HERWIG and PYTHIA

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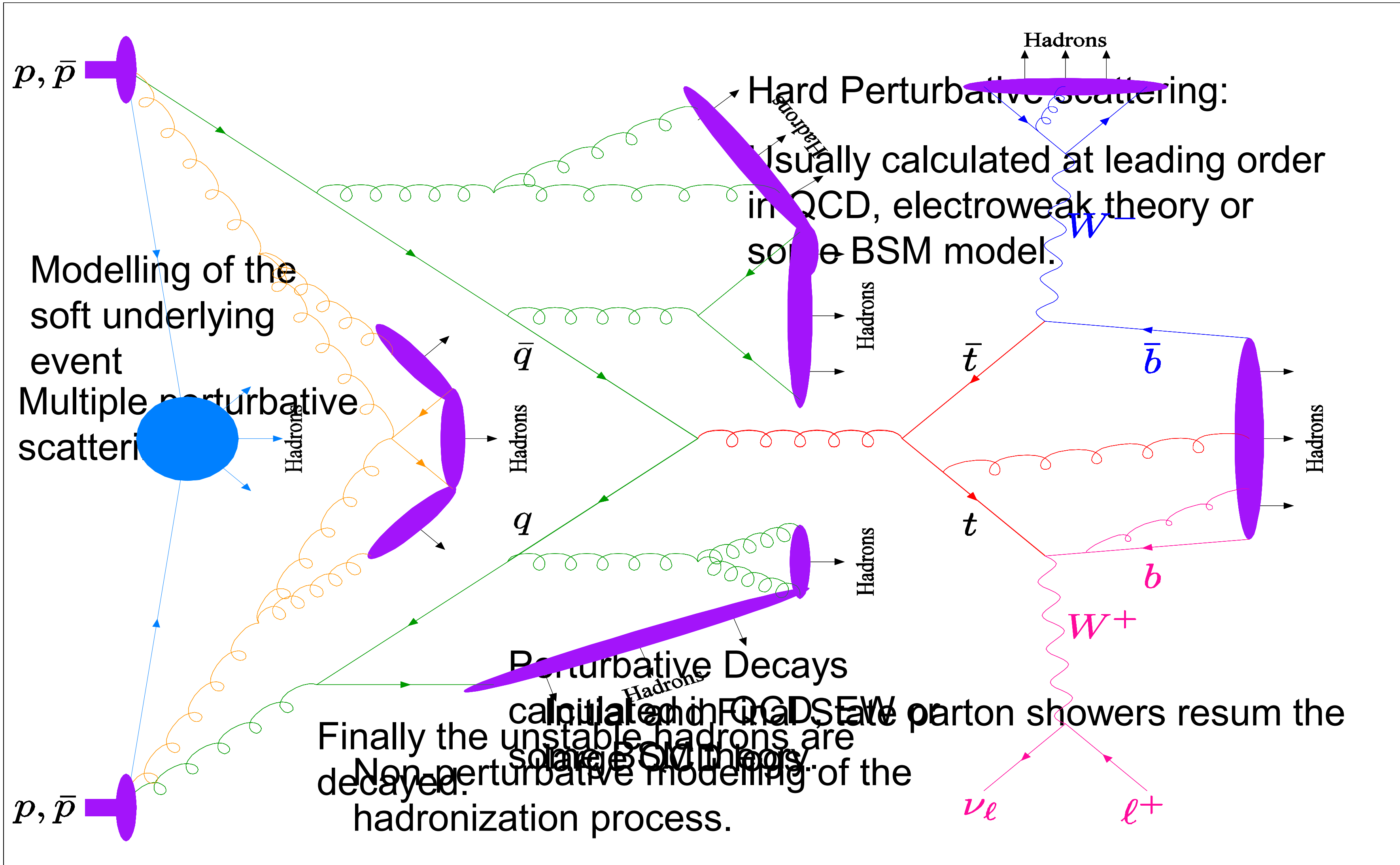
Summary

- Introduction
- Basics of Monte Carlo Simulations
- Processes inside the Generators
- The Les Houches Accord
- Future

Introduction

- Monte Carlo event generators are programs which starting with some fundamental process predict the stable particles which will interact with a detector.
- There are a number of Monte Carlo event generators in common use
  - PYTHIA
  - HERWIG
  - SHERPA
- They all split the event generation up into the same pieces.
- The models and approximations they use for the different pieces are of course different.

A Monte Carlo Event



Hard Perturbative scattering:

Usually calculated at leading order in QCD, electroweak theory or some BSM model.

Modelling of the soft underlying event

Multiple perturbative scattering.

Perturbative Decays calculated in QCD, EW or some BSM theory.

Initial and Final State parton showers resum the large QCD logs.

Finally the unstable hadrons are decayed.

Non-perturbative modelling of the hadronization process.

Monte Carlo Event Generators

- For BSM physics the main pieces of the event generators are

2) Hard Process
    - New intermediate particles
    - New particles produced
    - Changes to SM distributions
3) Decays
    - Decays of new particles produced in the hard process or previous decays.

Built In Models

- Traditionally models of new physics are built into the event generator.
- This will often include hard processes and decays.
- Relatively few models have been implemented and the sophistication of the simulation varies.

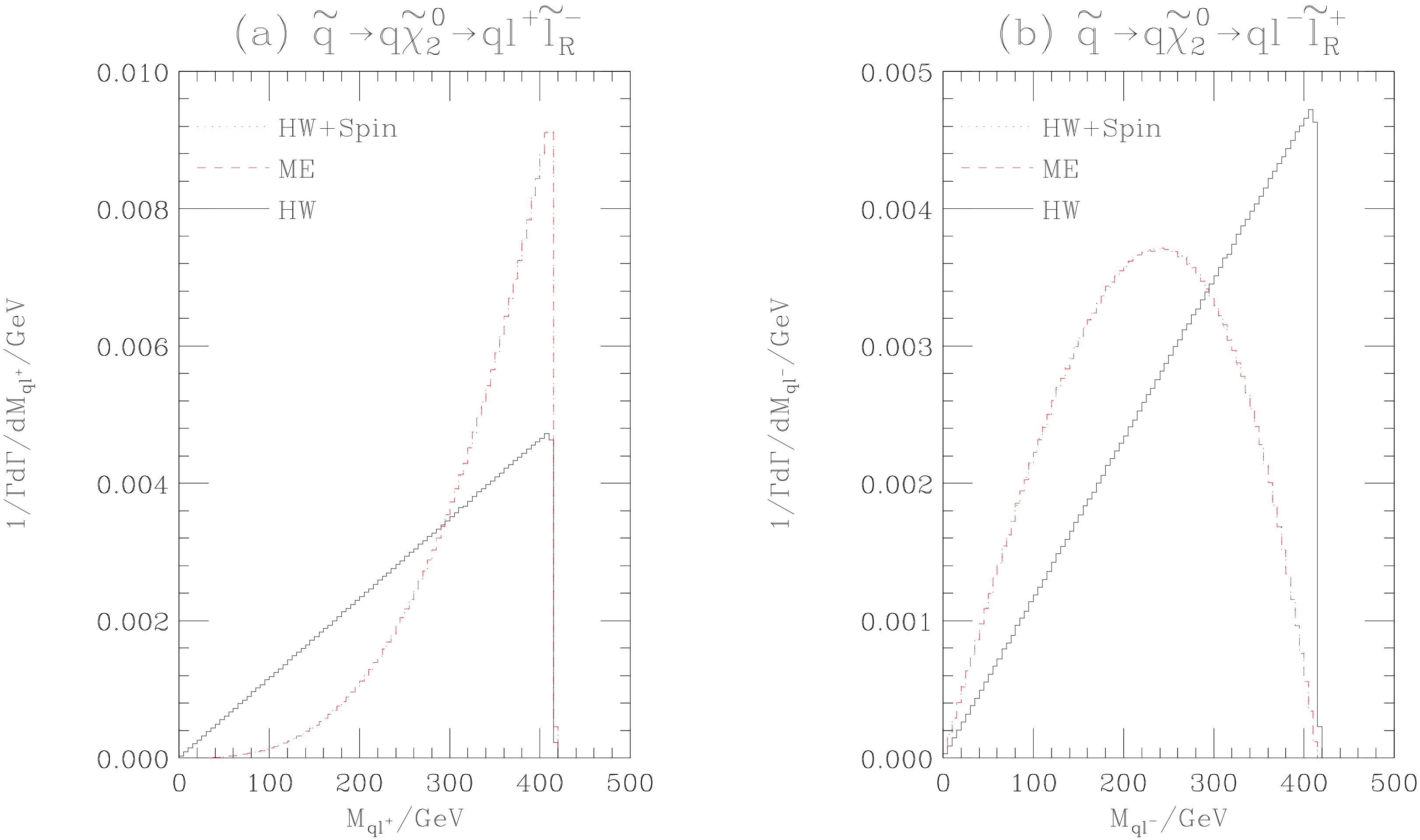
Built In Models

	HERWIG	PYTHIA
SUSY	✔	✔
SUSY+RPV	✔	✔
RS Gravitons	✔	✔
Z'/W'	✘	✔
Technicolor	✘	✔
Left-Right Models	✘	✔
Compositeness	✘	✔
Excited fermions	✘	✔
Leptoquarks	✘	✔
Fourth generation	✘	✔

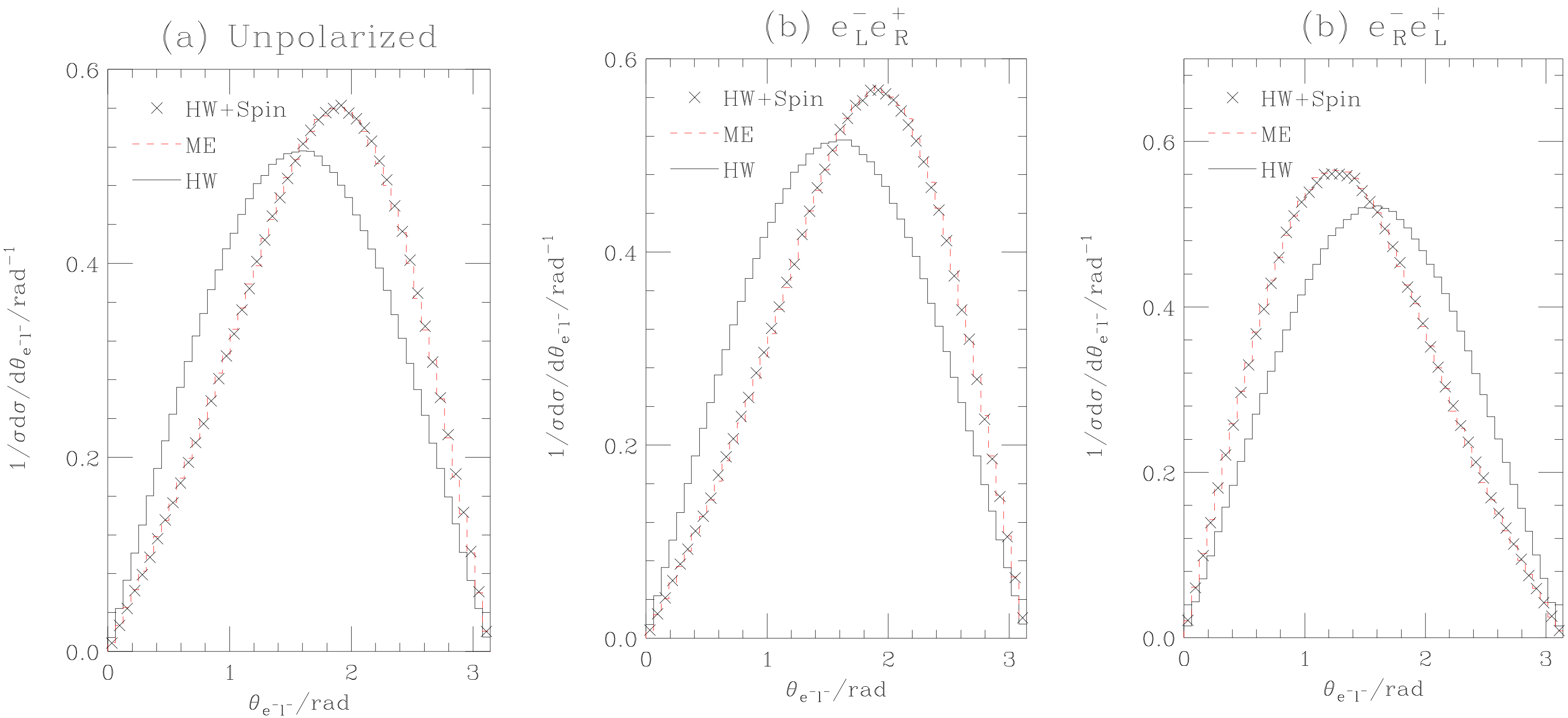
Built In Models

- In general a lot more effort has gone into the simulation of SUSY than everything else put together.
- In general the simulation of SUSY is very sophisticated including simulation of the hard process, matrix elements for the decays and (in HERWIG) spin correlations between the production and decay.

Spin Correlations



Spin Correlations



Les Houches Accord

- In 2001 there was a paradigm change in the way new processes were implemented in event generators.
- The old procedure
  - Email author of program to ask for a new process to be included
  - Author thinks about it
  - Maybe gets implemented.

Les Houches Accord

- Had many problems
  - Only authors of the programs could add new processes.
  - Large demand on a small number of people.
  - Often processes people wanted (needed?) did not get implemented.

Les Houches Accord

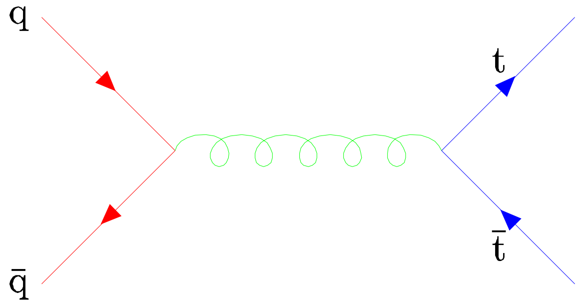
- At the 2001 Les Houches meeting an agreement was reached on a method of passing information between programs generating partonic processes and general purpose event generators.
- Based on a common block.

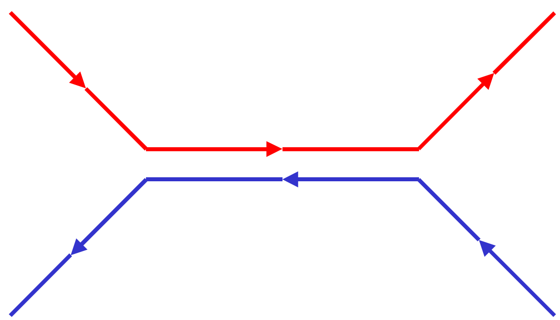
Les Houches Accord

- Basic idea was that the Matrix Element Generator (MEG) provides
  - Momenta and types of the particles.
  - A option for the cross section calculation.
  - The colour flow for the process.
  - Optionally information on intermediate particles which need special treatment.

Les Houches Accord

- Most of the rest is fairly self explanatory but colour flow isn't.
- If we take the large number of colours limit we can assign a colour flow.
- Needed by the event generator to get the simulation of QCD radiation and hadronization right.





Les Houches Accord

- New paradigm
  - If asked to implement a new process a generator author will say do it yourself using the Les Houches accord.
  - We have provided a simple tutorial to help with this

http://www.ippp.dur.ac.uk/montecarlo/leshouc

Les Houches Accord

- Implemented in both HERWIG and PYTHIA
- Some problems
  - Particles involved need to be known to the generator.
  - HERWIG not good at handling coloured non-SM particles.
- But has proven very successful.

Les Houches Accord

- Many of the matrix element generators use it
  - MADGRAPH
  - ALPGEN
  - CALCHEP
- Together with some BSM packages (e.g. CHARYBDIS)
- Also used by many private programs to pass information into the general purpose event generators.

Future

- It may be a good idea to have a simple way of tell generators about new particles and their decays, perhaps based on what already exists for SUSY.
- In general this will be good enough for most cases.
- However there are some situations where sophisticated simulation is needed.

Future

- It order to decide whether the spin of SUSY particles can be measured need spin correlations.
- In this case the event generator has to perform all the simulation (otherwise it's almost impossible to get it right.)
- This was done for the MSSM in HERWIG.
- However it was a lot of work and even simple extensions (NMSSM etc.) can't be handled.

Herwig++

- In designing the new Herwig++ generator we decide to go with a different approach.
- A C++ helicity library based on the HELAS formalism is used for all matrix element and decay calculations.
- This makes coding new matrix elements for both production and decay much easier.
- Also easy to do the spin correlations as we have access to the spin unaveraged matrix elements.

Herwig++

- In principle we could write a matrix element generator using this as the basis.
- However a lot of work and there are all ready many good programs available.
- Settle for a more limited aim.
- Code the hard $2 \to 2$ matrix elements based on the spin structures (there's less possibilities than you might think).
- Code the $1 \to 2$ and $1 \to 3$ decays in the same way.

Herwig++

- For most models then only need to supply the Vertices , i.e. the Feynman rules for a new model.
- C++ inheritance should help even there with say the NMSSM inheriting from the MSSM and only having to implement the new features.
- May be supplemented with special treatment for some models.

Conclusions

- The existing HERWIG and PYTHIA programs will remain the workhorses of event simulation in the near future.
- Unlikely to be any new models implemented in them directly.
- New processes should use the Les Houches.
- The simulation in the new C++ generators will be different and hopefully allow more models to be studied.