



Quantum Chromodynamics

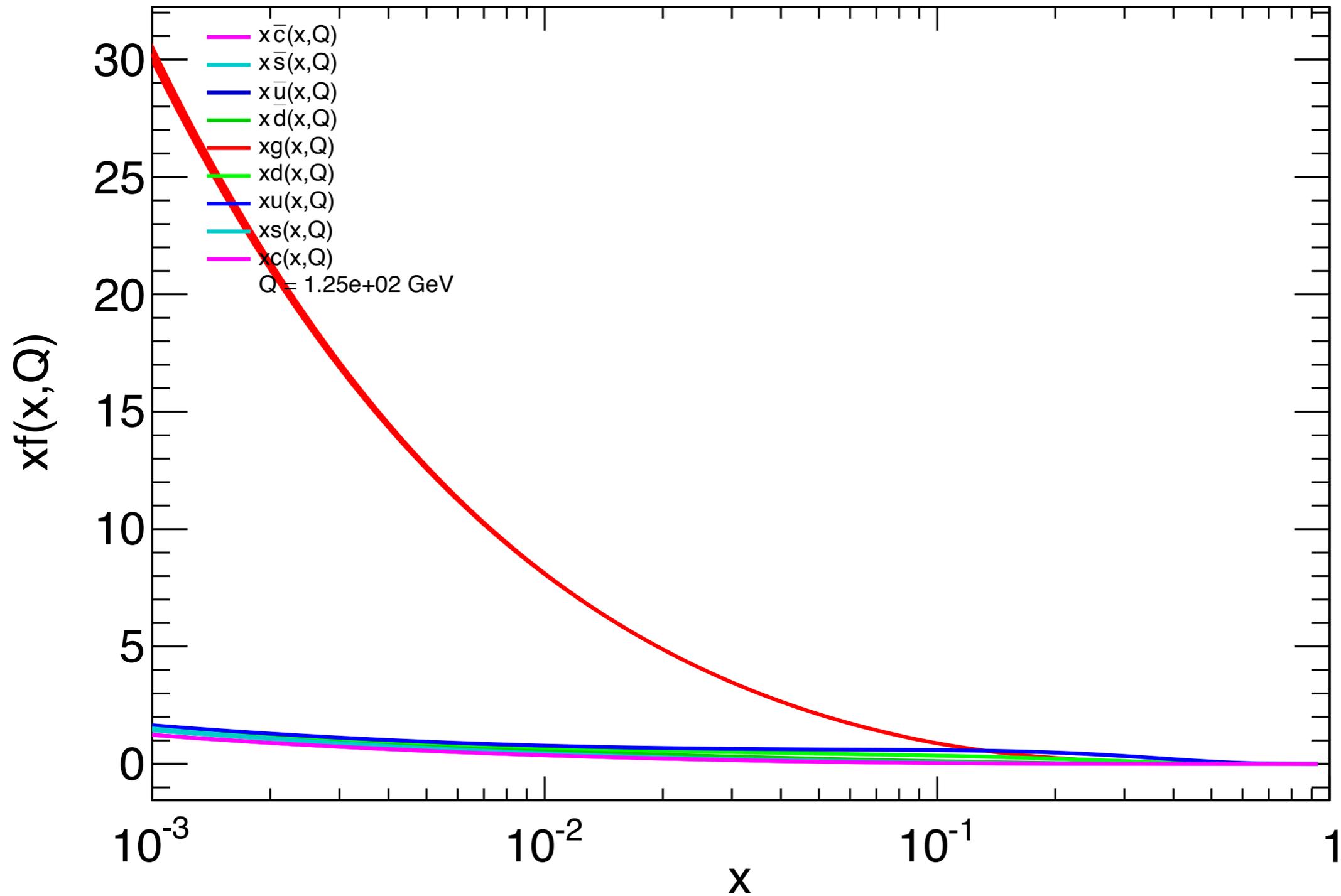
Claude Duhr

BND School 2016
Antwerpen, September 2016

PDFs

PDFs

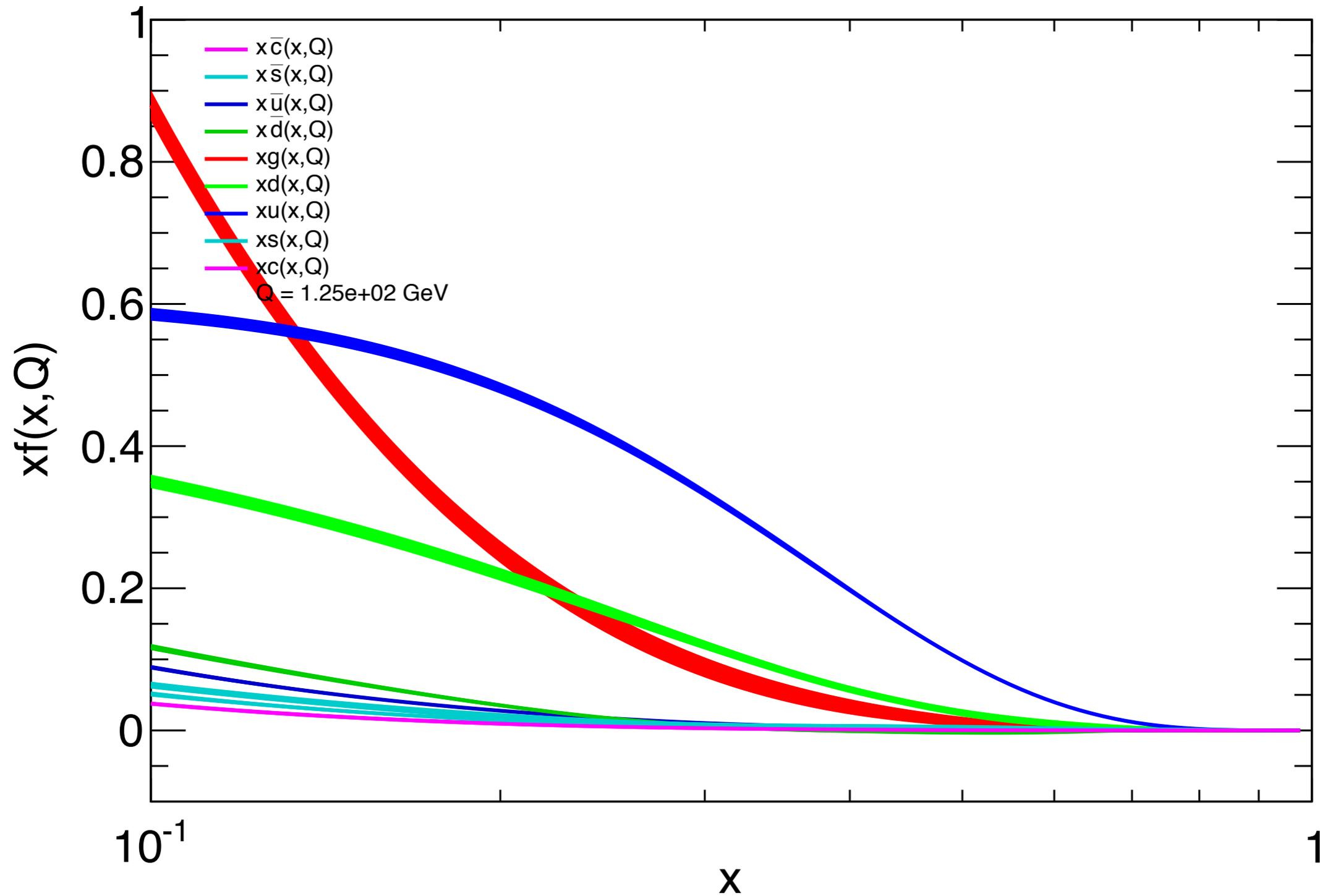
NNPDF3.0 PDFs



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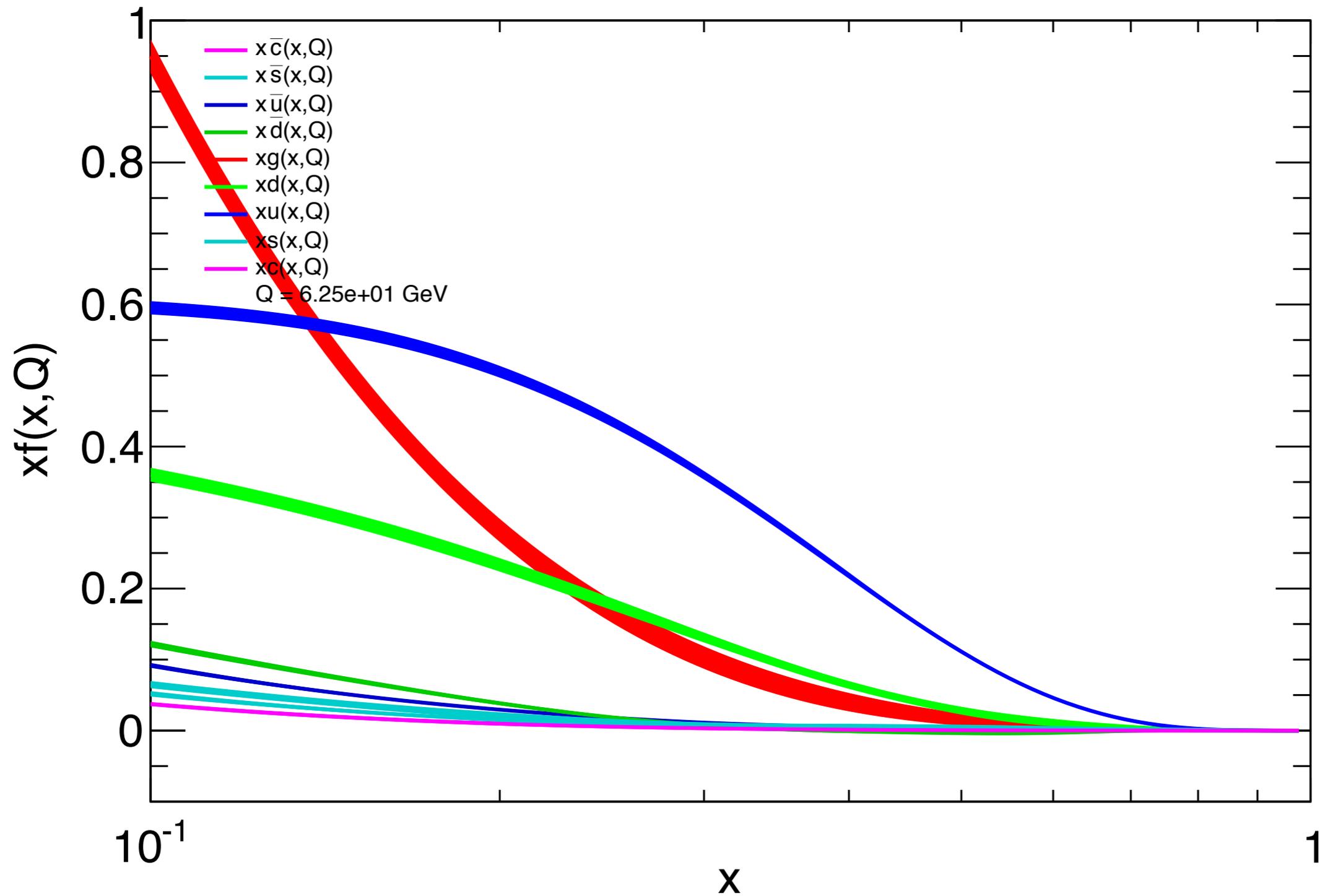
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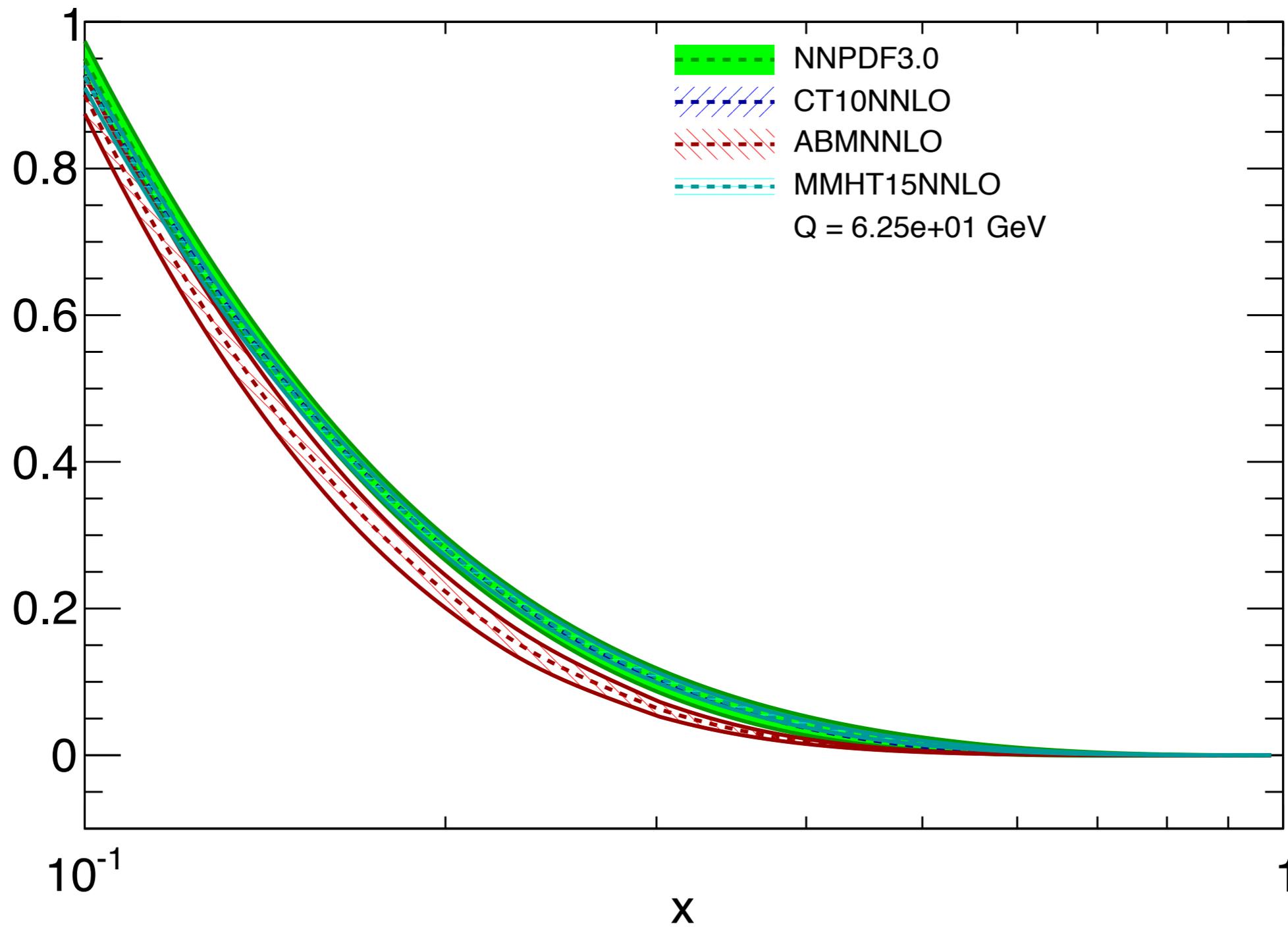
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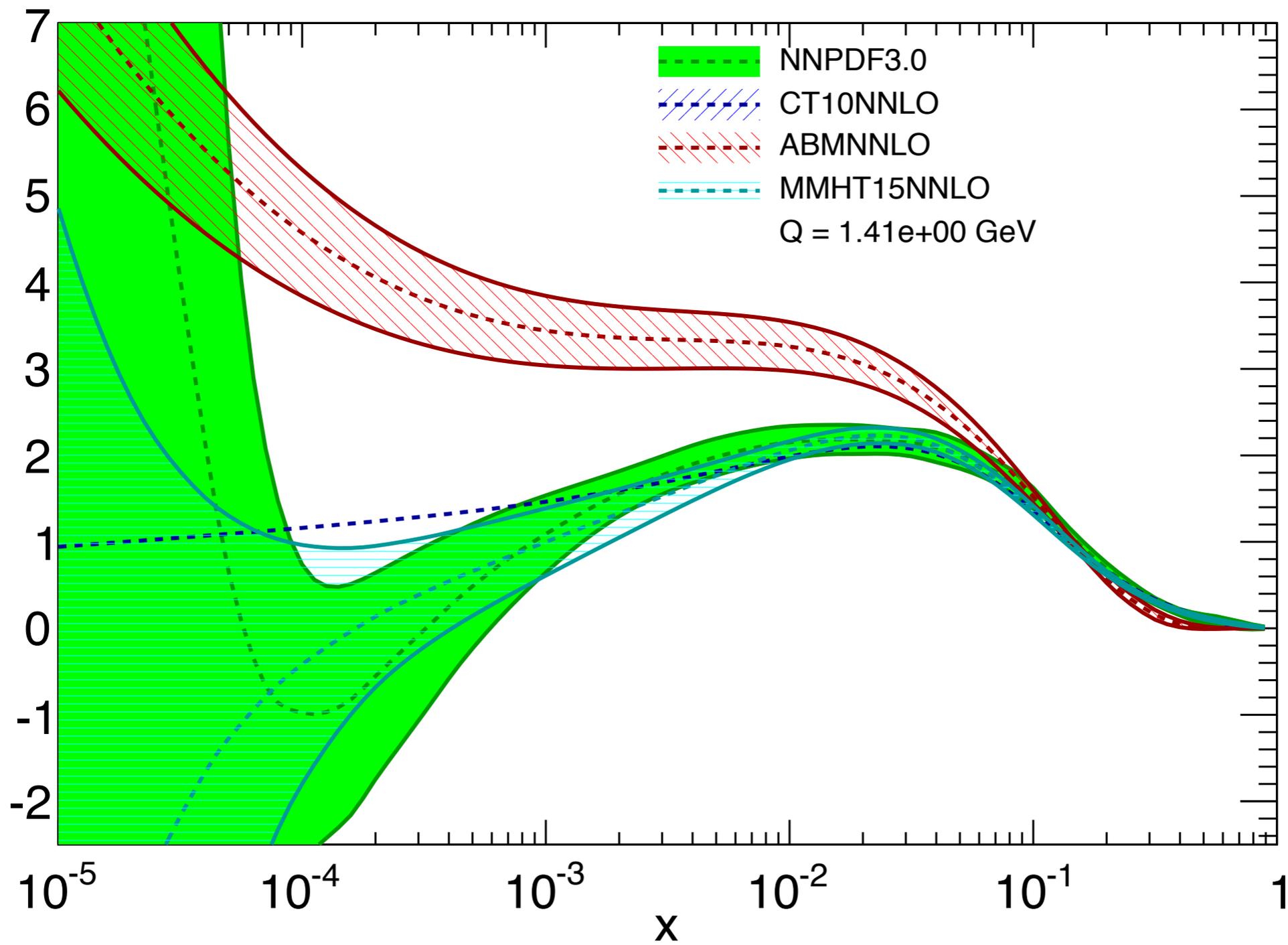
$xg(x,Q)$, comparison



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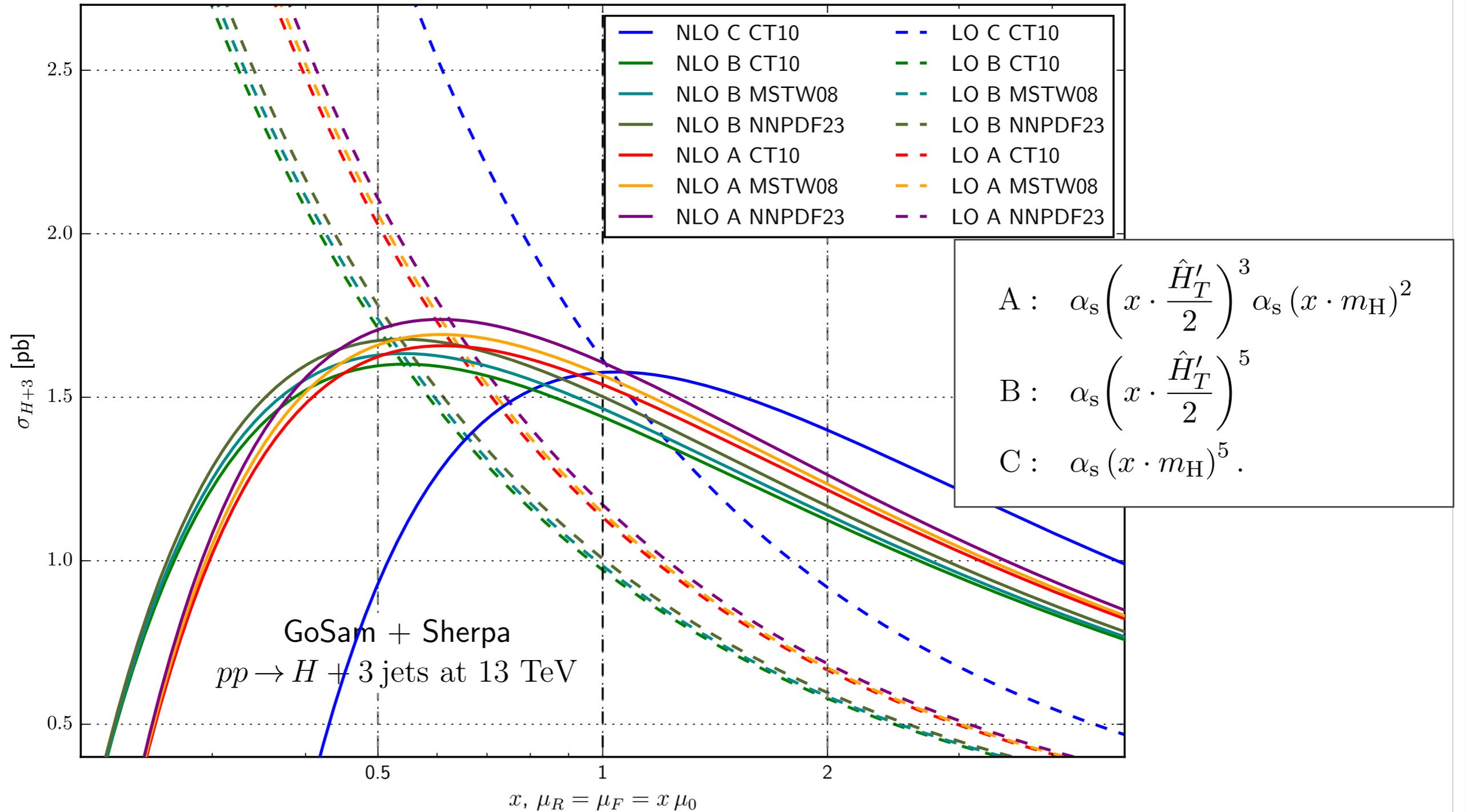
$xg(x,Q)$, comparison



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QCD @ NLO

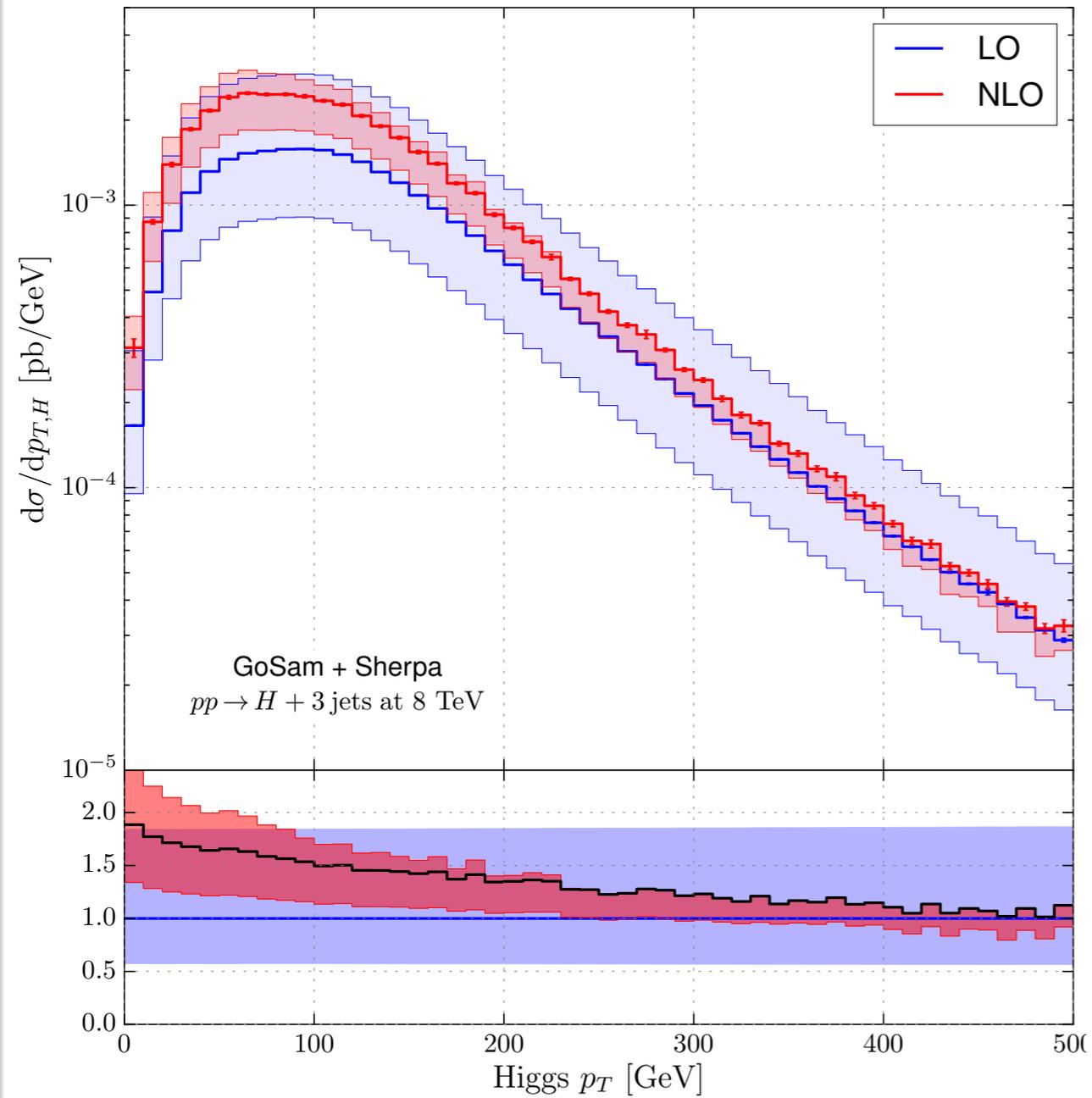
H + 3j @ NLO



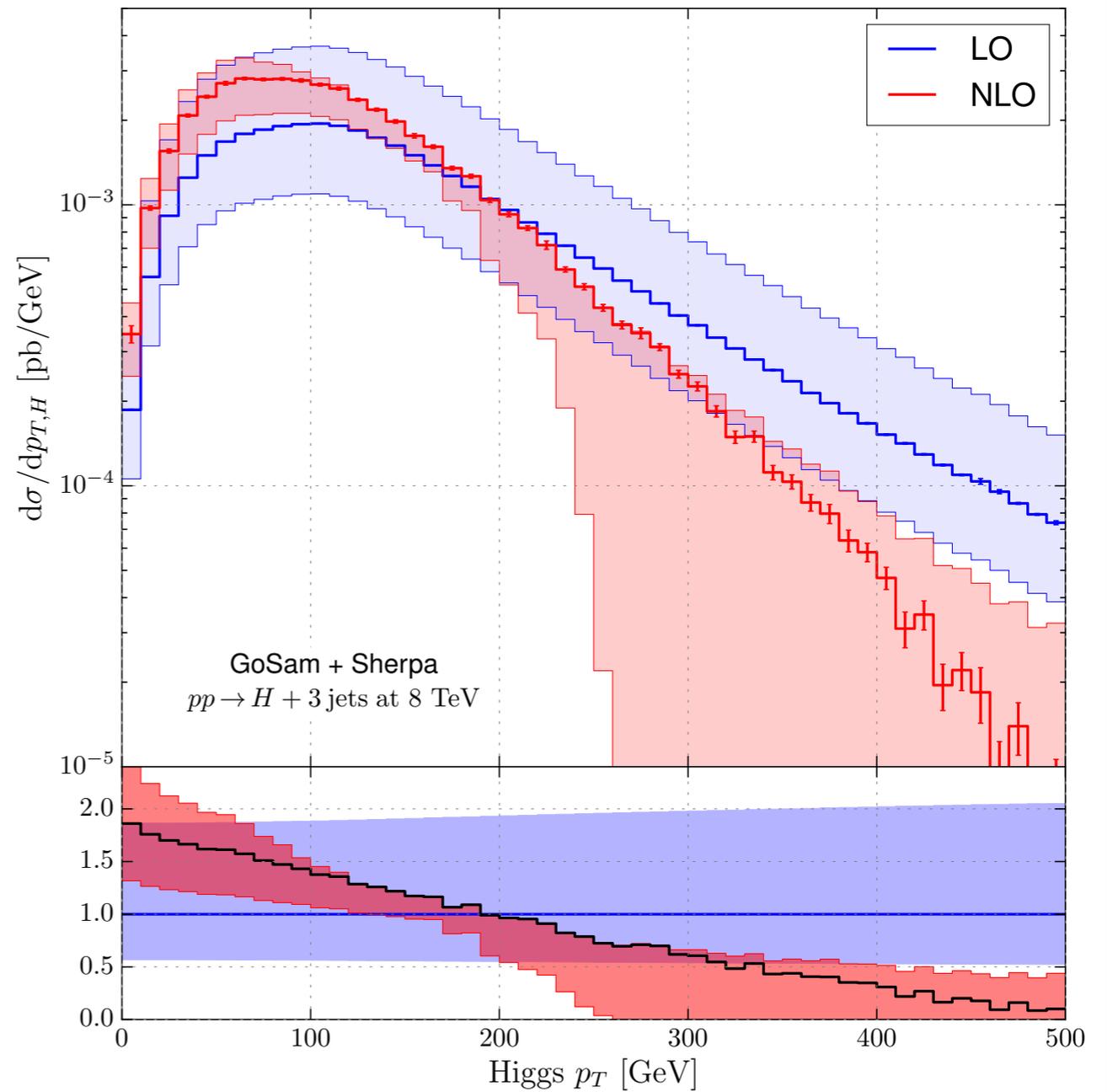
[Greiner, Hösche, Luisoni, Schönherr, Winter, Yundin]

H + 3j @ NLO

[Greiner, Hösche, Luisoni, Schönherr, Winter, Yundin]



Scale choice A



Scale choice C

NNLO and beyond

QCD @ NNLO

$$\hat{\sigma}_{ij}^{VV} = \frac{1}{2\hat{s}} \int d\Phi_n (2\text{Re}\mathcal{M}_n^{(0)} \mathcal{M}_n^{(2)*} + |\mathcal{M}_n^{(1)}|^2)$$

$$\hat{\sigma}_{ij}^{RV} = \frac{1}{2\hat{s}} \int d\Phi_{n+1} 2\text{Re}\mathcal{M}_{n+1}^{(0)} \mathcal{M}_{n+1}^{(1)*}$$

$$\hat{\sigma}_{ij}^{RR} = \frac{1}{2\hat{s}} \int d\Phi_{n+2} |\mathcal{M}_{n+2}^{(0)}|^2$$

- In principle, the whole story generalises in a straightforward manner.
- In practise, there is a huge jump in complexity when going from NLO to NNLO.

Virtual corrections

- At one loop, we know a complete basis of integrals in 4 dimensions.
- At two loops, we only know very few and specific integrals.
 - ➔ 2-to-2 massless, 2 scales (e.g. dijets): ~1999
 - ➔ 2-to-2 one leg off shell, 3 scales (e.g. $Z+j$): ~2000-01
 - ➔ 2-to-2 two legs off shell, 4 scales (e.g. ZZ): ~2014
 - ➔ We do not know any two-loop 2-to-3 integrals...
- Apart from these integrals, we only know a few very specific two-loop integrals:
 - ➔ $t\bar{t}$ (num.)
 - ➔ some integrals for electroweak corrections

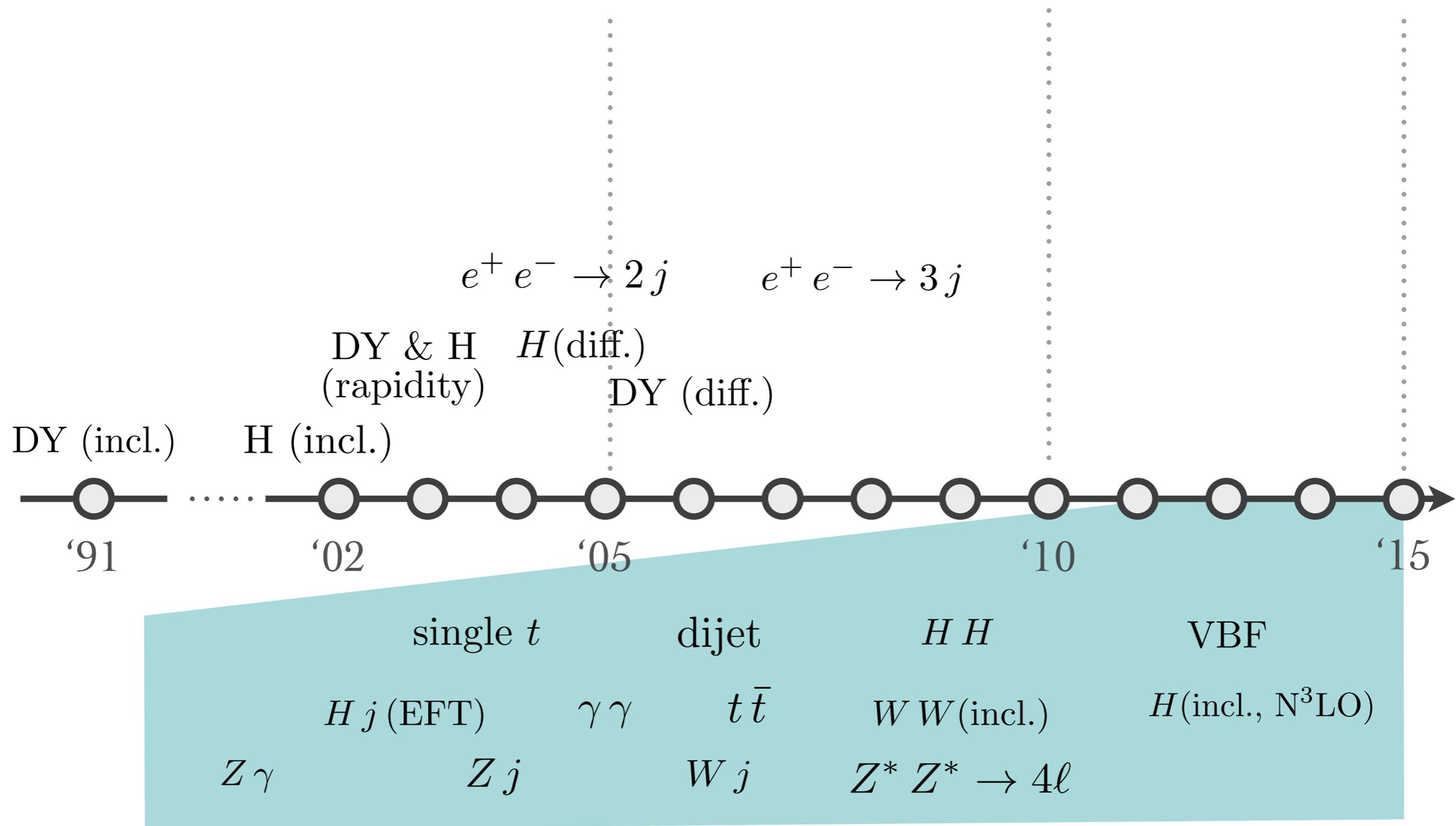
IR divergences @ NNLO

- Even if we can compute the virtual amplitudes, we still need to combine them with the real radiation contributions.
- We do not have a fully general subtraction scheme as we have at NLO, but a lot of progress in the last years:
 - ➔ Antenna subtraction. [Gehrmann, Gehrmann-de Ridder, Glover]
 - ➔ qT subtraction. [Catani, Grazzini]
 - ➔ Colourful NNLO [Somogyi, Tróscányi]
 - ➔ Stripper. [Czakon]
 - ➔ N-jettiness subtraction. [Boughezal, Focke, Liu, Petriello; Gaunt, Stahlhofen, Tackmann, Walsh]

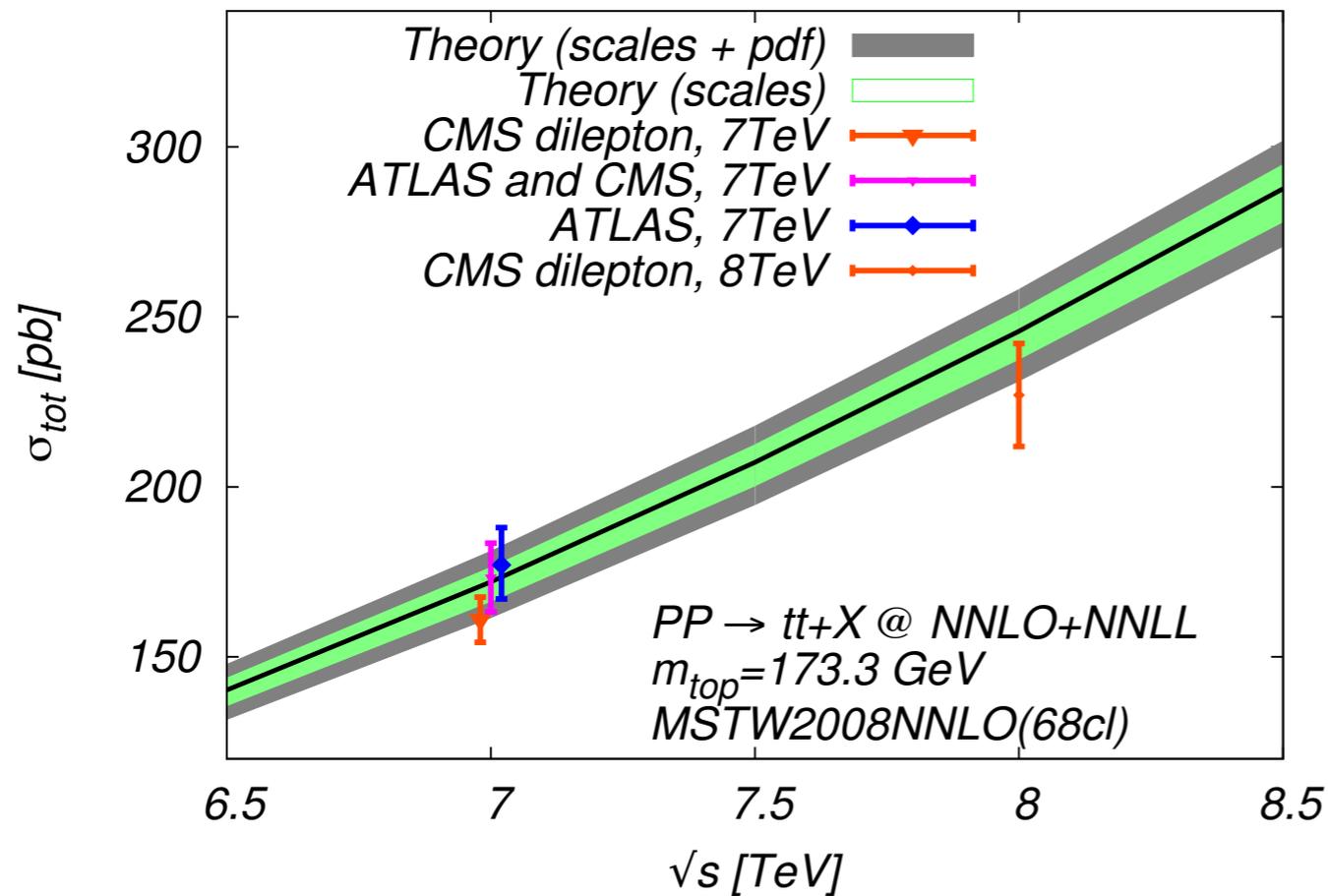
IR divergences @ NNLO

	Analytic	FS Colour	IS Colour	Local
Antenna	✓	✓	✓	✗
qT	✓	✗	✓	✓
Colourful	✓	✓	✗	✓
Stripper	✗	✓	✓	✓
N-jettiness	✓	✓	✓	✓

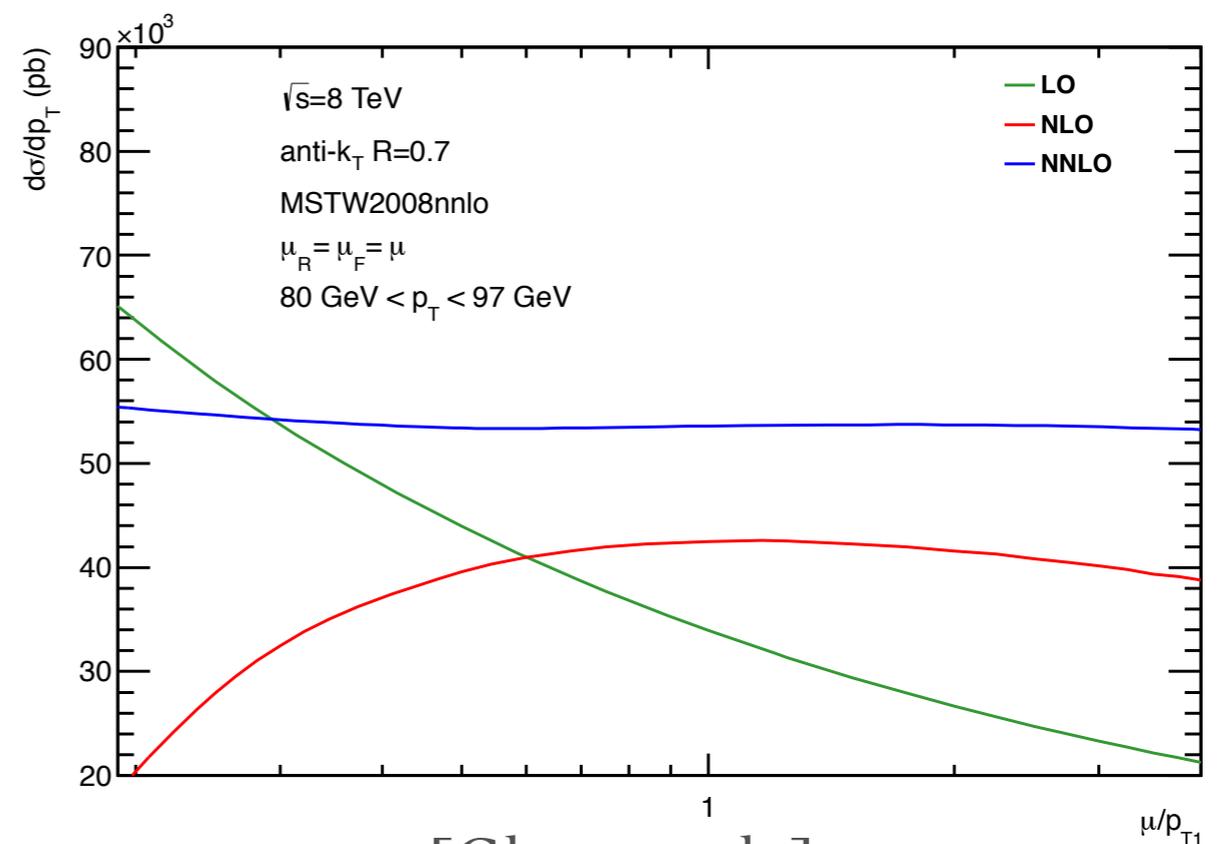
QCD @ higher orders



QCD @ higher orders



[Czakon, Fiedler, Mitov]

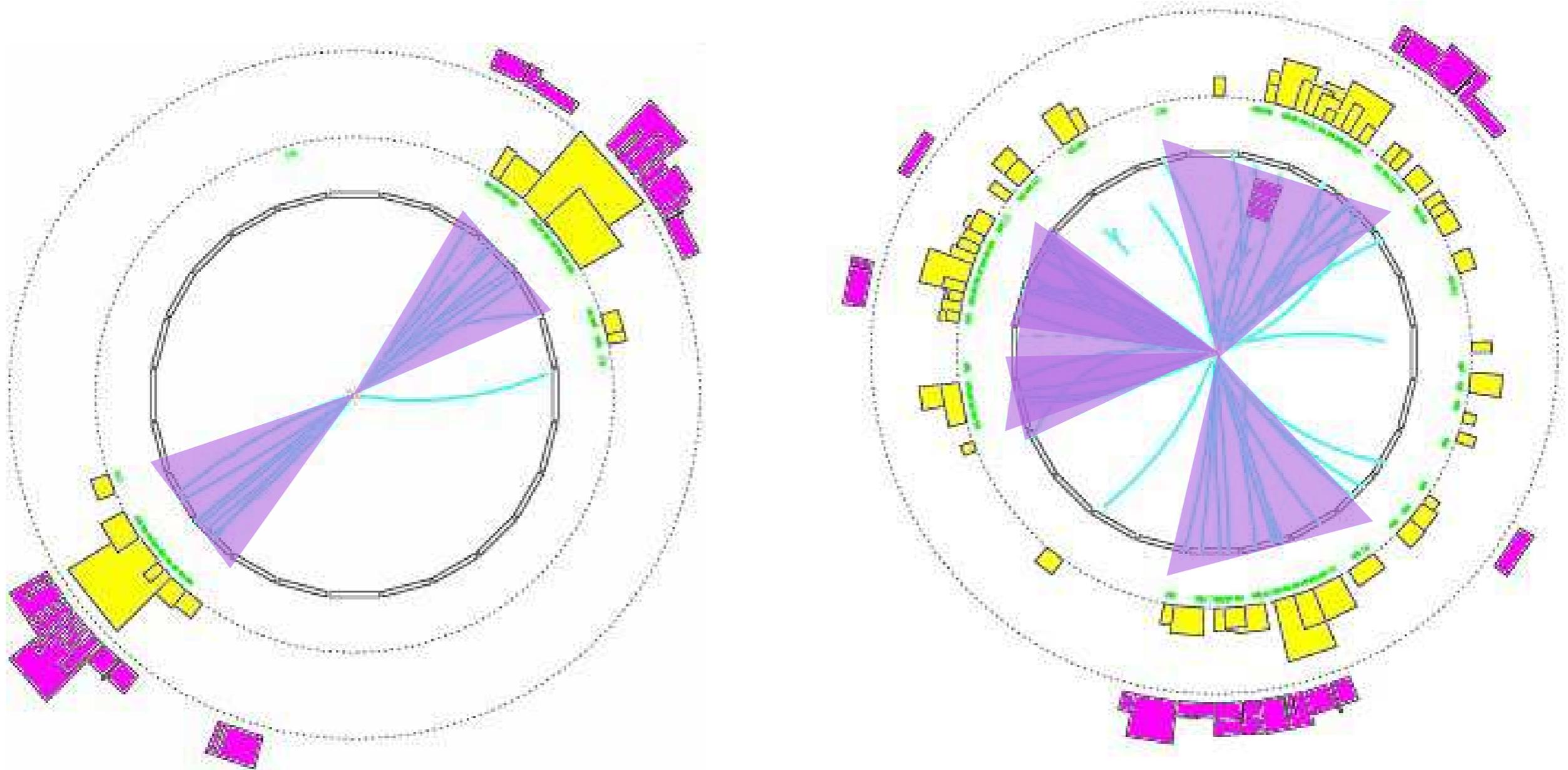


[Gluons only]

[Currie, Glover, Gehrmann,
Gehrmann-de Ridder, Pries, Wells]

Jets

Jets



[Slide from G. Salam]