Threshold resummation at highest energies

PDFs with Threshold Resummation, NNLO jet predictions.

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Why threshold resummation?

Resummed calculation provide the **state of the art** accuracy for many processes at LHC, e.g. ggh, large mass top quark production, etc.

Logarithmic contributions in fixed order perturbative calculations **become large in some kinematic regions**, thus spoiling the perturbative expansions.

Logarithmic enhancement appears **close to threshold** $x \to 1$.

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Issues discussed here:

- Inconsistent use of fixed order PDFs with resummed partonic cross sections may lead to inaccurate predictions:
  $\Rightarrow$ **Resummed PDFs** are required to provide a consistent calculation.
- Threshold resummation techniques allows to construct approximate jet NNLO predictions
  $\Rightarrow$ **Threshold approx. validity range** for LHC & Tevatron experiments.

Threshold resummation overview

We take a factorised cross-section

$$\sigma(x, Q^2) = x \int_x^1 \frac{dz}{z} \mathcal{L}\left(\frac{x}{z}, Q^2\right) \frac{\hat{\sigma}(z, Q^2, \alpha_S)}{z}$$

we transform it to **Mellin space**

$$\sigma(N, Q^2) = \mathcal{L}(N, Q^2)\hat{\sigma}(N, Q^2, \alpha_S) = \mathcal{L}(N, Q^2)\sigma_0(N, Q^2)C(N)$$

Using different techniques we compute a resummed coefficient function that includes terms of the type $\alpha_S^k \ln^p N$ to all orders in perturbation theory.

$$\begin{aligned} C(N) &= 1 + \sum_{n=1}^{\infty} \alpha_s^n \sum_{k=0}^{2n} c_{nk} \ln^k N + \mathcal{O}(1/N) \\ &= g_0(\alpha_S) \exp\left[\frac{1}{\alpha_S} g_1(\alpha_S \ln N) + g_2(\alpha_S \ln N) + \alpha_S g_3(\alpha_S \ln N) + \ldots\right] \end{aligned}$$

The functions g_i resum $\alpha_S^n \ln^n N$ to all orders. These terms are numerically large near the partonic threshold $x, N \to 1, \infty$:

- their resummation **improves** the perturbative expansion, reduces scale uncertainties and allows to construct approximate higher-order results.

Outline

1. PDFs with threshold resummation
   (Bonvini, Marzani, Rojo, Rottoli, NNPDF, arXiv:1507.01006)

2. Jet threshold resummation approximation benchmark at NNLO
   (S.C., Pires, arXiv:1407.7031)

PDFs with threshold resummation

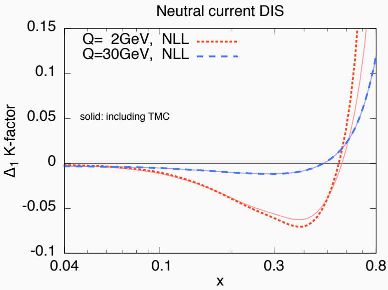
(Bonvini, Marzani, Rojo, Rottoli, NNPDF, arXiv:1507.01006)

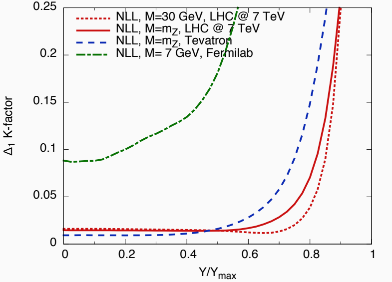
We have produced for the first time threshold-improved PDFs at NLO+NLL and NNLO+NNLL using a variant of the NNPDF3.0 fit.

TROLL computes threshold-enhanced terms of Higgs, Drell-Yan and DIS up to N^{3}LL accuracy (https://www.ge.infn.it/∼bonvini/troll/).

$$\sigma_{\mathrm{N}^j\mathrm{LO+N}^k\mathrm{LL}} = \sigma_{\mathrm{N}^j\mathrm{LO}} + \sigma_{\mathrm{LO}} \times \Delta_j K_{\mathrm{N}^k\mathrm{LL}}$$

TROLL delivers $\Delta_j K_{\mathrm{N}^k\mathrm{LL}}$.





NNPDF3.0res Dataset

~3000 data points, accuracy competitive with global fit, except for large-x gluon.

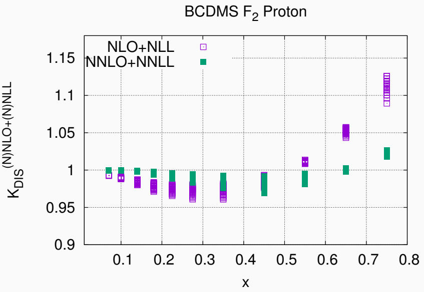
Experiment	Observable	Ref.	NNPDF3.0 global (N)NLO	NNPDF3.0 DIS+DY+top (N)NLO [+(N)NLL]
NMC	σ^{NC}_{dis}, F_2^d/F_2^p	[124, 125]	Yes	Yes
BCDMS	F_2^d, F_2^p	[126, 127]	Yes	Yes
SLAC	F_2^d, F_2^p	[128]	Yes	Yes
CHORUS	$\sigma^{CC}_{\nu N}$	[129]	Yes	Yes
NuTeV	$\sigma^{CC,charm}_{\nu N}$	[130]	Yes	Yes
HERA-I	σ^{NC}_{dis}, σ^{CC}_{dis}	[131]	Yes	Yes
ZEUS HERA-II	σ^{NC}_{dis}, σ^{CC}_{dis}	[132–135]	Yes	Yes
H1 HERA-II	σ^{NC}_{dis}, σ^{CC}_{dis}	[136, 137]	Yes	Yes
HERA charm	$\sigma^{NC,charm}_{dis}$	[138]	Yes	Yes
DY E866	$\sigma^{NC}_{DY,p}$, $\sigma^{NC}_{DY,d}/\sigma^{NC}_{DY,p}$	[139–141]	Yes	Yes
DY E605	$\sigma^{NC}_{DY,p}$	[142]	Yes	Yes
CDF Z rap	$\sigma^{NC}_{DY,p}$	[143]	Yes	Yes
CDF Run-II k_t jets	σ_{jet}	[144]	Yes	No
D0 Z rap	$\sigma^{NC}_{DY,p}$	[145]	Yes	Yes
ATLAS Z 2010	$\sigma^{NC}_{DY,p}$	[146]	Yes	Yes
ATLAS W 2010	$\sigma^{CC}_{DY,p}$	[146]	Yes	No
ATLAS 7 TeV jets 2010	σ_{jet}	[147]	Yes	No
ATLAS 2.76 TeV jets	σ_{jet}	[148]	Yes	No
ATLAS high-mass DY	$\sigma^{NC}_{DY,p}$	[149]	Yes	Yes
ATLAS W p_T	$\sigma^{CC}_{DY,p}$	[150]	Yes	No
CMS W electron asy	$\sigma^{CC}_{DY,p}$	[151]	Yes	No
CMS W muon asy	$\sigma^{CC}_{DY,p}$	[152]	Yes	No
CMS jets 2011	σ_{jet}	[153]	Yes	No
CMS $W+c$ total	$\sigma^{NC,charm}_{DY,p}$	[154]	Yes	No
CMS 2D DY 2011	$\sigma^{NC}_{DY,p}$	[155]	Yes	Yes
LHCb W rapidity	$\sigma^{CC}_{DY,p}$	[156]	Yes	No
LHCb Z rapidity	$\sigma^{NC}_{DY,p}$	[157]	Yes	Yes
ATLAS CMS top prod	$\sigma(t\bar{t})$	[158–163]	Yes	Yes

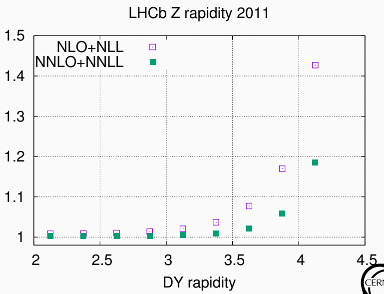
K-factors

Effect of resummation included supplementing fixed order computation with **K-factors**

$$K^{\mathrm{N}^k\mathrm{LO+N}^k\mathrm{LL}} = \frac{\sigma^{\mathrm{N}^k\mathrm{LO+N}^k\mathrm{LL}}}{\sigma^{\mathrm{N}^k\mathrm{LO}}}$$

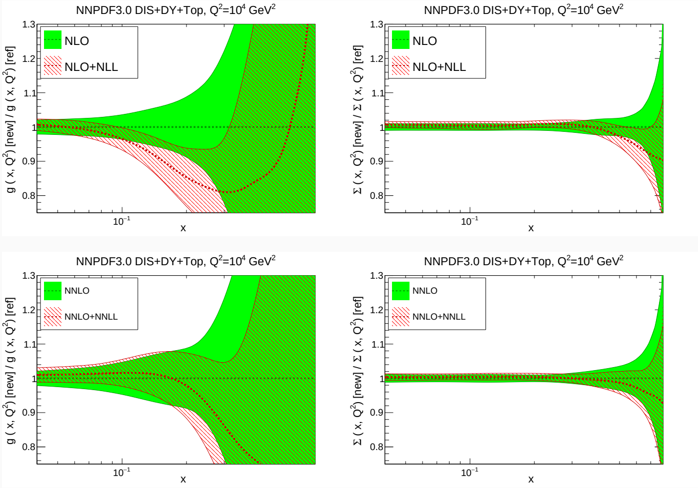
Some examples of **K-factor** values:





DIS+DY+Top comparison

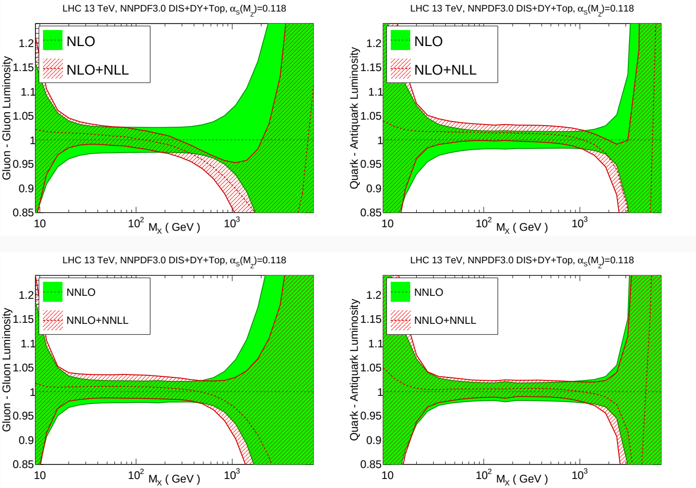
PDFs reduced in the large-x region, at intermediate values of x quark PDFs slightly enhanced (sum rule), negligible effects at $x < 0.01$.



Limitations: larger uncertainties due to reduced dataset.

DIS+DY+Top comparison

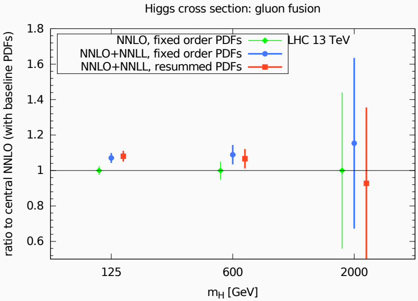
Similar results at the level of partonic luminosities.



The impact on the PDFs is more important at NLL than NNLL, as expected since NLL captures part of the NNLO corrections to the DIS str. functions.

Phenomenology

Inclusion of resummation in PDFs compensates the enhancement from resummation in partonic cross section for when M_X is large.



- SM Higgs not affected by resummation of PDFs
- $m_H \sim 600$ GeV cancellations of 1/2 of the enhancement
- $m_H \sim 2$ TeV NNLO+NNLL with resummed PDFs similar to FO PDFs (larger uncertainty)

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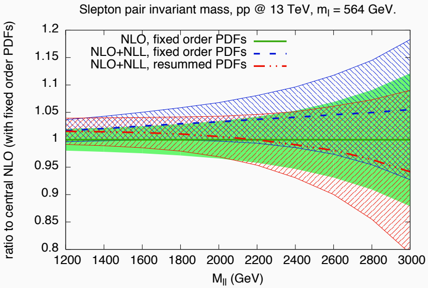


- 2-5% enhancement NLO+NLL calculation with FO PDFs
- 1-2% enhancement NLO+NLL calculation with resummed PDFs only of $M_{ll} < 2$ TeV
- At higher masses suppression of NLO+NLL calculation with resummed PDFs

Jet threshold resummation approximation benchmark at NNLO

(S.C., Pires, arXiv:1407.7031)

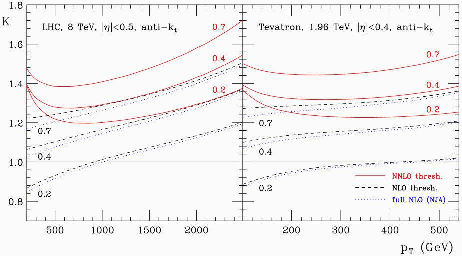
Threshold approximate NNLO predictions

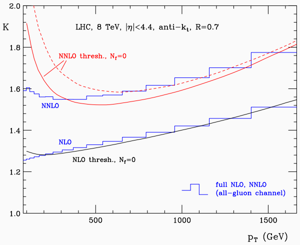
Approximate NNLO results from an improved threshold calculation for the single jet inclusive production (de Florian, Hinderer, Mukherjee, Ringer, Volgesang '13)

- $pp \to j + X$ with the **threshold limit** given by the vanishing of the invariant mass of the system that recoils against the observed jet $s_4 = P_X^2 \to 0$
- near **threshold**, **phase space** available for **real-gluon** emission is **limited**
- higher kth order **coefficient functions** dominated by **large logarithmic corrections**

$$\alpha_S^k w_{ab}^{(k)} \to \alpha_S^k \left(\frac{\log^m(z)}{z} \right)_+ , \quad m \leq 2k-1, \quad z = \frac{s_4}{s}$$

Examples for all-channels and gluons only channel (rapidity integrated):





NNLO benchmark predictions for jet production

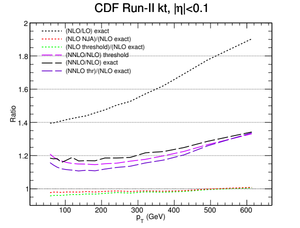
We try to understand and characterise the validity of the NNLO threshold approximation by comparing it with the exact computation using the gg-channel.

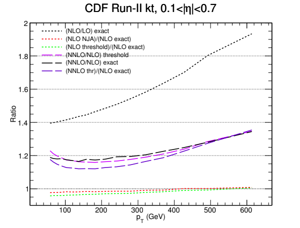
- $\mu_R = \mu_F = p_T$ for both predictions
- comparison performed differential in p_T and rapidity following the exact experimental setups.
- NNPDF23_nnlo_as_0118 set for all fixed order predictions

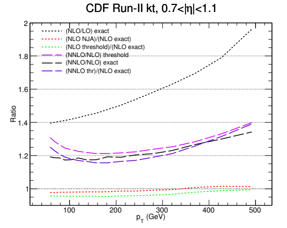
Data Set		Points	$\sqrt{s}$ (TeV)	R	η coverage	p_T coverage
LHC	CMS 2011	133	7	0.7	$\|\eta\| < 2.5$	$[114, 2116]$ GeV
	ATLAS 2010	90	7	0.4	$\|\eta\| < 4.4$	$[20, 1500]$ GeV
	ATLAS 2011	59	2.76	0.4	$\|\eta\| < 4.4$	$[20, 500]$ GeV
Tevatron	CDF k_t	76	1.96	0.7	$\|\eta\| < 2.1$	$[54, 700]$ GeV
	D0 cone	110	1.96	0.7	$\|\eta\| < 2.3$	$[50, 665]$ GeV

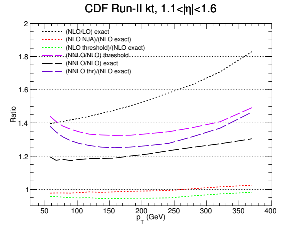
Tevatron CDF Run-II $\sqrt{s} = 1.96$ TeV

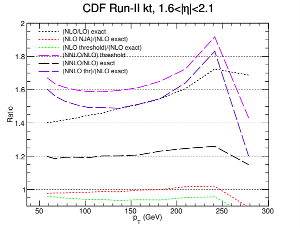
Differences $\leq 15\%$ at low-p_T in the central regions,
in the forward region differences $\geq 40\%$ for all p_T regions.





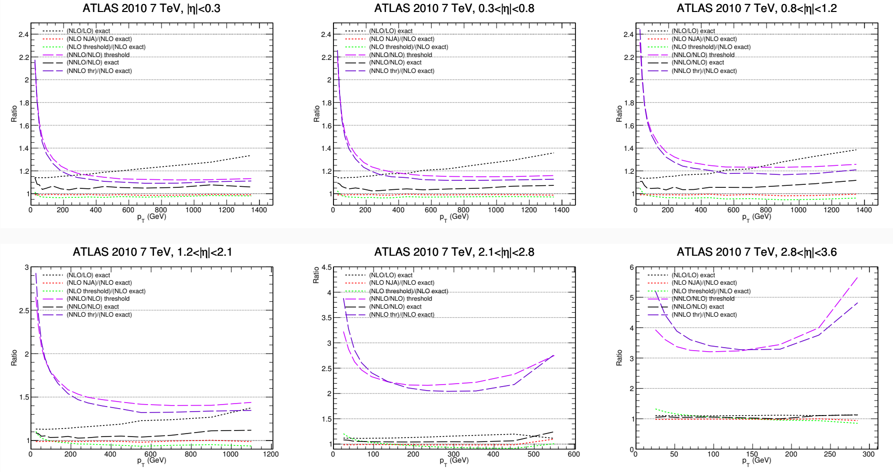






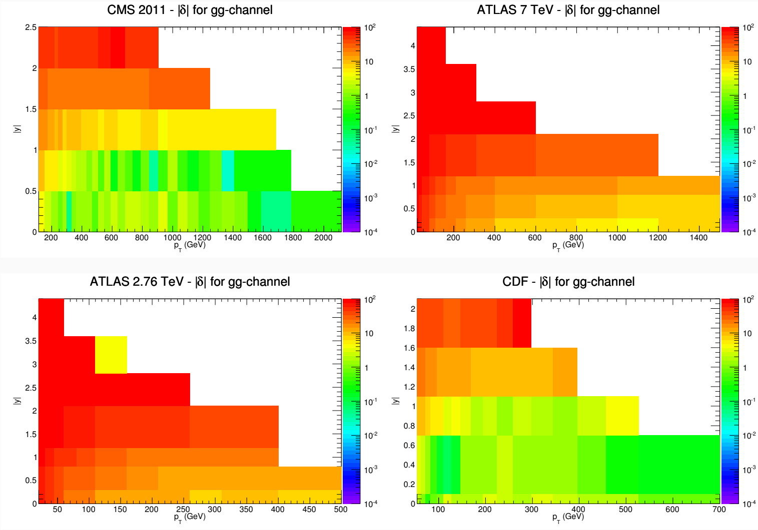
LHC ATLAS 2010 $\sqrt{s} = 7$ TeV

Large differences at small-p_T and increase with rapidity, exact NNLO k-factor decreases with rapidity, NNLO threshold k-factor increases with rapidity.



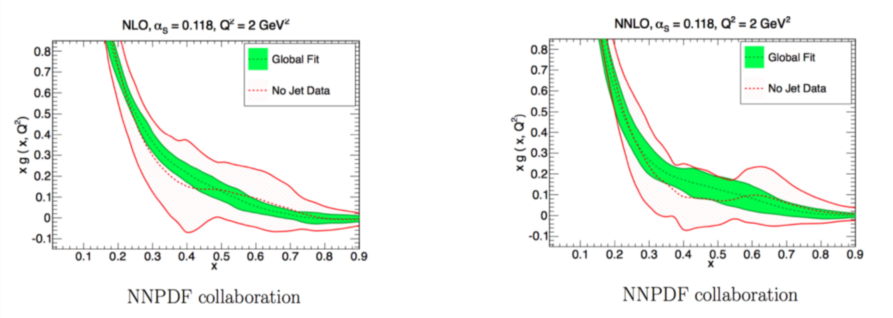
Threshold approximation - gg channel

Relative difference $|\delta|$ between exact and approximate gg-channel K-factors as a function of p_T and $|y|$ for CMS, ATLAS 7 TeV and 2.76 TeV and CDF bins.



Gluon-PDF

- jet data has a big impact on the medium to large-x gluon PDF
- fit at NNLO obtained using a $|\delta| < 10\%$ criteria which excluded many jet data points
- need exact NNLO all-channel prediction to include full jet dataset.



Summary

- First ever (global) fit of PDFs with threshold resummation
  - PDFs reduced in the large-x region
  - Resummation in PDFs compensates the enhancement from resummation in partonic cross section.
  - Improvements required before a global PDF resummed fit.
- Performed comparison between exact NNLO results and approximate NNLO results from threshold resummation in the gg-channel.
  - largest differences arise at low-p_T for central rapidities and all p_T at large rapidities
  - differences are smaller at the Tevatron than at the LHC 7 TeV.

Thanks for your attention!

CMS 2011 $\sqrt{s} = 7$ TeV