NLM Experimental Introduction

Joey Huston
Michigan State University

for the SM conveners
Guenther Dissertori, Stefan Dittmaier, Nigel Glover

Snow-Houches

- There is an ongoing workshop in the US titled ‘Snowmass’ even though the final meeting will be held in Minneapolis at the end of July
- Many of the issues being investigated are the same as what we are interested in at Les Houches

+

==Snow-Houches

- So we have been coordinating some of the common work between the two-> and Eric has pointed out that until recently, there has been a mass of snow at Les Houches

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 1) is the easiest, 2) is less so and parts of 3) are in the realm of pure speculation
- And typically we have been more interested in 1) and 2) at Les Houches, but it's interesting to broaden our (time) horizons
- For Snowmass, we have broken down each question into a series of more definite sub-issues that should be addressed. For details, see slides from my talk at the kickoff meeting at Fermilab (in extra slides of this talk)

…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

Snowmass outline

(1) PDF's

(a) current knowledge and uncertainties

(b) likely improvements from LHC data, particularly precision Drell-Yan measurements

(c)PDF luminosities and uncertainties for 14, 33 and 100 TeV

(d) improvements from an LHeC (including alpha_s)

(2) Cross sections at 14, 33 and 100 TeV

(a)MCFM LO, NLO

-what cross sections to choose?

-what differential distributions to show?

-scale, PDF and alpha_s uncertainties?

-comparisons to BFKL predictions a la HEJ

(b)NLO, NNLO and beyond

-NLO extrapolation to higher parton multiplicities

-improvements in NLO+PS, a la CKKW->comparisons

-Higgs(+jets) cross sections as function of energy

-importance of BFKL logs as a function of energy

c)perturbative series convergence for boosted final states

(3) Higgs+jets uncertainties

(a)resummation of jet veto logs->pointing to a new scheme for Higgs+jets uncertainties?

(b)importance of jet veto logs as a function of energy

(4) NLO QCD+NLO EW

(a)wishlist? putting current calculations together in one framework

(b)impact of the 'Sudakov zone' as a function of energy; gamma gamma processes

(Partial) Les Houches worklist

1) Higgs-related

a) PDF uncertainties for gluon-gluon fusion

-trace differences between CTEQ, MSTW and NNPDF to see if uncertainty can be reduced

b) acceptances and uncertainties of acceptances for Higgs (gg->Higgs->WW/ZZ)

c) Higgs+jets cross sections

-comparisons of @MC@NLO, Powheg MINLO, MEPS@NLO, HEJ, etc

-comparisons of W/Z+jets with above (+LoopSim) as a testbed

-revisit tag jets: hadronization uncertainties for high rapidity jets

d) Higgs+jets uncertainties

-new scheme for jet veto uncertainties using Higgs+0, Higgs+1 jet resummation calculations

-comparison of Higgs+0 jet resummation results

2) PDFs

a) impact of LHC data, current and future

b) impact of/need for an LHeC

c) combination of PDF sets

d) impact of NNLO jet calculations

3) (N)NLO QCD + (N)NLO EWK

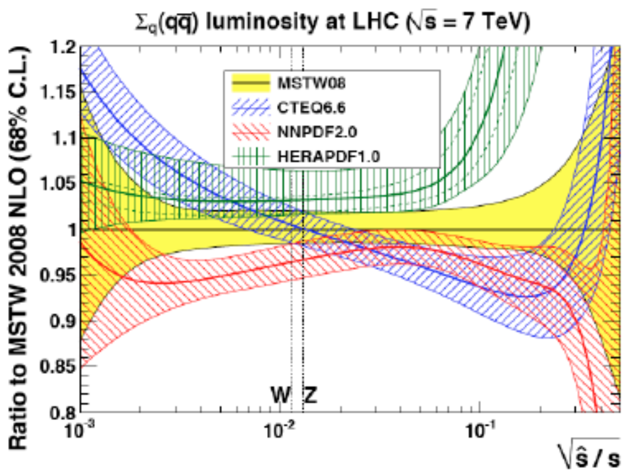
a) wishlist of calculations->see Stefan's talk on Thursday

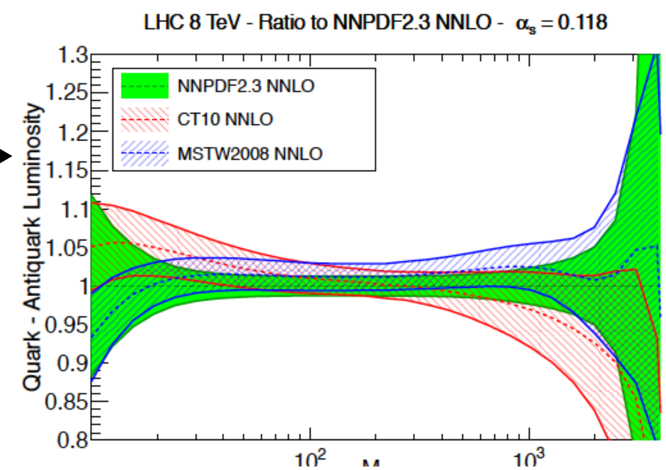
b) study of the 'Sudakov Zone', ~1 TeV

c) PDFs with QED corrections, photon PDFs, gamma-gamma processes

PDFs

- There has been a great deal of PDF benchmarking, with the latest exercise given in 1211.5142



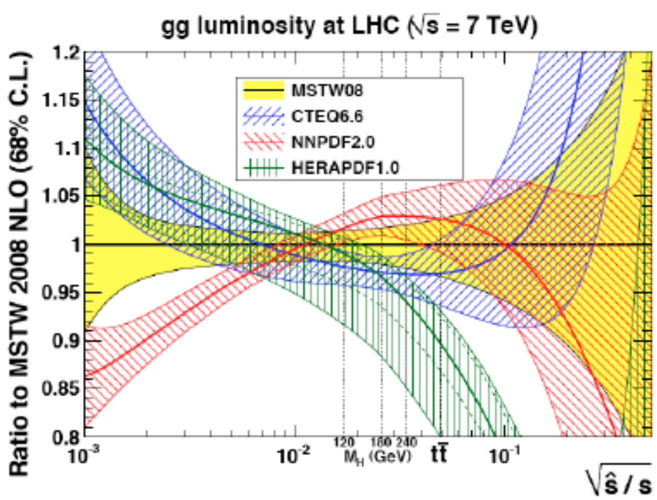


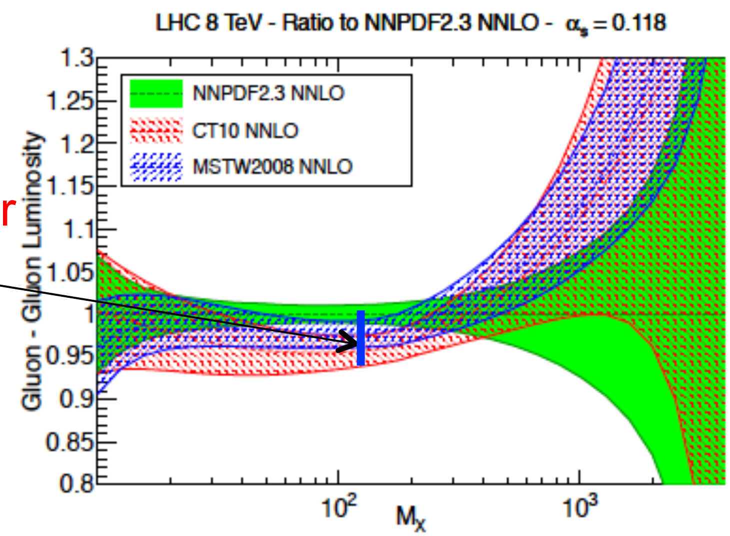
improvements from 2010 to 2012…

…and from NLO to NNLO

so Higgs PDF uncertainty under good control

α_s uncertainty still +/-0.002





PDF benchmarking

- Not officially a PDF4LHC document, but used as input
- Comparisons only at NNLO, but NLO comparisons available at http://nnpdf.hepforge.org/html/pdfbench/catalog

arXiv:1211.5142v2 [hep-ph] 5 Apr 2013

CERN-PH-TH/2012-263
Edinburgh 2012/21
SMU-HEP-12-16
LCTS/2012-26
IFUM-1003-FT

Parton distribution benchmarking with LHC data

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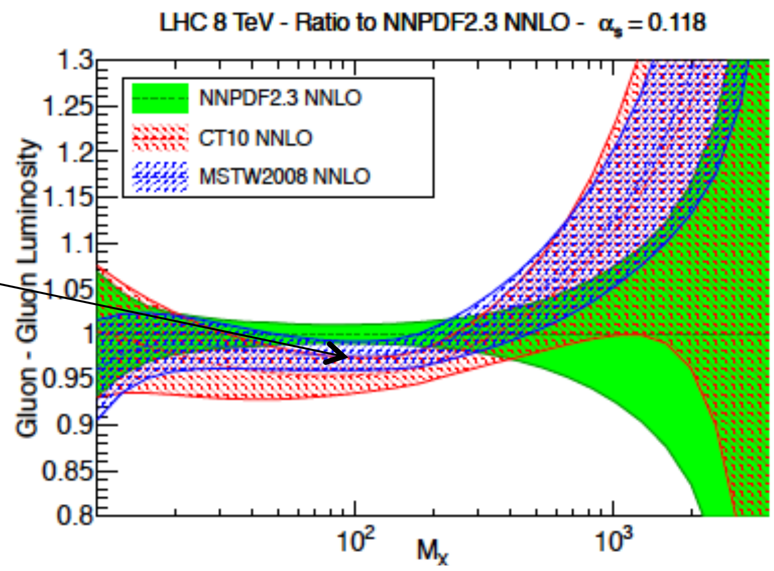
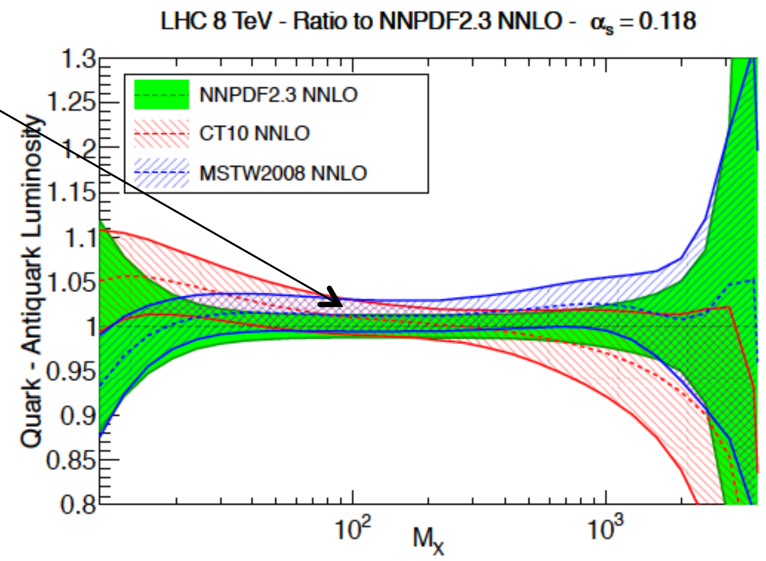
Abstract:

We present a detailed comparison of the most recent sets of NNLO PDFs from the ABM, CT, HERAPDF, MSTW and NNPDF collaborations. We compare parton distributions at low and high scales and parton luminosities relevant for LHC phenomenology. We study the PDF dependence of LHC benchmark inclusive cross sections and differential distributions for electroweak boson and jet production in the cases in which the experimental covariance matrix is available. We quantify the agreement between data and theory by computing the χ^2 for each data set with all the various PDFs. PDF comparisons are performed consistently for common values of the strong coupling. We also present a benchmark comparison of jet production at the LHC, comparing the results from various available codes and scale settings. Finally, we discuss the implications of the updated NNLO PDF sets for the combined PDF+α_s uncertainty in the gluon fusion Higgs production cross section.

NNLO PDF uncertainties

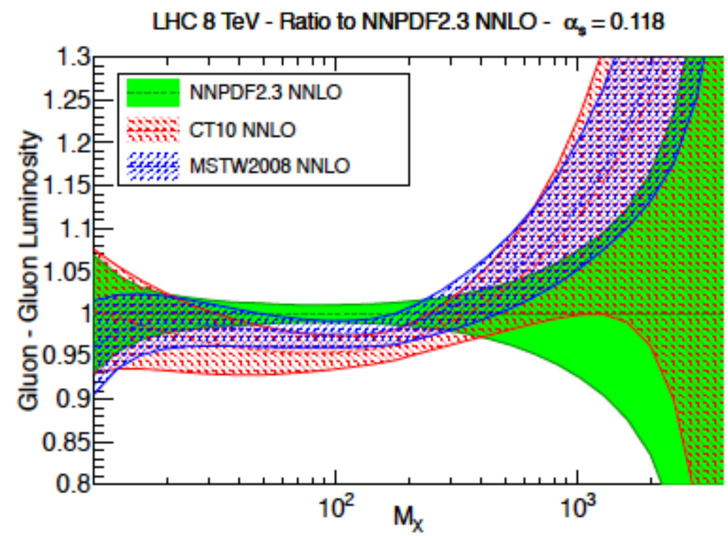
- Factor of 2 expansion of MSTW2008 error basically works for gg initial states (like 125 Higgs)
- …but maybe an overestimate for qQ initial states

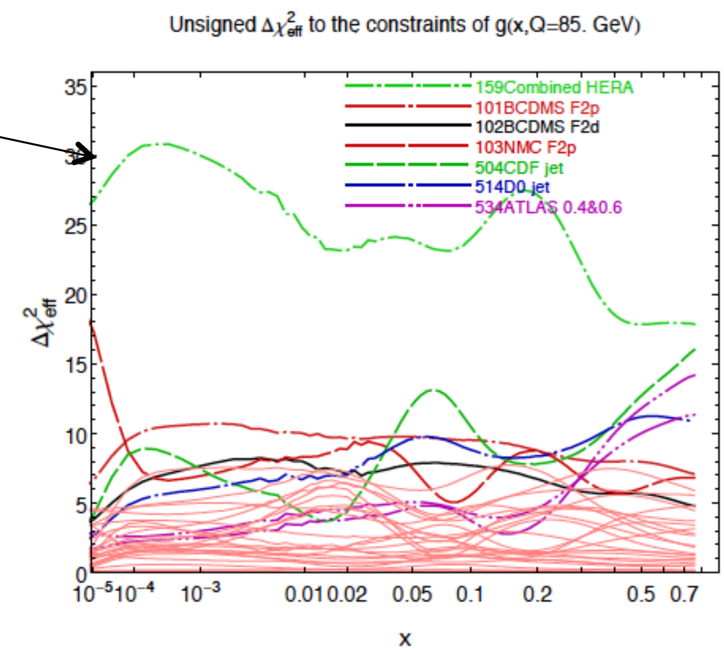




…but are they good enough?

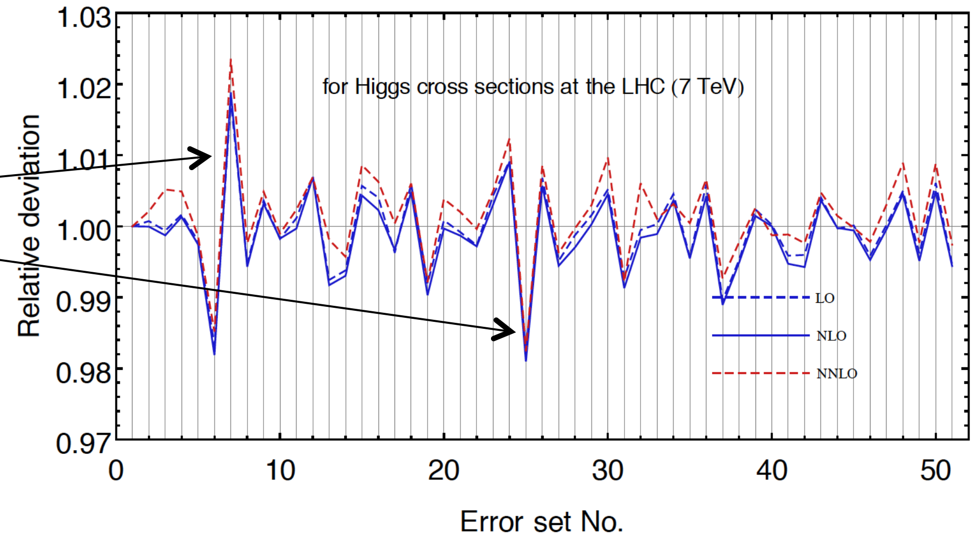
- Can we further improve the gg PDF luminosity uncertainty in the Higgs mass region?
- NNPDF2.3 marks the high edge and CT10 the low edge
  - full gg uncertainty is ~ factor of 2 more than any of the individual group uncertainties
- The gluon in this region is determined primarily by the HERA combined Run 1 data set, so one would think that the gluon distributions would be essentially the same
- There may be issues relating to specific heavy quark schemes/ charm quark masses
- A project for Les Houches





…but are they good enough?

- For CT10, the Higgs cross section uncertainty is largely determined by a few eigenvectors
- Detailed study of those eigenvectors may add to knowledge of how to further reduce uncertainty
- Can also use the Lagrange Multiplier method

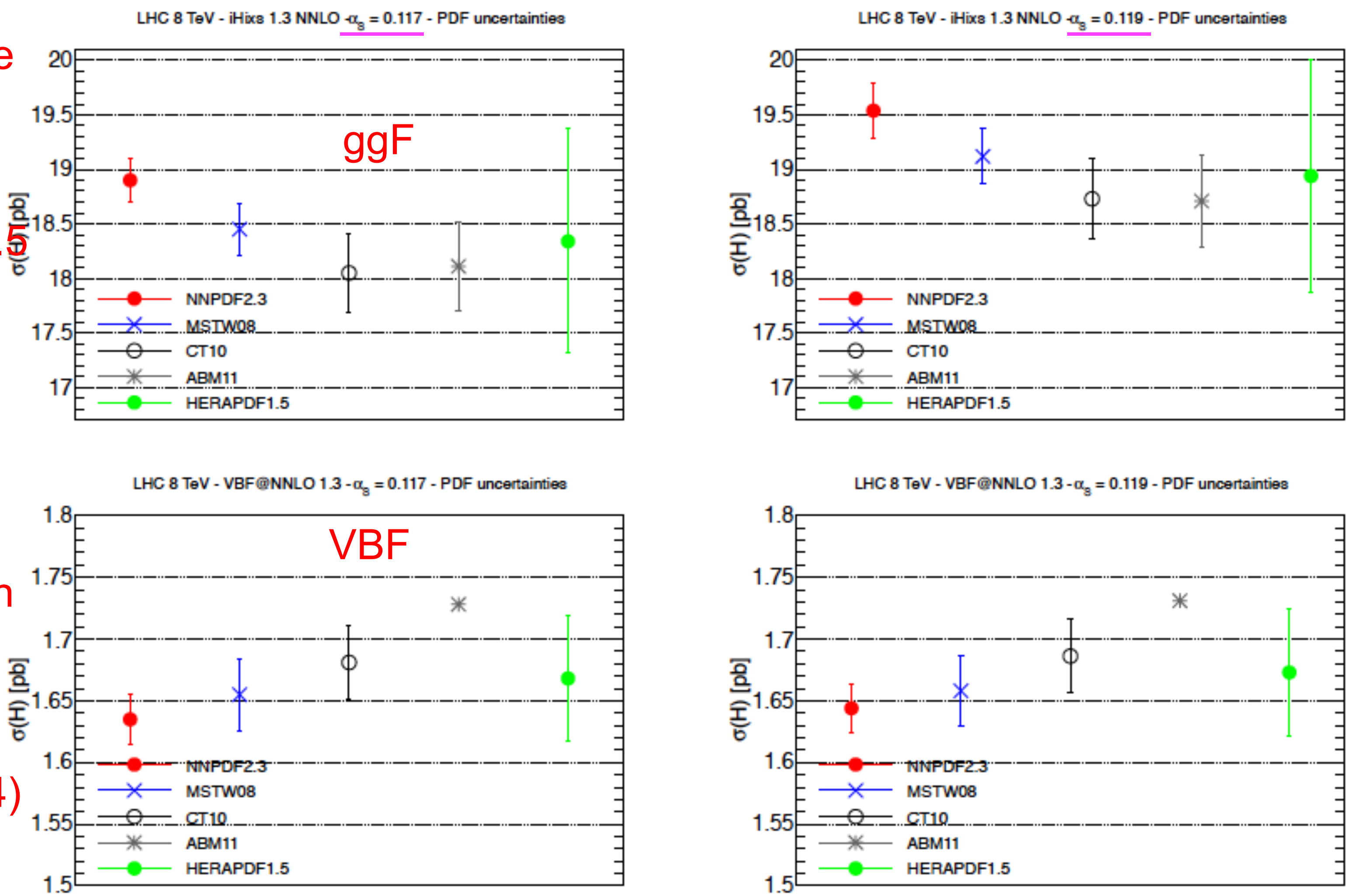


8 TeV Higgs cross section predictions

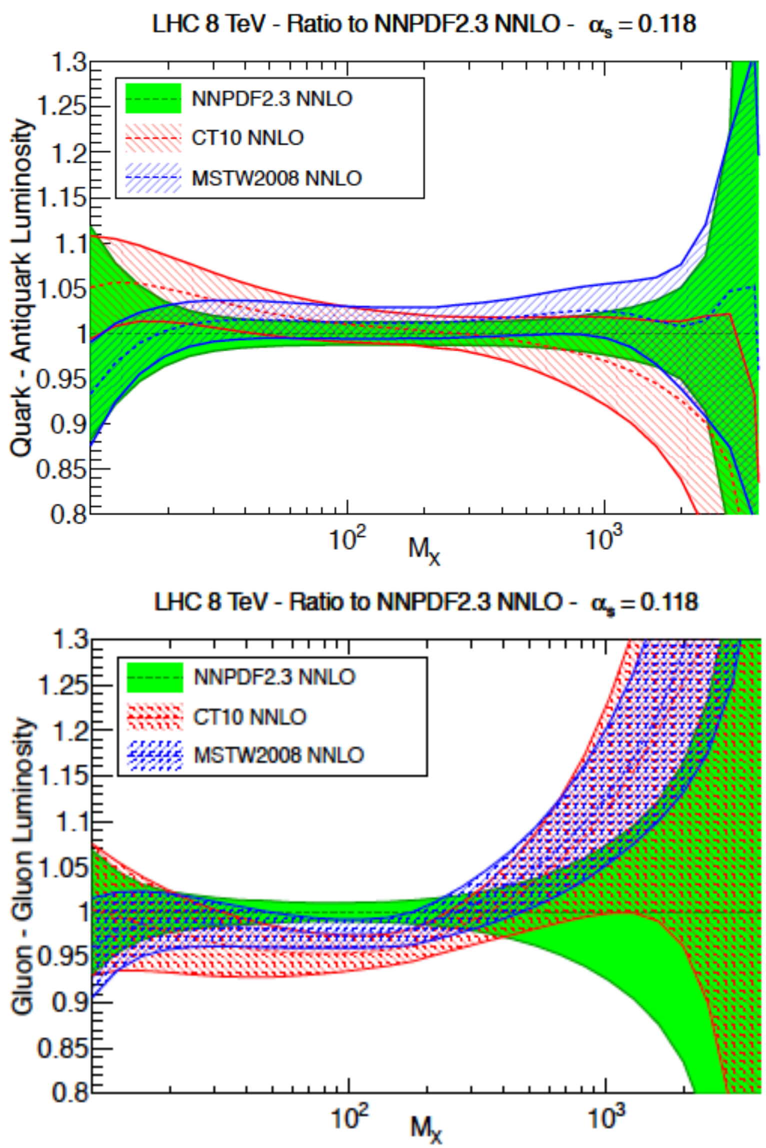
cross sections calculated at NNLO using a scale of m_H

ABM11 and HERAPDF1.5 predictions within error envelope

NB: ABM11 cross section would be lower if native value of α_s (0.1134) used



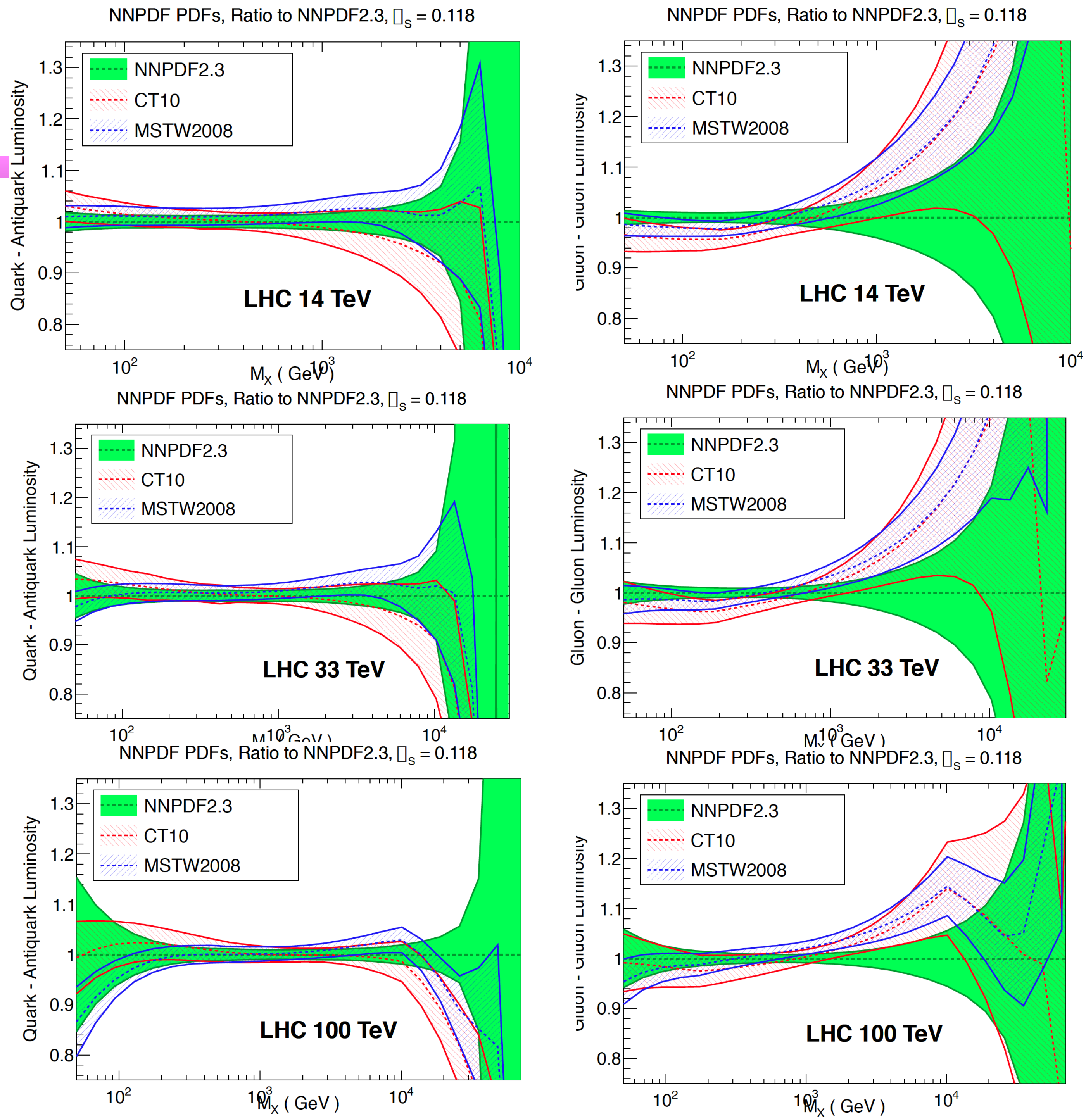
PDFs



- 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%?
- CT can use Lagrange Multiplier technique to look at this; NNPDF can use their Monte Carlo approach

Energy dependence of PDF uncertainties

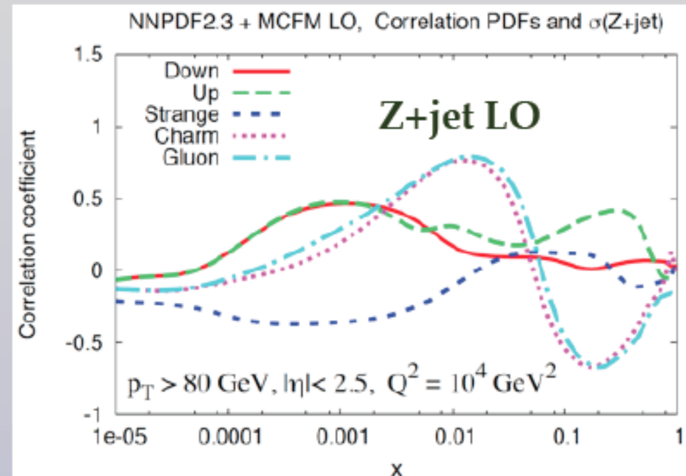
…figures by Juan Rojo for Snowmass white paper

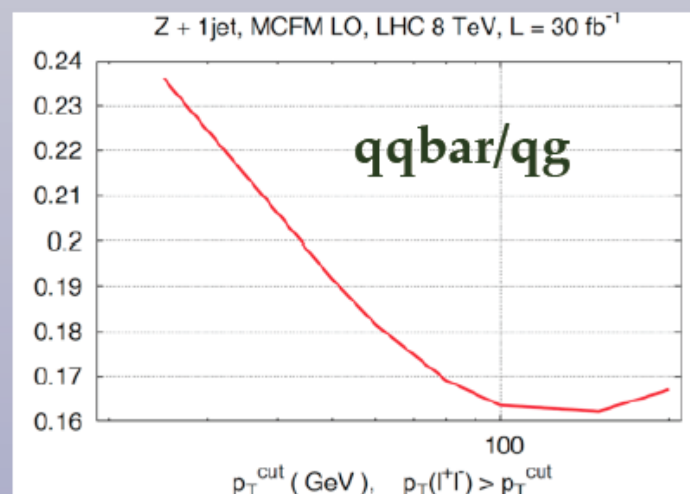


Using LHC data to improve PDF precision

New avenues to the gluon (I)

- In global PDF fits, the **gluon** is directly constrained by **jet data** only (and HERA at small-x)
- Jets are NLO with **large scale uncertainties** (though NNLO close, **arxiv:1301.7310**), and experimental errors substantial because of the **JES**
- Given the crucial role of the gluon for LHC physics, **complementary LHC observables directly sensitive the gluon** would be beneficial
- One possibility is **Z/W boson production at large pT** (in association with jets). Cross section > 80% **dominated by gluon-quark scattering** (ISR of extra jets gluon dominated)
- The measurement can be only with leptons (double differential in pT and rapidity), thus with **very small systematic errors**
- Statistical errors will be negligible
- This measurement will be equivalent to **measuring the partonic luminosity relevant for gg > H**





correlated systematic error information crucial

…and the experimental precision achieved for tT production at the LHC, plus the completion of the NNLO tT cross section means that top production is an important PDF benchmark

…but we need NNLO tT differential cross sections for full exploitation

Uta Klein: Drell-Yan

What may we have with 100 fb^{-1} ...

✓ We may anticipate for 100 fb^{-1} NC and CC DY data over a wide kinematic range of 60 to 1500 GeV with negligible stat. precision (well <0.1%) around the peak region up to 5% at M~ 1 TeV while the systematic uncertainties are expected to be ½ of the present systematic uncertainties, e.g. for NC DY in the range of 0.5% at the peak up to 5% at high masses

➔ exploring more and more fully the data driven background estimates and the tag and probe based efficiency calculations (significant reduction of stats. component of the systematic uncertainty).

However, with increased statistics, and such small level of systematic uncertainties there may be also NEW effects at the sub-percent level 'discovered'.

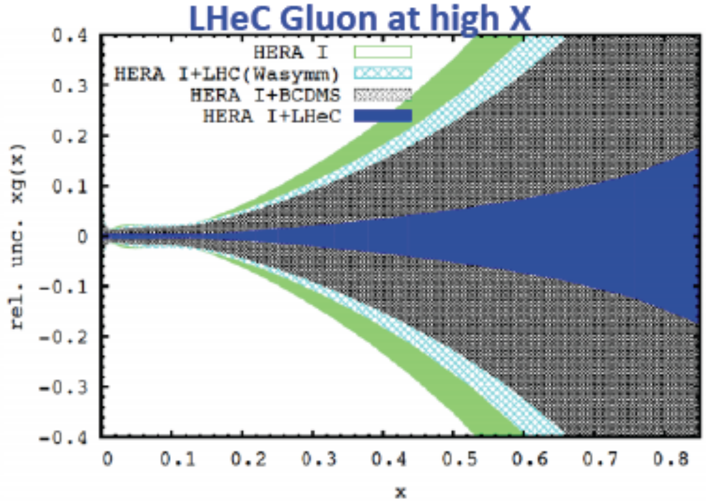
Do we need an LHeC?

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

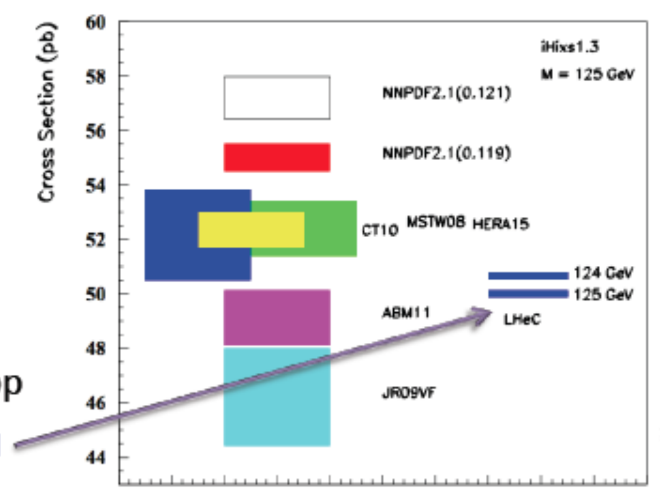


At the LHeC , Higgs is cleanly produced via ZZ or WW fusion, complementary to the dominant gg fusion at pp

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

NNLO pp–Higgs Cross Sections at 14 TeV

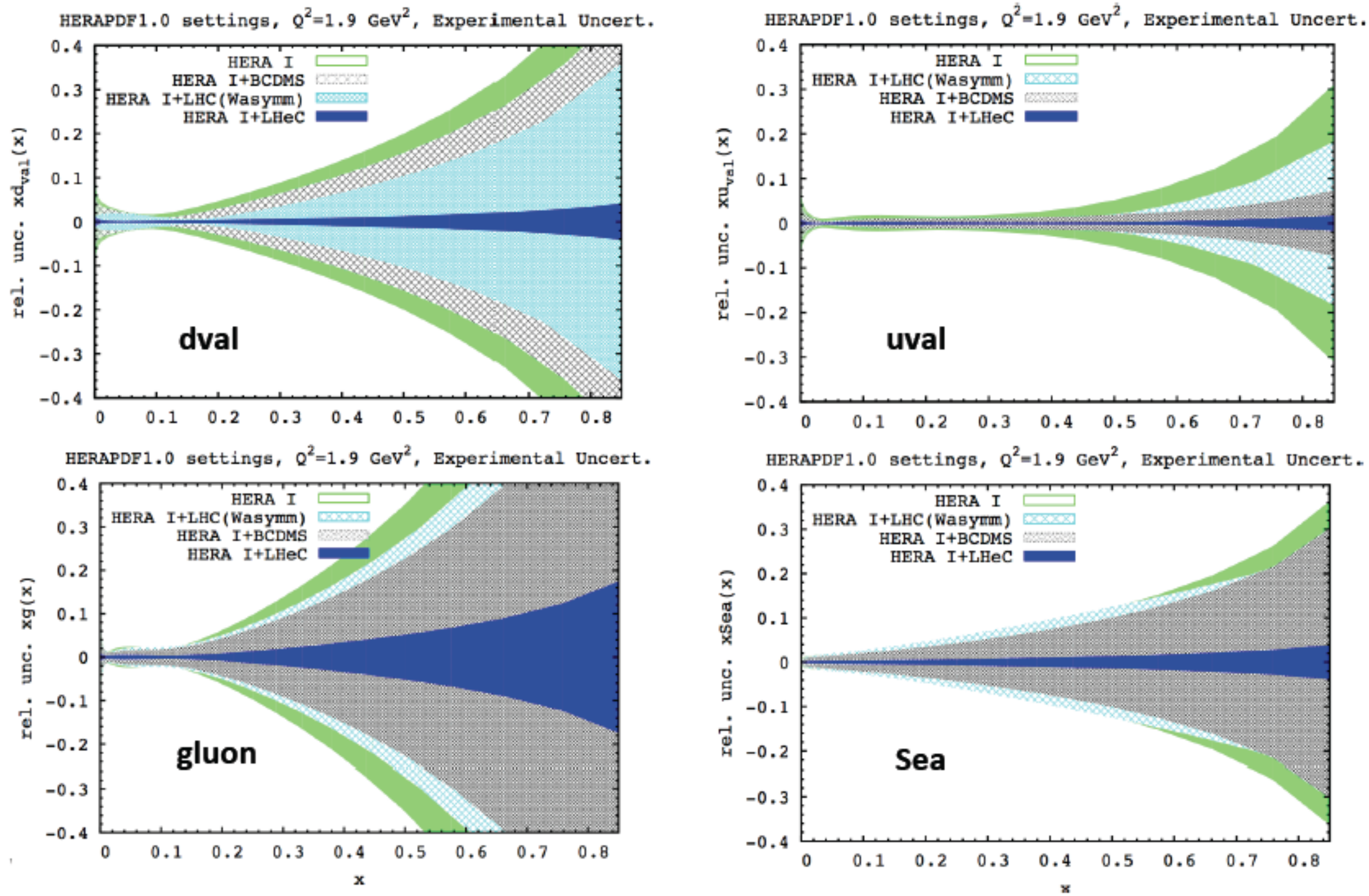


- precision from LHeC can add a significant constraint on MH

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

Impact of LHeC on PDFs: zoom on high x

* Experimental uncertainties are shown at the starting scale Q^2=1.9 GeV^2



Higher Order Calculations

- Les Houches NLO wishlist, started in 2005, and incremented in 2007 and 2009 was officially closed in 2011, since all of the calculations on the list were complete, and there are no technical impediments towards calculations of new final states, either with dedicated or semi-automatic calculations
- Note that dedicated calculations can be factors of 10 faster than semi-automatic

Process ($V \in \{Z, W, \gamma\}$)	Comments
Calculations completed since Les Houches 2005	
1. $pp \to VV$ jet	WW jet completed by Dittmaier/Kallweit/Uwer [27, 28]; Campbell/Ellis/Zanderighi [29]. ZZ jet completed by Binoth/Gleisberg/Karg/Kauer/Sanguinetti [30] WZ jet, $W\gamma$ jet completed by Campanario et al. [31, 32]
2. $pp \to$ Higgs+2 jets	NLO QCD to the gg channel completed by Campbell/Ellis/Zanderighi [33]; NLO QCD+EW to the VBF channel completed by Ciccolini/Denner/Dittmaier [34, 35] Interference QCD-EW in VBF channel [36, 37]
3. $pp \to VVV$	ZZZ completed by Lazopoulos/Melnikov/Petriello [38] and WWZ by Hankele/Zeppenfeld [39], see also Binoth/Ossola/Papadopoulos/Pittau [40] VBFNLO [41, 42] meanwhile also contains $WWW, ZZW, ZZZ, WW\gamma, ZZ\gamma, WZ\gamma, W\gamma\gamma, Z\gamma\gamma, \gamma\gamma\gamma, W\gamma\gamma j$ [43, 44, 45, 46, 47, 21]
4. $pp \to t\bar{t}b\bar{b}$	relevant for $t\bar{t}H$, computed by Bredenstein/Denner/Dittmaier/Pozzorini [48, 49] and Bevilacqua/Czakon/Papadopoulos/Pittau/Worek [50]
5. $pp \to V$+3 jets	W+3 jets calculated by the Blackhat/Sherpa [51] and Rocket [52] collaborations Z+3jets by Blackhat/Sherpa [53]
Calculations remaining from Les Houches 2005	
6. $pp \to t\bar{t}$+2jets	relevant for $t\bar{t}H$, computed by Bevilacqua/Czakon/Papadopoulos/Worek [54, 55]
7. $pp \to VV\,b\bar{b}$,	Pozzorini et al. [25], Bevilacqua et al. [23]
8. $pp \to VV$+2jets	W^+W^++2jets [56], W^+W^-+2jets [57, 58], VBF contributions calculated by (Bozzi/)Jäger/Oleari/Zeppenfeld [59, 60, 61]
NLO calculations added to list in 2007	
9. $pp \to b\bar{b}b\bar{b}$	Binoth et al. [62, 63]
NLO calculations added to list in 2009	
10. $pp \to V+4$ jets	top pair production, various new physics signatures Blackhat/Sherpa: W+4jets [22], Z+4jets [20] see also HEJ [64] for $W + n$jets
11. $pp \to Wb\bar{b}j$	top, new physics signatures, Reina/Schutzmeier [11]
12. $pp \to t\bar{t}t\bar{t}$	various new physics signatures
also completed: $pp \to W\gamma\gamma$ jet	Campanario/Englert/Rauch/Zeppenfeld [21]
$pp \to 4$ jets	Blackhat/Sherpa [19]

Table 1: The updated experimenter's wishlist for LHC processes

Last to be calculated

- a 4 top final state

arXiv:1206.3064v1 [hep-ph] 14 Jun 2012

Constraining BSM Physics at the LHC: Four top final states with NLO accuracy in perturbative QCD

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Abstract: Many theories, from Supersymmetry to models of Strong Electroweak Symmetry Breaking, look at the production of four top quarks as an interesting channel to evidentiate signals of new physics beyond the Standard Model. The production of four-top final states requires large partonic energies, above the $4m_t$ threshold, that are available at the CERN Large Hadron Collider and will become more and more accessible with increasing energy and luminosity of the proton beams. A good theoretical control on the Standard Model background is a fundamental prerequisite for a correct interpretation of the possible signals of new physics that may arise in this channel. In this paper we report on the calculation of the next-to-leading order QCD corrections to the Standard Model process $pp \to t\bar{t}t\bar{t} + X$. As it is customary for such studies, we present results for both integrated and differential cross sections. A judicious choice of a dynamical scale allows us to obtain nearly constant K-factors in most distributions.

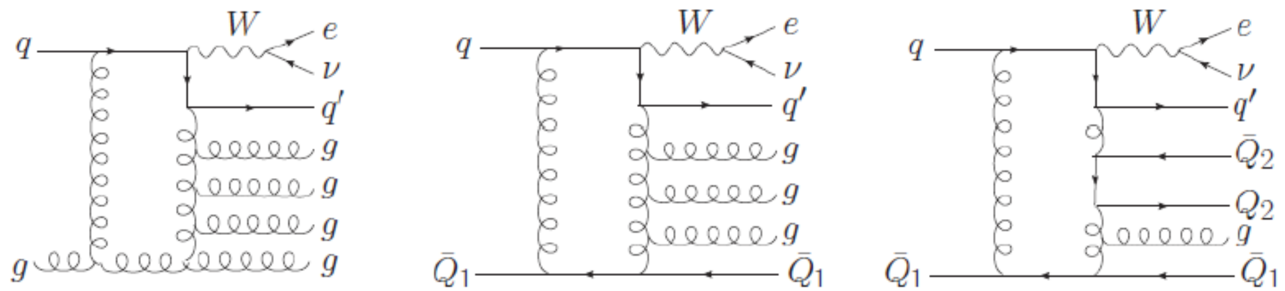
Keywords: NLO Computations, Heavy Quark Physics, Standard Model, Beyond Standard Model

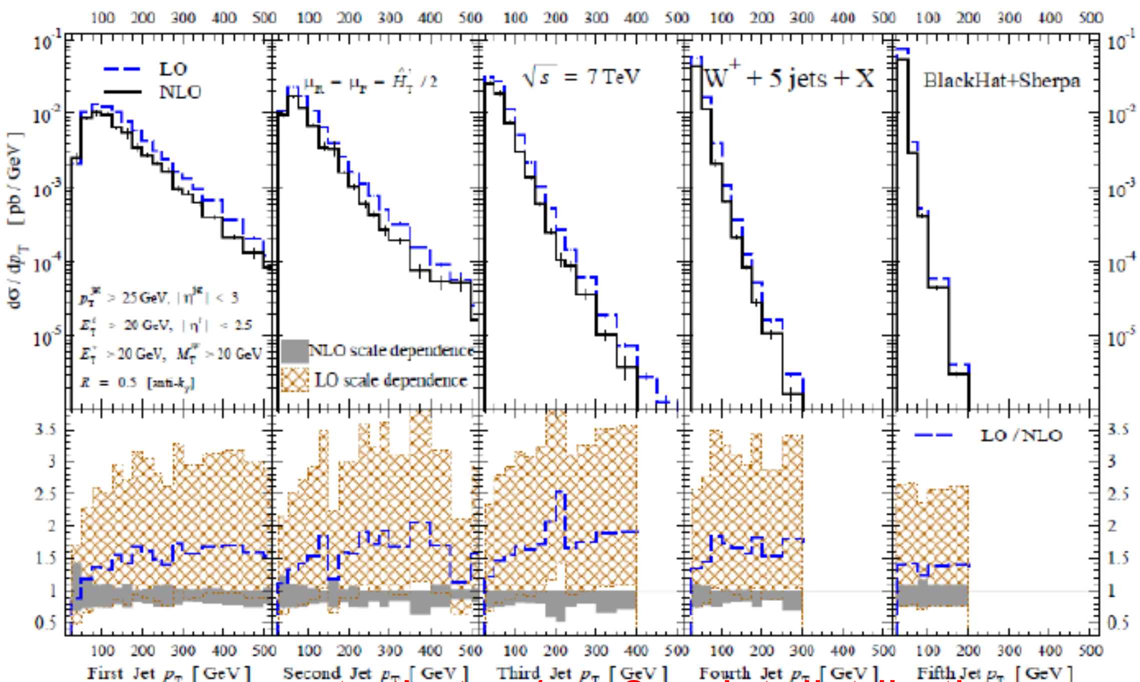
WUB/12-12, TTK-12-22

The NLO multiplicity frontier:

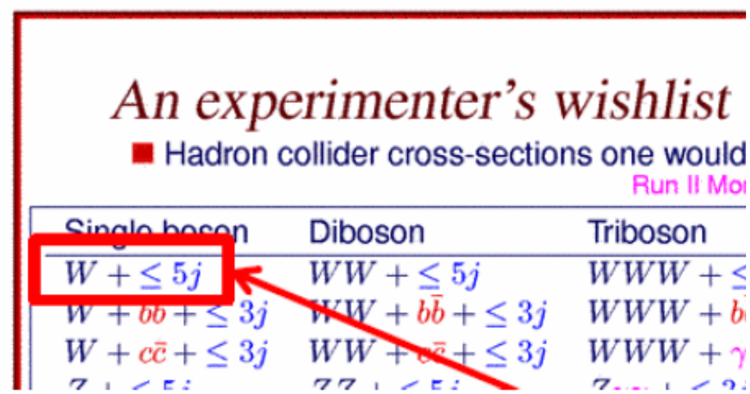
Febres Cordero

W + 5 jets





New request from J. Huston:
Did we say NLO?
We meant NNLO



note that n-1, n-2,… jet distributions always softer at NLO than at LO …but not in NLO+PS? Why?

What's next for the Les Houches NLO wishlist?

- Nothing: We've retired the NLO wishlist
- It's being replaced by a NNLO wishlist plus a wishlist for EW corrections for hard processes

Below we construct a table of calculations needed at the LHC, and which are feasible within the next few years. Certainly, results for inclusive cross sections at NNLO will be easier to achieve than differential distributions, but most groups are working towards a partonic Monte Carlo program capable of producing fully differential distributions for measured observables.

- $t\bar{t}$ production: Done, but still need differential for full power
  needed for accurate background estimates, top mass measurement, top quark asymmetry (which is zero at tree level, so NLO is the leading non-vanishing order for this observable, and a discrepancy of theory predictions with Tevatron data needs to be understood). Several groups are already well on the way to complete NNLO results for $t\bar{t}$ production [84, 85, 86, 87].
- W^+W^- production:
  importand background to Higgs search. At the LHC, $gg \to WW$ is the dominant subprocess, but $gg \to WW$ is a loop-induced process, such that two loops need to be calculated to get a reliable estimate of the cross section. Advances towards the full two-loop result are reported in [88, 89].
- inclusive jet/dijet production: gg done; full by end of year? Ask Nigel after his talk.
  NNLO parton distribution function (PDF) fits are starting to become the norm for predictions and comparisons at the LHC. Paramount in these global fits is the use of inclusive jet production to tie down the behavior of the gluon distribution, especially at high x. However, while the other essential processes used in the global fitting are known to NNLO, the inclusive jet production cross section is only known at NLO. Thus, it is crucial for precision predictions for the LHC for the NNLO corrections for this process to be calculated, and to be available for inclusion in the global PDF fits. First results for the real-virtual and double real corrections to gluon scattering can be found in [90, 91].

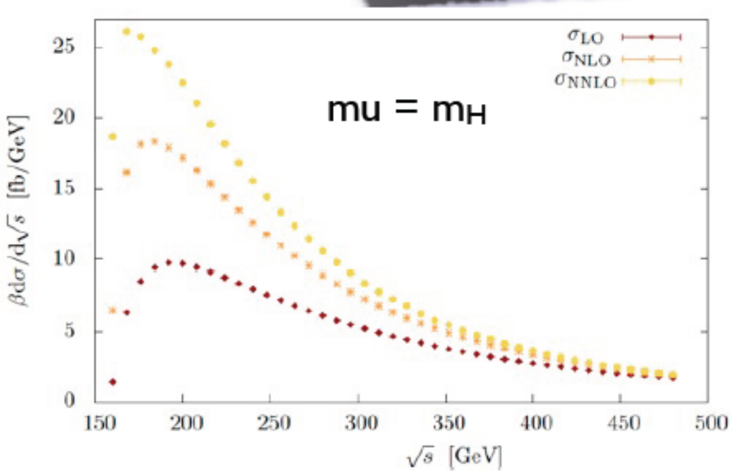
NNLO wishlist: continued

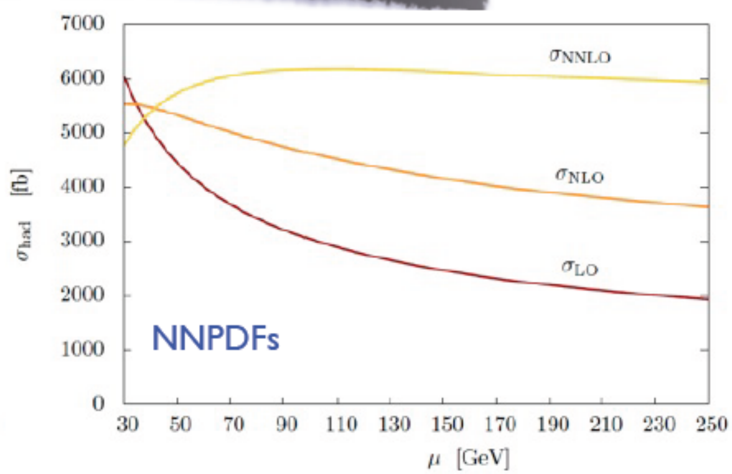
- V+1 jet production: <2 years
  $W/Z/\gamma$ + jet production form the signal channels (and backgrounds) for many key physics processes, for both SM and BSM. In addition, they also serve as calibration tools for the jet energy scale and for the crucial understanding of the missing transverse energy resolution. The two-loop amplitudes for this process are known [92, 93], therefore it can be calculated once the parts involving unresolved real radiation are available.
- V+γ production: by end of year?
  important signal/background processes for Higgs and New Physics searches. The two-loop helicity amplitudes for $q\bar{q} \to W^{\pm}\gamma$ and $q\bar{q} \to Z^0\gamma$ recently have become available [94].
- Higgs+1 jet production: gg done; full by end of year?
  As mentioned previously, events in many of the experimental Higgs analyses are separated by the number of additional jets accompanying the Higgs boson. In many searches, the Higgs + 0 jet and Higgs + 1 jet bins contribute approximately equally to the sensitivity. It is thus necessary to have the same theoretical accuracy for the Higgs + 1 jet cross section as already exists for the inclusive Higgs cross section, i.e. NNLO. The two-Loop QCD Corrections to the Helicity Amplitudes for $H \to 3$ partons are already available [95].

Radja Boughezal

arXiv:1303.4405

H+jet @ NNLO: gg-channel





$$\sigma_{\rm LO}(pp \to Hj) = 2713^{+1216}_{-776}\ \text{fb},$$
$$\sigma_{\rm NLO}(pp \to Hj) = 4377^{+760}_{-738}\ \text{fb},$$
$$\sigma_{\rm NNLO}(pp \to Hj) = 6177^{-204}_{+242}\ \text{fb}.$$

$\sigma_{NLO}/\sigma_{LO} = 1.6$

$\sigma_{NNLO}/\sigma_{NLO} = 1.3$

so sizeable increase of cross section in going to NNLO

clear implications for Higgs+jets studies going on by ATLAS and CMS

how to take best advantage?

what can we guess for Higgs + 2 jets?

NLO ME+PS

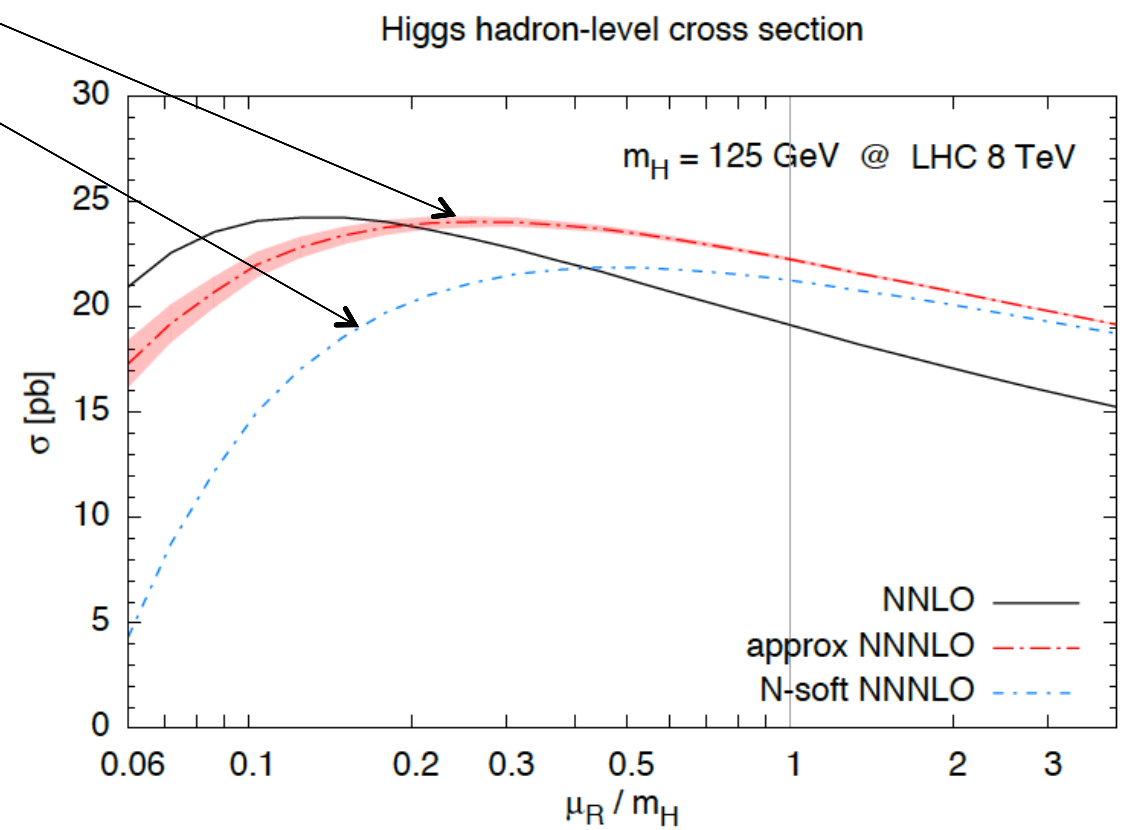
- There are several frameworks now, such as Sherpa and aMC@NLO, in which multiple jets can be included at NLO, with additional jets at LO, with additional additional jets via the parton shower
- For example, Higgs + 0, 1 and 2 jets at NLO, with up to 3 additional jets at LO (matrix element) in Sherpa
- The result is a MC dataset similar to what is seen in the data, with a NLO(+NLL) accuracy
- This is a good framework to try to further understand Higgs cross sections plus their uncertainties
- More on this, I'm sure, in the Tools presentation

Beyond NNLO

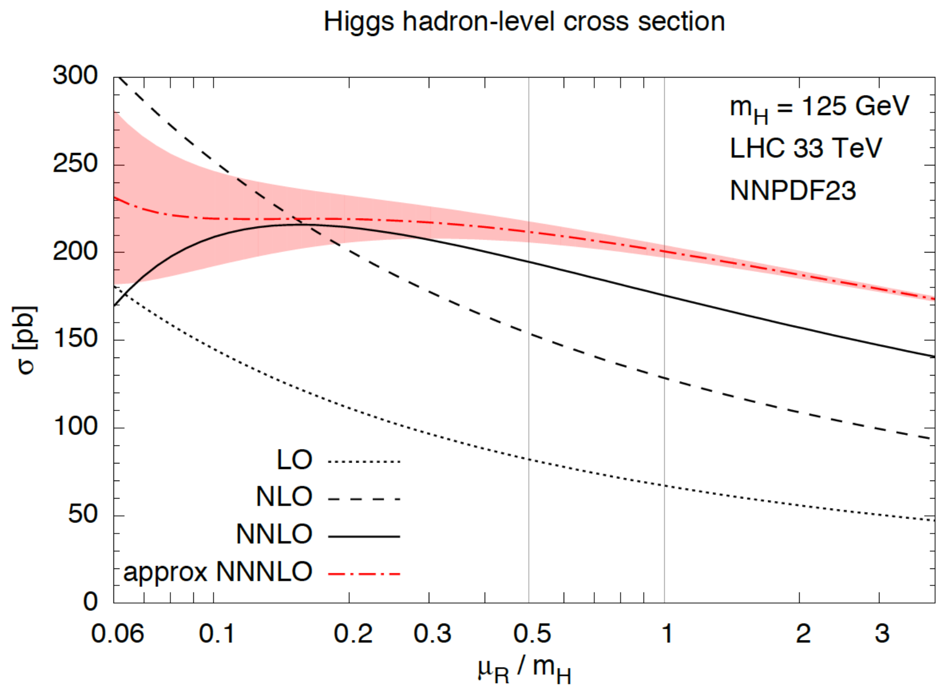
- Note the considerable flattening of the scale uncertainty at approximate NNNLO
- Note also the importance of including BFKL logs in addition to soft logs
- Note also that the net result is an increase in the (gg->) Higgs cross section that we currently use for our comparisons
- Snowmass+Les Houches project: investigate effects of BKFL logs in resummation for the higher energy accelerators, plus the explicit expected effects of BFKL logs in hard scattering processes, a la HEJ, compared to fixed order predictions for multi-jet final states, such as from Blackhat+Sherpa

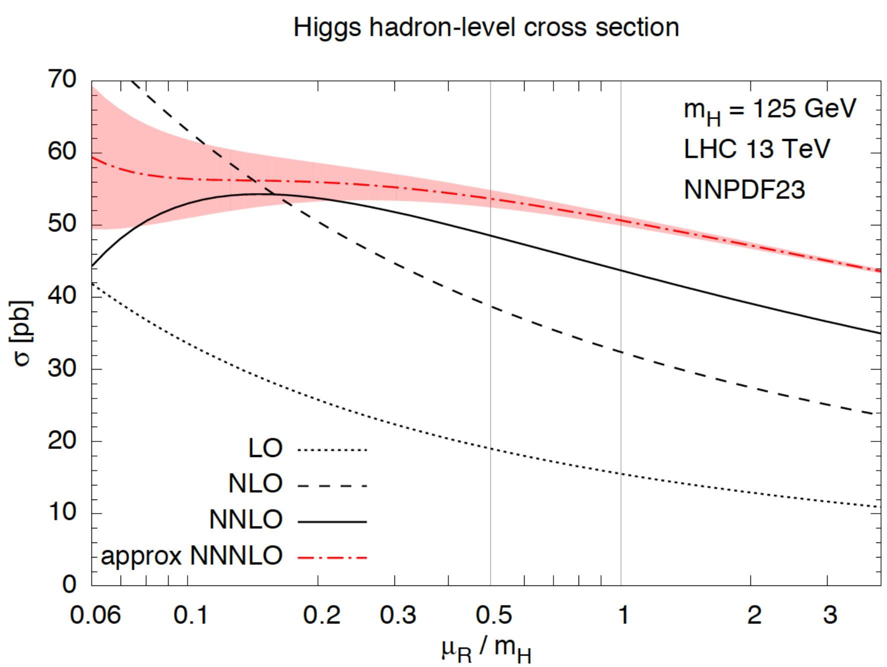
Plot produced by Marco Bonvini

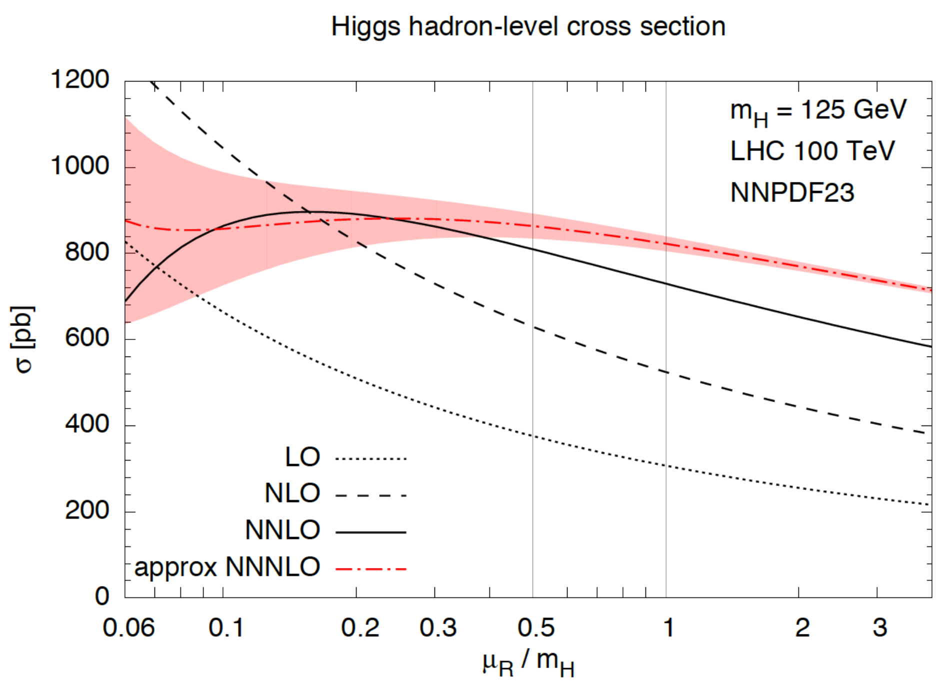
Paper==‘Higgs production in gluon fusion beyond NNLO’, R. Ball et al; arXiv:1303.3590



Energy dependence: plots by Marco Bonvini

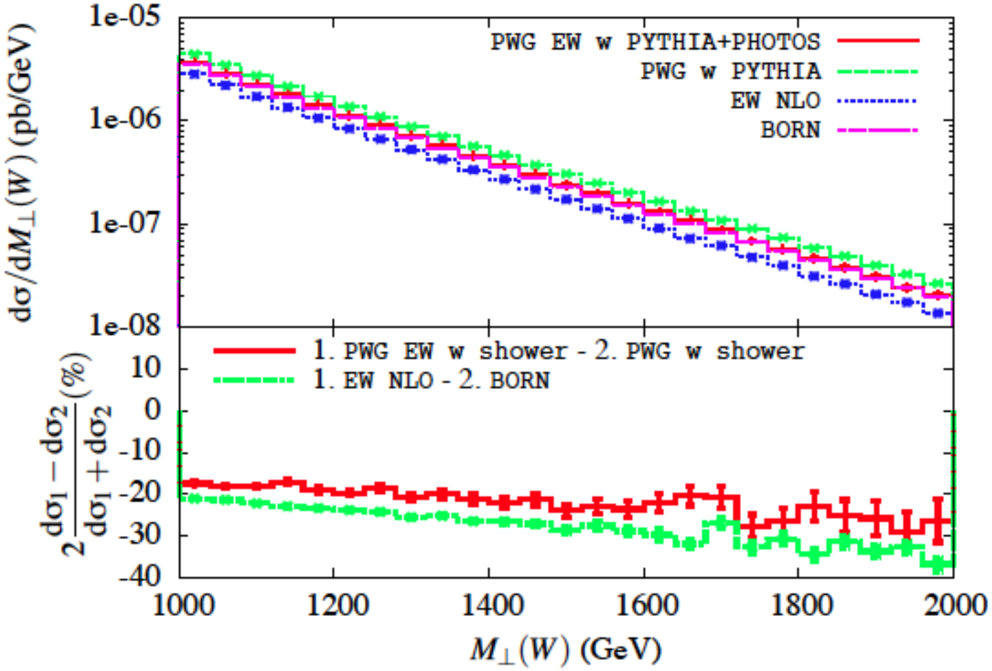






QCD+EWK

- How well do we know the DY cross section for a mass of 2 TeV?
- Would we recognize a real deviation from SM, say a broad resonance, if we saw it?



Brookhaven, Ap

Uta Klein

A wish list for discussion & studies

.. some tasks are already under study also in LPCC and EW experimental and theory WG's

- ❖ Numerical stability of NNLO and NLO calculations, e.g. issues related to choice of symmetric p_T cuts, intrinsic integration settings, and the case of fine bins and high precision (→ smaller than exp. uncertainties, so <0.5% per bin), etc.
- ➔ "optimal" choice (and documentation) of EW parameters and SM inputs
- ➔ high precision (<0.1% per bin) "APPLgrids at NNLO" .. ?
- ❖ Precision evaluation of missing HO EW (ISR, interferences, weak) corrections and QED FSR modelling; application of missing HO EW corrections and remaining systematics
- ❖ Uncertainties due to further missing HO QCD effects as usually estimated by "scale uncertainties" → realistic prescription for NNLO (CPU time!)
- ❖ Improved modelling of $p_T(W,Z)$: implementation of resummation into NLO MC models (but e.g also control of resummation scale)
- ❖ Improved modelling and measurement proposals for non-resonant photon-induced dilepton productions, but also for the NLO gamma-p induced dilepton and W productions
- ❖ Improved modelling of real W and Z radiation beyond LO approach outlined by U.Baur, arXiv:hep-ph/0611241

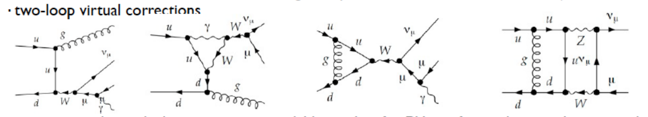
QCD+EWK effects

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

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

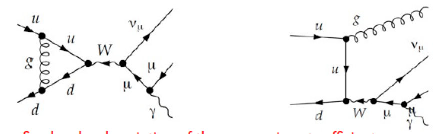
- The first mixed QCDxEW corrections include different contributions:
  - emission of two real additional partons (one photon + one gluon/quark)
  - emission of one real additional parton (one photon with QCD virtual corrections, one gluon/quark with EW virtual corrections)
  - two-loop virtual corrections



- 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

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

Fixed order corrections exactly evaluated and available in simulation codes

Subsets of corrections partially evaluated or approximated

$O(\alpha^2)$
- 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)

$O(\alpha\alpha\_s)$
- 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

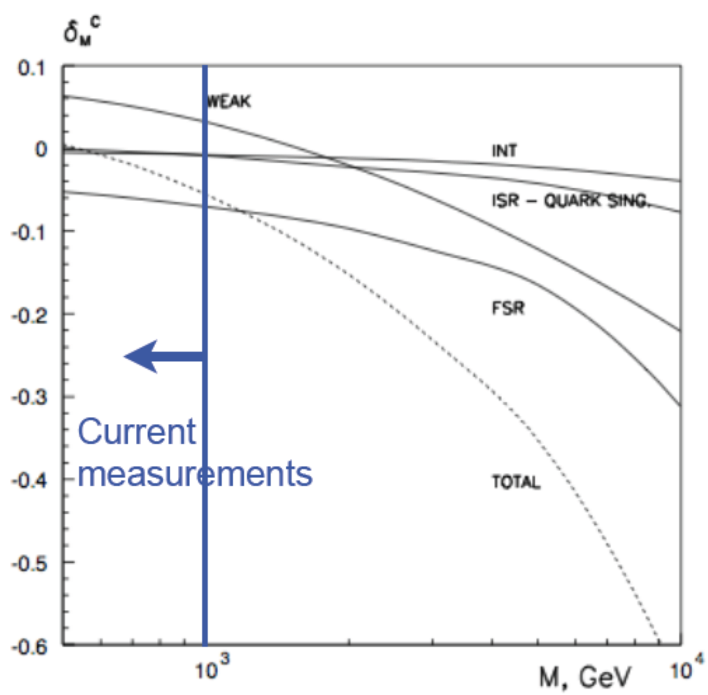
Cue Rod Serling

You are traveling through another dimension, a dimension not only of sight and sound, but of scales much larger than the W mass…

The Sudakov Zone

Mishra
Durham
EWK
workshop

What about electroweak processes



Zykunov, arXiv: hep-ph/0702-203

- EWK corrections for most processes at LHC are < the current experimental precision.
- However, most everything we could measure in 2010 (jets, photons, W, Z) will enter the "Sudakov zone" in 2012.

If experimental and PDF errors are < EWK corrections, then I'll call the measurement as being in the Sudakov zone. Typically need a few dozen events above 1 TeV to be in this zone.

Quick recap of Sudakov zone survey

Mishra

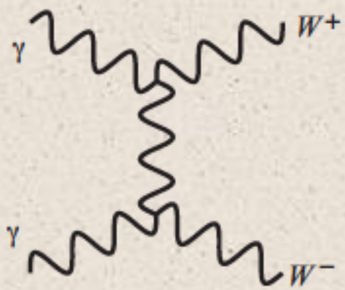
Are we in the Sudakov zone ?

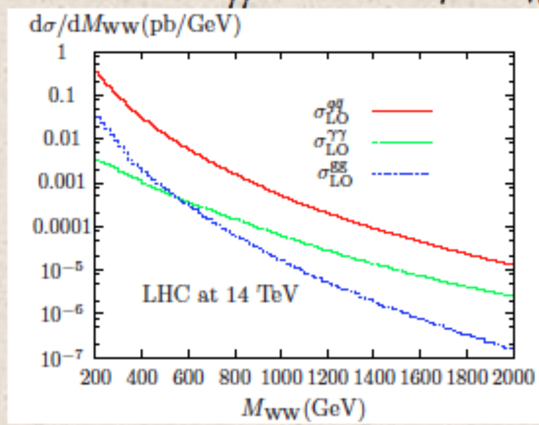
Process	Now	End 2012	14 TeV
Incl. W/Z	No	No	No
$\ell\ell\gamma$, $\ell\nu\gamma$	No	No	Yes
W/Z tail	No	Yes	Yes
W/Z+jets tail	Close	Yes	Yes
WW leptonic	No	Close	Yes
WZ,ZZ leptonic	No	No	No
WW semi-leptonic	Yes	Yes	Yes
WZ,ZZ semi-leptonic	No	Yes	Yes

Photon PDFs

2) Photon induced processes can be kinematically enhanced.

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

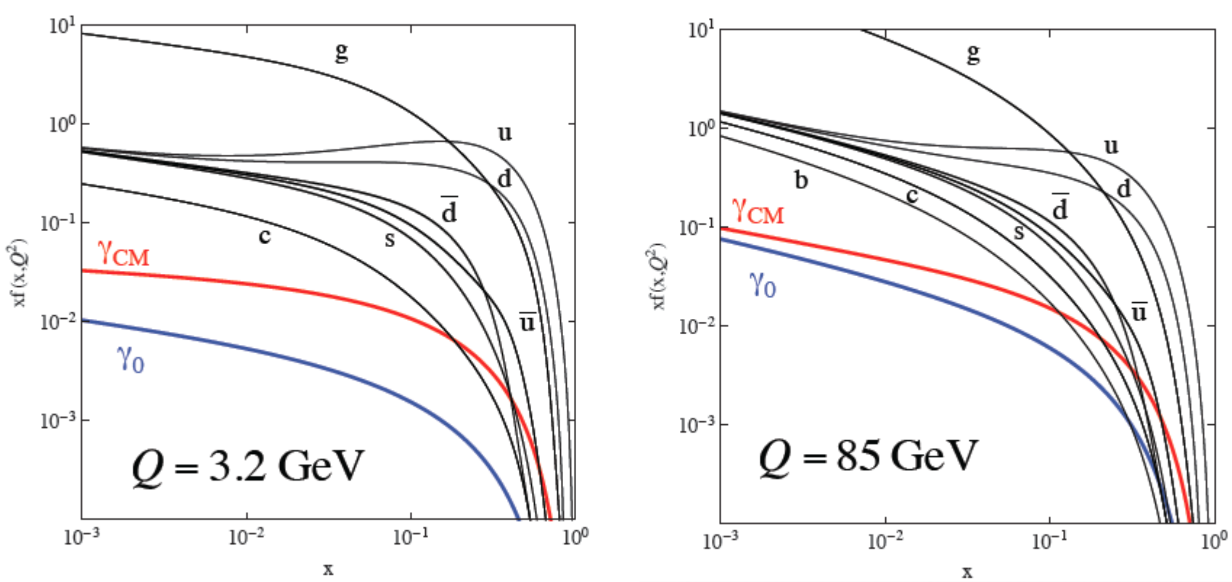




significant fraction of high mass WW pairs from γγ, even after kinematic cuts

Bierweiler et al., JHEP 1211 (2012) 093

Carl Schmidt



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

The future looks bright

- …but the (near) future also looks busy
- Near-term (tentative) schedule
  - Tuesday afternoon: Rivet tutorial, NLO+MC discussion
  - Wednesday morning: NNLO +beyond
  - Wednesday afternoon: PDF discussion (try to link back to US vis a vis Snowmass)
  - Thurs morning: QCD+EWK-> review by Stefan Dittmaier and then discussion
  - Thursday afternoon: Higgs +jets/Higgs resummation (link back to US; great deal of work/discussion has already gone on)