Muon P_T Scale at High Energies in the CMS Detector

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Introduction

Background

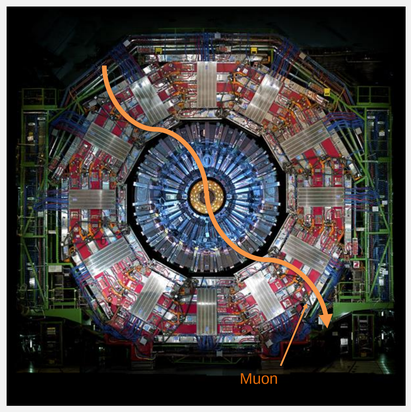

Figure 1: CMS tracker view, endcap removed.[1] Fictitious muon track added to emphasize effect.

For searches beyond the Standard Model with the Compact Muon Solenoid (CMS) Detector, a detailed understanding of systematic uncertainty in the transverse momentum (P_T) scale of the detector is necessary. From cosmic ray muon studies,[2] we know that within the barrel of CMS, there is a 5% uncertainty in the P_T scale of muons at 1000 GeV. While this uncertainty is negligible for low energy muons, at high energies, such as in the search for massive new particles (e.g., Z'), the 5% uncertainty must be addressed.

Within CMS, the P_T of muons is measured using the radius of curvature of the muon's path. At high momentum, the muon scale becomes less certain. This uncertainty is believed to arise[2] from a weak mode within the detector.

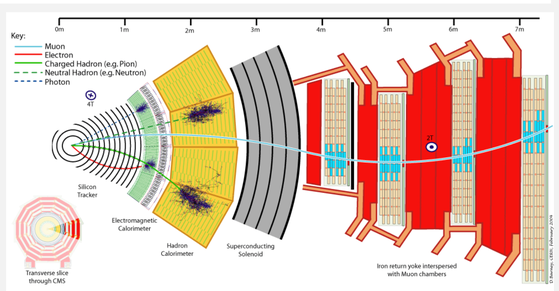

Figure 2: Interaction paths and detector diagram for section of CMS.[3] Shows path of muon through muon system.

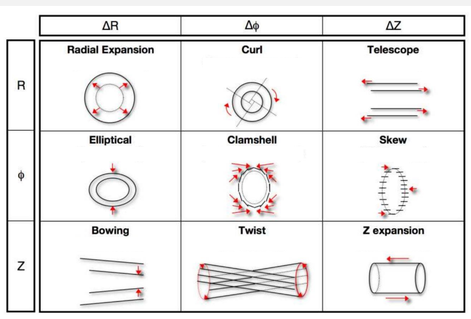

Figure 3: Diagram of weak modes[5] within the ATLAS detector, the other general purpose detector at the Large Hadron Collider.

For the Run 2 CMS detector the scale for high P_T muons and their effect on reconstructed invariant mass have not yet been studied. For the lower mass studies, such as Z boson studies, the scaling has little effect.[6]

Our Study

In our study, we analyzed the effects of P_T scaling uncertainty on Drell-Yan invariant mass. Drell-Yan is the quark-antiquark annihilation producing a virtual photon or a Z boson, which then decay into a pair of oppositely charged leptons.[7] In our study, we focused on the dimuon ($\mu^+\mu^-$) final state.

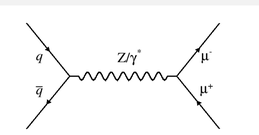

Figure 4: Drell-Yan Feynman diagram, decay to two muons, generated in ROOT. No final state radiation

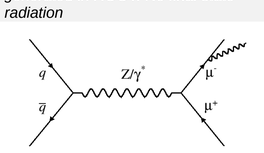

Figure 5: Drell-Yan Feynman diagram, with final state radiation. Generated in ROOT.

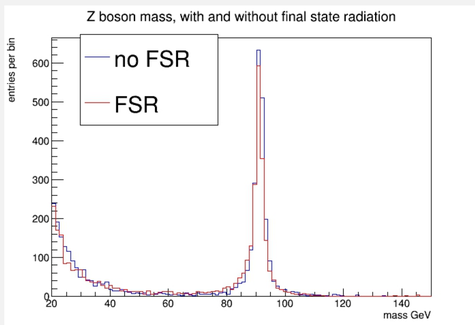

Figure 6: Invariant mass plots of Drell-Yan dimuons, featuring Z boson peak (approx. 91 GeV). Generated from events with (red curve) and without (blue curve) final state radiation.

Results

P_T Scaling

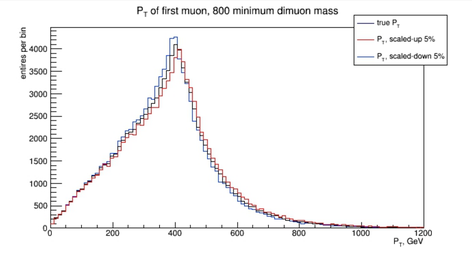

Figure 7: P_T values from muons (minimum dimuon mass 800 GeV). Black curve: true P_T, Red curve: P_T scaled up by factor of (1.0+0.05(pt/1000)), and Blue Curve: P_T scaled down by (1.0-0.05(pt/1000)).

P_T scaled from true value by a factor of

$$n = 1.0 \pm 0.05\left(\frac{P_T}{1000}\right) \quad \textit{(Eq. 1).}$$

Produces a 5% scaling at 1000 GeV.

Mass Difference

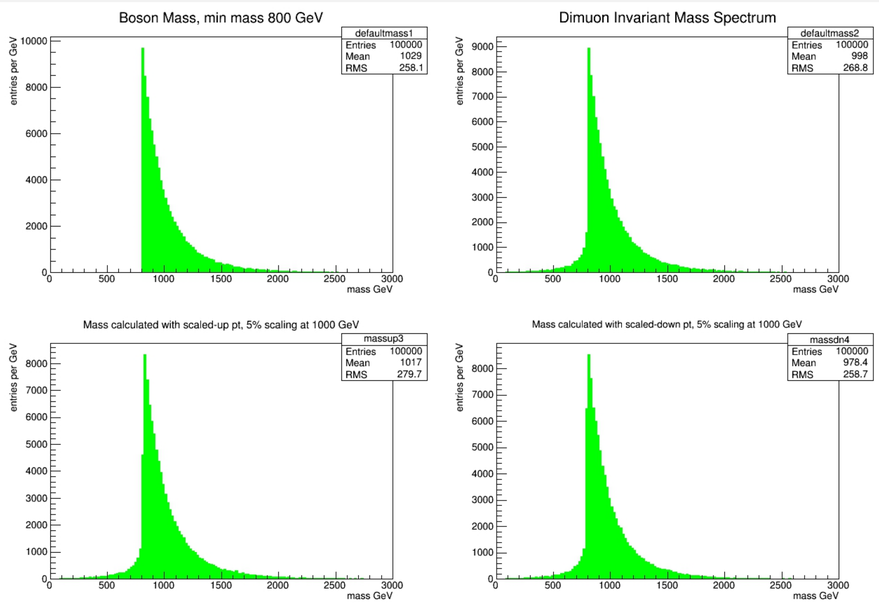

Figure 8: Mass plots for 100,000 event generation, min dimuon mass 800 GeV. One of three sets (800 GeV, 1300 GeV, 1800 GeV). Top Left: Boson mass generated without final state radiation. Top Right: Boson mass generated with final state radiation. Bottom Left: Boson mass with FSR calculated with 5% up-scaling in P_T at 1000 GeV. Bottom Right: Boson mass with FSR calculated with 5% down-scaling in P_T at 1000 GeV. Scaling dependent on mass. See Eq. 1 for scale factor.

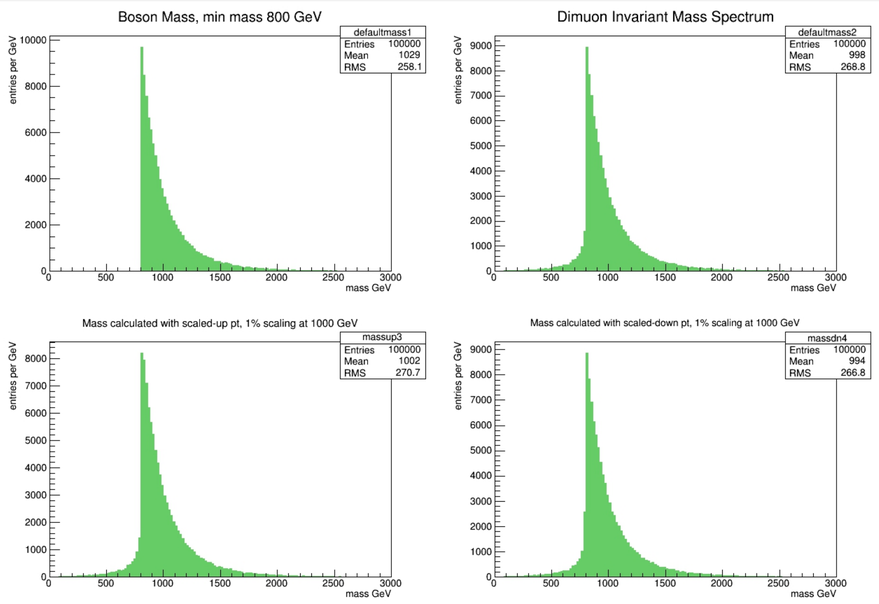

Figure 8: Mass plots for 100,000 event generation, min dimuon mass 800 GeV. One of three sets (800 GeV, 1300 GeV, 1800 GeV). Top Left: Boson mass generated without final state radiation. Top Right: Boson mass generated with final state radiation. Bottom Left: Boson mass with FSR calculated with 1% up-scaling in P_T at 1000 GeV. Bottom Right: Boson mass with FSR calculated with 1% down-scaling in P_T at 1000 GeV. Scaling dependent on mass.

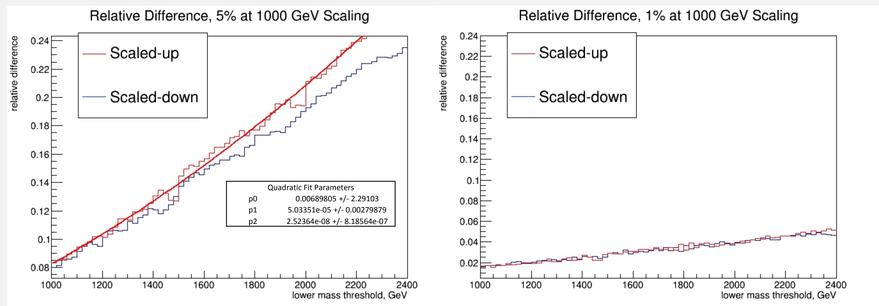

Figure 9: Relative difference plots. Left: 5% scaling, scale up featuring a quadratic fit. Right: 1% scaling. Relative difference calculated as (entries scaled – true entries)/ (true entries).

Conclusions

We have developed a parameterization of the uncertainty as a function of minimum dimuon mass in Drell-Yan background at high dimuon masses. We fit a quadratic function to the relative difference plots to extract the following parameters, where *unc* is the uncertainty.

$$unc = 6.90 \times 10^{-3} + 5.03 \times 10^{-5}\, m_{min} + 2.52 \times 10^{-8} {m_{min}}^2$$

Quadratic Fit Parameters, 5% scaled up	
p0	0.00689805 +/- 2.29103
p1	5.03351e-05 +/- 0.00279879
p2	2.52364e-08 +/- 8.18564e-07

Table 1: Parameters from a quadratic fit of 5% scaled-up relative difference graphs (see Figure 9)

Methods

Event generation and analysis performed within the CMSSW framework

- CMSSW_7_4_4
- Generated three sets of 100k each event files
  - 100k at 800 GeV dimuon min mass
  - 100k at 1300 GeV dimuon min mass
  - 100k at 1800 GeV dimuon min mass

PYTHIA 8 Event Generation

PYTHIA 8 is a Monte Carlo generator. We used PYTHIA 8 within the CMSSW Framework for GEN level production.

Drell-Yan Commands

- WeakZ0:gmZmode = 0
- WeakSingleBoson:ffbar2gmz = on
- 23:onMode = off
- 23:onIfAny = 13

Figure 10: Image of the Greek oracle Pythia, for whom the event generator is named.[8]

Analysis

- Used Edm Analyzer Plugin to grab the "genpartices"
- Applied a ROOT class system to reconstruct mass plots
  - 3 total files, DimuonClass.C, DimuonClass.h, and runDimuonClass.C
  - Merged for 300k events with additional macro

Equation used for mass calculation:

$$M_{\mu 1 \mu 2} = \sqrt{2 P_{T1} P_{T2} (\cosh(\eta_1 - \eta_2) - \cos(\phi_1 - \phi_2))}. \qquad \textit{(Eq. 2)}$$

(We are ignoring the muon mass.)

Further Study

Further study would be to repeat this analysis on a Full Simulation, modeling the detector.

References

1. Image taken from https://www.flickr.com/photos/badastronomy/8040228597
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6. S. Drell and T. Yan, "Massive Lepton-Pair Production in Hadron-Hadron Collisions at High Energy," Phys. Rev. Lett. 25(1970)316, doi: 10.1103/PhysRevLett.25.316
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