Indirect Top Mass Measurement

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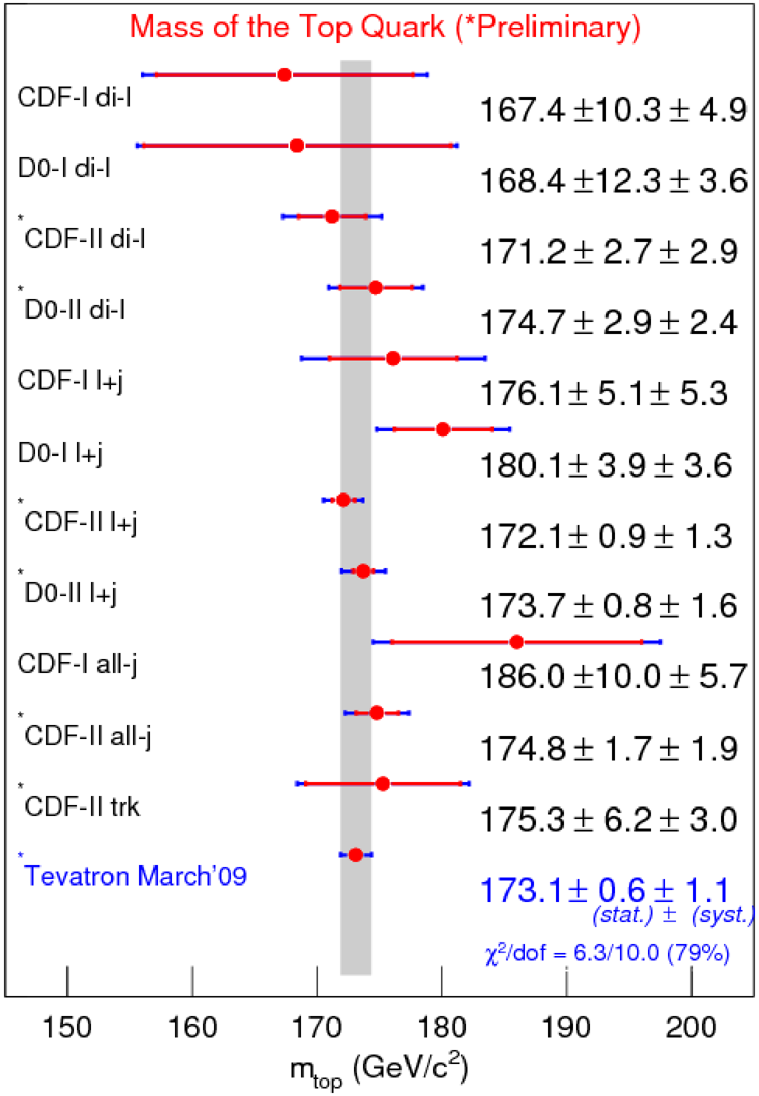
Tevatron Top Mass Combination : March 2009

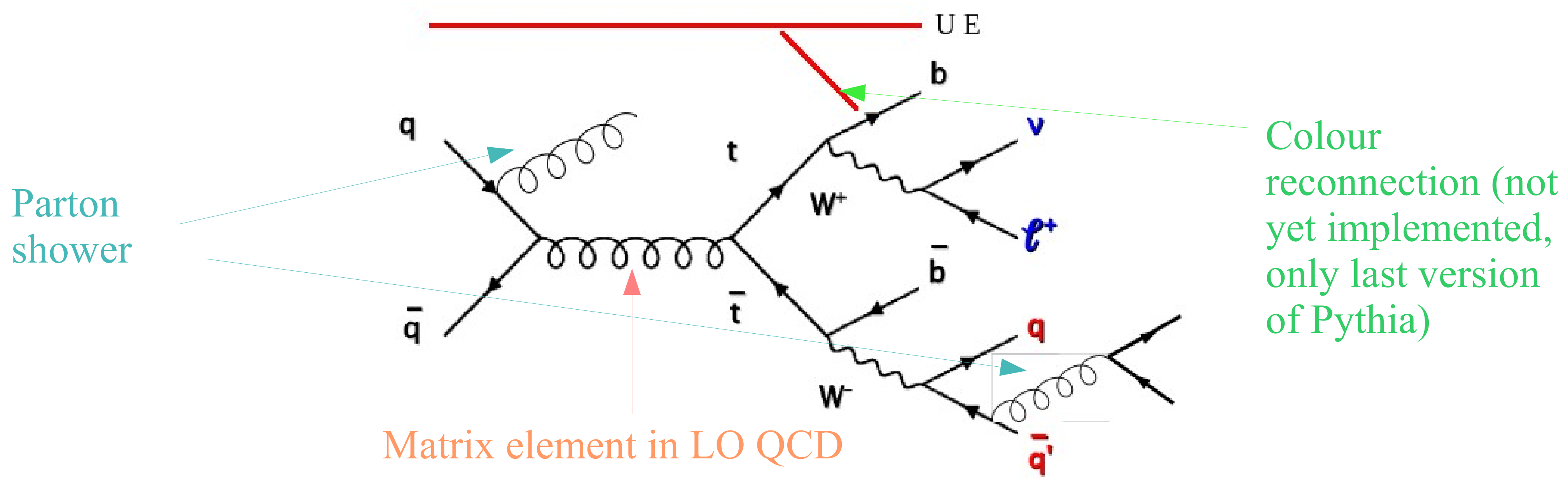


- Tevatron combined top mass (direct measurements) :

$$M_{top} = 173.1 \pm 0.6(stat) \pm 1.1(sys)\, GeV$$

Top Mass Interpretation

- The current direct measurements of top mass based on data/MC comparisons lead to a not well-defined mass (even if we know that it is close to the pole mass) .
  - Problem of consistent matching between perturbative parton shower and fixed order calculations
  - Non perturbative aspects to quantify and test (ex : colour reconnection) (arXiv:hep-ph/0703081)



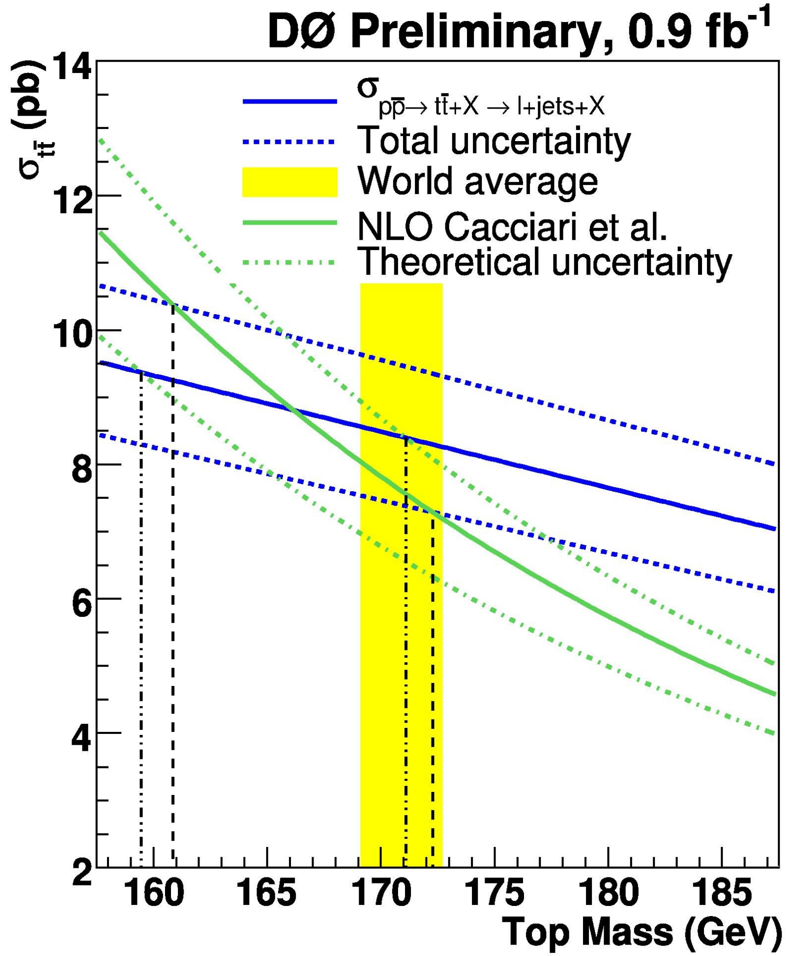
- **New approach** : extraction of the mass from top pair production cross section allows for an unambiguous interpretation in the pole mass definition.

Top Mass Extraction From Cross Section Measurements : First Approach

- **Summer 2007 :**
  - Both experimental and theoretical cross sections depend on top mass : their intersection gives the top mass.
  - Both cross sections have uncertainties : the intersection of the uncertainty bands gives the uncertainty on the top mass.
  - Extracted top mass (D0 Note 5459) :

Lepton+jets channel :

$$m_{top} = 166.1 + 6.1 - 5.3\,(stat + sys) + 4.9 - 6.7\,(theory)\,GeV$$



Outline

- New method using probabilities
- Contribution of the different uncertainties
- Study of cross section ratio
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Error Interpretation Using Probabilities

- The theoretical and experimental cross sections have uncertainties.
  - If you know the shape of these uncertainties, you can combine them according to probability rules to obtain the probability of having a given top mass.

Theoretical dependencies

- According to the factorization theorem, the total cross section of t-tbar pair production at the Tevatron is :

$$\sigma_{tot}(p\bar{p}\to t\bar{t},S)=\sum_{i,j}\int dx_i dx_j \underbrace{f_{i,p}(x_i,\mu_F)f_{j,\bar{p}}(x_j,\mu_F)}_{\text{PDF}}$$

$$\underbrace{\times\hat{\sigma}_{i,j}(ij\to t\bar{t};\hat{s}=x_i x_j S,\mu_F,\mu_R,m_{top})}_{\text{Partonic cross section}}$$

- Theoretical t-tbar cross section uncertainties depend on :
  - the PDFs error
  - the factorization scale μ_F , the renormalization scale μ_R error

Experimental dependencies

- The experimental cross section is measured as **:**

$$\sigma(p\bar{p}\to t\bar{t})=\frac{N_{observed}-N_{background}}{A_{tot}\int Ldt}$$

Evaluated by MC (A_{tot})

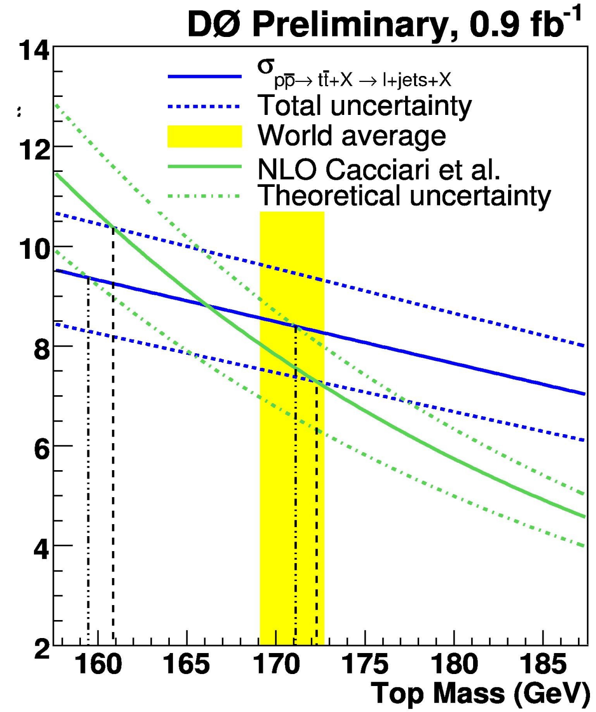
Slight dependency with top mass ($\int Ldt$ / A_{tot})

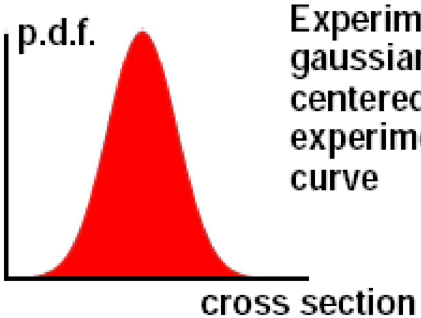
- Experimental t-tbar cross section uncertainties depend on :
  - systematics
  - statistics

Combining Uncertainties

- We want to determine the probability density function (p.d.f.) for the top mass $f(m_t)$. So we have to know the different p.d.f.s for all the sources of uncertainties :
  - Experimental uncertainty : taken gaussian $f_{exp}(\sigma|m_t)$
  - Theoretical uncertainties :
    - PDFs : taken gaussian and calculated from CTEQ or MRST sets $f_{th,\ PDF}(\sigma|m_t)$
    - Renormalization and factorization scales $f_{th,\ \mu}(\sigma|m_t)$

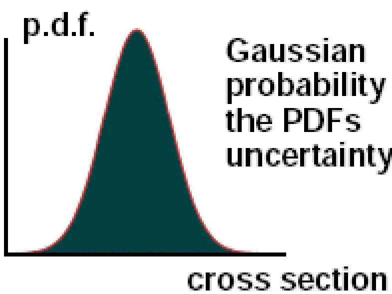
$$f(m_t) = f_{exp}(\sigma \mid m_t) \times [\, f_{th,PDF}(\sigma \mid m_t) \otimes f_{th,\mu}(\sigma \mid m_t) \,]$$





Experimental gaussian : centered on experimental curve

x



Gaussian probability due to the PDFs uncertainty

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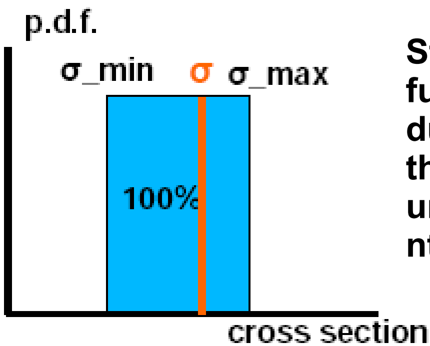


Step function due to the scale uncertai nty

Results

- Result of the top mass extraction using the combined dilepton, lepton+tau and lepton+jets t-tbar cross section (D0 Note 5907, paper to be submitted to PRD rap.com.):

$$\sigma_{tt} = 8.18 + 0.98 - 0.87 (stat + sys + lumi)(pb)$$

  - P.M. Nadolsky et al. NLO calculation, Phys Rev D 78 013004 (2008)

$$M_{top} = 165.5 + 6.1 - 5.9\, GeV$$

  - M.Cacciari NLO +NLL calculations, JHEP 09, 127 (2009) :

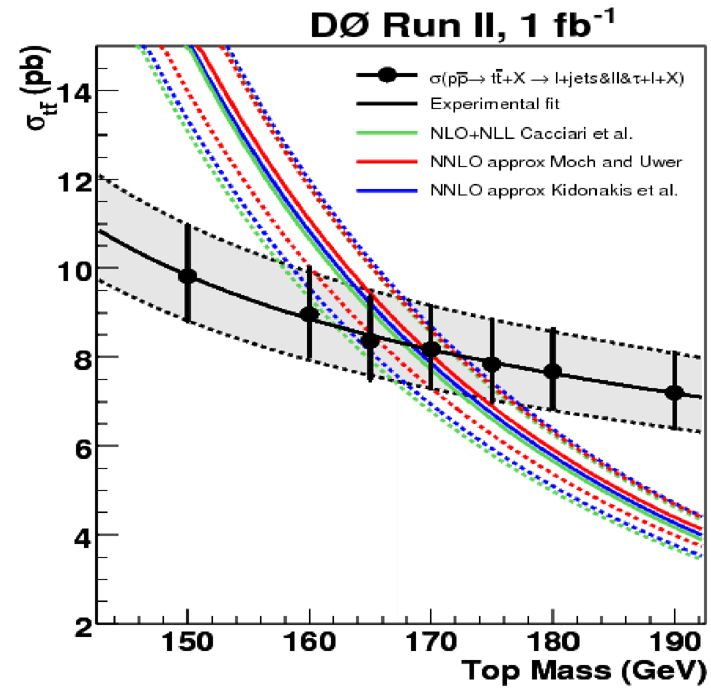
$$M_{top} = 167.5 + 5.8 - 5.6\, GeV$$

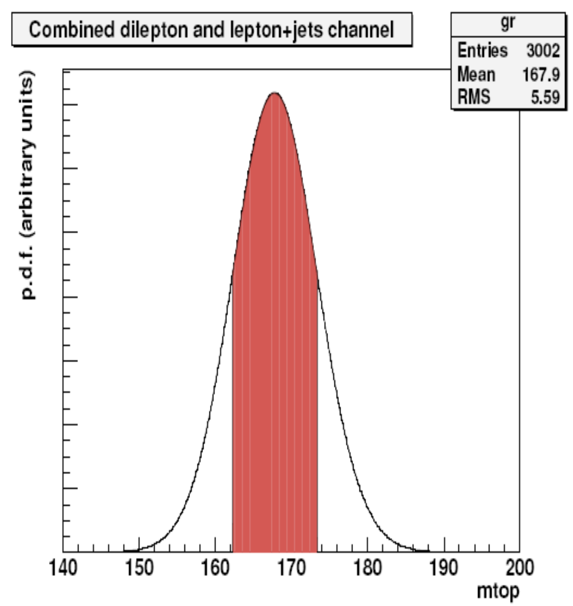
  - S.Moch and P.Uwer approximate NNLO calculations Phys Rev D 78, 034003 (2008) :

$$M_{top} = 169.1 + 5.9 - 5.2\, GeV$$

  - N. Kidonakis and R.Vogt approximate NNLO calculations, Phys. Rev D 78,074005 (2008) :

$$M_{top} = 168.2 + 5.9 - 5.4\, GeV$$





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Contribution of the Different Uncertainties to the Uncertainty on the Top Mass

- The extraction gives a global error on the top mass. We want to determine exactly how the different uncertainties contribute to the error on the mass.
- Study on the S.Moch and P.Uwer NNLO result : $M_{top} = 169.1 + 5.9 - 5.2\,GeV$

  - First, we divide each uncertainty by 10.

Moch NNLO	PDF uncertainty	Scale uncertainty	Experimental uncertainty
/10	-4.6/+5.3 **- 11%**	-5.3/+5.8 **- ~1%**	-2.7/+2.4 **- 54%**

  - Isolating one uncertainty : the other two are taken equal to 0.

Moch NNLO	Theoretical uncertainty alone	PDF uncertainty alone	Scale uncertainty alone	Experimental uncertainty alone
Top mass extracted	-2.9/+2.2 **-54%**	-2.5/+2.3 **-57%**	Error of 1.3 GeV **-88%**	-4.6/+5.3 **-11%**

- The most important contribution to the error is the experimental uncertainty**.** (if we divide this error by 2, the error will be : -3.5/+3.5 **-37%**)
- The improvement of cross section measurements will significantly improve the extracted top mass.

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Study of Cross Section Ratio

- **How to reduce the experimental and theoretical uncertainty on the cross section to improve the precision on the extracted top mass ?**

- Improvement of the precision possible by study of cross section ratio : need to know the correlations to compute the ratio. The possible correlations are :

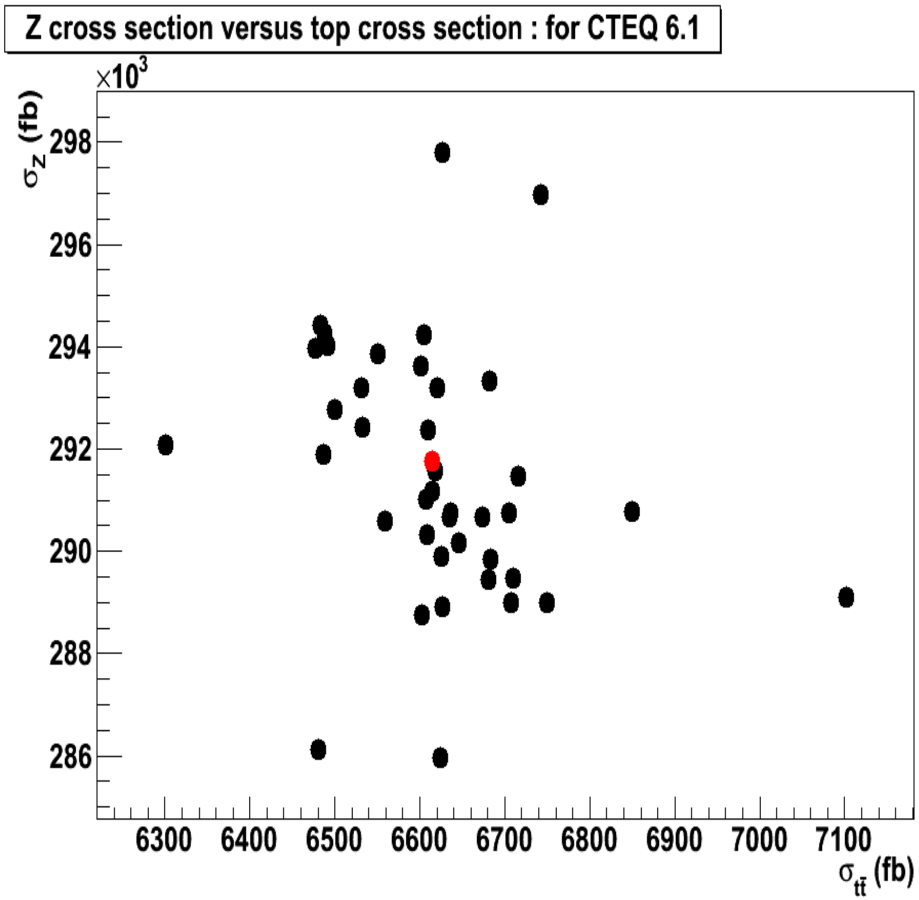
  - **Experimental correlations** : common luminosity error and other systematics
  - **Theoretical correlations** :
    - PDFs uncertainty correlation
    - Renormalization and factorization scales uncertainty correlation

Study of Z and ttbar Processes

- **We will study the two processes :**
  - **Z into ee**
  - **Top pair production**

- **We study the theoretical correlations between the Z and ttbar cross section :**
  - **PDF correlations** : we use MCFM with CTEQ 6.1 set for the determination of the 40 PDF's uncertainties and the central value of the cross section for both Z ->ee and ttbar.
  - **Scales correlations** : we use MCFM for different values of the renormalization and factorization scale. These values are taken between $m_x/2$ and $2m_x$ with X=t or Z. We compare the evolution with the scales of both Z and ttbar cross sections to check for correlations.

Correlations of the PDF Uncertainties



- No clear correlation
- Measurement of the correlation :

$$\cos\varphi = -0.08$$

where cosφ characterizes whether the PDF degrees of freedom of two quantities are correlated (cosφ=1) or not.
(see CTEQ article : arXiv 0802.0007)

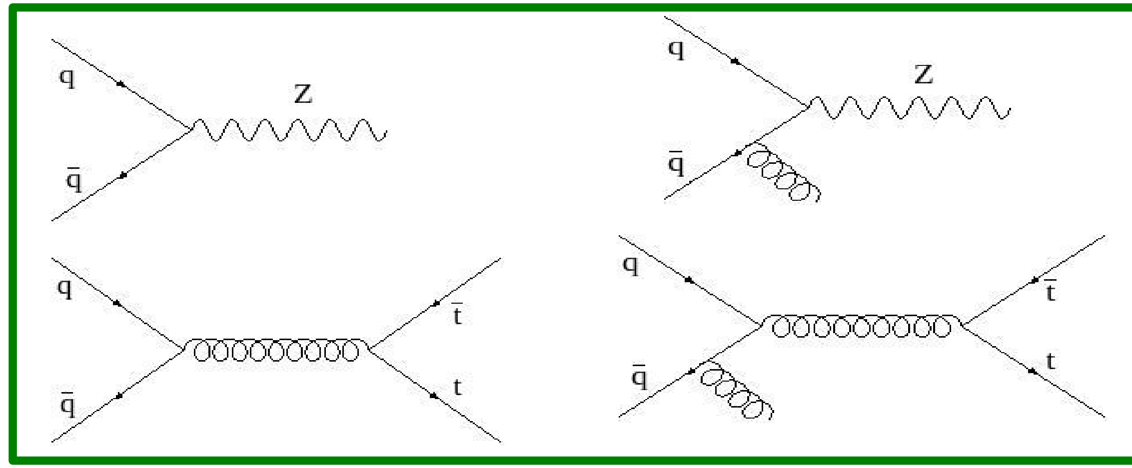
- For CTEQ 6.6 : cosφ= -0.03 (arXiv 0802.0007).
- Conclusion : The PDF uncertainty of the Z and the ttbar cross sections are uncorrelated and will be added quadratically when computing the ratio.

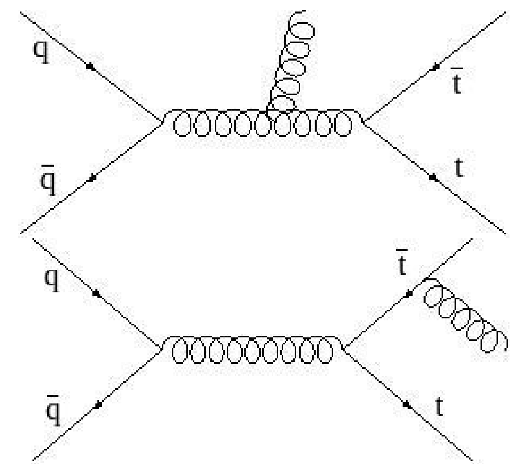
Study of the Scale Uncertainties

LO NLO

Z process

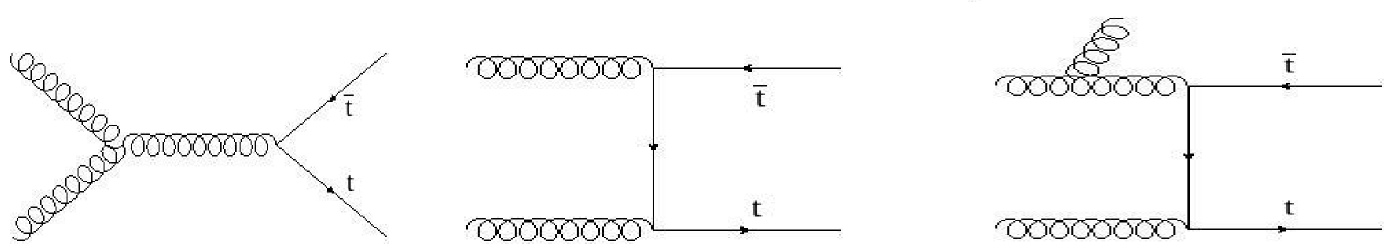
top process



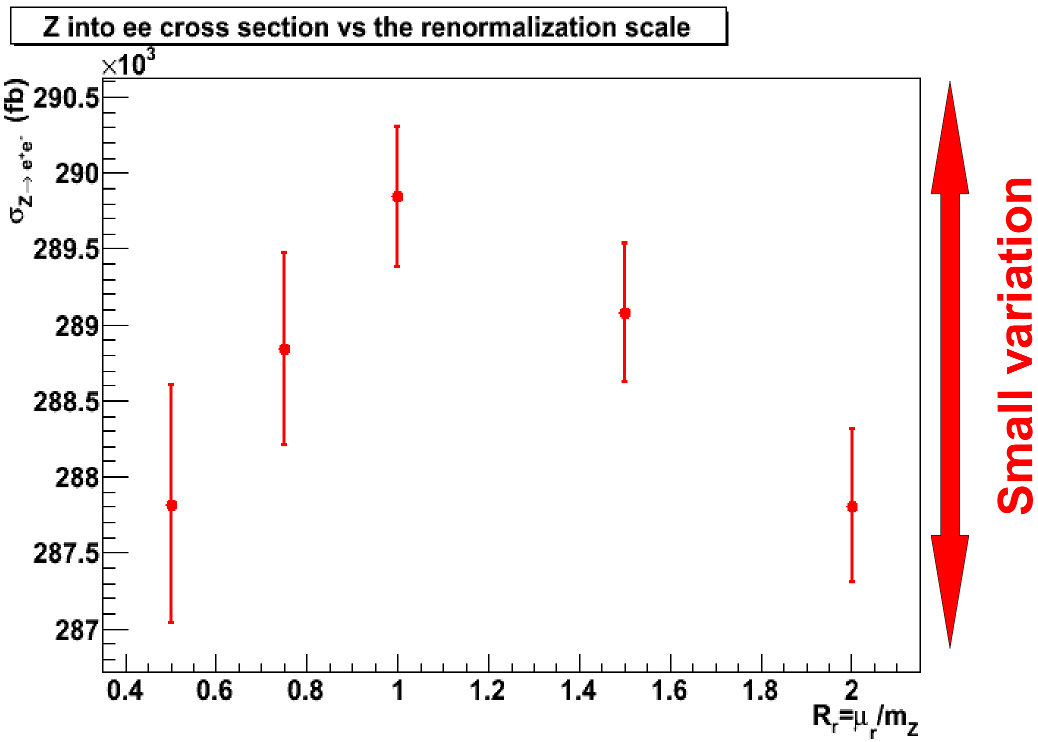


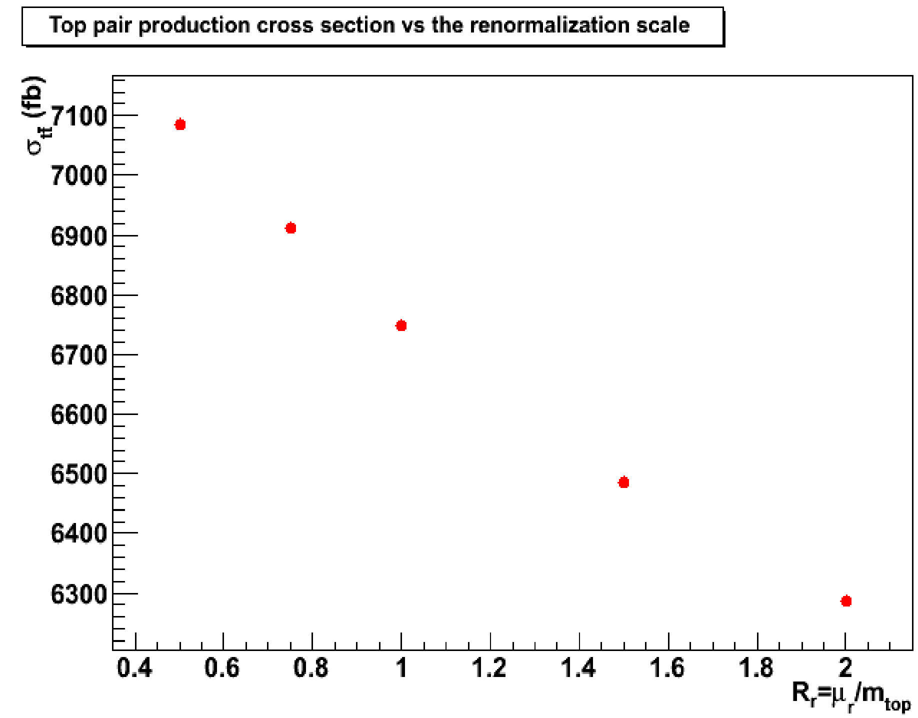
- The renormalization and factorization scales are NON physical parameters.
- But there is some possibilities for correlations :
  Similar Feynman diagrams can lead to a correlation of the factorization and renormalization scale.

15 % at the Tevatron



Renormalization Scale Variation





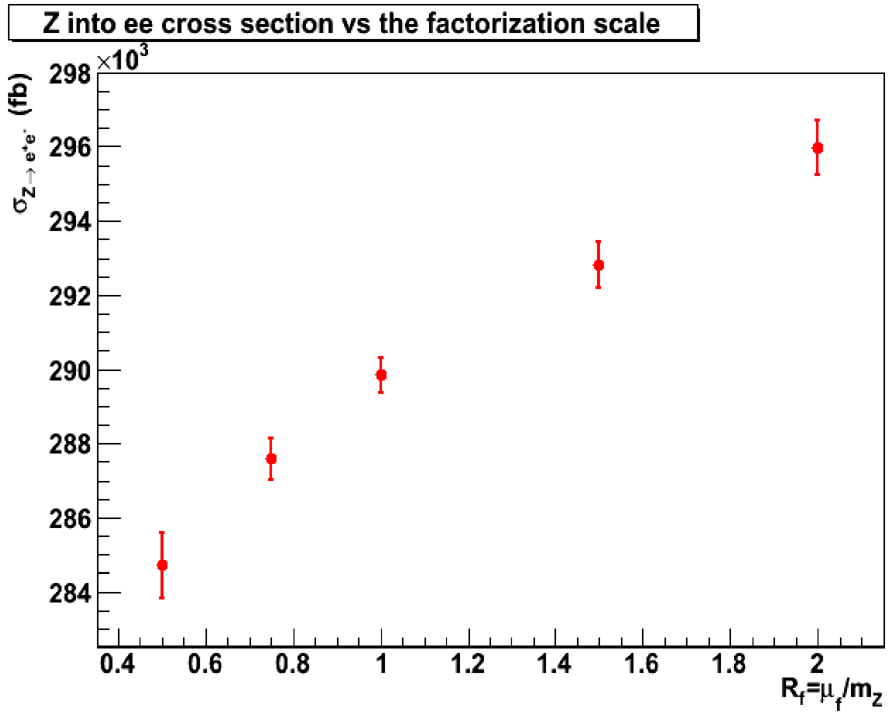
Renormalization scale varying and factorization scale equal to m_X :

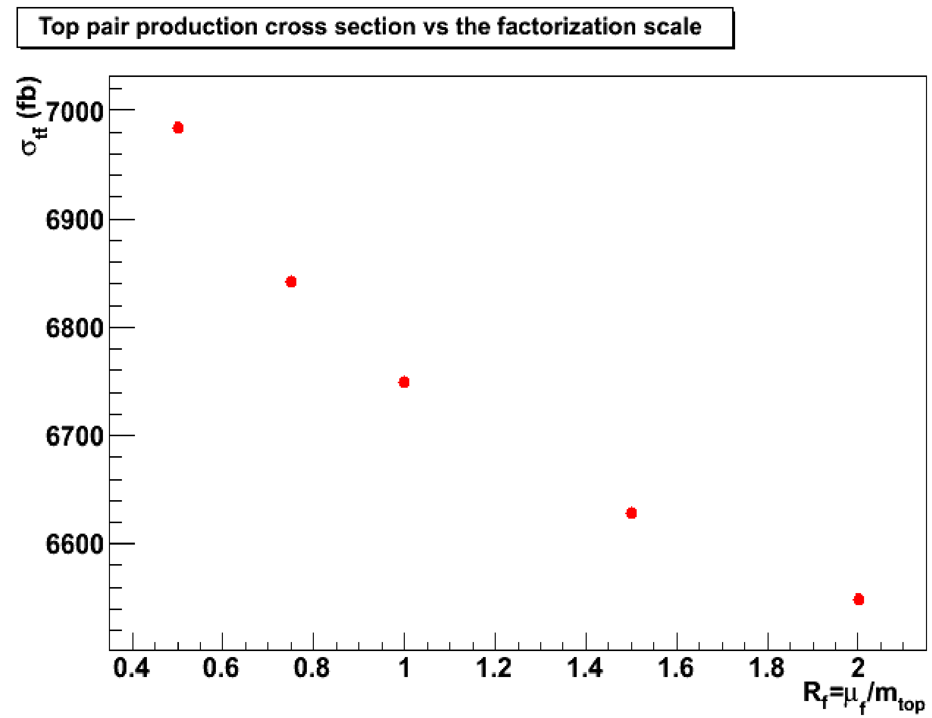
Different behavior.

Due to insensitivity of the Z cross section to the strong coupling constant.

No renormalization scale physical correlation.

Factorization Scale Variation



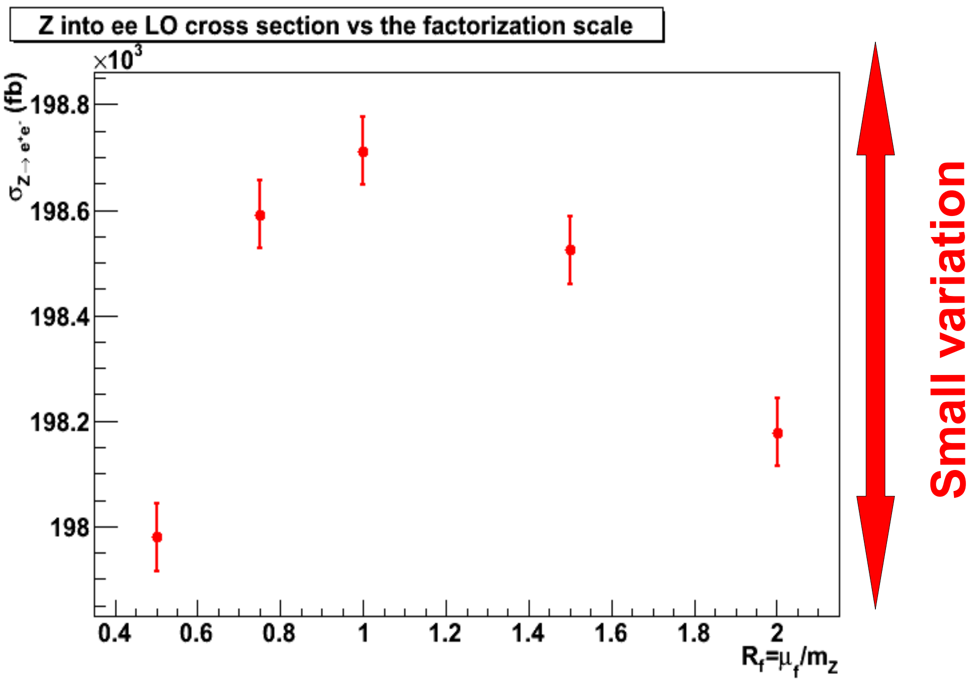


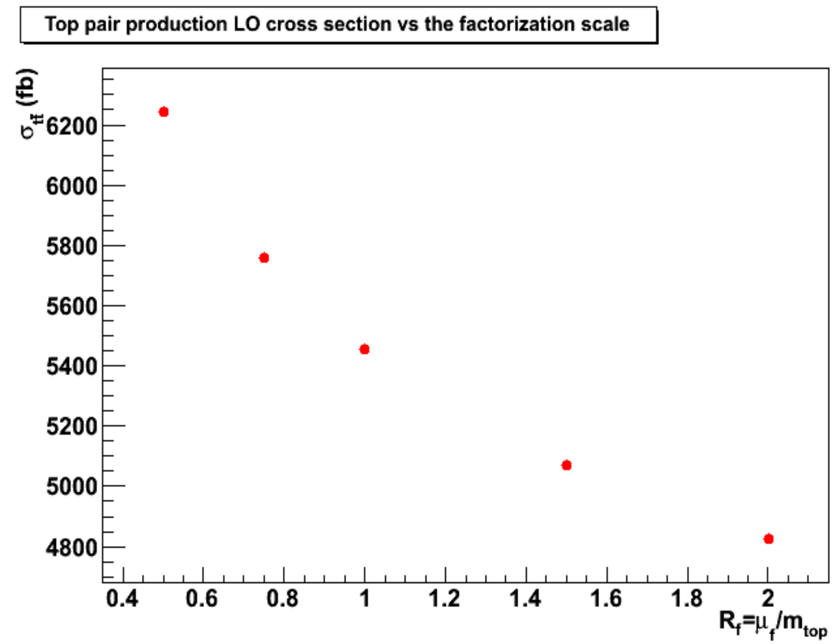
Factorization scale varying and renormalization scale equal to m_X :

At NLO : an opposite behavior appears in contradiction to the hypothesis of similar process.

Maybe due to main PDF contribution to the cross section. We check for anticorrelation at LO.

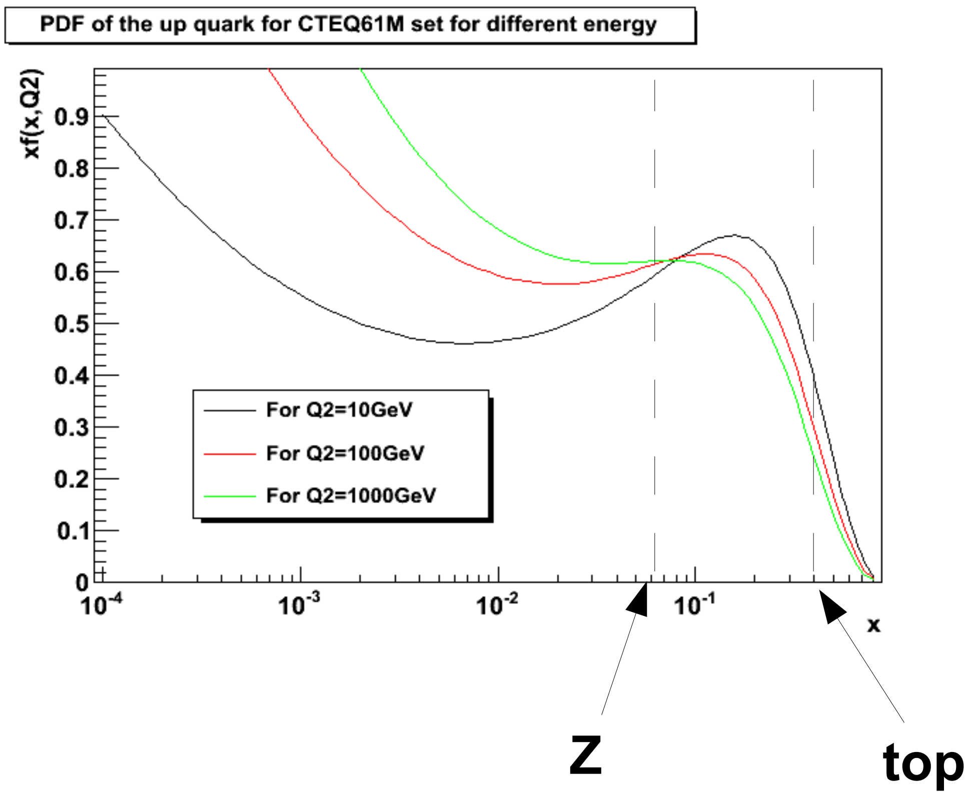
LO Factorization Scale Variation





At LO : The correlation disappears. The anticorrelation at NLO was not due to main PDF contribution.
But the LO behavior can be understood with the PDF evolution.

Evolution of the PDF with the Energy



The top and the Z processes depend on the same PDF.

For the top : x~0.18
For the Z : x~0.046

- Conclusion for the possible correlations for the factorization scale uncertainty :
  - **For NLO** : an opposite behavior appears. The explanation with similar Feynman diagram is not relevant. Maybe due to main PDF contribution.
  - **For LO** : no more opposite behavior but shape explained by the PDF.
  - **Combination** : the opposite behavior at NLO is a combination of the PDF and the partonic cross section contributions. So we don't use the opposite behavior as an anti-correlation.

Combination of the Uncertainties for the Cross Section Ratio

- **At the Tevatron** :
  - **For the PDF uncertainty** : no correlation appears. The errors will be added quadratically.
  - **For the scale uncertainty** : no clear physical correlation appears. The errors will be added quadratically.

$$\sigma_{top} = 6.75 + 0.61 - 0.45 (PDF) + 0.36 - 0.46 (scale) (pb)$$

$$\sigma_{Z} = 290 + 10 - 11 (PDF) + 6.1 - 5.1 (scale) (pb)$$

$$\frac{\sigma_{top}}{\sigma_{Z}} = 2.33 + 0.23 - 0.18 (PDF) + 0.13 - 0.16 (scale) (.10^{-2})$$

- **At the LHC :** after the same studies, we found :
  - **For the PDF uncertainty :** an anti-correlation appears. The errors will be added.
  - **For the scale uncertainty :** no clear physical correlation appears. The errors will be added quadratically.

$$\sigma_{top} = 801 + 28 - 29 (PDF) + 89 - 91 (scale) (pb)$$

$$\sigma_{Z} = 2.25 + 0.12 - 0.14 (PDF) + 0.19 - 0.30 (scale) (pb) (.10^{3})$$

$$\frac{\sigma_{top}}{\sigma_{Z}} = 3.44 + 0.30 - 0.34 (PDF) + 0.48 - 0.60 (scale) (.10^{-1})$$

Summary

- The extraction of a well-defined top mass from cross section measurement is in good agreement with the world average.

- The possible theoretical correlations have been studied with MCFM 5.2 and the CTEQ 6.1 set :

  - **At the Tevatron** :
    - No PDF correlation
    - No scale correlation

$$\frac{\sigma_{top}}{\sigma_Z} = 2.33 + 0.23 - 0.18 (PDF) + 0.13 - 0.16 (scale) (.10^{-2})$$

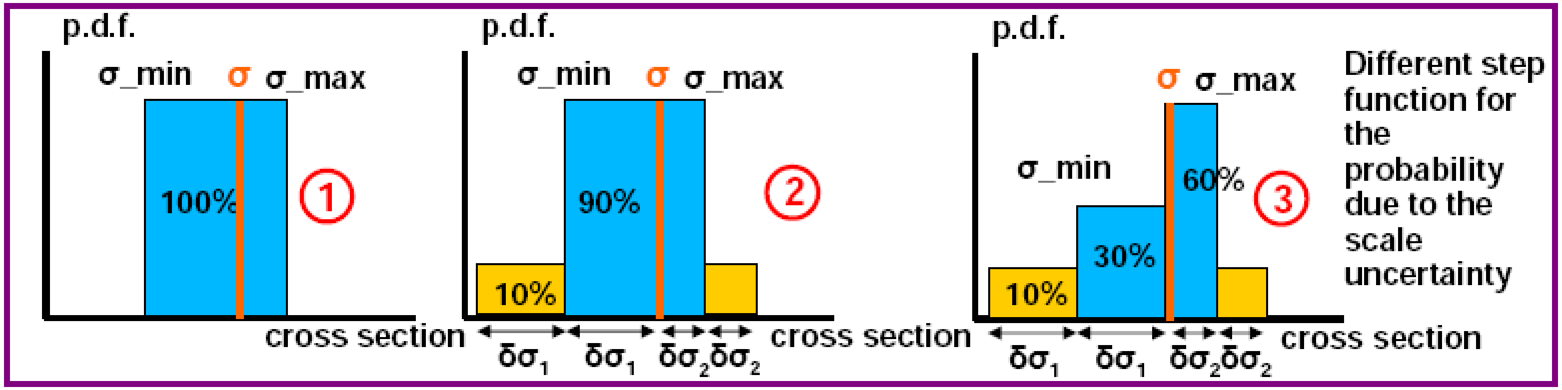
  - **At the LHC** :
    - PDF anti-correlation
    - No scale correlation

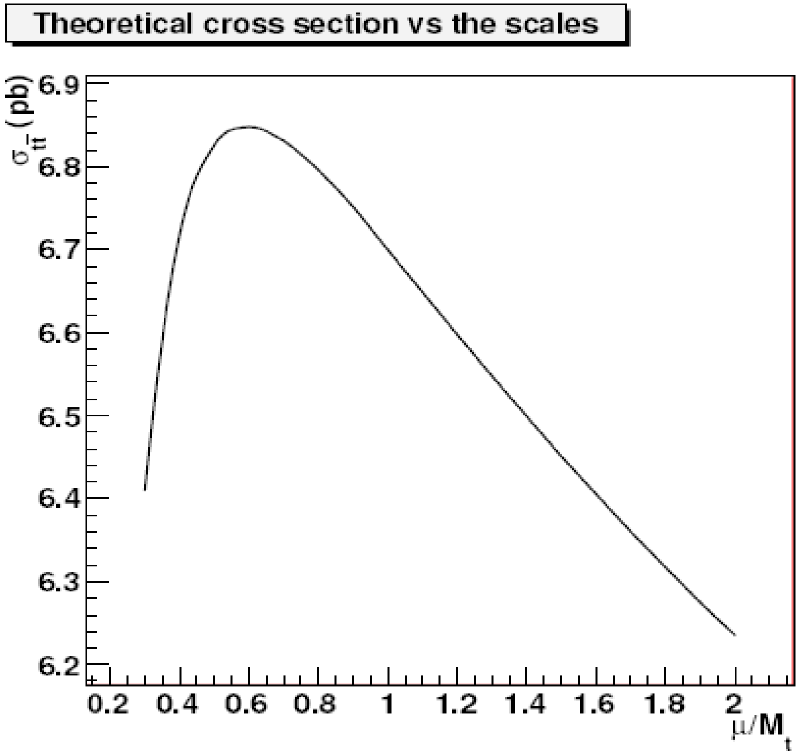
$$\frac{\sigma_{top}}{\sigma_Z} = 3.44 + 0.30 - 0.34 (PDF) + 0.48 - 0.60 (scale) (.10^{-1})$$

- There is no reduction of the theoretical uncertainties on the ratio of the cross sections due to correlation.
- Would need to work on the experimental Z/ttbar ratio to use it for the mass extraction (no manpower found for the moment).

Backup

Different Shapes for the Scale p.d.f.





- The p.d.f. for the cross section can be construct from the p.d.f for the scales using the relation between the cross section and the scales.
- A flat prior on the scales leads to higher probabilities for higher values of the cross section.
- At the Tevatron, the extracted top mass is insensitive to the scale p.d.f. shape.