Lessons from W+3 jets @ NLO: comments on scale choices in LO calculations

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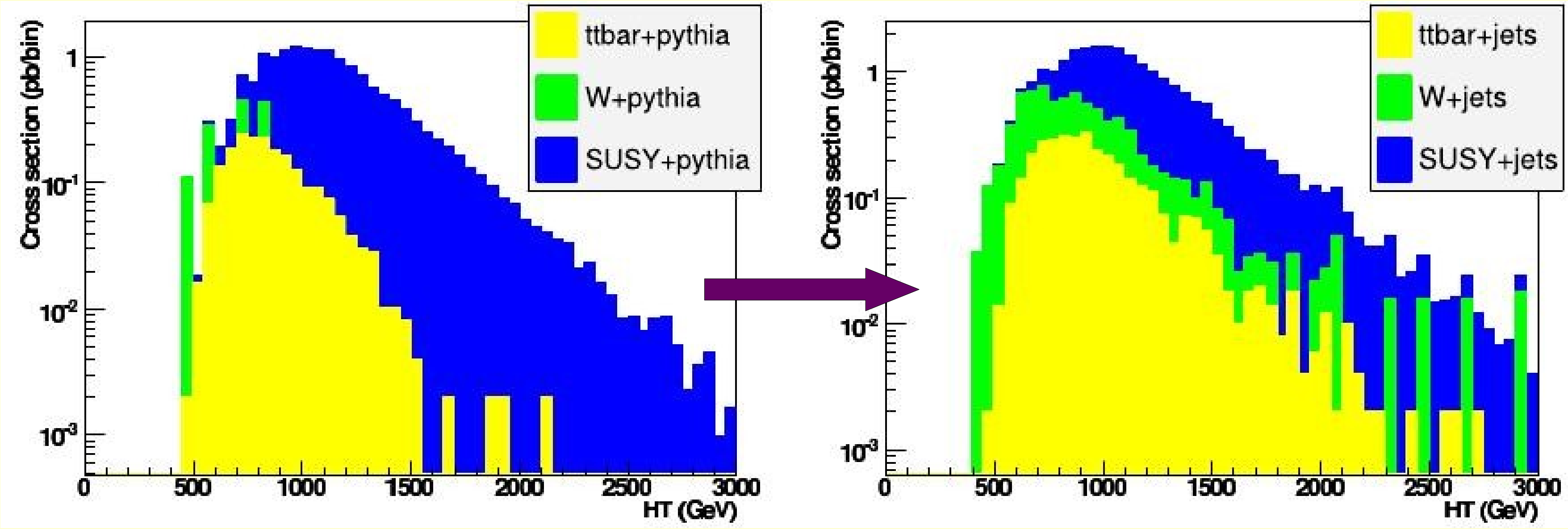
This discussion is based on work done in collaboration with R.K. Ellis and G. Zanderighi

Outline

- This is not a comprehensive discussion
- This is not a talk about BLM scale choice
- I assume that everybody knows CKKW/MLM procedure
- I assume that everybody enjoys hearing about NLO QCD computations once again
- The main point:
  - when we do NLO/LO comparisons, it is misleading to use LO with fixed renormalization/factorization scales
  - dynamical scales in LO computations typically compare well with NLO computations for "energy-related" distributions
  - for spin correlations and azimuthal angle distributions, I am not aware of any argument to this effect

CKKW / MLM

- CKKW/MLM procedure sets a new standard for LO calculations.
- Employed extensively in experimental analysis in recent years.
- What are its limitations?



Plots from J. Alwall's talk

The need for the NLO

- An obvious drawback of CKKW/MLM is that it is a LO procedure and there is no mechanism in place to guarantee that the final result is independent of the renormalization and factorization scales

- This is a troublesome feature, especially if there are many external particles

$$\sigma_n \sim \alpha_s(\mu)^n \Leftrightarrow \mu^2 \frac{\partial \sigma_n}{\partial \mu^2} \sim n\beta_0 \alpha_s(\mu) \sigma_n(\mu)$$

- The uncertainty can easily be a factor 2 to 4

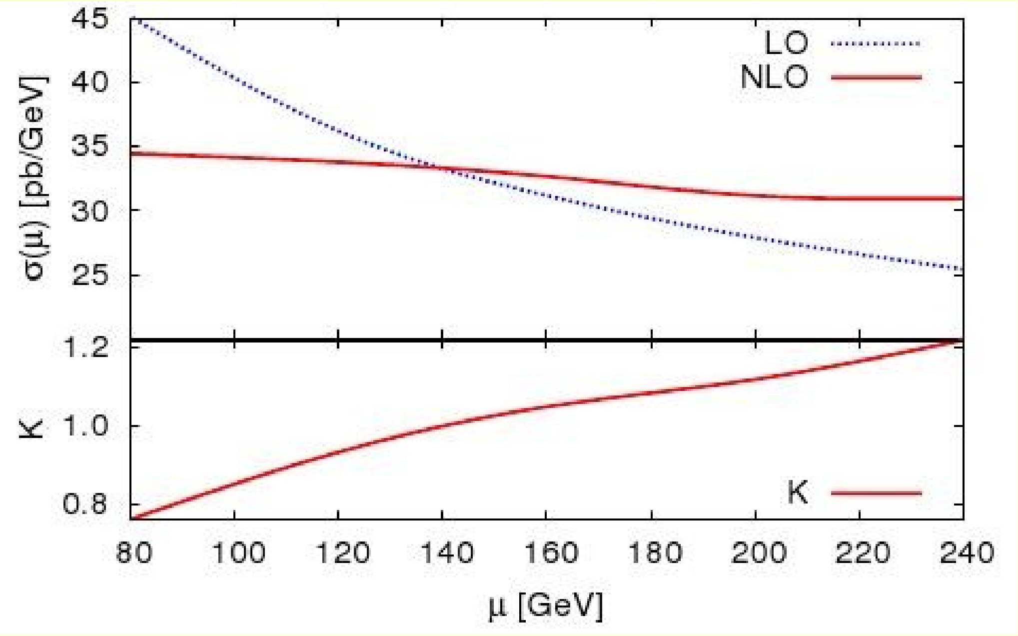
- CKKW typically does somewhat better than that but I do not know if this is controllable or "just so"

Rates and shapes

- We like to distinguish between normalizations and shapes since
  - normalization can be fixed in "control" phase-space regions
  - shapes are obtained using control regions as boundary conditions for tuning theoretical tools
- This procedure can be problematic if tools are too simplistic
- Availability of NLO QCD predictions for a given process gives the cross-check of the extrapolation because all the relevant scales in this case are generated dynamically
- NLO QCD calculations can fail at very small and at very large momentum

W+3 jets @ NLO

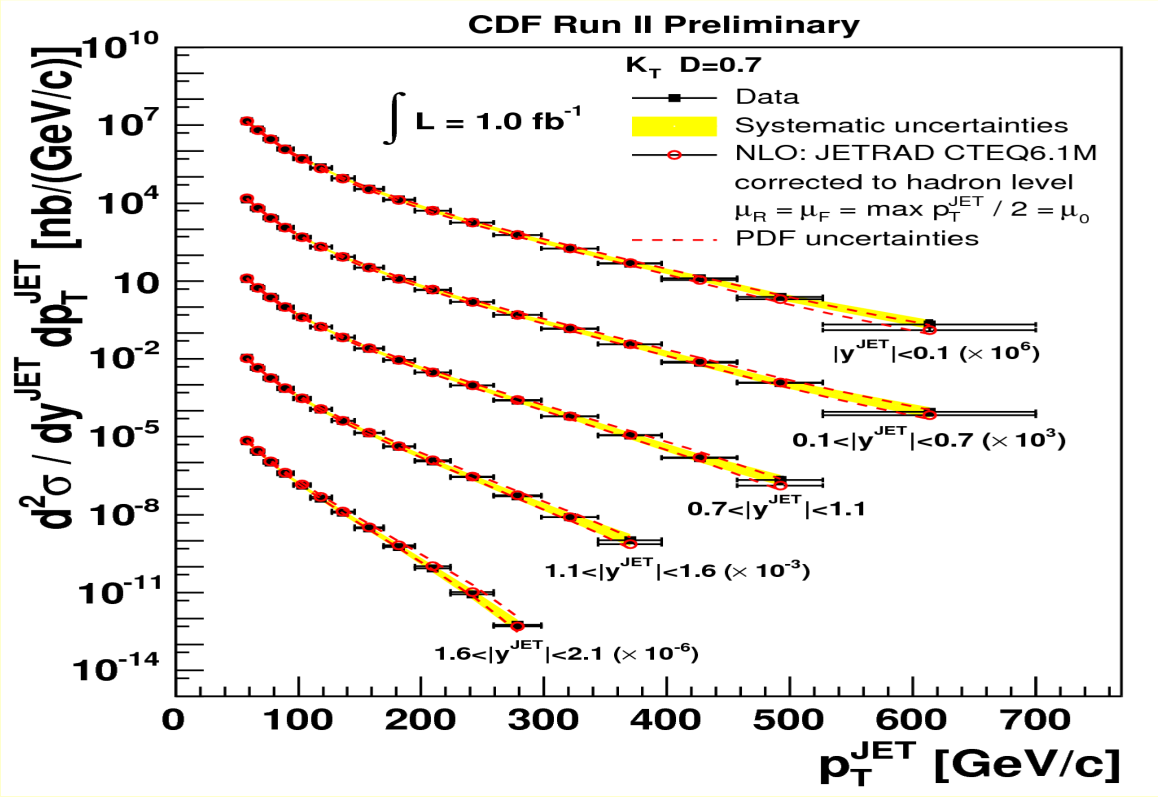
- Predictions for W+3jet cross-sections at the LHC are uncertain at LO and nearly perfect at NLO
- Do small corrections to cross-sections guarantee small changes in shapes? The answer is no, we need to choose scales wisely if we want to describe distributions well



The residual uncertainty is about ten percent for both W+ and W-

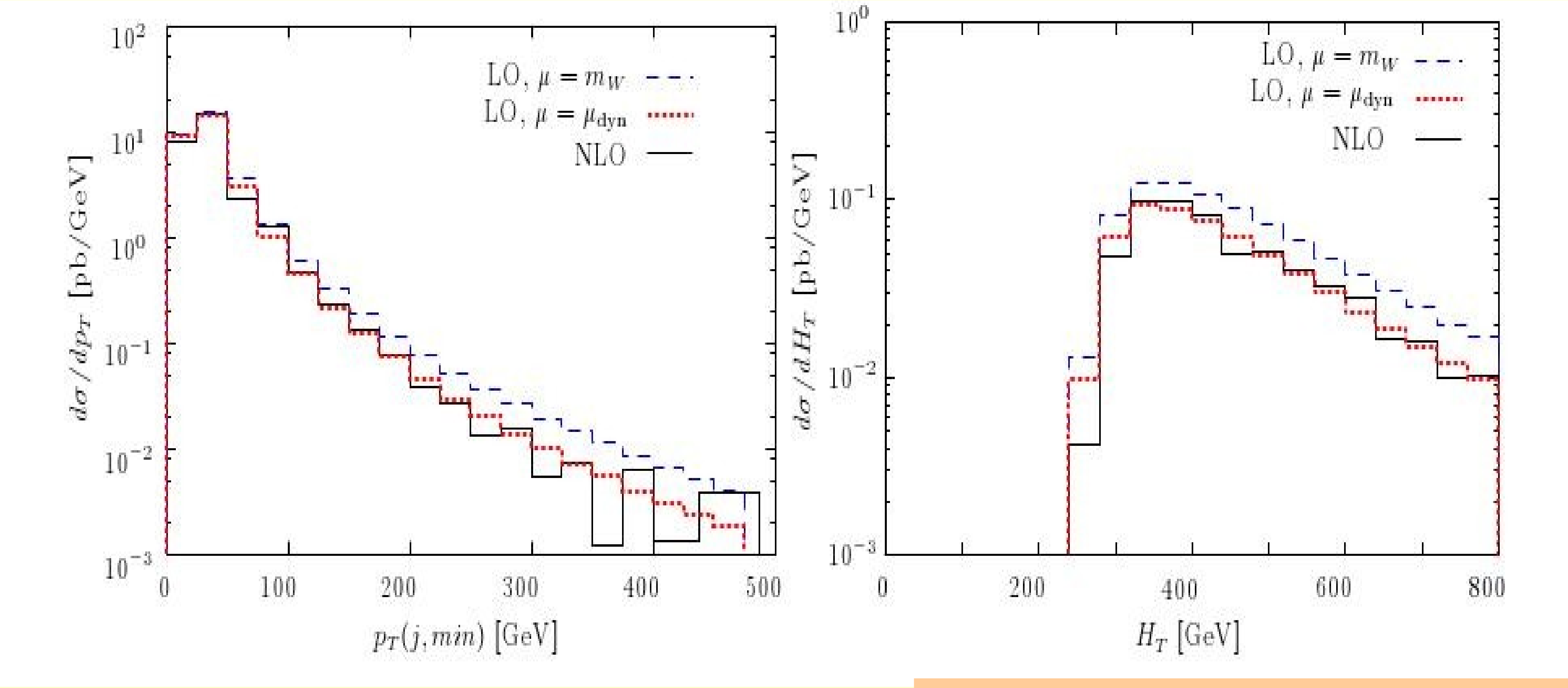
Choice of scales

- Any collider physics is very multi-scale – even a single observable may be sensitive to a variety of physics effects
- Any generic argument for choosing a renormalization/factorization scale should relate to the location of a given event in the phase-space



Choice of scales reshapes the distributions

- Bauer and Lange showed that choosing the scale of the strong coupling constant leads to important effects.



W+2 jets production at the LHC

$$\mu_{\rm dyn} = \sqrt{\left(\frac{m_{JJ}}{2}\right)^2 + m_W^2}$$

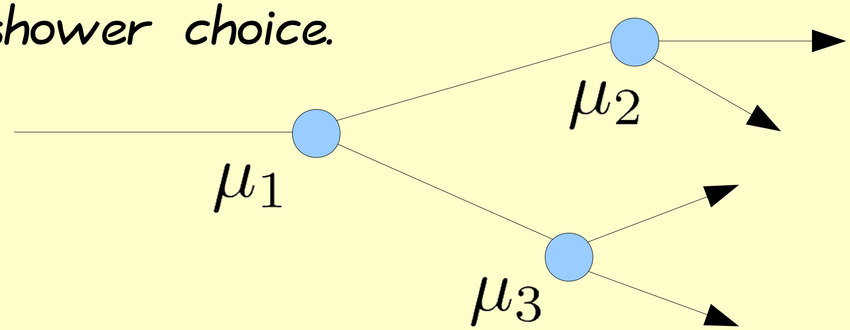
Bauer, Lange

CKKW and the scale setting

- *The Bauer-Lange analysis works well because it respects a well-known feature of how QCD partons multiply*

$$\mathrm{Prob}(a \to bc) \sim \alpha_s(p_\perp)$$

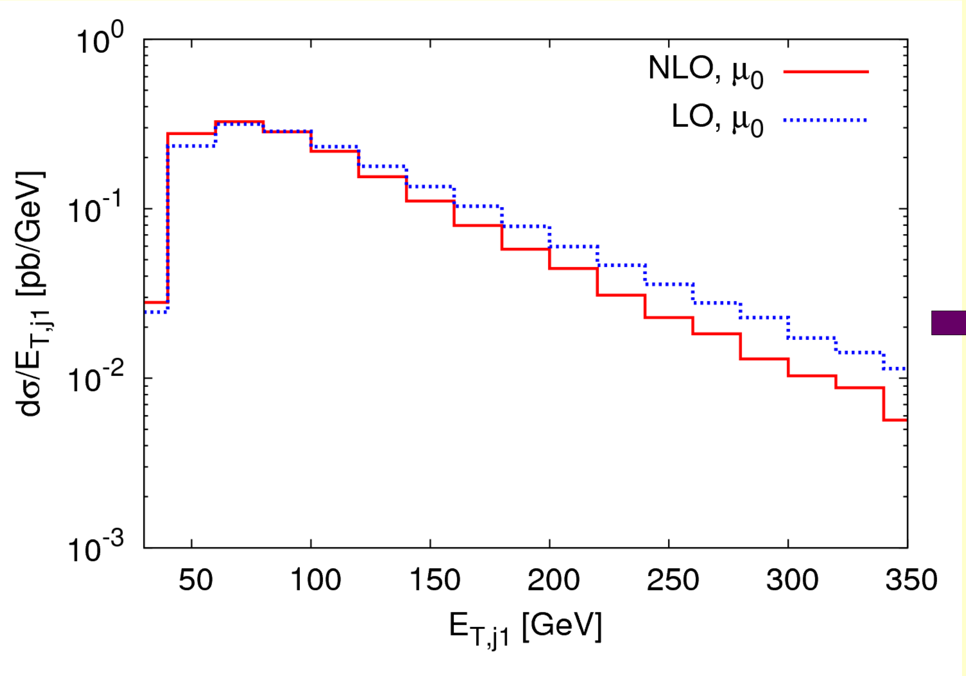
- *The CKKW/MLM procedure respects this choice and, in fact, does more local scale adjustment. Should work well!* *The scales are chosen on an event-by-event basis by identifying most probable "history" of a given event*
  - *iteratively cluster particles that are closest according to some measure (usually, $k_\perp$ algorithm is used).*
  - *for each node, choose the relative momentum of the daughters as the scale for the strong coupling constant – this is the parton shower choice.*

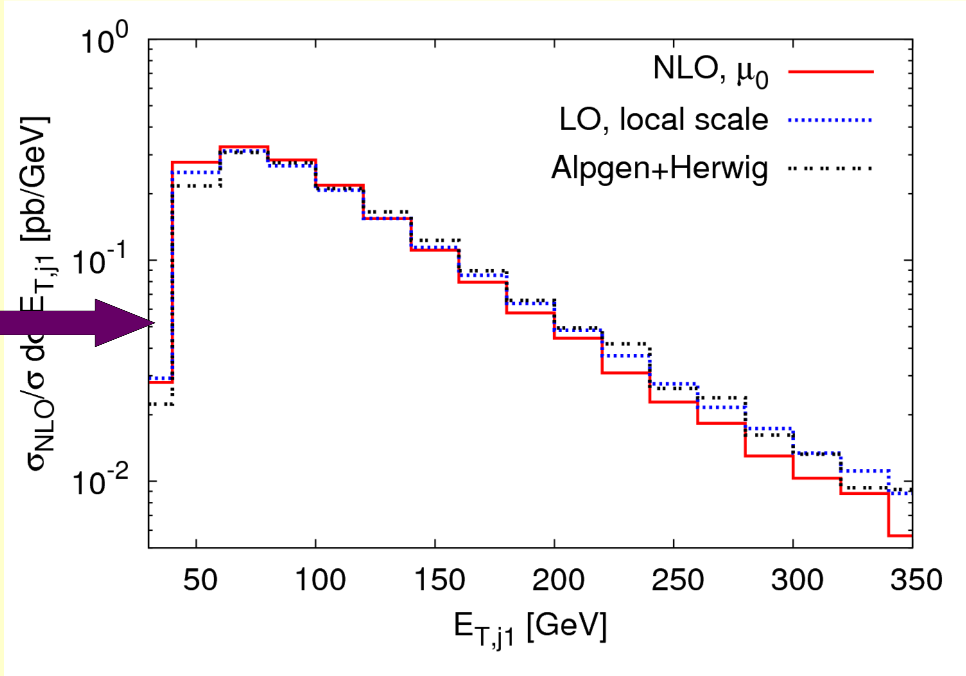


$$|\mathcal{M}|^2 \sim \prod_{i=1}^{N_{\rm part}} \alpha_s(\mu_i)$$

W+3 jets @ NLO

- Small corrections to total cross-sections do not guarantee that corrections to tails of kinematic distributions are also small. But CKKW/MLM procedure does a very good jobs in describing shapes.

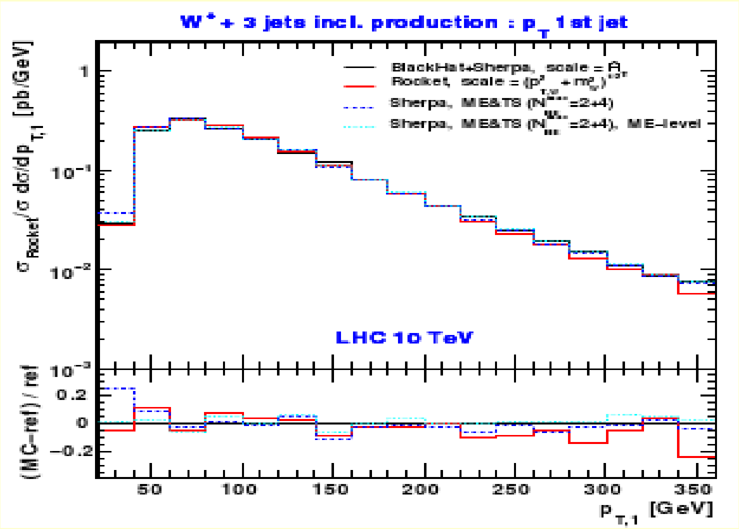


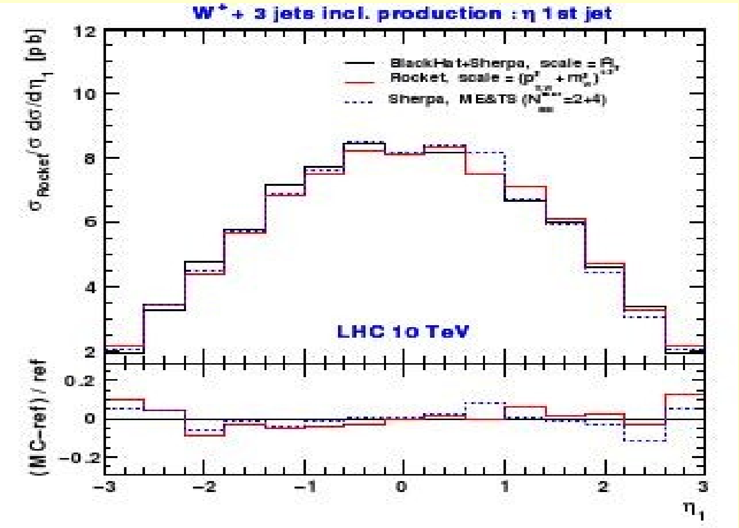


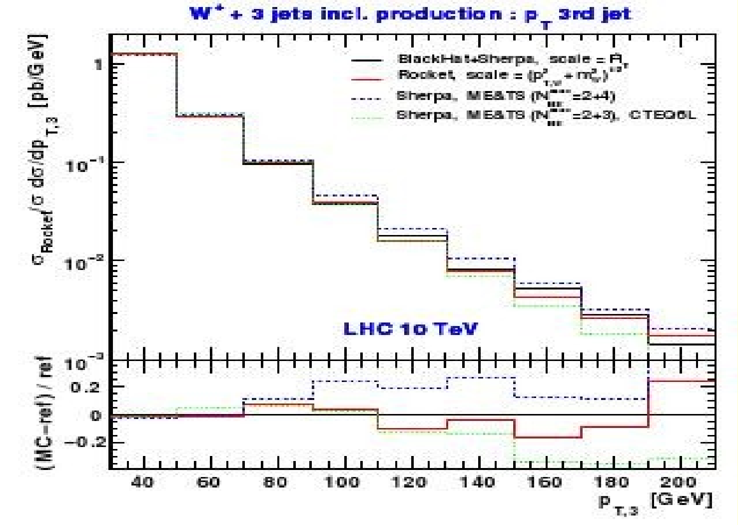
In the right panel, we see that ALPGEN/HERWIG does a much better job. The reason is that CKKW or MLM procedures as well as parton showers have correct scales for the strong coupling constant implemented.

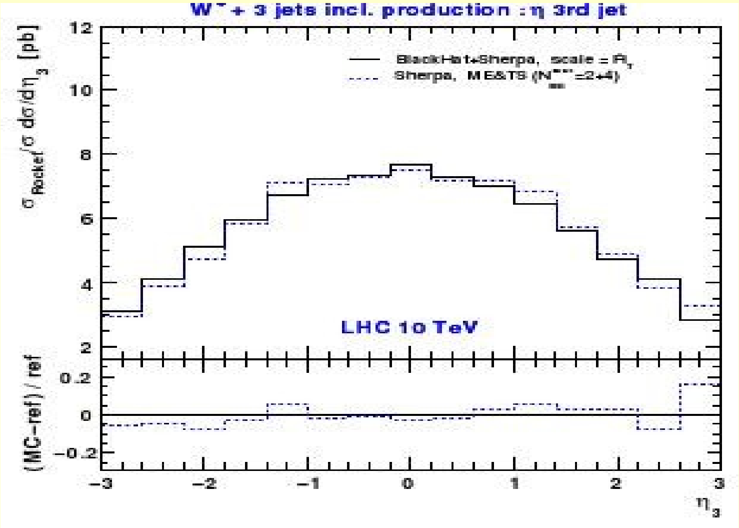
Comparisons for W+3 jets

- *Dedicated comparisons between Rocket,/Blackhat+Sherpa/Sherpa*









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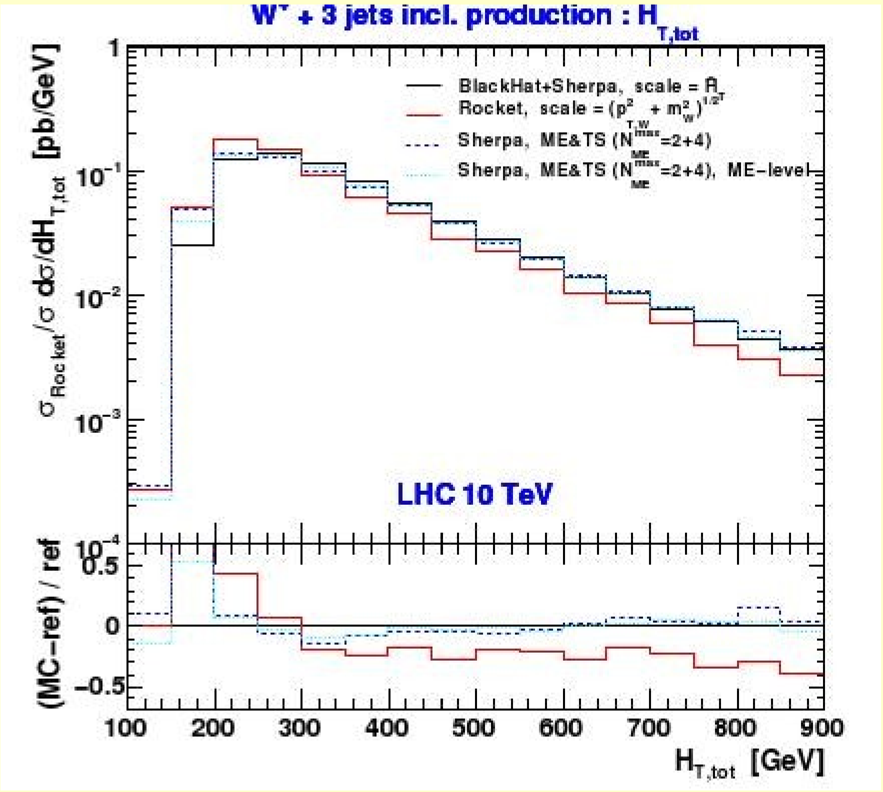
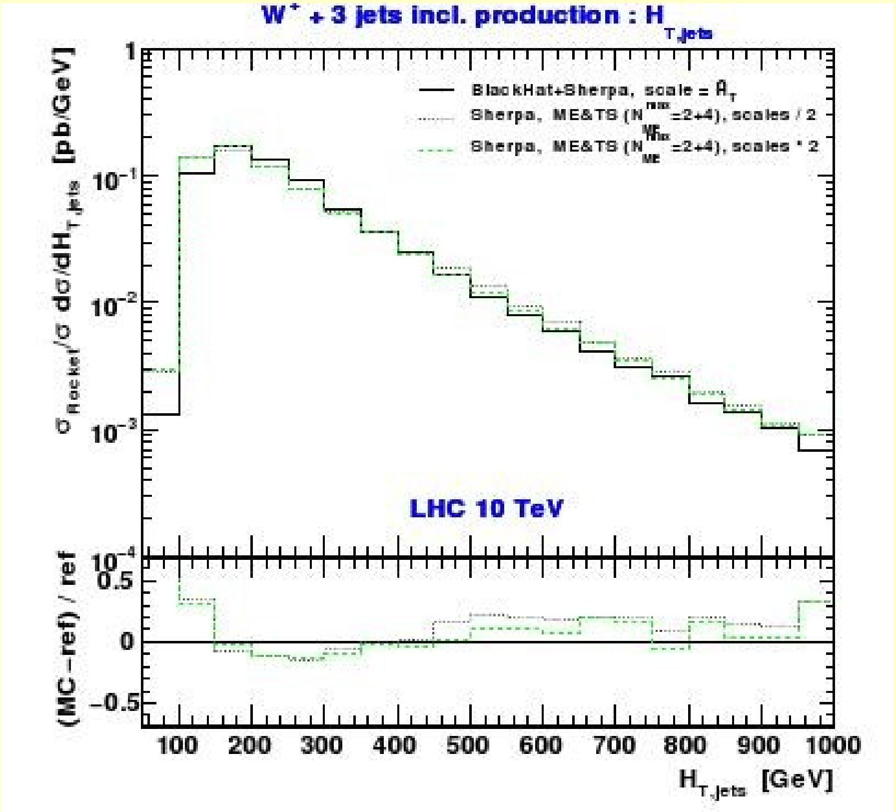
Comparisons for W+jets

- *For the total transverse energy, the story is slightly less satisfactory – NLO calculations exhibit stronger dependence on scales than CKKW-based leading order results!*





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Conclusions

- CKKW/MLM procedures employ dynamical scales consistent with the QCD dynamics
- Leading order calculations with dynamically-adjusted scales compare very well with NLO computations, shape-wise
- Indication that shapes – to a large extent – can be understood as a consistent description of branching processes
- In the limit when kinematic invariants become large, there still can be (relatively) strong scale dependences of NLO QCD results – in fact stronger than indicated by CKKW/MLM
- For experimentalists, the message is that CKKW/MLM works better than (at least I) expected and this seems to be a generic, process-independent feature