BSM Tools

Peter Richardson
(CERN, TH)

- Introduction.
- What is BSM Simulation?
- Questions and issues for the Workshop
- Models
- Accuracy
- Plans

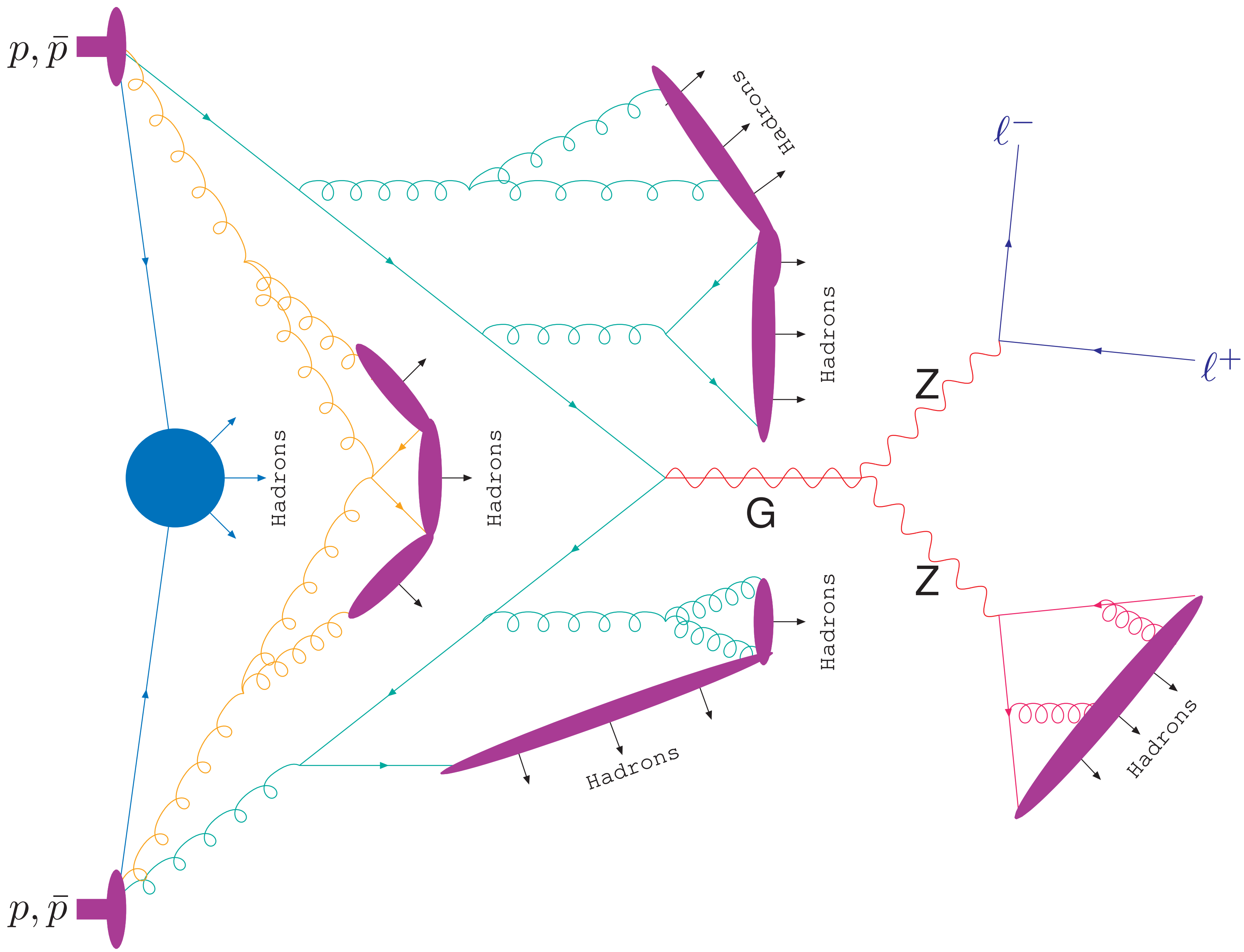
Introduction

- We all hope that new physics will be discovered by the LHC.
- In order to study what different models can be observed and their signals we need simulations.
- So how to we go about simulating new physics?

What is BSM simulation?

- It's best to start by recalling the features of SM simulation.

- The simulation is split into a number of phases:
  - Hard Process;
  - Parton Shower;
  - Secondary Decays;
  - Multiple Scattering/Soft Underlying Event;
  - Hadronization;
  - Hadron Decays.



p, p̄
p, p̄
Hadrons
Hadrons
Hadrons
Hadrons
Hadrons
Hadrons
Hadrons
G
Z
Z
ℓ−
ℓ+

What is BSM Simulation

- In general the main difference in BSM simulations are the different:
  - Hard Production Processes;
    - Production of new heavy particles, *e.g.* SUSY,
    - Modifications to SM production processes, *e.g.* Extra Dimensions,
    - New phenomenon, *e.g.* Black Holes.
  - Decays.
    - Decays of the new particles in a model,
    - Modifications to the decay of SM particles,
- The rest of the simulation is the same as for the Standard Model.

BSM Simulation

- The simulation will always start with a model of new physics.
- In most cases the model will:
  - Predict new particles;
  - Have additional parameters.
- Given the Lagrangian/Feynman rules we can then calculate the things we need to perform a simulation:
  - Particle properties, masses, lifetimes and decay modes;
  - Production cross sections.
- There are obviously some exceptions to this, *e.g.* black holes.

Simulation Questions

- There are two main questions in BSM simulations:
- What models do we need simulations for?
- How accurate do the simulations need to be?
- Particularly for this workshop:
  - Do we have simulations for all the models we realistically need?
  - Is the accuracy of the current simulations good enough or do we need more?

Models

- There are only a limited number of models which are currently available:
  - SUSY, and some of its variants;
  - Small/Large Extra Dimension Models;
  - Technicolour;
  - New gauge bosons;
  - compositeness;
  - leptoquarks;
  - doubly charged Higgs;
  - black holes.
- More man hours have been spent on SUSY than all the rest put together (probably by orders of magnitude.)
- Do we need other models ?
- For example, universal extra dimensions to contrast with SUSY, little Higgs models, others?

What's available?

- All the major event generators have SUSY, HERWIG and PYTHIA have RPV extensions.
  - ISAJET and PYTHIA include technicolour models.
  - HERWIG and PYTHIA include resonant gravitons.
  - ISAJET has some ADD extra dimension processes.
  - PYTHIA has some compositeness and left/right model processes.
  - Some models in automatic ME generators.
  - Some separate programs for Black Holes.

- Processes were only added when the authors were interested in the physics.

- In the future it is unlikely that many more processes will be added.

- People will have to code the processes themselves via the Les Houches accord.

Les Houches Accord

- The Les Houches Accord is designed to interface parton level calculations with general purpose event generators.
- Mainly been used for SM processes but could also be used for BSM physics
- Allows people other than the authors of programs to add processes.
- Should we be encouraging people to produce such programs?
- Would a publicly available collection of such programs be useful?

How much accuracy?

- There are a number of questions related to this.
  - How accurate does the spectrum calculation from the fundamental parameters need to be?
    - *e.g.* in SUSY how accurate do we need to be in calculating the weak scale parameters from GUT scale inputs.
  - How accurate does the cross section need to be?
    - Do we really need higher orders, if so where?
  - How accurate does the treatment of the decay need to be?
    - Do we need higher orders?
    - Do we need spin correlations?

Spectrum Calculations

- Some models, *i.e.* SUSY, have large numbers of parameters.
- In SUSY we are forced to use models of high scale physics which predict in terms of a small number of fundamental parameters the low energy parameters of the model.
- In this case a lot of calculations need to be done before the calculation of the cross sections and decays we need for the simulation can be done.
- There are a number of programs available for this, *e.g.* ISAJET, SOFTSUSY, SPHENO, SPYTHIA, SUSPECT, SUSYGEN.
- Also programs for Higgs mass calculations, *e.g.* FeynHiggs, subhpole.
- Do we need more accuracy here?

Spectrum Calculations

- There are now a number of spectrum calculators available.
- Interfacing these to event generators is complicated and prone to error.
- Idea for a universal interface between spectrum calculators, decay packages and event generators.
- There will be a number of sessions discussing this in the SUSY decay packages session.

Cross section calculations

- Obviously we would like $\mathrm{N}\ldots\mathrm{LO}$ calculations for everything.
- Equally this isn't practical.
- So what do we really need, NLO or is LO good enough until we actually see something?
- Processes in generators are coded at leading order, some processes now available at NLO for the SM.
- Some NLO (and for Higgs physics NNLO) calculations are available.

NLO Cross Section Calculations

- There are a number of programs which calculate next-to-leading order cross sections.
- The major programs are
  - PROSPINO for squark/gluino production in hadron collisions.
  - Various NLO Higgs production calculations
- Many other BSM NLO calculations have been done.
- Some of these may be available.
- As always it would be helpful if more were available.

Monte Carlo Event Generators

- There are many BSM event generators available.
- These event generators fall into two classes.
- General Purpose Event Generators
  - These programs were written for SM simulation but have been extended to include BSM simulation.
  - There are three generators ISAJET, PYTHIA, HERWIG.
- BSM Generators
  - These generators usually only handle the hard production and decay of the BSM particles.
  - Usually they are interfaced to one of the general purpose event generators for the parton shower and hadronization phases.
  - Examples include SUSYGEN, Black Hole Generators.

Automatic Matrix Element Generators

- There are also programs available which automatically calculate matrix elements.
- Some of these include BSM physics, or will do soon
  - COMPHEP
    - Automatic calculation of cross sections using trace techniques.
    - Phase Space integration by VEGAS.
  - AMEGIC++
    - Automatic calculation of cross sections using helicity amplitudes.
    - Phase Space integration using automatic multi-channel techniques.
  - MadGraph
    - Calculation of matrix elements using helicity techniques.
    - Phase Space integration using automatic multi-channel techniques.
  - GRACE
    - Calculation of matrix elements using helicity techniques.
    - Phase-space integration using BASES.

Decay Calculations

- How accurate does the decay calculation need to be?
- In most cases the branching ratios are total widths are calculated at leading order.
- Some exceptions most programs have some corrections and radiative processes, *e.g.* $H \to gg$.
- HDECAY calculates Higgs decays at NLO.
- SDECAY should be available soon which has many SUSY decays at NLO.
- Do we need to do better?

Decay Simulations

- Inside the event generators decays are usually treated via either a phase-space decay or with the correct leading-order matrix element.

- Do we need spin correlations?

Decay Simulations

- 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.

Decay Simulations

- 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.
- Which of these techniques should we be using?
- Do we really need these correlations?

Future

- Virtually all the programs I have talked about are in FORTRAN.
- Hopefully we will be using C++ by the time of LHC switch on.
- What do we need/want in C++?

Plans

- Start on Wednesday with plenary talks, reviews of where we are
  - Review of SUSY Spectrum Codes, Sabine Kraml
  - Review of Decay Codes Abdel Djouadi
  - Presentations on event generator status Peter Skands, Peter Richardson, Steffen Schumann.
- After this plan to discuss what people want additional presentations/discussions on.
- One session already planned on Monday afternoon on experimental needs.
- A number of sessions on spectrum/decay interfaces.