Single top theory

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Single top theory

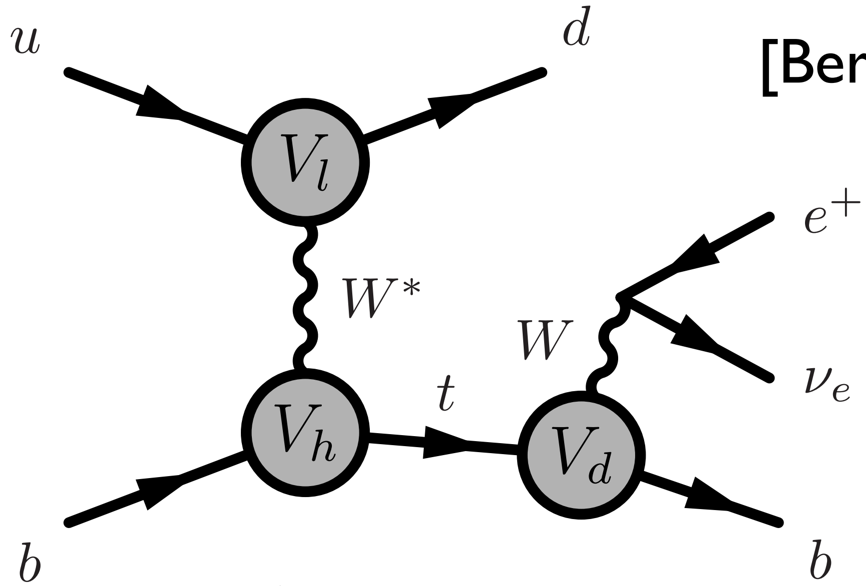
Many things are changed since the work of Willenbrock and Dicus (1986) that showed the relevance of single top physics at hadron colliders (using tree level diagrams):

- I'll review the progress of the last year (since the end of TOP2015)
- Just a selection, I apologize (too much progress!)
- You will see that, after 30 years of computations and measurements, "single top" is more and more an important tool that triggers progress in high energy physics

- t-channel

t-channel single top production and decay @ NNLO in narrow width approximation

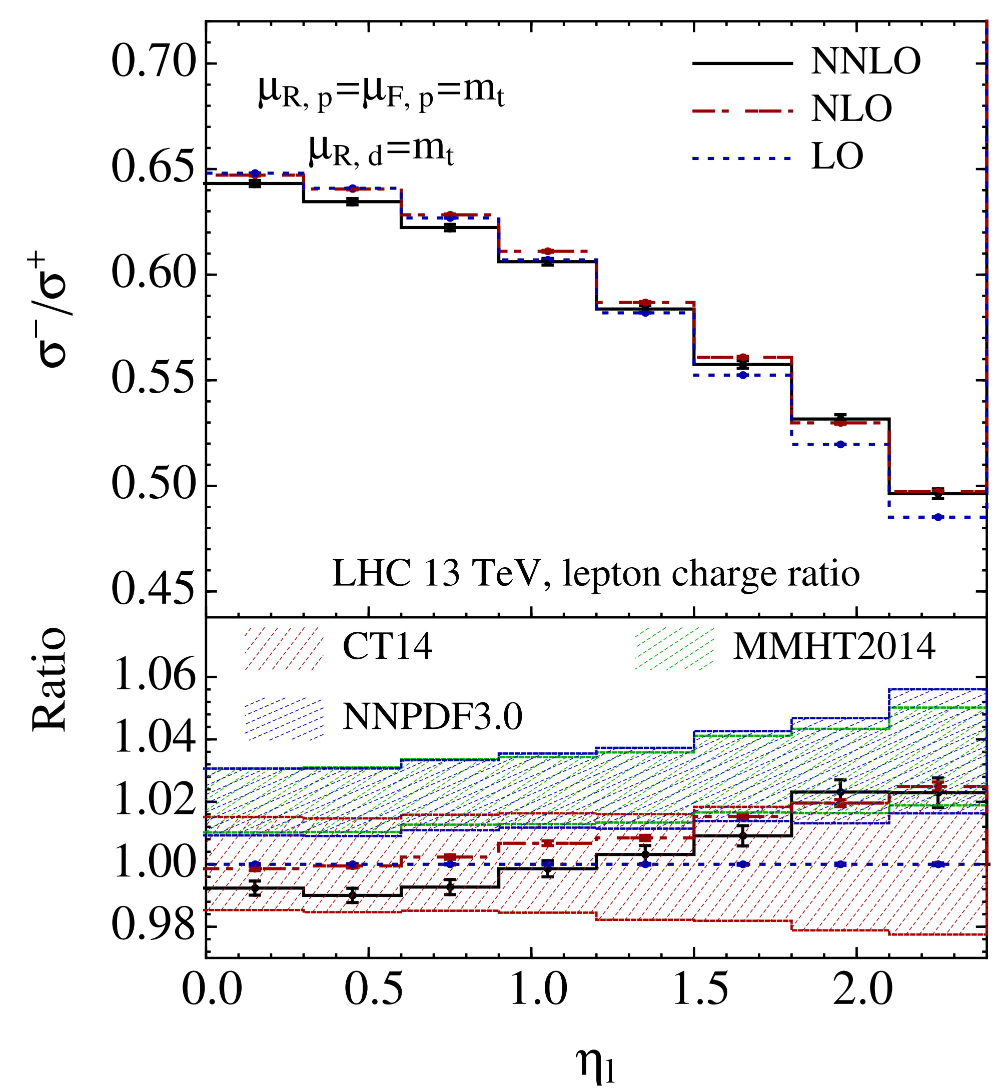
[Berger Gao Yuan Zhu 1606.08463]



- ✓ structure function approach
- ✓ higher precision on inclusive distributions wrt reconstructed top variables
- ✓ might be important for pdf studies

$$
\begin{aligned}
\sigma^{\rm LO} &= \frac{1}{\Gamma_t^0} {\rm d}\sigma^0 {\rm d}\Gamma_t^0 \\
\delta\sigma^{\rm NLO} &= \frac{1}{\Gamma_t^0}\left[{\rm d}\sigma^1 {\rm d}\Gamma_t^0 + {\rm d}\sigma^0({\rm d}\Gamma_t^1 - \frac{\Gamma_t^1}{\Gamma_t^0}{\rm d}\Gamma_t^0)\right] \\
\delta\sigma^{\rm NNLO} &= \frac{1}{\Gamma_t^0}\left[{\rm d}\sigma^2 {\rm d}\Gamma_t^0 + {\rm d}\sigma^1({\rm d}\Gamma_t^1 - \frac{\Gamma_t^1}{\Gamma_t^0}{\rm d}\Gamma_t^0)\right. \\
&\left. + {\rm d}\sigma^0({\rm d}\Gamma_t^2 - \frac{\Gamma_t^2}{\Gamma_t^0}{\rm d}\Gamma_t^0 - \frac{\Gamma_t^1}{\Gamma_t^0}({\rm d}\Gamma_t^1 - \frac{\Gamma_t^1}{\Gamma_t^0}{\rm d}\Gamma_t^0))\right]
\end{aligned}
$$

SETUP
2j1b
antikt 0.5
ptj>40GeV
|etaj|<5 (2.4b)
ptl>30GeV
|etal|<2.4



BTW this is not the unique way to merge corrections from production and decay

- LHC13
- CT14
- scales=mt=173.2

inclusive [pb]	LO	NLO	NNLO
t quark	$143.7^{+8.1\%}_{-10\%}$	$138.0^{+2.9\%}_{-1.7\%}$	$134.3^{+1.0\%}_{-0.5\%}$
$\bar{t}$ quark	$85.8^{+8.3\%}_{-10\%}$	$81.8^{+3.0\%}_{-1.6\%}$	$79.3^{+1.0\%}_{-0.6\%}$

Matching

The matching of parton showers to matrix elements that involve top-quark resonances poses nontrivial technical and theoretical problems

Standard mappings deteriorate the efficiency of the IR cancellation

- ➡ In general subraction schemes (CS, FKS) only the ingoing and outgoing momenta are relevant
- ➡ counter events kinematic has the primary condition to adsorbe the momenta of the extra radiated parton among the particles of the Born process, irrespective of the presence of internal resonances
- ➡ when the b quark in top decay emit a gluon (g) the shift in mass virtuality among event and counter event is of the order of

$$m_{bg}^2/E_{bg}$$

- ➡ virtualities match only if

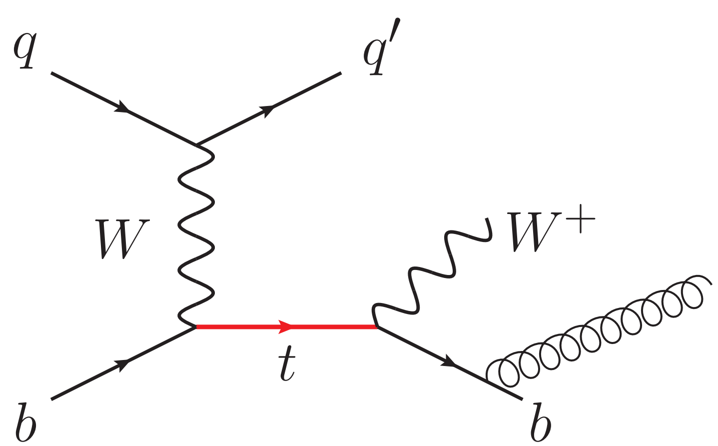
$$m_{bg}^2 \ll \Gamma_t E_{bg}$$

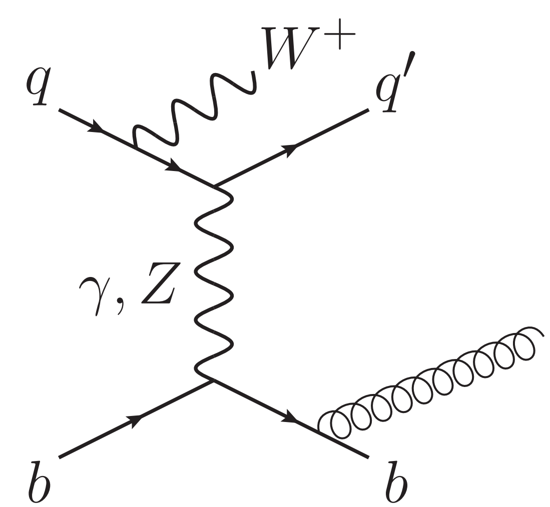
Matching

In the case of POWHEG for example, for the method to work correctly R/B must become large only in the collinear limit

$$\Delta(p_T^2) = \exp\left[-\int \frac{R(\Phi_B, \Phi_{\rm rad})}{B(\Phi_B)} \theta(k_T(\Phi_{\rm rad}) - p_T) {\rm d}\Phi_{\rm rad}\right]$$

Last, but not less important, PS has to be instructed about when preserve resonance mass during the shower to avoid arbitrary shift of the resonance invariant mass resulting in an unphysical distortion of the top line shape





Matching

The solutions found in POWHEG-BOX-VRES [Jezo Nason 2015]

- division of the contribution following the possible resonance histories introducing appropriate multiplicative factors for all the contributions
- apply resonance aware mappings, in such a way to minimize the mismatch among real and subtractions
  - ✓ the delicate separation of the real contribution into resonance histories that preserve collinear factorization and allows for subtractions computed in the resonance frame

Matching

The solutions found in MG5_aMC@NLO

[Frederix Frixione Papanastasiou Prestel Torrielli 2016]

- division of the contribution following the possible resonance histories combining input from the amplitude structure, the FKS singular region and information on the kinematical configuration

- remapping of the event kinematics to match the resonance invariant mass, resorting on numerical methods to compute the new jacobian factor, no need of further analytic integrations

Matching

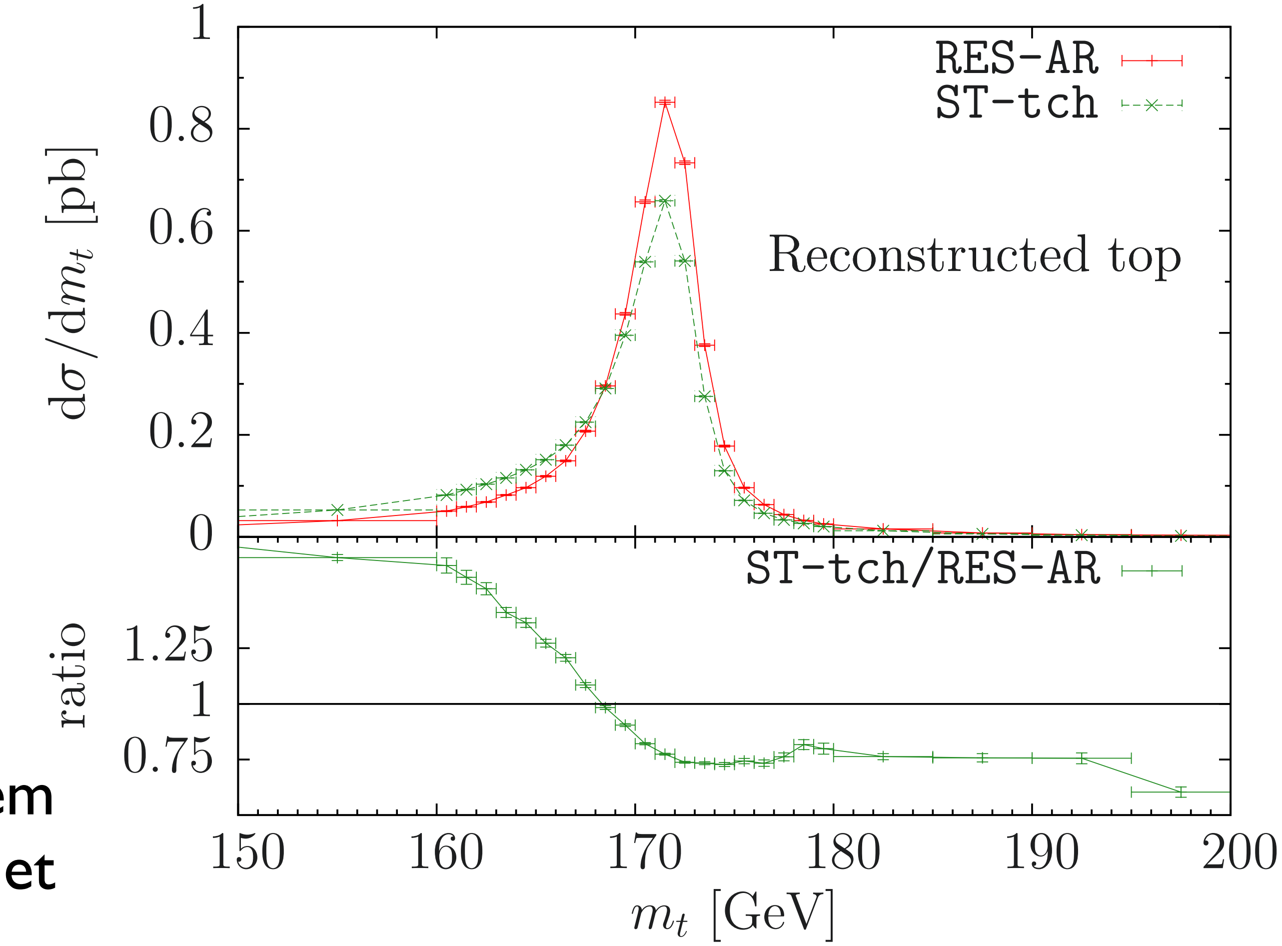
POWHEG-BOX results [Jezo Nason 2015]

NORES: POWHEG-BOX-V2
RES-HR: POWHEG-BOX-RES generating hardest radiation
RES-AR: POWHEG-BOX-RES generating hardest radiation from production and from decay
ST_tch: POWHEG generator, radiation in the decay generated by the shower

LHC @ 8TeV
pdf: MSTW2008NLO
jets: pt>25, |eta|<4.5, anti kt alg., R=0.5

RES-AR vs ST-tch

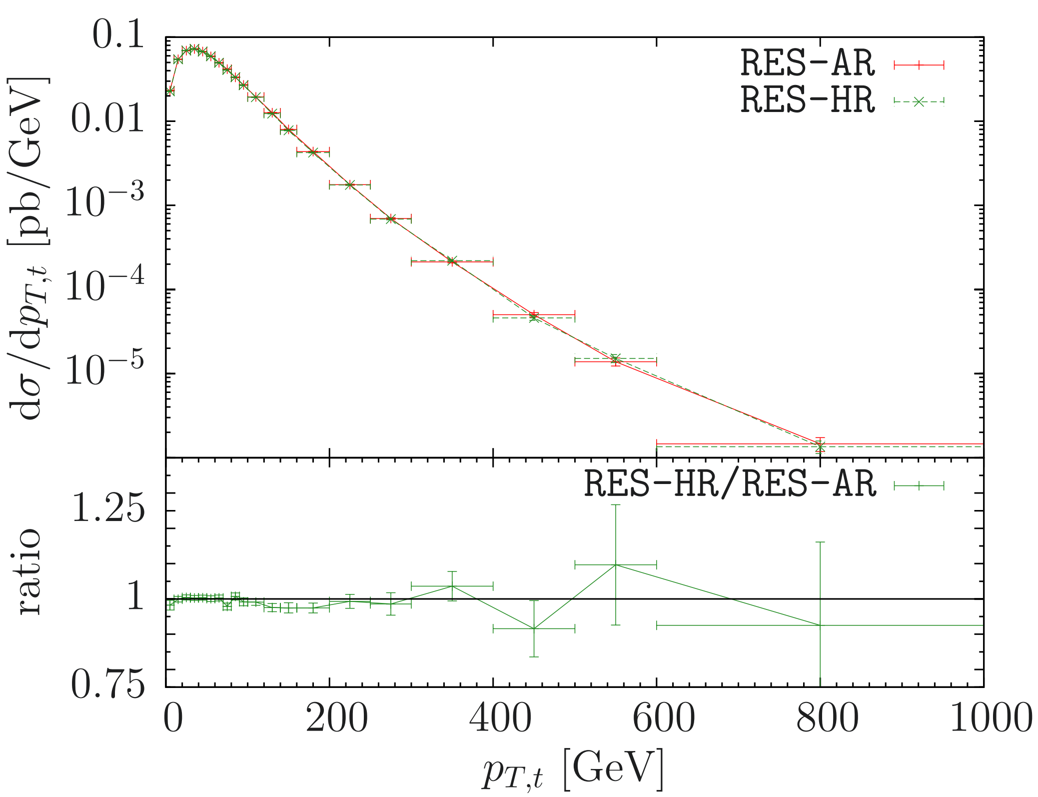
- The different treatment of radiation from the decay produces a shift in the reconstructed top mass of about 1GeV.
- More detailed pheno studies are nedeed!

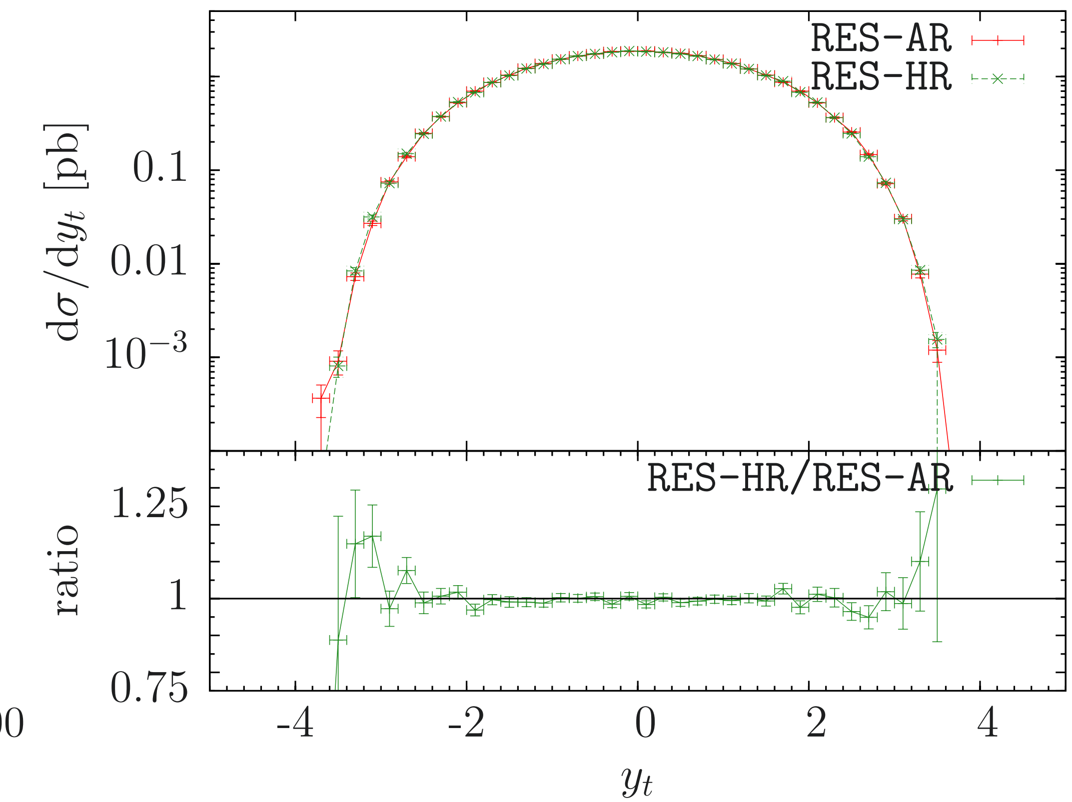


the reconstructed top is the system built with the W and the b jet

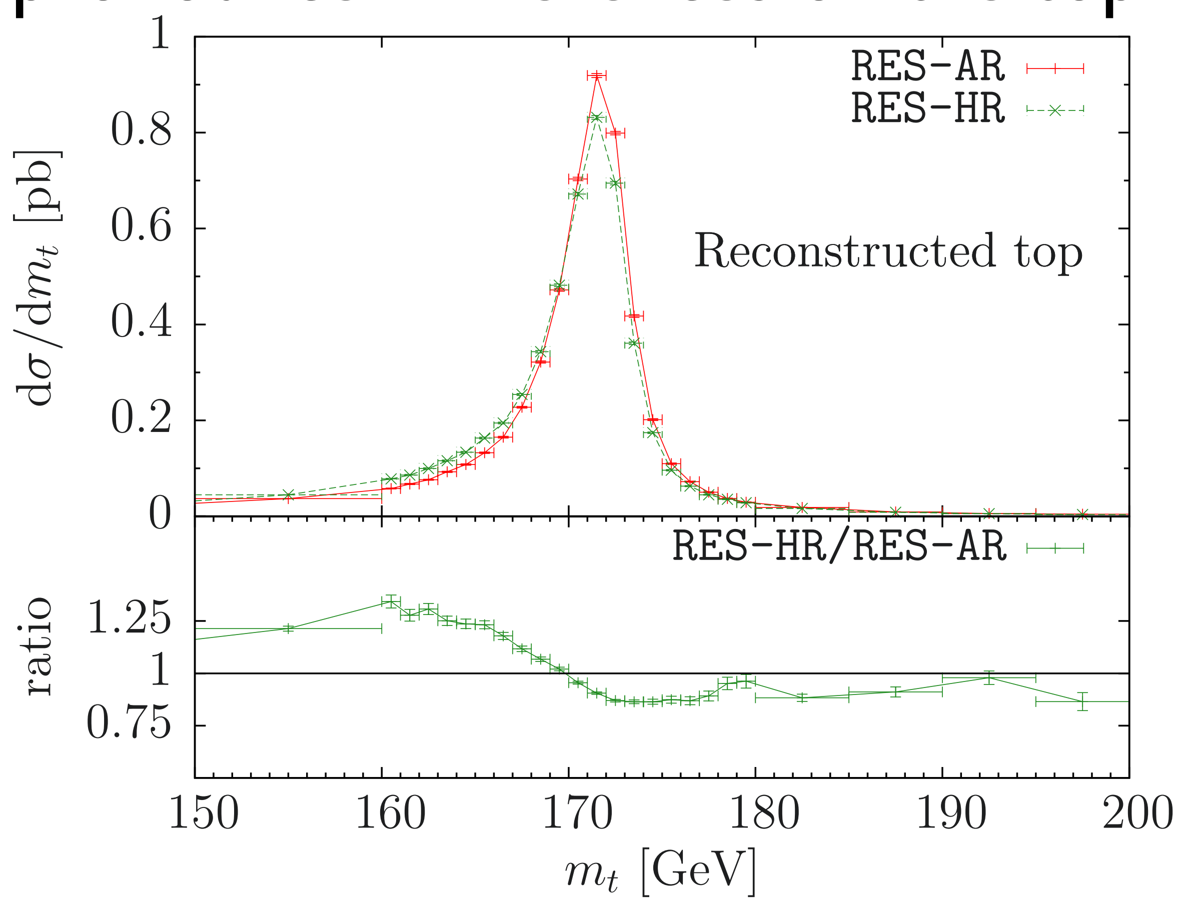
POWHEG-BOX results [Jezo Nason 2015] RES-AR vs RES-HR

top quark distributions in good agreement



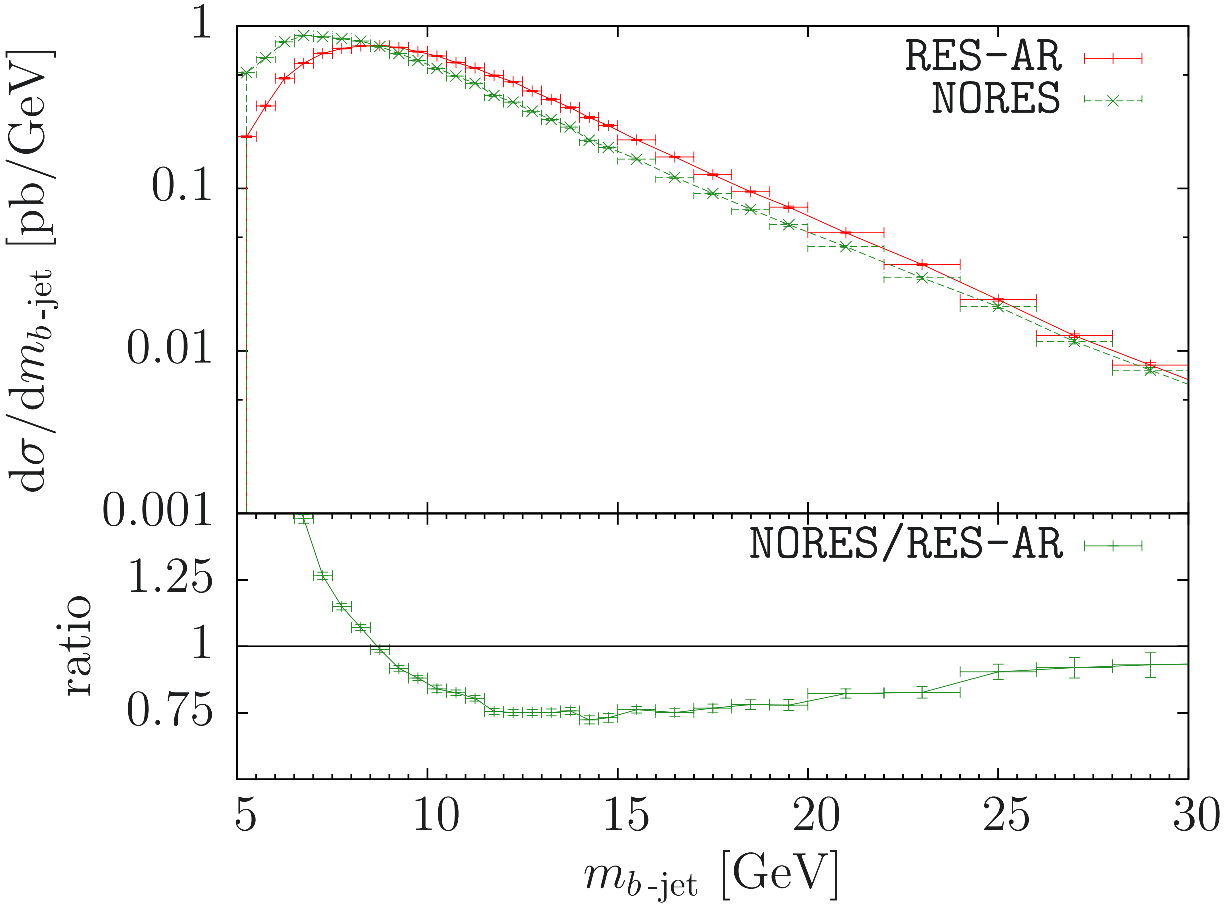


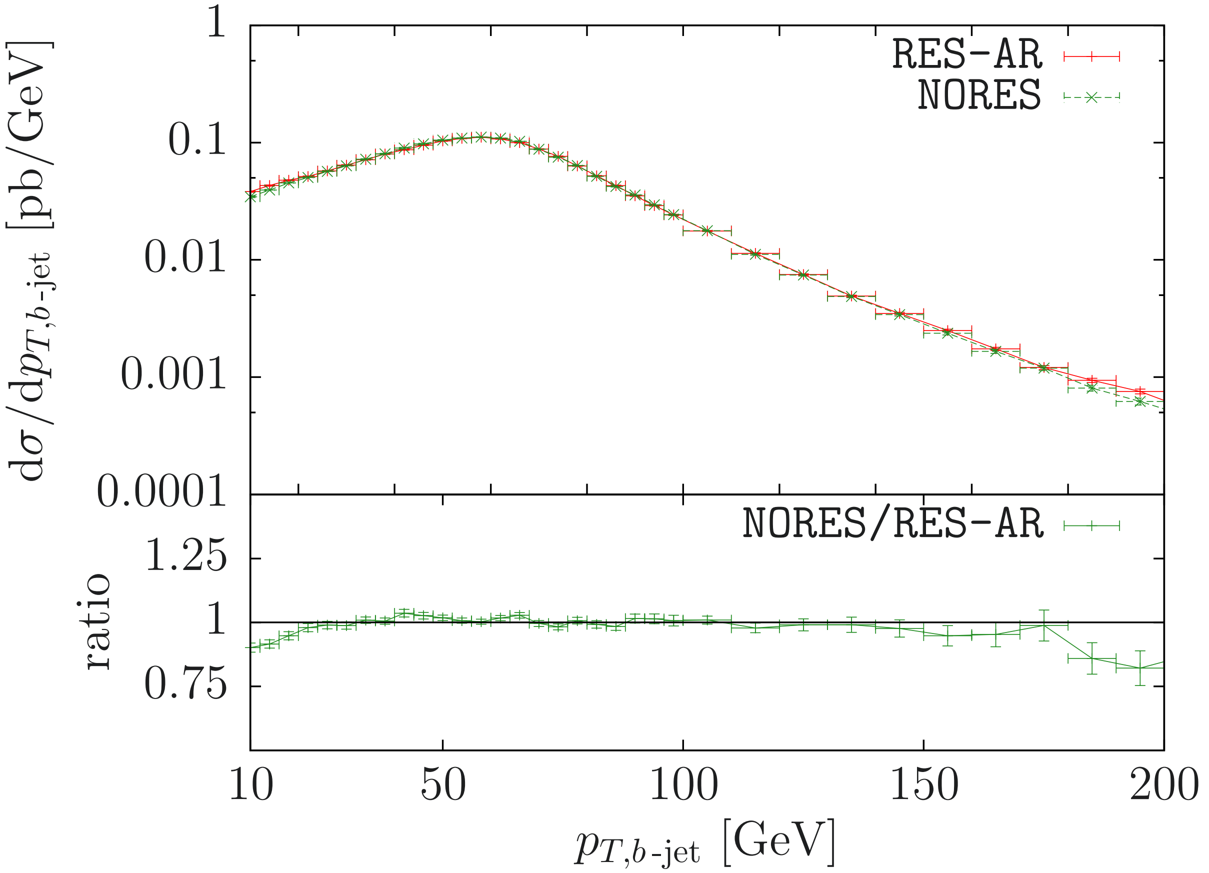
less pronounced differences on the top lineshape



POWHEG-BOX results [Jezo Nason 2015] RES-AR vs NORES

Marked distortions in many distributions





missing: comparison with a generator with the on-shell approximation

Matching

MG5_aMC@NLO results

[Frederix Frixione Papanastasiou Prestel Torrielli 2016]

LHC @ 8TeV
pdf: MSTW2008NLO
jets: pt>25, |eta|<4.5, kt alg., R=0.5

$$140 \text{ GeV} < M(W^+, J_b) < 200 \text{ GeV}$$

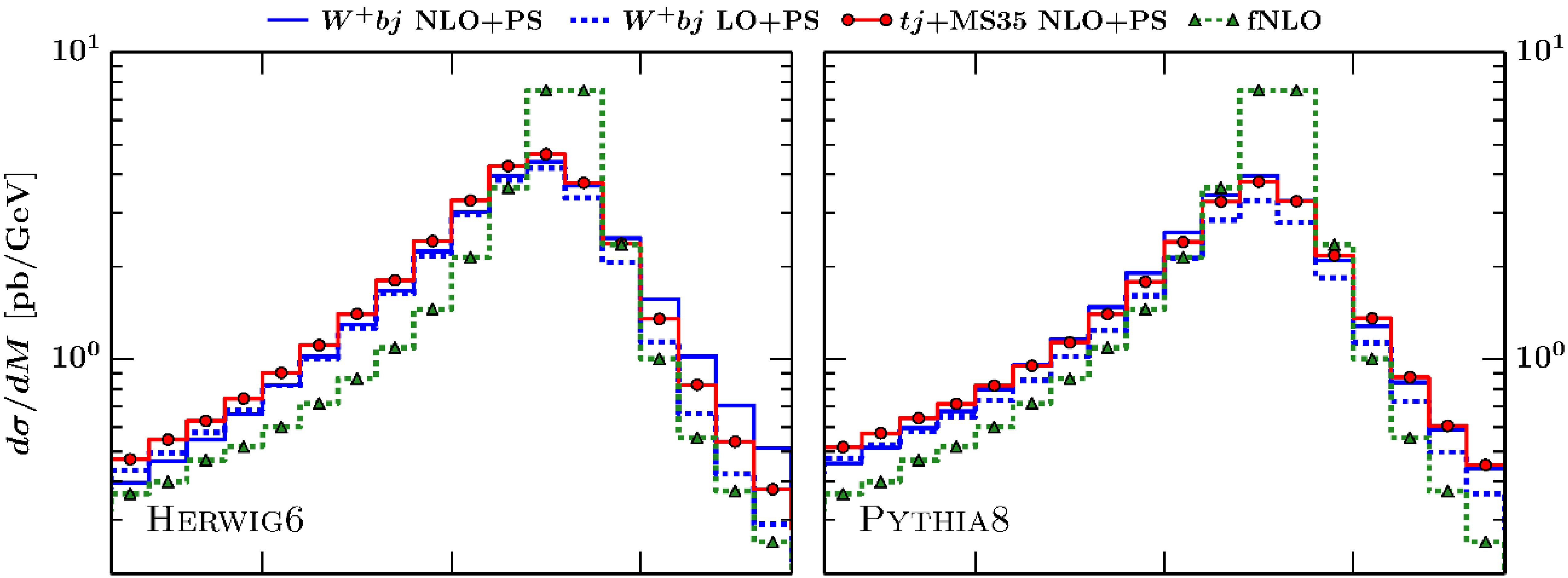
same cuts as before plus cut on the reconstructed top mass

fNLO: Wbj partone level @ NLO
tj+MSxs NLO+PS: top decay described by PS,
BW smearing (for off-shellness), Spin correlation
Wbj NLO+PS: exploiting the algorithms to describe resonances

- Detailed study of the dependance of the predictions on the variation of the technical parameters
- Useful to understand the associated uncertainties.

MG5_aMC@NLO results

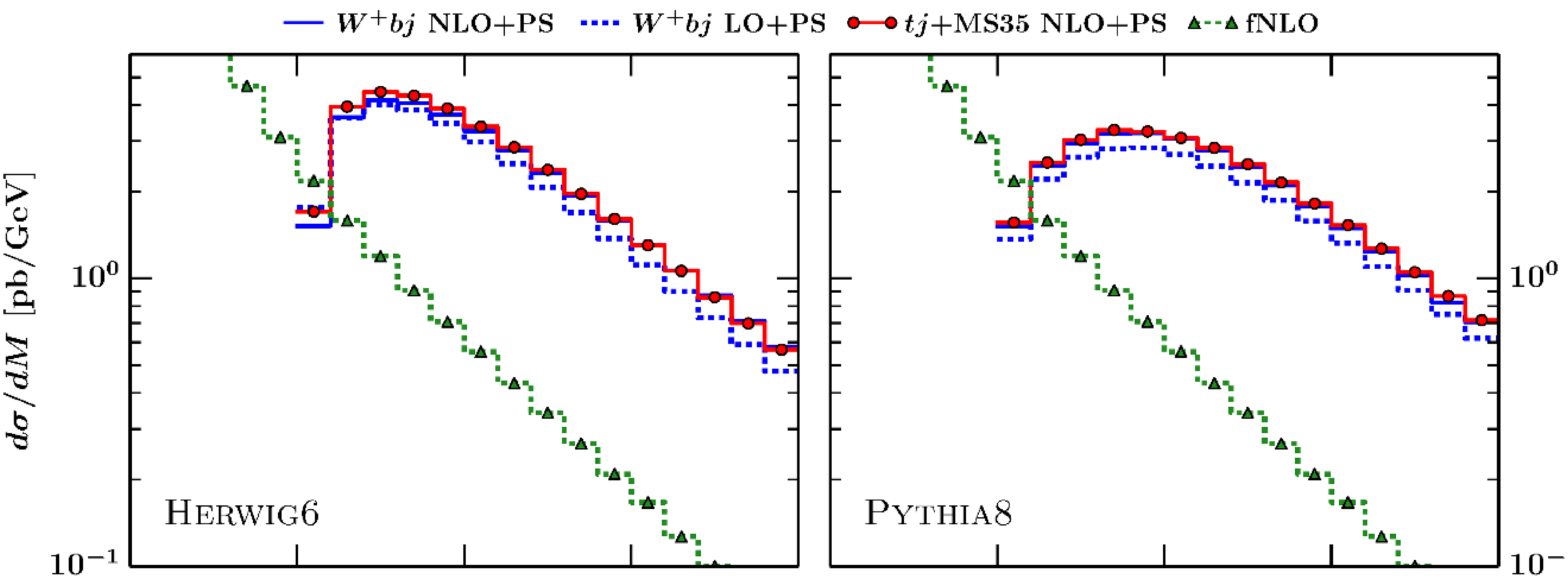
[Frederix Frixione Papanastasiou Prestel Torrielli 2016]



PS smears and flatten the sharp peak of fixed order prediction

MG5_aMC@NLO results

[Frederix Frixione Papanastasiou Prestel Torrielli 2016]



harder distribution of b-jet mass wrt fNLO

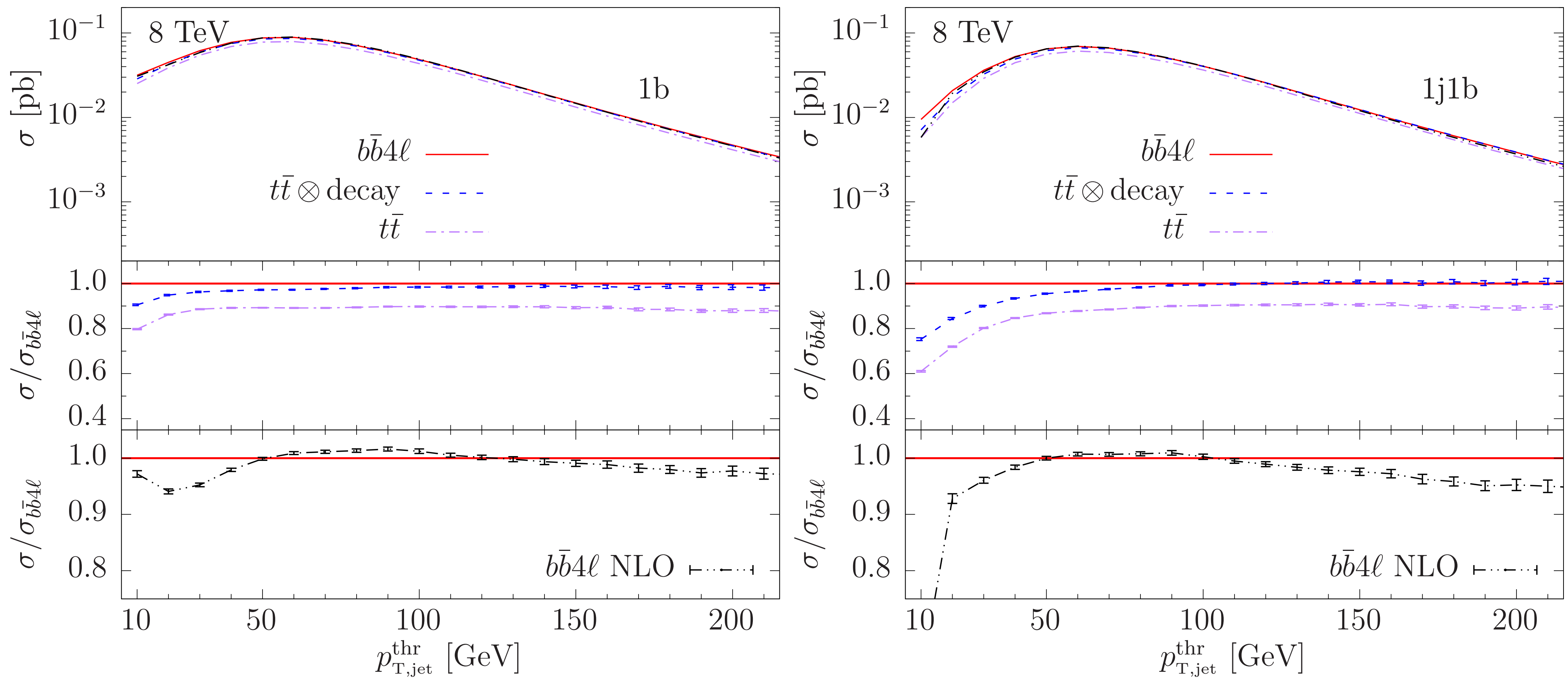
- Wt-channel

Matching

POWHEG-BOX-VRES for Wt

New tt and wt generator exploiting the algorithms to treat resonances (bb4l)

[Jezo Lindert Nason Oleari Pozzorini 2016]



$p_T^l > 20$ GeV, $|\eta^l| < 2.5$, $p_T^{\mathrm{miss}} > 20$ GeV Anti_kt R=0.5 $p_T^j > 30$ GeV, $|\eta^j| < 2.5$

✓ Increasingly important single top contribution at small pt jet threshold

✓ Detailed study @ NLO+PS of Wt and HWt also in [Demartin Maier Maltoni Mawatari Zaro 2016]

Comparison among fixed order computations for tW production

WWbb [Cascioli, Kallweit, Maierhofer, Pozzorini 2013]

- full off-shell effects
- 4F, no resummation of the collinear log
- inclusion of bb-jets

$$d\sigma_{W^+W^-b\bar{b}} = d\sigma_{t\bar{t}} + d\sigma^{FtW}_{W^+W^-b\bar{b}},$$

Table 2 Full $W^+W^-b\bar{b}$ predictions and finite-top-width contributions for bins with 0,1 and ≥ 2 b-jets. Same conventions as in Table 1.

	μ_0	σ [fb]	σ_0 [fb]	σ_1 [fb]	σ_{2+} [fb]
LO	μ_{WWbb}	$1232^{+34\%}_{-24\%}$	$37^{+38\%}_{-25\%}$	$367^{+36\%}_{-24\%}$	$828^{+33\%}_{-23\%}$
NLO	μ_{WWbb}	$1777^{+10\%}_{-12\%}$	$65^{+20\%}_{-17\%}$	$571^{+14\%}_{-14\%}$	$1140^{+7\%}_{-10\%}$
K	μ_{WWbb}	1.44	1.73	1.56	1.38
LO	m_t	$1317^{+35\%}_{-24\%}$	$35^{+37\%}_{-25\%}$	$373^{+36\%}_{-24\%}$	$909^{+35\%}_{-24\%}$
NLO	m_t	$1817^{+8\%}_{-11\%}$	$63^{+20\%}_{-17\%}$	$584^{+14\%}_{-14\%}$	$1170^{+5\%}_{-9\%}$
K	m_t	1.38	1.80	1.56	1.29
	μ_0	σ^{FtW} [fb]	σ_0^{FtW} [fb]	σ_1^{FtW} [fb]	σ_{2+}^{FtW} [fb]
LO	μ_{WWbb}	$91^{+41\%}_{-27\%}$	$13^{+42\%}_{-27\%}$	$71^{+40\%}_{-27\%}$	$7^{+45\%}_{-29\%}$
NLO	μ_{WWbb}	$107^{+6\%}_{-11\%}$	$20^{+18\%}_{-17\%}$	$82^{+4\%}_{-10\%}$	$5^{+2\%}_{-10\%}$
K	μ_{WWbb}	1.18	1.49	1.16	0.77
LO	m_t	$63^{+36\%}_{-25\%}$	$8^{+36\%}_{-25\%}$	$49^{+36\%}_{-24\%}$	$6^{+46\%}_{-29\%}$
NLO	m_t	$100^{+17\%}_{-16\%}$	$16^{+22\%}_{-18\%}$	$77^{+16\%}_{-15\%}$	$6^{+12\%}_{-16\%}$
K	m_t	1.58	1.89	1.58	1.10

Wt(tWb) MCFM [Campbell Ellis Giele Williams + FT]

- Narrow width approximation
- 5F, resummation of the collinear log
- no bb-jets

$$d\sigma_{t\bar{t}} = \lim_{\Gamma_t \to 0} \left(\frac{\Gamma_t}{\Gamma_t^{phys}} \right)^2 d\sigma_{W^+W^-b\bar{b}}(\Gamma_t),$$

Leptons:

$p_{T,\ell} > 20\,\text{GeV}, \quad |\eta_\ell| < 2.5, \quad p_{T,miss} > 20\text{GeV},$

Jets: antikt, R=0.4

$p_T > 30$ GeV and $|\eta| < 2.5$

PDF's: NNPDF in Cascioli et al

MSTW2008 in MCFM

σ(fb)	Cascioli et al: 0+1 b-jet off-shell	MCFM tW
LO	84^{+35}_{-16} 57^{+21}_{-10}	89
NLO	102^{+7}_{-5} 93^{+16}_{-9}	97

Quite good agreement

logs of Q/mb do not seems to play a big role [Maltoni Ridolfi Ubiali 2013]

Comparison among fixed order computations for tW production

- in 5F: Resummation of initial state logarithms important at high Bjorken x
- in 4F: possibly large logs of Q/mb always accompained by universal suppression factors

[Maltoni Ridolfi Ubiali 2013]

- The bulk of the cross section comes from the collinear region

- The suggested general strategy might still be to use 5F for accurate prediction of total Xsections and 4F for more exclusive predictions

A unified description (also for t-channel) in a single tool is hard to obtain, but desirable

- s-channel

top mass determination
fitting single top cross section measurements
[Alekhin Moch Thier 1608.05212]

- Implementation of approximated NNLO s-channel cross section
- Based on soft gluon corrections [Kidonakis 2006, 2007, 2010]

Channel	ABM12 [20]	ABMP15 [52]	CT14 [53]	MMHT14 [54]	NNPDF3.0 [55]
$t\bar{t}$	167.3 ± 0.6	167.1 ± 0.6	174.1 ± 0.6	174.0 ± 0.6	173.7 ± 0.6
	(167.9 ± 0.6)	(167.6 ± 0.6)	(174.7 ± 0.6)	(174.6 ± 0.6)	(174.3 ± 0.6)
t-channel	168.1 ± 4.0	167.1 ± 4.0	170.6 ± 4.1	171.3 ± 4.1	175.0 ± 4.2
	(168.7 ± 4.0)	(167.6 ± 4.0)	(171.3 ± 4.1)	(171.9 ± 4.1)	(175.7 ± 4.2)
s- & t-channel	167.6 ± 3.6	166.7 ± 3.6	169.4 ± 3.7	170.0 ± 3.7	172.7 ± 3.7
	(168.2 ± 3.6)	(167.2 ± 3.6)	(170.0 ± 3.7)	(170.6 ± 3.7)	(173.4 ± 3.7)

TABLE 4: Results for m_t^{pole} for different PDFs from the conversion of $m_t(m_t)$ at NNLO (in parenthesis at N^3LO) using the value of $\alpha_s(m_Z)$ corresponding to the respective PDF set.

- Tevatron data for s-channel cross section

Conclusion

- After 30 years since the proposal to study its creation at hadron colliders, single top is now an essential laboratory
  - ✓ NNLO computations
  - ✓ resummation (not discussed here)
  - ✓ NLO+PS matching of hard events with resonance production
  - ✓ flavour schemes
- Progress in all directions
- Still several open issues, but groups are working very hard to solve them

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Stay tuned!