Resummation probed by Parton Showers in Drell-Yan + Jets

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On behalf of the CMS Collaboration

12th June 2014

PSR14

CMS-PAS-FSQ-13-003

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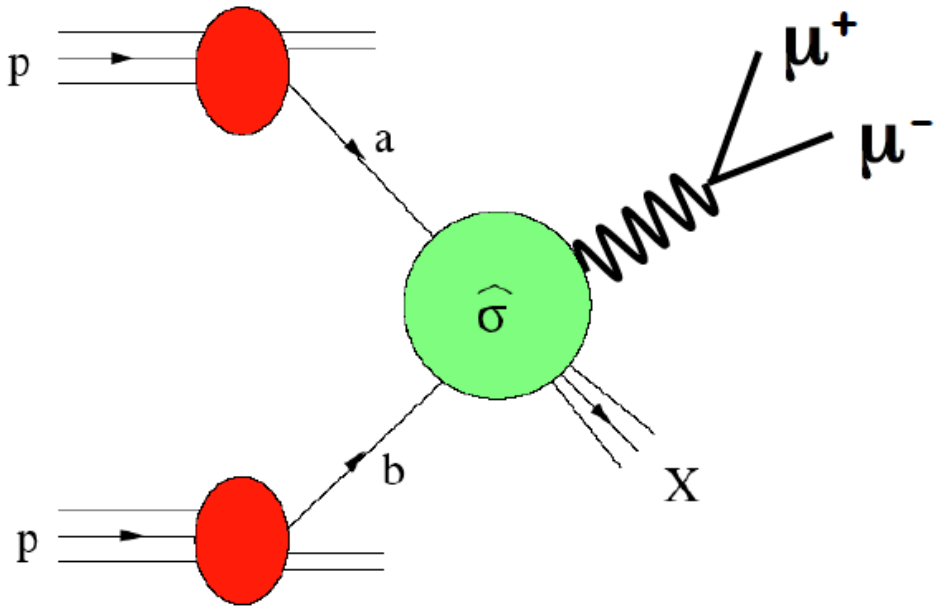
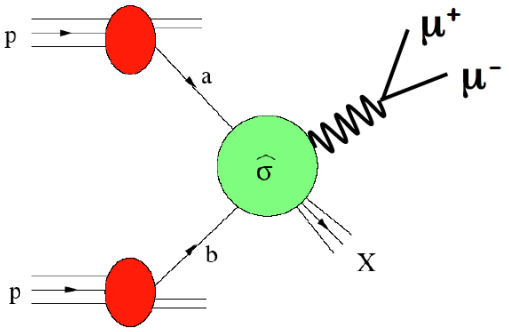
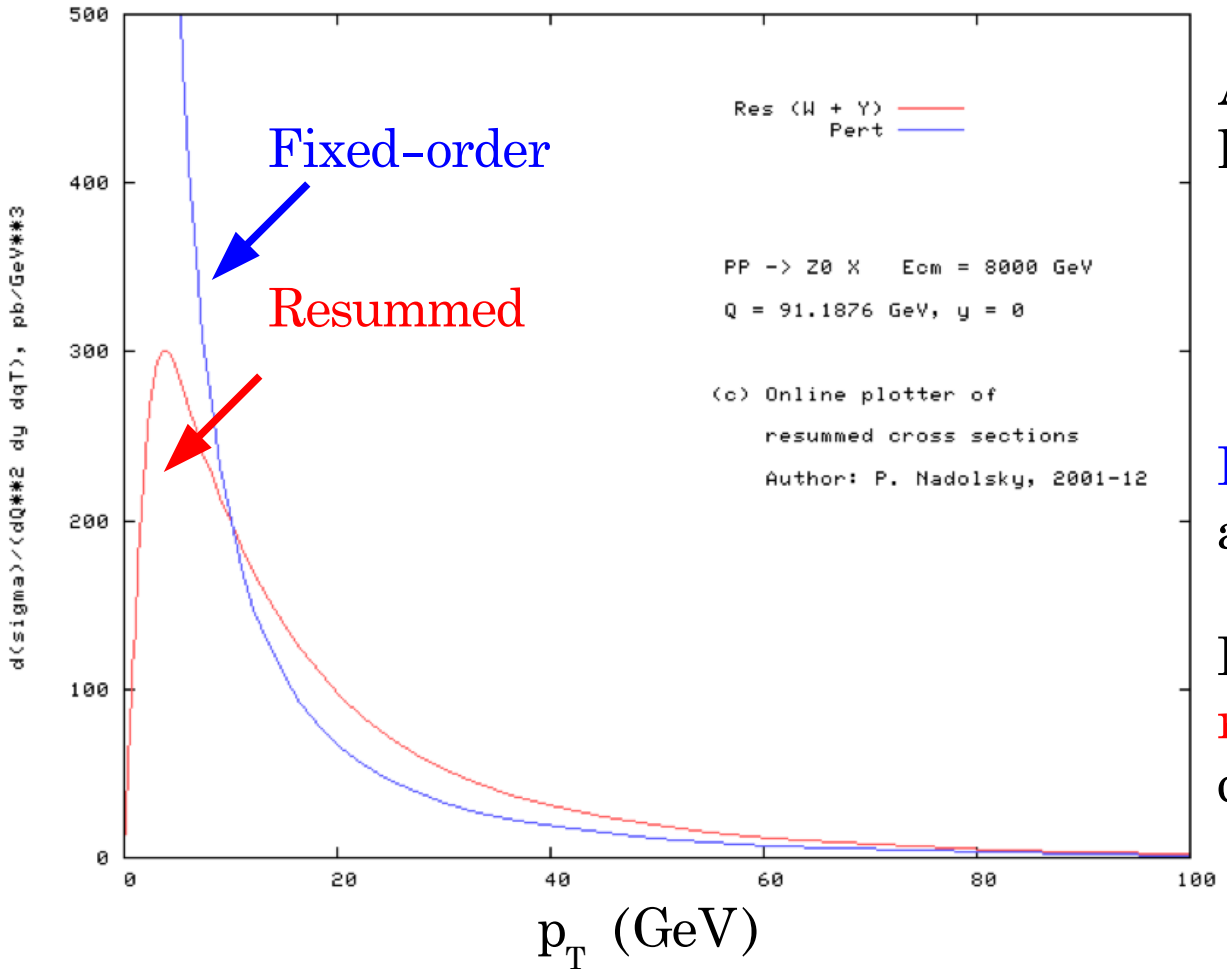


Introduction



$$\sigma_{pp} = \sum_q \int dx_1 dx_2 \, f_q(x_1, {\mu_F}^2) f_{\bar{q}}(x_2, {\mu_F}^2) \, \hat{\sigma}_{q\bar{q}\to l^+l^-}$$



At small scale :
large logarithms appear

$$\alpha_S{}^n \ln^{2n-1} \frac{M^2}{{p_T}^2}$$

Fixed-order calculation diverges at small scales

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

Introduction

Differential transverse momentum distribution

- Resummed leading logarithms to all orders

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}{p_\mathrm{T}}^2} \sim \frac{\mathrm{d}}{\mathrm{d}{p_\mathrm{T}}^2} \exp\left(-\frac{\alpha_\mathrm{S}}{2\pi} C_F \ln^2\left(\frac{M^2}{{p_\mathrm{T}}^2}\right)\right)$$

Different approach to test Resummation

- Parton Showers

$$\Delta(t) = \exp\left(-\int_{t_0}^{t} \frac{\mathrm{d}t'}{t'} \int \frac{\mathrm{d}z}{z} \frac{\alpha_\mathrm{S}}{2\pi} P(z) \frac{f(x/z,t)}{f(x,t)}\right)$$

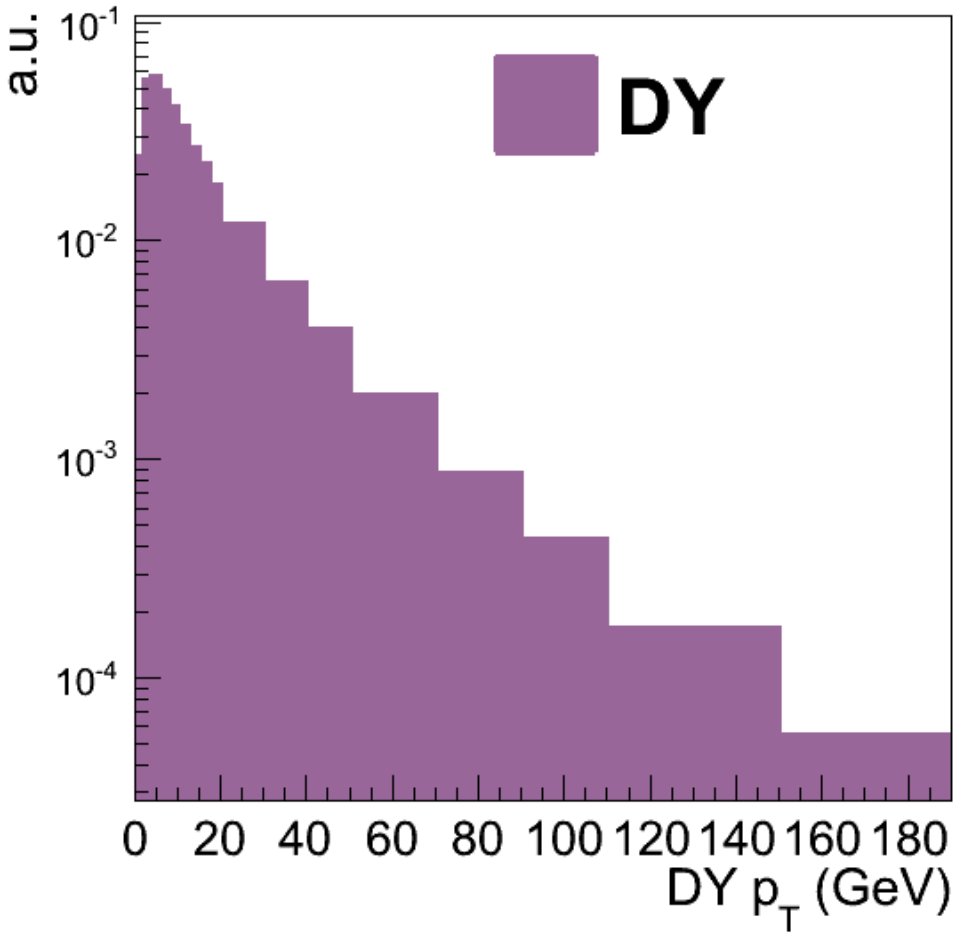
Sudakov form factor of initial state parton radiation
arises from the resummation of the soft and collinear gluon emissions

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

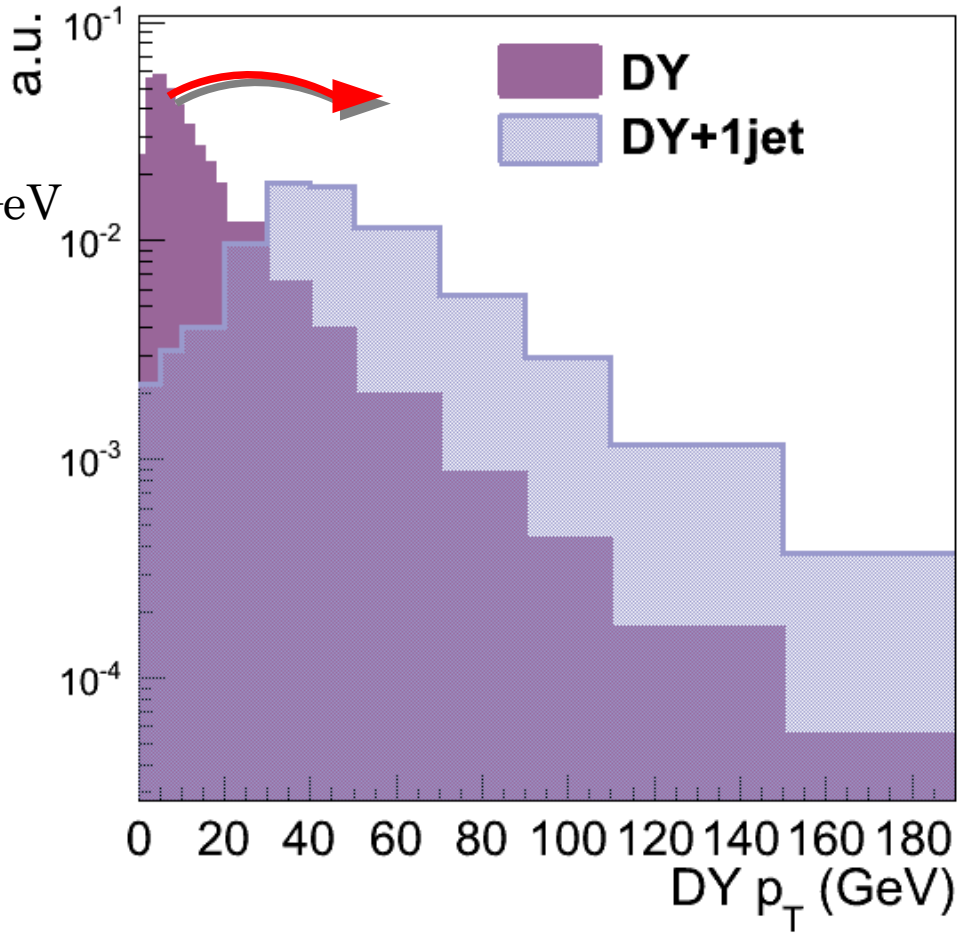
DY dilepton pair transverse momentum distribution

- 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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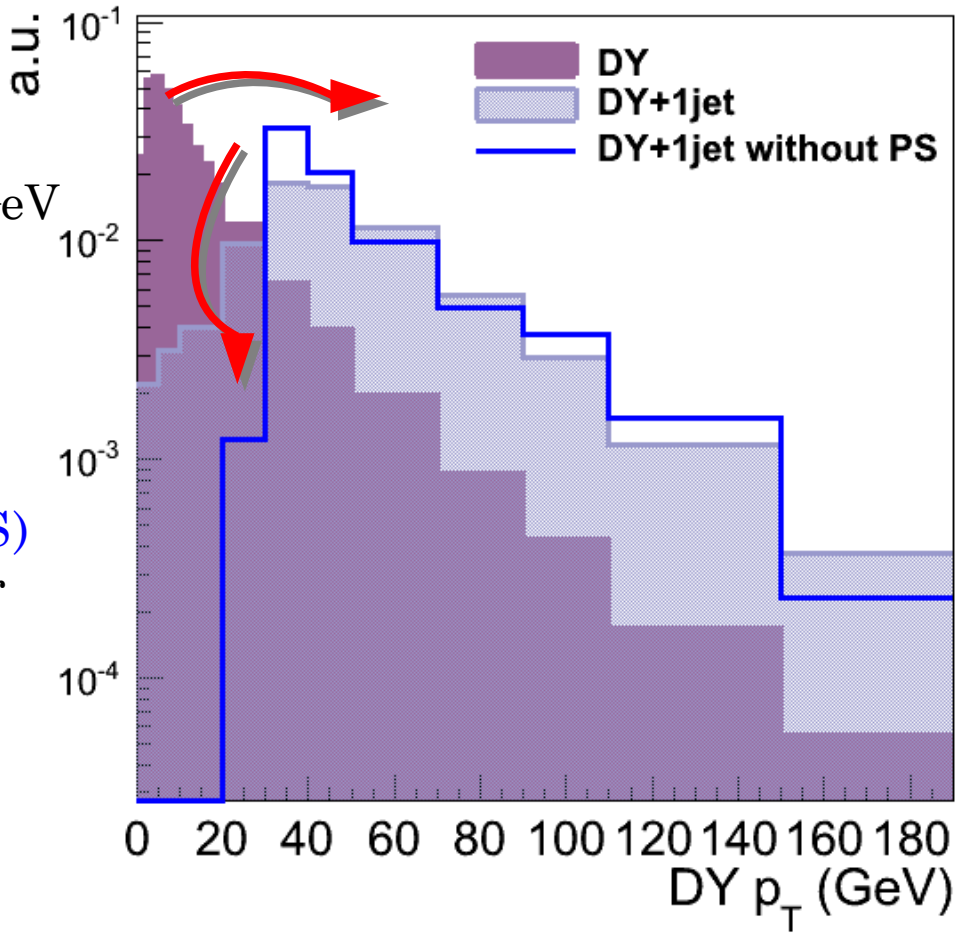
Rise at small p_T comes from soft gluon resummation

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



Test Resummation with DY + Jets by MC parton shower algorithm

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 with the CMS Detector
- 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

$$\alpha_S{}^n \ln^{2n-1} \frac{M^2}{{p_T}^2}$$

- Cross sections are normalized by cross section in the Z Peak region (60-120GeV)

Transverse Momentun Distribution

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

Jet Multiplicity

$$\langle N_{\mathrm{jets}} \rangle$$

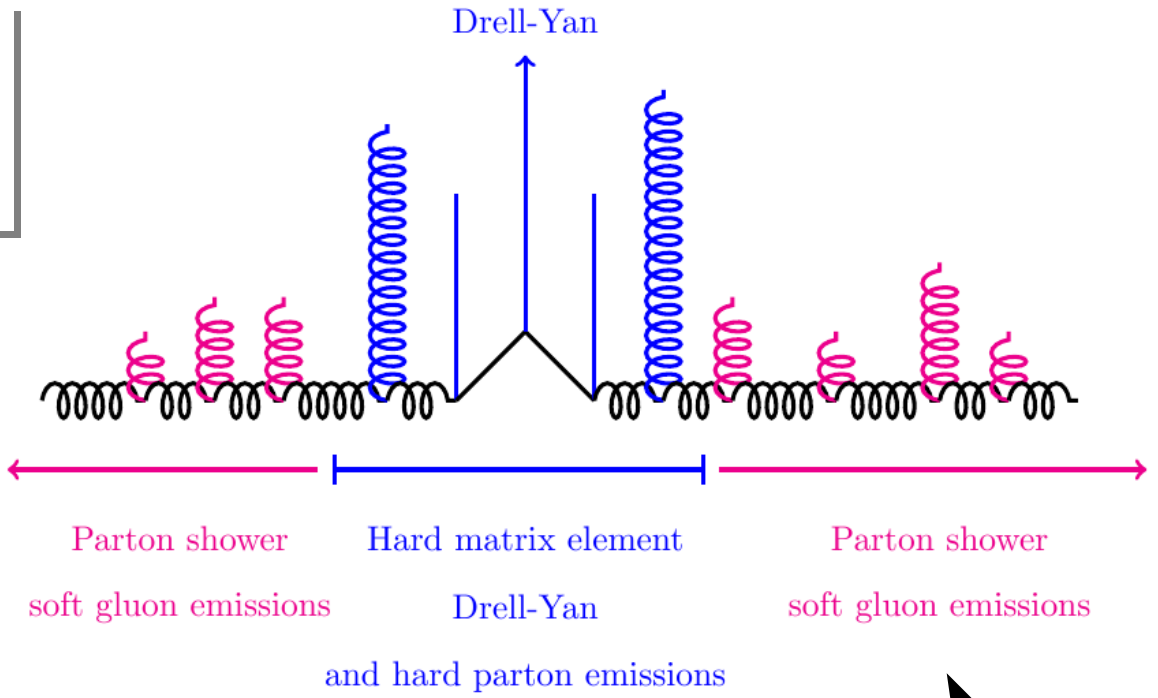
Cross Section Measurement

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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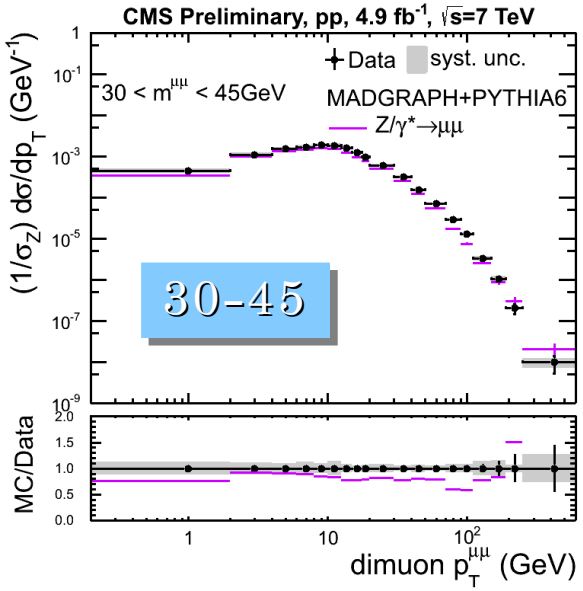
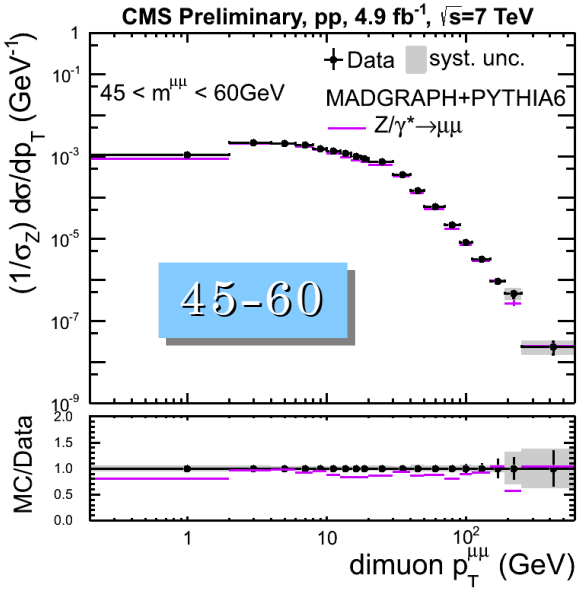
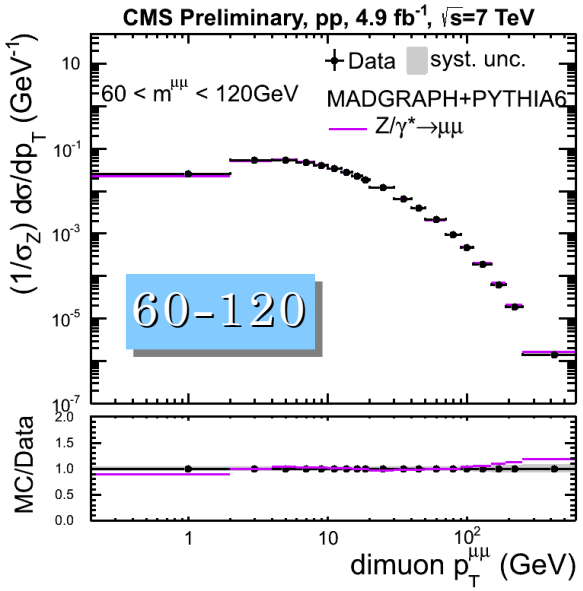
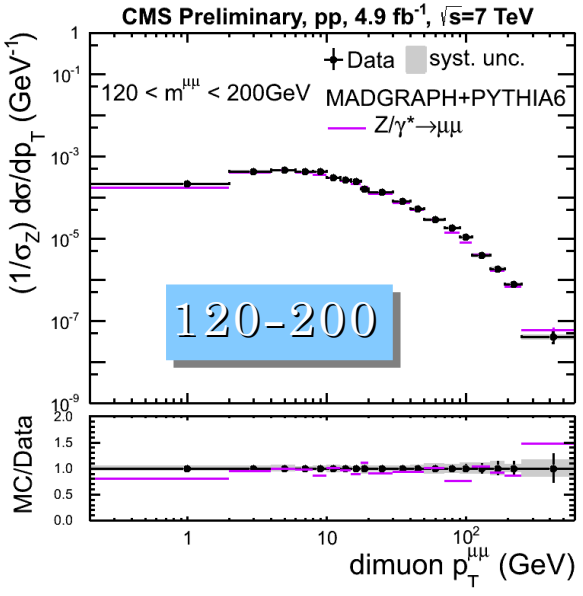
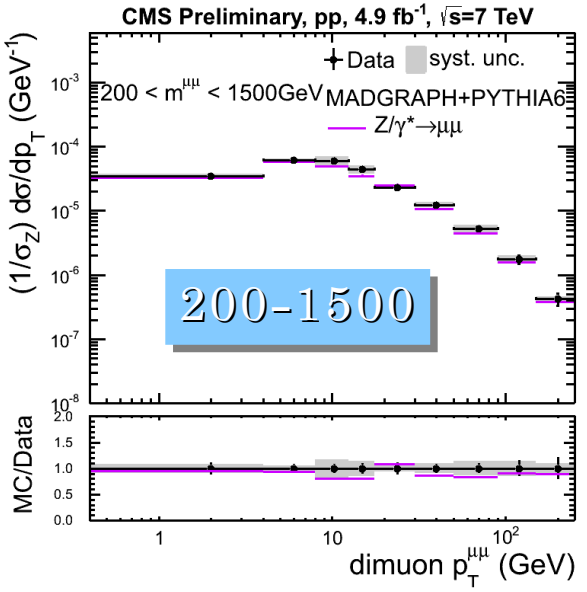




- Corrected data to stable particle level
- Normalized cross sections
- Dominant systematic uncertainty
  inclusive DY: Unfolding (8%)
  DY+jets: JEC (10%)



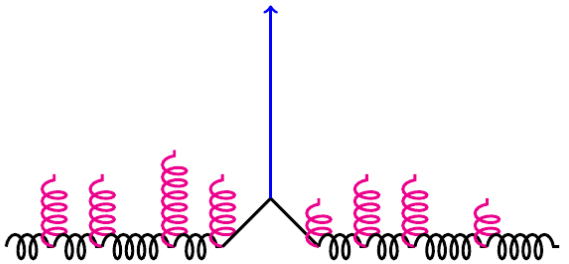




Monte Carlo Comparison

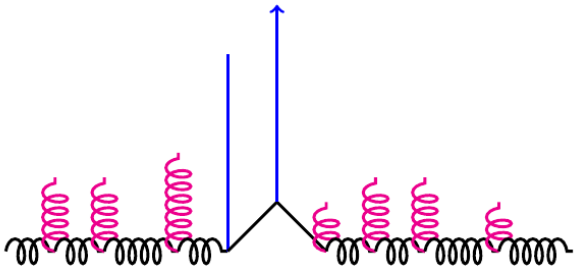
- PYTHIA6 (Z2*)
- Inclusive DY production

Lowest Order in α_s



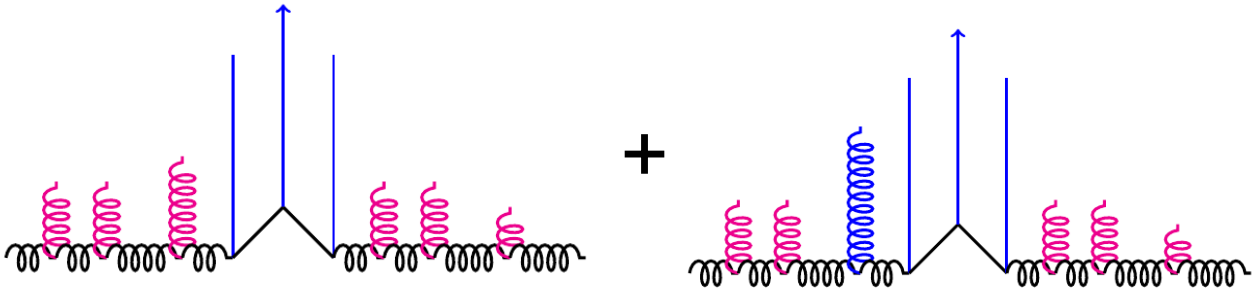
- PYTHIA6 (Z2*)
- $O(\alpha_s)$ DY production

First Order in α_s

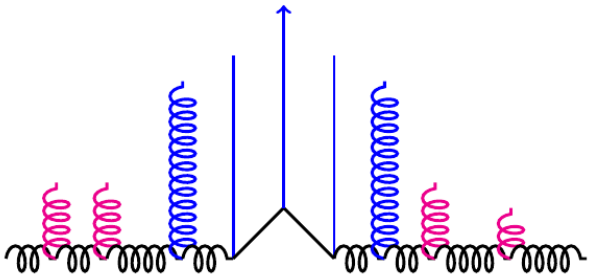


DY is balanced by the hard parton emission

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

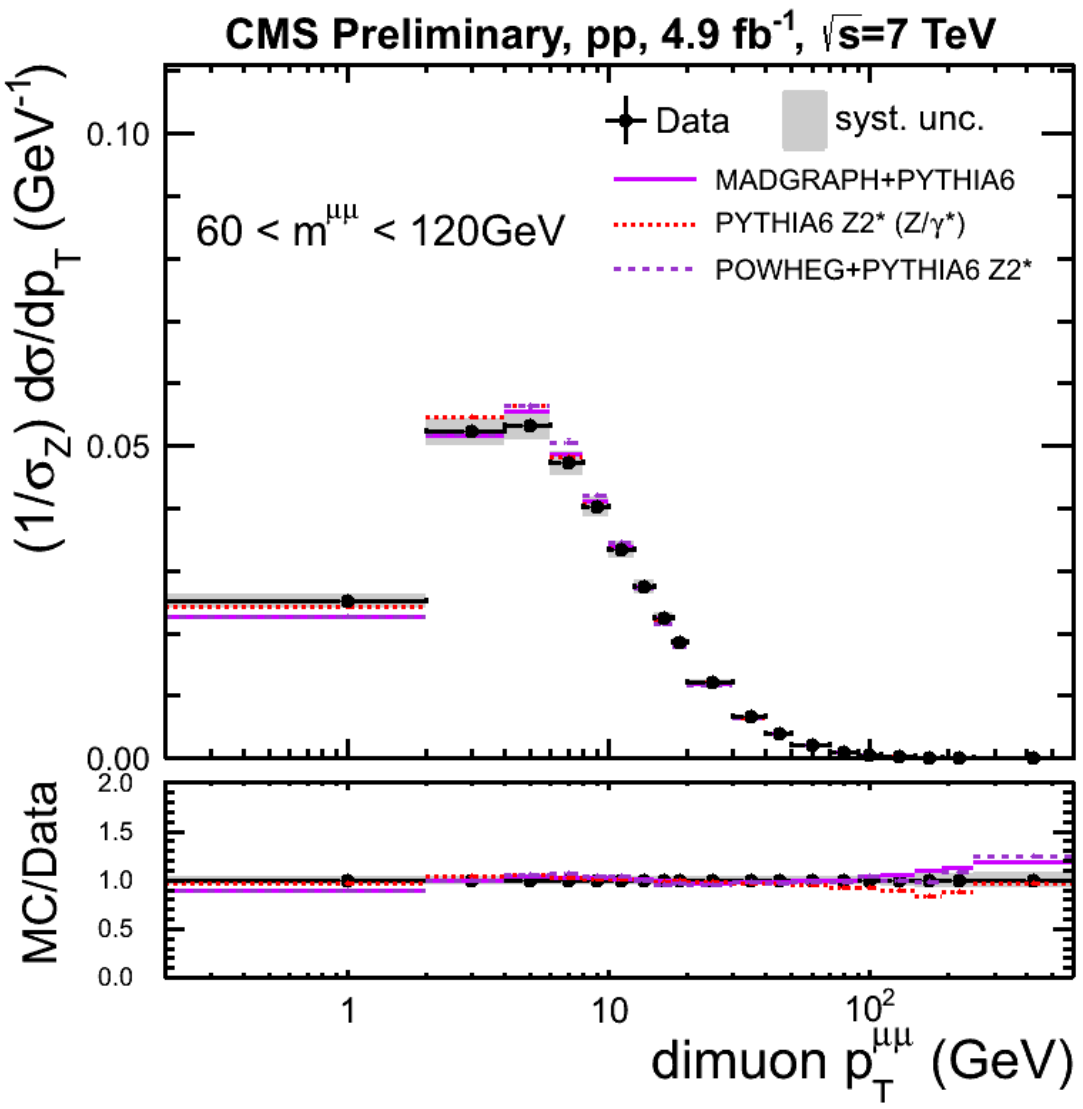


- MadGraph+PYTHIA6 (Z2)
- 4 partons in the matrix element calculation



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

Inclusive

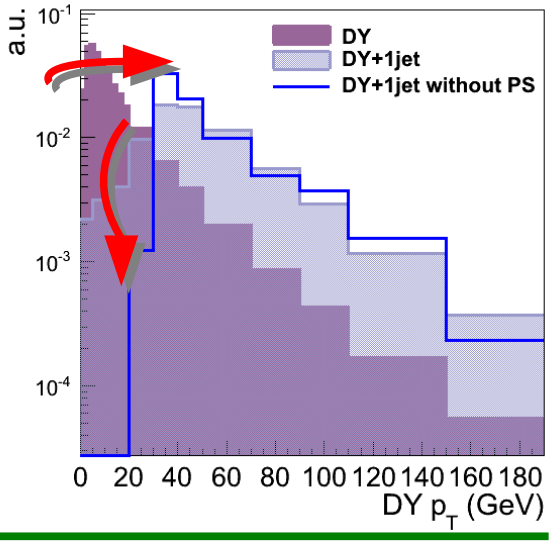


Inclusive DY :
all MC show nice agreement to data

Lowest order and higher order calculations provide a reasonable result

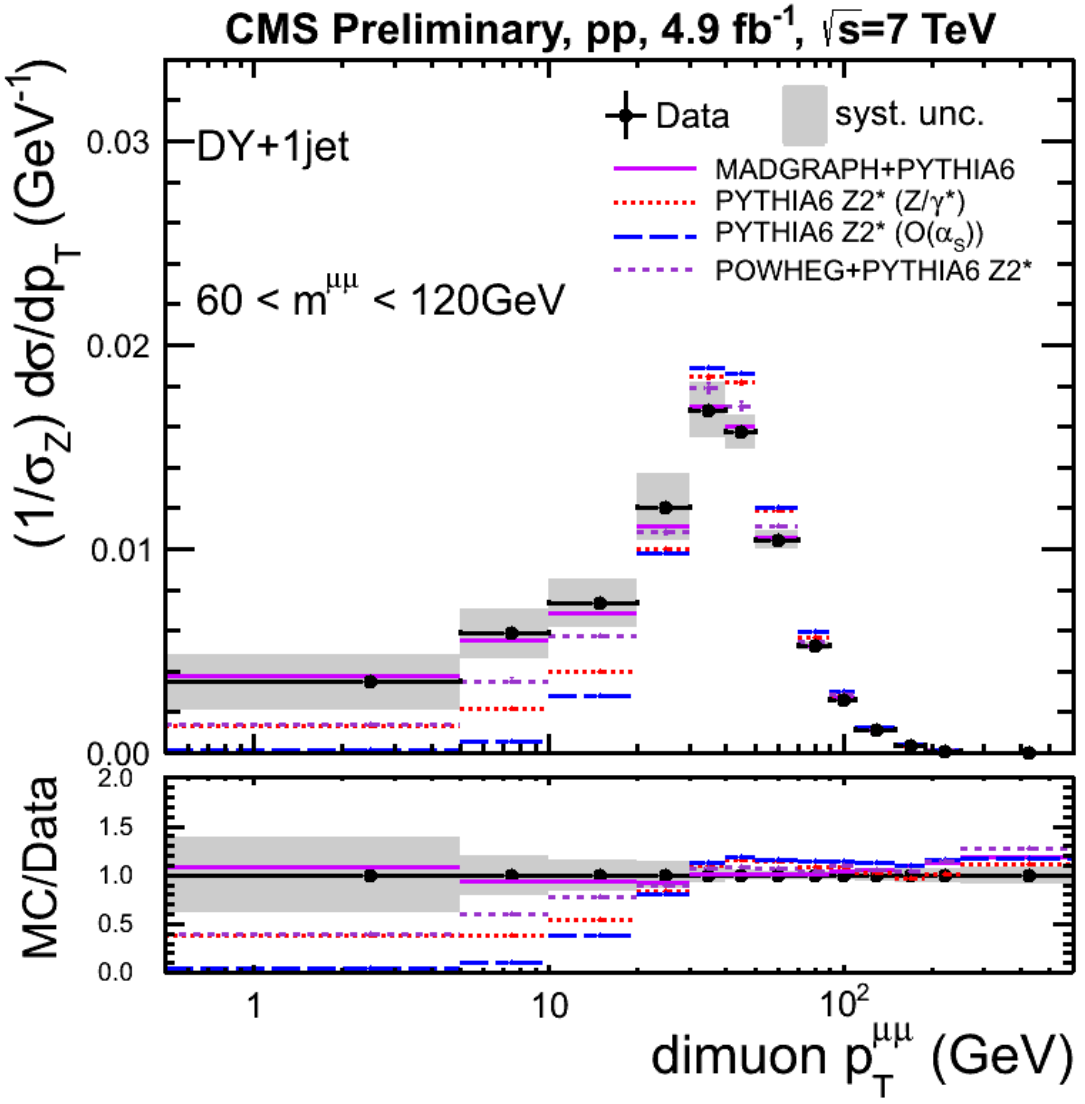
Maximum of distribution:
around 5 GeV

Region of soft gluon resummation can be enlarged



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

DY+1jet



Maximum of the distribution is shifted to higher p_T

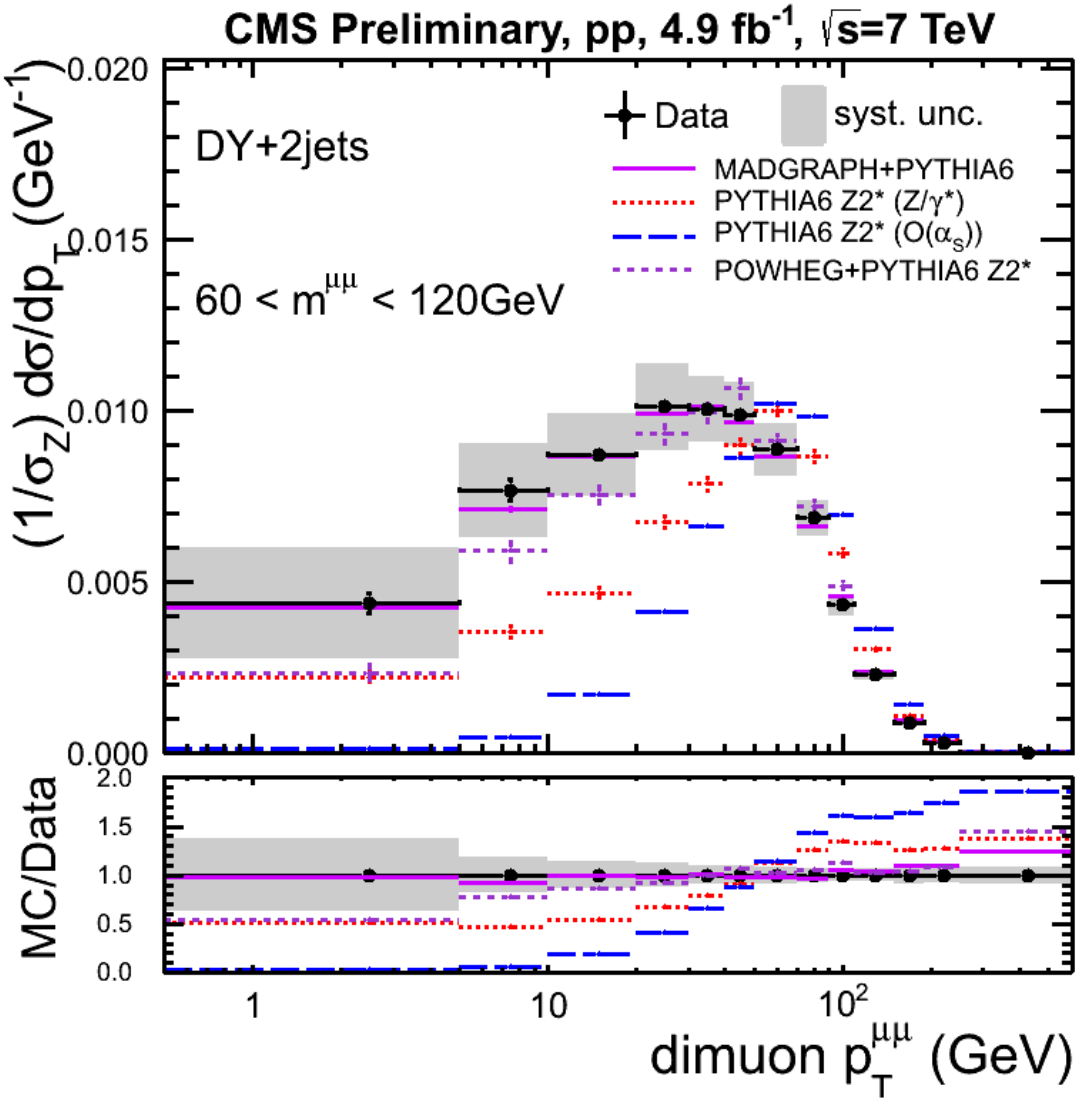
DY + 1 jet :
Data compared to lowest order in α_s and higher order calculation plus parton shower

Region of soft gluon resummation:

Well described by higher order calculation, lowest order in α_s fails

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

DY+2jets



Low p_T region is filled by soft gluon emissions

DY + 2 jets :
Two jets balance each other and the DY lepton pair gains p_T from soft gluons

Region of soft gluon resummation:

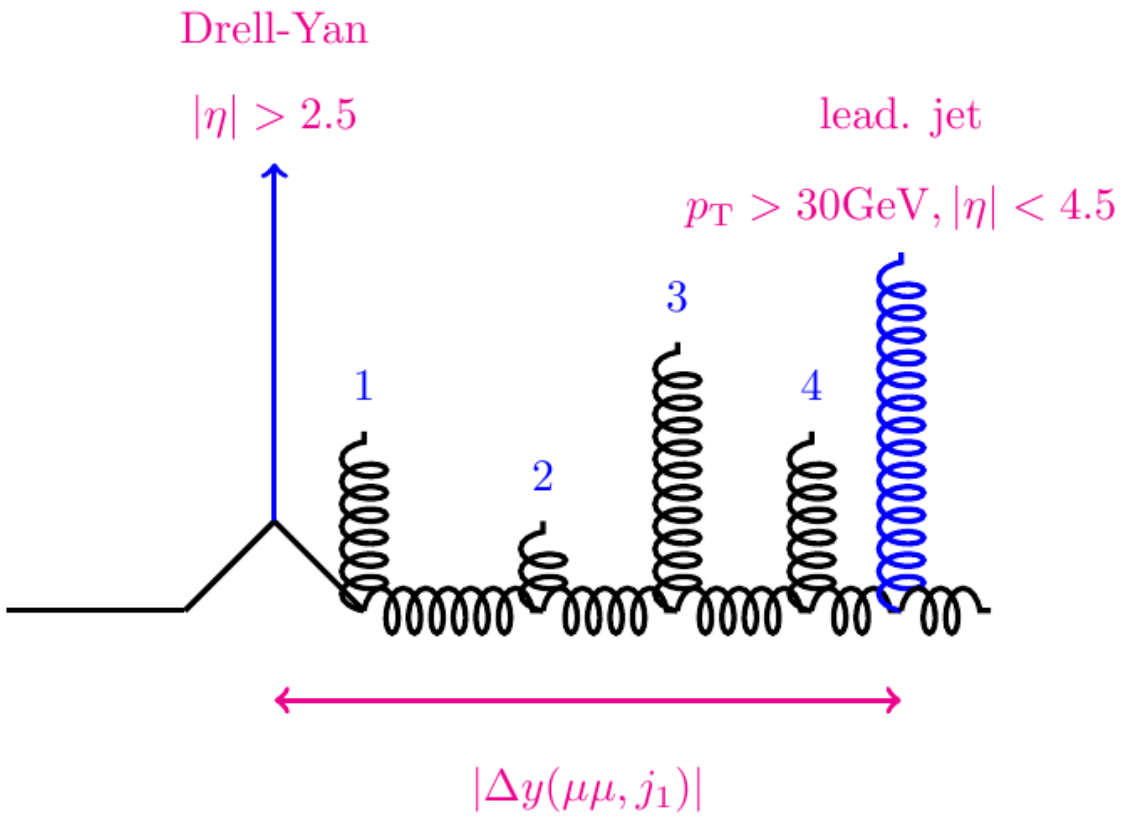
Well described by higher order calculation, lack of low p_T leptons in lowest order α_s

Jet Multiplicity

DY+1jet

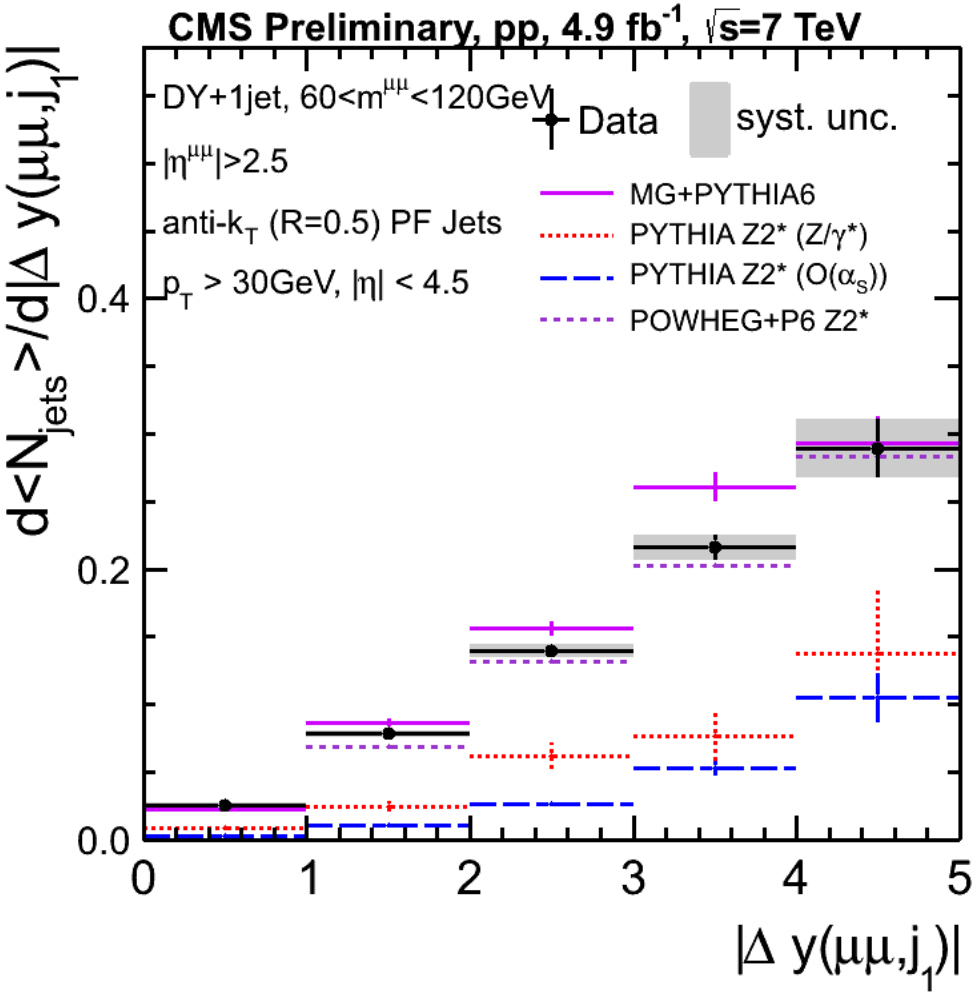
- Average Number of Jets in Δy of DY and the leading jet
- Forward Drell-Yan production $|\eta| > 2.5$

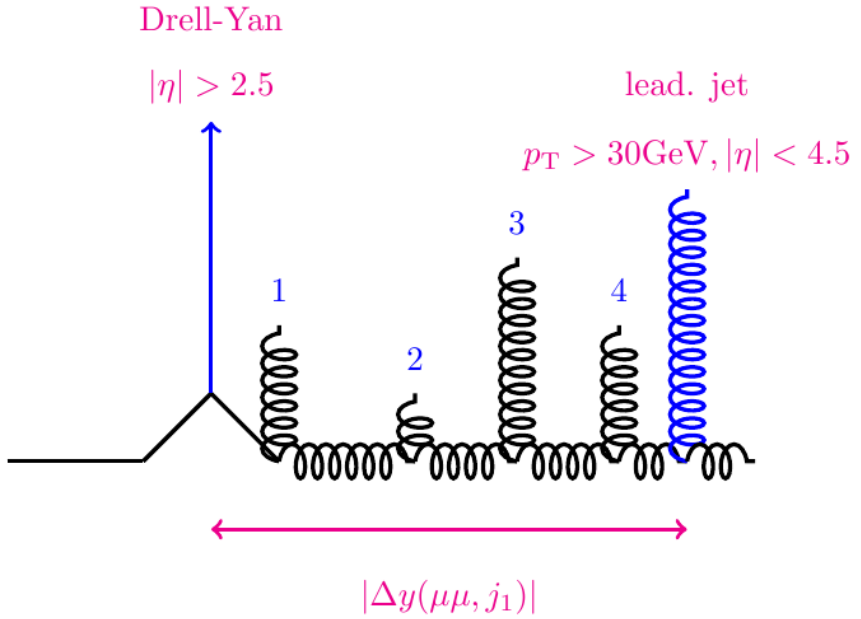
$$\eta^{DY} = \eta(\mu_1) + \eta(\mu_2)$$



Jet Multiplicity

DY+1jet





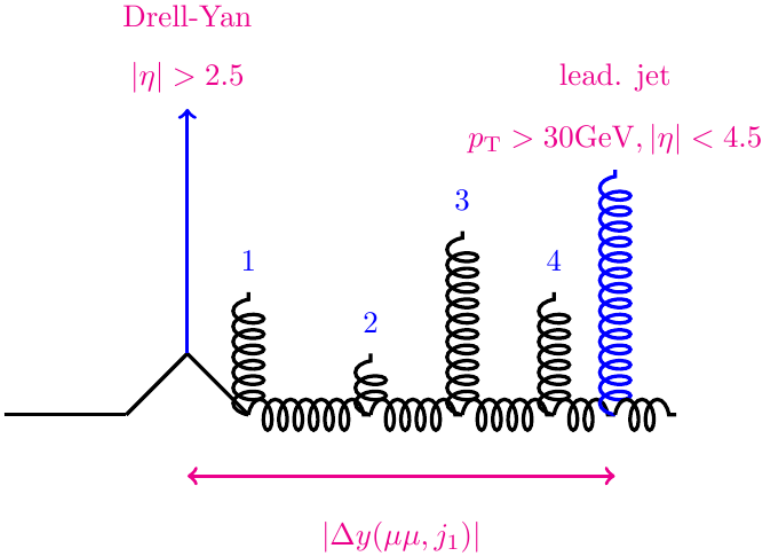
- Increasing jet multiplicity with increasing Δ y
- Calculations to higher order O(α_S) show good description
- Lowest and first order calculations predict too low jet multiplicity

Summary

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

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

- Jet multiplicity as a function of Δy



- Increased sensitivity to soft gluon resummation by using DY + jets
- Parton Showers describe the region of soft gluon resummation
- Merged parton showers and fixed order calculation provides best agreement
- Higher order calculation is needed to describe the low p_T region

Backup

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

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

DY+1jet

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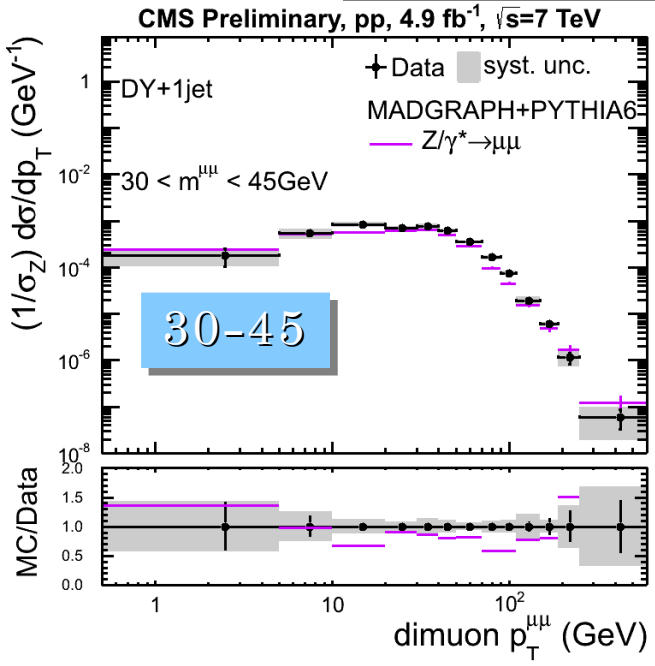

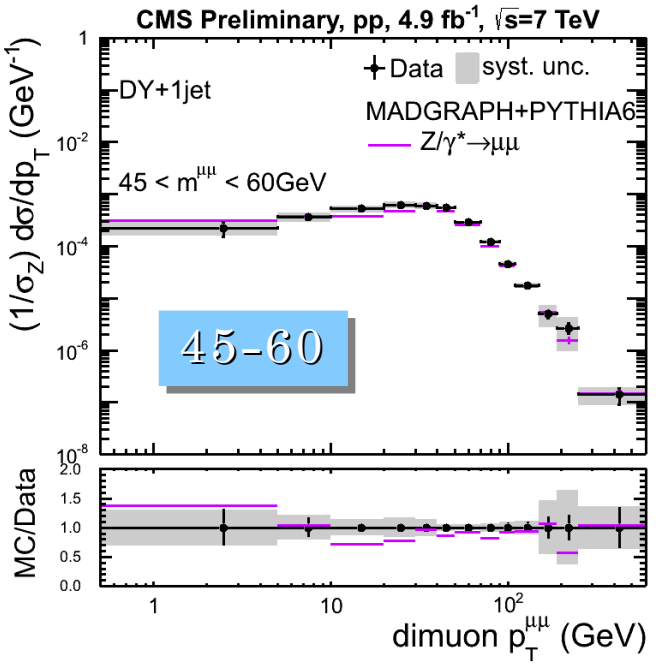

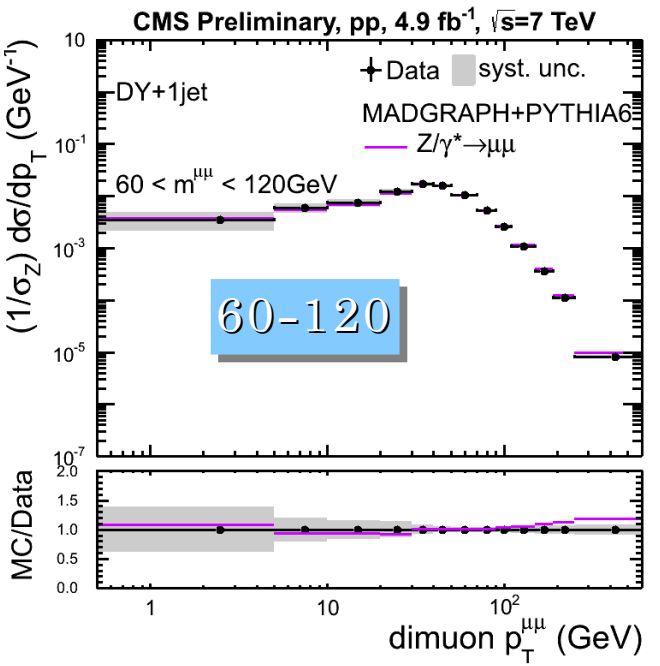

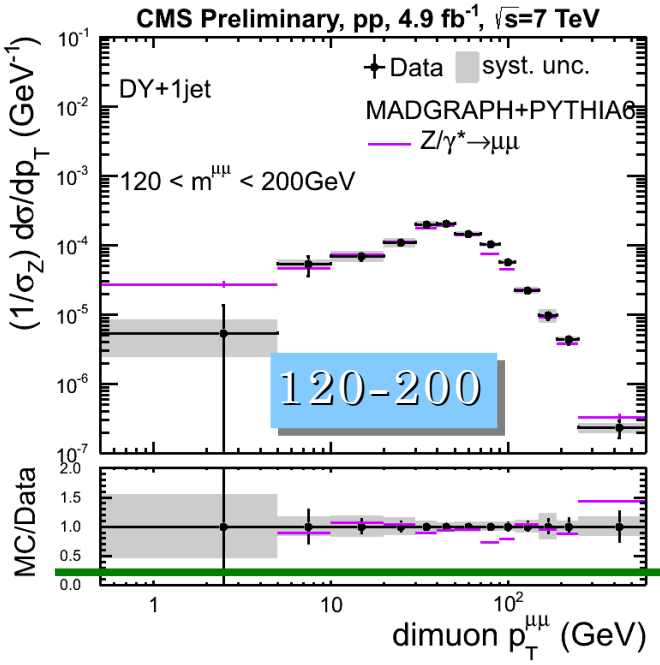

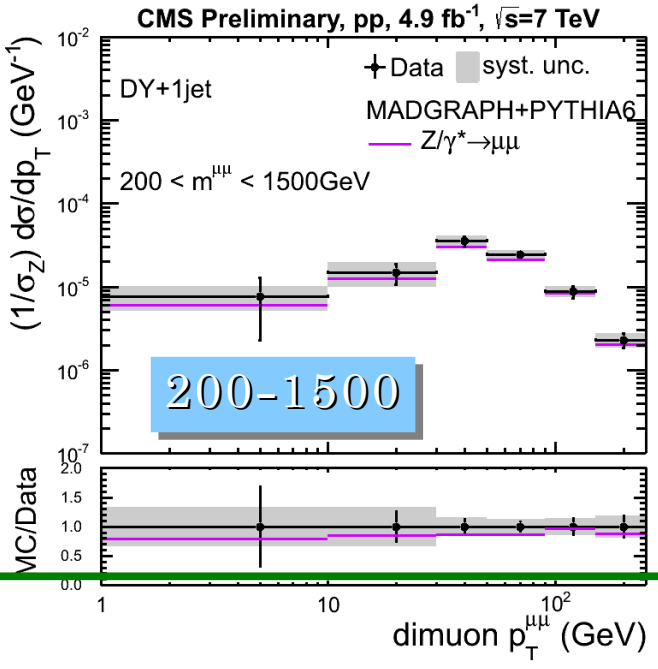

Results $d^2\sigma/dm^{\mu\mu}dp_T^{\mu\mu}$

DY+2jets

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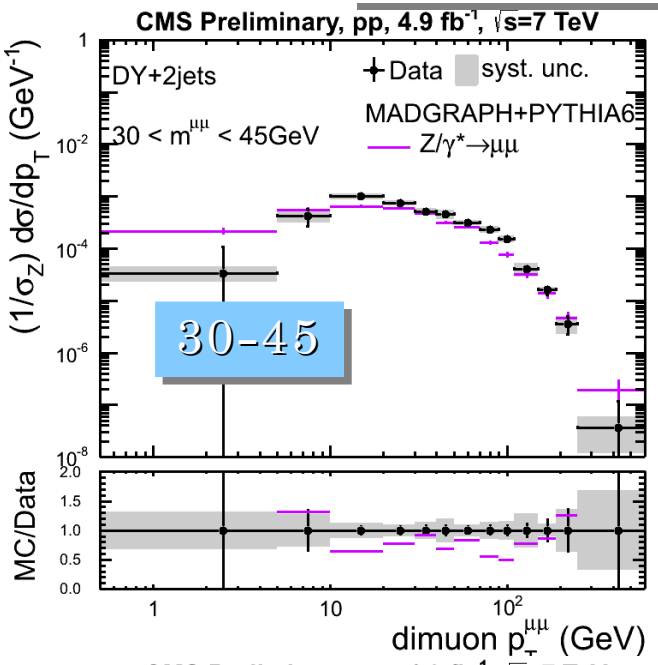
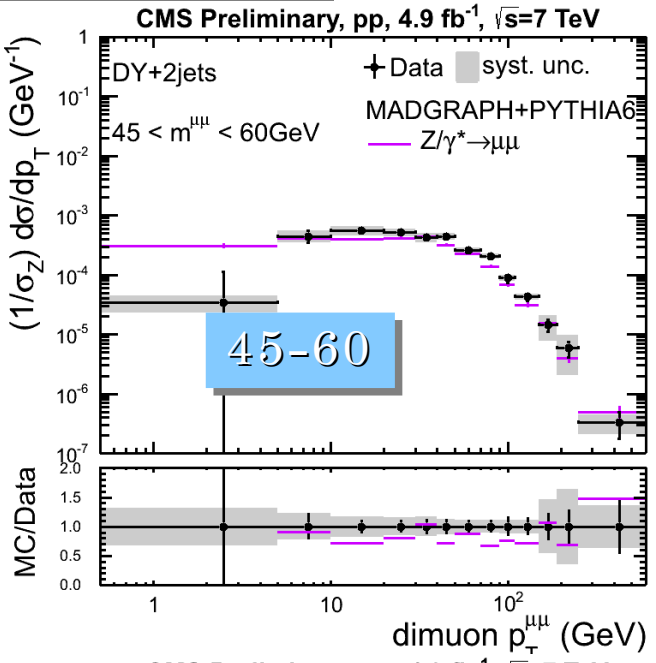
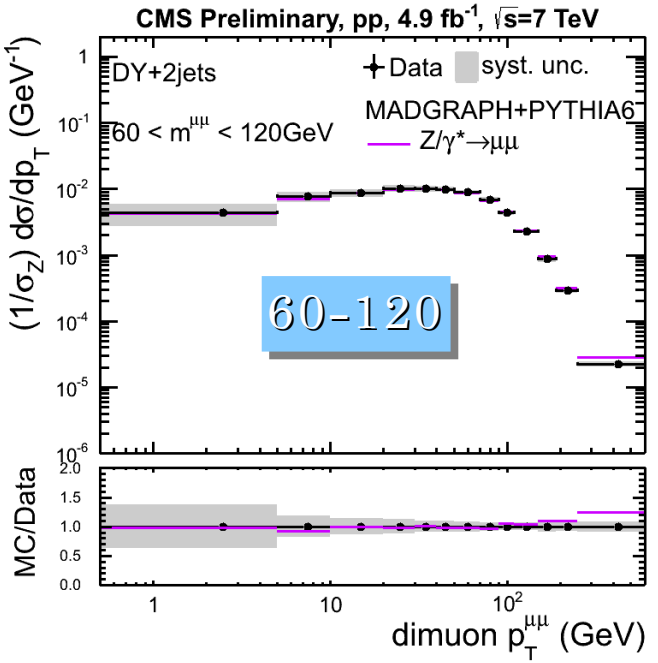
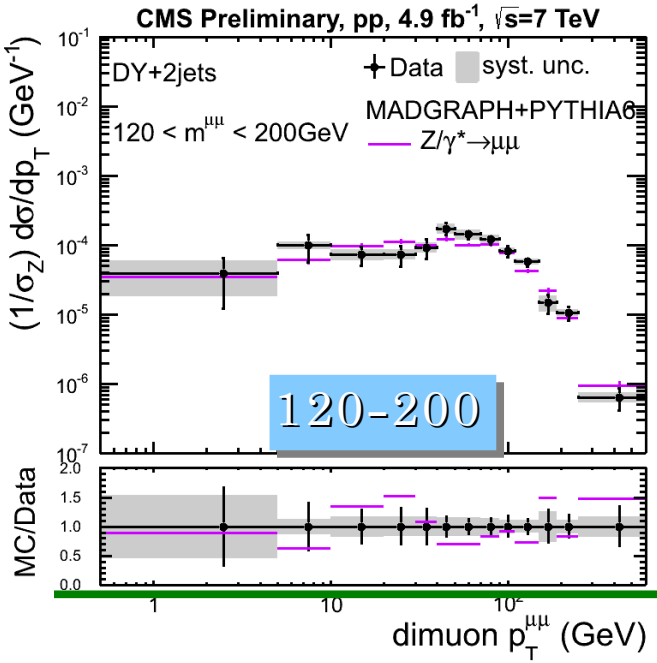
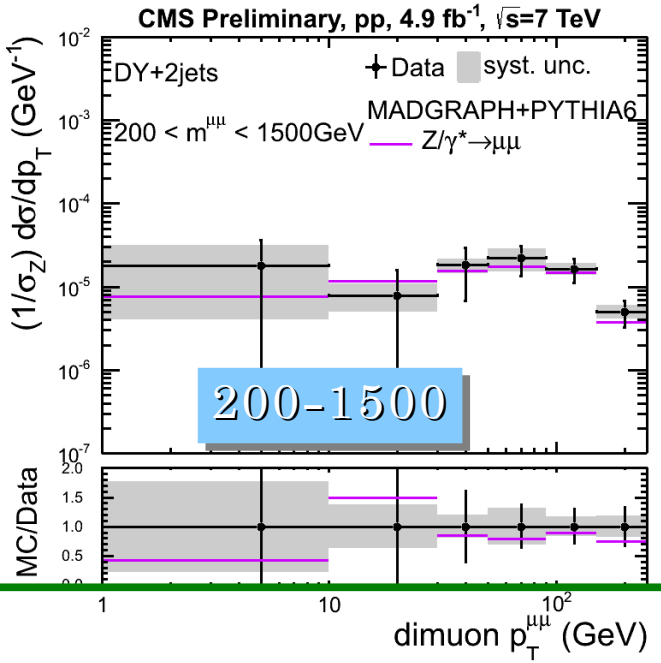








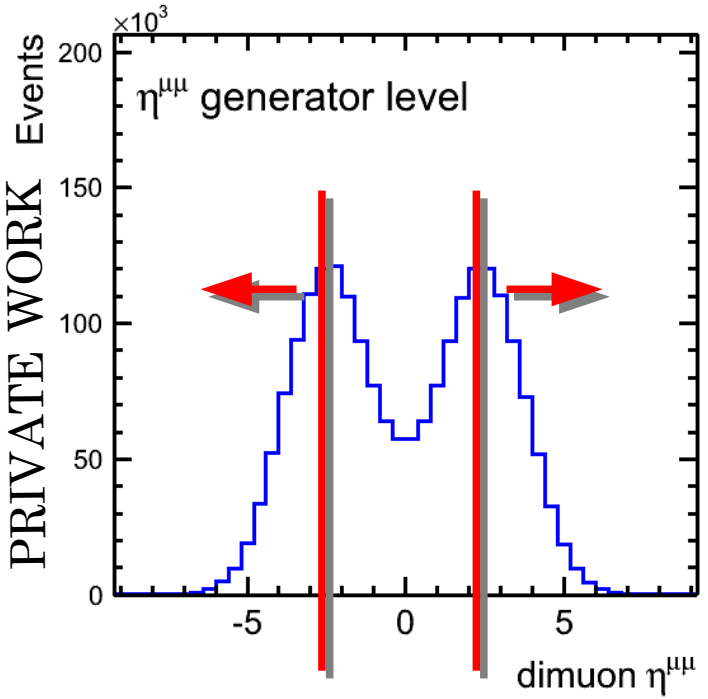


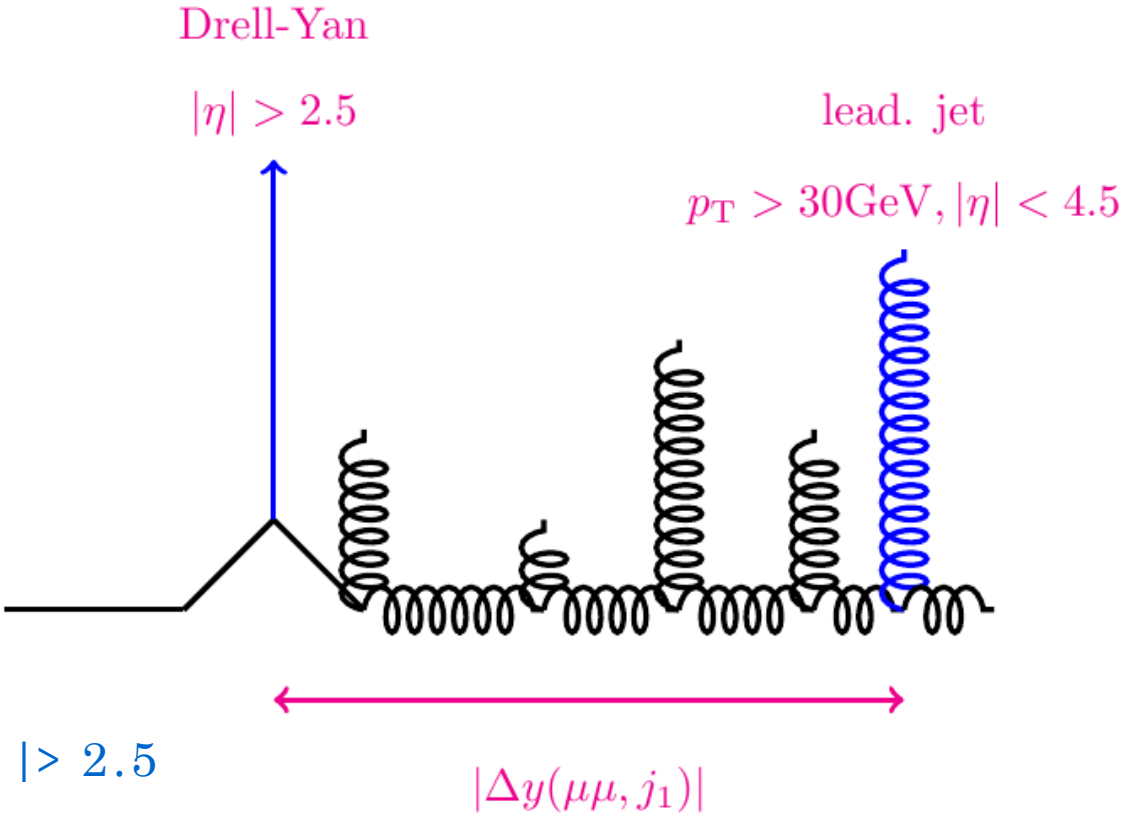
Drell-Yan

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

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 $|\eta| > 2.5$

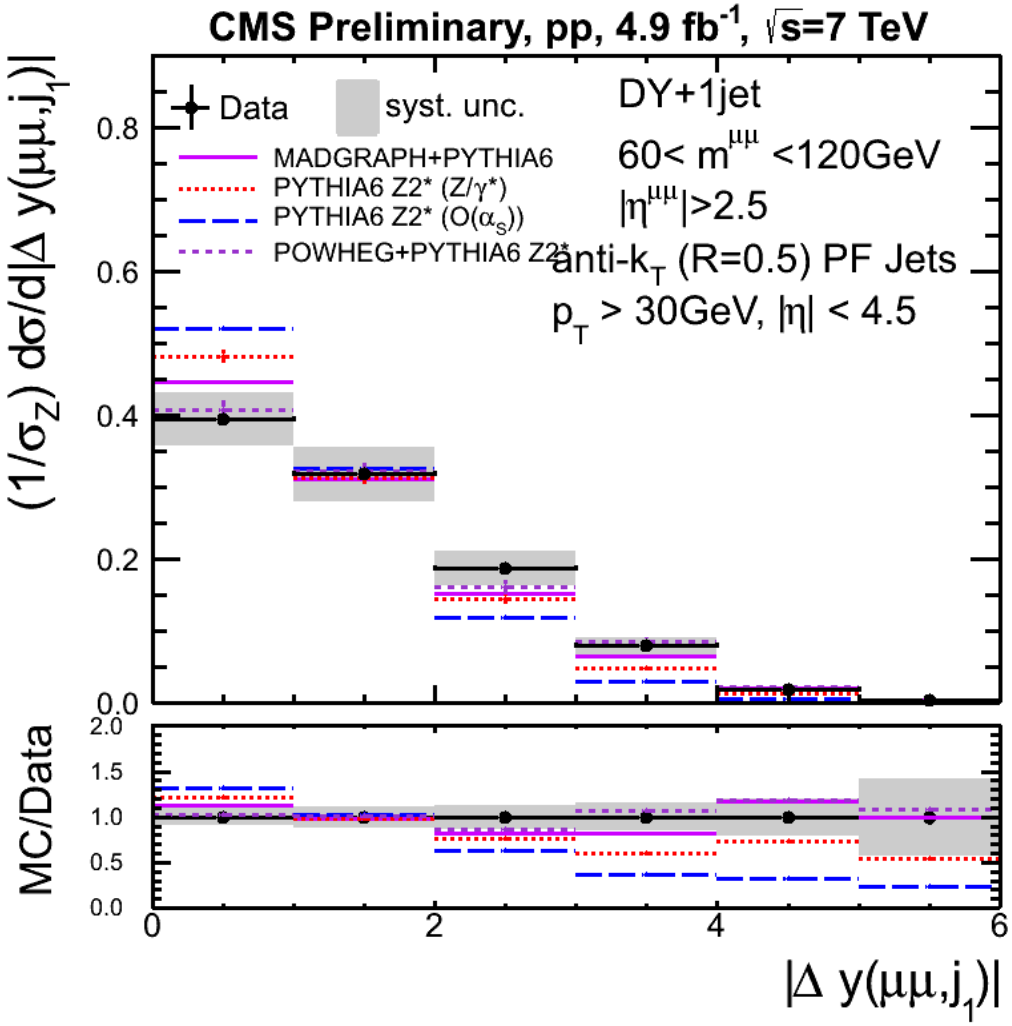
$$\eta^{DY} = \eta(\mu_1) + \eta(\mu_2)$$

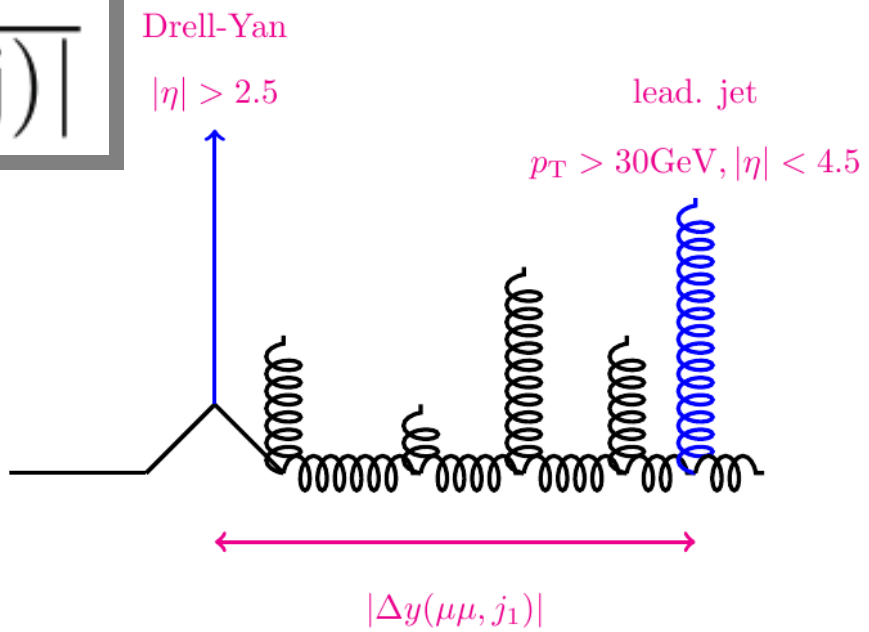
- Drell-Yan production in association with at least one jet and at least two jets

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

Results

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

DY+1jet

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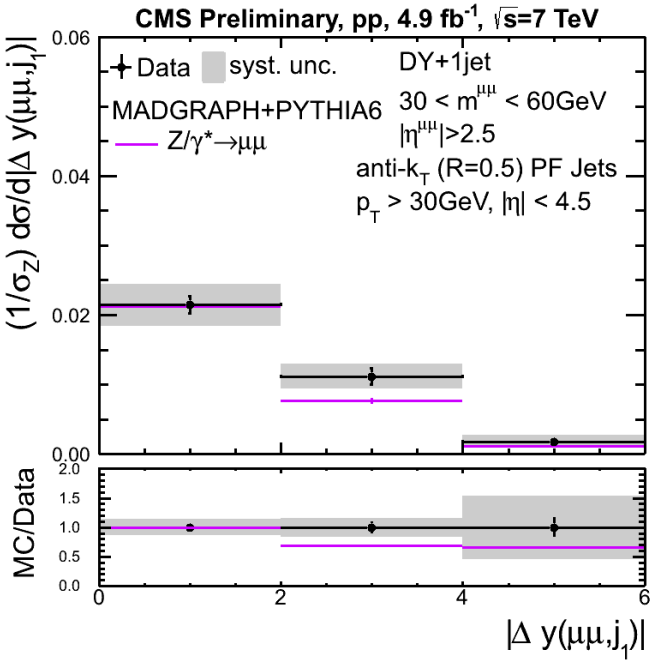
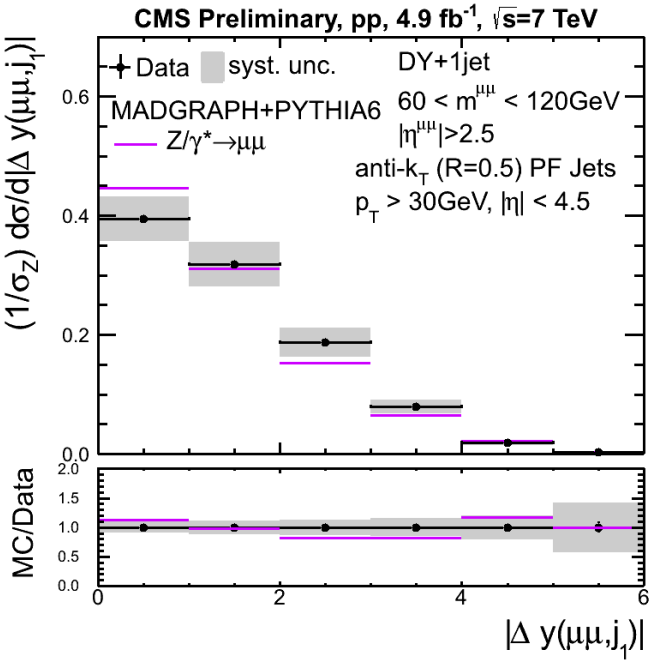
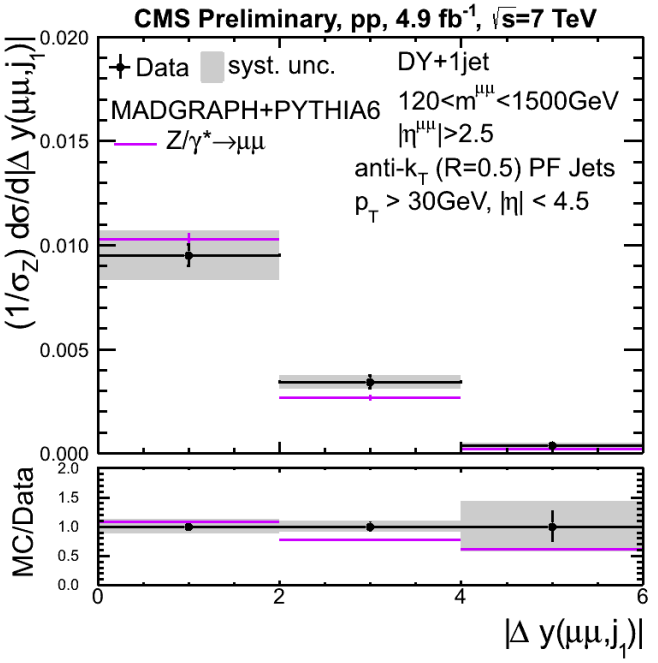
30-60



60-120



120-1500



Results

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

DY+2jets

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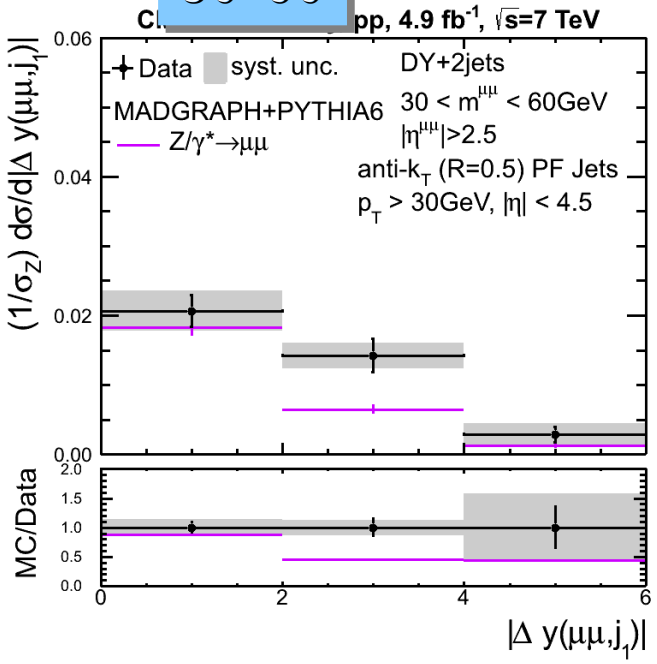
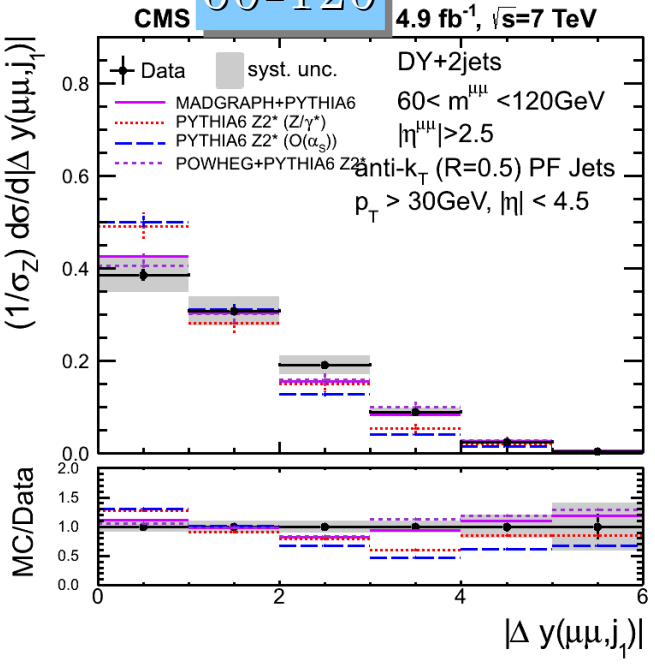
30-60



60-120



120-1500