Event Generation on HPC – Status Report

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SciDAC PI Meeting

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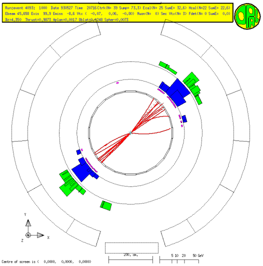
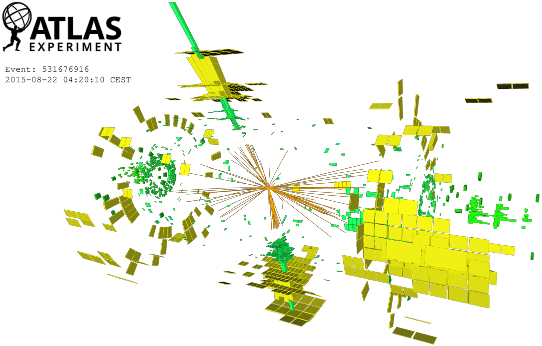
Event generators from 1978 to 2018

[Andersson,Gustafson,Ingelman,Sjöstrand] Phys.Rept.97(1983)31, [Buckley et al.] arXiv:1101.2599

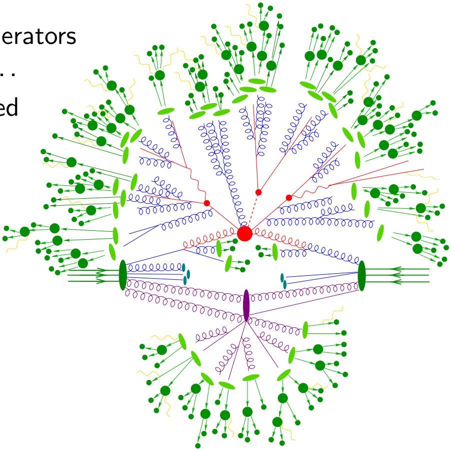




- Started with Lund string model for fragmentation $\rightarrow$ Complete description of (2-jet) events in $e^+e^- \rightarrow$hadrons
- Experimental situation much more involved today: Multi-jet events, hadronic initial states, pileup, ...

Event generators in 2018

[Buckley et al.] arXiv:1101.2599



- (N)LO Matrix Element (ME) generators
  BlackHat+Comix, MadGraph5, ...
- Parton showers (PS), mostly based on dipole/antenna picture
- Multiple interaction models possibly interleaved with shower
- Hadronization models
  string/cluster fragmentation
- Hadron decay packages
- Photon emission generators
  YFS formalism or QED shower

Much of the development focused on precision
Requires close interaction of ME & PS generators

Short-distance cross sections

- Computing Feynman graphs gets complicated quickly
  Example: n gluons $\to$ *all* tree graphs connecting n external points

# of gluons	# of diagrams	# of gluons	# of diagrams
5	25	9	559405
6	220	10	10525900
7	2485	11	224449225
8	34300	12	5348843500

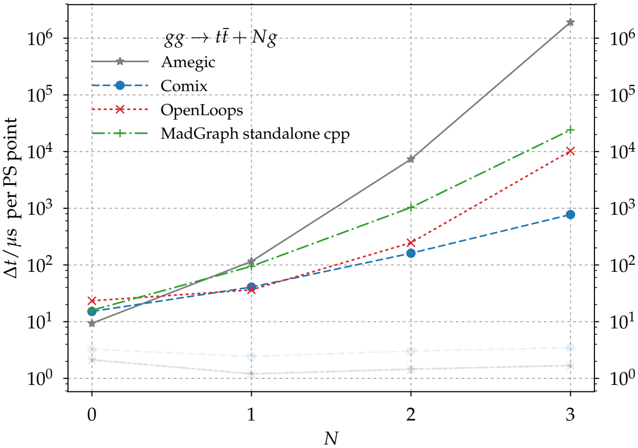
  - Must eliminate common subexpressions [Berends,Giele] NPB306(1988)759
    Ideally also parallelize the calculation [Gleisberg,SH] arXiv:0808.3674
- But that is not all: We have multiple parton species (not only gluons)

Process	W^-+0j	W^-+2j	W^-+4j	W^-+6j
Processes (mapped)	1 (1)	18 (42)	88 (324)	280 (1332)
RAM (per process)	<1MB	1 (0.056) MB	23 (0.26) MB	435 (1.6) MB
Initialization time	<1s	<1s	33s	51m 52s
Startup time	<1s	<1s	<1s	2s
Integration time	8s	22m 8s	1d 5h	32d 19h
MC uncertainty [%]	0.18	0.25	0.66	1.29

Numbers generated on dual 18-core Intel® Xeon® E5-2699 v3 2.30GHz

  - Integration times cumulative for all MPI ranks
  - Initialization to be performed only once, on single CPU
  - Startup time common to all MPI ranks for any subsequent run

Short-distance cross sections



- Bad computational strategy costs orders of magnitude in performance (This is effectively comparing Feynman diagrams to recursion relations)
- Most challenging calculations done with best technology (Comix) but still sacrificing speed for ability to maintain code base (Consider that development mostly done by graduate students)

Short-distance cross sections

- Constructed 100-line example code showing basic algorithms
  $\rightarrow$ 850 lines total needed to perform realistic scaling test

```
def Amplitude(event,j):
    nn = len(j)
    for i in range(nn):
        j[i][i].ConstructJ(event[i].mom,-1 if i<2 else 1)
    for n in range(2,nn+1):
        for b in range(nn-n):
            j[b][b+n-1].j = []
            for m in range(b,b+n-1):
                V3(j[b][m],j[m+1][b+n-1],j[b][b+n-1])
                for l in range(m+1,b+n-1):
                    V4(j[b][m],j[m+1][l],j[l+1][b+n-1],j[b][b+n-1])
            if n<nn-1:
                j[b][b+n-1].AddPropagator()
    A = j[nn-1][nn-1].j[0]*j[0][nn-2].j[0]
    return A
```

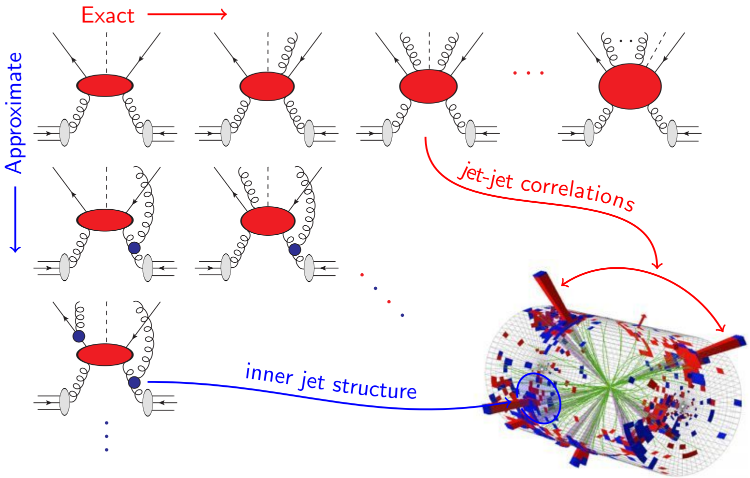
- Timing in ms/point for one/all partial amplitudes (pypy jit compiler)

# gluons	one	all
5	0.037	0.068
6	0.066	0.211
7	0.114	0.773
8	0.179	3.050

# gluons	one	all
9	0.312	15.199
10	0.504	79.695
11	0.703	400.596
12	1.003	2257.200

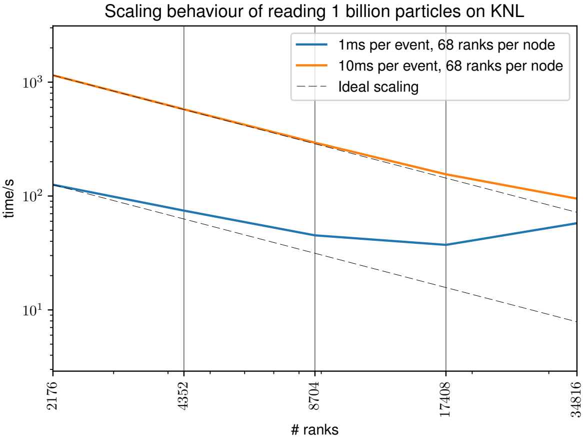
- Within factor 2 of C++ $\rightarrow$ Basis for discussion with HPC experts

Event processing



- Short-distance cross section and QCD evolution linked at higher order in perturbation theory → cannot be simulated entirely independent
- Separation of event generation into hard process and parton shower jobs requires reconstruction of diagram topologies at parton shower stage

Event processing



- Main task is to decouple existing matrix element generators (BlackHat+Comix) from parton shower, write out /read in events in HDF5 format, and enable reconstruction of diagram topologies
- Test program ready for benchmark (↗ plot above)

  Note: MPI parallelization not yet leveraged (in talks with HDF5 experts)

  Compare timing to reconstruction: 1ms (W+2j) – 1s (W+6j)

Outlook

Parton-level event generator

- Simplified test program for optimization of algorithms
- Planning on discussion/meeting with experts

Particle-level event processing

- Decoupled parton-level event generation from remaining simulation
- First scaling tests with simple HDF5 interfaces
- Promising even without full MPI capabilities of HDF5