Event Generators Working Group Status Update

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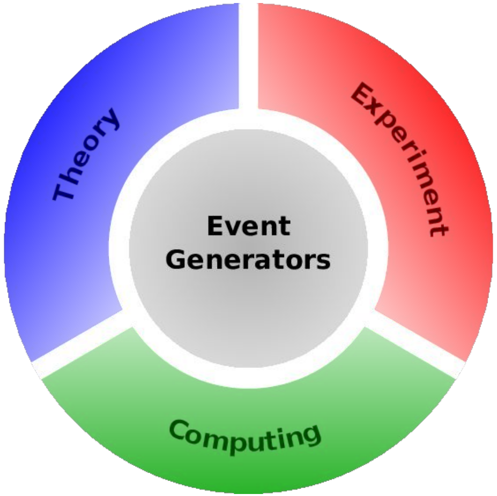
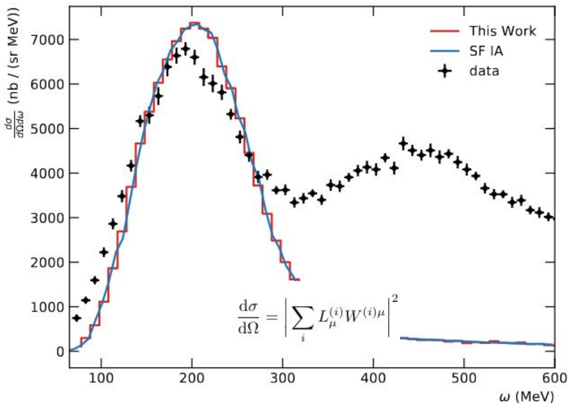
Status of Event Generators [arXiv:2203.11110]

- Overview of status of Monte-Carlo event generators for HEP
  - Contributions from 187 authors at 102 institutions
  - Guided by experimental needs and requirements
- Physics models and computing algorithms employed across facilities and experiments
  - Higher-order QCD & EW perturbative corrections
  - Factorization theorems & parton evolution equations
  - Resummation of QCD & QED effects
  - Hadronization & final-state modeling
  - New physics simulations
- Detailed discussion of MCs for facilities relevant to DOE HEP
  - High Energy Colliders (LHC, μ, …)
  - Neutrino Experiments (Dune, HK, …)
  - Electron-Ion Collider
  - Forward Physics Facility
  - Future Lepton Colliders (FCC-ee, ILC, …)



Status of Event Generators arXiv:2203.11110

- Generators traditionally developed in context of high-energy colliders (LEP, LHC, …) can provide blueprints & components for frameworks at other experiments. For example
  - Novel neutrino generator arXiv:2110.15319
  - Generators for EIC, discussed at MC4EIC workshop, Nov 2021 https://indico.bnl.gov/event/13298/



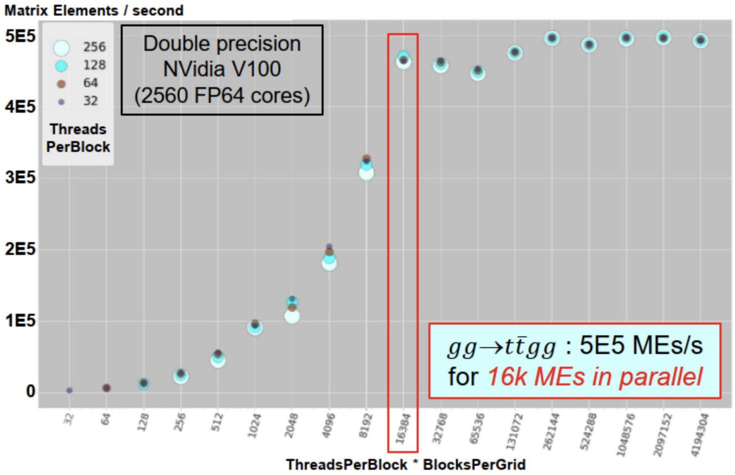
- Event generators are part of a larger ecosystem of tools
  - Interfaces: HepMC, LHEF, LHAPDF, …
  - Analysis & data preservation frameworks: Rivet, Nuisance, …
  - Tuning tools: Professor, Nuisance, …
  - Machine learning techniques: See dedicated document arXiv:2203.07460

Status of Event Generators arXiv:2203.11110

- Computing performance and portability play a key role at LHC arXiv:2109.14938
- Driven by push to high precision simulations in absence of clear signs for new physics
- Main aspects
  - Profiling and benchmarking
  - Efficient phase-space sampling
  - Reduction of negative weights
  - Reweighting for uncertainty estimates
  - Porting software to modern hardware: GPUs and vectorization on CPUs
- Current HEP-CCE activities
  - Portable LO matrix element generators
  - Testing new architectures
  - Negative weight reduction

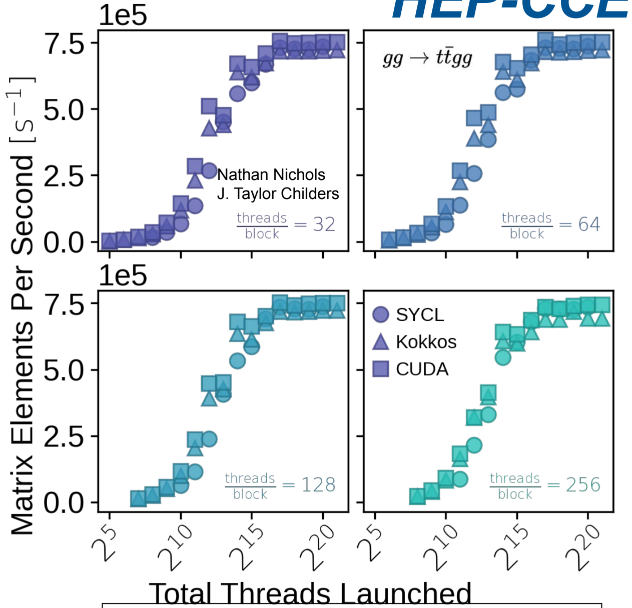
Platform Independent Madgraph5_aMC@NLO

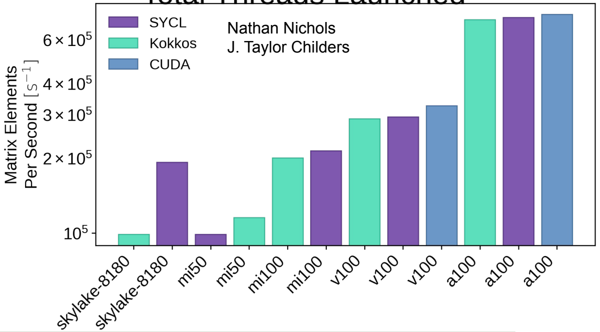
- MadGraph is one of the primary event generators used by ATLAS & CMS and will be responsible for generating a large portion of simulated collisions in the next decade.
- MadGraph uses a python framework that generates process specific compiled codes, originally all FORTRAN based.
- Recently extended to generate serial C++ matrix element calculations called by “MadEvent” which is still FORTRAN
- This code generation framework comes with a PLUGIN capability through which support for other languages and, in our case, portability frameworks can be implemented.
- This enabled the first port of MadGraph to an accelerator [ref], with some performance measures shown here



Platform Independent [Madgraph5_aMC@NLO]

- HEP-CCE is adding backends that use Kokkos and Sycl, broadening reach to architectures in future Exascale machines.
- This effort benefits from an Aurora Early Science Project award received by the ATLAS group at Argonne which provides early access to Intel GPUs and support from Intel/LCF experts.
- These results show matrix element calculations per second for the process *gg* → *tt* + *gg* on NVidia A100 and V100, Intel Skylake CPUs, and AMD MI-50 and MI-100.
- The results show Kokkos & Sycl both perform within 10% of the native CUDA codes, but offer the ability to run on many other systems without rewriting your software.
- We have run on the latest Intel GPUs targeted for Aurora and seen promising results that are currently under NDA.
- The codes are being developed here, still a work in progress: https://github.com/madgraph5/madgraph4gpu





BlockGen - A prototype parton-level event generator for GPUs

- Matrix element generators like MadGraph use most of the computing time in precision event simulations for the LHC. Providing a scalable solution is important for HL-LHC
- First prototype generator for high multiplicity calculations on GPUs, including multiple algorithms which can be dynamically switched to achieve optimal performance.
- Timing studies in comparison to existing CPU codes (MadGraph, Comix, Amegic) show factor 10+ speedup at low particle multiplicity, factor ~4 at high multiplicity.
- https://arxiv.org/abs/2106.06507

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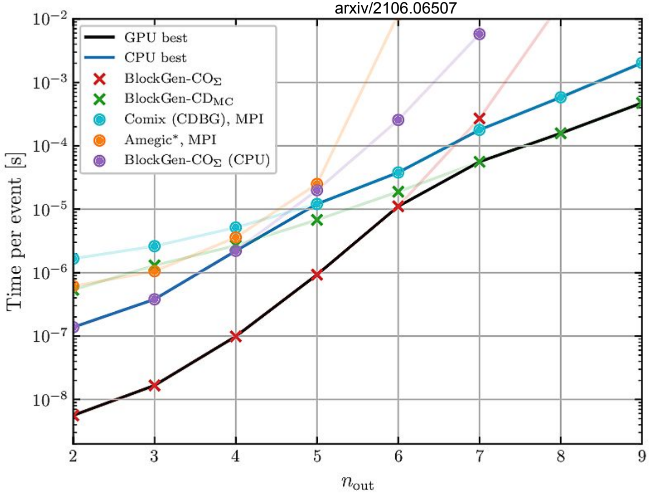
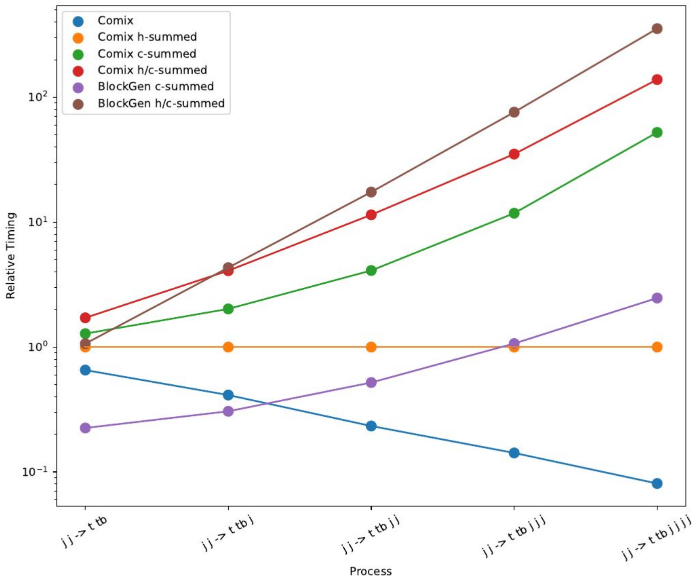
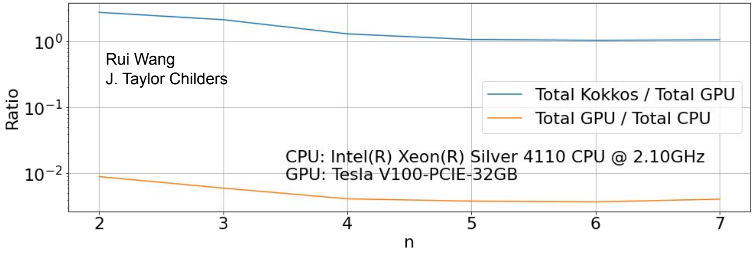


BlockGen - A prototype parton-level event generator

- Ported BlockGen code from C++ to Kokkos
  All-gluon version fully functional
- Profiled resulting code and found agreement with dedicated CUDA version in arXiv:2106.06507
- Fermionic currents and phase-space generator being added to code → extension to general-purpose MC
- Going forward, profiling of phase space generator will become a focus point, results from Sherpa point towards a major bottleneck in this component





Computing performance improvements in Sherpa

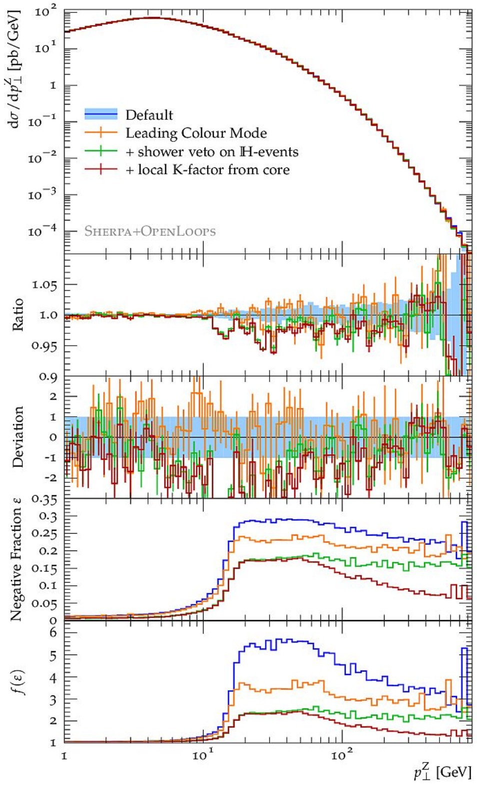
- Sherpa is one of the leading LHC event generators
  Used mostly by ATLAS, somewhat by CMS
- Reduced computational footprint while keeping formal precision targets arXiv:2110.15211, arXiv:2112.09588
  - Negative weight fraction a driver of computing requirements:
    For fraction of neg. weights *f* one needs to generate $1/(1-2f)^2$ as many events to achieve same statistical precision as sample with purely positive weights
  - Can reduce negative weights through controlled approximations

	Negative Weight Fraction
Default	18.1%
Leading Colour Mode	14.0%
+ shower veto on ℍ-events	9.6%
+ local K-factor from core	9.1%

Negative weight fraction in Z+jets

	Negative Weight Fraction
Default	24.8%
Leading Colour Mode	18.7%
+ shower veto on ℍ-events	14.5%
+ local K-factor from core	12.6%

Negative weight fraction in tt+jets



- Not a long-term development, but already used by experiments!

Summary and Outlook

- Current HEP-CCE activities
  - Portable LO matrix element calculators (MadGraph5, BlockGen)
  - Testing new architectures
- Next-to-leading order calculations a natural next target
  - Frameworks are more complex than LO and present some unique challenges
    - Quadruple precision arithmetic
    - Complicated phase space integrals
    - Increased memory consumption
- Important to keep optimizing existing frameworks
  - Low hanging fruit sometimes found by detailed profiling
  - New opportunities, e.g. ML-assisted unweighting arXiv:2109.11964