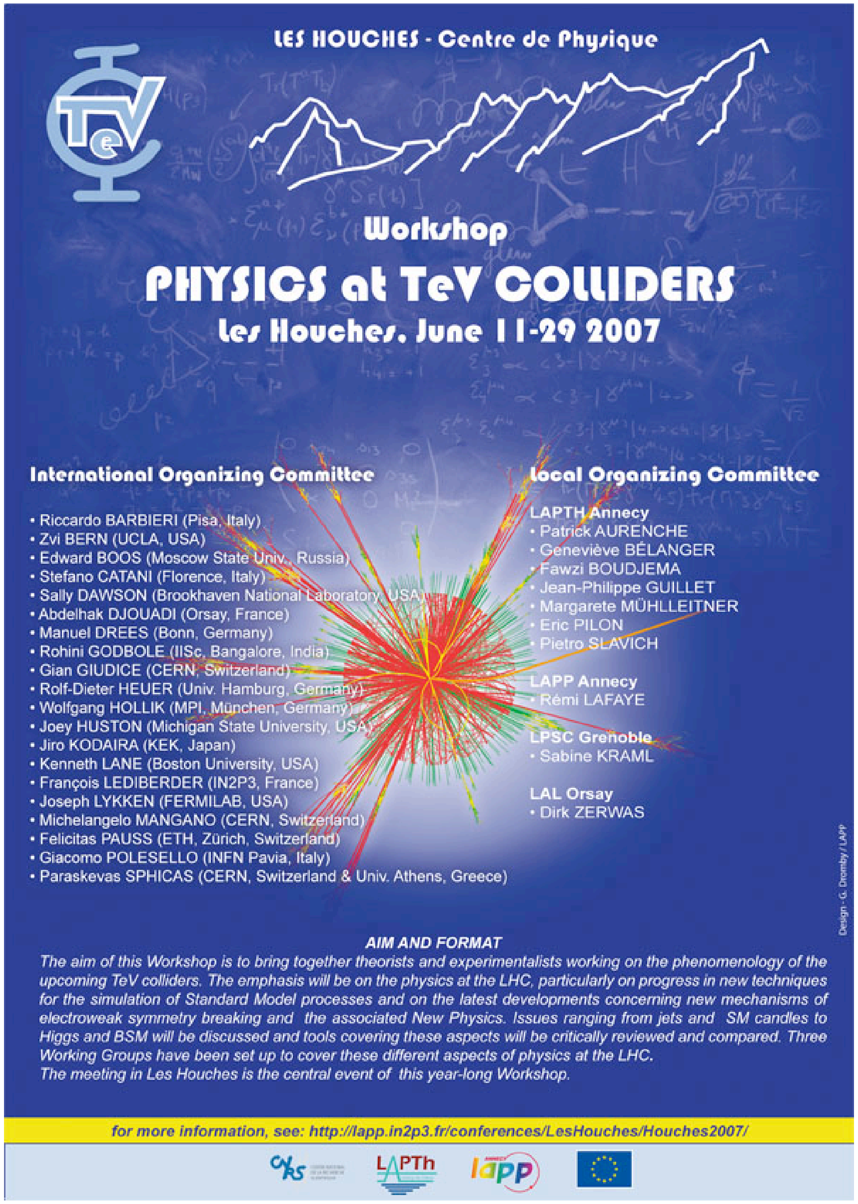
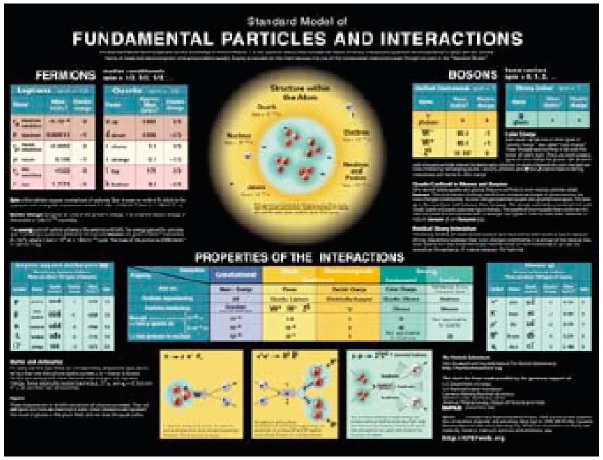
NLO event generators and cross sections

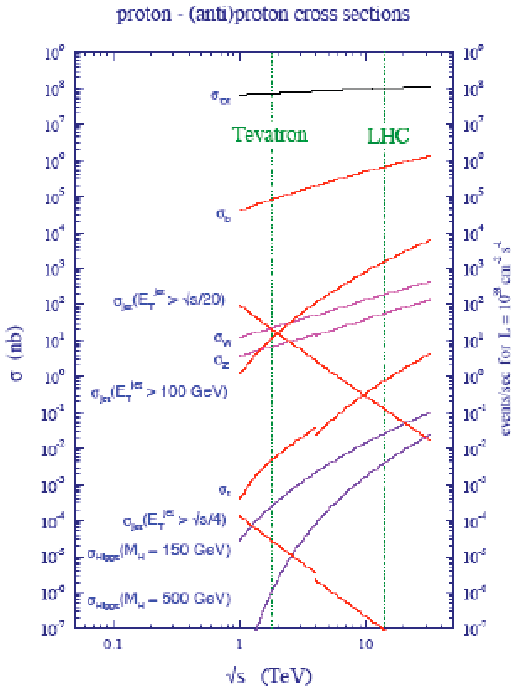


- J. Huston
  - Michigan State University
- B. Kersevan
  - Ljubljana University
- D. Soper
  - U. of Oregon
- Charge
  - integrating NLO calculations and MC's, NNLO issues,NLO wish list, contact with experiments, ...

Discovering the SM at the LHC

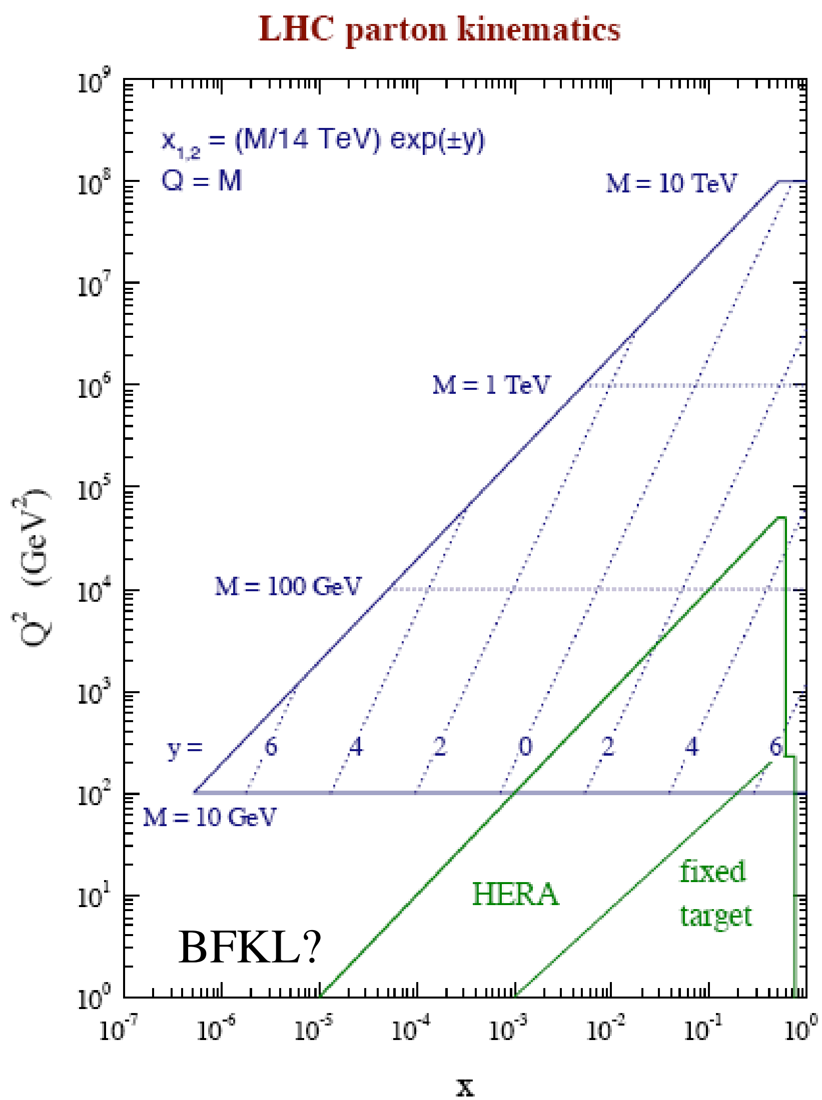
- We're all looking for BSM physics at the LHC
- Before we publish BSM discoveries from the early running of the LHC, we want to make sure that we measure/understand SM cross sections
  - detector and reconstruction algorithms operating properly
  - SM physics understood properly
  - SM backgrounds to BSM physics correctly taken into account
- ATLAS/CMS will have a program to measure production of SM processes: inclusive jets, W/Z + jets, heavy flavor during first inverse femtobarn
  - so experimenters need/have a program now of Monte Carlo production and studies to make sure that we understand what issues are important
  - **and we also need tool and algorithm and theoretical prediction developments (such as at NLO)**





Cross sections at the LHC

- Experience at the Tevatron is very useful, but scattering at the LHC is not necessarily just “rescaled” scattering at the Tevatron
- Small typical momentum fractions x in many key searches
  - dominance of gluon and sea quark scattering
  - large phase space for gluon emission and thus for production of extra jets
  - intensive QCD backgrounds
  - or to summarize,…lots of Standard Model to wade through to find the BSM pony



Ratios:LHC to Tevatron pdf luminosities

- Processes that depend on qQ initial states (e.g. chargino pair production) have small enchancements
- Most backgrounds have gg or gq initial states and thus large enhancement factors (500 for W + 4 jets for example, which is primarily gq) at the LHC
- W+4 jets is a background to tT production both at the Tevatron and at the LHC
- tT production at the Tevatron is largely through a qQ initial states and so qQ->tT has an enhancement factor at the LHC of ~10
- Luckily tT has a gg initial state as well as qQ so total enhancement at the LHC is a factor of 100
  - but increased W + jets background means that a higher jet cut is necessary at the LHC
  - known known: jet cuts have to be higher at LHC than at Tevatron
  - luckily WbBjj has a small enhancement factor

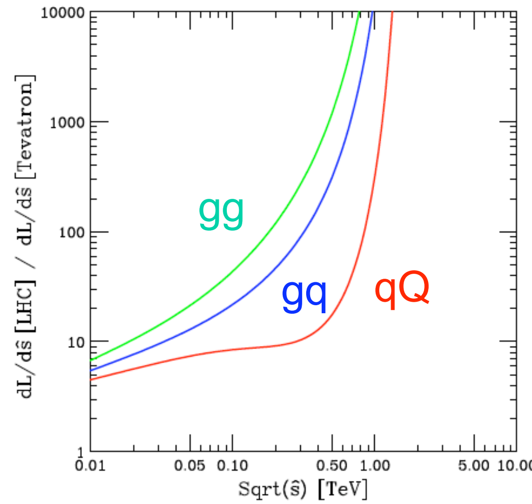


Figure 11. The ratio of parton-parton luminosity $\left[\frac{1}{\hat{s}}\frac{dL_{ij}}{d\tau}\right]$ in pb integrated over y at the LHC and Tevatron. Green=gg (top), Blue=$g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$ (middle), Red=$d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$ (bottom).

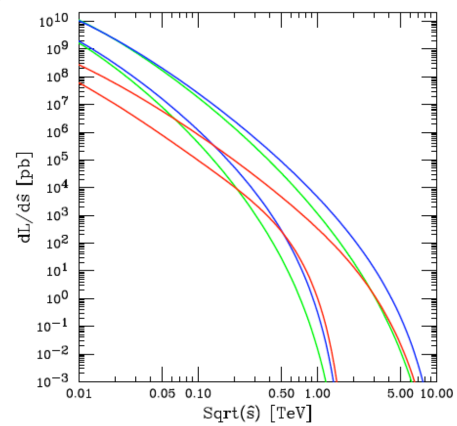


Figure 10. The parton-parton luminosity $\left[\frac{1}{\hat{s}}\frac{dL_{ij}}{d\tau}\right]$ in pb integrated over y. Green=gg, Blue=$g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$, Red=$d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$. The top family of curves are for the LHC and the bottom for the Tevatron.

The LHC will be a very *jetty* place

- Total cross sections for tT and Higgs production saturated by tT (Higgs) + jet production for jet p_T values of order 10-20 GeV/c
- $\sigma_{W+3\ jets} > \sigma_{W+2\ jets}$

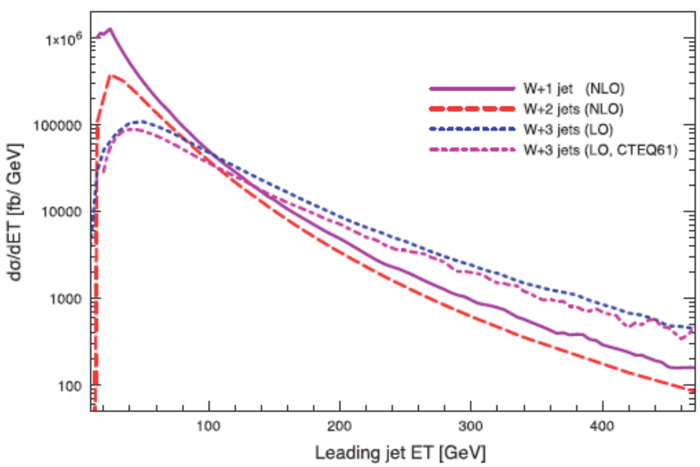


Figure 91. Predictions for the production of $W+ \geqslant 1, 2, 3$ jets at the LHC shown as a function of the transverse energy of the lead jet. A cut of 20 GeV has been placed on the other jets in the prediction.

- Indication that can expect interesting events at LHC to be very *jetty* (especially from gg initial states)
- Also can be understood from point-of-view of Sudakov form factors

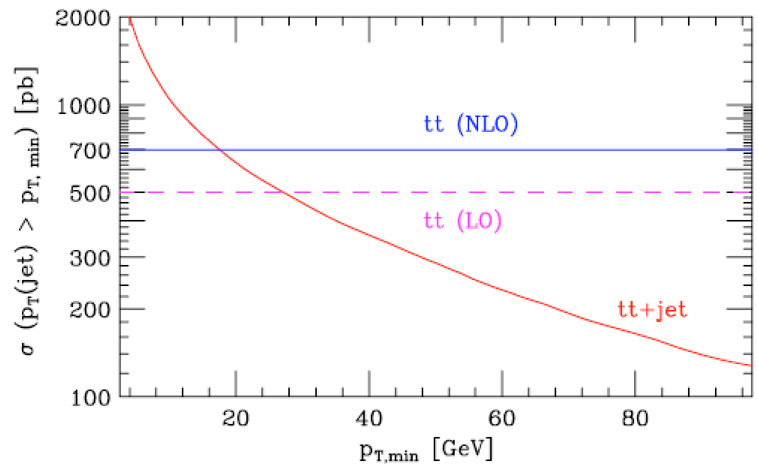


Figure 95. The dependence of the LO $t\bar{t}$+jet cross section on the jet-defining parameter $p_{T,\min}$, together with the top pair production cross sections at LO and NLO.

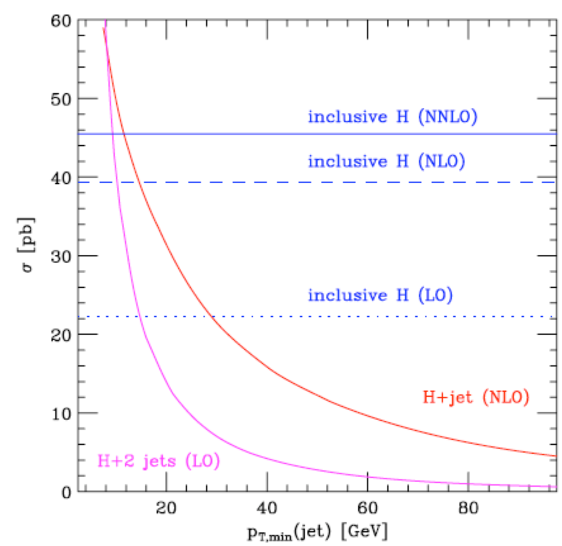


Figure 100. The dependence of the LO $t\bar{t}$+jet cross section on the jet-defining parameter $p_{T,\min}$, together with the top pair production cross sections at LO and NLO.

NLO corrections

- NLO is the first order for which the normalization, and sometimes the shape, is believable
- NLO is necessary for precision comparisons of data to theory
- Sometimes backgrounds to new physics can be extrapolated from non-signal regions, but this is difficult to do for low cross section final states and/or final states where a clear separation of a signal and background region is difficult

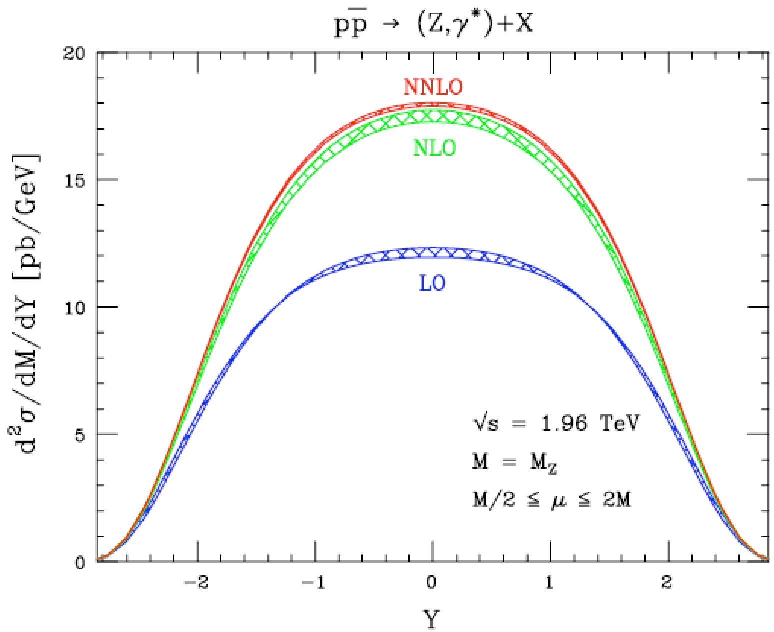


Figure 38. Predictions for the rapidity distribution of an on-shell Z boson in Run 2 at the Tevatron at LO, NLO and NNLO. The bands indicate the variation of the renormalization and factorization scales within the range $M_Z/2$ to $2M_Z$.

NLO corrections

Sometimes it is useful to define a K-factor (NLO/LO). Note the value of the K-factor depends critically on its definition. K-factors at LHC (mostly) similar to those at Tevatron.

Table 1. K-factors for various processes at the Tevatron and the LHC, calculated using a selection of input parameters. In all cases, the CTEQ6M PDF set is used at NLO. $\mathcal{K}$ uses the CTEQ6L1 set at leading order, whilst $\mathcal{K}'$ uses the same set, CTEQ6M, as at NLO. Jets satisfy the requirements $p_T > 15$ GeV and $|\eta| < 2.5$ (5.0) at the Tevatron (LHC). In the $W + 2$ jet process the jets are separated by $\Delta R > 0.52$, whilst the weak boson fusion (WBF) calculations are performed for a Higgs of mass 120 GeV.

	Typical scales		Tevatron K-factor			LHC K-factor		
Process	μ_0	μ_1	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$
W	m_W	$2m_W$	1.33	1.31	1.21	1.15	1.05	1.15
$W + 1$ jet	m_W	$\langle p_T^{\text{jet}} \rangle$	1.42	1.20	1.43	1.21	1.32	1.42
$W + 2$ jets	m_W	$\langle p_T^{\text{jet}} \rangle$	1.16	0.91	1.29	0.89	0.88	1.10
$t\bar{t}$	m_t	$2m_t$	1.08	1.31	1.24	1.40	1.59	1.48
$b\bar{b}$	m_b	$2m_b$	1.20	1.21	2.10	0.98	0.84	2.51
Higgs via WBF	m_H	$\langle p_T^{\text{jet}} \rangle$	1.07	0.97	1.07	1.23	1.34	1.09

K-factors may differ from one because of new subprocesses/contributions at higher order and/or differences between LO and NLO pdf’s

Counterexample:shape dependence of a K-factor

- Inclusive jet production probes very wide x,Q^2 range along with varying mixture of gg,gq,and qq subprocesses
- Over limited range of p_T and y, can approximate effect of NLO corrections by K-factor but not in general
  - in particular note that for forward rapidities, K-factor <<1
  - LO predictions will be large overestimates
  - see extra slides for discussion as to why

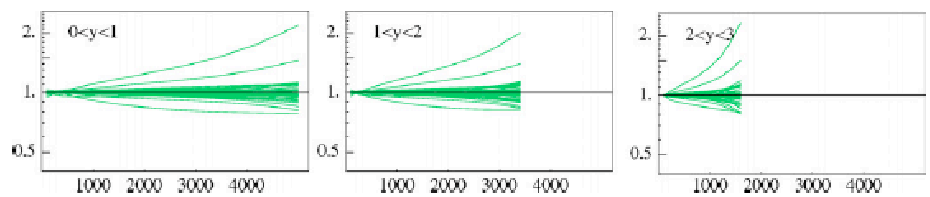


Figure 105. The ratios of the jet cross section predictions for the LHC using the CTEQ6.1 error pdfs to the prediction using the central pdf. The extremes are produced by eigenvector 15.

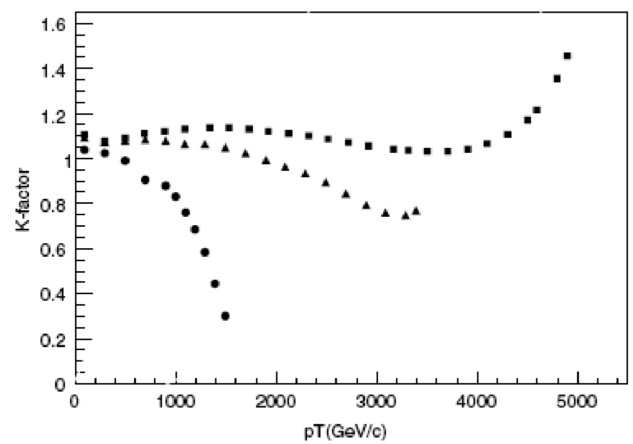


Figure 106. The ratios of the NLO to LO jet cross section predictions for the LHC using the CTEQ6.1 pdfs for the three different rapidity regions (0–1 (squares), 1–2 (triangles), 2–3 (circles)).

Now we come to the “maligned” experimenter’s NLO wishlist

- Missing many needed NLO computations — Campbell

An experimenter’s wishlist

- Hadron collider cross-sections one would like to know at NLO

Run II Monte Carlo Workshop, April 2001 → almost 6 years to the day and yet not a single calculation finished! Shame

Single boson	Diboson	Triboson	Heavy flavour
$W + \leq 5j$	$WW + \leq 5j$	$WWW + \leq 3j$	$t\bar{t} + \leq 3j$
$W + b\bar{b} + \leq 3j$	$WW + b\bar{b} + \leq 3j$	$WWW + b\bar{b} + \leq 3j$	$t\bar{t} + \gamma + \leq 2j$
$W + c\bar{c} + \leq 3j$	$WW + c\bar{c} + \leq 3j$	$WWW + \gamma\gamma + \leq 3j$	$t\bar{t} + W + \leq 2j$
$Z + \leq 5j$	$ZZ + \leq 5j$	$Z\gamma\gamma + \leq 3j$	$t\bar{t} + Z + \leq 2j$
$Z + b\bar{b} + \leq 3j$	$ZZ + b\bar{b} + \leq 3j$	$WZZ + \leq 3j$	$t\bar{t} + H + \leq 2j$
$Z + c\bar{c} + \leq 3j$	$ZZ + c\bar{c} + \leq 3j$	$ZZZ + \leq 3j$	$t\bar{b} + \leq 2j$
$\gamma + \leq 5j$	$\gamma\gamma + \leq 5j$		$b\bar{b} + \leq 3j$
$\gamma + b\bar{b} + \leq 3j$	$\gamma\gamma + b\bar{b} + \leq 3j$		
$\gamma + c\bar{c} + \leq 3j$	$\gamma\gamma + c\bar{c} + \leq 3j$		
	$WZ + \leq 5j$		
	$WZ + b\bar{b} + \leq 3j$		
	$WZ + c\bar{c} + \leq 3j$		
	$W\gamma + \leq 3j$		
	$Z\gamma + \leq 3j$		

NLO calculation priority list from Les Houches 2005: theory benchmarks

G. Heinrich and J. Huston

process ($V \in \{Z, W, \gamma\}$)	relevant for	
1. $pp \to V\,V$+jet	$t\bar{t}H$, new physics	+
2. $pp \to H + 2$ jets	H production by vector boson fusion (VBF)	*
3. $pp \to t\bar{t}\,b\bar{b}$	$t\bar{t}H$	+
4. $pp \to t\bar{t} + 2$ jets	$t\bar{t}H$	
5. $pp \to V\,V\,b\bar{b}$	VBF→ $H \to VV$, $t\bar{t}H$, new physics	
6. $pp \to V\,V + 2$ jets	VBF→ $H \to VV$	
7. $pp \to V + 3$ jets	various new physics signatures	+
8. $pp \to V\,V\,V$	SUSY trilepton	*

Table 2. The wishlist of processes for which a NLO calculation is both desired and feasible in the near future.

*completed since list
+people are working

- $pp \to$ VV + jet: One of the most promising channels for Higgs production in the low mass range is through the $H \to WW^*$ channel, with the W's decaying semi-leptonically. It is useful to look both in the $H \to WW$ exclusive channel, along with the $H \to WW$+jet channel. The calculation of $pp \to WW$+jet will be especially important in understanding the background to the latter.
- $pp \to H$+2 jets: A measurement of vector boson fusion (VBF) production of the Higgs boson will allow the determination of the Higgs coupling to vector bosons. One of the key signatures for this process is the presence of forward-backward tagging jets. Thus, QCD production of H + 2 jets must be understood, especially as the rates for the two are comparable in the kinematic regions of interest.
- $pp \to t\bar{t}b\bar{b}$ and $pp \to t\bar{t}$ + 2 jets: Both of these processes serve as background to $t\bar{t}H$, where the Higgs decays into a $b\bar{b}$ pair. The rate for $t\bar{t}jj$ is much greater than that for $t\bar{t}b\bar{b}$ and thus, even if 3 b-tags are required, there may be a significant chance for the heavy flavour mistag of a $t\bar{t}jj$ event to contribute to the background.
- $pp \to VVb\bar{b}$: Such a signature serves as non-resonant background to $t\bar{t}$ production as well as to possible new physics.
- $pp \to$ VV + 2 jets: The process serves as a background to VBF production of Higgs.
- $pp \to$ V + 3 jets: The process serves as background for $t\bar{t}$ production where one of the jets may not be reconstructed, as well as for various new physics signatures involving leptons, jets and missing transverse momentum.
- $pp \to VVV$: The process serves as a background for various new physics subprocesses such as SUSY tri-lepton production.

[23] Process 2 has been calculated since the first version of this list was formulated [138].

What about time lag in going from availability of matrix elements to having a parton level Monte Carlo available? See e.g. H + 2 jets. Other processes are going to be just as complex.

tTj

- An important calculation at NLO that would have made the list, except we knew that Dittmaier, Uwer and Weinzierl were alread working on it

- NLO corrections are small with scale choice near m_t
- Bonus feature: tTj asymmetry at Tevatron small at NLO

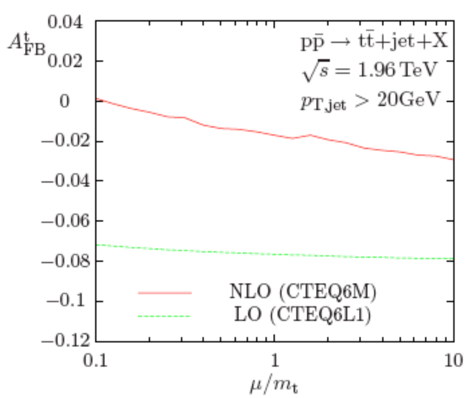


FIG. 4: Scale dependence of the LO and NLO forward–backward charge asymmetry of the top quark in $p\bar{p} \to t\bar{t}$+jet+X at the Tevatron, where the renormalization and factorization scales are set equal to μ.

bonus because tT and tTj asymmetries in opposite directions

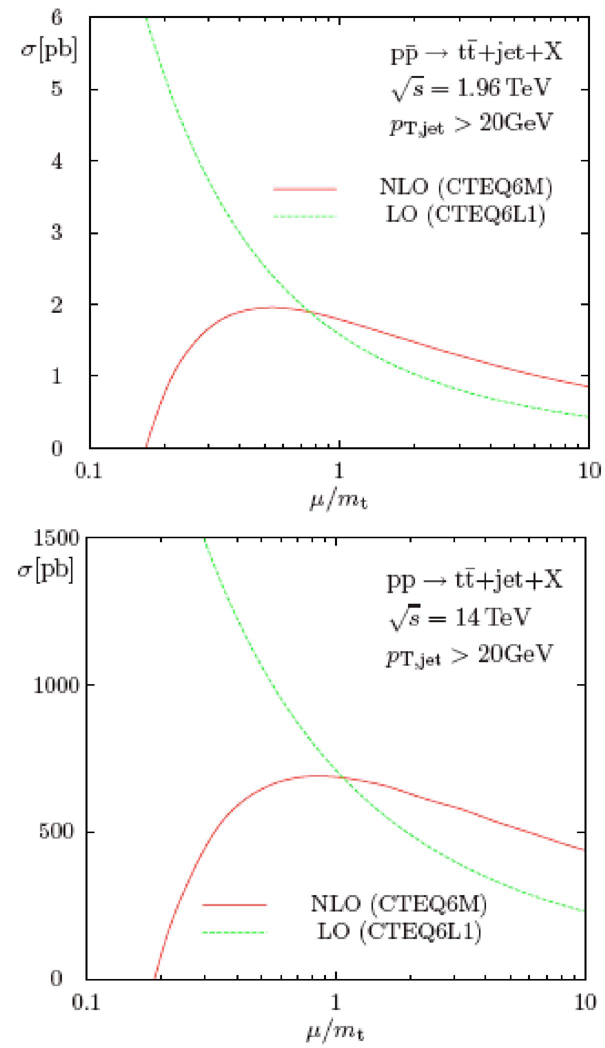


FIG. 3: Scale dependence of the LO and NLO cross sections for $t\bar{t}$+jet production at the Tevatron (upper plot) and at the LHC (lower plot), where the renormalization and factorization scales are set equal to μ.

From LHC theory initiative white paper

- time ordered LHC shopping list
  - ☞ need for $10-30\ \text{fb}^{-1}$ (2008-2010):
    - → full NLO QCD corrections to $pp \to t\bar{t} \to b\bar{b} + 4f$
    - → NLO QCD corrections to $t\bar{t}j$, $t\bar{t}\gamma$, $W/Z+ \geq 3$ jets production
    - → NNLO QCD corrections to PDF's, 2-jet production
  - ☞ need for $300\ \text{fb}^{-1}$ (2012-2013):
    - → NLO QCD corrections to $gg \to HH$, $t\bar{t}W$, $t\bar{t}Z$ production
    - → NLO EW corrections are needed for all hard scattering processes
  - ☞ need for $3000\ \text{fb}^{-1}$ (> 2015):
    - → NLO QCD corrections to $WWWjj$, $jj\gamma\gamma$, $Q\bar{Q}\gamma j$ production
    - → probably many more processes as time and physics knowledge base evolves

Some issues/questions

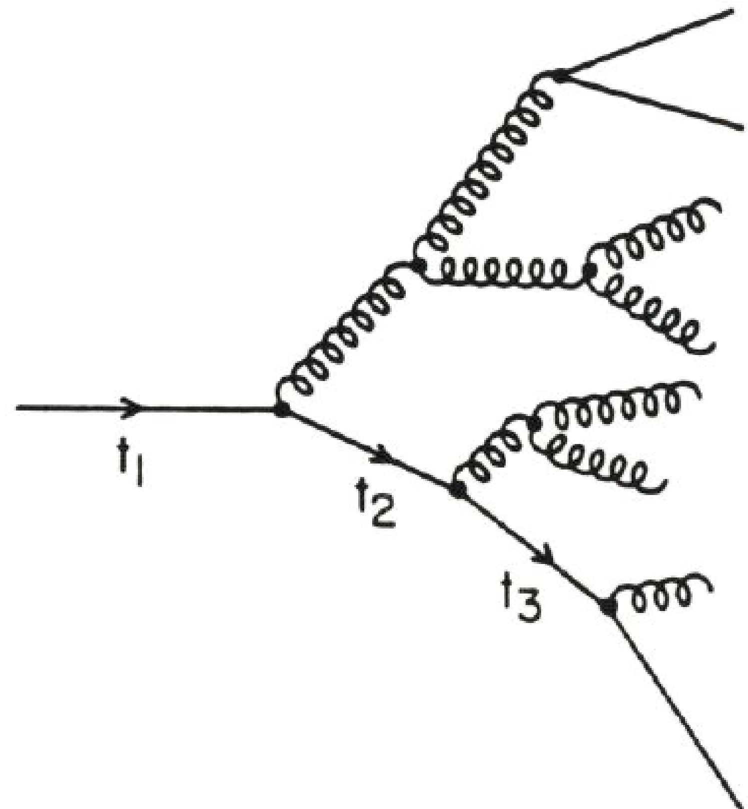
- What if we don't finish every process on the Les Houches list in time?
  - and/or we think of new ones
- Can we make some generalizations based on
  - type of reaction, initial state partons, kinematics
    - gg s-channel reactions have large K-factors?
  - past experience
    - tTg->tTbB?
  - and data/(LO)theory at the Tevatron?
- Can we learn anything more about NLO multi-jet cross sections from threshold resummation?
- Or, calculate soft and collinear approximations to NLO (George Sterman)?
  - collinear regions in phase and loop space universal (and fairly simple)
  - soft gluon regions change with number of jets, but are also simple
  - generate a relatively simple approximation to NLO following from same factorization formulas used to prove threshold resummation

Some issues/questions

- Once we have the calculations, how do we (experimentalists) use them?
  - and I would say that experimentalists have a history of not using the NLO calculations available
- Best is to have NLO partonic level calculation interfaced to parton shower/hadronization
  - but that has been done only for relatively simple processes and is very (theorist) labor intensive
    - still waiting for inclusive jets in MC@NLO, for example
  - need more automation
  - interface issues?
- Even with partonic level calculations, need ability to write out ROOT ntuples of parton level events
  - so that can generate once with loose cuts and distributions can be re-made without the need for the lengthy re-running of the predictions
  - what I do for example with MCFM
    - but 10's of Gbytes
- Is it useful/feasible to establish some conventions so that new calculations can easily be incorporated into programs such as MCFM or NLOJET++ ?

Parton showers

- There has been a great deal of progress in coupling LO and NLO calculations with parton showers
- What about improvements to the parton showers themselves?
  - adding information from fixed order matrix elements (a la CKKW/mlm)
  - improving accuracy of parton shower to NLL
  - quantifying the uncertainties of parton showering
  - learning from SCET



Don’t forget

- NNLO: we need to know some processes (such as inclusive jet production) at NNLO
- Resummation effects: affect important physics signatures
  - mostly taken into account if NLO calculations can be linked with parton showering Monte Carlos

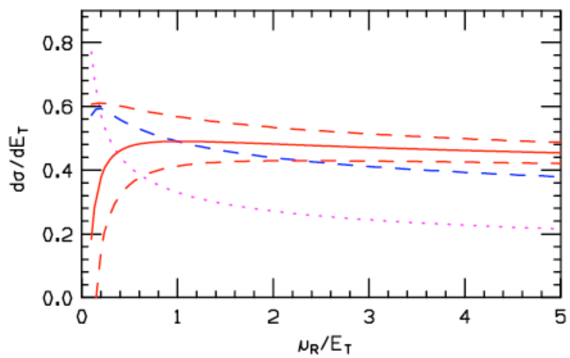


Figure 16. The single jet inclusive distribution at $E_T = 100$ GeV, appropriate for Run I of the Tevatron. Theoretical predictions are shown at LO (dotted magenta), NLO (dashed blue) and NNLO (red). Since the full NNLO calculation is not complete, three plausible possibilities are shown.

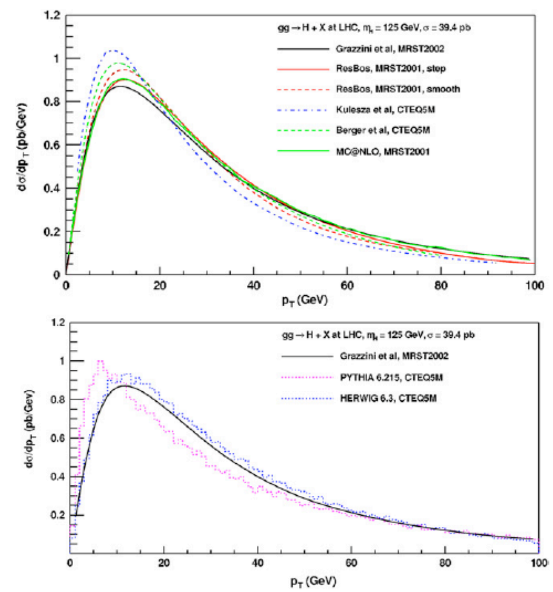


Figure 102. The predictions for the transverse momentum distribution for a 125 GeV mass Higgs boson at the LHC from a number of theoretical predictions. The predictions have all been normalized to the same cross section for shape comparisons. This figure can also be viewed in colour on the benchmark website.

…and

- BFKL logs: will we finally see them at the LHC?

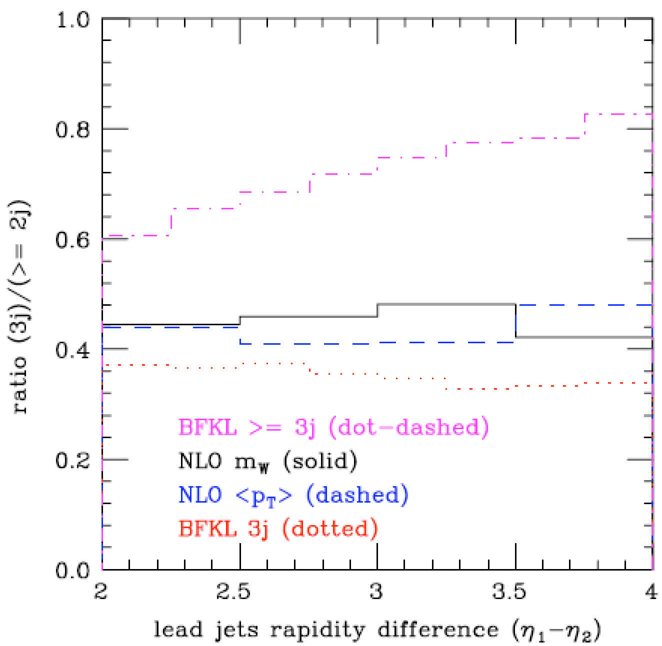
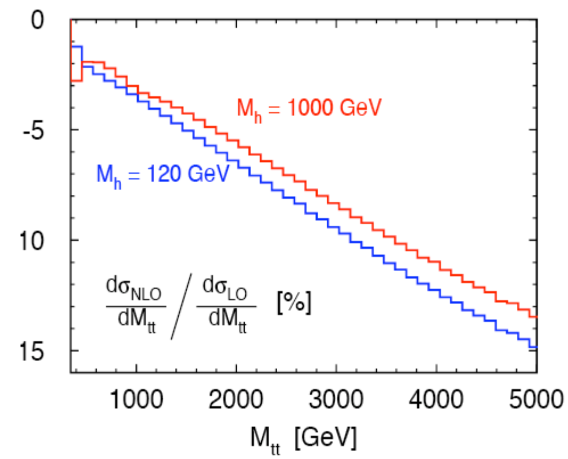


Figure 92. The rate for production of a third (or more) jet in $W+\geqslant 2$ jet events as a function of the rapidity separation of the two leading jets. A cut of 20 GeV has been placed on all jets. Predictions are shown from MCFM using two values for the renormalization and factorization scale, and using the BFKL formalism, requiring either that there be exactly 3 jets or 3 or more jets.

What if we turn on the LHC and *everything* is BFKL? Will anyone except Jeppe be happy?

- EW logs: $\alpha_W \log^2(p_T^2/m_W^2)$ can be a big number at the LHC



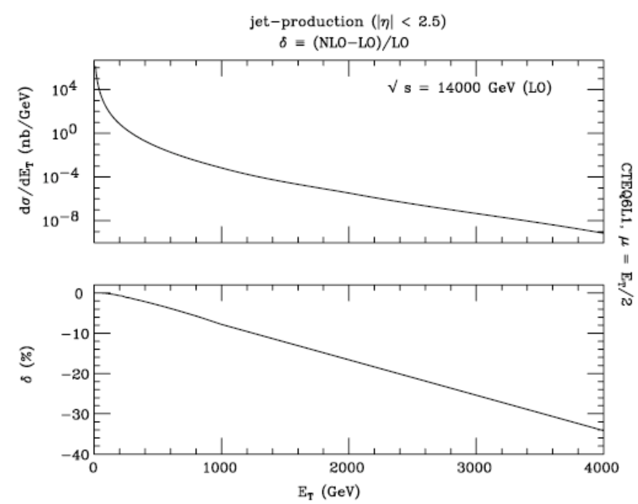


Figure 107. The effect of electroweak logarithms on jet cross sections at the LHC.

Summary

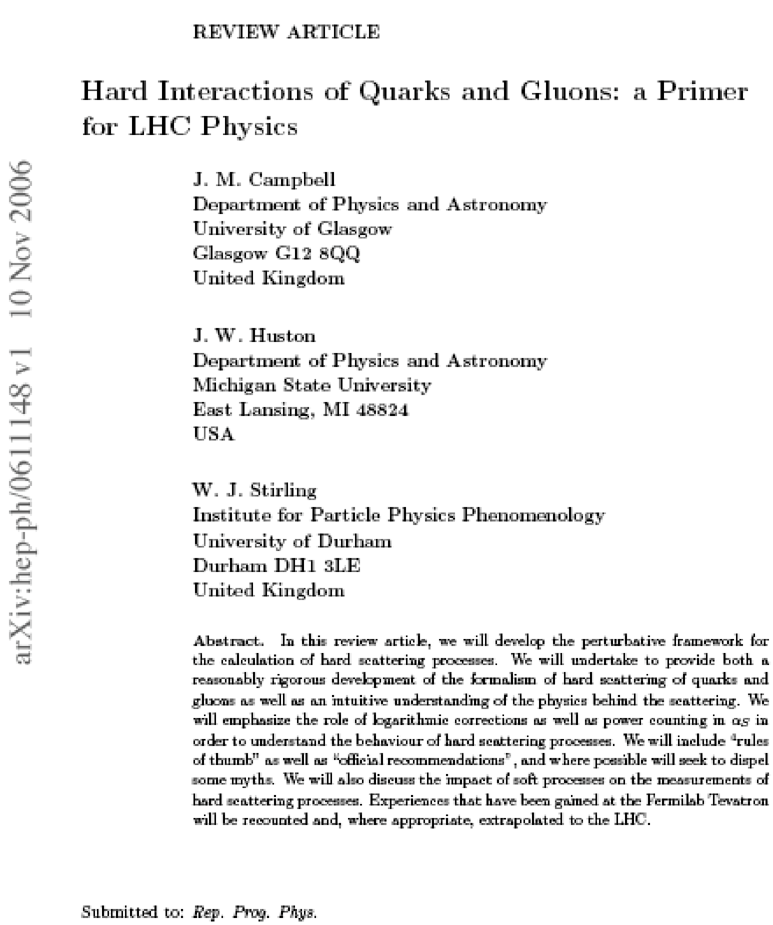
- Physics will come flying hot and heavy when LHC turns on at full energy in 2008
- Important to establish both the SM benchmarks and the tools we will need to properly understand this flood of data
  - and in particular, the needed NLO and Monte Carlo implementations

- See http://www.lpthe.jussieu.fr/LesHouches07Wiki/index.php/Preliminary_Programme for talks/program of work
- In particular, this afternoon
  - NLO wishlist (progress/additions)
  - output of NLO calculations (stand-alone use or interface to parton showers)
  - SCET, BFKL, ...
  - getting control of parton shower uncertainties (+ NLL parton showers?)
  - MC tuning in the presence of matching
  - important LHC tests. Wish list of measurements?

Some references

- Also online at ROP

http://stacks.iop.org/0034-4885/70/89



arXiv:hep-ph/0611148 v1 10 Nov 2006

REVIEW ARTICLE

Hard Interactions of Quarks and Gluons: a Primer for LHC Physics

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Abstract. In this review article, we will develop the perturbative framework for the calculation of hard scattering processes. We will undertake to provide both a reasonably rigorous development of the formalism of hard scattering of quarks and gluons as well as an intuitive understanding of the physics behind the scattering. We will emphasize the role of logarithmic corrections as well as power counting in α_S in order to understand the behaviour of hard scattering processes. We will include "rules of thumb" as well as "official recommendations", and where possible will seek to dispel some myths. We will also discuss the impact of soft processes on the measurements of hard scattering processes. Experiences that have been gained at the Fermilab Tevatron will be recounted and, where appropriate, extrapolated to the LHC.

Submitted to: *Rep. Prog. Phys.*

LES HOUCHES
centre de physique

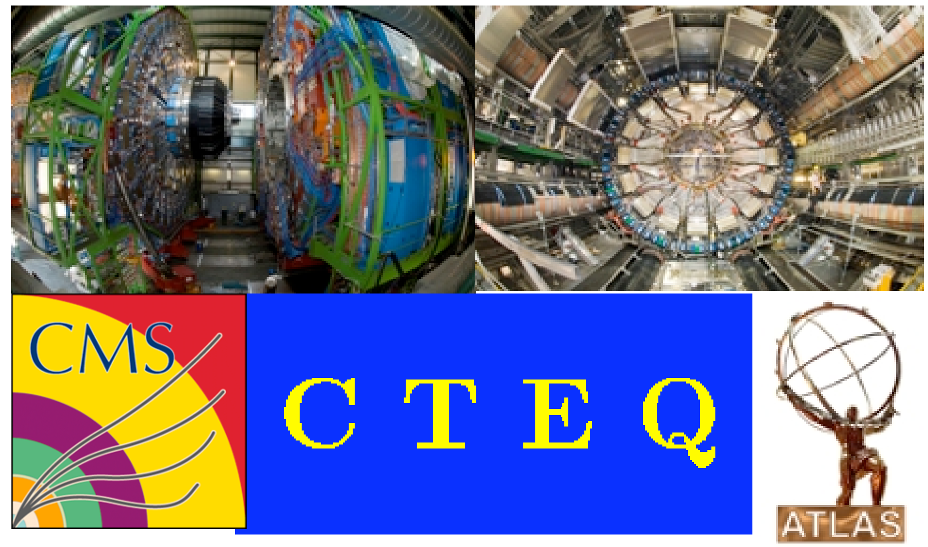
Les Houches Physics at TeV colliders 2005, Standard Model and Higgs Working Group: Summary report.
C. Buttar *et al. hep-ph/0604120*

Standard Model benchmarks

See www.pa.msu.edu/~huston/_
Les_Houches_2005/Les_Houches_SM.html

Also: CTEQ LHC Workshop

- May 14-15 Kellogg Biological Station*, Michigan State University
- Program
  - * The LHC environment
  - * Benchmark QCD measurements
  - * W/Z production as luminosity monitor
  - * W/Z/photon+light/heavy-flavor jets
  - * ttbar/single-top production
  - * Simulation tools: from parton-level to full event
  - * Next generation of parton shower models
  - * The Tevatron reach to new physics
  - * New physics searches with 1 fb^{-1}
  - * Theory tools for new physics searches



http://tigger.uic.edu/~varelas/cteq_lhc_workshop/

*no medical experiments were performed on participants during their stay

Extra slides

Sudakov form factors

- Sudakov form factor gives the probability for a gluon **not** to be emitted; basis of parton shower Monte Carlos
- Consider tT production
- In going from the Tevatron to the LHC, you are moving from primarily qQ initial states to gg initial states
- …and to smaller values of parton x
  - so there's more phase space for gluon emission
- So significantly more *extra* jets associated with the tT final state

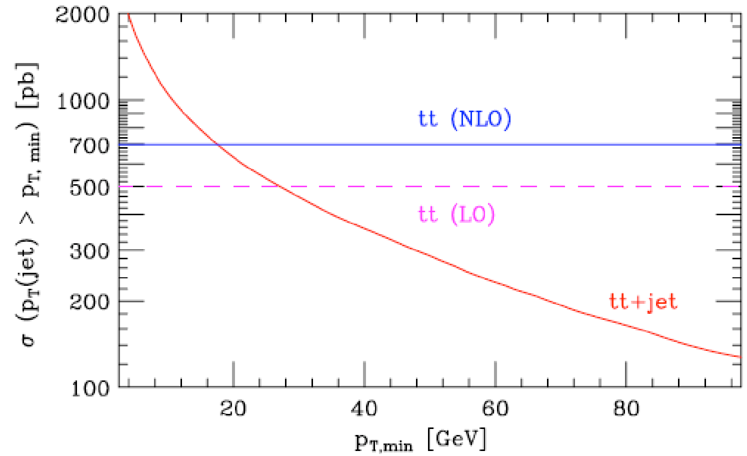


Figure 95. The dependence of the LO $t\bar{t}$+jet cross section on the jet-defining parameter $p_{T,\min}$, together with the top pair production cross sections at LO and NLO.

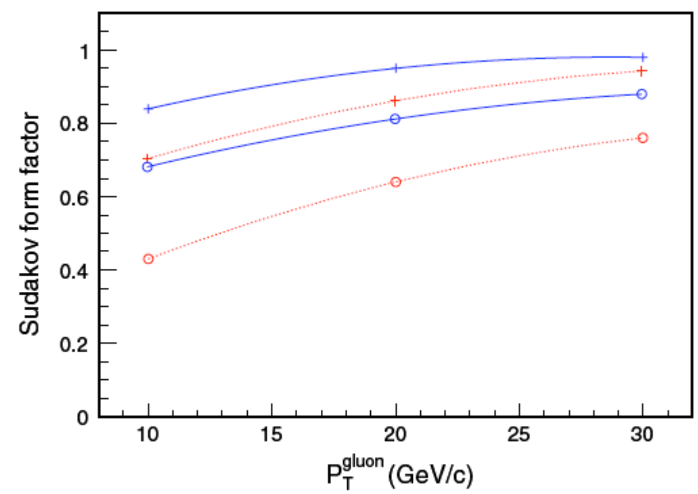


Figure 96. The Sudakov form factors for initial-state quarks and gluons at a hard scale of 200 GeV as a function of the transverse momentum of the emitted gluon. The form factors are for quarks (blue-solid) and gluons (red-dashed) at parton x values of 0.3 (crosses) and 0.03 (open circles).

Aside: Why K-factors < 1 for inclusive jet prodution?

- Write cross section indicating explicit scale-dependent terms
- First term (lowest order) in (3) leads to monotonically decreasing behavior as scale increases
- Second term is negative for $\mu < p_T$, positive for $\mu > p_T$
- Third term is negative for factorization scale $M < p_T$
- Fourth term has same dependence as lowest order term
- Thus, lines one and four give contributions which decrease monotonically with increasing scale while lines two and three start out negative, reach zero when the scales are equal to p_T, and are positive for larger scales
- At NLO, result is a roughly parabolic behavior

Consider a large transverse momentum process such as the single jet inclusive cross section involving only massless partons. Furthermore, in order to simplify the notation, suppose that the transverse momentum is sufficiently large that only the quark distributions need be considered. In the following, a sum over quark flavors is implied. Schematically, one can write the lowest order cross section as

$$E\frac{d^3\sigma}{dp^3} \equiv \sigma = a^2(\mu)\,\hat{\sigma}_B \otimes q(M) \otimes q(M) \tag{1}$$

where $a(\mu) = \alpha_s(\mu)/2\pi$ and the lowest order parton-parton scattering cross section is denoted by $\hat{\sigma}_B$. The renormalization and factorization scales are denoted by μ *and* M, respectively. In addition, various overall factors have been absorbed into the definition of $\hat{\sigma}_B$. The symbol $\otimes$ denotes a convolution defined as

$$f \otimes g = \int_x^1 \frac{dy}{y}\, f(\frac{x}{y})\, g(y). \tag{2}$$

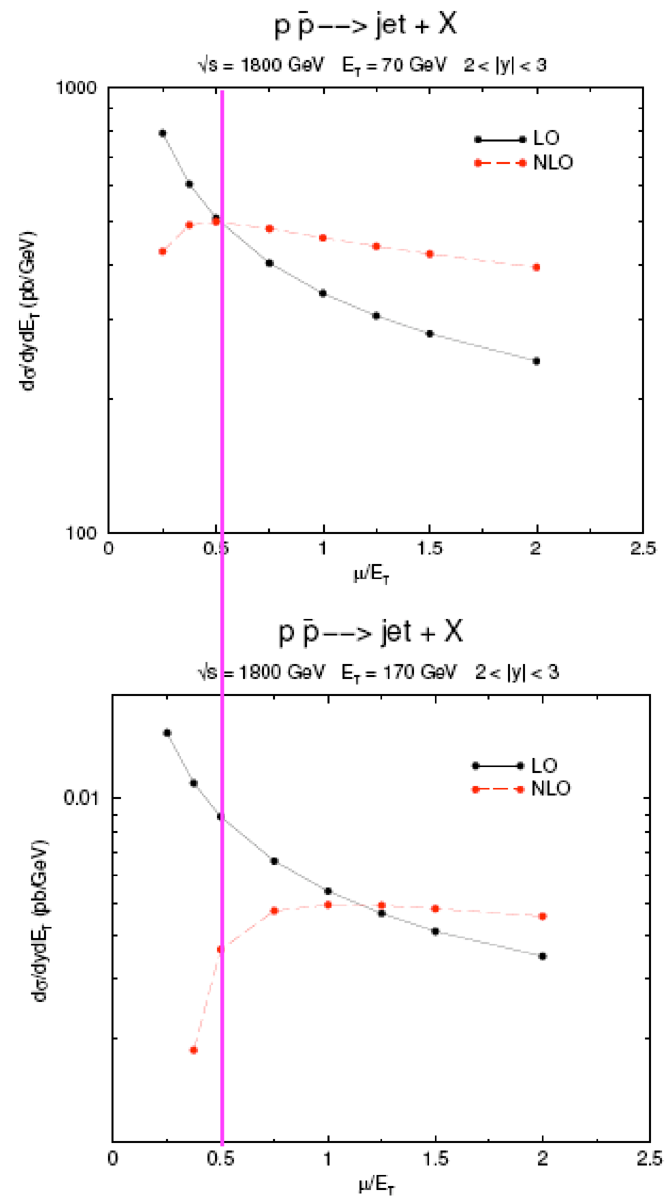
When one calculates the $\mathcal{O}(\alpha_s^3)$ contributions to the inclusive cross section, the result can be written as

$$\begin{aligned}
&(1) \quad \sigma = a^2(\mu)\,\hat{\sigma}_B \otimes q(M) \otimes q(M) \\
&(2) \quad + 2a^3(\mu)\, b \ln(\mu/p_T)\hat{\sigma}_B \otimes q(M) \otimes q(M) \\
&(3) \quad + 2a^3(\mu)\, \ln(p_T/M) P_{qq} \otimes \hat{\sigma}_B \otimes q(M) \otimes q(M) \\
&(4) \quad + a^3(\mu)\, K \otimes q(M) \otimes q(M).
\end{aligned} \tag{3}$$

In writing Eq. (3), specific logarithms associated with the running coupling and the scale dependence of the parton distributions have been explicitly displayed; the remaining higher order corrections have been collected in the function K in the last line of Eq. (3). The μ

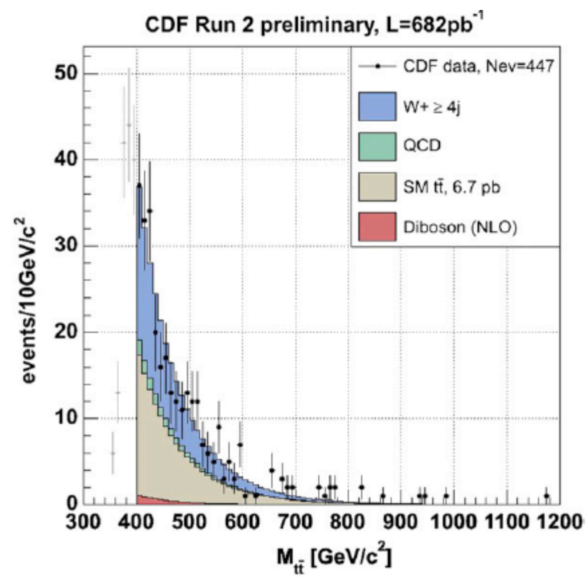
Why K-factors < 1?

- First term (lowest order) in (3) leads to monotonically decreasing behavior as scale increases
- Second term is negative for $\mu<p_T$, positive for $\mu>p_T$
- Third term is negative for factorization scale $M < p_T$
- Fourth term has same dependence as lowest order term
- Thus, lines one and four give contributions which decrease monotonically with increasing scale while lines two and three start out negative, reach zero when the scales are equal to p_T, and are positive for larger scales
- NLO parabola moves out towards higher scales for forward region
- Scale of $E_T/2$ results in a K-factor of ~1 for low E_T, <<1 for high E_T for forward rapidities at Tevatron



Another example, from the Tevatron

- Suppose you measure the high m_{tT} region looking for new physics
- Suppose that your measurement agrees well with Pythia
- Have you missed something?
- Yes, because NLO prediction at high mass is about half of LO prediction
  - partially pdf's
  - partially matrix elements



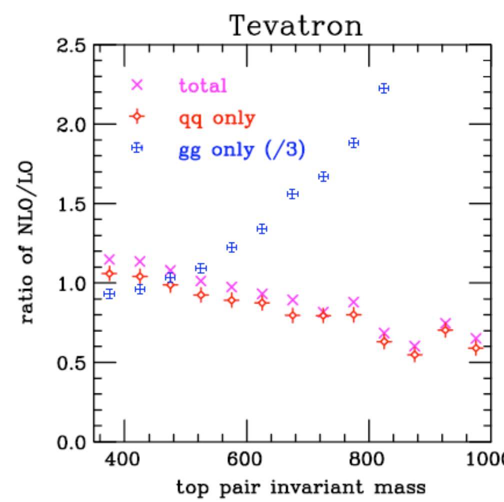


Figure 68. The ratio of the NLO to LO predictions for the $t\bar{t}$ mass at the Tevatron. The predictions include the ratio for the total cross section and for the specific $q\bar{q}$ and gg initial-states. Note that the total also includes a gq contribution (not present at LO) and that the gg ratio is divided by a factor of 3.

What about tT at the LHC?

- The cross section is dominated by the gg subprocess so the K-factor is approximately constant and > 1
  - unlike the Tevatron

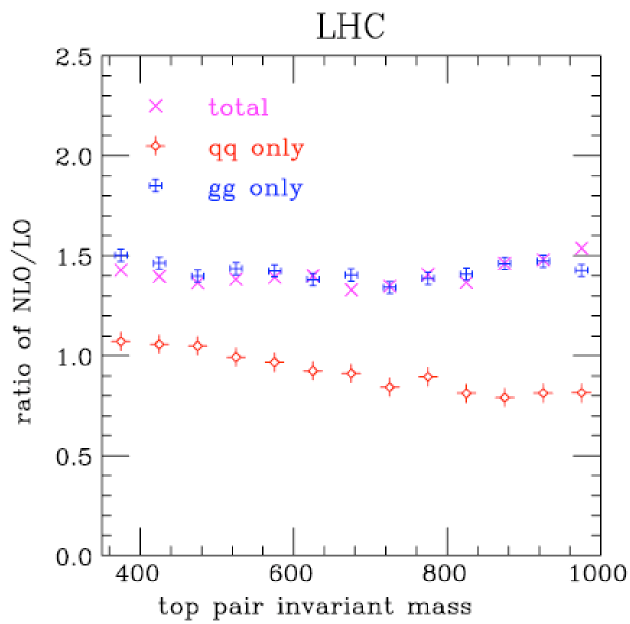


Figure 94. The ratio of the NLO to LO predictions for the $t\bar{t}$ mass at the LHC. The predictions include the ratio for the total cross section and for the specific $q\bar{q}$ and gg initial-states. Note that the total also includes a gq contribution (not present at LO).

SM benchmarks for the LHC

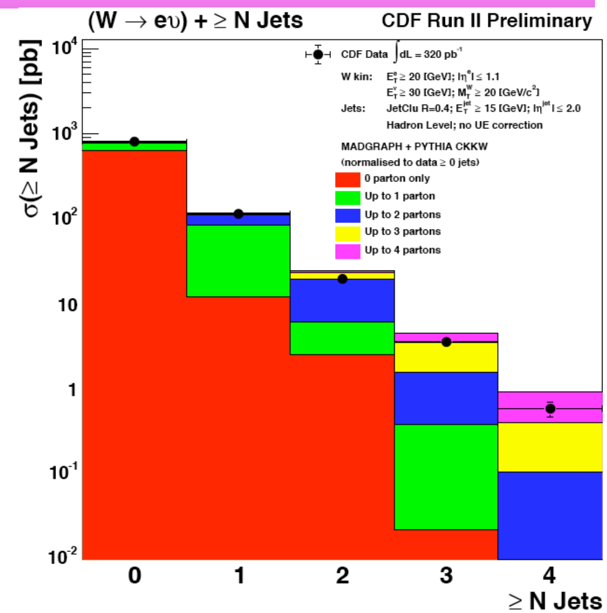
See www.pa.msu.edu/~huston/_
Les_Houches_2005/Les_Houches_SM.html
(includes CMS as well as ATLAS)

- pdf luminosities and uncertainties
- expected cross sections for useful processes
  - inclusive jet production
    - simulated jet events at the LHC
    - jet production at the Tevatron
      - a link to a CDF thesis on inclusive jet production in Run 2
      - CDF results from Run II using the kT algorithm
  - photon/diphoton
  - Drell-Yan cross sections
  - W/Z/Drell Yan rapidity distributions
  - W/Z as luminosity benchmarks
  - W/Z+jets, especially the *Zeppenfeld* plots
  - top pairs
    - ongoing work, list of topics (pdf file)

W + jets at the Tevatron

- Interesting for tests of perturbative QCD formalisms
  - matrix element calculations
  - parton showers
  - …or both
- Backgrounds to tT production and other potential new physics
- Observe up to 7 jets at the Tevatron
- Results from Tevatron to the right are in **a form that can be easily compared to theoretical predictions (at hadron level)**
  - see www-cdf.fnal.gov QCD webpages
  - in process of comparing to MCFM and CKKW predictions
  - *remember for a cone of 0.4, hadron level ~ parton level*

note emission of each jet suppressed by ~factor of α_s



agreement with MCFM for low jet multiplicity