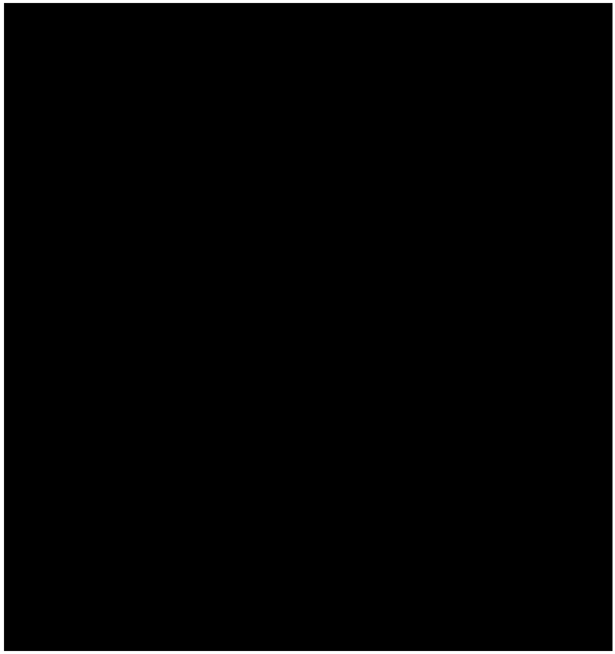
QCD Summary Report

S. Ellis

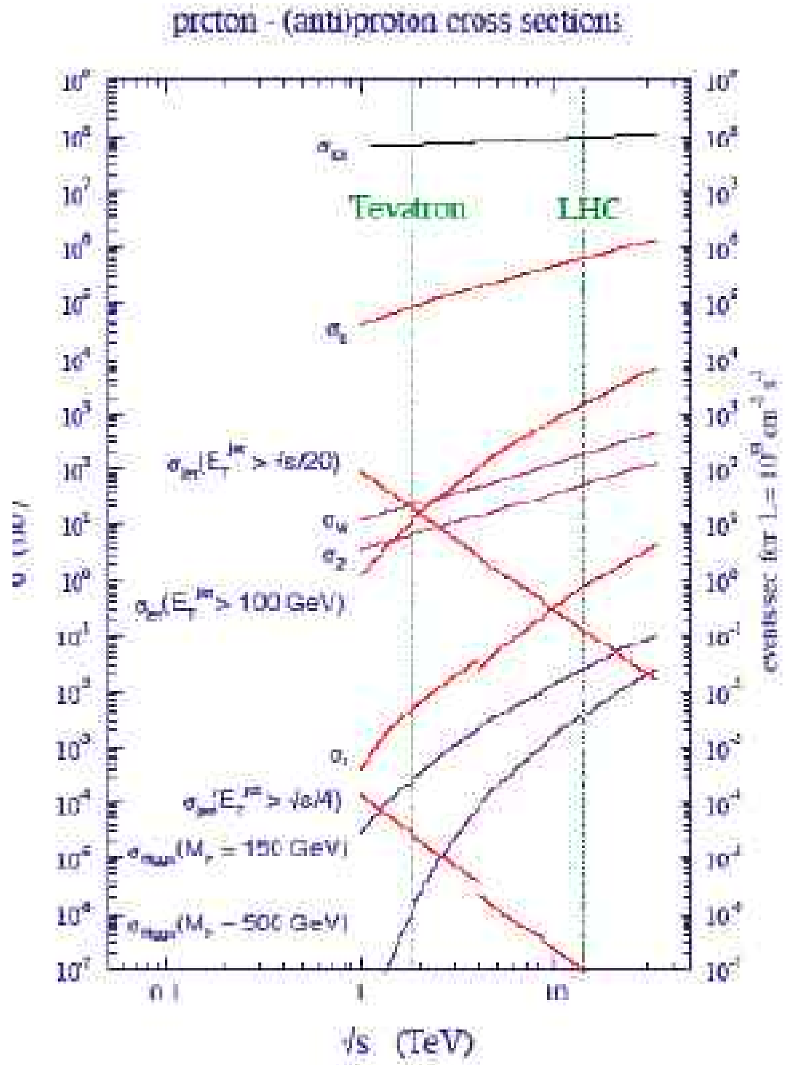
U. of Washington

“Gee, I sure hope Joey wrote me a good talk.”



SM physics

- Before we publish new physics at the LHC, we need to understand SM physics
- A lot of prior knowledge can come from the Tevatron



QCD Group

- Most of the tools we want to use/develop in this workshop are QCD-related
  - ME/MC generation
  - NLO
  - jet algorithms
  - pdf's and pdf uncertainties
  - …

QCD Physics group goals

- QCD sub-groups
  - pdf's and event classification
    - extraction of pdf's purely at high-momentum transfers
    - establishment of jet contracts between experiments and theorists
    - subtleties and practicalities of jet algorithms
  - hard scattering and hadronization
    - testing of matrix element-parton showering matching
    - underlying event tunes and model development
    - tests of hadronization and tunes/universality of tunes
  - diffraction

- Top and Electroweak
  - top production and decay
  - analysis techniques
  - improved tagging strategies

great deal of overlap
…and that's why much of our parallel session time here (and in other TeV4LHC meetings) was spent in joint meeting

Conveners and info

- QCD conveners
  - M. Albrow, F. Chlebana, A. de Roeck, S. Ellis, W. Giele, J. Huston, W. Kilgore, S. Mrenna, W.K. Tung, M. Wobisch, M. Zielinski
    - Goal is to have a large group just by staffing it with conveners
- Group website
  - www.pa.msu.edu/~huston/tev4lhc/wg.html
- Many presentations over the course of 4 meetings at Fermilab, Brookhaven and CERN as well as in several interim group meetings

Outline for final report

1. Introduction/motivation
2. PDF's:tools and issues
    1. fastNLO
    2. LHAPDF
        1. pdf reweighting techniques
        2. Sudakov FF's
    3. CTEQ α_s series and CTEQ7
    4. use of NLO pdf's (MC's)
3. Monte Carlo parameters
    1. underlying event tuning at the Tevatron
        1. Pythia and Jimmy
        2. CTEQ6.1
    2. extrapolation to the LHC: predictions and uncertainties
5. Matrix element/parton shower tools
    - W+jets: CKKW/MCFM comparisons to data
    - extrapolation to the LHC: backgrounds to VBF
    - Samper case study: Higgs + 2 jets
6. Jet production
    - MC@NLO: inclusive jet production
    - jet algorithms:advice for the LHC
7. Diffraction
8. White paper on remaining measurements at the Tevatron
9. SM Benchmarks for the LHC
    - relation to Tevatron measurements
10. Conclusions

C. Group: LHAPDF

LHAPDF/LHAGLUE

- The Les Houches Accord PDF library is replacement for PDFLIB.
- LHAGLUE is a “PDFLIB-like” interface for HERWIG and PYTHIA

→ See talk by J. Huston (Dec.1 2005 QCD working group) for summary of LHAPDF and LHAGLUE.

LHAPDF

LHAPDF V5 coming soon!

- Will be possible to keep PDFs from multiple sets stored in memory.
- Feedback from Tevatron experiments implemented
  - pftopdg.f added from PDFLIB.
    - Some CDF and D0 programs use this.
    - pftopdg converts flavor convention of PDFLIB to PDG convention
  - Various generic names changed to be unique to LHAPDF

    These are only internal names which do NOT affect the average user.
- NEW: LHAPDF v5 available ups/upd at FNAL...
  - "lhapdf" "v5_0_0_beta" "Linux+2.4 2.3.2" "GCC3_4_3" "development"
  - "lhapdf_source" "v5_0_0_beta" "NULL" "" "development"

  → Thanks to Lynn Garren!
- Please check v5! Your suggestions/problems can still be dealt with in v5.

→ CDF and D0 use will help validate and develop tools and ideas that will also be useful to the LHC. This is important!

LHAPDF

Implementing the weighting technique for PYTHIA

- Two options for using the weight technique
  - Store 40 weights for each event (we do it this way).
  - Store X_1, X_2, F_1, F_2, and Q^2 and calculate the weights "offline".
- Momentum fractions for the 2 initial partons from the hard scattering

$$X_1 = PARI(33) \text{ and } X_2 = PARI(34)$$

- Flavor type of 2 initial partons

$$F_1 = MSTI(15) \text{ and } F_2 = MSTI(16)$$

- Q^2 for the hard scattering

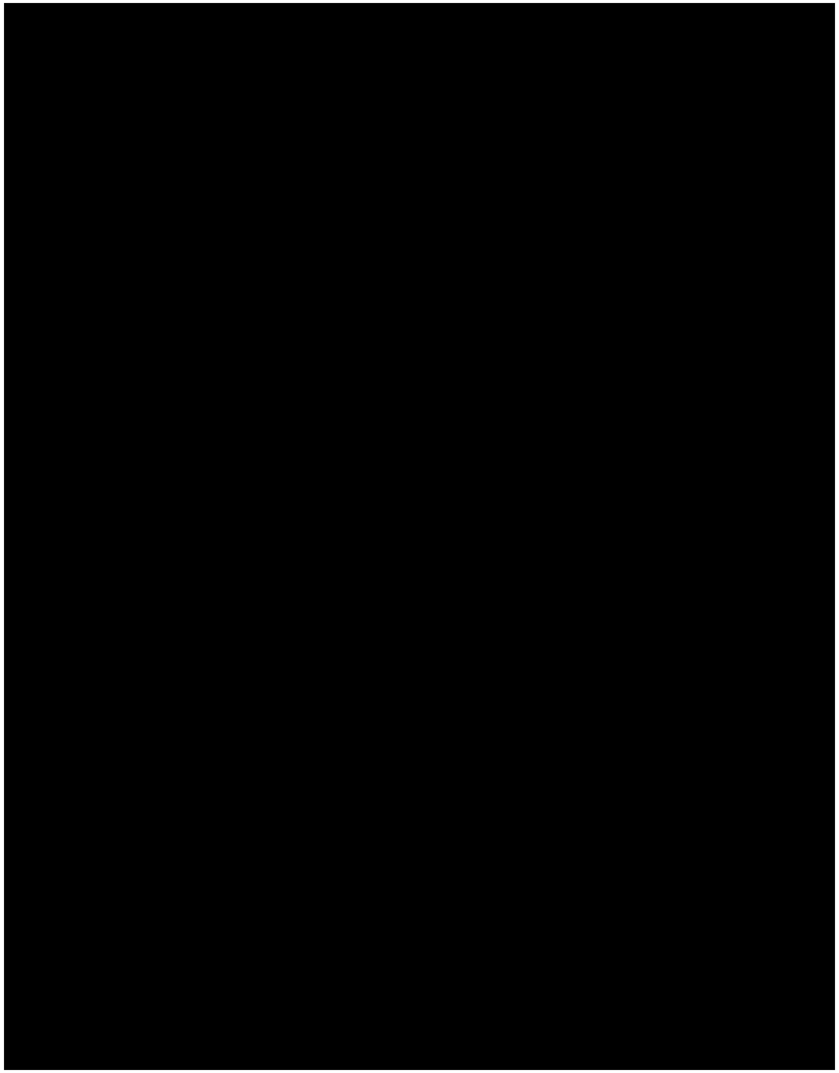
$$Q^2 = PARI(24)$$

This is everything you need to calculate PDF weights using LHAPDF, but we are in the process of writing a general robust code for all users, so you won't have to.

→ Thanks to Torbjorn Sjostrand for the PYTHIA help!

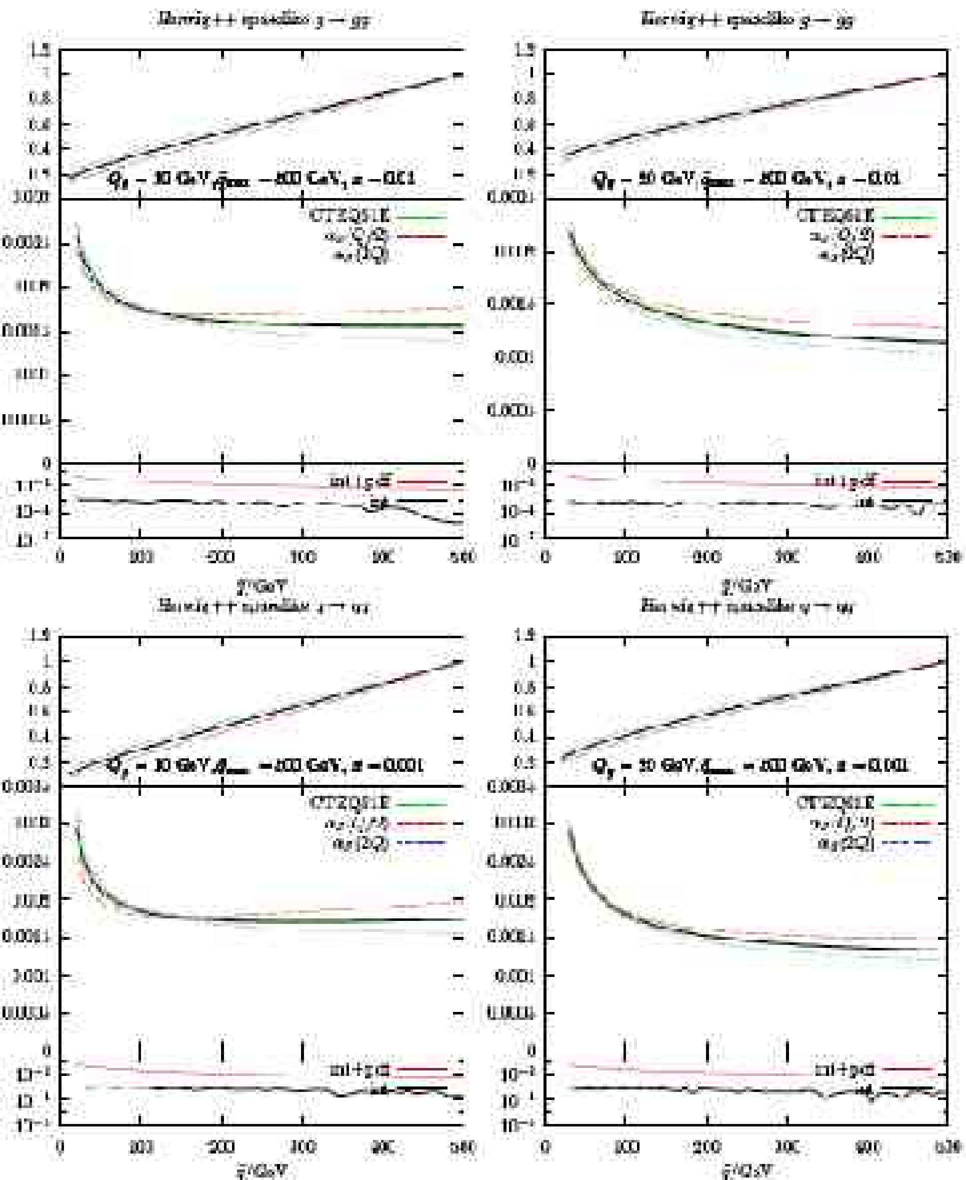
J. Huston: LO vs NLO pdf's for parton shower MC's

- 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) use NLO pdf's
  - 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.

Uncertainties on Sudakov form factors

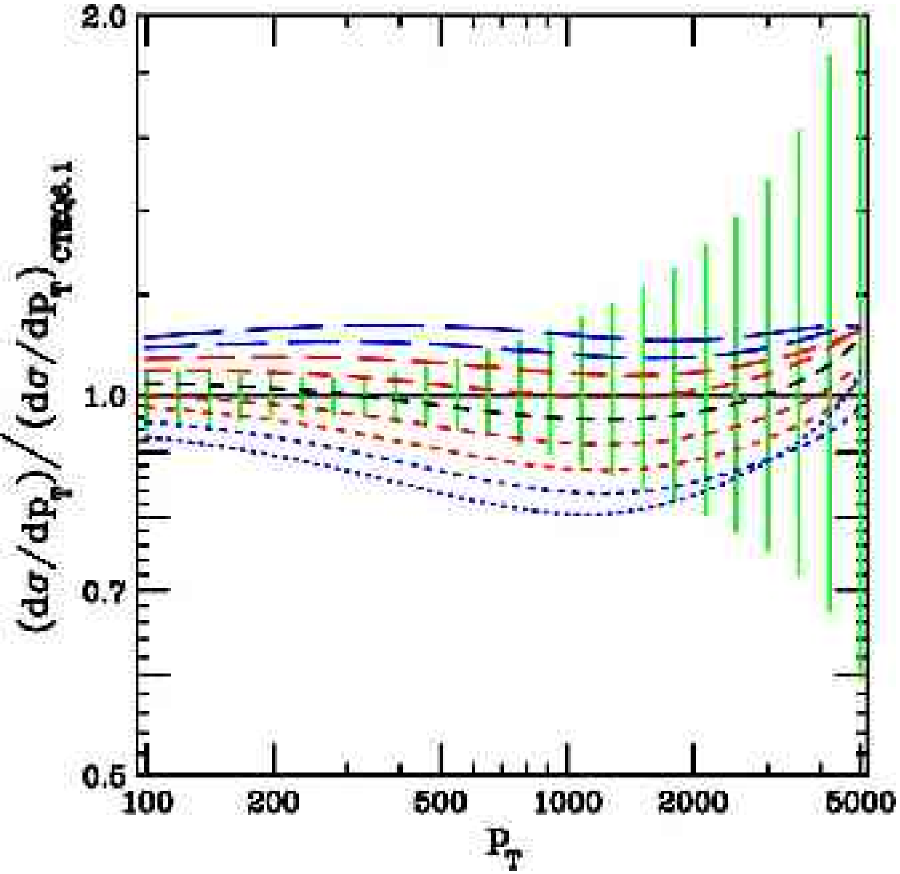


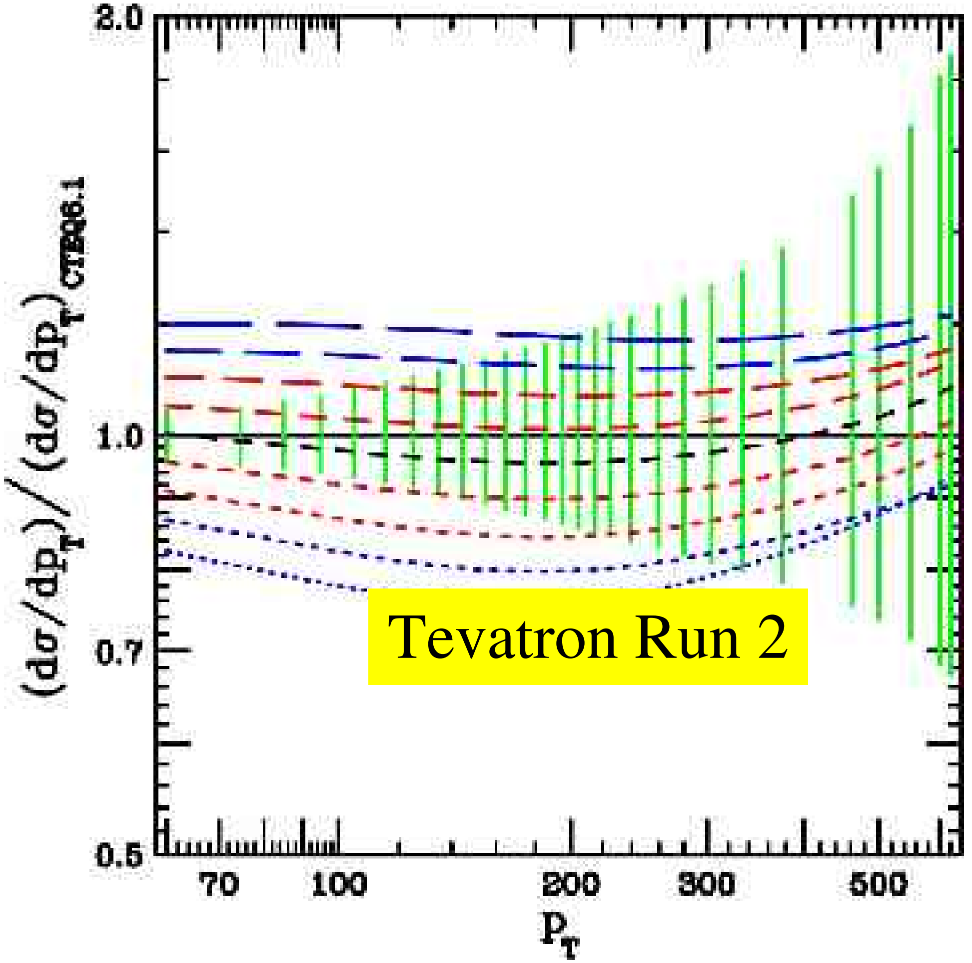
- Stefan Gieseke showed that the Sudakov form factors have very little dependence on the particular pdf's used
  - hep-ph/0412342
  - +talk given at Brookhaven meeting
- So pdf weighting works for parton shower Monte Carlos as well as fixed order calculations
  - use of error pdf's

D. Stump: CTEQ α_s series

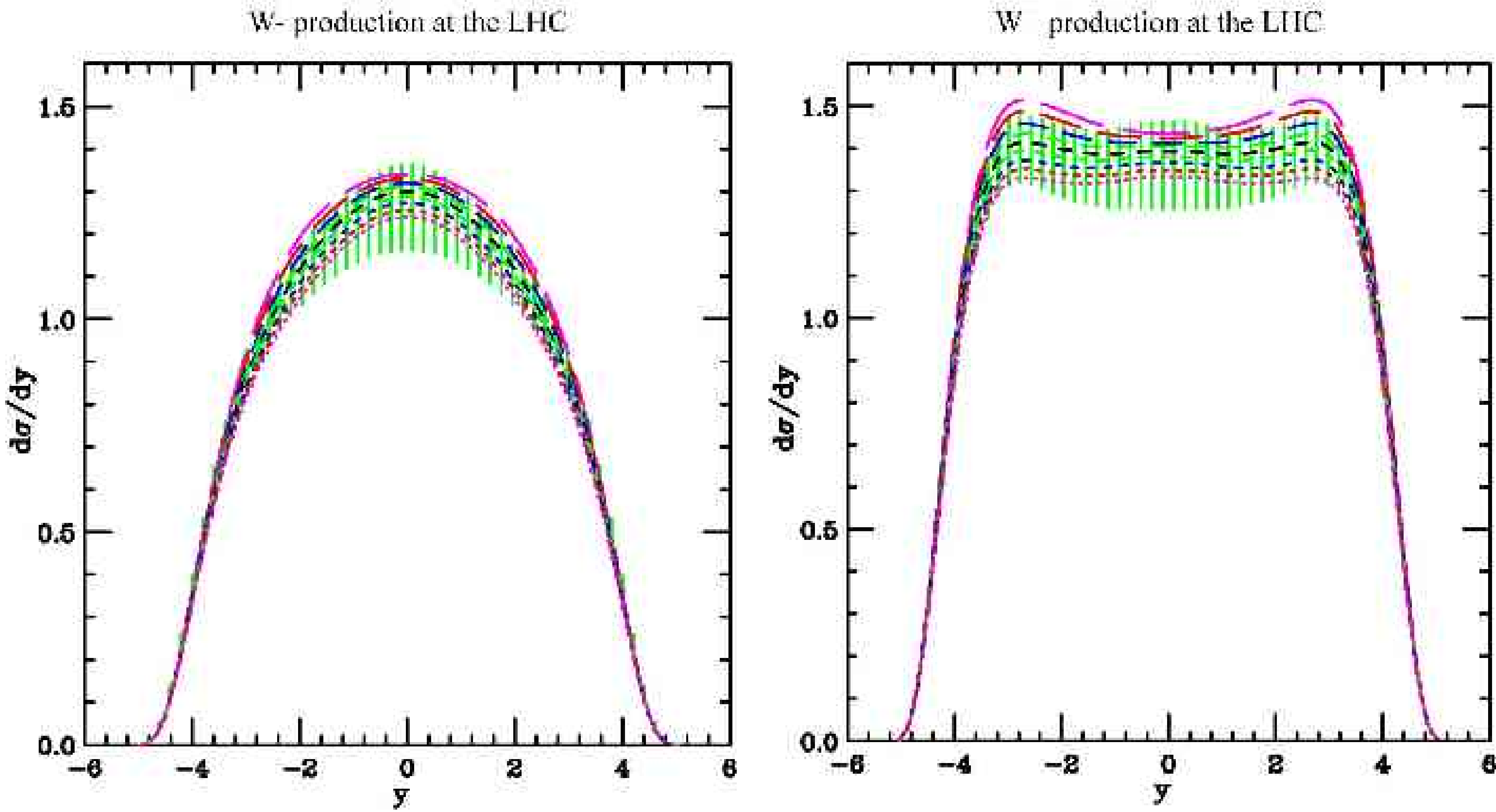
Inclusive jet production

LHC





Example. $W^{\pm}$ production at the LHC

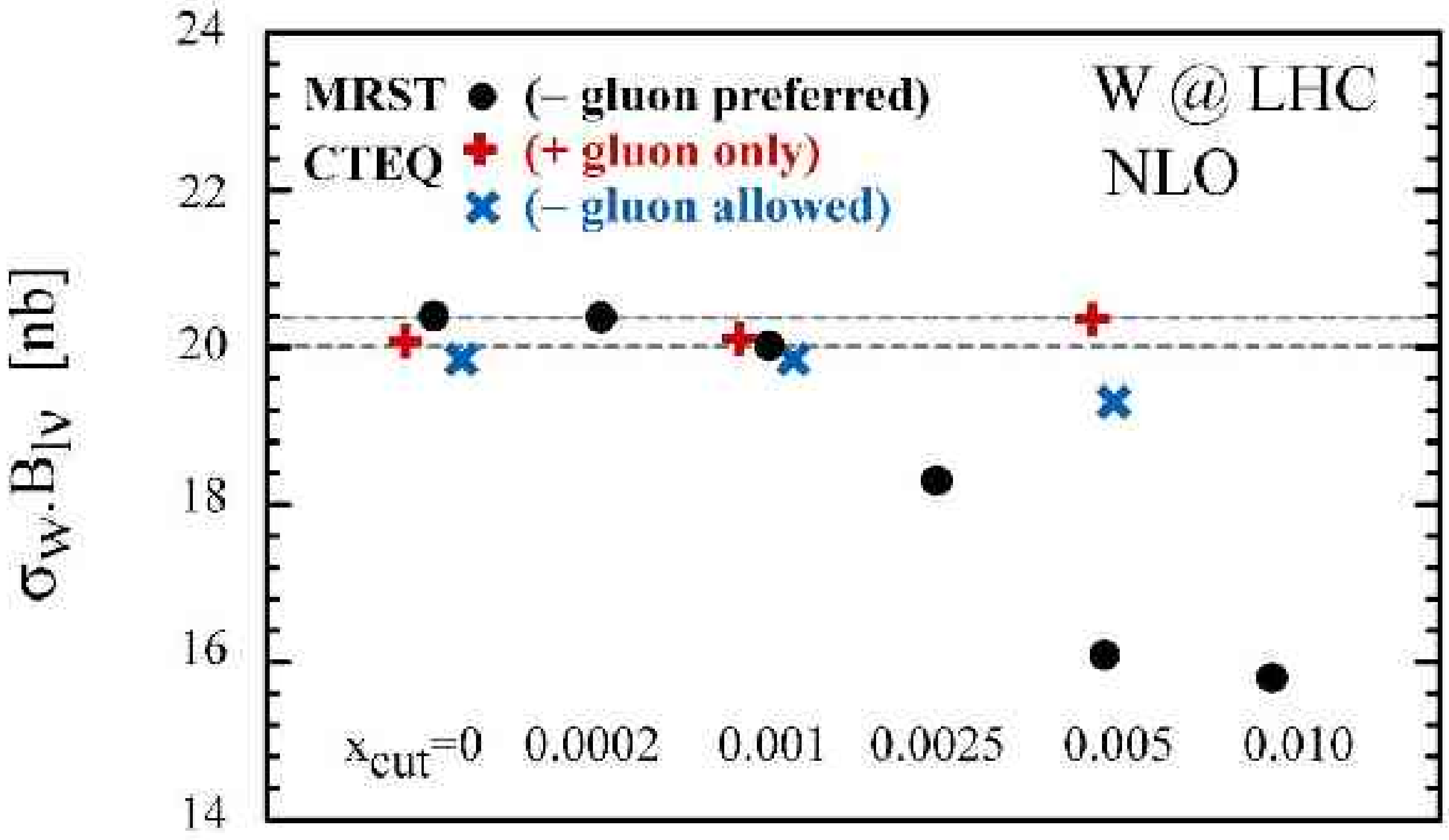


Green shaded area = PDF uncertainty; Curves = α_s series from 0.110 to 0.12

Stability of NLO predictions

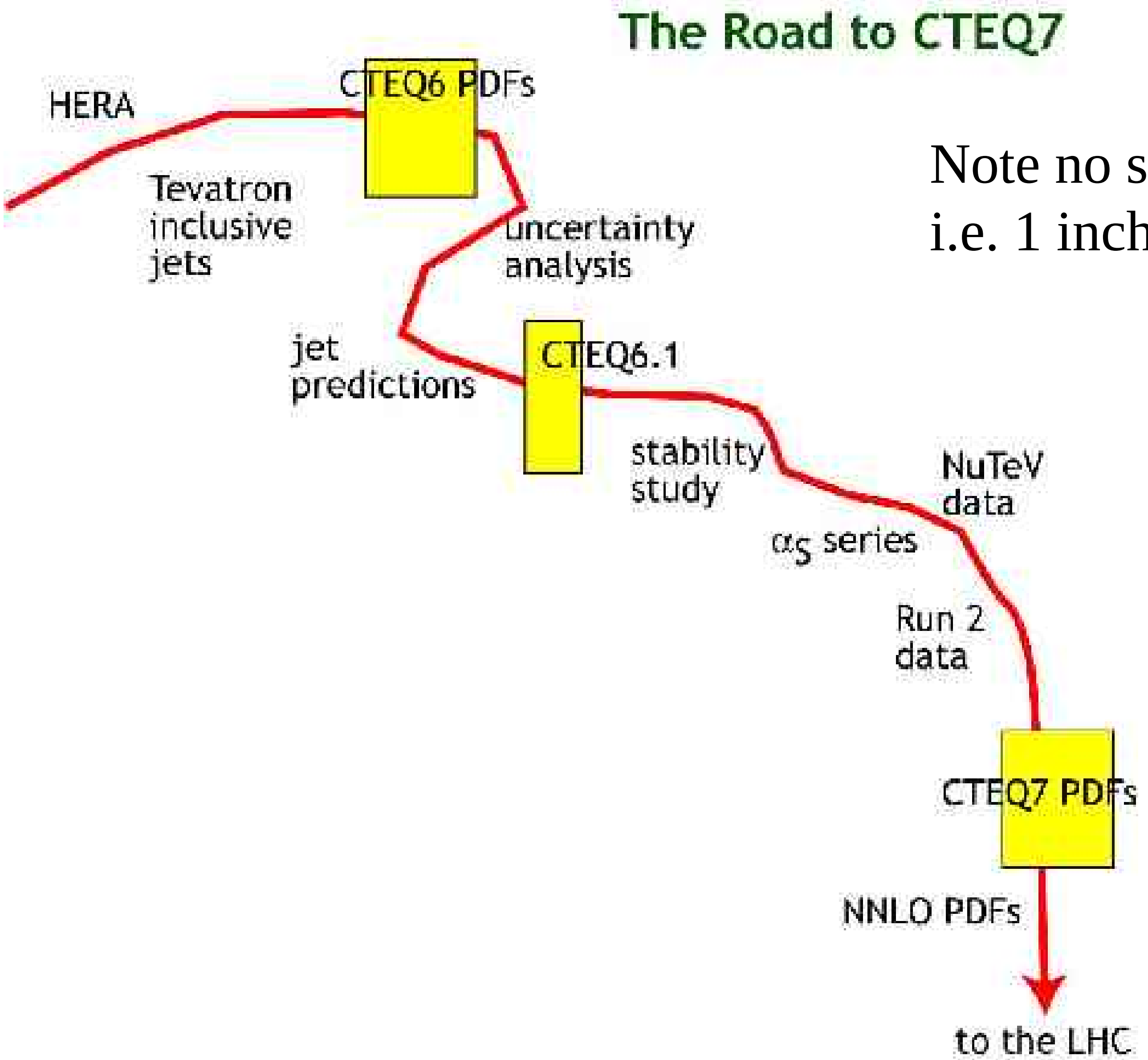
Results, graphically:

CTEQ stability study



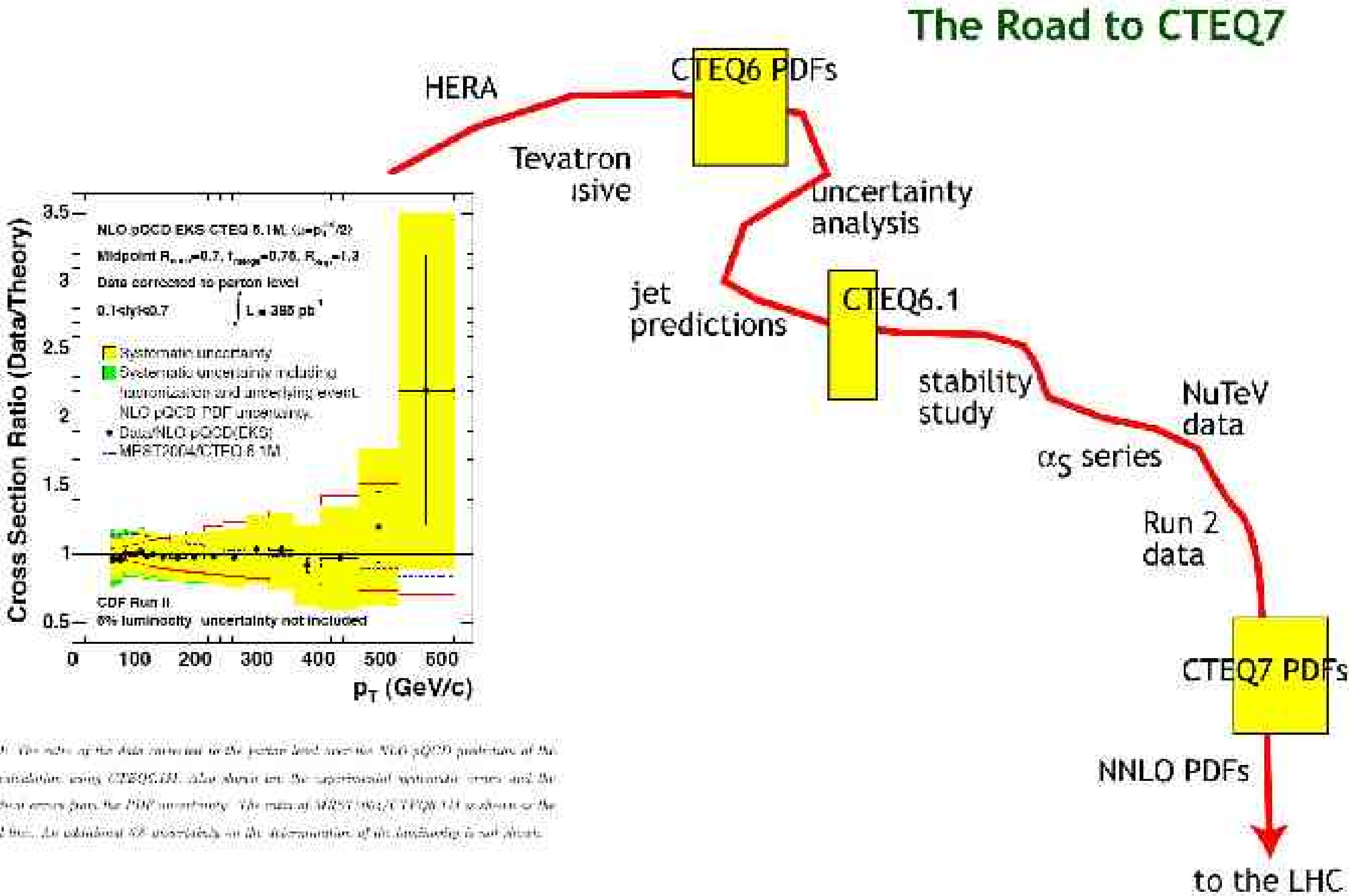
The predicted total cross section of $W^+ + W^-$ production at the LHC, for NLO calculations.

CTEQ7



Note no scale:
i.e. 1 inch = 1 month

CTEQ7



The Road to CTEQ7
HERA
CTEQ6 PDFs
Tevatron
isive
uncertainty analysis
jet predictions
CTEQ6.1
stability study
NuTeV data
α_S series
Run 2 data
CTEQ7 PDFs
NNLO PDFs
to the LHC
NLO pQCD EKS CTEQ 6.1M
Data corrected to parton level
Systematic uncertainty
Data/NLO pQCD(EKS)
CDF Run II
Cross Section Ratio (Data/Theory)
p_T (GeV/c)
0
100
200
300
400
500
600
0.5
1
1.5
2
2.5
3
3.5

CTEQ6.1 Tune

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

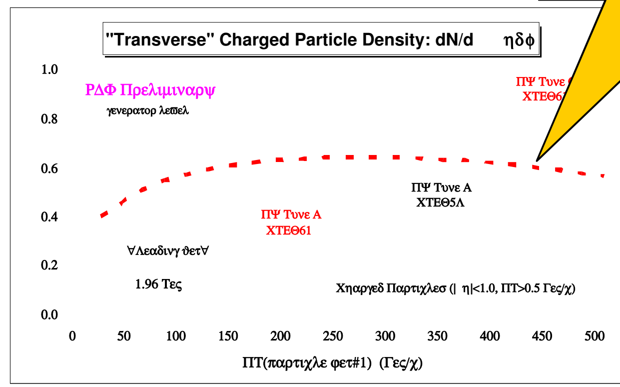
PYTHIA 6.2 CTEQ6.1

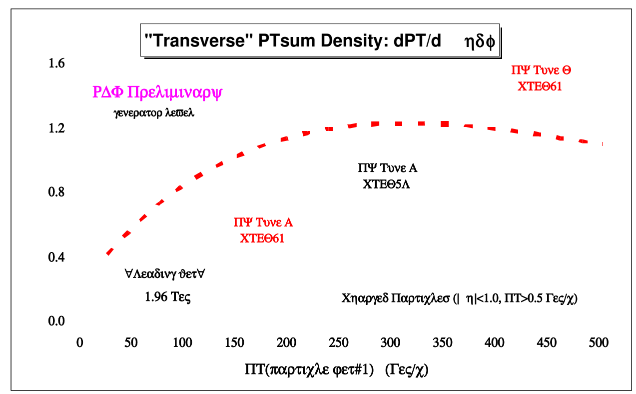
UE Parameters

ISR Parameters

Intrensic KT

Parameter	Tune Q	Tune QW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.2 GeV	1.2 GeV
PARP(84)	0.5	0.5
PARP(83)	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
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(92)	5.0	15.0





JIMMY at CDF

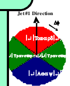
JIMMY
Runs with HERWIG and adds multiple parton interactions!

JIMMY was tuned to fit the energy density in the "transverse" region for "leading jet" events!

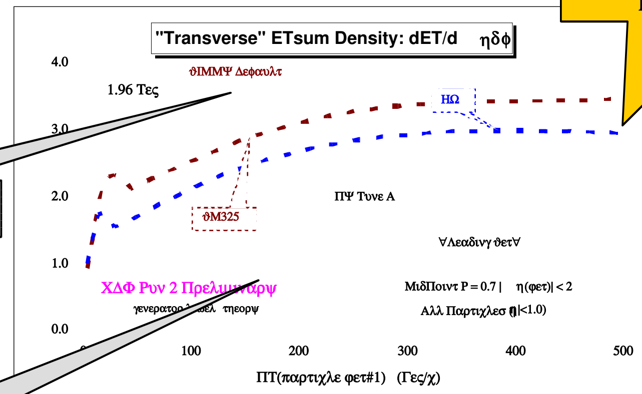
The Energy in the "Underlying Event" in High P_T Jet Production

JIMMY: MPI

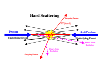
J. M. Butterworth
J. R. Forshaw
M. H. Seymour

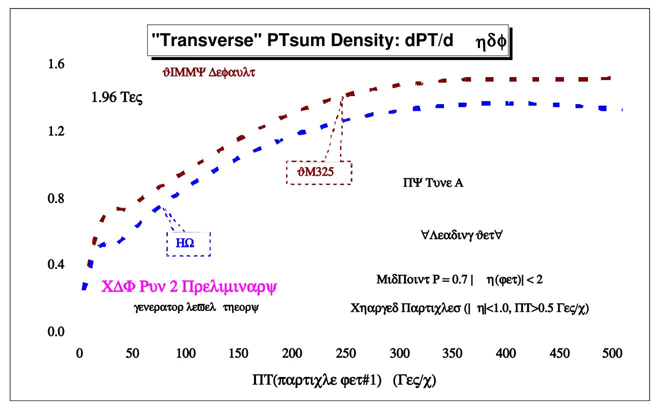


PT(JIM)= 2.5 GeV/c.



PT(JIM)= 3.25 GeV/c.





"Transverse" <Densities> vs P_T(jet#1)

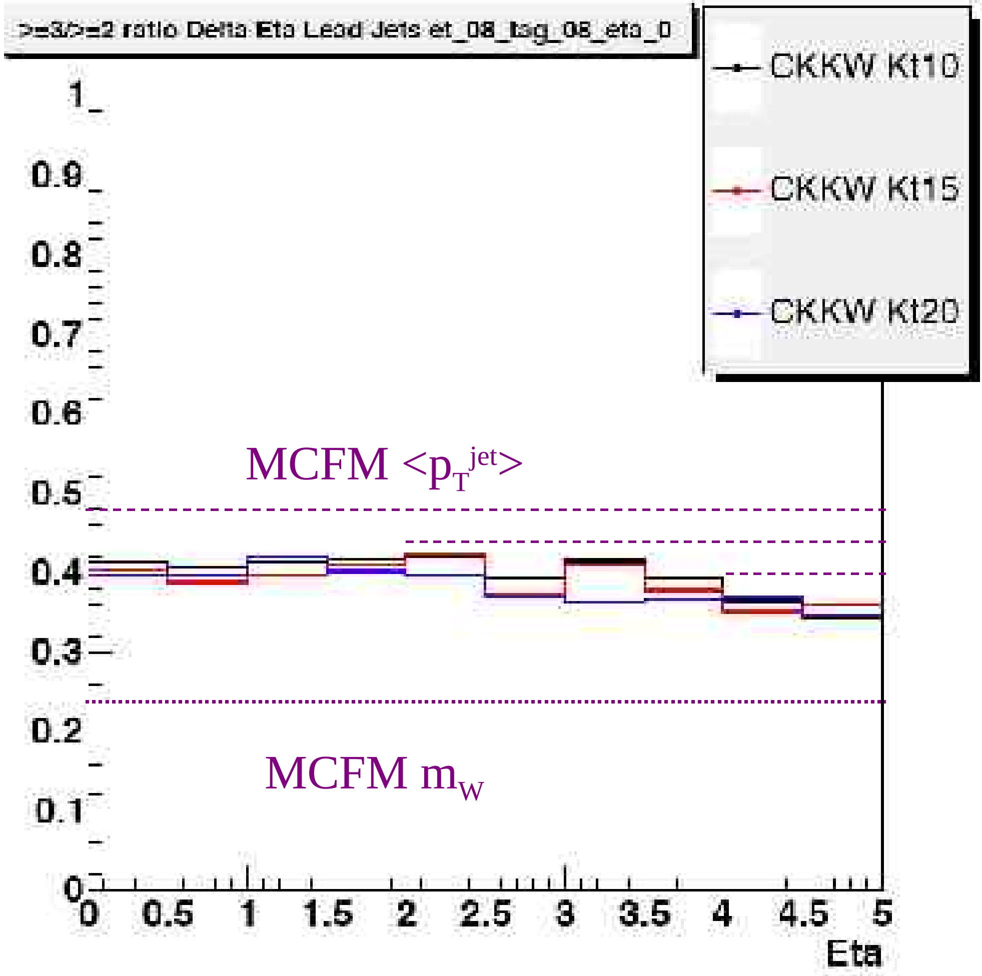
J. Huston: Tevatron W + jets studies

- We can't help with the VBF Higgs discovery channel at the Tevatron but we can look at the rates for central jet emission in W/Z + jet(s) events
- Cross section larger for W + jets so that is primary investigation

- Will compare measured cross sections to LO +PS predictions and to fixed order (LO and NLO) predictions from MCFM
- In particular, are interested in comparing to CKKW cross sections generated by Steve Mrenna
- As usual, data is not blessed yet, so that can't be shown to this audience, but will be included in final TeV4LHC writeup
- Predictions will be extrapolated to the LHC

CKKW matching variation

- Look at probability for 3rd jet to be emitted as a function of the rapidity separation of the tagging jets
- Relatively flat probability, stable with CKKW scale
- Bracketed by two predictions for MCFM using m_W and $<p_T^{jet}>$ as scales



Next-to-Leading Order: LHC requirements

From the TEVATRON experiments we learned:

- Leading order works well for most *shape* predictions, but fail as far as cross section normalization goes.

- However, normalization fails.

At Next-to-Leading order:

- Understanding of the uncertainty on the shape of distribution.

- A first estimate of the cross section normalization. (i.e. a definition of the strong coupling constant)

Given the expected precision and types of searches at the LHC Next-to-Leading Order predictions are highly desirable.

Next-to-Leading Order: LHC requirements

A start of the basic NLO needs for a serious phenomenology program at the LHC (from Les Houches 2005):

2. PP V V + jet (new physics and Higgs search background)
3. PP H + 2 jets (Higgs production through vector boson fusion background)
4. PP T Tbar + B Bbar (Higgs plus top quark background)
5. PP V V + B Bbar (new physics and Higgs search background)
6. PP V V + 2 jets (Higgs search background)
7. PP V + 3 jets (Generic background)
8. PP V V V (background to tri-lepton searchs)
9. Etcetera

$V \in \{ W, Z, \gamma \}$

The SAMPER project

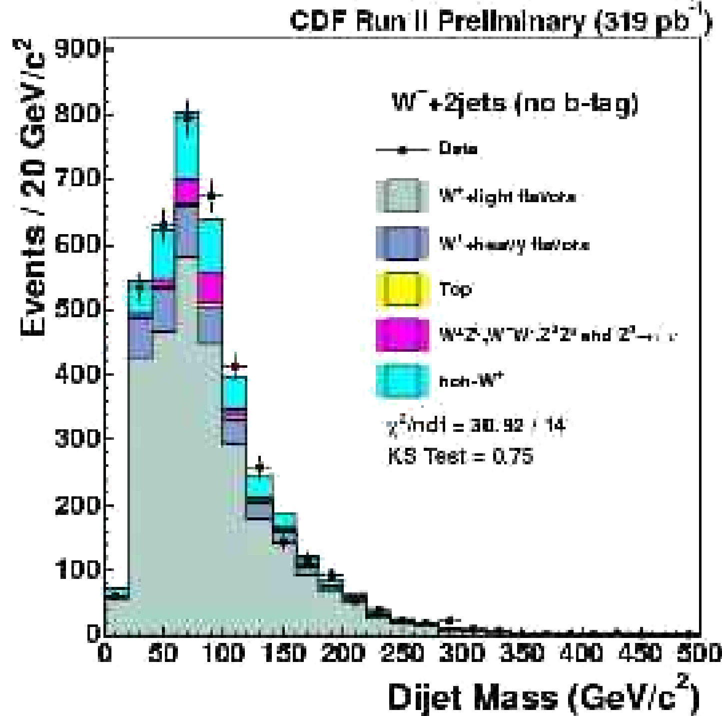
(Semi-numerical AMPlitude EvaluatoR)

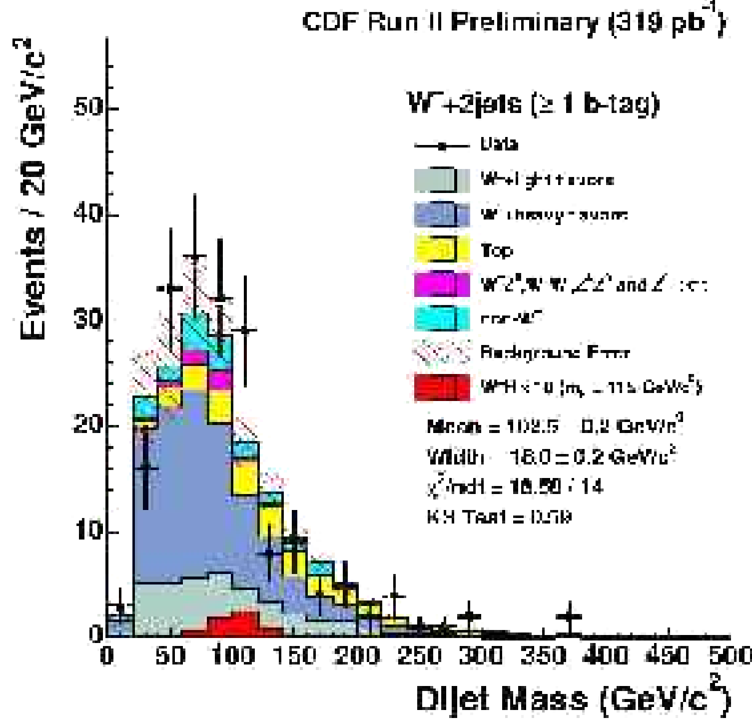
Giulia Zanderighi, Keith Ellis and Walter Giele.
hep-ph/0508308
hep-ph/0506196
(Phys.Rev.D72:054018,2005)

- Next-to-Leading Order: LHC requirements
- Issues in Loop calculus: the semi-numerical approach
- First proof of the method: Higgs + 4 partons at one loop
- Future directions: multiplicity and complexity

Future Directions

- At this point we are sure we can calculate *2 3* one loop amplitudes efficiently and maintain numerical stability all over phase space.
- This leaves us with implementing the virtual corrections in a monte carlo and add the unresolved Leading order *2 4* contributions. Currently this is in progress for the process *PP H + 2 jets* through gluon fusion.
- When successful we can start implementing *all 2 3* processes for the LHC at Next-to-Leading order.





Mea Culpa @ NLO

What is this about? The title is Joey's attempt to shame the speakers!!

We (Steve Ellis and Bill Kilgore) "promised" Joey we would prepare a JETS@NLO MC calculation (code) by the end of the Workshop.

Unfortunately we have failed miserably, and have no results to report. So here is our *hairshirt*, which we will wear until the calculation is finished.

The interested reader/listener is encouraged to study the results of S. Frixione and B. Webber (and collaborators) plus Eric Laenen and Patrick Motylinski, whose efforts in various arenas (e.g., vector boson production, heavy flavor production) of MC@NLO are further along.

Sorry about that, we are ashamed!!

Steve & Bill

M. Wobisch: cone jet algorithms

Run II Workshop had proposed the infrared-safe Midpoint Cone Algorithm:

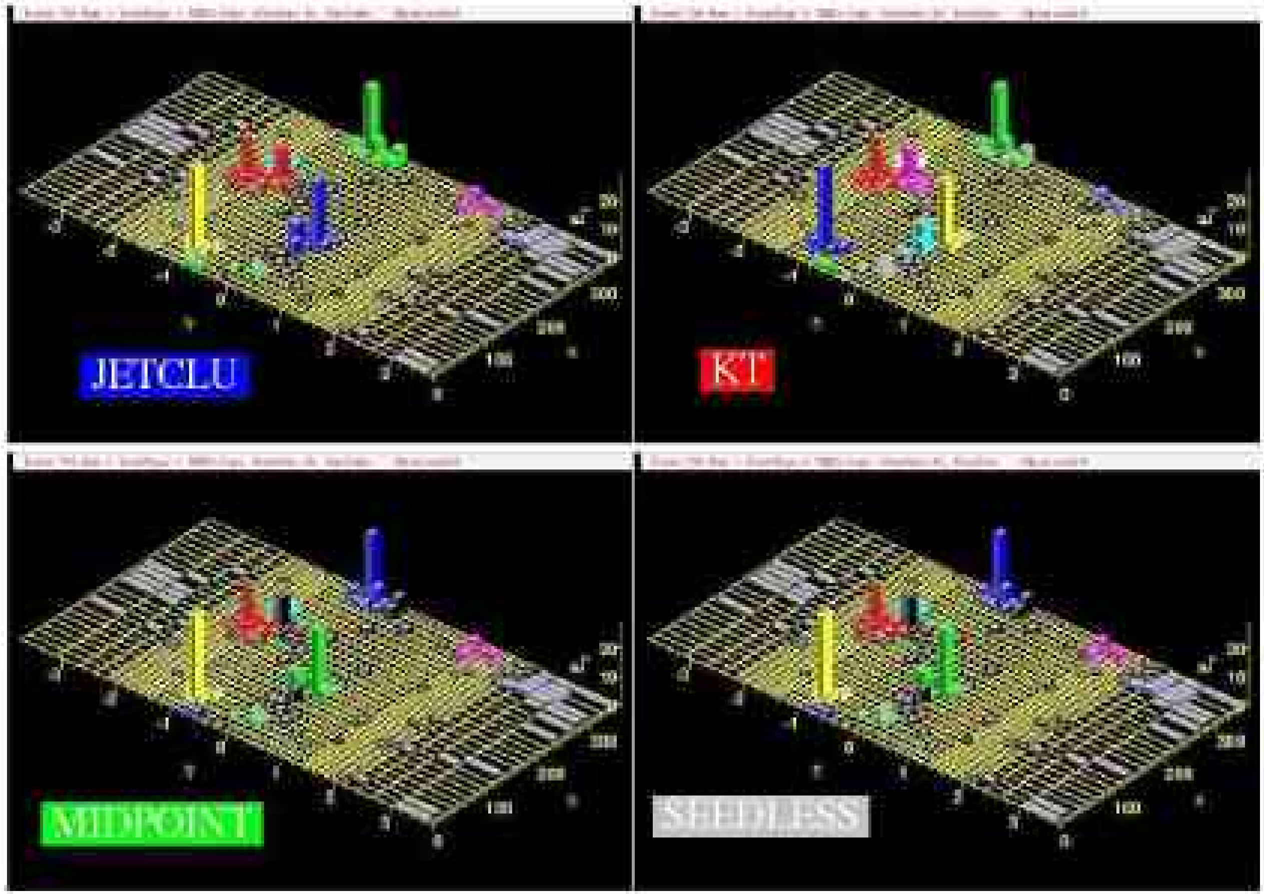
Iterative cone algorithm, using midpoints between jets as additional seeds
three parameters: R_{cone} (jet cone), f_{overlap}, $p_{T\,\mathrm{min}}$ (fractional energy in overlap treatment)

- use every particle as seed:
  – seed specifies cone axis / draw cone with R_{cone} around cone axis
  – define proto-jet fourvector from particle four-vectors (in E-Scheme)
  – use proto-jet axis as new cone axis
  – iterate until jet axis = cone axis
- now use all midpoints between pairs of jets as additional seeds
  $\Rightarrow$ repeat iterative procedure
- Overlap treatment: (only for jets with $p_T > p_{T\,\mathrm{min}}$)
  – if a jet shares more than a fraction f_{overlap} of it's p_T with a higher p_T jet $\longrightarrow$ merge jets
  – if the fractional overlapping p_T is below f_{overlap} $\longrightarrow$ split jets

comments
– usually: jet axis = cone axis — not when overlap treatment is used
– jets are basically defined by iterative procedure – overlap treatment is an exception

Discovery

CDF saw that the midpoint cone algorithm can leave some towers unclustered (“dark towers”)



Solution

solution proposed: S.D. Ellis, J. Huston, M. Tonnesmann, hep-ph/0111434

- introduce smaller "search cone" in iterative procedure to define jet direction
  $\Rightarrow$ stable jet solutions can be closer
- once a stable solution is found, use the **full** cone radius to define the jet
  $\Rightarrow$ consequence: jet axis $\neq$ cone axis
- "midpoint step" uses full cone radius (otherwise not infrared-safe)
  (this is not correctly described in the first CDF Run II jet publication!! hep-ex/0505013)
- Since initial stable solutions can be closer, overlap treatment is more often needed to define the final jet configuration $\longrightarrow$ overlap treament becomes a standard-procedure
- overlap treatment may merge many nearby jets
  $\Rightarrow$ this results in merged jets with huge spacial extension (CDF: "fat jets")
  $\longrightarrow$ way out: increase f_{overlap} parameter from 0.5 to 0.75
  $\Rightarrow$ largely overlapping jets are still counted separately

Problem

... as before in Run I:

CDF and DØ are using different jet algorithms!!!!

- However, for QCD jet cross sections the consequences are very small
  $\Rightarrow$ only 6% difference between the inclusive jet cross sections for both algorithms
- But beware: The effect may be much larger for multi-jet production!!
  3-jet, 4-jet – when the jet-jet separation is more critical – not been studied so far!
- Totally unrealistic to assume that either CDF or DØ would change
  to the other algorithm during Run II
- The difference of 6% is not a huge effect (same as luminosity uncertainty)
- But important to settle this issue for the LHC experiments!!