Charged Higgs bosons: Cross sections – status and review of methods

LHCHXSG WG3,
Dec 9th, 2016

Based on the work of a lot of people who contributed to this group in the last few years!

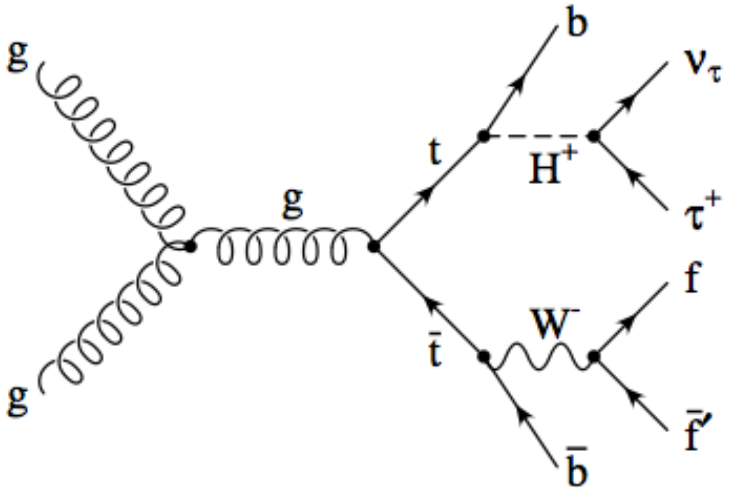
Outline

- Available numbers & how they were calculated
  - Theory basics
  - Light and heavy H+ production
  - Intermediate region
  - MSSM (QCD) corrections
  - Plans (up for discussion)

Light H+

mH+ < mt:

- Production in top quark decays
- Relevant couplings:
  - g(tbH+) ~ mt cot β + mb tan β
  - g(τνH+) ~ mτ tan β



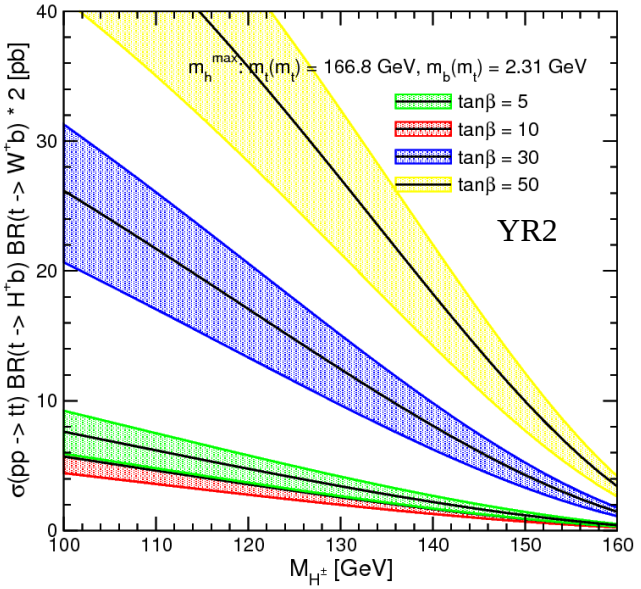
- Production cross section:
  - σ(pp → tt) ⊗ BR(t → bH+) [2HDM, dominant at the LHC]

=> Only need ttbar cross section [calculated **and** measured with precision better than 10%] and a tool to calculate this BR (many on the market; fast and efficient)

Light H+: Numbers

Combine your favourite top production (e.g. ttbar) cross section at your favourite center-of-mass with the BR(t->bH+) [1].

Light H+ cross section vs mH+ for various values of tan beta, including uncertainties



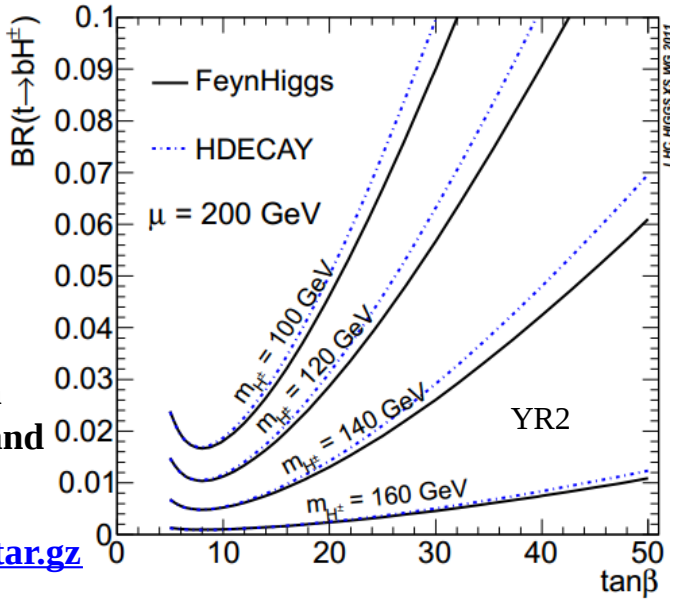
Uncertainties:

- ttbar cross section, pdf, scale, α_s, ≈10%

  $\Delta mt \approx 5\%$

- Missing higher-order terms, BR(t → bH+) 5% (one-loop EW), 2% (two-loop QCD)
- From Δb uncertainties: 0%-25% [mostly small, except for large tan β and large |Δb|], also in [1]

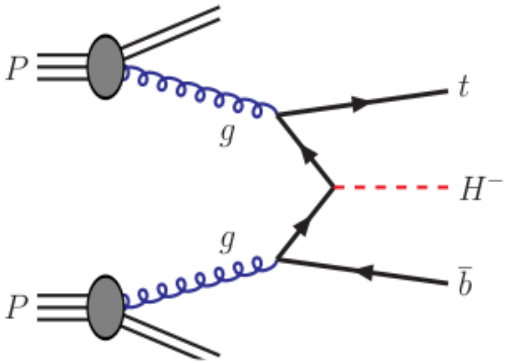
Comparison FeynHiggs and HDecay



[1] https://twiki.cern.ch/twiki/pub/LHCPhysics/MSSMCharged/mhmax-tb.tar.gz

Heavy H+: 4FS vs 5FS

Four-flavour scheme

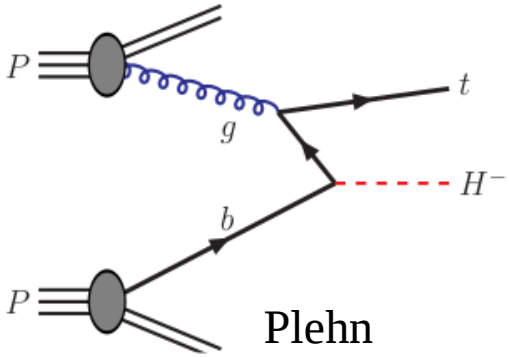


Dittmaier, Krämer, Spira, Walser
PRD83 (2011) 055005

- Exact g → bb splitting and mass/off-shell effects
- No resummation of log(mH+/mb)

Needed e.g. for distributions involving the b quarks
[thus probably „better“ paradigm for MC generators]

Five-flavour scheme



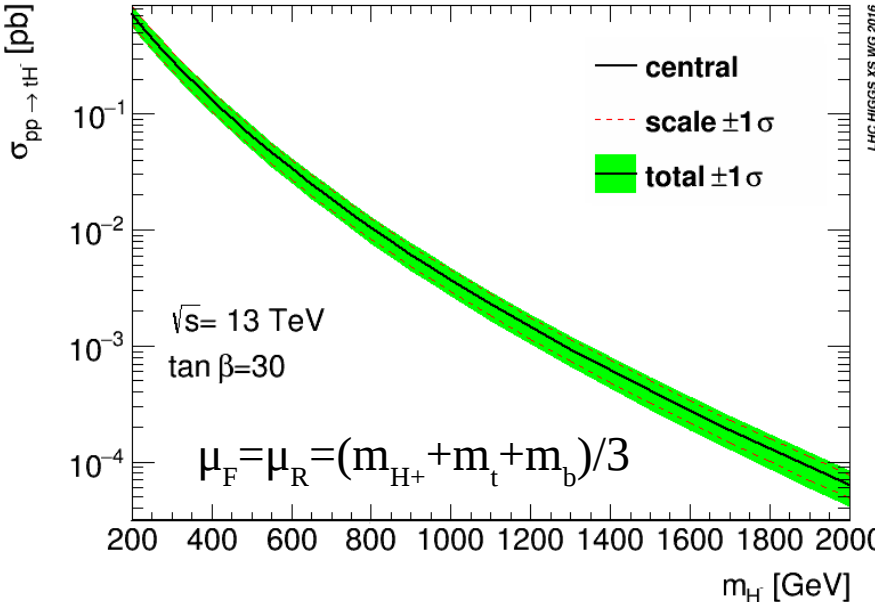
Plehn
PRD67 (2003) 014018

- b from proton PDF massless/on-shell, no pT
- Resummation of log(mH+/mb)

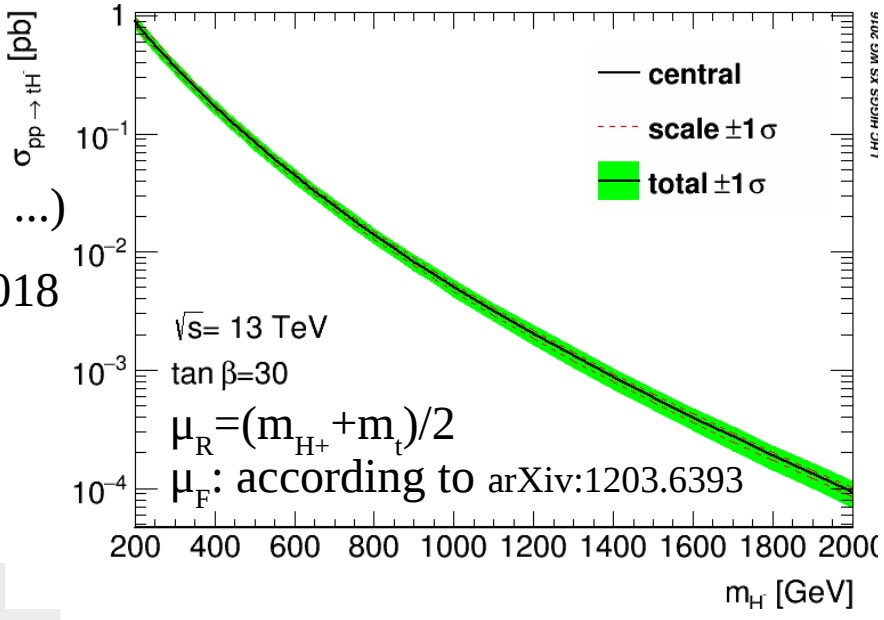
Gives total cross section with typically smaller uncertainty
[but evaluating b PDF uncertainty properly is non-trivial]

Heavy H+: calculations (YR4)

- 4FS:
  - MadGraph5_aMCatNLO
  - Calculation: Dittmaier, Krämer, Spira, Walser, PRD83 (2011) 055005
  - Uncertainty: ≈20% (scale) + ≈5% (pdf, α_s, m_b) = ≈25% total [increases with tan β, m_{H+}]

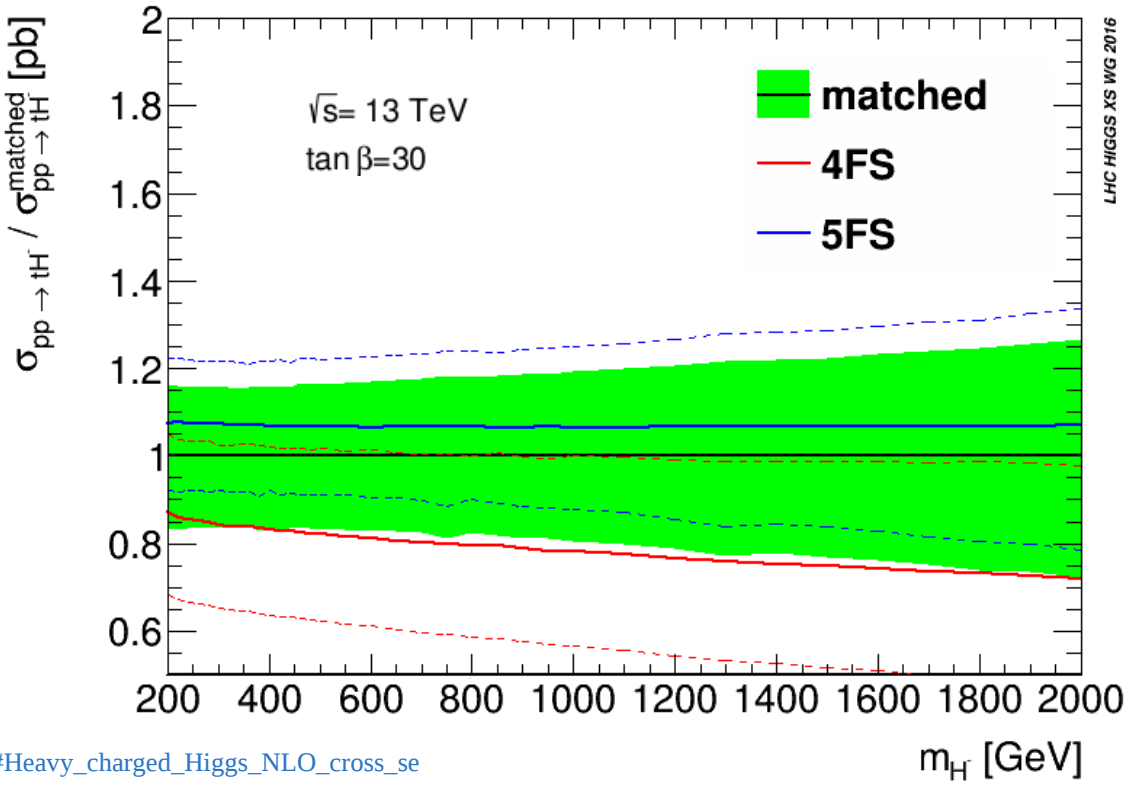


- 5FS:
  - Prospino2
    +private modifications (LHAPDF interface, ...)
  - Calculation: Plehn, PRD67 (2003) 014018
  - $\mu_F = \mu_R$* [phase space factor]
  - Uncertainty: ≈10% (scale) + ≈8% (pdf, α_s, m_b) = ≈18% total



Heavy H+: Matching

- „Santander-matched“ cross section (of 4FS and 5FS)
  - Harlander, Krämer, Schumacher, CERN-PH-TH/2011-134
  - $\sigma_{\text{matched}} = \dfrac{\sigma_{4\text{F}} + w\sigma_{5\text{F}}}{1+w}$ with weight $w = \log \dfrac{m_{H^\pm}}{m_b} - 2.$
  - Total uncertainty (scale, pdf, mb, α_s): about 10%-20%

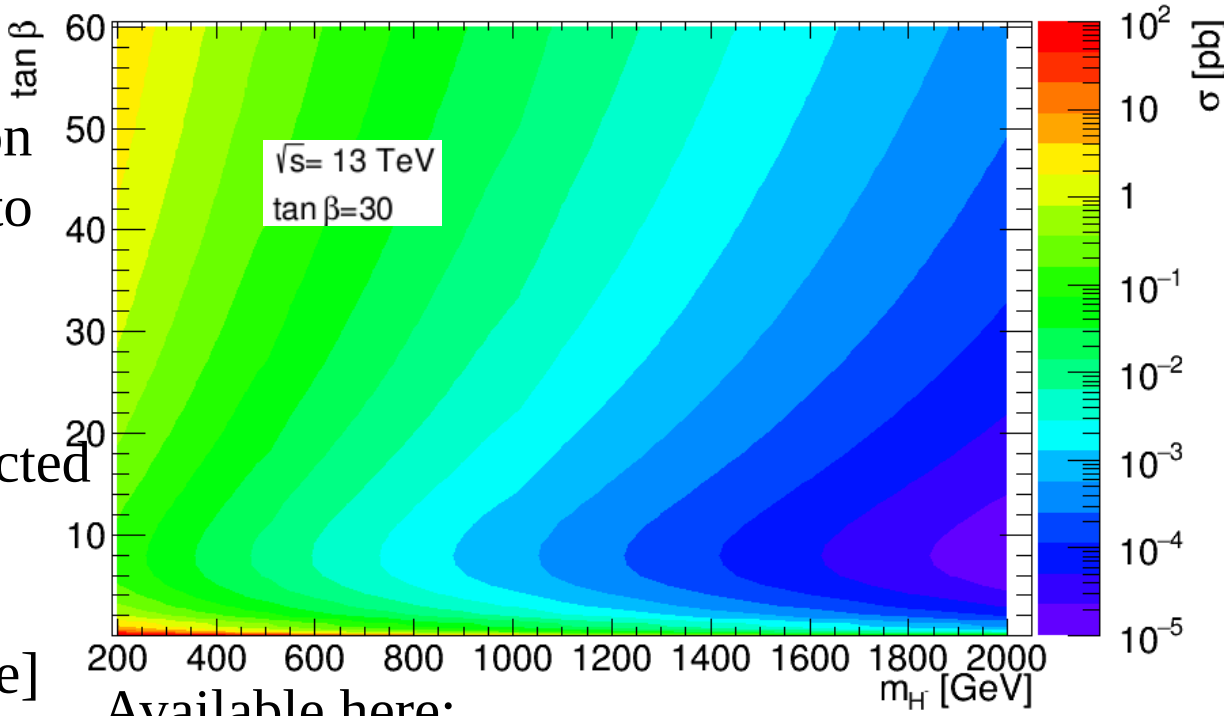


Available here:

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/MSSMCharged#Heavy_charged_Higgs_NLO_cross_se

Heavy H+: available results

- Grids
  - independent calculation of terms proportional to y_t^2 / y_b^2 [new in YR4]
  - $y_t y_b$ term: 0 for 5FS, small for 4FS → neglected [max contribution at tan β=8: 5% for m<600 GeV, 1% above]
- Uncertainties



Available here:

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/MSSMCharged#Heavy_charged_Higgs_NLO_cross_se

$m_{H^\pm}$ [GeV]	tan β	4FS σ	4FS $\Delta\sigma^{scale}$	4FS $\Delta\sigma^{pdf}$	4FS $\Delta\sigma^{tot}$	5FS σ	5FS $\Delta\sigma^{scale}$	5FS $\Delta\sigma^{pdf}$	5FS $\Delta\sigma^{tot}$	matched σ	matched $\Delta\sigma^{tot}$
200	1	2.90	13.1	3.1	16.6	3.63	4.1	6.6	11.8	3.36	12.5
200	8	0.0961	15.7	3.2	18.9	0.1194	6.4	5.9	13.8	0.1109	14.4
200	30	0.718	18.0	3.2	21.2	0.886	8.5	5.6	15.7	0.825	16.2
600	1	0.143	13.3	4.9	18.9	0.186	2.7	8.1	12.9	0.175	12.6
600	8	0.00461	16.7	5.0	21.9	0.00602	5.1	7.8	15.1	0.00566	14.8
600	30	0.0336	19.6	5.1	24.7	0.0440	7.3	7.7	17.0	0.0413	16.9
1000	1	0.0162	14.2	6.8	21.0	0.0217	2.3	10.6	14.7	0.0204	14.2
1000	8	0.000516	17.4	7.0	24.4	0.000697	5.2	10.0	16.6	0.000655	16.8
1000	30	0.00371	20.8	7.0	27.8	0.00506	7.9	9.7	18.8	0.00475	19.4

MSSM parameter dependence

- Dominant SUSY-QCD contributions: can be absorbed in so-called „Δb corrections“, taken into account by modifying the b-Higgs coupling:

$$\frac{m_b \tan\beta}{v} \rightarrow \frac{m_b \tan\beta}{v} \frac{1}{1+\Delta_b}$$

- Relevant for production, both t → bH+ and gg/gb → tH+[b] have tbH+ vertex
- Relevant also for decay H+ → tb [partial cancelation of both corrections]

- A grid of Δb values can be found here:
  https://twiki.cern.ch/twiki/pub/LHCPhysics/MSSMCharged/deltab.tar
- Corrections factorize (at good approximation) and can be added to the provided cross section values for any scenario, see recipe on twiki:

Recipe to add delta_b corrections, for a point with charged Higgs mass mhp and tan beta tb (recipe from Sven Heinemeyer):

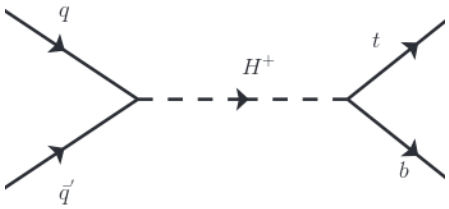
- Find the delta_b value corresponding to tb
- Calculate tbeff = tb/sqrt{1 + delta_b}
- Using the cross sections without SUSY-QCD NLO corrections, get the cross section which corresponds to tbeff (!)
- Multiply the result from the previous bullet with 1/(1 + delta_b) => this is your cross section [Note: corrected on 2014-01-27 thanks to Alexandre Nikitenko]

- For small tan β, additional model-dependent S-QCD corrections of O(10%)
- S-Electroweak corrections could be relevant for a light MSSM spectrum

Instead of a summary

- From a talk I gave 2 years ago:
  - extend mass range of cross sections: up to 1 TeV?
  - calculate mH+ / tan β grid in a smarter way: y_b / y_t terms
  - Recommendation for transition region mH+ ≈ mt
  - Rigorous evaluation of beyond-Δb MSSM uncertainties / low tan β

- Almost all goals reached – what's next [discussion items]?
  - fully integrate transition region in our recommendations
    - in particular, deal with discontinuities at the borders
    - simulation
  - Subdominant production modes, e.g.
    - s channel, pair production
  - Unified xsec root files with MSSM neutral
    - Partially done (S. Liebler, P. Keskinen et al)



Resources

- Heavy H+

Citation guide

Please quote **as a minimum** these papers if you use the numbers:

- [1] C. Degrande, M. Ubiali, M. Wiesemann, M. Zaro, Heavy charged Higgs boson production at the LHC. JHEP 1510 (2015) 145 , arXiv:1507.02549
- [2] M. Flechl, R. Klees, M. Kr\"amer, M. Spira, M. Ubiali, Improved cross-section predictions for heavy charged Higgs boson production at the LHC. Phys. Rev. D 91, 075015, arXiv:1409.5615
- [3] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs Cross Sections: 4. Deciphering the nature of the Higgs sector. arXiv:1610.07922
- [4] S. Dittmaier, M. Kr\"amer, M. Spira, M. Walser, Charged-Higgs-boson production at the LHC: NLO supersymmetric QCD corrections. Phys.Rev., D83:055005, 2011
- [5] E. L. Berger, T. Han, J. Jiang, T. Plehn. Associated production of a top quark and a charged Higgs boson. Phys.Rev., D71:115012, 2005

  - recent talks
    - M. Ubiali (cHarged16): https://indico.cern.ch/event/497135/timetable/#all

- Intermediate region

Citation guide

Please refer to this paper if you use the intermediate-mass numbers:

- [1] C. Degrande, R. Frederix, V. Hirschi, M. Ubiali, M. Wiesemann, M. Zaro, arXiv:1607.05291 .

  - talks
    - M. Zaro (expert, Hdays16): https://indico.cern.ch/event/568401/timetable/#all
    - MF (experimentalist's view, cHarged16): https://indico.cern.ch/event/497135/timetable/#all