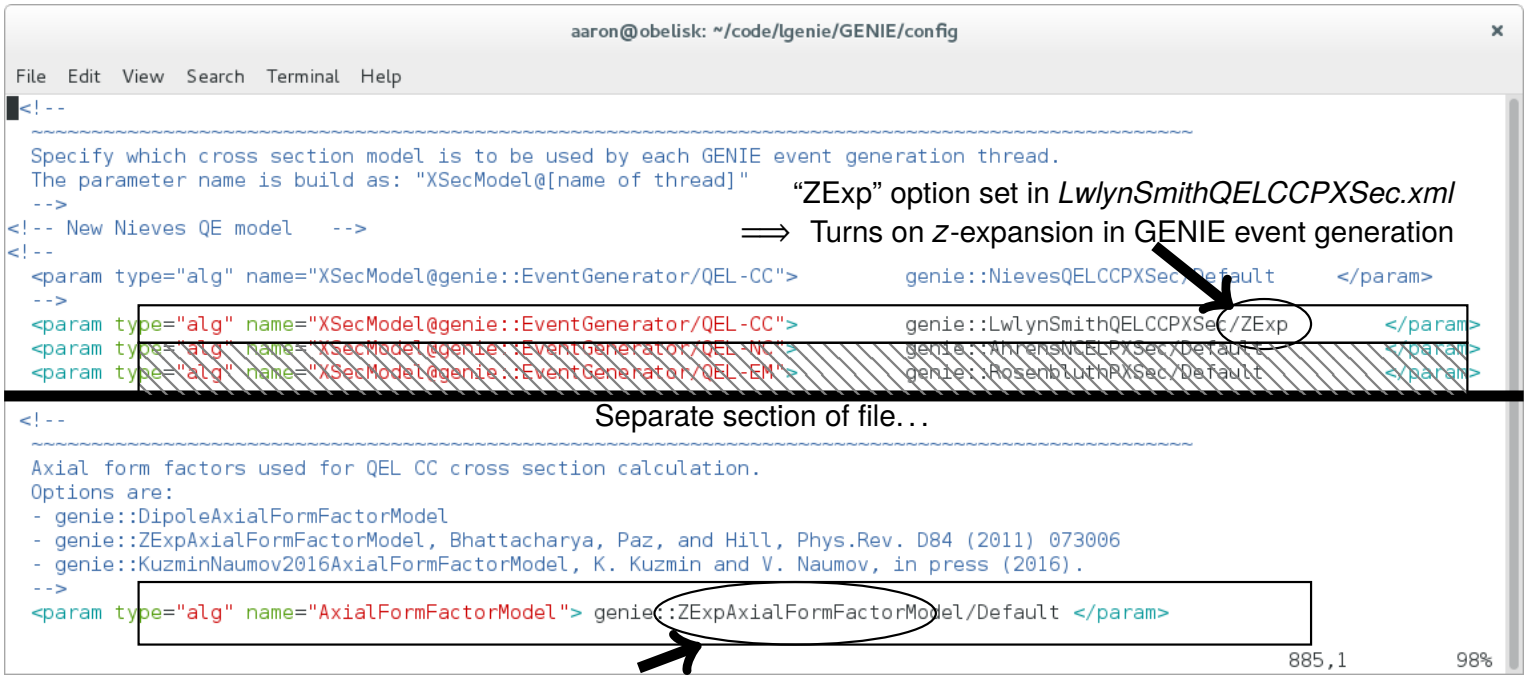
Separate section of file...

Revert to "ZExpAxialFormFactorModel" when instantiating LwlynSmithFFCC cross section module

$\Longrightarrow$ Turns on z-expansion in reweighting routines

Configuring *z*-Expansion

In *$GENIE/config/UserPhysicsOptions.xml*:



"ZExp" option set in *LwlynSmithQELCCPXSec.xml*

$\Longrightarrow$ Turns on *z*-expansion in GENIE event generation

Revert to "ZExpAxialFormFactorModel" when instantiating LwlynSmithFFCC cross section module

$\Longrightarrow$ Turns on *z*-expansion in reweighting routines

- Both of these options should be set to *z*-expansion defaults in out-of-the-box "z-expansion-tutorial" GENIE version
- Without these set, GENIE will default to dipole model
  - *z*-expansion reweighting utilities will fail with a warning and generate weights =1...

Spline Generation and Manipulation

Splines

To run GENIE with z-expansion, need to update the splines to include z-expansion cross section

- The use of splines speeds up computation:
  - "lookup table" for cross sections
  - Calculate and save splines *a priori*
- A set of default splines provided on hepforge
  - no z-expansion included
  - http://www.hepforge.org/archive/genie/data/2.10.0/
- Fastest way to add z-expansion is to calculate only CCQE spline and append it to pre-existing set of non-CCQE splines
  - Also possible to run in CCQE-only mode with CCQE spline

Splines: Generation

Generate a z-expansion CCQE spline for ν_μ on carbon
(if copy/pasting, be careful of newlines...):

```
$ gmkspl -p 14 -t 1000060120 --event-generator-list CCQE
  -o numu-c-zccqe.xml
```

This looks up and uses the "CCQE" list in
$GENIE/config/EventGeneratorListAssembler.xml

Splines: Generation

Generate a z-expansion CCQE spline for ν_μ on carbon
(if copy/pasting, be careful of newlines...):

```
$ gmkspl -p 14 -t 1000060120 --event-generator-list CCQE
  -o numu-c-zccqe.xml
```

This will generate the file *numu-c-zccqe.xml*

This is what the spline file should look like:

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

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```
<?xml version="1.0" encoding="ISO-8859-1"?>

<!-- generated by genie::XSecSplineList::SaveSplineList() -->

<genie_xsec_spline_list version="2.00" uselog="1">

<spline name="genie::LwlynSmithQELCCPXSec/ZExp/nu:14;tgt:1000060120;N:2112;proc:Weak[CC],QES;" nknots="44">
        <knot> <E>    0.01000 </E> <xsec>          0 </xsec> </knot>
        <knot> <E>   0.030175 </E> <xsec>          0 </xsec> </knot>
        <knot> <E>   0.050351 </E> <xsec>          0 </xsec> </knot>
        <knot> <E>   0.070526 </E> <xsec>          0 </xsec> </knot>
        <knot> <E>   0.090701 </E> <xsec>          0 </xsec> </knot>
        <knot> <E>    0.11088 </E> <xsec> 8.211871327e-15 </xsec> </knot>
        <knot> <E>     0.1409 </E> <xsec> 3.420258124e-12 </xsec> </knot>
        <knot> <E>    0.17906 </E> <xsec> 1.271358108e-11 </xsec> </knot>
        <knot> <E>    0.22756 </E> <xsec> 2.808187262e-11 </xsec> </knot>
        <knot> <E>    0.28918 </E> <xsec> 4.966851112e-11 </xsec> </knot>
        <knot> <E>     0.3675 </E> <xsec> 7.40552e-11 </xsec> </knot>
        <knot> <E>    0.46702 </E> <xsec> 9.743752762e-11 </xsec> </knot>
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        <knot> <E>    0.95849 </E> <xsec> 1.403464385e-10 </xsec> </knot>
        <knot> <E>     1.2181 </E> <xsec> 1.433663175e-10 </xsec> </knot>
"numu-c-zccqe.xml" 53L, 3222C                                          1,1           Top
```

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        <knot> <E>    0.01000 </E> <xsec>           0 </xsec> </knot>
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        <knot> <E>     1.2181 </E> <xsec> 1.433663175e-10 </xsec> </knot>
"numu-c-zccqe.xml" 53L, 3222C                                          1,1           Top
```

This was the configuration option set in *UserPhysicsOptions.xml*

A complete spline file will have many more splines than this.

Splines: Adding

Can add splines together to merge them into a single file
Try this with the spline (*numu-c-xccqe.xml*) provided in supplemental material:

```
$ gspladd -f numu-c-xccqe.xml,numu-c-zccqe.xml -o numu-c-full.xml
```

You now have a full set of splines for ν_μ on carbon including the z-expansion!

Splines: Adding

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```

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You can check that the z-expansion has been added by searching the new file:

```
$ grep -n ZExp numu-c-full.xml
```

```
> 559:<spline name="genie::LwlynSmithQELCCPXSec/ZExp/nu:14;tgt:
  1000060120;N:2112;proc:Weak[CC],QES;" nknots="44">
```

So the z-expansion spline starts on line 559

Splines: Adding

Can add splines together to merge them into a single file
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  1000060120;N:2112;proc:Weak[CC],QES;" nknots="44">
```

So the z-expansion spline starts on line 559

Keeping a non-CCQE spline set handy is allows you to quickly add back in CCQE with a set of z-expansion parameters

In practice, better to use reweighting to swap between parameter sets (lecture-cise 2!)

z-Expansion Parameters

Changing z-Expansion Parameters

Parameters are again found in *UserPhysicsOptions.xml*:

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

File Edit View Search Terminal Help

```
<!--
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Value of axial form factor at Q2=0
-->
<param type="double" name="QEL-FA0"> -1.2670 </param>
[redacted]
  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
  Value of Z-expansion parameters for QEL axial form factor
  - Normalization of expansion controlled by QEL-FA0
  -->
<param type="bool"   name="QEL-Q4limit"> true   </param>
<param type="int"    name="QEL-Kmax">    4      </param>
<param type="double" name="QEL-T0">     -0.28   </param>
<param type="double" name="QEL-Tcut">    0.1764 </param> <!-- 9*m_pi^2 -->
<param type="double" name="QEL-Z_A1">    2.30   </param>
<param type="double" name="QEL-Z_A2">   -0.6    </param>
<param type="double" name="QEL-Z_A3">   -3.8    </param>
<param type="double" name="QEL-Z_A4">    2.3    </param>

<!--
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Parameter eta controlling the strange axial form factor
-->
                                                              181,1          20%
```

Compare to z-expansion:

$$t = -Q^2 \qquad z(t; t_c, t_0) = \frac{\sqrt{t_c - t} - \sqrt{t_c - t_0}}{\sqrt{t_c - t} + \sqrt{t_c - t_0}} \qquad F_A(t) = \sum_{k=0}^{k_{max}} a_k z^k(t)$$

Changing z-Expansion Parameters

Parameters are again found in *UserPhysicsOptions.xml*:

```
aaron@obelisk: ~/code/lgenie/GENIE/config
File  Edit  View  Search  Terminal  Help
<!--
 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 Value of axial form factor at Q2=0
 -->
 <param type="double" name="QEL-FA0"> -1.2670 </param>
[redacted]
  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
  Value of Z-expansion parameters for QEL axial form factor
  - Normalization of expansion controlled by QEL-FA0
  -->
 <param type="bool"   name="QEL-Q4limit"> true   </param>
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 <param type="double" name="QEL-T0">      -0.28  </param>
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<!--
 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 Parameter eta controlling the strange axial form factor
 -->
                                                                      181,1         20%
```

number of free parameters k_{max}

z-expansion parameter values a_k

Compare to z-expansion:

$$t = -Q^2 \qquad z(t; t_c, t_0) = \frac{\sqrt{t_c - t} - \sqrt{t_c - t_0}}{\sqrt{t_c - t} + \sqrt{t_c - t_0}} \qquad F_A(t) = \sum_{k=0}^{k_{max}} a_k z^k(t)$$

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[redacted]
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  Value of Z-expansion parameters for QEL axial form factor
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 <param type="bool"   name="QEL-Q4limit"> true   </param>
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 -->
                                                                181,1          20%
```

kinematic cut t_c

Compare to z-expansion:

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<!--
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Parameter eta controlling the strange axial form factor
-->
                                                                    181,1          20%
```

convergence parameter t_0

Compare to z-expansion:

$$t = -Q^2 \qquad z(t; t_c, t_0) = \frac{\sqrt{t_c - t} - \sqrt{t_c - t_0}}{\sqrt{t_c - t} + \sqrt{t_c - t_0}} \qquad F_A(t) = \sum_{k=0}^{k_{max}} a_k z^k(t)$$

Changing z-Expansion Parameters

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<!--
 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
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 -->
                                                              181,1          20%
```

turn on/off large-Q^2 sum rules
when true, fixes $a_{k_{max}+1} - a_{k_{max}+4}$

Compare to z-expansion:

$$t = -Q^2 \qquad z(t;t_c,t_0) = \frac{\sqrt{t_c - t} - \sqrt{t_c - t_0}}{\sqrt{t_c - t} + \sqrt{t_c - t_0}} \qquad F_A(t) = \sum_{k=0}^{k_{max}+4} a_k z^k(t)$$

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```

$F_A(Q^2 = 0) = g_A$, fixes a_0

```
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                                                            181,1          20%
```

These parameters are queried at the start of a run, so no recompiling

Changing parameters requires making new splines

Running GENIE with z-Expansion

Running GENIE

Time to start running GENIE!

Running GENIE

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At this point, we should have:

- configured GENIE for z-expansion
- default parameters for z-expansion
- a spline file generated (*numu-c-zccqe.xml*)

Running GENIE

Time to start running GENIE!

At this point, we should have:

- configured GENIE for *z*-expansion
- default parameters for *z*-expansion
- a spline file generated (*numu-c-zccqe.xml*)

Let's generate a 10k event sample of 1 GeV ν_μ on carbon

Be sure to keep this sample! We'll want it later

Running GENIE

Here's the command (careful of newline):

```
$ gevgen -r 1 -p 14 -t 1000060120 -e 1 -n 10000 --cross-sections
  numu-c-zccqe.xml --event-generator-list CCQE
```

For help with the command line arguments, try `$ gevgen -h`

Running GENIE

Here's the command (careful of newline):

```
$ gevgen -r 1 -p 14 -t 1000060120 -e 1 -n 10000 --cross-sections
  numu-c-zccqe.xml --event-generator-list CCQE
```

This will generate a raw event file *gntp.1.ghep.root*

This file contains all of the data for the simulated CCQE interactions

For help with the command line arguments, try `$ gevgen -h`

Running GENIE

Here's the command (careful of newline):

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  numu-c-zccqe.xml --event-generator-list CCQE
```

This will generate a raw event file *gntp.1.ghep.root*

This file contains all of the data for the simulated CCQE interactions

To turn this into a ROOT-readable file, we need to turn this into a "GENIE summary tree" file format using the GENIE ntuple converter:

```
$ gntpc -i gntp.1.ghep.root -f gst -o gntp.1.gst.root
```

This will output a "gst" formatted file

For help with the command line arguments, try `$ gevgen -h`

GST File

Let's quickly look inside the gst file:

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

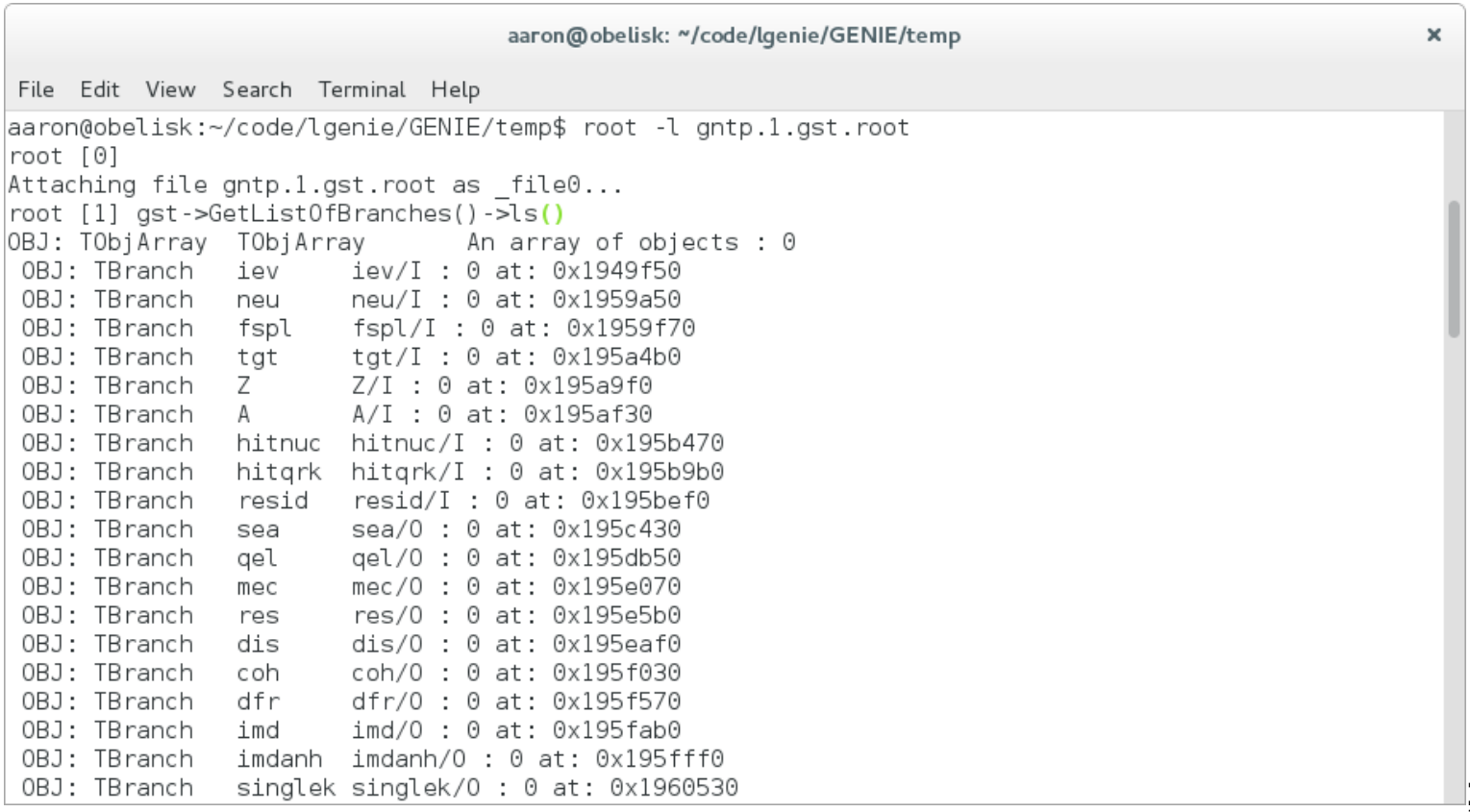
File Edit View Search Terminal Help

```
aaron@obelisk:~/code/lgenie/GENIE/temp$ root -l gntp.1.gst.root
root [0]
Attaching file gntp.1.gst.root as _file0...
root [1] gst->GetListOfBranches()->ls()
OBJ: TObjArray  TObjArray       An array of objects : 0
 OBJ: TBranch   iev     iev/I : 0 at: 0x1949f50
 OBJ: TBranch   neu     neu/I : 0 at: 0x1959a50
 OBJ: TBranch   fspl    fspl/I : 0 at: 0x1959f70
 OBJ: TBranch   tgt     tgt/I : 0 at: 0x195a4b0
 OBJ: TBranch   Z       Z/I : 0 at: 0x195a9f0
 OBJ: TBranch   A       A/I : 0 at: 0x195af30
 OBJ: TBranch   hitnuc  hitnuc/I : 0 at: 0x195b470
 OBJ: TBranch   hitqrk  hitqrk/I : 0 at: 0x195b9b0
 OBJ: TBranch   resid   resid/I : 0 at: 0x195bef0
 OBJ: TBranch   sea     sea/O : 0 at: 0x195c430
 OBJ: TBranch   qel     qel/O : 0 at: 0x195db50
 OBJ: TBranch   mec     mec/O : 0 at: 0x195e070
 OBJ: TBranch   res     res/O : 0 at: 0x195e5b0
 OBJ: TBranch   dis     dis/O : 0 at: 0x195eaf0
 OBJ: TBranch   coh     coh/O : 0 at: 0x195f030
 OBJ: TBranch   dfr     dfr/O : 0 at: 0x195f570
 OBJ: TBranch   imd     imd/O : 0 at: 0x195fab0
 OBJ: TBranch   imdanh  imdanh/O : 0 at: 0x195fff0
 OBJ: TBranch   singlek singlek/O : 0 at: 0x1960530
```

;

GST File

Let's quickly look inside the gst file:



Quite extensive! A full list of the variables is found in Sec. 7.6.2 of the Physics & User Manual: arXiv 1510.05494v1 [hep-ph]

Try plotting something:

```
$ root[0] gst->Draw("Q2","")
```

Plotting the Simulated Sample

Let's plot the event sample we just generated.

This uses the script *example1.C* and the dipole sample *gntp.ma135.gst.root* provided in the supplemental materials.

```
$ root -l example1.C
```

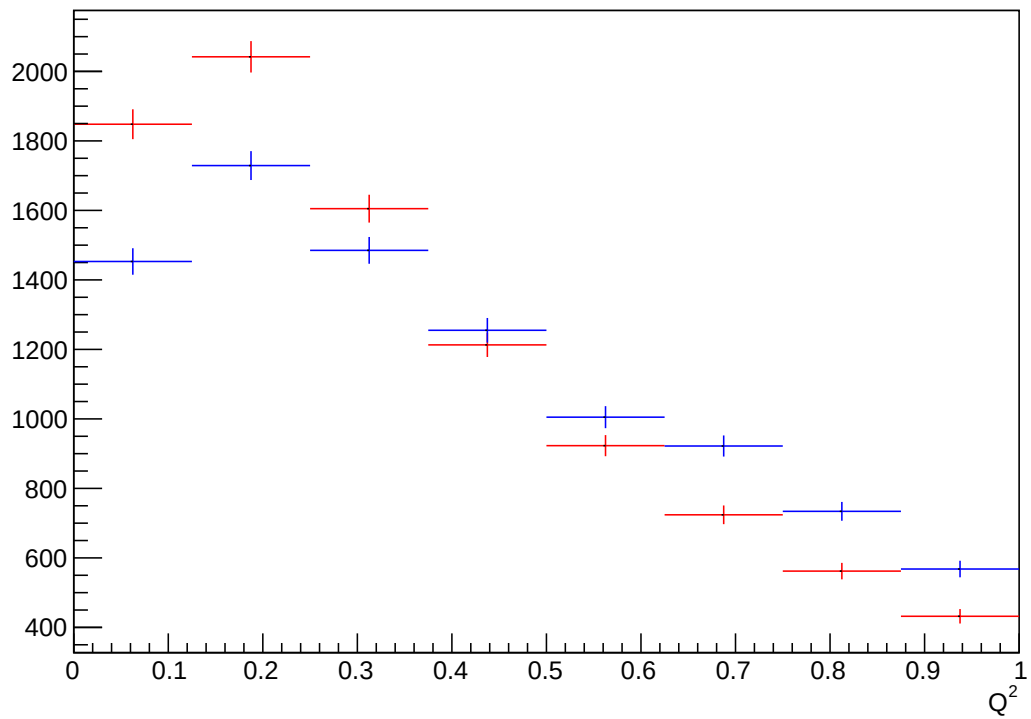
Plotting the Simulated Sample

Let's plot the event sample we just generated.

This uses the script *example1.C* and the dipole sample *gntp.ma135.gst.root* provided in the supplemental materials.

```
$ root -l example1.C
```

It should look something like this:



Fin

That's it!

Now you're ready to run the *z*-expansion on your own.

Before moving on to exercises, I suggest making backup copies of

- your spline file (*numu-c-zccqe.xml*)
- your raw event file (*gntp.1.ghep.root*)
- your gst file (*gntp.1.gst.root*)

so they are not accidentally overwritten.

Exercises

Exercise 1.1

Reference arXiv 1108.0423 has z-expansion parameter values:

- $a_1 = 2.9\,, \quad a_2 = -8\,; \quad t_0 = 0$

Try generating a sample of 10k CCQE events and comparing to the z-expansion sample we generated in the lecture (*gntp.1.gst.root*)

Remember:

- Change the parameters in *UserPhysicsOptions.xml* (comment out the default values)
- Generate new CCQE splines
- Run GENIE with the new splines
- Convert the ntuple to a summary tree

The ROOT script *example1.C* from the lecture is useful for plotting the two samples in this exercise. Feel free to edit it as you wish.

Exercise 1.2

The z-expansion sum rules are applied to restrict the large-Q^2 behavior of the form factor. Without the sum rules, the form factor is unbounded as Q^2 increases.

Try comparing two z-expansion data samples, one each of sum rules on and off.

- How does the Q^2 distribution compare between the two?
- What happens if the neutrino energy is increased to 10 GeV?

Exercise 1.3

(Extra credit)

Reconfigure GENIE for dipole model and generate a 10k event CCQE dipole sample with $m_A = 0.99\ \mathrm{GeV}$.

- The default GENIE value for m_A is $0.99\ \mathrm{GeV}$, so this only involves turning off the z-expansion configuration flags

Compare this to the z-expansion sample we generated in the lecture.

Extra

You can also try generating event samples with both CCQE and non-CCQE events.

If you have extra time, feel free to snoop around in some of the places we didn't delve into:

- Look in some of the configuration files highlighted on slide 4
- Look in *$GENIE/src/LlewellynSmith/* for the z-expansion source code