SHERPA: Overview and latest developments

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LCG Generator Services meeting 25.06.2008

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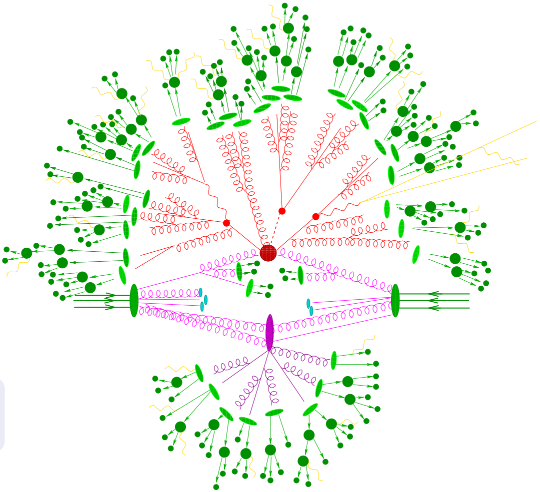
[1] for SHERPA: J. Archibald, T. Gleisberg, S. Höche, F. Krauss, M. Schönherr, S. Schumann, FS, J. Winter

- Initial state parton shower (QCD)
- Underlying event
- Signal process
- Final state parton shower (QCD)
- Fragmentation
- Hadron decays
- QED radiation



Sherpa **is the framework steering these event phases.**

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 electroweak : 2
  End process
}(processes)

(selector){
  JetFinder sqr(20/E_CMS) 1.
  Mass 11 -11 66 116
}(selector)
```

- Non-existent sections/parameters can be specified in files in fallback locations, or use default values
- Parameter-overwriting from the command line possible
- Tag replacing functionality

Running the generator: **3-step strategy**

First run: Generating the ME libraries

```
$ Sherpa EVENTS=10000 OUTPUT=2
  ....
  Single_Process::Tests for 2_2__d__db__e-__e+
     Prepare gauge test and init helicity amplitudes. This may take some time.
  In String_Handler::Complete : this may take some time....
  Single_Process::CheckLibraries : Looking for a suitable library. This may take some time.
  Library_Loader::LoadLibrary(): Failed to load library 'libProc_P2_2_2_6_14_16_5_0.so'.
  Single_Process::WriteLibrary :
     Library for 2_2__d__db__e-__e+ has been written, name is P2_2_2_6_14_16_5_0
  ....
  Amegic::InitializeProcesses :
     Some new libraries were created and have to be compiled and linked.
     Type "./makelibs" in '/home/frank/sherpa/trunk/SHERPA/Run/LHC' and rerun.
```

Compiling the libraries

- Written out in C++
- Using autotools for compilation setup
- Simply type `./makelibs`

Running the generator: **3-step strategy**

Second run: Integration, event generation

```
$ Sherpa EVENTS=10000 OUTPUT=2
....
All_Processes::CalculateTotalXSec for 2_3__j__j__e-__e+__j
Starting the calculation. Lean back and enjoy ... .
523.701 pb +- ( 16.9984 pb = 3.24582 % ) 5000 ( 46.1 % )
full optimization:  ( 0 s elapsed / 45 s left / 45 s total )
....
508.574 pb +- ( 0.672573 pb = 0.132247 % ) 310000 ( 75.2 % )
2_3__j__j__e-__e+__j : 508.574 pb +/- 0.132247 %, exp. eff: 0.926893 %.
Store result : xs for 2_3__j__j__e-__e+__j : 508.574 pb +/- 0.132247%,
       max : 0.000140913
----------------------------------------------------------
-- SHERPA generates events with the following structure --
----------------------------------------------------------
Perturbative       : Signal_Processes:Amegic
Perturbative       : Hard_Decays:
Perturbative       : Jet_Evolution:Apacic
Perturbative       : Multiple_Interactions:None
Hadronization      : Beam_Remnants
Hadronization      : Hadronization: Ahadic
Hadronization      : Hadron_Decays
---------------------------------------------------------
  Event 600 ( 7 s elapsed / 114 s left / 121 s total )
```

Process integration

Active modules

Event generation

Event record

Internal event structure

- Event (≈ `HepMC::GenEvent`) = list of linked `Blobs` (≈ `HepMC::GenVertex`)
- Four-momentum conservation locally fulfilled
- Particle status codes similar to HepMC

Example `Blob` for signal process

```
Blob [0]( 1, Signal Process    , 2 -> 3 @ (0,0,0,0)
Incoming particles :
[G] 2 u        1 (   4 ->    1) [( 5.3229e+01,-3.7077e-01,-5.2213e-01, 5.3225e+01), p^2=-3.6380e-12, m= 0.0000e+00] (615,  0)
[G] 2 G        1 (   4 ->    1) [( 8.8449e+01, 2.3747e-01,-1.7765e-01,-8.8449e+01), p^2= 0.0000e+00, m= 0.0000e+00] (613,615)
Outgoing particles :
[H] 2 e-       2 (   1 ->    5) [( 5.1618e+01,-1.8670e+01,-4.8114e+01, 9.6923e-01), p^2= 0.0000e+00, m= 0.0000e+00] (  0,  0)
[H] 2 e+       3 (   1 ->    5) [( 5.5660e+01, 3.9427e+01, 2.0197e+01,-3.3698e+01), p^2= 4.5475e-13, m= 0.0000e+00] (  0,  0)
[H] 2 u        4 (   1 ->    5) [( 3.4400e+01,-2.0890e+01, 2.7217e+01,-2.4946e+00), p^2=-6.8212e-13, m= 0.0000e+00] (613,  0)
```

Other output formats

- HepEvt
- HepMC, if linked with the HepMC package

Sherpa release 1.1

- 1.1.0 released in April 2008, bugfix release 1.1.1 in May 2008
- Available on GENSER (**thanks for the quick response!**), in ATLAS and CMS

New features ($\rightsquigarrow$ later)

- Ahadic++ – Cluster fragmentation module
- Hadrons++ – Complete hadron and τ decay module
- Photons++ – QED radiation in the YFS formalism
- CKKW merging for processes with decay chains
- Expandability through dynamically linked user libraries

Important UI changes

- Particle ID's now conform with PDG
- New default parameters, **see Changelog** before using old setups!
- One sectioned input file ("run card") instead of separate files

$\Rightarrow$ **Migration script for old setups provided**

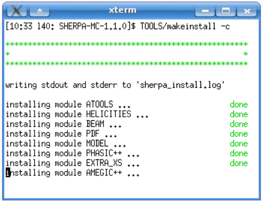
Installation

What you need

- SHERPA tarball from `http://sherpa-mc.de`
- C++ compiler (g++), fortran compiler (g77+libg2c or gfortran)
- Autotools: automake, autoconf, libtool

Installation procedure

- `tar xzf Sherpa-1.1.1.tar.gz`
- `cd SHERPA-MC-1.1.1`
- `TOOLS/makeinstall -c`
- That's it. Should take 10-20 mins.



Linking to optional external packages

- HepMC library version 2.x: For output in HepMC event record
  `TOOLS/makeinstall --copt --enable-hepmc2=/path/to/hepmc/`
- LHAPDF: For using common interface to many PDF sets
  `TOOLS/makeinstall --copt --enable-lhapdf=/path/to/lhapdf/`

Matrix elements: AMEGIC++

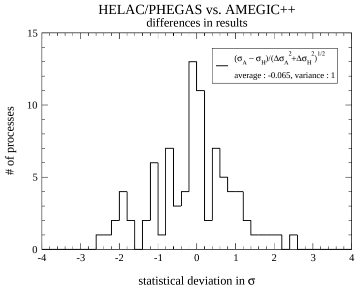
JHEP 0202(2002)044

Features

- Fully automated matrix element calculation in SM, MSSM and ADD using helicity amplitudes
- Expandable with additional vertices/models
  (Technicolor and Little Higgs being worked on by users)
- High performance by writing out matrix elements and dedicated phase space channels into compiled libraries

Validation

- MC4LHC cross section comparison
  `http://mlm.web.cern.ch/mlm/mcwshop03/mcwshop.html`
- $e^+e^- \to 6f$ comparison with HELAC/PHEGAS
  EPJ C34(2004) 173 see ⇒
- MSSM $2 \to 2$ comparison with WHIZARD/O'Mega & SMadGraph
  Phys. Rev. D73(2006)055005



Parton shower: APACIC++

Comput.Phys.Commun.174:876-902,2006

Features

- Similar to old Pythia parton shower
  Comput.Phys.Commun.82:74-90,1994
- Virtuality ordered
- Veto on increasing angles

Differences with respect to Pythia

- Choice of renormalisation and factorisation scales
- Treatment of masses in the PS
- Alterations for CKKW merging

More about two new shower modules:
CSSHOWER++
ADICIC++
⇝ later!

Merging ME and PS

Combining the advantages, avoiding the disadvantages

Matrix Elements	**Parton Showers**
+ Exact to fixed order	+ Resum all leading logarithms to all orders
+ Include all interferences	+ Produce exclusive multi-particle final state
– Only low FS multiplicity	– No interference effects

$\Downarrow$

- **Hard radiation** well described by **ME**
- **Correct intrajet evolution** provided by **PS**

Merging a la CKKW

JHEP 0111(2001)063

Particularities

- Avoid double counting of emissions!
- Correct scale settings in all steps

Strategy

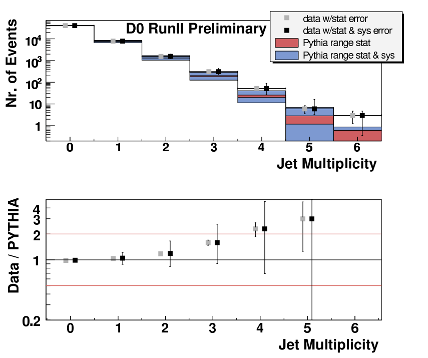
- Separate phase space by Q_{cut} (k_T type measure)
  - Region of jet production: ME
  - Region of jet evolution: PS
- Select final state and kinematics according to cross section made finite by Q_{cut}
- Backwards clustering to identify core process and “shower history”
- Reweight ME with Sudakov form factors and α_s scale corrections
- Start PS at hard scale, and veto emissions harder than Q_{cut}

$\Rightarrow$ Correct jet observables

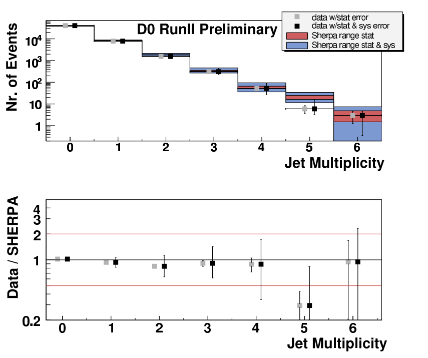
CKKW merging: Z+jets @ Tevatron

D0 note 5066-CONF

Pythia 6.2 (normalized to data)



SHERPA 1.0 (normalized to data)



CKKW merging: Z+jets @ Tevatron

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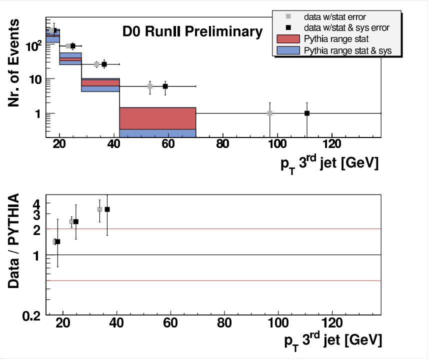

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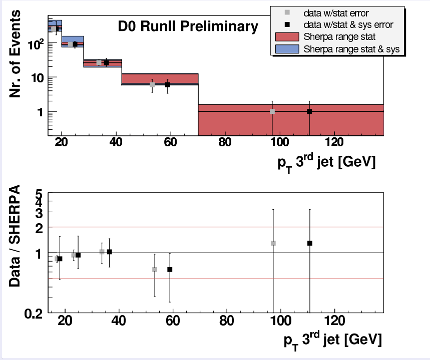
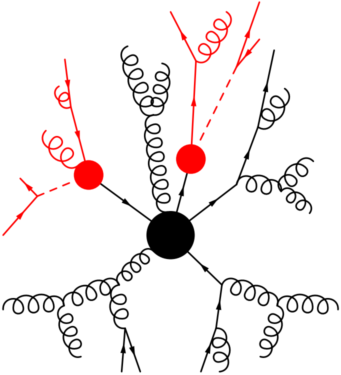


CKKW with decay chains

S. Hoeche, F. Krauss, J. Winter: in preparation



Heavy flavour production in SHERPA

- Narrow width approximation ⇒ Full matrix element factorises into **production** and **decay** parts

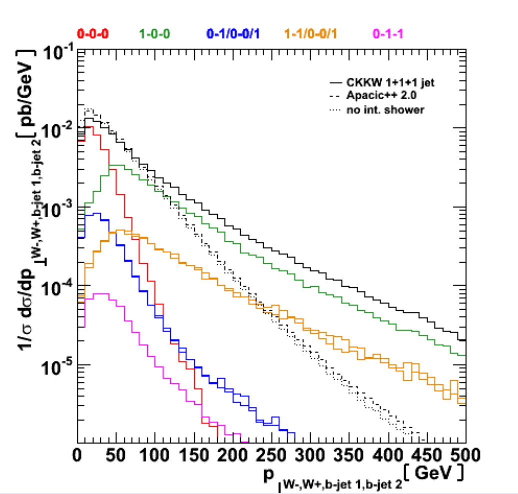
$$\mathcal{A}^{(n)} = \mathcal{A}^{(\mathbf{n}_{\rm prod})}_{\rm prod} \otimes \prod_i \mathcal{A}^{(n_i)}_{{\rm dec},i}$$

- AMEGIC++ provides diagrams for decay chains
- APACIC++ provides production and decay shower off heavy partons
- **CKKW merging** is applied separately and independently in production and decay

Implemented fully general and applicable e. g. in SUSY decay chains.

CKKW with decay chains

Example: $t\bar{t}$ production



Does it make a difference?

Black solid vs. Black dashed:
Yes.

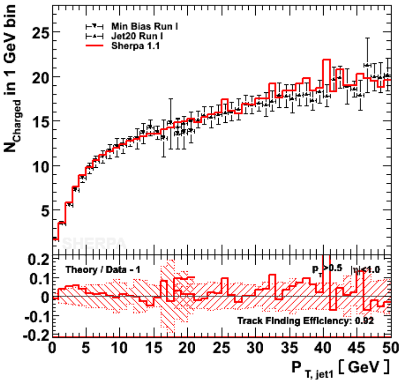
Where does it come from?

- 1 jet in prod., 0 in decay
- 1 jet in prod., 1 in decay

Multiple parton interactions: AMISIC++

hep-ph/0601012

$N_{\rm charged}$ vs. $p_{\rm T,jet1}$ in CTC



- Based on the PYTHIA model
  PRD36(1987)2019
- Parton showers attached to secondary interactions
- With CKKW: Starting scale for MI evolution $\mu_{\rm MI}$ chosen according to p_T of QCD partons in k_T-clustered core process
- Veto PS emissions harder than $\mu_{\rm MI}$

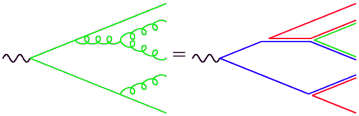
Although based on the same model as Pythia, tuned parameters can not be re-used, because of PS attached

Cluster fragmentation: AHADIC++

Eur. Phys. J. C36 (2004) 381

Cluster fragmentation

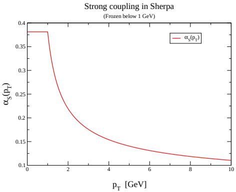
- Large N_C-limit
- Split perturbative gluons non-perturbatively into $q\bar{q}$
- Colour connected pairs form colourless clusters



- After evolution in parton showers: colour singlets close in phase space
- Clusters ($\approx$ excited hadrons) decay into clusters or hadrons

Cluster fragmentation: AHADIC++

Eur. Phys. J. C36 (2004) 381



QCD "as if"

- Splittings $\propto \alpha_s(p_\perp)/p_\perp^2$
  (non-perturbative tunable α_s)
- Limit allowed $p_\perp$ in gluon splitting

Dynamic cluster-hadron boundary

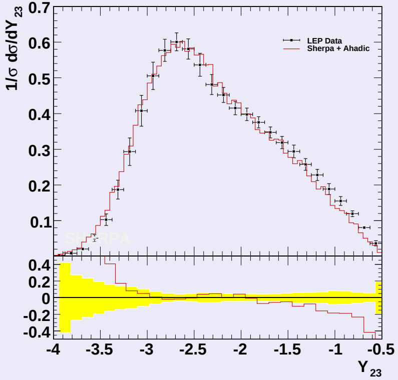
- Cluster decays $C \to CC$
- Decay product lighter than heaviest matching hadron $\to$ Transition to hadron (compensate recoil locally)
- Initial cluster light enough $\to$ Decay to hadron pair

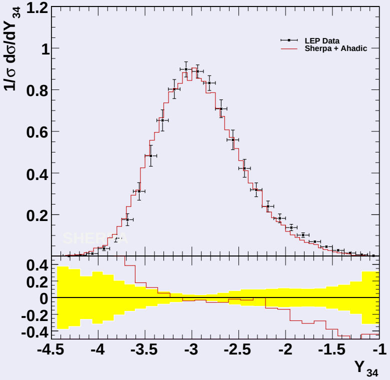
Particularities

- Include diquarks throughout
- Use dipole splitting kinematics

AHADIC++: Results

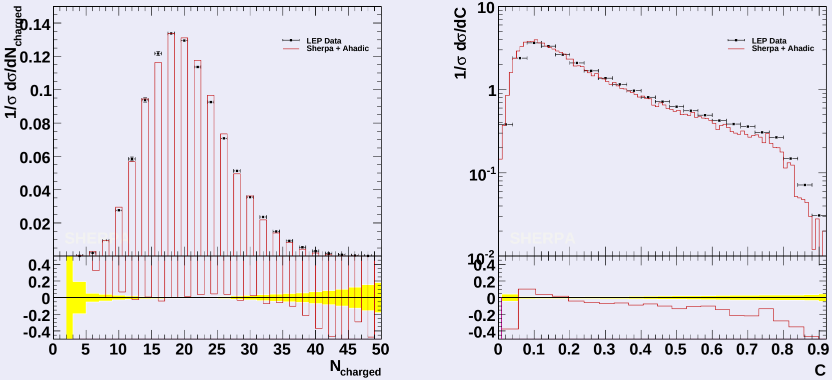
LEP I data





AHADIC++: Results

LEP I data



Hadron and τ decays: HADRONS++

F. Krauss, T. Laubrich, FS: in preparation

Highlights

- Decay kinematics according to matrix elements with form factors
- Kinematical corrections for spin correlations
- Treatment of neutral meson mixing and related CP violation

Other features

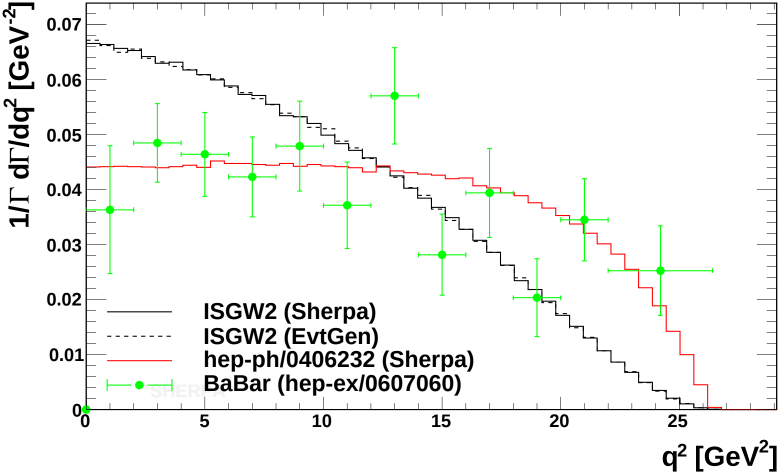
- Mass smearing of unstable resonances
- Partonic decays for incomplete decay tables

Status

- Decay tables for $\approx$ 400 particles
- $\approx$ 2500 decay channels
- $\approx$ 400 decay channels with form factors

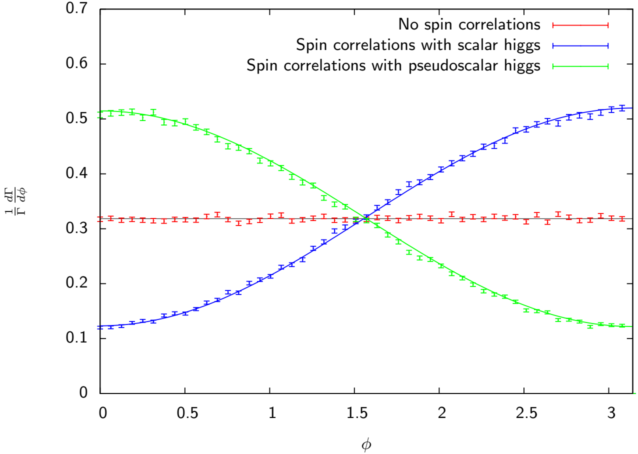
Matrix elements and form factor models in $B \to \pi \nu_l \bar{l}$

F. Krauss, T. Laubrich, FS: in preparation



Spin correlations in $h \to \tau^-\tau^+ \to \pi^-\nu_\tau\pi^+\bar{\nu_\tau}$

F. Krauss, T. Laubrich, FS: in preparation



Angle between τ decay planes (Analytical results: Z.Phys.C64:21-30,1994)

CP violation in the interference

F. Krauss, T. Laubrich, FS: in preparation

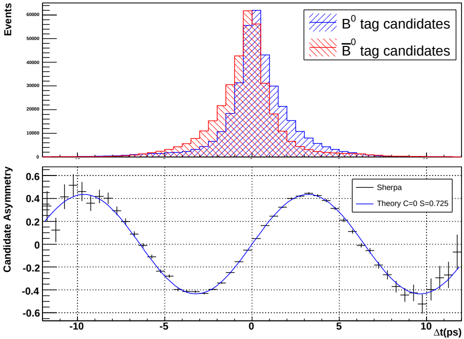
Asymmetry in decays to common final state f

$$A_{CP}(t) = \frac{\Gamma(B^0(t)\to f)\ -\ \Gamma(\bar{B}^0(t)\to f)}{\Gamma(B^0(t)\to f)\ +\ \Gamma(\bar{B}^0(t)\to f)} = S\cdot\sin(\Delta m_B t) - C\cdot\cos(\Delta m_B t)$$

Example: $B_d \to J/\Psi K_S$

$$S = \Im(\lambda_{f_{CP}}) = \sin(2\beta) = 0.725$$

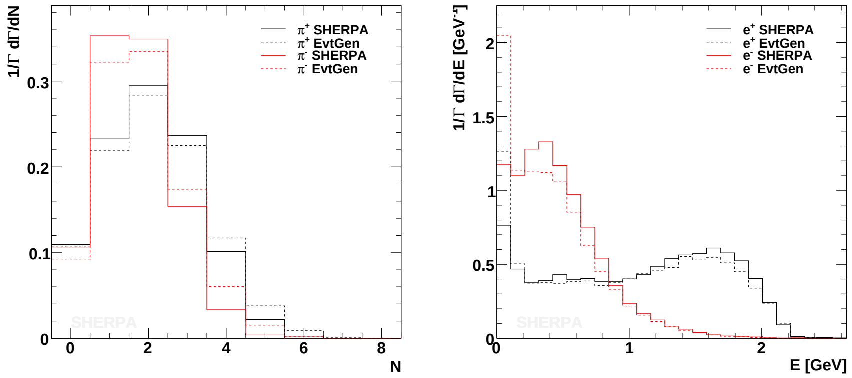
$$C = 0$$



Inclusive observables

F. Krauss, T. Laubrich, FS: in preparation

Results for inclusive B^+ decay: π multiplicities and $e^\pm$ spectrum



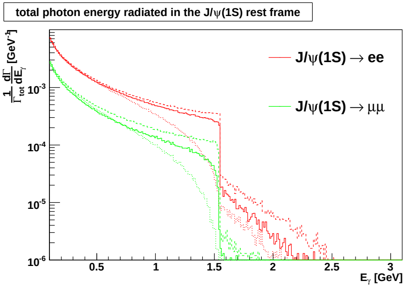
Comparison with EvtGen (Nucl.Instrum.Meth.A462:152-155,2001)

Corrections for higher order QED effects: PHOTONS++ F. Krauss, M. Schönherr: in preparation

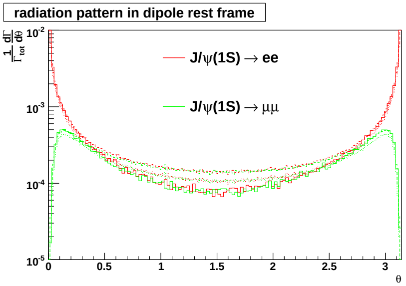
- Sums all contributions of soft photon radiation (real and virtual) using the Yennie-Frautschi-Suura-Formalism (YFS)
  $\Rightarrow$ exact as $k \to 0$, perturbative series for hard emission effects
- Hard emission effects up to $\mathcal{O}(\alpha)$ incorporated generally via approximated matrix elements in the quasi-collinear limit
- Important cases with $\mathcal{O}(\alpha)$ real and/or virtual exact matrix elements
  $V \to FF$, $V \to SS$, $S \to FF$, $S \to SS$, $\tau \to \ell\nu_\ell\nu_\tau$
- ME corrections for radiative semi-leptonic meson decays $(1 \to 3 + \gamma)$ under way (form factor model)
- Implemented for hadron and τ decays
- No limitation on final state complexity

Leptonic hadron decays: $J/\psi \to \ell\bar{\ell}$

F. Krauss, M. Schönherr: in preparation



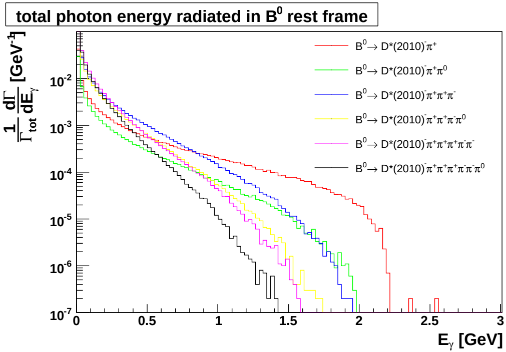
total radiated energy in the J/ψ rest frame

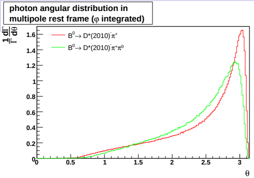


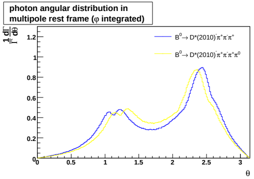
angular spectrum in the rest frame of the dipole

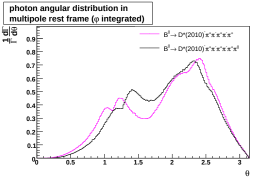
- soft only (dotted)
- collinear approximated ME (dashed)
- exact ME (solid)

Multipoles: ($B \to D^{*-}$+Pions)









Energy spectrum and angular radiation patterns for fixed kinematical configurations.

High multiplicity matrix elements: COMIX

T. Gleisberg, S. Höche: in preparation

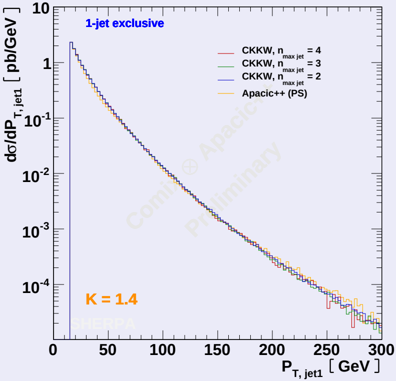
- Revisited Berends-Giele recursion: JHEP08(2006)062 $\Rightarrow$ new matrix element generator COMIX
- Fully general implementation of SM interactions, e. g.
  - pp $\rightarrow W/Z$ + N jets (N up to 6, all partons!)
  - pp $\rightarrow$ N jets + t [W^+b + M jets] $\bar{t}$ [$W^-\bar{b}$ + M jets] (N/M up to 2/1)
  - pp $\rightarrow$ N gluons (N up to 12)
  - pp $\rightarrow$ N jets (N up to 8, all partons!)

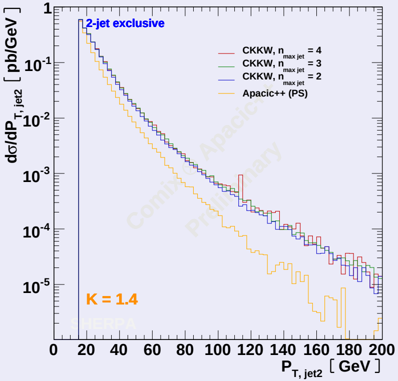
Example from MC4LHC comparison vs. COMIX

σ [pb]	Number of jets						
e^-e^+ + QCD jets	0	1	2	3	4	5	6
COMIX	723.5(4)	187.9(3)	69.7(2)	27.14(7)	11.09(4)	4.68(2)	2.02(2)
ALPGEN	723.4(9)	188.3(3)	69.9(3)	27.2(1)	10.95(5)	4.6(1)	1.85(1)
AMEGIC++	723.0(8)	188.2(3)	69.6(2)	27.21(6)	11.1(1)		

Merging with COMIX

Exclusive jet p_T in Z+jets production at the Tevatron





Merging with COMIX

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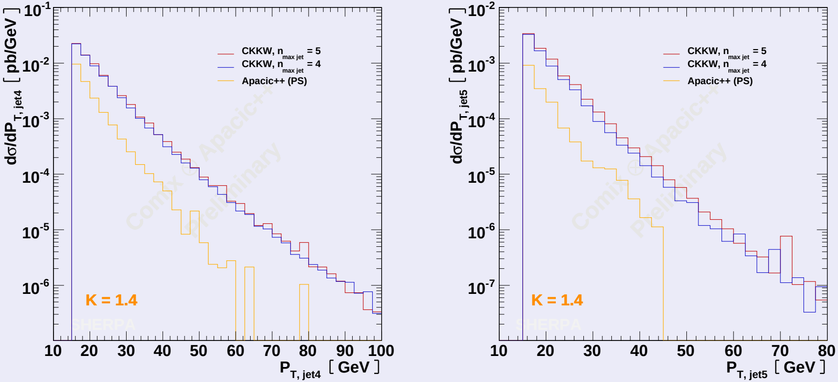


New showers: CSSHOWER++ and ADICIC++

JHEP03(2008)038 and arXiv:0712.3913

- So far in SHERPA: Virtuality ordered, (old-)Pythia-like shower APACIC++.
- Recent efforts: Two new shower modules, to study shower and merging systematics.
- Will be easily switchable in future SHERPA

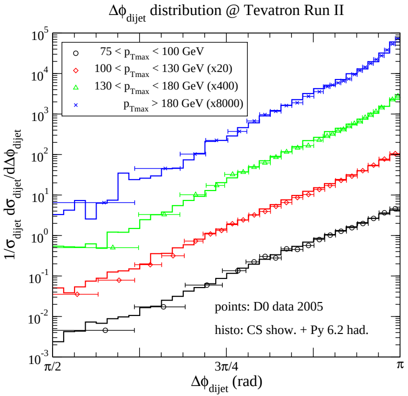
CSSHOWER++

- Based on Catani-Seymour dipole subtraction
- Dipole terms can be used to describe splittings
- Correct soft & collinear limits, better treatment of colour coherence

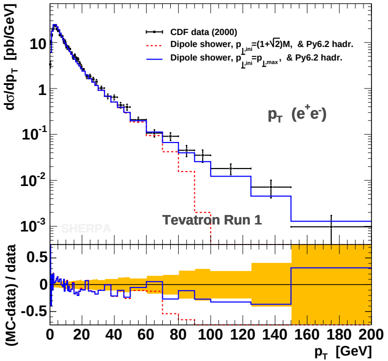
ADICIC++

- Emission off colour dipoles (associated to initial and/or final state colour lines)
- Idea implemented in Ariadne, very good performance for LEP/HERA
- In addition: Initial state emission formulated completely perturbative

First results with CSSHOWER++ and ADICIC++ (no merging yet)



CSSHOWER++: Inclusive Jet production



ADICIC++: Boson p_T in Drell-Yan

Immediate future

- Merging between all combinations of shower and matrix element generators
- Inclusive decays, including spin correlations, finite width treatment

Ideas how to handle such a version "1.2" in the beginning?
Experimental, but still available from GENSER?

Input from GENSER

- Please keep using our bug tracker for your suggestions.
- Latest issue reported: Making SHERPA relocatable. Good idea.
- Will also try to improve our LHAPDF linking, should help especially in non-standard installations like on GENSER.

http://sherpa-mc.de

- Downloads
- Announcement mailing list
- Documentation