DrellYan production in pp and pA collisions

Rivet plugin validation & intrinsic k_t dependency

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DESY.

Outline

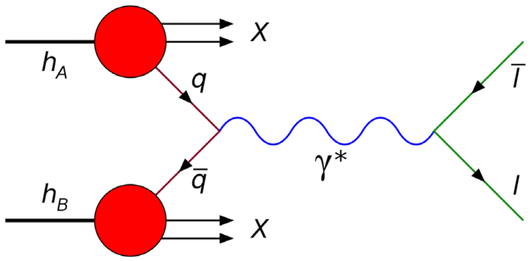
- Motivation
- Analyses
- Validation with POWHEG+ Pythia8
- Detailed study with MC@NLO + Cascade3
- Summary and Outlook

Motivation

DY process

What is DY?

A quark and an antiquark annihilate, creating a $\boldsymbol{\gamma}$ or Z which then decays into a pair of leptons.

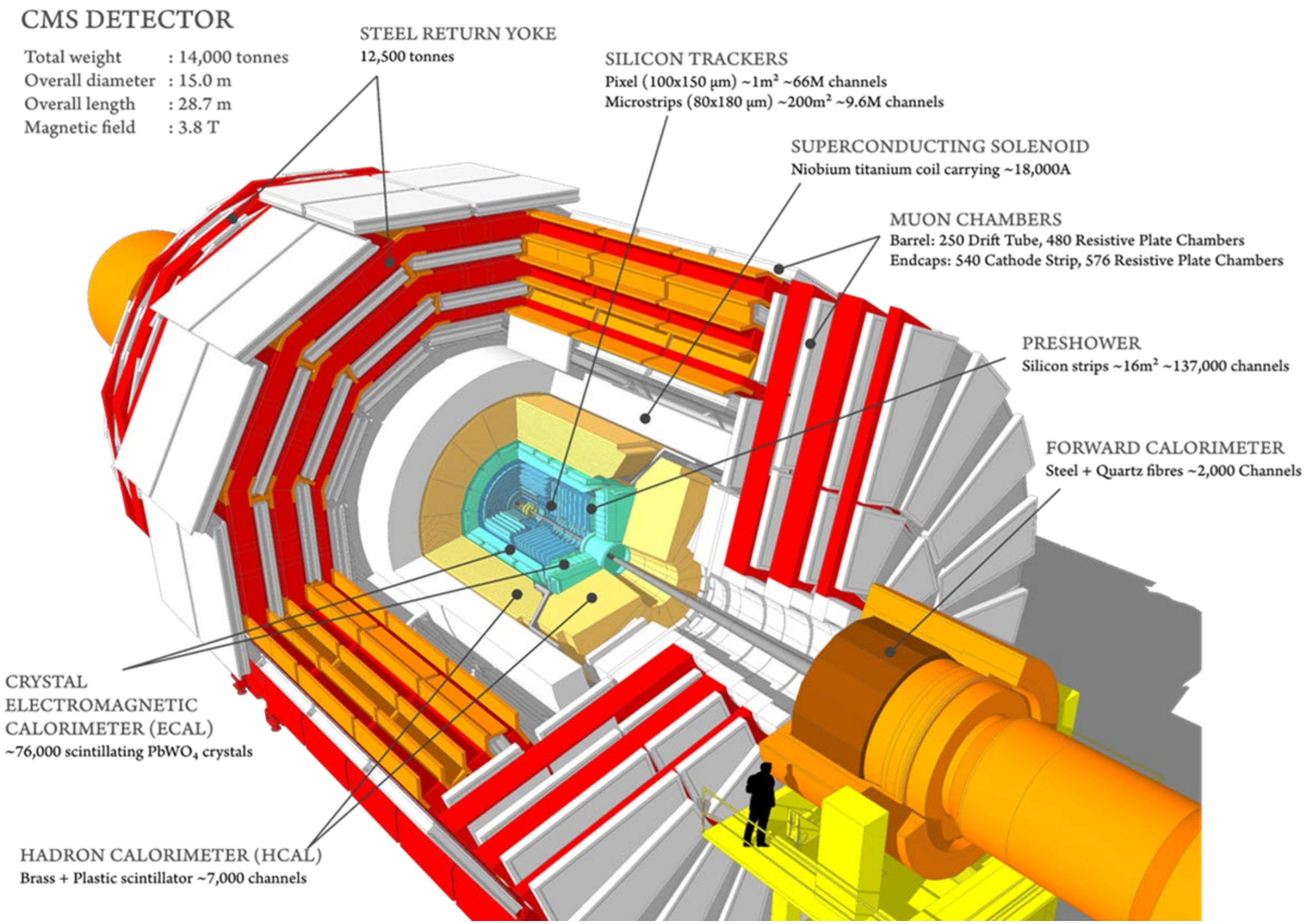


Why is DY important?

- a ”standard candle” for electroweak precision measurements at LHC
- helps to understand the QCD evolution, resummation, factorization (collinear, TMD)
- used for extraction of the PDFs
- at low mass and low energy gives access to partons’ intrinsic k_t

CMS Detector

The **C**ompact **M**uon **S**olenoid (CMS) is a general-purpose detector at the **L**arge **H**adron **C**ollider (LHC).



CMS Detector

Research areas

- New physics and Standard model of particle physics
- Higgs boson and precise differential measurements of different processes
- Its strength lies in the muon system.
- It records pp, PbPb, and p-Pb collisions.
- …

Analyses

Two DY analyses from CMS collaboration were coded and validated:

- Project A: Study of Drell-Yan dimuon production in proton-lead collisions at $\sqrt{s_{NN}}$ = 8.16 TeV (CMS_2021_I1849180)
- Project B: Study of Z production in PbPb and pp collisions at $\sqrt{s_{NN}}$ = 2.76 TeV in the dimuon and dielectron decay channels (CMS_2014_I1322726)

STEP 1 — Validating the correctness of the routine code (produced with rivet) and of the provided data (powheg+pythia)
specifying the effect of different flavor

STEP 2 — Repeating the prediction with CASCADE + MC@NLO

STEP 3 — Checking the effect of having different TMDs with different intrinsic k_t

Rivet

What is Rivet?

The Rivet toolkit (**R**obust **I**ndependent **V**alidation of **E**xperiment and **T**heory) is a system for validation of Monte Carlo event generators. The phenomenologists, MC generator developers and experimentalists on the LHC are using rivet for different purposes .

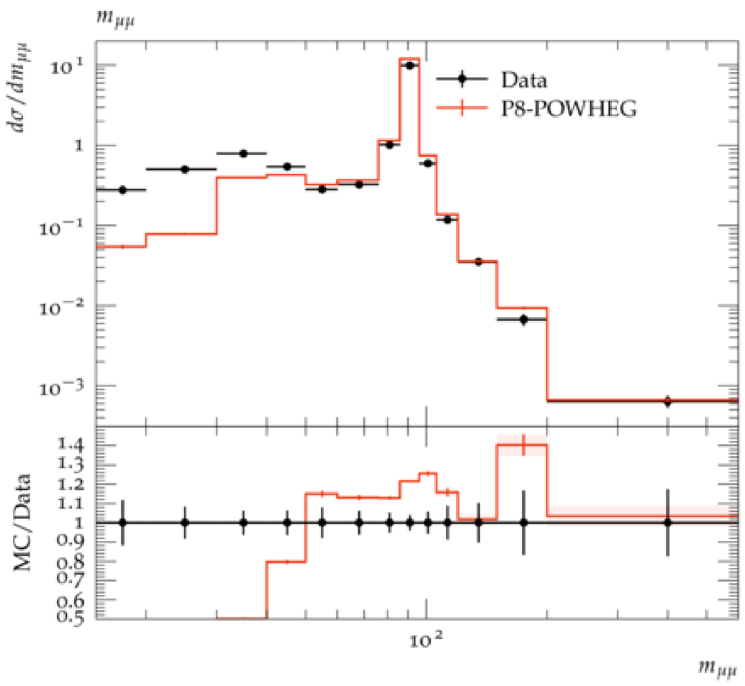
Features

- Object-oriented C++ framework for analysis algorithms (with Python interface)
- Automatic caching of expensive calculations, for efficiently running many analyses on each event
- Close matching of standard observables to experimental analysis definitions
- Reference data connection to HepData

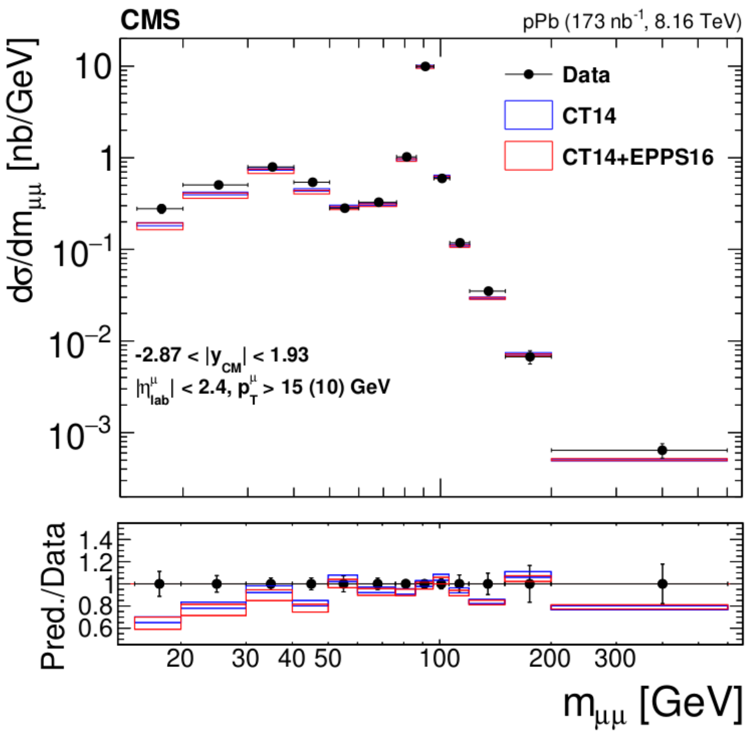
Validation ✓

Project A (powheg+pythia): mass

Rivet plugin



Paper

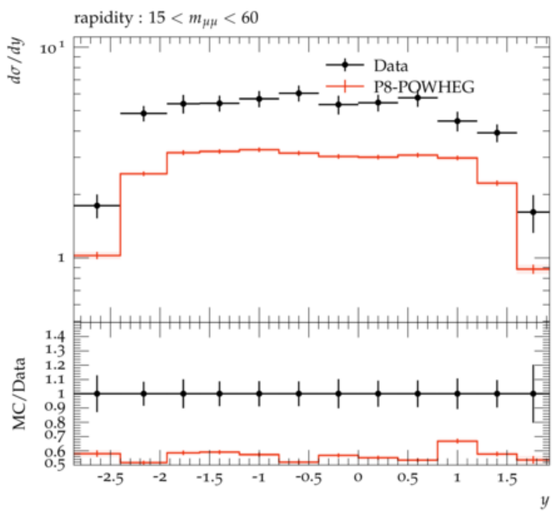


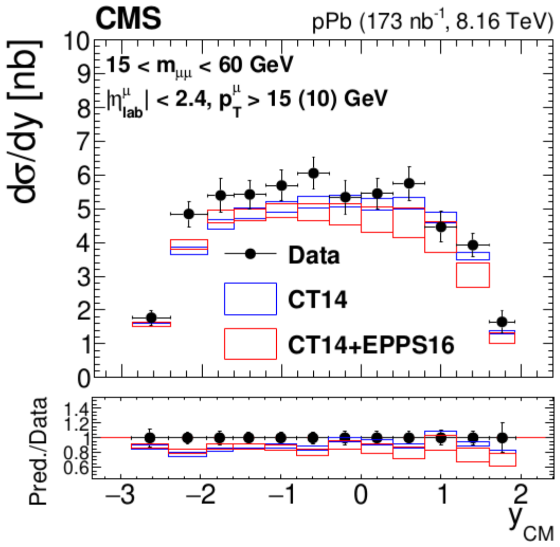
Validation ✓

Project A (powheg+pythia) : y_{cm}

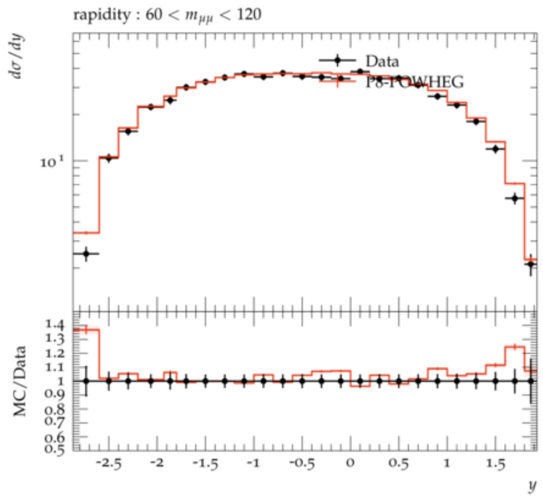
Rivet plugin | **Paper**

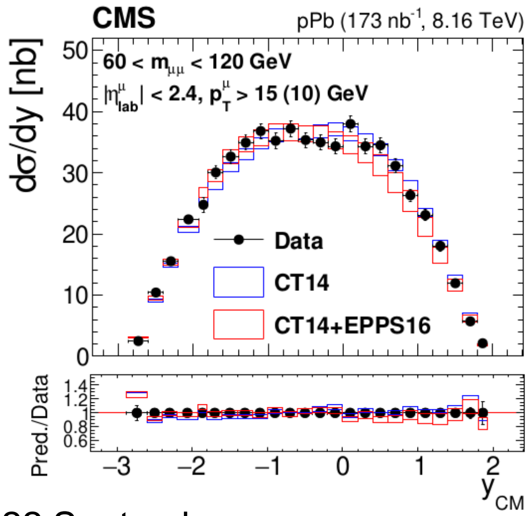
low mass





high mass



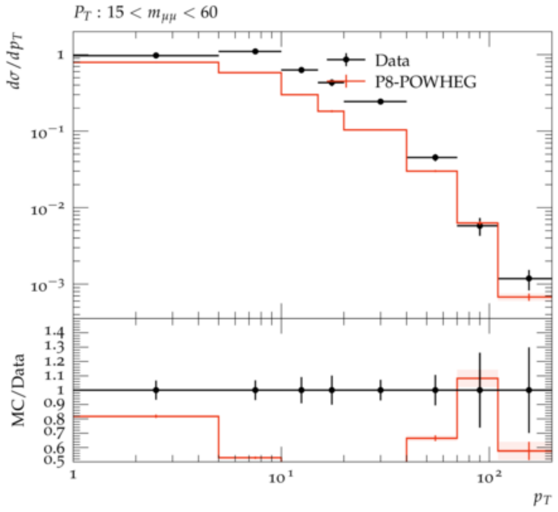


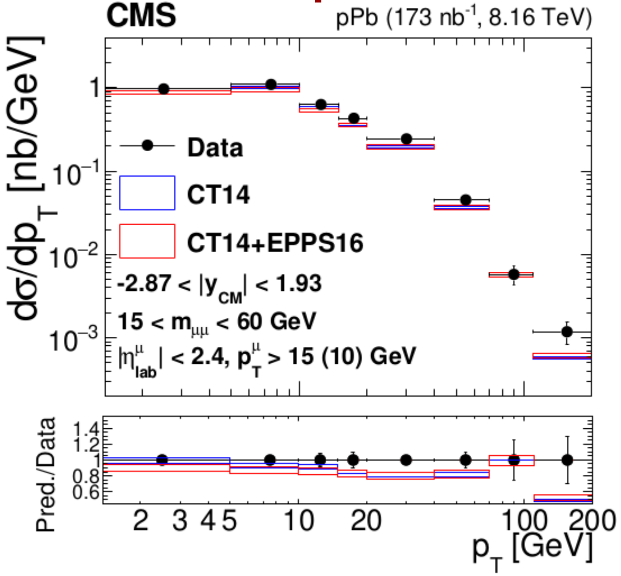
Validation ✓

Project A (powheg+pythia): Pt

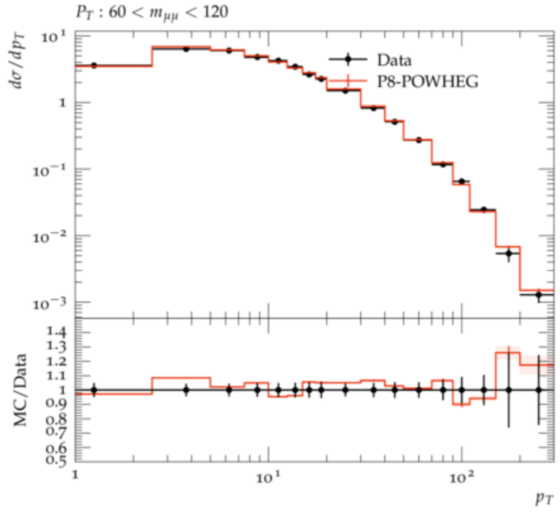
Rivet plugin | **Paper**

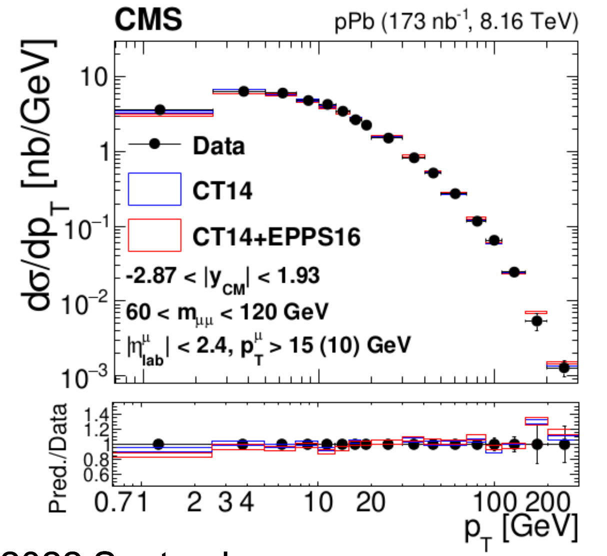
low mass





high mass





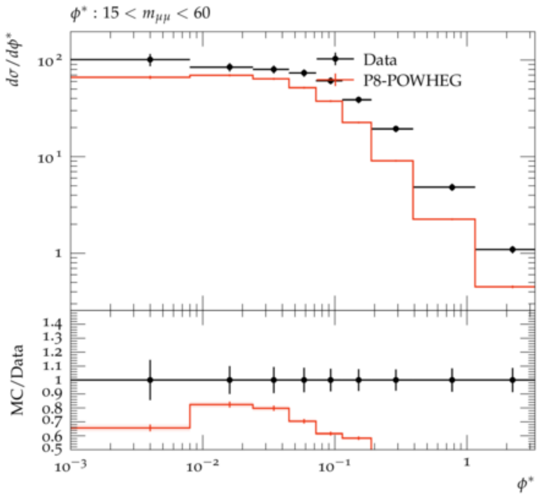
Validation ✓

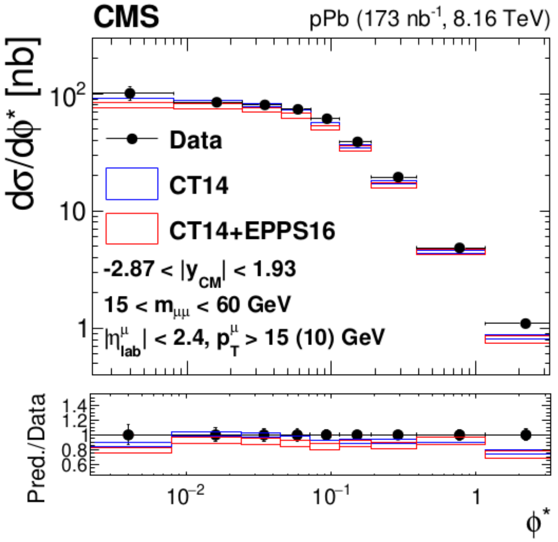
STEP 1

Project A (powheg+pythia) : φ*

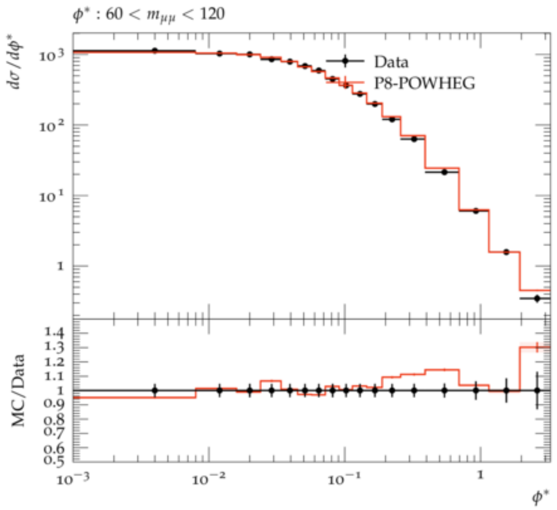
Rivet plugin | **Paper**

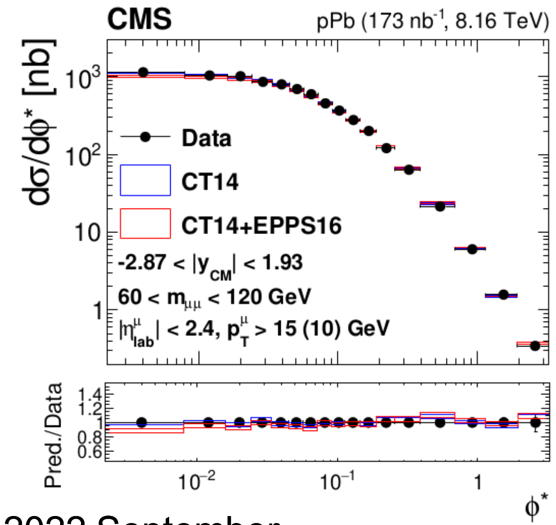
low mass





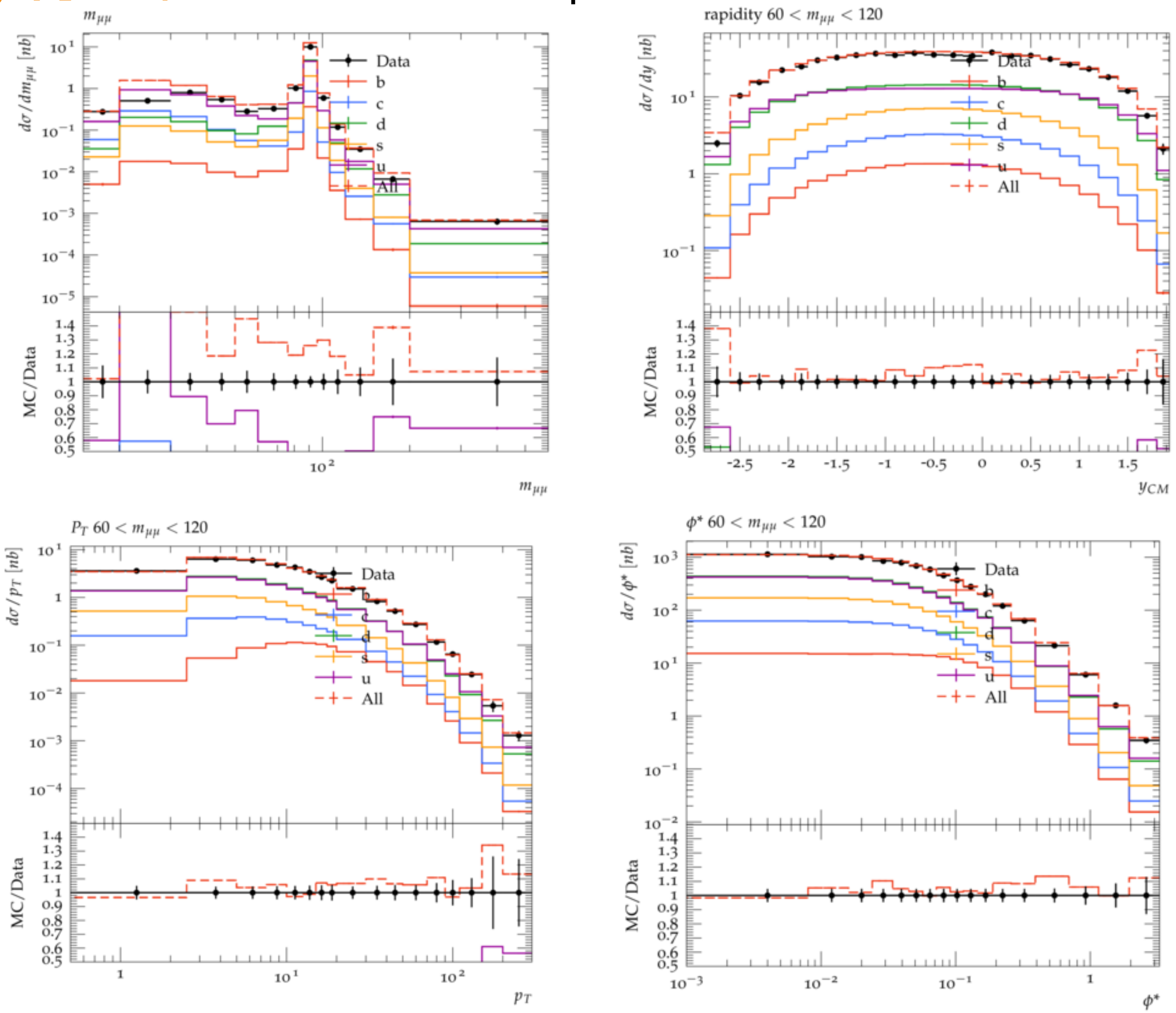
high mass





Flavour decomposition

Project A (powheg+pythia) : Closer look inside proton to check each flavor contribution



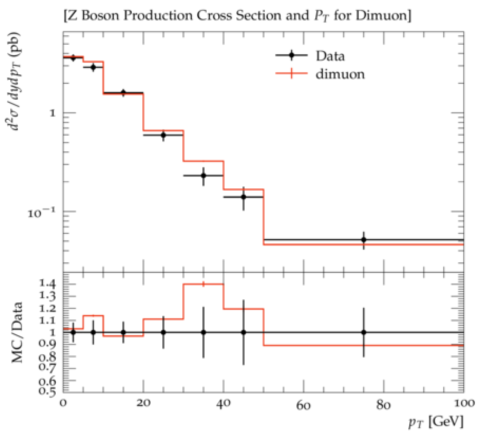
Validation ✓

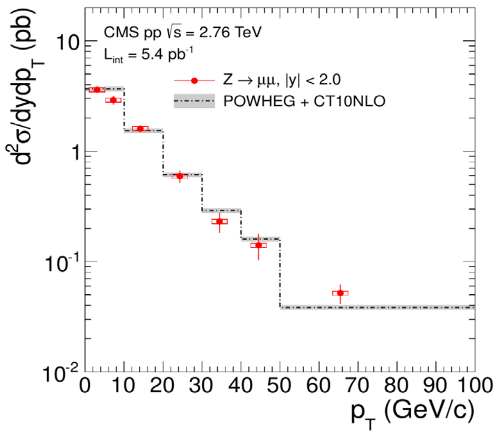
STEP 1

Project B (powheg+pythia) : Pt

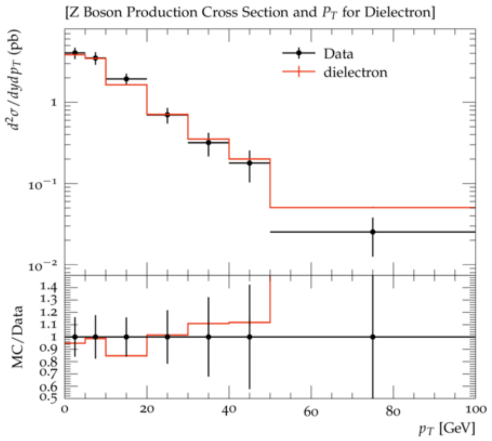
Rivet plugin | **Paper**

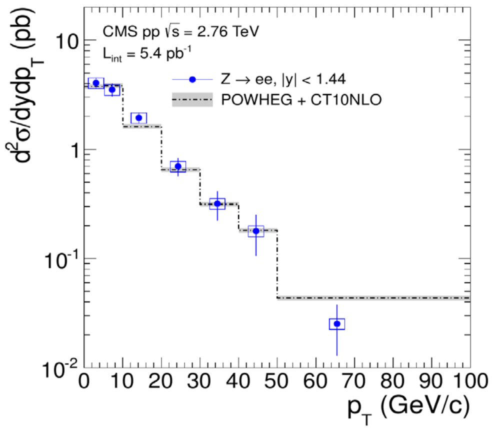
dimuon





dielectron





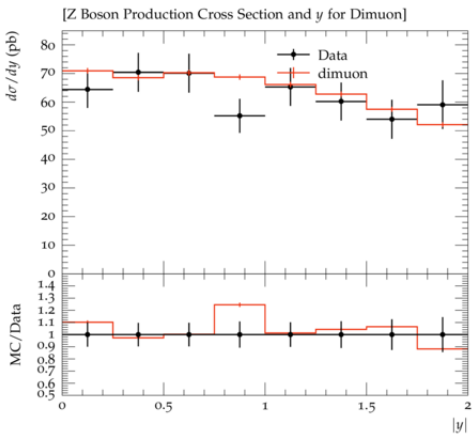
Validation ✓

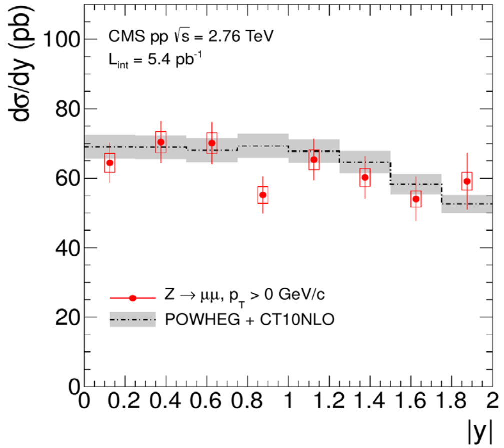
STEP 1

Project B (powheg+pythia) : |y|

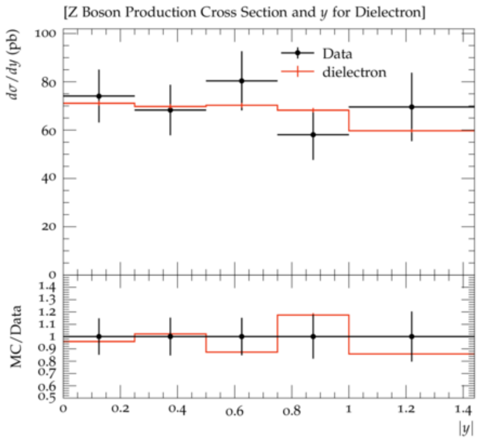
Rivet plugin | **Paper**

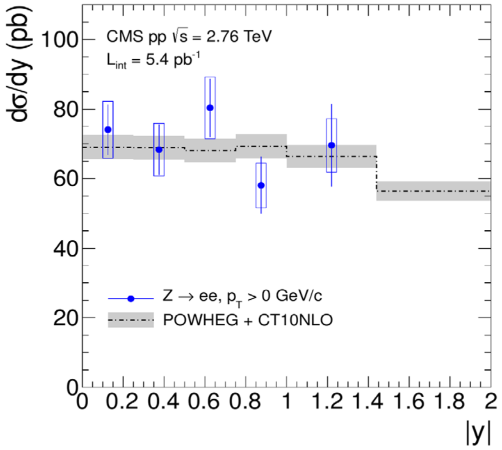
dimuon





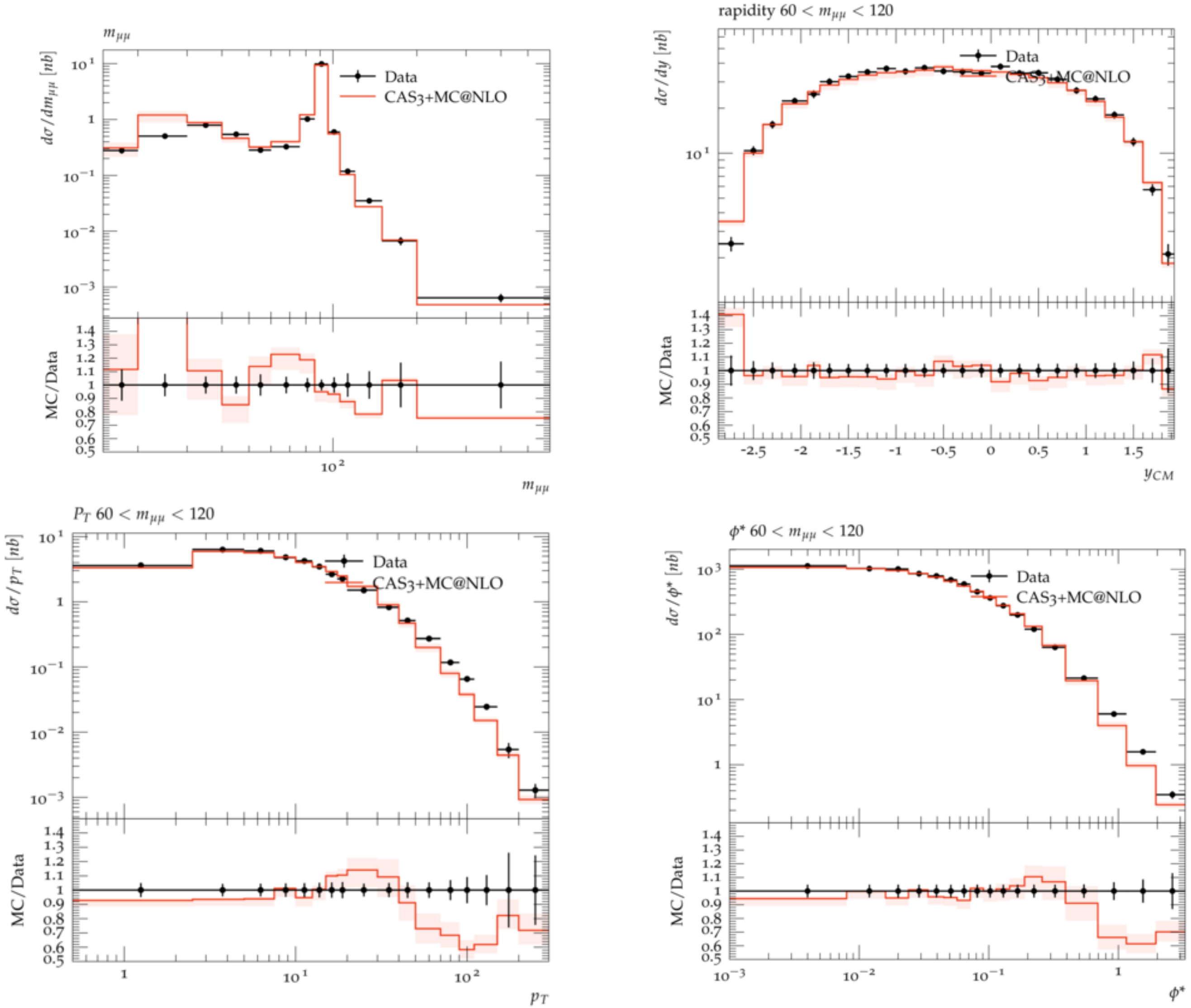
dielectron





Results

Project A: Cascade + MC@NLO

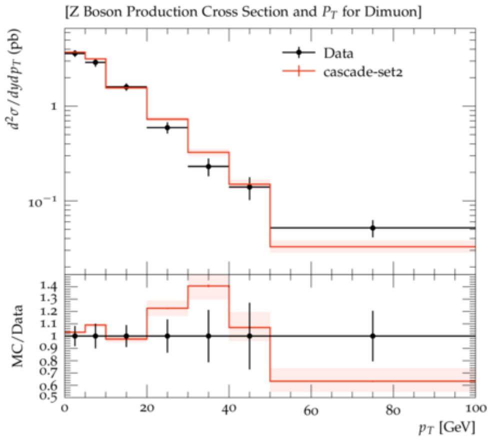


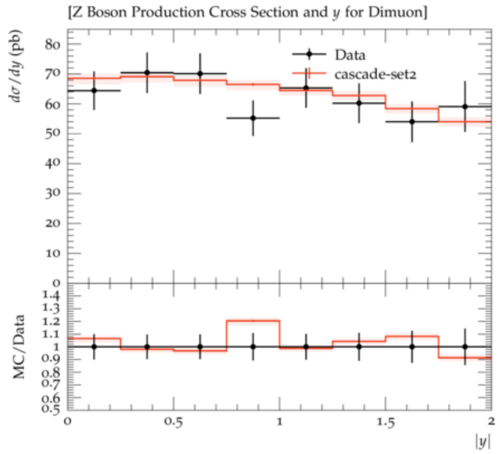
Results

Project B: Cascade + MC@NLO

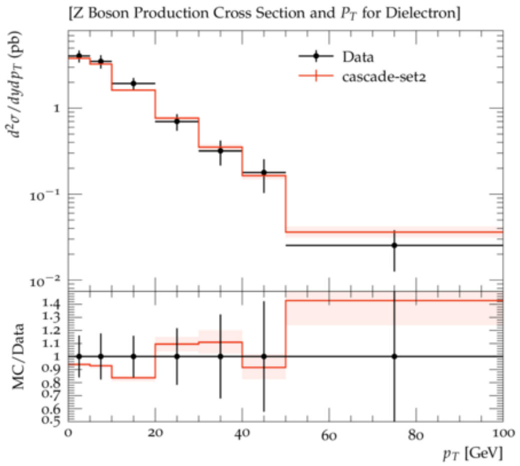
P_T | **|y|**

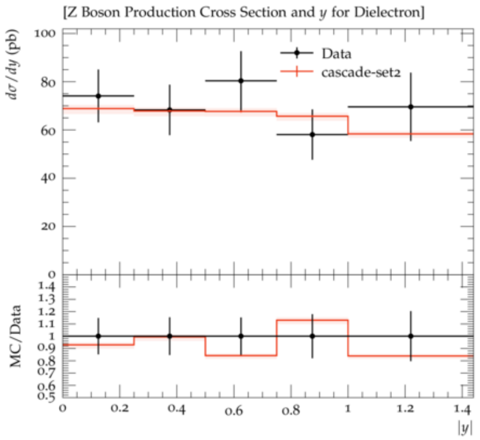
dimuon





dielectron





Results

TMDs from PB method

Besides longitudinal momenta, partons also have small transverse momentum inside the incoming hadrons

collinear PDF

intrinsic k_t: represents the intrinsic transverse momentum of the initial states partons

$$\mathcal{A}_{0,b}(x, k_{t,0}^2, \mu_0^2) = f_{0,b}(x, \mu_0^2) \cdot \exp(-|k_{t,0}^2|/\sigma^2)$$

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1+D_{\bar{U}}x), \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

$$\sigma^2 = q_0^2/2$$

q_0=0 GeV
q_0=0.5 GeV

Is there any difference in TMDs with different intrinsic k_t?

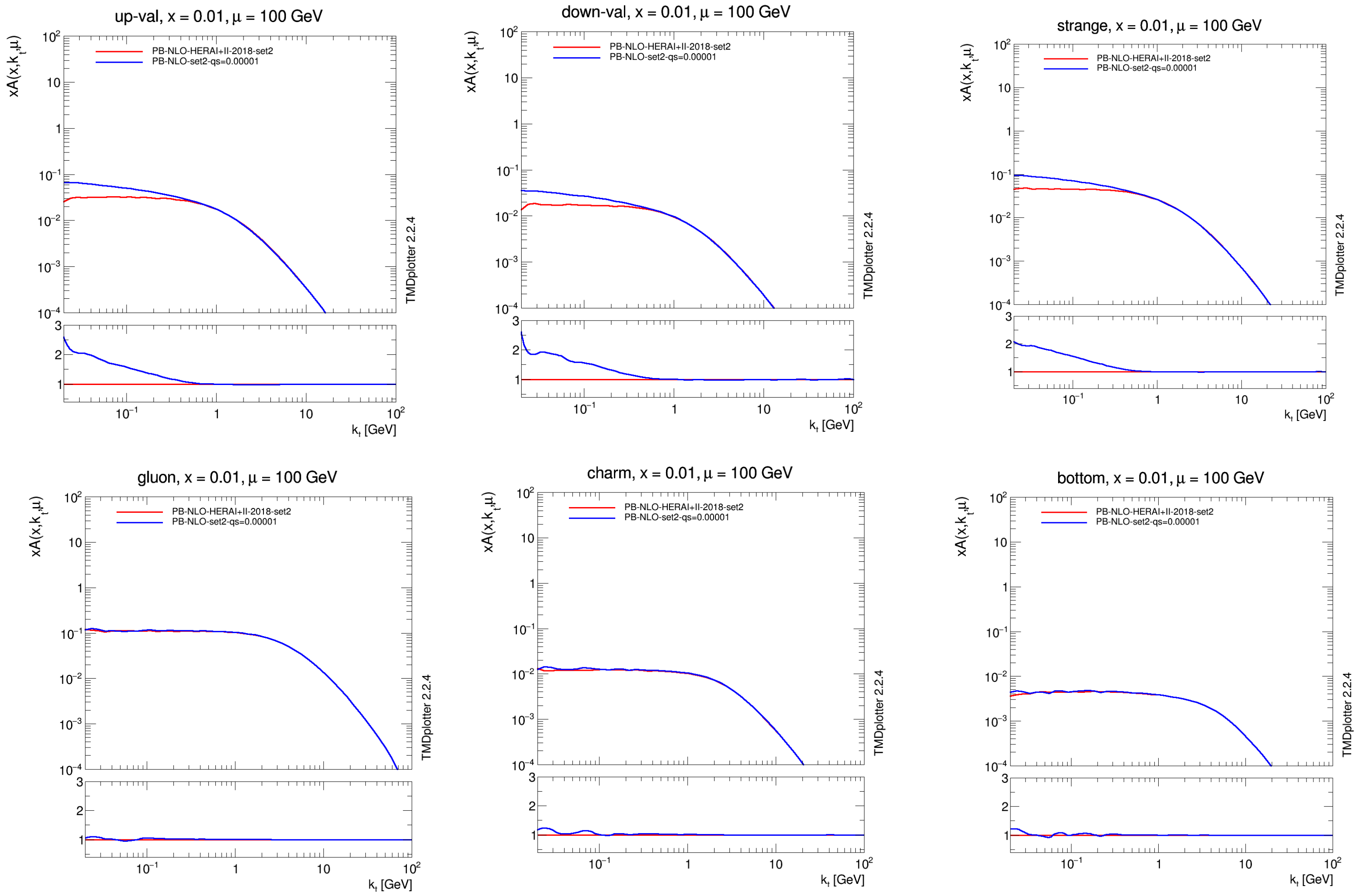
STEP 3

Results

TMDs with different intrinsic k_t

The effect of having different intrinsic kt is visible in light quarks.

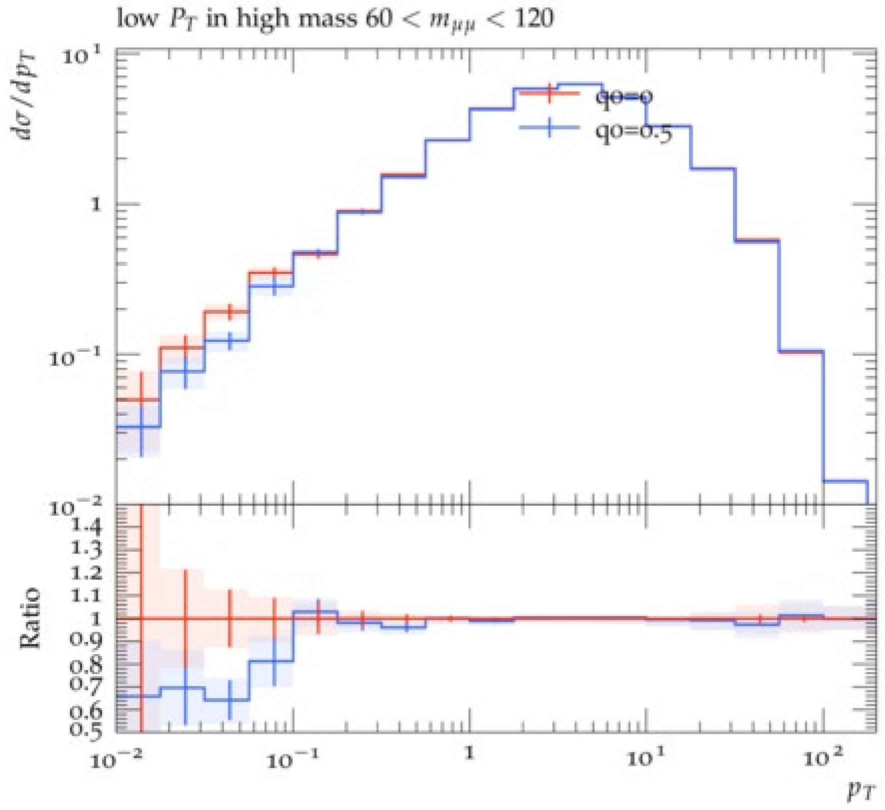
In gluon and heavy quarks there is no difference.

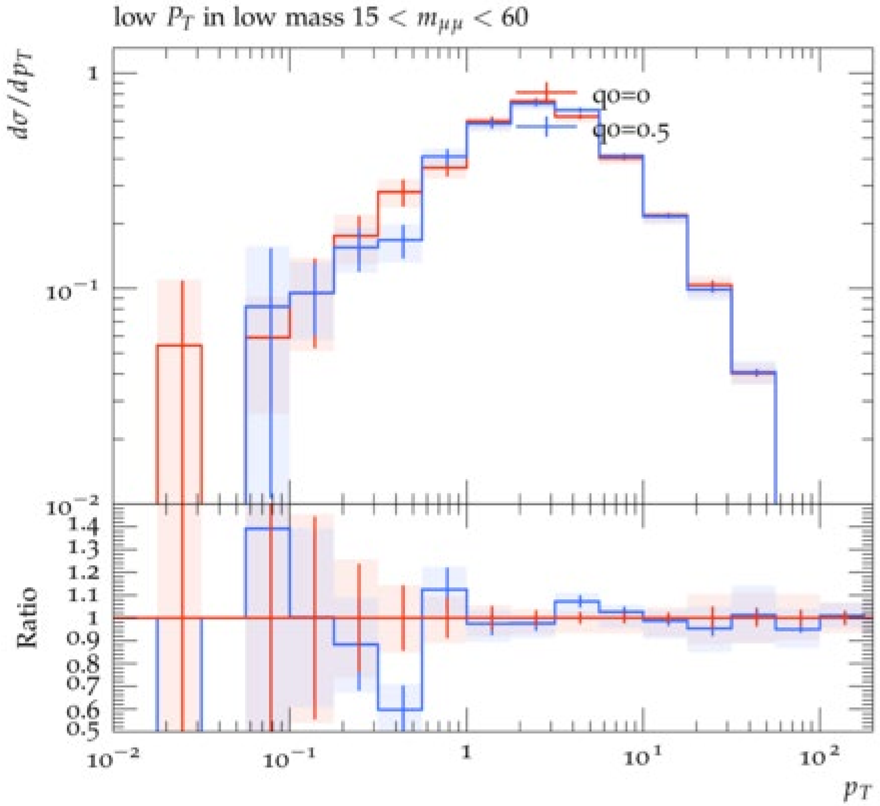


Is there any sensitivity to intrinsic k_t in pt spectrum?

Results

DY pt spectrum





The sensitivity to intrinsic k_t observed only at very small pt (where no observable exists).
A measurement at smaller pt for DY spectrum is proposed to the LHC expert.

Summary

- Two rivet plugins are coded and validated for CMS DY analyses which can be used for the future comparison of the prediction from any event generator
- The contribution of different flavour for different observable is studied
- The study was repeated with CASCADE MC generator
- The effect of having TMDs with different intrinsic k_t was checked

Thank you

DESY.

Backup

DESY.

Methodology

Technical info

Project A: Step I
Hard process : **POWHEG**

CM Energy = 8.16 TeV
Beam energy = 4.050 TeV
PDF = 13100 CT14nlo

MC generator : **Pythia8**
TimeShower:QCDshowe =on
SpaceShower:QCDshowe =on

Project B: Step I
Hard process : **POWHEG**

CM Energy = 1.380 TeV
Beam energy = 1.380 TeV
PDF = 13100 CT14nlo

MC generator : **Pythia8**
TimeShower:QCDshowe =on
SpaceShower:QCDshowe =on

Project A: Step II
Hard process : **MC@NLO**

CM Energy = 8.16 TeV
Beam1 energy = 6.500 TeV
Beam2 energy = 2.560 TeV
PDF = 1102200 PBset2
subtraction term=HERWIG6

MC generator : **Cascade3**
TimeShower = 0
SpaceShower = 0
TMD = 102200 PB-NLO-set2-qs=0.5

Project B: Step II
Hard process : **POWHEG**

CM Energy = 1.380 TeV
Beam energy = 1.380 TeV
PDF = 1102200 PBset2
subtraction term=HERWIG6

MC generator : **Cascade3**
TimeShower:QCDshowe =on
SpaceShower:QCDshowe =on
TMD = 102200 PB-NLO-set2-qs=0.5

Motivation

DY process

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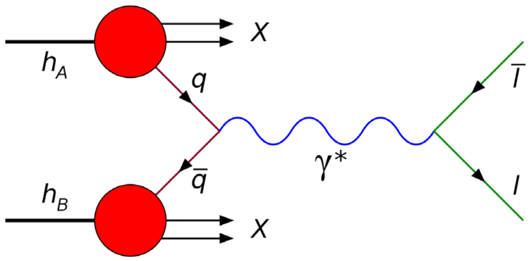

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- a "standard candle" for electroweak precision measurements at LHC
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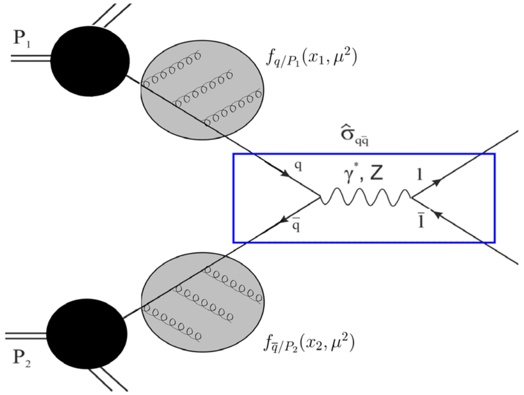
DESY.



The description of the DY data in a wide kinematic regime is problematic:
DY observables with multiple energy scales involved (DY $p_\perp$ spectrum) with different physics.
in low $p_\perp$ region: soft gluons need to be resummed.

Tools:

Rivet (Robust Independent Validation of Experiment and Theory): A C++ tool for validation of Monte Carlo event generator

POWHEG (Positive Weight Hardest Emission Generator): to calculate the exact hard matrix element at NLO

MADGRAPH5 aMC@NLO: to matrix element processes are calculated with collinear parton densities (PDF), as provided by LHAPDF with proper subtraction term for CASCADE

Pythia8: MC event generator used for validation

Cascade3: MC event generator used for intrinsic kt study

DESY.

Reference to PYTHIA8 , CASCADE, Rivet

- **Pythia 8:**
- Torbj¨orn Sj¨ostrand et al. “An introduction to PYTHIA 8.2”. In:ComputerPhysics Communications191 (June 2015), pp. 159–177.issn: 0010-4655.doi:10.1016/j.cpc.2015.01.024.url:http://dx.doi.org/10.1016/j.cpc.2015.01.024

  Torbj¨orn Sj¨ostrand, Stephen Mrenna, and Peter Skands. “PYTHIA 6.4physics and manual”. In:Journal of High Energy Physics2006.05 (May2006), pp. 026–026.issn: 1029-8479.doi:10.1088/1126-6708/2006/05/026.url:http://dx.doi.org/10.1088/1126-6708/2006/05/026

- **CASCADE 3:**
- S. Baranov et al. “CASCADE3 A Monte Carlo event generator based onTMDs”. In:The European Physical Journal C81.5 (May 2021).issn: 1434-6052.doi:10.1140/epjc/s10052-021-09203-8.url:http://dx.doi.org/10.1140/epjc/s10052-021-09203-8

- **RIVET:**

  Christian Bierlich et al. Robust Independent Validation of Experiment and Theory: Rivet version 3.SciPost Phys., 8:026, 2020.

DESY.

Results

Project A: Cascade + MC@NLO