Improvements in Sherpa 1.2.0

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Recap

Last GENSER talk: 25/06/2008 on Sherpa 1.1

- Many improvements in soft physics modules
- Version has been sucessfully used by experiments since then
- Announced that 1.2 will be a non-complete, early version ⇒ **NOT TRUE ANYMORE!**
  We decided to take the time and make it a full-featured version

This time: Sherpa 1.2

- Released in September 2009
- Full-featured version with good documentation
- Many improvements in perturbative physics
- Recommended version for all types of studies

Input files

Example run card Run.dat for Drell-Yan@LHC

```
(beam){
  BEAM_1 = 2212
  BEAM_ENERGY_1 = 7000.
  BEAM_2 = 2212
  BEAM_ENERGY_2 = 7000.
}(beam)

(processes){
  Process 93 93 -> 11 -11 93{1}
  Order_EW 2
  CKKW sqr(30/E_CMS)
  End process
}(processes)

(selector){
  Mass 11 -11 66 116
}(selector)

(me){
  ME_SIGNAL_GENERATOR = Comix
}(me)
```

- No major syntax changes since 1.1
- Minor changes mainly related to Matrix Elements/Shower/Merging
- Many examples provided

Running the generator

Example with Run.dat from above: `$ Sherpa EVENTS=1000`

Initialisation phase (≈ 10s)

```
Welcome to Sherpa, Frank Siegert,,,. Initialization of framework underway.
Run_Parameter::Init(): Setting memory limit to 1.85934 GB.
-----------------------------------------------------------------------------
-----------    Event generation run with SHERPA started .......   -----------
-----------------------------------------------------------------------------
Initialize the Standard Model from  / Model.dat
 List of Particle Data
  [...]
Initialized the beams Monochromatic*Monochromatic
PDF set 'cteq6l' loaded from 'libCTEQ6Sherpa'.
PDF set 'cteq6l' loaded from 'libCTEQ6Sherpa'.
Initialized the ISR: (SF)*(SF)
Initialized the Beam_Remnant_Handler.
Initialized the Shower_Handler.
Initialized the Fragmentation_Handler.
Matrix_Element_Handler::BuildProcesses(): Looking for processes ........ done ( 21712 kB, 0.21 s ).
Matrix_Element_Handler::InitializeProcesses(): Performing tests ........ done ( 21712 kB, 0.01 s ).
Initialized the Matrix_Element_Handler for the hard processes.
Hadron_Decay_Map::Read:
   Initializing hadron decay tables. This may take some time.
Initialized the Hadron_Decay_Handler, Decay model = Hadrons
Initialized the Soft_Photon_Handler.
```

Running the generator cont'd

Process integration phase

```
Process_Group::CalculateTotalXSec(): Calculate xs for '2_2__j__j__e-__e+' (Comix)
Starting the calculation. Lean back and enjoy ... .
1578.62 pb +- ( 33.9433 pb = 2.15018 % ) 5000 ( 11374 -> 43.9 % )
full optimization:  ( 0 s elapsed / 35 s left / 35 s total )
1558.11 pb +- ( 23.1044 pb = 1.48285 % ) 10000 ( 18148 -> 73.8 % )
full optimization:  ( 1 s elapsed / 32 s left / 33 s total )
1544.39 pb +- ( 15.634 pb = 1.01231 % ) 15000 ( 23892 -> 87 % )
full optimization:  ( 1 s elapsed / 31 s left / 32 s total )
  [...]
1544.45 pb +- ( 0.779992 pb = 0.050503 % ) 310000 ( 326517 -> 97.7 % )
integration time:  ( 29 s elapsed / 0 s left / 29 s total )
2_2__j__j__e-__e+ : 1544.45 pb +- ( 0.779992 pb = 0.050503 % )  exp. eff: 24.5427 %
```

Start integration of first process ($pp \to e^+e^-$)

Integration result.

```
Process_Group::CalculateTotalXSec(): Calculate xs for '2_3__j__j__e-__e+__j' (Comix)
Starting the calculation. Lean back and enjoy ... .
702.12 pb +- ( 32.3368 pb = 4.60559 % ) 5000 ( 12603 -> 39.6 % )
full optimization:  ( 2 s elapsed / 140 s left / 142 s total )
739.826 pb +- ( 20.9066 pb = 2.82589 % ) 10000 ( 23313 -> 46.6 % )
full optimization:  ( 4 s elapsed / 137 s left / 141 s total )
752.44 pb +- ( 14.9464 pb = 1.9864 % ) 15000 ( 32661 -> 53.4 % )
full optimization:  ( 6 s elapsed / 133 s left / 139 s total )
  [...]
752.729 pb +- ( 1.35971 pb = 0.180637 % ) 310000 ( 458515 -> 71.9 % )
integration time:  ( 134 s elapsed / 0 s left / 134 s total )
2_3__j__j__e-__e+__j : 752.729 pb +- ( 1.35971 pb = 0.180637 % )  exp. eff: 1.73125 %
```

Start integration of second process ($pp \to e^+e^-$jet)

Integration result.

Running the generator cont'd

Event generation phase

```
-----------------------------------------------------------
-- SHERPA generates events with the following structure --
-----------------------------------------------------------
Perturbative       : Signal_Processes
Perturbative       : Hard_Decays
Perturbative       : Jet_Evolution:CSS
Perturbative       : Lepton_FS_QED_Corrections:Photons
Perturbative       : Multiple_Interactions:None
Hadronization      : Beam_Remnants
Hadronization      : Hadronization:Ahadic
Hadronization      : Hadron_Decays,Photons
----------------------------------------------------------
  Event 100 ( 1 s elapsed / 15 s left ) -> ETA: Tue Nov 17 17:58
  Event 200 ( 3 s elapsed / 14 s left ) -> ETA: Tue Nov 17 17:58
    [...]
  Event 1000 ( 21 s elapsed / 0 s left ) -> ETA: Tue Nov 17 17:58

In Event_Handler::Finish : Summarizing the run may take some time.
+-----------------------------------------------------+
|                                                     |
|  Total XS is 1738.97 pb +- ( 27.118 pb = 1.55 % )  |
|                                                     |
+-----------------------------------------------------+
-----------------------------------------------------------------------
Please cite the publications listed in 'Sherpa_References.tex'.
  Extract the bibtex list by running 'get_bibtex Sherpa_References.tex'
  or email the file to 'slaclib2@slac.stanford.edu', subject 'generate'.
-----------------------------------------------------------------------
```

Active event phases

Event generation

Total cross section

References to cite

Documentation

Physics publications

- **Main reference**:
  "Event generation with SHERPA 1.1,"
  JHEP **0902** (2009) 007 [arXiv:0811.4622 [hep-ph]]
  still valid, with **updates** for the following topics (→ later):
- "Comix, a new matrix element generator,"
  JHEP **0812** (2008) 039 [arXiv:0808.3674 [hep-ph]]
- "A Parton shower algorithm based on Catani-Seymour dipole factorisation,"
  JHEP **0803** (2008) 038 [arXiv:0709.1027 [hep-ph]]
- "QCD matrix elements and truncated showers,"
  JHEP **0905** (2009) 053 [arXiv:0903.1219 [hep-ph]]
- "Automating dipole subtraction for QCD NLO calculations,"
  Eur. Phys. J. C **53** (2008) 501 [arXiv:0709.2881 [hep-ph]]

Manual

- Extensive manual describing (almost) all switches and short "Howtos"
- Available with the tarball (in html or info format)
- Also online: `http://projects.hepforge.org/sherpa/doc/SHERPA-MC-1.2.0`

Example setups

Examples contained in the release tarball:

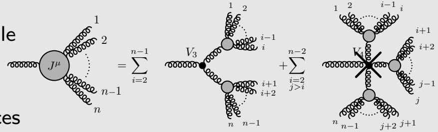
- Tevatron_ZJets
- Tevatron_WJets/
- Tevatron_QCD/
- Tevatron_UE/
- Tevatron_TopPair/
- Tevatron_DiBoson/
- LHC_ZJets/
- LHC_TTH/
- LHC_SUSY/
- LHC_4thGen/
- LHC_ADD/
- LHC_AGC/
- LEP91/
- EGamma/
- PEPII_BaBar/
- NLO_W/

New matrix element generator COMIX

JHEP **0812** (2008) 039 [arXiv:0808.3674 [hep-ph]]

Construction principle

- Generalised Berends-Giele type recursive relations
- Vertex decomposition of all four-particle vertices



Growth in computational complexity solely determined by number of external legs at model's vertices

Full standard model implemented, extension to MSSM under way
Particularly suited for large multiplicity MEs (e.g. SM background processes)

Performance in QCD benchmark

$gg \to ng$	Cross section [pb]				
n $\sqrt{s}$ [GeV]	8 1500	9 2000	10 2500	11 3500	12 5000
Comix	0.755(3)	0.305(2)	0.101(7)	0.057(5)	0.026(1)
PRD67(2003)014026	0.70(4)	0.30(2)	0.097(6)		
NPB539(1999)215	0.719(19)				

Comparison of tree-level ME generators

Example: Drell-Yan + b-pair + jets MC4LHC workshop 2004

σ [pb]	Number of jets					
$e^-e^+ + b\bar{b}$ + jets	0	1	2	3	4	5
ALPGEN	18.95(8)	6.80(3)	2.97(2)	1.501(9)	0.78(1)	
AMEGIC	18.90(2)	6.82(2)	3.06(4)			
Comix	18.90(3)	6.81(2)	3.07(3)	1.536(9)	0.763(6)	0.37(1)
CompHEP	19.45(2)					
GR@PPA	18.70(2)	6.74(2)				
HELAC	19.2(2)	7.0(2)				
MadGraph	18.7(1)	6.72(2)	2.96(1)			

Example: b-pair + jets MC4LHC workshop 2004

σ [pb]	Number of jets						
$t\bar{t}$ + jets	0	1	2	3	4	5	6
ALPGEN	755.4(8)	748(2)	518(2)	310.9(8)	170.9(5)	87.6(3)	45.1(8)
AMEGIC	754.4(3)	747(1)	520(1)				
Comix	754.8(8)	745(1)	518(1)	309.8(8)	170.4(7)	89.2(4)	44.4(4)
CompHEP	757.8(8)	752(1)	519(1)				
HELAC	745(5)	711(7)	515(5)				
MadGraph	754(2)	749(2)	516(1)	306(1)			

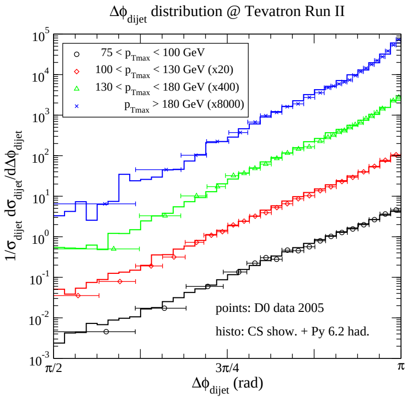
New shower module CSSHOWER++

JHEP **0803** (2008) 038 [arXiv:0709.1027 [hep-ph]]

JHEP **0803** (2008) 038

- Based on Catani-Seymour local subtraction terms
  - projection onto leading term in $1/N_C$
  - spin averaged

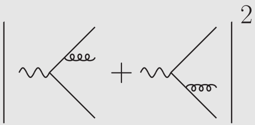
  $\Rightarrow$ Shower algorithm based on colour-connected emitter-spectator dipoles
- Splittings based on dipoles $\Rightarrow$ local momentum conservation, exact mappings
- Emissions ordered in $k_\perp$
- "Truncated" option available (necessary for merging)



Reminder: Why combine ME and PS

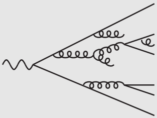
Two approaches

Matrix Elements



- $+$ Exact to fixed order
- $+$ Include all interferences
- $+$ $N_C = 3$ (summed or sampled)
- $-$ Perturbation breaks down due to large logarithms

Parton Showers



- $+$ Resum logarithmically enhanced contributions to all orders
- $+$ Produce high-multiplicity final state
- $-$ Only approximation to ME for splitting
- $-$ Large N_C limit only

$\Downarrow$

Goal: Combine advantages

- Describe **particular final state** by **ME** (hard QCD radiation)
- Don't spoil the **inclusive picture** provided by the **PS** (intrajet evolution)

Merging algorithm

JHEP **0905** (2009) 053 [arXiv:0903.1219 [hep-ph]]

Main idea

Phase space slicing for extra QCD radiation:

- Soft/collinear emissions $Q_{ij} < Q_{\text{cut}}$ from parton shower
- Hard emissions $Q_{ij} > Q_{\text{cut}}$ from matrix element

in terms of separation criterion Q

Outline of algorithm

1. Generate ME event above Q_{cut} according to σ and $d\sigma$
2. Translate ME event into shower language: **Branching history**
3. Reweight $\alpha_s(\mu^2) \rightarrow \alpha_s(p_\perp^2)$ for each branching
4. Start truncated shower evolution:
   - Emissions in PS regime? $\Rightarrow$ **Keep**
   - Emission in ME regime? $\Rightarrow$ **Reject event**

$\Downarrow$

Evolution in PS regime preserved
Emissions above Q_{cut} ME-corrected

Is it relevant? Results for $p\bar{p} \to e^+e^- + \text{jets}$ at $\sqrt{s} = 1960\,\text{GeV}$

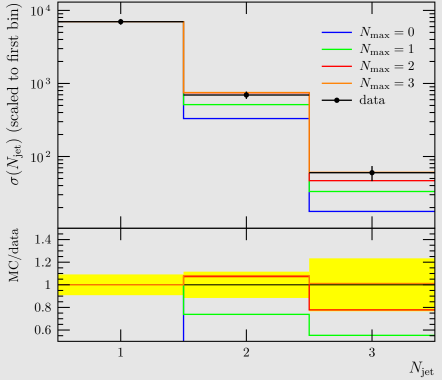
PRL 100,102001 arXiv:0711.3717 [hep-ex]

Algorithm implemented in SHERPA framework

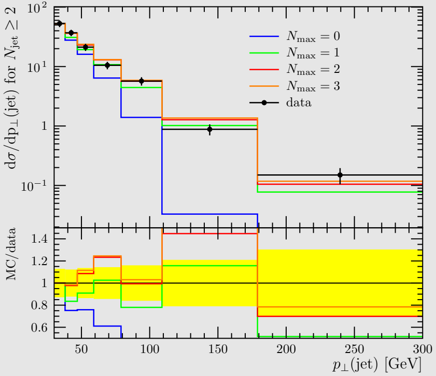
CSSHOWER++ Shower based on Catani-Seymour subtraction

COMIX Matrix elements based on Berends-Giele recursion

Jet multiplicity



$p_\perp$(jet) in $N_{\text{jet}} \geq 2$ events

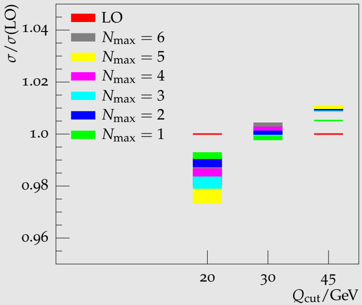


Is it consistent? Results for $p\bar{p} \to e^+e^- +$ jets at $\sqrt{s} = 1960\,\mathrm{GeV}$

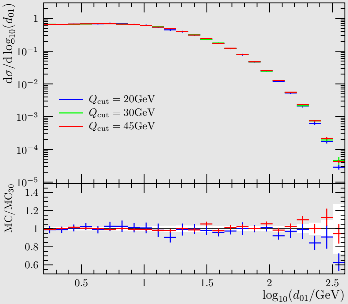
Consistency tests

- Total LO cross section stable?
- Observables independent from "unphysical" merging cut?

Total cross sections



$1 \to 0$ jet resolution ($k_\perp$)



Dipole subtraction for MEs at NLO in QCD

Eur. Phys. J. C **53** (2008) 501 [arXiv:0709.2881 [hep-ph]]

Reminder: NLO cross sections

$$\sigma_n^{\mathrm{NLO}} = \int_n \mathrm{d}\sigma_n^{\mathrm{tree}} + \int_n \left(\mathrm{d}\sigma_n^{\mathrm{virt}} + \int_1 \mathrm{d}\sigma_{n+1}^{\mathrm{sub}}\right) + \int_{n+1} \left(\mathrm{d}\sigma_{n+1}^{\mathrm{real}} - \mathrm{d}\sigma_{n+1}^{\mathrm{sub}}\right)$$

SHERPA's features

- Phase space integration: $\int_n$ and $\int_{n+1}$
- LO matrix element: $\mathrm{d}\sigma_n^{\mathrm{tree}}$
- Real emission matrix element: $\mathrm{d}\sigma_{n+1}^{\mathrm{real}}$
- Subtraction terms a la Catani Seymour: $\mathrm{d}\sigma_{n+1}^{\mathrm{sub}}$
- Integrated subtraction terms: $\int_1 \mathrm{d}\sigma_{n+1}^{\mathrm{sub}}$

$\Rightarrow$ Plug in one-loop matrix element $\mathrm{d}\sigma_n^{\mathrm{virt}}$ and NLO calculation done.

Interface to one-loop ME

- Preliminary draft from Les-Houches workshop 2009 implemented
- Example code/setup available and documented
- Already used by the BlackHat collaboration for W+3jets at NLO

FeynRules interface

FeynRules

- Mathematica package
- Generates Feynman rules from given Lagrangian

Interface to Sherpa

- Sherpa output built-in to FeynRules
- FeynRules Pseudo-model built-in to Sherpa: `MODEL = FeynRules`
- Sherpa reads files generated by FeynRules

$\Rightarrow$ Scattering processes for almost arbitrary models directly from Lagrangian

Rivet interface

- Compile time option to link to Rivet
- Allow to run Rivet analyses directly on top of Sherpa events
- No intermediate HepMC output files/pipes necessary

Example run card extract

```
(run){
  ANALYSIS = Rivet
  ANALYSIS_OUTPUT = aidafilename
}(run)

(analysis){
  BEGIN_RIVET {
    -a D0_2008_S7662670 CDF_2007_S7057202 D0_2004_S5992206
  } END_RIVET
}(analysis)
```

And more ...

- Hidden valley parton shower
- YFS for hard leptons
- LesHouches interface for one-loop amplitudes
- Hadronisation improvements
- Weighted events externally usable now

Minimum Bias

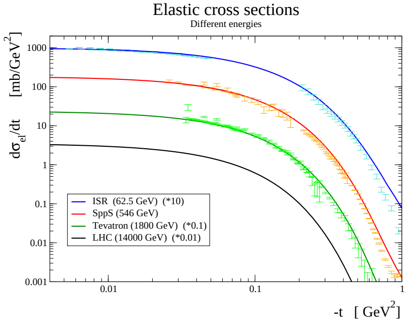
Model

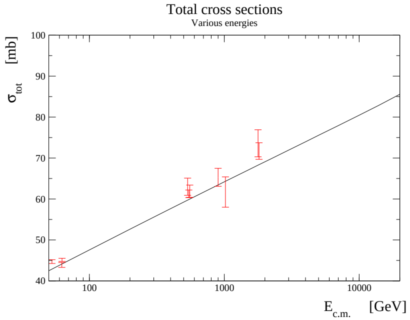
- Based on optical theorem and eikonal picture, BFKL-inspired
- Model for inclusive properties by Khoze, Martin, Ryskin
- Extended to describe all aspects of min bias:
  - total cross section
  - elastic scattering
  - diffraction
  - jet production

Status in SHERPA (→ Krauss, Zapp)

- Started implementing KMR model in naive form
- Will be a completely separate event type complementary to current SHERPA
- Still some TODO's, including tuning of the few parameters
- Publish as SHERPA 1.3, which will be unchanged for everything else than MinBias (i.e. equal to the then current 1.2.x just with the addition of the MinBias option)

Minimum Bias - First results





Other features worked on

- Interleaved QCD + QED evolution and merging
- Inclusive hard decays
- Shower/Merging in DIS
- ADICIC++ shower based on emission off colour dipoles (similar to ARIADNE)
- Merging with NLO matrix elements

Conclusion

Sherpa 1.2.0

- Full-featured and well-documented physics release
- Available on GENSER
- ATLAS/CMS/LHCb work on updating their interfaces to use it

Any questions or comments?

- Sign up to our announcement mailing list
  `https://www.hepforge.org/lists/listinfo/sherpa-announce`
- Find the code and documentation on our homepage
  `http://sherpa-mc.de/`
- Contact the SHERPA team: info@sherpa-mc.de

GENSER validation

- Recently discussion with GENSER about how to validate SHERPA
- Current validation metric (=hard scattering cross sections) flawed
- Any final conclusions from GENSER side? What is the aim of the validation?
- Suggestion: Define a Rivet analysis with respect to which changes are checked

Backup Slides

Merging algorithm: Branching history

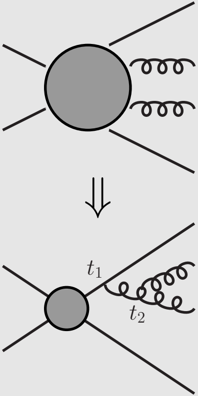
Translate ME event into shower language

Problem: ME only gives final state, no history
Solution: Backward-clustering (running the shower reversed)

1. Take N-particle final state
2. Identify most probable splitting (lowest shower measure)
3. Recombine partons using inverted shower kinematics
   → N-1 particles + splitting variables for one node
4. Repeat 2 and 3 until core process

⇓

Most probable branching history a la shower.



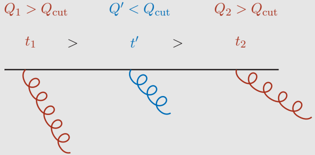
Merging algorithm: Emissions in PS regime

Interpretation of $\mathcal{P}^{\mathrm{PS}}_{\mathrm{no},\,a}(t, t')$

- No-branching probability for shower emissions **below** Q_{cut}
- **Truncated** at production and decay scale t', t

Truncated shower

Some splittings are pre-determined by ME



Mismatch of Q and t allows intermediate radiation!
$\Rightarrow$ "Truncated" shower necessary to fill phase space below Q_{cut}

1. Shower between t_1 and t_2
2. Then insert pre-determined node t_2
3. Restart evolution from there

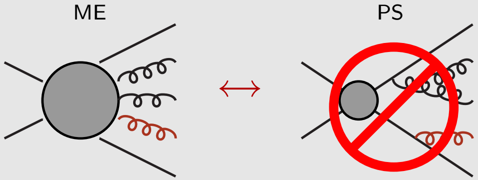
Merging algorithm: Emissions in ME regime

Interpretation of $\mathcal{P}^{\mathrm{ME}}_{\mathrm{no},\,a}(t, t')$

- No-branching probability for shower emissions **above** Q_{cut}
- Truncated at production and decay scale t', t

Has to be allowed in shower evolution, **but:**

What if something is emitted? → CKKW-L



Emissions in this regime should be described by MEs!
⇒ Reject event to avoid double counting

Consequences

- Reduction of cross section $\sigma \to \sigma \cdot \mathcal{P}^{\mathrm{ME}}_{\mathrm{no},\,a}(t, t')$
- Compensated by higher order ME's

⇒ Leading order cross section stable

Merging algorithm: Parton separation criterion

Reminder

$$\mathcal{K}_{ab}^{\mathrm{PS}}(z,t) = \mathcal{K}_{ab}(z,t)\,\Theta\left[Q_{\mathrm{cut}} - Q_{ab}(z,t)\right] \quad \text{and} \quad \mathcal{K}_{ab}^{\mathrm{ME}}(z,t) = \mathcal{K}_{ab}(z,t)\,\Theta\left[Q_{ab}(z,t) - Q_{\mathrm{cut}}\right]$$

- Q_{cut} has to regularise QCD radiation MEs (like a jet resolution)
- Otherwise completely arbitrary until now

$$Q_{ij}^2 \;=\; 2\,p_i p_j \min_{k\neq i,j} \frac{2}{C_{i,j}^k + C_{j,i}^k}$$

Final state partons $(ij) \to i,\, j$

$$C_{i,j}^k \;=\; \begin{cases} \dfrac{p_i p_k}{(p_i+p_k)p_j} - \dfrac{m_i^2}{2\,p_i p_j} & \text{if } j = g \\[2ex] 1 & \text{else} \end{cases}$$

Initial state parton $a \to (aj)\,j$

$$C_{a,j}^k \;=\; C_{(aj),\,j}^k$$

with $p_{aj} = p_a - p_j$

- The minimum is over all possible colour partners k of parton (ij)
- Identifies regions of soft ($E_g \to 0$) and/or (quasi-)collinear ($\approx k_\perp^2 \to 0$) enhancements
- Similar to jet resolution (e.g. Durham in e^+e^- case), but with flavour information