Tools for new physics discovery

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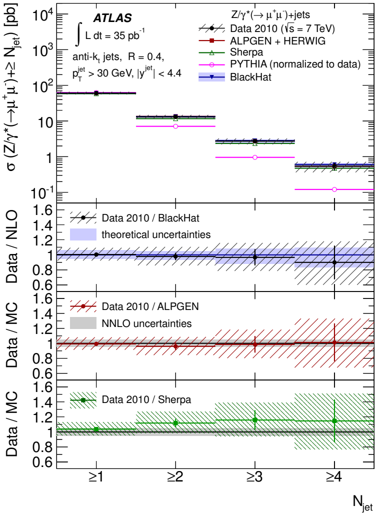
Status of Z+Jets



[ATLAS] PRD85(2012)032009

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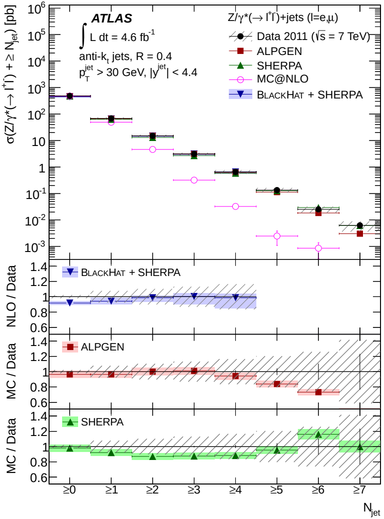
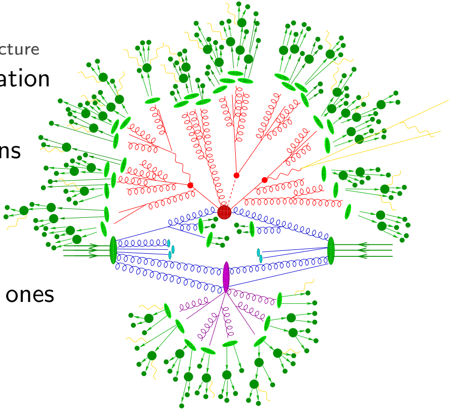


[ATLAS] arXiv:1304.7098

Event generation at hadron colliders

1. Matrix Element (ME) generators red blobs
   simulate "central" part of the event
2. Parton Showers (PS) red & blue tree structure
   produce additional "hard" QCD radiation
3. Multiple interaction models purple blob
   simulate "secondary hard" interactions
4. Fragmentation models light green blobs
   hadronize QCD partons
5. Hadron decay modules dark green blobs
   decay primary hadrons into observed ones
6. Photon emission generators yellow stuff
   simulate additional QED radiation



General-purpose event generators

[Buckley et al.] Phys.Rept.504(2011)145

Herwig

- Originated in coherent shower studies → angular ordered PS
- Front-runner in development of MC@NLO and POWHEG
- Simple in-house ME generator & spin-correlated decay chains
- Original framework for cluster fragmentation

Pythia

- Originated in hadronization studies → Lund string
- Leading in development of models for non-perturbative physics
- Pragmatic attitude to ME generation → external tools
- Extensive PS development and earliest ME+PS matching

Sherpa

- Started with PS generator APACIC++ & ME generator AMEGIC++
- Hadronization pragmatic add-on, but extensive decay package
- Leading in development of automated ME⊕PS merging (at NLO)
- Automated framework for NLO calculations and MC@NLO

MCnet

Analysis and tuning tools

Rivet [Buckley et al.] arXiv:0103.0694

- LHC-successor to HZTool
  Collection of exp. data & matching analysis routines
- Spirit: "Right MC describes everything at the same time"

Professor [Buckley et al.] EPJC65(2010)331

- Tuning in multi-dimensional parameter space of MC
- Generate event samples at random parameter points
  Analyze them with Rivet
  Parametrize observables
  Minimize χ^2 and cross-check

Tune comparisons

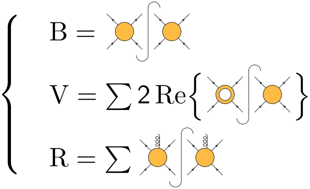
Deviation metrics per gen/tune and observable group:

Gen	Tune	UE	Dijets	Multijets	Jet shapes	W and Z	Fragmentation	B frag
AlpGen	HERWIG6	–	1.83	5.36	2.48	0.91	–	–
	PYTHIA6-AMBT1	–	1.55	2.80	0.61	0.53	–	–
	PYTHIA6-D6T	–	1.38	2.67	2.31	1.67	–	–
	PYTHIA6-P2010	–	1.09	2.65	2.03	1.48	–	–
	PYTHIA6-P2011	–	1.12	2.60	0.48	0.24	–	–
	PYTHIA6-Z2	–	1.48	2.63	0.55	0.48	–	–
	PYTHIA6-profQ2	–	1.16	2.65	1.43	1.29	–	–
HERWIG	AUET2-CTEQ6L1	0.43	0.55	0.77	0.35	0.58	22.80	2.38
	AUET2-LOxx	0.25	0.71	0.60	0.39	0.88	22.13	2.29
Herwig++	2.5.1-UE-EE-3-CTEQ6L1	0.27	0.87	0.78	0.51	0.98	10.58	1.32
	2.5.1-UE-EE-3-MRSTLOxx	0.23	1.05	0.78	0.50	0.65	10.58	1.32
PYTHIA6	AMBT1	0.39	1.20	0.54	0.77	0.27	0.93	1.65
	AUET2B-CTEQ6L1	0.16	0.92	0.44	0.59	0.74	0.67	1.29
	AUET2B-LOxx	0.13	1.33	0.55	0.58	1.15	0.67	1.30
	D6T	0.58	0.79	0.50	0.56	1.25	0.36	2.63
	DW	0.81	0.78	0.61	0.56	1.33	0.36	2.63
	P2010	0.30	0.93	0.82	1.07	0.30	0.44	1.75
	P2011	0.12	0.89	0.67	1.02	0.53	0.43	2.13
	ProfQ2	0.51	0.67	0.81	0.51	0.64	0.30	1.65
	Z2	0.18	0.94	0.73	0.80	0.30	0.95	2.78
Pythia8	4C	0.30	0.97	0.93	0.50	0.90	0.38	1.12
Sherpa	1.3.1	0.68	0.47	0.34	0.71	0.36	0.75	2.48

[LH'11 SM WG] arXiv:1203.6803 [hep-ph]

NLO matrix element generators

NLO prediction



Singularities in V & R subtracted before MC-integration

$$\sigma^{NLO} = \int \mathrm{d}\Phi_B \left(\mathrm{B} + \tilde{\mathrm{V}}\right) + \int \mathrm{d}\Phi_R \, \mathrm{R} = \int \mathrm{d}\Phi_B \left[\left(\mathrm{B} + \tilde{\mathrm{V}} + \mathrm{I}\right) + \int \mathrm{d}\Phi_{R|B} \, (\mathrm{R} - \mathrm{S})\right]$$

Commonly used techniques:

- **Dipole method** [Catani,Seymour] NPB485(1997)291 [Catani,Dittmaier,Seymour,Trocsanyi] NPB627(2002)189, implemented in
  - AMEGIC++ [Gleisberg,Krauss] EPJC53(2008)501, Comix [SH] colorful
  - HELAC/PHEGAS [Czakon,Papadopoulos,Worek] JHEP08(2009)085 polarized
  - MADDIPOLE [Frederix,Gehrmann,Greiner] JHEP09(2008)122, JHEP06(2010)086
- **FKS method** [Frixione,Kunszt,Signer] NPB467(1996)399, implemented in
  - MADFKS [Frederix,Frixione,Maltoni,Stelzer] JHEP10(2009)003

Several other implementations, not part of automated tree-level tools

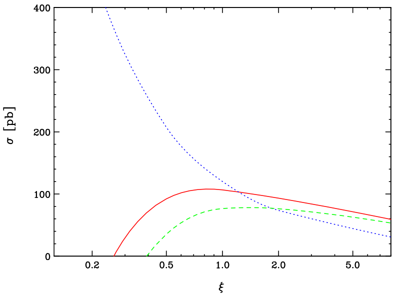
NLO matrix element generators

Plethora of (semi-)automated programs to compute virtual correction

- **Tensor reduction** [Denner,Dittmaier] NPB734(2006)62 [Binoth,Guillet,Pilon,Heinrich,Schubert] JHEP10(2005)015
  - Golem95 [Binoth,Cullen,Greiner,Guffanti,Guillet,Heinrich,Karg,Kauer,Reiter,Reuter]
  - MadGolem [Binoth,Goncalves Netto,Lopez-Val,Mawatari,Plehn,Wigmore]
  - OpenLoops [Cascioli,Maierhöfer,Pozzorini]
- **Generalized unitarity** [Bern,Dixon,Dunbar,Kosower] NPB435(1995)59 NPB513(1998)3 [Ossola,Papadopoulos,Pittau] NPB763(2007)147, [Forde] PRD75(2007)125019
  - BlackHat [Bern,Dixon,Febres-Cordero,Ita,Kosower,LoPresti,Maître,Ozeren,SH]
  - GoSam [Cullen,Greiner,Heinrich,Luisoni,Mastrolia,Ossola,Reiter,Tramontano]
  - HelacNLO [Bevilacqua,Czakon,Garzelli,vanHameren,Kardos,Papadopoulos,Pittau,Worek]
  - MadLoop [Hirschi,Frederix,Frixione,Garzelli,Maltoni,Pittau]
  - NJet [Badger,Biedermann,Uwer,Yundin]
  - NLOX [Reina,Schutzmeier,Quackenbush]
  - OpenLoops [Cascioli,Maierhöfer,Pozzorini]
  - Rocket [Ellis,Giele,Kunszt,Melnikov,Zanderighi]
- **Numerical integration** [Becker,Goetz,Reuschle,Schwan,Weinzierl] PRL108(2012)032005

NLO matrix element generators

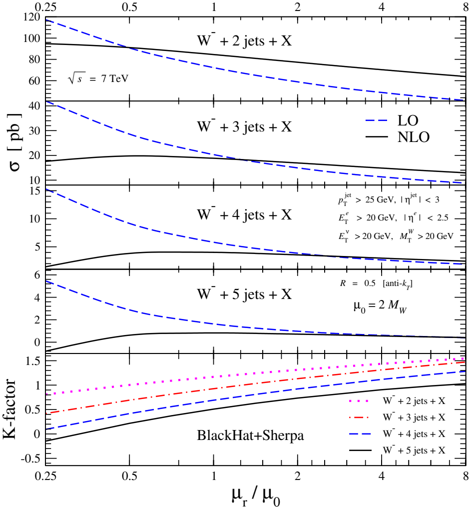
$t\bar{t}+2j$ [Bevilacqua et al.] PRL104(2010)162002



- Methods moved well beyond proof-of-concept stage
- Many cutting edge results now obtained with BLHA

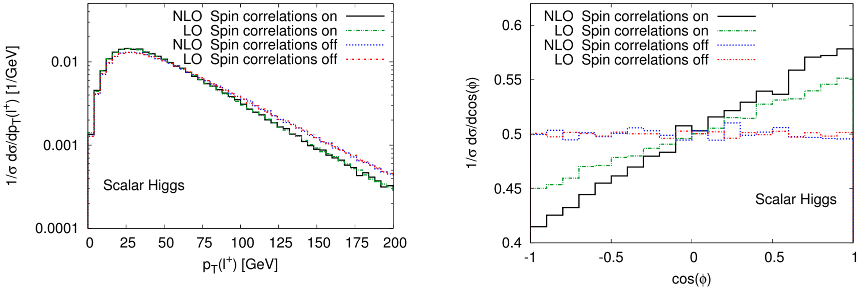
[Binoth et al.] CPC181(2010)1612

$W+5j$ [Bern et al.] arXiv:1304.1253



Spin-correlated decay chains

[Artoisenet,Frederix,Mattelaer,Rietkerk] JHEP03(2013)015



- Inclusion of spin correlations via post-processing (N)LO event samples from aMC@NLO through MadSpin
- In $t\bar{t}h$, effects of spin correlations on the p_T-shape of charged lepton more important than NLO QCD corrections

Jet scaling - understanding parton showers analytically

- Consider "core" process (e.g. W-production) plus n jets
- Cross section ratios

$$R_{(n+1)/n} = \frac{\sigma_{n+1}^{\text{excl}}}{\sigma_{n}^{\text{excl}}}$$

$\sim$ stable against QCD corrections [Gerwick et al.] JHEP10(2012)162

- **Staircase Scaling**:

$$R_{(n+1)/n} = \text{const} \quad \left(\sigma_n = \sigma_0\, R^n\right)$$

- First predicted for W/Z+jets [Berends,Giele,Kuijf] NPB321(1989)39
- Induced by democratic jet cuts

- **Poisson Scaling**:

$$R_{(n+1)/n} = \frac{\bar{n}}{n+1} \quad \left(\sigma_n = \frac{\bar{n}^n e^{-\bar{n}}}{n!}\right)$$

- Independent emission picture (like soft γ radiation in QED)
- Driven by large emission probability

- Analytically tractable using resummed jet rates [Gerwick et al.] JHEP04(2013)089
- Resummed abelian contributions yield Poisson distribution
  Deviations leading to Poisson due to secondary emissions

NLO predictions for W+n jets

[BlackHat] arXiv:1304.1253

- W+jets at 7 TeV, $E_T^e > 20\ \text{GeV}\,,\quad |\eta^e| < 2.5\,,\quad \not{E}_T > 20\ \text{GeV}$
  $p_T^j > 25\ \text{GeV}\,,\quad |\eta^j| < 3\,,\quad M_T^W > 20\ \text{GeV}$

Jets	$\frac{W^- + (n+1)}{W^- + n}$		$\frac{W^+ + (n+1)}{W^+ + n}$	
	LO	NLO	LO	NLO
1	0.2949(0.0003)	0.238(0.001)	0.3119(0.0005)	0.242(0.002)
2	0.2511(0.0005)	0.220(0.001)	0.2671(0.0004)	0.235(0.002)
3	0.2345(0.0008)	0.211(0.003)	0.2490(0.0005)	0.225(0.003)
4	0.218(0.001)	0.200(0.006)	0.2319(0.0008)	0.218(0.006)

- Fit to straight line for $W + n$ jets gives $(n \geq 2)$

$$R_{n/(n-1)}^{\mathrm{NLO},\,W^-} = 0.248 \pm 0.008 - (0.009 \pm 0.002)\, n$$

$$R_{n/(n-1)}^{\mathrm{NLO},\,W^+} = 0.263 \pm 0.009 - (0.009 \pm 0.003)\, n$$

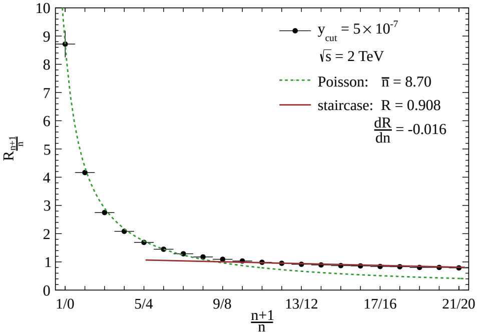
- Extrapolate to six jets

$W^- + 6$ jets : 0.15 ± 0.01 pb

$W^+ + 6$ jets : 0.30 ± 0.03 pb

Comparison with Monte-Carlo results

[Gerwick et al.] JHEP10(2012)162

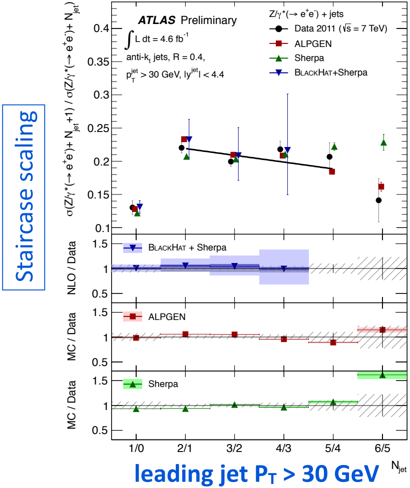


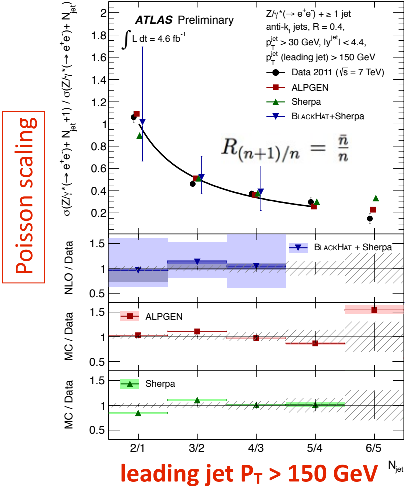
- e^+e^--collider at $\sqrt{s} = 2$ TeV & $y_{\rm cut} = 5 \cdot 10^{-7}$
- Simulated results from Sherpa parton shower ($g \to q\bar{q}$ off)
- Good fit to a Poisson for low multi, transition to $\sim$ staircase at $n = 8$

Experimental observation

- First measurement by ATLAS in Z+jets

[ATLAS] arXiv:1304.7098



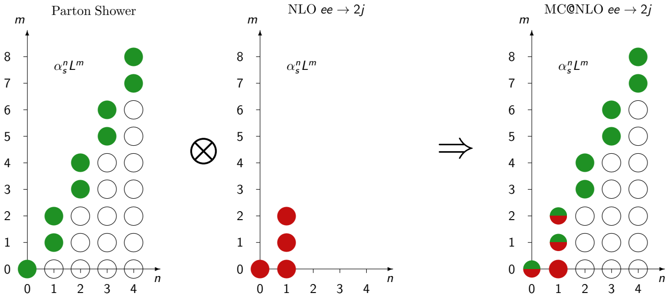


Matching NLO calculations and parton showers

[Frixione,Webber] JHEP06(2002)029
[Nason] JHEP11(2004)040, [Frixione,Nason,Oleari] JHEP11(2007)070

Objective

- NLO accurate parton-level prediction for n-jet process
- Combined with resummation encoded in parton shower



Example: $e^+e^- \to$hadrons

Matching NLO and PS

Differential event rate to $\mathcal{O}(\alpha_s)$ in PS

$$\frac{\mathrm{d}\sigma_{\mathrm{PS}}}{\mathrm{d}\Phi_B} = \mathrm{B}\left[\Delta^{(\mathrm{K})}(t_c,\mu_Q^2) + \int_{t_c}^{\mu_Q^2}\mathrm{d}\Phi_1\,\mathrm{K}(\Phi_1)\,\Delta^{(\mathrm{K})}(t(\Phi_1),\mu_Q^2)\right]$$

K - sum of PS kernels for n-parton final state

Make this NLO-correct:

- Radiation pattern from ME corrected PS
  Correction weight $w = \mathrm{D}/\mathrm{BK}$, where $\mathrm{D} \to$ dipole term
- Replace $\mathrm{B} \to \bar{\mathrm{B}}^{(\mathrm{D})} = \mathrm{B} + \tilde{\mathrm{V}} + \mathrm{I} + \int \mathrm{d}\Phi_1\,(\mathrm{D} - \mathrm{S})$
- Add hard remainder function $\int \mathrm{d}\Phi_R\,\mathrm{H}^{(\mathrm{D})}$, where $\mathrm{H}^{(\mathrm{D})} = [\,\mathrm{R} - \mathrm{D}\,]$

Differential event rate to $\mathcal{O}(\alpha_s)$ in matched calculation

$$\frac{\mathrm{d}\sigma_{\mathrm{NLOPS}}}{\mathrm{d}\Phi_B} = \bar{\mathrm{B}}^{(\mathrm{D})}\left[\Delta^{(\mathrm{D})}(t_c,\mu_Q^2) + \int_{t_c}^{\mu_Q^2}\mathrm{d}\Phi_1\,\frac{\mathrm{D}}{\mathrm{B}}\,\Delta^{(\mathrm{D})}(t(\Phi_1),\mu_Q^2)\right] + \int \mathrm{d}\Phi_1\,\mathrm{H}^{(\mathrm{D})}$$

MC@NLO and POWHEG differ only in choice of D

Inclusive jet production at the LHC

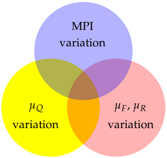
- Automated MC@NLO technique including full color correlations implemented in SHERPA

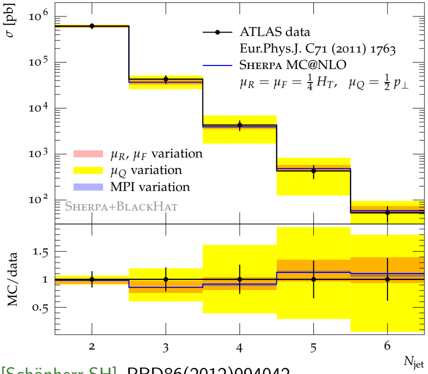
  [Krauss,Schönherr,Siegert,SH] JHEP09(2012)049
  [Schönherr,SH] PRD86(2012)094042

- Validated in QCD jets production
  - CT10, $\alpha_s(M_Z) = 0.118$
  - Full hadron level, incl. MPI
  - Virtual corrections $\rightarrow$ BlackHat

    [Berger et al.] PRD78(2008)036003
    [Giele,Glover,Kosower] NPB403(1993)633
  - $p_{T,j1} > 20$ GeV, $p_{T,j2} > 10$ GeV
  - $\mu_{R/F} = H_T/4$, $\mu_Q = p_T/2$

- Implementation allows to assess renormalization/factorization and resummation scale uncertainty

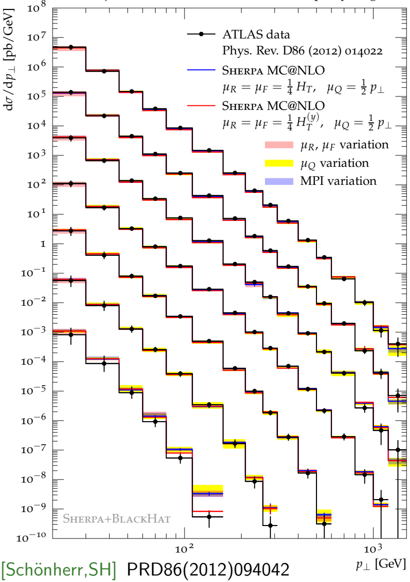




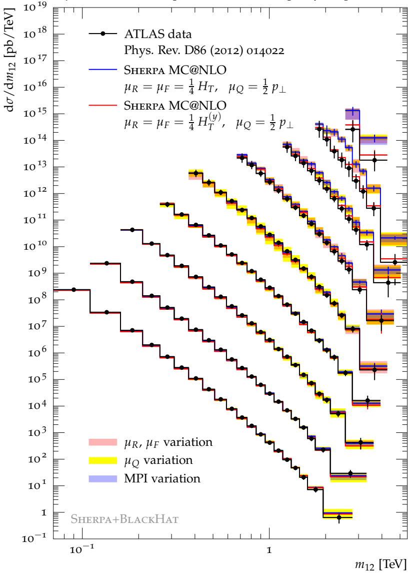
[Schönherr,SH] PRD86(2012)094042

Inclusive jet production at the LHC

Inclusive jet transverse momenta in different rapidity ranges



Dijet invariant mass spectra in different rapidity ranges



[Schönherr,SH] PRD86(2012)094042

The MINLO scale

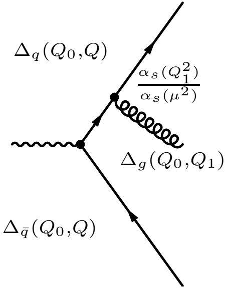
[Hamilton,Nason,Zanderighi] JHEP10(2012)155

- Inspired by CKKW-style ME+PS merging procedures, which
  - Reweight each jet production vertex with $\alpha_s(Q_i^2)/\alpha_s(\mu^2)$
  - Multiply by survival probabilities $\Delta(Q_0, Q)$ of partons at NLL
- Modifications to preserve NLO accuracy of the procedure
  - Define common renormalization scale

$$\mu_R = \left(\prod_{i=1}^{N} Q_i \right)^{1/N}$$

  - Subtract $\mathcal{O}(\alpha_s)$ contribution from NLL Sudakov

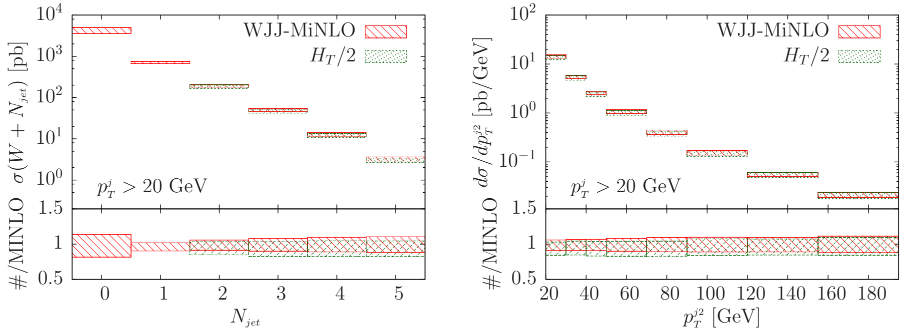
$$\Delta(Q_0, Q) \to \Delta(Q_0, Q) + C \frac{\alpha_s}{\pi} \left[\log^2 \frac{Q}{Q_0} + B \log \frac{Q}{Q_0} \right]$$



- Extended to ME+PS@NLO-like procedure in
  [Hamilton,Nason,Oleari,Zanderighi] arXiv:1212.4504

W+di-jet production at the LHC

[Campbell,Ellis,Nason,Zanderighi] arXiv:1303.5447



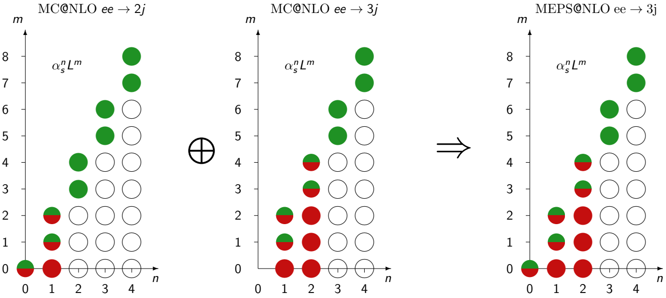
- Good agreement of MINLO with $H_T/2$ in POWHEG sim of W+2 jet
- MINLO can be extended to $p_T \to 0$ due to Sudakov suppression

ME+PS merging at NLO

[Lavesson,Lönnblad] JHEP12(2008)070, [Lönnblad,Prestel] JHEP02(2013)094
[Gehrmann et al.] JHEP01(2013)144, [Krauss et al.] JHEP04(2013)027
[Frederix,Frixione] JHEP12(2012)061

Objectives

- NLO accurate predictions for $k_{T,j} > k_{T,\mathrm{cut}}$ and variable n
- Logarithmic accuracy of PS throughout



Example: $e^+e^- \to$hadrons

ME+PS merging at NLO in a nutshell

- Analyze exclusive contribution from k hard partons at LO

$$\langle O\rangle_k^{\mathrm{excl}} = \int \mathrm{d}\Phi_k\,\mathrm{B}_k \prod_{i=0}^{k-1} \Delta_i^{(\mathrm{K})}(t_{i+1}, t_i; > Q_{\mathrm{cut}})\,\Theta(Q_k - Q_{\mathrm{cut}})$$

$$\times \left[\Delta_k^{(\mathrm{K})}(t_c, t_k)\,O_k + \int_{t_c}^{t_k} \mathrm{d}\Phi_1\,\mathrm{K}_k\,\Delta_k^{(\mathrm{K})}(t_{k+1}, t_k)\,\Theta(Q_{\mathrm{cut}} - Q_{k+1})\,O_{k+1} \right]$$

ME+PS merging at NLO in a nutshell

- Analyze exclusive contribution from k hard partons

$$\langle O\rangle_k^{\mathrm{excl}} = \int \mathrm{d}\Phi_k\,\mathrm{B}_k \prod_{i=0}^{k-1} \Delta_i^{(\mathrm{K})}(t_{i+1}, t_i; > Q_{\mathrm{cut}})\,\Theta(Q_k - Q_{\mathrm{cut}})$$

$$\times \left[\Delta_k^{(\mathrm{D})}(t_c, t_k)\,O_k + \int_{t_c}^{t_k} \mathrm{d}\Phi_1\,\frac{\mathrm{D_k}}{\mathrm{B_k}}\,\Delta_k^{(\mathrm{D})}(t_{k+1}, t_k)\,\Theta(Q_{\mathrm{cut}} - Q_{k+1})\,O_{k+1} \right]$$

- PS evolution kernels $\rightarrow$ dipole terms

ME+PS merging at NLO in a nutshell

- Analyze exclusive contribution from k hard partons

$$\langle O\rangle_k^{\rm excl} = \int {\rm d}\Phi_k\, \bar{\rm B}_k^{\rm (D)} \prod_{i=0}^{k-1} \Delta_i^{\rm (K)}(t_{i+1},t_i;>Q_{\rm cut})\,\Theta(Q_k-Q_{\rm cut})$$

$$\times\left[\Delta_k^{\rm (D)}(t_c,t_k)\,O_k + \int_{t_c}^{t_k}{\rm d}\Phi_1\,\frac{\rm D_k}{\rm B_k}\,\Delta_k^{\rm (D)}(t_{k+1},t_k)\,\Theta(Q_{\rm cut}-Q_{k+1})\,O_{k+1}\right]$$

- PS evolution kernels → dipole terms
- Born matrix element → NLO-weighted Born

ME+PS merging at NLO in a nutshell

- Analyze exclusive contribution from k hard partons

$$\langle O\rangle_k^{\rm excl} = \int {\rm d}\Phi_k\, \bar{\rm B}_k^{\rm (D)} \prod_{i=0}^{k-1} \Delta_i^{\rm (K)}(t_{i+1},t_i;>Q_{\rm cut})\,\Theta(Q_k-Q_{\rm cut})$$

$$\times\left[\Delta_k^{\rm (D)}(t_c,t_k)\,O_k + \int_{t_c}^{t_k} {\rm d}\Phi_1\,\frac{\rm D_k}{\rm B_k}\,\Delta_k^{\rm (D)}(t_{k+1},t_k)\,\Theta(Q_{\rm cut}-Q_{k+1})\,O_{k+1}\right]$$

$$+\int {\rm d}\Phi_{k+1}\,{\rm H}_k^{\rm (D)}\,\Delta_k^{\rm (K)}(t_k;>Q_{\rm cut})\,\Theta(Q_k-Q_{\rm cut})\,\Theta(Q_{\rm cut}-Q_{k+1})\,O_{k+1}$$

- PS evolution kernels → dipole terms
- Born matrix element → NLO-weighted Born
- Add hard remainder function

ME+PS merging at NLO in a nutshell

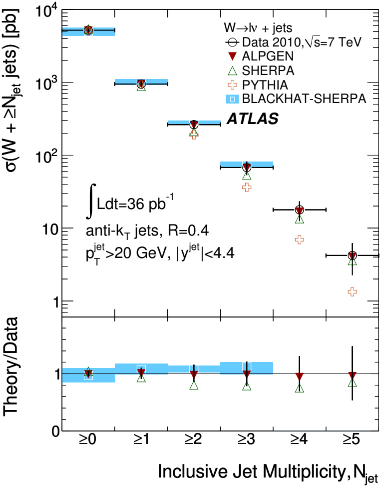
- Analyze exclusive contribution from k hard partons

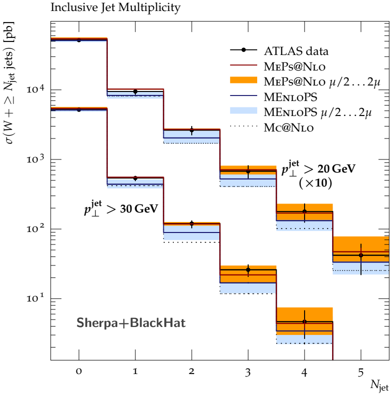
$$\langle O\rangle_k^{\rm excl} = \int {\rm d}\Phi_k\,\bar{\rm B}_k^{\rm (D)}\prod_{i=0}^{k-1}\Delta_i^{\rm (K)}(t_{i+1},t_i;>Q_{\rm cut})\,\Theta(Q_k-Q_{\rm cut})$$
$$\times\prod_{i=0}^{k-1}\left(1+\int_{t_{i+1}}^{t_i}{\rm d}\Phi_1{\rm K}_i\,\Theta(Q_i-Q_{\rm cut})\right)F_i(t_{i+1},t_i;\mu_F^2)$$
$$\times\left[\Delta_k^{\rm (D)}(t_c,t_k)\,O_k+\int_{t_c}^{t_k}{\rm d}\Phi_1\,\frac{\rm D_k}{\rm B_k}\,\Delta_k^{\rm (D)}(t_{k+1},t_k)\,\Theta(Q_{\rm cut}-Q_{k+1})\,O_{k+1}\right]$$
$$+\int{\rm d}\Phi_{k+1}\,{\rm H}_k^{\rm (D)}\,\Delta_k^{\rm (K)}(t_k;>Q_{\rm cut})\,\Theta(Q_k-Q_{\rm cut})\,\Theta(Q_{\rm cut}-Q_{k+1})\,O_{k+1}$$

- PS evolution kernels $\to$ dipole terms
- Born matrix element $\to$ NLO-weighted Born
- Add hard remainder function
- Subtract $\mathcal{O}(\alpha_s)$ terms from truncated vetoed PS
  $F_i(t,t';\mu_F^2)$ $\to$ subtractions for PDF ratio in initial-state evolution

W+jets production at the LHC

[ATLAS] PRD85(2012)092002
[SH,Krauss,Schönherr,Siegert] JHEP04(2013)027

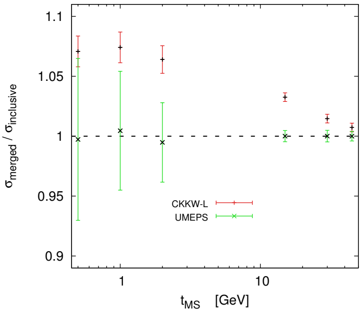




- ME⊕PS@NLO with 0,1&2 jet PL at NLO plus 3&4 jet PL at LO
- Compare to MENLOPS with up to 4 jets at LO

Unitarized ME+PS merging

[Lönnblad,Prestel] JHEP02(2013)094



- Unitarity condition of PS:

$$1 = \Delta^{(\mathrm{K})}(t_c) + \int_{t_c} \mathrm{d}\Phi_1\, \mathrm{K}(\Phi_1)\, \Delta^{(\mathrm{K})}(t)$$

- CKKW-like merging violates PS unitarity as ME ratio replaces splitting kernels in emission terms, but not in Sudakovs

$$\mathrm{K}(\Phi_1) \to \frac{\mathrm{R}(\Phi_1, \Phi_B)}{\mathrm{B}(\Phi_B)}$$

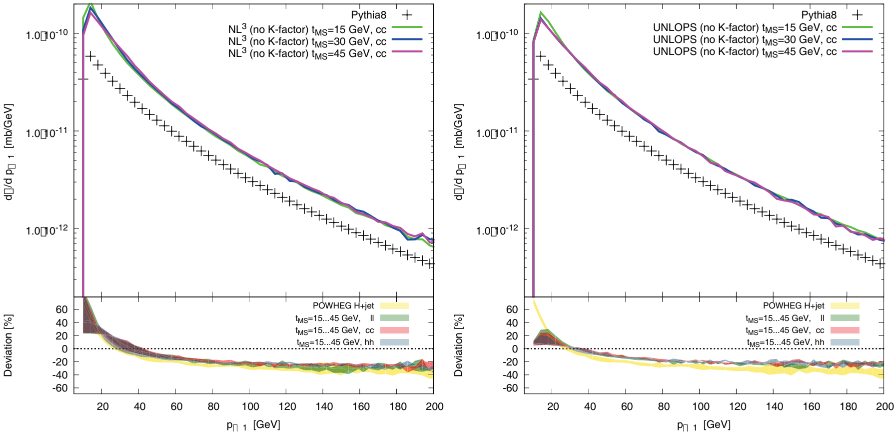
- Mismatch removed by explicit subtraction

$$1 = \underbrace{\left\{ \Delta^{(\mathrm{K})}(t_c) + \int_{t_c} \mathrm{d}\Phi_1 \left[\mathrm{K}(\Phi_1) - \frac{\mathrm{R}(\Phi_1, \Phi_B)}{\mathrm{B}(\Phi_B)} \right] \Theta(t - t_{ms})\, \Delta^{(\mathrm{K})}(t) \right\}}_{\text{unresolved emission / virtual correction}}$$

$$+ \underbrace{\int_{t_c} \mathrm{d}\Phi_1 \left[\mathrm{K}(\Phi_1)\Theta(t_{ms} - t) + \frac{\mathrm{R}(\Phi_1, \Phi_B)}{\mathrm{B}(\Phi_B)} \Theta(t - t_{ms}) \right] \Delta^{(\mathrm{K})}(t)}_{\text{resolved emission}}$$

Higgs+jets production at the LHC

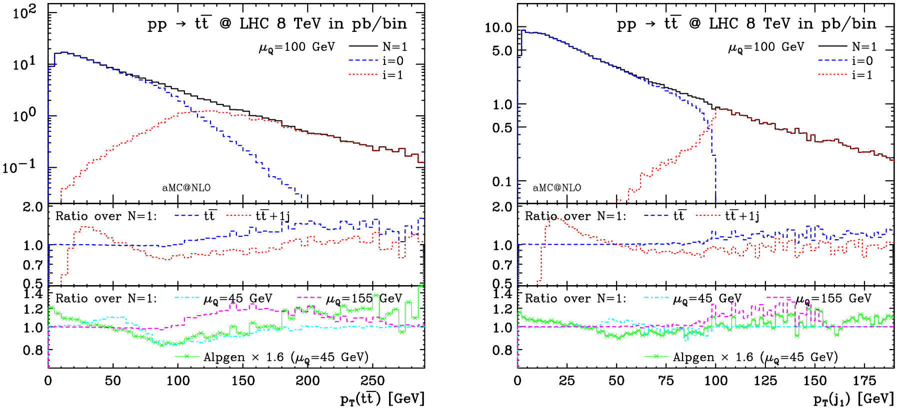
[Lönnblad,Prestel] JHEP03(2013)166



- Compare NL^3 with UNLOPS merging
- Both parametrically $\mathcal{O}(\alpha_s)$ correct!

Top pair production at the LHC

[Frederix,Frixione] JHEP12(2012)061



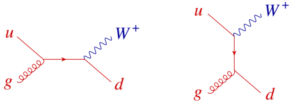
- Alternative Ansatz, not includig truncated PS
- Logarithmic accuracy remains to be quantified

Summary

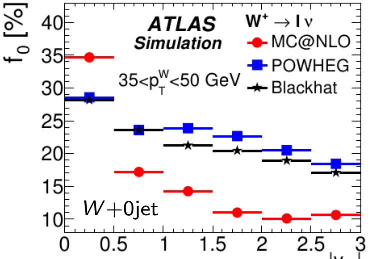
- Many exciting new developments
  - Automated NLO calculations
  - ME+PS merging at NLO
  - Jet scaling
- Still more to expect
  - NLO automation for BSM
  - Improved parton showers
  - Non-perturbative QCD models
  - ...

Parton-shower effects on matching

- Leading W production modes at LHC:

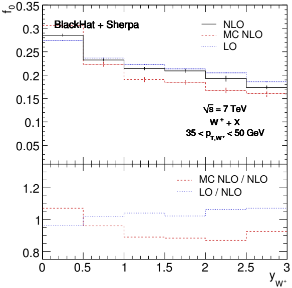


- Angular-momentum conservation in s-channel induces $\sim$ left-handed W
- (N)LO result [BlackHat] PRD84(2011)034008 not reproduced by W+0j MC@NLO



[ATLAS] EPJC72(2012)2001

W+0j MC@NLO ✗



W+1j MC@NLO ✓