Monte Carlo Event Generators

Introduction / Overview

Current interests & active research directions

Over to You: input(s) from Warwick?

Discussion: Overlaps and Potential for Common Projects

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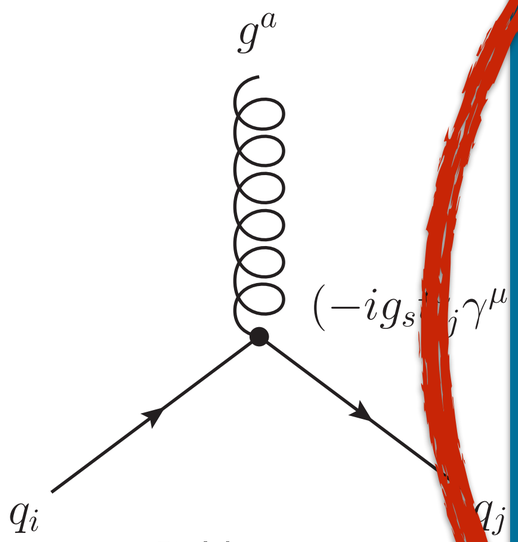
Kickoff — Monash-Warwick Alliance on Particle Physics, Dec 2020

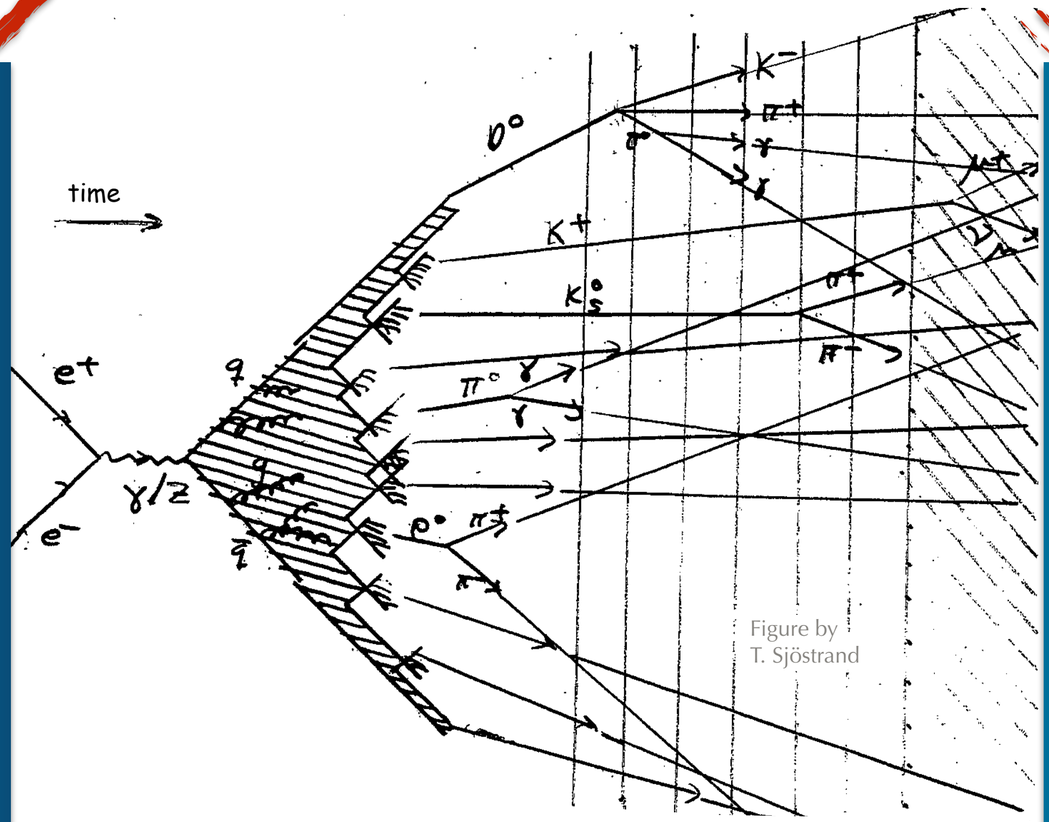
Overview — Phenomenology

THEORY → **PHENOMENOLOGY** → **EXPERIMENT**



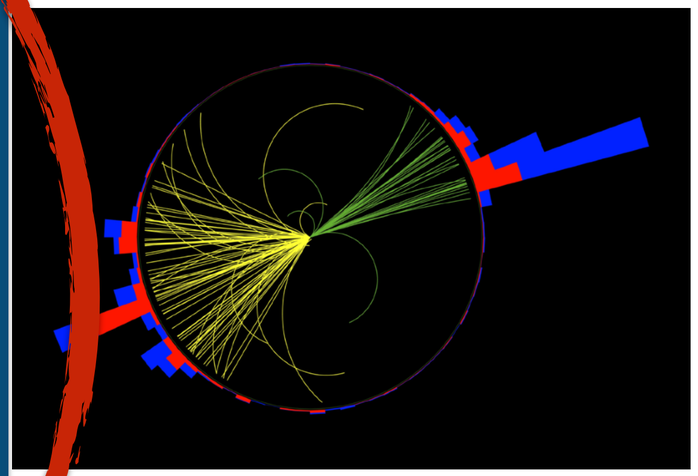
Field content, Symmetries

FUNDAMENTAL PARAMETERS



Cross Sections, Resonance Decays, Bremsstrahlung, MPI, Hadronisation, Hadron Decays, "Ideal Observables"

OBSERVABLES



Real-World Measurements, Triggers, Acceptance, Resolution, Backgrounds, Calibration, Unfolding, …

INTERPRETATION

MC Event Generators

(My) Topics of Expertise within Phenomenology

Areas in red ~ those on which I am / have been directly involved in Pythia's modelling

Model Building

Field Content, Symmetries

EFTs (with/without UV completions)

Derived Quantities: Masses, Mixings & Couplings

Outside (my) scope:
Heavy-Ion Collisions, Cosmic Rays, Low-Energy & Fixed-Target Interactions,…

Perturbation Theory for Cross Sections and Decay Rates

Factorisation & PDFs

N^nLO Amplitudes

Phase-Space Integrations, IR Safety, Pole Cancellations

All-Orders Resummations / **Parton Showers**

QED/EW Corrections

Matching, Merging, and **Matrix-Element Corrections**

Beyond Perturbation Theory

Confinement

Lattice QCD

Strings / Clusters

Beam Remnants

Heavy flavours, onia, light nuclei, exotic hadrons, …

Hadron Structure

"Colour Reconnections" & Collective Effects

MPI / UE Models

Minimum-Bias

Elastic & Diffractive Scattering

Hadron ($+\tau$) Decays

Hadronic Matrix Elements

OPE, Form Factors, Wilson Coefficients

EvtGen (Warwick)

QED Corrections

Photos?

Polarisation

Parameter Constraints:

MC Tuning (manual or automated)

Global Fits

Blue ~ some further areas (non-exhaustive) of potential overlap/interest for MWAPP ?

Specific Current (+ recent) Research Directions

1. **Breaking the (N)LL Paradigm of Parton Showers**
2. **Combining Showers and Matrix Elements — on a laptop**
3. **Specific Phenomenology: Top Quarks & VBF** ← Ask if you are interested
4. **Making Algorithms do What You Want: Final States on Demand and Automated MC Theory Uncertainties**
5. **String Fluctuations and String Interactions**
6. **Minor Directions:** QED Corrections (and EW showers), and Physics at FCC-ee / CEPC / FCC-hh / CPPC

Most of these have direct benefits in experimental contexts

All of them could benefit from collaboration on requirements, sensitive tests / new observables, …

1. Breaking the (N)LL Precision Paradigm for Parton Showers

Parton showers describe the formation and substructure of bremsstrahlung jets

Ubiquitous aspect of high-energy scattering of coloured partons.

Currently all based on iterated lowest-order kernels + (E,p) cons & running couplings

DGLAP kernels (incoherent) or dipole/antenna functions (coherent)

At Monash, we develop **VINCIA**, an antenna shower integrated in and available in Pythia 8.3.

Main feature: **improved coherence** especially in **initial-final colour flows** & **top decays**

+ unique "sector shower" with sophisticated t and b **mass corrections** *(see 2003.00702)*

+ **QED multipole** shower and collinear **EW shower** *(see 2002.04939 & 2002.09248)*

Several groups worldwide now developing proofs of concept going beyond current state of the art

VINCIA is among them, with several new techniques that we are now combining into a second-order shower framework (see, e.g., *1303.4974, 1611.00013, 2003.00702*)

These new shower models will need sophisticated experimental tests

Do they describe the finer nuances of jet substructure reliably, in diverse contexts?

+ Observables to tell apart a nicely tuned LL shower from the real thing. (No mean feat — after all, we've had decades of experience trying to tune the LL ones as best we can…)

2. New Efficient Methods for Matrix-Element Corrections

Showers are only accurate in soft/ collinear limits

Many techniques exist to correct the distributions of **hard, wide-angle jets** using (fixed-order) matrix elements

Typically requires (e.g., **CKKW-L**) computing all possible ways your shower can reach each given ME configuration

Number of histories grows similarly to number of Feynman diagrams > factorially

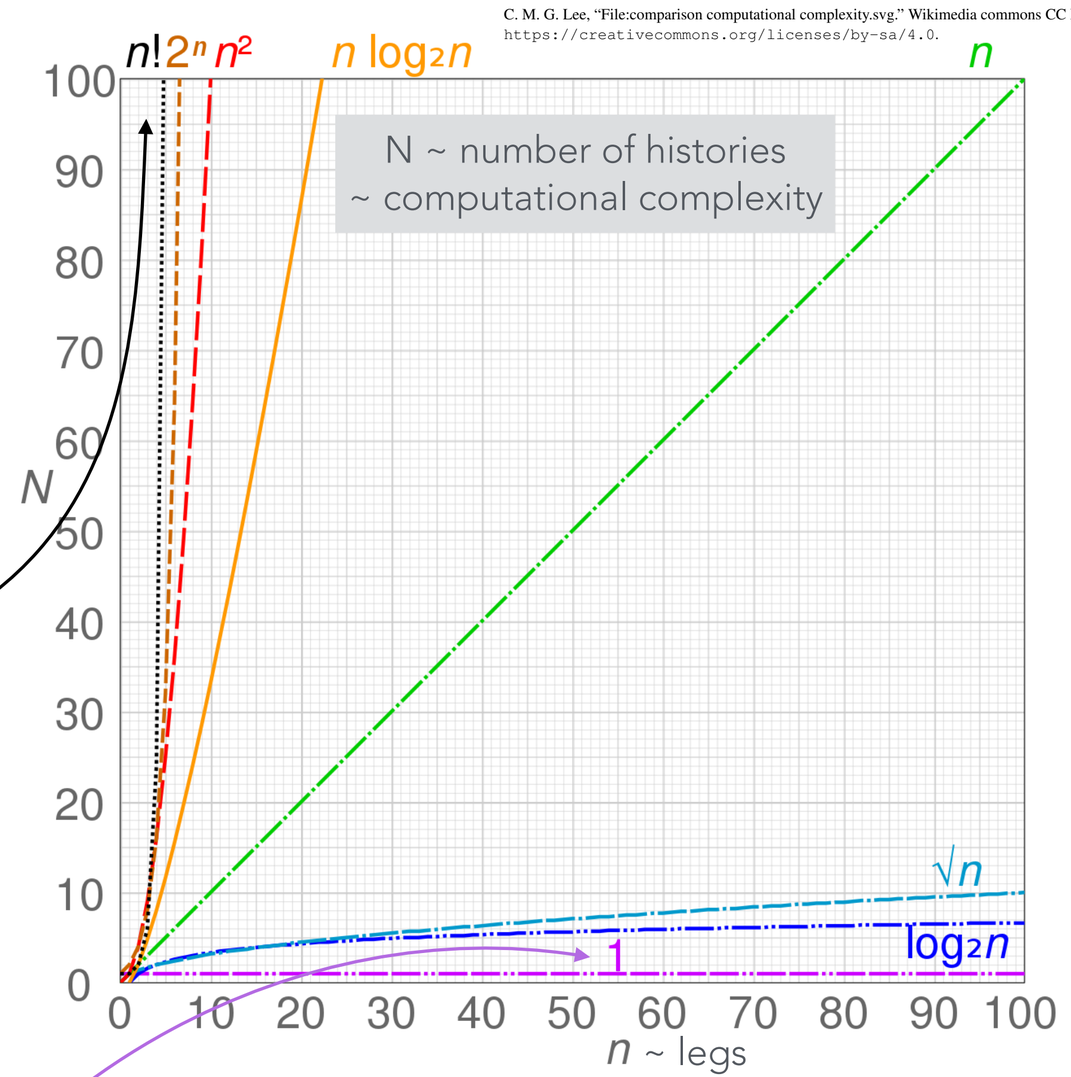
Significant bottleneck

Can one improve on that?

Enter Sector Showers (via VINCIA)

Redefine shower operator to make it **bijective**; only a single kernel allowed to populate each region ("sector") of phase space.

Maintains LL accuracy with **constant complexity**



Proof of concept ("LO sector merging") will be available to try out in Pythia 8.304

4. Making Algorithms do What You Want

Enhanced kernels: e.g., can artificially increase rate of $g \to b\bar{b}$, $q \to q\gamma$, or even $\gamma \to e^+e^-$ branchings in shower. (Can also **decrease** others.)

➜ easier to get statistics for **"rare" occurrences**, like B hadrons from $gg \to gg$ cross section, at the price of having weighted events (which Pythia computes automatically).

Not sure how much people have yet tried this capability out in anger, but would like to get input on uses / issues / potential future developments.

Automated uncertainties: shower computes variation weights on the fly eg for renormalisation-scale variations & self-diagnosing of shower accuracy

Already some use eg by ATLAS; not sure how widespread?

These projects both relied on deconstructing the "Sudakov veto algorithm" and putting it back together in new ways. (E.g., **1102.2126, 1605.08352**)

I could imagine exploring (no promises!) techniques for non-perturbative aspects e.g., to increase the probability for specific (rare) **heavy-flavour hadrons**, perhaps specific **kinematics** (LHCb acceptance?), or whatever would make a difference to alleviate efficiency bottlenecks ➜ get what you want.

Machine learning biases based on which events you throw away and which you keep?

5. String Fluctuations & String Interactions

Striking discoveries in high-multiplicity min-bias events

Strangeness enhancements and collective flow ("CMS ridge")

Hard to study strangeness without PID

ATLAS+CMS limited to mainly K^0_S, Λ ➜ ALICE and LHCb can reveal full picture

Theorists are arguing: thermal effects, string interactions, …

Pythia's hadronisation model — the "Lund string model" — dates back to the early 80s. No **major** revisions since ➜ high time for a service check at the very least?

Many new ideas …

Lund: thermal string fragmentation, **ropes** and **shoving** (DIPSY + implementation in Pythia)

Monash: QCD **colour reconnections**, thermal excitations on an expanding string, out-of-equilibrium fragmentation, fragmentation in a background field, string **interactions**, …

+ Several alternative models (e.g., EPOS with hydro).

Personally, I think we are **either** seeing **interactions among QCD strings**, a **new type of QCD strings**, or else a **breakdown of QCD strings**

Either way — immensely interesting! I don't have a good overview of LHCb activities.

(Note on **MCnet**)

www.montecarlonet.org

Longstanding **collaboration of general-purpose MC** authors

Herwig, Pythia, Sherpa (+ Rivet, MadGraph, and a few more specialised)

Started as EU FP6 RTN, then FP7 ITN, now Horizon 2020 ITN (budget ~ 3.4M€).

Current nodes:

Manchester, Durham, Glasgow, UCL (UK), UCL (B), Göttingen, Karlsruhe, Lund + several industrial and **associate partners** (including **Monash**)

Activities:

Yearly **MCnet summer schools** (eg Monash Prato in 2018; next probably in Germany end of July) *+ ad hoc* partnerships e.g., with CTEQ school, MadGraph schools….

Academic Studentships: 3-6 months, open to anyone to work on a project with MC authors embedded at a node (not available at associate partners unfortunately).

Produced the first major **MC review** (in 2011, so slightly dated by now).

Phys.Rept. 504 (2011) 145-233 • e-Print: 1101.2599 [hep-ph]

(Some) Specific Interests

Radiation patterns in top quark decays (in/out of cone, jet substructure, coherence, mass calibrations, uncertainties)

+ Ditto in Weak Boson Fusion Processes

Collaboration on optimisations / biasing of sampling algorithms?

Identified particles (esp strange vs non-strange, and baryons, with/without hard heavy flavour) in minimum-bias events (or UE):

Complementary (and new) measurements in LHCb region

Spectra and correlations, in/out of jets, …

Physics question: how to tell thermal apart from stringy physics, in real world?

Happy to arrange a dedicated Zoom chat / seminar on these or any of the topics mentioned in this talk if interest at Warwick.

Over to You

+ Discussion