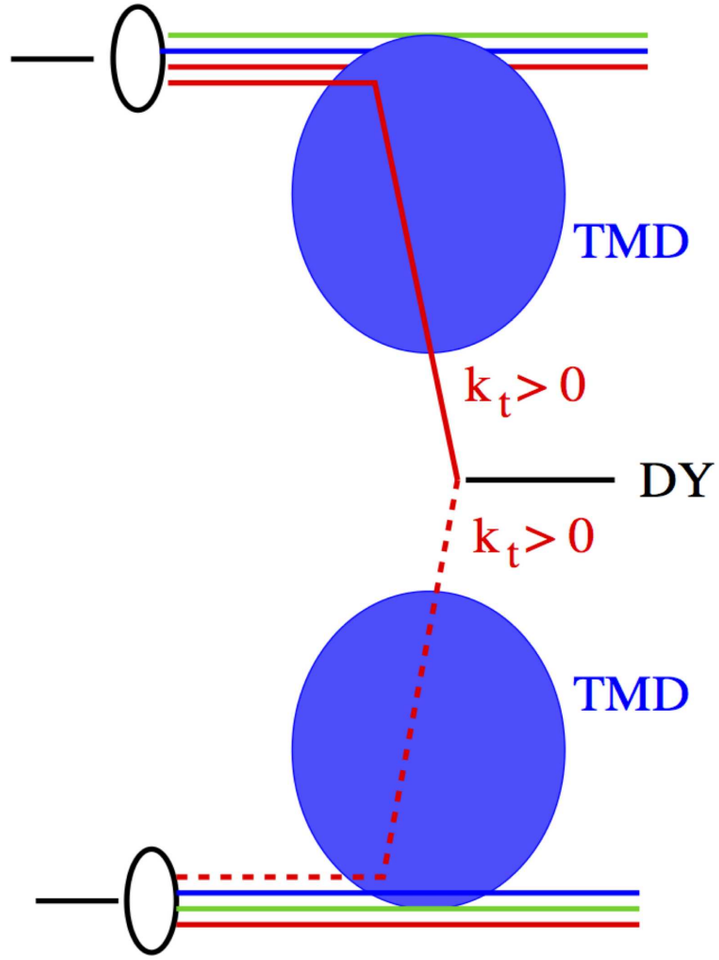
Parton Branching and PYTHIA8

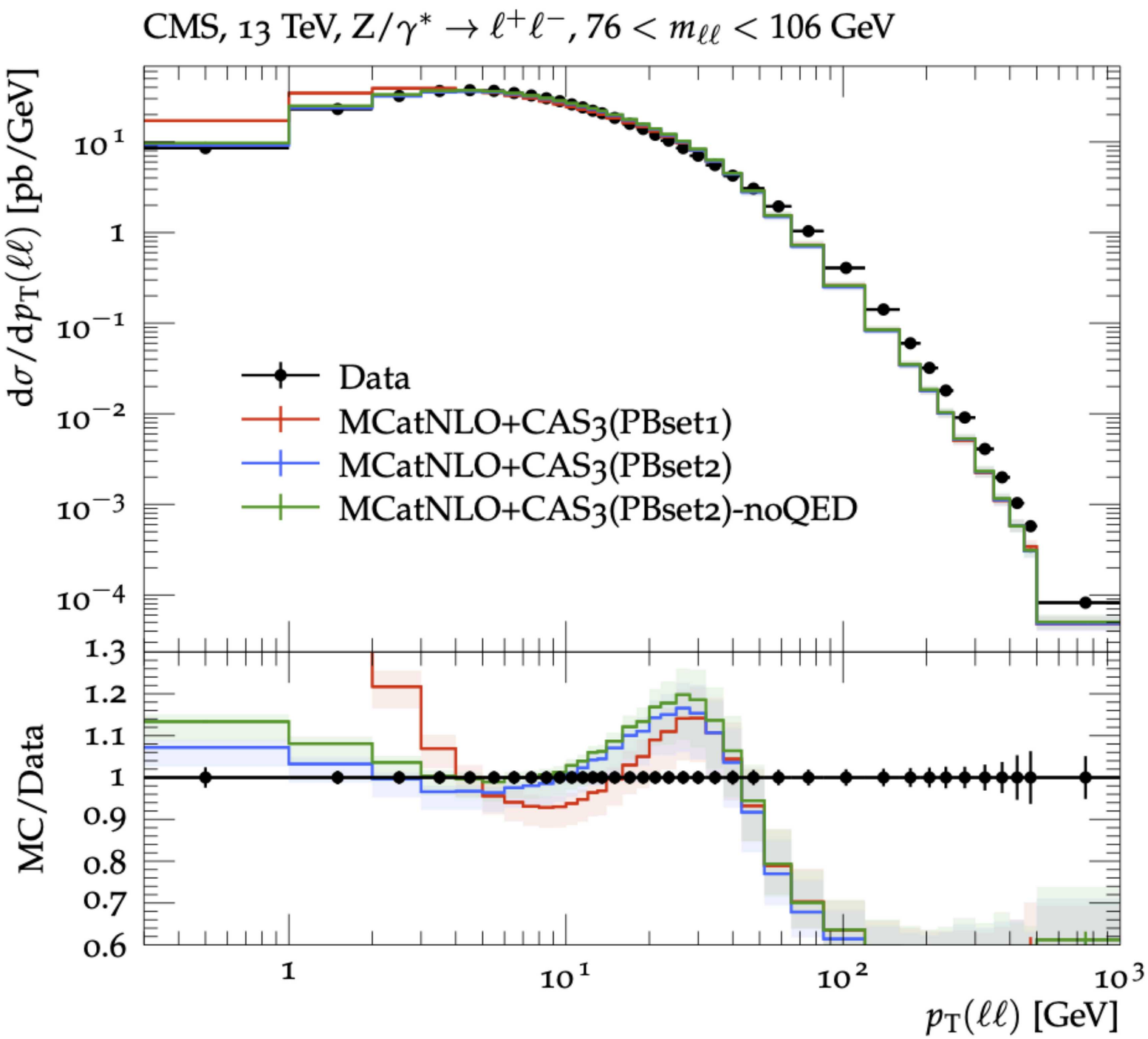
- Recap of PB method
- Parton Branching method and PYTHIA8

Drell-Yan production: q_T - spectrum

- DY production
  - $q\bar{q} \to Z_0$
  - use NLO calculations: MC@NLO
  - add k_t for each parton as function of x and μ according to TMD
    - keep final state mass fixed
    - preserve rapidity
      - but x_1 and x_2 (light-cone fraction) are different after adding k_t



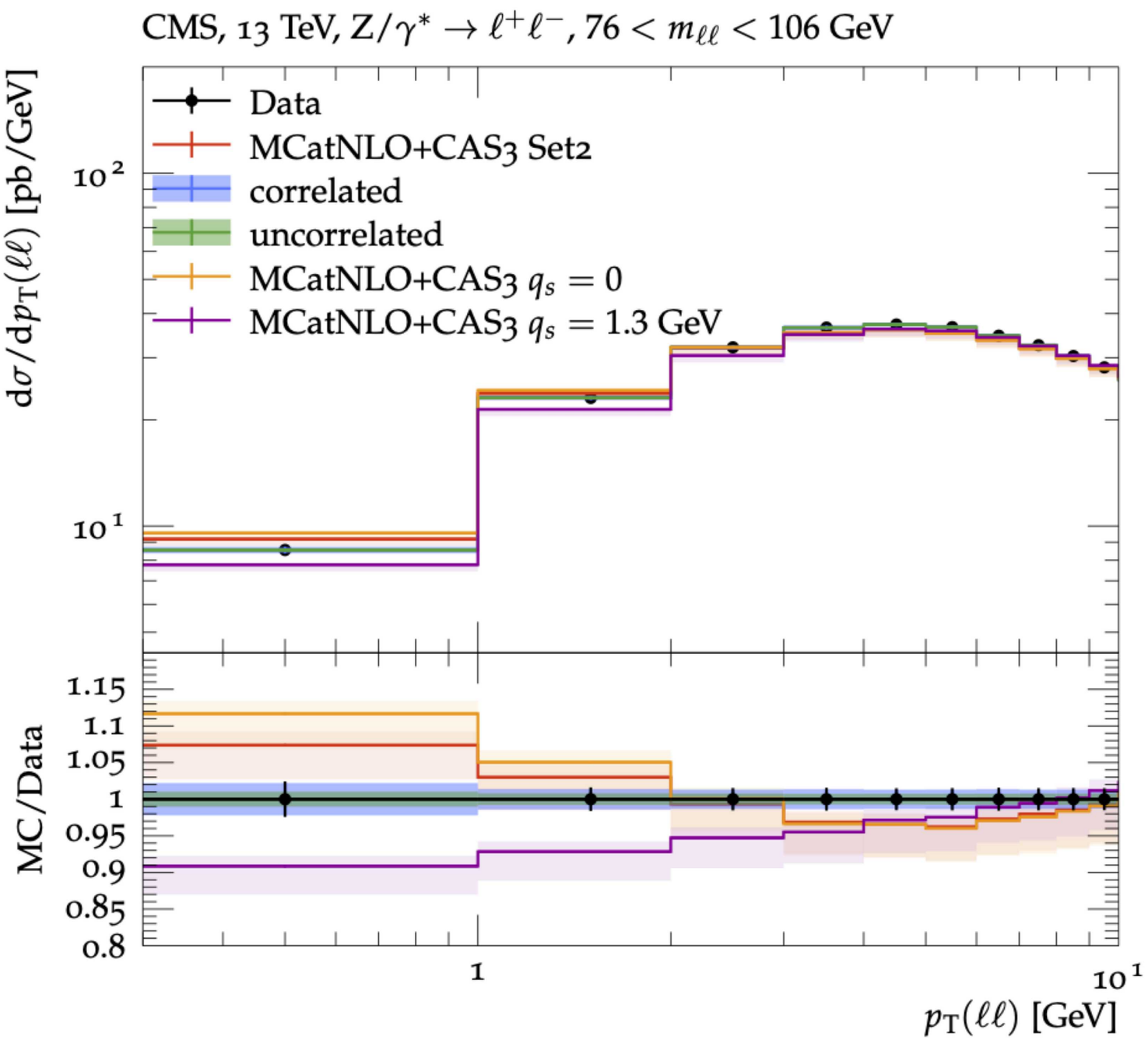
Z - production at 13 TeV (CMS)



Bubanja, I. et al, arXiv: 2312.08655

- very good description of low p_T region with PB-set 2 (with $\alpha_s(q(1-z))$)
  - at larger p_T contribution from higher order matrix elements important
- Uncertainties in PB method mainly from scale of MC@NLO matrix element

Intrinsic k_T in DY - production at 13 TeV (CMS)



Bubanja, I. et al, arXiv: 2312.08655

- in TMD, intrinsic k_T distribution:
  - Gauss with zero mean, width q_s

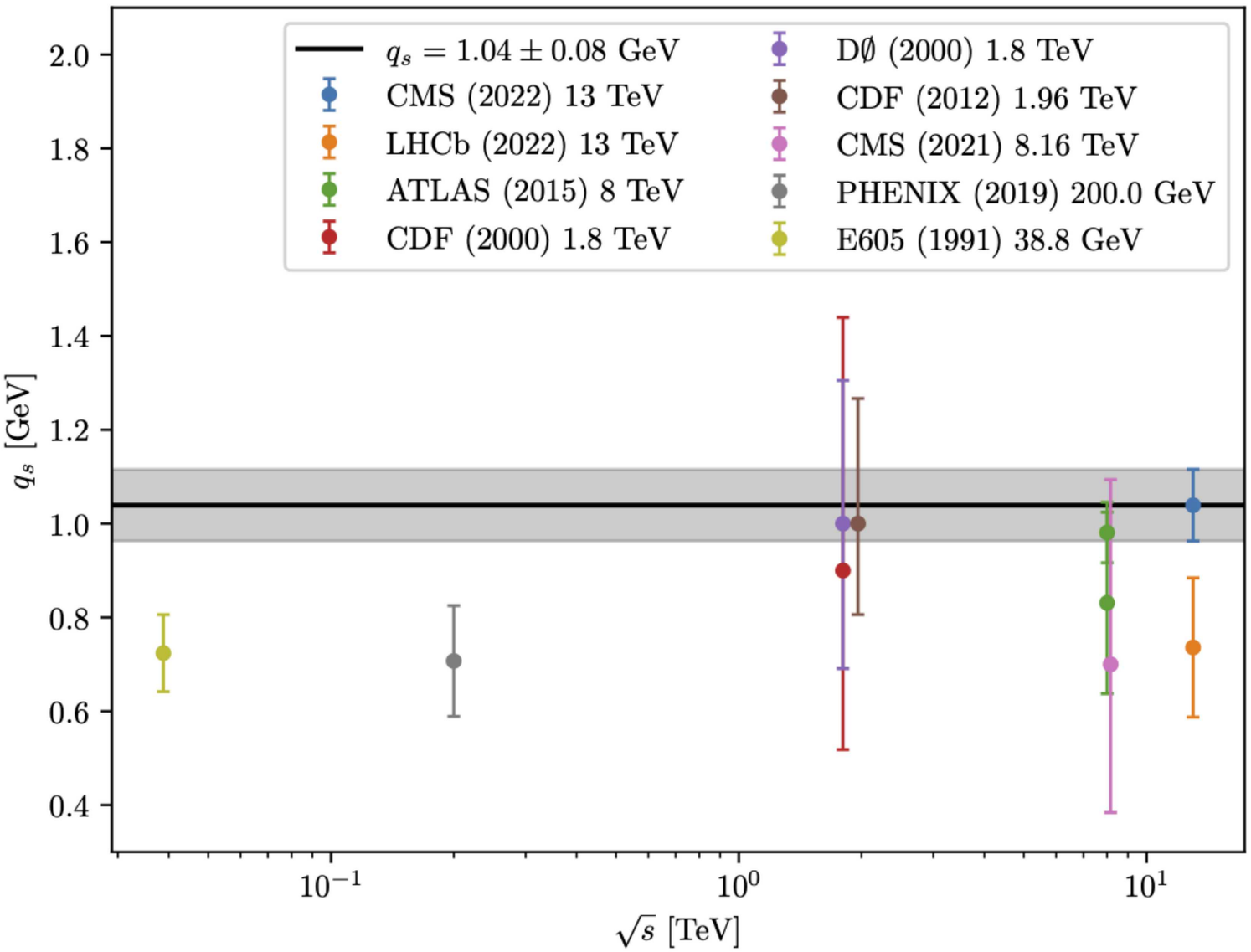
$$\sim \exp\left(-|k_T^2|/q_s^2\right)$$

- Focus on small k_T region:
  - **in lowest** p_T bin, sensitivity to intrinsic k_T

- Use DY production at different m_{DY} and $\sqrt{s}$ to determine q_s

- Is intrinsic k_T dependent on m_{DY} and $\sqrt{s}$?

Fit of Intrinsic k_T in DY – production vers $\sqrt{s}$



Bubanja, I. et al, arXiv: 2312.08655

- Gauss with zero mean, width q_s

$$\sim \exp\left(-|k_T^2|/q_s^2\right)$$

Fit to determine q_s of intrinsic k_T distribution from DY production as a function of $\sqrt{s}$

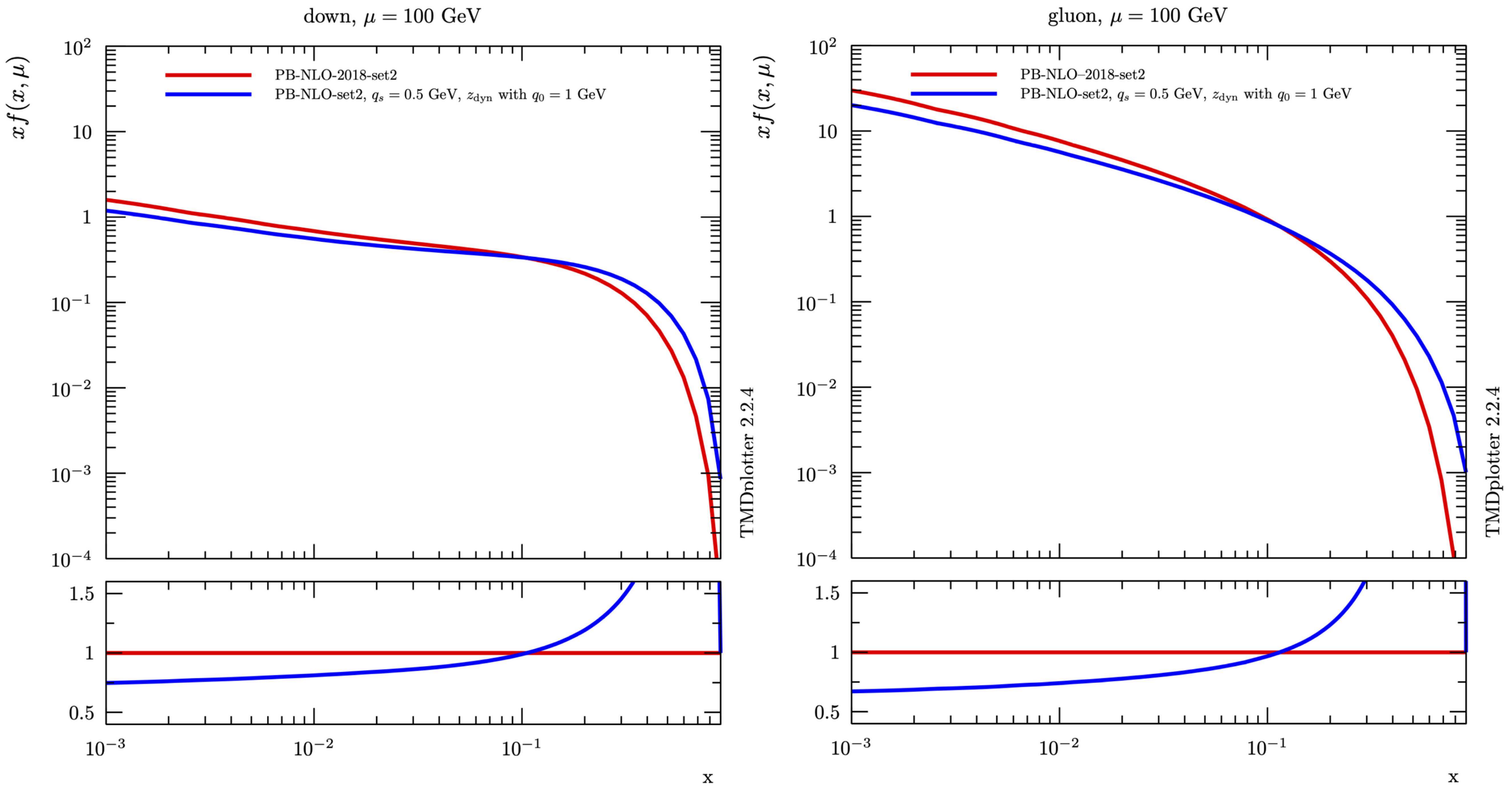
- obtain q_s rather independent on $\sqrt{s}$

The role of soft gluons

Importance of non-perturbative gluons

Bubanja, I. et al, arXiv: 2312.08655

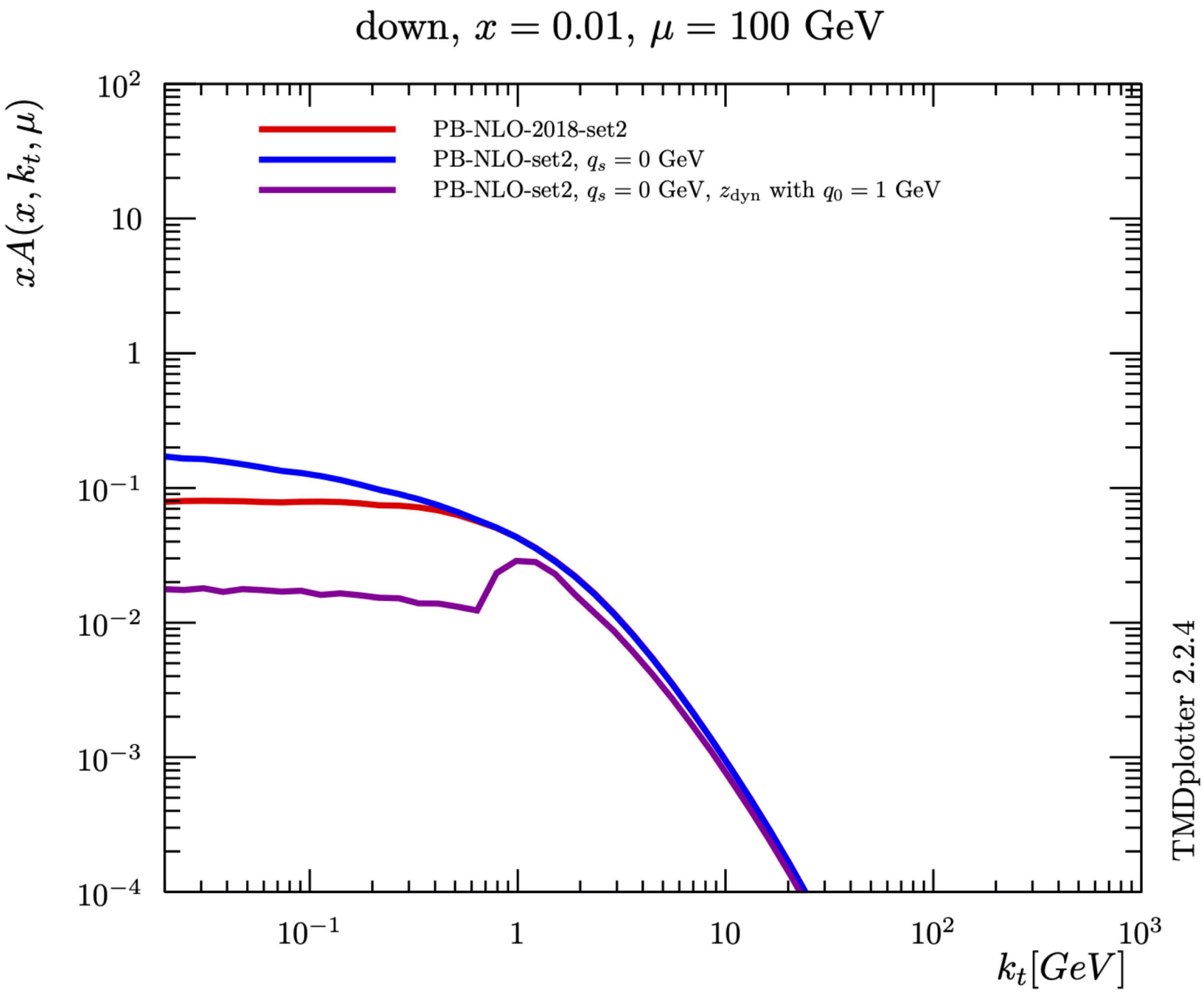
- Apply $z_{\rm dyn} = 1 - q_0/q'$ with $q_0 = 1$ GeV on inclusive distributions



Role of soft gluons in TMD distributions

Bubanja, I. et al, arXiv: 2312.08655

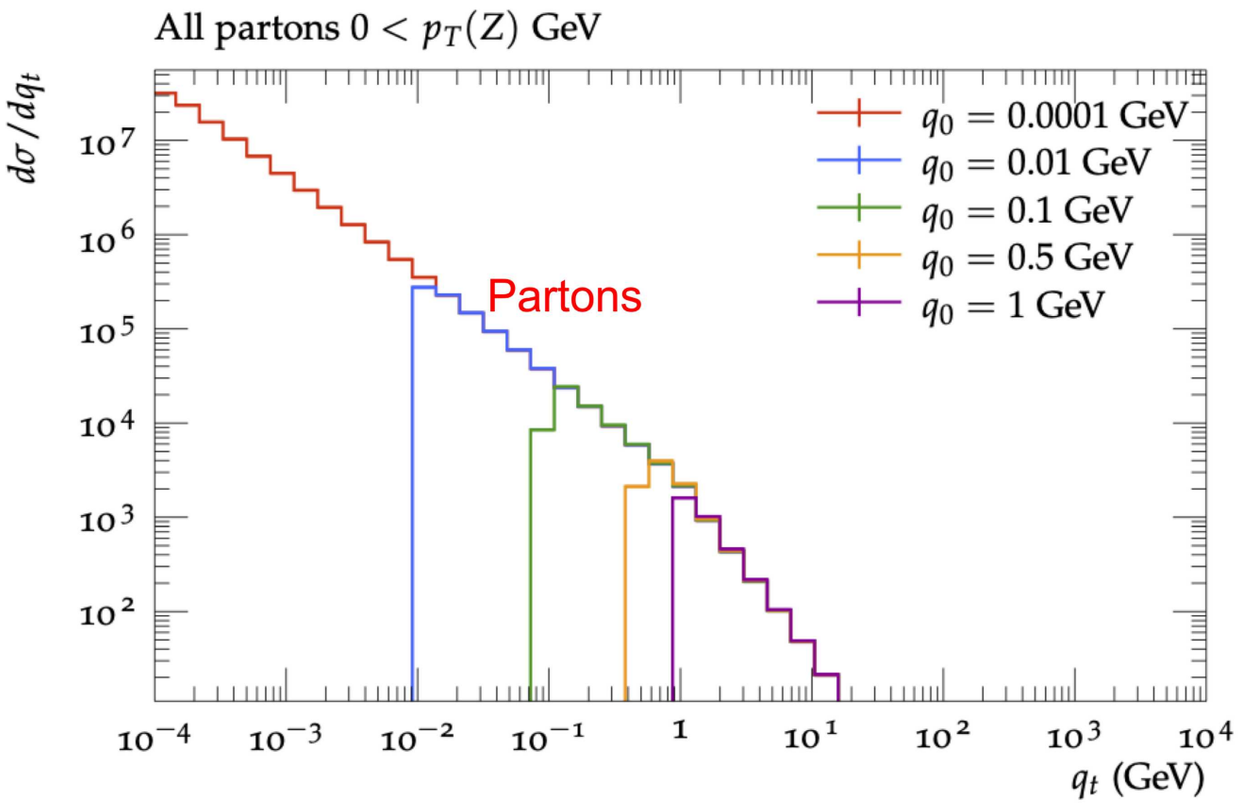
- Perform evolution with PB method with and without cut $z_{\rm dyn} = 1 - \dfrac{q_0}{\mu'}$

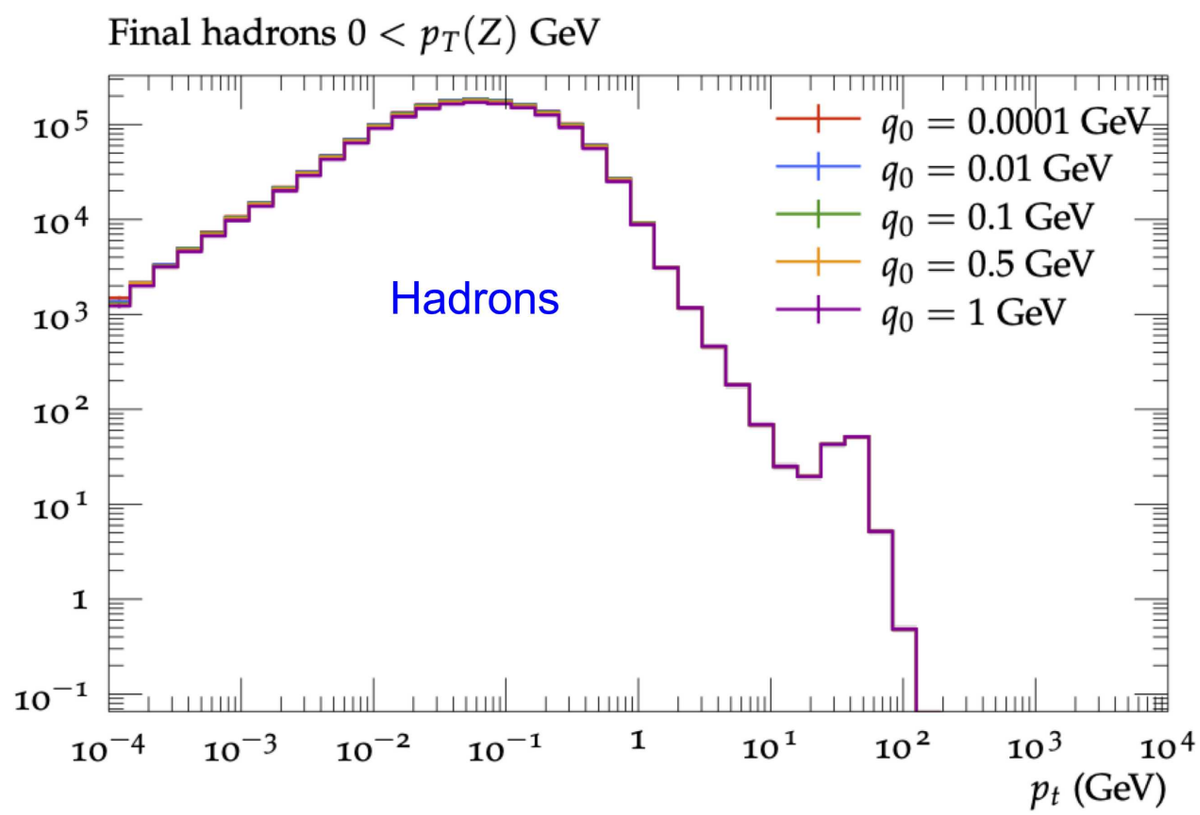


Soft gluons in Parton Shower

M. Mendizabal arXiv: 2309.11802

- With PB-TMD parton shower study effect of $z_{\rm dyn} = 1 - \dfrac{q_0}{\mu'}$





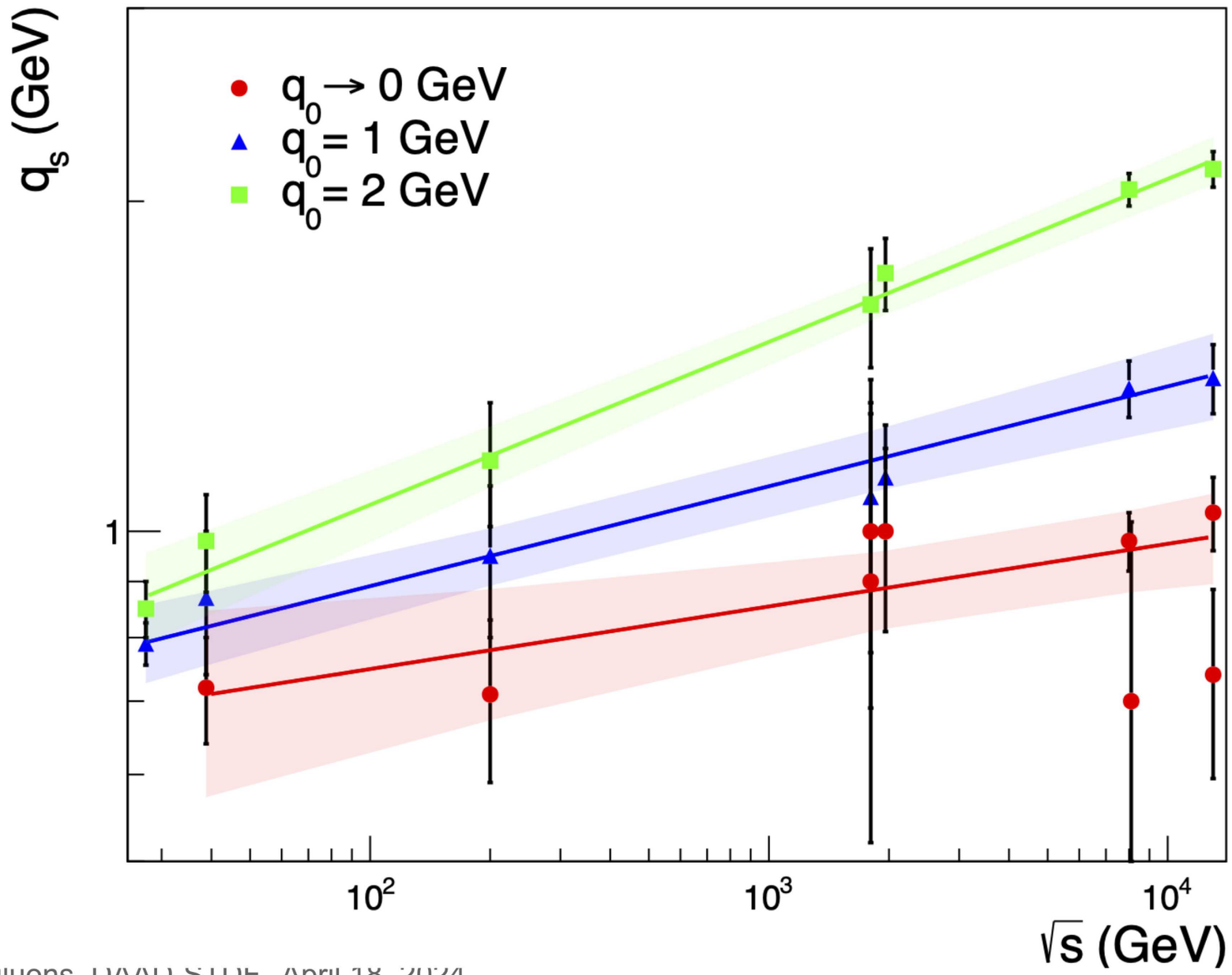
- in Lund string fragmentation these soft partons do not change hadron spectra
  - no issue for hadrons or jets from parton shower !

- no effect on hadron spectra !

Effect of soft gluons in inclusive DY pt spectra

Effect of removing soft gluons from TMD

- Perform evolution with PB method with cut $z_{\rm dyn} = 1 - \dfrac{q_0}{\mu'}$ Bubanja, I. et al, arXiv: 2404.04088
  - to mimic parton shower approach in MC event generators
- Determine width of intrinsic kt distribution



Parton Shower MC event generators

- Parton shower follows backward evolution:

$$\Pi = \exp\left[-\int_{\mu_l^2}^{\mu_h^2} \frac{d\mu'^2}{\mu'^2} \int^{z_{\rm dyn}} \frac{dz}{z} \hat{P}(z) \frac{f(x/z,\mu^2)}{f(x,\mu^2)}\right]$$

- Emitted partons should have *resolvable* energy (or p_T) with: $p_T > q_0 \sim 1\mathrm{GeV}$

$$z_{\rm dyn} = 1 - \frac{q_0}{\mu'}$$

- With $z_{\rm dyn} \ll 1$ soft gluons with $p_T < 1\mathrm{GeV}$ are neglected.

- What is the role of these soft gluons ?

PYTHIA8 vrs PB

- **PYTHIA8**
  - Parton shower
    - pt ordering

      $z_{dyn}=1-p_{t0}{}^2/q^2$
      - with $p_{T0}=2\,GeV$
    - calculation of Q

      $Q^2 \quad = p_T{}^2\,/\,(1-z)$
  - calculation of pt and eta
  - in parton-parton CM frame
  - α_s at small pt: pt0ref

$$\int^{z_{\rm dyn}} \frac{dz}{z} P(z)$$

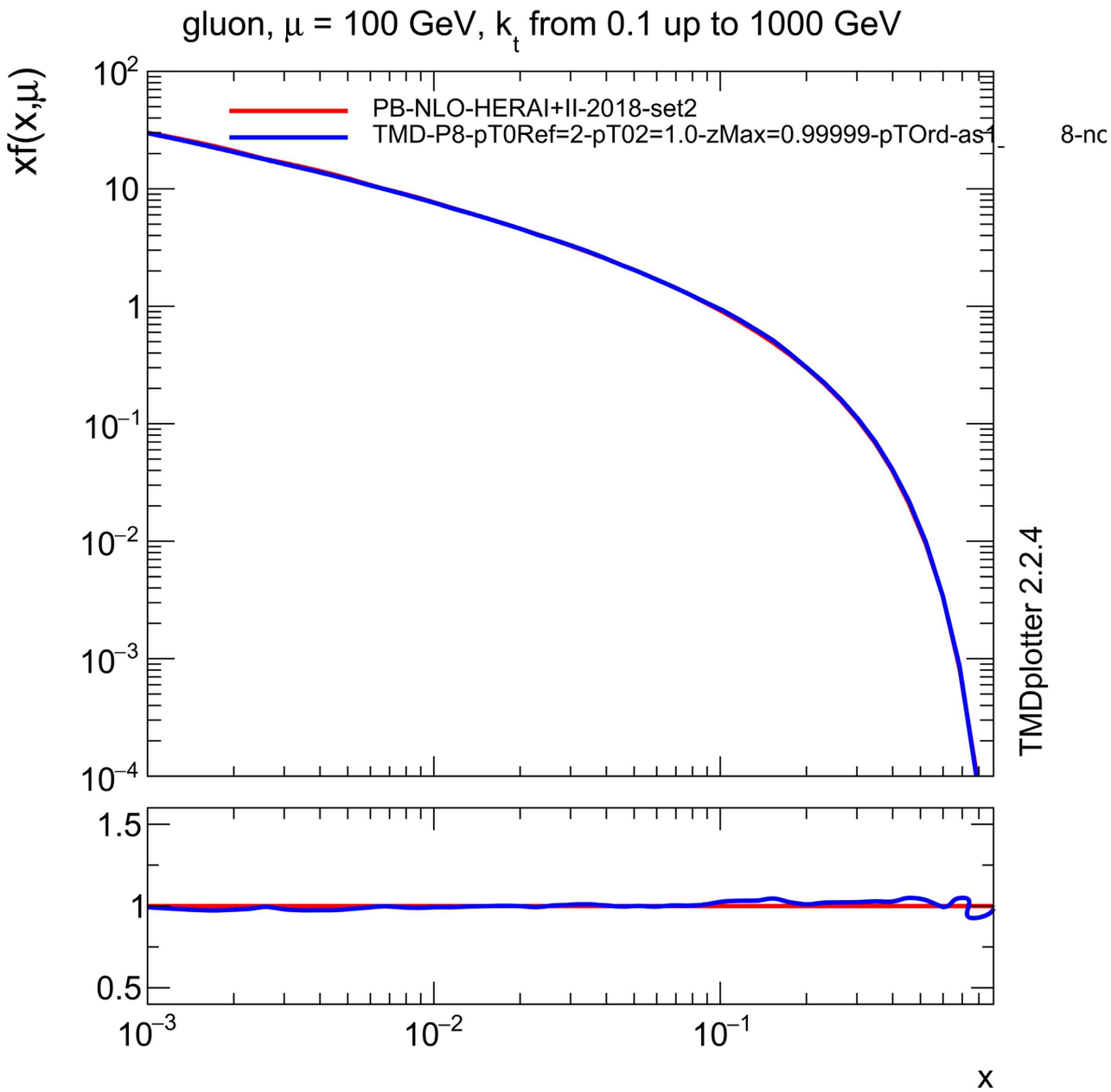
- **PB (set2)**
  - TMD distribution
    - angular ordering

      $z_{dyn}=1-q_0/q$
      - with $q_0=0.01\,GeV$
    - calculation of Q

      $Q^2 \quad = p_T{}^2\,/\,(1-z)^2$
  - calculation of pt and eta in pp-CMS frame
  - α_s at small pt: qcut=1

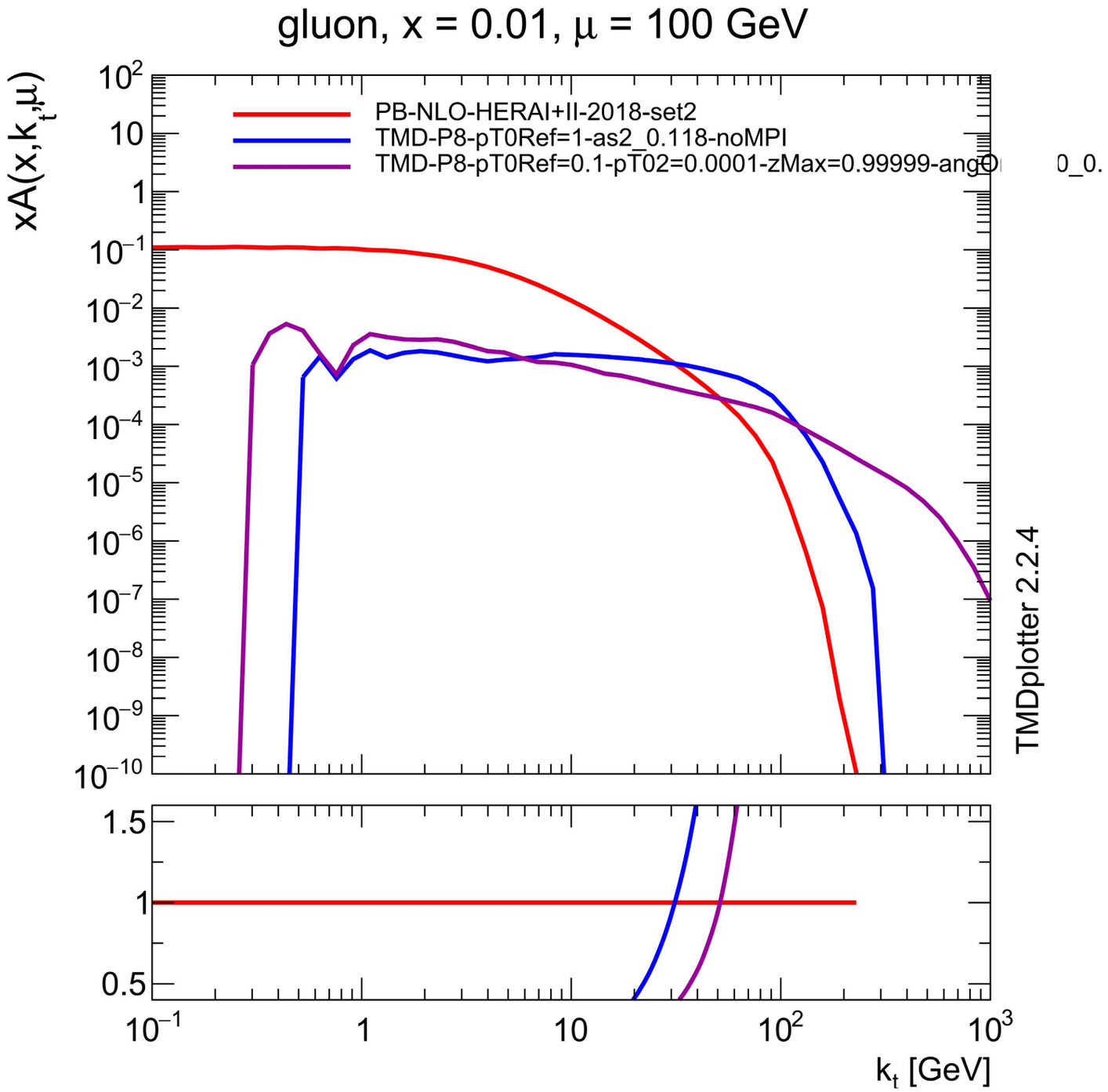
Checks in PYTHIA8

- Determine effective TMD from PYTHIS8 parton shower
  - use Toy hard process with shower, fill TMDlib grid
- First check, that integrated parton distribution is reproduced



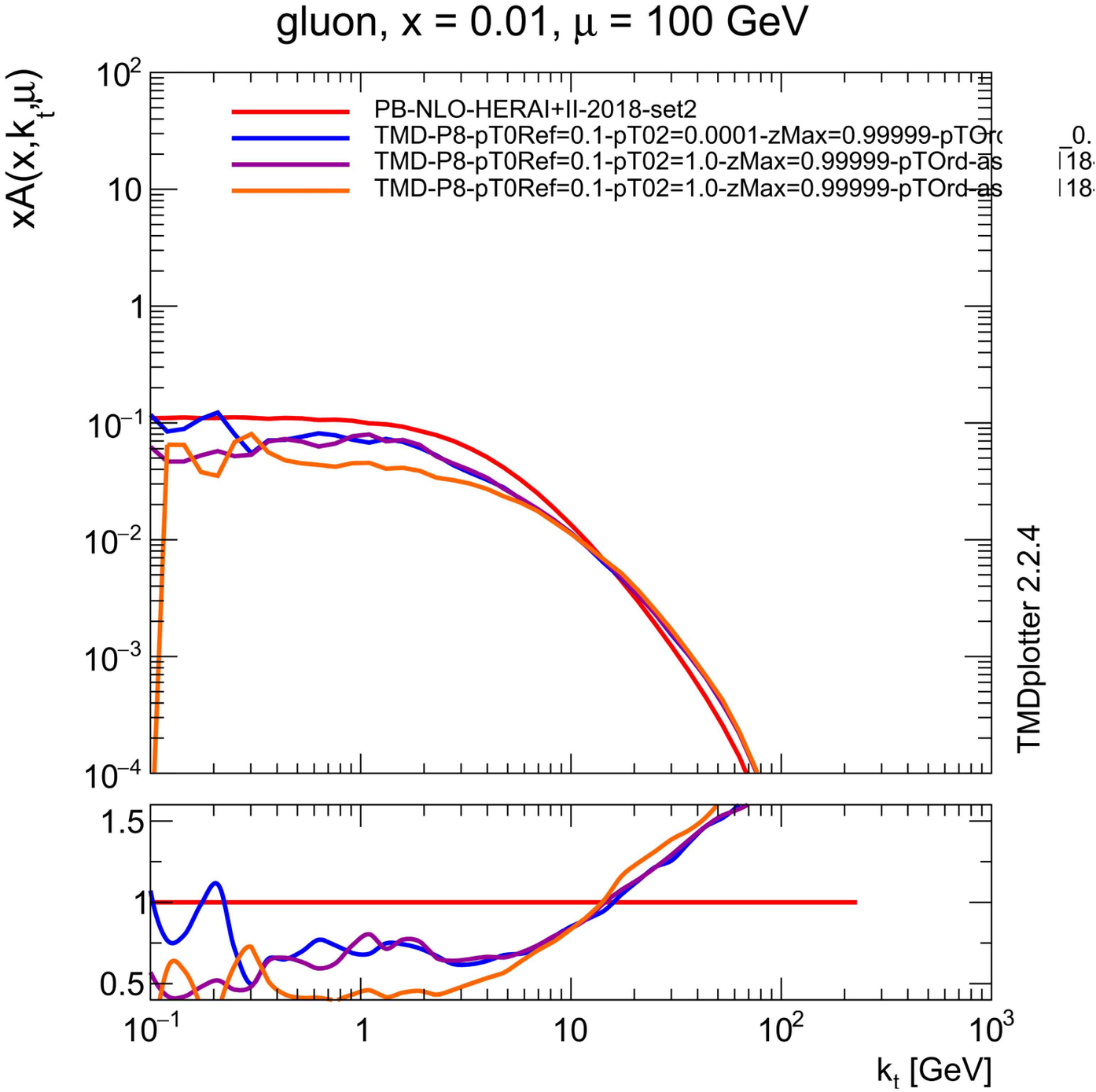
Checks in PYTHIA8

- Determine effective TMD from PYTHIS8 parton shower
  - use Toy hard process with shc fill TMDlib grid
- First: Check, that integrated parto distribution is reproduced
- Second: Check transverse mome distribution (as in DY)



Checks in PYTHIA8

- Determine effective TMD from PYTHIS8 parton shower
  - use Toy hard process with show fill TMDlib grid
- **First**: Check, that integrated partor distribution is reproduced
- **Second**: Check transverse momentum distribution (as in DY)
- **Third**: change ordering condition ir P8



Checks in PYTHIA8

- With simple changes in PYTHIA8, very similar shape to PB TMDs can be obtained.
  - Change of ordering condition
  - Looks very promising
    - next: Discussion with PYTHIA authors

Next steps

- Investigate predictions of P8 with different UE tunes and changing pT0ref:
  - in DY pt spectrum very significant changes are observed- dependence on width of intrinsic kt distribution
  - Do we observe similar effect in soft particle production ?
    - Do we see sensitivity to intrinsic kt distribution ?

- Run $dn/d\eta$ for different pT0ref in initial state shower
  - check also different intrinsic kt widths.

- Do we need a PYTHIA8 setup for these studies (can be easily provided)...

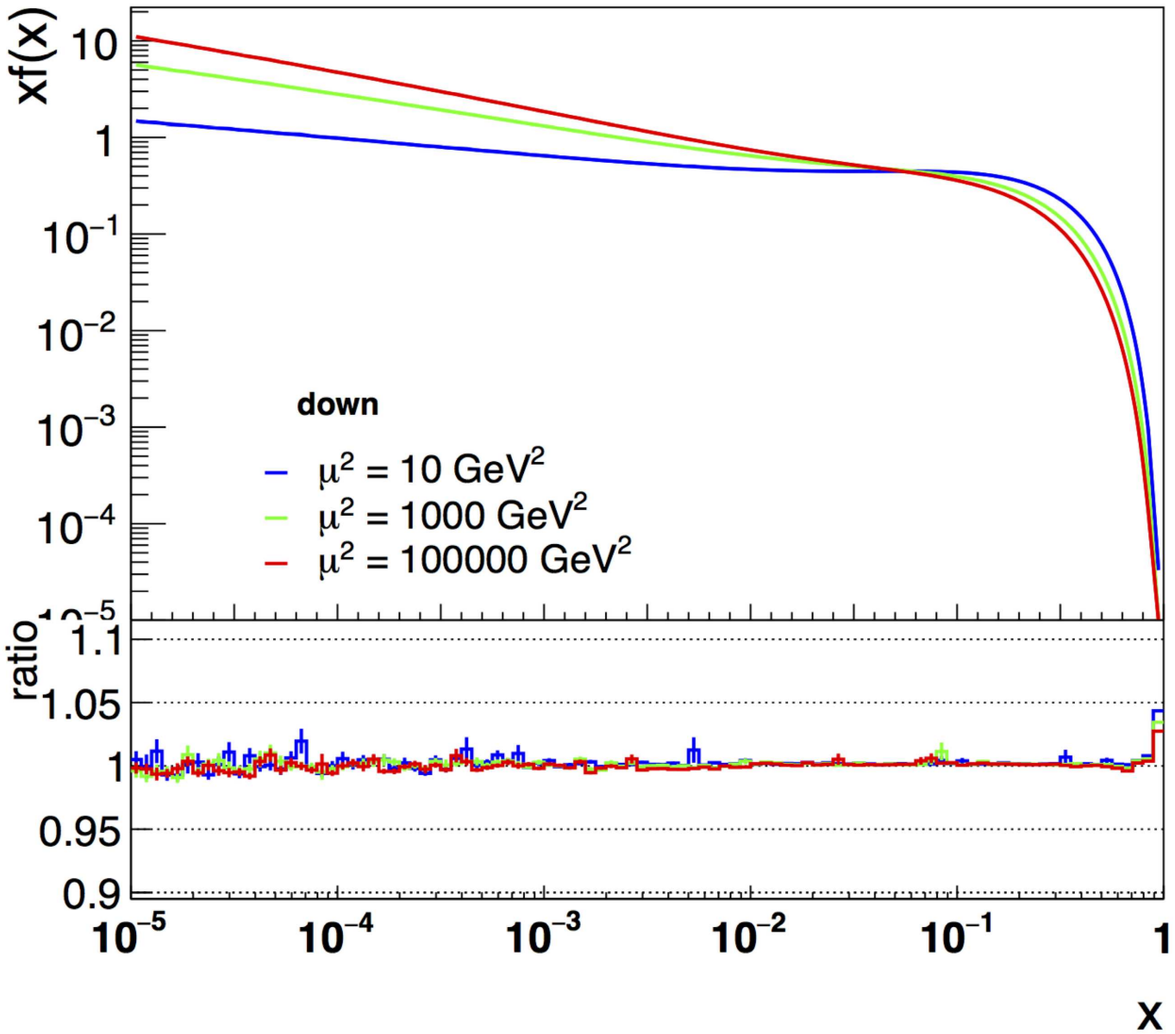
Future program

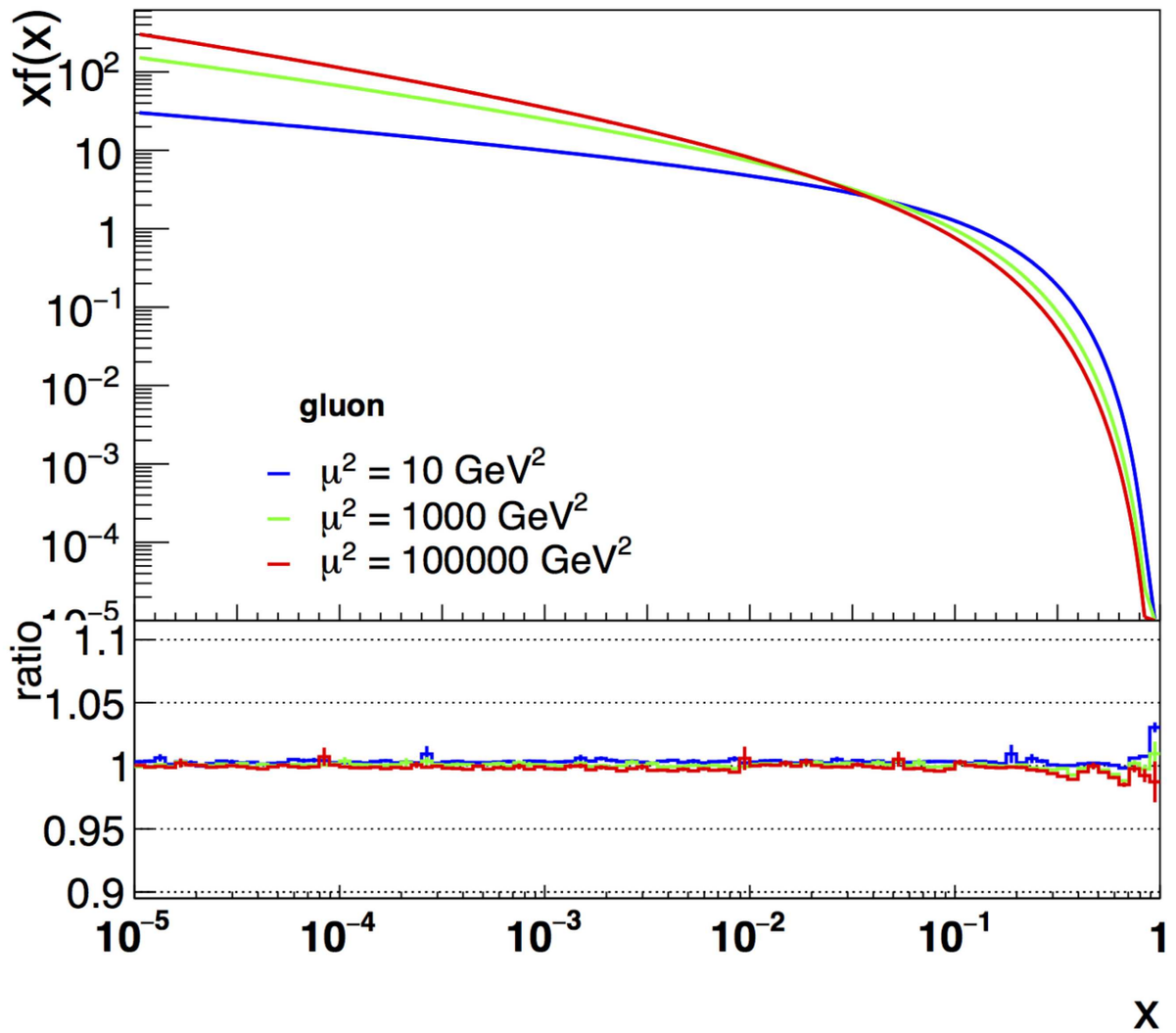
- Extend our Thursday meetings to a discussion on Parton Branching and Pythia8
  - **invite also other interested people**

- Aim of the meetings should be on progress reports but also on learning MC techniques and the structure of Monte Carlo event generators

Appendix

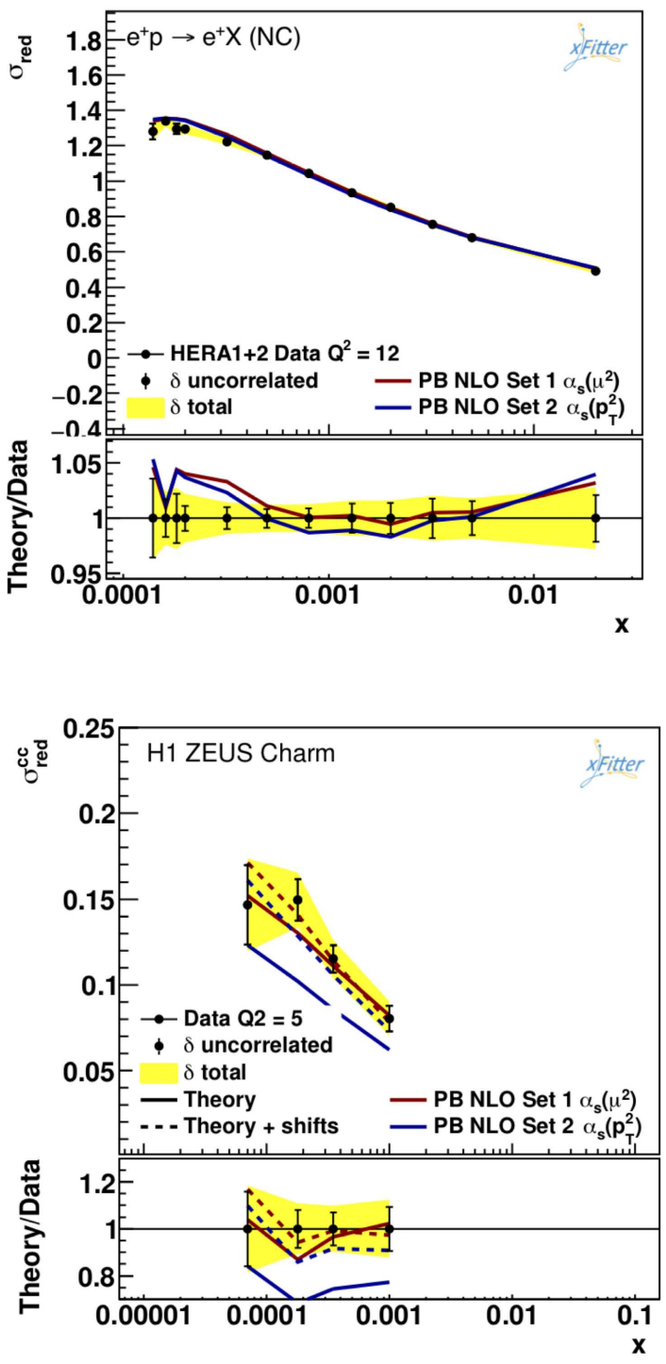
Validation of method with QCDnum at NLO

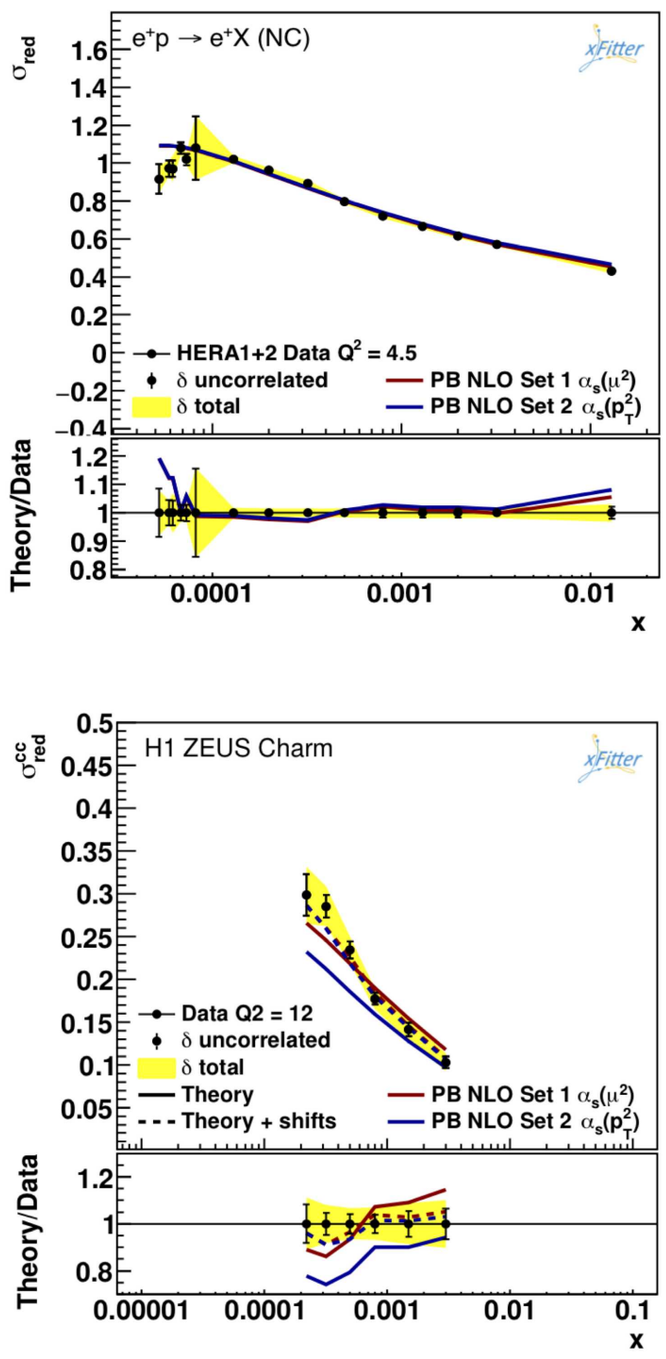


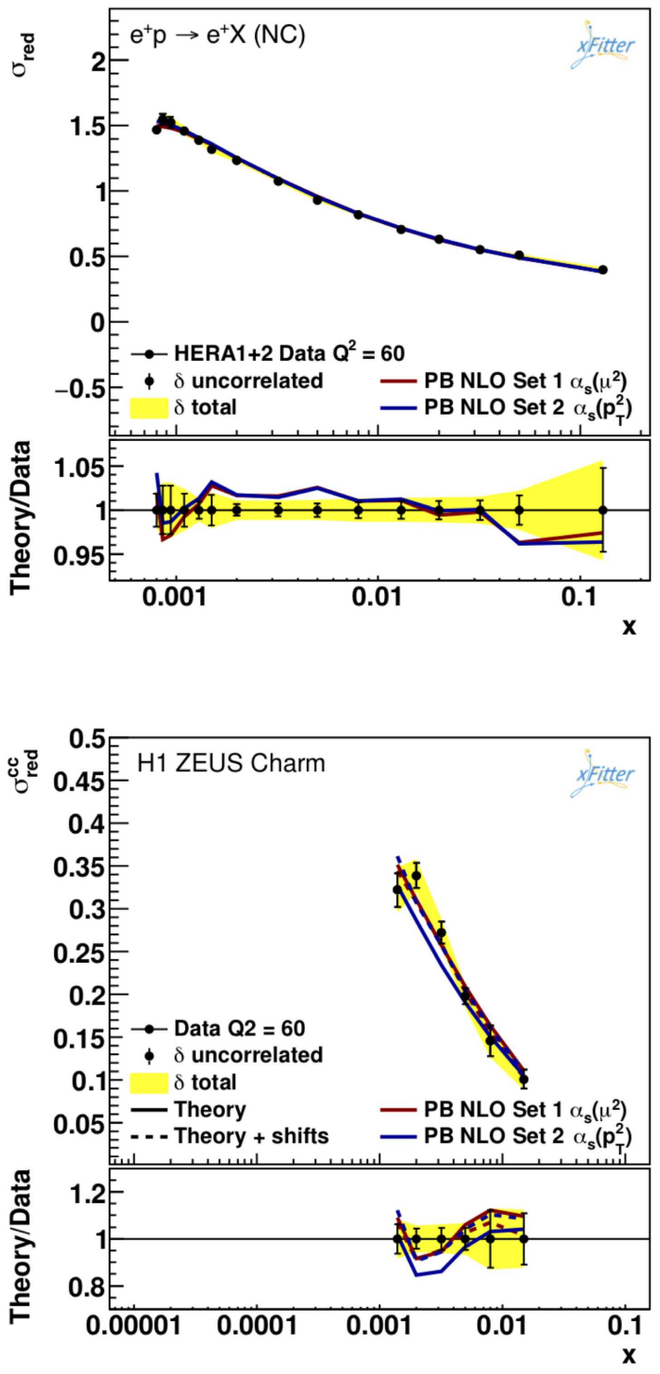


- Very good agreement with NLO - QCDnum over all x and μ^2
  - the same approach works also at NNLO !

Fits to DIS x-section at NLO: F_2 and F_2^c

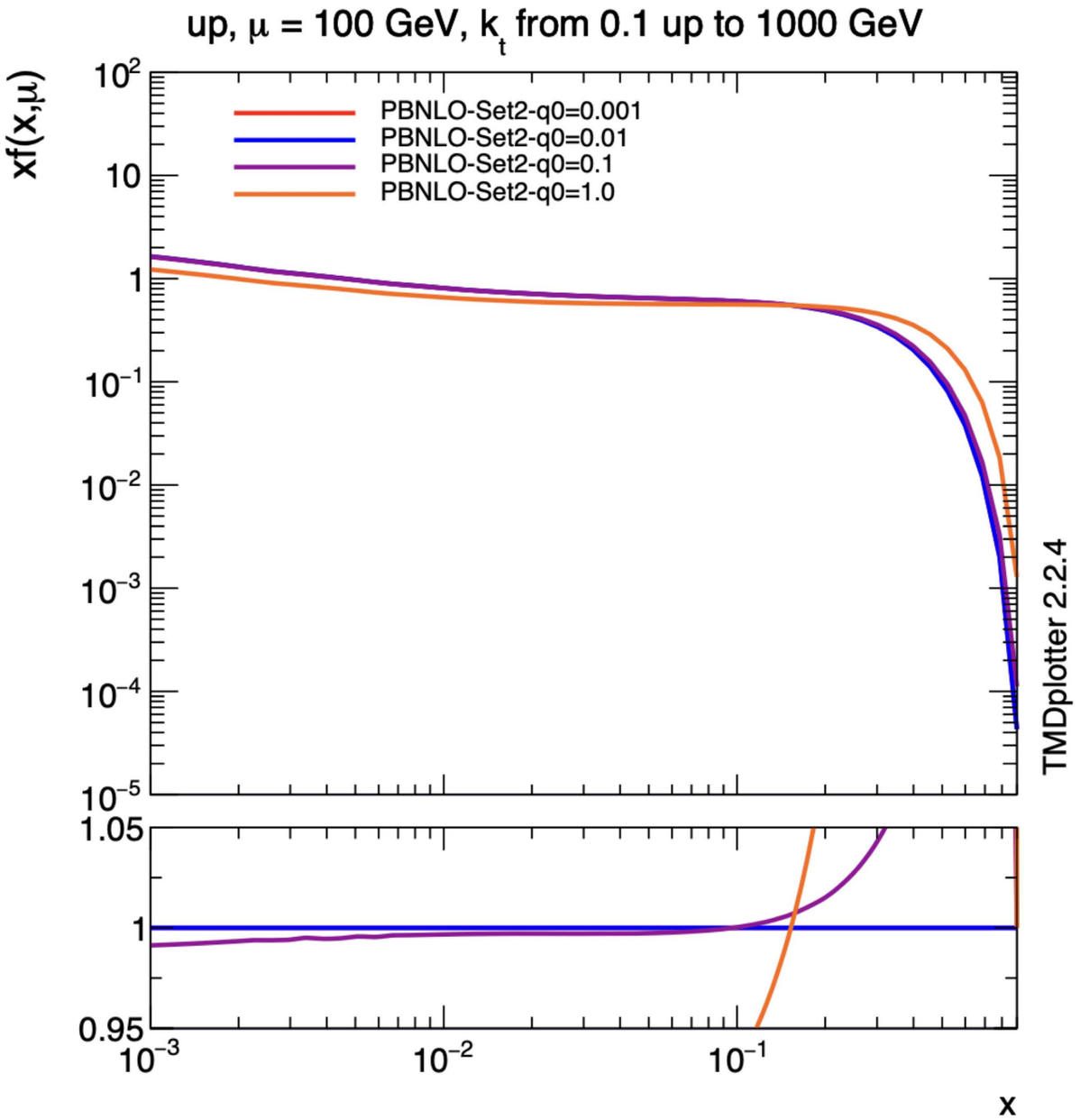


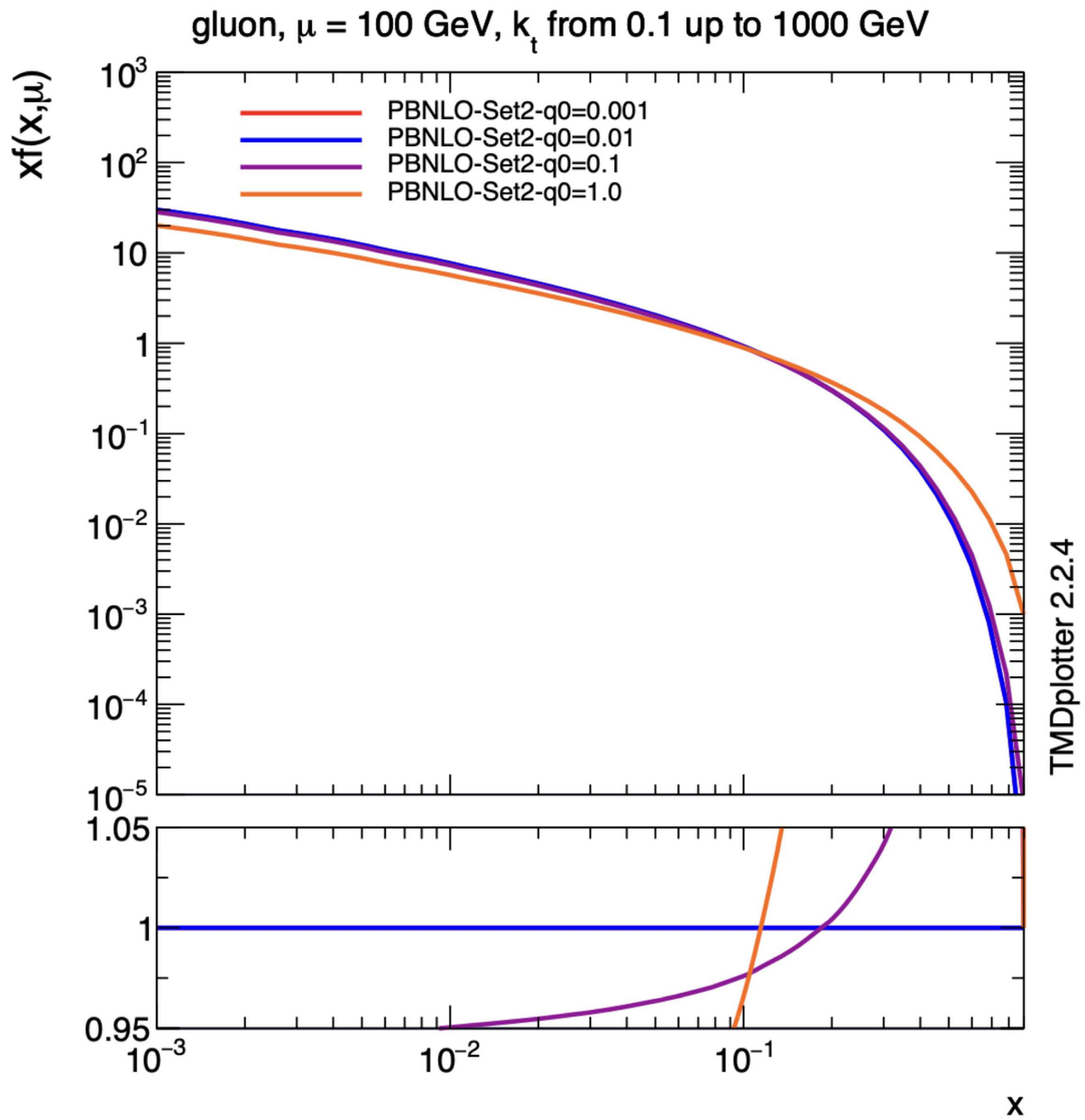




Role of soft gluons in inclusive distributions

- Perform evolution with PB method with and without cut $z_{\rm dyn} = 1 - \dfrac{q_{t\ \rm cut}}{\mu'}$

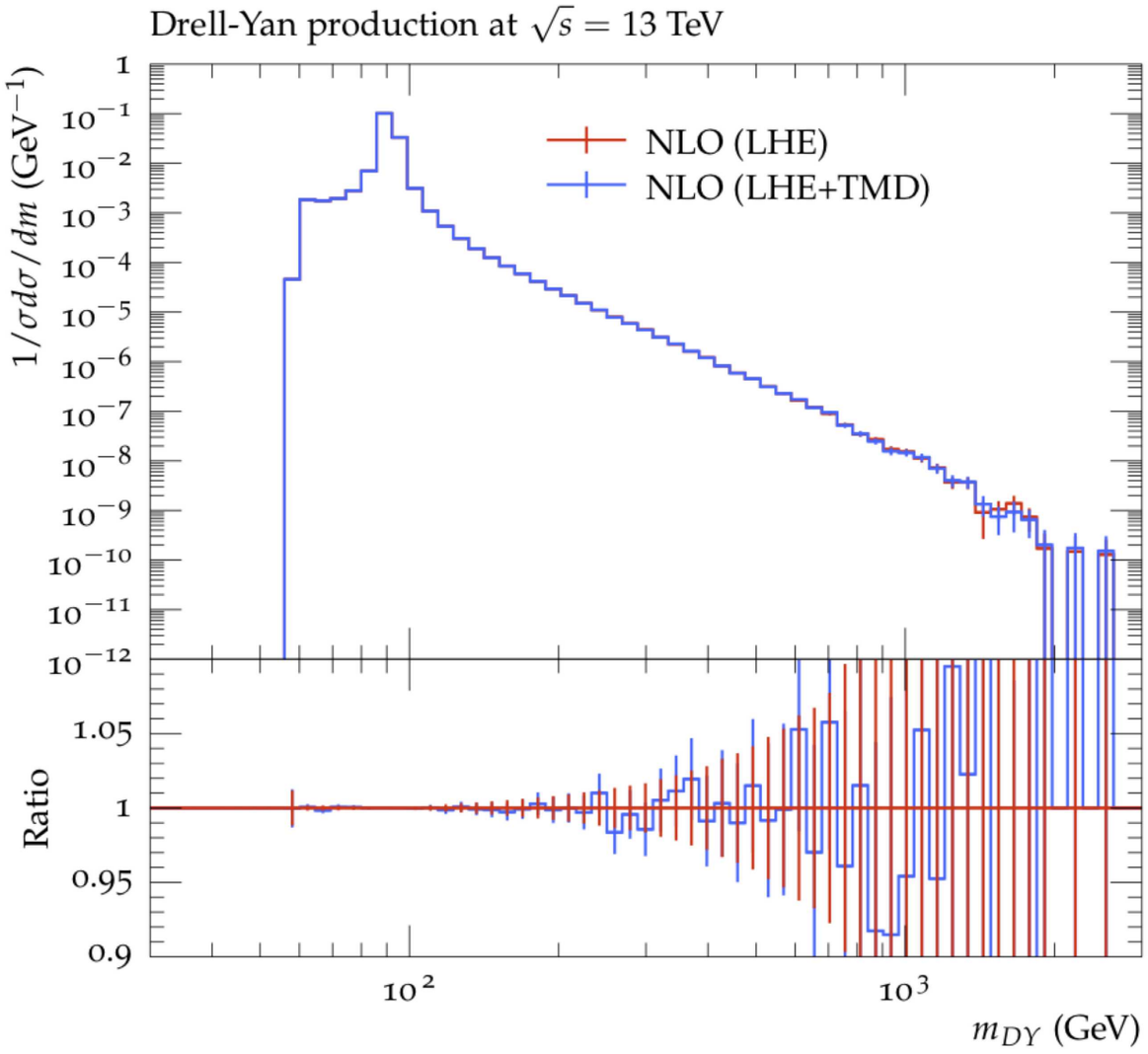


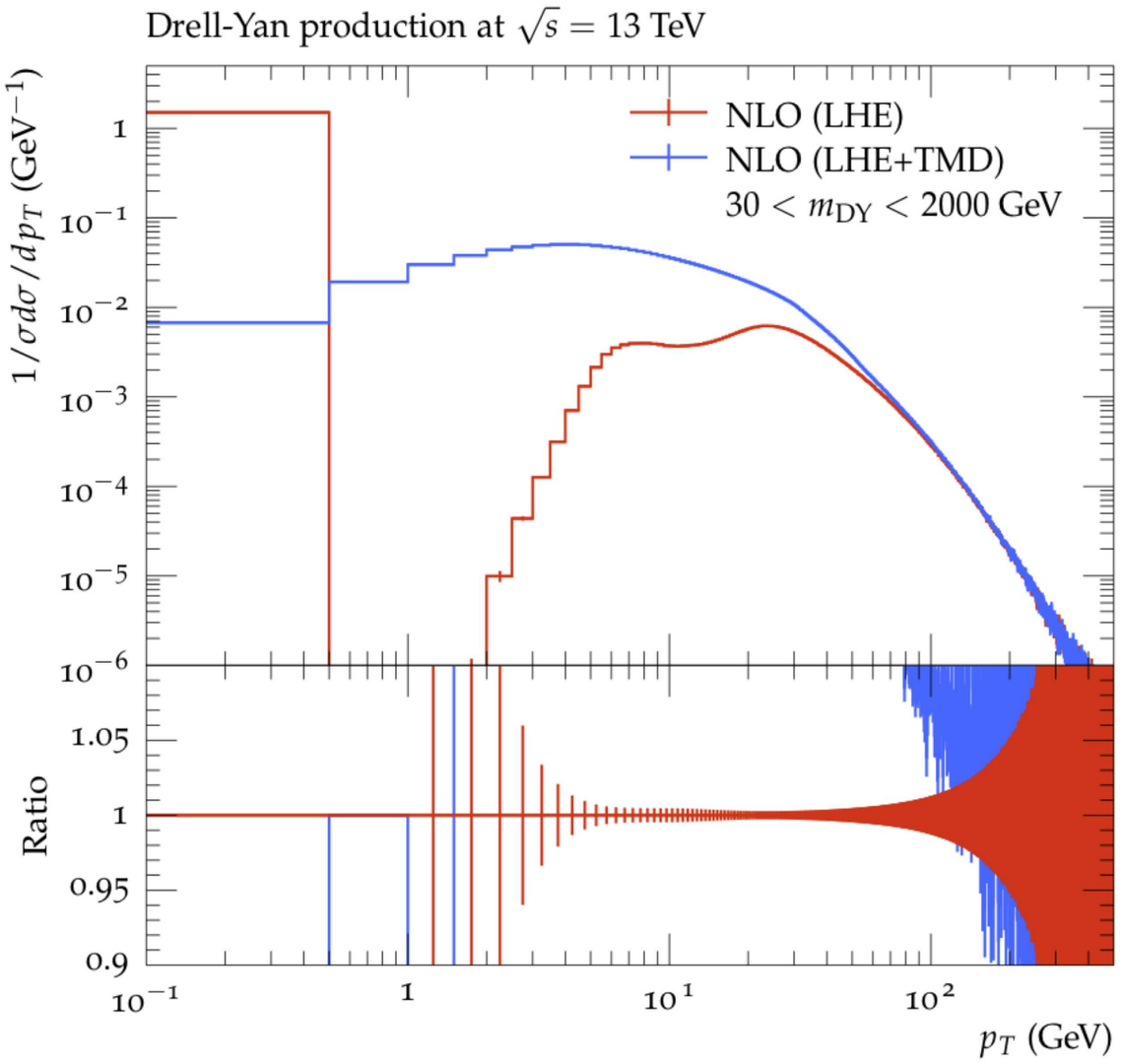


Including TMDs for DY production with MC@NLO

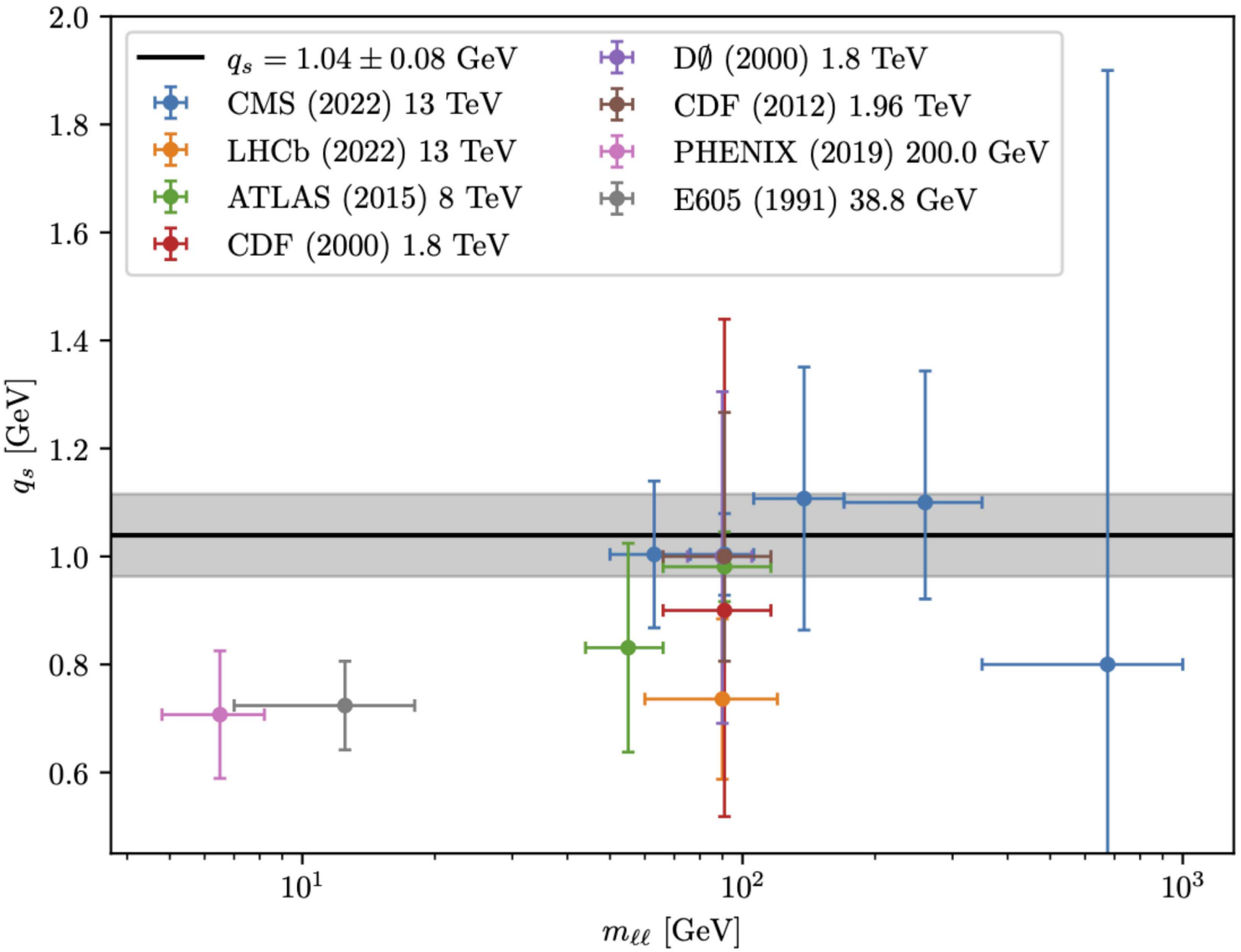
DY production: Bermudez Martinez, A. et al, arXiv 1906.00919, 2001.06488
CASCADE3 S. Baranov et al, arXiv 2101.10221

- MC@NLO subtracts soft & collinear parts
  from NLO (added back by TMD and/or parton shower)
  - MC@NLO without shower and/or TMD unphysical (here herwig6 subtraction)





Fit of Intrinsic k_T in DY – production vers m_{DY}



Bubanja, I. et al, arXiv: 2312.08655

- Gauss with zero mean, width q_s

$$\sim \exp\left(-|k_T^2|/q_s^2\right)$$

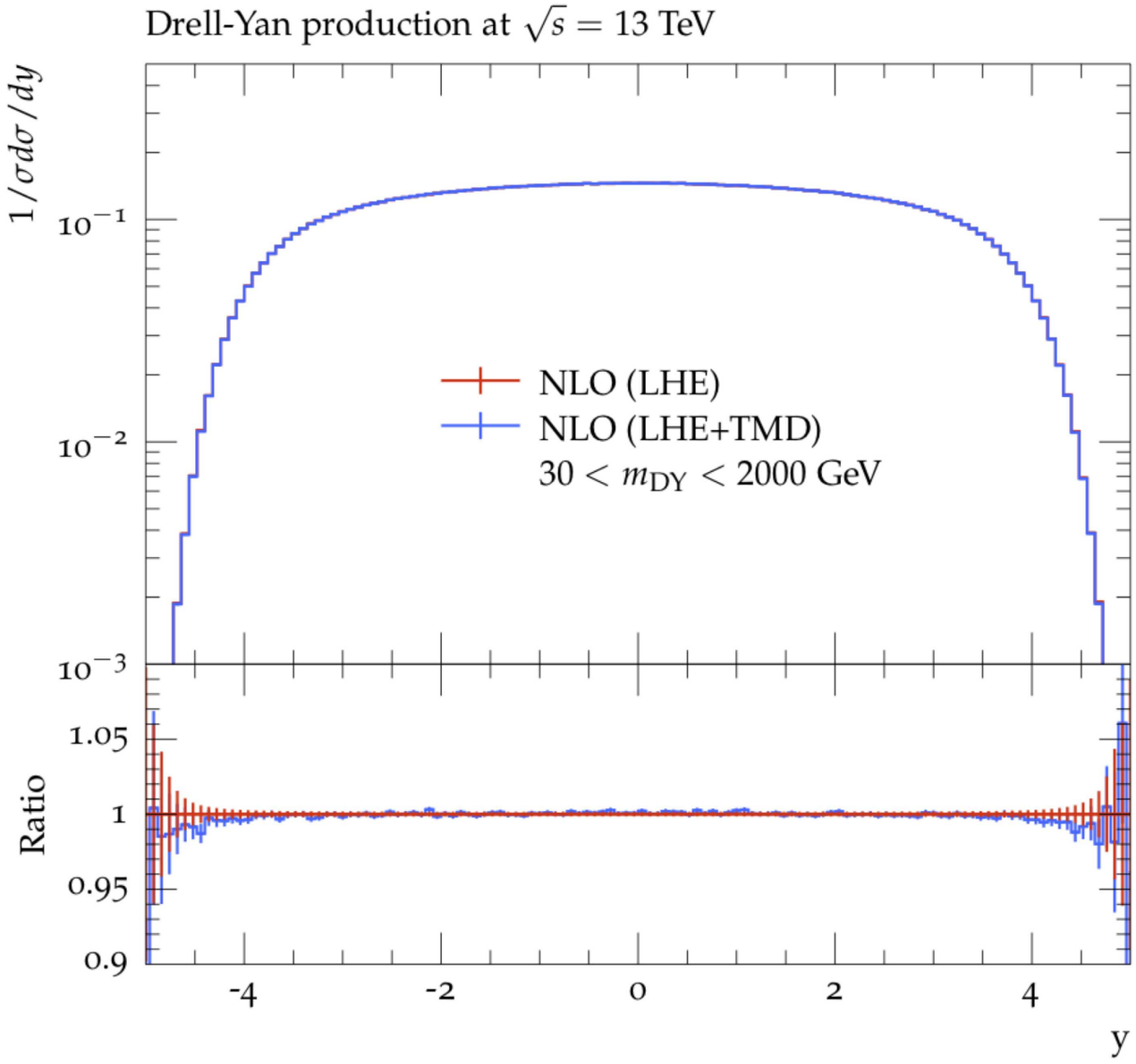
Fit to determine q_s of intrinsic k_T distribution from DY production as a function of m_{DY}

- obtain q_s rather independent on m_{DY}

Including TMDs for Z production with MC@NLO

- Are other features of DY production preserved ?

DY production: Bermudez Martinez, A. et al, arXiv 1906.00919, 2001.06488
CASCADE3 S. Baranov et al, arXiv 2101.10221



- Rapidity of DY pair not changed … (but x_1 and x_2)