Argonne NATIONAL LABORATORY

Future Developments in Monte Carlo Event Generators

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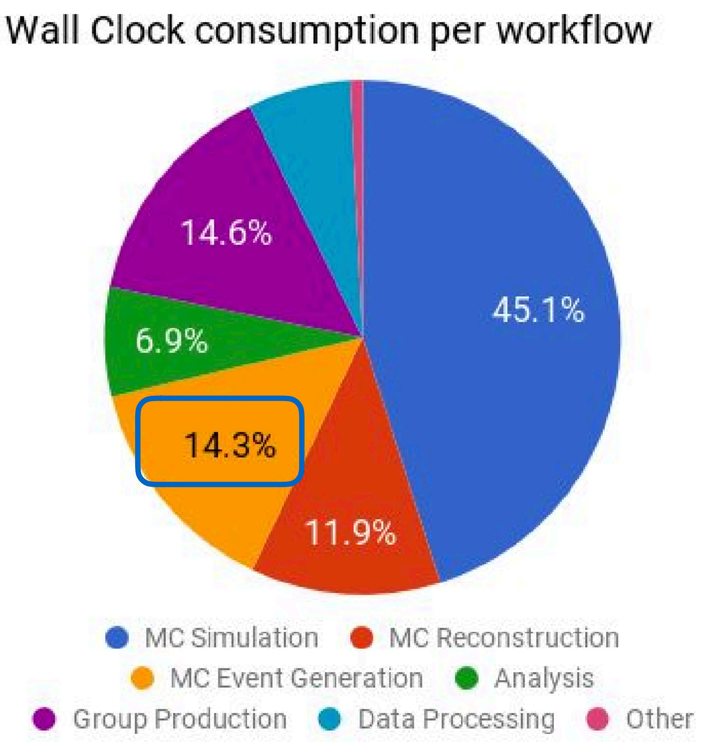
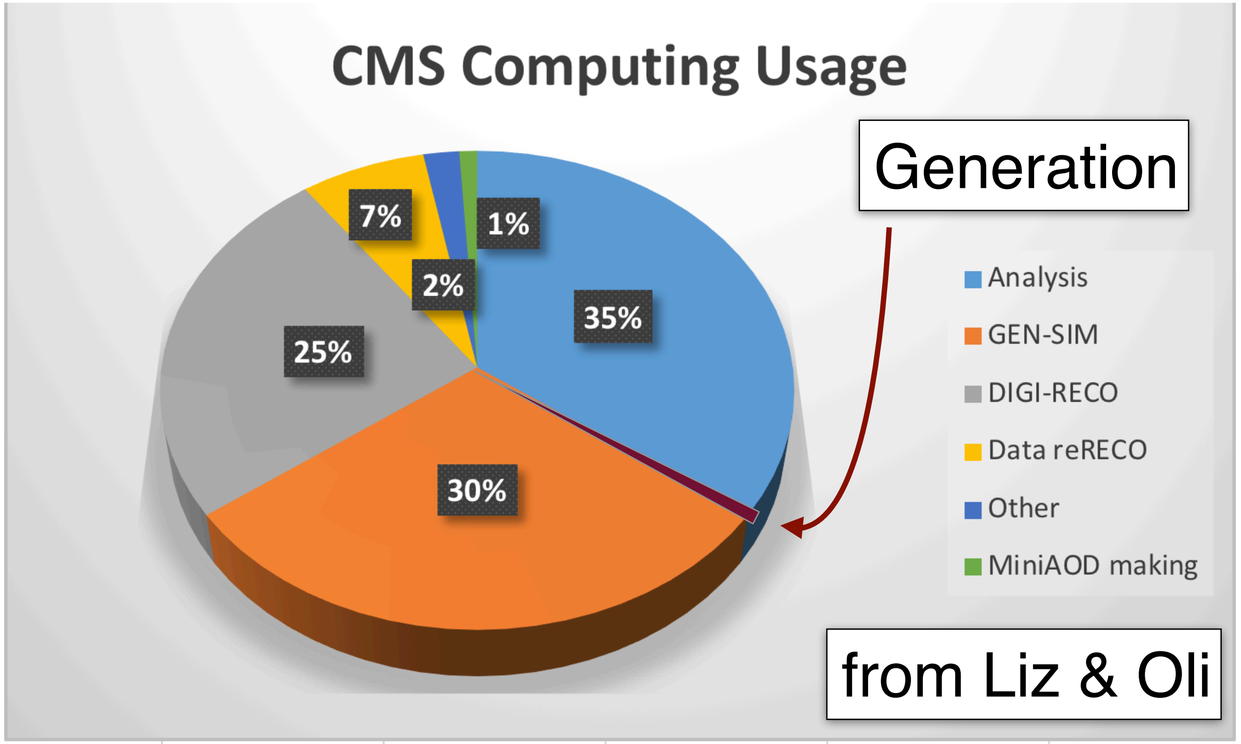
U.S. DEPARTMENT OF ENERGY

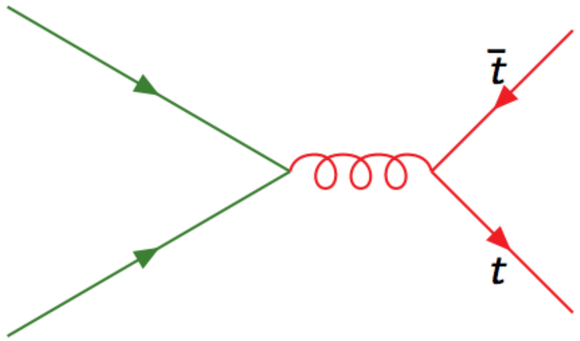
Generators are computationally intensive





- Annual usage in ATLAS is typically in the 10-15%, CMS typically in the range of 2-5%
- These values vary from year to year.
- A little troubled by the huge differences

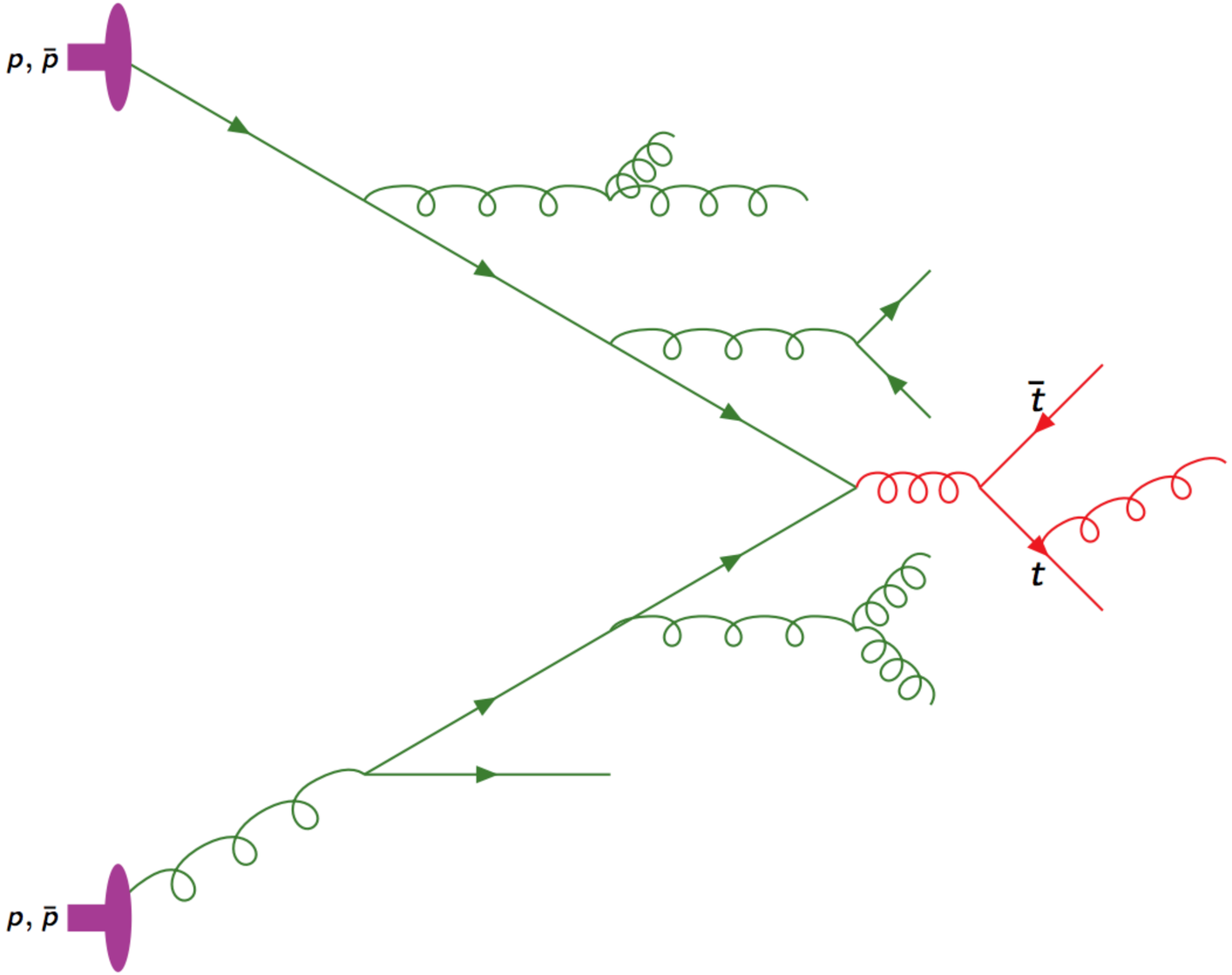
Reminder of what a generator is doing



Calculate hard scatter at fixed order

P. Richardson Herwig Talk

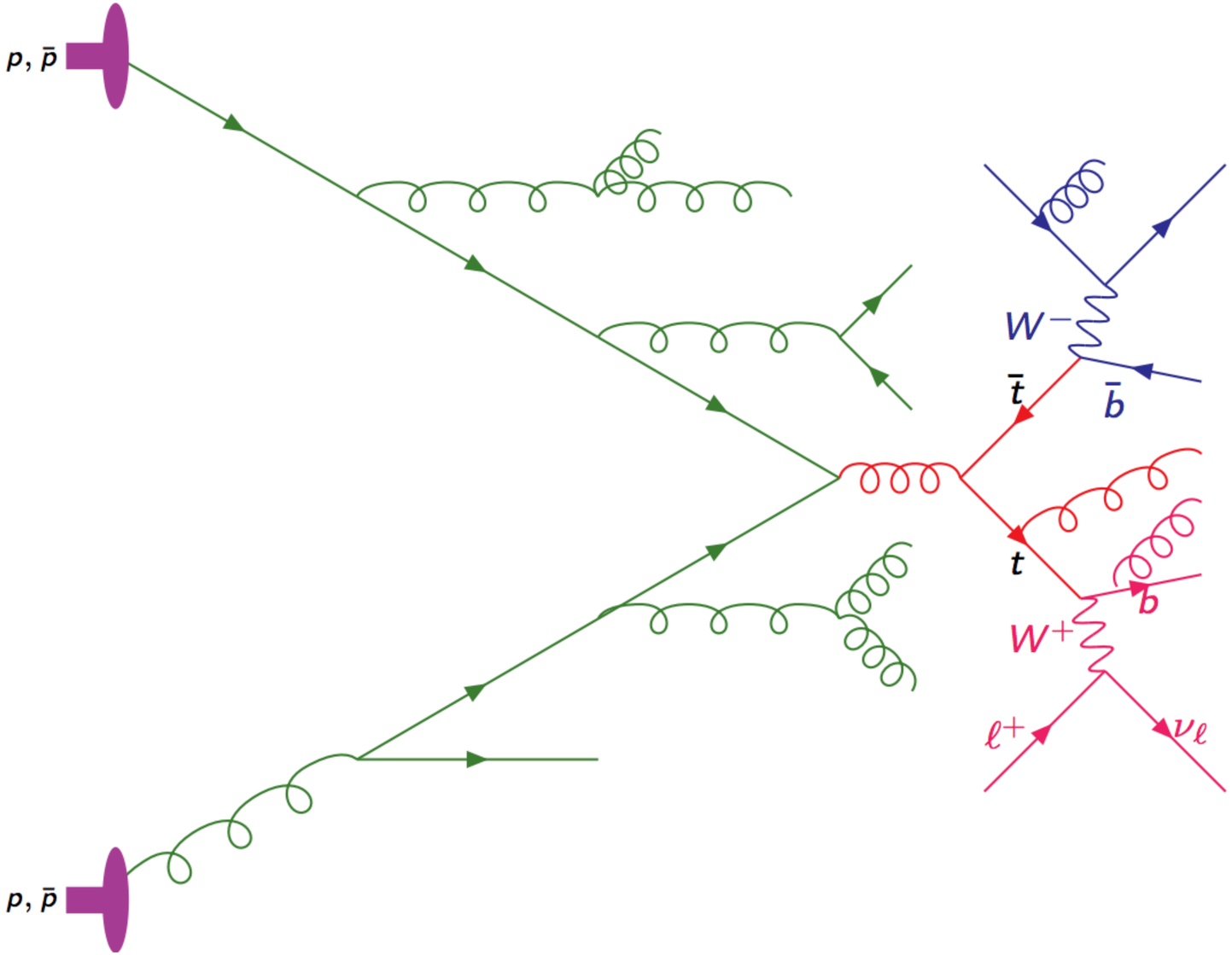
Reminder of what a generator is doing



Calculate initial and final parton shower

P. Richardson Herwig Talk

Reminder of what a generator is doing



Calculate decays of heavy particles at fixed order

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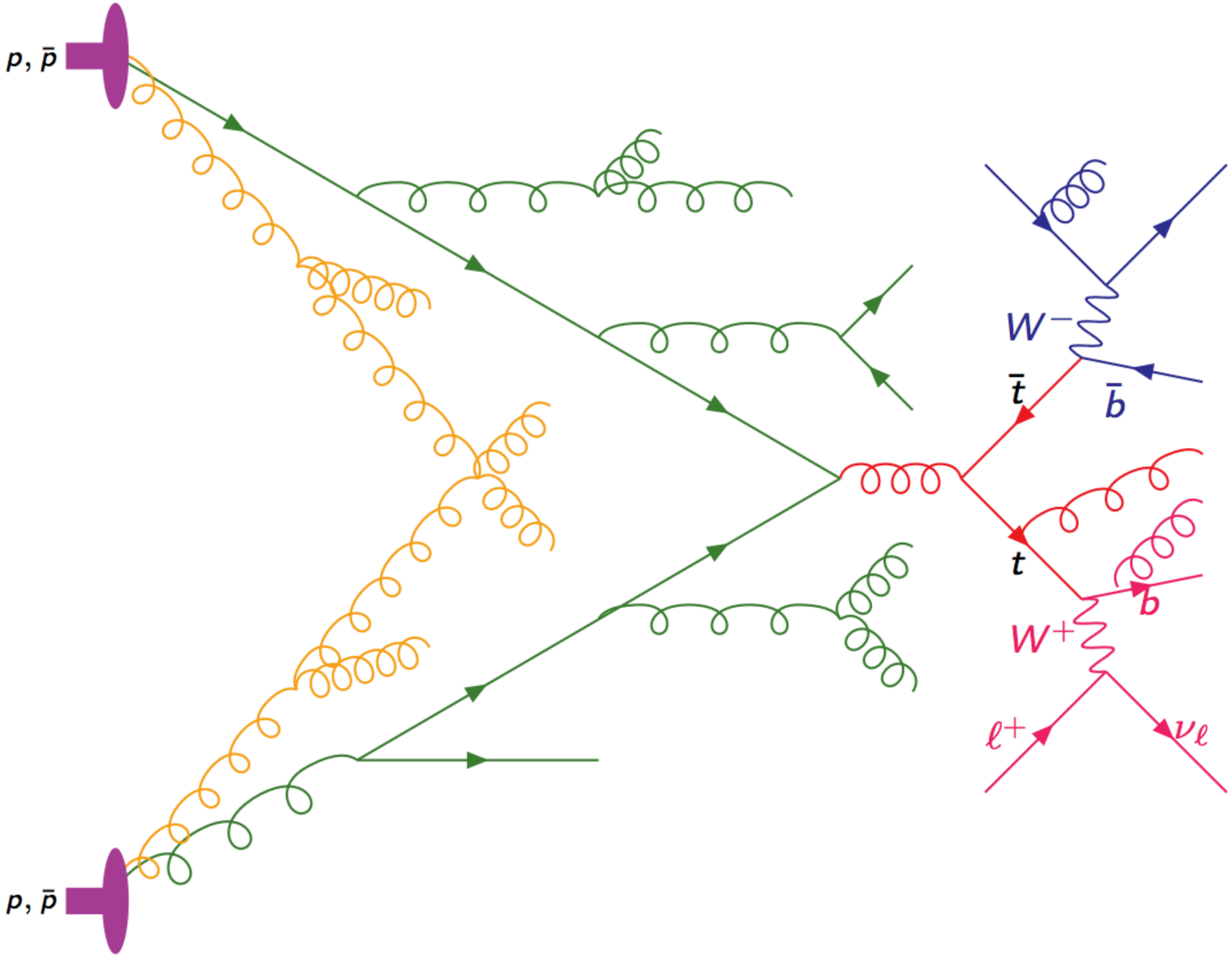
Reminder of what a generator is doing



Secondary hard processes

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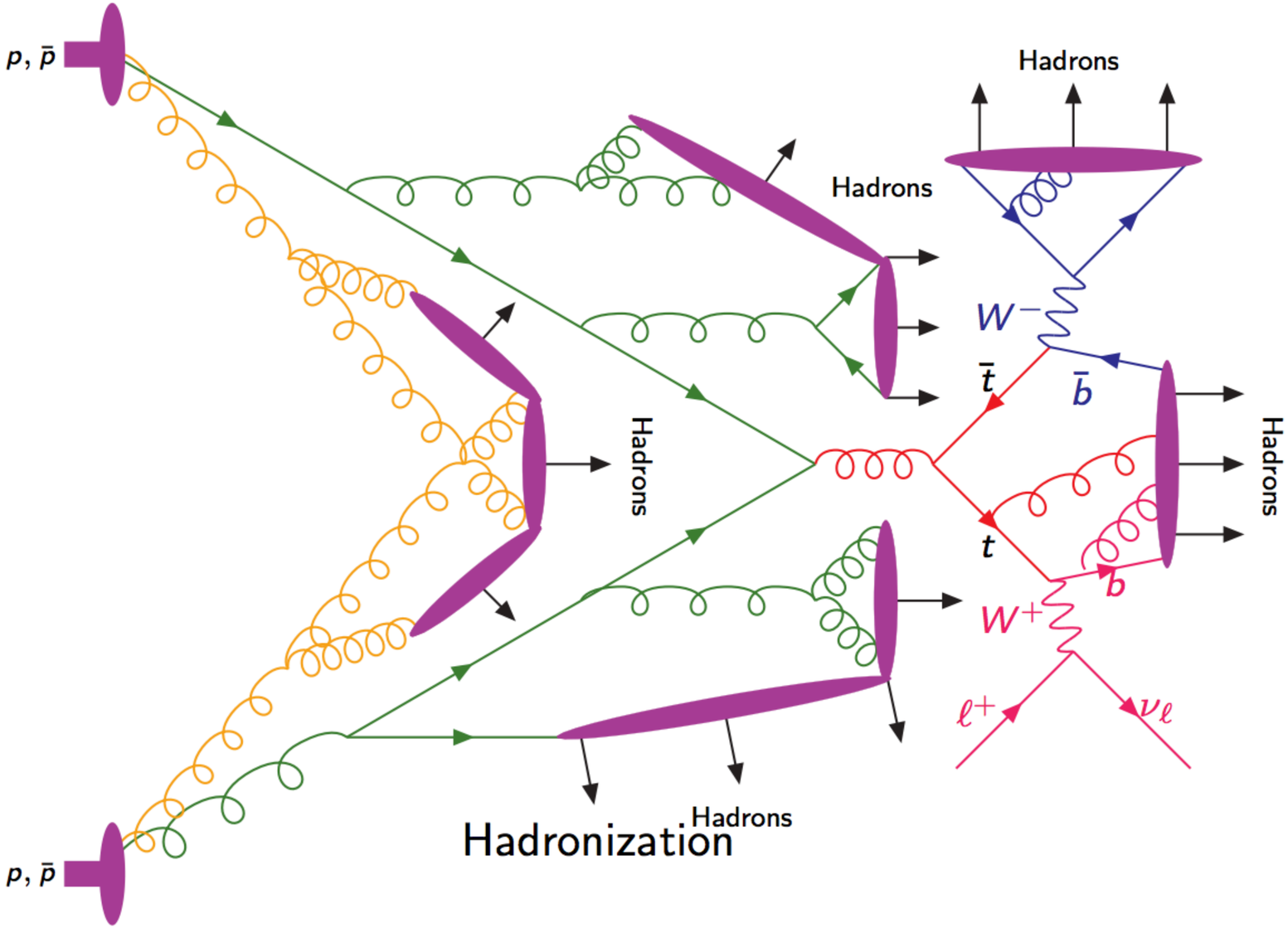
Reminder of what a generator is doing



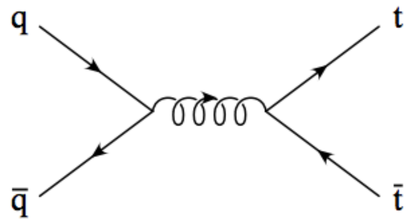
Hadronize remaining particles

P. Richardson Herwig Talk

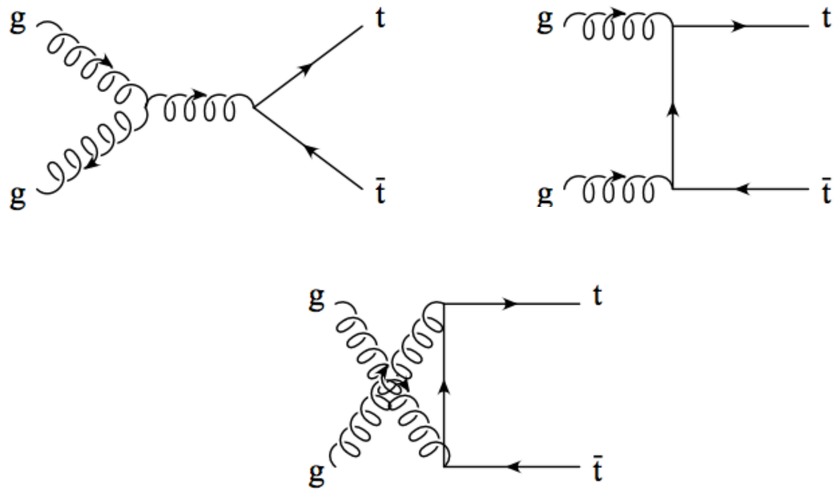
Challenges at Leading Order

- LO Generators (HERWIG/Pythia) are still widely used for LHC studies. Both now C++
- Also model hadronization, pile-up, minimum bias events, the underlying event, and jet structure and sub-structure.
- Top & W-boson mass uncertainties are still dominated by uncertainties in modeling hadronization.
- Computationally LO Generators are light.

qq→tt (tevatron)

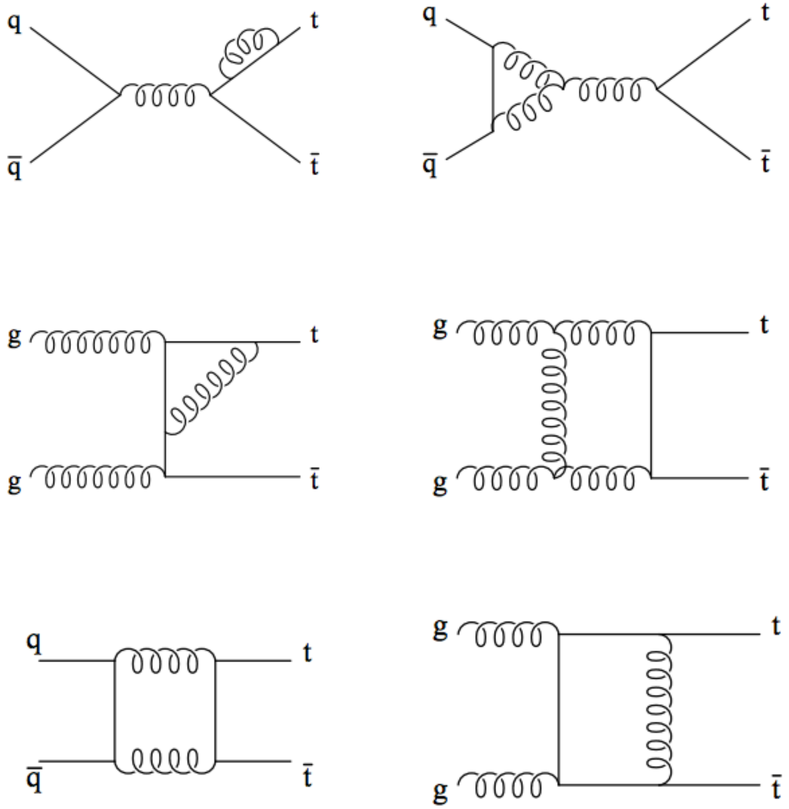


qq→tt (LHC)



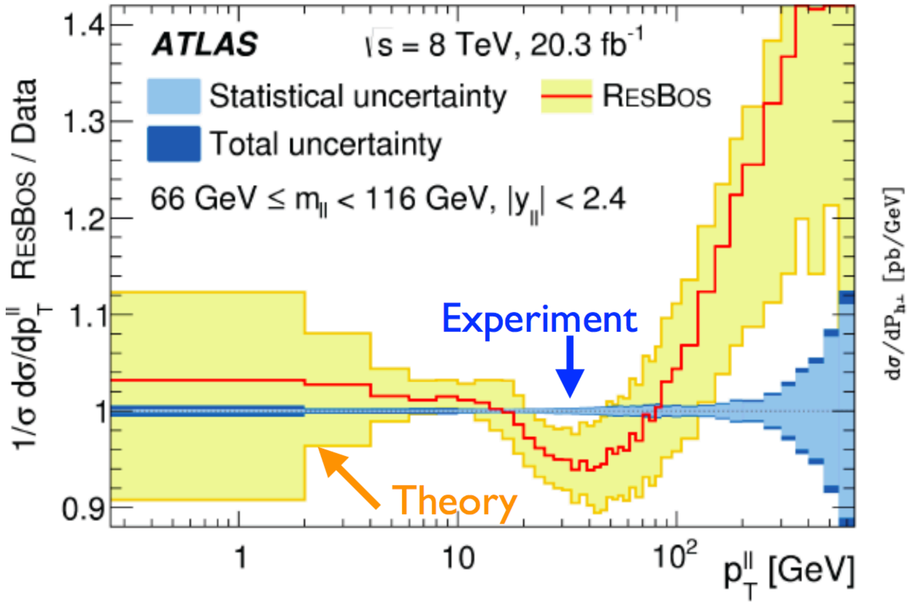
Challenges at Next-to-Leading Order

- NLO Generators (aMC@NLO/Sherpa) are also widely used for LHC studies.
- Computational intensity grows roughly factorially with number of particles and virtual loops. O(100k) diagrams at LO for W+5jets, O(100k) at NLO for W+3jets
- All possible diagrams must be represented in memory during event generation
- Virtual loops also drive compute intensity and in rare cases require quad precision due to large cancellations between individual diagrams.
- Currently pair hard scatter with LO showering, but NLO showering is being developed and increases computational intensity further.



Going Boldly Beyond NLO

- ATLAS W+jets production, leading jet pT shows we are already in the NNLO regime,
- Theoretical methods for calculating high multiplicity processes do not yet exist at NNLO with the current limit being 2 jets
- Theorist community and MC development community continues to innovate and push the orders of perturbative QCD
- HL-LHC we will drive the need for more MC events at high order to support high precision studies across high-dimensional phase spaces.
- HPCs are becoming a focus of the community, as this does become a genuine computing problem: high-dimensional phase-space require more MC integrand evaluations.



Theory errors more than an order of magnitude larger than experimental ones

https://indico.cern.ch/event/557731/contributions/2268995/attachments/1342762/2022840/Boughezal-HPC2016-Sep22.pdf

Future plans and development

- Clearly we are not writing generators, so what can we do about it?
- We are working with MC generator authors to increase compute performance on the architectures we use on the Grid and elsewhere.
- Optimization of NLO generators is ongoing.
- As you go to NLO and beyond the integration of cross sections dominates, AKA grid-pack generation
- Therefore much development is focusing on this step and how to parallelize it.

Future plans and development

- Sherpa as an example of the problems we face.

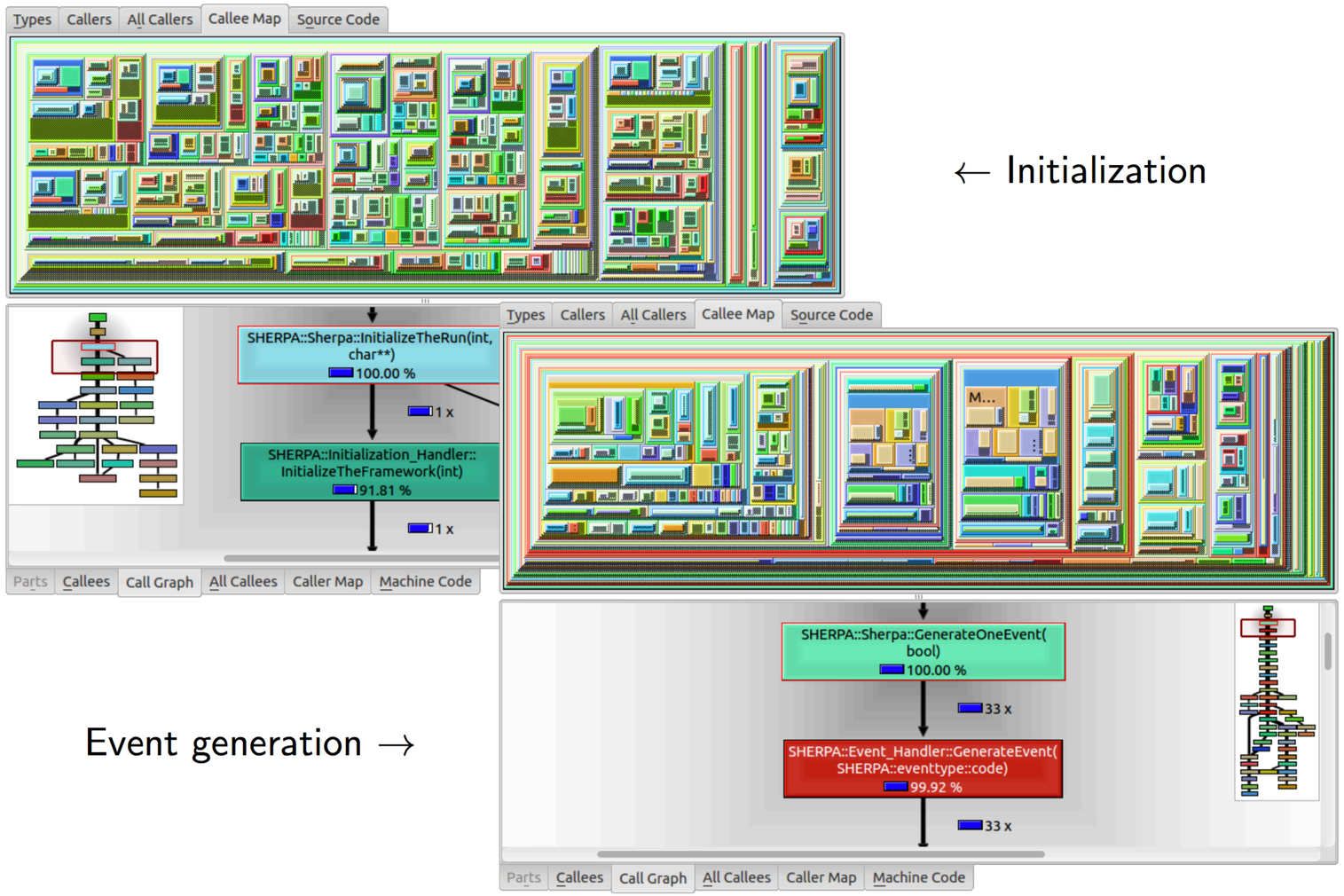
Future plans and development

- Sherpa as an example of the pro

Sherpa C++ gprof

The caveat of object oriented code

SLAC



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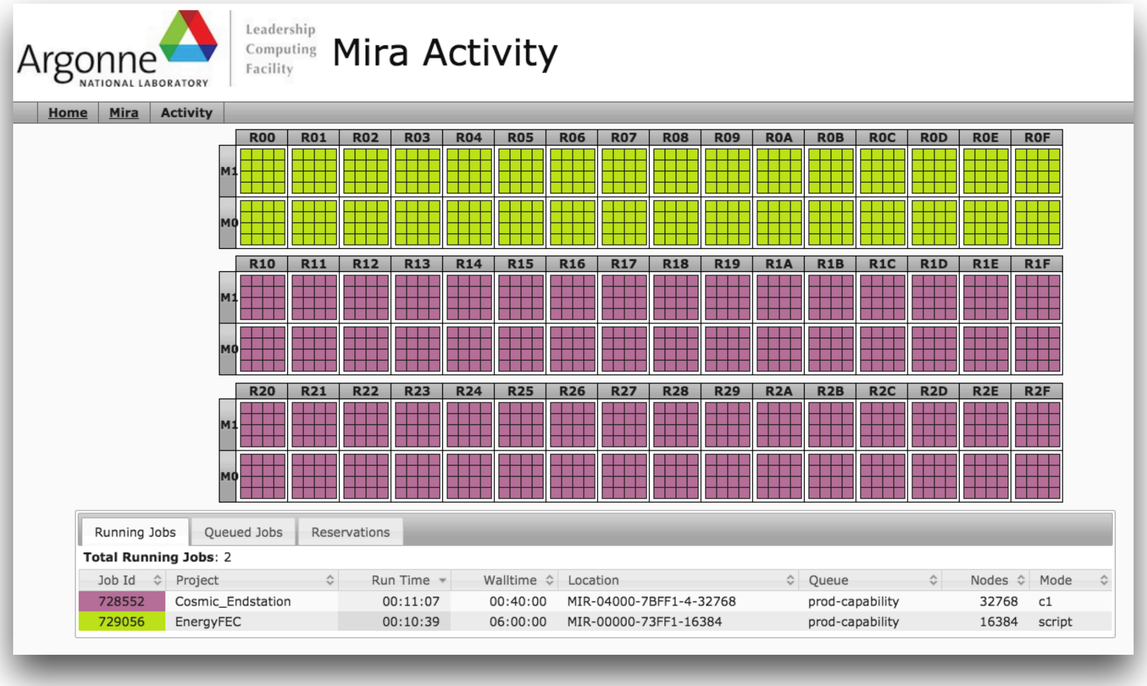
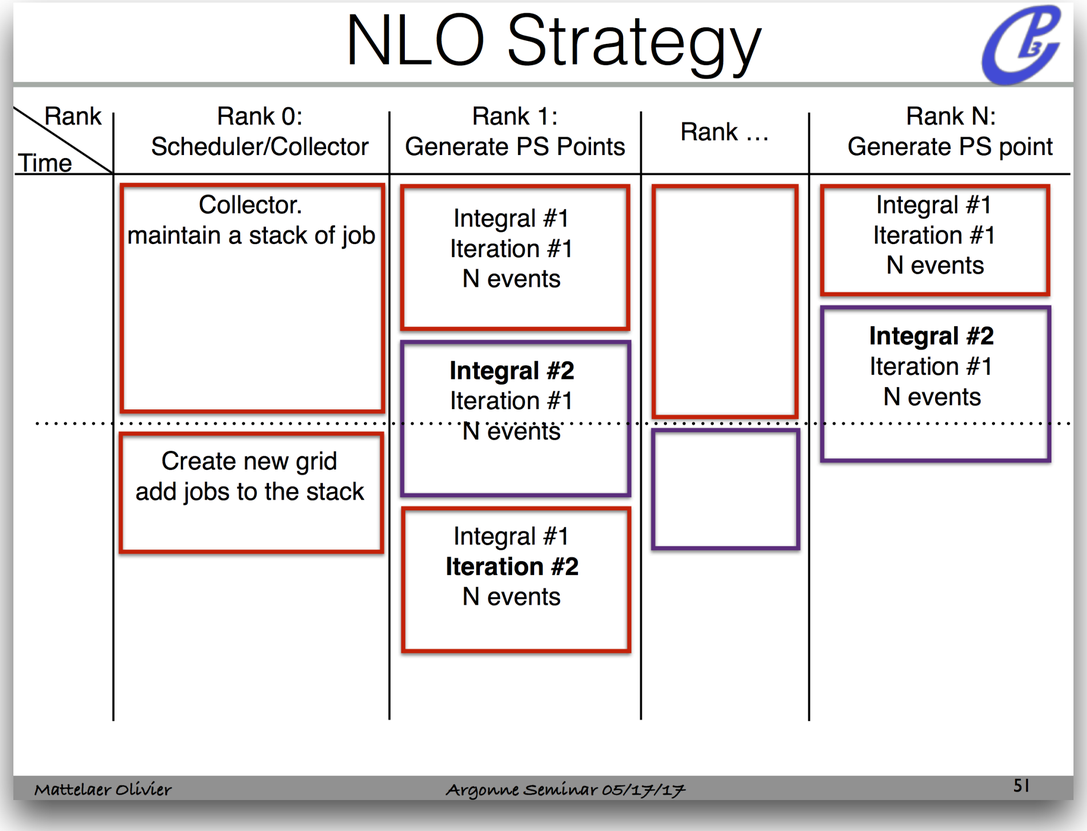
Future plans and development

- Sherpa as an example of the problems we face.
- BUT with out-of-the-box parallelization ran integration (grid-pack gen) and generation at 128k parallel threads on Mira. (but very poorly)



Future plans and development

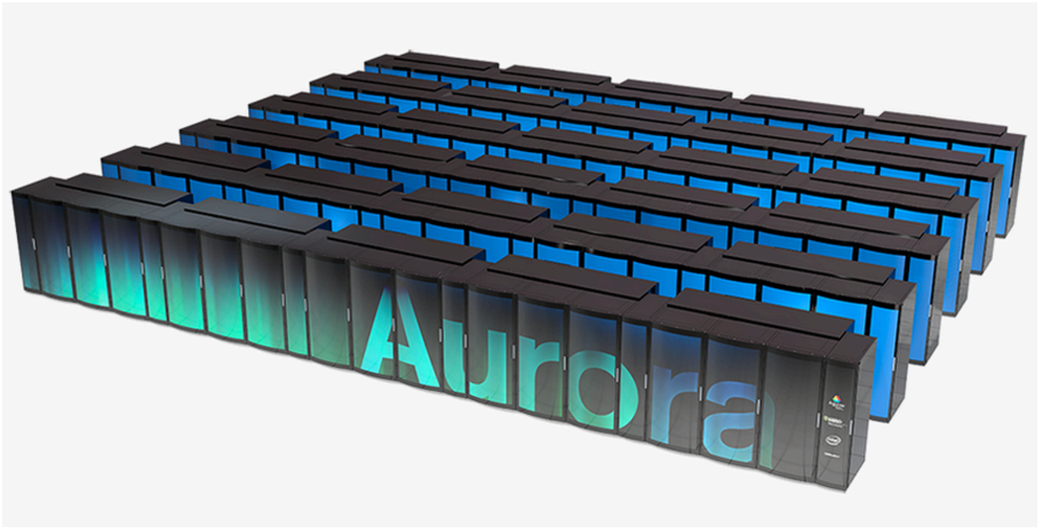
- Sherpa as an example of the problems we face.
- BUT with out-of-the-box parallelization ran integration (grid-pack gen) and generation at 128k parallel threads on Mira.
- MadGraph devs studying new methods for parallelization beyond the node level with a complete rewrite of their integration step



https://indico.hep.anl.gov/indico/getFile.py/access?resId=0&materialId=slides&confId=1101

Future plans and development

- SciDAC project in US DOE for R&D into new integration techniques
  - VEGAS has been the standard for 20+ years in importance sampling
  - What new MC techniques are out there?
  - Can you use Machine Learning to drive the phase-space exploration
- The goal is to produce a pluggable algorithm that is compatible with Sherpa & MadGraph_aMC@NLO
- Will be useable on a desktop and an HPC



Summary

- MC Event Generation will grow in computing requirements, driven by
  - increased luminosity
  - precision studies
  - searches for SM disagreements
- NLO and NNLO are computationally and memory intensive processes that grow factorially with multiplicity and order
- Existing frameworks are being upgraded to support more parallelism at larger scales
- New MC Integrator being developed that will use new methods from the Math community and enable faster grid-pack generation

$$\sum_{a,b} \int dx_1 dx_2 d\Phi_{\text{FS}}\, f_a(x_1, \mu_F) f_b(x_2, \mu_F)\, \hat{\sigma}_{ab\to X}(\hat{s}, \mu_F, \mu_R)$$