Parton Shower Corrections and Resummation Effects in Drell-Yan Processes

Samantha Dooling

LHC Physics Discussion – SM and QCD

Content

Nonperturbative and Parton Shower Corrections from NLO MC

- Corrections to perturbative calculations for inclusive jet production
- Take into account multiparton interaction, parton showering and hadronisation

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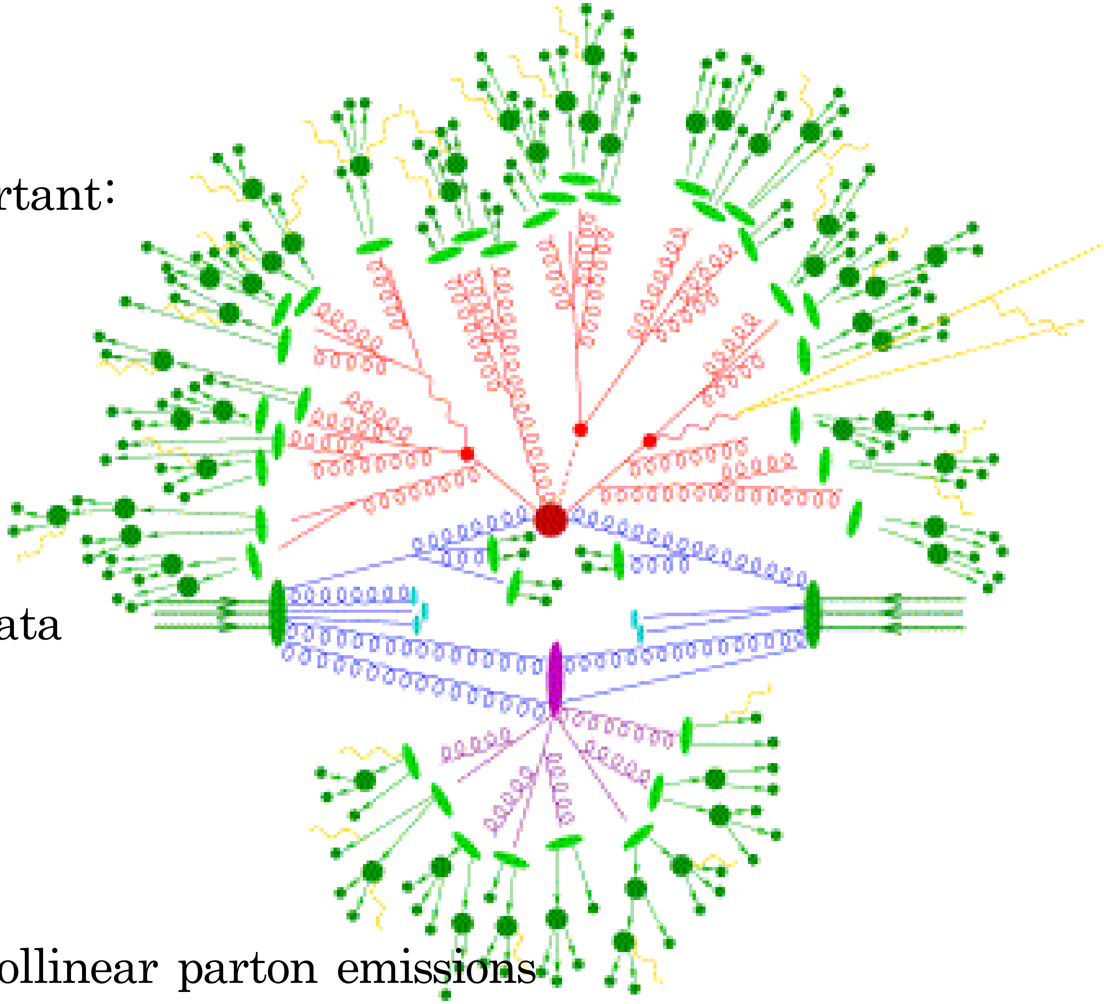
Probing Resummation with Drell-Yan plus Jets Data

- QCD emissions have to be resummed to all orders at small scales
- Parton shower algorithm models the soft gluon resummation

CMS-PAS-FSQ-13-003

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ13003

Motivation



Measurements of QCD processes are important:

- Stringently test of pQCD
- Constrain PDF (at high x)
- Determine strong coupling constant

▷ In high energy physics experimental data is compared to MC predictions

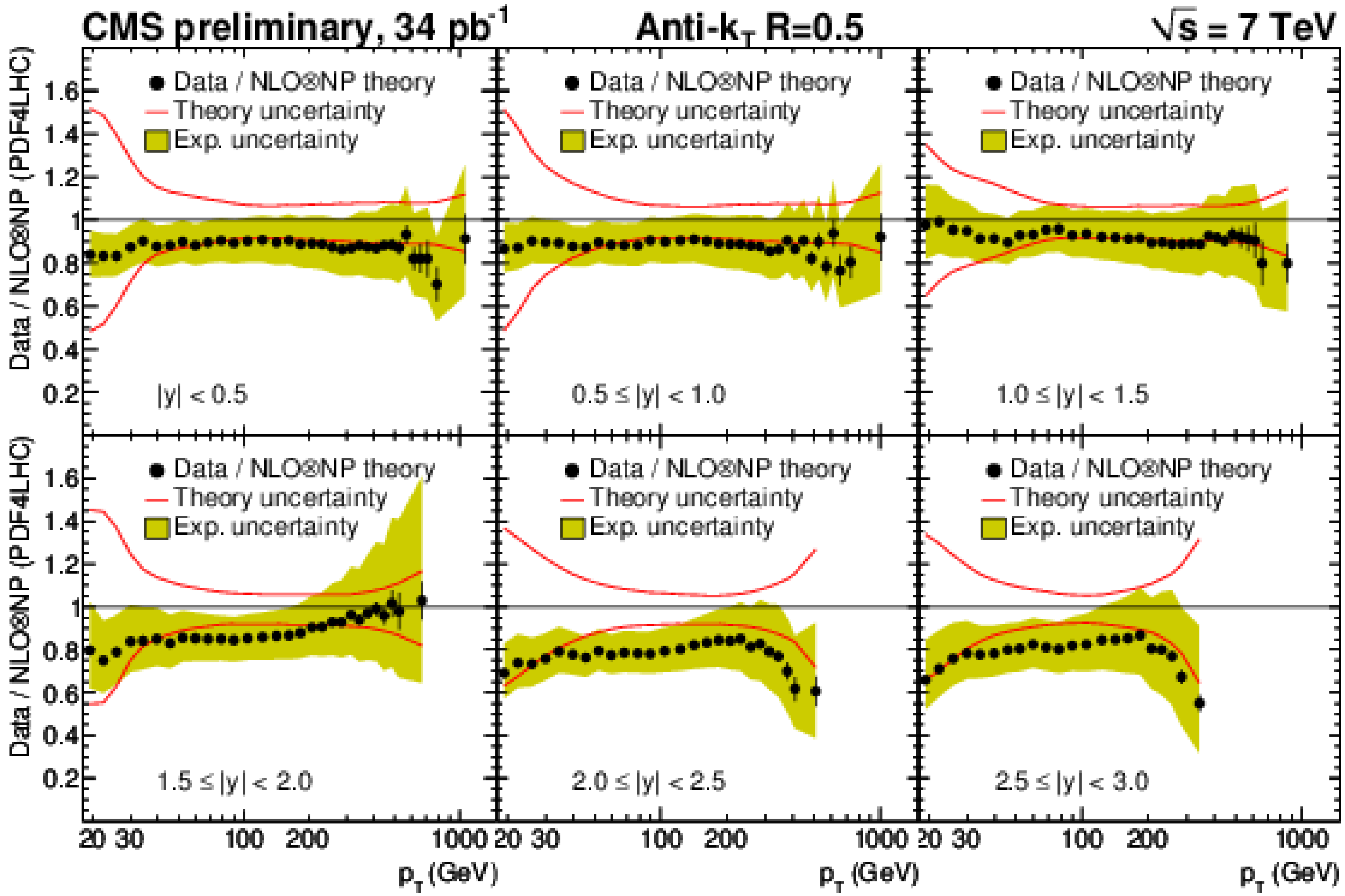
Fixed-order perturbative calculation +

Parton shower (PS) algorithm: Soft and collinear parton emissions

❖ Is the PS algorithm a sufficient approximation?

How does the PS model the extremes: high jet p_T, rapidity or small Z p_T? ❖

Motivation



- Jet measurement over a much larger kinematic range than previous collider experiments
- Comparison of NLO⊗NP with data shows good agreement at central rapidities, but
- Large differences at higher rapidity

❖ Study the kinematic of the parton shower at high rapidities ❖

Nonperturbative Correction

To compare theory with experimental data corrected to stable particle level

- NLO perturbative calculations have to be corrected to account for NP effects by using SMC:

$$\frac{d^2\sigma}{dp_T dy} = \frac{d^2\sigma_{NLO}}{dp_T dy} K^{NP}$$

- Previously estimated by LO generators

- New approach by taking a NLO-matched

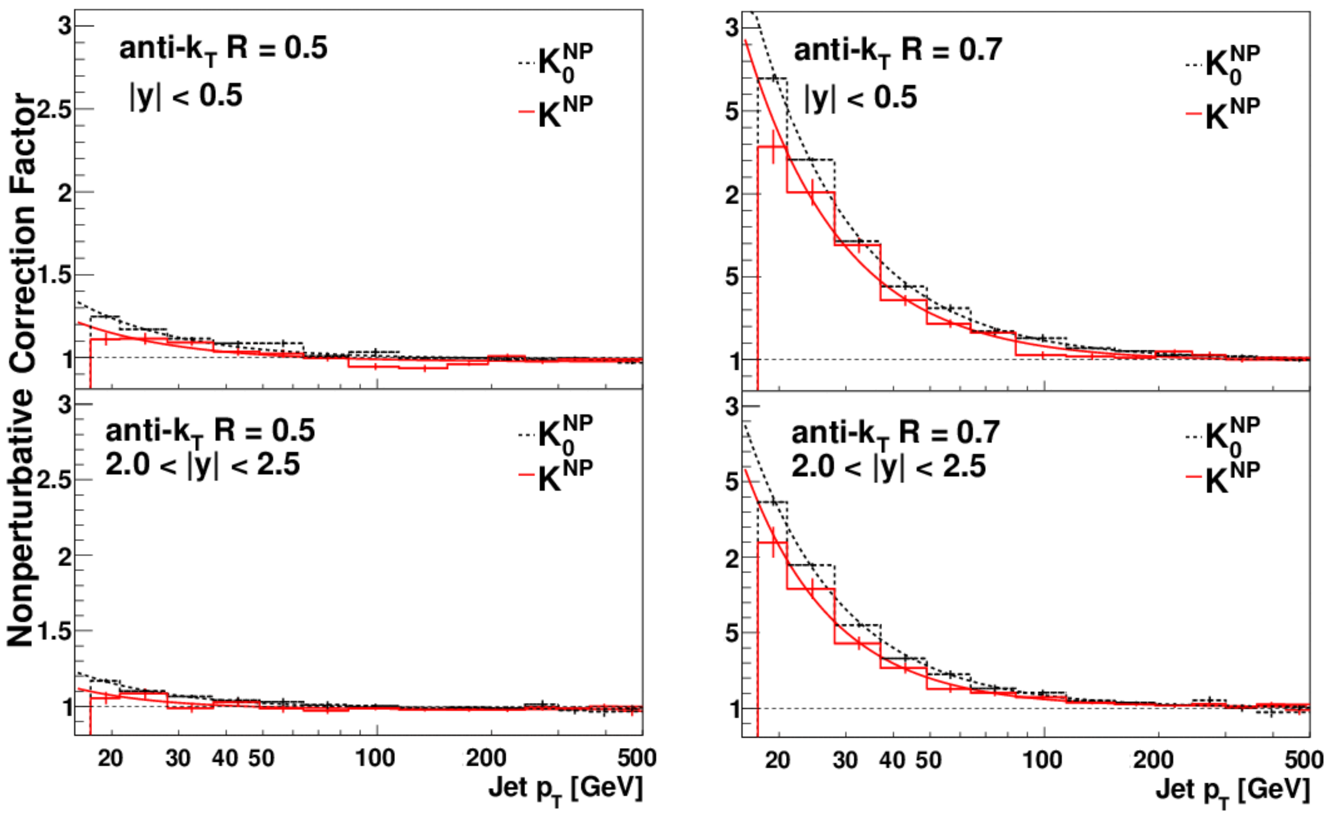
  Powheg + Pythia6 event generator

$$K^{NP} = N_{NLO-MC}^{(ps+mpi+had)} / N_{NLO-MC}^{(ps)}$$

$$K^{PS} = N_{NLO-MC}^{(ps)} / N_{NLO-MC}^{(0)}$$

❖ Study separate corrections factors to single out NP and PS effects ❖

Nonperturbative Correction



Non-negligible effect from nonperturbative effects at small p_T

Difference between LO and NLO correction

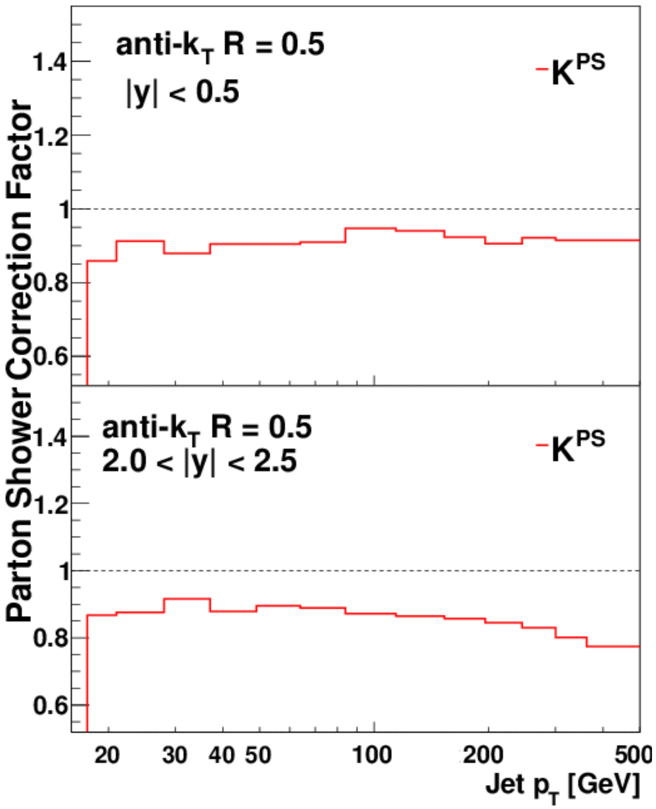
- Matching of MPI to the NLO calculation because the MPI p_T scale is different in LO and NLO

$$K_0^{NP} = N_{LO-MC}^{(ps+mpi+had)} / N_{LO-MC}^{(ps)}$$

$$K^{NP} = N_{NLO-MC}^{(ps+mpi+had)} / N_{NLO-MC}^{(ps)}$$

Parton Shower Correction

$$K^{PS} = N^{(ps)}_{NLO-MC} / N^{(0)}_{NLO-MC}$$



- Depends on rapidity and p_T especially in the forward region
- Significant effect in the forward region at large p_T has to be taken into account in the future

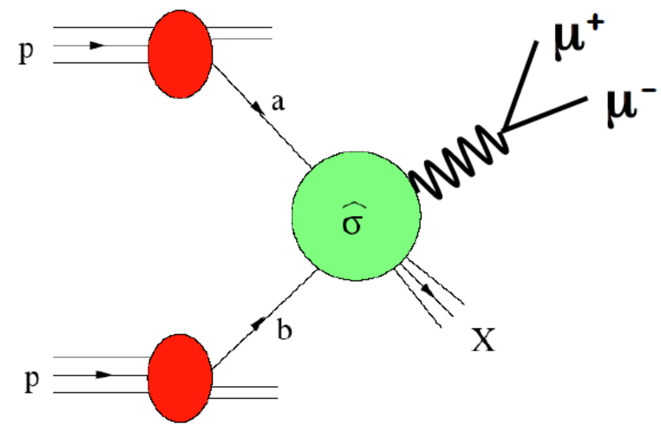
New result for α_s extraction including CMS inclusive jet data (arxiv:hep-ex/1410.6765)

$$\alpha_S(M_Z) = 0.1185^{+0.0063}_{-0.0042}$$

Including PS Correction

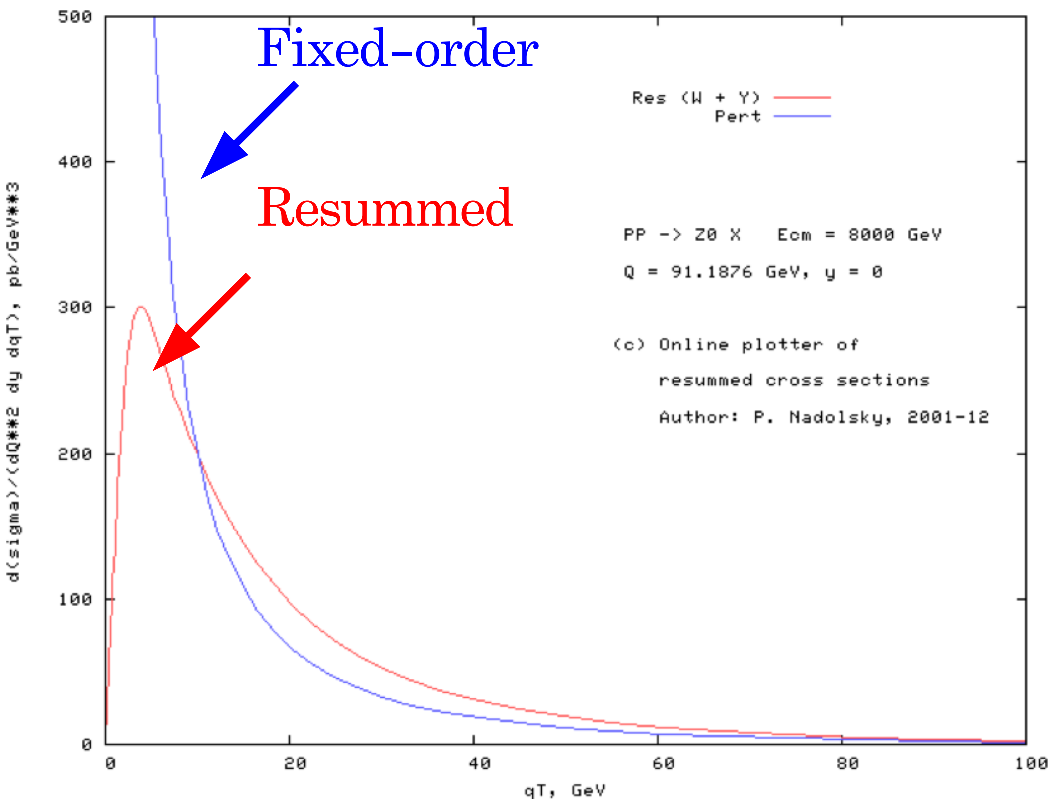
$$\alpha_S(M_Z) = 0.1204 \pm 0.0018$$

Drell-Yan Process



Factorisation theorem:

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



Z p_T (GeV)

At small scales :

large logarithms spoil the

perturbative calculation

Fixed-order calculation diverges

Partonic cross section needs to be

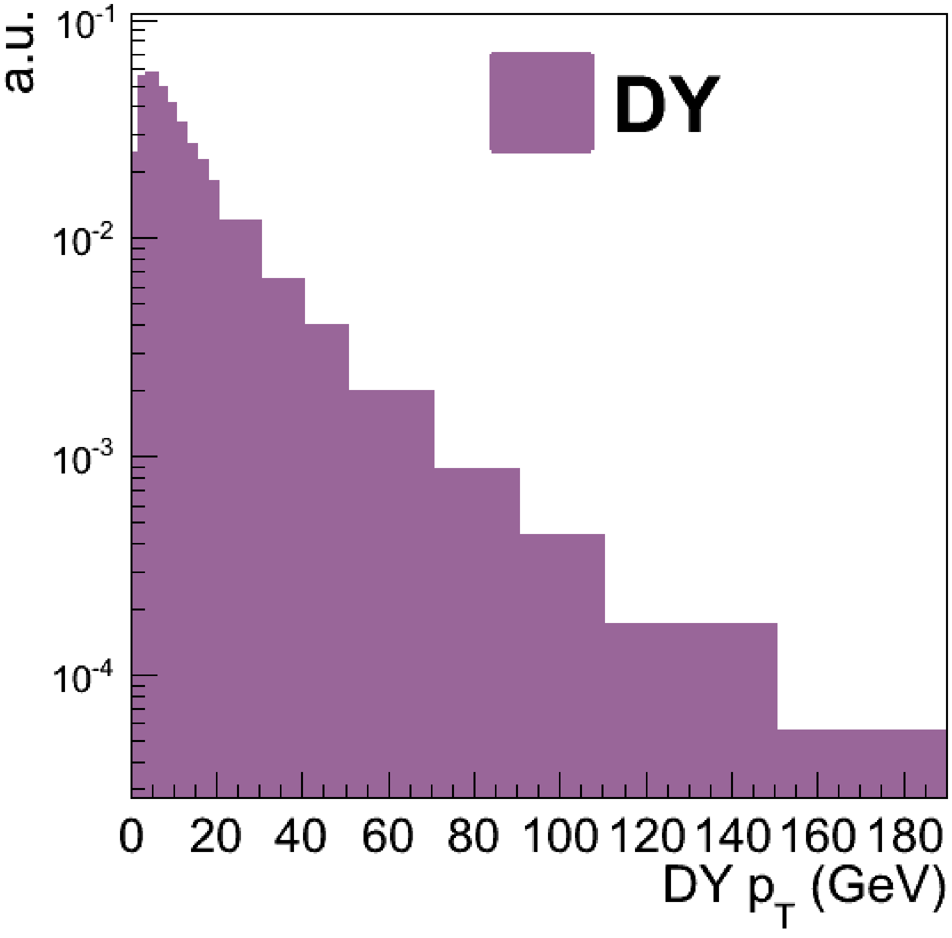
resummed to all orders

Transverse Momentum Distribution

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

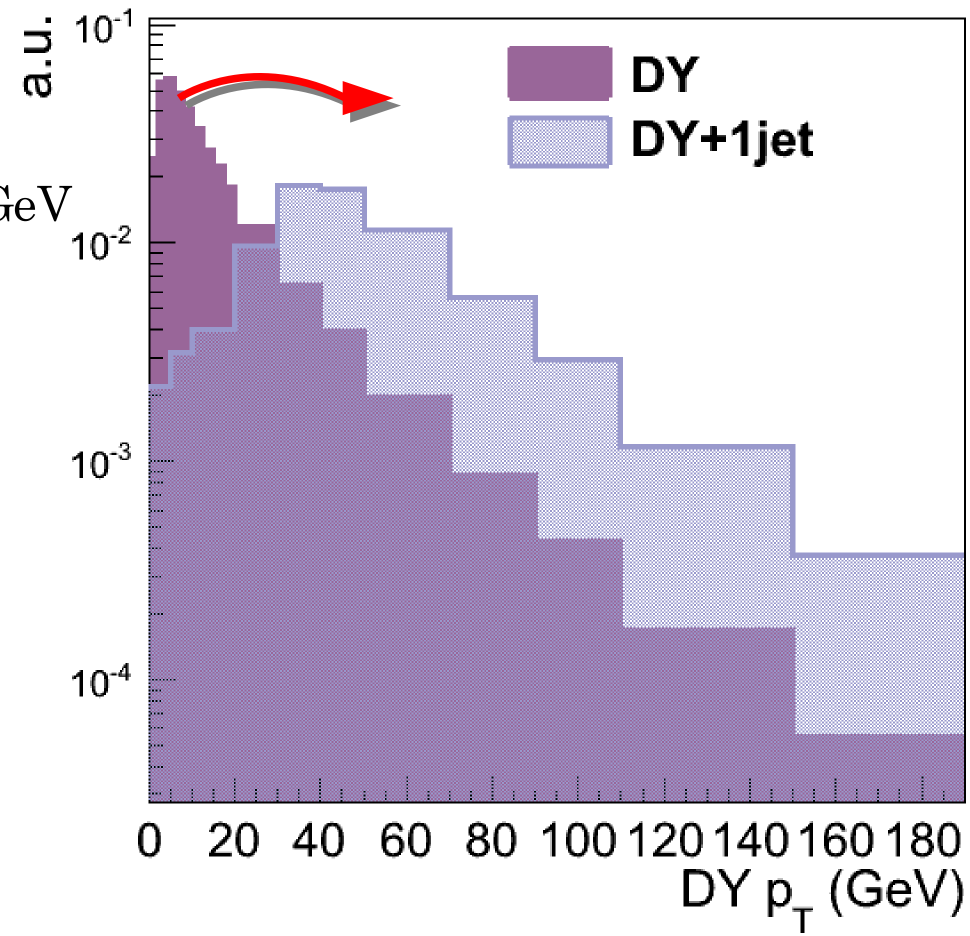


Transverse Momentum Distribution

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 $p_T \sim 35$ GeV



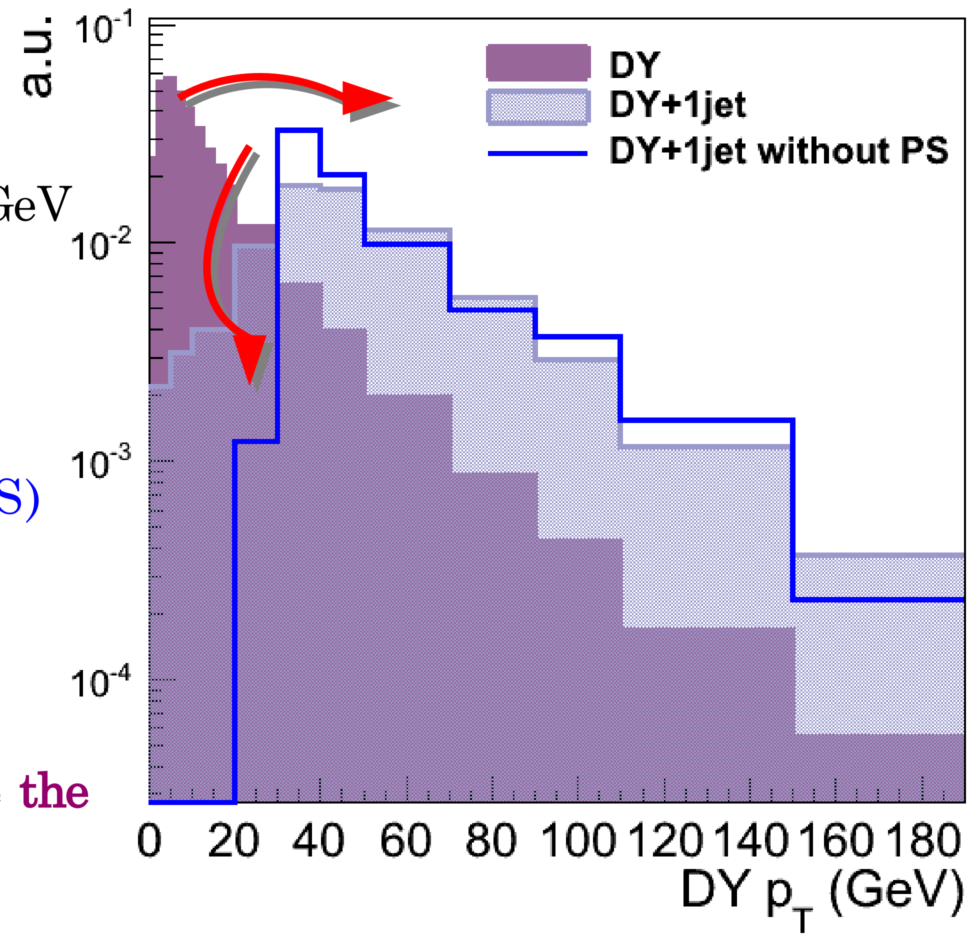
Increases the phase space for soft gluon radiation

Transverse Momentum Distribution

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



Rise at small p_T (soft gluon resummation)

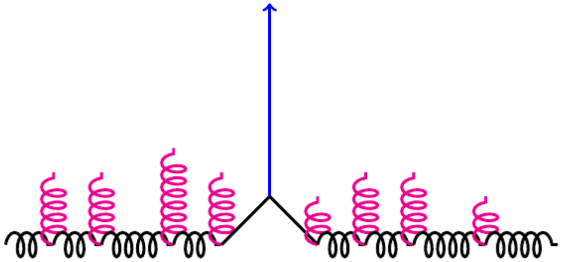
Treated by the initial state parton shower (PS) algorithms of the SMC

How well does the PS approximation describe the resummation of soft gluons?

Monte Carlo Predictions

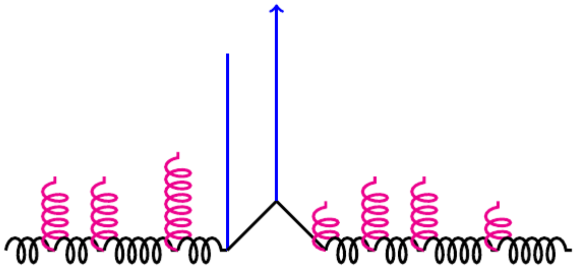
- PYTHIA6
- Inclusive DY production

Lowest Order in α_s

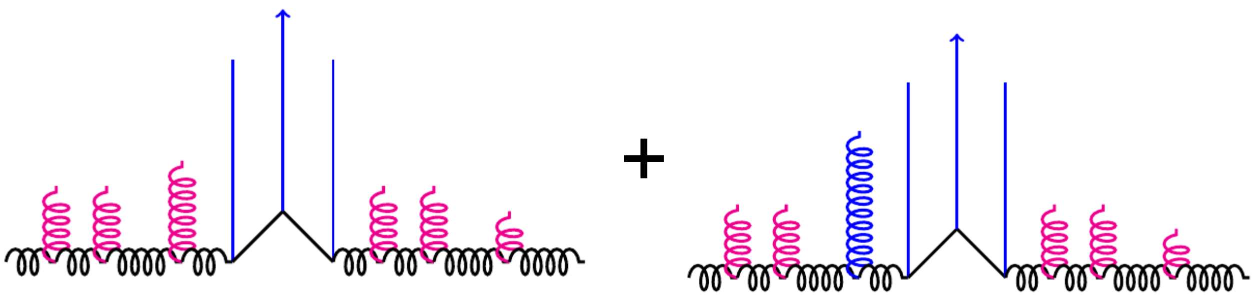


- PYTHIA6
- $O(\alpha_s)$ DY production

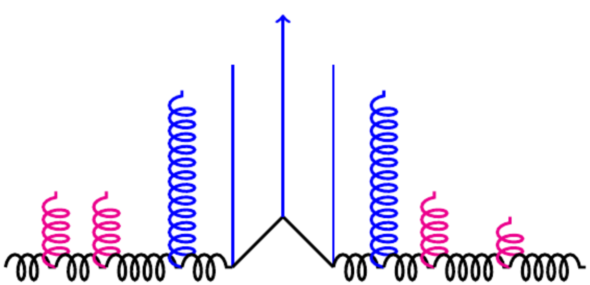
First Order in α_s



- POWHEG+PYTHIA6
- DY + 2 jets at NLO



- MADGRAPH+PYTHIA6
- DY plus 4 partons at LO

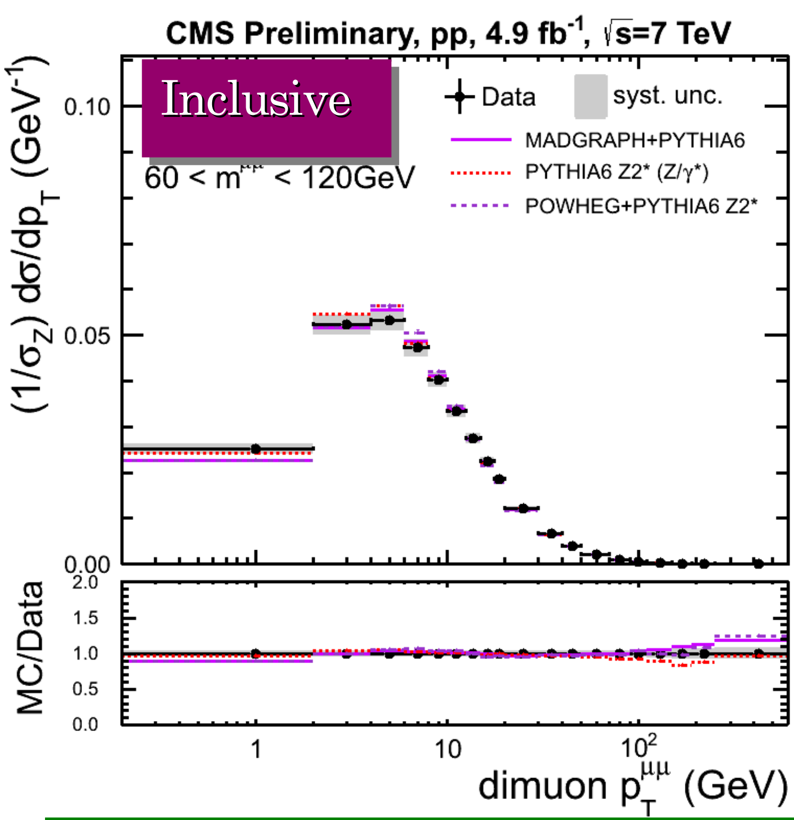


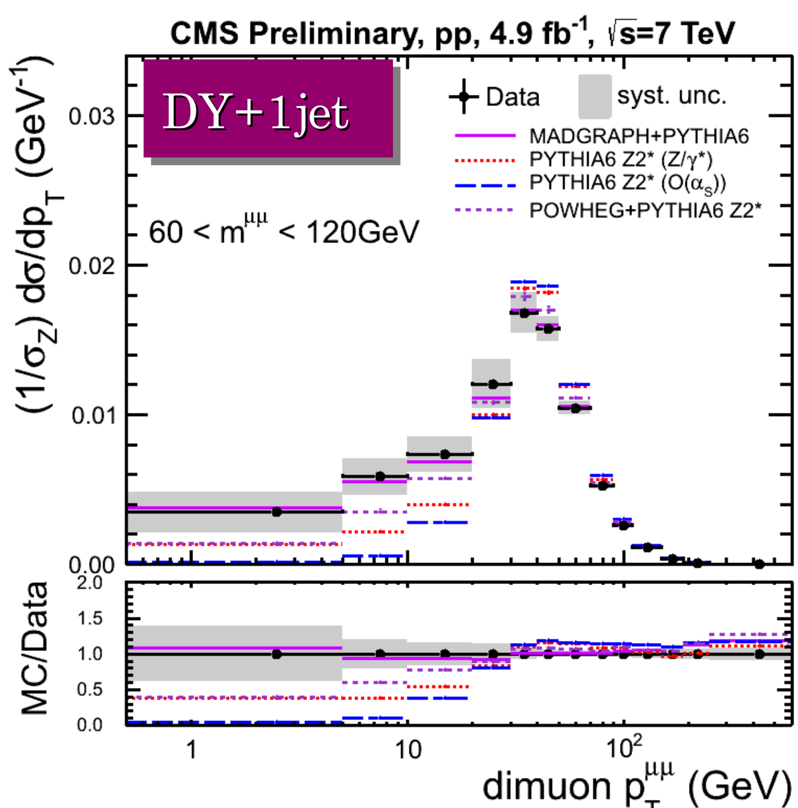
Differential Cross Section in Dimuon p_T

Inclusive DY : all MC show good agreement to data

DY+ jets :

- Lowest order α_s fails: too low cross section at low p_T
- Higher $O(\alpha_s)$: improved agreement to data
- Madgraph shows best agreement





$p_T^{\mu_1} > 20\ GeV$

$p_T^{\mu_2} > 10\ GeV$

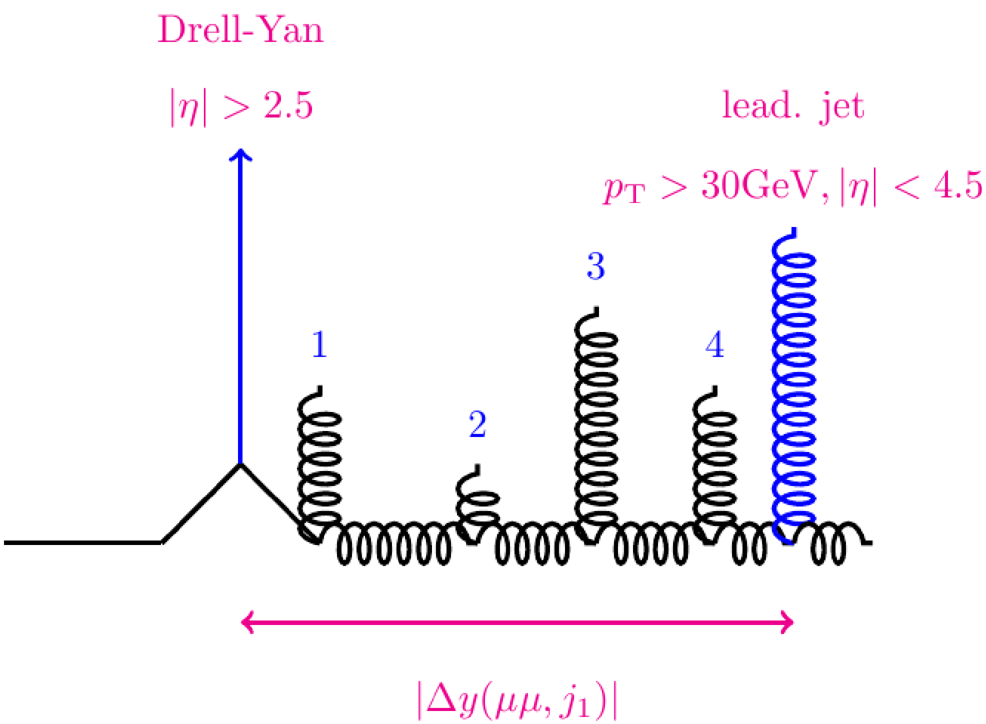
$|\eta^{\mu}| < 2.1$

$p_T^{jet} > 30\ GeV$

$|\eta^{jet}| < 4.5$

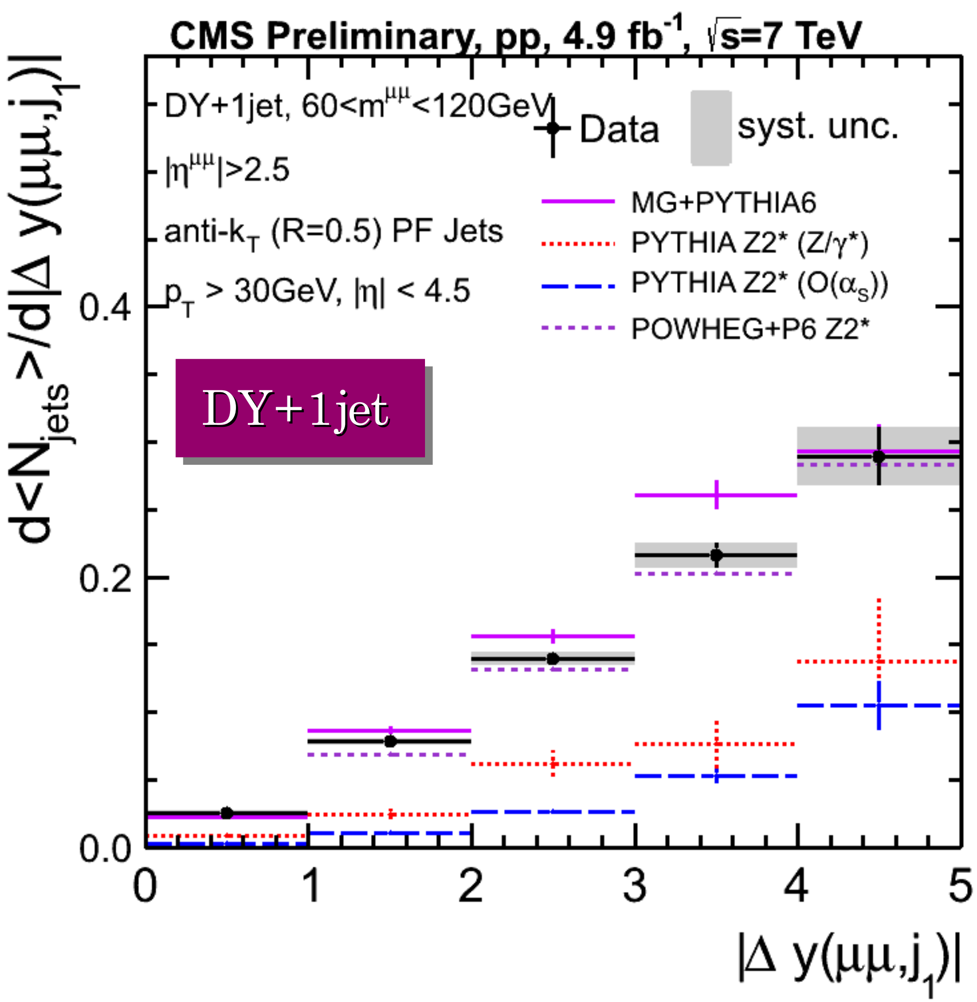
Jet Multiplicity

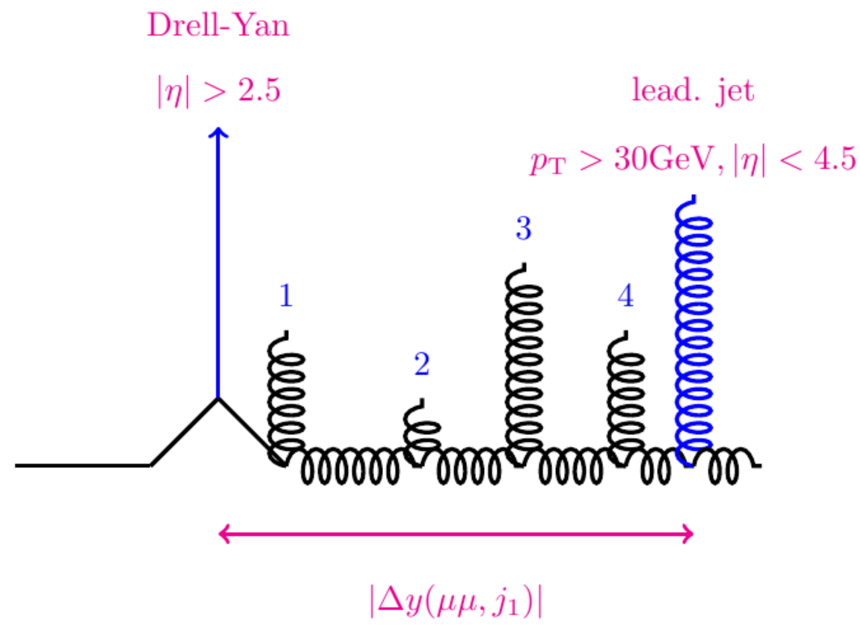
- Average Number of Jets in Δy of DY and the leading jet
- Forward DY production ($|\eta| > 2.5$)



- Sensitive to small-x physics
- Parton shower approximation is expected to fail at high rapidities

Jet Multiplicity





- 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

New Nonperturbative and Parton Shower Corrections for inclusive Jets

- Use NLO-matched Shower Monte Carlo Generator
- Parton shower correction significant over whole p_T range, most significant at large y
- Dependence on p_T and y can influence shape of parton distribution functions and α_S

Resummation in Drell-Yan plus Jet measurements

- Normalized differential cross section in transverse momentum of the dimuon pair

(2011 CMS data, 7 TeV, 4.9fb^{-1})

- Increased sensitivity to soft gluon resummation by using DY + jets
- Soft gluon resummation is well described by parton shower algorithm in inclusive DY
- Fixed-order calculation plus parton shower algorithm is needed in DY+jets

Backup

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 $p_T > 30$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, $Z \to \tau\tau$, 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

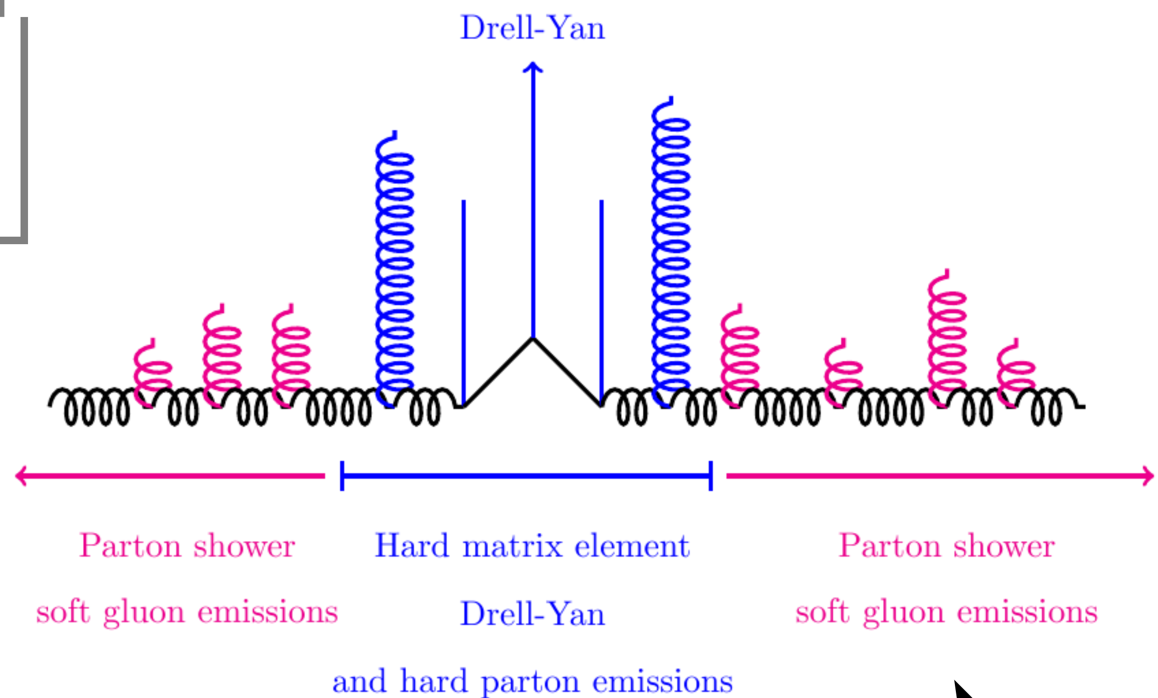
Cross Section Measurement

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



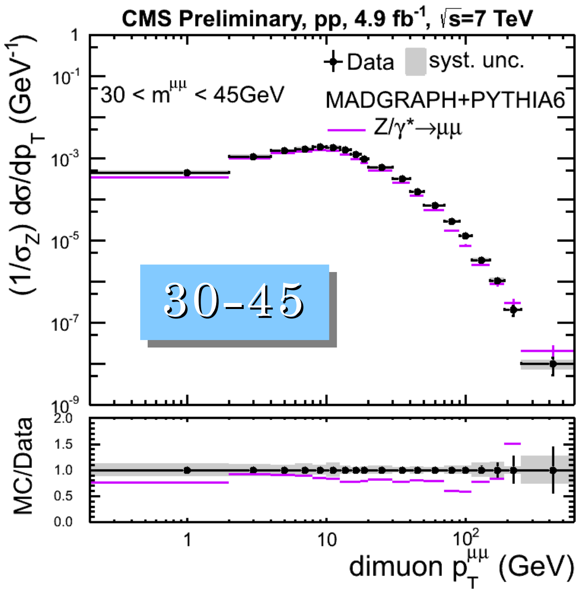
MadGraph generates the hard process with $\leq$ 4 partons

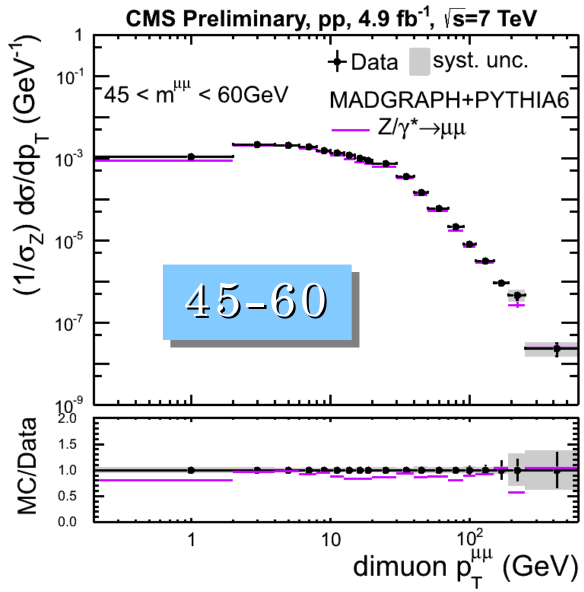
Parton shower is modelled by PYTHIA6

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

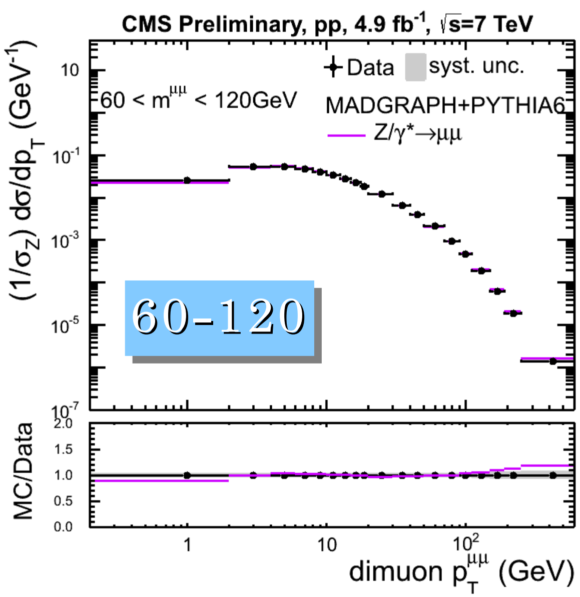
Inclusive

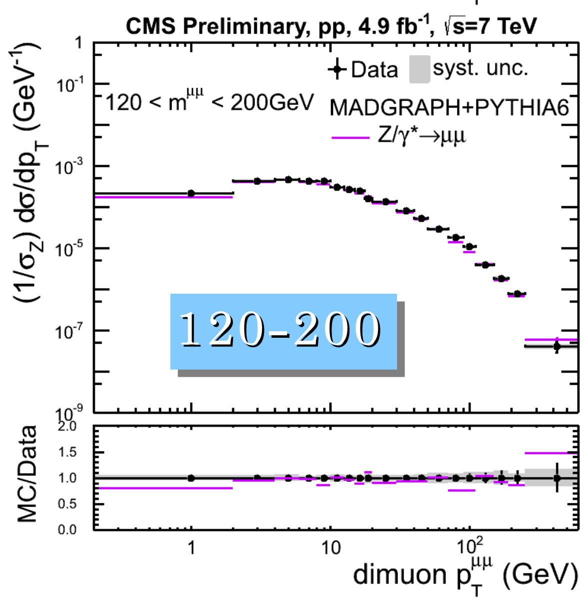
CMS-PAS-FSQ-13-003

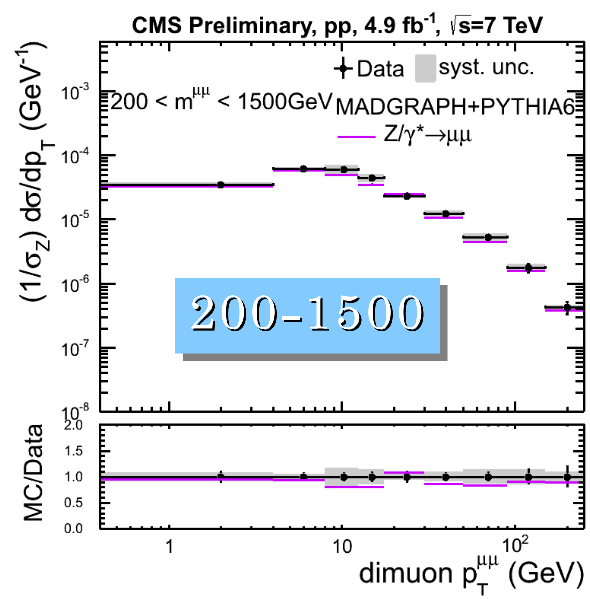




- Corrected data to stable particle level
- Normalized cross sections
- Dominant systematic uncertainty
  inclusive DY: Unfolding (8%)
  DY+jets: JEC (10%)





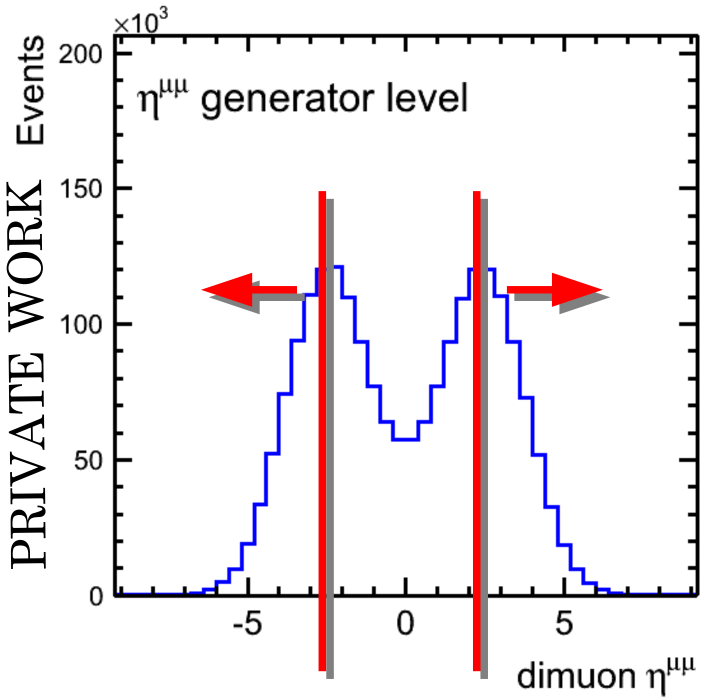


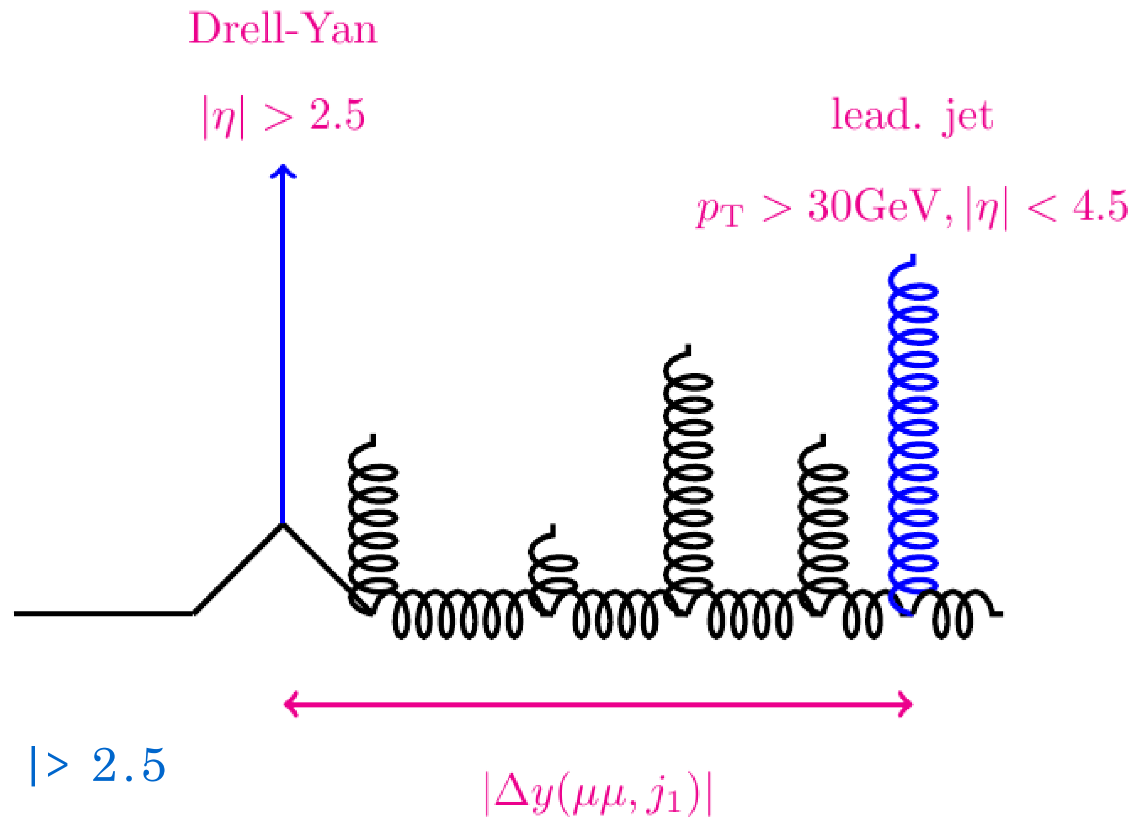
Drell-Yan

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

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





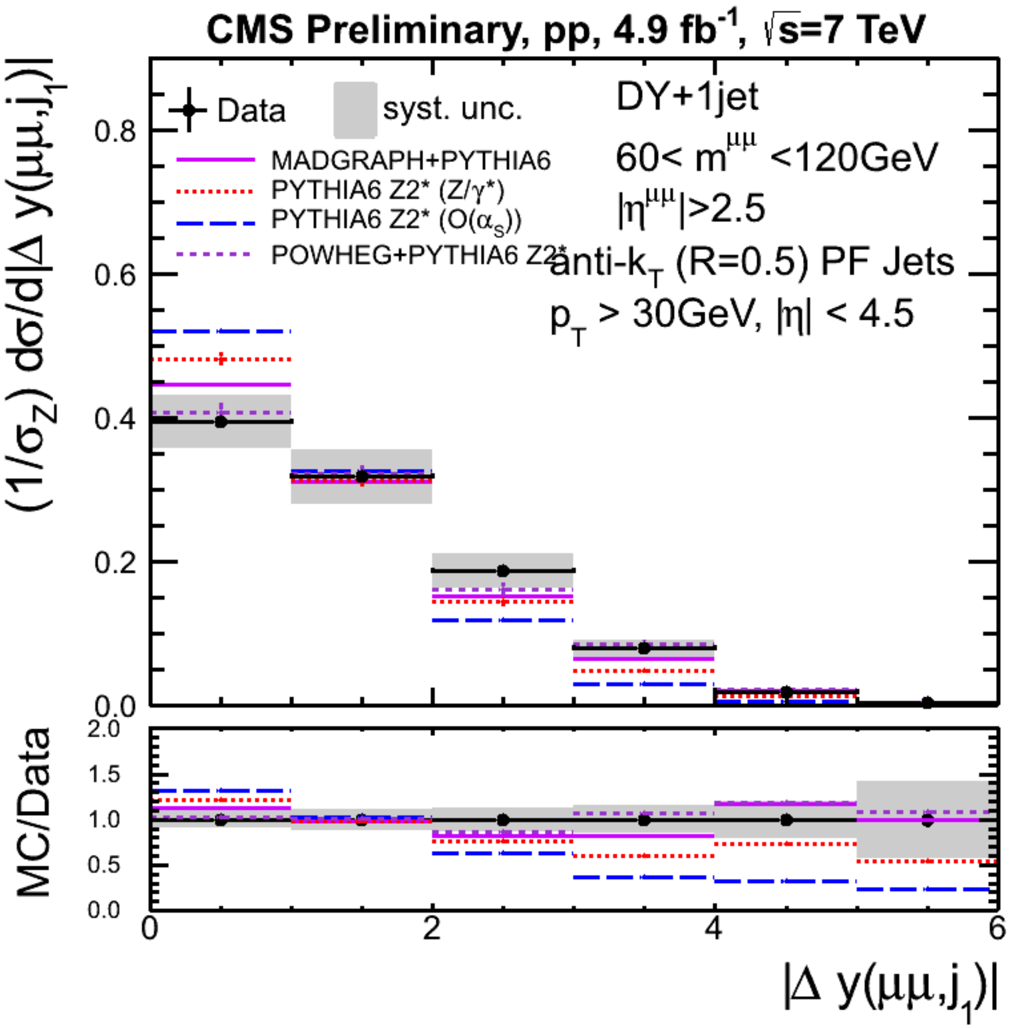
- Forward Drell-Yan production $|\eta| > 2.5$
- Drell-Yan production in association with at least one jet and at least two jets

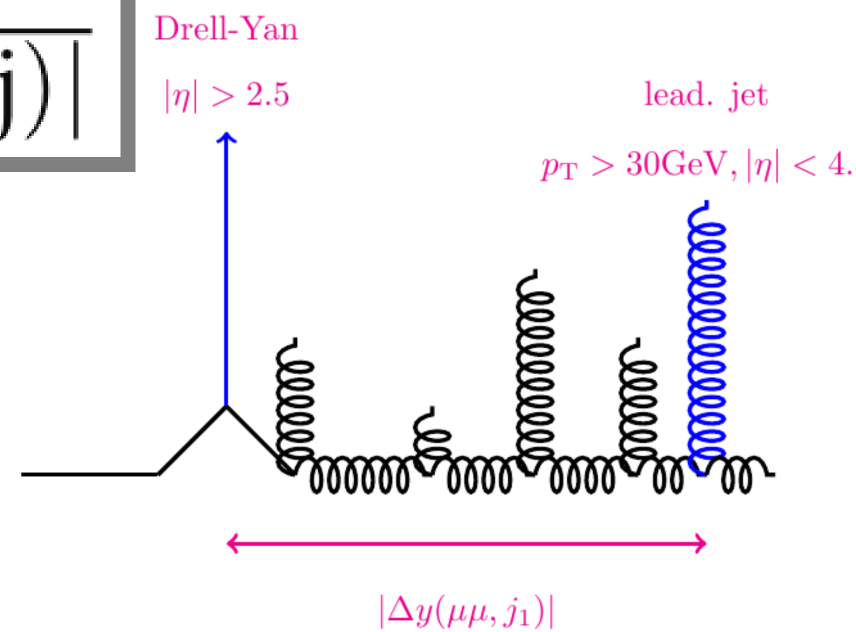
Results

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

60-120

DY+1jet



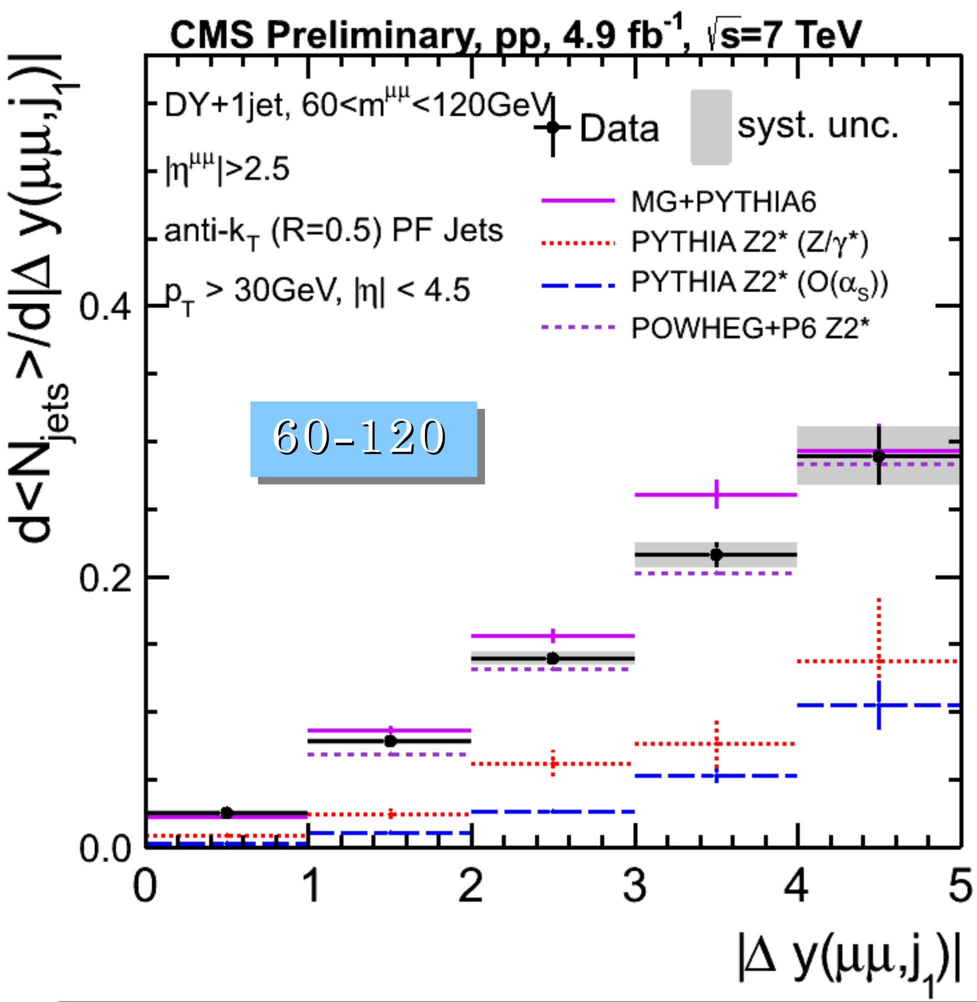


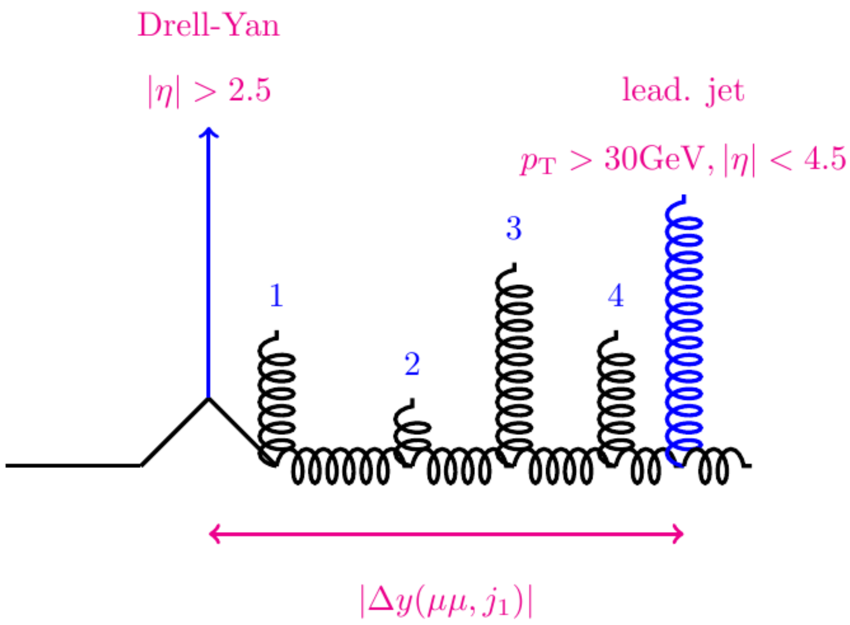
- Large rapidity separation, up to 6
- Decreasing cross section
- General behaviour is described by MC
- Higher order calculations provide better agreement to data

Jet Multiplicity

DY+1jet

- Average Number of Jets in 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

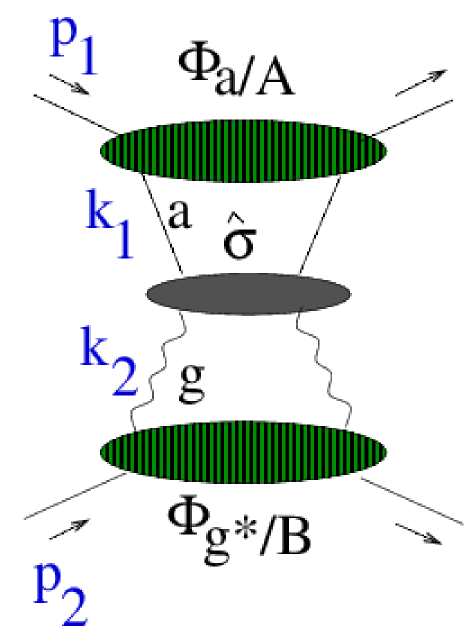
Longitudinal Momentum Shift

Dooling et al.
arXiv:1212.6264

In SMC:

hard subprocess is generated with full 4-momentum for the external lines

Factorized jet cross section at high rapidity



Momentum of the partons initiating the hard scatter: $k_j^{(0)} = x_j p_j$ on-shell and fully collinear with the incoming momenta

Applying shower algorithm

Complete final states: $k_j \neq x_j p_j$ no longer collinear

Energy momentum conservation ▷ Reshuffling in x_j (long. mom fraction)

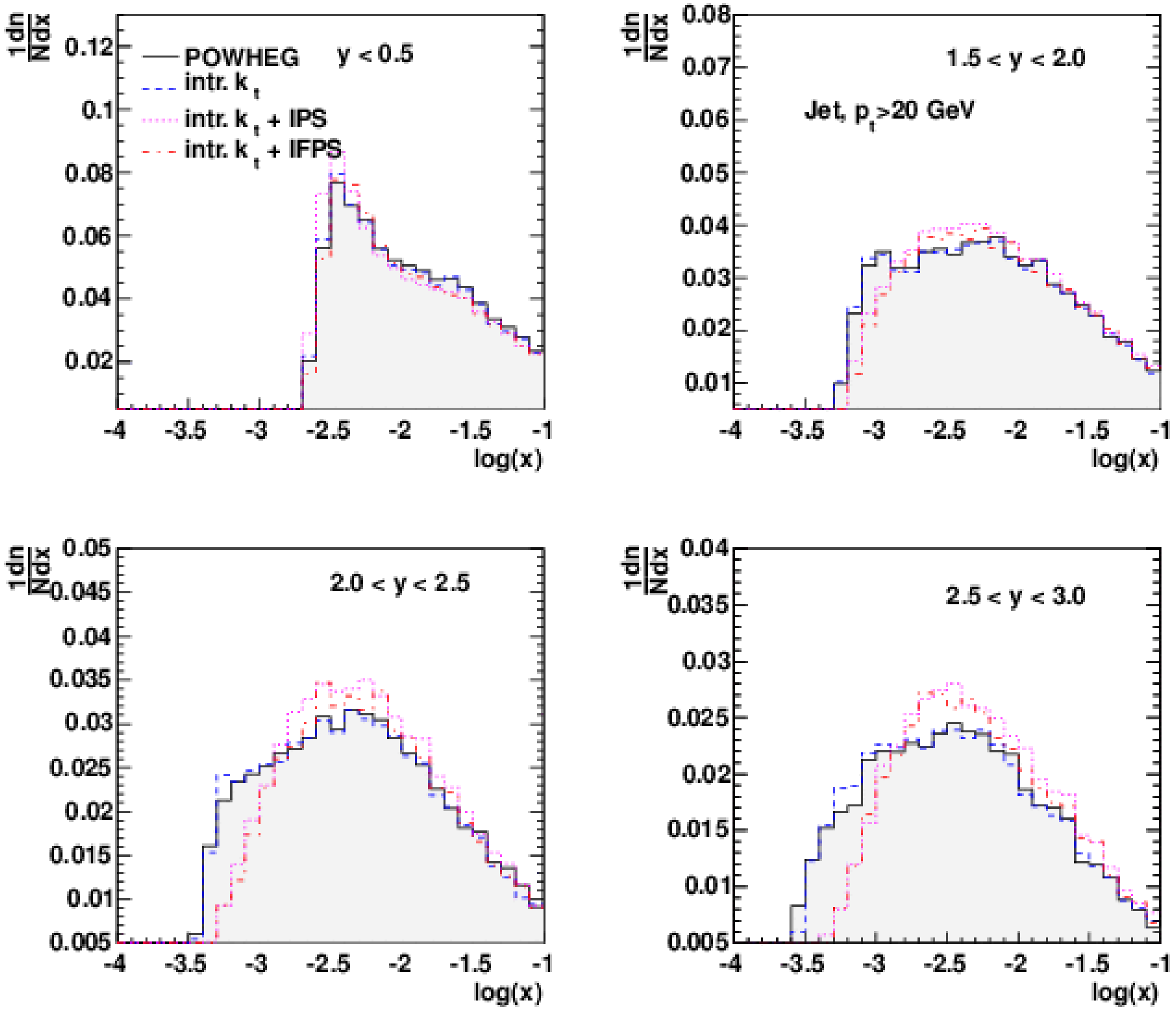
Collinear approximation ⊗ energy momentum conservation

=

kinematic shift in longitudinal momentum distribution due to showering

Longitudinal Momentum Shift – Inclusive Jets

Jet measurement in the rapidity range $y < 2.5$



Compute x_j from POWHEG before parton showering and after parton showering (using PYTHIA6)

Kinematic reshuffling in x is negligible for central rapidities but becomes significant for $y > 1.5$

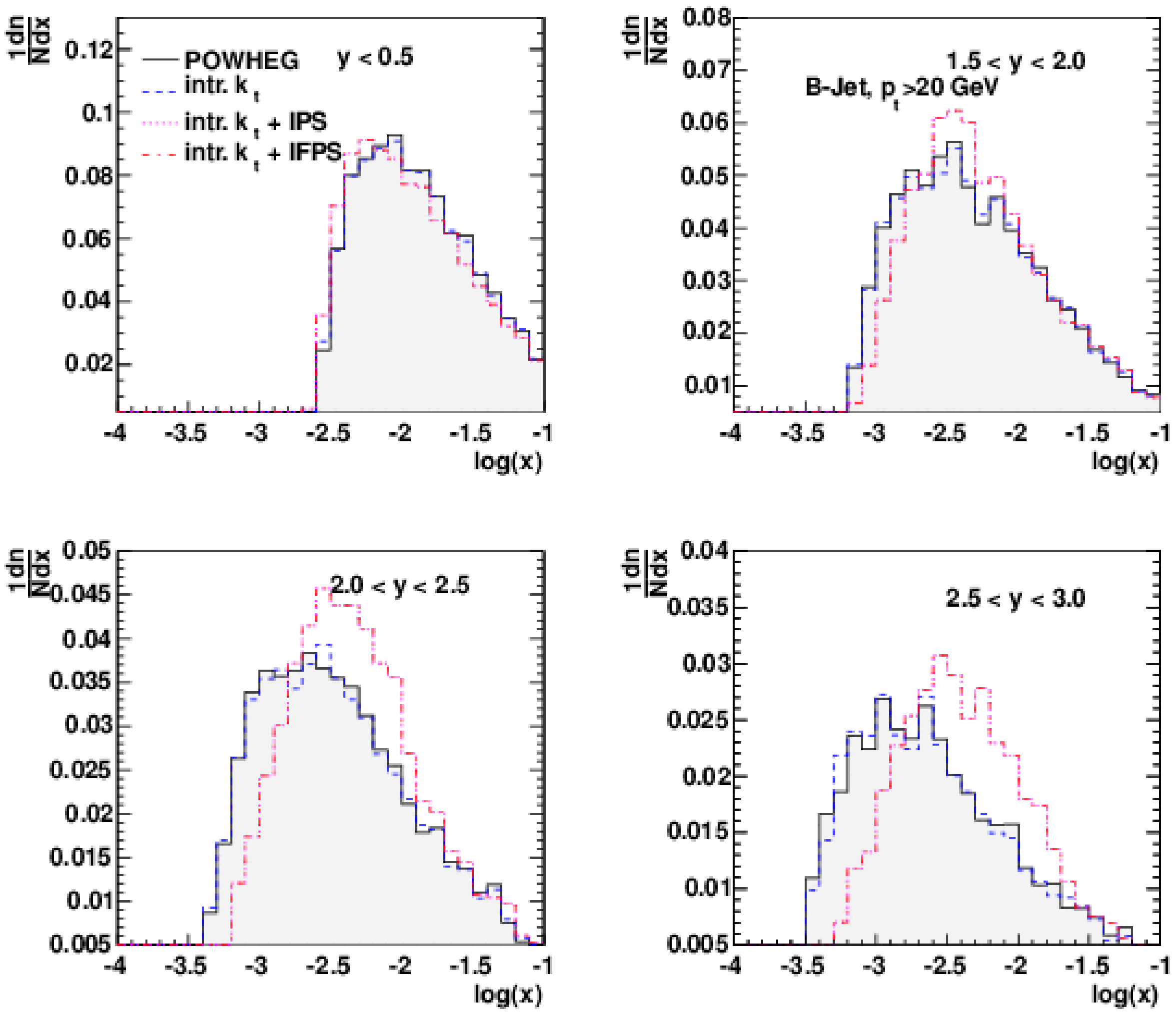
▷ Kinematic shift can affect predictions through the PDFs

Dooling et al.
arXiv:1212.6264

Longitudinal Momentum Shift – B-Jets

CMS
arXiv:1202.4617

x distribution before and after showering



B-jet production is well described by NLO-matched generators at central rapidities

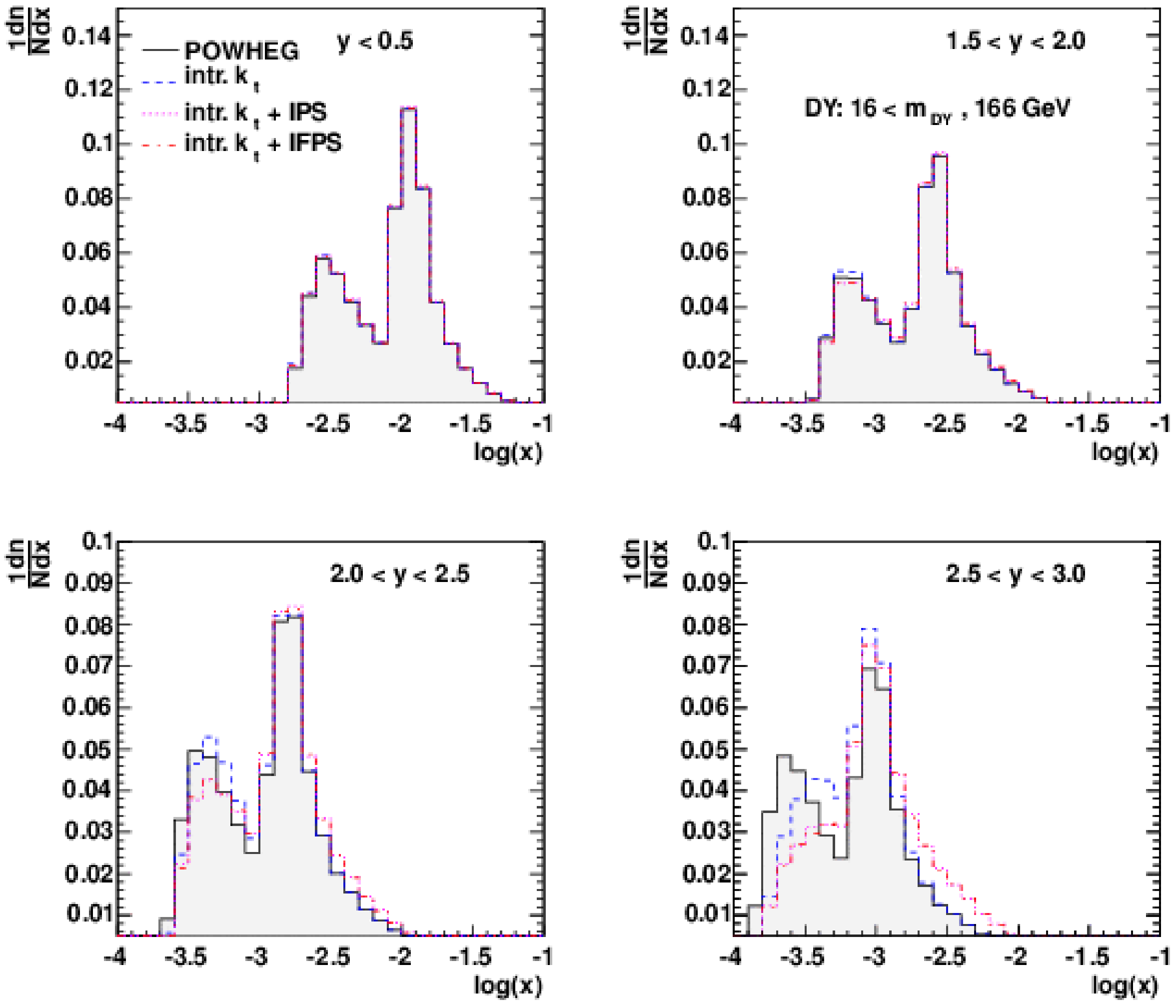
But data is below the prediction at large y and large p_T

▷ Reshuffling in longitudinal momentum fraction in forward region

Dooling et al.
arXiv:1212.6264

Longitudinal Momentum Shift – Drell-Yan

x distribution before and after showering of DY production in 16 < m < 166 GeV



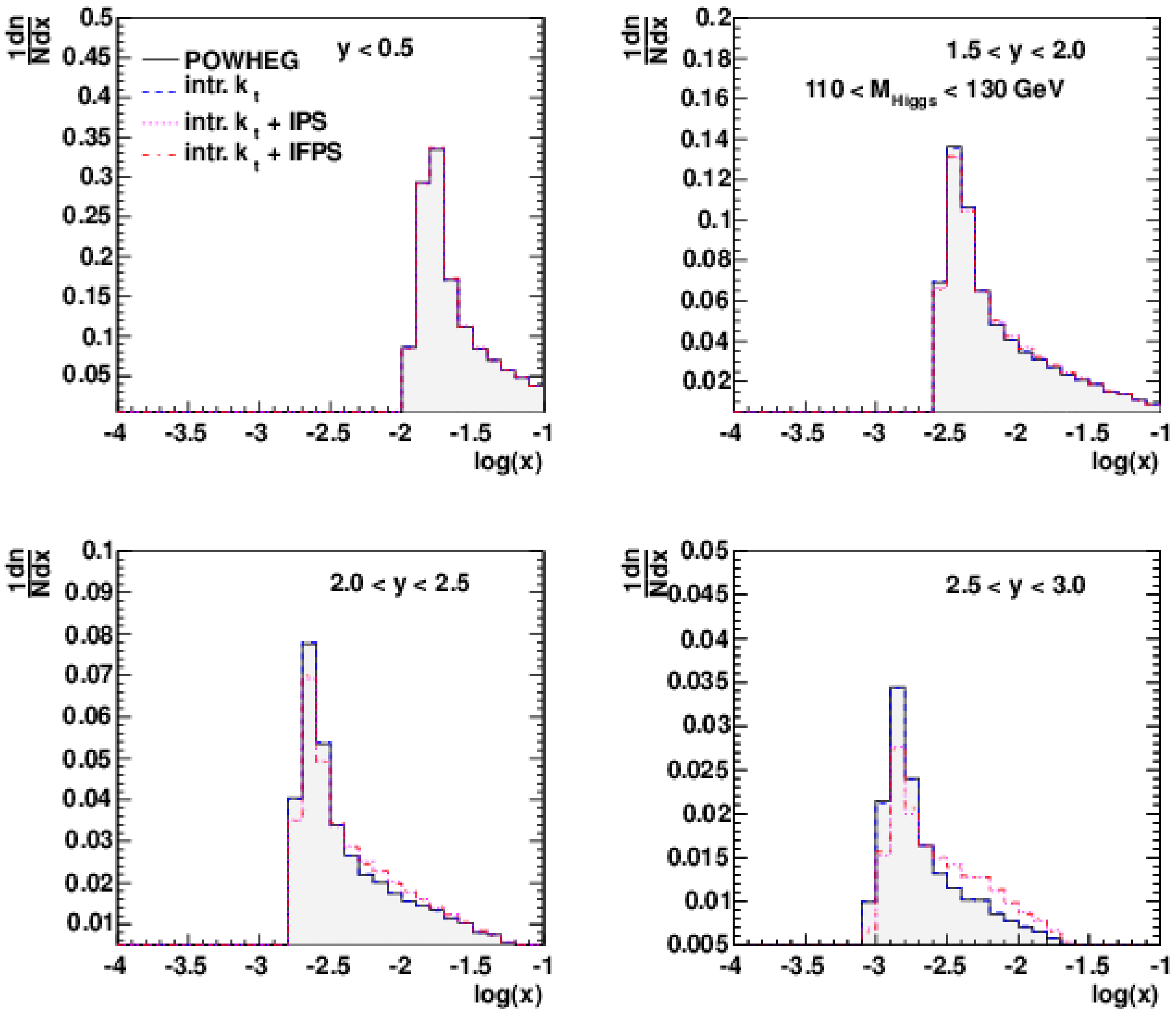
Double peak structure comes from the continuum DY production in addition to the Z_0

- Kinematic reshuffling in x for forward Drell-Yan production is not negligible
- Kinematic effect influences quark induced processes

Dooling et al.
arXiv:1212.6264

Longitudinal Momentum Shift – Higgs

Higgs production for $110 < m < 130$ GeV at $\sqrt{s} = 7$TeV



The accessible longitudinal momentum fraction x is limited by the Higgs mass

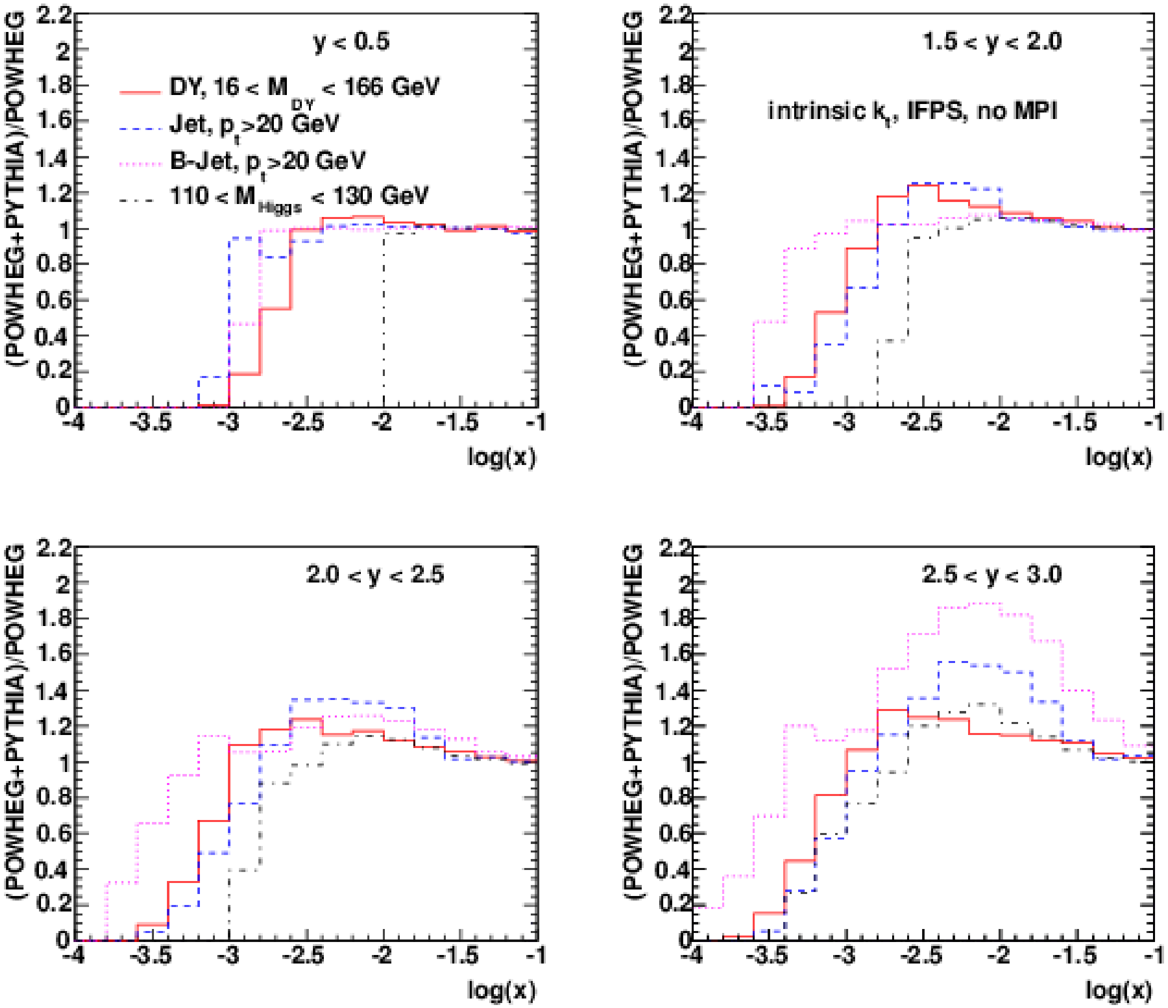
- Reshuffling in x is observed but the effect is smaller compared to the other processes

- The effect of the kinematic shift becomes significantly larger with increasing center-of-mass energy

Dooling et al.
arXiv:1212.6264

Backup Slides

x distribution before and after showering of the different processes



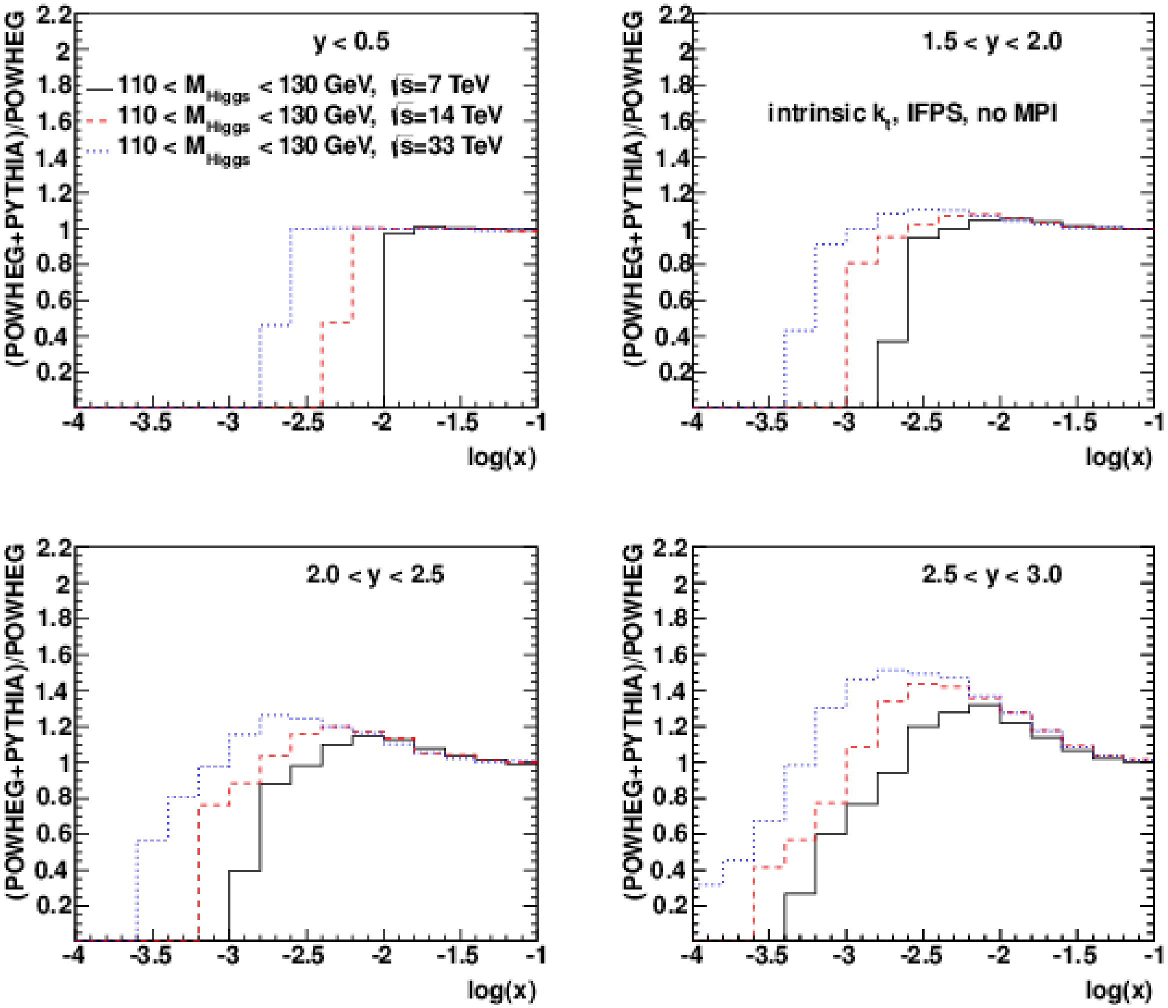
Ratio Cross Section before and after the showering versus longitudinal momentum fraction

- Effect is common in all the different processes

Dooling et al.
arXiv:1212.6264

Backup Slides

x distribution before and after showering of the Higgs processes for different energies



Ratio Cross Section before and after the showering versus longitudinal momentum fraction for different energies

- More pronounced shift for increasing energy

Dooling et al.
arXiv:1212.6264

Backup Slides

CMS
arXiv:1202.4617

Inclusive b-jet production in CMS