

# 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  $\$GENIE/config$

```
aaron@obelisk: ~/code/genie/config
File Edit View Search Terminal Help
aaron@obelisk:~/code/genie/config$ ls
AhrensWELPXSec.xml          DISInteractionListGenerator.xml      LwlyrSmtHFFCC.xml           QELXSec.xml
AlvarezCharmPKSec.xml      DISKinematicsGenerator.xml          LwlyrSmtHFFMC.xml          QMDDSPKSec.xml
AlansinoACharVacasSKPXSec2014.xml  DISPrimaryLeptonGenerator.xml      LwlyrSmtHQELCPXSec.xml     QMDDIS1rucFunc.xml
AlansinoACharVacasSKKSec.xml      DIXSec.xml                          master_config.xml          ReInDFRFXSec.xml
AlvarezJusoCOPHPXSec.xml      EffectiveSF.xml                     MECGenerator.xml           ReInSeghalCOPHPXSec.xml
APMAGamaGenerator.xml         EmpiricalMECPXSec2015.xml          NECInteractionListGenerator.xml  ReInSeghalRESPXSec.xml
APMAGamaInteractionListGenerator.xml  EventGeneratorListAssembler.xml    NECKSec.xml                 ReInSeghalRESXSec.xml
BardinINDRhadCorPXSec.xml      EventGenerator.xml                  Messenger_inuke_verbose.xml   ReInSeghalSPPKSec.xml
BaryonResonanceDecayer.xml      FermiMomentumTables.xml           Messenger_laconic.xml       ReInSeghalSPKSec.xml
BBM3ELFormFactorsModel.xml      FermiMover.xml                      Messenger_rambLing.xml      RESHadronicSystemGenerator.xml
BBM05ELFormFactorsModel.xml      FQBodeRitchie.xml                  Messenger_whisper.xml       RESInteractionListGenerator.xml
BergerSeghalCOPHPXSec2015.xml     FluxDriverExpansion.xml            Messenger.xml                RESKinematicsGenerator.xml
BergerSeghalFMCCHPLXPXSec2015.xml  GIBUJ.xml                           NievesGELCPXSec.xml        RESPPrimaryLeptonGenerator.xml
BergerSeghalRESPXSec2014.xml      GLRESGenerator.xml                 NievesSinoVacasMECPXSec2016.xml  RESXSec.xml
BethH1GochModel.xml            GLRESInteractionListGenerator.xml   NuCLIndEnergyAggregator.xml   RosenbluthPXSec.xml
BezrukovGusaeModel.xml          GLRESPXSec.xml                     NuCLDeciInteractionSis.xml    RSHelicityApplModelCC.xml
BYDF.xml                        GRV8LO.xml                          NuCLerModelMap.xml          RSHelicityApplModelEM.xml
BYSTrucFunc.xml                H3APMGamaPKSec.xml                 NuCLonDecayPrimaryVtxGenerator.xml  RSHelicityApplModelEMp.xml
CharmHadronization.xml          HadronTransporter.xml              NuEInteractionListGenerator.xml    RSHelicityApplModelINC.xml
COHElasticPXSec.xml             HAIntranuka2014.xml                NuEKinematicsGenerator.xml       RSHelicityApplModelMCP.xml
COHEHadronicSystemGenerator.xml  HAIntranuka2015.xml                NuElectronPXSec.xml           RSPPHadronicSystemGenerator.xml
COHEKinematicsGenerator.xml     HAIntranuka.xml                    NuElectronVSec.xml            RSPPIInteractionListGenerator.xml
COHadronicSystemGenerator.xml    HIntranuka2014.xml                 NuEPrimaryLeptonGenerator.xml     RSPResonanceSelector.xml
COHInteractionListGenerator.xml  HIntranuka2015.xml                 NuETargetRemnantGenerator.xml    SOHadronicSystemGenerator.xml
COKinematicsGenerator.xml       HIntranuka.xml                     P3PAschoslakulichPXSec.xml     SKInteractionListGenerator.xml
COPPrimaryLeptonGenerator.xml    IMDRubilationPXSec.xml             PaisGELambdaPXSec.xml         SKKinematicsGenerator.xml
COH5Sec.xml                     InitialStateAppender.xml            PauliBlocker.xml              SKPrimaryLeptonGenerator.xml
CollinsSpittleFragm.xml         InteractionListAssembler.xml        PDFLIB.xml                    SlowReclCharmD1SPXSec0.xml
Default.xml                     Intranuka2014.xml                   PetersonFragm.xml             SpectralFuncId.xml
DFRChapelLovichPXSec.xml        Intranuka2015.xml                   PetrakInCharmModel.xml        SpectralFunc.xml
DFRHadronicSystemGenerator.xml   Intranuka.xml                       PhysInteractionsSelector.xml     StrumiaVassaniLBDPXSec.xml
DFRInteractionListGenerator.xml  KNOHadronization.xml               PythiaDecayer.xml             ToyInteractionSelector.xml
DFRKinematicsGenerator.xml      KNOptimHadronization.xml           PythiaHadronization.xml        TransverseMomentumFFModel.xml
DFRPrimaryLeptonGenerator.xml    KokoulinPetrakInModel.xml          QELEventGenerator.xml          UnstablePartiDecayer.xml
DipoleLFormFactorModel.xml      KovalenkoGELCharmPKSec.xml         QELHadronicSystemGenerator.xml   UserPhysicsOptions.xml
DipoleFormFactorModel.xml        KuznetsovGEMInNauovRESPXSec2014.xml  QELInteractionListGenerator.xml  VertGenerator.xml
DISHadronicSystemGenerator.xml   LocalFGF.xml                       QELKinematicsGenerator.xml      ZExpkialFormFactorModel.xml
aaron@obelisk:~/code/genie/config$
```

# Configuring z-Expansion

The configuration files are in  $\$GENIE/config$

```
aaron@obelisk: ~/code/genie/config
File Edit View Search Terminal Help
aaron@obelisk:~/code/genie/config$ ls
AhrensWCELXSec.xml          DISInteractionListGenerator.xml      LwlyrSmltHFCC.xml             QELXSec.xml
AlvarezCharmKSec10.xml     DISKinematicsGenerator.xml          LwlyrSmltHQELCCPXSec.xml     QPMIDSPXSec.xml
AlansinoAthrVacasSKPXSec.xml DISPrimaryLeptonGenerator.xml       master_config.xml            QPMIDSSrncFunc.xml
AlvarezSinoCOPXPSec.xml    EffectivSWF.xml                    NECGenerator.xml              ReInDFRFXSec.xml
APMGammaGenerator.xml      EmpiricalMECPXSec2015.xml          NECInteractionListGenerator.xml ReInSeghalCOPXPSec.xml
APMGammaInteractionListGenerator.xml EventGeneratorListAssembler.xml    NECXSec.xml                  ReInSeghalRESPXSec.xml
BardinINDrAdCorFXSec.xml   EventGenerator.xml                 Messenger_lacoin.xml          ReInSeghalSPPXSec.xml
BaryonResonanceDecayer.xml FERMIONementTables.xml            Messenger_rambLing.xml       ReInSeghalSPPXSec.xml
BBM3ELFormFactorsModel.xml FermiMover.xml                     Messenger_whisper.xml        RESHadronicSystemGenerator.xml
BBM3ELFormFactorsModel.xml FQBbodeRitchie.xml                Messenger.xml                 RESInteractionListGenerator.xml
BergerSeghalCOPXPSec2015.xml FluxDriverExpansion.xml           MessageGenerator.xml          RESKinematicsGenerator.xml
BergerSeghalFPCOPXPSec2015.xml GIBUJ.xml                          NievesSinoVacasMECPXSec2016.xml RESPPrimaryLeptonGenerator.xml
BergerSeghalRESPXSec2014.xml GLRESGenerator.xml                 NucleonEnergyAggregator.xml  RESXSec.xml
BethH6IochModel.xml        GLRESIXSec.xml                     NucleonExcitationList.xml    RosenbluthFXSec.xml
BezrukovGaussModel.xml     GRWS0.xml                           NucleonExcitationListSis.xml RShellicityApplModelCC.xml
BYDF.rnc                   H3APMGammaPXSec.xml                NuElectronMap.xml            RShellicityApplModelEM.xml
CharmHadronization.xml     HadronTransporter.xml              NuLeptonDecayPrimaryVtxGenerator.xml RShellicityApplModelEMp.xml
COHElasticPXSec.xml        H4Intranuka2014.xml                 NuInteractionListGenerator.xml RShellicityApplModelLHCn.xml
COHEHadronicSystemGenerator.xml H4Intranuka2015.xml                 NuKinematicsGenerator.xml    RShellicityApplModelMCP.xml
COHEKinematicsGenerator.xml H4Intranuka.xml                     NuElectronPXSec.xml          RSPPHadronicSystemGenerator.xml
COHadronicSystemGenerator.xml H4Intranuka2014.xml                 NuElectronVSec.xml           RSPPIInteractionListGenerator.xml
COKinematicsGenerator.xml   H4Intranuka2015.xml                 NuEPrimaryLeptonGenerator.xml RSPResonanceSelector.xml
COPPrimaryLeptonGenerator.xml H4Intranuka2015.xml                 NuETargetRemnantGenerator.xml SOHadronicSystemGenerator.xml
COHSec.xml                 H4Intranuka.xml                     P3PParochosLakulichPXSec.xml SKInteractionListGenerator.xml
COHXSec.xml                 H4Intranuka2014.xml                 P4SDELambdaPXSec.xml        SKKinematicsGenerator.xml
CollinsSpittleFragm.xml    IMXSec.xml                          PDFLIB.xml                   SKPrimaryLeptonGenerator.xml
DFTKopelLovichPXSec.xml    InteractionListAssembler.xml        PetersonFragm.xml            SlowReclCharmD1SPXSecL0.xml
DFRHadronicSystemGenerator.xml Intranuka2014.xml                   PhysInteractionSelector.xml   SpectralFuncLid.xml
DFRInteractionListGenerator.xml Intranuka2015.xml                   PythiaDecayer.xml            StrumiaWassianLBDPXSec.xml
DFRKinematicsGenerator.xml  Intranuka.xml                       PythiaHadronization.xml     ToyInteractionListGenerator.xml
DFRPrimaryLeptonGenerator.xml KNOHadronization.xml                QELEventGenerator.xml        TransverseFunctionFFModel.xml
DipoleFormFactorModel.xml  KNOHadronicSystemGenerator.xml       GELHadronicSystemGenerator.xml UnselempiricalDecayer.xml
DipoleFormFactorModel.xml  KovalenkoGELCharmPXSec.xml          GELInteractionListGenerator.xml UserPhysicsOptions.xml
DISHadronicSystemGenerator.xml KuznetsovRiminasovRESPXSec2014.xml GELKinematicsGenerator.xml   VertexGenerator.xml
LocalFGP.xml                LocalFGP.xml                          GELPrimaryLeptonGenerator.xml ZxpxkLepFormFactorModel.xml
aaron@obelisk:~/code/genie/config$
```

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

# Configuring z-Expansion

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

```
aaron@obelisk: ~/code/lgenie/GENIE/config
File Edit View Search Terminal Help
<!--
-----
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`:

```
aaron@obelisk: ~/code/lgenie/GENIE/config
File Edit View Search Terminal Help
<!--
-----
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" value="genie::NievesQELCCPXSec/Default" />
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-CC" value="genie::LwlynSmithQELCCPXSec/ZExp" />
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-CC" value="genie::AntreaticELPXSec/Default" />
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-EM" value="genie::RosenbluthRXSec/Default" />
-----
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" value="genie::ZExpAxialFormFactorModel/Default" />
-----
885,1 98%
```

# Configuring z-Expansion

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

```
aaron@obelisk: ~/code/lgenie/GENIE/config
File Edit View Search Terminal Help
<!--
-----
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 -->
<!--
-->
<!-- "ZExp" option set in LwlynSmithQECCPXSec.xml
--> => Turns on z-expansion in GENIE event generation
<!--
-->
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-CC" genie::NievesQECCPXSec/Default </param>
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-CC" genie::LwlynSmithQECCPXSec/ZExp </param>
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-CC" genie::AhrensQECCPXSec/Default </param>
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-EM" genie::RosenbluthQECCPXSec/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%
```

Revert to "ZExpAxialFormFactorModel" when instantiating LwlynSmithFFCC cross section module  
=> Turns on z-expansion in reweighting routines



# Configuring z-Expansion

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

```
<!--
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 -->
<!-- "ZExp" option set in LwlynSmithQELCCPXSec.xml
=> Turns on z-expansion in GENIE event generation
-->
<!--
<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-CC" genie::AntiprotonELPXSec/Default </param>
<param type="alg" name="XSecModel@genie::EventGenerator/QEL-EM" genie::RosenbluthFFCCSec/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>
-->
```

Revert to "ZExpAxialFormFactorModel" when instantiating LwlynSmithFFCC cross section module  
=> 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  $\nu_\mu$  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  $\nu_\mu$  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  
File Edit View Search Terminal Help  
<?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::LWlynSmithQELCCPXS/zExp/nu:14;tgt:1000060120;N:2112;proc:Weak[CC],QES;" nknots="44">  
<knot> 0.01000 </E> <xsec> 0 </xsec> </knot>  
<knot> 0.030175 </E> <xsec> 0 </xsec> </knot>  
<knot> 0.050351 </E> <xsec> 0 </xsec> </knot>  
<knot> 0.070526 </E> <xsec> 0 </xsec> </knot>  
<knot> 0.090701 </E> <xsec> 0 </xsec> </knot>  
<knot> 0.11088 </E> <xsec> 8.211871327e-15 </xsec> </knot>  
<knot> 0.1409 </E> <xsec> 3.420258124e-12 </xsec> </knot>  
<knot> 0.17906 </E> <xsec> 1.271358108e-11 </xsec> </knot>  
<knot> 0.22756 </E> <xsec> 2.808187262e-11 </xsec> </knot>  
<knot> 0.28918 </E> <xsec> 4.966851112e-11 </xsec> </knot>  
<knot> 0.3675 </E> <xsec> 7.40552e-11 </xsec> </knot>  
<knot> 0.46702 </E> <xsec> 9.743752762e-11 </xsec> </knot>  
<knot> 0.5935 </E> <xsec> 1.178956961e-10 </xsec> </knot>  
<knot> 0.75423 </E> <xsec> 1.320122511e-10 </xsec> </knot>  
<knot> 0.95849 </E> <xsec> 1.403464385e-10 </xsec> </knot>  
<knot> 1.2181 </E> <xsec> 1.433663175e-10 </xsec> </knot>  
</spline>  
</genie_xsec_spline_list>  
</?xml>  
"numu-c-zccqe.xml" 53L, 3222C  
1,1 Top
```

# Splines: Generation

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

```
$ gmksp1 -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/igenie/GENIE/temp  
File Edit View Search Terminal Help  
<?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" p="14;tgt:1000060120;N:2112;proc:Weak[CC],QES;" nknots="44">  
    <knot> 0.01000 </E> <xsec> 0 </xsec> </knot>  
    <knot> 0.030175 </E> <xsec> 0 </xsec> </knot>  
    <knot> 0.050351 </E> <xsec> 0 </xsec> </knot>  
    <knot> 0.070526 </E> <xsec> 0 </xsec> </knot>  
    <knot> 0.090701 </E> <xsec> 0 </xsec> </knot>  
    <knot> 0.11088 </E> <xsec> 8.211871327e-15 </xsec> </knot>  
    <knot> 0.1409 </E> <xsec> 3.420258124e-12 </xsec> </knot>  
    <knot> 0.17906 </E> <xsec> 1.271358108e-11 </xsec> </knot>  
    <knot> 0.22756 </E> <xsec> 2.808187262e-11 </xsec> </knot>  
    <knot> 0.28918 </E> <xsec> 4.966851112e-11 </xsec> </knot>  
    <knot> 0.3675 </E> <xsec> 7.40552e-11 </xsec> </knot>  
    <knot> 0.46702 </E> <xsec> 9.743752762e-11 </xsec> </knot>  
    <knot> 0.5935 </E> <xsec> 1.178956961e-10 </xsec> </knot>  
    <knot> 0.75423 </E> <xsec> 1.320122511e-10 </xsec> </knot>  
    <knot> 0.95849 </E> <xsec> 1.403464385e-10 </xsec> </knot>  
    <knot> 1.2181 </E> <xsec> 1.433663175e-10 </xsec> </knot>  
  </spline>  
</genie_xsec_spline_list>  
  
"numu-c-zccqe.xml" 53L, 3222C
```

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  $\nu_\mu$  on carbon including the z-expansion!

## 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  $\nu_{\mu}$  on carbon including the z-expansion!

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

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  $\nu_{\mu}$  on carbon including the z-expansion!

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

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>
-----
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*_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
-->
```

Compare to z-expansion:

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

# 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>

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"> -6.28 </param>
<param type="double" name="QEL-Tcut"> 0.1764 </param> <!-- 9*_pi^2 -->
<param type="double" name="QEL-Z_A1"> 2.36 </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
-->
```

number of free parameters  $k_{\max}$

z-expansion parameter values  $a_k$

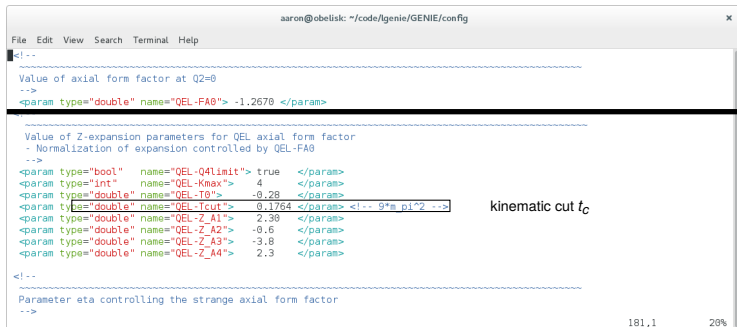
181,1 28%

Compare to z-expansion:

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

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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>

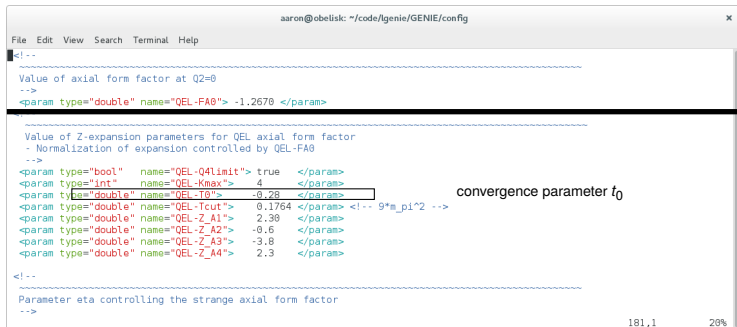
Value of Z-expansion parameters for QEL axial form factor
- Normalization of expansion controlled by QEL-FA0
-->
<param type="bool" name="QEL-Q4limit"> true </param>
<param type="int" name="QEL-Kmax"> 4 </param>
<param type="double" name="QEL-T0"> -0.28 </param>
<param type="double" name="QEL-Tcut"> 0.1764 </param> <!-- 9*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
-->
```

Compare to z-expansion:

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

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Parameters are again found in *UserPhysicsOptions.xml*:



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-->
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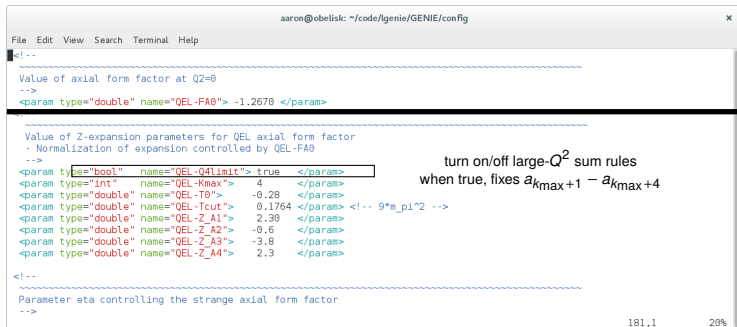
Value of Z-expansion parameters for QEL axial form factor
- Normalization of expansion controlled by QEL-FA0
-->
<param type="bool" name="QEL-Q4limit"> true </param>
<param type="int" name="QEL-Kmax"> 4 </param>
<param type="double" name="QEL-T0"> -6.28 </param> convergence parameter t_0
<param type="double" name="QEL-Tcut"> 0.1764 </param> <!-- 9*pi^2 -->
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-->
<param type="double" name="QEL-FA0"> -1.2670 </param>

-----
Value of Z-expansion parameters for QEL axial form factor
- Normalization of expansion controlled by QEL-FA0
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<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
-->
```

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

181,1 20%

Compare to z-expansion:

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

# 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" value="-1.2670" />
-----
Value of Z-expansion parameters for QEL axial form factor
- Normalization of expansion controlled by QEL-FA0
-->
<param type="bool" name="QEL-Q4limit" value="true" />
<param type="int" name="QEL-Kmax" value="4" />
<param type="double" name="QEL-T0" value="-0.28" />
<param type="double" name="QEL-Tcut" value="0.1764" />
<param type="double" name="QEL-Z_A1" value="2.30" />
<param type="double" name="QEL-Z_A2" value="-0.6" />
<param type="double" name="QEL-Z_A3" value="-3.8" />
<param type="double" name="QEL-Z_A4" value="2.3" />
<!--
Parameter eta controlling the strange axial form factor
-->
```

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

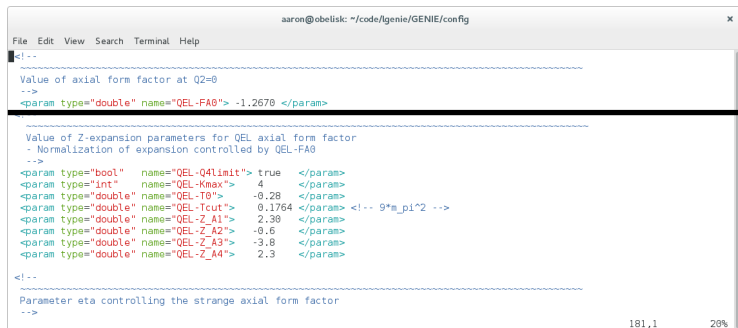
Compare to z-expansion:

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



# Changing z-Expansion Parameters

Parameters are again found in *UserPhysicsOptions.xml*:



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<!--
-----
Value of axial form factor at Q2=0
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<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 28%

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

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*)

# 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  $\nu_\mu$  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
```

# 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

# 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

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



# 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 gnnp.1.gst.root
root [0]
Attaching file gnnp.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/0 : 0 at: 0x195c430
OBJ: TBranch   qel     qel/0 : 0 at: 0x195db50
OBJ: TBranch   mec     mec/0 : 0 at: 0x195e070
OBJ: TBranch   res     res/0 : 0 at: 0x195e5b0
OBJ: TBranch   dis     dis/0 : 0 at: 0x195eaf0
OBJ: TBranch   coh     coh/0 : 0 at: 0x195f030
OBJ: TBranch   dfr     dfr/0 : 0 at: 0x195f570
OBJ: TBranch   imd     imd/0 : 0 at: 0x195fab0
OBJ: TBranch   imdanh  imdanh/0 : 0 at: 0x195fff0
OBJ: TBranch   singlek  singlek/0 : 0 at: 0x1960530
```

# 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 gnup.1.gst.root
root [0]
Attaching file gnup.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/0 : 0 at: 0x195c430
OBJ: TBranch   qel      qel/0 : 0 at: 0x195db50
OBJ: TBranch   mec      mec/0 : 0 at: 0x195e070
OBJ: TBranch   res      res/0 : 0 at: 0x195e5b0
OBJ: TBranch   dis      dis/0 : 0 at: 0x195eaf0
OBJ: TBranch   coh      coh/0 : 0 at: 0x195f030
OBJ: TBranch   dfr      dfr/0 : 0 at: 0x195f570
OBJ: TBranch   imd      imd/0 : 0 at: 0x195fab0
OBJ: TBranch   imdanh   imdanh/0 : 0 at: 0x195fff0
OBJ: TBranch   singlek  singlek/0 : 0 at: 0x1960530
```

Quite extensive! A full list of the variables is found in Sec. 7.6.2 of the Physics & User Manual: [arXiv 1510.05494v1 \[hep-ph\]](https://arxiv.org/abs/1510.05494v1)

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
```

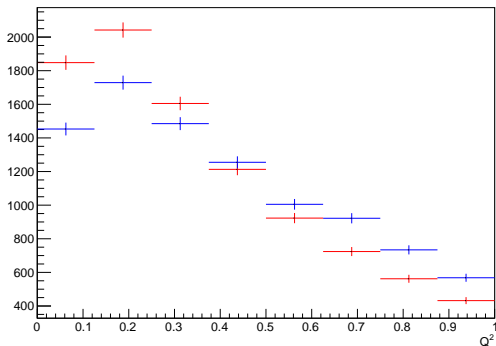
# Plotting the Simulated Sample

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:

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

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  $m_A = 0.99$  GeV.

- The default GENIE value for  $m_A$  is 0.99 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