Charged Higgs Report

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

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Outline

Part I:

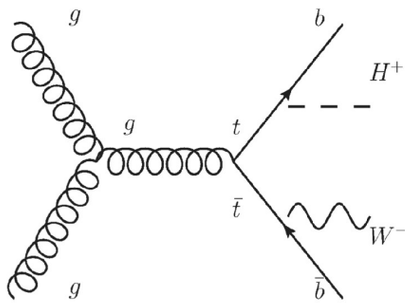
- Review of the recommendations for MSSM/2HDM
- Status of interference calculation
- Negative weights in H^+ signal MC

Part II:

- Discussion of possible $H^{+(+)}$ channels (incl. review of current experimental results)

Recommendations for the MSSM/2HDM

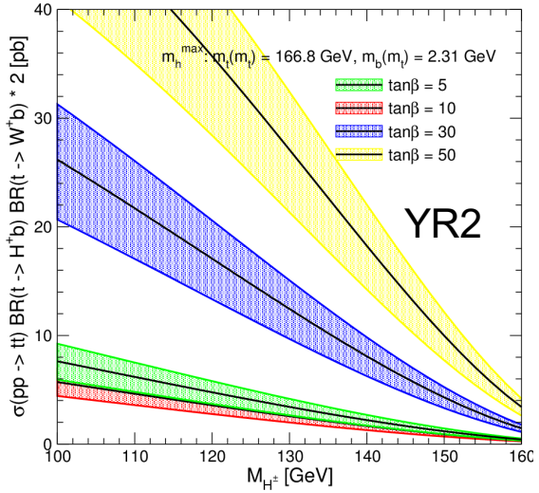
Low mass



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

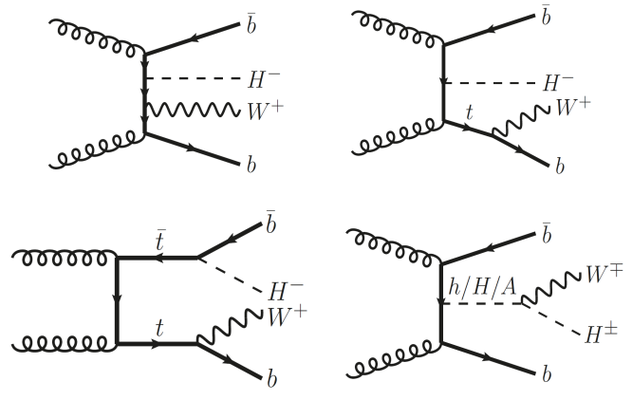
NNLO
PRL 110 (2013)

NLO: Phys. Rev. D76 (2007), hep-ph/9301237
NNLO: eg. hep-ph/9806244

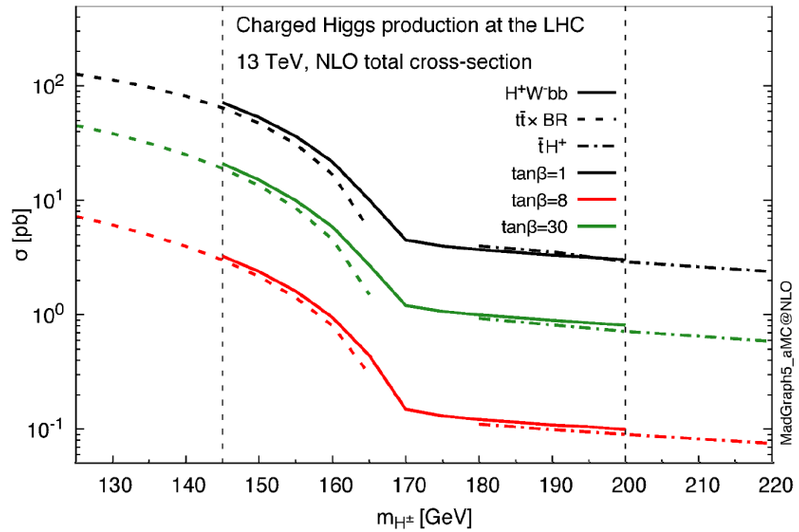


Intermediate mass

NLO $pp \rightarrow H^+W^-bb$

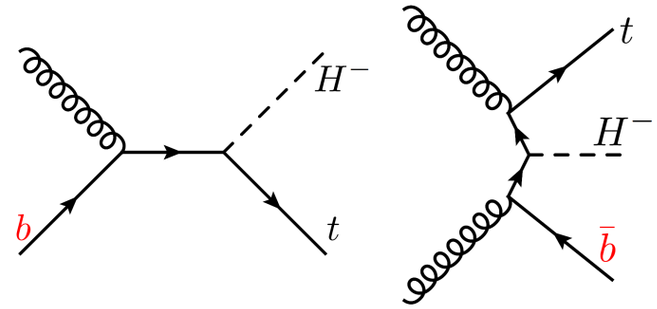


https://arxiv.org/abs/1607.05291

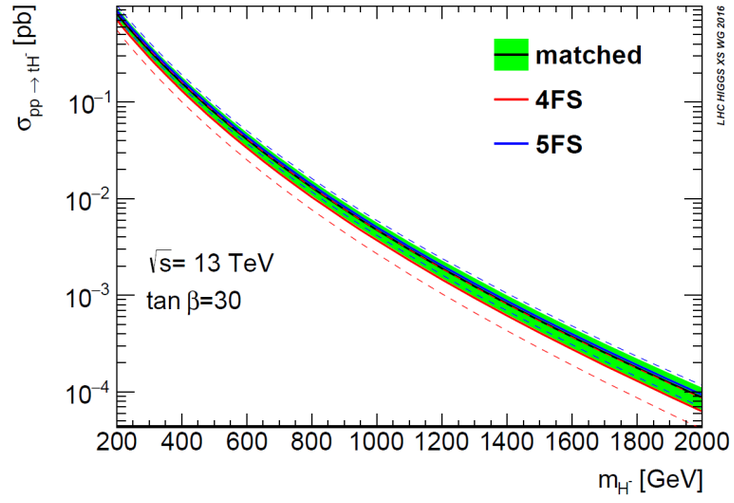


Differential cross sections at LO

High mass



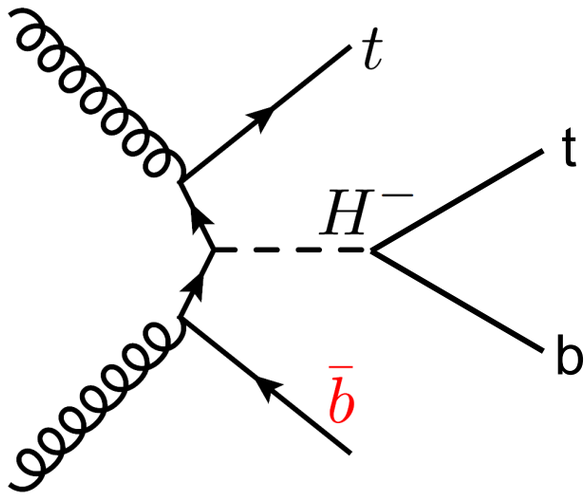
Tools: 4FS: MG5_aMCatNLO,
5FS: Prospino

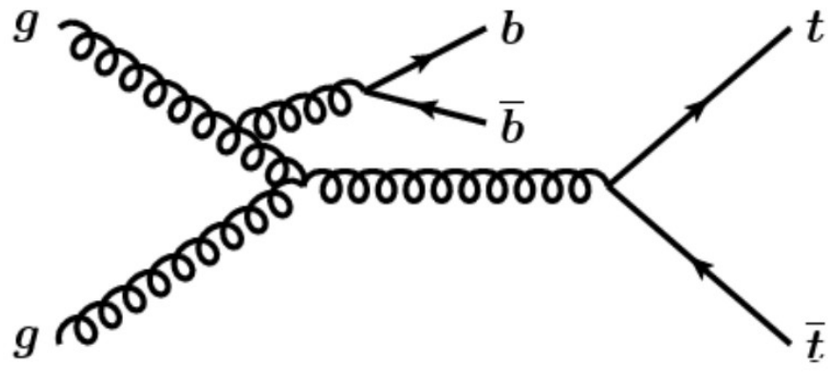


Differential cross sections at NLO

Status of the Interference Calculation

For example, in the tb channel:





- The tH^+, $H^+ \rightarrow tb$ signal has the same final state as tt+bb background

- These diagrams (and many others) can interfere with each other

- This has not been taken into account in the previous results by ATLAS and CMS

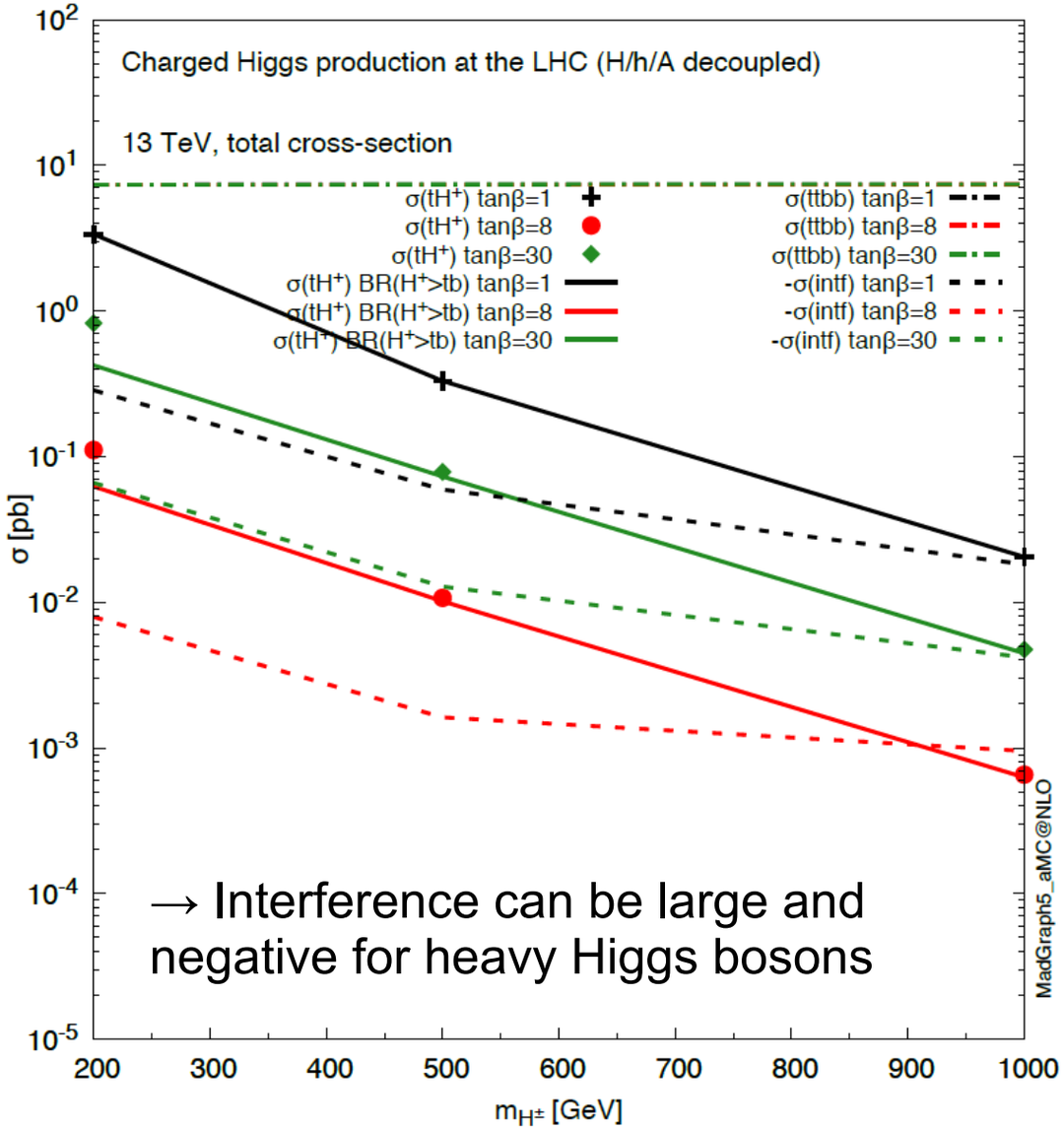
- The H^+ contacts were asked to assess the size of this effect and provide recommendations

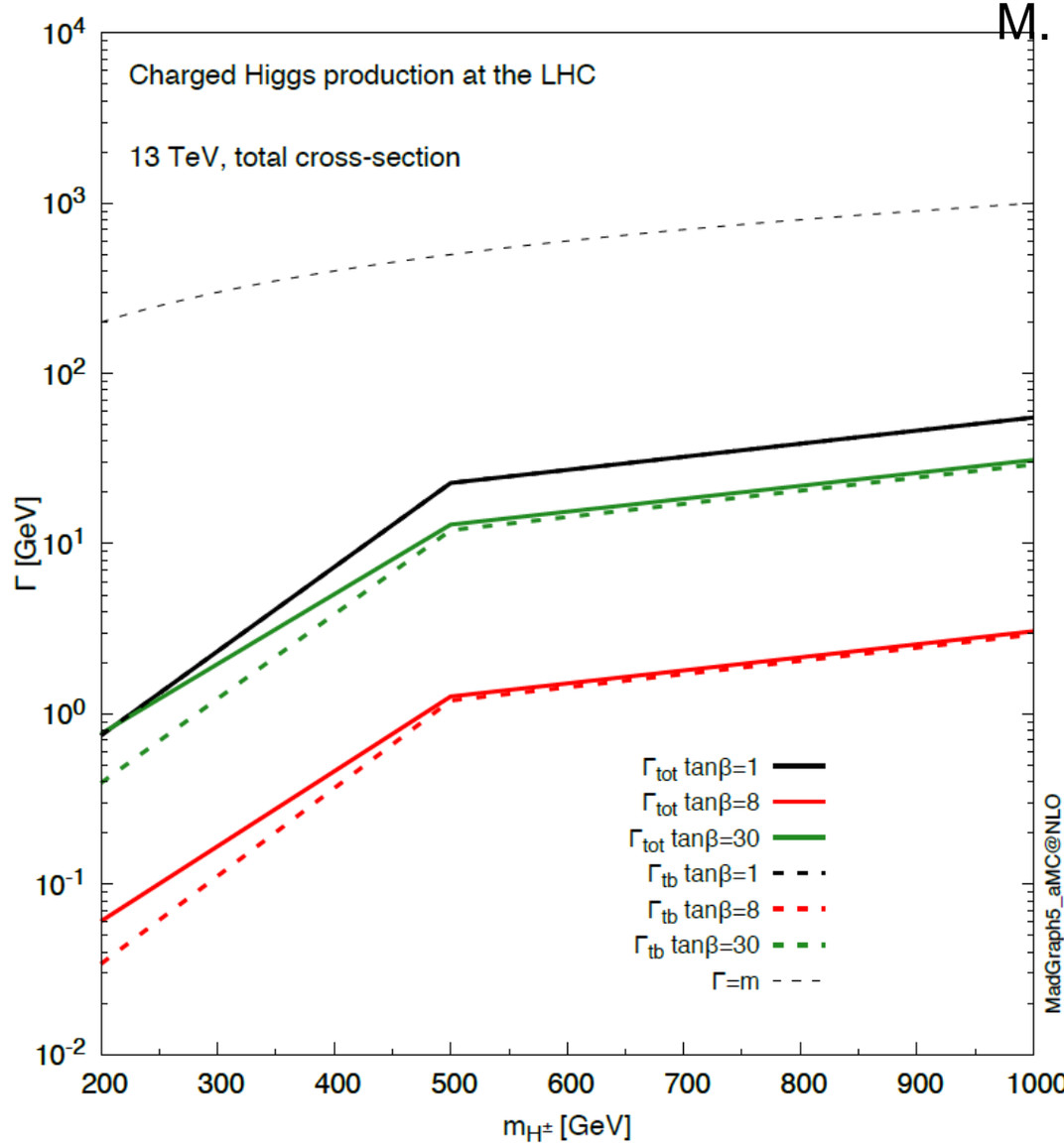
- We started this task and discussed the issue at our last H+ meeting, where we also invited experts on the subject from the theory

Status of the Interference Calculation

Very preliminary study with MG5_aMCatNLO: Case 1 with h/A/H heavy → H^+ decays only to tb or τν

M. Zaro



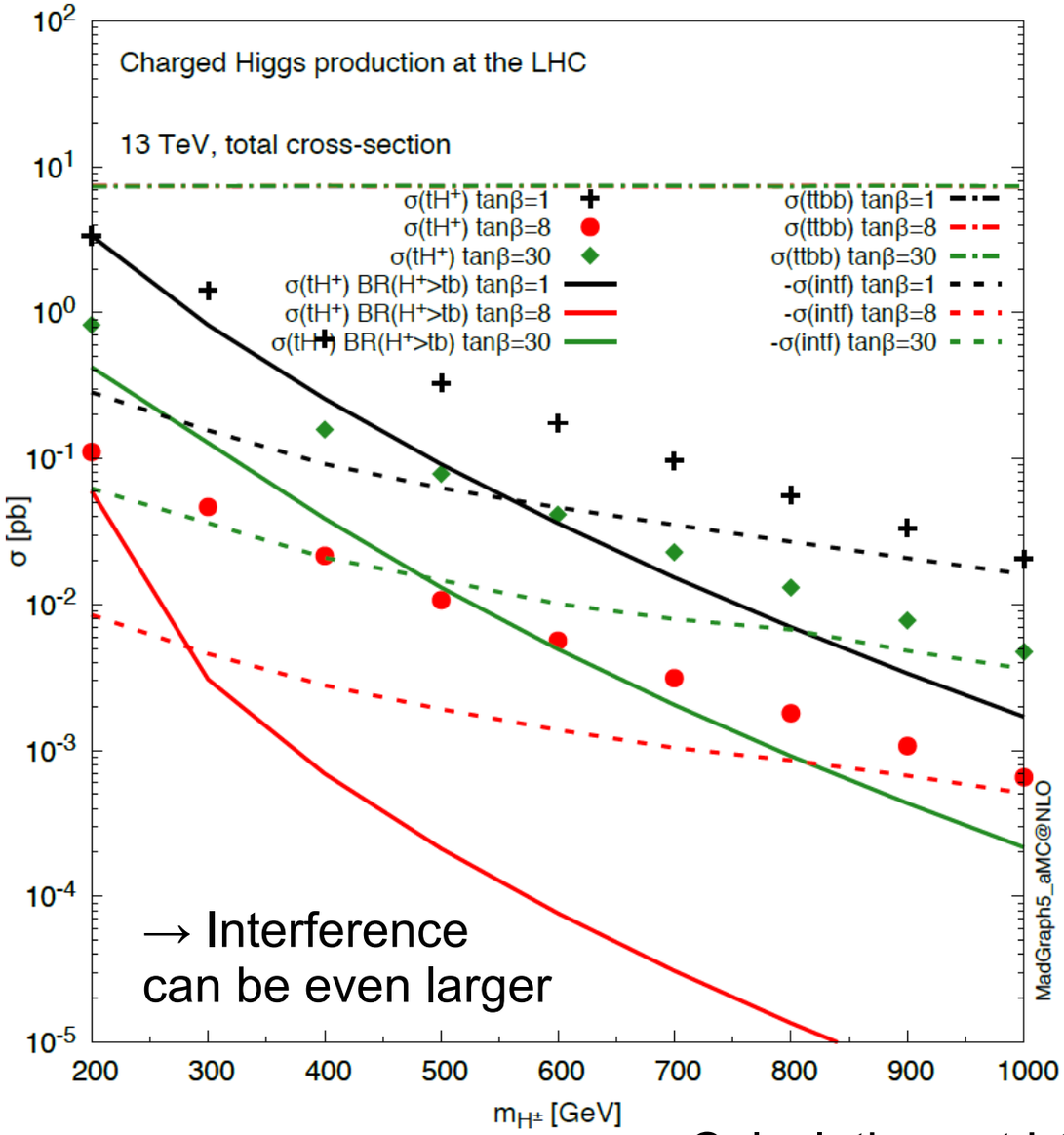


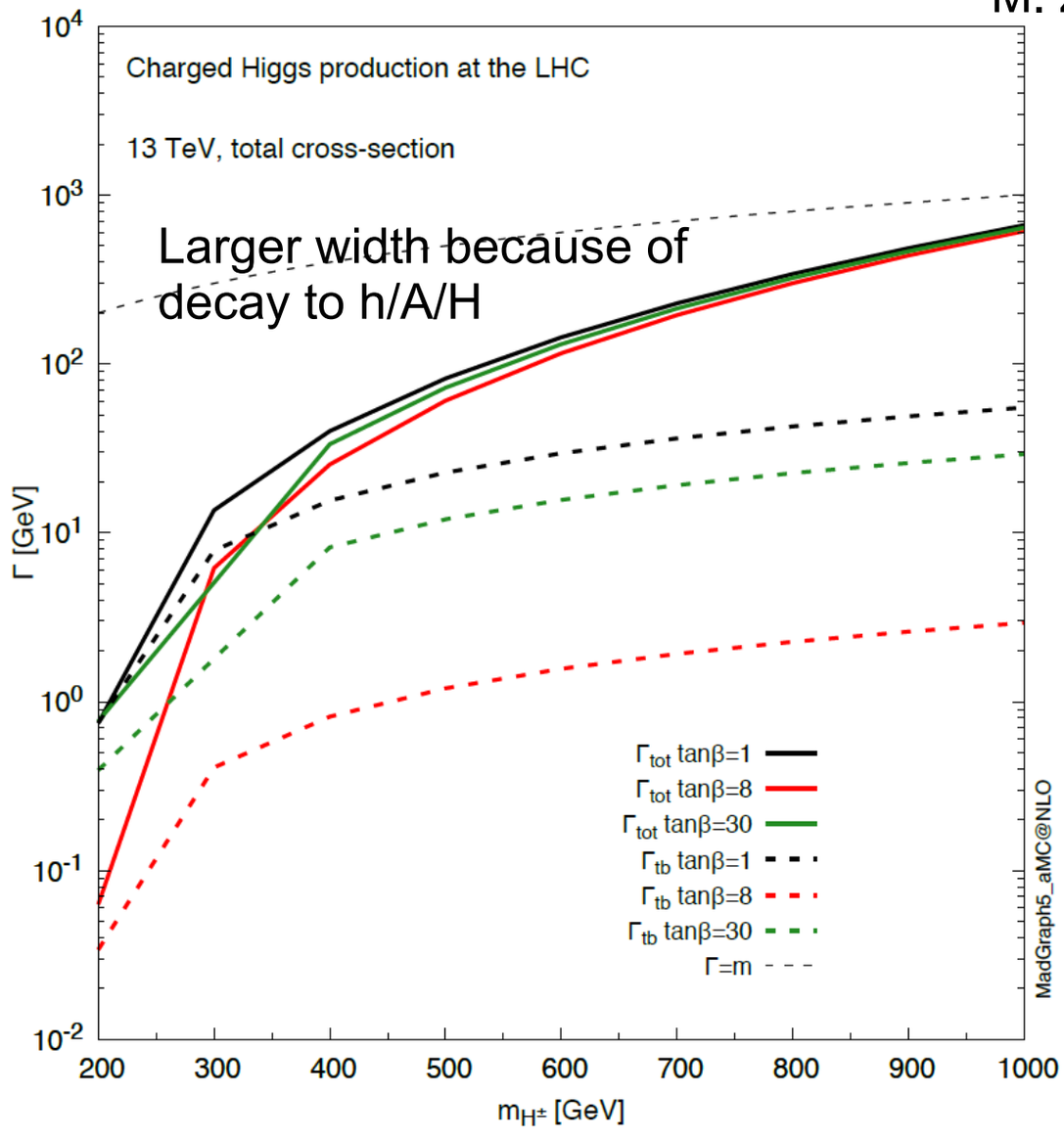
Calculations at LO only, no cuts applied

Status of the Interference Calculation

Very preliminary study with MG5_aMCatNLO: Case 2 with h/A/H masses of 120/130/140 GeV

M. Zaro





Calculations at LO only, no cuts applied

Status of the Interference Calculation

A. Arhrib, R. Benbrik, S. Moretti, Rui Santos, P. Sharma: arXiv:1712.05018

- Have assessed the interference in **pp → tH$^-$ → tW$^-$bb**
- Decay modes contributing to this final state: Wh(bb), WH(bb), WA(bb) and tb→Wbb
- In arXiv:1604.04965 it was found, that interference between the signal contributions is negligible
- 2HDM Benchmark points (II - type-II, F – Flipped, lower table for type-III):

	$\tan\beta$	$\sin(\beta-\alpha)$	$m_{H^\pm}$ (GeV)	m_A (GeV)	m_{12}^2 (GeV^2)	$\Gamma(A)$	$\Gamma(H^\pm)$
BP1 (II)	10.25	0.98	509.14	248.27	52287.83	0.47	72.85
BP2 (II)	16.75	0.99	545.82	268.41	33622.43	1.29	91.97
BP3 (II)	18.80	0.99	457.71	247.22	16427.97	1.50	34.83
BP4 (F)	37.21	0.99	469.45	258.03	9800.68	5.45	50.45
BP5 (F)	44.10	1.00	519.45	288.32	10200.34	10.46	85.45

	$\tan\beta$	$\sin(\beta-\alpha)$	$m_{H^\pm}$ (GeV)	m_A (GeV)	$\Gamma(A)$	$\Gamma(H^\pm)$
BP1	15.84	0.99	480.75	369.89	2.79	60.72
BP2	19.41	0.99	307.23	225.46	1.69	12.78
BP3	38.11	0.99	447.45	258.33	6.10	52.77

Status of the Interference Calculation

- Parton-level cross sections for signal, background and signal-background interference:

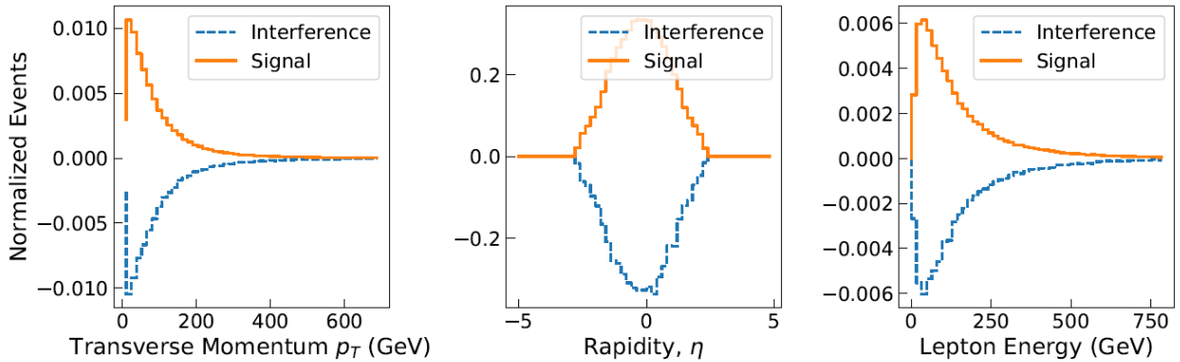
BP	Signal (pb)	Background (pb)	Total (pb)	Interference (pb)
BP1	0.031	10.03	9.96	-0.101
BP2	0.052	9.96	10.02	-0.008
BP3	0.144	10.07	10.18	0.034
BP4	0.469	9.94	10.31	-0.102
BP5	0.742	10.43	10.72	-0.452

BP	Signal (pb)	Background (pb)	Total (pb)	Interference (pb)
BP1	0.059	10.35	10.27	-0.139
BP2	0.978	9.95	10.92	-0.008
BP3	0.291	10.02	10.34	0.029

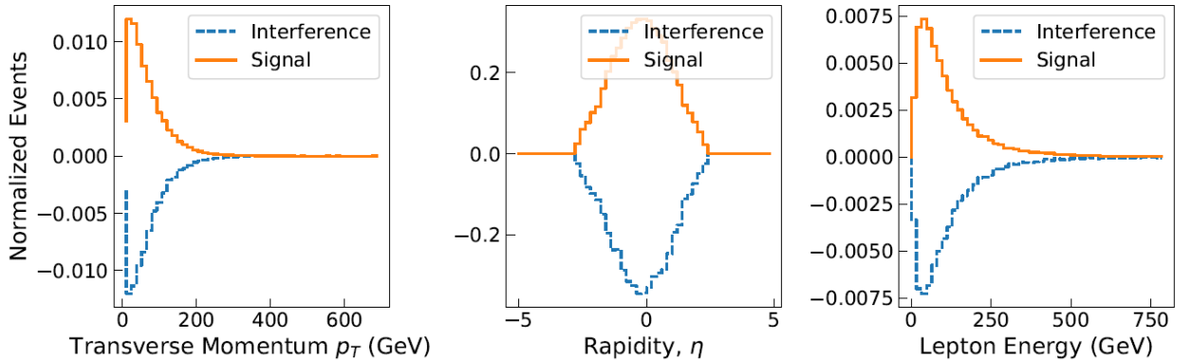
→ Negative interference in 6 out of the 8 BPs

- MG5 signal generation and Delphes simulation, differential distributions:

BP5



BP2 in type-III



→ Shape for signal and interference contribution the same

→ Gives hope that interference will lead to an overall yield change, but not a change of the observables

Status of the Interference Calculation

- Any interference can be neglected in case of narrow-width
  → the model-independent limits for a generic narrow-width H^+ are valid

- In case of a specific model, where the H^+ width is large → interference needs to be assessed

- S. Moretti, P. Sharma et al have assessed the interference
  - for $H^+ \rightarrow WH$ using 5FS signal: interference was found to be very large up to O(100%)
  - for $H^+ \rightarrow tb$ using 5FS signal: interference was found to be negligible
  - interference probably depends on the flavor scheme (4FS vs. 5FS)
  - they agreed to repeat their calculation for $H^+ \rightarrow tb$ in the MSSM for a 4FS signal

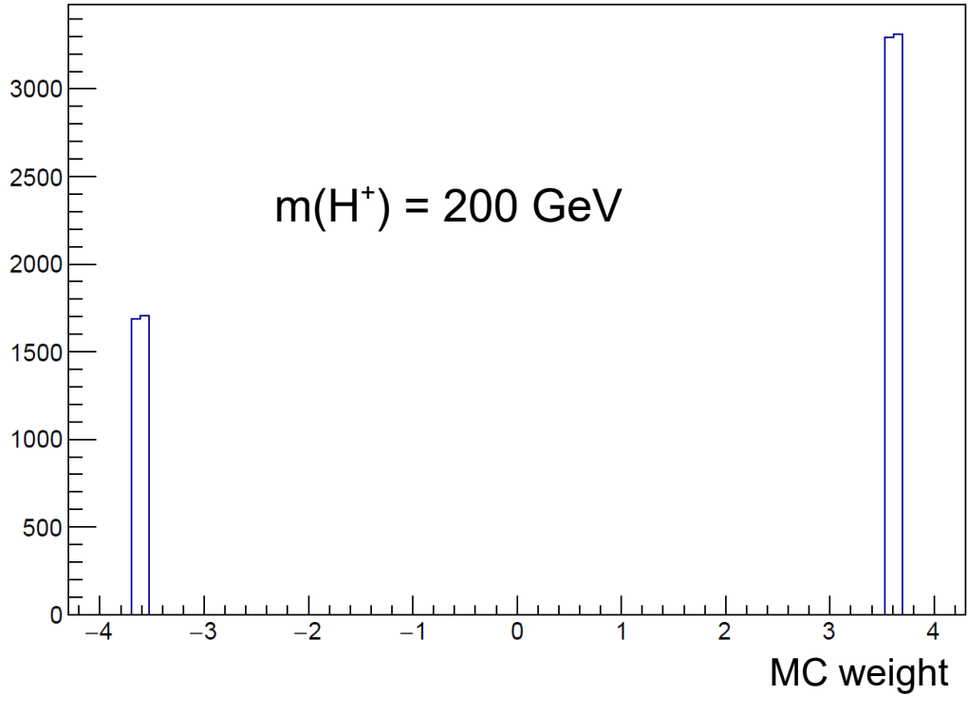
- The size of the interference depends on the background rejection:
  Better background rejection → less interference
  → Size of the interference is analysis-dependent
  → The very preliminary studies by Marco for $H^+ \rightarrow tb$ were done for an inclusive phasespace and therefore most-likely over-estimate the effect

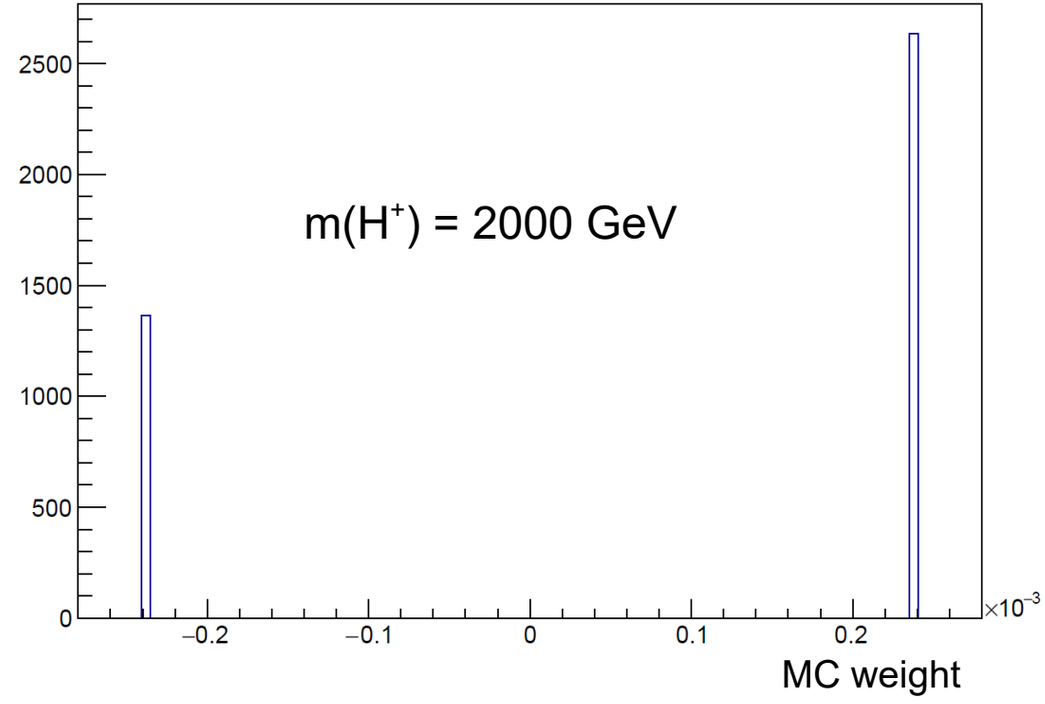
- Since top-associated H^+ searches are very complicated, a simple recipe to account for any interference would be appreciated by the experimentalists, eg. a scale-factor of the signal yields

We will follow-up on this task.

Negative Weights in H^+ Signal MC

- Issue brought up by ATLAS:
- H^+ signal modelled with MG5_aMCatNLO
- Large fraction of MC events with negative weights leads to a strong decrease of available MC statistics (35% neg. weights → up to 70% of the events cancel each other out)
- This forces the analysers to produce more events → expensive and slow
- Is there a work around, viable alternative?





Discussion of possible $H^{+(+)}$ channels and models

- tH^+ or $t \to H^+b$, $H^+ \to \tau\nu$
- tH^+, $H^+ \to tb$
- $tH^+ \to Wh$ (WH, WA)
- VBF $H^+ \to WZ$
- $H^+ \to W\gamma$
- $t \to H^+b$, $H^+ \to c\bar{s}$, $c\bar{b}$
- tH^+, $H^+ \to \chi^+\chi^0$
- s-channel production
- H^+H^- pair production
- H^{++}
- H^+ in NMSSM

It's not realistic for the experiments to explore all of them for the final Run-2 papers.

Need feedback on priority of each channel.

Is you favorite channel or model not on the list? Let us know!

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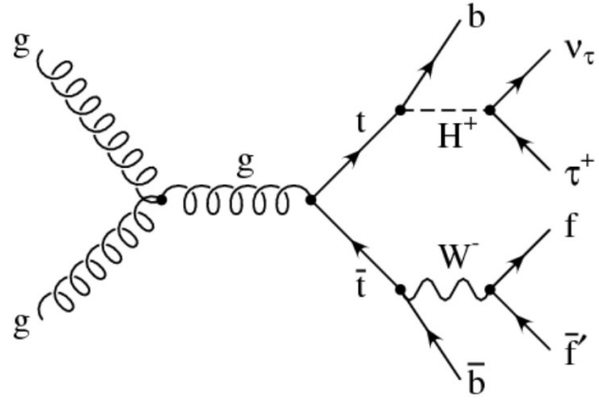
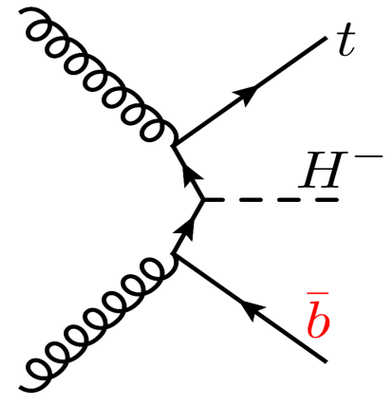
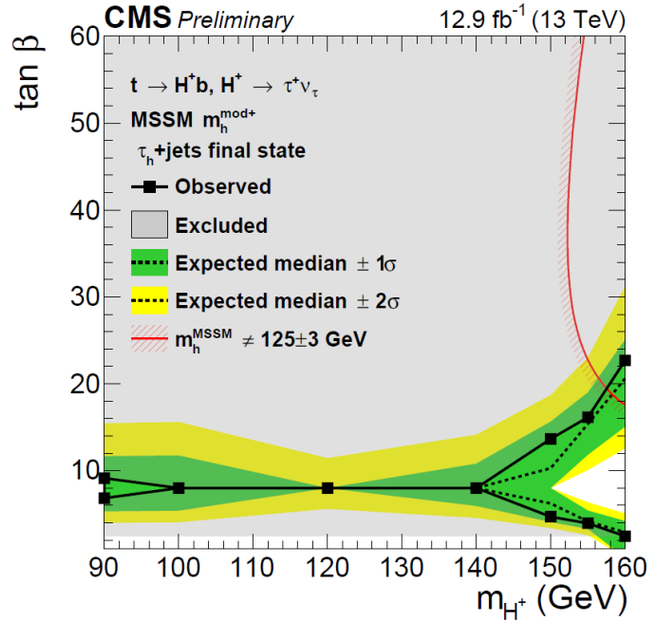
Low mass



High mass

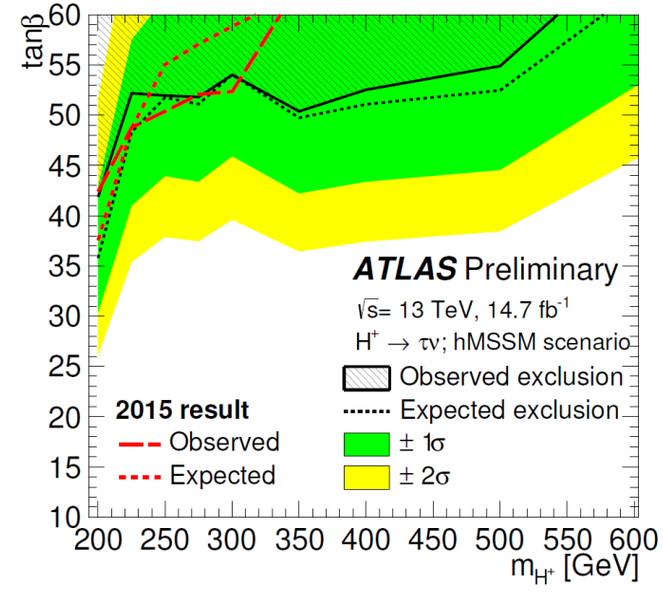




Very strong exclusions

Intermediate range:

Experimental results coming soon!



Models: MSSM

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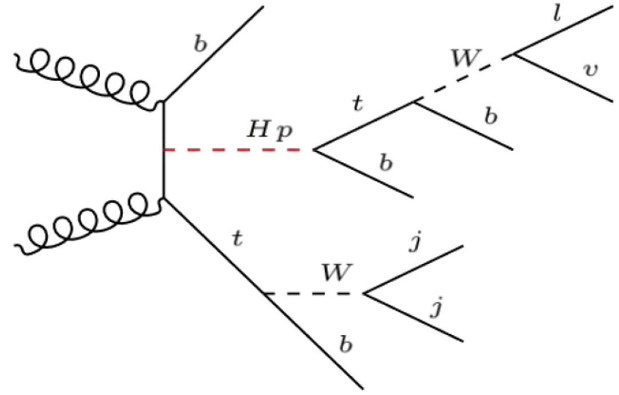
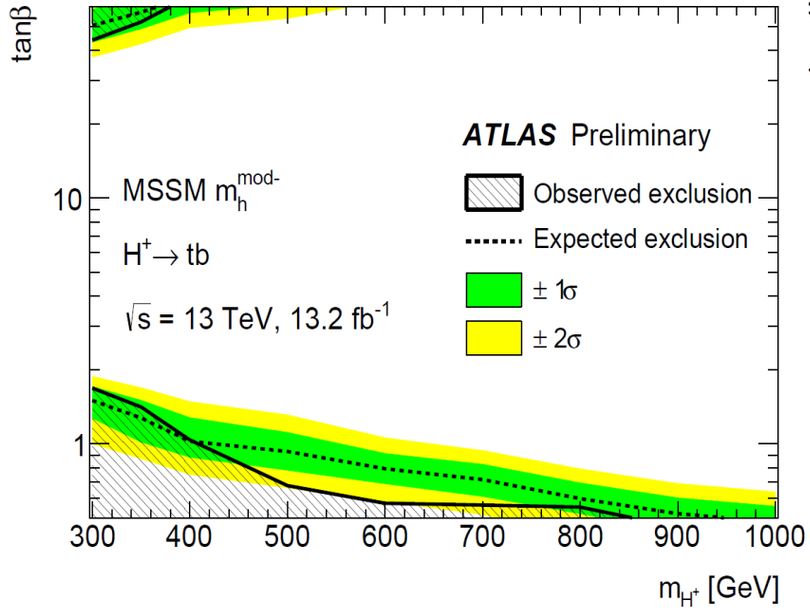
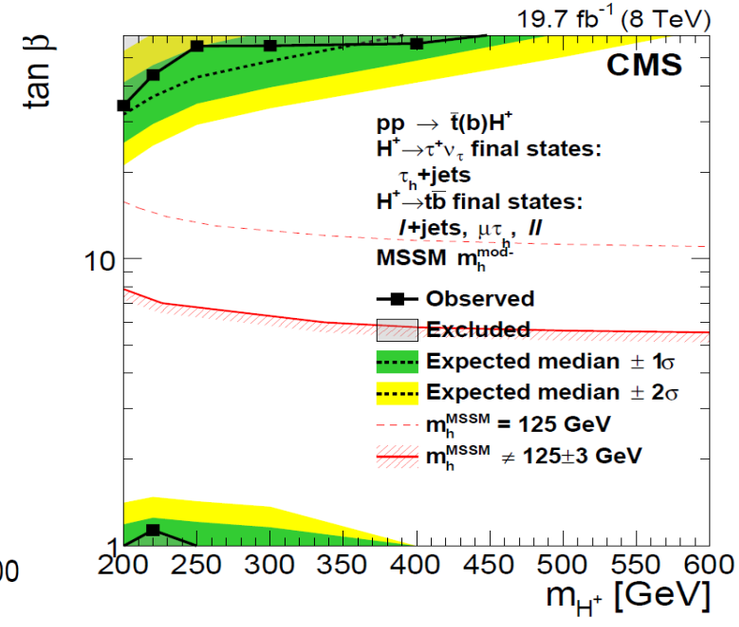


Difficult!

Large background uncertainties.

Systematics limit the sensitivity.





Unique sensitivity to low and high tanβ

Models: MSSM

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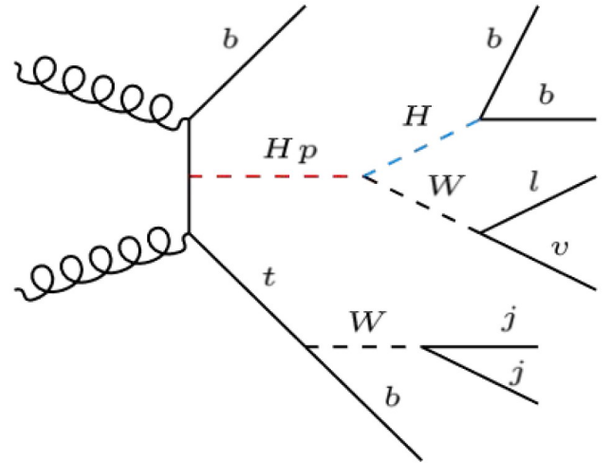
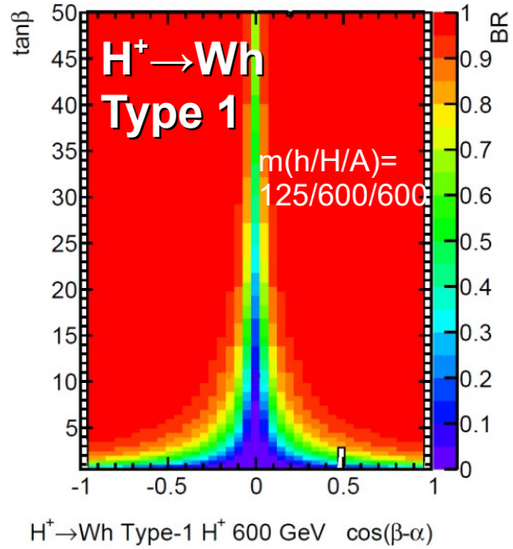
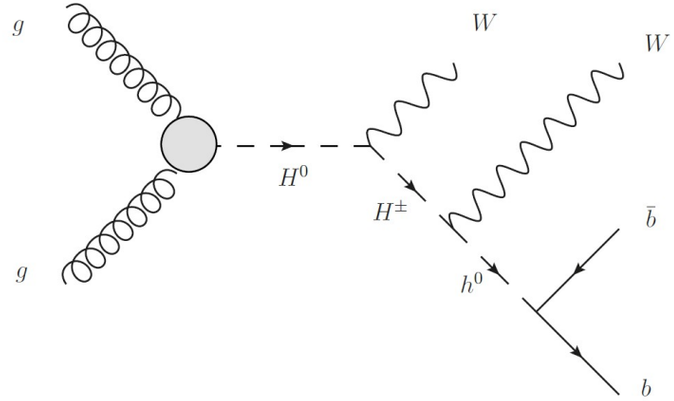


Similarily difficult!

Same final state as tH^+, $H^+ \to tb$

In arXiv:1604.04965 [hep-ph], it is shown that $H^+ \to WH$ can reach a similar sensitivity as tb with 30 times less data (assuming m(H^+) of 500 GeV).





H^+ production via multi-Higgs cascades

ATLAS 8 TeV search:
http://arxiv.org/abs/1312.1956

Models: 2HDM

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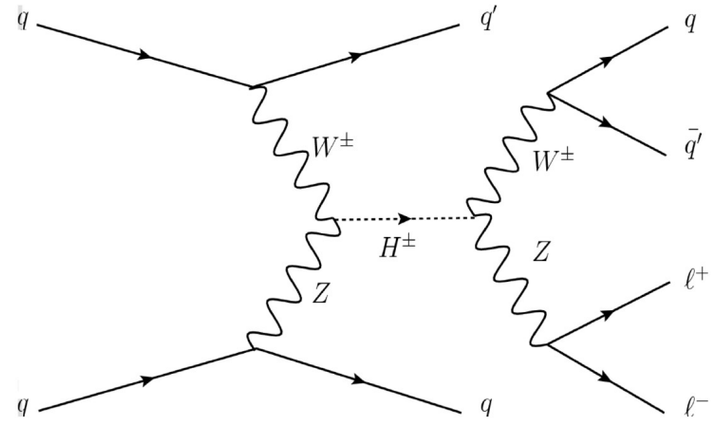
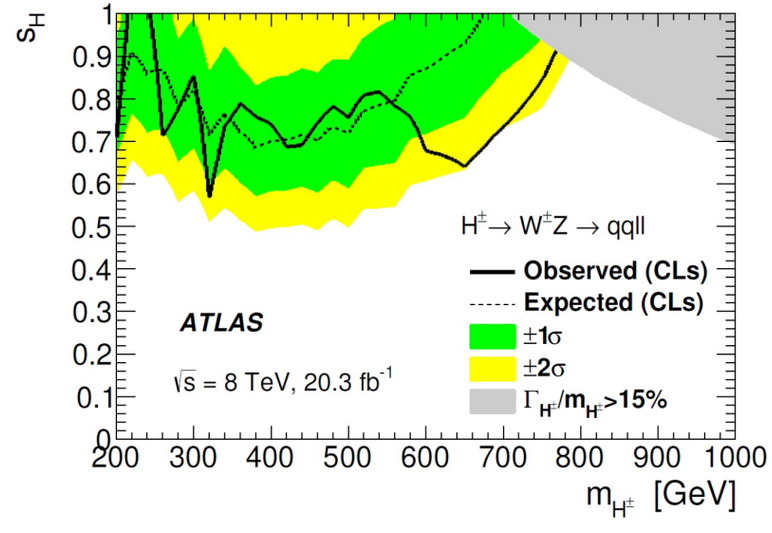
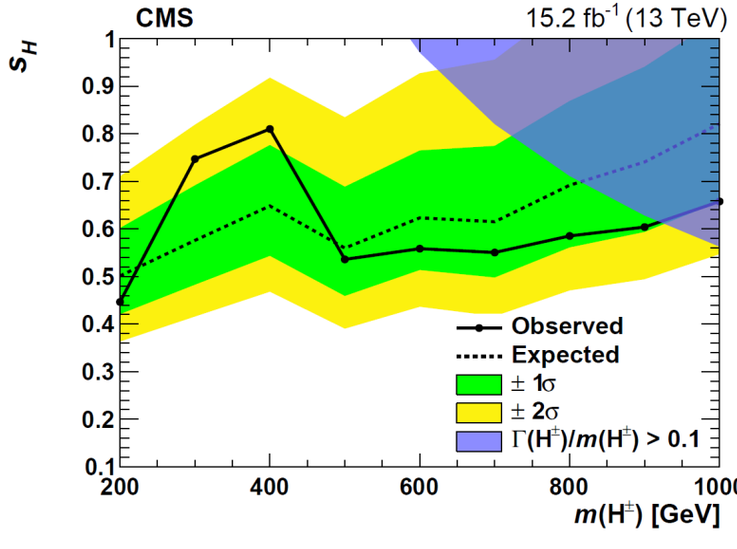


- H^+ produced via VBF
- decays to WZ

- suppressed in 2HDM, can be enhanced in Tripletts





Models: Higgs Triplet, Georgi-Machacek

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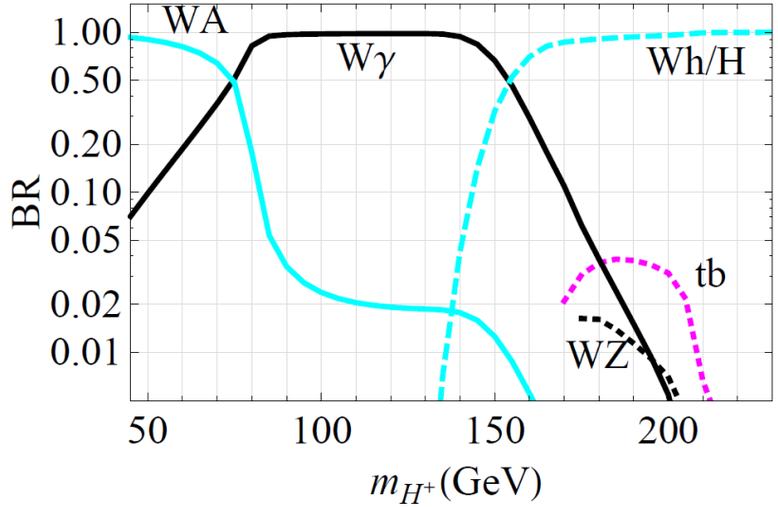
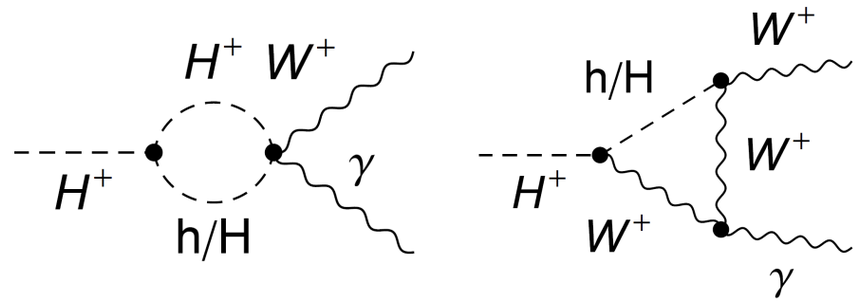
- In the 2HDM, there are no tree couplings of H^+ to WZ or $W\gamma$, but these decays can be induced on 1-loop level (similar to $H \to \gamma\gamma$, or $H \to Z\gamma$), BR ~ 10^{-3}
- In Higgs Triplett models these decays can occur on tree level

http://arxiv.org/abs/1311.4367



(a) $m_A = m_{H^\pm} - 10$ GeV, $m_h = 125$ GeV $m_H = 300$ GeV, $\sin\alpha = 0.9$.



H^+ production:

- $q\bar{q} \to Z/\gamma^* \to H^+H^-$
- $q\bar{q} \to W^* \to H^+h$

Models: Tripletts, „Stealth“ model

“Stealth model”: Two scalar doublets and broken Z_2 symmetry (generalized Inert Doublet Model). One doublet is the Higgs doublet and provides EWSB, the other doublet is fermiophobic.

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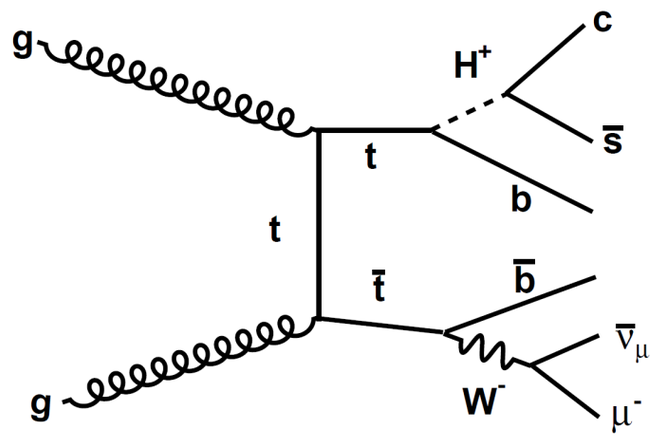
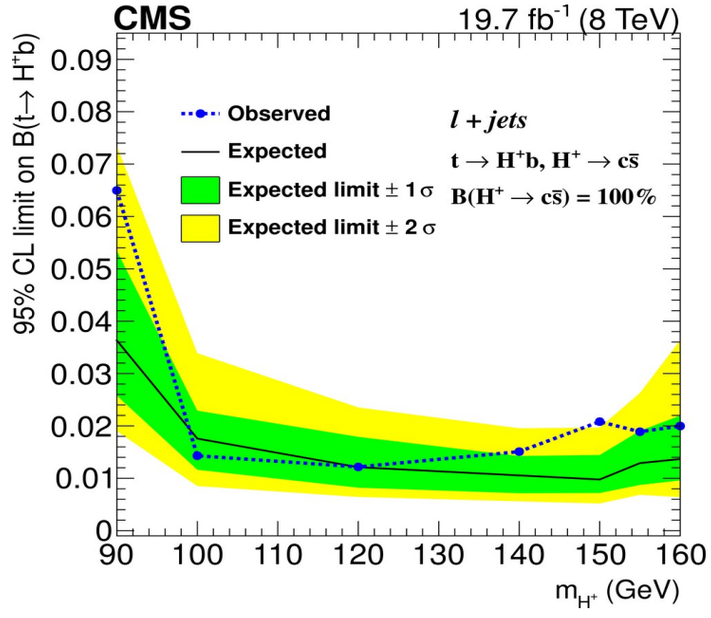
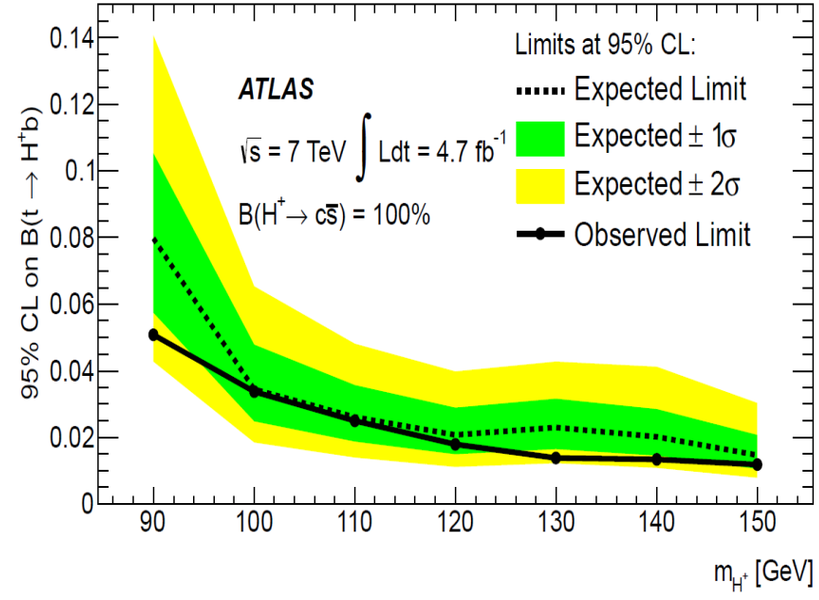


Could profit from c-tagging

$c\bar{b}$ expected to be more sensitive due to b-tagging (see eg. arXiv:1203.5769)

Models: MSSM, 2HDM





The $\tau\nu$ is stronger at low mass.

Are there models where $c\bar{s}$ or $c\bar{b}$ could be more relevant than $\tau\nu$?

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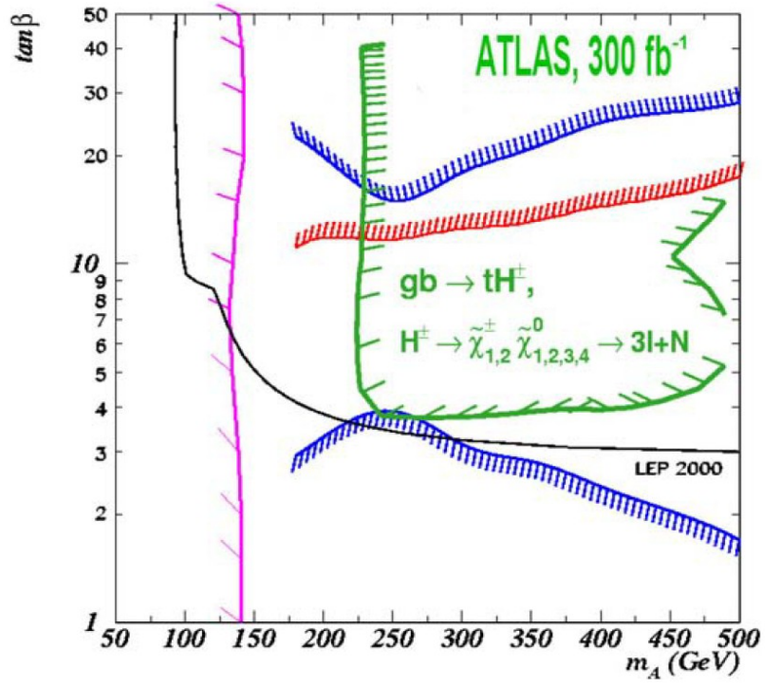
- H^{++}
- H^+ in NMSSM

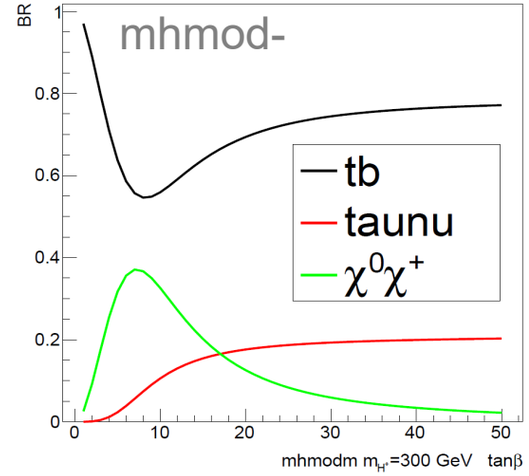
Decay of H^+ to SUSY particles may cover most difficult region in tanβ („wedge“).

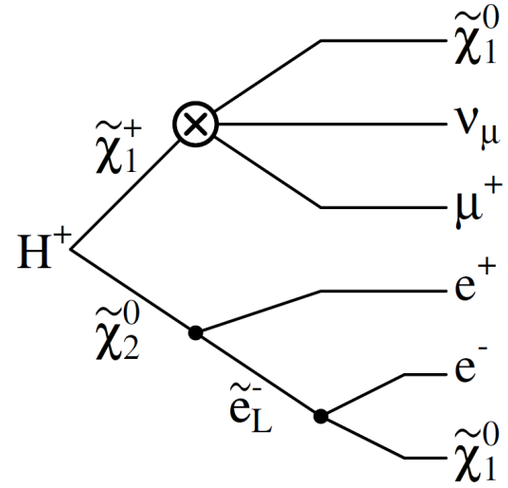
Requires SUSY.

2005 14 TeV prospect study from 2005:



http://arxiv.org/abs/hep-ph/0504216



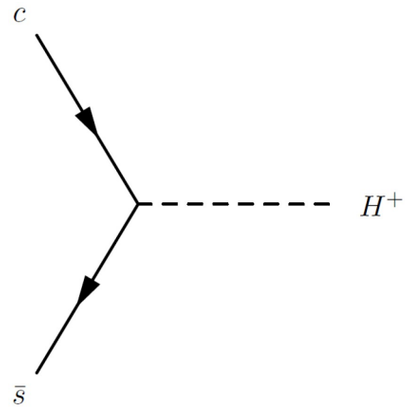


Models: MSSM

Is there a scenario that would lead to $H^+ \to \chi^+\chi^0$ despite no other evidence of SUSY?

Discussion of possible $H^{+(+)}$ channels and models

- tH^+ or $t \to H^+b$, $H^+ \to \tau\nu$
- tH^+, $H^+ \to tb$
- $tH^+ \to Wh$ (WH, WA)
- VBF $H^+ \to WZ$
- $H^+ \to W\gamma$
- $t \to H^+b$, $H^+ \to c\bar{s}$, $c\bar{b}$
- tH^+, $H^+ \to \chi^+\chi^0$
- **s-channel production**
- H^+H^- pair production
- H^{++}
- H^+ in NMSSM



No associated top → easier from the experimental point of view:

Mass reconstruction, background reduction.

But H^+ width becomes very large for low tanβ and high mass

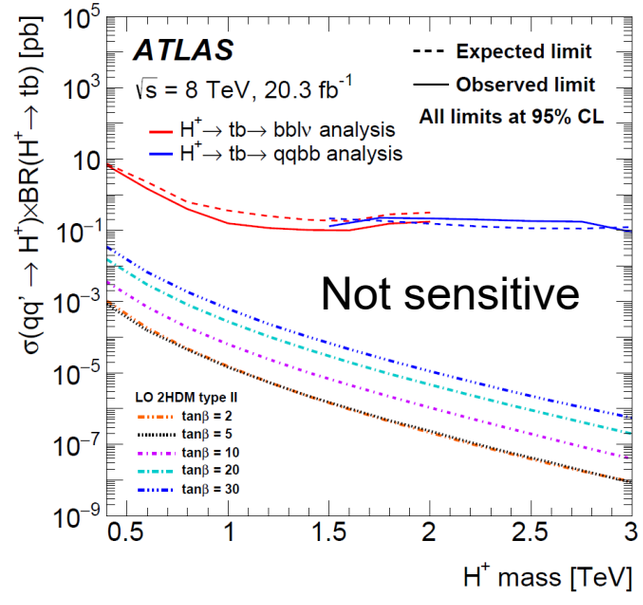
Models: 2HDM

8 TeV LO σ* BR ($H^+ \to tb$) for type-II 2HDM:

Computed using MG5 + NLOCT (1406.3030)

m_{H^+} [GeV]		tanβ = 0.5	1	2	10	20	30	50
400	σ × 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	σ × 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	σ × 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	σ × BR [ab]	23	3.9	0.96	4.6	20	47	140
	Γ [GeV]	280	69	17	3.1	9.9	22	61
2000	σ × 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	σ × 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

Recasting W'→tb to H^+:



HIGG-2013-28

At tanβ=50 1 TeV, only factor 1.5 smaller than tH^+ x-sec

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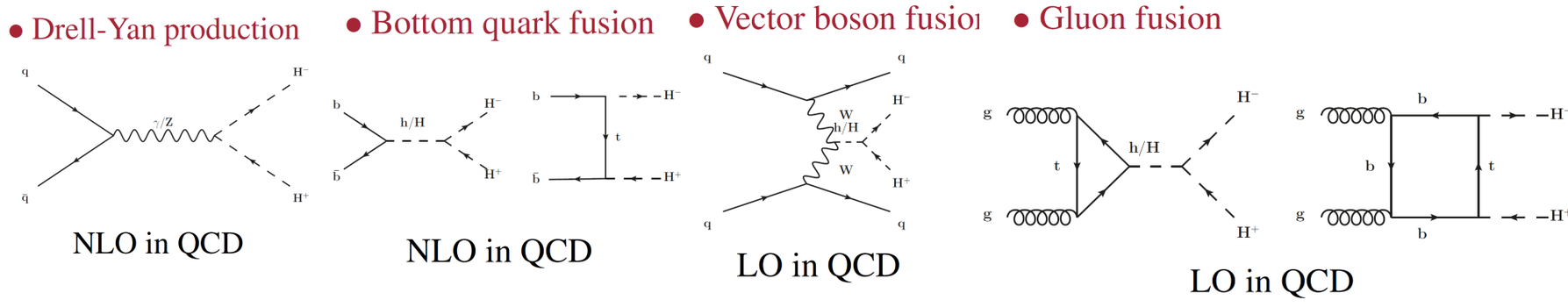
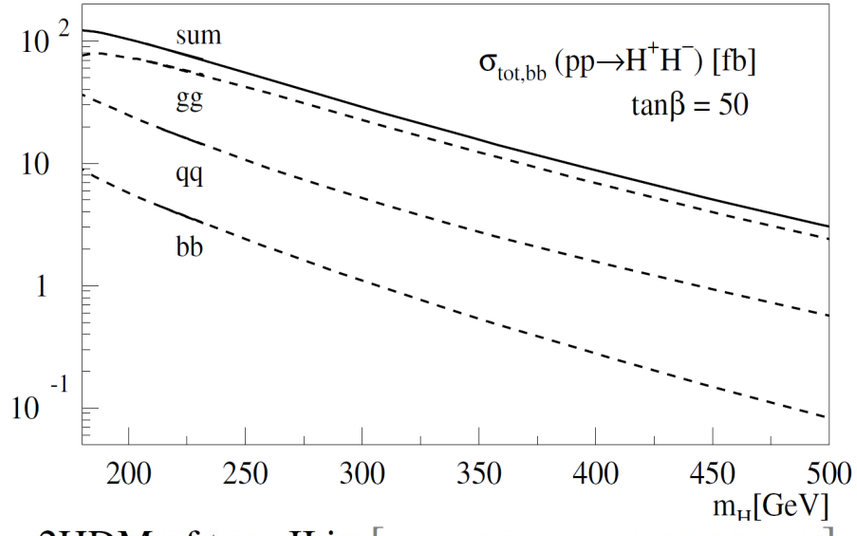
See also talk by J. Baglio at Charged2016

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





2HDM of type II in [Alves, Plehn, PRD 71 (2005) 115014]

Could explore many different final states

Very small cross sections!

Need lots of luminosity.

Could be enhanced for resonant production

Models where this could be enhanced?

Discussion of possible $H^{+(+)}$ channels and models

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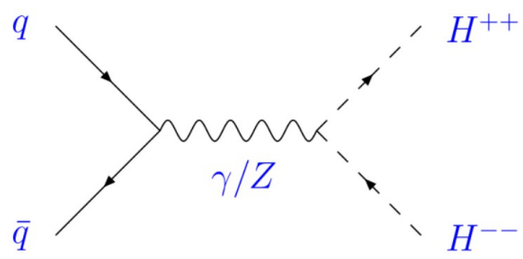
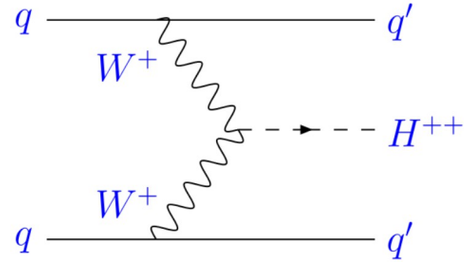
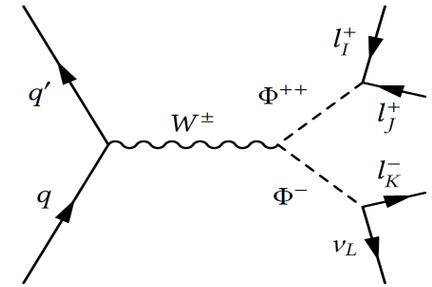
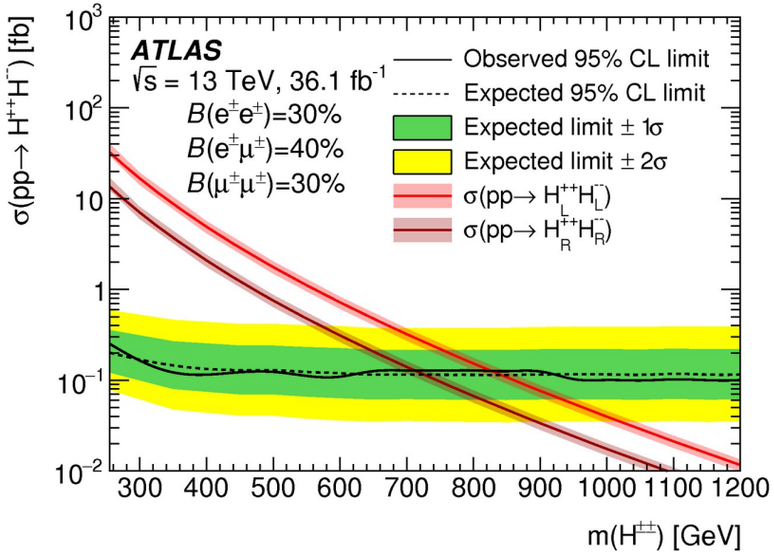


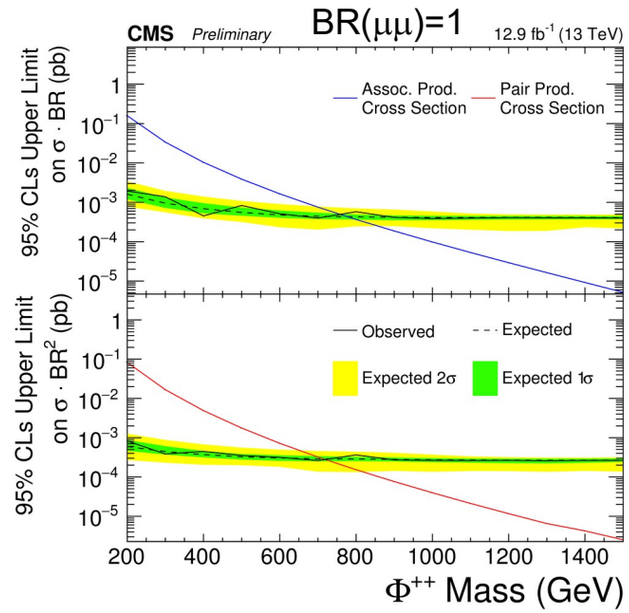




Models: L-R Symmetry, Tripletts (GM), type-II seesaw, Zee-Babu, Little Higgs, related also the Bilepton model (paper)

Decays to pairs of W, or leptons





LRS predictions from arXiv:0305288

Where in WG3 does the H^{++} belong?

Conclusions

- Inputs for the main decay channels incl. intermediate range for MSSM are available and useful
- Interference between H^+ signal and background: discussions and calculations have started
- General interest to explore new channels and models,
  but need input from theory and experiments for motivation and priority

  „If you could do only one H^+ search, which one would you do?“
- As soon as priorities are clear, need to work on providing the models

Backup