NLM Experimental and Theoretical Summary

Joey Huston
Michigan State University

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

(Partial) Les Houches worklist from Day 1

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 *->Higgs

c) Higgs+jets cross sections*->overlap with Higgs/MC

-comparisons of @MC@NLO, Powheg MINLO, MEPS@NLO, HEJ, etc*->overlap with Higgs/MC

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

-revisit tag jets: hadronization uncertainties for high rapidity jets

d) Higgs+jets uncertainties*->overlap with Higgs

-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->still waiting

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

a) wishlist of calculations*

b) study of the 'Sudakov Zone'*

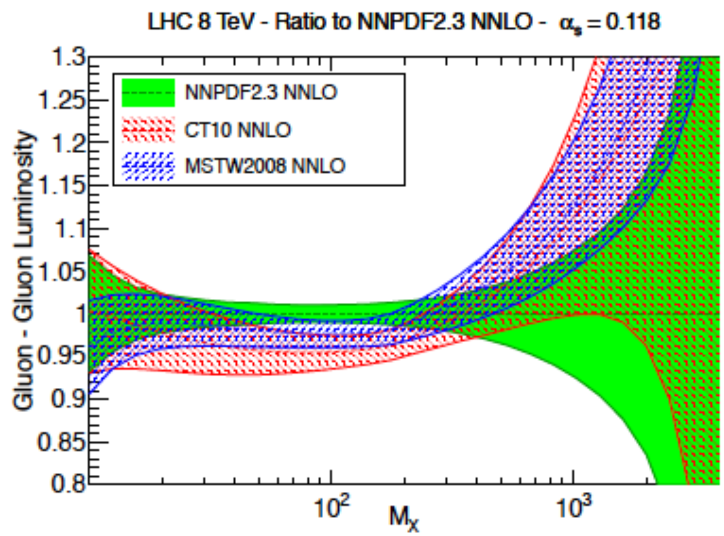
c) PDFs with QED corrections, photon PDFs, gamma-gamma processes*

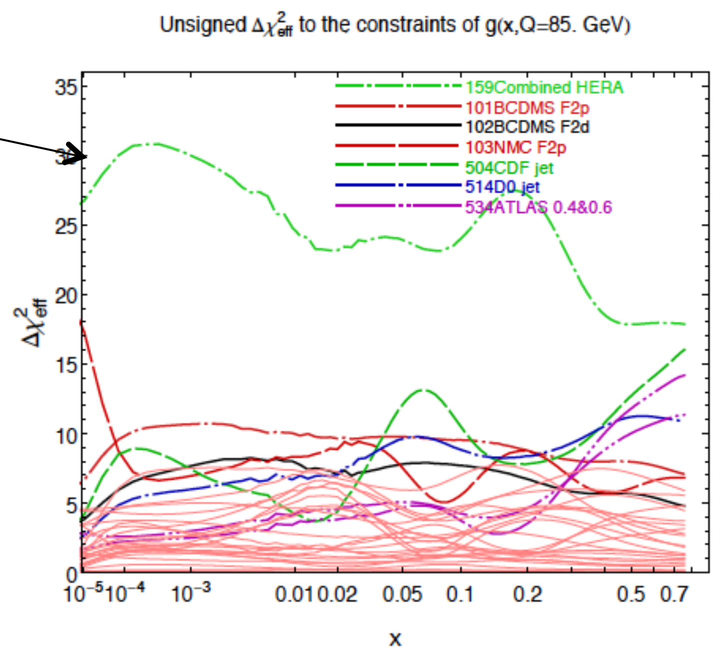
d) update of BLHA*

*addressed at Les Houches

…but are they good enough?

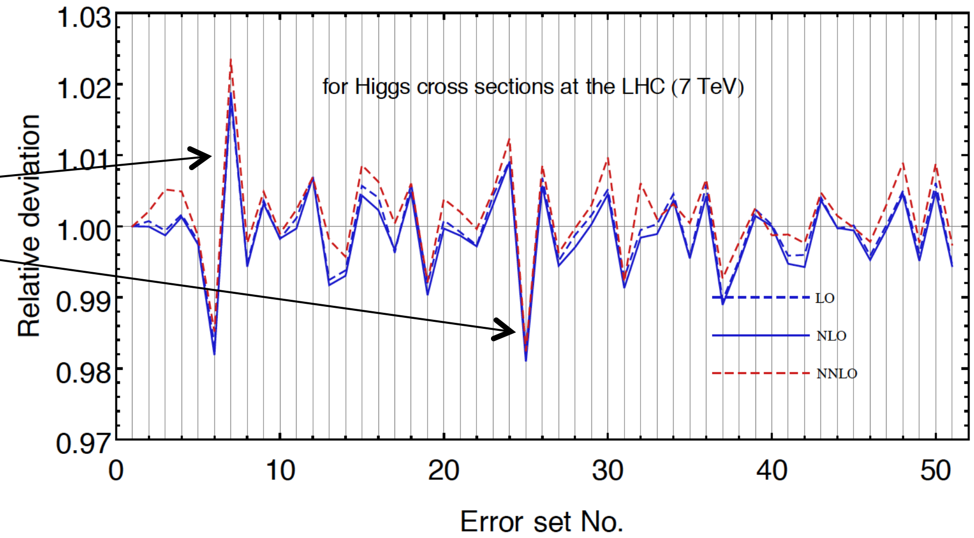
- Can we further improve the gg PDF luminosity uncertainty in the Higgs mass region?
- NNPDF2.3 marks the high edge and CT10 the low edge
    - full gg uncertainty is ~ factor of 2 more than any of the individual group uncertainties
- The gluon in this region is determined primarily by the HERA combined Run 1 data set (for CT10); the correlation with the HERA data is not large, but there are 500 data points
- Studies started:
    - examine correlations in NNPDF (to be expanded to MSTW,…) try to understand any differences in the impacts of various experiments
    - effects of different heavy quark schemes
    - influence of LHC data

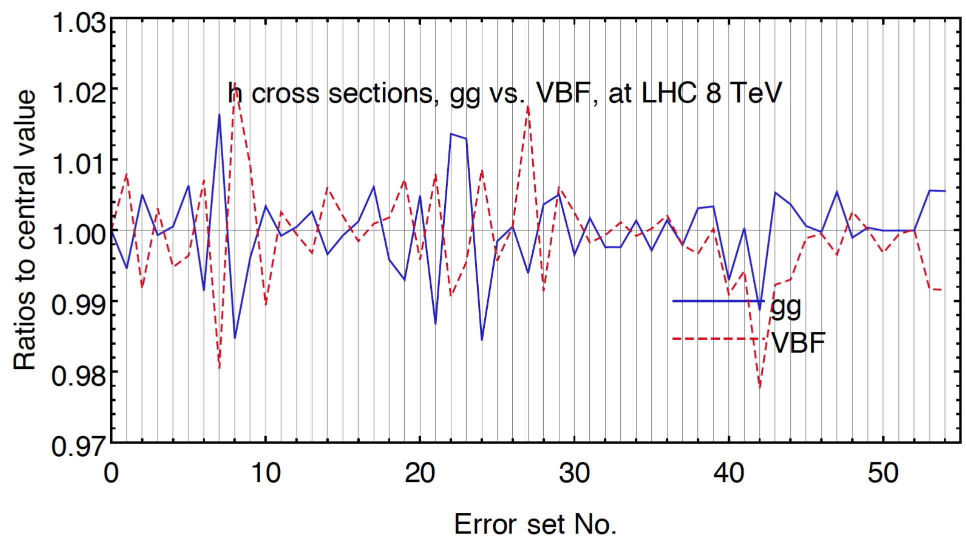




…but are they good enough?

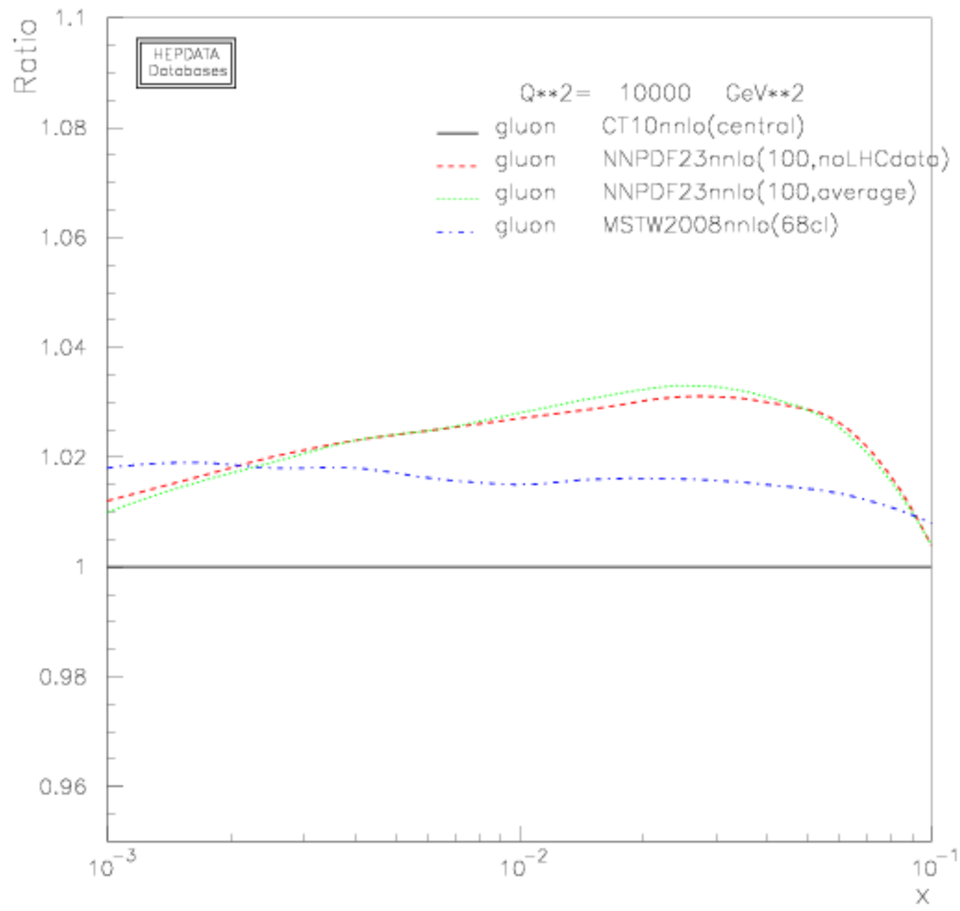
- For CT10, the gg Higgs cross section uncertainty is largely determined by a few eigenvectors
- Detailed study of those eigenvectors may add to knowledge of how to further reduce uncertainty
- It's also interesting to see the anti-correlation of the gg fusion subprocess with the VBF subprocess, expressed in terms of the individual eigenvectors
  - note this anti-correlation breaks down for higher eigenvector (more poorly determined) directions





Influence of collider data

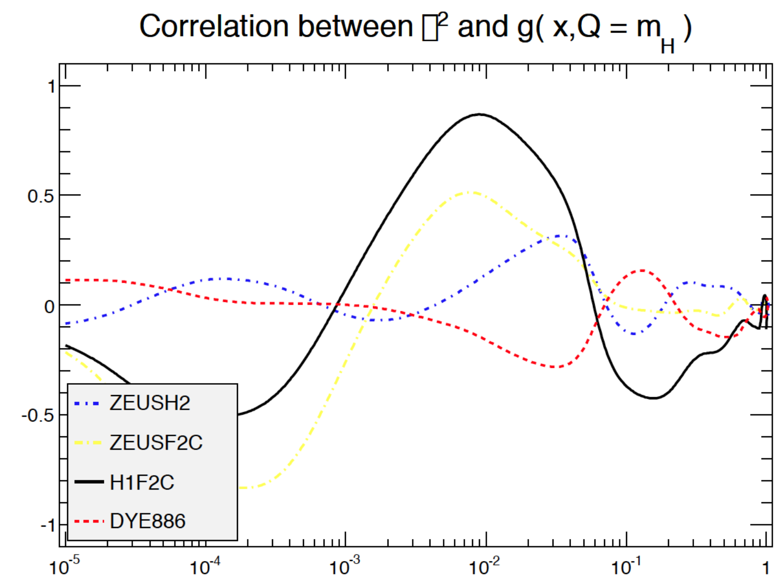
- Compare NNPDF2.3 with and without collider data (green and red curves)
- Very little difference, at least partially because LHC does not have much constraining power yet

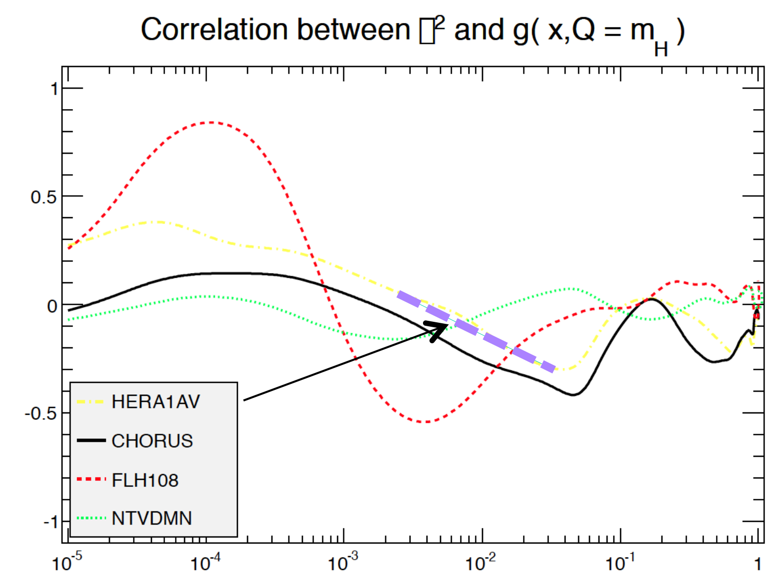


PDF Higgs projects

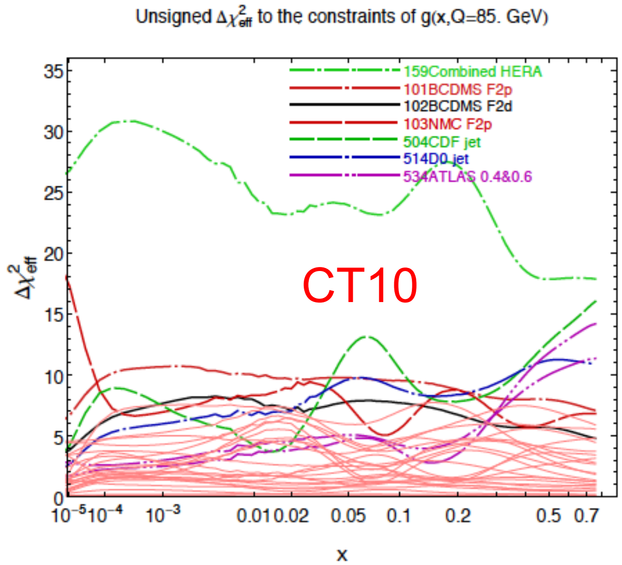
- With NNPDF2.3, look at correlations between different experiments and the gluon distribution as a function of x
- Strong correlations with H1F2c and ZEUSF2c
- Mild **anti**-correlation with the HERA Run 1 combined data
  - curve is yellow, so I superimposed a dashed purple line in the relevant region

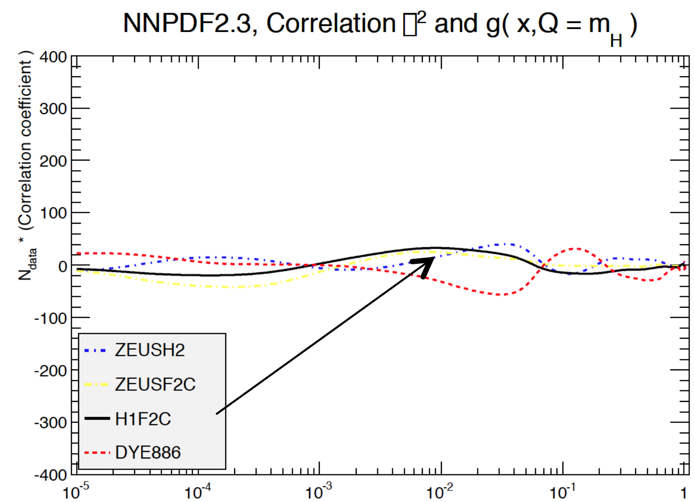
S. Forte and J. Rojo



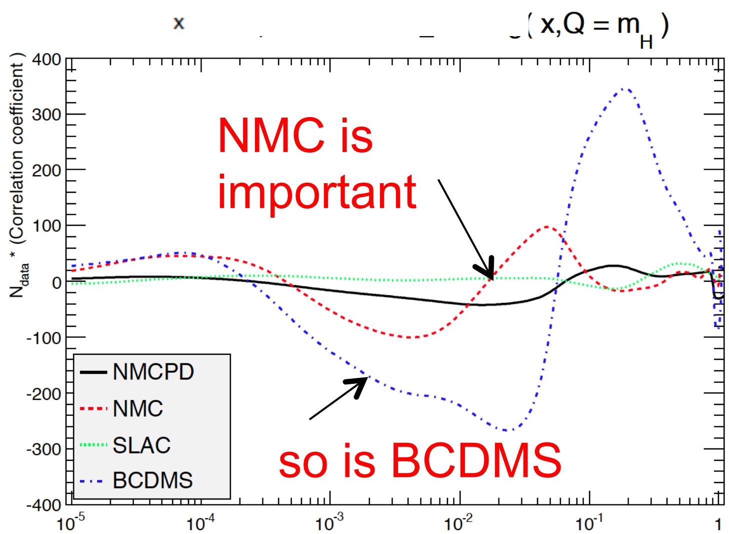


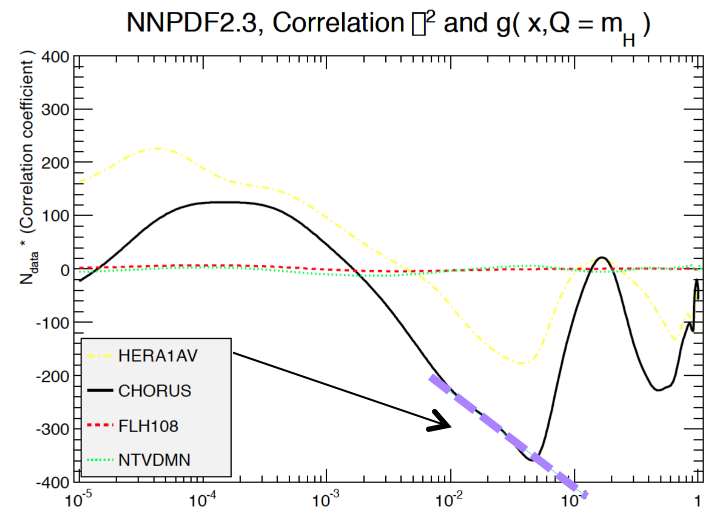
PDF Higgs Projects





so I'm not comparing exactly the same thing for CT10 and NNPDF2.3, but conclusions can still be drawn

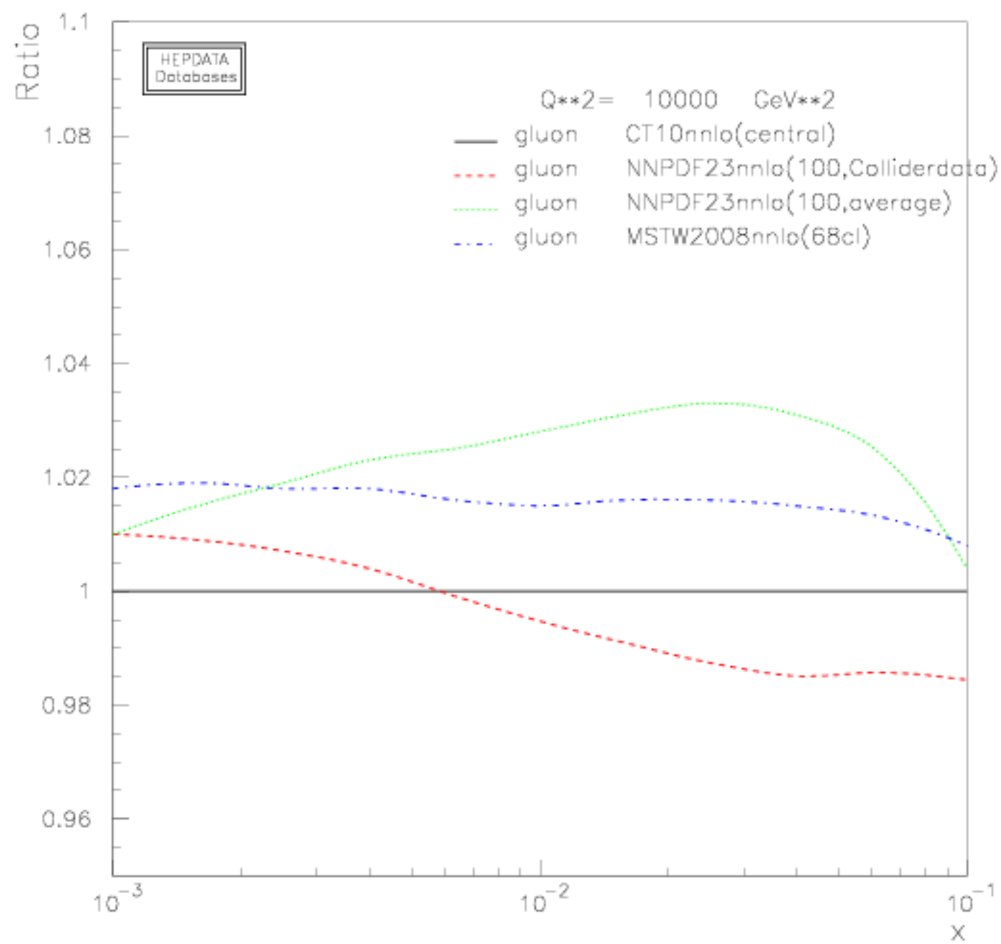




This is just the beginning if we are to improve our understanding of the gluon PDF in the Higgs x range. Summary in Les Houches writeup.

PDF Higgs Projects

- NNPDF2.3 fit only to collider data leads to a slightly different gluon and a prediction for the gg->Higgs cross section at 8 TeV in better agreement with CT10 and MSTW08
  - but factor of 2 larger uncertainties
- We will re-investigate the impact of BCDMS and NMC data on Higgs cross section predictions
  - impact is on the order of a few percent, but this is one place where that order of magnitude is critical



so we may be able to improve the PDF uncertainty but there is still a strong $\alpha_s(m_Z)$ dependence

Fits of the fits: META PDFs

PDFs from different groups have different physics inputs. But if we only focus on the phenomenological studies at the LHC with the limited x and Q ranges, the idea of META PDF is reasonable and also feasible.

Procedure (for LHC):
1, selecting a specific x-Q range, and a parameterization form to describe all the PDFs at an initial scale above the bottom quark mass;
2, check that the fitted PDFs can well represent the original PDFs at the x-Q range studied;
3, choosing a scheme to combine the PDF measurements of different groups in the new PDF parameter space;

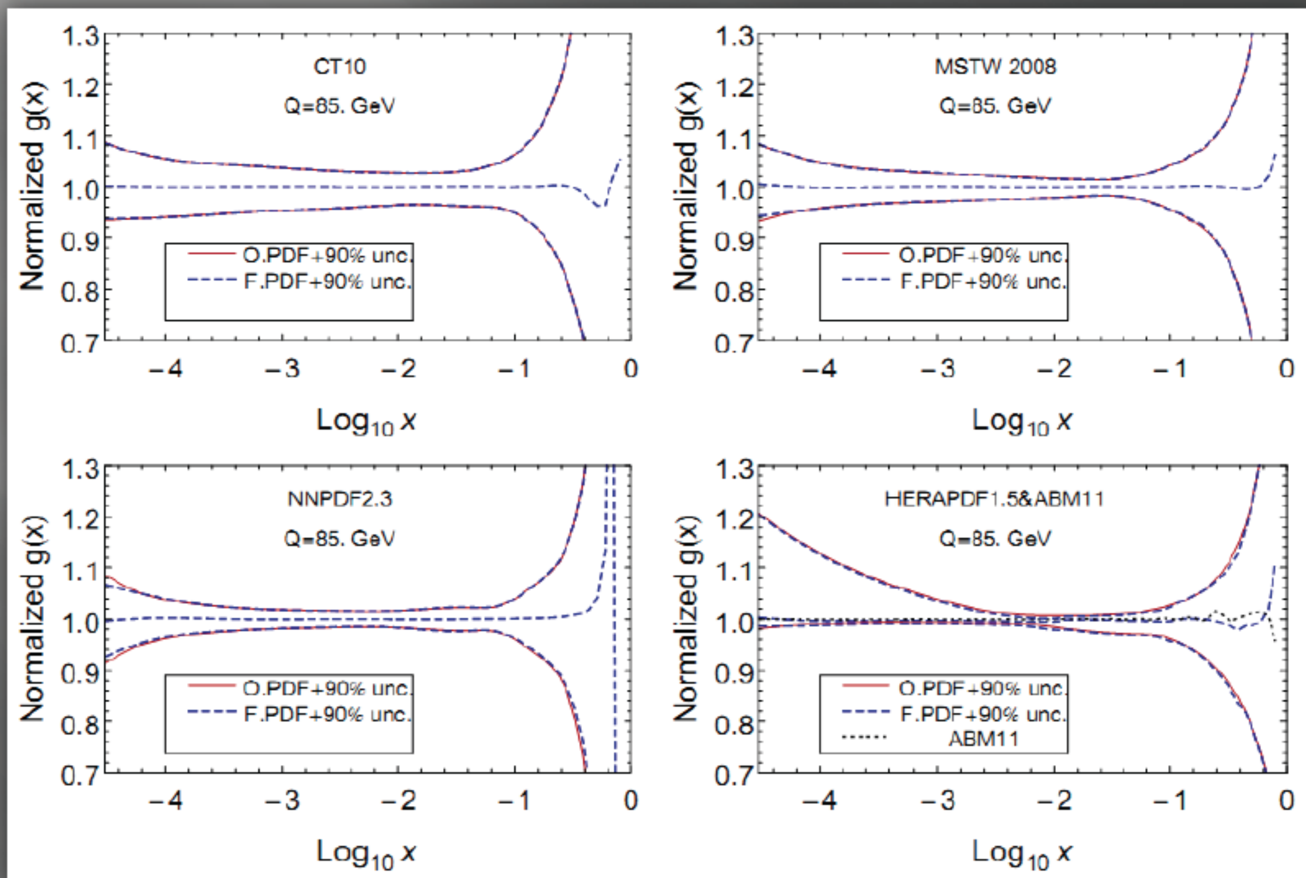
Benefits:
1, A nature way to compare and combine the LHC predictions from different PDF groups independent of the process, works similarly as the PDF4LHC prescriptions but directly in the PDF parameter space;
2, Especially desirable for including results from large number of PDF groups, in this case also minimizing numerical computation efforts for massive NNLO calculations;

Jun Gao: talk (by vidyo) Wed aft

Agreement of the original and fitted PDFs at arbitrary Q

PRELIMINARY

The meta PDFs are fitted at Q=8 GeV and evolved to higher Q using a common numerical program, HOPPET, then compared to the original PDFs at same scales. Excellent agreement, minor discrepancies at small x are further reduced by evolution.



Combining PDFs from different groups

Once the original PDF samples are faithfully converted into their META forms, we can combine PDF sets from all groups into one META PDF set

Example: combining CT10, MSTW2008, NNPDF2.3 sets

1,Generation of replicas. The PDFs of the three groups at $\alpha_S(M_Z)$=0.118 are generally compatible with each other. Knowing the PDF eigenvectors from each set, we can select 100 MC replicas for each set or generate them for CT10/MSTW using a method similar to the MSTWMC study. Note the differences between the Hessian and MC interpretation of statistical features. We assume the Gaussian distribution in the cases of CT10 and MSTW when generating the replicas.

G. Watt, et al., 1205.4024

2,Averaging all samples. Merge them and get 300 MC replicas. Perform the fit and get the covariance matrix in the PDF parameter space. Reduction of the systematic errors but not experimental errors. Assuming Gaussian distributions in the PDF parameter space, we can find the eigenvector directions, drop ones with small eigenvalue, and arrive at a "Hessian-like" META PDF with 50 eigenvectors (100 error sets).

Further development: reweighting schemes

We explore several possible choices for the META PDF

→ Scheme A: assuming a quadratic dependence of $\chi^2(N|f)$ on PDF parameters x_i , it is straightforward to prove that for the HERA-like fit ($\Delta\chi^2=1$), HERAPDF or ABM, the PDF reweighting with weight $\sim\exp[-\chi^2(N|f)/2]$ is exactly equivalent to the corresponding refitting. Gaussian→ Gaussian.

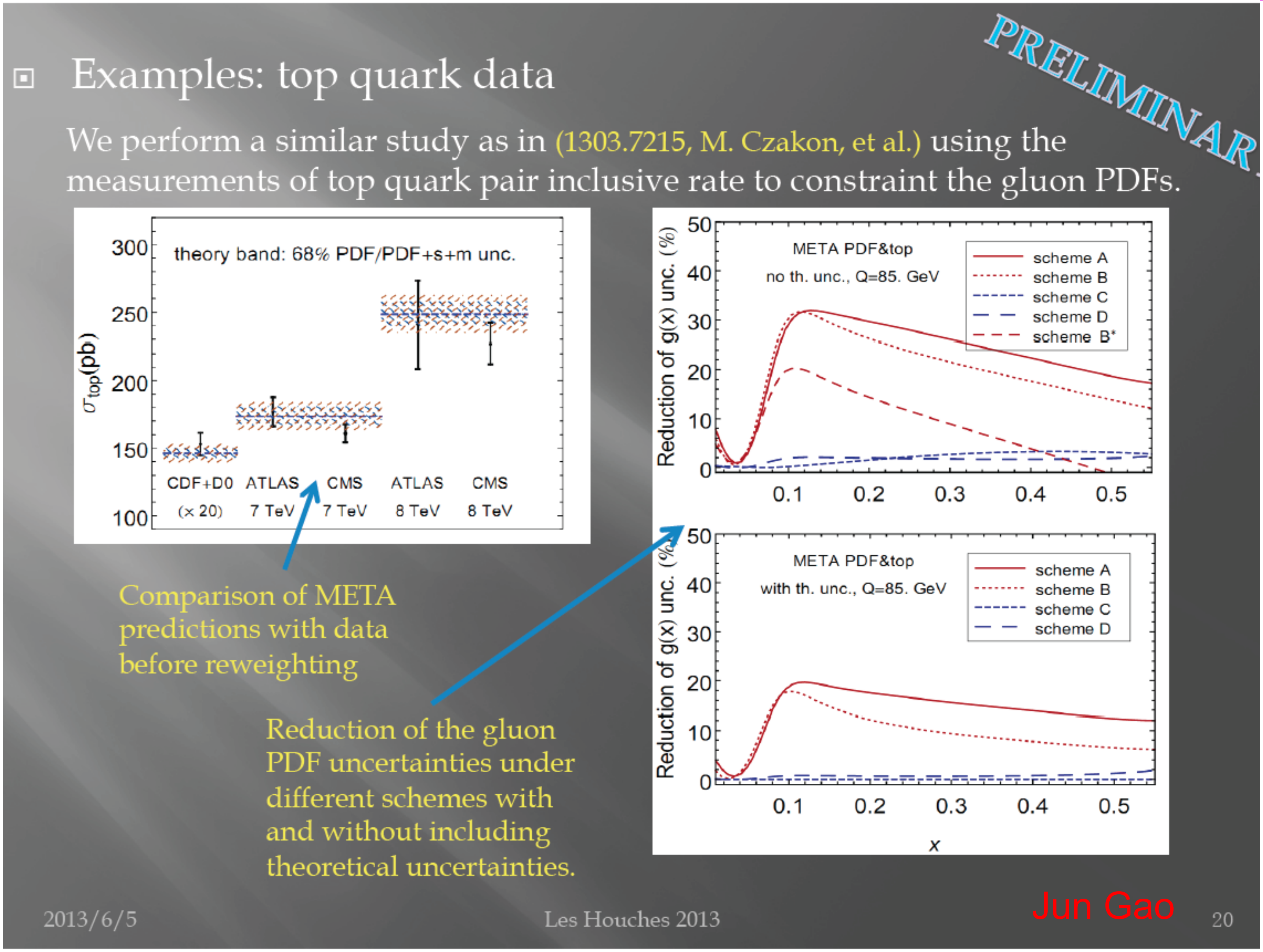
→ Scheme D: one variation of scheme A can be motivated by the CTEQ total χ^2 tolerance criterion. $\Delta\chi^2=100$ for 90%, translated to $\Delta\chi^2=h_0=37$ for 68%, and the weight function $\sim\exp[-\chi^2(N|f)/(2h_0)]$.

Scheme B: using the same weight $\sim\exp[-(\chi^2-(n-1)\ln\chi^2)/2]$ as NNPDF, but only keep up to the quadratic terms on x_i in the exponential, so we still get a Gaussian after reweighting.

Scheme B*: first generating 50,000 unweighted MC replicas based on the prior of META PDF, then reweight them using the exact NNPDF function form.

Scheme C: MSTW-like, here we fix the best-fit and eigenvector directions. The new PDF uncertainties are determined by the minimum of the original displacements and the newly allowed ones (according to MSTW dynamic tolerance) by data N in each of the directions.

Meta-PDFs



effect of tolerance on impact of new data in global fits needs to be better understood

CTEQ/MSTW may be different than NNPDF?

investigate for Les Houches Writeup

use-cases for META-PDFS or equivalent

Photon PDFs

THE WAY IT IS DONE (BY US)

NNPDF2.3 QED DIS-ONLY FIT
$N_{\mathrm{rep}} = 500$

↓

CONSTRUCTION OF NNPDF2.3 QEDPRIOR AT Q_0^2:

(A) QUARK AND GLUON PDFS FROM NNPDF2.3 GLOBAL
(B) PHOTON PDFS FROM NNPDF2.3 DIS-ONLY

↓

EVOLVE NNPDF2.3 QEDPRIOR UPWARDS FOR ALL Q^2
USE COMBINED QCD+QED DGLAP EQUATIONS

↓

COMPUTE HORACE+DYNNLO PREDICTIONS FOR
LHC W, Z PRODUCTION WITH NNPDF2.3 QEDPRIOR

REWEIGHT THE $N_{\mathrm{rep}} = 500$
REPLICAS WITH LHC W, Z DATA

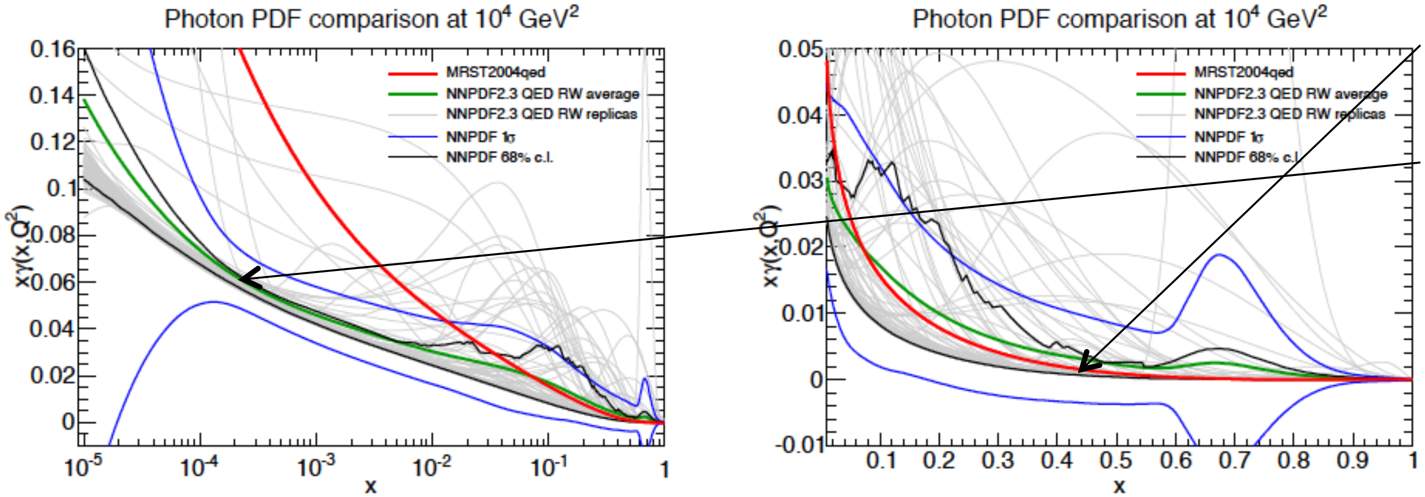
↓

CONSTRUCT THE FINAL NNPDF2.3 QED SET
BY UNWEIGHTED THE REWEIGHED
PDFS OF THE PREVIOUS STEP

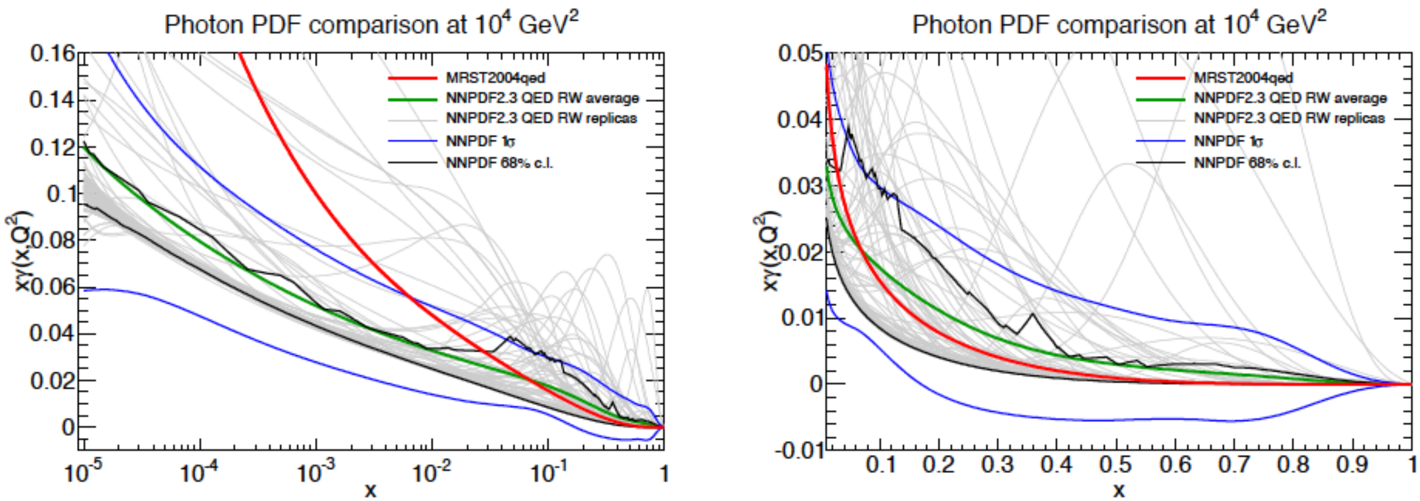
S. Forte and S. Carrazza

THE PHOTON PDF

NLO RESULTS



NNLO RESULTS



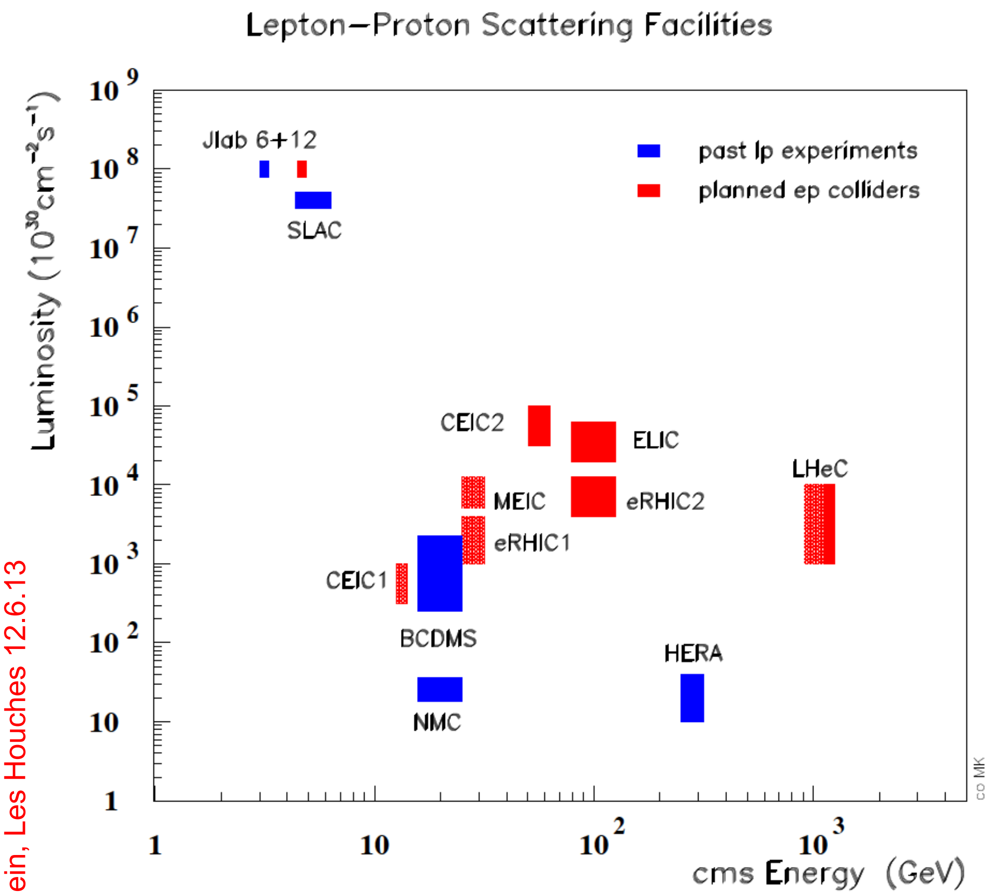
S. Forte and S. Carrazza

Result consistent with MRST2004 at high x, smaller at low x, with most of constraint coming from LHCb data

CT study in progress… maybe update of MRST2004? would like to improve understanding of γ PDFs for Les Houches writeup

Large Hadron Electron Collider - LHeC

Information on http://cern.ch/lhec



ep/A synchronous to pp/AA

- LHC is the only place for TeV energy DIS
- ~60 GeV electron beam upgrade to the LHC
- DIS at TeV energies: $Q^2_{max} 10^6$, $x > 10^{-6}$
- **A new Higgs facility** – new detector

Noteable:

- Unprecedent precision (α_s to per mille)
- Complete unfolding of PDFs (1st time)
- Precision electroweak measurements
- Novel precision input for LHC physics
- BSM (RPV SUSY, e*, CI, lq resonances?)
- Quark Gluon Plasma – initial formation

QCD

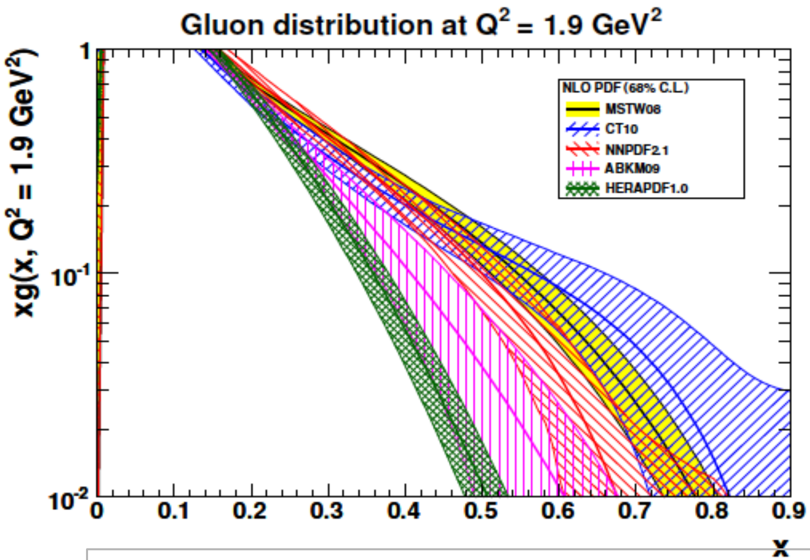
- Discovery/disproval of saturation at low x
- Less conventional partons (kt, diff., GPDs)
- Nuclear structure in huge kinematic range
- Top with 10pb cross section in DIS, tPDF

Max Klein, Les Houches 12.6.13

The LHeC is a new laboratory for energy frontier particle physics of unique character.

Ref's: CDR arXiv:1205:2913, summary: arXiv:1211.4831, relation to LHC: arXiv:1211:5102

LHeC – Partons and α_s

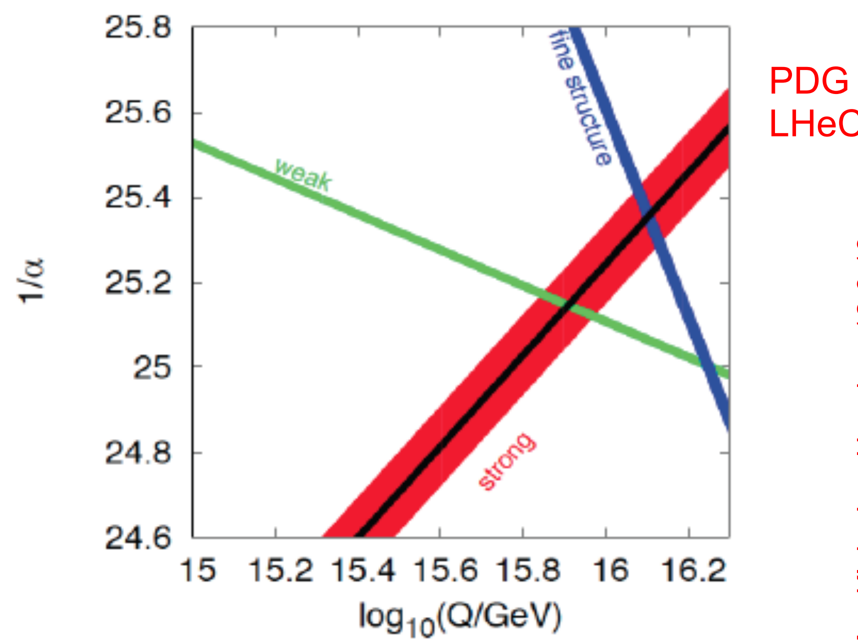


Per mille measurement accuracy
Testing QCD lattice calculations
α_s small in DIS or high with jets?
DIS without BCDMS..
Leads to unprecedented level of precision in all of DIS, e.g. charm mass to 3MeV; N^{3}LO
Constraining GUT (CMSSM40.2.5)

Gluon at large x > 0.5 unknown
LHeC: xg to 10% accuracy at x=0.7
Saturation, BFKL at low x?

Full set of PDFs in huge x,Q^2 range
uv,dv,dbar,ubar,s,sbar,c,b,top, xg
Important for HL LHC – high M, CI

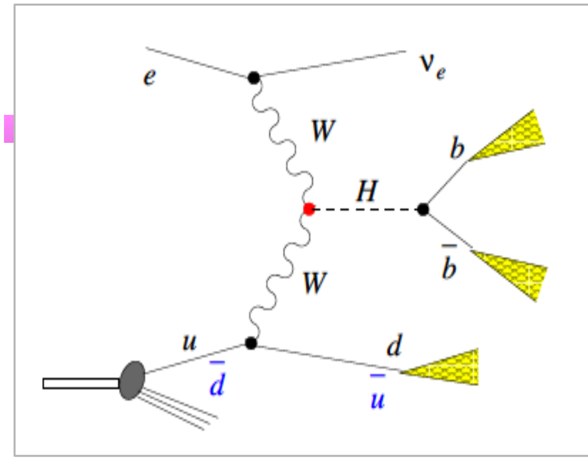
Partons from LHeC comprise:
unintegrated, diffractive, GPD
photon, neutron, nuclear



Max Klein, Les Houches 12.6.13

Ref's: CDR arXiv:1205:2913, summary: arXiv:1211.4831, relation to LHC: arXiv:1211:5102

Higgs with the LHeC



ZZ → H ~10 times lower rate

Unique production mechanism (WW,ZZ)
Clean experimental conditions:
No pileup, simpler final state …

LHeC at 10^34cm-1s-1: arXiv:1211:5102
Nb: Cross section and luminosity as large as are projected for the ILC. Access to difficult channels (ττ, cc – under study)

With its unique Higgs measurements and precision N^3LO PDFs and $\delta\alpha_s$,
ep upgrade transforms the LHC facility into a precision Higgs factory.
[cf arXiv:1211:5102 + OB, MK: arXiv:1305:2090]

LHeC Higgs		CC (e^-p)
Polarisation		-0.8
Luminosity [ab^{-1}]		1
Cross Section [fb]		196
Decay	BrFraction	N^H_{CC} e^-p
$H \to b\bar{b}$	0.577	113 100
$H \to c\bar{c}$	0.029	5 700
$H \to \tau^+\tau^-$	0.063	12 350
$H \to \mu\mu$	0.00022	50
$H \to 4l$	0.00013	30
$H \to 2l2\nu$	0.0106	2 080
$H \to gg$	0.086	16 850
$H \to WW$	0.215	42 100
$H \to ZZ$	0.0264	5 200
$H \to \gamma\gamma$	0.00228	450
$H \to Z\gamma$	0.00154	300

Rates for E_e=60 GeV, proportional to E_e
Initial study for CDR:
H →bbar: selection efficiency: ~2.5%
which gives 5000 events with S/B=1.
corresponding to 0.7% coupling precision.
[cf: CDR, U.Klein ICHEP12, B.Mellado LPCC]

NLO ME+PS

- There are several frameworks now, such as Sherpa, aMC@NLO, MINLO 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
  - hope to have Higgs+3 jets at NLO soon, e.g. from Gosam
- 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…with comparison to the well-known W+jets
- Covered in more detail in MC summaries, but on next slide are some details of a study being carried out
- See wiki

- Intended both for Les Houches and for Snowmass
  - note the higher energies
- Coordination needed with other (related) studies going on at Les Houches
- See wiki

Process: H+0,1jet and W+0,1jet inclusive

- cms energy: 7, 8, 14, 33 and 100 TeV (→why not do all energies for this as well?)
- PDFs: CT10
- R=0.6
- ptjet cuts: 7,8TeV: 30GeV; 14TeV: 40GeV; 33TeV: 40GeV,80GeV; 100TeV: 40GeV,160GeV
- |yjet| < 5

Observables:

- Jet veto effect (sigma_n-sigma_(n+1))/(sigma_n); sigma(n+1)/sigma(n)) versus ptmin of additional jets (on top of the n-jet requirement): 5 GeV bins from 0-100 GeV→using the constant 40(30) GeV cut, correct?
- pt of the leading jet (10 GeV bins from 30 to 100 GeV, 20 GeV bins from 100-500 GeV, 50 GeV bins from 500-1000 GeV, 100 GeV bins from 1000-2000 GeV,200 GeV bins from 2000-4000 GeV)
- pt of the second jet (same binning)
- pt of W: same binning as pt of the leading jet, except that 10 GeV bins from 0 to 100 GeV
- HT: scalar sum of pts of jets above the pt cut, lepton and missing ET: 50 GeV/c bins from 0-500 GeV/c, 100 GeV/c bins from 500-1000 GeV/c, 200 GeV/c bins from 1000-2000 GeV/c, 500 GeV/c bins from 2000-10000 GeV/c
- HTjet (ST): scalar sum of pts of jets above the pt cut

Process: H+2jet, W+2jet inclusive

- cms energy: 7, 8, 14, 33, 100 TeV
- PDFs: CT10
- R=0.6
- ptjet cuts: 7,8TeV: 30GeV; 14TeV: 40GeV; 33TeV: 40GeV,80GeV; 100TeV: 40GeV,160GeV
- |yjet| < 5

Observables:

- Deltay_FB: rapidity difference between most forward and backward jets: [0,12], bin size 0.5
- Average no. of jets per event versus Deltay_FB: [0,8], bin size 0.5
- Jet veto efficiency (sigma3-jet/sigma2-jet) versus Deltay_FB: [0,8], bin size 0.5
- Jet veto effect (sigma_n-sigma_(n+1))/(sigma_n); sigma(n+1)/sigma(n)) versus ptmin of additional jets (on top of the n-jet requirement): 5 GeV bins from 0-100 GeV→using the constant 40(30) GeV cut, correct?
- pt of the leading jet (10 GeV/c bins from 20 to 100 GeV/c, 20 GeV/c bins from 100-500 GeV/c, 50 GeV/c bins from 500-1000 GeV/c, 100 GeV/c bins from 1000-2000 GeV, 200 GeV from 2000-4000 GeV)
- pt of the second jet (same binning)
- pt of the W (same binning except 10 GeV bins from 0 to 100 GeV)
- HT: scalar sum of pts of jets above the pt cut, lepton and missing ET: 50 GeV/c bins from 0-500 GeV/c, 100 GeV/c bins from 500-1000 GeV/c, 200 GeV/c bins from 1000-2000 GeV/c, 500 GeV/c bins from 2000-10000 GeV/c
- HTjet (ST): scalar sum of pts of jets above the pt cut (same binning)

NNLO QCD+NLO EW wishlist

Process	known	desired	details
H	$d\sigma$ @ NNLO QCD $d\sigma$ @ NLO EW finite quark mass effects @ NLO	$d\sigma$ @ NNNLO QCD + NLO EW MC@NNLO finite quark mass effects @ NNLO	H branching ratios and couplings
$H+j$	$d\sigma$ @ NNLO QCD (g only) $d\sigma$ @ NLO EW finite quark mass effects @ LO	$d\sigma$ @ NNLO QCD + NLO EW finite quark mass effects @ NLO	H p_T
$H+2j$	σ_{tot}(VBF) @ NNLO(DIS) QCD $d\sigma$(gg) @ NLO QCD $d\sigma$(VBF) @ NLO EW	$d\sigma$ @ NNLO QCD + NLO EW	H couplings
$H+V$	$d\sigma$ @ NNLO QCD $d\sigma$ @ NLO EW	with $H \to b\bar{b}$ @ same accuracy	H couplings
$t\bar{t}H$	$d\sigma$(stable tops) @ NLO QCD	$d\sigma$(top decays) @ NLO QCD + NLO EW	top Yukawa coupling
HH	$d\sigma$ @ LO QCD (full m_t dependence) $d\sigma$ @ NLO QCD (infinite m_t limit)	$d\sigma$ @ NLO QCD (full m_t dependence) $d\sigma$ @ NNLO QCD (infinite m_t limit)	Higgs self coupling

Table 1: Wishlist part 1 – Higgs ($V = W, Z$)

add a column here for current exp precision and that expected at 14 TeV

N. Glover, S. Dittmaier

NNLO QCD + NLO EWK wishlist

Process	known	desired	details
$t\bar{t}$	σ_{tot} @ NNLO QCD $d\sigma$(top decays) @ NLO QCD $d\sigma$(stable tops) @ NLO EW	$d\sigma$(top decays) @ NNLO QCD + NLO EW	precision top/QCD, gluon PDF, effect of extra radiation at high rapidity, top asymmetries
$t\bar{t} + \text{j}$	$d\sigma$(NWA top decays) @ NLO QCD	$d\sigma$(NWA top decays) @ NNLO QCD + NLO EW	precision top/QCD top asymmetries
single-top	$d\sigma$(NWA top decays) @ NLO QCD	$d\sigma$(NWA top decays) @ NNLO QCD (t channel)	precision top/QCD, V_{tb}
dijet	$d\sigma$ @ NNLO QCD (g only) $d\sigma$ @ NLO weak	$d\sigma$ @ NNLO QCD + NLO EW	Obs.: incl. jets, dijet mass $\rightarrow$ PDF fits (gluon at high x) $\rightarrow \alpha_s$ CMS http://arxiv.org/abs/1212.6660
3j	$d\sigma$ @ NLO QCD	$d\sigma$ @ NNLO QCD + NLO EW	Obs.: $R3/2$ or similar $\rightarrow \alpha_s$ at high scales dom. uncertainty: scales CMS http://arxiv.org/abs/1304.7498
$\gamma + \text{j}$	$d\sigma$ @ NLO QCD $d\sigma$ @ NLO EW	$d\sigma$ @ NNLO QCD +NLO EW	gluon PDF $\gamma + \text{b}$ for bottom PDF

Table 2: Wishlist part 2 – jets and heay quarks

N. Glover, S. Dittmaier

NNLO QCD + NLO EWK wishlist

N. Glover,
S. Dittmaier

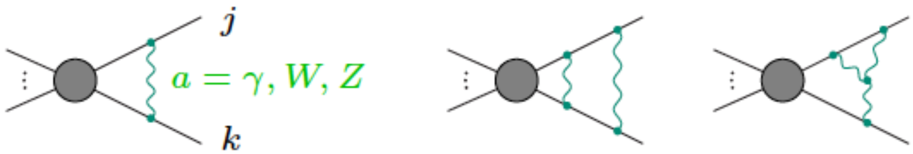
Process	known	desired	details
V	$d\sigma$(lept. V decay) @ NNLO QCD $d\sigma$(lept. V decay) @ NLO EW	$d\sigma$(lept. V decay) @ NNNLO QCD + NLO EW MC@NNLO	precision EW, PDFs
$\mathrm{V+j}$	$d\sigma$(lept. V decay) @ NLO QCD $d\sigma$(lept. V decay) @ NLO EW	$d\sigma$(lept. V decay) @ NNLO QCD + NLO EW	$\mathrm{Z+j}$ for gluon PDF $\mathrm{W+c}$ for strange PDF
$\mathrm{V+jj}$	$d\sigma$(lept. V decay) @ NLO QCD	$d\sigma$(lept. V decay) @ NNLO QCD + NLO EW	study of systematics of $\mathrm{H+jj}$ final state
$\mathrm{VV'}$	$d\sigma$(V decays) @ NLO QCD $d\sigma$(stable V) @ NLO EW	$d\sigma$(V decays) @ NNLO QCD + NLO EW	off-shell leptonic decays TGCs
$\mathrm{gg \to VV}$	$d\sigma$(V decays) @ LO QCD	$d\sigma$(V decays) @ NLO QCD	bkg. to $H \to VV$ TGCs
$\mathrm{V}\gamma$	$d\sigma$(V decay) @ NLO QCD $d\sigma$(PA, V decay) @ NLO EW	$d\sigma$(V decay) @ NNLO QCD + NLO EW	TGCs
$\mathrm{Vb\bar{b}}$	$d\sigma$(lept. V decay) @ NLO QCD massive b	$d\sigma$(lept. V decay) @ NNLO QCD massless b	bkg. for $\mathrm{VH \to b\bar{b}}$
$\mathrm{VV'}\gamma$	$d\sigma$(V decays) @ NLO QCD	$d\sigma$(V decays) @ NLO QCD + NLO EW	QGCs
$\mathrm{VV'V''}$	$d\sigma$(V decays) @ NLO QCD	$d\sigma$(V decays) @ NLO QCD + NLO EW	QGCs, EWSB
$\mathrm{VV'+j}$	$d\sigma$(V decays) @ NLO QCD	$d\sigma$(V decays) @ NLO QCD + NLO EW	bkg. to H, BSM searches
$\mathrm{VV'+jj}$	$d\sigma$(V decays) @ NLO QCD	$d\sigma$(V decays) @ NLO QCD + NLO EW	QGCs, EWSB
$\gamma\gamma$	$d\sigma$ @ NNLO QCD		bkg to $H \to \gamma\gamma$

Table 3: Wishlist part 3 – EW gauge bosons ($\mathrm{V = W, Z}$)

Electroweak Corrections

Electroweak radiative corrections at high energies

Sudakov logarithms induced by soft gauge-boson exchange



etc.

+ sub-leading logarithms from collinear singularities

Typical impact on $2 \longrightarrow 2$ reactions at $\sqrt{s} \sim 1\,\mathrm{TeV}$:

$$\delta_{\mathrm{LL}}^{1-\mathrm{loop}} \sim -\frac{\alpha}{\pi s_{\mathrm{W}}^2} \ln^2\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq -26\%, \qquad \delta_{\mathrm{NLL}}^{1-\mathrm{loop}} \sim +\frac{3\alpha}{\pi s_{\mathrm{W}}^2} \ln\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq 16\%$$

$$\delta_{\mathrm{LL}}^{2-\mathrm{loop}} \sim +\frac{\alpha^2}{2\pi^2 s_{\mathrm{W}}^4} \ln^4\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq 3.5\%, \qquad \delta_{\mathrm{NLL}}^{2-\mathrm{loop}} \sim -\frac{3\alpha^2}{\pi^2 s_{\mathrm{W}}^4} \ln^3\left(\frac{s}{M_{\mathrm{W}}^2}\right) \simeq -4.2\%$$

$\Rightarrow$ Corrections still relevant at 2-loop level

Note: differences to QED / QCD where Sudakov log's cancel

- massive gauge bosons W, Z can be reconstructed
  $\hookrightarrow$ no need to add "real W, Z radiation"
- non-Abelian charges of W, Z are "open" $\longrightarrow$ Bloch–Nordsieck theorem not applicable

Extensive theoretical studies at fixed perturbative (1-/2-loop) order and suggested resummations via evolution equations

Beccaria et al.; Beenakker, Werthenbach; Ciafaloni, Comelli; Denner, Pozzorini; Fadin et Hori et al.; Melles; Kühn et al., Denner et al. '0

S. Dittmaier

Electroweak Corrections

Electroweak radiative corrections at high energies (continued)

- NLO EW high-energy logs – an approximation for full NLO EW ?
  - – miss finite contributions of $\mathcal{O}(\alpha)$
  - – do not include photonic radiation effects
  - + very simple approximation in Sudakov regime:
    s and $|t|$ large for $2 \to 2$ $\Rightarrow$ large p_{T} !
  - – fail in non-Sudakov regime:
    e.g. s large, but $|t|$ NOT large for $2 \to 2$ $\Rightarrow$ e.g. large M_{ll} in Drell–Yan !
  - + generically included in ALPGEN Chiesa, Montagna, Piccinini et al. '13
- Real W and Z emission processes
  - ◇ cannot be fully separated from underlying process
    (e.g. hadronically decaying W/Z's in jet environment)
  - ◇ partially compensate negative EW corrections
    $\hookrightarrow$ strongly dependent on W/Z reconstruction / separation
  - ◇ can be included by multipurpose LO MC's for $\mathcal{O}(\alpha)$
    Note: 2-loop EW high-energy logs require WW/WZ/... emission
    and 1-loop W/Z emission counterparts !

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Electroweak Corrections

Electroweak radiative corrections at high energies (continued)

Example: Drell–Yan production

Neutral current: $\mathrm{pp} \to \mathrm{l}^+\mathrm{l}^-$ at $\sqrt{s} = 14\,\mathrm{TeV}$ (based on S.D./Huber arXiv:0911.2329)

$M_{\mathrm{ll}}/\mathrm{GeV}$	$50-\infty$	$100-\infty$	$200-\infty$	$500-\infty$	$1000-\infty$	$2000-\infty$
σ_0/pb	738.733(6)	32.7236(3)	1.48479(1)	0.0809420(6)	0.00679953(3)	0.000303744(1)
$\delta^{\mathrm{rec}}_{\mathrm{q\bar{q},phot}}/\%$	−1.81	−4.71	−2.92	−3.36	−4.24	−5.66
$\delta_{\mathrm{q\bar{q},weak}}/\%$	−0.71	−1.02	−0.14	−2.38	−5.87	−11.12
$\delta^{(1)}_{\mathrm{Sudakov}}/\%$	0.27	0.54	−1.43	−7.93	−15.52	−25.50
$\delta^{(2)}_{\mathrm{Sudakov}}/\%$	−0.00046	−0.0067	−0.035	0.23	1.14	3.38

no Sudakov domination!

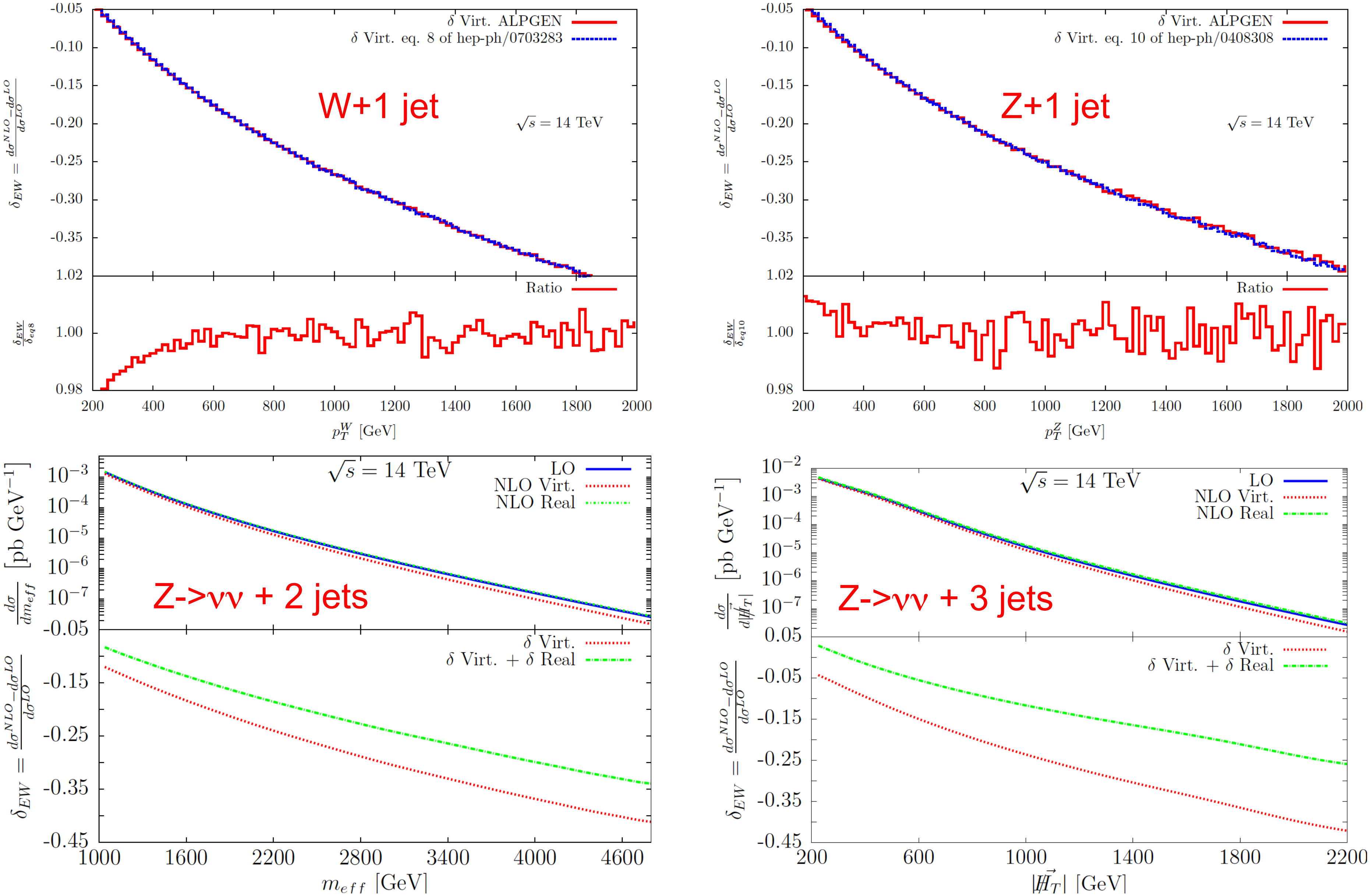
Charged current: $\mathrm{pp} \to \mathrm{l}^+\nu_{\mathrm{l}}$ at $\sqrt{s} = 14\,\mathrm{TeV}$ (based on Brensing et al. arXiv:0710.3309)

$M_{\mathrm{T},\nu_{\mathrm{l}}\mathrm{l}}/\mathrm{GeV}$	$50-\infty$	$100-\infty$	$200-\infty$	$500-\infty$	$1000-\infty$	$2000-\infty$
σ_0/pb	4495.7(2)	27.589(2)	1.7906(1)	0.084697(4)	0.0065222(4)	0.00027322(1)
$\delta^{\mu^+\nu_\mu}_{\mathrm{q\bar{q}}}/\%$	−2.9(1)	−5.2(1)	−8.1(1)	−14.8(1)	−22.6(1)	−33.2(1)
$\delta^{\mathrm{rec}}_{\mathrm{q\bar{q}}}/\%$	−1.8(1)	−3.5(1)	−6.5(1)	−12.7(1)	−20.0(1)	−29.6(1)
$\delta^{(1)}_{\mathrm{Sudakov}}/\%$	0.0005	0.5	−1.9	−9.5	−18.5	−29.7
$\delta^{(2)}_{\mathrm{Sudakov}}/\%$	−0.0002	−0.023	−0.082	0.21	1.3	3.8

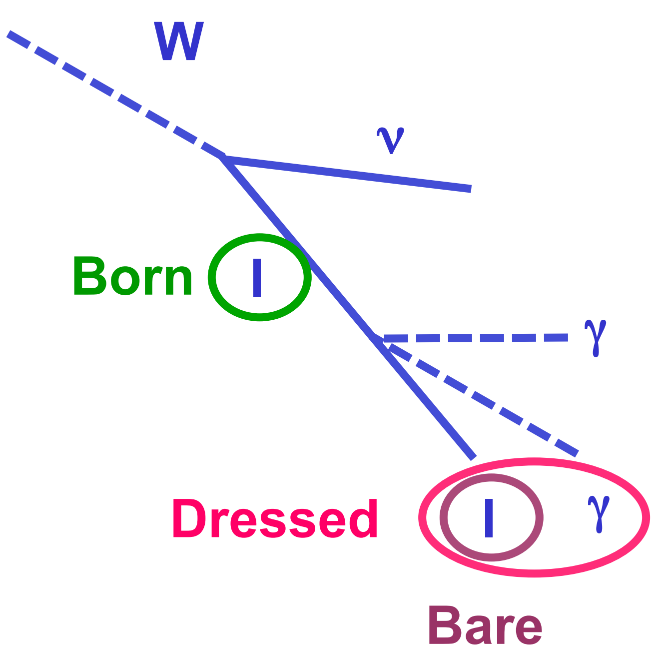
Sudakov domination!

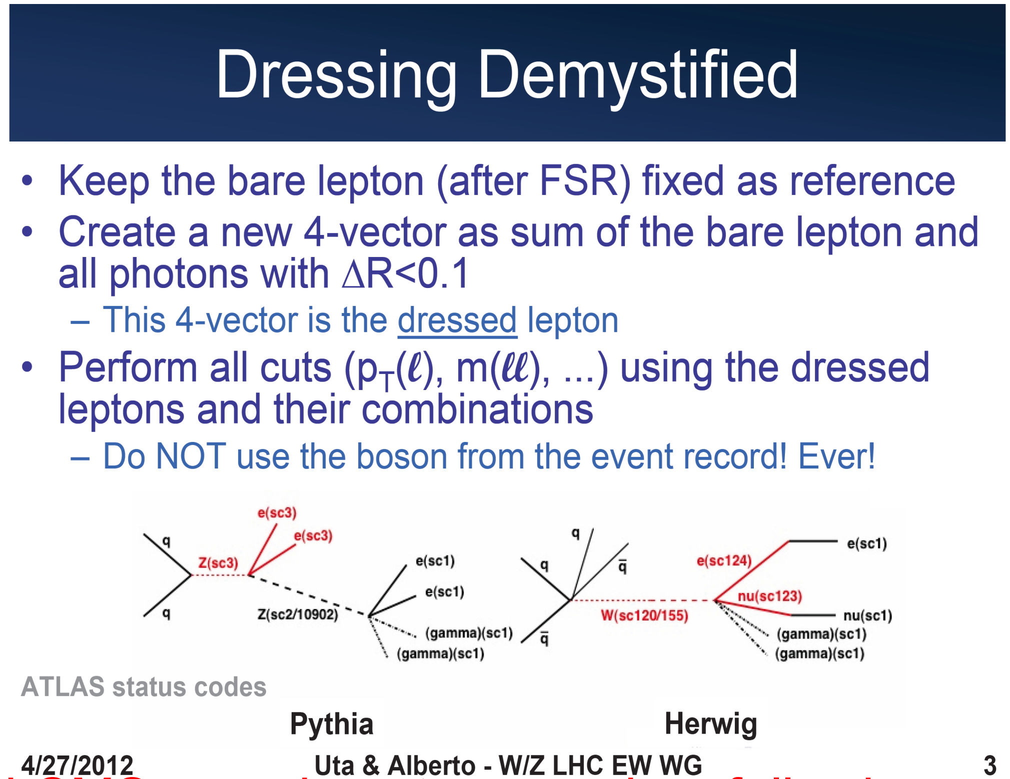
S. Dittmaier

M. Chiesa et al arXiv:1305.6837



Lepton Definitions – as agreed on in W,Z LPCC EW WG (CMS, ATLAS, Lhcb) in May 2012



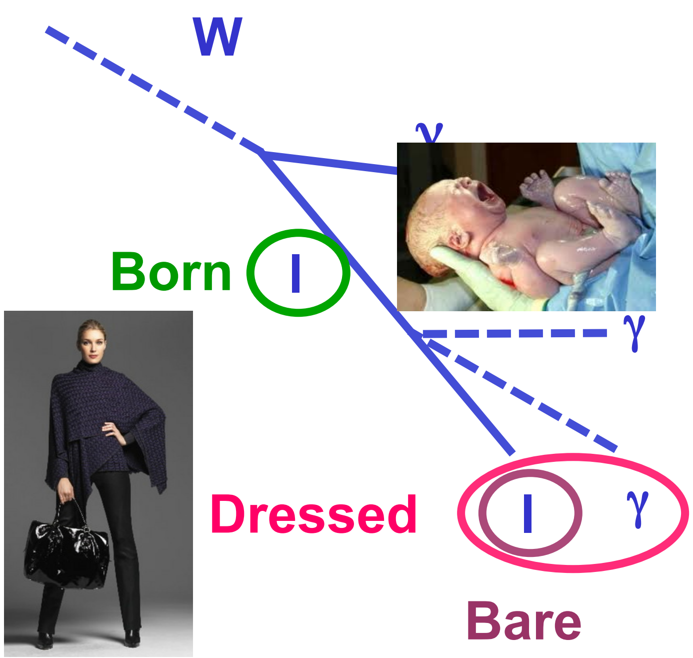


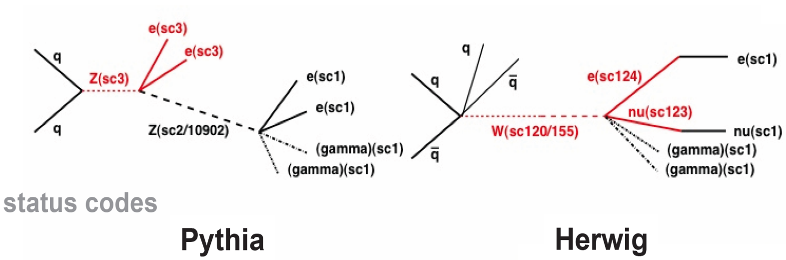
During series of meetings, Lhcb and CMS experiments agreed on following up ATLAS proposal of lepton definitions, in particular to add 'dressed' leptons ➔ presented at 22.5.2012 in the LPCC session https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=178469

Uta Klein

From slides by Atlas W,Z contacts Alberto Belloni & Uta Klein @ W,Z LPCC subgroup meeting 27.4.2012

Lepton Definitions – as agreed on in W,Z LPCC EW WG (CMS, ATLAS, Lhcb) in May 2012





Dressing Demystified

- Keep the bare lepton (after FSR) fixed as reference
- Create a new 4-vector as sum of the bare lepton and all photons with ΔR<0.1
  - This 4-vector is the <u>dressed</u> lepton
- Perform all cuts ($p_T(\ell)$, $m(\ell\ell)$, ...) using the dressed leptons and their combinations
  - Do NOT use the boson from the event record! Ever!

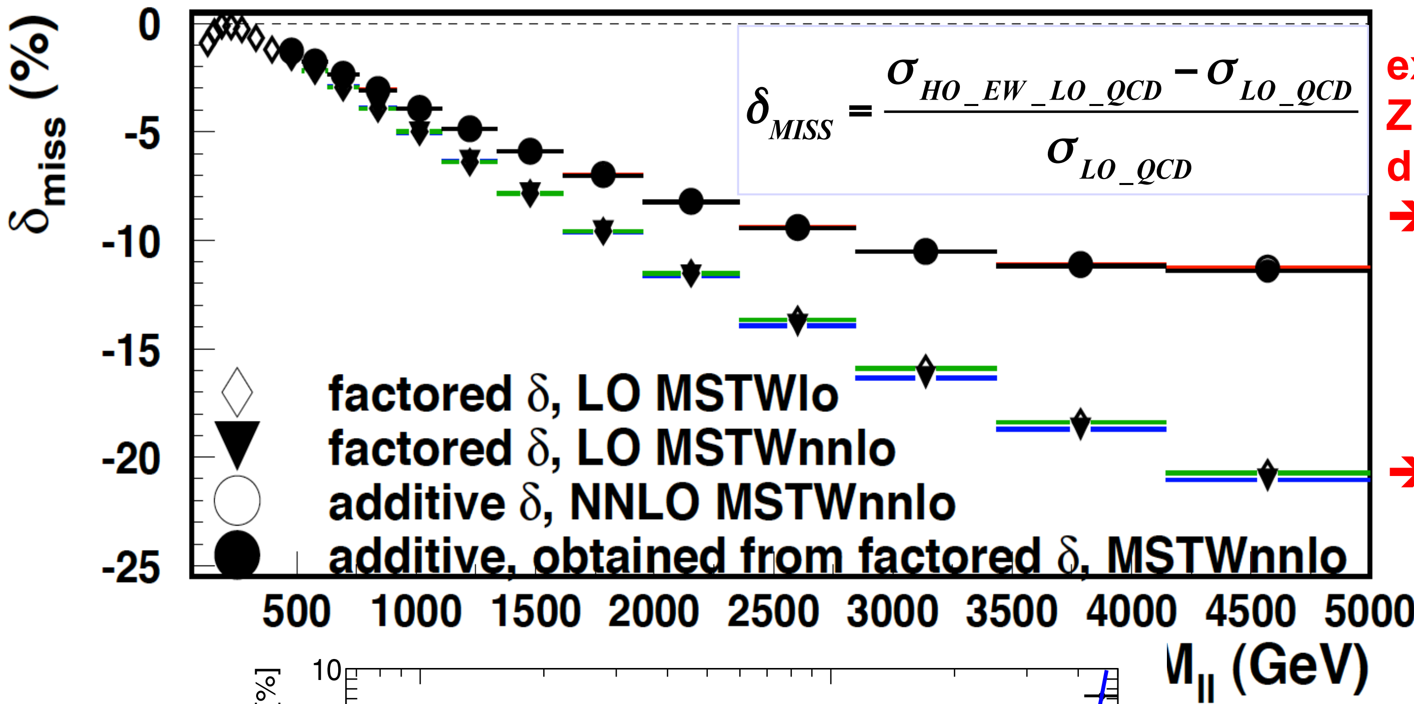
4/27/2012 Uta & Alberto - W/Z LHC EW WG 3

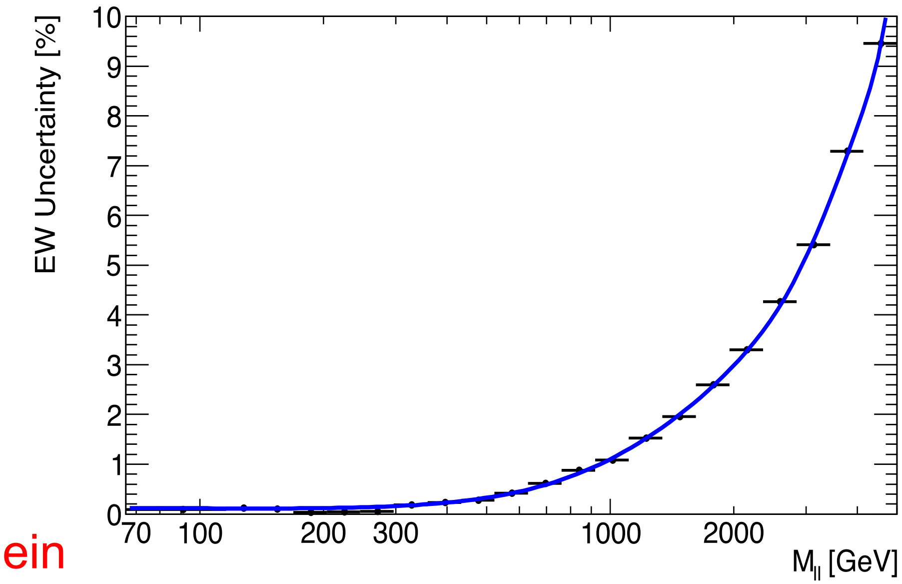
During series of meetings, Lhcb and CMS experiments agreed on following up ATLAS proposal of lepton definitions, in particular to add 'dressed' leptons ➔ presented at 22.5.2012 in the LPCC session https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=178469

Uta Klein

From slides by Atlas W,Z contacts Alberto Belloni & Uta Klein @ W,Z LPCC subgroup meeting 27.4.2012

Issue : Application of HO EW corrections





example: for 8 TeV Z' searches, NC DY dominant background

- ➔ **lepton defined on QED FSR corrected level (NO HO EW corrections for Z' signals!!)**
- ➔ **HO EW corrections of NC DY background have large uncertainty due to method of application**
- ➔ **under discussion with theorists**
- ➔ **Current ATLAS procedure : choose black dots as nominal values and apply symmetric uncertainty which is up to 9% at 4.5 TeV**

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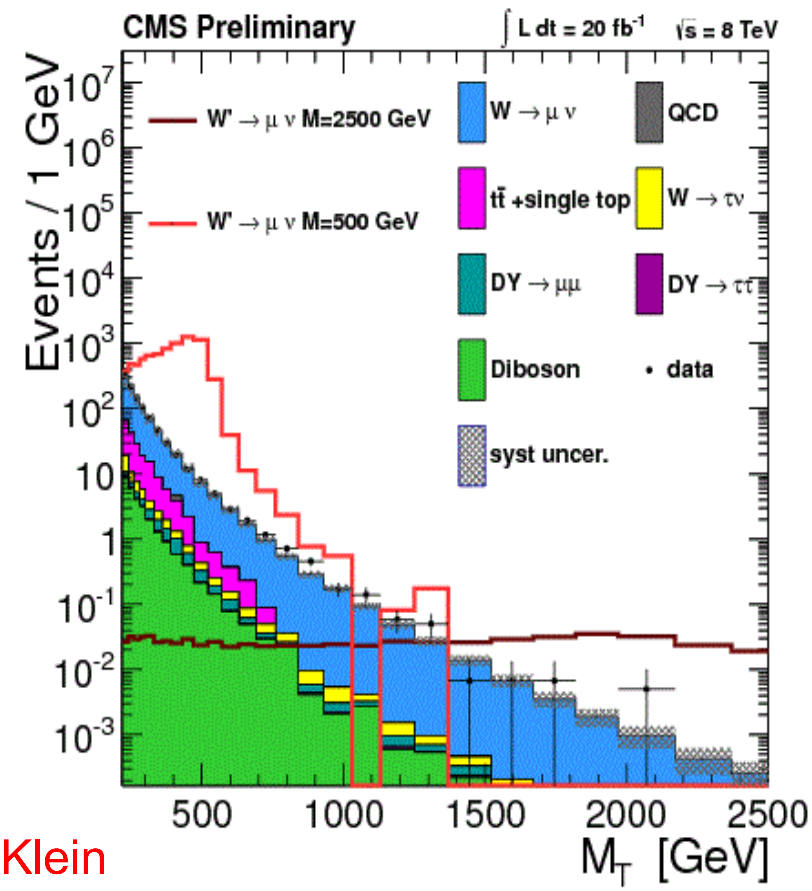
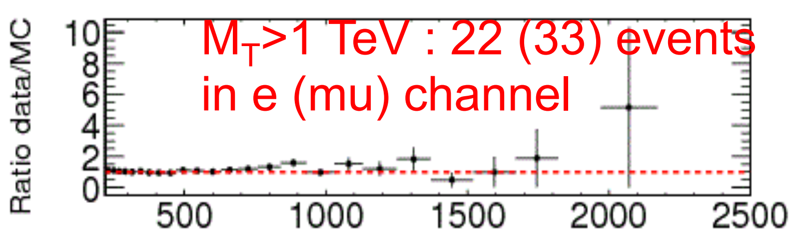
Searches at 8 TeV – consistency of systematic uncertainties?

20 fb^{-1}

W': CMS-PAS-EXO-12-060





M_T>1 TeV : 22 (33) events in e (mu) channel

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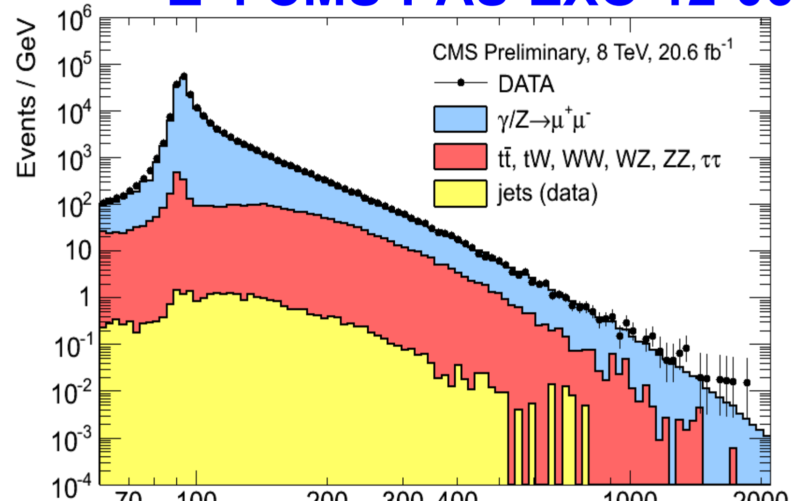
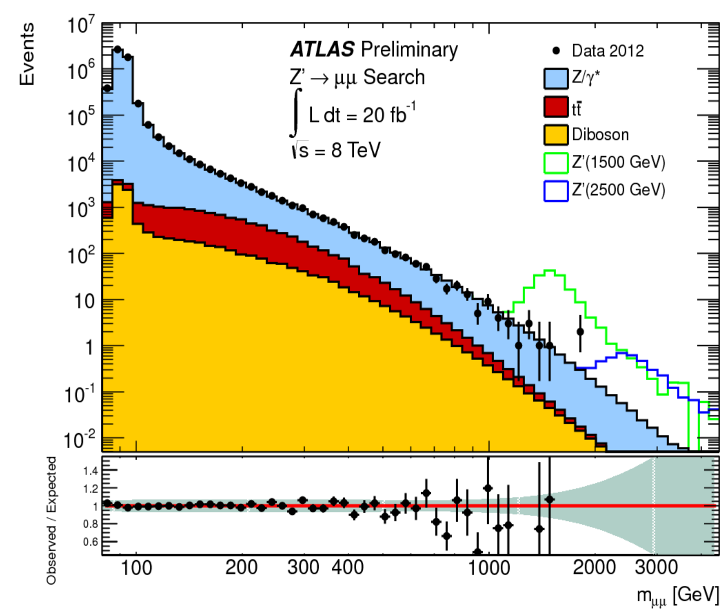
Z' : CMS-PAS-EXO-12-061



Z' : ATLAS-CONF-2013-017



shaded band: mass-dep. bgd. syst.

NC & CC DY : A wish list for discussion & studies

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

- ➔ "optimal" choice and documentation of EW parameters and SM inputs for *matched* QCD and EW calculations to be used by theorists and experimentalists → task for Les Houches ? or LPCC? or both?
- ➔ improved communication between Les Houches and LPCC activities!
- ❖ Precision evaluation of missing HO EW (ISR, interferences, weak) corrections and QED FSR modelling; application of missing HO EW corrections and remaining systematics
- ❖ Improved modelling of p_T(W,Z) : implementation of resummation into NLO MC models (but e.g also control of resummation scale)

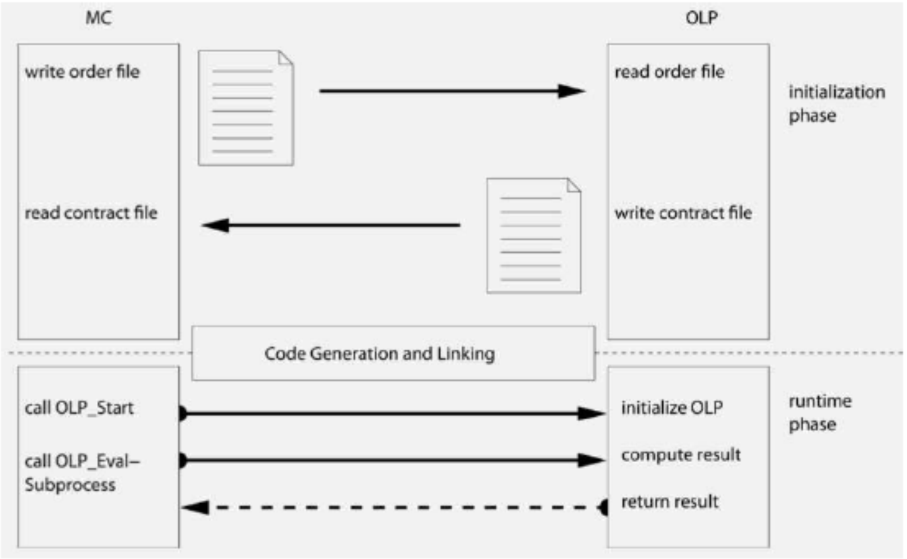
➔ missing HO EW corrections (+systematic uncertainties) for more complex kinematic variables like phi*(Z), M_T(W), W polarisation ➔ crucial W mass measurement precision!

- ❖ Improved modelling and uncertainties 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

Uta Klein

Binoth Les Houches Accord (BLHA) version 2

Standard interface between one-loop programs (OLPs) and Monte Carlos (MCs)



idea:

- MCs can import virtual corrections where available
- OLPs can team up with different MCs

Gudrun’s task

Binoth Les Houches Accord (BLHA) version 2

main new features:

- new function `OLP_SetParameter` allows to pass (dynamical) parameters in a flexible way
- outcome of OLP internal precision test is transmitted to MC
- settings can be different for individual subprocesses
  $\rightarrow$ important for merged samples with different jet multiplicities, mixed QCD/EW corrections, ...
- keyword `Extra` allows to set OLP specific parameters
- open to extensions concerning spin/colour correlated matrix elements
- flexibility in view of different EW schemes

Examples of new order/contract files: NJet

order file

```
# order for pp->2j loop and pp->3j tree
InterfaceVersion            BLHA2
Model                       SMdiag
CorrectionType              QCD
IRregularisation            CDR
AlphaPower                  0
AlphasPower                 2
AmplitudeType               Loop

# optional OLP-specific parameters
Extra Precision             1e-5
Extra NJetMultiPrec         1

# process list 2j
1 -1 -> 21 21
21 21 -> 21 21

AlphasPower                 3
AmplitudeType               Tree

# process list 3j
1 -1 -> 21 21 21
21 21 -> 21 21 21
```

contract file

```
# order for pp->2j loop and pp->3j tree
# Generated file. Do not edit by hand.
# Signed by NJet 1901099545.
# 12 1 1e-05 0.01 0 1 1 1 1 0 3 5
InterfaceVersion BLHA2 | OK
Model SMdiag | OK
CorrectionType QCD | OK
IRregularisation CDR | OK
AlphaPower 0 | OK
AlphasPower 2 | OK
AmplitudeType Loop | OK
# optional OLP-specific parameters
Extra Precision 1e-5 | OK
Extra NJetMultiPrec 1 | OK
# process list 2j
1 -1 -> 21 21 | 1 1 # 41 2 4 9 0 (-1 -2 3 4)
21 21 -> 21 21 | 1 2 # 40 2 4 64 0 (-2 -1 3 4)
AlphasPower 3 | OK
AmplitudeType Tree | OK
# process list 3j
1 -1 -> 21 21 21 | 1 3 # 51 6 4 9 1 (-1 -2 3 4 5)
21 21 -> 21 21 21 | 1 4 # 50 6 4 64 1 (-2 -1 3 4 5)
```

$pp \to 2j$ (loop) and $pp \to 3j$ (tree)

S. Badger, V. Yundin

Examples of new order/contract files: GoSam

order file

```
# OLE_order.lh
InterfaceVersion        BLHA2
Model                   SMdiag
CorrectionType          QCD
IRregularisation        DRED
AlphaPower              2
Extra Precision         0.0001
AlphasPower             0
# process list
1 -2 -> 11 -12
-2 1 -> 11 -12
AlphasPower             1
# process list
1 -2 -> 11 -12 21
21 1 -> 11 -12 2
21 -2 -> 11 -12 -1
1 21 -> 11 -12 2
-2 1 -> 11 -12 21
-2 21 -> 11 -12 -1
```

contract file

```
# vim: syntax=olp
#@OLP GOLEM 1.0
#@IgnoreUnknown True
#@IgnoreCase False
#@SyntaxExtensions
InterfaceVersion BLHA2 | OK
Model SMdiag | OK # Ignored by OLP
CorrectionType QCD | OK
IRregularisation DRED | OK
AlphaPower 2 | OK
Extra Precision 0.0001 | OK
AlphasPower 0 | OK
1 -2 -> 11 -12 | 1 0
-2 1 -> 11 -12 | 1 1
AlphasPower 1 | OK
1 -2 -> 11 -12 21 | 1 2
21 1 -> 11 -12 2 | 1 3
21 -2 -> 11 -12 -1 | 1 4
1 21 -> 11 -12 2 | 1 5
-2 1 -> 11 -12 21 | 1 6
-2 21 -> 11 -12 -1 | 1 7
```

$$pp \to W + 0, 1\,\text{jet (loop)}$$

J.F. Graf von Soden-Fraunhofen, G. Luisoni, G. Heinrich

NJET activities at LH13

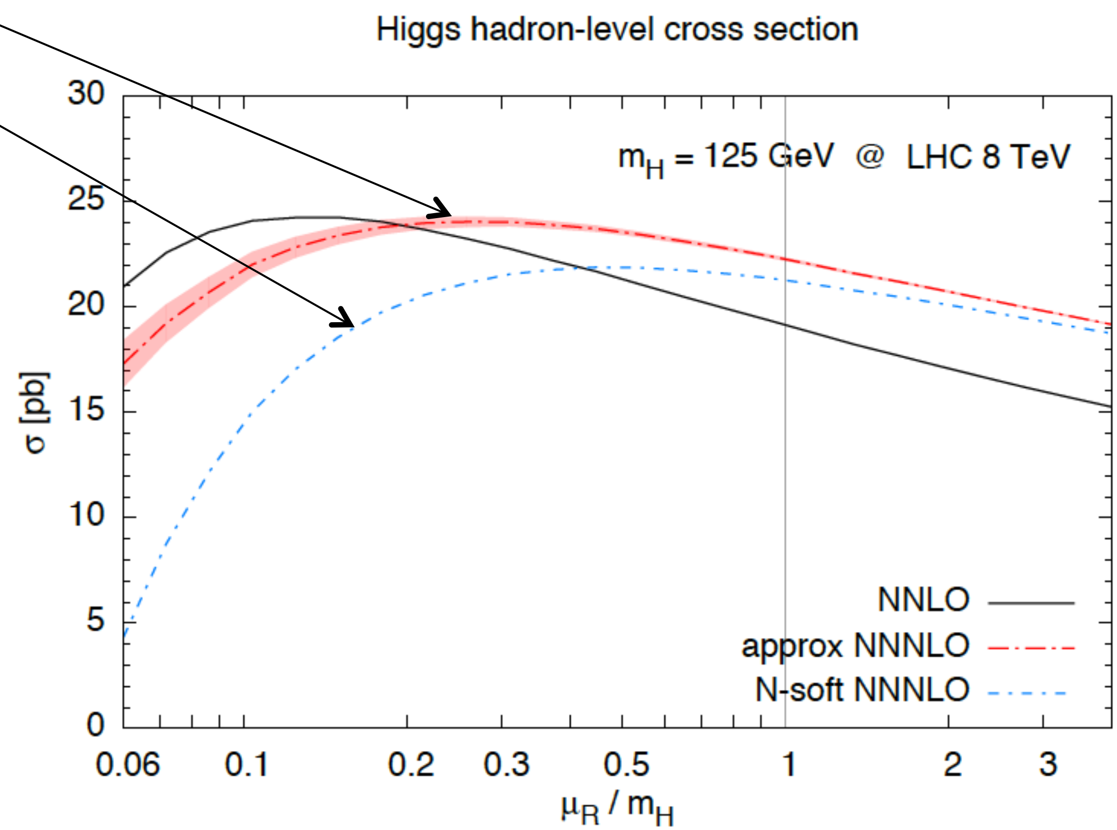
- Implementation of BLHA accord version 2
- Interface with Herwig++ with Simon Plätzer
  - Passing colour/spin correlated ME via BLHA
  - Direct comparisons to NLOJET++
  - Parton shower matching
- Interfacing NJET to Sherpa for NLO multi-jets
  - Step-by-step guide on the wiki

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



Scale dependence at N3LO

- Scale dependence estimated at N3LO
- Depends on (uncalculated) value of K
- Guess reasonable value of K may be 20-30
- Effective value from previous slide ~25
- We would be unhappy if it were 0 or 40
- Will not know until full calculation is complete: 1-2 years

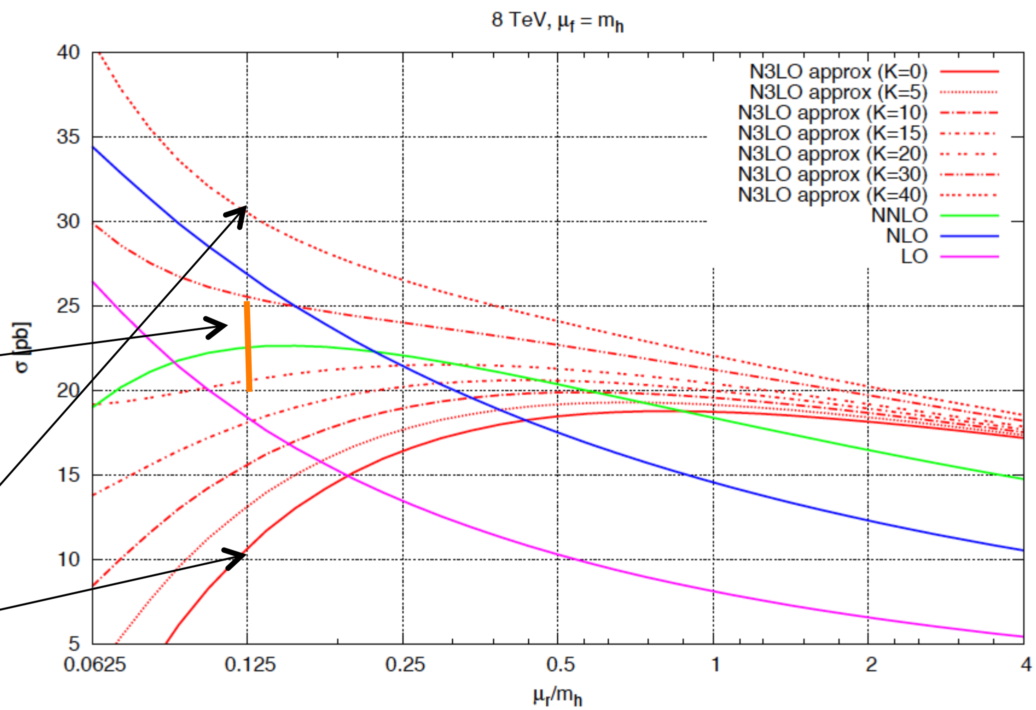


Figure 1: Scale variation of the different orders of the gluon fusion cross section at 8 TeV. μ_f is fixed to m_h and only μ_r is varied. The scaling coefficient K is varied from 0 to 40 to estimate the impact of the unknown N^3LO contributions.

A Lazapolous, S. Buehler
arXiv:1306.2223

Something to think about when calculating at N3LO+NNLO EWK

Results: Proton – Pb^{82+} calibration at 3.5/4 Z TeV

- The p-Pb ramp performed in October 2011 was used to estimate the momentum at 3.5 Z TeV.
- The p-Pb physics fill of 2012 was used to make the same estimate for 4 Z TeV.
- In both cases the accuracy is limited by the knowledge of the central frequency.
  - Estimated uncertainty on the difference: ±4 Hz
  - The error can be improved in 2013 using both p-Pb and Pb-p data. Can be obtained largely parasitically.

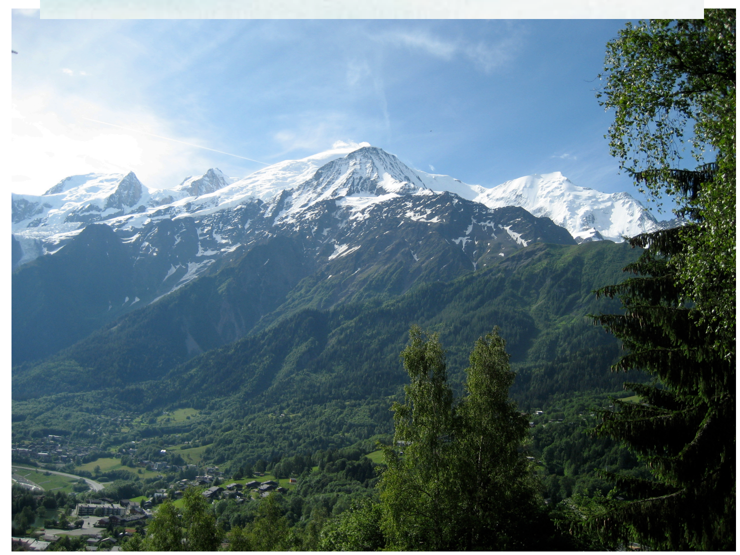
Run	Δf (Hz)	P (TeV/c)
2011	78.0	3.47 ± 0.10
2012	61.3	3.92 ± 0.13

→ hopefully, this is a gross over-estimate but our 8 TeV data may really be 8.1 TeV data or 7.58 TeV data

The future looks bright

- Les Houches (in situ) has been very productive
- As usual, the close environment has meant that it has been a very good breeding ground for both ideas and cold germs (the infamous Les Houches A'cold)
- The trick is to continue this flood of enthusiasm until the studies are finished and published
- So the conveners will be bugging everyone
- …and Fawzi will be bugging the conveners
- …and we can meet back here in 2015 and start to see how our predictions are starting to agree/disagree with the `14 TeV' data
- …and if 2d) (impact of NNLO jet calculations on PDFs) happens in the next 6 months, we may be able to fit it into the NLM writeup

pay your bar tab before then



…and finally

Dear 2nd session:
SM
RULES
DO NOT
ERASE
« amicaly, »
1st session
NLO
2-4
2-5