Status of MonteCarlo simulations of signals and backgrounds at the LHC

CMS Italia

Spoleto

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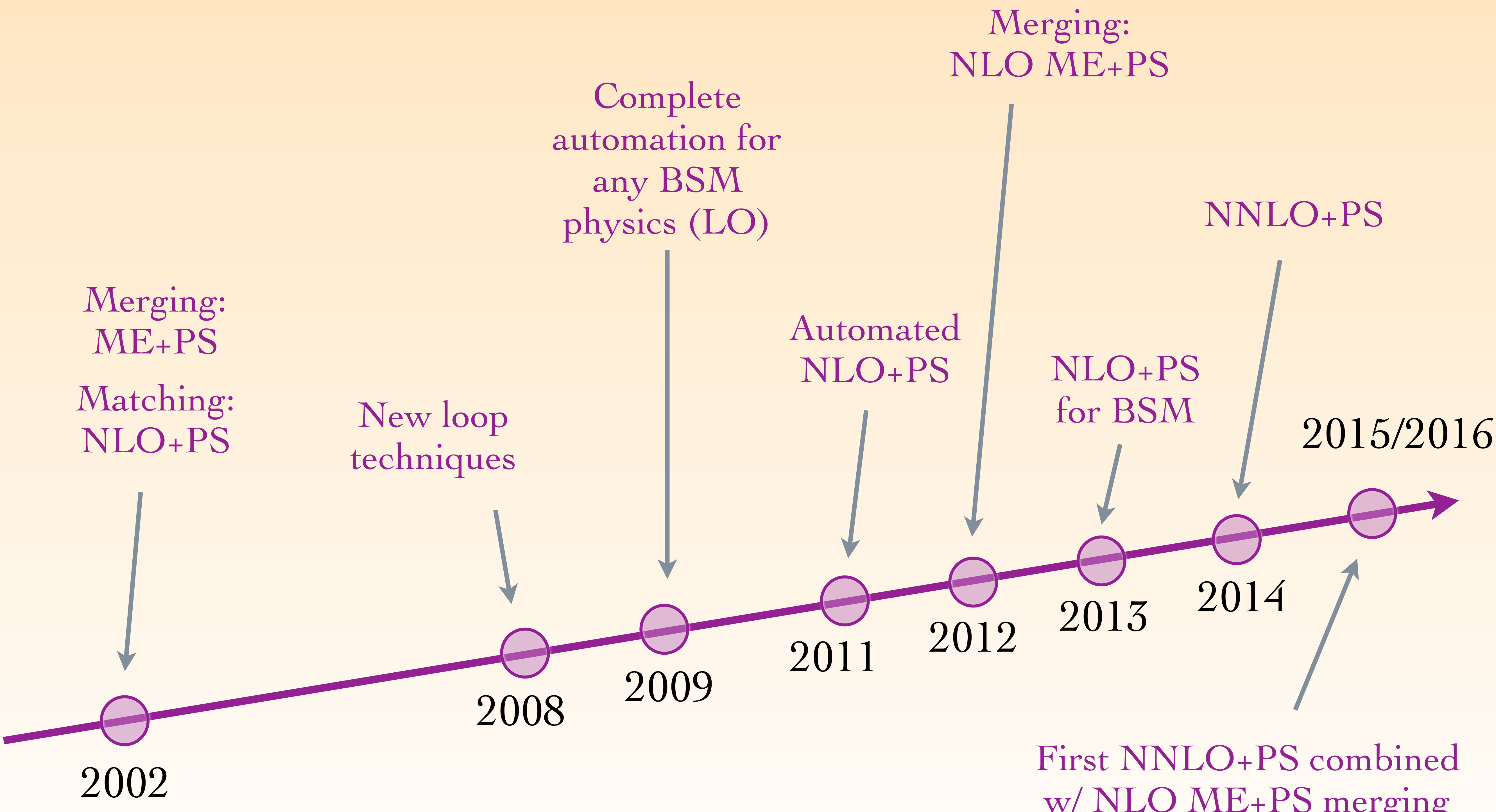
Recent progress in accuracy of Predictions



Slide from Rikkert Frederix, LHCP16

Why NLO Monte-Carlos?

- NLO corrections improve the trustworthiness of simulations and give reliable predictions of rates and shapes
- NLO is the first order for which theoretical uncertainties (scale and PDF) are reliable
- Matching to PS makes it possible to have a fully-differential description of the final state
- This gives a better understanding of data, together with less need of fine-tuning
- Most of modern NLO MonteCarlos strongly rely on automation, which hides computational complexity to the final user

  Powheg(Box): Alioli, Nason, Oleari, Re
  Powhel: Bevilacqua, Garzelli, Kardos, Trocsanyi, Worek
  Sherpa(+Openloops): Krauss, Schonherr, Siegert + Kallweit, Lindert, Pozzorini, Maierhofer
  MadGraph5_aMC@NLO: Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Shao, Torrielli, MZ

What can be done?

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- In general, all processes up to 2→4 can be simulated on clusters; unweighted events can be generated within (several) hours
  Current record: tt+3jets Sherpa+Openloops, Hoche et al, arXiv:1607.06934
- Calculation of scale and PDF uncertainties can be done on the fly. No need of extra runs

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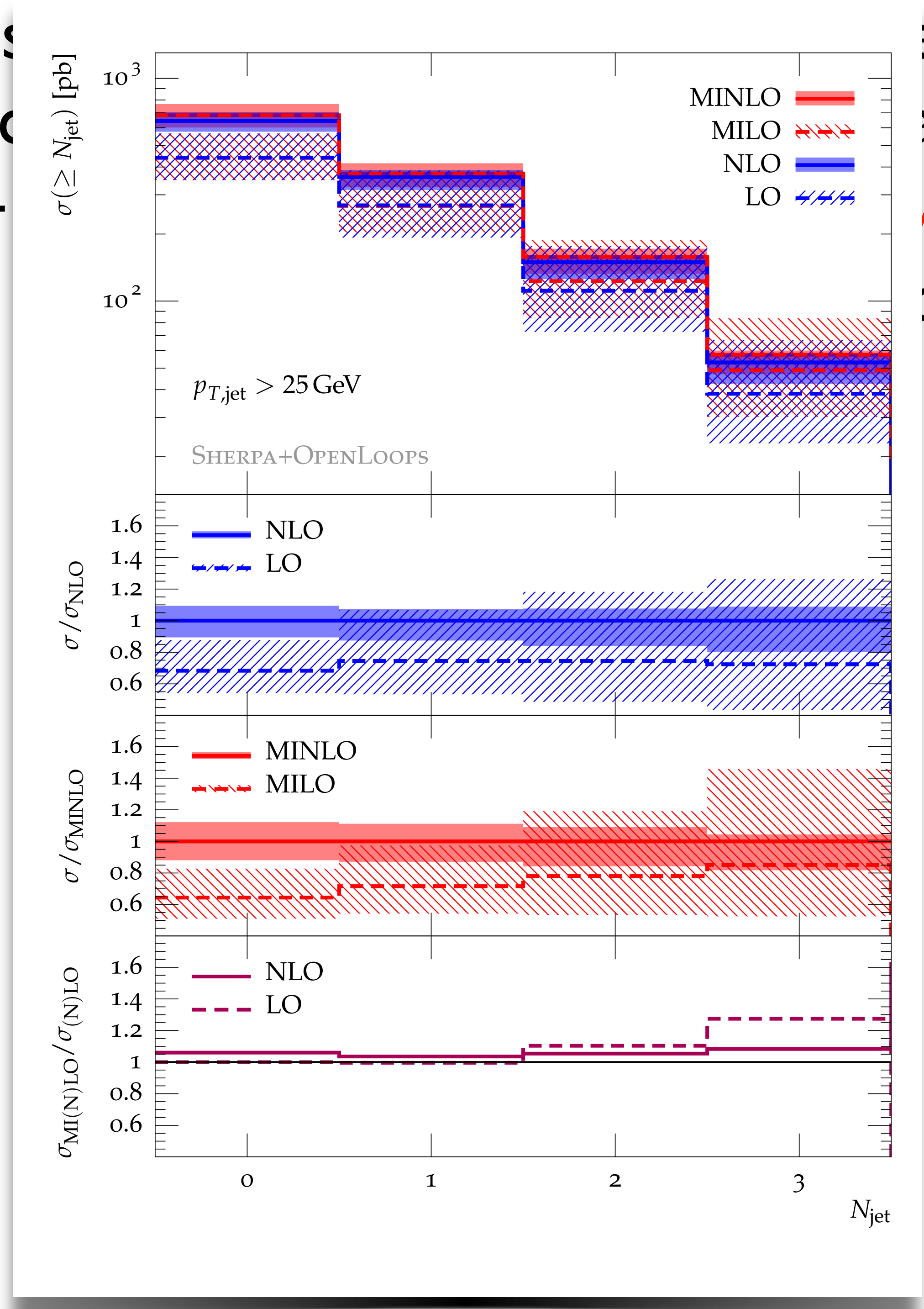

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- Unstable particles can be decayed preserving (tree-level) spin correlations
  Frixione, et al, arXiv:hep-ph/0702198; MadSpin: Artoisenet et al, arXiv:1212.3460; Decayer: Garzelli et al, arXiv:1405.5859

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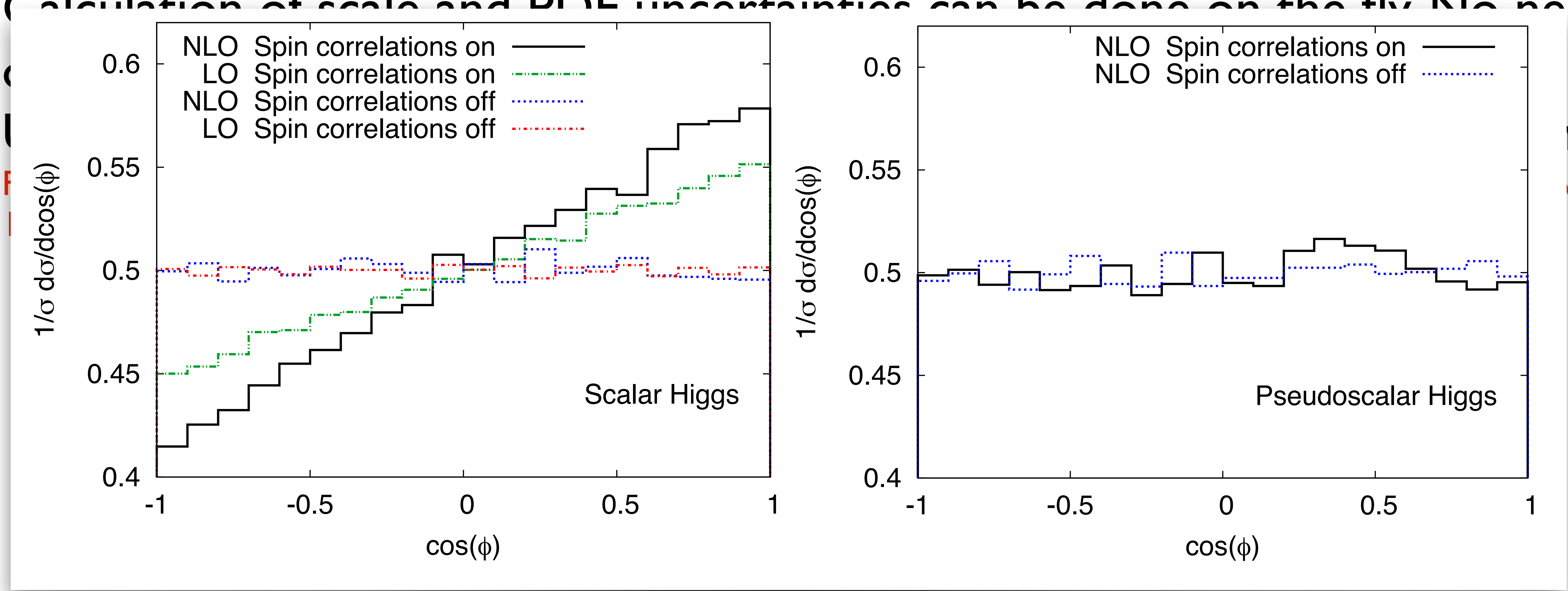

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  Jezo et al, arXiv:1509.09071 & 1607.04538; Frederix et al, arXiv:1603.01178

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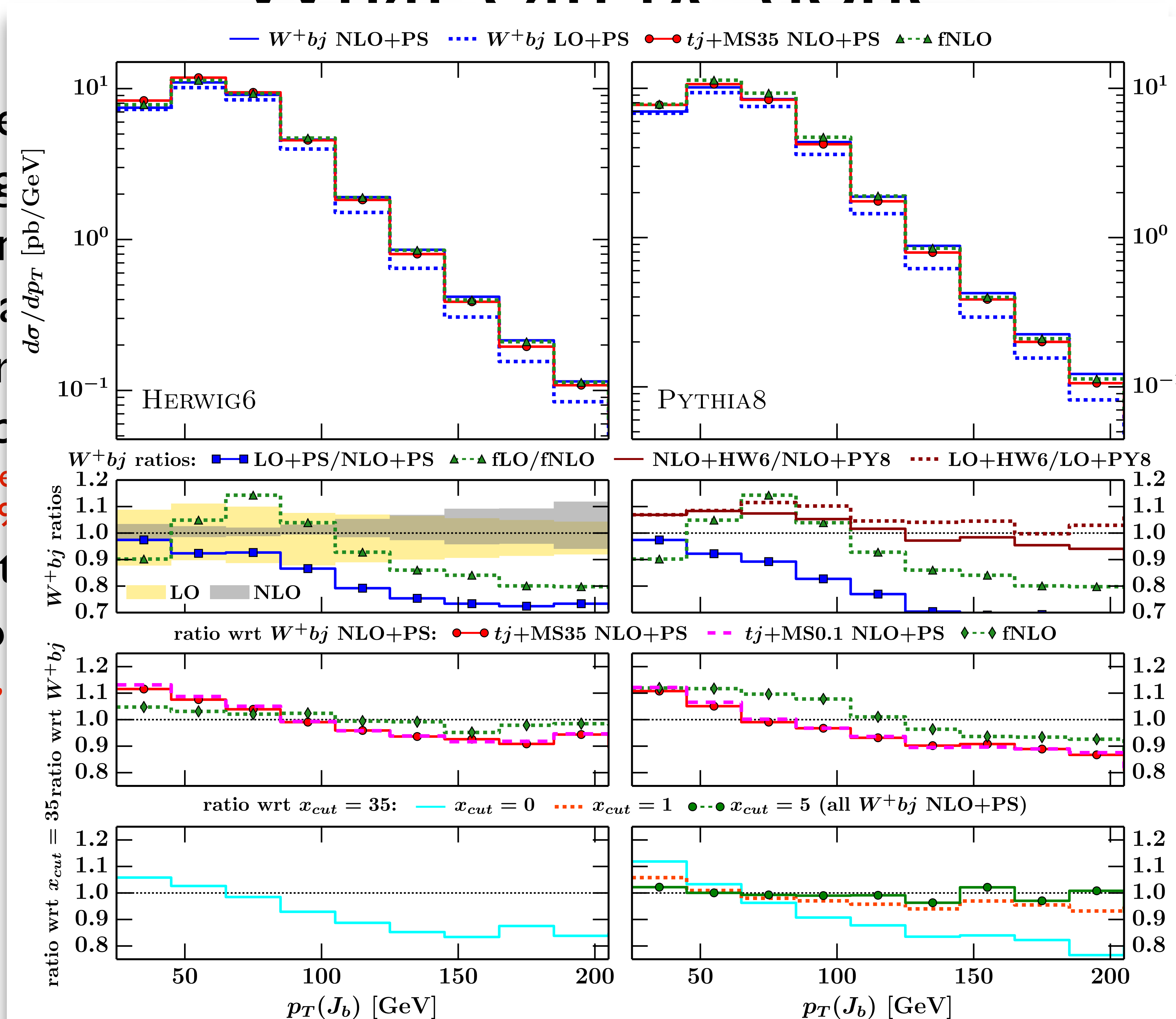

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- Similarly to LO (MLM/CKKW) techniques exist to include higher multiplicities and generate merged samples of events
  Minlo: Hamilton, Nason, Zanderighi, arXiv:1206.3572; FxFx: Frederix, Frixione, arXiv:1209.6215; UNLOPS: Lonnblad, Prestel, arXiv:1211.7278; MEPS@NLO: Schonherr, Hoeche, Krauss, Siegert, arXiv:1212.0386

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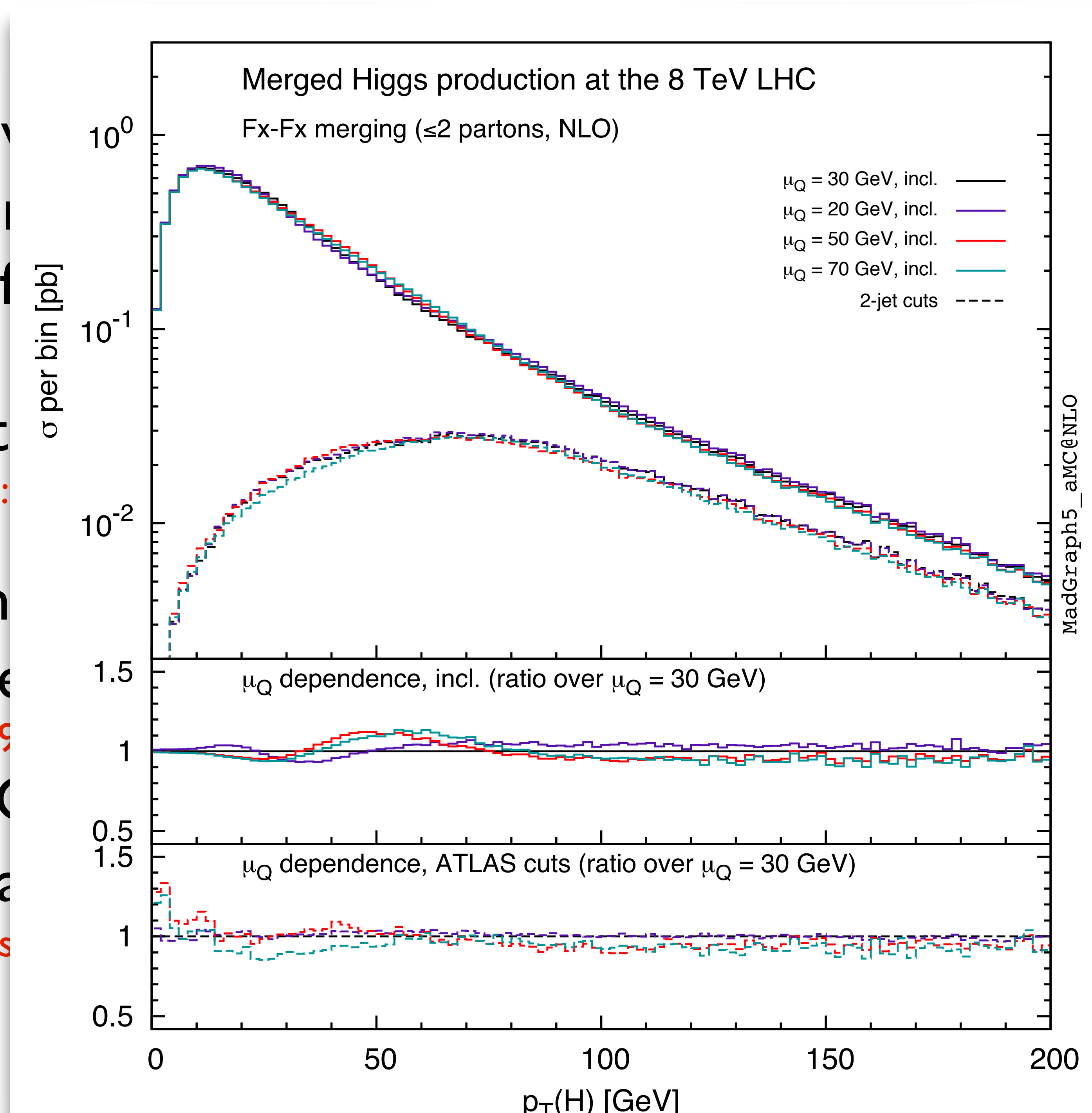
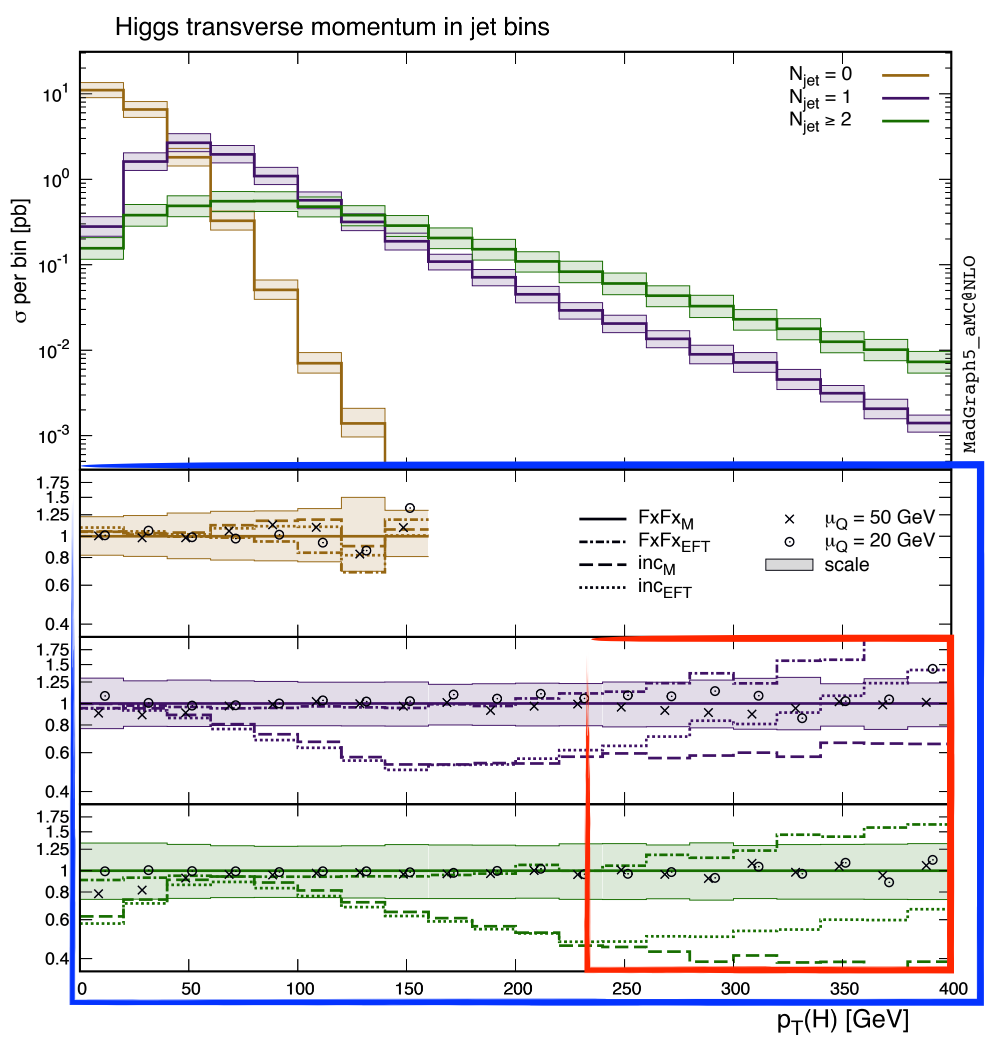


FxFx merging for Higgs production with m_t/m_b effects

Frederix, Frixione, Vryonidou, Wiesemann, arXiv:1604.03017

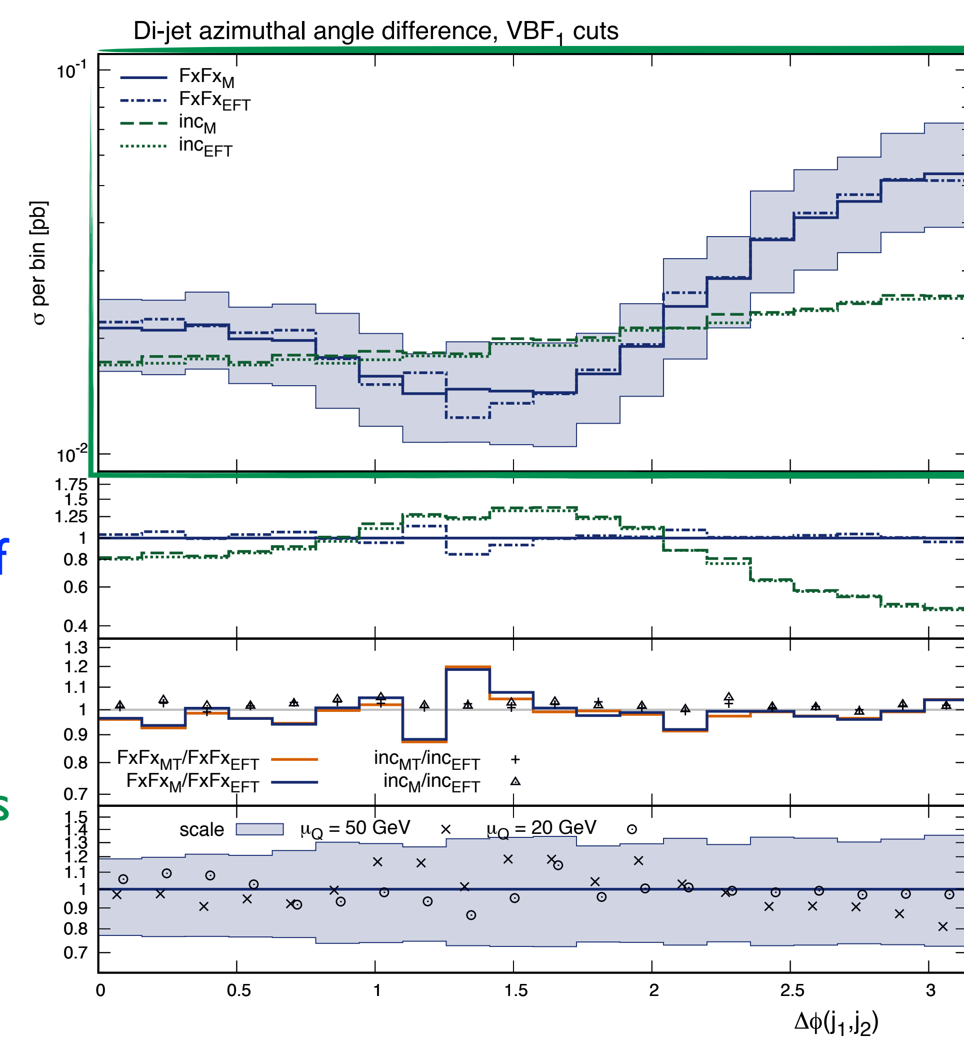
- Higgs boson production in gluon fusion, with FxFx merging (up to +2j) and exact top/bottom mass effects in the loops (except for the 2-loop amplitudes)



Mass effects are important in the high-pT tails

Merging gives a simultaneously accurate description of different jet bins

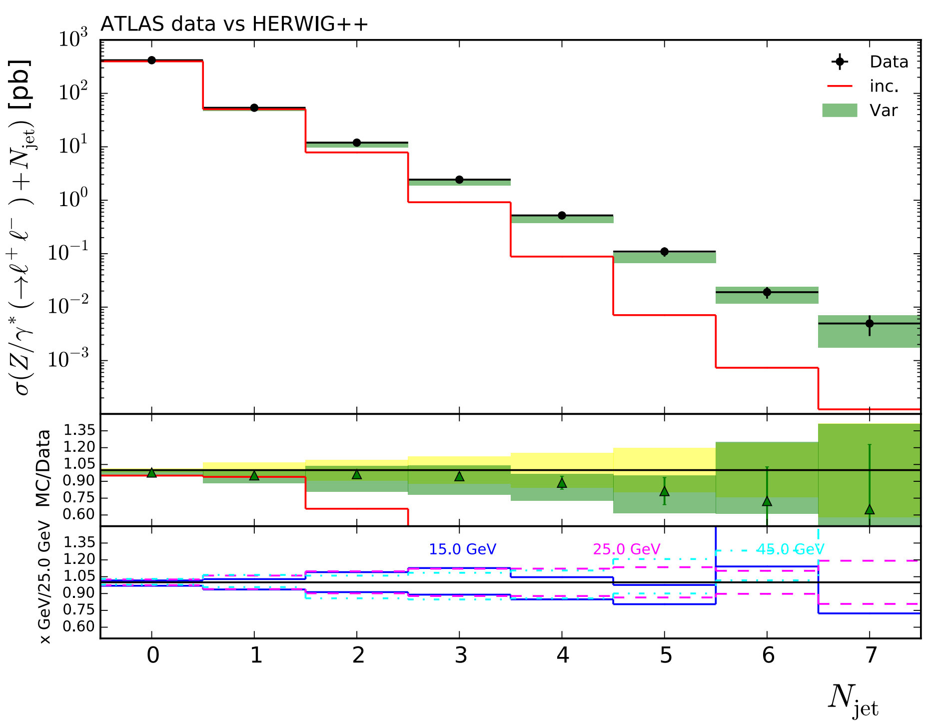
Merging is crucial to describe effects such as the dijet correlation

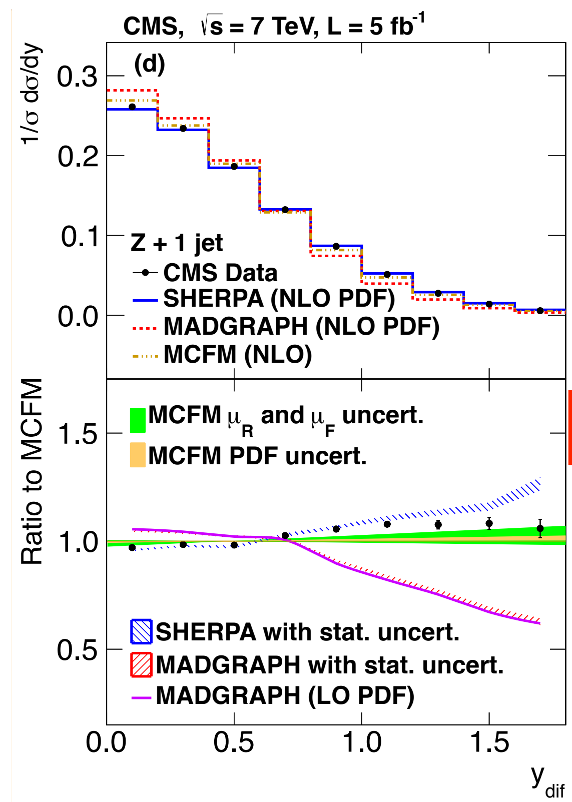


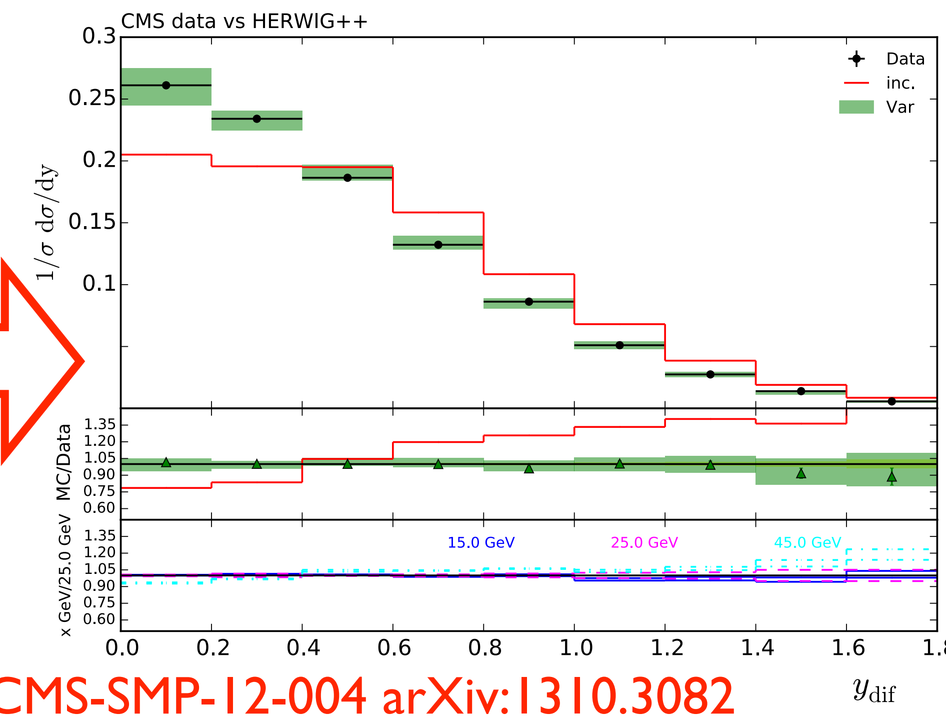
FxFx merging vs data: V+jets

Frederix, Frixione, Papaefstathiou, Prestel, Torrielli, arXiv:1511.00847

- Z+jets and W+jets at NLO, with FxFx merging (up to +2j) and compared to 7 TeV ATLAS and CMS data
- Normalisation kept as out of the code, no rescaling factors applied
- Good theory/data agreement found for most variables. Few exceptions, where also differences between PS (HW++ vs PY8) are there
- NLO corrections (and merging) are crucial







CMS-SMP-12-004 arXiv:1310.3082

Disclaimer

- Automation does not mean that everything is settled!
- There are still many things to understand for NLO+PS calculations
- Comparison with data crucial to validate tools

Complex backgrounds to $t\bar{t}H$

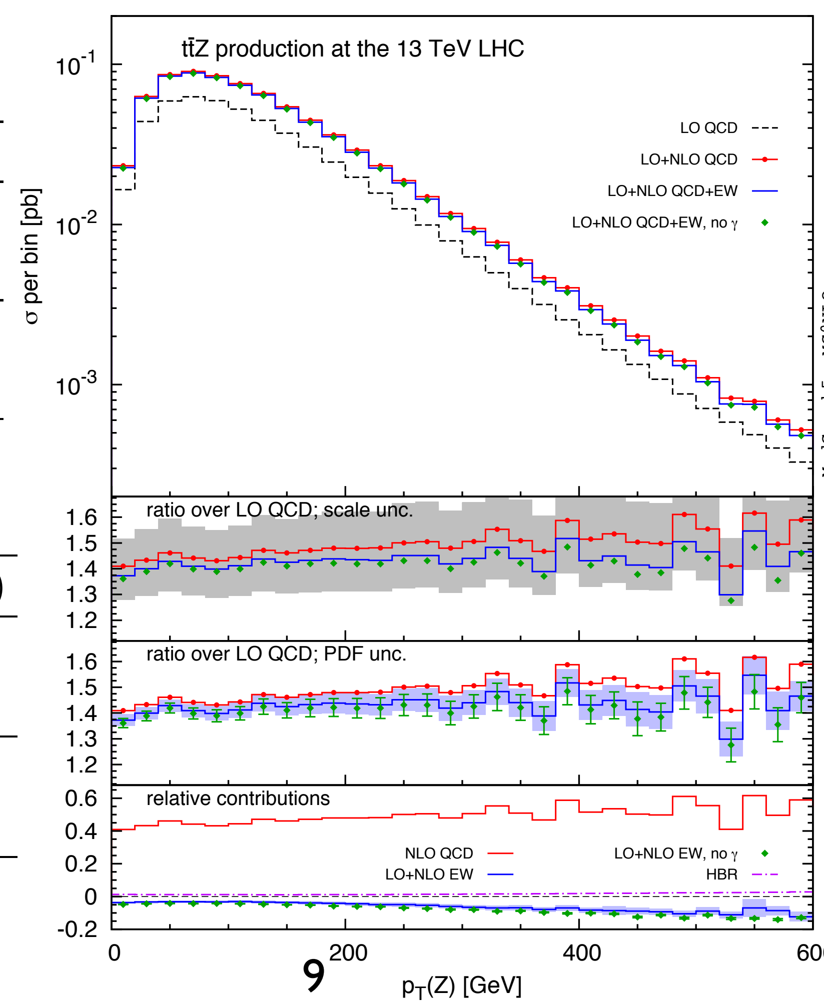
Complex backgrounds for $t\bar{t}H$: $t\bar{t}V$

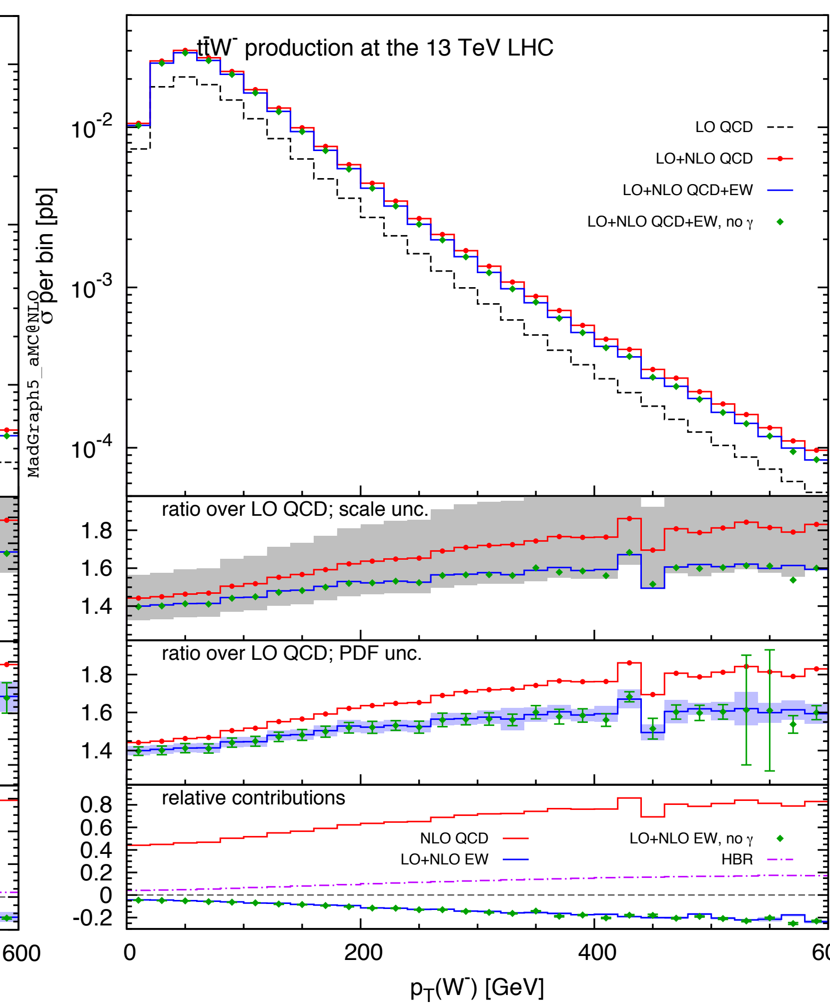
- ttV(V=W,Z,γ): simulation-wise, well within reach of NLO+PS generators
  - Cross-section known up to NLO QCD+EW (V=W,Z)
    Frixione, Hirschi, Pagani, Shao, MZ, arXiv:1504.03446
  - +1j can be included with NLO merging

EW corrections

$t\bar{t}W^+$: $\delta(\%)$	13 TeV
NLO QCD	$50.1^{+14.2}_{-13.5} \pm 2.4$ $(59.7^{+18.9}_{-17.7} \pm 3.1)$
LO EW	0
LO EW no γ	0
NLO EW	-7.7 ± 0.2 (-19.2 ± 0.7)
NLO EW no γ	-8.0 ± 0.2 (-20.0 ± 0.5)
HBR	3.88 (7.41)

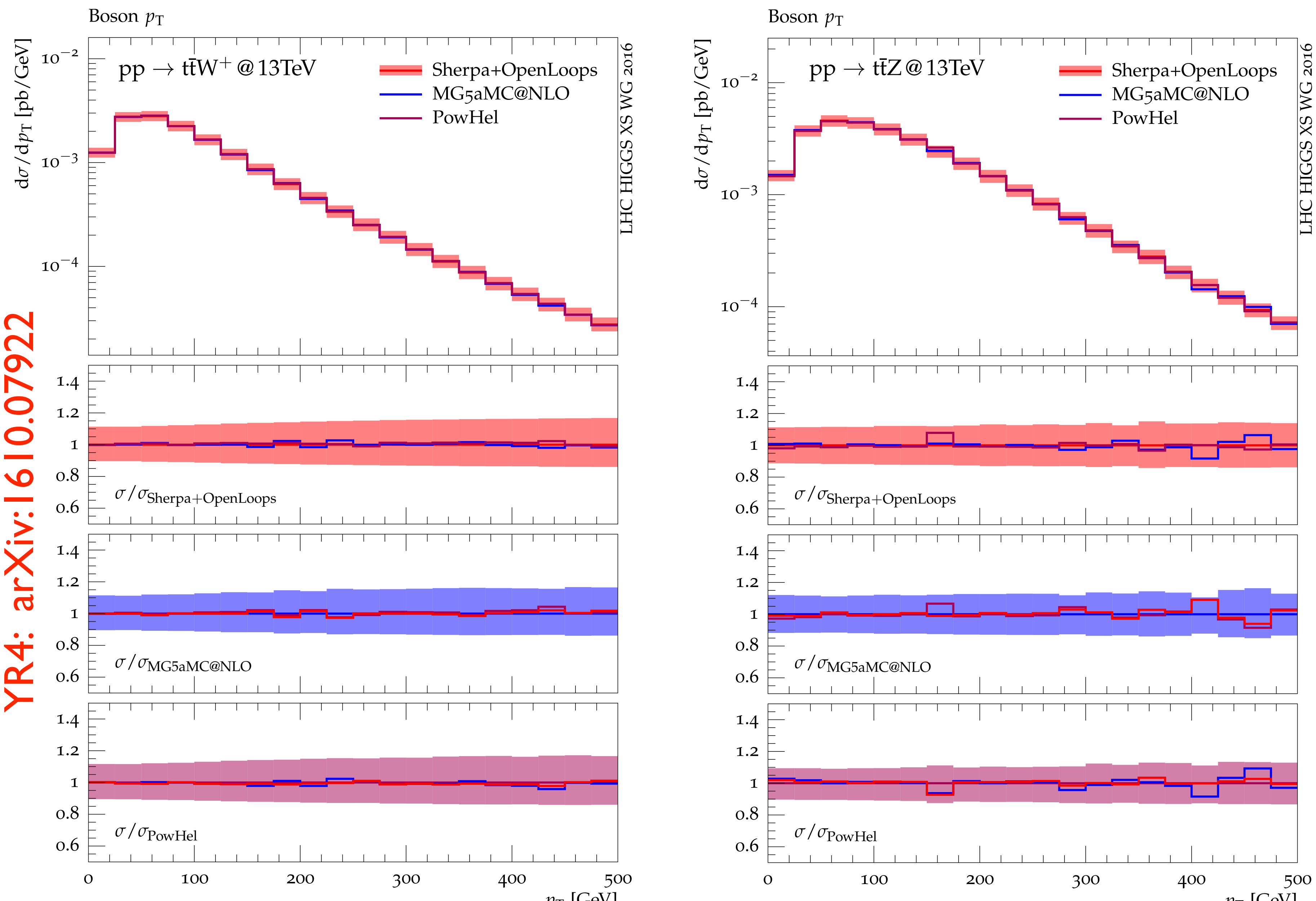
$t\bar{t}Z$: $\delta(\%)$	13 TeV
NLO QCD	$45.9^{+13.2}_{-15.5} \pm 2.9$ $(40.2^{+11.1}_{-15.0} \pm 4.7)$
LO EW	0.0 ± 0.7 (2.1 ± 1.6)
LO EW no γ	-1.1 ± 0.0 (-0.3 ± 0.0)
NLO EW	-3.8 ± 0.2 (-11.1 ± 0.5)
NLO EW no γ	-4.1 ± 0.1 (-11.5 ± 0.3)
HBR	0.96 (2.13)





$t\bar{t}V$ tool comparison

- Very good agreement among various tools and O(10%) Th. Unc.

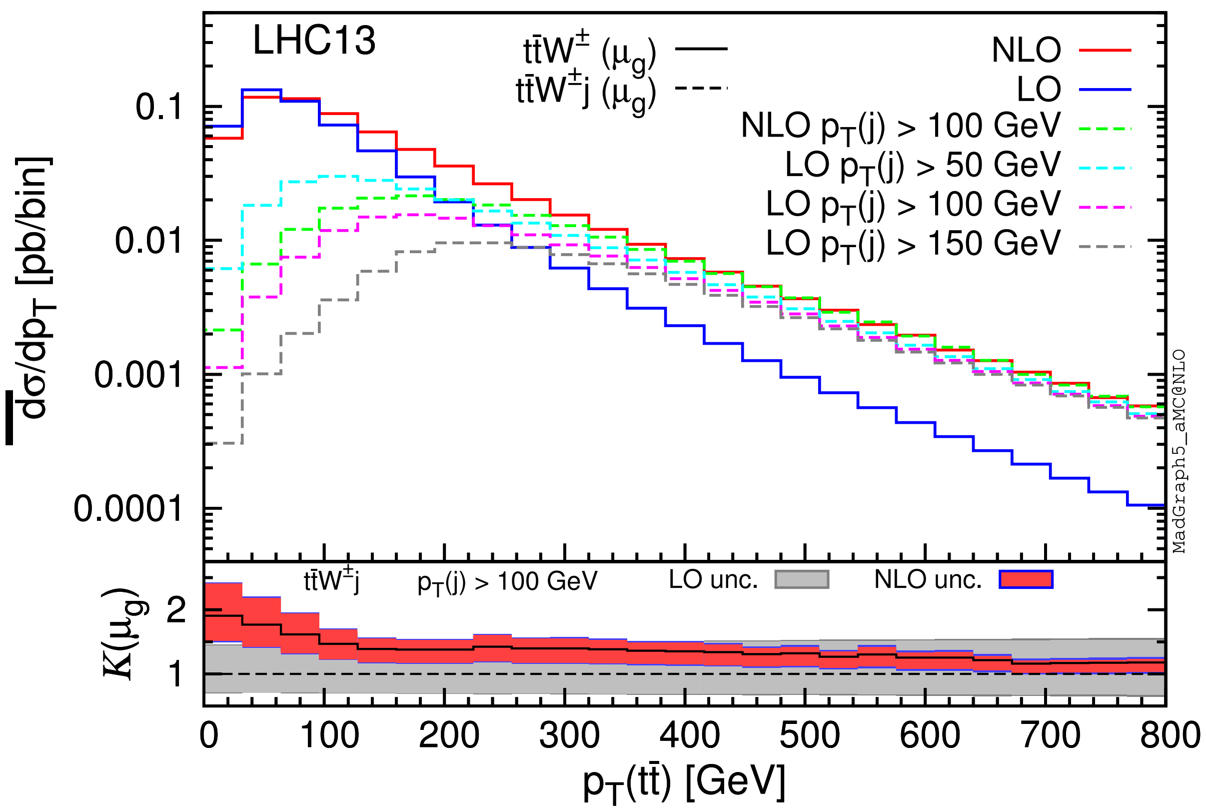


YR4: arXiv:1610.07922

Complex backgrounds for $t\bar{t}H$: $t\bar{t}V$

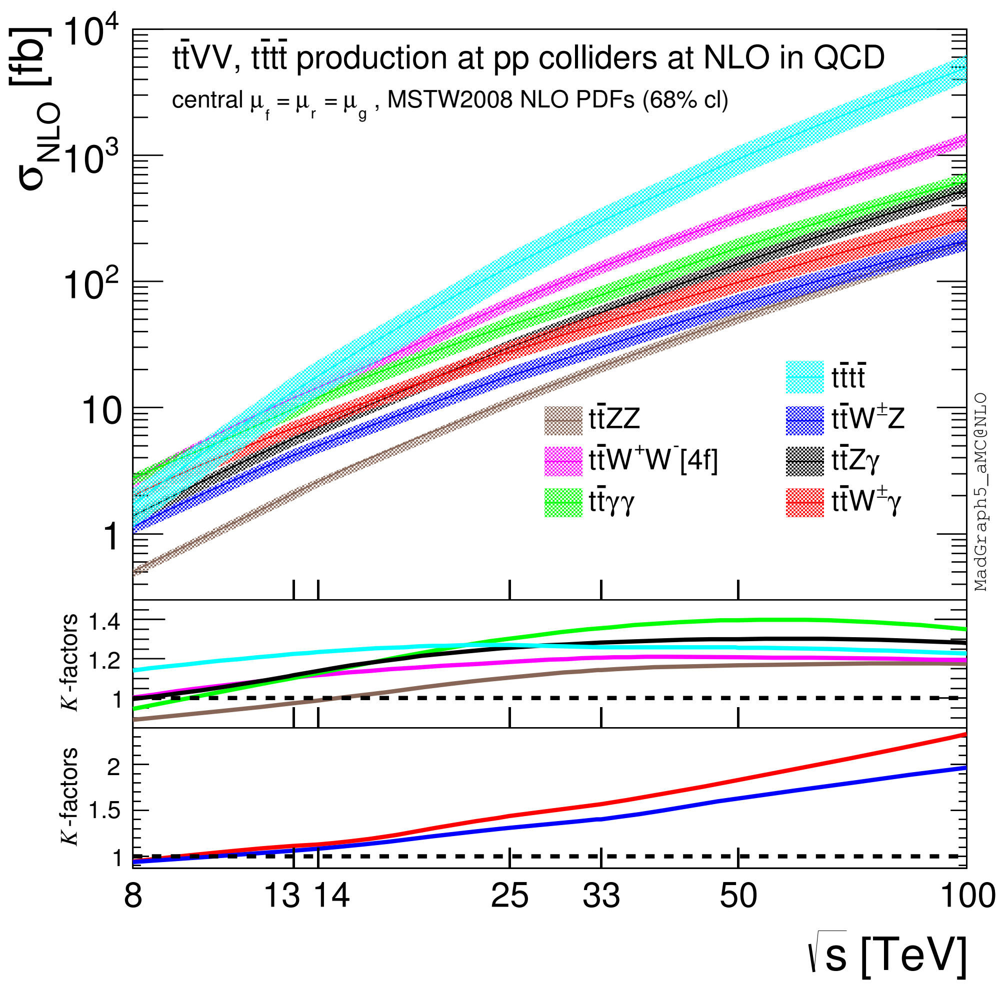
- NLO corrections are huge for the $p_T(t\bar{t})$
- This is due to configurations where the $t\bar{t}$ pair recoils against a hard jet (and a soft V).
- Do we expect large corrections also at NNLO?
- Probably not: $t\bar{t}Wj$ receives rather small corrections at NLO
- This also happens for $t\bar{t}VV$

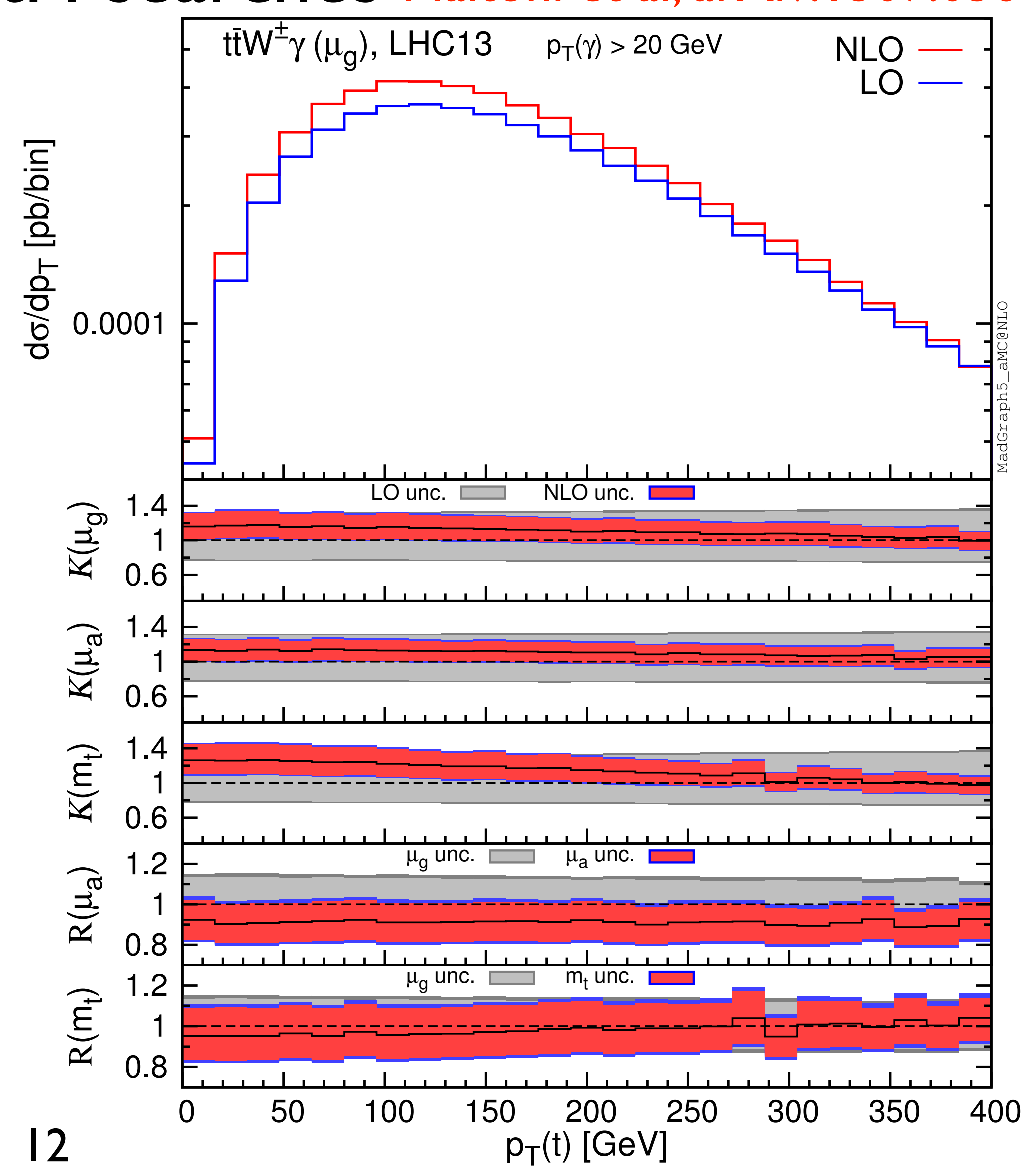
Maltoni et al, arXiv:1507.05640



Complex backgrounds for $t\bar{t}H$: $t\bar{t}VV$

- All $t\bar{t}$+VV processes studied at NLO+PS accuracy
- NLO corrections essential for realistic phenomenology
- Detailed study in the context of $t\bar{t}H$ searches Maltoni et al, arXiv:1507.05640



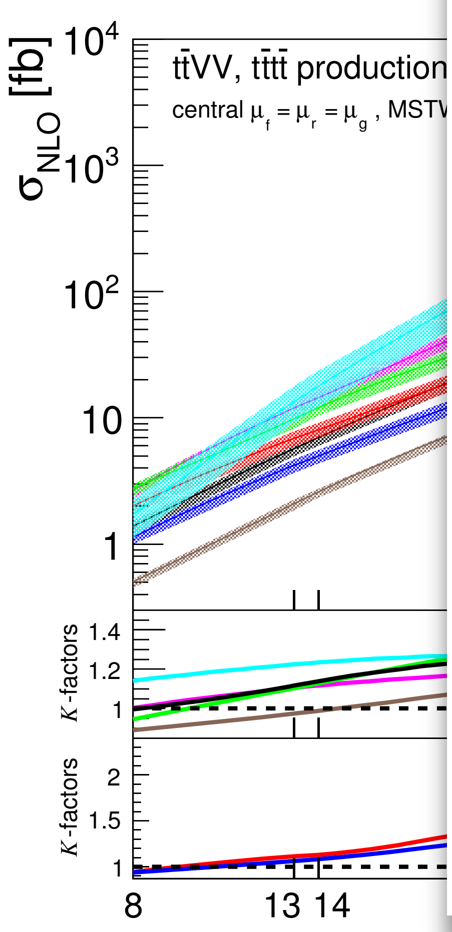


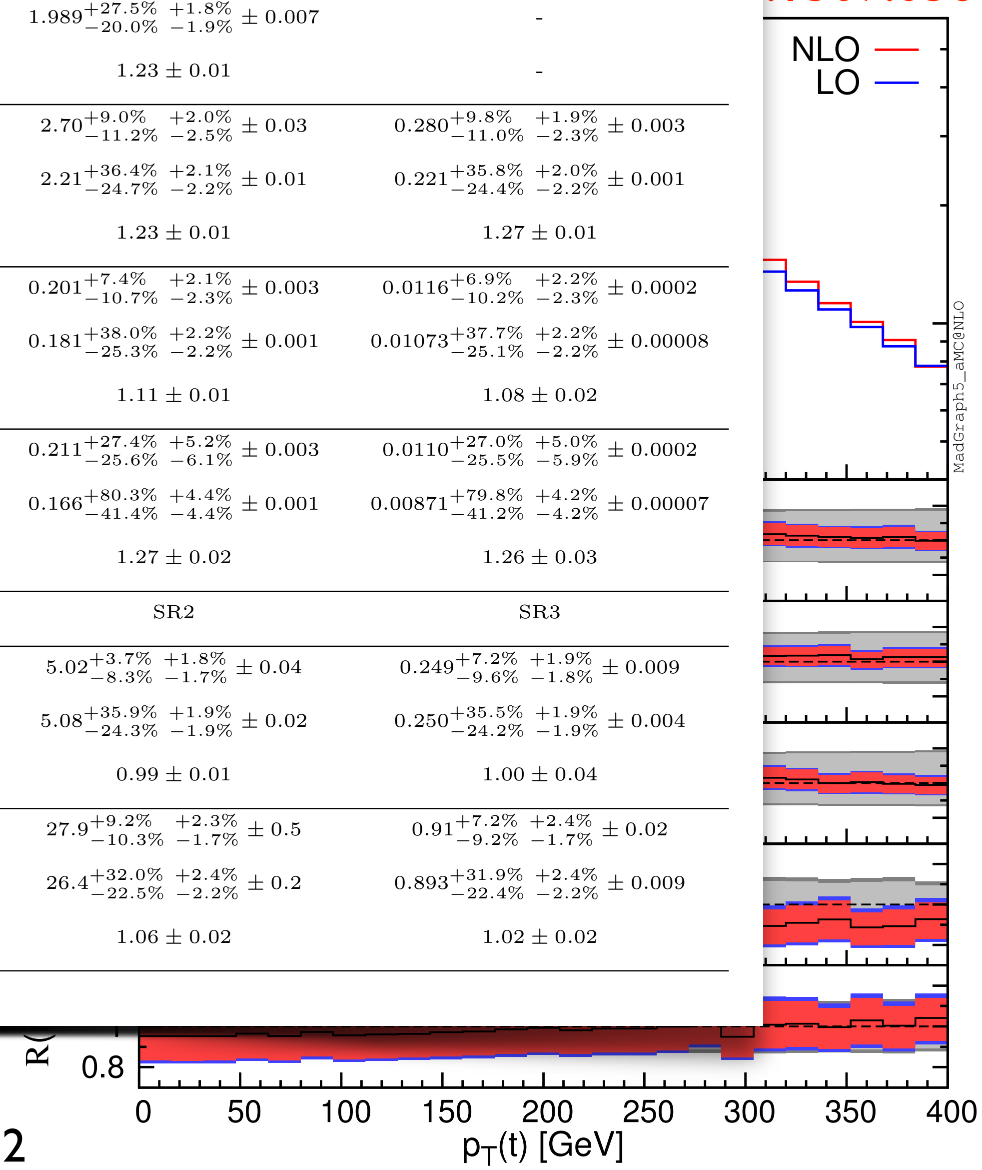
Co… tH:

- All $t\bar{t}$+VV p…
- NLO correc…
- Detailed stu…

:1507.05640

13 TeV σ[fb]		SR1	SR2	SR3
	NLO+PS	$1.54^{+5.1\%}_{-9.0\%}{}^{+2.2\%}_{-2.6\%} \pm 0.02$	$1.47^{+5.2\%}_{-9.0\%}{}^{+2.0\%}_{-2.4\%} \pm 0.02$	$0.095^{+7.4\%}_{-9.7\%}{}^{+2.0\%}_{-2.4\%} \pm 0.002$
$t\bar{t}H(H \to WW^*)$	LO+PS	$1.401^{+35.6\%}_{-24.4\%}{}^{+2.1\%}_{-2.2\%} \pm 0.008$	$1.355^{+35.2\%}_{-24.1\%}{}^{+2.0\%}_{-2.2\%} \pm 0.008$	$0.0855^{+34.9\%}_{-24.0\%}{}^{+2.0\%}_{-2.2\%} \pm 0.0007$
$K = 1.10$	K^{PS}	1.10 ± 0.02	1.09 ± 0.02	1.11 ± 0.02
	NLO+PS	$0.0437^{+5.5\%}_{-9.2\%}{}^{+2.3\%}_{-2.8\%} \pm 0.0004$	$0.119^{+6.3\%}_{-9.6\%}{}^{+2.1\%}_{-2.5\%} \pm 0.002$	$0.0170^{+5.0\%}_{-8.5\%}{}^{+2.0\%}_{-2.4\%} \pm 0.0003$
$t\bar{t}H(H \to ZZ^*)$	LO+PS	$0.0404^{+36.1\%}_{-24.6\%}{}^{+2.2\%}_{-2.3\%} \pm 0.0002$	$0.1092^{+35.3\%}_{-24.2\%}{}^{+2.0\%}_{-2.2\%} \pm 0.0008$	$0.0152^{+34.7\%}_{-23.9\%}{}^{+1.9\%}_{-2.1\%} \pm 0.0001$
$K = 1.10$	K^{PS}	1.08 ± 0.01	1.09 ± 0.02	1.12 ± 0.02
	NLO+PS	$0.563^{+4.6\%}_{-8.8\%}{}^{+2.2\%}_{-2.7\%} \pm 0.007$	$0.669^{+6.0\%}_{-9.4\%}{}^{+2.1\%}_{-2.6\%} \pm 0.008$	$0.0494^{+7.1\%}_{-9.9\%}{}^{+2.1\%}_{-2.5\%} \pm 0.0007$
$t\bar{t}H(H \to \tau^+\tau^-)$	LO+PS	$0.513^{+35.9\%}_{-24.5\%}{}^{+2.2\%}_{-2.3\%} \pm 0.003$	$0.611^{+35.4\%}_{-24.2\%}{}^{+2.1\%}_{-2.2\%} \pm 0.003$	$0.0438^{+35.1\%}_{-24.1\%}{}^{+2.0\%}_{-2.2\%} \pm 0.0003$
$K = 1.10$	K^{PS}	1.10 ± 0.02	1.10 ± 0.01	1.13 ± 0.02
	NLO+PS	$5.77^{+15.1\%}_{-12.7\%}{}^{+1.6\%}_{-1.2\%} \pm 0.07$	$2.44^{+13.1\%}_{-11.6\%}{}^{+1.7\%}_{-1.4\%} \pm 0.01$	-
$t\bar{t}W^\pm$	LO+PS	$4.57^{+27.7\%}_{-20.2\%}{}^{+1.8\%}_{-1.9\%} \pm 0.03$	$1.989^{+27.5\%}_{-20.0\%}{}^{+1.8\%}_{-1.9\%} \pm 0.007$	-
$K = 1.22$	K^{PS}	1.26 ± 0.02	1.23 ± 0.01	-
	NLO+PS	$1.61^{+7.7\%}_{-10.5\%}{}^{+2.0\%}_{-2.5\%} \pm 0.02$	$2.70^{+9.0\%}_{-11.2\%}{}^{+2.0\%}_{-2.5\%} \pm 0.03$	$0.280^{+9.8\%}_{-11.0\%}{}^{+1.9\%}_{-2.3\%} \pm 0.003$
$t\bar{t}Z/\gamma^*$	LO+PS	$1.422^{+36.8\%}_{-24.9\%}{}^{+2.2\%}_{-2.3\%} \pm 0.008$	$2.21^{+36.4\%}_{-24.7\%}{}^{+2.1\%}_{-2.2\%} \pm 0.01$	$0.221^{+35.8\%}_{-24.4\%}{}^{+2.0\%}_{-2.2\%} \pm 0.001$
$K = 1.23$	K^{PS}	1.13 ± 0.02	1.23 ± 0.01	1.27 ± 0.01
	NLO+PS	$0.288^{+8.0\%}_{-11.1\%}{}^{+2.3\%}_{-2.6\%} \pm 0.003$	$0.201^{+7.4\%}_{-10.7\%}{}^{+2.1\%}_{-2.3\%} \pm 0.003$	$0.0116^{+6.9\%}_{-10.2\%}{}^{+2.2\%}_{-2.3\%} \pm 0.0002$
$t\bar{t}W^+W^-$	LO+PS	$0.260^{+38.4\%}_{-25.5\%}{}^{+2.3\%}_{-2.3\%} \pm 0.001$	$0.181^{+38.0\%}_{-25.3\%}{}^{+2.2\%}_{-2.2\%} \pm 0.001$	$0.01073^{+37.7\%}_{-25.1\%}{}^{+2.2\%}_{-2.2\%} \pm 0.00008$
$K = 1.10$	K^{PS}	1.11 ± 0.01	1.11 ± 0.01	1.08 ± 0.02
	NLO+PS	$0.340^{+27.5\%}_{-25.8\%}{}^{+5.5\%}_{-6.4\%} \pm 0.004$	$0.211^{+27.4\%}_{-25.6\%}{}^{+5.2\%}_{-6.1\%} \pm 0.003$	$0.0110^{+27.0\%}_{-25.5\%}{}^{+5.0\%}_{-5.9\%} \pm 0.0002$
$t\bar{t}t\bar{t}$	LO+PS	$0.271^{+80.9\%}_{-41.5\%}{}^{+4.6\%}_{-4.6\%} \pm 0.001$	$0.166^{+80.3\%}_{-41.4\%}{}^{+4.4\%}_{-4.4\%} \pm 0.001$	$0.00871^{+79.8\%}_{-41.2\%}{}^{+4.2\%}_{-4.2\%} \pm 0.00007$
$K = 1.22$	K^{PS}	1.26 ± 0.02	1.27 ± 0.02	1.26 ± 0.03
13 TeV σ[ab]		SR1	SR2	SR3
	NLO+PS	$9.60^{+3.5\%}_{-8.4\%}{}^{+1.8\%}_{-1.8\%} \pm 0.06$	$5.02^{+3.7\%}_{-8.3\%}{}^{+1.8\%}_{-1.7\%} \pm 0.04$	$0.249^{+7.2\%}_{-9.6\%}{}^{+1.9\%}_{-1.8\%} \pm 0.009$
$t\bar{t}ZZ$	LO+PS	$9.71^{+36.3\%}_{-24.5\%}{}^{+1.9\%}_{-1.9\%} \pm 0.02$	$5.08^{+35.9\%}_{-24.3\%}{}^{+1.9\%}_{-1.9\%} \pm 0.02$	$0.250^{+35.5\%}_{-24.2\%}{}^{+1.9\%}_{-1.9\%} \pm 0.004$
$K = 0.99$	K^{PS}	0.99 ± 0.01	0.99 ± 0.01	1.00 ± 0.04
	NLO+PS	$62.0^{+9.0\%}_{-10.2\%}{}^{+2.2\%}_{-1.6\%} \pm 0.7$	$27.9^{+9.2\%}_{-10.3\%}{}^{+2.3\%}_{-1.7\%} \pm 0.5$	$0.91^{+7.2\%}_{-9.2\%}{}^{+2.4\%}_{-1.7\%} \pm 0.02$
$t\bar{t}W^\pm Z$	LO+PS	$60.2^{+32.2\%}_{-22.6\%}{}^{+2.4\%}_{-2.3\%} \pm 0.3$	$26.4^{+32.0\%}_{-22.5\%}{}^{+2.4\%}_{-2.2\%} \pm 0.2$	$0.893^{+31.9\%}_{-22.4\%}{}^{+2.4\%}_{-2.2\%} \pm 0.009$
$K = 1.06$	K^{PS}	1.03 ± 0.01	1.06 ± 0.02	1.02 ± 0.02





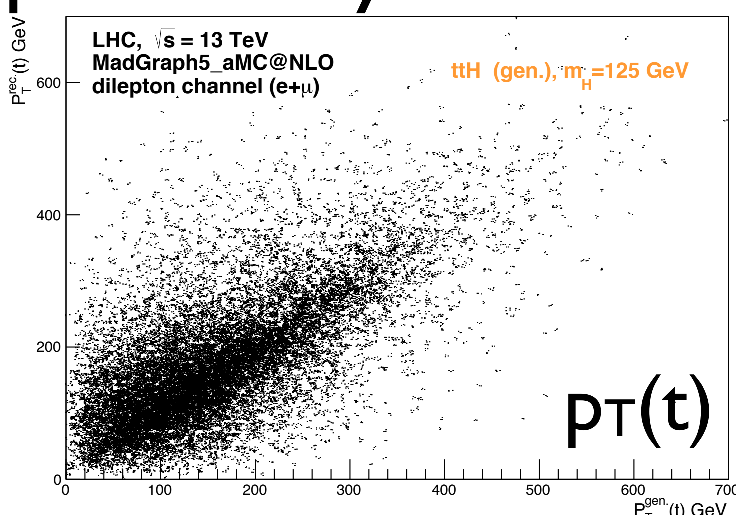
Complex backgrounds for $t\bar{t}H$: $t\bar{t}b\bar{b}$

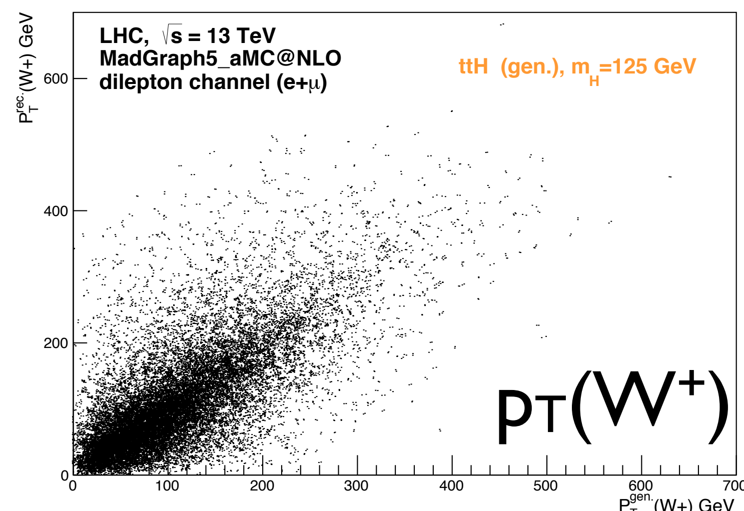
- ttbb: among the most difficult processes for MCs
  - Mass effects are crucial to fill all the phase-space and to cover all kinematics configurations (boosted $H \to bb$, b-jets outside acceptance, …)
  - Calculations with m_b=0 need unphysical cuts to have predictions also in the 1-b bin
  - $g \to bb$ splitting can affect rate in the M_{bb}~120 GeV region
    Cascioli et al, arXiv:1309.5912

Spin correlations: not only for the Higgs properties

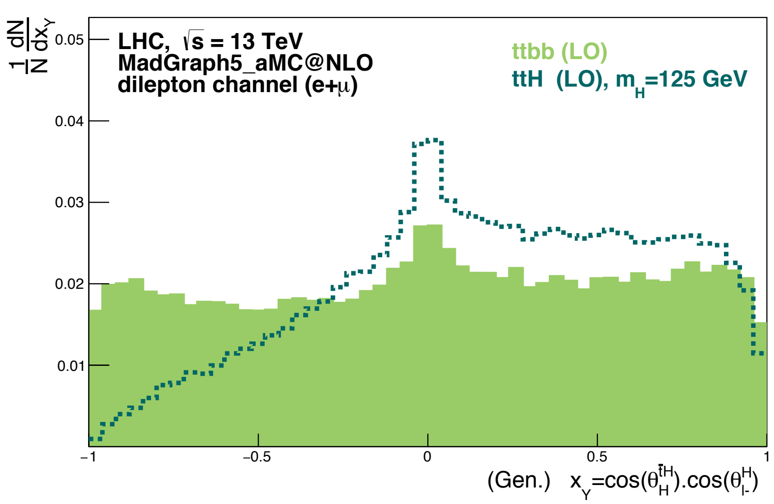
Amor dos Santos et al. arXiv:1503.07787

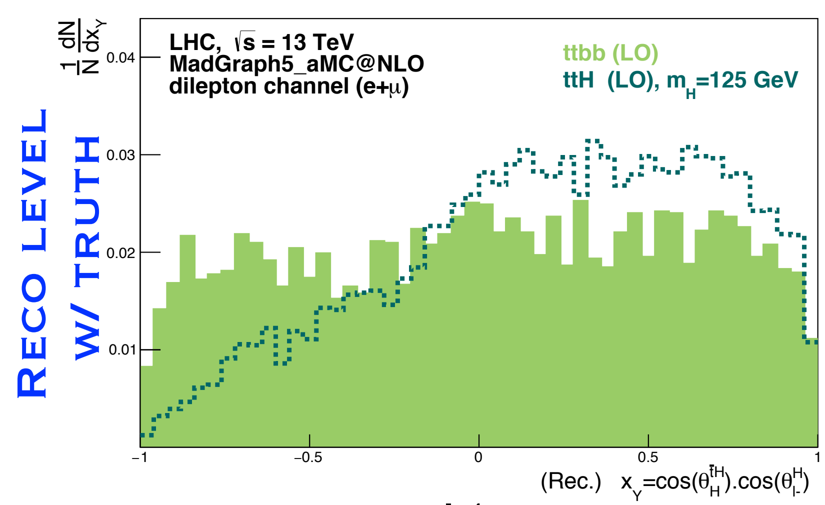
- Spin correlations can be used to separate S ($t\bar{t}H$) and B ($t\bar{t}b\bar{b}$)
- Check robustness of variables against PS / detector simulation
- Dilepton decays allow for good reconstruction of top/W

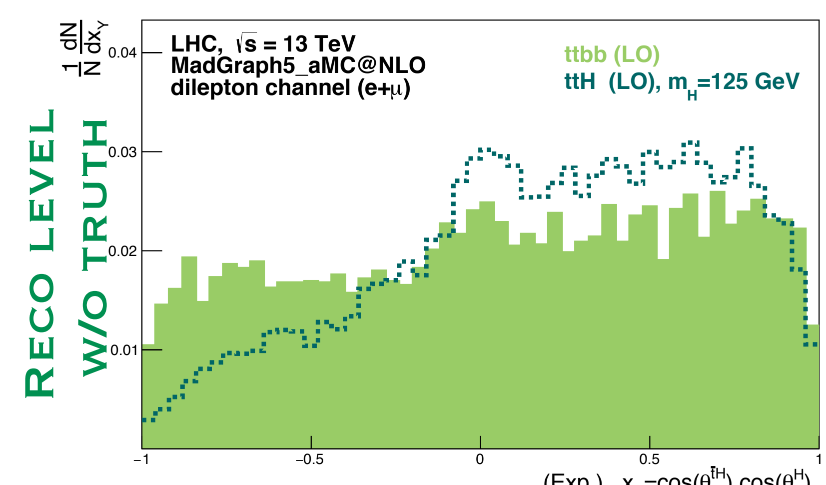




- Product of cosines can be used for S/B discrimination







$t\bar{t}b\bar{b}$ with massive b-quarks

Cascioli et al, arXiv:1309.5912

	ttb	ttbb	ttbb($m_{\mathrm{bb}} > 100$)
$\sigma_{\mathrm{LO}}[\mathrm{fb}]$	$2644^{+71\%+14\%}_{-38\%-11\%}$	$463.3^{+66\%+15\%}_{-36\%-12\%}$	$123.4^{+63\%+17\%}_{-35\%-13\%}$
$\sigma_{\mathrm{NLO}}[\mathrm{fb}]$	$3296^{+34\%+5.6\%}_{-25\%-4.2\%}$	$560^{+29\%+5.4\%}_{-24\%-4.8\%}$	$141.8^{+26\%+6.5\%}_{-22\%-4.6\%}$
$\sigma_{\mathrm{NLO}}/\sigma_{\mathrm{LO}}$	1.25	1.21	1.15
$\sigma_{\mathrm{MC}}[\mathrm{fb}]$	$3313^{+32\%+3.9\%}_{-25\%-2.9\%}$	$600^{+24\%+2.0\%}_{-22\%-2.1\%}$	$181.0^{+20\%+8.1\%}_{-20\%-6.0\%}$
$\sigma_{\mathrm{MC}}/\sigma_{\mathrm{NLO}}$	1.01	1.07	1.28
$\sigma^{2\mathrm{b}}_{\mathrm{MC}}[\mathrm{fb}]$	3299	552	146
$\sigma^{2\mathrm{b}}_{\mathrm{MC}}/\sigma_{\mathrm{NLO}}$	1.00	0.99	1.03

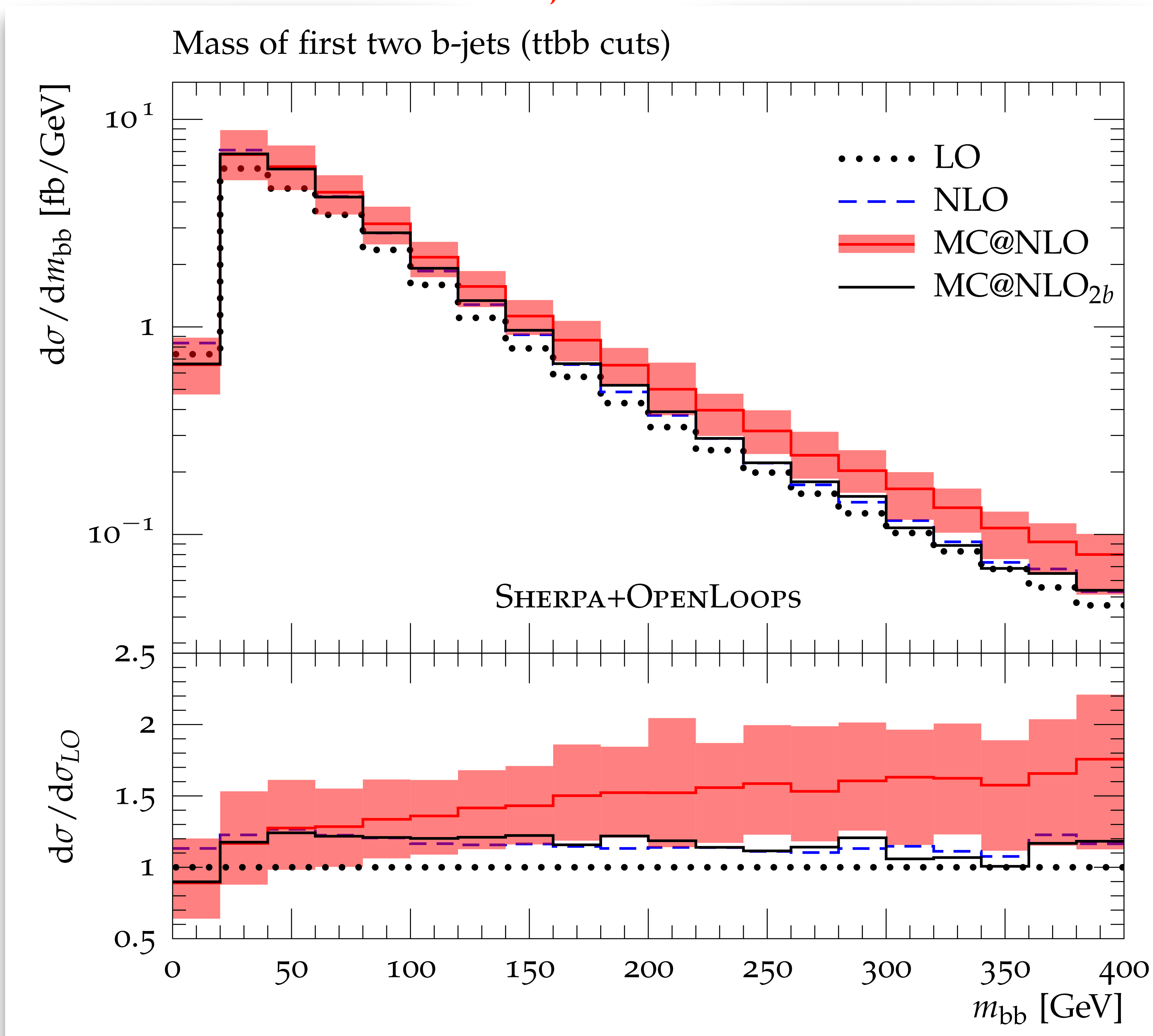
without g→bb splittings in the shower

PS effects are 4x larger in the Higgs signal region than for the total cross section

Turning g→bb splittings off in the shower brings the effects in the Higgs signal region to similar values as for the total cross section

$t\bar{t}b\bar{b}$ with massive b-quarks

Cascioli et al, arXiv:1309.5912



without g→bb splittings in the shower

b($m_{bb} > 100$)

$3.4^{+63\%+17\%}_{-35\%-13\%}$

$1.8^{+26\%+6.5\%}_{-22\%-4.6\%}$

15

$1.0^{+20\%+8.1\%}_{-20\%-6.0\%}$

28

6

03

r the total

ects in the

ss section

$t\bar{t}b\bar{b}$ tool comparison

YR4: arXiv:1610.07922

- A comparison of the existing tools has been performed in the YR4
- To be regarded as a starting point, more detailed studies are required
  - Comparison at parton-level only (shower without hadronization)
  - Shower parameters have been modified with respect to the default values to ensure consistency between the various tools

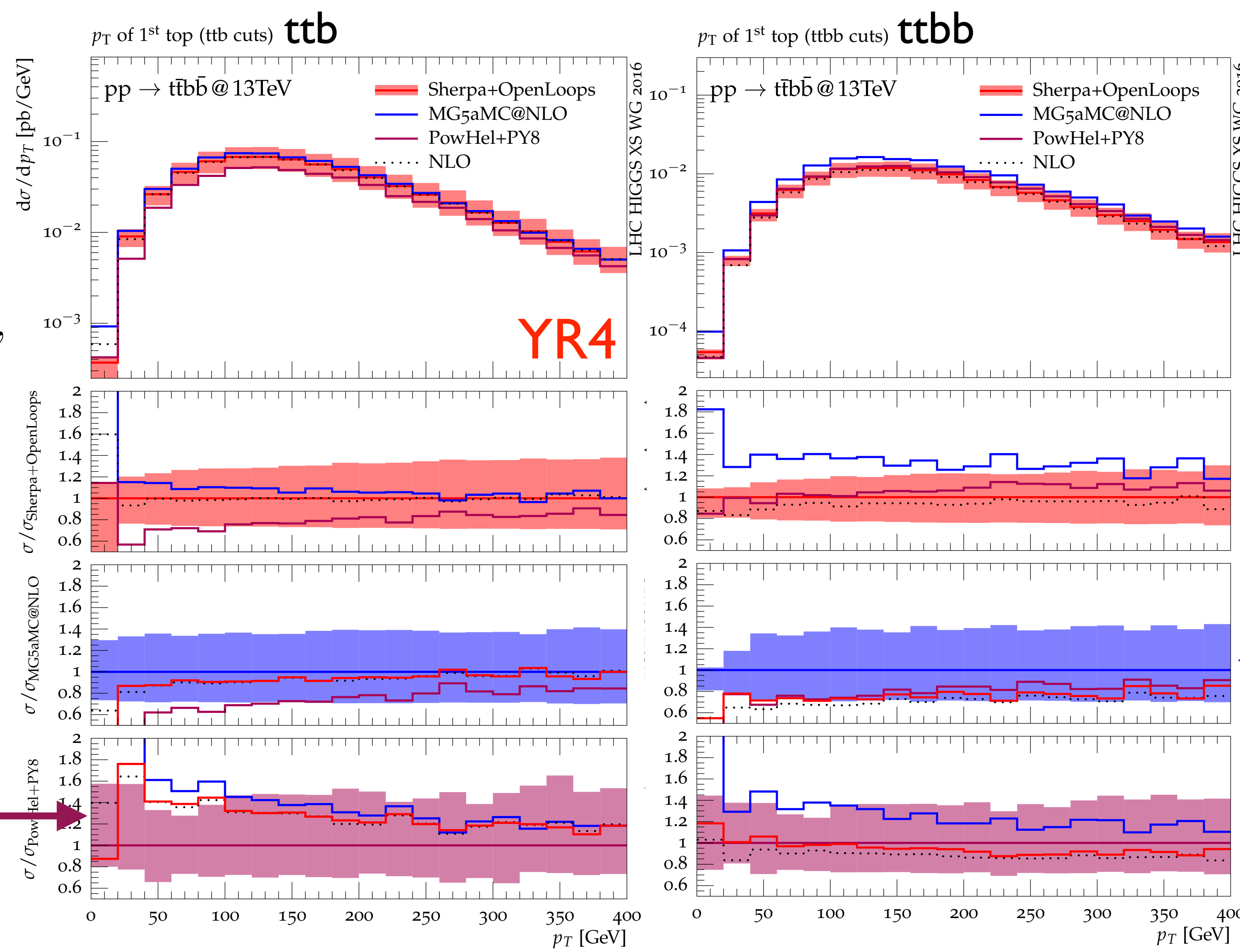
$t\bar{t}b\bar{b}$ tool comparison

YR4: arXiv:1610.07922

Selection	Tool	$\sigma_{\rm NLO}$ [fb]	$\sigma_{\rm NLO+PS}$ [fb]	$\sigma_{\rm NLO+PS}/\sigma_{\rm NLO}$
$n_b \geq 1$	SHERPA+OPENLOOPS	$12820^{+35\%}_{-28\%}$	$12939^{+30\%}_{-27\%}$	1.01
	MADGRAPH5_AMC@NLO		$13833^{+37\%}_{-29\%}$	1.08
	POWHEL		$10073^{+45\%}_{-29\%}$	0.79
$n_b \geq 2$	SHERPA+OPENLOOPS	$2268^{+30\%}_{-27\%}$	$2413^{+21\%}_{-24\%}$	1.06
	MADGRAPH5_AMC@NLO		$3192^{+38\%}_{-29\%}$	1.41
	POWHEL		$2570^{+35\%}_{-28\%}$	1.13

$$\mu_{F,0} = \frac{H_T}{2} = \frac{1}{2} \sum_{i=t,\bar{t},b,\bar{b},j} E_{T,i},$$

$$\mu_{R,0} = \left(\prod_{i=t,\bar{t},b,\bar{b}} E_{T,i} \right)^{1/4}$$



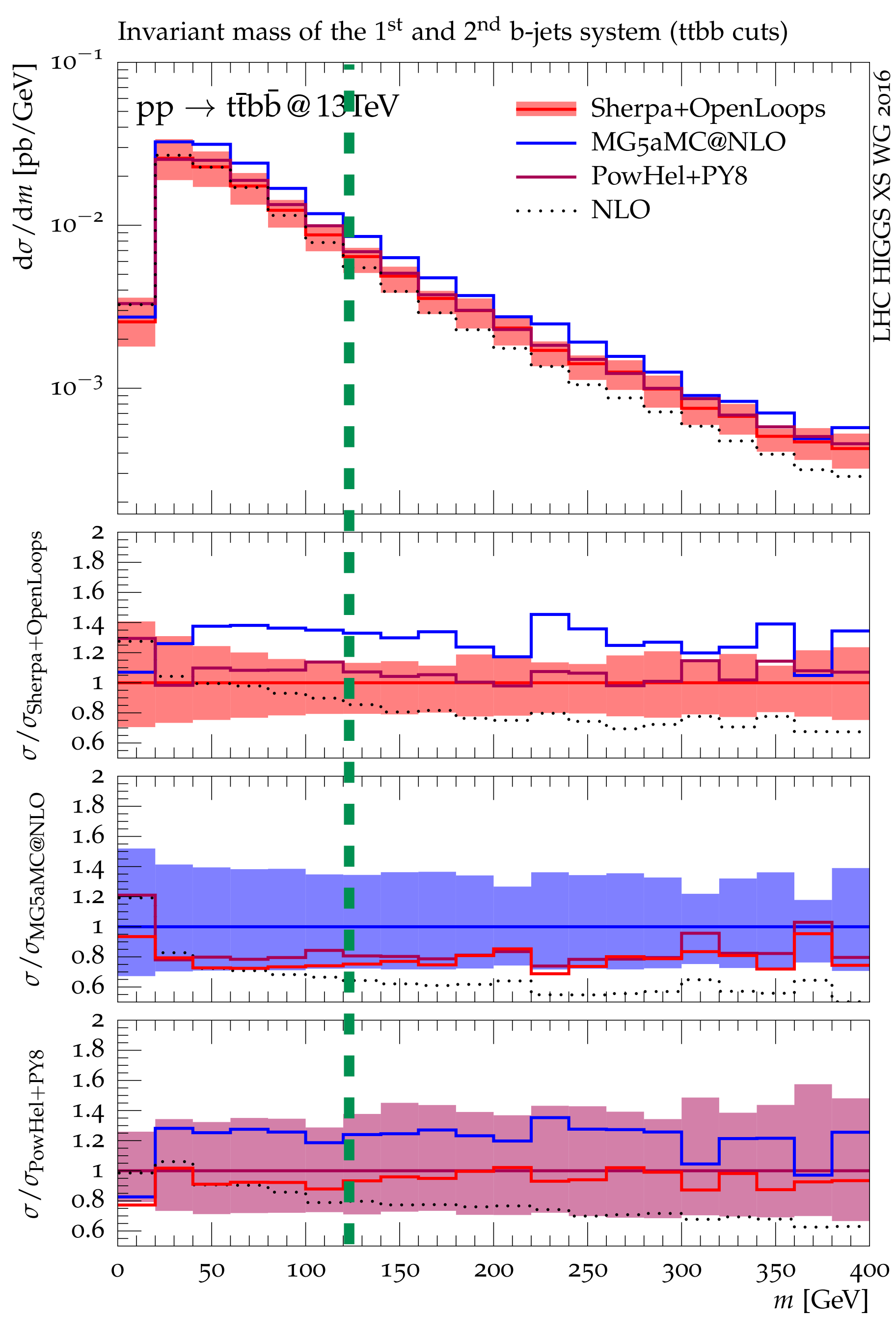
PowHel uses m_b=0 + M_{bb} cut

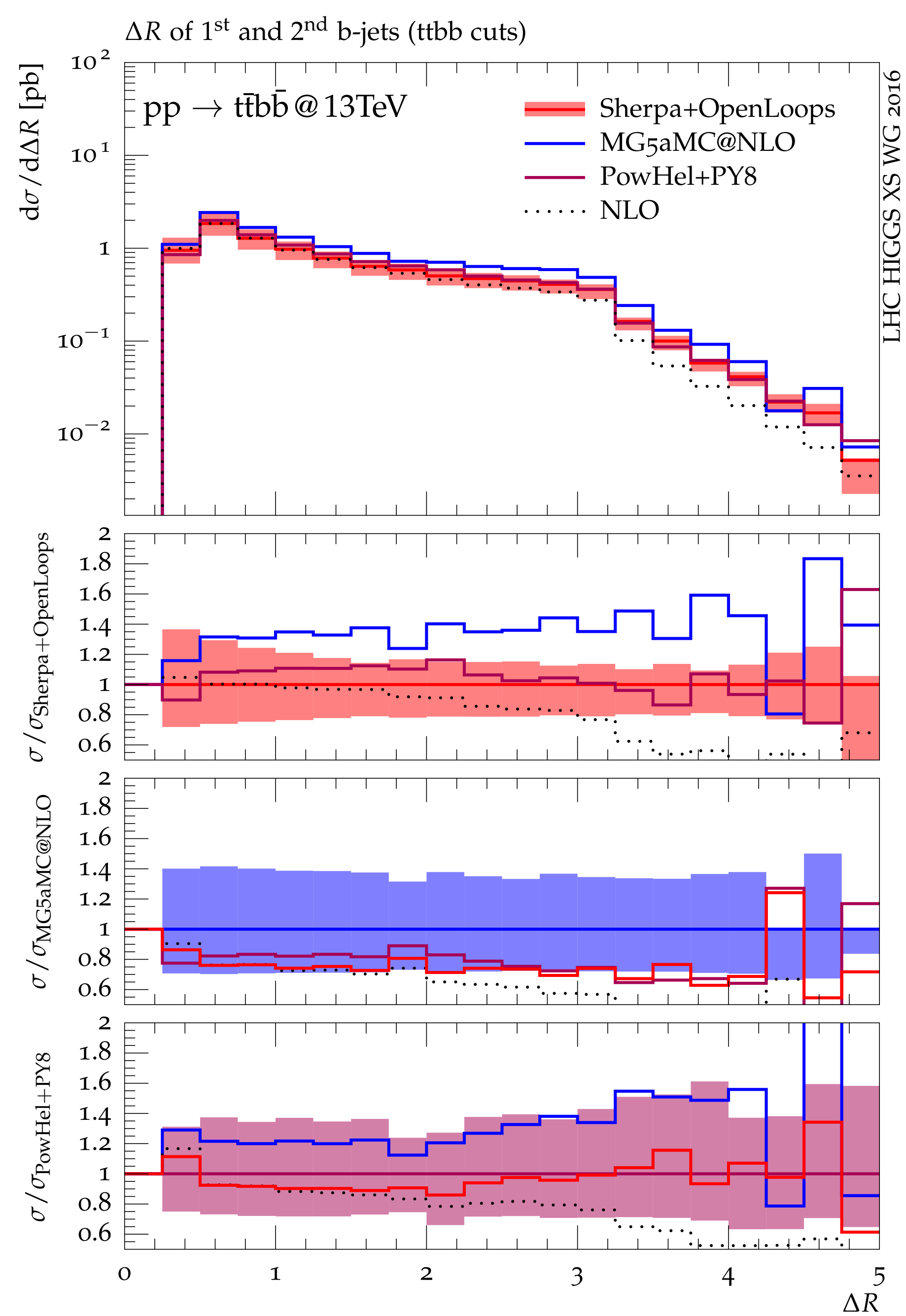
discrepancy due to shower scale and matching details in MG5_aMC

$t\bar{t}b\bar{b}$ tool comparison

YR4: arXiv:1610.07922

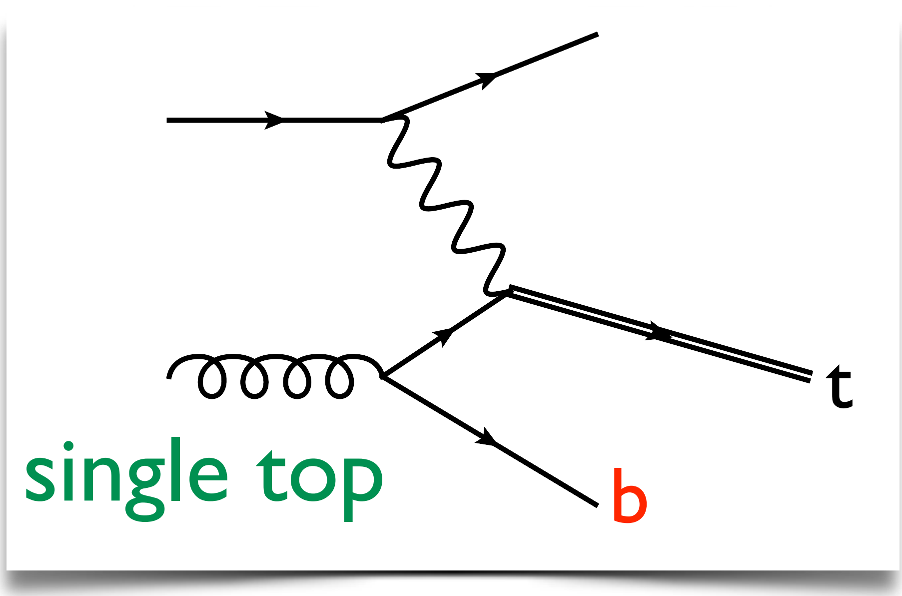
Large discrepancies appear also in the signal region

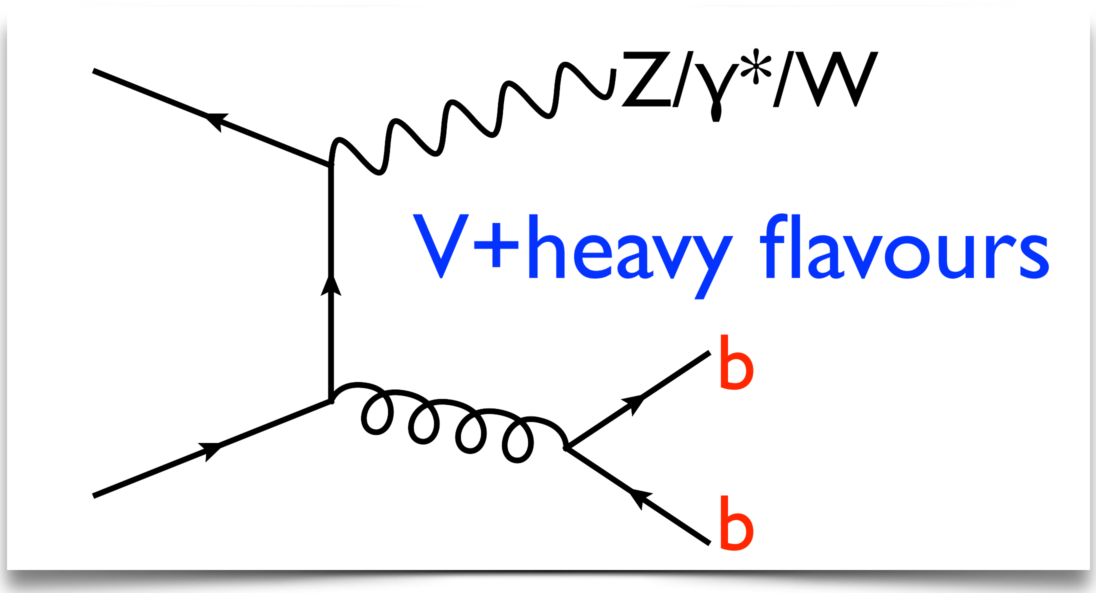




How to improve?

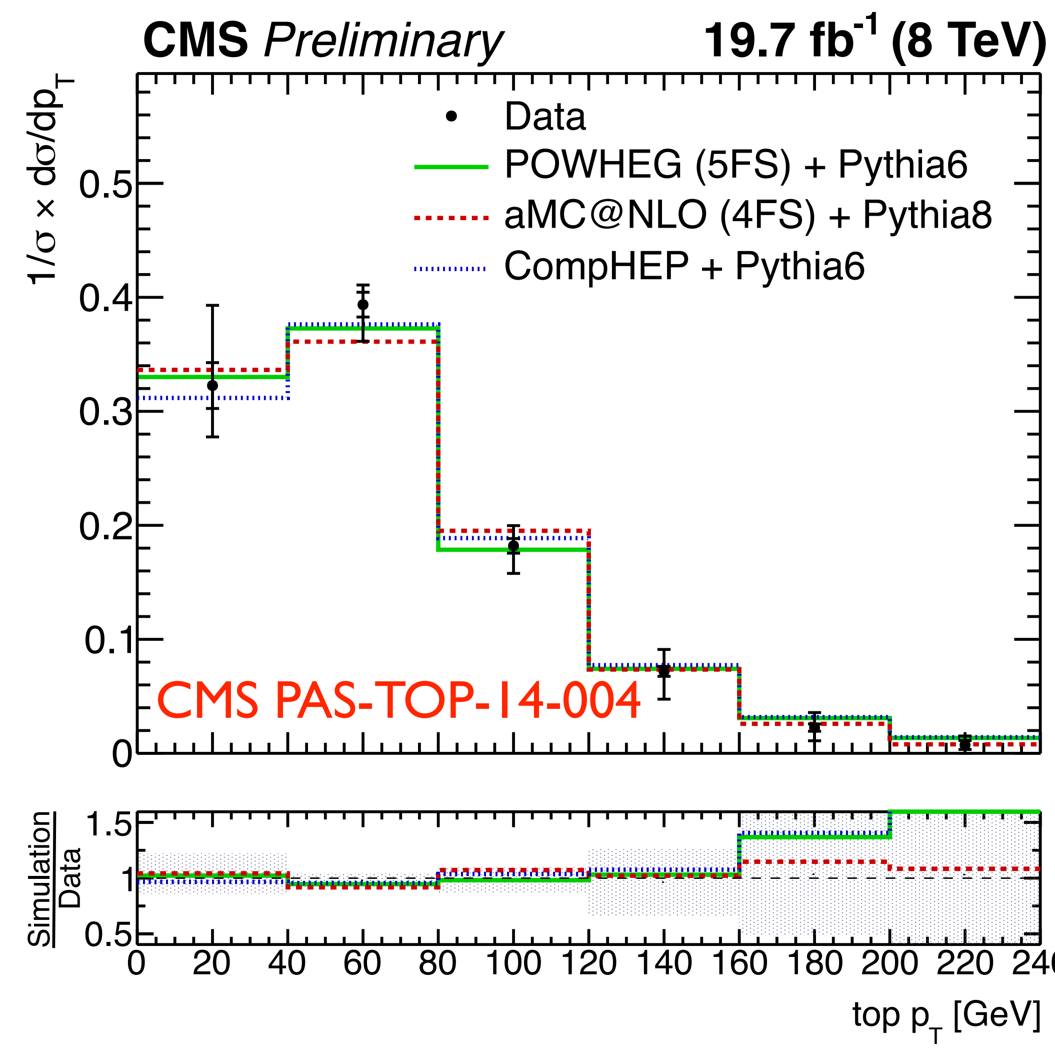
- NNLO corrections far out of reach
- Are we bound to live with O(40%) uncertainties?
- Source of uncertainties: missing higher orders ($\mu_{R/F}$ variations) and details of the implementation (m_b effects, μ_{SH}, parton shower, matching scheme, …); part of the problems are related to the low scale introduced by the bottom quark
- Can we learn something looking at simpler processes?





Single top

- Single-top production gives access to the initial state g→bb splitting
- The process is known to good accuracy
  - NNLO in the 5FS
  - NLO+PS in the 4FS
  - NLO w/ off-shell effects
- It would be interesting to have experimental analyses testing various MCs/showers at a differential level
- Don't limit to the top quark, look also at b jets…



Zbb:

- Keep on measuring Zbb, and publishing all possible variables!
- First Zbb@NLO+PS computed long time ago
  Frederix et al, arXiv:1106.6019
- 4FS predictions are considered superior for processes with b quarks… Is it true?
- First CMS analyses published in 2013-2014
  - CMS, arXiv:1310.1349 (CMS-EWK-11-15)
  - CMS, arXiv:1402.1521 (CMS-SMP-13-004)
  - 4FS xsect lower than measurements

	μ_F^2
MG5F	$m_Z^2 + p_T^2(\text{jets})$
MG4F	$m_{T,Z} \cdot m_T(b, b)$
ALPGEN	$m_Z^2 + \sum_{\text{jets}}(m_{\text{jets}}^2 + p_{T\,\text{jets}}^2)$
aMC@NLO	$\boxed{m_{\ell\ell'}^2 + p_T^2(\ell\ell') + \frac{m_b^2 + p_T^2(b)}{2} + \frac{m_b'^2 + p_T^2(b')}{2}}$

Cross section	Measured	MadGraph (5F)	aMC@NLO (5F)	MCFM (parton level)	MadGraph (4F)	aMC@NLO (4F)
σ_{Z+1b} (pb)	$3.52 \pm 0.02 \pm 0.20$	3.66 ± 0.22	$3.70^{+0.23}_{-0.26}$	$3.03^{+0.30}_{-0.36}$	$3.11^{+0.47}_{-0.81}$	$2.36^{+0.47}_{-0.37}$
σ_{Z+2b} (pb)	$0.36 \pm 0.01 \pm 0.07$	0.37 ± 0.07	$0.29^{+0.04}_{-0.04}$	$0.29^{+0.04}_{-0.04}$	$0.38^{+0.06}_{-0.10}$	$0.35^{+0.08}_{-0.06}$
σ_{Z+b} (pb)	$3.88 \pm 0.02 \pm 0.22$	4.03 ± 0.24	$3.99^{+0.25}_{-0.29}$	$3.23^{+0.34}_{-0.40}$	$3.49^{+0.52}_{-0.91}$	$2.71^{+0.52}_{-0.41}$
$\sigma_{Z+b/Z+j}$ (%)	$5.15 \pm 0.03 \pm 0.25$	5.35 ± 0.11	$5.38^{+0.34}_{-0.39}$	$4.75^{+0.24}_{-0.27}$	$4.63^{+0.69}_{-1.21}$	$3.65^{+0.70}_{-0.55}$

Theoretical progresses

- Processes with b quarks in the initial scales are characterised by scales much lower than ŝ
  Maltoni, Ridolfi, Ubiali, arXiv:1203.6303, +Lim, arXiv:1605.09411
- The "correct" scale can be determined by looking at the logarithms that are appear in the 4FS after integrating the b quark phase space, which appear in the form

$$L(z,\hat\tau) = \log\left[\frac{M_H^2}{m_b^2}\boxed{\frac{(1-z)^2}{\hat\tau}}\right]$$

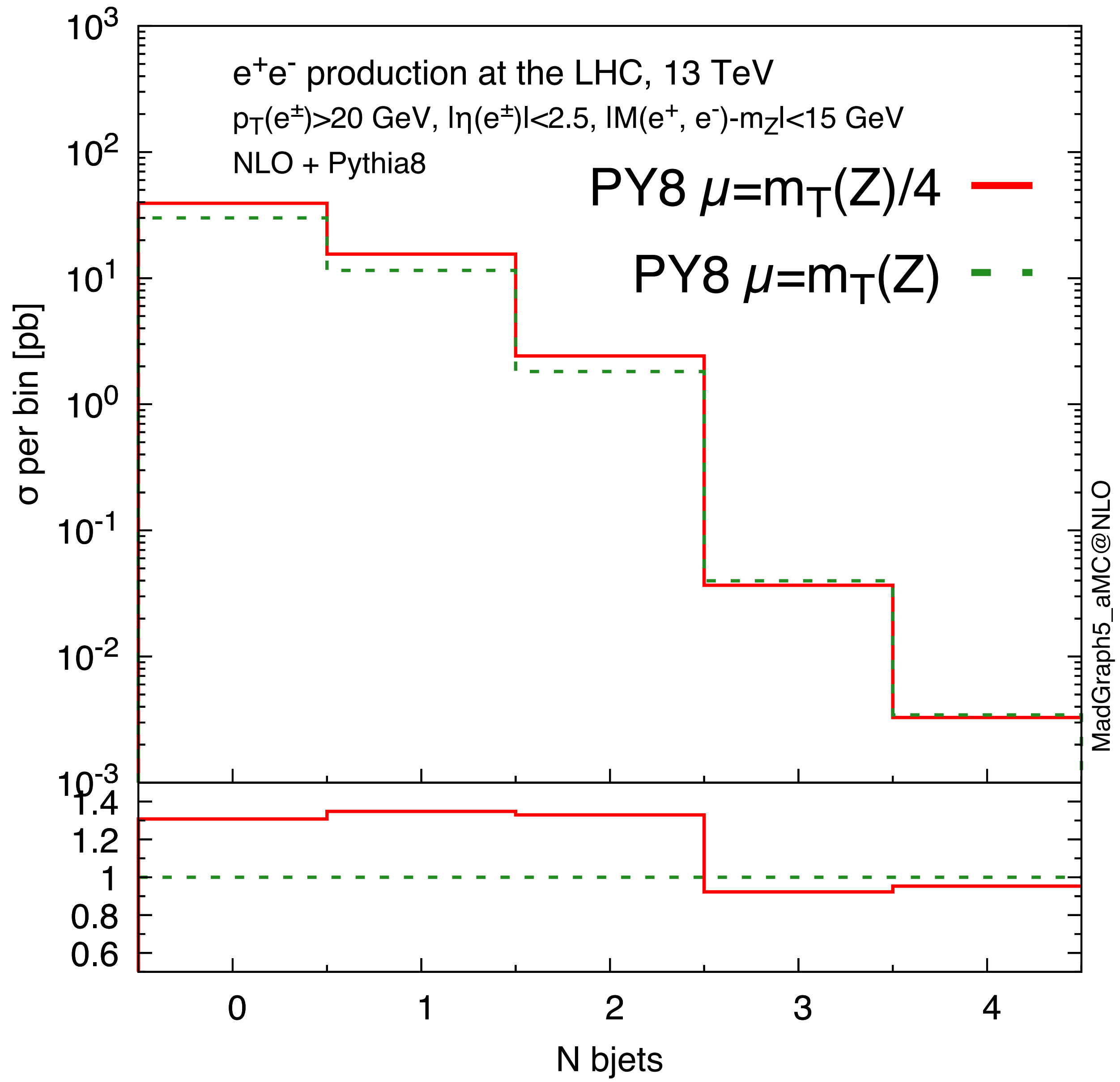
Kinematical suppression factor, which reduce the effective scale entering the log

- In particular

$$\begin{aligned} b\bar{b}H,\, M_H = 125\,\mathrm{GeV}: &\qquad \tilde\mu_F \approx 0.36\, M_H \\ b\bar{b}Z',\, M_{Z'} = 91.2\,\mathrm{GeV}: &\qquad \underline{\tilde\mu_F \approx 0.38\, M_{Z'}} \\ b\bar{b}Z',\, M_{Z'} = 400\,\mathrm{GeV}: &\qquad \tilde\mu_F \approx 0.29\, M_{Z'} \end{aligned}$$

- What happens to bbZ if a lower scale is used?

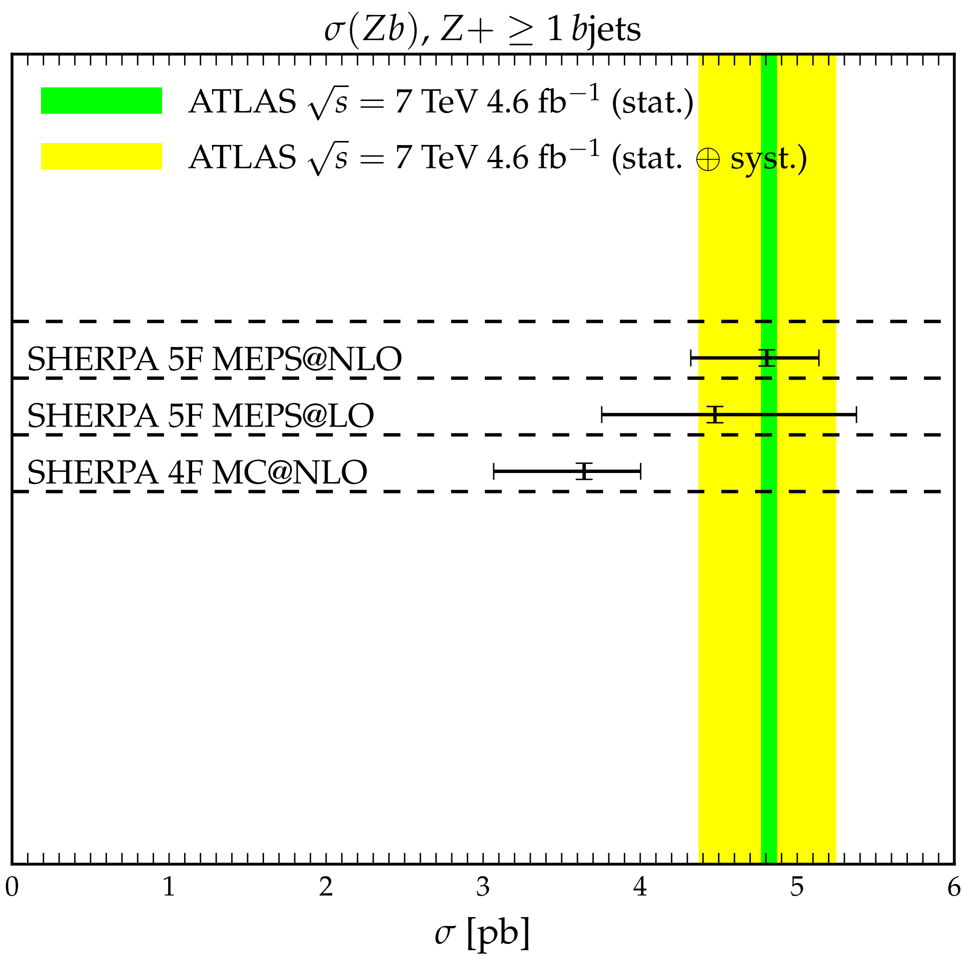
The cross-section grows

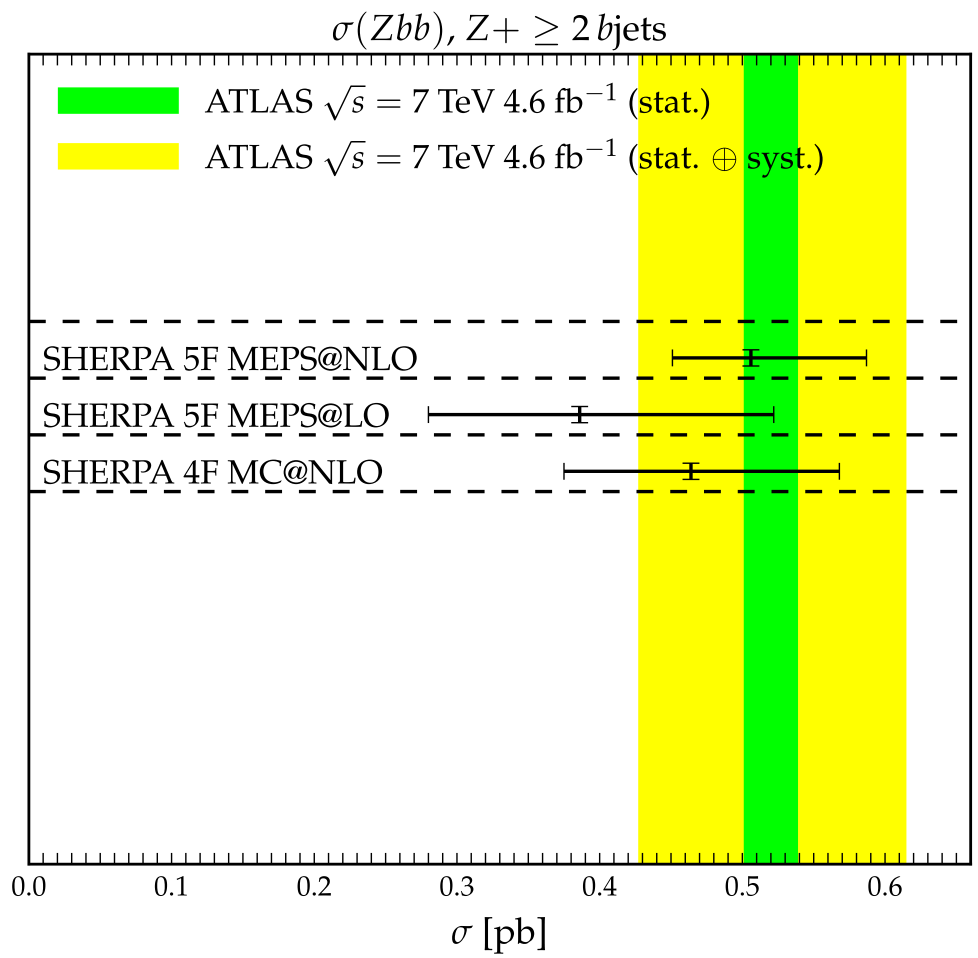


A reduced scale increases the cross-section of ~1.3 (at 13 TeV)

Recent update from SHERPA

Krauss, Napoletano, Schumann, arXiv:161204640





4FS still low-ish, $\mu=m_T(Z)/2$ is used

Better agreement for shapes

Conclusions

- NLO MonteCarlos are very powerful tools. Automation is crucial to make things simple for the final user
- Progress is going beyond NLO: NNLO+PS MCs and NNLO+PS with NLO+PS merging
- Despite this, there are still many aspects being understood or still to understand, in particular for processes with associated b quarks
  - Correct scale to use for the process
  - Description of extra g→bb splittings in the parton shower
- A solid understanding of these effects needs validation against data
- Which tools do a good job and which does not? Why?
- No measurement is useless!