Creating Unique Parton Shower Histories with Sector Showers

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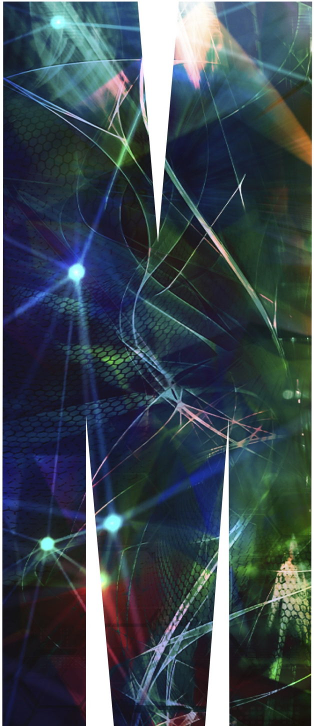
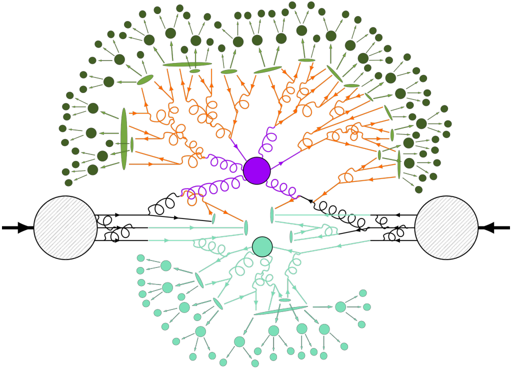


Facorisation of Collider Events

Three energy regimes:

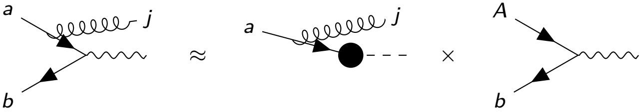
- High-energy "hard" regime: (multiple) $2 \to n$ scattering with small n
- Low-energy "soft" regime: forming and fragmentation of (visible) hadrons
- Transition regime: QCD bremsstrahlung of partons (+QED/EW emissions)

"Transition regime" modelled by **parton showers**.

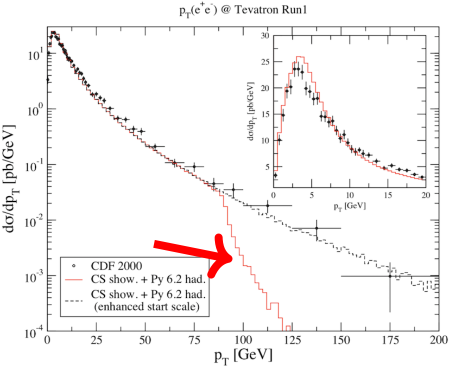


Soft/Collinear Factorisation

- QCD matrix elements **factorise** for **small-angle** (collinear) and **low-energy** (soft) radiation



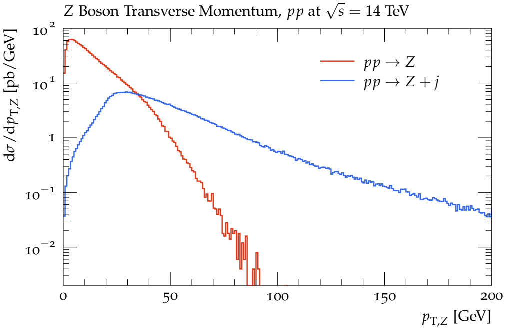
- **outside** soft/collinear regions, factorisation is not given, cf. e.g. $p\bar{p} \to Z + \text{jets}$:



[Höche, Krauss, Schumann, Siegert 0903.1219]

What's missing

- the shower always starts from the Born process $pp \to Z$ and adds quarks and gluons by **soft/collinear approximation**
- outside soft/collinear regions $pp \to Z + \mathrm{jet(s)}$ matrix element(s) should be used



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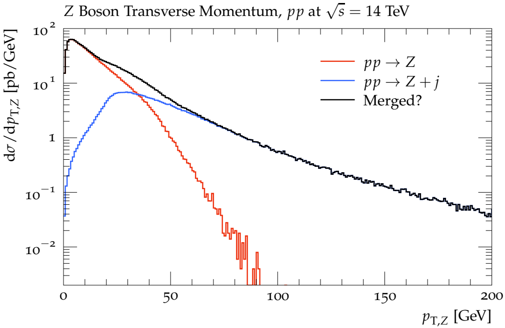

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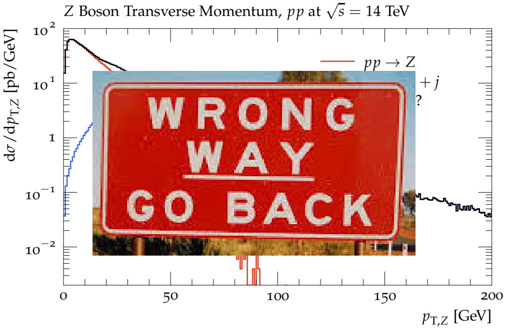
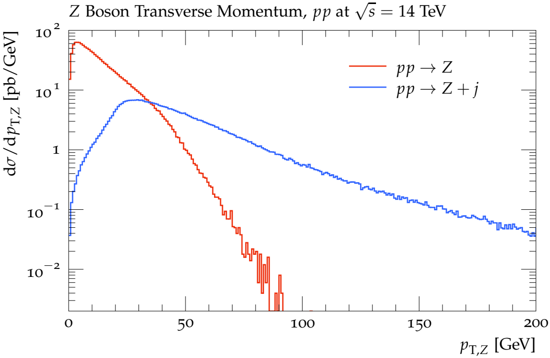


- simply adding the two **double-counts** emissions

How to do better: MEPS

- **Merging:** introduce (arbitrary) **merging scale** and let each calculation populate the phase space where it does best:

  Parton shower generates **soft/collinear** radiation
  Fixed-order calculation generates **hard** jet(s)



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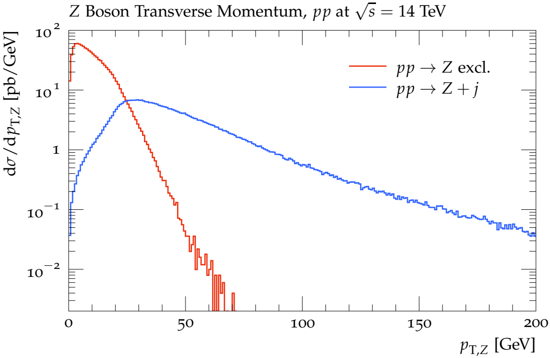

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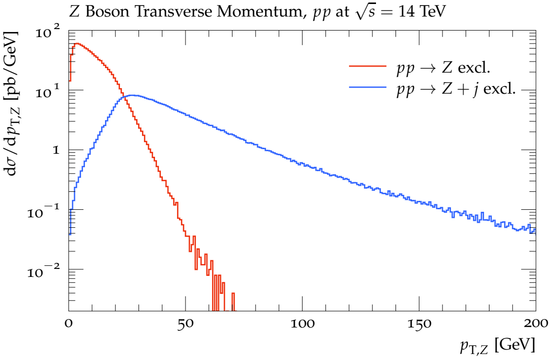

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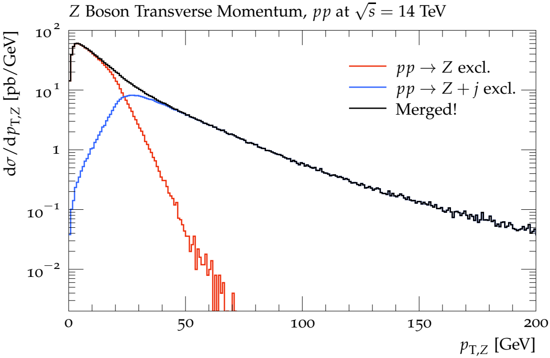
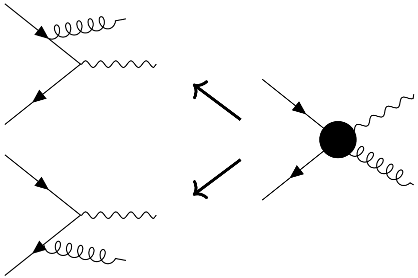


What we can learn from history

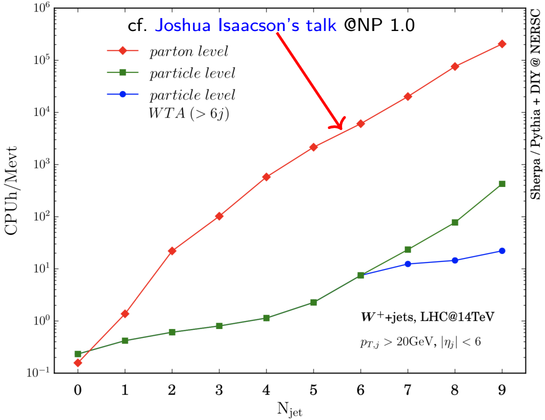
- to construct the shower history, we have to ask ourselves:

"How would our parton shower have generated this state?"



- $\mathcal{O}(n!)$ histories for n hard jets

The scaling of the method: time

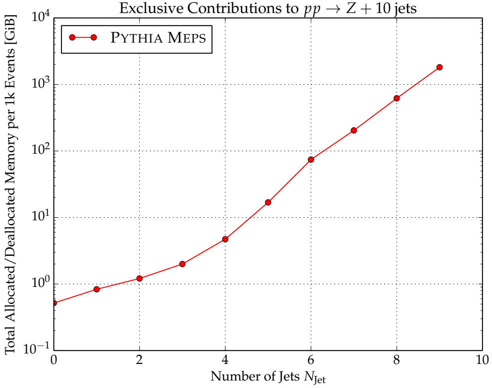


[Höche, Prestel, Schulz 1905.05120]

- hard process most expensive, but can be generated "once and for all"
- shower re-run for each particle-level analysis
- deterministic **jet clustering** ("WTA" – winner takes all) improves scaling, but does not represent **shower history**

The scaling of the method: resources

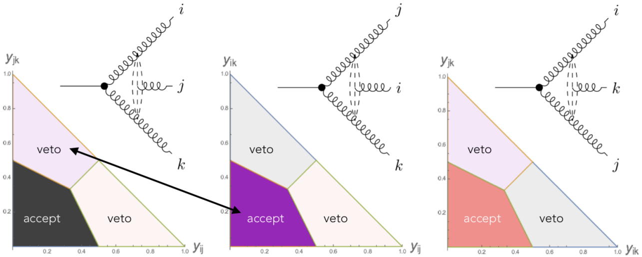
- Pythia 8.3 + HDF5 event files [Höche, Prestel, Schulz 1905.05120] + Valgrind



- for high multiplicities memory usage becomes extremely challenging

Sector showers [Brooks, CTP, Skands 2003.00702; Lopez-Villarejo, Skands 1109.3608]

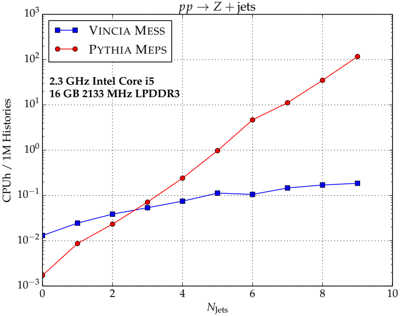
- **Idea**: make shower evolution bijective, i.e. **uniquely invertible**
- divide phase space into non-overlapping sectors, e.g. for $gg \mapsto ggg$ branchings:

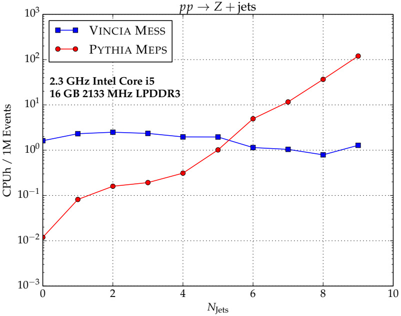


- branchings in the shower are accepted **if and only if** they correspond to **correct sector**
- sector showers effectively combine **shower** with **deterministic jet-clustering algorithm**

Scaling revisited: time [Brooks, CTP 2008.09468]

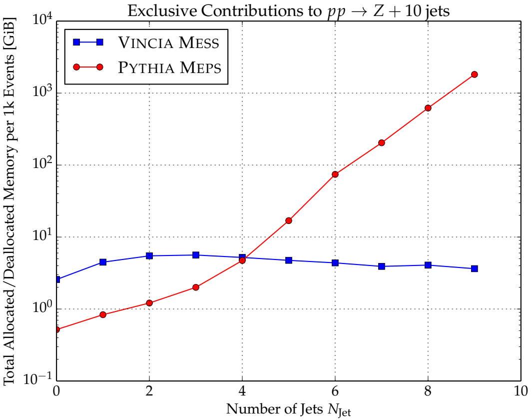
- CPU time in $pp \to Z + 9$ jet merging:





Scaling revisited: resources [Brooks, CTP 2008.09468]

- **memory** allocation/deallocation per 1k **events** in $pp \to Z + 10$ jet merging:



Note: the 10th jet is only hypothetical, so that every multiplicity is treated as an "intermediate" node

Conclusions

- ME + conventional showers:
    - **factorial** scaling of memory usage and run time
- ME + sector showers:
    - **linear** scaling of history-construction time
    - **constant** overall run time and memory usage
- stand-alone sector showers **slower** than conventional ones, but improvements possible