

# Vector Boson Scattering (VBS) Analysis

Albert Guo, 9/29/2016

Mentor: Prof. Bin Zhou (Michigan)

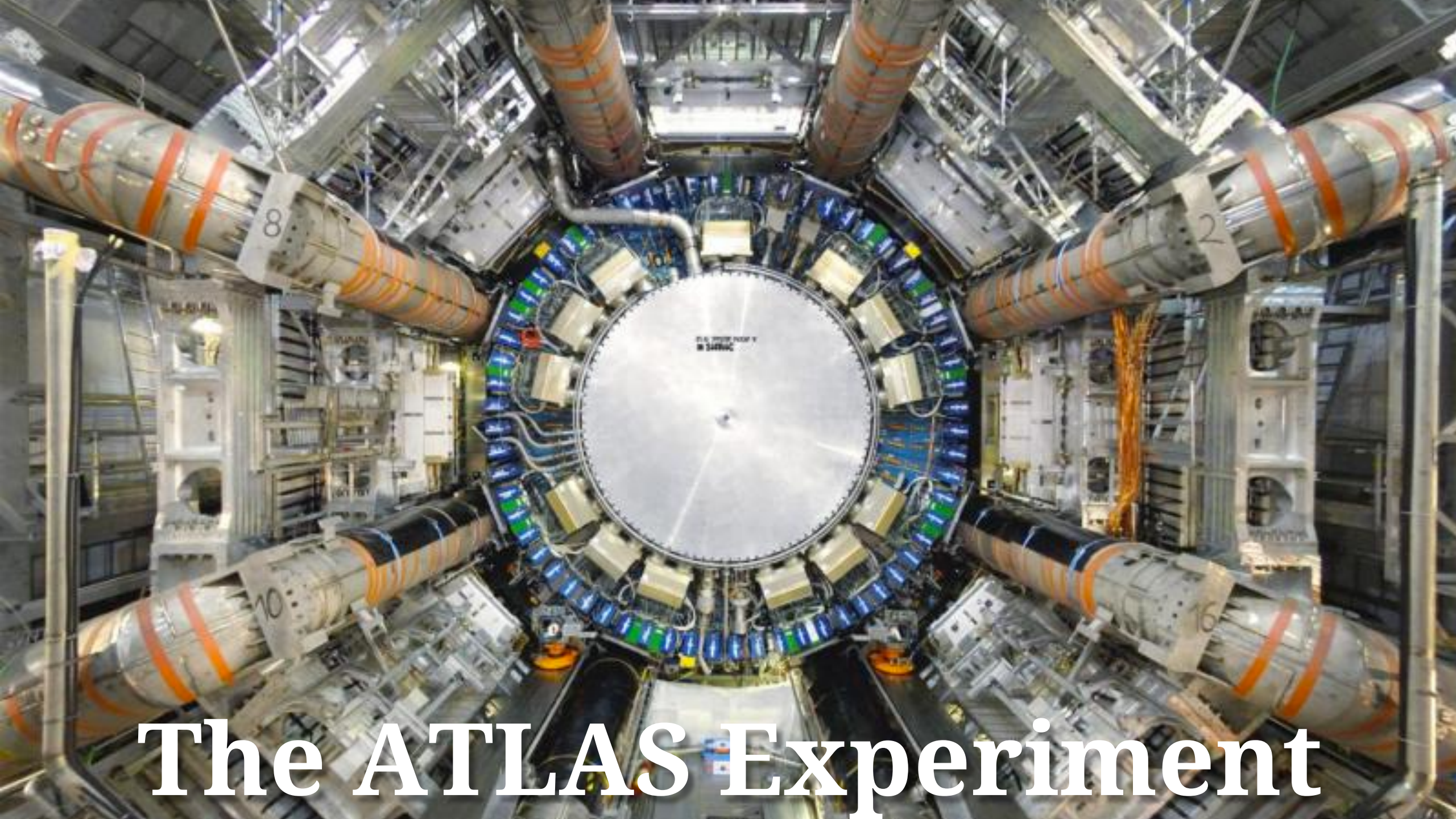
Postdoc: Dr. Yusheng Wu (CERN)



# The Standard Model

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	2/3	2/3	2/3	0	0
spin →	1/2	1/2	1/2	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
<b>QUARKS</b>	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	-1/3	-1/3	-1/3	0	
	1/2	1/2	1/2	1	
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	1/2	1/2	1/2	1	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
<b>LEPTONS</b>	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	$\pm 1$	
	1/2	1/2	1/2	1	
	<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino	<b>W</b> W boson	<b>GAUGE BOSONS</b>

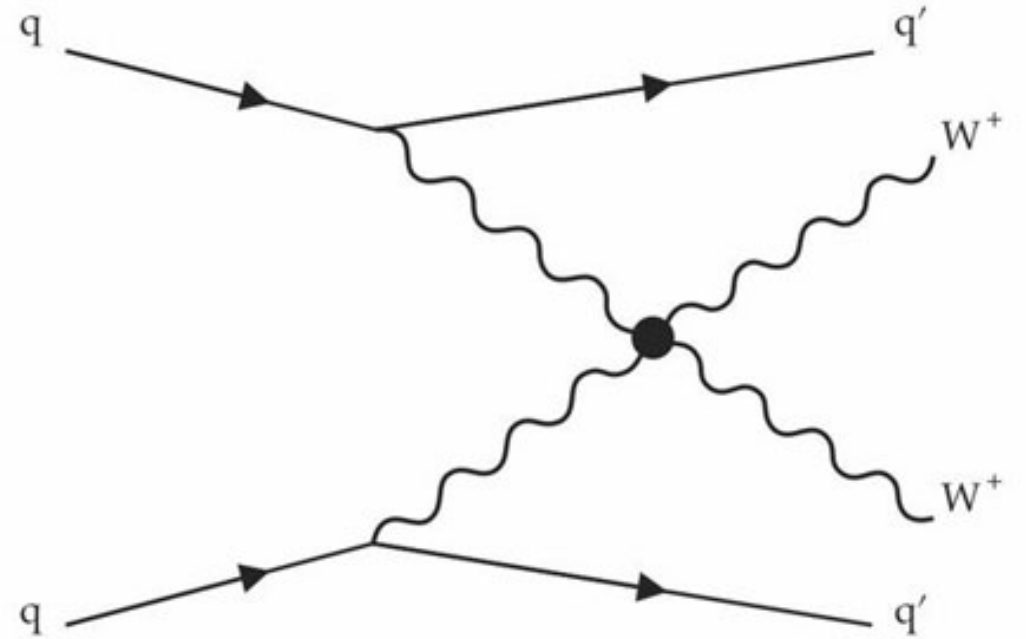




# The ATLAS Experiment

# Vector Boson Scattering

- In the standard model of particle physics, the  $W^+$ ,  $W^-$ , and  $Z$  are so-called vector bosons that transmit the weak force responsible for nuclear decay.
- But those bosons can also scatter off each other with a cross section that is sensitive to the many details of the theory.

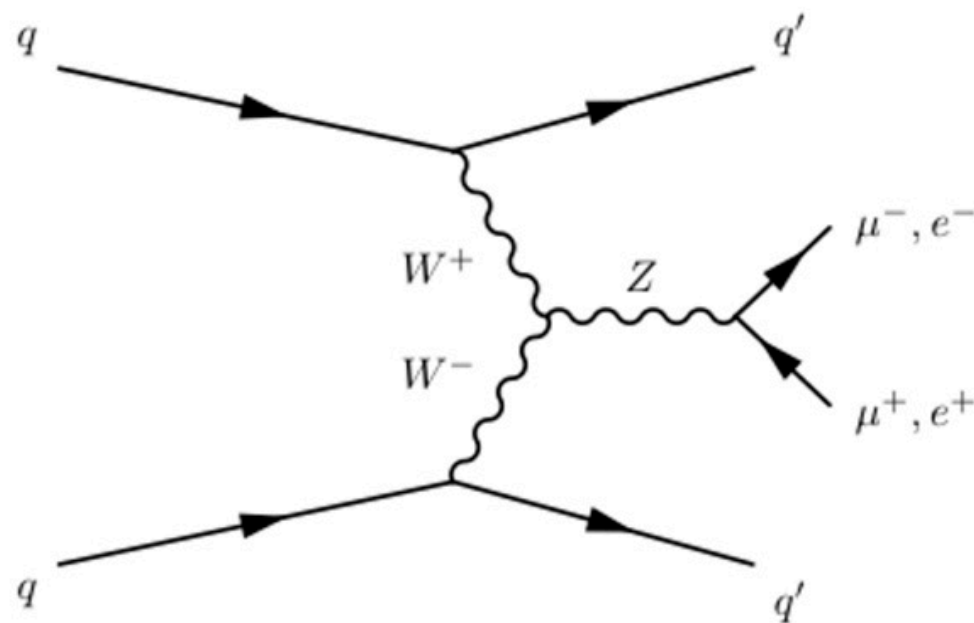




# Monte Carlo Simulation Generated Events

VBFNLO is a flexible parton level Monte Carlo program

1. **the simulation of vector boson fusion (VBF)**
2. QCD induced single and double vector boson production plus two jets
3. double and triple vector boson production (plus jet) in hadronic collisions at next-to-leading order (NLO) in the strong coupling constant
4. Higgs boson plus two jet production via gluon fusion at the one-loop level.



Feynman diagram of Z boson production via weak boson fusion

# Current Work and Goals

- With the understanding of background physics, run the simulation program with certain configuration (e.g. support for ROOT Framework, evaluation of scalar and tensor one-loop integrals, etc.) to calculate the scattering cross-section
- Compare the simulation result to the previous runs with different configurations
- Each run takes about 20 hours on the server
- Extract the information from the generated LHE file to a ROOT tree
- Further analysis of the histograms from the ROOT tree



```
visitor-16004448:~ Albert_Guo$ ssh -X zuguo@umt3int01.physics.lsa.umich.edu
```

```
[zuguo@umt3int01.physics.lsa.umich.edu's password:
```

```
Last login: Thu Sep 29 04:16:25 2016 from pb-d-128-141-62-66.cern.ch
```

```
Rocks 6.1 (Emerald Boa)
```

```
Profile built 20:01 07-Jul-2013
```

```
Kickstarted 20:10 07-Jul-2013
```

```
UM-ATLAS Interactive node
```

June 7, 2013 HB2013

14

```
ROCKS Frontend umrocks6
```

```
AGL Rolls Built
```

WW/WZ/ZZ scattering at the LHC

```
[zuguo@umt3int01 ~]$ cd /atlas/data19/zuguo/install-2.7.1-old/bin/
```

```
[zuguo@umt3int01 bin]$ ls
```

```
cuts.dat  file  grid2_1.out.1  grid2_1.out.3  grid2_1.out.5  histograms.root  vbfnlo.dat  
event.lhe  ggflo  grid2_1.out.2  grid2_1.out.4  grid2_1.out.6  vbfnlo          xsection.out
```

```
[zuguo@umt3int01 bin]$ vi file
```

```
[zuguo@umt3int01 bin]$
```

- fully leptonic final states

$W^\pm W^\pm jj \rightarrow l^\pm \nu l^\pm \nu jj$

$W^\pm W^\mp jj \rightarrow l^\pm \nu l^\mp \nu jj$

$W^\pm Z jj \rightarrow l^+ l^- l^\pm \nu jj$

$ZZ jj \rightarrow l^+ l^- l^+ l^- jj$

$ZZ jj \rightarrow l^+ l^- \nu \nu jj$

equally charged leptons, best  $\sigma_{EW}$  to  $\sigma_{QCD}$  ratio  
oppositely charged leptons, huge  $tt$  background  
clean channel due to three lepton final state  
very clean channel due to four lepton final state  
more difficult to measure, but higher BR

Log in UM's server remotely



# Information on global parameters

PROCESS		210		
LOPROCESS_PLUS_JET	=	F		
KK_MOD	cut on $ \Delta\eta_{jj} $ and $m_{jj}$	F		
ANOM_CPL	=	F		
LEPTONS	=	11	-11	Jun 11, 2011 HB2013
LO_ITERATIONS	=	6		
NLO_ITERATIONS	=	6		
LO_POINTS	=	26		
NLO_POINTS	=	26		
NLO_SWITCH	=	F		
EWCOR_SWITCH	=	F		
FERMIONLOOP	=	3		
LHA_SWITCH	=	T		
HEPMC_SWITCH	=	F		
LHA_FILE	=	event.lhe		

$W^\pm W^\pm jj \rightarrow l^\pm \nu l^\pm \nu jj$  equally charged leptons, best  $\sigma_{EW}$  to  $\sigma_G$

checking whether gfortran accepts -g... (cached) yes  
checking for g++... g++  
checking whether we are using the GNU C++ compiler... yes  
checking whether g++ accepts -g... yes  
checking dependency style of g++... gcc3  
checking how to run the C++ preprocessor... g++ (-E  
checking for ld used by g++... /usr/bin/ld  
checking if the linker (/usr/bin/ld) is GNU ld... yes  
checking whether the g++ linker (/usr/bin/ld) supports shared libraries... yes  
checking for g++ option to produce PIC... -fPIC -DPIC  
checking if g++ PIC flag -fPIC -DPIC works... yes  
checking if g++ static flag -static works... no  
checking if g++ supports -c -o file.o... yes  
checking if g++ supports -c -o file.o... (cached) yes  
checking whether the g++ linker (/usr/bin/ld) supports shared libraries... yes  
checking dynamic linker characteristics... (cached) GNU/Linux ld.so  
checking how to hardcode library paths into programs... immediate  
checking whether ln -s works... yes  
checking which Fortran compiler we are using... gfortran  
checking for processes to include... all  
checking for LHAPDF... not required

checking for LOOPTOOLS... checking link to LoopTools... configure: error: "Could not link with LoopTools. Are you sure the path given is correct and that the same compiler (gfortran/ifort) is used for VBFNLO and LoopTools?"

# Learning Skills



- Physics
  - Scattering processes in more details
  - Parameters and terminology used
- ATLAS software environment
- Linux commands and Bash scripts
- ROOT Analysis Framework
  - The Toolkit for Multivariate Data Analysis with ROOT (TMVA), a standalone project ([link is external](#)) that provides a ROOT-integrated machine learning environment for the processing and parallel evaluation of sophisticated multivariate classification techniques.

# References

- <https://design-guidelines.web.cern.ch/badge-logo>
- <https://www.itp.kit.edu/vbfnlo/wiki/doku.php?id=overview>
- <http://scitation.aip.org/content/aip/magazine/physicstoday/news/10.1063/PT.5.7098>
- <http://atlasexperiment.org/news/2014/ATLAS-highlights-from-moriond-2014.html>