Tools for BSM

Frank Krauss

IPPP Durham

DIS08, London, 9.4.2008

Outline

1. Subject of the talk: New event generators
2. Parton level event generators
3. Merging matrix elements + parton showers
4. Improved treatment of chains in Herwig++
5. Propaganda: Introducing SHERPA
6. Conclusions

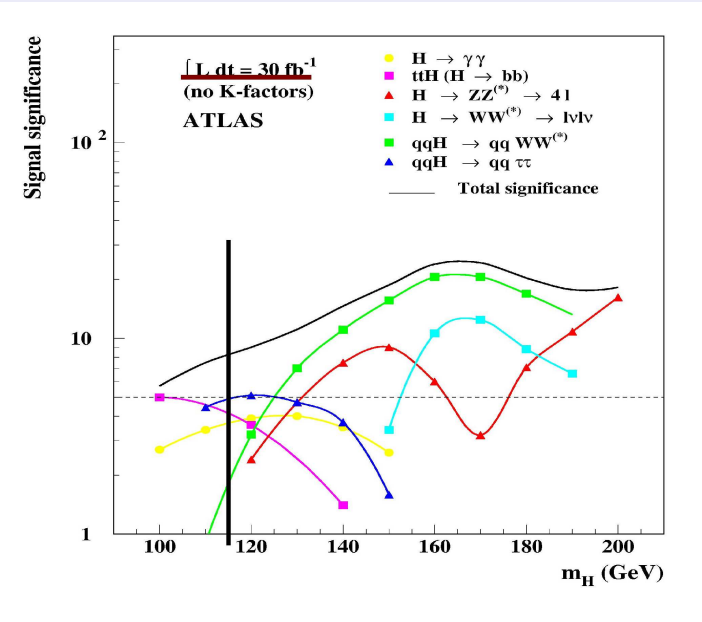
Why simulate events?

Reminder: Physics @ LHC

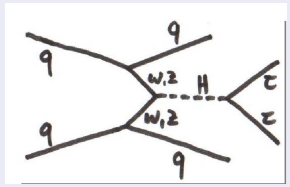
- Many interesting signals:
  Higgs (or alternative EWSB), SUSY, ED's, ...
- But: Severe backgrounds in nearly all channels,
  (almost always with large influence of QCD)
  $\Longrightarrow$ depend on detailed understanding of QCD.
- Examples:
  - Central jet-veto in VBF (Higgs)
  - Multi-jet backgrounds for SUSY (e.g. Z+jets)
- Todays signals = tomorrows backgrounds.

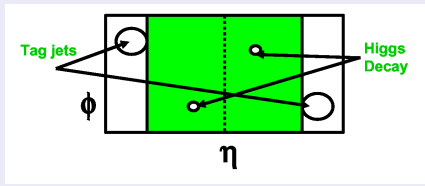
Why simulate events?

Higgs searches



Central jet veto in VBF





- Signal/background ratio depends on central jet veto.
  (rapidity gap between two "tagging jets", beautiful signal at leading order)
- But: How many jets come at higher orders?
  $\Longrightarrow$ currently studied.

Why does anyone write a new event generator?

New tools on the market: Pythia8, Herwig++, Sherpa
Reflecting increased needs (precision, new physics, etc.):

- getting rid of old errors (having new ones)
- easier implementation of new physics models
- incorporate new, better methods!
- systematic inclusion of HO QCD

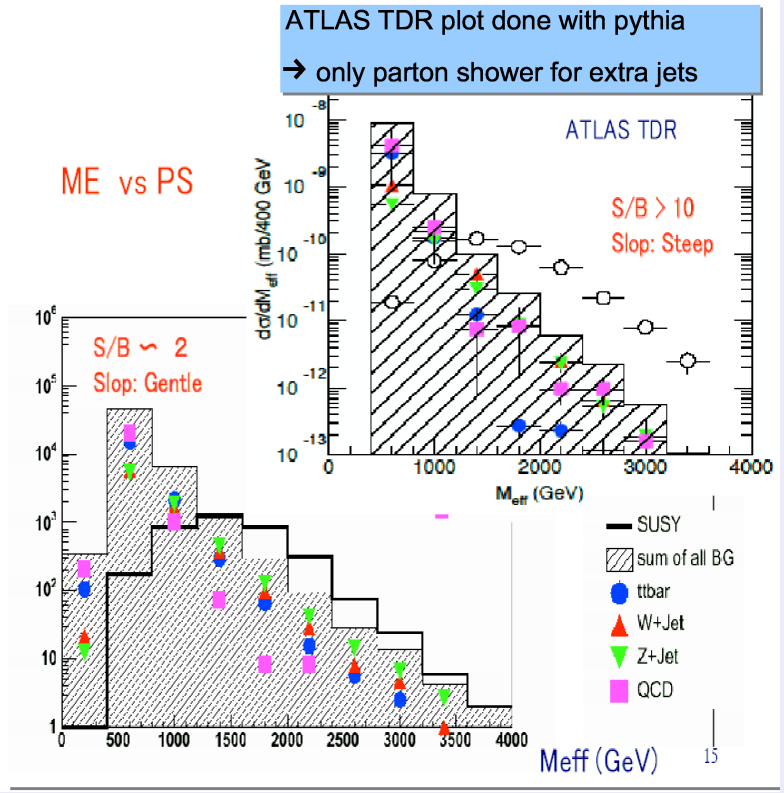
Physics improvement (1): Flexibility with BSM models

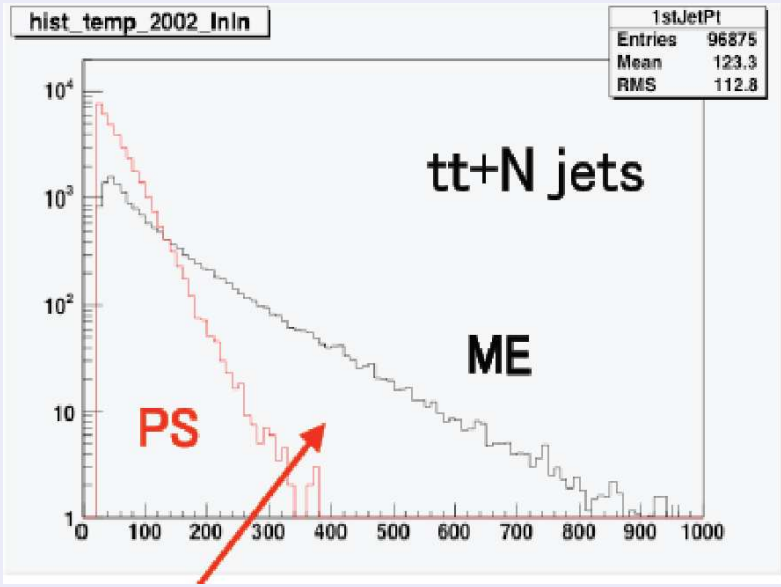
- For parton-level generators (like MadGraph etc.):
  Aim at "direct" link from model Lagrangian to relevant Feynman rules in format accessible to the generator.

  $\Longrightarrow$ in preparation (C.Duhr, S.Schumann, etc.)
- In Herwig++: Build a library of **all** possible/relevant $2 \to 2$ production and $1 \to 2, 3$ decay matrix elements.
- Not to forget: standardization (LesHouches formats) helps.
  Examples: Output of MSSM spectrum generators and parton-level matrix elements (straightforward for the former, more tricky for the latter: handling the shower).

Physics improvement (2): The impact of HO QCD

Example: SUSY searches (4 jets + $\not{E}_T$), observable: M_{eff}





Automated cross section calculation

Example AMEGIC++

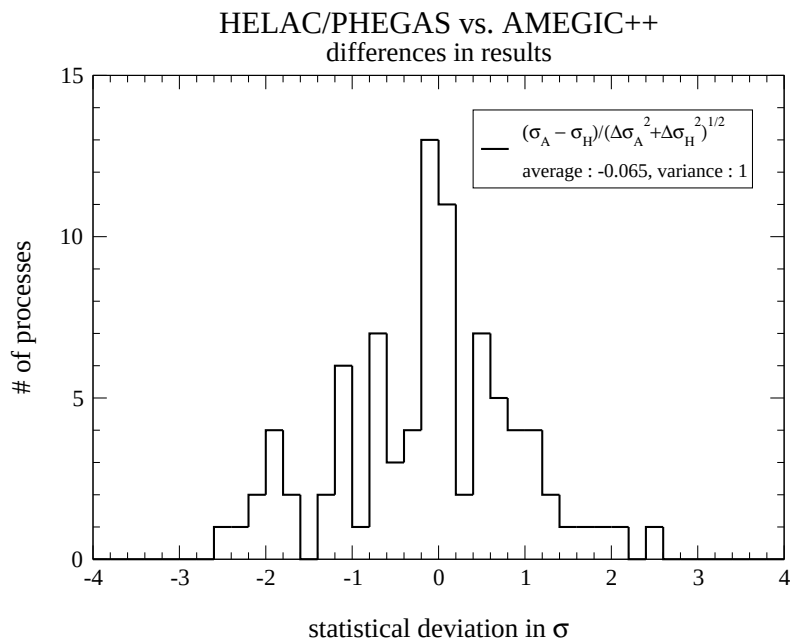
F.K., R.Kuhn, G.Soff, JHEP **0202** (2002) 044.

- Uses helicity/recursion methods;
- Helicity method supplemented with "factoring out" (taming the factorial growth)
- Phase space integration through multi-channeling (i.e. one phasespace mapping/Feynman diagram)
- Implemented & tested models: SM, SM+AGC, SM+Phantom, THDM, MSSM, ADD; MWTC, 4th generation, Z'-W' and $\mathrm{LH_{TP}}$ in prep..
- Tested in $>$ 2500 SM & $>$ 500 MSSM channels.
- Still under development (higher multis, more models, ...)

Standard Model @ Linear Collider

Consistency of HELAC/PHEGAS & AMEGIC++

T.Gleisberg, F.K., C.Papadopoulos, A.Schälicke and S.Schumann, Eur. Phys. J. C **34** (2004) 173



MSSM

Automated (and checked) tools

K.Hagiwara *et al.*, arXiv:hep-ph/0512260;

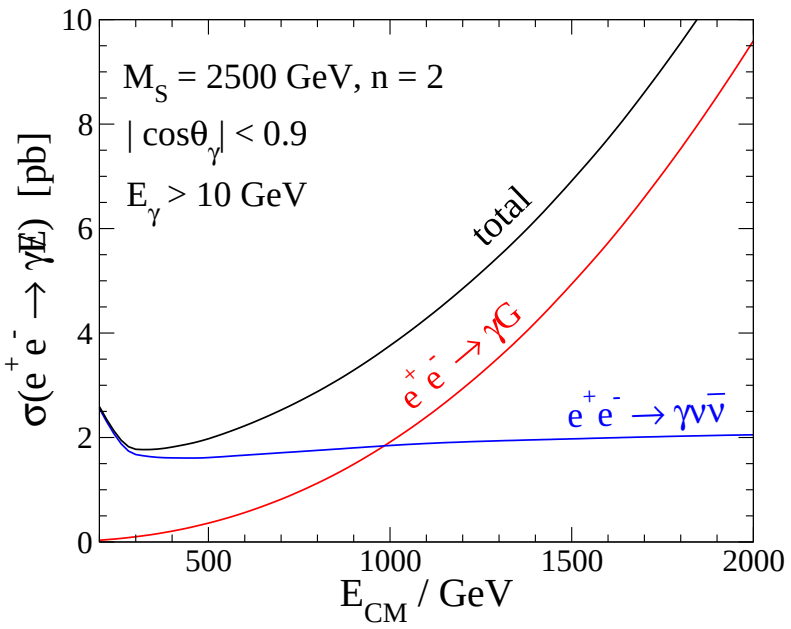
- 3 validated tools for MSSM studies: (S)MadGraph, O'Mega/Whizard & Amegic;
- completely different approaches & notations;
- SUSY spectra through SLHA interface;
- checked roughly 500 pair-production processes;
- some simple studies for LHC and LC.
- Further tools: CalcHEP/CompHEP, Pythia (Fortran), ...

EDs @ Linear Collider

ADD model: Production of gravitons

T.Gleisberg, F.K., K.Matchev, A.Schälicke, S.Schumann and G.Soff, JHEP **0309** (2003) 001

- Helicity method for spin-2 particles.
- ADD model fully implemented.
- Future:
  - add spin-3/2 particles (gravitinos),
  - UED, RPV-SUSY, MWTC, Z', 4th generation, . . .



COMIX - a new matrix element generator for Sherpa

T.Gleisberg & S.Hoeche, in preparation

- Colour-dressed Berends-Giele amplitudes in the SM
- Fully recursive phase space generation
- Example results (cross sections):

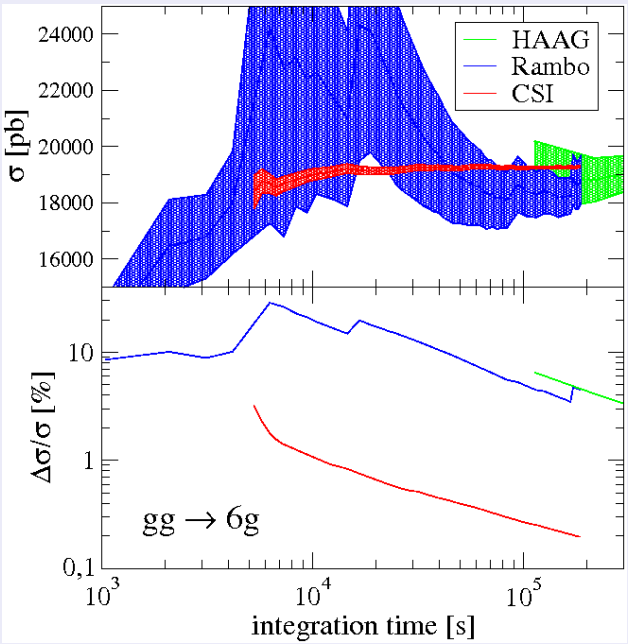
$gg \to ng$	Cross section [pb]				
n	8	9	10	11	12
$\sqrt{s}$ [GeV]	1500	2000	2500	3500	5000
Comix	0.755(3)	0.305(2)	0.101(7)	0.057(5)	0.019(2)
Maltoni (2002)	0.70(4)	0.30(2)	0.097(6)		
Alpgen	0.719(19)				

σ [μb]	Number of jets						
$b\bar{b}$ + QCD jets	0	1	2	3	4	5	6
Comix	4.78(5)	8.83(2)	1.826(8)	0.459(2)	0.1500(8)	0.0544(6)	0.023(2)
ALPGEN	4.76(6)	8.83(1)	1.822(9)	0.459(2)	0.150(2)	0.053(1)	0.0215(8)
AMEGIC++	4.73(4)	8.84(2)	1.817(6)				

COMIX - a new matrix element generator for Sherpa

T.Gleisberg & S.Hoeche, in preparation

- Colour-dressed Berends-Giele amplitudes in the SM
- Fully recursive phase space generation
- Example results (phase space performance):



From partons to hadrons

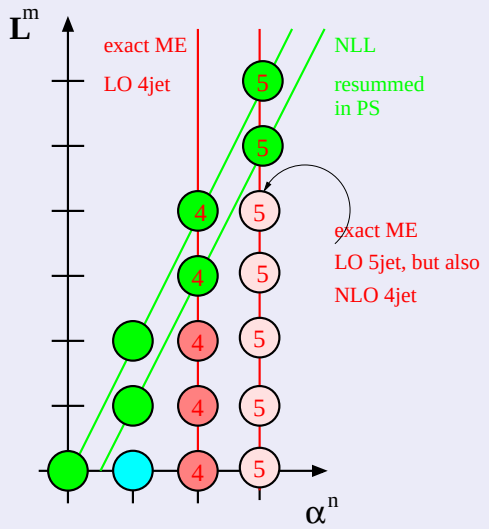
- Experimental definition of jets based on hadrons.
- But: Hadronization through phenomenological models

(need to be tuned to data).

ME vs. PS

- MEs: hard, large-angle emissions; interferences.
- PS: soft, collinear emissions; resumation of large logarithms.
- Combine both, avoid double-counting.

α_s vs. Log



Combining MEs & PS: LO-Merging

S.Catani, F.K., R.Kuhn and B.R.Webber, JHEP **0111** (2001) 063
F.K., JHEP **0208** (2002) 015

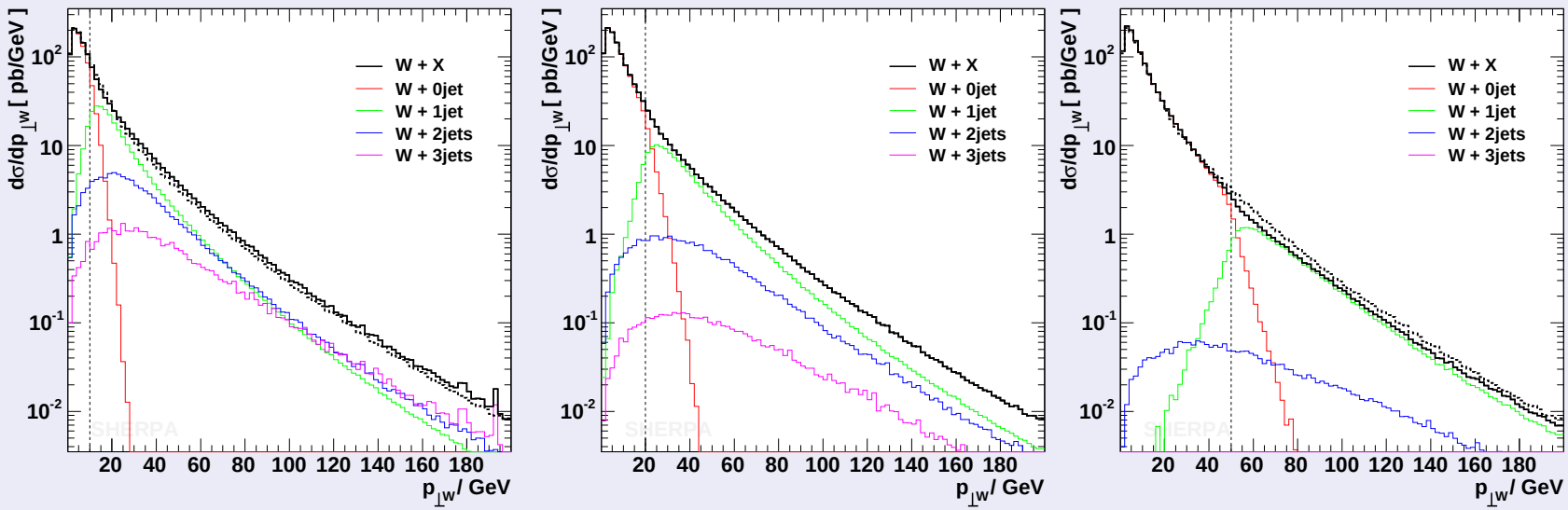
- Want:
  - All jet emissions correct at tree level + LL,
  - Soft emissions correctly resummed in PS
- Method:
  - Separate Jet-production/evolution by $Q_{\rm jet}$ ($k_\perp$ algorithm).
  - Produce jets according to LO matrix elements
  - re-weight with Sudakov form factor + running α_s weights,
  - veto jet production in parton shower.
- Process-independent implementation.
- New feature: Also for cascade decays.

Combining MEs & PS: Independence on Q_{jet}

F.K., A.Schälicke, S.Schumann and G.Soff, Phys. Rev. D **70** (2004) 114009

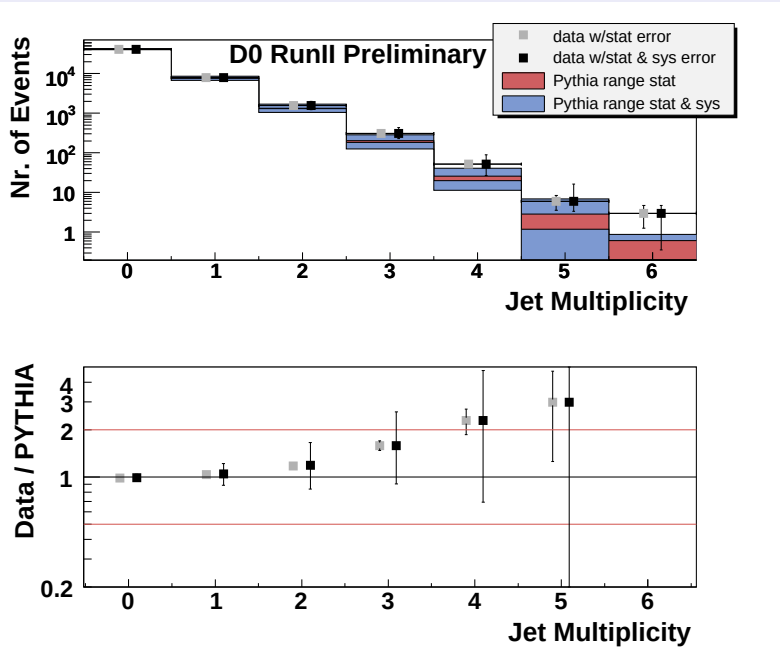
Example: $p_\perp$ of W in $p\bar{p} \to W + X$ @ Tevatron

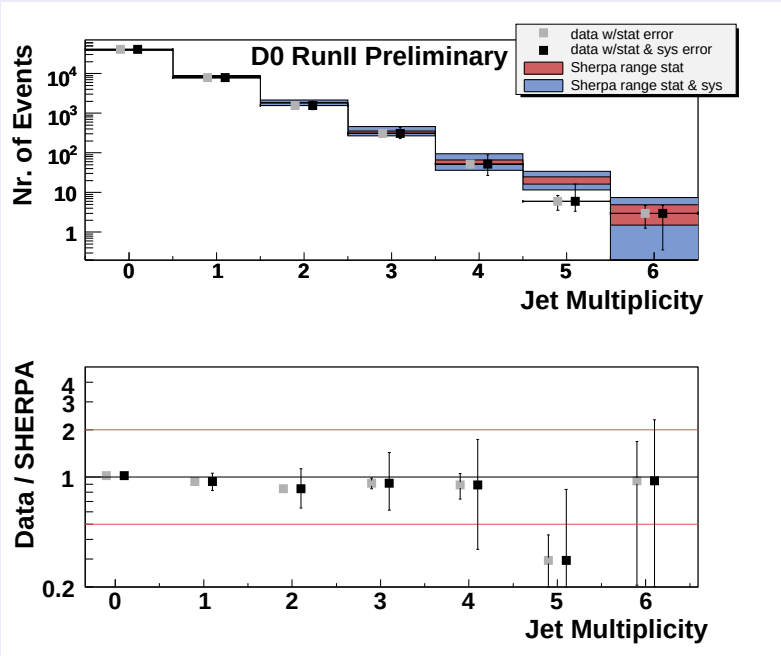
$Q_{\text{jet}} = 10\,\text{GeV}$ $Q_{\text{jet}} = 30\,\text{GeV}$ $Q_{\text{jet}} = 50\,\text{GeV}$



Comparison with RunII $Z + X$ data: Jet multis

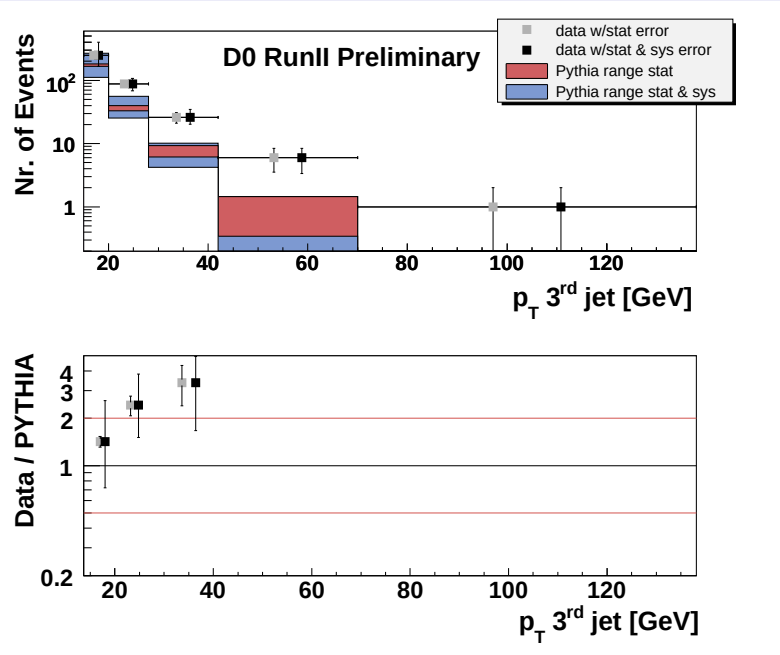
(D0-Note 5066)

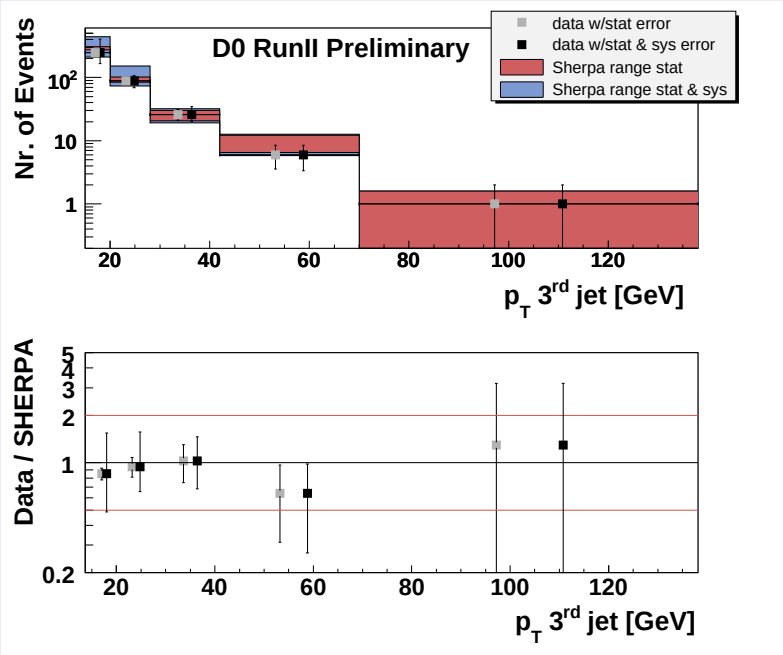




Comparison with RunII $Z + X$ data: $p_\perp^{j_3}$

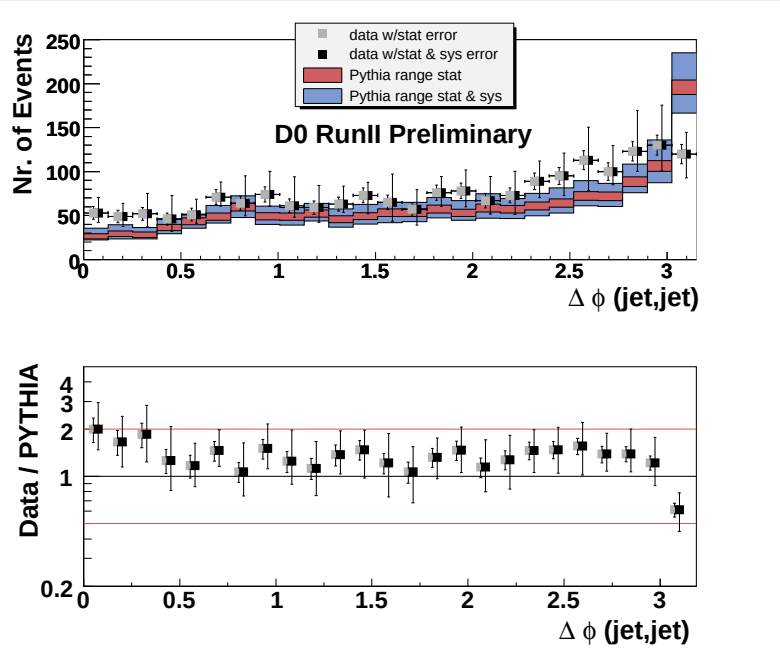
(D0-Note 5066)

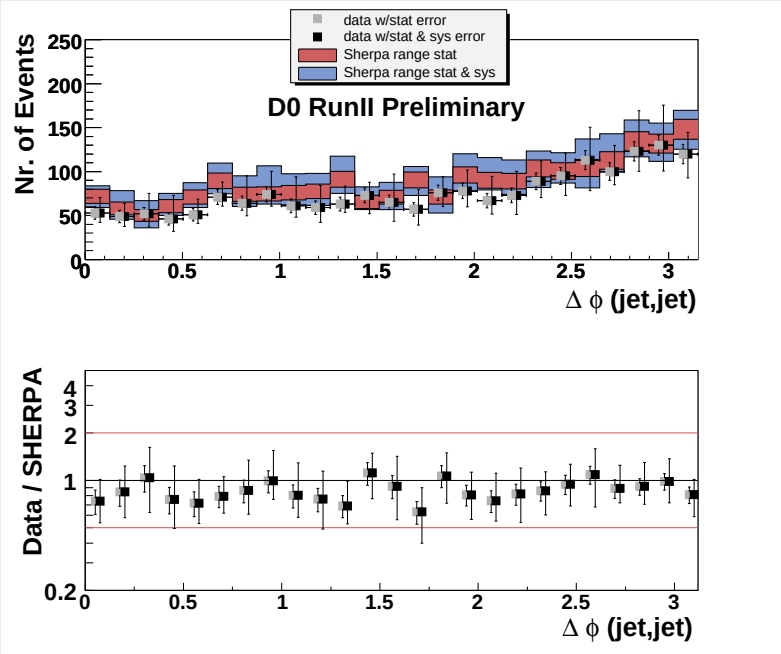




Comparison with RunII $Z + X$ data: $\Delta\phi^{j_1 j_2}$

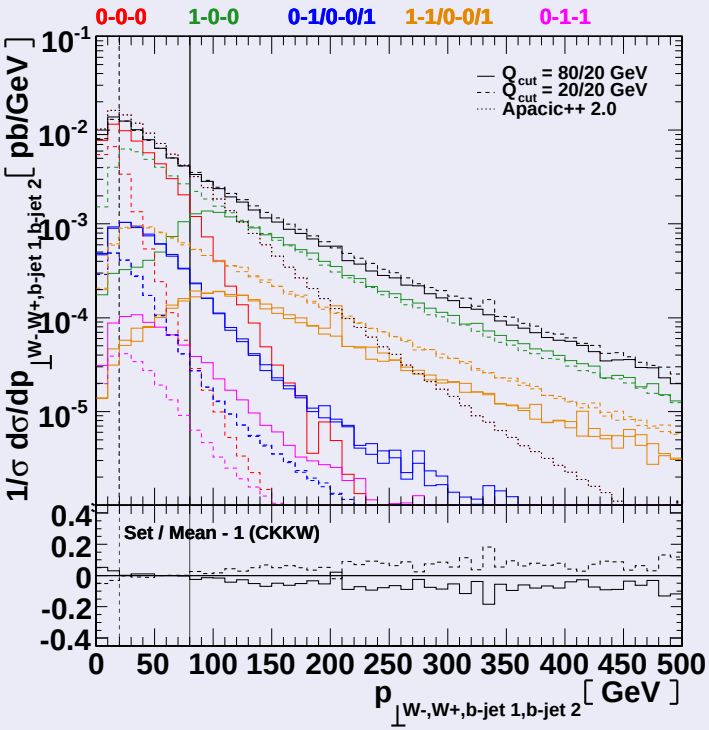
(D0-Note 5066)

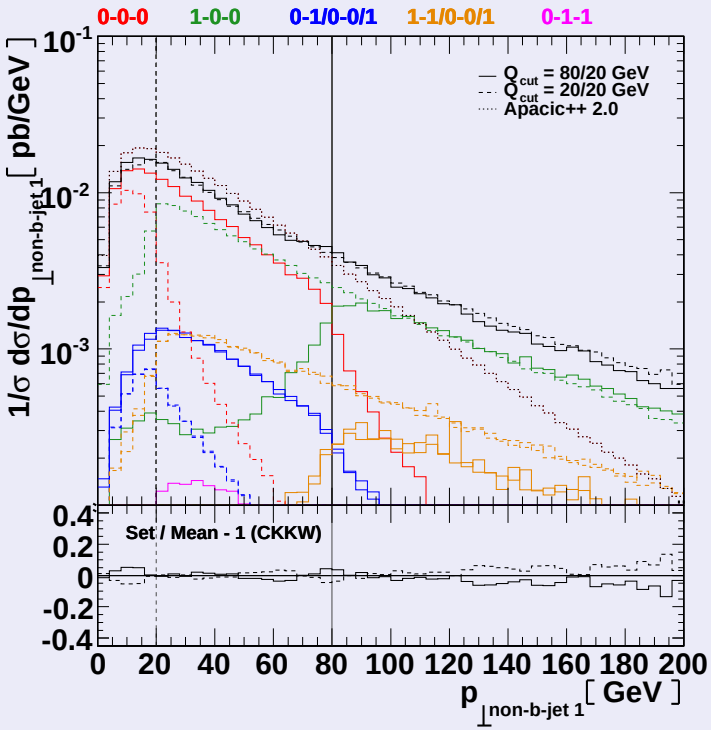




A new feature: Merging in decay chains

Example: top-pair production @ LHC





Introducing Herwig++

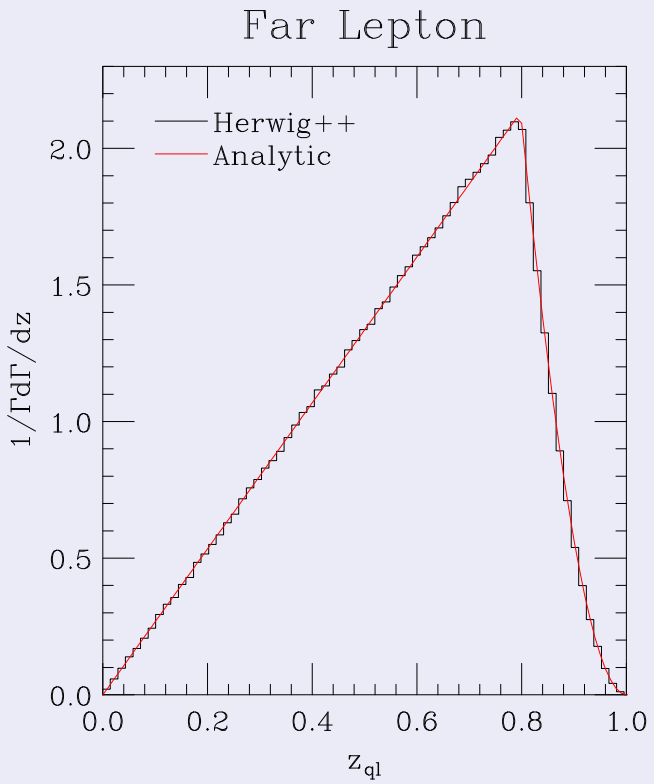
M.Bahr *et al.*, arXiv:0803.0883 [hep-ph]

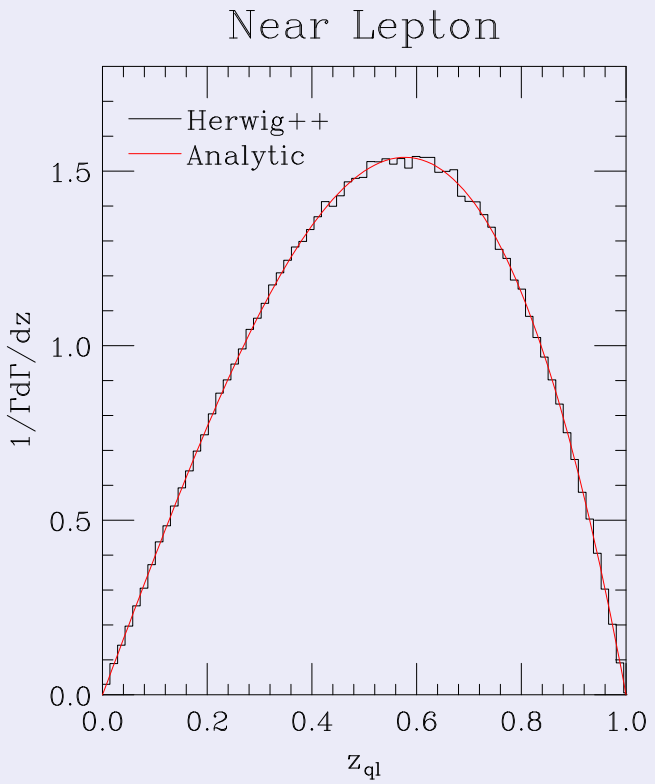
- New event generator, building on "old" f77 Herwig.
- Includes: A new parton shower formalism, an improved cluster fragmentation model, improved hadron decays, first implementations of MC@NLO/PowHEG techniques, etc..
- Builds on long decay chains for BSM simulation: Spin correlations and (well-known from hadron decays) off-shell effects.
- Models so far: SM, RS, MSSM, MUED; NMSSM, LH, $\mathrm{LH_{TP}}$ in forthcoming releases.

Modelling spin-correlations in Herwig++

M.Bahr *et al.*, arXiv:0803.0883 [hep-ph]

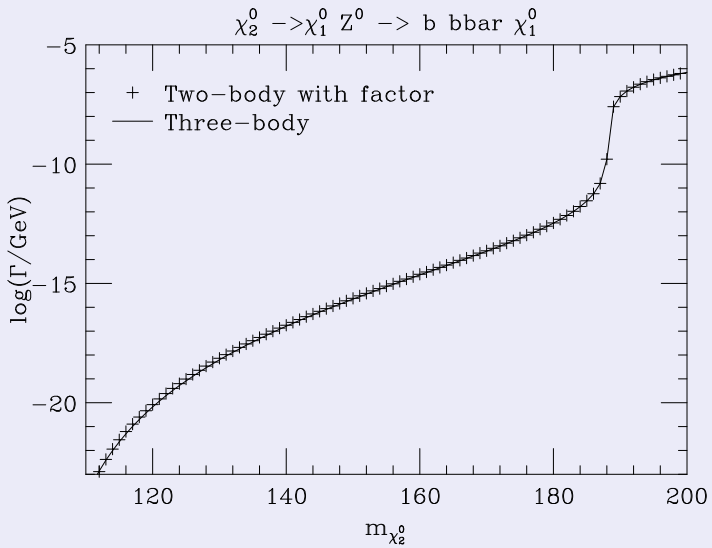
Example process: $\tilde{q}_L - > q\tilde{\chi}_2 - > qe\tilde{e}_R - > qee\tilde{\chi}_1$

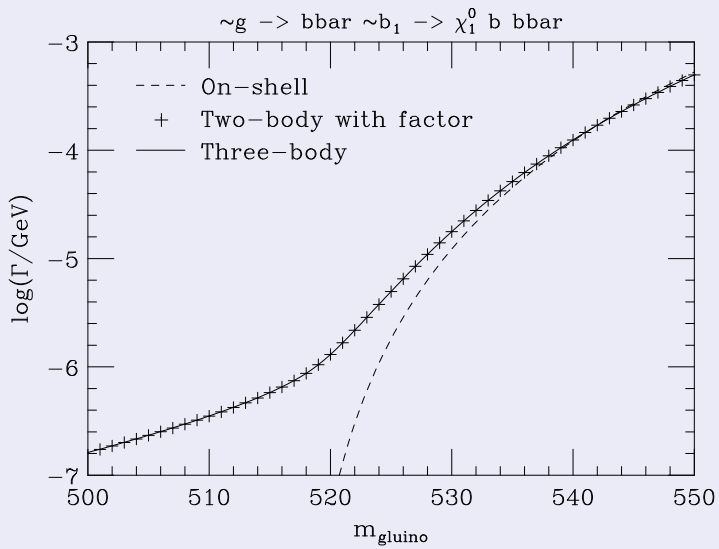




Modelling off-shell effects in Herwig++

M.Bahr *et al.*, arXiv:0803.0883 [hep-ph]





Introducing SHERPA

T.Gleisberg, S.Höche, F.K., A.Schälicke, S.Schumann and J.C.Winter, JHEP **0402** (2004) 056

- New event generator, written from scratch in C++.
- Fully automated matrix element generation, many models.
- New ME generator in preparation.
- Parton shower implementation (similar to PYTHIA), new improved parton shower formulations ready.
- Unique feature: Multijet ME+PS merging,
- Cluster hadronization model (still to be tuned to data), also interface to string fragmentation of Pythia.
- Hadron and tau decays completed, spin correlations.
- Underlying event according to old Pythia model, new model based on BFKL evolution to be released.

Summary & outlook

- Many interesting signals at LHC "spoiled" by QCD.
- Simulation tools mandatory for success of LHC
- Various new OO-projects in C++: Triggered new paradigms on how to simulate BSM/backgrounds

  Example: methods of merging of ME& PS extremely powerful complementary to MC@NLO - use both.
- Many new ideas on how to efficiently implement new models: standardization, interfaces to Lagrangians, etc..
- Inclusion of spin correlations/offshell effects is now state-or-the art.
- Herwig++, Pythia8 & Sherpa versatile tools - new features becoming available.
- Time to validate essential tools is now!