# The elephant in the room: Event Generation in the HL-LHC phase

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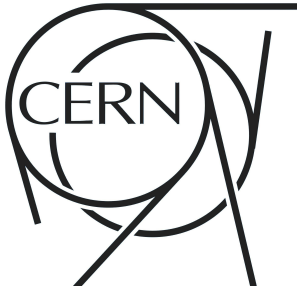
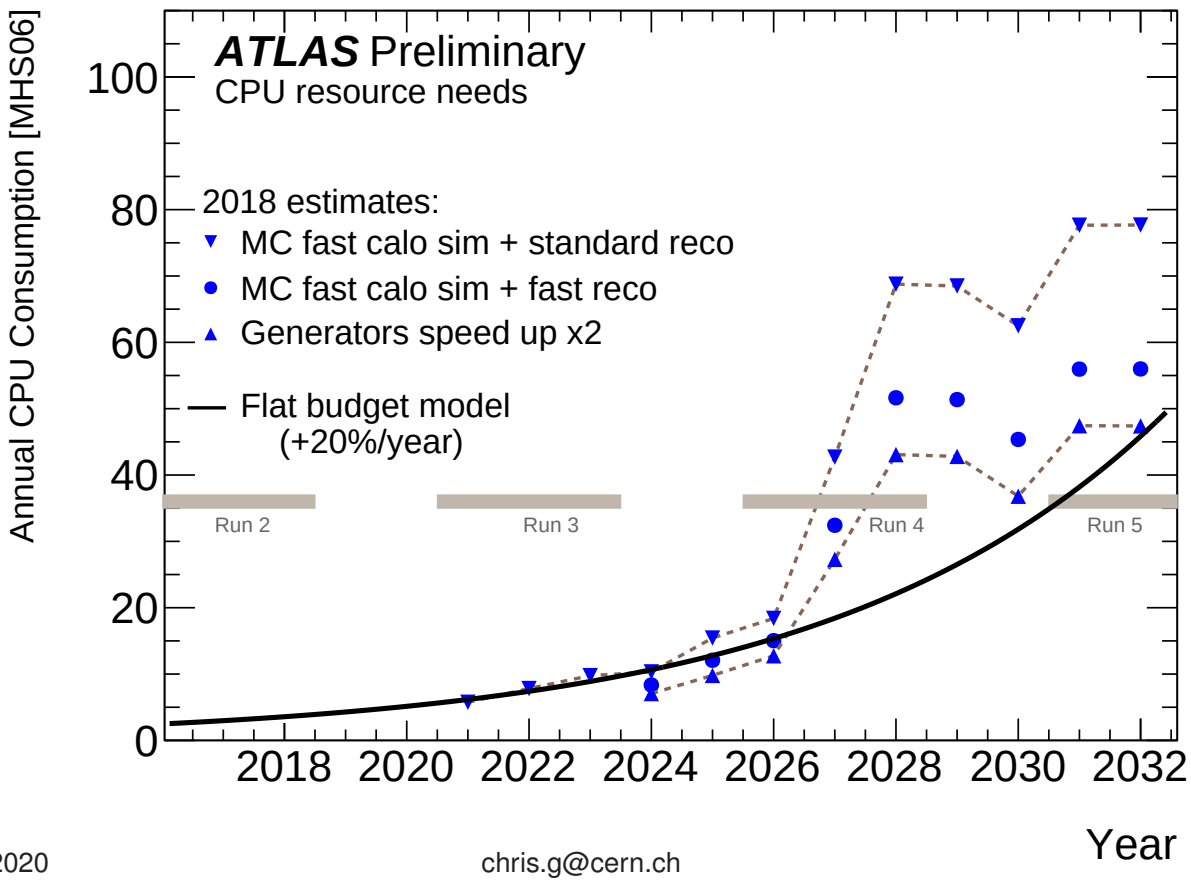


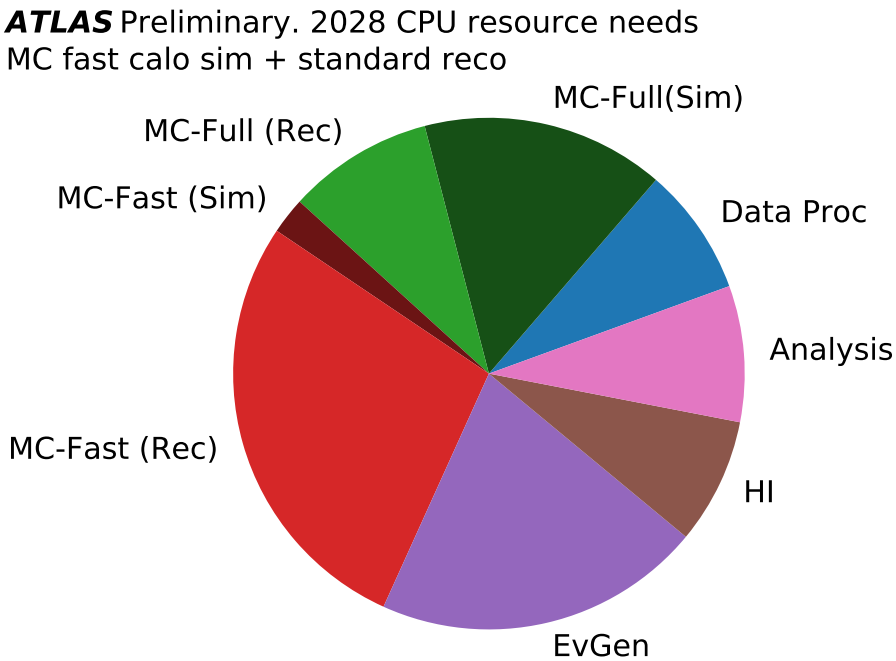
# Wishful thinking

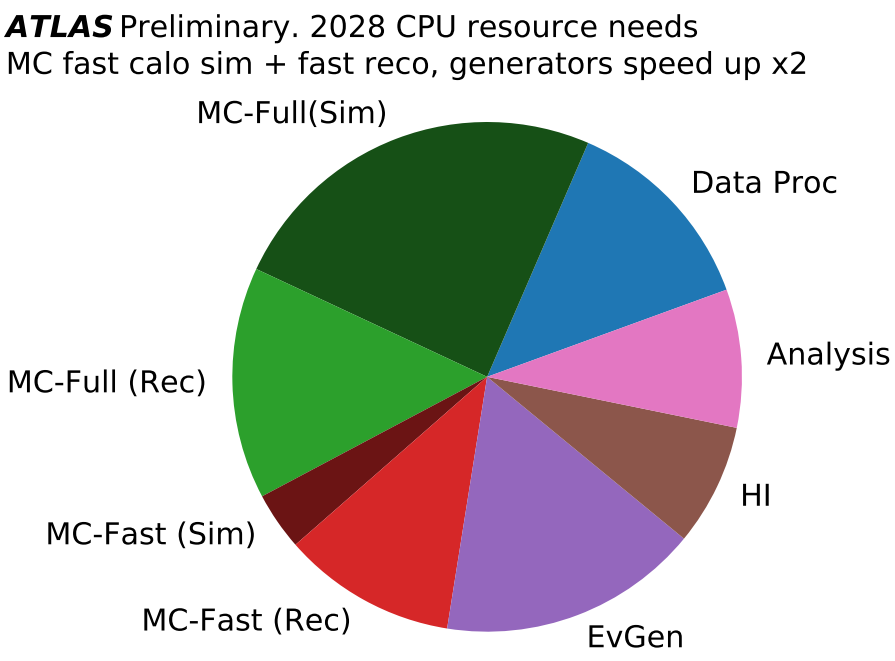
- flat budget not going to get us annual 20% CPU increase as Moore's law no longer holds
- no magical factor-2 'speed up' of generators in sight, but some CPU reductions possible
- still LHC measurements in danger of being limited by Monte Carlo statistics



# Projected CPU breakdown

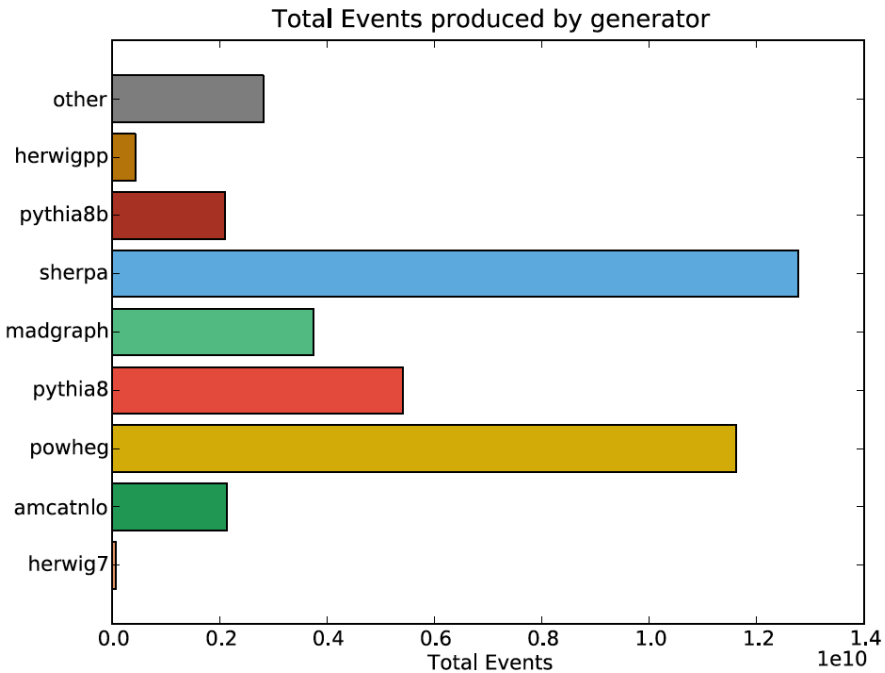
- left plot assumes FastCalo simulation used for 75% of the Monte Carlo simulation
- right plot assumes faster version of reconstruction (seeded by the EvGen information) and magical factor-2 speed-up of generators

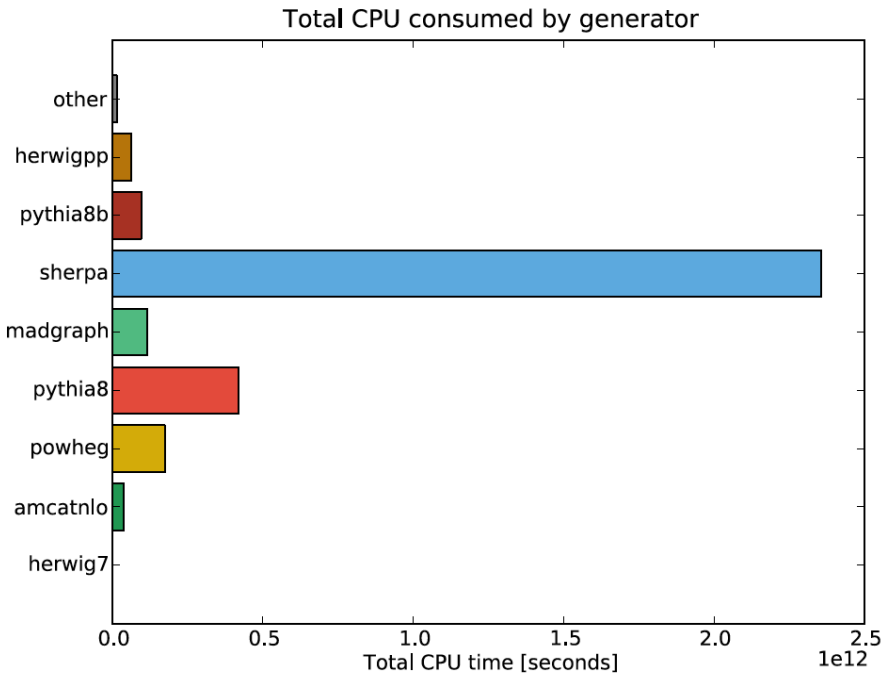


# Breakdown by generator

- left plot: does not account for alternative bulk setups
- right plot: most CPU spent on high-precision calculations for $V + 0, 1, 2j$@NLO+$3, 4j$@LO and $t\bar{t} + 0, 1j$@NLO+$2, 3, 4j$@LO

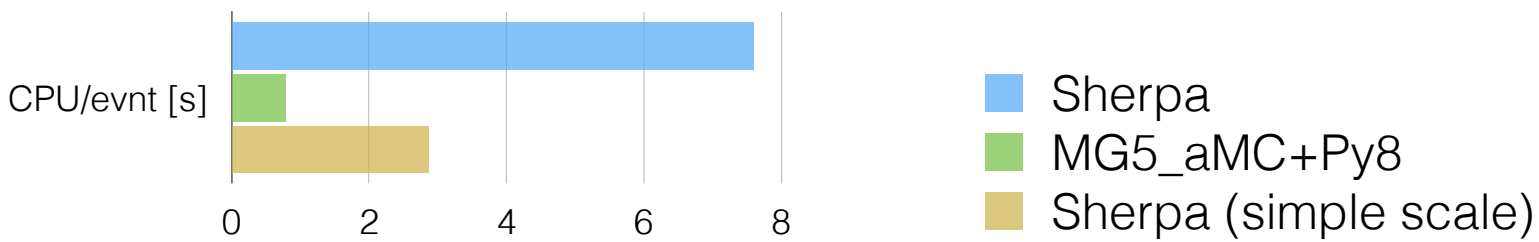



- outlook: CPU spent on expensive setups expected to increase faster than for fast setups

# Benchmarking between ATLAS and CMS

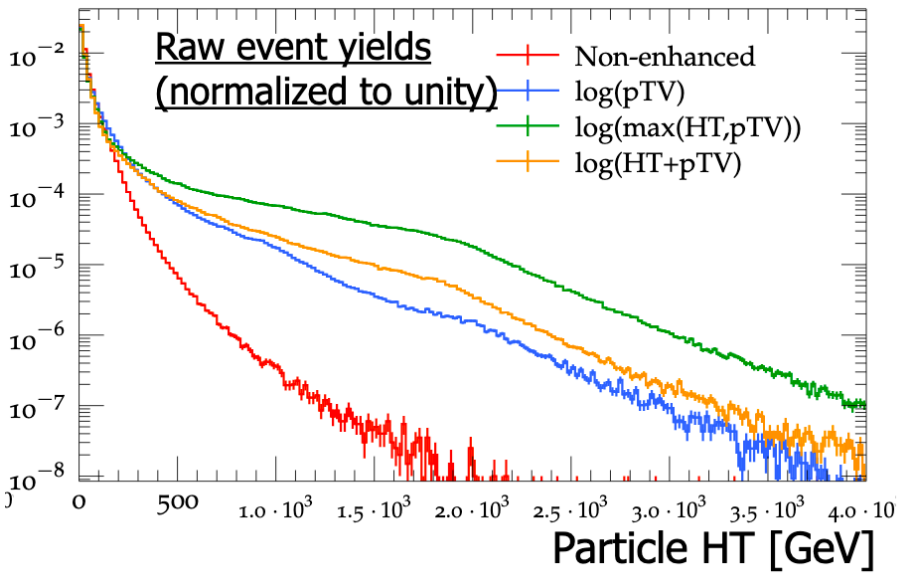
- careful comparisons between ATLAS and CMS key setups performed as part of HSF effort
- $W$+jets@NLO: less accurate scale choice used in FxFx setup significantly reduces CPU consumption for MEPS@NLO setup with no visible impact on modelling




- apart from that, performance fairly similar once setup differences properly accounted for

# Populating extreme regions of phase space

- phase-space slicing: add a cut at the generator level, stitch together multiple slices
  - cross-section falls ‘naturally’ within in the slice
- phase-space biasing: produce events flat within a given interval
  - events are assigned weights to produce physical distribution

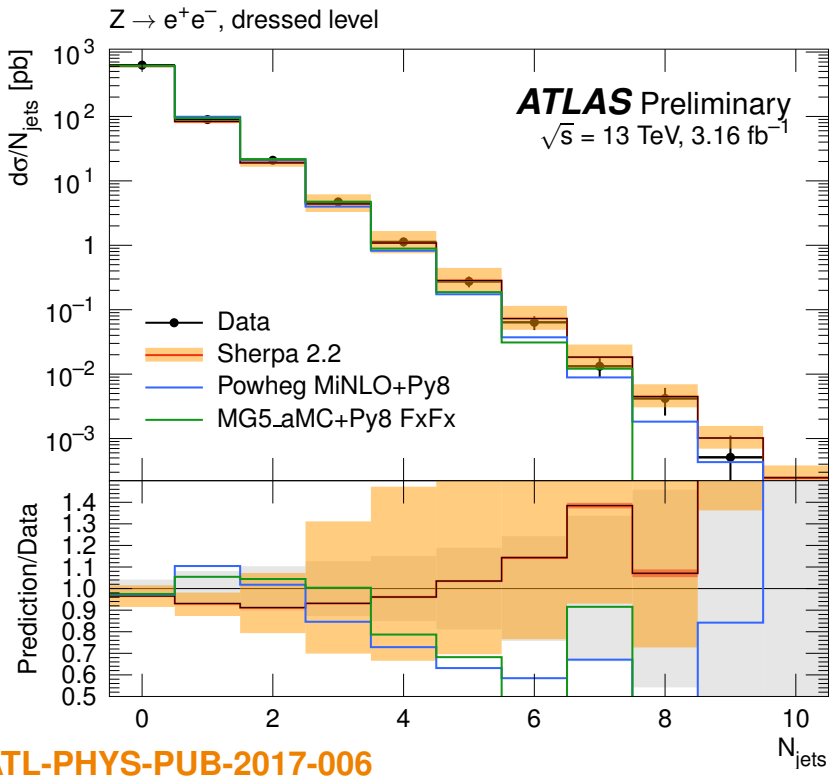


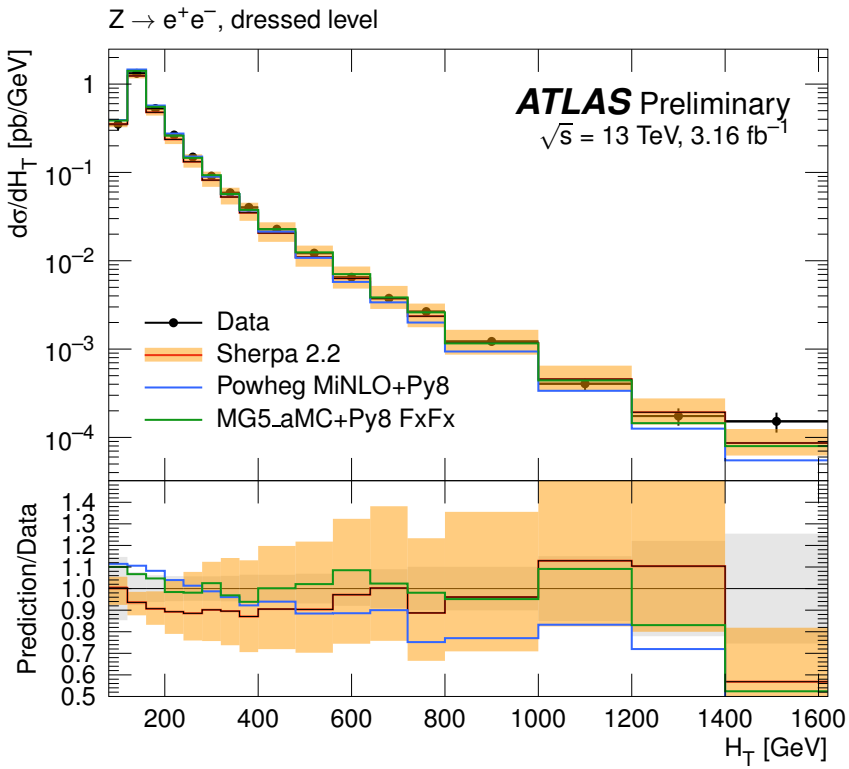
# Negative weights are expensive

- current ATLAS Sherpa $V$+jets setup: negative weight fraction ($f_{\text{nw}}$) about 30 % for $70 < p_{\text{T}}^{V} < 140$, 15–20 % above/below that slice and $< 10$ % above 250 GeV
- relative uncertainty increased by factor $1/(1-2f_{\text{nw}})$, so sample size needs to be factor $(1-2f_{\text{nw}})^2$ larger
  - $f_{\text{nw}} = 10$ % implies statistical error becomes factor 1.25 larger
    - need factor 1.5 as many events
  - $f_{\text{nw}} = 20$ % implies statistical error becomes factor 1.7 larger
    - need factor 2.8 as many events
  - $f_{\text{nw}} = 30$ % implies statistical error becomes factor 2.5 larger
    - need factor 6.3 as many events
  - $f_{\text{nw}} = 40$ % implies statistical error becomes factor 5 larger
    - need factor 25 as many events
- new setup in preparation where $f_{\text{nw}}$ improved inclusively from 18 % down to 9 % by using approximate colour treatment

# On-the-fly variations

- multiweights huge CPU saving compared to explicit variations for generator uncertainties
  - setup with ∼100 weights only ∼30% slower
- more variations to be included in the future
  - parton-shower scale variations, electroweak corrections, . . .
  - but some algorithmic variations cannot be achieved through reweighting

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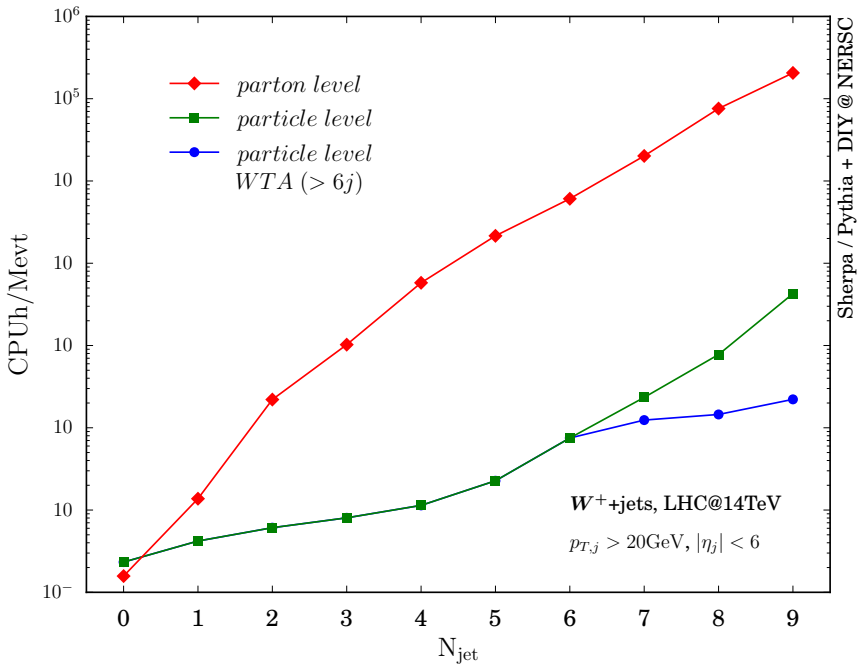
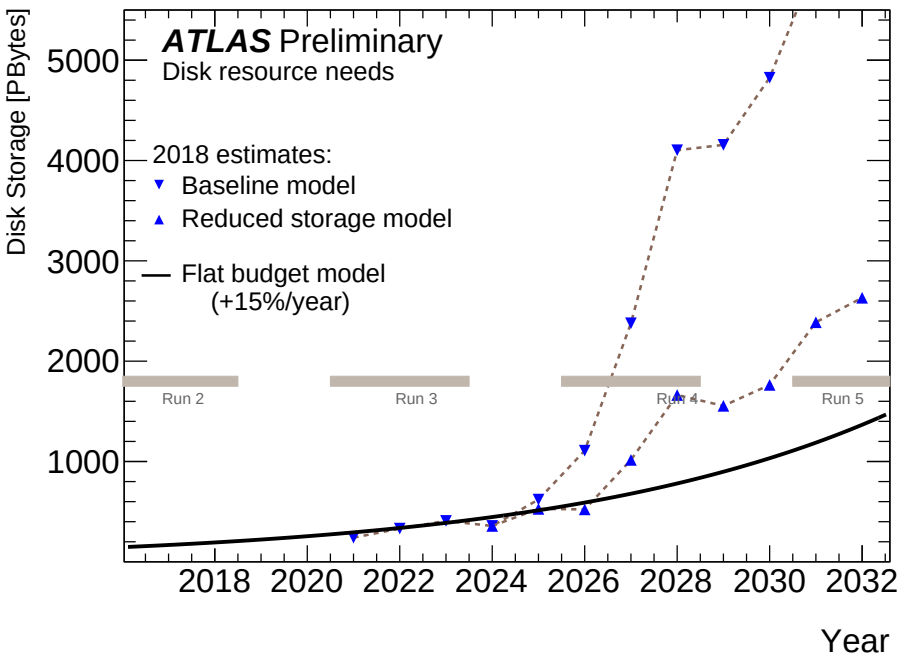
# Need for infrastructure changes

- efforts ongoing to exploit HPC workflows for most expensive part of calculations
- save intermediate truth record and apply multiple shower and hadronisation models
- potential for 'trivial factor-2 gain' by sharing parton-level results between ATLAS and CMS
- move to GPU architectures would require complete re-write of MC generators

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# Event generation in light of near-infinite data statistics

- demand for higher-order corrections and multi-jet merging grows as measurements become ever more precise
  - NNLO QCD set to replace NLO as default accuracy for matched setups in not too distant future
  - merged setups already at NLO QCD+$EW_{virt}$, supplemented with additional legs at LO accuracy
- current drive towards high precision not supported by CPU budget in the long run
  - might have to consider producing large samples only at LO, then reweight to higher accuracy?
  - bypass traditional grid-based computing in favour of HPC workflows for part of the calculations?
- already now impossible to keep up with the data for inclusive regions of phase space
  - at this rate also not unrealistic: some crucial measurements might just not get done

# Summary