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

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Institute for Particle Physics Phenomenology

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arXiv:1306.2703*

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

Contents

1. **MePs@Nlo**

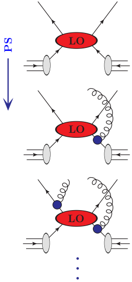
   Introduction of the method to merge Mc@Nlo for $p\bar{p} \to t\bar{t}$, $p\bar{p} \to t\bar{t} + 1j$, $p\bar{p} \to t\bar{t} + 2j$, etc. used in Sherpa.
   $\Rightarrow$ More details in tomorrow's talk at 09:25, QCD session.

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
$\rightarrow$ 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

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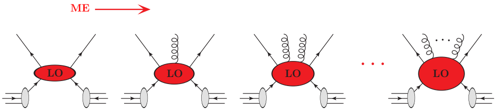

Matrix elements

fixed-order in α_s
$\rightarrow$ hard wide-angle emissions
$\rightarrow$ interference terms

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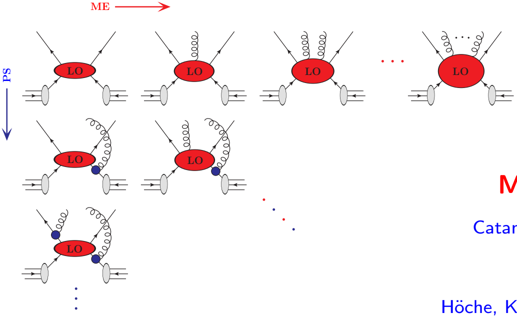

MEPS (CKKW,MLM)

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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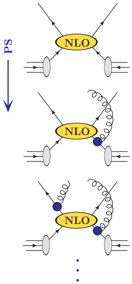

NLOPS (MC@NLO,POWHEG)

Frixione, Webber JHEP06(2002)029
Nason JHEP11(2004)040, Frixione et.al. JHEP11(2007)070
Höche, Krauss, MS, Siegert JHEP09(2012)049

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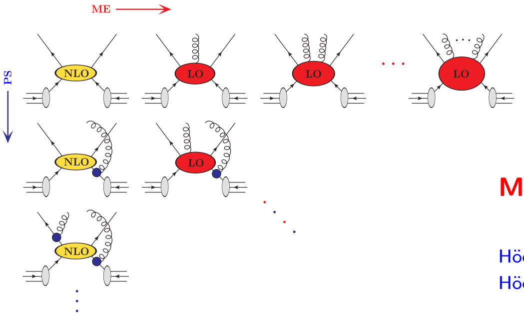

MENLOPS

Hamilton, Nason JHEP06(2010)039
Höche, Krauss, MS, Siegert JHEP08(2011)123
Höche, Krauss, MS, Siegert JHEP01(2013)144

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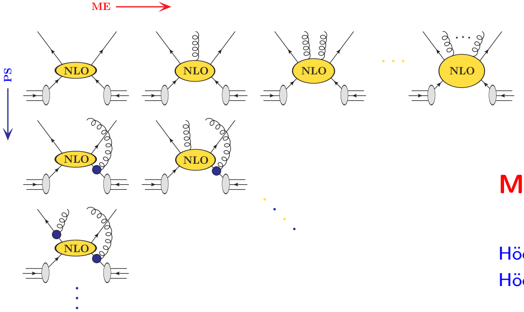

MEPS@NLO

Lavesson, Lönnblad JHEP12(2008)070
Höche, Krauss, MS, Siegert JHEP04(2013)027
Höche, Krauss, MS, Siegert JHEP01(2013)144

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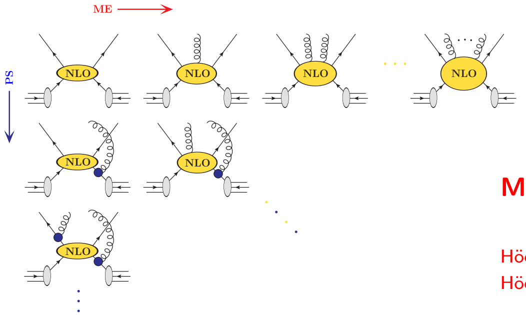

MEPS@NLO

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- **MEPS@NLO combines multiple NLOPS – keeping either accuracy**

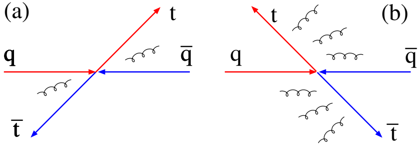
Contents

Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}} + $ jets – $\mathrm{A_{FB}}$

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→2 splittings, recoil to large-N_c partner) → respects colour correlations by choice of radiating dipoles/recoil partners

⇒ it is important to respect colour-correlations

Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}}+$jets – A_{FB}

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

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

- A_{FB} is ratio of expectation values
  $\to$ conventional scale variations by factor 2 will largely cancel for uncertainty on A_{FB}

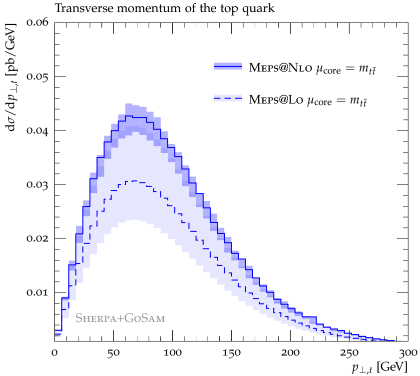
$\Rightarrow$ use different functional forms of the scale defintion that behave differently in $\Delta y > 0$ and $\Delta y < 0$ for a realistic estimate of uncertainty

Results – $p\bar{p} \to t\bar{t} +$ jets – A_{FB}

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

Setup: $p\bar{p} \to t\bar{t}+$ jets

- purely perturbative calculation (no hadronisation, MPI, etc.)
- 0,1 jets @ NLO
  $Q_{\text{cut}} = 7$ 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
  $Q_{\text{cut}} \in \{5, 7, 10\}$ 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) $\mu_{\text{core}} = \mu_{\text{QCD}} = 2\,|p_i p_j|$
  $i, j \ldots N_c \to \infty$ colour partners, chooses between s, t, u

$\Rightarrow$ different behaviour for forward/backward configurations

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

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

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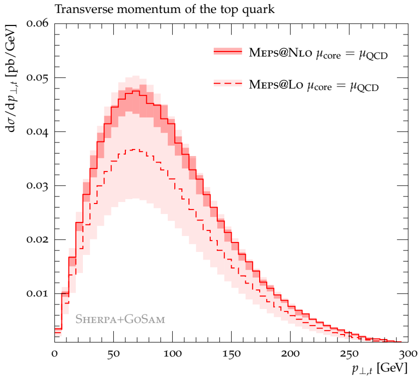

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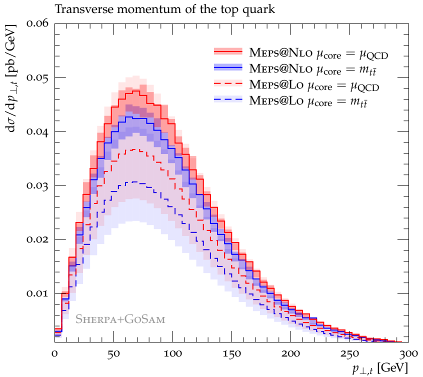
Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703



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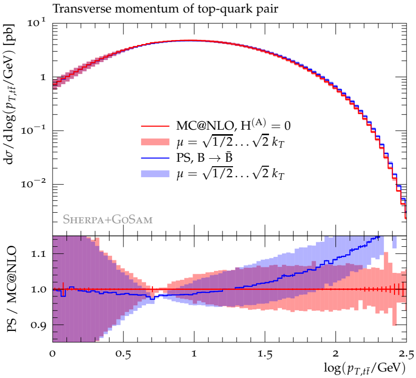
⇒ different behaviour for forward/backward configurations

Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}}+\mathrm{jets}$ – $\mathrm{A_{FB}}$

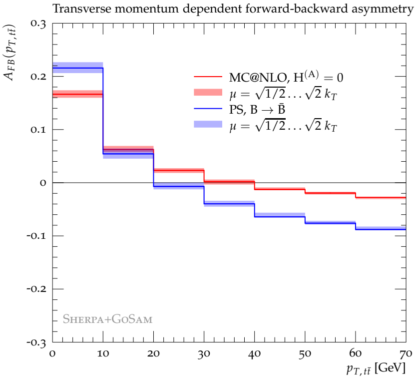


Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703

Importance of
$N_c = 3$ colour coherence
(SHERPA's MC@NLO)
vs.
$N_c \to \infty$ colour coherence
(SHERPA's CSSHOWER++)

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

Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}} + \mathrm{jets}$ – A_{FB}



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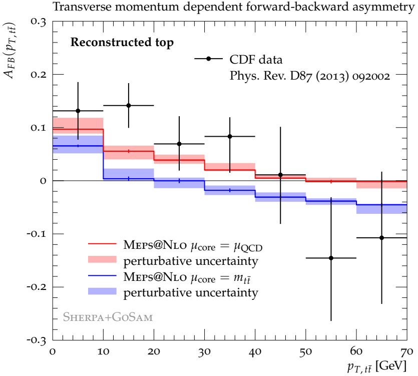
Results – $p\bar{p} \to t\bar{t} + \text{jets}$ – A_{FB}

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

CDF data Phys.Rev.D87(2013)092002



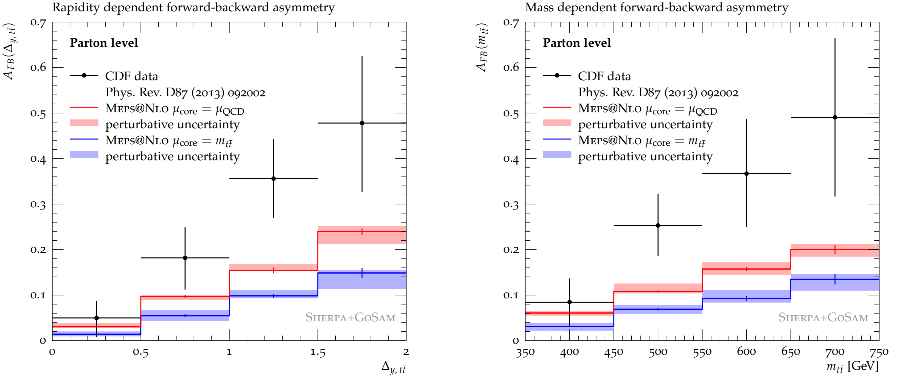
$p\bar{p} \to t\bar{t}$+jets (0,1 @ NLO)

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

Results – $p\bar{p} \to t\bar{t} + \text{jets}$ – 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 bahviour, but consistently below data

Results – $\mathrm{p\bar{p}} \to \mathrm{t\bar{t}} + \mathrm{jets}$ – $\mathrm{A_{FB}}$

Inclusive asymmetries
on parton level

Höche, Huang, Luisoni, MS, Winter arXiv:1306.2703
CDF data Phys.Rev.D87(2013)092002

Source	$A_{\rm FB}$ [%]	$A_{\rm FB}(m_{t\bar{t}})$ [%]		$A_{\rm FB}(p_{T,t\bar{t}})$ [%]	
	inclusive	$m < 450$ GeV	$m > 450$ GeV	$p_T < 50$ GeV	$p_T > 50$ GeV
CDF data	16.4 ± 4.7	8.4 ± 5.5	29.5 ± 6.7	–	–
MEPS@NLO, $\mu = \mu_{\rm QCD}$	$8.5\,^{+0.5}_{-0.5}$	$6.1\,^{+0.2}_{-0.1}$	$12.7\,^{+1.1}_{-0.6}$	$9.5\,^{+0.7}_{-0.0}$	$-3.4\,^{-0.8}_{-0.1}$
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, $\mu = \mu_{\rm QCD}$	$15.0\,^{+1.9}_{-1.4}$	$11.0\,^{+1.4}_{-1.1}$	$22.2\,^{+2.3}_{-2.0}$	$16.6\,^{+2.2}_{-1.6}$	$-1.1\,^{+1.7}_{-1.2}$
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 $p\bar{p} \to t\bar{t}$	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

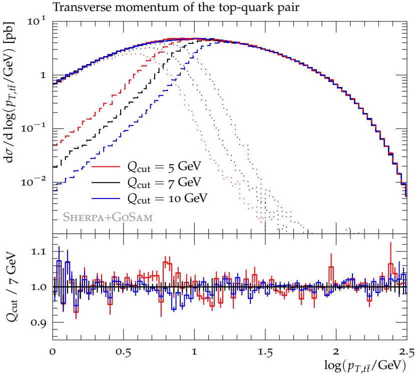
current release SHERPA-2.0.β_2, when fully tuned SHERPA-2.0.0

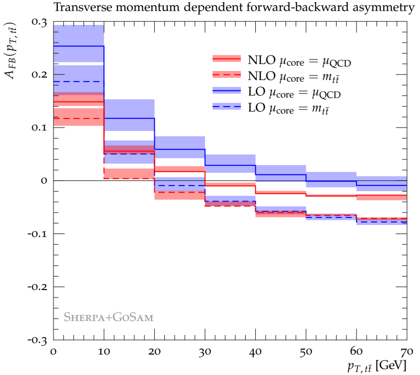
http://sherpa.hepforge.org

Thank you for your attention!

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

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





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