Intrinsic k_T and low mass DY production

With Parton Branching method

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Heading Agenda

- Introduction
- PB-TMDs and Drell-Yan production at NLO
- Low mass Drell-Yan production
- Conclusion

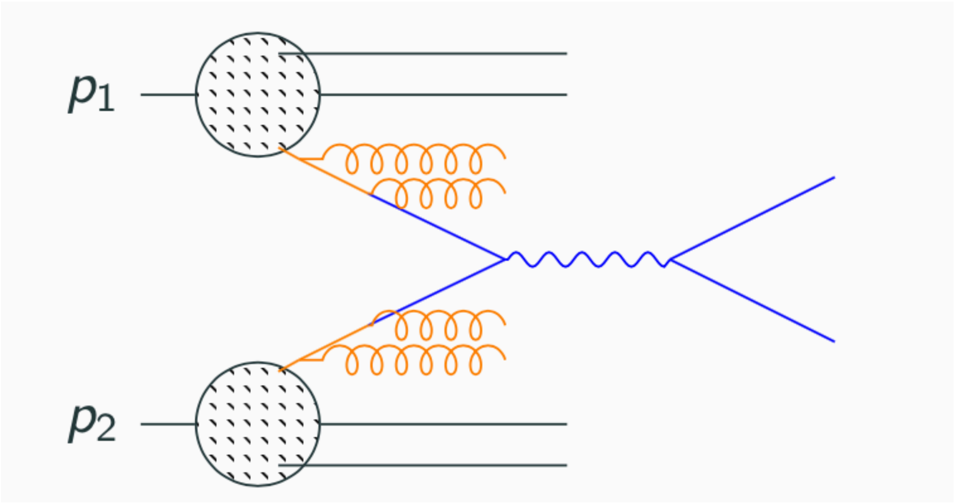
Introduction

Low mass DY issues

- For *proton-proton* collisions the collinear factorization theorem is commonly used

$$\sigma_h \sim \int f_1 \otimes f_2 \otimes \sigma_{partonic}$$

Transverse momentum of the intial parton is neglected



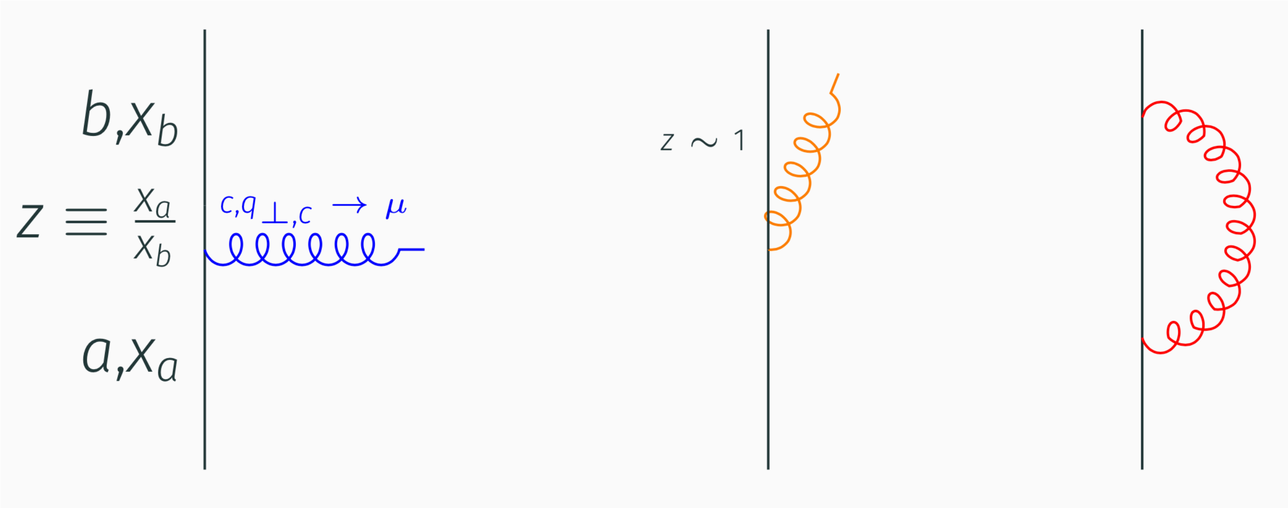
- Many observables are described using collinear factorization

- However, to describe the Z boson p_T spectrum at $p_T < Q$ soft gluon resummation to all orders is needed

PB-TMDs and DY production at NLO

PB-TMDs and DY production at NLO

DGLAP evolution



EVOLUTION → Real resolvable splittings + Non resolvable splittings + Virtual correction

DGALP — Splitting functions — Sudakov

$$f_a(x,\mu^2) = f(x,\mu_0^2)\Delta_a(\mu^2) + \int_{\ln \mu_0^2}^{\ln \mu^2} d\ln \mu_1^2 \frac{\Delta_a(\mu^2)}{\Delta_a(\mu_1^2)} \sum_b \int_x^{z_m} d\, z_1 P_{ab}^R(\mu_1^2, z_1) f_b\left(\frac{x}{z_1}, \mu_0^2\right) \Delta_b(\mu_1^2) + \cdots$$: f is the collinear PDF

- When $z \sim 1$ the emission is not resolvable → z_m is introduced
- DGLAP does not contain transverse momentum

PB-TMDs and DY production at NLO

PB-TMDs evolution

- TMD evolution with PB, where A is the TMD:

$$A_a(x,\mu^2,k_\perp) = A(x,\mu_0^2,k_\perp)\Delta_a(\mu^2) + \int \frac{d^2\mu_1}{\pi\mu_1^2}\Theta(\mu^2-\mu_1^2)\Theta(\mu_1^2-\mu_0^2)\frac{\Delta_a(\mu^2)}{\Delta_a(\mu_1^2)} \times \sum_b \int_x^1 dz_1 \Theta(z_m(\mu_1)-1) P_{ab}^R(\mu_1^2,z_1) A_b\left(\frac{x}{z_1},\mu_0^2,k_\perp\right)\Delta_b(\mu_1^2) + \cdots$$

- At every splitting the kinematics of the emitted and propagating partons are computed

- The TMD factorization theorem

$$\sigma_{q\bar{q}}(x_1,x_2,\mu^2)$$

$$\sigma_h = \sum_{q\bar{q}} \int d^2k_{T_1} d^2k_{T_2} \int dx_1 dx_2 A_q(x_1,k_{T_1},\mu^2) A_{\bar{q}}(x_2,k_{T_2},\mu^2)\sigma_{q\bar{q}}(x_1,x_2,k_{T_1},k_{T_2},\mu^2)$$

PB-TMDs and DY production at NLO

Angular ordering

- The evolution in PB formalism applies angular ordering

- It enters the evolution as:

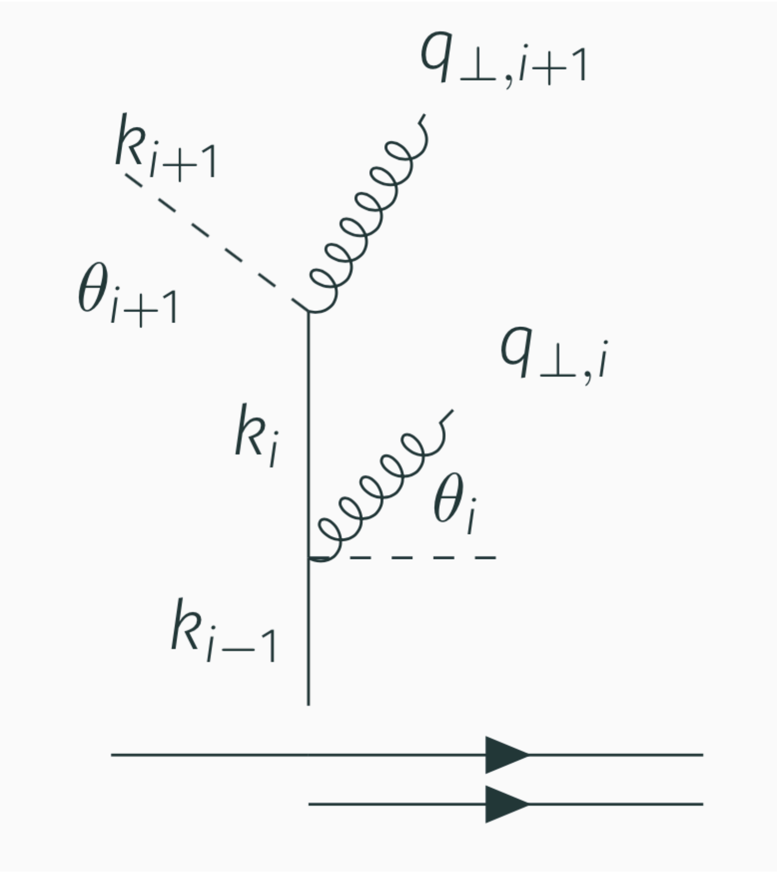
$$q_{\perp,c}^2 = (1-z)^2 \mu'^2 \qquad z_m = 1 - \left(\frac{q_0}{\mu'}\right) \qquad \alpha_s\left((1-z)^2\mu'\right)$$

- The radiation scale is proportional to the angle of the momentum of the radiated particle respect ot the particle beam

$$\frac{q_{\perp,i}}{1-z_i} = |\, k_{i-1} |\sin\theta_i = \mu'$$

- The first radiation is the one with smallest angle

$$\theta_i < \theta_{i+1}$$



q_0: minimum transverse momentum of the emitted parton

PB-TMDs and DY production at NLO

Soft gluon resumation effects

- As mentioned before collinear factorization needs soft gluon resumantion
- The matrix element is computed using MC@NLO
- DY lepton-pair transverse momentum:
  - MC@NLO at a partonic level using Herwig6 substraction terms
  - MC@NLO + PB-TMDs
- At LHC energies soft gluon resummation impacts the low p_T region

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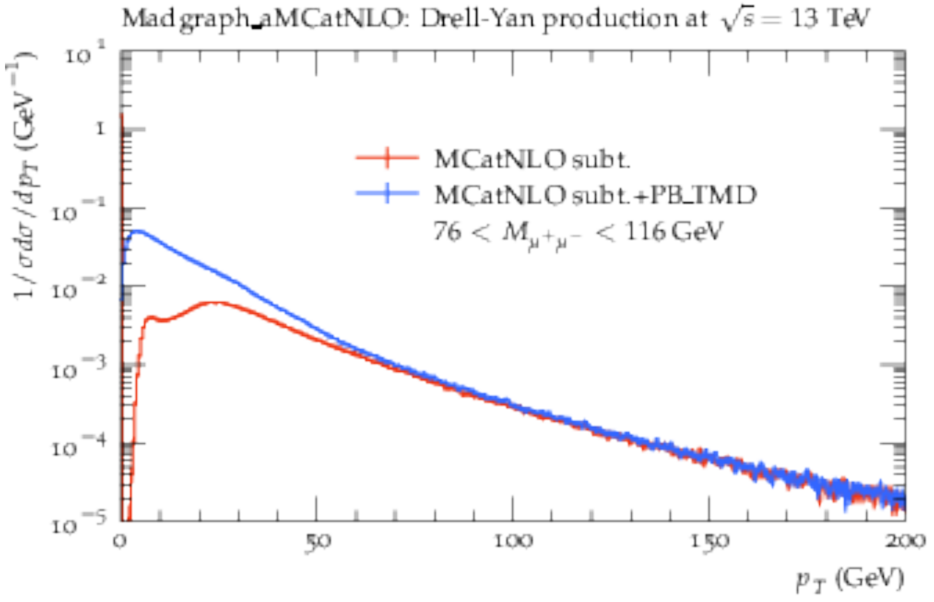
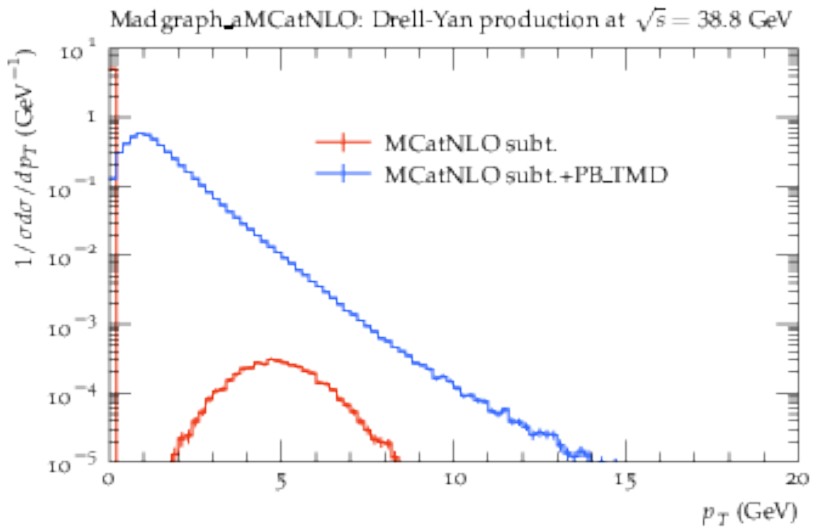
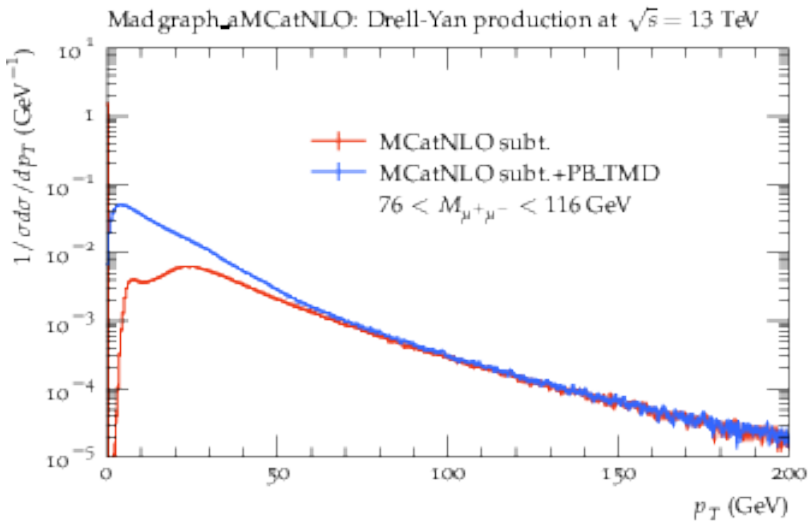


PB-TMDs and DY production at NLO

Soft gluon resumation effects at low mass DY

- To see the effect of soft gluon resumation at low mass DY we follow the same procedure
- At low mass DY the largest contribution comes from the soft gluon resummation, both at large and low p_T
- This effect allows studies of contribution from soft gluon emission





Intrinsic k_T of initial state partons

In PB formalism

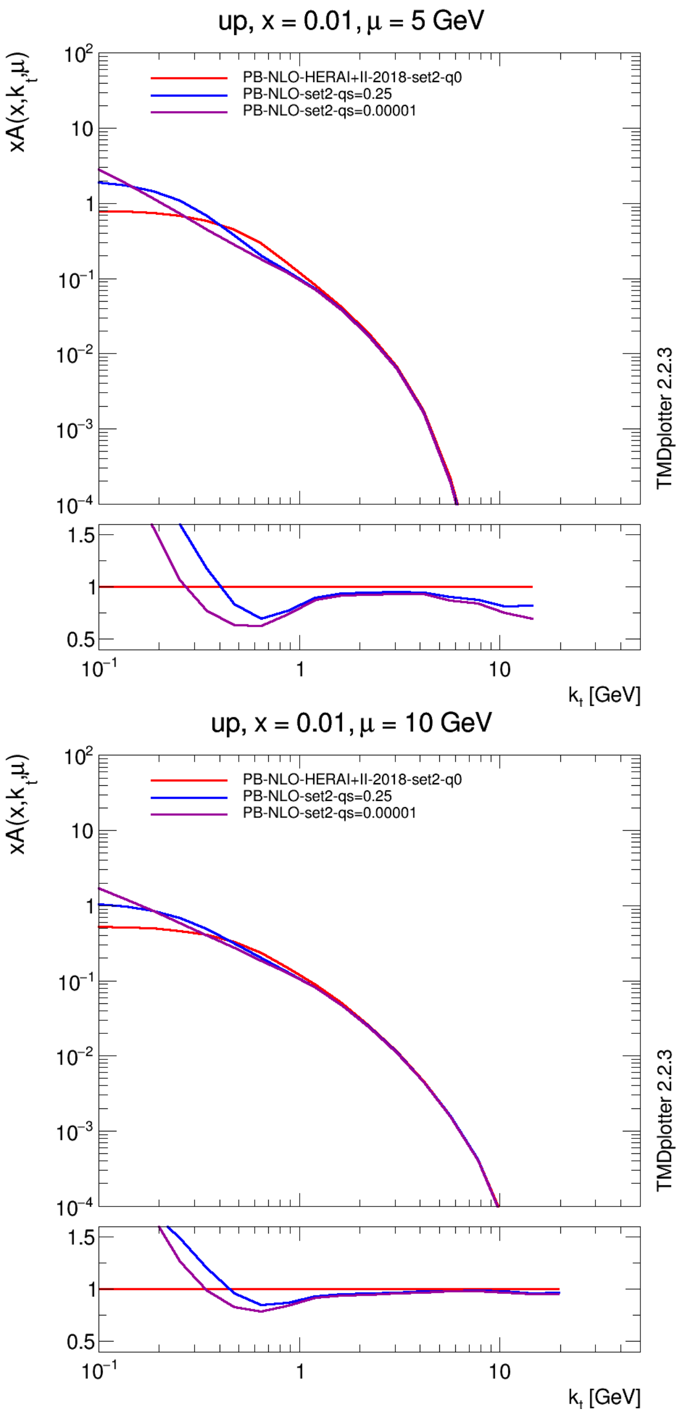
- The intrinsic k_T of the intial state parton is generated from a gaussian distribution

$$A_{0,a}(x, k_{T_0}, \mu_0) = f_{0,a}(x, \mu_0) e^{-\frac{k_{T_0}^2}{\sigma^2}}$$

- The parameter to study is q_s, the width of the distribution:

$$\sigma = \frac{q_s}{\sqrt{2}}$$

- Small values of q_s makes larger TMDs at low k_T region
  - PB-NLO-HERAI+II-2018-Set2-q0 with $q_s = 0.5$ GeV
  - PB-NLO-2018-Set2 with $q_s = 0.25$ GeV
  - PB-NLO-2018-Set2 with $q_s = 0.00001$ GeV



Low mass DY production

Low mass DY production

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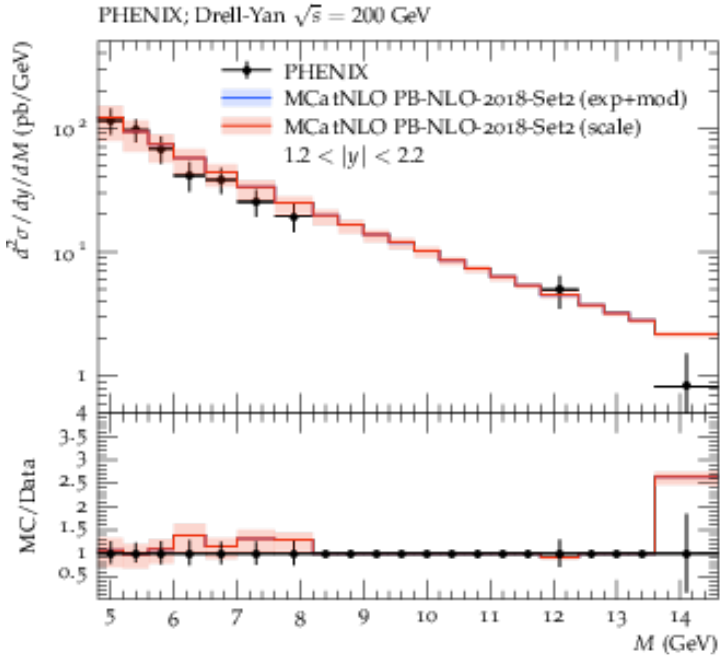
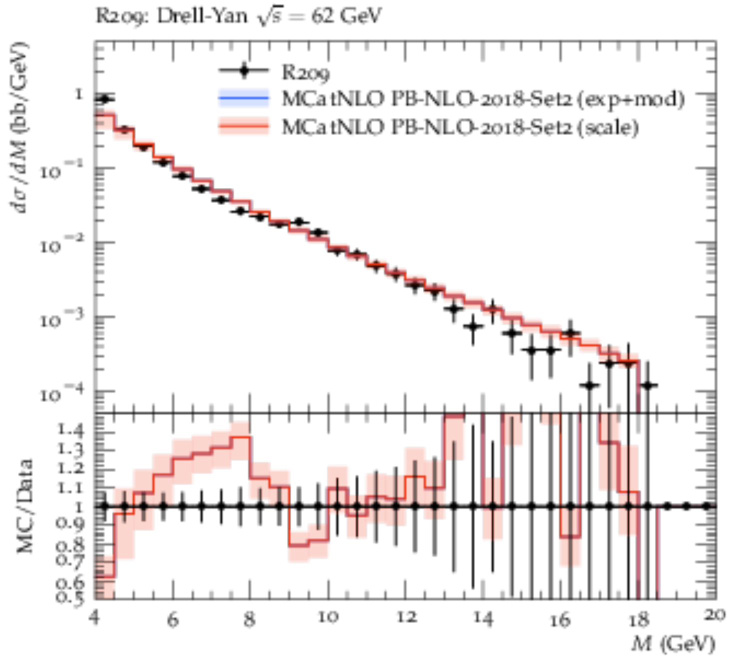
Lepton pair mass

- Theoretical predictons from PB-TMDs and NLO matrix elements with MC@NLO matching are compared to measurements for different center of mass energies:

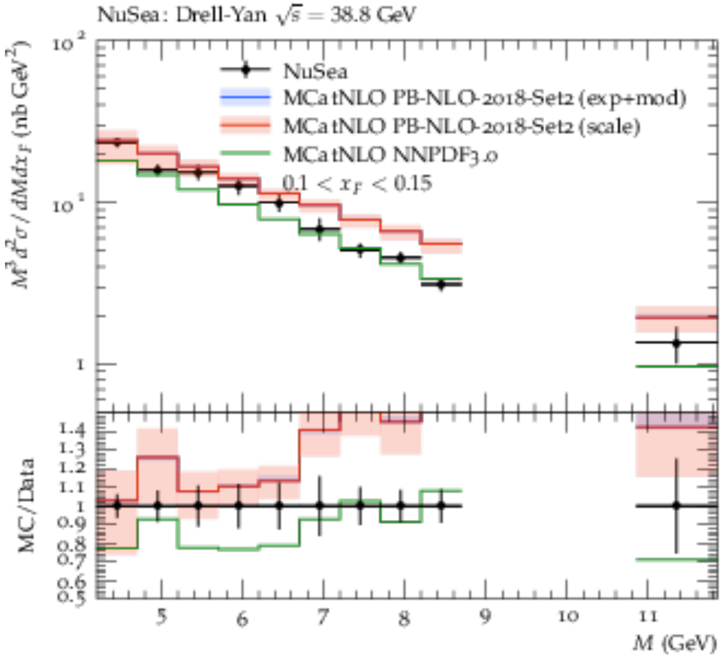
PHENIX($\sqrt{s} = 200$ GeV)



R209($\sqrt{s} = 62$ GeV)



NuSea($\sqrt{s} = 38.8$ GeV)



- We find good description of the lepton pair mass spectrum

Where the band represents the uncertainties

Low mass DY production

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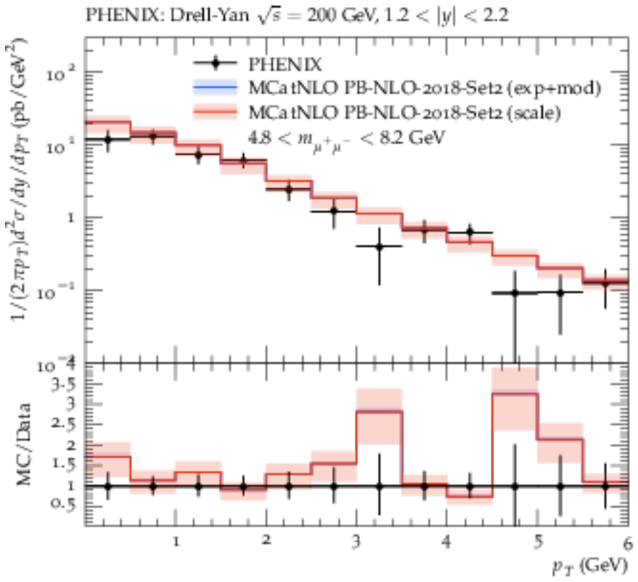
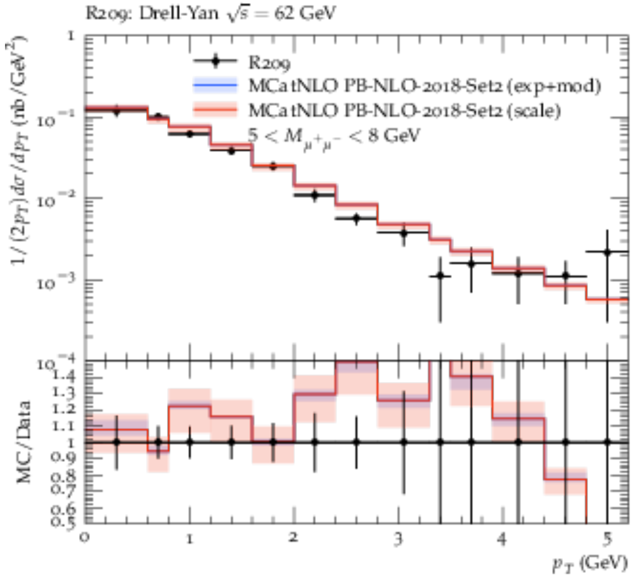
Lepton pair pT

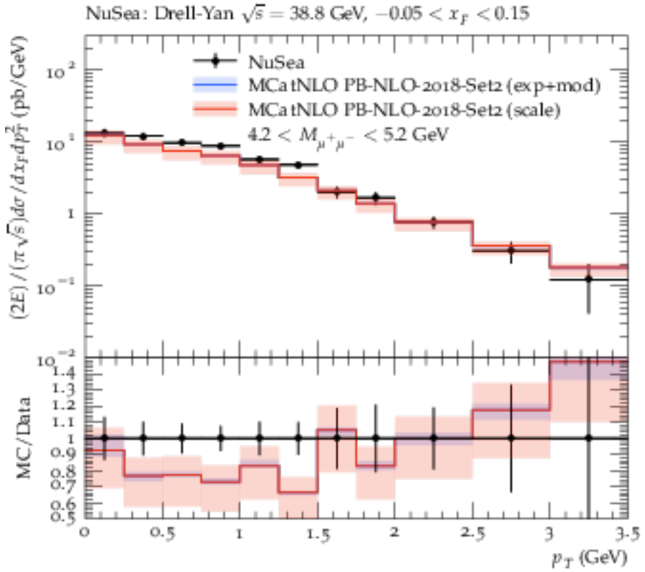
PHENIX($\sqrt{s} = 200$ GeV)
$4.8 < m_{\mu^+\mu^-} < 8.2$ GeV



R209($\sqrt{s} = 62$ GeV)
$5 < m_{\mu^+\mu^-} < 8$ GeV



NuSea($\sqrt{s} = 38.8$ GeV)
$4.2 < m_{\mu^+\mu^-} < 5.2$GeV



- The description of the data is good, with a $\frac{\chi^2}{ndf} = 1.04(PHENIX), 1.27(R209), 1.07(NuSea)$
- For this set-up (Set2) $q_s = 0.5$ GeV

Low mass DY production

How sensitive is PB-TMDs to intrinsic k_T ?

- We plot $\frac{\chi^2}{ndf}$ as a function of q_s for different center of mass energies

- Lower mass DY measurements show a larger sensitivity to the choice of the q_s

- An overal minumim is observed for $q_s \in (0.3 - 0.4)$GeV

- For Set2 $q_s = 0.5$GeV

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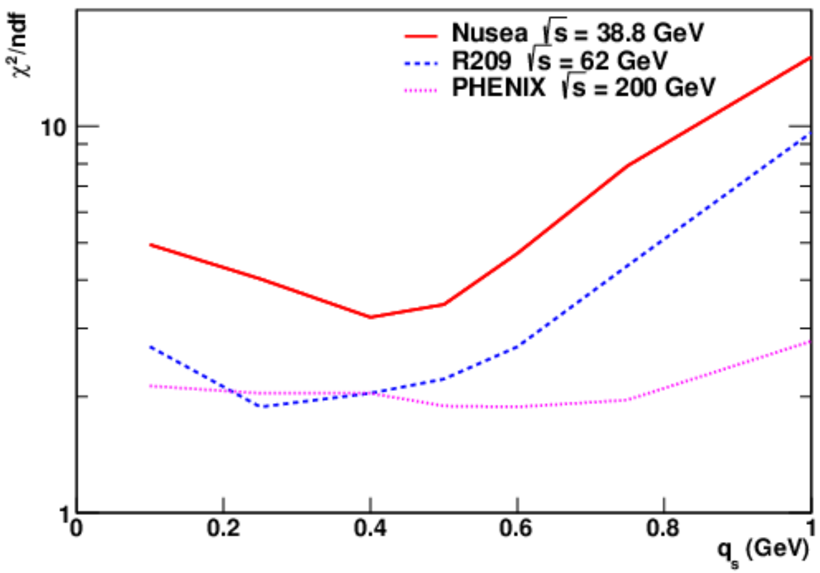


Low mass DY production

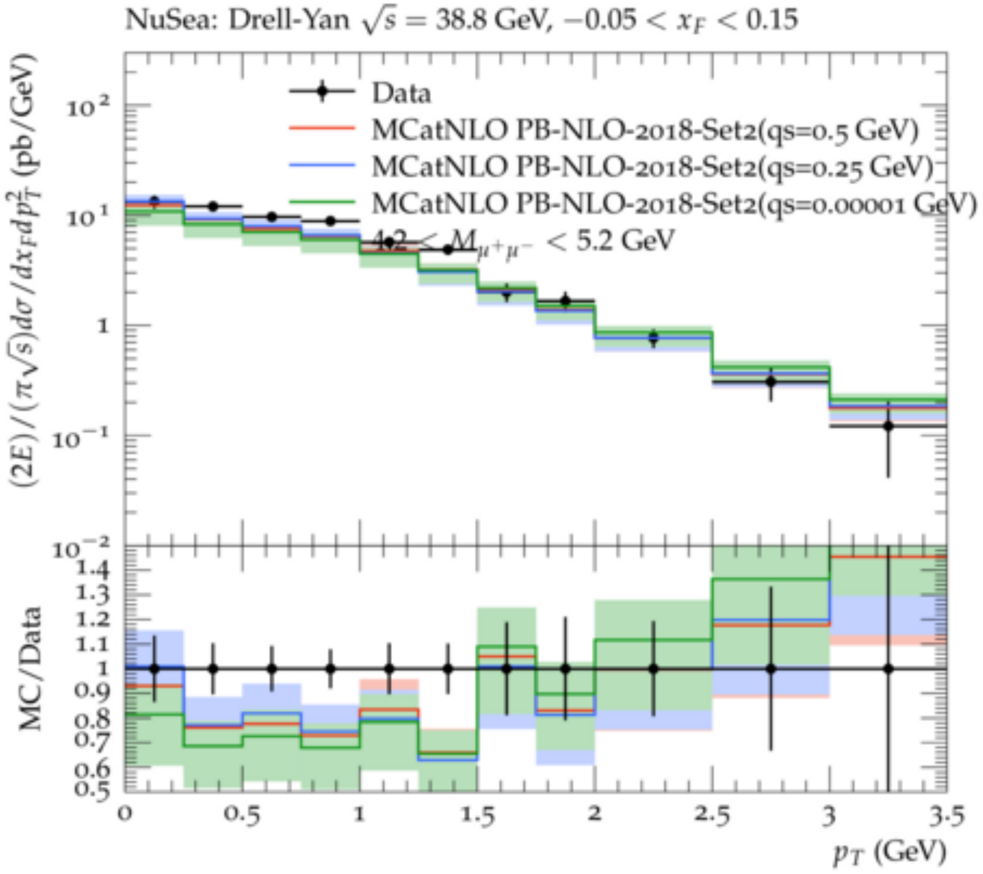
Are we really sensitive to intrinsic KT?

- Predictions for different values of q_s for NuSea measurements
  - MCatNLO PB-NLO-2018-Set2 with $q_s = 0.5$ GeV
  - MCatNLO PB-NLO-2018-Set2 with $q_s = 0.25$ GeV
  - MCatNLO PB-NLO-2018-Set2 with $q_s = 0.00001$ GeV

- The set-up shows a small sensitivity for different values of q_s

- The low sensitivity comes from the TMD evolution (next slide)

NuSea($\sqrt{s} = 38.8$ GeV)
$4.2 < m_{\mu^+\mu^-} < 5.2$GeV



Low mass DY production

Why are we not as sensitive as expected?

- Reminder: Angular ordering enters the evolution as

$q^2_{\perp,c} = (1-z)^2 \mu'^2$

$z_m = 1 - \left(\frac{q_0}{\mu'}\right)$

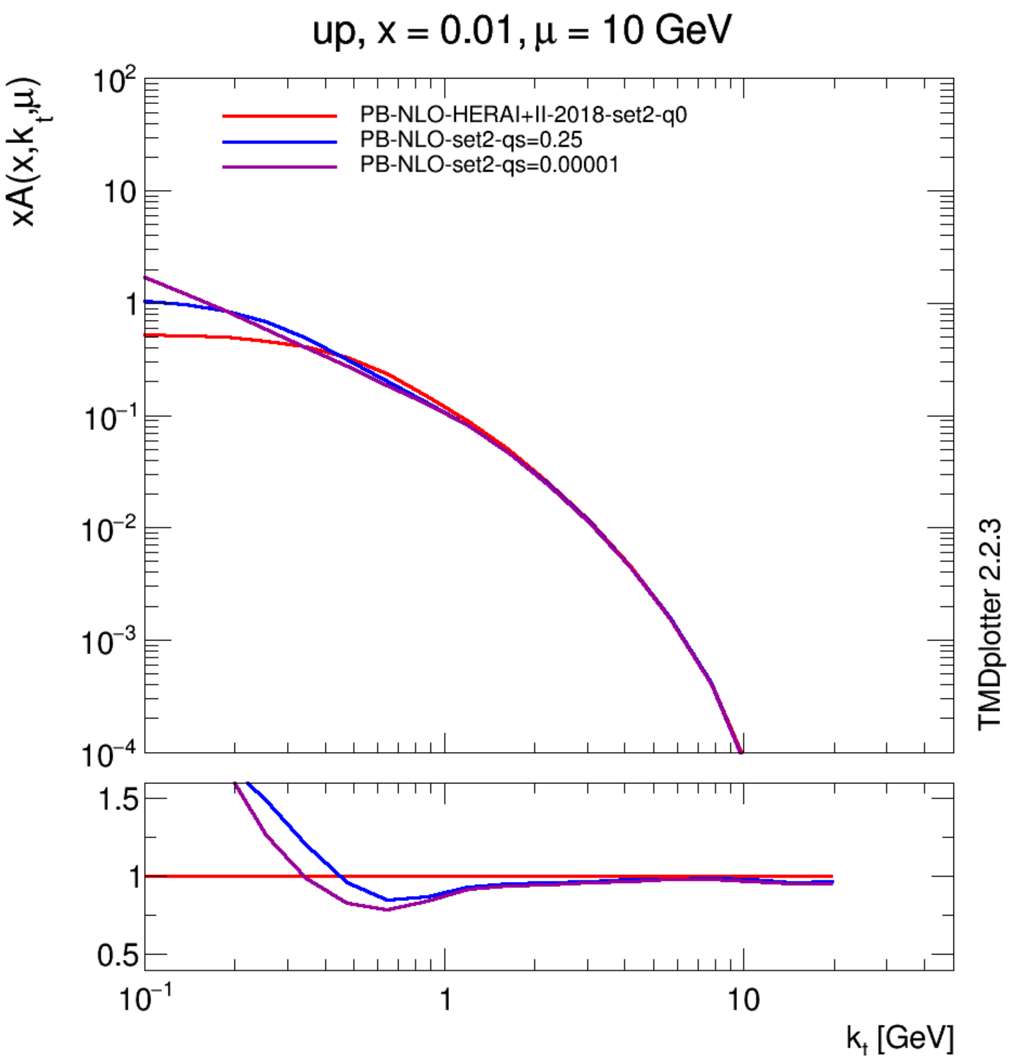
$\alpha_s\left((1-z)^2 \mu'\right)$

z_m: resolvabe/non-resolvable splittings

- In our current set-up $q_0 = 0.01$ is fixed → $z_m \sim 1$. At large z_m values:

PB-TMD ev. converges to DGLAP ev.

- In this way non-perturvative emissions are treated in a similar way as perturvative ones, simulating non-perturvative effects



Summary and outlook

Summary

- We investigated the p_T spectra of DY lepton-pair production at small DY masses and low center of mass energies

- Measurements at low center of mass energies are well described within PB formalism, with $\frac{\chi^2}{ndf} \sim 1$

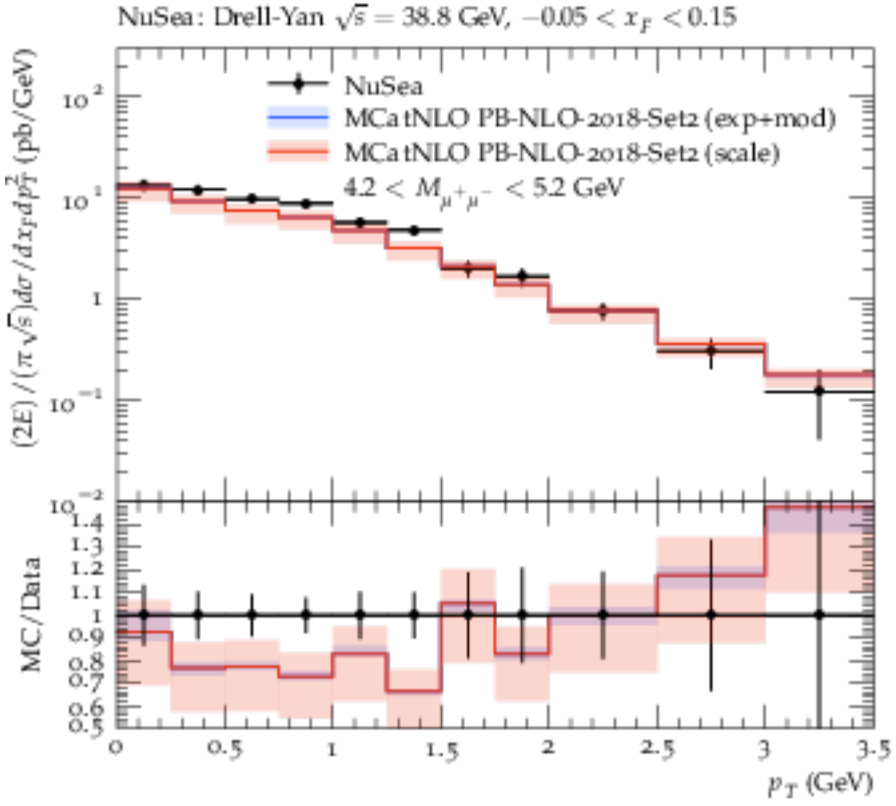
- We determined an optimal value for $q_s \in (0.3 - 0.4)$GeV

- However, a lack of sensitivity is observed to the intrinsic k_T, due to the large value of z_m

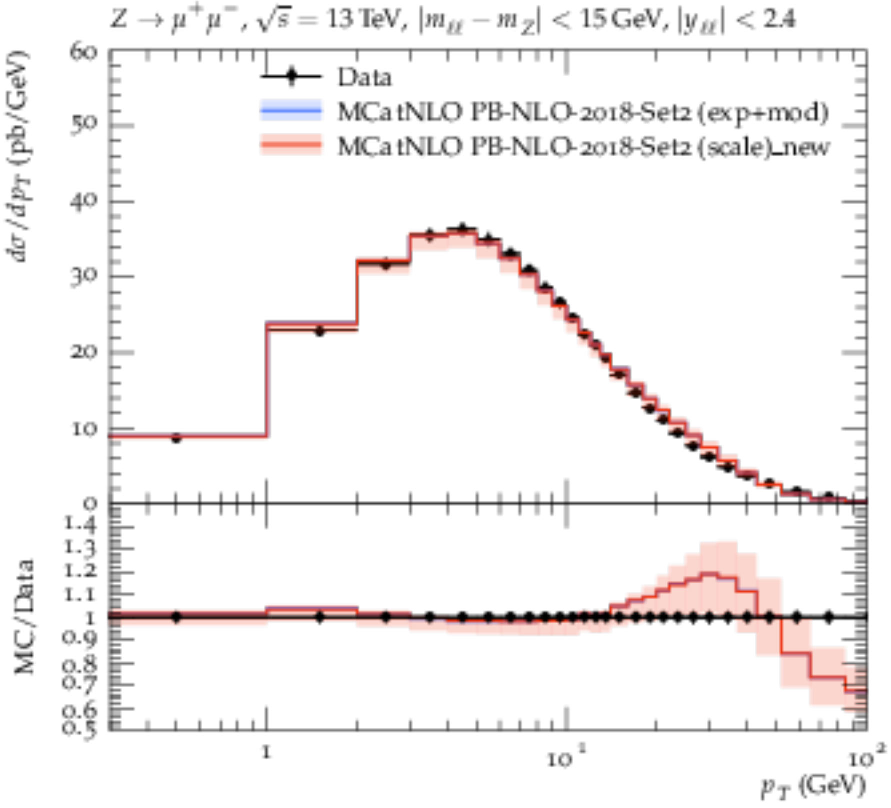
Summary and outlook

- A large value of $z_m \sim 1$ reduces the contributions from non-perturvative effects. Making PB formalism safe to use at different center of mass energies with the same configuration

NuSea($\sqrt{s} = 38.8$ GeV)
$4.2 < m_{\mu^+\mu^-} < 5.2$GeV
$\chi^2/ndf = 1.07$



CMS($\sqrt{s} = 13$ TeV)
$|m_{l^+l^-} - m_Z| < 15$ GeV
$\chi^2/ndf = 0.8$



Thank you

Back up

Tune of intrinsic kT with pythia8

- We use NuSea to tune the intrinsic kT within Pythia8

$$\frac{\chi^2}{ndf} = 0.9$$

- However, at 8 TeV we see that the tune does not work for the low p_T

- The same effect is observed a tune of the intrinsic kT at 8 TeV does not work for lower mass DY processes

- This shows that finding a right tune for different DY mass processes is non trivial