Sar Wors, Cagliari, 8 July 2019

Improving the perturbative accuracy of TMD PDF extractions: preliminary results

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in collaboration with
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3DSPIN
MAPPING THE PROTON IN 3D

erc
European Research Council

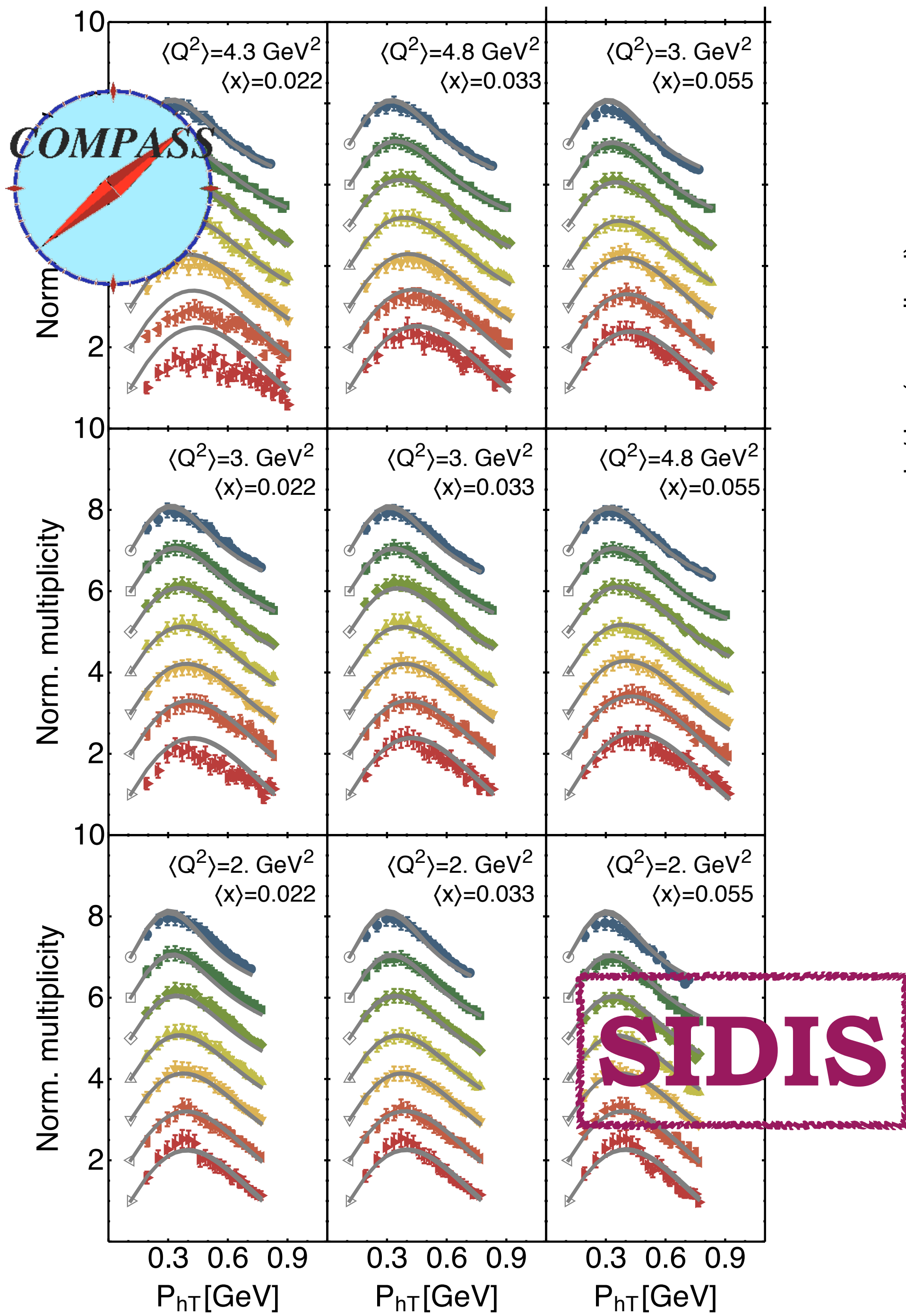
INFN
Istituto Nazionale di Fisica Nucleare

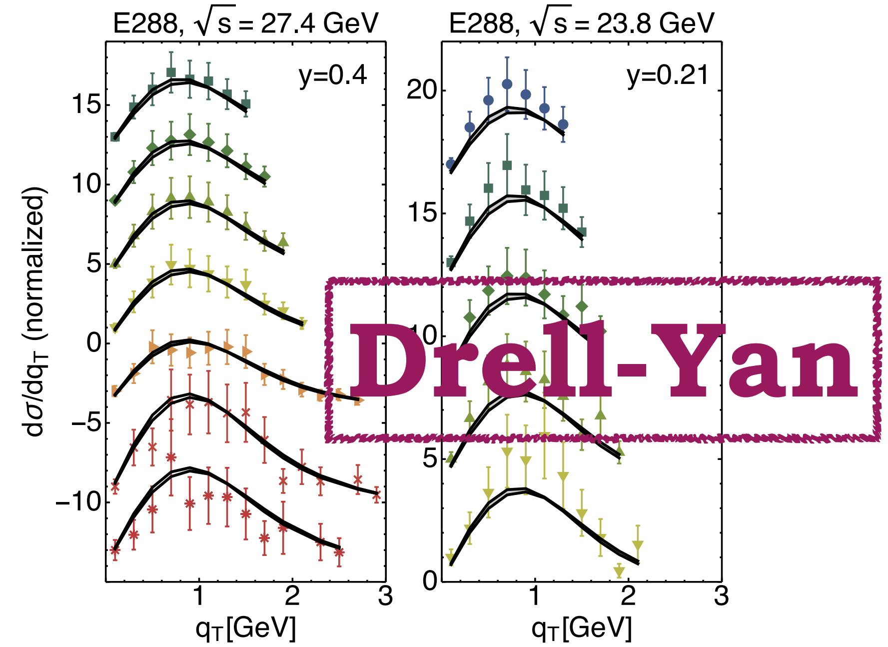
UNIVERSITÀ DI PAVIA

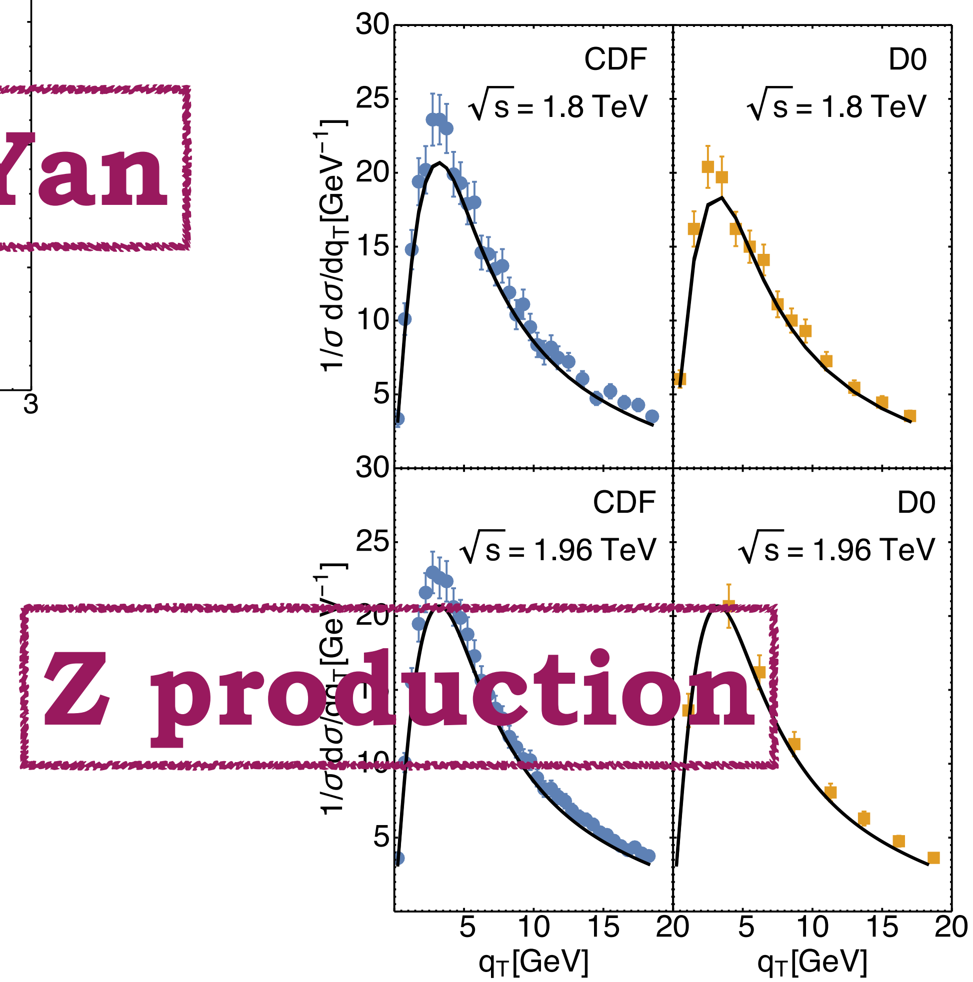
Pavia 2017 fit
NLL

$\chi^2 = 1.55$

Fermilab







Bacchetta, Delcarro, Pisano, Radici, Signori
arXiv:1703.10157

Improving our fitting framework

Z production
&
Drell-Yan

LHC data

up to N3LL

theoretical predictions
(not a fit yet)

Taking better care of uncertainties

Experimental uncertainties

$$m_i \pm \sigma_{i,\mathrm{stat}} \pm \sigma_{i,\mathrm{unc}} \pm \sigma_{i,\mathrm{corr}}^{(1)} \pm \cdots \pm \sigma_{i,\mathrm{corr}}^{(k)}$$

statistic

systematic

the central value of
the *i-th* measurement

Experimental uncertainties

$$m_i \pm \sigma_{i,\text{stat}} \pm \sigma_{i,\text{unc}} \pm \sigma^{(1)}_{i,\text{corr}} \pm \cdots \pm \sigma^{(k)}_{i,\text{corr}}$$

uncorrelated

correlated

additive **multiplicative**

$$\chi^2 = \sum_{i,j=1}^{n} (m_i - t_i) V^{-1}_{ij} (m_j - t_j)$$

$$\sigma^{(l)}_{i,\text{corr}} \equiv \delta^{(l)}_{i,\text{corr}} m_i$$

covariance matrix

$$V_{ij} = s_i^2 \delta_{ij} + \left(\sum_{l=1}^{k_a} \delta^{(l)}_{i,\text{add}} \delta^{(l)}_{j,\text{add}} + \sum_{l=1}^{k_m} \delta^{(l)}_{i,\text{mult}} \delta^{(l)}_{j,\text{mult}} \right) m_i m_j$$

χ^2 chisquare

systematic shift

$$d_i = \sum_{\alpha=1}^{k} \lambda_\alpha \sigma_{i,\mathrm{corr}}^{(\alpha)}$$

shift

$$\frac{\partial \chi^2}{\partial \lambda_\alpha} = 0$$

nuisance parameters

$$\bar{t}_i = t_i + d_i$$

shifted prediction

$$\chi^2 = \sum_{i=1}^{n} \left(\frac{m_i - \bar{t}_i}{s_i} \right)^2 + \sum_{\alpha=1}^{k} \lambda_\alpha^2$$

recover the form of the uncorrelated definition

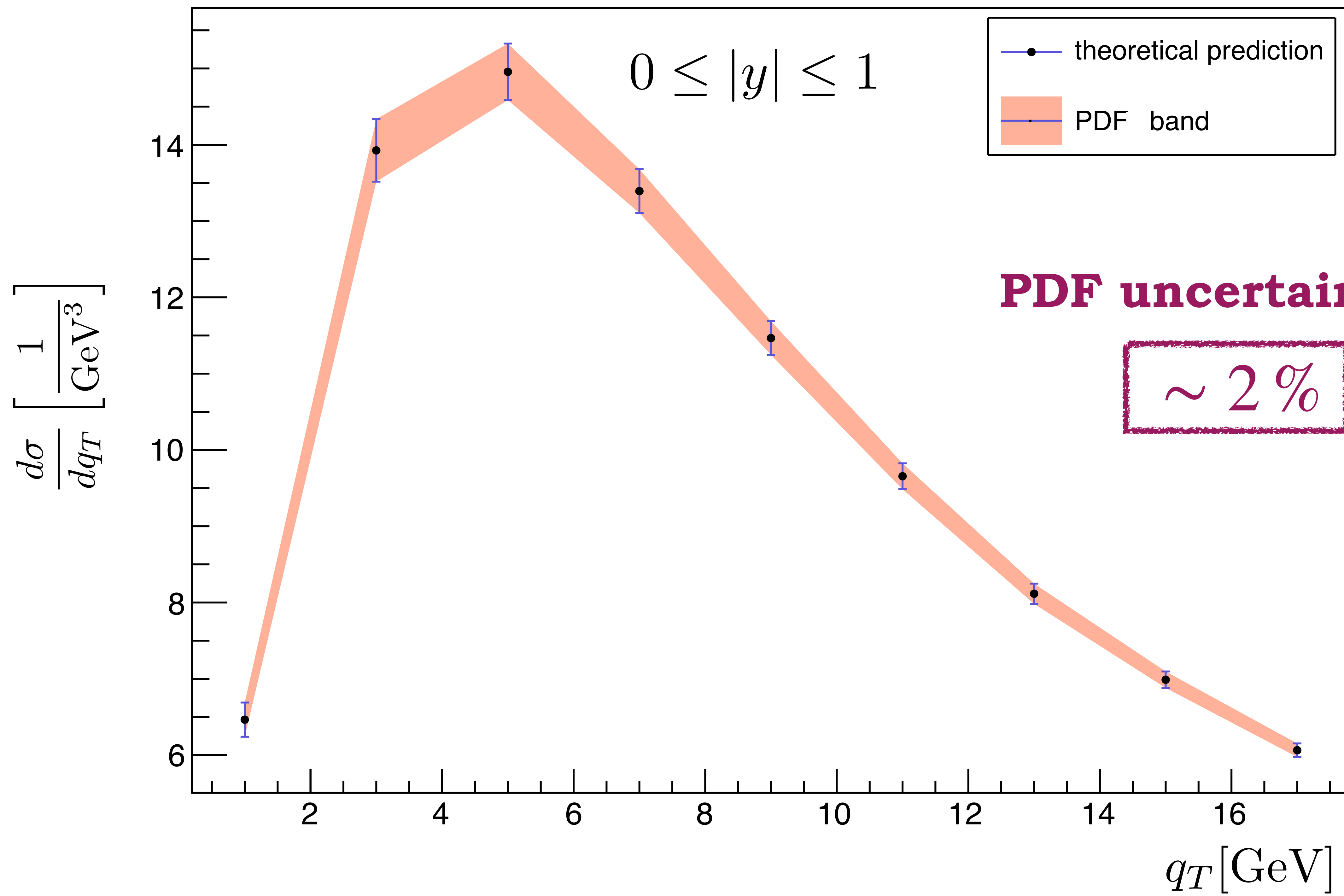
penalty term

PDF uncertainty

Hessian method

MMHT2014 @nlo
NNLL

[ATLAS 7 TeV]

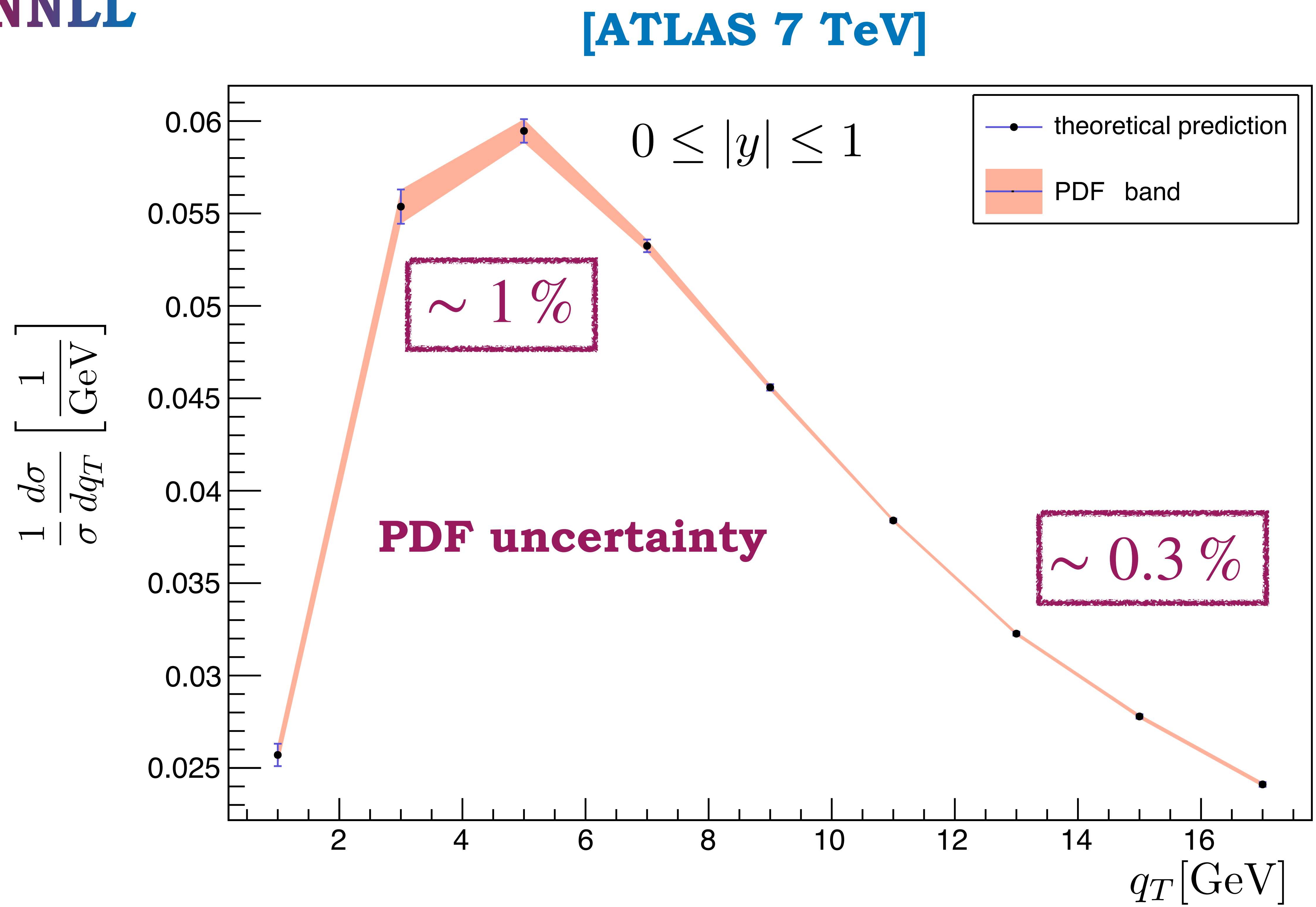


PDF uncertainty

$\sim 2\,\%$

Hessian method

MMHT2014 @nlo
NNLL



More and improved mathematical tools

Integrations

Experiments measure quantities like:

$$\sigma = \int_{Q_{\min}}^{Q_{\max}} dQ \int_{y_{\min}}^{y_{\max}} dy \int_{q_{T,\min}}^{q_{T,\max}} dq_T \left[\frac{d\sigma}{dQ dy dq_T} \right]$$

no narrow-width approximation

integration over the range in boson rapidity

integration over bins in q_T

y binning **ATLAS** data

Lepton cuts

η lepton rapidity

on the final-state leptons in Drell-Yan

why are they necessary?

ATLAS

$|\eta| \leq 2.4$

LHCb

$2 \leq |\eta| \leq 4.5$

CMS

$|\eta| \leq 2.1$

$p_t \geq 20 \quad \text{GeV}$

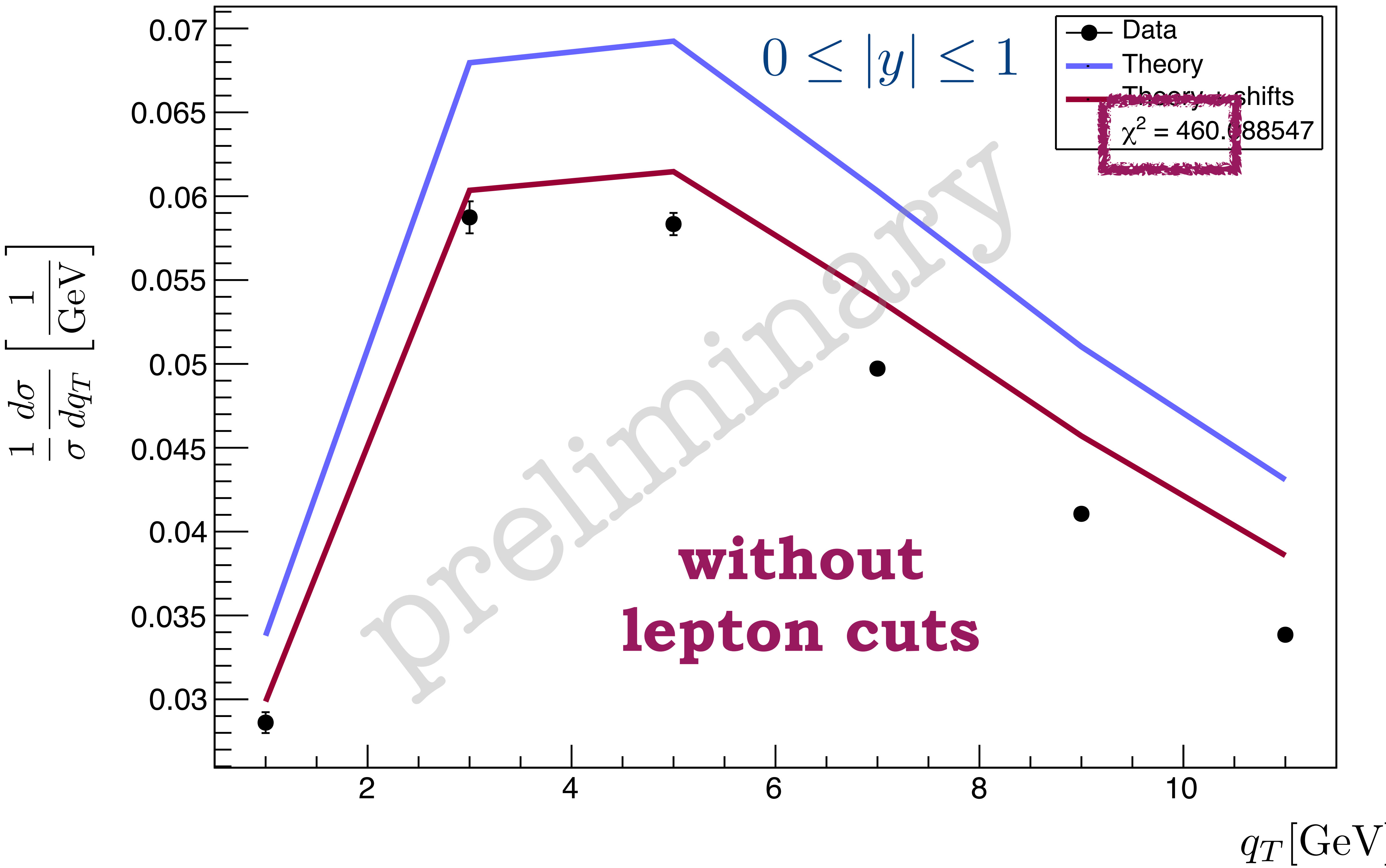
phase-space reduction factor

$$\mathcal{P}(Q, y, q_T) = \frac{\int_{\text{fid. reg.}} d\Omega \quad g_\perp^{\mu\nu} L_{\mu\nu}}{\int d\Omega \quad g_\perp^{\mu\nu} L_{\mu\nu}}$$

they make a HUGE difference

Pavia 2019
N3LL

ATLAS 7 TeV



Pavia 2019
N3LL

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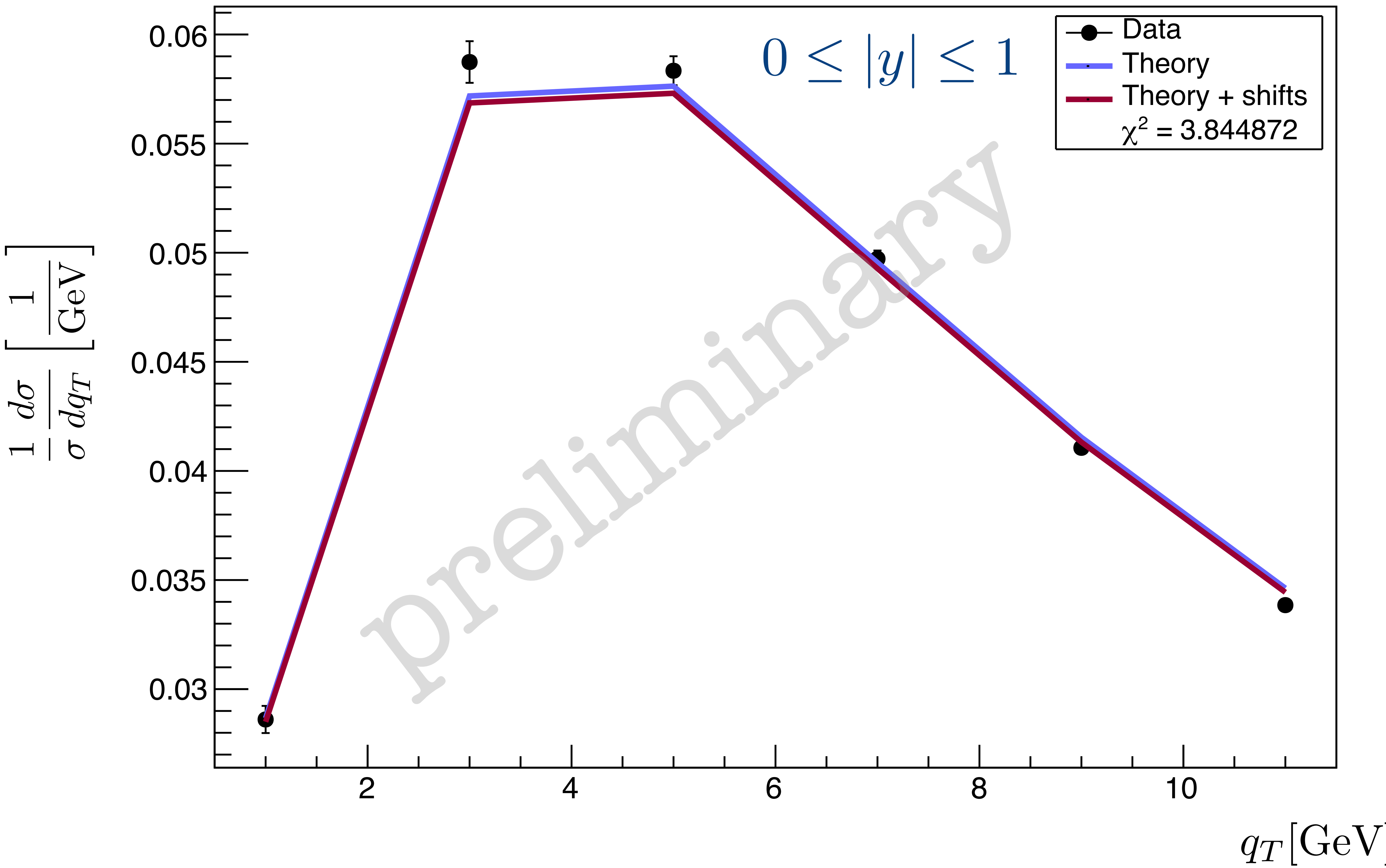
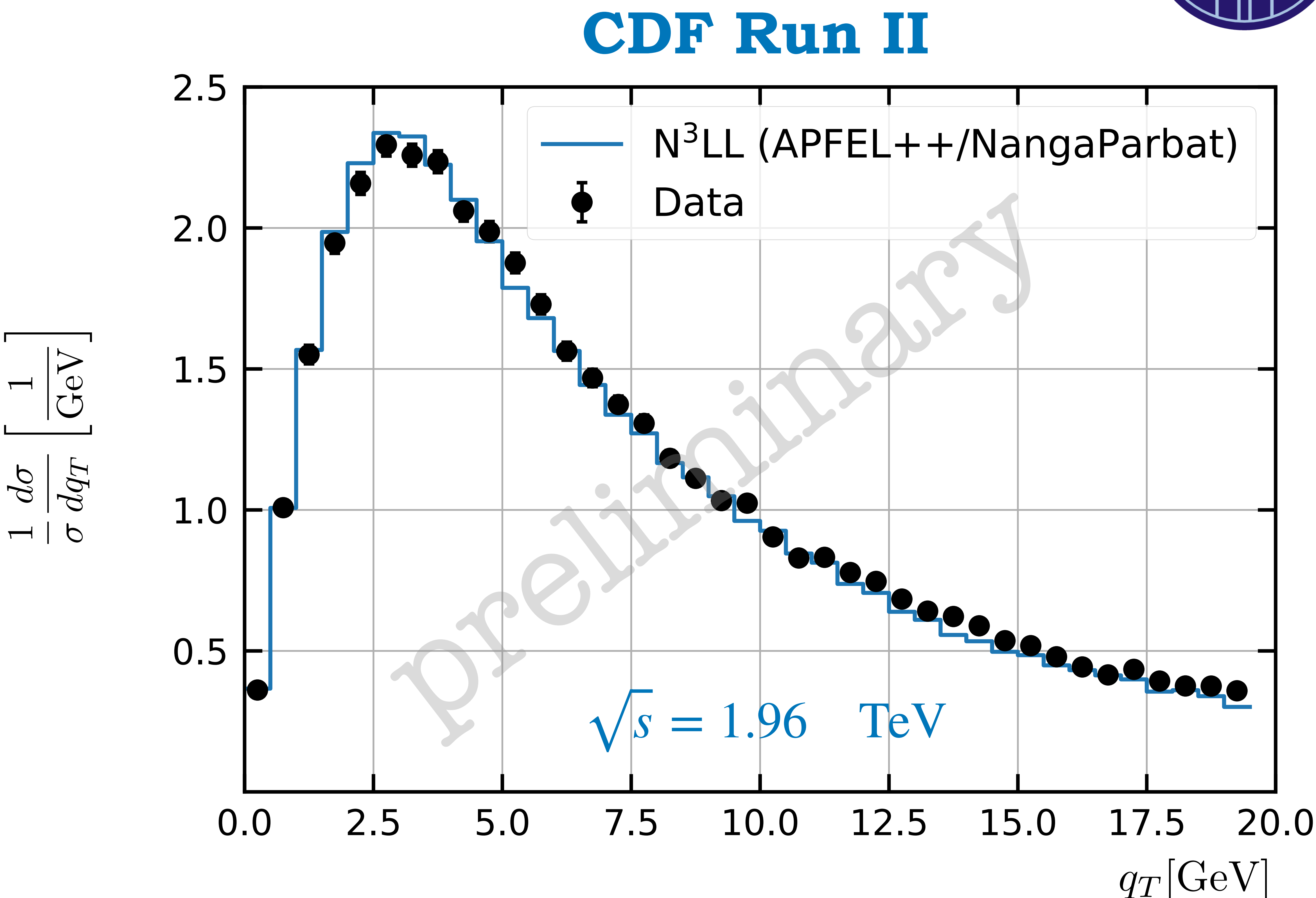


Preliminary results

Pavia 2019
N3LL



Non-perturbative function

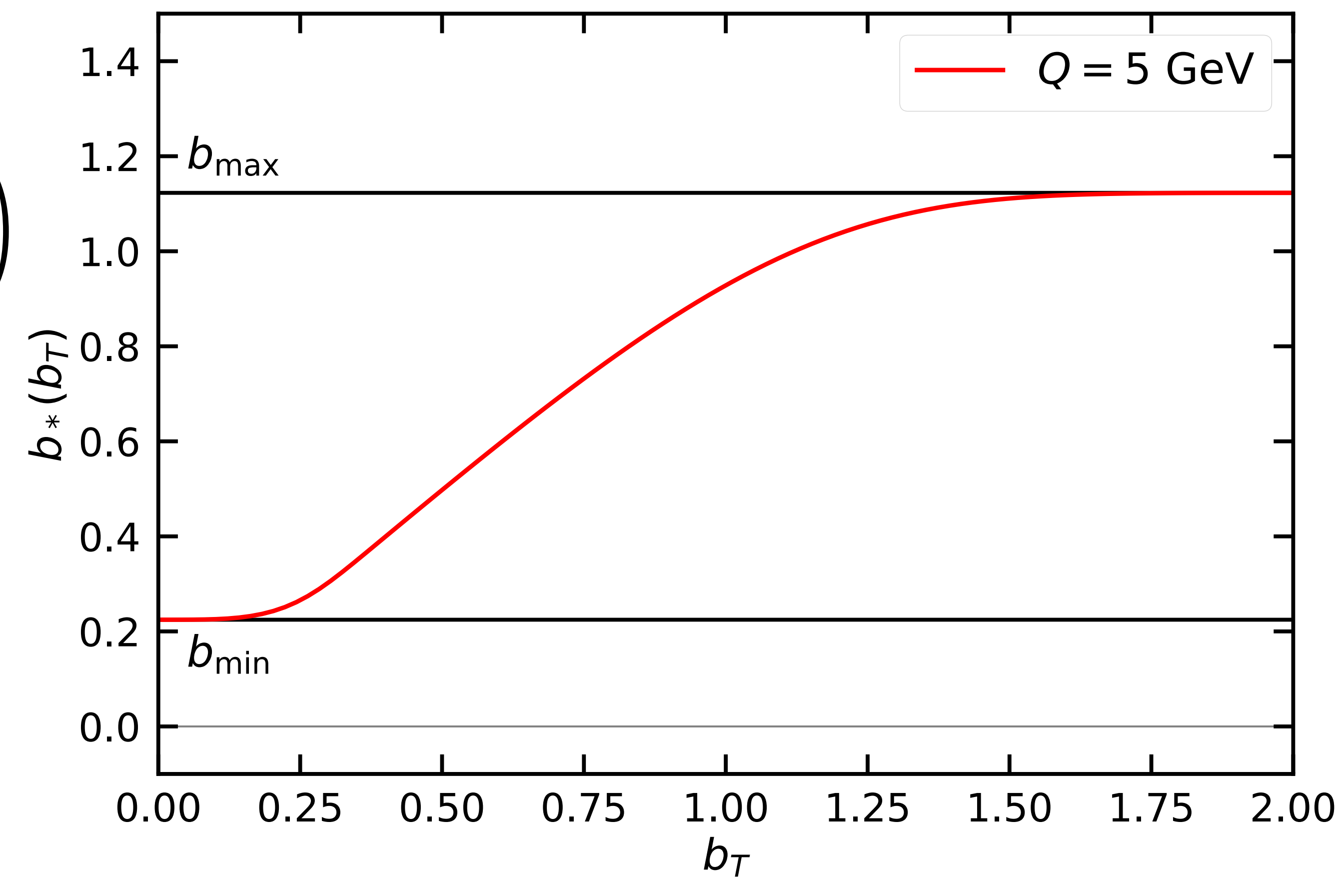
$$\tilde{f}_{1\mathrm{NP}}(x, b_T^2) = \frac{1}{2\pi} e^{-g_1 \frac{b_T^2}{4}} \left(1 - \frac{\lambda g_1^2}{1 + \lambda g_1} \frac{b_T^2}{4}\right)$$

x dependence → $$g_1(x) = N_1 \frac{(1-x)^{\alpha} x^{\sigma}}{(1-\hat{x})^{\alpha} \hat{x}^{\sigma}}$$

b-min choice

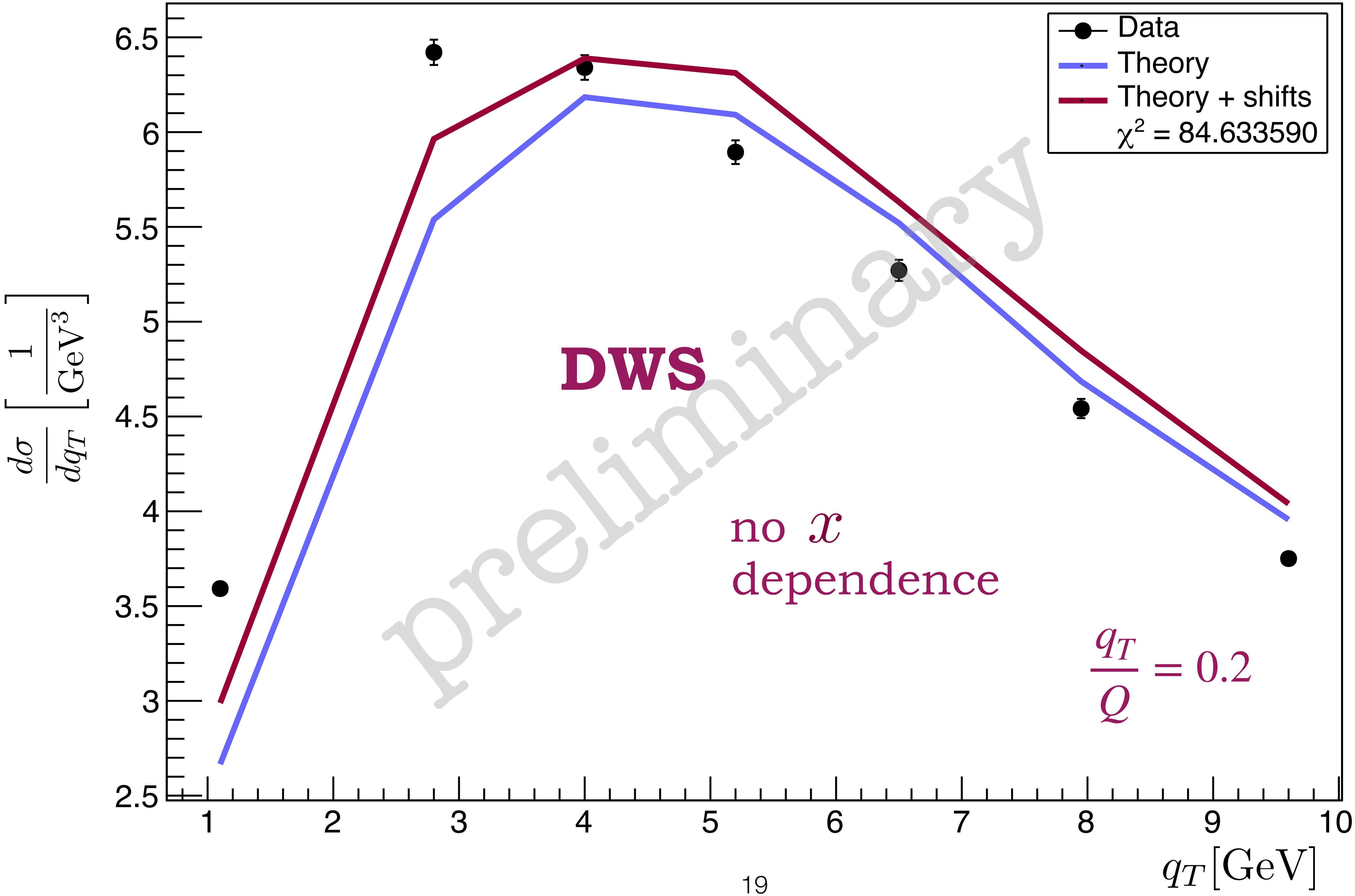
$$\bar{b}_\star(b_T; b_{\mathrm{min}}, b_{\mathrm{max}}) = b_{\mathrm{max}} \left(\frac{1 - e^{-b_T^4/b_{\mathrm{max}}^4}}{1 - e^{-b_T^4/b_{\mathrm{min}}^4}} \right)$$

$$b_{\mathrm{max}} = 2e^{-\gamma_E}$$
$$b_{\mathrm{min}} = 2e^{-\gamma_E}/Q$$

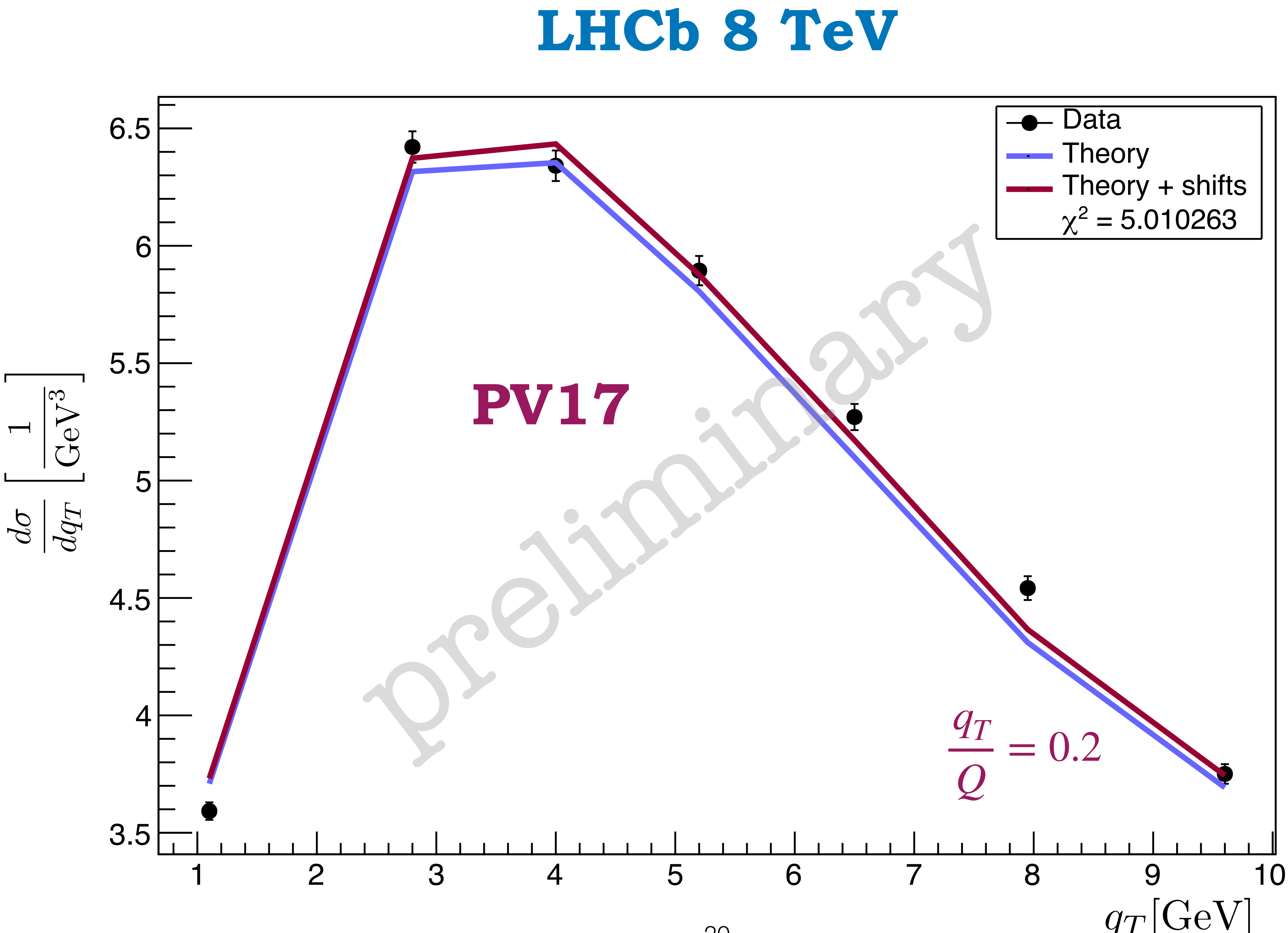


Davies-Webber-Stirling non-perturbative function

LHCb 8 TeV



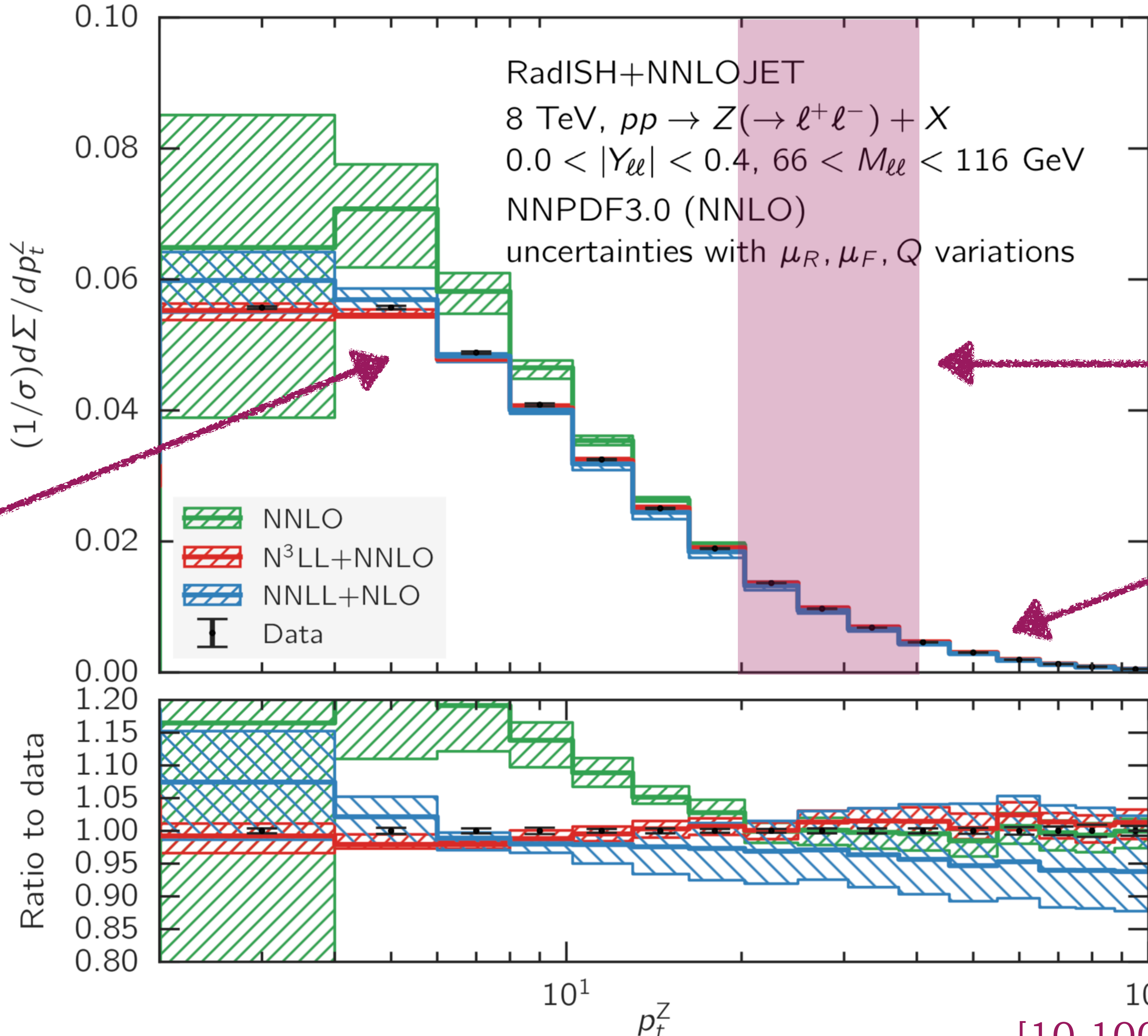
Impact of the NP function



Current state-of-the-art

N3LL + NNLO

ATLAS data



TMD

matching region

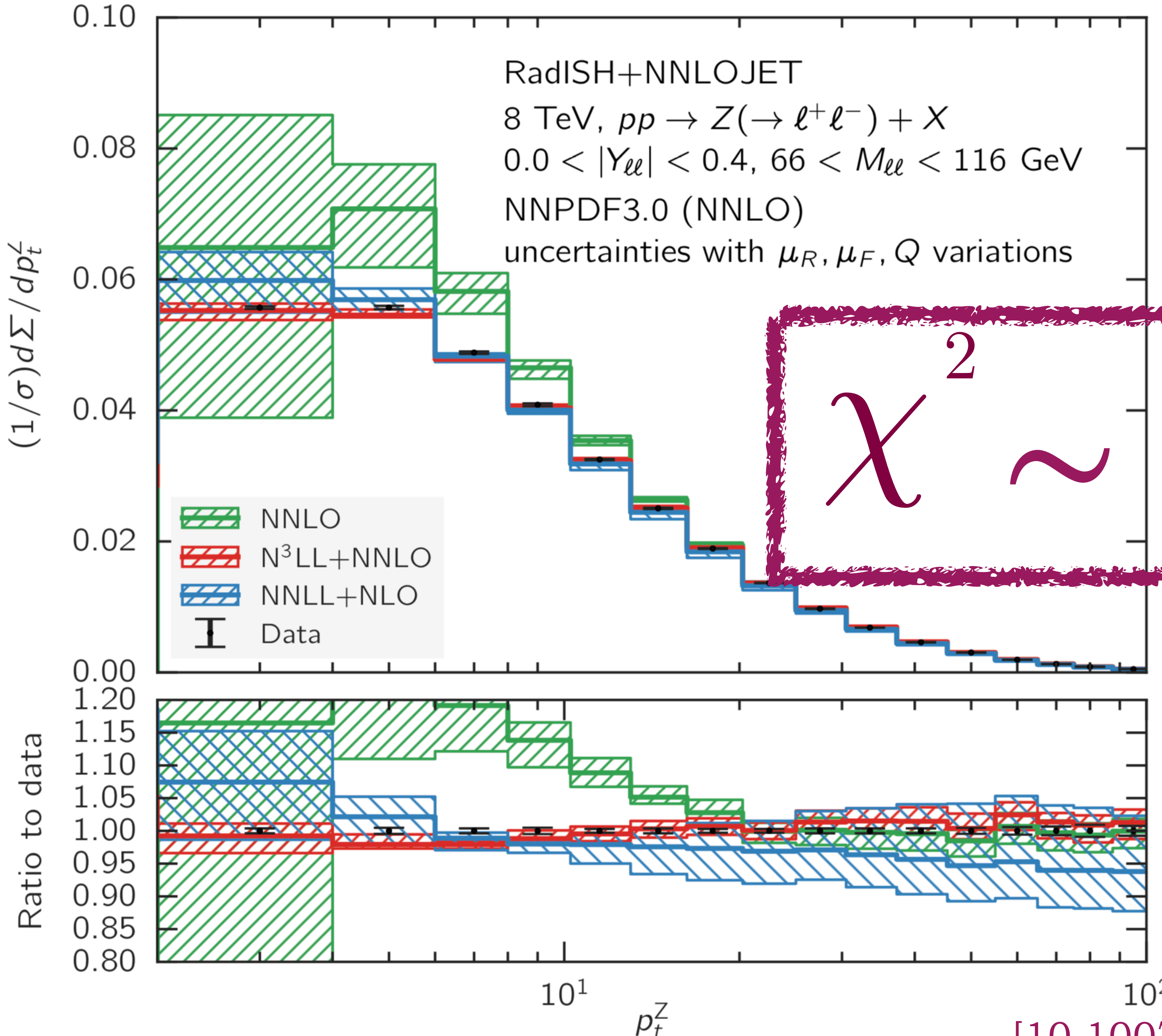
collinear

[10.1007/JHEP12(2018)132]

Current state-of-the-art

N3LL + NNLO

ATLAS data

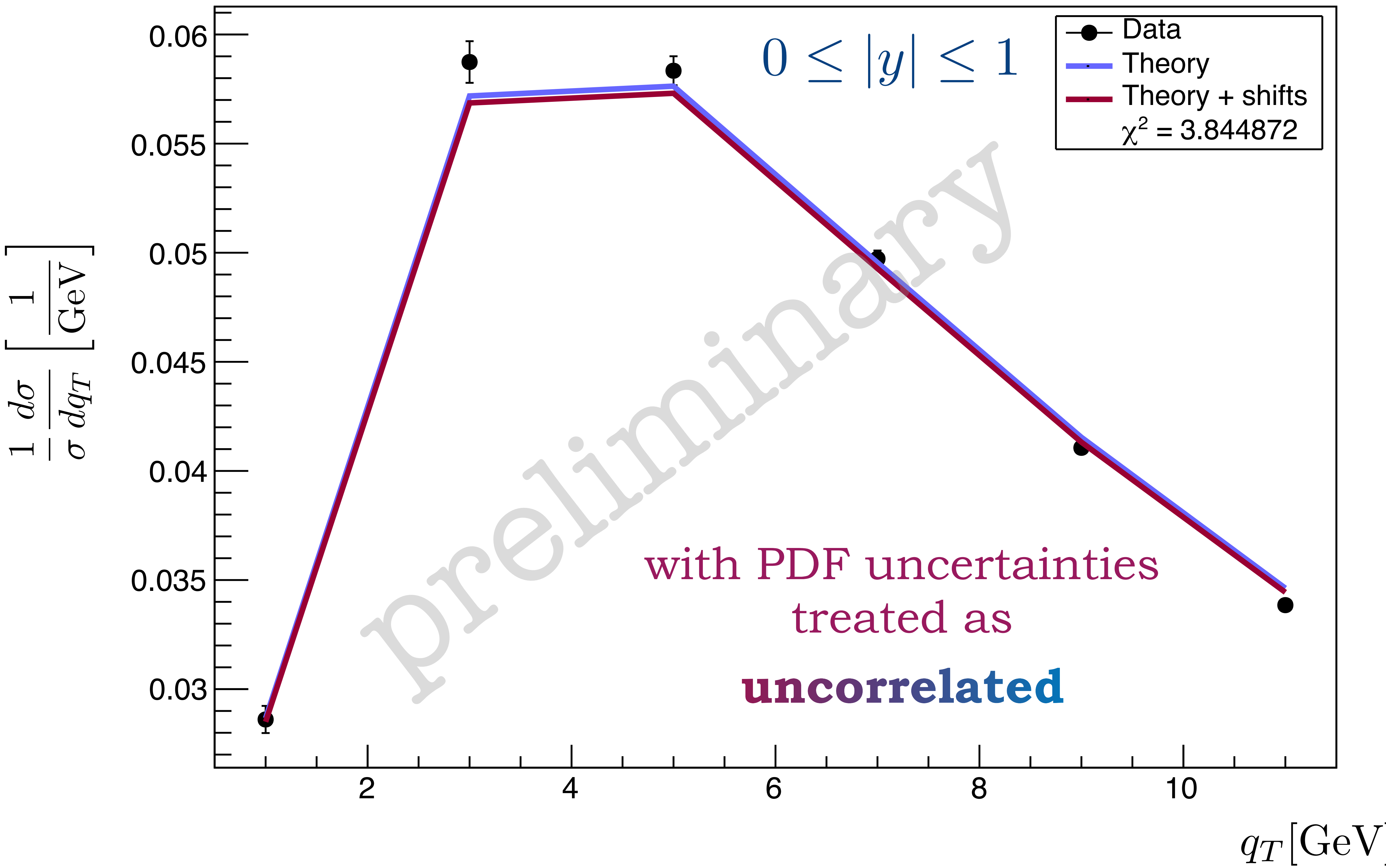


$$\chi^2 \sim 10^1$$

[10.1007/JHEP12(2018)132]

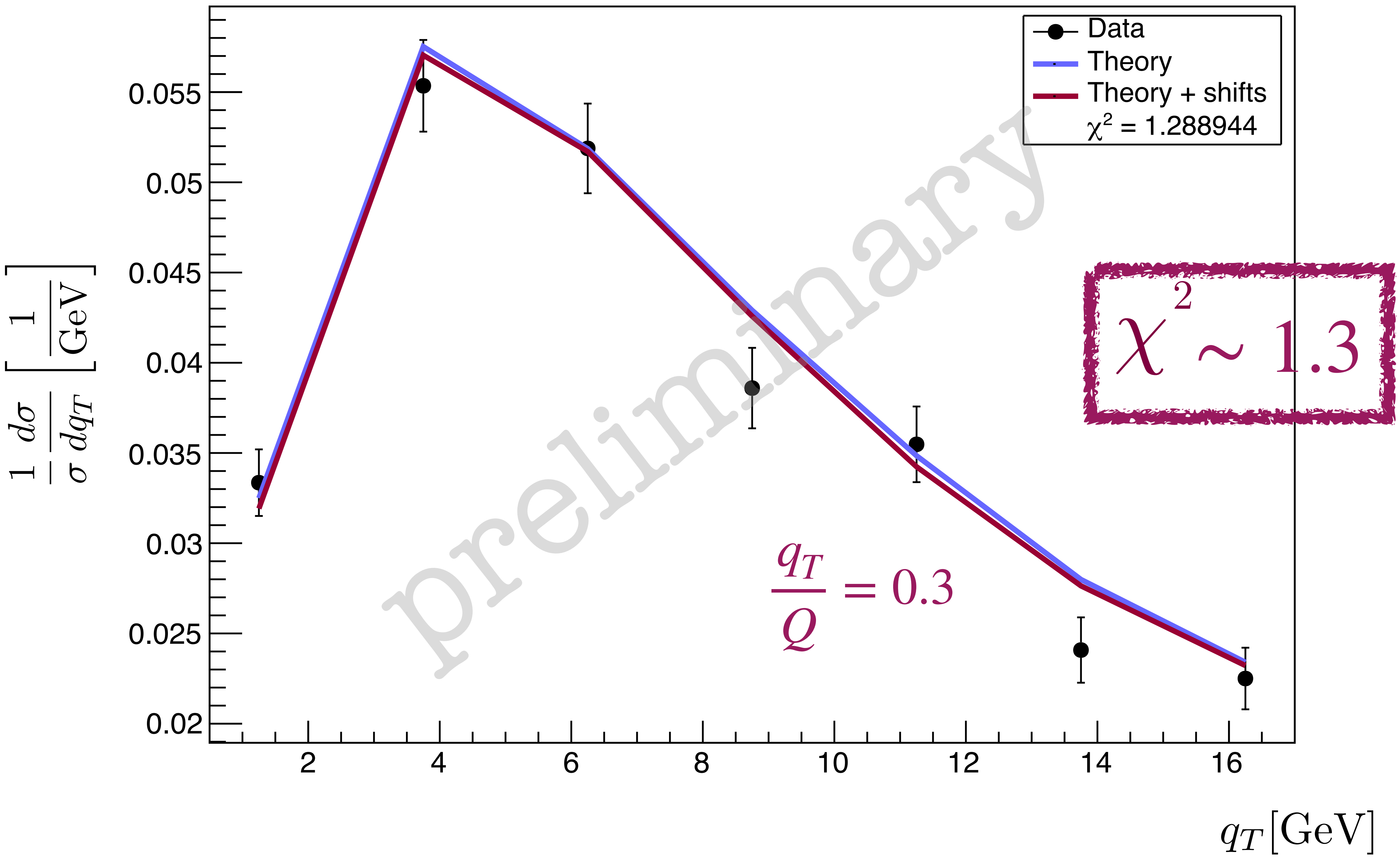
Pavia 2019
N3LL

ATLAS 7 TeV



Pavia 2019
N3LL

CMS 8 TeV



state-of-the-art accuracy with a fitting framework

N3LL

we have encouraging preliminary results on theoretical predictions,
so...

state-of-the-art accuracy with a fitting framework

N3LL

we have encouraging preliminary results on theoretical predictions,
so...

we are ready to fit!

Backup

Hessian formula

$$\Delta X = \frac{1}{2}\left(\sum_{i=1}^{N_p}\left[X(S_i^+) - X(S_i^-)\right]^2\right)^{\frac{1}{2}}$$

$$X = \frac{d\sigma}{dq_T}$$

$$X = \frac{1}{\sigma}\frac{d\sigma}{dq_T}$$

DWS

$$\tilde{f}_{DWS}(x, b_T^2) = e^{-\left[g_1 + \frac{g_2}{2}\ln\left(\frac{Q^2}{Q_0^2}\right)\right]\frac{b_T^2}{4}}$$

Davies-Webber-Stirling non-perturbative function