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PDFs in an event generator

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LHC and the Standard Model: Physics and Tools,
CERN, 16 June 2017

PDF4LHC Meeting, CERN, 22-23 Feb 2008

Some Comments and Actions

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- NLO PDF's are great for high-Q^2 precision tests,
  but ill suited for much of the bread-and-butter physics
  generators have to contend with, because of
  $\star$ (gluon) positivity, or at least strange behaviour at small Q^2,
  $\star$ not matched to LO ME's + parton showers.

Why MB/UE physics prefer LO PDFs

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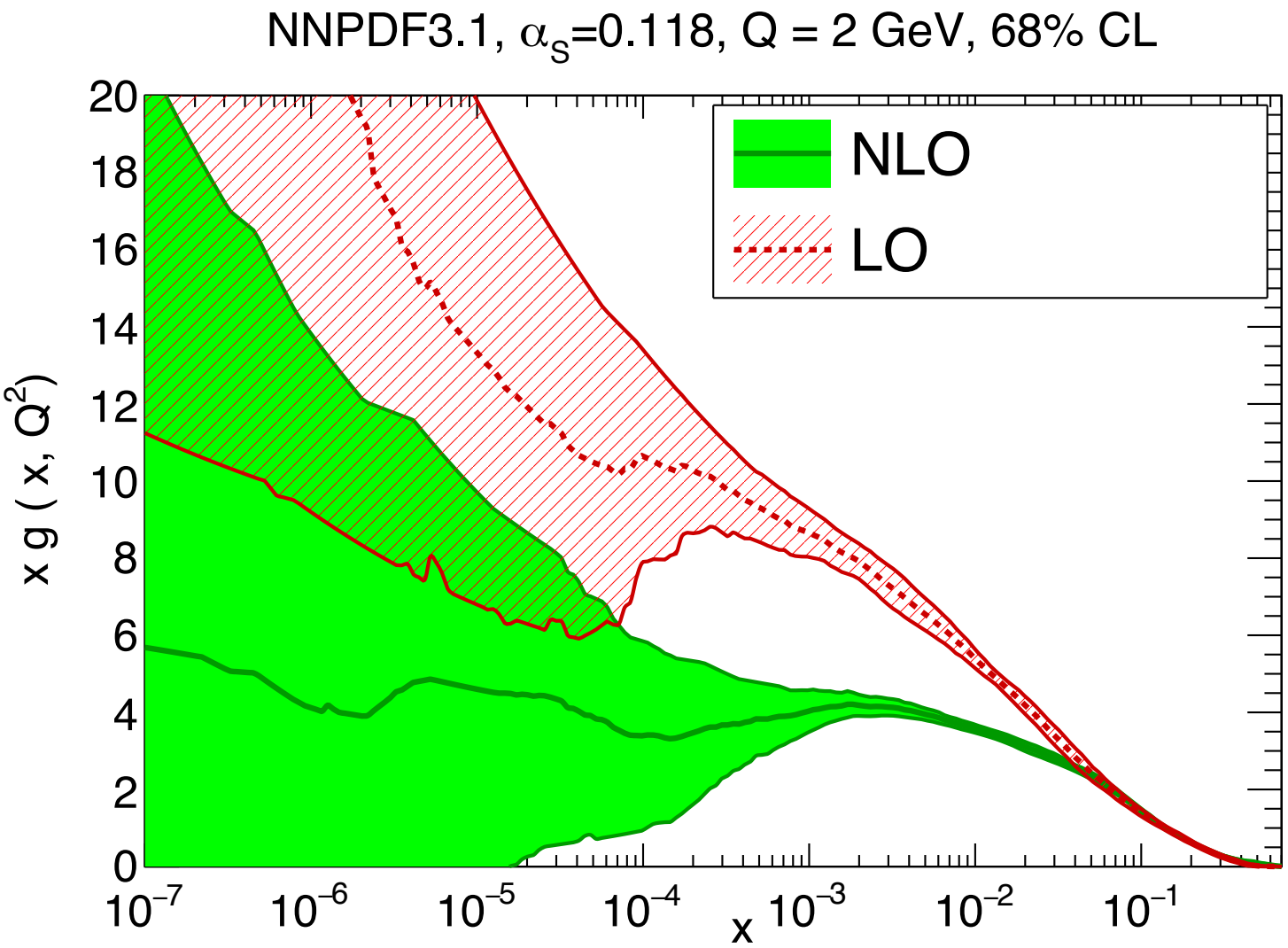
Original date: 24 Aug 2012
Last changed: 24 Aug 2014

From hard to soft scales

- $\mathrm{LO_{ME}} \otimes \mathrm{NLO_{PDF}} = \mathrm{NLO_{ME}} \otimes \mathrm{LO_{PDF}} = \mathrm{LO}$.
- NLO MEs typically give positive $\ln(1/x)$ corrections, compensated by negative $\ln(1/x)$ corrections to NLO PDFs, driving PDFs small or even negative at small x and Q.
- No big issue for hard processes: large x and Q.
- Nonperturbative hadronization at/below scales $Q_0 \approx 1$ GeV. Must fill gap between Q_{hard} and Q_0 e.g. for jet substructure.
- Parton showers: traditional way to fill gap.
  Still almost always LL (NLL start to appear).
- ISR (& sometimes FSR) depend on PDFs down to Q_0.
  (Backwards evolution of $a \to bc$ contains PDF ratio $x' f_a(x', Q)/x f_b(x, Q)$.)
- Need PDFs down to $Q = 1$ GeV and $x = 10^{-8}$ at the LHC
  $\Rightarrow$ NLO $\ln(1/x)$ terms important.

The gluon PDF at low Q: LO vs. NLO



(J Rojo)

g members are positive, NLO 68% envelope goes negative!

Apologies: have not studied other PDF sets.

Multiparton interactions

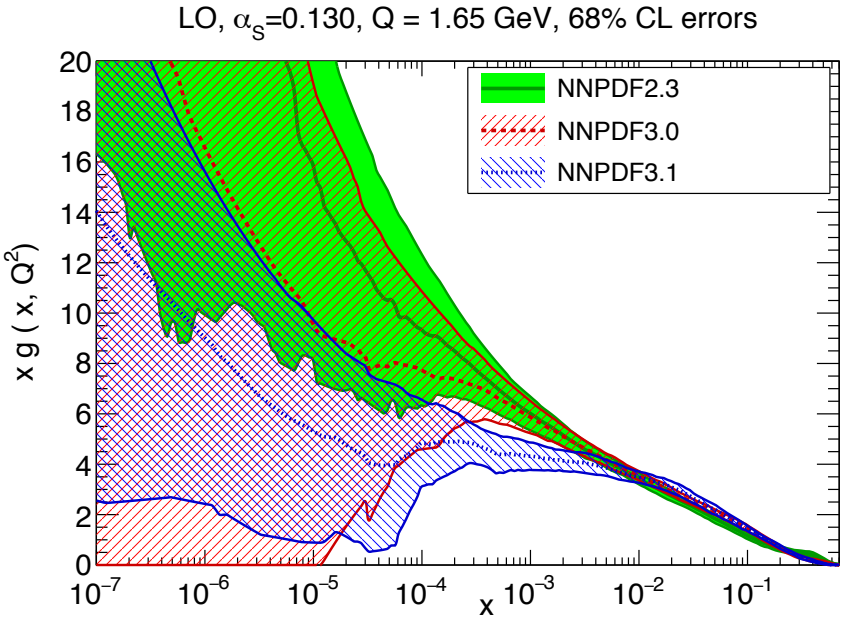
Divergent $p_\perp \to 0$ QCD $2 \to 2$ cross section dominated by t-channel g exchange. Needs regularization, e.g.

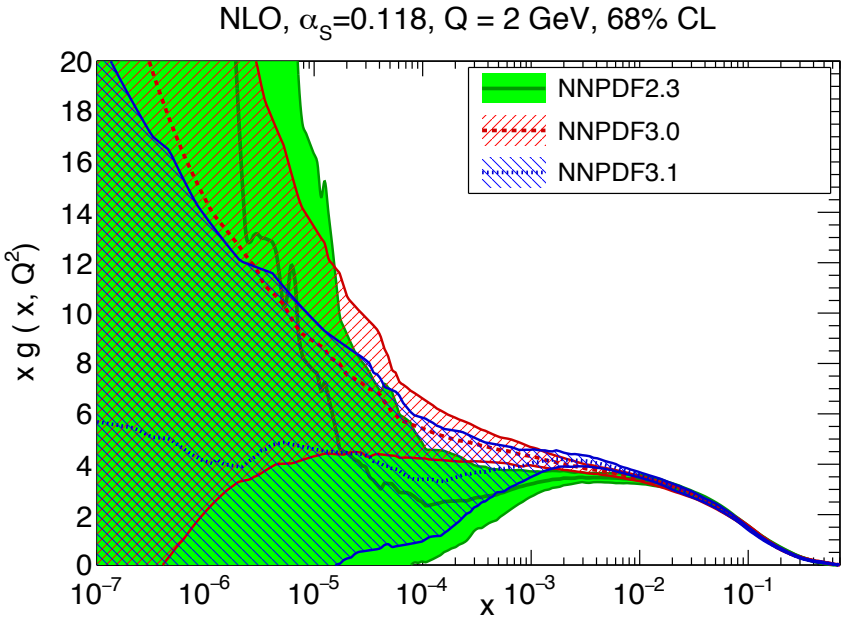
$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_\perp^2} \propto \frac{\alpha_\mathrm{s}^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_\mathrm{s}^2(p_{\perp 0}^2 + p_\perp^2)}{(p_{\perp 0}^2 + p_\perp^2)^2}$$

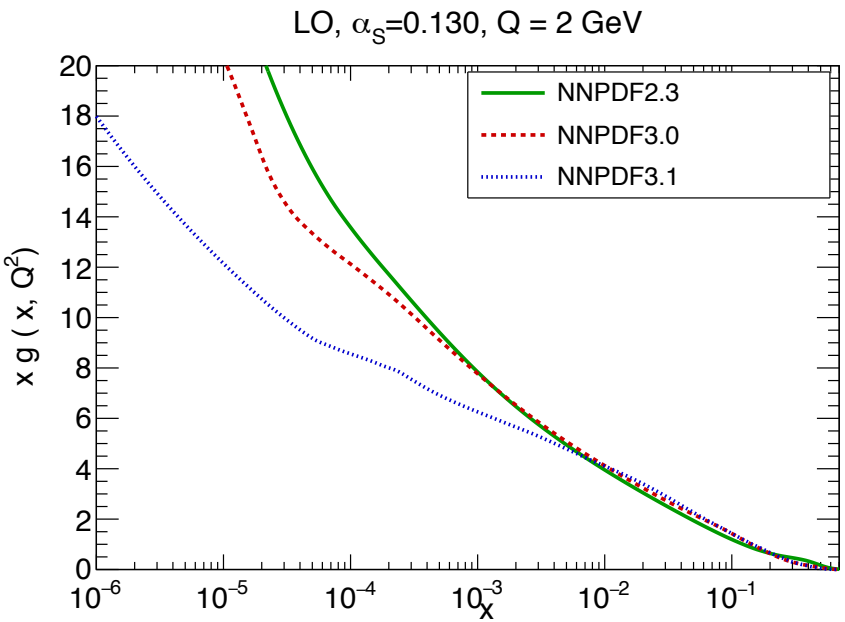
with $p_{\perp 0} \approx 2.5 - 3$ GeV at LHC energies.

- Typical hard process has ~ 10 MPIs, with $\langle p_\perp \rangle \approx p_{\perp 0}$.
- Will use PDFs down to and even below $Q = p_\perp = 1$ GeV and $x = 4p_\perp^2/s \approx 10^{-8}$; phenomenology sensitive down to ~ 2 GeV and $\sim 10^{-7}$.
- NLO QCD MEs unstable at $p_\perp = 2$ GeV (?) $\Rightarrow$ out.
- What is most physically meaningful at 1 – 2 GeV, $\mathrm{LO_{ME}} \otimes \mathrm{LO_{PDF}}$ or $\mathrm{LO_{ME}} \otimes \mathrm{NLO_{PDF}}$?
- My assumption: $\mathrm{LO_{PDF}}$.

The gluon PDF at low Q: time evolution







(J Rojo)

g PDF still not well constrained: error band slowly coming down; central value unstable.

Need to retune generators when default PDF is changed.
Also energy dependence.

What to do?

Some arguments why assume $xg(x, Q_0) \propto x^{-\epsilon}$, $\epsilon \approx 0.10$:

1. HERA $F_2(x, Q_0) \propto x^{-\epsilon}$ probes g indirectly via sea.
2. Expect $\sigma_{\rm pp}(s) \propto xg(x, Q_0)$ for $x \propto 1/s \to 0$ (Regge–Gribov).
3. MPI models with eikonalized minijet production gives similar relationship between $\sigma_{\rm pp}(s)$ and $xg(x, Q_0)$.

Catches: Q_0 small but unspecified; normalization only from F_2.

PDF fits: small changes at (medium) high x can have large impact at small x by momentum conservation.

Time to revive LO$*$ philosophy: do not respect momentum sum rule but let each x range take what is appropriate locally? (Applies to Q_0 ansatz, not evolution.)

PYTHIA options and outlook

- PYTHIA allows one "hard" PDF for MEs, possibly NLO, and another "soft" PDF for ISR/MPI, preferably LO.
- PYTHIA only has LO ME internally, so NLO PDFs possible but not guaranteed more accurate.
- External (LHEF) $\mathrm{NLO}_{\mathrm{ME}} \otimes \mathrm{NLO}_{\mathrm{PDF}}$ hard-process input fine.
- If strong request, e.g. for match & merge, could transition smoothly from "hard" NLO to "soft" LO PDF:

$$f_i(x, Q) = h(Q) f_i^{\mathrm{hard}}(x, Q) + (1 - h(Q)) f_i^{\mathrm{soft}}(x, Q)$$

  Especially trivial if both use same (x, Q) grid.
- Do not forget low-(x, Q) needs!
- Retunes necessary, but not always trivial. Example: $\mathrm{d}n_{\mathrm{charged}}/\mathrm{d}\eta$ at large η reflects low-x shape.