Event Generators for High-Energy Physics Experiments

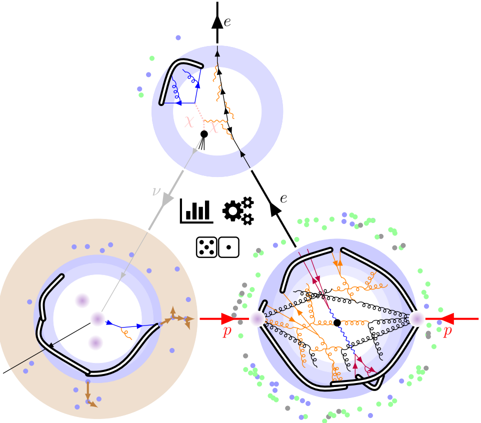
Joshua Isaacson

Based on: Snowmass White Paper (arxiv:2203.11110)

Seattle Snowmass Summer Meeting 2022: Computational Frontier

18 July 2022

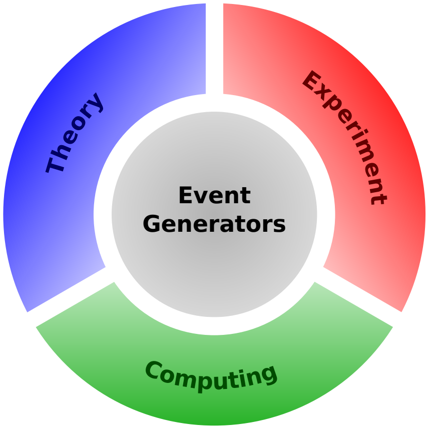
Introduction



- The success of HEP experiments critically relies on advancements in physics modelling and computational techniques, driven by a close dialogue between large experimental collaborations and small teams of event generator authors.
- Development, validation, and long-term support of event generators requires a vibrant research program at the interface of theory, experiment, and computing

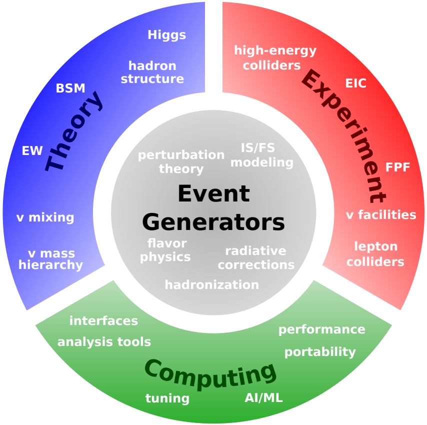
Introduction

- White paper brought together all event generator communities in HEP for the first time
- Need to continue this collaboration through the creation of a joint theoretical-experimental-computing working group cross-cutting through all experiments



Why do we need generators?

- Precision understanding of Standard Model
- Ability to model BSM processes
- Essential role in planning and design of future experiments
- Connects the theory and experimental community
- Modelling non-perturbative effects



Standardized interfaces and analysis tools

Standardized interfaces:

- Reduce unnecessary duplication of effort
- Key interfaces:
  - File formats: LHE and HepMC
  - "Afterburners" (*i.e* EvtGen)
  - LHAPDF and TMDlib
- Ultimate goal is to have all experiments rely on a set of common interfaces. For example, all events outputs should use HepMC.

Analysis tools

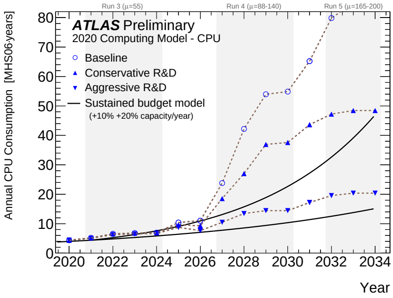
- Rivet:
  - More than 1000 analyses are currently bundled
  - Mainly LHC, but includes other colliders
- Nuisance:
  - Tool for neutrino data/MC comparisons
  - Unofficial unified interface to multiple generator output formats

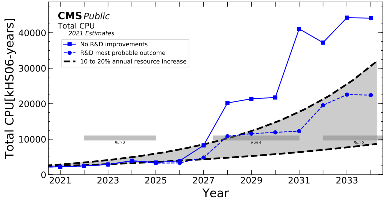
Data Preservation:

- Need to develop ability to preserve analyses reliant on machine-learning
- Deserves top-down structural attention in HEP as it profoundly affects the reproducibility and long-term scientific impact

Tuning and systematics

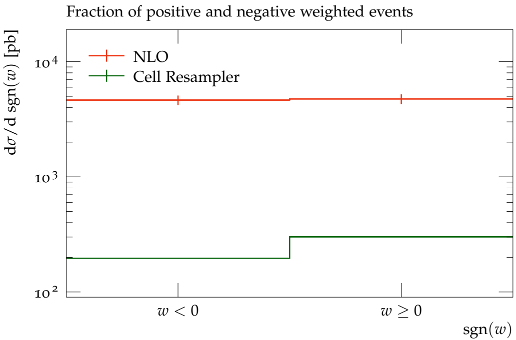
- Uncertainties from the theory can be classified as arising from:
  1. Underlying first-principles SM calculations
  2. Allowed range of parameters of a given phenomenological model, ideally constrained by and derived from a tune to data
  3. Choice of phenomenological model
- All of the above need to be considered before a claim of discrepancy.
- 1 and 2 can be controlled to some extent, 3 is harder to quantify
- Must be careful when tuning to not violate physics constraints





- Unweighting efficiency
- Handling (reducing) negative weights
- Efficiently propagating theory uncertainties (*i.e.* PDFs, scale variations, etc.)
- Modelling Bose-Einstein correlations, hadron rescattering, color reconnections, etc.
- Matching / merging schemes have factorial growth problem
- Preliminary GPU implementations

Computing Bottlenecks



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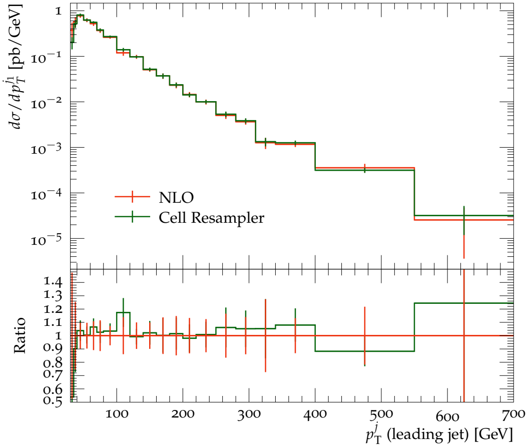

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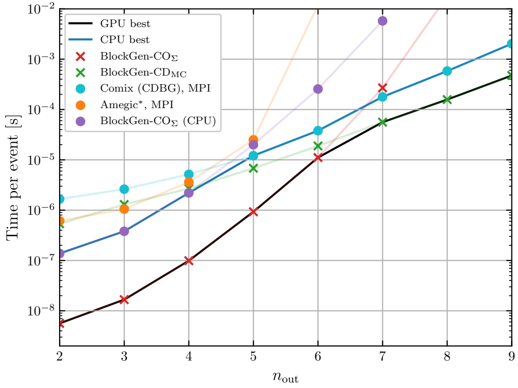

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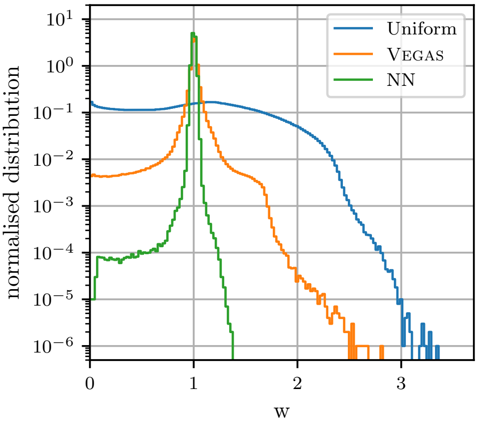
Role of Machine Learning

- NNPDF parton densities
- Phase space integration
- Matrix element emulation
- Differentiable programming for optimization
- Generative networks
- See arxiv:2203.07460 for more discussion



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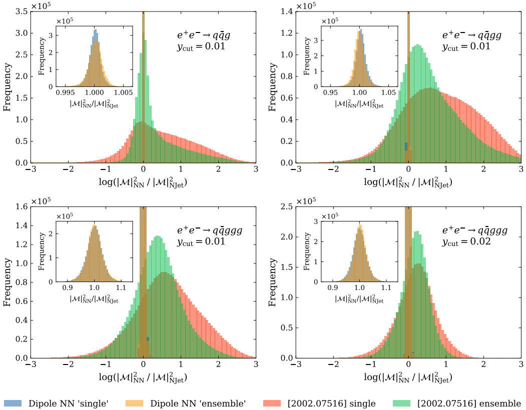

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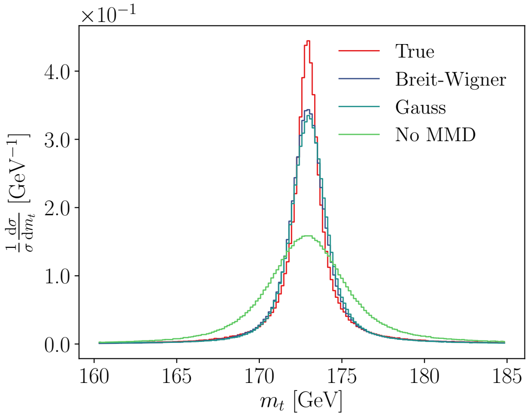

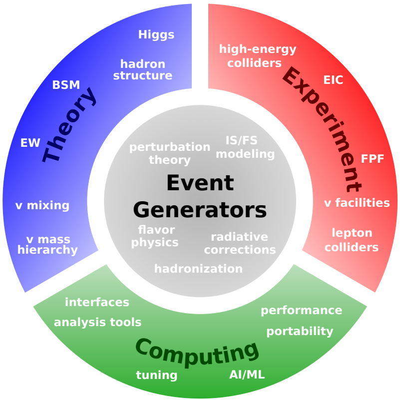

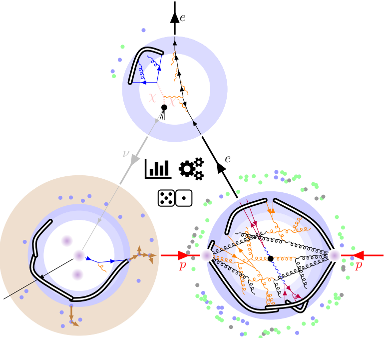

- **Event Generators are vital for the success of high energy experiments**
- **Event Generators bridge theory, experiment, and computing**