HPC framework for event generation at colliders

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Why improve event generators?

Event generation will consume significant fraction of resources at LHC soon
Need to scrutinize both generator usage and underlying algorithms
Dedicated effort in HEP Software Foundation (HSF)
https://hepsoftwarefoundation.org/workinggroups/generators.html

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ComputingandSoftwarePublicResults
Timing and Scaling

- Hard scattering simulation (ME) much more demanding than parton shower (PS) & hadronization
- Complexity of merging ME&PS grows quickly due to inherent $N!$ scaling of underlying algorithms

- ME evaluation time naively scales as $\sim O(3^N)$
- Monte-Carlo unweighting efficiency degrades quickly, as dimensionality of integral is $3N-4$
- Overall scaling $\sim O(4^N)$
Adapting current generators for HPC

- Separate ME generation from PS evolution and ME+PS merging
- Store intermediate status of event in HDF5 files
- Parallelize event processing at particle level using ASCR’s DIY

- Performance limited by number of events being processed per rank
- Scaling of optimization step (strong & weak) up to ~ 2048 cores
- Acceptable (though limited) performance on KNL w/o modifications

**Graphs:**

1. **Cray Arctica, 5.625 - 45 TB/s**
   - Cray X5-2698v3, 2x16 cores
   - 128 GB DDR4 2133 MHz
   - Normalized wall time
   - Strong: time
   - Weak: time × (MC err)^2

2. **HSW: Xeon E5-2698v3, 2x16 cores**
   - 128 GB DDR4 2133 MHz
   - Wall time KNL / Wall time HSW

3. **LHC @ 14 TeV**
   - \( p_{T,j} > 200 \text{GeV}, |\eta| < 6 \)
   - LO, grid warmup only
   - Wall time HSW

4. **Xeon Phi 7250, 68 cores**
   - 90 GB DDR4 2400 MHz
   - Wall time HSW

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**Fermilab**

**HPC framework for event generation at colliders**
Adapting current generators for HPC

- Scaling of event generation step (strong & weak) up to ~ 2048 cores
- Performance limited by number of events being processed per rank (Average timing can only be expected if statistics is large enough)
- Performance of particle-level simulation limited by I/O speed on Cori
  
  Good results with burst buffer, but room for improvement
Physics performance

Jet-$p_T$ spectra in $pp \to W^+ + N$ jets at $\sqrt{s} = 14$TeV

- $n_{\text{max}} = N$
- $n_{\text{max}} = N + 1$
- $n_{\text{max}} = N + 2$
- $n_{\text{max}} = N + 3$

Top quark measurements

Jet substructure

Exotica
Possible efficiency improvements

Christina Gao, Joshua Isaacson, Claudius Krause, SH

- Testing ideas for novel adaptive integrator, using established MC multi-channeling, combined with neural importance sampling via TensorFlow
- Promising results for simplest non-trivial processes, more complicated cases being tested

- If successful, mandates re-write of matrix-element generator Comix to enable vectorization and support of different architectures
- Possibility to use NumPY / TensorFlow will be explored
Summary and Outlook

Technical improvements
- Parallelized Pythia particle-level event generation using DIY
- Improved performance of Sherpa, particularly I/O (HDF5)
- Optimization & event generation now scale up to ~2k cores
- First novel results not previously attainable on WLCG

Physics impact
- New workflow allows to reduce EvGen time in experiments
- Novel opportunity of generator tuning based on theory
  Cross-cut with SciDAC “HEP Data Analytics on HPC”
- Novel opportunities for jet substructure analyses