Uncertainties on H and ttbar Predictions at the LHC
(and update on Intrinsic Charm)

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On behalf of CTEQ-TEA group

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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
   Dulat et al, arXiv:1309.0025[hep-ph]

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:
   $m_c(m_c) = 1.15^{+0.18}_{-0.12}$ GeV Gao et al, Eur.Phys.J. C73 (2013) 2541
   Use m_c(pole)=1.3 GeV for this study
   - some correlation between m_c and IC

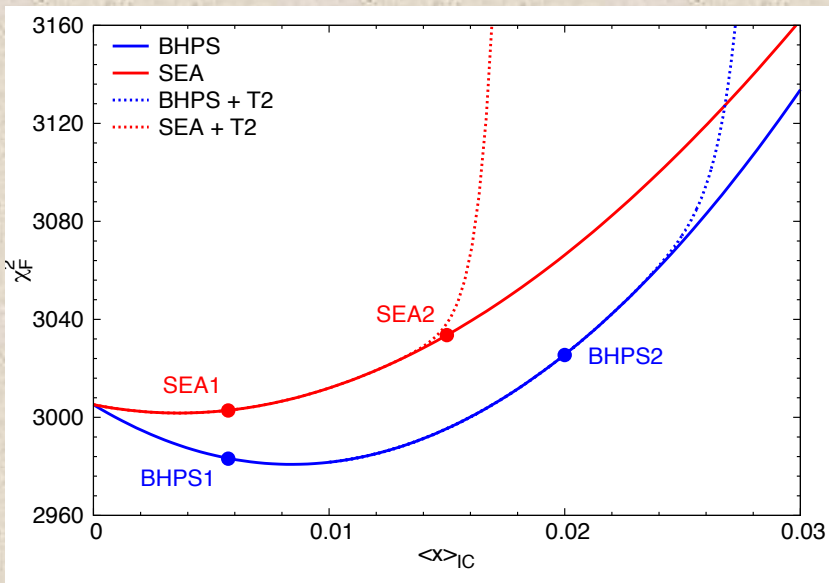
3) Two model Intrinsic Charm distributions at Q_c=1.3 GeV
   - BHPS valence-like model (Brodsky et al, Phys. Lett. **93B**, 451 (1980))
   - SEA-like model

$$\langle x \rangle_{IC} = \int_0^1 x\left[c(x,Q_c) + \bar{c}(x,Q_c)\right]dx$$

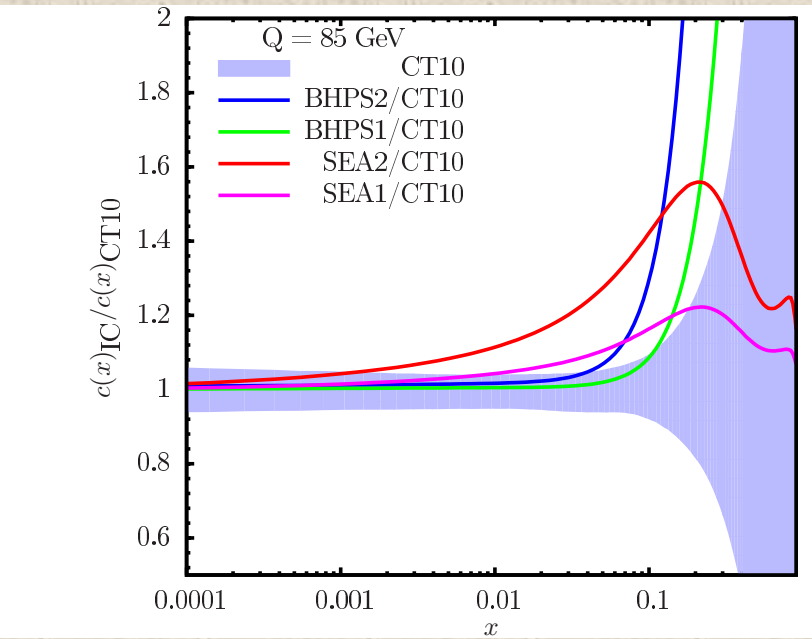
4) 90% CL limits:

$$\langle x \rangle_{IC} \leq 0.025 \quad \text{BHPS}$$

$$\langle x \rangle_{IC} \leq 0.015 \quad \text{SEA}$$



Intrinsic Charm at LHC

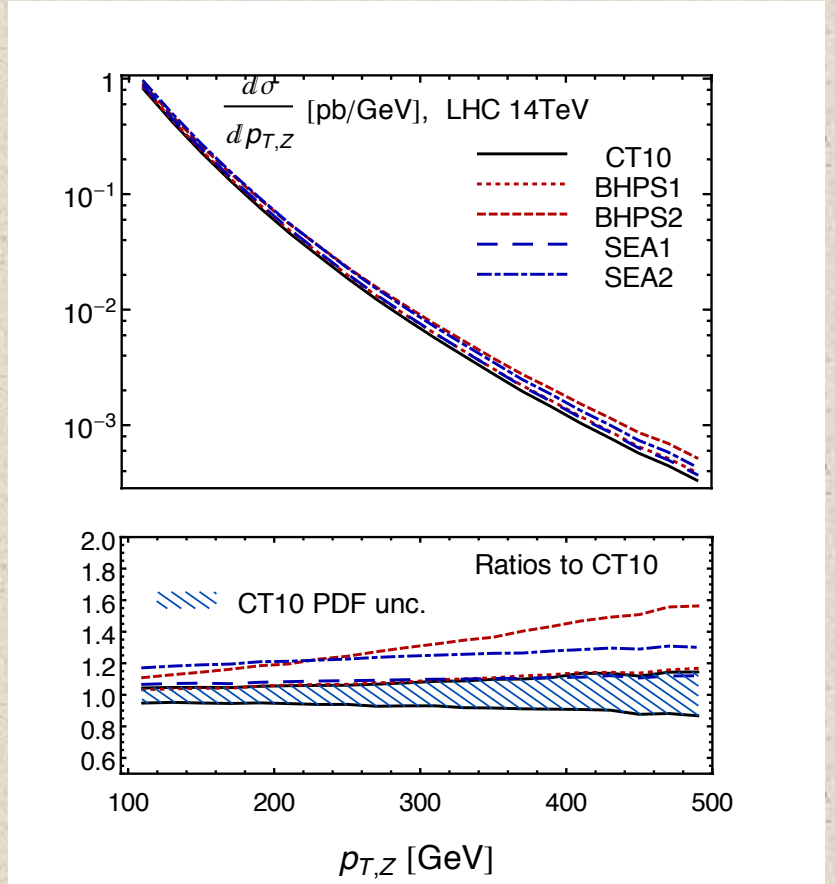


IC vs CT10 charm PDF

SEA1/BHPS1: $\langle x \rangle_{\rm IC} = 0.57\%$

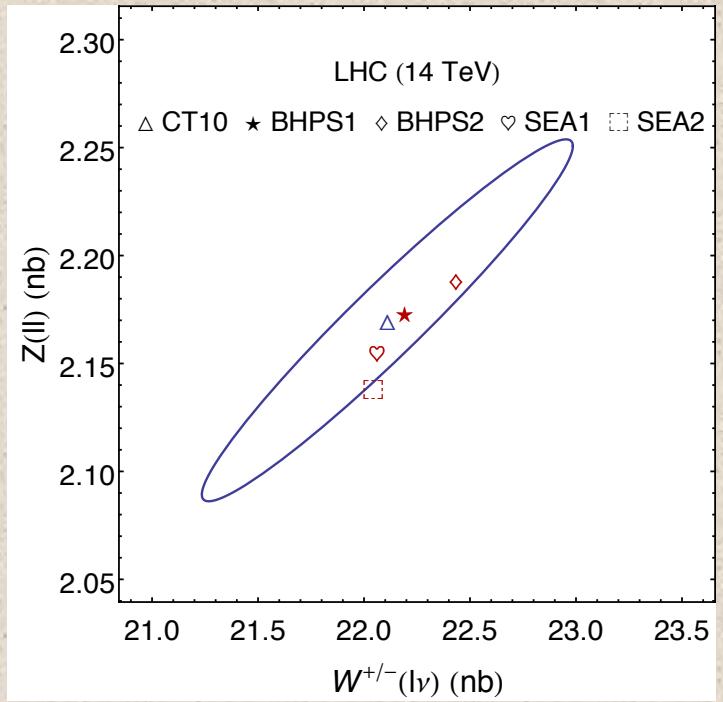
SEA2: $\langle x \rangle_{\rm IC} = 1.5\%$

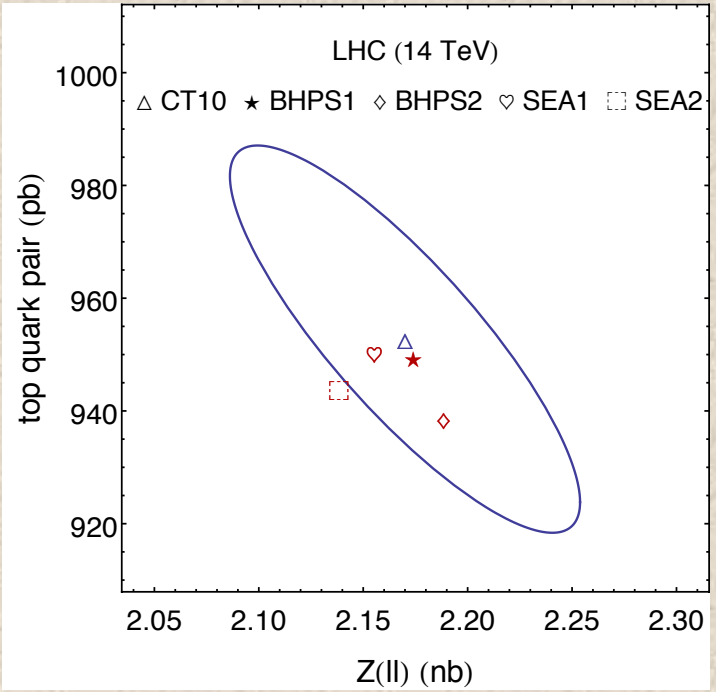
BHPS2: $\langle x \rangle_{\rm IC} = 2.0\%$



$pp \to Zc$ 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)

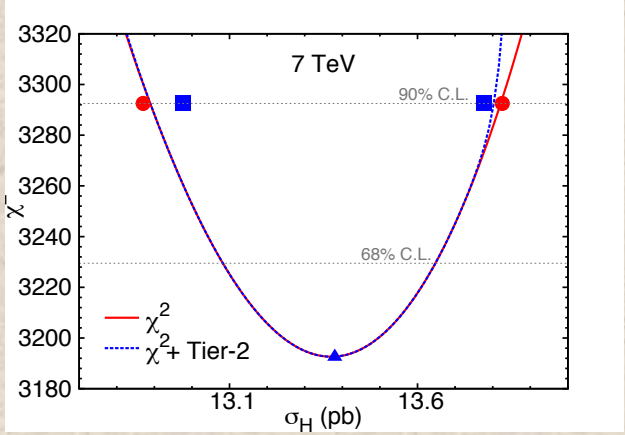
$$(\delta X)^2 = \frac{1}{4}\sum_{k=1}^{n}\left(X(a_k^+) - X(a_k^-)\right)^2$$

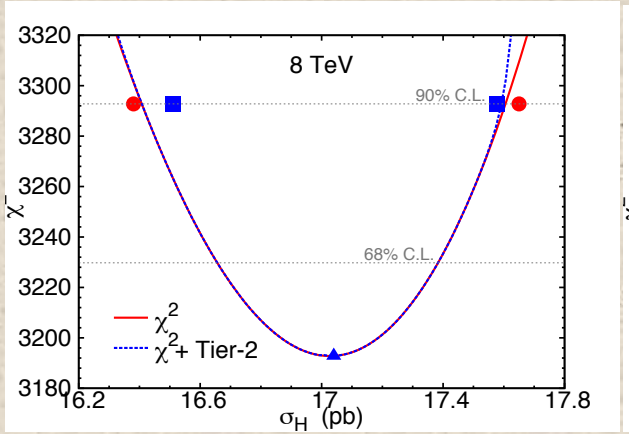
- Error sets can be used by anyone for any observable
- Assume quadratic and linear dependence of χ^2, X on a_k

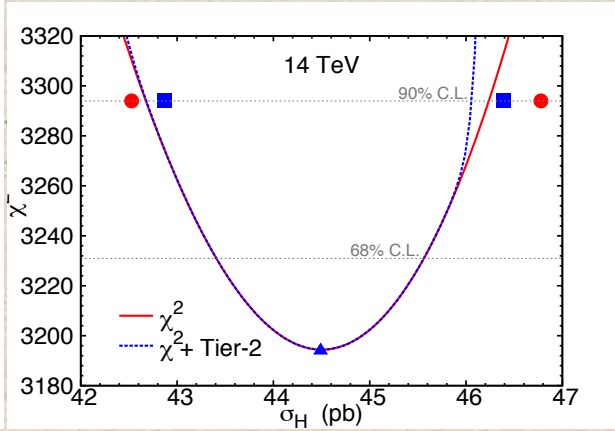
2) Lagrange Multiplier (LM) method is more robust

- Find best fit for each constrained value of observable X
- No assumptions on dependence of χ^2, X on a_k
- Can validate Hessian method
- Can display correlations between PDFs and Observable
- Must calculate separately for each observable

Uncertainties in $gg \rightarrow H$



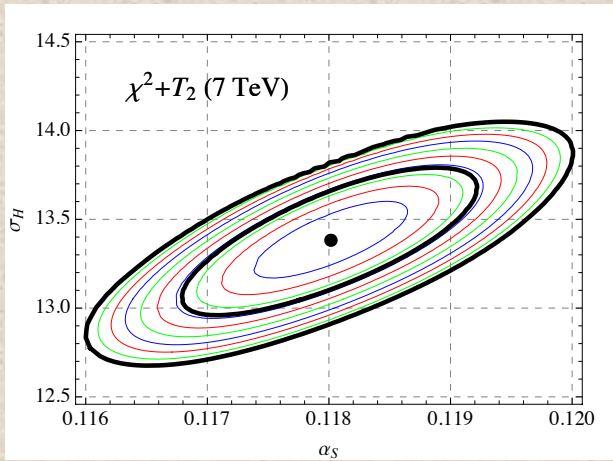


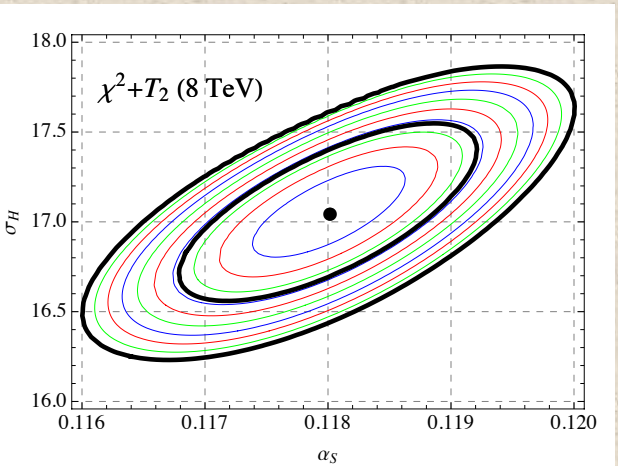


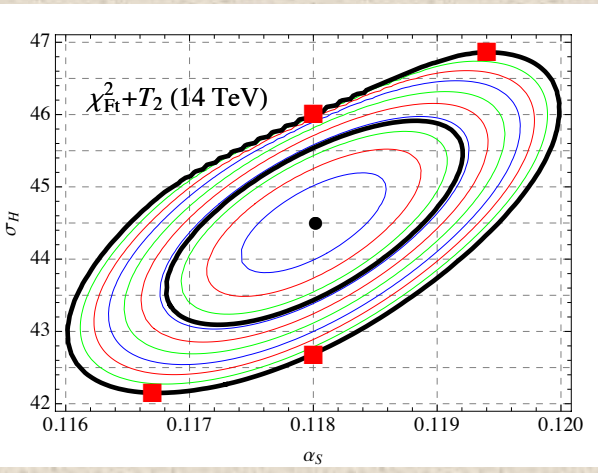
- Curves are LM, circles/squares are Hessian
- Red use χ^2
- Blue add Tier-2 penalty to ensure no specific experiment is too badly fit
- Allowed Tolerance is 100 at 90% CL

- Small differences in asymmetries, but in general the two methods agree well for this observable

Combined PDF+α_S Uncertainties



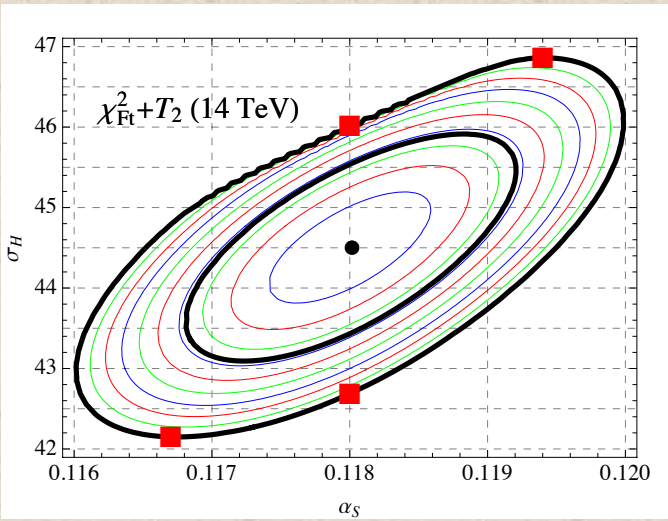




- Can include α_S uncertainty as contribution to total χ^2 in LM method
- Use PDF4LHC choice of α_S=0.118±0.002 at 90% CL
- Black curves are 68% and 90% CL contours

- Hessian method adds α_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

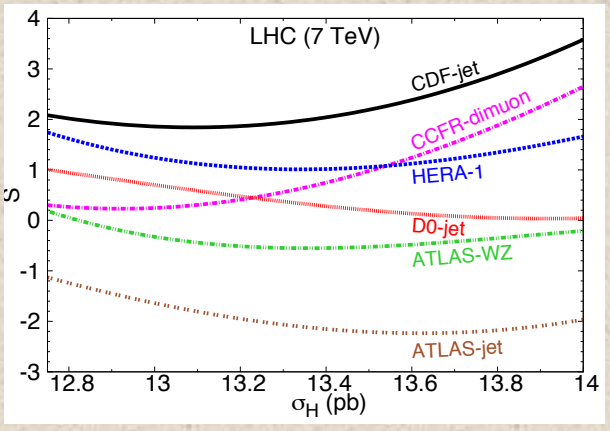
CT10H Extreme Sets

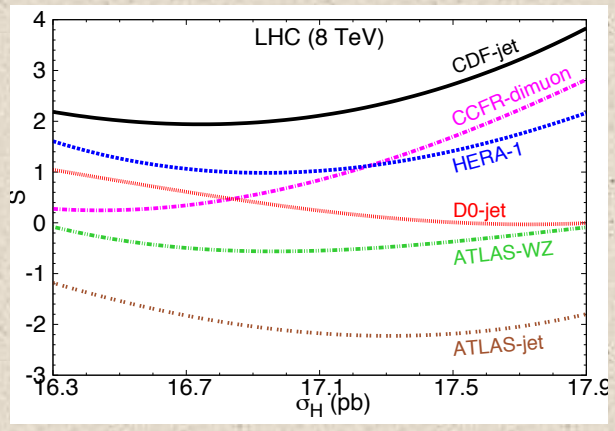


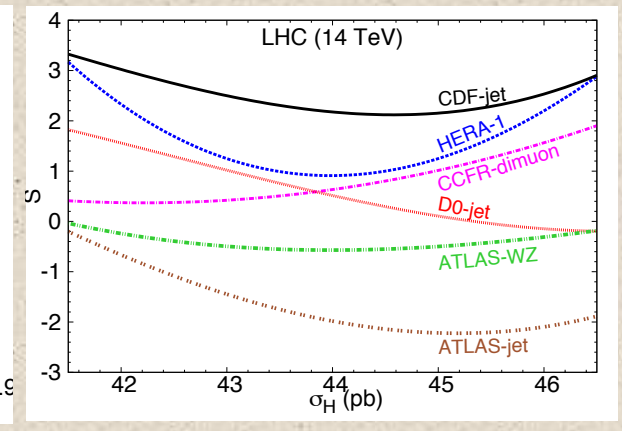
- PDF sets that give extreme values of Higgs cross section at 90% CL are publically available as CT10H sets
- Shown on contour plot as Red squares
- PDF uncertainly only or PDF+α_S uncertainty

- Useful for efficient $gg \rightarrow H$ analyses

Sensitivity to Data Sets

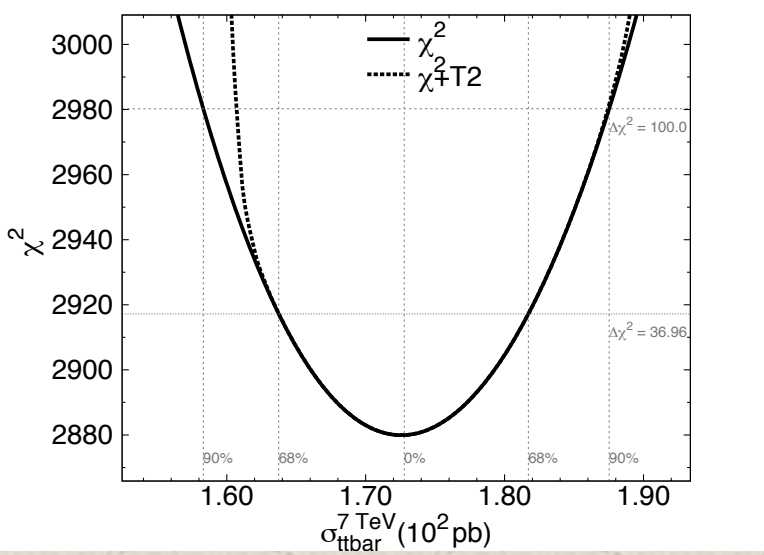


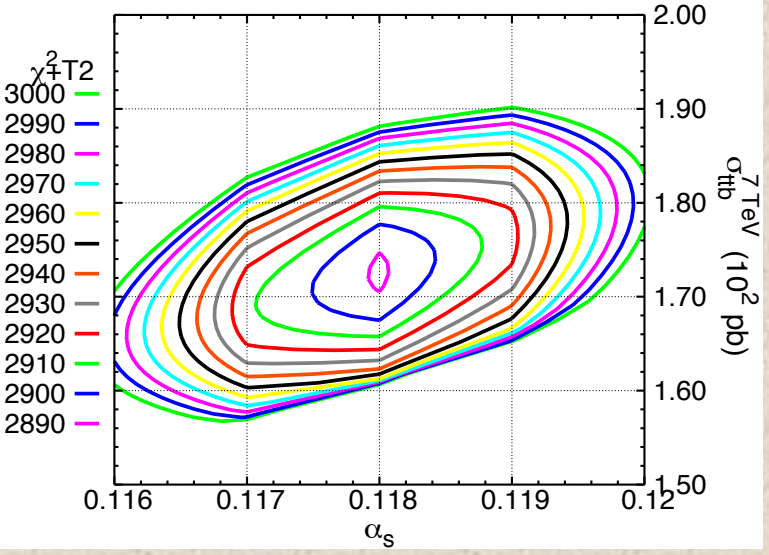




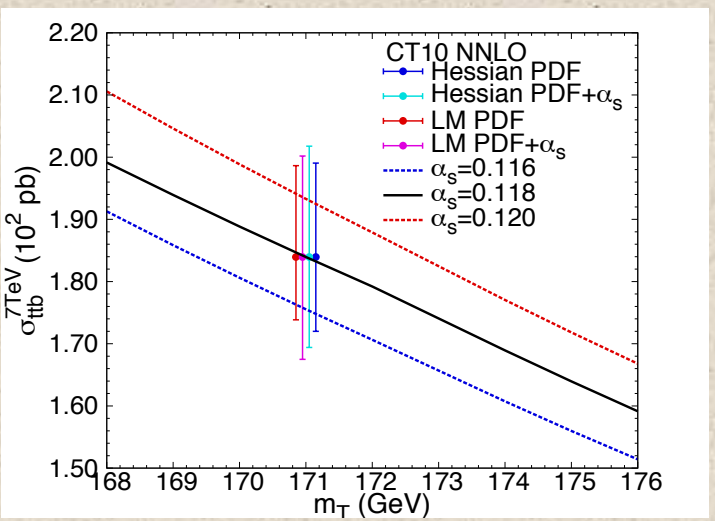
- How sensitive are included data sets to value of σ_H ?
- "Effective Gaussian Variable" S maps cumulative χ^2 distribution for N_{pt} onto cumulative Gaussian distribution
  - +1,+2,+3,… equivalent to that many sigma deviations
  - Negative values correspond to anomalously well-fit data
- Most strongly 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 $gg \rightarrow ttbar$

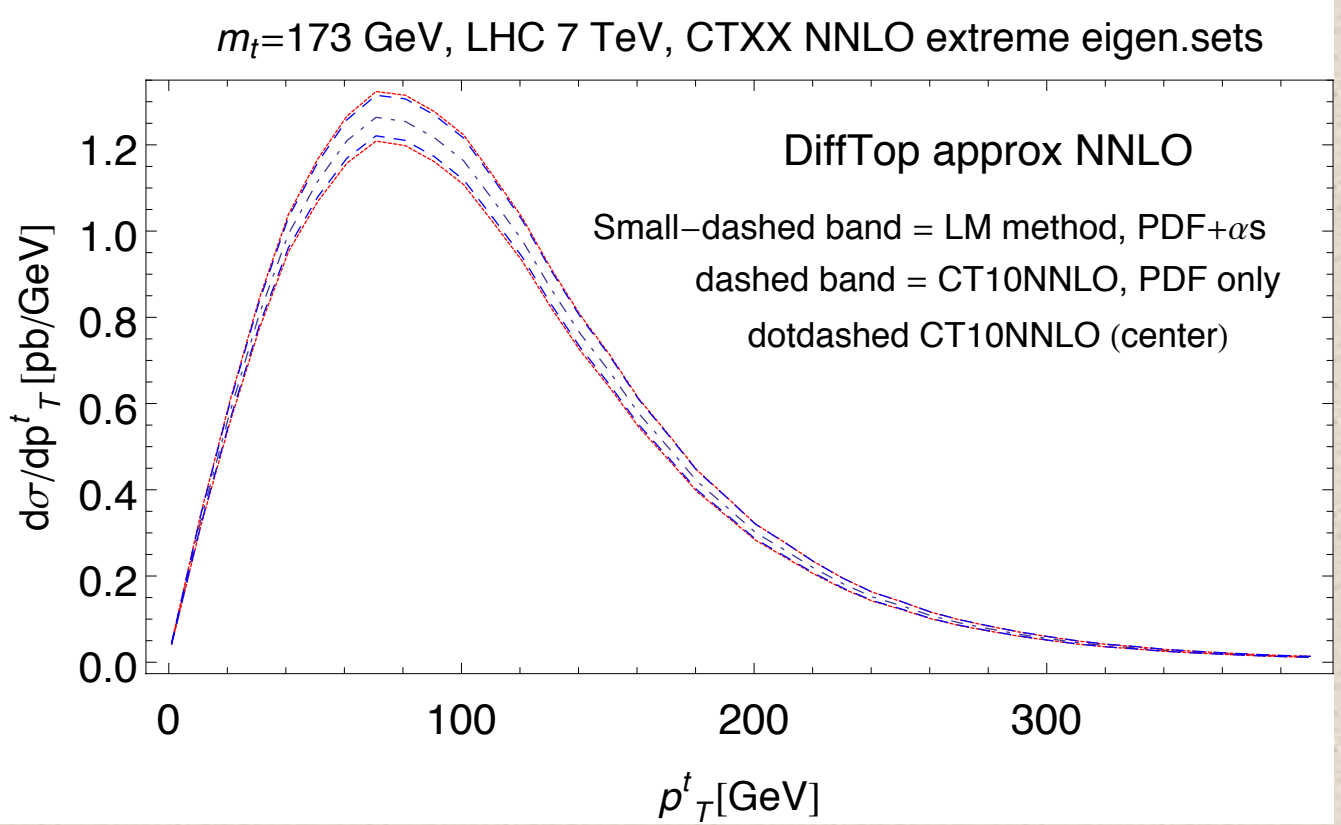




- Same analyses applied to $gg \rightarrow$ttbar
- HERA combined data (T2) constrains low values of cross section
- But T2 less important for combined PDF+α_S
- Hessian and LM consistent



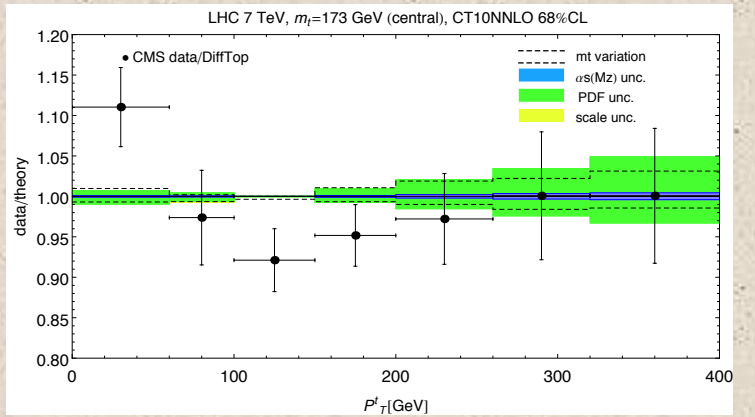
CT10tt extreme sets

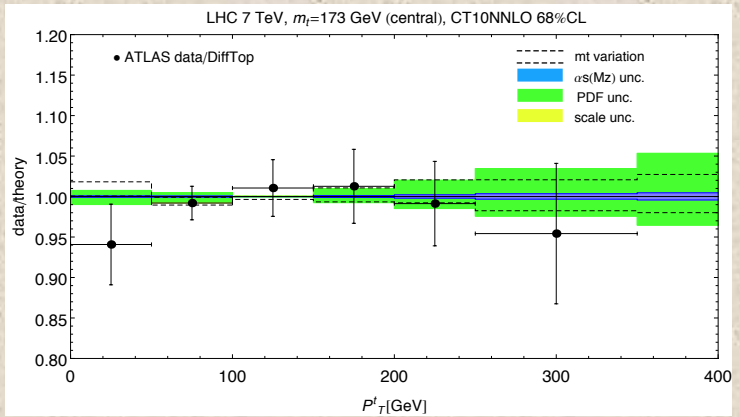


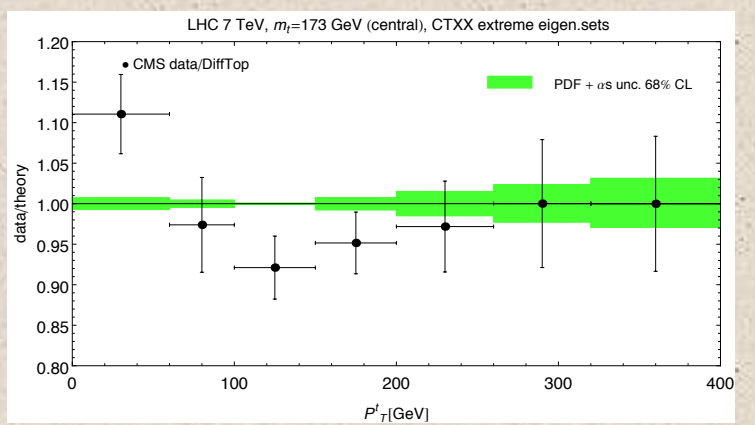
- Pairs of CT10tt extreme sets (PDF, PDF+α_S) to be released
  - for focused ttbar analyses

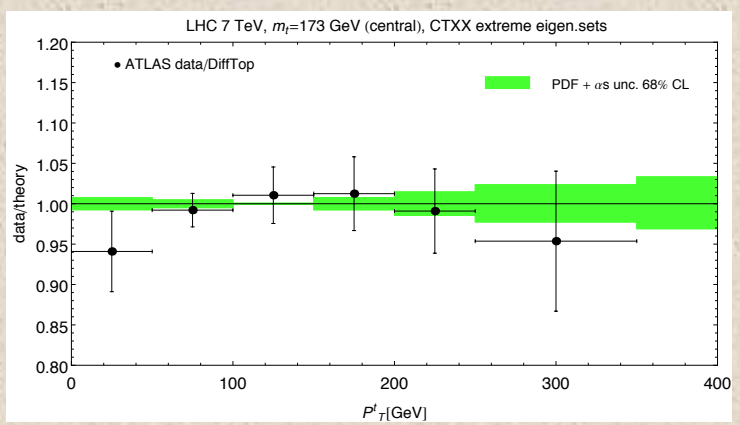
Results provided by DiffTop group (M. Guzzi, K. Lipka, S. Moch)

CT10tt extreme sets









- 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)