W-boson production in TMD factorisation

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Doktoratskolleg
Particles and Interactions

Outline

Introduction

- The precise measurement of W cross section and similar observables need a good determination of QCD non-perturbative inputs.
- W-production is a natural test for the TMD factorisation
- W-spectrum is interesting because allows to test flavour dependence in TMD.
- We study different sources of uncertainties in several observables.

Presentation based on hep/ph:2011.05351

TMD factorisation

Our cross section is given by

$$\frac{d\sigma}{d{m_T}^2 dy dq_T^2} = \int_0^\infty dQ^2 \frac{8}{N_c} \frac{\alpha_{\text{em}}}{s} l_W\left(Q^2, q_T, m_T^2\right) \times \sum_{ff'} \sum_{GG'} z_{ll'}^{GG'} z_{ff'}^{GG'} \Delta_G(q) \Delta^*_{G'}(q) W_{f_1 f_1}^{ff'}\left(Q^2, q_T, x1, x2\right) \quad (1)$$

The dependence in transverse mass is fully encode in the leptonic part $l_W\left(Q^2, q_T, m_T^2\right)$. m_T is the transverse mass defined by

$$m_T^2 = \left(|\mathbf{l}_T| + \left|\mathbf{l}'_T\right|\right)^2 - \left(\mathbf{l}_T + \mathbf{l}'_T\right)^2 \quad (2)$$

Hadronic contribution

The hadronic part is given by

$$W_{f_1 f_1}^{ff'}(Q, q_T, x1, x2, \mu, \zeta) = \int \frac{d^2\mathbf{b}}{4\pi} e^{i(\mathbf{b}\cdot\mathbf{q})} f_{1,f\leftarrow q}(x_1, \mathbf{b}, \mu, \zeta)\, f_{1,f'\leftarrow q}(x_2, \mathbf{b}, \mu, \zeta) \tag{3}$$

where $f_{1,f\leftarrow q}(x, \mathbf{b}, \mu, \zeta)$ is the unpolarised quark TMDPDF, given by

$$f_{1,f\leftarrow h}(x, \mathbf{b}, \mu, \zeta) = C(x, \mathbf{b}, \mu, \zeta) \otimes f_1(x, \mu)\, f_{NP}(x\mathbf{b}) \tag{4}$$

$C(x, \mathbf{b}, \mu, \zeta)$ is a perturbative coefficient, f_1 is the collinear PDF and $f_{NP}(x, \mathbf{b})$ is a non-perturbative parametrisation of the TMDPDF. It must go to zero as $\frac{q_T}{Q} \to 1$ $(bQ \to 0)$ and suppress the cross section as $\frac{q_T}{Q} \to 0$ $(bQ \to \infty)$

Sources of uncertainties

- **Scale variation.** We use the ζ-prescription defined in hep/ph:1803.11089 and we include the non-perturbative fixing of the ζ-scale as defined in hep/ph:1912.06532 and hep/ph:1907.10356. Therefore the scale variation is done changing the μ in the hard coefficient $\left|C\left(Q^2,\mu^2\right)\right|^2$ and in the TMDPDFs.
- **Uncertainties from reference PDF set using replicas.** We compute in each bin the cross section for each replica of NNPDF31_nnlo_as_0118 and estimate the uncertainty through the standard deviation.
- **Predictions from different PDF sets.** We use the same sets of PDF than hep/ph:1912.06532.
- **Uncertainties from TMD parametrization.** We use the set of replicas for a TMD parametrisation provided in hep/ph:1912.06532 to estimate the uncertainty.

Observables

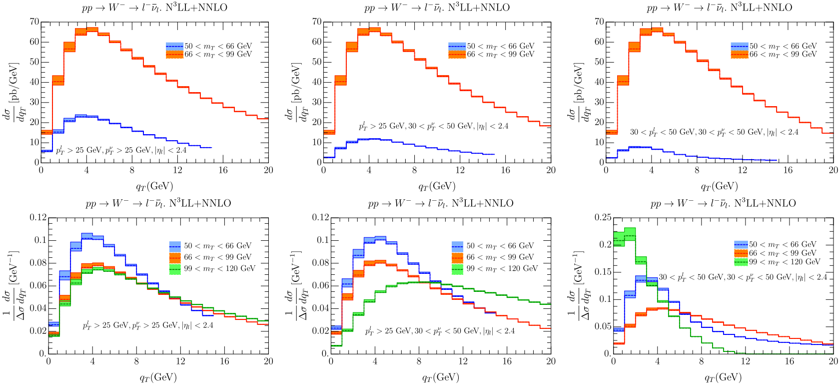
- For the $W^{\pm}$, $Z/W^{\pm}$ and W^{-}/W^{+} we use the parametrisation hep/ph:1912.06532

$$f_{NP}(x,\mathbf{b}) = \exp\left\{-\frac{\lambda_1(1-x)+\lambda_2 x + x(1-x)\lambda_5}{\sqrt{1+\lambda_3 x^{\lambda_4}\mathbf{b}^2}}\mathbf{b}^2\right\} \quad (5)$$

with: B_{NP}=1.93,c_0=0.0427,λ_1=0.224,λ_2=9.24,λ_3=375,λ_4=2.15,λ_5=-4.9 and the PDF NNPDF31 hep/ph:1706.00428

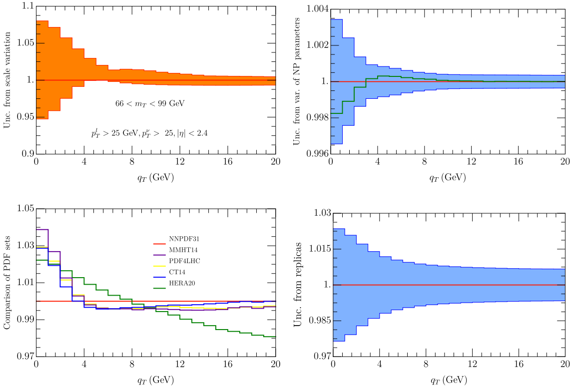
- We compute the χ^2/d.o.f for the CMS hep/ex:1606.05864; ATLAS hep/ex:1108.6308; D∅ hep:9803003 and CDF Phys. Rev. Lett. 66 (1991) 2951–2955 experiments using several parametrisations and PDF sets.

W^- spectra

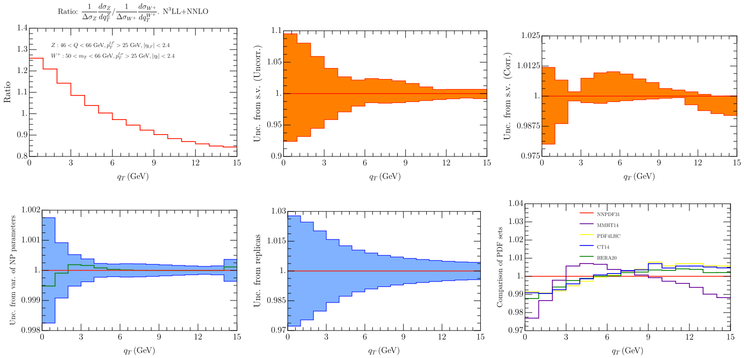


$pp \to W^- \to l^- \bar{\nu}_l$. N^{3}LL+NNLO
$\frac{d\sigma}{dq_T}$ [pb/GeV]
q_T(GeV)
$50 < m_T < 66$ GeV
$66 < m_T < 99$ GeV
$p_T^l > 25$ GeV, $p_T^\nu > 25$ GeV, $|\eta_l| < 2.4$
$p_T^l > 25$ GeV, $30 < p_T^\nu < 50$ GeV, $|\eta_l| < 2.4$
$30 < p_T^l < 50$ GeV, $30 < p_T^\nu < 50$ GeV, $|\eta_l| < 2.4$
$\frac{1}{\Delta\sigma}\frac{d\sigma}{dq_T}$ [GeV^{-1}]
$99 < m_T < 120$ GeV

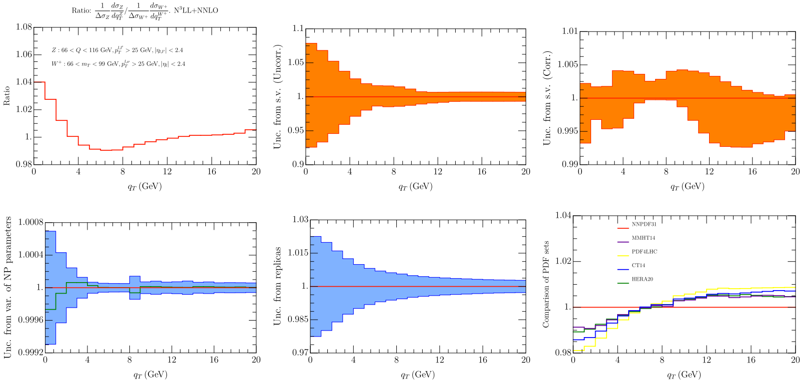
W^+ spectra


Unc. from scale variation
66 < m_T < 99 GeV
p_T^l > 25 GeV, p_T^ν > 25, $|\eta|$ < 2.4
q_T (GeV)
Unc. from var. of NP parameters
q_T (GeV)
Comparison of PDF sets
NNPDF31
MMHT14
PDF4LHC
CT14
HERA20
q_T (GeV)
Unc. from replicas
q_T (GeV)

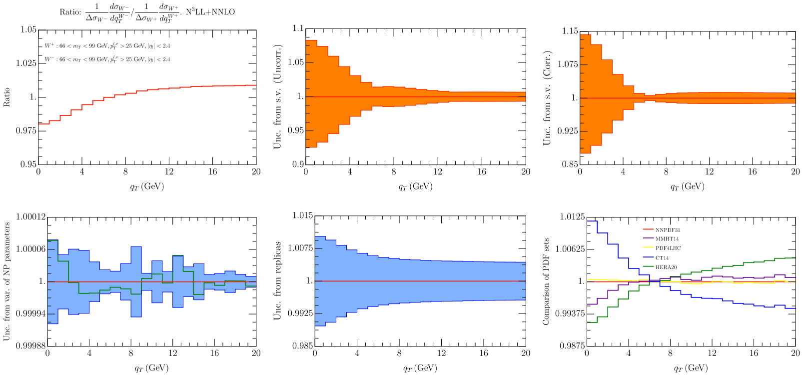
Ratio Z/W^+


Ratio: $\frac{1}{\Delta\sigma_Z}\frac{d\sigma_Z}{dq_T^Z} / \frac{1}{\Delta\sigma_{W^+}}\frac{d\sigma_{W^+}}{dq_T^{W^+}}$. N^{3}LL+NNLO
Ratio
Unc. from s.v. (Uncorr.)
Unc. from s.v. (Corr.)
Unc. from var. of NP parameters
Unc. from replicas
Comparison of PDF sets
NNPDF31
MMHT14
PDF4LHC
CT14
HERA20
q_T (GeV)

Ratio Z/W^+


Ratio: $\frac{1}{\Delta\sigma_Z}\frac{d\sigma_Z}{dq_T^Z}/\frac{1}{\Delta\sigma_{W^+}}\frac{d\sigma_{W^+}}{dq_T^{W^+}}$. N^{3}LL+NNLO
$Z : 66 < Q < 116$ GeV, $p_T^{l,l'} > 25$ GeV, $|\eta_{l,l'}| < 2.4$
$W^+ : 66 < m_T < 99$ GeV, $p_T^{l,\nu} > 25$ GeV, $|\eta_l| < 2.4$
Ratio
Unc. from s.v. (Uncorr.)
Unc. from s.v. (Corr.)
Unc. from var. of NP parameters
Unc. from replicas
Comparison of PDF sets
NNPDF31
MMHT14
PDF4LHC
CT14
HERA20
q_T (GeV)

Ratio W^-/W^+


Ratio: $\frac{1}{\Delta\sigma_{W^-}}\frac{d\sigma_{W^-}}{dq_T^{W^-}} / \frac{1}{\Delta\sigma_{W^+}}\frac{d\sigma_{W^+}}{dq_T^{W^+}}$. N^{3}LL+NNLO
$W^+ : 66 < m_T < 99$ GeV, $p_T^{l,\nu} > 25$ GeV, $|\eta| < 2.4$
$W^- : 66 < m_T < 99$ GeV, $p_T^{l,\nu} > 25$ GeV, $|\eta| < 2.4$
Ratio
Unc. from s.v. (Uncorr.)
Unc. from s.v. (Corr.)
Unc. from var. of NP parameters
Unc. from replicas
Comparison of PDF sets
NNPDF31
MMHT14
PDF4LHC
CT14
HERA20
q_T (GeV)

Comparisons with experiments

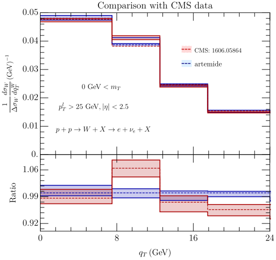
- In the comparison with CMS, ATLAS, CDF and D∅ we use the parametrisation of the TMD given in hep/ph:1912.06532

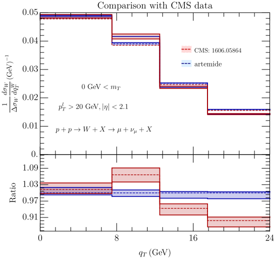
$$f_{NP}\left(x,\mathbf{b}\right)=\exp\left\{-\frac{\lambda_1\left(1-x\right)+\lambda_2 x+x\left(1-x\right)\lambda_5}{\sqrt{1+\lambda_3 x^{\lambda_4}\mathbf{b}^2}}\mathbf{b}^2\right\} \quad (6)$$

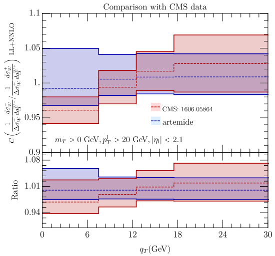
  with: B_{NP}=1.93,c_0=0.0427,λ_1=0.224,λ_2=9.24,λ_3=375,λ_4=2.15,λ_5=-4.97 and the PDF NNPDF31 hep/ph:1706.00428

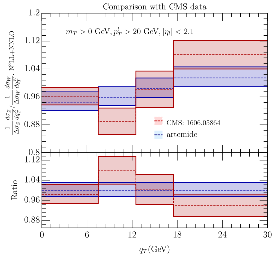
- To compute the χ^2/d.o.f we

CMS 8 TeV

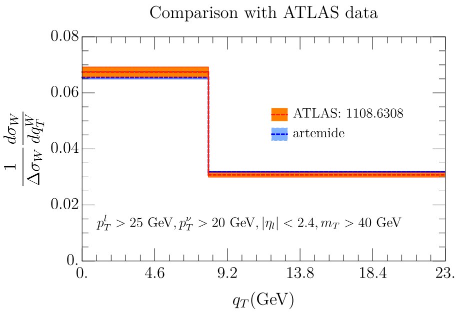

Comparison with CMS data
CMS: 1606.05864
artemide
0 GeV < m_T
$p_T^l > 25$ GeV, $|\eta| < 2.5$
$p + p \to W + X \to e + \nu_e + X$
$\frac{1}{\Delta\sigma_W}\frac{d\sigma_W}{dq_T^W}$ (GeV)$^{-1}$
Ratio
q_T (GeV)


Comparison with CMS data
CMS: 1606.05864
artemide
0 GeV < m_T
$p_T^l > 20$ GeV, $|\eta| < 2.1$
$p + p \to W + X \to \mu + \nu_\mu + X$
$\frac{1}{\Delta\sigma_W}\frac{d\sigma_W}{dq_T^W}$ (GeV)$^{-1}$
Ratio
q_T (GeV)


Comparison with CMS data
CMS: 1606.05864
artemide
$m_T > 0$ GeV, $p_T^l > 20$ GeV, $|\eta_l| < 2.1$
$C\left(\frac{1}{\Delta\sigma_W^-}\frac{d\sigma_W^-}{dq_T^{W^-}} / \frac{1}{\Delta\sigma_W^+}\frac{d\sigma_W^+}{dq_T^{W^+}}\right)$ LL+NNLO
Ratio
q_T(GeV)

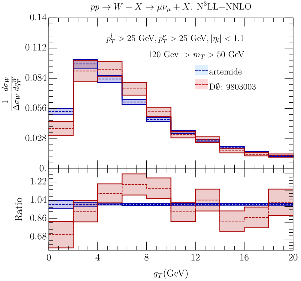

Comparison with CMS data
$m_T > 0$ GeV, $p_T^l > 20$ GeV, $|\eta_l| < 2.1$
CMS: 1606.05864
artemide
$\frac{1}{\Delta\sigma_Z}\frac{d\sigma_Z}{dq_T^Z} / \frac{1}{\Delta\sigma_W}\frac{d\sigma_W}{dq_T^W}$. N^{3}LL+NNLO
Ratio
q_T(GeV)

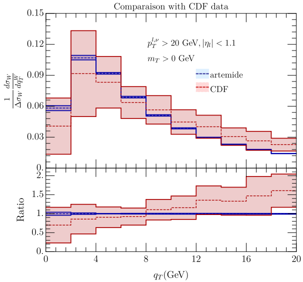
ATLAS 7 TeV

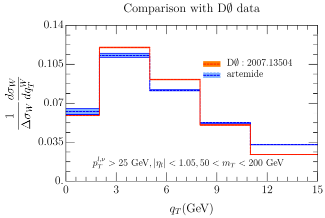


Comparison with ATLAS data
ATLAS: 1108.6308
artemide
$p_T^l > 25$ GeV, $p_T^\nu > 20$ GeV, $|\eta_l| < 2.4$, $m_T > 40$ GeV
$\frac{1}{\Delta\sigma_W}\frac{d\sigma_W}{dq_T^W}$
q_T(GeV)
0.08
0.06
0.04
0.02
0.
0.
4.6
9.2
13.8
18.4
23.

D and CDF


$p\bar{p} \to W + X \to \mu\nu_\mu + X$. N^{3}LL+NNLO
$p_T^l > 25$ GeV, $p_T^\nu > 25$ GeV, $|\eta_l| < 1.1$
120 Gev $> m_T > 50$ GeV
artemide
DØ: 9803003
$\frac{1}{\Delta\sigma_W}\frac{d\sigma_W}{dq_T^W}$
Ratio
q_T(GeV)


Comparaison with CDF data
$p_T^{l,\nu} > 20$ GeV, $|\eta_l| < 1.1$
$m_T > 0$ GeV
artemide
CDF
$\frac{1}{\Delta\sigma_W}\frac{d\sigma_W}{dq_T^W}$
Ratio
q_T(GeV)


Comparison with DØ data
DØ : 2007.13504
artemide
$p_T^{l,\nu} > 25$ GeV, $|\eta_l| < 1.05$, $50 < m_T < 200$ GeV
$\frac{1}{\Delta\sigma_W}\frac{d\sigma_W}{dq_T^W}$
q_T(GeV)

χ^2/D.O.F

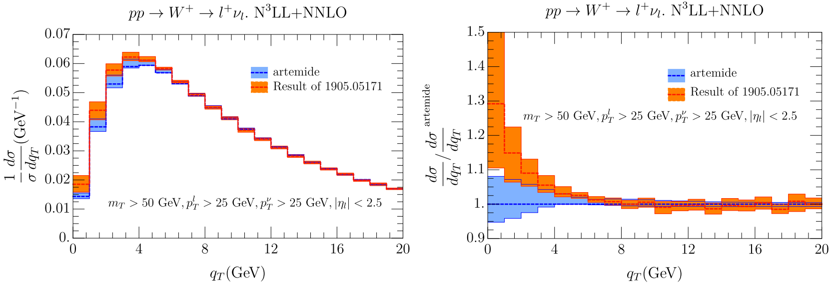
Ref. of Fit and Data set	CDF $\sqrt{s}=1{,}8$ TeV	D0 $\sqrt{s}=1{,}8$ TeV	ATLAS	CMS $e\nu$	CMS $\mu\nu$
hep/ph:1912.06532 SIDIS+DY	0.650	1.845	1.565	7.284	21.502
hep/ph:1902.08474 DY	0.651	2.003	1.549	7.783	22.302
hep/ph:1902.08474 DY (high energy)	0.627	1.326	1.999	6.347	20.923
Case 4 of hep/ph:2002.12810 (LHC)	0.694	2.312	1.333	7.681	21.704

We use the extraction of TMD of hep/ph:1912.06532

	CDF $\sqrt{s}=1{,}8$ TeV	D0 $\sqrt{s}=1{,}8$ TeV	ATLAS	CMS $e\nu$	CMS $\mu\nu$
Number of points	10	10	2	4(3)	4
NNPDF31	0.650	1.845	1.565	7.284 (1.694)	21.502
HERA20	0.617	2.009	0.853	6.024(0.310)	16.090
MMHT14	0.667	2.166	1.406	7.465(1.505)	21.751
CT14	0.677	2.608	1.324	7.974 (1.482)	21.972
PDF4LHC	0.660	2.061	1.405	7.733(1.605)	22.075

artemide vs hep/ph:1905.05171

We use the parametrisation of the TMD given in hep/ph:1912.06532



Comparison with Pythia 8.3 AZ tune

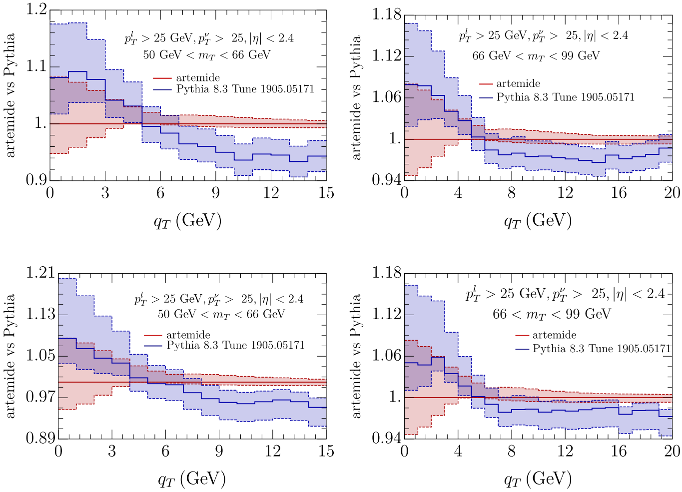
- We use Pythia 8.3 with AZ tune as hep/ph:1905.05171
- We use the parametrisation of the TMD given in hep/ph:1912.06532

$$f_{NP}\left(x,\mathbf{b}\right)=\exp\left\{-\frac{\lambda_1\left(1-x\right)+\lambda_2 x+x\left(1-x\right)\lambda_5}{\sqrt{1+\lambda_3 x^{\lambda_4}\mathbf{b}^2}}\mathbf{b}^2\right\} \quad (7)$$

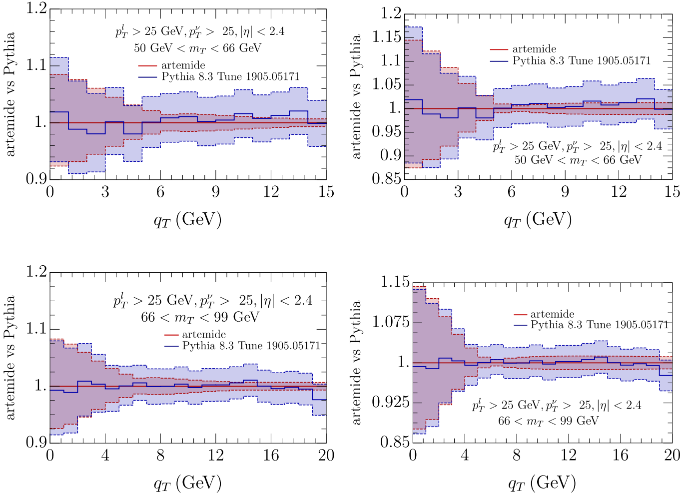
with:

B_{NP}=1.93,c_0=0.0427,λ_1=0.224,λ_2=9.24,λ_3=375,λ_4=2.15,λ_5=-4.97 and the PDF NNPDF31 hep/ph:1706.00428

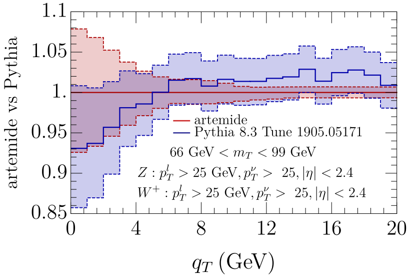
artemide vs Pythia 8.3: $W^{\pm}$

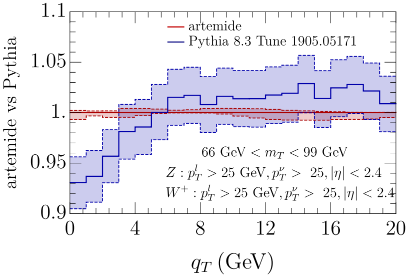


artemide vs Pythia 8.3: W^-/W^+



artemide vs Pythia 8.3: Z/W





Summary and outlook

- We have done the most complete study (up to our knowledge) of the W kinematic within TMD factorisation.
- Observables at low m_T do not show suppressed cross section and an uncertainties very similar to those of m_T around the W mass.
- Scale uncertainties can be improved including one more perturbative order N3LO, which nevertheless require a new TMD extraction.
- We have a reasonable agreement for the CDF and D at $\sqrt{s} = 1.8$ TeV and ATLAS at $\sqrt{s} = 7$ TeV, whilst CMS leads to a poorly agreement.
- We raise the question whether flavour dependence in TMD might improve the experimental agreement.
- The 2 GeV binning of TeVatron is more suitable to understand QCD effects than LHC binning, beside its precision.

Thank for your attention!