QCD Working Group Summary from Les Houches workshop (with emphasis on Higgs related issues)

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for the QCD convenors (Stefano Catani, Michael Dittmar, Dave Soper, Stefan Tapprogge) and the QCD WG members

Physics at TeV Colliders

- Workshop at Les Houches,France from June 8-18, 1999 (ties to Run 2 workshop and to LHC SM workshop
  - ~75 participants in 3 areas:
    - QCD/SM
    - SUSY
    - Higgs
  - great deal of overlap between SUSY and Higgs group and between QCD and Higgs group (especially regarding question of resummation)
- I'll give a few highlights relating to Monte Carlo and resummation issues; too much material to present a complete summary.
- There will be a ~100 page writeup from the QCD group that tries to tie together all of the subjects discussed in the fall plus discussion at the LHC plenary meeting in October.

Theoretical Predictions

There are a variety of programs available for comparison of data to theory and/or predictions.

- Tree level
- Leading log Monte Carlo
- N^nLO
- Resummed

In general, agree quite well…but before you appeal to new physics, check the ME.

Perhaps biggest effort…include NLO ME corrections in Monte Carlo programs… correct normalizations.

Resummed description describes soft gluon effects (better than MC's)…has correct normalization (but need HO to get it)

threshold
dijet, direct γ

k_T
W,Z, Higgs

Important to know strengths/weaknesses of each.

Monte Carlos vs exact tree level calculations

- Monte Carlo programs like Isajet, Pythia, Herwig use only the leading pole approximation to the matrix elements
- …approximation might not work well in some kinematic configurations
- Test with N jet configurations in CDF

Event generators/Monte Carlos

- Automatic calculation of tree-level cross sections has become a growth industry (witness the number of talks in Saturday session)
  - for example, COMPHEP (automatic evaluation of matrix element^2 for hard subprocesses with multiparticle final states)
- Inclusion of NLO corrections in leading log Monte Carlos is currently a very hot topic and success is near here in (1993,1994,1995,1996,1997,1998,1999…)
  - So far no rigorous solutions for inclusion of NLO terms, but many ideas
  - NB: would also like to include NLO branching in parton showering (and thus increase the double-counting headaches)

Brief review of CSS resummation formalism

Problem

— QCD corrections to the Q_T dist'n contain log's:

$$\frac{d\sigma^{Fixo}}{dQ_T^2} \xrightarrow{Q_T \to 0} \sum_{n=1,m=0}^{\infty,\, 2n-1} \alpha_s^n\, c_{nm} \frac{1}{Q_T^2} L^m + O\left(\frac{1}{Q_T}\right) =$$

Singular + Regular

— Each "Big Bad Log" (D.Soper) $L = \ln\left(\frac{Q^2}{Q_T^2}\right)$ factor due to emission of a soft/collinear gluon

— The coeff.s of α_s carry potentially large logs → no convergence

Solution

— Reorganize the perturbative sum in terms of $\alpha_s^n L^m$

$$\frac{d\sigma^{CSS}}{dQ_T^2} \sim \alpha_s^l \frac{L+1}{Q_T^2}$$

$$\begin{aligned}
(\alpha_s + \alpha_s^2 L^2 + \alpha_s^3 L^4 + \alpha_s^4 L^6 + \ldots \quad & \leftarrow A_1, B_1, C_0 \\
\alpha_s^2 \quad + \alpha_s^3 L^2 + \alpha_s^4 L^4 + \ldots \quad & \leftarrow A_2, B_2, C_1 \\
\alpha_s^3 \quad + \alpha_s^4 L^2 + \ldots \quad & \quad \ldots \\
\ldots \quad) \quad & \quad \ldots
\end{aligned}$$

RGE analysis shows that the singular terms exponentiate

— Solution of the RGE eqs. gives:

$$\frac{d\sigma^{CSS}}{dQ_T^2} \sim$$

$$\int db^2 \exp\Big\{ i\, \vec{Q}_T \vec{b} -$$ Fourier

$$\int_{c_1^2/b^2}^{c_2^2 Q^2} \frac{d\bar{\mu}^2}{\bar{\mu}^2} \left[A(\alpha(\mu)) \ln\left(\frac{c_2 Q^2}{\bar{\mu}^2}\right) - B(\alpha(\mu)) \right] -$$ Sudakov

$$\left[g_1 b^2 + g_2 b^2 \ln\left(\frac{Q^2}{Q_0^2}\right) + g_1 g_3\, b \ln(100\, x_1 x_2) \right] \Big\} *$$ LY

$$* \left[\tilde{C}_{a/h_1}(\alpha(\mu), b, x_1)\, \tilde{C}_{b/h_2}(\alpha(\mu), b, x_2) + x_1 \leftrightarrow x_2 \right]$$

— $\vec{Q}_T$ cons. is explicit in impact parameter ($\vec{b}$) space

— Large logs under control : A, B, and C can be calculated in PT:

$$A(\alpha(\mu)) = \sum_{i=1}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^i A_i, \quad B(\alpha(\mu)) = \sum_{i=1}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^i B_i$$

— The partially summed cross section is:

$$\frac{d\sigma^{Res}}{dQ_T^2} = \frac{d\sigma^{CSS}}{dQ_T^2} + \frac{d\sigma^{Y}}{dQ_T^2} = \frac{d\sigma^{CSS}}{dQ_T^2} + \frac{d\sigma^{Fixo}}{dQ_T^2} - \frac{d\sigma^{Asy}}{dQ_T^2}$$

At low Q_T: $\frac{d\sigma^{Fixo}}{dQ_T^2} \approx \frac{d\sigma^{Asy}}{dQ_T^2} \Rightarrow \frac{d\sigma^{Res}}{dQ_T^2} \approx \frac{d\sigma^{CSS}}{dQ_T^2}$

At high Q_T: $\frac{d\sigma^{CSS}}{dQ_T^2} \approx \frac{d\sigma^{Asy}}{dQ_T^2} \Rightarrow \frac{d\sigma^{Res}}{dQ_T^2} \approx \frac{d\sigma^{Fixo}}{dQ_T^2}$

But: CSS and Asy are calculated up to some fixed order in α_s ⇒ at high Q_T, the order of CSS and Asy mismatch

Plan B: Matching — works like Black Magic

from Csaba Balazs talk

Questions on resummation/Monte Carlos

1. Differences between the b-space approach and the p_T-space approach. How much information is "lost" ignoring the non perturbative region?

...under investigation

How much uncertainty is there in the form of the non-perturbative parameterization?

…under investigation; will compare Ladinsky-Yuan to new Brock et al parameterization (see figure)

How much uncertainty is there in the matching?

…under investigation; will try different reasonable choices for matching plus new suggestions by Collins and Soper

How much of an advantage is there in not having to match?

…religious issue?

Is there anything at all disturbing in that the form factor in the CSS approach goes to 0 as b->0?

…not to John and Dave

Resummation questions continued...

2. The CSS formalism works very well in predicting distributions like W/Z pt, after having used fixed target Drell-Yan data to fix the non perturbative parameters. These are mainly qqbar states. How much of an uncertainty is there in predicting gg-dominated states?

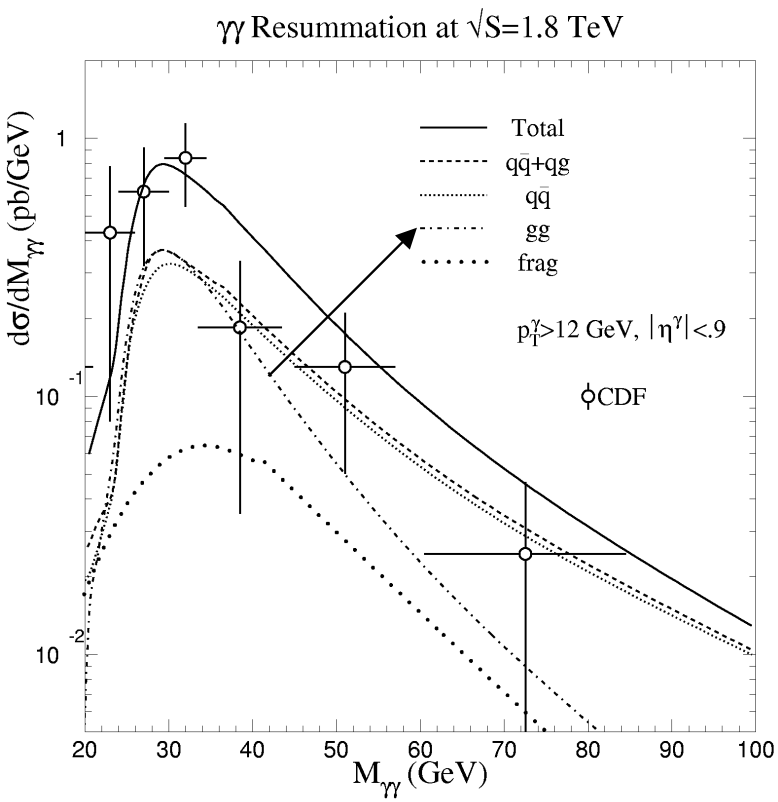
See figures.

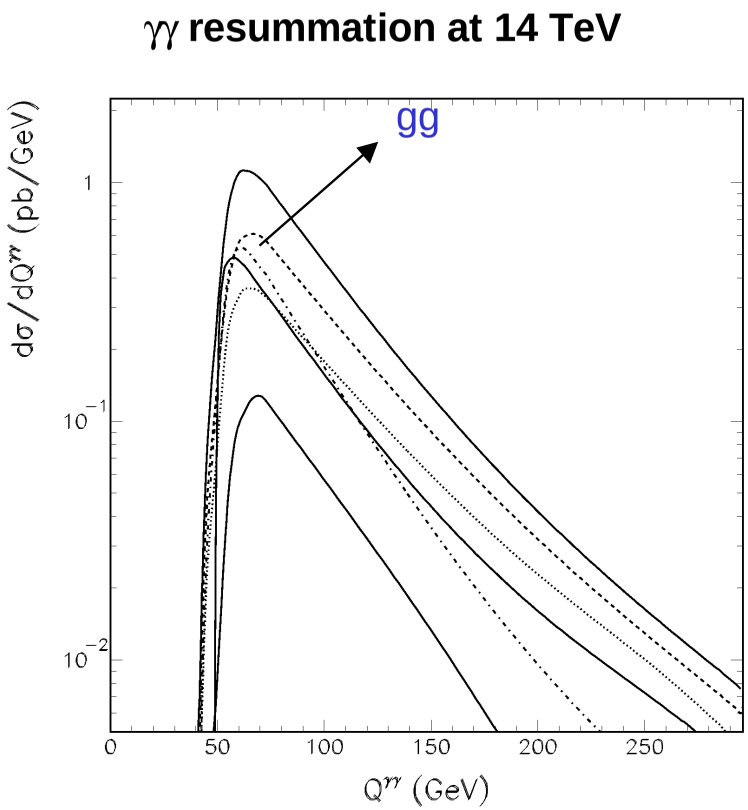
Is there any data that can be used to reduce this uncertainty? Now? In Run 2?

Diphoton production both at LHC and Run 2.

Diphoton production at the Tevatron and LHC

gg scattering is an important process for diphoton production at both the Tevatron And the LHC. May be able to constrain resummation formalism for gg processes.





Resummation questions continued...

3. Exactly what physics is in CSS resummation calculations that is not in leading log shower Monte Carlos?

…under investigation

If the same logs are there, why does so much of the k_T have to be put in by hand in the Monte Carlo programs?

See figures.

What has been put into Pythia for Higgs production at the LHC?

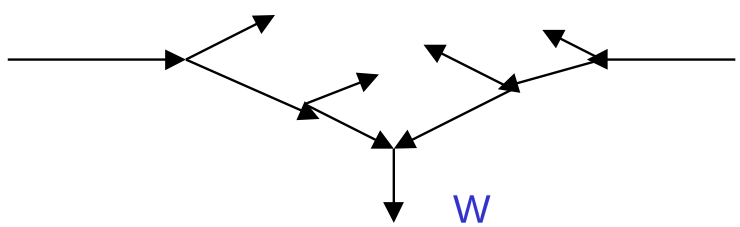
Default value of 0.44 GeV/c.

What needs to be put in to more closely match the CSS predictions?

Process and kinematics dependent.

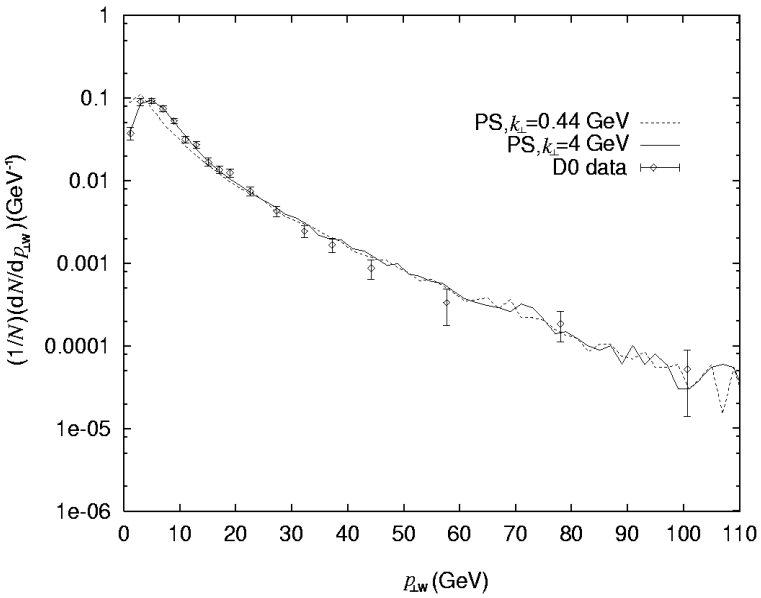
Description of k_T in Monte Carlos

- Sjostrand found that Pythia did not describe p_T distribution of W's for D0 unless an initial state intrinsic k_T of 4 GeV/c was added to each parton
- Because of branchings before hard collision, 4 GeV/c k_T results in $[<p_{TW}^2>]^{0.5}$ = 2. 1 GeV/c



hep-ph/9812455

•Monte Carlo perturbative generation of W p_T through gluon emission not sufficient?

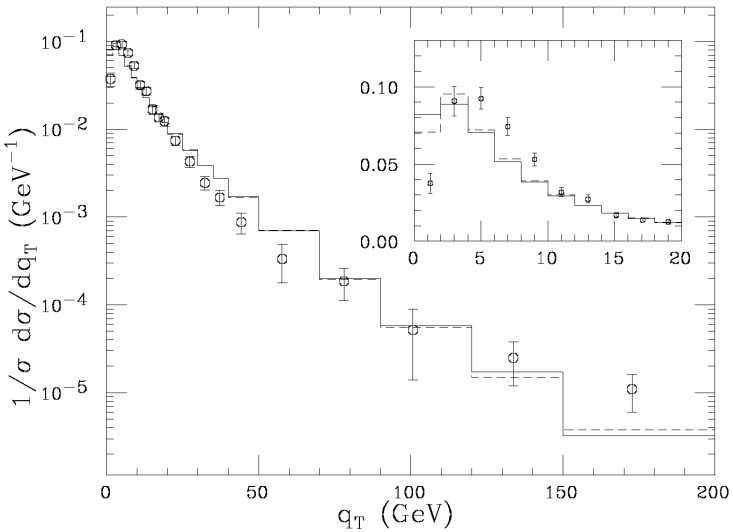


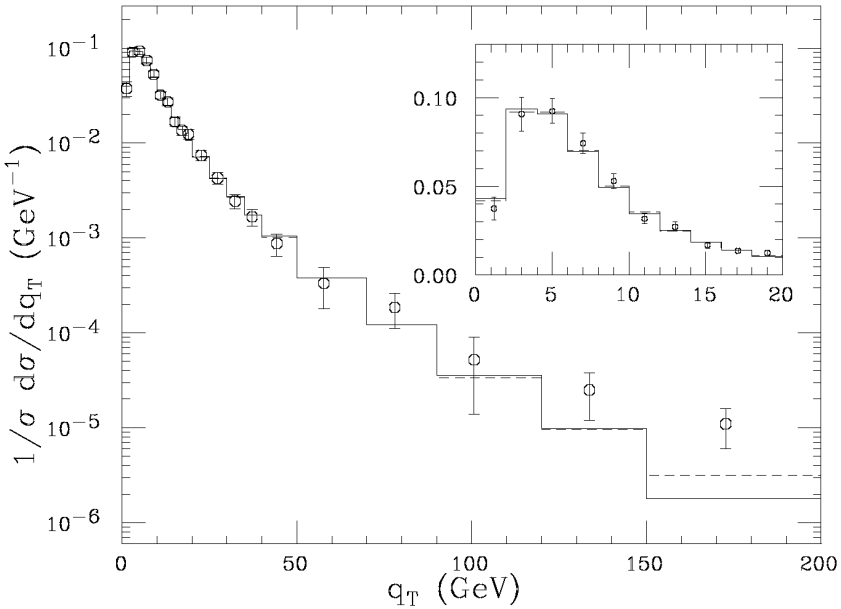
..but D0 W p_T distributions not Corrected for detector effects

More comparisons to D0

hep-ph/9808388; G. Corcella and Mike Seymour

Agreement is much better after detector correction; no need for intrinsic k_T?

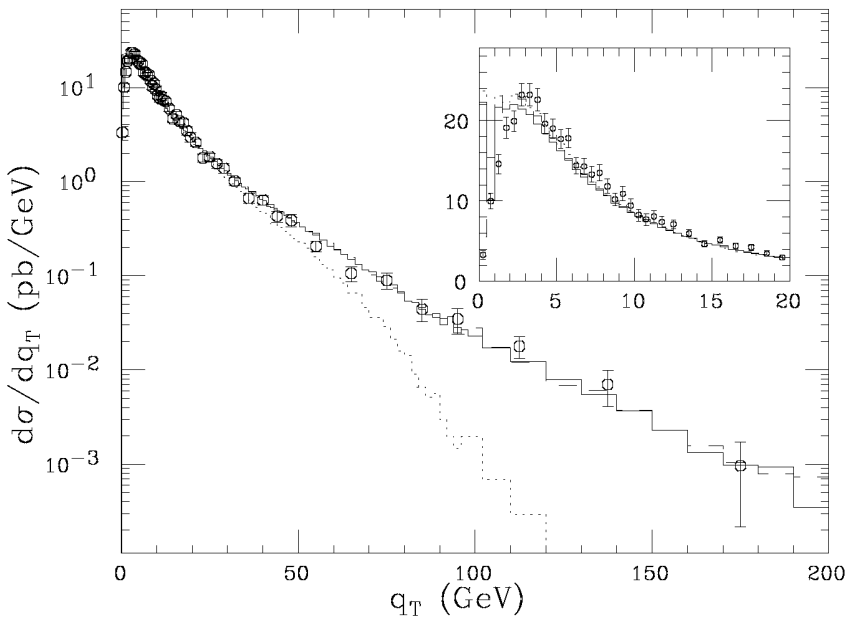




W q_T distribution from D0 compared to Herwig with ME corrections but no correction for detector effects; solid line has no k_T while dashed has 1 GeV/c rms

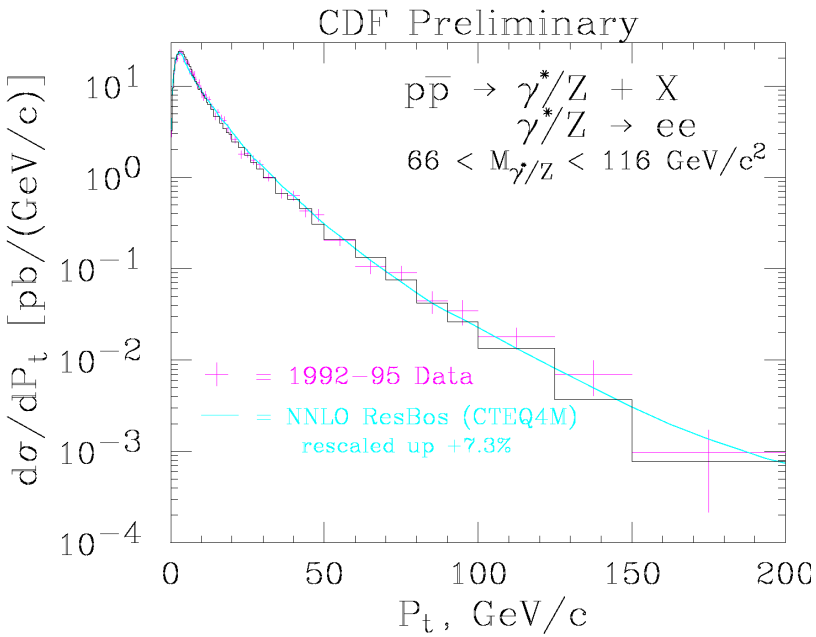
CDF Z p_T distribution

- Comparison of Herwig to CDF Z q_T distribution without (dotted) and with (solid and dashed) matrix element corrections. Solid has zero k_T while dashed has rms k_T of 1 GeV/c
- "There is perhaps some evidence that Herwig does not produce enough smearing at low q_T even with an intrinsic k_T of 1 GeV/c"



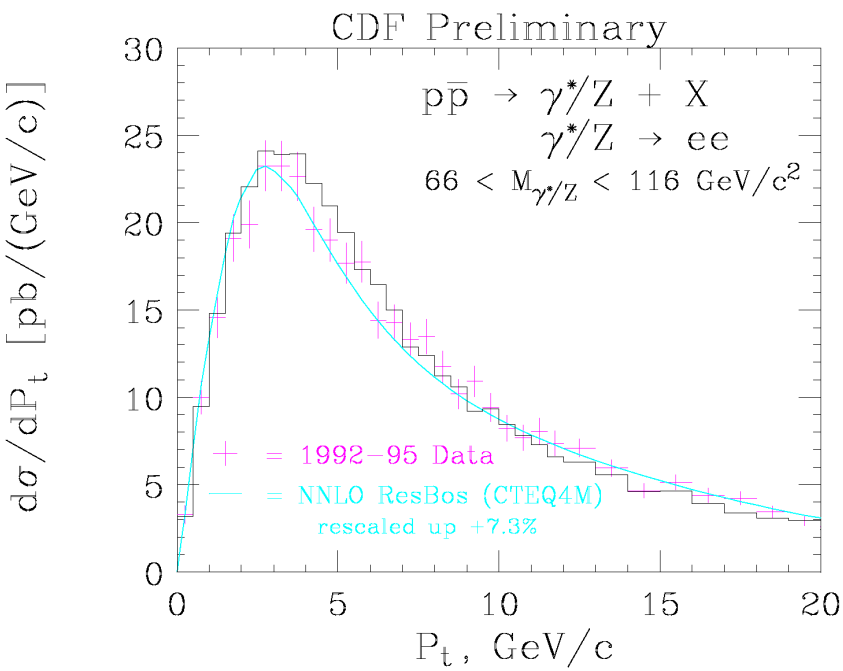
Comparison of CDF Z p_T to Resbos and Pythia

Histogram is Pythia 6.125 with σ_{kT}=2.15 GeV/c (default is 0.44 GeV/c)



from Willis Sakumoto

…so *intermediate* amount of intrinsic k_T is needed to describe Z production at Tevatron



Resummation questions continued…

4. Where are the areas of uncertainty for CSS predictions for Higgs production (besides the gg initial state)?

…under investigation

Does the top mass matter in the top loop when calculating the Higgs p_T distribution?

…under investigation

Are there higher order calculations that need to be made to help with matching?

Resummation questions continued...

5. What is the relationship between resummation, Monte Carlos and k_T smearing models (as are used to describe E706 data)?

   …since single photon production is an inclusive process, no double logs to be resummed as for Drell-Yan or diphoton production

   …yet there are significant deviations of data from theory that can be well described by Gaussian k_T-smearing models (and by the soft gluon radiation effects contained in Herwig and Pythia)

   See figures.

Questions

A useful exercise would be to try to quantify all of the uncertainties on the Higgs resummation calculation (non-perturbative parameters, matching, scale dependence, …).

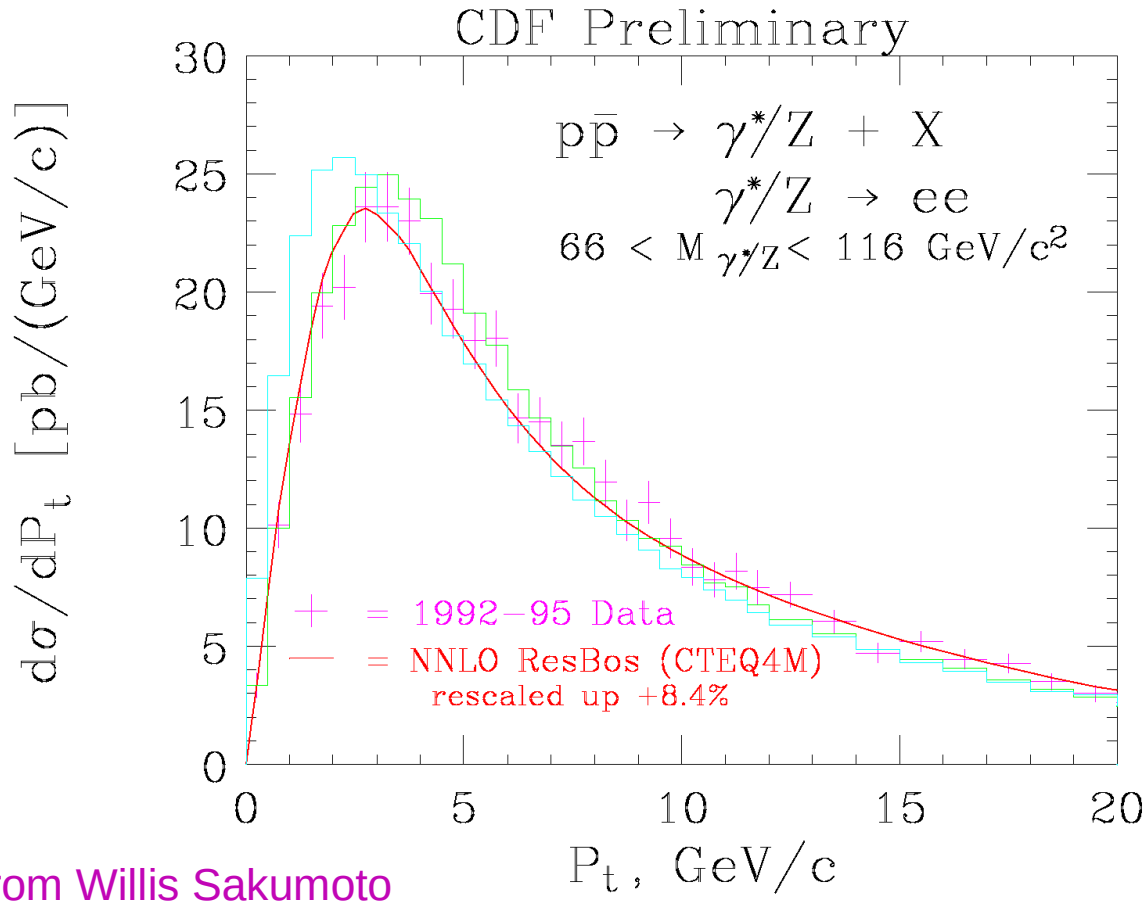
In progress: should be available for Les Houches writeup and LHC workshop plenary session.

Further comparisons for CDF Z p_T

Comparison of:

- default k_T in Pythia (blue histogram) ; χ^2=228/50 dof
- "best fit" (2.15 GeV/c; green histogram); χ^2 = 38.6/50 dof

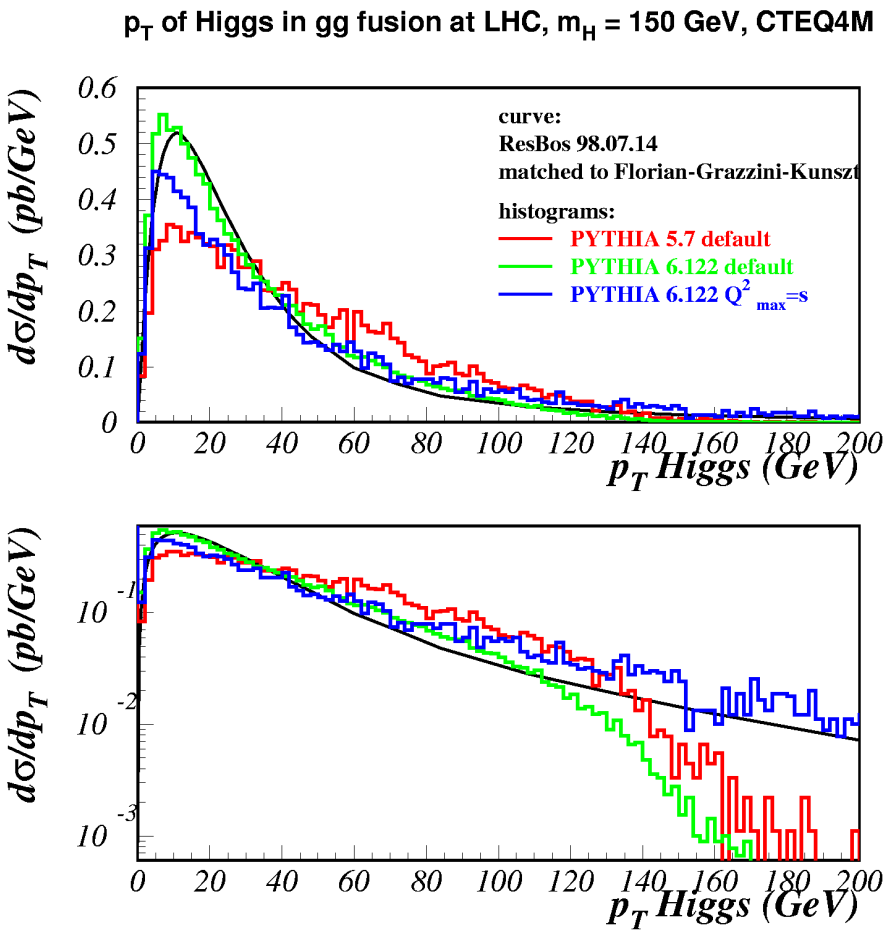
Note that there are still some detailed differences in shape between Pythia prediction and that of ResBos



from Willis Sakumoto

Comparison of Higgs production at LHC

- Note dramatic change from Pythia 5.7 to Pythia 6.122 and agreement between ResBos at low p_T
- Pythia does not describe high p_T end well (without large scale) but is not expected to (extra radiation by setting Q^2_{max}=2 is a step in that direction); ResBos is matched to NLO ME at high p_T

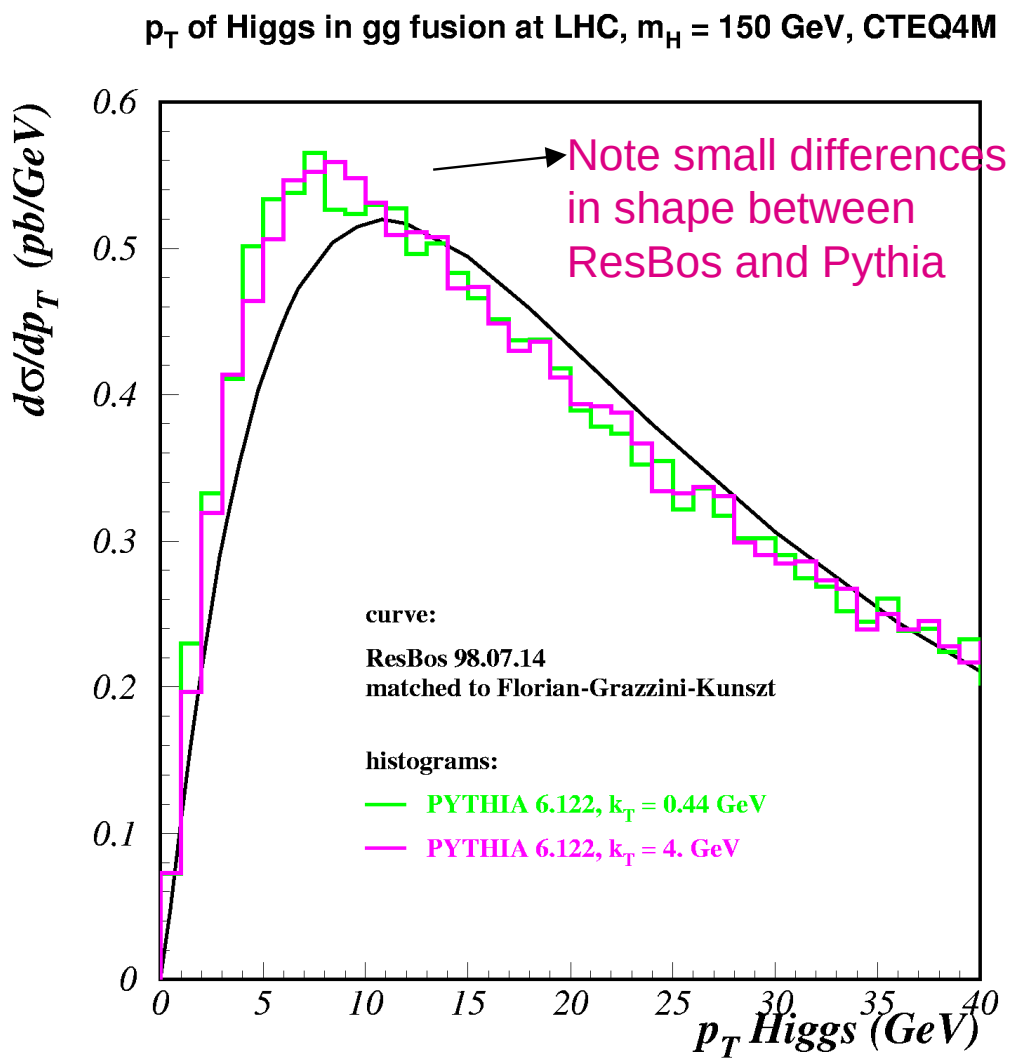


NB: CMS decided not to build a preshower detector based on Pythia 5.7; don't become too reliant on Monte Carlos (or at least not on just one Monte Carlo)

Ivica Puljak and Csaba Balazs

Effect of "intrinsic" k_T on Pythia predictions

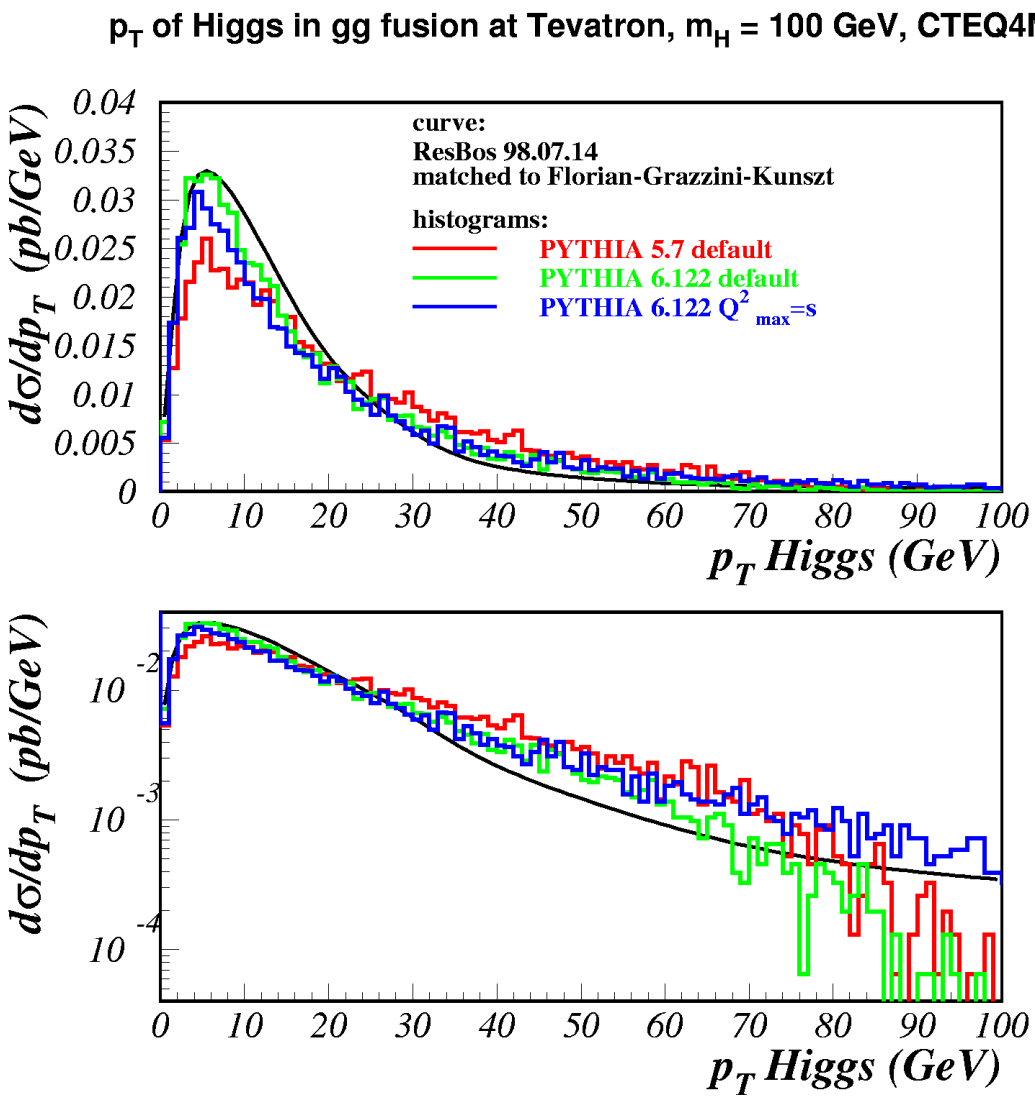
- No difference between k_T value of 0.44 GeV/c and 4 GeV/c
  - Large center-of-mass energy and gg initial state leads to a large number of branchings; effect of k_T is washed out by the time that hard collision takes place



Does ResBos retain sensitivity to the non-perturbative physics?

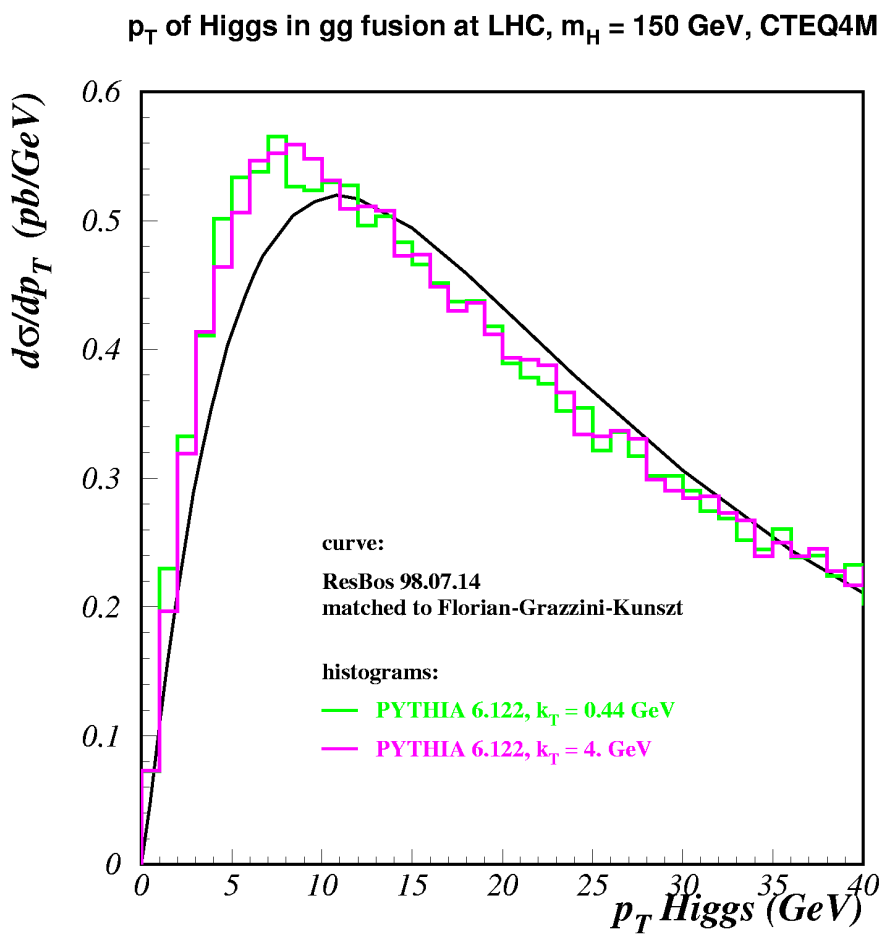
Higgs production at the Tevatron

…again relatively good agreement between Pythia and ResBos



Higgs production at the Tevatron

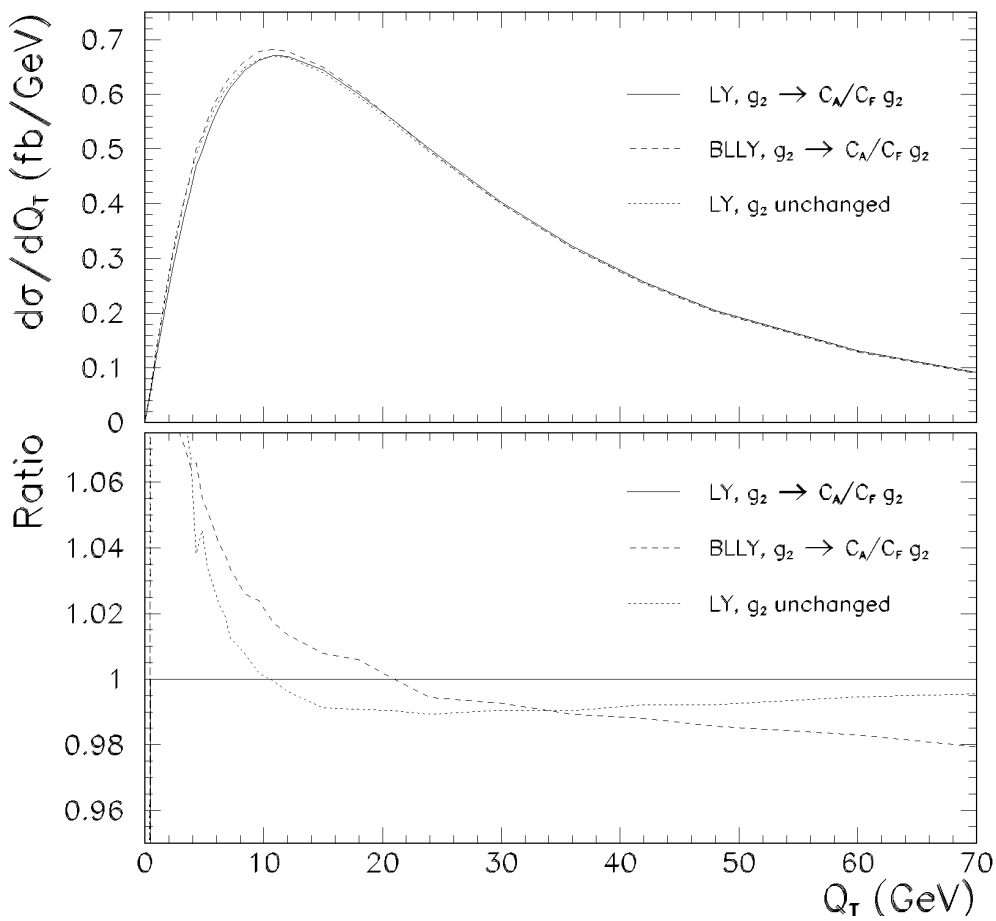
…again, little difference between the two values of k_T



Uncertainties in CSS formalism

Ladinsky-Yuan (LY): standard parameterization of non-perturbative coefficients
Brock-Ladinsky-Landry-Yuan(BLLY): new fit including CDF Z data hep-ph/9905391

•Little difference in p_T distribution between the two parameterizations; also does not matter greatly whether g_2 is scaled by color factors or not (to go from qqbar to gg)



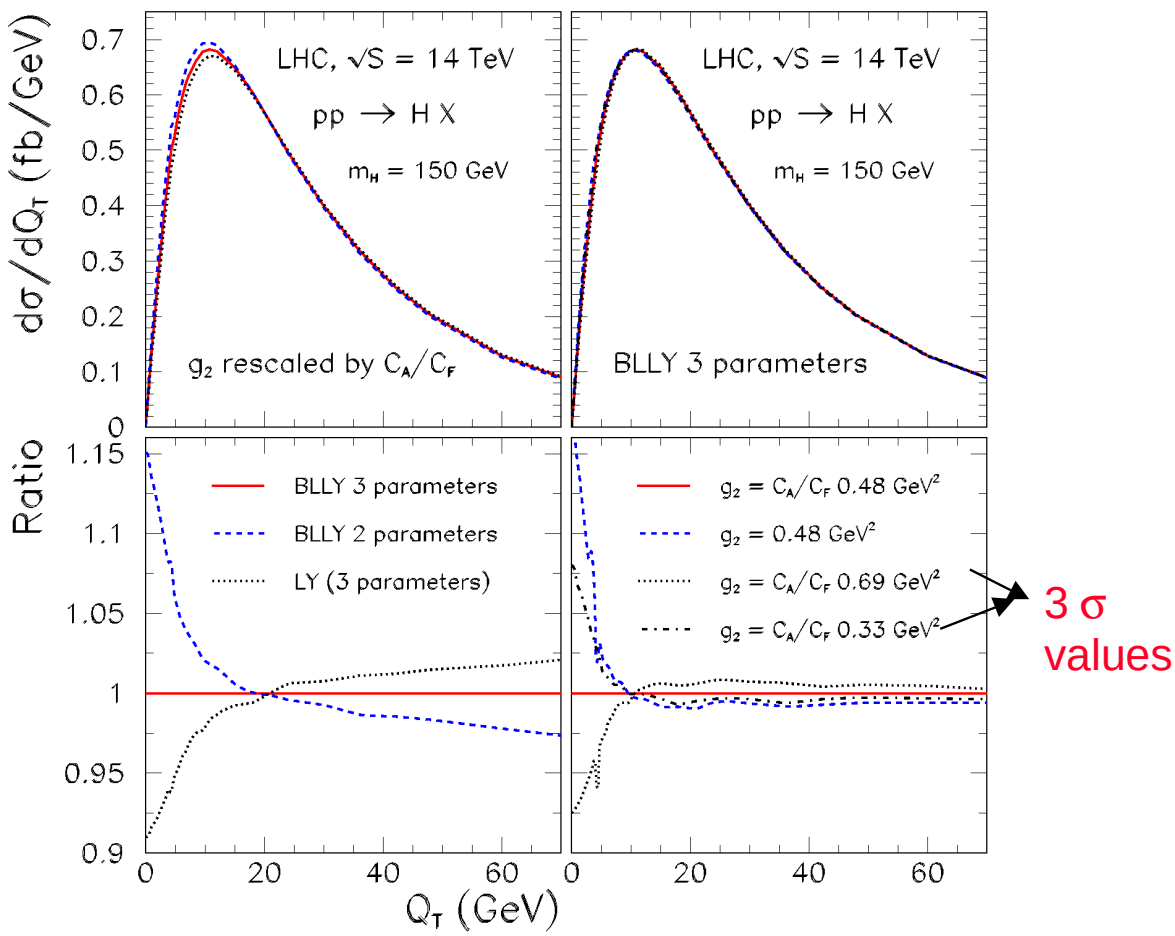
Csaba Balazs

Uncertainties in CSS formalism

For 150 GeV Higgs at LHC

- Try using BLLY 2 parameter and 3 parameter fits
- Try not scaling g_2 by C_A/C_F
- Try extreme values of g_2

10-15% effects at low p_T (<10 GeV/c)



3 σ values

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