The Differential Cross Section of Drell-Yan Process in Muon Channel with 36 pb^{-1} CMS data

Approval for Moriond : EWK-10-010

University of Florida:
D. Acosta, D. Bourilkov, I. Furic, M. Fisher, J. Gartner,
G.P. Di Giovanni, N. Kypreos

Ohio State University :
S. Durkin, K. Kotov, C. Hill

University of Rochester :
A. Bodek, P. deBarbaro, Y. Chung, D. Vishnevskiy, J. Han

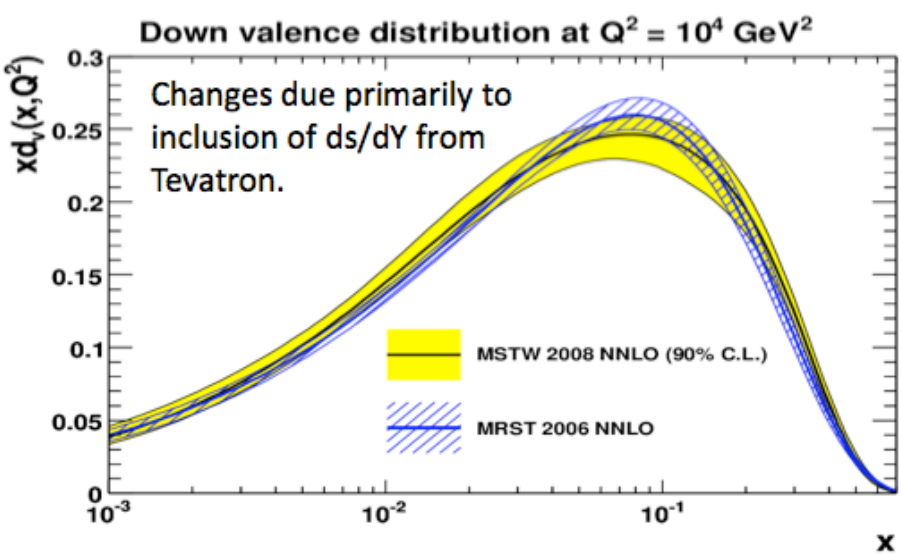
Texas Tech University :
N. Akchurin, E. Yazgan

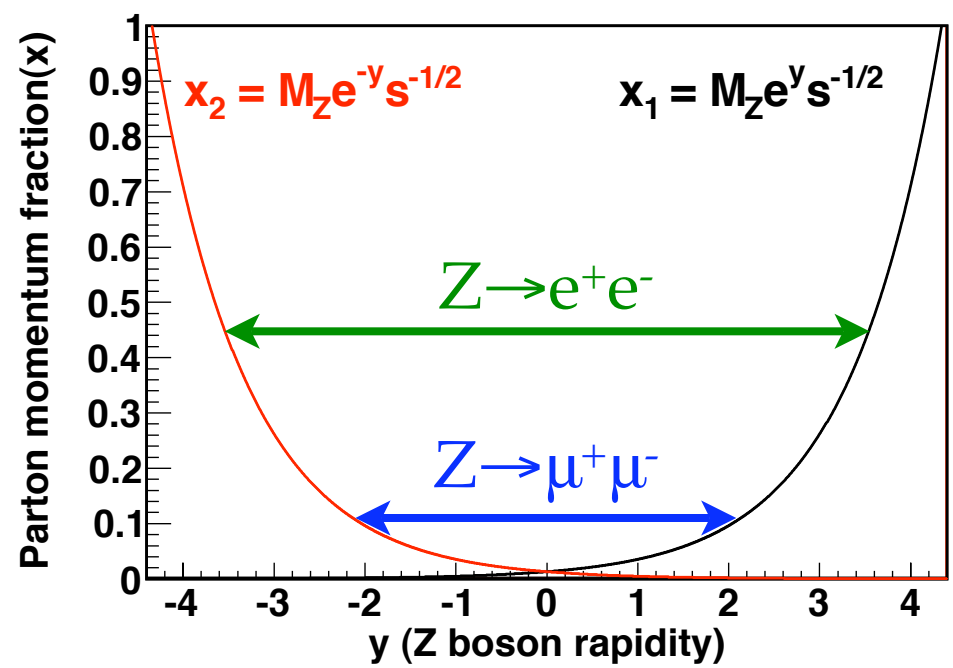
ETH Zürich :
M. Dittmar, J. Eugster, P. Meridiani, A. K. Sanchez

EWK Meeting / Mar. 07th, 2011

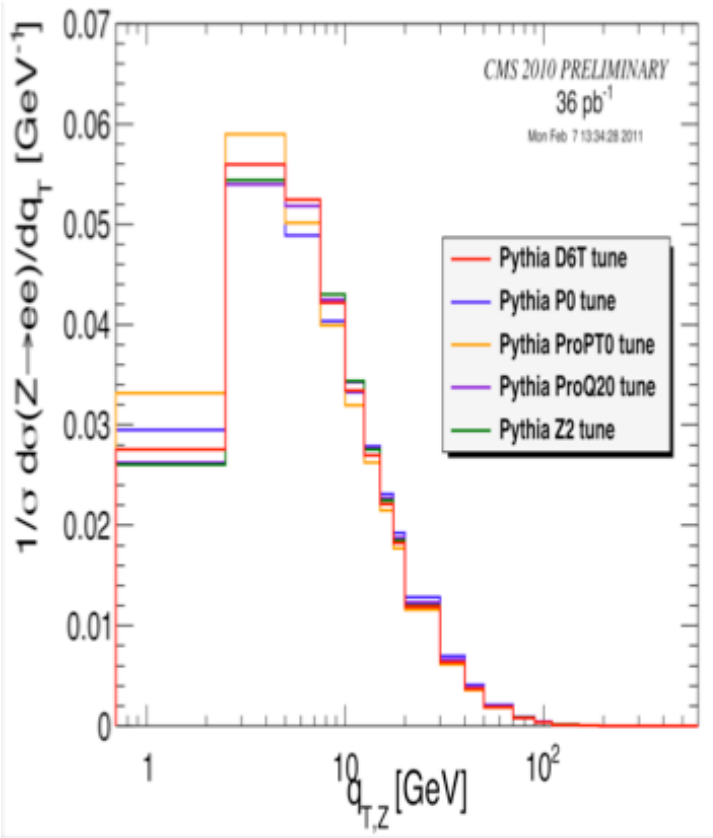
Physics Motivation

- Parton distribution functions (PDFs) are critical for all processes
  - PDFs are used to calculate cross sections for physics processes
  - PDFs cannot be predicted with present theories, needs to be measured
  - The measurement which constrains PDFs (y, P_T) is important to measure PDFs
- The rapidity is determined by with the ratio of the parton momentum fraction (x)
  - $y = \frac{1}{2} ln \frac{E + P_L}{E - P_L} = ln(x_1/x_2)$ where x_1 and x_2 is x of quark and anti-quark
- The measurement at high y probes the high and low x region (not well-known)
  - Important to extend the measurement to high y
  - *$Z \rightarrow e^+e^-$ channel reaches up to y ~ 3.5*





- Z boson in the transverse plane balances the momentum of the recoiling system
- The measurement of $d\sigma/dP_T$ for Z boson production at LHC constrains :
  - Non perturbative prediction of soft gluons in the low P_T range
  - QCD gluon radiation in the initial state in the high P_T range
- The large sensitivity to the underlying event tuning in the generator



Pythia is used to test the sensitivity of P_T spectrum

- ***We combine the result of $Z\rightarrow\mu^+\mu^-$ and $Z\rightarrow e^+e^-$ channel for better precision***

Report History

- Documents
  - PAS : EWK-10-010 for $d\sigma/dP_T$ and $d\sigma/dy$ measurement
  - CMS note :
    - $d\sigma/dP_T$: AN-10-444 ($Z\rightarrow\mu^+\mu^-$), AN-11-029 ($Z\rightarrow e^+e^-$)
    - $d\sigma/dy$: AN-10-449 ($Z\rightarrow\mu^+\mu^-$), AN-10-367 ($Z\rightarrow e^+e^-$)
  - CADI : *http://cms.cern.ch/iCMS/analysisadmin/cadi?ancode=EWK-10-010*
- Pre-Approval talk is presented on Feb. 8th, 2011
  - ARC : C Charlot, T Cox, GM Dallavalle, K Hahn, M Mannelli
  - Twiki page for ARC comment and authors' response : *https://twiki.cern.ch/twiki/bin/viewauth/CMS/TransverseMomentumAndRapidityDistributionsOfZBosonsARCQuestions*
  - Main issue for Pre-Approval presentation
    - Make the analysis more coherent in terms of method applied
      - The task was completed using the response matrix method
      - The background estimation method was converged
    - All comments were addressed to ARC
- The symbol ( ) is used for ``For Approval'' ⇒ Placed in the plot for approval

Contents

- The measurement of $d\sigma/dP_T$ and $d\sigma/dy$
  - The analysis of muon channel is presented in this talk
  - The analysis of electron channel will be presented by Giovanni (next talk)
  - The combined result for both channels will be presented at the end
- Contents of presentation
  - Analysis Overview
  - Data set
  - Event Selection
  - Background Estimation
  - Unfolding Procedure using Response Matrix
  - Acceptance and Efficiencies
    - Acceptance x Efficiency
    - Reconstruction Efficiency : Muon ID and Trigger efficiency
  - Systematic Uncertainty
  - Preliminary Result
  - Summary

Analysis Overview

- The differential cross section is defined as

$$\frac{1}{\sigma}\frac{d\sigma}{dX}(Z/\gamma^* \to \mu^+\mu^-) = \frac{\bar{A} \times \bar{\epsilon}}{N_{Tot} - B_{Tot}} \times \frac{\sum_k R_{ik}(N_k - B_k)}{\Delta_i \cdot (A \times \epsilon)_i} \quad where\ i = 1, ..., M\ and\ X = P_T^i, y_i$$

  - The response matrix ($\boldsymbol{R_{ik}}$) method is used for unfolding
  - We are interested in the shape of the cross section → normalized to 1/σ
  - The normalization of 1/σ cancels ∫***Ldt***, the overall scale of the efficiency

- Analysis Procedure
  - Select the signal candidates
  - Subtract the estimated background
    - QCD background is estimated using the data, others are from MC
  - Unfold the spectrum using the response matrix ($\boldsymbol{R_{ik}}$)
  - Correct for acceptance and efficiency
    - Efficiencies (trigger and muon ID) are measured using data
  - Get the result for (1/σ)(dσ/dX)
  - Assign the systematic uncertainty

Data set

- Data : Nov04 Rereco data set is used
  - Trigger requirement : Single muon trigger is used
    - HLT_Mu9 for run 132440 - 147195 (8.24 pb^{-1})
    - HLT_Mu11 for run 147196 - 148058 (9.47 pb^{-1})
    - HLT_Mu15 for run 148059 - 149442 (18.44 pb^{-1})
  - Jason file is required to select the runs taken in a good detector condition
  - The total integrated luminosity = 36 pb^{-1}
- MC simulation :

Physics Process	MC Sample
Drell-Yan	/DYToMuMu_M-20_CT10_TuneZ2_7TeV-powheg-pythia/Fall10
$t\bar{t}$	/TTJets_TuneZ2_7TeV-madgraph-tauola/Fall10
W+jet	/WJetsToLNu_TuneZ2-7TeV-madgraph-tauola/Fall10
QCD	/QCD_Pt-20_MuEnrichedPt-15_TuneZ2_7TeV-pythia6/Fall10
$Z \to \tau^+\tau^-$	/DYToTauTau_M-20_CT10_TuneZ2-7TeV-powheg-pythia-tauola
W+t	/TToBLNu_TuneZ2_tW-channel_7TeV-madgraph/Fall10
WW	/WWtoAnything_TuneZ2_7TeV-pythia6-tauola/Fall10
WZ	/WZtoAnything_TuneZ2_7TeV-pythia6-tauola/Fall10
ZZ	/ZZtoAnything_TuneZ2_7TeV-pythia6-tauola/Fall10

Event Selection

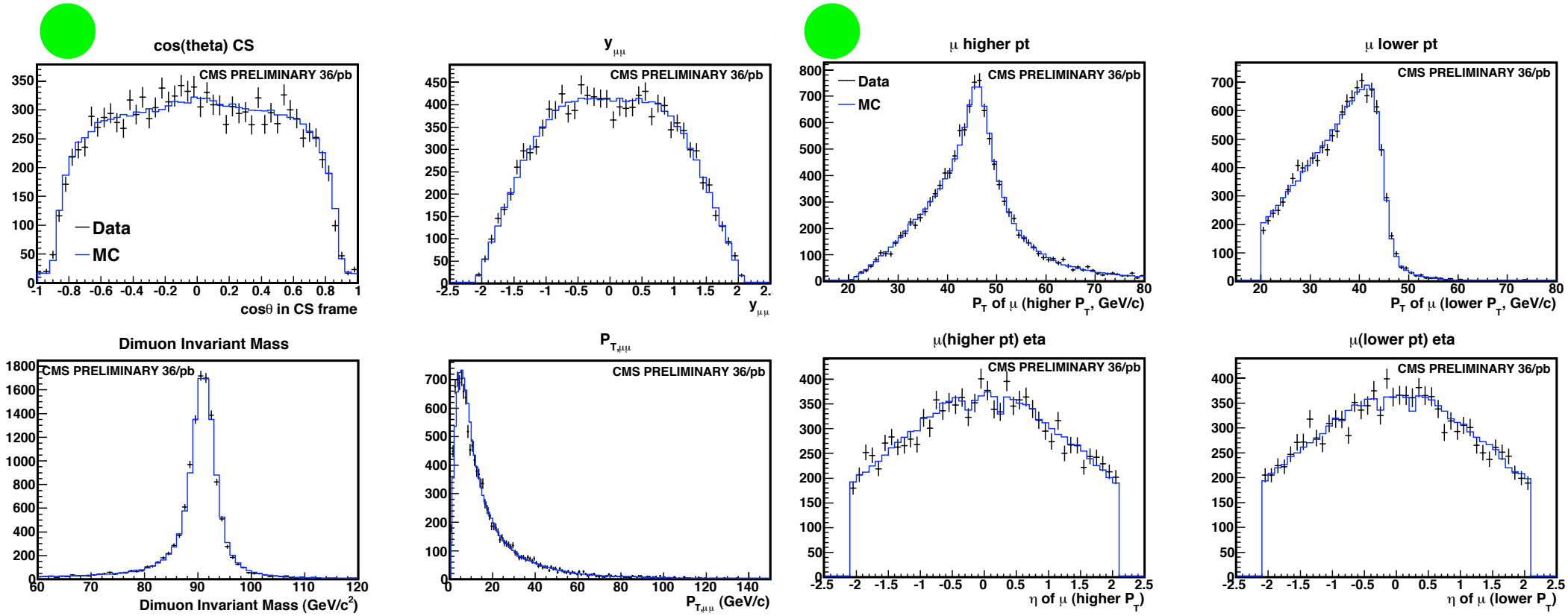
- Muon selection : the official EWK muon ID cut used (CMS AN-10-264)
  - $P_T > 20$ GeV/c
  - $|\eta| < 2.1$
  - Tracker && Global muon
  - Number of Silicon hits > 10
  - Number of pixel hits ≥ 1
  - Number of muon stations ≥ 2
  - $|d_{xy}| < 0.2$ cm
  - $\chi^2/\mathrm{ndf} < 10$
  - Isolation selection : EM isolation is removed from the fractional isolation
    - $(E_{iso}^{Trk} + E_{iso}^{Had})_{\Delta R<0.3}/P_T < 0.15$

- Opposite charged dimuon pairs are selected
- The mass window : $60 < M(\mu\mu) < 120$ GeV/c^2

- After the selection, more than ~ 12 K Z candidates remain

Kinematic Distributions

- Kinematic distributions for Z boson ($\mu^+\mu^-$) and μ



- There is good agreement for kinematic distributions between data and MC

Background Estimation

- The main background source is ttbar and QCD background
- Background Estimation for QCD process
  - QCD background is estimated using a data-driven method
  - Construct a probability function in (P_T, η) : p(P_T, η)
    - p(P_T, η) is for an exclusive single muon events to have an isolated muon
    - non-QCD backgrounds in the sample is subtracted using MC
  - Apply p(P_T, η) on the data to estimate QCD background in the signal candidate
- Background Estimation for Electroweak process
  - The backgrounds from Electroweak Processes are estimated using simulation
  - Electroweak process considered are W+jet, diboson(WW/WZ/ZZ), $Z \to \tau\tau$, ttbar

	Number of Events
DATA	12370 ± 111
$Z/\gamma^* \to \mu^+\mu^-$	11908 ± 109
$t\bar{t}$ + Jets	18.4 ± 4.3
W + Jets	0.47 ± 0.69
QCD	2.2 ± 1.5
$Z/\gamma^* \to \tau^+\tau^-$	15.5 ± 3.9
t + W	1.2 ± 1.1
WW	2.5 ± 1.6
WZ	5.9 ± 2.4
ZZ	4.7 ± 2.2

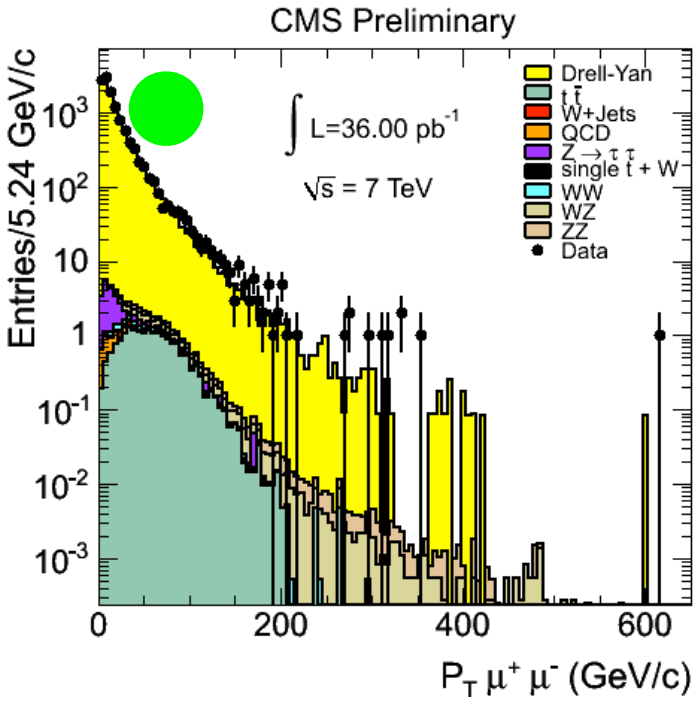
The main background contribution is ttbar in high P_T and $Z/\gamma^* \to \tau\tau$ in low P_T

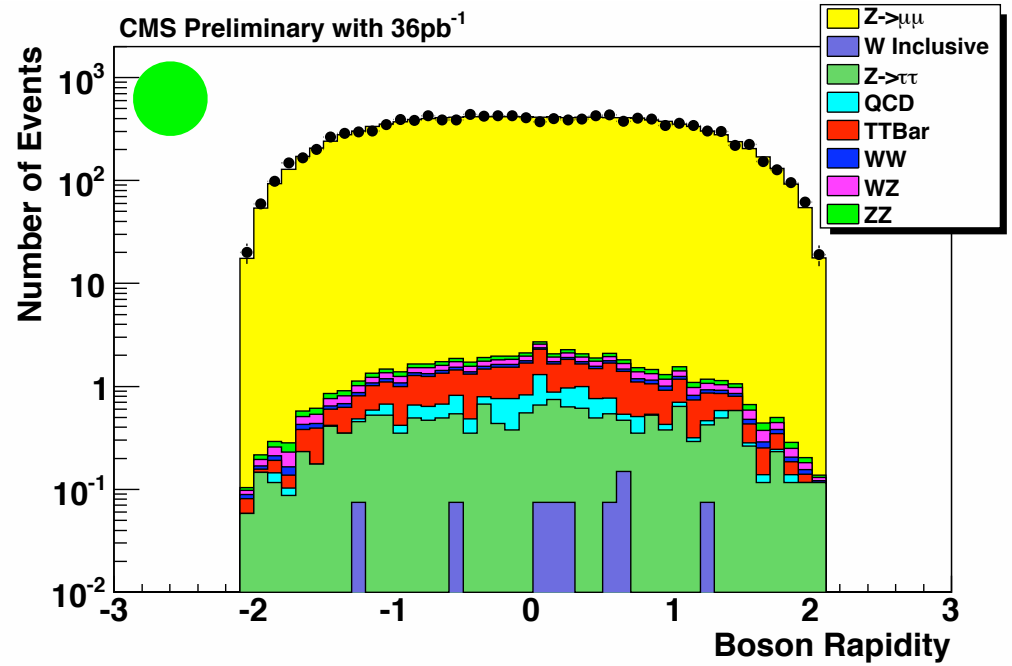
Total number of background is ~ 53

All backgrounds are estimated as a function of PT and y !!

P_T and y Distribution

- P^T and y distribution of data, signal MC, and the backgrounds





- The consistency check between $d\sigma/dP_T$ and $d\sigma/dy$ analysis

	$d\sigma/dP_T$	$d\sigma/dy$
Z yield	12370 ± 111	12382 ± 111
Background	53 events	53 events
Total cross section	945.9 ± 8.8 pb	948.8 ± 8.8 pb

Good agreement between $d\sigma/dP_T$ and $d\sigma/dy$!!

Response Matrix

- Response matrix : R_{ij} = P(observed in i | true value in j)
  - Response matrix is used to unfold the detector resolution effect

$$x_j^{measured} = \sum_i R_{ij} x_i^{true} \quad \Rightarrow \quad x_j^{true} = \sum_j R_{ij}^{-1} x_i^{measured}$$

R_{ij} for $d\sigma/dP_T$:

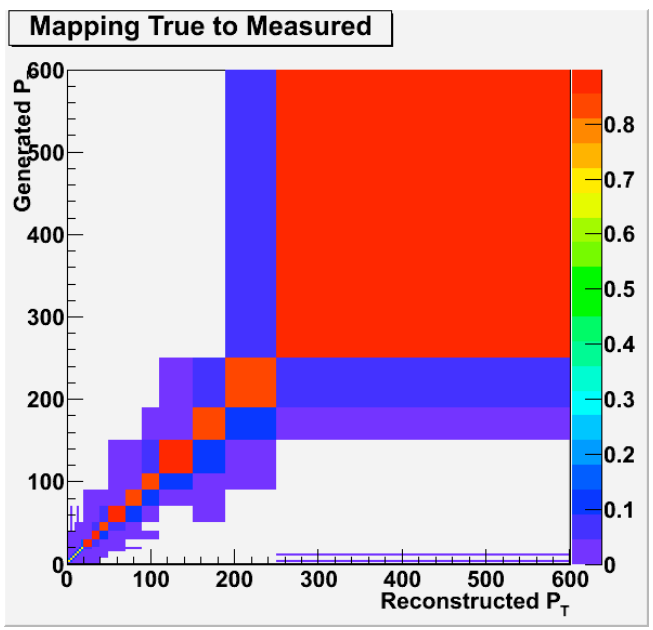
FSR effect considered separately

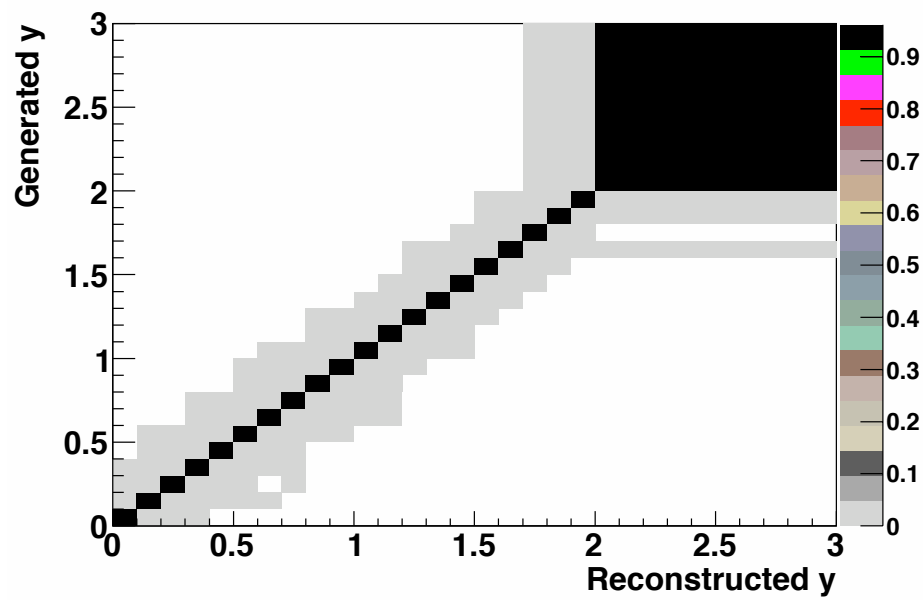
Diagonal term is 70 ~ 90 %

R_{ij} for $d\sigma/dy$:

Smearing effect is small

Diagonal term is ~ 93 %





- The bin size for the analysis is determined to minimize the smearing effect

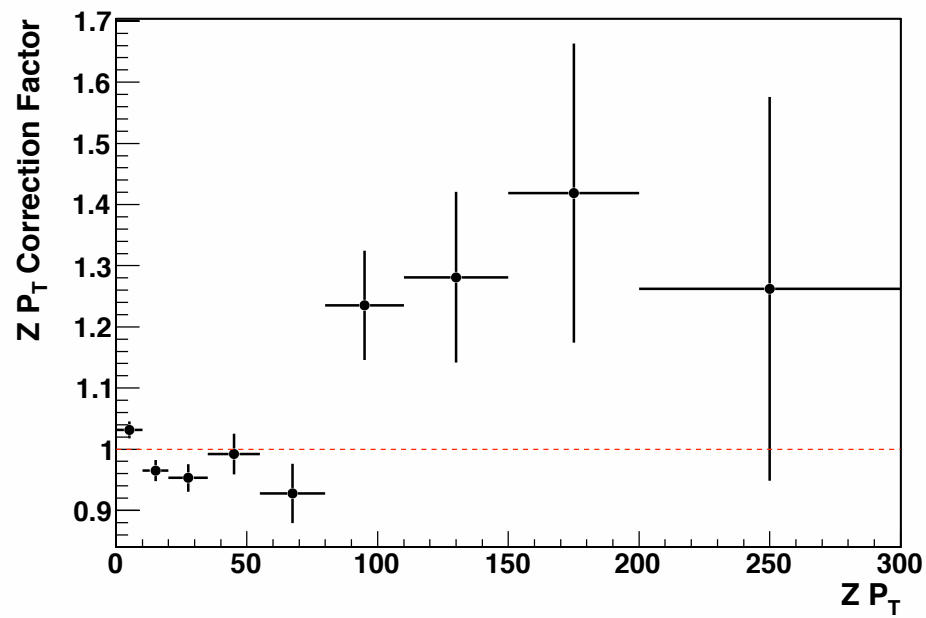
P_T Resolution and Z P_T Correction

- Muon P_T resolution for $d\sigma/dP_T$
  - P_T resolution affects response matrix → important to simulate P_T resolution well
  - P_T resolution is extracted from mass distribution in data (3x3 for P_T and η)
  - The extracted P_T resolution is applied into MC
- Z P_T correction for $d\sigma/dy$
  - The discrepancy between data and MC is shown in P_T spectrum
  - MC is tuned for P_T spectrum to match to data
- The response matrix is obtained using the tuned MC at the end

The extracted resolution

η Region	Res. in MC (%)	Res. in data (%)
0.0 - 0.9	1.487	1.107
0.9 - 1.2	1.517	1.387
1.2 - 2.1	2.629	2.807

Z P_T correction factor



Acceptance x Efficiency

- Acceptance
  - The acceptance is measured using POWHEG MC
  - The acceptance definition :
    - Denominator : # of events in $60 < M(\mu\mu) < 120$ GeV/c^2 in gen. level
    - Numerator : # of events in $60 < M(\mu\mu) < 120$ GeV/c^2 in rec. level after Pt, η cut
  - Parton showering in Pythia is used for FSR effect
    - One step unfolding used for $d\sigma/dy$
    - Two steps unfolding used for $d\sigma/dP_T$: FSR effect is unfolded separately
- Efficiency of single muon object : trigger (ϵ^{μ}_{trig}), muon ID (ϵ^{μ}_{ID})
  - The efficiencies are measured in data and MC using tag and probe (T&P) method
  - The scale factor (data/MC) in terms of muon P_T , η is applied into MC
  - The tuned MC is used to measure the efficiencies as a function of boson P_T , y
- Efficiency of the single muon trigger for dimuon pair (E_{trig})

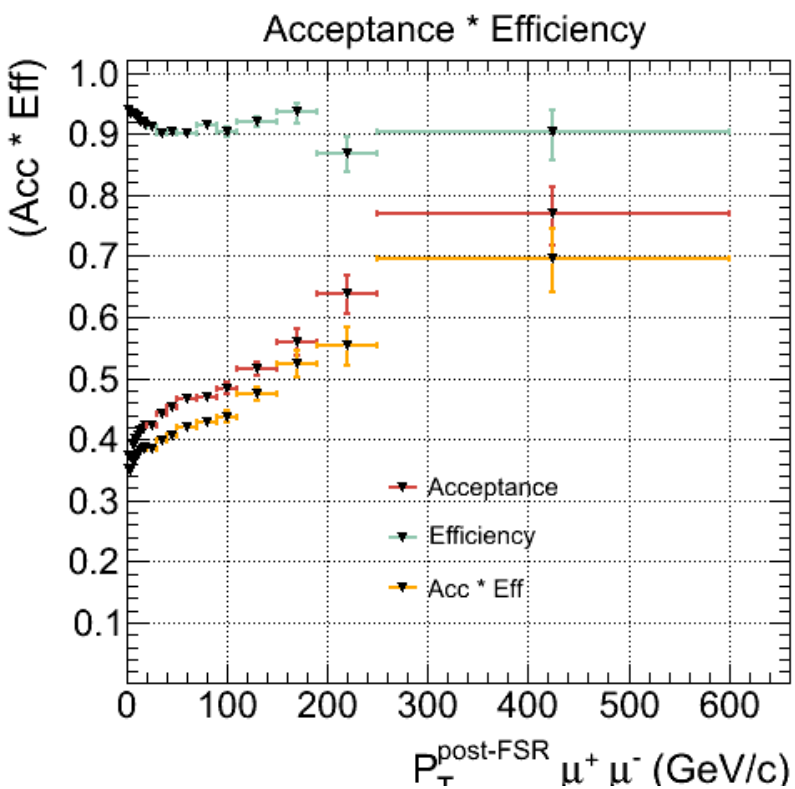
$$E_{trig} = \epsilon^{\mu}_{trig} + \epsilon^{\mu}_{trig} - (\epsilon^{\mu}_{trig})^2$$

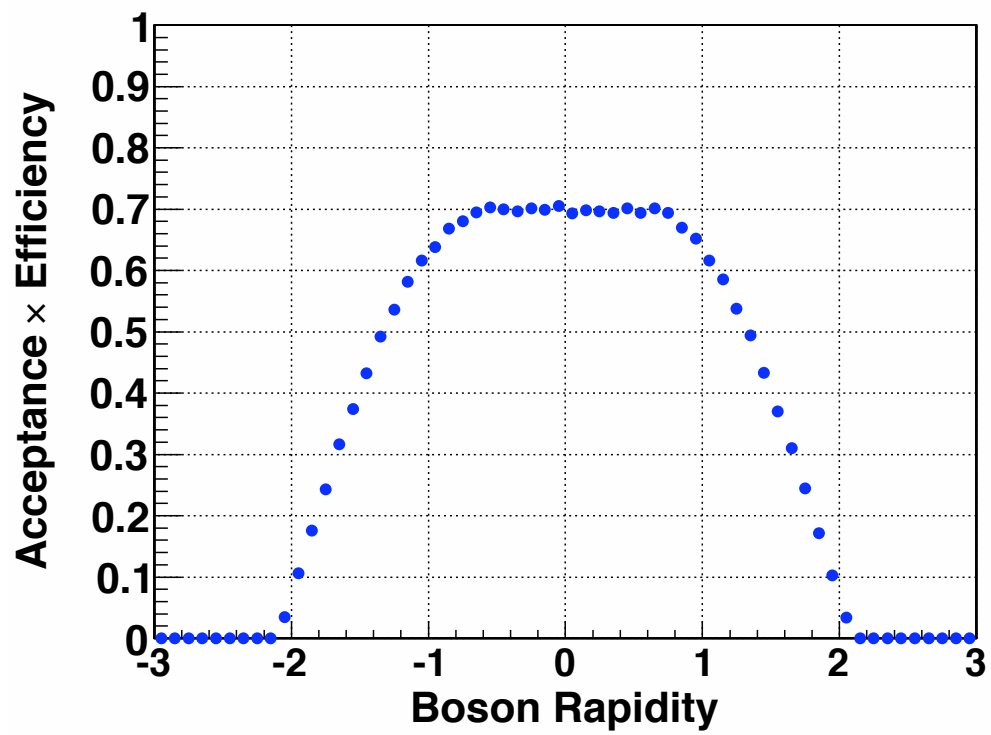
: the overall trigger efficiency is ~ 0.993

- Muon selection (ID) efficiency
  - The single muon ID efficiency (ϵ^{μ}_{ID}) is measured in η (η and P_T for $d\sigma/dP_T$)
    - $\epsilon^{\mu}_{ID}(data) = 0.965 \pm 0.002$ and scale factor = 0.9883 ± 0.0017
  - The muon selection efficiency for Z boson (E_{ID}) : total efficiency = 0.931

$$E_{ID}(y, P_T) = \epsilon^{\mu}_{ID}(\eta_1) \times \epsilon^{\mu}_{ID}(\eta_2) \times \rho(\eta_1, \eta_2)$$

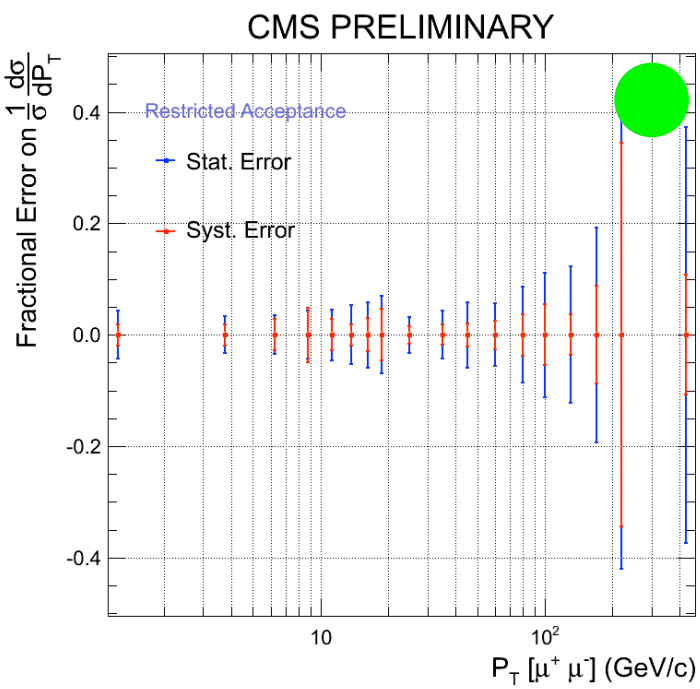
- Acceptance x Efficiency in P_T and y
  - The tuned MC for efficiencies is used to measure Acceptance x Efficiency
  - Acceptance x Efficiency in P_T, y is applied as a correction factor





Systematic Uncertainties

- Systematic uncertainty considered for :
  - Background estimation : the background level is very small, so assign 100 %
  - Efficiencies (trigger, muon ID) : varied by ±1σ deviation of scale factor
  - Z P_T spectrum modeling :
    - $d\sigma/dP_T$: Pythia UE tunes are used for assigning the uncertainty
    - $d\sigma/dy$: the deviation between with and without PT correction is assigned
  - PDFs uncertainty : AxE changes from CT10 PDFs error set
    - The modified tolerance method is used [arXiv:hep-ph/0605240v2]
  - The systematic uncertainties are summed in quadrature in P_T, y



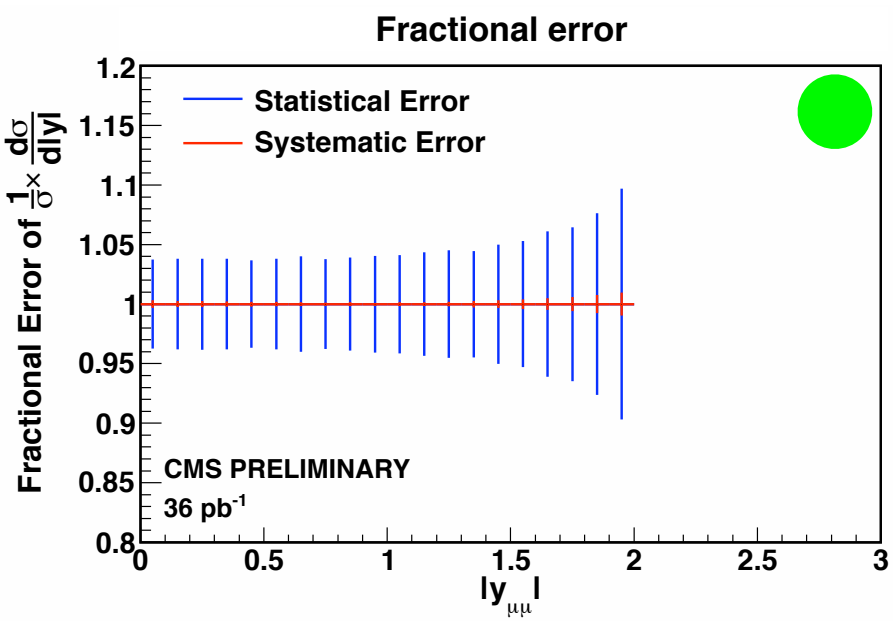


Table of Systematic Uncertainty

- Systematic uncertainties for $d\sigma/dP_T$ and $d\sigma/dy$

Systematic uncertainty for $d\sigma/dP_T$

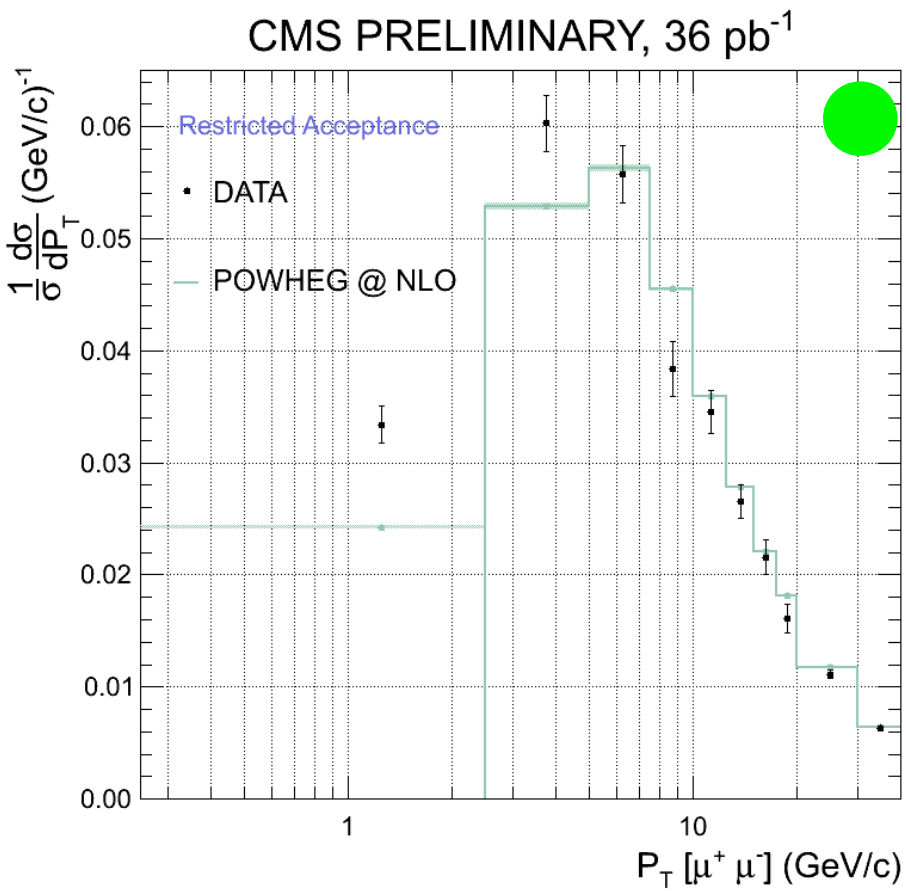
Bin	Z p_T GeV/c	Pos. Syst. Error $(\mathrm{GeV}/c)^{-1}$	Neg. Syst. Error $(\mathrm{GeV}/c)^{-1}$
1	0.0-2.5	0.00088	0.00087
2	2.5-5.0	0.0016	0.0016
3	5.0-7.5	0.0018	0.0018
4	7.5-10.0	0.0018	0.0018
5	10.0-12.5	0.0011	0.0011
6	12.5-15.0	0.00055	0.00054
7	15.0-17.5	0.00083	0.00083
8	17.5-20.0	0.00070	0.00070
9	20.0-30.0	0.00018	0.00018
10	30.0-40.0	0.00011	0.00011
11	40.0-50.0	0.000063	0.000062
12	50.0-70.0	0.000039	0.000039
13	70.0-90.0	0.000027	0.000026
14	90.0-110.0	0.000024	0.000024
15	110.0-150.0	0.0000051	0.0000050
16	150.0-190.0	0.0000042	0.0000041
17	190.0-250.0	0.0000024	0.0000024
18	250.0-600.0	0.00000012	0.00000012

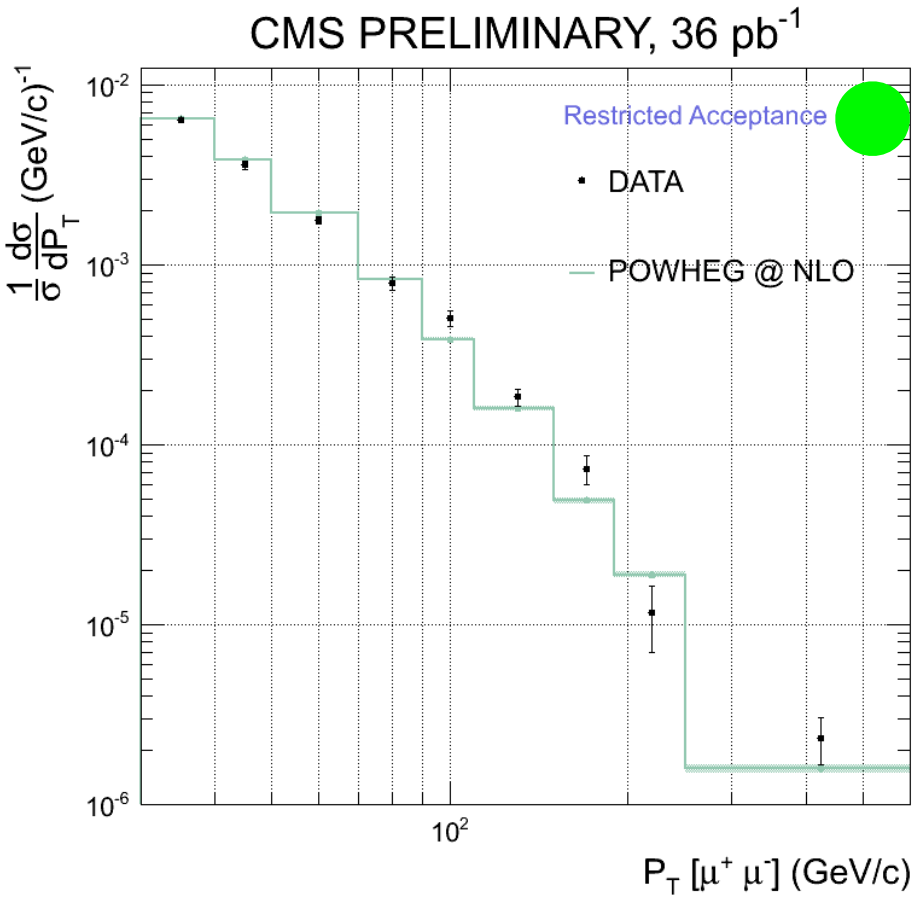
Fractional systematic uncertainty for $d\sigma/dy$

y bin	Background	Trigger	Muon ID	Z P_T	Total Systematic
0.05	0.00198	0.00003	0.00235	0.00065	0.00313
0.15	0.00065	0.00003	0.00231	0.00083	0.00253
0.25	0.00095	0.00003	0.00219	0.00106	0.00261
0.35	0.00059	0.00003	0.00199	0.00103	0.00232
0.45	0.00017	0.00003	0.00177	0.00105	0.00206
0.55	0.00058	0.00003	0.00143	0.00114	0.00192
0.65	0.00048	0.00003	0.00109	0.00087	0.00147
0.75	0.00051	0.00003	0.00076	0.00071	0.00116
0.85	0.00032	0.00003	0.00044	0.00137	0.00147
0.95	0.00066	0.00003	0.00039	0.00060	0.00098
1.05	0.00003	0.00003	0.00077	0.00137	0.00157
1.15	0.00056	0.00003	0.00133	0.00034	0.00148
1.25	0.00037	0.00003	0.00190	0.00019	0.00195
1.35	0.00087	0.00003	0.00248	0.00059	0.00270
1.45	0.00028	0.00006	0.00310	0.00006	0.00311
1.55	0.00130	0.00003	0.00381	0.00063	0.00407
1.65	0.00109	0.00003	0.00466	0.00010	0.00479
1.75	0.00145	0.00006	0.00575	0.00000	0.00593
1.85	0.00130	0.00009	0.00760	0.00015	0.00771
1.95	0.00073	0.00009	0.00964	0.00110	0.00973
2.50	0.00217	0.00007	0.00982	0.00130	0.01014

Result of $d\sigma/dP_T$

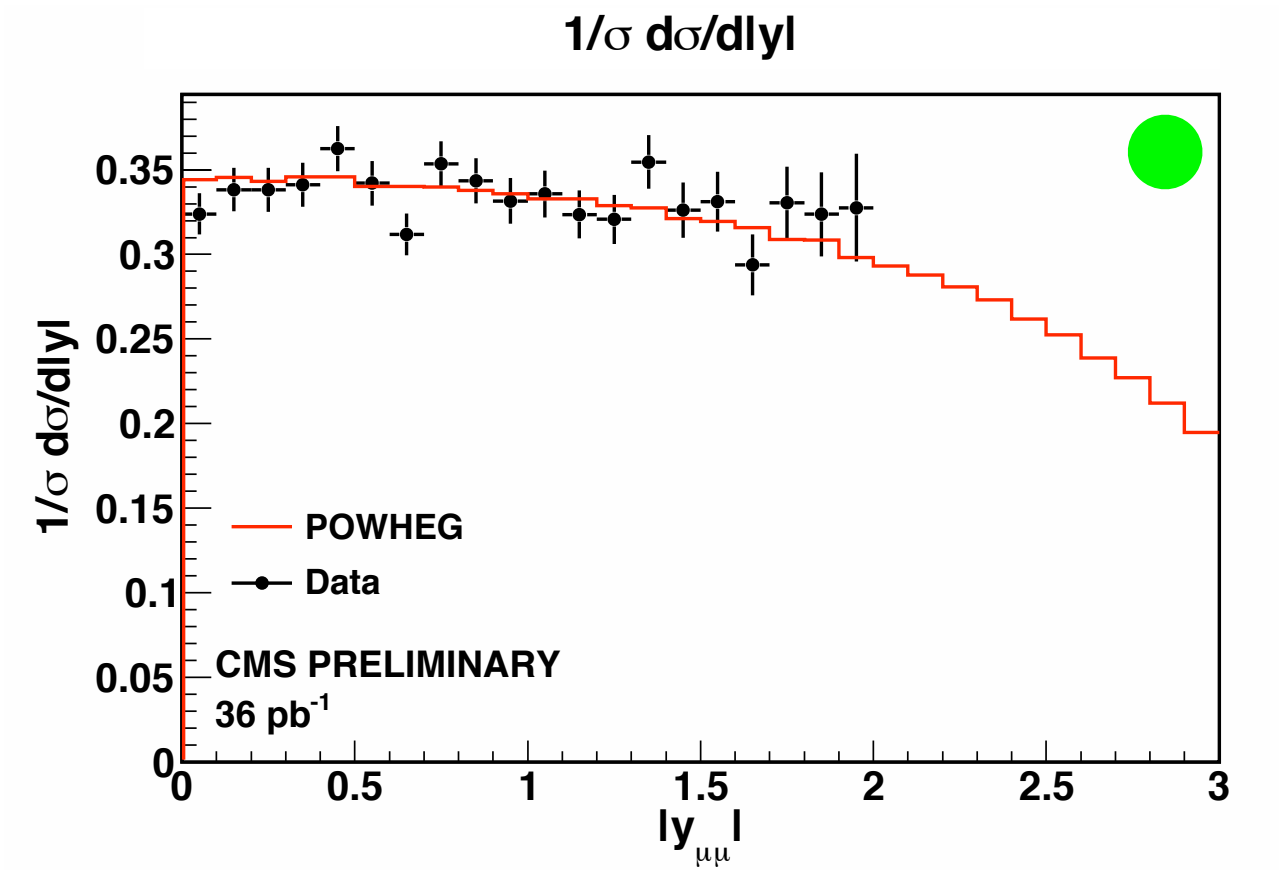
- $(1/\sigma)d\sigma/dP_T$ measurement is compared with POWHEG prediction
  - The differential cross section is measured in the restricted acceptance region
  - Low P_T region (PT<10) shows disagreement with POWHEG
  - The data has 1 ~ 2 sigma excess around $100 < P_T < 200$ GeV/c region
    - Giovanni will address this issue in the next talk





Result of dσ/dy

- (1/σ)dσ/dy measurement is compared with POWHEG prediction
  - The differential cross section is measured in the restricted acceptance region
  - (1/σ)dσ/dy is symmetric for y<0 and y>0 region, so folded into |y|
  - (1/σ)dσ/dy for |y| is measured using the response matrix method
  - The measurement shows a good agreement with POWHEG (χ^2/ndf = 19.4/19)

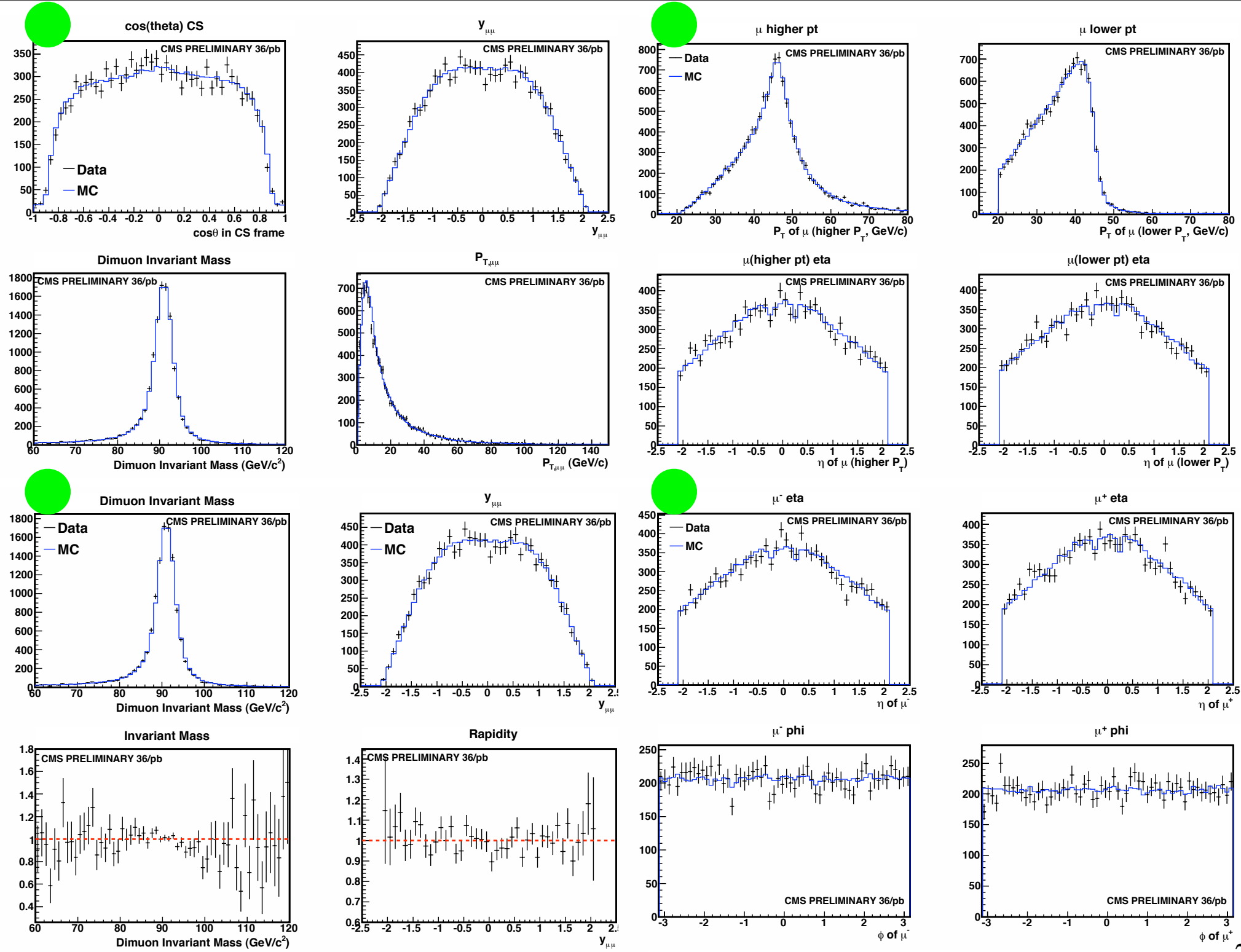


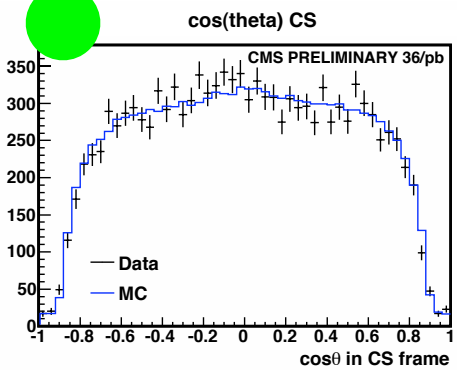
Summary

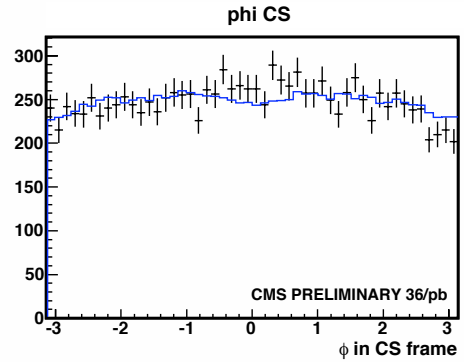
- We measured the differential cross section for P_T and y in the muon channel
  - The integrated luminosity = 36 pb^{-1} is used
  - The measurements are compared with POWHEG prediction
    - $(1/\sigma)d\sigma/dP_T$
      - The measurement shows disagreement in low P_T ($P_T < 10$ GeV/c)
      - The small excess (1 ~ 2 sigma) is found in high P_T, $100 < P_T < 200$ GeV/c
    - $(1/\sigma)d\sigma/dy$
      - The measurement shows good agreement with POWHEG prediction

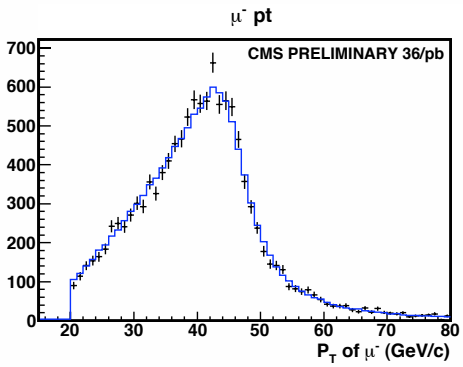
- The presentation of $(1/\sigma)d\sigma/dP_T$, y for electron channel is following ...
  - Giovanni will present the combined result at the end

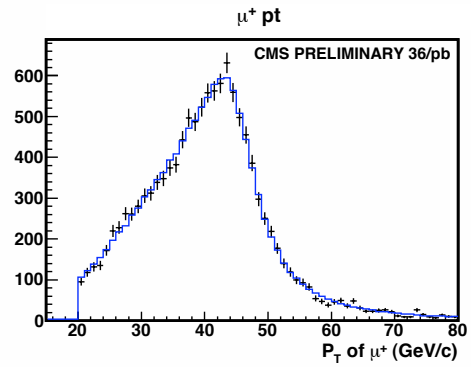
Plots for Approval

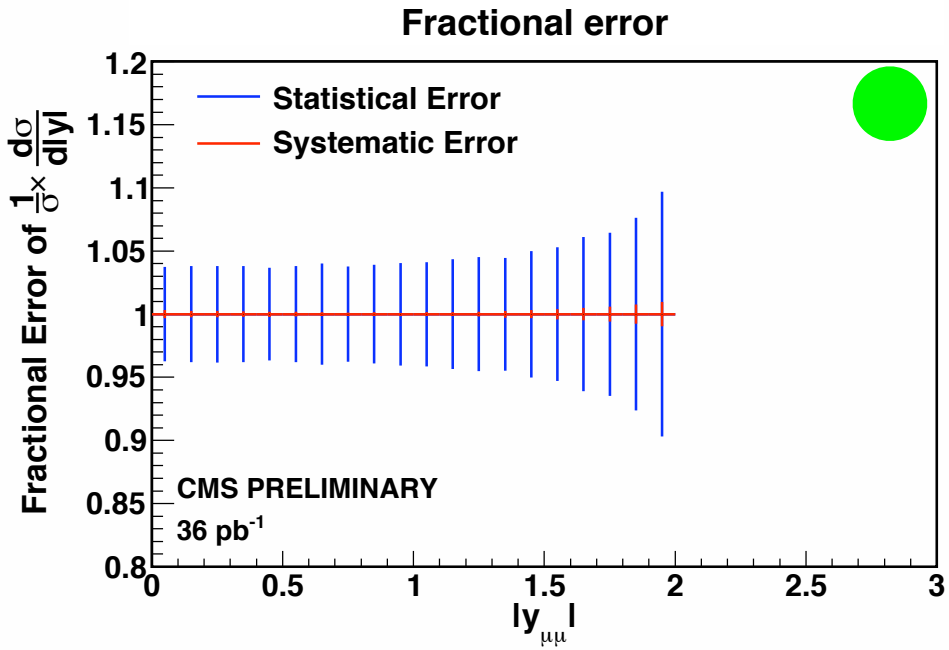

cos(theta) CS
CMS PRELIMINARY 36/pb
Data
MC
cosθ in CS frame
$y_{\mu\mu}$
CMS PRELIMINARY 36/pb
$y_{\mu\mu}$
μ higher pt
Data
MC
CMS PRELIMINARY 36/pb
P_T of μ (higher P_T, GeV/c)
μ lower pt
CMS PRELIMINARY 36/pb
P_T of μ (lower P_T, GeV/c)
Dimuon Invariant Mass
CMS PRELIMINARY 36/pb
Dimuon Invariant Mass (GeV/c^2)
$P_{T\mu\mu}$
CMS PRELIMINARY 36/pb
$P_{T\mu\mu}$ (GeV/c)
μ(higher pt) eta
CMS PRELIMINARY 36/pb
η of μ (higher P_T)
μ(lower pt) eta
CMS PRELIMINARY 36/pb
η of μ (lower P_T)
Dimuon Invariant Mass
Data
MC
CMS PRELIMINARY 36/pb
Dimuon Invariant Mass (GeV/c^2)
$y_{\mu\mu}$
Data
MC
CMS PRELIMINARY 36/pb
$y_{\mu\mu}$
μ^- eta
Data
MC
CMS PRELIMINARY 36/pb
η of μ^-
μ^+ eta
CMS PRELIMINARY 36/pb
η of μ^+
Invariant Mass
CMS PRELIMINARY 36/pb
Dimuon Invariant Mass (GeV/c^2)
Rapidity
CMS PRELIMINARY 36/pb
$y_{\mu\mu}$
μ^- phi
CMS PRELIMINARY 36/pb
φ of μ^-
μ^+ phi
CMS PRELIMINARY 36/pb
φ of μ^+

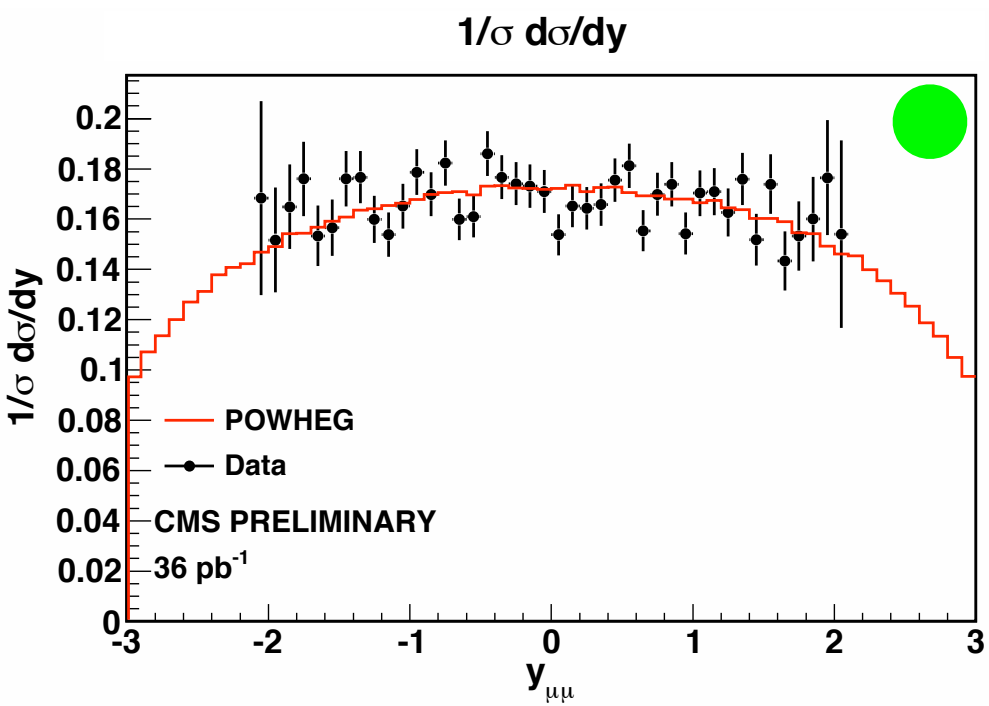

cos(theta) CS
CMS PRELIMINARY 36/pb
Data
MC
cosθ in CS frame

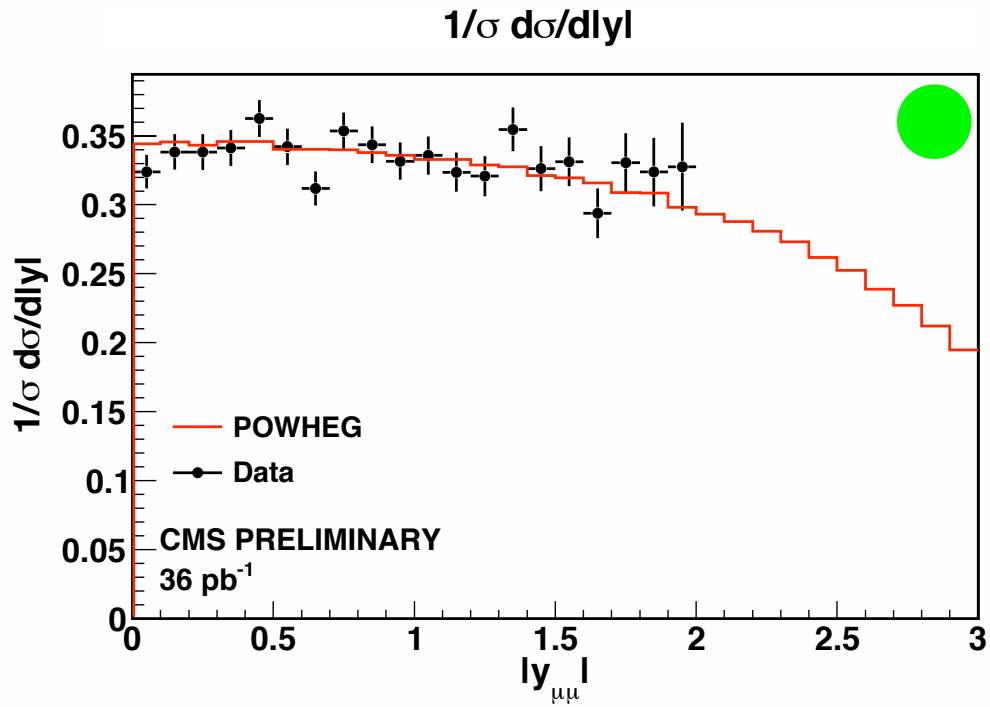

phi CS
CMS PRELIMINARY 36/pb
ϕ in CS frame

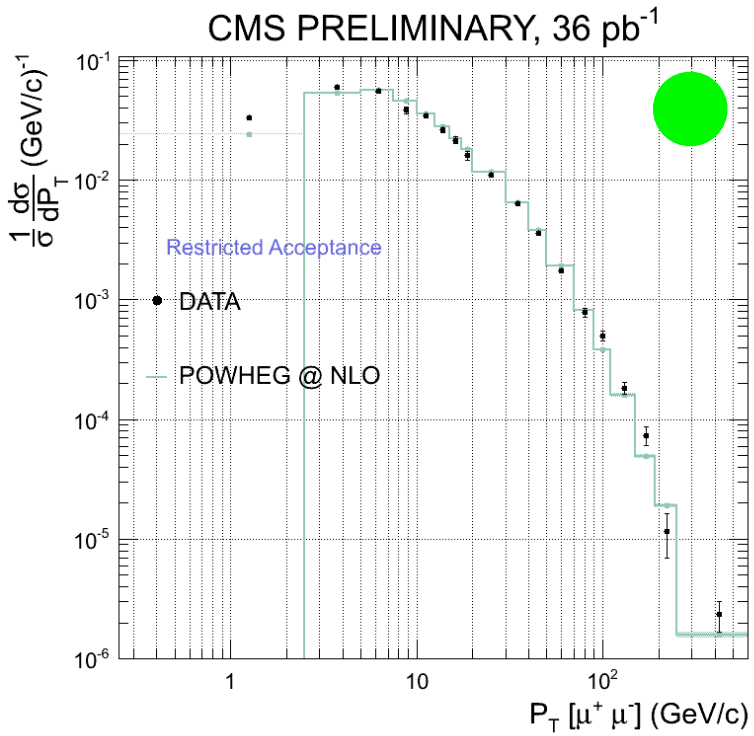

μ- pt
CMS PRELIMINARY 36/pb
P_T of μ- (GeV/c)

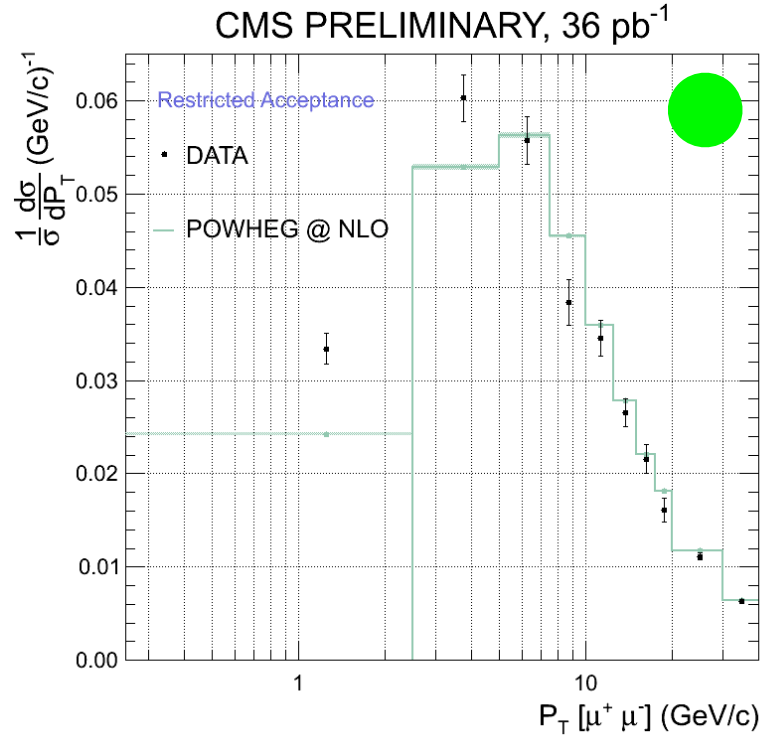

μ+ pt
CMS PRELIMINARY 36/pb
P_T of μ+ (GeV/c)

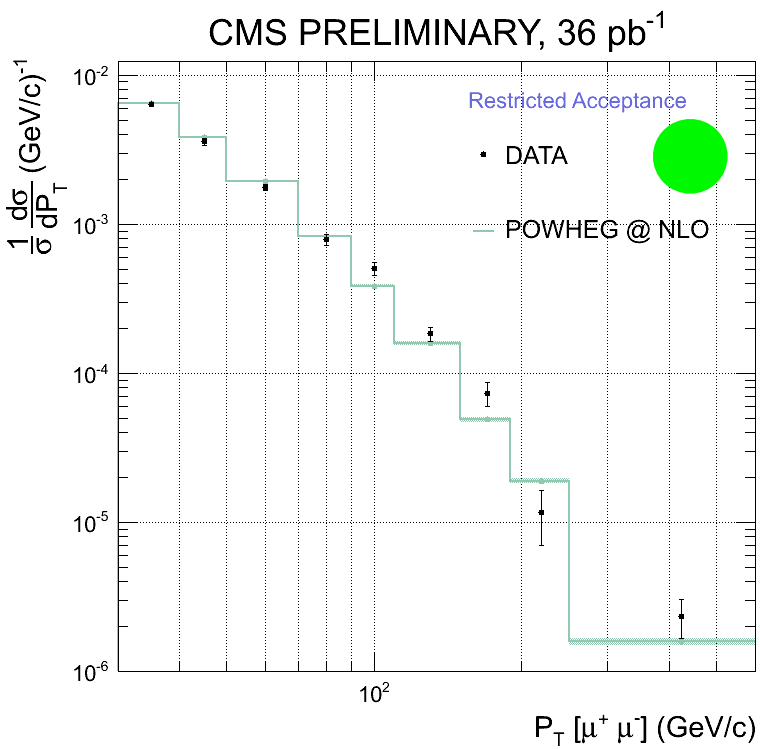

Fractional error
Statistical Error
Systematic Error
Fractional Error of 1/σ × dσ/d|y|
CMS PRELIMINARY
36 pb-1
|y_μμ|

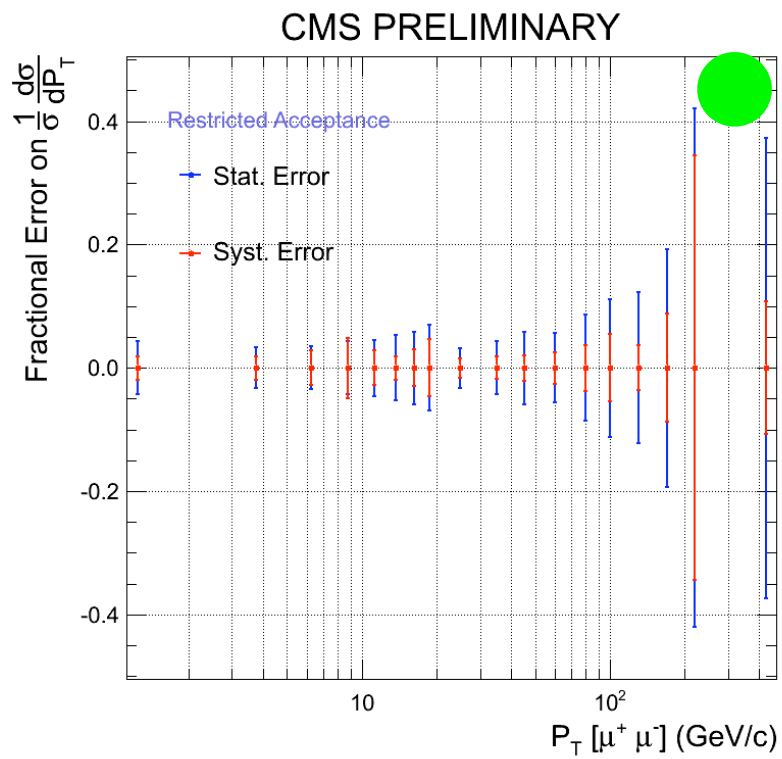

1/σ dσ/dy
POWHEG
Data
CMS PRELIMINARY
36 pb-1
1/σ dσ/dy
y_μμ

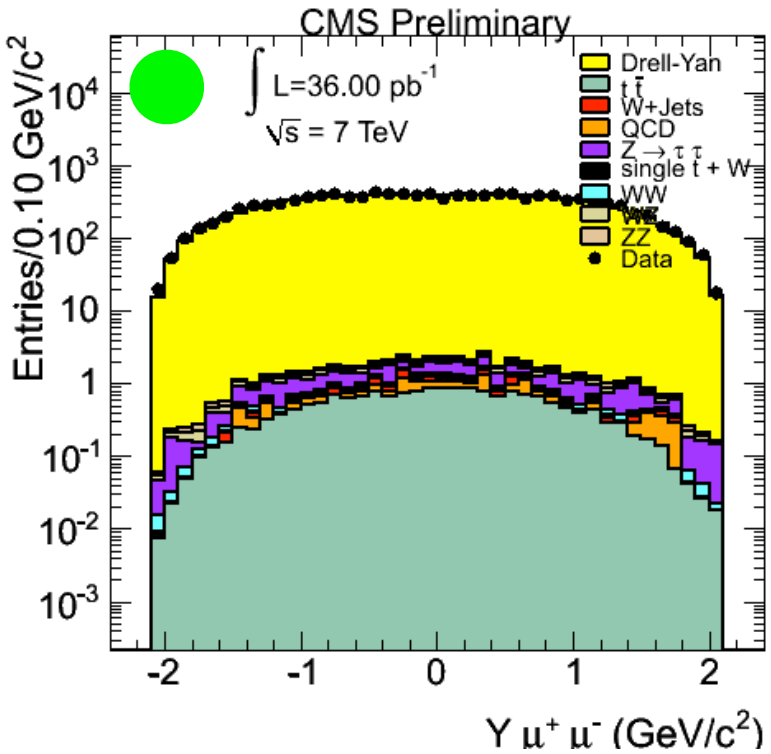

1/σ dσ/d|y|
POWHEG
Data
CMS PRELIMINARY
36 pb-1
1/σ dσ/d|y|
|y_μμ|

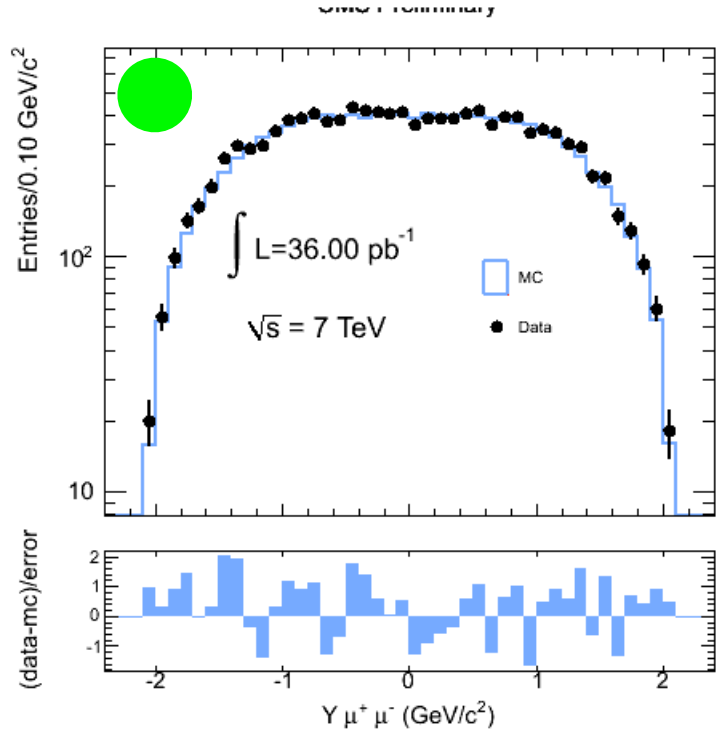

CMS PRELIMINARY, 36 pb^{-1}
$\frac{1}{\sigma}\frac{d\sigma}{dP_T}$ (GeV/c)$^{-1}$
Restricted Acceptance
DATA
POWHEG @ NLO
P_T [$\mu^+ \mu^-$] (GeV/c)

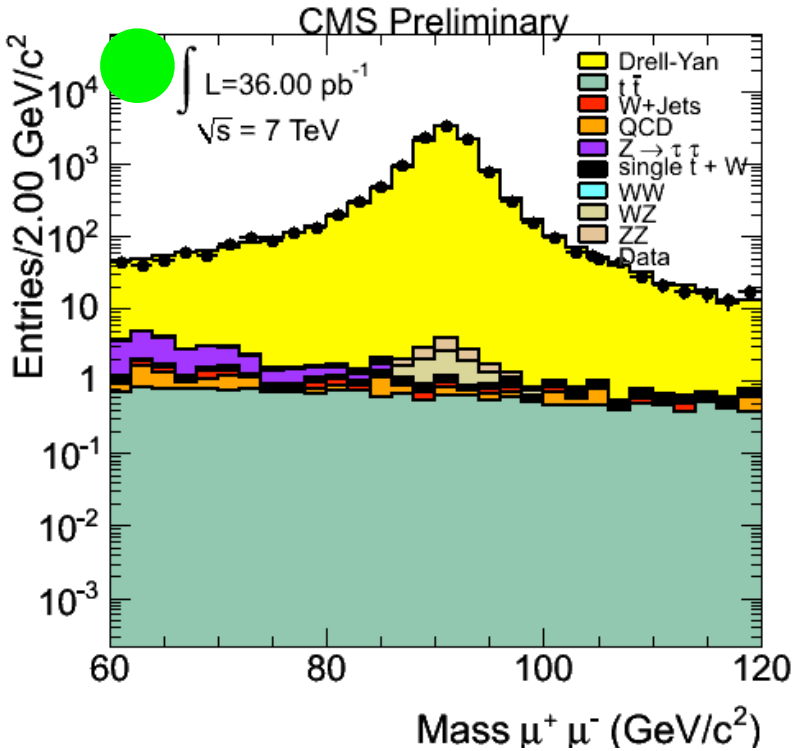

CMS PRELIMINARY, 36 pb^{-1}
$\frac{1}{\sigma}\frac{d\sigma}{dP_T}$ (GeV/c)$^{-1}$
Restricted Acceptance
DATA
POWHEG @ NLO
P_T [$\mu^+ \mu^-$] (GeV/c)

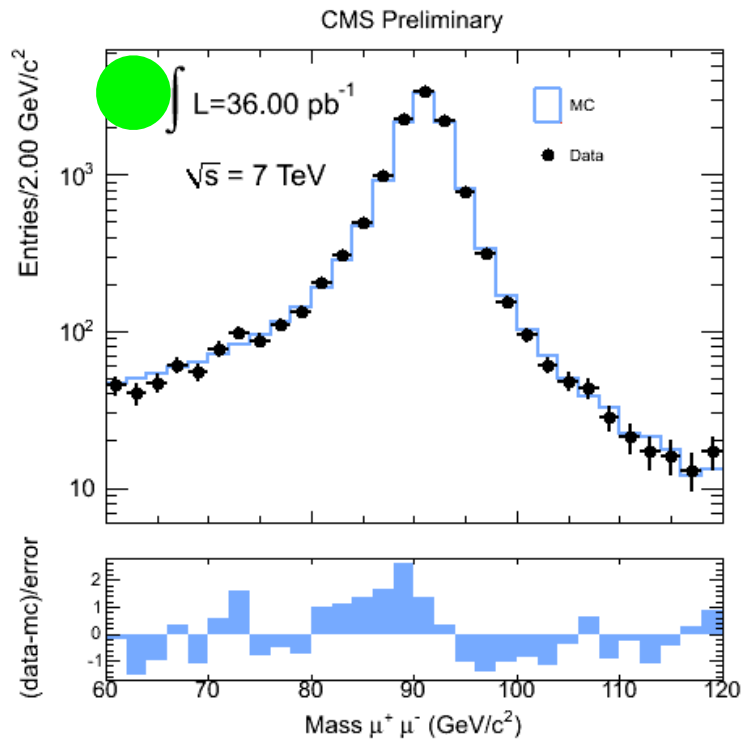

CMS PRELIMINARY, 36 pb^{-1}
$\frac{1}{\sigma}\frac{d\sigma}{dP_T}$ (GeV/c)$^{-1}$
Restricted Acceptance
DATA
POWHEG @ NLO
P_T [$\mu^+ \mu^-$] (GeV/c)

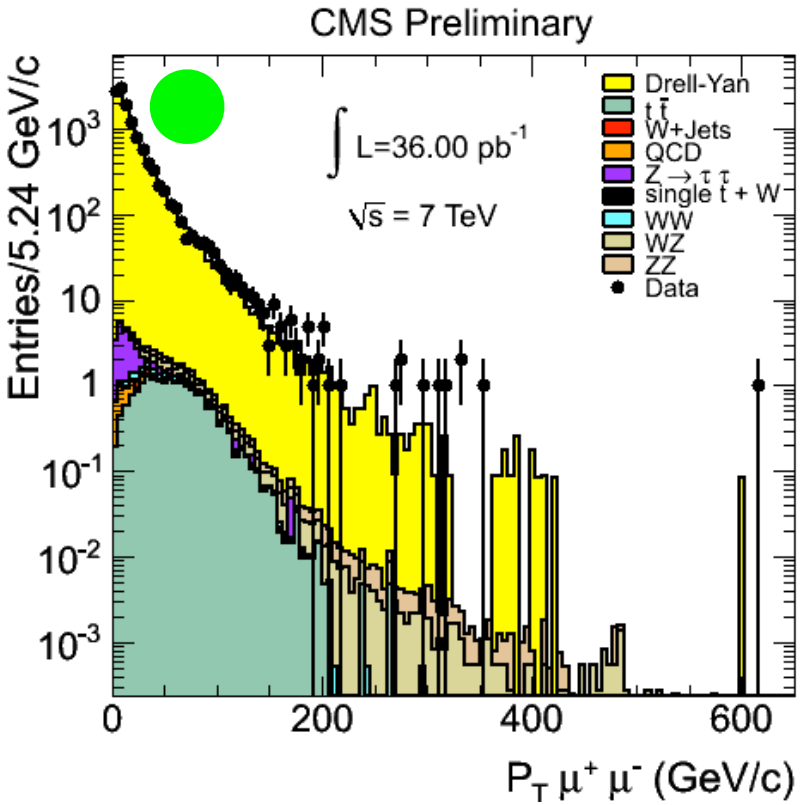

CMS PRELIMINARY
Fractional Error on $\frac{1}{\sigma}\frac{d\sigma}{dP_T}$
Restricted Acceptance
Stat. Error
Syst. Error
P_T [$\mu^+ \mu^-$] (GeV/c)

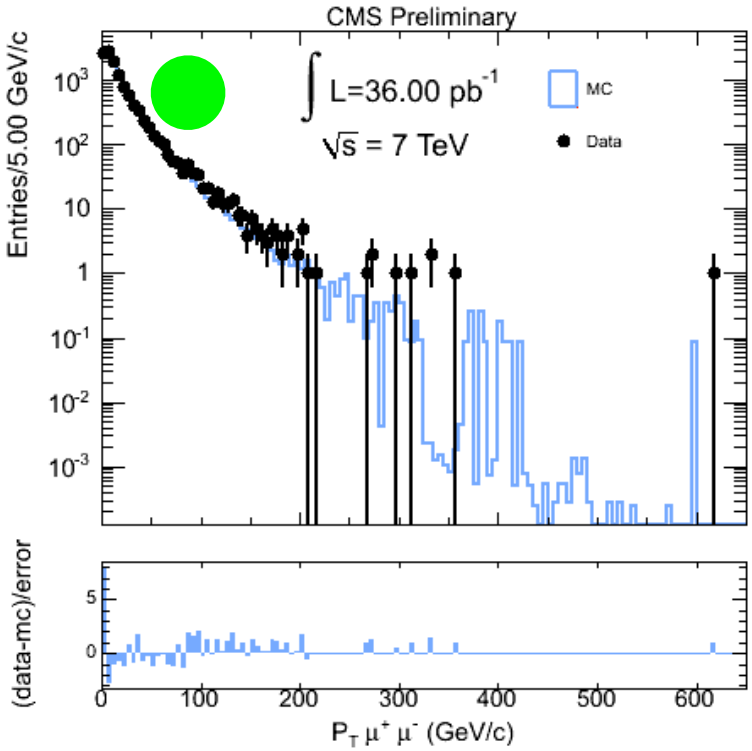

CMS Preliminary
∫ L=36.00 pb-1
√s = 7 TeV
Drell-Yan
t t̄
W+Jets
QCD
Z → τ τ
single t + W
WW
WZ
ZZ
Data
Entries/0.10 GeV/c2
Y μ+ μ- (GeV/c2)


∫ L=36.00 pb-1
√s = 7 TeV
MC
Data
Entries/0.10 GeV/c2
(data-mc)/error
Y μ+ μ- (GeV/c2)


CMS Preliminary
∫ L=36.00 pb-1
√s = 7 TeV
Drell-Yan
t t̄
W+Jets
QCD
Z → τ τ
single t + W
WW
WZ
ZZ
Data
Entries/2.00 GeV/c2
Mass μ+ μ- (GeV/c2)


CMS Preliminary
∫ L=36.00 pb-1
√s = 7 TeV
MC
Data
Entries/2.00 GeV/c2
(data-mc)/error
Mass μ+ μ- (GeV/c2)


CMS Preliminary
Entries/5.24 GeV/c
∫ L=36.00 pb-1
√s = 7 TeV
Drell-Yan
t t̄
W+Jets
QCD
Z → τ τ
single t + W
WW
WZ
ZZ
Data
P_T μ+ μ- (GeV/c)


CMS Preliminary
Entries/5.00 GeV/c
∫ L=36.00 pb-1
√s = 7 TeV
MC
Data
(data-mc)/error
P_T μ+ μ- (GeV/c)

Differential Z Cross Section $d\sigma/dY$ and $d\sigma/dP_T$ in the Electron Channel

Bryan Dahmes, Giovanni Franzoni, Jason Haupt,
Kevin Klapoetke, Jeremy Mans, Vladimir Rekovic

AN-10-367 and AN-11-029

CMS approval – March 7th 2011

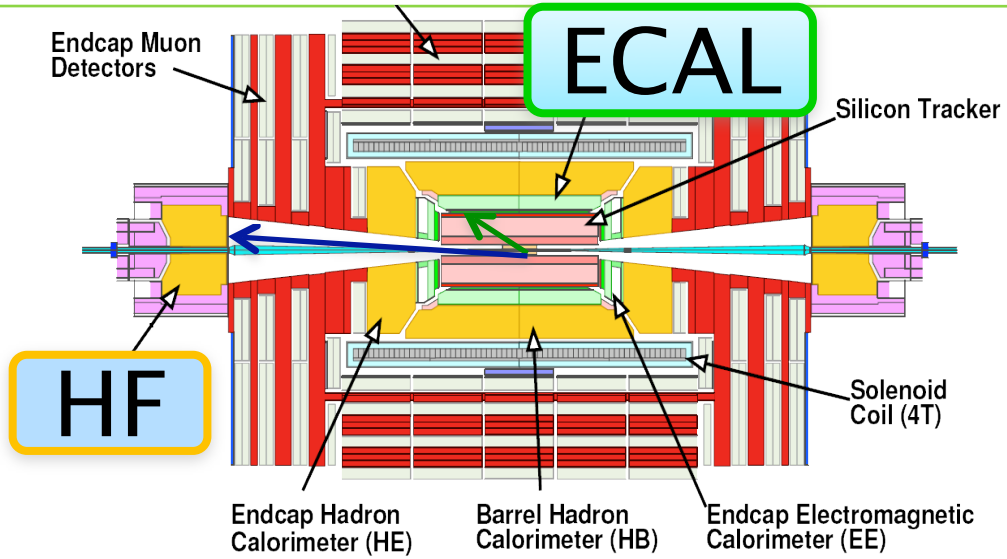
Reconstruction Strategy for Z

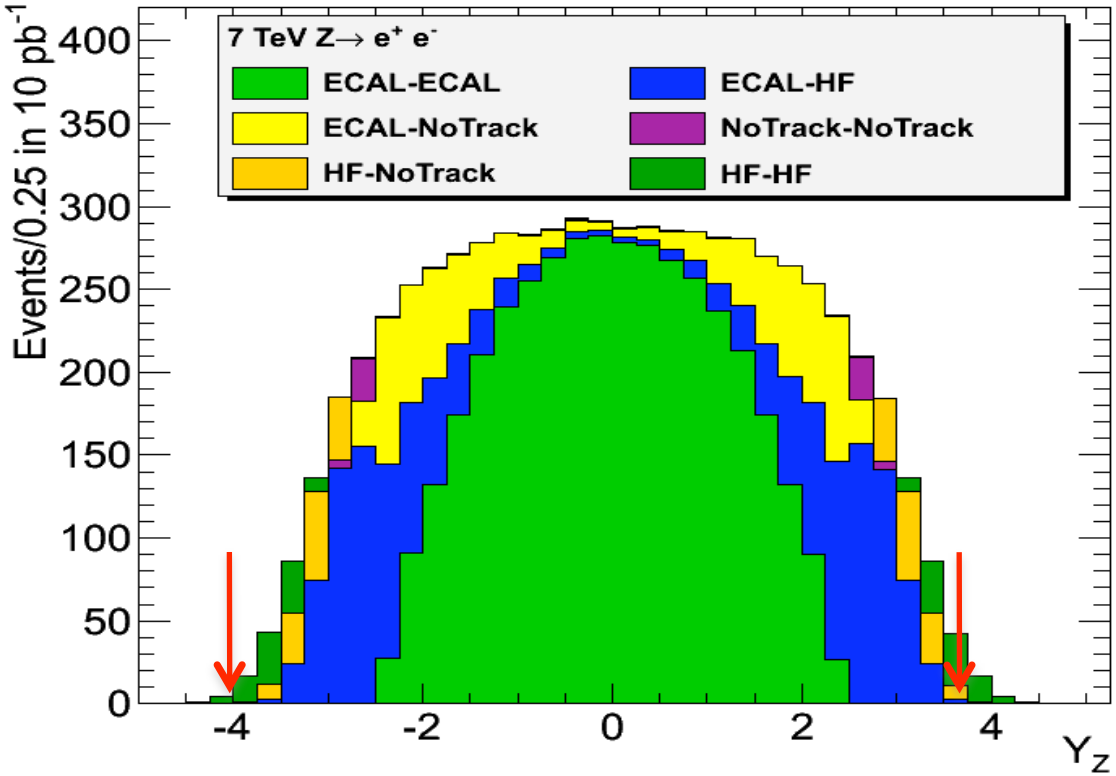
In the P_T analysis

- **only ECAL** electrons with $|\eta| < 2.1$ to match muon analysis.

In the Y analysis

- consider **ECAL electrons** within tracking acceptance $|\eta| < 2.5$.
- Large $|Y|$ → **access low values of x**, where p.d.f. uncertainties are relatively larger
- use **HF electrons** to extend 2.1→3.5 the accessible rapidity range
- HF electron ID based on longitudinal and transverse shower shape variables.





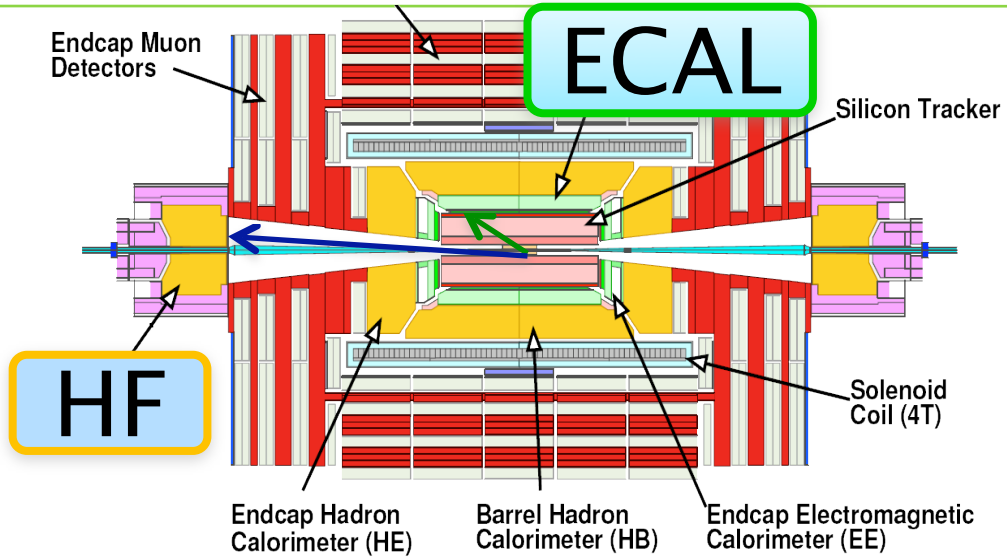
Reconstruction Strategy for Z

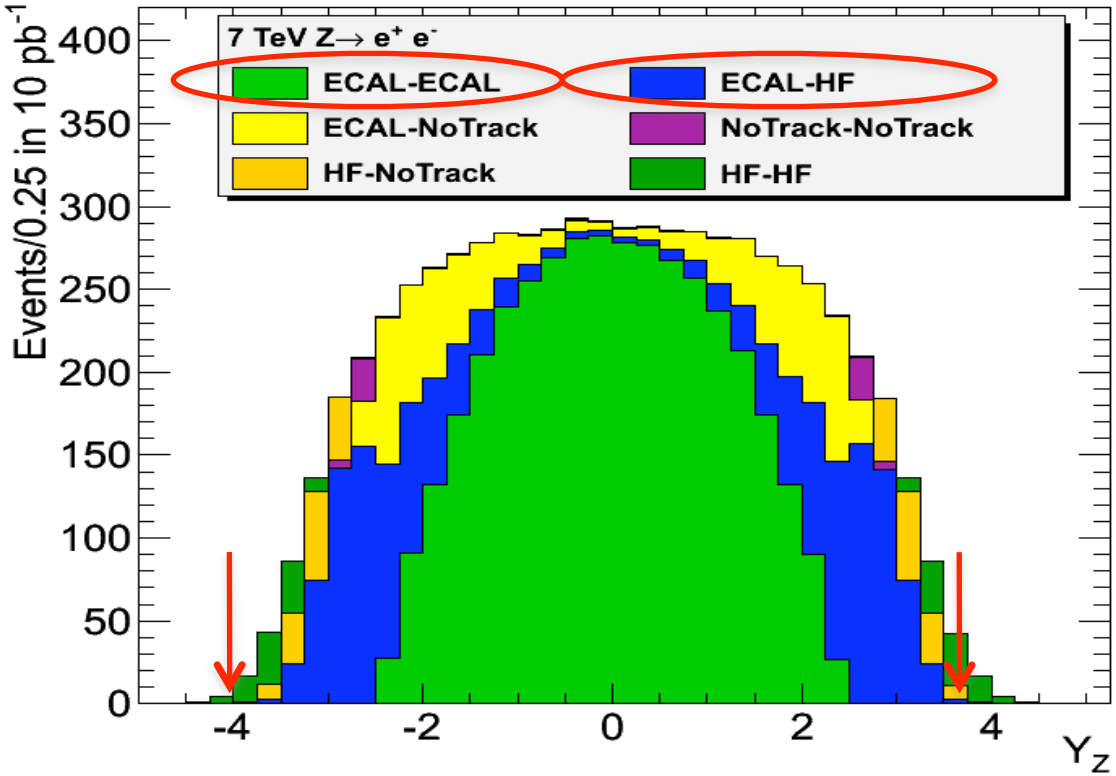
In the P_T analysis

- **only ECAL** electrons with $|\eta| < 2.1$ to match muon analysis.

In the Y analysis

- consider **ECAL electrons** within tracking acceptance $|\eta| < 2.5$.
- Large $|Y|$ → **access low values of x**, where p.d.f. uncertainties are relatively larger
- use **HF electrons** to extend 2.1→3.5 the accessible rapidity range
- HF electron ID based on longitudinal and transverse shower shape variables.





Z Definitions/Electron Selection

- **Definition of Z candidate: pair of electrons 60 GeV/c^2 < m(ee) < 120 GeV/c^2**

Z definition in $d\sigma/dY$	Electron 1 (HLT matched)	Electron 2
ECAL-ECAL	ECAL $\|\eta\|$ <2.5 + track + HLT	ECAL $\|\eta\|$ <2.5 + track
ECAL-HF	ECAL $\|\eta\|$ <2.5 + track + HLT	HF 3.1 < $\|\eta\|$ < 4.6

Z definition in $d\sigma/dP_T$	Electron 1 (HLT matched)	Electron 2
ECAL 2.1-ECAL 2.1	ECAL with $\|\eta\|$ <2.1 + track + HLT	ECAL with $\|\eta\|$ <2.1 + track

ECAL Electron1 (2) Definition
GSF track matched
EWK Electron WP80 (WP95)
P_T > 20 GeV
HLT

HF Electron Definition
HF EM Cluster
HF Electron ID
P_T > 20 GeV

- **Single electron efficiencies** are measured with the **tag & probe** technique and framework
- **Tag** = ECAL electron, that passed WP80 and matches to HLT path
- **Probe** = With mass (60–120 GeV) **Scluster > 20 GeV → GsfElectron → WP80(95)→ HLT**

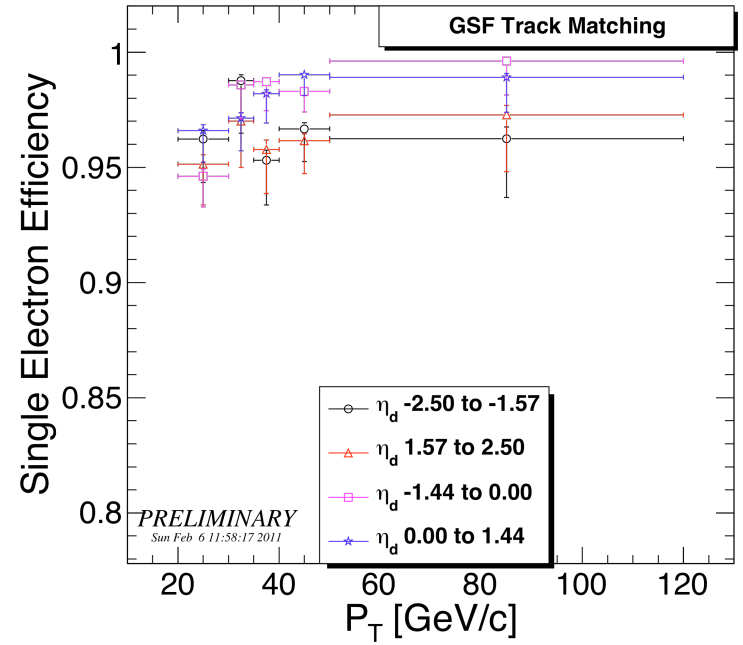
Single Electron Efficiencies

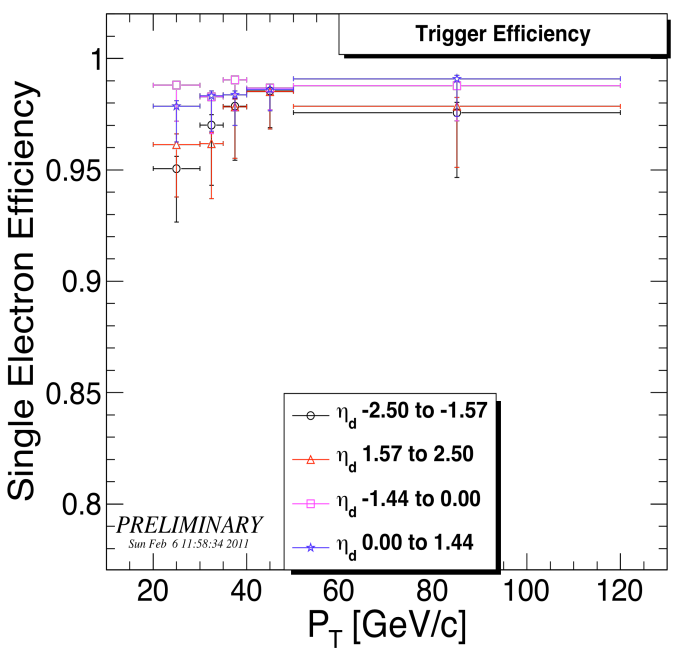
- Z-shape measurement is ***differential*** in **Y, P_T**

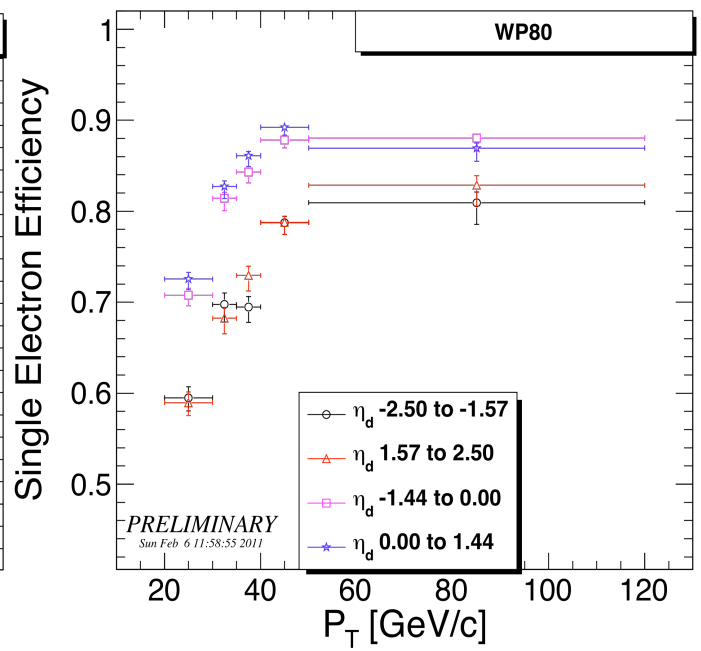
1. Measure **single electron** efficiencies from as function of:

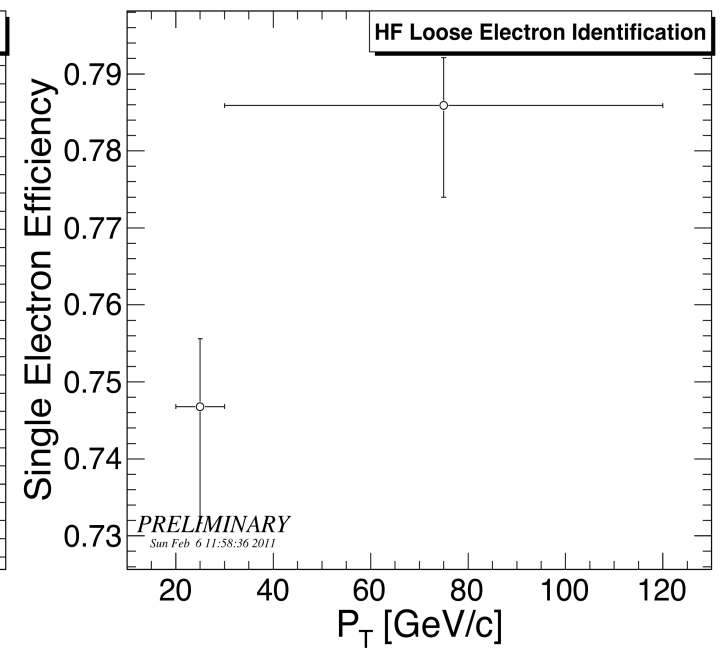
   P_T, η_{det}

2. Convolve single electron → Z efficiencies







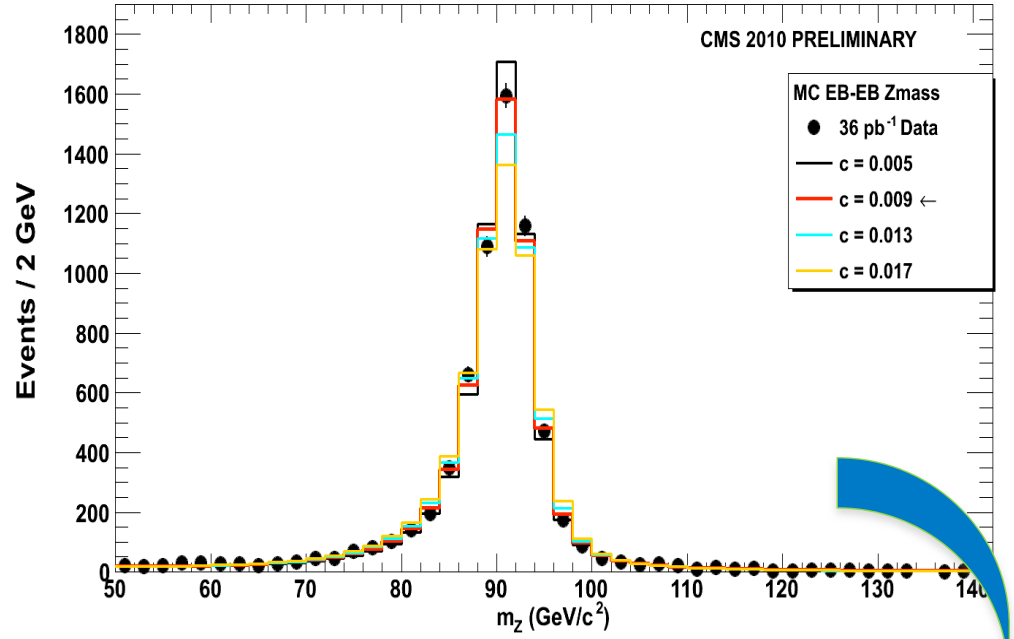


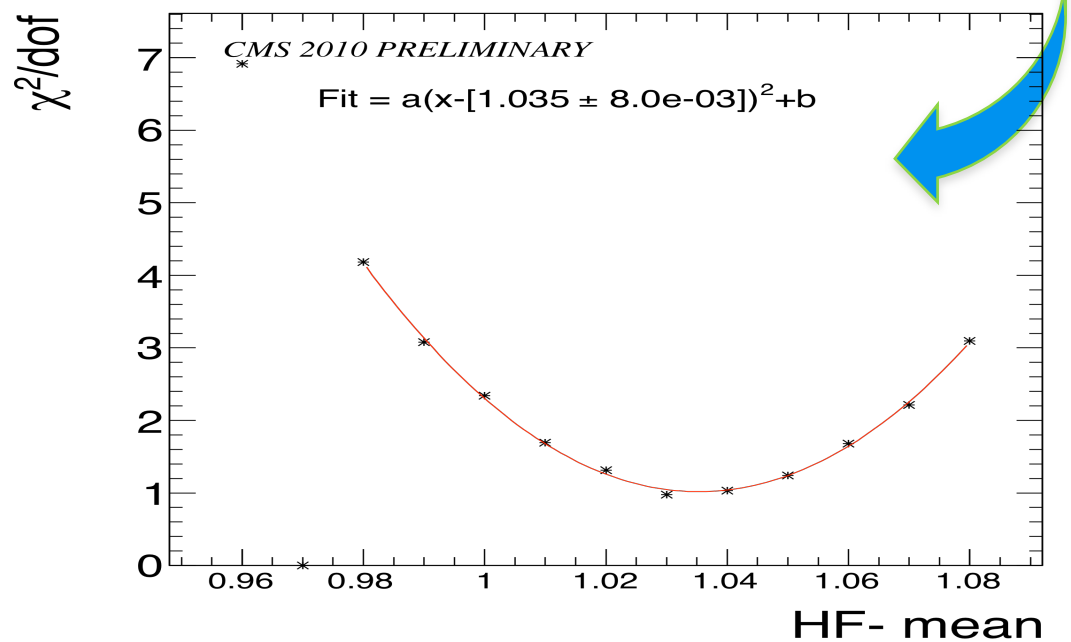
Data-driven Smeared Monte Carlo

- ***Efficiency of measured Z*** from convolution of single electron efficiencies
- Provide statistics to determined unfolding

→ Need large sample (100M)

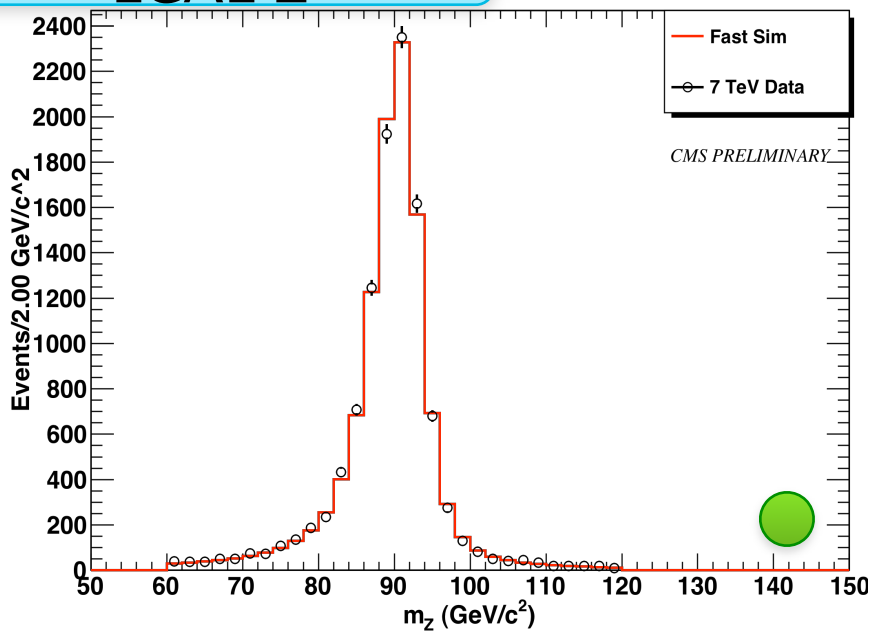
- Smeared Monte Carlo based on parameterized smearing of energies and positions
- Derive smearing parameters from data
- Minimization of χ^2 between invariant mass of smeared Monte Carlo (colored histograms) and data



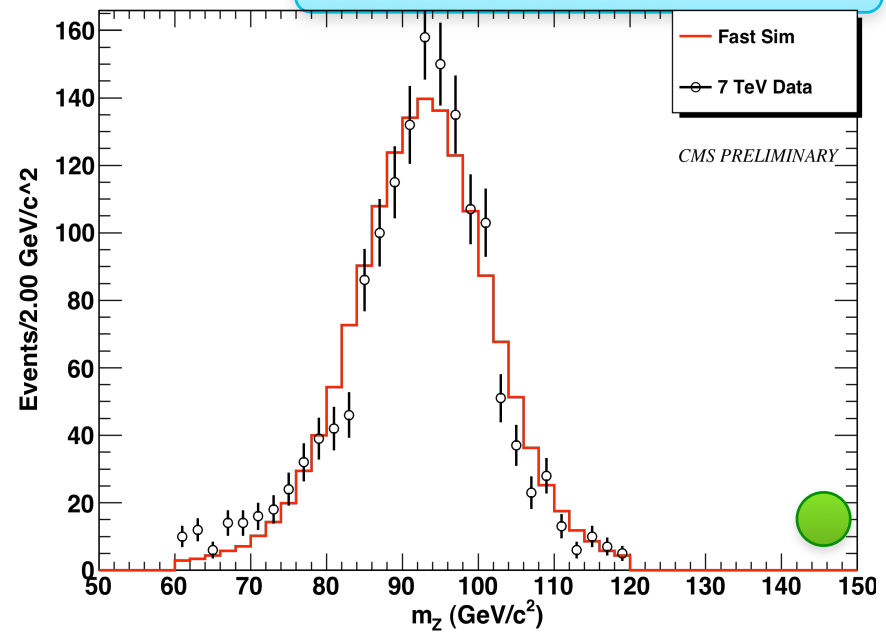


Consistency between smeared MC, full MC and data

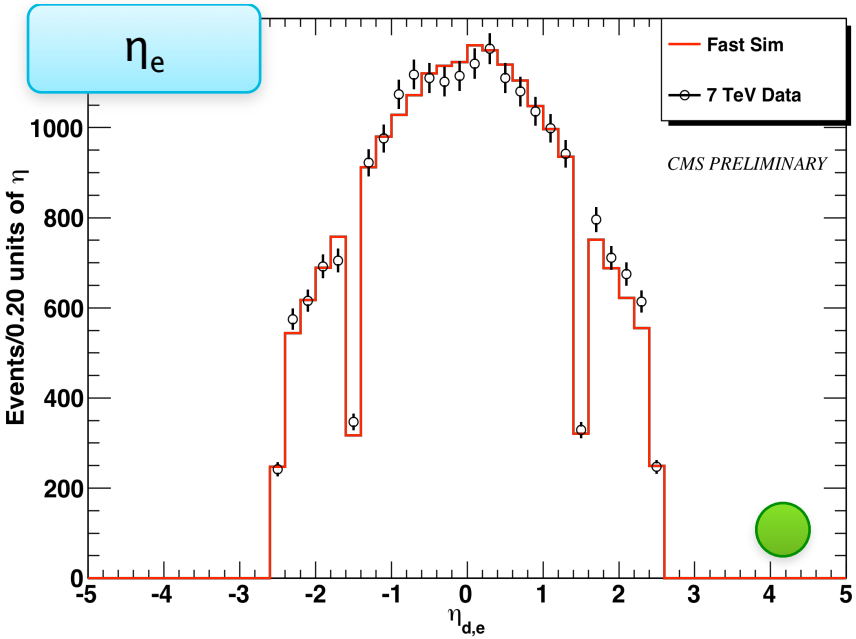
Type 1 ECAL-ECAL Z



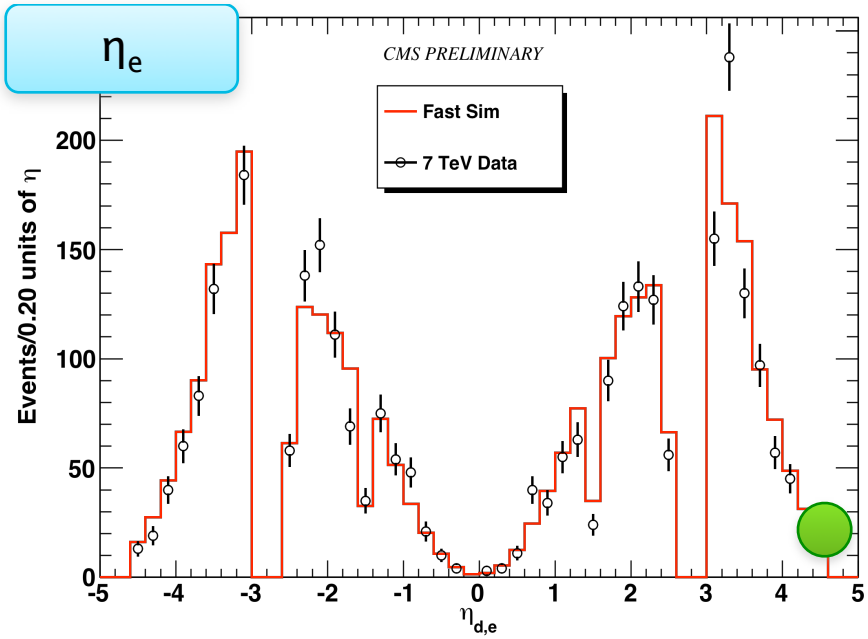
Type 2 ECAL-HF Z



η_e

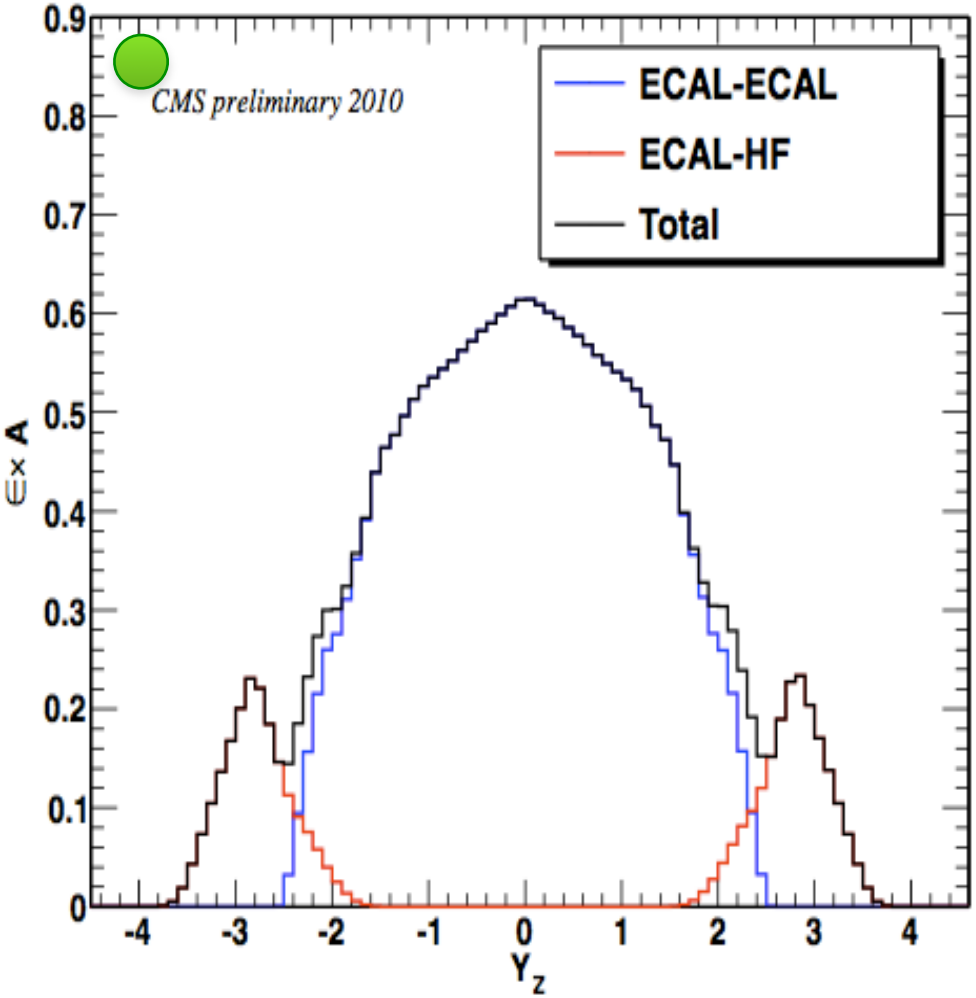


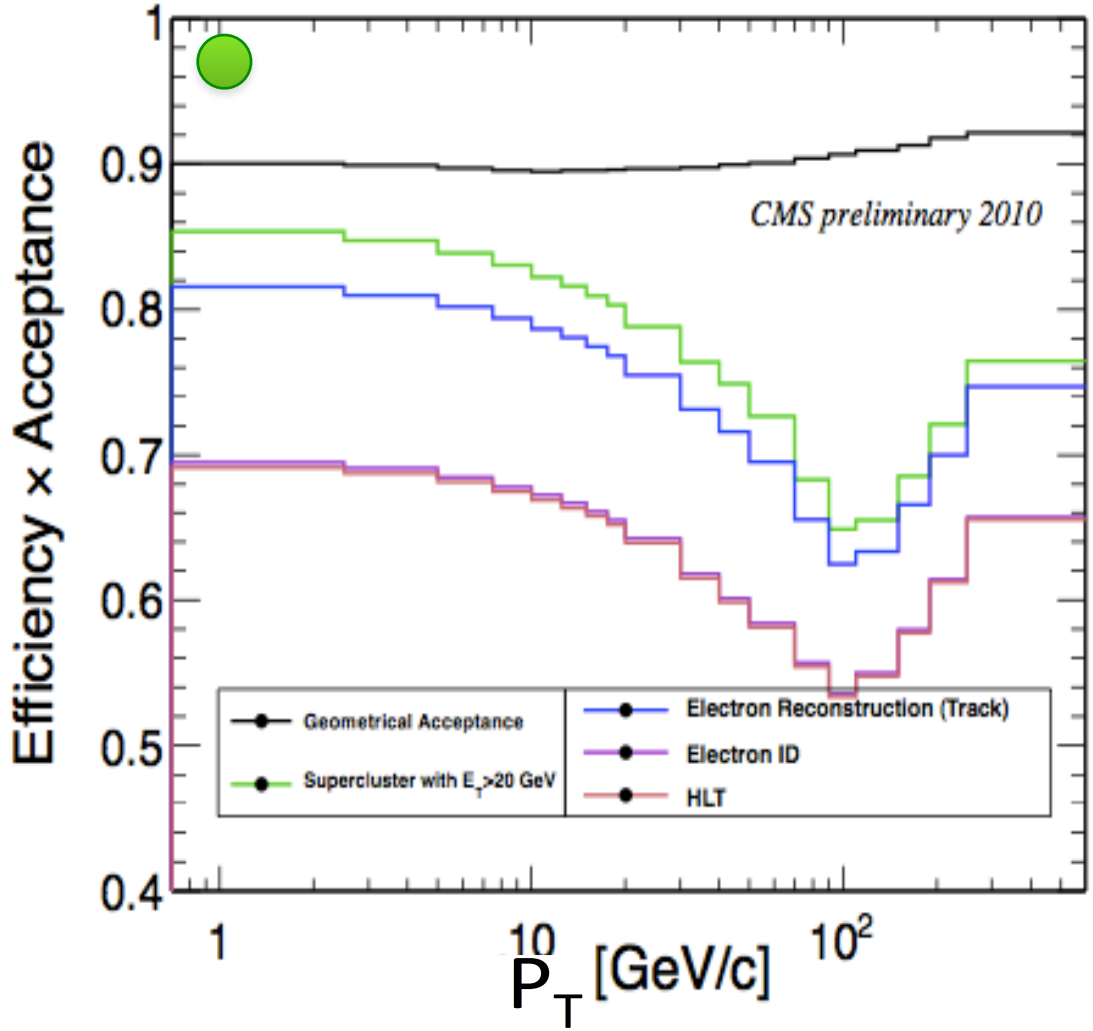
η_e



(ε x A) for Measured Z

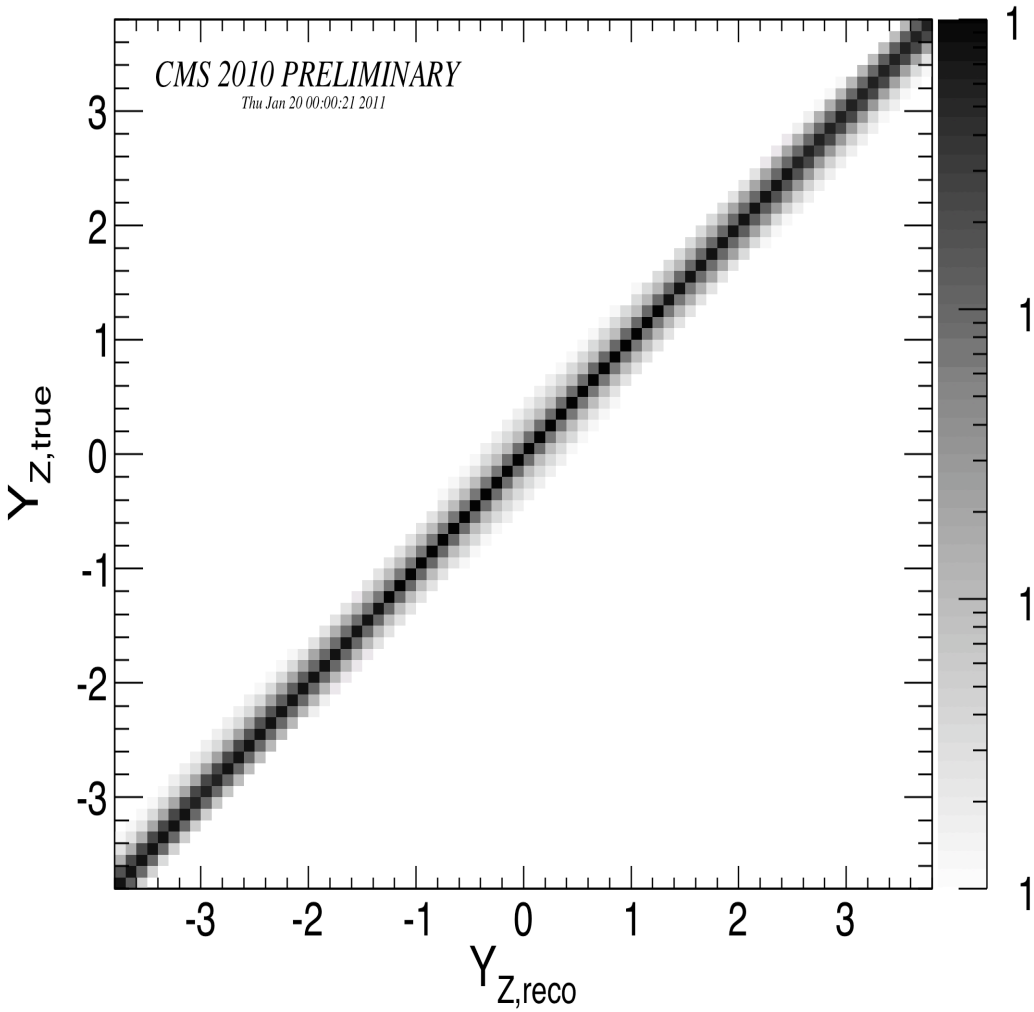
$$\varepsilon_{full} = \left[\frac{N(Superclusters)}{N(Electrons)}\right]^{MC} \times \left[\frac{N(TrackMatched)}{N(Superclusters)}\right]^{data} \times \left[\frac{N(WP80)}{N(TrackMatched)}\right]^{data} \times \left[\frac{N(L1+HLT)}{N(WP80)}\right]^{data}$$

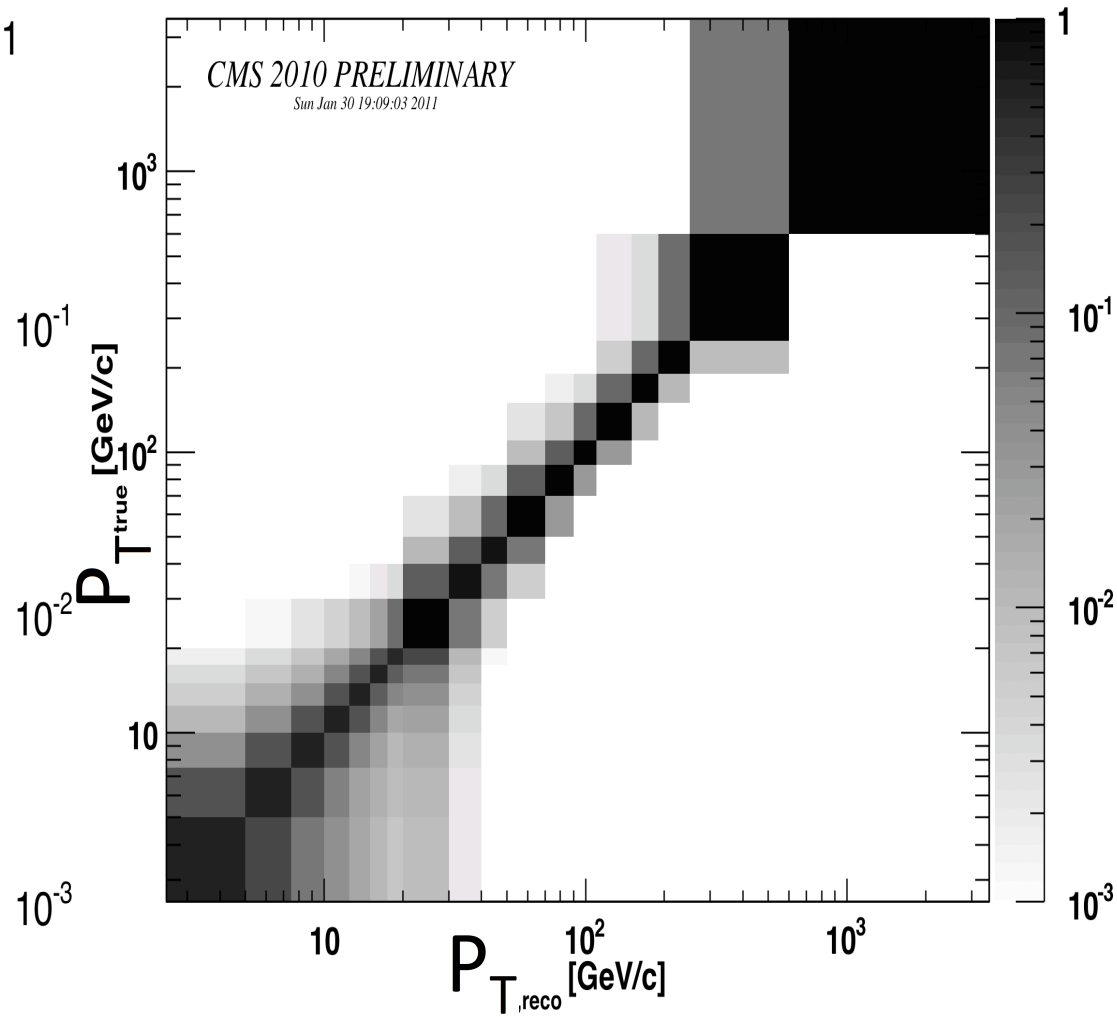




- Total σ(Z) 930 pb^{-1}, in excellent agreement w/ CMS published (931)

Bin migration and unfolding for Y and P_T





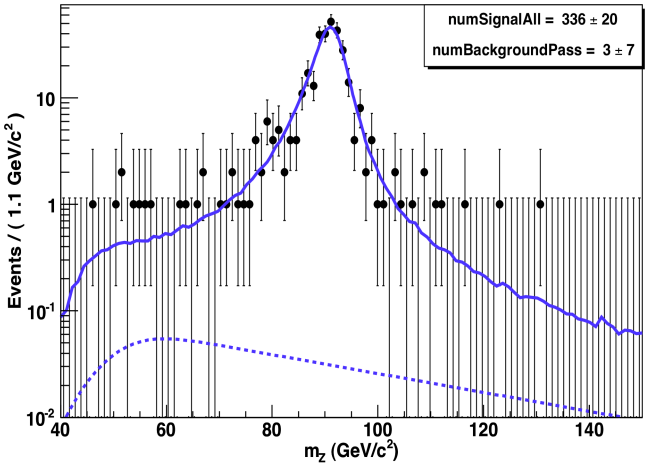
$$M(i,j) = P(X^{j}{}_{Z,meas} \mid X^{i}{}_{Z,true})$$

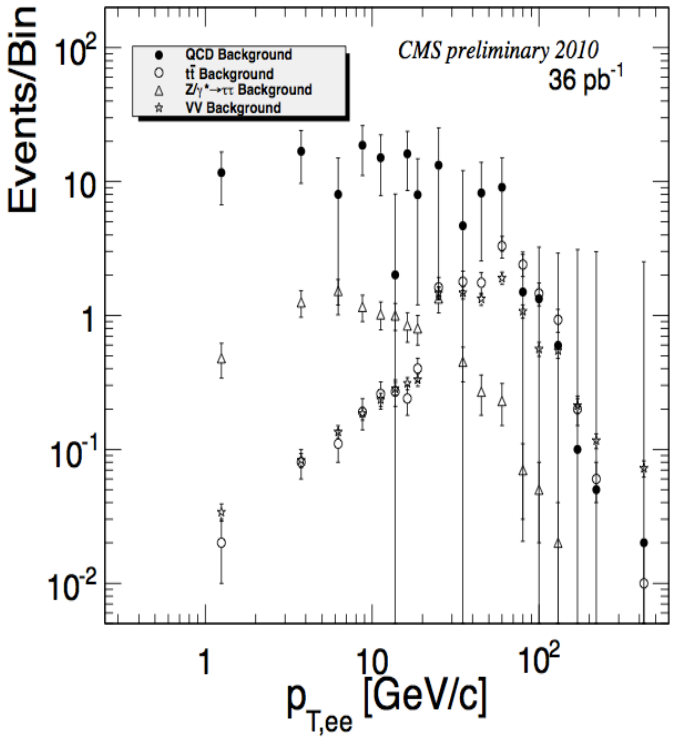
- Migration matrix obtained from the parameterized Monte Carlo
- Unfolding matrix obtained by inversion

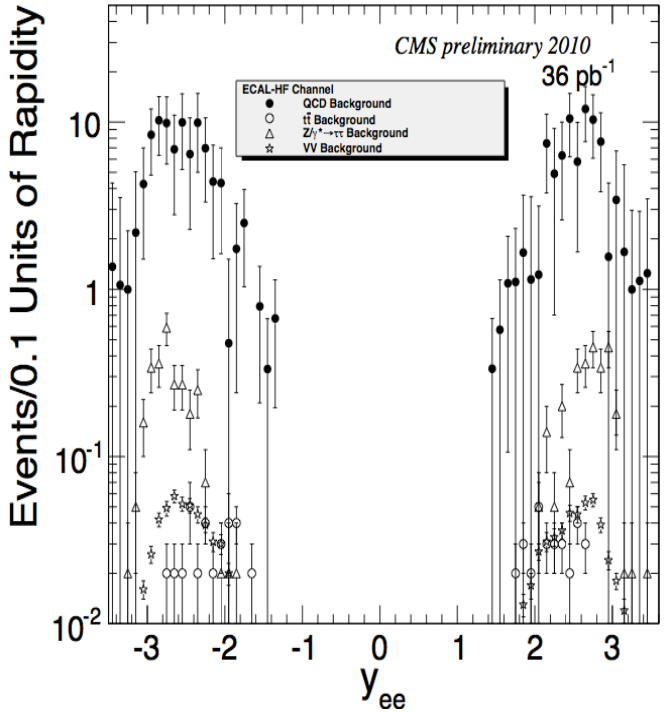
Background Subtraction

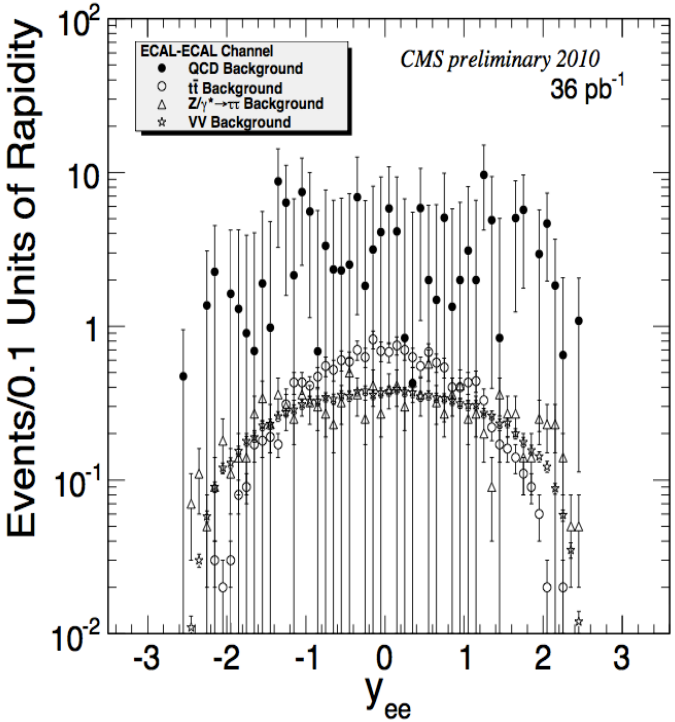
- Extract BG contribution from fit: DATA = SIGNAL + BG
- Dominant background from QCD
- SIG template: POWHEG and smeared Monte Carlo
- BG template: QCD-enriched sample inverting WP95/HFId
- Small sidebands statistics drives the BKG systematic error
- Backgrounds from other sources with real electrons (t-tbar, ττ, VV) estimated from Monte Carlo

Eg: $0.2 < Y_Z < 0.3$









Systematic Uncertainties

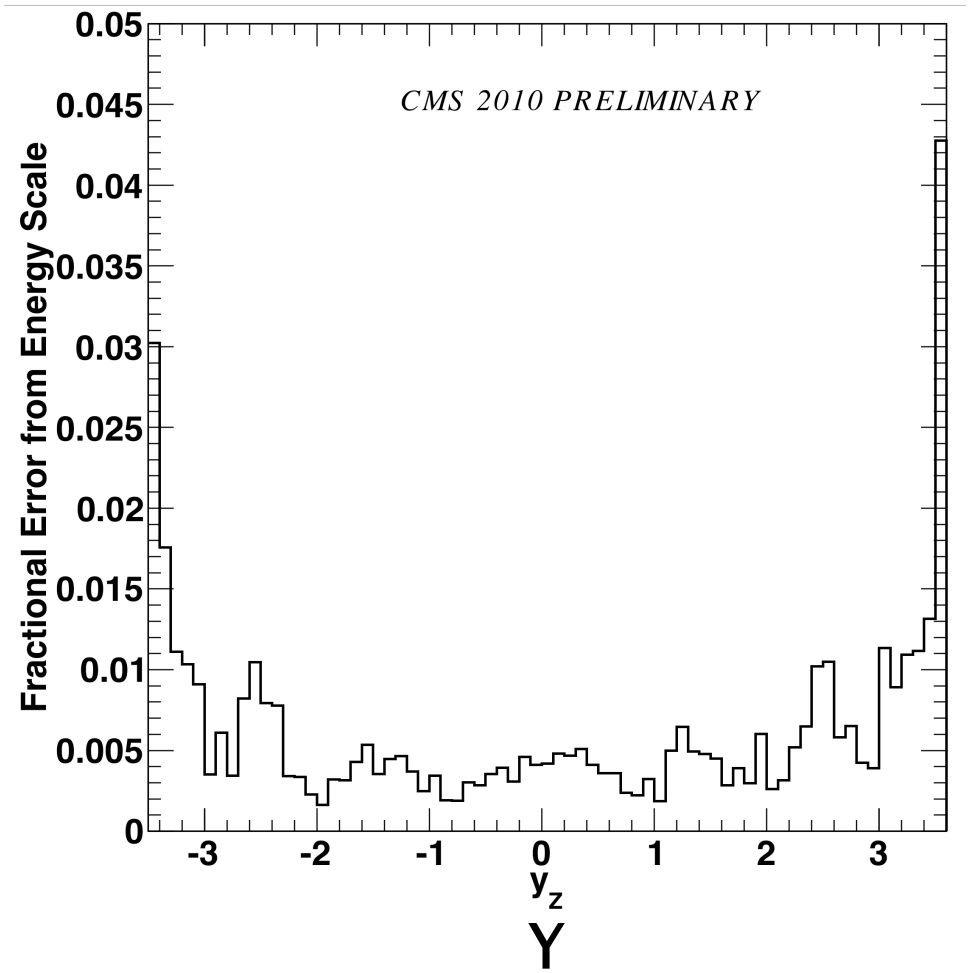
- Different sources of systematic errors are considered:
  - Background subtraction
  - Energy scale
  - From electron efficiencies

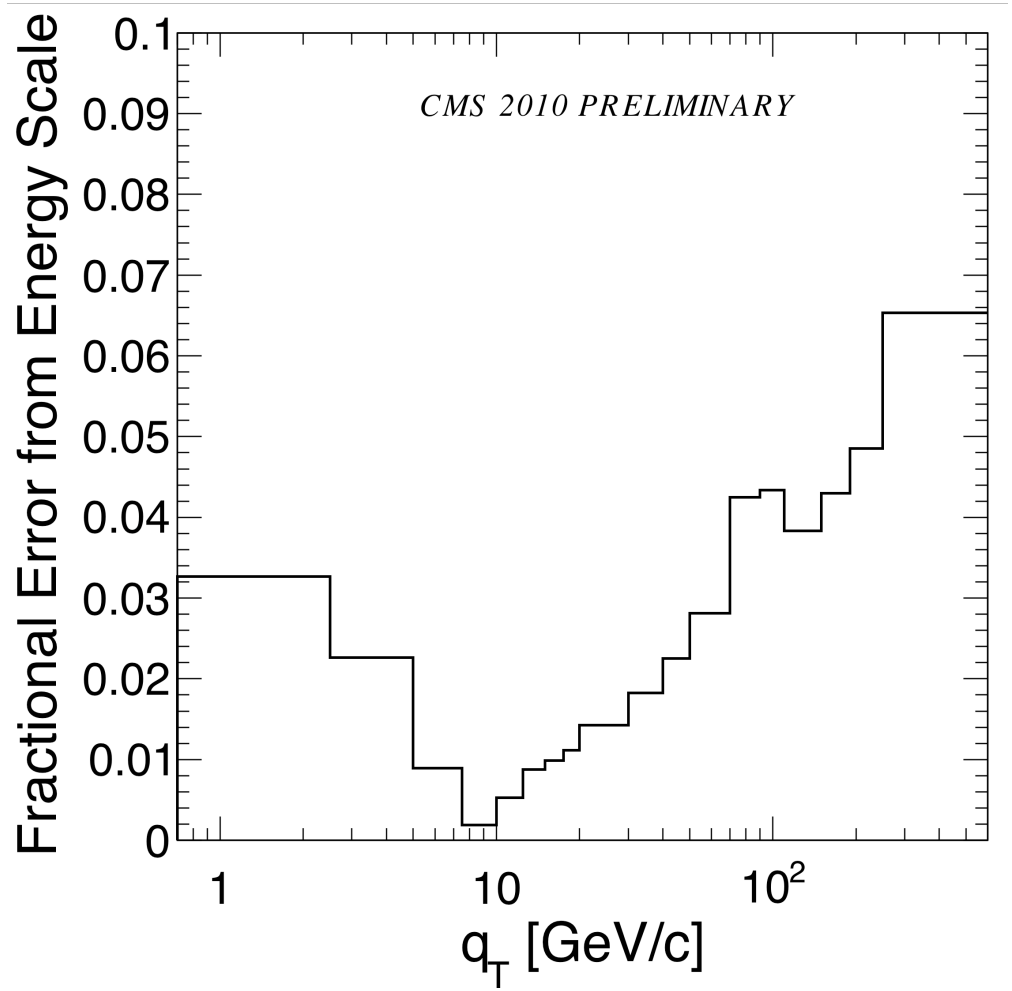
significant

- Uncertainties in the **PDF's** used to compute efficiencies give rise to systematics to the measurement
- Unfolding

small

Error from Energy Scale





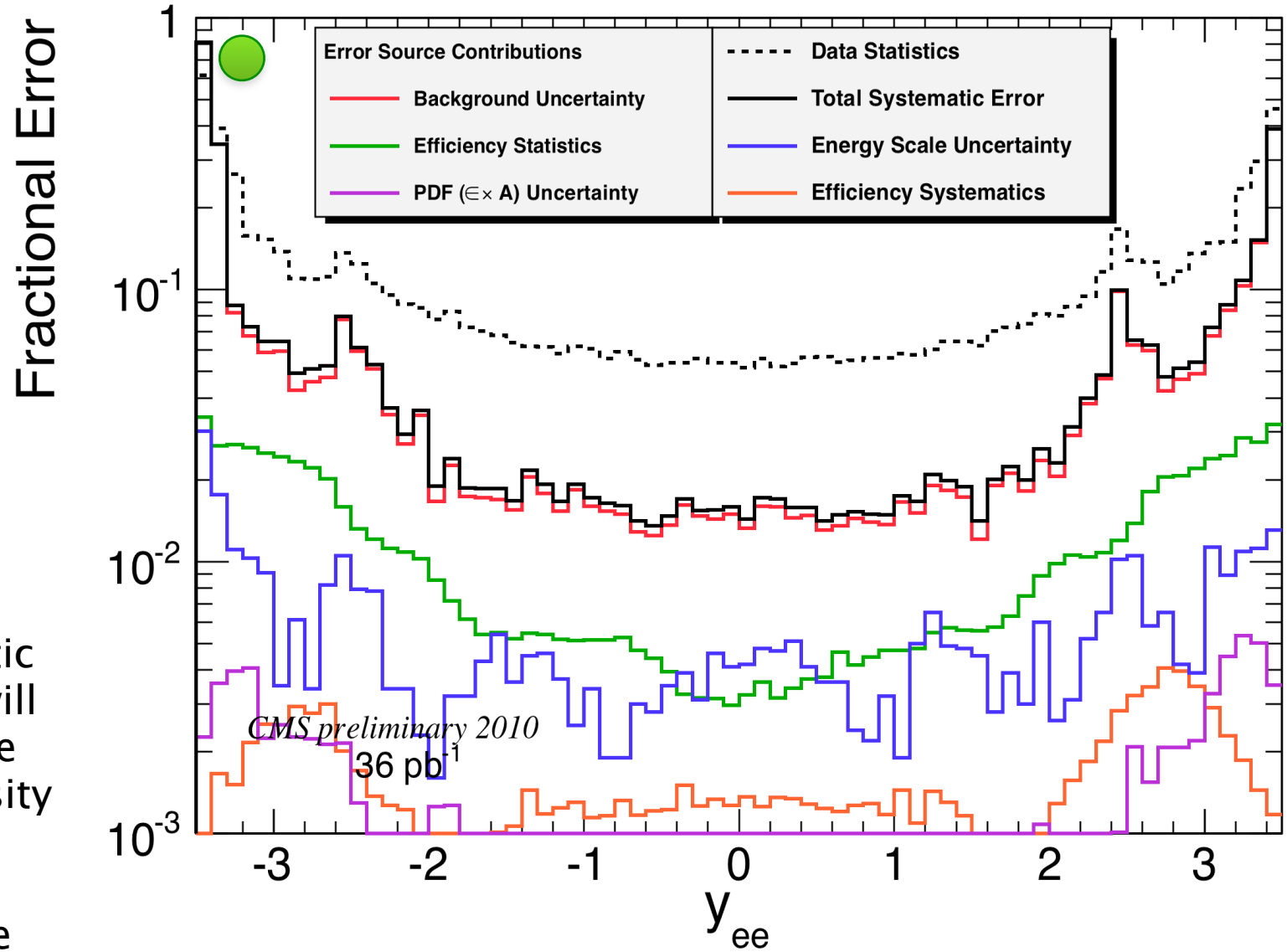
Two sources of systematatic:

- Vary energy scale: ± 1% EB, ± 3% EE, ±10% HF
- Vary local energy scale to account for uncertainty in transparency corrections:

  EB : ± |eta|*0.13%

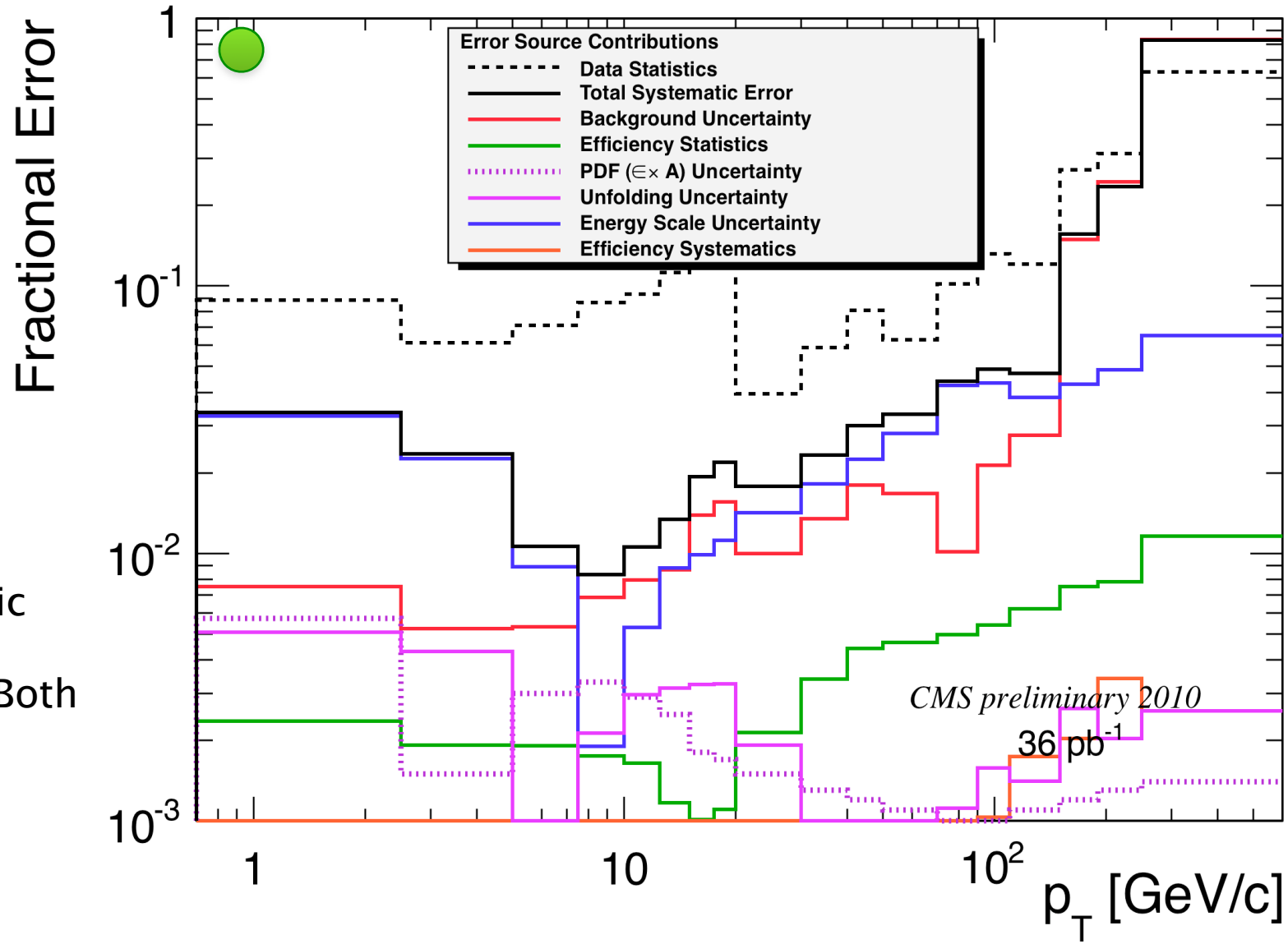
  EE : ±2% ± |eta|*1.5%

All Errors for Y Analysis



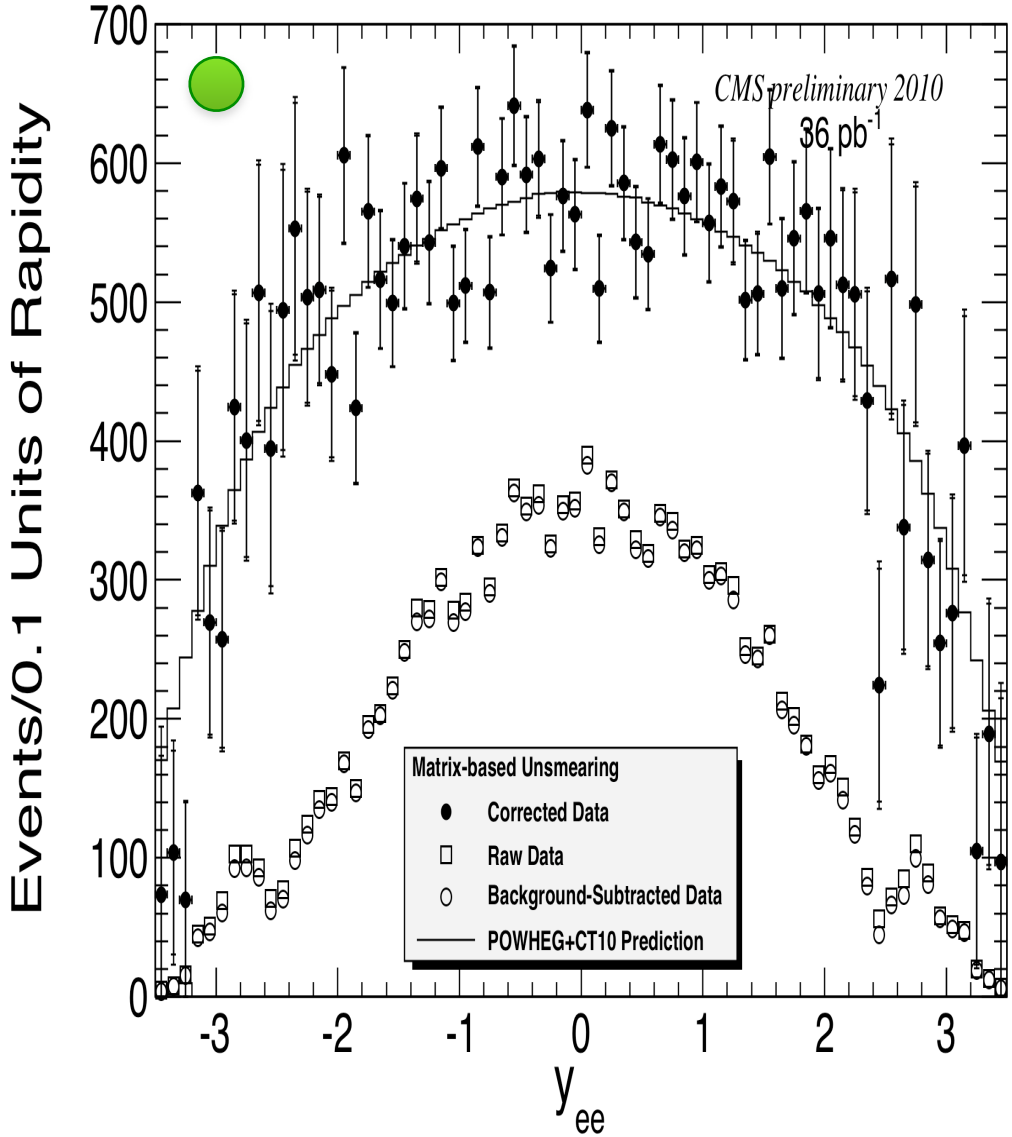
- Data statistics largest error
- Leading systematic from BKG, which will decrease with more integrated luminosity
- Impact of PDF errors: same recipe as muon analysis

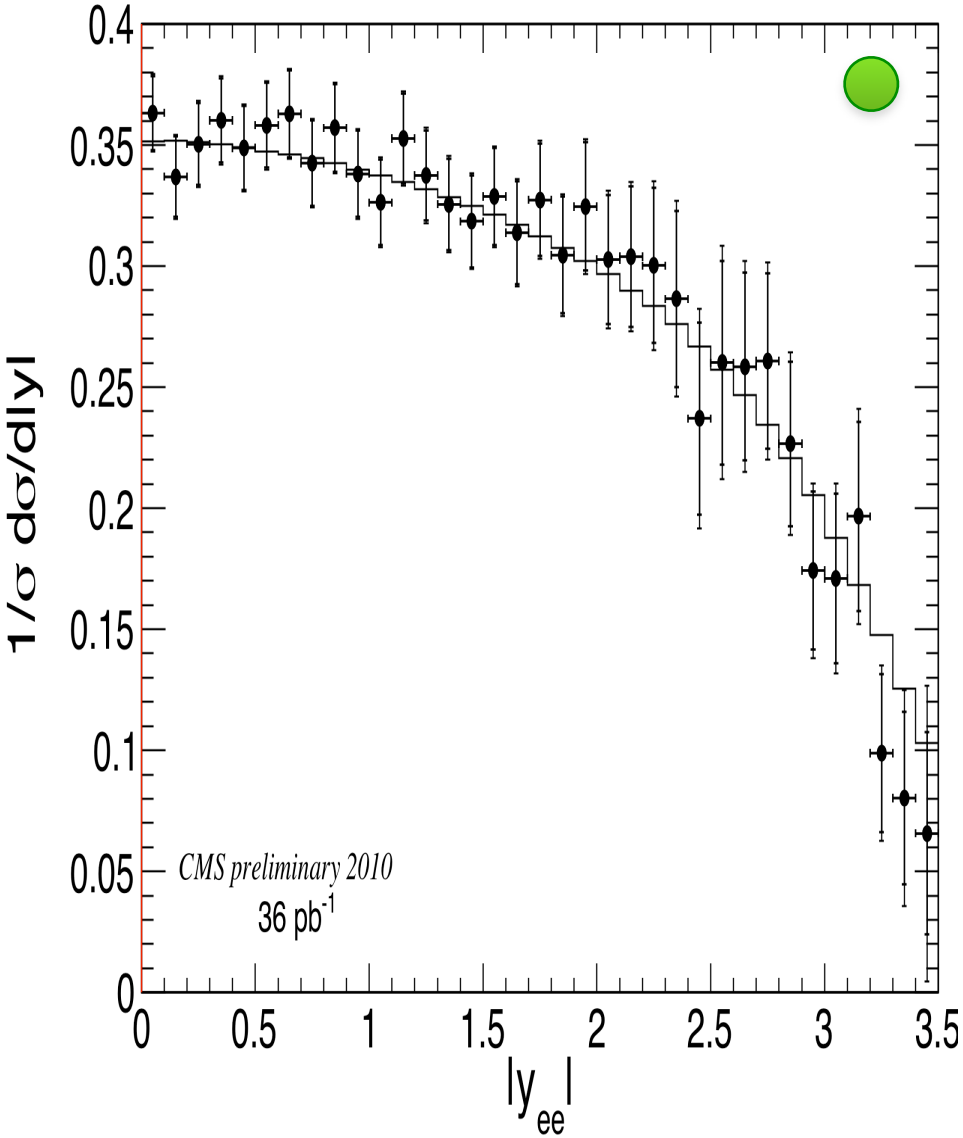
All Errors for P_T Analysis



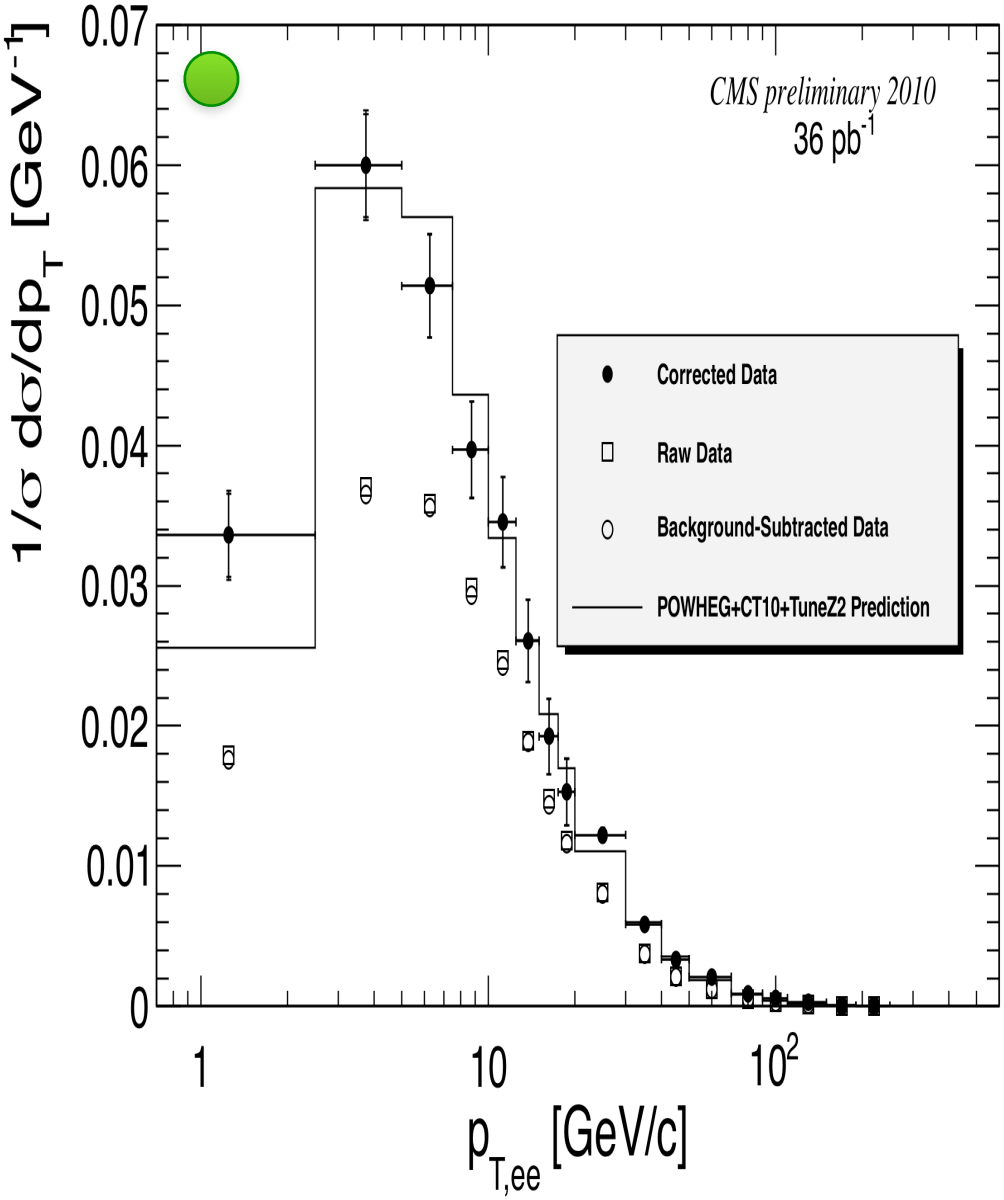
- Data statistics largest error
- Largest systematic from Energy Scale and Background. Both will decrease with more integrated luminosity
- Impact of PDF errors: same recipe as muon analysis

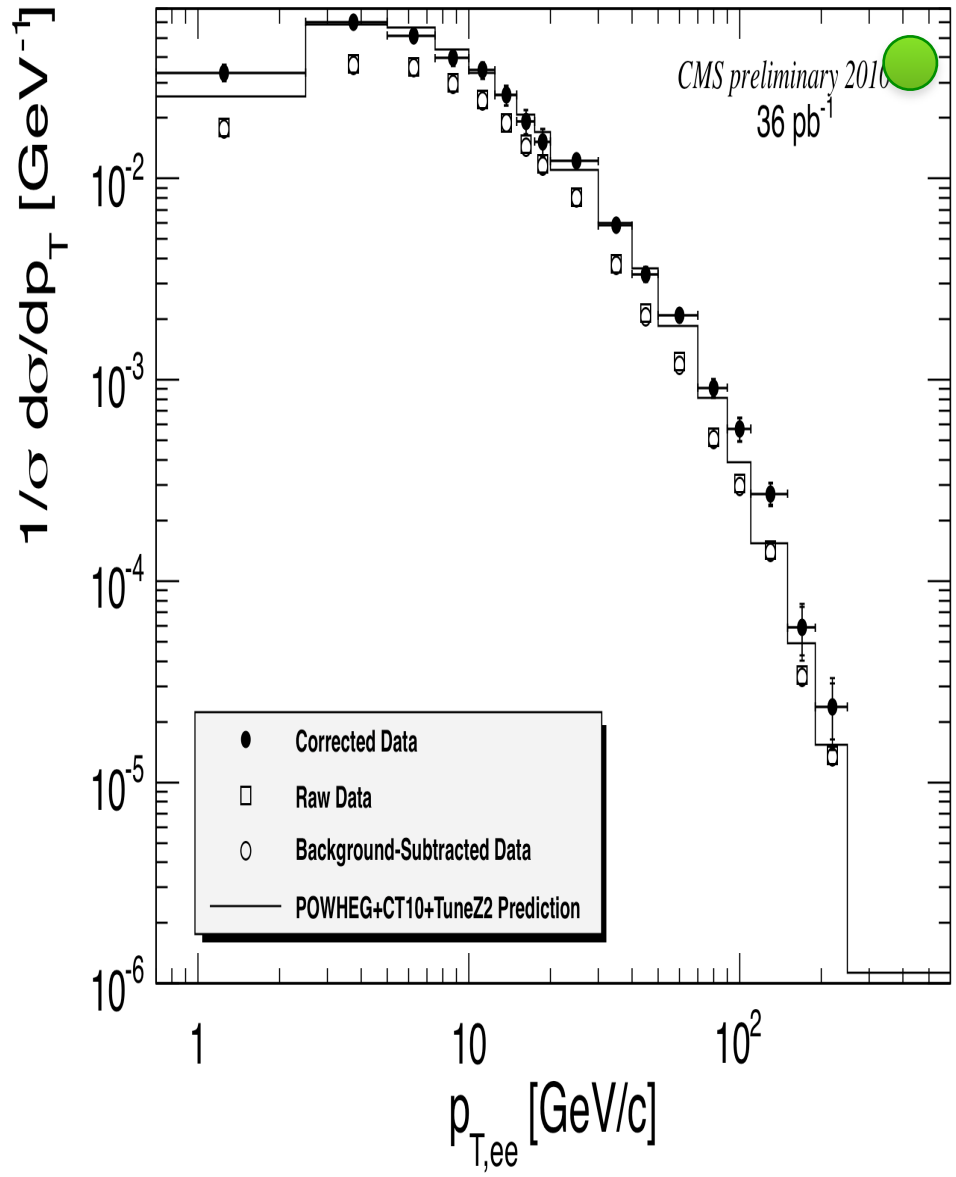
Result for Y and |Y| with 36 pb^{-1}





The Final Result for P_T with 36 pb^{-1}





The combined measurement
EWK-10-010

Measurement of Differential Cross Sections for Z Bosons at $\sqrt{(s)} = 7TeV$

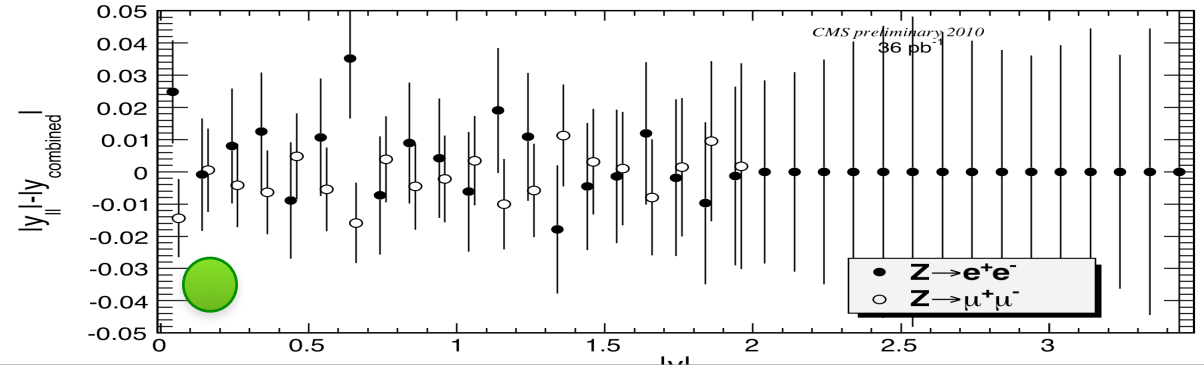
Combination of electron muon results

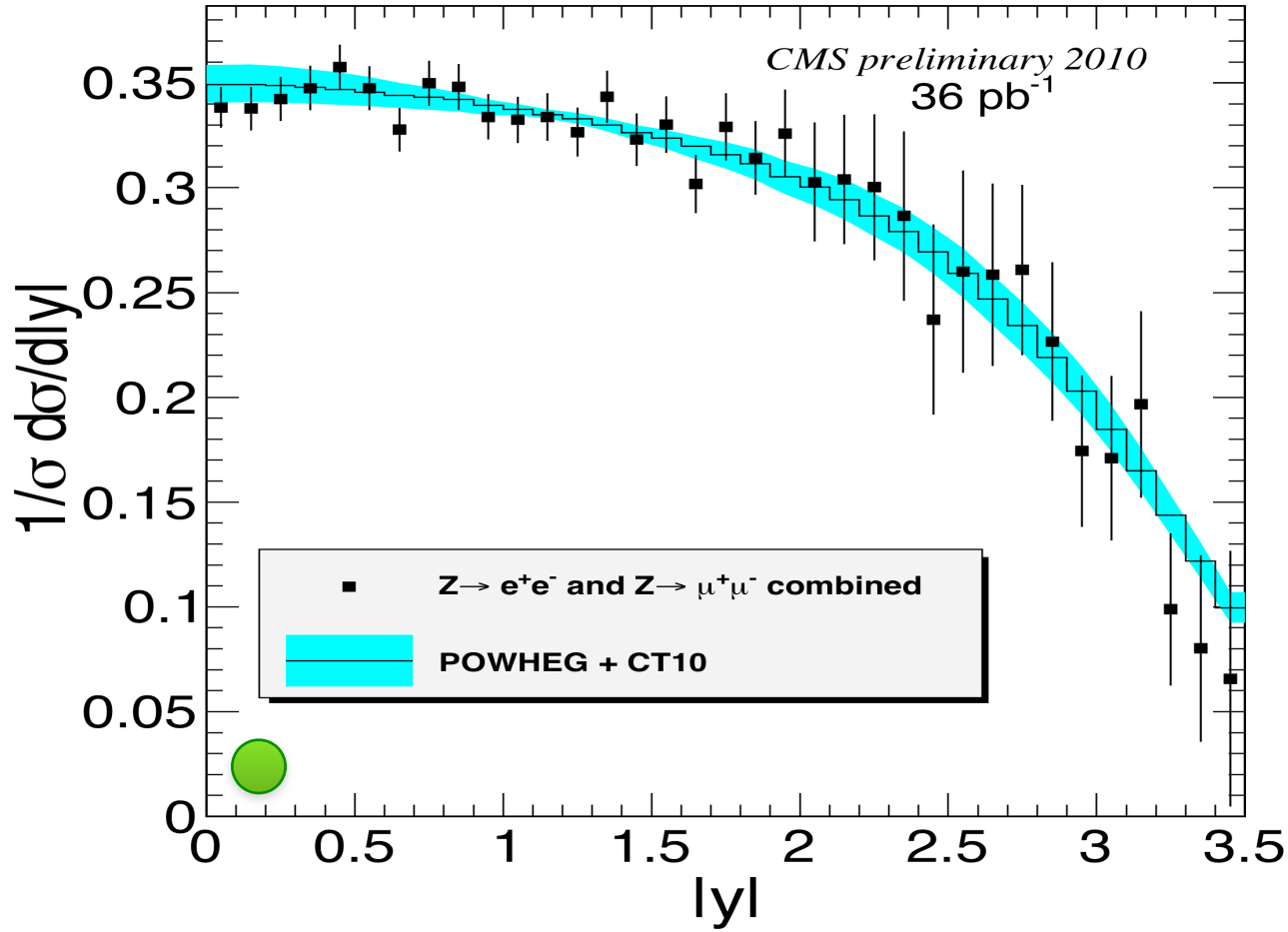
- Results from the electron and muon channels are combined, where both available

- Combination weighted by total errors
- Errors are treated as uncorrelated between the two analyzes
  - PDF errors is the only source of systematic error which is correlated; it's a ***negligible*** (and accounted for only once in the combination)

Combined dσ/dY

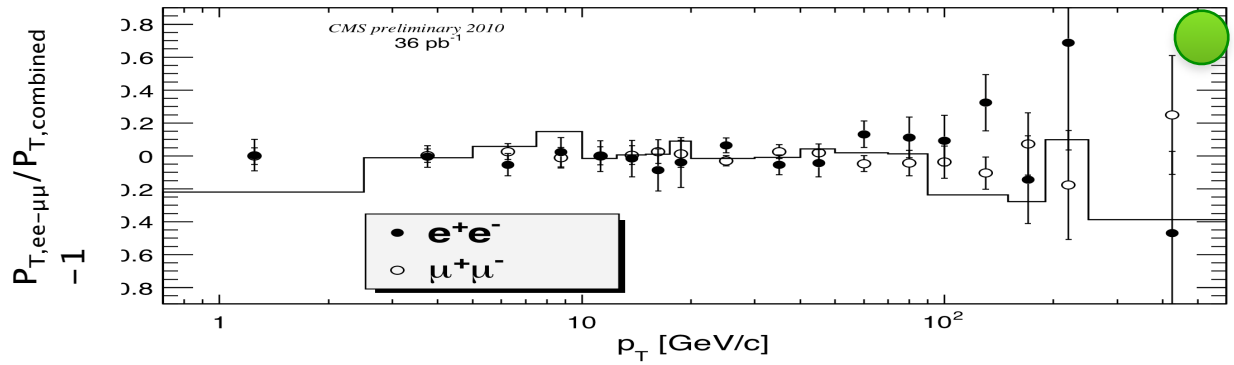
- **dσ/dY** has sensitivity to the parton distribution functions
- Electron and muon measurements agree in joint coverage |Y|<2.1
- Blue band is the ***theory uncertainty*** from PDF errors
- The combined result is consistent with the prediction from:
  - POWHEG
  - CT10w PDF





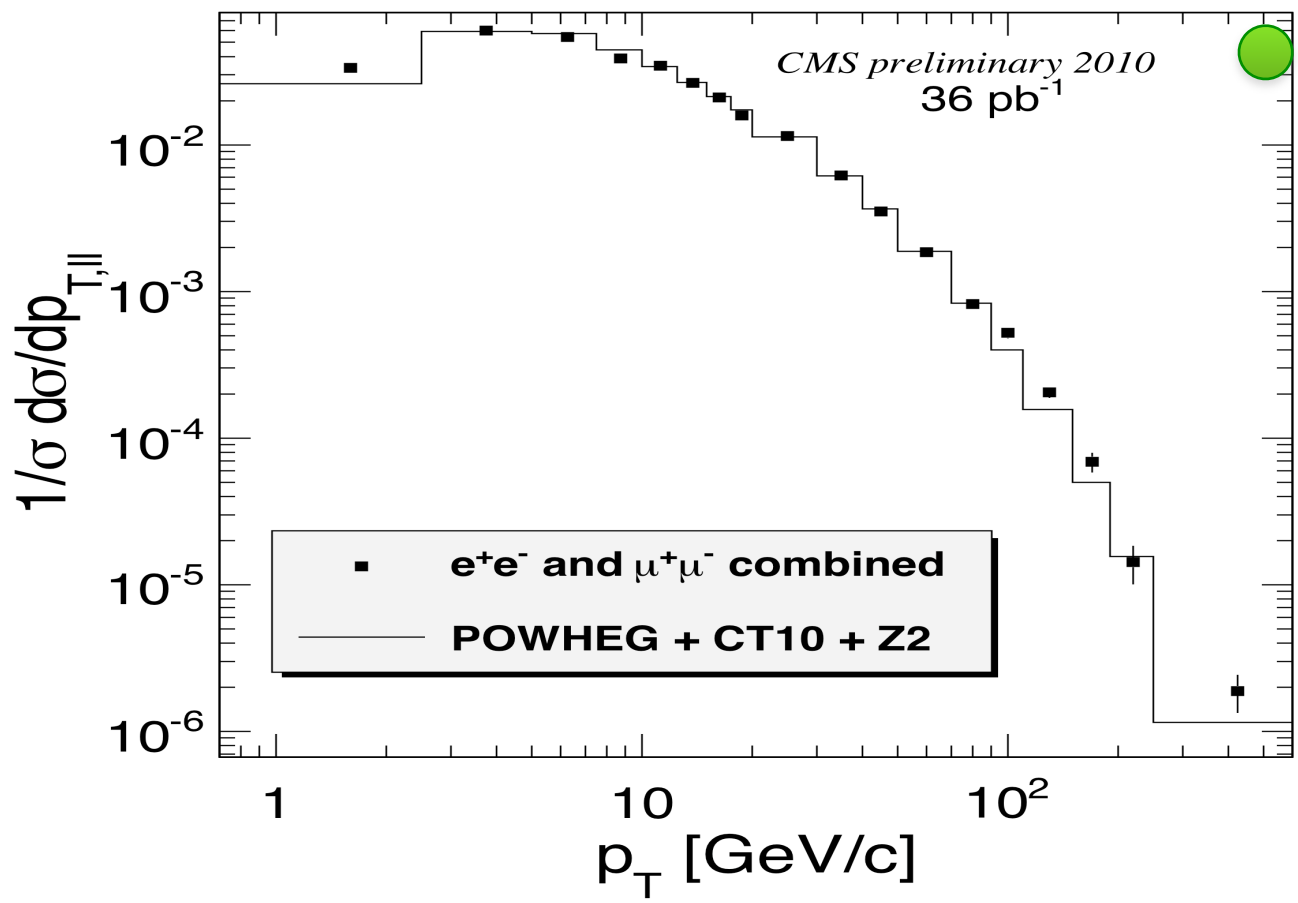
Combined $d\sigma/dP_T$

- Electron and muon measurements agree within the uncertainty, throughout the P_T range covered

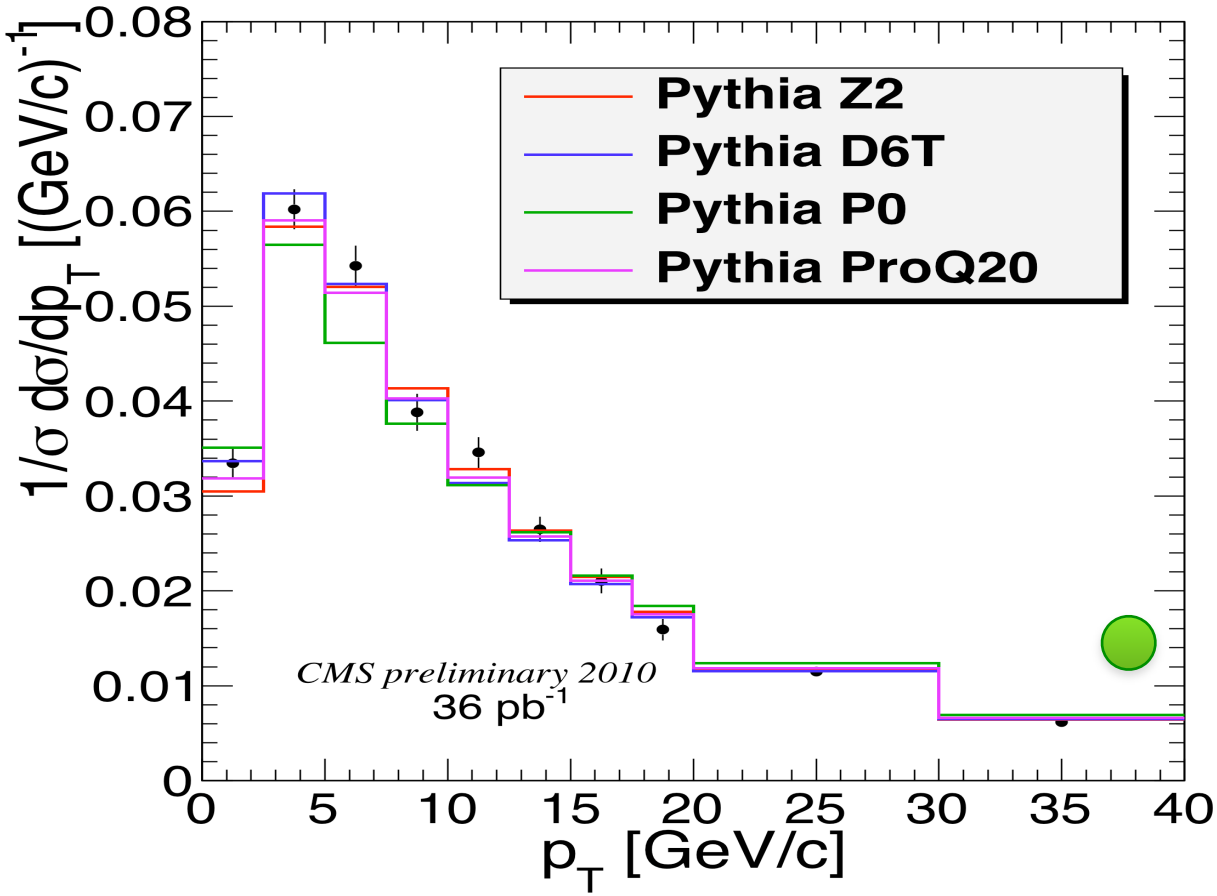


- Deviation of the combined result from the POWHEG +CT10w

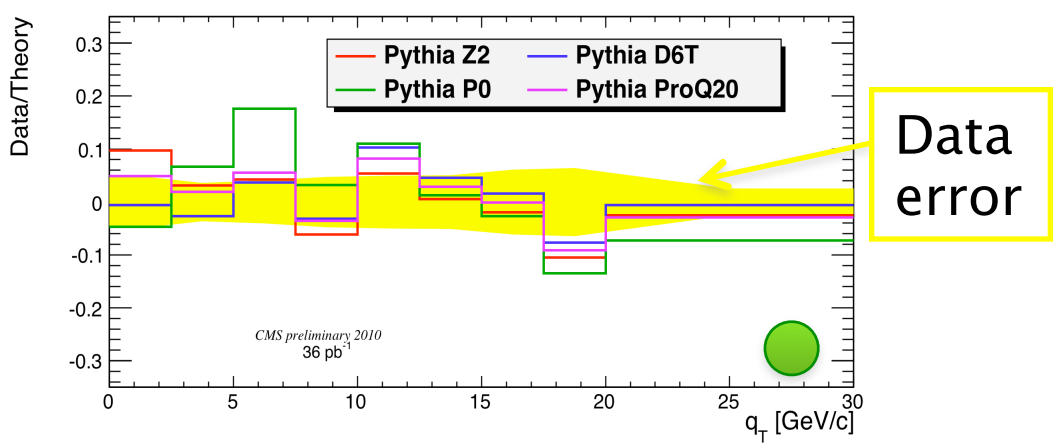
- Identify two P_T ranges:
  - **Low P_T**: non perturbative prediction of soft gluons → MC tunes
  - **High P_T**: QCD gluon radiation in the initial state



Low P_T range: data VS Pythia tunes

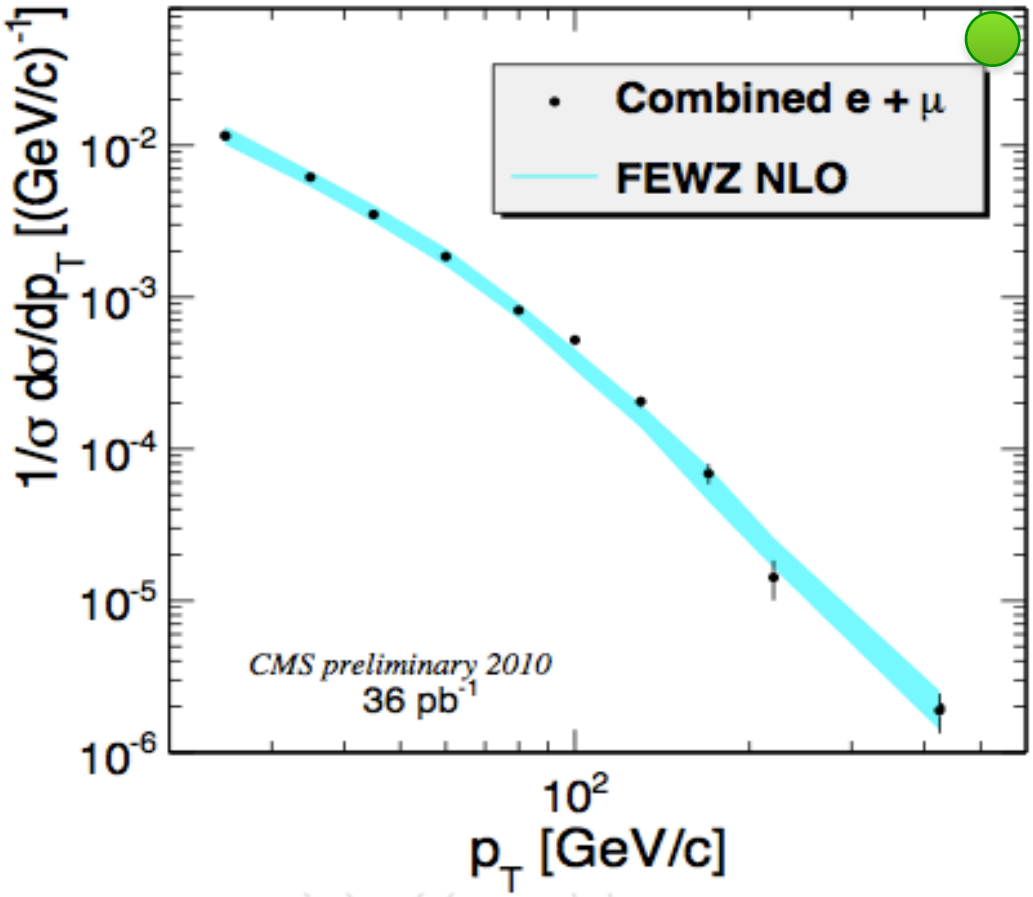


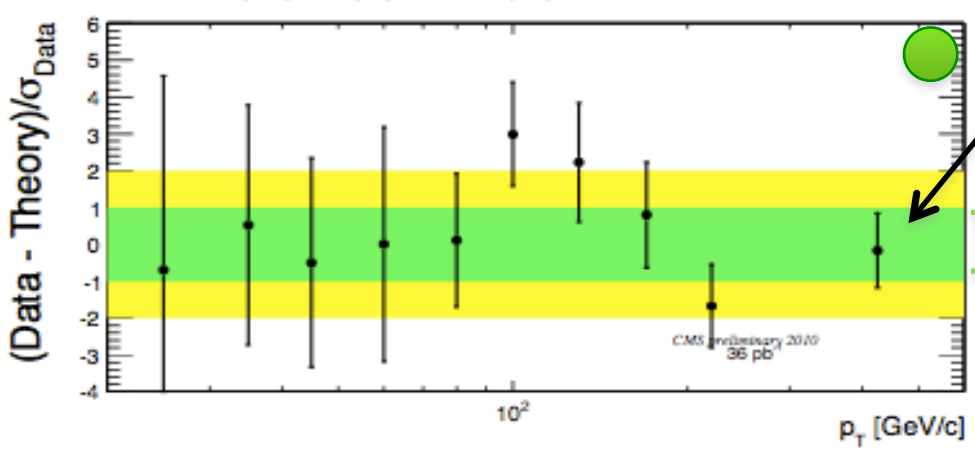
- Using Pythia alone in this study
  - applying different tunes to POWHEG does not significantly affect PT shape
- We observe good agreement for the D6T, ProQ20 and Z2 tunes
- poorer agreement with the P0 tune



Tune	χ^2/ndof	p-value
Z2 [16]	12.3/8	0.138
D6T [17]	7.9/8	0.441
Perugia-0 (P0) [18]	38.0/8	0.00008
ProQ20 [19]	9.9/8	0.272

High P_T range: data VS FEWZ





$1\sigma_{data}$

- For the high end of P_T compare to "Fully Exclusive W,Z Production" (FEWZ)
- Limit comparison to P_T>20 GeV/c and normalized to the total cross section above 20 GeV/c
- Theory error from varying FEWZ renormalization and factorization scales respectively
- Agreement between predictions of FEWZ and the observation within the errors of the data and theory prediction.

Conclusions

Electron channel results

- We performed a **measurement of differential cross section** in Y and P_T of the Z boson in electron channel with 36 pb^{-1} of data
- The largest systematic uncertainties are of statistical nature → will be reduced

Final result: electron + muon

- The muon and electron results are consistent
- POWHEG + CT10w prediction for $d\sigma/dY$ agrees with data
- POWHEG + CT10w prediction for $d\sigma/dP_T$ deviates from data
  - P_T <30 GeV/c : good agreement with D6T, ProQ20 and Z2 tunes.
  - P_T >20 GeV/c : good agreement with FEWZ

Other plots in EWK-10-010 for approval

Smeared dσ/dY result

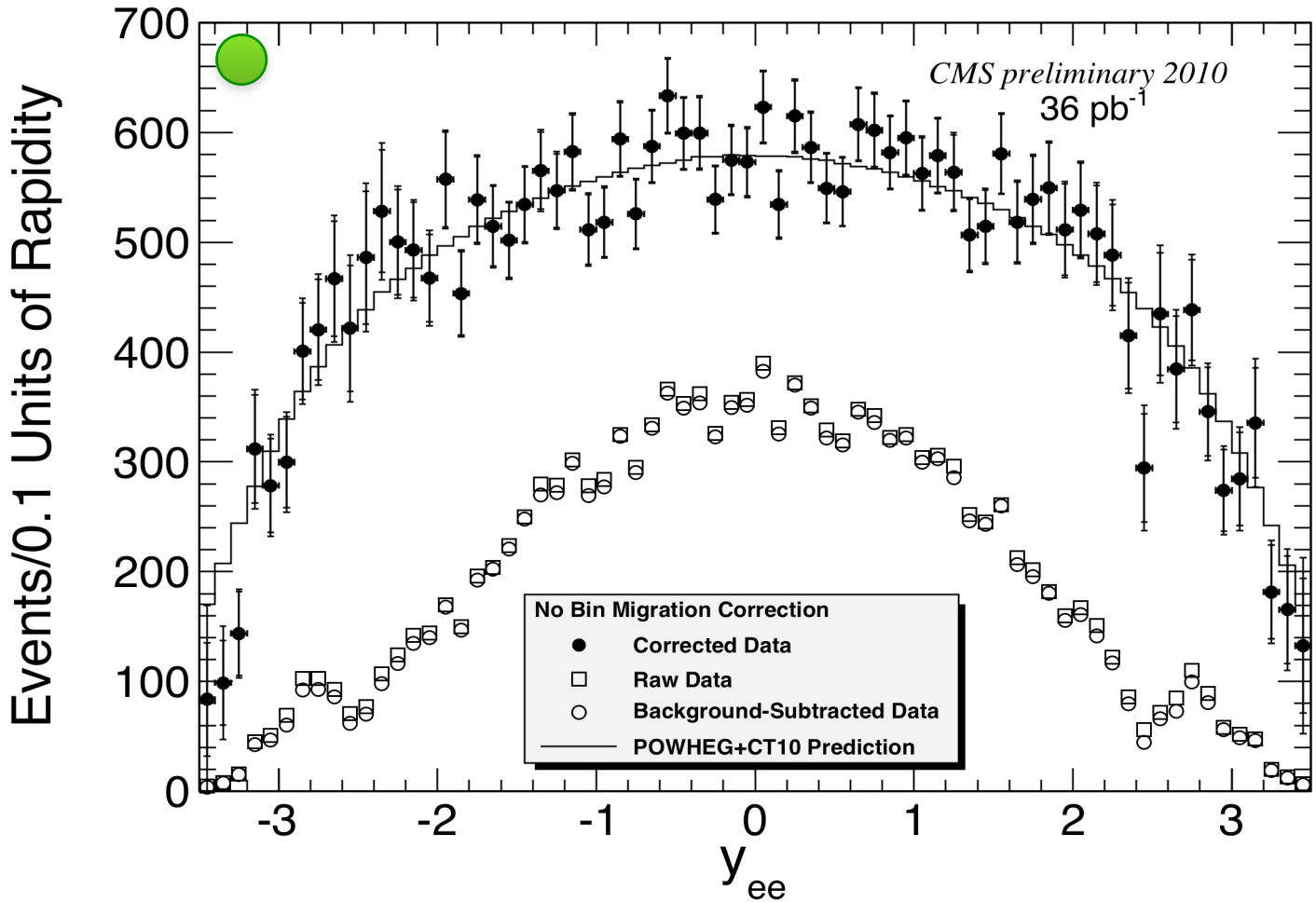


Figure 19: The final results for the rapidity measurement in the electron channel. The raw data distribution is shown with empty squares before background subtraction and empty circles after background subtraction. The data distribution corrected by efficiency and acceptance is shown with full circles. No bin-migration correction is applied in this figure. The errors on the full circles are shown for statistical uncertainties and statistical+systematic separately. The smeared prediction of POWHEG and CT10w PDF is shown for comparison.

THE END

BACK-UP

Data for the Analyses

- 2010 dataset:

Dataset	Integrated Luminosity [pb^{-1}]
/EG/Run2010A-Dec22ReReco_v1/RECO	3.2
/Electron/Run2010B-Dec22ReReco_v1/RECO	33.0

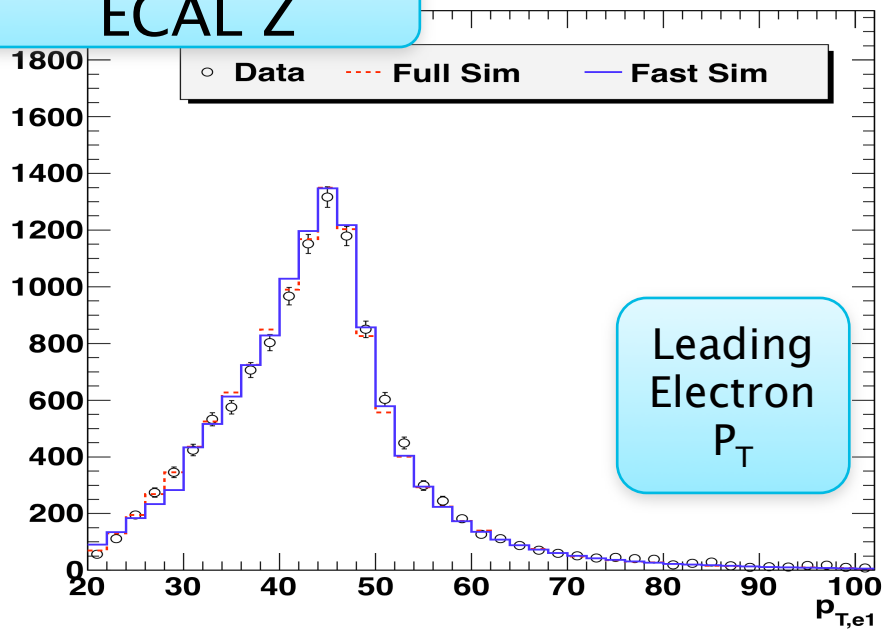
- Monte Carlo datasets:

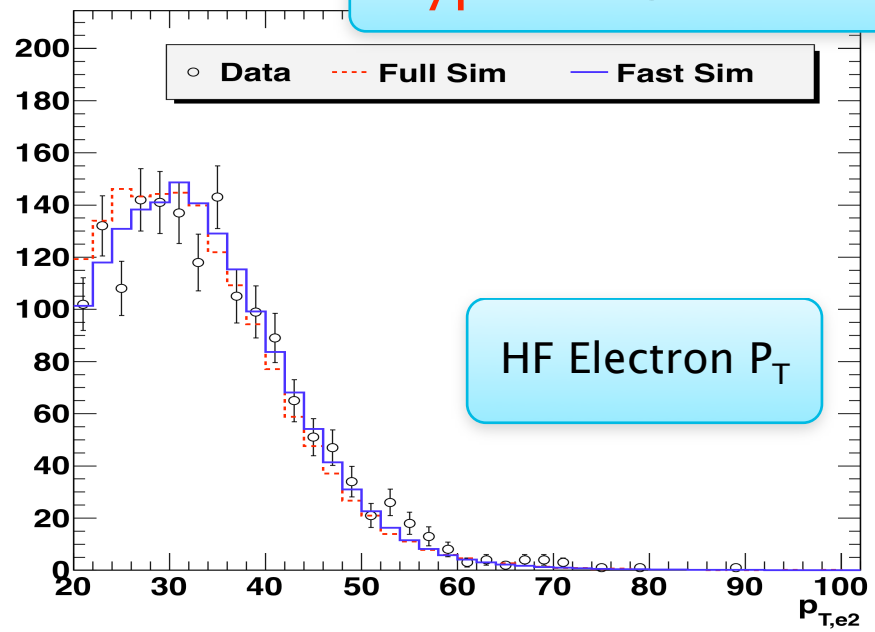
Process	Dataset	Events	Cross-section
$t\bar{t}$	/TTJets_TuneZ2_7TeV-madgraph-tauola/Fall10-START38_V12-v3/GEN-SIM-RECO	1164732	167 ± 24 pb
$Z \to \tau^+\tau^-$	/DYToTauTau_M-20_TuneZ2_7TeV-pythia6-tauola/Fall10-START38_V12-v1/GEN-SIM-RECO	2057446	1300 pb
$pp \to WW-$	/WWtoAnything_TuneZ2_7TeV-pythia6-tauola/Fall10-START38_V12-v1/GEN-SIM-RECO	1981760	27.79 pb
$pp \to WZ$	/WZtoAnything_TuneZ2_7TeV-pythia6-tauola/Fall10-START38_V12-v1/GEN-SIM-RECO	1954752	10.4 pb
$pp \to ZZ$	/ZZtoAnything_TuneZ2_7TeV-pythia6-tauola/Fall10-START38_V12-v1/GEN-SIM-RECO	2073368	4.3 pb

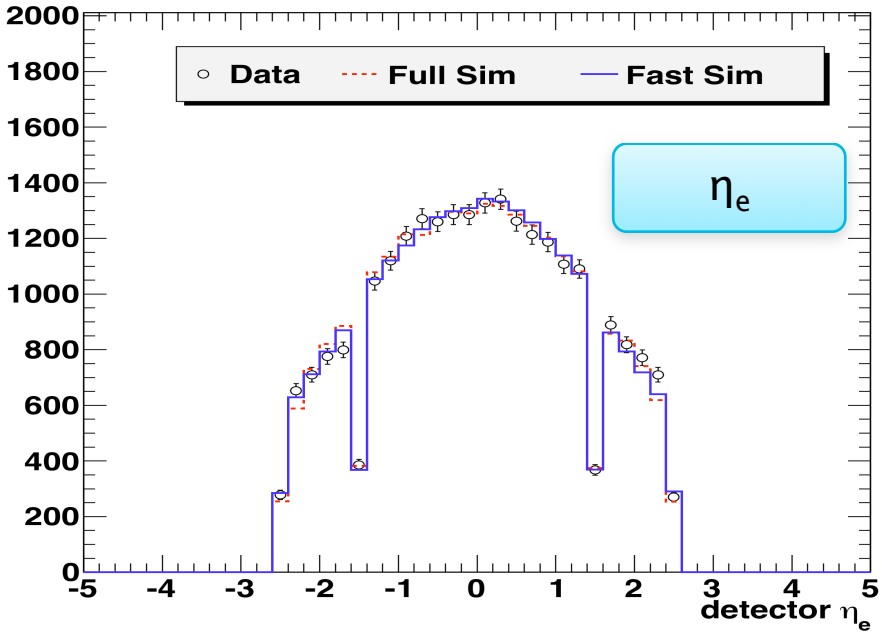
Consistency between smeared MC, full MC and data

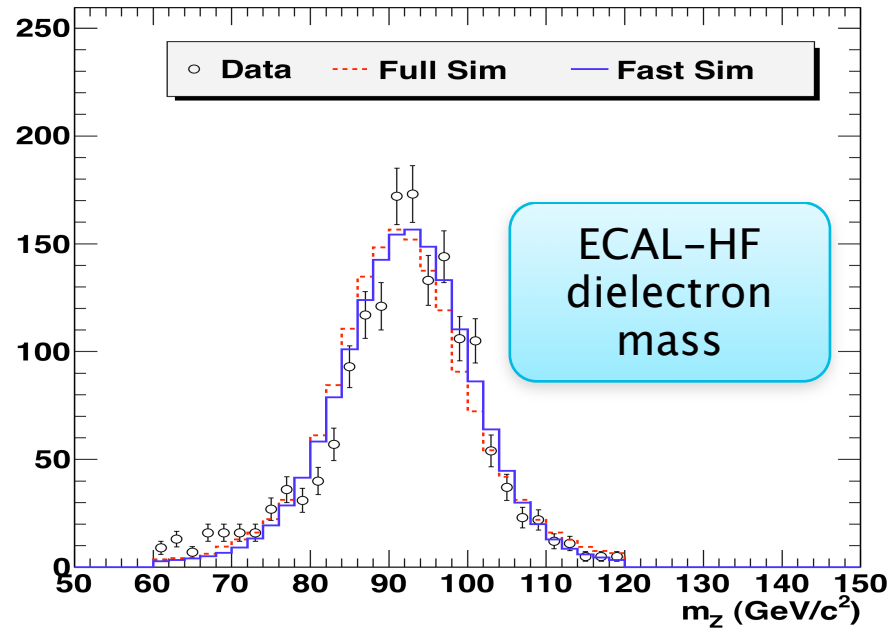
Type 1 ECAL-ECAL Z

Type 2 ECAL-HF Z

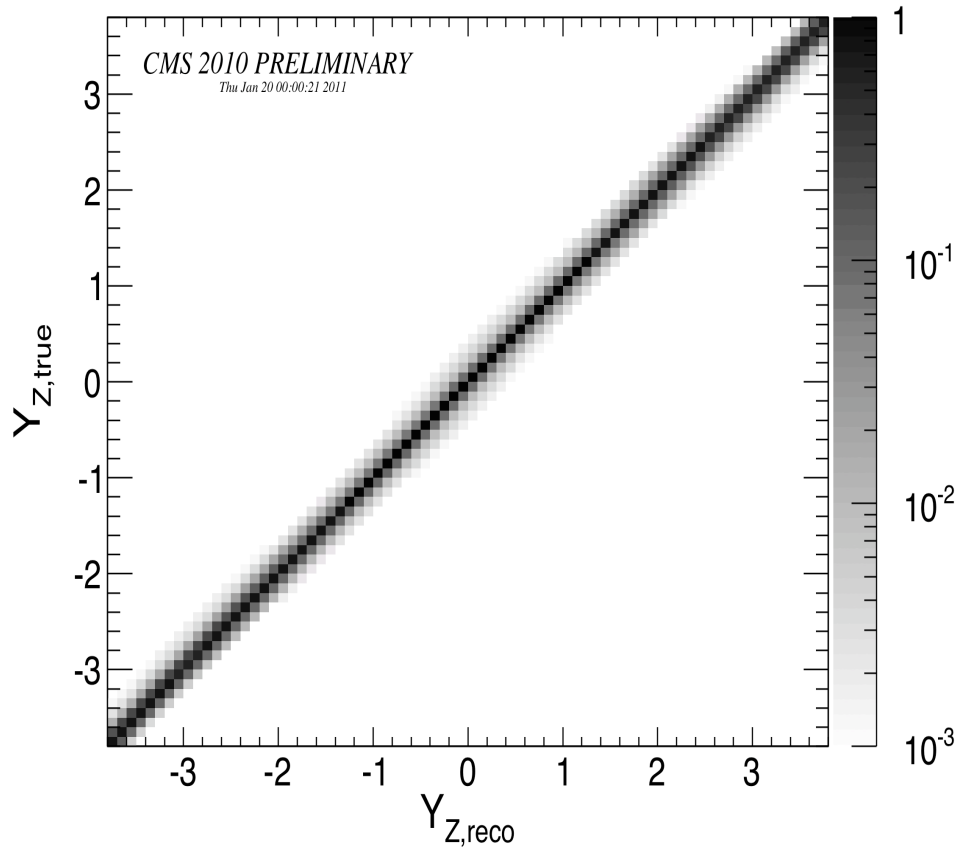


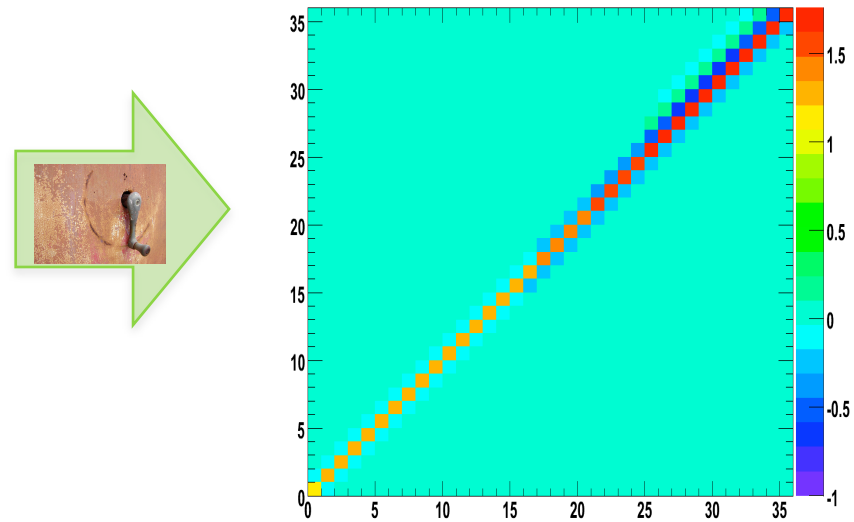






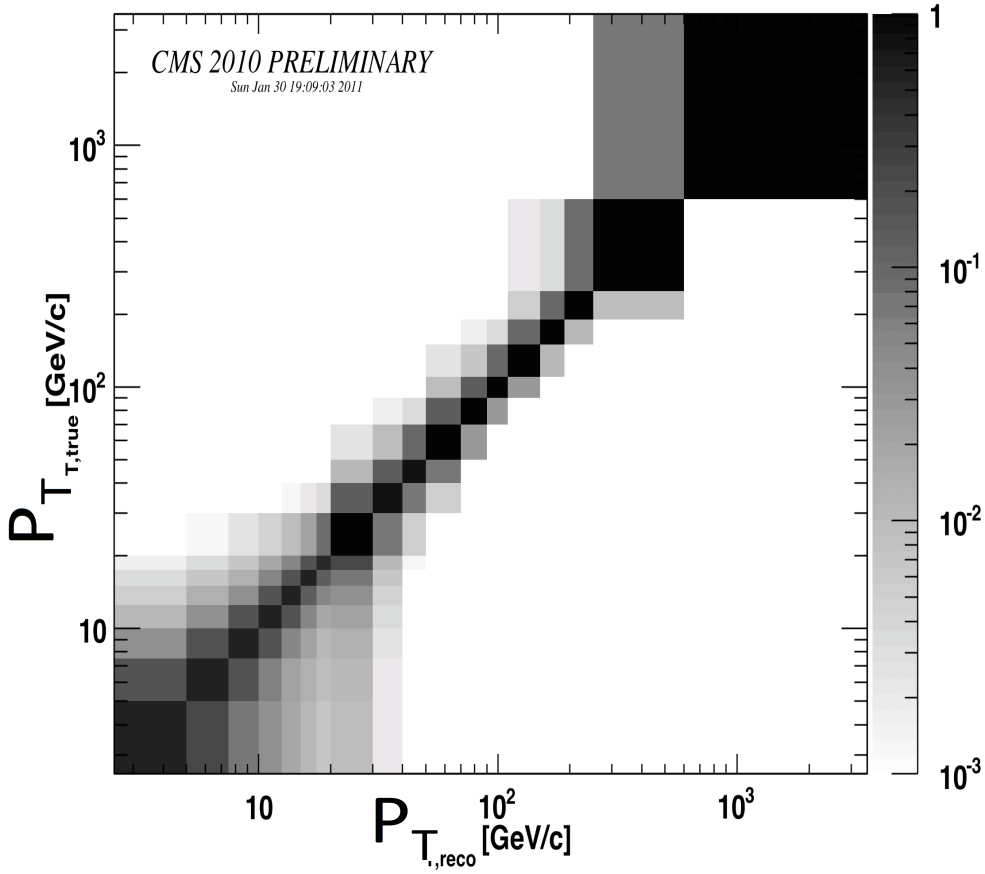
Bin migration and unfolding for Y

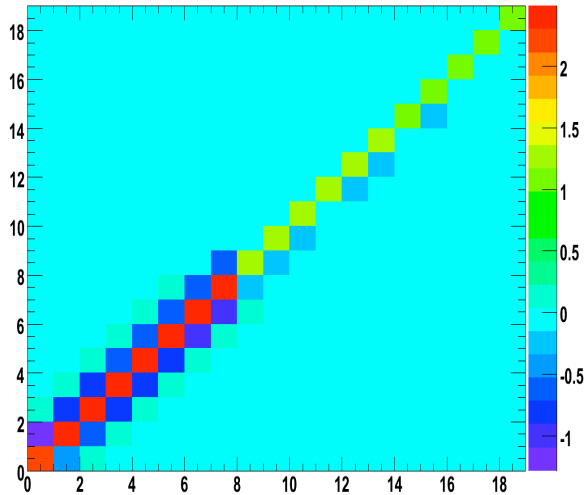




- X_{ee}^{meas} is not necessarily equal to X_{ee}^{true} , due to physics (Final State Radiation) and detector effects.
- Migration matrix obtained implemented in fast Monte Carlo
- Unfolding matrix obtained by inversion. Note: quadratic sum of elements in a row/column systematically larger than one

Bin migration and unfolding for P_T





- X_{ee}^{meas} is not necessarily equal to X_{ee}^{true} , due to physics (Final State Radiation) and detector effects.
- Migration matrix obtained implemented in fast Monte Carlo
- Unfolding matrix obtained by inversion. Note: quadratic sum of elements in a row/column systematically larger than one

Factorization of Single Electron

- Offline electron efficiency can be factorized due to several contributions:

$$\varepsilon_{offline} = \left[\frac{N(Superclusters)}{N(Electrons)}\right]^{MC} \times \left[\frac{N(TrackMatched)}{N(Superclusters)}\right]^{data} \times \left[\frac{N(WP80)}{N(TrackMatched)}\right]^{data}$$

- HLT efficiency is measured w.r.t. offline:

$$\varepsilon_{full} = \varepsilon_{offline} \times \left[\frac{N(L1+HLT)}{N(offline)}\right]^{data}$$

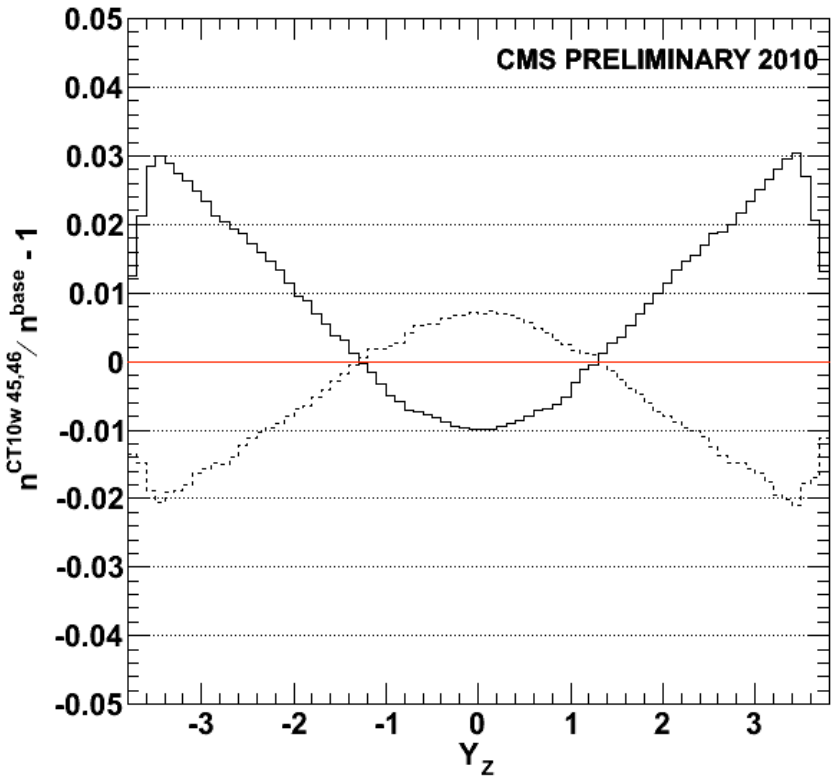
- For HF there is no trigger nor track requirement:

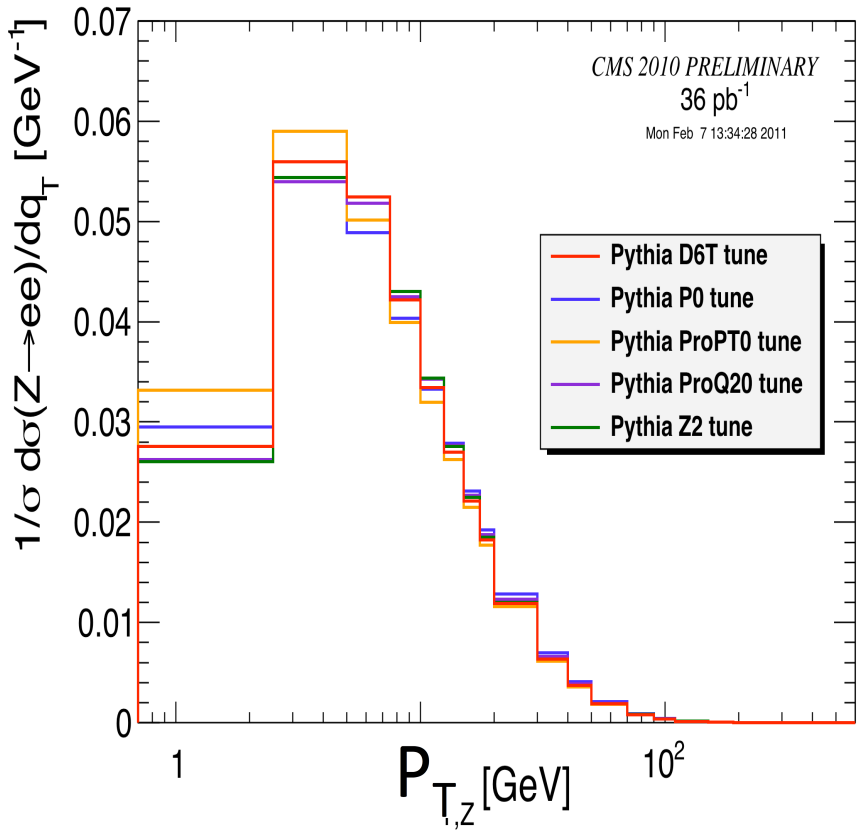
$$\varepsilon_{hf} = \left[\frac{N(HFClusters)}{N(Electrons)}\right]^{MC} \times \left[\frac{N(HLTElectronID)}{N(HFClusters)}\right]^{data}$$

Review of physics output

- **dσ/dY** has sensitivity to the parton distribution functions
- rapidity measurement dominated by events with small P_T

- **$d\sigma/dP_T$** has sensitivity sensitivity to:
  - **low P_T** : soft gluons, non perturbative QCD → underlying event tune
  - **high P_T** : QCD gluon radiation

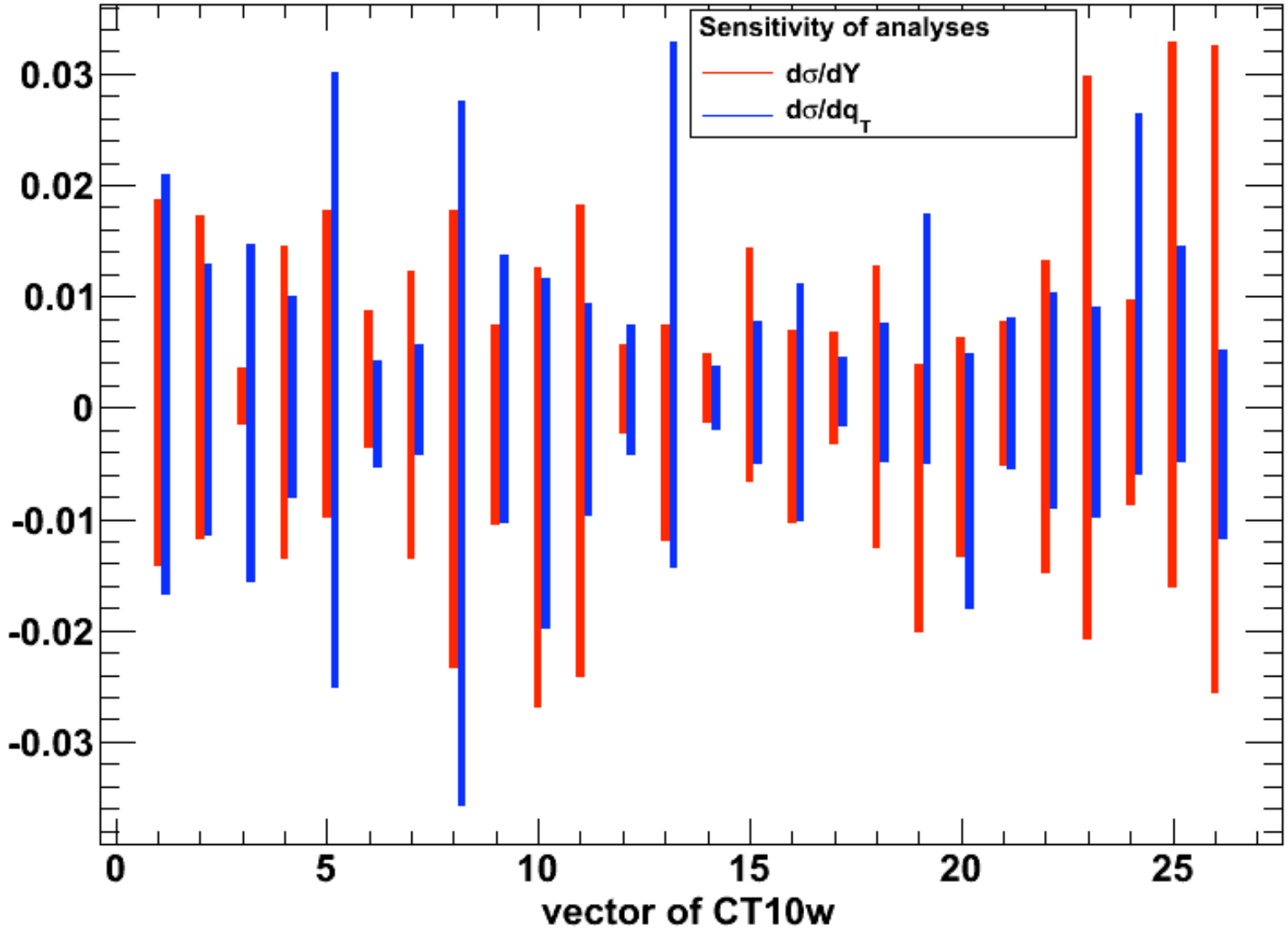




Sensitivities of Y and P_T Analyses to

As expected: Y and P_T analyses have different sensitivity to PDF models in CT10w.

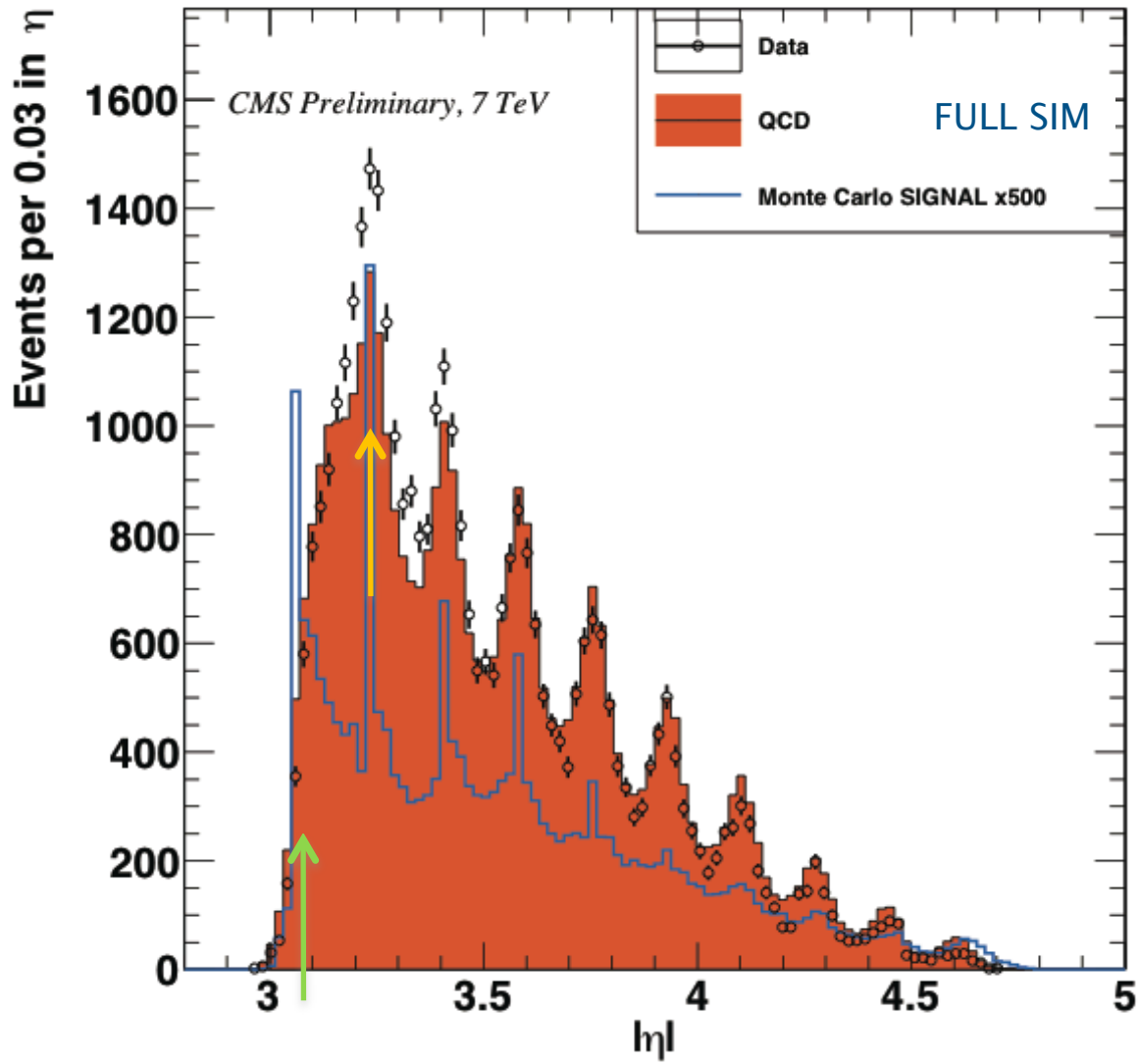
Maximum sensitivity is about 3%.



ARC: cross check efficiencies high |Y|

My main concern is on the deconvolution in the Y electron analysis in the ECAL EE and HF transition region |eta|~2.5 where we see in Fig5b a structure indicating poor acceptance+unsmearing correction in this region as the structure is also present in the raw data (Fig. 14 of the AN 2010/367). This could be due to too poor knowledge of the reco efficiency in the HF, Fig. 2f of the AN 2010/367 where possibly

- RECO feature gives signal excess $3.05<|\eta|<3.08$
- Equally present in fast and FULL simulation
- Not of immediate solution
- → restrict acceptance for the measurement to $3.1<|\eta|<4.6$ in order to exclude the problematic region
- Muon punch through generate excess at $|\eta|\approx 3.2$



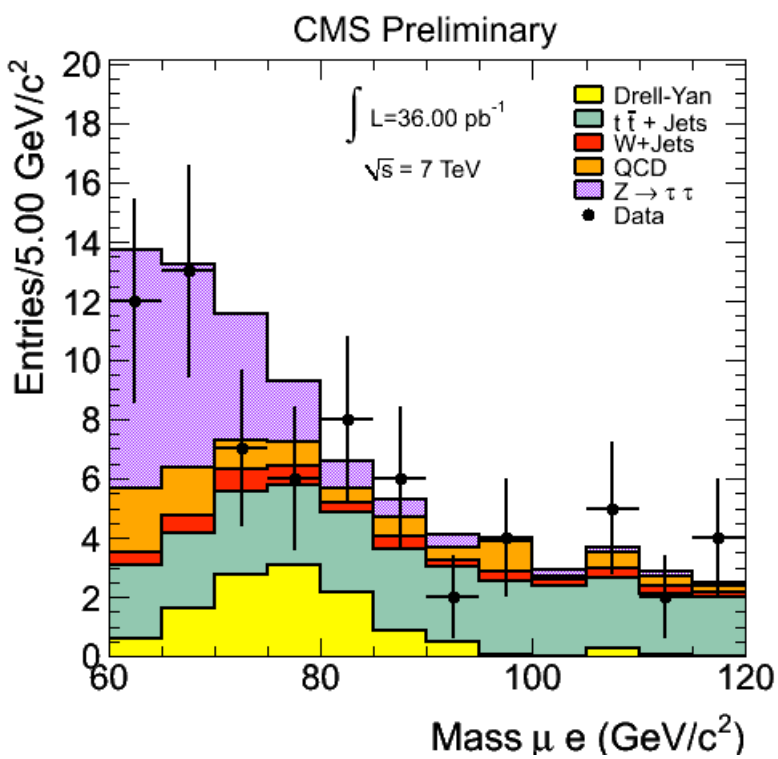
Back-up Slides (muon)

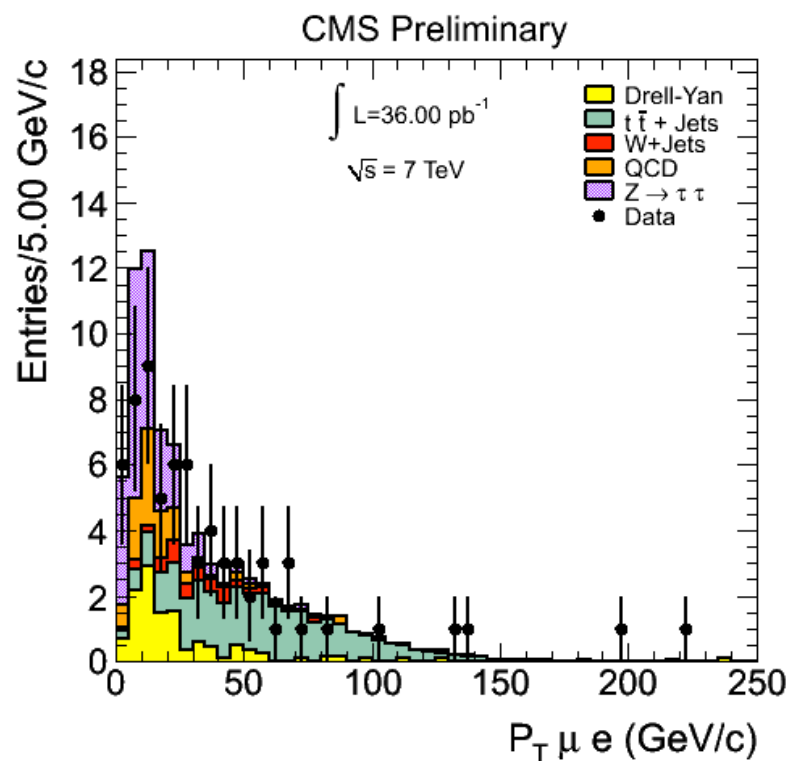
$t\bar{t}$ Background in Data-Driven Method

- $t\bar{t}$ contribution is estimated using a data-driven method
  - The probability of having μμ in the final state is the half of having eμ pair

$$N^{rec}_{\mu^+\mu^-} = \frac{1}{2}\frac{(A\times\epsilon)_{\mu^+\mu^-}}{(A\times\epsilon)_{e^\pm\mu^\mp}}\cdot C\cdot N^{rec}_{e^\pm\mu^\mp}$$

    - The difference between μμ and eμ for the acceptance and efficiency is corrected
    - The fractional contamination of eμ for the final result is also corrected (C)
  - The background measured in the data agrees with MC prediction
    - Data : 18.1 ± 4.3 vs. MC(MadGraph) : 14.7 ± 3.8 in $P_T > 30$ GeV / c





Response Matrix

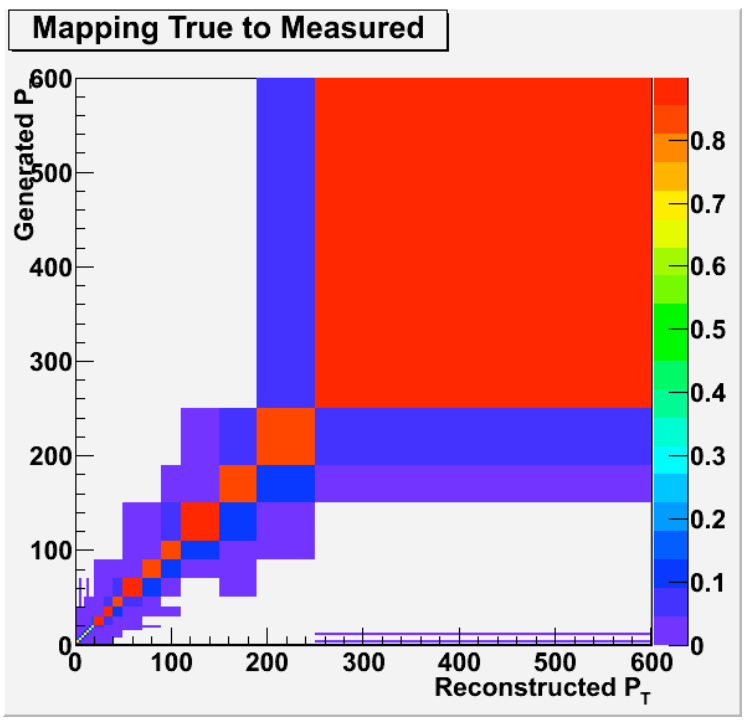
- Response matrix : R_{ij} = P(observed in i | true value in j)
  - Response matrix is used to unfold the detector resolution effect

$$x_j^{measured} = \sum_i R_{ij} x_i^{true} \quad \Rightarrow \quad x_j^{true} = \sum_j R_{ij}^{-1} x_i^{measured}$$

$$\sigma_i^2 = \sum_j (R_{ij}^{-1})^2 x_j^{measured}$$

R_{ij} for $d\sigma/dP_T$:

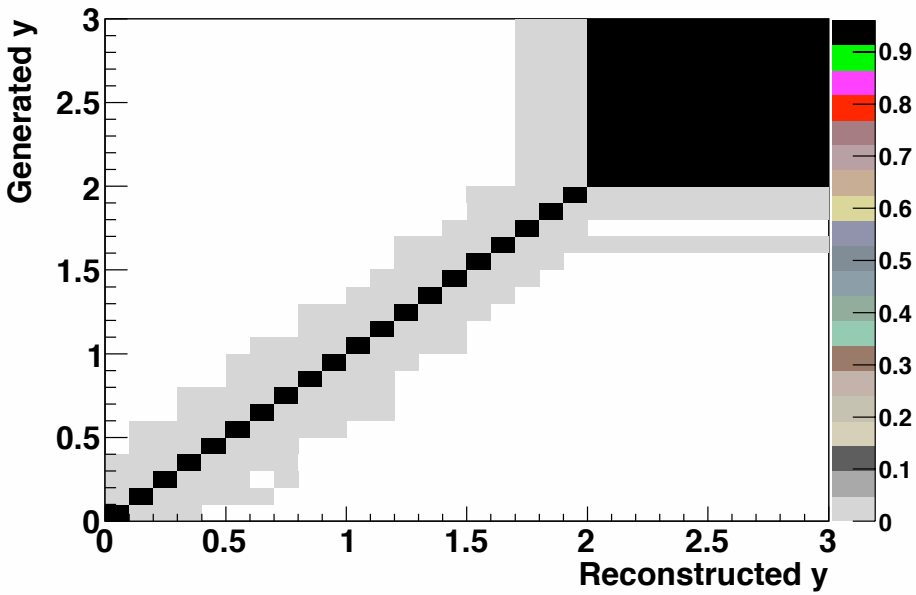
FSR effect considered separately



R_{ij} for $d\sigma/dy$:

Smearing effect is small

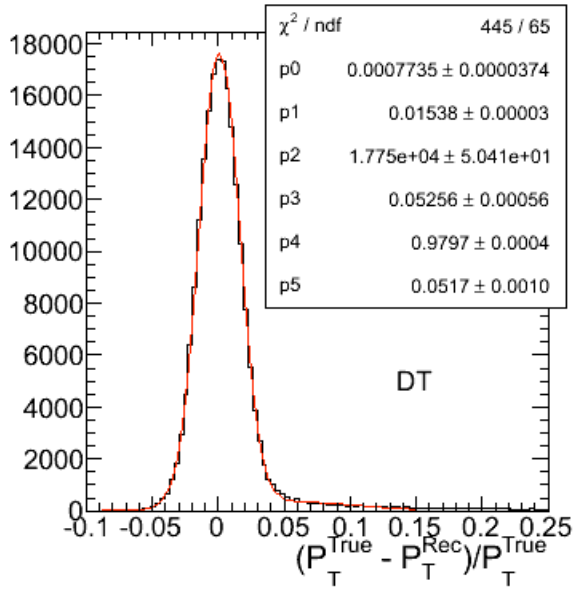
Diagonal term is ~ 93 %

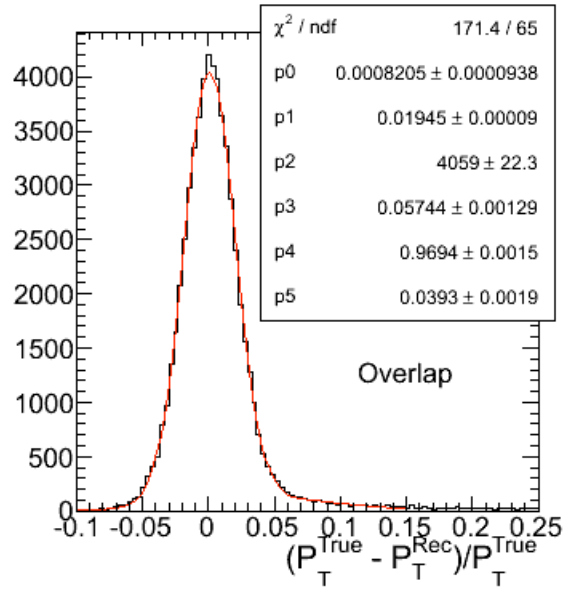


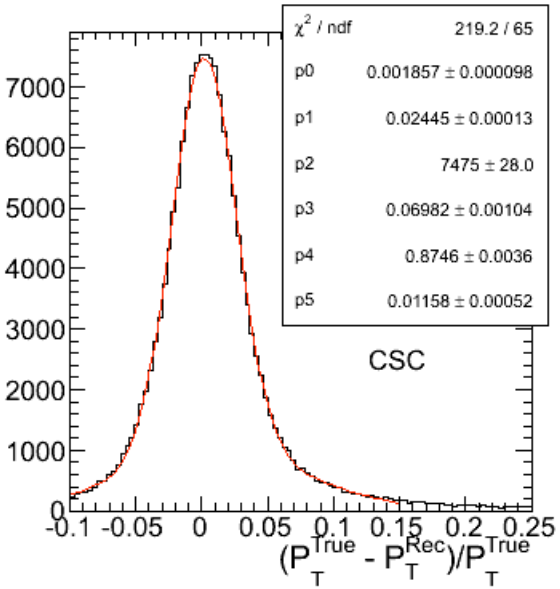
P_T Resolution for $d\sigma/dP_T$

- P_T resolution
  - P_T resolution affects response matrix → important to simulate P_T resolution well
  - P_T resolution is measured in data
  - The measured P_T resolution is applied into MC for $d\sigma/dP_T$ measurement
  - Parameterize the P_T resolution in MC in terms of muon P_T and η
    - P_T : (20 - 40), (40 - 50), and (50 and above) GeV/c
    - η : DT region ($\eta<0.9$), Overlap region ($0.9\leq\eta\leq1.2$), CSC region ($1.2<\eta\leq2.1$)
    - Double gaussian fits are used to describe the tail well
  - The functional form from MC is used to get the resolution in data and MC

$$f(x) = N_0 \times (f_{12} \times G(m_1, \sigma_1) + (1 - f_{12}) \times G(m_2, \sigma_2))$$



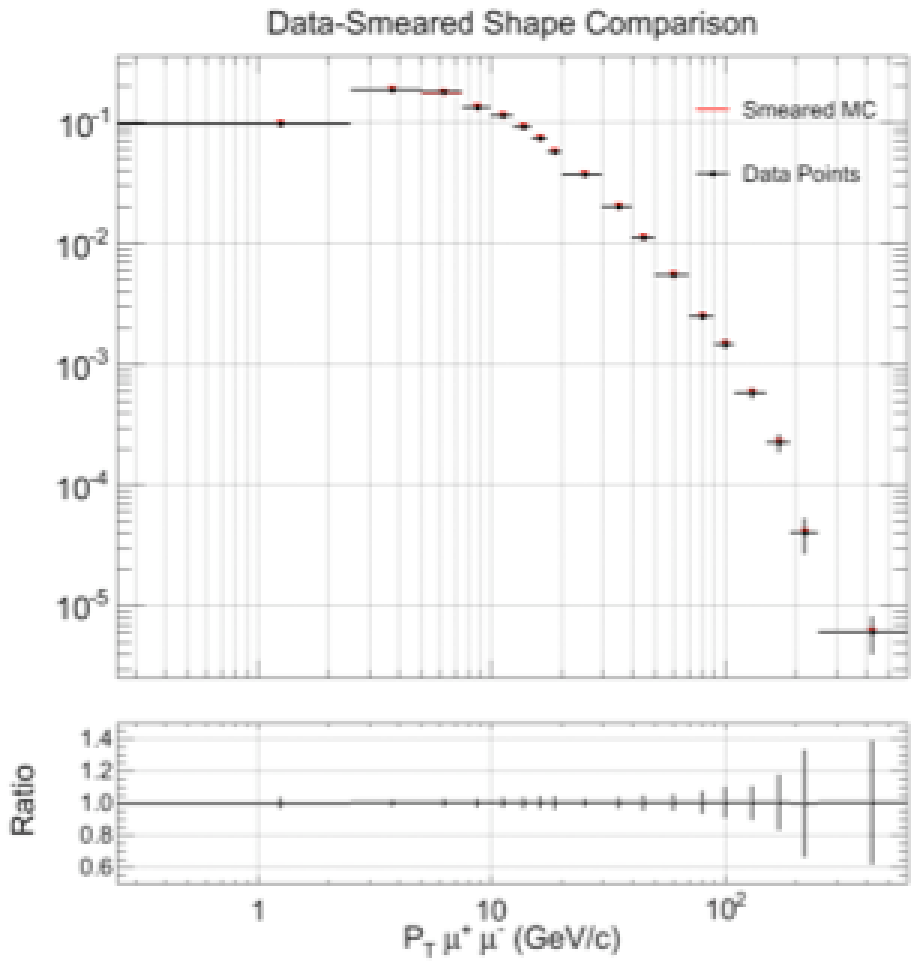




- The fractional muon P_T resolution in data and MC

η Region	Res. from Voigtian, MC (%)	Res. from direct fit, MC (%)	Res. from Voigtian, data (%)
DT	1.487	1.538	1.107
Overlap	1.517	1.945	1.387
CSC	2.629	2.975	2.807

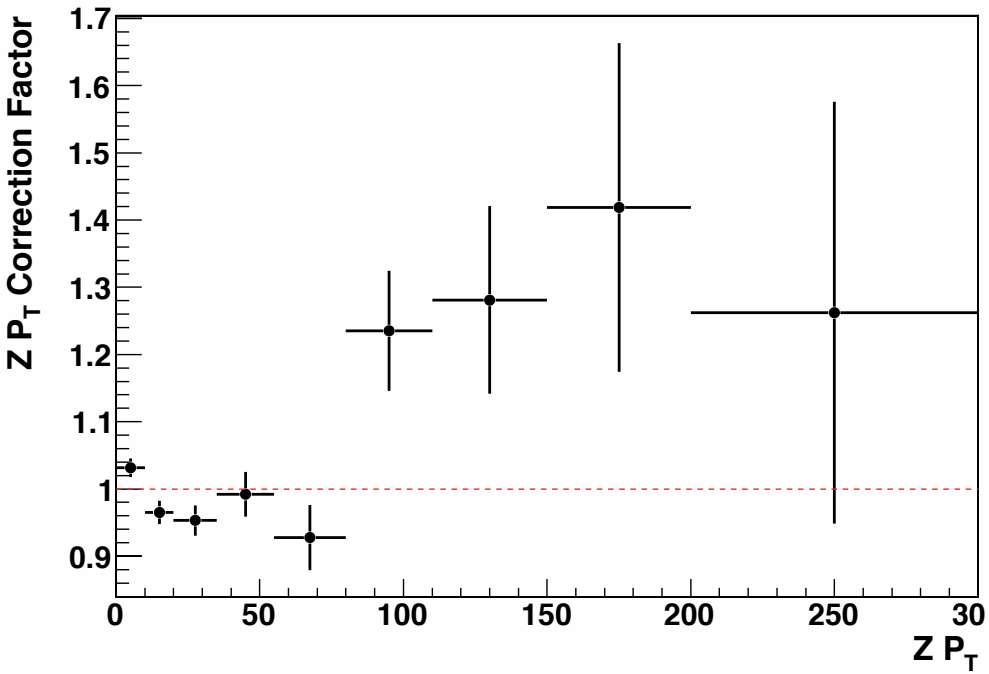
- The ratio (data/MC) of P_T resolution measured from Voigtian fit is applied into MC
- P_T shape comparison
  - After applying the data-driven P_T resolution, P_T shape is compared

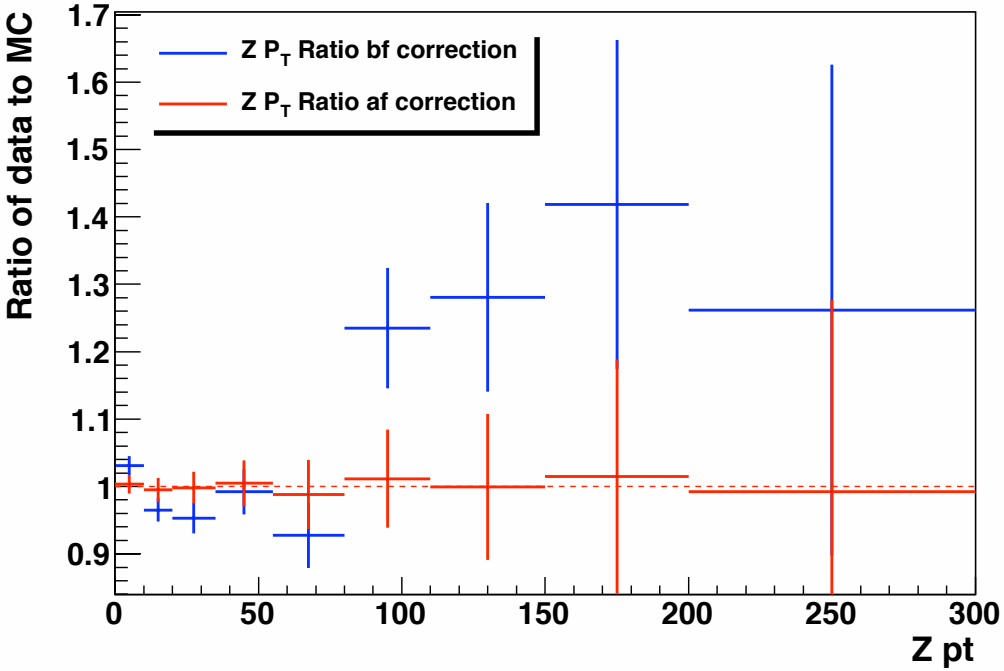


- The tuned MC agrees data well for P_T spectrum
- The response matrix is finally obtained using the tuned MC for P_T resolution

Z P_T Correction for $d\sigma/dy$

- $d\sigma/dy$ measurement is less sensitive for P_T resolution than $d\sigma/dP_T$
- P_T distribution in data and MC
  - Most of kinematic distributions show a good agreement in data and MC
  - P_T distribution shows a discrepancy between data and MC, need to be tuned
  - Estimate the ratio of data to MC in P_T (reconstructed level)
  - Apply the ratio of data to MC as a correction factor in the generated level
- P_T correction factor is included to get the response matrix for $d\sigma/dy$

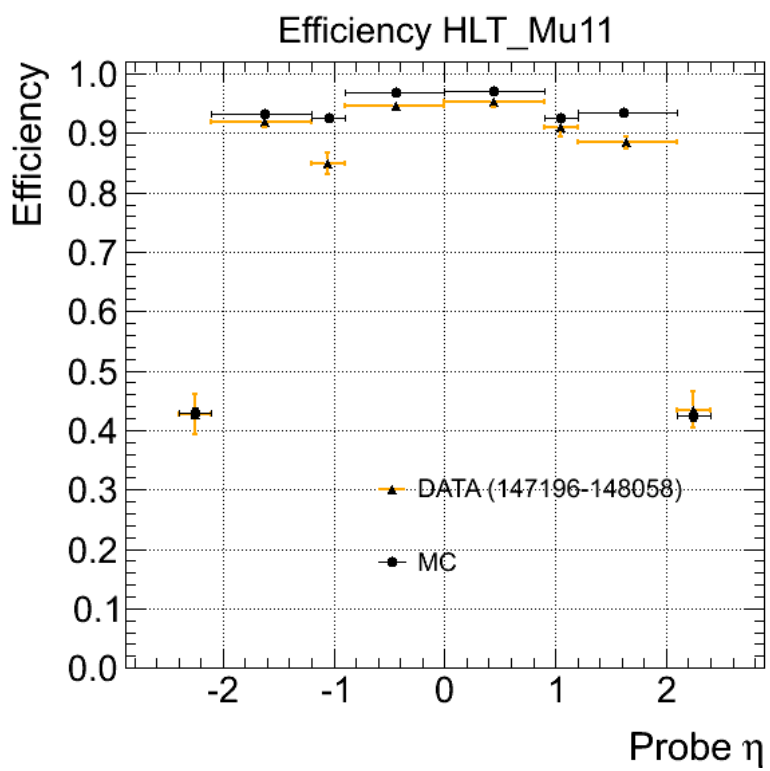


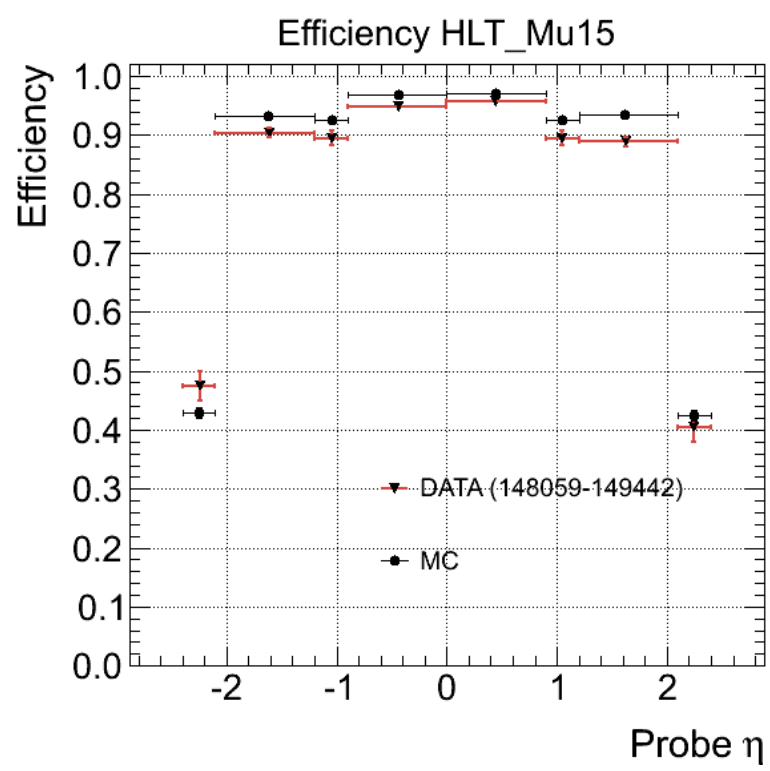


Trigger Efficiency

- The trigger threshold for single muon has been changed in time
- The trigger efficiency in time
  - The efficiency is measured for HLT_Mu9(A/B), HLT_Mu11, HLT_Mu15, respectively
  - The clean Z sample is used for the efficiency
  - The trigger efficiency of single muon object (ε_{trig}) is measured using T&P method
  - The efficiency of the single muon trigger for dimuon pair (E_{trig})

$$E_{trig} = \epsilon^{\mu}_{trig} + \epsilon^{\mu}_{trig} - (\epsilon^{\mu}_{trig})^2$$: the overall trigger efficiency is ~ 0.993



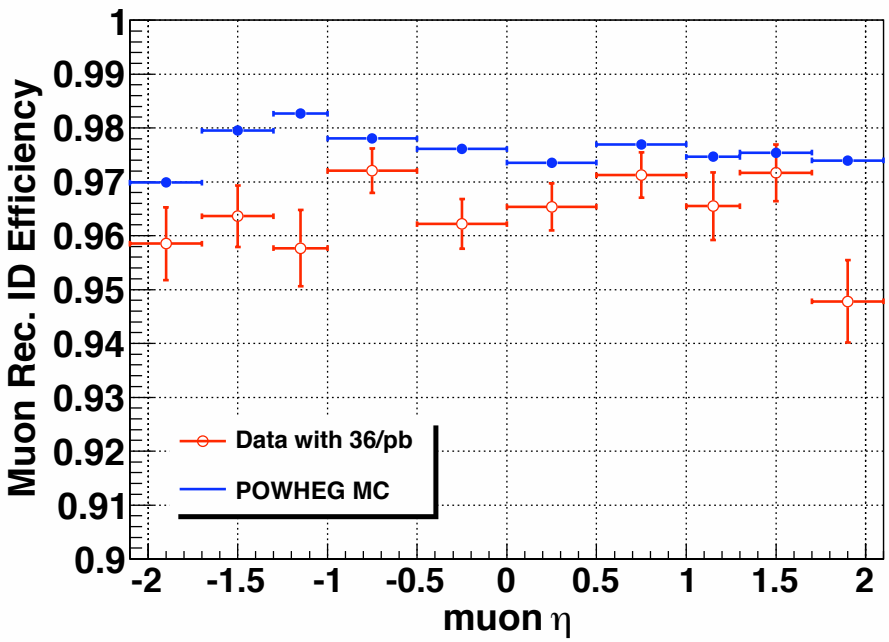


Muon Selection Efficiency

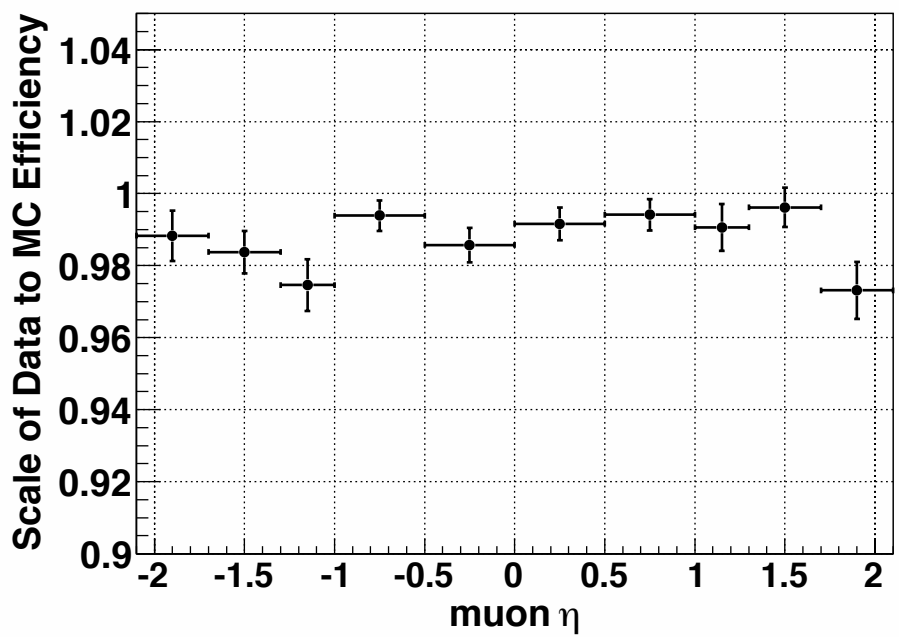
- Muon selection (ID) efficiency
  - The single muon ID efficiency (ϵ^{μ}_{ID}) is measured in η (η and P_T for $d\sigma/dP_T$)
    - $\epsilon^{\mu}_{ID}(data) = 0.965 \pm 0.002$and scale factor = 0.9883 ± 0.0017
  - The muon selection efficiency for Z boson (E_{ID}) : total efficiency = 0.931

$$E_{ID}(y, P_T) = \epsilon^{\mu}_{ID}(\eta_1) \times \epsilon^{\mu}_{ID}(\eta_2) \times \rho(\eta_1, \eta_2)$$

Muon ID efficiency

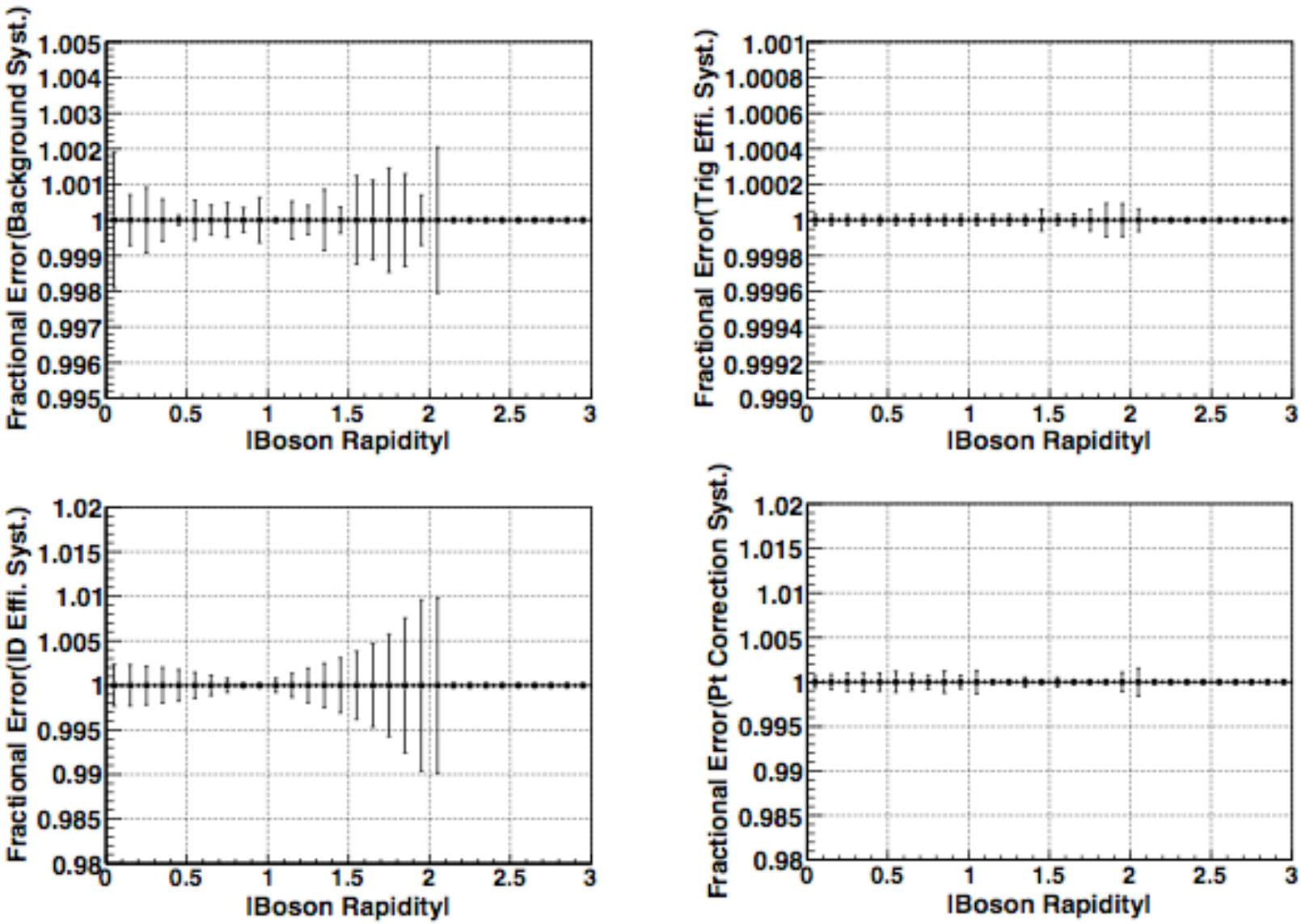


Scale factor of muon ID efficiency



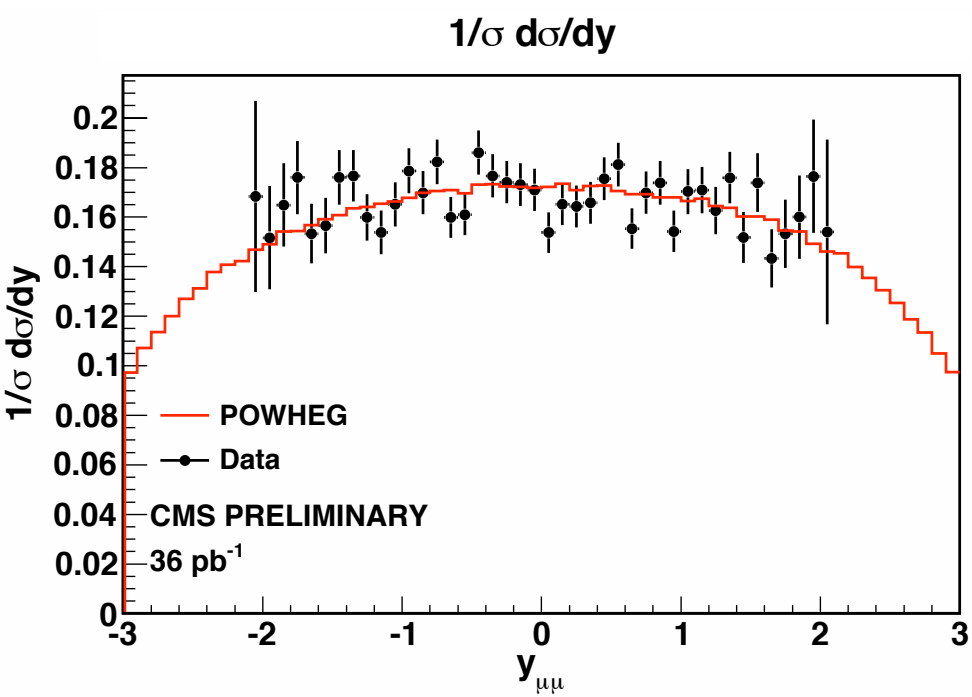
Systematic Uncertainty

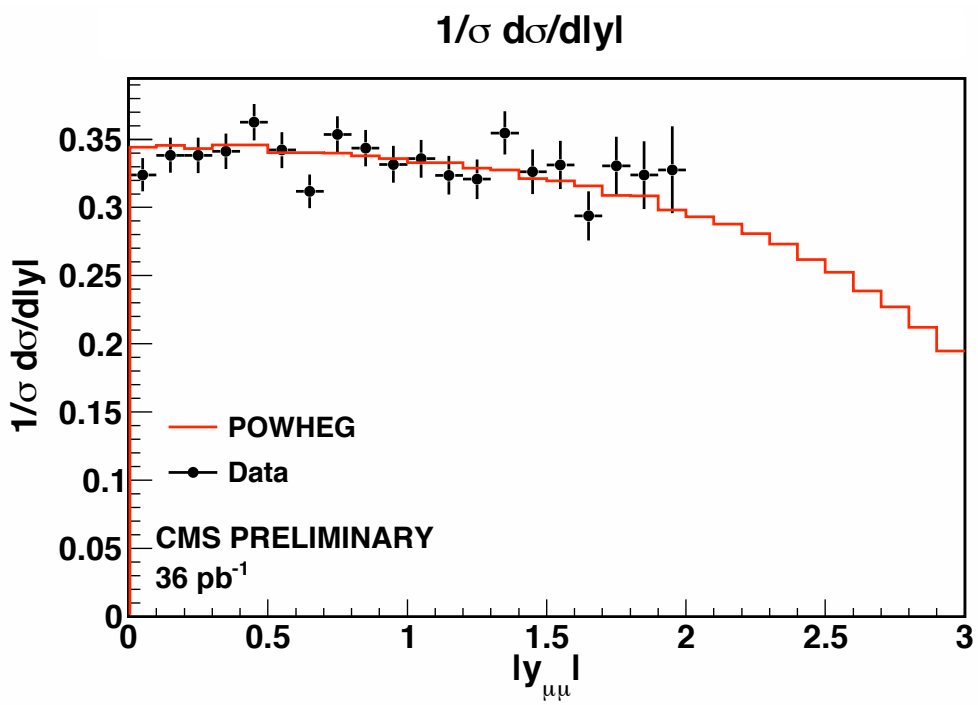
- The fractional systematic uncertainties for dσ/dy

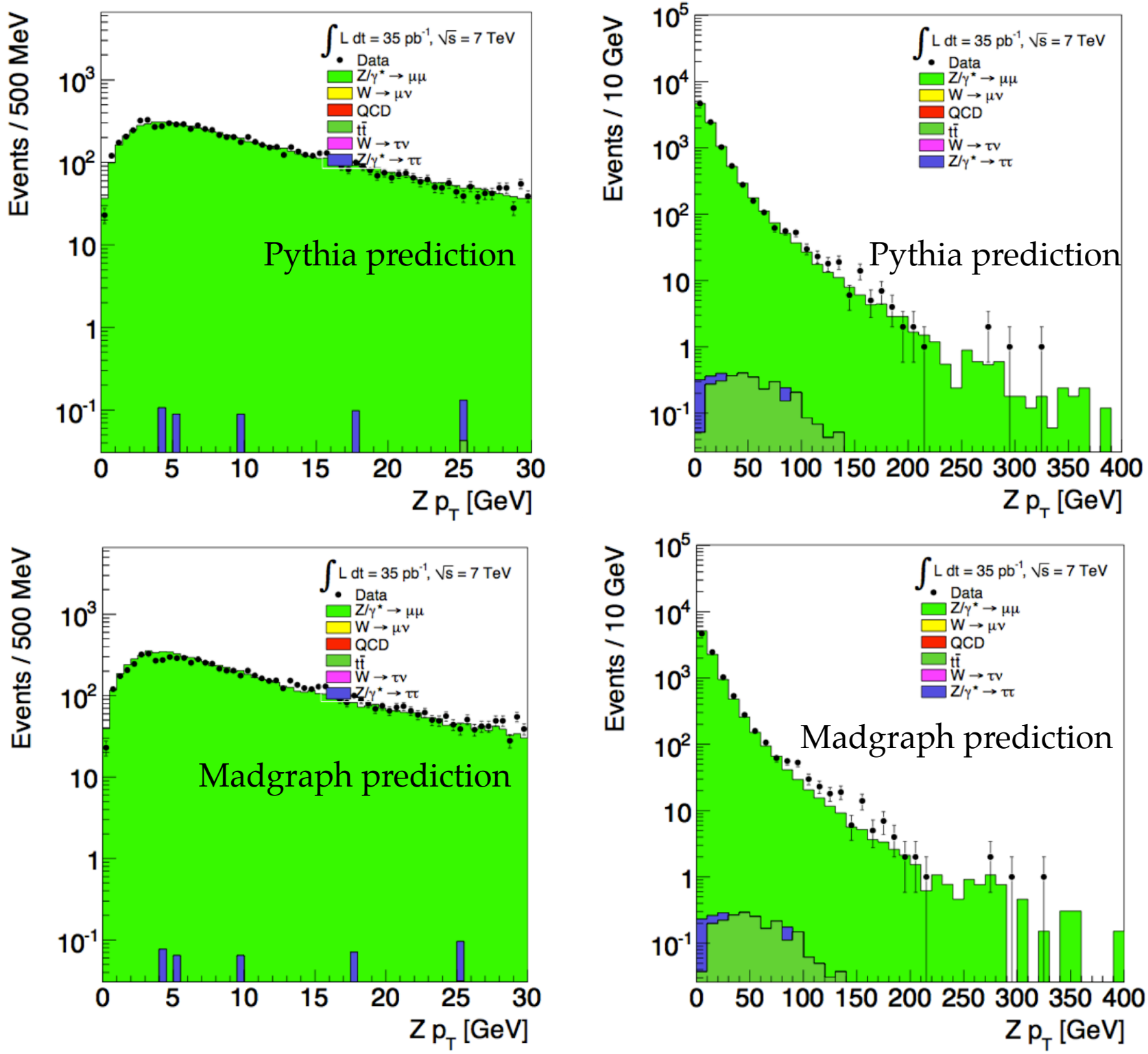


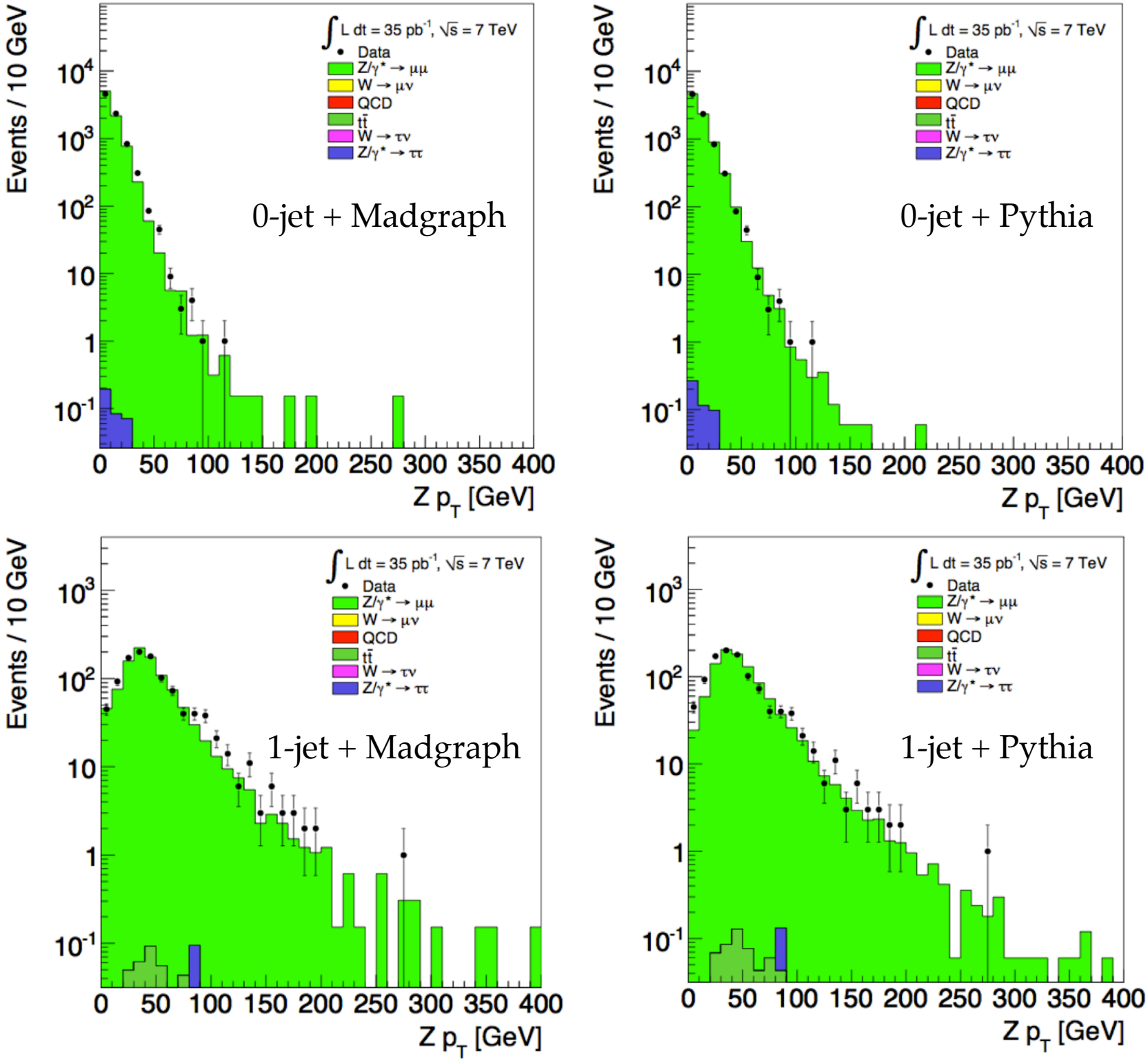
Result of dσ/dy

- (1/σ)dσ/dy measurement compared with POWHEG
  - (1/σ)dσ/dy for y<0 and y>0 is measured using the bin correction method
  - (1/σ)dσ/dy for |y| is measured using the response matrix method
  - The measurement shows a good agreement with POWHEG (χ^2/ndf = 19.4/19)






∫L dt = 35 pb⁻¹, √s = 7 TeV
Data
Z/γ* → μμ
W → μν
QCD
tt̄
W → τν
Z/γ* → ττ
Pythia prediction
Events / 500 MeV
Z p_T [GeV]
Pythia prediction
Events / 10 GeV
Z p_T [GeV]
Madgraph prediction
Events / 500 MeV
Z p_T [GeV]
Madgraph prediction
Events / 10 GeV
Z p_T [GeV]


∫L dt = 35 pb⁻¹, √s = 7 TeV
Data
Z/γ* → μμ
W → μν
QCD
tt̄
W → τν
Z/γ* → ττ
0-jet + Madgraph
0-jet + Pythia
1-jet + Madgraph
1-jet + Pythia
Events / 10 GeV
Z p_T [GeV]