NLO event generation with SHERPA
Status and plans

Stefan Höche [1]

ITP, University of Zürich

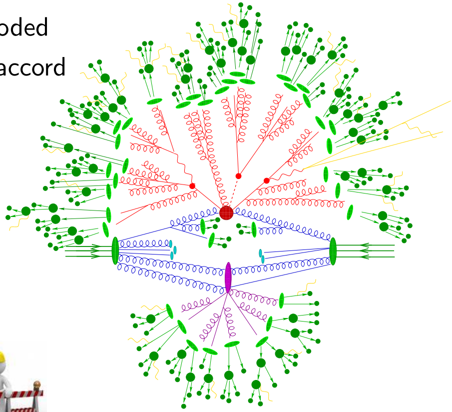
Monte Carlo readiness workshop

CERN, March 30^{th} 2010

[1] for SHERPA: J. Archibald, T. Gleisberg, SH, H. Hoeth, F. Krauss, M. Schönherr, S. Schumann, F. Siegert, J. Winter, K. Zapp

At matrix element (ME) level
[J. Archibald, T. Gleisberg]

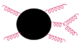
- Some 1-loop matrix elements hard-coded
- Interface using Binoth Les Houches accord
- General implementation of Catani-Seymour subtraction method
- Analysis framework for parton-level events



At parton shower (PS) level
[SH, F. Krauss, M. Schönherr, F. Siegert]

- Implementation of POWHEG
- Merging of ME⊗PS at NLO

NLO matrix element generation

Parts of NLO calculations $\longrightarrow$ $\mathcal{A}_{\mathrm{LO}}$:  $\mathcal{A}_{\mathrm{NLO,Virtual}}$:  $\mathcal{A}_{\mathrm{NLO,Real}}$: 

$$\sigma^{NLO} = \int \mathrm{d}\Phi_B\,(B+V) + \int \mathrm{d}\Phi_R\,R = \int \mathrm{d}\Phi_B\,\Big[(B+V+I) + \int \mathrm{d}\Phi_B^{(1)}\,(R-S)\Big]$$

S - subtraction term constructed such that IR singularities in R are removed

I - integrated subtraction term locally compensates $S \to 0 \stackrel{!}{=} I - \int \mathrm{d}\Phi_{(1)}\,S$

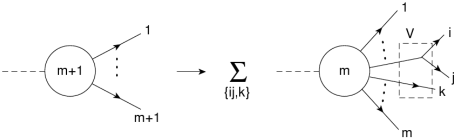
S and I are universal and "easy" to automate, V is more difficult

SHERPA implements the Catani-Seymour subtraction scheme

NPB485(1997)291, NPB627(2002)189 $\longrightarrow$ EPJC53(2008)501

Schematically: $S \to \sum_{ij,k} B_{\widetilde{ij},k} \otimes V_{ij,k}$

$V_{ij,k}$ - dipole terms
spin & color dependent



Sharing the workload ...

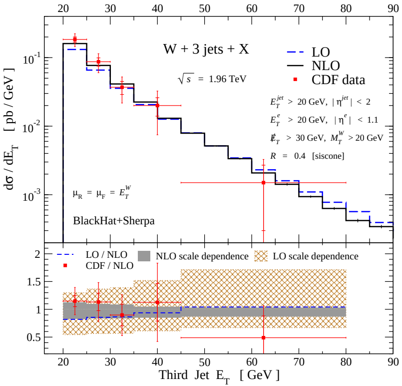
$$\sigma^{NLO} = \int \mathrm{d}\Phi_B \left[\left(\mathsf{B} + \mathsf{V} + \mathsf{I} \right) + \int \mathrm{d}\Phi_B^{(1)} \left(\mathsf{R} - \mathsf{S} \right) \right]$$

ME-level events using the Binoth Les Houches accord arXiv:1001.1307 [hep-ph]

- BlackHat PRD78(2008)036003, PRL102(2009)222001, PRD80(2009)074036 or Golem CPC180(2009)2317, PLB683(2010)154 provide virtual piece or more
- SHERPA takes care of Born, real emission and subtraction
- Phase-space generation using (modified) tree-level integrators separately for B-like and R-like phase space

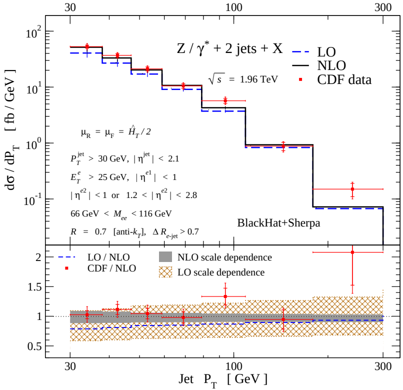
W+3 jets @ Tevatron

PRD80(2009)074036



Z+2 jets @ Tevatron

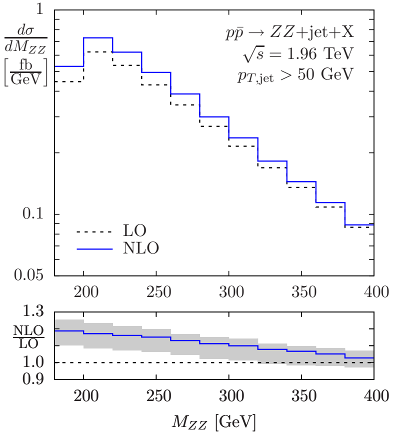
PoS RADCOR2009(2009)002



Predictions from Golem ⊗ SHERPA

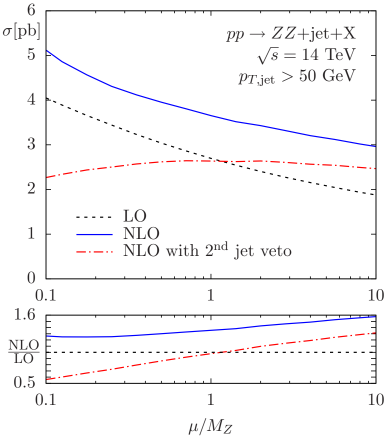
ZZ+jet @ Tevatron, mass spectrum

PLB683(2010)154



ZZ+jet @ LHC, scale variation

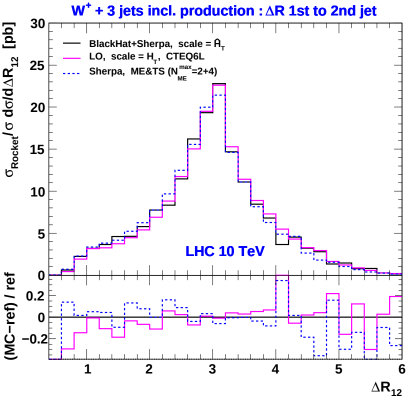
PLB683(2010)154

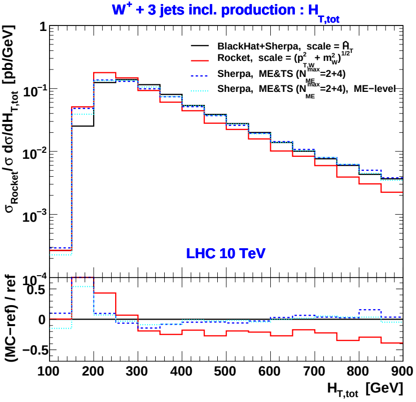


NLO predictions for W+3jets arXiv:1003.1241 [hep-ph]

Compare BlackHat, Rocket JHEP06(2008)038 and SHERPA

- Different scale choices at NLO can yield > 20% deviations ...
- SHERPA's ME⊗PS results in good agreement once rescaled to $\sigma_{\rm NLO}$





Implementing the POWHEG algorithm

The POWHEG master formula schematically

JHEP11(2004)040, JHEP11(2007)070, arXiv:1002.2581 [hep-ph], ...

$$\mathrm{d}\sigma_{\mathrm{NLO}} = \mathrm{d}\Phi_B\,\bar{B}(\Phi_B)\left[\Delta(k_{T,\mathrm{min}}) + \sum \mathrm{d}\Phi_B^{(1)}\,\frac{R(\Phi_B,\Phi_B^{(1)})}{B(\Phi_B)}\Delta(k_T)\right]$$

with the NLO differential cross section $\bar{B} = B + V + I + \mathrm{d}\Phi_B^{(1)}\,[\,R - S\,]$

and the POWHEG-Sudakov $\Delta(k_T) = \exp\left\{-\sum\int_{k_T}\mathrm{d}\Phi_B^{(1)}\,\frac{R(\Phi_B,\Phi_B^{(1)})}{B(\Phi_B)}\right\}$

Two problems to be solved

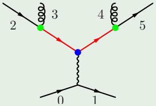
- Generate differential NLO cross section $\mathrm{d}\Phi_B\,\bar{B}(\Phi_B)$
  $\Rightarrow$ Requires integrator for N- and $N+1$-particle phase space
- Generate real emission according to POWHEG-Sudakov $\Delta(k_T)$
  $\Rightarrow$ Requires parton shower-like algorithm to exponentiate $\sum\int\mathrm{d}\Phi^{(1)}R/B$

Implementing the POWHEG algorithm, Part I

Integration proceeds in two steps …

Step I: The Born phase space via recycling

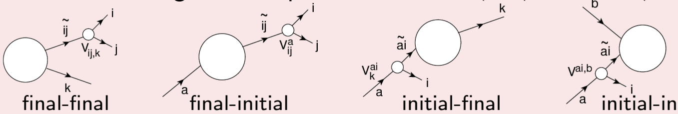
Standard phase-space generator, e.g. single channels from NPB9(1969)568
VEGAS-refined CLNS-80/447(1980) and combined in multi-channel CPC83(1994)141



$$\longleftrightarrow \quad D_{iso}(23,45) \otimes P_0(23) \otimes P_0(45) \otimes D_{iso}(2,3) \otimes D_{iso}(4,5)$$

Step II: The real-emission phase space new

Extra emission generator (EEG) produces extra parton starting from Φ_B
Kinematics according to CS dipole terms NPB485(1997)291, NPB627(2002)189



FF dipoles combined into multi-channel to improve integration behaviour

Implementing the POWHEG algorithm, Part II

Need MC generator to exponentiate $\Gamma(k_T) = \sum \int_{k_T}^{Q} \mathrm{d}\Phi^{(1)} R/B$

We know how to deal with this CPC82(1994)74

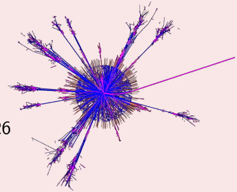
- Dice k_T of emission as $k_T = \Gamma^{-1}\left[\,-\log\#\,\right]$
- If Γ unknown, use overestimate $\tilde{\Gamma}$ and accept as $w = \Gamma(k_T)/\tilde{\Gamma}(k_T) \;>\#'$

Now the whole trick is to find a suitable $\tilde{\Gamma}$

In fact, we have a pretty good estimate already ...

Γ's of existing parton showers are an ideal candidate

- We employ SHERPA's dipole-like parton shower (CSS) based on CS subtraction JHEP03(2008)038, PRD81(2010)034026
- Splitting functions are potentially enhanced, adapting to R/B larger than CSS approximation

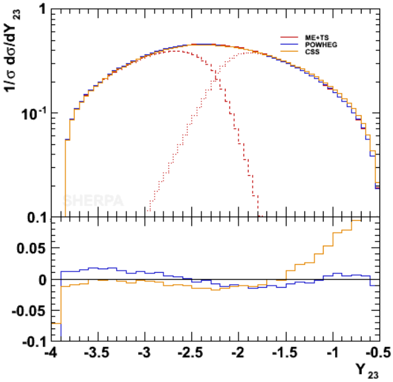


First results very preliminary

Integration results from EEG compared to method using independent $d\Phi_R$-generator

Process	σ [pb]	Type
$e^+e^- \to 2jets$	29436(20)	EEG
	29445(19)	$d\Phi_R$
	28375(18)	LO
$e^+e^- \to 3jets$	9460(100)	EEG
$y_{\rm cut} = 10^{-1.26}$	9370(140)	$d\Phi_R$
	7730(80)	LO
$p\bar{p} \to e^-\bar{\nu}_e$	1334(1)	EEG
	1333(1)	$d\Phi_R$
	1101.0(3)	LO
$p\bar{p} \to e^+e^-$	239.48(13)	EEG
$66 < m_{ee} < 116{\rm GeV}$	239.56(10)	$d\Phi_R$
	197.28(10)	LO

Differential k_T-jet rate Durham algorithm in $e^+e^- \to jets$ at $E_{\rm cms} = 91.2$ GeV



Summary

So far

- SHERPA provides NLO event generation at ME-level ...
- ... and interfaces to "1-loop"-engines (BlackHat, Golem, ...)

To do

- Finish POWHEG-implementation for non-trivial processes
- Work on NLO ME$\otimes$PS merging

Looking forward to meet the challenge