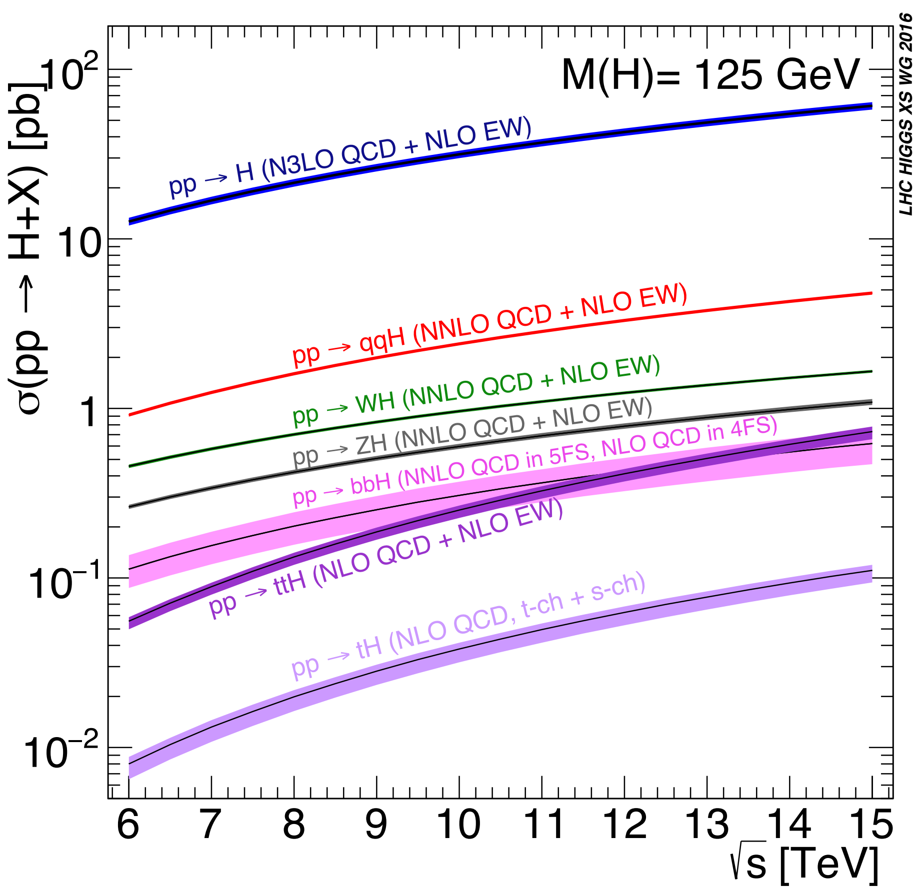
SIMONE MARZANI
UNIVERSITÀ DI GENOVA &
INFN-SEZIONE DI GENOVA

DOUBLE-RESUMMED HIGGS CROSS-SECTION

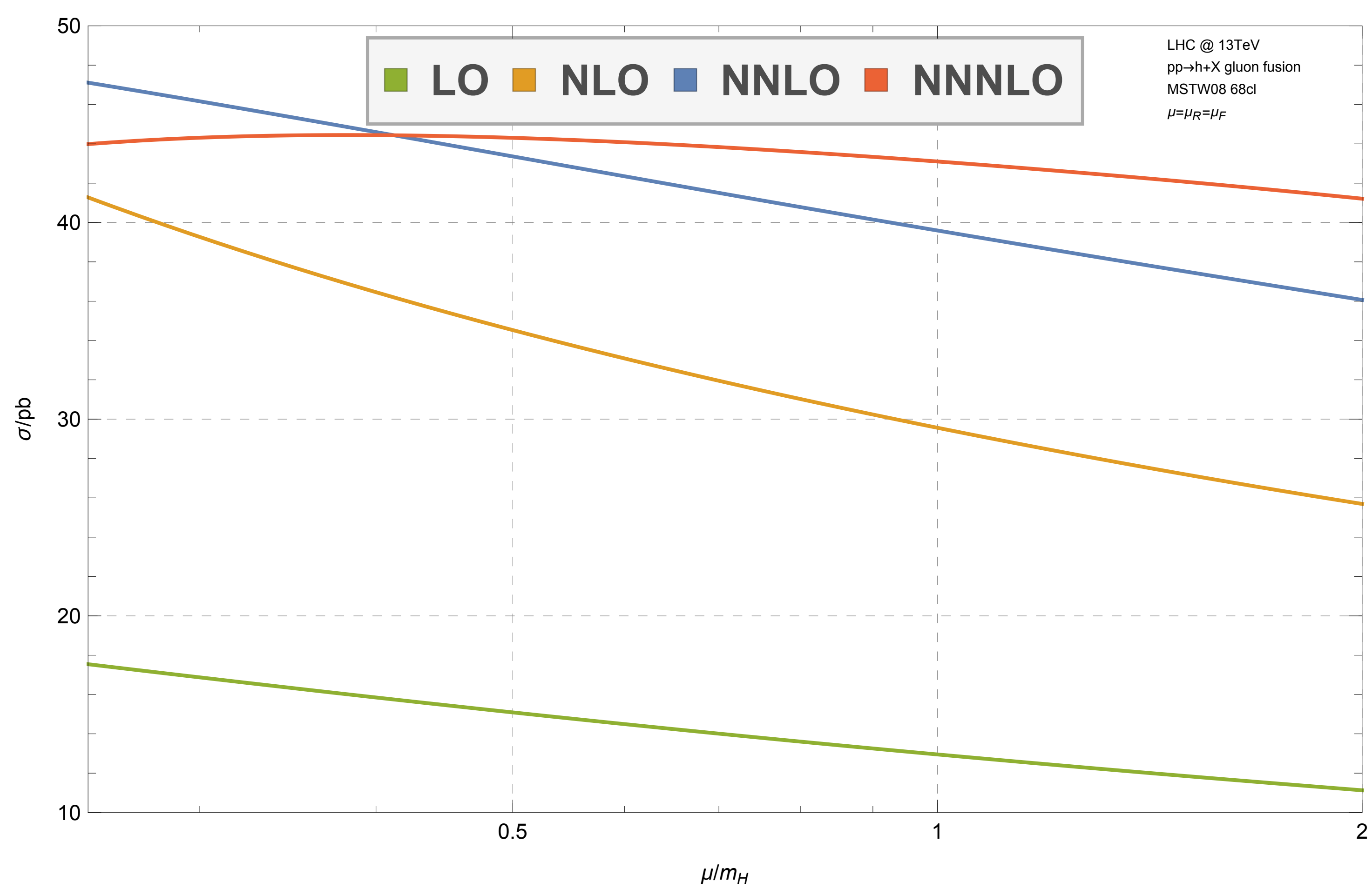
QCD@LHC 2018

Dresden, 27th-31st September 2018

HIGGS PRODUCTION AT THE LHC AND BEYOND



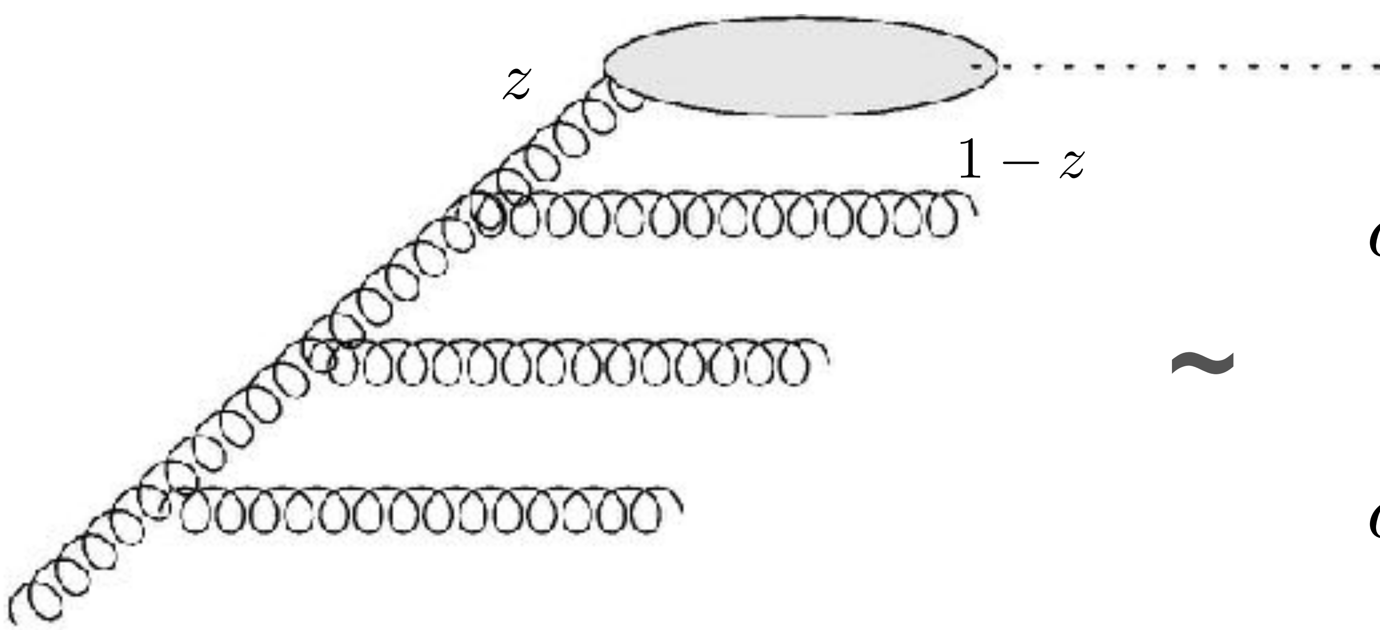
- theoretical calculations have been pushed to a remarkable precision
- one of the few processes for which three-loop corrections are known (in the infinite top mass limit)
- gluon fusion by far the dominant production channel
- it suffers from large QCD corrections



Anastasiou et al. (2015,2016)

HIGHER-ORDER CORRECTIONS

- Higher-order QCD corrections correspond to emission of extra partons or virtual corrections
- these corrections are enhanced in particular regions of phase-space



$$\sim \quad \alpha_s^k \left[\frac{\log^{2k-1}(1-z)}{1-z}\right]_+ , \; z \to 1$$

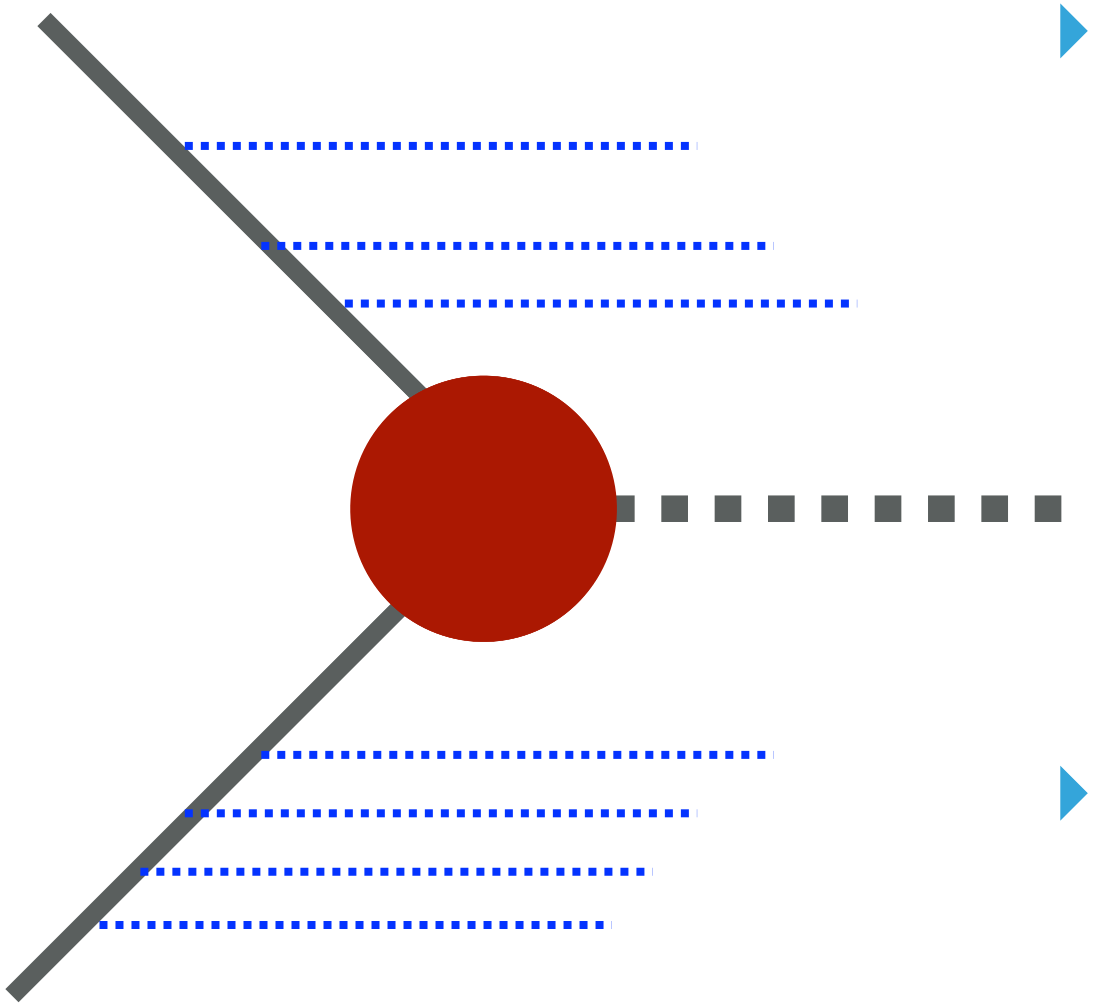
$$\alpha_s^k \frac{\log^{k-1} z}{z} , \; z \to 0$$

WE WILL MOST CONVENIENTLY WORK IN MELLIN SPACE
SOFT-GLUON RESUMMATION: Z→1 ⇨ LOGS OF N
BFKL RESUMMATION: Z→0 ⇨ POLES IN N (SAY N=0)

All-order techniques offer a complementary way to tackle perturbative corrections

LARGE-X RESUMMATION

PRODUCTION AT THRESHOLD



- absolute threshold: the initial-state energy is just enough to produce the final state with invariant mass Q

$$x = \frac{Q^2}{s} \to 1$$

- emissions forced to be soft, leading to log-enhanced contributions order-by-order in perturbation theory

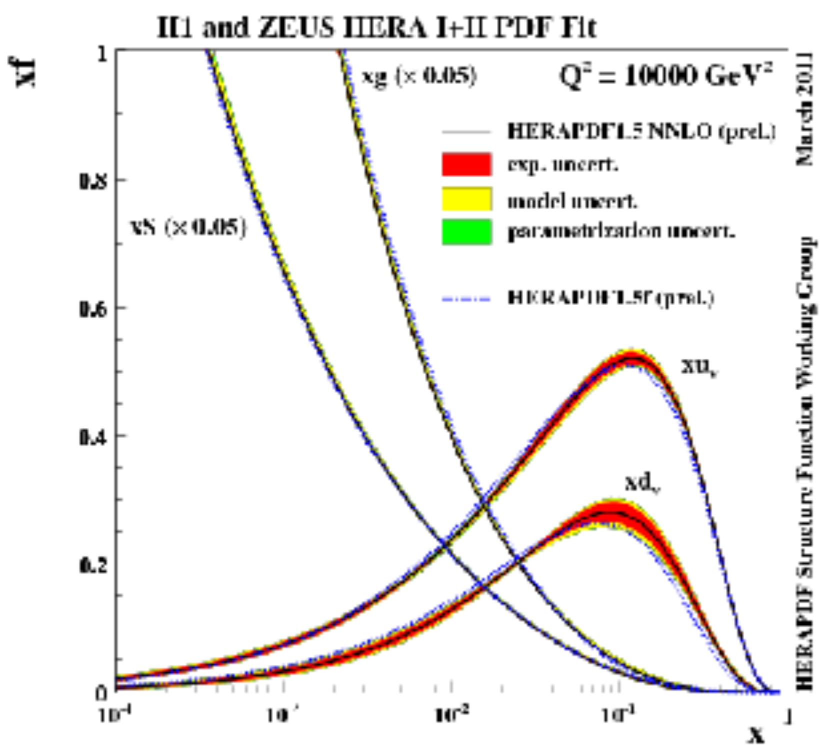
$$\text{LO} : Q^2 = \hat{s}$$

$$\text{beyond LO} : Q^2 = z\hat{s}$$

$$C(z, \alpha_s) \sim \sigma_0 \sum_{n=1} \sum_{k=-1}^{2n-1} \alpha_s^n \left[\frac{\ln^k(1-z)}{1-z} \right]_+$$

$\delta(1-z)$ → ($k=-1$)

WHY BOTHER WITH THRESHOLD AT THE LHC?



- Gluon PDF shows a steep increase at low *x*

$$\hat{s} = x_1 x_2 s$$

- region of partonic threshold is enhanced in the convolution

$$\sigma(x, Q) = \sigma_0 C\left(\frac{x}{x_1 x_2}, \alpha_s(\mu)\right) \otimes f_1(x_1, \mu) \otimes f_2(x_2, \mu)$$

- Mellin-space argument: a saddle-point approximation indicates the region that gives the bulk of the contribution to the inverse Mellin integral

Bonvini, Forte, Ridolfi (2012)

- this region turns out to be fairly narrow around the (real) saddle-point

THRESHOLD RESUMMATION OF COEFFICIENT FUNCTIONS

- momentum space: distributional terms for $z \to 1$
- moment space: terms that do not vanish at large N

$$C_{\rm res}(N,\alpha_s) = \bar{g}_0\left(\alpha_s,\mu_{\rm F}^2\right)\exp\bar{\mathcal{S}}(\alpha_s,N),$$

$$\bar{\mathcal{S}}(\alpha_s,N) = \int_0^1 dz\, \frac{z^{N-1}-1}{1-z}\left(\int_{\mu_{\rm F}^2}^{m_{\rm H}^2\frac{(1-z)^2}{z}} \frac{d\mu^2}{\mu^2} 2A\left(\alpha_s(\mu^2)\right) + D\left(\alpha_s([1-z]^2 m_{\rm H}^2)\right)\right),$$

$$\bar{g}_0(\alpha_s,\mu_{\rm F}^2) = 1 + \sum_{k=1}^{\infty}\bar{g}_{0,k}(\mu_{\rm F}^2)\alpha_s^k,$$

Anastasiou *et al.* (2014)

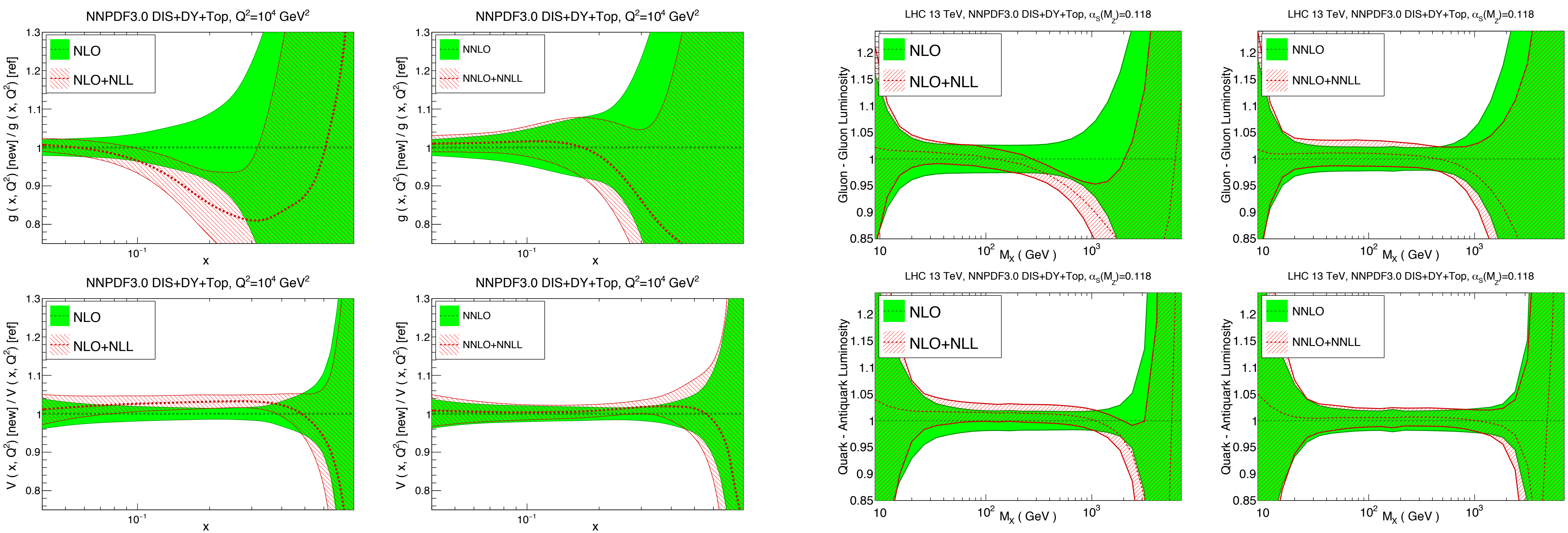
$$A(\alpha_s) = \sum_{k=1}^{\infty} A_k\alpha_s^k, \qquad D(\alpha_s) = \sum_{k=1}^{\infty} D_k\alpha_s^k,$$

Catani *et al.* (2002); Moch, Vogt (2005); Laenen, Magnea (2005) [...]

- state of the art N^{3}LL (4-loop cusp only partially known) Moch et al. (2018)
- constants can go in the exponent of in front of it (good for estimating uncertainties)
- DGLAP evolution free of large logs (in MSbar) Korchemsky (1989); Albino and Ball (2001)

PARTONS WITH THRESHOLD RESUMMATION

- consistency suggests that one should use PDFs determined with resummed coefficient functions



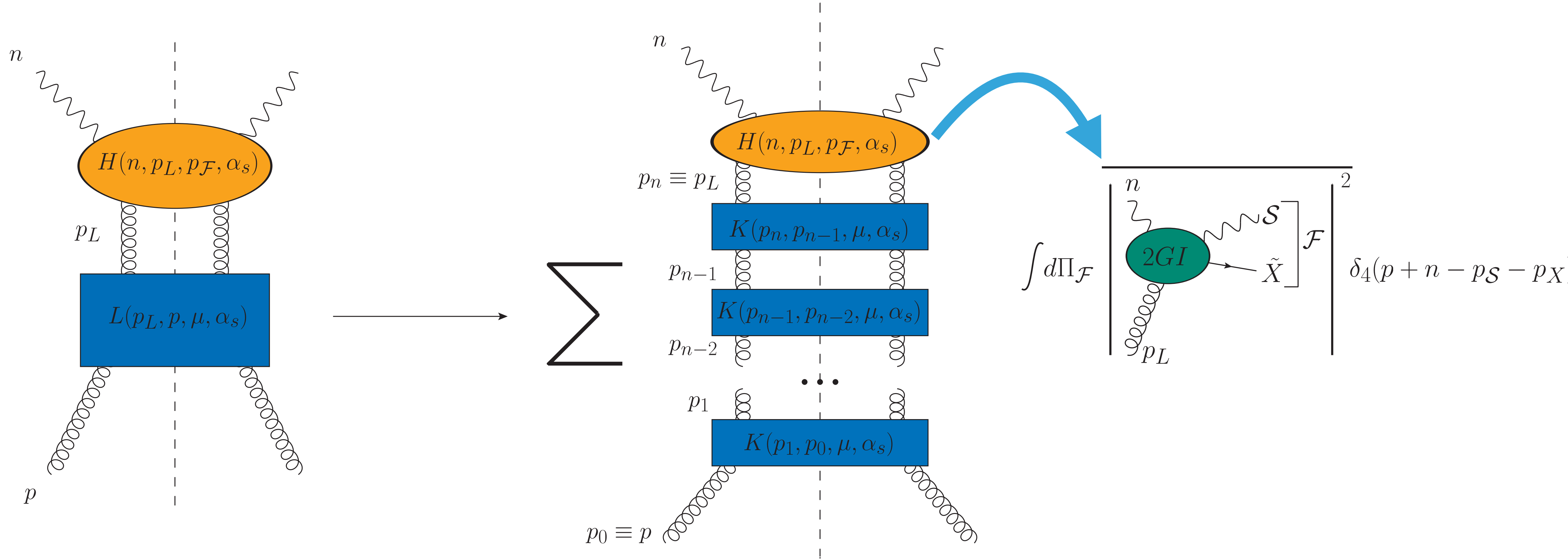
Bonvini *et al.* (2015)

- comparison to global fit: larger uncertainties because of reduced dataset
- only "proof-of-concept" studies because of restricted dataset

SMALL-X RESUMMATION

COEFFICIENT FUNCTIONS AT SMALL X

- the high-energy behaviour of coefficient function is obtained using k_t-factorisation Catani, Ciafaloni, Hautmann (1991); Collins, Ellis (1991)
- derivation in terms of ladder expansion allowed for its generalisation to differential distributions Caola, Forte, SM (2010); Forte, Muselli (2016); Muselli (2017)



- for most processes of interest (DIS, DY) resummation starts at NLLx

DGLAP EVOLUTION AT SMALL-X

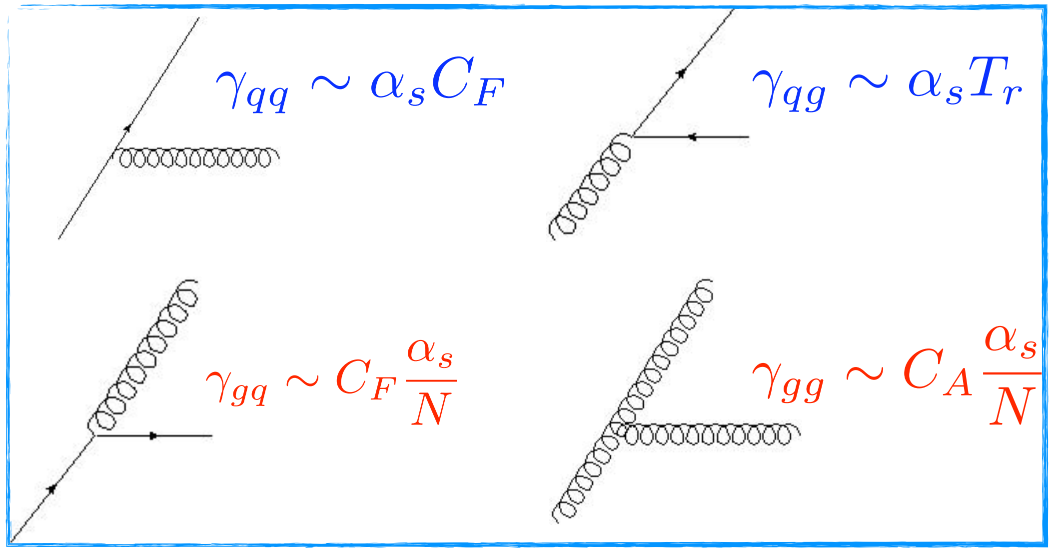
- DGLAP evolution in the singlet sector

$$Q^2 \frac{d}{dQ^2} \begin{pmatrix} f_g \\ f_q \end{pmatrix} = \Gamma(N, \alpha_s(Q^2)) \begin{pmatrix} f_g \\ f_q \end{pmatrix}, \qquad \Gamma(N, \alpha_s) \equiv \begin{pmatrix} \gamma_{gg} & \gamma_{gq} \\ \gamma_{qg} & \gamma_{qq} \end{pmatrix}$$

- the gluon splitting functions start at LL*x*

$$\gamma_{gg} \sim c_1 \frac{\alpha_s}{N} + c_2 \left(\frac{\alpha_s}{N}\right)^2 + \dots$$

$$\gamma_{gq} \sim \frac{C_F}{C_A} \gamma_{gg}$$



- while the quarks are NLL*x*

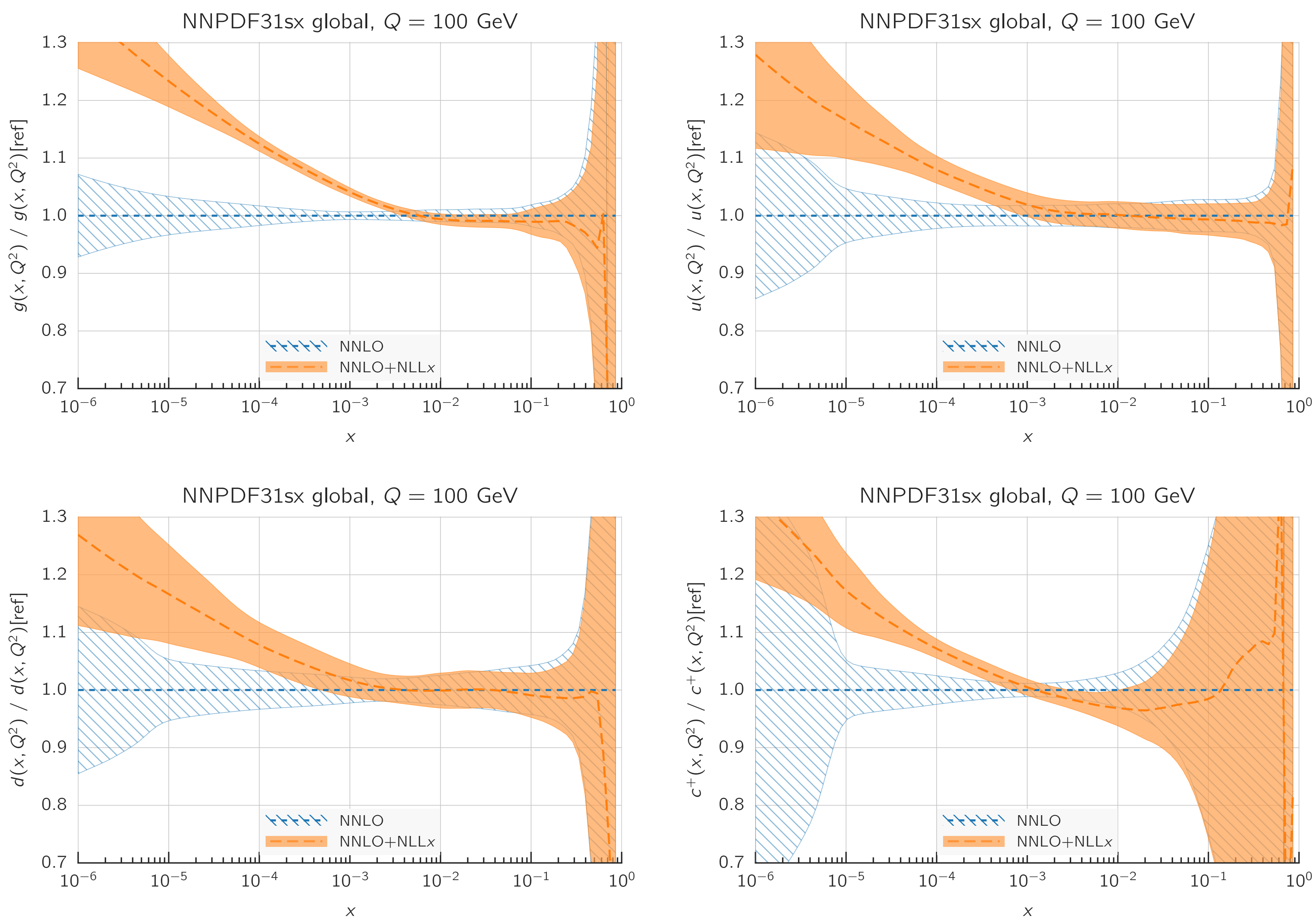
$$\gamma_{qg} \sim \alpha_s d_0 + d_1 \alpha_s \frac{\alpha_s}{N} + c_2 \alpha_s \left(\frac{\alpha_s}{N}\right)^2 + \dots$$

$$\gamma_{qq}^{(\mathrm{PS})} \sim \frac{C_F}{C_A} \left(\gamma_{qg} - \alpha_s d_0\right)$$

PARTON DENSITIES WITH SMALL-X RESUMMATION

- resulting PDFs show interesting features
- agreement at large *x* but they're much steeper at low *x*

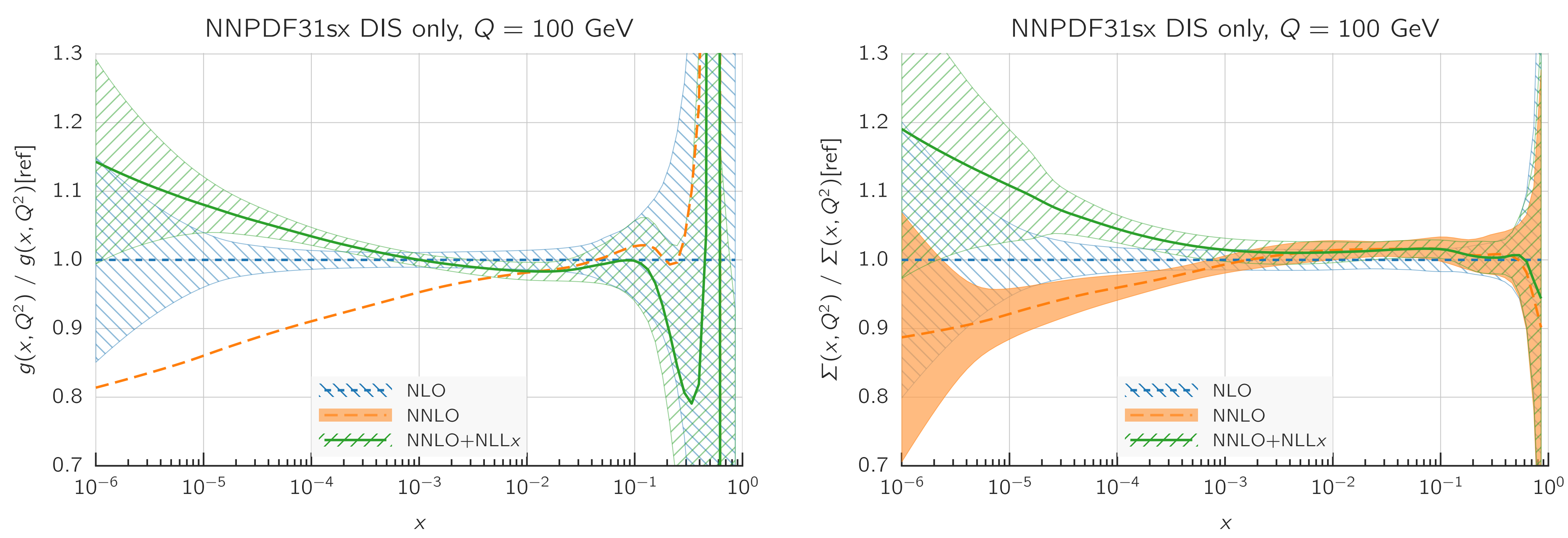
Ball *et al.* (2018); see also xFitter Developers (2018)



PERTURBATIVE STABILITY

- NNLO and NNLO+NLLx differ quite dramatically
- one could question the reliability of the resummed procedure
- what gives us confidence we're not talking rubbish?
- resummation cures perturbative instability of NNLO

Ball *et al.* (2018);

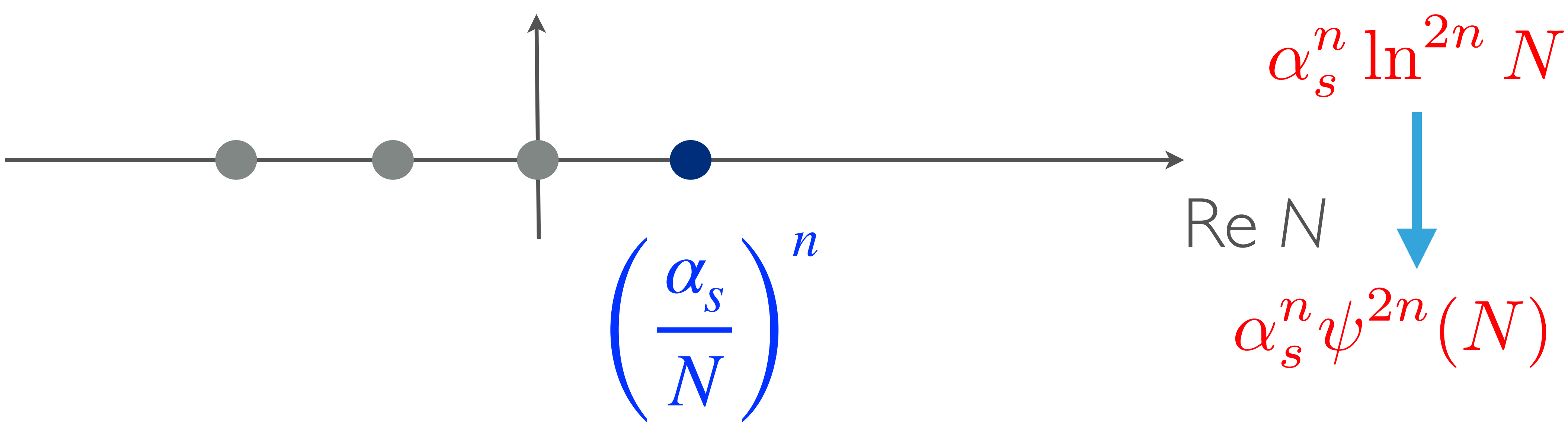


DOUBLE RESUMMATION

DOUBLE RESUMMATION: PARTONIC COEFFICIENT FUNCTIONS

$$C_{ij}(x,\alpha_s) = C_{ij}^{\rm fo}(x,\alpha_s) + \Delta C_{ij}^{\rm lx}(x,\alpha_s) + \Delta C_{ij}^{\rm sx}(x,\alpha_s)$$

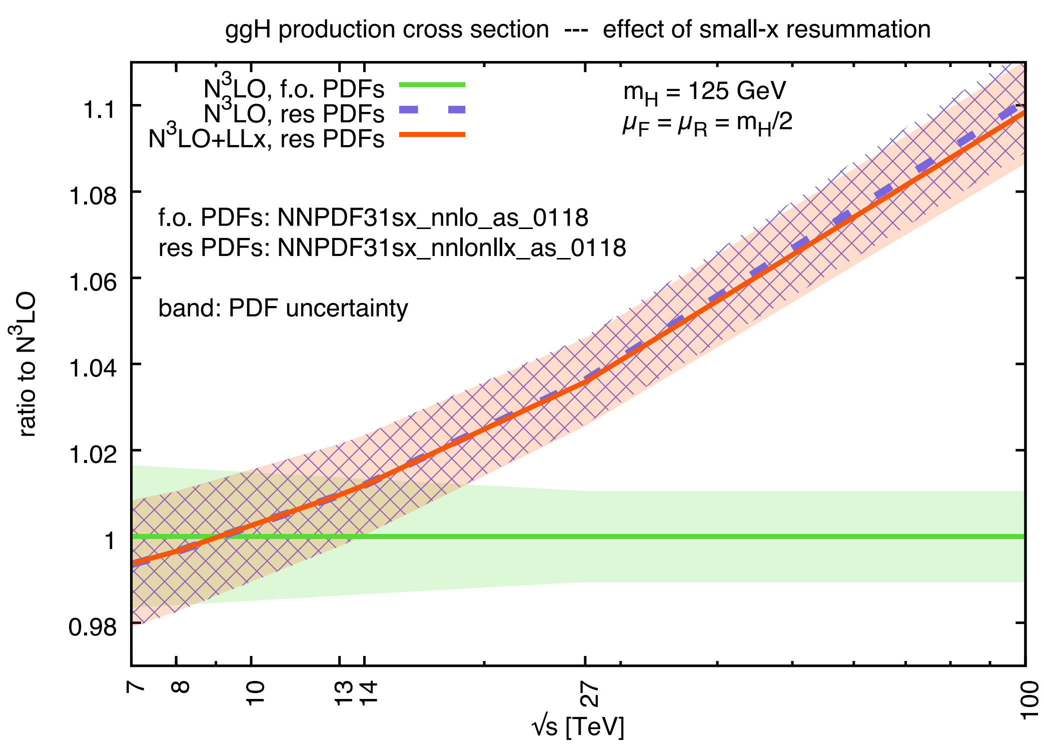
- How to merge together small-*x* and large-x resummations?
- Look at singularity structure in Mellin space!

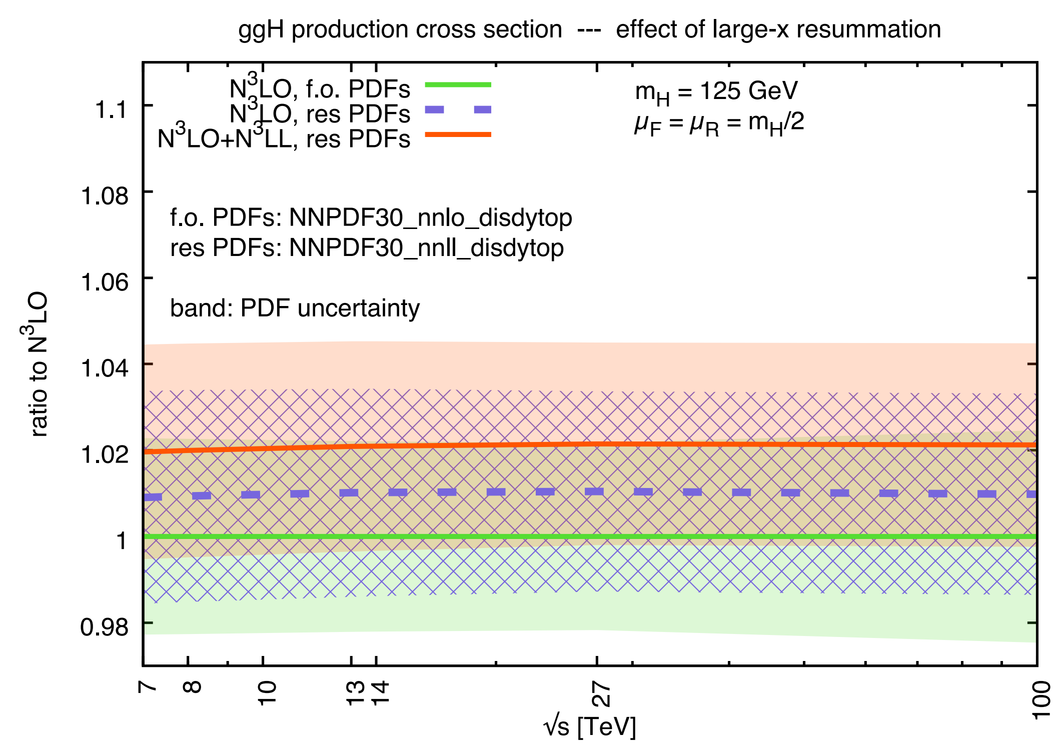


- double-resummed results should respect singularity structure order-by-order

Ball, Bonvini, Forte, SM, Ridolfi (2013)

DOUBLE RESUMMATION: PARTON DENSITIES

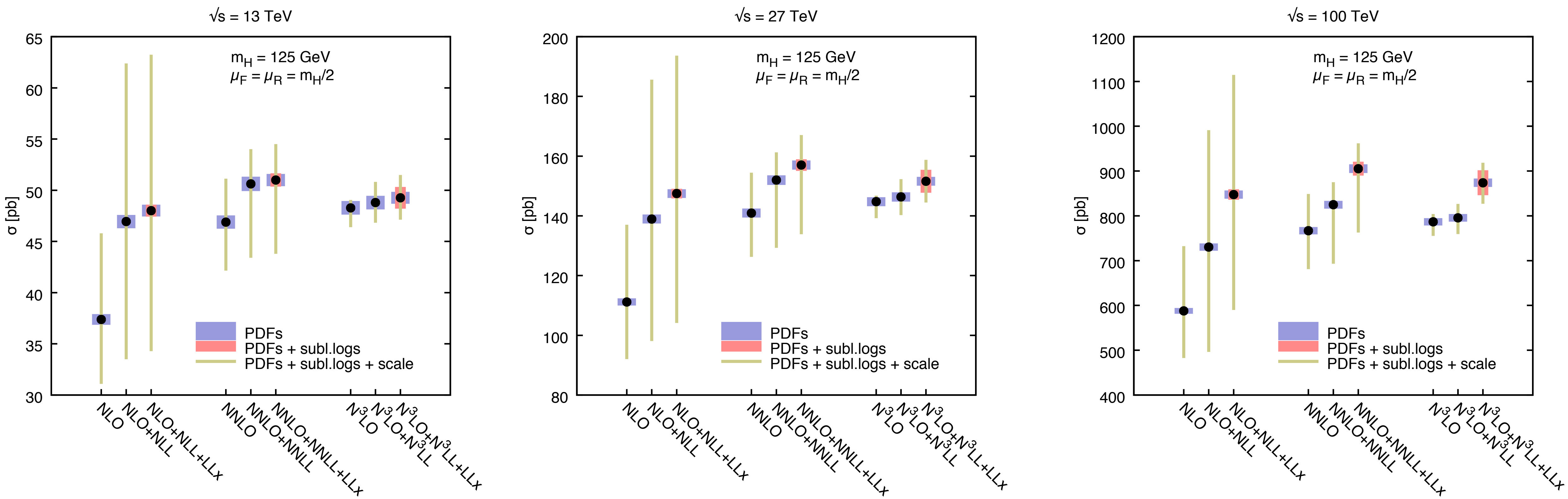




- ideally we would like to use double-resummed PDFs
- we have to make a choice: small-x resummation strongly affects the NNLO gluon PDF, while threshold is a small correction
- use small-x resummed PDFs for double resummation

Bonvini and SM (2018)

DOUBLE RESUMMATION: RESULTS



- faster convergence of perturbative expansion
- reliable theoretical uncertainties using scale variations and subleading logs)
- large effect at 100 TeV driven by small-*x* resummation of the gluon

Bonvini and SM (2018)

CONCLUSIONS & OUTLOOK

- consistent combined implementation of threshold and small-x resummation;
- application to Higgs production: small correction to the N^{3}LO at the LHC, which becomes larger as the c.o.m. energy grows;
- (almost) entirely due to small-*x* resummation in PDFs.

- Differential distributions: Q_T has always played a central role
  - joint Q_T and threshold resummation at NNLL Theeuwes and SM (2017); Forte, Muselli and Ridolfi (2017)
  - double Q_T and small-*x* resummation SM (2016); Zhou *et al.* (2016)
  - triple resummation (?)

THANK YOU!