

NLO merging in $t\bar{t}+\text{jets}$

Marek Schönherr

Institute for Particle Physics Phenomenology

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[arXiv:1306.2703](#)*

LHCphenOnet



*in collaboration with S. Höche, J. Huang, G. Luisoni, J. Winter

Contents

1 MEPs@NLO

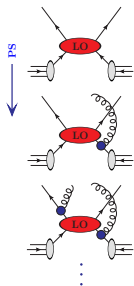
Introduction of the method to merge MC@NLO for $p\bar{p} \rightarrow t\bar{t}$,
 $p\bar{p} \rightarrow t\bar{t} + 1j$, $p\bar{p} \rightarrow t\bar{t} + 2j$, etc. used in SHERPA.
 \Rightarrow More details in tomorrow's talk at 09:25, QCD session.

2 Results

Results for top pair production at the Tevatron,
with emphasis on the forward-backward asymmetry.

3 Conclusions

Method

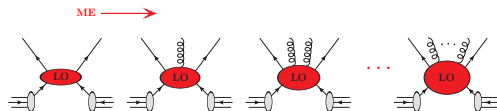


Parton showers

resummation of (soft-)collinear limit
 → intrajet evolution

- matrix elements (ME) and parton showers (PS) are approximations in different regions of phase space
- MEPS combines multiple LOPS – keeping either accuracy
- NLOPS elevate LOPS to NLO accuracy
- MENLOPS supplements core NLOPS with higher multiplicities LOPS

Method



Matrix elements

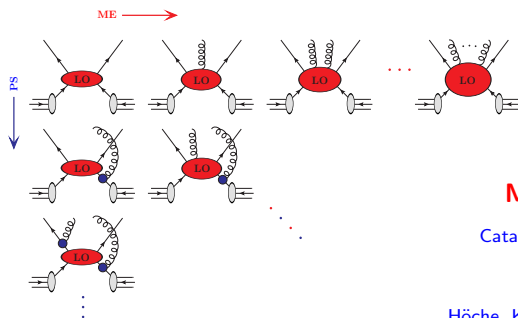
fixed-order in α_s

→ hard wide-angle emissions

→ interference terms

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Method



MEPs (CKKW, MLM)

Catani, Krauss, Kuhn, Webber JHEP11(2001)063

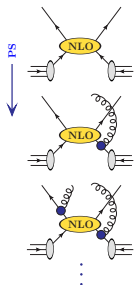
Lönnblad JHEP05(2002)046

Alwall et.al. EPJC53(2008)473-500

Höche, Krauss, Schumann, Siegert JHEP05(2009)053

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NLOPS (MC@NLO, POWHEG)

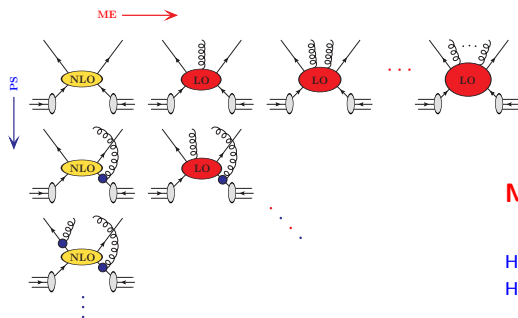
Frixione, Webber JHEP06(2002)029

Nason JHEP11(2004)040, Frixione et.al. JHEP11(2007)070

Höche, Krauss, MS, Siebert JHEP09(2012)049

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MENLOPs

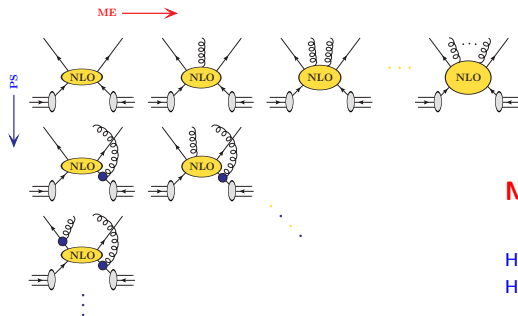
Hamilton, Nason JHEP06(2010)039

Höche, Krauss, MS, Siegert JHEP08(2011)123

Höche, Krauss, MS, Siegert JHEP01(2013)144

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MEPS@NLO

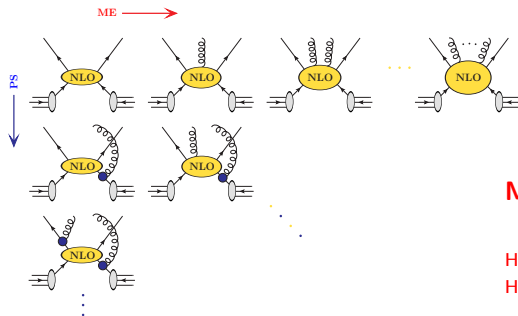
Lavesson, Lönnblad JHEP12(2008)070

Höche, Krauss, MS, Siebert JHEP04(2013)027

Höche, Krauss, MS, Siebert JHEP01(2013)144

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MEPs@NLO

Lavesson, Lönnblad JHEP12(2008)070

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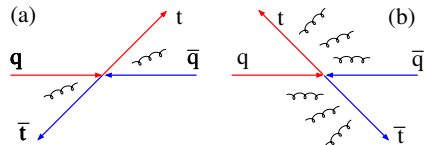
Results – $p\bar{p} \rightarrow t\bar{t} + \text{jets} - A_{FB}$

Skands, Webber, Winter JHEP07(2012)151

Parton showers and the $t\bar{t}$ -asymmetry at the Tevatron

- if colour coherence is respected, PS creates an asymmetry because of asymmetric colour flow
- HERWIG respects colour correlations through angular ordering
- CSSHOWER++ (CS dipoles, $1 \rightarrow 2$ splittings, recoil to large- N_c partner) \rightarrow respects colour correlations by choice of radiating dipoles/recoil partners

\Rightarrow **it is important to respect colour-correlations**



Results – $p\bar{p} \rightarrow t\bar{t} + \text{jets} - A_{\text{FB}}$

- Definition of forward-backward asymmetry of an observable \mathcal{O}

$$A_{\text{FB}}(\mathcal{O}) = \frac{\frac{d\sigma_{t\bar{t}}}{d\mathcal{O}|_{\Delta y > 0}} - \frac{d\sigma_{t\bar{t}}}{d\mathcal{O}|_{\Delta y < 0}}}{\frac{d\sigma_{t\bar{t}}}{d\mathcal{O}|_{\Delta y > 0}} + \frac{d\sigma_{t\bar{t}}}{d\mathcal{O}|_{\Delta y < 0}}}$$

- A_{FB} is ratio of expectation values
 → conventional scale variations by factor 2 will largely cancel for uncertainty on A_{FB}
- ⇒ use different functional forms of the scale definition that behave differently in $\Delta y > 0$ and $\Delta y < 0$ for a realistic estimate of uncertainty

Results – $p\bar{p} \rightarrow t\bar{t} + \text{jets} - A_{\text{FB}}$

Setup: $p\bar{p} \rightarrow t\bar{t} + \text{jets}$

- purely perturbative calculation (no hadronisation, MPI, etc.)
- 0,1 jets @ NLO
 $Q_{\text{cut}} = 7 \text{ GeV}$
- perturbative scale variations
 $\mu_{R/F} \in [\frac{1}{2}, 2] \mu_{\text{def}}$
 $\mu_Q \in [\frac{1}{\sqrt{2}}, \sqrt{2}] \mu_{\text{core}}$
- variation of merging parameter
 $Q_{\text{cut}} \in \{5, 7, 10\} \text{ GeV}$
- scale choices: $\alpha_s^{k+n}(\mu_{\text{eff}}) = \alpha_s^k(\mu) \alpha_s(t_1) \cdots \alpha_s(t_n)$

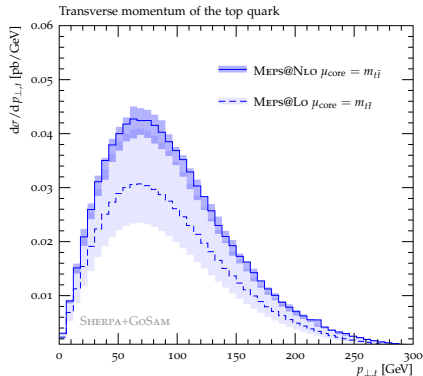
- 1) $\mu_{\text{core}} = m_{t\bar{t}}$

- 2) $\mu_{\text{core}} = \mu_{\text{QCD}} = 2 |p_i p_j|$

$i, j \dots N_c \rightarrow \infty$ colour partners, chooses between s, t, u

⇒ different behaviour for forward/backward configurations

Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703



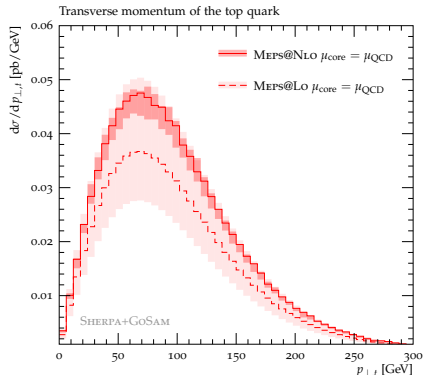
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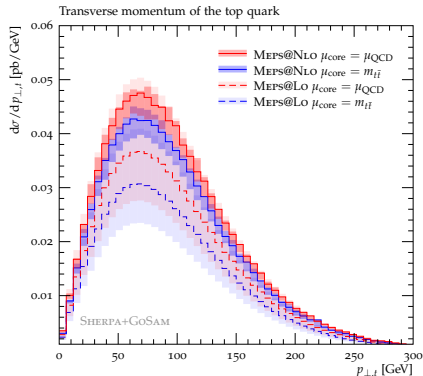
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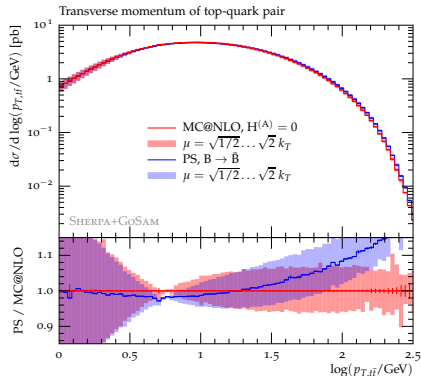
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Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703



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Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703

Importance of

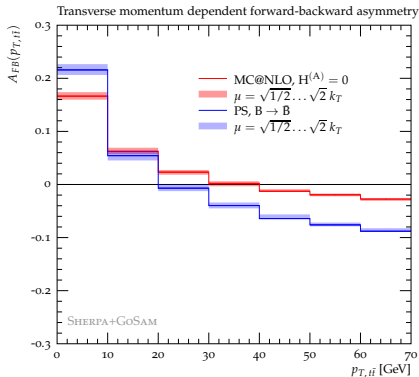
$N_c = 3$ colour coherence
 (SHERPA's MC@NLO)

vs.

$N_c \rightarrow \infty$ colour coherence
 (SHERPA's CSSHOWER++)

- small effect on standard (rapidity blind) observables, e.g. $p_{\perp, t\bar{t}}$
 → some destructive interference at large $p_{\perp, t\bar{t}}$
- large effect on $A_{FB}(p_{\perp, t\bar{t}})$
 → subleading colour terms increase asym. radiation pattern

Results – $p\bar{p} \rightarrow t\bar{t} + \text{jets} - A_{FB}$



Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703

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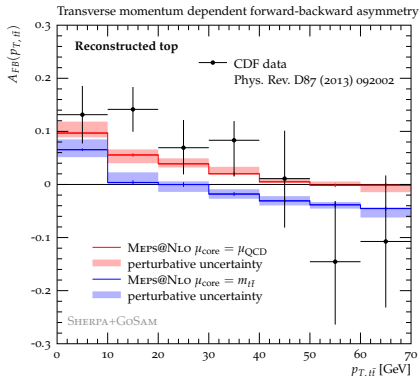
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Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703

CDF data Phys.Rev.D87(2013)092002



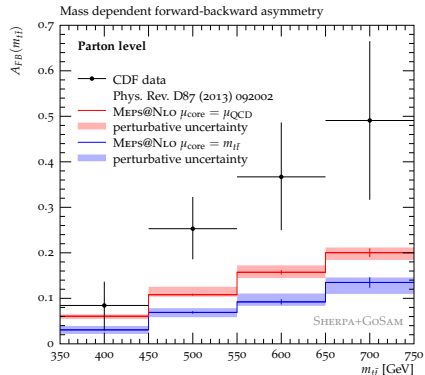
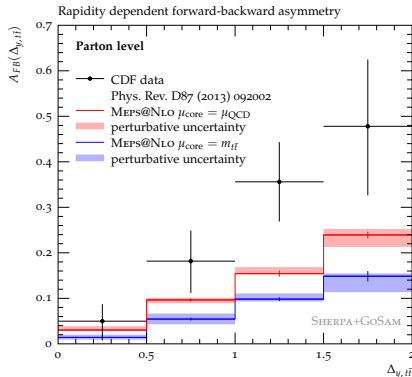
$p\bar{p} \rightarrow t\bar{t} + \text{jets}$ (0,1 @ NLO)

- $A_{FB}(p_{\perp, t\bar{t}})$ NLO accurate in all but the first bin
- tops reconstructed from decay products (jets, lepton, MET)
- no EW corrections

Results – $p\bar{p} \rightarrow t\bar{t} + \text{jets} - A_{FB}$

Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703

CDF data Phys.Rev.D87(2013)092002



- parton level (exact top quarks)
- no EW corrections ($\approx 20\%$) effected
- right qualitative behaviour, but consistently below data

Results – $p\bar{p} \rightarrow t\bar{t} + \text{jets} - A_{\text{FB}}$

Inclusive asymmetries
on parton level

Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703

CDF data Phys.Rev.D87(2013)092002

Source	A_{FB} [%]	$A_{\text{FB}}(m_{t\bar{t}})$ [%]		$A_{\text{FB}}(p_{T,t\bar{t}})$ [%]	
	inclusive	$m < 450 \text{ GeV}$	$m > 450 \text{ GeV}$	$p_T < 50 \text{ GeV}$	$p_T > 50 \text{ GeV}$
CDF data	16.4 ± 4.7	8.4 ± 5.5	29.5 ± 6.7	–	–
MEPs@NLO, $\mu = \mu_{\text{QCD}}$	$8.5^{+0.5}_{-0.5}$	$6.1^{+0.2}_{-0.1}$	$12.7^{+1.1}_{-0.6}$	$9.5^{+0.7}_{-0.0}$	$-3.4^{+0.8}_{-0.1}$
MEPs@NLO, $\mu = m_{t\bar{t}}$	$4.8^{+0.7}_{-0.3}$	$3.1^{+0.8}_{+0.1}$	$7.9^{+0.5}_{-1.1}$	$5.8^{+0.8}_{-0.4}$	$-7.2^{+0.5}_{-0.4}$
MEPS, $\mu = \mu_{\text{QCD}}$	$15.0^{+1.9}_{-1.4}$	$11.0^{+1.4}_{-1.1}$	$22.2^{+2.3}_{-2.0}$	$16.6^{+2.2}_{-1.6}$	$-1.1^{+1.7}_{-1.2}$
MEPS, $\mu = m_{t\bar{t}}$	$8.2^{+0.9}_{-0.8}$	$5.9^{+0.6}_{-0.6}$	$12.5^{+1.3}_{-1.2}$	$9.9^{+1.1}_{-1.1}$	$-7.9^{+0.6}_{-0.6}$
NLO $p\bar{p} \rightarrow t\bar{t}$	6.0	4.1	9.3	7.0	-11.1

Conclusions

- MEPS merging methods have evolved to NLO: MEPs@NLO
- taking colour correlations properly into account already produces an asymmetry in parton showers
- asymmetry increases when parton shower includes subleading colour terms
- decreasing uncertainties LOPS/MEPs/NLOPS \rightarrow MEPs@NLO
- uncertainties on asymmetry observables should be evaluated by choosing different functional forms with different properties towards the asymmetry
- can be improved by adding higher order calculations
 - (N)NLL resummation
 - NNLO corrections

Bärnreuther, Czakon, Mitov Phys.Rev.Lett.109(2012)132001

Czakon, Mitov JHEP01(2013)080

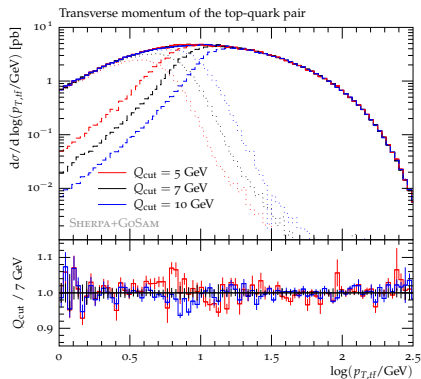
Czakon, Fiedler, Mitov arXiv:1303.6254

current release SHERPA-2.0. β_2 , when fully tuned SHERPA-2.0.0

<http://sherpa.hepforge.org>

Thank you for your attention!

Results – $p\bar{p} \rightarrow t\bar{t} + \text{jets}$



- very small Q_{cut} dependence
- scale variation shrinks going LO to NLO (both factor and functional form)

Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703

