Rencontres de Moriond 2013, La Thuile, March 2013

Longitudinal shifts, showering and nonperturbative corrections in matched NLO-shower event generators

F. Hautmann (Oxford)

- collaboration with S. Dooling, P. Gunnellini and H. Jung

Eur. Phys. J. C72 (2012) 2254 [arXiv:1209.6549 [hep-ph]]; arXiv:1212.6164 [hep-ph]

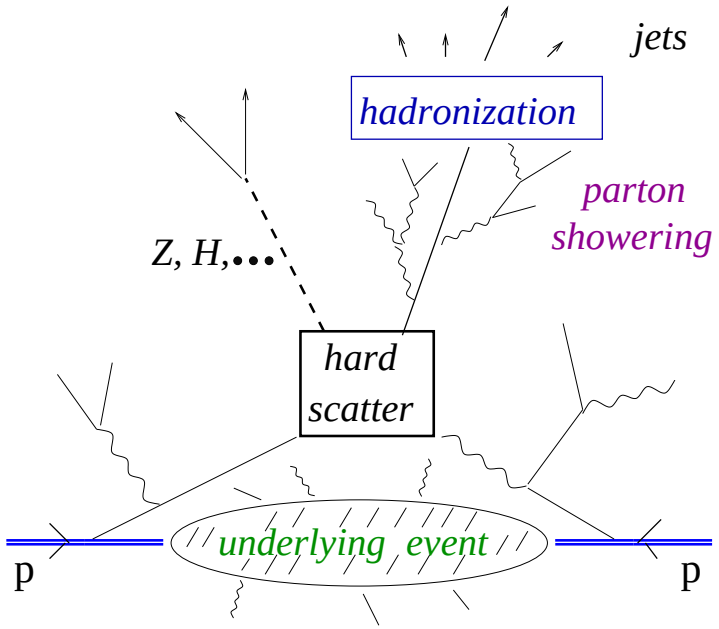
OUTLINE

I. Motivation: (multi-)jet final states at the LHC

II. Showering and nonperturbative corrections from Monte Carlo event generators

III. Collinearity approximations and kinematic shifts in parton shower algorithms

I. Motivation: jets in pp collisions

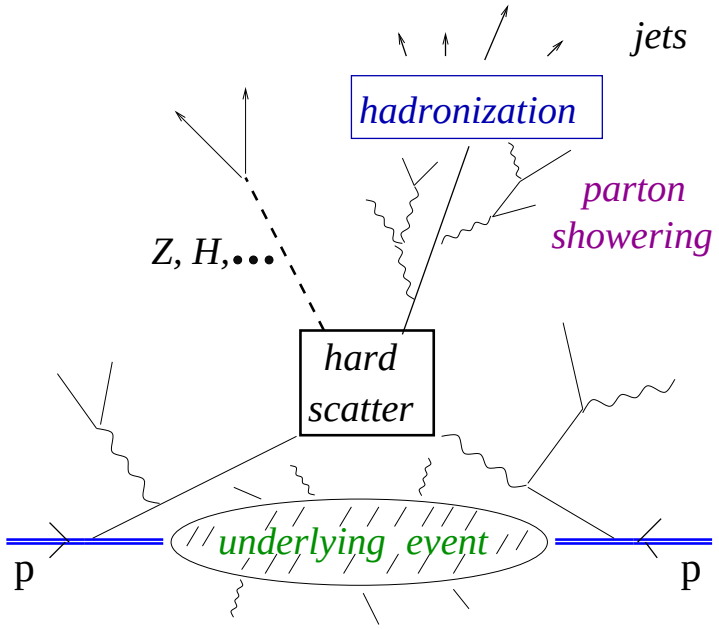


♠ Complex jet final states associated with massive SM / BSM states:

- background to searches
- detailed understanding of QCD physics

⇒ QCD factorization, parton shower evolution, resummations;

QCD tuning of MC event generators



- Baseline standard model predictions:

— NLO QCD calculations $\oplus$ NP (nonperturbative) corrections from MC

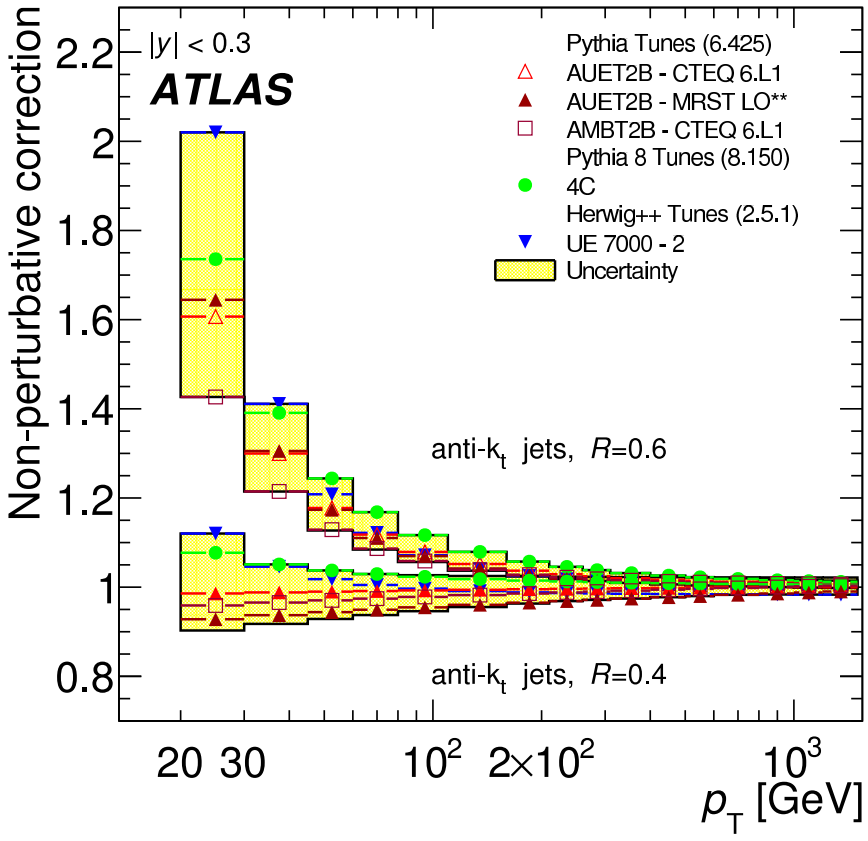
— NLO-matched shower event generators

[See, e.g., Nason and Webber, arXiv:1202.1251,

Höche and Schönherr, arXiv:1208.2815]

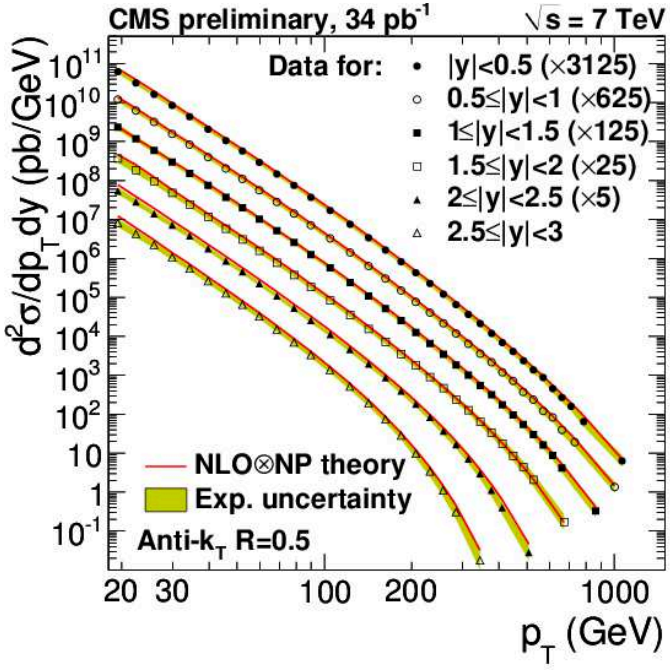
ATLAS Non-perturbative Correction

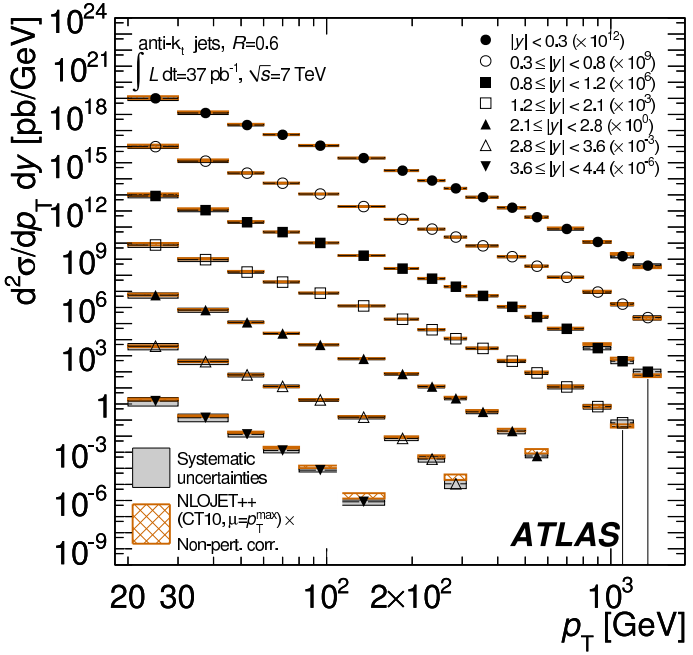
[ATLAS, PRD86 (2012) 014022]



- hadronization $\oplus$ underlying events
- jet size dependence

♠ Jets measured at the LHC over kinematic range much larger than in any previous collider experiment



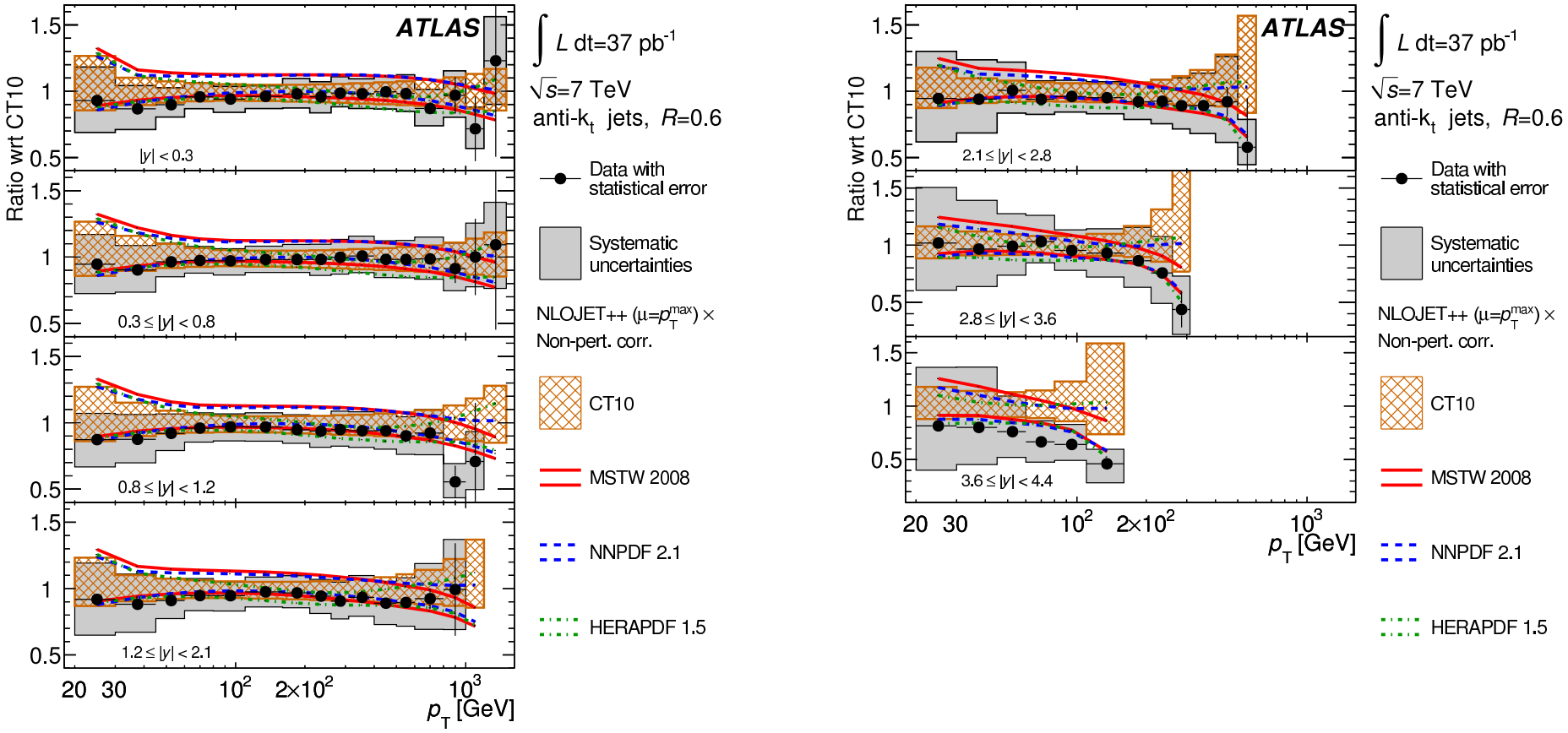


CMS, PRL 107 (2011) 132001; arXiv:1212.6660 *ATLAS, PRD 86 (2012) 014022*

- agree with NLO ⊕ NP for central rapidities and inclusive cross sections
- challenge theory in the case of
  - — high rapidity
  - — multi-jet observables

Inclusive jets

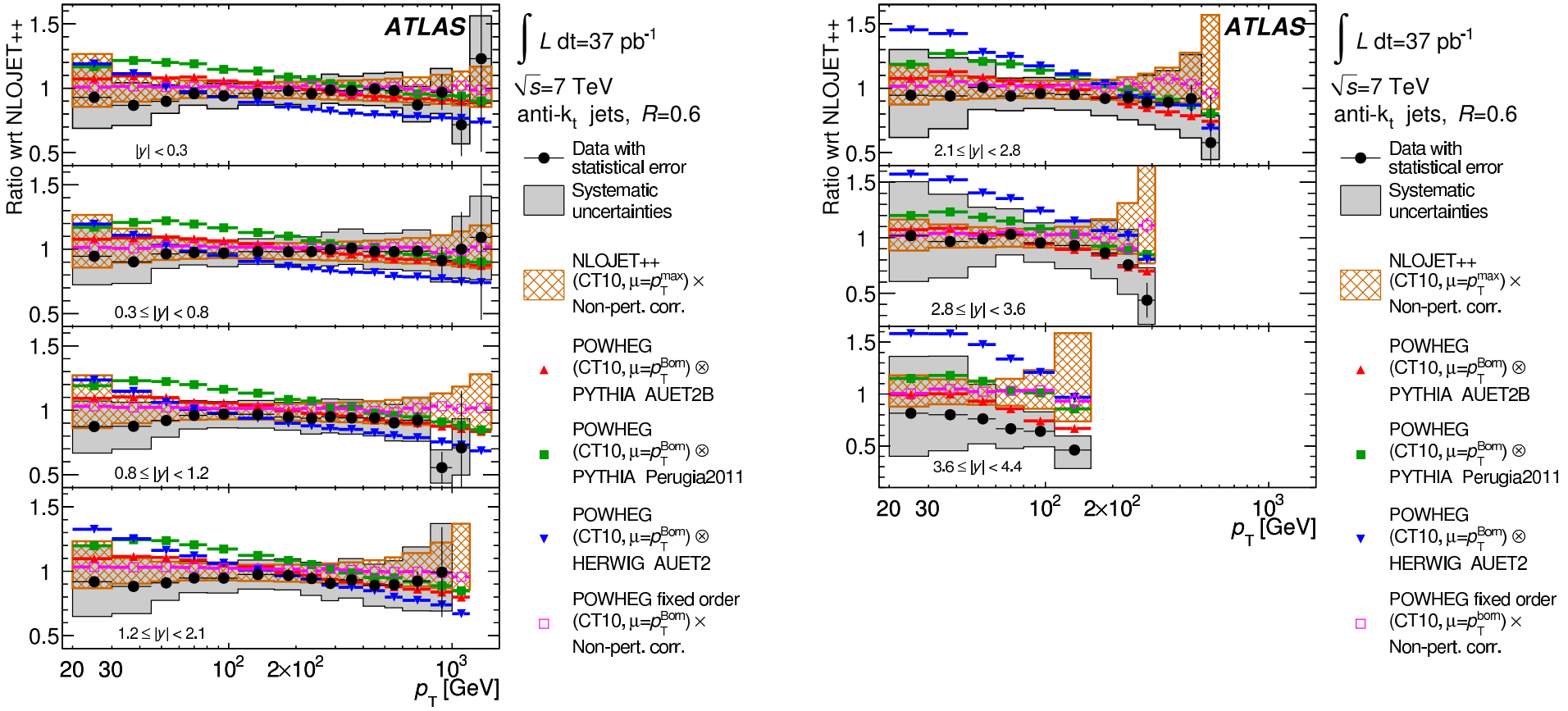
[ATLAS, Phys. Rev. D86 (2012) 014022 [arXiv:1112.6297]]



- NLO calculation agrees at central rapidities
- increasing deviations with increasing y for large p_T

Inclusive jets

[ATLAS, Phys. Rev. D86 (2012) 014022 [arXiv:1112.6297]]



- higher order radiation from parton shower in POWHEG significant
- large differences between POWHEG/ PYTHIA and POWHEG/ HERWIG at forward rapidities

II. NONPERTURBATIVE (NP) AND SHOWERING CORRECTIONS

• Estimates using leading order (LO-MC):

$$K_0^{NP} = N_{LO-MC}^{(ps+mpi+had)} / N_{LO-MC}^{(ps)}$$

[CMS, PRL 107 (2011) 132001; ATLAS, PRD86 (2012) 014022]

— natural definition with LO-MC

— but affected by potential inconsistency if combined with NLO parton-level results

• Alternatively, assign NP correction factors by using NLO-MC:

[Dooling, Gunnellini, Jung & H, arXiv:1212.6164 [hep-ph]]

$$K^{NP} = N_{NLO-MC}^{(ps+mpi+had)} / N_{NLO-MC}^{(ps)}$$

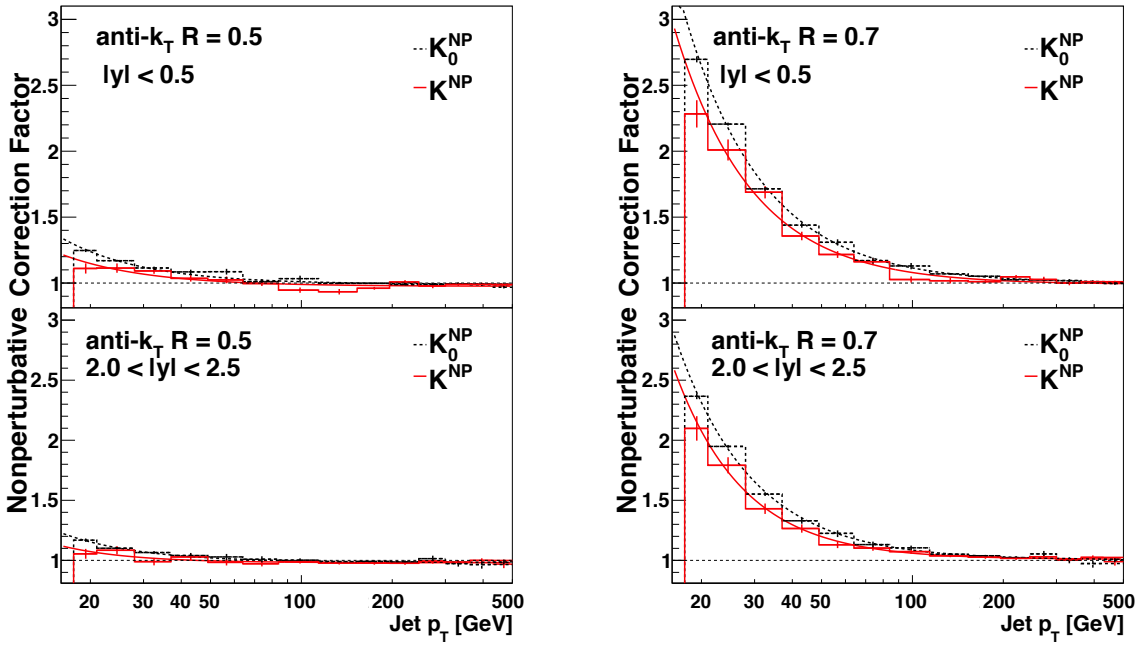
$$K^{PS} = N_{NLO-MC}^{(ps)} / N_{NLO-MC}^{(0)}$$

♣ K^{NP} differs from K_0^{NP}

♣ K^{PS} is new: not considered in previous analyses

The K^{NP} correction factor to jet transverse momentum distributions

[Dooling, Gunnellini, Jung & H, arXiv:1212.6164 [hep-ph]]

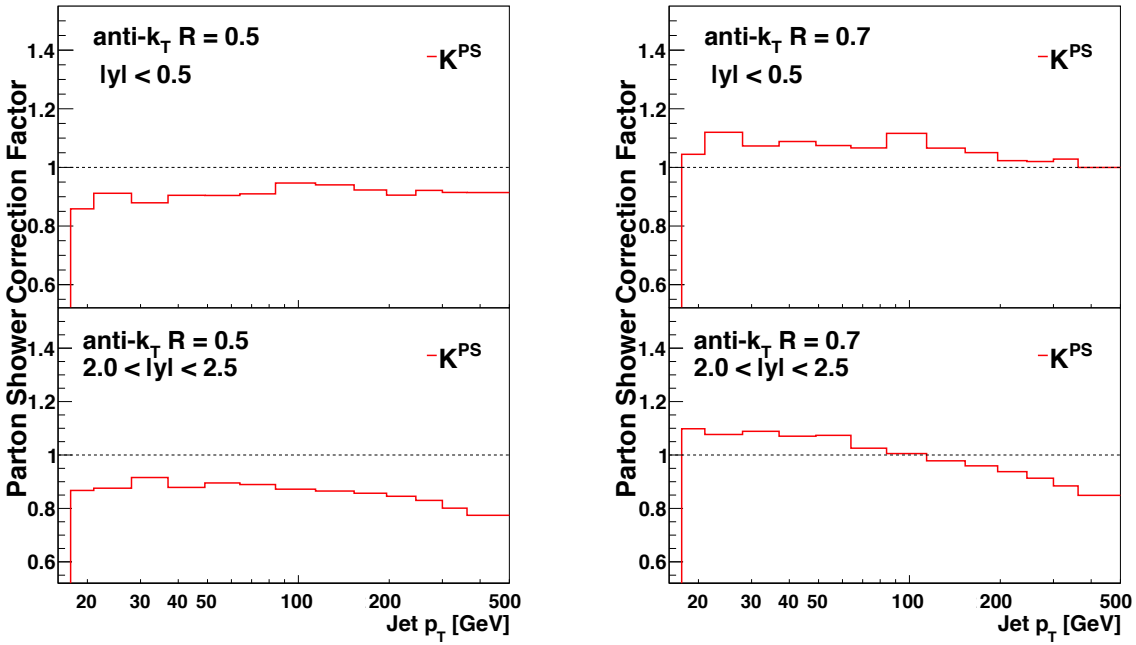


▷ non-negligible differences from definition of the hard process

▷ MPI p_T cut-off scale different in the LO and NLO cases

The K^{PS} correction factor to jet transverse momentum distributions

[Dooling, Gunnellini, Jung & H, arXiv:1212.6164 [hep-ph]]

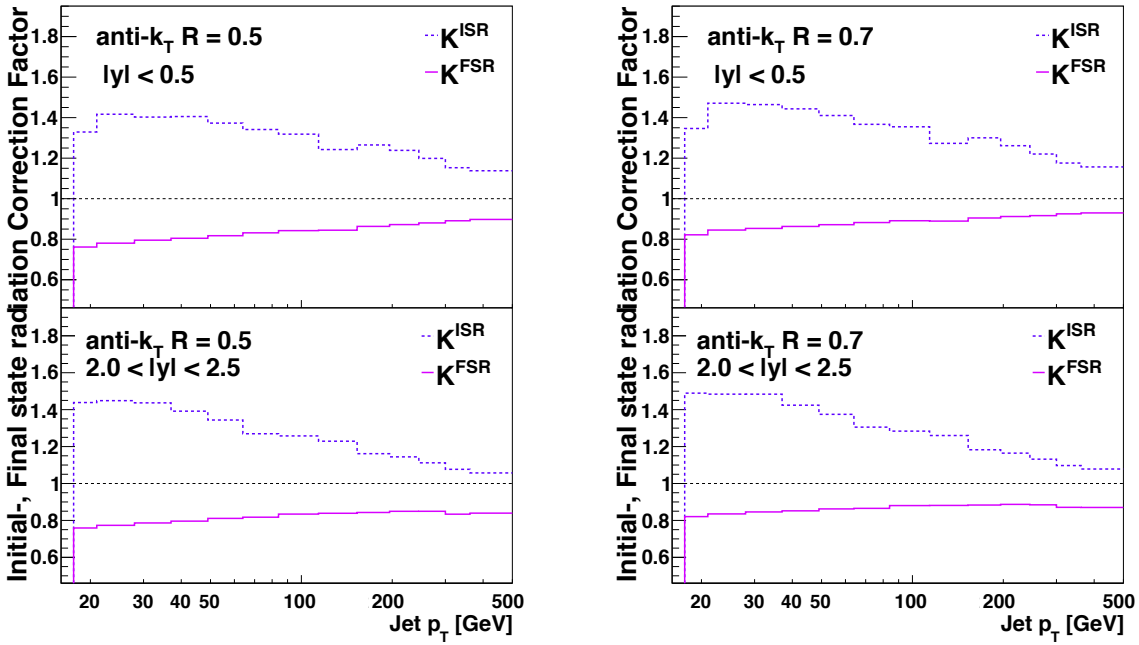


▷ not just a "K-factor" — y and p_T dependent, especially when rapidity is non-central

▷ unlike the NP correction, finite effects also at large p_T

Initial-state shower and final-state shower contributions to K^{PS}

[Dooling, Gunnellini, Jung & H, arXiv:1212.6164 [hep-ph]]

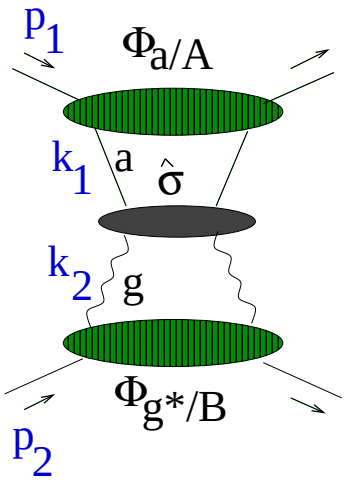


▷ ISR and FSR inter-related ⇒ combined effect not additive — may dip below FSR only

▷ ISR largest at low p_T, FSR significant for all p_T

III. LONGITUDINAL MOMENTUM SHIFTS FROM INITIAL STATE PARTON SHOWERS

[Jung & H, EPJC 72 (2012) 2254 [arXiv:1209.6549]]



To single−log accuracy in jet transverse momentum and rapidity

$k_1 = x_1 p_1$

$k_2 = x_2 p_2 + k_{T\,2}\,, \quad x_1 >> x_2$

Figure 1: Factorized structure of the jet cross section at high rapidity.

▷ Hard event generation $\Rightarrow$ $k_j^{(0)} = x_j p_j \quad (j = 1, 2)$

▷ Complete final states after showering $\Rightarrow$ $k_j \neq x_j p_j \quad (j = 1, 2)$

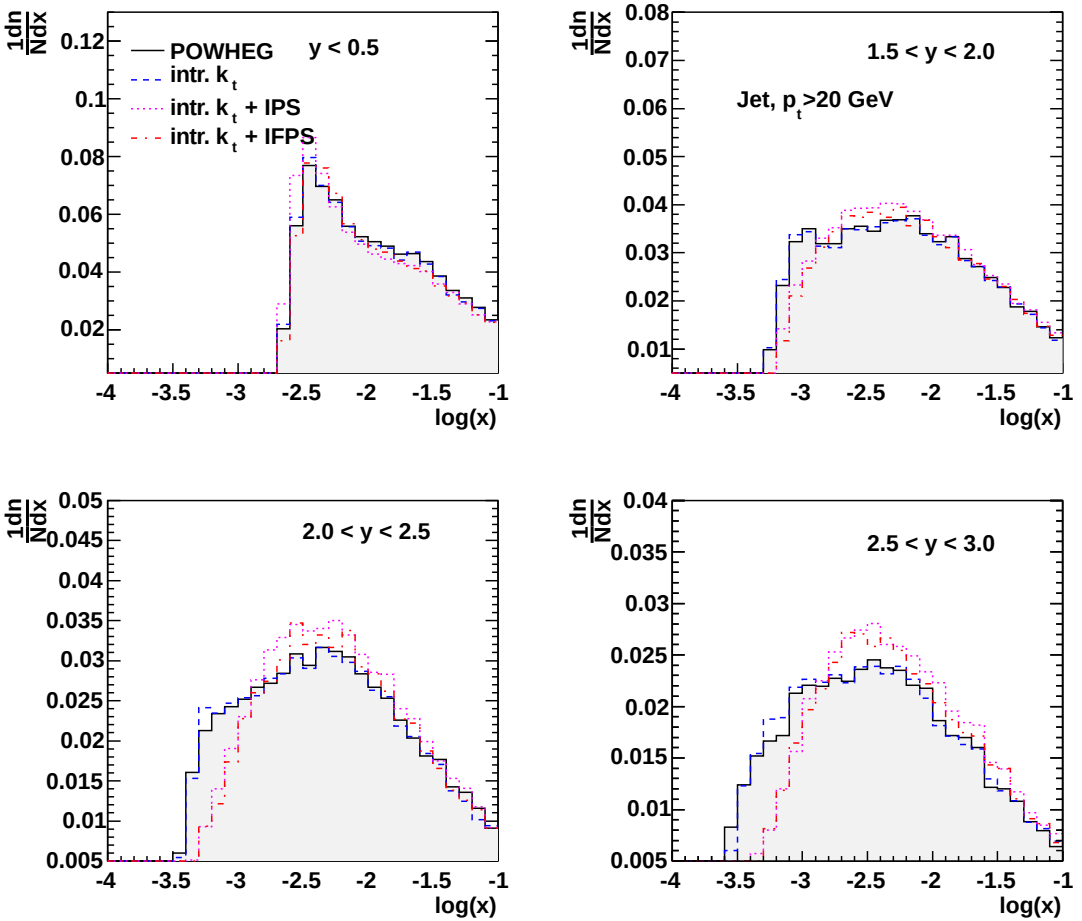
♠ Energy momentum conservation $\Rightarrow$ reshuffling in x

$\Rightarrow$ event-by-event longitudinal shift whose size depends on the observable and phase space region, and increases with increasing rapidity

Longitudinal momentum shifts

collinearity approximation $\oplus$ energy-momentum conservation $\Rightarrow$

$\Rightarrow$ kinematic shift in longitudinal momentum distributions due to showering

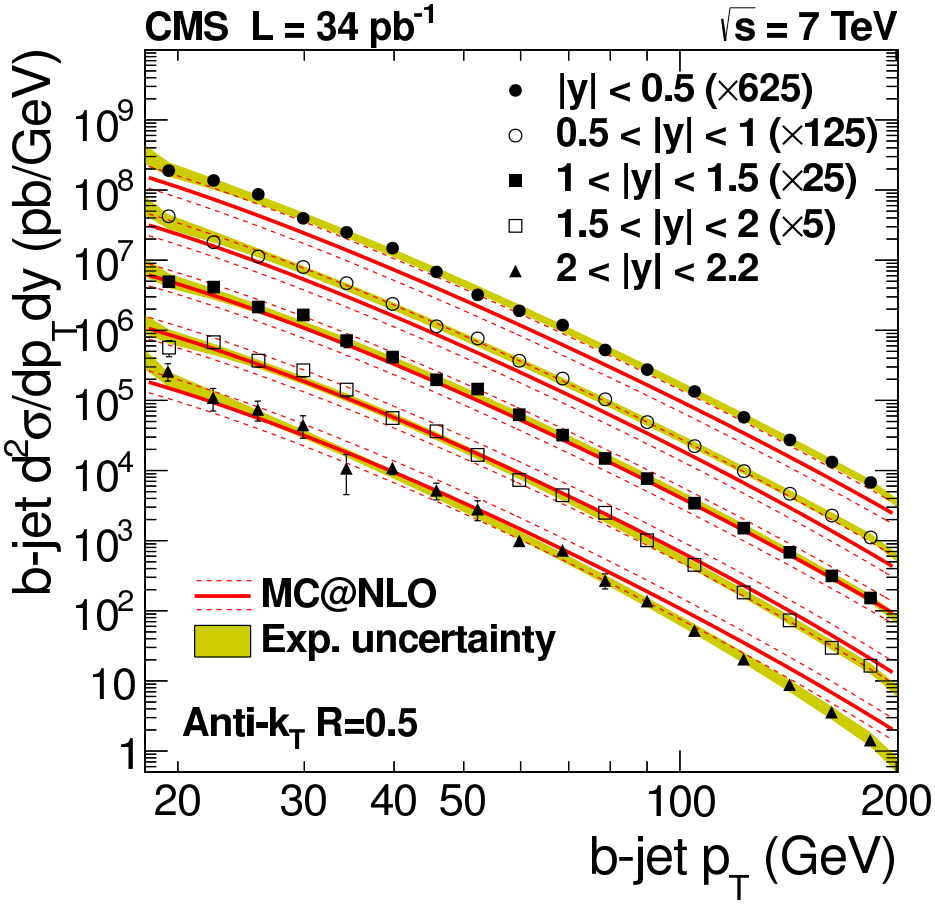


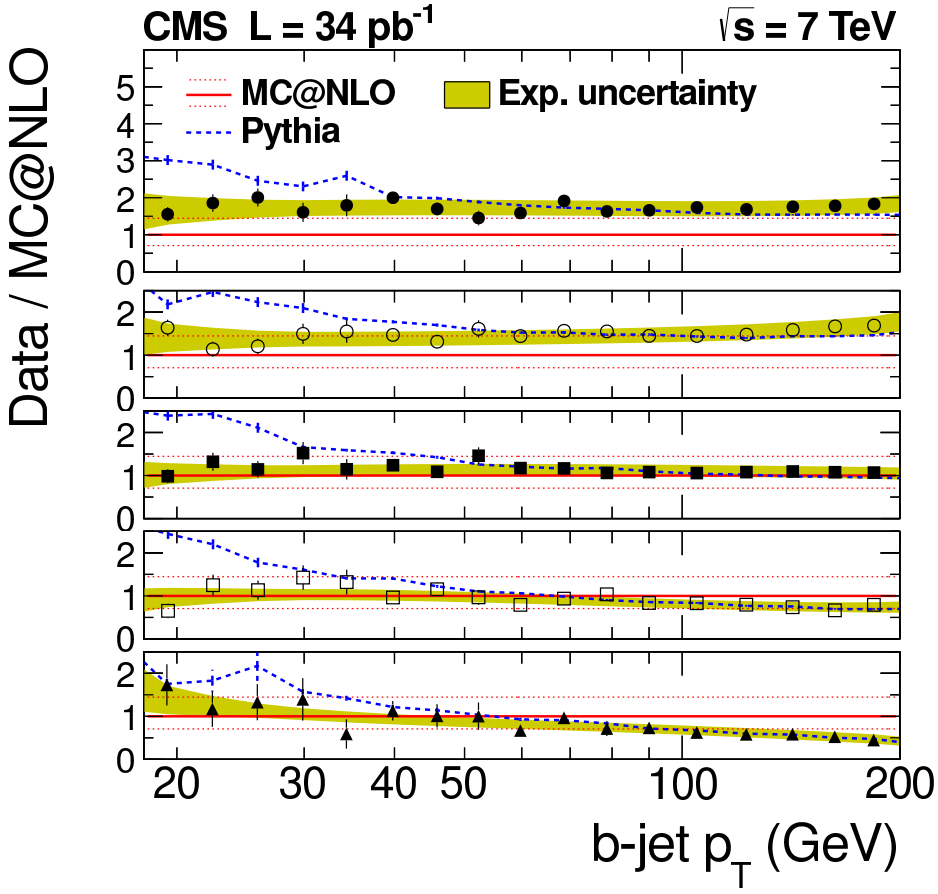
▷ small effect for central production; non-negligible for $y > 1.5$

HEAVY FLAVORS

Inclusive b-jets

[CMS, JHEP1204 (2012) 084 [arXiv:1202.4617]]

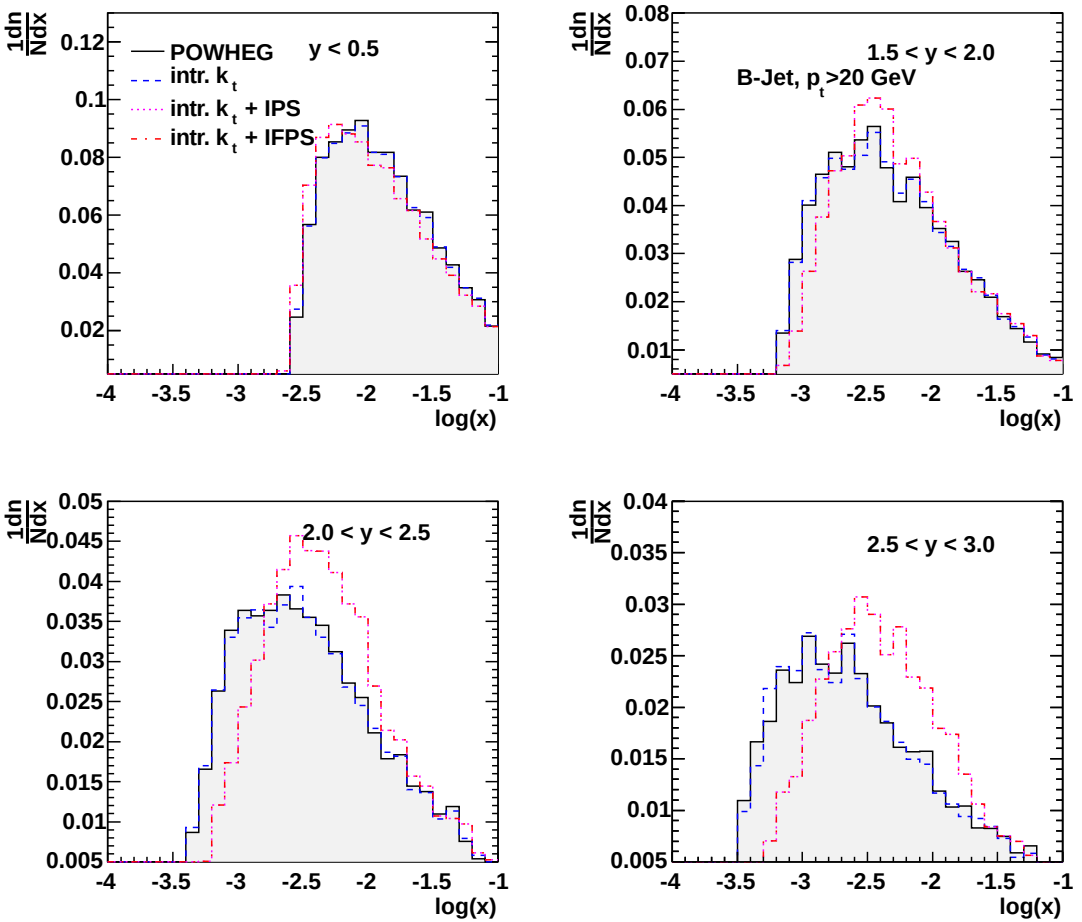




- reasonable description by NLO-matched shower MC@NLO at central rapidities
  - data below the prediction at large y and large p_T

Longitudinal momentum shifts in b-jet production

x distribution from POWHEG for b-jets before and after showering



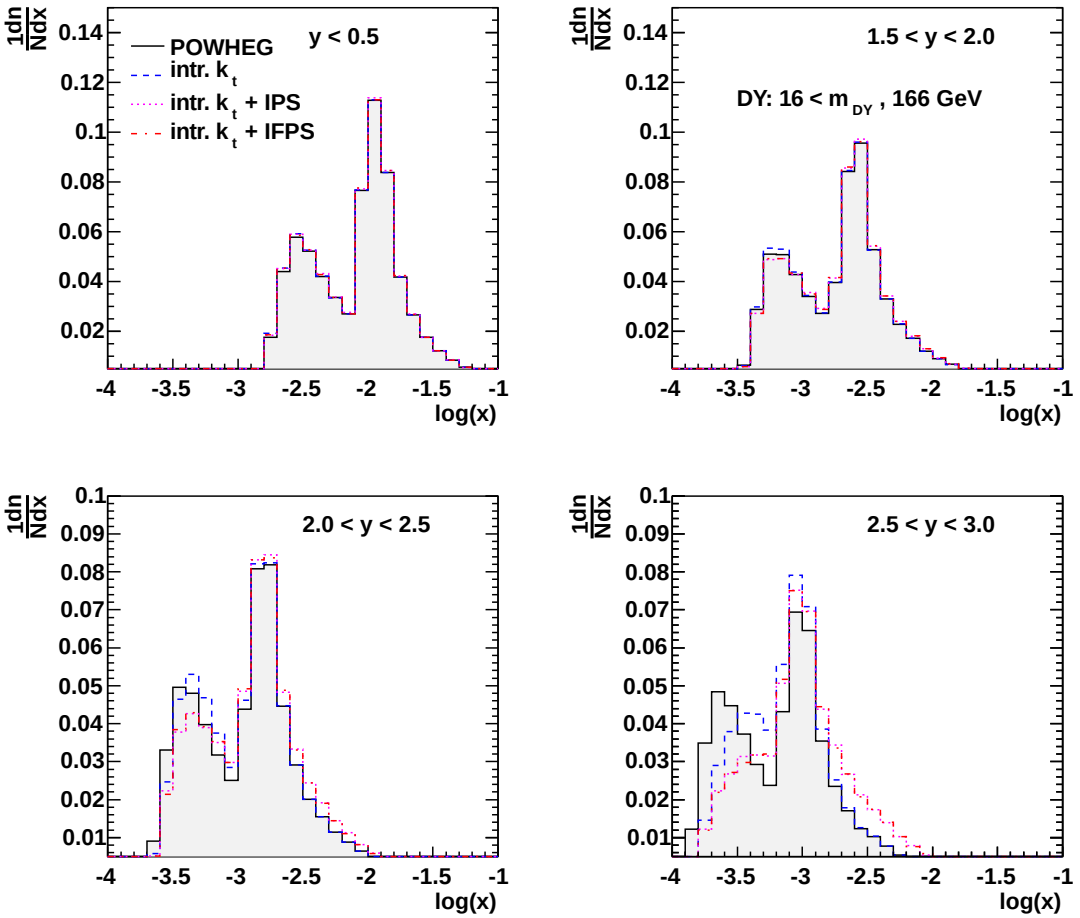
- reshuffling in momentum fractions x after showering

due to emitted $k_\perp$ and energy-momentum conservation

▷ non-negligible effect at large y

The Drell-Yan case

$16 < m_{DY} < 166$ GeV

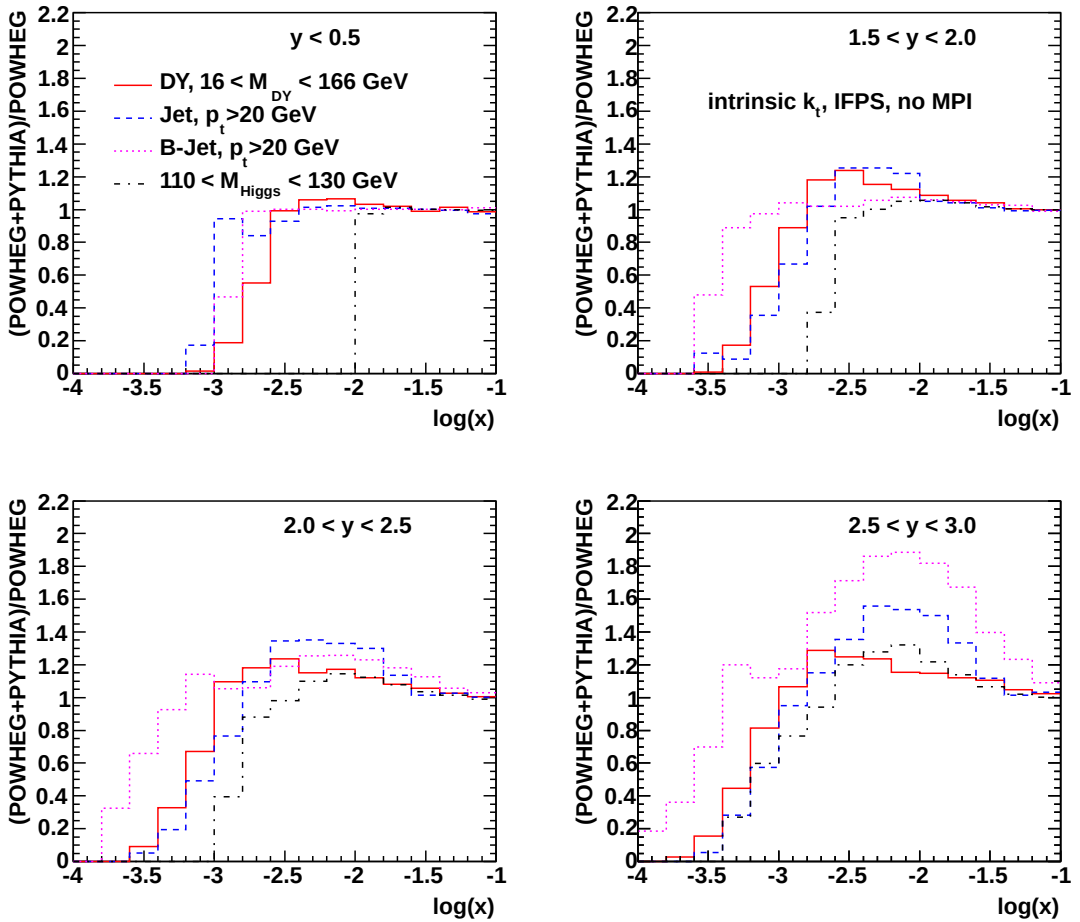


▷ double peak from continuum DY production

▷ cfr. dynamical forward DY enhancement *[Hentschinski, Jung & H, NPB865 (2012) 54]*

Ratio of cross sections after and before showering

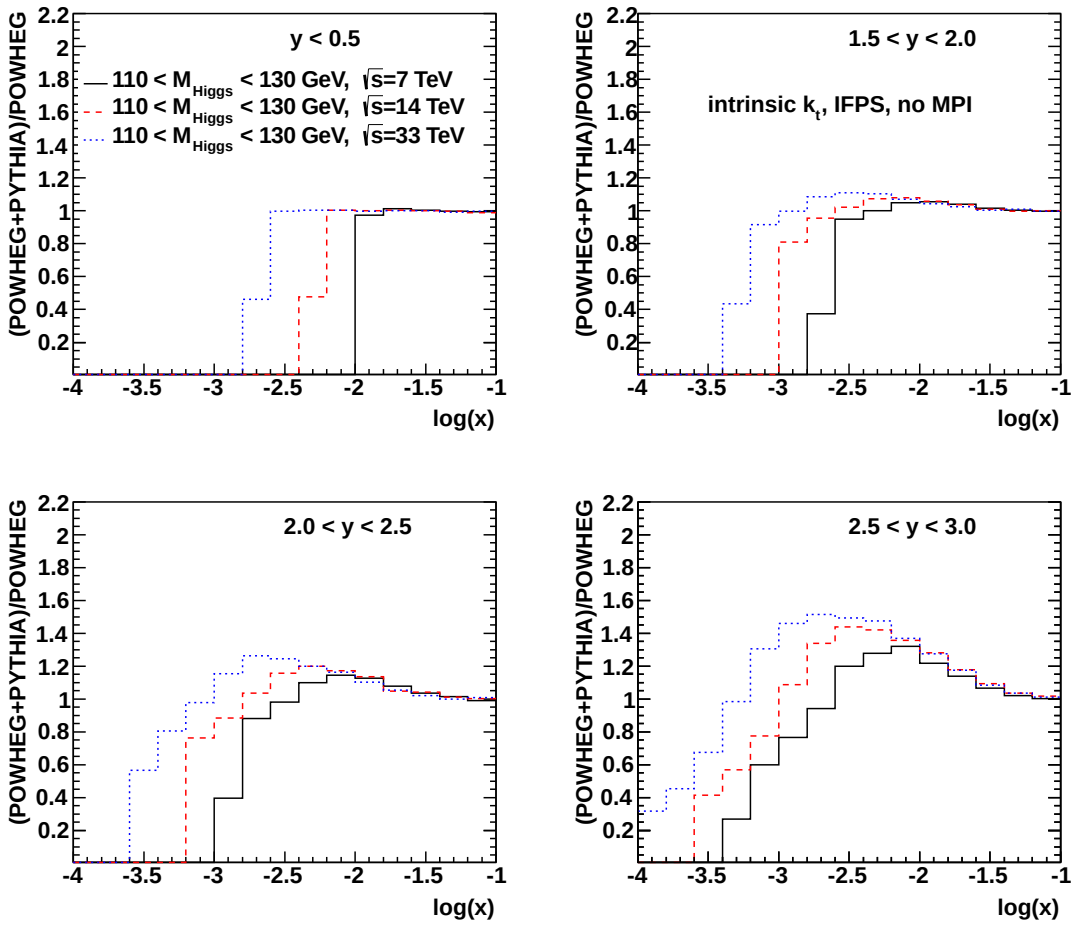
▷ versus longitudinal momentum fraction for different processes



- effect is common to any calculation matching NLO with collinear showers

Ratio after / before showering for Higgs production

▷ versus longitudinal momentum fraction for different energies



- more pronounced shift for increasing energy

CONCLUSIONS

• New definition of nonperturbative and showering correction factors affects comparisons of theory with measurements of final states containing jets

▷ non-negligible differences from K^{NP} at low to intermediate p_T

▷ K^{PS} significant over whole p_T range, largest at large y

▷ y and p_T dependence influences jet distributions shapes as well as pdfs

• Longitudinal momentum shifts from initial state showers

▷ largest for inclusive jets and b-flavor jets in higher rapidity bins

▷ non-negligible for forward DY and Higgs production with increasing energy

▷ impact of this region on total cross sections?

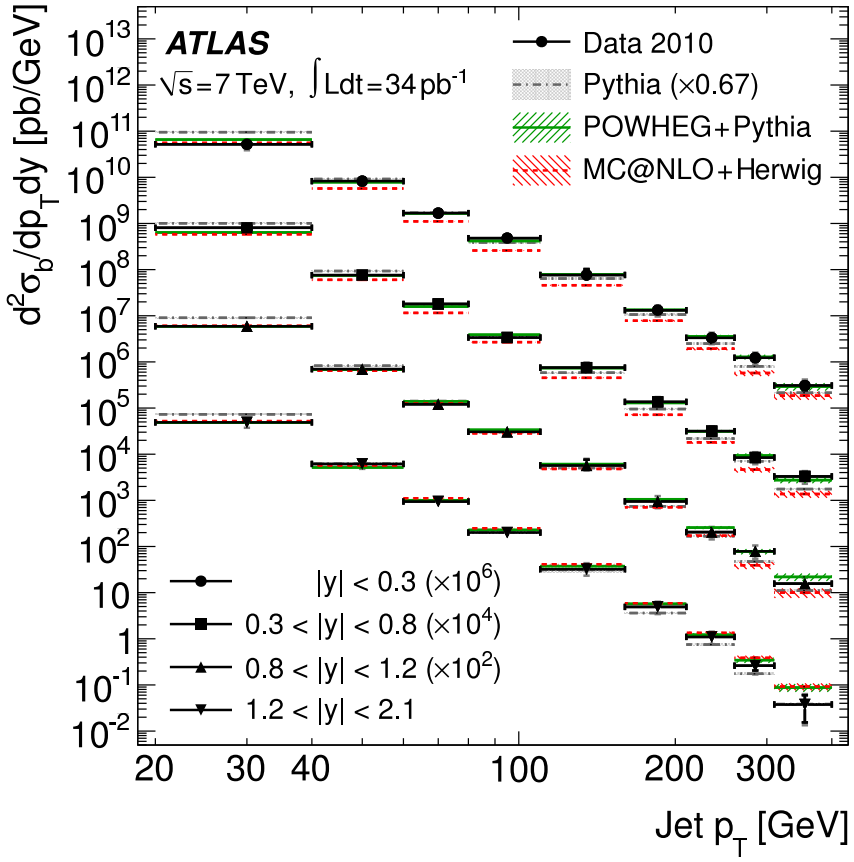
• Keep track of non-collinear momentum components from the outset?

$\Rightarrow$ new approaches to include nonperturbative effects (MPI, finite-k_T, hadronization) in shower generators

EXTRA SLIDES

Inclusive b-jets

[ATLAS, EPJC71 (2011) 1846 [arXiv:1109.6833]]

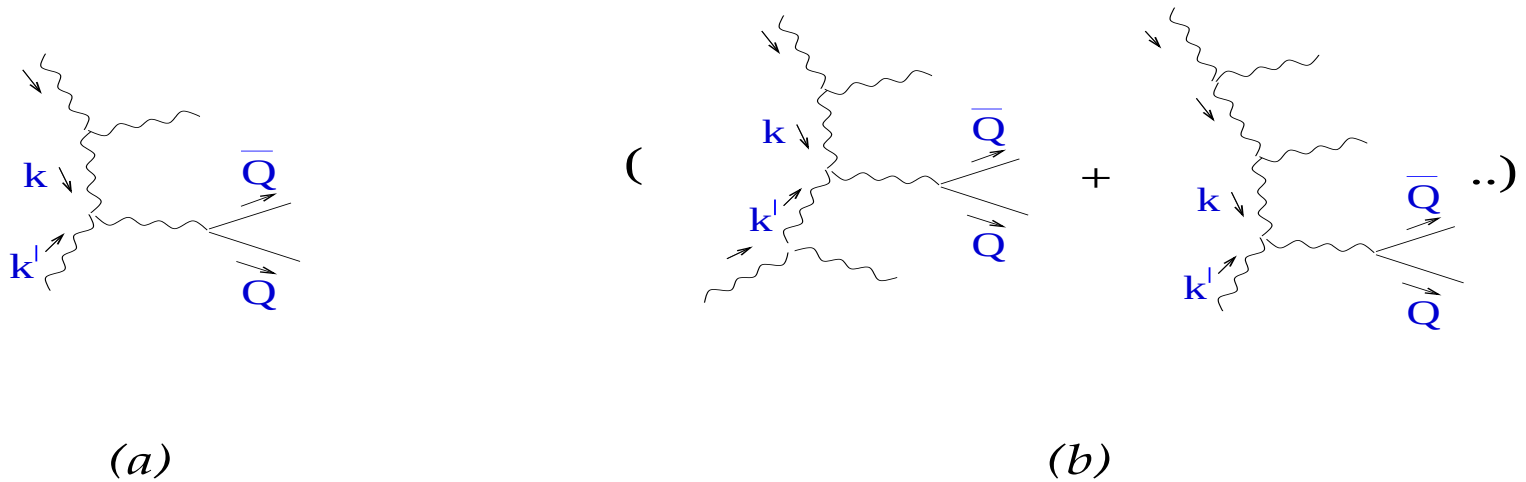


- data below NLO-matched calculations POWHEG and MC@NLO at large y and large p_T

Heavy flavor production: high-energy behavior

$$\sigma_{gg,N} \simeq C \left(\frac{m_Q^2}{K_T^2}\right)^{N+1} \ln(1 + K_T^2/(4m_Q^2))$$

$\Rightarrow$ strong triple-pole singularity in moments conjugate to k_T
from $m_Q^2 \ll (k_T + k'_T)^2 \ll k_T^2 \simeq k_T'^2$



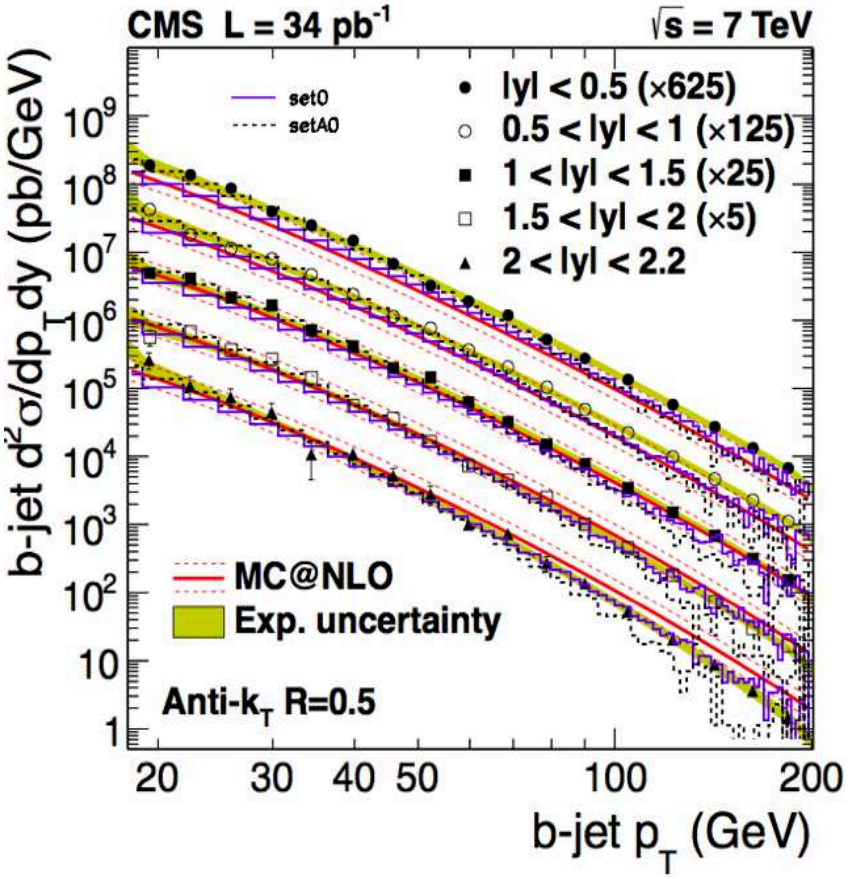
(*a*) heavy quark hadroproduction from gluon showering;

(*b*) next correction from extra jet emission

- not included by collinear showers (even at NLO [MC@NLO])
- obtainable by $k_\perp$-shower

b-jets using $k_\perp$-dependent showers

[H. Jung et al., arXiv:1206.1796]



- similar description to MC@NLO at central rapidities
- shape in p_T closer to data at large y

$\diamondsuit$ Is this effect of QCD high-energy resummation or mainly kinematics?