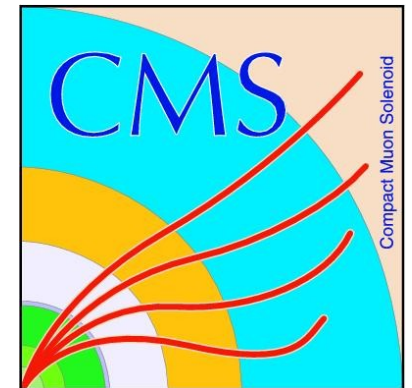

Measurement of double differential Drell-Yan and associated jets cross section at low and high invariant masses in proton-proton collisions at $\sqrt{s} = 7$ TeV

Samantha Dooling

On behalf of the CMS Collaboration
30th April 2014

DIS 2014

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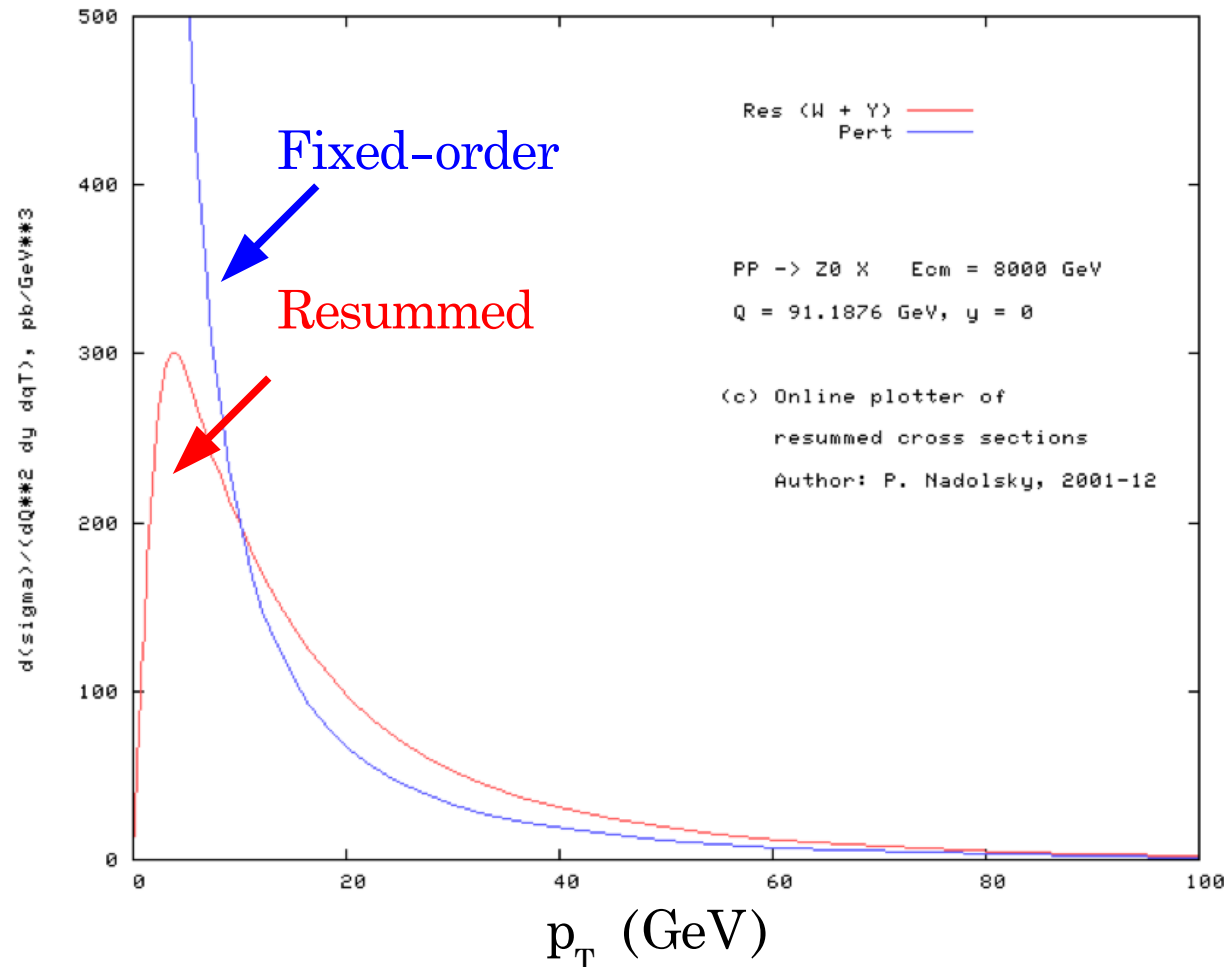
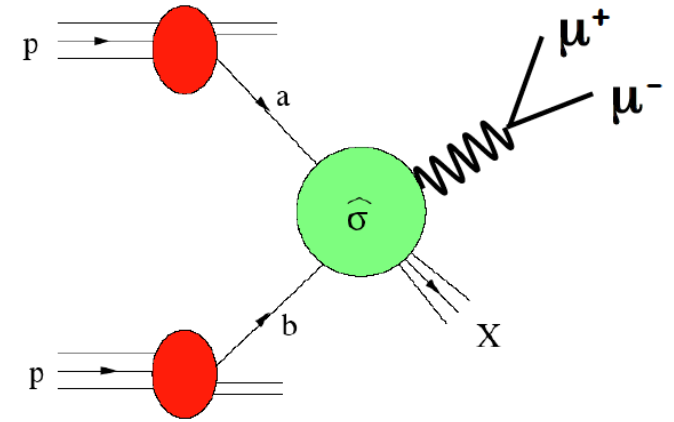
Content

- Introduction to the Drell-Yan process and Resummation
- Motivation
- Event Selection
- Cross Section Measurement
- Results
- Summary & Conclusions

Introduction

The Drell-Yan (DY) process:

$q \bar{q}$ annihilation into a virtual photon or Z boson decaying into two leptons



Differential hard cross section = convolution of **parton density fct** and **partonic cross section**

At small scale : large logarithms appear

Fixed-order calculation diverges at small scales

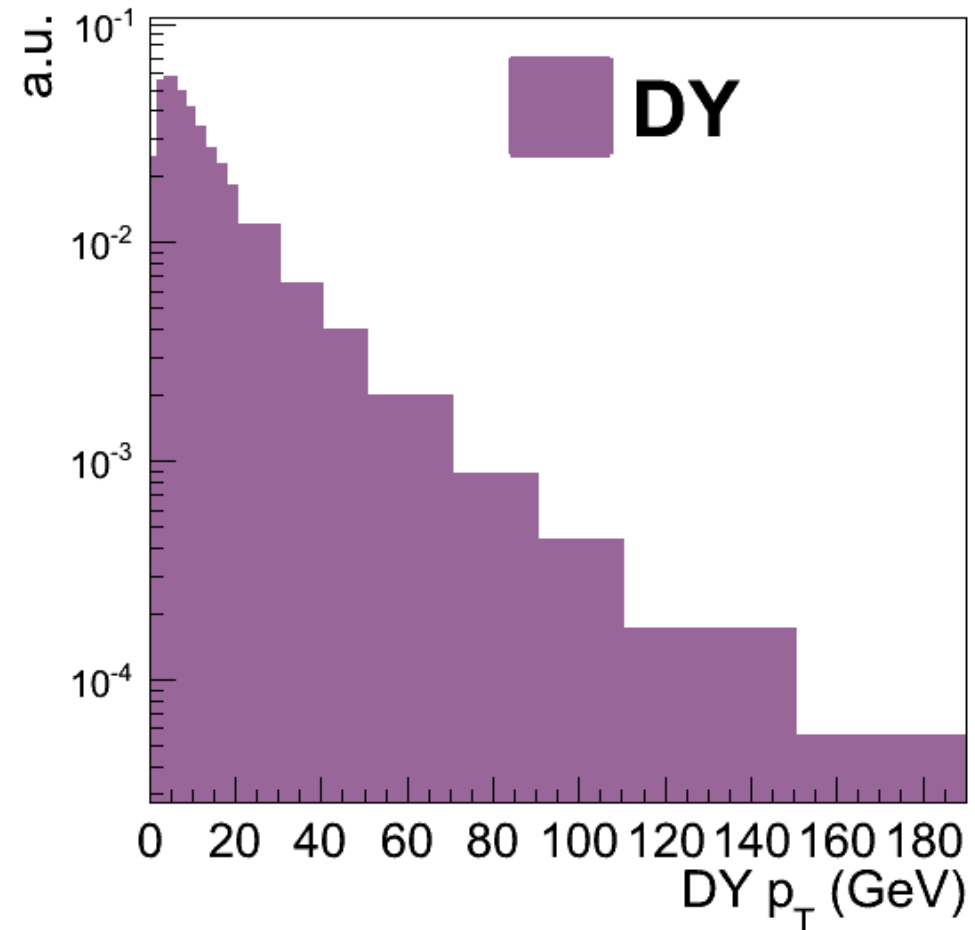
Partonic Cross Section needs to be **resummed** to describe the decrease at low p_T

Motivation

DY dilepton pair transverse momentum distribution

- ▶ **Small p_T** : resummed higher-order contributions dominate
- ▶ **Large p_T** : perturbative QCD corrections at fixed-order

Inclusive **DY** transverse momentum
Maximum $p_T \sim 5$ GeV



Motivation

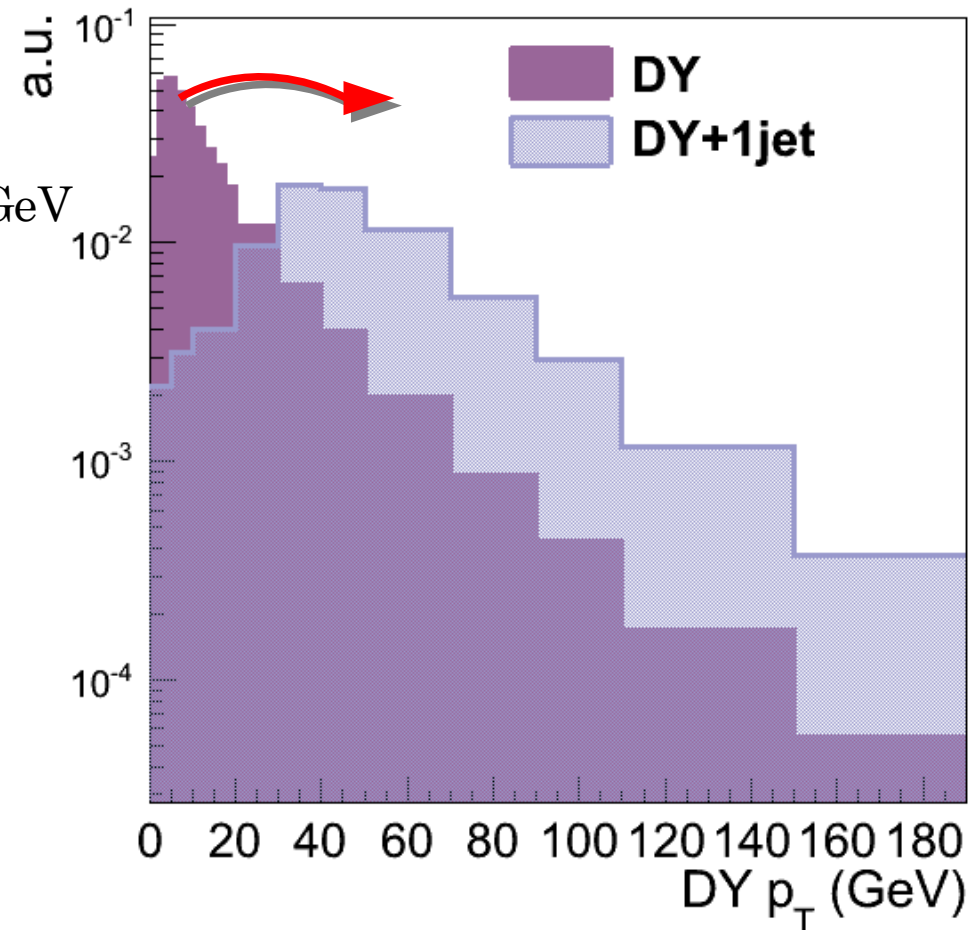
DY dilepton pair transverse momentum distribution

- ▶ **Small p_T** : resummed higher-order contributions dominate
- ▶ **Large p_T** : perturbative QCD corrections at fixed-order

DY in association with jets ($p_T > 30 \text{ GeV}$)

Maximum is shifted towards higher $p_T \sim 35 \text{ GeV}$

Increases the phase space for soft gluon radiation



Motivation

DY dilepton pair transverse momentum distribution

- ▶ **Small p_T** : resummed higher-order contributions dominate
- ▶ **Large p_T** : perturbative QCD corrections at fixed-order

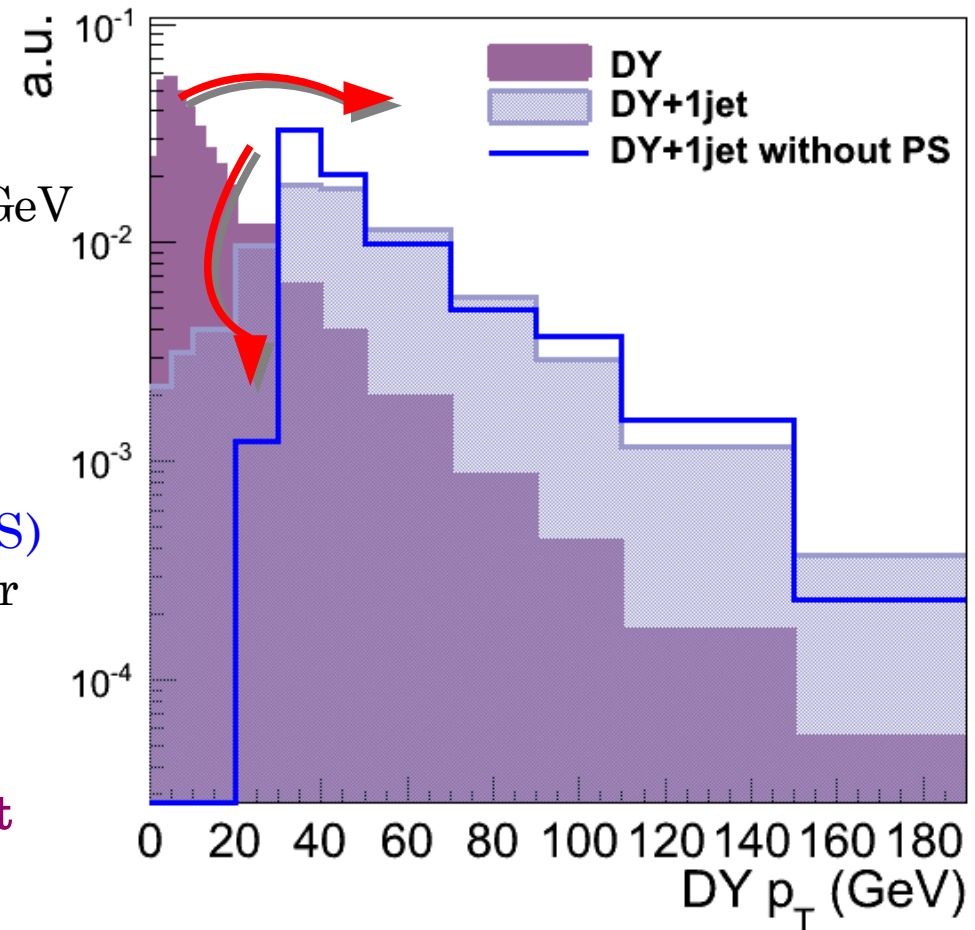
DY in association with jets ($p_T > 30 \text{ GeV}$)

Maximum is shifted towards higher $p_T \sim 35 \text{ GeV}$

Rise at small p_T comes from soft gluon resummation

Treated by the **initial state parton shower (PS)** algorithms of the Monte Carlo event generator

Allows to observe perturbative large p_T jet resummation



Event Selection

- Two opposite charged muons
- Muons have to be isolated to ensure they emerge from an electroweak process

$$|\eta_{\mu}^{lead, sublead}| < 2.1$$

$$p_T^{lead} > 20 \text{ GeV}, p_T^{sublead} > 10 \text{ GeV}$$

- Jets are defined by the anti- k_T algorithm ($R=0.5$)
- Jet $p_T > 30 \text{ GeV}$ and $|\eta| < 4.5$
- Separate the jets from the two muons by $\Delta R > 0.5$

Drell-Yan Measurement

- Measurement is performed in bins of the dimuon invariant mass (30-1500GeV)
- Investigate transverse momentum spectra as a function the Drell-Yan lepton pair mass to change the scale
- Relevant background contributions:
ttbar, QCD, $Z \rightarrow \tau \tau$, W+jets, diboson
- Background is subtracted from data events
- Data is corrected to stable particle level
- Systematic uncertainties:
Unfolding, JEC, pileup reweighting, efficiency correction, background estimation
- Cross sections are normalized by cross section in the Z Peak region (60-120GeV) to reduce systematics

Cross Section Measurement

Inclusive

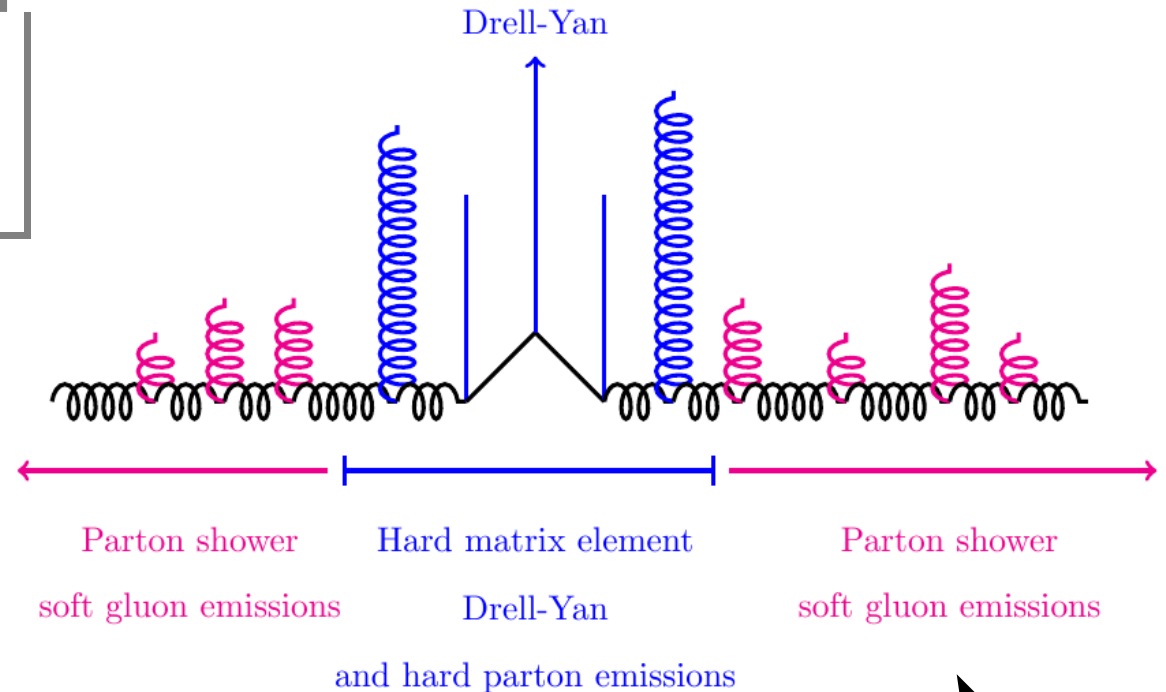
DY+1jet

DY+2jets

$$d^2\sigma/dm^{\mu\mu}dp_T^{\mu\mu}$$

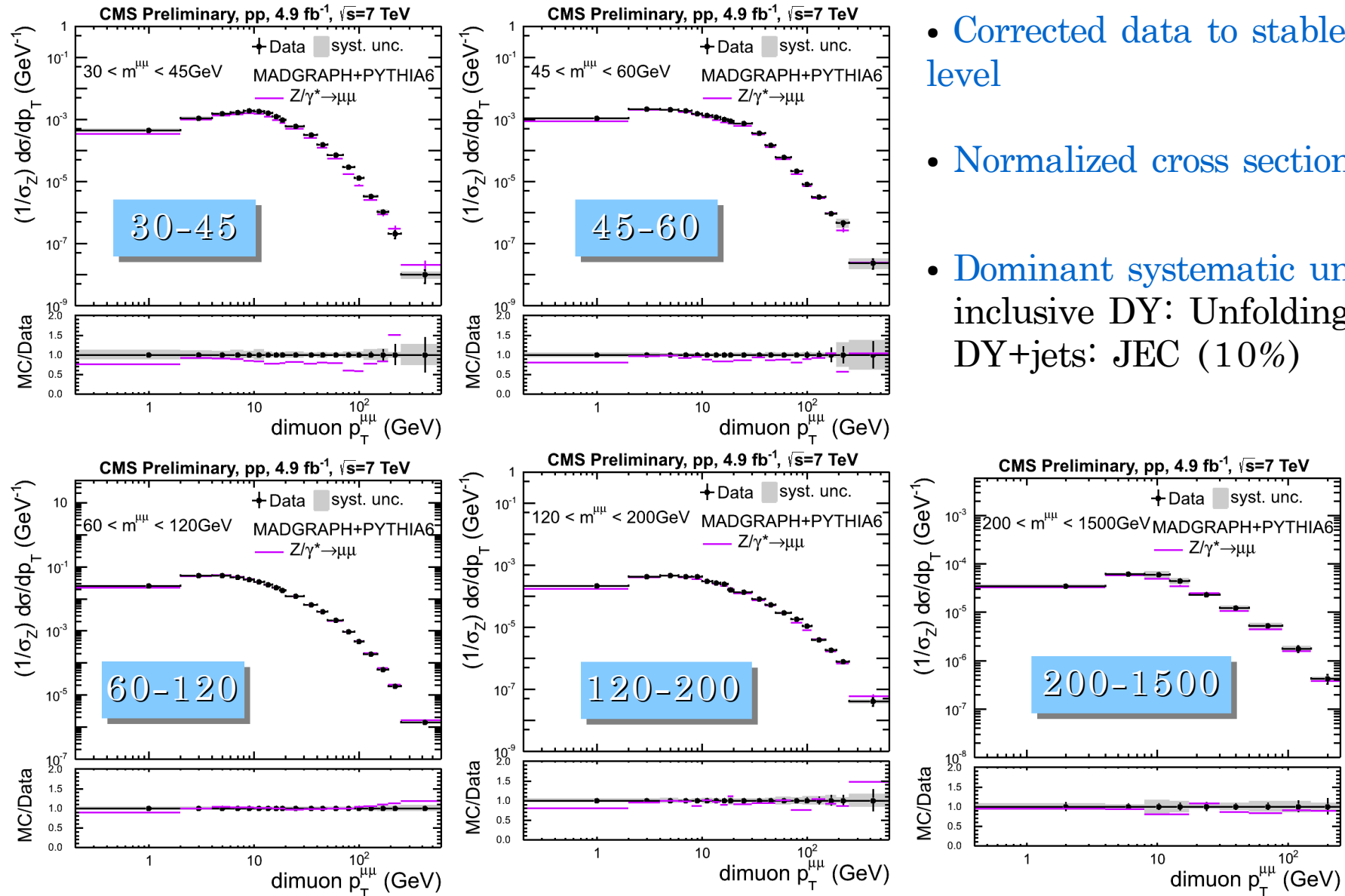
- Double differential cross section in p_T and mass
- Five bins in invariant mass
- Inclusive Drell-Yan production
- Drell-Yan production in association with at least one jet
- Drell-Yan production in association with at least two jets

Data is compared to Monte Carlo predictions



MadGraph generates the hard process with ≤ 4 partons

Parton shower is modelled by PYTHIA6

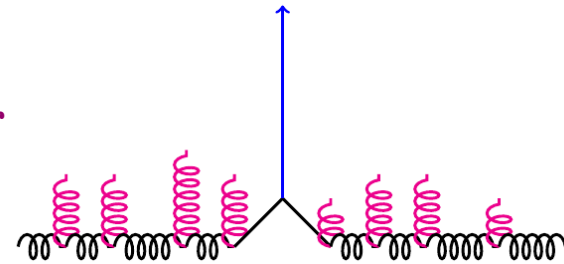


- Corrected data to stable particle level
- Normalized cross sections
- Dominant systematic uncertainty inclusive DY: Unfolding (8%)
DY+jets: JEC (10%)

Monte Carlo Comparison

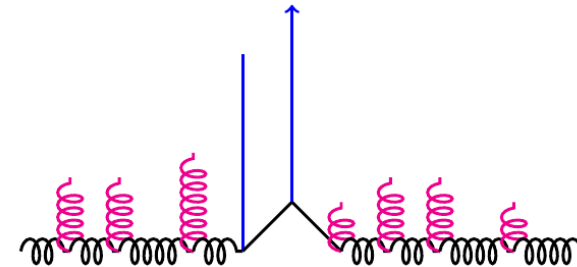
- PYTHIA6 (Z2*)
- Inclusive DY production

Lowest Order
in α_s



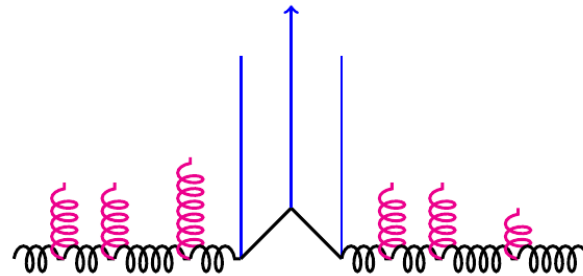
- PYTHIA6 (Z2*)
- $O(\alpha_s)$ DY production

First Order
in α_s

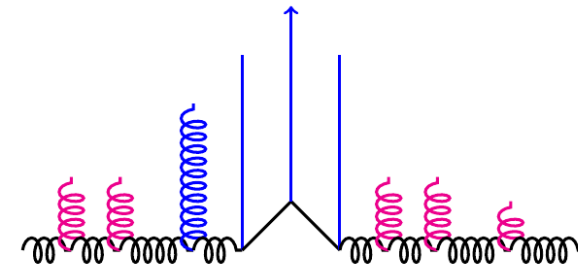


DY is
balanced by
the hard
parton
emission

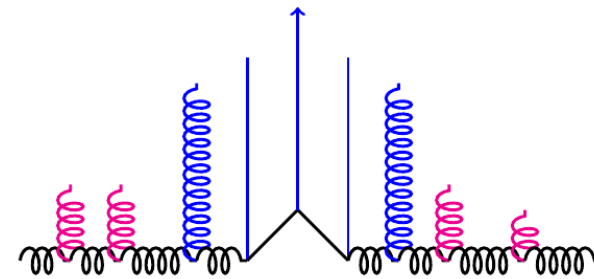
- POWHEG+PYTHIA6 (Z2*)
- DY + 2 jets at NLO
- HERAPDF



+



- MadGraph+PYTHIA6 (Z2)
- 4 partons in the matrix element calculation

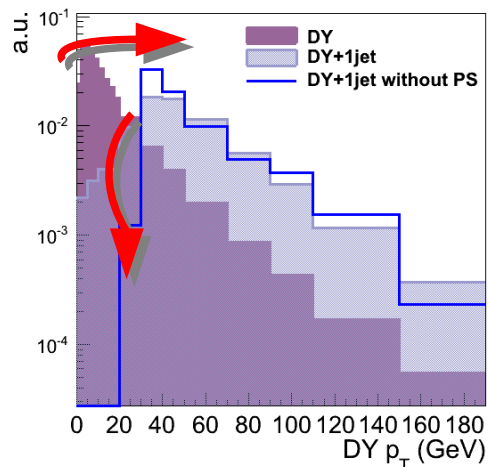
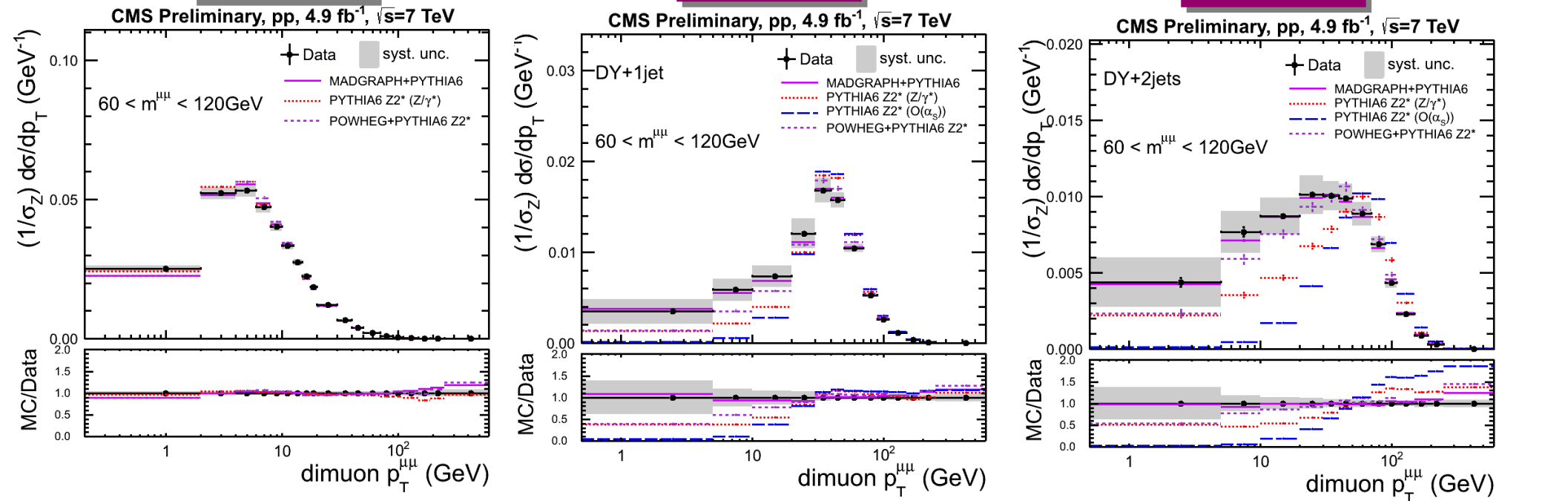


Results $d^2\sigma/dm^{\mu\mu} dp_T^{\mu\mu}$

Inclusive

DY+1jet

DY+2jets



- Maximum of the distribution is shifted to higher p_T when requiring additional jets
- Inclusive DY : all MC show nice agreement to data
- DY+ jets :
 - Lowest order α_s fails: too low cross section at low p_T
 - Higher O(α_s): good agreement

Drell-Yan

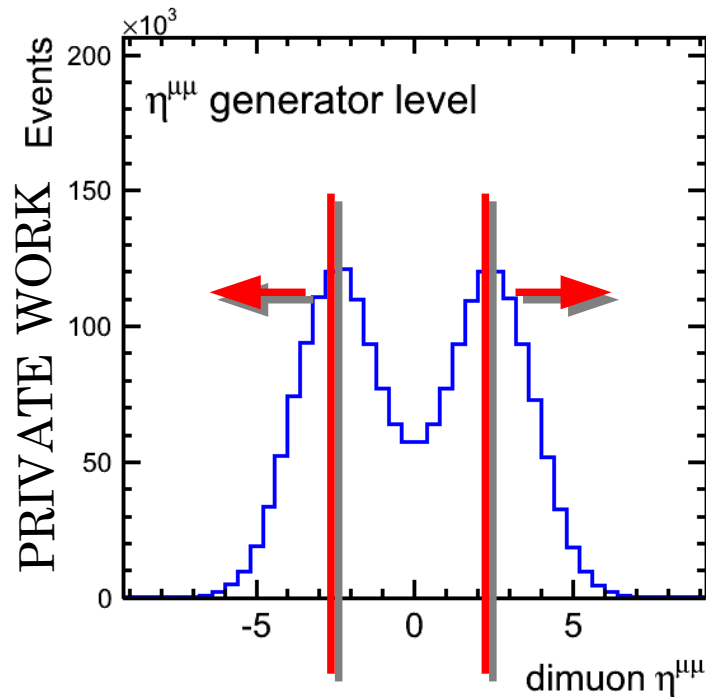
$$\frac{d^2\sigma}{dm d|\Delta y(\mu\mu, j)|}$$

DY+1jet

DY+2jets

○ Double differential cross section in absolute rapidity separation between DY and leading Jet and mass

○ Three bins in invariant mass
30-60, 60-120, 120-1500GeV

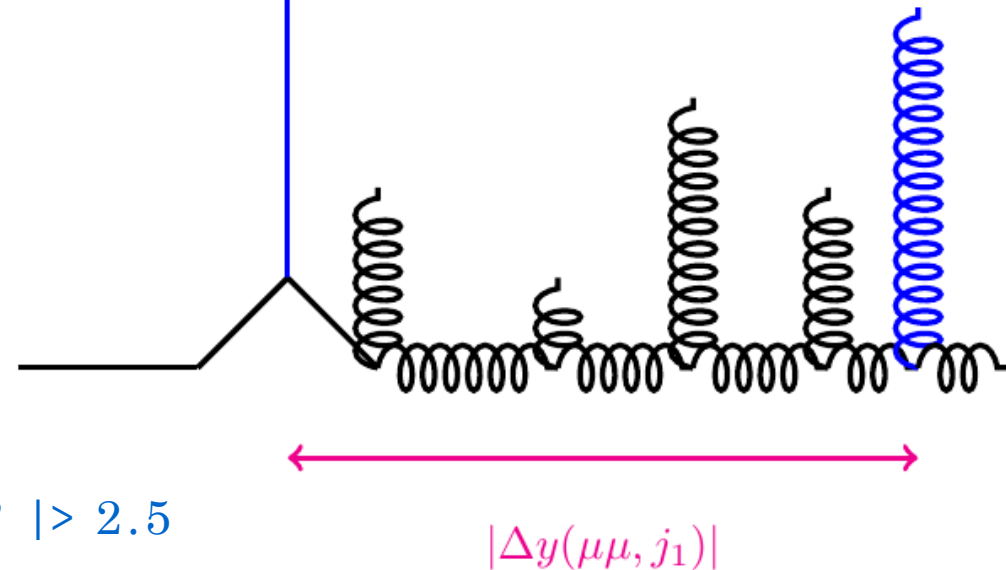


Drell-Yan

$|\eta| > 2.5$

lead. jet

$p_T > 30\text{GeV}, |\eta| < 4.5$



○ Forward Drell-Yan production $|\eta| > 2.5$

$$\eta^{\text{DY}} = \eta(\mu_1) + \eta(\mu_2)$$

○ Drell-Yan production in association with at least one jet and at least two jets

Results

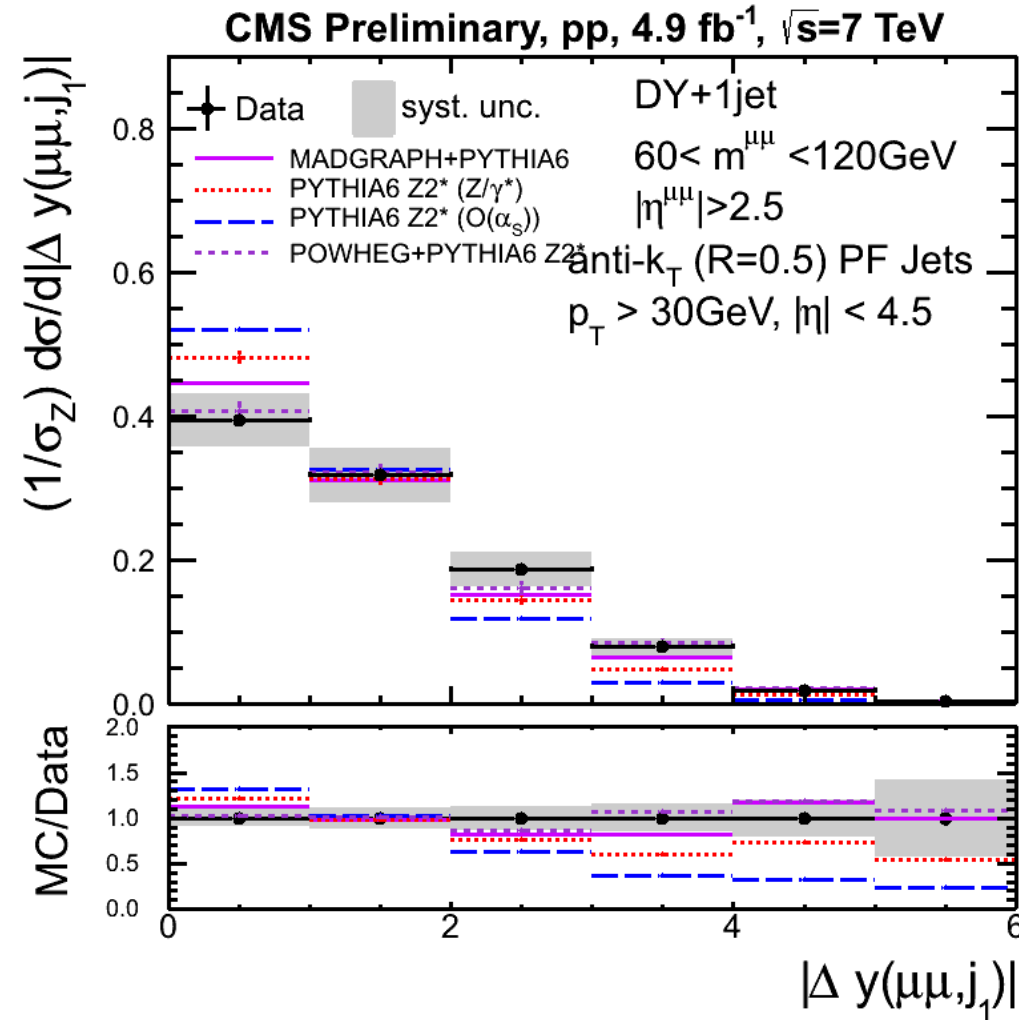
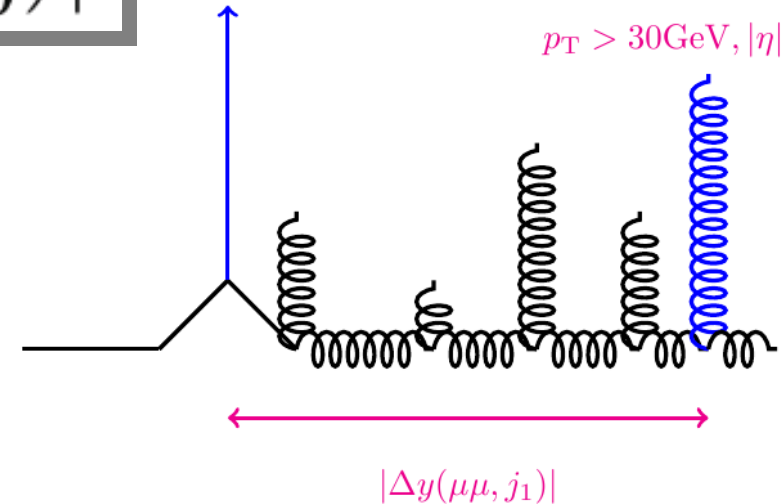
60-120

DY+1jet

$$\frac{d^2\sigma}{dm d|\Delta y(\mu\mu, j)|}$$

Drell-Yan
 $|\eta| > 2.5$

lead. jet
 $p_T > 30\text{GeV}, |\eta| < 4.5$

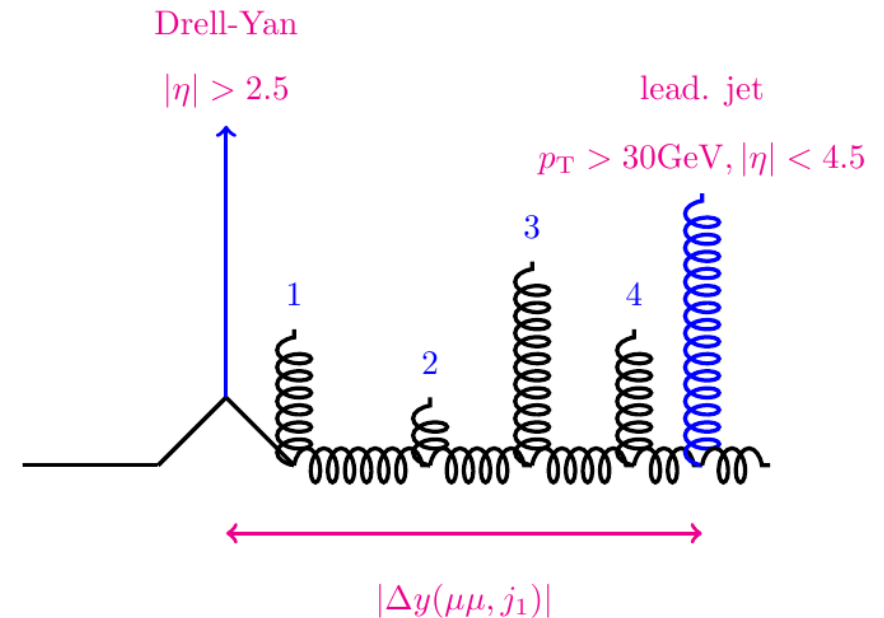
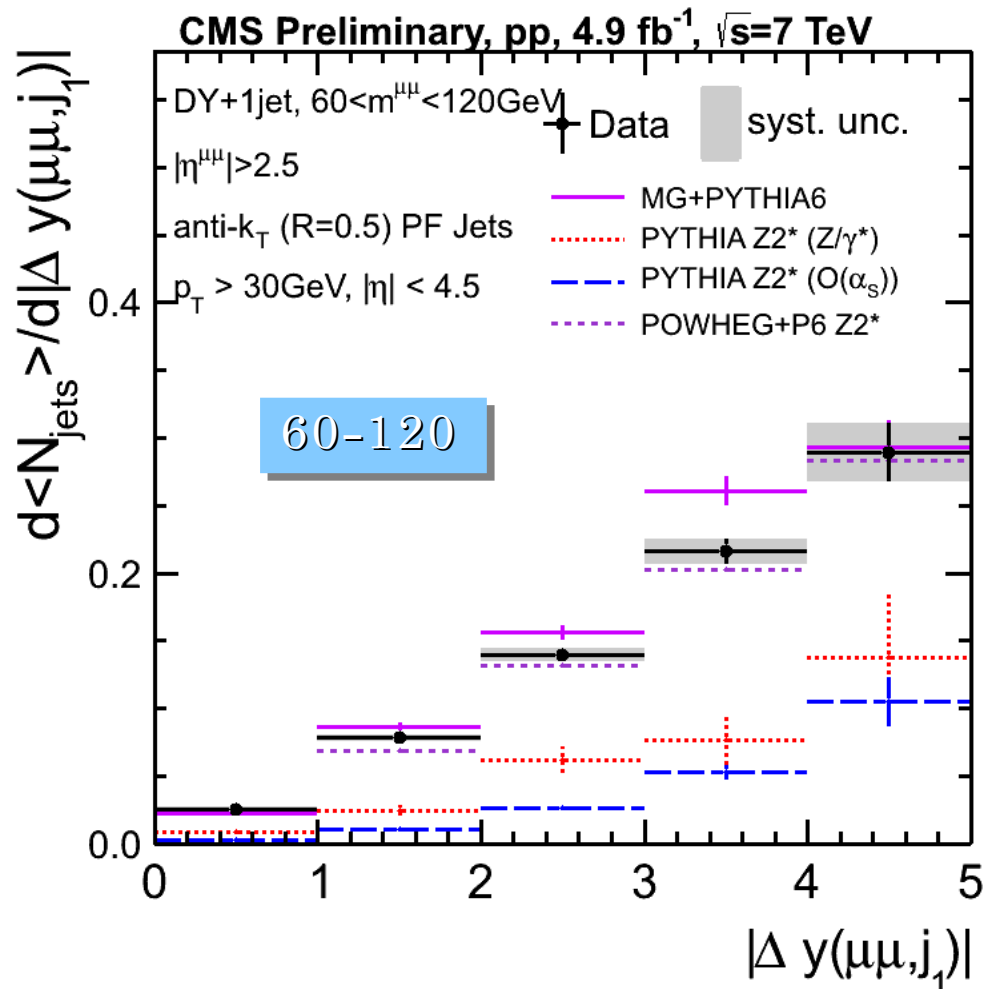


- Large rapidity separation, up to 6
- Decreasing cross section
- General behaviour is described by MC
- Higher order calculations provide better agreement to data

Jet Multiplicity

DY+1jet

- ▶ Average Number of Jets in Δy of DY and the leading jet
- ▶ Forward DY production ($|\eta| > 2.5$)



- ▶ Increasing jet multiplicity with increasing Δy
- ▶ Calculations to higher order $O(\alpha_s)$ show good description
- ▶ Lowest and first order calculations predict too low jet multiplicity

Summary

► Double differential cross section in mass and transverse momentum of the dimuon pair (2011 Data, 4.9fb^{-1})

$$d^2\sigma/dm^{\mu\mu}dp_T^{\mu\mu}$$

► Normalized cross section for the three production processes (inclusive DY, DY+1jet, DY+2jets)

- Increased sensitivity to soft gluon resummation by using DY + jets
- Soft gluon resummation is well described by parton shower algorithm

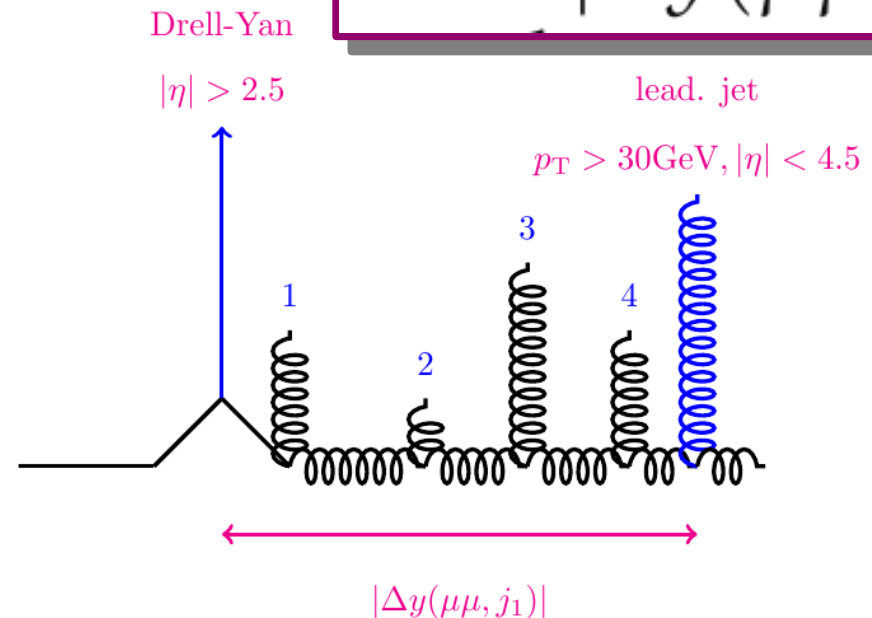
► Double differential cross section in mass and absolute rapidity separation between forward DY and leading jet

$$\frac{d^2\sigma}{dm d|\Delta y(\mu\mu, j)|}$$

- Higher order calculations provide better agreement to data

► Jet multiplicity as a function of Δy

- Increase of average jet multiplicity
- Calculations to higher order $O(\alpha_s)$ show good description

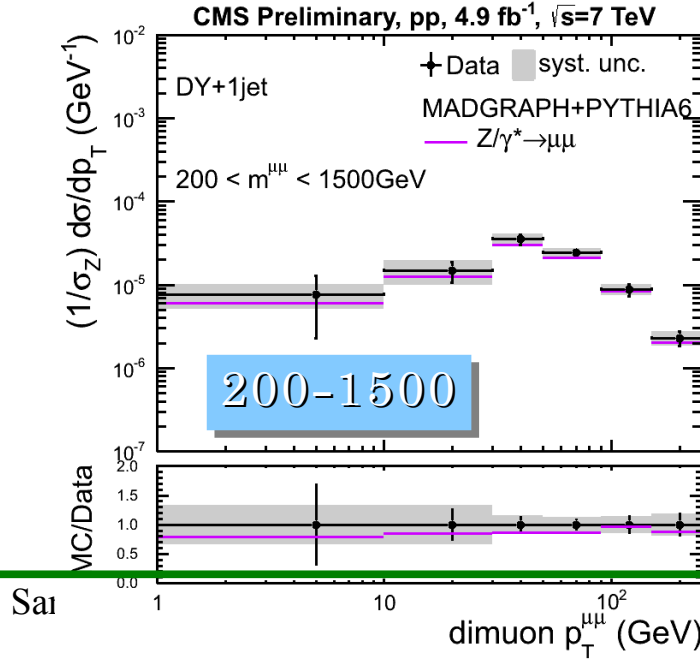
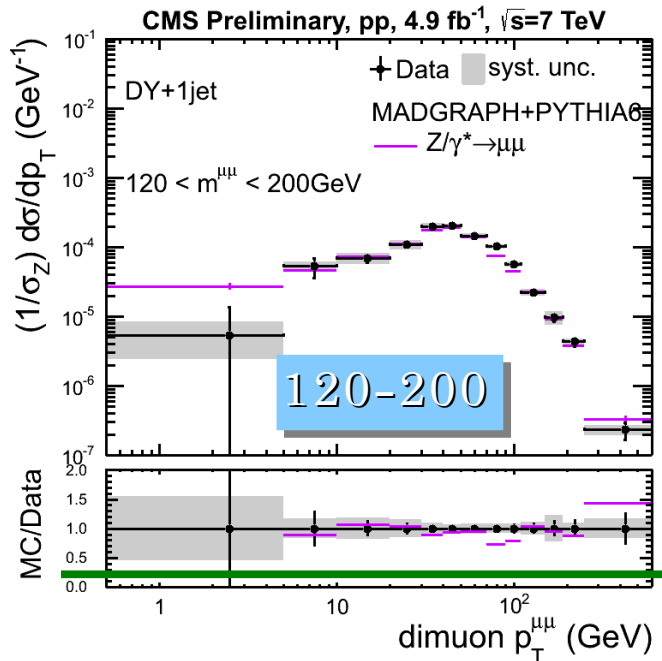
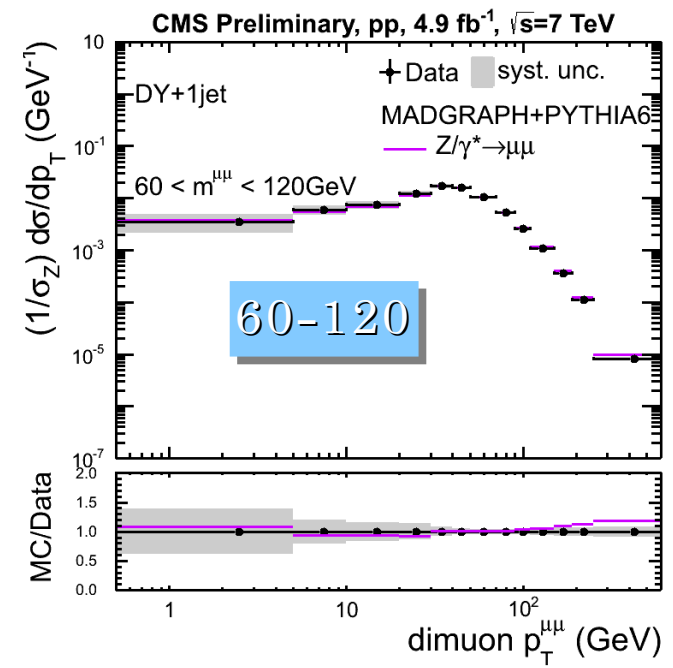
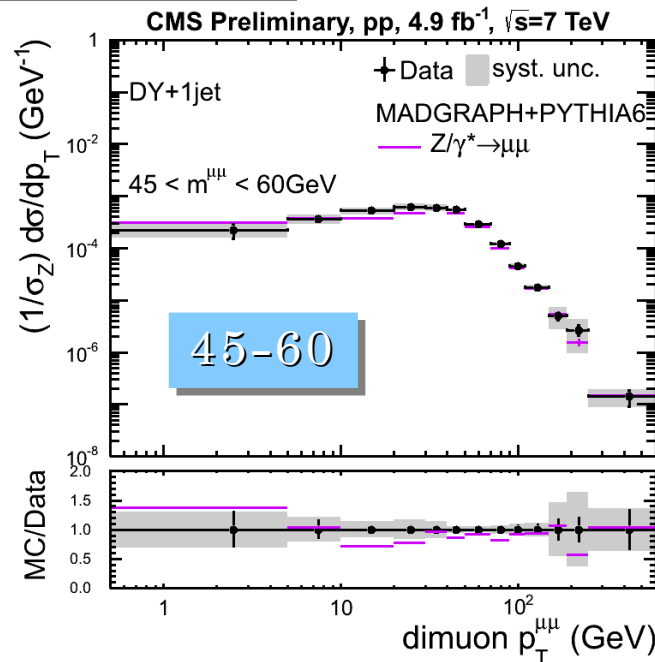
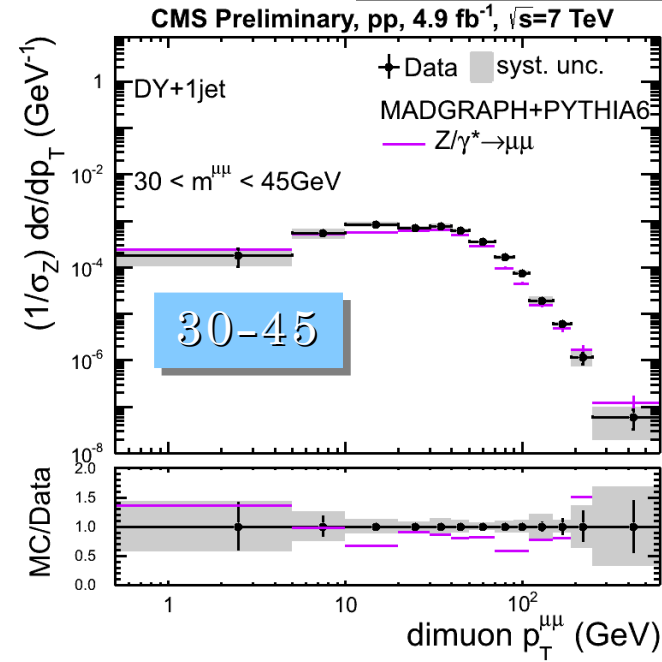


Backup

Results $d^2\sigma/dm^{\mu\mu} dp_T^{\mu\mu}$

DY+1jet

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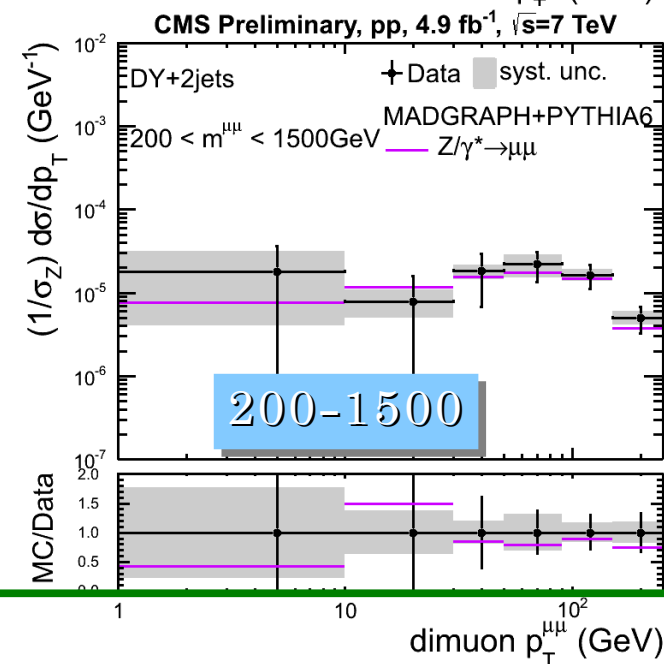
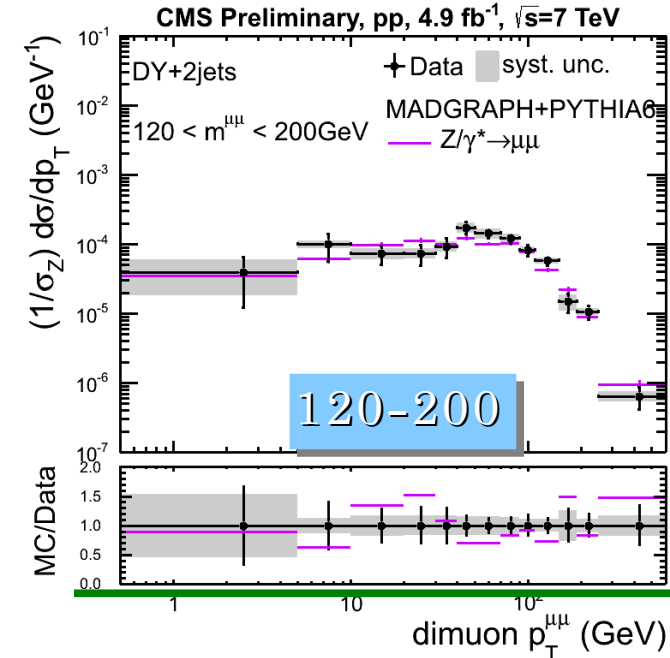
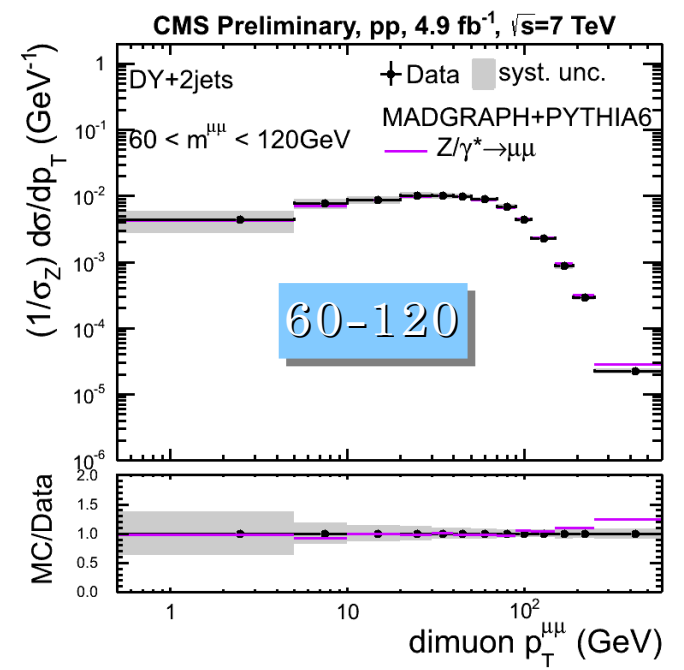
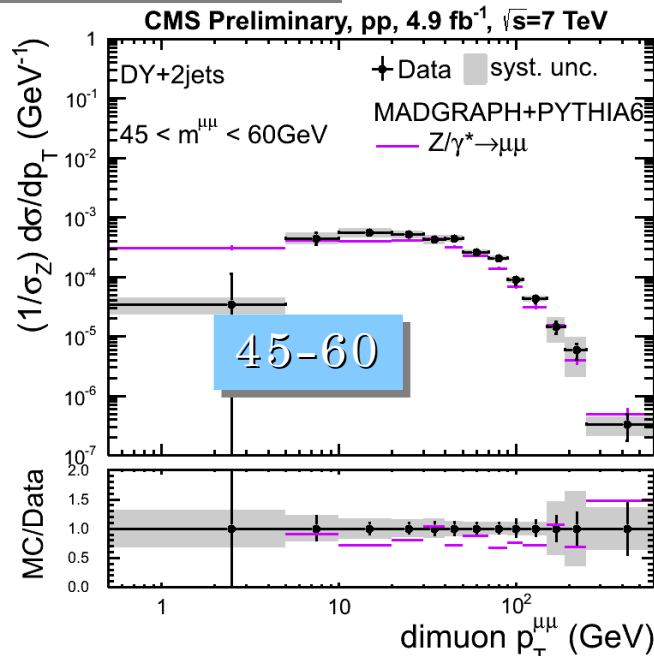
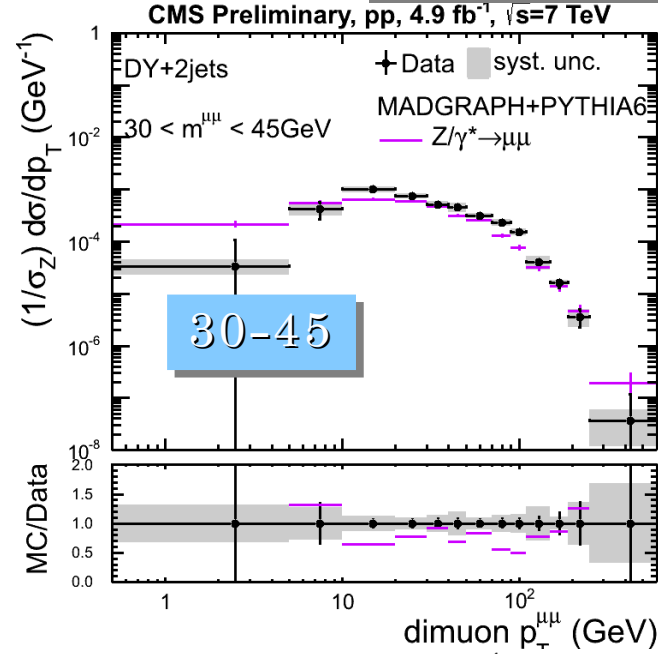
on-Synchrotron (DESY)

18

Results $d^2\sigma/dm^{\mu\mu} dp_T^{\mu\mu}$

DY+2jets

CMS-PAS-FSQ-13-003



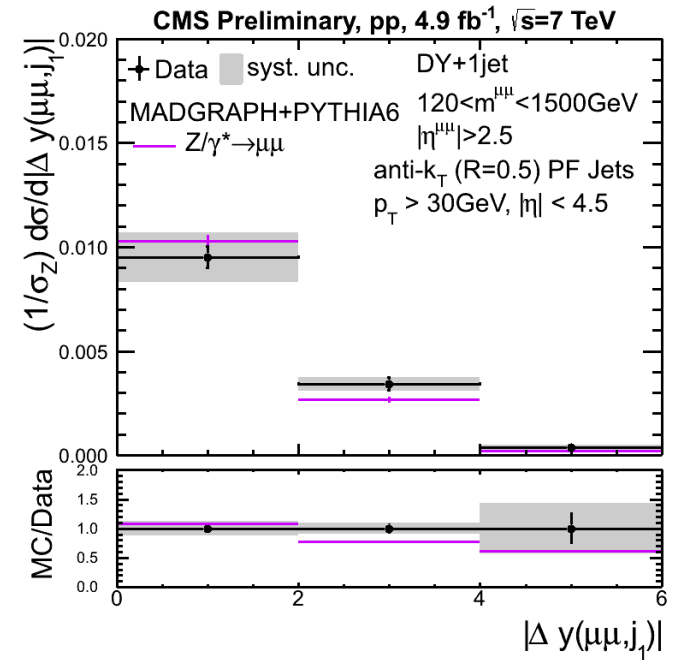
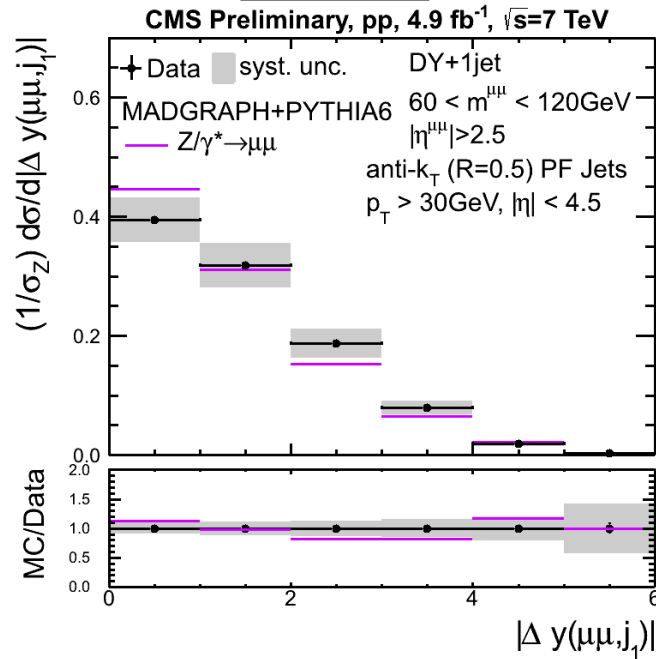
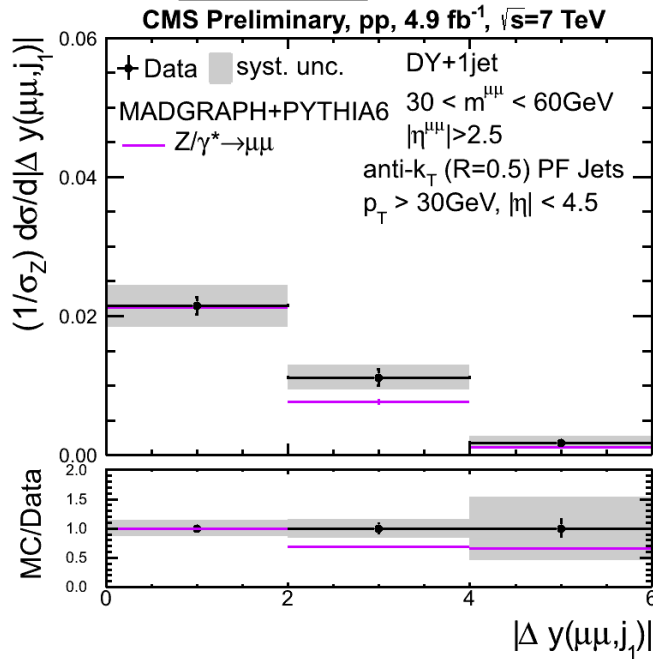
kronen-Synchrotron (DESY)

$$\frac{d^2\sigma}{dm d|\Delta y(\mu\mu,j)|}$$

30-60

60-120

120-1500



$$\frac{d^2\sigma}{dm d|\Delta y(\mu\mu,j)|}$$

