Automisation of the POWHEG Method and Consistent Combination with CKKW Merging

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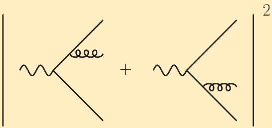
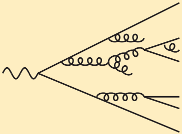
Approaches to real emission corrections

Matrix Element



Parton Shower



- \+ **Exact** to fixed order
- − Perturbative series breaks down due to **large logarithms**

- \+ Resums logarithms to **all orders**
- − Only **approximation** to real emission ME

Combine Advantages ⇒ ME⊗PS

- avoid double-counting by dividing phase space ⇒ Q_{cut}
- **ME** to describe **hard radiation**, **PS** for **intrajet evolution**

JHEP11(2001)063, JHEP05(2002)046, JHEP08(2002)015, JHEP05(2009)053

Review: Multijet Merging with LO MEs – ME⊗PS

$$\langle O\rangle \;=\; \int \mathrm{d}\Phi_B\, B(\Phi_B) \left[\Delta(t_0)\; O(\Phi_B) + \int \mathrm{d}\Phi_{R|B}\, \mathcal{K}(t,z,\phi)\, \Delta(t)\; O(\Phi_R)\right]$$

- ordinary LO+PS restricted to soft emissions with $Q < Q_\text{cut}$
- phase space $Q > Q_\text{cut}$ filled by ME
- supplement Sudakov suppression $\Delta(t)$ to recover unitarity at LL level
- **preserves LO accuracy of every ME emission and LL accuracy of PS**
- PS Sudakov form factor $\Delta(t) = \exp\left[-\sum\int \mathrm{d}\Phi_{R|B}\, \mathcal{K}(t,z,\phi)\right]$

JHEP11(2001)063, JHEP05(2002)046, JHEP08(2002)015, JHEP05(2009)053

Review: Multijet Merging with LO MEs – ME⊗PS

$$\langle O\rangle = \int \mathrm{d}\Phi_B\, B(\Phi_B) \Big[\Delta(t_0)\, O(\Phi_B) + \overbrace{\int \mathrm{d}\Phi_{R|B}\, \mathcal{K}(t,z,\phi)\, \Delta(t)\, \Theta(Q_{\text{cut}} - Q)}^{\text{PS domain}}\, O(\Phi_R)\Big]$$

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- ordinary LO+PS restricted to soft emissions with $Q < Q_\text{cut}$
- phase space $Q > Q_\text{cut}$ filled by ME
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arXiv:1008.5399

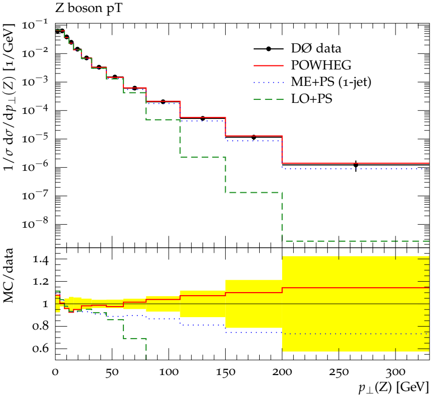
POWHEG Algorithm

$$\langle O\rangle = \int \mathrm{d}\Phi_B\,\bar{B}(\Phi_B)\left[\bar{\Delta}(t_0)\,O(\Phi_B) + \sum\int_{t_0}\mathrm{d}\Phi_{R|B}\,\frac{R(\Phi_R)}{B(\Phi_B)}\,\bar{\Delta}(t)\,O(\Phi_R)\right]$$

- method for matching NLO calculation to PS resummation
  JHEP11(2004)040, JHEP11(2007)070
- correct PS to ME and supplement NLO weight
  → **preserves both NLO and LL accuracy**
- NLO event weight $\bar{B} = B + V + I + \int \mathrm{d}\Phi_{R|B}\,[R - S]$
  - **B**orn, **R**eal from automated tree-level generators
  - **V**irtual e.g. via Binoth Les Houches Accord CPC181(2010)1612
    → for results here BLACKHAT & MCFM libraries interfaced
  - **I**ntegrated/**S**ubtraction terms from automated implementation of Catani-Seymour subtraction terms EPJC53(2008)501
- POWHEG Sudakov $\bar{\Delta}(t) = \exp\left[-\sum\int \mathrm{d}\Phi_{R|B}\,\frac{R(\Phi_R)}{B(\Phi_B)}\right]$

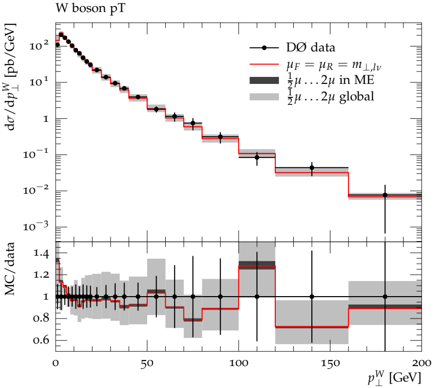
arXiv:1008.5399

Results – inclusive W/Z production at Tevatron



Data from DØ :

Phys.Lett.B693(2010)522-530



Data from DØ :

Phys.Lett.B513(2001)292-300

arXiv:1009.1127

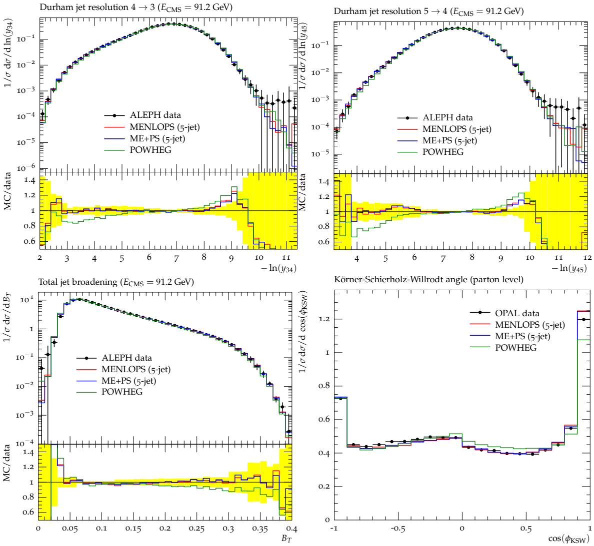
Multijet Merging with NLO MEs – MENLOPS

$$\langle O\rangle = \int \mathrm{d}\Phi_B\,\bar{B}(\Phi_B)\left[\bar{\Delta}(t_0)\,O(\Phi_B) + \overbrace{\int \mathrm{d}\Phi_{R|B}\,\frac{R(\Phi_R)}{B(\Phi_B)}\,\bar{\Delta}(t)\,\Theta(Q_{\text{cut}}-Q)\,O(\Phi_R)}^{\text{POWHEG domain}} + \underbrace{\int \mathrm{d}\Phi_{R|B}\,\frac{R(\Phi_R)}{B(\Phi_B)}\,\Delta(t)\,\Theta(Q-Q_{\text{cut}})\,O(\Phi_R)}_{\text{ME domain}}\right]$$

- replaces PS domain with POWHEG for core process
  ⇒ **NLO accuracy preserved for inclusive observables**
- ME⊗PS used for hard higher order emissions
  ⇒ **preserves LO accuracy of every ME emission & LL accuracy of PS**
- higher order emissions receive local K-factor $\frac{\bar{B}(\Phi_B)}{B(\Phi_B)}$
- developed in parallel by JHEP06(2010)039, but using global K-factor

arXiv:1009.1127

Results – $e^+e^- \to jets$ at LEP

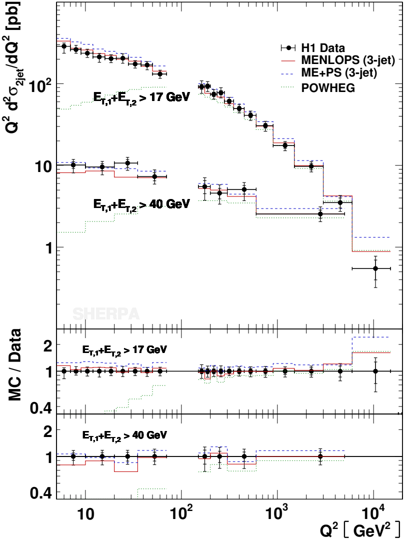


Data from ALEPH:
EPJC35(2004)457-486
Data from OPAL:
EPJC20(2001)601-615

Observables sensitive to multijet emissions benefit from improved description in MENLOPS

arXiv:1009.1127

Results – $e^+p \to e^+ + jets$ at HERA



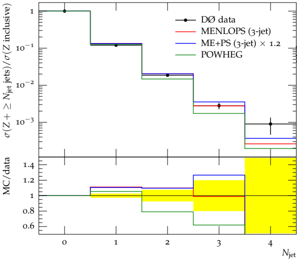
Data from H1:
EPJC19(2001)289-311

POWHEG unable to describe data at low Q^2 due to severe restrictions on additional emissions by factorisation theorem
→ overcome by inclusion higher order MEs EPJC67(2010)73

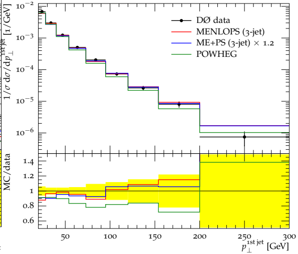
arXiv:1009.1127

Results – $p\bar{p} \to \ell^+\ell^- + X$

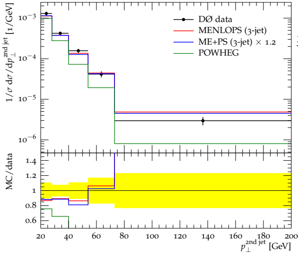
Inclusive jet multiplicity



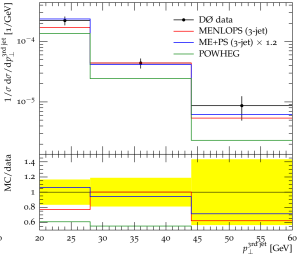
pT of 1st jet (constrained electrons)



pT of 2nd jet (constrained electrons)



pT of 3rd jet (constrained electrons)



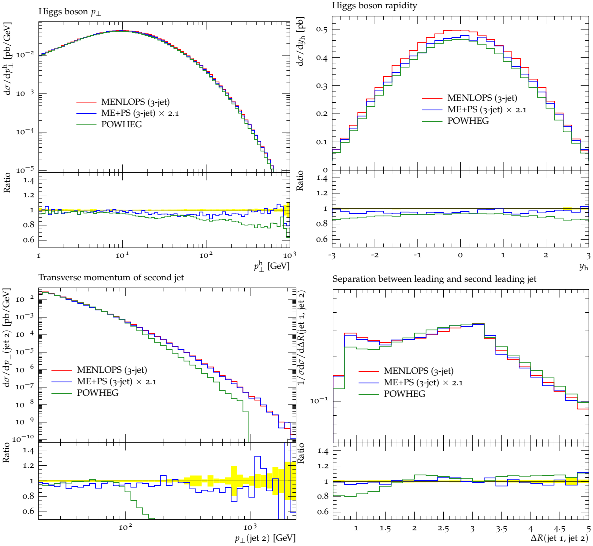
Data from DØ :
Phys.Lett.B658(2008)112-119
Phys.Lett.B678(2009)45-54

POWHEG and MENLOPS agree well on $p_\perp$ of hardest jet

MENLOPS superior for 2nd and 3rd jet

arXiv:1009.1127

Results – $pp \to h + jets$ at LHC @ 14 TeV

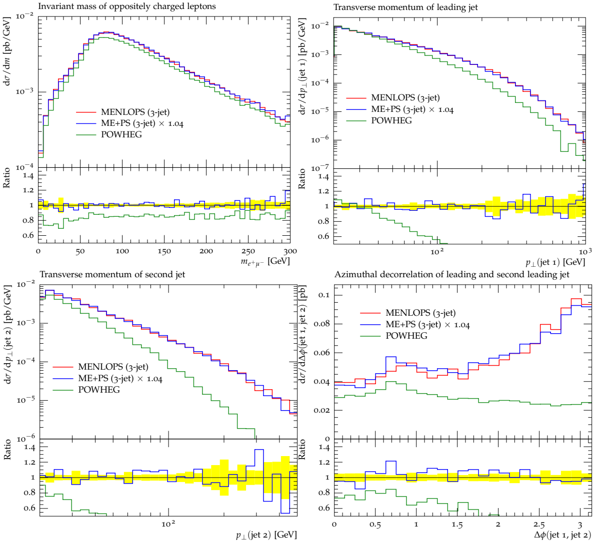


Good agreement on inclusive observables

Multijet dependent observables benefit from MENLOPS

arXiv:1009.1127

Results – $pp \to W^+[\to e^+\nu_e]\,W^-[\to \mu^-\bar{\nu}_\mu] + X$ at LHC



Good agreement on inclusive observables

Spectrum of hardest jet already receives large contributions from higher order emissions

ME corrections to shapes essential

Conclusions

- ME⊗PS works well for shapes, but needs K-factor
- POWHEG reproduces NLO cross section and shape of first emission, but additional hard jets at LL only
- MENLOPS combines ME⊗PS and POWHEG
  ⇒ NLO cross accuracy in core process
  ⇒ multijet observables as in ME⊗PS
- automated (except V) in SHERPA framework
  ⇒ will be in a forthcoming release

- also want NLO accuracy in higher order emission
  ⇒ multijet emission dependent observable described at NLO
  . . . working on it

Thank you.

JHEP05(2009)053

Backup: ME⊗PS Merging

Divide phase space using jet measure Q_cut:

→ emissions with $Q > Q_\text{cut}$ by ME
→ emissions with $Q < Q_\text{cut}$ by PS

Shower on top of higher order ME:

Problem: ME only gives final state, no history as PS input

Solution: Backward clustering (inverted probabilistic PS splittings)

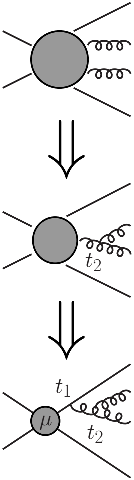
⇒ **ME final state with branching history and PS starting scale μ and branching scales t_i**

Veto PS emissions with $Q > Q_\text{cut}$

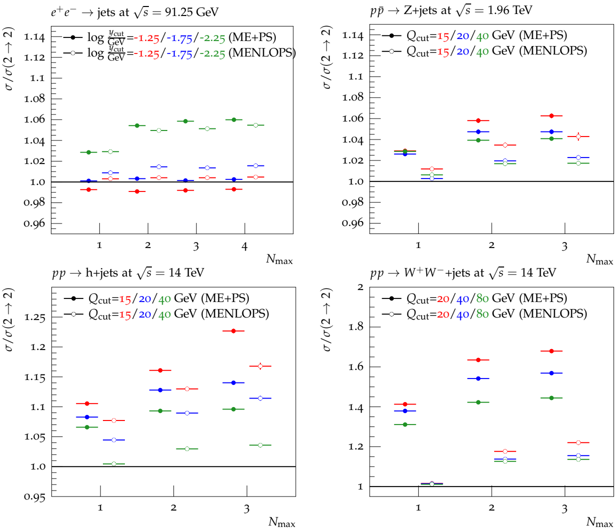
→ Reject event → Sudokov suppression

If $t \neq Q^2$ then truncated shower necessary

Scales:



Backup: Unitarity Violation



Formally of $\mathcal{O}(\alpha_s^2)$ in MENLOPS
$\to N_{\text{max}} = 1$ shows size of unitarity violation in MENLOPS alone

Due to mismatch in non-logarithmic terms in ME and PS in real emission correction and Sudakov

Indicates potential size of higher order corrections