Z’ → μ μ Analysis

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Introduction

What is Z'?

More massive than SM Z

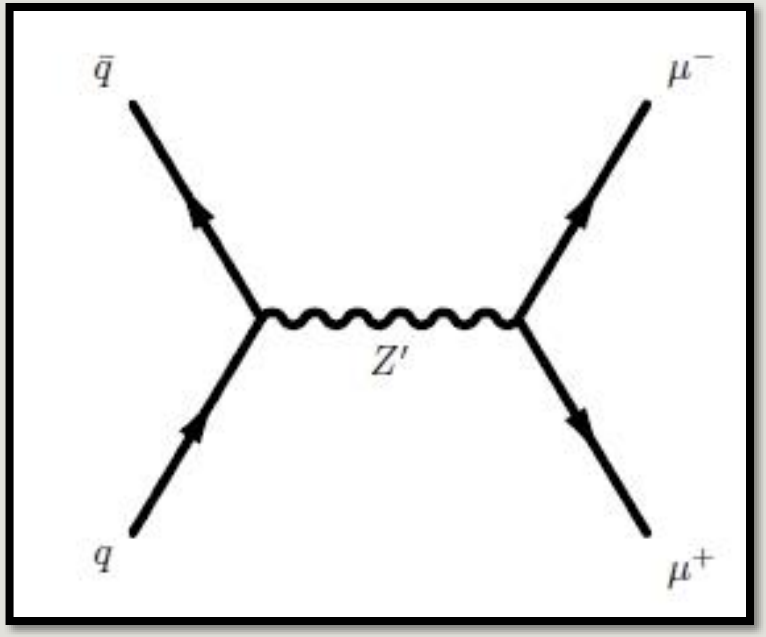
Neutral

Spin 1

Colorless

Self-adjoint (it is its own antiparticle)

Decay into leptons



Why Z’→μμ?

Predicted in many theories beyond the Standard Model

- Does it exist?
- What are its properties?
- Is it described by any current models or is it new?

CMS is optimized for searches using high P_T muons

Previous searches at $\sqrt{s} = 7TeV$ and $8TeV$

New mass regions can be explored with higher energies!

Data Samples

Data Sample

/SingleMuon/Run2015B-16Oct2015-v1/AOD
/SingleMuon/Run2015C_25ns-05Oct2015-v1/AOD
/SingleMuon/Run2015C-PromptReco-v1/AOD
/SingleMuon/Run2015D-PromptReco-v3/AOD
/SingleMuon/Run2015D-PromptReco-v4/AOD

The MC samples are used Spring 15:
For background:

- W+Jets
- TTbar
- dibosons(WW WZ ZZ)
- Gamma Z→MuMu (Drell Yan)
- QCD background

For Signal:

- Z'→mumu (5TeV)

NTuple

What is Ntuple?
A NTuple is a data format to store event and it stores a simple tree.
Created by end user and Portable size.

Why do we need Ntuple?
When we collect data from the detector, it record a raw data, too big to analyze. So we need to kick out a lot of informa tion in each event. Thus, only useful data for your analysis is stored.

•How to create a Ntuple from AOD?

Use EDanalyzer to create Ntuple from AOD:
  1. Load a lot of tools.(e.g. Configration files, Standard Sequences)
  2. Set the maximum number of events, files to load.
  3. Select tags you interested in AOD files.
  4. Read event by event and tell computer what you want to do.
  5. Debug.

Exsample Tags

```
process.maketreeMuon = cms.EDAnalyzer("MaketreeMuons",
    outputFile              =
cms.string('CMSSW745_Data2015_ZprimeMuMu_13TeV_tree.root'
),
    genEventInfo            = cms.InputTag('generator'),
    rhoIsoInputTag          = cms.InputTag("kt6PFJetsForIsolation",
"rho"),
    #rhoIsoInputTag         = cms.InputTag("kt6PFJetsCentral:rho"),
    PileupSrc               = cms.InputTag("addPileupInfo"),
    thePFMETCollectionToken  = cms.InputTag("pfMet"),
    METSignificance         =
cms.InputTag("METSignificance","METSignificance"),
    globalMuons             = cms.InputTag('muons'),
    globalMuonTracks        = cms.InputTag('globalMuons'),
  .
```

Event Selection

Trigger

The main trigger for analysis: **SingleMu HLT_Mu50** that selects single muons with pT >50GeV in the pseudorapidity range of the muon detector acceptance, $|\eta| < 2.4$.

Single muon trigger efficiency for high-pt muons is measured by the **Counting Tag&Probe**

- increases statistics at high pT
- consistent results w.r.t. standard Tag and probe

Event Selections

The full selection is:

Both muons must pass this selection:

- Muon must be a **global muon** and a **tracker muon**: (isGlobalMuon && isTrackerMuon)
- At least **two muon stations** in the fit; this implies trackerMuon : (numberOfMatchedStations > 1)
- |dxy w.r.t Primary Vertices| < 0.2 cm
- At least **one pixel hit**:

  (globalTrack.hitPattern.numberOfValidPixelHits >= 1)
- Number of **tracker layers with hits > 5** (globalTrack.hitPattern.trackerLayersWithMeasurement > 5)
- **dpT/pT < 0.3** to supress misreconstructed muons
- Relative **tracker isolation less than 10%**: (isolationR03.sumPt / innerTrack.pt < 0.10)
- **pT > 53 GeV**

Muon Selection	
Variable	**Value**
is Global && is Tracker Muon	True
N(muon hits)	>0
N(muon stations)	> 1
dxy wrt PV	< 2 mm
N(pixel hits)	> 0
N(tracker layers)	> 5
σpt/pt	< 0.3
Tracker Iso (ΔR=0.3)	< 0.1
p_T	> 53 GeV

The Dimuons candidates:

- Since we are looking for two muons which come from a single event (DY, Z, Z'), it makes sense that **both muons come from the same vertex.** We apply a vertex cut that calculates a probability that the two muons are from the same vertex.
- To reduce the background from cosmic ray muons that are in-time with a collision event and pass the primary vertex and impact parameter cuts, we require that the three-dimensional angle between the two muons momenta must be < (π-0.02 rad)
- We only want to keep one di-muon candidate per event, and we want to keep the di-muon with the highest pT.
- At least one muon must be trigger-matched to the single muon HLT path (**HLT_Mu50**) within $\Delta R < 0.2$.

DiMuon and Event Selection
good offline-reconstructed PV
opposite-sign muons
χ^2/d.o.f. of a common vertex fit < 20
3D opening angle α between the two muons momenta < (π - 0.02)
One of the muons matched within $\Delta R < 0.2$ to the **HLT_Mu50** muon candidate

Data vs. MC

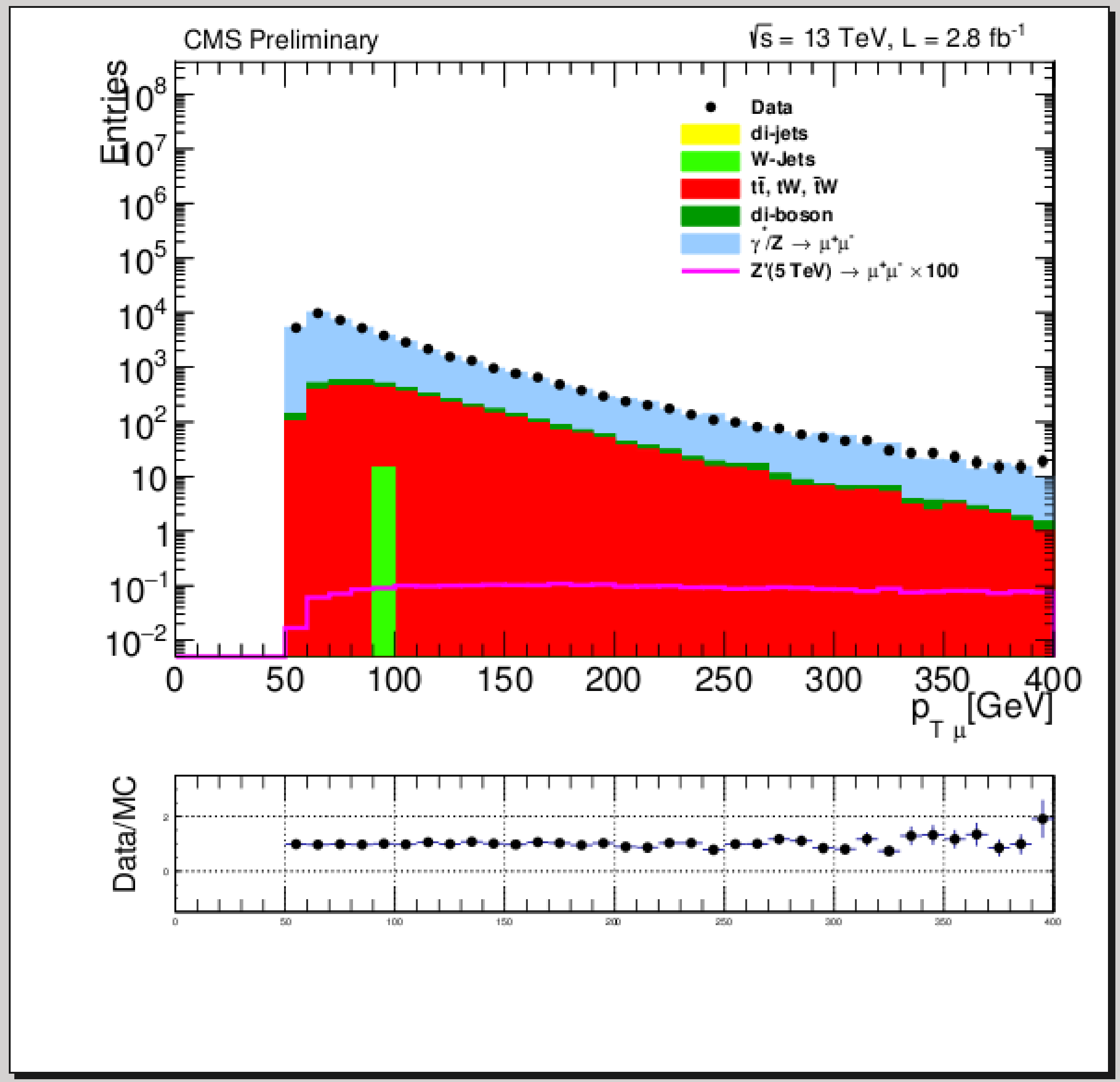


Figure 1: pT plot of the leading muon for the Data and MC for signal and background.

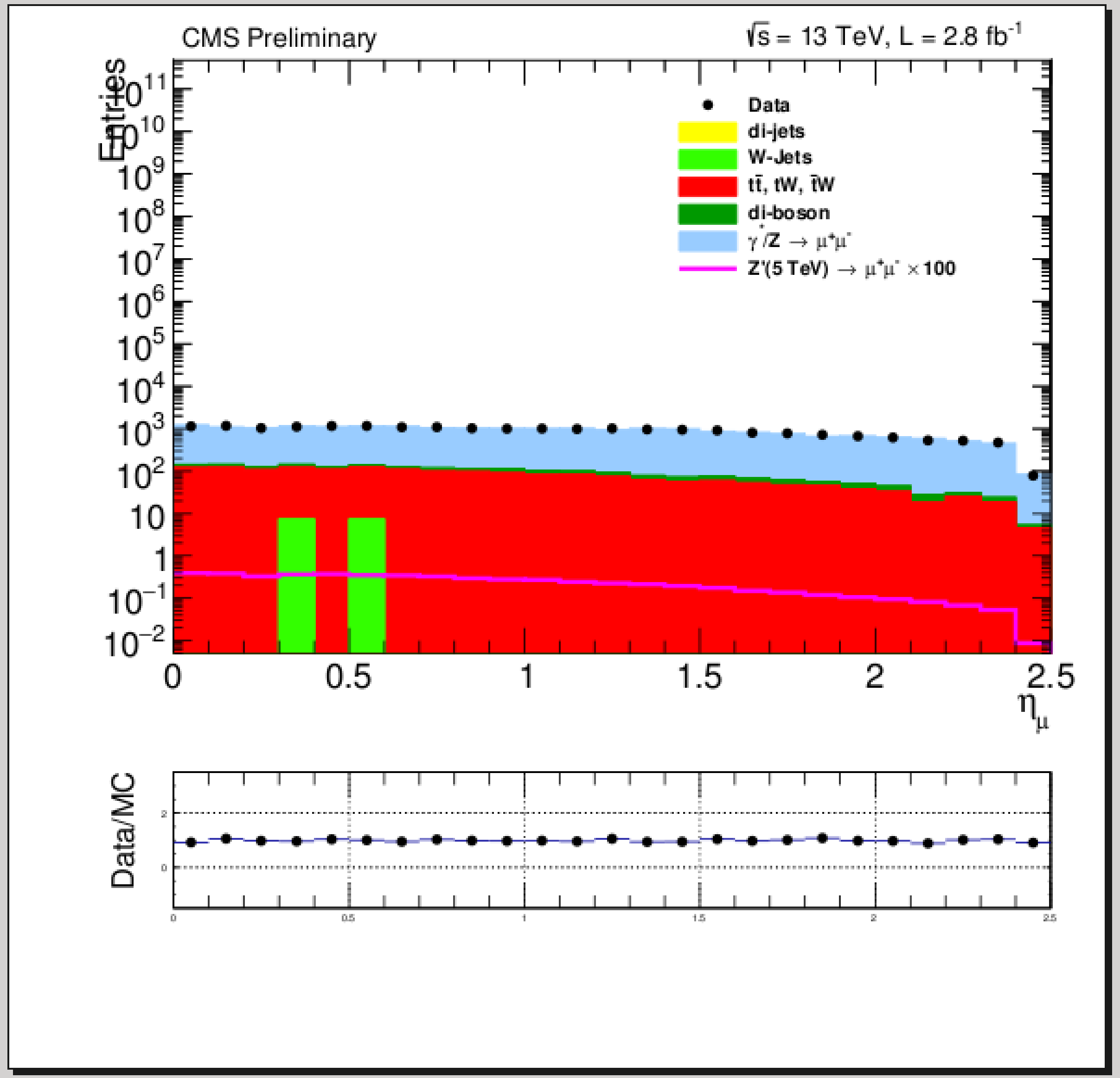


Figure 2: Eta plot of the leading muon for the Data and MC for signal and background.

Reconstruction Efficiency

Reconstruction efficiency

Use tag & probe , a kind of data driven technique, to check the reconstruction efficiency.

In Z->$\mu\mu$ events, select a muon with tight criteria, then see whether another muon would pass loose criteria or not.

Use all data compared with Drell-Yan MC sample.

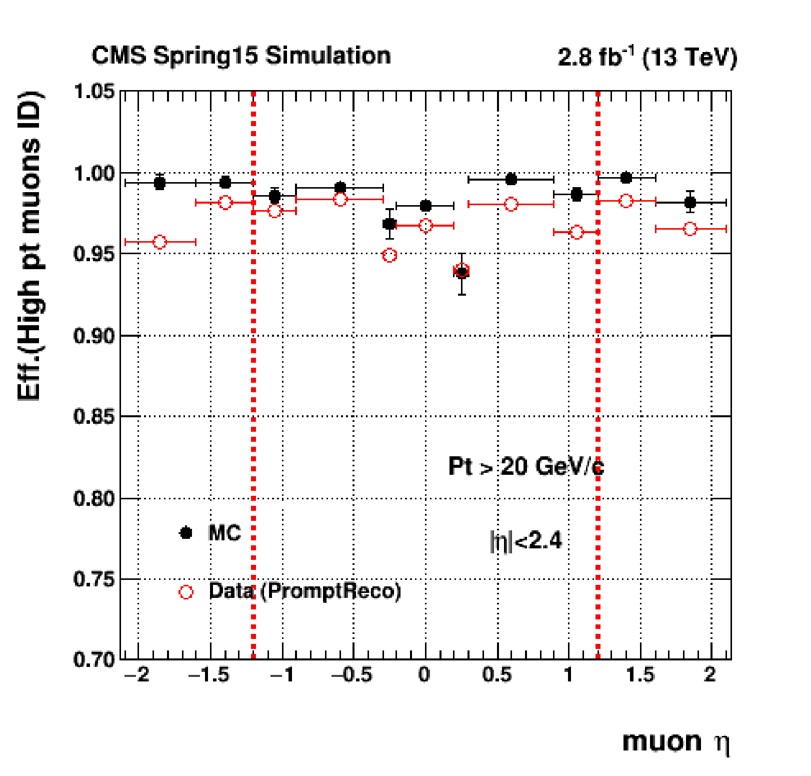
Tag & Probe Selection

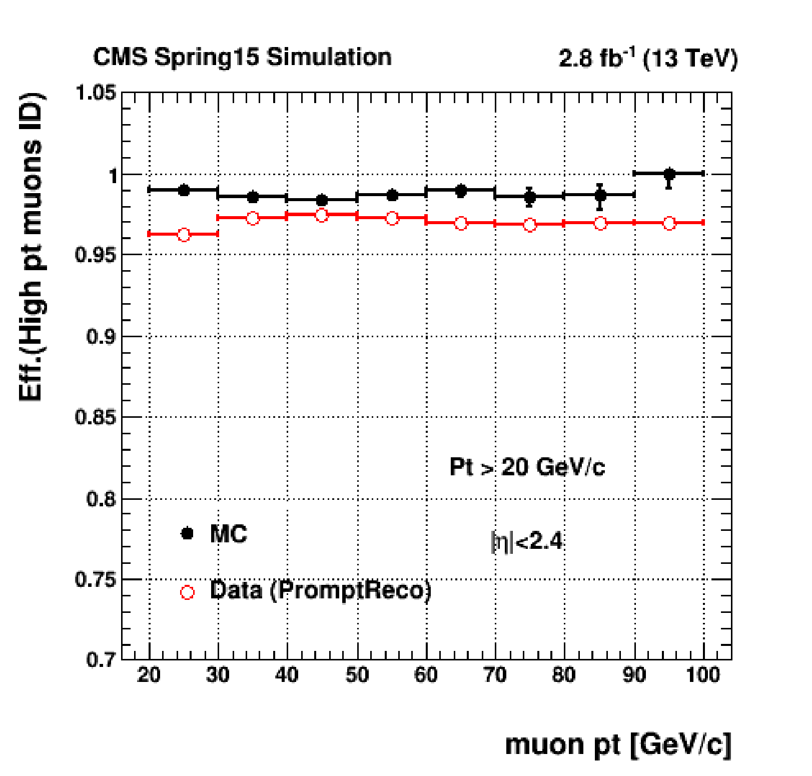
Tag Selection	Probe Selection
isGlobalMuon && isTrackerMuon $p_T > 20GeV$ $\lvert\eta\rvert < 2.4$ $\lvert dxy\rvert < 0.2$ $nTrackerLayerwithHits > 5$ $Pixel\ Hits > 0$ $Muon\ Hits > 0$ $MatchedStations > 1$ $\frac{\delta p_T}{p_T} < 0.3$	isTrackerMuon $p_T > 20GeV$ $\lvert\eta\rvert < 2.4$

Tags have the opposite-sign charge of probes.
Dimuons reconstruct Z with Z mass cut: $60 < m_Z < 120$

Reconstruction efficiency

Efficiency = $\frac{N_{TT}}{N_{TP}}$





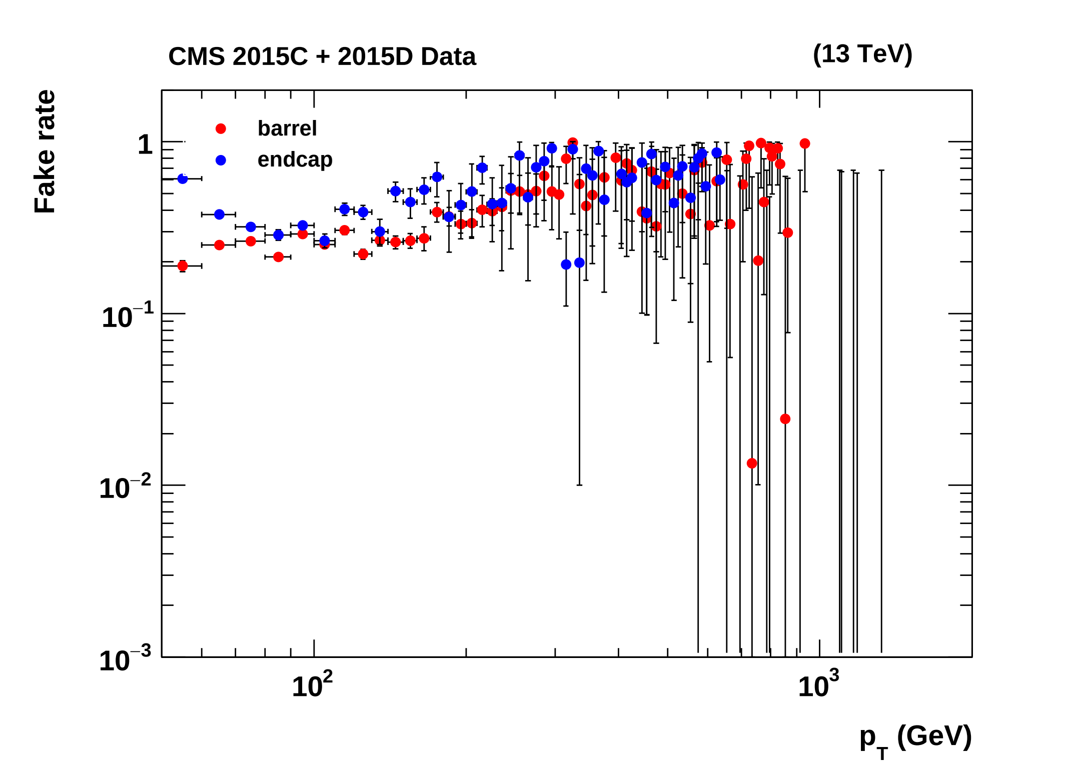
Fake Rate

Non-prompt Background

	loose
dxy wrt PV	< 2 mm
|dZ|	< 2 mm
N (tracker layers)	> 5
N(pixel hits)	> 0
HLT Matching	True

- Jet may fake muon ==> so called 'fake muon' ==> mainly from W+jets and QCD (di-jet)
- We are looking for 2 muons, thus:
  - 1 fake + 1 signal or 2 fakes
- Fake rate technique used here, is to:
  - FR measured from data in a fake-enriched region using loose selection
  - Fake rate (FR): the possibility to have a jet-fake-muon
  - N.B.: visible EWK fraction in the fake-enriched region

$$FR = \frac{\text{N of muons passing signal muon cut}}{\text{N of muons passing 'loose' cuts}}$$



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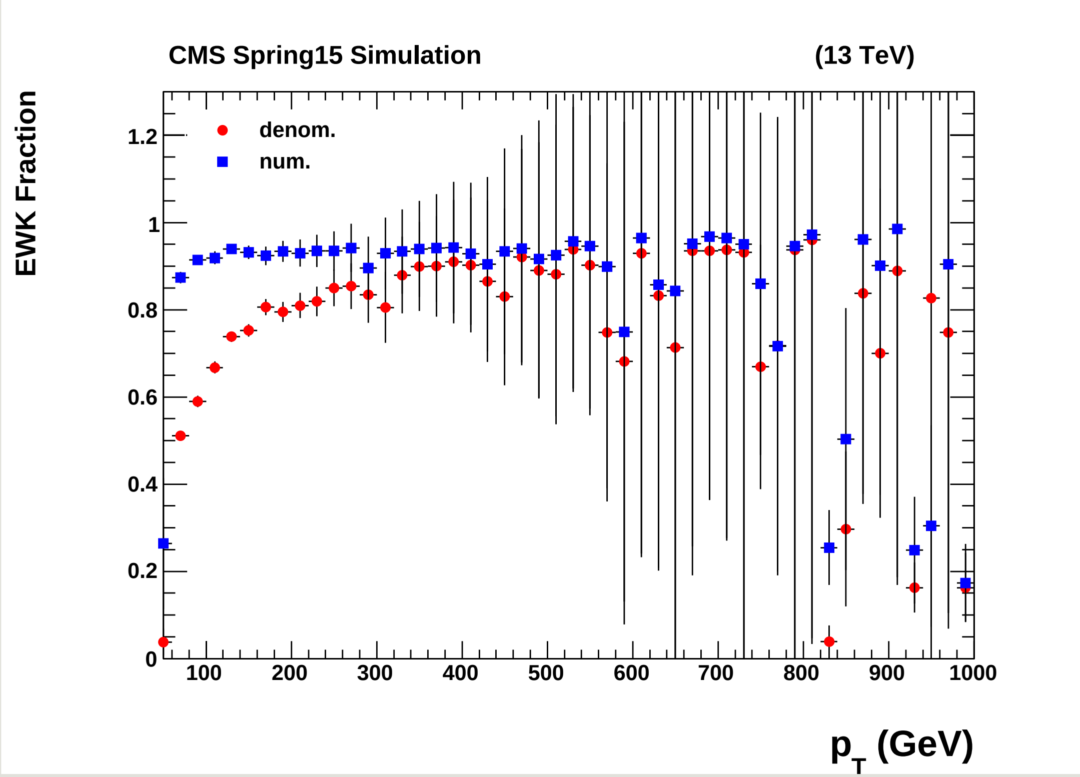
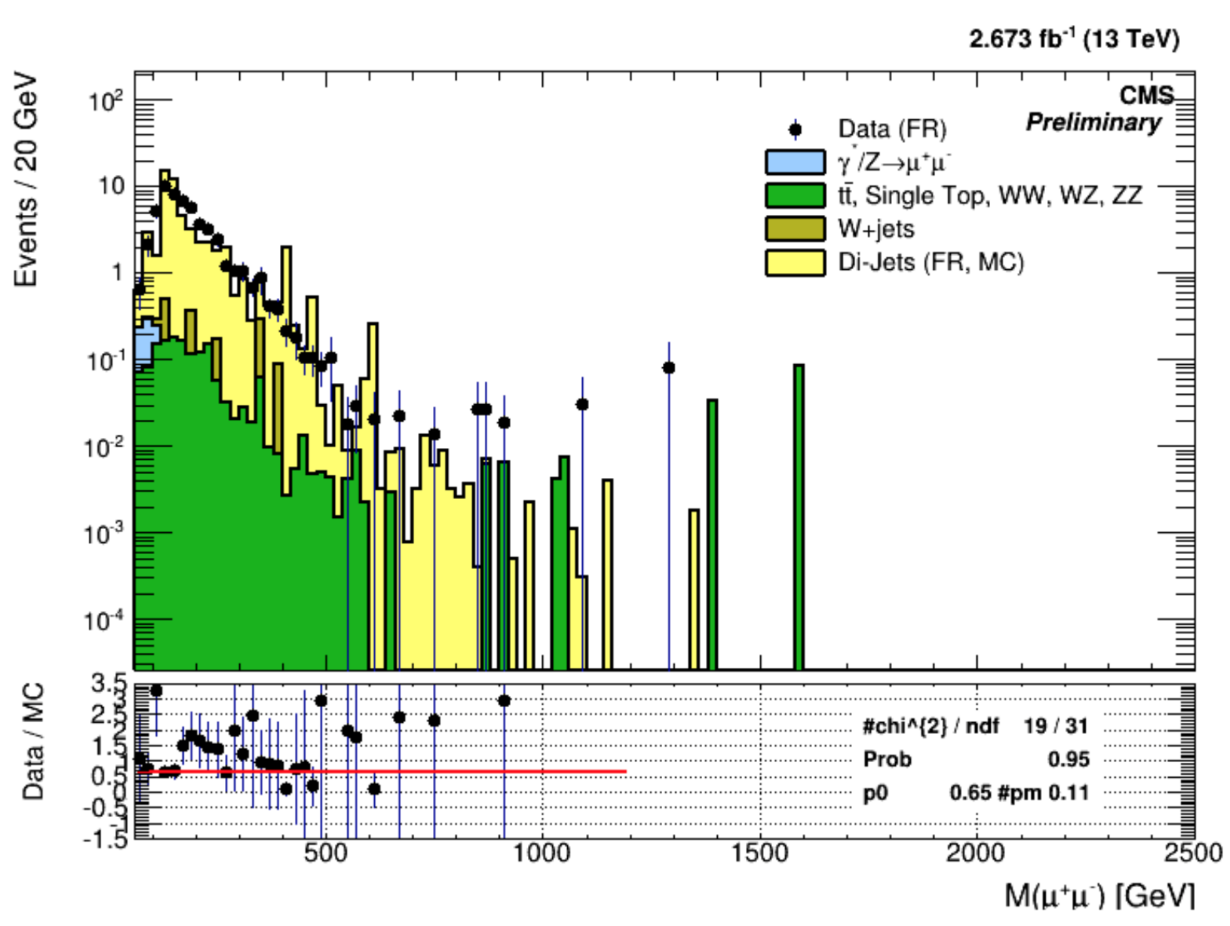


Non-prompt Background

To get the final estimate in SR:

- ~~Apply FR to control data sample with 1 'non-signal' muon~~
- QCD estimate:
  - Control data sample with 2 muons failed to pass signal cuts
- W+jets estimate:
  - Control MC sample with 1 signal muon and 1 muon failed signal cuts



Results and Significance

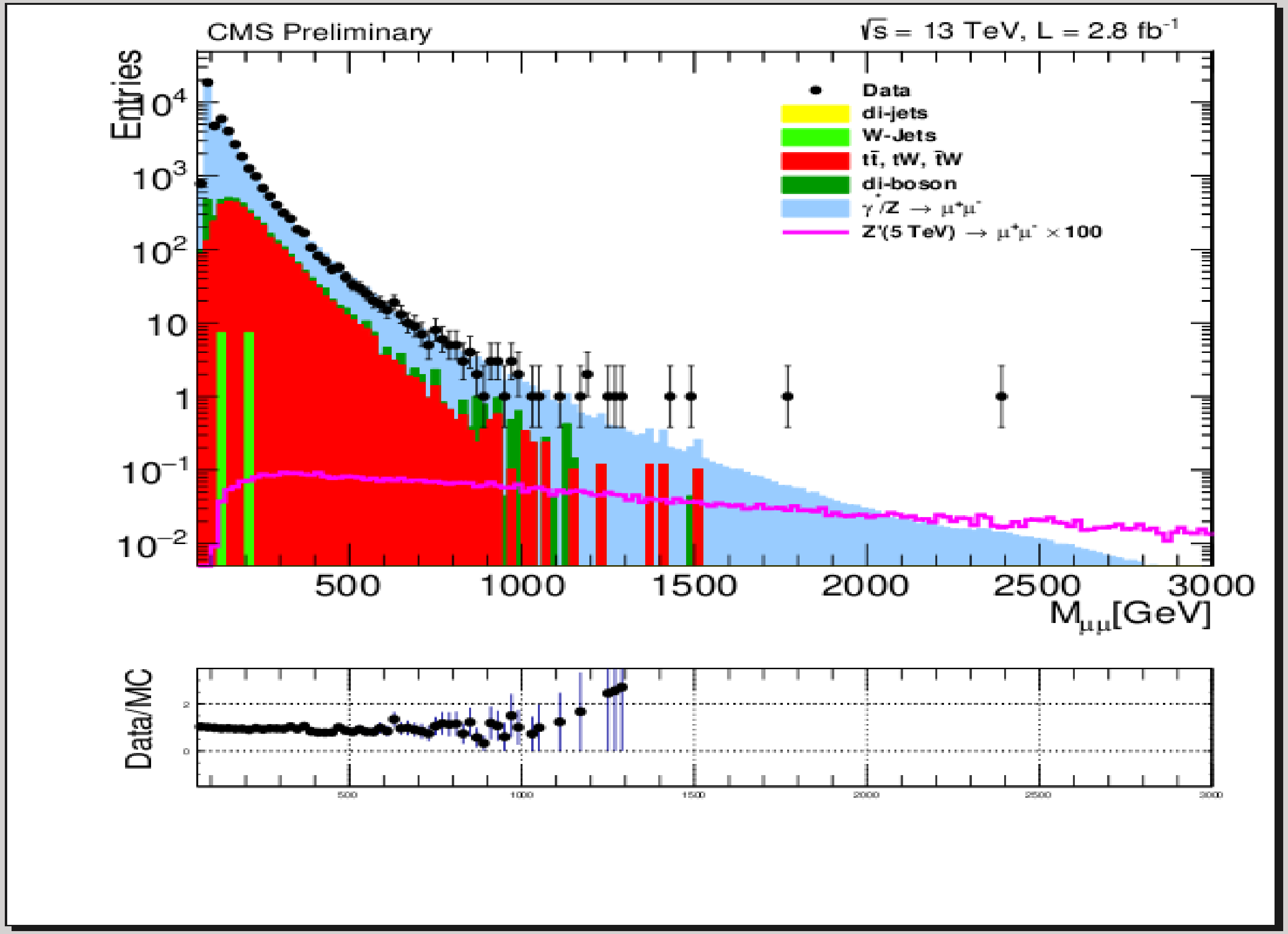
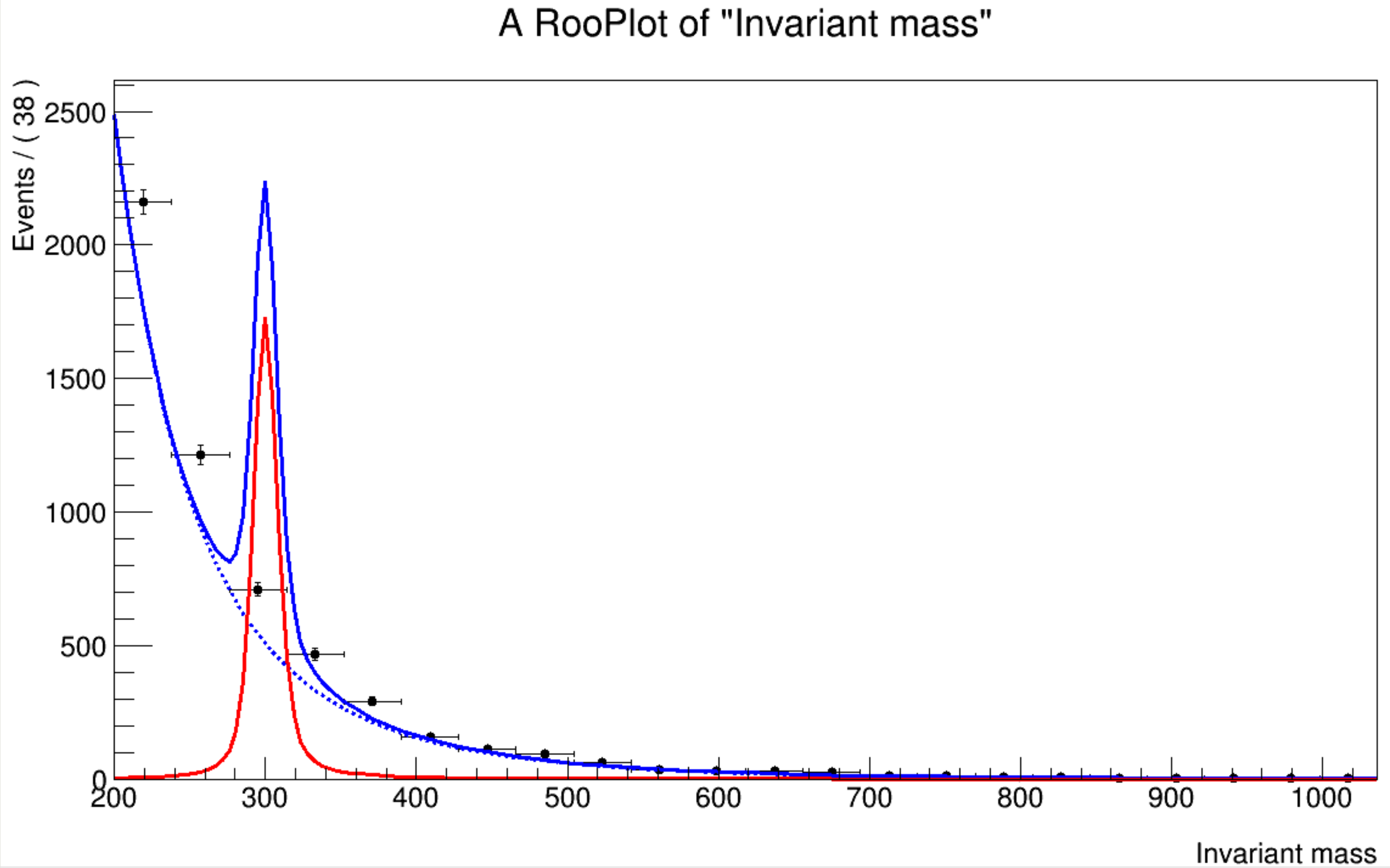
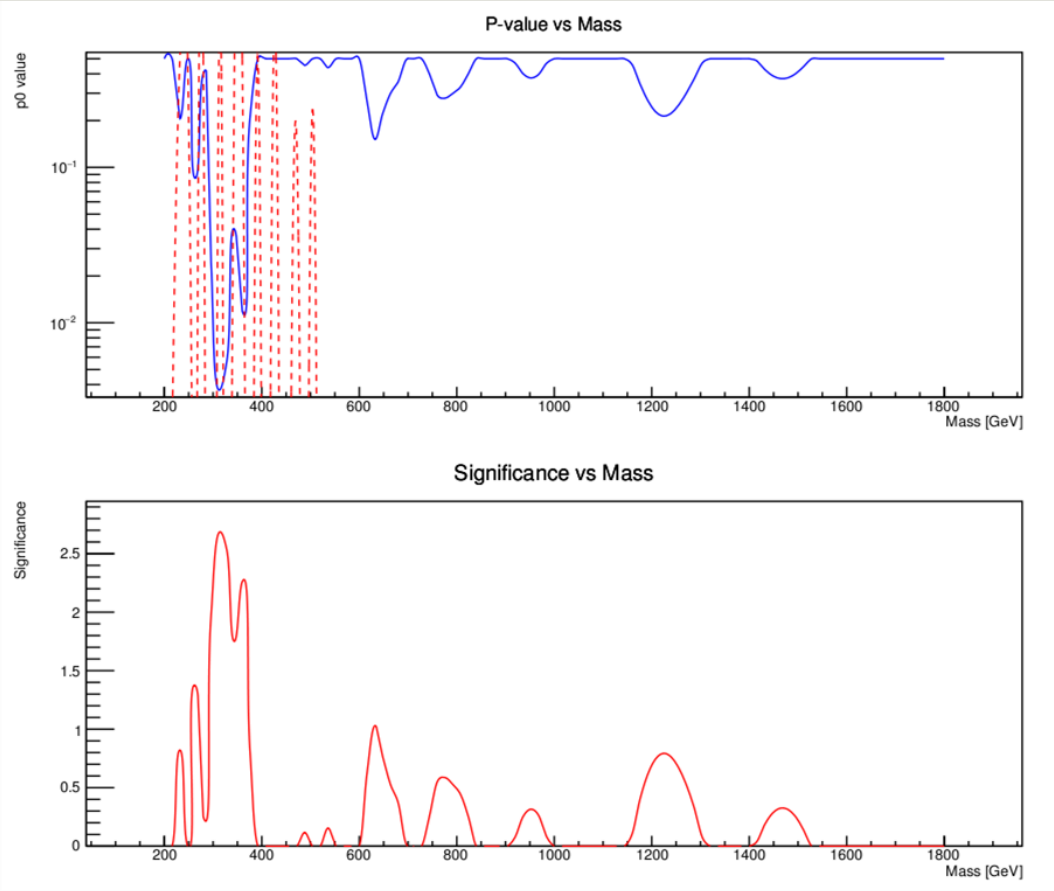


Figure 3: The $Z^{'} \rightarrow \mu^{+}\mu^{-}$ mass plot for the Data and MC for signal and background The plots show a good agreement between Data and MC.

Distribution and Significance



Distribution and Significance



Summary

Summary

- A search for new high-mass narrow resonance $Z^{'}$ decaying to $\mu^{+}\mu^{-}$ pairs corresponding to $L_{int} = 2.8fb^{-1}$ collected at $\sqrt{s}$=13 TeV in 2015 is performed.
- The used data/MC samples, event selections, background estimates, efficiency curve are given.
- The final $\mu^{+}\mu^{-}$ invariant mass spectrum is in agreement with the expectations from SM.
- The p-value for null-hypothesis and the significance as a function of M($\mu^{+}\mu^{-}$) between 200 GeV and 1800 GeV is obtained.
- The upper limit on the $Z^{'}$ production cross section times the Br($Z^{'} \rightarrow \mu^{+}\mu^{-}$) could be calculated easily next step which can be used to compare with some theoretical predictions including Sequential Standard Model, Superstring Model.

- What we have learned during this CMS analysis school:
  1. CMS environment setting
  2. PPD and data preparation: learn how to look for datasets
  2. Generator: how to use PYTHIA8 (simulation/reconstruction/exploration of Monte Carlo truth information/...)
  3. Muons/Electrons/Photons candidates selections
  4. Statistics: how to use the RooFit and RooStats to perform some fits
  5. Combination of the above for long exercise of Z' to $\mu^+\mu^-$ pairs analysis.

On behalf of Group 2 (ZprimeToDiLeptons), we thank all the facilitators in short/long exercise sessions especially Vieri Candelise and Yu Chul Yang for their patient instructions !