

# HERA AND THE LHC

A workshop on the implications of HERA for LHC physics

## HERA-LHC Workshop 2: Heavy Quarks Jets and Energy flows Monte Carlo tools

Parton density functions  
Multijet final states  
and energy flows  
Heavy quarks  
Diffraction  
Monte Carlo tools

Startup Meeting  
March 25-27 2004  
Pre-Workshop Meeting  
11-13 October 2004  
CERN, Geneva  
Final Meeting  
January 2005  
DESY, Hamburg

Mike Seymour  
Manchester/CERN

TeV4LHC

September 17<sup>th</sup> 2004

[www.desy.de/~hera+lhc](http://www.desy.de/~hera+lhc)

[hera+lhc.workshop@cern.ch](mailto:hera+lhc.workshop@cern.ch)

# HERA-LHC workshop

- Heavy quarks
  - Heavy Quark production: charm, beauty, quarkonia
  - Heavy Flavour Fragmentation
  - Heavy Quark Parton Distribution Functions
  - Triggering on Heavy Flavour processes
- Multi-jet final states and energy flows
  - Underlying event and minimum bias
  - Rapidity gaps and survival probabilities
  - Multi-jet topologies and multi-scale QCD
  - Parton shower/ME matching
- Monte Carlo tools
  - General Monte Carlos
  - PDF Libraries
  - NLO Calculations
  - Monte Carlo Programs with kt Factorization
  - Diffraction
  - MC Validation and Tuning
  - Next Generation Generators

## HERA-LHC workshop

### *Working Group 3*

### *Heavy quarks (charm and beauty)*

#### ▶ HQ production: charm, beauty, quarkonia

- ▶ Theory: massive vs massless approach, kT factorization.
- ▶ Measurements-HERA: results and comparison with theory.
- ▶ Measurements-LHC: strategies, potential and uncertainties
- ▶ QQbar correlations: tests for theory, HERA c $\bar{c}$ , LHC perspectives.
- ▶ MC tuning with HERA data (using Jetweb).
- ▶ Nonlinear effects in gluon evolution: fits to HERA data, possible detection at LHC via charm enhancement

#### ▶ HF Fragmentation

- ▶ HERA fragmentation measurements and future potential
- ▶ Tests of fragmentation descriptions in a hadronic environment
- ▶ HF Fragmentation tuning in MC on HERA+LEP data and how to use it for LHC

#### ▶ HQ PDF's

- ▶ Overview of HERA HF str. functions measurements and future HERA potential.
- ▶ Theory vs HERA data. Predictions & uncertainties for LHC.
- ▶ Kinematical coverage of LHC experiments.
- ▶ New processes sensitive to HQ PDF e.g. b $\bar{b}$   $\rightarrow$  Higgs, etc..

#### ▶ Triggering HF processes

- ▶ Triggering and Data acquisition HERA and HERAb experience
- ▶ LHC HF Trigger strategies and uncertainties in rates
- ▶ Backgrounds determination and elimination at trigger and in the offline analyses.

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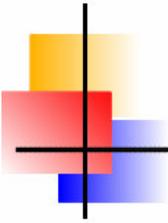
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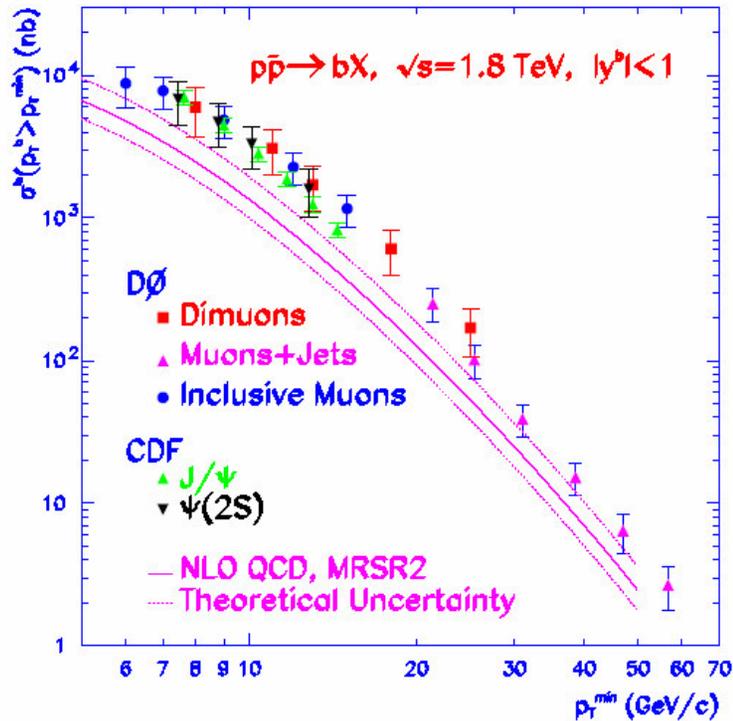


# *b* quark $p_T$ spectrum at Tevatron

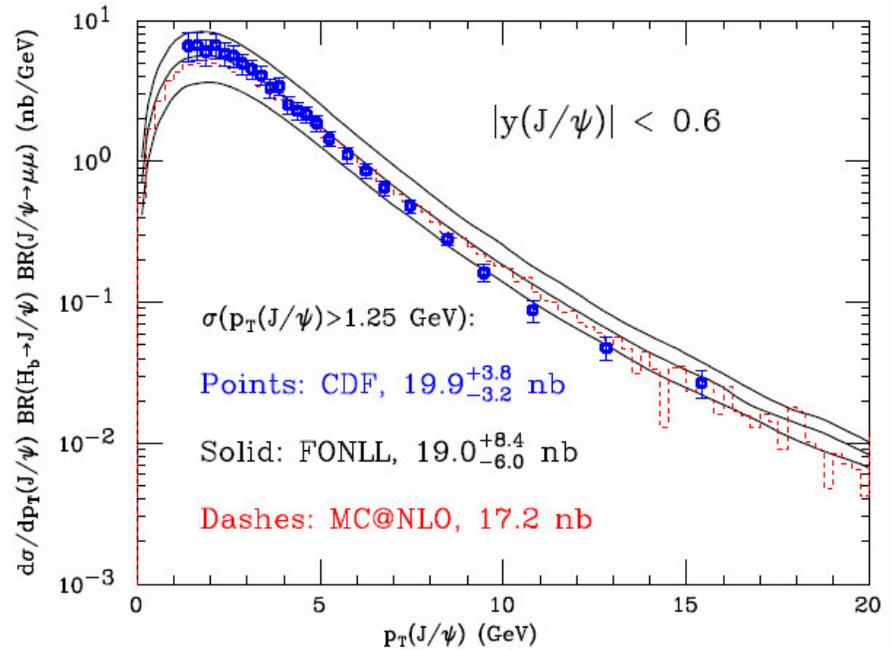
now seems to be ok **Cacciari, Nason!** Combination of

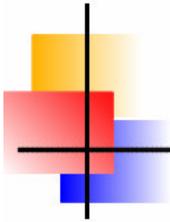
- ▶ proper FF use
- ▶ NLL  $\ln(p_T/m)$  resummation

It was



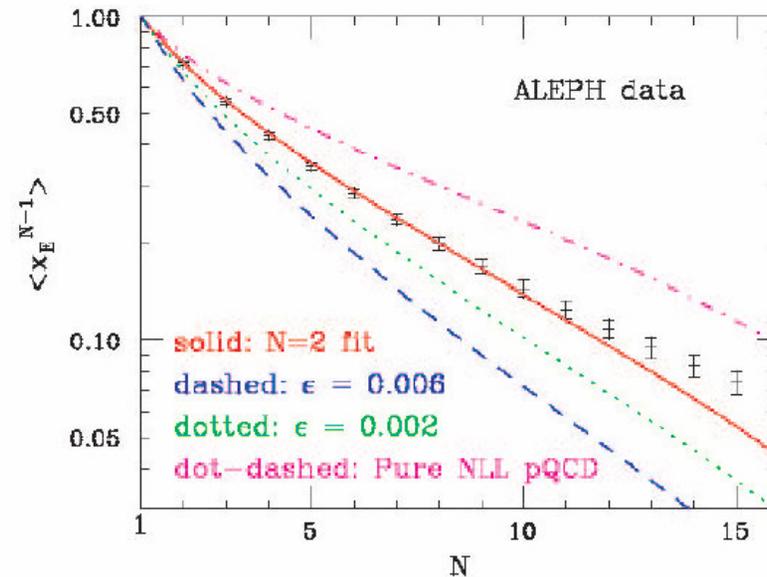
It is now **Cacciari, Frixione, Mangano, Nason, Ridolfi**





## Appropriate fits

In addition, rather than fit  $\epsilon_P$ , i.e. the whole FF *function*, it is better to fit only dominant moments of  $D_{Q, NP}^H$  to  $e^+e^-$  data. This gives already a much better description there.



Peterson Fragmentation Function  $\sim$  ruled out!

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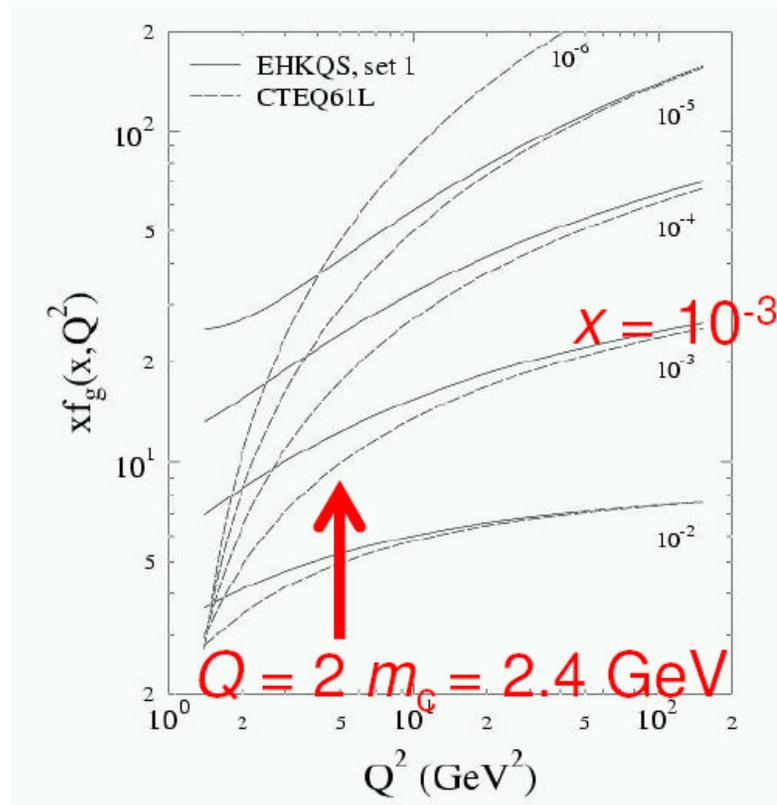
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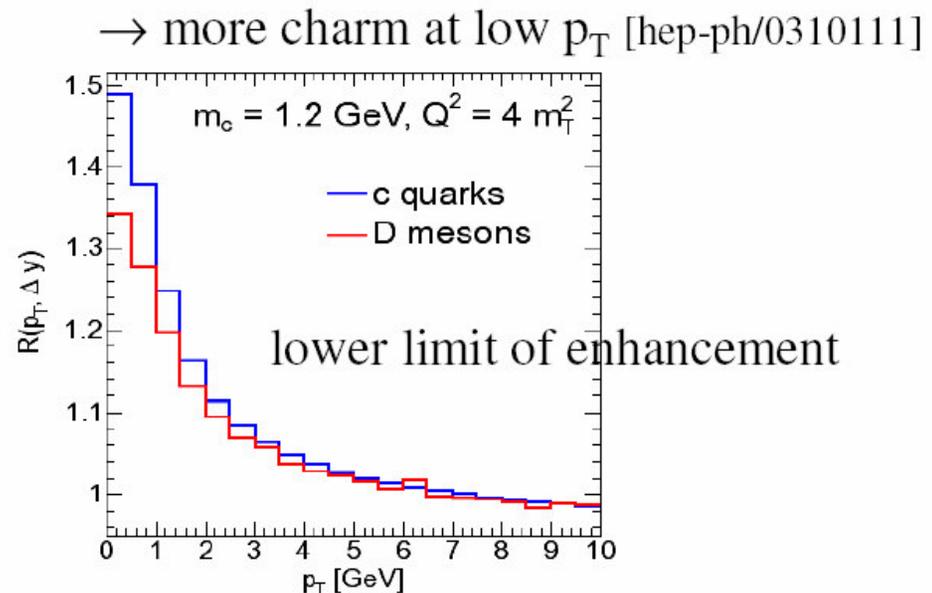
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# Charm enhancement at LHC due to nonlinear gluon evolution



- Fits to HERA  $F_2$  data at small  $x$ , small  $Q^2$  improved by adding nonlinear terms (nonDGLAP) to gluon evol. [hep-ph/0211239]
- At LO, implies higher  $xf_g$  in  $x$  region probed by LHC



- ALICE can reconstruct D mesons down to  $p_T \approx 0$  and look for the effect [hep-ph/0403098]

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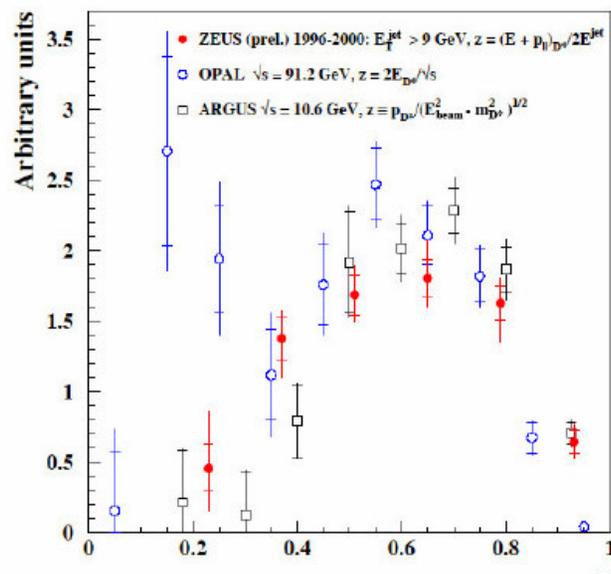
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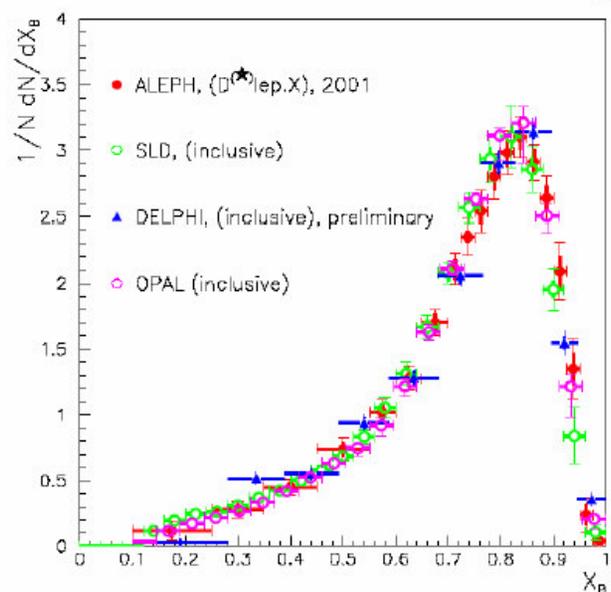
# HQ Fragmentation



Lots of data on heavy quark fragmentation:

Different energies: 10  $\rightarrow$  90 GeV

Different quark: charm and bottom



Many theoretical descriptions exist:  
 Fixed order, resummed, with power corrections, with phenomenological Models, from MC hadronization

# HQ Fragmentation

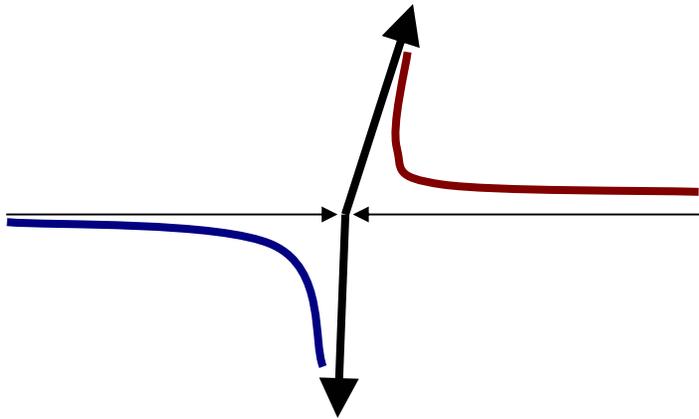
Tests/things to be done:

- Perturbative scaling from low to high energy
- Non-perturbative scaling from charm to bottom
- Universality of non-perturbative component
- Tuning of non-perturbative component  
(I.e.hadronization) in MC
- Check fragmentation picture in hadronic environments  
(HERA/Tevatron/LHC)

HERA can be a very useful mid-point between  $e^+e^-$  collisions and full hadronic collisions at Tevatron/LHC

# Fragmentation/Hadronization in the Hadronic Environment

- Fragmentation function usually measured in  $e^+e^-$  collisions
- Hadronic environment not same due to colour structure



- “String reacceleration”
- Conventional NLO approach:
  - convolutions always reduce collinear momentum fraction
- Cacciari/Nason considered non-covariant momentum fractions  
→ Consider in dipole rest-frame?

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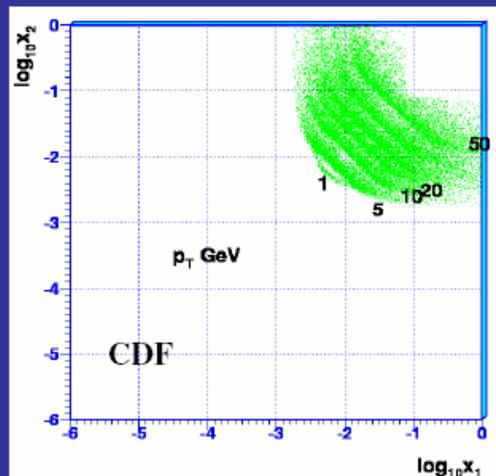
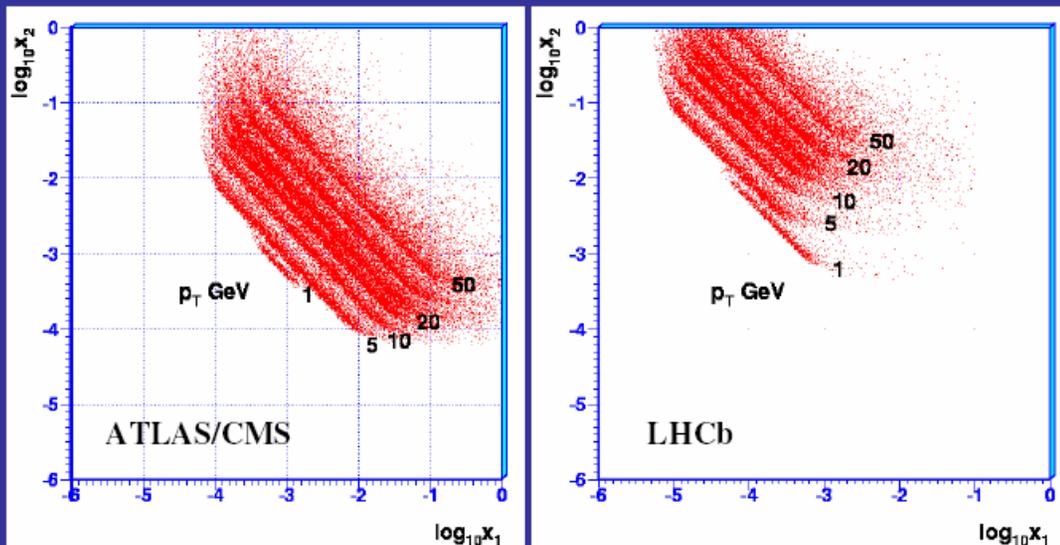
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# Parton kinematics for b-events: ATLAS/CMS/LHCb vs CDF



- Bjorken  $x_1$  vs  $x_2$  for events where one of B hadrons passed trigger & offline cuts

- ATLAS/CMS X down to  $10^{-4}$   
Starts from  $p_T > 10$  GeV – the picture shows also lines for lower  $p_T$  just to demonstrate that minimal x doesn't change below 10 GeV.

- LHCb most sensitive to knowledge of structure functions at x as low as  $10^{-5}$

- CDF x-range for b-prod. within  $10^{-3}$   
LHC 1-2 orders lower although not all the LHC statistics at the limiting x

- HERA may cover the LHC x range

# Monte Carlo Tools

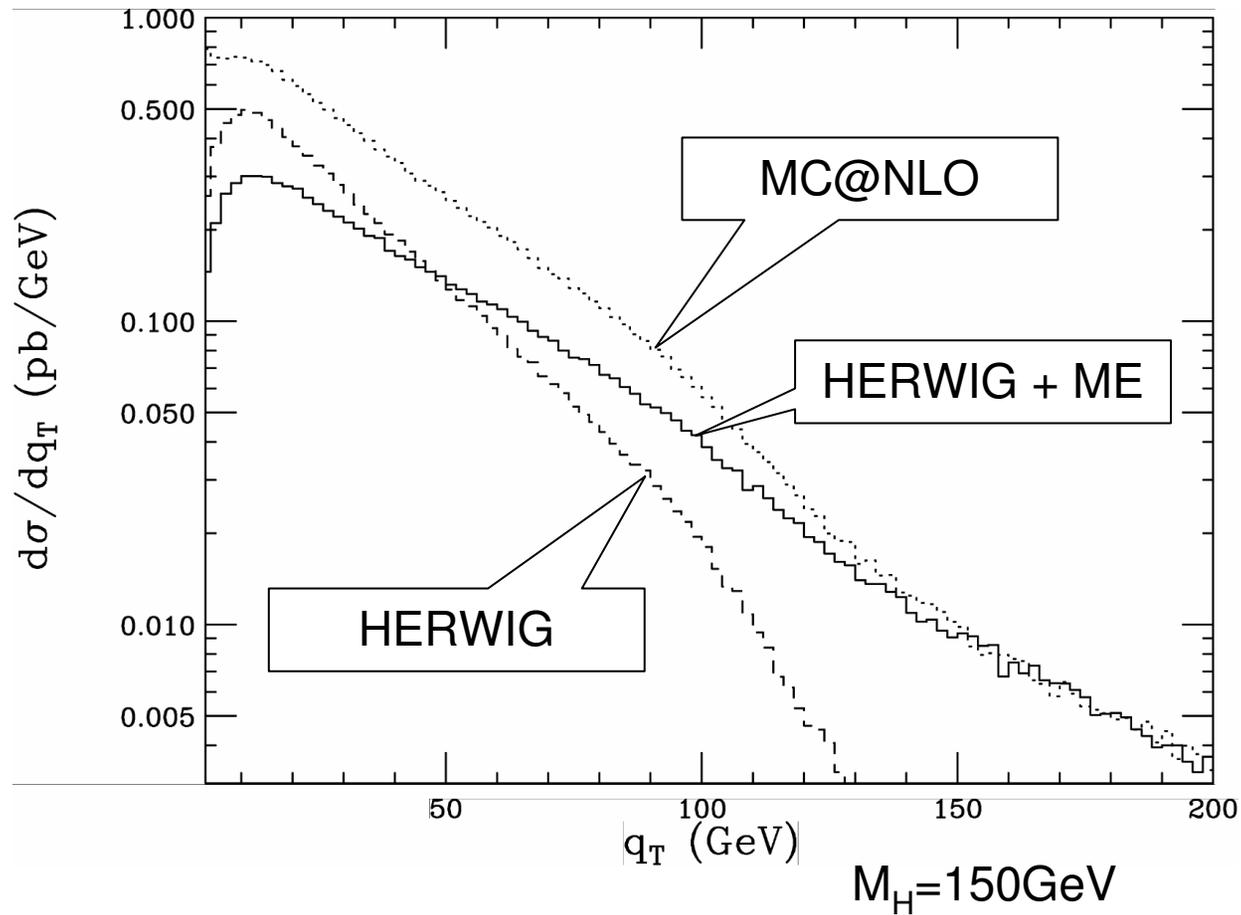
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  - Next Generation Generators
    - ThePEG
    - Pythia7
    - HERWIG++
    - SHERPA
- Steve Mrenna  
(QCD session)

# Status of HERWIG

- ‘Frozen’: HERWIG6.5 will be the final FORTRAN version
- Under development: recent or forthcoming features:
  - Clean interface to Jimmy generator for multiple interactions
    - Jimmy works in underlying event mode for the first time  see later
  - Bug fix in matrix element correction code for W/Z production
    - affects lepton kinematics only  see later
  - Matrix element corrections for Higgs production 

# Matrix Element Corrections to $gg \rightarrow \text{Higgs}$

G. Corcella, S. Moretti, in progress



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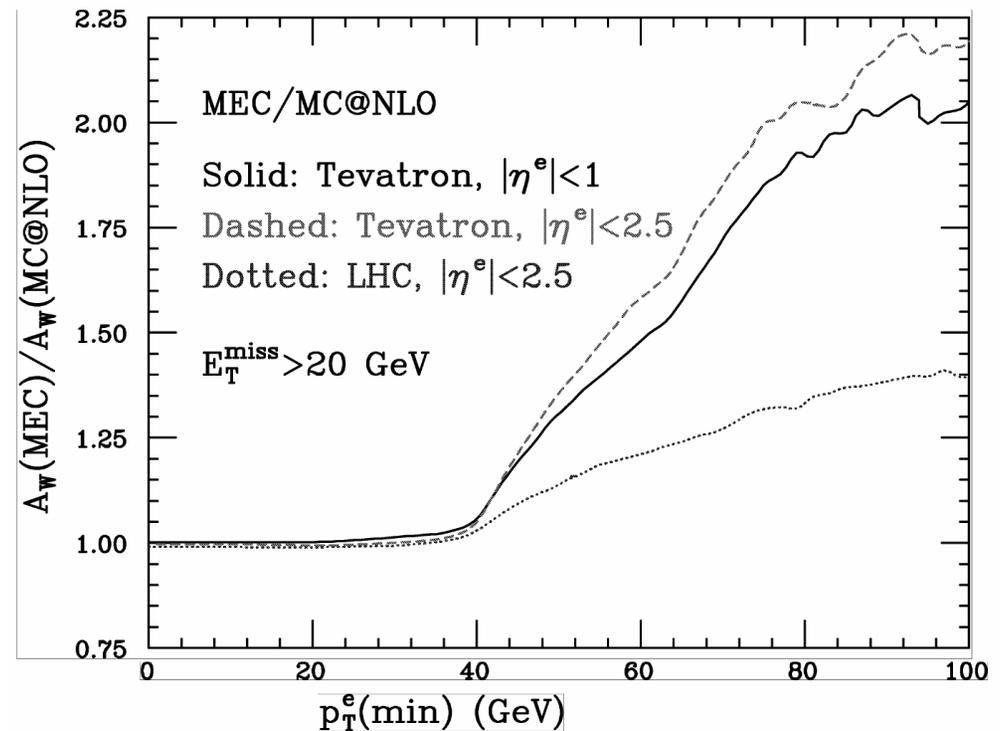
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Bryan  
Webber

# MC Validation – W selection efficiency

Frixione, Mangano, MHS

- Total W cross section extremely well predicted
- Differential distributions known accurately enough to correct for efficiency? (SF, MLM study: NLO and MC@NLO)
- HERWIG + ME vs NLO:
- Bug in lepton orientation (for fixed W kinematics)
- New study in progress...

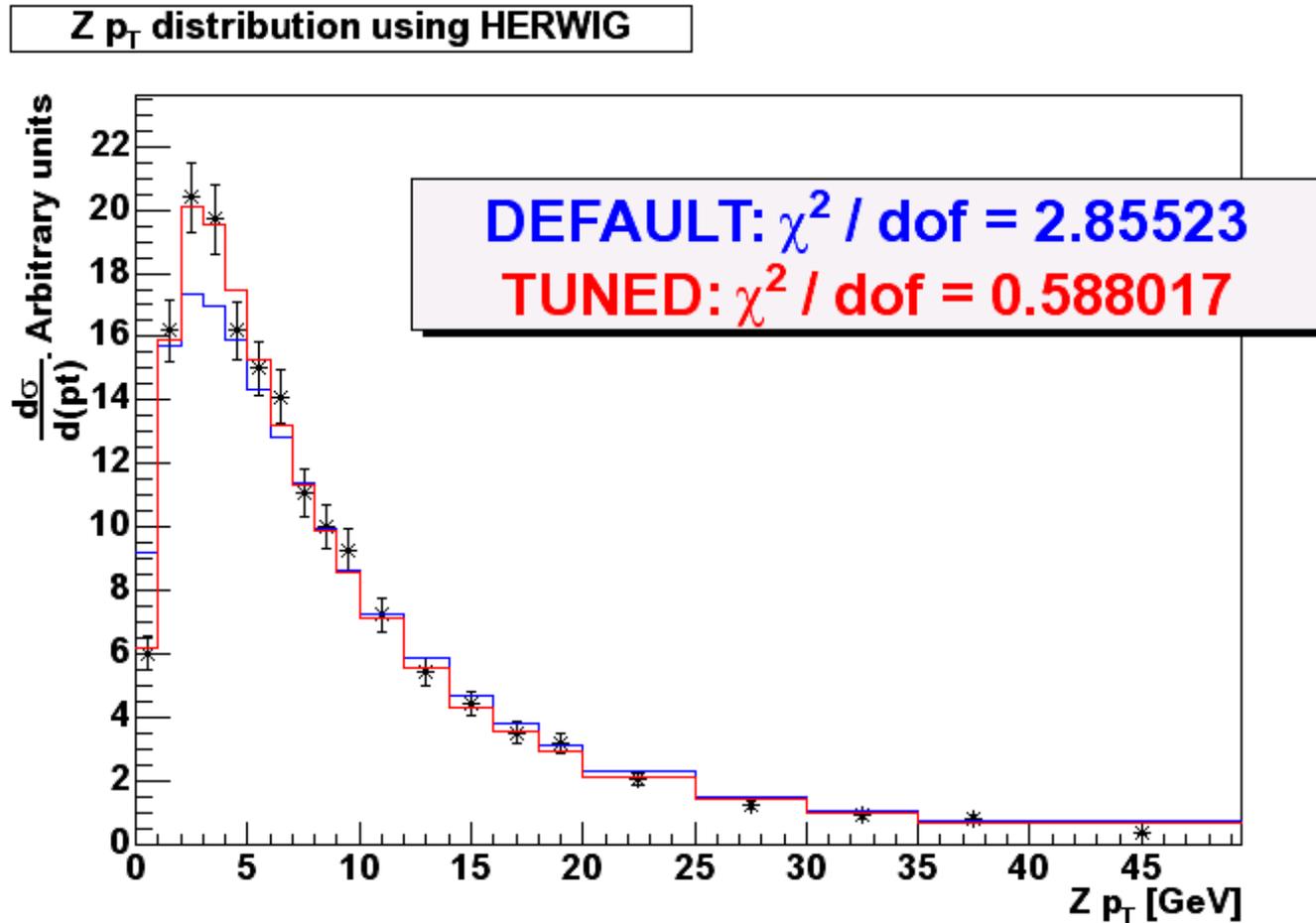


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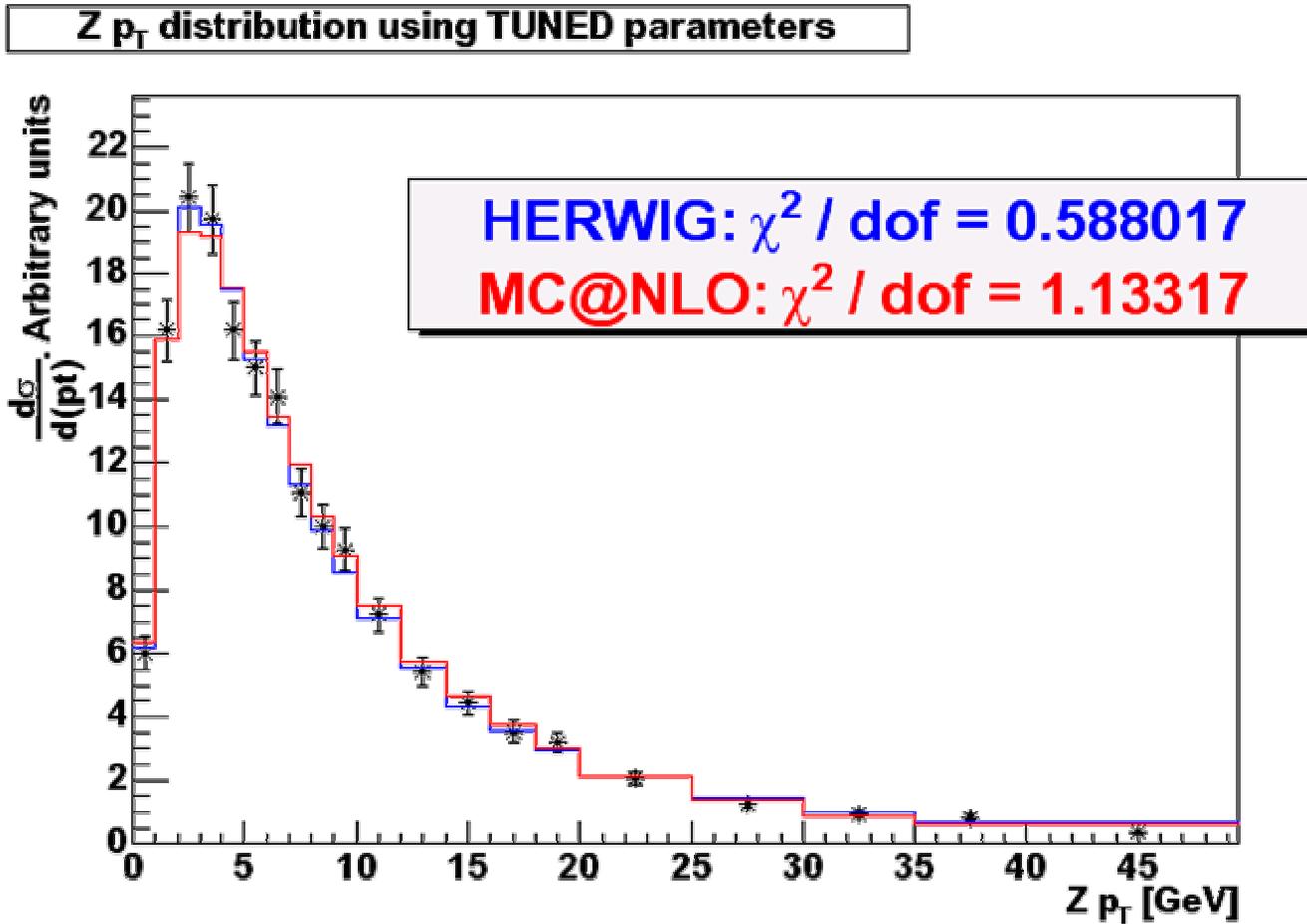
# Tuning HERWIG on W/Z pt distributions

E.Nurse, MHS



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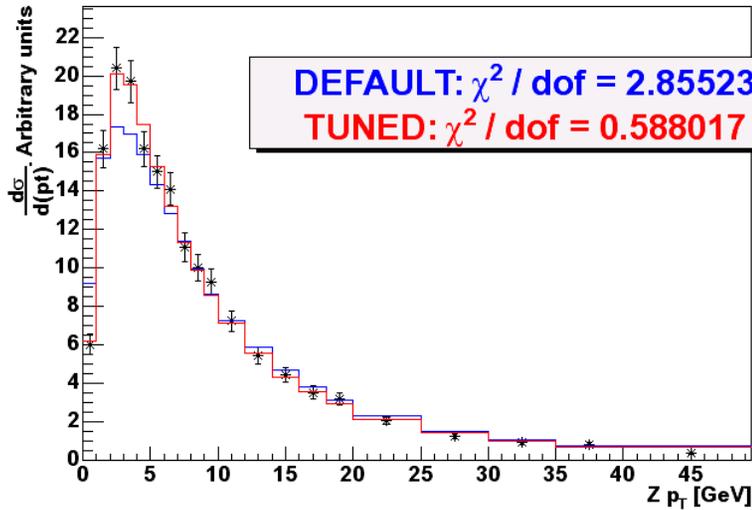
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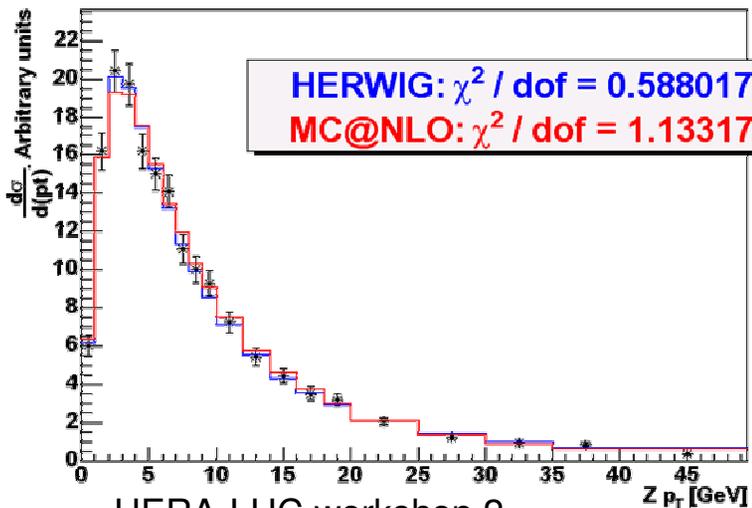
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E.Nurse, MHS

Z p<sub>T</sub> distribution using HERWIG



Z p<sub>T</sub> distribution using TUNED parameters



	PTRMS	QCDLAM	VQCUT
DEFAULT	0.0	0.18	0.48
HERWIG TUNE	1.6	0.14	0.19
MC@NLO TUNE	1.35	0.19	0.50

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# HZTool and JetWeb

- HZTool
  - Monte Carlo tools for HERA Physics workshop 1998/9
  - Subroutine package: one for **every** H1/ZEUS published analysis  
(and some UA5, CDF, OPAL  $\gamma\gamma$ , ...)  
written by principle author of the analysis
  - Input: Hadronic events in HEPEVT format
  - Output: KUMAC for figure with data and model
  - Result:
    - Anyone can compare their new/tuned model with your data without scouring your paper for every last cut and definition or variables
    - Openness about cuts, algorithms...

# HZTool and JetWeb

- HZTool
- JetWeb
  - Web based front-end for HZTool, for validation/tuning of MC models and database of model tunings and results
  - At present semiautomatic:
    - can request runs of standard MC generators with your parameters
    - new generators/versions have to be implemented by librarian
  - Demonstration: <http://jetweb.ucl.ac.uk/>
- CEDAR
  - Next generation: full integration of JetWeb with Durham database of particle reactions

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# JetWeb

Automated Data Comparisons for High Energy Physics



18/02/04: This server is currently read-only. See [news](#) for details.

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## best fits, all data

- [HERWIG](#)
- [PYTHIA](#)

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## summaries, all fits

- [HERWIG latest](#)
- [PYTHIA latest](#)
- [HERWIG all](#)
- [PYTHIA all](#)

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## documentation, downloads

- [Latest News](#)
- [Bibliography](#)
- [Generator Parameters](#)
- [Developer Resources](#)

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## simulations

- [HERWIG](#)
- [PYTHIA](#)

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## experiments

- [HERA\(H1,ZEUS\)](#)
- [LEP \(OPAL\)](#)
- [Tevatron \(CDF, D0\)](#)
- [HEPDATA](#)

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[Search the DataBase](#)

[Maintenance](#)

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## Selected Results

- [Studies for a Future Linear Collider](#)
- [Minimum PT of hard scatters](#)
- [Intrinsic KT photon/proton](#)
- [PYTHIA parton showers PARP67](#)
- [Parton Distribution Functions in Photon](#)
- [HERWIG Soft Underlying Event](#)
- [HERWIG Photon Radius](#)
- [HERWIG fragmentation parameters \(CLMAX,PSPLT\)](#)

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If you do use any results from here, please quote [Comp. Phys. Comm. vol 153/2 164-178 \(2003\)](#)

The current focus of this project is on jet and heavy flavour production in hadron-like collisions (which includes hadron-photon and photon-photon). There is no reason why other data shouldn't be incorporated though.

If you'd like join in, or have any comments or suggestions please [contact us](#) at [jetweb@hep.ucl.ac.uk](mailto:jetweb@hep.ucl.ac.uk)

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The story so far:

6410 jobs submitted to Manchester PBS, 5782 completed  
2800 jobs submitted to UCL PBS, 2598 completed  
171 jobs submitted to UCL NQS, 142 completed  
68 jobs submitted to GridPP, 35 completed  
641 jobs submitted to Sheffield PBS, 536 completed

# Monte Carlo Tools

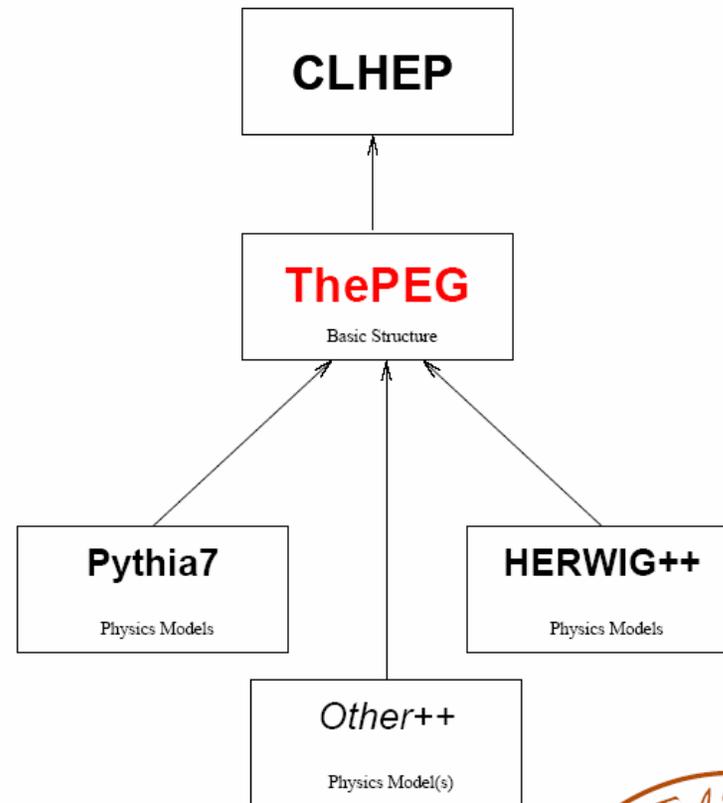
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# THEPEG & future Event Generators

THEPEG consists of the parts of PYTHIA7 which were not specific to the PYTHIA physics models. It provides a general structure for implementing models for event generation.

Both PYTHIA7 and HERWIG++ are built on THEPEG.

But it is open for anyone...



# Status

**THEPEG** version 1.0 $\alpha$  exists and is working. Snapshots of the current development code is available from <http://www.thep.lu.se/ThePEG>.

**PYTHIA7** is now based on THEPEG. Version 1.0 $\alpha$  exists and is working. Snapshots of the current development code is available from <http://www.thep.lu.se/Pythia7>.

**HERWIG++** is also based on THEPEG. Version 1.0 exists and is working. Can be obtained from <http://www.hep.phy.cam.ac.uk/theory/Herwig++/>.



PYTHIA7/THEPEG (L.L., T. Sjöstrand) includes some basic  $2 \rightarrow 2$  matrix elements, a couple of PDF parameterizations, remnant handling, initial- and final-state parton showers, Lund string fragmentation and particle decays.

HERWIG++ (S. Gieseke, A. Ribon, P. Richardson, M. Seymour, P. Stephens, B. Webber) includes a new parton shower algorithm, improved cluster fragmentation. Mainly  $e^+e^-$ , but initial-state PS is coming.



# SHERPA

SHERPA is an alternative C++ framework for event generation developed by F. Krauss et al.

It is a simpler design than THEPEG, and may have a lower learning threshold.



# Multi-jet final states and energy flows

- Underlying event and minimum bias
- Rapidity gaps and survival probabilities
- Multi-jet topologies and multi-scale QCD
- Parton shower/ME matching

Bryan Webber  
Frank Krauss

# Underlying Events at HERA

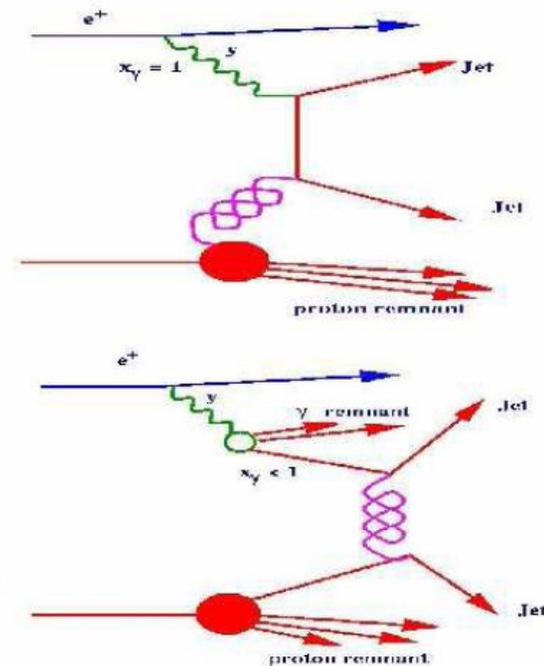
- photon  $\approx$  hadron but with point-like coupling to quarks and non-zero virtuality
  - an extra complication
  - an extra diagnostic handle
- Varying  $x_\gamma$  (fraction of photon's energy used in hard process) tunes underlying event on/off
- Underlying event in (small-x) DIS?

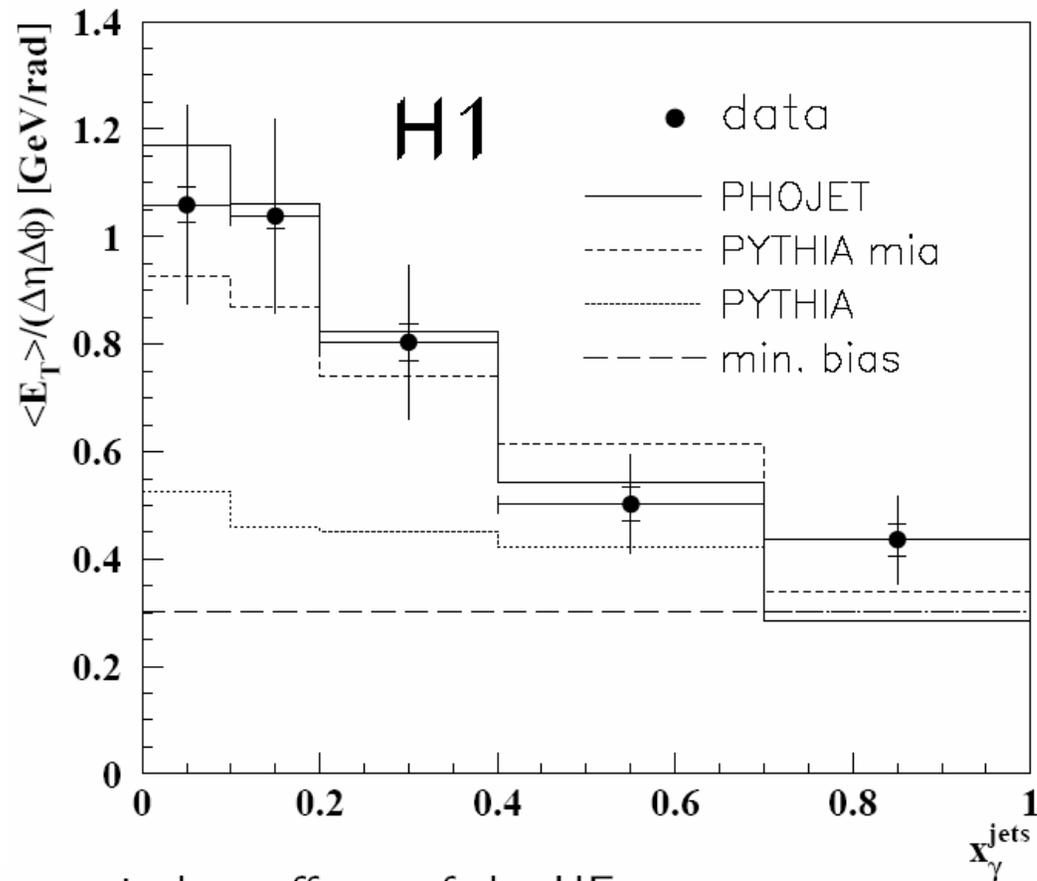
# Where is the underlying event at HERA

In photoproduction, HERA behaves just like a hadron-hadron collider.

Almost on-shell photon from the electron fluctuates into a vector meson state and collides with the proton.

The photon may also interact directly with partons in the proton and we can control which happens by looking at  $x_\gamma$ , the fraction of the photon momentum which goes into the hard scattering.





- We can vary  $x_{\gamma}$  to isolate effects of the UE
- We can study the dependence on CM energy
- We can let the photon go off-shell and study *perturbative* multiple scatterings – related to saturation.



# Underlying Events – Recent Progress

- **HERWIGv6.505 + Jimmy v4.1**  
(<http://hepwww.rl.ac.uk/theory/seymour/herwig/>)
  - Plug and play add-on to HERWIG
  - Simulates underlying event in high- $E_t$  jet processes and any other hard process correctly (for first time!)
- **Sjöstrand and Skands completely new model for multiple interactions in PYTHIA** (JHEP 0403:053,2004 and [hep-ph/0408302](http://arxiv.org/abs/hep-ph/0408302))
  - Includes completely new initial-state cascade model
  - Colour (re)connection within and between interactions
  - Multiple interactions within one parton-parton collision
- **Borozan and MHS model of multi- hard and soft scatters**
  - Proof of principle for possible future model...

# Underlying Events – Work in Progress

- **Understanding Jimmy**
  - small-x partons play a huge role
    - eg PTMIN=3 GeV @ LHC probes  $x \sim 10^{-7}$
  - proton radius parameter from Godbole et al model?
- **Understanding new PYTHIA**
  - huge job! Need to tune
    - new initial state shower?
    - colour connection options?
    - matter distribution?
- **New models**
  - SHERPA (Frank Krauss et al)
  - Jimmy+Ivan → HERWIG++
  - Multiple interactions in the LDC model (Leif Lönnblad)

# Summary

- HERA may be our last chance for high-energy ep collisions for a long time to come
- Now may be our last chance to design/influence HERA analyses
- HERA-LHC workshop has plenty of overlap with TeV4LHC
  - Opportunity to learn from each other (and get to know each other!)
  - Opportunity to duplicate effort and reinvent the wheel
- Monte Carlo tools and underlying events are big topics