Ignazio Scimemi (UCM)

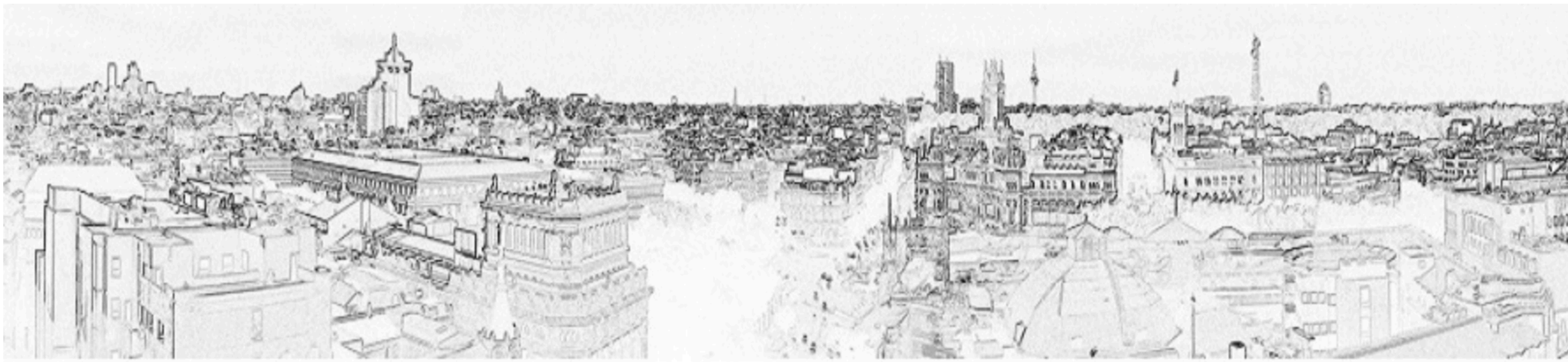
Analysis of DY and vector boson production in TMD formalism

Most recent results in collaboration with **Alexey Vladimirov**

arXiv:1706….

http://jacobi.fis.ucm.es/REF2017/

Resummation, Evolution, Factorization 2017



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Presentation

Dates: 13/11/2017-17/11/2017

REF 2017 is the 6th workshop in the series of workshops on **Resummation, Evolution, Factorization**. Previous discussion meetings and workshops were

7-10 November 2016 Antwerp (Belgium)
2-5 November 2015 DESY Hamburg (Germany)
1-3 June 2015 Amsterdam (The Netherlands)
8-11 December 2014 Antwerp (Belgium)

Outline & Issues

- Resume of TMD factorization and unpolarized TMDs
- **Limits and goals of DY fitting**
- **Scale prescriptions, convergence, models, theoretical errors,..**
- The impact of LHC
- arTeMiDe

....TMD factorization ....

.. for DY and heavy boson production we have (Collins 2011, Echevarria, Idilbi, Scimemi (EIS) 2012)

$$\frac{d\sigma}{dQ^2 dq_T dy} = \sum_q \sigma_q^\gamma H(Q^2, \mu^2) \int \frac{d^2\mathbf{b}}{4\pi} e^{-i\mathbf{q_T}\cdot\mathbf{b}} \Phi_{q/A}(x_A, \mathbf{b}, \zeta_A, \mu) \Phi_{q/B}(x_B, \mathbf{b}, \zeta_B, \mu)$$

$$\sqrt{\zeta_A \zeta_B} = Q^2$$

…and similar formulas are valid for SIDIS (EIC) and hadron production in ee colliders

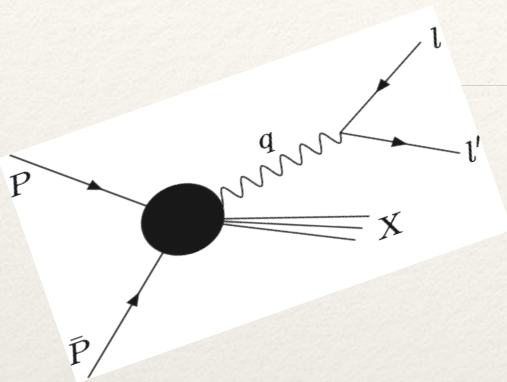
The pathological behavior is associated to a particular kind of divergences: rapidity divergences

The renormalization of the rapidity divergences is responsible for the new resummation scale

We have new nonperturbative effects which cannot be included in PDFs.

THE CASE OF UNPOLARIZED TMDS IS THE MOST STUDIED: FOR THE REST OF TMDS THE NNLO ERA IS JUST STARTED!

TMD's factorization and Operator Product Expansion: general outlook



Factorized hadronic tensor

$q^2 = Q^2 \gg q_T^2$

Q=M=di-lepton invariant mass

Factorization $q_T^2 \sim \Lambda_{QCD}^2$ → $\tilde{M} = H(Q^2/\mu^2)\, \tilde{F}_n(x_n, b; Q^2, \mu^2)\, \tilde{F}_{\bar{n}}(x_{\bar{n}}, b; Q^2, \mu^2)$

OPE $q_T^2 \gg \Lambda_{QCD}^2$ → $\tilde{F}_n = \tilde{C}_{n\leftarrow j}(x_n, b, Q^2, \mu^2) \otimes f_{j\leftarrow h}(x_n, \mu^2) + \mathcal{O}(x_n b^2/B^2)$

Very important

The factorization theorem predicts that each coefficient can be extracted on its own.
The evolution of TMD is universal (process independent)
Renomalons: power corrections are x-dependent

ALL THESE MATCHINGS ON COLLINEAR FUNCTIONS ARE JUST THE ASYMPTOTIC EXPANSION OF A MORE COMPLEX STRUCTURE: HOW CAN WE EXPLORE IT?

Status of unpolarized TMDs in perturbation theory

- Evolution to N3LO Y. Li, H.X. Zhu, arXiv:1604.01404 A. Vladimirov, arXiv:1610.05791
- Soft function at NNLO M.G. Echevarría, I.S., A. Vladimirov, arXiv:1511.05590.
- NNLO coefficients for TMDPDFs M.G. Echevarría, I.S., A. Vladimirov, arXiv:1604.07869
  T. Lübbert, J. Oredsson, M. Stahlhofen, arXiv:1602.01829, T. Gehrmann, T. Lübbert, Li Lin Yang arXiv:1403.6451
- NNLO coefficients for TMD Fragmentation Functions M.G. Echevarría, I.S., A. Vladimirov, arXiv:1509.06392, arXiv:1604.07869

It is possible to make a complete analysis of unpolarized TMD in Drell-Yan and SIDIS using NNLO results

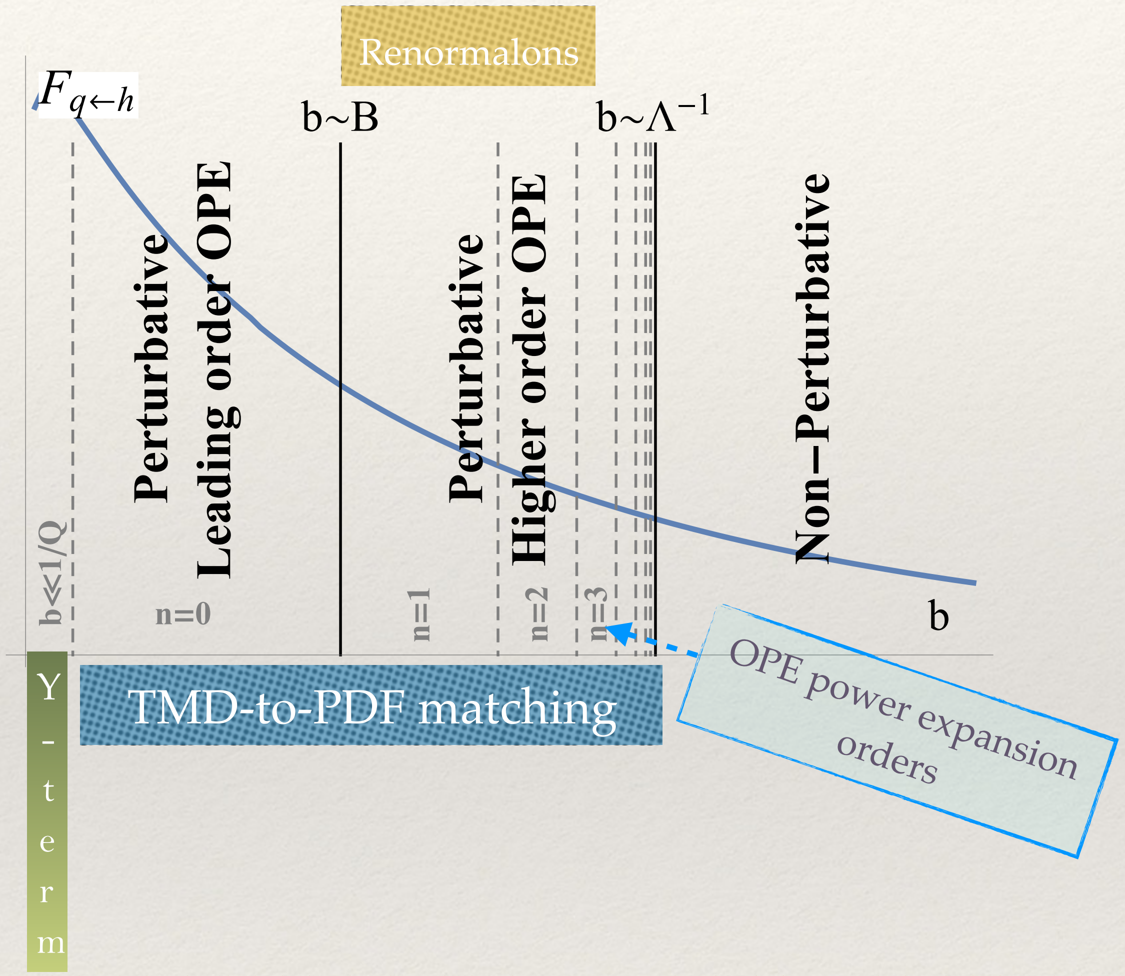
The study of polarized TMDs at the same precision is just started:

D. Gutierrez-Reyes, I.S., A. Vladimirov, arXiv:1702.06558

See also talk of T. Rogers

Regions in *b*-space

The factorization theorem works in b-space.
The perturbative expansion does not work on the whole space…



EACH REGION NEEDS A PARTICULAR TREATMENT

NOT ALL REGIONS ARE EQUALLY IMPORTANT FOR EACH EXPERIMENT

TMD evolution

$$\mu^2 \frac{d}{d\mu^2} F_{f\leftarrow h}(x,\mathbf{b};\mu,\zeta) = \frac{1}{2}\gamma_F^f(\mu,\zeta) F_{f\leftarrow h}(x,\mathbf{b};\mu,\zeta),$$

$$\zeta \frac{d}{d\zeta} F_{f\leftarrow h}(x,\mathbf{b};\mu,\zeta) = -\mathcal{D}^f(\mu,\mathbf{b}) F_{f\leftarrow h}(x,\mathbf{b};\mu,\zeta),$$

$$\zeta \frac{d}{d\zeta} \frac{\gamma_F^f(\mu,\zeta)}{2} = \mu^2 \frac{d}{d\mu^2}(-\mathcal{D}^f(\mu,\mathbf{b})) = -\frac{\Gamma^f(\mu)}{2}$$

We have a double evolution in factorization and rapidity scales

$$F_{f\leftarrow h}(x,\mathbf{b};\mu_f,\zeta_f) = R^f[\mathbf{b};(\mu_f,\zeta_f)\leftarrow(\mu_i,\zeta_i)] F_{f\leftarrow h}(x,\mathbf{b};\mu_i,\zeta_i)$$

$$R^f[\mathbf{b};(\mu_f,\zeta_f)\leftarrow(\mu_i,\zeta_i)] = \exp\left[\int_P \left(\gamma_F^f(\mu,\zeta)\frac{d\mu}{\mu} - \mathcal{D}^f(\mu,\mathbf{b})\frac{d\zeta}{\zeta}\right)\right]$$

The evolution is **Path** independent only when all perturbative terms are included: Is there a best choice for initial and final scales?

TMD evolution

The perturbative expression for the evolution kernel work only `up to a certain scale`…

$$R^f[\mathbf{b};(\mu_f,\zeta_f)\leftarrow(\mu_i,\zeta_i);\mu_0]=\exp\left[\int_{\mu_i}^{\mu_f}\frac{d\mu}{\mu}\gamma_F^f(\mu,\zeta_f)-\int_{\mu_0}^{\mu_i}\frac{d\mu}{\mu}\Gamma^f(\mu)\ln\left(\frac{\zeta_f}{\zeta_i}\right)\right]\left(\frac{\zeta_f}{\zeta_i}\right)^{-\mathcal{D}^f_{\rm perp}(\mu_0,\mathbf{b})-g_K\mathbf{b}^2}.$$

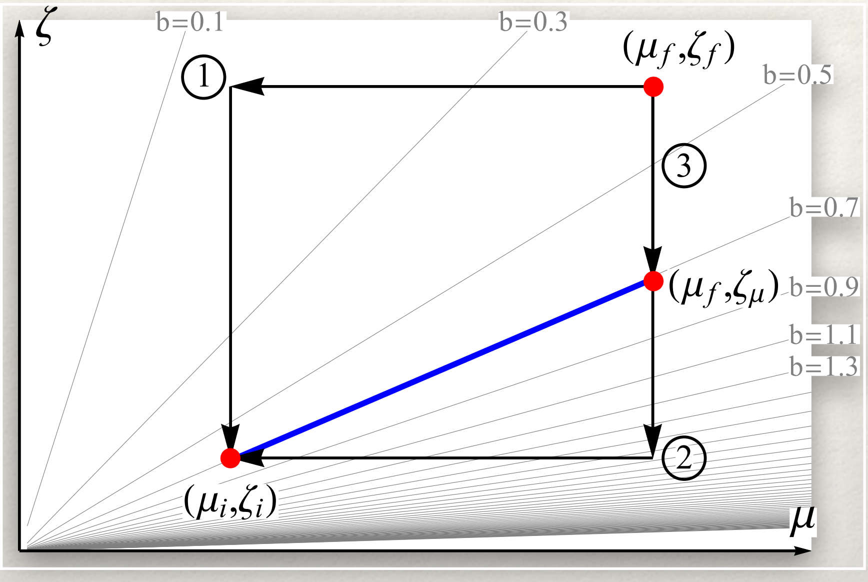
…and in principie we include some (RENORMALON CONSISTENT) corrections

What is the best prescription to choose scales?

b prescription is not satisfactory:*

- It is not consistent with renormalon calculations (I.S., A. Vladimirov 2016)
- It introduces undesired quadratic corrections (which alter model building)

ζ-prescription



We choose $\zeta = \zeta(\mu) \equiv \zeta_\mu$

such that double logs are eliminated in PDF matching

$$C_{q\leftarrow q}(x,\mathbf{L}_\mu;\mu,\zeta) = \delta(\bar{x}) + a_s(\mu)C_F\Big[-2\mathbf{L}_\mu\Big(\frac{2}{(1-x)_+} - 1 - x\Big) + 2\bar{x} + \delta(\bar{x})\Big(-\mathbf{L}_\mu^2 + 2\mathbf{L}_\mu\mathbf{l}_\zeta - \frac{\pi^2}{6}\Big)\Big]\dots$$

In practice we implement.. $$\mu^2\frac{dF(x,\mathbf{b};\mu,\zeta_\mu)}{d\mu^2} = 0.$$ ...and obtain iso-evolution curves..

$$\zeta_\mu = \frac{2\mu}{b}\exp\Big(-\gamma_E + a_s\Big[\frac{11C_A - 4T_FN_f}{36}\mathbf{L}_\mu^2 + C_F\Big(-\frac{3}{4} + \pi^2 - 12\zeta_3\Big) + C_A\Big(\frac{649}{108} - \frac{17\pi^2}{12} + \frac{19}{2}\zeta_3\Big)$$
$$+ T_FN_f\Big(-\frac{53}{27} + \frac{\pi^2}{3}\Big)\Big] + \mathcal{O}(a_s^2)\Big).$$

See also the talk of V. Vaidya

ζ-prescription

In this prescription the structure of coefficient is much simpler

$$C_{q\leftarrow q}(x,\mathbf{L}_\mu;\mu,\zeta_\mu) = \delta(\bar{x}) + a_s(\mu)C_F\Big[-2\mathbf{L}_\mu\Big(\frac{2}{(1-x)_+}-1-x\Big)+2\bar{x}+\delta(\bar{x})\Big(-3\mathbf{L}_\mu-\frac{\pi^2}{6}\Big)\Big]+\cdots$$

We do not introduce undesired power corrections

We have several proof of scale stability: TMD area, ...

$$\int_0^1 dx C_{q\leftarrow q}(x,\mathbf{L}_\mu;\mu,\zeta_\mu) = 1 + a_s(\mu)C_F\Big(1-\frac{\pi^2}{6}\Big)+\cdots$$

Cancellation of logs

$$\mu^2\frac{d}{d\mu^2}C_{f\leftarrow f'}(x,\mathbf{b};\mu,\zeta_\mu)\otimes f_{f'\leftarrow h}(x,\mu) = 0\ ,$$

We are left with the freedom to choose

$$\mu=\mu_0=\mu_b=\frac{C_0}{b}\sqrt{1+\frac{b^2}{b^2_{max}}}$$

Perturbative orders…

Name	$\|C_V\|^2$	$C_{f\leftarrow f'}$	Γ	γ_V	$\mathcal{D}$	PDF set	a_s(run)	ζ_μ
NLL	a_s^0	a_s^0	a_s^2	a_s^1	a_s^1	nlo	nlo	NLL
NLO	a_s^1	a_s^1	a_s^2	a_s^1	a_s^1	nlo	nlo	NLO
NNLL	a_s^1	a_s^1	a_s^3	a_s^2	a_s^2	nnlo	nnlo	NNLL
NNLO	a_s^2	a_s^2	a_s^3	a_s^2	a_s^2	nnlo	nnlo	NNLO

NEW!!

…Theoretical uncertainties…

- Evolution factor $\mu_0 \to C_1\mu_0$
- Hard factorization scale $\mu_f \to C_2\mu_f$
- TMD to PDF matching at small b $\mu_i \to C_3\mu_i$

DATA: Z-boson production….

	CDF run I	D0 run I
$\sqrt{s}$	1.8 TeV	1.8 TeV
process	$p+\bar{p} \to Z \to e^+e^-$	$p+\bar{p} \to Z \to e^+e^-$
M_{ll} range	66-116 GeV	75-105 GeV
y	y-integrated	y-integrated
Observable	$\frac{d\sigma}{dq_T}$	$\frac{d\sigma}{dq_T}$
Exp. $\sigma_{\rm tot}$ [pb]	248 ± 17	$\sigma = 221 \pm 11$

	CDF run II	D0 run II
$\sqrt{s}$	1.96 TeV	1.96 GeV
process	$p+\bar{p} \to Z \to e^+e^-$	$p+\bar{p} \to Z \to e^+e^-$
M_{ll} range	66-116 GeV	70-110 GeV
y	y-integrated	y-integrated
Observable	$\frac{d\sigma}{dq_T}$	$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$
Exp. $\sigma_{\rm tot}$ [pb]	256 ± 2.91	$\sigma = 255$

	ATLAS	ATLAS
$\sqrt{s}$	7 TeV	8 TeV
process	$pp \to Z \to ee + \mu\mu$	$pp \to Z \to \mu\mu$
M_{ll} range	66 - 116 GeV	66 - 116 GeV
lepton cuts	$p_T > 20$ GeV $\lvert\eta\rvert < 2.4$	$p_T > 20$ GeV $\lvert\eta\rvert < 2.4$
y	$-2.4 < y < 2.4$	$-2.4 < y < 2.4$
Observable	$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$	$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$

	CMS	CMS
$\sqrt{s}$	7 TeV	8 TeV
process	$pp \to Z \to ee + \mu\mu$	$pp \to Z \to \mu\mu$
M_{ll} range	60-120 GeV	60-120 GeV
lepton cuts	$p_T > 20$ GeV $\lvert\eta\rvert < 2.1$	$p_T > 15$ GeV $\lvert\eta\rvert < 2.1$
y	$\lvert y\rvert < 2.1$	$\lvert y\rvert < 2.1$
Observable	$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$	$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$

	LHCb	LHCb	LHCb
$\sqrt{s}$	7 TeV	8 TeV	13 TeV
process	$pp \to Z \to \mu\mu$	$pp \to Z \to \mu\mu$	$pp \to Z \to \mu\mu$
M_{ll} range	60-120 GeV	60-120 GeV	60-120 GeV
lepton cuts	$p_T > 20$ GeV $2 < \eta < 4.5$	$p_T > 20$ GeV $2 < \eta < 4.5$	$p_T > 20$ GeV $2 < \eta < 4.5$
y	$2 < y < 4.5$	$2 < y < 4.5$	$2 < y < 4.5$
Observable	$d\sigma(q_T)$	$d\sigma(q_T)$	$\frac{d\sigma}{dq_T}$
Norm. exp.	$\sigma = 76.0 \pm 3.1$ pb	$\sigma = 95.0 \pm 3.2$ pb	$\sigma = 198.0 \pm 13.3$ pb

NEW!

DATA: and Drell-Yan....

NEW!

	E288 200	E288 300	E288 400
$\sqrt{s}$	19.4 GeV	23.8 GeV	27.4 GeV
process	p+Cu$\to \gamma \to \mu^+\mu^-$	p+Cu$\to \gamma \to \mu^+\mu^-$	p+Cu$\to \gamma \to \mu^+\mu^-$
Q range	4-9 GeV	4-9 GeV	5-14 GeV
ΔQ-bin	1 GeV	1 GeV	1 GeV
y	y=0.4	y=0.21	y=0.03
Observable	$E\frac{d^3\sigma}{d^3q}$	$E\frac{d^3\sigma}{d^3q}$	$E\frac{d^3\sigma}{d^3q}$

	ATLAS	ATLAS
$\sqrt{s}$	8 TeV	8 TeV
process	$pp \to Z/\gamma^* \to \mu\mu$	$pp \to Z/\gamma^* \to \mu\mu$
M_{ll} range	46 - 66 GeV	116 - 150 GeV
lepton cuts	$p_T > 20$ GeV $\|\eta\| < 2.4$	$p_T > 20$ GeV $\|\eta\| < 2.4$
y	$-2.4 < y < 2.4$	$-2.4 < y < 2.4$
Observable	$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$	$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$

Lepton cuts...

Lepton cuts have implemented numerically for LHC.
However all experiments suffer from lepton cuts: they should always be reported!!

Normalization of the cross sections

Not all experiments provide a value for total cross sections:

- N_{E288}=0.8 fixed
- For CDF, D0 we use DYNNLO
- for LHC we normalize areas of partially integrated cross sections. N=th/exp Generally good agreement, within errors

order	ATLAS Z-boson 7TeV	ATLAS Z-boson 8TeV	ATLAS 46-66 8TeV	ATLAS 116-150 8TeV	CMS 7TeV	CMS 8TeV	LHCb 7TeV	LHCb 8TeV	LHCb 13TeV
NLL	*0.80(1)*	0.79(1)	**0.86(1)**	**0.74(0)**	*0.83(1)*	*0.84(1)*	0.86(1)	0.87(1)	0.85(1)
NLO	*0.89(1)*	0.87(1)	**0.96(3)**	**0.81(1)**	*0.91(2)*	*0.93(2)*	0.95(2)	0.95(1)	**0.94(1)**
NNLL	*0.95(2)*	0.93(2)	**1.04(4)**	**0.86(1)**	*0.98(2)*	*1.00(2)*	**1.01(2)**	**1.01(2)**	**1.00(1)**
NNLO	*0.94(1)*	0.92(1)	**1.01(2)**	**0.85(1)**	*0.97(1)*	*0.99(1)*	**1.00(1)**	**1.01(1)**	**0.99(1)**

Models, data, stability

Data are sensitive to models for non-perturbative part of TMDs.
We explore models with

- Minimal set of parameters
- renormalon consistency
- Independent on number of data points (Stability)
- We do not include Y-terms: we should select q_T/Q proper interval

To be checked on data!!

Models fun

$$R^f[\mathbf{b};(\mu_f,\zeta_f)\leftarrow(\mu_i,\zeta_i);\mu_0]=\exp\left[\int_{\mu_i}^{\mu_f}\frac{d\mu}{\mu}\gamma_F^f(\mu,\zeta_f)-\int_{\mu_0}^{\mu_i}\frac{d\mu}{\mu}\Gamma^f(\mu)\ln\left(\frac{\zeta_f}{\zeta_i}\right)\right]\left(\frac{\zeta_f}{\zeta_i}\right)^{-\mathcal{D}^f_{\rm perp}(\mu_0,\mathbf{b})-g_K\mathbf{b}^2}.$$

Renormalon for kernel

$$F_{q\leftarrow h}(x,\mathbf{b};\mu,\zeta)=\int_x^1\frac{dz}{z}\sum_f C_{q\leftarrow f}(z,\mathbf{b};\mu,\zeta)\,f_{f\leftarrow h}\left(\frac{x}{z},\mu\right)f_{NP}(z,\mathbf{b})$$

Non-perturbative corrections to TMD-PDF matching

$f_{NP}=1$	$f_{NP}=e^{-\lambda_1 b^2}$	$f_{NP}=e^{-\lambda_1 b}$	$f_{NP}=1,\ g_K\neq 0$

Basic (historical) ansatz

Renormalon? It predicts zb^2 corrections…I.S., A. Vladimirov 2016

MODEL 1

$$f_{NP}(\mathbf{b})=e^{-\lambda_1 b}(1+\lambda_2 b^2).$$

Ansatz in D'Alesio, Melis, I.S. , M.G. Echevarria 2014

MODEL 2

$$f_{NP}(z,\mathbf{b})=\exp\left(\frac{-\lambda_q z\mathbf{b}^2}{\sqrt{1+z^2\mathbf{b}^2\frac{\lambda_q^2}{\lambda_1^2}}}\right)+\text{ren.}$$

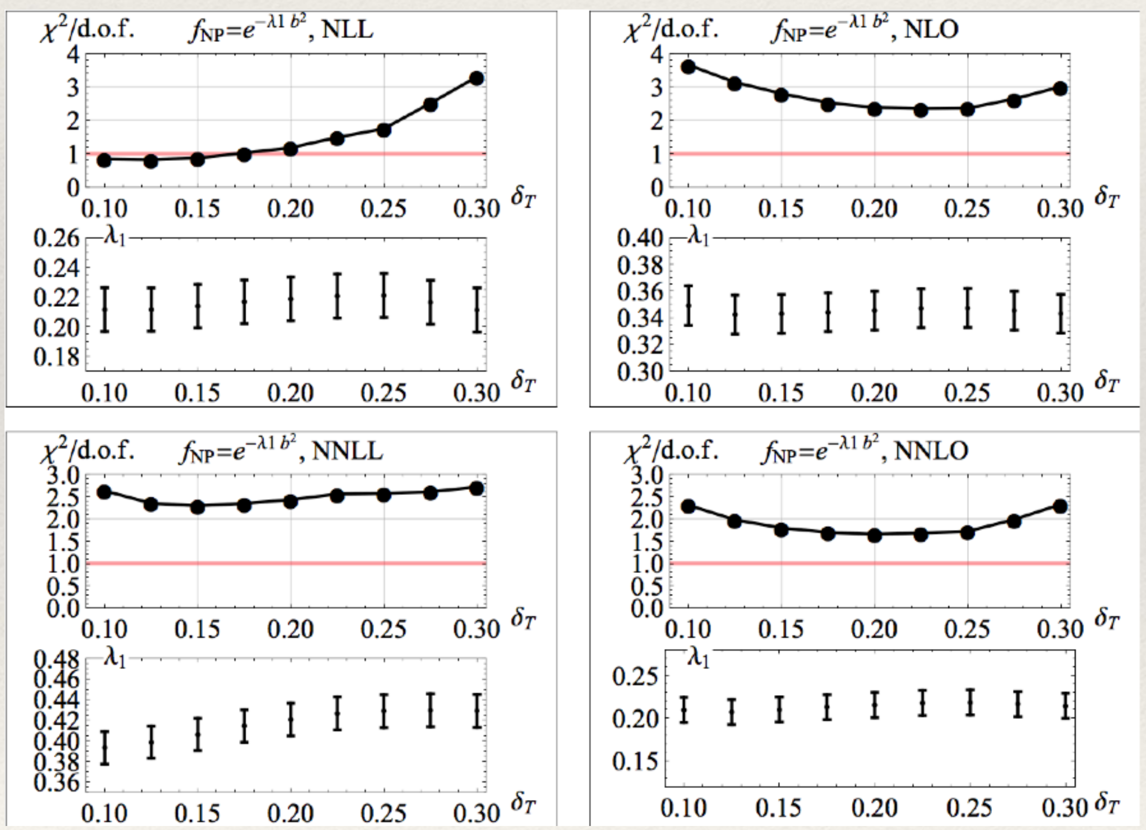
$$\lambda_q=10\ \text{GeV}^2,\ \text{fixed}$$

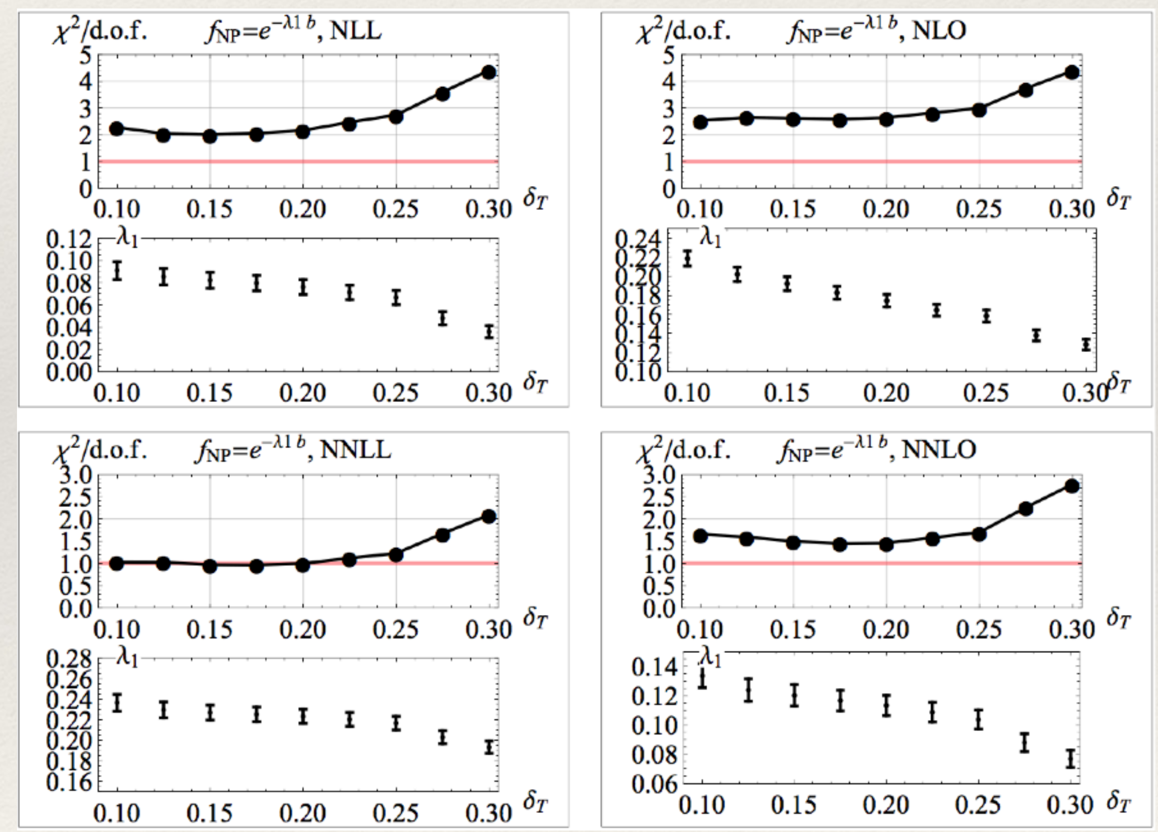
NEW (renormalon consistent) ansatz!

arTeMiDe

Stability

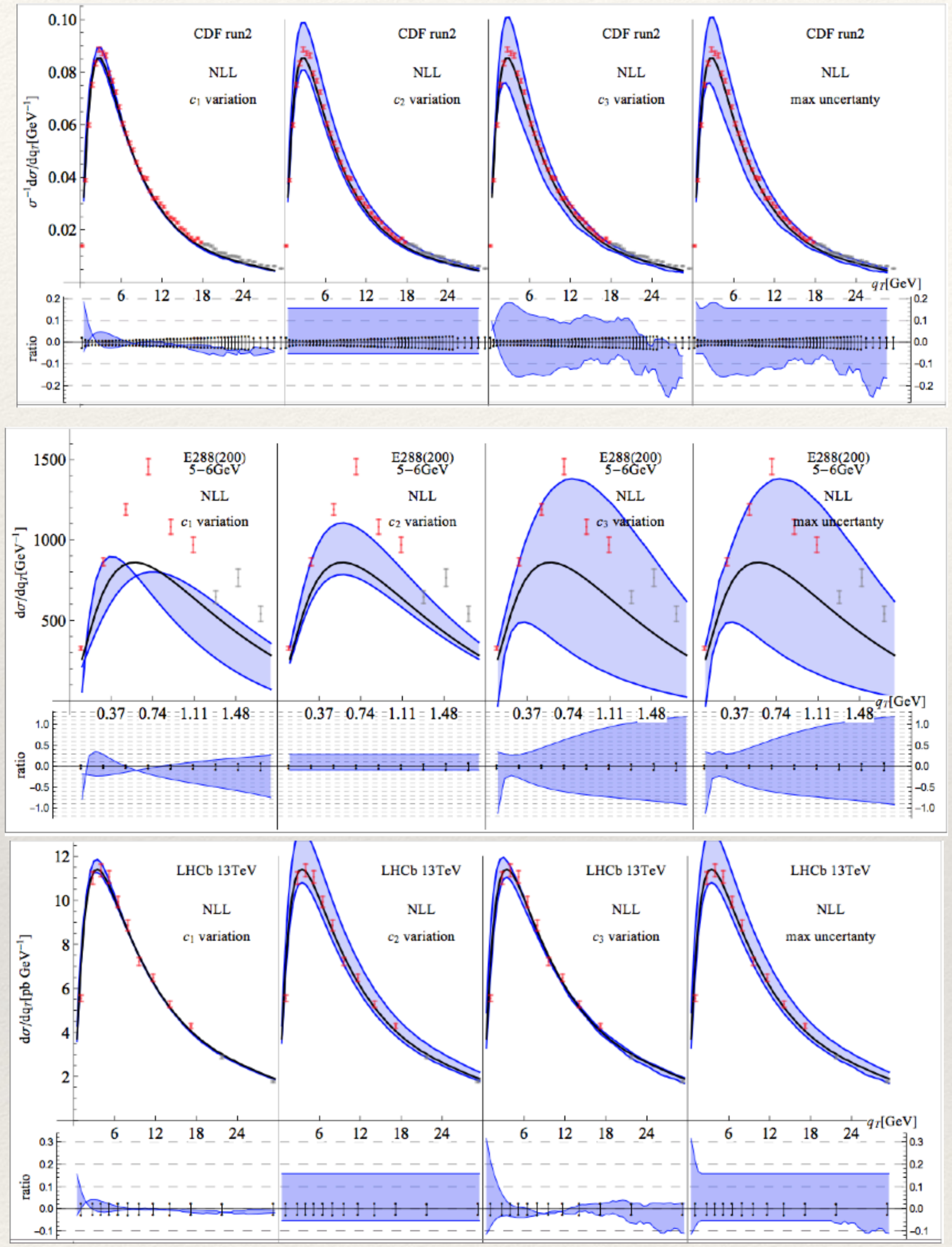
- Different models show different stability of chi^2: *Gaussian disfavored/ Exponential favored*
- Stability increases with perturbative order: *NLL very unstable/NNLO very stable*
- We obtain a plateau only for $\delta_T = q_T/Q \lesssim 0.2$





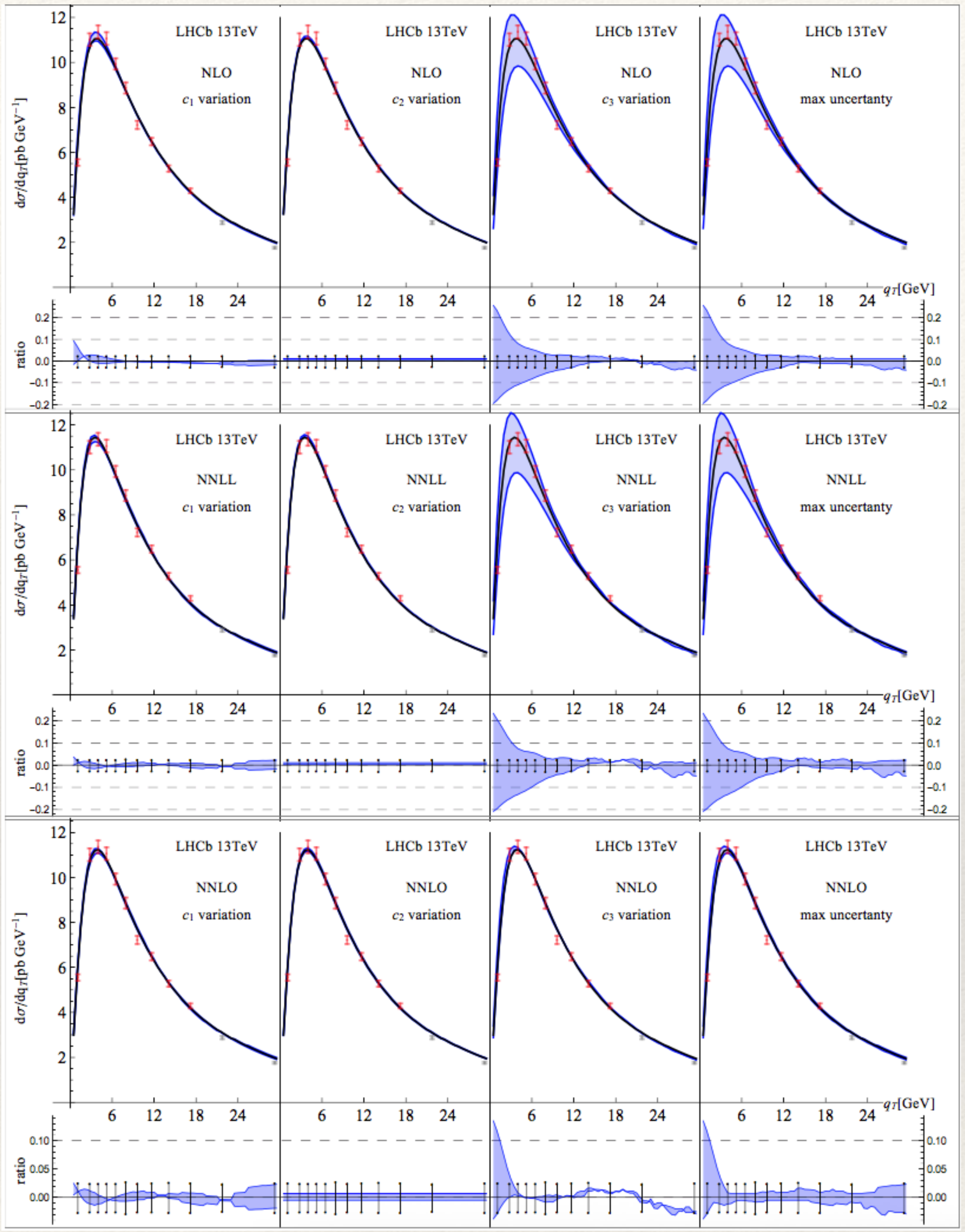
This addresses issues raised in the talks of C. Pisano, O. Gonzalez

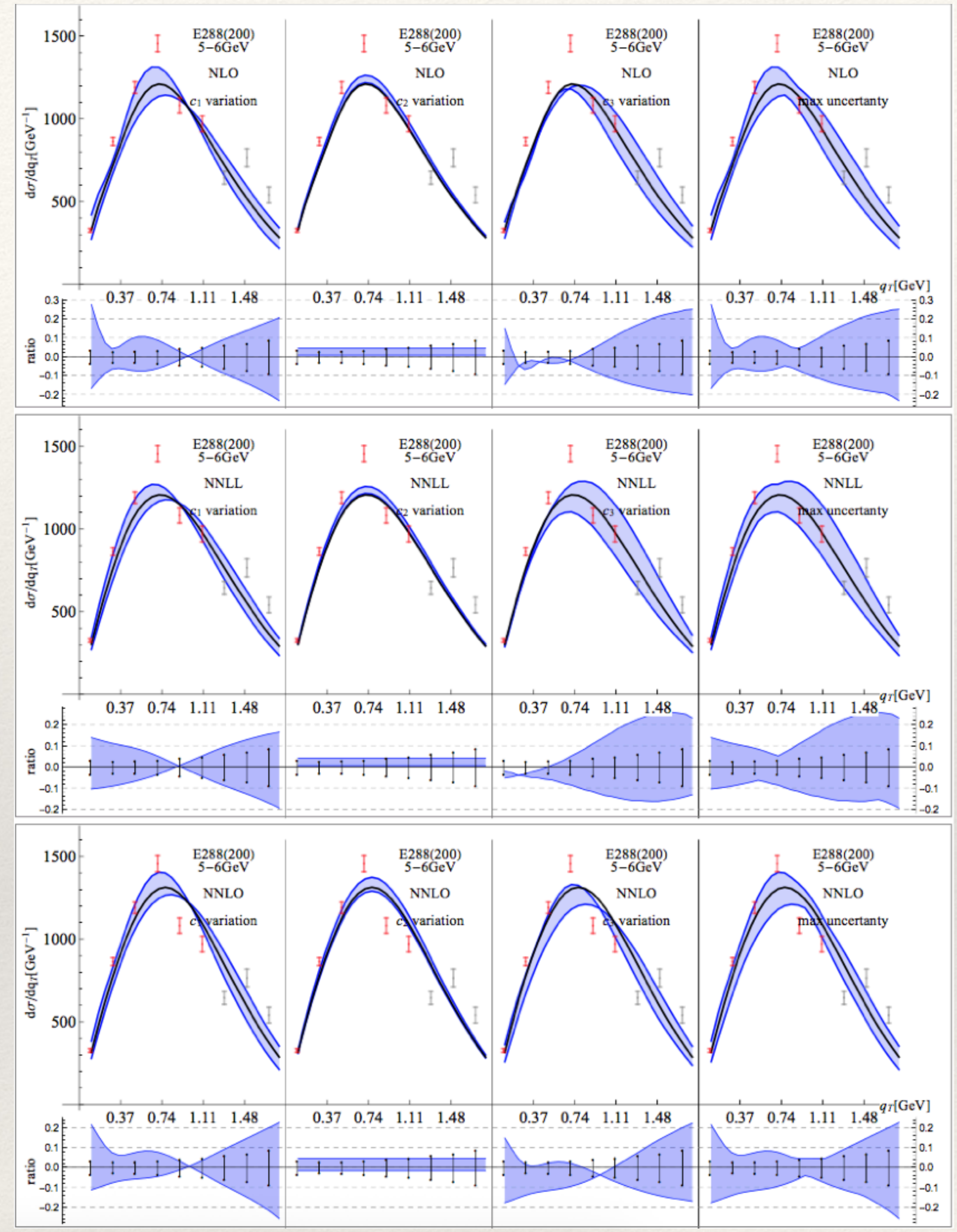
arTeMiDe : theoretical errors NLL



NLL cannot be trusted for this kind of fits.

arTeMiDe: theoretical errors NLO-NNLL-NNLO

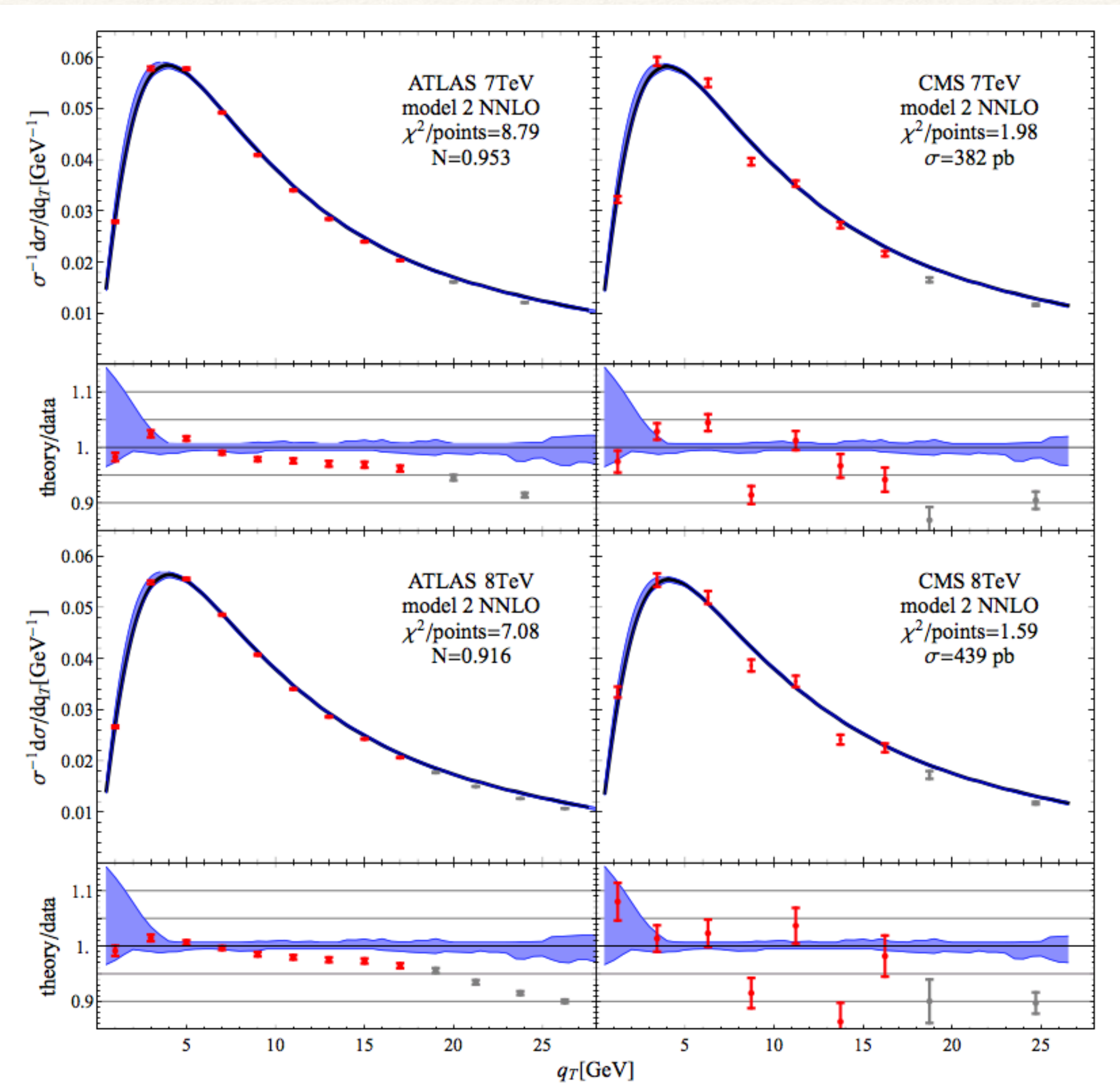


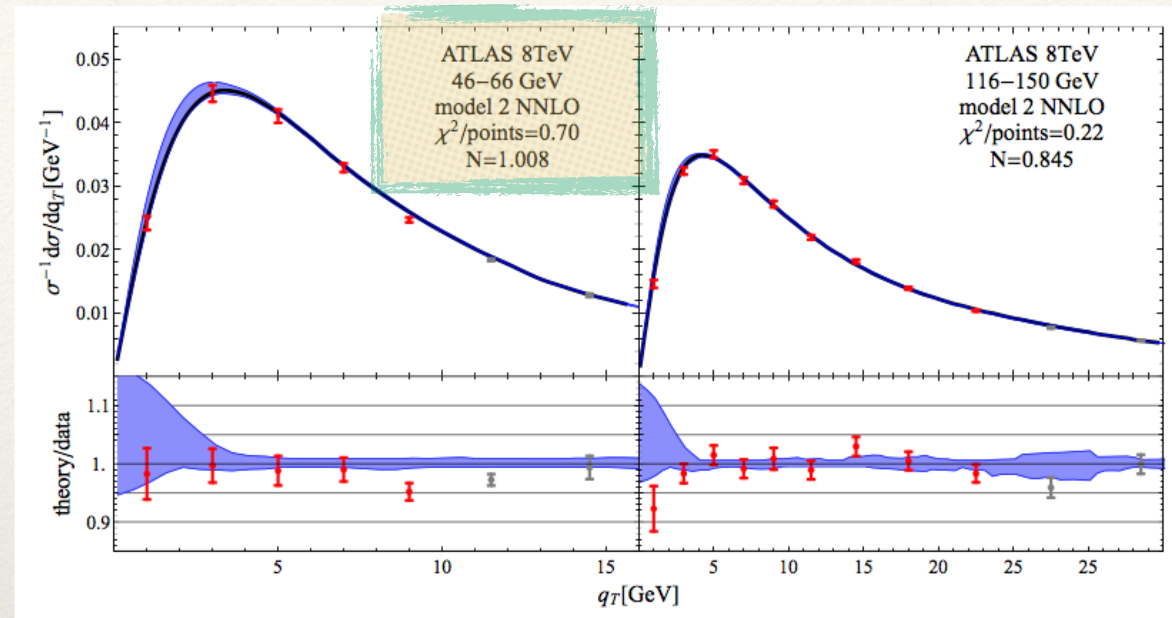


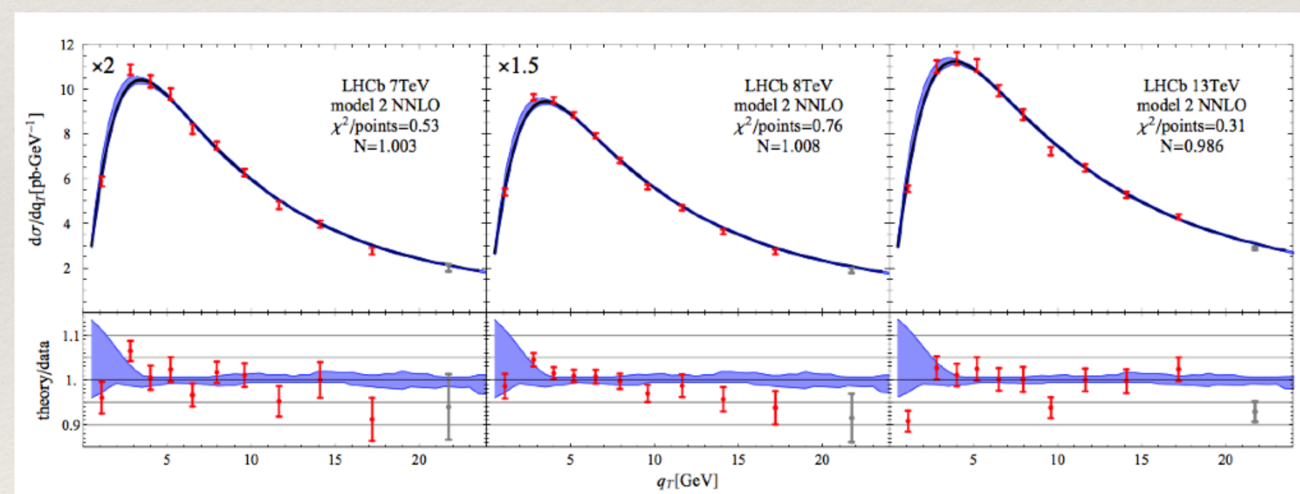
- The origin of error is a bit different in high energy and low energy data
- A NNLO analysis is always necessary
- In E288 the lepton cuts are unknown…

arTeMiDe :

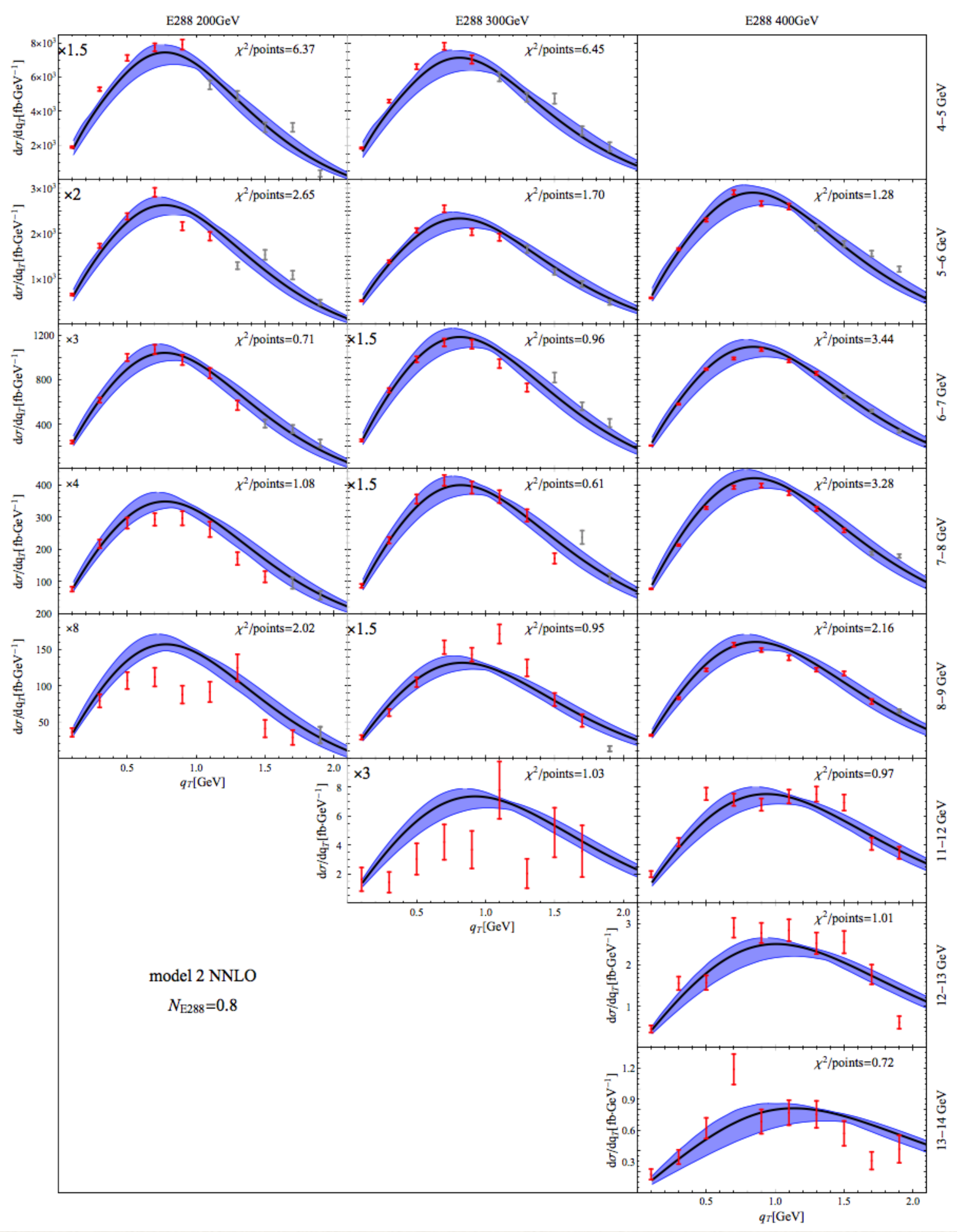
results for LHC in Drell-Yan and Z-production at NNLO







E288 at NNLO



E288 200GeV
E288 300GeV
E288 400GeV
4–5 GeV
5–6 GeV
6–7 GeV
7–8 GeV
8–9 GeV
11–12 GeV
12–13 GeV
13–14 GeV
model 2 NNLO
N_{E288}=0.8
q_T[GeV]

Fit results: high energy data

This fit includes Z-boson production (Tevatron, LHC) and the rest of LHC data

Order	$f_{NP} = 1$	$f_{NP} = e^{-\lambda_1 b^2}$	$f_{NP} = e^{-\lambda_1 b}$	$f_{NP} = 1,\ g_K \neq 0$
NLL	3.04	1.18 $\lambda_1 = 0.22(1)$	2.16 $\lambda_1 = 0.076(7)$	0.68 $g_K = 0.030(2)$
NLO	7.92	2.38 $\lambda_1 = 0.34(2)$	2.64 $\lambda_1 = 0.174(7)$	2.70 $g_K = 0.058(3)$
NNLL	9.16	2.43 $\lambda_1 = 0.42(2)$	0.99 $\lambda_1 = 0.223(7)$	3.49 $g_K = 0.067(3)$
NNLO	3.43	1.66 $\lambda_1 = 0.22(2)$	1.46 $\lambda_1 = 0.113(7)$	1.83 $g_K = 0.034(3)$

Non-perturbative part is needed

The only gK correction is very unstable

Fit results: all data

Order	$\frac{\chi^2}{d.o.f.}$	λ_1	λ_2
$f_{NP} = e^{-\lambda_1 b}$			
NLL	9.22	$0.007^{+0.001}_{-0.001}$	-
NLO	4.68	$0.153^{+0.001}_{-0.001}$	-
NNLL	5.07	$0.127^{+0.001}_{-0.001}$	-
NNLO	3.76	$0.142^{+0.002}_{-0.002}$	-
Model 1: $f_{NP} = e^{-\lambda_1 b}(1 + \lambda_2 b^2)$			
NLL	9.21	$0.0^{+0.002}$	$-0.66^{+0.06}_{-0.06} \times 10^{-2}$
NLO	2.62	$0.197^{+0.002}_{-0.002}$	$-3.15^{+0.05}_{-0.05} \times 10^{-2}$
NNLL	1.43	$0.172^{+0.006}_{-0.006}$	$-2.21^{+0.25}_{-0.24} \times 10^{-2}$
NNLO	1.84	$0.156^{+0.006}_{-0.006}$	$-3.79^{+0.27}_{-0.27} \times 10^{-2}$
Model 2: $f_{NP} = \exp\left(\frac{-z\lambda_q b^2}{\sqrt{1+z^2 b^2 \frac{\lambda_q^2}{\lambda_1^2}}}\right)$ + ren.			
NLL	9.07	$0.0^{+0.0002}$	$0.31^{+0.03}_{-0.03} \times 10^{-2}$
NLO	2.64	$0.206^{+0.001}_{-0.001}$	$0.92^{+0.01}_{-0.01} \times 10^{-2}$
NNLL	1.46	$0.178^{+0.005}_{-0.005}$	$0.61^{+0.09}_{-0.09} \times 10^{-2}$
NNLO	1.79	$0.162^{+0.005}_{-0.005}$	$1.26^{+0.84}_{-0.84} \times 10^{-2}$

One more parameter is sufficient to have a reasonable fit

Renormalon effects

The value of this agrees with the fit of only high energy data (stability of fitted parameters with respect to data sets)

Impact of the non-perturbative part of evolution kernel

Order	$\frac{\chi^2}{d.o.f.}$	λ_1	λ_2	g_K
$f_{NP} = e^{-\lambda_1 b}$				
NLL	8.90	$0.0^{+0.0001}$	-	$0.25^{+0.03}_{-0.02} \times 10^{-2}$
NLO	1.90	$0.171^{+0.006}_{-0.006}$	-	$2.25^{+0.17}_{-0.14} \times 10^{-2}$
NNLL	1.16	$0.171^{+0.005}_{-0.005}$	-	$1.17^{+0.14}_{-0.12} \times 10^{-2}$
NNLO	1.94	$0.174^{+0.006}_{-0.006}$	-	$1.50^{+0.15}_{-0.13} \times 10^{-2}$
Model 1: $f_{NP} = e^{-\lambda_1 b}(1 + \lambda_2 b^2)$				
NLL	2.44	$0.036^{+0.002}_{-0.002}$	$32.13^{+3.30}_{-3.28} \times 10^{-2}$	$4.71^{+0.24}_{-0.24} \times 10^{-2}$
NLO	1.89	$0.164^{+0.009}_{-0.009}$	$-1.06^{+0.83}_{-0.79} \times 10^{-2}$	$2.12^{+0.35}_{-0.36} \times 10^{-2}$
NNLL	1.08	$0.195^{+0.013}_{-0.014}$	$3.27^{+1.39}_{-1.30} \times 10^{-2}$	$1.98^{+0.35}_{-0.35} \times 10^{-2}$
NNLO	1.83	$0.158^{+0.009}_{-0.009}$	$-2.69^{+0.79}_{-0.79} \times 10^{-2}$	$0.61^{+0.58}_{-0.58} \times 10^{-2}$
Model 2: $f_{NP} = \exp\left(\frac{-z\lambda_q b^2}{\sqrt{1+z^2 b^2 \frac{\lambda_q^2}{\lambda_1^2}}}\right)$ + ren.				
NLL	8.90	$0.00^{+0.0002}$	$-2.48^{+0.70}_{-0.70} \times 10^{-2}$	$0.95^{+0.16}_{-0.16} \times 10^{-2}$
NLO	1.91	$0.165^{+0.008}_{-0.007}$	$0.37^{+0.23}_{-0.22} \times 10^{-2}$	$2.07^{+0.35}_{-0.35} \times 10^{-2}$
NNLL	1.06	$0.185^{+0.009}_{-0.009}$	$-0.93^{+0.30}_{-0.31} \times 10^{-2}$	$2.02^{+0.28}_{-0.33} \times 10^{-2}$
NNLO	1.80	$0.178^{+0.70}_{-0.69}$	$0.55^{+0.25}_{-0.27} \times 10^{-2}$	$0.70^{+0.33}_{-0.33} \times 10^{-2}$

Non-perturbative corrections to the evolution kernel can be confused with quadratic corrections of different origin (check on lattice??)

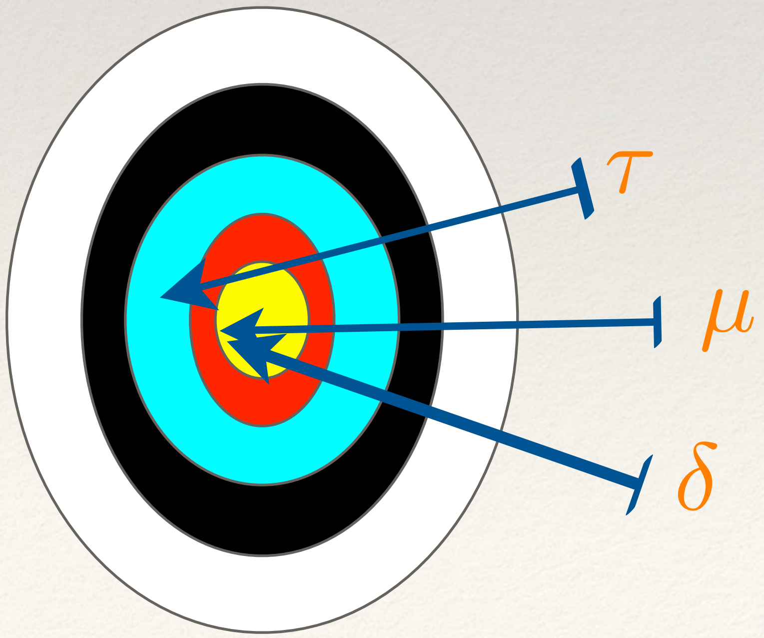
$$\frac{\chi^2}{309 \text{ points}} = 1.86$$
$$g_K = 0.0015 \pm 0.002 \text{ GeV}^2$$
$$\lambda_2 = 0$$

$$\frac{\chi^2}{309 \text{ points}} = 1.77$$
$$g_K = 0$$
$$\lambda_2 = -0.038 \pm 0.003 \text{ GeV}^2$$

$$\frac{\chi^2}{309\text{points}} = 1.80$$
$$g_K = 0.006 \pm 0.0005 \text{ GeV}^2$$
$$\lambda_2 = -0.0269 \pm 0.008 \text{ GeV}^2$$

Conclusions

- A NNLO analysis is necessary for fitting data and extracting TMD (many issues solved just increasing the perturbative order).
- LHC provides very precise data that should be included in fits (especially data off the Z-boson peak). ATLAS and CMS could do better at 13 TeV!!
- We have discussed a number of issues which are relevant in TMD analysis (data choice, normalizations, prescriptions, scale choices, stability, theoretical errors,..etc.)
- All this is included in arTeMiDe (to be released soon)



Back up

Stability

- Different models show different stability of chi^2: *Gaussian disfavored/ Exponential favored*
- Stability increases with perturbative order: *NLL very unstable/NNLO very stable*
- We obtain a plateau only for $\delta_T = q_T/Q \lesssim 0.2$