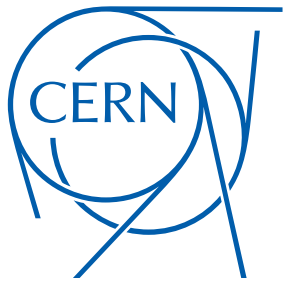
Top production in SHERPA

Marek Schönherr

CERN

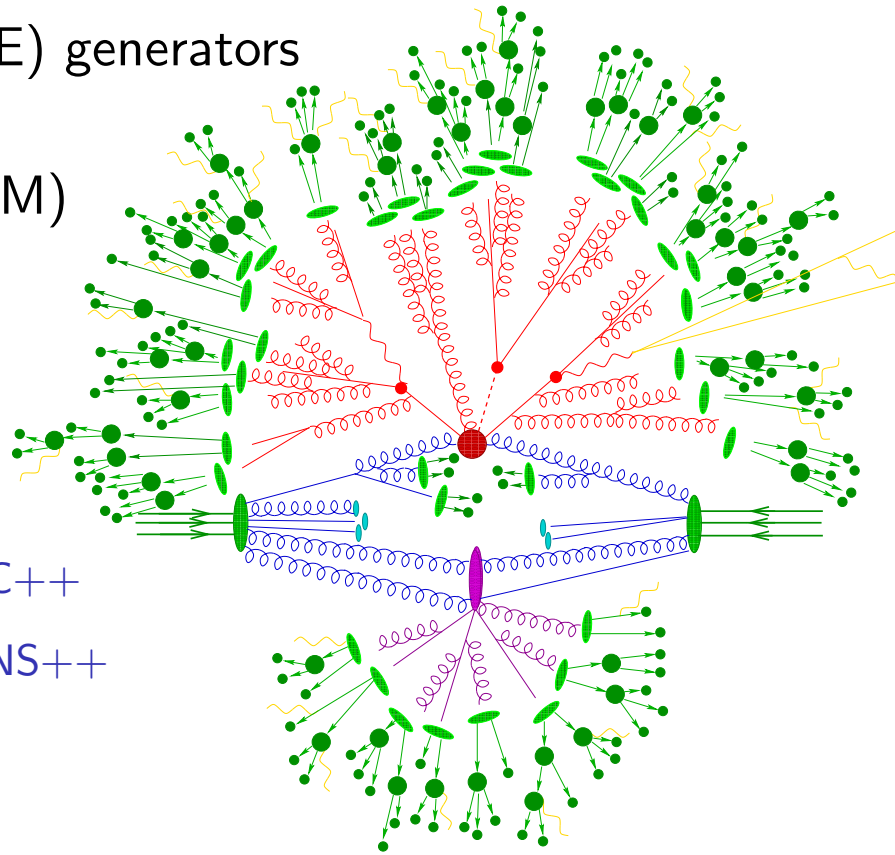
CMS top quark workshop



The SHERPA event generator framework

JHEP02(2009)007

- Two multi-purpose Matrix Element (ME) generators AMEGIC++, COMIX
- A hard decays module (W, Z, h, t, BSM)
- Two Parton Shower (PS) generators CSSHOWER, DIRE
- A multiple interaction simulation à la PYTHIA AMISIC++
- A cluster fragmentation module AHADIC++
- A hadron and τ decay package HADRONS++
- A higher order QED generator using YFS-resummation PHOTONS++



Sherpa's traditional strength is the perturbative part of the event

LO, NLO, NNLO, LOPS, **NLOPS**, NNLOPS, MEPS, MENLOPS, **MEPS@NLO**

Acronyms and nomenclature

Fixed order calculations

- matrix elements only, implies fixed multiplicities
- no parton shower, no non-perturbative physics, no particle level

$\Rightarrow$ LO, NLO, NNLO

Parton shower matched calculations

- combination of fixed order calculation and parton shower for one multiplicity
- particle level predictions, no multijet observables

$\Rightarrow$ LOPS, **NLOPS**, NNLOPS $\Rightarrow$ S-MC@NLO

Multijet merged calculations

- combination of parton shower matched calculations for increasing final state multiplicities (mostly jets)
- particle level predictions, multijet observables

$\Rightarrow$ MEPS(@LO), **MEPS@NLO** (special case MENLOPS)

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Top quark decays

Höche, Kuttimalai, Schumann, Siegert arXiv:1412.6478

- in most situations it is sufficient to simulate top-quark prodcution through a resonance-shape-improved narrow-width approximation
  - produce top quarks on-shell
  - adjust mass a posteriori according to Breit-Wigner
  - add spin-correlated decay
  - add QCD parton shower and QED corrections for production and each decay (radiation off intermediate t and W)

  $\Rightarrow$ allows for higher final state multiplicity
- per default all decay channel used
  $\rightarrow$ inclusive production
  $\rightarrow$ mechanism to select individual channels, cross section optionally adjusted accordingly
- spin-correlated decay chains of arbitrary length using spin density matrices Richardson JHEP11(2001)029, Knowles CPC58(1990)271

Single-top prodcution

Bothmann, Krauss, MS arXiv:1711.02568

t- and s-channels

- available S-MC@NLO
- available in $N_f = 4$ and $N_f = 5$ consistent setups
- in $N_f = 5$: same signature, gauge invariantly separated by number of EW t-channel propagators
  s-channel: $n_{\text{t-ch}} = 0$, t-channel: $n_{\text{t-ch}} \geq 1$
- in $N_f = 4$: t-channel: $g \to b\bar{b}$-splittings

tW-channels

- available in S-MC@NLO in $N_f = 5$
- at NLO separated from $t\bar{t}$ through removal of $t\bar{t}$ doubly resonant diagrams
  Frixione et.al. arXiv:0805.3067
- $N_f = 4$ would need full $WWbb$-calculation

Single-top prodcution

process	scales ($N_f = 5$)	scales ($N_f = 4$)
$pp \to tq/\bar{t}q$ (t-channel)	$-Q_W^2$	$\mu_{\mathrm{F}}^2 = \mu_{\mathrm{Q}}^2 = m_{\mathrm{T}}^{t\,2}$, $\mu_{\mathrm{R}}^2 = m_{\mathrm{T}}^{b\,2}$
$pp \to t\bar{b}/\bar{t}b$ (s-channel)	Q_W^2	Q_W^2
$pp \to tW^-/\bar{t}W^+$ (associated production)	$m_{\mathrm{T}}^{t\,2}$	—

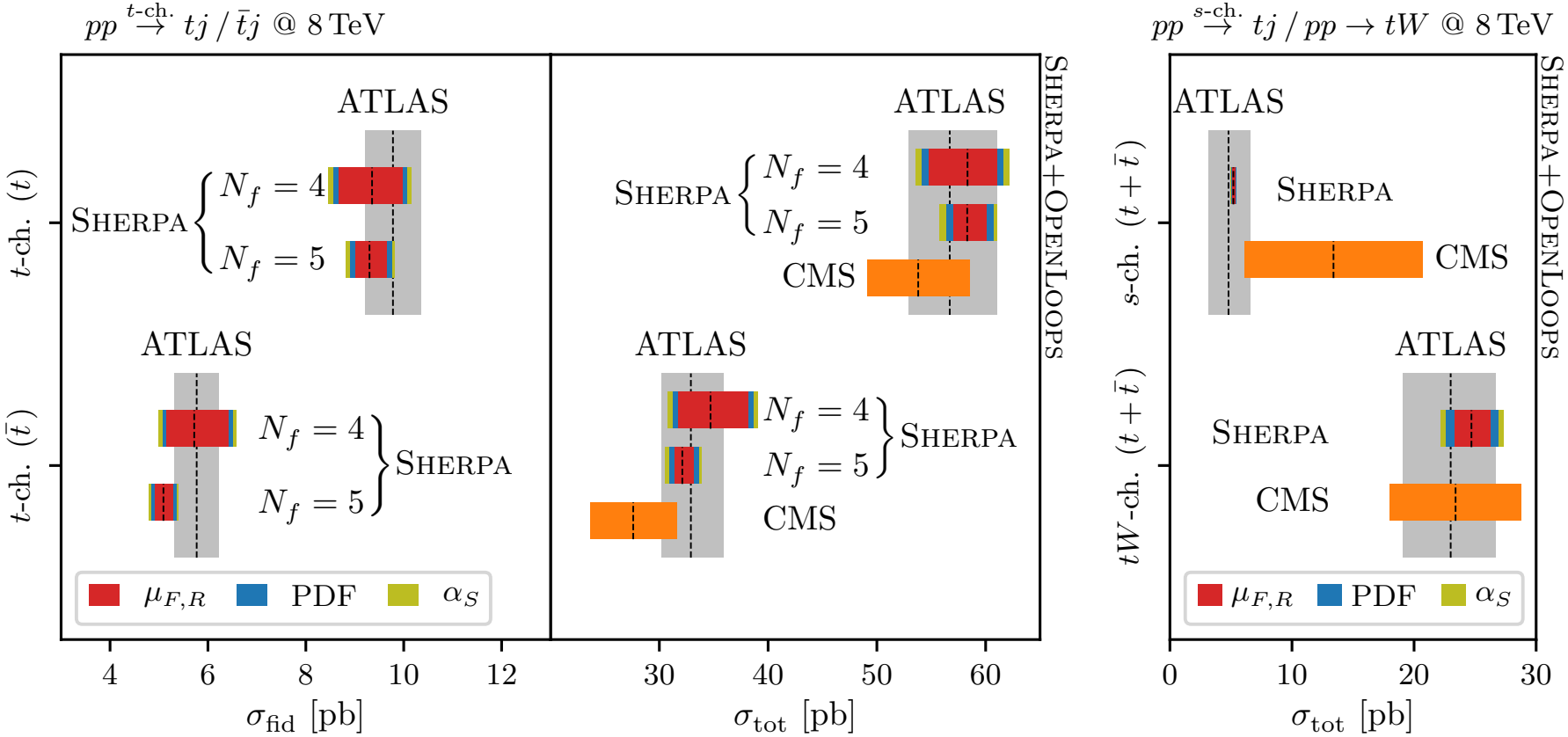
PDF: $\Rightarrow$ `NNPDF30_nlo_as_0118`

Single-top prodcution

			SHERPA ($N_f = 5$)				SHERPA ($N_f = 4$)			ATLAS [7, 10, 8]		CMS [6, 9, 5]	
				$\mu_{R,F}$	α_s	PDF		$\mu_{R,F}$	α_s	PDF		tot.		tot.
t-channel	tot.	t	58.3	$^{+1.8}_{-1.4}$	$^{+0.4}_{-0.6}$	± 0.7	58.3	$^{+2.8}_{-3.6}$	$^{+0.6}_{-0.7}$	± 0.6	56.7	$^{+4.3}_{-3.8}$	53.8	± 4.7
		$\bar{t}$	32.1	$^{+1.0}_{-0.8}$	$^{+0.3}_{-0.4}$	± 0.5	34.7	$^{+3.5}_{-3.0}$	$^{+0.5}_{-0.5}$	± 0.5	32.9	$^{+3.0}_{-2.7}$	27.6	± 4.0
	fid.	t	9.30	$^{+0.36}_{-0.29}$	$^{+0.06}_{-0.10}$	± 0.11	9.35	$^{+0.63}_{-0.69}$	$^{+0.09}_{-0.11}$	± 0.10	9.78	± 0.57	—	
		$\bar{t}$	5.09	$^{+0.21}_{-0.17}$	$^{+0.04}_{-0.06}$	± 0.08	5.72	$^{+0.71}_{-0.57}$	$^{+0.08}_{-0.09}$	± 0.08	5.77	± 0.45	—	
s-ch.	tot.	t	3.31	$^{+0.09}_{-0.07}$	$^{+0.01}_{-0.02}$	± 0.06	3.26	$^{+0.09}_{-0.07}$	$^{+0.01}_{-0.02}$	± 0.06	4.8	$^{+1.8}_{-1.6}$	13.4	± 7.3
		$\bar{t}$	1.89	$^{+0.05}_{-0.04}$	$^{+0.01}_{-0.01}$	± 0.04	1.87	$^{+0.05}_{-0.04}$	$^{+0.01}_{-0.01}$	± 0.04				
tW-ch.	tot.	t	12.3	$^{+0.8}_{-0.7}$	$^{+0.2}_{-0.2}$	± 0.4	—				23.0	$^{+3.7}_{-3.9}$	23.4	± 5.4
		$\bar{t}$	12.3	$^{+0.8}_{-0.7}$	$^{+0.2}_{-0.2}$	± 0.4	—							

- good description of incl. and fiducial xsec with $N_f = 4$ and $N_f = 5$

Single-top production



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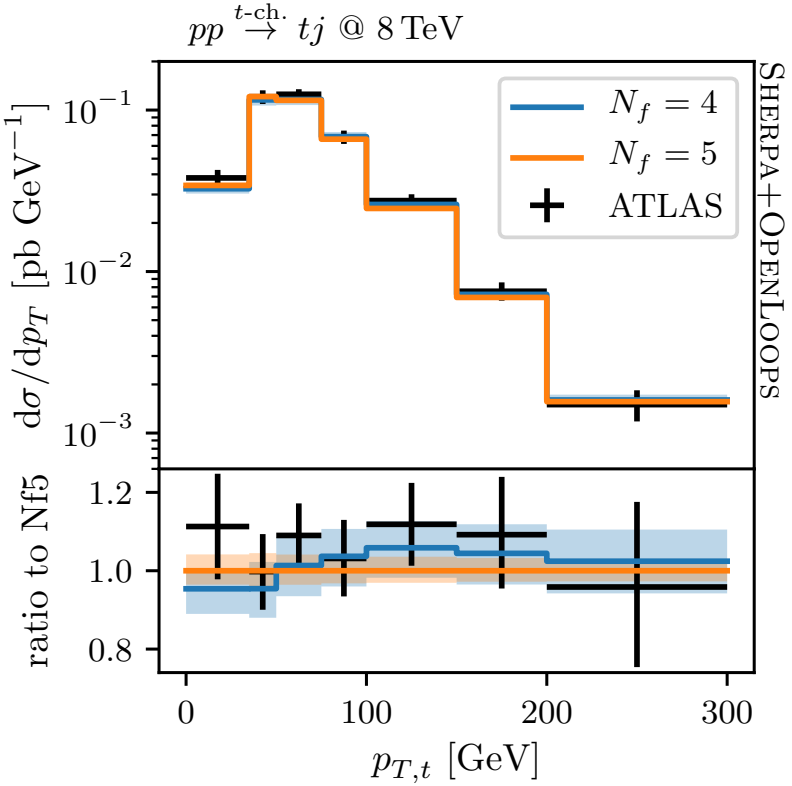

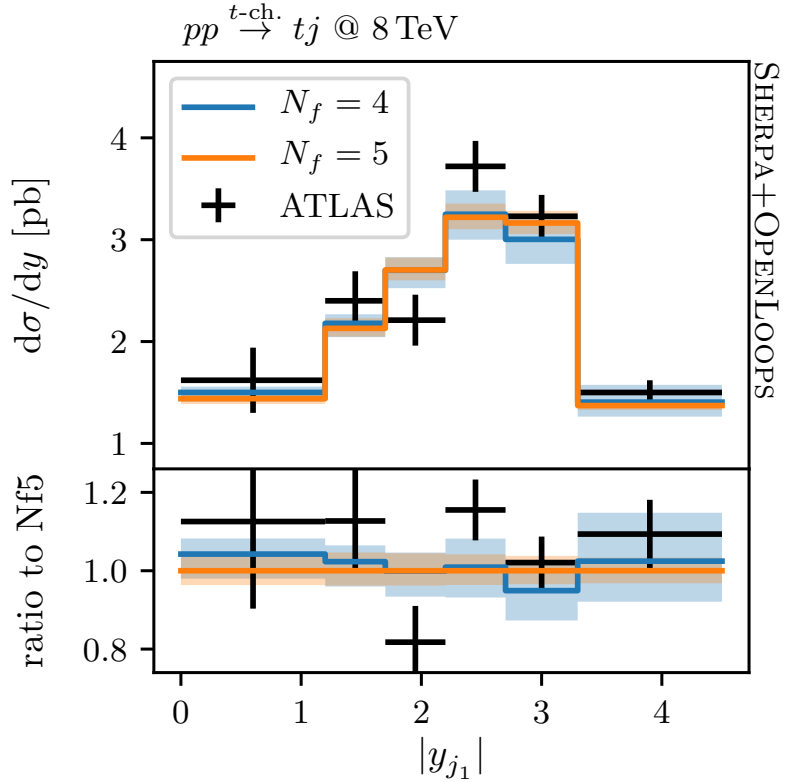

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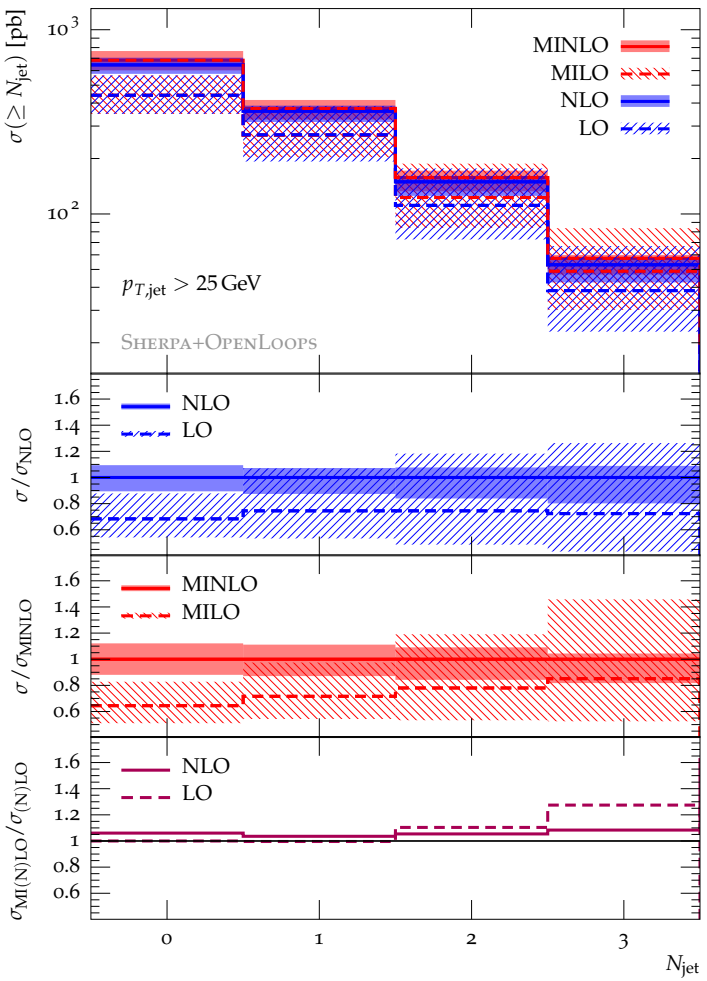
NLO QCD calculations – $pp \to t\bar{t} + 3$jets

Höche, Maierhöfer, Moretti, Pozzorini, Siegert arXiv:1607.06934

- First computation of $t\bar{t}$+3 jets at NLO / MiNLO accuracy
- Sherpa NLO MC framework using Comix Gleisberg,Höche arXiv:0808.3674 combined with OpenLoops Cascioli,Maierhöfer,Pozzorini arXiv:1111.5206
- Public results in NTuple format à la BlackHat collaboration arXiv:1310.7439 for easy analysis & recycling available at NERSC (login req'd)
- Scale dependence studied using $H_{T,m} = \sum m_\perp$ and MiNLO Hamilton,Nason,Zanderighi arXiv:1206.3572 extended to massive partons



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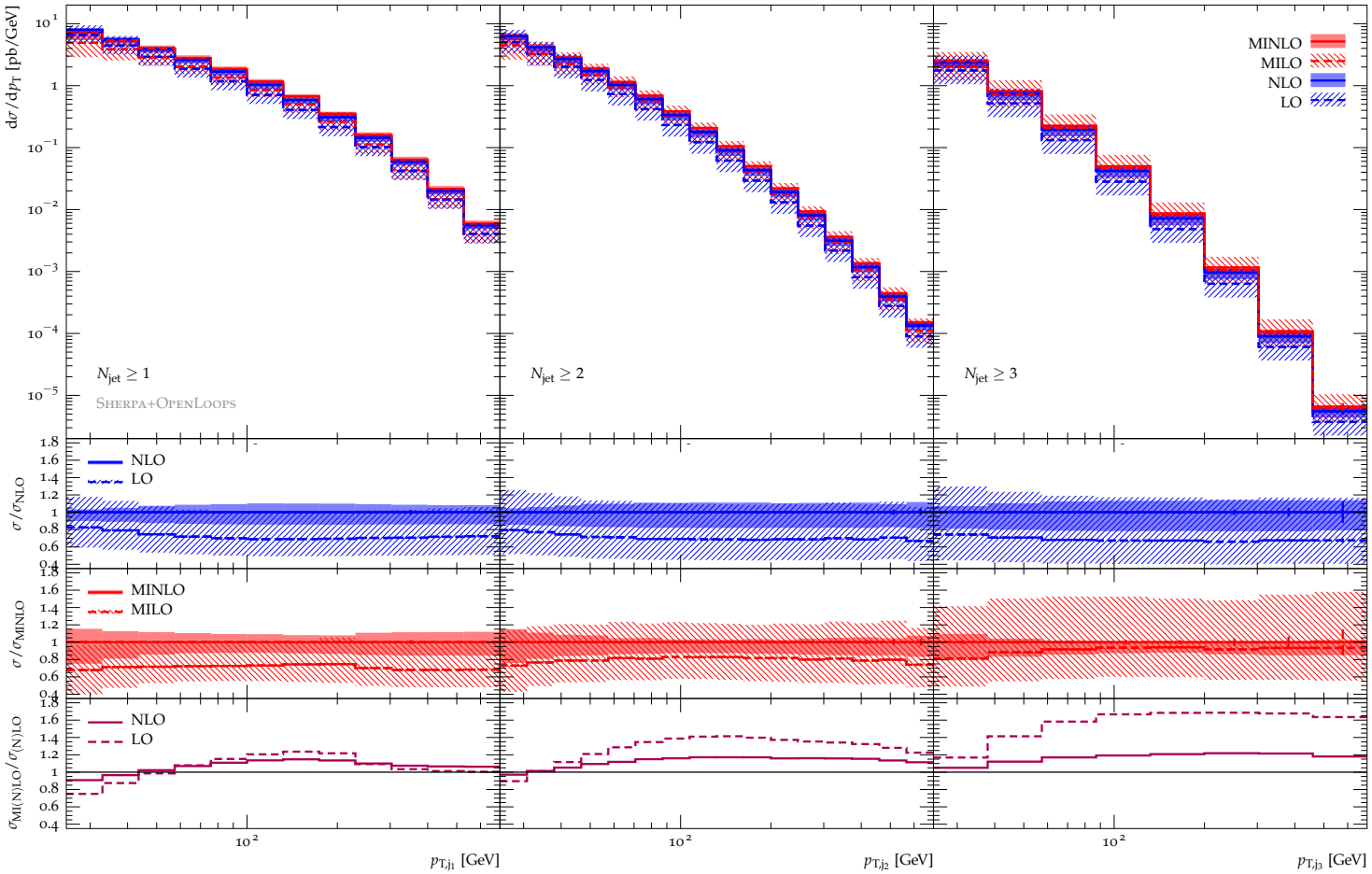
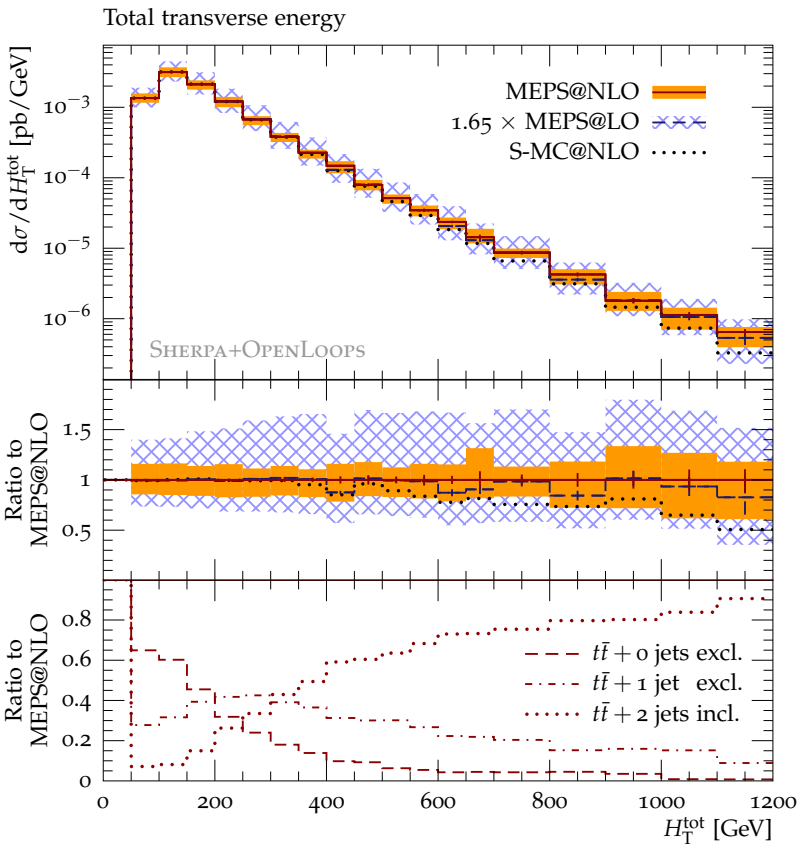
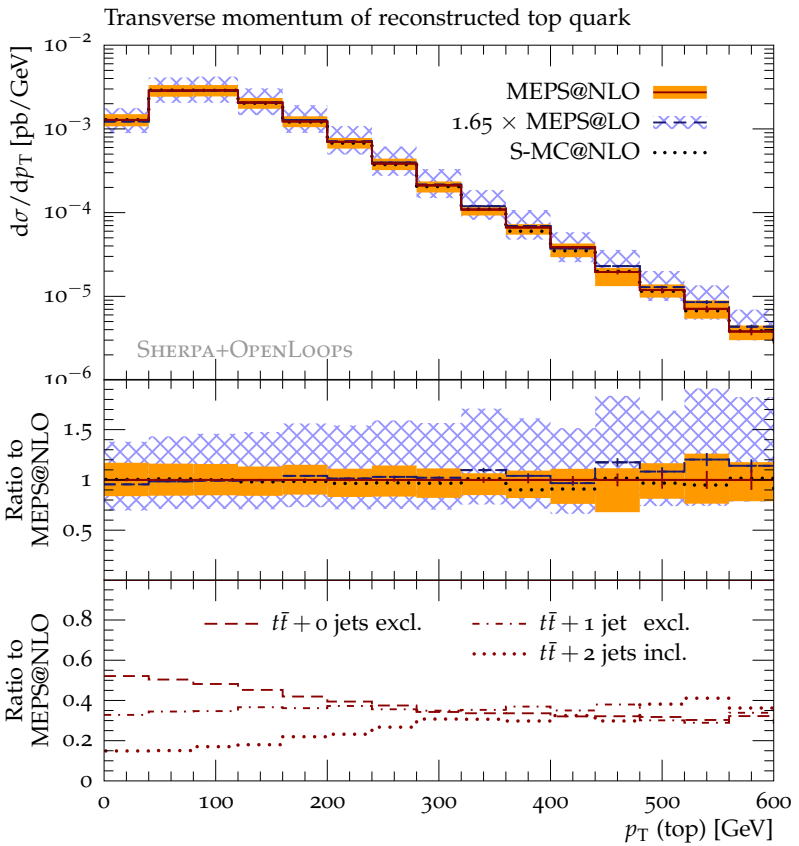


- Inclusive jet-p_T spectra

Multijet merging – $pp \to t\bar{t} +$ jets

Höche, Krauss, Maierhöfer, Pozzorini, MS, Siegert in PLB748(2015)74-78

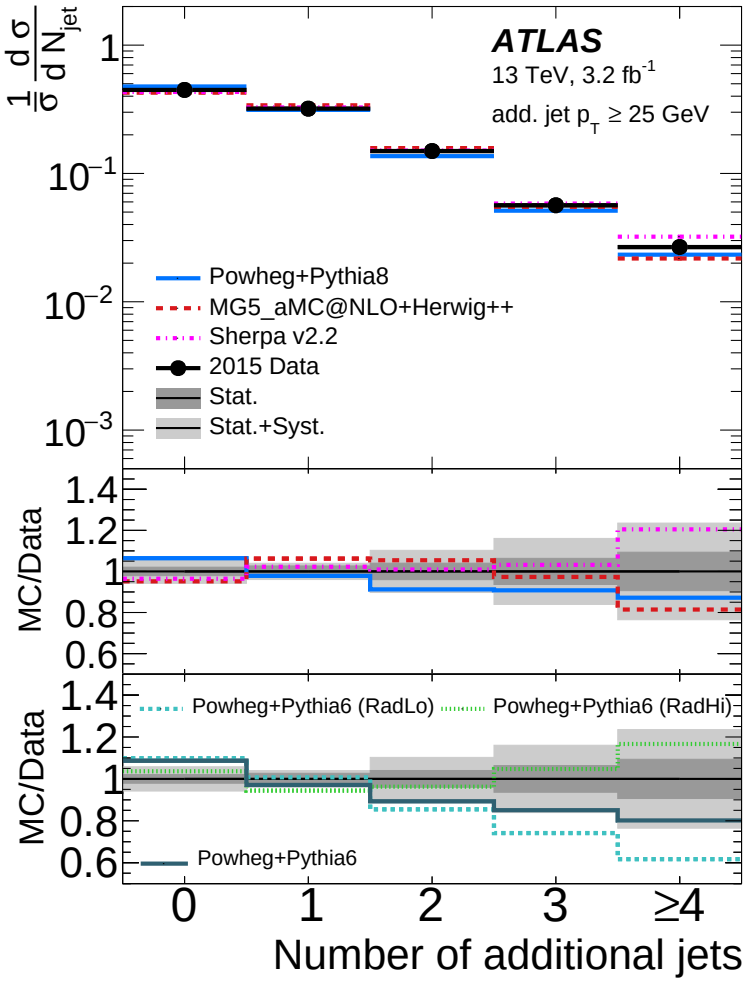


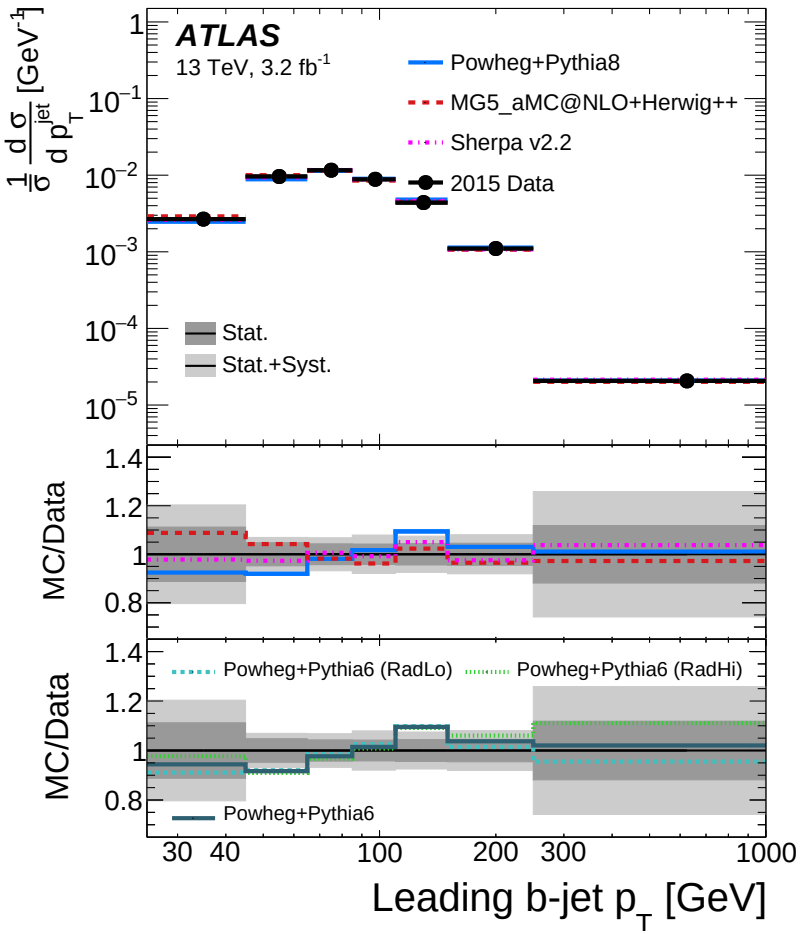


Multi-jet merging at NLO

ATLAS arXiv:1610.09978

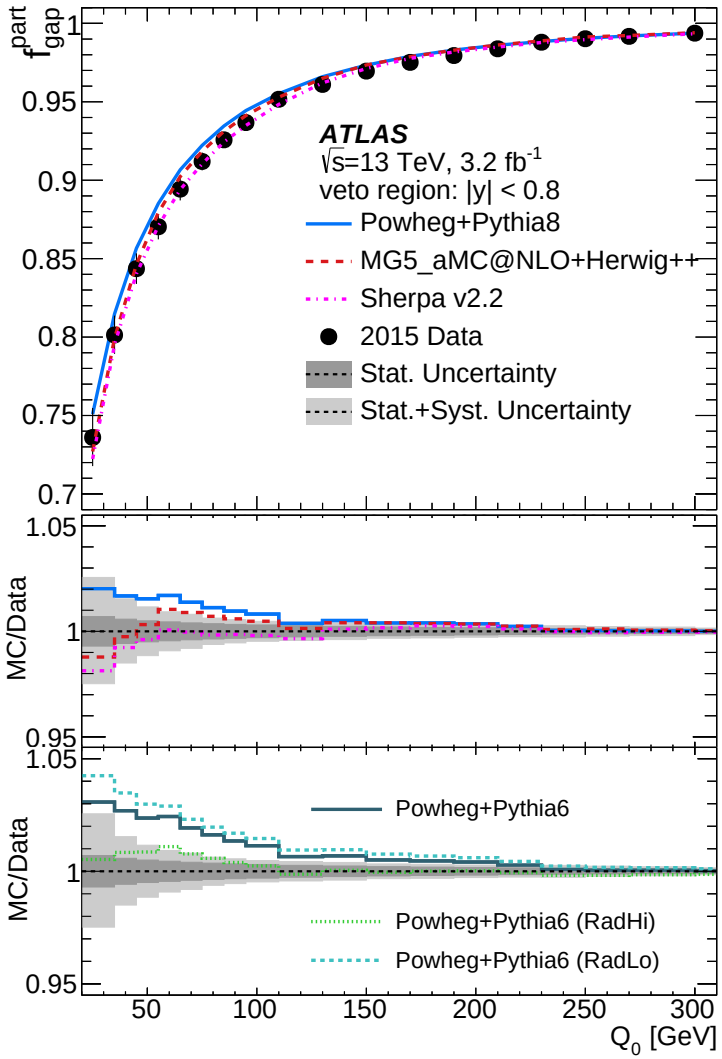
$pp \to t\bar{t} + 0, 1j\text{@NLO} + 2, 3, 4j\text{@LO}$

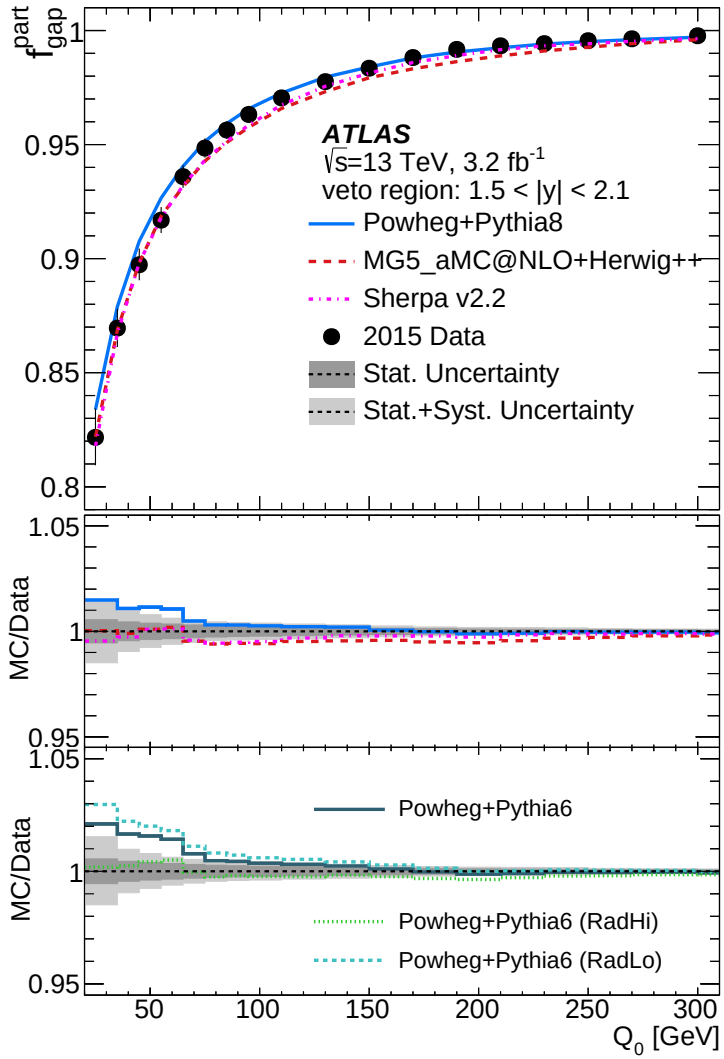




Gap fractions

ATLAS arXiv:1610.09978





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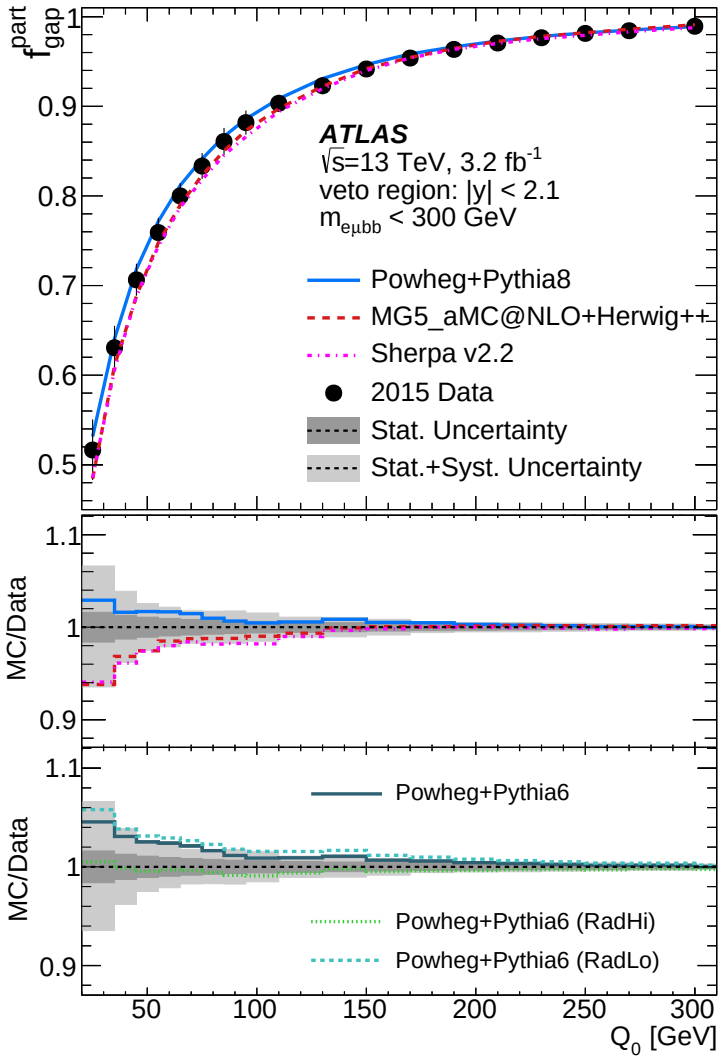
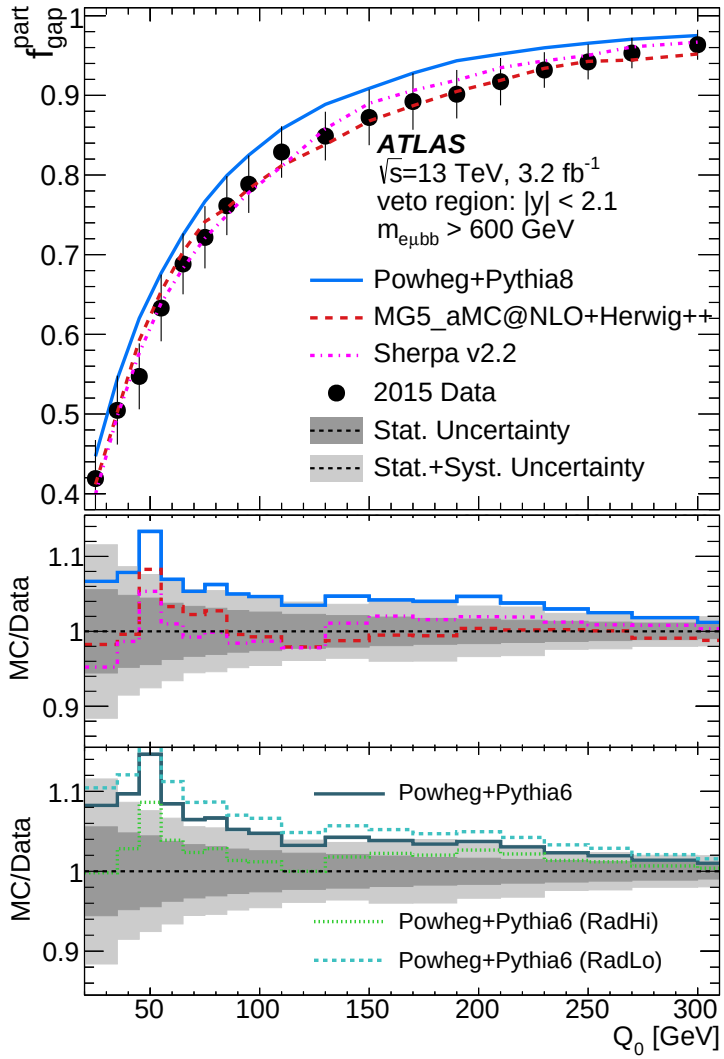
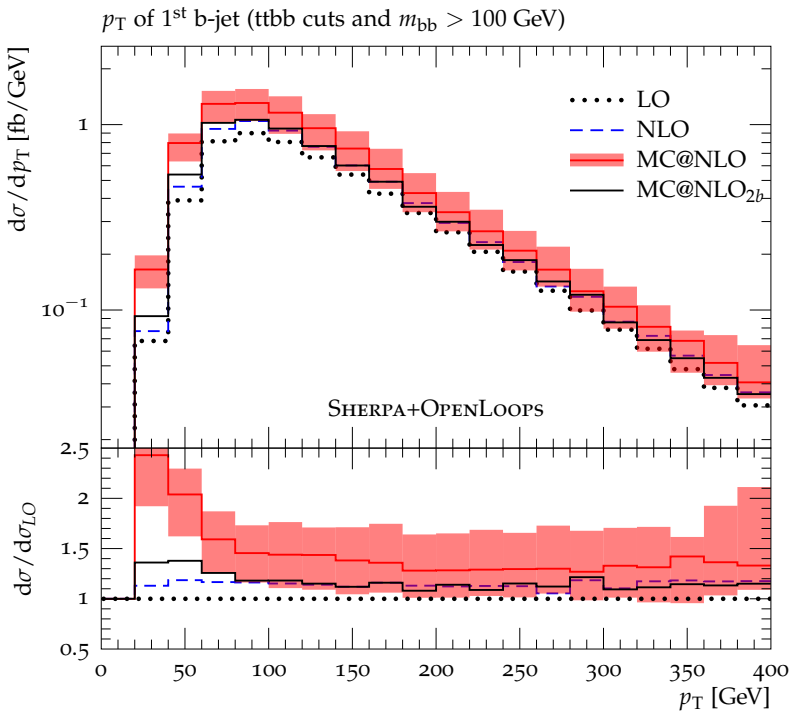
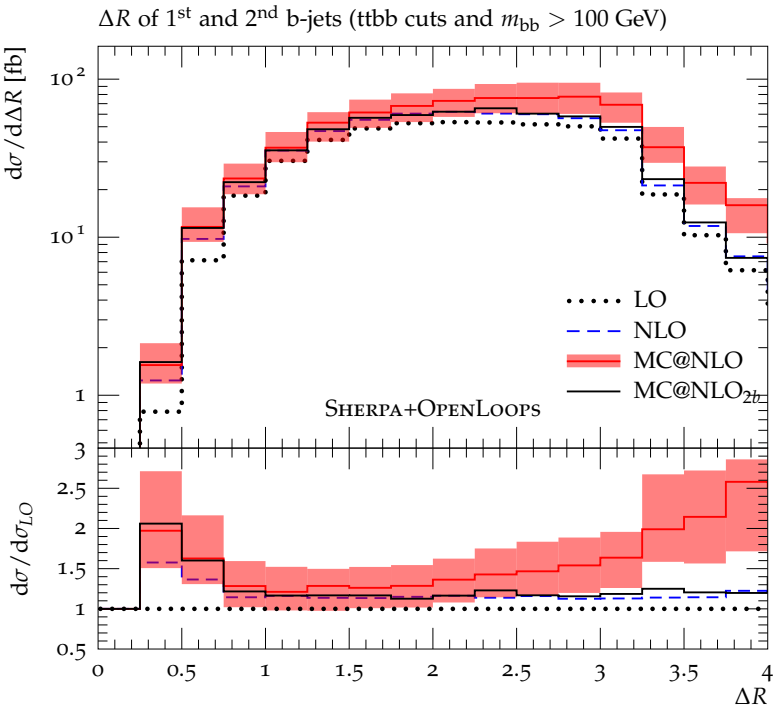




$t\bar{t}b\bar{b}$ production

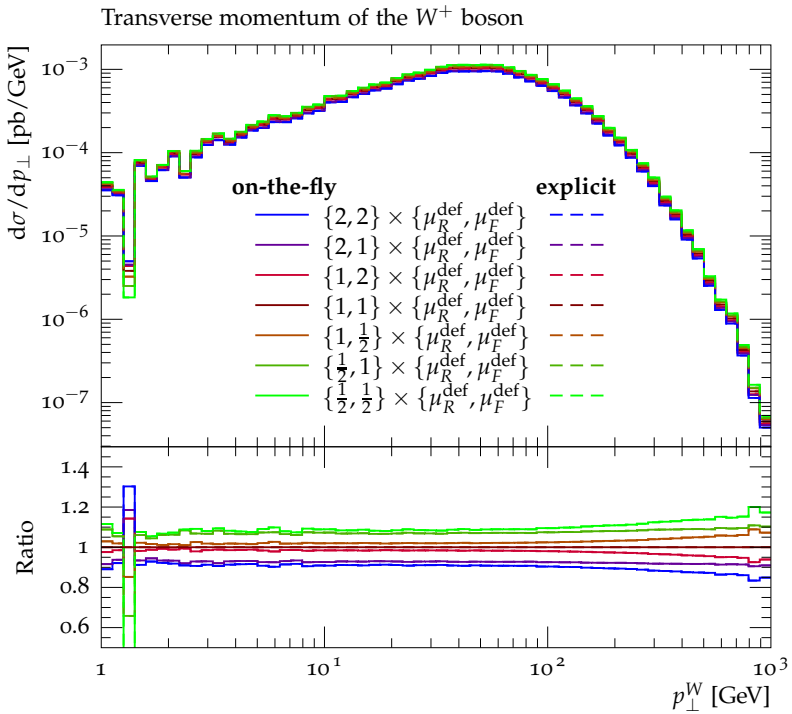
Cascioli, Maierhöfer, Moretti, Pozzorino, Siegert arXiv:1309.5912

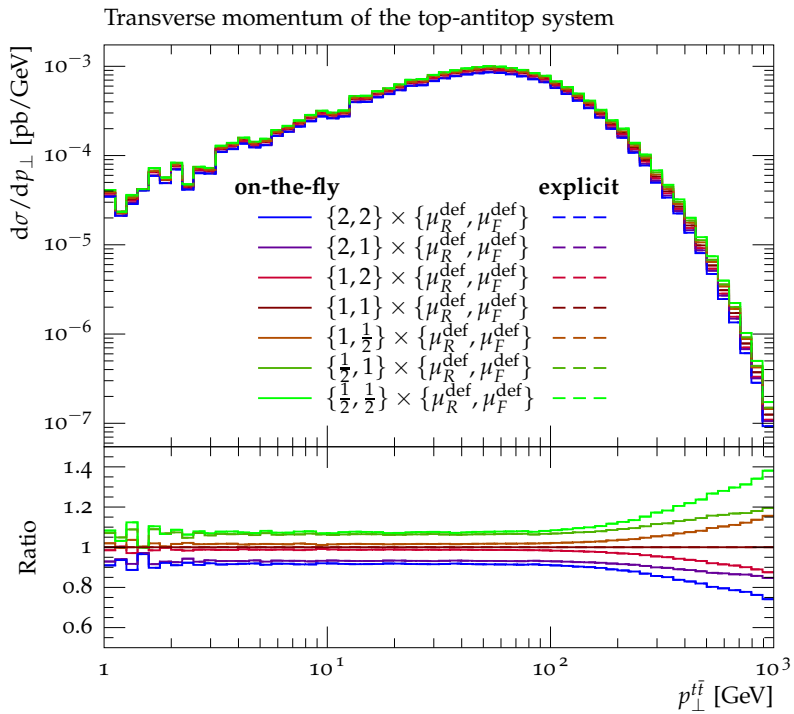




- S-MC@NLO matched calculation,
  how large is the contribution from secondary $g \to b\bar{b}$ splittings?
- active discussions in LHC HXSWG

Rare processes – ttW





- S-MC@NLO for $t\bar{t}W$ production
- exemplifies on-the-fly scale variations

Conclusions

- SHERPA offers precise calculation of single-top and top-pair processes
- on-the-fly variations of μ_R, μ_F, α_s and PDF for
  - LO, NLO
  - LOPS, NLOPS (S-MC@NLO), NNLOPS through plugin
  - MEPS, MENLOPS, MEPS@NLO
- NLO QCD MEPS@NLO with approx. NLO EW corrections
  $\rightarrow$ for $t\bar{t}$ currently validated
- multijet merging for loop induced processes further tested, use as:
  - MEPS@LOOP^2
  - reweight MEPS@NLO Higgs production in HEFT with top mass dependence (approximate in virtual corrections only)
- a new parton shower DIRE
- vastly extended support for UFO BSM format
- default PDF: `NNPDF30_nnlo_as_0118`
  including corresponding tune of non-perturbative parameters

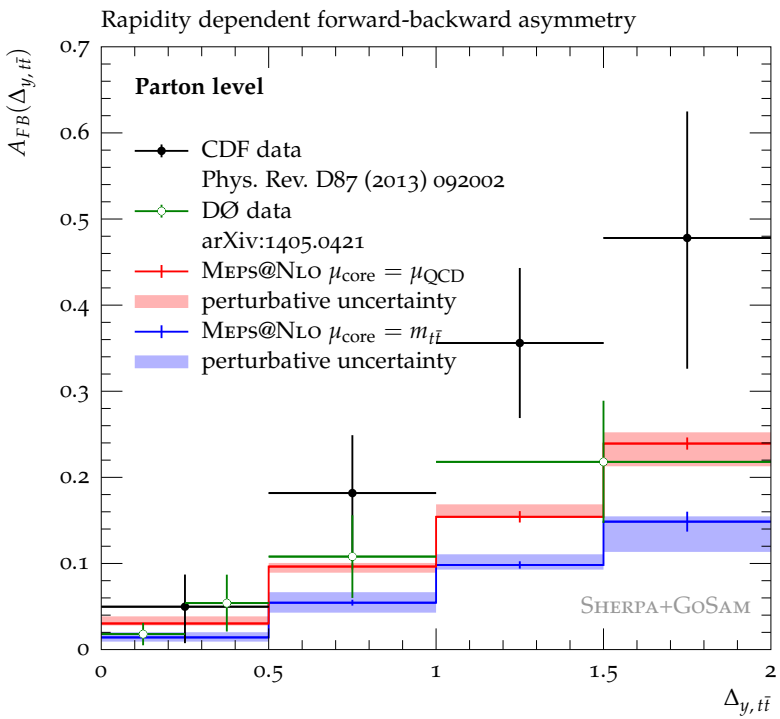
http://sherpa.hepforge.org

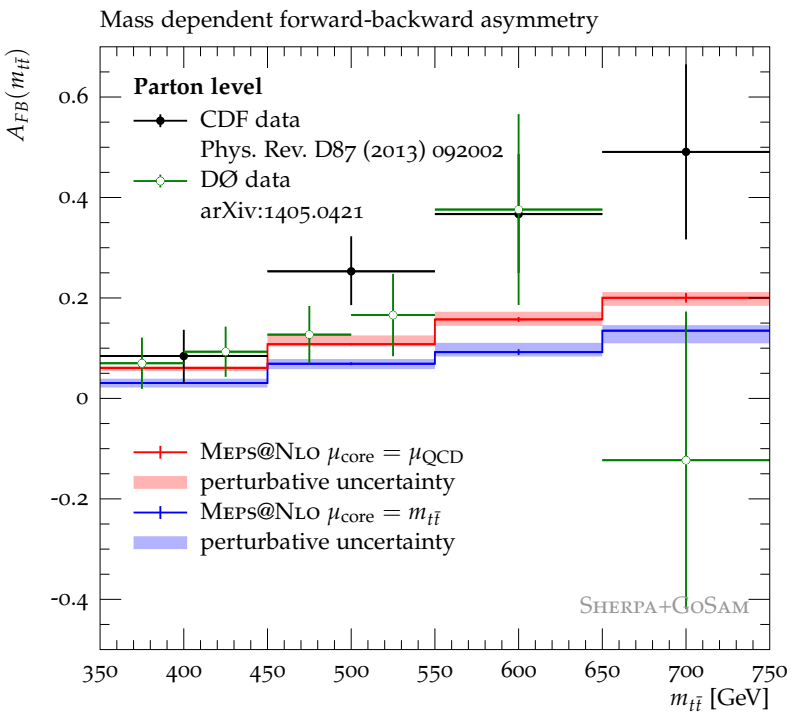
Thank you for your attention!

Backup

Example: Forward-backward asymetry @ Tevatron

Höche, Huang, Luisoni, MS, Winter Phys.Rev.D88(2013)1,014040



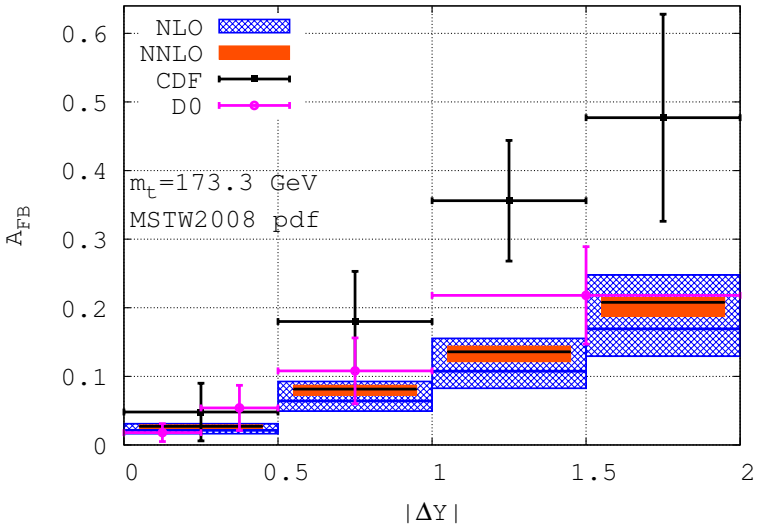


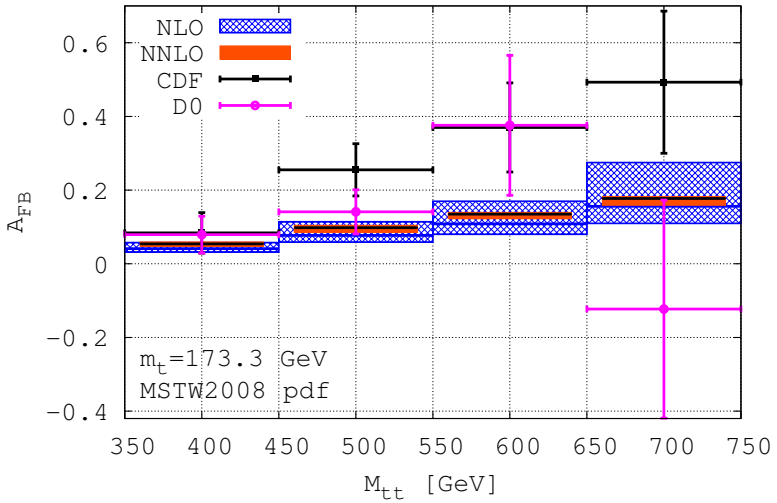
Chose two different $\mu_{\text{core}} \rightarrow$ largest impact

Electroweak histories not an issue, but merging works nicely

Recent NNLO+NNLL results: Forward-backward asymetry @ Tevatron

Czakon, Fiedler, Mitov arXiv:1411.3007





MEPS@NLO result very well reproduced by higher order calculation