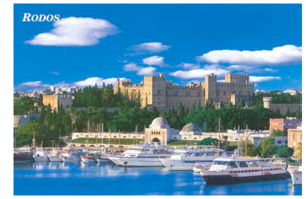
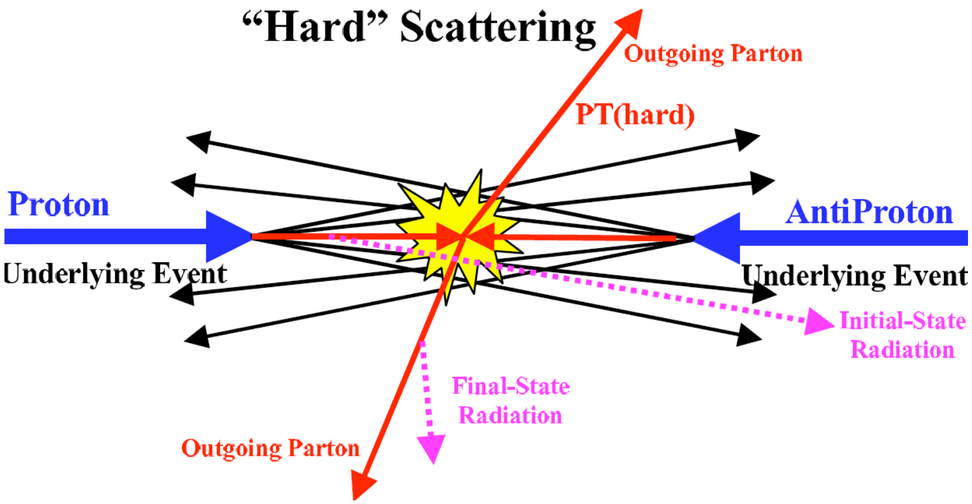


Event signatures for hadron-hadron colliders

"…and Standard Model Benchmarks for the LHC"

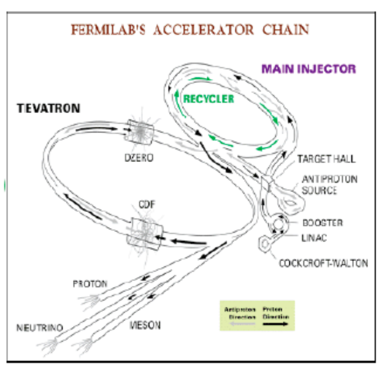


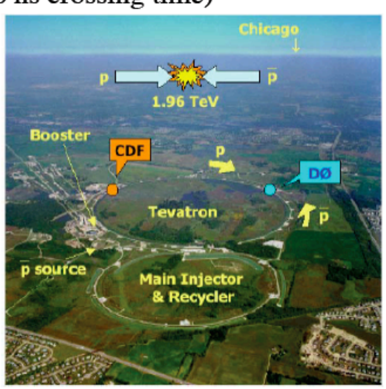
Joey Huston
Michigan State University
CTEQ SS 2006 Rhodes
huston@msu.edu

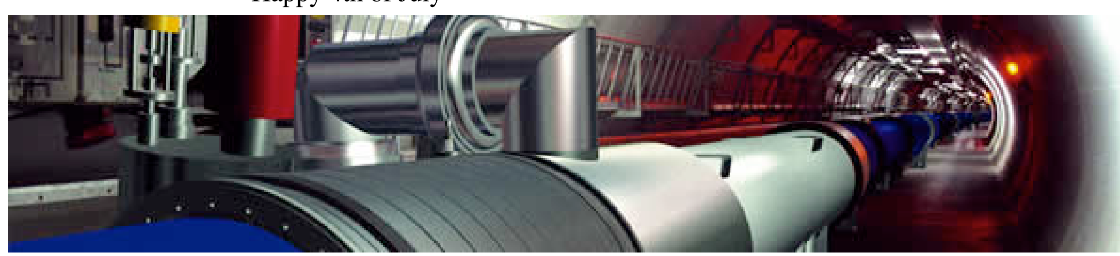
Happy 4th of July

- lessons from the Tevatron
- rules-of-thumb for the LHC
- using the language of American politics

36 bunches (396 ns crossing time)



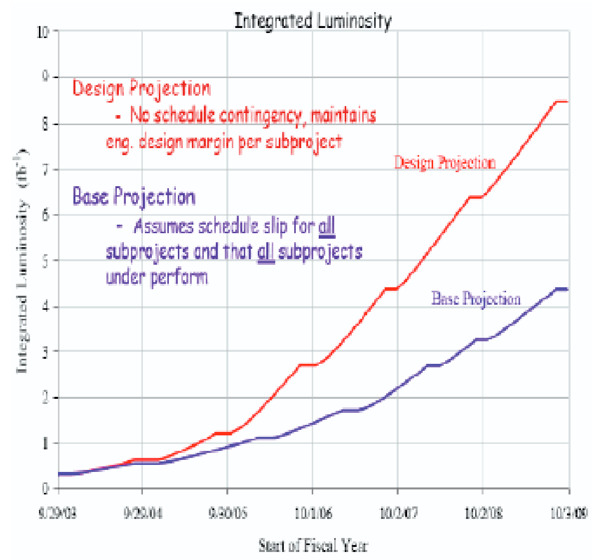


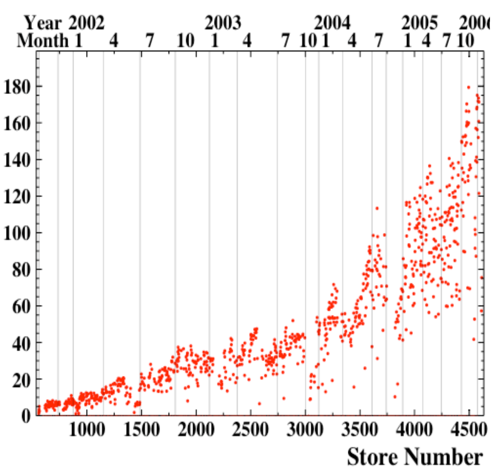


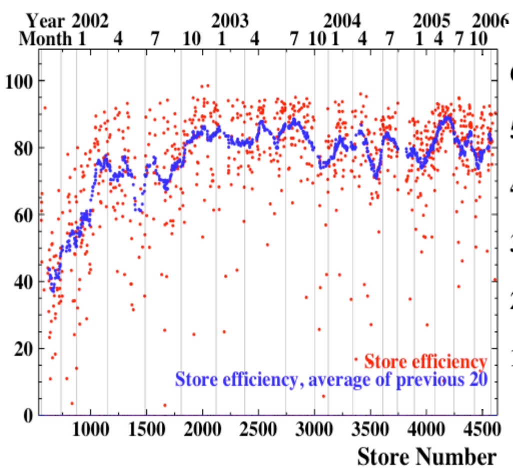
Let me just say

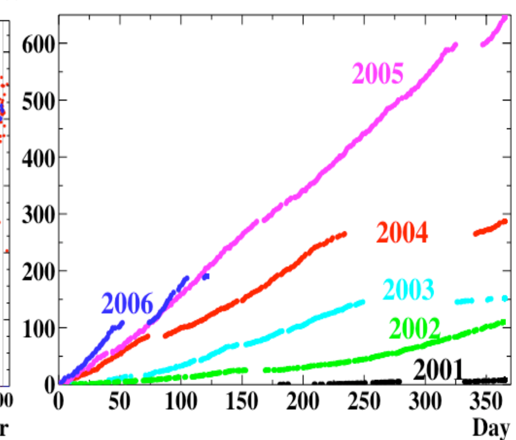
- Tevatron (and CDF and D0) are running well

ultimately 4-9 fb^{-1}









- over 1.2 fb^{-1} on tape
- 1 fb^{-1} analyses presented at Moriond
- coming off of shutdown now
- FY06 design goal = 800 pb^{-1}

What to expect at the LHC

…according to a theorist

Murayama LP03

What to expect at the LHC

…according to a theorist

Murayama LP03

- According to a current Secretary of Defense
  - known knowns
  - known unknowns
  - unknown unknowns

What to expect at the LHC

…according to a theorist

Murayama LP03

- According to a current Secretary of Defense
  - known knowns
    - SM at the Tevatron
      - signatures of W/Z/γ/leptons/jets/$\not{E}_T$
  - known unknowns
    - SM at the LHC
      - same as above but in a new kinematic environment, with perhaps a few surprises
  - unknown unknowns
    - ???

LHC bandwagon

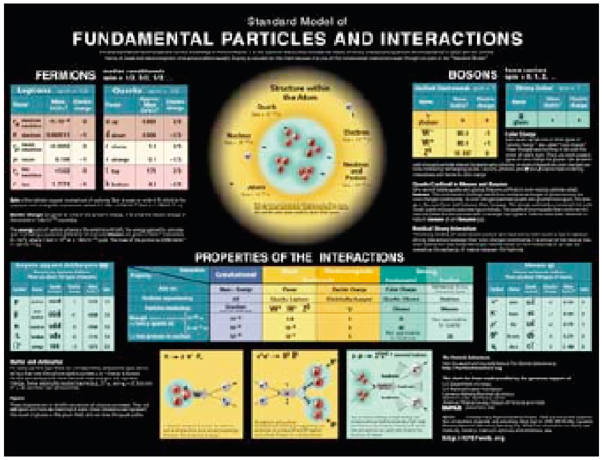
- A lot of useful experience with the Standard Model can be carried forward from Fermilab and HERA and workshops have taken place to summarize that knowledge
  - HERA-LHC published
  - TeV4LHC near completion
  - I'm almost finished with a review article for ROP with John Campbell and James Stirling titled "Hard interactions of quarks and gluons: a primer for LHC physics"
    - much of what I will show here is from that article I'm trying to include as many "rules-of-thumb" for LHC physics as possible, including the importance of large logarithmic corrections
    - …and to dispel some myths

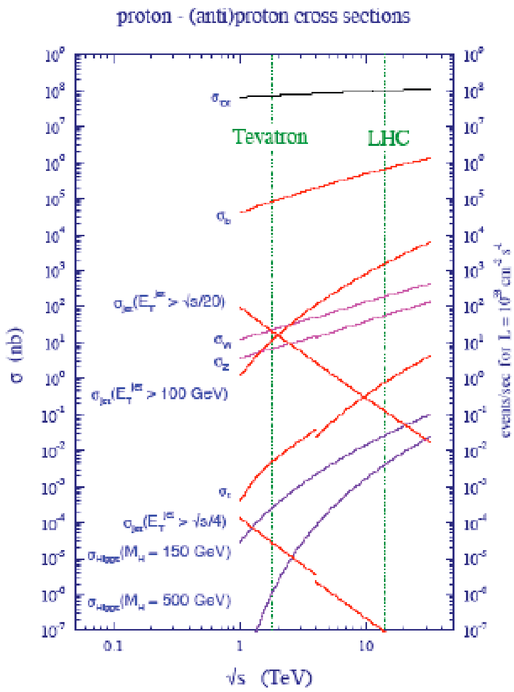
soft and/or collinear logs

$$d\sigma = \sigma_0(W{+}1\,\mathrm{jet})\left[1 + \alpha_s(L^2 + L + 1) + \alpha_s^2(L^4 + L^3 + L^2 + L + 1) + \ldots\right]$$

Discovering the SM at the LHC

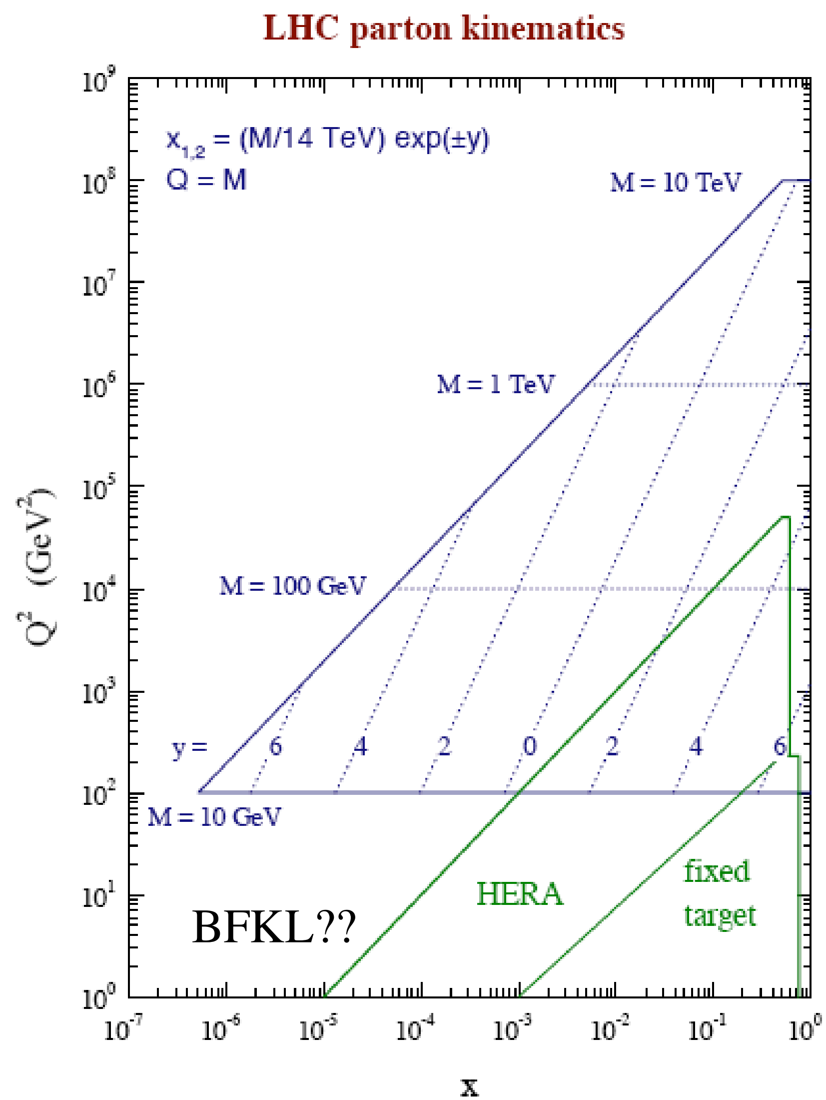
- We're all looking for BSM physics at the LHC
- Before we publish BSM discoveries from the early running of the LHC, we want to make sure that we measure/understand SM cross sections
  - detector and reconstruction algorithms operating properly
  - SM physics understood properly
  - SM backgrounds to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





Cross sections at the LHC

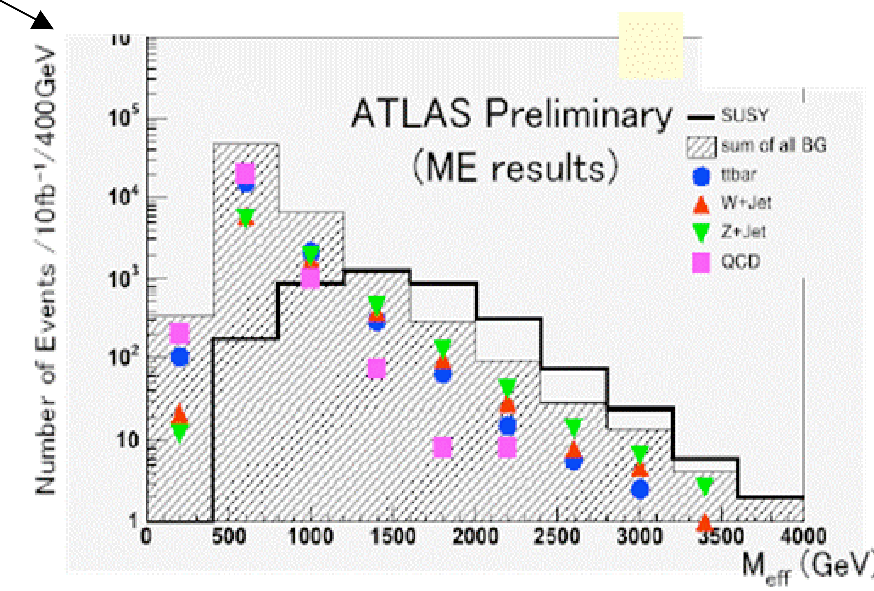
- Experience at the Tevatron is very useful, but scattering at the LHC is not necessarily just "rescaled" scattering at the Tevatron
- Small typical momentum fractions x in many key searches
  - dominance of gluon and sea quark scattering
  - large phase space for gluon emission
  - intensive QCD backgrounds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



Early running

- Here are the assumptions I'm going by (maybe pessimistic)
  - 2007: turn-on with 10 pb^{-1} of data at 900 GeV
    - useful for debugging detector, understanding responses
  - 2008: first serious data: 100 pb^{-1}
    - jet energy scale known to order of 5%
    - first possible "easy" discoveries, such as low scale SUSY
    - low mass Z'
  - 2009: really serious: 10 fb^{-1}
    - jet energy scale known to 3%
    - *easy* Higgs discoveries
  - 2010+: really, really serious:100 fb^{-1}
    - jet energy scale known to 1-2%
    - discoveries by the wazoo
    - reservations to Stockhom

- It's during this time that we have to put all of our SM cross sections in order
  - leptons
  - bosons
  - jets
  - top pairs
  - missing E_T
  - and combinations thereof



es

Detector performance on day 1

from Mangianotti

	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/γ scale	~ 1% (ATLAS), 4% (CMS) 1-2 % ?	Minimum-bias, $Z \to ee$ $Z \to ee$ 1 hz at 10^{33}
HCAL uniformity Jet scale	2-3 % < 10%	Single pions, QCD jets $Z (\to ll) +1j$, $W \to jj$ in tt events
Tracking alignment	20-500 μm in $R\phi$?	Generic tracks, isolated μ , $Z \to \mu\mu$

Ultimate statistical precision achievable after few days of operation. Then face systematics ….
E.g. : tracker alignment : 100 μm (1 month) → 20μm (4 months) → 5 μm (1 year) ?

Channels (examples …)	Events to tape for 10 fb^{-1} (per experiment)
$W \to \mu\nu$	7×10^7
$Z \to \mu\mu$	1.1×10^7
$tt \to WbWb \to \mu\nu + X$	0.08×10^7
QCD jets p_T>150	~ 10^7
Minimum bias	~ 10^7
$\tilde{g}\tilde{g}$ m = 1 TeV	10^3 - 10^4

“We have a strategery”

Goal # 1

Understand and calibrate detector and trigger in situ using well-known physics samples

e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.

- $tt \to bl\nu\, bjj$ 10^3 evts/day after cuts → jet scale from $W \to jj$, b-tag perf., etc.

Understand basic SM physics at $\sqrt{s} = 14$ TeV → first checks of Monte Carlos

(hopefully well understood at Tevatron and HERA)

e.g. - measure cross-sections for e.g. minimum bias, W, Z, tt, QCD jets (to ~ 10-20 %),
look at basic event features, first constraints of PDFs, etc.

- measure top mass (to 5-7 GeV) → give feedback on detector performance

Note : statistical error negligible after few weeks run

Goal # 2

Prepare the road to discovery:

-- measure backgrounds to New Physics : e.g. tt and W/Z+ jets (omnipresent ...)

-- look at specific “control samples” for the individual channels:

e.g. ttjj with $j \neq b$ “calibrates” ttbb irreducible background to ttH → ttbb

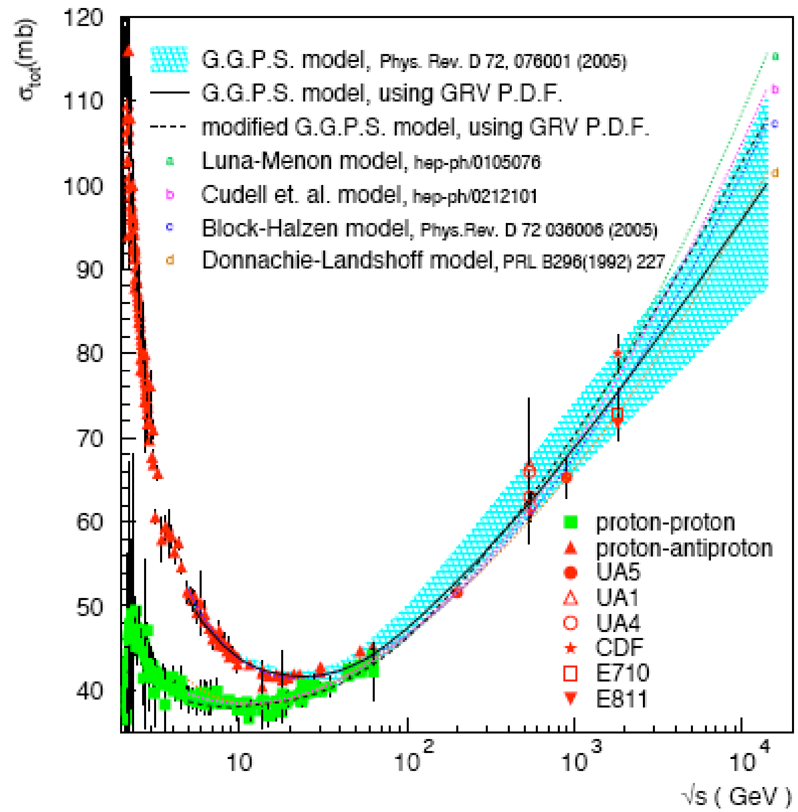
Goal # 3

Look for New Physics potentially accessible in first year (e.g. Z′, SUSY, some Higgs ? ...)

…from Mangianotti talks

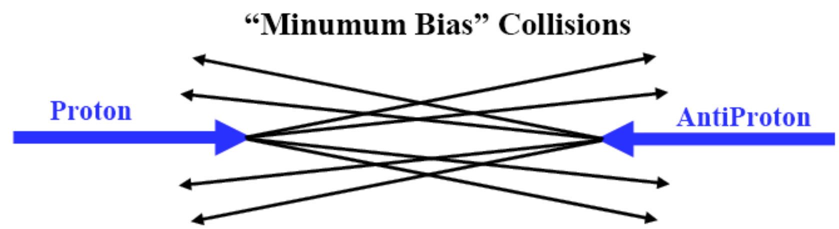
Total inelastic cross section at LHC

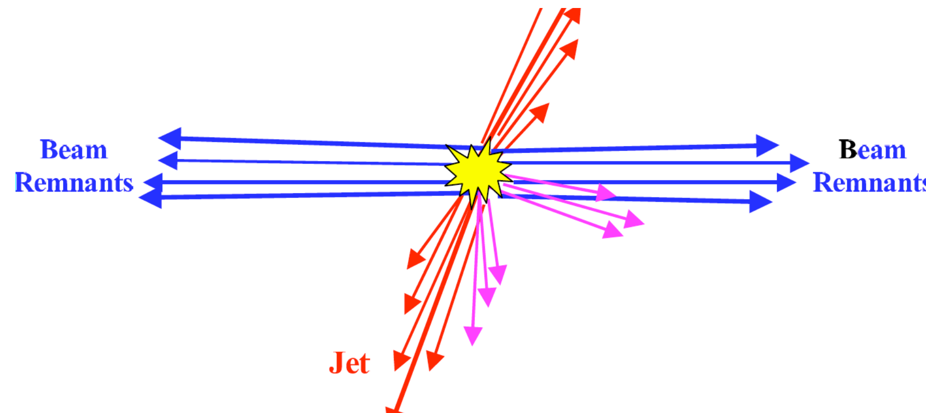
- Fair amount of uncertainty on extrapolation to LHC
  - ln(s) or $ln^2(s)$ behavior
- Also uncertainty on $dN_{charged}/d\eta$ and $dN_{charged}/dp_T$
  - role of semi-hard multiple parton interactions
  - reasonable expectation is 7-8 particles per unit rapidity and $<p_T>\sim0.65$ GeV/c
- Both can be measured using the early data, although extrapolating measured cross section to full inelastic cross section will still have large uncertainties

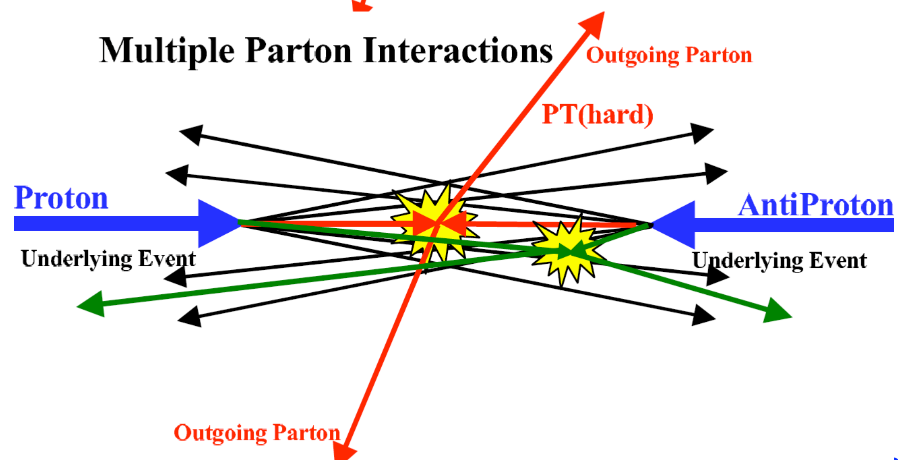


Underlying event at the Tevatron and LHC

- Most proton-(anti)proton collisions are boring, with a peripheral or glancing collision producing a handful of particles with low transverse momentum in the final state
  - so-called minimum bias events
- More interesting are the collisions where there is a hard interaction of a parton from one proton with a parton from the other, for example producing two jets
- Of course, this hard collision takes place on top of the interactions of the other partons in the two hadrons
- This may include the soft beam remnants as well as semi-hard multiple parton interactions
  - which become more important the higher the center-of-mass energy
- The underlying event and pile-up from extra minimum bias events need to be taken into account in most analyses

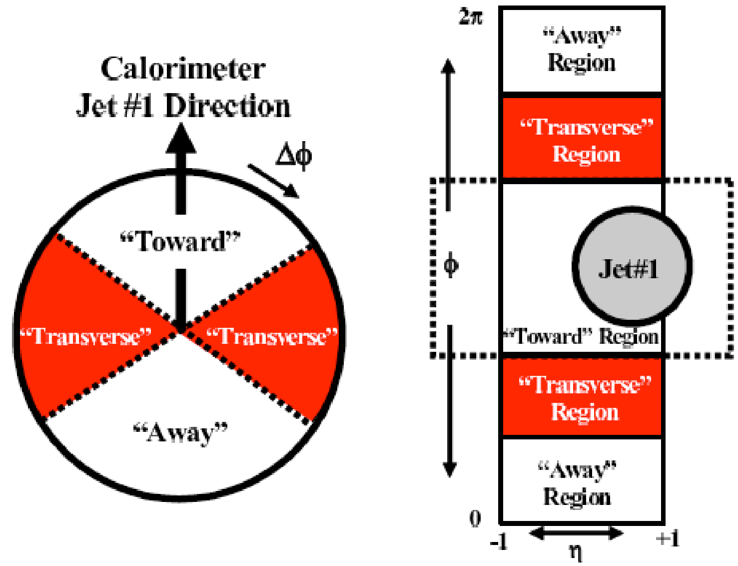


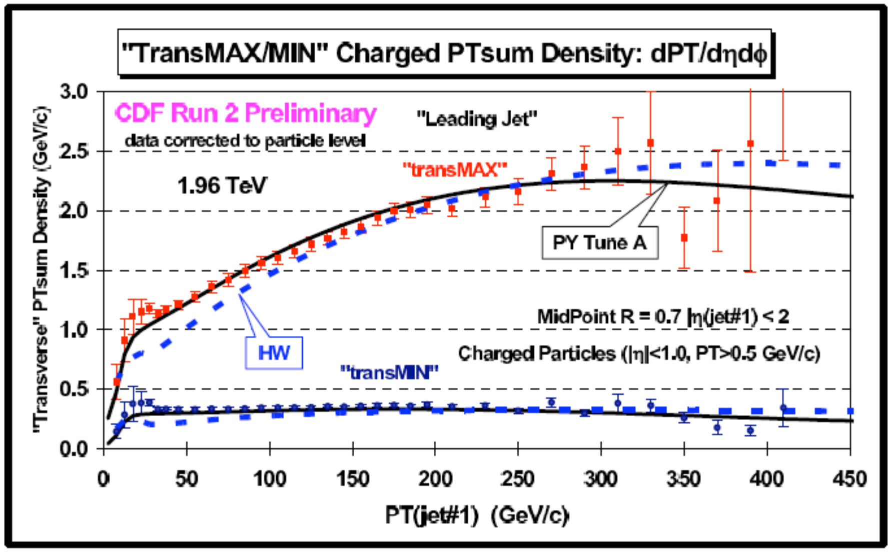




Underlying event at the Tevatron

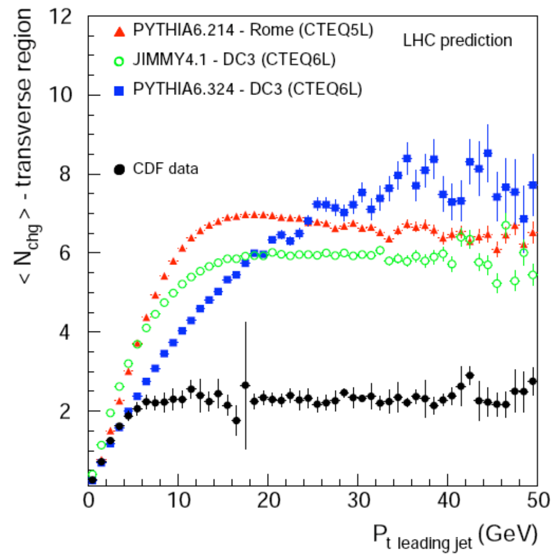
- Define regions transverse to the leading jet in the event
- Label the one with the most transverse momentum the MAX region and that with the least the MIN region
- The transverse momentum in the MAX region grows as the momentum of the lead jet increases
  - receives contribution from higher order perturbative contributions
- The transverse momentum in the MIN region stays basically flat, at a level consistent with minimum bias events
  - no substantial higher order contributions
- Monte Carlos can be tuned to provide a good description of the data

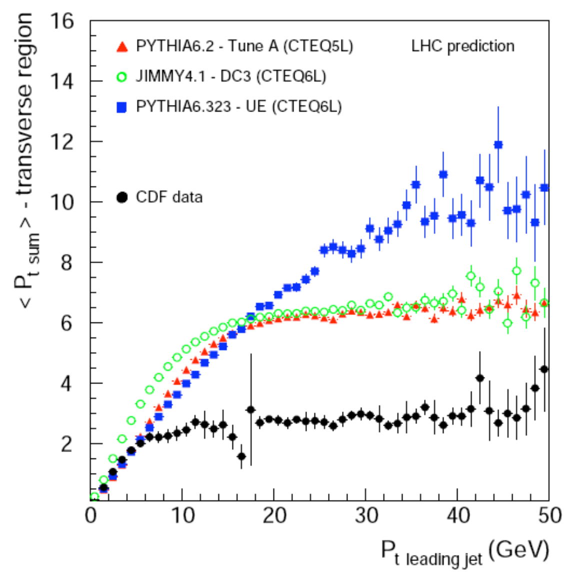




Underlying event at the LHC

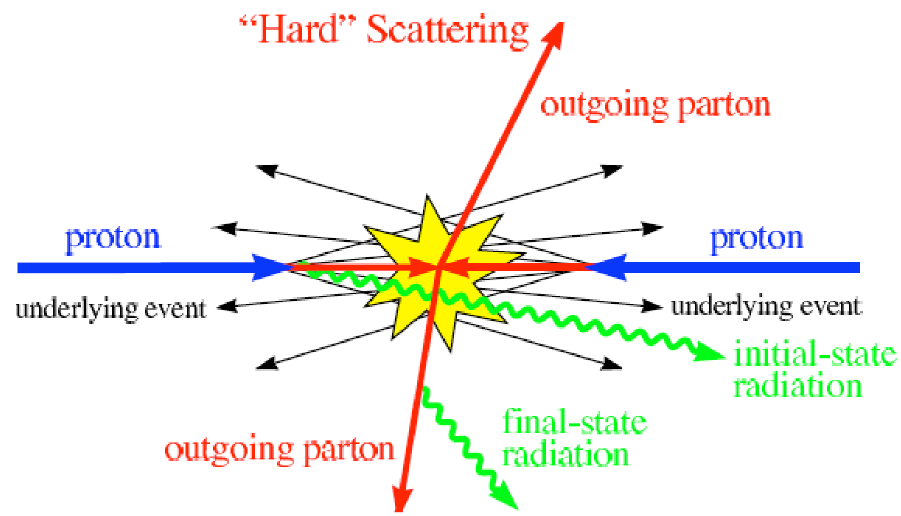
- We can project the size of the underlying event for the LHC
- There's a great deal of uncertainty regarding the level of underlying event at 14 TeV, but it's clear that the UE is larger at the LHC than at the Tevatron
  - and will be harder (more mini-jets from multiple parton scattering)
  - thus, some jets will in the event will come from the underlying event and may be forced to use a higher jet p_T threshold in analyses
- Should be able to establish reasonably well with the first collisions in 2008

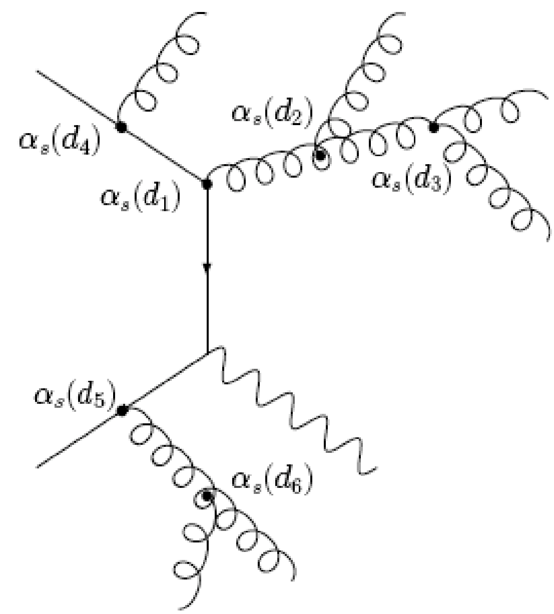




Gluon radiation

- In addition, there can be additional emissions from the initial and/or final state partons
  - included in higher multiplicity tree level/NLO calculations and as well in parton shower Monte Carlos
  - some information can also be summarized in terms of Sudakov form factors
    - a “rule-of-thumb”





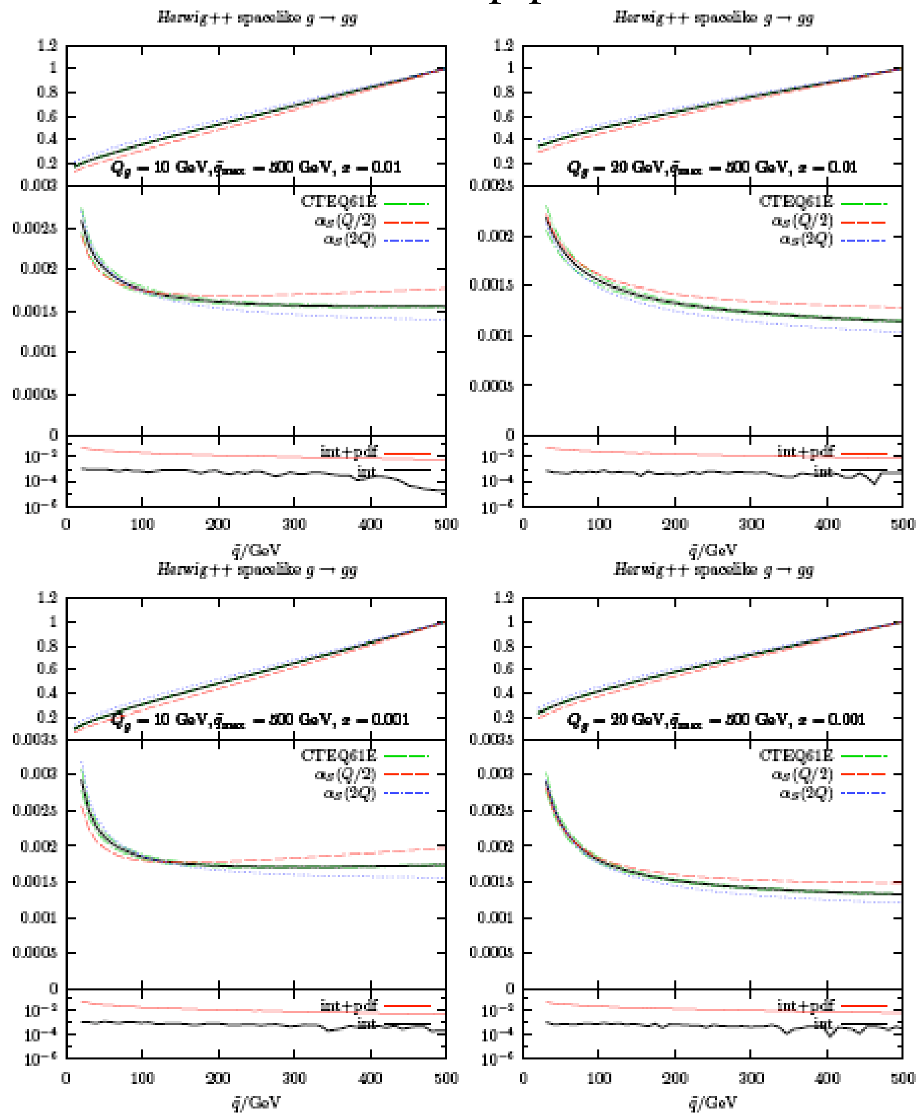
Initial state Sudakov form factors

- The Sudakov form factor gives the probability for a parton not to radiate, with a given resolution scale, when evolving from a large scale down to a small scale
  - below Sudakov form factor for initial state radiation is shown

$$\Delta(t) \equiv \exp\left[-\int_{t_0}^{t} \frac{dt'}{t'} \int \frac{dz}{z} \frac{\alpha_s}{2\pi} P(z) \frac{f(x/z,t)}{f(x,t)}\right]$$

  - for final state, pdf weighting is not present
- Probability of emission increases with color charge (gluon vs quark), with larger max scale, with decreasing scale for a resolvable emission and with decreasing parton x
  - NB: Sudakovs do not depend strongly on initial state pdf's; thus p_T distribution of final state should not depend on initial pdf's (to first order)

Stefan Gieseke hep-ph/0412342



Sudakov form factors

- Curves from top to bottom correspond to x values of 0.3,0.1, 0.03, 0.01, 0.001, 0.0001
  - Sudakov form factors for q->qg for x<0.03 are similar to form factor for x=0.03 (and so are not shown)
- Sudakov form factors for g->gg continue to drop with decreasing x
  - g->gg splitting function P(z) has singularities both as z->0 and as z->1 (as Peter said)
  - q->qg has only z->1 singularity
- For example, probability for an initial state gluon of x=0.01 not to emit a gluon of >=20 GeV when starting from an initial scale of 500 GeV is ~70%, i.e. there is a 30% probability for such an emission

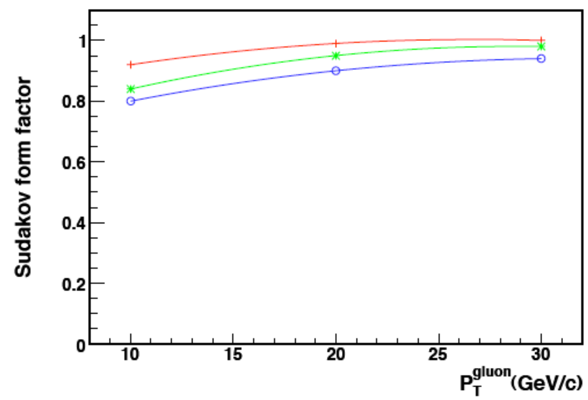


Figure 20. The Sudakov form factors for initial state quarks at a hard scale of 100 GeV/c as a function of the transverse momentum of the emitted gluon. The form factors are for (top to bottom) parton x values of 0.3,0.1 and 0.03.

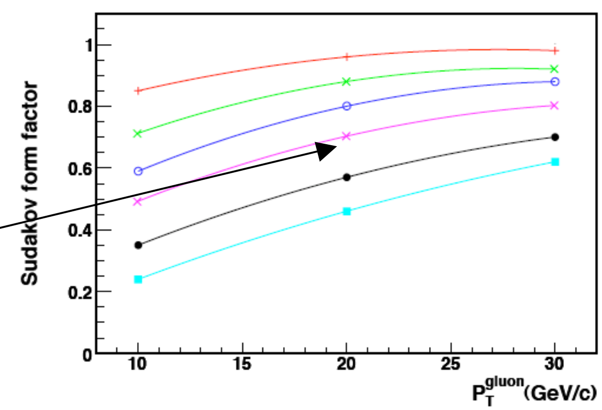


Figure 18. The Sudakov form factors for initial state gluons at a hard scale of 100 GeV/c as a function of the transverse momentum of the emitted gluon. The form factors are for (top to bottom) parton x values of 0.3,0.1,0.03,0.01,0.001 and 0.0001.

Resolution scale -> ~p_T of gluon

Sudakov form factors

- If I go to small x, or high scale or a gluon initial state, then probability of a ISR gluon emission approaches unity
- The above sentence basically describes the LHC

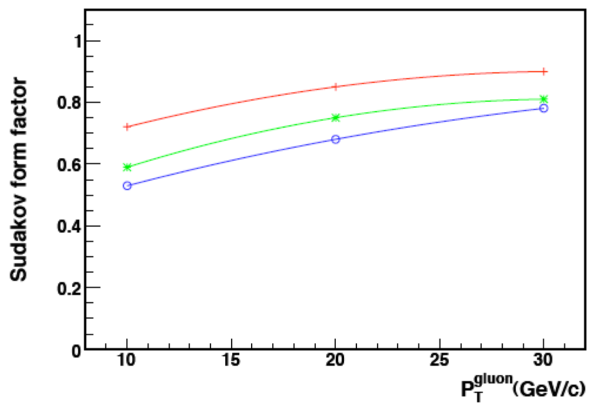


Figure 21. The Sudakov form factors for initial state quarks at a hard scale of 500 GeV/c as a function of the transverse momentum of the emitted gluon. The form factors are for (top to bottom) parton x values of 0.3,0.1 and 0.03.

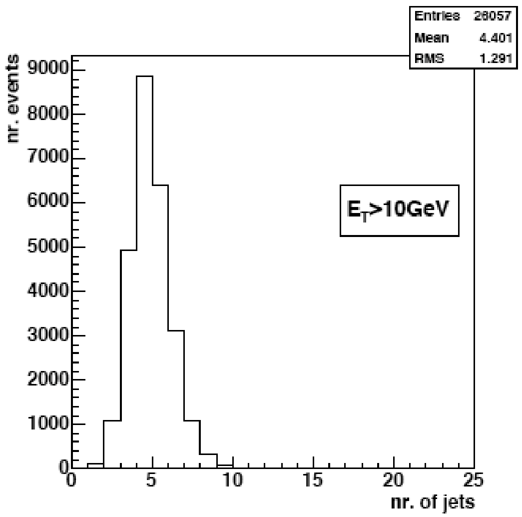


Figure 75. The jet multiplicity in $t\bar{t}$ events with a lepton + jets final state at the LHC. A cut of 10 GeV has been applied to the jets.

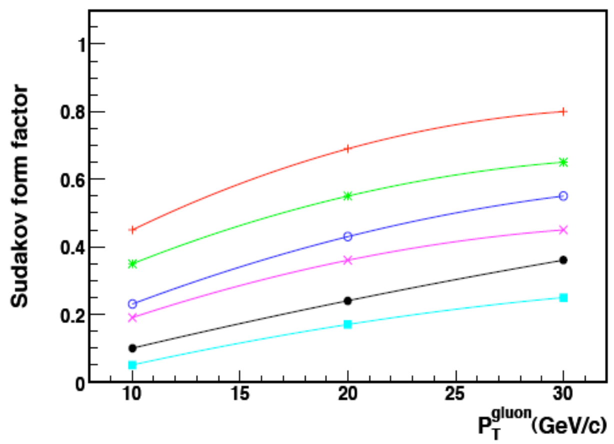


Figure 19. The Sudakov form factors for initial state gluons at a hard scale of 500 GeV/c as a function of the transverse momentum of the emitted gluon. The form factors are for (top to bottom) parton x values of 0.3,0.1,0.03,0.01,0.001 and 0.0001.

NLO

- Perturbative calculations have a realistic normalization (and sometimes shape) only at NLO
  - NLO calculations can guide us in our experimental analyses; acceptances, templates, etc…
  - …and in some cases we can make direct comparisons of corrected data to NLO
  - but we have to be willing to either correct the data to the parton level or the theory to the hadron level
- Parton level calculations have been performed for all 2->2 hard scattering and some 2->3 hard processes
  - state of the art is W/Z + 2 jets
  - W/Z + 3 jets perhaps in the next few years
    - problem with multi-leg virtual integrations
    - many loop integrals
    - enormous expressions large numerical cancellations

- See www.cedar.ac.uk/hep code for collection of NLO codes, such as

AYLEN/EMILIA (de Florian et.al.): $pp \to (W,Z) + (W,Z,\gamma)$

DIPHOX (Aurenche et.al.): $pp \to \gamma j, \gamma\gamma, \gamma^* p \to \gamma j$

HQQB (Dawson et.al.): $pp \to t\bar{t}H, b\bar{b}H$

$\boxed{\text{MCFM (Campbell, Ellis): } pp \to (W,Z) + (0,1,2)\,j,\ (W,Z) + b\bar{b}}$

NLOJET++ (Nagy): $pp \to (2,3)\,j,\ ep \to (3,4)\,j, \gamma^* p \to (2,3)\,j$

VBFNLO (Figy et.al.): $pp \to (W,Z,H) + 2\,j$

See Laura's talk for more details.

NLO vs LO: example from the Tevatron

LO->NLO may not be just a K-factor

Don't rely just on LO predictions J. Campbell, J. Huston; hep-ph/0405276

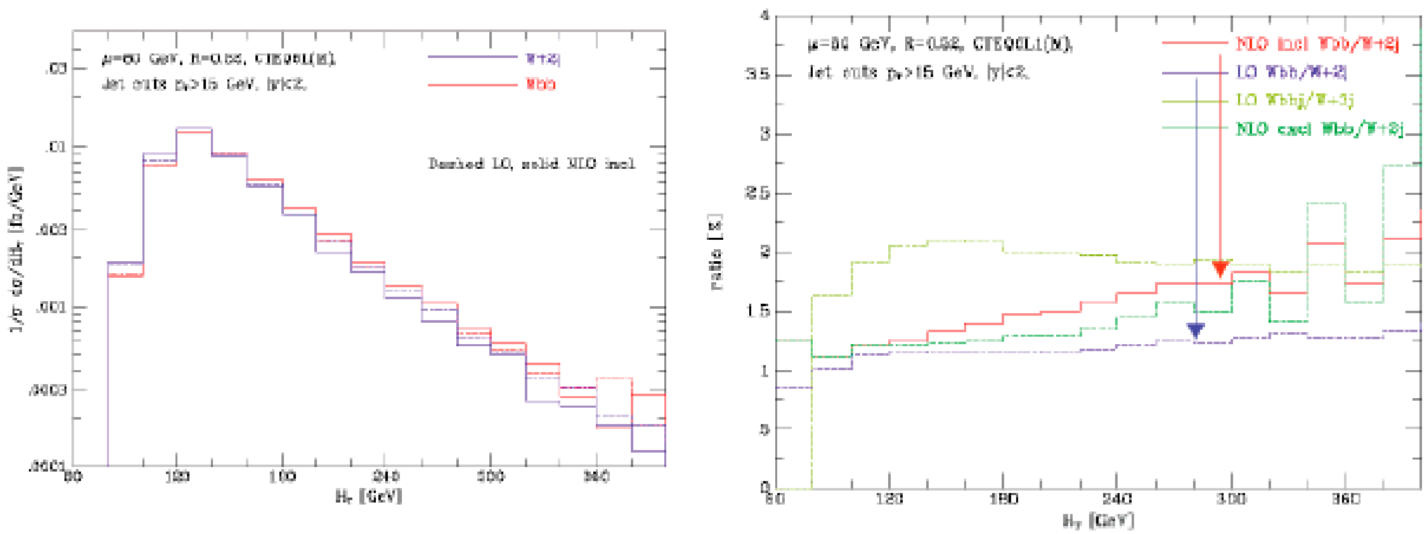


Figure 12: The H_T distributions for $Wb\bar{b}(j)$ and $Wjj(j)$, normalized to the same area.

Wbb and Wjj have similar H_T distribution at LO; different at NLO

Lesson: H_T is a dangerous variable to use for any analysis for which shape discrimination is important

…less inclusive variables have less difference between LO and NLO

…CKKW formalism may describe some/most of this effect

K-factors

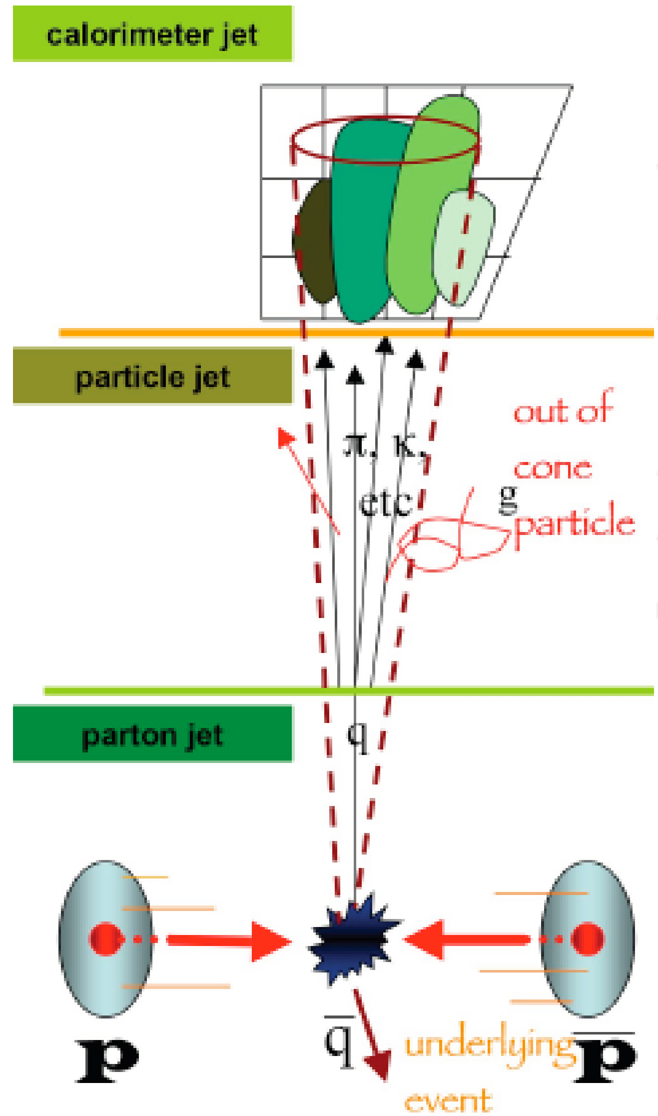
Table 1. K-factors for various processes at the Tevatron and the LHC, calculated using a selection of input parameters. In all cases, the CTEQ6M PDF set is used at NLO. $\mathcal{K}$ uses the CTEQ6L1 set at leading order, whilst $\mathcal{K}'$ uses the same set, CTEQ6M, as at NLO. Jets satisfy the requirements $p_T > 15$ 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

from review paper; in process of adding more processes; any favorites missing?

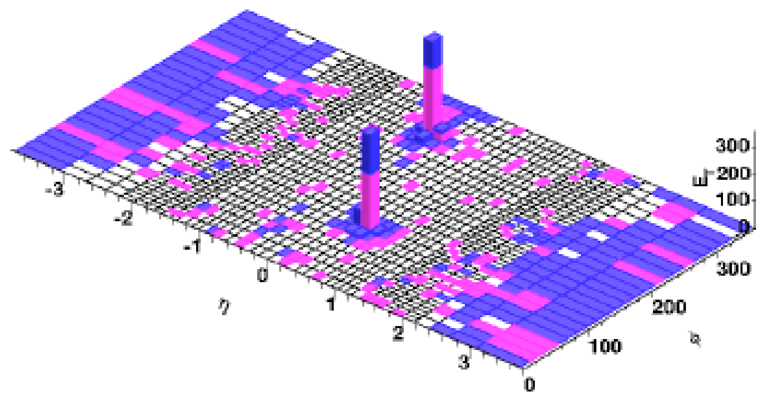
Jet algorithms

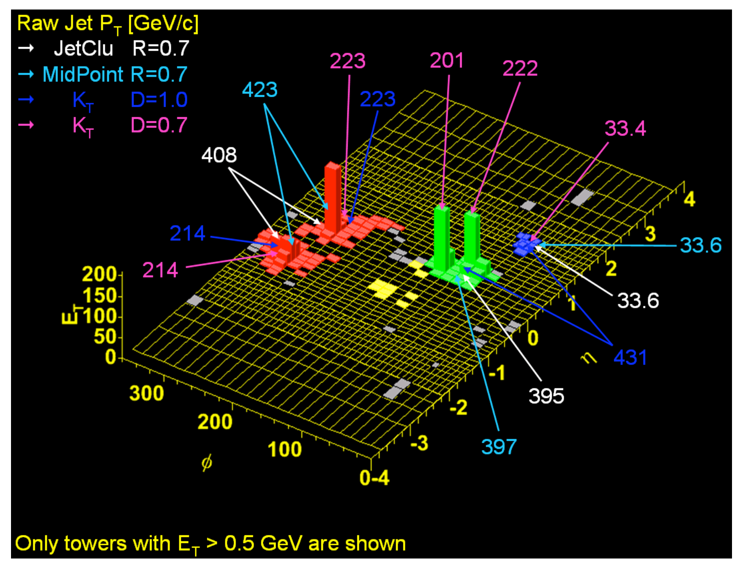
- A high energy hard collision produces outgoing partons
- These are highly virtual and can emit further gluons (parton showers)
- Once the shower reaches a low scale, color is neutralized and the final state particles are produced
    - first resonances such as $A_1, A_2, \rho\ldots$
    - eventually $\pi, K, p, \gamma, \ldots$
- These particles deposit energy in the calorimeters and it's based on this energy (in most cases) that the jet reconstruction is based
- For this reconstruction, need a jet algorithm; two basic types based on
    - closeness in momentum space: k_T algorithm
    - closeness in coordinate space: cone algorithm
- Can also apply these jet algorithms to particle level or parton level…and would like to get a similar answer as at calorimeter level



Jet algorithms

- For some events, the jet structure is very clear and there's little ambiguity about the assignment of towers to the jet
- But for other events, there is ambiguity and the jet algorithm must make decisions that impact precision measurements
- If comparison is to hadron-level Monte Carlo, then hope is that the Monte Carlo will reproduce all of the physics present in the data and influence of jet algorithms can be understood
    - more difficulty when comparing to parton level calculations





Midpoint algorithm

* Midpoint algorithm: cone algorithm (R=0.7) (clusters particles whose trajectories/towers are close together). In contrast to JetClu's use of E_T and η, Midpoint uses p_T and $\cancel{\phi}$ y

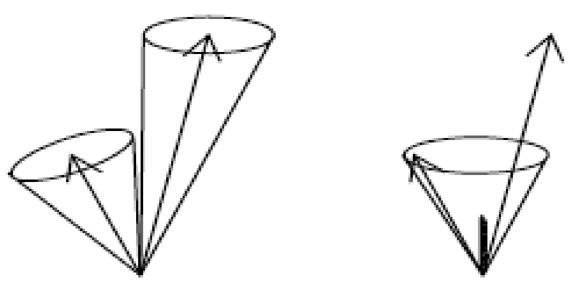
* Need to do this consistently at parton, hadron and calorimeter level.

* Calor Jets: begin with 1 GeV seed towers† $\rightarrow$ cluster towers ($P_T >$ 100MeV) into a centroid if $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta Y)^2} < 0.7$.

* Start new search cones at the midpoints of stable cones‡

* Overlapping jets- merge jets if overlapping energy is $>$ 0.75 the energy of the smaller jet

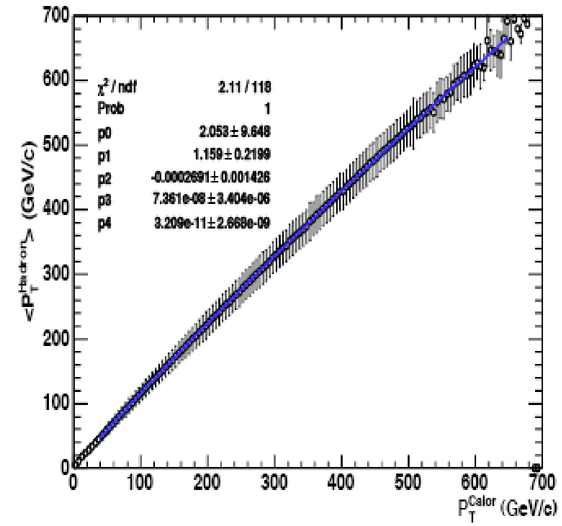
* Calculate jet quantites from final stable cones: $P_T, \cancel{E_T}, Y, \phi$ etc

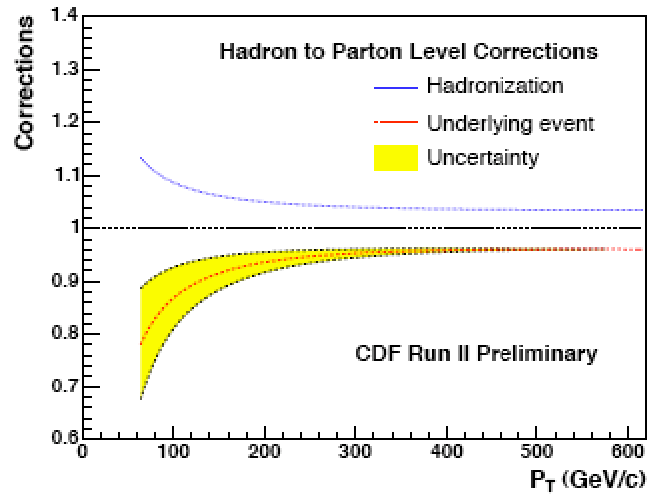


† Clustering begins around seeds, presence of soft radiation can cause merging of jets
* Ideally algroithm is insensitive to soft radiation.
‡ Addition of midpoints lessens the sensitivity

Jet Corrections

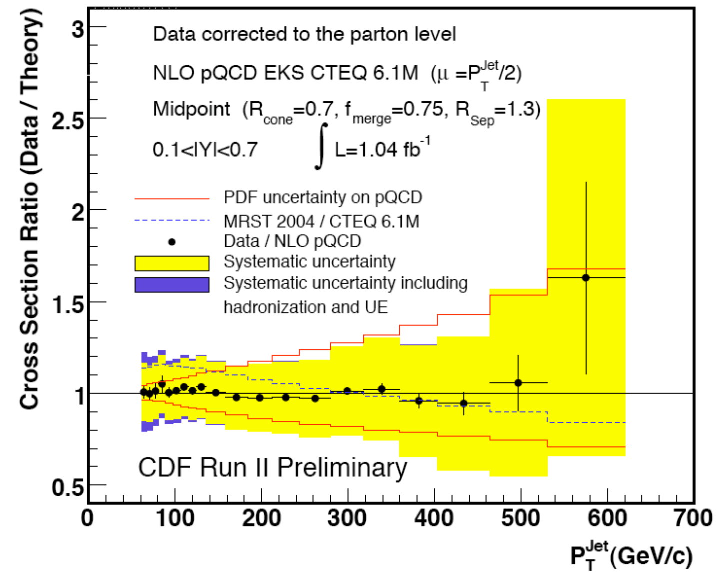
- Need to correct from calorimeter to hadron level (different response of calorimeter to EM and HAD energy)
- And for
  - underlying event and out-of-cone for some observables
  - resolution effects
  - hadron to parton level for other observables (such as comparisons to parton level cross sections)
    - can correct data to parton level or theory to hadron level…<u>or both and be specific about what the corrections are</u>
  - note that loss due to hadronization is basically constant at 1 GeV/c for all jet p_T values at the Tevatron (for a cone of radius 0.7)
    - for a cone radius of 0.4, the two effects cancel to within a few percent
  - interesting to check over the jet range at the LHC

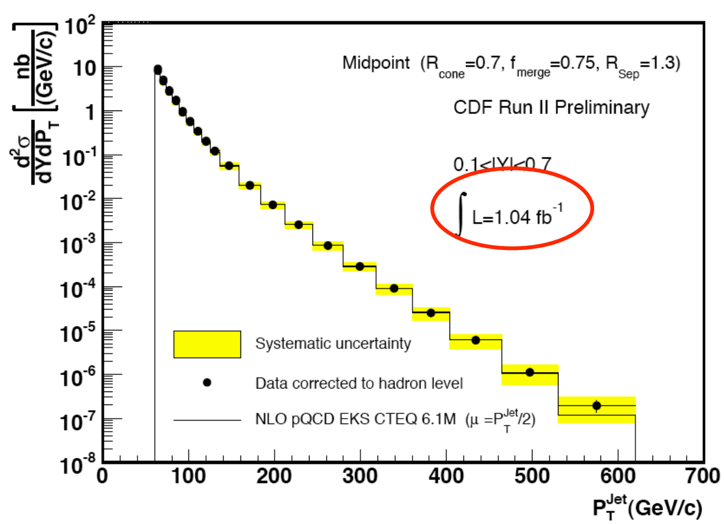


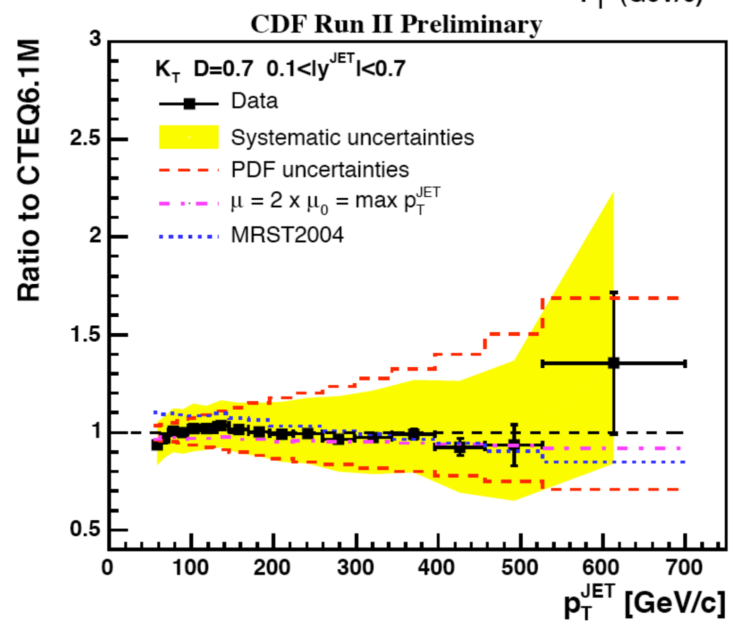


CDF Run 2 results

- CDF Run II result in good agreement with NLO predictions using CTEQ6.1 pdf's
  - enhanced gluon at high x
- ...and with results using k_T algorithm
  - the agreement would appear even better if the same scale were used in the theory (k_T uses $p_T^{max}/2$)
- need to have the capability of using different algorithms in analyses as cross-checks



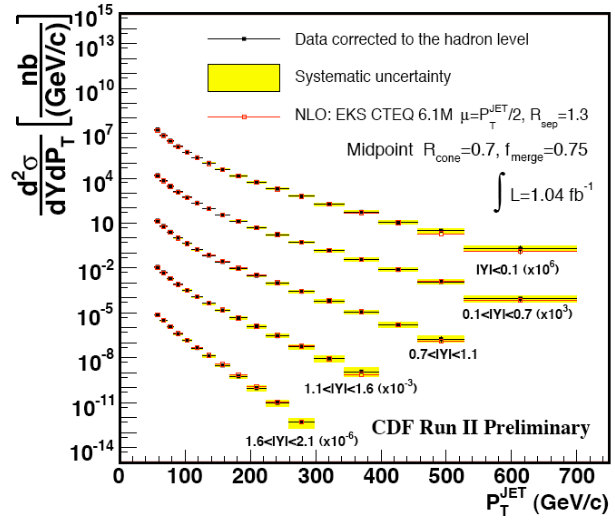


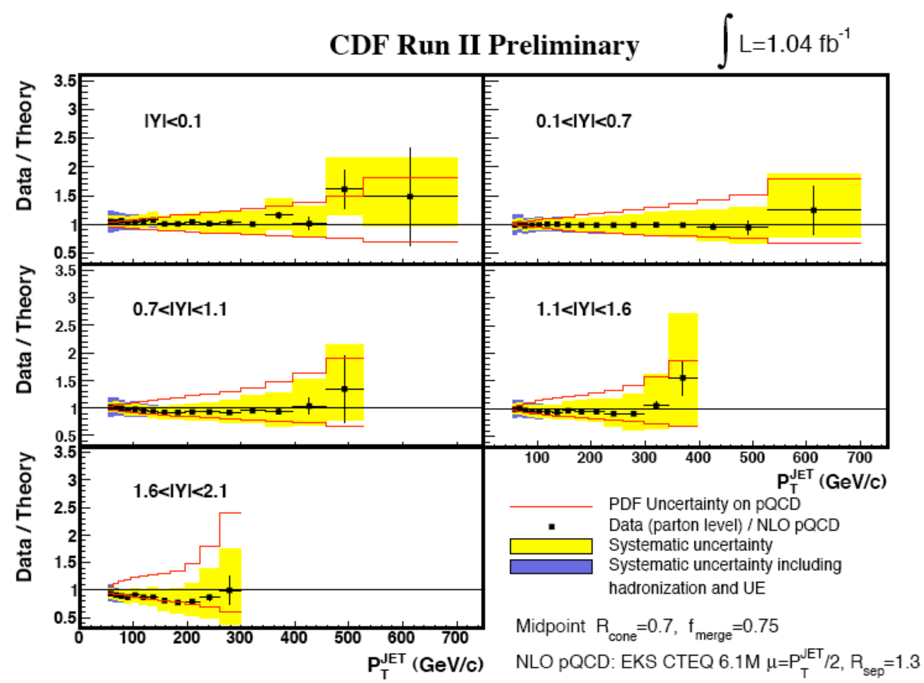


Rhodes

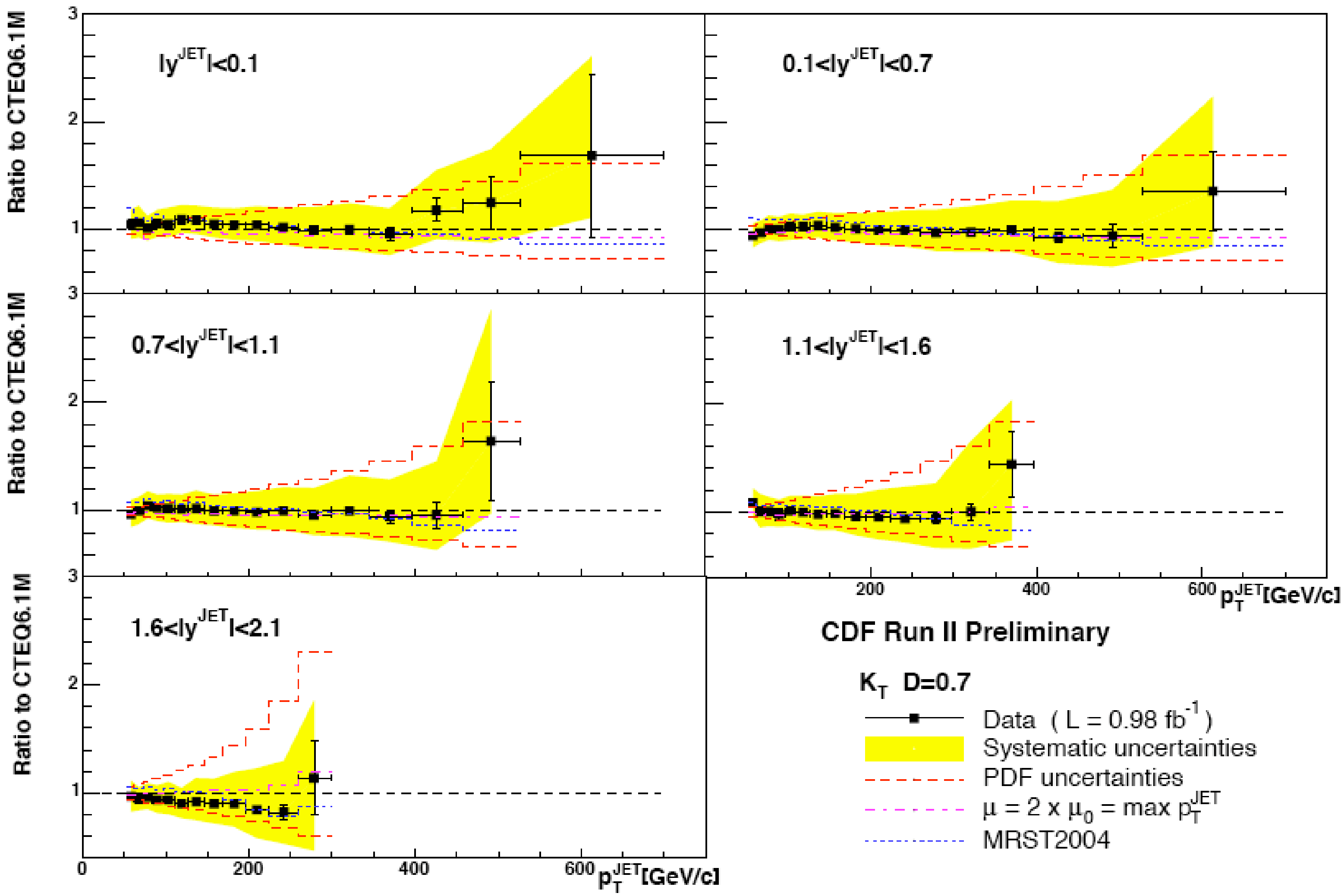
CDF Run 2 cone results

- Precise results over a wide rapidity range
  - new physics will be central; a pdf explanation is universal over rapidity
- Good agreement with CTEQ6.1 predictions using CDF midpoint algorithm
- PDF uncertainties are on the same order or less than systematic errors
- Should reduce uncertainties for next round of CTEQ fits
  - so long to eigenvector 15?
  - see Mandy's talk





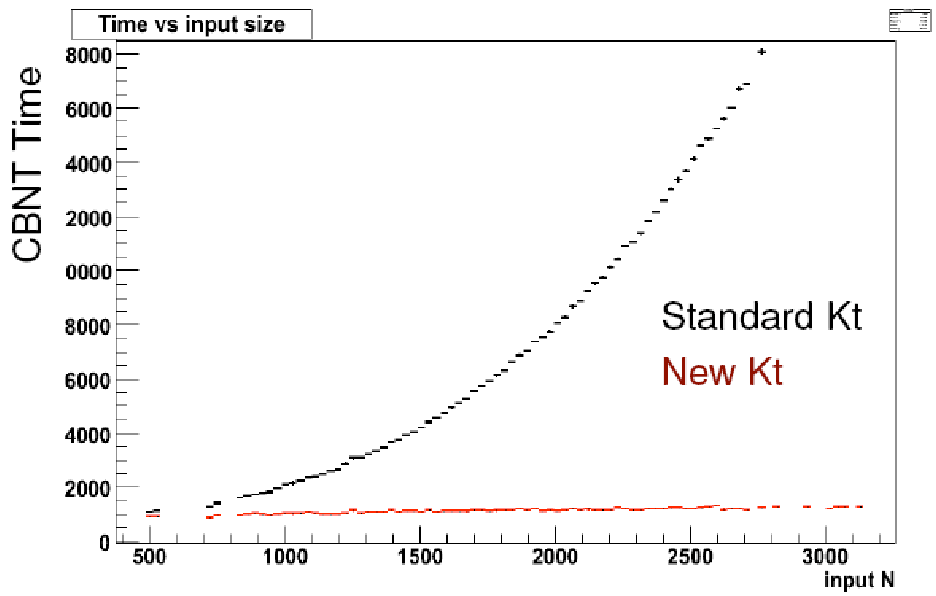
Forward jets with the k_T algorithm



Need to go lower in p_T for comparisons of the two algorithms, apply k_T to other analyses

New k_T algorithm

- k_T algorithms are typically slow because speed goes as $O(N^3)$, where N is the number of inputs (towers, particles,…)
- Cacciari and Salam (hep-ph/0512210) have shown that complexity can be reduced and speed increased to O(N) by using information relating to geometric nearest neighbors
  - i.e. towers, particles that are nearby in momentum space also tend to be nearby in coordinate space
  - should be useful for LHC
- Optimum is if analyses at LHC use **both** cone and k_T algorithms for jet-finding



So what’s the problem(s)

- Matching a cone algorithm at (NLO) parton level and at detector level
- Parton configurations that will be included in a jet at NLO will not be at hadron level due to stochastic smearing because of parton showering/hadronization

•$z = p_T^{jet2}/p_T^{jet1}$; $d = \Delta R$ between partons
•At NLO; two partons within region I or II will be called one jet
•R_{sep} parameter was introduced into the theory because experiment reconstructs separate jets if $\Delta R > R_{sep}$*Rcone

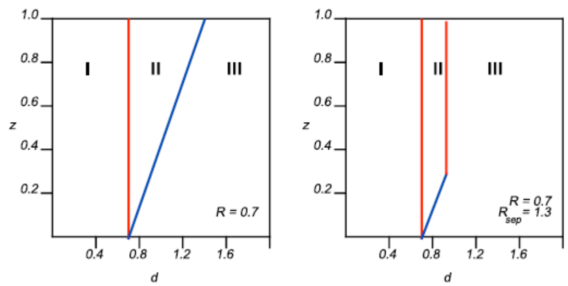


Figure 15. The parameter space (d,Z) for which two partons will be merged into a single jet.

midpoint seed was intended to remove need for R_{sep} …but it’s smearing not seeds

table cone) – How can that happen?

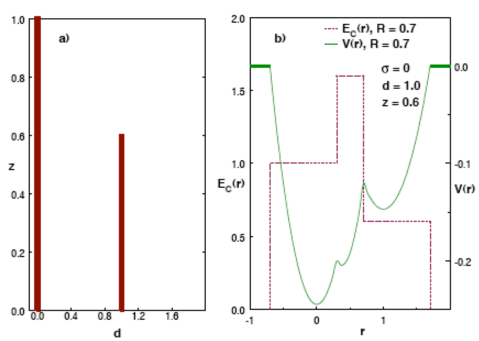
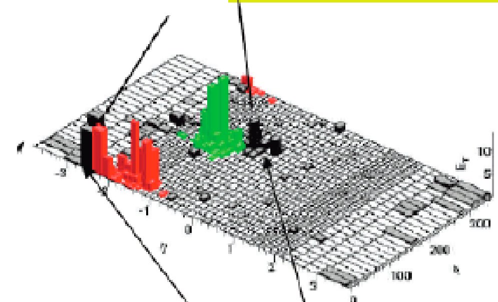


Figure 18. A schematic depiction of a specific parton configuration and the results of applying the midpoint cone jet clustering algorithm. The potential discussed in the text and the resulting energy in the jet are plotted.

have lost central solution (both partons) and right solution… some energy ends up unclustered in any jet



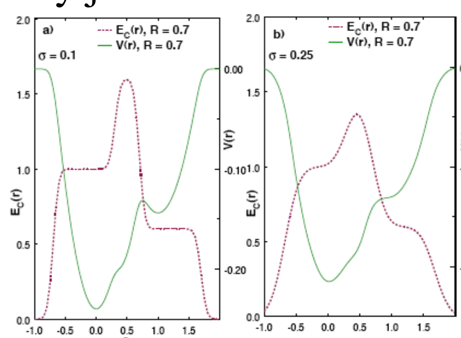
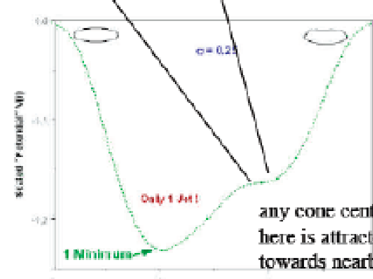


Figure 19. A schematic depiction of the effects of smearing on the midpoint cone jet clustering algorithm.



any cone centered here is attracted towards nearby large cluster of energy

way of understanding these dark towers begins by defining a “Snowmass potential” in terms of the 2-dimensional vector $\vec{r} = (y, \phi)$ via

$$V(\vec{r}) = -\frac{1}{2}\sum_j p_{T,j}\left(R_{cone}^2 - (\vec{r}_j - \vec{r})^2\right)\Theta\left(R_{cone}^2 - (\vec{r}_j - \vec{r})^2\right). \quad (39)$$

Some major silliness

- Matching a cone algorithm at (NLO) parton level and at detector level
- Parton configurations that will be included in a jet at NLO will not be at hadron level due to stochastic smearing because of parton showering/hadronization
- Modified midpoint algorithm uses smaller initial search cone (R/2), reduces unclustered energy
  - recovers right solution, but in most cases not central
    - i.e. R_{sep} still needed
  - default midpoint algorithm has ~2% of 400 GeV/c dijet events with >50 GeV/c of unclustered energy
- **All cone algorithms are IR-sensitive**
  - D0 version of midpoint algorithm has IR-sensitivity <1%
  - CDF version has IR-sensitivity of ~1%
    - but essentially no unclustered energy
- **Both algorithms are IR-safe**

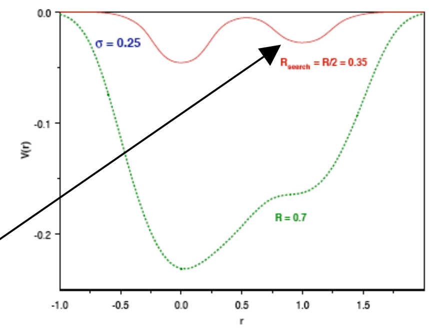
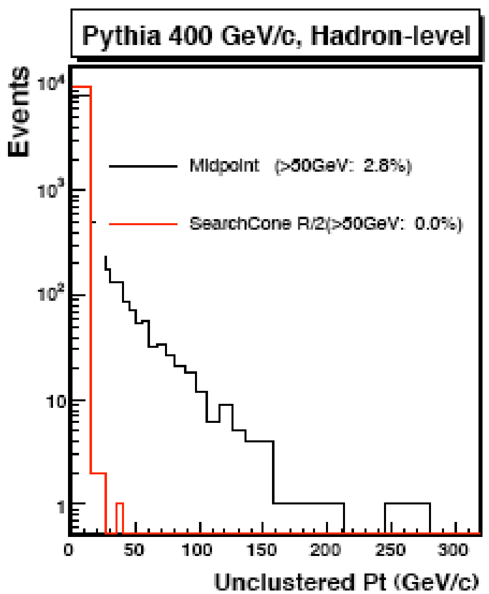
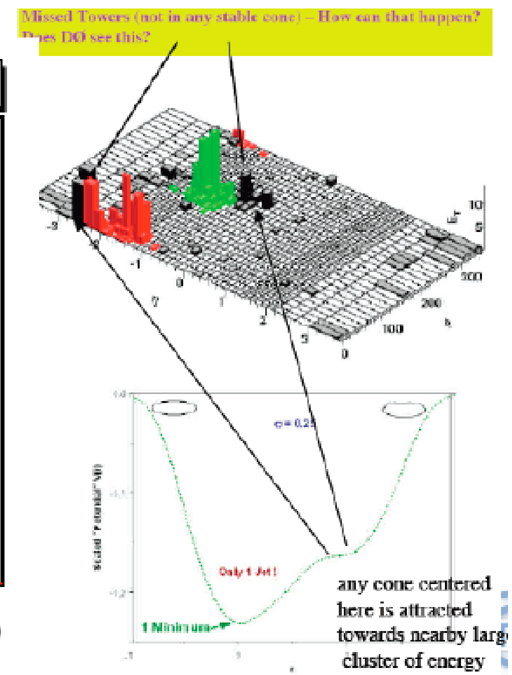


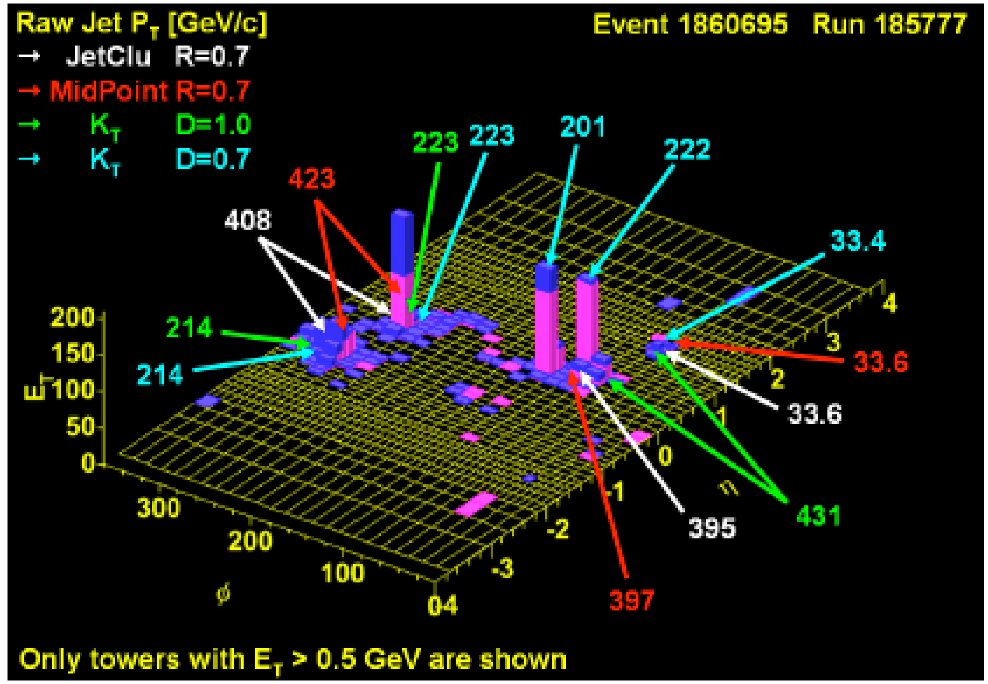
Figure 20. A schematic depiction of the effects of smearing on the midpoint cone jet clustering algorithm and the result of using a smaller initial search cone.





Can’t we all just get along?

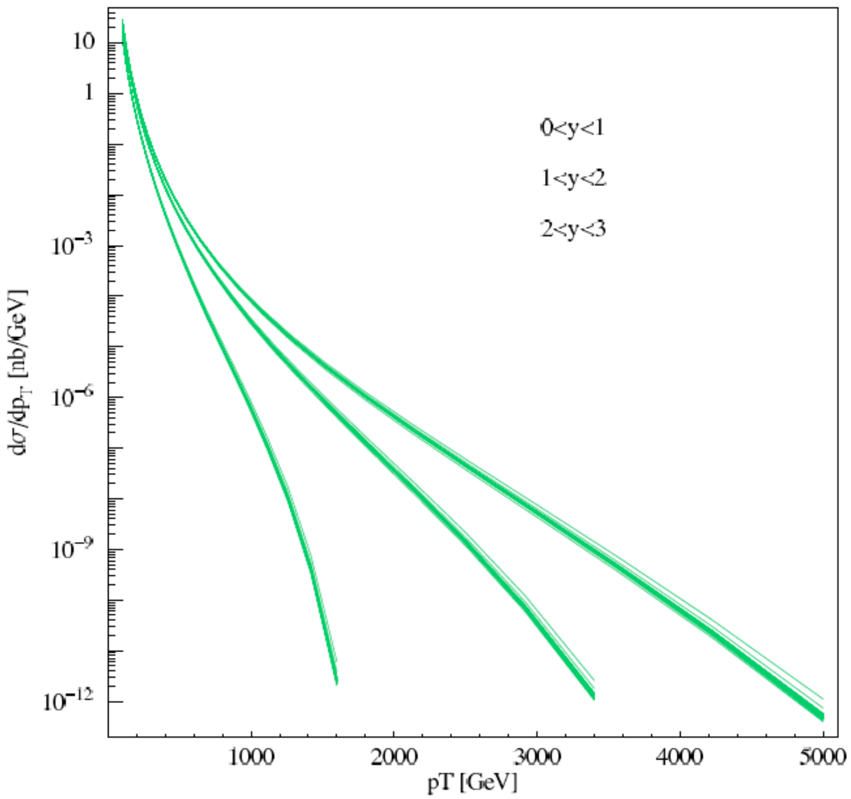
- I still believe that at the LHC, need both k_T and cone jet algorithms
- I’m working now on a version of the jet cone algorithm that matches as closely as possible seedless pQCD
  - unlike Odyseus, trying to bypass both Scylla and Charybdis



- Trying to summarize/think for TeV4LHC writeup
- Further discussion this summer

Predictions for LHC

These are predictions for ATLAS based on the CTEQ6.1 central pdf and the 40 error pdf's using the midpoint jet algorithm.



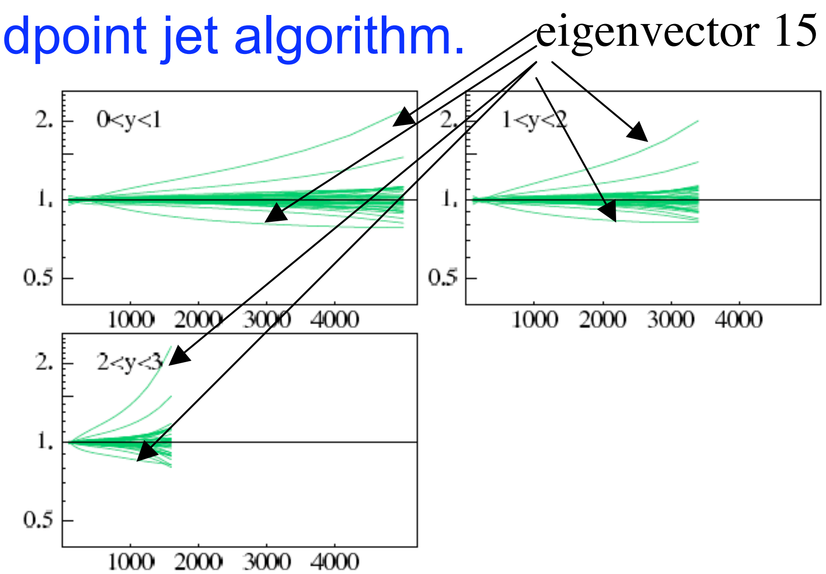


FIG. 31: The uncertainty range of the inclusive jet cross section at the LHC. The curves are graphs of the ratios of the cross sections for the 40 eigenvector basis sets compared to the central (CTEQ6.1M) prediction (ordinate) versus p_T in GeV (ordinate).

Need to have jet measurements over full rapidity range and good control over rapidity variations of jet systematics.

Predictions for LHC:K-factors

These are predictions for ATLAS based on the CTEQ6.1 central pdf and the 40 error pdf's using the midpoint jet algorithm.

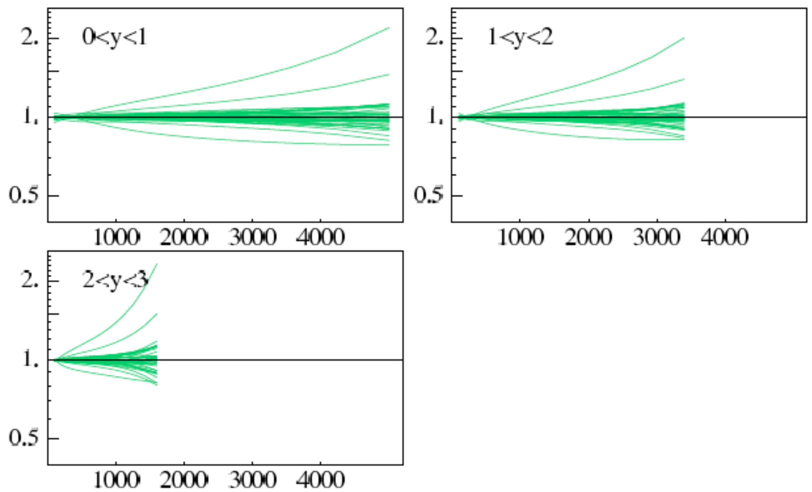


FIG. 31: The uncertainty range of the inclusive jet cross section at the LHC. The curves are graphs of the ratios of the cross sections for the 40 eigenvector basis sets compared to the central (CTEQ6.1M) prediction (ordinate) versus p_T in GeV (ordinate).

K-factor = NLO/LO

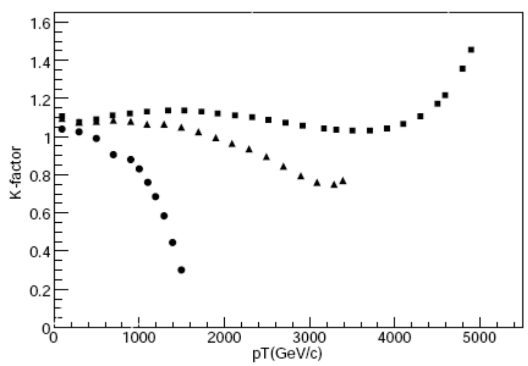
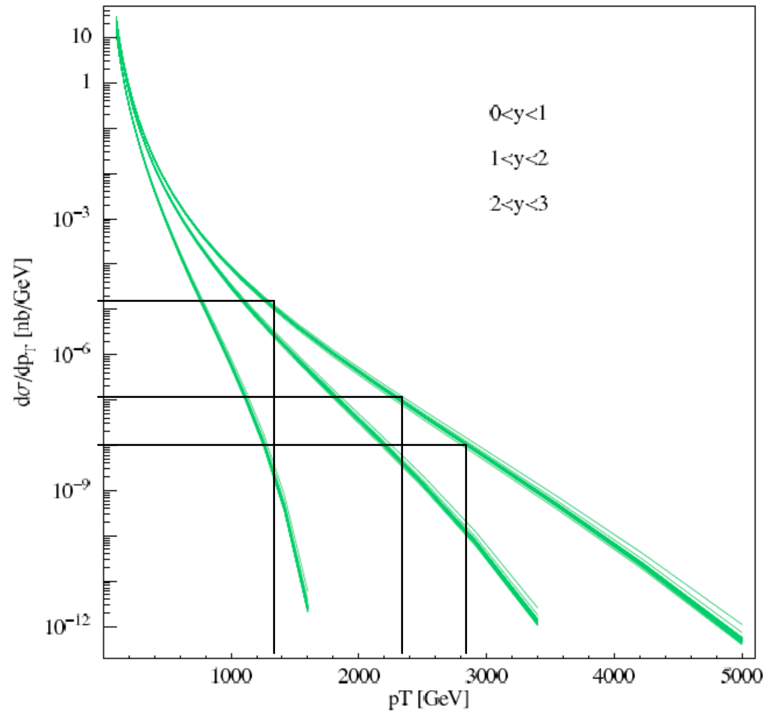


Figure 93. The ratios of the NLO to LO jet cross section predictions for the LHC using the CTEQ6.1 pdf's for the three different rapidity regions (0–1 (squares), 1–2 (triangles), 2–3 (circles)).

Statistical reach

- Reach is ~
  - 1.4 TeV/c for 100 pb^{-1}
    - basically no constraints on pdf's
  - 2.4 TeV/c for 10 fb^{-1}
  - 2.8 TeV/c for 100 fb^{-1}
- For sensitive to compositeness scales of~
  - 4-5 TeV/c
  - 10-13 TeV/c
  - 13-16 TeV/c



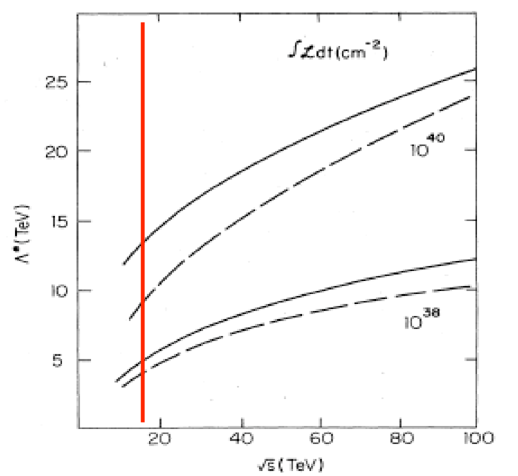
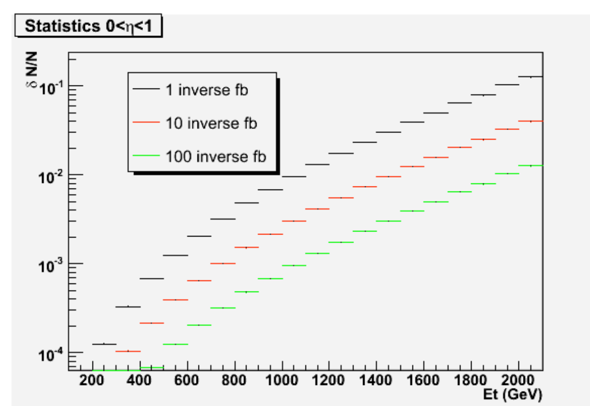
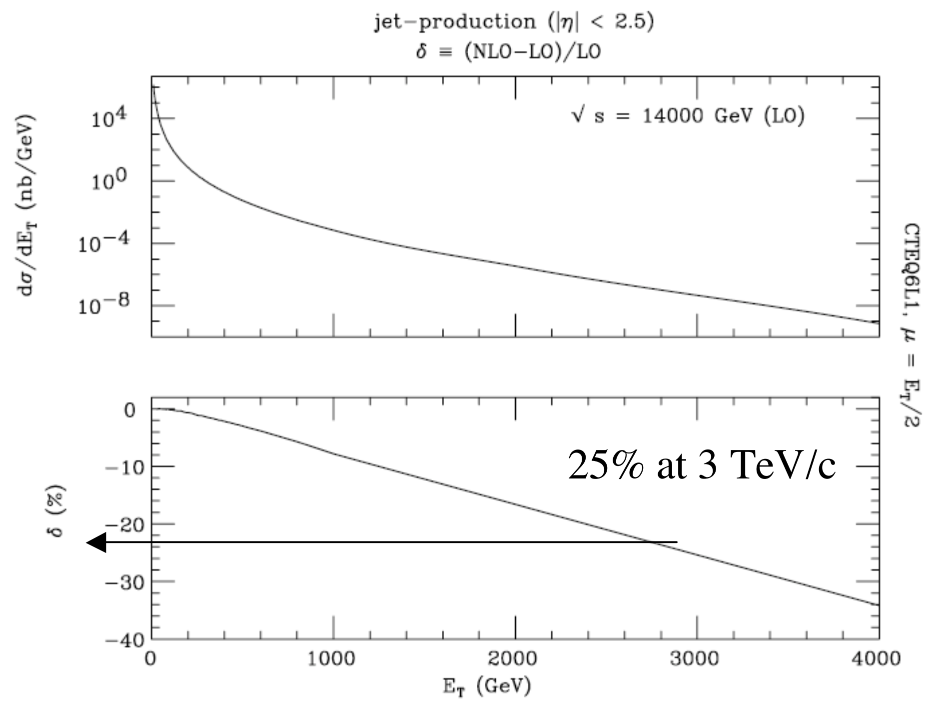


FIG. 236. Maximum compositeness scale Λ^* probed in jet production at $y=0$ in pp collisions as a function of $\sqrt{s}$ for integrated luminosities of 10^{40} and 10^{38} cm^{-2} according to the criterion (8.18). $\eta_0=-1$ (solid lines), $\eta_0=+1$ (dashed lines).



Example: *Unexpected* new SM physics

- In a recent paper (hep-ph/0503152), Stefano Moretti and Douglas Ross have shown large 1-loop weak corrections to the inclusive jet cross section at the LHC
- Effect goes as $\alpha_W \log^2(E_T^2/M_Z^2)$
    - at the LHC, this log can get large
    - no cancellation with real W emission since W is massive and phase space is restricted
- Confirmation is important
- Other (unsuspected) areas where weak corrections are important?

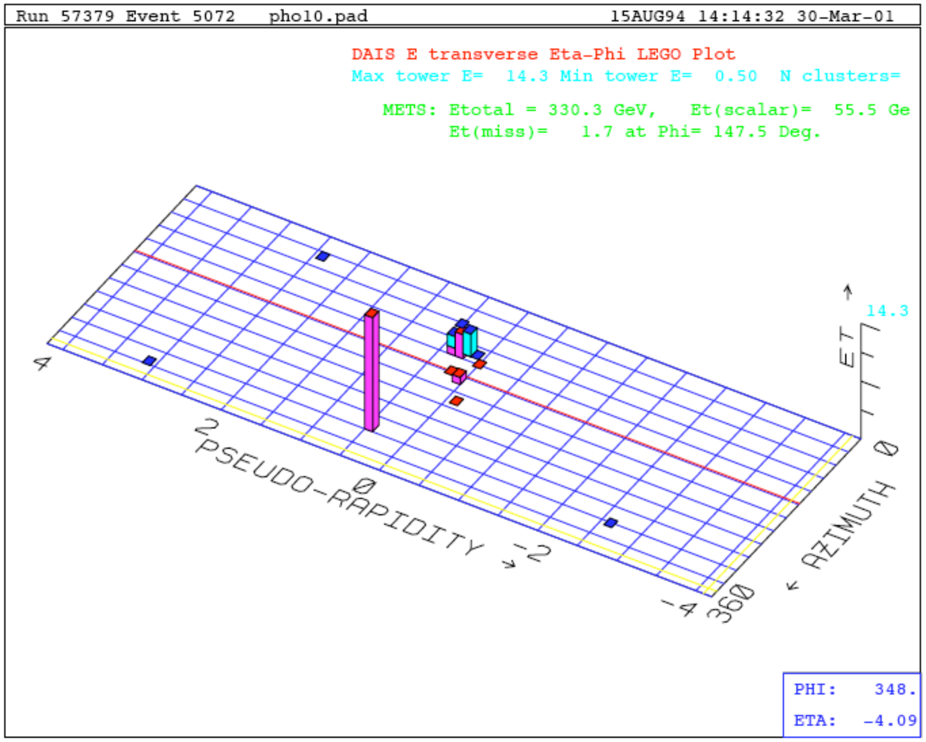


In *Rumsfeldese*, this is now one of the "known unknowns".

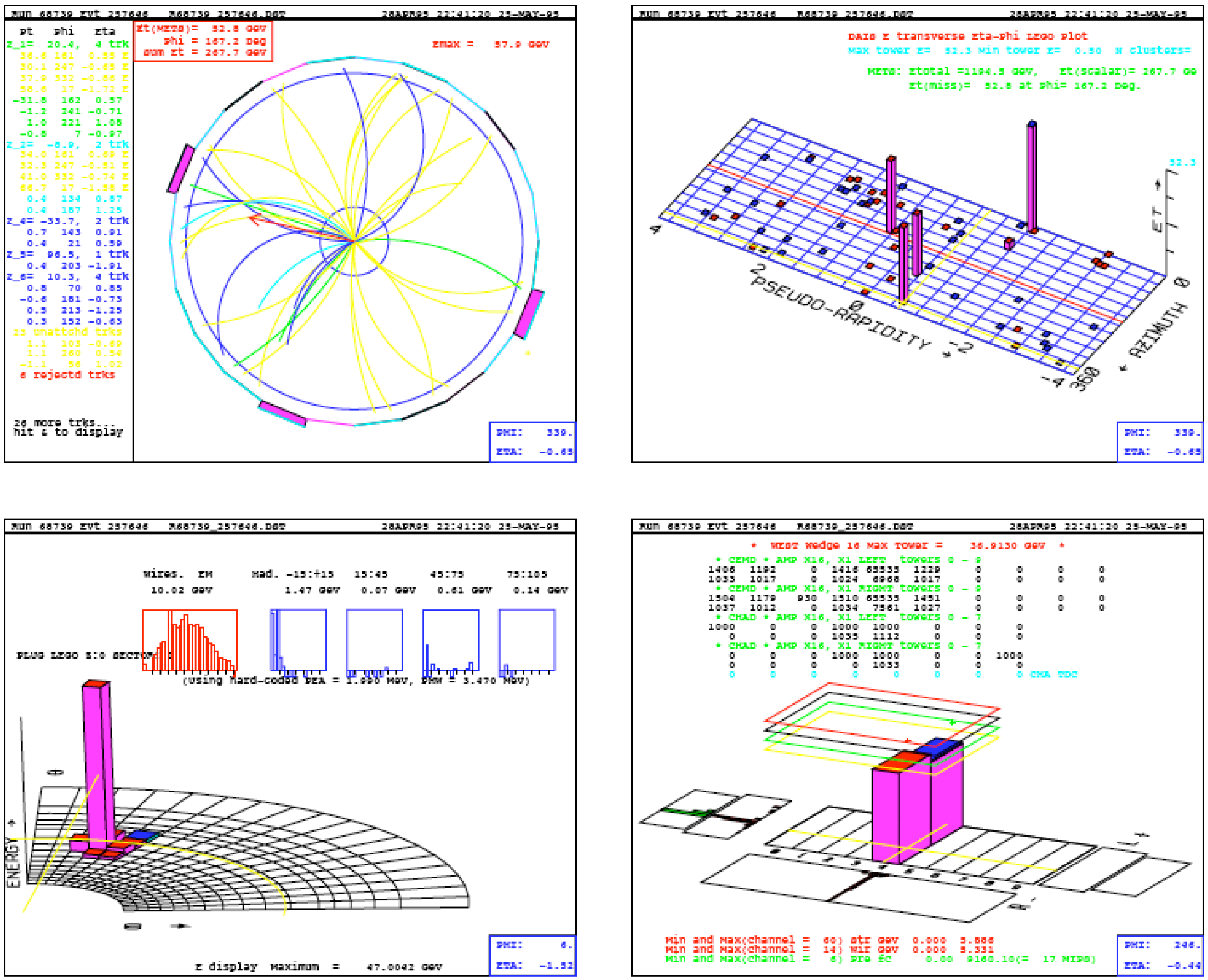
What are our unknown unknowns?

Photon/electron signatures

- Photon profile in calorimeter is very localized, both in depth (z) and in (η,ϕ)
- Typically most of energy is in one (EM) tower
  - an isolation cut for the towers around the photon (tracks nearby) is applied to reduce the background from jets faking a photon
- Contrast with jet on opposing side which is spread in (η,ϕ) and has energy balance between EM and hadronic portions of the calorimeter
- Electron, of course, is similar to photon except that there is a track pointing towards the EM cluster and ratio of E/p is close to unity



Sometimes you get lucky (and sometimes you don't)



…the famous $\gamma\gamma e^+e^-\not{E}_T$ event from CDF in Run 1

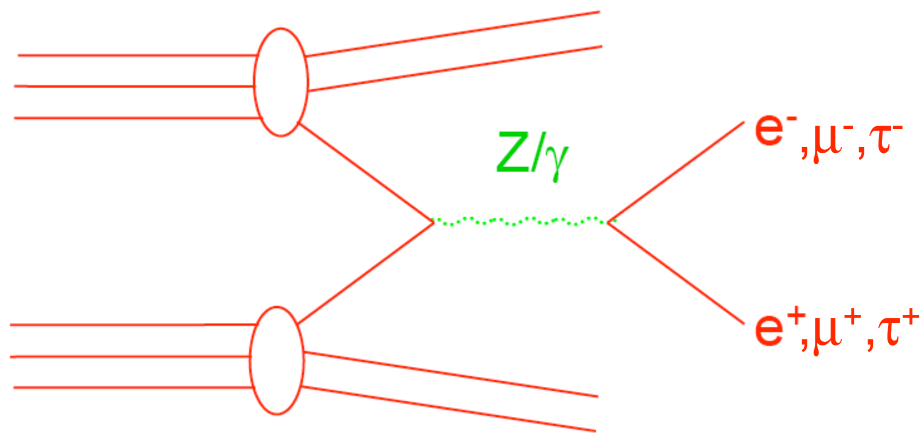
…new physics??

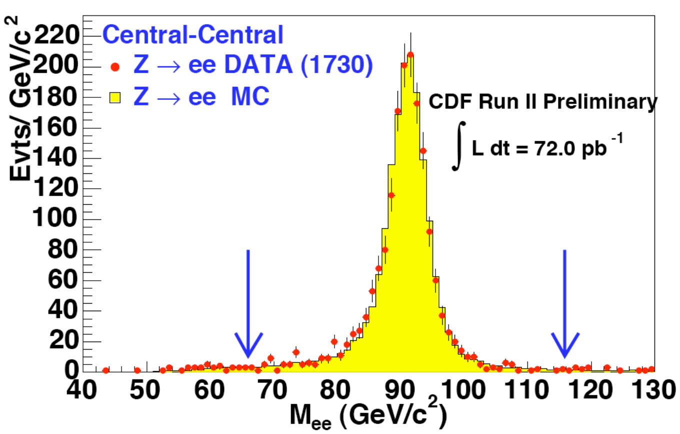
…WW$\gamma\gamma$??

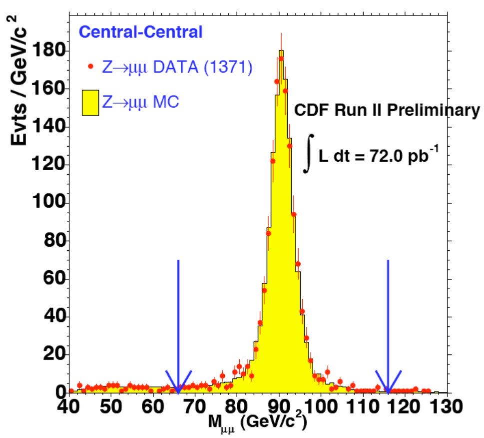
…alas, this seems to be one-of-a-kind

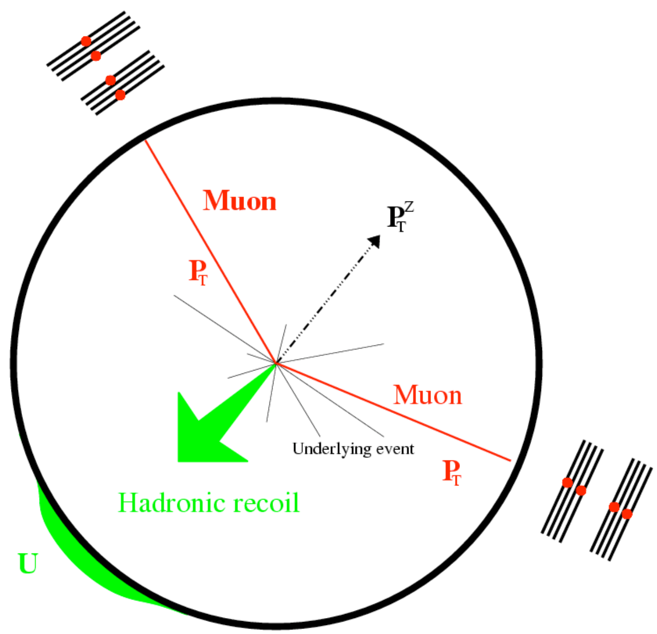
Z production (and decay)

- Look for two isolated leptons, of opposite charge, p_T>25 GeV/c
- Very clean signature, little background





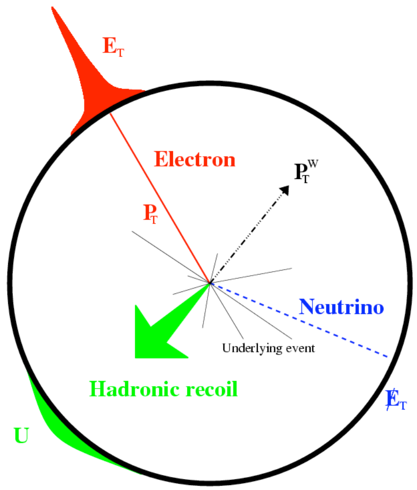




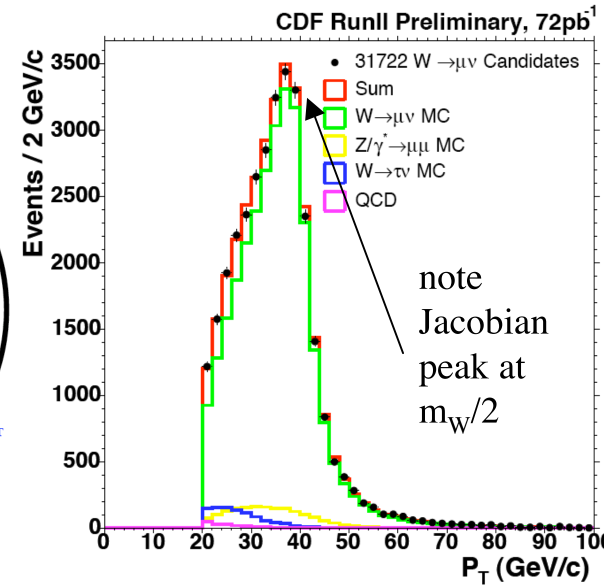
See Sarah's lecture

W production (and decay)

- single charged lepton:
  - high p_T
  - isolated
- E_T^{miss} (from neutrino)

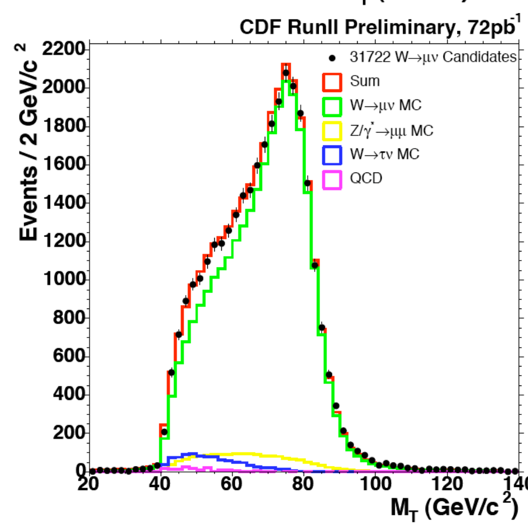


- less redundancy in trigger and offline selection
- more difficult to control backgrounds and systematics
- need to understand hadronic recoil
  - especially for determination of W mass



note Jacobian peak at $m_W/2$

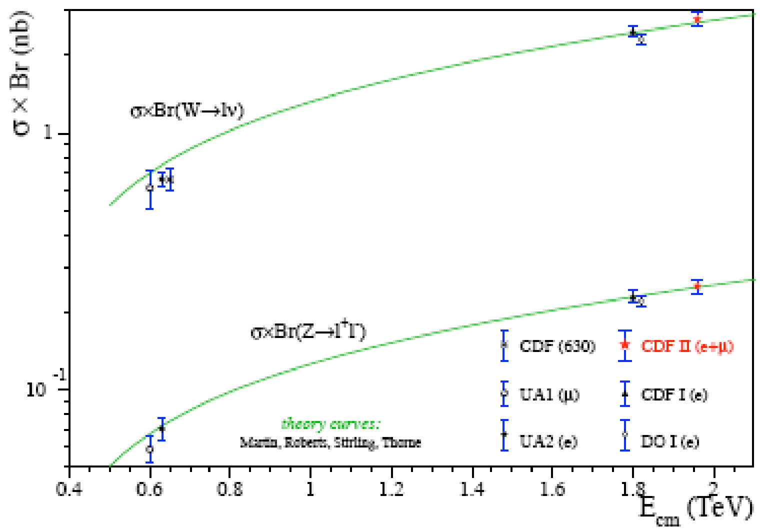
transverse mass peaks at m_W

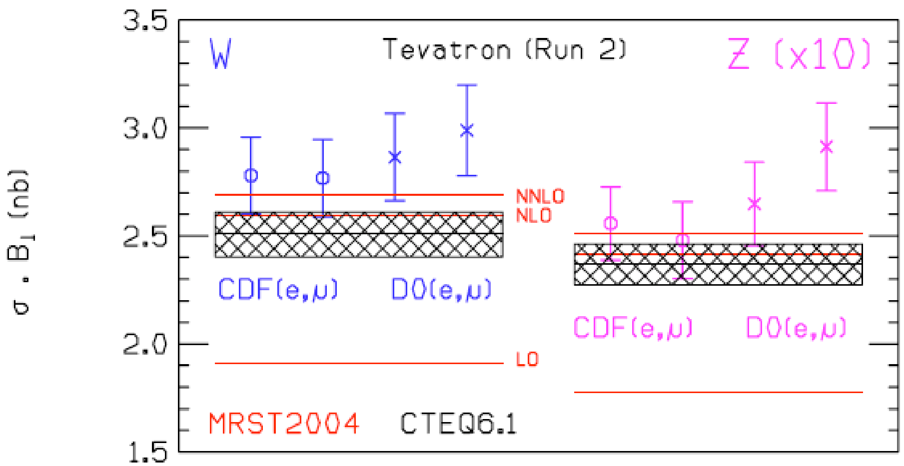


See Sarah's lecture

W/Z at the Tevatron

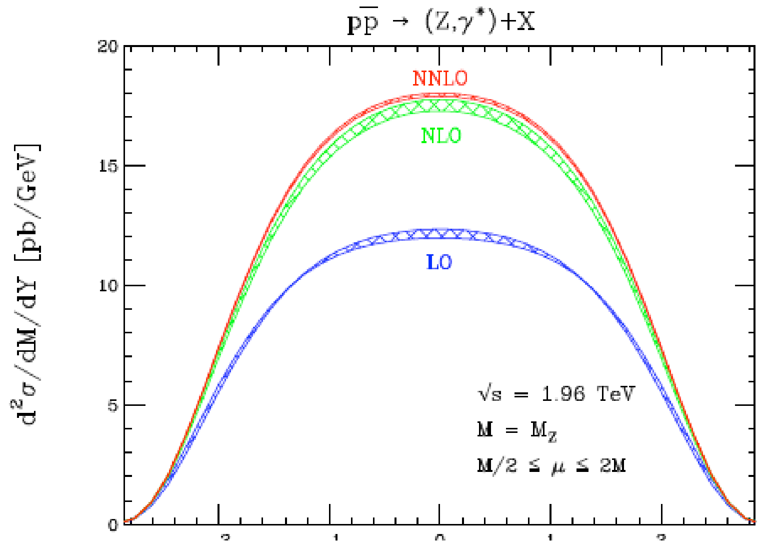
- W/Z cross sections serve as precision physics monitors
  - all cross sections at LHC could be normalized to W/Z
- Both experimental and theoretical errors are under control
  - NNLO a small (positive) correction to NLO
- Note that CTEQ and MRST NLO predictions agree within CTEQ6.1 pdf errors (but MRST at edge of CTEQ6.1 error band)
  - see Mandy's lectures for more details on pdf uncertainties

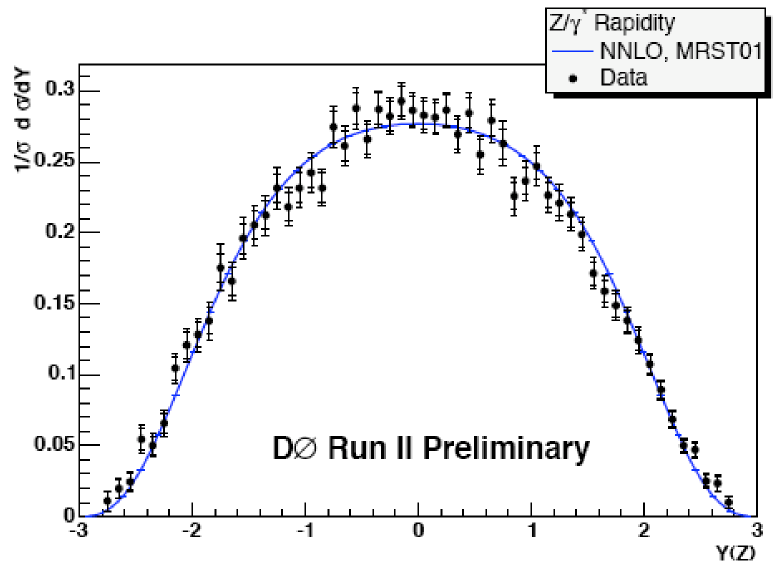




Rapidity distributions

- Little shape difference from NLO to NNLO
  - K-factor should be sufficient
- Z rapidity distributions could/will be used as input for pdf fits





p_T distributions

- Drell-Yan production serves as good benchmark for understanding ISR effects
  - applied in CDF to top mass uncertainty
  - should be extended to LHC

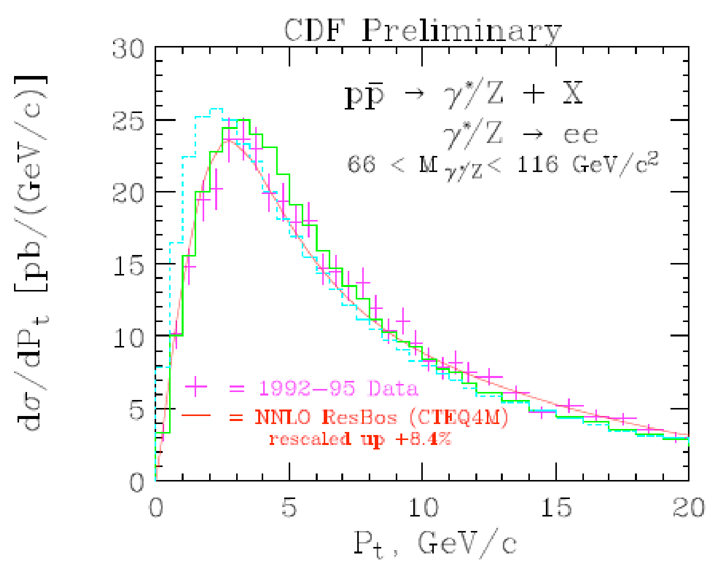


Figure 4. The transverse momentum distribution (low p_T) for $Z \to e^+e^-$ from CDF in Run 1, along with comparisons to predictions from Pythia and ResBos. The Pythia solid-green curve has had an additional 2 GeV/c of k_T added to the parton shower.

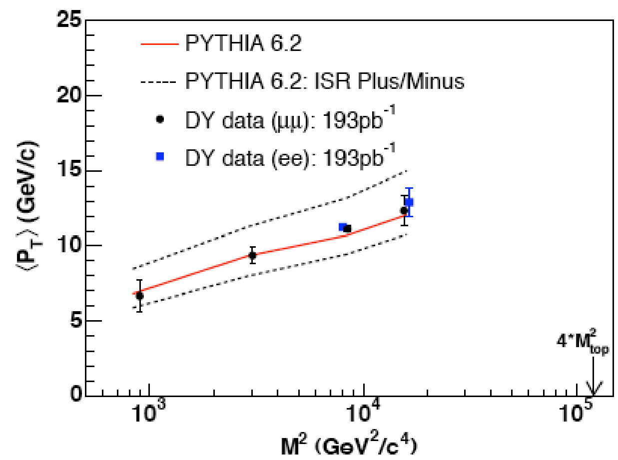


Figure 6. The average transverse momentum for Drell-Yan pairs from CDF in Run 2, along with comparisons to predictions from Pythia.

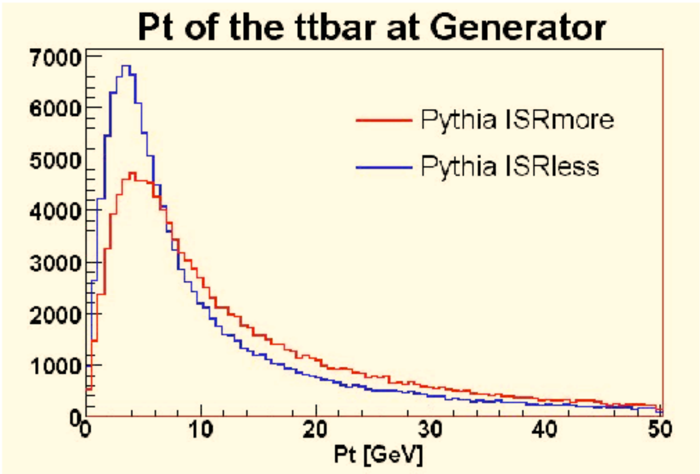


Figure 7. The Pythia predictions for the $t\bar{t}$ transverse momentum using the 'Plus/Minus' tunes.

Rhodes

W/Z at the LHC

- Expect similar systematics, both experimental and theoretical, at the LHC for W/Z production as at the Tevatron, plus a huge rate
- Current pdf uncertainties on order of 4-5%; should improve by LHC turn-on
- Very useful to use W/Z cross sections as luminosity monitor/cross section normalization, especially in early days before total inelastic cross section well-determined
  - W/Z cross sections highly correlated vis a vis pdf uncertainties

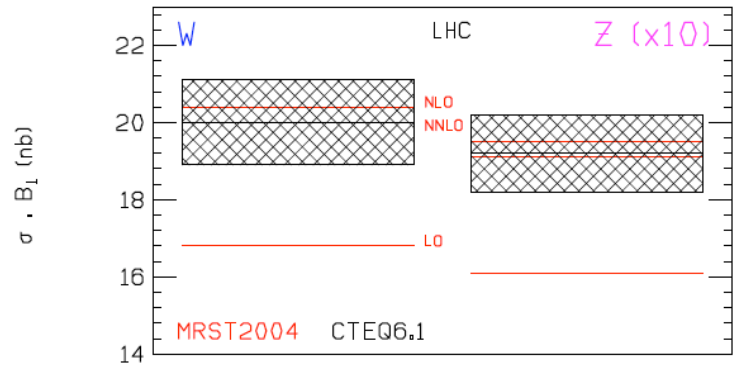
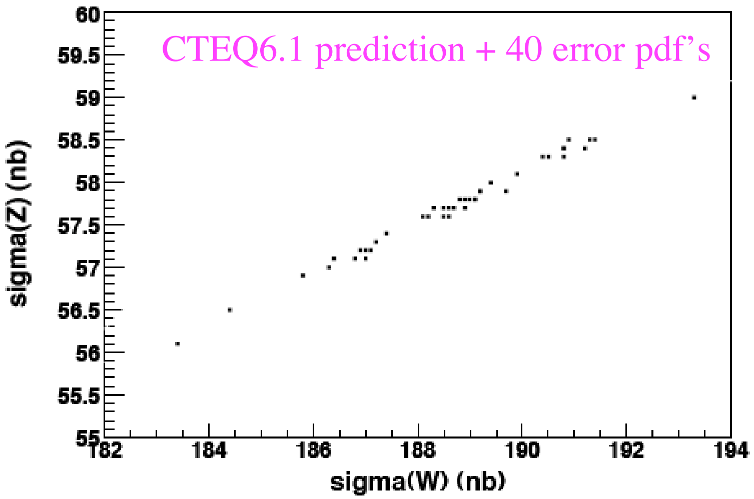
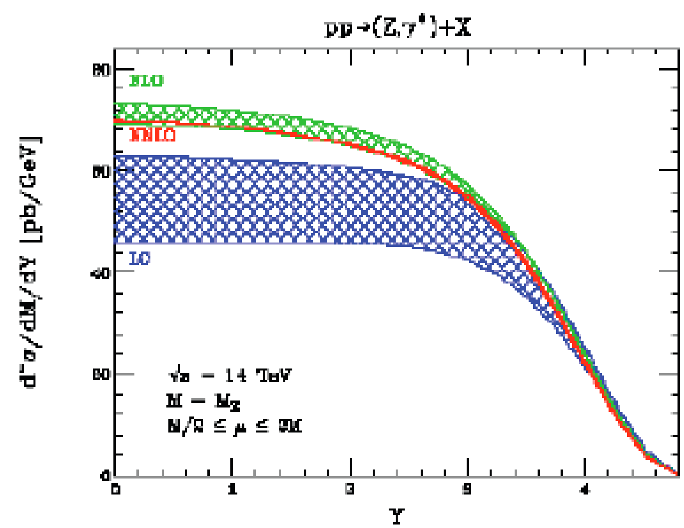


Figure 76. Predicted cross sections for W and Z production at the LHC using MRST2004 and CTEQ6.1 PDF's. The overall PDF uncertainty of the NLO CTEQ6.1 prediction is approximately 5%, consistent with Figure 71.

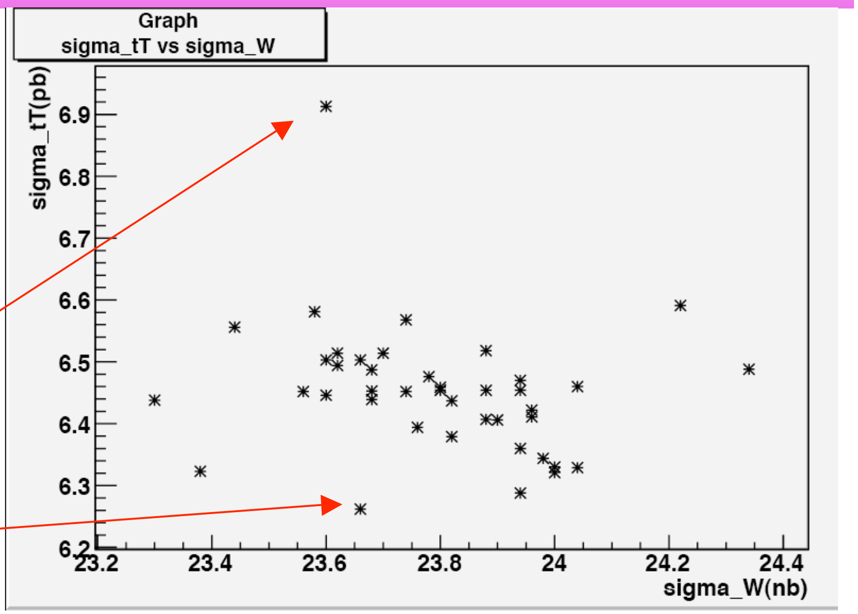


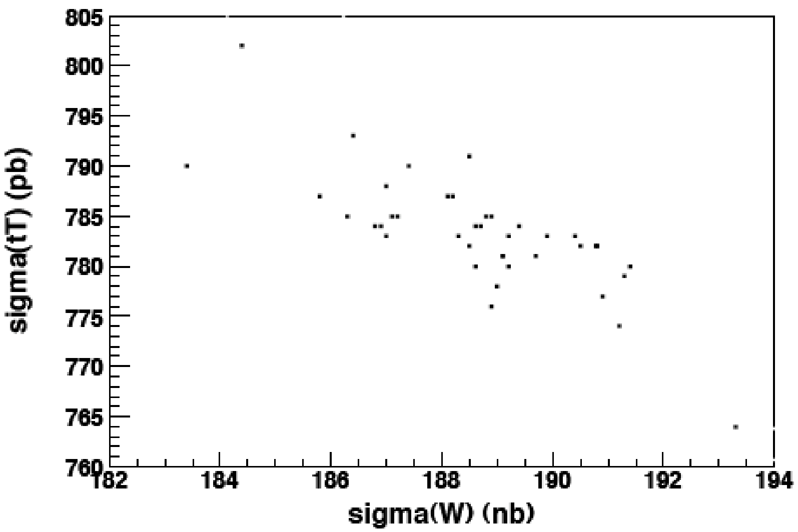


  - W/Z rapidity distributions known to NNNLO

Top vs W cross section

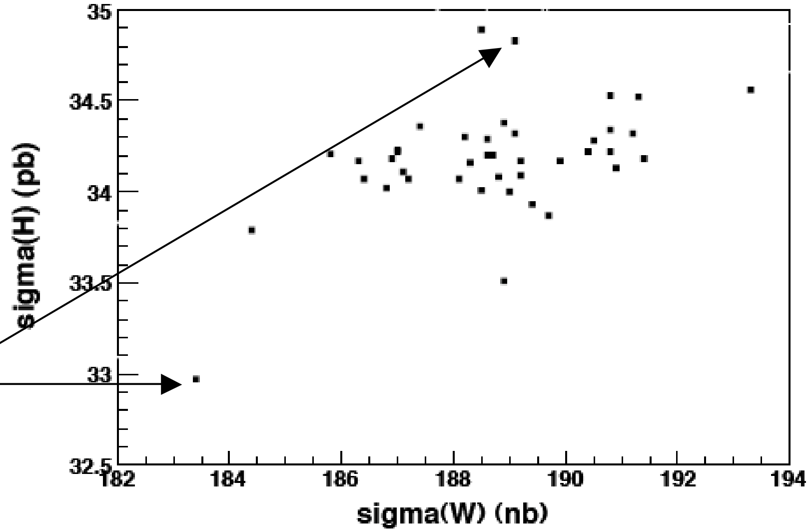
- Plot predictions for 40 error pdf's (CTEQ6.1) for top and W cross sections at the Tevatron and LHC
- Not much correlation at Tevatron
  - big excursions caused by eigenvector 15; high x gluon
- More anti-correlation at LHC; more momentum for gluons, less for sea quarks (at lower x) that produce W's





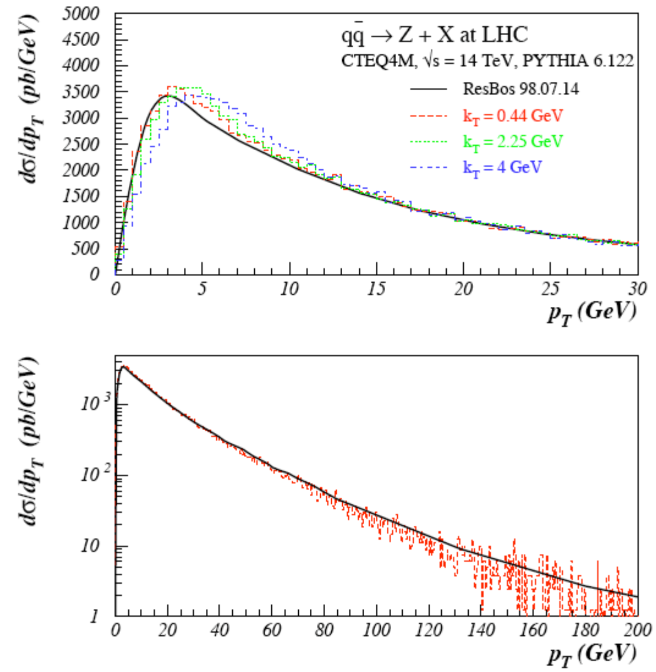
Higgs vs W cross section

- More anti-correlation at LHC; more momentum for gluons, less for sea quarks (at lower x) that produce W's
- Where's eigenvector 15?
- Causes extremes for Higgs cross section, as reflection of high x gluon to low x
  - momentum conservation: more gluon at high x means less gluon at lower x and vice versa



W/Z at the LHC

- p_T distribution of W/Z/decay leptons should be well-described by pQCD using DGLAP, as in ResBos, a resummation program
  - should peak at a few GeV, similar to Tevatron
- Note that there may be additional effects for transverse momentum distributions of W/Z at LHC due to low x resummation effects (BFKL logs
  - **one of the first steps at the LHC will be to understand the dynamics of W/Z production**



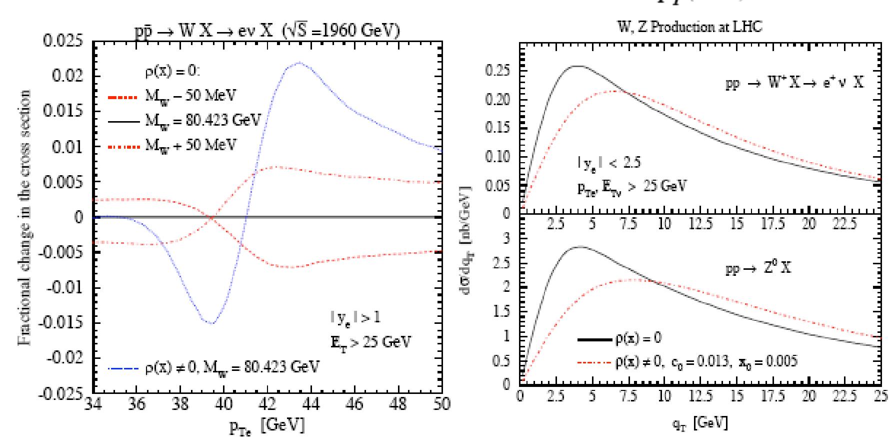
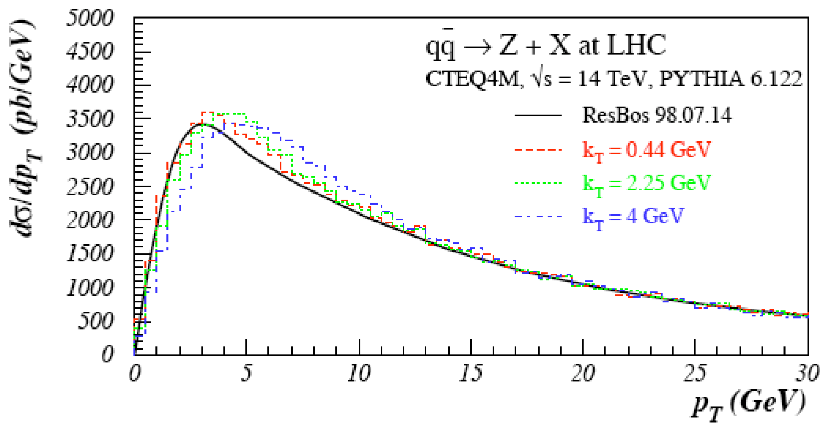
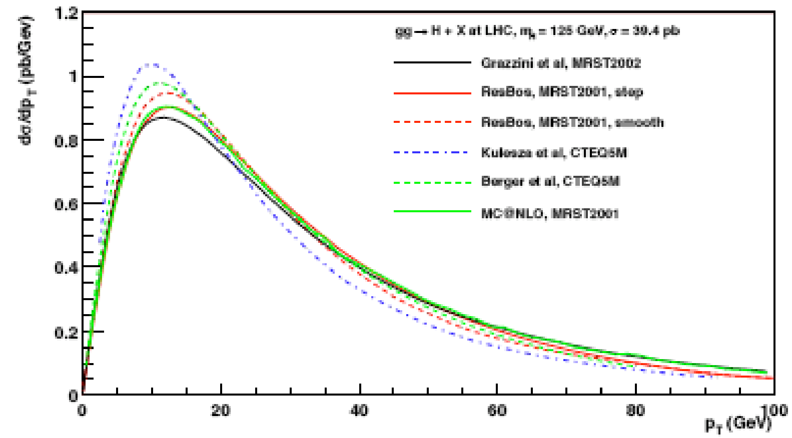


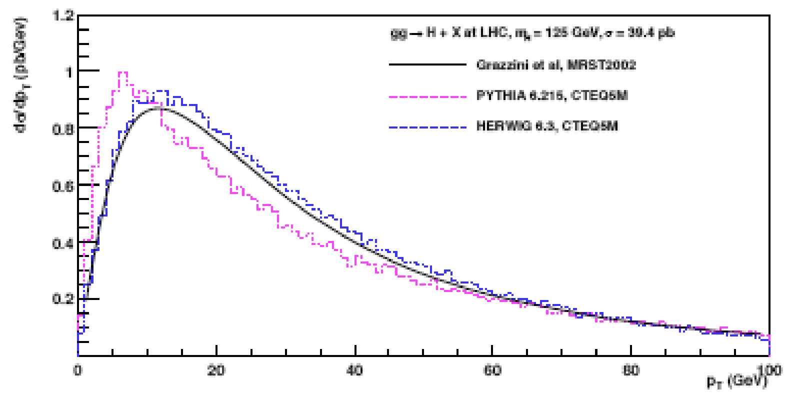
Figure 2. A) The fractional difference in the distribution $d\sigma/dp_{Te}$ for the forward-rapidity sample of electrons ($|y_e| > 1$) at the Tevatron. B) Transverse momentum distributions of (i) W^+ bosons and (ii) Z^0 bosons at the Large Hadron Collider.

Aside: Higgs p_T at the LHC

- Note:
  - average p_T for Higgs production at the LHC much larger than average p_T for Z



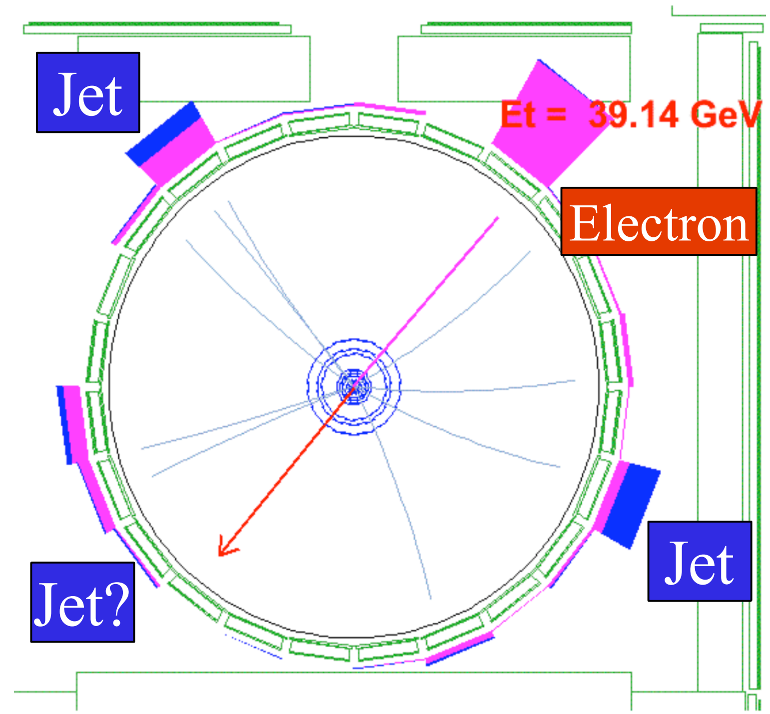




    - color factor of gluon compared to quark
    - z->0 pole in gluon splitting function
    - see Peter's lectures
  - predictions are in reasonable agreement with each other
  - Pythia with virtuality-ordered shower peaks lower, but the new p_T-ordered shower agrees with the other predictions

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
- Define W->eν
  - high p_T track, large EM shower deposition, E/p near 1, lateral shower profile consistent with electron, electron candidate is relatively isolated, plus subtantial missing transverse energy
  - define jet using a cone algorithm with a radius of 0.4
    - use smaller cone size for events that may be complicated

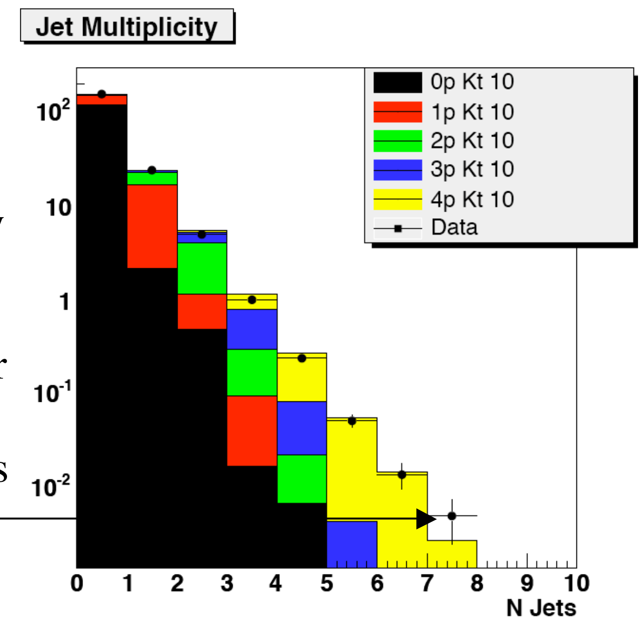


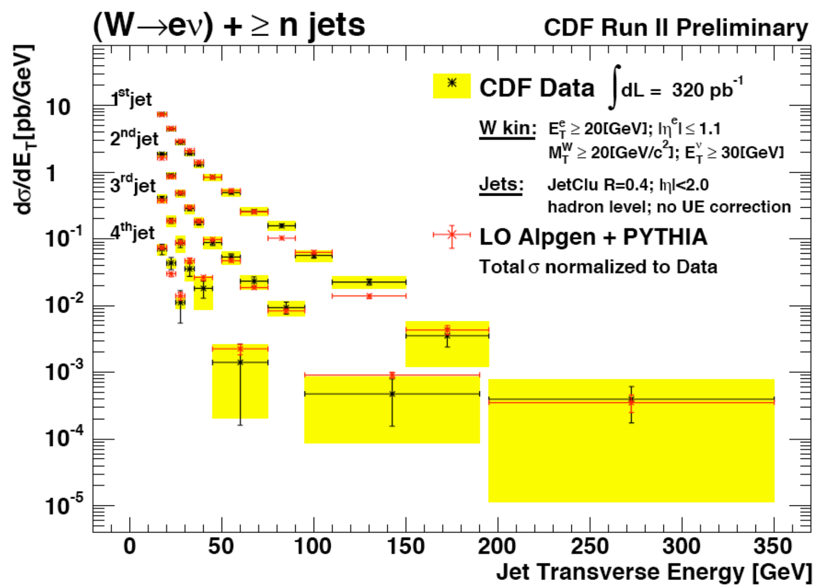
W + jets at the Tevatron

- 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, corrected to hadron level**
  - see www-cdf.fnal.gov QCD webpages
  - *remember for a cone of 0.4, hadron level ~ parton level*

note emission of each jet suppressed by ~factor of α_s

parton shower can produce 1 or 2 extra jets but not more





s

CKKW

- CKKW procedure combines best of exact (LO) matrix element and parton shower description of multijet events
- Currently implemented in Sherpa Monte Carlo and approximately implemented in ALPGEN (mlm procedure)
- ME-PS matching scheme: vetos events at the PS stage that infringe on the phase space already covered by ME
- W+n parton samples can then be combined without double counting

See Peter's lectures for more detail

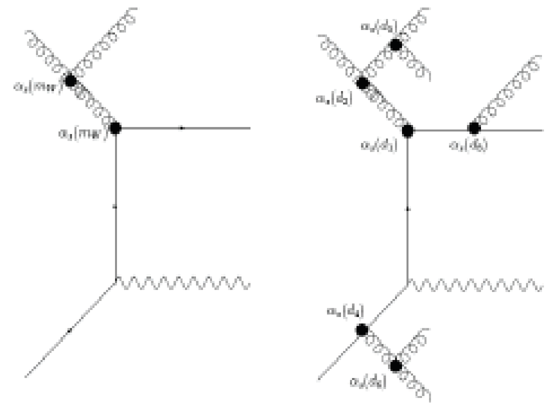
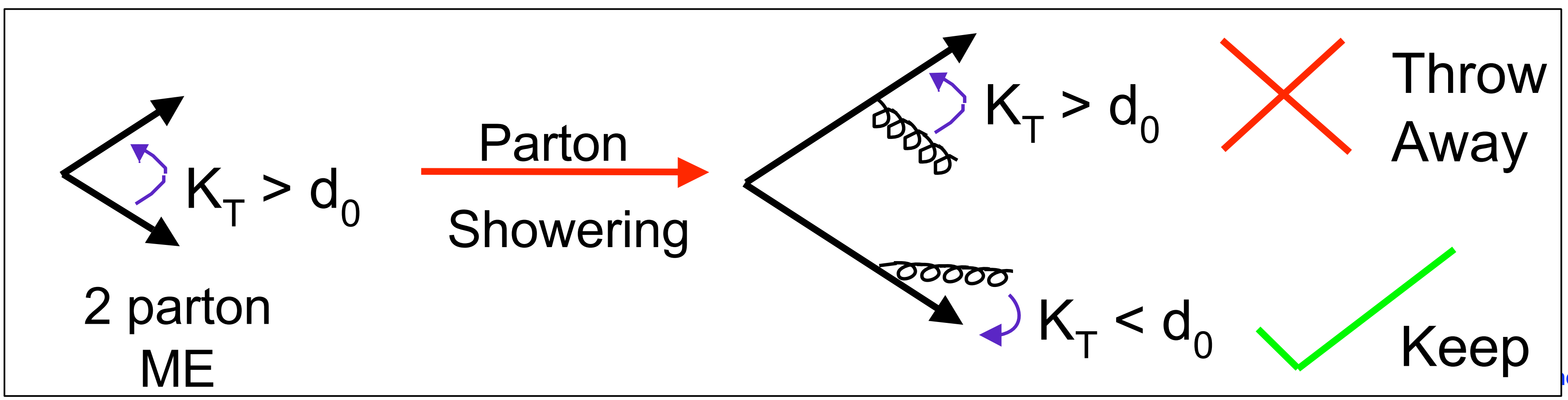
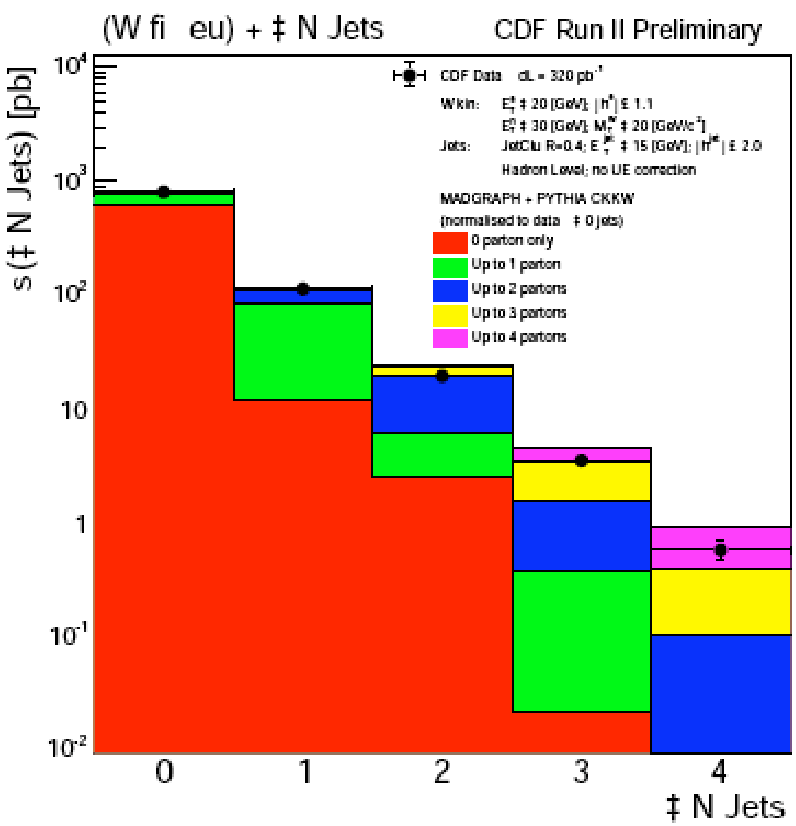


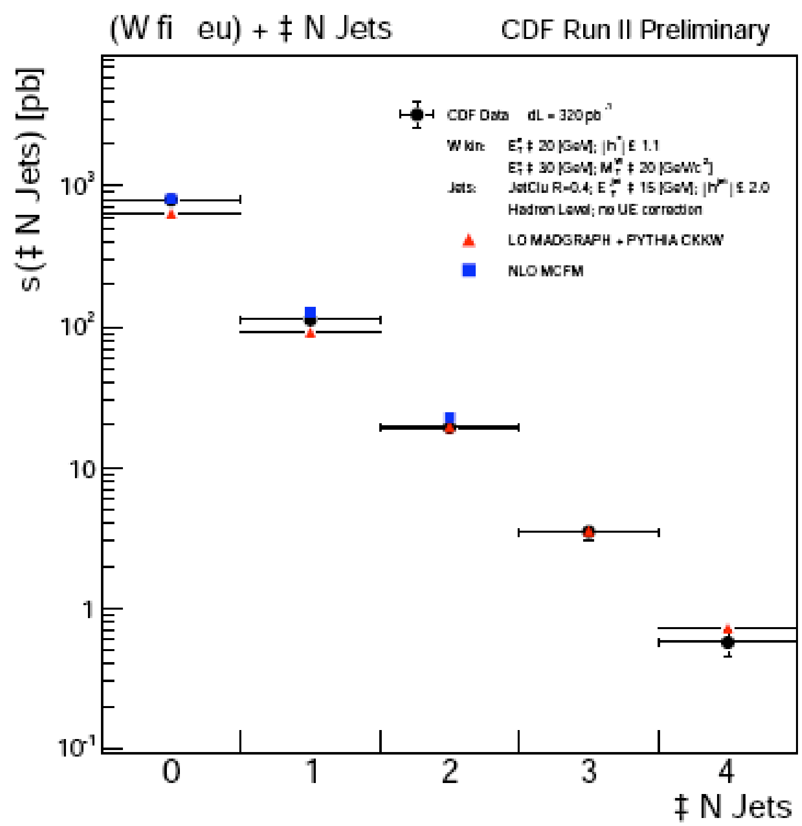
Figure 15. In the NLO formalism, the same scale, proportional to the hardness of the process, is used for each QCD vertex. For the case of the $W+$ 2 jet diagram shown above to the left, a scale related to the mass of the W boson, or to the average transverse momentum of the produced jets, is typically used. The figure to the right shows the results of a simulation using the CKKW formalism. Branchings occur at the vertices with resolution parameters d_i, where $d_1 > d_2 > d_3 > d_4 > d_5 > d_6$ Branchings at the vertices 1-3 are produced with matrix element information while the branchings at vertices 4-6 are produced by the parton shower.



W + jets at the Tevatron

N jet multiplicity: compared on the left to a combined matrix element + parton shower description using the CKKW formalism for matching, and on the right to the CKKW and NLO predictions





Pop quiz

- What's the difference between the diagrams on the top and bottom?

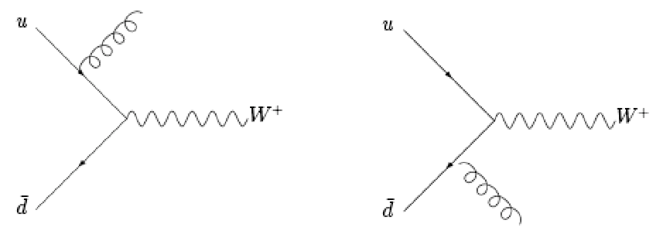


Figure 1. Lowest order diagrams for the production of a W and one jet at hadron colliders.

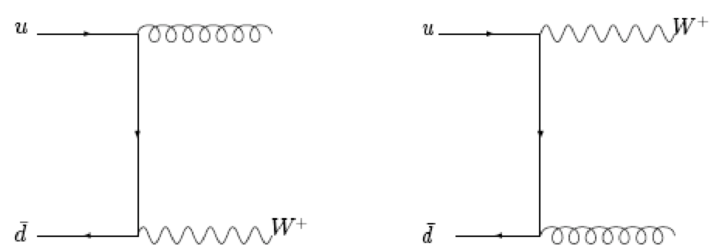
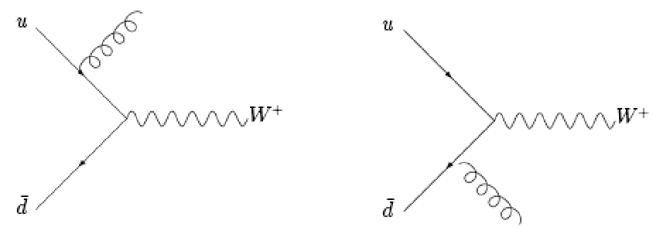


Figure 3. An alternative way of drawing the diagrams of Figure 1.

Pop quiz

- What's the difference between the diagrams on the top and bottom?
- Possible answers:
  a) the top is initial state radiation, the bottom are 2->2 processes



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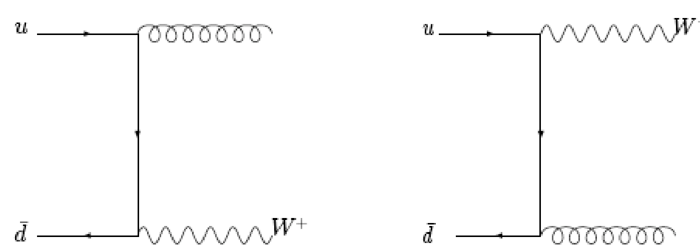

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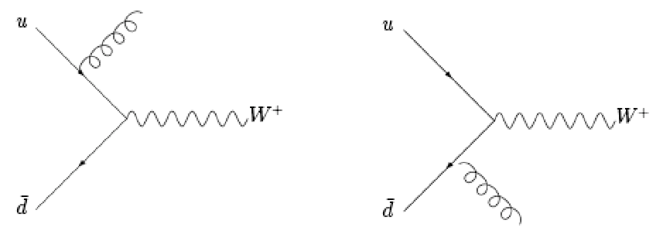

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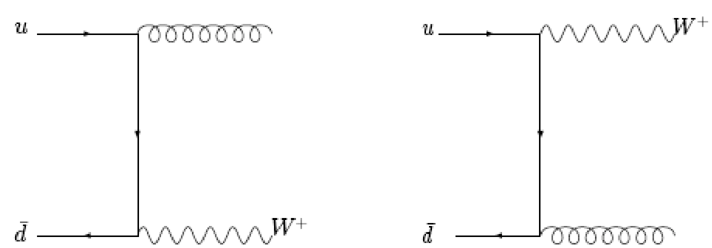

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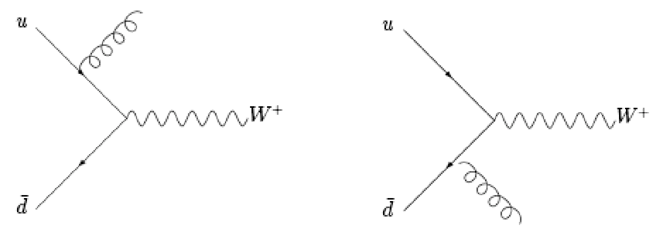

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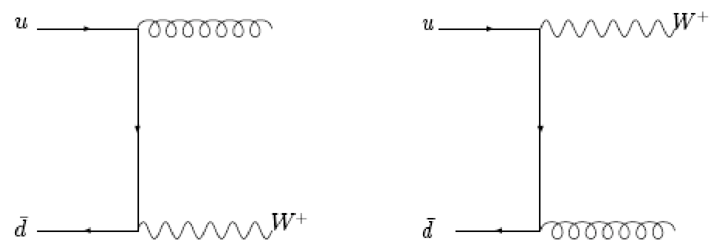

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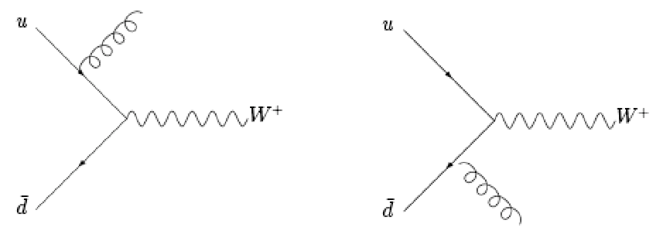

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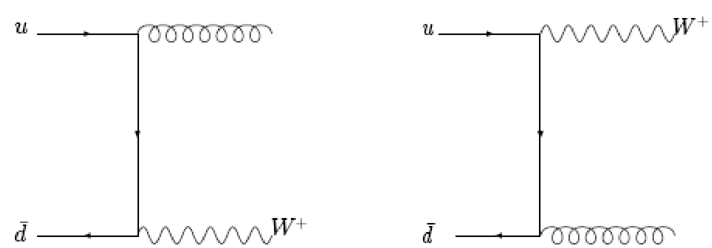

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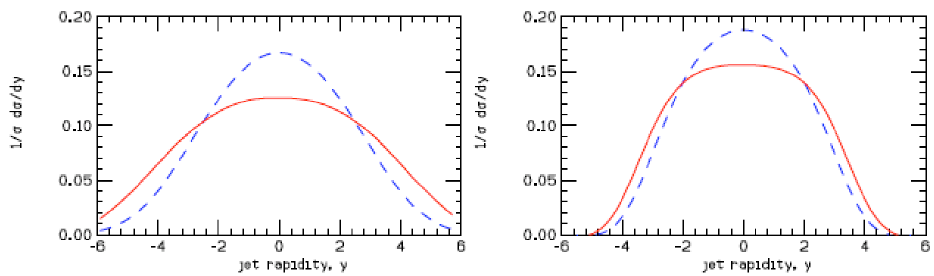
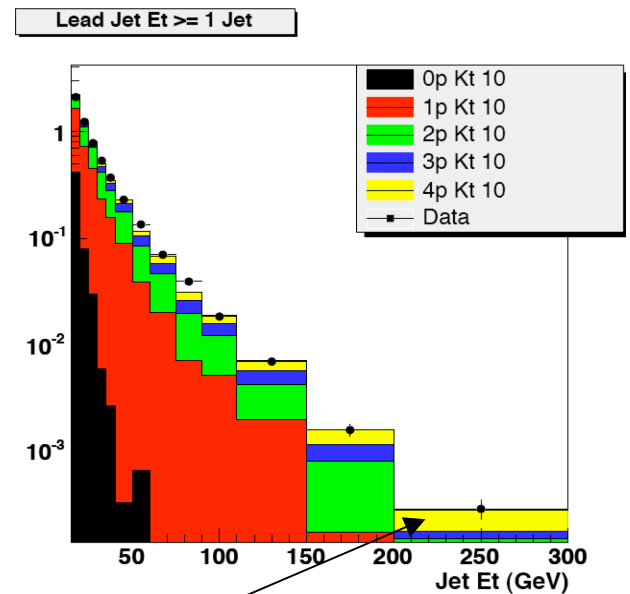


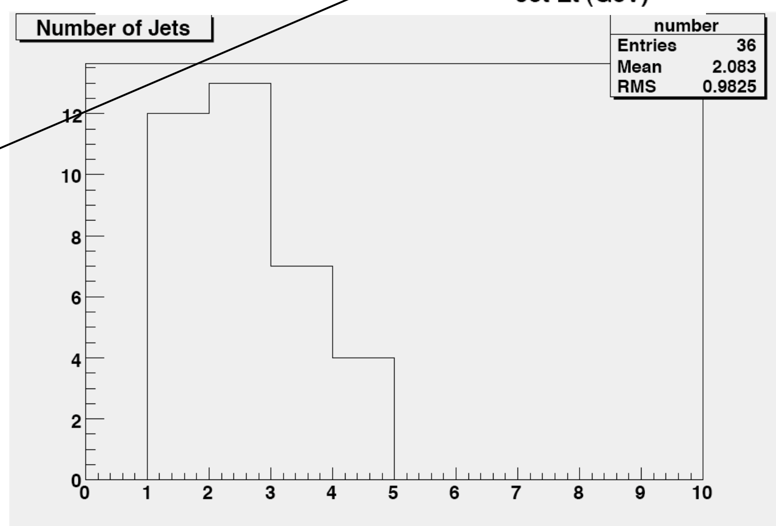
Figure 2. The rapidity distribution of the additional parton found in the real radiation corrections to Drell-Yan production of a W at the LHC. The parton is required to have a p_T larger than 2 GeV (left) or 50 GeV(right). Contributions from $q\bar{q}$ annihilation (solid red line) and the qg process (dashed blue line) are shown separately.

Myth: ISR is peaked in the forward direction. Not if you bin by p_T.

(Thou shalt) Listen to the logs[1]

- Look at W + >= 1 jet events and require the lead jet to have >200 GeV/c transverse energy
- What is the average jet multiplicity (>15 GeV/c) for these events?
  - 2.1
- It's not just α_s anymore; there's now also a large log (E_T^{jet1}/15 GeV/c) involved
  - in CKKW formalism, most of cross section for bin created by W + 4 parton matrix element
  - or another way of saying it is that there's a Sudakov suppression for any events that don't emit such additional hard gluons



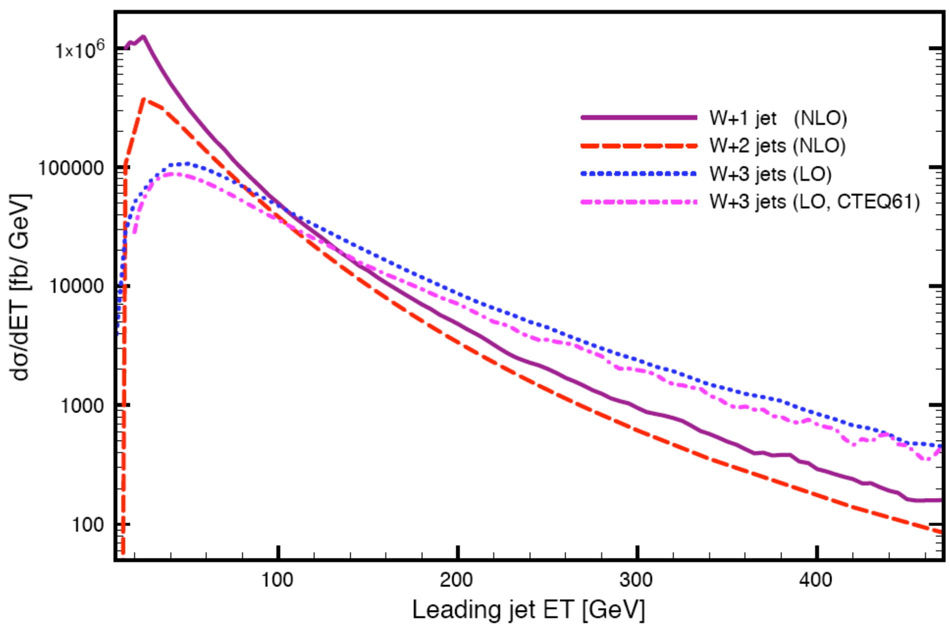


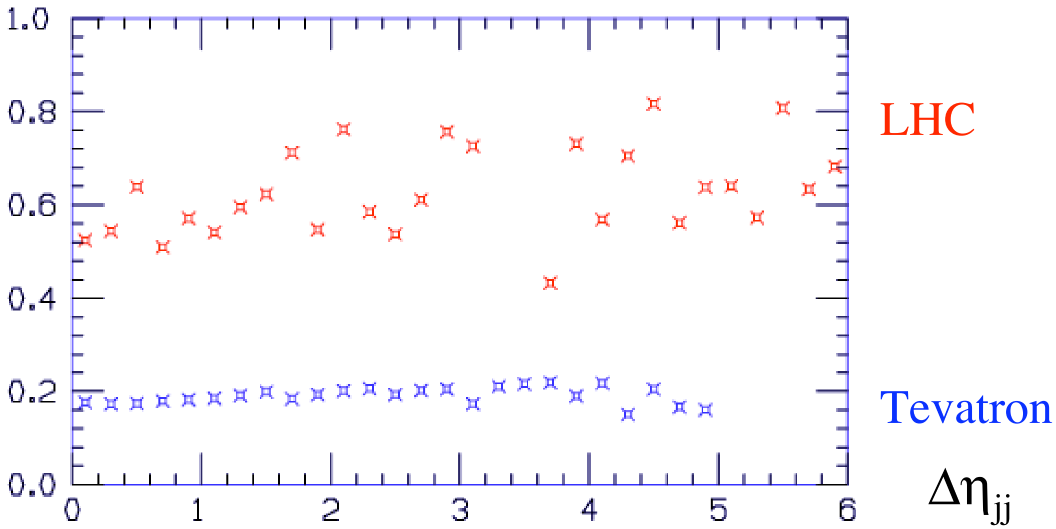
[1] an 11th commandment

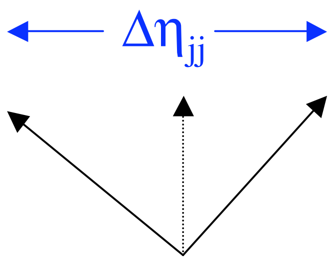
W + jets at LHC

- For high leading jet E_T, W + 3 jet is larger than W+ 2 jet
  - Sudakov suppression again
- Look at probability for 3rd jet to be emitted as a function of the rapidity separation of the tagging jets
  - relevant for VBF Higgs searches
- At LHC, ratio (p_T^{jet}>15 GeV/c) much higher than at Tevatron

$$\frac{\text{W+3 jet}}{\text{W+>=2 jet}}$$







Benchmark studies for LHC (from Les Houches 2005)

- Goal: produce predictions/event samples corresponding to 1 and 10 fb^{-1}
- Cross sections will serve as
  - benchmarks/guidebook for SM expectations in the early running
    - are systems performing nominally? are our calorimeters calibrated?
    - are we seeing signs of “unexpected” SM physics in our data?
    - how many of the signs of new physics that we undoubtedly will see do we really believe?
  - feedback for impact of ATLAS data on reducing uncertainty on relevant pdf’s and theoretical predictions
  - venue for understanding some of the subtleties of physics issues
- Has gone (partially) into Les Houches proceedings; hope to expand on it later
- *Companion* review article on hard scattering physics at the LHC by John Campbell, James Stirling and myself

Review paper

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

www.pa.msu.edu/~huston/seminars/Main.pdf

J. M. Campbell
Department of Physics and Astronomy
University of Glasgow
Glasgow G12 8QQ
United Kingdom

J. W. Huston
Department of Physics and Astronomy
Michigan State University
East Lansing, MI 48840
USA

W. J. Stirling
Institute for Particle Physics Phenomenology
University of Durham
Durham DH1 3LE
United Kingdom

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 behaviors 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.

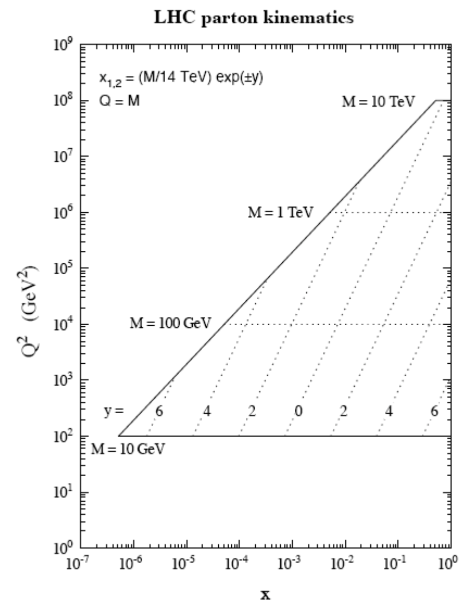
SM benchmarks for the LHC

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

Parton kinematics

- To serve as a handy “look-up” table, it’s useful to define a parton-parton luminosity
- Equation 3 can be used to estimate the production rate for a hard scattering at the LHC



$$\frac{dL_{ij}}{d\hat{s}\,dy} = \frac{1}{s}\,\frac{1}{1+\delta_{ij}}\,[f_i(x_1,\mu)f_j(x_2,\mu) + (1 \leftrightarrow 2)]\ . \tag{1}$$

The prefactor with the Kronecker delta avoids double-counting in case the partons are identical. The generic parton-model formula

$$\sigma = \sum_{i,j}\int_0^1 dx_1\,dx_2\,f_i(x_1,\mu)\,f_j(x_2,\mu)\,\hat{\sigma}_{ij} \tag{2}$$

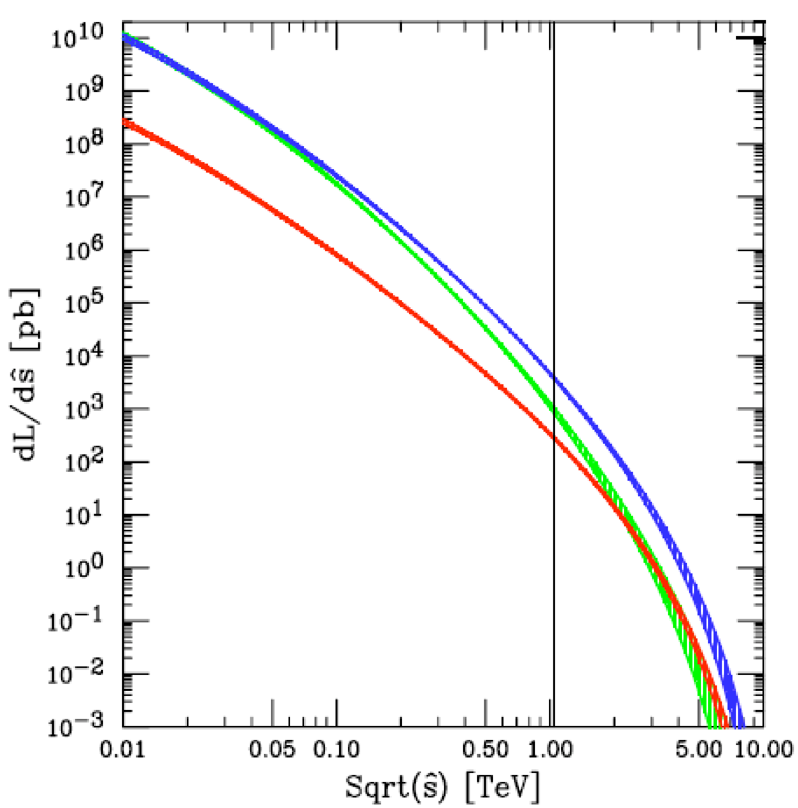
can then be written as

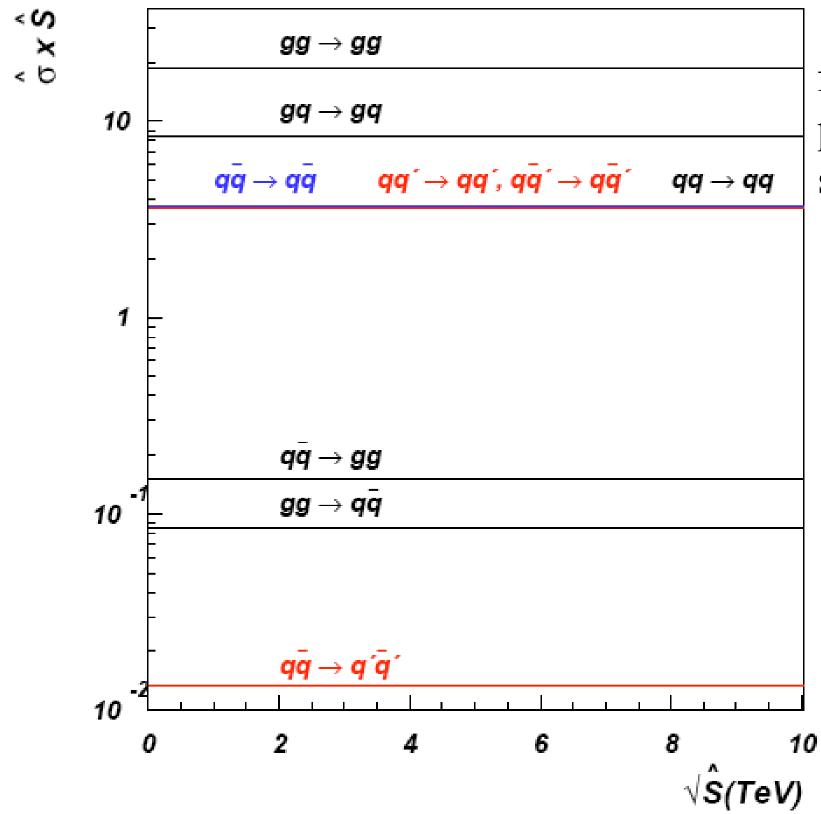
$$\sigma = \sum_{i,j}\int \left(\frac{d\hat{s}}{\hat{s}}\,dy\right)\left(\frac{dL_{ij}}{d\hat{s}\,dy}\right)(\hat{s}\,\hat{\sigma}_{ij})\ . \tag{3}$$

Cross section estimates

$$\sigma = \frac{\Delta \hat{s}}{\hat{s}} \left(\frac{dL_{ij}}{d\hat{s}} \right) (\hat{s}\, \hat{\sigma}_{ij})$$

for the gluon pair production rate for $\hat{s}$=1 TeV and $\Delta \hat{s} = 0.01\hat{s}$, we have $\frac{dL_{gg}}{d\hat{s}} \simeq 10^3$ pb and $\hat{s}\, \hat{\sigma}_{gg} \simeq 20$ leading to $\sigma \simeq 200$ pb





for p_T=0.1* sqrt(s-hat)

Fig. 2: Left: 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=$d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$. Right: parton level cross sections $[\hat{s}\hat{\sigma}_{ij}]$ for various processes

Luminosities as a function of y

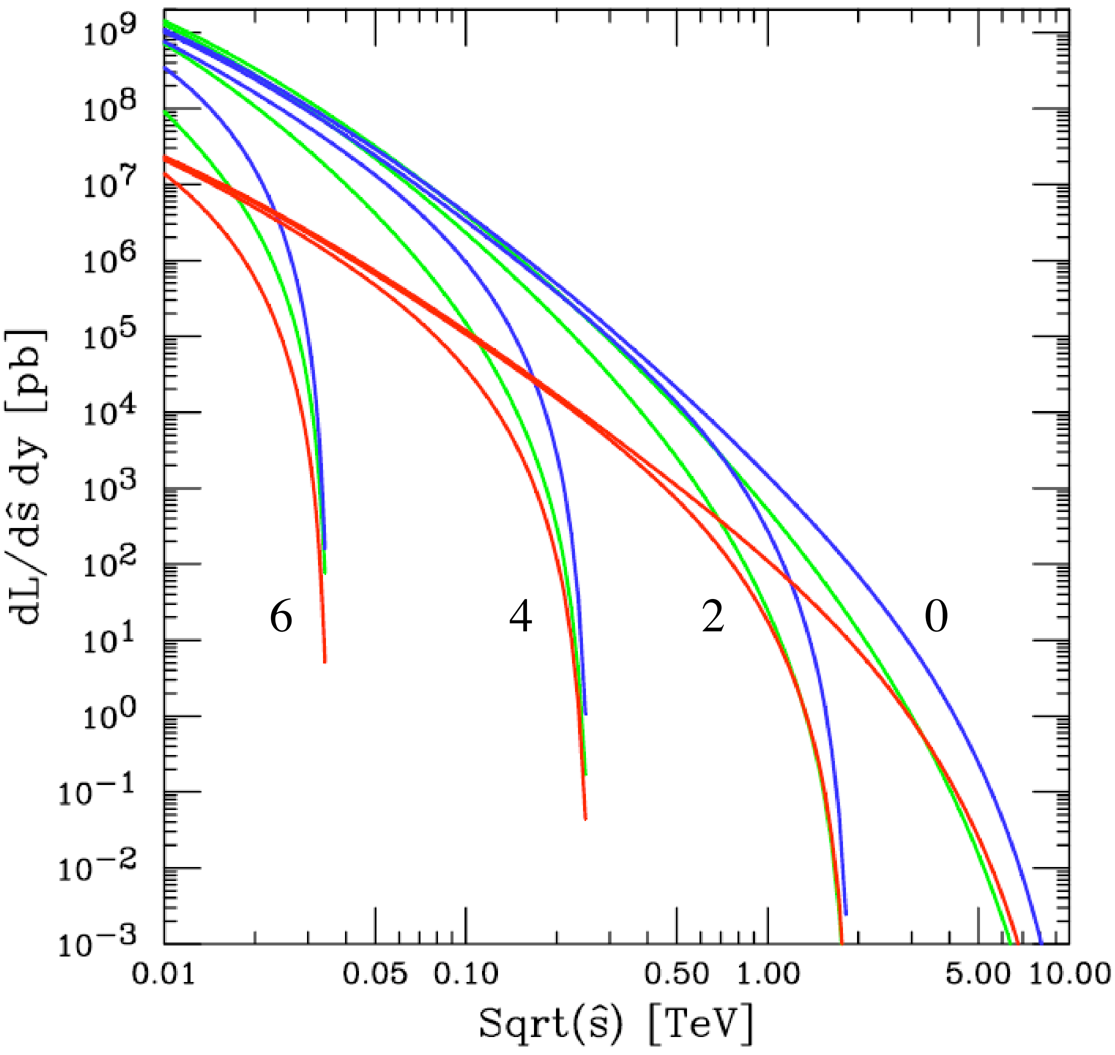


Fig. 3: dLuminosity/dy at $y = 0, 2, 4, 6$. Green=gg, Blue=$g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$, Red=$d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$.

LHC to Tevatron pdf luminosities

- Processes that depend on qQ initial states (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
- 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 (30-40 GeV/c rather than 15 GeV/c)

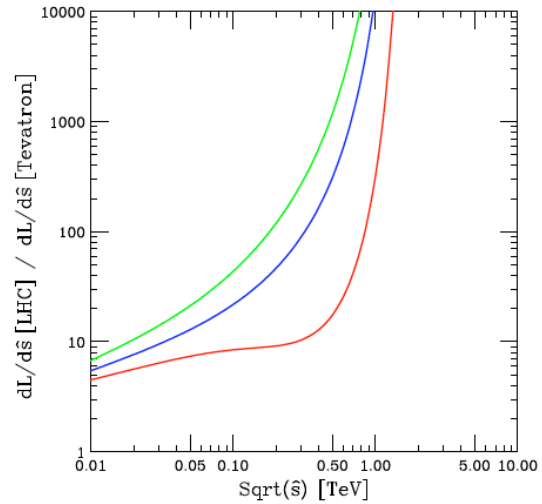


Figure 11. The ratio of parton-parton luminosity $\left[\frac{1}{\hat{s}}\frac{dL_{ij}}{d\tau}\right]$ in pb integrated over y at the LHC and Tevatron. Green=gg (top), Blue=$g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$ (middle), Red=$d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u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

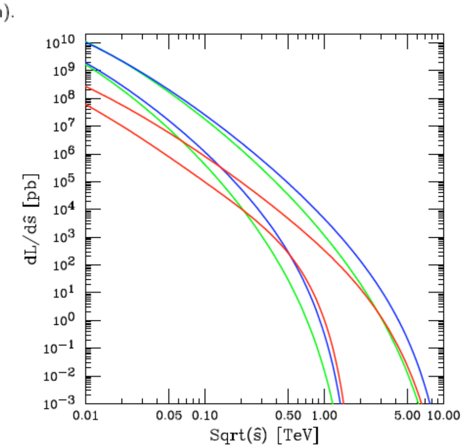


Figure 10. The parton-parton luminosity $\left[\frac{1}{\hat{s}}\frac{dL_{ij}}{d\tau}\right]$ in pb integrated over y. Green=gg, Blue=$g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$, Red=$d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$.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

gg luminosity uncertainties

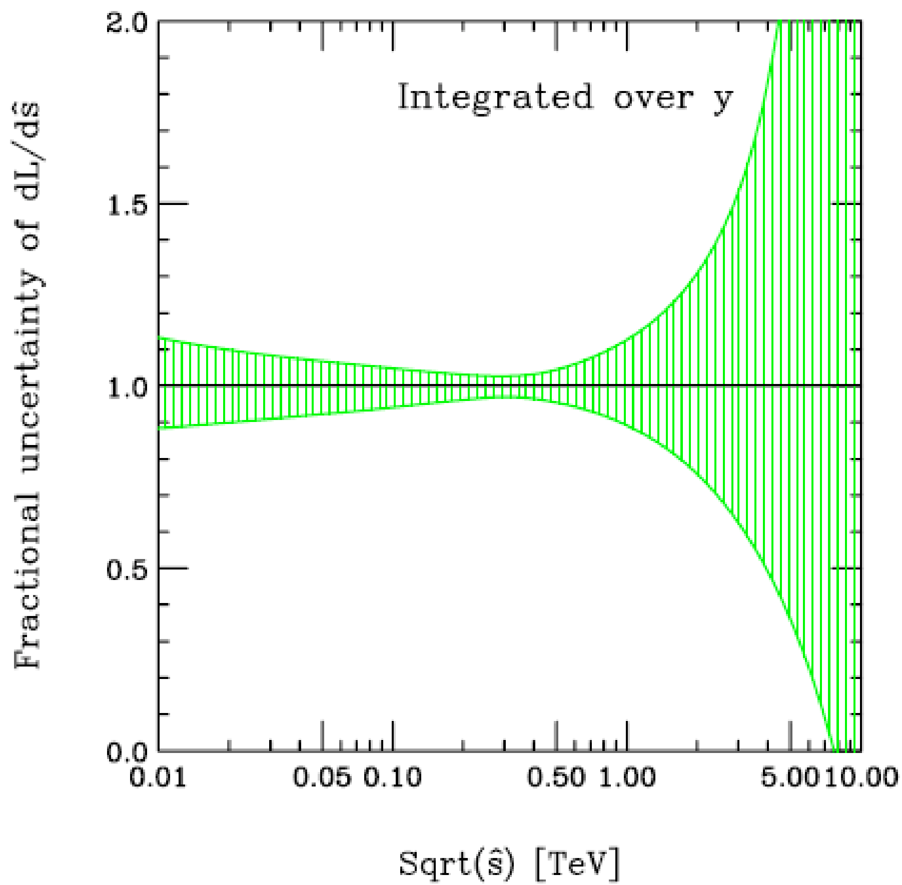


Fig. 4: Fractional uncertainty of gg luminosity integrated over y.

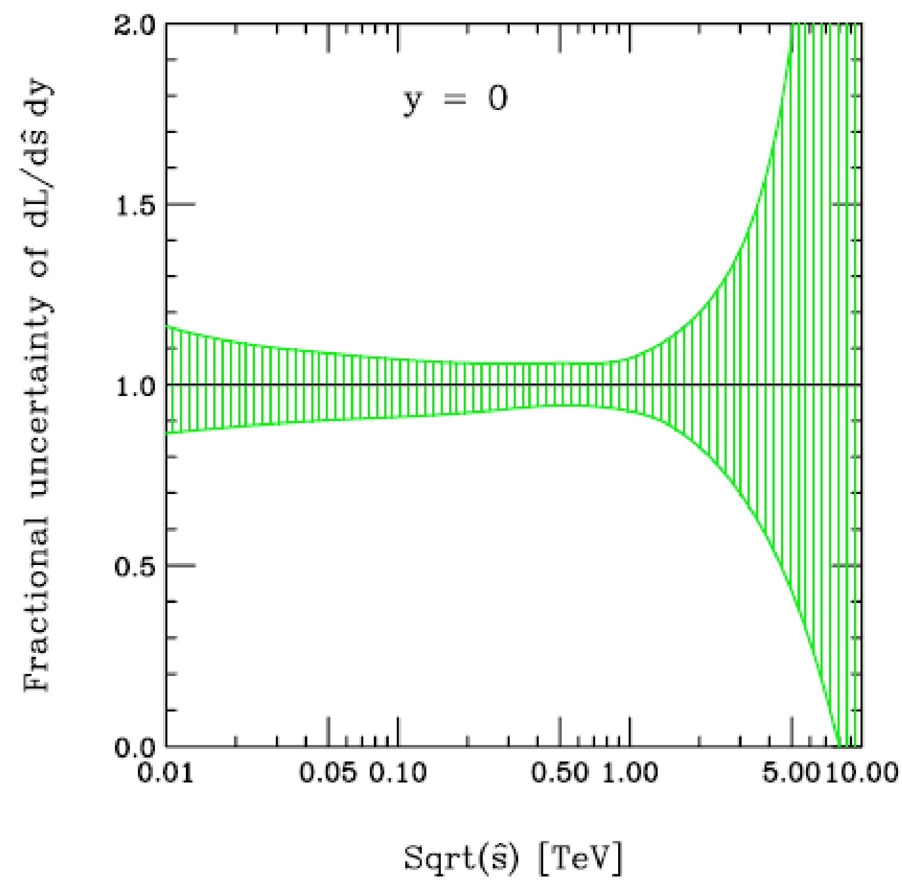


Fig. 5: Fractional uncertainty of gg luminosity at $y = 0$.

…more in extra slides at end of talk

The "maligned" experimenter's 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

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

- Note have to specify how inclusive final state is
  - what cuts will be made?
  - how important is b mass for the observables?
- How uncertain is the final state?
  - what does scale uncertainty look like at tree level?
  - new processes coming in at NLO?
- Some information may be available from current processes
  - pp->tT j may tell us something about pp->tTbB?
    - j=g->bB
  - CKKW may tell us something about higher multiplicity final states

can we develop rules-of-thumb about size of HO corrections?

1. pp->WW jet
2. pp->H + 2 jets now complete
   1. background to VBF production of Higgs
3. pp->tT bB
   1. background to tTH
4. pp->tT + 2 jets
   1. background to tTH
5. pp->WWbB
6. pp->V V + 2 jets
   1. background to WW->H->WW
7. pp->V + 3 jets
   1. beneral background to new physics
8. pp->V V V
   1. background to SUSY trilepton

Are there any other cross sections that should be on this list?

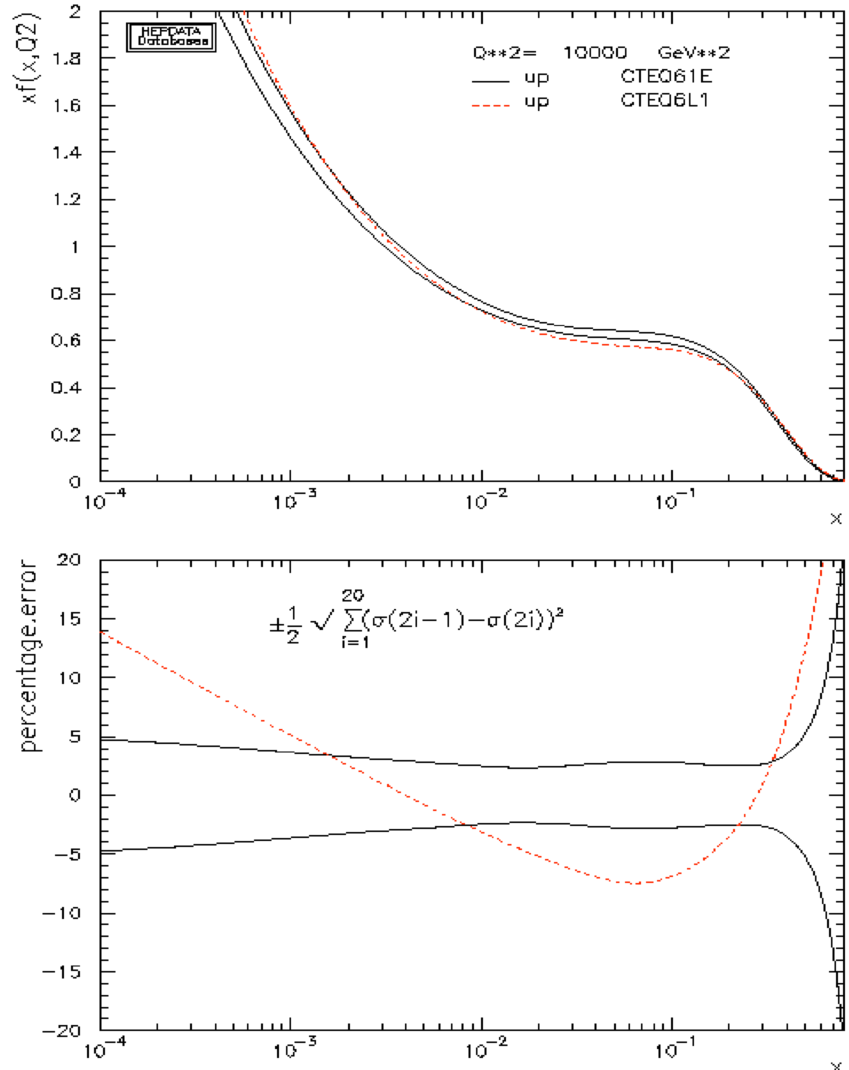
Summary

- Now is the time to set up the SM tools and measurement program we need for the first few years of the LHC running
  - still great deal of preparation for early SM analyses needed
- Theoretical program to develop a broad range of tools for LHC
  - up to us (experimentalists) to make use of them/drive the development of what we need
- Program for SM benchmarks for LHC underway
  - www.pa.msu.edu/~huston/Les_Houches_2005/Les_Houches_SM.html
- Review paper available in almost final form
  - www.pa.msu.edu/~huston/seminars/Main.pdf
  - one of the authors has been honored in advance for his role on the paper

- Once LHC turns on, everything is going to move quickly
- The detector is going to be "as is" and constantly changing
  - "We take data not with the detector we want, but with the detector we have."

LO vs NLO pdf's for parton shower MC's

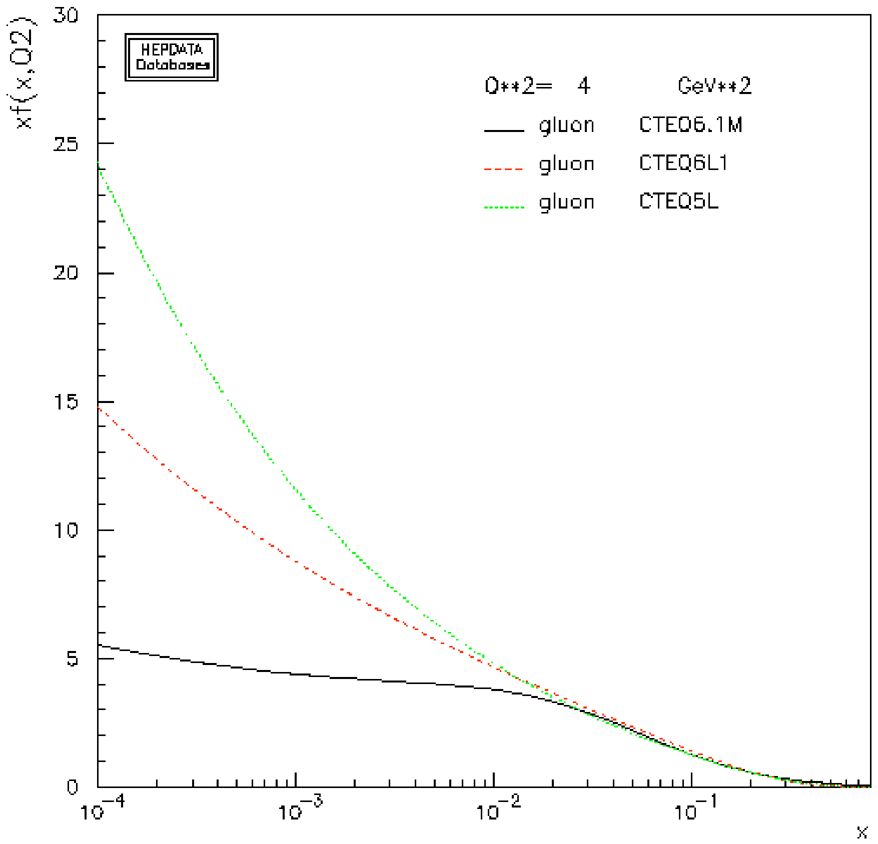
- For NLO calculations, use NLO pdf's (duh)
- What about for parton shower Monte Carlos?
    - somewhat arbitrary assumptions (for example fixing Drell-Yan normalization) have to be made in LO pdf fits
    - DIS data in global fits affect LO pdf's in ways that may not directly transfer to LO hadron collider predictions
    - LO pdf's for the most part are outside the NLO pdf error band
    - LO matrix elements for many of the processes that we want to calculate are not so different from NLO matrix elements
    - by adding parton showers, we are partway towards NLO anyway
    - any error is formally of NLO
- (my recommendation) <u>use NLO pdf's</u>
    - pdf's must be + definite in regions of application (CTEQ is so by def'n)
- Note that this has implications for MC tuning, i.e. Tune A uses CTEQ5L
    - need tunes for NLO pdf's



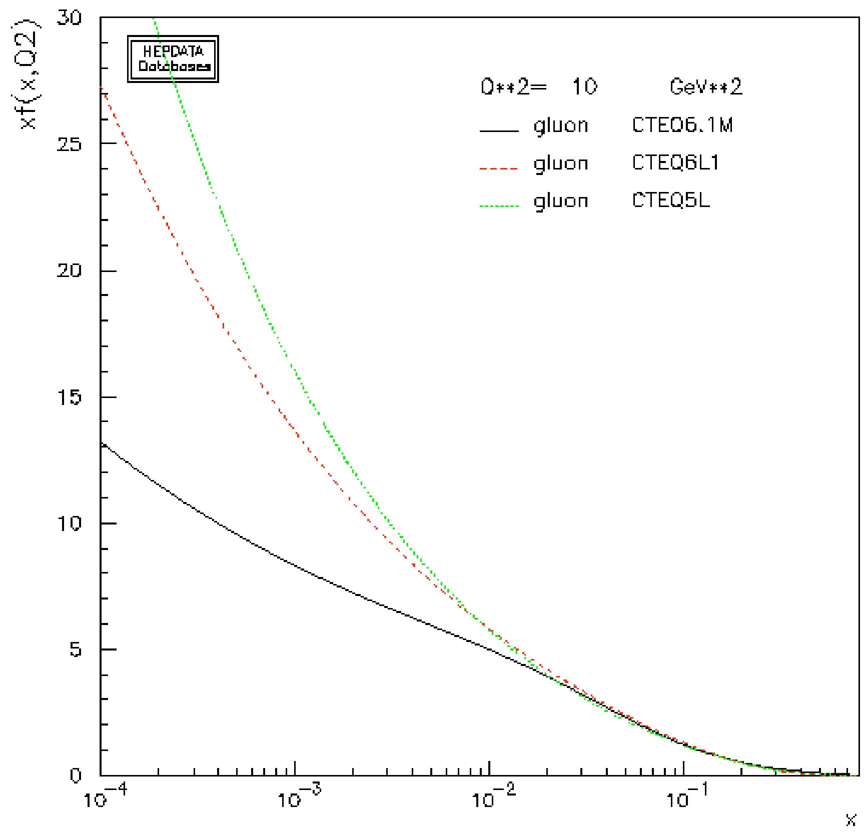
. . .but at the end of the day this is still LO physics;

There's no substitute for honest-to-god NLO.

Impact on UE tunes



- 5L significantly steeper at low x and Q^2
- Rick Field has produced a tune based on CTEQ6.1



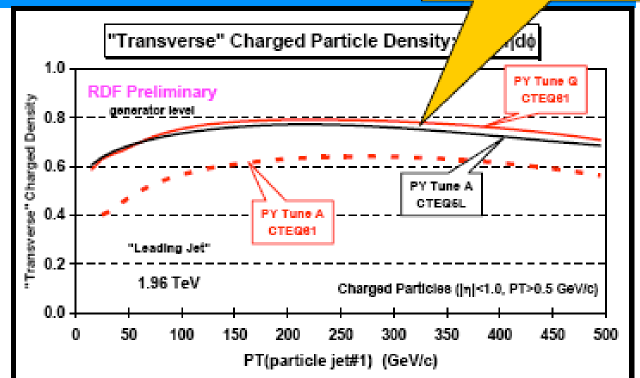
Rick’s tune

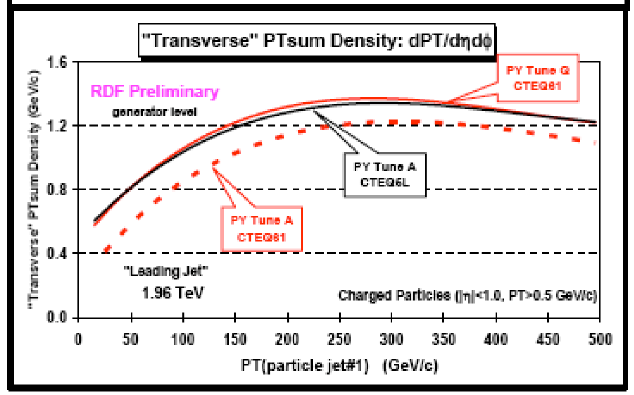
CTEQ6.1 Tune

I used LHAPDF! See the next talk by Craig Group!

PYTHIA 6.2 CTEQ6.1

	Parameter	Tune Q	Tune QW
UE Parameters	MSTP(81)	1	1
	MSTP(82)	4	4
	PARP(82)	1.2 GeV	1.2 GeV
	PARP(83)	0.5	0.5
	PARP(84)	0.4	0.4
	PARP(85)	0.9	0.9
	PARP(86)	0.95	0.95
	PARP(89)	1.8 TeV	1.8 TeV
	PARP(90)	0.25	0.25
ISR Parameters	PARP(62)	1.0	1.25
	PARP(64)	1.0	0.2
	PARP(67)	4.0	4.0
Intrensic KT	MSTP(91)	1	1
	PARP(91)	1.0	2.1
	PARP(92)	5.0	15.0





TeV4LHC - Fermilab
October 20, 2005

Rick Field - Florida/CDF

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…will be discussed in detail in TeV4LHC writeup

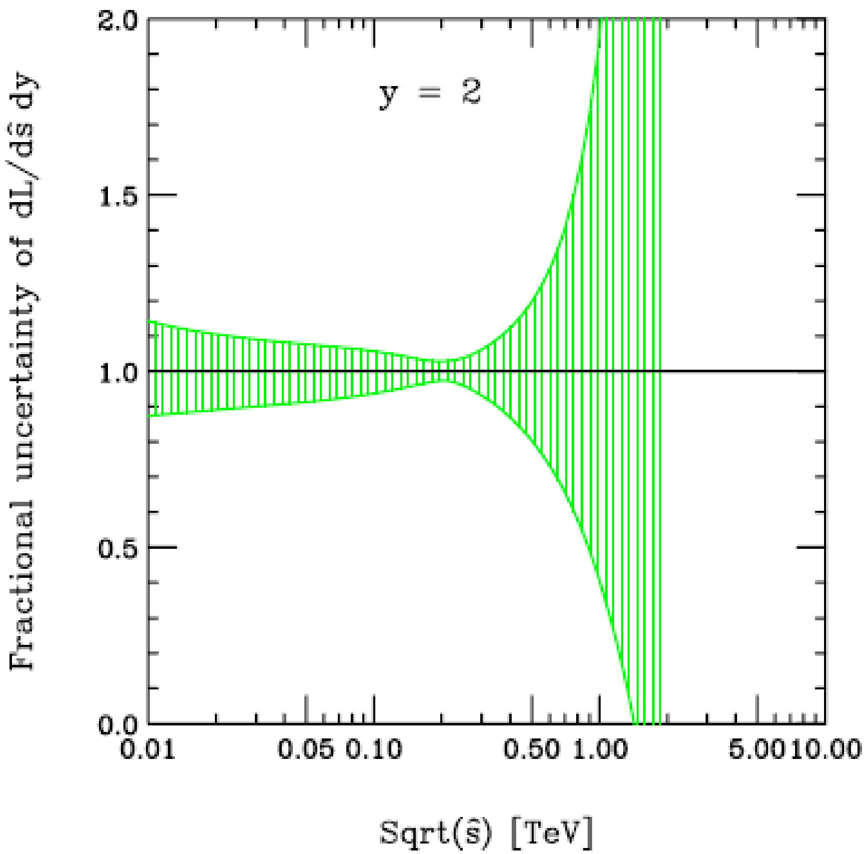
More…

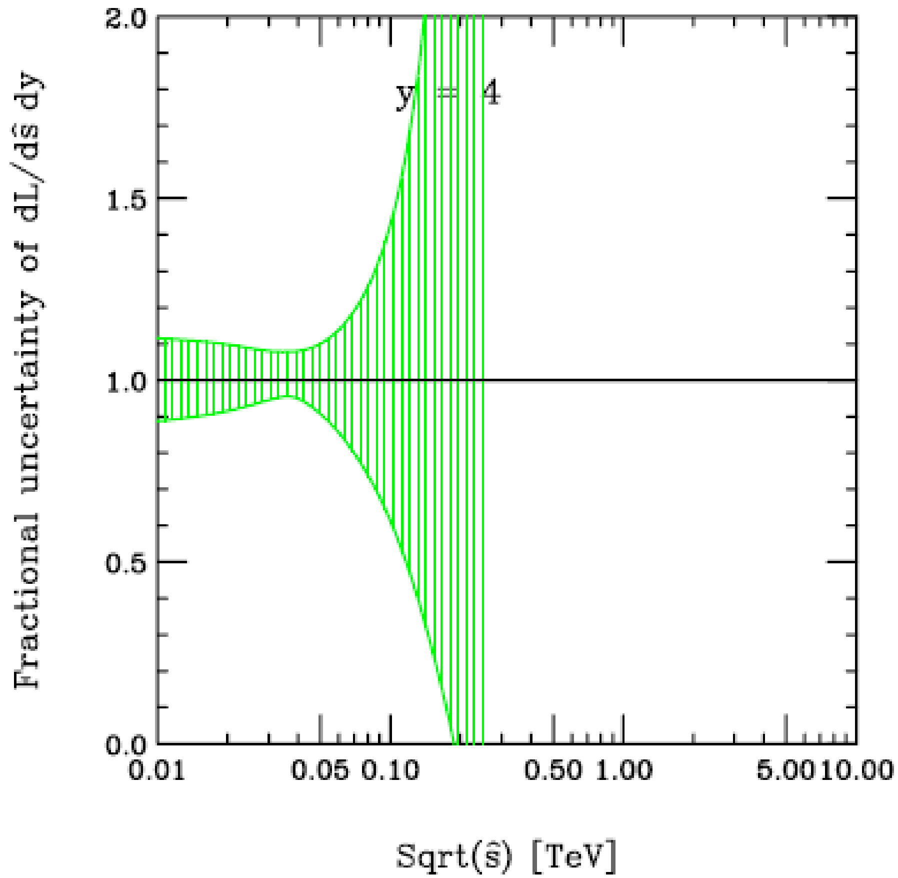
- technical benchmarks
  - jet algorithm comparisons
    - midpoint vs simple iterative cone vs kT
      - top studies at the LHC
      - an interesting data event at the Tevatron that examines different algorithms
    - Building Better Cone Jet Algorithms
      - one of the key aspects for a jet algorithm is how well it can match to perturbative calculations; here is a 2-D plot for example that shows some results for the midpoint algorithm and the CDF Run 1 algorithm (JetClu)
      - here is a link to Fortran/C++ versions of the CDF jet code
  - fits to underlying event for 200 540, 630, 1800, 1960 GeV data
    - interplay with ISR in Pythia 6.3
    - establish lower/upper variations
    - extrapolate to LHC
    - effect on target analyses (central jet veto, lepton/photon isolation, top mass?)

…plus more benchmarks that I have no time to discuss

- variation of ISR/FSR a la CDF (study performed by Un-Ki Yang)
  - low ISR/high ISR
  - FSR
- power showers versus wimpy showers a la Peter Skands
- number of additional jets expected due to ISR effects (see also Sudakov form factors)
- impact on top analyses
- effect on benchmarks such as Drell-Yan and diphoton production
  - goal is to produce a range for ISR predictions that can then be compared at the LHC to Drell-Yan and to diphoton data
- Sudakov form factor compilation
  - probability for emission of 10, 20, 30 GeV gluon in initial state for hard scales of 100, 200, 500, 1000, 5000 GeV for quark and gluon initial legs
  - see for example, similar plots for quarks and gluons for the Tevatron from Stefan Gieseke
- predictions for W/Z/Higgs p_T and rapidity at the LHC
  - compare ResBos(-A), joint-resummation and Berger-Qiu for W and Z

gg luminosity uncertainties





gq luminosity uncertainties

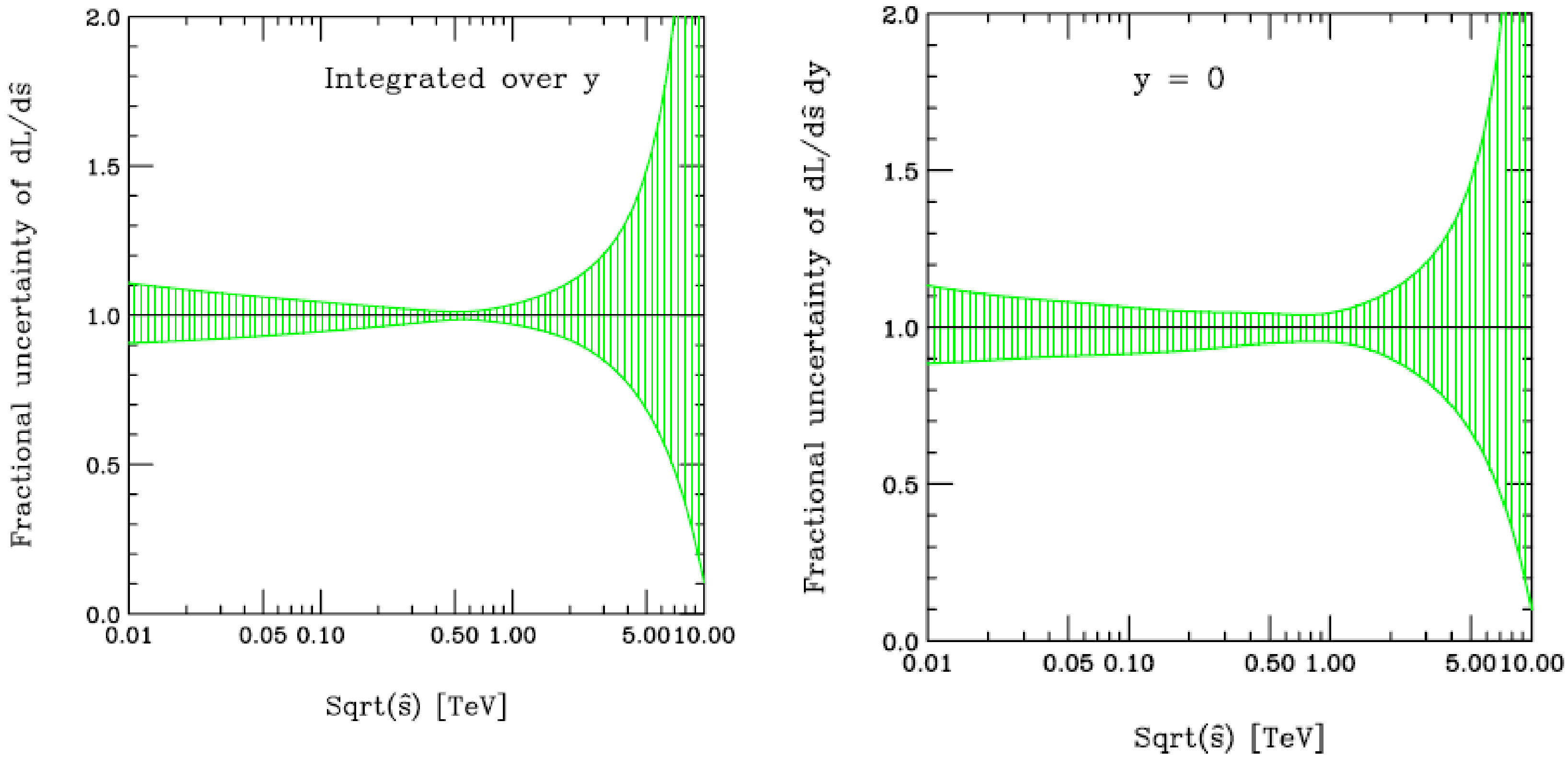
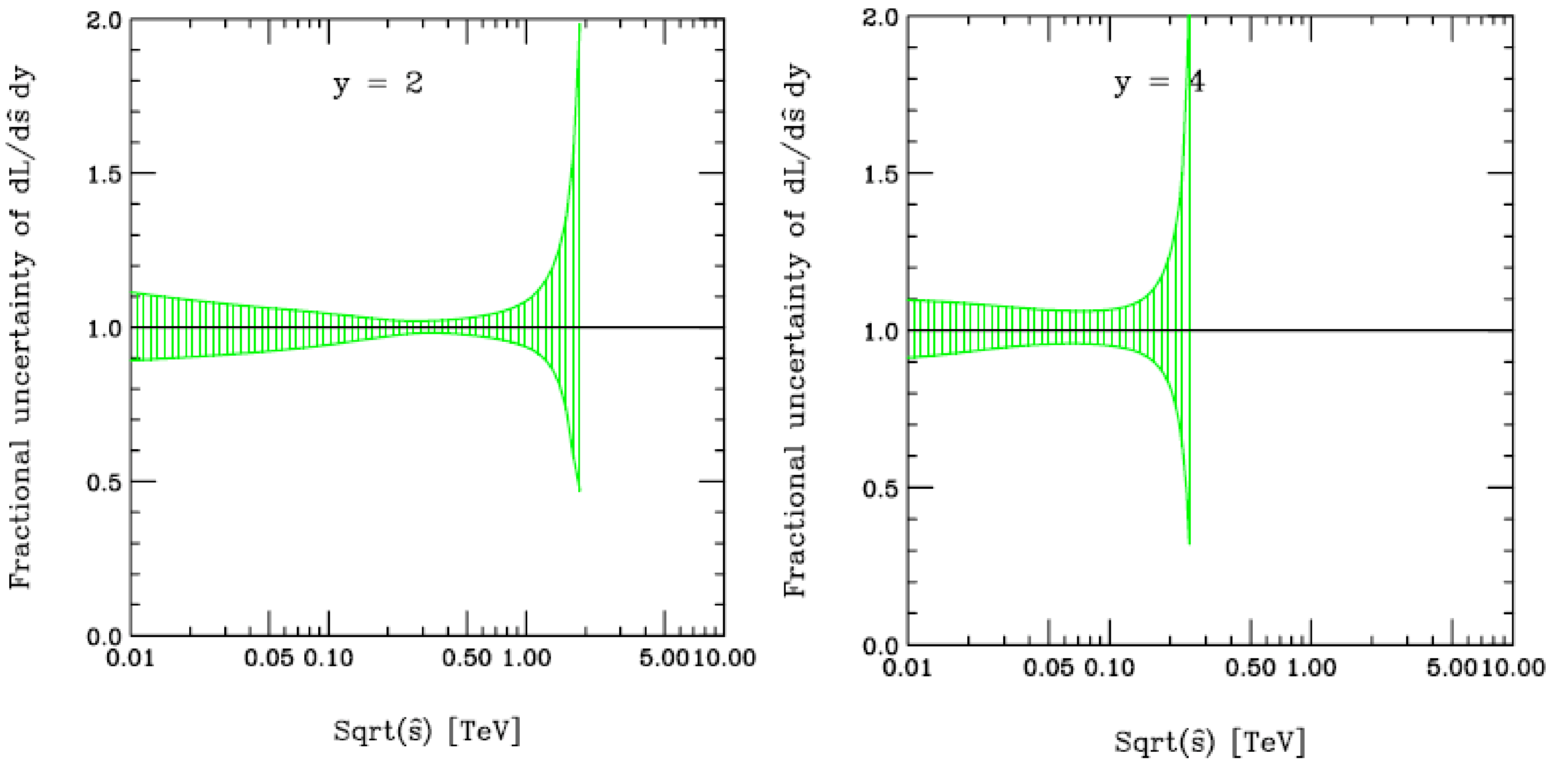
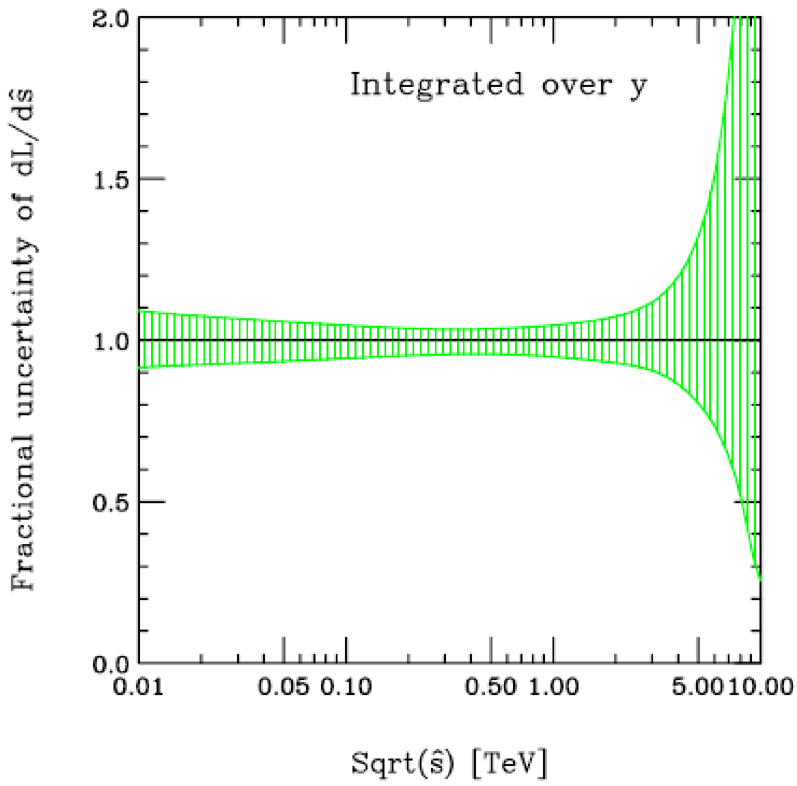


Fig. 6: Fractional uncertainty for Luminosity integrated over y for $g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$,

gq luminosity uncertainties



qQ luminosity uncertainties



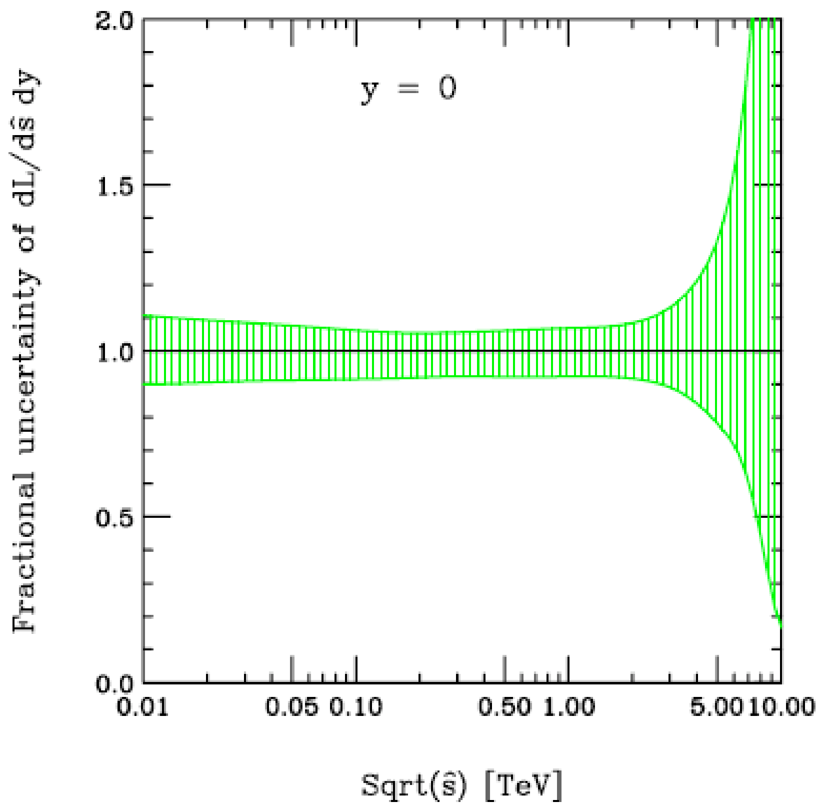


Fig. 7: Fractional uncertainty for Luminosity integrated over y for $d\bar{d} + u\bar{u} + s\bar{s} + c\bar{c} + b\bar{b} + \bar{d}d + \bar{u}u + \bar{s}s + \bar{c}c + \bar{b}b$.

qQ luminosity uncertainties