Searches for additional charged Higgs bosons in the MSSM in ATLAS and CMS

SUSY18, Barcelona
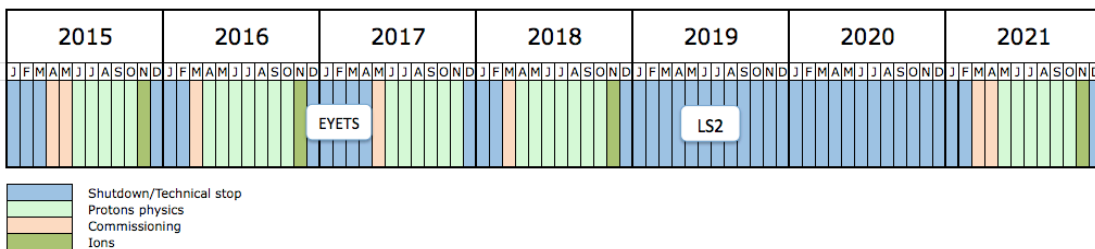
Christian Autermann,

for the ATLAS and CMS collaborations

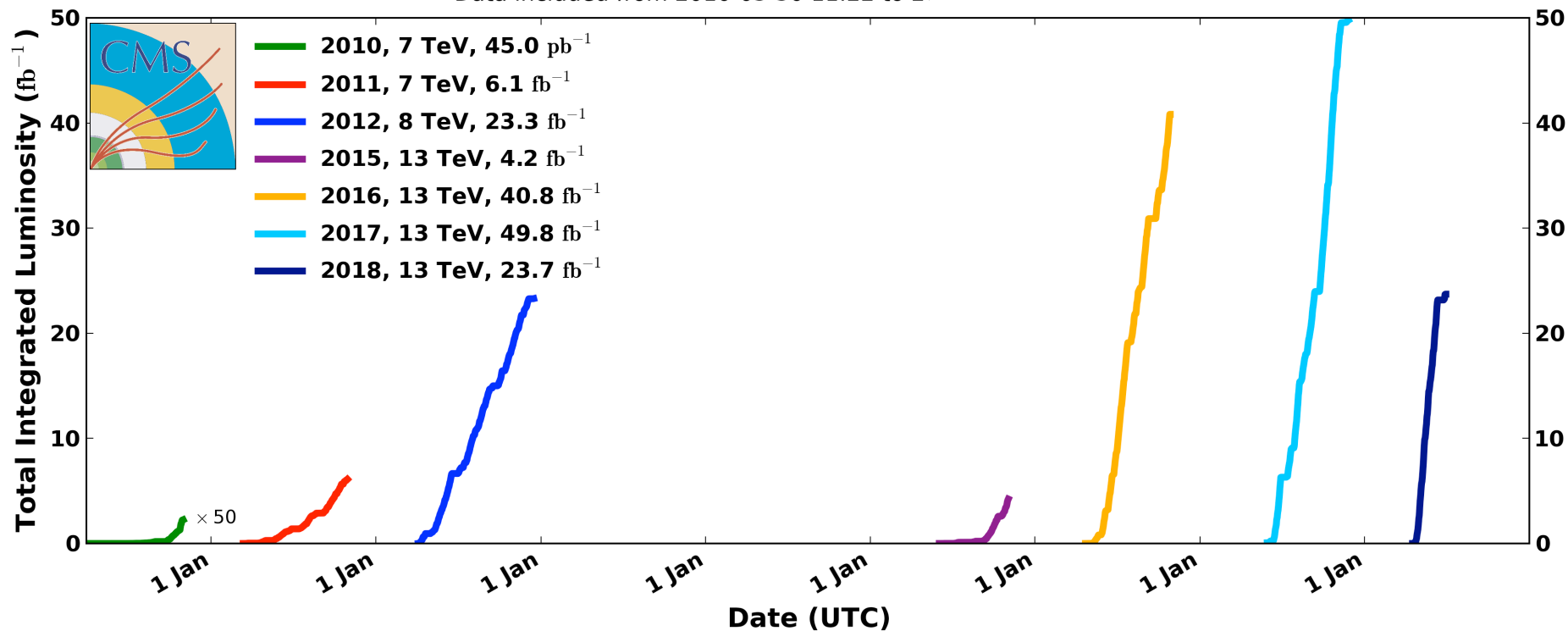**RWTH**AACHEN
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Overview

- Introduction
  - LHC data and luminosity
  - Two Higgs-doublet models
  - Higgs triplet models

- $H^+ \to tb$

- $H^+ \to \tau\nu$

- $H^+ \to WZ$

- $H^{++} \to WW$, $H^{++} \to l^+l^+l^-l^-$

- Conclusion

Delivered luminosity

CMS Average Pileup, pp, 2016, $\sqrt{s} = 13$ TeV

$<\mu> = 27$

Mean number of interactions per crossing

CMS Integrated Luminosity

Data included from 2010-03-30 11:22 to 20

- 2010, 7 TeV, 45.0 pb^{-1}
- 2011, 7 TeV, 6.1 fb^{-1}
- 2012, 8 TeV, 23.3 fb^{-1}
- 2015, 13 TeV, 4.2 fb^{-1}
- 2016, 13 TeV, 40.8 fb^{-1}
- 2017, 13 TeV, 49.8 fb^{-1}
- 2018, 13 TeV, 23.7 fb^{-1}

Total Integrated Luminosity (fb^{-1})

$\times 50$

Date (UTC)

Introduction

$$H^\pm \to tb$$
$$H^\pm \to \tau\nu$$
$$H^\pm \to WZ$$
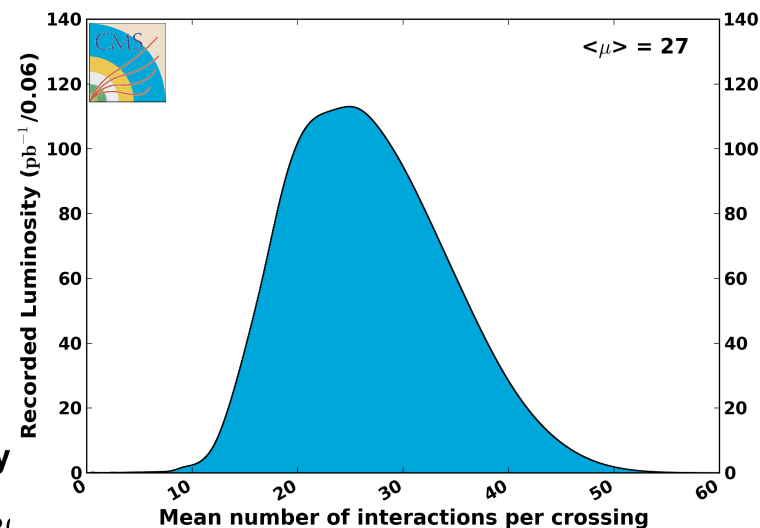
- No charged fundamental scalar in the SM
- Charged Higgs bosons $H^\pm$:
  - e.g. MSSM
- coupling of the charged Higgs bosons to charged leptons and neutrinos
  - ~cot β in Type-I 2HDM
  - ~tan β in Type-II 2HDM,
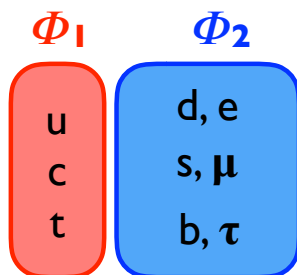 - where tan β is the ratio of the vacuum expectation values of the two Higgs boson doublets

| Type-I	Type-II (MSSM)		Lepton-specific		Flipped	
Φ_1	Φ_1	Φ_2	Φ_1	Φ_2	Φ_1	Φ_2
all charged fermions	u c t	d, e s, μ b, τ	u, d c, s t, b	e μ τ	u, e c, μ t, τ	d s b
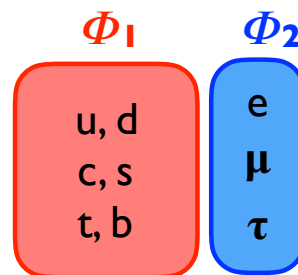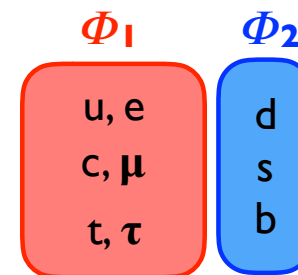
Introduction

- Doubly charged Higgs bosons H^{++}, H^{--}:
  - left-right symmetric (LRS) models,
  - Higgs triplet models,
  - the little Higgs model,
  - type-II see-saw models
  - scalar singlet dark matter,
  - Zee–Babu neutrino mass model
  - Georgi–Machacek model,
    - scalar sector of the Standard Model (SM) is extended by the addition of one complex and one real SU(2) triplet.
    - hVV (and hhVV) coupling enhanced compared to the SM
    - presence of additional doubly charged scalars
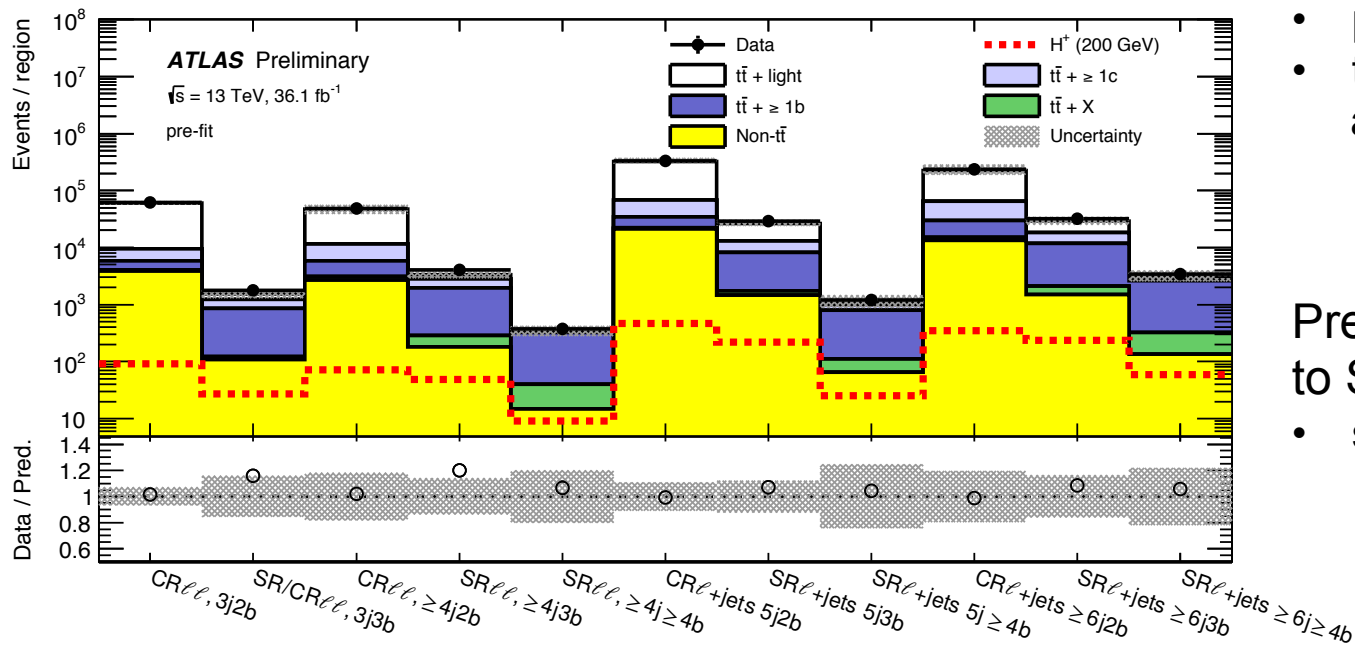
$H^{\pm\pm} \rightarrow WW$
$H^{\pm\pm} \rightarrow l^{\pm} l^{\pm}$

$H^+ \rightarrow tb$
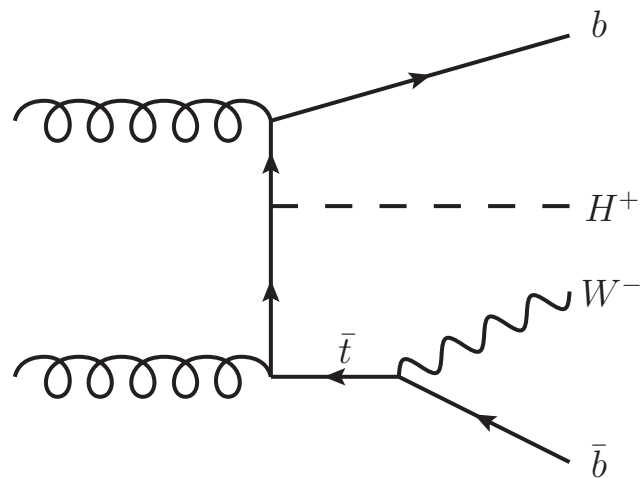
- dominant channel for $m(H^\pm) > m(top)$
- one or two leptons (e, μ) + jets
- signal to background discrimination
  - using jet & b-tag multiplicities
  - MVA techniques (BDTs)
- limit extraction, 200 – 2000 GeV
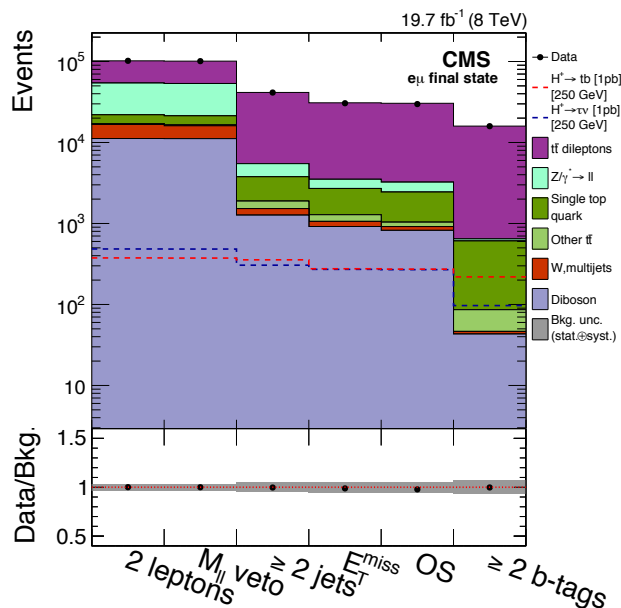 - simultaneous fit in signal-rich and in signal-depleted regions of BDT output dist.
    - per SR & $m(H^+)$
    - tt+$\geq$1b, tt+$\geq$1c allowed to float
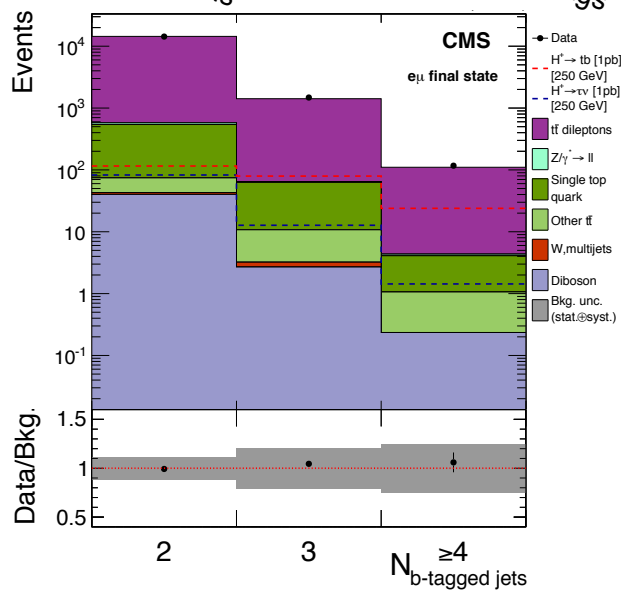

Pre-fit comparison of data to SM expectation
- signal and control regions
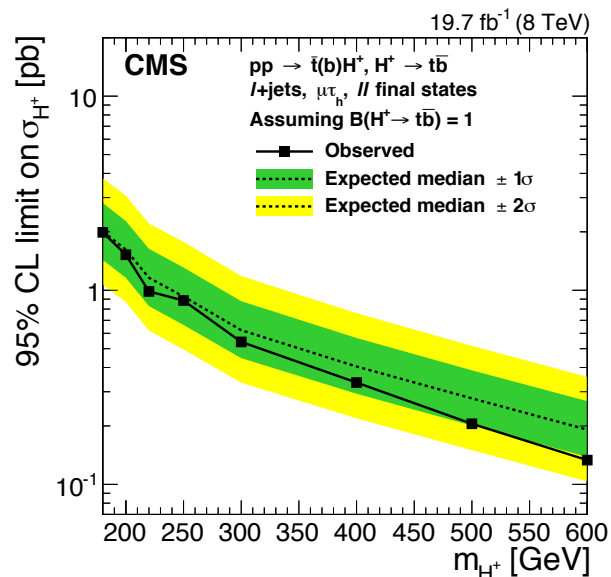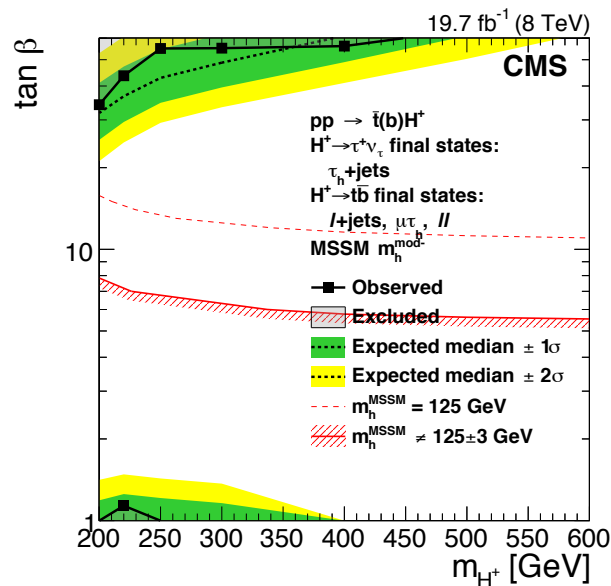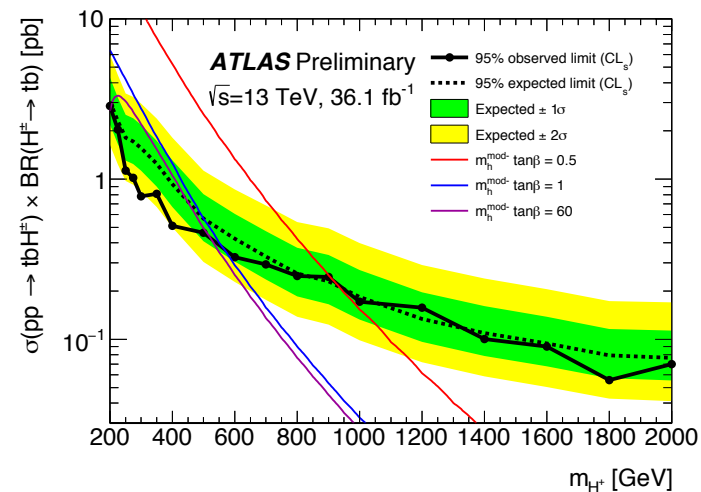
H⁺ → tb

- Legacy Run I result
  - still competitive limits with 8 TeV, 19.7 fb⁻¹
- individual analyses – final states
  - l+jets :   single-lepton trigger (e, μ)
  - τ^h+μ: single-μ trigger
  - ll: ee, $\mu\mu$, eμ trigger

  statistically combined to final result

- Run II searches with higher statistics
  - better handle of systematics

H+ → tb

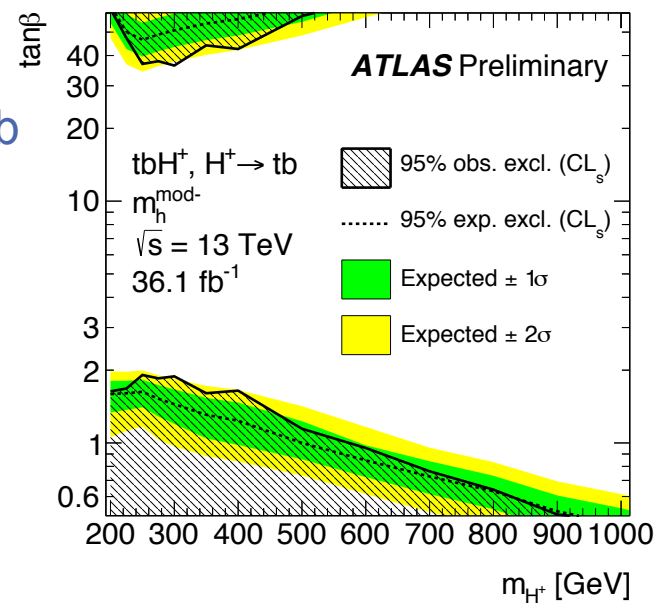Model independent cross section limit

MSSM interpretation
m_h^mod scenario

H+→ tb
H+→τν

H+→ tb

H⁺ → $\tau\nu$

ATLAS
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
$\tau+\mu$ signal region

- Data
- H⁺ 200 GeV
- H⁺ 400 GeV
- t$\bar{t}$ & single-top
- MisID j → τ
- MisID e/μ → τ
- W/Z+jets
- Diboson

Events / 0.1
Data / SM
Uncertainty
BDT score, 200 to 400 GeV
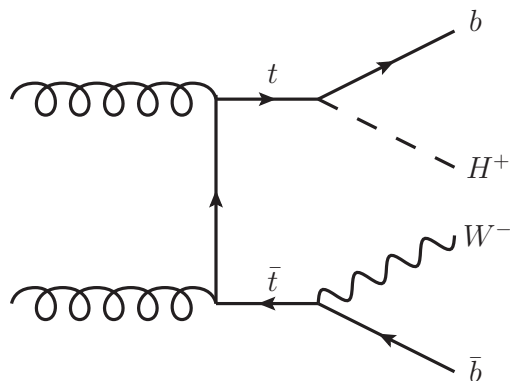
- dominant decay mode for light charged Higgs m(H$^\pm$) < m(top)

  $\leftrightarrow$ complementary to H$^\pm$ → tb

- τ^{had} + jets, τ^{had} + lepton final states depending on W decay mode
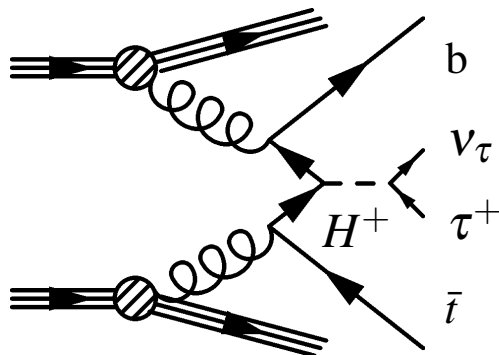 - p$_T^{miss}$, lepton triggers used, respectively

- MVA discriminant, 90 – 2000 GeV
  - BDTs for both final states & 5 m(H$^\pm$) bins
  - input variables include p$_T^{miss}$, object's p$_T$, b-tagging, $\Delta\phi$, ΔR, tau-polarization

- τ^{had} background from MC
  - tt normalized to the data

- τ^{had} from mis-ID of jets / e
  - data-driven estimation inverting BDT-score
  - from MC and validated in Z→ee CR
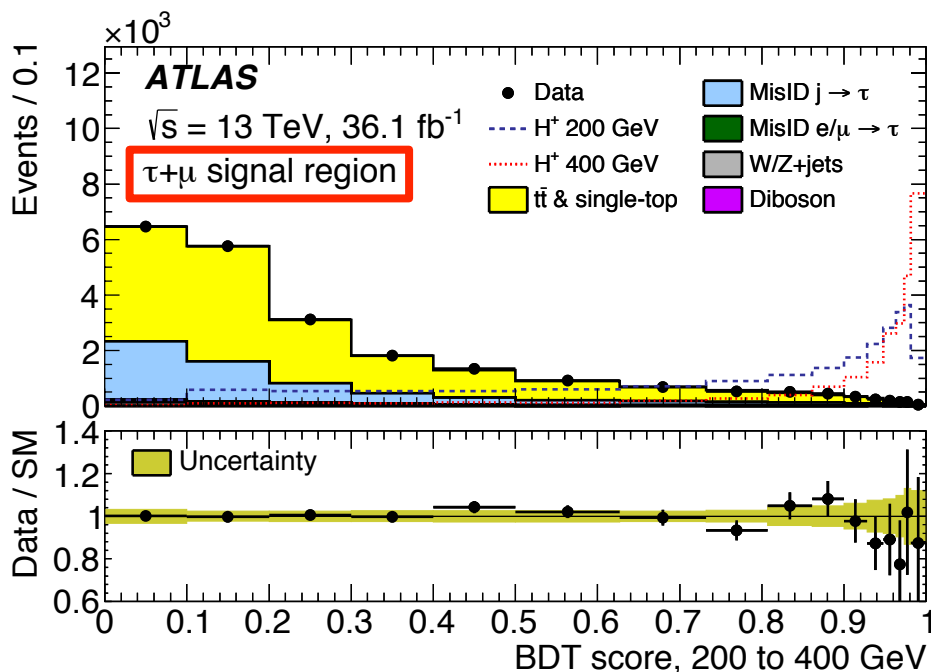
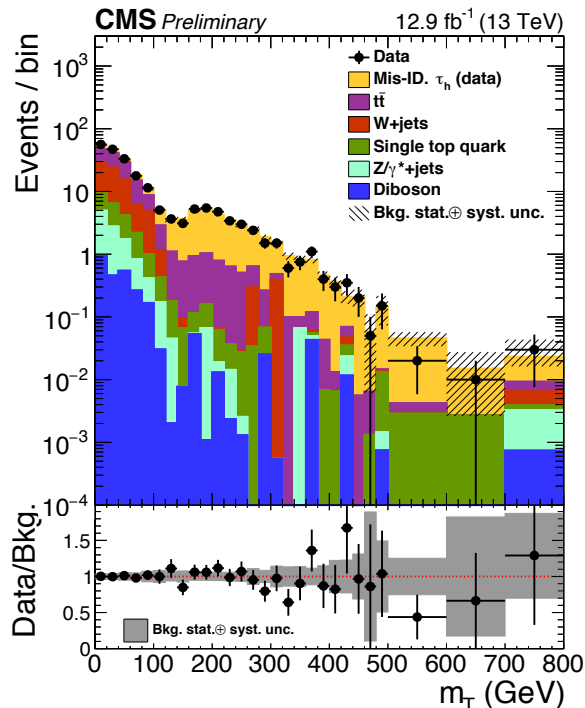$$\Delta\phi(\not{E}_T, \tau^{\mathrm{h}})$$

$R_{\mathrm{bb}}^{j_n}$

Bkg. stat.$\oplus$syst. unc.

Bkg. stat. unc

Data/Bkg.

Data/Bkg.

Bkg. stat.$\oplus$ syst. unc.

m_T (GeV)

- signal sensitive variable m_T

$$m_T^2 = 2 \cdot p_T^{\tau^{\mathrm{h}}} |\vec{\not{E}}_T| \left(1 - \cos\Delta\phi(\not{E}_T, \tau^{\mathrm{h}})\right)$$

- binned max. likelihood fit on m_T

MSSM interpretation

$H^{\pm} \rightarrow W^{\pm}Z$

35.9 fb^{-1} (13 TeV)

- WZ jj electroweak vector boson scattering measurement

- exactly 3 leptons (e, μ)
- two jets: high m(jj), $\Delta\eta_{jj}$, $\eta^*_{3\ell} = \eta_{3\ell} - \frac{1}{2}(\eta_{j_1} + \eta_{j_2})$
- $p_T^{miss} > 30$ GeV
- veto cuts against
  - non-prompt leptons and Z: m(ll), top: b-tag

- Zγ, WW, ZZ, EW WZjj: prompt leptons
  - from MC simulation
- QCD WZjj:
  - simulation normalized to data in control region (failing m(jj), η_{jj}, η^*_{3l})
- non-prompt leptons: from data
  - "tight-to-loose" wrt lepton identification and isolation

$H^\pm \rightarrow W^\pm Z$
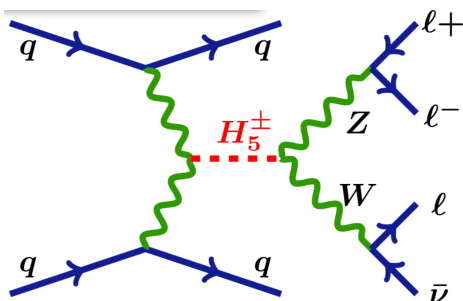
- VBF channel: Georgi-Machacek model
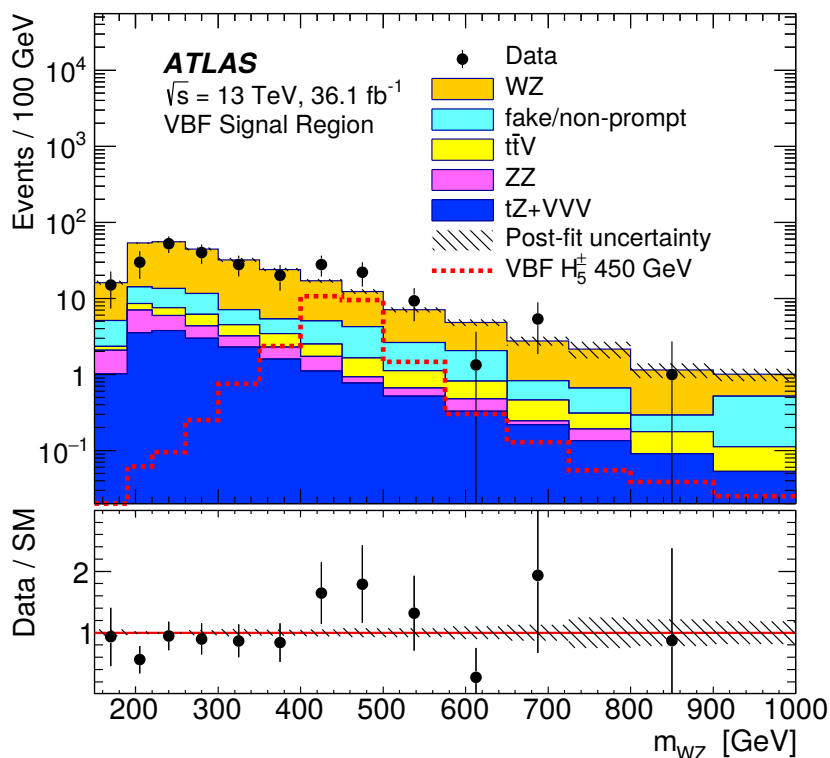- 3 leptons (e, μ)

Similar backgrounds & estimation methods

- SM WZqq main background:
  - MC simulation validated in CR
  - inverting 100 < m_{jj} < 500 GeV or $\Delta\eta$ < 3.5
- ZZ, tZ, ttX: prompt leptons
  - MC simulation
- non-prompt leptons: γ or jet "fakes"
  - data-driven "Matrix method"

- background-only fit to the data
  - pulls < 1 s.d. compared to prefit values

- slight excess at m(WZ) $\approx$ 450 GeV

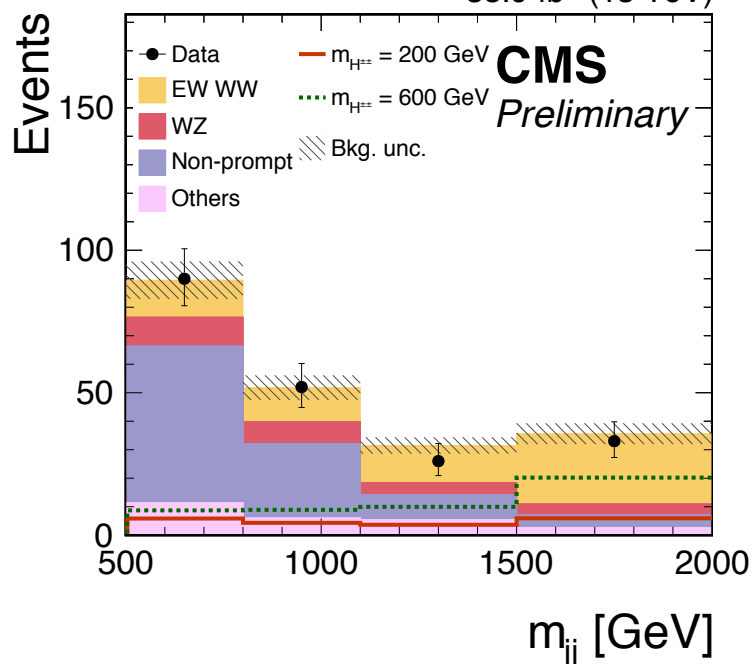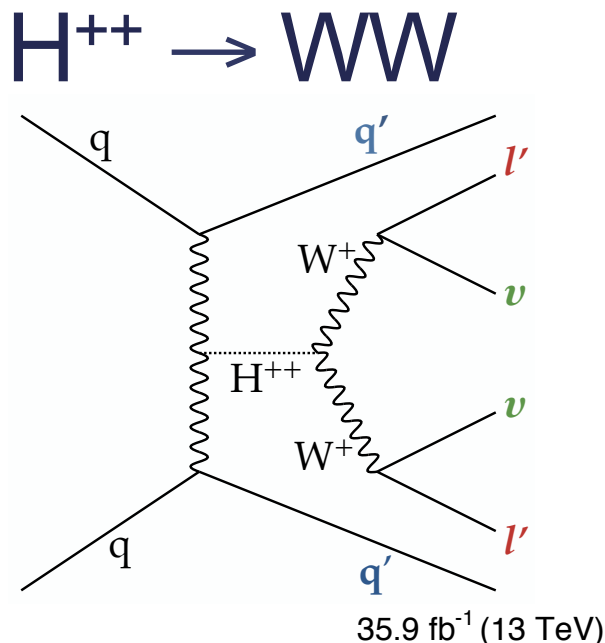# H$^\pm$ → W$^\pm$Z

- SM WZjj measurement:
  σ/σ_{SM} = 0.6±0.4 @ 1.9 (2.7) s.d.
- H$^\pm$ narrow width assumption
- Combined fit of H$^\pm$ signal and WZjj background:

- Excess observed in VBF category only
- Excess at m(H$^\pm$) ≈ 450 GeV: 2.9 s.d. (local), 1.6 s.d. (global)

$H^{++} \rightarrow WW$
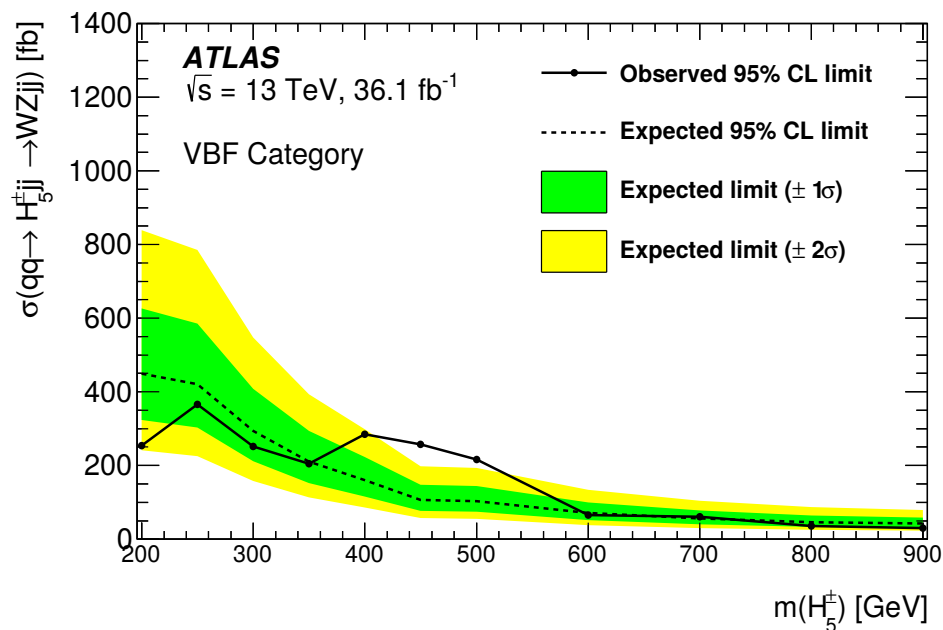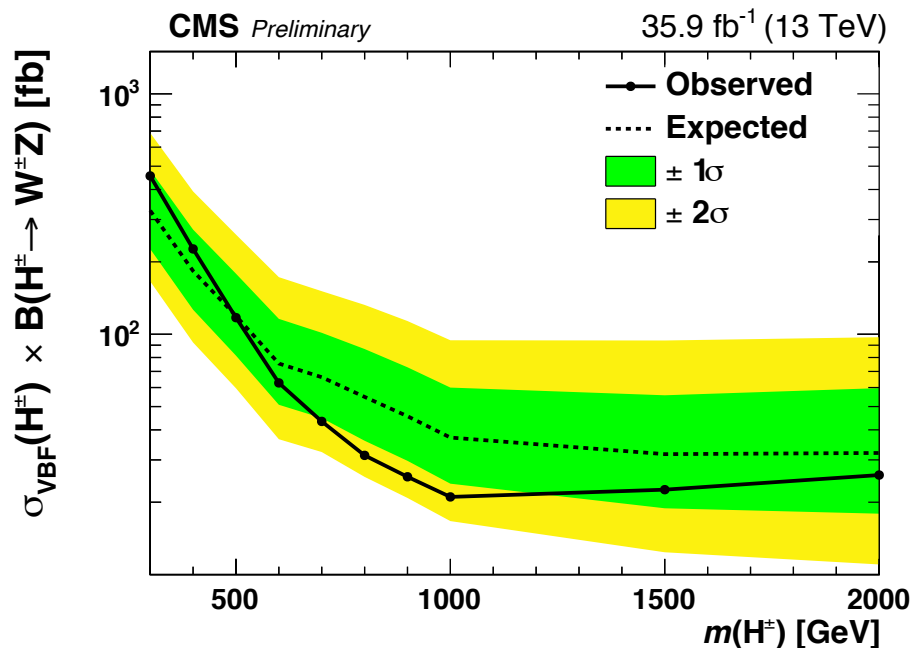
- $H^{++} \rightarrow WW$ dominates for large Higgs triplet vacuum expectation value v_Δ
- Vector boson fusion (VBF)
- Higgs triplet – Georgi-Machacek model

- two like-sign charged leptons e, μ
  - → little SM background

$35.9\ \text{fb}^{-1}$ (13 TeV)

$35.9\ \text{fb}^{-1}$ (13 TeV)

top: b-tag, WZ: 3rd

$_\text{ll}$, m_jj) plane

und: simulation

data control

$H^{++} \rightarrow l^+l^+$

- $H^{++} \rightarrow ll$ dominates for small Higgs triplet vacuum expectation value v_Δ
- 2, 3, 4 lepton (e, μ) signal regions, 250 – 1300 GeV

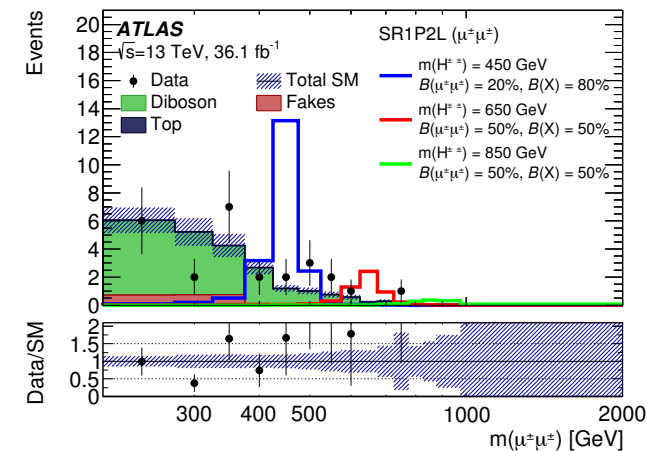- irreducible like-sign charged lepton SM background from $W^\pm W^\pm$, WZ, ZZ, ttX MC
- non-prompt e, μ "fake" background
  - data-driven estimation from data-sideband regions
  - e.g. requiring no b-tagged jet
- Max. likelihood fit in m(ll), $\overline{M}$ in signal & control regions

$$H^{++} \rightarrow l^+ l^+$$

- $H^{\pm\pm}_L$ and $H^{\pm\pm}_R$ have different couplings to the Z

- EW W⁻W⁻ measured to σ/σ_{SM}=0.9±0.2 @ 5.5 (5.7) s.d.

- lower limit on m($H^{\pm\pm}$) between 660 and 870 GeV for H_L & H_R, B(ll)=1

ATLAS
$\sqrt{s}$ = 13 TeV, 36.1 fb⁻¹
$B(e^\pm e^\pm)$=0%
$B(e^\pm \mu^\pm)$=100%
$B(\mu^\pm \mu^\pm)$=0%

— Observed 95% CL limit
---- Expected 95% CL limit
Expected limit ± 1σ
Expected limit ± 2σ
$\sigma(pp\rightarrow H^{++}_L H^{--}_L)$
$\sigma(pp\rightarrow H^{++}_R H^{--}_R)$

m($H^{\pm\pm}$) [GeV]

ATLAS
$\sqrt{s}$ = 13 TeV, 36.1 fb⁻¹
$B(e^\pm e^\pm)$=30%
$B(e^\pm \mu^\pm)$=40%
$B(\mu^\pm \mu^\pm)$=30%

— Observed 95% CL limit
---- Expected 95% CL limit
Expected limit ± 1σ
Expected limit ± 2σ
$\sigma(pp\rightarrow H^{++}_L H^{--}_L)$
$\sigma(pp\rightarrow H^{++}_R H^{--}_R)$

m($H^{\pm\pm}$) [GeV]

$\sigma(pp\rightarrow H^{++}H^{--})$ [fb]
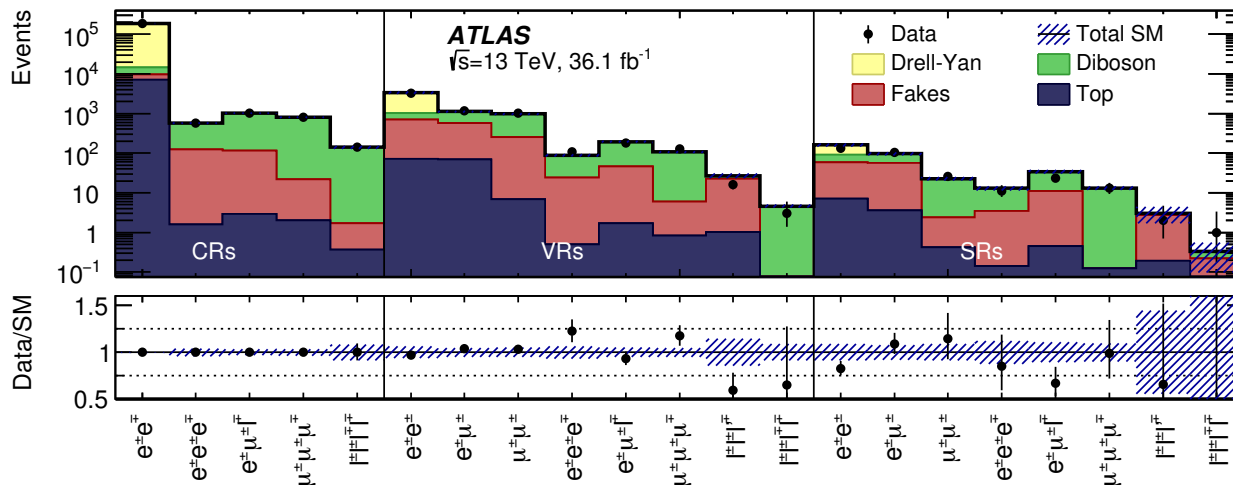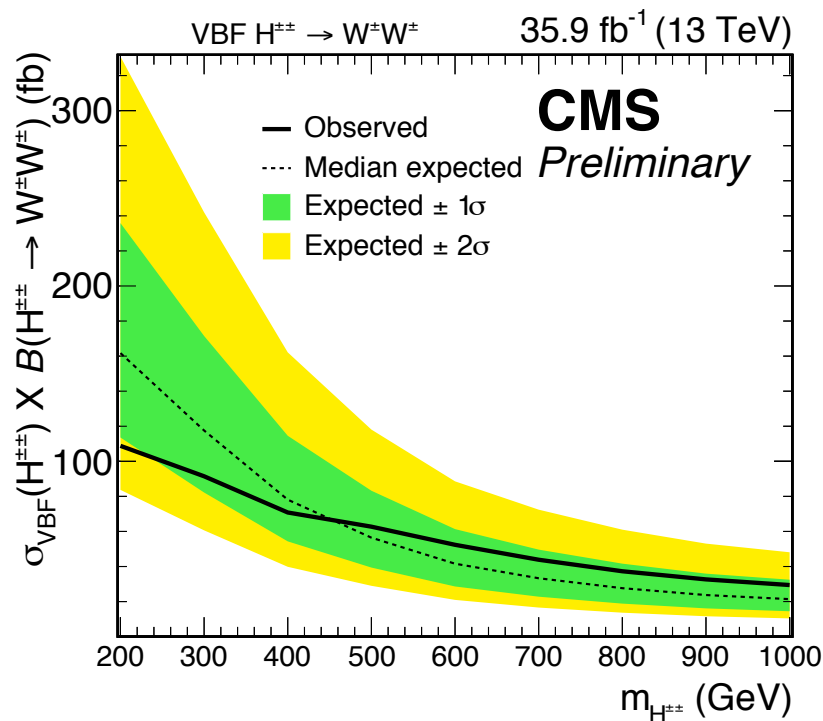
CMS-PAS-HIG-16-036 CDS $H^{++} \rightarrow l^+ l^+$

includes associative production & taus
12.9 fb⁻¹, 13 TeV
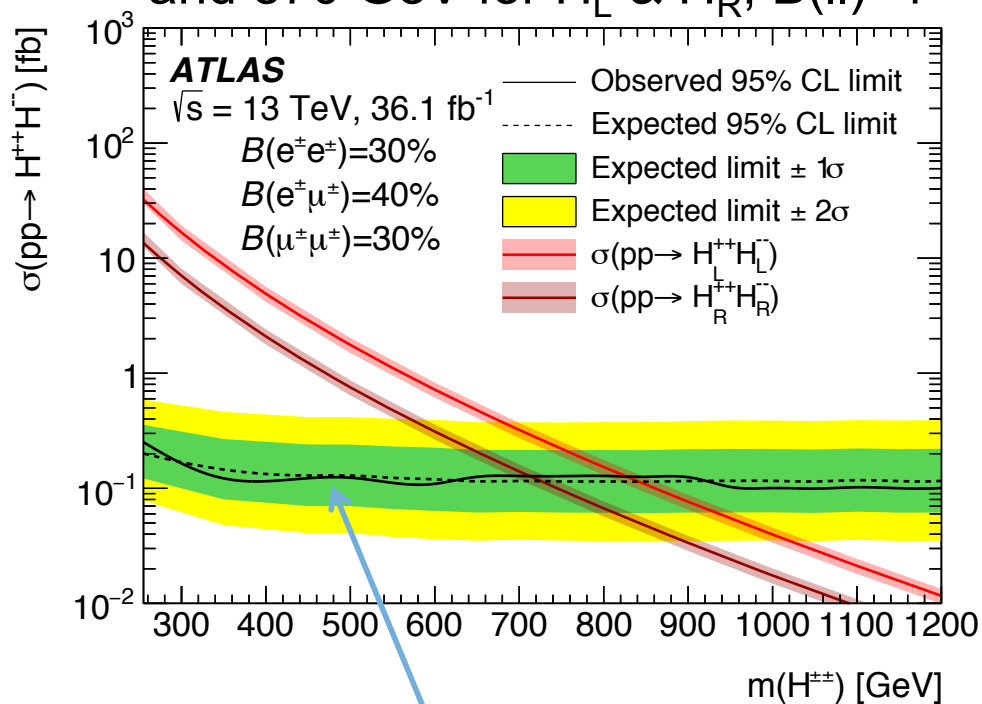
limit ~3 – 4 signal events
for B($H^{\pm\pm} \rightarrow l^\pm l^\pm$) = 1

Conclusion

- Several new results in different charged Higgs channels
  - many more results expected on the full Run II 13 TeV data
- No signs of physics beyond the standard model so far
- Age of "easy discoveries" at the LHC has gone; sensitivity will grow with ~√integrated luminosity, i.e. √time !
  - improving systematics with more statistics
- Only ~1% of high-luminosity LHC dataset analyzed so far

- Changes in analysis strategy:
  - Combinations
  - More specific final states
  - Sophisticated background suppression & signal identification
  - Difficult accessible signal phase-space
  - Unconventional signal models
  - ...

■ Analyzed   ■ HL LHC