Higgs Boson Production Cross Sections

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PHYSICS AT THE TERA SCALE Helmholtz Alliance

Black Forest Grid

[1]Many thanks to M. Mühlleitner, S. Dittmaier, R. Harlander, M. Krämer and M. Spira

Motivation

Why a talk about Higgs boson production cross sections?

- LHC will start running soon
- Initially: Won't have much sensitivity to Higgs boson(s).
- But: For some parts of parameter space, especially MSSM at high $\tan\beta$: early exclusion potential
- To properly exclude a model, and not just put a limit on $\sigma \times \mathrm{BR}$, need not only central values, but also theory uncertainties
- We as experimentalists should try to understand, what the "state of the art" calculations are, and not only take some tool that gives numbers

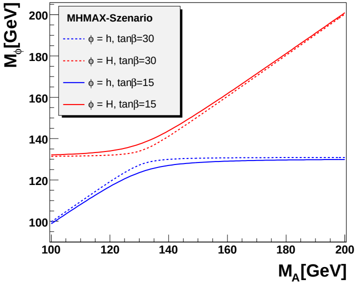
Higgs Sector of the Minimal Supersymmetric Standardmodel

- SUSY: need two Higgs doublets
- MSSM: 5 Higgs bosons, h^0, H^0 (CP=+1), A^0 (CP=-1), $H^\pm$
- couplings at tree level depend only on $\sin\alpha_{\mathrm{eff.}}$ (mixing between scalars) and $\tan\beta$ (ratio of two vevs)
- in general 105 parameters, can be reduced by assumptions to 5
- still too many, choose representative benchmark scenarios, reducing number of additional parameters to two, in general m_{A^0} and $\tan\beta$
- MHMAX scenario: maximizes the lightest Higgs boson mass, smallest LEP exclusion
- mass spectrum and couplings e.g. from Feynhiggs 2.6.5

Neutral Higgs Bosons

- SM cross sections can be rescaled to MSSM values $\Rightarrow$ analyses take SM inputs
- dedicated MSSM analyses especially for large $\tan\beta$:

$\frac{g_{MSSM}}{g_{SM}}$	u-type	d-type
h	$\propto \frac{1}{\sin\beta}$	$\propto \frac{1}{\cos\beta}$
H	$\propto \frac{1}{\sin\beta}$	$\propto \frac{1}{\cos\beta}$
A	$\propto \cot\beta$	$\propto \tan\beta$

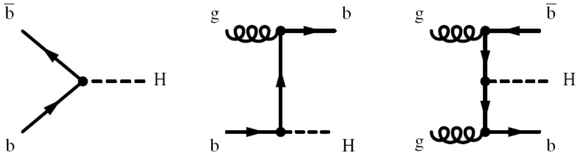


- always one scalar degenerate with pseudoscalar, similar couplings
- other scalar is SM-like

- b-associated production becomes important
- modification of gluon-gluon-fusion cross section

bbH - b quark associated Higgs boson production

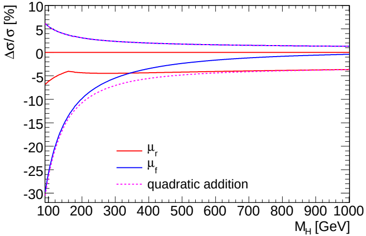
- Not important in the Standard Model, becomes relevant in models with increased coupling to down-type fermions, e.g. MSSM at high $\tan\beta$
- Theory: How to organize the perturbative series:



- 5-flavor ($b\bar{b} \to H$): absorb collinear logarithms in b-quark-pdf, should be better for high masses
- 4-flavor ($gg \to b\bar{b}H$): keep full mass dependence, but keeps large logarithms, should be better for small masses

Scale Uncertainties of 5f calculation

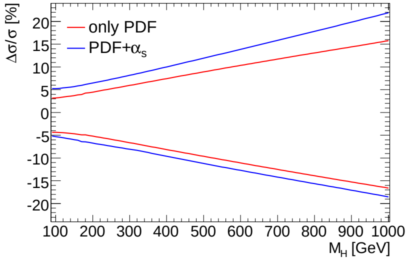
- $b\bar{b} \to H$: Calculation by R. Harlander, W. Kilgore (Phys. Rev. D68:013001, 2003), NNLO QCD, 5 flavor scheme, public code bbh@nnlo
- $\sqrt{s} = 10\,\mathrm{TeV}$, MSTW2008NNLO PDF-set
- Central scales: $\mu_r = M_H$, $\mu_f = \frac{1}{4}m_H$, varied μ_f between $0.1M_H$ and $0.7M_H$, μ_r between $0.2M_H$ and $5M_H$.



- factorization scale dominates at low masses, high masses perhaps better to use renormalization scale variation

PDF and α_s Uncertainties of 5f calculation

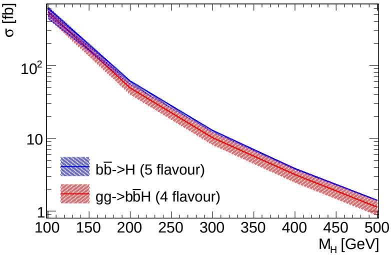
- PDF uncertainties estimated from MSTW2008 error sets
- In addition have to consider α_s-variation for MSTW fits.
- Followed the recipe in arXiv:0905:3531 [hep-ph] (90% CL).



- PDF uncertainty negligible compared to scale uncertainties for low masses, will dominate at high masses

Comparison to 4f calculation

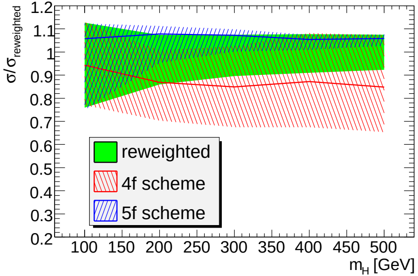
- 4f by M. Krämer, M. Spira and S. Dittmaier (Phys. Rev. D70: 074010,2004), also by Dawson et al. (Phys. Rev. D69 (2004) 074027)
- $\mu_0 = \frac{1}{4}(M_H + 2m_b)$, variation by factor of 2
- MRST2004NLO 4-flavor pdf, cannot use MSTW2008, since this is a 5-flavor PDF
- Compare with 5f calculation, using MRST2004NNLO 5-flavor pdf, here only μ_f variation (ok for low masses)



- At least the two bands overlap (high masses?)

5f vs. 4f scheme

- What is a common value?
- Proposal by Robert Harlander (5f) and Michael Krämer (4f): take a weighted mean:



$$w = \frac{\ln(M_H[\mathrm{GeV}]/37)}{1+\ln(M_H[\mathrm{GeV}]/37)}$$

$$\sigma_{\mathrm{wgt}} = w \cdot \sigma_{5\mathrm{f}} + (1-w) \cdot \sigma_{4\mathrm{f}}$$

- apply this also to the scale uncertainties
- PDF uncertainties: Assume that the relative uncertainties are the same for MSTW2008 as for MRST2004

Test of Rescaling procedure

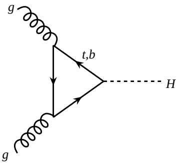
- always involved: bottom-Yukawa coupling
- Rescale from SM to MSSM by ratio of Yukawa couplings
- Calculation by A. Mück, M. Krämer and S. Dittmaier: $b\bar{b} \to H$ in NLO QCD, NLO EW and NLO sQCD (JHEP 0703:114, 2007)
- Use this calculation to check the reweighting procedure:
  - get SM cross section
  - reweight it using Feynhiggs 2.6.5
  - compare to exact result
- main concern here: Make MSSM parameters consistent between Feynhiggs 2.6.5 and the calculation
- numbers from Alexander Mück
- Parameters looking mostly good, some small discrepancies remaining

Rescaling Checks II

		$\sigma_{\rm MSSM}/\sigma_{\rm SM}$					
		h^0		H^0		A^0	
$M_A[\mathrm{GeV}]$	$\tan\beta$	exact	resc.	exact	resc.	exact	resc.
120	20	308	302	35	43	342	345
150	20	27	23	317	323	343	345
200	20	4.1	3.9	341	342	344	345
120	30	675	674	41	50	715	723
150	30	30	24	689	701	718	723
200	30	4.1	3.9	718	721	721	724

- mostly within 2%
- only discrepancies for scalar Higgs with smaller enhancement, not observable anyway
- source understood, difference in $h^0 - H^0$-mixing, within uncertainty of parameter ($\sin\alpha_{\rm eff}$).

gluon-gluon-fusion



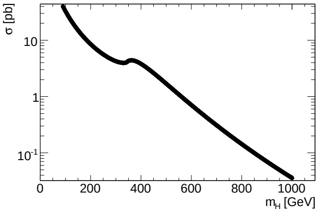
- additional important production mechanism
- in SM known to NNLO +NNLL +EW (in limit of infinite top mass)
- MSSM: bottom loop also important, need massive calculation, available only in NLO, e.g. in Higlu (M. Spira)
- Proposal by M. Spira:

$$\sigma = k(\mathrm{NLO} \to \mathrm{NNLO}) \cdot \sigma_{tt}^{\mathrm{Higlu;NLO}} + \sigma_{tb}^{\mathrm{Higlu;NLO}} + \sigma_{bb}^{\mathrm{Higlu;NLO}}$$

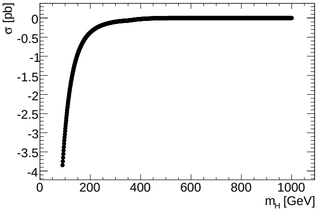
- then rescale by ratios of couplings

Ingredients for scalar Higgs bosons

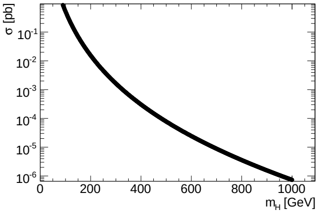
top-loop only



interference



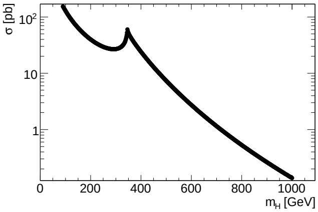
bottom-loop only



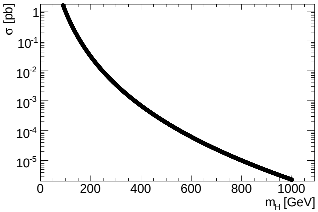
- k-factor NLO→NNLO for top-loop only, e.g. from HggTotal
- ≈ 1.25, weak mass dependence

Ingredients for pseudoscalar Higgs bosons

top-loop only



bottom-loop only



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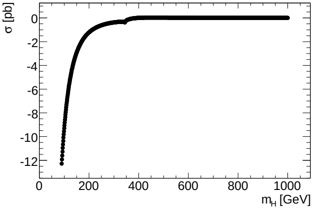

- ps. Higgs with SM couplings
- NNLO for top-loop: C. Anastasiou, K. Melnikov (Phys. Rev. D67:037501, 2003) and R. Harlander, W. Kilgore (JHEP 0210:017, 2002), not yet in!
- different shapes

Comparison with Feynhiggs Reweighting

- Feynhiggs: Rescale with ratio partial widths into gluons
- Input: SM cross section from Grazzini/de Florian
- Compare SM cross section from the shown recipe: about 10 to 15% higher (different PDF?)
- Check for example with $m_A = 150\,\mathrm{GeV}$, $\tan\beta = 20$, MHMAX-scenario:

$\phi =$	h^0	H^0	A^0
$\frac{\sigma(gg\to\phi)_{\mathrm{Higlu-rescaled}}}{\sigma(gg\to\phi)_{\mathrm{Feynhiggs-rescaled}}}$	1.20	1.70	1.95

- large differences!
- squark-loops? These are not (yet) included in Higlu!
- Private numbers from M. Spira: Squark-Loops have around 7% effect
- Nota bene: Feynhiggs is not a dedicated tool for cross section calculations!

Summary

- Cross sections for neutral MSSM Higgs bosons at high tan β
  - bbH: difference between 4f and 5f remaining
  - reweigh for common central value?
  - rescaling precription (as done in Feynhiggs) seems to be very well justified
  - inclusion of electroweak corrections?
  - ggF: difference between reweighing of Higlu and Feynhiggs prescription
  - Importance of squark-loops?
- Important: Cooperation between theory and experiment
  - will need cross sections at $\sqrt{s} = X\,\mathrm{TeV}$ to place limits
  - public code? If it is there for one calculation, and not for another one, guess which one we will use...