NLO+PS ttbb in PowHel

Adam Kardos

University of Debrecen

in collaboration with
Giuseppe Bevilacqua (MTA-DE) &
Maria Vittoria Garzelli (Univ. Hamburg)

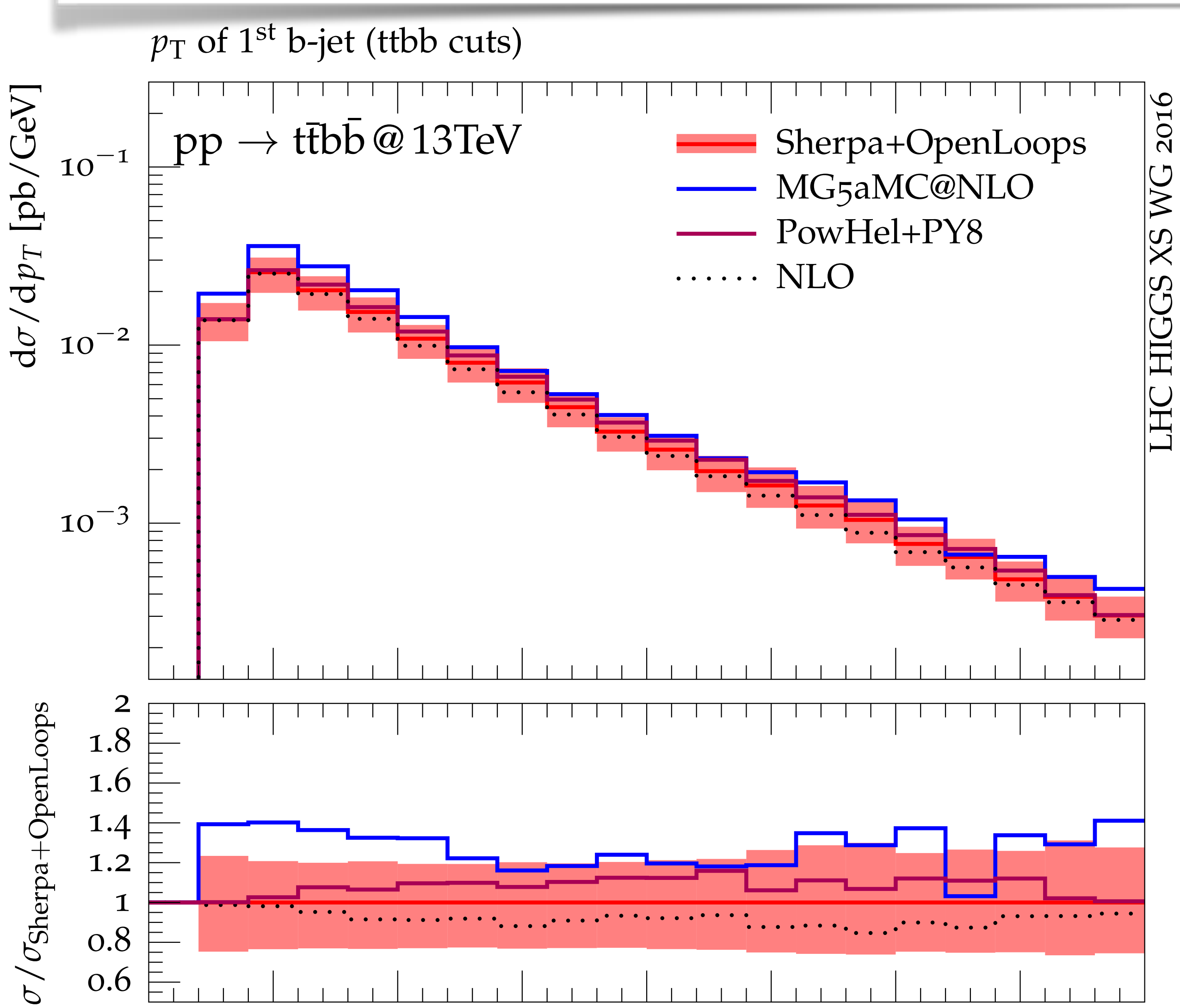
Appeared as: arXiv:1709.06915

Common meeting on tt+b-jet backgrounds to ttH(bb)
6th, November, 2017

Introduction/Motivation

I.6.8.g Summary and conclusions

In summary, we have presented a systematic study of Monte Carlo simulations of $pp \to t\bar{t} + b$-jets at 13 TeV that compares various NLO+PS predictions based on different matching methods, parton showers and matching schemes. While the inclusion of b-mass effects is the only fully consistent way of describing inclusive $t\bar{t} + b$-jets production in terms of $t\bar{t}b\bar{b}$ matrix elements, the observed agreement between SHERPA+OPENLOOPS and POWHEL predictions indicates that also simulations with massless b-quarks and appropriate generation cuts provide predictions in agreement well within the scale uncertainties.



[LHC HXSWG '16]

- Agreement between PowHel+PYTHIA and Sherpa+OpenLoops is very good
- Different matchings are used: Powheg and MC@NLO
- Even the matrix elements are different (massless ⟷ massive b's)
- What happens if the matching and the SMC is the same in both cases?

Implementation

- `PowHel` = `POWHEG-BOX` + `HELAC-NLO`
- To deal with processes having massive b's it needed a major facelift:
- $\Longrightarrow$`PowHel` = `POWHEG-BOXv2` + `HELAC-NLO-2.0`
- Massive bottom support throughout
- A general, multi purpose phase space generator is introduced
  - fully automatic
  - truly multi-channel
  - deals with s- and t-channel branchings

Technicalities

In the 4FNS calculation the HXSWG recommendation was adopted for the renormalization and factorization scales:

$$\mu_{\mathrm{R},0} = \left(\prod_{i=\mathrm{t},\bar{\mathrm{t}},\mathrm{b},\bar{\mathrm{b}}} E_{\perp,i} \right)^{1/4} \qquad \mu_{\mathrm{F},0} = \frac{H_\perp}{2} = \frac{1}{2} \sum_{i=\mathrm{t},\bar{\mathrm{t}},\mathrm{b},\bar{\mathrm{b}},j} E_{\perp,i}$$

Due to massive b's the Born is finite $\Longrightarrow$ no need for technical cuts nor suppression factors

In order to get back the NLO p_T distribution for the extra parton at high p_T an h_{damp} definition is needed in `POWHEG-BOX/PowHel`:

$$h_{\mathrm{damp}} = \frac{E_{\perp,\mathrm{t}} E_{\perp,\bar{\mathrm{t}}}}{p_{\perp,j}^2 + E_{\perp,\mathrm{t}} E_{\perp,\bar{\mathrm{t}}}} \Theta\left(\left(E_{\perp,\mathrm{t}} E_{\perp,\bar{\mathrm{t}}} E_{\perp,\mathrm{b}} E_{\perp,\bar{\mathrm{b}}} \right)^{1/4} - p_{\perp,j} \right) ,$$

Several h_{damp} definitions could be devised, this is one from the several possible ones.

Phenomenology

ttbb was measured at 8 TeV by CMS [Eur.Phys.J. C76 (2016) no.7, 379]

The system of cuts for visible phase space:

- Jet clustering with anti-k_T, R=0.5
- b jet: a jet with at least one b hadron inside
- additional b jets and b jets from (anti)top decay are distinguished
- Only considering leptonic (anti)top decays (ee, eμ, $\mu\mu$)
- Leptons: $p_T > 20$ GeV, $|\eta| < 2.4$
- b jets from (anti)top decays: $p_T > 30$ GeV, $|\eta| < 2.4$
- Additional jets and additional b jets: $p_T > 20$ GeV, $|\eta| < 2.4$

The system of cuts for full phase space:

- Previous kinematic range only applies to additional jets and additional b jets.
- No requirement on the t-tbar system
- Corrected to consider all possible W decay products

Phenomenology

Used parameters in the 4FNS calculation:

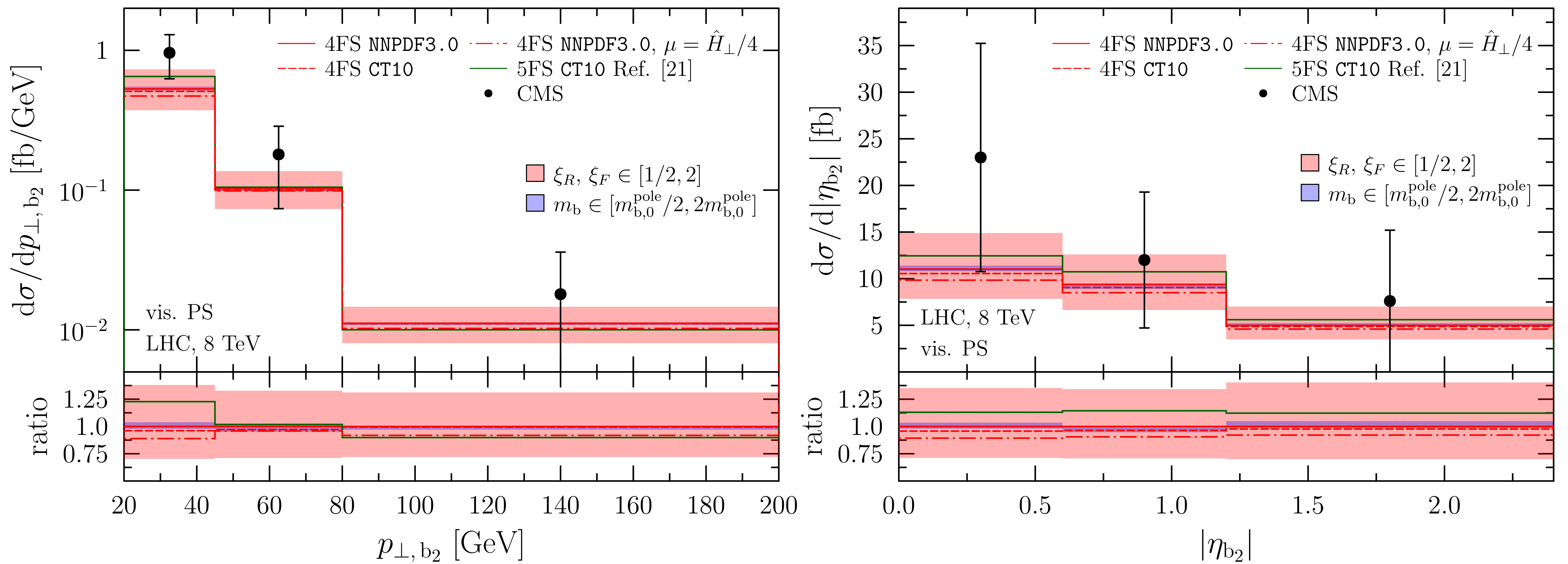
- m_t = 172.5 GeV, m_b = 4.75 GeV
- PDFs: `NNPDF30_nlo_as-0118_nf_4` & `CT10nlo_nf4`
- PS: `PYTHIA6` with Perugia 2011 C tune
- Scale uncertainty: 7 point with $\xi_R, \xi_F \in [1/2, 2]$
- bottom mass uncertainty: $m_b \in$ [4.5 GeV, 5 GeV]
- tops are decayed in `PYTHIA`

For illustrative purposes the original 5FNS prediction is also shown (used in the CMS paper as well)

The 5FNS prediction uses a different scale: $\mu_R = \mu_F = \hat{H}_\perp/4$

(For better comparison a line is added for 4FNS using $\mu_R = \mu_F = \hat{H}_\perp/4$

Pheno in visible PS

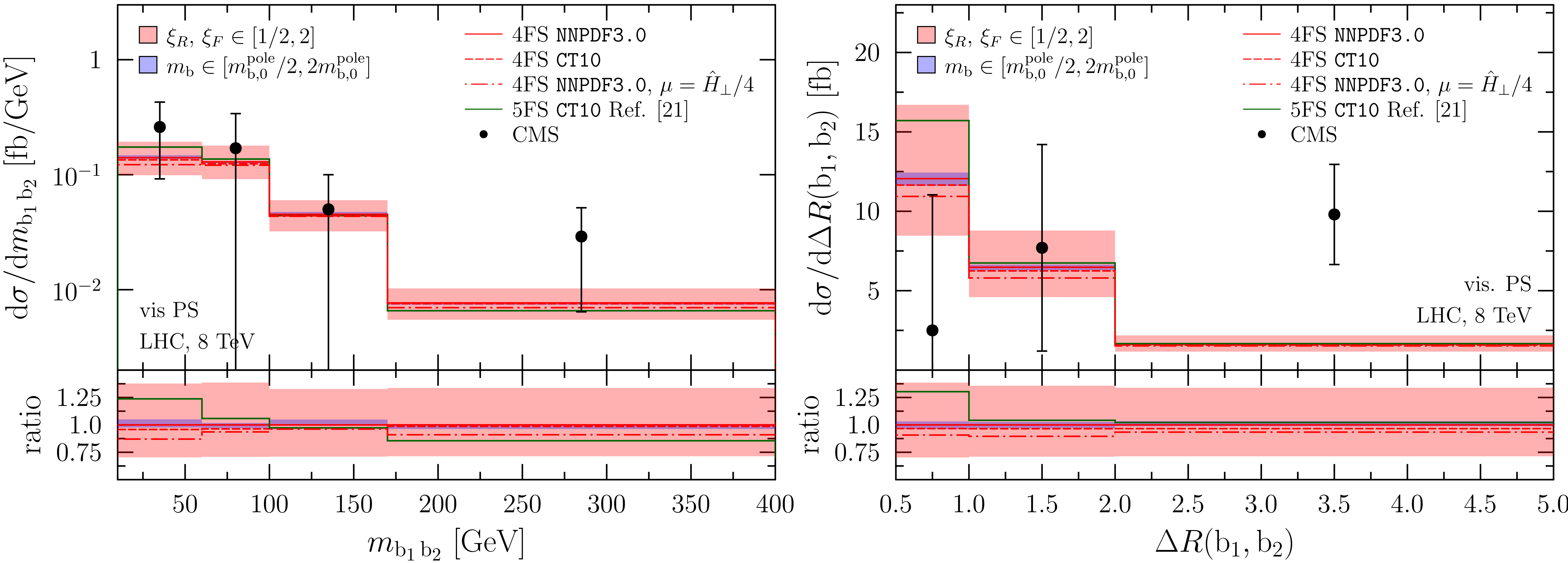


p_T and pseudorapidity for the additional subleading b jet

All predictions agree within uncertainty bands. The large difference between 4FNS and 5FNS in the first bin of $p_{T,b2}$ most likely due to different h_{damp} choice

Red band corresponds to scale uncertainty for the Yellow Report scale choice and `NNPDF3.0`.

Pheno in visible PS

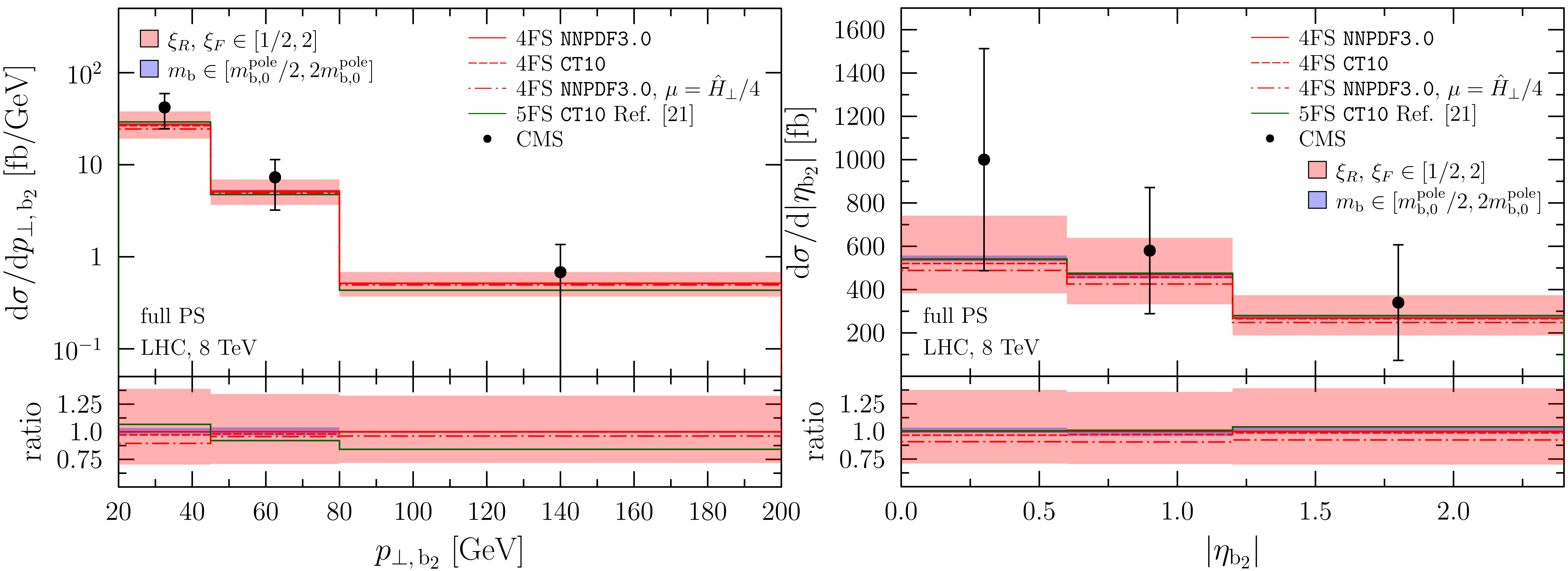


Mass and separation of the leading and subleading additional b jets

The 5FNS results in less separation between additional b jets and less mass for the b_1-b_2 system.

Note also the large difference (2.5 σ) between prediction and measurement for large separation. This observable is a though one to measure⟹improvements are welcome.

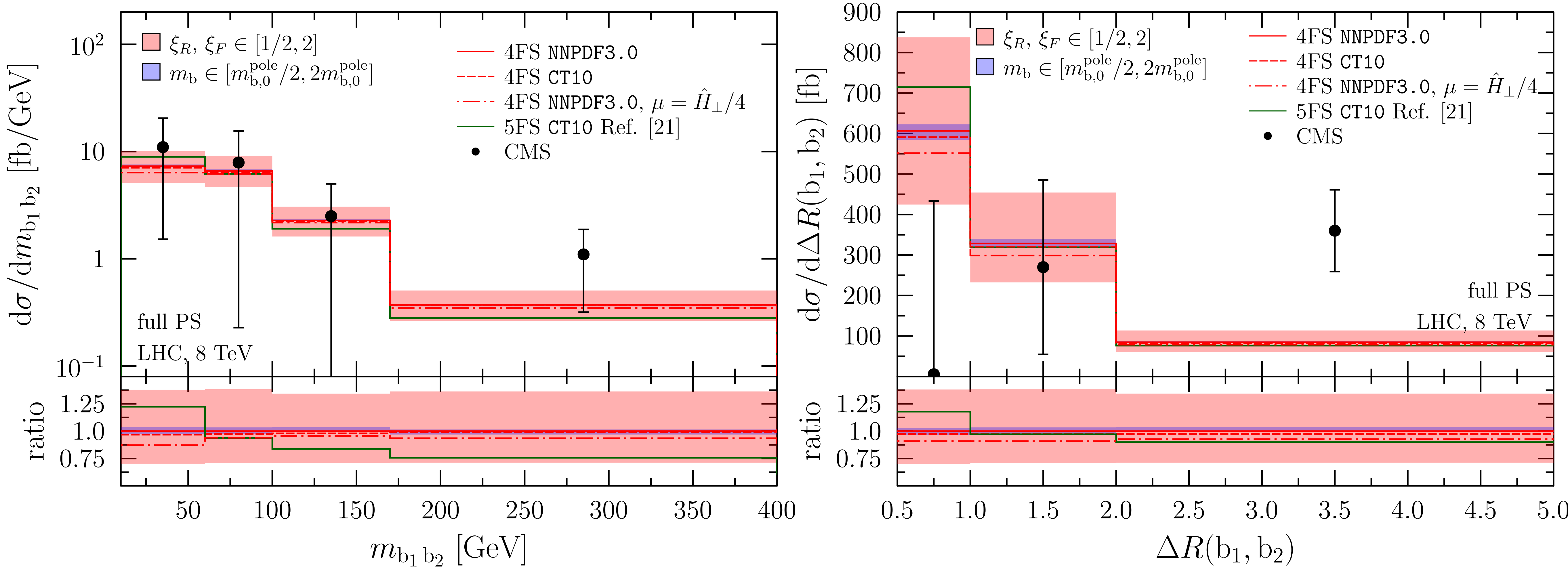
Pheno in full PS



p_T and pseudorapidity for the additional subleading b jet

When no cut is imposed on the decay products of the t-tbar system the 4FNS and 5FNS predictions get very close to each other.

Pheno in full PS

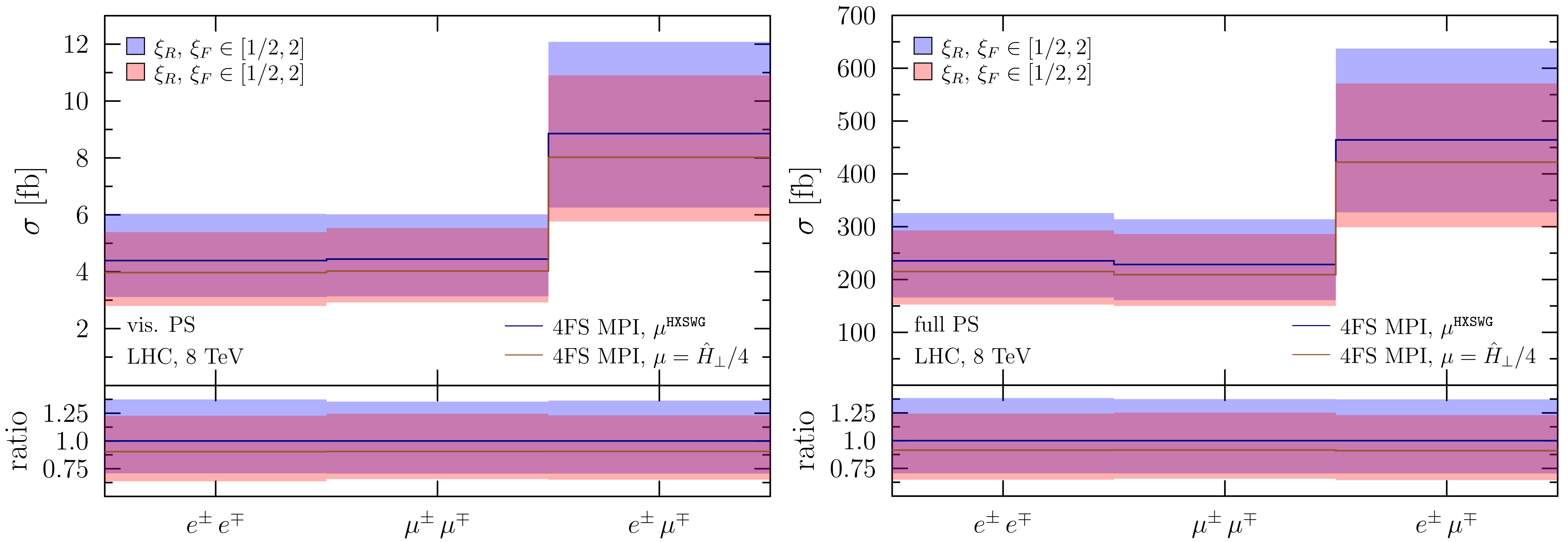


Mass and separation of the leading and subleading additional b jets

Same tendencies as for the visible PS cuts: smaller mass is favored by the system of additional b jets and less separation in the 5 FNS calculation.

The effect of b mass variation is within a few percent throughout.

Cross sections:



Cross sections for different channels with different PS cuts

μ^{HXSWG} stands for the scale choice of the Yellow Report (blue line and band).

The scale of the Yellow Report seems to result in slightly larger scale uncertainty band and a bit higher cross section.

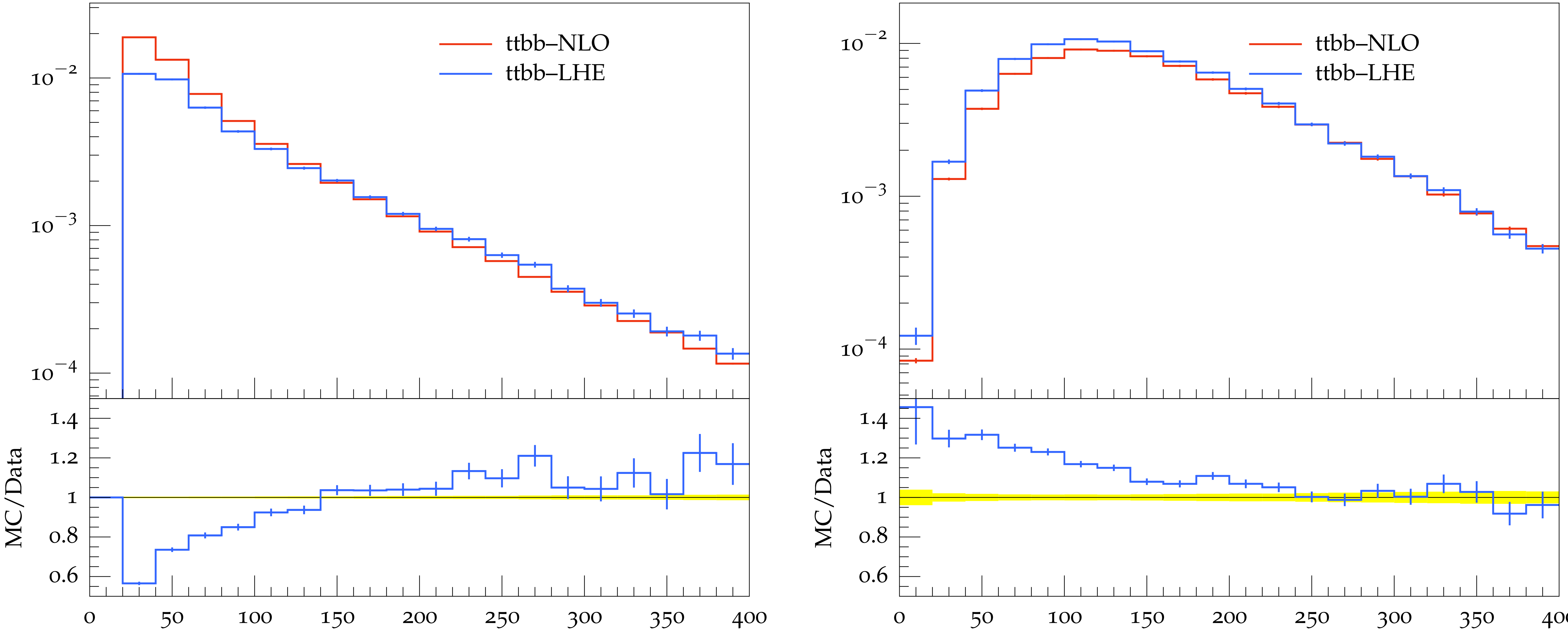
Conclusions

- 4FNS ttbb production in `PowHel` is now available
- Predictions are compared to CMS measurements where two distinct additional b jets were observed
- The 4FNS and 5FNS predictions with `PowHel` are in reasonable agreement
- At current stat. theory describes the data, except for $\Delta R(b_1,b_2)$ where for large values a slight tension (~2.5 σ) is visible for both 4FNS and 5FNS
- In current version spin correlations are neglected (top decayed by `PYTHIA`)
- Given the selection of observables the spin correlations cannot play a major role
- b mass variation is a very-very small effect considering the size of scale uncertainties

Thank you for your attention!

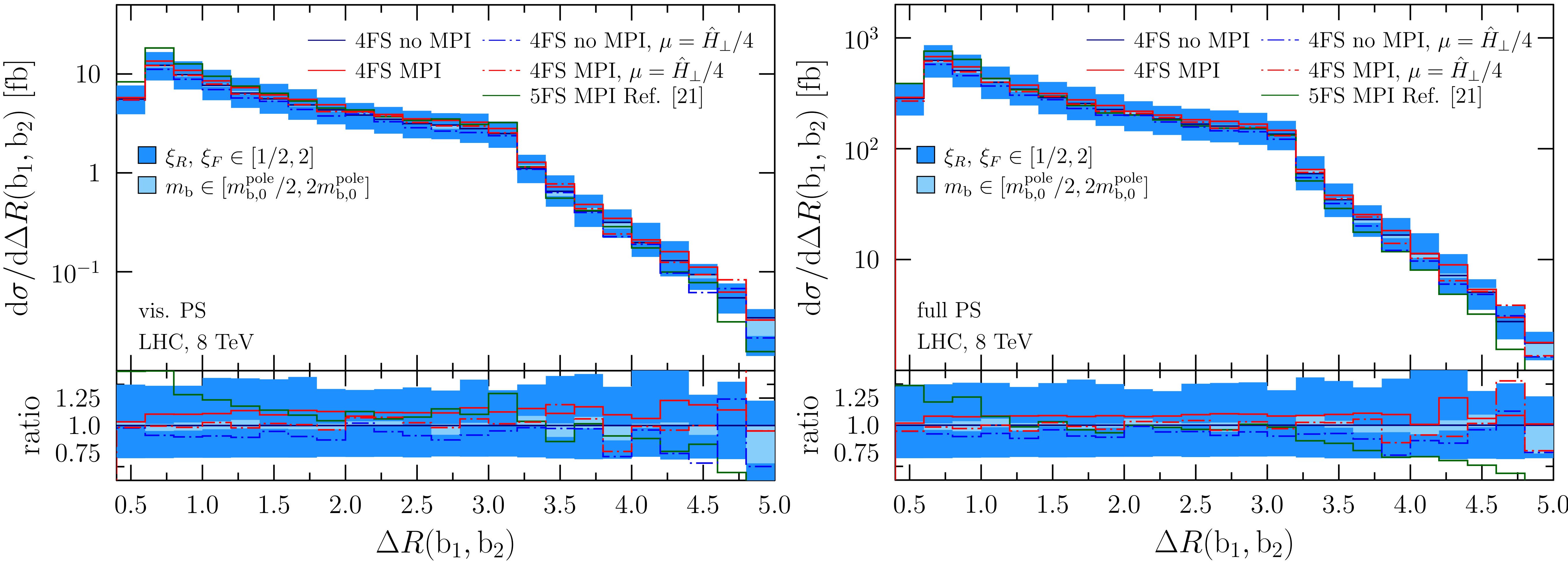
Extra slides

Justification of choice for h_{damp}



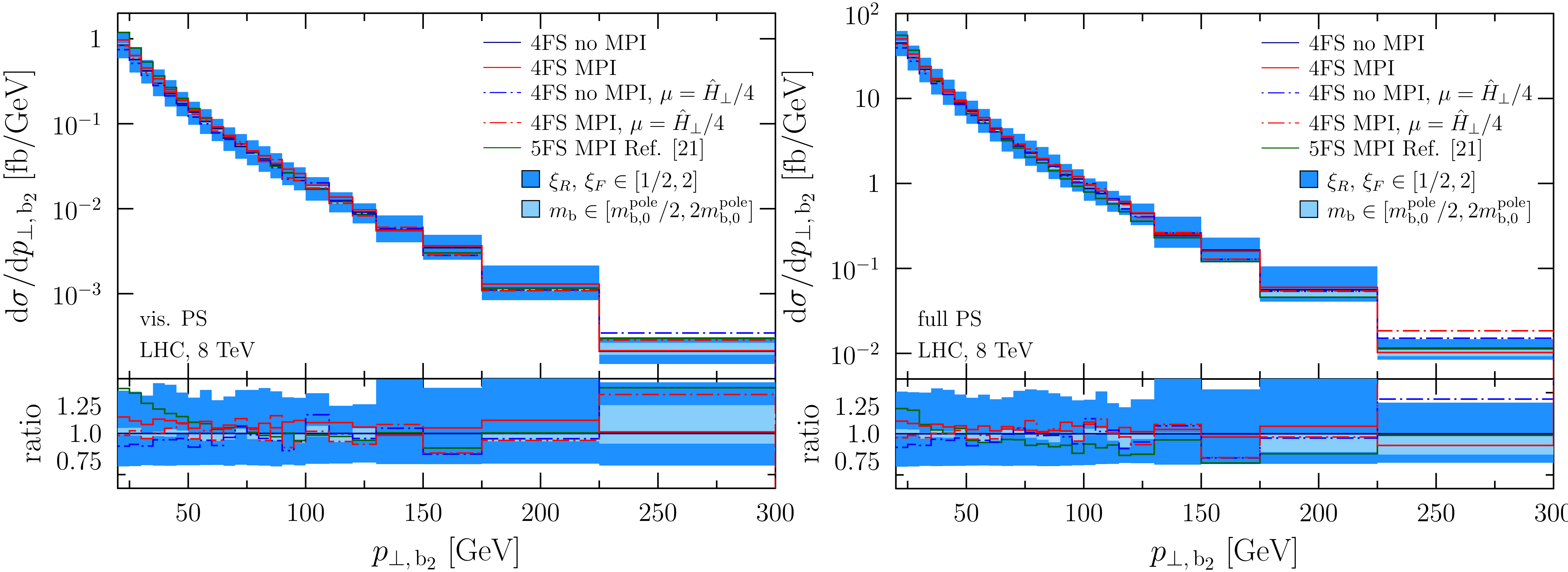
Extra parton (L) and top (R) p_T distributions at fixed-order (red) and at the LHE (blue) level corresponding to the cut scheme `ttb' of the Yellow Report.

MPI and b mass variation effects



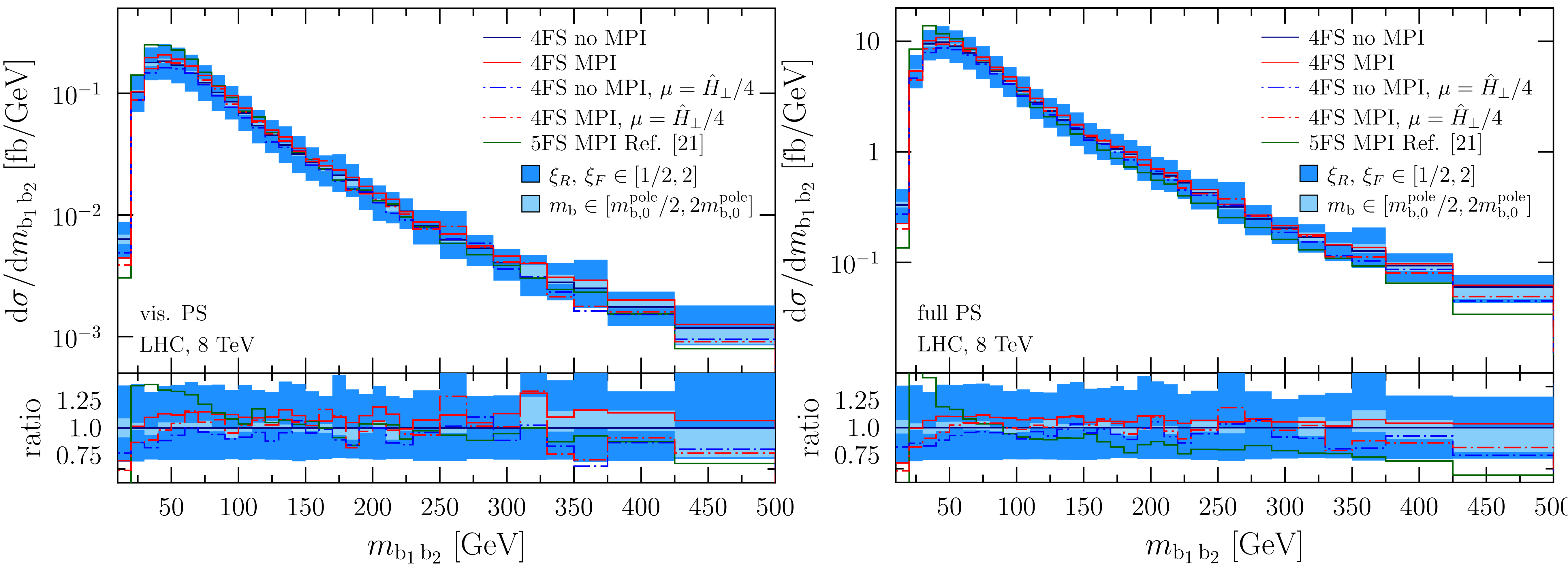
MPI and mass effects on leading and subleading additional b jet separation

MPI and b mass variation effects



MPI and mass effects on subleading additional b jet p_T

MPI and b mass variation effects



MPI and mass effects on the mass of the leading and subleading additional b jet