CT10 AND CT1X* NNLO NEWS

J. Huston for the CTEQ-TEA group

S. Dulat, J. Gao, M. Guzzi, T.J. Hou, H-L Lai, P. Nadolsky, J. Pumplin, T-J Hou, D. Stump, C.-P. Yuan

PDF4LHC meeting CERN 16/04/2013

*=2 or 3

CT10 and CT1X NNLO fits

- **CT10 NNLO** – officially published in **arXiv:1302.6246**, is an NNLO counterpart either to CT10 NLO or CT10W NNLO
- In good agreement with early LHC data
- **CT1X NNLO** – a preliminary extension of CT10 NNLO that includes latest HERA data on $F_L(x,Q)$ and $F_2^c(x,Q)$, LHC 7 TeV data (ATLAS W & Z, ATLAS jets, CMS W asymmetry)
- The new data provide only minor improvements compared to the CT10 data set. We investigate its agreement with the CT10 data sets and await for more precise LHC data to be included in the CT1X public release

CT10 NNLO PDF vs CT10 NLO PDF

(1) gluon smaller at low x
(2) charm larger for x>0.01
(3) gluon smaller at large x

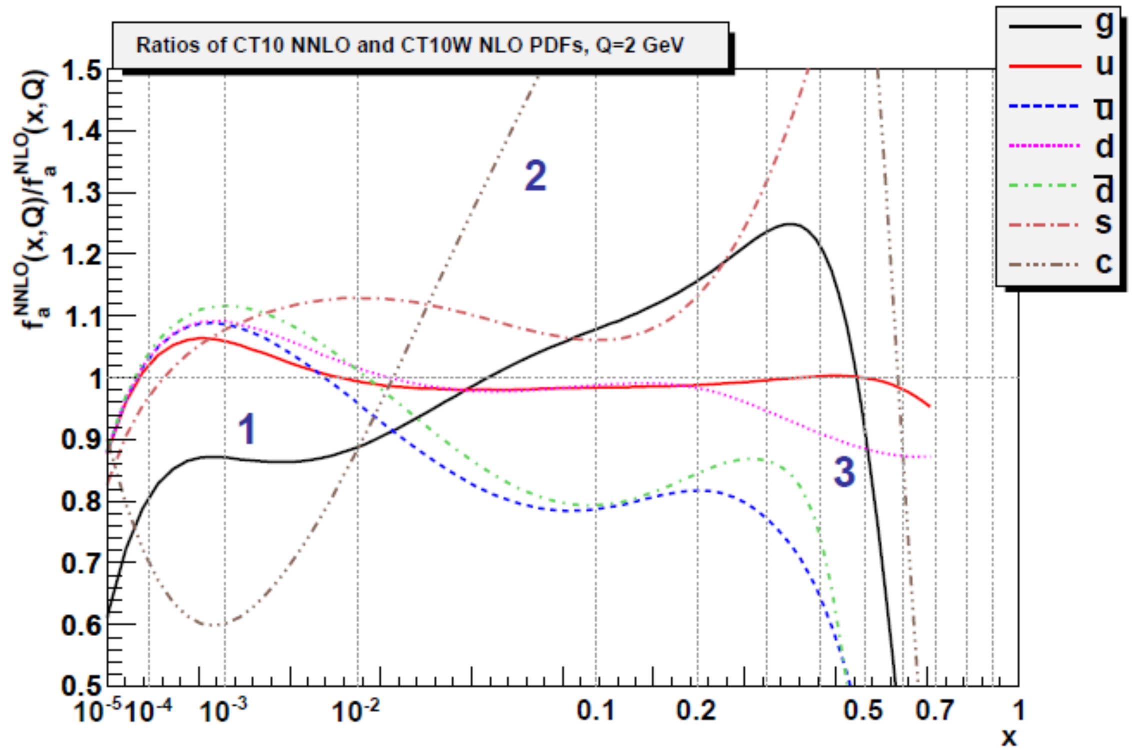
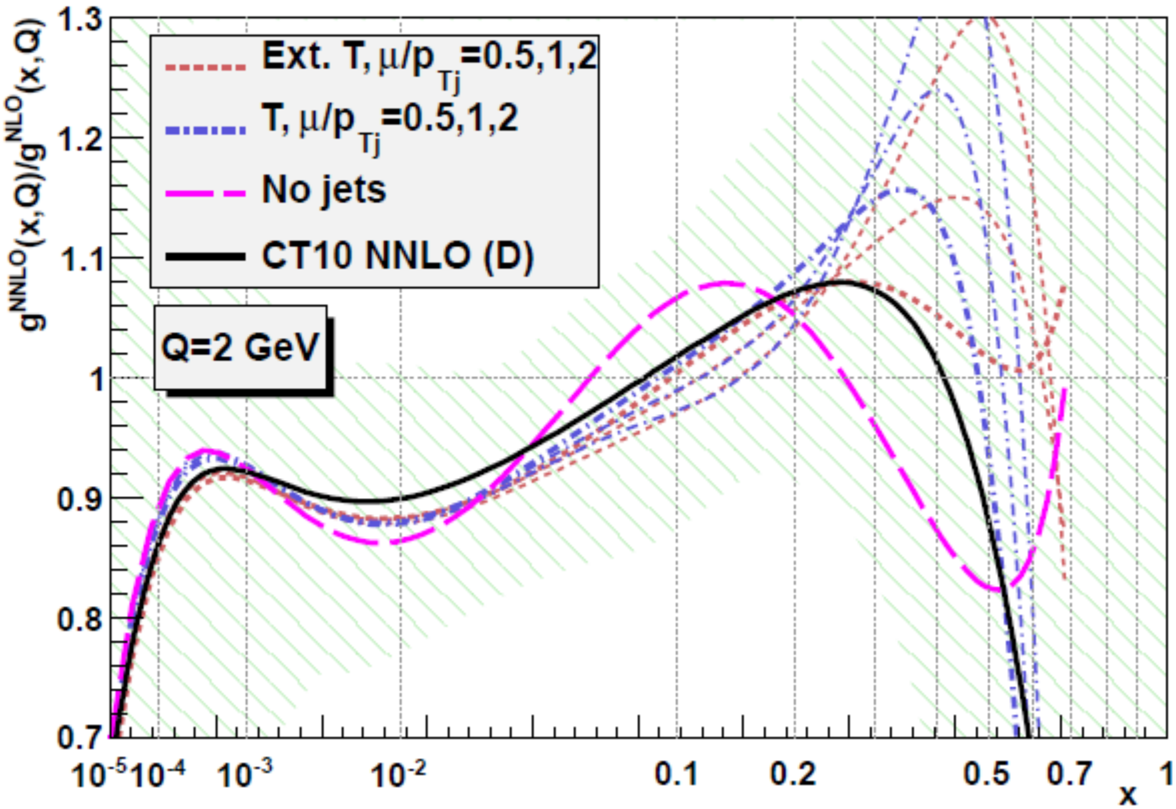


FIG. 3: Ratios of various CT10NNLO central fit parton distributions to those of the CT10W central fit, at $Q = 2\,\mathrm{GeV}$.

Role of correlated systematic errors

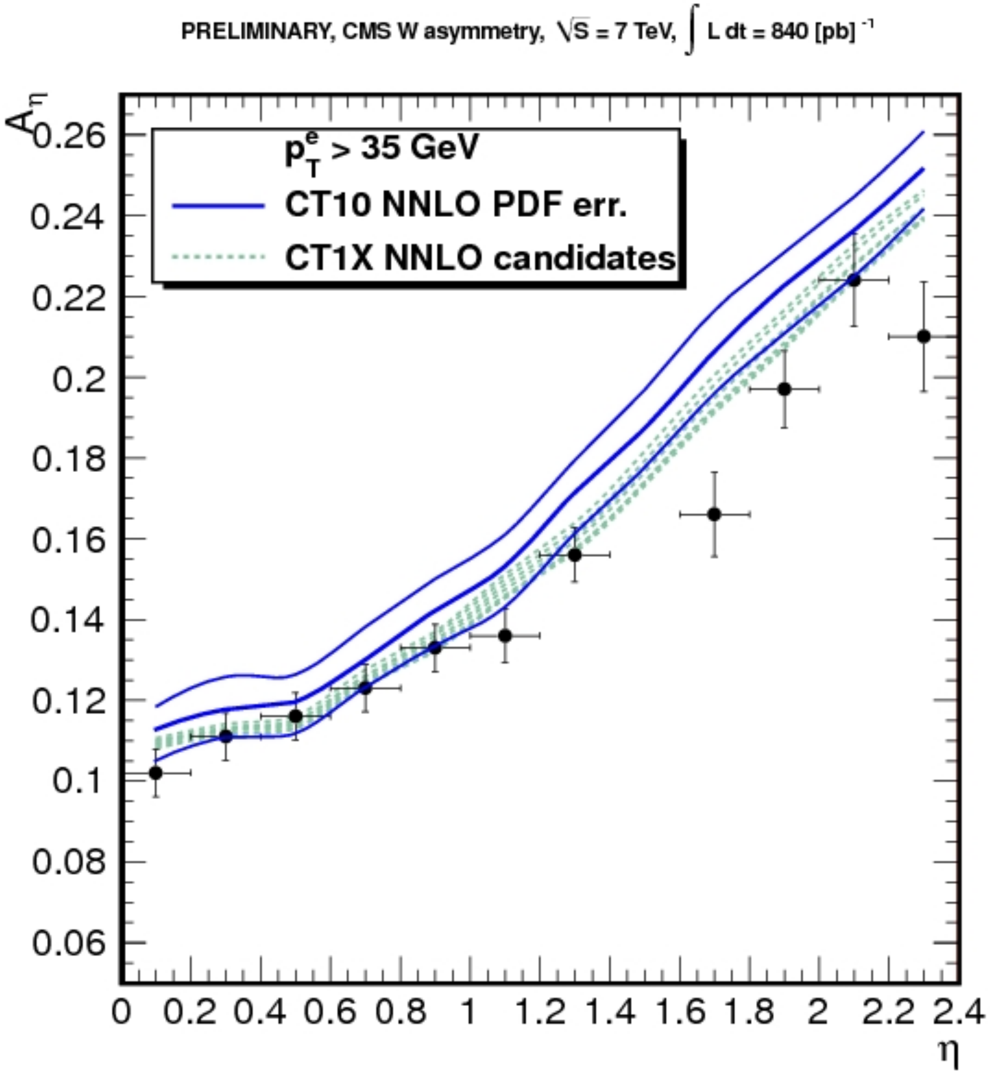


One of the objectives of the CT10 NNLO study was to investigate the role of correlated systematic errors and theoretical uncertainties

For example, the large-x g(x,Q) depends on the implementation of corr. syst. errors in Tevatron jet experiments, as well as on the assumptions about QCD scales. The CT10 NNLO gluon error sets are constructed so as to span the full range of uncertainty due to experimental errors, corr. syst. errors, and various scale choices

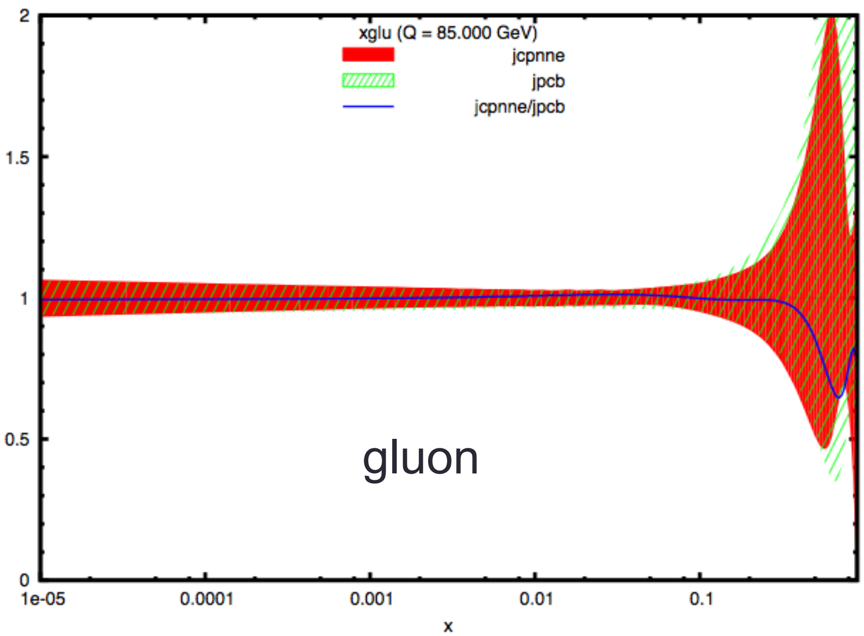
CT10 NNLO and CT1X NNLO vs. CMS 7 TeV W asymmetry (840 1/pb)

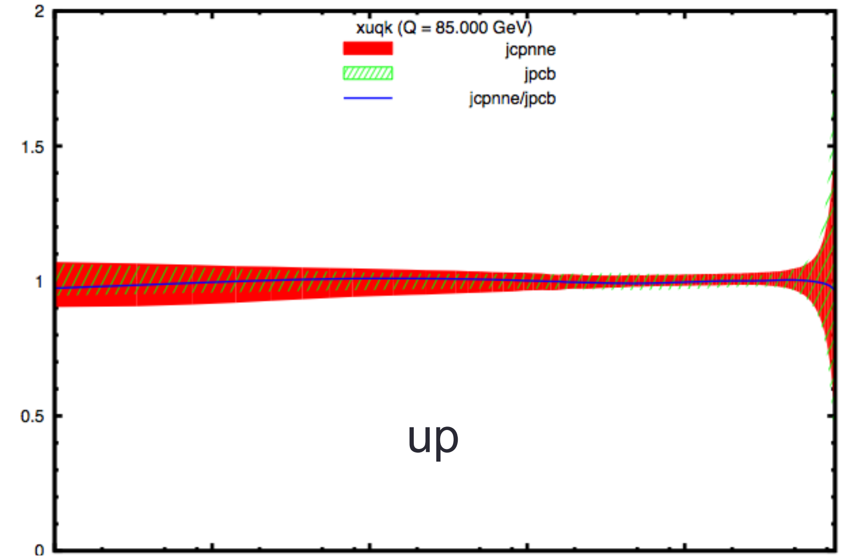
- The blue band is the CT10 NNLO PDF uncertainty
- The green curves are from the CT1X fits with different weights assigned to D0 Run-2 W asymmetry and CMS W asymmetry
- A fit including ATLAS, but not CMS, 7 TeV data leads to similar result as CT1X.

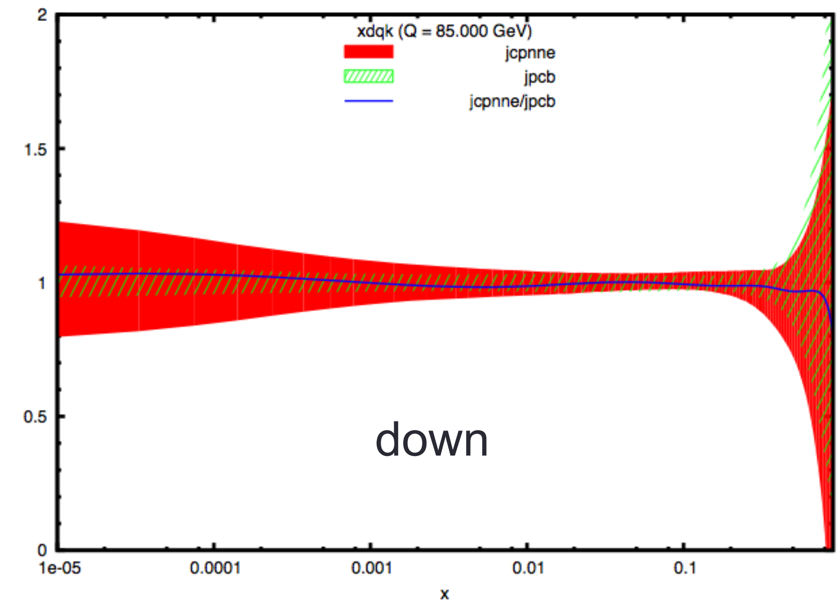


Uncertainties compared to CT10NNLO

- More flexible parameterization so uncertainty has increased slightly, even with LHC data (ATLAS W/Z, jet data (R=0.6), CMS W asymmetry) included
- jpcb=CT10
- jcpnne=CT1X







Charm quark mass dependence in a global QCD analysis
J. Gao, M. Guzzi, P. Nadolsky, arXiv:1304.3494

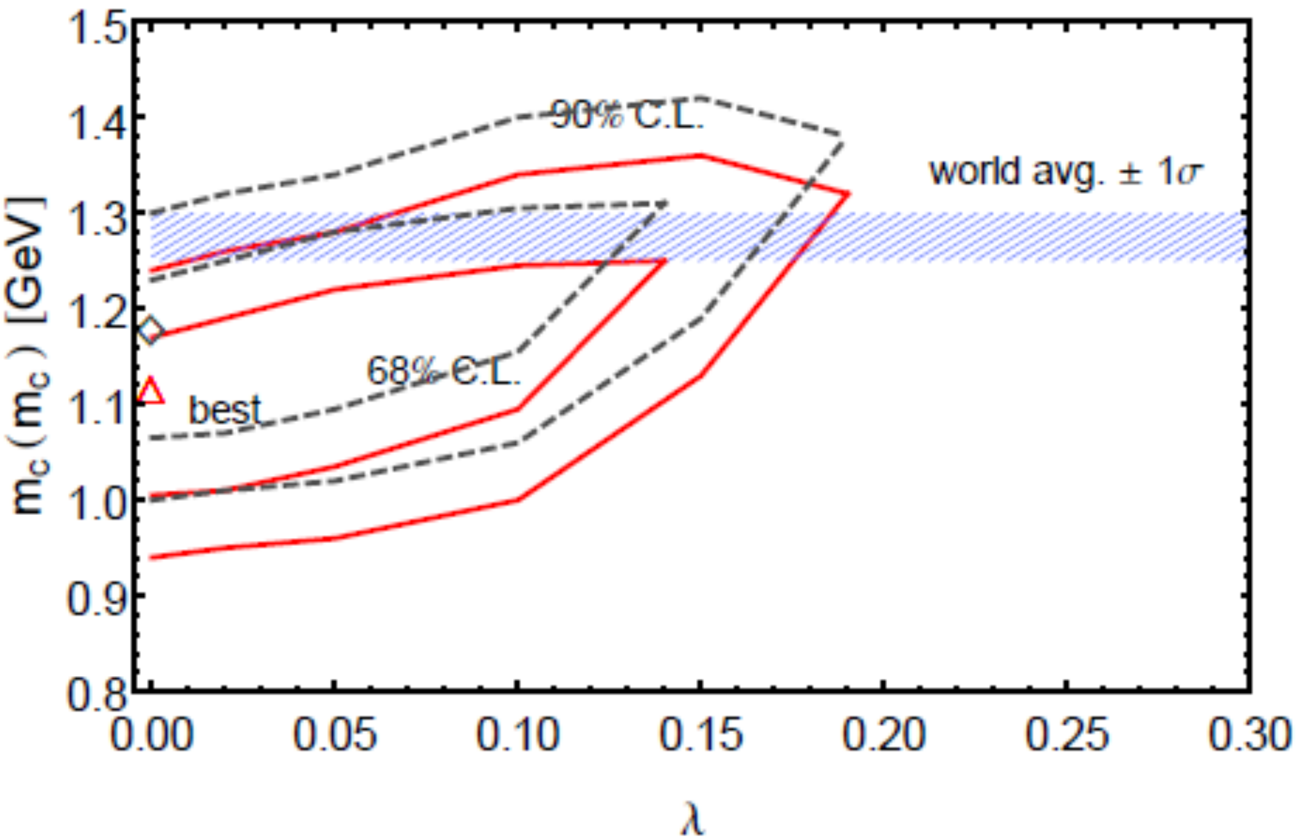
- The assumed value of m_c and the implementation of a particular general mass scheme has an impact on precision LHC variables
- Constraints on the MSbar mass $m_c(m_c)$ from the CT10 NNLO data set were found to be

$$m_c(m_c) = 1.12^{+0.11+0.16}_{-0.17-0.02}\,GeV$$

where the first (second) error is due to PDFs (other sources)

- The best-fit value of $m_c(m_c)$ is consistent with the world average 1.275+/-0.025 GeV within errors
- It has a significant dependence on the form of the rescaling parameter (controlled by a parameter λ in the generalized re-scaling prescription by Nadolsky and Tung, 2009)

68% and 90%CL contours for $m_c(m_c)$ from the CT10 NNLO analysis

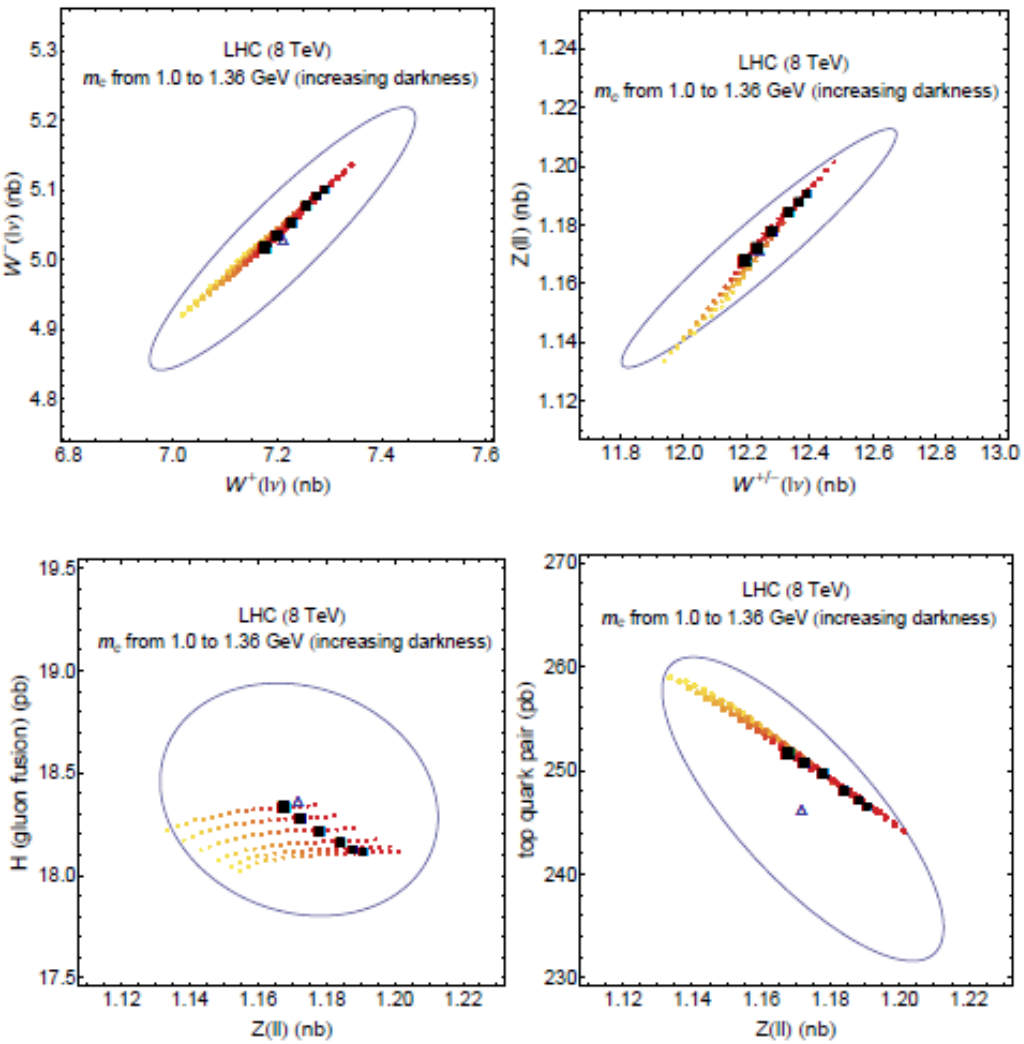


By choosing λ between 0 and infinity, one can vary the rescaling variable in the DIS coefficient functions with incoming heavy quarks to be between the χ variable of the ACOT-χ scheme and Bjorken x.

λ=0, rescaling variable=χ for all x values

Preferred regions for $m_c(m_c)$ vs. the rescaling parameter . The best-fit values and confidence intervals are shown for two alternative methods for implementation of correlated systematic errors.

Uncertainty in LHC total cross sections due to $m_c(m_c)$ and rescaling parameter λ



Error ellipses: CT10 NNLO PDF errors

Yellow-red scattered points: both m_c and λ are varied

$1<m_c<1.36$ GeV
$0<\lambda<0.2$

Black squares: only λ is varied
$m_c(m_c)=1.275$ GeV
$0<\lambda<0.2$

Using a fixed world-average $m_c(m_c)$ reduces the total uncertainty of the fit

CT10IC (intrinsic charm at NNLO)

- An update of CTEQ6.6 IC PDFs, but with CT10NNLO setup.

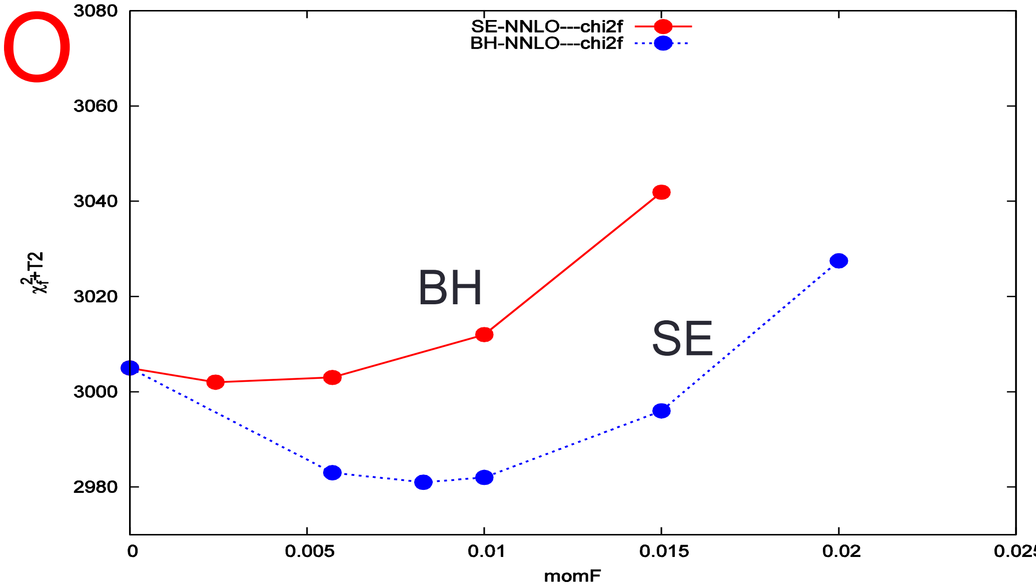
- We consider two intrinsic charm models:
  Brodsky [S. J. Brodsky, P. Hoyer, C. Peterson, and N. Sakai, Phys. Lett. B93, 451 (1980).] (BH1 and BH5), and a
  sea-like model (SE2, SE4).

- In the CT10IC fits, we replaced the HERA charm data sets by the combined HERA1 NC+CC DIS (2009) data.

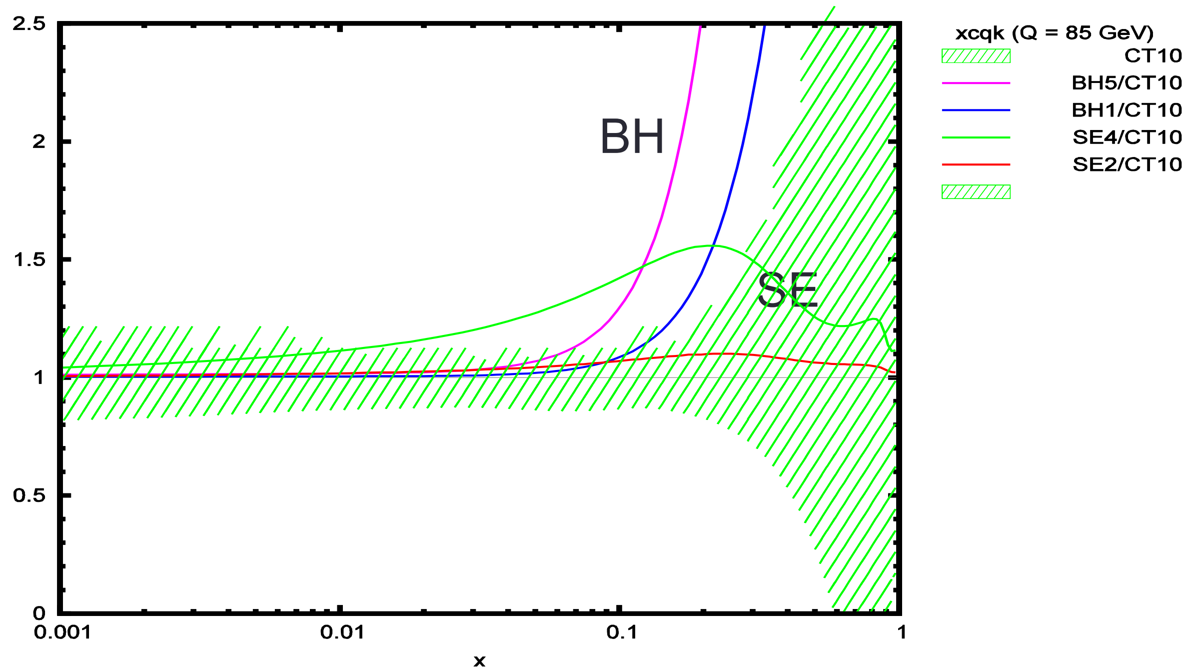
CT10IC at NNLO

The goodness of fits versus the momentum fraction of intrinsic charm.

$$< x >_{IC} = \int x(c + \bar{c})dx$$

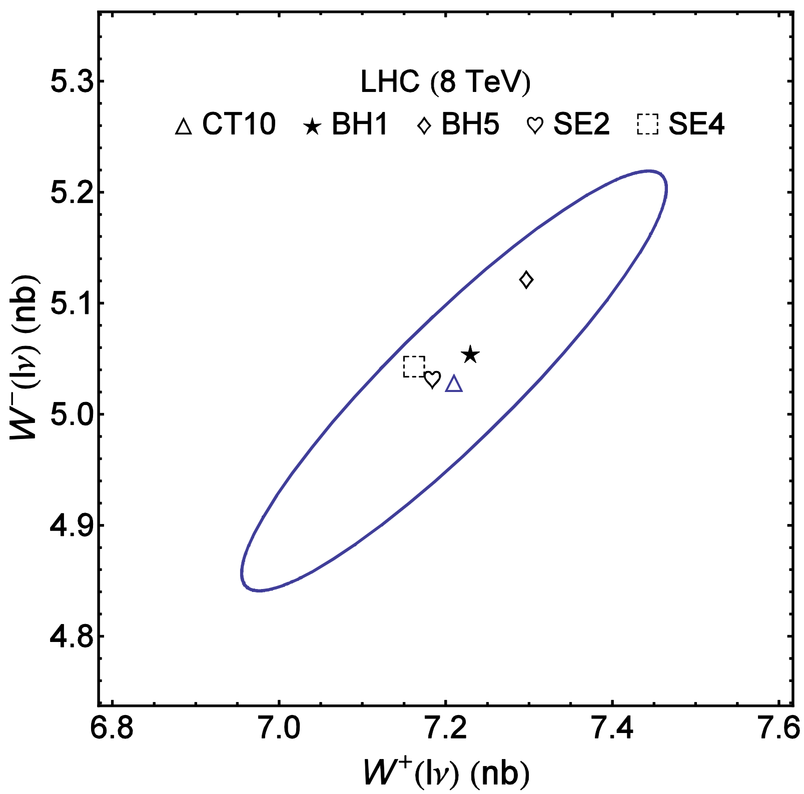


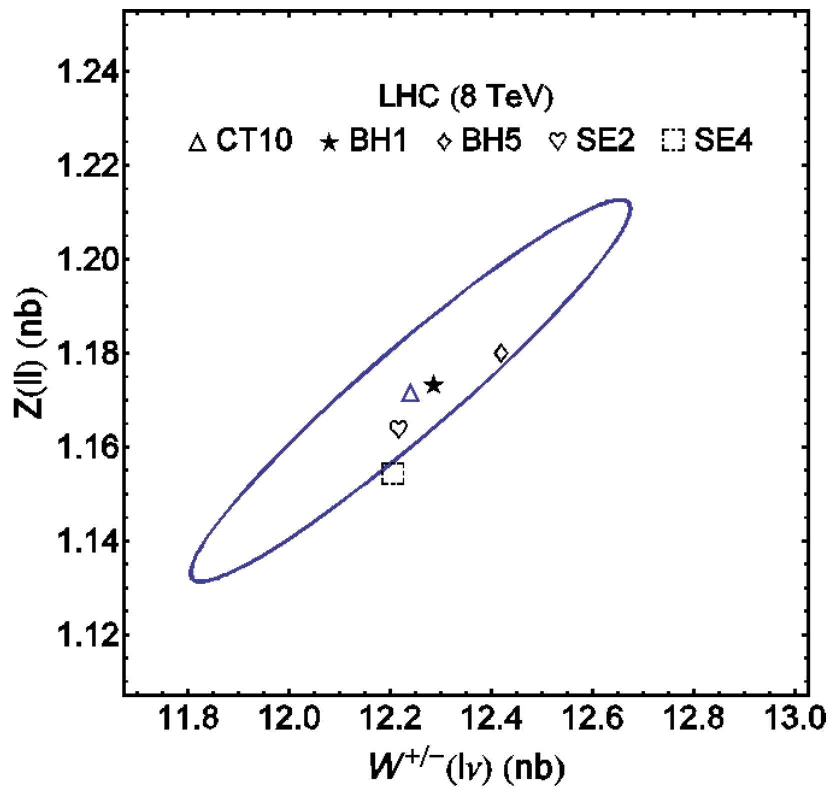
The charm PDFs in the 4 CT10IC fits,
as compared to the CT10NNLO error band.



Uncertainty in LHC total cross sections due to Intrinsic Charm

The 4 new points, the star, diamond, heart, and empty square, for results from BH1, BH5, SE2 and SE4, respectively. The ellipses are for CT10NNLO.





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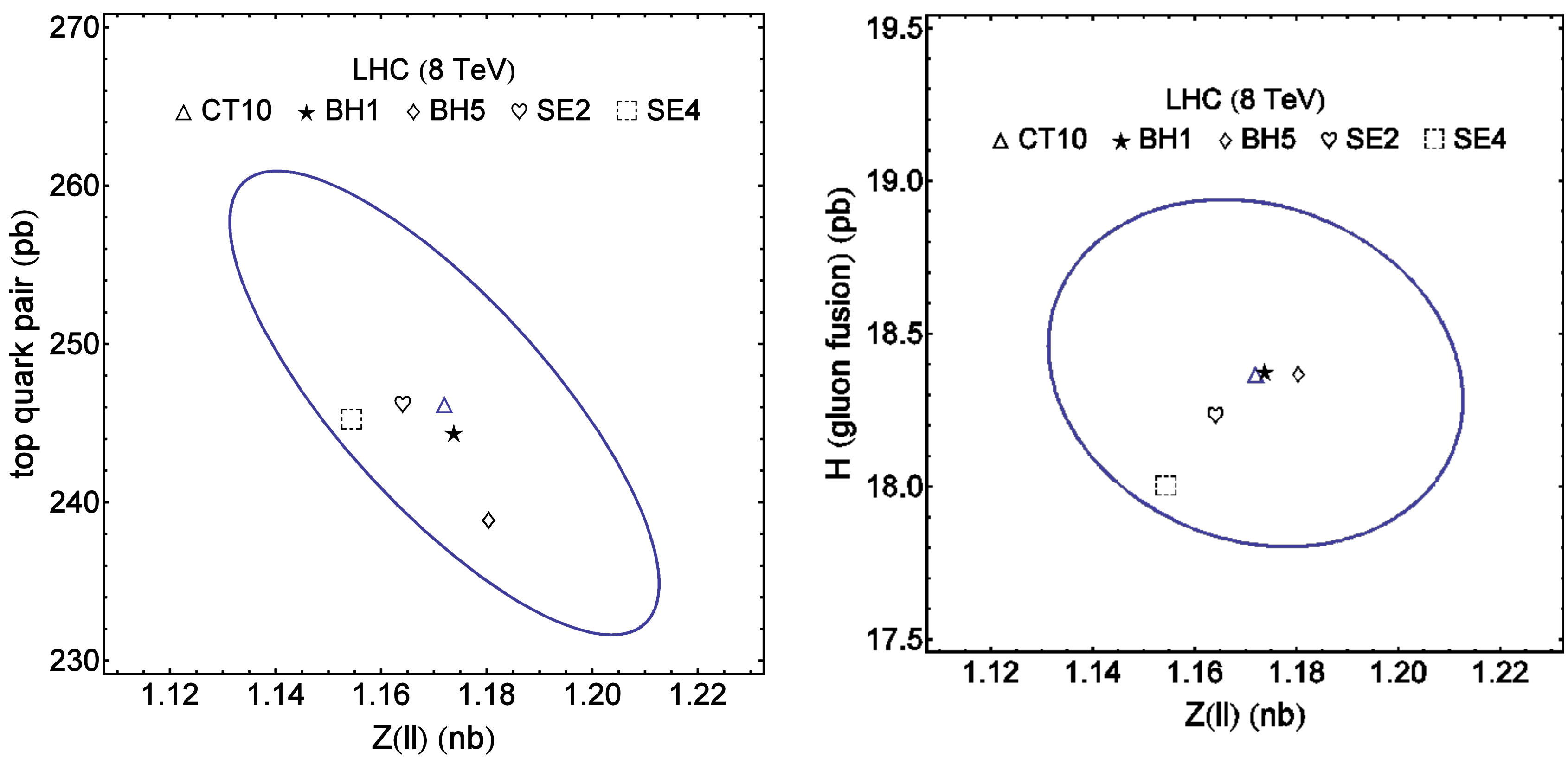


And now for something almost completely different…

- Snowmass on the Mississippi
  - <~1 year workshop similar to European Planning study, but perhaps more comprehensive
  - BNL meeting April 3-6

  http://www.bnl.gov/snowmass2013/
  - next meeting for the QCD group after LoopFest at Florida State May 16

  http://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=223649

- Les Houches
  - SM session June 3-12
  - coordinating with the QCD part of the Snowmass workshop
  - http://phystev.in2p3.fr/Houches2013/

Snowmass Charge

- The charge for the QCD group (like every other group) is to determine the
  1. current state of the art
  2. what is likely/priority for the next 5 years?
  3. what is likely/priority for longer time scale (20 years)?
- Of course a) is the easiest, b) is less so and parts of c) are in the realm of pure speculation
- We have broken down each question into a series of more definite sub-issues that should be addressed. For details, see my talk at the kickoff meeting at Fermilab, and at the Brookhaven meeting 2 weeks ago
- Here I will discuss a few PDF-related issues

…keeping in mind not only the LHC, but…

A. hadron colliders

1. LHC 13 TeV, 300/fb , spacing: 25 ns (50 ns), pileup: 19 (38) events/crossing
2. LHC 13 TeV, 3000/fb (HL-LHC) , spacing: 25 ns, pileup: 95 events/crossing
3. LHC 30 TeV, 3000/fb (HE-LHC) , spacing: 50 ns, pileup: 225 events/crossing
4. VHE-LHC 100 TeV, 3000/fb, spacing: 50 ns, pileup: 263 events/crossing
5. VLHC at 100 TeV, 1000/fb , spacing: 19 ns, pileup: 40 events/crossing

future machines, especially hadron colliders

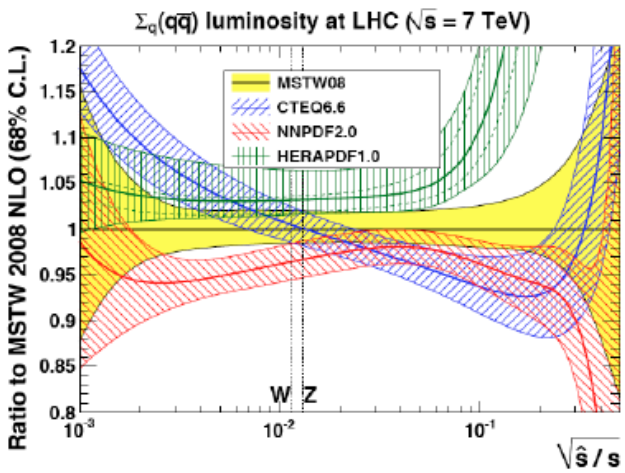
…sorry, not much work on linear colliders so far

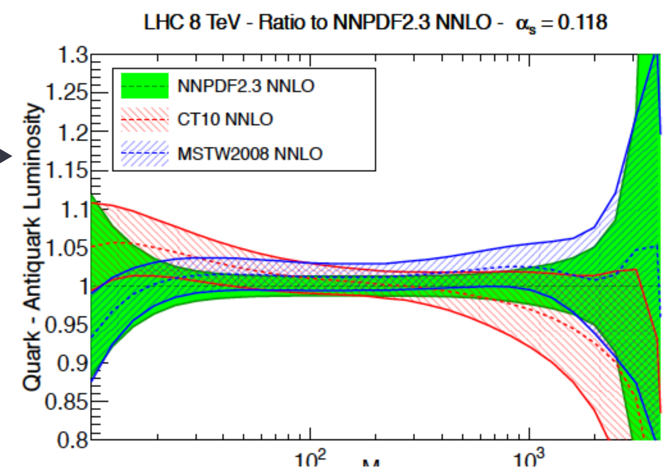
unitarity

pileup numbers are the average number of interactions per crossing at the peak luminosity, as explained

PDFs

- I gave a talk at this meeting on ‘PDFs for the LHC’ reporting specifically on the new benchmark results at NNLO (arXiv:1211.5142)



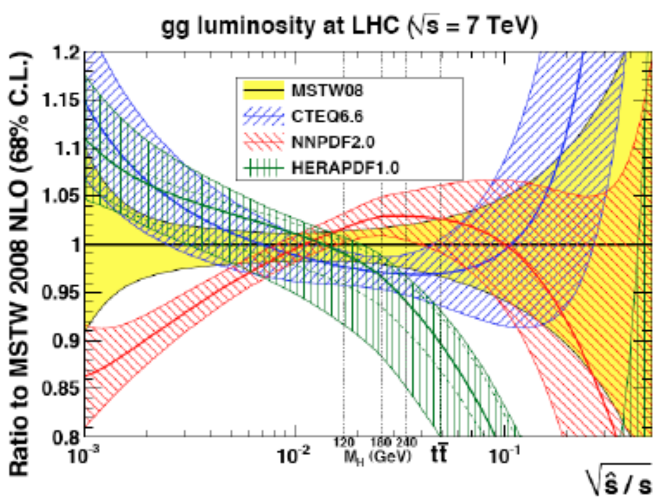


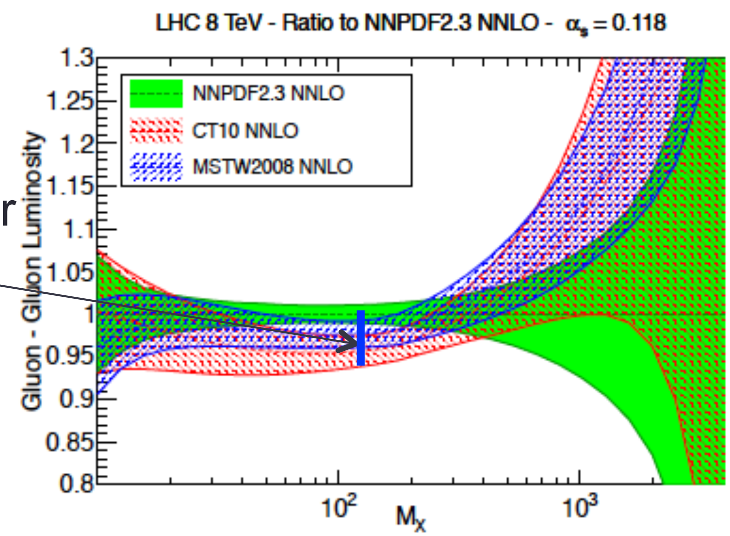
improvements from 2010 to 2012…

…and from NLO to NNLO

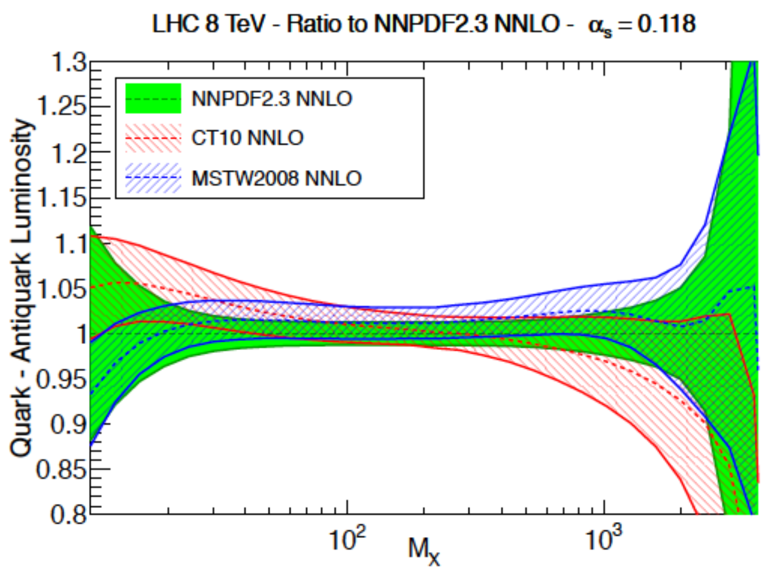
so Higgs PDF uncertainty under good control

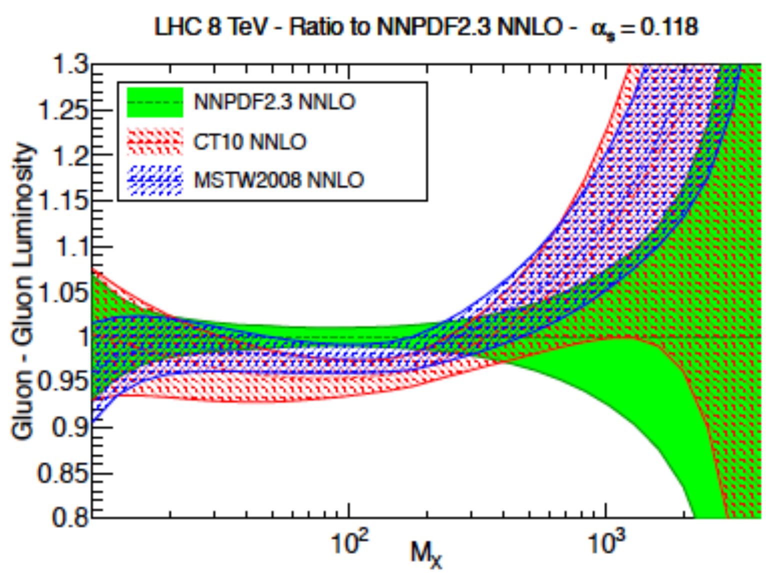
α_S uncertainty still +/-0.002





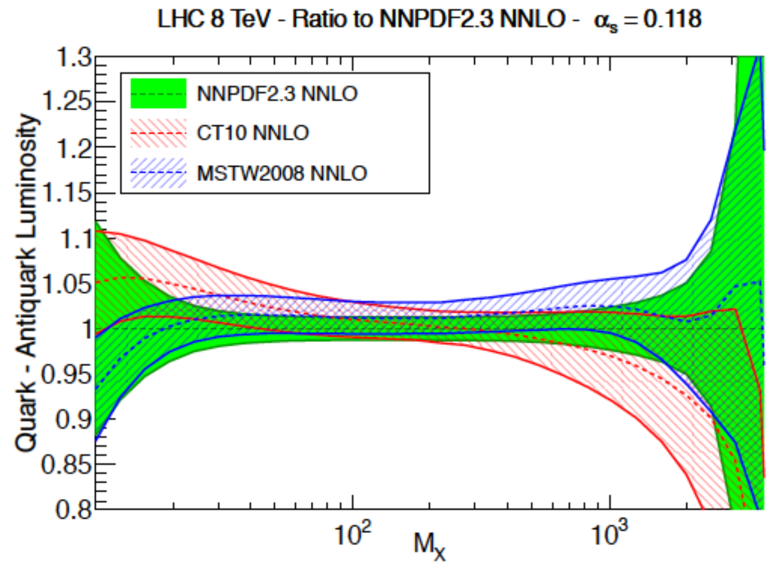
PDFs

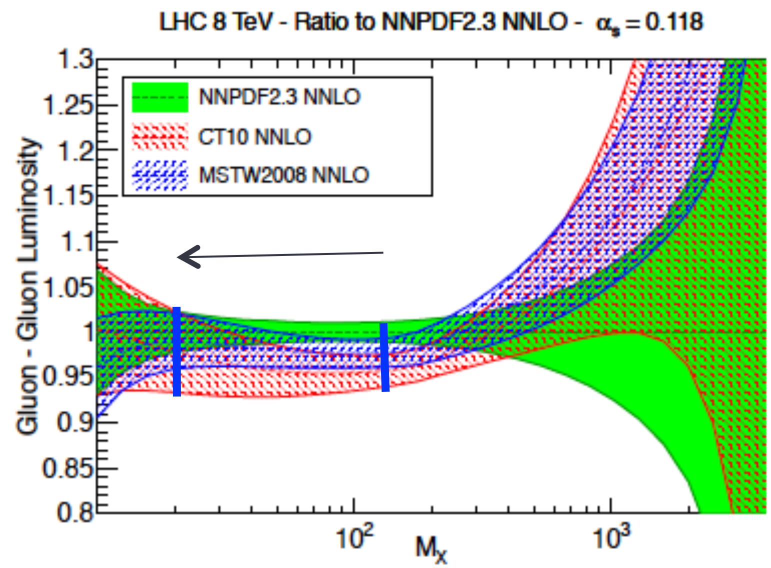




- But what about at high mass?
- Are we going to believe a 50% excess at multi-TeV dijet masses, especially if we believe that it's produced by a gg initial state?
- These are 68% CL PDF errors
- We assume that we can extrapolate from 68% to 90%CL (CT PDF uncertainties actually performed at 90%CL)
- What about non-Gaussian behavior going to 95%, 98%?
- Can use Lagrange Multiplier technique to look at this; NNPDF can use their Monte Carlo approach
- This is something we would like to do for the Snowmass report

PDFs





- What about uncertainties for higher energies
  - 13 TeV
  - 33 TeV
  - 100 TeV
- To first order, can just rescale horizontal axis for the plots to the left
  - but uncertainties do decrease with increasing Q^2
- So this is an approximation of the gg uncertainty for gg->Higgs (125 GeV) at 33 TeV
- We can calculate exactly the uncertainties for the different energies
- This is something we would like to do for the Snowmass writeup

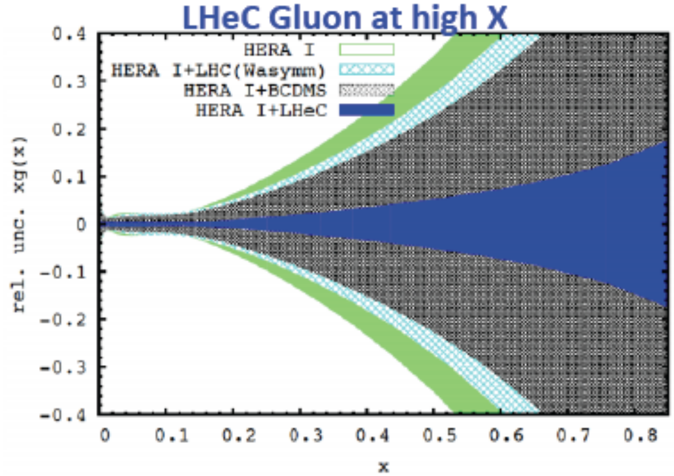
Do we need an LHeC?

PDFs at the LHeC

- PDFs are essential for precision physics at the LHC :
  - **one of the main theory uncertainties in Higgs production**
  - Measurements at high pT, high invariant masses, sensitive to new physics effects, have significant PDF uncertainties (high x)

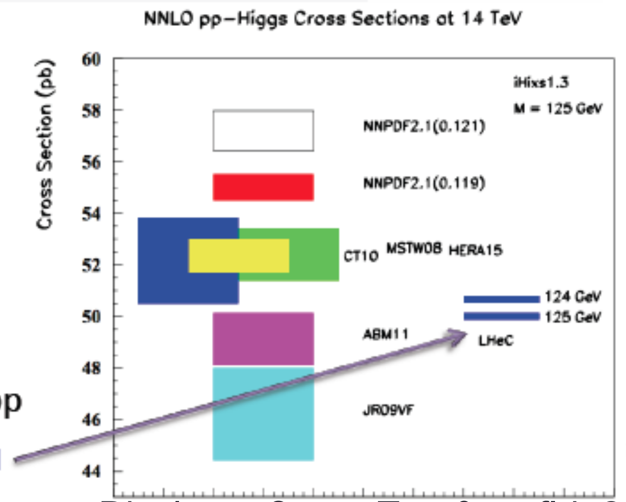
- LHeC could provide a complete PDF set with precise gluon, valence at high x, as well as strong coupling

LHeC Gluon at high X



LHeC promises per mille accuracy on alphas!

case	cut [Q^2 in GeV^2]	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.26



At the LHeC , Higgs is cleanly produced via ZZ or WW fusion, complementary to the dominant gg fusion at pp

- precision from LHeC can add a significant constraint on MH

Voica Radescu (see also Max Klein at https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=226756)

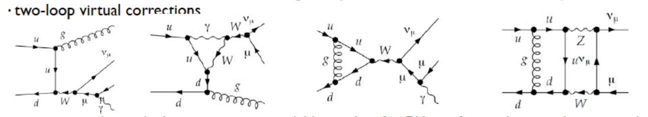
QCD+EWK effects

A. Vicini: there has been a great deal of progress in the last few years, but all of the separate pieces have not been put together in a common framework, allowing a 'best' estimate of cross sections and uncertainties

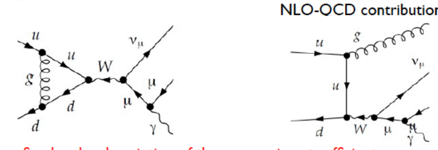
Mixed QCDxEW corrections the Drell-Yan cross section

$$\sigma_{tot} = \sigma_0 + \alpha_s\sigma_{\alpha_s} + \alpha_s^2\sigma_{\alpha_s^2} + \ldots + \alpha\sigma_\alpha + \alpha^2\sigma_{\alpha^2} + \ldots + \boxed{\alpha\alpha_s\,\sigma_{\alpha\alpha_s}} + \alpha\alpha_s^2\,\sigma_{\alpha\alpha_s^2} + \ldots$$

- The first mixed QCDxEW corrections include different contributions:
  - emission of two real additional partons (one photon + one gluon/quark)
  - emission of one real additional parton (one photon with QCD virtual corrections, one gluon/quark with EW virtual corrections)
  - two-loop virtual corrections



- an exact complete calculation is not yet available, neither for DY nor for single gauge boson production
  W.B. Kilgore, C. Sturm, arXiv:1107.4798
- The bulk of the mixed QCDxEW corrections, relevant for a precision MW measurement, is factorized in QCD and EW contributions:
  (leading-log part of final state QED radiation) X (leading-log part of initial state QCD radiation || NLO-QCD contribution to the K-factor)



In any case, a fixed order description of the process is not sufficient...

Alessandro Vicini - University of Milano   Brookhaven, April 4th 2013   9

Perturbative expansion of the Drell-Yan cross section

$$\begin{aligned}\sigma_{tot} = \sigma_0 &+ \boxed{\alpha_s\sigma_{\alpha_s} + \alpha_s^2\sigma_{\alpha_s^2}} + \ldots \\ &+ \boxed{\alpha\sigma_\alpha} + \boxed{\alpha^2\sigma_{\alpha^2}} + \ldots \\ &+ \boxed{\alpha\alpha_s\,\sigma_{\alpha\alpha_s}} + \alpha\alpha_s^2\,\sigma_{\alpha\alpha_s^2} + \ldots\end{aligned}$$

Fixed order corrections exactly evaluated and available in simulation codes

Subsets of corrections partially evaluated or approximated

O(α²)

- EW Sudakov logs J.Kühn, A.Kulesza, S.Pozzorini, M.Schulze, Nucl.Phys.B797:27-77,2008, Phys.Lett.B651:160-165,2007, Nucl
- QED LL
- QED NLL (approximated)
- additional light pairs (approximated)

O(αα_s)

- EW corrections to ffbar+jet production
- QCD corrections to ffbar+gamma production

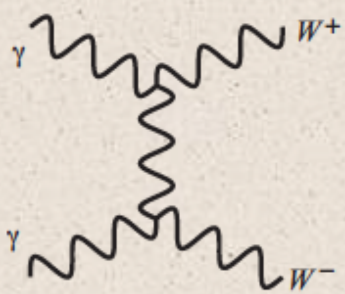
A.Denner, S.Dittmaier, T.Kasprzik, A.Mueck, arXiv:0909.39

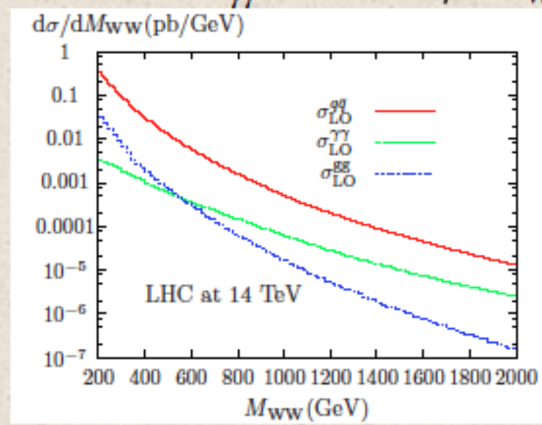
Les Houches project: put those pieces together

Photon PDFs: Carl Schmidt

2) Photon induced processes can be kinematically enhanced.

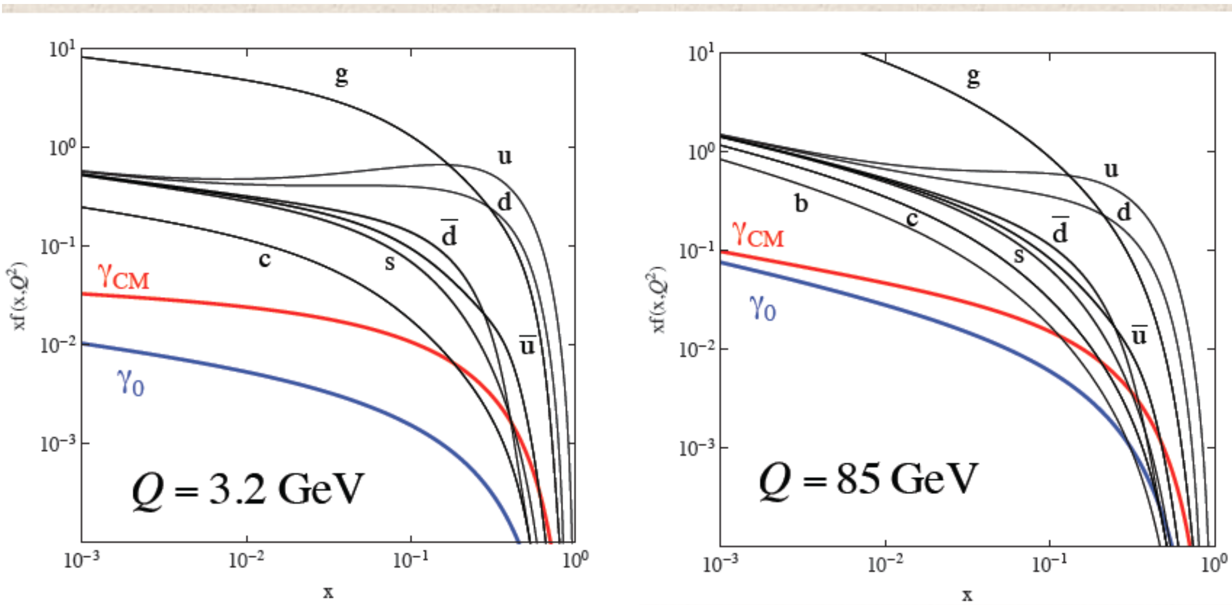
$$\gamma\gamma \rightarrow W^+W^- \quad \text{asymptotically} \quad \hat{\sigma}_{\gamma\gamma} \approx 8\pi\alpha^2/M_W^2$$





significant fraction of high mass WW pairs from γγ, even after kinematic cuts

Bierweiler et al., JHEP 1211 (2012) 093



photon PDFs can be larger than anti-quarks at high x

the LHC (and higher energy machines) is a γγ factory

Snowmass+Les Houches project: investigate this

Summary

- CT1X under development; will include LHC data with correlated error information
- We will also be producing a set of photon PDFs in the near future
- Snowmass/Les Houches studies in progress; please contribute if you can
  - send an email to listserv@slac.stanford.edu with the command 'subscribe snowmass-qcd' in the body of the email