Measurements of φ* differential cross sections for Drell–Yan events in p-p collisions at √s = 8 TeV with CMS

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Abstract

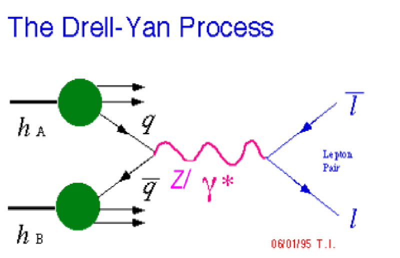
Measurements of φ* differential cross sections for inclusive Drell–Yan events in the dielectron and dimuon final states are presented. The kinematic variable φ* , constructed from the lepton angles, is correlated with the transverse momentum of the vector boson. The data were collected with the CMS experiment at a centre-of-mass energy of 8 TeV and correspond to an integrated luminosity of 19.7 fb^{-1}. The differential cross section dσ/dφ* normalised to the total cross section within the fiducial volume is measured with a precision of about 1% and is compared with theoretical predictions. The measured spectrum, for the range φ*< 0.1, differs from the theoretical predictions by at most 5% (ResBos), 4% (MADGRAPH) and 9% (POWHEG). For higher values of φ* the deviations are as high as 9%, 5% and 18% in the three cases respectively.

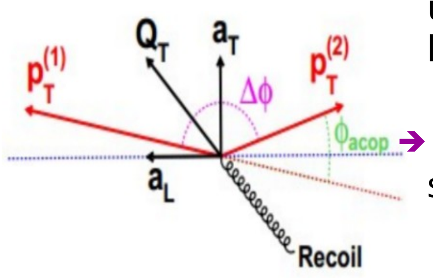
Drell-Yan Process and Φ^* Definition

- Drell Yan process is produced from one of the colliding protons annihilates with an anti-quark from a proton traveling in the opposite direction.

$$q\bar{q} \rightarrow Z\gamma^* \rightarrow \ell^+\ell^-$$

- It serves as excellent tests of perturbative calculations.
- Used to validate theoretical calculations of Higgs boson production.



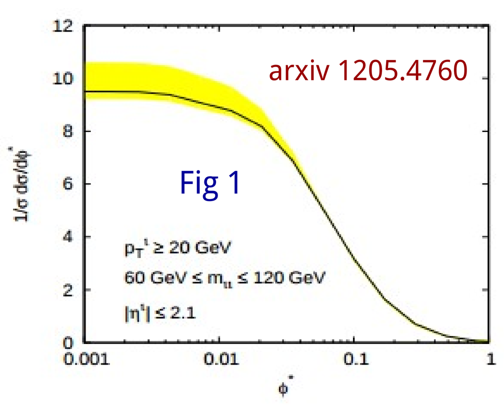


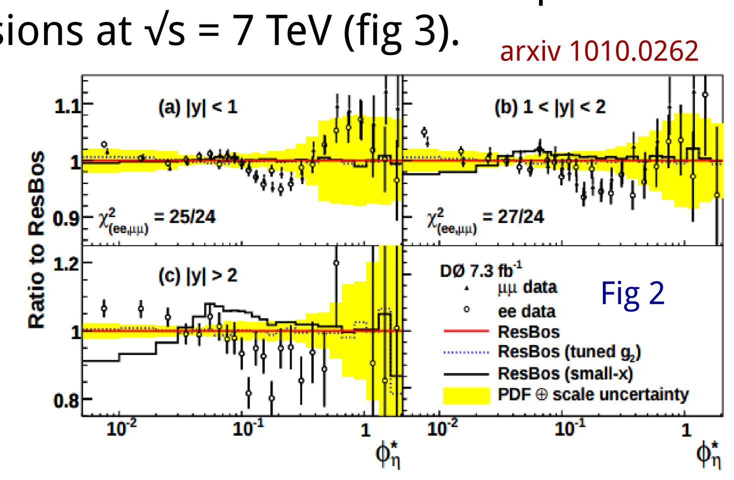
- Direct measurements of the Z/γ* spectrum at low Z transverse momentum (q_T) is limited by experimental resolution & systematic uncertainties.
- Novel variable φ* has been proposed which utilizes the angular correlation among the leptons as a measure to probe q_T .
- Φ* has less sensitivity to experimental systematic uncertainties compared to q_T .

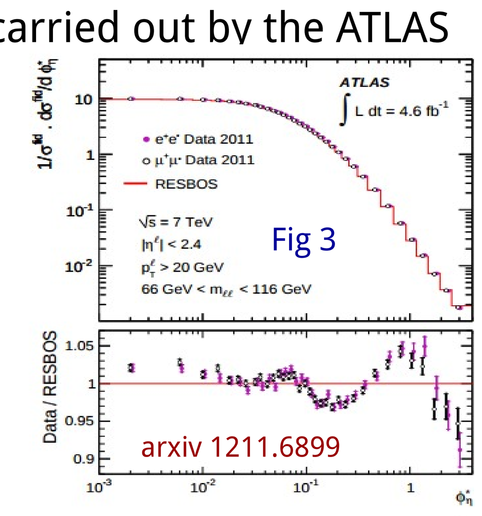
$$\phi^* = \tan(\phi_{acop/2}) \sin(\theta_\eta^*),$$

Experimental Results and Theoretical Predictions

- Theoretical predictions at NNLL+NLO for the normalised φ* distribution in pp collisions at √s = 7 TeV (fig 1).
- φ* distributions for the Drell Yan process have been measured by the D0 Collaboration at the Tevatron for $p\bar{p}$ collisions at √s = 1.96 TeV (fig 2).
- At LHC, Drell-Yan cross-section measurements w.r.t φ* have been carried out by the ATLAS collaboration for pp collisions at √s = 7 TeV (fig 3).







Data/MC Event selection

Data

- Single muon triggerred data collected with a q_T threshold of 24 GeV and pseudorapidity of |2.1|.

MC

- Signal Drell Yan→μμ from POWHEG[1] event generator.

Backgrounds

- Drell Yan→ττ : Low and intermediate invariant Z-mass region.
- tt+jets : High-mass region of Drell -Yan mass spectrum.
- Diboson, W+Jets

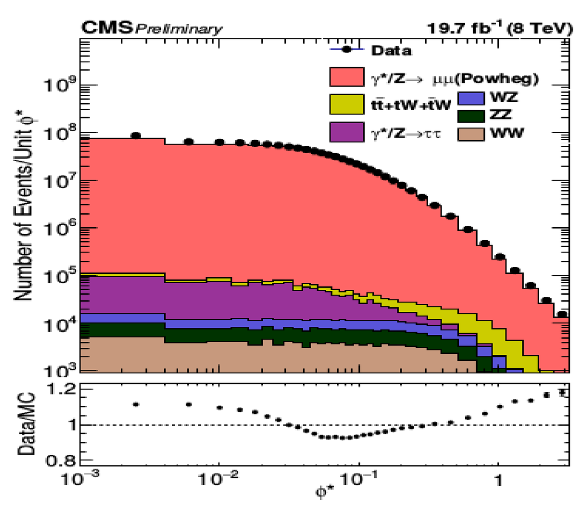
Muon Selection

- CMS recommended Run-I muon identification and isolation[2] criteria used.

Dimuon Selection

- Inclusive dimuon (opposite sign) events
- $p_T(\mu_1) > 30$ GeV & $|\eta(\mu_1)| < 2.1$
- $p_T(\mu_2) > 20$ GeV & $|\eta(\mu_2)| < 2.4$
- Invariant Mass(GeV):

60 < M μμ < 120



φ* distribution, before unfolding, in dimuon final state. POWHEG signal and background simulations, normalized to luminosity, are overlaid.

Background Subtraction and Unfolding

Background Subtraction:

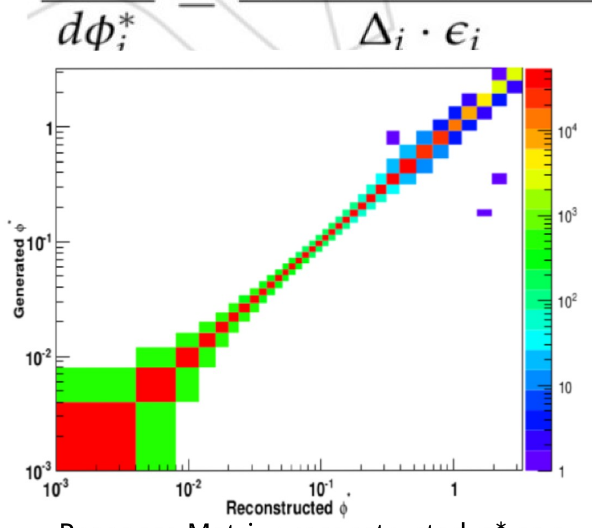
- Level of background is quite low ~10^{-3} compared to the signal.
- Contribution from different backgrounds estimated in different ways :
  1.) tt+jets is the dominant background process, estimated from simulation by varying cross-section by ±10%.
  2.) ZZ, WZ estimate from simulation with a 20% uncertainty applied to the corresponding yield.

Unfolding Data:

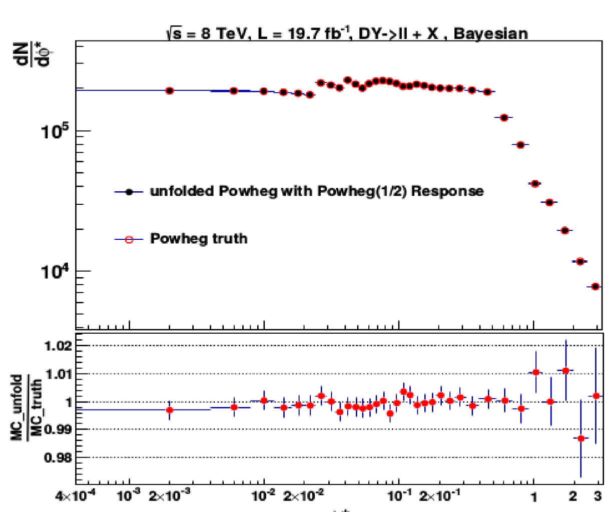
- Measured data spectrum must be unfolded to compare with theoretical predictions .
- Necessary to correct for bin migration and event efficiency due to detector resolution.

$$\frac{d\sigma^{fid}}{d\phi_i^*} = \frac{\sum_k R_{ik}(N_k - B_k)}{\Delta_i \cdot \epsilon_i}$$

- Unfolded data with Iterative Bayesian method included in RooUnfold[3] package.
- Order of bin-migration is ~1%.
- Closure tests were performed to validate the procedure.

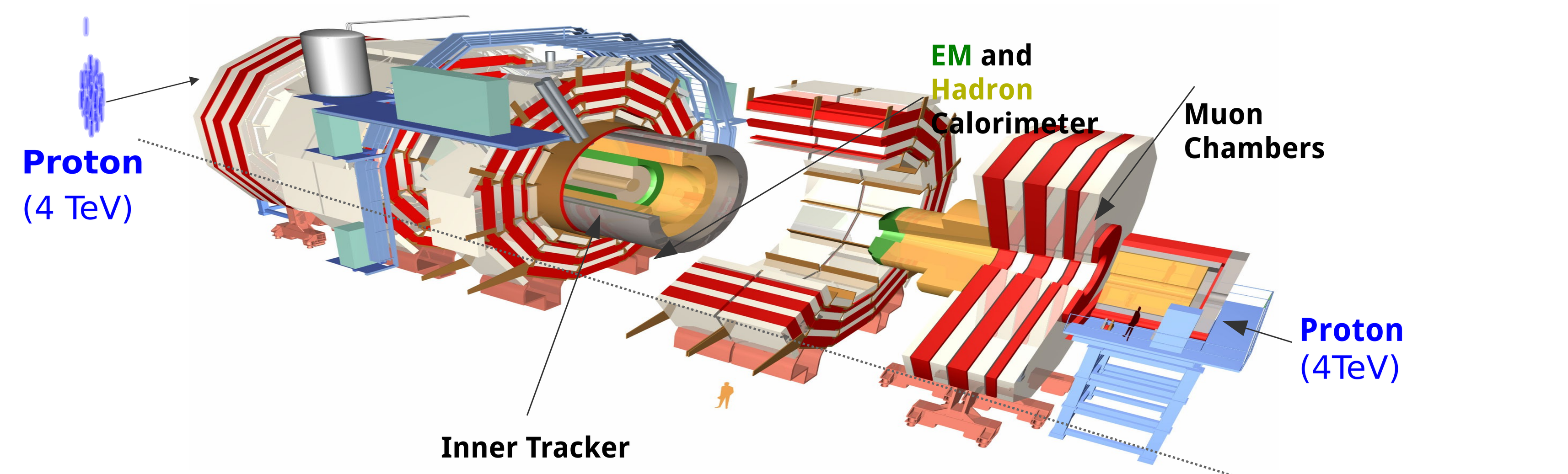


Response Matrix : reconstructed φ* as a function of generated φ*.



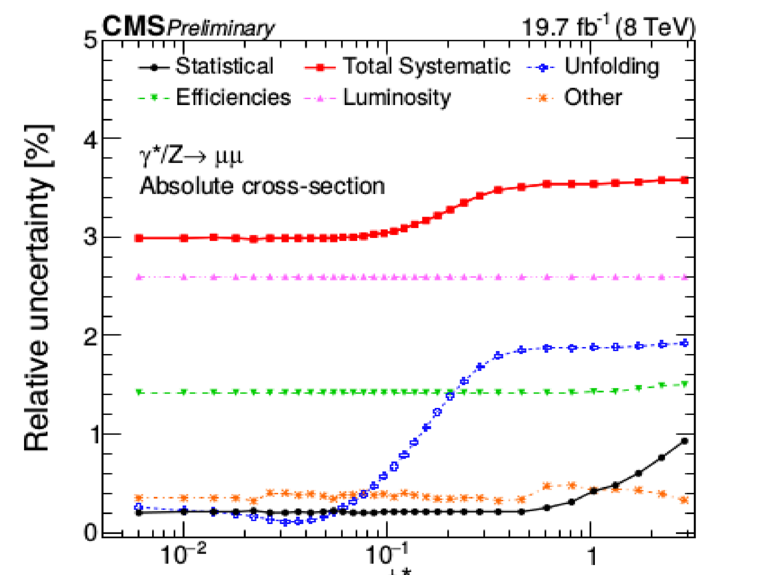
Half Sample Closure test with unfolded φ* distribution.

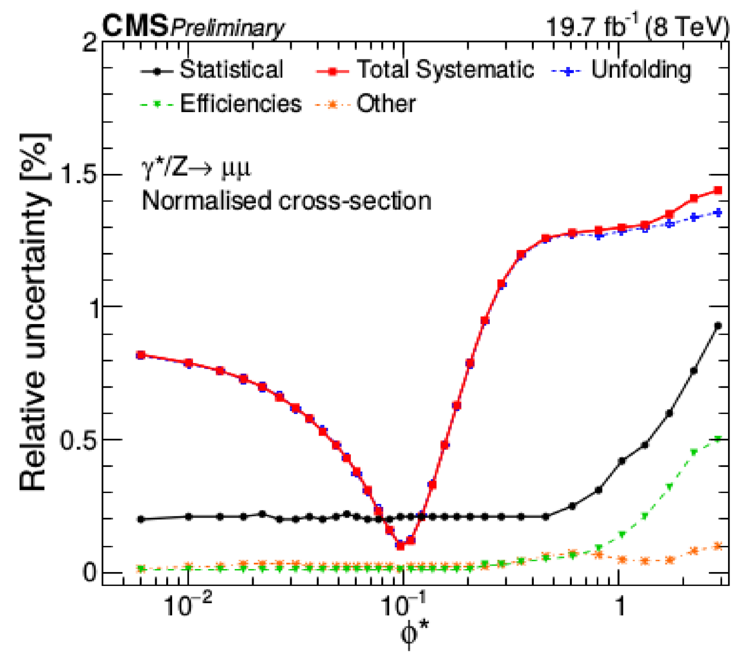
CMS Detector



Systematic Uncertainities

- Different components of uncertainties considered :
  - Luminosity
  - Pile-up
  - Muon identification
  - Momentum Scale resolution
  - Background
  - Modeling of final state radiation (FSR)
  - Parton Distribution function (PDF)
  - Unfolding systematics due to model dependence

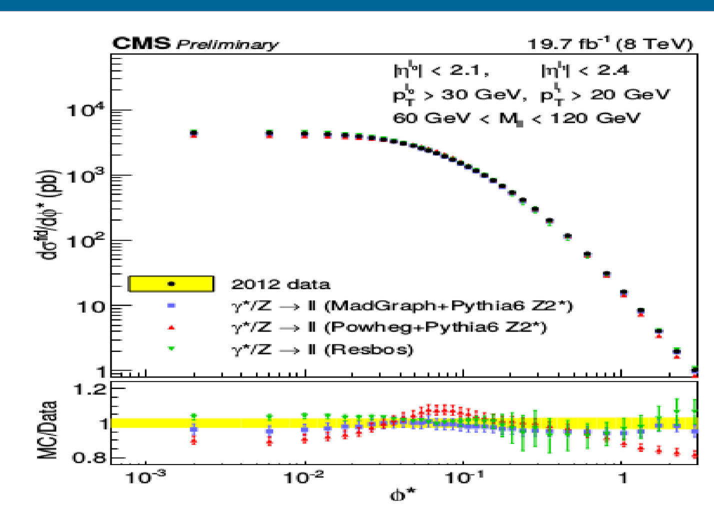


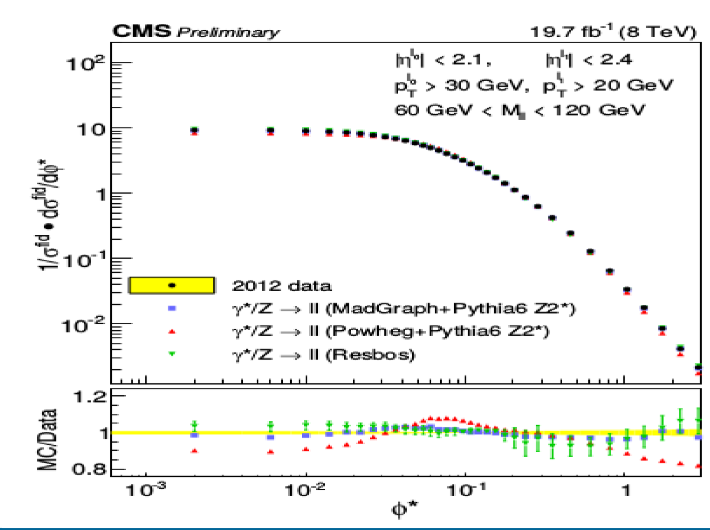


- **Absolute cross-section measurement :**
  - Total uncertainty is dominated by the Luminosity uncertainty (2.6 %).
  - At low φ* region, muon efficiency uncertainties (~1.4%) and for φ*> 1, unfolding uncertainty (~1.3%) are the dominant sources.
- **Normalized cross-section measurement :**
  - Uncertainities much lower than absolute measurements.
  - Uncertainitie due to model dependance is the dominant source, followed by MC statistics (0.1% in lower & 0.4% in higher φ* bins).

Results

- Absolute and normalized differential cross-section measured within the fiducial volume.
- Predictions from three different theoretical calculations, including ResBos[4], MADGRAPH[5] and POWHEG are compared to unfolded 8 TeV data.
- The total cross section obtained from FEWZ[6] has been used for the normalisation of the MADGRAPH and POWHEG predictions.
- None of the predictions match the measurements perfectly for the entire range of φ* .
- While the maximum discrepancy of MADGRAPH and ResBos with respect to the data is below 5% (for the range φ* < 0.1), that of POWHEG is greater than 10%.





Summary

- φ* is based on measurements of angles and is correlated with dilepton transverse momentum q_T in Drell-Yan events.
- Absolute (dσ/dφ*) and normalized (1/σ dσ/dφ*) differential cross section measurements are presented based on 19.7 fb^{-1} of pp collision data at centre of mass energy of 8 TeV recorded by the CMS detector.
- Precision of better than 1% is obtained for φ* < 0.25 for normalized measurements, giving high precision information of the spectrum at low q_T.
- Prediction from MADGRAPH shows better agreement with the data compared to the predictions from POWHEG and ResBos.
- None of the theoretical calculations succeed in predicting the measurements perfectly over the entire range of φ*.

References

1.) P. Nason, "A new method for combining NLO QCD with shower Monte Carlo algorithms", JHEP 11 (2004) 040.

2.) CMS Collaboration, "Performance of CMS muon reconstruction in pp collision events at √s=7 TeV", JINST 7 (2012) P10002.

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5.) J. Alwall et al., "MadGraph 5 : Going Beyond", JHEP 1106 (2011) 128.

6.) Y. Li and F. Petriello, "Combining QCD and electroweak corrections to dilepton production in FEWZ",Phys.Rev. D86 (2012) 094034.