SHERPA for LHCb

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Seminar, TU Dortmund, 30.10.2008

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

This talk is only partly about B physics. Sorry! [2]
So what is it about? Event generation at the LHC.

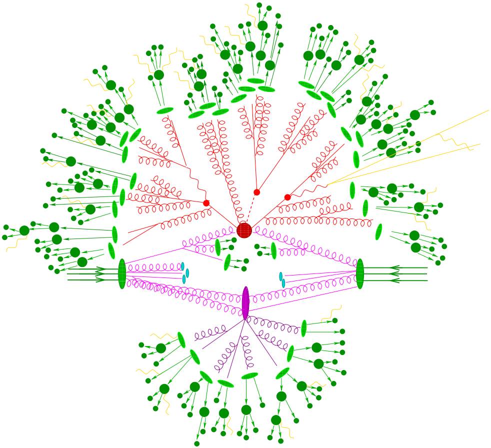
Event Phases:

PERTURBATIVE PHYSICS

- Initial state parton shower (QCD)
- Underlying event
- Signal process
- Final state parton shower (QCD)

SOFT PHYSICS

- Fragmentation
- Hadron decays
  B physics! Yay!
- QED radiation



[2] Thanks for inviting me anyways!

Multi-purpose event generator

- Developed since $\sim$ 1999
- Traditional core strengths: Matrix elements for hard signal process, and their matching to the shower
- 1.1.0 released in April 2008, current bugfix release 1.1.2
- Available on GENSER
- Interfaces in ATLAS and CMS, soon also in LHCb (production and decay)

New features in 1.1 ($\rightsquigarrow$ 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, e.g.: Hadron decay matrix elements, random number generators, BSM models for the signal process, ...

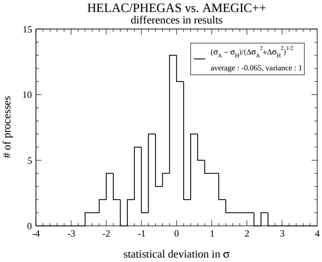
JHEP 0202(2002)044

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 $\Rightarrow$
- MSSM $2 \to 2$ comparison with WHIZARD/O'Mega & SMadGraph
  Phys. Rev. D73(2006)055005



arXiv:0808.3674

Features

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

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

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

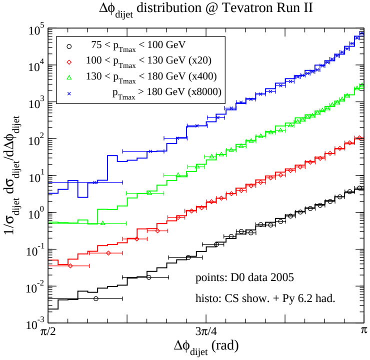
Recent efforts: Two new shower modules, to study shower and merging systematics.

CSSHOWER++ JHEP 03 (2008), 038

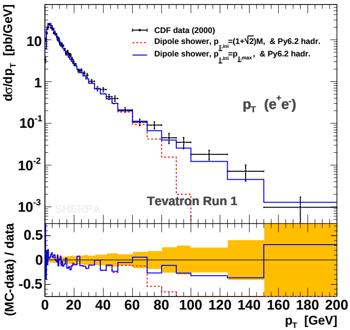
- Based on Catani-Seymour dipole subtraction
- Dipole terms can be used to describe splittings
- Correct soft & collinear limits, better treatment of colour coherence

ADICIC++ JHEP 07 (2008), 040

- 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 completely perturbative



CSSHOWER++: Inclusive Jet production



ADICIC++: Boson p_T in Drell-Yan

Combining the advantages, avoiding the disadvantages

Matrix Elements

+ Exact to fixed order
+ Include all interferences
– Only low FS multiplicity

Parton Showers

+ Resum all leading logarithms to all orders
+ Produce exclusive multi-particle final state
– No interference effects

$\Downarrow$

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

JHEP 0111(2001)063

Particularities

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

Strategy

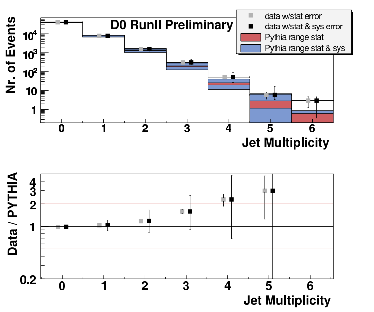
- Separate phase space by Q_{cut} (k_T type measure)
  - Region of jet production: ME
  - Region of jet evolution: PS
- Select jet multiplicity and kinematics according to ME above Q_{cut}
- Backwards clustering to identify core process and “shower history”
- Reweight ME with Sudakov form factors and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

$\Rightarrow$ Correct jet observables

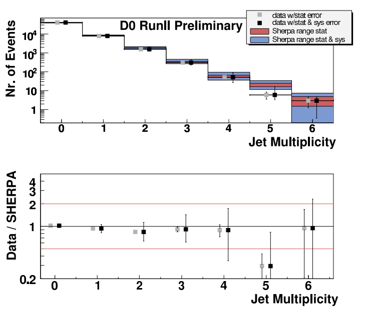
CKKW merging: Z+jets @ Tevatron

D0 note 5066-CONF

Pythia 6.2 (normalized to data)



Sherpa 1.0 (normalized to data)



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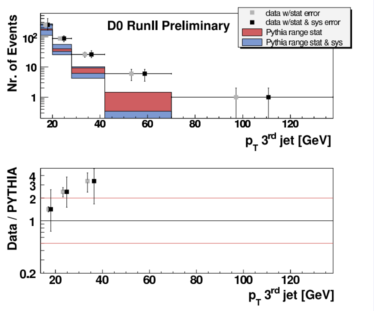

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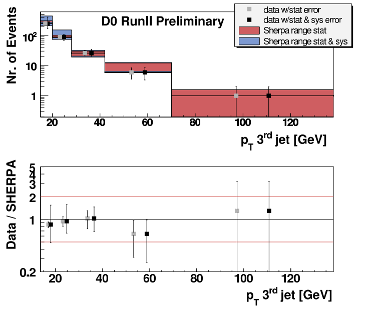
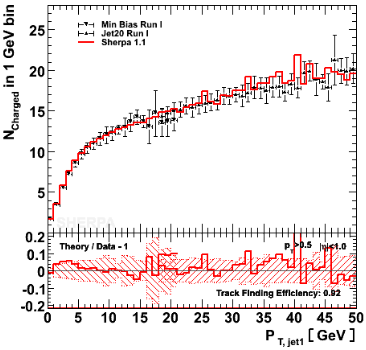


hep-ph/0601012

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



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

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

Eur. Phys. J. C36 (2004) 381

Formation of colourless clusters

- Split perturbative gluons non-perturbatively into $q\bar{q}$
  - $\propto \alpha_s(p_\perp)/p_\perp^2$ (non-perturbative tunable α_s)
  - Limit allowed $p_\perp$ (soft event phase!)
  - dipole kinematics with spectator ($\rightarrow$ no fake gluon mass needed)
- Colour connected pairs form colourless clusters ($\approx$ excited hadrons)

Cluster decay and transition: Dynamic cluster-hadron boundary

- Two cases for transition to hadrons, depending on cluster mass:
  - $m_C \approx$ mass of heaviest hadron with matching flavours
  - $m_C <$ summed mass of two heaviest hadrons it can decay into

  In these cases competition between $C \rightarrow H$ and $C \rightarrow H_1 H_2$
- Otherwise: Cluster decay $C \rightarrow C_1 C_2$ (by emitting gluon)

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

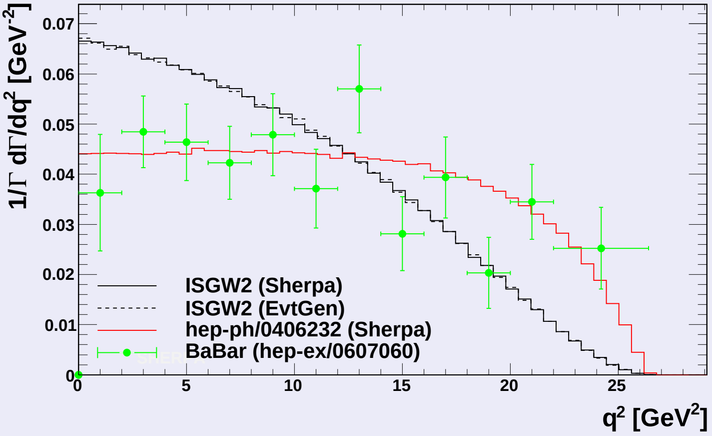
Other features

- 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
- Interface as DecayTool for LHCb under way

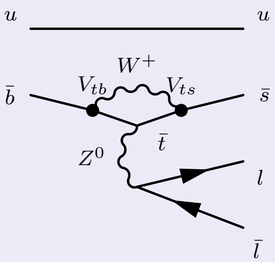
Example: Form factor models in $B \to \pi \nu_l \bar{l}$

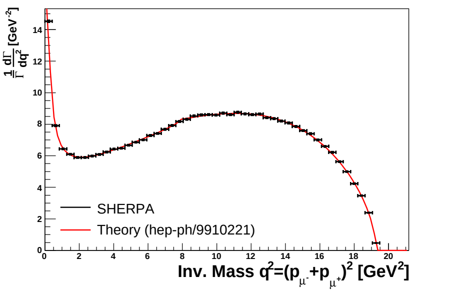


F. Krauss, T. Laubrich, FS: in preparation

Example: $B \to K^* l^+ l^-$

- flavour-changing neutral current in Standard Model only in higher orders
- highly suppressed SM amplitude (four vertices, one of them V_{ts}!)
- $\Rightarrow$ high sensitivity to BSM physics
- Matrix element parametrisation: Ali, Ball, Handoko, Hiller (arXiv:hep-ph/9910221)

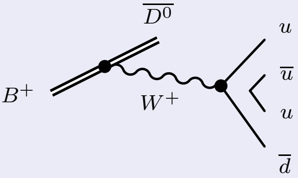


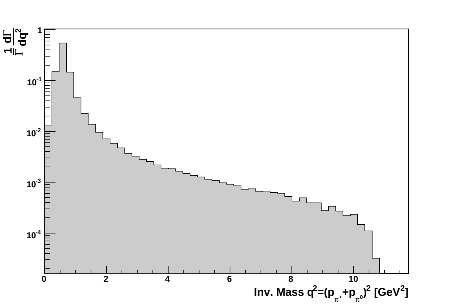


F. Krauss, T. Laubrich, FS: in preparation

A priori not well known (non-perturbative QCD), but idea:

- reuse existing currents from semileptonic B decays and τ decays, e. g. $B \to \bar{D}\nu\bar{l}$ and $\tau \to \nu_\tau\pi^+\pi \implies B \to \bar{D}\pi^+\pi$

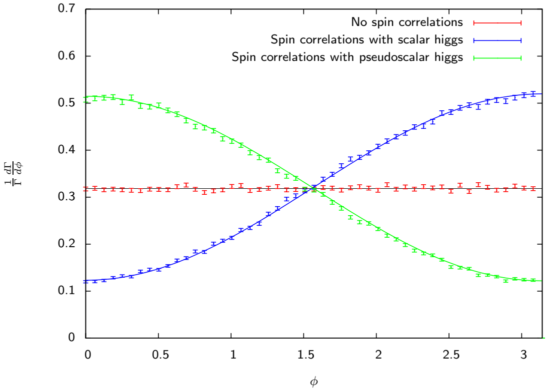




F. Krauss, T. Laubrich, FS: in preparation

What are spin correlations about?

- Decay cascade ⇔ cutting propagators into polarisation vectors/spinors/. . .
- Correlation between polarisation in "left" ME and "right" ME not accounted for if they are done independently ⇒ correction applied by spin correlation algorithm



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

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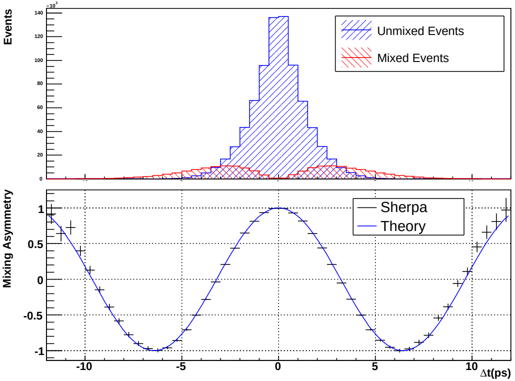
Explicit mixing probabilities

$$P(B^0 \to \bar{B}^0) = \left|\left\langle \bar{B}^0 \right| B^0_{\text{phys}}(t)\right\rangle\Big|^2 \sim \left|\frac{q}{p}\right|^2 \left(\cosh \frac{\Delta\Gamma\, t}{2} - \cos \Delta m\, t\right)$$
$$P(\bar{B}^0 \to B^0) = \left|\left\langle B^0 \right| \bar{B}^0_{\text{phys}}(t)\right\rangle\Big|^2 \sim \left|\frac{p}{q}\right|^2 \left(\cosh \frac{\Delta\Gamma\, t}{2} - \cos \Delta m\, t\right)$$



CP violation in the interference

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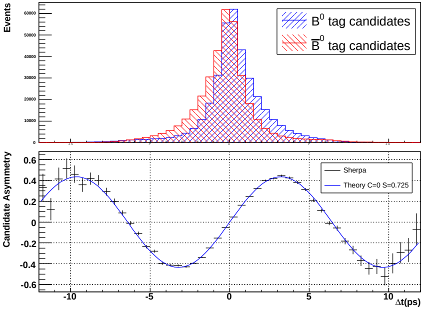
Asymmetry in decays to common final state f

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

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

$$\begin{aligned} S &= \Im(\lambda_{f_{CP}}) \\ &= \sin(2\beta) \\ &= 0.725 \\ C &= 0 \end{aligned}$$



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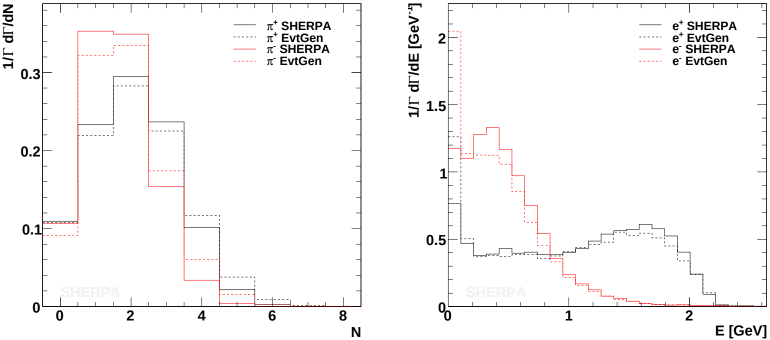
Results for inclusive B^+ decay: π multiplicities and $e^\pm$ spectrum



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

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: $J/\psi \to \ell\bar{\ell}$

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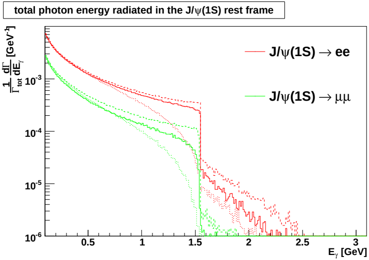
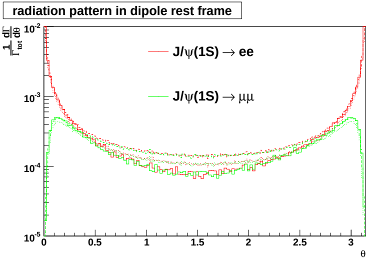


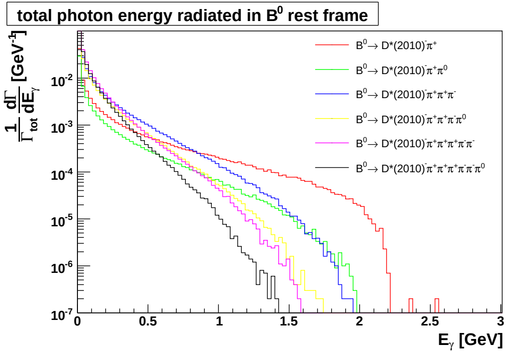
total radiated energy in the J/ψ rest frame

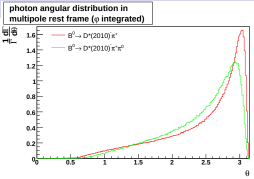


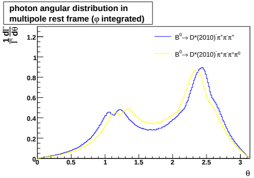
angular spectrum in the rest frame of the dipole

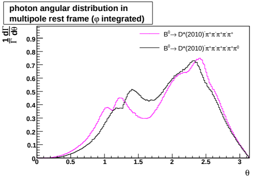
- soft only (dotted)
- collinear approximated ME (dashed)
- exact ME (solid)

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









Energy spectrum and angular radiation patterns for fixed kinematical configurations.

Immediate future

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

Distant future

- NLO matrix elements
- Merging shower with NLO matrix elements

http://sherpa-mc.de

- Downloads
- Announcement mailing list
- Documentation