BSM in HERWIG

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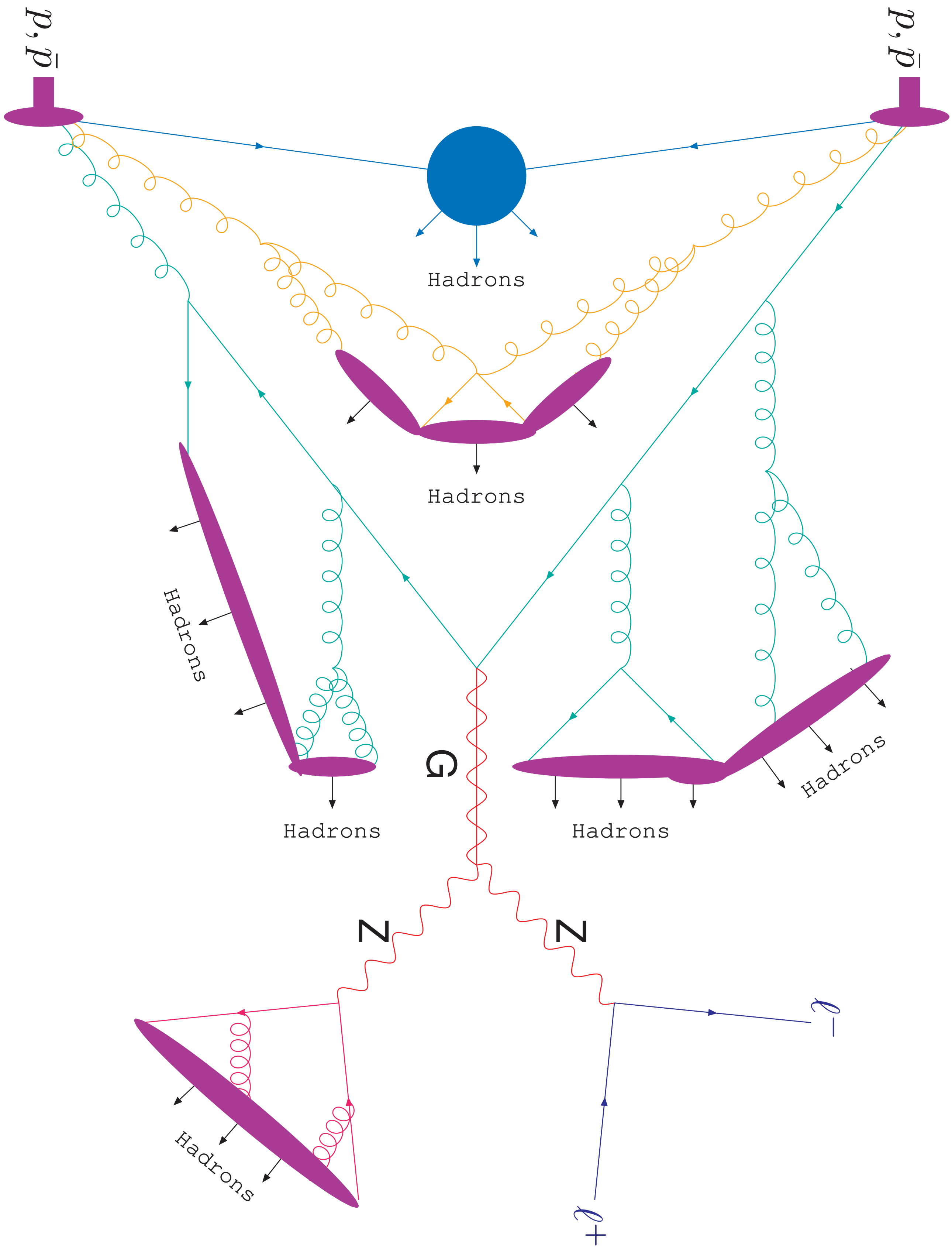
Introduction

- HERWIG is a general-purpose event generator.
- As with all these programs the main emphasis is on the simulation of SM processes.
- BSM physics was added later but a lot of processes are now included in a sophisticated way.
- The main program is available from

  http://hepwww.rl.ac.uk/theory/seymour/herwig/

SM simulation in HERWIG

- As with all event generators HERWIG splits the simulation up into a number of parts:
  - Hard Process;
  - Parton Shower;
  - Secondary Decays;
  - Multiple Scattering/Soft Underlying Event;
  - Hadronization;
  - Hadron Decays.



$p, \bar{p}$
$p, \bar{p}$
Hadrons
Hadrons
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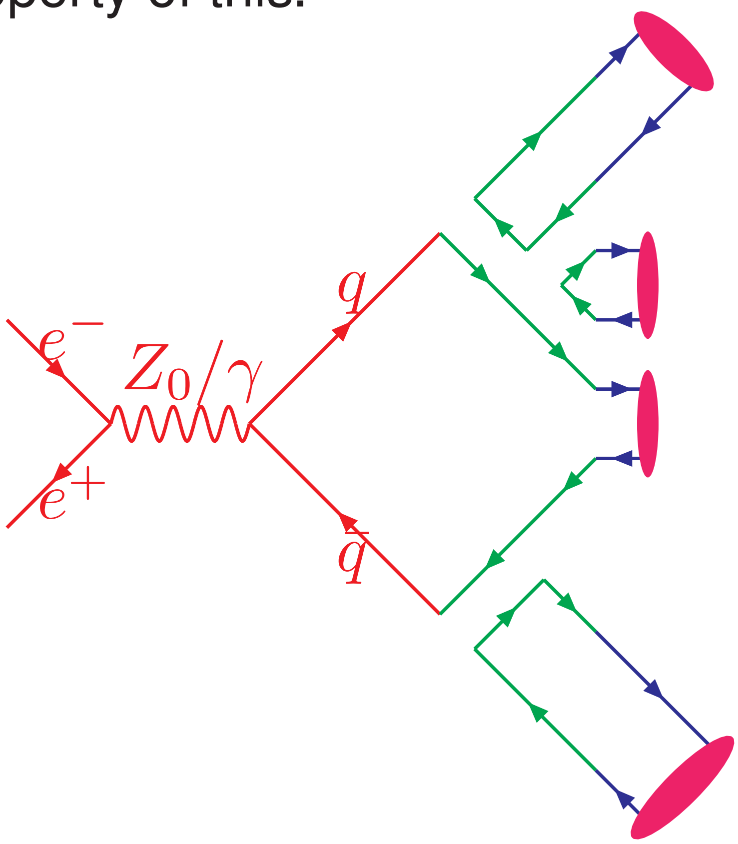
Models in HERWIG

- HERWIG uses the angular ordered parton shower algorithm which resums both soft and collinear singularities.

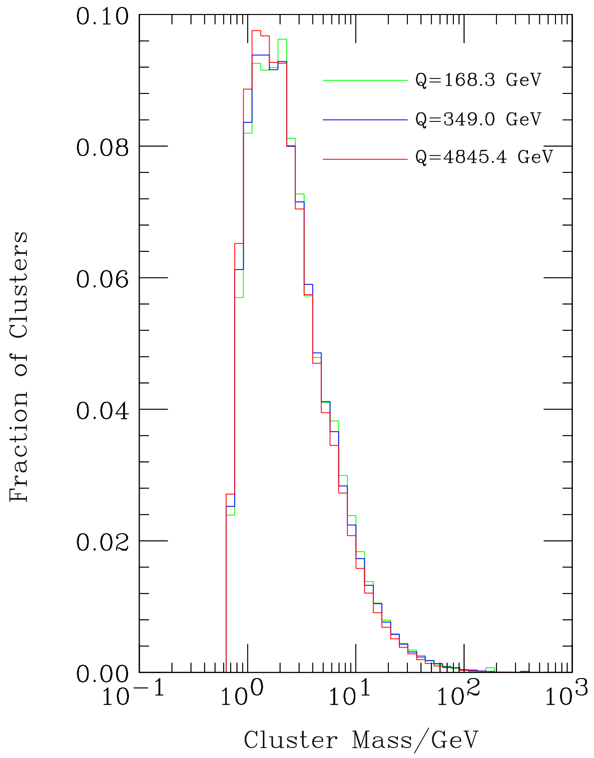
- The hadronization model is based on one property of this.



- First split the gluons into $\mathrm{q\bar{q}}$ pairs.

- Each quark is then uniquely paired with an antiquark in a colour singlet cluster.

Cluster Hadronization Model



- The mass spectrum of pairs of colour singlet clusters after gluon splitting.
- Called colour 'pre-confinement'.
- Assume these clusters are superpositions of resonances.
- Decay according to phase space to hadrons.
- The hadrons decays are then performed using phase space and the measured branching ratios.

BSM Physics

- BSM physics enters as either:
  - New hard processes;
  - Decays of new particles.
- In HERWIG there is a wide range of both.

SUSY Spectrum

- HERWIG does not include any built in code for SUSY spectrum calculations.
- Instead we have an interface ISAWIG to ISAJET for these calculations.
- This also calculates R-parity violating decays.
- Available from

  http://www.hep.phy.cam.ac.uk/ richardn/HERWIG/ISAWIG/
- May include a Les Houches spectrum interface in the future.

SUSY Production

- HERWIG includes a wide range of SUSY production processes:
  - $2 \rightarrow 2$ SUSY particle pair production as predicted by the MSSM;
  - A wide range of SUSY Higgs production processes;
  - Single sparticle production via R-parity violation.
- The production of these particles is followed by their decay.

SUSY Decays

- Until recently all generators assumed the production and decay of heavy particles took place independently.
- The decays were then either performed according to phase space or using the correct matrix element for the decay.
- This neglects correlations between the production and decay of the particles and between the different decays.
- These effects can be important. They are measurable at the Tevatron or LHC in top decay and are important for SUSY at a future linear collider.

SUSY Decays

- How do we include such correlations?

- There are two different approaches used in generators.

- The first calculates the matrix element as a $2 \to n$ body process, including any decays.
  - This is the traditional method.
  - Has problems if many final-state particles or decay modes.

- The second calculates helicity amplitudes for the production and decay.
  - Production and decay performed separately.
  - Spin density and decay matrices encode the information.
  - Reproduces the matrix element in a step by step algorithm.
  - Allows many final-state particles and decay modes to be simulated.

SUSY Decays

- First method has been used to include correlations in SUSYGEN for some $\mathrm{e}^+\mathrm{e}^-$ SUSY processes.

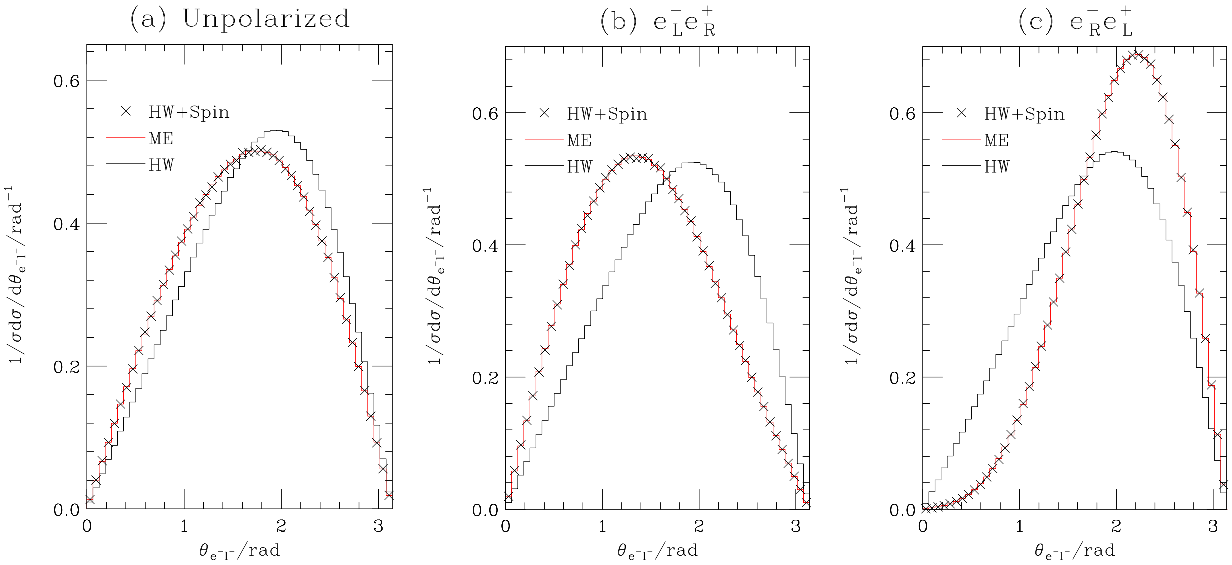
- Whereas HERWIG has correlations in all SUSY production processes and many SM processes using the second method.

- This method allows us to have all correlations in LHC SUSY events which would be impossible with the other method.

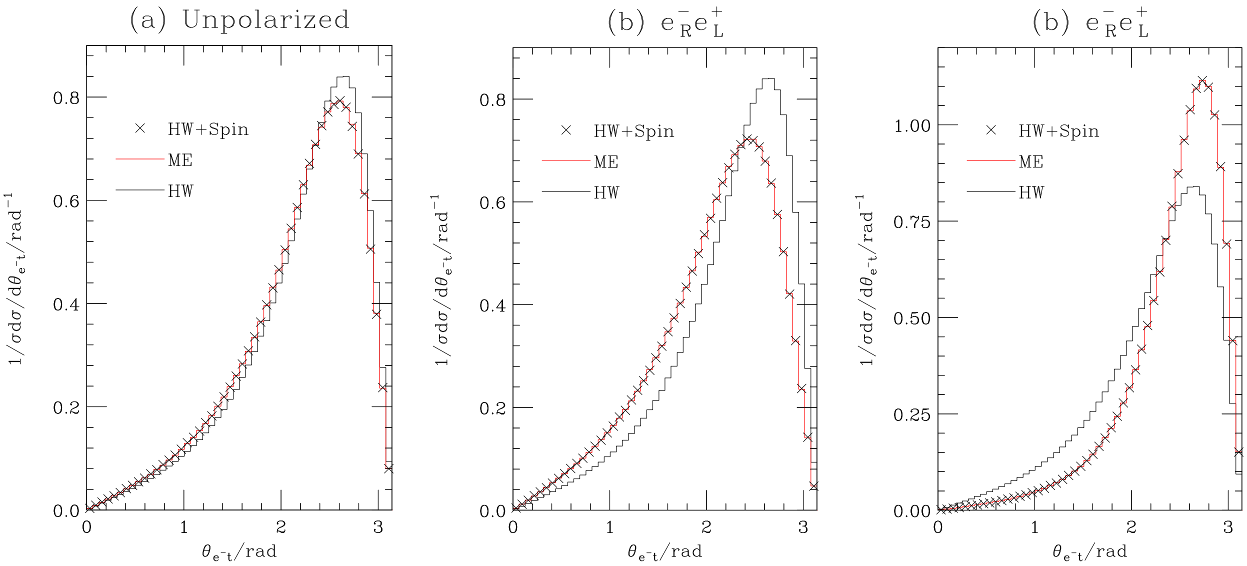
Top pair production in e^+e^- collisions

- Study the semi-leptonic decays of both top quarks and look at the correlations.

- Between the lepton produced in the antitop decay and the beam.



- Between the lepton and the top quark.



R-parity violation

- HERWIG was the first generator to fully included R-parity violation.
- There are a wide range of single production processes.
- There is also a wide range of decays included.
- These decays are now fully included in the spin correlation treatment.

Other BSM physics

- In addition to SUSY HERWIG also includes resonant graviton production which is predicted by R-S type models.
- There is also the possibility of a Z' resonance.
- It is unlikely that the authors will add any new processes to the FORTRAN code.
- The code now includes a Les Houches Accord interface to allow the user to add new processes.
- We have already used this to write a black hole generator.
- This allows anyone to add new processes (and use them with both HERWIG and PYTHIA)

Conclusions

- HERWIG is an advanced tool for the simulation of SUSY.
- There is little other BSM physics included.
- Any new processes will have to be added via the Les Houches accord
- This should allow anyone to simulate the model of their choice.
- Eventually will be replaced in C++.