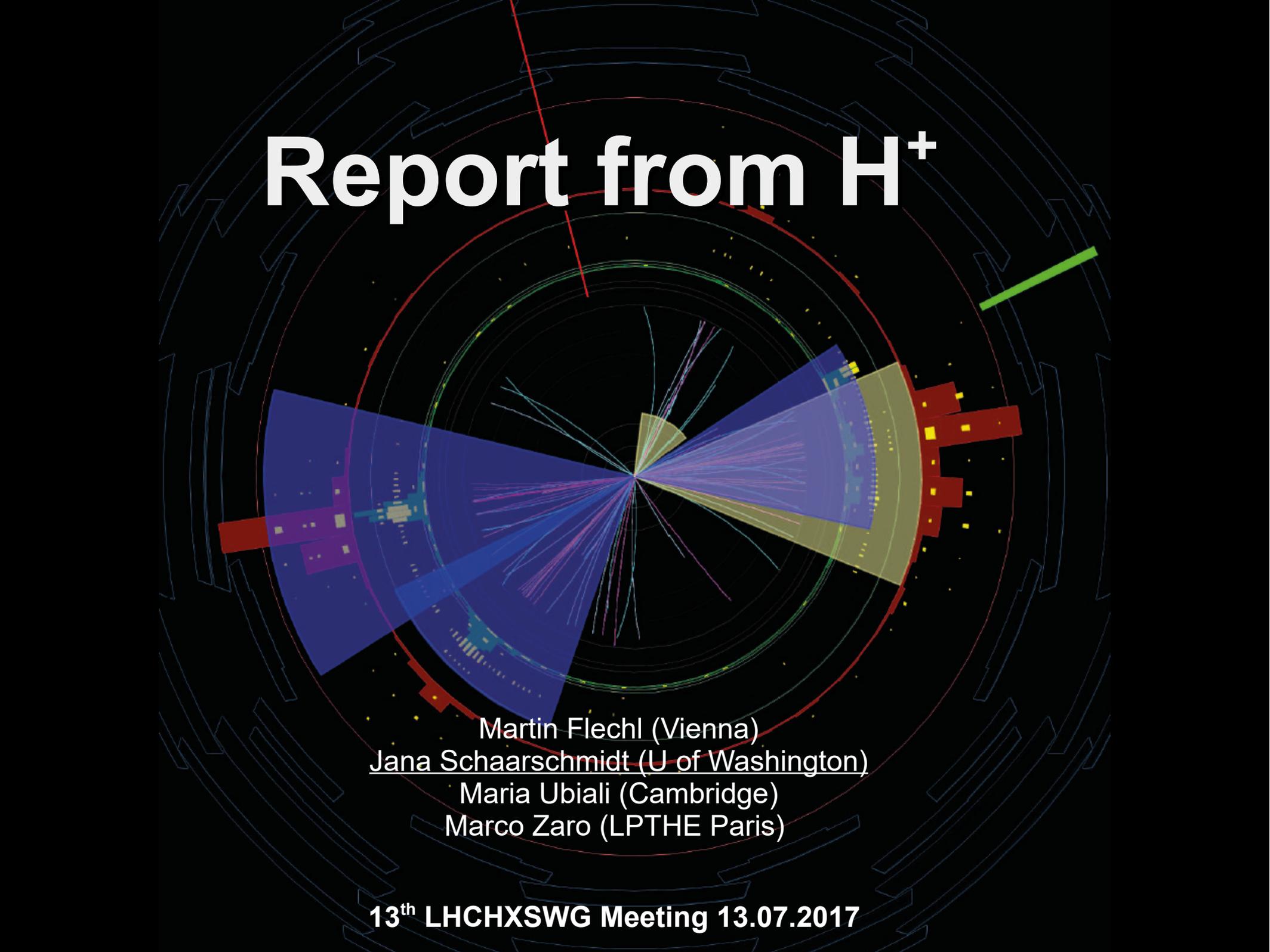


Report from H⁺



Martin Flechl (Vienna)
Jana Schaarschmidt (U of Washington)
Maria Ubiali (Cambridge)
Marco Zaro (LPTHE Paris)

- H^+ production landscape: Low mass, intermediate mass, high mass
- YR4 recap
- Search results
- Possibilities for extending the group's mandate

- $m_{H^+} < m_{\text{top}}$ ($< 145 \text{ GeV}$)
- H^+ produced predominantly in top decays
- Production cross section:

$$\sigma(pp \rightarrow tt) * \text{BR}(t \rightarrow bH^+) * \text{BR}(t \rightarrow bW)$$

↑
NNLO

↑
PRL 110 (2013)

↑
NLO: Phys. Rev. D76

(2007), hep-ph/9301237

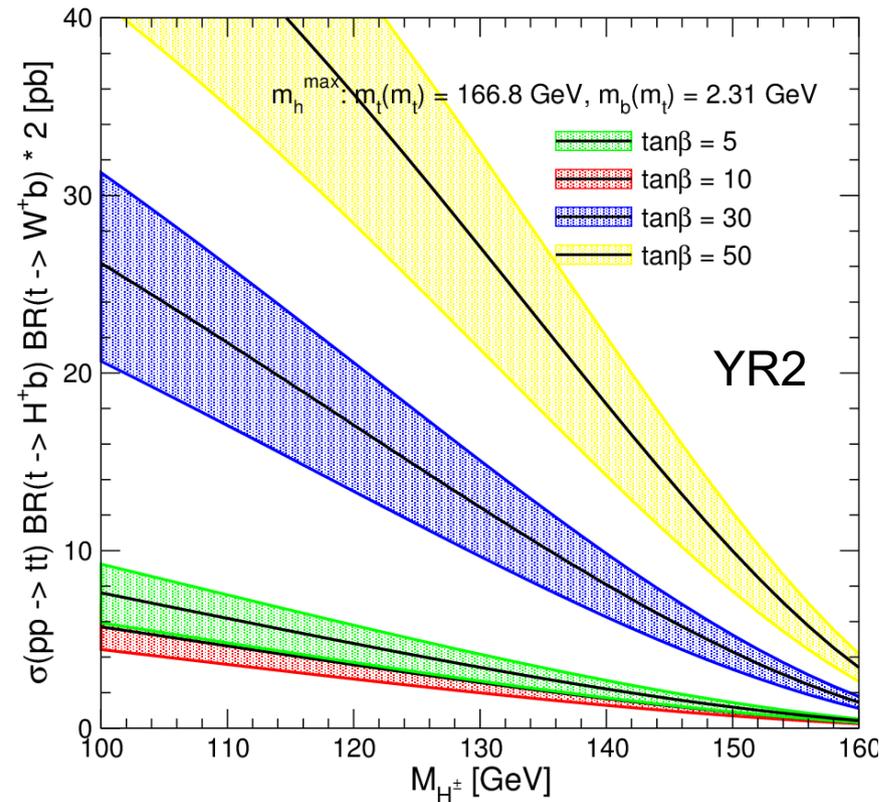
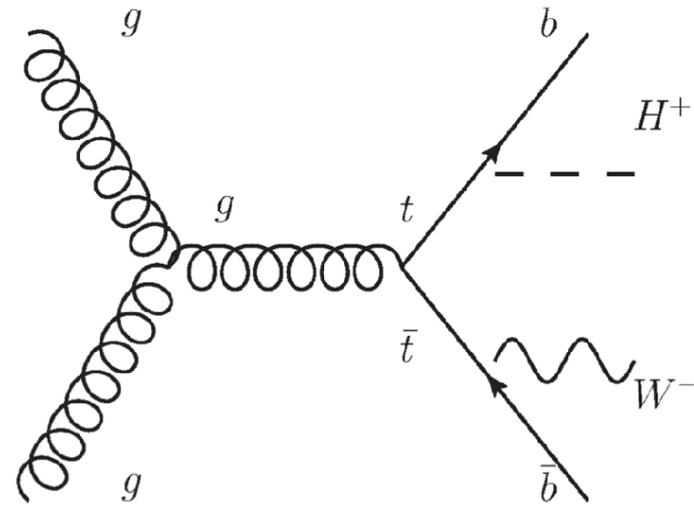
↑
NNLO: eg. hep-ph/9806244

Uncertainties:

$\sigma(tt)$, pdf, α_s , scales $\sim 10\%$

$\Delta m_t \sim 5\%$

$\Delta b \sim 0\text{-}25\%$

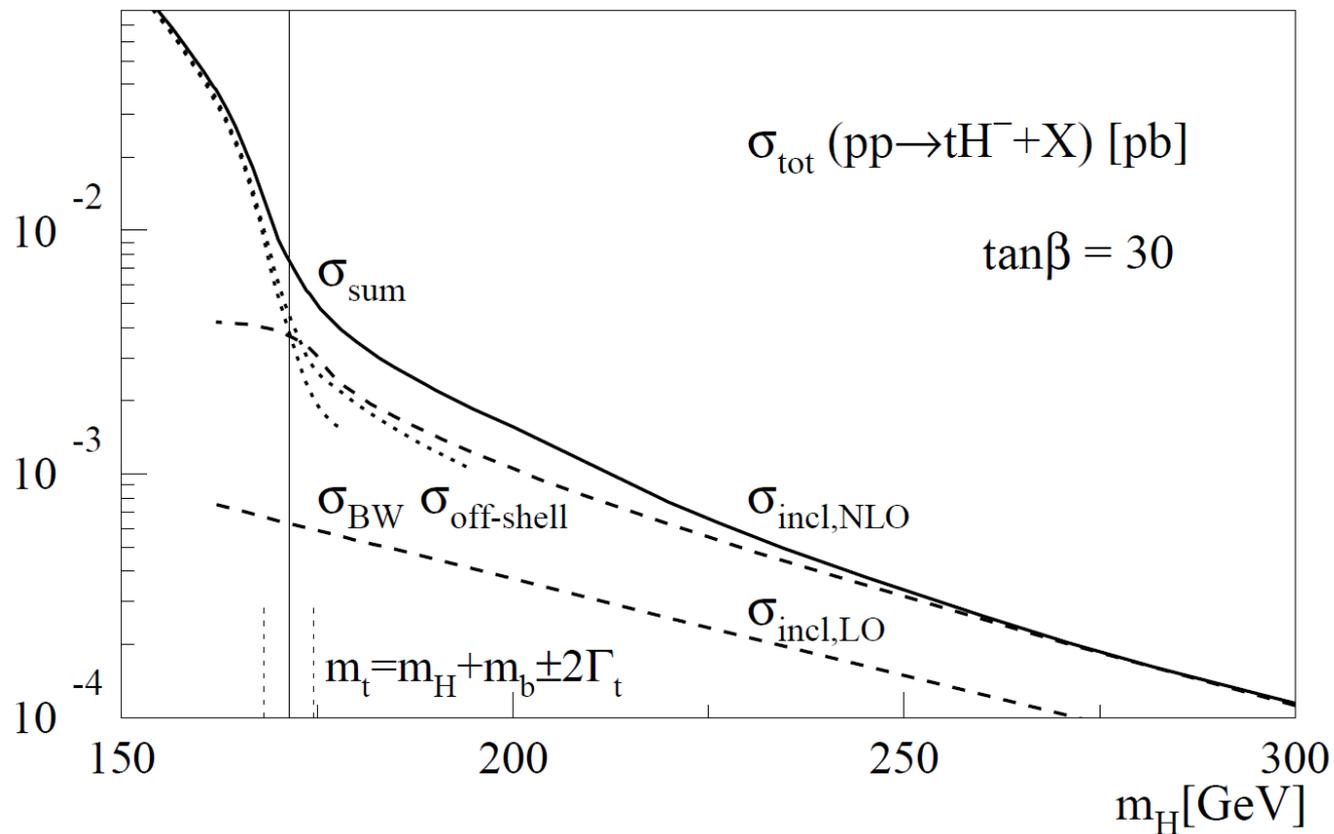


145 – 200 GeV, $m_{H^+} \sim m_{\text{top}}$

Contributions from top decay and tH^+ production. Not trivial to combine due to interference.

- See also [talks by Maria & Marco](#) at H⁺ meeting
- Talk by [Martin](#) at Charged 2016

Possible strategy 1: (Incoherent but simple) sum of both processes



- can use state-of-the-art calculations for both processes (NNLO+NNLL)

- experiments can simulate both processes separately (both at NLO)

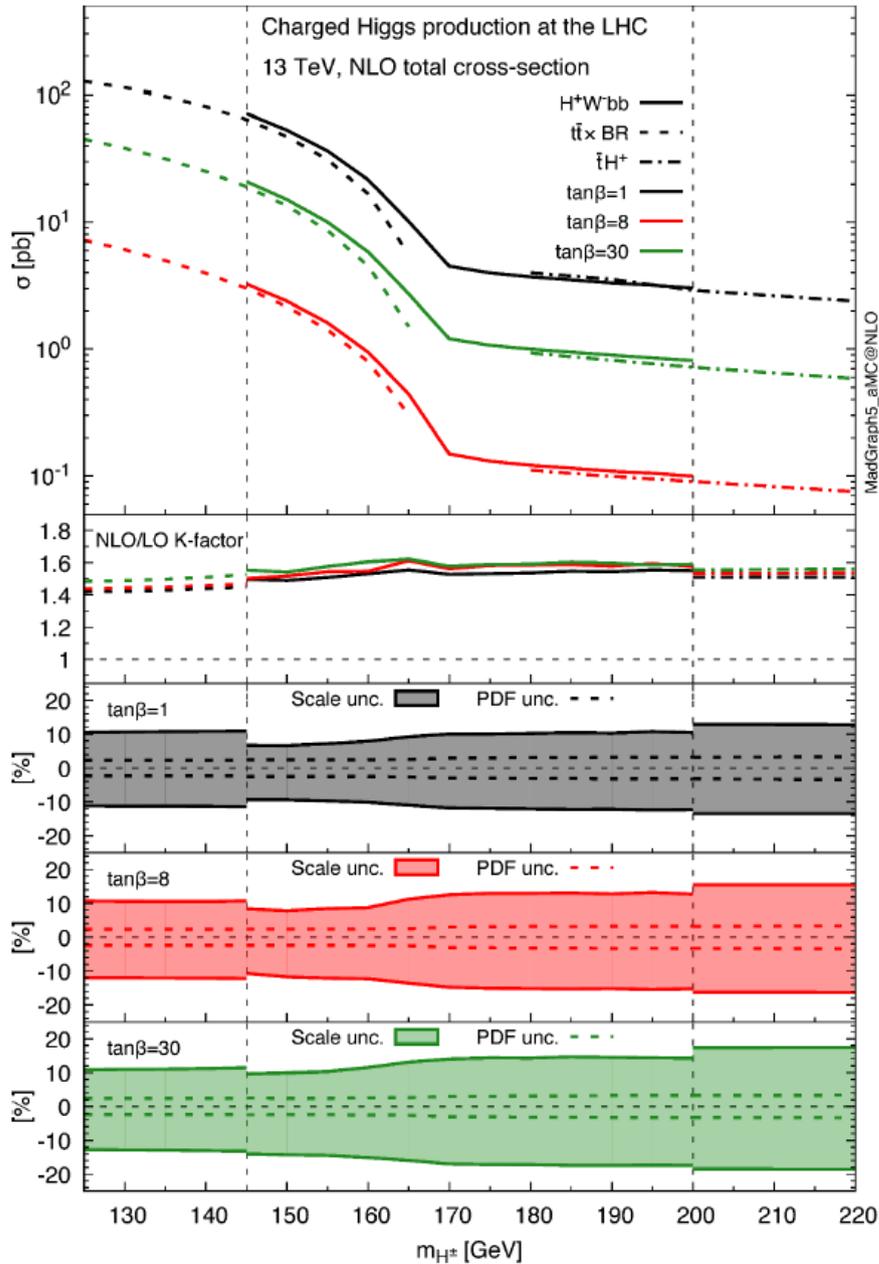
- negative interference might be included “by hand” with some assumptions

[hep-ph:0312286](#)

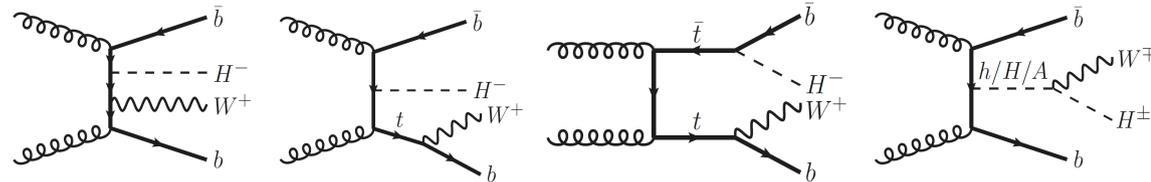
Strategy 2: Coherent calculation

<https://arxiv.org/abs/1607.05291>

(2016)



Calculating the full process at NLO pp → H⁺W⁺bb



- 4FS, massive b-quarks, type-II 2HDM
- Possible to transfer to type-I 2HDM

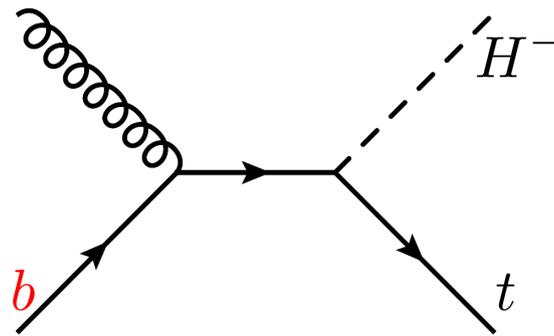
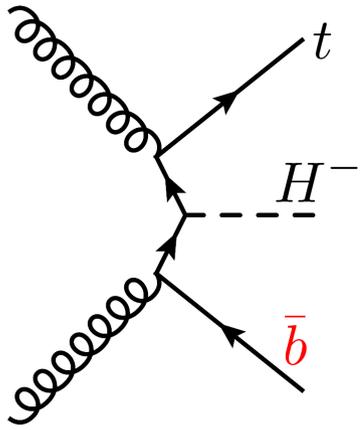
- no differential NLO cross sections (just LO)
- how to simulate kinematics?

Proposal:

for simulation, use LO 4FS pp → H⁺W⁺bb (eg. MG5)
rescale the cross section to NLO result

Works only if k-factor ratio is flat in the small phase space that the experiments use.

To be checked and followed-up on!



$m_{H^+} > m_{\text{top}} (\sim 200 \text{ GeV})$

H⁺ predominantly produced in association with a top (in 2HDM)

Numbers have been updated in YR4

4FS:

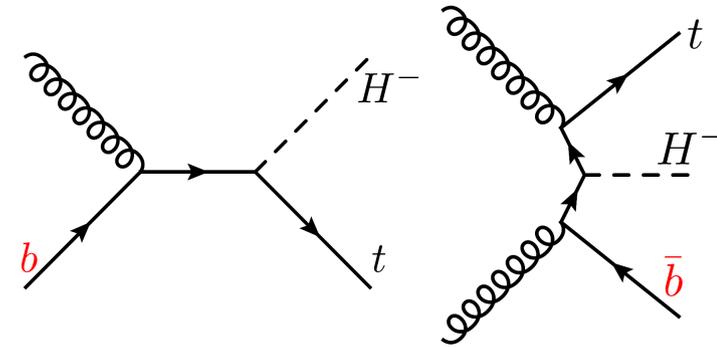
- no initial b-quarks
- LO processes:
 - $gg \rightarrow tbH^+$
 - $qq \rightarrow tbH^+$

5FS:

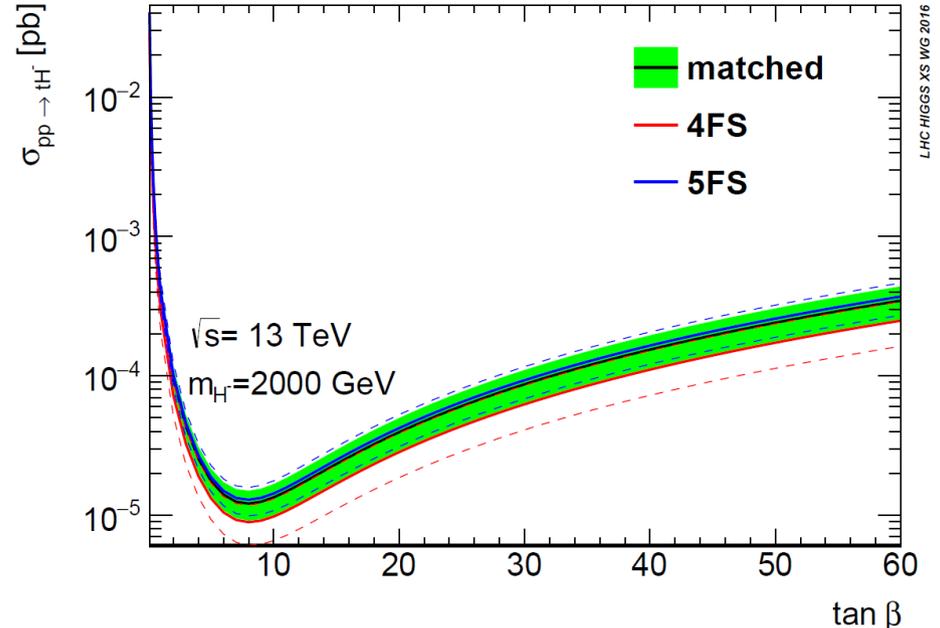
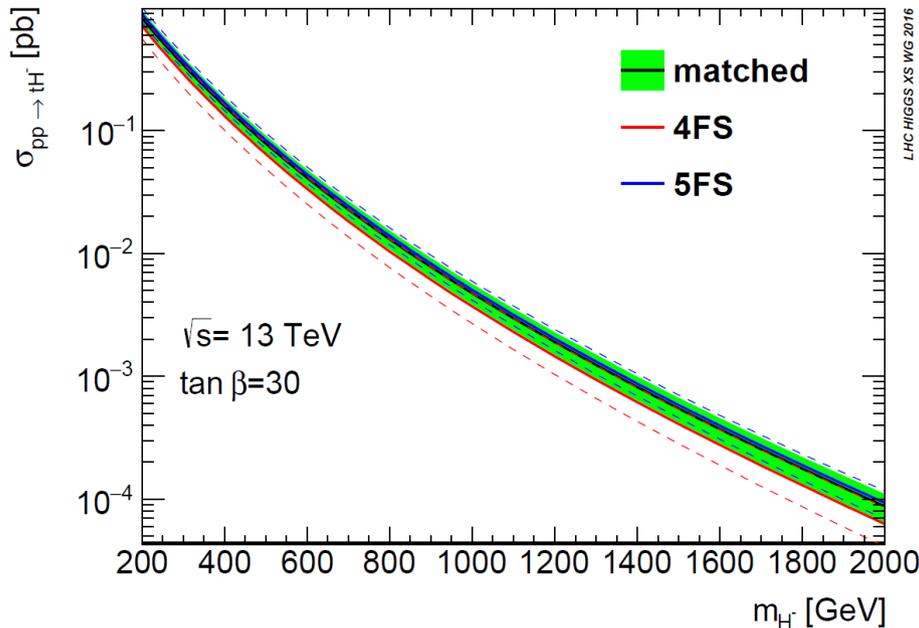
- employs b-quark PDF
- LO: $gb \rightarrow tH^+$
- NLO includes $gg \rightarrow tbH^+, qq \rightarrow tbH^+$

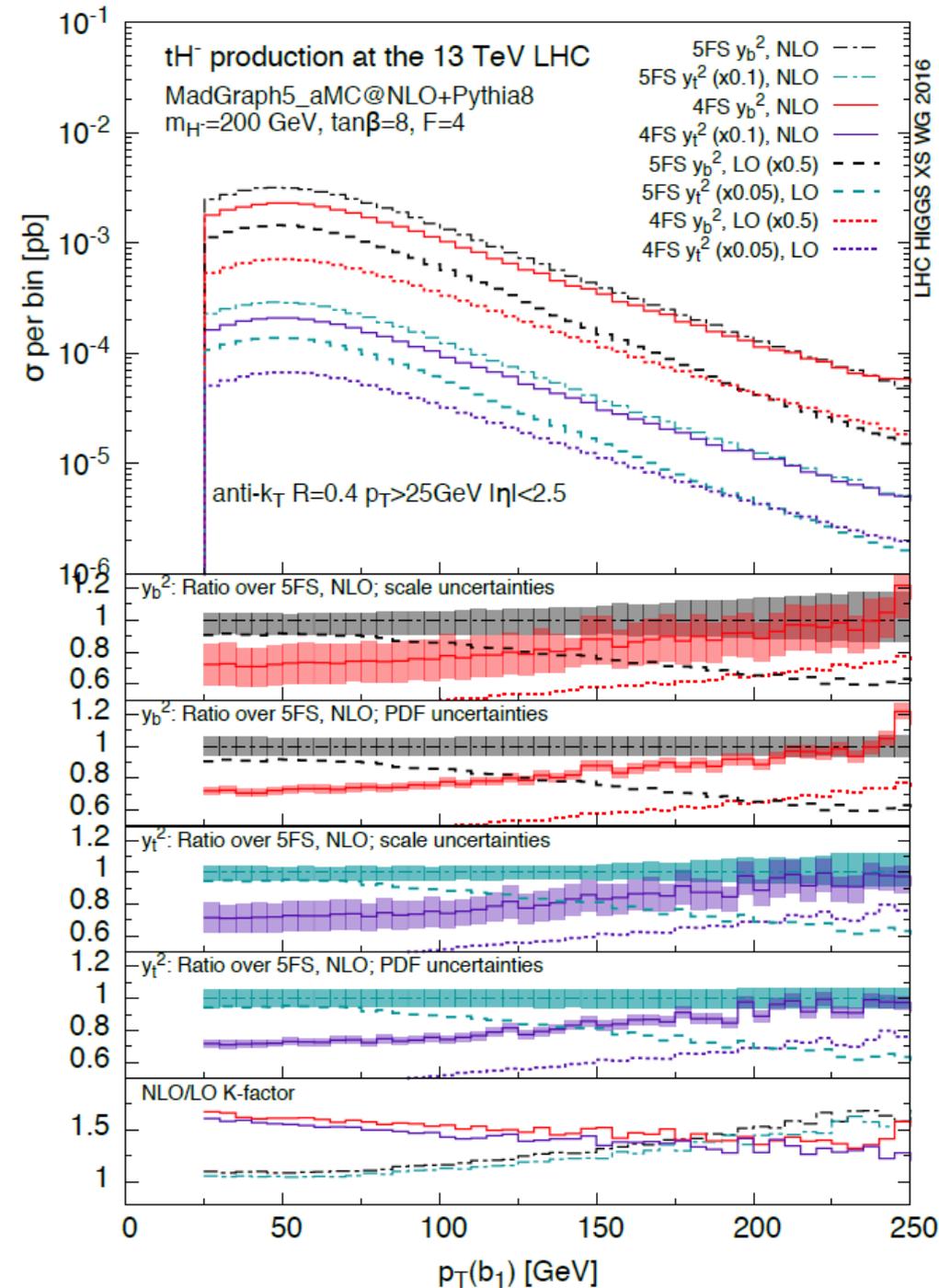
- The two approaches are identical at infinite order in pQCD, but at finite order there are differences
- Separately computed and then matched, uncertainties also matched

- Contributions proportional to y_b^2 and y_t^2 separately computed
- Uncertainties contain variations of $\mu_R, \mu_F, \mu_b, \text{PDF}, \alpha_s$
- Tools: 4FS: MG5_aMCatNLO, 5FS: Prospino



Santander matching:
$$\sigma^{\text{matched}} = \frac{\sigma^{4\text{FS}} + w \sigma^{5\text{FS}}}{1 + w} \quad \text{with} \quad w = \ln \frac{M_\phi}{m_b} - 2$$





Type-II 2HDM.

5FS (0912.3430, 1203.1341), 4FS (1507.02549)

NLO increases agreement between 4FS and 5FS

5FS gives good description of b-inclusive observables (p_T top, H)

4FS gives better description of exclusive variables (eg. leading b-quark)

4FS is recommended to be used for modelling the kinematics of tH⁺ signal processes used in the searches

4FS also reduces systematic uncertainties related to parton shower matching (explicit shower scale recommendations provided)

Twiki: <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGMSMCharged>

Numbers that are available:

Light H^+ :

Numbers for production $\sigma(tt) \cdot BR(t \rightarrow H^+b) \cdot BR(t \rightarrow Wb) \cdot 2$

Uncertainties on $\Gamma(t \rightarrow H^+b)$

Intermediate H^+ :

NLO cross sections in the range 145-200 GeV, scale and PDF uncertainties
 $\tan\beta$ 0.1-60 for type-I and type-II 2HDM

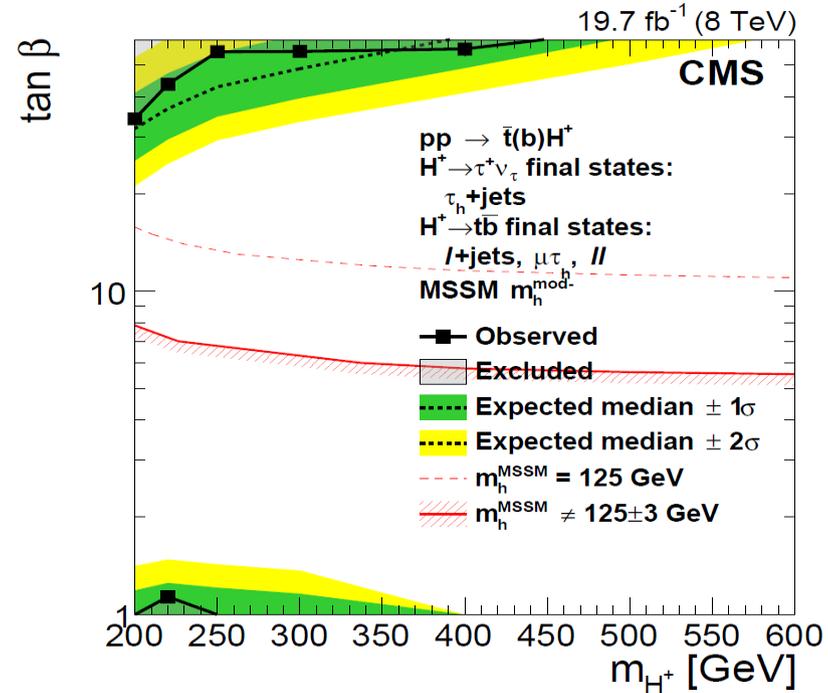
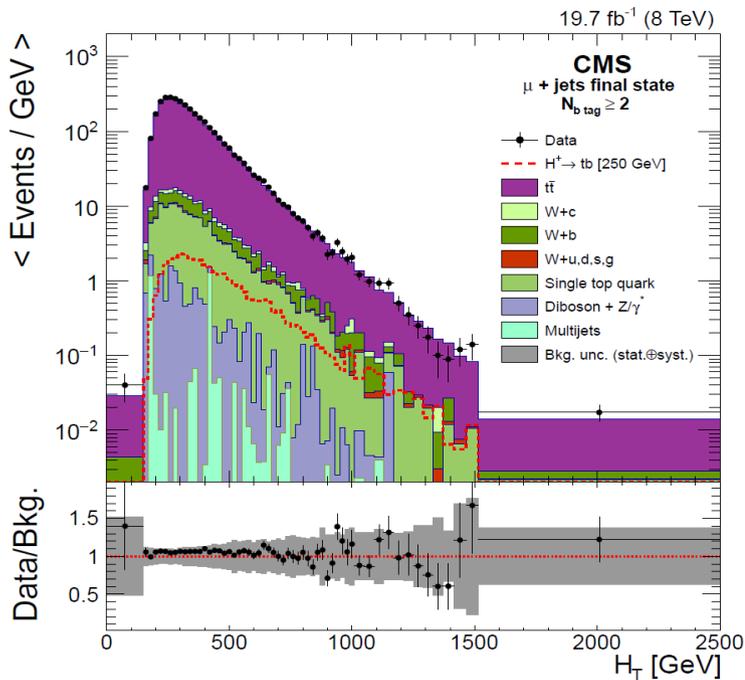
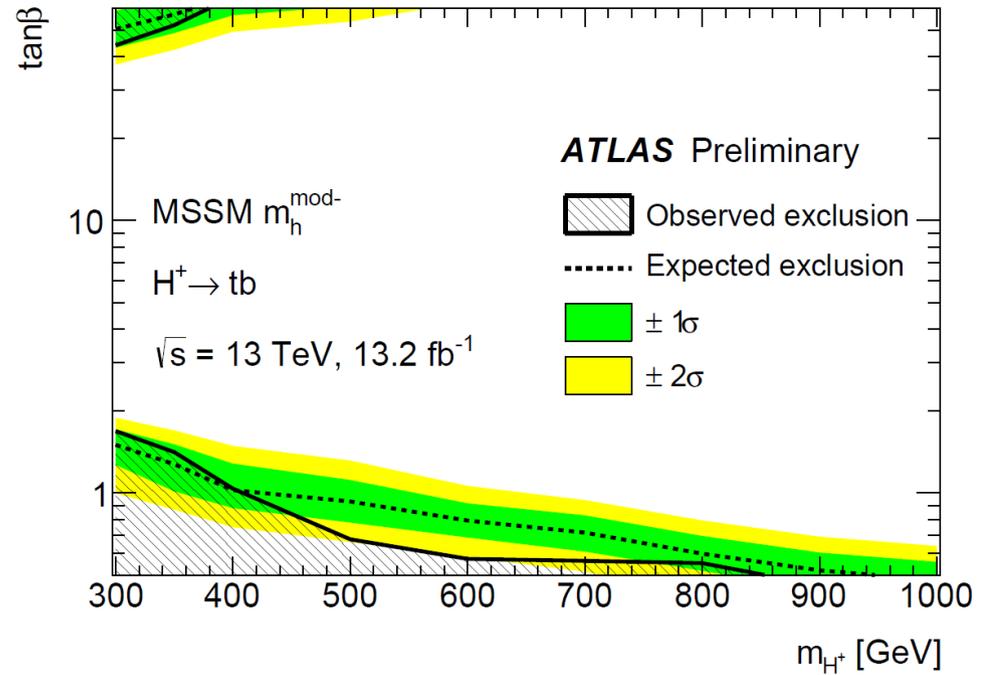
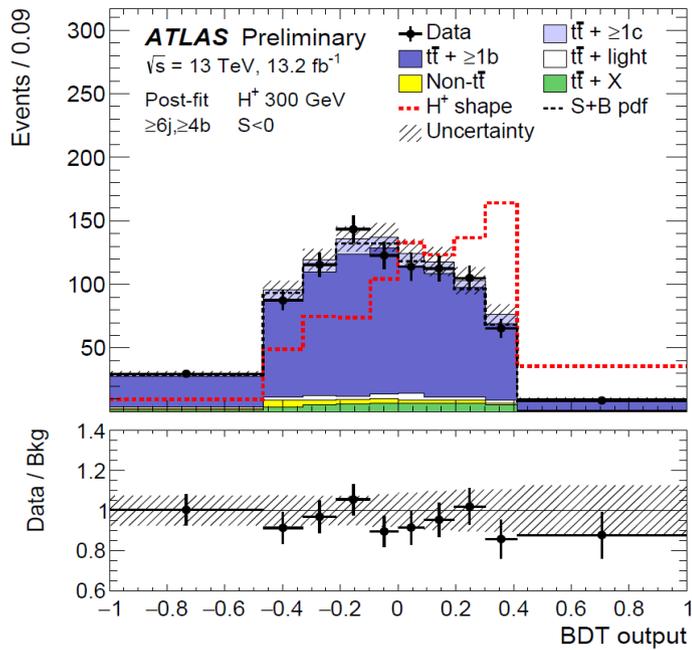
Heavy H^+ :

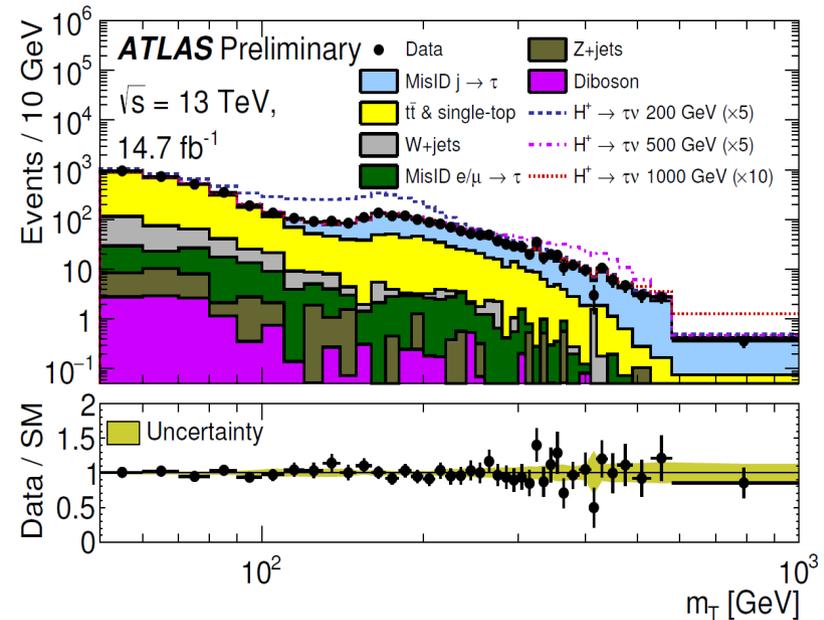
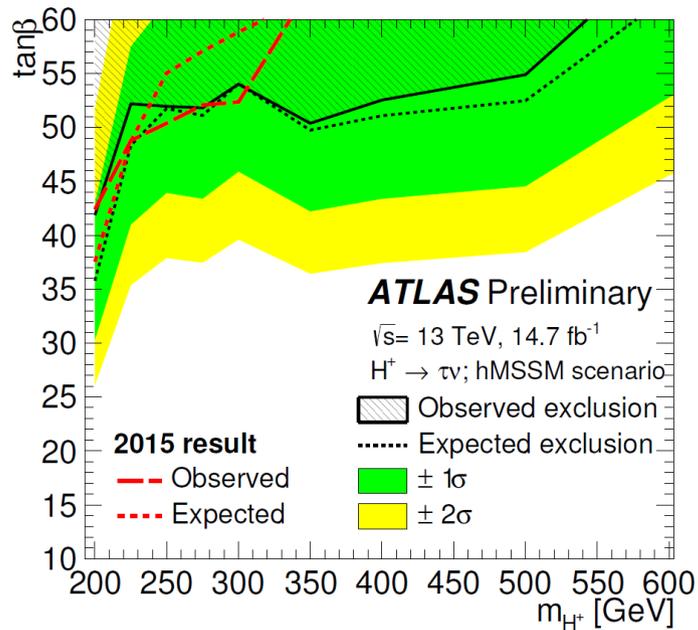
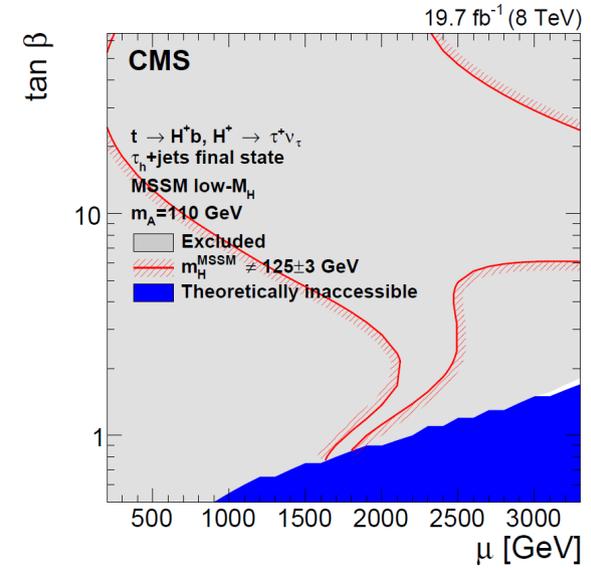
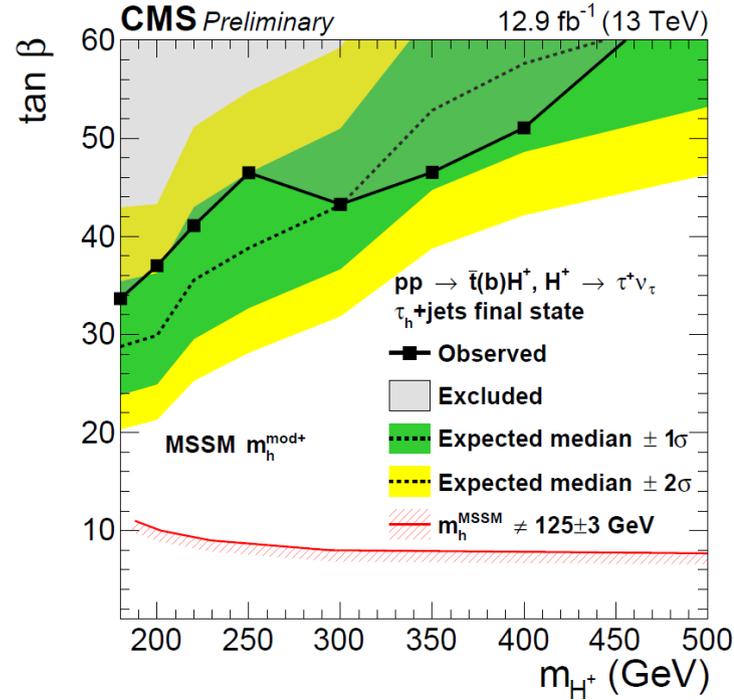
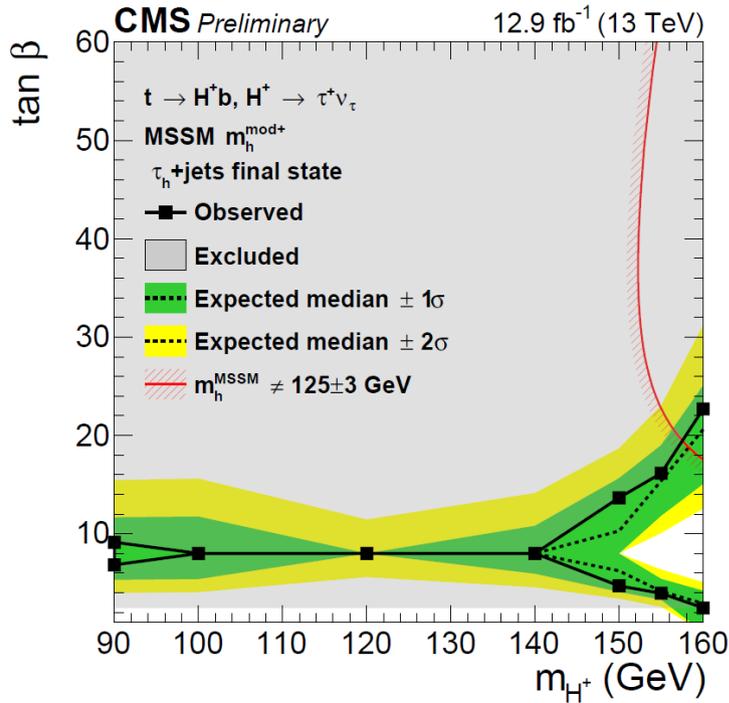
NLO cross sections 200-2000 GeV, $\tan\beta$ 0.1-60 for 2HDM type-II

- Can be applied to type-I, lepton-specific and flipped 2HDM using this [recipe](#):
 $\sigma(\text{type-I}, \tan\beta) = \sigma(\text{type-II}, \tan\beta=1) \cdot \cot^2\beta$ (and type-II=type-IV, type-I=type-III)
- Can be converted to MSSM cross sections by applying SUSY-QCD (*delta-b*) corrections provided for: mhmax, mhmod+-, tau-phobic, light-stop, light-stau, low-mH

H^+ decay branching fractions:

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGBRs>





GM model: Nucl. Phys. B 262 (1985) 463.

Higher order predictions:

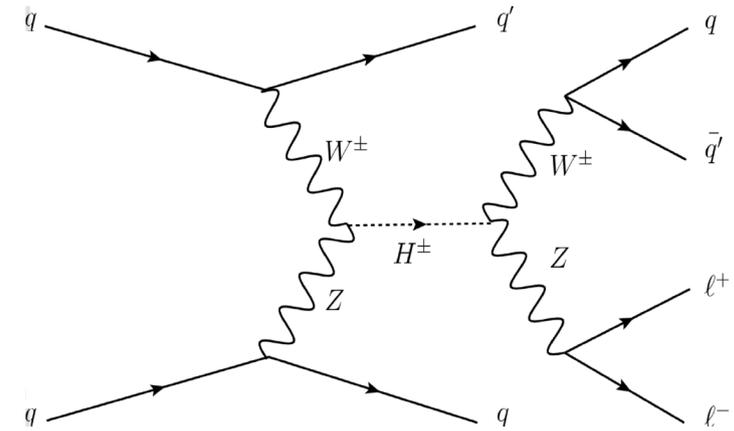
<https://arxiv.org/abs/1512.01243>, LHCHSWG-2015-001

Isospin-triplet scalars are added to the SM Higgs sector while preserving custodial SU(2) symmetry.

Those additional scalars do not couple to fermions

→ no ggF or tH^+ production mode

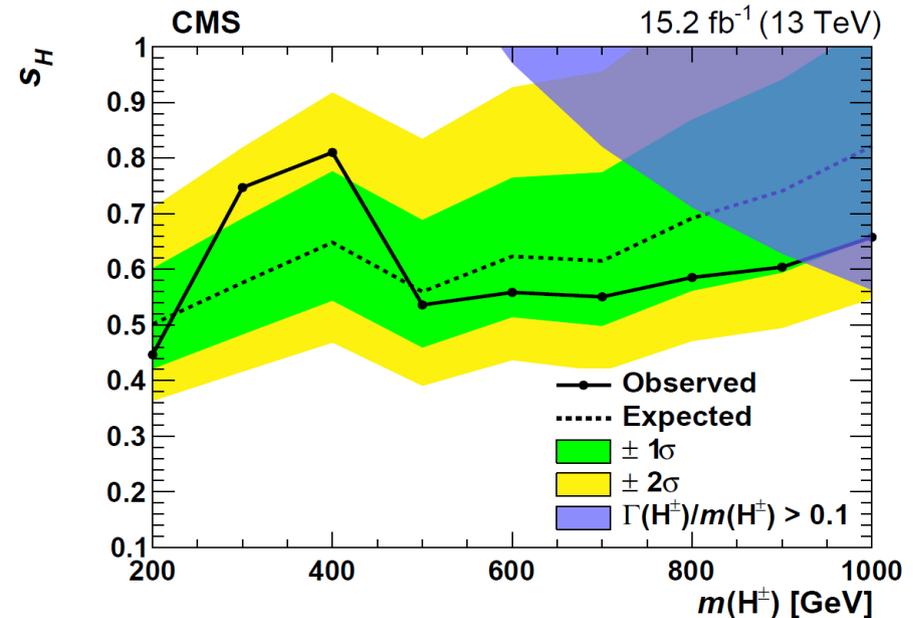
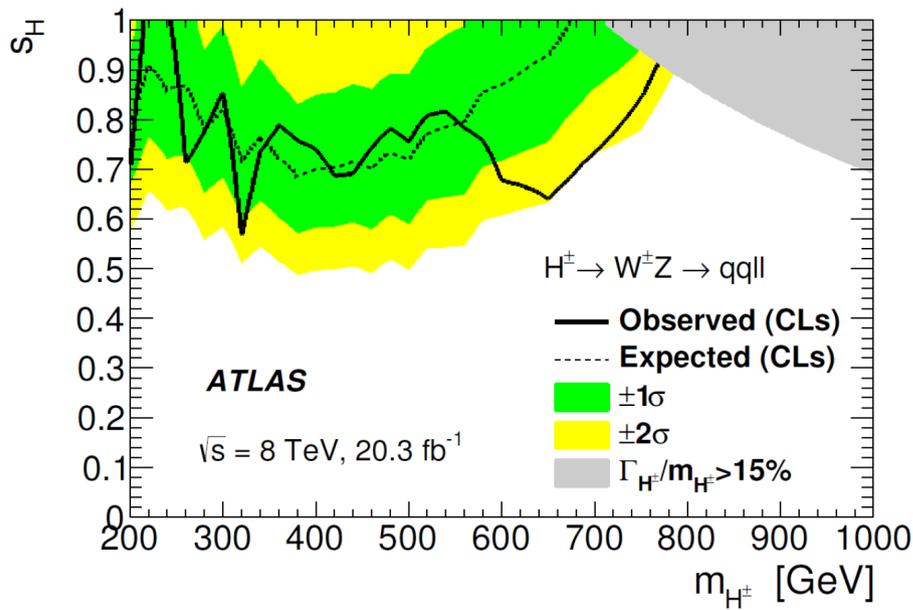
→ coupling to W/Z at tree level



GM models are investigated in the extended scalars group

ATLAS and CMS set limits in the GM model on the s_H parameter:

s_H quantifies the fraction of the W and Z masses that are generated by the Higgs triplet $\sigma_H^+ \sim s_H^2$



- The initial mandate of the group is
 - provide cross sections and guidance for MSSM H^\pm
This work is mostly completed in YR4 (pending intermediate mass range issues)
 - also: watch for new 2HDM developments in theory and generators,
be aware of experimental requirements and update recommendations/numbers as needed
- Possible ways to extend the mandate? Need input from experiments.

s-channel production

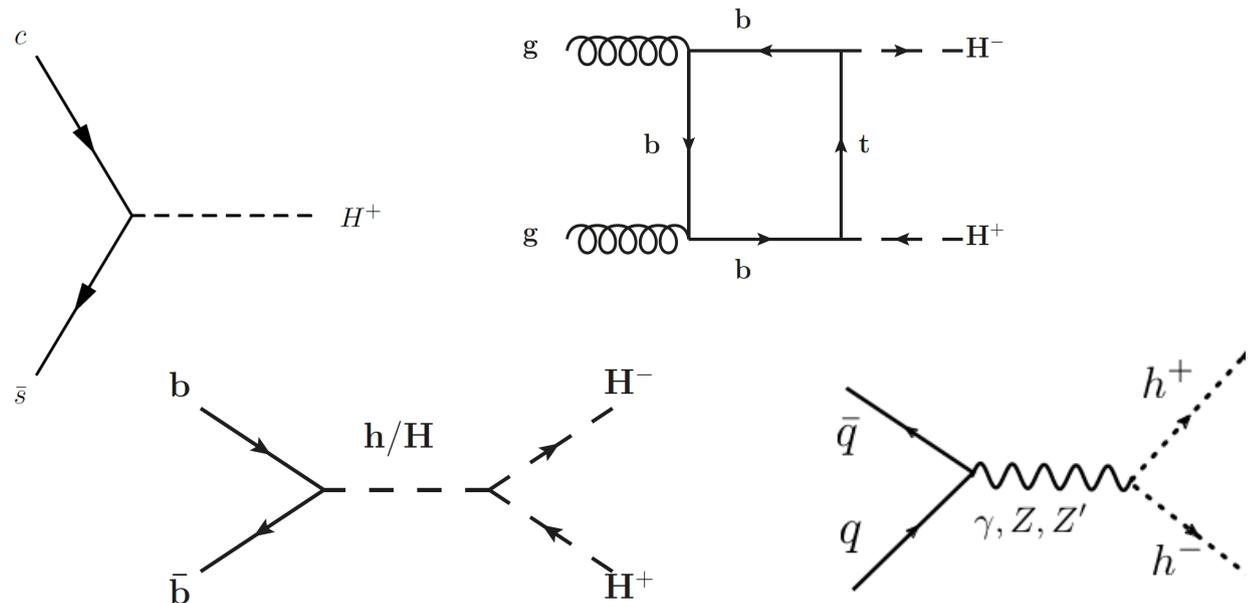
H^+H^- pair production

NMSSM h^\pm

Triplet/GM models (already investigated in extended scalars group)

H^{++}, H^-

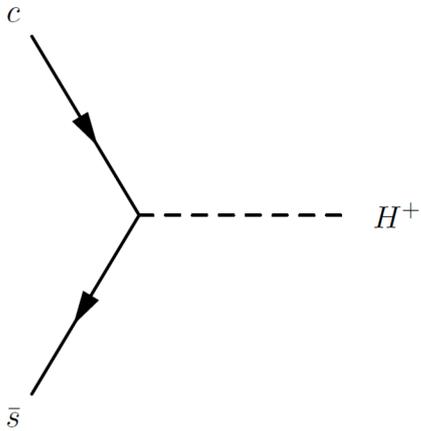
Stealth model (1311.4367)



See also the [talk by K. Huitu](#) at Charged2016

Are those interesting and relevant? Other channels/models? We welcome feedback on that.

How to deal with the overlap to the other WG3 subgroups?



No associated top \rightarrow easier from the experimental point of view:

Mass reconstruction, background reduction.

But H^+ width becomes very large for low $\tan\beta$ and high mass

Might be interesting also beyond 2HDM

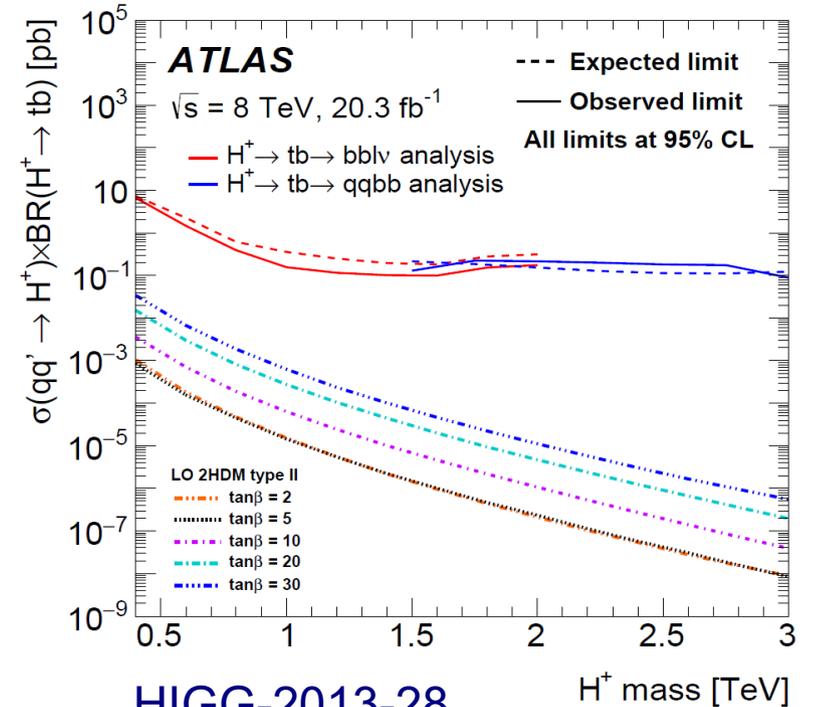
8 TeV LO $\sigma^* \text{ BR} (H^+ \rightarrow tb)$ for type-II 2HDM:

Computed using MG5 + NLOCT (1406.3030)

m_{H^+} [GeV]		$\tan\beta$						
		0.5	1	2	10	20	30	50
400	$\sigma \times \text{BR}$ [fb]	14	3.8	1.1	3.6	15	34	94
	Γ [GeV]	60	15	3.8	0.72	2.3	5.2	14
800	$\sigma \times \text{BR}$ [fb]	0.72	0.17	0.047	0.19	0.82	1.9	5.3
	Γ [GeV]	140	36	9.0	1.6	5.2	11	32
1000	$\sigma \times \text{BR}$ [fb]	0.24	0.055	0.015	0.063	0.28	0.63	1.8
	Γ [GeV]	145	80	11	2	6.4	14	39
1600	$\sigma \times \text{BR}$ [ab]	23	3.9	0.96	4.6	20	47	140
	Γ [GeV]	280	69	17	3.1	9.9	22	61
2000	$\sigma \times \text{BR}$ [ab]	6.9	0.96	0.21	1.1	4.7	11	36
	Γ [GeV]	340	85	21	3.8	12	27	74
3000	$\sigma \times \text{BR}$ [ab]	0.89	0.07	0.0088	0.039	0.20	0.55	2.5
	Γ [GeV]	490	120	31	5.5	17	39	110

ATLAS search for s-channel produced $H^+ \rightarrow tb$ (re-interpretation of $W' \rightarrow tb$)

2-5 orders of magnitude above prediction

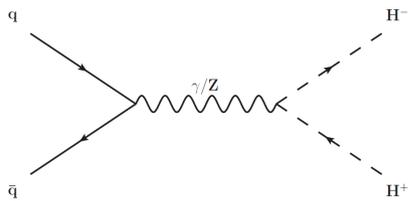


At $\tan\beta=50$ 1 TeV, only factor 1.5 smaller than tH^+ x-sec

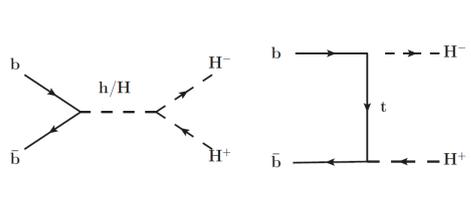
See also talk by J. Baglio at Charged2016

In general: Search for and observation of (SM or BSM) HH is a major goal for future (HL LHC)

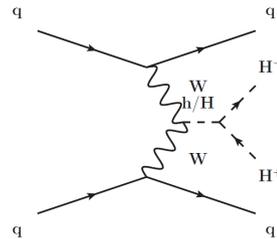
- Drell-Yan production
- Bottom quark fusion
- Vector boson fusion
- Gluon fusion



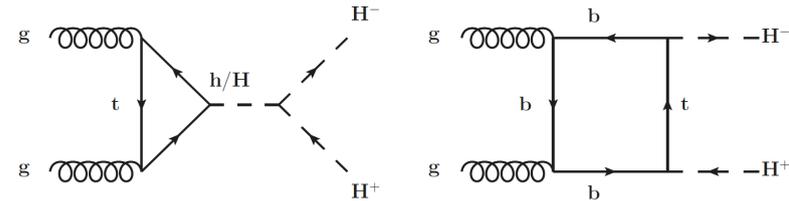
NLO in QCD



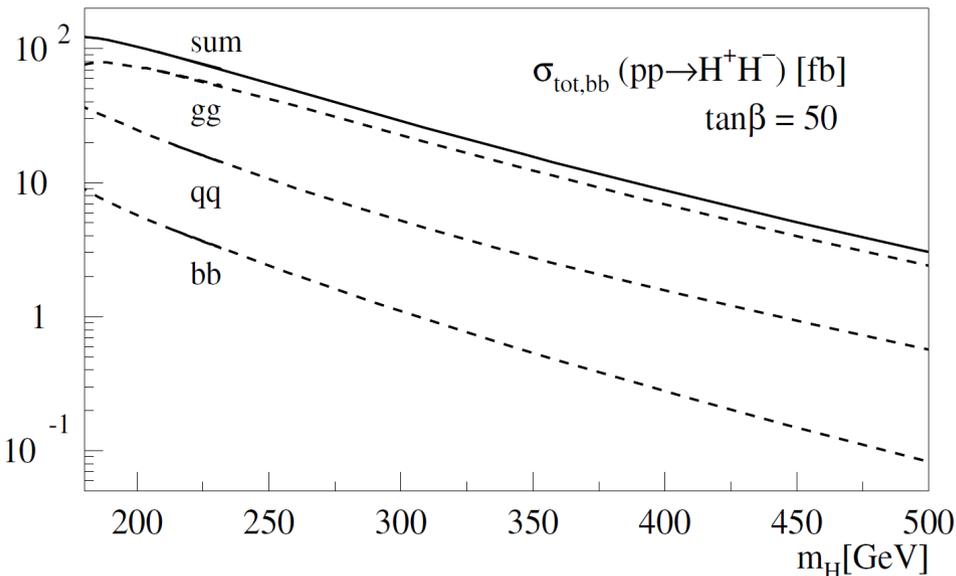
NLO in QCD



LO in QCD



LO in QCD



Could explore many different final states

Very small cross sections!

Need lots of luminosity.

Would be enhanced for resonant production.

- NLO inclusive and fully differential cross sections for light and heavy H^+
- Have been/will be used by the experiments for their searches
 - No excess (yet)
 - Limits set in various MSSM scenarios, and also the GM model
 - No public result yet for intermediate mass range
- Still under investigation in intermediate mass range:
How to use coherent NLO calculation in the signal simulations?
- If and how to extend the mandate of the H^+ subgroup in WG3?

What are the experiments priorities?

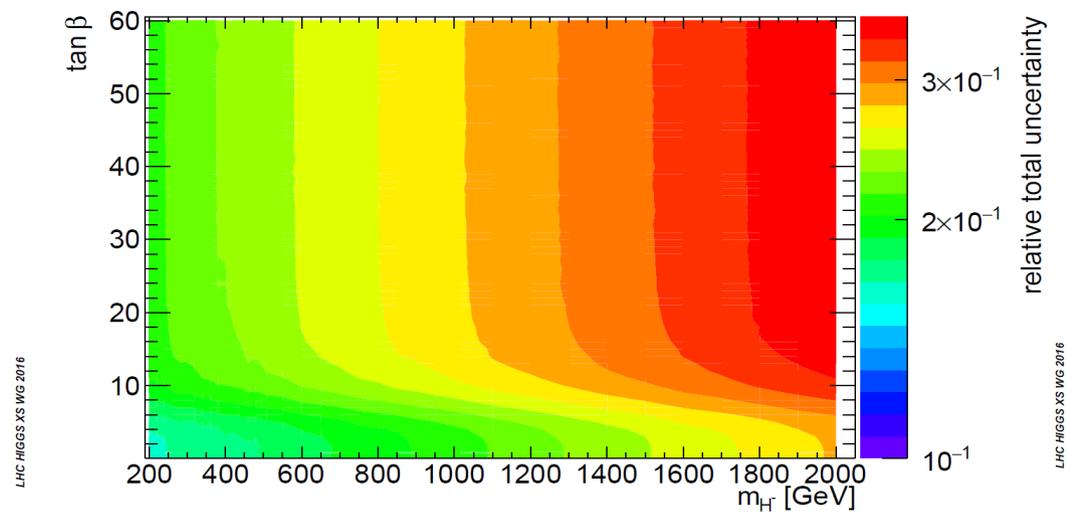
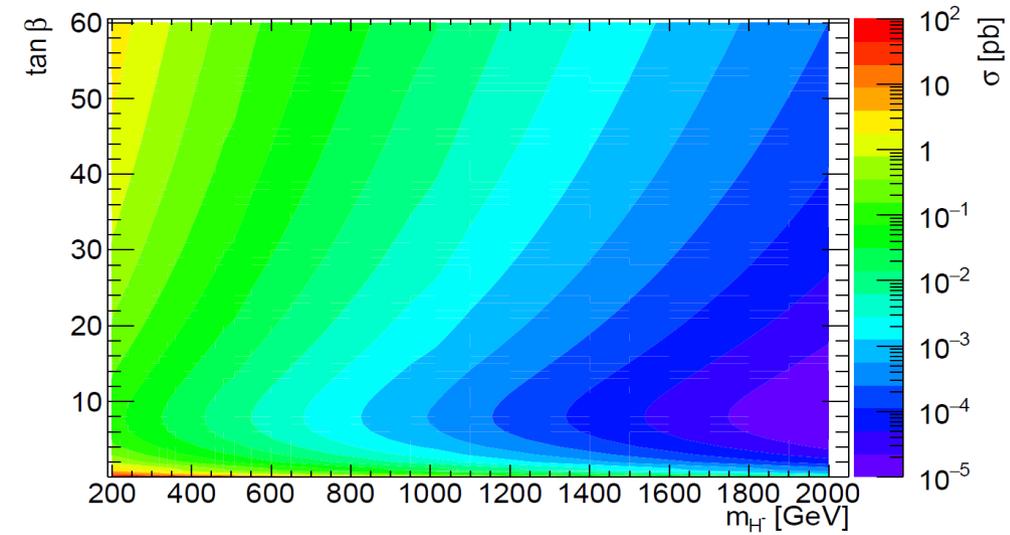
We are happy to work on new channels, but we cannot provide inputs for all models.

Please give us concrete feedback.

Backup

YR4 Recap

4FS cross sections:



5FS cross sections:

