Heavy flavors on CT14

Tie-Jiun Hou
In collaboration with CTEQ-TEA group

Southern Methodist University

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CTEQ-TEA group

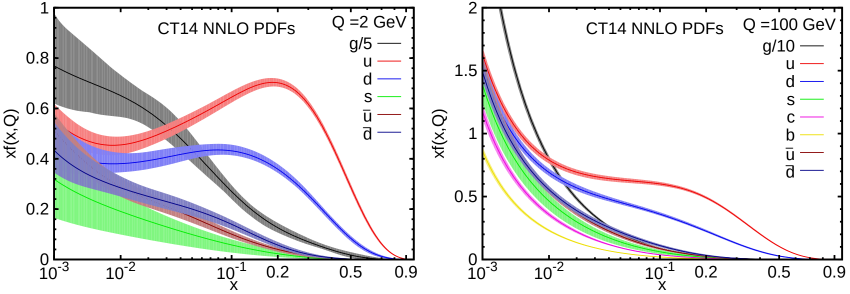
- CTEQ – Tung et al. (TEA)
  in memory of Prof. Wu-Ki Tung, who established CTEQ Collaboration in early 90's.
- Current members:
  Sayipjamal Dulat (Xinjiang U.)
  Tie-Jiun Hou, Pavel Nadolsky (Southern Methodist U.)
  Jun Gao(Argonne Nat. lab.)
  Marco Guzzi(U. of Manchester)
  Joey Huston, Jon Pumplin, Carl Schmidt,
  Dan Stump, C.-P. Yuan(Michigan State U.)

Outline

- Brief introduction on CT14
- Intrimsic charm
- $gg \to H$ production and $pp \to t\bar{t}$ production
- Summary

CT14 Global Analysis

- CT10 includes only pre-LHC data
- CT14 is the first CT analysis including LHC Run 1 data
- CT14 also includes the new D0 Run 2 data on W-lepton charge asymmetry
- CT14 uses a more flexible parametrization in the non-perturbative PDFs.



Update for CT14

- Based on CT10 data set, but updated with new HERA F_L and F_2^c, and drop Tevatron Run 1 CDF and D0 inclusive jet
- Included some LHC Run 1 (at 7 TeV) data:
  ATLAS and LHCb W/Z production,
  ATLAS, CMS and LHCb W-lepton charge asymmetry,
  ATLAS and CMS inclusive jet
- Replace old (0.75 1/fb) by new D0 (9.7 1/fb) W-electron rapidity asymmetry data
- CT14 has 28 shape parameters, and CT10 has 25.
- The total number of data points is 3174 with $\chi^2/\text{d.o.f.} = 1.104$
- For further detail of the CT14, please check Prof. C.-P. Yuan's talk

Brief Review on the Uncertainty Estimation Method

The fitting function form of PDF are in general in the form,

$$f(x, Q_0) = a_0 x^{a_1}(1-x)^{a_2} F(x, \{a_3, ...\})$$

$f(x, Q)$ with energy scale $Q > Q_0$ would then be generated by evolution. The PDF, i.e. $\{a_i\}$, is obtained by minimize the global χ^2 function,

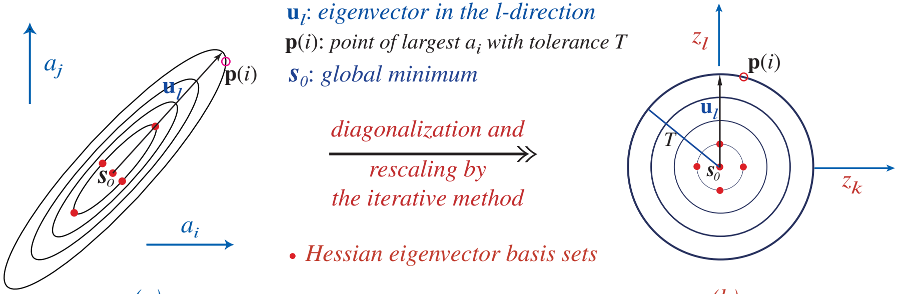
$$\chi^2_{global} = \sum_e \chi^2_e(a, r),$$

$$\text{where} \quad \chi^2_e(a, r) = \sum_\nu \frac{[D_\nu - \sum_k r_k \beta_{k\nu} - T_\nu(a)]^2}{\alpha_\nu^2} + \sum_k r_k^2.$$

Here e is the index of the experimental data set and ν is the index of the data point in a particular data set. D_ν is the central value of experimental data, $T_\nu(a)$ is the theoretical prediction, which is a function of a set of n PDF parameters, $\{a_1, \ldots, a_n\}$, α_ν is the uncorrelated error, and $\beta_{k\nu}$ is the kth correlated systematic error estimate. . In addition, $\{r_k\}$ is a set of Gaussian random variables; thus, $r_k\beta_{k\nu}$ is a (correlated) shift applied to D_ν to represent the contribution from systematic error.

Hessian Method

2-dim (i,j) rendition of d-dim (~16) PDF parameter space



(a)
Original parameter basis

(b)
Orthonormal eigenvector basis

$$\delta^+ X = \sqrt{\sum_{i=1}^{N_a}\left[\max\left(X_i^{(+)} - X_0, X_i^{(-)} - X_0, 0\right)\right]^2}, \delta^- X = \sqrt{\sum_{i=1}^{N_a}\left[\max\left(X_0 - X_i^{(+)}, X_0 - X_i^{(-)}, 0\right)\right]^2},$$

Hessian Method

The χ^2/N_{pt} is not sufficient to discribe the goodness-of-fit for individual experiment. The chi-square probability for $\chi^2/N_{pt} \geq 11.0/10$ is 0.358; the probability for $\chi^2/N_{pt} \geq 110.0/100$ is 0.232. And the probability for $\chi^2/N \geq 1100.0/1000$ is only 0.015. For this reason, we define the effective Gaussian variable, the "*spartyness*", S_n,

$$C(\chi^2, N) = \int_0^{\chi^2} P(\xi, N) d\xi = \int_{-\infty}^{S_n} \frac{e^{-x^2/2} dx}{\sqrt{2\pi}}.$$

In practice, we use the approximation for S_n

$$S_n \approx L(\chi^2, N_{pt}) = \frac{(18N_{pt})^{3/2}}{18N_{pt}+1} \left\{ \frac{6}{6 - \ln(\chi^2/N_{pt})} - \frac{9N_{pt}}{9N_{pt}-1} \right\}$$

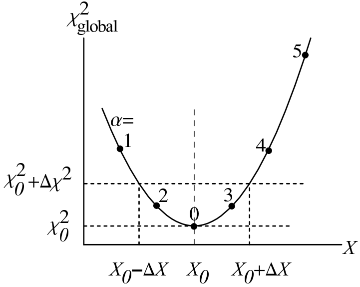
Ideally, the variable S_n has an approximately Gaussian distribution with mean 0 and standard deviation 1. Additional $Tier-2$ penalty for each experiment, $T_2(i) = (S_n(i)/S_{n,best}(i))^{16}$, is included to test the goodness-of-fit for those $S_n(i) > 0$.

Lagrange Multiplier Method

Conaider a particular physical quantity, say $X(\{a_i\})$, which is a function of PDFs.

$$F(\lambda, \{a_i\}) = \chi^2(\{a_i\}) + \lambda(X(\{a_i\}) - X(\{a_i^{(0)}\}))$$

By minimizing this function with various fixed λ value, say $\lambda_1, ...\lambda_j..., \lambda_n$, we will obtain n parameter sets $\{a_i(\lambda_j)\}$ and corresponding $X(\{a_i(\lambda_j)\})$ and $\chi^2(\{a_i(\lambda_j)\})$. With suitable choice of $\Delta\chi^2$, we obtain the uncertainty of the physical quantity $X(\{a_i\})$.



The $\Delta\chi^2 = T^2$, with $T = 10$, is considered as uncertain region of 90% CL.

Intrinsic Charm

Base on the CT14, we study the Intrinsic charm to compare with the result base on CT10. In this update study, we consider two models. One is the Brodsky, Hoyer, Peterson, and Sakai (BHPS) model, which can be parameterized as

$$\hat{c}(x) = A\, x^2 \left[6x(1+x)\ln x + (1-x)(1+10x+x^2)\right].$$

The other is the SEA model.

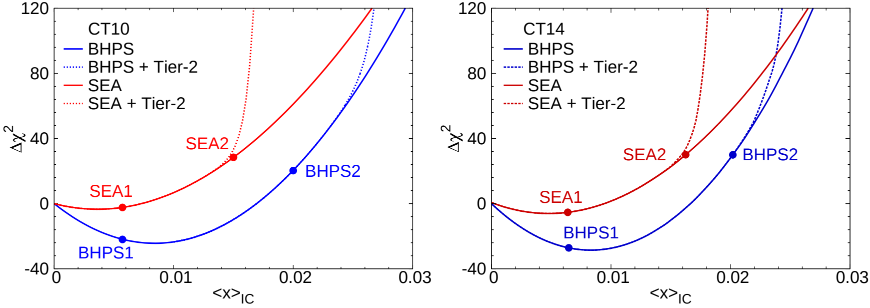
$$\hat{c}(x) = A\ \left(\overline{d}(x, Q_0) + \overline{u}(x, Q_0)\right).$$

They are characterized by the momentum fraction of the at Q_c.

$$\langle x \rangle_{\mathrm{IC}} = \int_0^1 x\,[2\hat{c}(x)]\,dx,$$

The charm PDF becomes active at $Q_c = m_c = 1.3$ GeV.

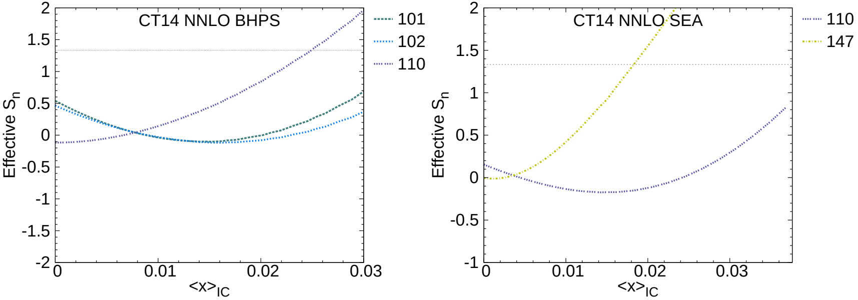
Intrinsic Charm



In the CT10 study, we concluded that, the upper limit on $\langle x \rangle_{\rm IC}$ on 90%C.L. are:

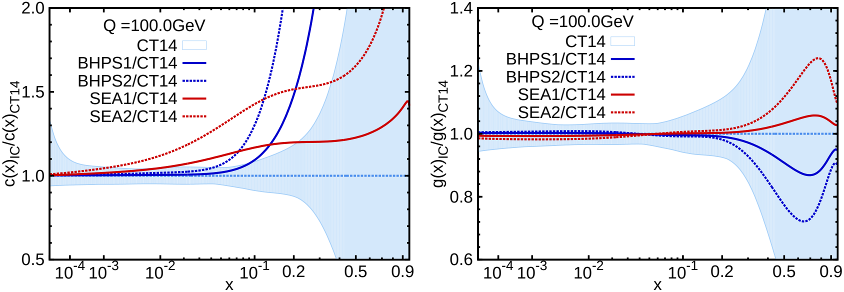
$$\langle x \rangle_{\rm IC} \lesssim 0.025 \quad \text{for Model BHPS,}$$
$$\langle x \rangle_{\rm IC} \lesssim 0.015 \quad \text{for Model SEA.}$$

Intrinsic Charm



The BHPS model is mostly constrainted by CCFR F_2 data, while the SEA model is mostly constrainted by the HERA charm DIS data.

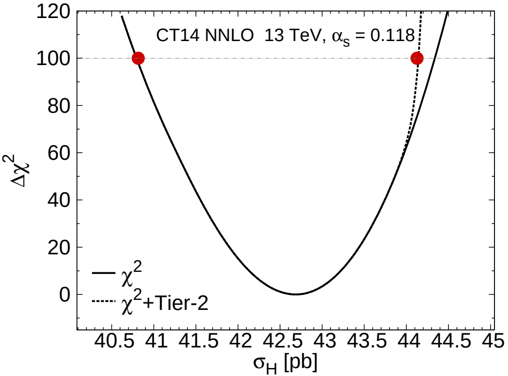
Intrinsic Charm



The BHPS model has large deviation from the CT14 only at large x region.

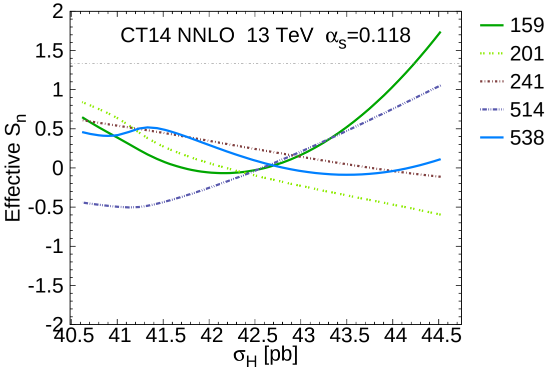
Higgs Boson Production

We check uncertainty of the $gg \to H$ production channel at 13 TeV from Hessian method by the Lagrange Multiplier method.



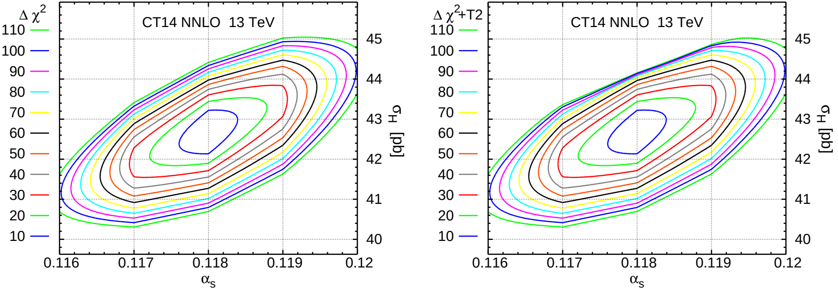
	13 TeV ($\alpha_s = 0.118$)
$gg \to H$ (pb), 90.0% C.L. (Hessian,PDF)	$42.68 + 3.32\% - 3.88\%$
$gg \to H$ (pb), 90.0% C.L. (LM,PDF)	$42.68 + 3.42\% - 3.80\%$

Higgs Boson Production



The HERA DIS data dislike the $gg \to H$ production to be too large.

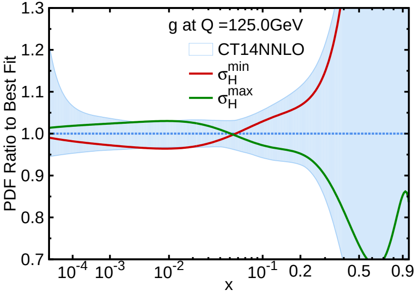
Higgs Boson Production

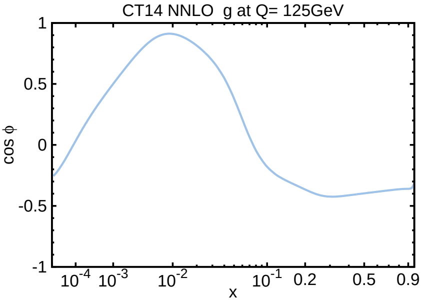


	13 TeV
$gg \to H$ (pb), 90.0% C.L. (Hessian,PDF+α_s)	$42.68 + 4.94\% - 5.28\%$
$gg \to H$ (pb), 90.0% C.L. (LM,PDF+α_s)	$42.68 + 5.19\% - 5.96\%$

The contour plot shows the correlation between Higgs boson production and α_s. The $gg \to H$ production increase as α_s incrase. (The right figure shows the correlation with the Tier-2 penalty to be taken into account.)

Higgs Boson Production

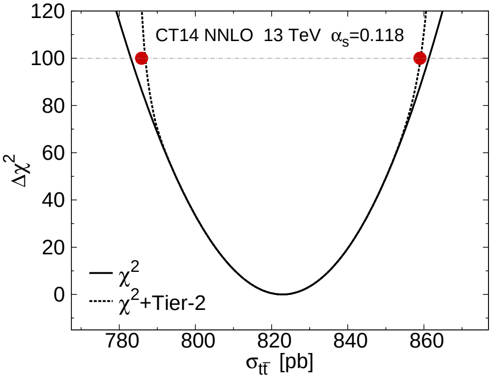




The $gg \to H$ production correlate to gluon strongly at x around 10^{-2}. The two extreme PDFs obtained by Lagrange Mulitpiler method on ggh production can envelop the gluon uncertainty.

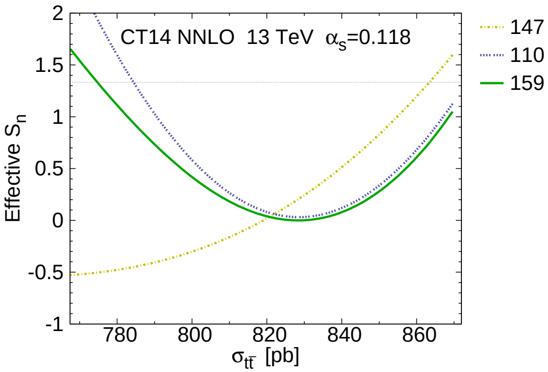
$t\bar{t}$ Production

The uncertainty of the $pp \to t\bar{t}$ production at 13 TeV from Hessian method is also checked by the Lagrange Multiplier method.



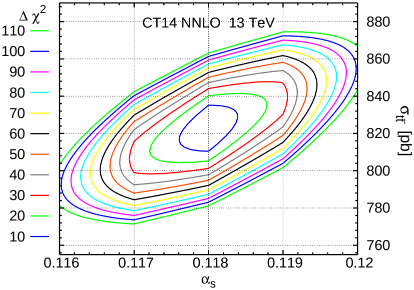
	13 TeV ($\alpha_s = 0.118$)
$pp \to t\bar{t}$ (pb), 90.0% C.L. (Hessian, PDF)	$822.64 + 4.41\% - 4.47\%$
$pp \to t\bar{t}$ (pb), 90.0% C.L. (LM, PDF)	$822.84 + 4.41\% - 4.37\%$

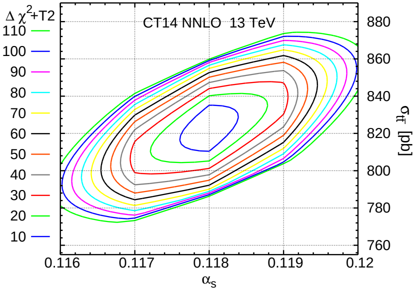
$t\bar{t}$ Production in LHC



The HERA charm production data dislike the $t\bar{t}$ production to be too large, while the HERA DIS data and CCFR F_2 data dislike the $t\bar{t}$ production to be too small.

$t\bar{t}$ Production in LHC

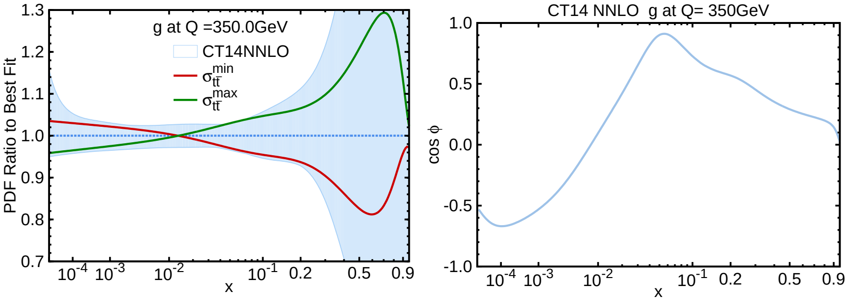




	13 TeV
$pp \to t\bar{t}$ (pb), 90.0% C.L. (Hessian,PDF$+\alpha_s$)	$822.64 + 5.84\% - 5.70\%$
$pp \to t\bar{t}$ (pb), 90.0% C.L. (LM,PDF$+\alpha_s$)	$822.84 + 5.98\% - 5.89\%$

The correlation contour between $t\bar{t}$ production and α_s.

$t\bar{t}$ Production in LHC



The $pp \to t\bar{t}$ production correlate to gluon PDF strongly at x around 0.06.

Summary

- The CT14 has more flexible parametrization which including the LHC Run 1(ATLAS, CMS, LHCb) W, Z and jet data and the new Tevetron D0 W-electron asymmetry data.
- CT14, at NNLO, NLO and LO, is about to be released in public.
- The CT14 based intrinsic charm updated study shows no significant change on acceptable momentum fraction range from CT10.
- The CT14 study on $gg \to H$ production and $pp \to t\bar{t}$ production show good agreement between Hessian method and Lagrage multiplier method. This consistency also reflect on the gluon uncertainty for both methods.
- The extreme sets for the intrinsic charm, $gg \to H$ and $pp \to t\bar{t}$ will be released in public too.