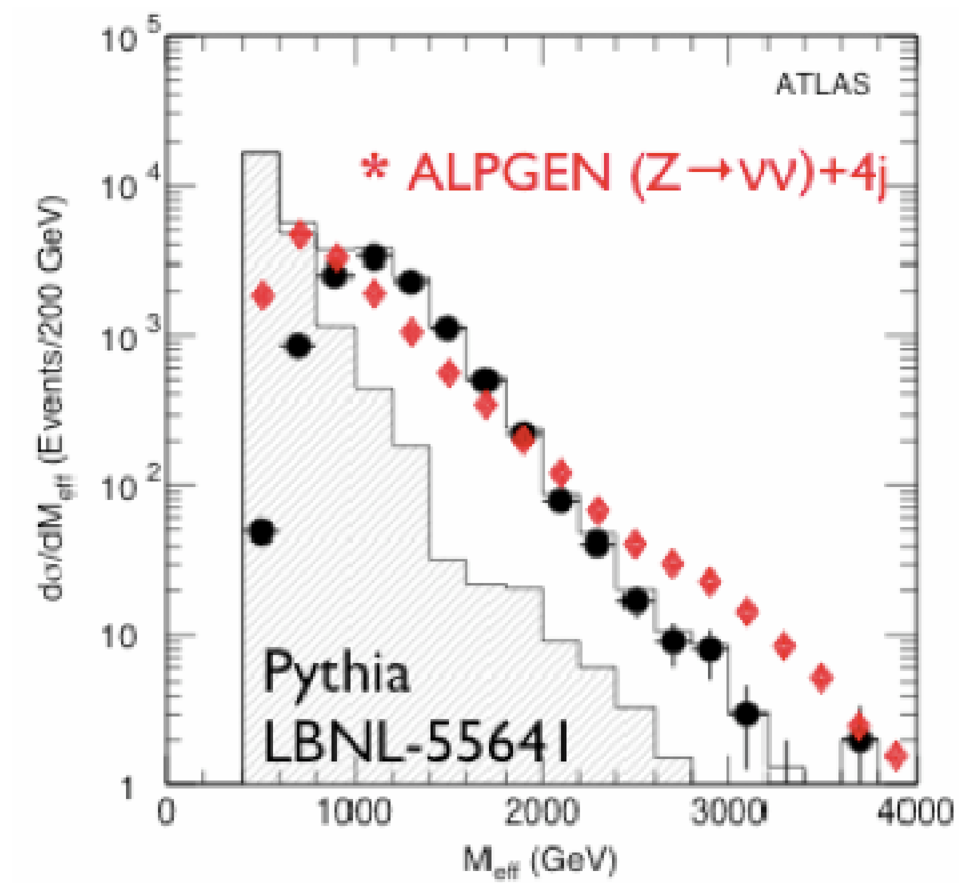
EF15. Precision measurements at colliders require tools to model and account for non-perturbative effects. The most common such tools, e.g., PYTHIA, require extensive tuning to data.

a) How do we estimate the errors from this method of accounting non-perturbative contributions?
b) It is possible that systematic effects from the modeling could give much larger effects?
c) Is it possible that we are tuning away subtle but novel effects from new physics?

- To be clear: in the past tuning could be used to account for hard (perturbative) effects
  - the community is now using a wider range of tools that are much more sophisticated; modeling is replaced by first-principles calculations of hard QCD matrix elements.
  - including NLO effects in parton showers is now well-understood (MC@NLO, POWHEG, SHERPA) and has also been automated (aMC@NLO); can begin to contemplate "MC@NNLO".
  - merging of multi-jet samples now standard (MLM, CKKW) and extended to NLO (e.g. SHERPA, aMC@NLO).



  - further systematic improvements underway, e.g. a proper description of sub-leading colors and higher logarithmic effects.
- This type of tuning should no longer be an issue.

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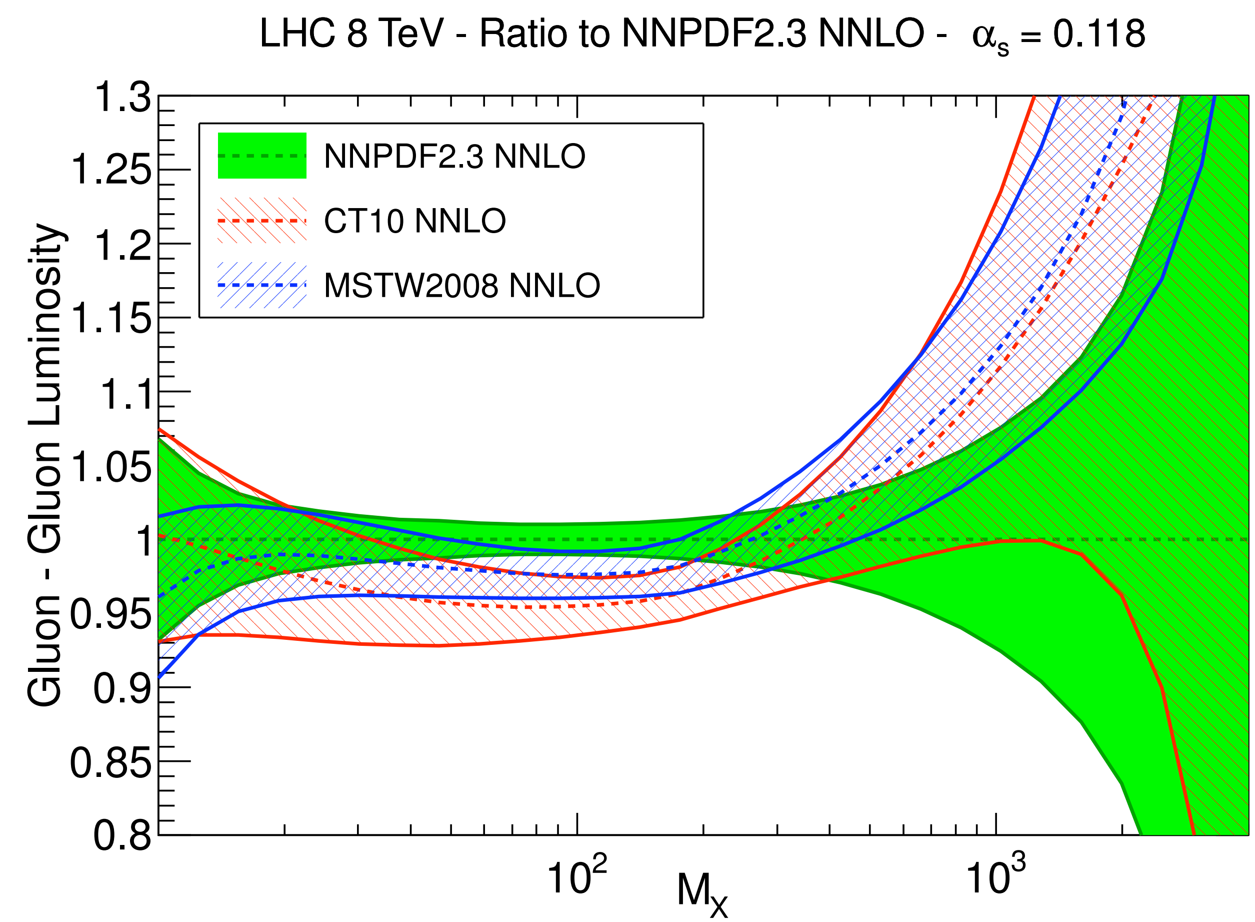
- Genuine non-perturbative effects remain, e.g. hadronization and the underlying event.
- Parameters controlling such effects are tuned to reproduce mostly exclusive properties of events observed in a wide range of data samples (LEP hadron data, min. bias and DY at hadron colliders).
- The generators contain models that must be tested; each one describes non-perturbative effects in different ways, e.g. hadronization by string fragmentation (Pythia) vs. cluster (Herwig & Sherpa).
  - tuning is part of the essential experiment-theory feedback loop; one must make reasonable assumptions to proceed but some prejudice remains.
  - uncertainties estimated by comparing predictions of different tools and tunes; good level of agreement between vastly different techniques means very little room for surprises.
- Broadly speaking, the impact of the non-perturbative corrections is not significant for the types of inclusive observables that we are interested in measuring for new physics searches, e.g. hadronization corrections typically result in ~ 1 GeV shift in jet energy.
- Similar to progress in pdf uncertainties: moving away from just comparing central tune of each tool to obtaining an envelope of systematic uncertainties for each individually;
  - important to raise profile and perceived importance to make sure this happens.

EF15a. Do we have good enough control of theoretical predictions for hadron colliders at high energies, i.e. in the LHC era and possibly beyond?



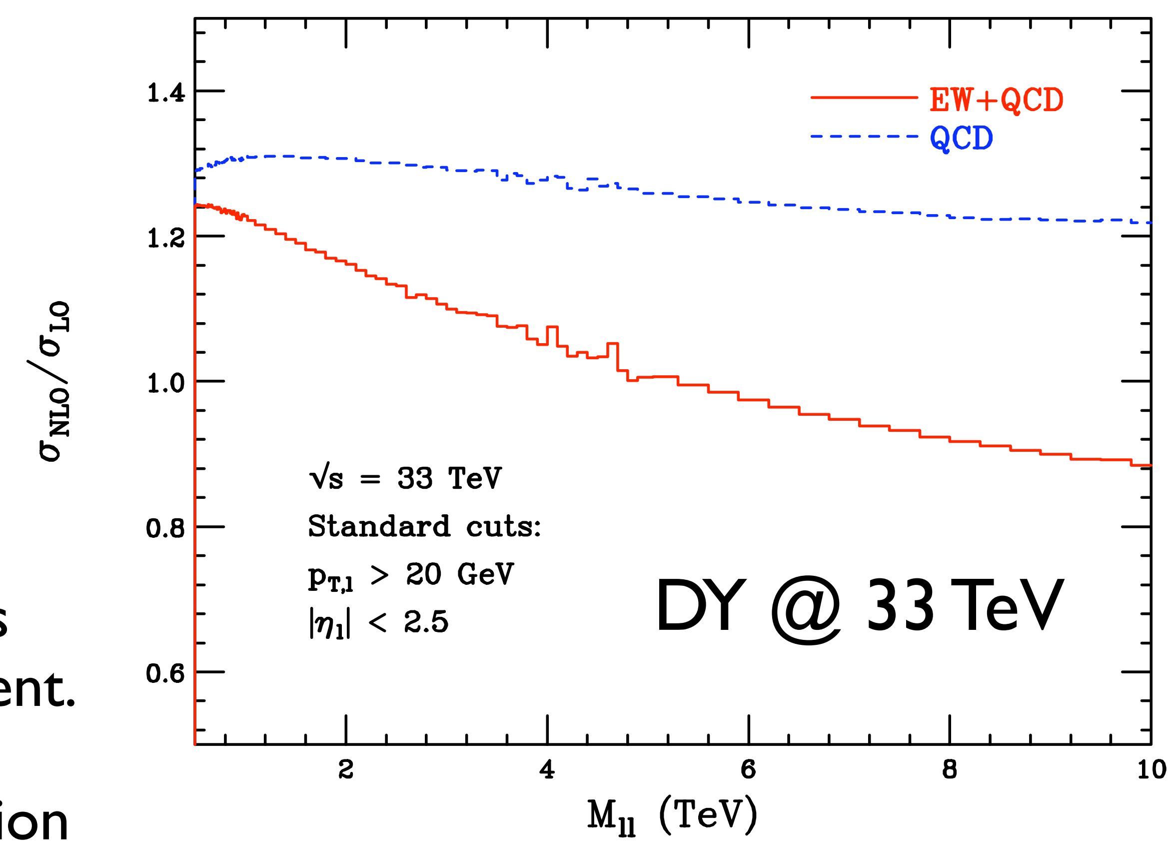
- A key input to every prediction is PDFs.
    - in general these are rather well-constrained and agreed-upon by the global-fitting groups (CTEQ, MSTW, NNPDF).
- Gluon PDF presents two challenges:
    - precise ... but not quite good enough: almost-maximal disagreement in the region important for gg→H; a resolution will reduce coupling uncertainties.
    - large uncertainties for high masses: won't hurt resonance searches but hampers hunt for broad excesses; difficult to extract parameters if discovery made.
        - some improvement from LHC data expected (e.g. differential top distributions); LHeC (HERA++) would help.

EF15a. Do we have good enough control of theoretical predictions for hadron colliders at high energies, i.e. in the LHC era and possibly beyond?

- Theoretical predictions for hadron colliders have matured greatly in the last 10 years.
- There has been an outrageous amount of progress; besides the generator improvements described earlier:
  - next-to-leading order predictions are not only de-rigueur but also on-demand (MadLoop, GoSam, HELAC-NLO, OpenLoops, ...).
  - available for calculations of unprecedented complexity:
    W+5 jets (BlackHat), top pairs+2 jets (HELAC-NLO).
  - the NNLO frontier is opening up (top pairs, dijets, H+jet) and N^3LO beckons ($gg \rightarrow H$).
- Of increasing importance at higher energies: isolating backgrounds by applying jet vetoes or categorizing events according to number of jets present.
  - can severely compromise theoretical accuracy due to large logarithms in pert. series.
  - alleviated by resummation: much progress for Higgs, with lessons to be applied elsewhere.
- For measurements dominated by higher order uncertainties, no reason to expect that they will not be reduced in another 5-10 years (HL-LHC).

EF15a. Do we have good enough control of theoretical predictions for hadron colliders at high energies, i.e. in the LHC era and possibly beyond?

- Final caveat: the importance of electroweak corrections in a QCD-driven environment.
- We now have the luxury of looking in detail at tails of distributions that access TeV scales.
- In these regions the effect of EW corrections is not parametrically given by α_W; instead it is enhanced by logarithms of (~ TeV)/(M_W).
- At 14 TeV this will be relevant in TeV tails of practically all processes of interest; exact results may not be available but leading logarithms can already be accounted for in ALPGEN.



- A range of issues:
  - how to combine QCD and EW corrections (add or multiply?); mostly unknown at present.
  - when corrections are large claims of precision are severely compromised.
  - require better estimates of photon pdf (underway).