Summary of Brookhaven Workshop "Higgs Cross Sections for the LHC"

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LHC Higgs Cross Section Working Group

Joint effort of ATLAS + CMS + LHCb + Theory

- 4 overall contacts (ATLAS + CMS + 2$\times$Theory)
- 10 subgroups on production modes and common issues
- 6 “orthogonal” subgroups on decay channels (since 2011)
- ex-officio contact people from experiments (Higgs / MC conveners)

Goals

- Cross-section predictions + related theory issues / uncertainties
- Provide inputs / prescriptions / recommendations for analyses and the LHC Higgs Combination Group

2010: CERN Yellow Report with focus on total cross sections

Updates at

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

Agenda for 2011

Second Yellow CERN Report (YR2) [S. Dittmaier]

"Handbook of Higgs XS: 2. Differential Distributions"

- General: recipes to assess theory uncertainties (THU) and parameter uncertainties (PU) for distributions
- results on production channels ggF, VBF, WH/ZH, ttH: distributions with THU+PU
- BRs: THU+PU
- MSSM: general recipes / results for specific scenario(s) for cross section and distributions with THU+PU
- PO: heavy Higgs mass / width, signal-background interference
- NLO-MC: tools and error estimates for $\sigma \times \varepsilon$
- specific topics: jet veto, more ?

Main goals of the BNL workshop

- Discussion of current issues – preparation for summer conferences
- Communication between LHC and Tevatron Higgs groups

Some of the theory-related issues that were discussed

- NLO-MC: towards systematic uncertainties / comparison of different tools
- PDF: updates, uncertainties, plans
- Parametric uncertainties in branching ratios
- Cuts and distributions: QCD (and EW) corrections, jet vetoes

Step I: Fixed order

[F. Krauss]

- MC tools: Powheg-Box, Sherpa, Herwig++
  (if volunteers are found)
- FO tools: HNNLO, HqT (no resum?), MCFM
- Settings:
  - Two Higgs masses: 130 & 160 GeV
  - Jets: Anti-kt with pTmin = 30 GeV, R = 0.4, 0.5, 0.6
  - MSTW2008NNLO for HNNLO, HqT (NNPDF NNLO?)
  - PDF4LHC recommendation for NLO (envelope of MSTW, CT10, NNPDF)
  - Typical scale variation (factor 2), document default choices & cross-check where possible
  - 3 error bands: PDFs and scales alone and both combined
- Observables:
  - σ_{tot}, y^H, p_T^H, H_T, p_T^{jet}, η^{jet}, $\Delta y_{H,jet}$, $p_T^{leptons}$, $\eta^{leptons}$, $\Delta R_{leptons}$, E_T^{miss}, $\Delta\Phi_{(lepton\ planes)}$
  - F. Siegert has produced a Rivet analysis for the MC codes to feed in.

→ Essentially a debugging of the matrix-element implementations

Pilot Project for Systematic Uncertainties in NLO MCs

Step II: After showering

[F. Krauss]

- MC tools: MC@NLO, Powheg-Box, Sherpa, HW++
  (if volunteers are found)
- FO tools: HqT with resummation
- Settings: as in fixed order, but: shower settings?
  - for Powheg-Box (Pythia, Herwig, or both?),
  - MC@NLO (F. Stoeckli has volunteered to run both HW and HW+)
  - vary scale choices in shower (possible in Sherpa)
  - offers possibility to check influence of differing PDFs/alphaS in ME/PS
  - tricky one: Pythia authors unhappy with UE switched off …
  - another tricky one: impact of Pythia tunes.
- Here it becomes a bit harder to see how we can be systematic about systematics.
- Add a few observables: jet veto probability, also: Njets, jet correlations, …
  (Rivet analysis exists, so should not be a problem for the MCs –
  add beam-thrust? Any help from the proponents in implementation?)

→ This is where things get interesting

Step III: After hadronisation/UE

[F. Krauss]

- Same MC tools.
- Basic idea: quantify impact of non-perturbative stuff.
- Can run Sherpa with two hadronisations, and switch on and off its UE (Pythia not so happy about it);
- Can run Powheg-box with different Pythia tunes .... or with Herwig +- Jimmy.

- I expect that this doesn't change picture drastically,
  but it is better to check.

→ By far the least systematic and (in my mind) still the least understood

Recent Progress and Plans from PDF Fits

PROGRESSS
SINCE LAST WG MEETING

[S. Forte]

- NNPDF2.0 → NNPDF2.1
  - INCLUSION OF HQ MASSES (FONLL-A)
  - F_2^c DATA INCLUDED
- CTEQ6.6 → CT10
  - IMPROVED STATISTICS (SIMILAR TO DYNAMICAL TOLERANCE)
  - MORE FLEXIBLE d_v, GLUON, STRANGENESS (BUT STILL $s = \bar{s}$)
  - COMBINED HERA DATA, RUN II JETS, W ASYM, Z RAPIDITY DISTN.

ANNOUNCED AND/OR PRESENTED IN PRELIMINARY FORM
(BUT NOT YET ON LHAPDF)

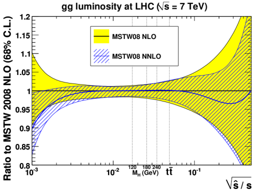
- CTEQ: NNLO
- NNPDF: NNLO (& LO) (2.1); INCLUSION OF LHC W ASYM DATA (2.2)
- HERAPDF: NNLO (1.0); INCLUSION OF HERAII AND HERA JET DATA (1.5)
- ABKM: INCLUSION OF JET DATA

NNLO STATUS

[S. Forte]

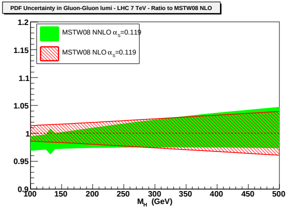
GLUON-GLUON PARTON LUMINOSITY

MSTW NNLO/NLO
best fit α_s



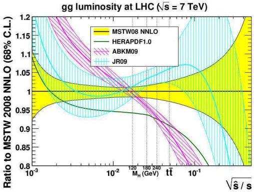
(G. Watt, 2011)

MSTW NNLO/NLO
fixed α_s



(J. Rojo, 2011)

LESS GLOBAL VS MSTW



(G. Watt, 2011)

- NLO VS NNLO MSTW LUMINOSITIES QUITE CLOSE
  ... BUT PARTLY DUE TO LOWER NNLO α_s (0.117 VS 0.120)
- DIFFERENCES AS DATASED VARIED MUCH LARGER
  ... BUT IN SOME CASE ALSO α_s QUITE DIFFERENT (ABKM: 0.113)

Preliminary NNPDF at NNLO

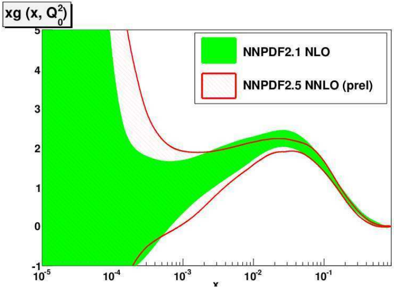
NNLO PROGRESS

[S. Forte]

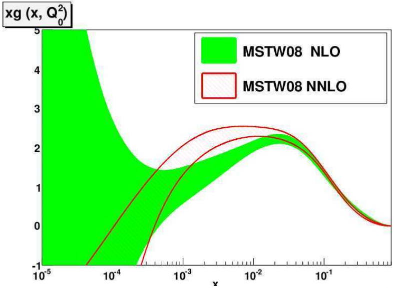
- CTEQ NNLO IN PREPARATION
- NNPDF NNLO PRESENTED IN PRELIM. FORM (DIS ONLY AT NNLO, FULL NNLO IN PREPARATION)
  - GLUON SIMILAR TO MSTW, BUT NO SMALL x INSTABILITY
  -

GLUON PDF: NLO VS NNLO

NNPDF



MSTW



Preliminary NNPDF at NNLO

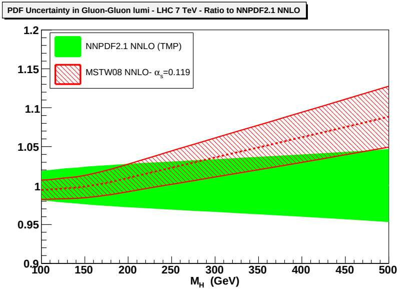
NNLO PROGRESS

[S. Forte]

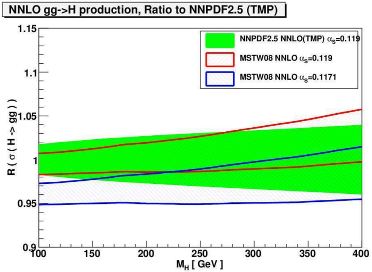
- CTEQ NNLO IN PREPARATION
- NNPDF NNLO PRESENTED IN PRELIM. FORM (DIS ONLY AT NNLO, FULL NNLO IN PREPARATION)
  - GLUON SIMILAR TO MSTW, BUT NO SMALL x INSTABILITY
  - LUMINOSITY & HIGGS XSECT QUITE CLOSE TO MSTW
    ... PROVIDED SAME α_s USED

GLUON LUMI & HIGGS XSECT: NNPDF VS MSTW

GLUON LUMI



HIGGS XSECT.



THE VALUE OF α_s

[S. Forte]

- DEDICATED MUNICH MEETING (FEB 2011):
  S. BETHKE PROPOSES TWO UPDATED VALUES:
  - (1) $\alpha_s = 0.1174 \pm 0.0011$
  - (2) $\alpha_s = 0.1187 \pm 0.0006$
  - BOTH INCLUDE NEW VALUE FROM τ DECAYS $\alpha_s = 0.1213 \pm 0.0014$ (WAS $\alpha_s = 0.1197 \pm 0.0016$)
  - VALUE (1) ALSO INCLUDES NEW SCET VALUE FROM e^+e^- THRUST (Abbate et al., 2010) $\alpha_s = 0.1135 \pm 0.0010$, BUT ALL UNCERTAINTIES RESCALED BY FACTOR 2
  - VALUE (2) EXCLUDES IT
- AVERAGING THE TWO MOST RELIABLE VALUES (GLOBAL EW FIT & τ, BOTH N^3LO, NO DEP. ON HADRON STRUCTURE) GIVES $\alpha_s = 0.1209 \pm 0.0013$

$\longrightarrow$ I would consider SCET thrust fits more reliable than τ decays ...

Parametric Uncertainty Estimation Baselines

[D. Rebuzzi]

- Parametric uncertainties estimated by changing *separately*, while leaving all others at their central values, each of the following relevant parameters: α_S, m_b, m_c, m_t

Parameter	Central Value	Uncertainty
α_S	0.119	$\pm$ 0.002 (90% CL)
m_b [GeV]	4.49 (*)	$\pm$ 0.03 (2σ) (**)
m_c [GeV]	1.41 (*)	$\pm$ 0.03 (2σ) (**)
m_t [GeV]	172.5	$\pm$ 2.5

(*) one-loop pole mass, from our TWiki

(**) errors from Ref. arXiv:0907.2110

- **Comments**:
  - One-loop pole masses (differently from MSbar masses) accidentally show negligible dependence on α_S, so that their variation can be independent from α_S (***)
  - Uncertainty on *b*- and *c*-masses taken from the indicated reference (PDG uncertainties are *way larger*: $m_b^{MSbar} = 4.19 + 0.18 - 0.06$ GeV, $m_c^{MSbar} = 1.27 + 0.07 - 0.09$ GeV)
  - Dependency of the EW NLO corrections to $H \to \gamma\gamma$ and $H \to gg$ on m_t accounted for automatically in HDECAY - all the other parametric uncertainties of the EW corrections are negligible

(***) Similar procedure followed in A. Djouadi, M. Spira, P.M. Zerwas hep-ph/9511344

Higgs Branching Ratios

Comparison with arXiv:1012.0530v3

[D. Rebuzzi]

- Parameter choice:

Parameter	LHC BR Group	arXiv:1012.0530v3
$\alpha_S(M_Z)$	0.119 ± 0.002 (90% CL)	0.1171 ± 0.0014 (68% CL)
m_b [GeV]	4.49 ± 0.03 (2σ) (*)	$4.419^{+0.18}_{-0.06}$ (**)
m_c [GeV]	1.41 ± 0.03 (2σ) (*)	$1.27^{+0.07}_{-0.09}$ (**)
m_t [GeV]	172.5 ± 2.5	-

(*) one-loop pole mass

(**) MSbar PDG mass and relative uncertainty (α_s = 0.1171 at NNLO in these uncertainties calculations)

- Results in percentage (selection):

Channel	M_H	LHC BR Group BR	Δm_c	Δm_b	$\Delta\alpha_s$	Δm_t	ΔBR	arXiv:1012.0530v3 BR	Δm_c	Δm_b	$\Delta\alpha_s$	ΔBR
$H \to b\bar{b}$	120	64.8	$^{+0.2}_{-0.2}$	$^{+0.6}_{-0.6}$	$^{+0.9}_{-1.0}$	$^{+0.02}_{-0.02}$	$^{+1.1}_{-1.2}$	65.1	$^{+0.7}_{-0.6}$	$^{+3.4}_{-1.2}$	$^{+0.7}_{-0.8}$	$^{+3.6}_{-1.6}$
	135	40.3	$^{+0.1}_{-0.1}$	$^{+1.0}_{-1.0}$	$^{+1.6}_{-1.7}$	$^{+0.04}_{-0.04}$	$^{+1.9}_{-1.9}$	40.2	$^{+0.4}_{-0.4}$	$^{+6.0}_{-2.1}$	$^{+1.3}_{-1.3}$	$^{+6.2}_{-2.5}$
	150	15.6	$^{+0.0}_{-0.1}$	$^{+1.3}_{-1.4}$	$^{+2.2}_{-2.3}$	$^{-0.01}_{-0.05}$	$^{+2.6}_{-2.7}$	15.5	$^{+0.2}_{-0.1}$	$^{+8.7}_{-3.0}$	$^{+1.9}_{-1.9}$	$^{+8.9}_{-3.6}$
$H \to WW$ (***)	120	14.2	$^{+0.2}_{-0.2}$	$^{+1.0}_{-1.0}$	$^{+1.6}_{-1.5}$	$^{-0.04}_{-0.02}$	$^{+1.9}_{-1.8}$	14.7	$^{+0.7}_{-0.6}$	$^{+2.3}_{-6.3}$	$^{+1.4}_{-1.4}$	$^{+2.8}_{-6.5}$
	135	40.2	$^{+0.1}_{-0.1}$	$^{+0.6}_{-0.6}$	$^{+0.9}_{-0.9}$	$^{-0.02}_{-0.01}$	$^{+1.1}_{-1.1}$	41.1	$^{+0.4}_{-0.4}$	$^{+1.4}_{-4.0}$	$^{+0.9}_{-0.9}$	$^{+1.7}_{-4.1}$
	150	69.8	$^{+0.1}_{-0.1}$	$^{+0.2}_{-0.3}$	$^{+0.3}_{-0.3}$	$^{-0.01}_{-0.00}$	$^{+0.4}_{-0.4}$	70.3	$^{+0.2}_{-0.1}$	$^{+0.5}_{-1.6}$	$^{+0.3}_{-0.3}$	$^{+0.7}_{-1.6}$

(***) Uncertainties (in percentage) on $H\to\tau\tau$ and $H\to ZZ,\gamma\gamma$ SAME AS $H\to WW$

ΔBR discrepancy (mostly) due to different quark masses and uncertainties

Higgs Branching Ratios

Comparison with arXiv:1012.0530v3 (cont'd)

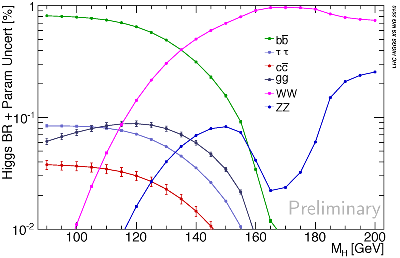
[D. Rebuzzi]

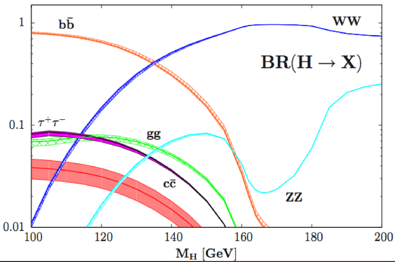
- Other channel comparisons:

ΔBR(H→cc) discrepancy (mostly) due to m_c

BR(H→gg): similar uncertainties but O(12-13%) discrepancy for central values, to be understood

Channel	M_H [GeV]	LHC BR Group BR [%]	LHC BR Group ΔBR [%]	arXiv:1012.0530v3 BR [%]	arXiv:1012.0530v3 ΔBR [%]
$H \to c\bar{c}$	120	3.00	$^{+9.5}_{-9.6}$	3.13	$^{+20.7}_{-22.8}$
	135	1.87	$^{+10.0}_{-10.1}$	1.93	$^{+20.5}_{-23.0}$
	150	0.72	$^{+10.6}_{-10.6}$	0.74	$^{+20.6}_{-23.2}$
$H \to gg$	120	8.81	$^{+5.9}_{-5.6}$	7.69	$^{+4.9}_{-7.8}$
	135	7.04	$^{+5.1}_{-4.9}$	6.10	$^{+3.9}_{-5.5}$
	150	3.43	$^{+4.3}_{-4.2}$	2.94	$^{+3.0}_{-3.4}$





Cuts and Distributions

Distributions require additional jets, mostly known at fixed NLO

- $gg \to H + 1j$ (HNNLO, FEHiP, MCFM), $gg \to H + 2j$ (MCFM)
- $qq \to Hqq + 1j$ [Figy, Hankele, Zeppenfeld]
- New: $b\bar{b} \to H + 1j$ at NLO [Harlander, Ozeren, Wiesemann]

However, additional scales introduce $\ln^2(p_T^{\rm jet}/m_H)$ terms

- Ideally should be resummed to all orders in α_s
- NLO MCs sum leading logs, but distributions are only at LO

$\Rightarrow$ Perturbative uncertainties in distributions / jet multiplicities / with jet veto are hard to quantify. Many cases where this is coming up

- $gg \to H(\to WW) + 0, 1j$ (most important at the moment)
- $gg \to H(\to \gamma\gamma) + 1j$
- $qq \to H + 2j$ (vector-boson fusion)
- $H \to b\bar{b}$
- $H \to \tau\tau$

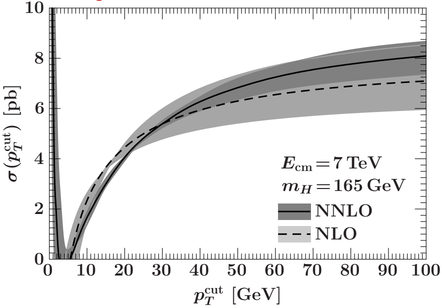
Perturbative Uncertainties From Jet Veto

Extensive discussions for $gg \to H + 0j$

- Naive scale variation at NNLO completely underestimates uncertainty
- Converged to BNL proposal: To estimate uncertainties using available fixed-order results take differences of inclusive jet cross sections (well motivated by known pert. structure and resummation results)

$$\sigma_0 = \sigma_{\text{total}} - \sigma_{\geq 1} \qquad \Rightarrow \qquad \Delta_0^2 = \Delta_{\text{total}}^2 + \Delta_{\geq 1}^2$$

Using naive scale variation for σ_0



$\Rightarrow$

Using above procedure for σ_0