HXSWG

Theory Uncertainty Task-Force

- mandate and goal -

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1. Introduction

- After the Higgs boson discovery, now it turns out to precision measurements era !
- Theory uncertainties are not negligible and became important than ever before !
  - Experimental accuracy $\Delta\mu(\sigma/\sigma_{SM})=\pm15\%$ (roughly ±10% for both stat.&syst.).
  - Theory uncertainty is O(±10-15%) dominated by QCD scale and PDF+α_s in ggF
- LHC Higgs combination WG's prescription (ATL-PHYS-PUB-2011-011, CMS Note-2011/005)
  - Subdivide nuisance parameters until they become uncorrelated.
  - Take Gaissian/Log-normal for pdf. Practically Gaussian as $\kappa\simeq1.0$ for QCD scale and PDF+α_s uncertainties.
- Need to update the prescription !
  1. QCD scale uncertainty
  2. PDF+α_s uncertainty
  3. BR uncertainty

2. Higgs Cross Sections

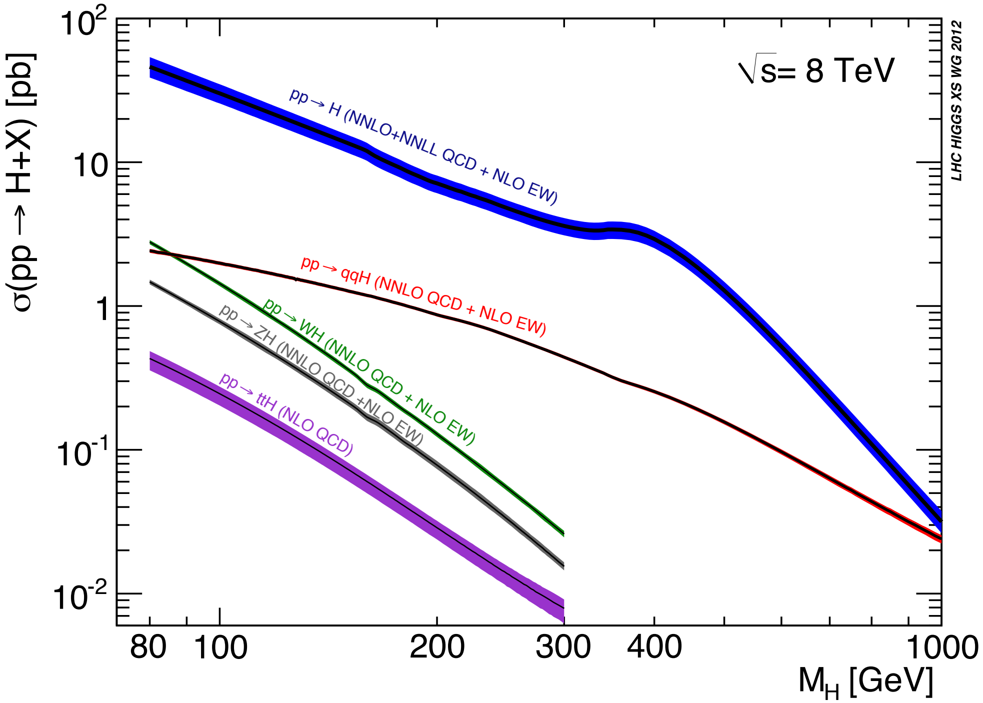
- Official numbers for Higgs cross sections at 7 and 8 TeV and spread sheet at
  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageAt7TeV
  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageAt8TeV
  - Now ggF and VBF cross sections with complex-pole-scheme (CPS) for entire mass range both at 7 and 8 TeV. WH/ZH and ttH in ZWA.
  - Always compared with two independent calculations, ex. dFG vs ABPS for ggF.
  - Assume factorization between QCD and EW radiative corrections.
  - QCD scale uncertainties, ex. ggF $1/2M_H < \mu_R,\mu_F < 2M_H$ ($1//2 < \mu_R/\mu_F < 2$)

7&8 TeV scan points in CERN Report 3

Higgs mass range and step (new proposal, work in progress):

Higgs Mass range	step size	# of points	addendum
[80,110] GeV	1 GeV	31 points	
[110,120] GeV	0.5 GeV	20 points	
[120,130] GeV	0.1 GeV	100 points	
[130,150] GeV	0.5 GeV	40 points	
[150,300] GeV	2 GeV	75 points	+ 165, 175, 185, 195 GeV (4 points)
[300,350] GeV	5 GeV	10 points	
[350,400] GeV	10 GeV	5 points	
[400,1000] GeV	20 GeV	30 points	+ 450, 550, 650, 750, 850, 950 GeV (6 points).

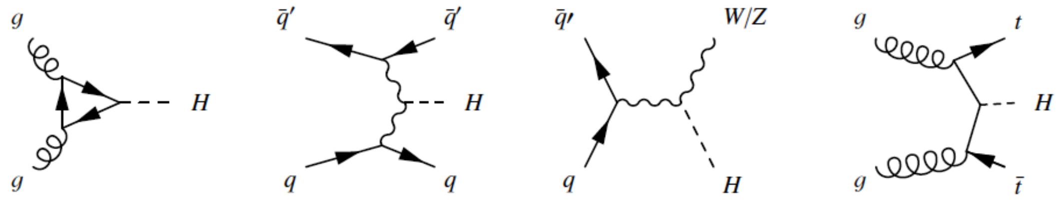
- 321 points in total for all ggF, VBF, WH/ZH and ttH processes (M_H=[80,1000]GeV).



Higgs cross section theory uncertainties

M_H=125 GeV

K-factor, QCD scale and PDF uncertainties



(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$

	7 TeV				8 TeV		
	$K_{NNLO/NLO}$ ($K_{NLO/LO}$)	Scale	PDF+α_s	Scale +PDF	Scale	PDF+α_s	Scale +PDF
ggF	+25% (+100%)	+7-8%	±8%	**±15%**	+7-8%	±8%	**±15%**
VBF	<1% (+5-10%)	±1%	±4%	**±5%**	±1%	±4%	**±5%**
WH/ ZH	+2-6% (+30%)	±1%	±4%	**±5%**	±1%	±4%	**±5%**
ttH	- (+5-20%)	+3 -9%	±8%	**+12 -18%**	+4 -9%	±8%	**+12 -17%**

- Renormalization and factorization scale uncertainty study by M. Cacciari et al. work in progress.
- Higher-order calculations, ex. ggF QCD scale: ±8%@NNLO **→ ±5%@NNNLO in few years ?**
- PDF+α_s (PDF4LHC prescription): ±8% → **<5% with improvements with LHC data ?**
  - jets, top, prompt photons and Z p_T distributions contribute gluon PDF determination.

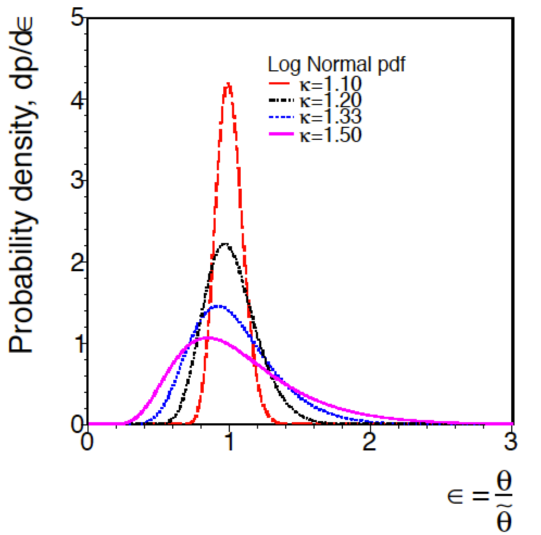
  (but paradoxically, ggF is the best measure to determine gg parton luminosity around M_H=125GeV!)

QCD scale uncertainty

- LHC Higgs combination WG's prescription (ATL-PHYS-PUB-2011-011, CMS Note-2011/005)
  - Subdivide nuisance parameters until they become uncorrelated.
  - Take Gaissian/Log-normal for pdf. Practically Gaussian as $\kappa \simeq 1.0$ for scale.
- New method by M. Cacciari and N. Houdeau. JHEP 09 (2011) 039
  - Preserves both characteristics of log-normal (tail) and flat-top.
  - Treats renormalization scale only, factorization scale is work in progress.
  - Questions are flat-top width and exponent. tail length.

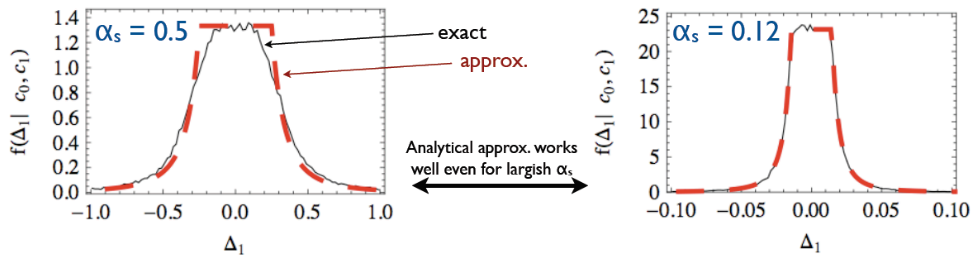
Gaussian/log-normal

$$\rho(\theta) = \frac{1}{\sqrt{2\pi}\ln(\kappa)} \exp\left(-\frac{(\ln(\theta/\tilde{\theta}))^2}{2(\ln\kappa)^2}\right)\frac{1}{\theta}$$

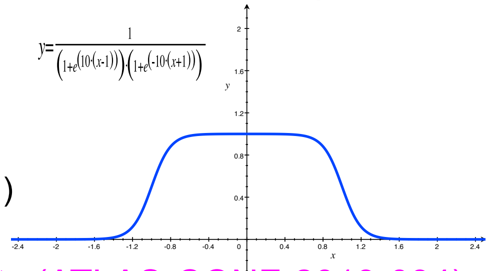


log-Cacciari-Houdeau

$$f(\Delta_k|c_0,\ldots,c_k) \simeq \left(\frac{k+1}{k+2}\right)\frac{1}{2\alpha_s^{k+1}\bar{c}_{(k)}}\begin{cases} 1 & \text{if } |\Delta_k| \le \alpha_s^{k+1}\bar{c}_{(k)} \\ \frac{1}{(|\Delta_k|/(\alpha_s^{k+1}\bar{c}_{(k)}))^{k+2}} & \text{if } |\Delta_k| > \alpha_s^{k+1}\bar{c}_{(k)} \end{cases}$$



log-double-Fermi-Dirac
to smoothen the edges
(used in ATLAS-CONF-2013-034)



Non-negligible effect in SM compatibility (ATLAS-CONF-2013-034)

PDF+α_s uncertainty

- Currently assume separate gg-initiated ±8% and qq-initiated ±4%.
  - Assumes NO PDF+α_s correlation between (ggF, ttH, tt, …) and (VBF, VH, VV, …).
- Full correlation study in CERN Report 2 (https://cds.cern.ch/record/1416519)
  - ggF – VBF ρ=-0.6 … due to sum rule of Σ(gg+qq+qqbar)=1.
  - ggF – WH ρ=-0.2 … due to small correlation between gg vs qqbar.
  - ggF – ttH ρ=-0.2 … it's the different Bijorken-x.

$M_{\mathrm{H}} = 120$ GeV	ggH	VBF	WH	$\mathrm{t\bar{t}H}$
ggH	1	−0.6	−0.2	−0.2
VBF	−0.6	1	0.6	−0.4
WH	−0.2	0.6	1	−0.2
$\mathrm{t\bar{t}}H$	−0.2	−0.4	−0.2	1
W	−0.2	0.6	0.8	−0.6
WW	−0.4	0.8	1	−0.2
WZ	−0.2	0.4	0.8	−0.4
Wγ	0	0.6	0.8	−0.6
$\mathrm{Wb\bar{b}}$	−0.2	0.6	1	−0.2
$\mathrm{t\bar{t}}$	0.2	−0.4	−0.4	1
$\mathrm{t\bar{b}}$	−0.4	0.6	1	−0.2
$\mathrm{t(\rightarrow \bar{b})q}$	0.4	0	0	0

Table 10

- All these issues should be handled correctly.

3. Higgs Decay Branching Ratios

A. Denner et al., Eur. Phys. J. C (2011) 71

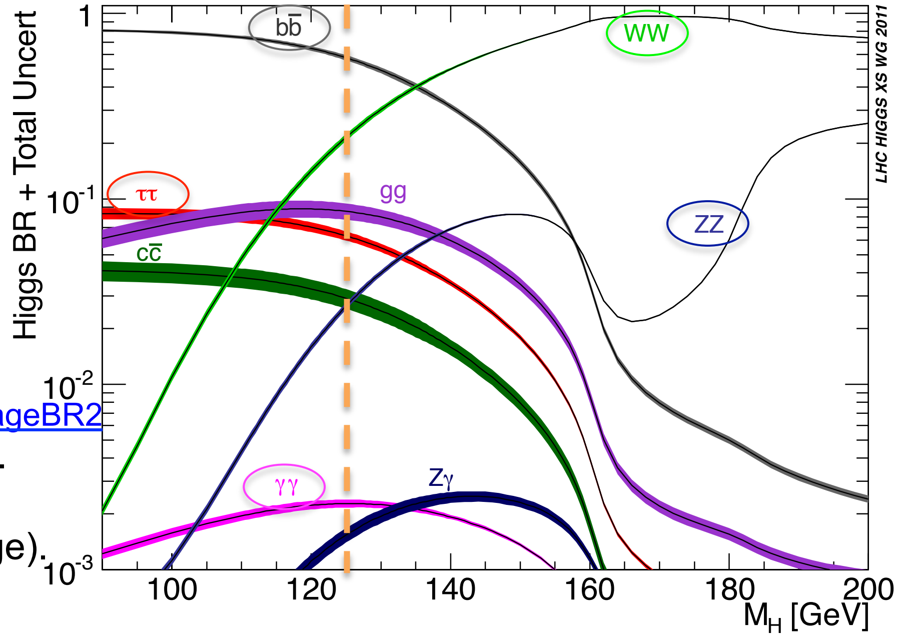
- Use HDECAY and Prophecy4f for best estimate.

$$\Gamma_H = \Gamma^{HDECAY} - \Gamma^{HDECAY}_{WW} - \Gamma^{HDECAY}_{ZZ} + \Gamma^{Prophecy4f}_{4f}$$

- What are the theory (THU) + parametric (PU) uncertainties ?
- Relatively large uncertainties for H→ττ, μμ, γγ, Zγ/WW/ZZ at low M_H.
- Smaller uncertainties relative to scale and PDF+α_s uncertainties in Higgs production.

M_H	Decay	THU	PU	Total
120GeV	H→bb	±1.3%	±1.5%	**±2.8%**
	H→ττ	±3.6%	±2.5%	**±6.1%**
	H→μμ	±3.9%	±2.5%	**±6.4%**
	H→γγ	±2.9%	±2.5%	**±5.4%**
	H→Zγ	±6.9%	±2.5%	**±9.4%**
	H→ZZ	±2.2%	±2.5%	**±4.8%**
	H→WW	±2.2%	±2.5%	**±4.8%**

Separation of BR THU and PU are in progress (prescription how to classify exists).
Stick to THU+PU **±5-10%** conservative uncertainty.



Updated numbers in CERN Report 2.
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR2
Major change was BR(H→ss) due to quark mass definition.

Will be updated in CERN Report 3 again (small THU change).

4. Proposal for theory uncertainty statistical treatment

- Long debate on QCD scale + PDF+α_s uncertainty handling.
- We suggest to separate either 1) theory uncertainty (THU) or 2) parametric uncertainty (PU).
- Statistical nature of THU behavior is unknown while PU is believed to behave as Gaussian (or log-normal) due to central limit theorem after many measurements. Such example is PDF+α_s uncertainty.

Source of theory uncertainties		
QCD scale	±8% for ggF, ±1% for VBF/VH, +4-9% for ttH	flat-prior
PDF+α_s	±8% for gg-initiated and ±4% for qq-initiated	Gaussian
BR uncertainty	±2-4% for THU ±2-3% for PU	flat-prior for THU Gaussian for PU
Higgs p_T	mixture of missing higher-order correction (ex. NLO EW), QCD scale, PDF+α_s, UE, etc.	flat-prior to be conservative
jet-bin uncertainty	inclusive 0,1,2-jet bin uncertainty is $\sigma_{\geq 0}$ (±10%), $\sigma_{\geq 1}$ (±20%), $\sigma_{\geq 2}$ (±20-30%, NLO)	flat-prior
underlying event	±10% for ggF+2j and ±3% for VBF	flat-prior
shape uncertainty in bkg. estimation	ex. Z+jets bkg., WW/ZZ bkg. etc.	flat-prior

Task-Force Mandate and Write-up

1. Summarize the recent progress in theory in QCD scale, PDF+α_s and BR uncertainties.
2. Provide the concrete recommendation on the theory uncertainty treatment (theoretical, parametric).
3. Provide the tools for the theory uncertainty handling, so that collaborations and any interested theorists can make use of it.
4. Document the new prescription within one month time-scale.

Executive Editor	ATLAS	Michael Duehrssen (CERN)
	CMS	André Tinoco Mendes (CERN)
	TH	Giampiero Passarino (Torino)

Contributor

1. QCD scale uncertainty	ggF subgroup
2. PDF+α_s uncertainty	PDF subgroup (PDF4LHC WG)
3. BR uncertainty	BR subgroup
	+ Statistics experts (ATLAS+CMS)

backup

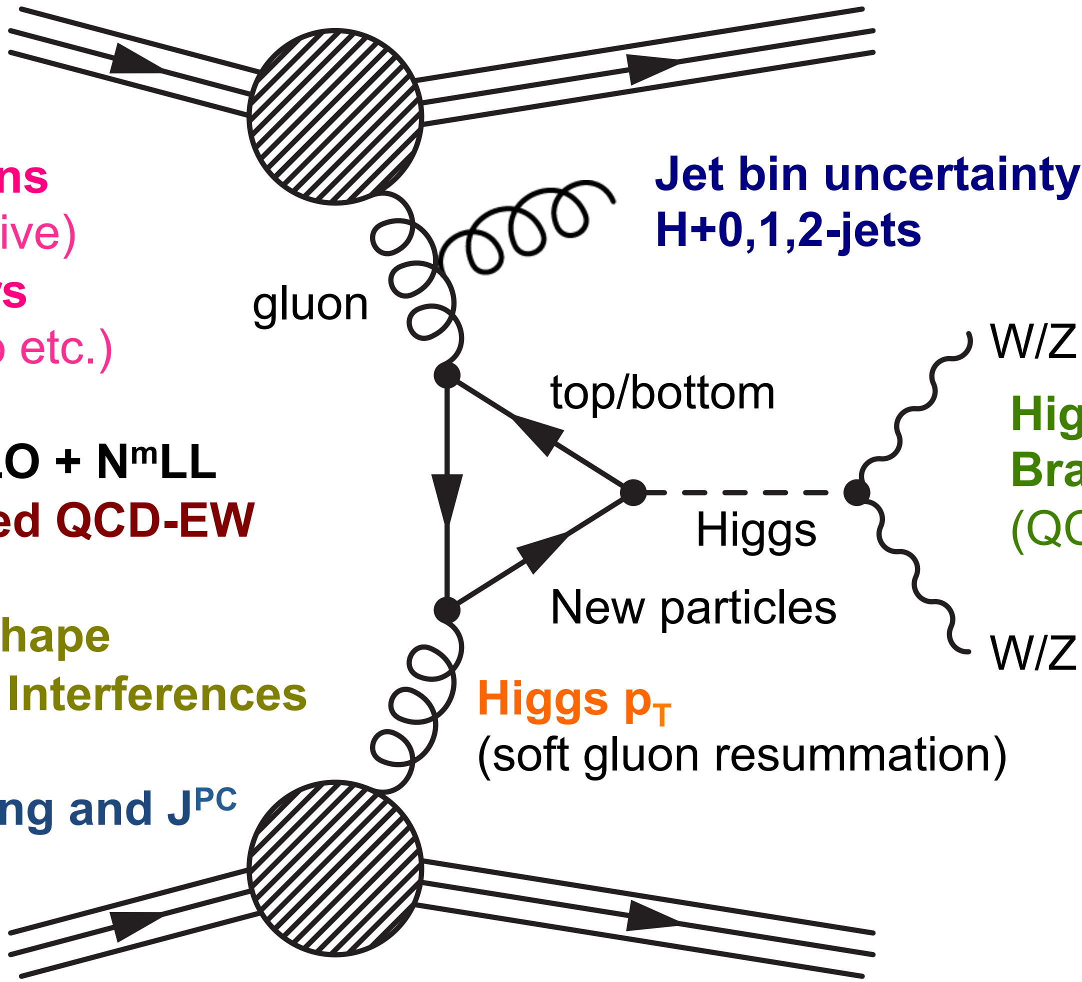
ggF, VBF, WH/ZH, ttH, BSM Higgs

Higgs Cross Sections
(inclusive/exclusive)
Differential K-factors
(effect of jet-veto etc.)

QCD correction N^kLO + N^mLL
EW correction, Mixed QCD-EW

Heavy Higgs Line Shape
SM Backgrounds & Interferences

Higgs Mass, Coupling and J^{PC}



Jet bin uncertainty
H+0,1,2-jets

Higgs decay
Branching ratios
(QCD/EW corr.)

Higgs p_T
(soft gluon resummation)

PDF+α_s uncertainties
Renormalization/Factorization scale dependence

ggF, VBF, WH/ZH, ttH, BSM Higgs

Cross Section

ggF
HIGLU (NNLO QCD+NLO EW)
iHixs (NNLO QCD+NLO EW)
FeHiPro (NNLO QCD+NLO EW)
HNNLO, HRes (NNLO+NNLL QCD)
ggh@NNLO (NNLO QCD)

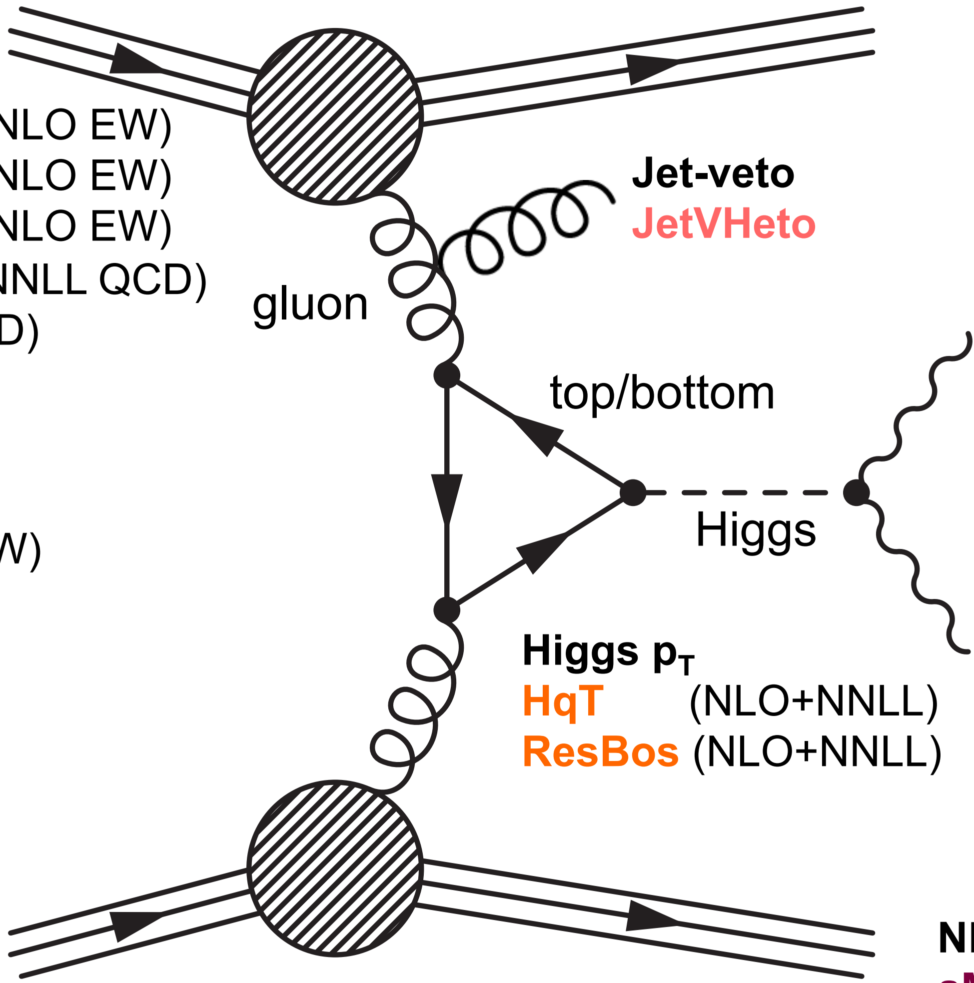
VBF
VV2H (NLO QCD)
VBFNLO (NLO QCD)
HAWK (NLO QCD+EW)
VBF@NNLO (NNLO)

WH/ZH
V2HV (NLO QCD)
VH@NNLO (NNLO)

ttH
HQQ (LO QCD)

bbH
bbH@NNLO (NNLO QCD)

+ private codes.



Jet-veto
JetVHeto

Higgs p_T
HqT (NLO+NNLL)
ResBos (NLO+NNLL)

PDF: MSTW2008, CT10, NNPDF2.1, etc.

MSSM/2HDM
FeynHiggs, SusHi
2HDMC, CPSuperH

Higgs Decay
(e)HDECAY (NLO)
Prophecy4f (NLO)

Higgs Properties
MELA/JHU, MEKD
MadGraph5

NLO MC
aMC@NLO, POWHEG,
SHERPA, HERWIG++
MCFM

How to take into account BR uncertainties ?

1. work with BR uncertainty
   - One has to take care of anti-correlation arising from ΣBR=1.
   - Current LHC Higgs combination framework does not allow partial anti-correlation but 100% +correlation or no-correlation only.
2. work with Higgs decay partial width
   - Work with the partial decay width uncertainty, just like BR = $\Gamma_i / \Sigma\Gamma_j$,
   - Correlations are automatically taken into account.
   - We need the full listings of partial decay width uncertainty.
3. work with Higgs coupling uncertainty
   - Live discusions now in Low Mass Higgs subgroup in LHC Higgs XS WG.
   - While partial widths are well-defined, this does not apply to couplings beyond LO.
   - One has to agree on a definition of the couplings. Then there are uncertainties that cannot be attributed to the couplings. etc. etc.

☞ Suggestion is to take approach 2. with partial decay width.

CMS has already adopted this prescription for their SM4 resutls.

BR Uncertainty Prescription (A. Denner, A. Korytov)

1. Nuisance parameters

   a) Parametric Uncertainty (PU): only 1 nuisance parameter

      - m_c, m_b, m_t and α_s uncertainties could be added in quadrature.
      - $H\rightarrow bb$ PU is the dominant source of the uncertainty.

   b) Theory Uncertainty (THU): 5 (6) nuisance parameters

      - Classify to $H\rightarrow ff$, tt, gg, γ+γ, (Zγ) and WW/ZZ

   ☞ Construct nuisance parameters in analogy to QCD scale and PDF uncertainties.

2. Tables

   1. Prepare full list of Γ_i and $d\Gamma_i$ as a function of M_H.
   2. Convert it into dBR_i/BR_i with $BR=\Gamma_i/\Sigma\Gamma_j$.
   3. Symmetrize the uncertainty by either max|+err,-err| or $\sqrt{(1+err)/(1-err)} - 1$.

Reference: BR paper Eur. Phys. J. C (2011) 71, Table 14.

☞ Suggestion is to take into account BR uncertainties with this prescription AFTER ICHEP.

Table 14 SM Higgs branching ratios and their relative parametric (PU), theoretical (TU) and total uncertainties for a selection of Higgs masses. For PU, all the single contributions are shown. For these four columns, the upper percentage value (with its sign) refers to the positive variation of the parameter, while the lower one refers to the negative variation of the parameter. Results for the full mass range, including the total uncertainties, are listed in tables at the end of the document

Channel	M_H [GeV]	BR	Δm_c	Δm_b	Δm_t	$\Delta\alpha_s$	PU	TU	Total
$H \to b\bar{b}$	120	6.48E−01	−0.2% +0.2%	+1.1% −1.2%	+0.0% −0.0%	−1.0% +0.9%	+1.5% −1.5%	+1.3% −1.3%	+2.8% −2.8%
	150	1.57E−01	−0.1% +0.1%	+2.7% −2.7%	+0.1% −0.1%	−2.2% +2.1%	+3.4% −3.5%	+0.6% −0.6%	+4.0% −4.0%
	200	2.40E−03	−0.0% +0.0%	+3.2% −3.2%	+0.0% −0.1%	−2.5% +2.5%	+4.1% −4.1%	+0.5% −0.5%	+4.6% −4.6%
	500	1.09E−04	−0.0% +0.0%	+3.2% −3.2%	+0.1% −0.1%	−2.8% +2.8%	+4.3% −4.3%	+3.0% −1.1%	+7.2% −5.4%
$H \to \tau^+\tau^-$	120	7.04E−02	−0.2% +0.2%	−2.0% +2.1%	+0.1% −0.1%	+1.4% −1.3%	+2.5% −2.4%	+3.6% −3.6%	+6.1% −6.0%
	150	1.79E−02	−0.1% +0.1%	−0.5% +0.5%	+0.1% −0.1%	+0.3% −0.3%	+0.6% −0.6%	+2.5% −2.5%	+3.0% −3.1%
	200	2.87E−04	−0.0% +0.0%	−0.0% +0.0%	+0.0% −0.1%	+0.0% −0.0%	+0.0% −0.1%	+2.5% −2.5%	+2.5% −2.6%
	500	1.53E−05	−0.0% +0.0%	−0.0% +0.0%	+0.1% −0.1%	−0.1% +0.0%	+0.1% −0.1%	+5.0% −3.1%	+5.0% −3.2%
$H \to \mu^+\mu^-$	120	2.44E−04	−0.2% +0.2%	−2.0% +2.1%	+0.1% −0.1%	+1.4% −1.3%	+2.5% −2.5%	+3.9% −3.9%	+6.4% −6.3%
	150	6.19E−05	−0.0% +0.0%	−0.5% +0.5%	+0.1% −0.1%	+0.3% −0.3%	+0.6% −0.6%	+2.5% −2.5%	+3.1% −3.2%
	200	9.96E−07	−0.0% −0.0%	−0.0% +0.0%	+0.1% −0.1%	+0.0% −0.0%	+0.1% −0.1%	+2.5% −2.5%	+2.6% −2.6%
	500	5.31E−08	−0.0% +0.0%	−0.0% +0.0%	+0.1% −0.1%	−0.0% +0.0%	+0.1% −0.1%	+5.0% −3.1%	+5.1% −3.1%
$H \to c\bar{c}$	120	3.27E−02	+6.0% −5.8%	−2.1% +2.2%	+0.1% −0.1%	−5.8% +5.6%	+8.5% −8.5%	+3.8% −3.7%	+12.2% −12.2%
	150	7.93E−03	+6.2% −6.0%	−0.6% +0.6%	+0.1% −0.1%	−6.9% +6.8%	+9.2% −9.2%	+0.6% −0.6%	+9.7% −9.7%
	200	1.21E−04	+6.2% −6.1%	−0.2% +0.1%	+0.1% −0.2%	−7.2% +7.2%	+9.5% −9.5%	+0.5% −0.5%	+10.0% −10.0%
	500	5.47E−06	+6.2% −6.0%	−0.1% +0.1%	+0.1% −0.1%	−7.6% +7.6%	+9.8% −9.7%	+3.0% −1.1%	+12.8% −10.7%
$H \to t\bar{t}$	350	1.56E−02	+0.0% +0.0%	−0.0% +0.0%	−78.6% +120.9%	+0.9% −0.9%	+120.9% −78.6%	+6.9% −12.7%	+127.8% −91.3%
	360	5.14E−02	−0.0% −0.0%	−0.0% +0.0%	−36.2% +35.6%	+0.7% −0.7%	+35.6% −36.2%	+6.6% −12.2%	+42.2% −48.4%
	400	1.48E−01	+0.0% +0.0%	−0.0% +0.0%	−6.8% +6.2%	+0.4% −0.3%	+6.2% −6.8%	+5.9% −11.1%	+12.2% −17.8%
	500	1.92E−01	−0.0% +0.0%	−0.0% +0.0%	−0.3% +0.1%	+0.1% −0.2%	+0.1% −0.3%	+4.5% −9.5%	+4.6% −9.8%

BR paper Eur. Phys. J. C (2011) 71, Table 14

H → gg	120	8.82E−02	−0.2% +0.2%	−2.2% +2.2%	−0.2% +0.2%	+5.7% −5.4%	+6.1% −5.8%	+4.5% −4.5%	+10.6% −10.3%
	150	3.46E−02	−0.1% +0.1%	−0.7% +0.6%	−0.3% +0.3%	+4.4% −4.2%	+4.4% −4.3%	+3.5% −3.5%	+7.9% −7.8%
	200	9.26E−04	−0.0% −0.0%	−0.1% +0.1%	−0.6% +0.6%	+3.9% −3.8%	+3.9% −3.9%	+3.7% −3.7%	+7.6% −7.6%
	500	6.04E−04	−0.0% +0.0%	−0.0% +0.0%	+1.6% −1.6%	+3.4% −3.3%	+3.7% −3.7%	+6.2% −4.3%	+9.9% −7.9%
H → γγ	120	2.23E−03	−0.2% +0.2%	−2.0% +2.1%	+0.0% +0.0%	+1.4% −1.3%	+2.5% −2.4%	+2.9% −2.9%	+5.4% −5.3%
	150	1.37E−03	+0.0% +0.1%	−0.5% +0.5%	+0.1% −0.0%	+0.3% −0.3%	+0.6% −0.6%	+1.6% −1.5%	+2.1% −2.1%
	200	5.51E−05	−0.0% −0.0%	−0.0% +0.0%	+0.1% −0.1%	+0.0% −0.0%	+0.1% −0.1%	+1.5% −1.5%	+1.6% −1.6%
	500	3.12E−07	−0.0% +0.0%	−0.0% +0.0%	+8.0% −6.5%	−0.7% +0.7%	+8.0% −6.6%	+4.0% −2.1%	+11.9% −8.7%
H → Zγ	120	1.11E−03	−0.3% +0.2%	−2.1% +2.1%	+0.0% −0.1%	+1.4% −1.4%	+2.5% −2.5%	+6.9% −6.8%	+9.4% −9.3%
	150	2.31E−03	−0.1% +0.0%	−0.6% +0.5%	+0.0% −0.1%	+0.2% −0.3%	+0.5% −0.6%	+5.5% −5.5%	+6.0% −6.2%
	200	1.75E−04	−0.0% −0.0%	−0.0% +0.0%	+0.0% −0.1%	+0.0% −0.0%	+0.0% −0.1%	+5.5% −5.5%	+5.5% −5.6%
	500	7.58E−06	−0.0% +0.0%	−0.0% +0.0%	+0.8% −0.6%	−0.0% +0.0%	+0.8% −0.6%	+8.0% −6.1%	+8.7% −6.7%
H → WW	120	1.41E−01	−0.2% +0.2%	−2.0% +2.1%	−0.0% +0.0%	+1.4% −1.4%	+2.5% −2.5%	+2.2% −2.2%	+4.8% −4.7%
	150	6.96E−01	−0.1% +0.1%	−0.5% +0.5%	−0.0% +0.0%	+0.3% −0.3%	+0.6% −0.6%	+0.3% −0.3%	+0.9% −0.8%
	200	7.41E−01	−0.0% −0.0%	−0.0% +0.0%	−0.0% +0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%
	500	5.46E−01	−0.0% +0.0%	−0.0% +0.0%	+0.1% −0.0%	−0.0% +0.0%	+0.1% −0.1%	+2.3% −1.1%	+2.4% −1.1%
H → ZZ	120	1.59E−02	−0.2% +0.2%	−2.0% +2.1%	−0.0% +0.0%	+1.4% −1.4%	+2.5% −2.5%	+2.2% −2.2%	+4.8% −4.7%
	150	8.25E−02	−0.1% +0.1%	−0.5% +0.5%	+0.0% +0.0%	+0.3% −0.3%	+0.6% −0.6%	+0.3% −0.3%	+0.9% −0.8%
	200	2.55E−01	−0.0% +0.0%	−0.0% +0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%
	500	2.61E−01	+0.0% −0.0%	−0.0% +0.0%	+0.0% +0.0%	−0.0% +0.0%	+0.1% −0.0%	+2.3% −1.1%	+2.3% −1.1%

Numbers are the nuisance parameter #.