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

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On behalf of the CMS Collaboration

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- Motivation
- Event Selection
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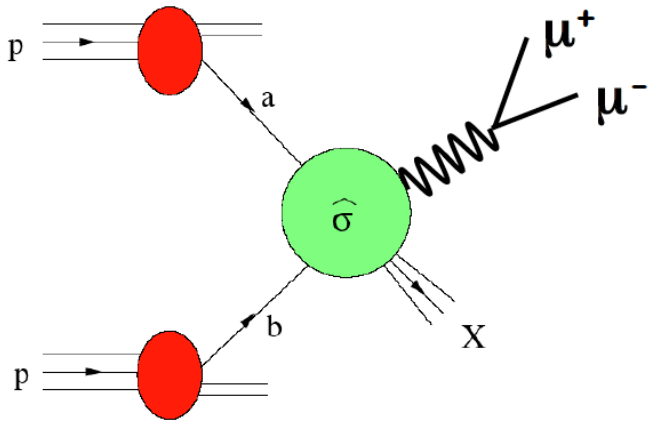
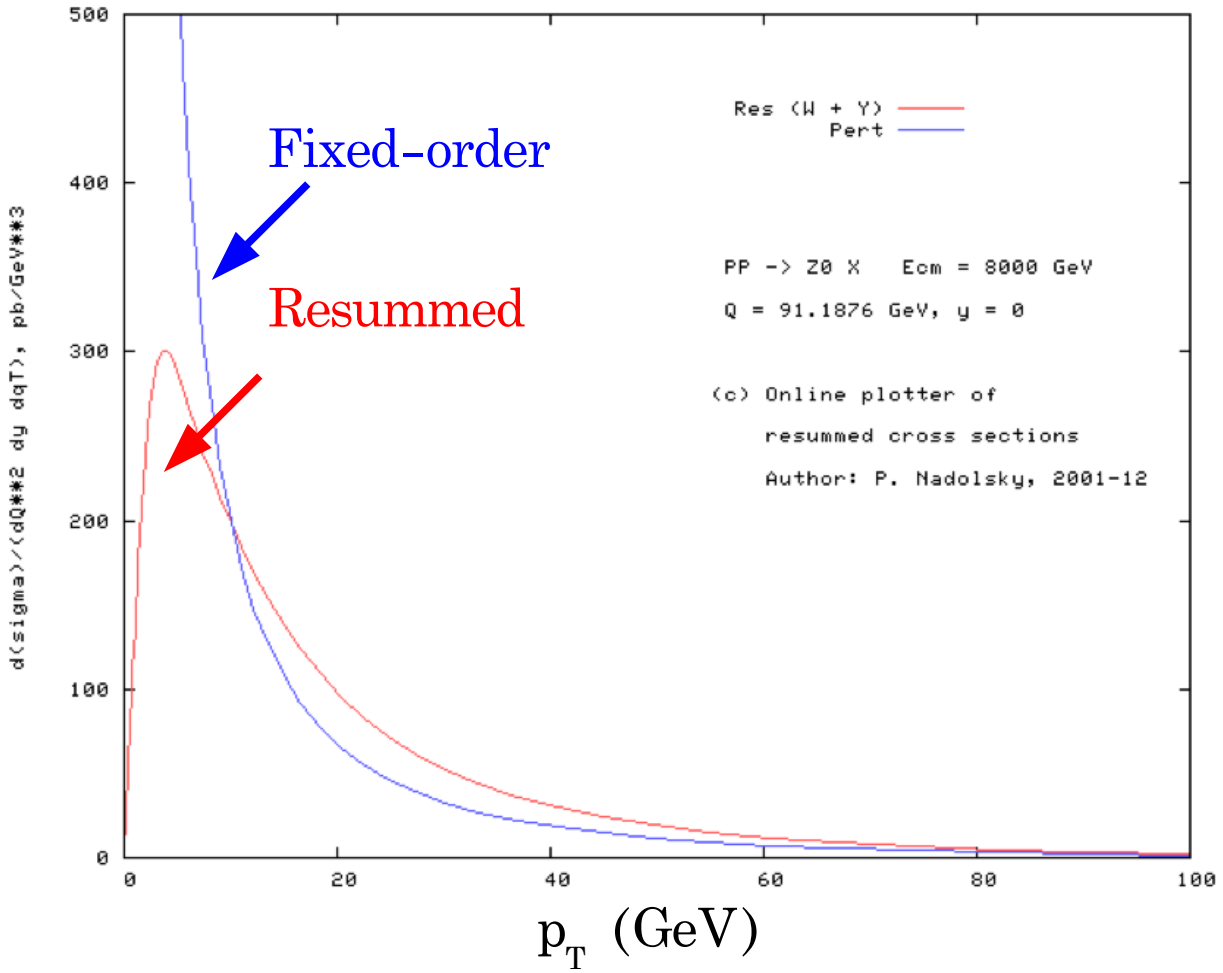
- Results
- Summary & Conclusions

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

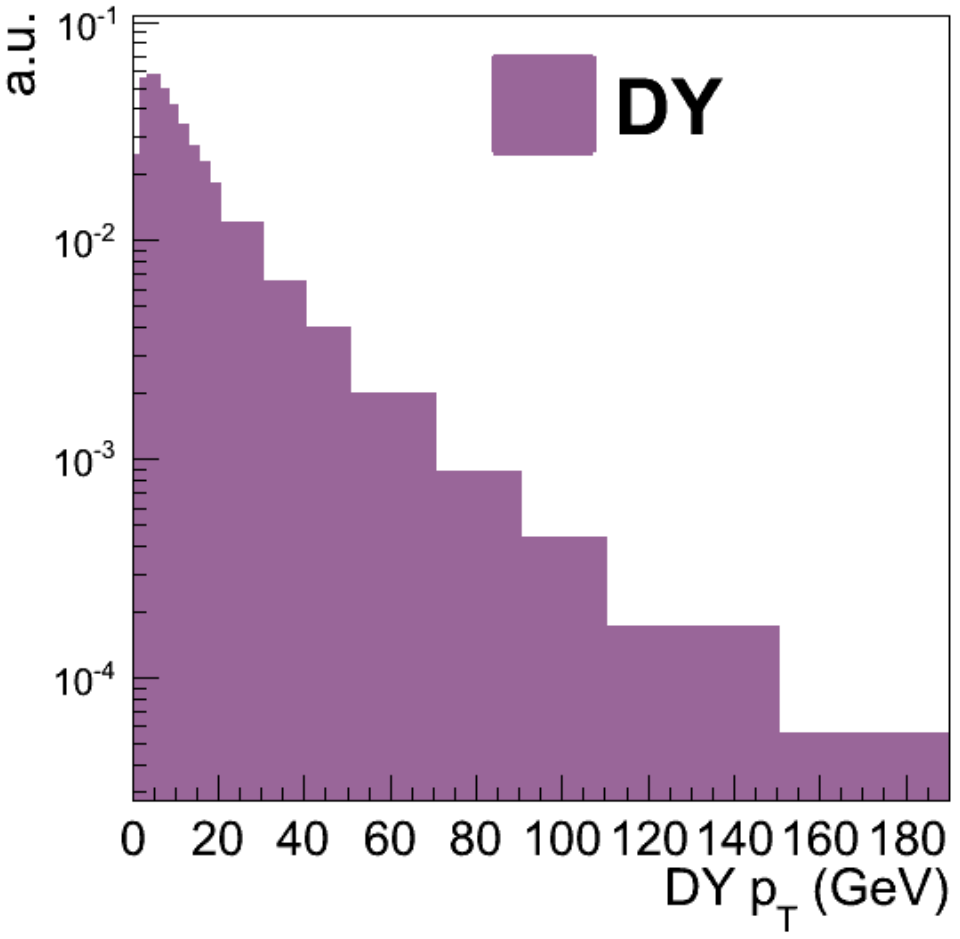
Partonic Cross Section needs to be resummed to describe the decrease at low p_T

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~ 5 GeV



Motivation

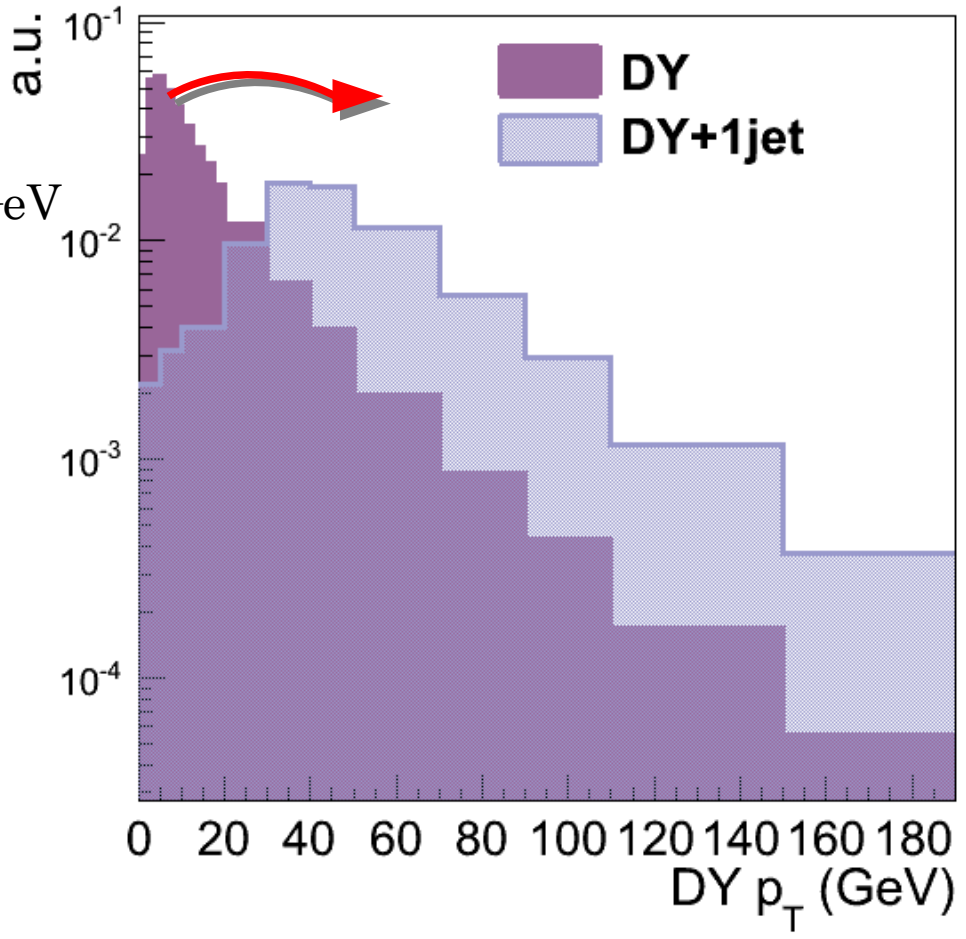
DY dilepton pair transverse momentum distribution

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

DY in association with jets (p_T>30GeV)

Maximum is shifted towards higher p_T~ 35 GeV

Increases the phase space for soft gluon radiation



Motivation

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DY in association with jets (p_T>30GeV)
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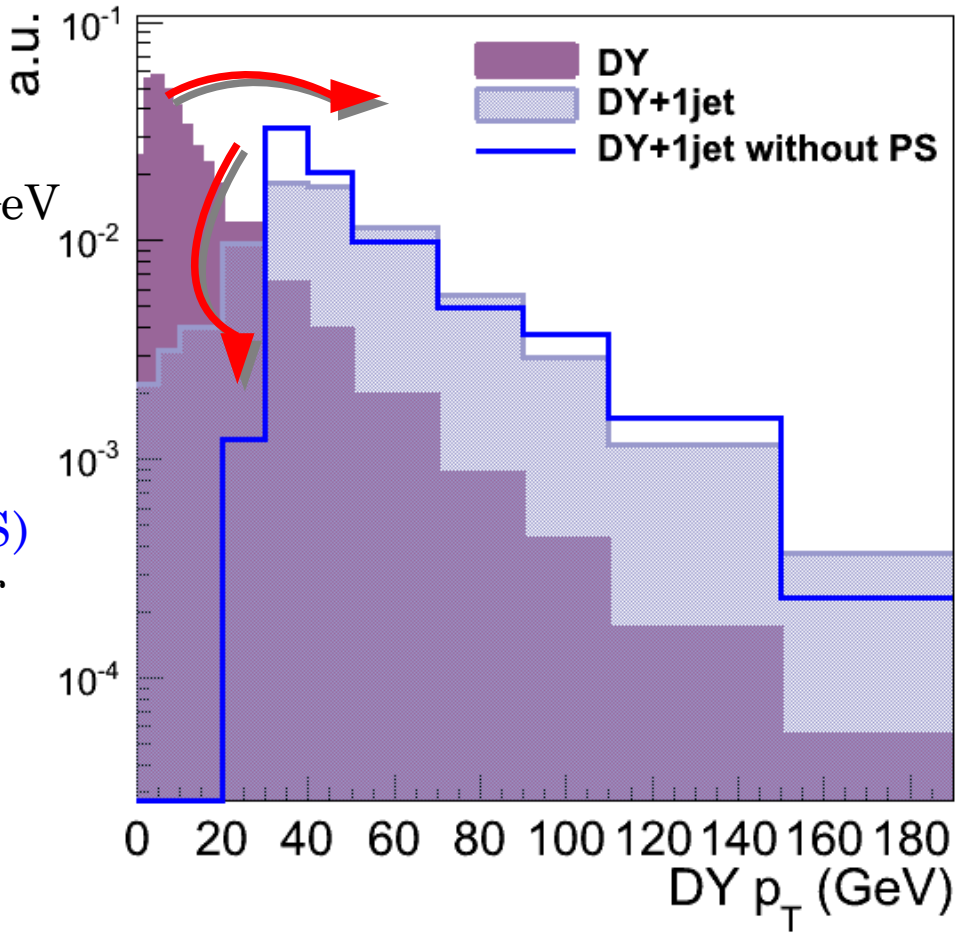
Rise at small p_T comes from soft gluon resummation

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

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

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

- Jets are defined by the anti-k_T algorithm (R=0.5)
- Jet p_T > 30GeV 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

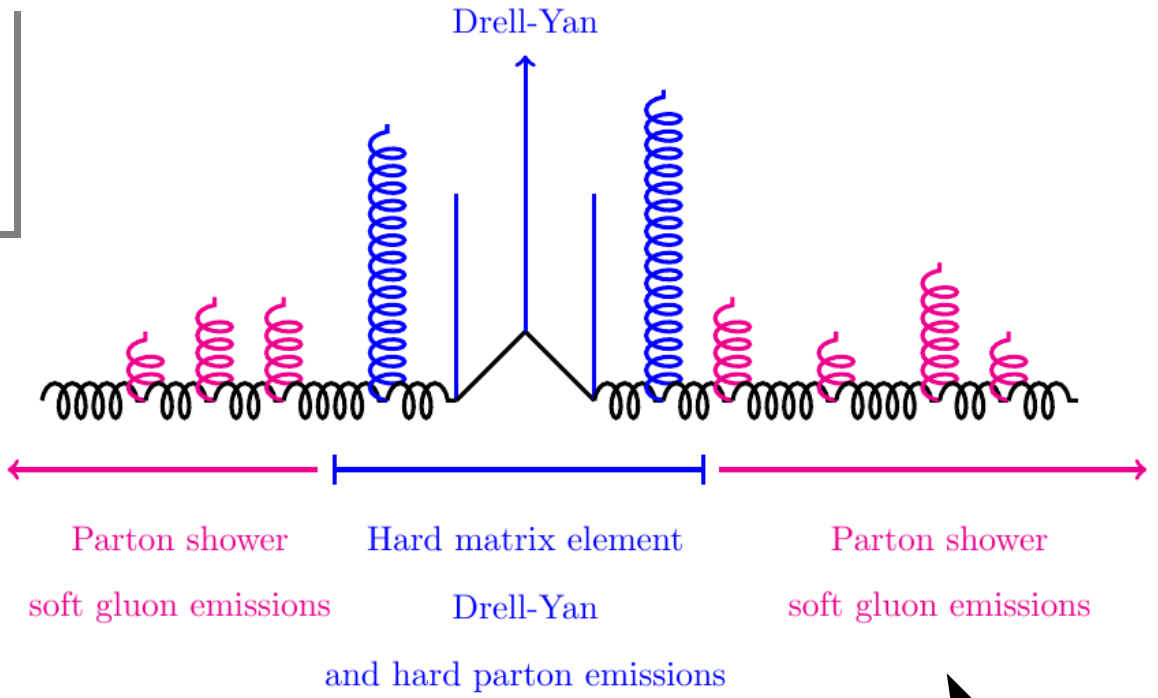
Cross Section Measurement

Inclusive | DY+1jet | DY+2jets

$$\mathrm{d}^2\sigma/\mathrm{d}m^{\mu\mu}\mathrm{d}p_{\mathrm{T}}^{\mu\mu}$$

- 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 $\leq$ 4 partons

Parton shower is modelled by PYTHIA6

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

Inclusive

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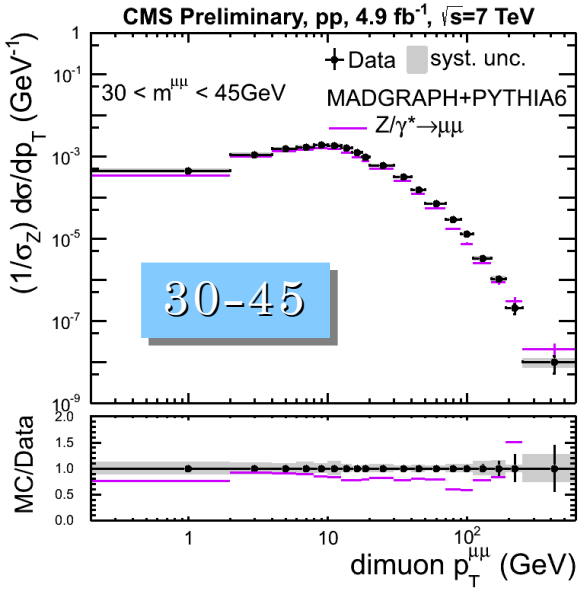
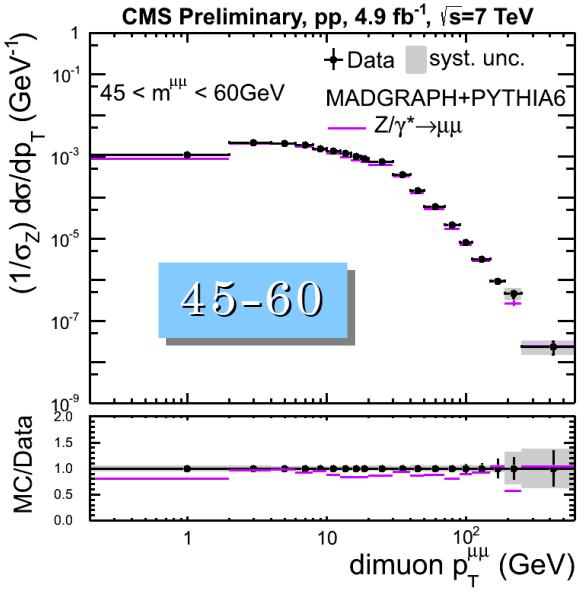
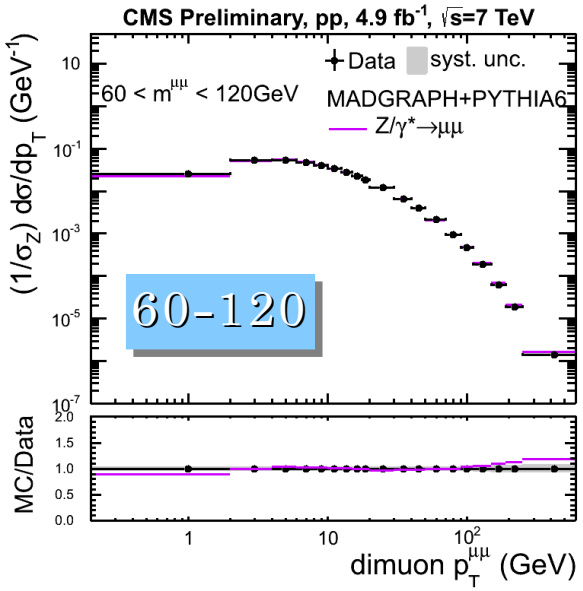
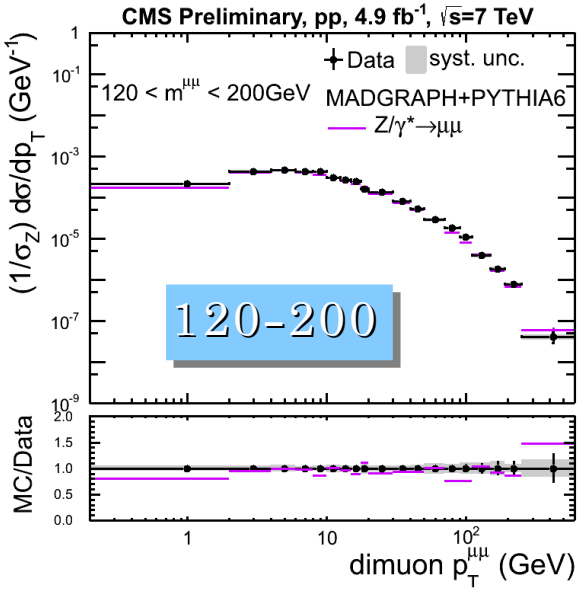
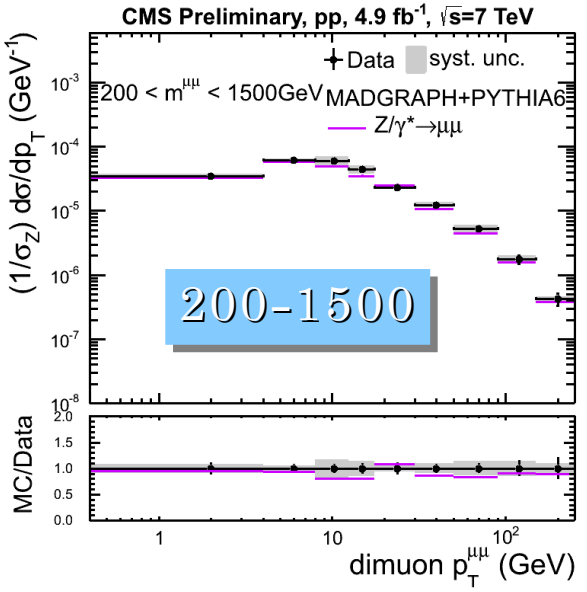




- Corrected data to stable particle level
- Normalized cross sections
- Dominant systematic uncertainty
  inclusive DY: Unfolding (8%)
  DY+jets: JEC (10%)



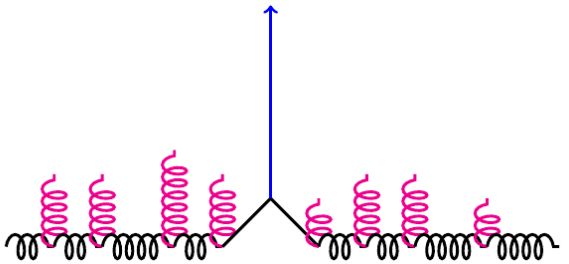




Monte Carlo Comparison

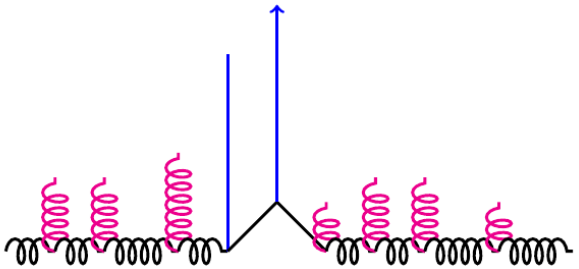
- PYTHIA6 (Z2*)
- Inclusive DY production

Lowest Order in α_s



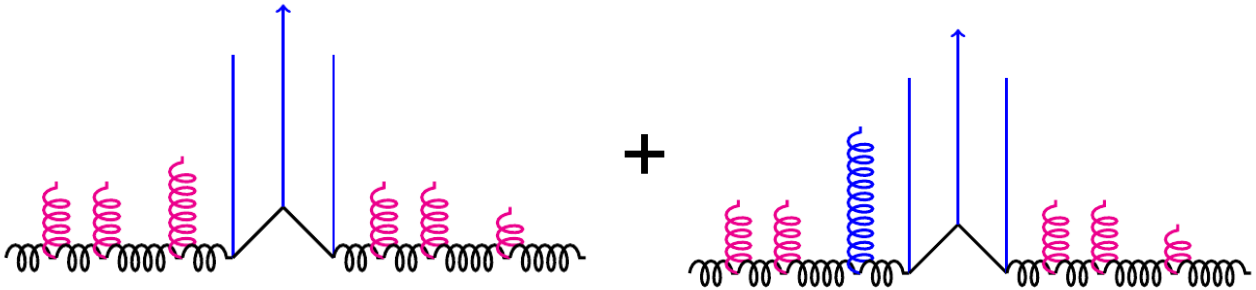
- PYTHIA6 (Z2*)
- $O(\alpha_s)$ DY production

First Order in α_s

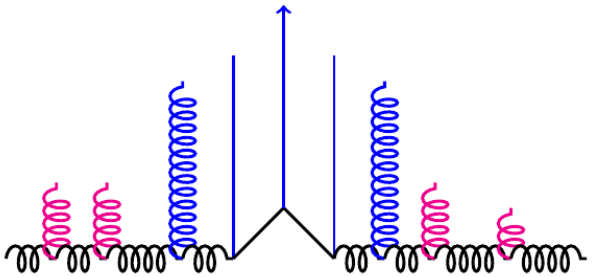


DY is balanced by the hard parton emission

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

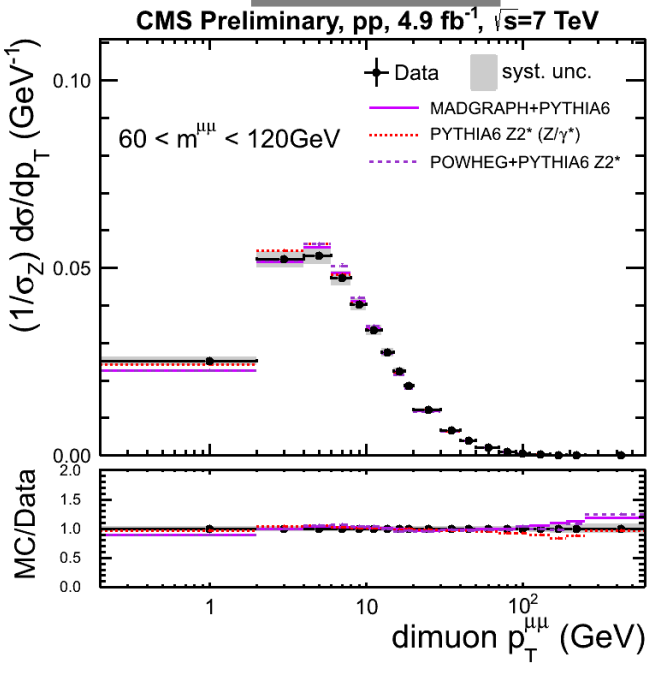


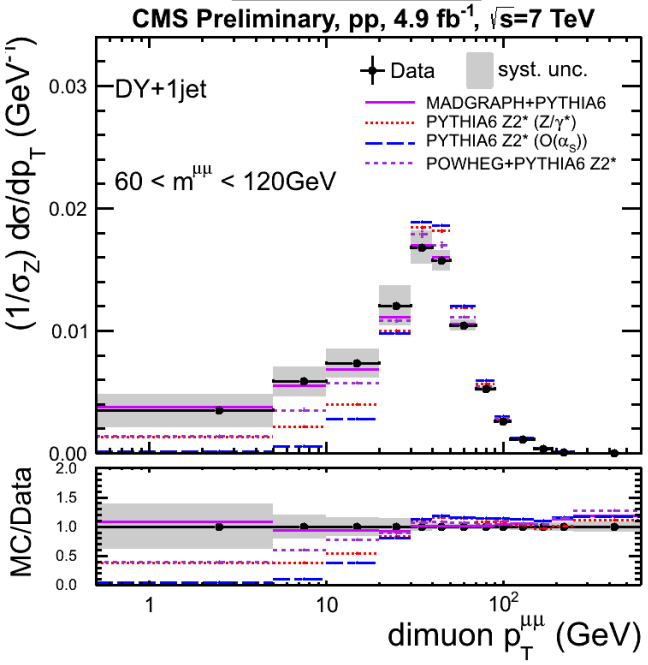
- MadGraph+PYTHIA6 (Z2)
- 4 partons in the matrix element calculation

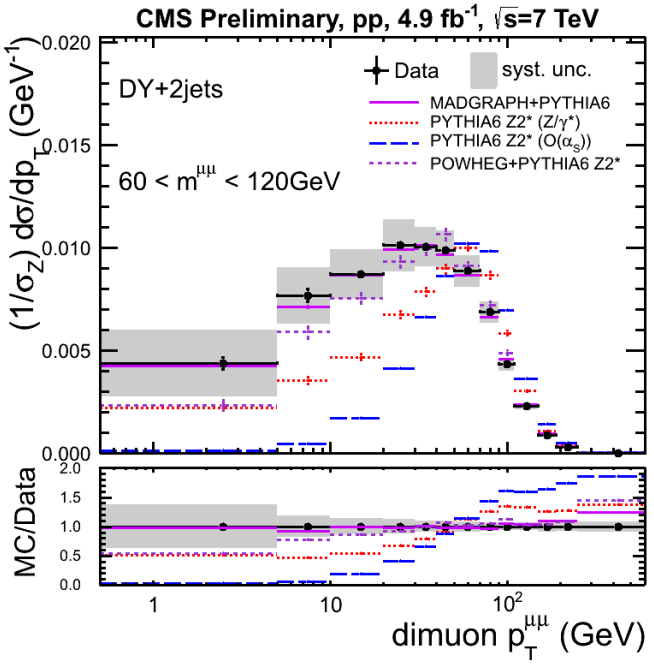


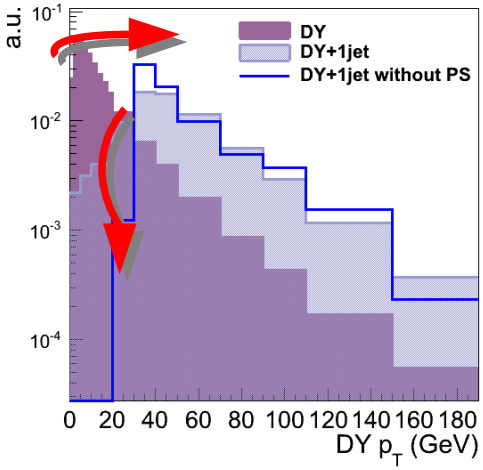
Results $d^2\sigma/dm^{\mu\mu}dp_T^{\mu\mu}$

Inclusive | DY+1jet | DY+2jets









- Maximum of the distribution is shifted to higher p_T when requiring additional jets

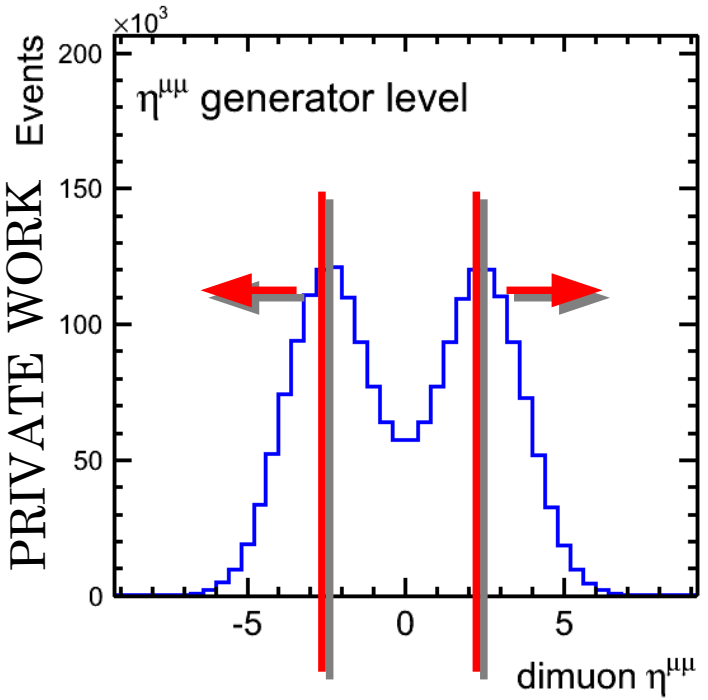
- Inclusive DY : all MC show nice agreement to data
- DY+ jets :
  - Lowest order α_s fails: too low cross section at low p_T
  - Higher O(α_s): good agreement

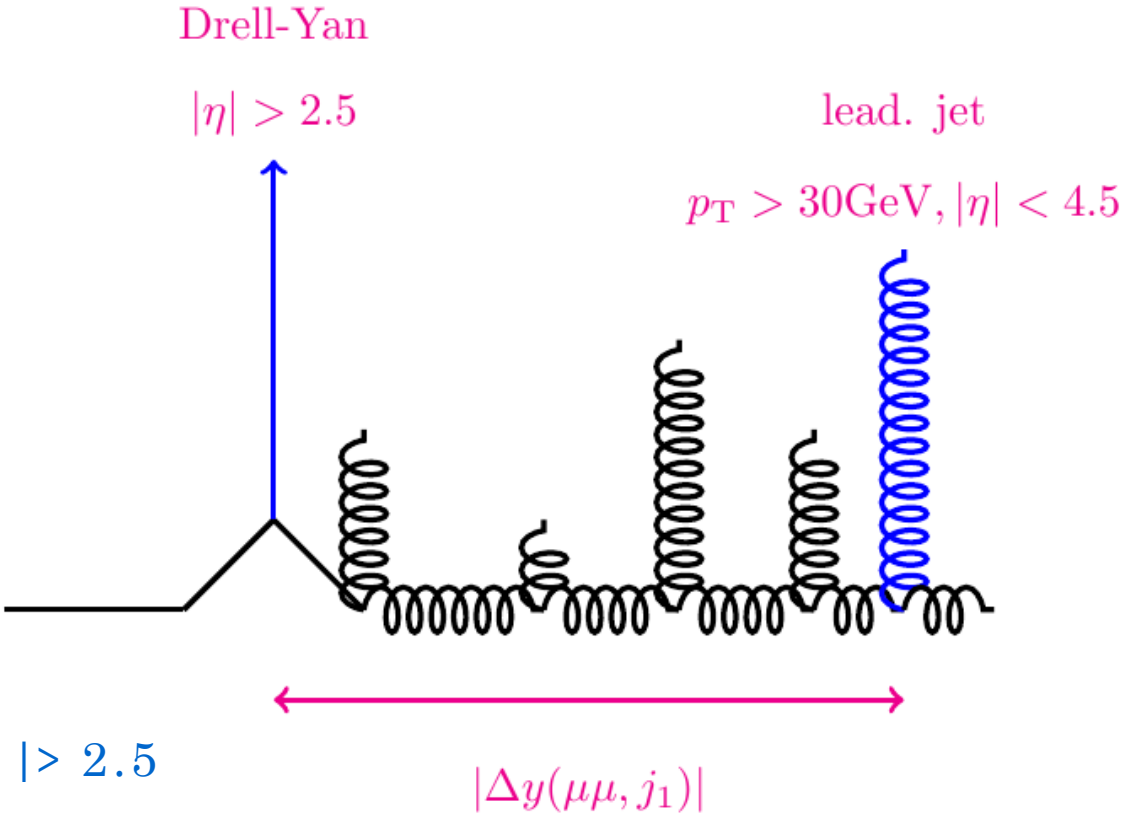
Drell-Yan

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

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





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

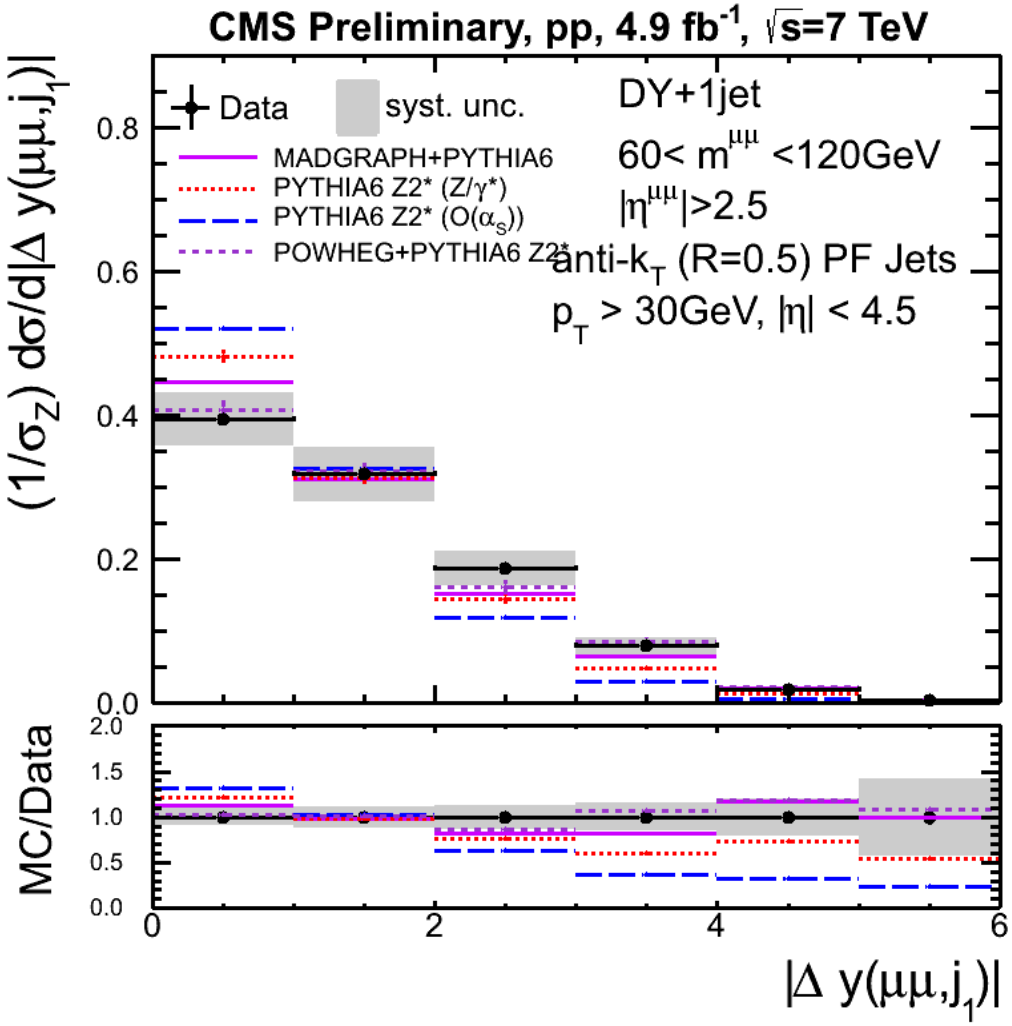
$$\eta^{DY} = \eta(\mu_1) + \eta(\mu_2)$$

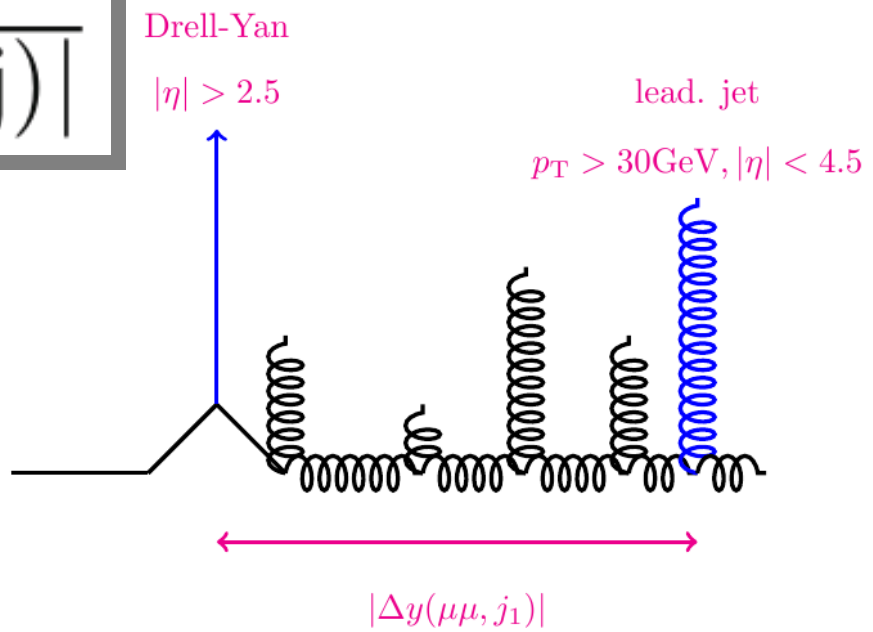
- Drell-Yan production in association with at least one jet and at least two jets

Results

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

60-120 DY+1jet



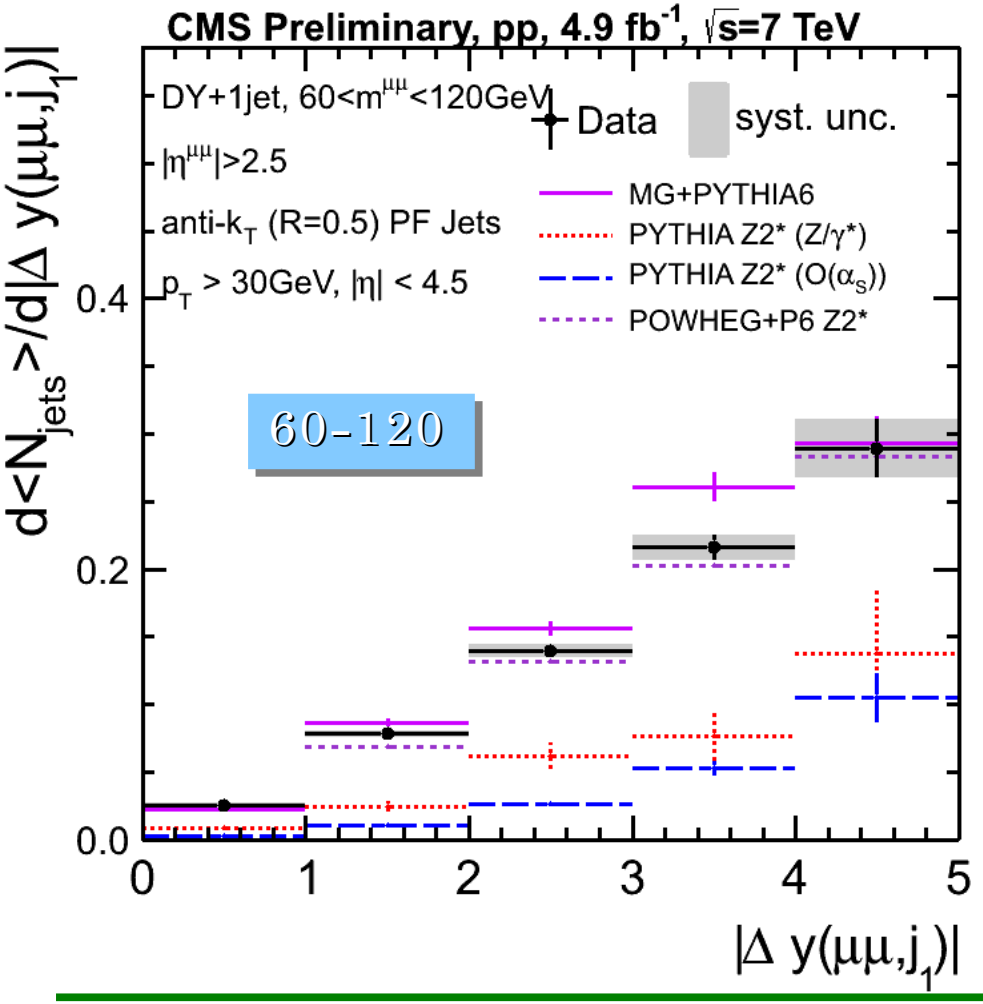


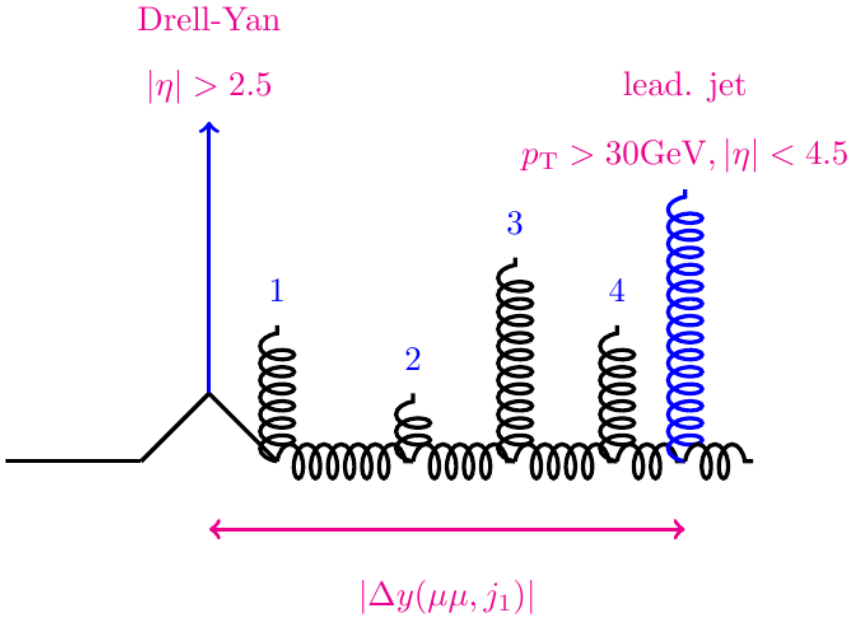
- Large rapidity separation, up to 6
- Decreasing cross section
- General behaviour is described by MC
- Higher order calculations provide better agreement to data

Jet Multiplicity

DY+1jet

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





- Increasing jet multiplicity with increasing Δ y
- Calculations to higher order O(α_s) show good description
- Lowest and first order calculations predict too low jet multiplicity

Summary

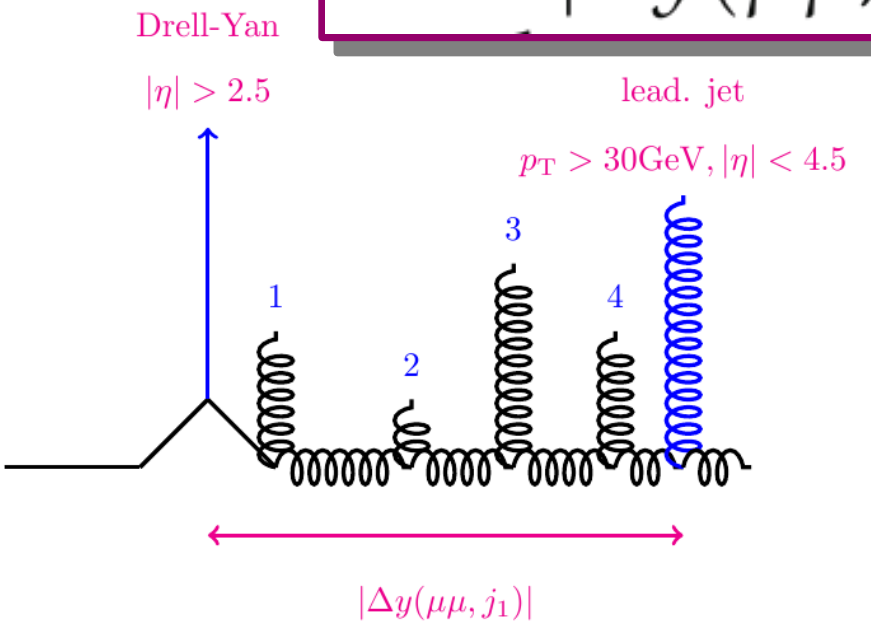
- Double differential cross section in mass and transverse momentum of the dimuon pair (2011 Data, 4.9fb^{-1})

$$\mathrm{d}^2\sigma/\mathrm{d}m^{\mu\mu}\mathrm{d}p_{\mathrm{T}}^{\mu\mu}$$

- 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
  - Higher order calculations provide better agreement to data

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



- Jet multiplicity as a function of Δy
  - Increase of average jet multiplicity
  - Calculations to higher order O(α_{S}) show good description

Backup

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

DY+1jet

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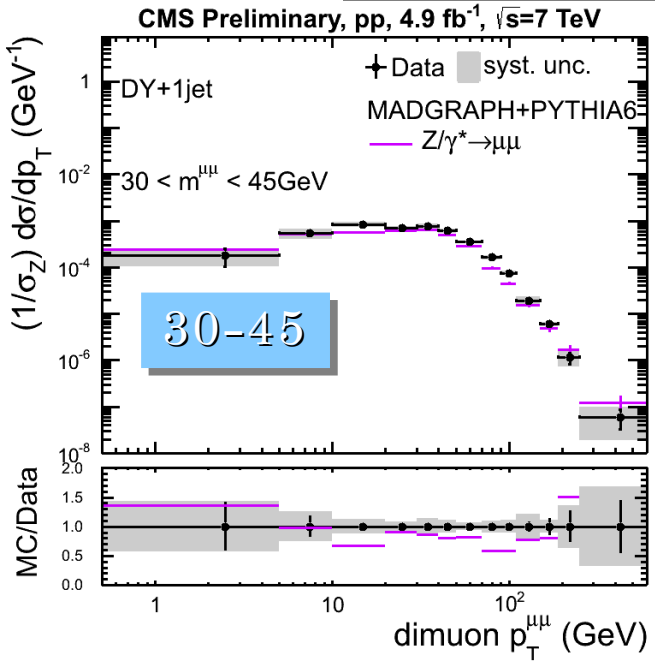

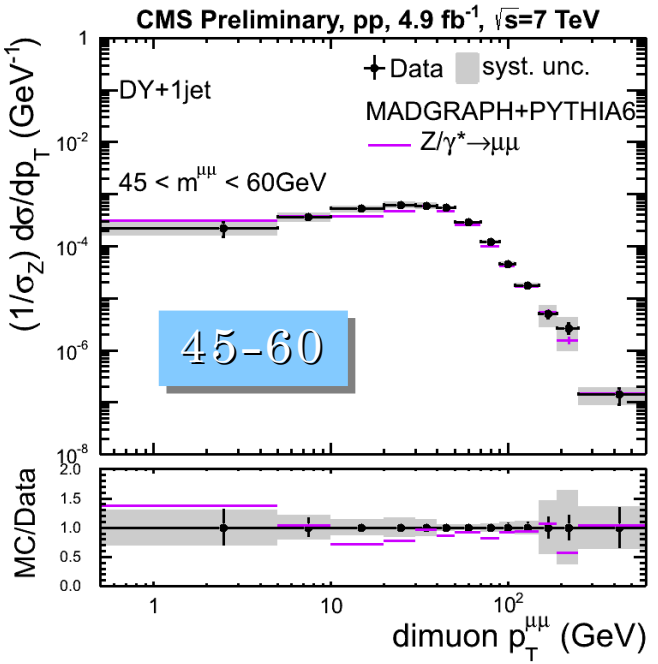

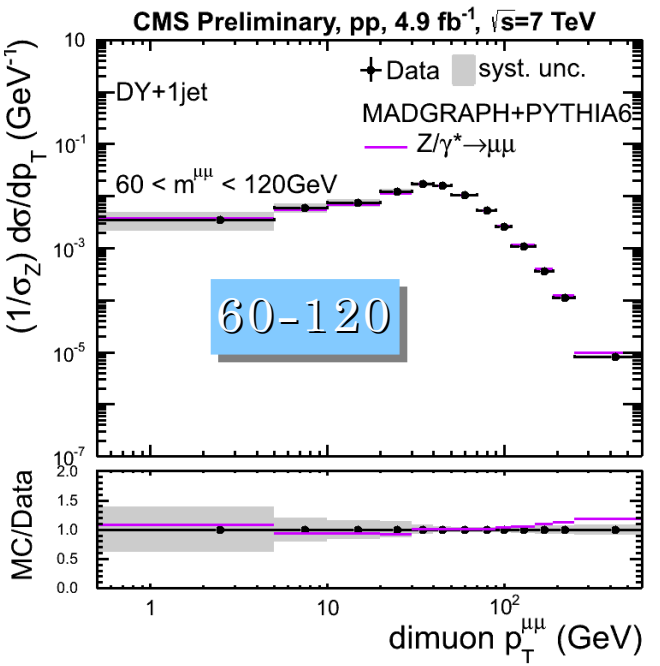

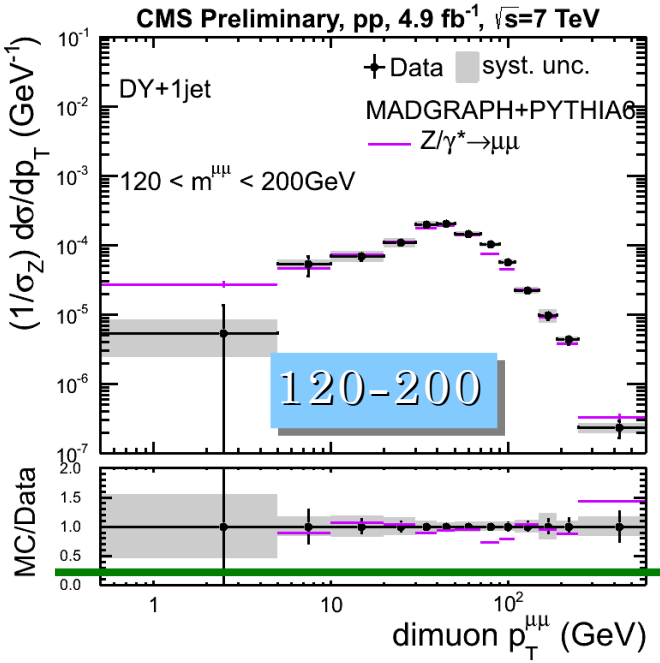

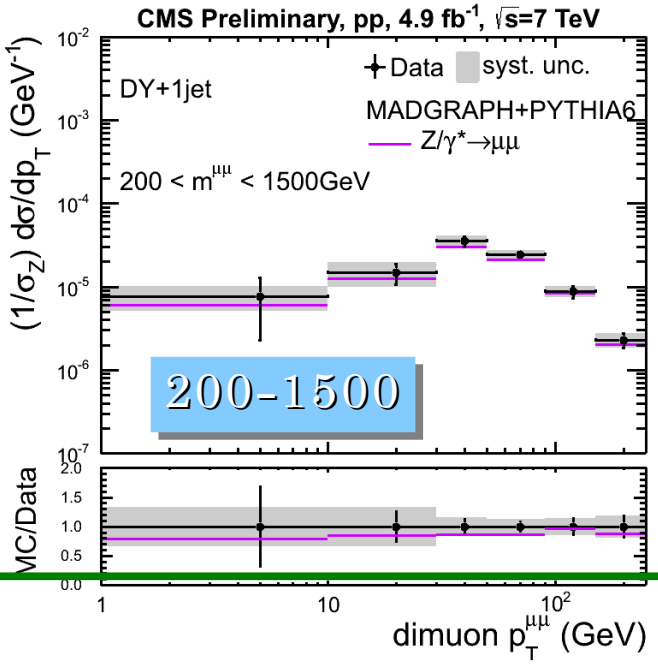

Results $d^2\sigma/dm^{\mu\mu}dp_T^{\mu\mu}$

DY+2jets

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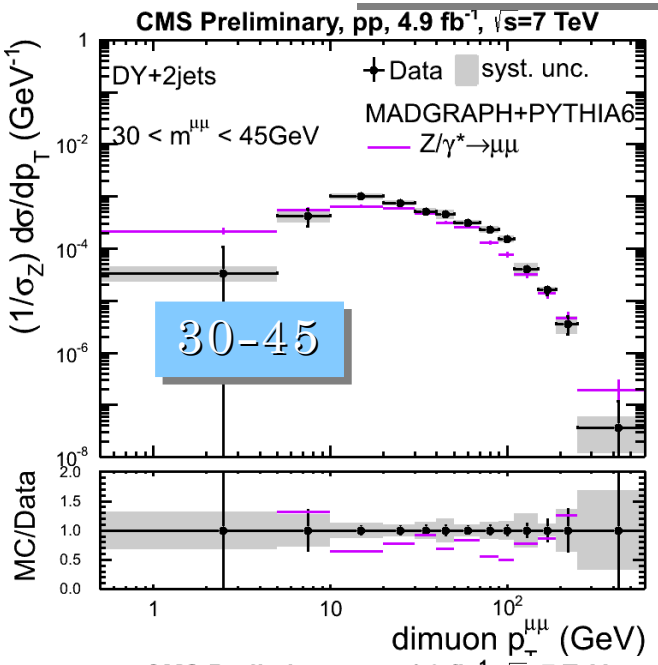

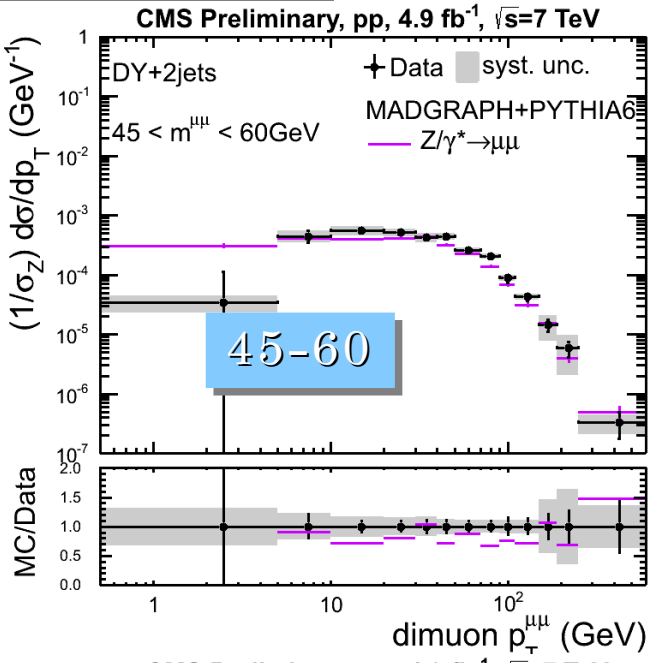

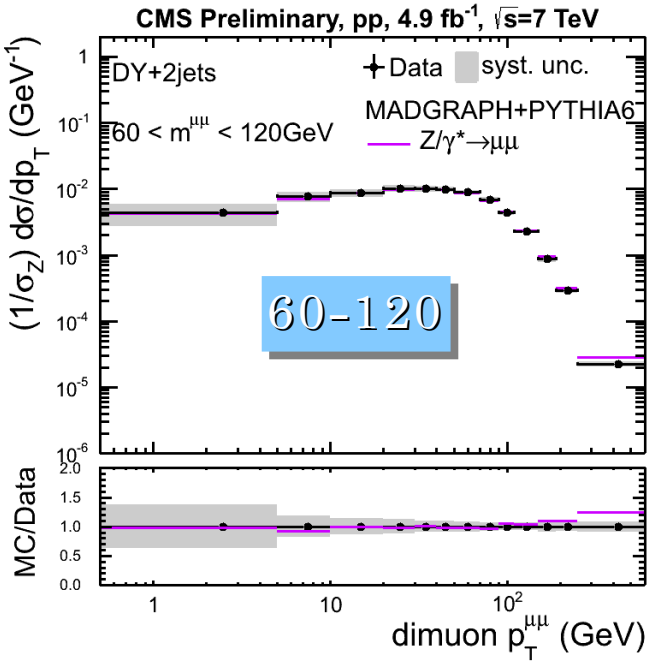

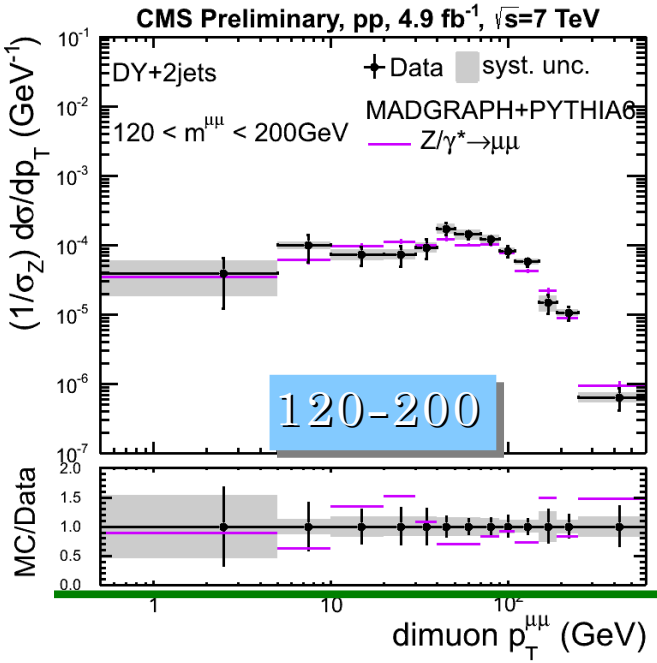

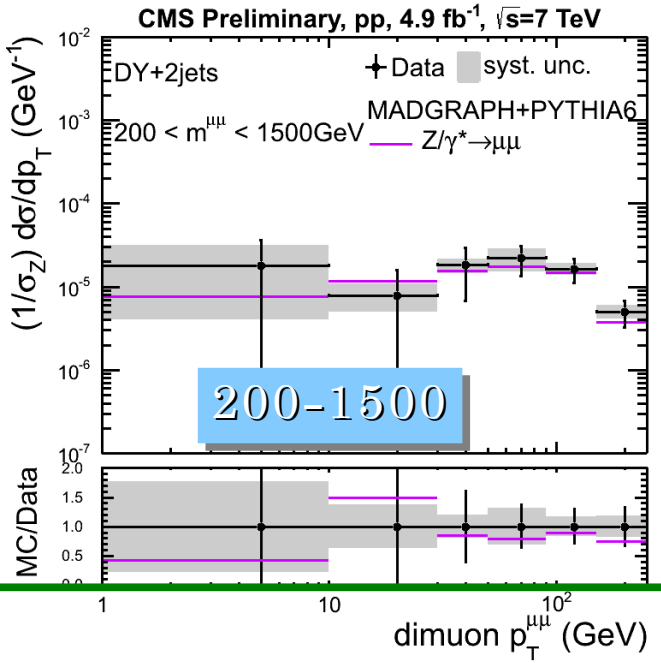

Results

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

DY+1jet

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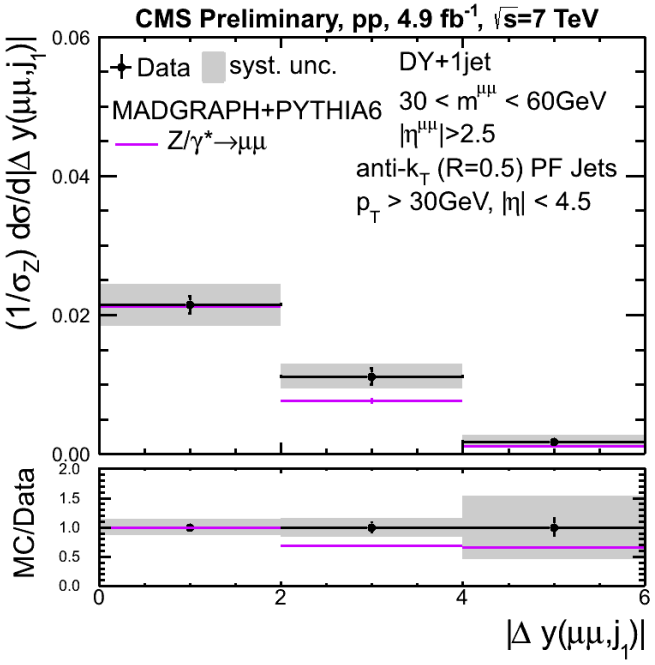
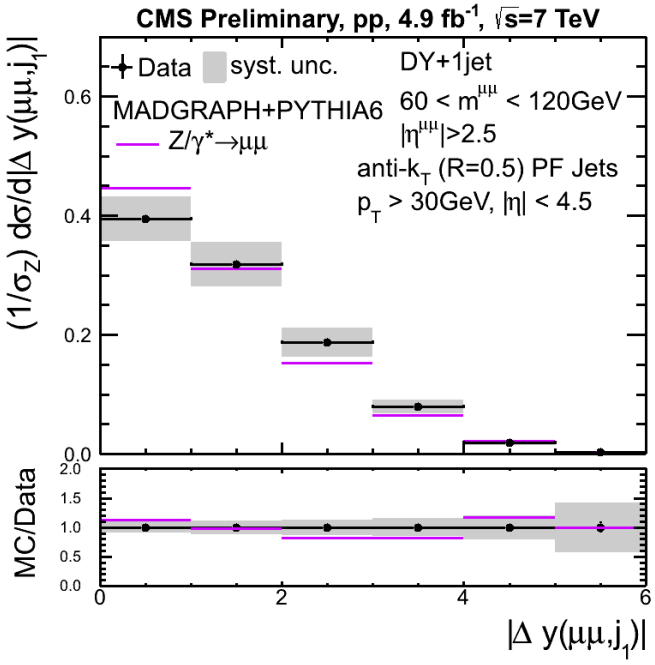
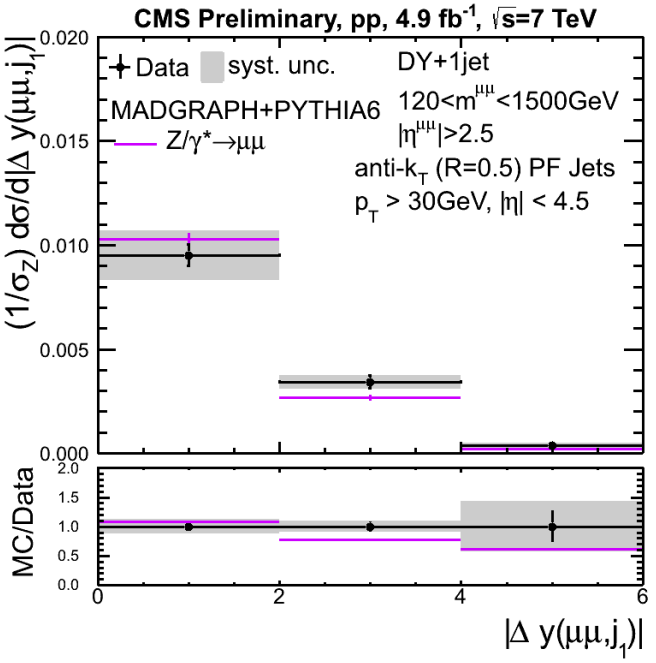
30-60



60-120



120-1500



Results

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

DY+2jets

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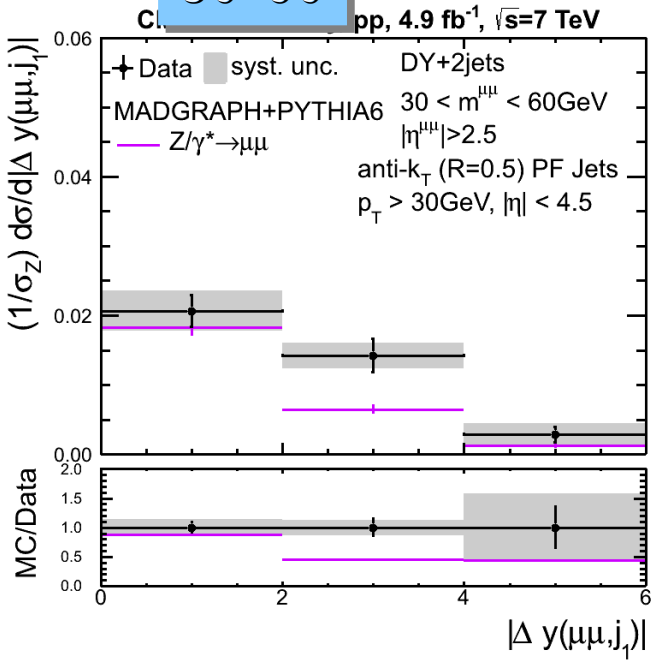
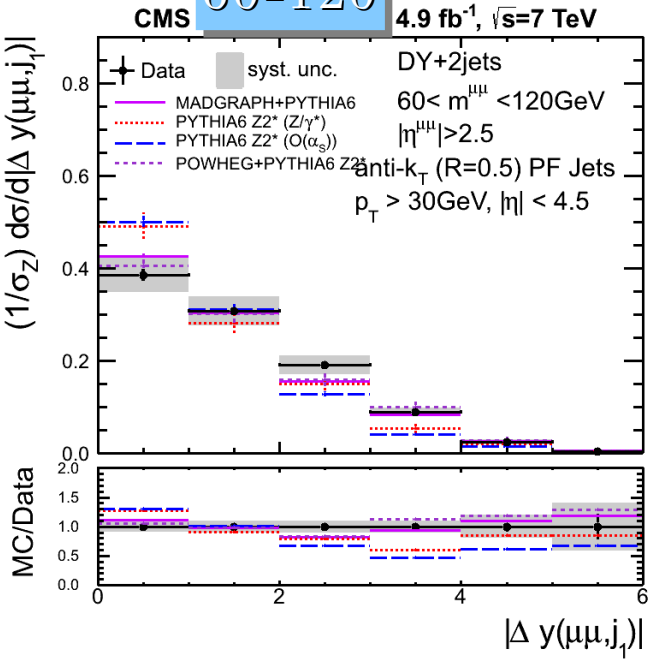
30-60



60-120



120-1500