# Search for $H^+ \rightarrow W^+ A$ with $A \rightarrow \mu\mu$


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Charged-Higgs@LHC Online
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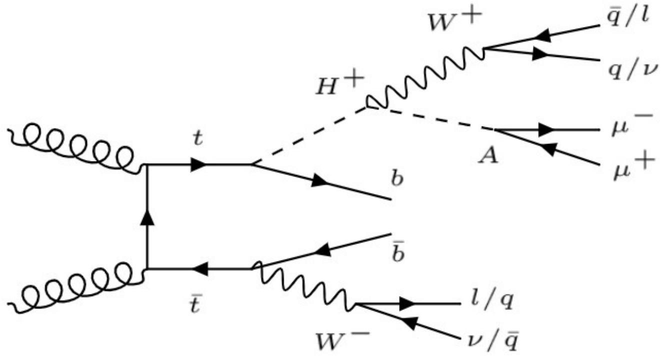
# Introduction

- Search for a light charged Higgs decaying to a CP-odd scalar (*A*) and a *W* boson
- Motivation: Extension of Higgs sector can offer solutions to outstanding problem in the Standard Model
  - Light CP-odd scalar can account for the anomalous muon magnetic moment, relevant in light of recent g-2 result
  - Bosonic decays of $H^+$ have been neglected in most current searches. These modes, when kinematically allowed, can dominate fermionic channels in BSM scenarios
  - ATLAS has not published on this decay in the past; the CMS result with 36 $fb^{-1}$ is the only public result at LHC
- Semi-leptonic decays (i.e. WW → eνjj ) targeted: $e^{\pm}\mu^{+}\mu^{-}$ final states
  - Simpler combinatorics compared to $\mu\mu\mu$ mode
- Using full-Run 2 dataset, 139 $fb^{-1}$
- Target mass ranges as follows:
  - $H^+$: 100–160 GeV
  - *A*: 15-75 GeV

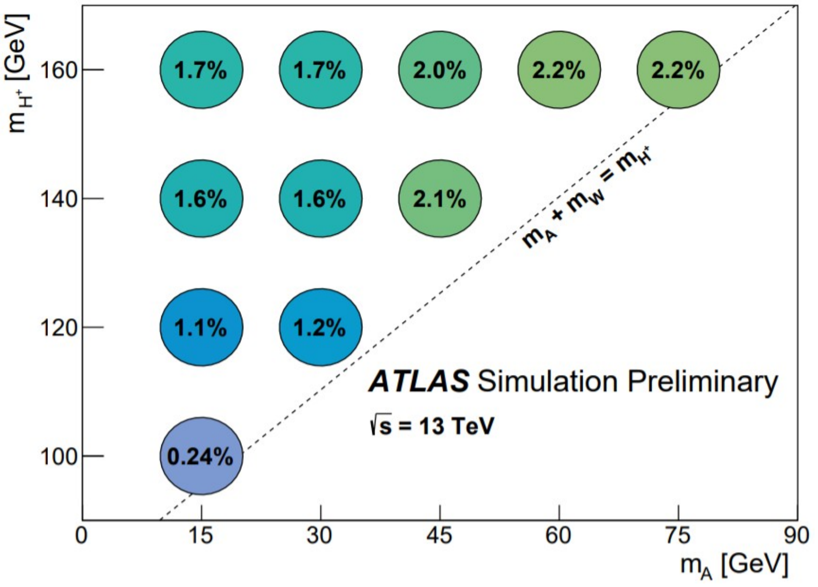


# Signal

- Target signature is scalar decaying to muons, we thus look for signal in opposite-sign (OS) dimuon spectrum
- Signal Selection for 'Inclusive' SR:

| | Event selection | |
|---|---|---|
| Trigger | single muon | di-muon |
| Muons | $p_T^{leading} > 27$ GeV, $p_T^{subleading} > 5$ GeV | $p_T^{leading} > 15$ GeV, $p_T^{subleading} > 15$ GeV |
| | exactly 2, opposite sign<br>$12 < m_{\mu\mu}$ [GeV] $< 77$<br>$p_T(\mu_2^{SS})/p_T(\mu_1^{OS}) > 0.2$ | |
| Electrons | exactly 1, $p_T > 20$ GeV | |
| Jets | $\geq 3$, $p_T > 20$ GeV<br>$\geq 1$ $b$-tagged jet | |

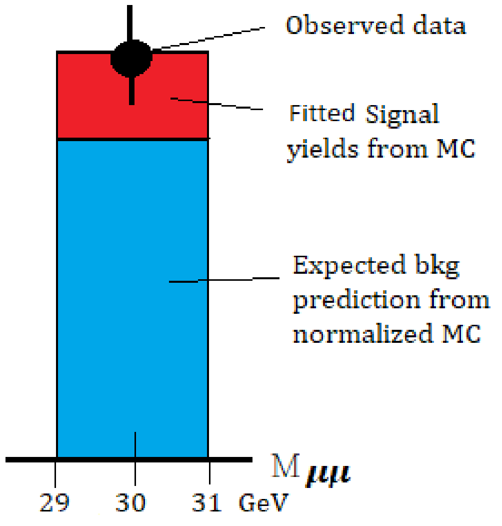
- Simulated 2D Mass Grid for signal samples




Simulated mass points and corresponding signal efficiencies in the inscribed circles

# Design Overview

- Search strategy: split 65 GeV wide $M_{\mu\mu}$ spectrum into small windows and do counting experiments in each window
  - Single-bin likelihood fit done for each mass window i.e. cut-and-count approach
  - Window size chosen such that S/B is maximized for each mass hypothesis
- Background estimation: MC constrained with data in Control Regions
  → Free floating parameters for major backgrounds are determined in a likelihood fit to the yields
  → Systematic uncertainties implemented as nuisance parameters in the fit
- Statistical Package: Histfitter

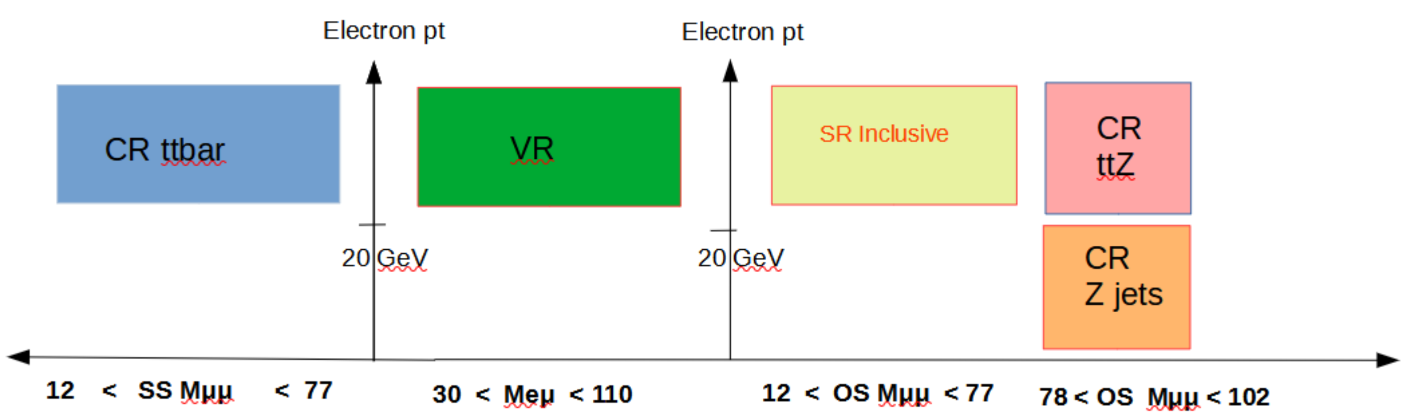


# Backgrounds: Control and Validation Regions

- Background distribution in SR:
  - Dominated by ttbar with one non-prompt lepton (80%), ttZ (6%), Z+jets (6%)
- CRttbar: same-sign muon region, to constrain the primary background. Enriched in muon fakes.
- CRZ and CRttZ : using the Z-peak in side-bands of SR to constrain Zjets & ttZ. CRZ is enriched in electron fakes.
- VR: designed to be signal-poor with a mixture of SS and OS dimuon events. Used to check if normalization from SS region can be used in OS region.

| | Shared Cuts |
|---|---|
| muons | Exactly 2<br>$p_T^{\text{leading}} > 27$ GeV, $p_T^{\text{subleading}} > 5$ GeV (single-mu trig)<br>$p_T^{\text{leading}} > 15$ GeV, $p_T^{\text{subleading}} > 15$ GeV (dimuon trig)<br>$p_T(\mu^{SS})/p_T(\mu^{OS}) > 0.2$ |
| electrons | Exactly 1 |
| jets | At least three, $p_T > 20$ GeV,<br>of which at least one is b-tagged jet |

| | CRZ | CRttZ | CR$t\bar{t}$ | SRIncl | VR |
|---|---|---|---|---|---|
| $M\mu\mu$ [GeV] | [78,102] | [78,102] | [12,77] | [12,77] | No $M\mu\mu$ cut |
| Electron $p_T$ [GeV] | < 20 | > 20 | | | |
| dimuon charge | OS | | SS | OS | No charge cut |
| $Me\mu$ [GeV] | No $Me\mu_1$ cut | | | | $30 < Me\mu_1 < 110$ |



# Background Model and Fit

- Background Model: using a semi-data driven approach where the MC is used as a base template for the backgrounds and the yield is normalized to the data in control regions using a maximum likelihood fit

- Fitting strategy:
  - **CR-only Fit ('Background-only')** : 3 free-floating parameters ( $\mu_{ttZ}$ , $\mu_{zjets}$ , $\mu_{ttbar}$ ) used for normalization of background yields to data. A single-bin likelihood fit is done simultaneously in 3 CRs. This configuration is used to test background modeling and get predictions in SR.
  - **Signal + Background Fit (Exclusion Fit)** : A simultaneous fit in 3 CRs + 1 SR window. Additional parameter $\mu_{signal}$ for the signal strength. Hypothesis testing done and limits extracted using CLs approach.
    - Hypothesis tests done for $M_A$ = [15,16,17,18.....45,47,49...71,73,75] GeV (45 in total)
    - Optimized $M_{\mu\mu}$ SR windows to maximize signal-to-background for each mass
      - 15 – 30 GeV : 1.5 GeV
      - 31 – 45 GeV : 2 GeV
      - 46 – 60 GeV:  3 GeV
      - 61 – 75 GeV : 4 GeV

# Results with CR-only Fit

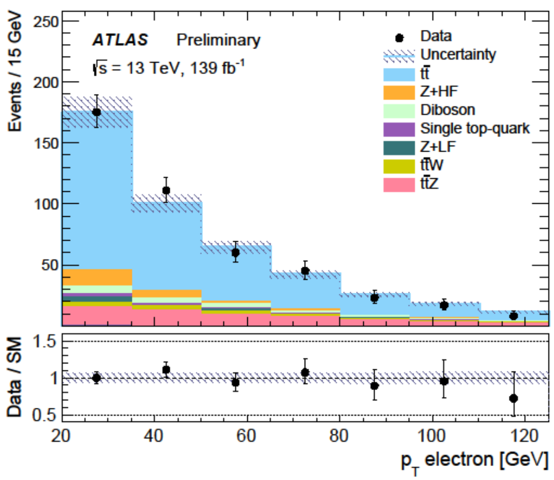
# Post-Fit Yields

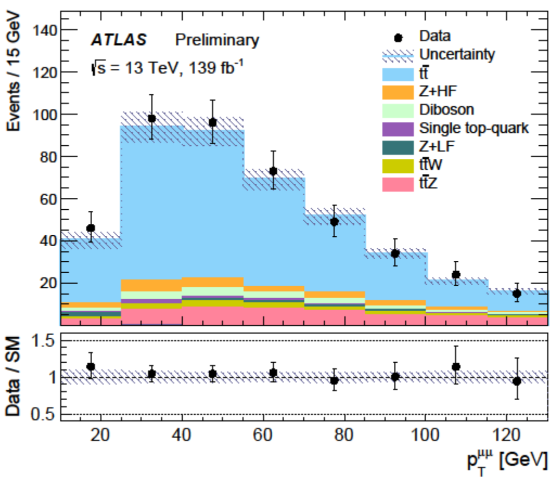
- Post-fit yields in various kinematic regions are shown with stat + sys errors
- CRZ, CRttbar & CRttZ agree by construction
- Encouraging to see good agreement in the VR and SRInclusive
  - shows normalization and fitting procedure is sound

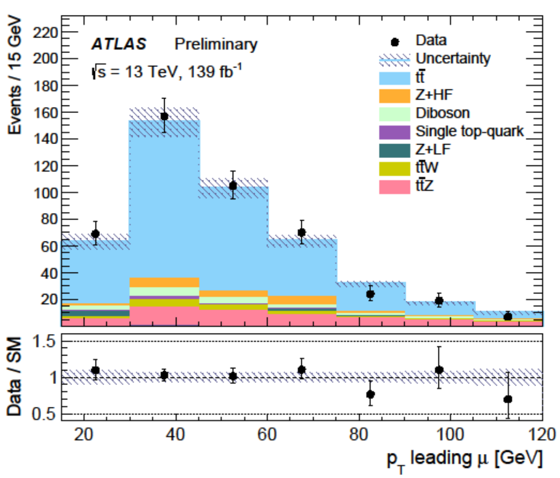
| Regions | | CRZ | $CRt\bar{t}$ | $CRt\bar{t}Z$ | VR | SRInclusive |
|---|---|---|---|---|---|---|
| Observed events | | 803 | 190 | 635 | 529 | 465 |
| Fitted background events | Total | 803 ±28 | 190 ±14 | 635 ±25 | 541 ±43 | 470 ±37 |
| | $t\bar{t}$ | 136 ±21 | 170 ±14 | 97 ±19 | 388 ±46 | 320 ±39 |
| | $Z$+HF | 491 ±49 | 0.72 ± 0.16 | 43 ± 8 | 18 ± 6 | 29 ± 6 |
| | $Z$+LF | 84 ±29 | 0.41 ± 0.14 | 12 ± 4 | 2.82 ± 0.98 | 13 ± 4 |
| | $t\bar{t}Z$ | 52 ±14 | 6.40 ± 1.64 | 327 ±83 | 76 ±19 | 64 ±16 |
| | diboson | 34 ±17 | 0.58 ± 0.29 | 147 ±73 | 32 ±16 | 22 ±11 |
| | $W$+jets | 0.01 ± 0.01 | 0.40 ± 0.39 | 0 ± 0 | 0.08 ± 0.07 | 0.49 ± 0.48 |
| | single top | 4.13 ± 0.29 | 4.38 ± 0.23 | 2.39 ± 0.12 | 9.00 ± 0.46 | 6.17 ± 0.33 |
| | $t\bar{t}W$ | 1.06 ± 0.15 | 7.43 ± 0.97 | 6.42 ± 0.83 | 14 ± 2 | 16 ± 2 |

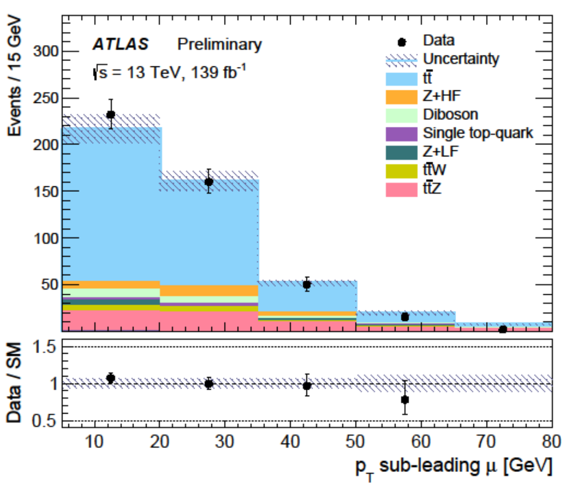
- Normalization parameters consistent with other analyses:
  - μ_ttbar = 1.04 +/- 0.10
  - μ_Z = 1.03 +/- 0.21
  - μ_ttZ = 1.61 +/- 0.41
  (compatible with 1.19 +/- 0.12 from
  the ttZ measurement paper )

# Bkg validation: Post-Fit Data/MC in SRInclusive



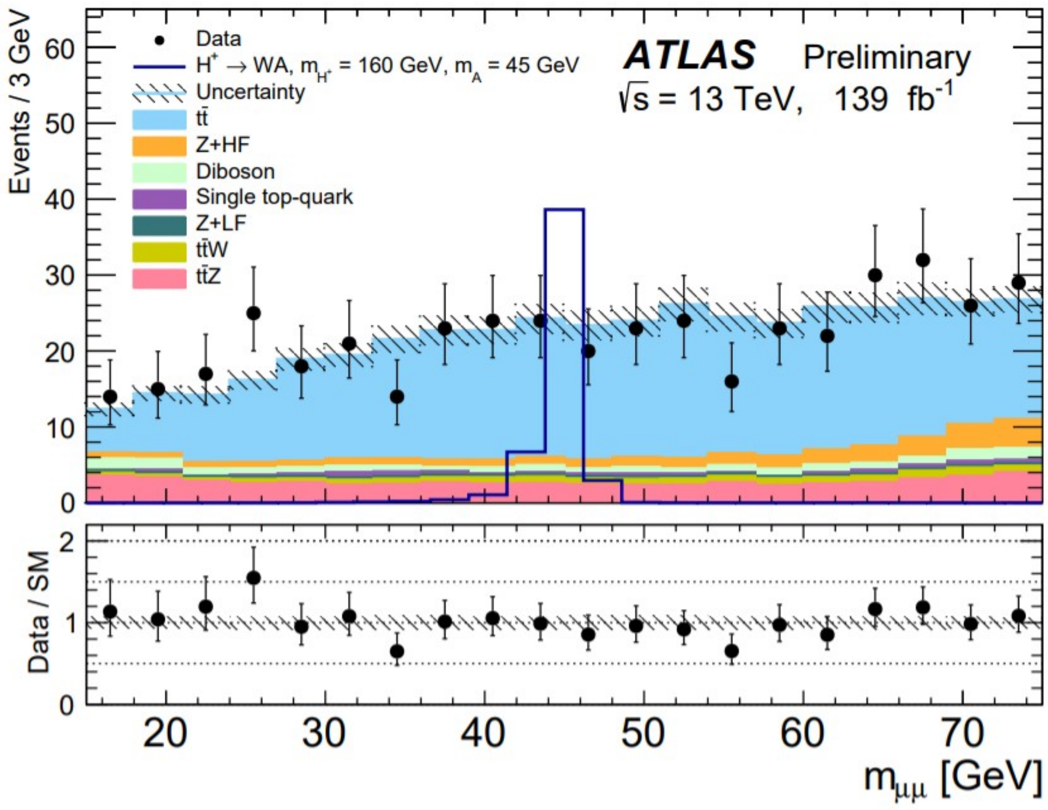




- Good data/MC agreement seen in all lepton kinematics in the SR
- Demonstrates that normalization from CR → SR and fitting procedure is reliable

# μμ mass spectrum

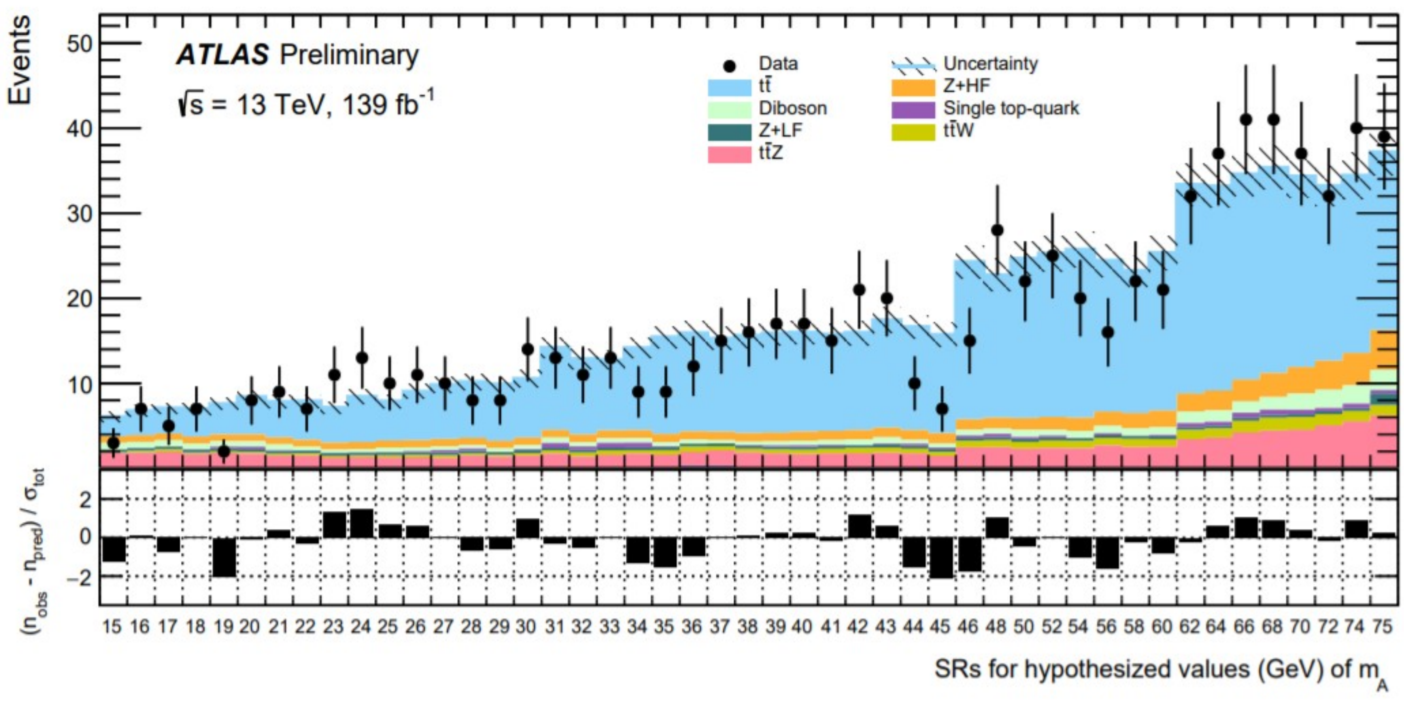
- Observing smooth distribution, no significant excess
  - Small dips 35, 45 and 55 GeV
  - Small bumps 24, 42, 65 GeV
- Signal overlaid on background for demonstration, not used in this fit




Assumptions on signal:
σ = 832 pb, B(t → bH+, H+→ WA, A→μμ) = 9e-6

# Data in SR windows

- Observed Vs expected events counts in individual SR regions after application of di-muon mass cuts to inclusive SR
- Steps at 30, 45, 60 GeV due to change in width of mass window

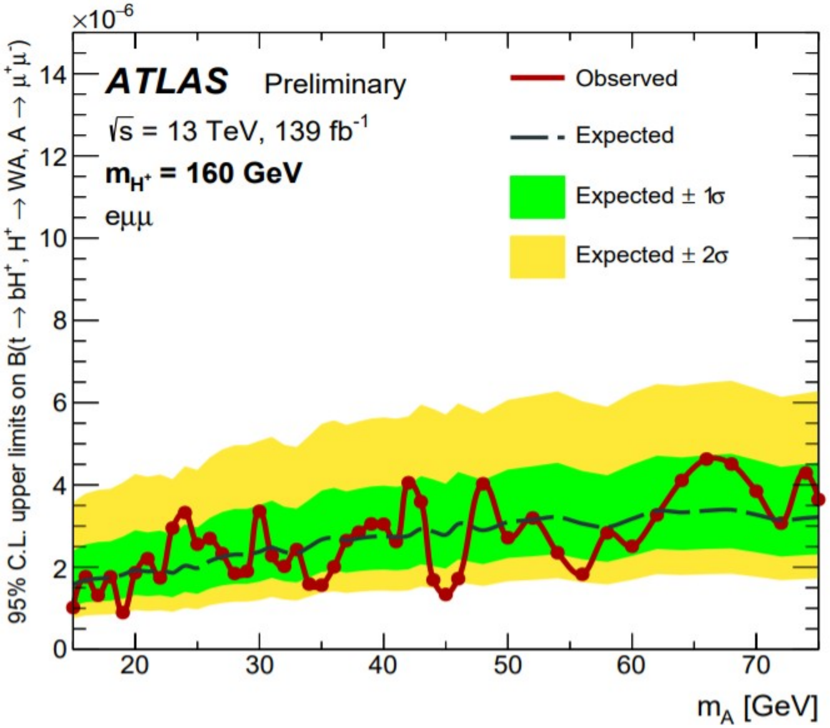


# Results with Signal + Background Fit (Exclusion Fit)

# Observed limits

- S + B fit : simultaneous single-bin fit in 3 CRs + 1 SR window. Limits set on B(t → bH+, H+→ WA, A→μμ)
- Hypothesis tests done:
  - in 1 GeV steps for $M_{\mu\mu}$ < 45 GeV
  - in 2 GeV steps for $M_{\mu\mu}$ > 45 GeV
- Optimized $M_{\mu\mu}$ SR windows to maximize signal-to-background for each mass-point
  - 15 – 30 GeV: 1.5 GeV
  - 31 – 45 GeV: 2 GeV
  - 46 – 60 GeV: 3 GeV
  - 61 – 75 GeV: 4 GeV
- Small peaks/dips match mass plot
- Most significant p-value is at mA = 24 GeV of 0.10 with significance of 1.24 σ

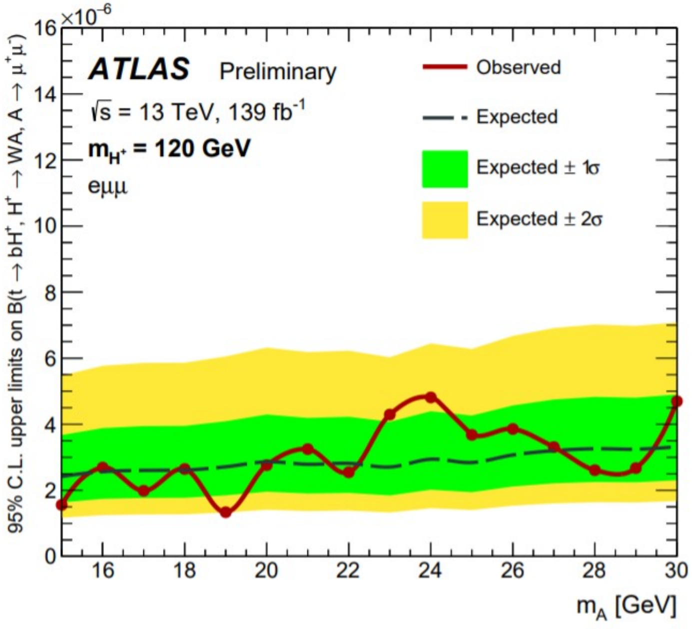
Determined prior to unblinding



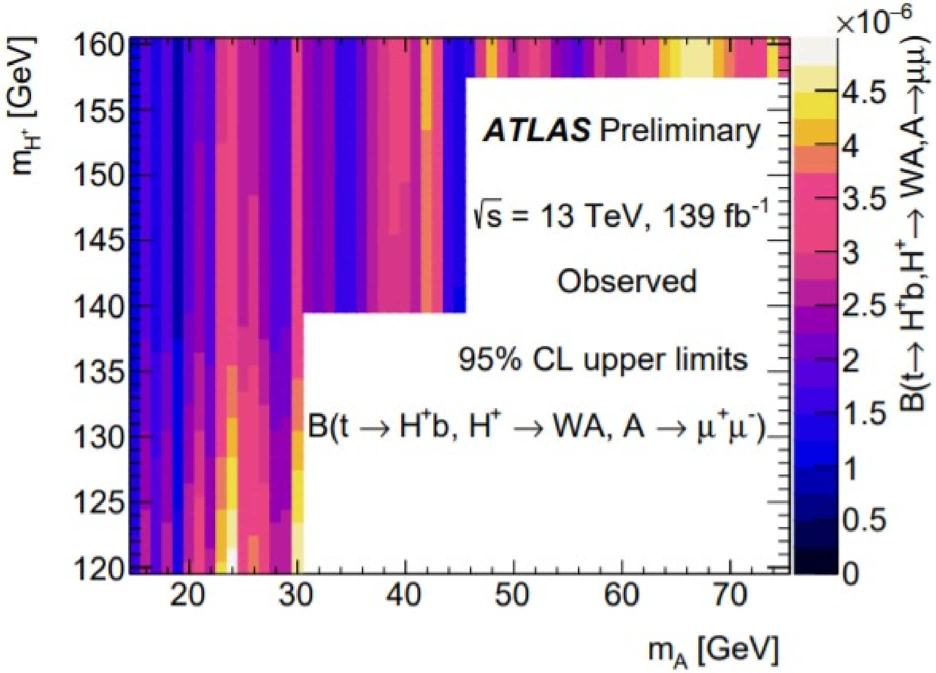

No significant excess observed

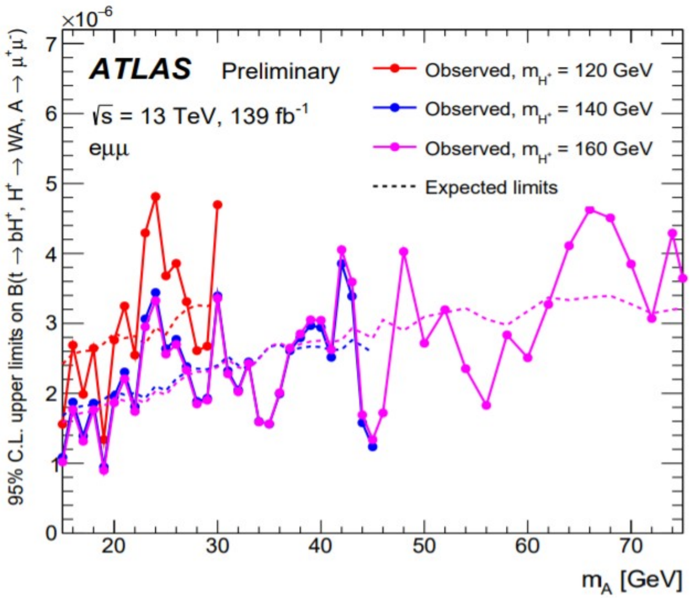
# Observed limits

- 2D limits generated by linearly interpolating between the 1D limits from the tested H+ mass points in 1 GeV steps




Limits for H+ = 120 GeV



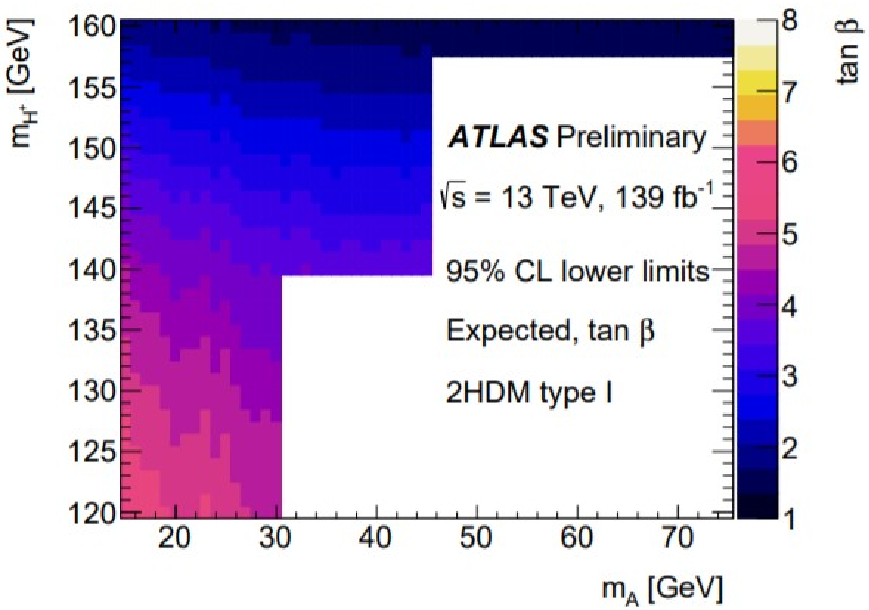



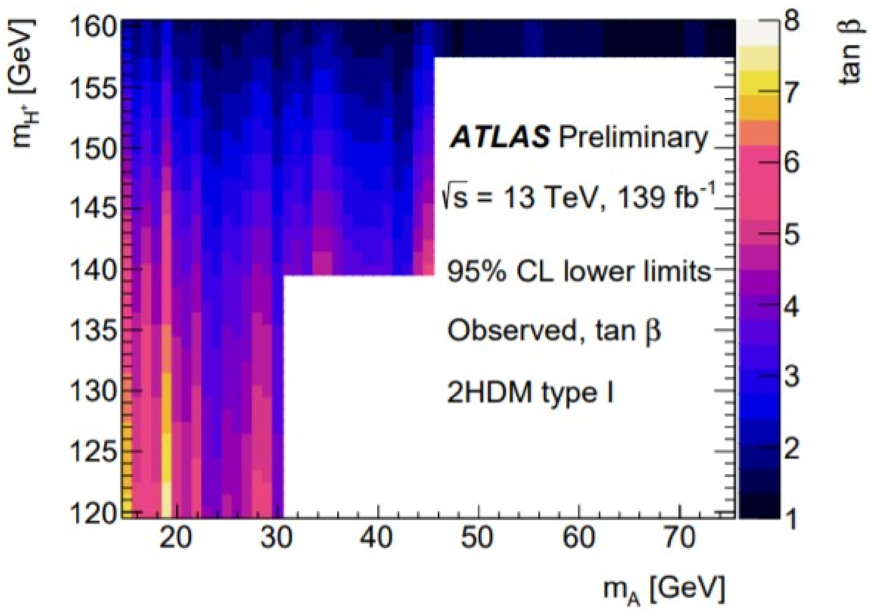



Limits overlaid for various H+ masses

# 2 Higgs Doublet Model (2HDM) Interpretation

- We re-interpret branching ratio results as lower limits on tan β in 2HDM Type I (reminder: tan β is ratio of the VEVs in 2 Higgs Doublet Fields)
- Values of tan β from 0.5 to 10 are tested, lower limits range from 1.1 to 7.7
- Interpolation done in 1 GeV steps, same method as before
- 2HDMC calculates all the branching ratios needed:
  - Given 2HDM type, $m_h$. $m_H$, $m_A$, $m_{H+}$, $m_{12}^{sq}$, tanβ, sin(β-α), $\lambda_6$ and λ
  - 3 scenarios defined in 1312.5571; we represent limits for type I scenario using mH = 300 GeV and $m_{12}^{sq}$ =25600 GeV



# Summary

- We present the first search in ATLAS for H+ → WA with 15 < $M_{\mu\mu}$ < 75 GeV
- No significant deviation from Standard Model expectation is observed. Data shows excellent agreement with SM predictions.
- The most stringent exclusion limits on B(t → bH+, H+→ WA, A→μμ) are placed by exploiting Run 2 dataset
- First lower limits on tan β in the (mH+, mA ) parameter space are set
- Public page for results to be live soon

# Backup

# Systematic Uncertainties

- All major systematic sources have been added to the fit
- Background MC:
  - Experimental: JET, JES, b-tagging, flavour tagging, pileup, muons, electrons
  - Theory: ttbar generator, shower and radiations systematics
- Signal MC:
  - Experimental: same as background
  - Cross-section uncertainties applied using Top recommendations
  - Custom systematic: Interpolation error for Splines

# Systematics Breakdown in SR

- Breakdown of systematics in representative SR bins, post-fit
- Average systematic across bins is ~ 20%
- Main source of error on bkg yields are from:
  - Uncertainty on normalization parameters
  - MC stat error
  - ttbar theory systematics
- Reduced systematics shown for brevity, see Note for full list

| **Uncertainty of channel** | SR15 | SR31 | SR48 | SR70 |
|---|---|---|---|---|
| Total background expectation | 5.47 | 13.55 | 21.89 | 32.52 |
| Total statistical ($\sqrt{N_{\mathrm{exp}}}$) | ±2.34 | ±3.68 | ±4.68 | ±5.70 |
| Total background systematic | ±0.87 [15.88%] | ±2.84 [20.99%] | ±4.87 [22.26%] | ±6.52 [20.05%] |
| MC_gamma_stat_SR15 | ±0.49 [8.9%] | ±0.00 [0.00%] | ±0.00 [0.00%] | ±0.00 [0.00%] |
| MC_gamma_stat_SR31 | ±0.00 [0.00%] | ±0.74 [5.5%] | ±0.00 [0.00%] | ±0.00 [0.00%] |
| MC_gamma_stat_SR70 | ±0.00 [0.00%] | ±0.00 [0.00%] | ±0.00 [0.00%] | ±1.32 [4.1%] |
| MC_gamma_stat_SR48 | ±0.00 [0.00%] | ±0.00 [0.00%] | ±0.94 [4.3%] | ±0.00 [0.00%] |
| alpha_ttbar__showerSysNominal | ±0.49 [9.0%] | ±2.10 [15.5%] | ±3.65 [16.7%] | ±4.88 [15.0%] |
| mu_ttZ | ±0.45 [8.3%] | ±0.45 [3.3%] | ±0.64 [2.9%] | ±1.16 [3.6%] |
| alpha_db_Xsec | ±0.39 [7.1%] | ±0.32 [2.3%] | ±0.30 [1.4%] | ±0.95 [2.9%] |
| alpha_ttbar__genSysNominal | ±0.38 [6.9%] | ±1.63 [12.0%] | ±2.83 [12.9%] | ±3.78 [11.6%] |
| mu_Top | ±0.21 [3.9%] | ±0.91 [6.7%] | ±1.59 [7.3%] | ±2.12 [6.5%] |
| alpha_MUON_SCALE | ±0.12 [2.1%] | ±0.17 [1.3%] | ±0.28 [1.3%] | ±0.56 [1.7%] |
| alpha_ttbar__radSysNominal | ±0.08 [1.4%] | ±0.33 [2.4%] | ±0.58 [2.6%] | ±0.77 [2.4%] |
| alpha_JET_Flavor_Response | ±0.06 [1.1%] | ±0.08 [0.62%] | ±0.12 [0.55%] | ±0.00 [0.00%] |
| alpha_zLF_Xsec | ±0.06 [1.1%] | ±0.06 [0.42%] | ±0.06 [0.26%] | ±0.06 [0.18%] |
| alpha_JET_GroupedNP_2 | ±0.05 [0.96%] | ±0.02 [0.16%] | ±0.22 [1.00%] | ±0.03 [0.10%] |
| mu_Z | ±0.05 [0.90%] | ±0.06 [0.42%] | ±0.08 [0.37%] | ±0.19 [0.57%] |
| alpha_MUON_ID | ±0.03 [0.63%] | ±0.12 [0.85%] | ±0.18 [0.80%] | ±0.06 [0.19%] |
| alpha_MUON_MS | ±0.03 [0.62%] | ±0.11 [0.85%] | ±0.62 [2.8%] | ±0.01 [0.02%] |
| alpha_JET_GroupedNP_1 | ±0.03 [0.56%] | ±0.03 [0.21%] | ±0.20 [0.93%] | ±0.06 [0.20%] |
| alpha_EG_Resolution | ±0.03 [0.55%] | ±0.10 [0.77%] | ±0.06 [0.26%] | ±0.05 [0.17%] |
| alpha_leptonWeight_EL_EFF_Reco | ±0.02 [0.36%] | ±0.12 [0.92%] | ±0.15 [0.67%] | ±0.19 [0.58%] |
| alpha_bTagWeight_FT_EFF_B_syst | ±0.02 [0.34%] | ±0.00 [0.03%] | ±0.02 [0.09%] | ±0.05 [0.15%] |
| alpha_leptonWeight_EL_EFF_Reco | ±0.02 [0.32%] | ±0.08 [0.59%] | ±0.13 [0.61%] | ±0.18 [0.55%] |
| alpha_EG_Scale | ±0.01 [0.26%] | ±0.14 [1.0%] | ±0.06 [0.29%] | ±0.03 [0.09%] |
| alpha_bTagWeight_FT_EFF_Light_syst | ±0.01 [0.23%] | ±0.01 [0.07%] | ±0.06 [0.25%] | ±0.07 [0.22%] |
| alpha_ttW_Xsec | ±0.01 [0.21%] | ±0.05 [0.34%] | ±0.10 [0.48%] | ±0.19 [0.58%] |
| alpha_leptonWeight_MUON_EFF_ | ±0.01 [0.21%] | ±0.05 [0.38%] | ±0.03 [0.16%] | ±0.04 [0.12%] |
| alpha_leptonWeight_EL_EFF_Iso_ | ±0.01 [0.14%] | ±0.03 [0.25%] | ±0.06 [0.26%] | ±0.08 [0.23%] |
| alpha_JET_GroupedNP_3 | ±0.01 [0.14%] | ±0.04 [0.30%] | ±0.00 [0.01%] | ±0.02 [0.08%] |
| alpha_bTagWeight_FT_EFF_C_syst | ±0.00 [0.04%] | ±0.00 [0.02%] | ±0.03 [0.15%] | ±0.01 [0.02%] |
| alpha_st_Xsec | ±0.00 [0.00%] | ±0.03 [0.20%] | ±0.02 [0.10%] | ±0.03 [0.08%] |

# Object selection and Triggers

- Muons

| Cut | Value/description |
|---|---|
| ID | LowPt |
| Acceptance | $p_T > 3\text{GeV}, \lvert\eta\rvert < 2.7$ |
| Isolation | FCLoose |
| IP | $z_0 \sin\theta < 0.5$ mm |
| | $d_0/\sigma_{d_0} < 3$ |

- Electrons

| Cut | Value/description |
|---|---|
| ID | MediumLLH |
| Acceptance | $p_T > 5\text{GeV}, \lvert\eta\rvert < 2.47$ |
| Isolation | FCLoose |
| High $p_T$ Isolation | FCHighPtCaloOnly |
| IP | $z_0 \sin\theta < 0.5$ mm |
| | $d_0/\sigma_{d_0} < 5$ |

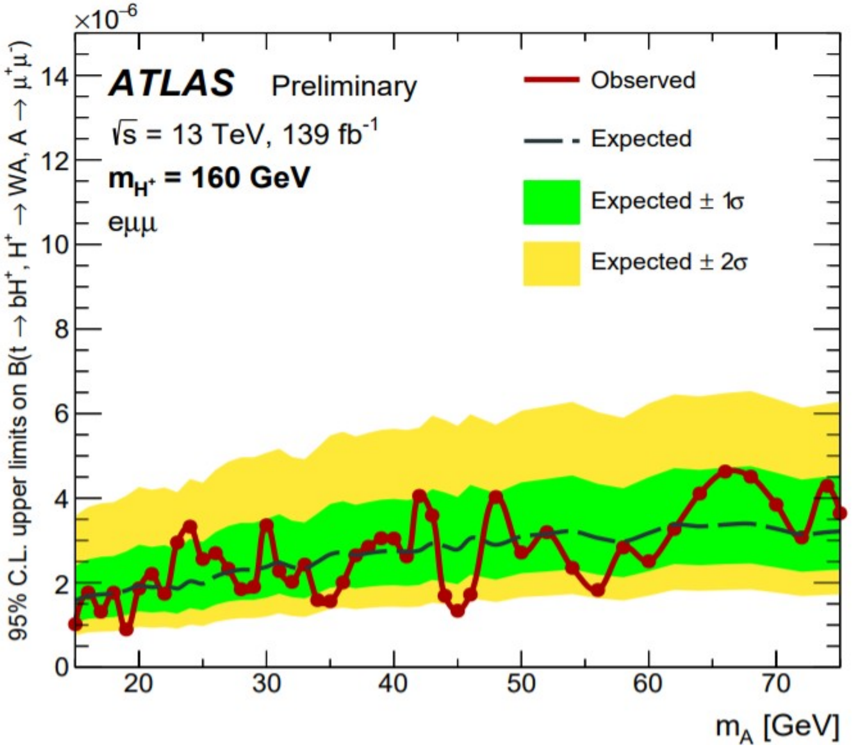
- Jets

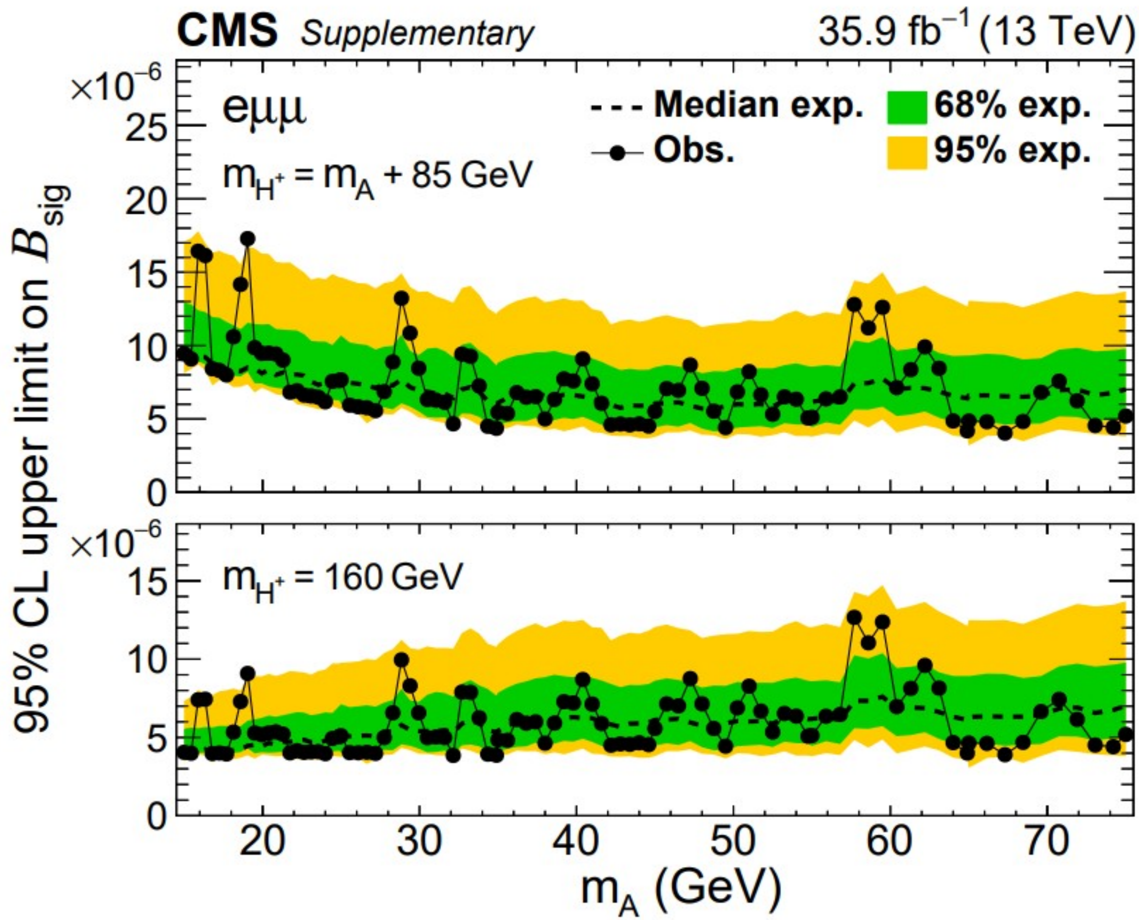
| Cut | Value/description |
|---|---|
| Acceptance | $p_T > 20\text{GeV}, \lvert\eta\rvert < 2.5$ |
| JVT | Tight WP, JVT > 0.5 for $\lvert\eta\rvert < 2.4$ and $20 < p_T < 60$ GeV |
| $b$-tagging | MC2c10 > 0.64, $\epsilon_b = 77.53\%$ |

- Triggers: single and di-muon triggers

| Trigger | Run period |
|---|---|
| HLT_mu20_iloose_L1MU15 | 276262 – 284484 |
| HLT_mu26_ivarmedium | 297730 – |
| HLT_2mu10 | 276262 – 284484 |
| HLT_2mu14 | 297730 – |

# Comparison with CMS



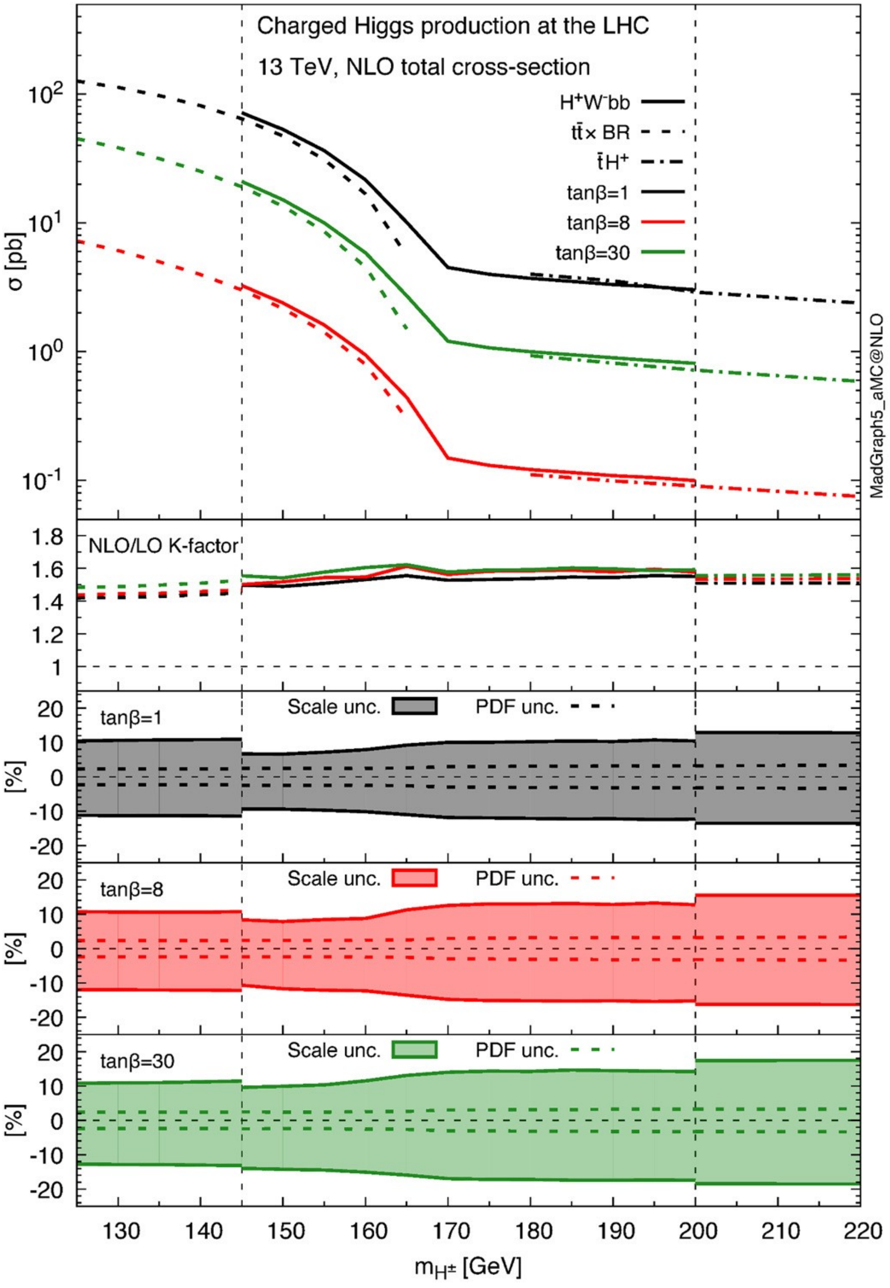

CMS result with 36 $fb^{-1}$

# Interpreting tt→ $H^+$→WA→μμ

- So far limits have been set on top branching ratio
  - Implicitly assumes only tt production mechanism
  - Needs top cross-section
- Today we would like to propose setting 2HDM tanβ li
  - Re-interpreting the branching ratio results.

# 2HDM tools

- 2HDMC calculates all the branching ratios needed
  - Given 2HDM type, $m_h$. $m_H$, $m_A$, $m_{H+}$, $m_{12}^{sq}$, tanβ, sin(β-α), $\lambda_6$ and $\lambda_7$
  - 3 scenarios defined 1312.5571
  - But for H+ it seems only type Higgs masses & tanβ matter
- More recently, Degrande et al. calculated pp→tH⁺bb at NLO with widths,
  - Grid of ($m_{H+}$, tanβ) available
  - Includes single top cross-section
  - More important as $m_{H+}$~$m_t$
  - But not what we simulated



# 2HDMC scenarios

| Parameter | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| Type | I | II | II |
| $M_h$ (GeV) | 125 | 125 | 125 |
| $M_H$ (GeV) | 300 | 300 | 400 |
| $M_A$ (GeV) | 330 | 270 | 500 |
| $M_{H^+}$ (GeV) | 230 | 335 | 550 |
| $M_h$ (GeV) | 25600 | 1798 | 15800 |
| $\tan\beta$ | 1.5 | 50 | 10 |
| $\sin(\beta - \alpha)$ | 0.901314 | 0.999001 | 0.999 |
| $\lambda_6$ | 0 | 0 | 0 |
| $\lambda_7$ | 0 | 0 | 0 |

- Try these scenarios but with $m_A$, $m_{H+}$, $\tan\beta$ scanned as required
- B and C give results always identical to 3 figures

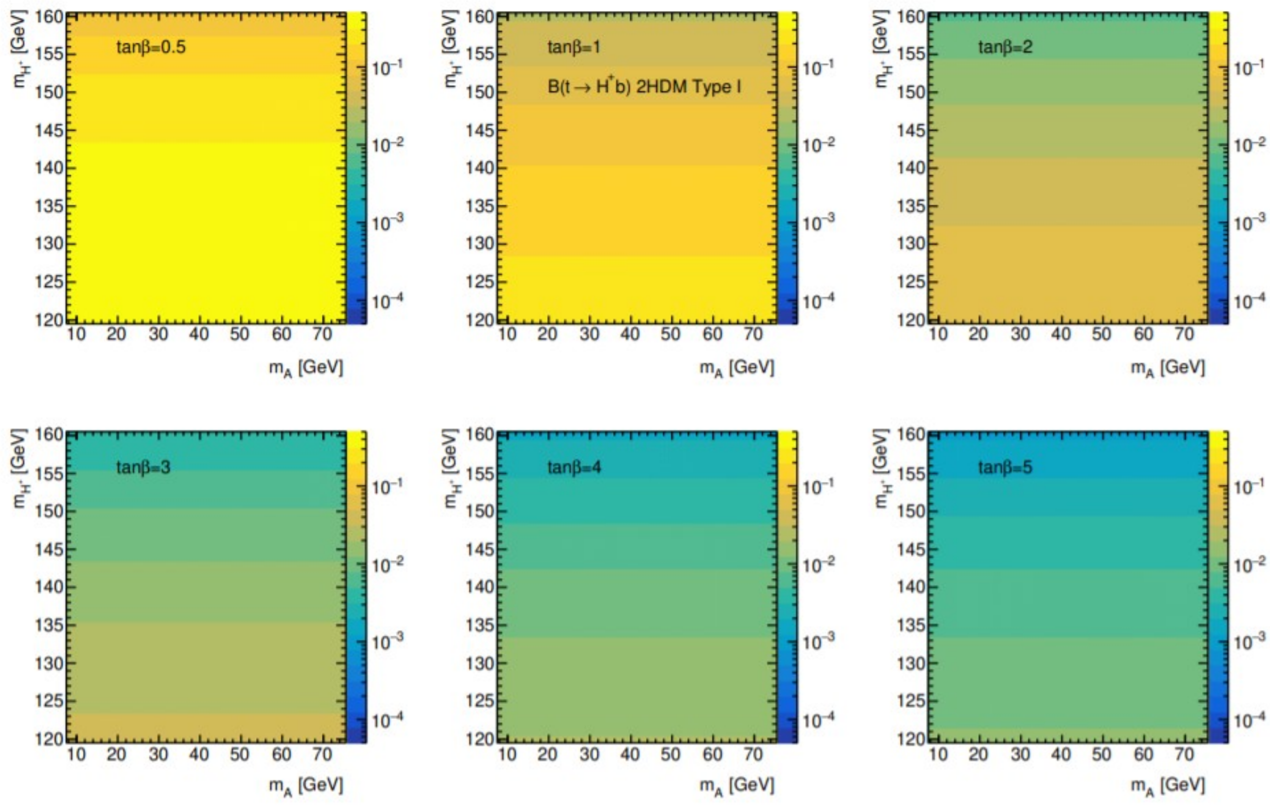
# 2HDM tools compared

| $m_{H^+}$ | $\tan\beta$ | Full NLO | 2HDMC | Ratio |
|---|---|---|---|---|
| 145 GeV | 1 | 70.4 fb | 79.7 fb | 0.88 |
| | 3 | 9.86 fb | 9.92 fb | **0.99** |
| | 10 | 3.63 fb | 3.56 fb | 1.02 |
| 160 GeV | 1 | 21.3 fb | 19.9 fb | **1.07** |
| | 3 | 2.70 fb | 2.32 fb | 1.16 |
| | 10 | 1.04 fb | 0.83 fb | 1.25 |

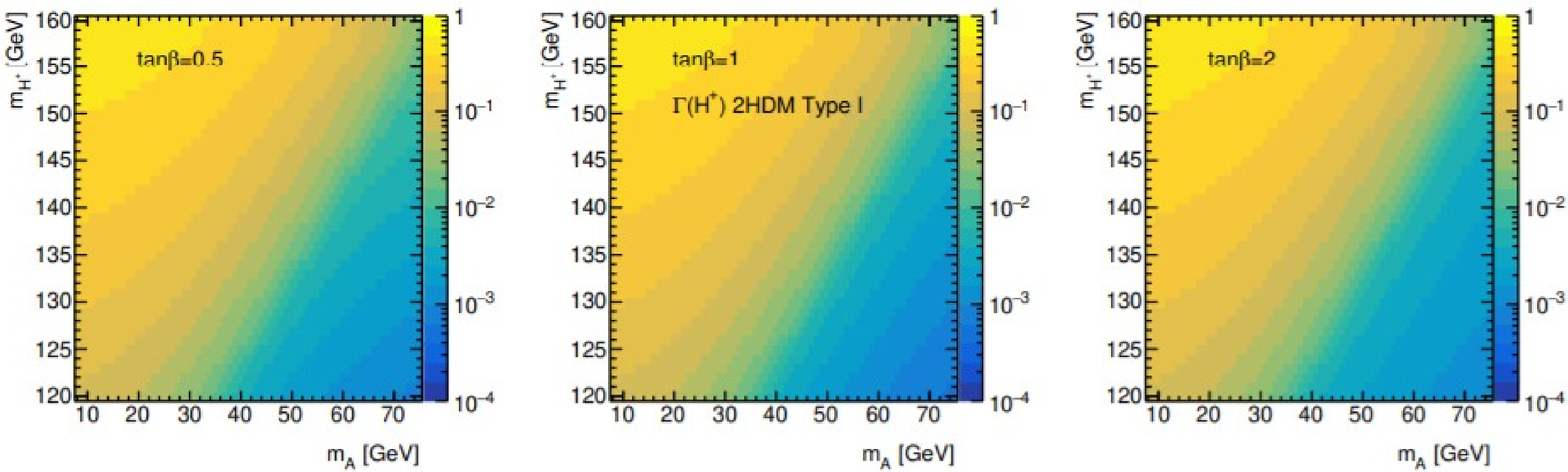
- We compare Degrande (full) with 2HDMC t→H+ BR, multiplied by 831.76~pb tt cross-section
  - Note: Degrande seems to be quoting only $H^+$ XS, not including $H^-$
- Significant increase at 160 GeV was expected
- Dependence upon tanβ - any thoughts anyone?
- We use $m_{H+}$ 100-160, Degrande 145-200, so matching would be tricky
- Fortunately limits are set at bold points where differences are small.

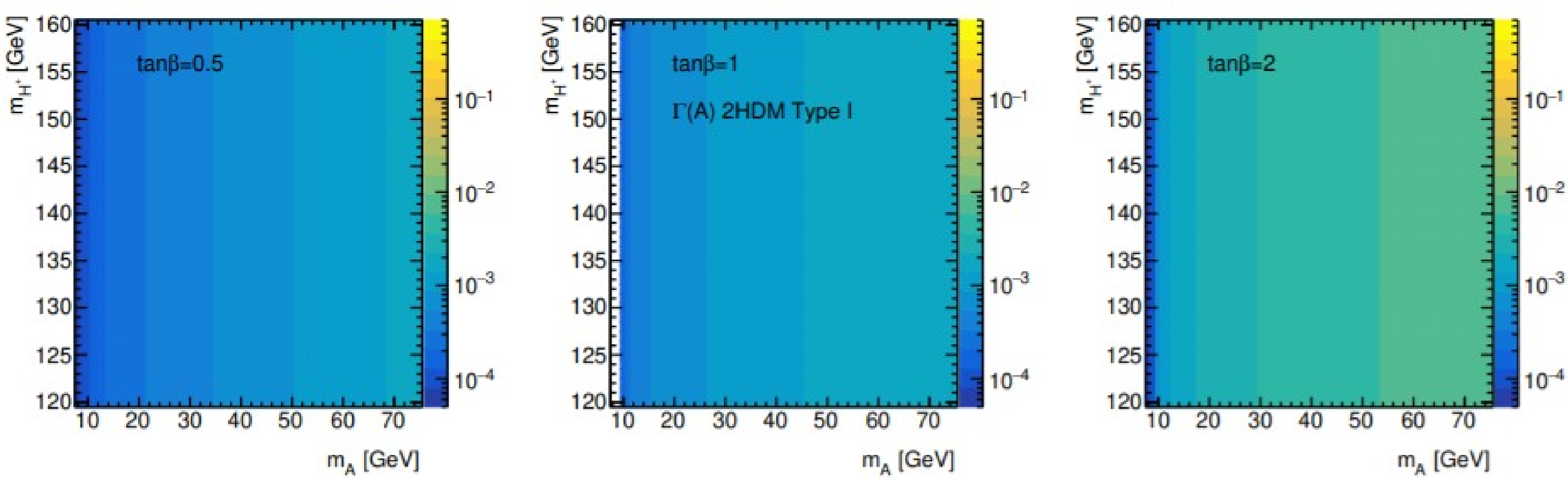
# BR (t→ H+b) in Scenario A

- Example BR's for different tan beta values



# Decay Widths



# Z+jets break down

- Action Item: What’s the breakdown of different flavour of Z-jets in CR and SR ? What if you float a different component of Z+jets?

- We summarize the breakdown of Z + jets by flavour on the right. HF dominates in both SR and CR

- If we let mu_z constrain only Z+jets ’Bfilter’ , we still get the same value i.e. mu_z = 1.03

| | CRZ | % | SR | % |
|---|---|---|---|---|
| Zjets 'Bfilter' | 440.6 | 78 | 20.4 | 50 |
| Zjets 'CfilterBVeto' | 34.1 | 6 | 7.3 | 18 |
| Zjets Bfilter + CFilter | 474.7 | 85 | 27.7 | 68 |
| Zjets all other | 83.9 | 15 | 12.5 | 31 |
| | | | | |
| total | 558.6 | | 40.2 | |

- We have updated the fit and classify the Bfilter and Cfilter as Z + HF. We let mu_Z constrain Z + HF in CRZ and we find mu_Z = 1.03 +/- .2

# Cutflow for signal

| | H160a15 | | H160a45 | | H160a75 | | H140a15 | | H120a15 | | H120a30 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | events | eff., % | events | eff., % | events | eff., % | events | eff., % | events | eff., % | events | eff., % |
| $\mathcal{L} \times \sigma \times \mathcal{B} \times \epsilon_{gen}$ | 135.5 | 100 | 141.4 | 100 | 140.9 | 100 | 138.2 | 100 | 142.1 | 100 | 145.0 | 100 |
| $\equiv 2$ muons | 55.8 | 41.2 | 62.3 | 44 | 68.8 | 48.8 | 51.1 | 37 | 43.6 | 30.7 | 50.3 | 34.7 |
| muon $p_{\mathrm{T}}$ selection | 45.0 | 33.2 | 54.0 | 38.2 | 63.2 | 44.9 | 37.8 | 27.4 | 27.6 | 19.4 | 30.6 | 21.1 |
| $\geq 3$ jets, 20 GeV | 36.7 | 27.1 | 44.4 | 31.4 | 52.0 | 36.9 | 32.6 | 23.6 | 24.1 | 17.0 | 27.0 | 18.6 |
| $\geq$1 b-jet | 26.9 | 19.9 | 32.5 | 23.0 | 38.5 | 27.3 | 26.6 | 19.3 | 20.7 | 14.5 | 23.1 | 16.0 |
| OS muons | 24.2 | 17.8 | 29.9 | 21.2 | 36.1 | 25.6 | 23.3 | 16.8 | 16.7 | 11.8 | 19.1 | 13.2 |
| $\equiv$1 electron | 5.3 | 3.9 | 6.8 | 4.8 | 8.2 | 5.8 | 4.9 | 3.5 | 3.4 | 2.4 | 4.1 | 2.8 |
| electron $p_T > 20$ GeV | 4.6 | 3.4 | 5.9 | 4.1 | 7.2 | 5.1 | 4.2 | 3.0 | 3.0 | 2.1 | 3.5 | 2.4 |
| Mass window | 4.2 | 3.1 | 4.8 | 3.4 | 5.2 | 3.7 | 3.8 | 2.7 | 2.6 | 1.8 | 2.9 | 2.0 |
| $\frac{p_{\mathrm{T}}(\mu_2^{SS})}{p_{\mathrm{T}}(\mu_1^{OS})} > 0.2$ | 3.8 | 2.8 | 4.4 | 3.1 | 4.9 | 3.5 | 3.5 | 2.5 | 2.4 | 1.7 | 2.6 | 1.8 |

- Observing respectable signal efficiencies across dimuon spectrum

# ttbar estimates with side-bands (April 2020)

- Testing out new CR for estimating ttbar: using sidebands of the signal windows. Sidebands have ~ 85% ttbar ..so can serve as good CR.
- Idea: We do the mass scan in 4 GeV signal windows for 15 < mμμ < 75 . Everything outside the signal window would be the CR to constrain ttbar.
- Concerns:
  - Blinded analysis, so can't look at the data in the sidebands right now.
  - Need to come up with a CR to study ttbar
  - Issue of using part of the SR as the CR i.e. region with high signal contamination (from another mass point however)