

**ISTEP2016 Tutorial**  
**Zprime Searches at 13TeV pp Collider**  
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**<https://pan.baidu.com/s/1b54D2m>**

## 1. Introduction

Various extensions of the Standard Models predict the existence of new kinds of heavy gauge bosons [1], either neutral ( $Z'$ ) or charged ( $W'$ ). Due to their simplicity and clean signature in leptonic decay, searches for  $Z'$  and  $W'$  serve as the benchmark to examine the potential of future high energy colliders.

In this study, we are particular interested in the Sequential Standard Model (SSM)[2]. The SSM  $Z'$  is a carbon copy of SM  $Z$  boson with the same couplings, but only with a heavier mass. In SSM,  $Z'$  is created through  $q\bar{q}$  annihilation and then decays with decay width  $\Gamma(Z') \sim 0.03 M_{Z'}$ .

A search for new high-mass narrow resonances in dimuon and dielectron invariant mass spectra has been obtained at the 7 and 8TeV LHC. With about  $20\text{fb}^{-1}$  of 8TeV data, the 95% CL lower limits on SSM  $Z'$  mass are 2.90TeV from ATLAS [3] and 2.90TeV from CMS [4]. The US Snowmass report [5] presented the ability to exclude a  $Z'$  at collision energy of 14/33 TeV with  $300/3000\text{fb}^{-1}$  of collected data. The 95% CL lower mass limits for SSM  $Z'$  mass is 6.44 TeV given  $300\text{fb}^{-1}$  at  $\sqrt{s}=14\text{TeV}$ .

[1] see e.g. arXiv:0801.1345; [sites.google.com/site/zprimeguide](https://sites.google.com/site/zprimeguide)

[2]G. Altarelli et.al., Z. Phys. C45 (1989) 109; V. Barger, W.Y. Keung, Phys.Lett. B94 (1980) 377-380.

[3] arXiv:1405.4123

[4] arXiv:1412.6302

[5] arXiv:1308.5874

2. Example Feynman Diagrams are shown in the following page: DY, TTbar, Diboson, Single top, and our Zprime signal

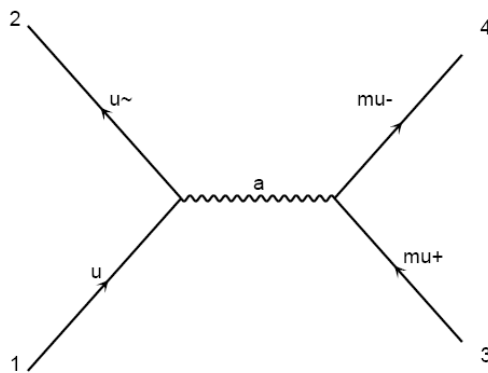


diagram 1 QCD=0, QED=2

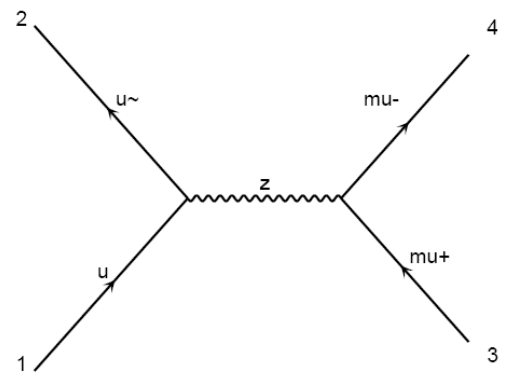


diagram 2 QCD=0, QED=2

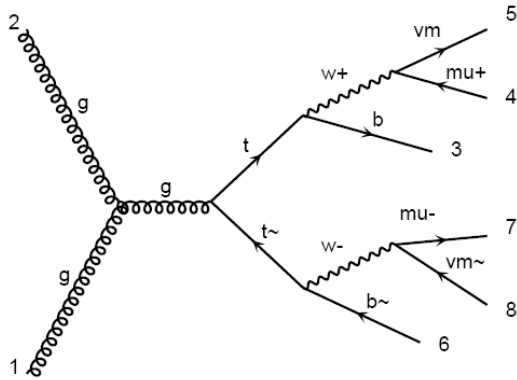


diagram 1 QCD=2, QED=4

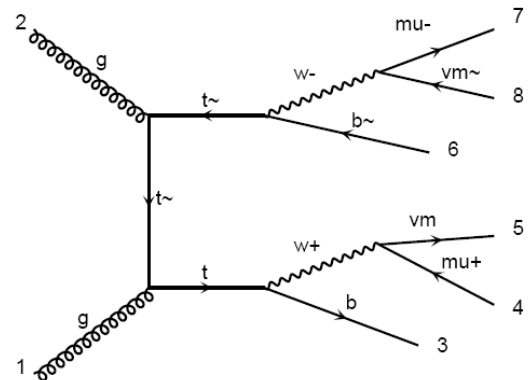


diagram 2 QCD=2, QED=4

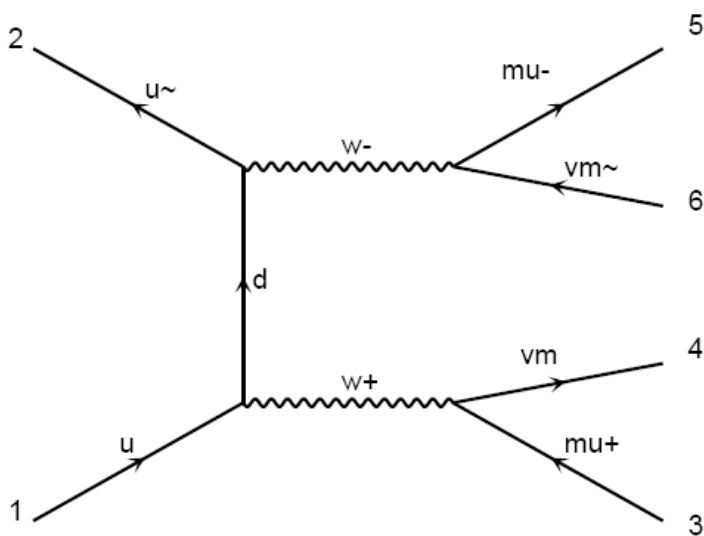


diagram 3 QCD=0, QED=4

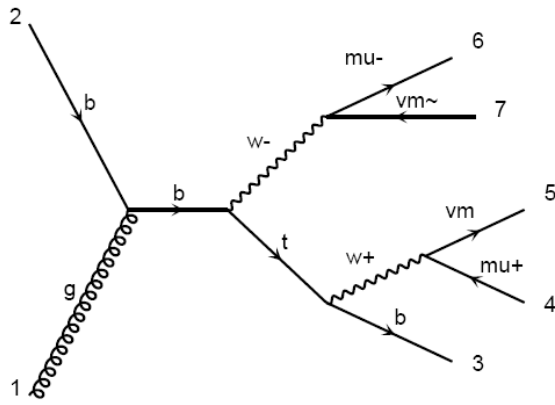


diagram 1      QCD=1, QED=4

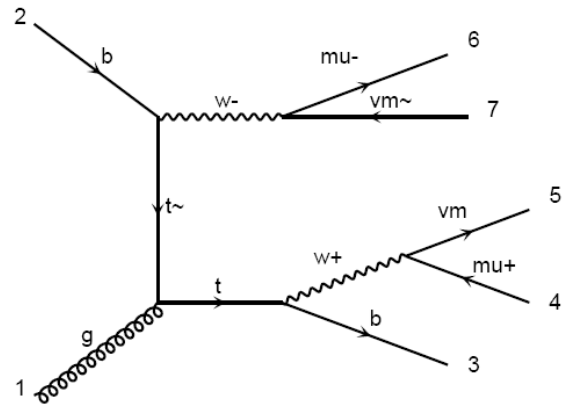


diagram 2      QCD=1, QED=4

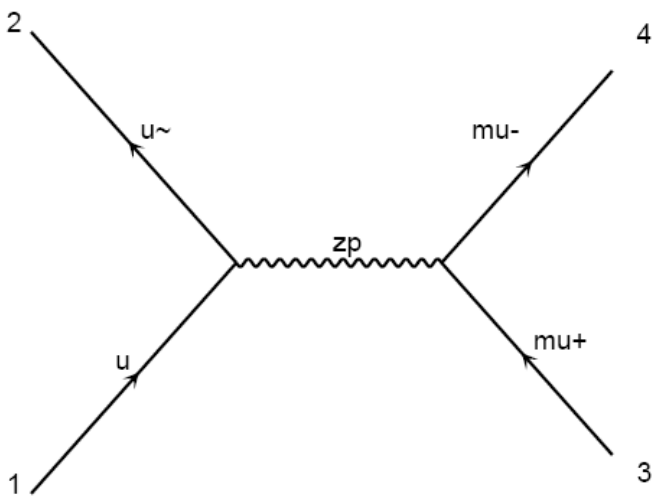
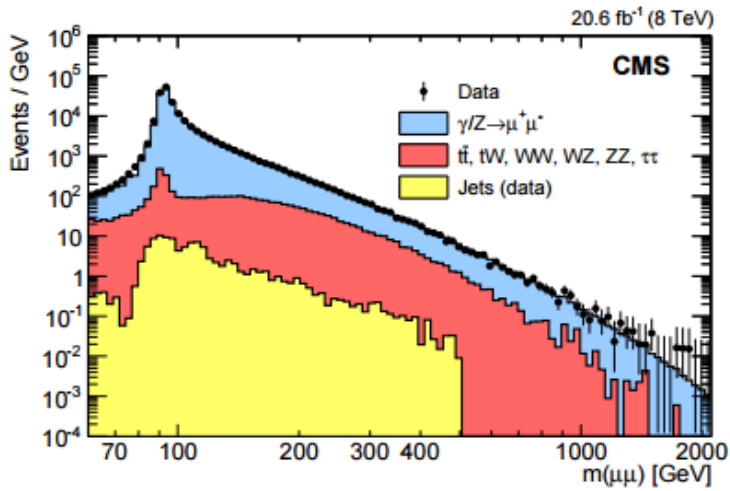


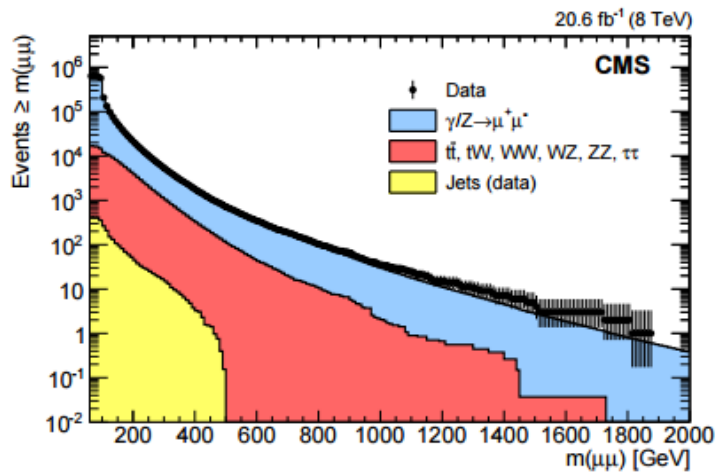
diagram 1      QCD=0, QED=2

### 3. CMS plots and limits (8TeV 2012)

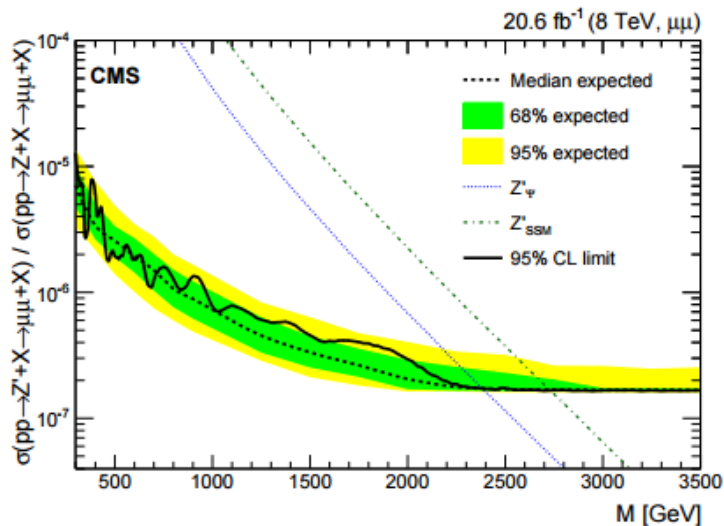
#### MII distributions



#### Cumulative MII distributions



#### CMS 8TeV mu-channel Limit plot (Brazilian Plot)



## 4. MG5\_aMC@NLO , Zprime and Background Samples

Download MG5\_aMC@NLO, “./bin/mg5”, “tutorial”, get familiar with it; “install pythia-pgs”, “install ExRootAnalysis”, “install Delphes”

We provide the Z' model directory “sm-ZP”, please put it under “models” in MG package;

generate pp>Zp>mu+mu- with CTEQ6L1, Switch on Pythia, cuts as:  
PTI>10GeV, |etal|<3., Mll>900GeV

For your refs:

MZ'(GeV)	Width(GeV)	Xsec (pb)
2000	59.8	0.01558 +- 2.035e-05 pb
2500	74.8	0.004547 +- 6.202e-06 pb
3000	89.9	0.001466 +- 2.782e-06 pb
3500	104.9	0.0005123 +- 1.173e-06 pb
4000	119.9	0.0001894 +- 3.144e-07 pb
4500	134.9	7.523e-05 +- 1.546e-07 pb

### BKG and Signal samples provided by us:

**DY 80K, 0.007476 +- 6.427e-06 pb**

**TTbar 40K, 0.0007598 +- 1.198e-06 pb**

**TW 10K, 8.888e-05 +- 2.135e-07 pb**

**WW 40K, 0.000338 +- 3.497e-07 pb**

**Note all these samples are applied with Mll>900GeV, assuming this is a special trigger of 2 muons with invariant mass larger than 900GeV.**

**We also provide signal samples for Z' mass from 2TeV to 4.5TeV, each with 10K.**

**These define the “lumi weight” or “lumi Scale factor” for each sample:  
Lumi/(Nevent/xsec)**

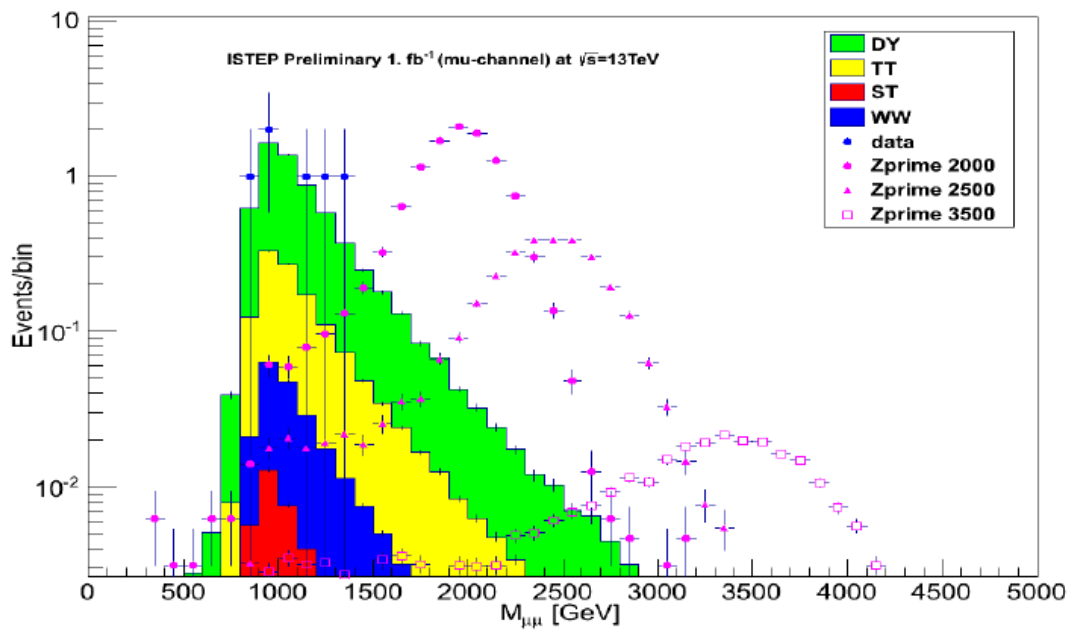
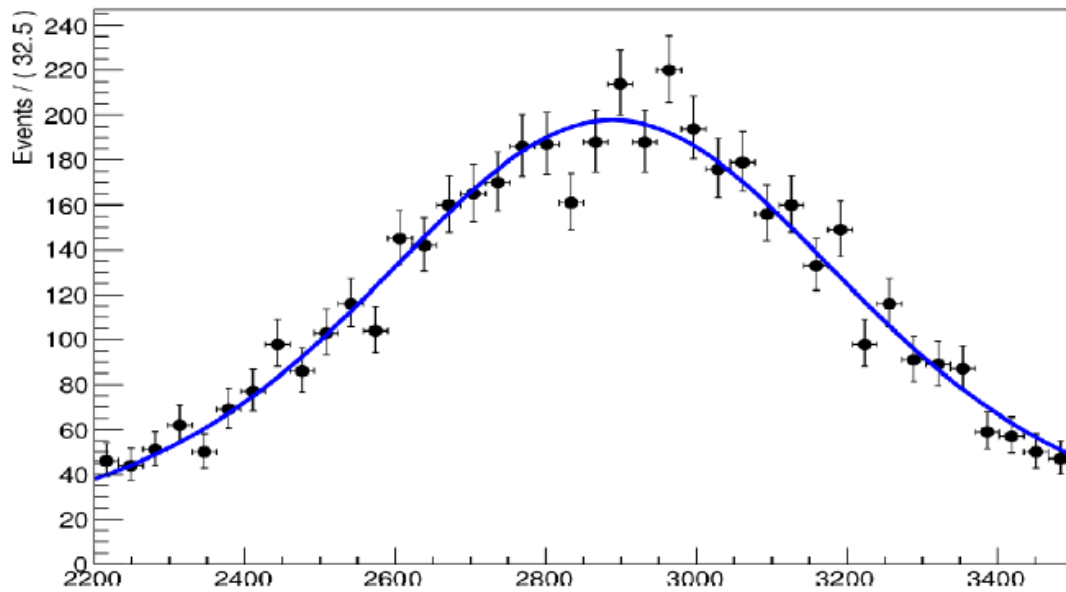
## 5. ISTEP2016 Zprime Tutorial

**<https://pan.baidu.com/s/1b54D2m>**

**default lumi is 1fb-1; Nevent/xsec stored as "SF"**

1. ".x producehiso.C" to get Mll histograms. (output is called out.root )
2. We also provide "data" named as "outdata.root". Use plot.C to make DATA/MC comparison plot. (Switch to Poisson Errorbars?)
3. fit2.C to fit Signal: `root -b -q fit2.C\(\"ZP3000\" \)`
4. cutcounting.C to perform simple statistic studies, based on histograms.
5. runsmalltuple.sh to get Ntuple instead of Histograms. Use "hadd" to have one single root file named as zprimetraining.root.
6. cutcounting2.C to perform simple statistic studies, based on ntuples.
7. Plot cumulative Mll distributions and other plots e.g. PTLI...
8. Run mva/mva-ana/MVA\_ana.C with input from step 5. Get familiar with MVA: training+application. Put TMVA.root under mva/test and use plotall.C to make plots. Try methods including BDTG, Fisher etc., and change their settings.  
(Note training and application are using the same inputs just for this toy study)
9. Compare significance from 4, 6 and 8.

## 6. Example Plots:



## 7. Advanced Projects

- 7.1 How to correct MC predictions for various backgrounds?
- 7.2 Can we suppress TTbar bkg?
- 7.3 We only consider WW but not WZ or ZZ for the diboson contributions, can you give an estimate how much WZ or ZZ contribute?
- 7.4 What other backgrounds are we still missing?
- 7.5 Bkg fitting?
- 7.6 Shape Analysis instead of Cut/counting?

You can think and test more

### Better approximation for significance

Poisson likelihood for parameter  $s$  is

$$L(s) = \frac{(s+b)^n}{n!} e^{-(s+b)}$$

For now  
no nuisance  
params.

To test for discovery use profile likelihood ratio:

$$q_0 = \begin{cases} -2 \ln \lambda(0) & \hat{s} \geq 0, \\ 0 & \hat{s} < 0. \end{cases} \quad \lambda(s) = \frac{L(s, \hat{\theta}(s))}{L(\hat{s}, \hat{\theta})}$$

So the likelihood ratio statistic for testing  $s = 0$  is

$$q_0 = -2 \ln \frac{L(0)}{L(\hat{s})} = 2 \left( n \ln \frac{n}{b} + b - n \right) \quad \text{for } n > b, \quad 0 \text{ otherwise}$$