Future experimental needs in event simulation

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Taming the Accuracy of Event Generators

29 June 2020
Projected integrated luminosity

- Peak luminosity
- Integrated luminosity

Luminosity [cm\(^{-2}\)s\(^{-1}\)]

Integrated luminosity [fb\(^{-1}\)]

Year

10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
Wishful thinking (pre-corona)

- flat budget not going to get us annual 20% CPU increase as Moore’s law no longer holds
- no magical factor-2 ‘speed up’ of generators in sight, but some CPU reductions possible
- still LHC measurements in danger of being limited by Monte Carlo statistics
Revised computing model

- baseline: assume Run-2 performance (compromise on physics quality)
- conservative: achieve better physics quality for same CPU time / event as in Run-2
- aggressive: CPU time / event halved, generate 30% (simulate 10%) fewer events
Projected CPU breakdown

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→ event generation on par with detector simulation
Breakdown by generator (bit outdated, but not too bad)

→ left plot: does not account for alternative multi-leg setups

→ right plot: most CPU spent on high-precision multi-leg calculations (e.g. for ATLAS: \( V + 0, 1, 2j@NLO+3, 4j@LO \) and \( tt + 0, 1j@NLO+2, 3, 4j@LO \))

→ outlook: CPU spent on expensive setups expected to increase faster than for fast setups
Negative weights are expensive

→ relative uncertainty increased by factor $1/(1 - 2f_{nw})$, so sample size needs to be factor $(1 - 2f_{nw})^2$ larger

→ $f_{nw} = 10\%$ implies statistical error becomes factor 1.25 larger
   → need factor 1.5 as many events

→ $f_{nw} = 20\%$ implies statistical error becomes factor 1.7 larger
   → need factor 2.8 as many events

→ $f_{nw} = 30\%$ implies statistical error becomes factor 2.5 larger
   → need factor 6.3 as many events

→ $f_{nw} = 40\%$ implies statistical error becomes factor 5 larger
   → need factor 25 as many events

→ setups notorious for large negative weight fraction are just not feasible for production
Populating extreme regions of phase space

- phase-space slicing: add a cut at the generator level, stitch together multiple slices
- cross-section falls ‘naturally’ within each slice
- phase-space biasing: produce events flat as a function of some observable
- events are assigned weights to produce physical distribution
On-the-fly variations

- multiweights huge CPU saving compared to explicit variations for generator uncertainties
  - setup with $\sim 100$ weights only $\sim 30\%$ slower

- more variations to be included in the future
  - parton-shower scale variations, alternative scale choices, electroweak corrections, ... 
  - but some algorithmic variations cannot be achieved through reweighting
(HL-)LHC: a jet factory

→ pretty much everything the detector sees is a jet to start with
→ excellent understanding of jet modelling and associated theoretical uncertainties is vital
→ ‘sit back and relax’ for data-statistical/experimental uncertainties to drop – except theory

![Graph showing ATLAS event counts and W+→τν branching]


![Graph showing CPU hours per event]

[JHEP 05 (2018) 077]
Parton shower modelling uncertainties

- analyses rely on reasonable modelling and a solid uncertainty estimate
- often a bottleneck: desire to have comprehensive survey of models but struggle to estimate associated uncertainty in CPU efficient way
Dawn of the multi-boson precision area

- differential analyses of multi-boson final states well underway
- challenging high-multiplicity final states with lots of combinations
  - full coverage of final states is important
  - (NLO multi-leg) setups not trivial to integrate
- as always: $VV\,+\,\text{jets}$ can be signal but also background for other measurements/searches
  - needs good statistical coverage in different regions of phase space / jet multiplicities
  - need good description of third jet activity and matching to parton shower
Topologies with suppressed colour flow

- pinning down weak boson fusion/scattering at the core of LHC physics programme
- vital probe of the electroweak gauge structure of the Standard Model
- stress test of perturbative QCD
- current models do not seem to live up to this challenge
- poor modelling, not all final states available, lack of multi-weight support, . . .
Event generation in times of near-infinite data statistics

What do experiments need? What can experiments afford?

- expensive high-precision calculations can only be supported, if they benefit a wide range of clients
- need to bear in mind that processes are typically both signal and background

What processes are they trying to measure? What final states do they probe?

- \( V + 0, 1j \) are also part of the \( V^+ \geq 2j \) phase space
- \( t\bar{t} + \) light jets also part of the \( t\bar{t} + \) heavy flavour jets final state
- need precise SM predictions both for the bulk as well as extreme kinematic regions

precision through higher-order corrections

- tends to simplify analysis, but difficult to sustain given CPU constraints

precision through correlation models

- ratios of different processes increasingly popular to constrain systematics
- not always clear how to correlate parton shower knobs across processes/regions of phase space (needs solid uncertainty estimate for the parton shower in the first place . . . )
Summary