Muon p_T Scale at High Energies in the CMS Detector

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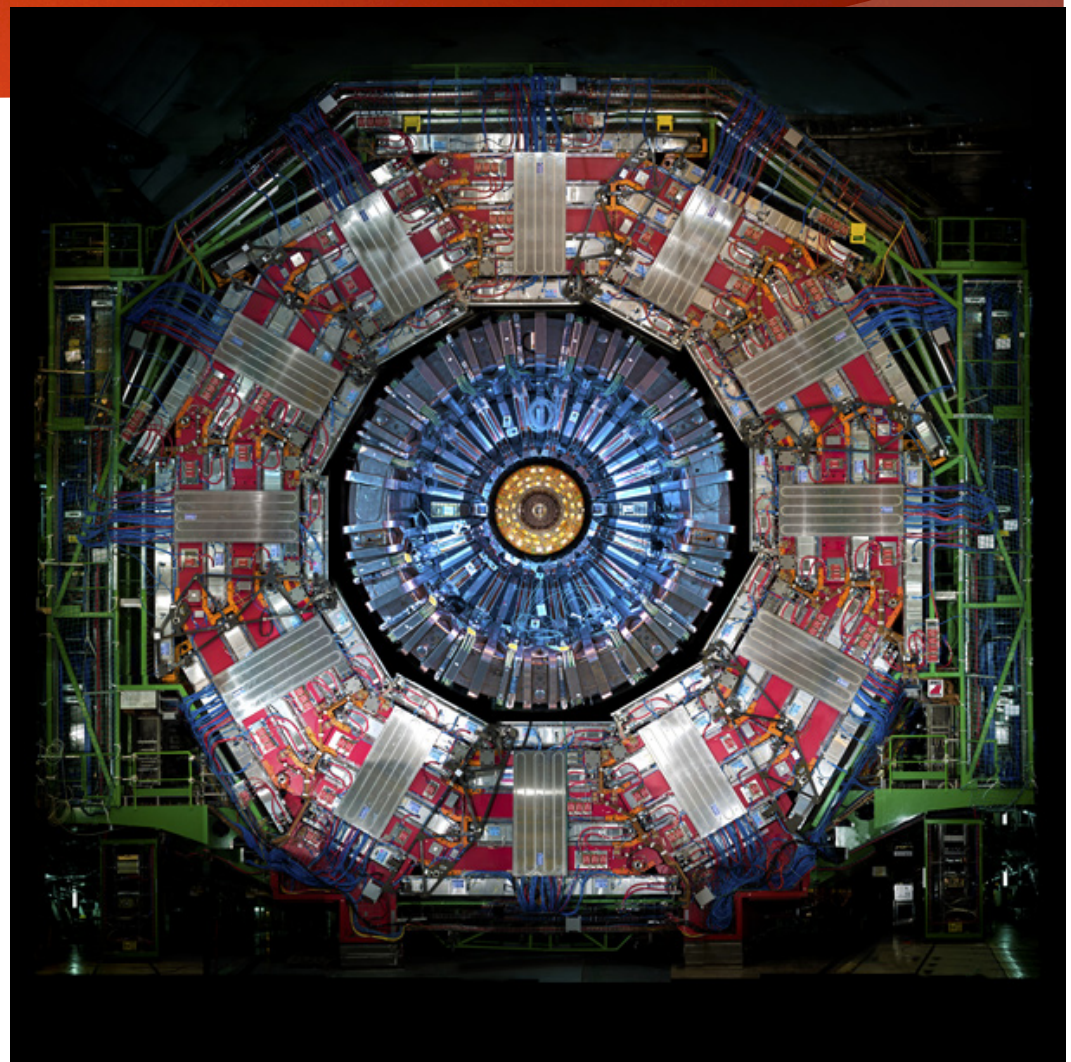
04 Aug 2015

Outline of Talk

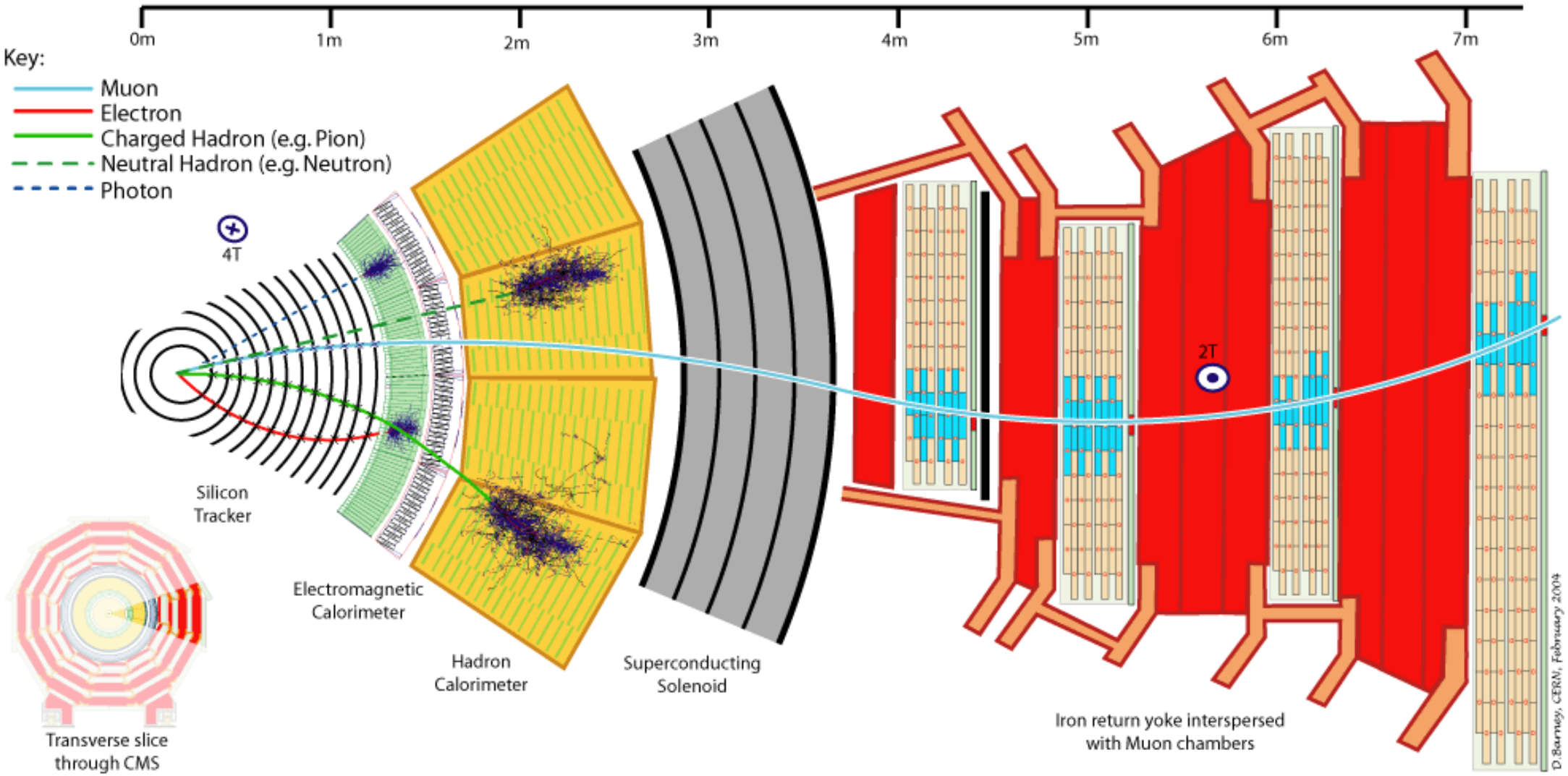
- CMS Detector
- p_T Scale
- Monte Carlo Generation
- Analysis
- Results
- Conclusions

Compact Muon Solenoid Detector

- One of two general purpose detectors operating at the LHC at CERN
- 3000 collaborators
- 4 Tesla Magnet heart of detector
- Measure muon momentum from radius of curvature of muon path



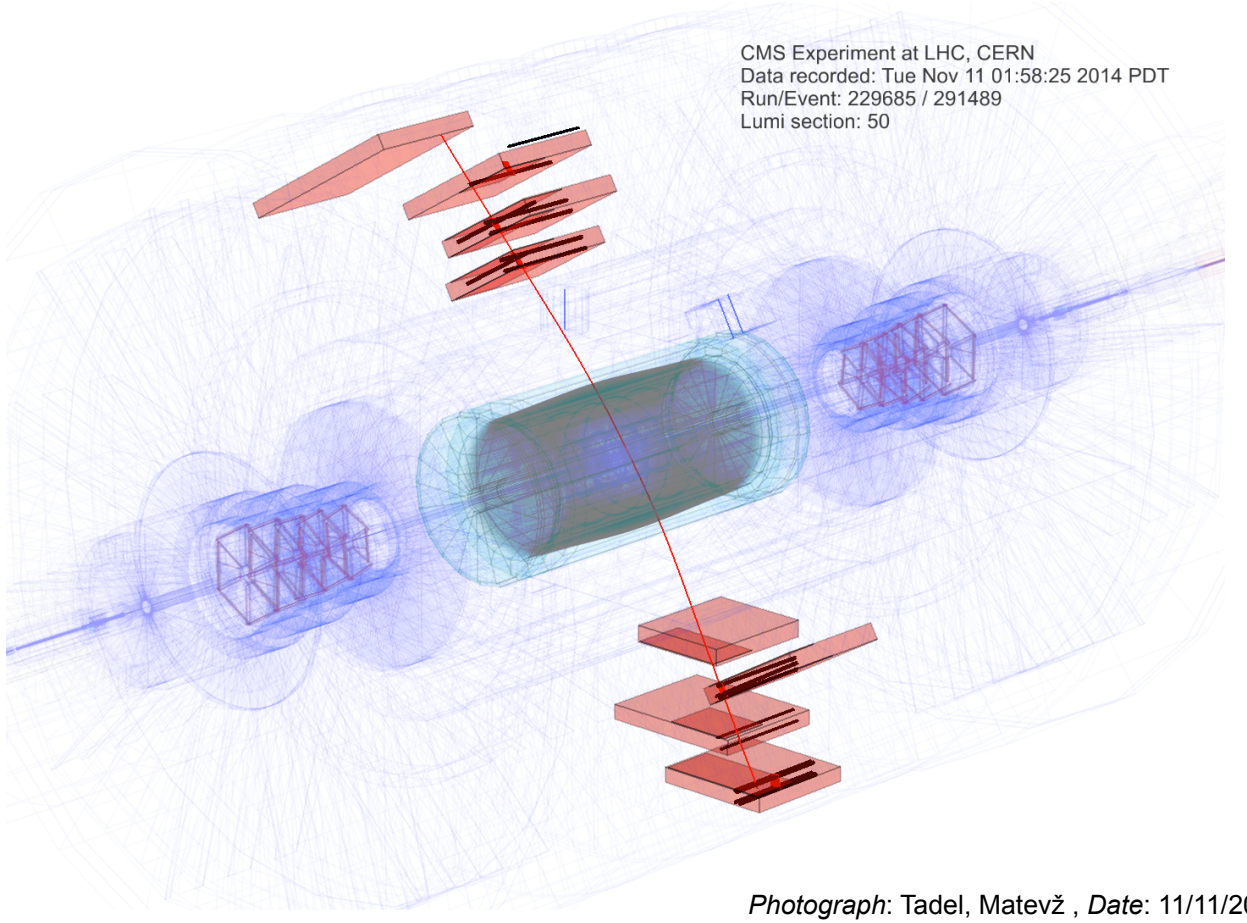
http://home.web.cern.ch/sites/home.web.cern.ch/files/styles/medium/public/image/update-for_the_public/2013/12/cms-detector.jpg?itok=gH6Ey4iS



https://www.phys.ksu.edu/reu2014/wabehn/index_files/image005.gif

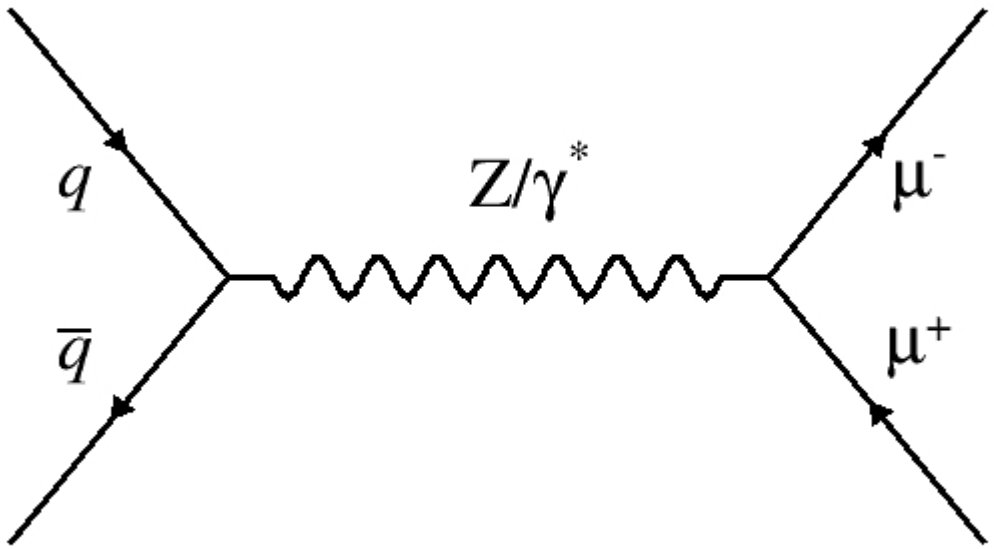
p_T Scaling

- Systematic uncertainty for high transverse momentum measurement (p_T)
- From cosmic ray studies
  - 5% scale uncertainty at 1000 GeV dimuon mass
- Believe from weak mode in detector
- **The effect of p_T scaling on Drell-Yan yield for high masses has not been studied for 13 TeV data runs**

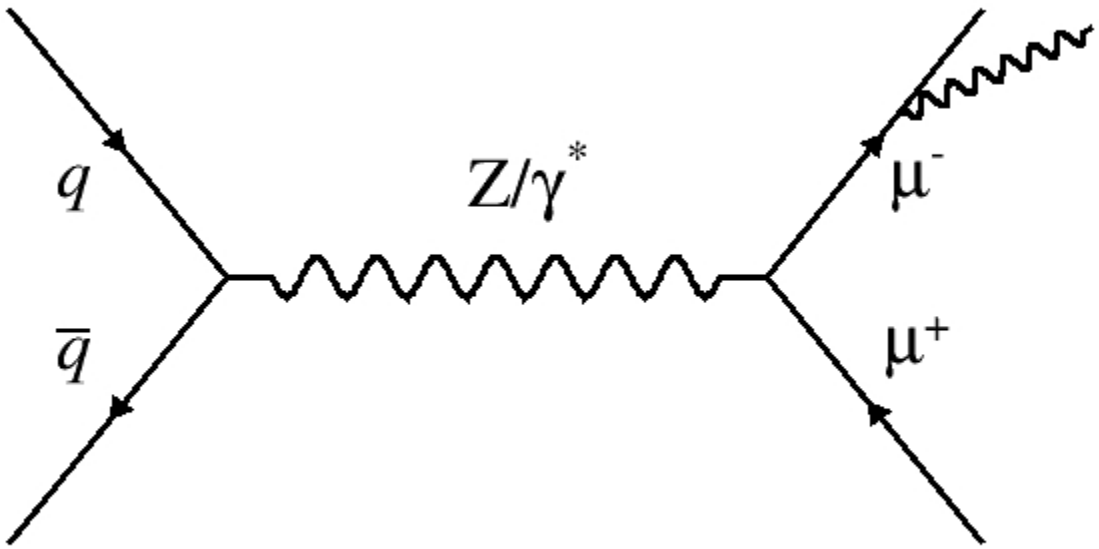


Photograph: Tadel, Matevž , *Date*: 11/11/2014

Drell-Yan



Drell-Yan process, no final state radiation



Drell-Yan process, with final state radiation

The Study

Goals

- Simulate Drell-Yan background at 13 TeV for high minimum masses
- Parameterize the resulting uncertainty in event yield

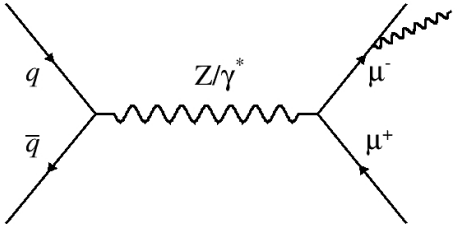
Procedure

- Initial Generation
- Primary Analysis
- Fit of Analysis

p_T uncertainty → **Shifted mass** → **Shifted number of entries** → **Uncertainty in number of entries**

Monte Carlo Generation with PYTHIA 8

- Named for Greek oracle, Pythia
- Event generator called within CMS Framework
  - Python configuration file
- PYTHIA Fragment for Drell-Yan
  - ‘WeakZ0:gmZmode = 0’
  - ‘WeakSingleBoson:ffbar2gmz = on’
  - ‘23:onMode = off’
  - ‘23:onIfAny = 13’
  - ‘PhaseSpace:mHatMin = ’ (set in command line)



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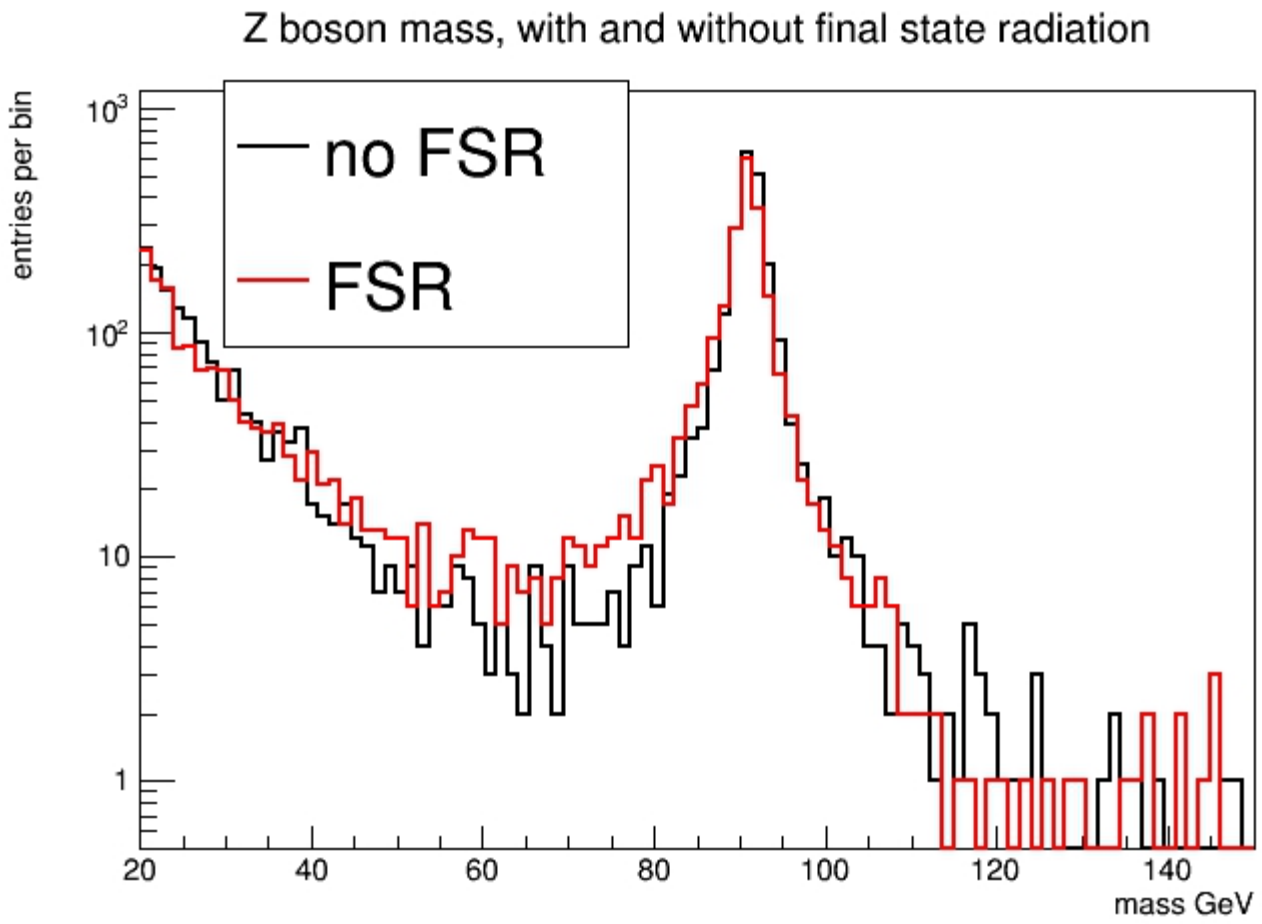
Initial Analysis



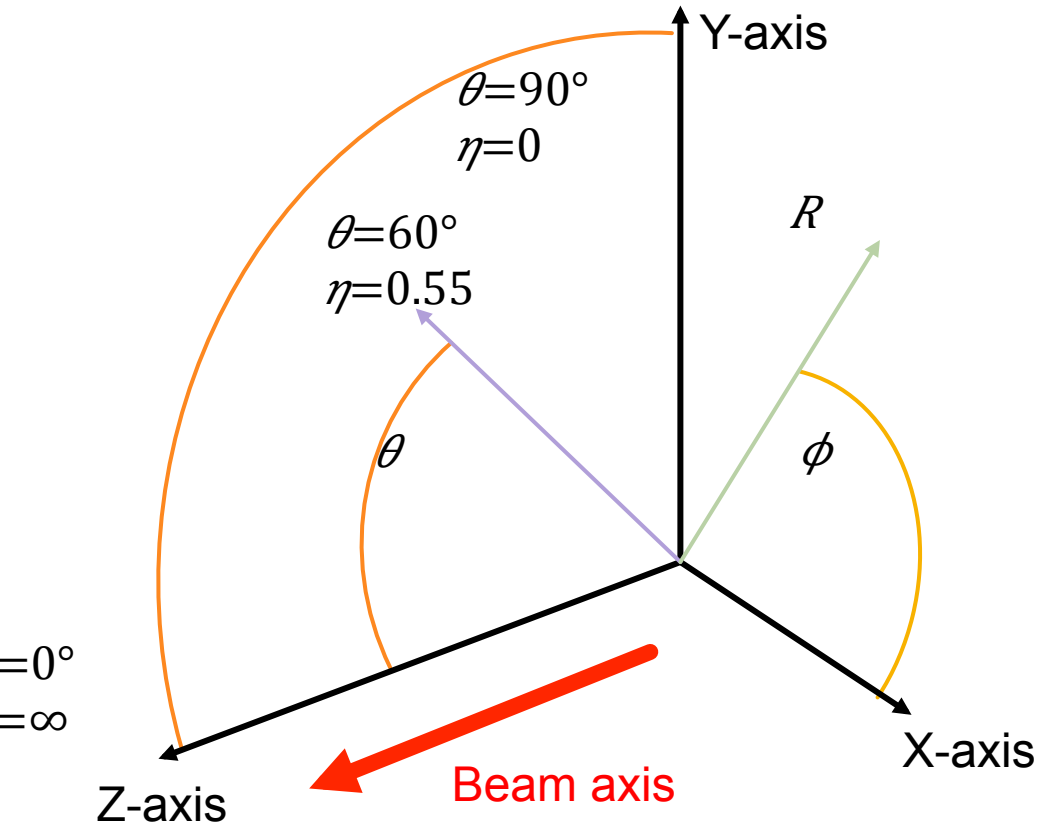
- EDAnalyzer
  - analyzer skeleton in CMS framework
  - Accesses data without changing it
- C++ plugins in Python script
  - Selects for particles using "GenParticleCollection" handle
  - Finds muons and muon parameters: η, ϕ, p_T, etc.
  - Modified to only accept final state muons
  - Outputs simpler data file for more in-depth analysis

ROOT 6 Analysis

- Used ROOT TTree:MakeClass() to scale p_T
  - $1.0 \pm 0.05(PT/1000)$ scaling factor on p_T
- Reconstructed Dimuon Mass
  - $M_{\mu 1 \mu 2} = \sqrt{2 P_{T1} P_{T2} (\cosh(\eta_1 - \eta_2) - \cos(\phi_1 - \phi_2))}$
- ROOT Class macros
  - DimuonClass.C, DimuonClass.h, runDimuonClass.C,
- Merge and fit macro
  - mergereldiff.C

https://upload.wikimedia.org/wikipedia/commons/thumb/7/7f/ROOT_Logo.png/297px-ROOT_Logo.png

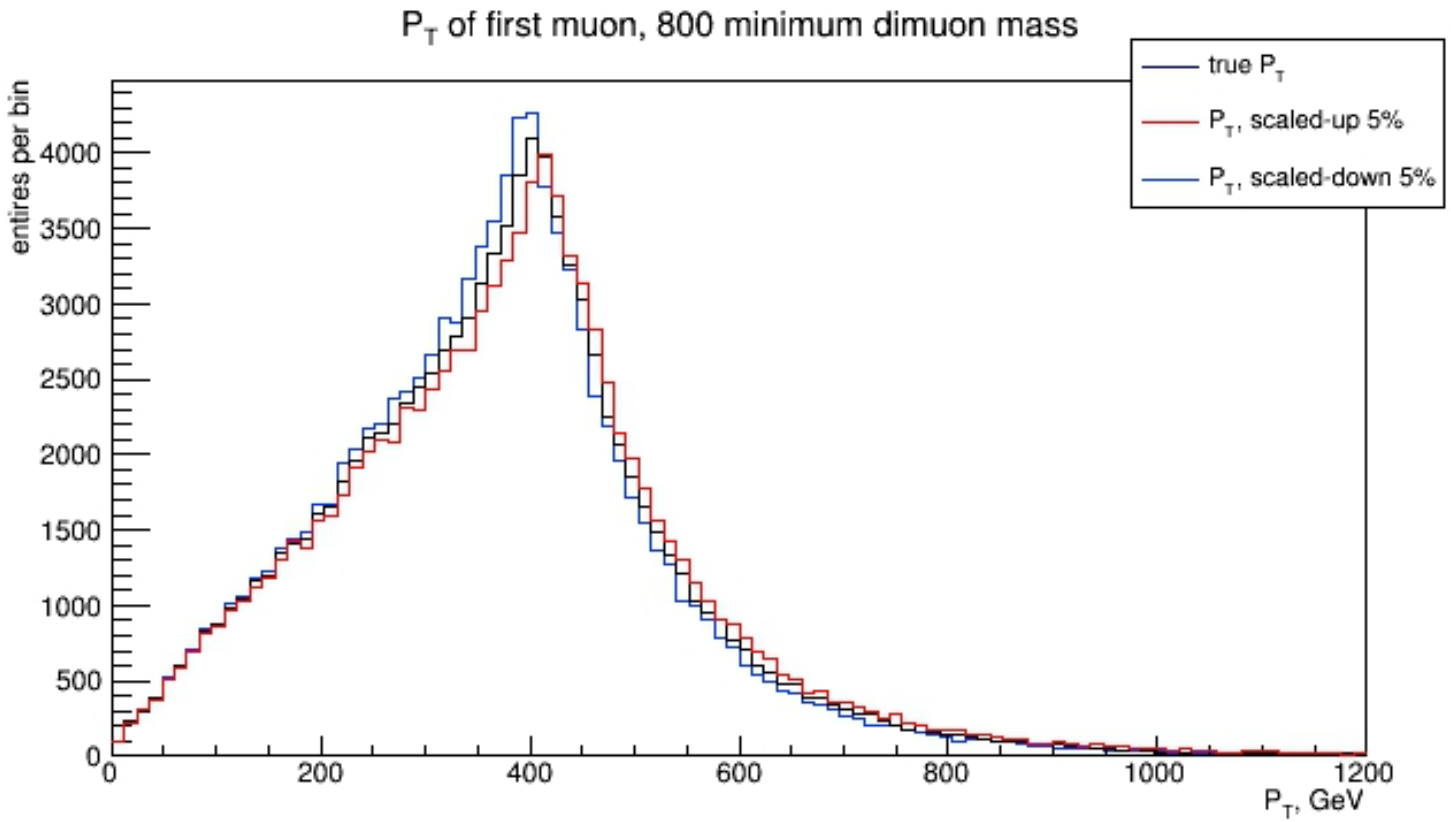
Relativistic Kinematics

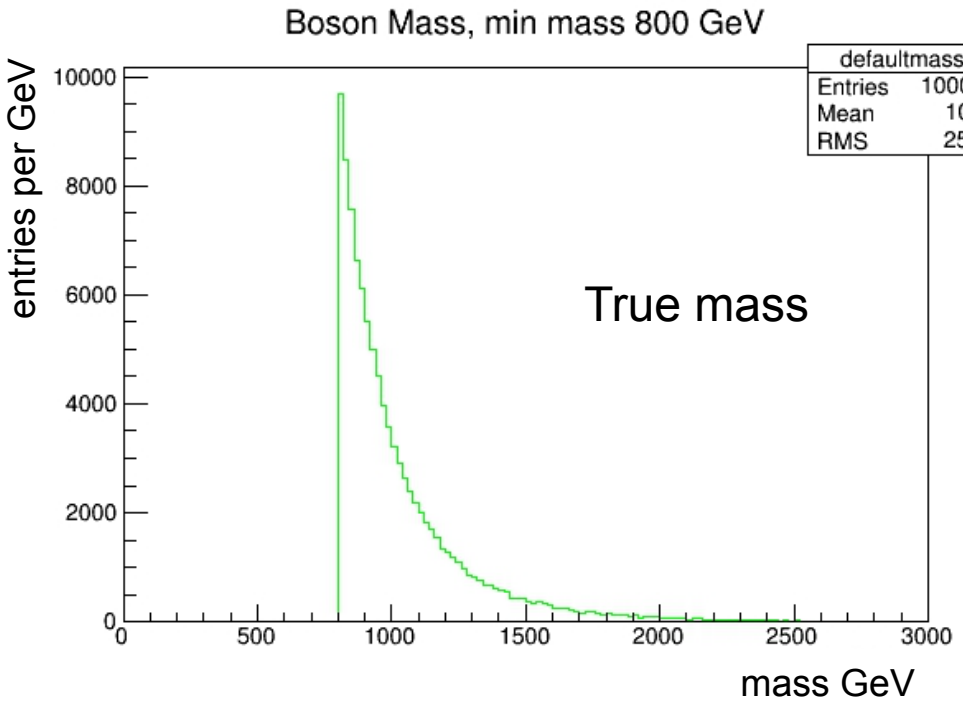


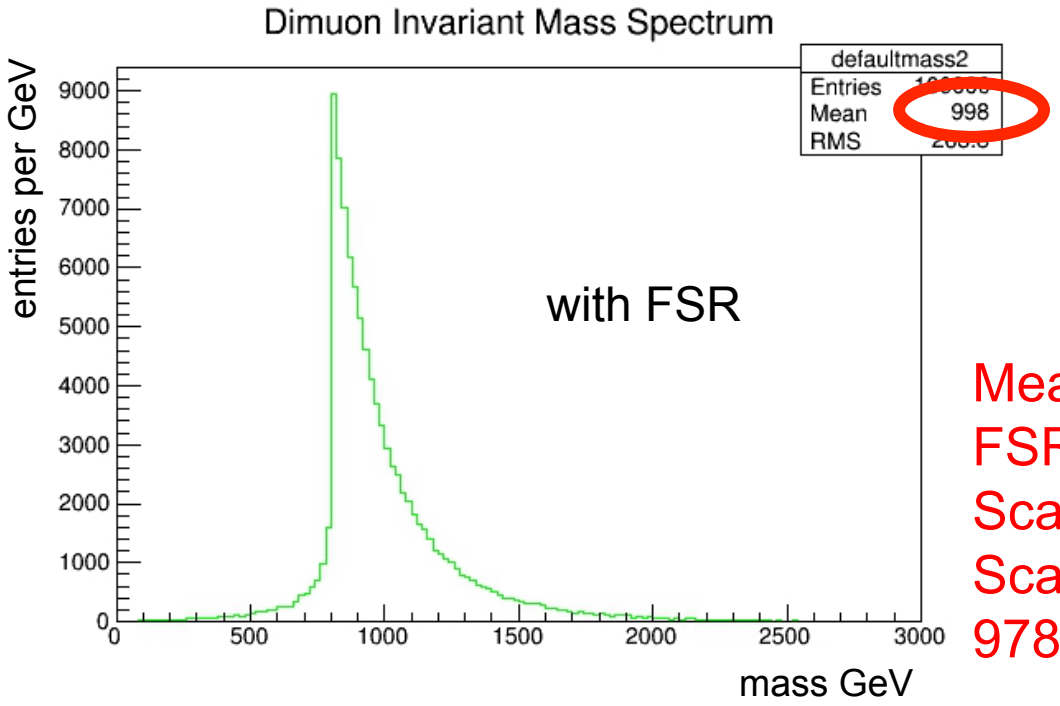
- Equation for invariant mass
  - $M_{\mu 1 \mu 2} = \sqrt{2} p_{T1} p_{T2} (\cosh(\eta_1 - \eta_2) - \cos(\phi_1 - \phi_2))$
  - η, pseudorapidity
    - $\eta = -\ln(\tan(\theta/2))$

Results

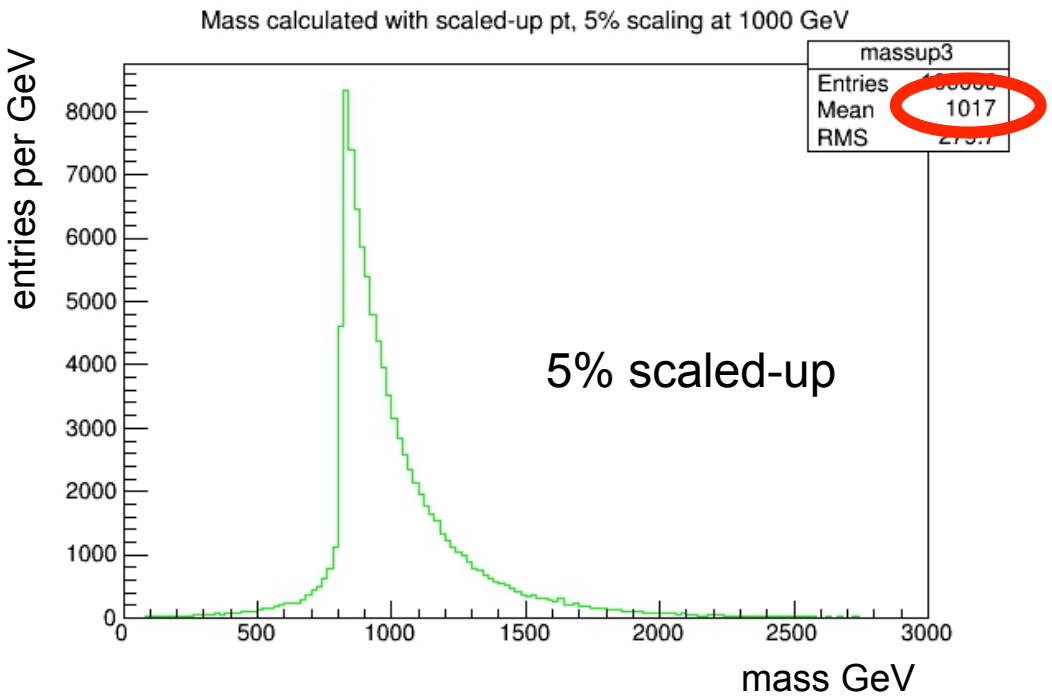
- 100,000 event files
  - 800 GeV min dimuon mass
  - 1300 GeV min dimuon mass
  - 1800 GeV min dimuon mass
- Analyzed
- Merged together for 300,000 events worth of statistics

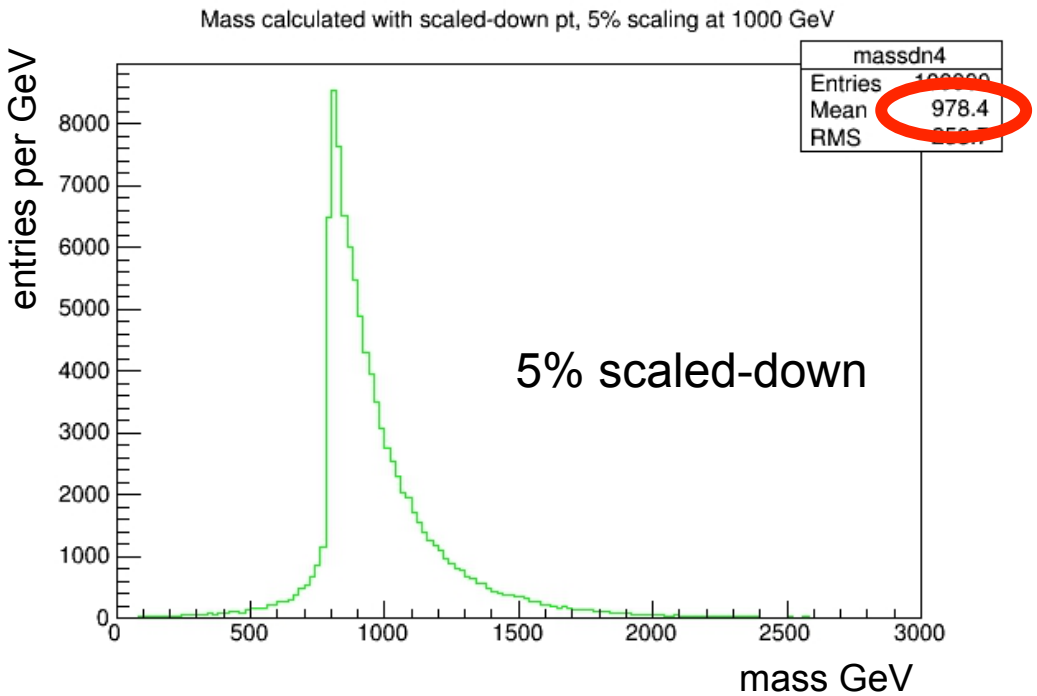


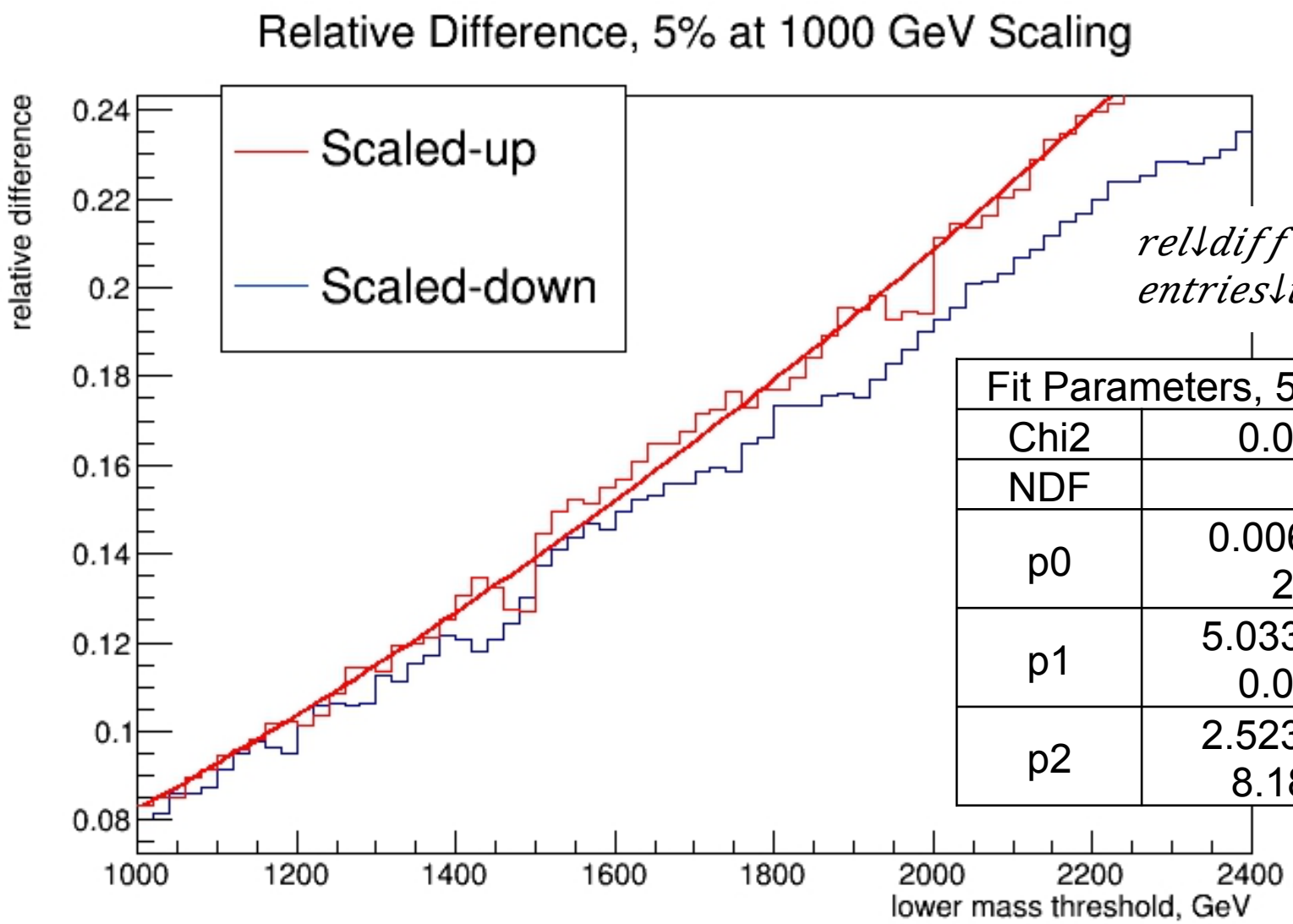




Mean Values:
FSR → 998
Scaled-up → 1017
Scaled-down → 978.4





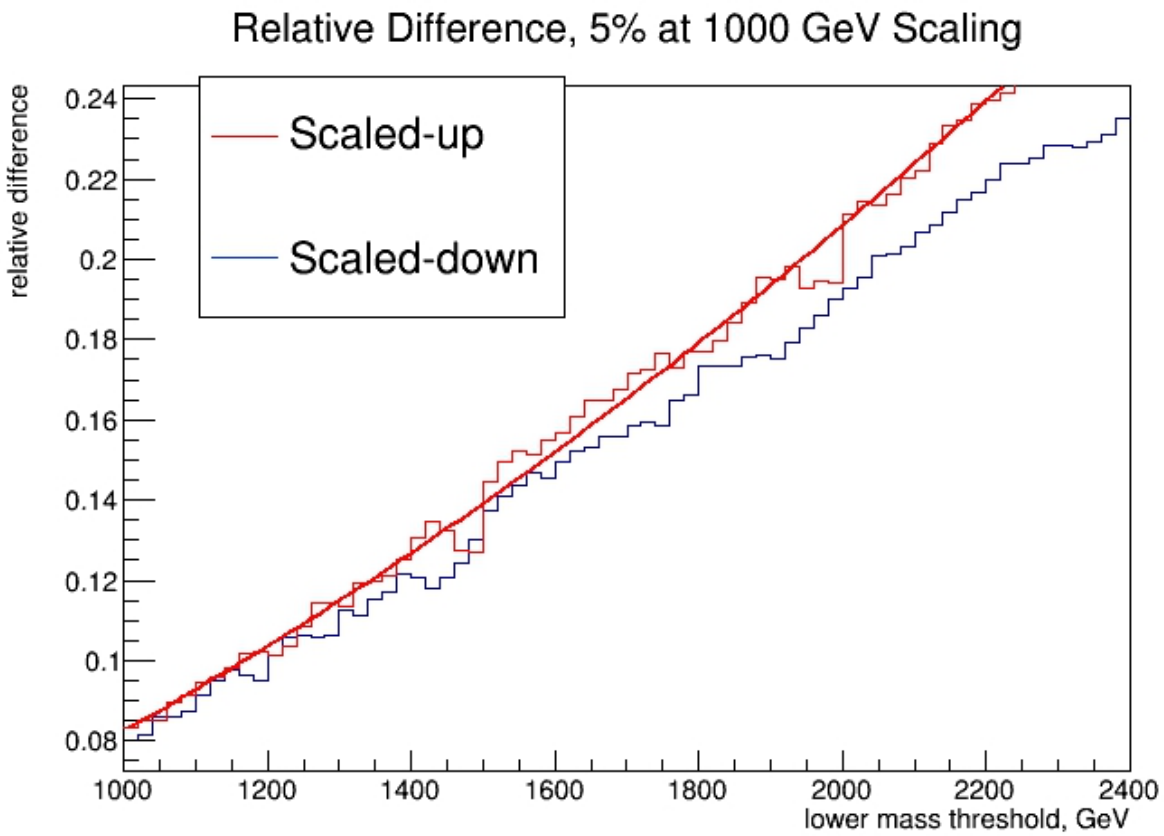


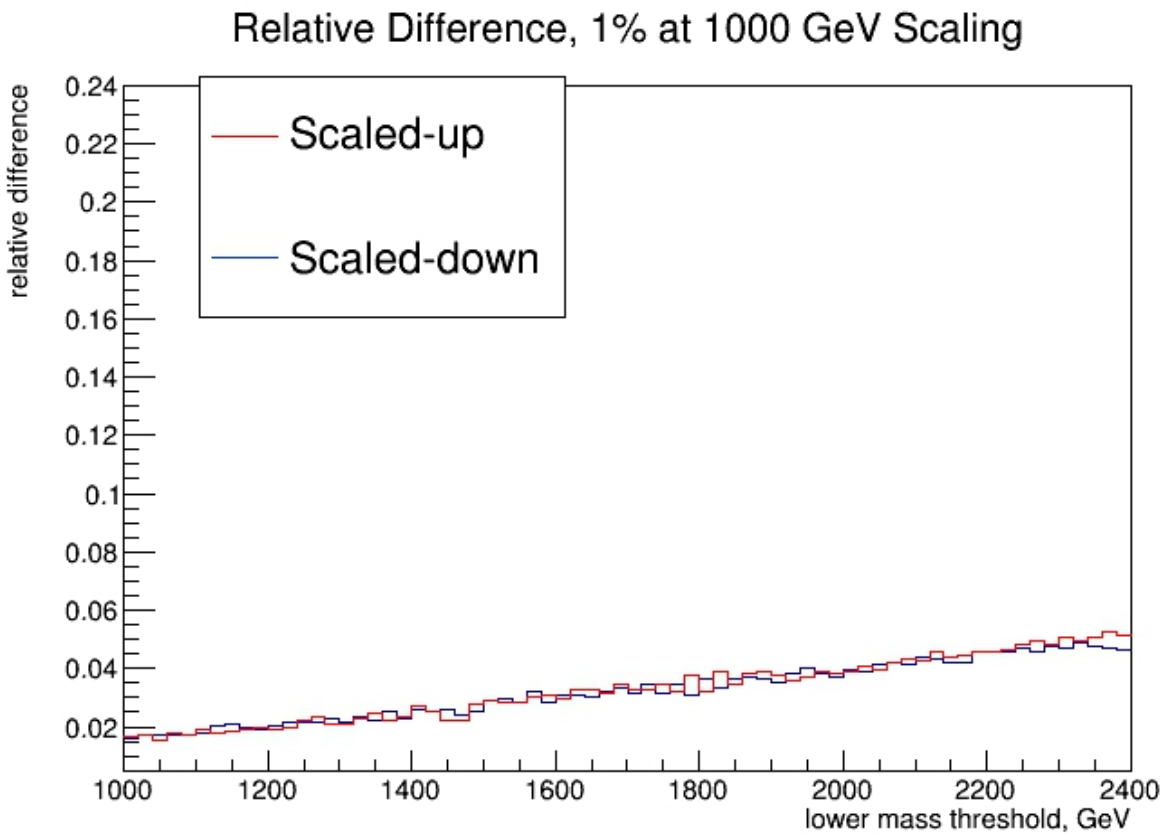
$$rel\downarrow diff = |(entries\downarrow scaled \geq M) - (entries\downarrow true \geq M)/(entries\downarrow true \geq M)|$$

Fit Parameters, 5% scaled up	
Chi2	0.00105287
NDF	67
p0	0.00689805 +/- 2.29103
p1	5.03351e-05 +/- 0.00279879
p2	2.52364e-08 +/- 8.18564e-07

Uncertainty in the yield!

$$rel\downarrow diff = |(entries\downarrow scaled \geq M) - (entries\downarrow true \geq M)/(entres\downarrow true \geq M)|$$





$$uncertainty\downarrow yield = 6.90\times10\uparrow-3 + 5.03\times10\uparrow-5\ m\downarrow min + 2.52\times10\uparrow-8\ m\downarrow min\uparrow 2$$

Conclusions

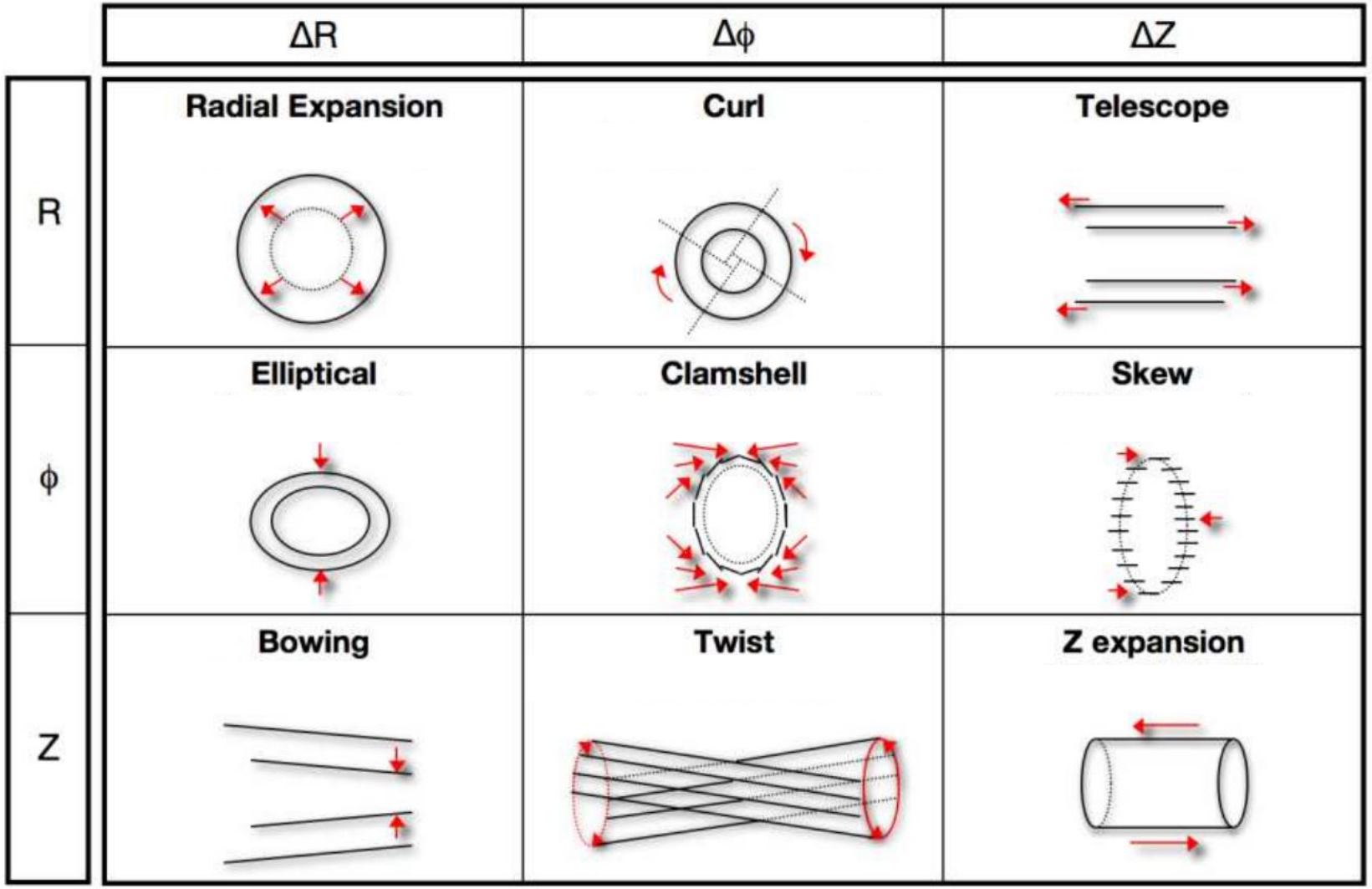
- Modeled effects of p_T scaling on invariant mass of dimuon production at 13 TeV
- PYTHIA 8 event generation
- 300,000 events
- Analysis in CMSSW and ROOT
- Quadratic parameterization of uncertainty as a function of minimum dimuon mass

$$uncertainty_{yield} = 6.90\times10^{-3} + 5.03\times10^{-5}\ m_{min} + 2.52\times10^{-8}\ m_{min}^{2}$$

Special Thanks

- Advisers Pushpa Bhat and Lenny Spiegel, Fermilab
- Graham Stoddard, Northern Illinois University
- Danny Nooman, Florida Institute of Technology
- Entire SIST Committee

Weak Modes



C. Escobar, "Track based alignment of the ATLAS Silicon Tracker," Proc. Sci. 26 (2008)