New Methods for Super-Fast Event Generators

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Particle physics and simulations

- first-principle simulations **defining feature of LHC physics**
- precision and complexity the key, progress Tevatron → LHC huge
- LHC life without Pythia, Herwig, Sherpa, Madgraph unthinkable
  LHC life without NLO,NNLO,NNNLO predictions impossible

- link experiment ↔ theory **crucial for our field**
- transforming simulation-based HL-LHC analyses

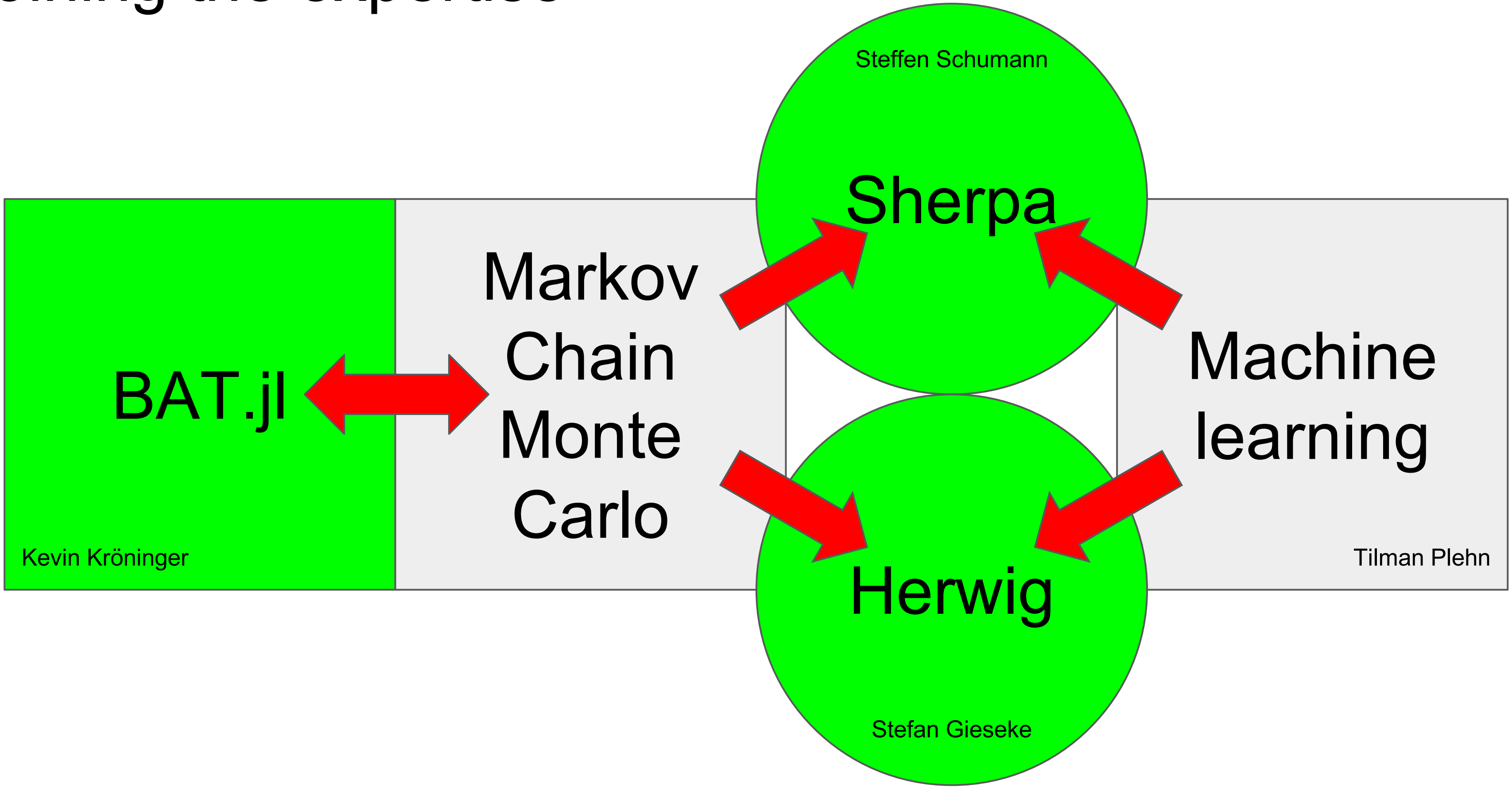
  1. computational speed directly translating into precision of predictions

  2. new analysis concepts beyond Sherpa-hypothesis tests, STXS, etc...

HL-LHC perspective

- current LHC precision on theory predictions 5%
  scaled to HL-LHC luminosity **setting 1% target**
- standard simulation chain stuck at (N)NLO
  new techniques and methods needed
- gain from **statistics**: Markov Chain Monte Carlo algorithms
  gain from **ML**: improved event generators
  gain from **statistics+ML**: simulation-based inference
- defining our team and tasks...

Joining the expertise



Research directions

Direction 1: Precision Monte Carlo codes

- improve phase space sampling performance, unweighting efficiencies (ML, MCMC)
- surrogate fast parton showers
  interplay with hadronization
- learn QCD cluster histories for shower merging
- enable NLO QCD and EW plus parton shower accuracy, also for multi-particle final states
- facilitate mass production of higher-order multi-particle processes, V+jets, tt+jets

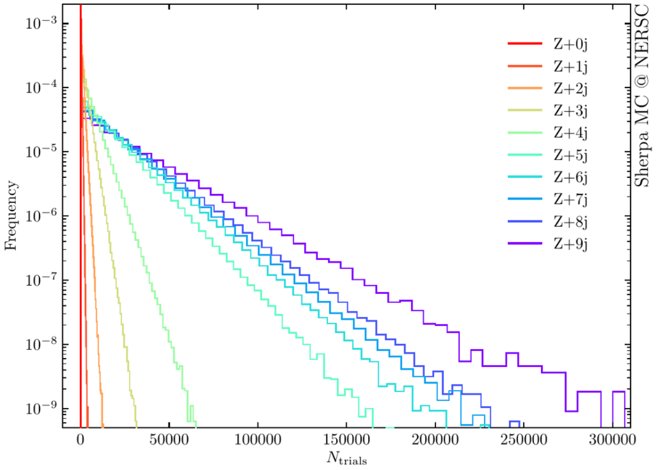


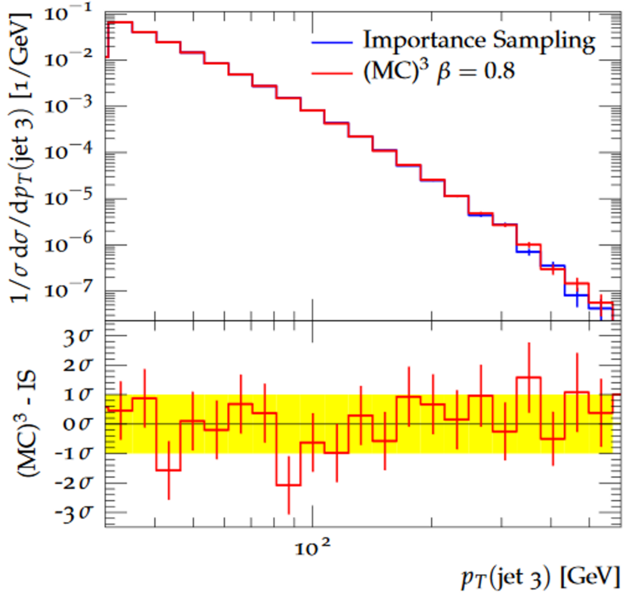
Figure: number of trails to generate unweighted events for Z+jets processes

[Höche et al. Phys. Rev. D **100** (2019) no.1, 014024]

Research directions

Direction 2: Sampling algorithms in BAT

- Development and improvement of fast sampling algorithms for multidimensional parameter spaces, in particular MCMC variants such as (MC)**3
- Systematic study and benchmarking of algorithms
- Optimization and performance tests including a comparison to existing sampling algorithms
- Interfacing the algorithms to Sherpa



Normalized differential distribution for the third-jet transverse momentum in Z+3 jets production. Shown are the predictions from pure Multi-Channel Importance Sampling (blue) and the (MC)**3 algorithm with a lag of 20 and β=0.8. [Comput. Phys. Commun. **186** (2015) 1]

Research directions

Direction 3: Machine learning methods

- speed gain in event generator modules
- training on data: parton shower
- fast wrappers, trained on MC generators
  amplification factors in analogy to fits
  gain through training on weighted events
- fast detector simulations
  avoid unnecessary MC steps, gain focus
- detector unfolding/inversion
  statistically correct over full phase space
- QCD inversion to hard process

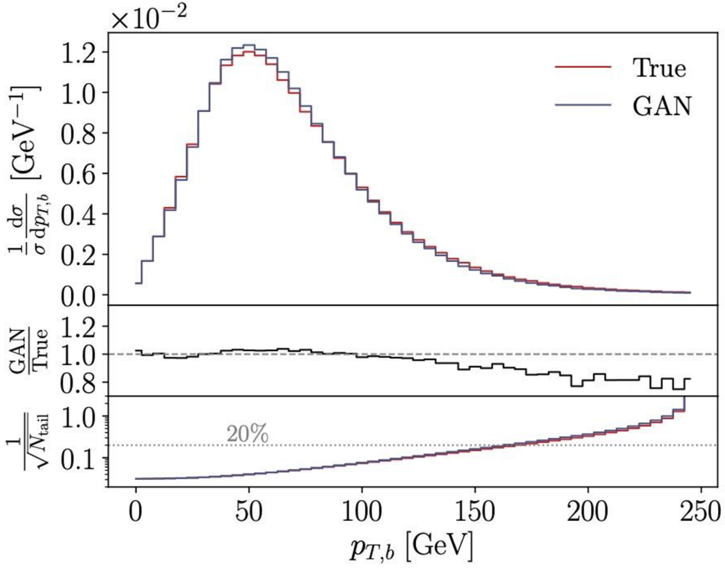


Figure: GANned top pair events compared to training data, including effect of low training statistics
[Butter, Plehn, Winterhalder SciPost 7 (2019) 6 075]

New ideas for LHC simulations

- MC development crucial for particle physics
  standard MC-work funded by BMBF
- Sherpa+Herwig+ML+statistics
  new concepts being developed, ready for benchmarking
- MCNet funding running out
  too physics-specific for AI-FG
  too tool-oriented for standard DFG
- either BMBF funds it or it will not happen

Addendum A - Preliminary work

Kevin Kröninger

- A. Caldwell, D. Kollar, **K. Kröninger**, *BAT: The Bayesian Analysis Toolkit*, Comput. Phys. Commun. **180** (2009) 2197-2209
- O. Schulz, …, **K. Kröninger** *et al.*, *BAT.jl -- A Julia-based tool for Bayesian inference*, arxiv:2008.03132
- **K. Kröninger**, S. Schumann, B. Willenberg, *(MC)**3 -- a Multi-Channel Markov Chain Monte Carlo algorithm for phase-space sampling*, Comput. Phys. Commun. **186** (2015) 1-10

Addendum A - Preliminary work

Steffen Schumann

- E. Bothmann, …, **S. Schumann** et al., Event Generation with Sherpa 2.2, SciPost Phys. **7** (2019) no.3, 034
- E. Bothmann, …, **S. Schumann** et al., Exploring phase space with Neural Importance Sampling, SciPost Phys. **8** (2020) no.4, 069
- B. Biedermann, ..., **S. Schumann** et al., Automation of NLO QCD and EW corrections with Sherpa and Recola, Eur. Phys. J. C **77** (2017), 492

Addendum A - Preliminary work

Tilman Plehn

- A. Butter, **T. Plehn,**
  Generative Networks for LHC Events, arXiv 2008.08558
- A. Butter, G. Kasieczka, B. Nachman, **T. Plehn**,
  GANplifying Event Samples, arXiv 2008.06545
- M. Bellagente, A. Butter, G. Kasieczka, **T. Plehn**, A. Rousselot, ...
  Invertible Networks or Partons to Detector and Back Again, arXiv 2006.06685
- A. Butter, **T. Plehn**, R. Winterhalder,
  How to GAN Event Subtraction, arXiv 1912.08824
- M. Bellagente, A. Butter, G. Kasieczka, **T. Plehn**, R. Winterhalder,
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- A. Butter, **T. Plehn**, R. Winterhalder,
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