Uncertainties on H and \( \text{ttbar} \) Predictions at the LHC
(and update on Intrinsic Charm)

Carl Schmidt
Michigan State University

On behalf of CTEQ-TEA group

April 29, 2014
DIS2014, Warsaw, Poland
Outline

1) Update of CTEQ-TEA activities discussed this morning
   CT10 update, MetaPDFs, photon PDF, etc.

2) Update of Intrinsic Charm Analysis
   Dulat et al, PRD 89, 073004 (2014)

3) Lagrange Multiplier (LM) Uncertainty Analysis on gg->H

4) Uncertainty Analysis on gg->ttbar
**Intrinsic Charm and CT10IC**

1) Update of CTEQ6.5 IC study from 2007 to CT10NNLO
   - includes combined H1 and ZEUS data, HERA inclusive charm

2) Recent CT10 global analysis study of charm quark mass:
   \[ m_c (m_c) = 1.15^{+0.18}_{-0.12} \text{ GeV} \]
   Use \( m_c (\text{pole}) = 1.3 \) GeV for this study
   - some correlation between \( m_c \) and IC

3) Two model Intrinsic Charm distributions at \( Q_c = 1.3 \) GeV
   - SEA-like model
   \[ \langle x \rangle_{IC} = \int_0^1 x \left[ c(x, Q_c) + \bar{c}(x, Q_c) \right] dx \]

4) 90% CL limits:
   \[ \langle x \rangle_{IC} \leq 0.025 \quad \text{BHPS} \]
   \[ \langle x \rangle_{IC} \leq 0.015 \quad \text{SEA} \]
Intrinsic Charm at LHC

IC vs CT10 charm PDF

\[ \langle x \rangle_{IC} = \begin{cases} 
0.57\% & \text{SEA1/BHPS1} \\
1.5\% & \text{SEA2} \\
2.0\% & \text{BHPS2} 
\end{cases} \]

\[ pp \to Zc \] at LHC may further constrain valence-like model
CT10 IC at LHC

W, Z and top production at LHC

CT10 IC distributions publicly available
PDF uncertainties in $gg \rightarrow H$

1) Most analyses use Hessian Method (n error PDF sets)

\[
(\delta X)^2 = \frac{1}{4} \sum_{k=1}^{n} \left( X(a_k^+) - X(a_k^-) \right)^2
\]

- Error sets can be used by anyone for any observable
- Assume quadratic and linear dependence of $\chi^2$, $X$ on $a_k$

2) Lagrange Multiplier (LM) method is more robust

- Find best fit for each constrained value of observable $X$
- No assumptions on dependence of $\chi^2$, $X$ on $a_k$
- Can validate Hessian method
- Can display correlations between PDFs and Observable
- Must calculate separately for each observable
Uncertainties in $gg \rightarrow H$

- Curves are LM, circles/squares are Hessian
- Red use $\chi^2$
- Blue add Tier-2 penalty to ensure no specific experiment is too badly fit
- Allowed Tolerance is 100 at 90% CL

- Small differences in asymmetries, but in general the two methods agree well for this observable
Combined PDF+$\alpha_s$ Uncertainties

- Can include $\alpha_s$ uncertainty as contribution to total $\chi^2$ in LM method
- Use PDF4LHC choice of $\alpha_s=0.118\pm0.002$ at 90% CL
- Black curves are 68% and 90% CL contours

- Hessian method adds $\alpha_s$ and PDF uncertainties in quadrature
- Hessian and LM agree well for Higgs cross section (despite non-quadratic behavior, especially obvious at 14 TeV)
- For instance 90% CL uncertainties at 14 TeV (% of central value):
  - LM: +5.2/-5.2    Hessian: +5.4/-5.0
CT10H Extreme Sets

- PDF sets that give extreme values of Higgs cross section at 90% CL are publicly available as CT10H sets
- Shown on contour plot as Red squares
- PDF uncertainty only or PDF+$\alpha_s$ uncertainty
- Useful for efficient $gg\to H$ analyses
Sensitivity to Data Sets

- How sensitive are included data sets to value of $\sigma_H$?
- “Effective Gaussian Variable” $S$ maps cumulative $\chi^2$ distribution for $N_{pt}$ onto cumulative Gaussian distribution
  - +1,+2,+3,… equivalent to that many sigma deviations
  - Negative values correspond to anomalously well-fit data
- Most strongly correlated data: high $p_T$ jet, inclusive HERA, CCFR-dimuon
  - HERA more strongly correlated with 14 TeV—smaller $x$
  - CCFR dimuon correlation due to gluon-charm interdependence
Uncertainties in $gg \rightarrow \text{ttbar}$

- Same analyses applied to $gg \rightarrow \text{ttbar}$
- HERA combined data (T2) constrains low values of cross section
- But T2 less important for combined PDF+$\alpha_S$
- Hessian and LM consistent
CT10tt extreme sets

$\mu=173$ GeV, LHC 7 TeV, CXX NNLO extreme eigen.sets

$\frac{d\sigma}{dp_T}$ [pb/GeV]

$p_T$ [GeV]

- Pairs of CT10tt extreme sets (PDF, PDF+$\alpha_s$) to be released
  - for focused ttbar analyses

Results provided by DiffTop group (M. Guzzì, K. Lipka, S. Moch)
• Comparison with CMS (left) and ATLAS (right) data
• Hessian top, LM extreme sets bottom
• Extreme sets useful if highly correlated with inclusive ttbar (note high $p_T$)

Results provided by DiffTop group (M. Guzzi, K. Lipka, S. Moch)
Conclusions

• Intrinsic Charm
  • Limits on valence-like and sea-like IC
  • CT10IC PDFs available for further study
  • LHC will probe further

• Lagrange Multiplier Uncertainty analysis
  • Less dependent on assumptions than Hessian analysis
  • Allows study of data correlations with particular observable
  • Test of Hessian results
    • Consistent with Hessian results for both Higgs and ttbar
  • CT10H extreme sets available for focussed studies
    (CT10tt extreme sets to come)