



# Parton Shower Monte Carlo Event Generators

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University of Manchester  
& CERN

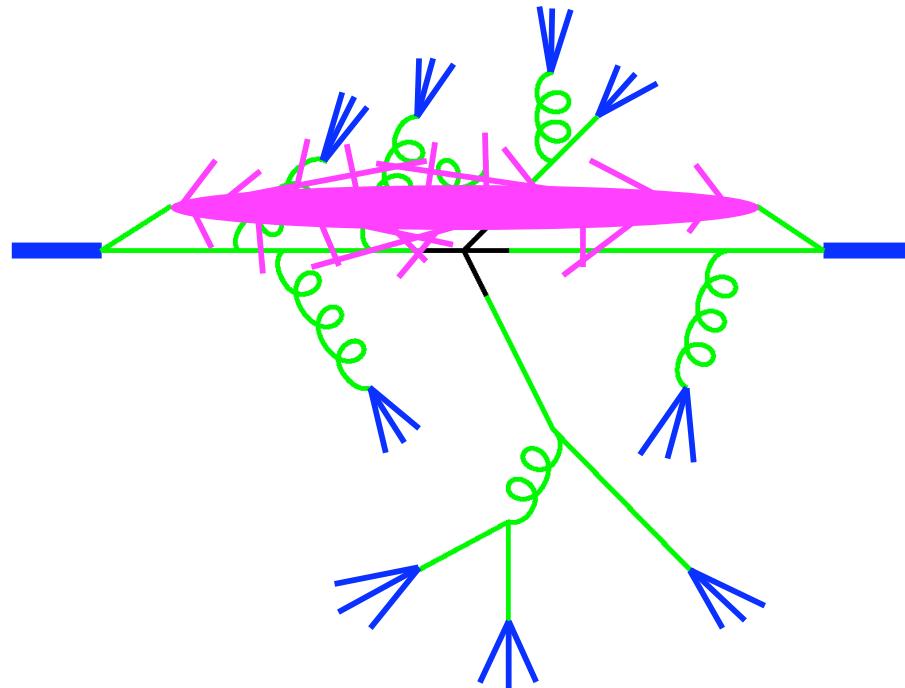
MC4LHC EU Networks' Training Event

May 4<sup>th</sup> – 8<sup>th</sup> 2009

<http://www.montecarlonet.org/>

# Structure of LHC Events

1. Hard process
2. Parton shower
3. Hadronization
4. Underlying event



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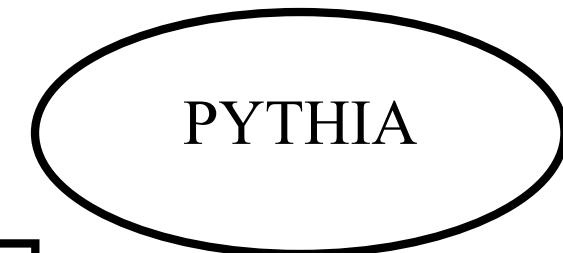


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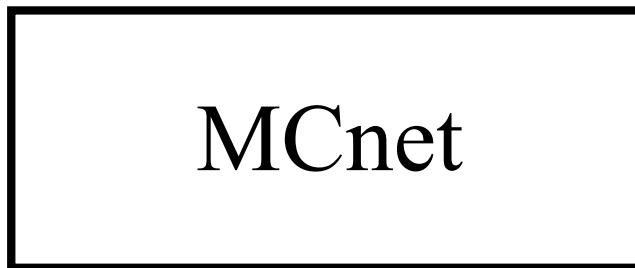
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Steffen Schumann  
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Frank Siegert  
Mike Seymour  
Marek Schoenherr

# Introduction, Overview and Status of MCnet's Monte Carlo Projects

- CEDAR
  - Rivet
- PYTHIA
- Herwig
  - ThePEG
- Sherpa
- Thanks to:
  - Andy Buckley, Lars Sonnenschein, Torbjörn Sjöstrand, Manuel Bähr, Frank Siegert
  - and all the Monte Carlo authors

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# CEDAR – RIVET

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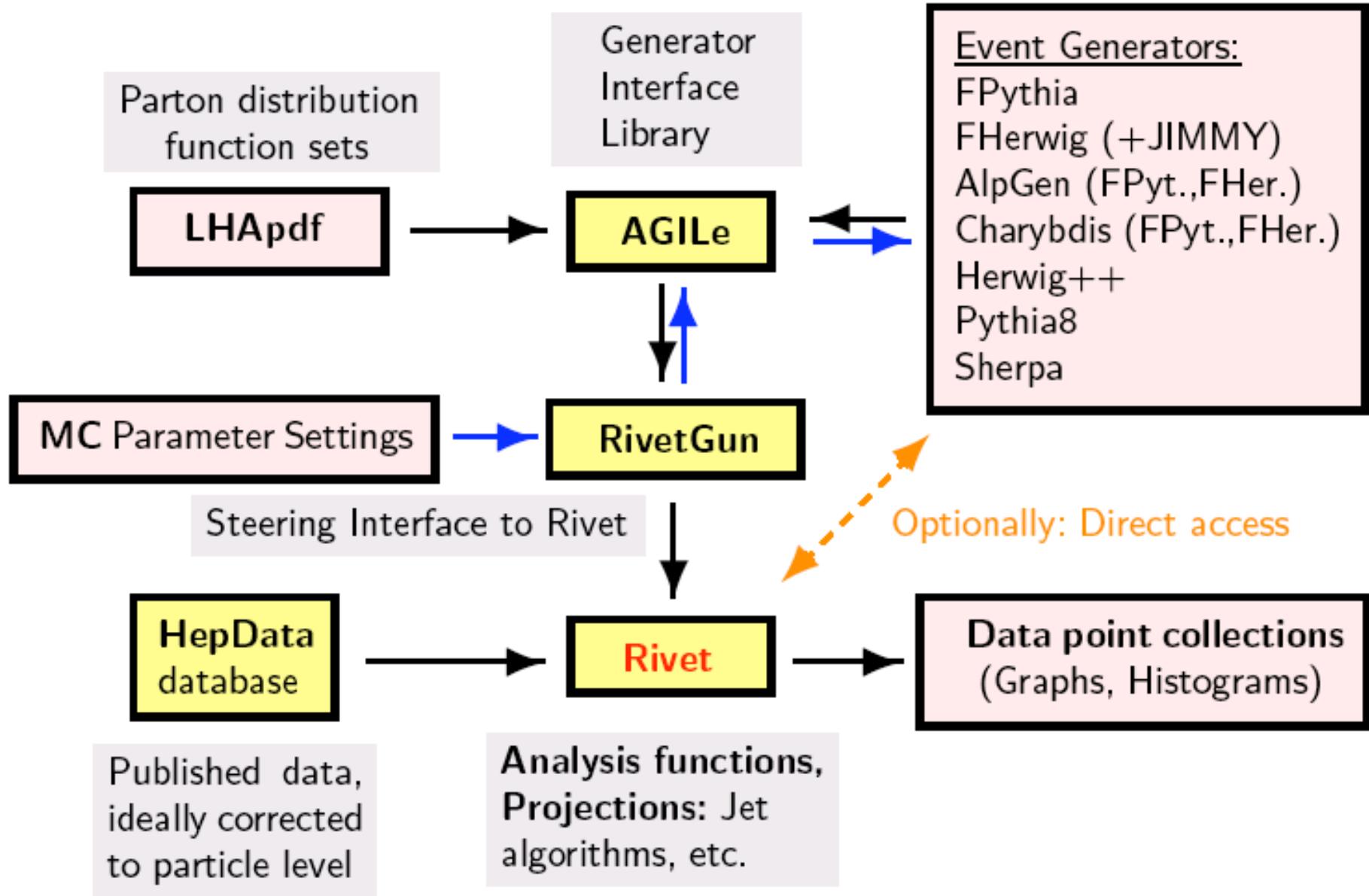
# Validation of Experiment and Theory with Rivet

- Why Rivet?
- Goal: To provide analyses which match exactly publications
- Phenomenologists spend an enormous amount of time to reproduce published data analyses in all details:
  - Jet algorithm details/how exactly applied
  - Publication might seem unambiguous at the time of writing, not so later on ...
- ⇒ Authors of published (corrected) analyses should implement it into Rivet at time of publication
  - Only in this way exact reproduction is guaranteed

# Validation of Experiment and Theory with Rivet

- Rivet is an Object Oriented C++ replacement for FORTRAN HZTool
- Combination of tools, analysis handler and analyses
- Structure is based on auto-cached Projections acting on HepMC events
- Analysis functions make use of projections to determine selection criteria and observables
- Histogramming etc. via AIDA interfaces
- AGILE/RivetGun replaces FORTRAN HZSteer
- Web portal at <http://projects.hepforge.org/rivet>

# Rivet dependency flow chart



# LEP Analyses available in Rivet

Published analyses (corrected for detector effects):

- ALEPH\_1991\_S2435284: Charged particle multiplicity
- ALEPH\_1996\_S3486095: Charged particle multiplicity
- DELPHI\_1995\_S3137023: Strange baryons
- DELPHI\_1996\_S3430090: Event shapes
- DELPHI\_2002\_069\_CONF\_603: b-fragmentation
- OPAL\_1998\_S3780481: Flavour dependent fragmentation
- OPAL\_2004\_S6132243: Multiplicities and sphericity (under construction)

# HERA Analyses available in Rivet

Published analyses (corrected for detector effects):

- H1\_1994\_S2919833: Energy flow and charged particle spectra
- H1\_1995\_S3167097: Energy flow in DIS
- H1\_2000\_S4129130: Energy flow and charged particle spectra
- ZEUS\_2001\_S4815815: Dijet photoproduction (used for p.d.f. fit)

- External user analysis plugging mechanism available

# Tevatron Analyses available in Rivet

Published analyses (corrected for detector effects):

- CDF\_1994\_S2952106: Color coherence
- CDF\_2001\_S4751469: Field & Stuart, Underlying event
- CDF\_2004\_S5839831: CDF underlying event
- CDF\_2005\_S6217184: Jet Shapes
- CDF\_2006\_S6653332:  $Z + b$  jet production
- CDF\_2007\_S7057202: Inclusive  $k_{\perp}$  jet cross section
- CDF\_2008\_LEADINGJETS: Underlying event in leading jet events
- CDF\_2008\_MINBIAS: Minimum bias cross section
- CDF\_2008\_NOTE\_9351: Underlying event in Drell-Yan events
- CDF\_2008\_S7541902: Jet pT and multiplicity distributions in  $W + \text{jets}$  events
- CDF\_2008\_S7782535: b-jet shapes
- D0\_2001\_S4674421: Differential  $W/Z$  boson cross section
- D0\_2004\_S5992206: Azimuthal dijet decorrelations
- D0\_2008\_S6879055: ratio  $\sigma(Z/\gamma^* + \text{n jets})/\sigma(Z/\gamma^*)$

# Rivet Projections

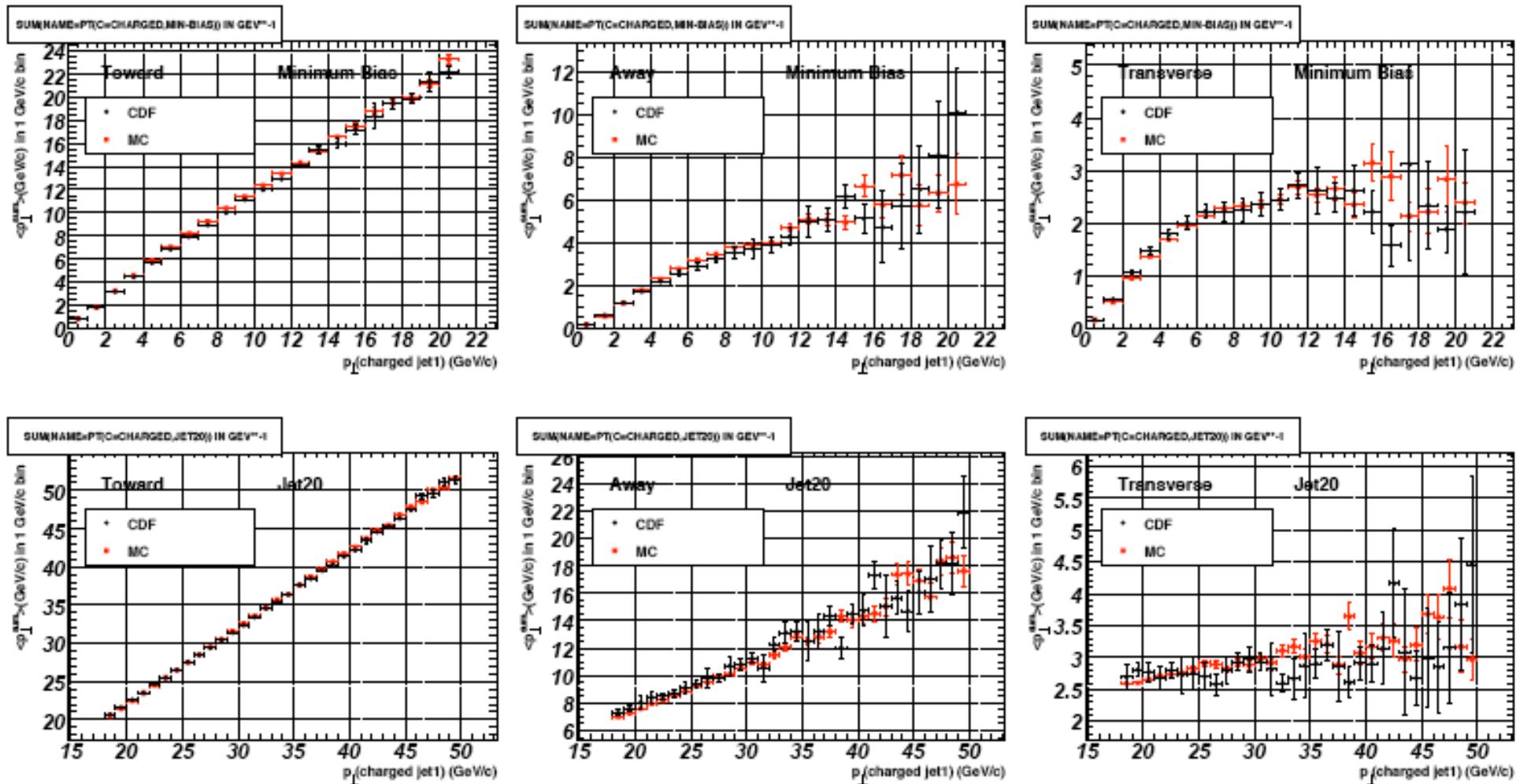
Provide Particle states and Observables (Jets/Event shape variables)

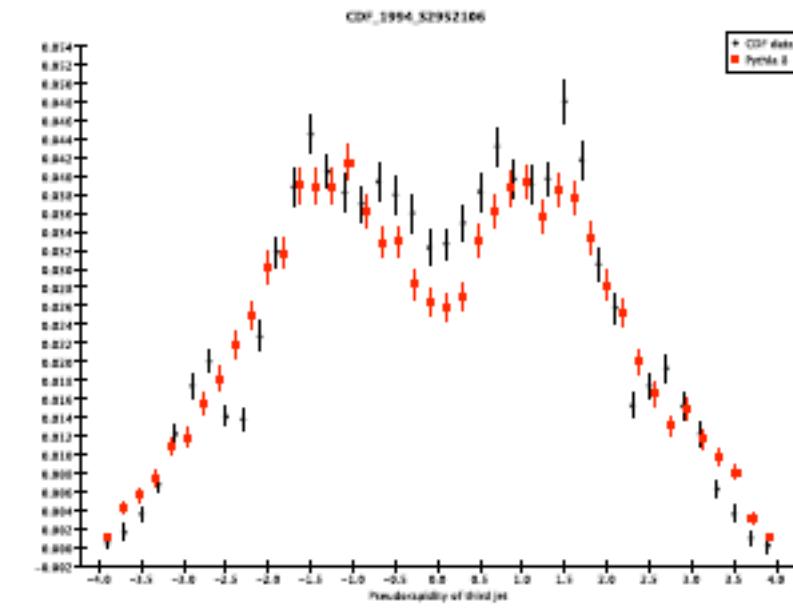
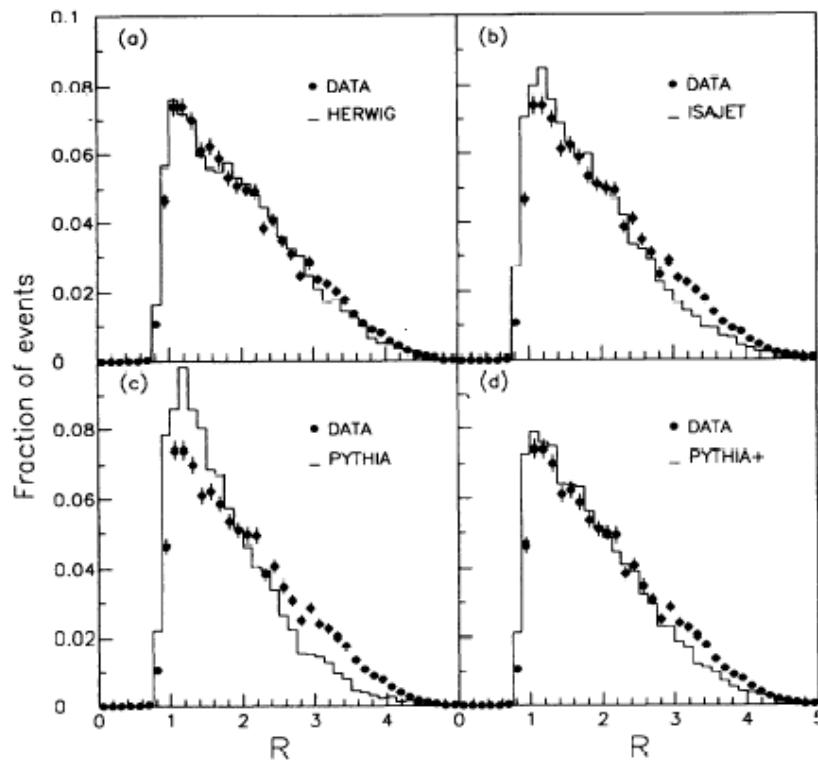
- AxesDefinition
- Beam
- CentralEtHCM
- ChargedFinalState
- ChargedLeptons
- D0ILConeJets
- DISKinematics
- DISLepton
- FastJets
- FinalStateHCM
- FinalState
- HadronicFinalState
- Hemispheres
- InitialQuarks
- IsolationEstimators
- IsolationProjection
- IsolationTools
- InvMassFinalState
- JetAlg
- JetShape
- KtJets
- LeadingParticlesFinalState
- LossyFinalState
- Multiplicity
- ParisiTensor
- PVertex
- Sphericity
- SVertex
- Thrust
- TotalVisibleMomentum
- TrackJet
- UnstableFinalState
- VetoedFinalState
- WZandh.hh

# Rivet Analysis: CDF\_2001\_S4751469: Field & Stuart, Underlying event

- MC = Pythia 6413, TuneA, 1M events

Two separated runs to populate JET20 and Minimum Bias charged jet  $p_{\perp}$  ranges





Distributions of third-hardest jet in multi-jet events  
 HERWIG has complete treatment of colour coherence,  
 PYTHIA+ has partial

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# Conclusions

- Rivet provides a framework for validation of experiment and theory
  - Authors should implement their publication results ASAP
- JetWeb (web based comparison, validation and tuning tool) makes use of Rivet
- Professor tuner (optimisation of MC event generators) makes use of Rivet
- Rivet provides also
  - a sophisticated analysis framework
  - with a rich repository of projections/predefined observables
  - uniform interface to various MC event generators
  - uniform interface to different jet algorithms through FastJet

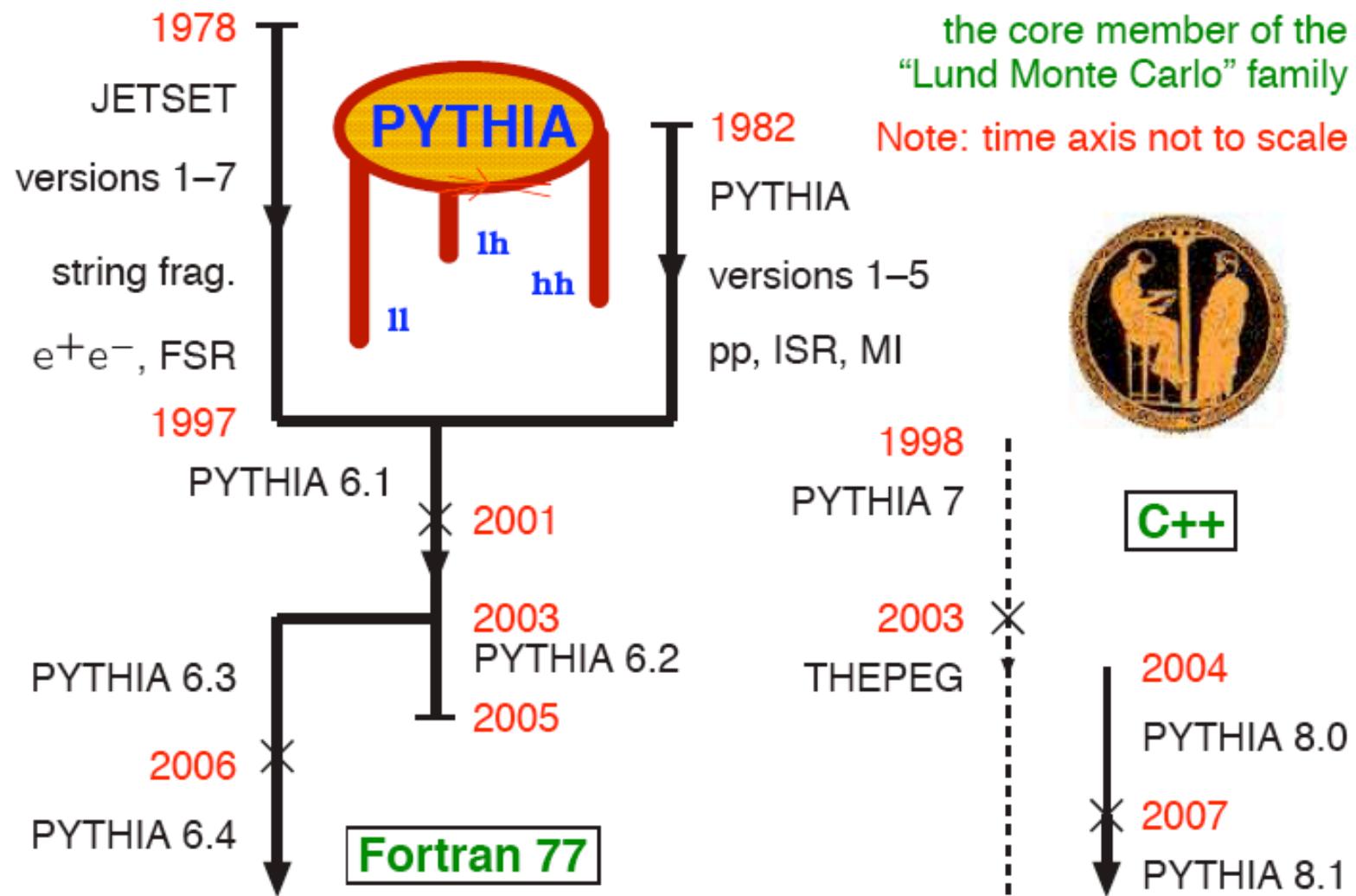
# PYTHIA

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# PYTHIA history



T. Sjöstrand, S. Mrenna, P. Skands, Comput. Phys. Comm. 178 (2008) 852

# PYTHIA Physics (part I)

## Hard processes:

- Built-in library of many leading-order processes.  
Standard Model: almost all  $2 \rightarrow 1$  and  $2 \rightarrow 2$ , a few  $2 \rightarrow 3$ .  
Beyond the SM: a bit of each (PYTHIA 8 not yet SUSY and TC).
- External input via Les Houches Accord and Les Houches Event Files from MadGraph, CompHep, AlpGen, ...
- Resonance decays, often but not always with angular correlations.

## Showers:

- Transverse-momentum-ordered ISR & FSR (PYTHIA 6 also older virtuality-ordered).
- Includes  $q \rightarrow qg$ ,  $g \rightarrow gg$ ,  $g \rightarrow q\bar{q}$ ,  $f \rightarrow f\gamma$ ,  $\gamma \rightarrow f\bar{f}$  ( $f = \text{fermion}$ ).
- ISR by backwards evolution.
- Dipole-style approach to recoils.
- Matching to ME's for first (=hardest) emission in many processes, especially gluon emission in resonance decays.

# PYTHIA Physics (part II)

## Underlying events and minimum-bias events:

- **Strength area: multiple parton–parton interactions**, with dampening of cross-section in  $p_\perp \rightarrow 0$  limit, impact-parameter dependence, and tailor-made PDF's.
- Combined evolution MI + ISR + FSR downwards in  $p_\perp$ .
- Beam remnants colour-connected to interacting systems, and detailed modelling of flavour and momentum structure.

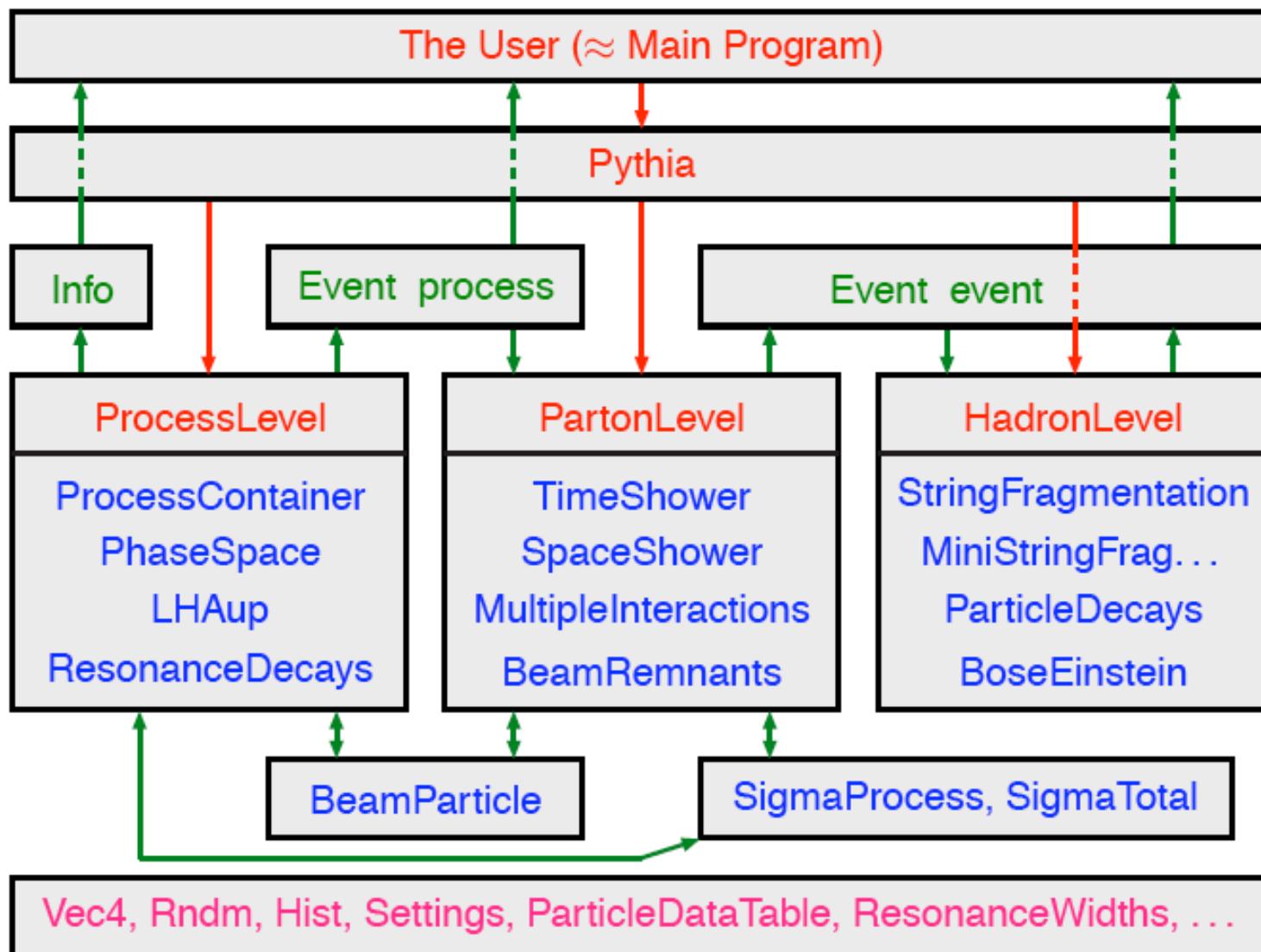
## Hadronization:

- **Strength area: string fragmentation** (“the Lund Model”).
- Particle decays, usually isotropic.
- Link to external decay packages, say for  $\tau$  (TAUOLA) or B (EVTGEN).
- Optional Bose-Einstein effects.

## Utilities: (to make program completely self-contained)

- Four-vectors, random numbers, parton densities, ...
- Event study routines: sphericity, thrust, jet finding.
- Simple built-in histogramming package (line-printer mode).

# PYTHIA 8 structure



# Trying It Out

- Download `pythia8108.tgz` from  
<http://www.thep.lu.se/~torbjorn/Pythia.html>.
- `tar xvfz pythia8108.tgz` to unzip and expand.
- `cd pythia8108` to move to new directory.
- `./configure ...` needed for external libraries + debug/shared  
(see `README`, libraries: HepMC, LHAPDF, PYTHIA 6).
- `make` will compile in 1 – 3 minutes  
(for archive library, same amount extra for shared).
- The `htmldoc/pythia8100.pdf` file contains *A Brief Introduction* ...  
(T. Sjöstrand, S. Mrenna, P. Skands, *Comput. Phys. Comm.* 178 (2008) 852).
- Open `htmldoc/Welcome.html` in a web browser for the full manual.
- Install the `phpdoc/` directory on a webserver and open  
`phpdoc/Welcome.html` in a web browser for an interactive manual.
- The `examples` subdirectory contains > 30 sample main programs:  
standalone, link to libraries, semi-internal processes, ...  
(`make mainNN` and then `./mainNN.exe > outfile`).
- A `Worksheet` contains step-by-step instructions  
and exercises how to write and run a main program.

# Example of a main program

```
// File: main01.cc. The charged multiplicity distribution at the LHC.  
#include "Pythia.h"  
using namespace Pythia8;  
int main() {  
    // Generator. Process selection. LHC initialization. Histogram.  
    Pythia pythia;  
    pythia.readString("HardQCD:all = on");  
    pythia.readString("PhaseSpace:pTHatMin = 20.");  
    pythia.init( 2212, 2212, 14000.);  
    Hist mult("charged multiplicity", 100, -0.5, 799.5);  
    // Begin event loop. Generate event. Skip if error. List first one.  
    for (int iEvent = 0; iEvent < 100; ++iEvent) {  
        if (!pythia.next()) continue;  
        if (iEvent < 1) {pythia.info.list(); pythia.event.list();}  
        // Find number of all final charged particles and fill histogram.  
        int nCharged = 0;  
        for (int i = 0; i < pythia.event.size(); ++i)  
            if (pythia.event[i].isFinal() && pythia.event[i].isCharged())  
                ++nCharged;  
        mult.fill( nCharged );  
        // End of event loop. Statistics. Histogram. Done.  
    }  
    pythia.statistics();  
    cout << mult;  
    return 0;  
}
```

# Online manual $\Rightarrow$ Graphical User Interface

The screenshot shows a Mozilla Firefox browser window with the title bar "Welcome - Mozilla Firefox". The address bar contains the URL "http://www.thep.lu.se/~torbjorn/php8100>Welcome.php". The page content is the PYTHIA 8 documentation. It features a circular logo on the left with two figures, followed by the text "PYTHIA 8" and "Welcome to PYTHIA - The Lund Monte Carlo!". A detailed description of PYTHIA 8 follows, mentioning it is the successor to PYTHIA 6, rewritten in C++, and the official "current" version. Below this, there are sections for "Program Overview" (with links to Frontpage, Program Flow, Settings Scheme, Particle Data Scheme, and Program Files) and "Setup Run Tasks" (with links to Save Settings, Main-Program Settings, Random-Number Seed, and PDF Selection). The bottom of the browser window shows the URL "http://www.thep.lu.se/~torbjorn/php8100/Frontpage.php?filepath=. \$filepath."

# Example: timelike parton showers

Welcome - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://www.thep.lu.se/~torbjorn/php8100/Welcome.php

Pythia Nyheter Personer Banker Workshops Resor Diverse

- Electroweak
- Onia
- Top
- Fourth Generation
- Higgs
- SUSY
- New Gauge Bosons
- Left-Right Symmetry
- Leptoquark
- Compositeness
- Extra Dimensions
- [A Second Hard Process](#)
- [Phase Space Cuts](#)
- [Couplings and Scales](#)
- [Standard-Model Parameters](#)
- [Total Cross Sections](#)
- [Resonance Decays](#)
- [Timelike Showers](#)
- [Spacelike Showers](#)
- [Multiple Interactions](#)
- [Beam Remnants](#)
- [Fragmentation](#)
- [Flavour Selection](#)
- [Particle Decays](#)
- [Bose-Einstein Effects](#)

the choice is not as unique. Here the factorization scale has been chosen as the maximum evolution scale. This would be the  $pT$  for a  $2 \rightarrow 2$  process, supplemented by mass terms for massive outgoing particles. Some small amount of freedom is offered by

**TimeShower:pTmaxFudge** 1.0 (default = 1.0; minimum = 0.5; maximum = 2.0)

While the above rules would imply that  $pT_{max} = pT_{factorization}$ , **pTmaxFudge** introduced a multiplicative factor  $f$  such that instead  $pT_{max} = f * pT_{factorization}$ . Only applies to the hardest interaction in an event. It is strongly suggested that  $f = 1$ , but variations around this default can be useful to test this assumption.

The amount of QCD radiation in the shower is determined by

**TimeShower:alphaSvalue** 0.137 (default = 0.137; minimum = 0.06; maximum = 0.25)

The *alpha<sub>strong</sub>* value at scale  $M_Z^2$ . The default value corresponds to a crude tuning to LEP data, to be improved.

The actual value is then regulated by the running to the scale  $pT^2$ , at which the shower evaluates *alpha<sub>strong</sub>*

**TimeShower:alphaSorder** (default = 1; minimum = 0; maximum = 2)

Order at which alpha<sub>strong</sub> runs,

0 : zeroth order, i.e. alpha<sub>strong</sub> is kept fixed.  
 1 : first order, which is the normal value.  
 2 : second order. Since other parts of the code do not go to second order there is no strong reason to use this option, but there is also nothing wrong with it.

http://www.thep.lu.se/~torbjorn/php8100/TimelikeShowers.php?filepath=files/

# Manual Sections

## Program Overview

Frontpage  
Program Flow  
Settings Scheme  
Particle Data Scheme  
Program Files  
Sample Main Programs

## Setup Run Tasks

Save Settings  
Main-Program Settings  
Beam Parameters  
Random-Number Seed  
PDF Selection  
Master Switches  
Process Selection

- QCD
- Electroweak
- Onia
- Top
- Fourth Generation
- Higgs
- SUSY
- New Gauge Bosons
- Left-Right Symmetry
- Leptoquark

- Compositeness
- Extra Dimensions
- A Second Hard Process
- Phase Space Cuts
- Couplings and Scales
- Standard-Model Parameters
- Total Cross Sections
- Resonance Decays
- Timelike Showers
- Spacelike Showers
- Multiple Interactions
- Beam Remnants
- Fragmentation
- Flavour Selection
- Particle Decays
- Bose-Einstein Effects
- Particle Data
- Error Checks
- Tunes

## Study Output

Four-Vectors  
Particle Properties  
Event Record  
Event Information

Event Statistics  
Histograms  
Event Analysis  
HepMC Interface

## Link to Other Programs

Les Houches Accord  
Access PYTHIA 6 Processes  
Semi-Internal Processes  
Semi-Internal Resonances  
Hadron-Level Standalone  
SUSY Les Houches Accord  
Beam Shape  
Parton Distributions  
External Decays  
User Hooks  
Random Numbers  
Implement New Showers

## Reference Material

PYTHIA 6 Translation Table  
Update History  
Bibliography  
Glossary  
Version

# Links to other programs

PYTHIA is standalone, but several ways to link to it.

Interfaces to existing external libraries/standards:

- Input from Les Houches Accord & Les Houches Event Files.
- Output to HepMC event format.
- SUSY Les Houches Accord (input file with masses, couplings, . . . ).
- Link to external decays, e.g. for  $\tau$  and B.
- Link to LHAPDF version 5.3.0 or later, or to your own PDF.

New possibilities, based on derived classes and pointers to them:

- Semi-internal process: write a derived matrix-element class,

```
SigmaProcess* mySigma = new MySigma();  
pythia.setSigmaPtr( mySigma);
```

and let PYTHIA do phase space integration, process mixing, . . .

- Semi-internal resonance in same style: calculate partial widths.
- Link to external random-number generator.
- Link to external shower, e.g. VINCIA for FSR.
- User hooks: veto events early on or reweight cross section.

# Herwig++ & ThePEG

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# The Herwig++ Project

- New development in C++ (uses ThePEG). Successor of HERWIG (Hadron Emission Reactions With Interfering Gluons)
- Keep the very successful treatment of soft gluon interference via angular ordering + cluster hadronization
- Improve in as many parts as possible and exploit OOCODE advantages (modularity, maintainability, flexibility)

Cambridge	CERN	Durham	Karlsruhe	Louvain
B. Webber	M. Seymour	P. Richardson	S. Gieseke	K. Hamilton
A. Sherstnev	P. Richardson	D. Grellscheid	M. Bähr	
S. Latunde-Dada	A. Siodmok	M. Gigg J. Tully	S. Plätzer L. D'Errico	

<http://projects.hepforge.org/herwig/>

<mailto:herwig@projects.hepforge.org>

# Timeline

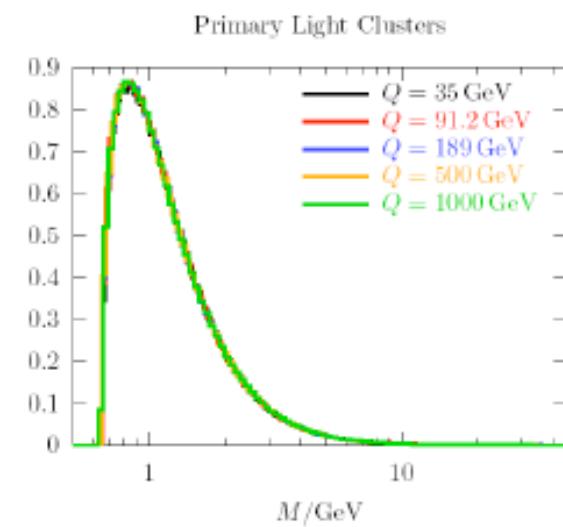
2001	Start in Cambridge/Manchester
2003	First e+e- version [Gieseke, Stephens, Webber, JHEP 03012(2003)045] [Gieseke, Ribon, Seymour, Stephens, Webber, JHEP 0402(2004)005]
2006	First version for hadronic collisions [Gieseke et al., Herwig++ 2.0 $\beta$ , arXiv:hep-ph/0602069] [Gieseke et al., Herwig++ 2.0, arXiv:hep-ph/0609306] [Bähr et al., Herwig++ 2.1, arXiv:0711.3137]
2008	Physics & Manual [Bähr et al., arXiv:0803.0883]
Now	Current version: Herwig++ 2.3.1 - complete simulation of hadronic collisions [Bähr et al., arXiv:0812.0529]
Future	Herwig++ 3.0 a.k.a. <b>Herwig 7</b>

# What's inside?

- ✓ Some useful hard processes available, mainly  $2 \rightarrow 2$  SM and BSM (SUSY, UED, RS). Rest via LH interface
- ✓ Completely new, improved (angular ordered) parton shower

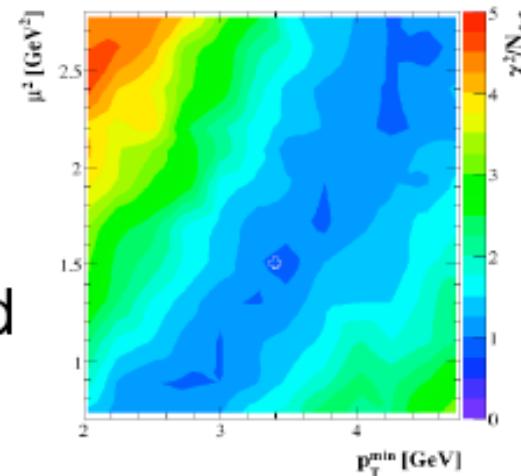
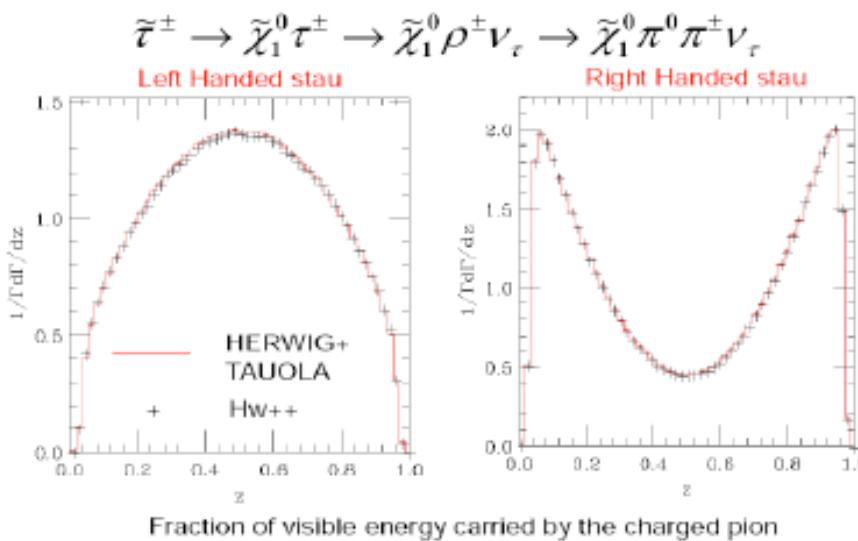


- ✓ ME corrections in  $e^+e^-$ , DY, top decay, Higgs production
- ✓ Cluster hadronization that is based on preconfinement



# What's inside?

- ✓ Underlying Event model (multiple parton-parton interactions) that fits the CDF data very well
- ✓ Hadronic decay model for meson and tau decays, baryon decays will be added soon.

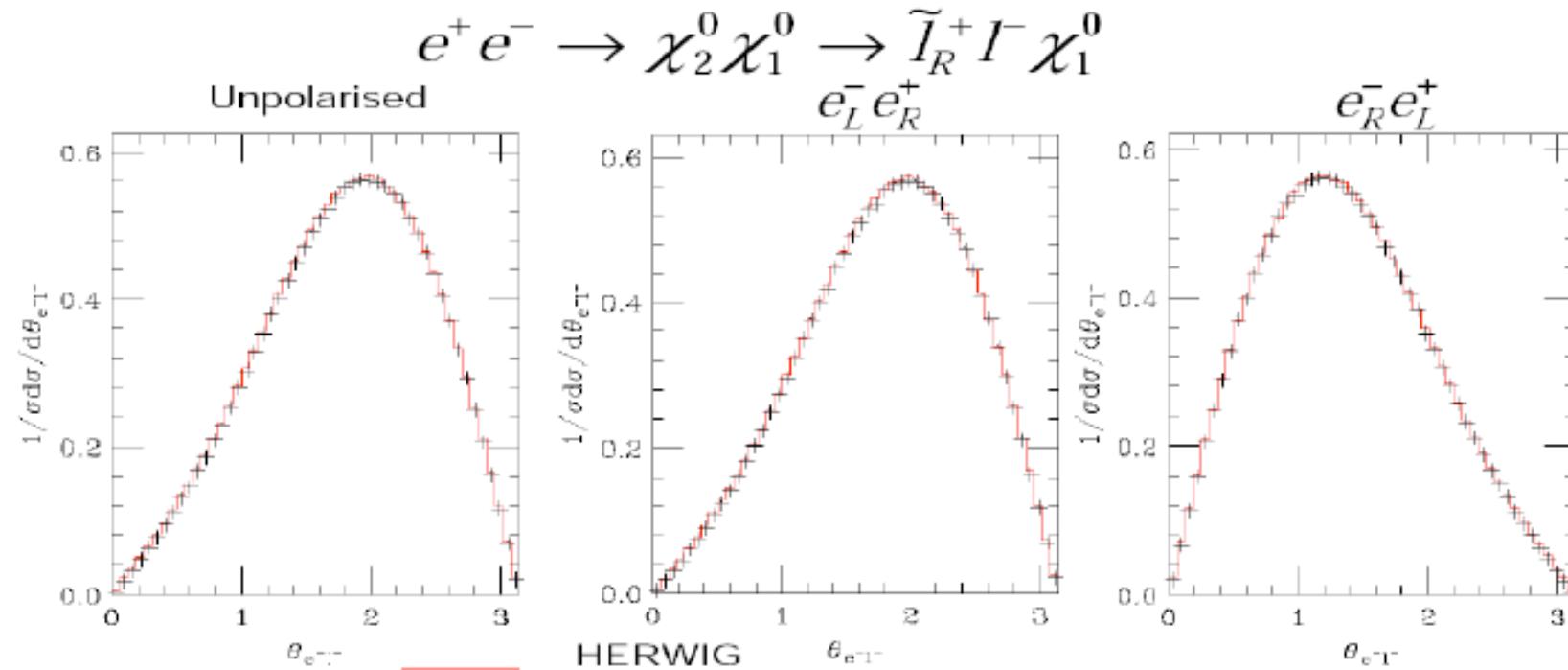


## Decay features:

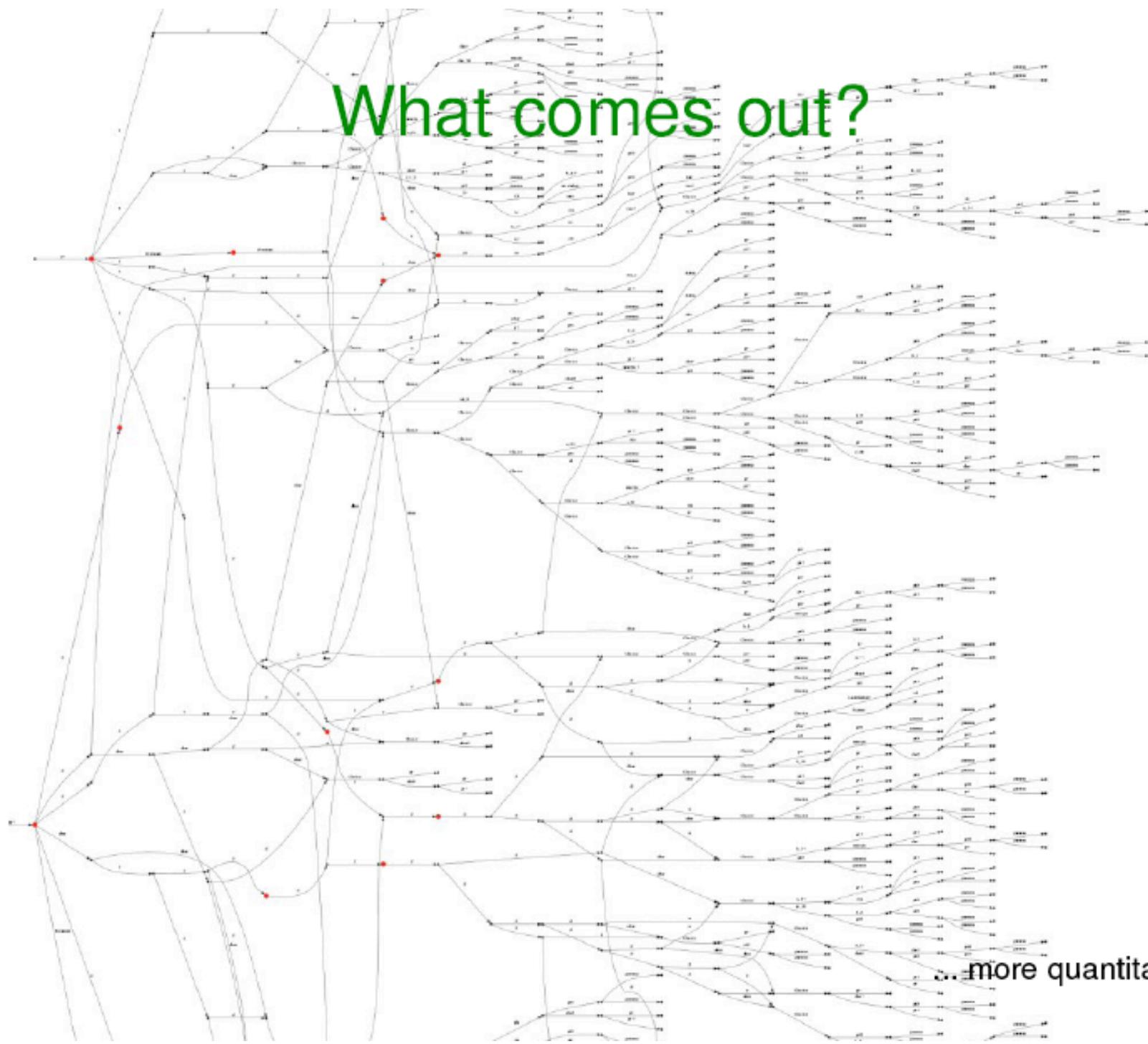
- ✓ decays using PDG'06
- ✓ Spin correlations in all decays (+ perturbatively created taus)
- ✓ Sophisticated treatment of off-shell effects
- ✓ Photon radiation in decays

# What's inside?

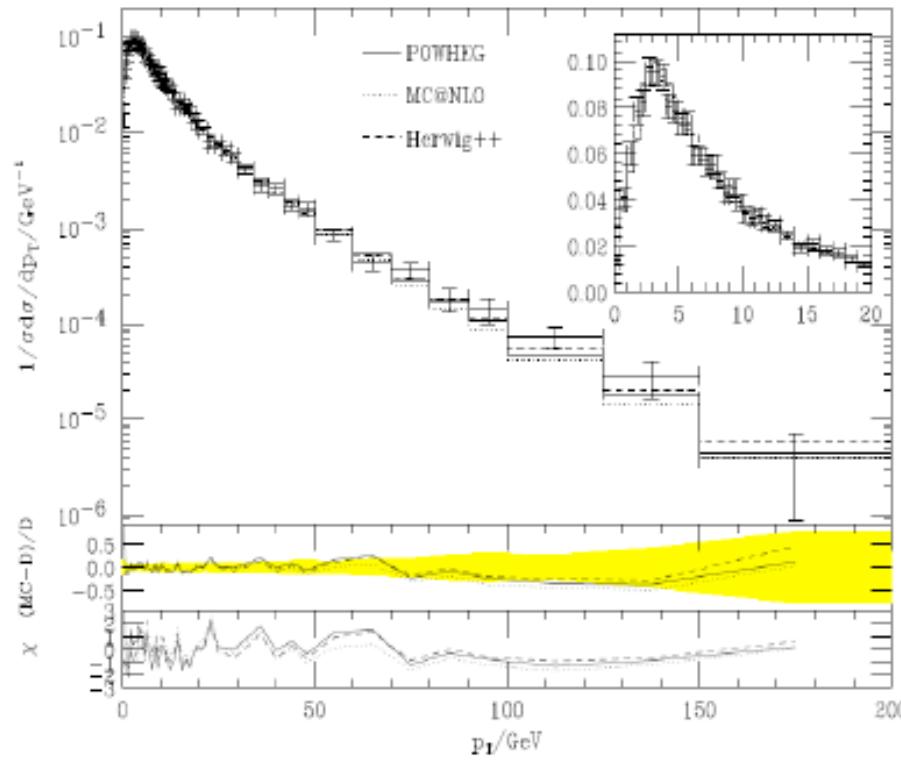
- ✓ Possibility to add a new BSM model by coding its Feynman rules! Includes spin correlations and off-shell effects.



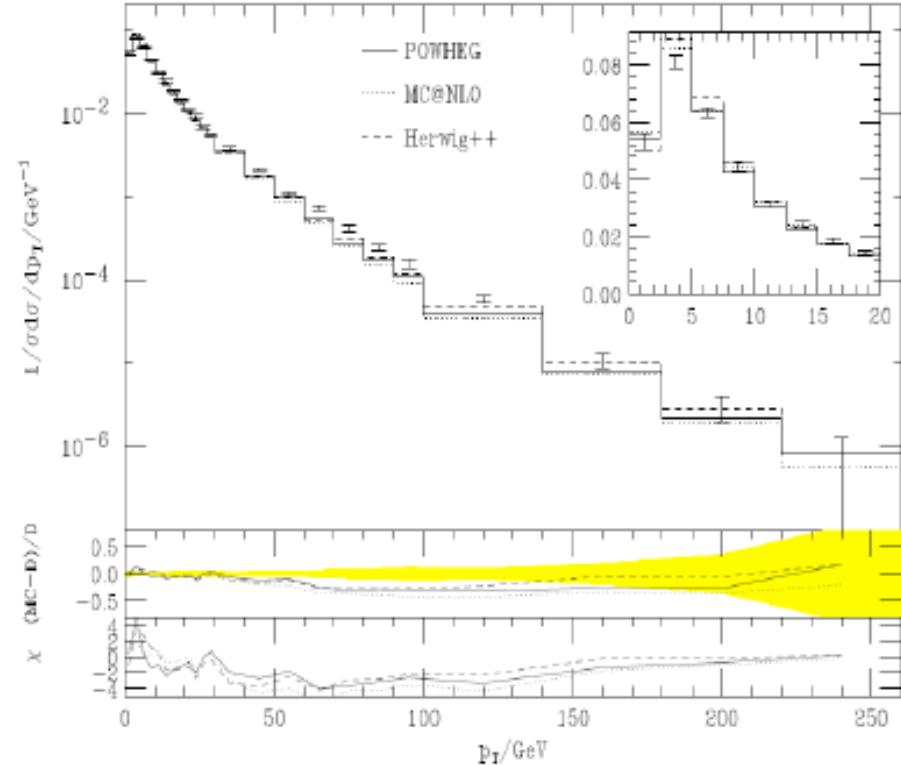
- ✓ Finally, everything has been tuned to LEP, SLD and B-factory data



# POWHEG method for Drell-Yan



CDF Run I – Z p<sub>T</sub> spectrum



D0 Run II – Z p<sub>T</sub> spectrum

[K. Hamilton, P. Richardson and J. Tully, arXiv:0806.0290]

# How can „I“ do all that?

- Download and install (`./configure && make && make install`)
- Get e.g. `LHC.in` from the share directory and do
  - `$HERWIGPATH/bin/Herwig++ read LHC.in (creates LHC.run)`
  - `$HERWIGPATH/bin/Herwig++ run LHC.run -N #events`
- Selecting top pair production (modify `LHC.in`)
  - `cd /Herwig/MatrixElements  
insert SimpleQCD:MatrixElements[0] MEHeavyQuark`
- Switching off Hadronization-Decays-Multiple Interactions
  - `cd /Herwig/EventHandlers  
set LHCHandler:HadronizationHandler NULL  
set LHCHandler:DecayHandler NULL  
set /Herwig/Shower/ShowerHandler:MPI No`
- Information on all possible switches:  
<http://projects.heforge.org/herwig/doxygen/classes.html>

# What's next?

- CKKW matrix element matching
- MC@NLO and POWHEG matching
- Dipole showers
- Initial state massive quarks
- More BSM models
- Multi-scale parton showering

# SHERPA

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## SHERPA

- Developed since 1999, originally ME+PS+Pythia, now self-contained
- Multi-purpose event generator employing CKKW merging formalism  
⇒ Main feature: jet physics
- Most recent version: SHERPA 1.1.2 (August 2008)
- Available on GENIE, in ATLAS, CMS and LHCb; also used for previous and ongoing CDF and D $\emptyset$  studies

## Physics Modules

- AMEGIC – Matrix element generator
- APACIC – Parton shower
- AMISIC – Underlying Event
- AHADIC – Cluster fragmentation
- HADRONS – Hadron and  $\tau$  decays
- PHOTONS – QED radiation in the YFS formalism

## Features

- Fully automated matrix element calculation using helicity amplitudes for processes up to  $2 \rightarrow 6$
- Spin correlated decay chain treatment
- Implemented models: SM, MSSM, ADD, SM+EHC, SM+AGC, Two-Higgs-Doublet, SM + U(1) phantom Higgs
- Externally expandable with additional vertices/models (Technicolor and Little Higgs being worked on by users)
- High performance by writing out optimized matrix elements and dedicated phase space channels into compiled libraries

## Validation

- MC4LHC cross section comparison  
<http://mlm.web.cern.ch/mlm/mcushop03/mcwshop.html>
- $e^+e^- \rightarrow 6f$  comparison with HELAC/PHEGAS  
Eur. Phys. J. C 34 (2004) 173
- MSSM 2  $\rightarrow$  2 comparison with WHIZARD/O'Mega & SMadGraph  
Phys. Rev. D 73 (2006) 055005

### Combining the advantages, avoiding the disadvantages

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

But:

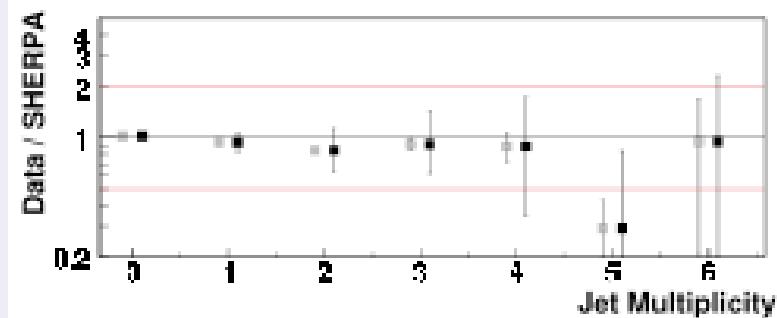
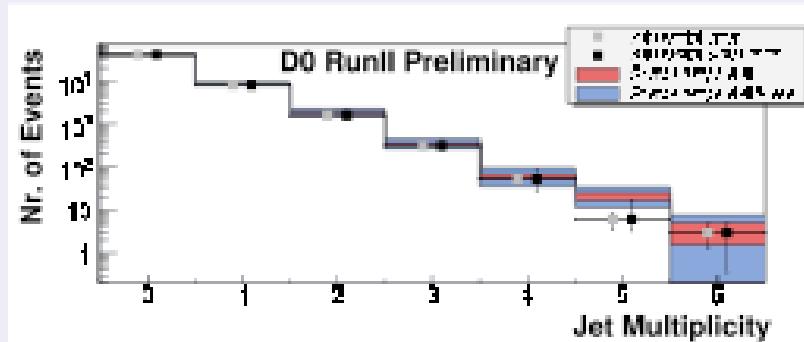
- Avoid double counting of emissions!
- Appropriate scale settings in all steps

### Strategy

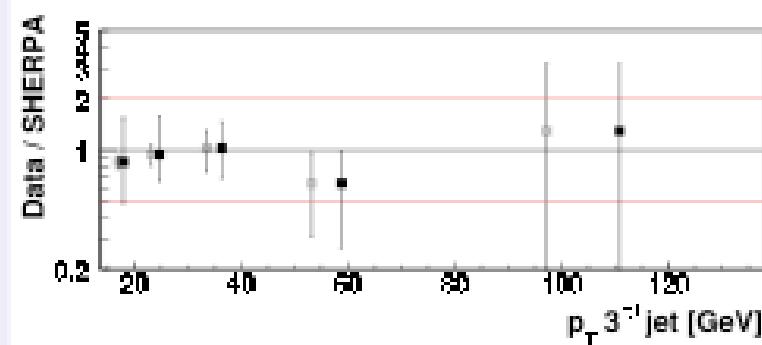
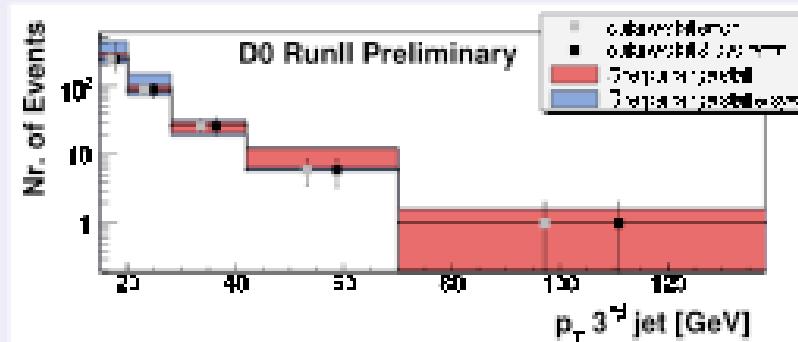
- Separate phase space by  $Q_{\text{cut}}$  ( $k_T$  type measure)
  - Region of jet production: ME
  - Region of jet evolution: PS
- Select final state and kinematics according to cross section above  $Q_{\text{cut}}$
- Backwards clustering to identify core process and "shower history"
- Reweight ME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

⇒ Correct jet observables

### Jet multiplicities



### $p_T$ or 3rd jet



### AMISIC

- Based on the PYTHIA model  
*Phys. Rev. D 36 (1987) 2019*
- Parton showers attached to secondary interactions
- With CKKW: Starting scale for MI evolution  $\mu_{\text{MI}}$  chosen according to  $p_T$  of QCD partons in  $k_T$ -clustered core process
- Veto PS emissions harder than  $\mu_{\text{MI}}$

Although based on the same model as Pythia, tuned parameters can not be re-used, because of different combination with PS and merging with CKKW!

### AHADIC

Cluster fragmentation with the following features:

- Splittings  $\propto \alpha_s(p_\perp)/p_\perp^2$  (non-perturbative tunable/measured  $\alpha_s$ )
- Limit allowed  $p_\perp$  in gluon splitting
- Dynamic cluster-hadron transition boundary
  - Cluster decays  $C \rightarrow CC$
  - Decay product lighter than heaviest matching hadron  $\rightarrow$  Transition to hadron (compensate recoil locally)
  - Initial cluster light enough  $\rightarrow$  Decay to hadron pair
- Include diquarks throughout
- Use dipole splitting kinematics

# Hadron decays: HADRONS, QED radiation: PHOTONS

## HADRONS features

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

## PHOTONS

- Sums all contributions of soft photon radiation (real and virtual) using the Yennie-Frautschi-Suura-Formalism (YFS)  
 $\Rightarrow$  exact as  $k \rightarrow 0$ , 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  
 $V \rightarrow FF, V \rightarrow SS, S \rightarrow FF,$   
 $S \rightarrow SS, \tau \rightarrow \ell\nu_\ell\nu_\tau$
- ME corrections for radiative semi-leptonic meson decays ( $1 \rightarrow 3 + \gamma$ ) under way (form factor model)
- No limitation on final state complexity

## Usage example: Drell-Yan@LHC

### Example run card Run.dat

```
(beam){  
    BEAM_1 = 2212  
    BEAM_ENERGY_1 = 7000.  
    BEAM_2 = 2212  
    BEAM_ENERGY_2 = 7000.  
}(beam)  
  
(processes){  
    Process : 93 93 -> 11 -11 93(3)  
    Order electroweak : 2  
    End process  
}(processes)  
  
(selector){  
    JetFinder sqr(20/E_CMS) 1.  
    Mass 11 -11 66 116  
}(selector)
```

- Z-production with up to 3 jets inclusively
- CKKW merging done automatically, only specify JetFinder with  $Q_{cut}$
- Run in 3-step-procedure:
  - **Sherpa**: process library write-out
  - **./makelibs**: library compilation
  - **Sherpa**: library read-in, integration and event generation

## Outlook

### Immediate future ⇒ version 1.2 (< 6 months)

- New high multiplicity matrix element generator: COMIX
- Shower based on Catani-Seymour dipole factorisation: CSSHOWER
- Merging between all combinations of shower and matrix element generators
- Inclusive decays, including spin correlations, finite width treatment

<http://sherpa-mc.de>

- Downloads
- Announcement mailing list
- Documentation
- Bug tracker

# Summary

- Rivet: generator-independent generator validation against corrected data/analysis framework
- Pythia 8:  $p_T$ -ordered dipole-style shower; string hadronization; interleaved multiparton interaction model; simple standalone structure
- Herwig++: Lorentz-invariant quasi-collinear angular-ordered parton shower; cluster hadronization; multiparton interactions; built on ThePEG
- Sherpa: CKKW matching built in from start; high-order matrix elements; cluster hadronization; multiparton interactions; standalone

Parton Shower MCs 4



Mike Seymour

