Review of Monte Carlo Event Generators in the UK

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Outline

- Motivation, projects and history
- Current Status
- Recent Highlights
- The Future
Basics of Event Generation

- Monte Carlo event generators combine:
  - hard perturbative QCD calculations;
  - approximate QCD evolution from high to low energy scales using the parton shower;
  - perturbative multiple parton scattering models of the underlying event;
  - non-perturbative models of the hadronization process;
  - simulations of hadron decays;

to provide simulations of complete events.

- They are essential tools that both encapsulate the current theoretical understanding of hadronic collisions and produce simulated events which can be compared with data.
A Monte Carlo Event

Hard Process, now calculated at (N)NLO
A Monte Carlo Event

Initial- and final-state parton shower

$p, \bar{p}$

$p, \bar{p}$
A Monte Carlo Event

\( p, \bar{p}, W^- \rightarrow t \bar{b}, \ell^+ \nu_\ell, W^+ \rightarrow t b \) Perturbative decays of heavy particles
A Monte Carlo Event

Secondary hard processes

Motivation and History

A Monte Carlo Event

\[ p, \bar{p}, W^-, t, \bar{t}, t, b, \ell^+, \nu \]

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MC in UK
A Monte Carlo Event

\[ p, \bar{p} \rightarrow W^- t \bar{t} \rightarrow W^+ \ell^+ \nu_{\ell} + b \bar{b} + \text{Hadrons} \]

Motivation and History
A Monte Carlo Event

Hadron Decays

$p, \bar{p}$
Projects with U.K. Involvement and Leadership

- Currently three major Monte Carlo event generators, U.K. leadership in two of them
  - Herwig (Richardson, IPPP & Seymour, Manchester)
  - SHERPA (Krauss, IPPP)

- Other projects
  - Leadership of High Energy Jets (HEJ) (Andersen, IPPP & Smillie, Edinburgh)
  - Involvement with MinLO and POWHEGBox (Hamilton, UCL Zanderighi, Oxford)

- Leadership in HepData project for data preservation (IPPP) and Rivet and Professor programs for data comparison/tuning (Glasgow, IPPP)

- Leadership of E.U. network MCnet.
History

- The U.K. has been a leader in MC development since the birth of the field. Webber, Cambridge HERWIG 1984→, Sakurai Prize 2012
- Significant investment in early-mid 2000s
  - 2 PRDAs to develop new program based on HERWIG in C++ (PPARC responsive RAs)
  - e-Science money to redevelop HepData and develop Rivet.
  - Additional permanent appointments Seymour, Richardson, Krauss.
- Significant investment from the IPPP.
- More recent appointments of Zanderighi, Hamilton, Zanderighi, Andersen, Smillie
Last 15 years in Monte Carlo

- The last fifteen years have seen significant changes in the Monte Carlo generator field.
- At the end of LEP
  - Main programs were FORTRAN HERWIG6 and PYTHIA6.
  - Parton showers with matching to the first hard emission for simple processes such as $e^+e^- \rightarrow q\bar{q}$ and Drell-Yan.
- Developments since LEP
  - Multiple emissions at LO, CKKW
  - Matching to NLO (1st approach Frixione and Webber)
  - Merging at NLO (NLO normalisation for multiple emissions) MINLO, Sherpa, Herwig 7.1
  - First NNLO Hamilton, Nason, Oleari, Zanderighi
New Programs

- At the end of LEP the existing FORTRAN generators needed to be rewritten to allow physics improvements and long term development:
  - HERWIG redeveloped as Herwig++ and then Herwig7;
  - PYTHIA → Pythia 8;
  - Sherpa developed from scratch;
- All in C++.

- New generation of event generators which are the workhorses at the LHC, together with specialised programs for the calculation of hard processes in the various merging schemes.
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At the LHC: ATLAS Z+jets

**ATLAS Preliminary**

- **Z/γ*(→ IT) + jets**
- **13 TeV, 3.16 fb⁻¹**
- anti-k, jets, R = 0.4
- \( p_T^{\text{jet}} > 30 \text{ GeV}, |y|^{\text{jet}} < 2.5 \)

**Data**

- **SHERPA 2.2**
- **ALPGEN + PY6**
- **MG5_aMC + PY8 CKKWL**
- **MG5_aMC + PY8 FxFx**

**Pred./Data**

- Pred./Data [pb/GeV]
- Pred./Data [pb]

**Z/γ*(→ IT) + 1 jet**

- **13 TeV, 3.16 fb⁻¹**
- anti-k, jets, R = 0.4
- \( p_T^{\text{jet}} > 30 \text{ GeV}, |y|^{\text{jet}} < 2.5 \)

**Data**

- **Z + 1 jet N_{\text{jet}}^\text{NNLO}**
- **BLACKHAT + SHERPA**
- **SHERPA 2.2**
- **ALPGEN + PY6**
- **MG5_aMC + PY8 CKKWL**
- **MG5_aMC + PY8 FxFx**

**Pred./Data**

- Pred./Data [pb/GeV]
- Pred./Data [pb]

ATLAS-CONF-2016-046
At the LHC: ATLAS $W^+\text{jets}$
Effect of Jet Veto in Gluon Fusion with HEJ

from 1706.01002, Andersen, et.al
Merging with bottom quarks

from 1612.04640 Krauss, Napoletano, Schumann
Merging $W^+ W^-$ and $W^+ W^- + \text{jet}$ with MINLO
Extending MINLO

JHEP 1605 (2016) 042 Frederix and Hamilton
Subleading-Logs

from Höche, Krauss, Prestel arXiv:1705.00982
The Future

- U.K continues to be the world-leader in MC development.
- Important synergy between:
  - event generator projects Herwig & Sherpa;
  - data preservation Rivet & HepData
  - higher order/multiplicity calculations HEJ, MINLO, POWHEGBox, BLACKHAT, ...
  - experimental community
- Can lead to new developments e.g. Contour.