Searches for BSM Higgs

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on behalf of the ATLAS & CMS Collaborations
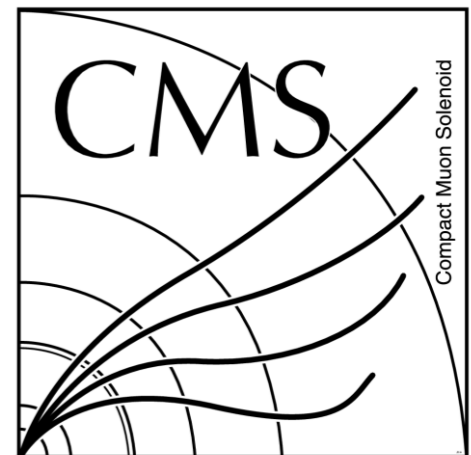
Searches for BSM Higgs at the LHC

Extended Higgs sectors are present in models for Naturalness,
Higgs portal models of dark matter, axions, Baryon asymmetry, Neutrino masses, etc

Searches for deviations from the SM in measurements of Higgs Boson properties
- Spin
- CP
- Couplings

See sessions on Monday

See dedicated parallel session talks on Charged Higgs, BSM Higgs → fermions, BSM Higgs → bosons, Higgs → light scalars, mono Higgs, and LFV/rare/invisible decays

Disclaimer: This is not a full list of analyzed channels. Focus mainly on recent results with 13 TeV dataset

Direct searches for BSM phenomena
→ evidence of new physics

Additional Higgs-like scalars
- neutral or charged
- decays to SM particles and to Higgs bosons **THIS TALK**

Di-Higgs covered tomorrow

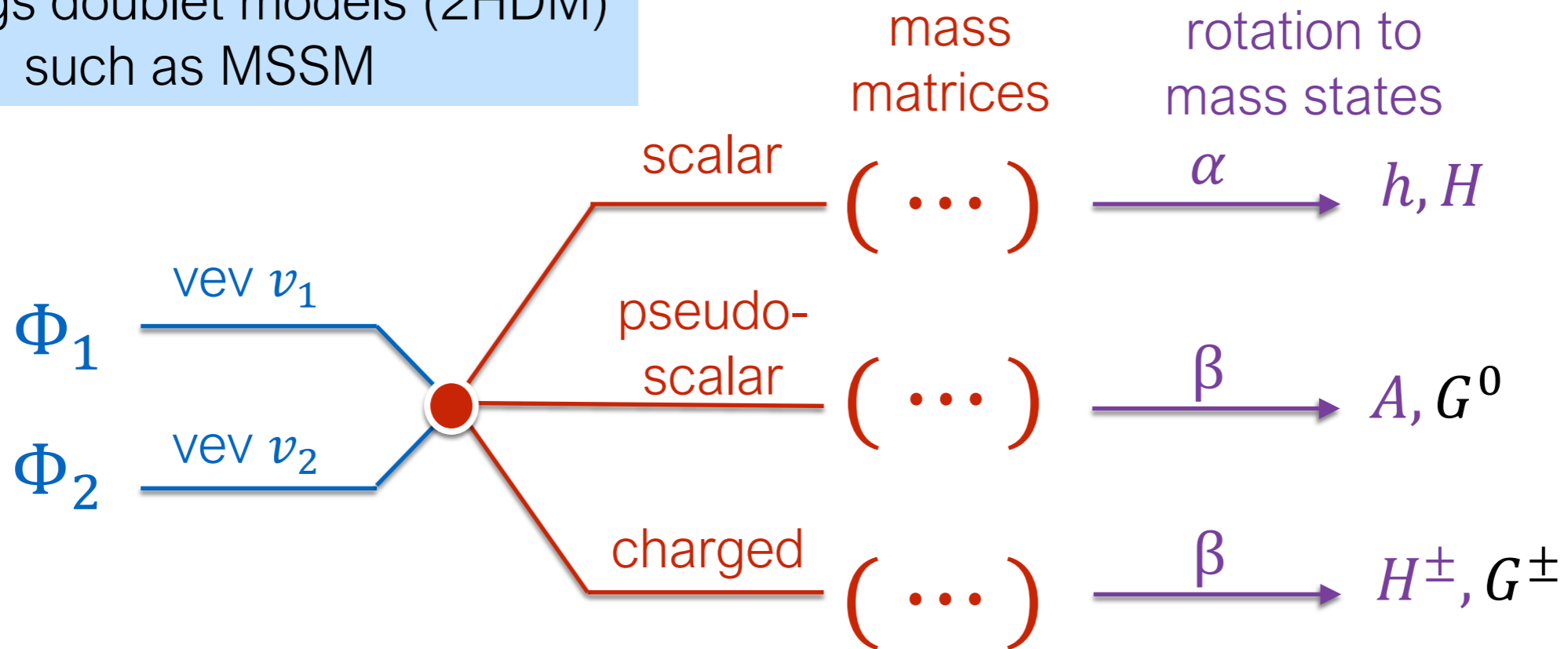BSM Higgs decays and couplings
- new light resonances
- long lived particles
- invisible decays
- flavor violating couplings

See talk by B. Maier

Extended Higgs Sector Benchmark Models
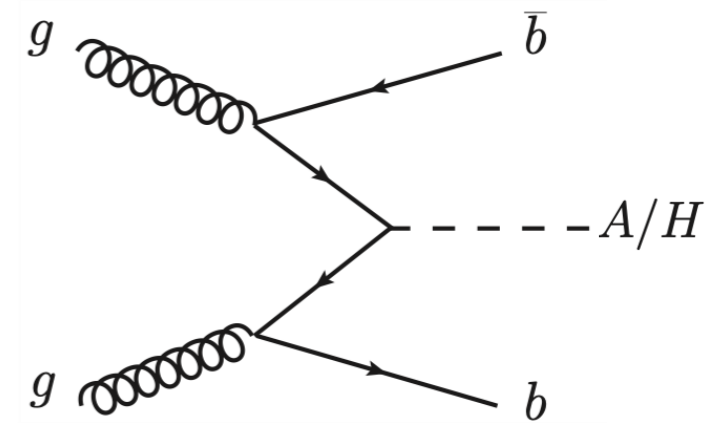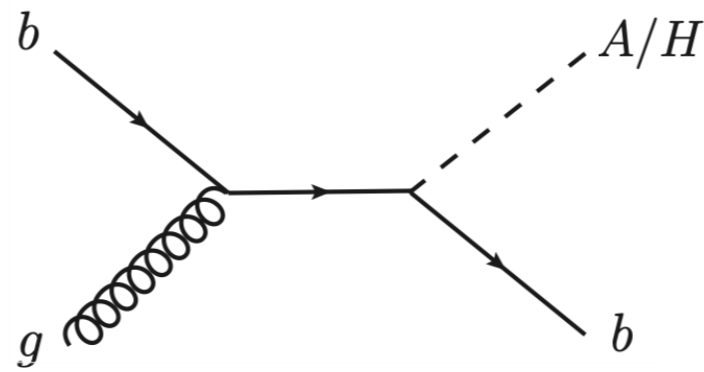
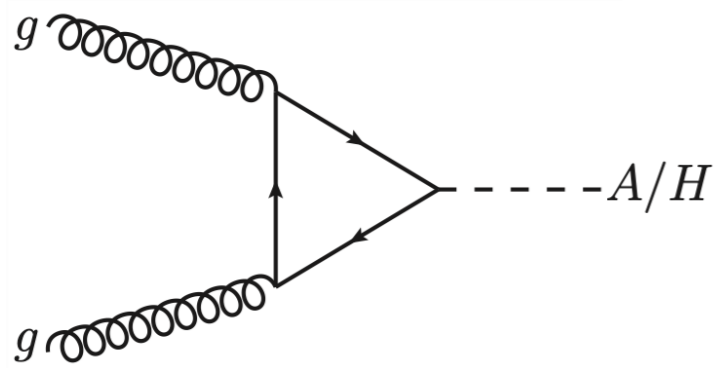Cover a broad range of phenomenology & final states - benchmarks guide searches
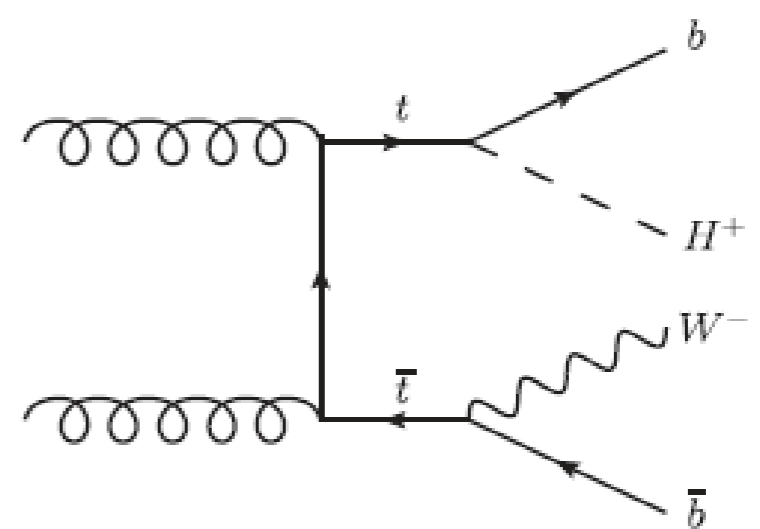
Two Higgs doublet models (2HDM) such as MSSM

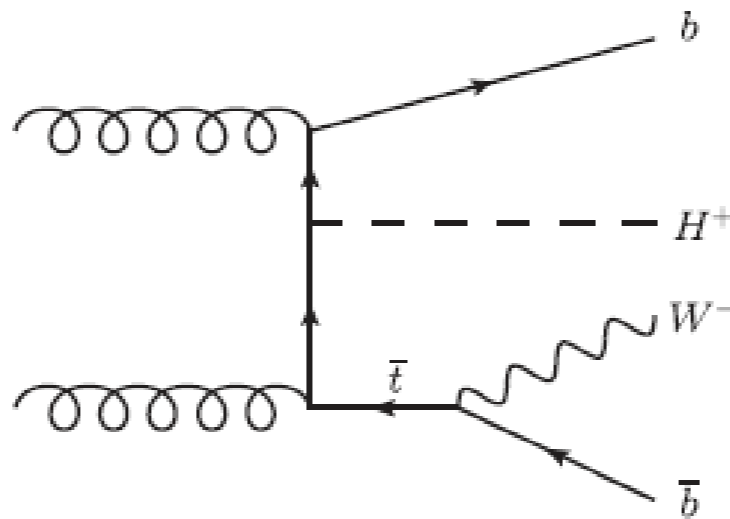mass matrices

rotation to mass states

Φ_1 — vev v_1

Φ_2 — vev v_2

scalar $\left(\cdots \right) \xrightarrow{\alpha} h, H$

pseudo-scalar $\left(\cdots \right) \xrightarrow{\beta} A, G^0$

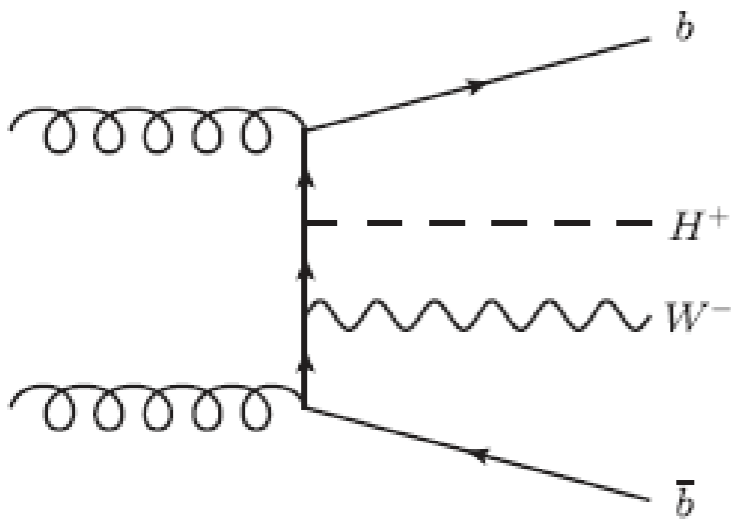charged $\left(\cdots \right) \xrightarrow{\beta} H^{\pm}, G^{\pm}$

Parameters $\alpha, \ \beta, \ m_h, \ m_H, \ m_A, \ m_{H\pm}$

Commonly use $\tan(\beta) = \frac{v_2}{v_1}$ and $\cos(\beta - \alpha)$

Triplet models - predict double charged Higgs bosons $H^{++/--}$

Neutral Higgs Production A/H

Charged Higgs Production $H^{\pm}$

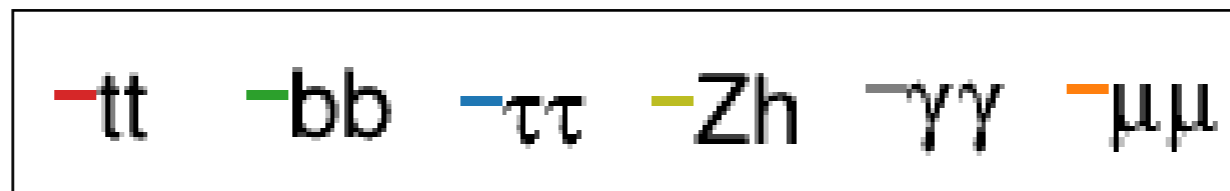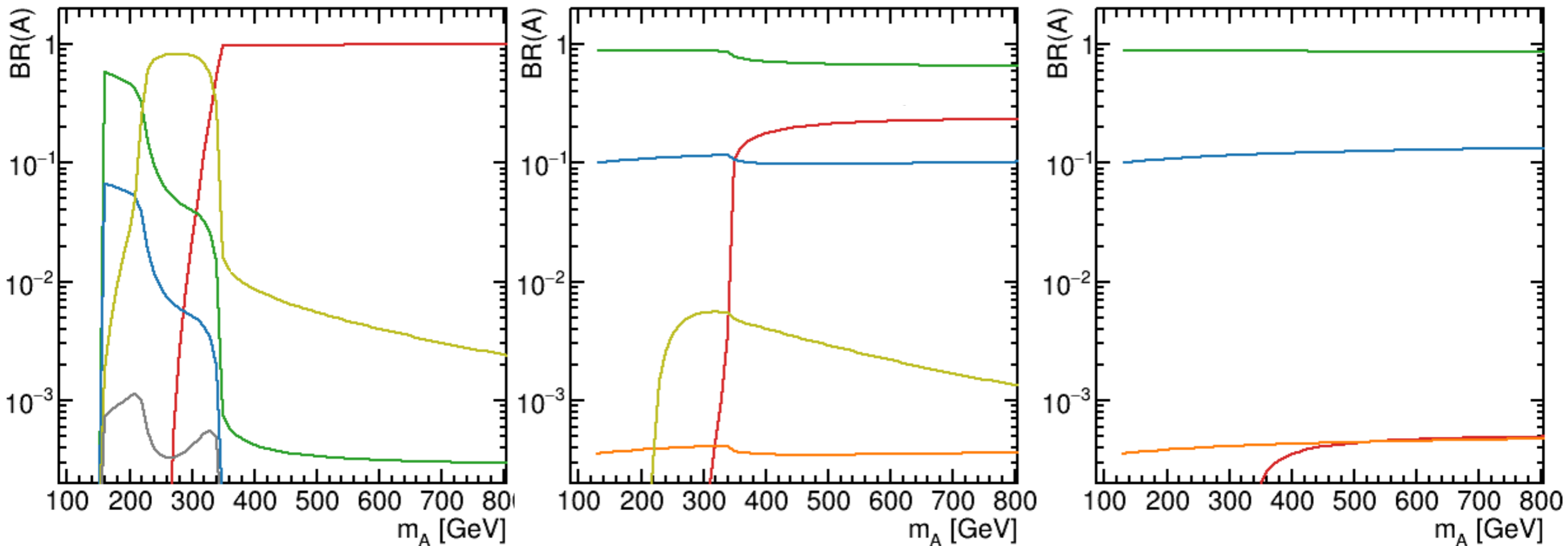Handbook of LHC Cross Sections: 4. Deciphering the Nature of the Higgs Sector
Handbook of LHC Cross Sections: 3. Higgs Properties

New Pseudo-Scalar Decay $BR(A)$

Rich phenomenology with several final states

Example benchmark hMSSM

$\tan\beta = 1$ $\qquad$ $\tan\beta = 10$ $\qquad$ $\tan\beta = 50$

Legend: tt, bb, ττ, Zh, γγ, μμ

Handbook of LHC Cross Sections: 4. Deciphering the Nature of the Higgs Sector
Handbook of LHC Cross Sections: 3. Higgs Properties

A/H→ττ

Target with b-veto

Target with b-tag
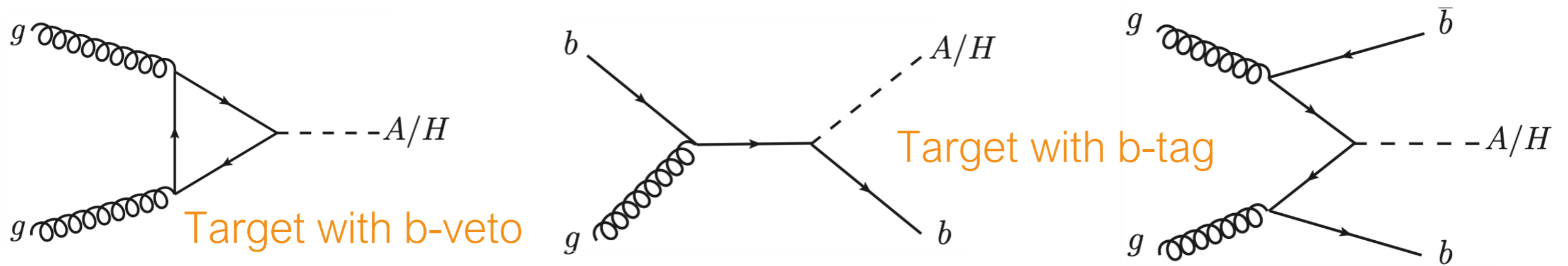
Two final states covered

τ_had τ_had
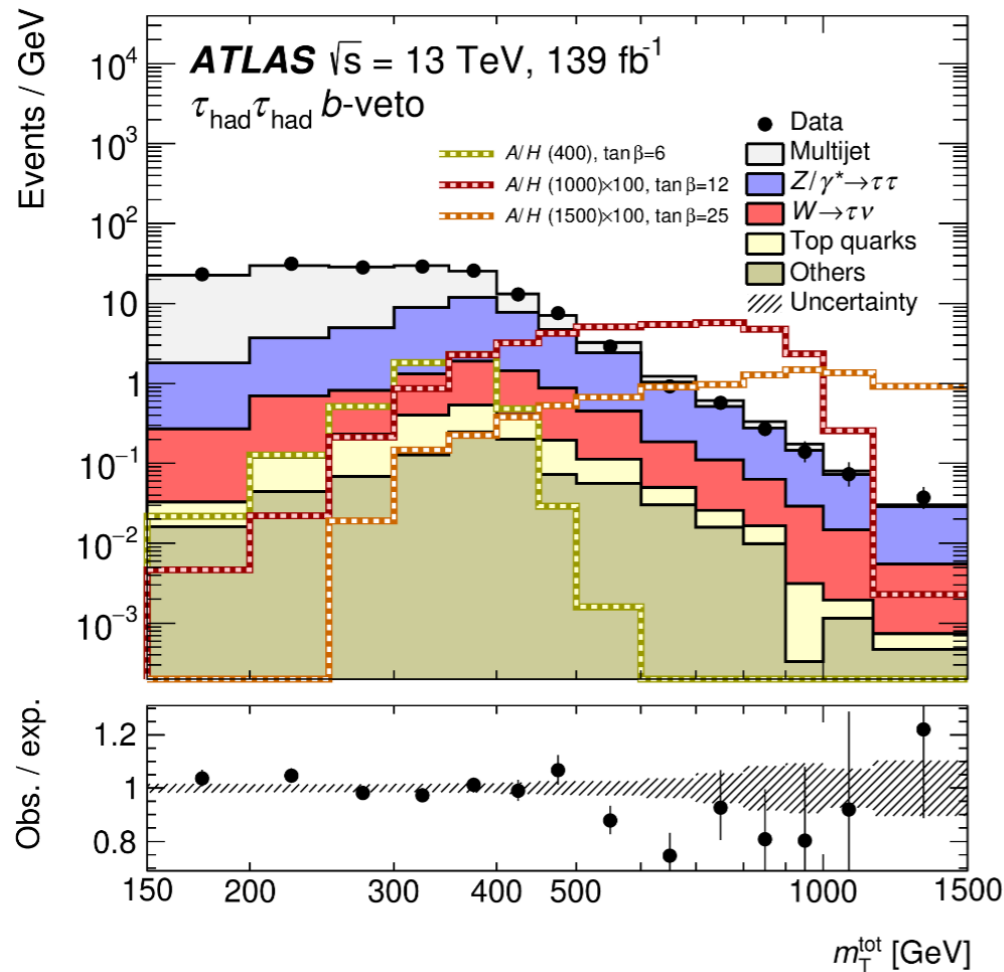
τ_lep τ_had
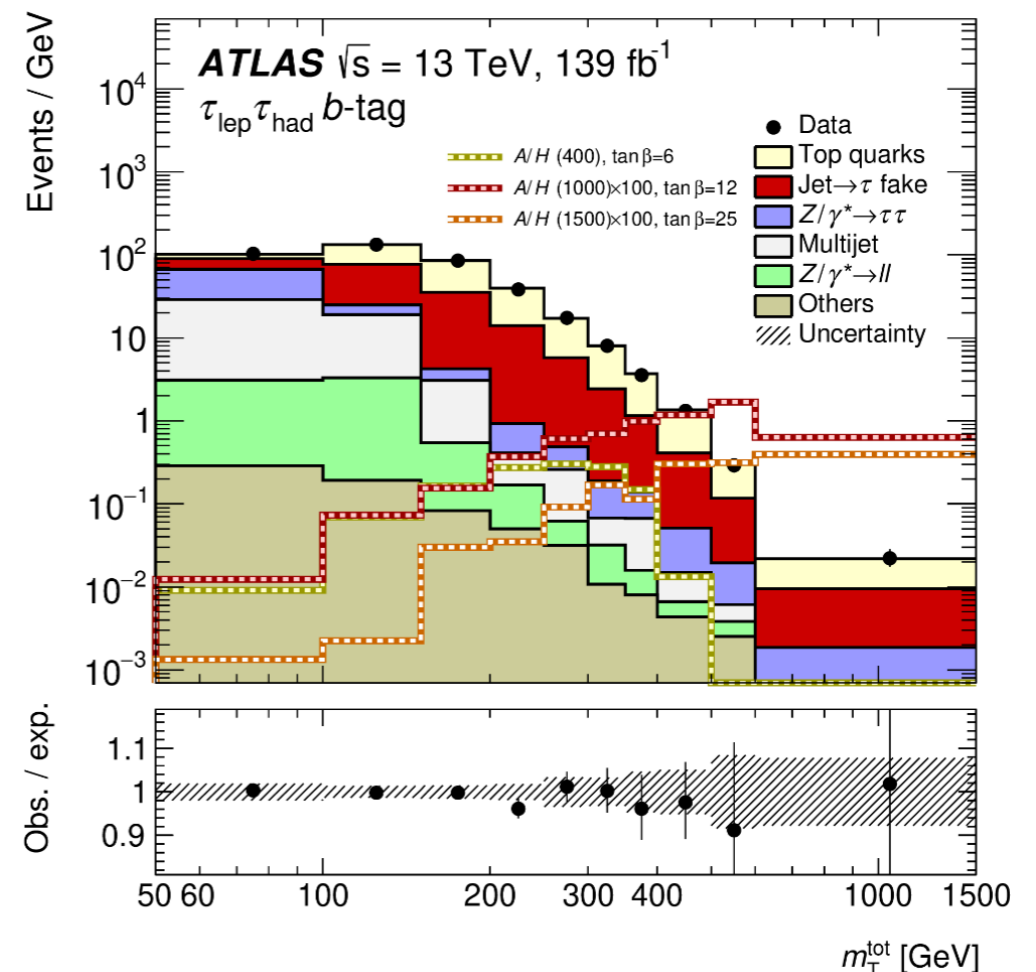
A/H→ττ

Target with b-veto

Target with b-tag
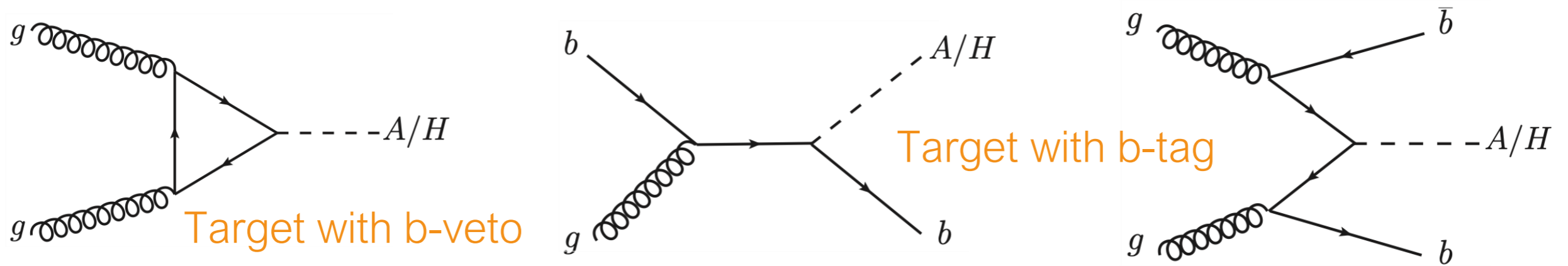
Key channel in several new physics scenarios such as 2HDM (MSSM) with large tanβ

b-veto regions

b-tag regions
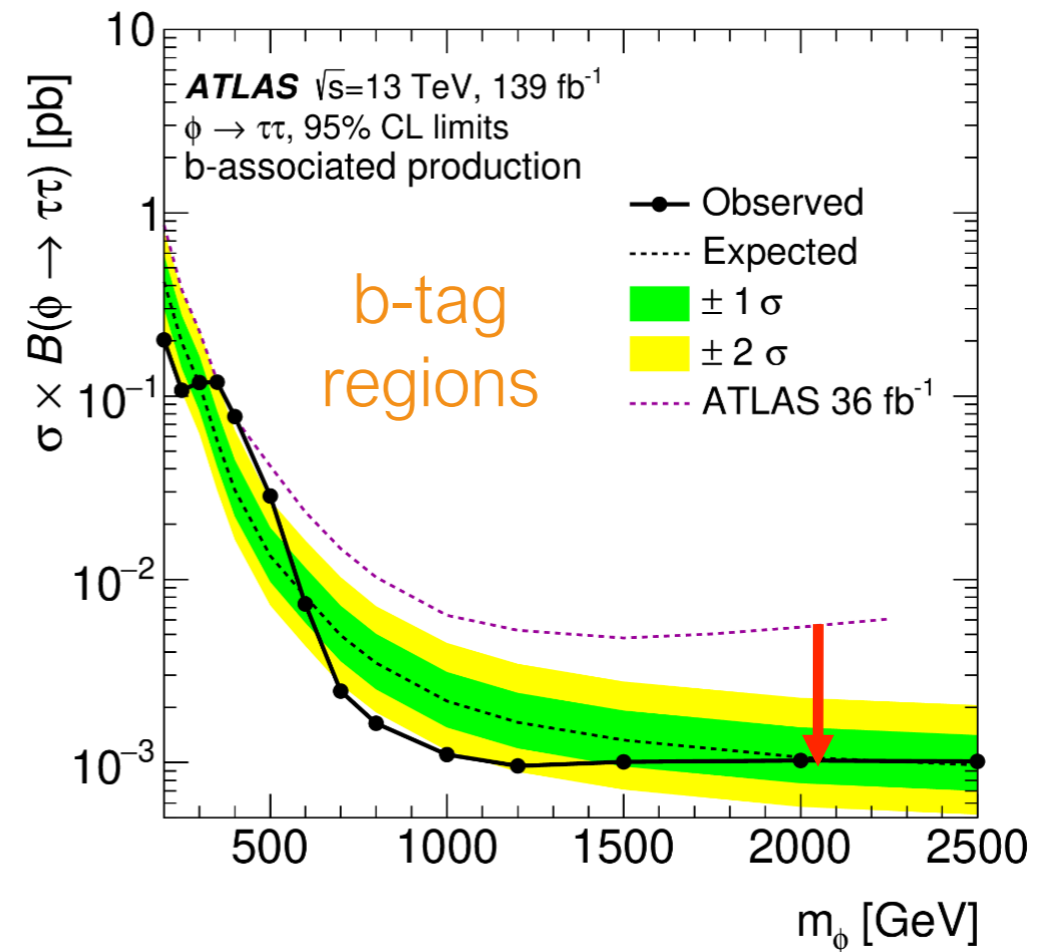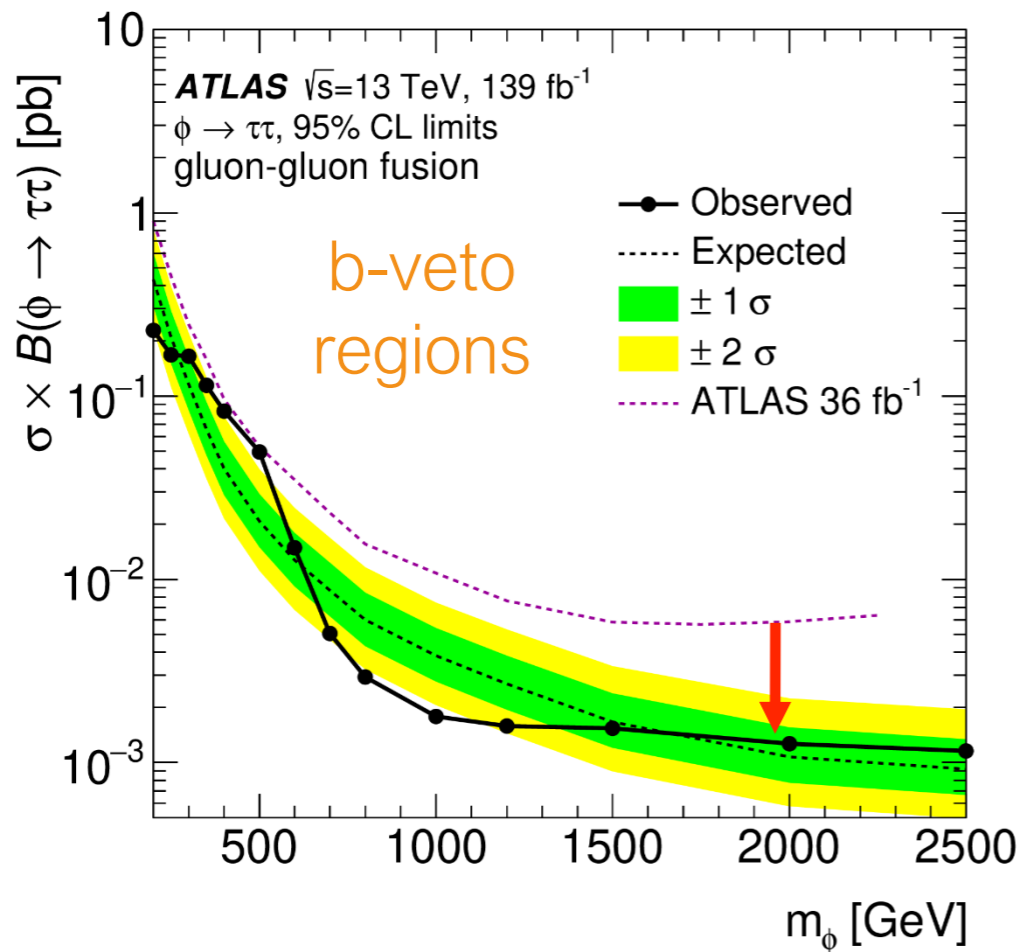
Higher sensitivity due to increased luminosity, improved tau ID and optimization

A/H→ γγ

Search for high mass resonance – excellent resolution of diphoton pair

$m_{\gamma\gamma}$ as final discriminant
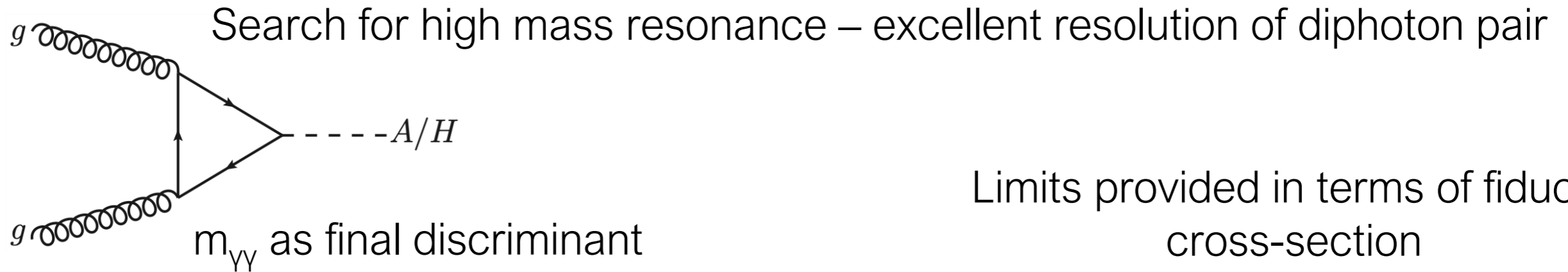
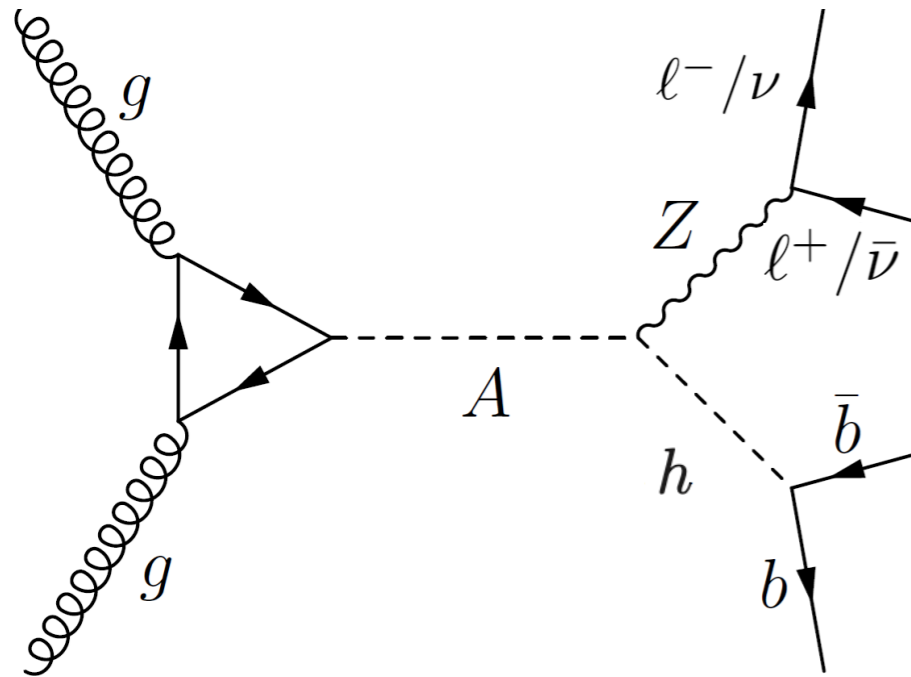Limits provided in terms of fiducial cross-section
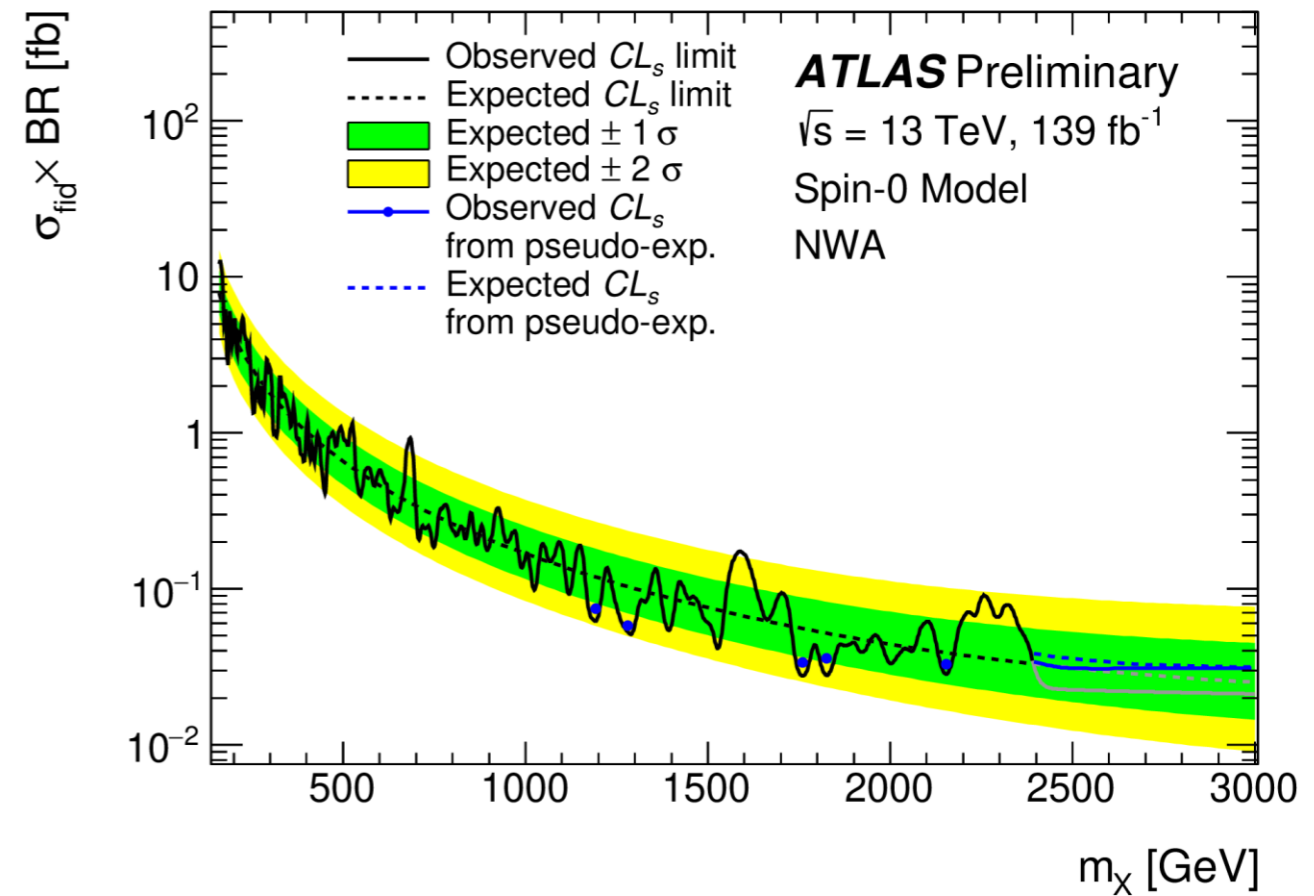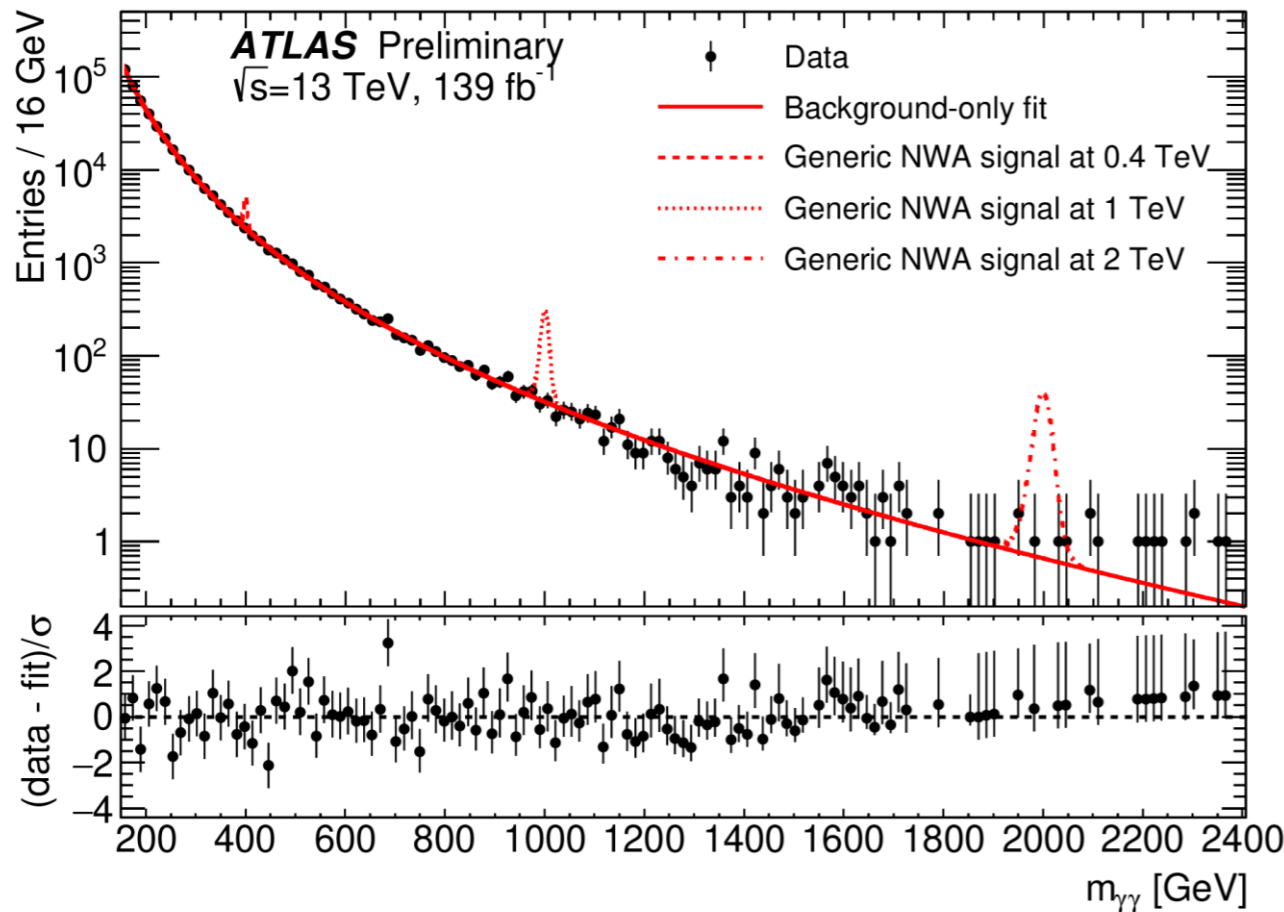
Signal: double-sided crystal ball

Background: power-law functional form - choice of function & systematics from MC templates

Narrow & large widths also considered (up to $\Gamma_X / m_X = 10\%$)

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A→Zh, Z→2e/2μ or 2ν, h →bb

Two channels:

- Zh → 2e/2μ bb (2l) - single lepton trigger & two identified leptons

- Zh →νν bb (0l) - E_T^{miss} trigger & E_T^{miss} > 150 GeV

Categorization: Resolved or merged bb system with 1 or 2 b-tags

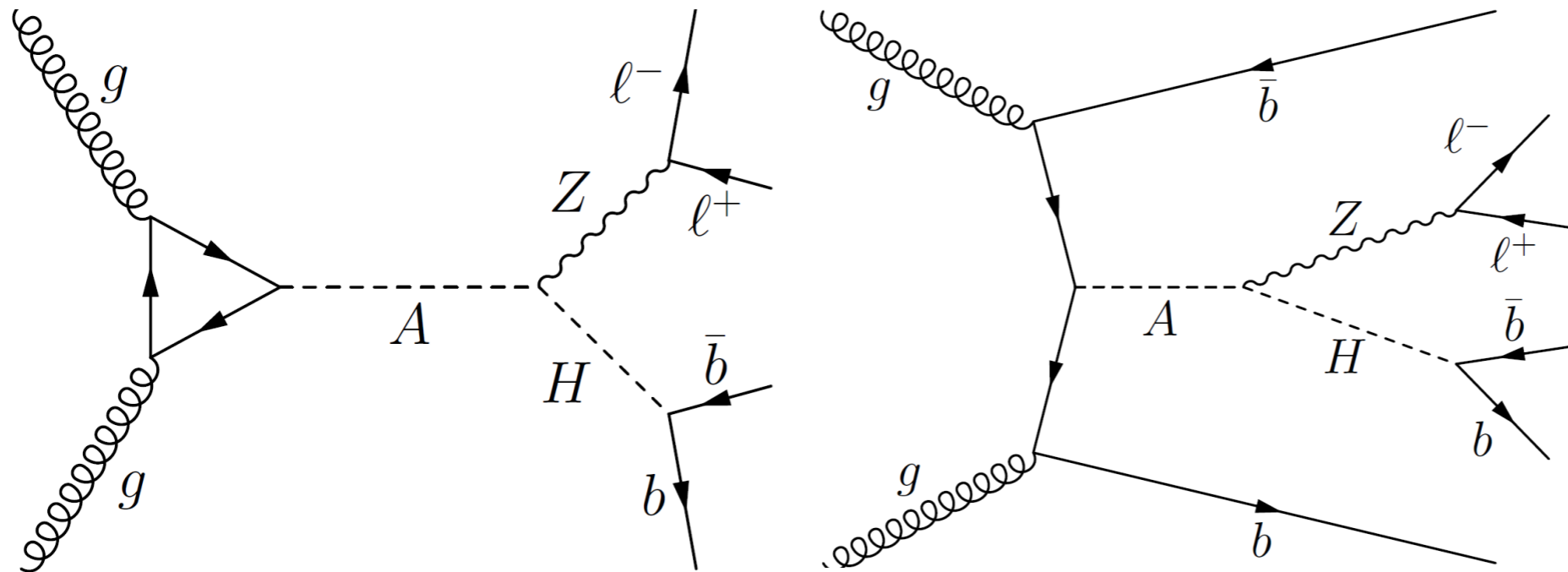## Invariant mass m_{Vh} (2l)

Transverse mass $m_{T,Vh}$ (0l)
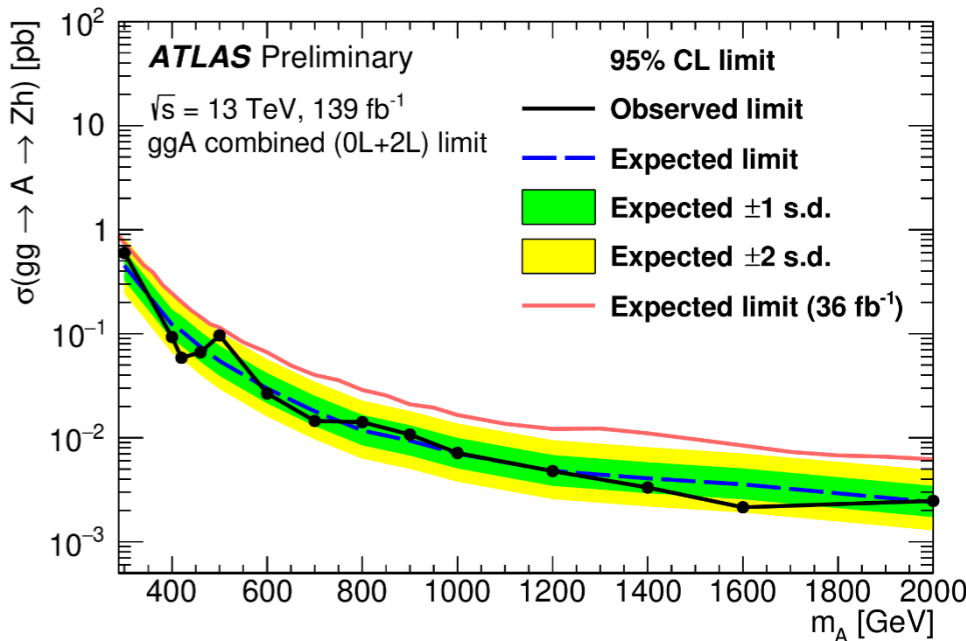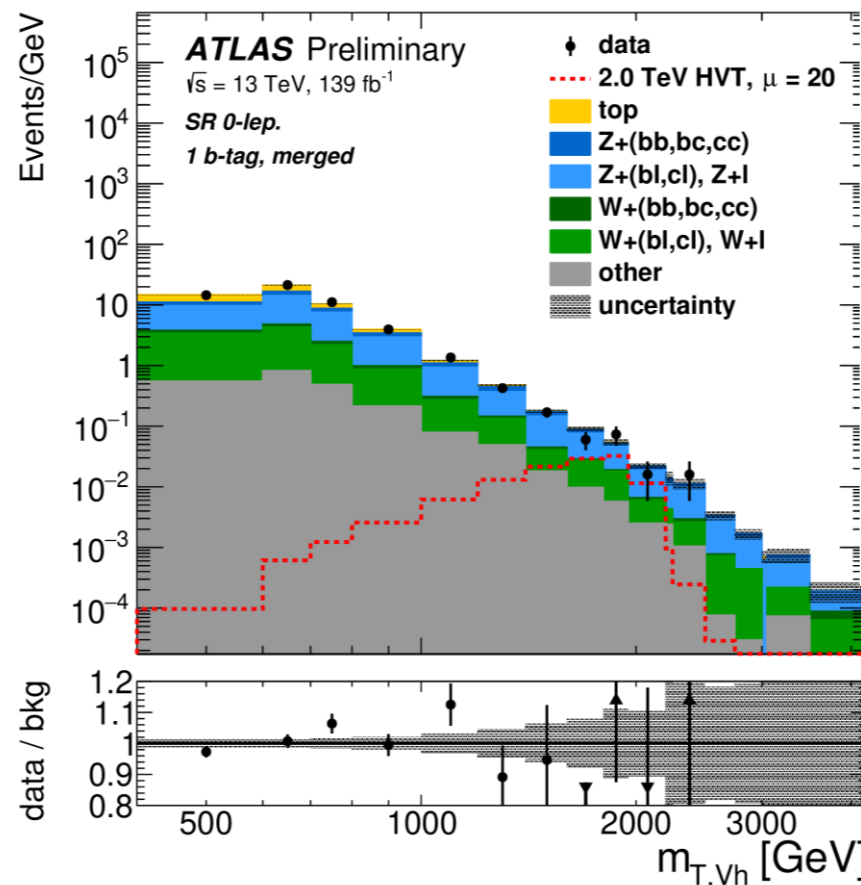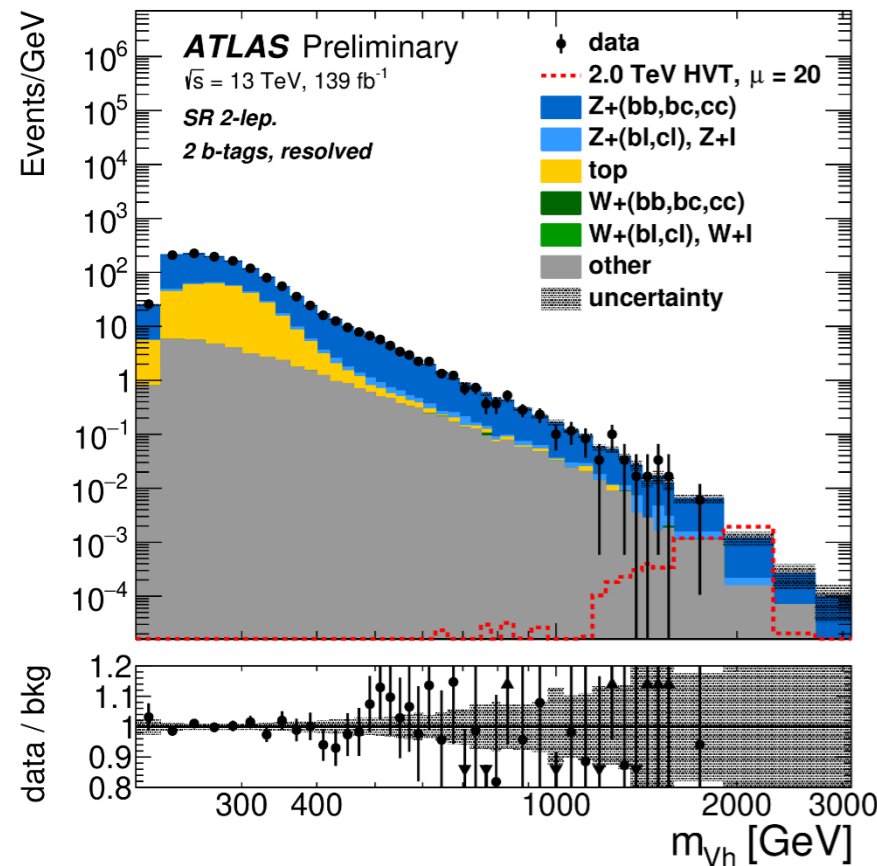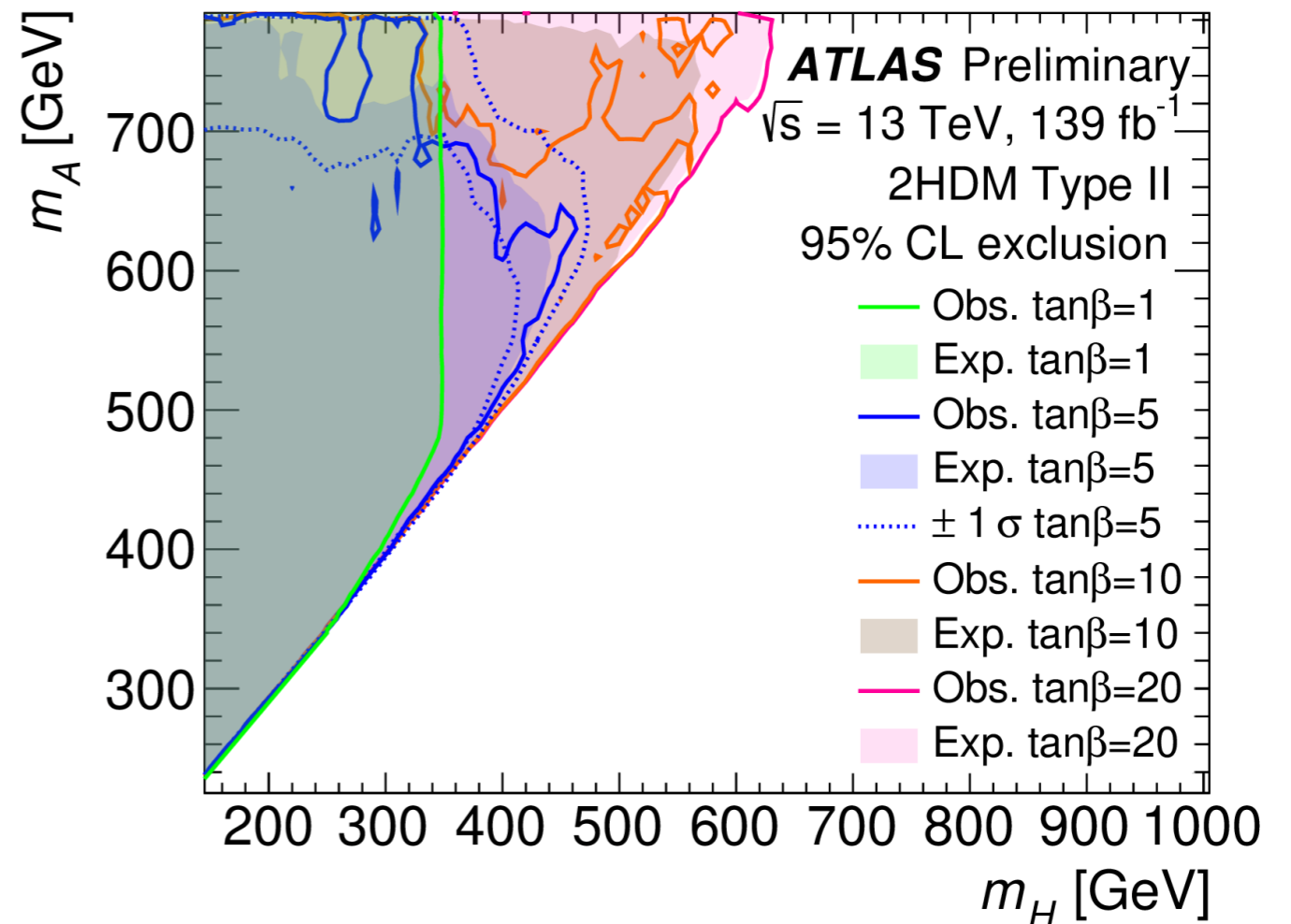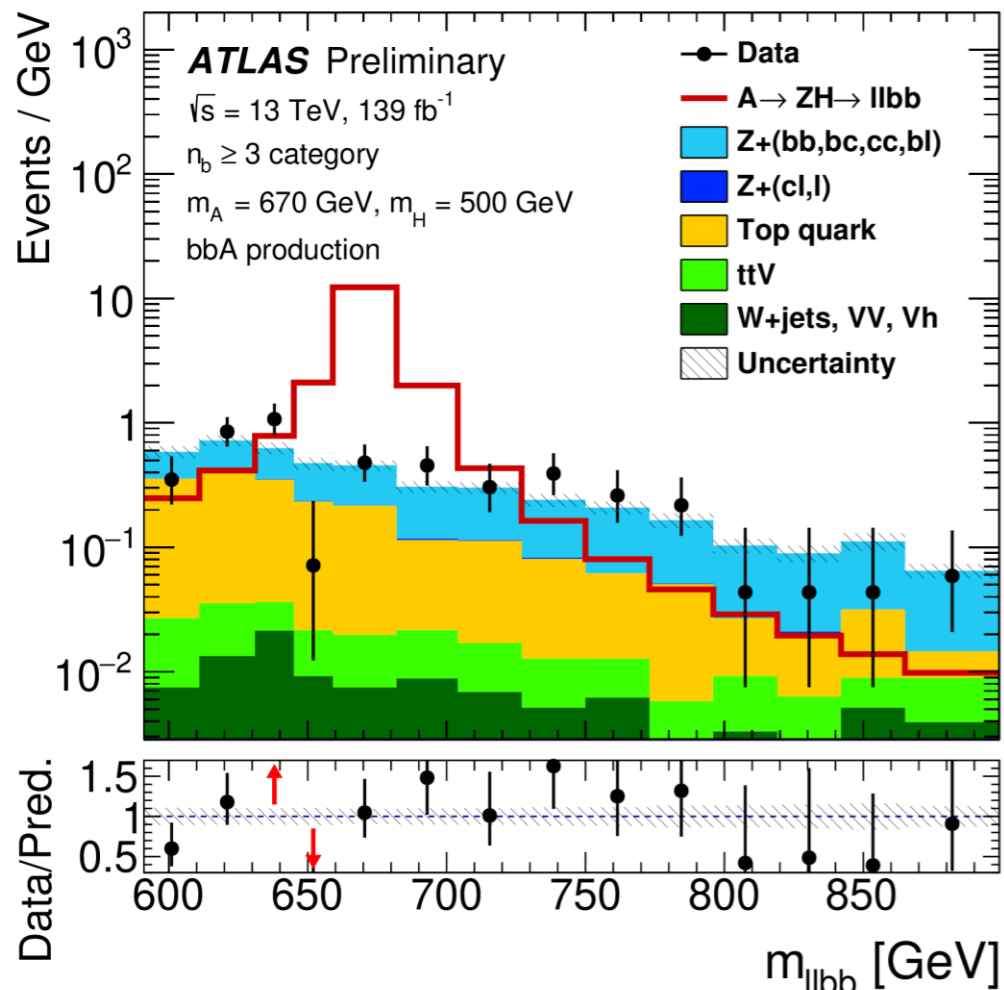

Important in several scenarios such as low tanβ MSSM
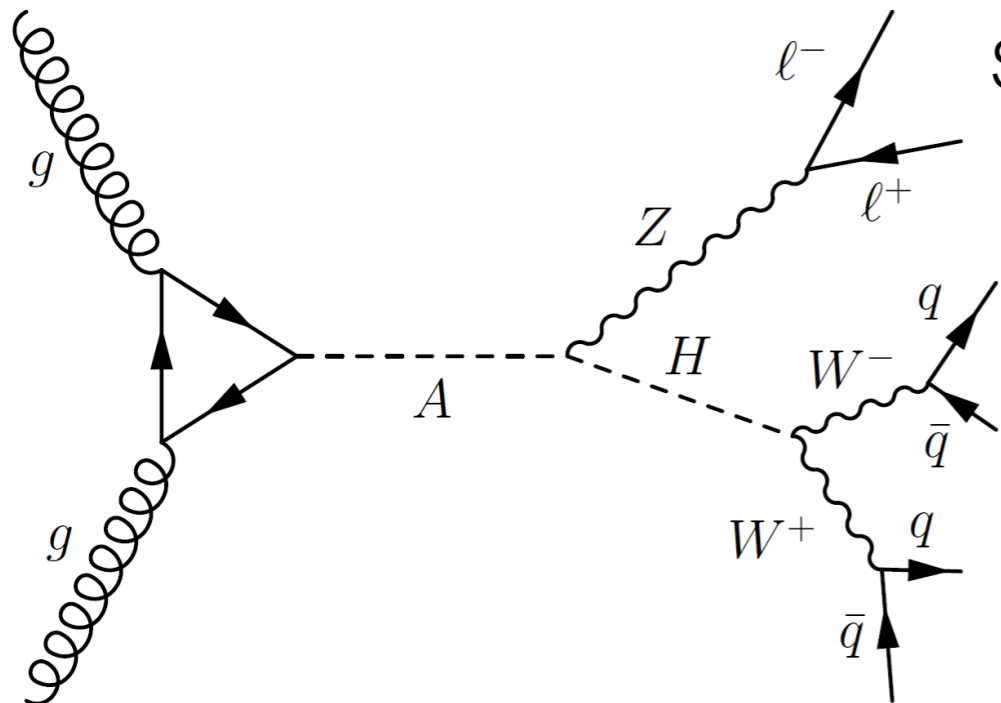
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A→ZH, Z→2e/2μ, H →bb

Scenario with different m_H and m_A, motivated by 2HDM

Scanning m_A (widths up to 20%) for different m_H windows with Z → 2e/2μ H→bb

ATLAS Preliminary
$\sqrt{s}$ = 13 TeV, 139 fb⁻¹
$n_b \geq 3$ category
m_A = 670 GeV, m_H = 500 GeV
bbA production

- Data
- A→ ZH→ llbb
- Z+(bb,bc,cc,bl)
- Z+(cl,l)
- Top quark
- ttV
- W+jets, VV, Vh
- Uncertainty

Events / GeV

Data/Pred.

m_{llbb} [GeV]

m_A [GeV]

ATLAS Preliminary
$\sqrt{s}$ = 13 TeV, 139 fb⁻¹
2HDM Type II
95% CL exclusion

- Obs. tanβ=1
- Exp. tanβ=1
- Obs. tanβ=5
- Exp. tanβ=5
- ± 1 σ tanβ=5
- Obs. tanβ=10
- Exp. tanβ=10
- Obs. tanβ=20
- Exp. tanβ=20

m_H [GeV]

ATLAS-HDBS-2018-13

A→ZH, Z→2e/2μ, H → WW → 4q

Scenario with different m_H and m_A, motivated by 2HDM

Scanning m_A (widths up to 20%) for different m_H windows with Z → 2e/2μ in H→WW→4q final state
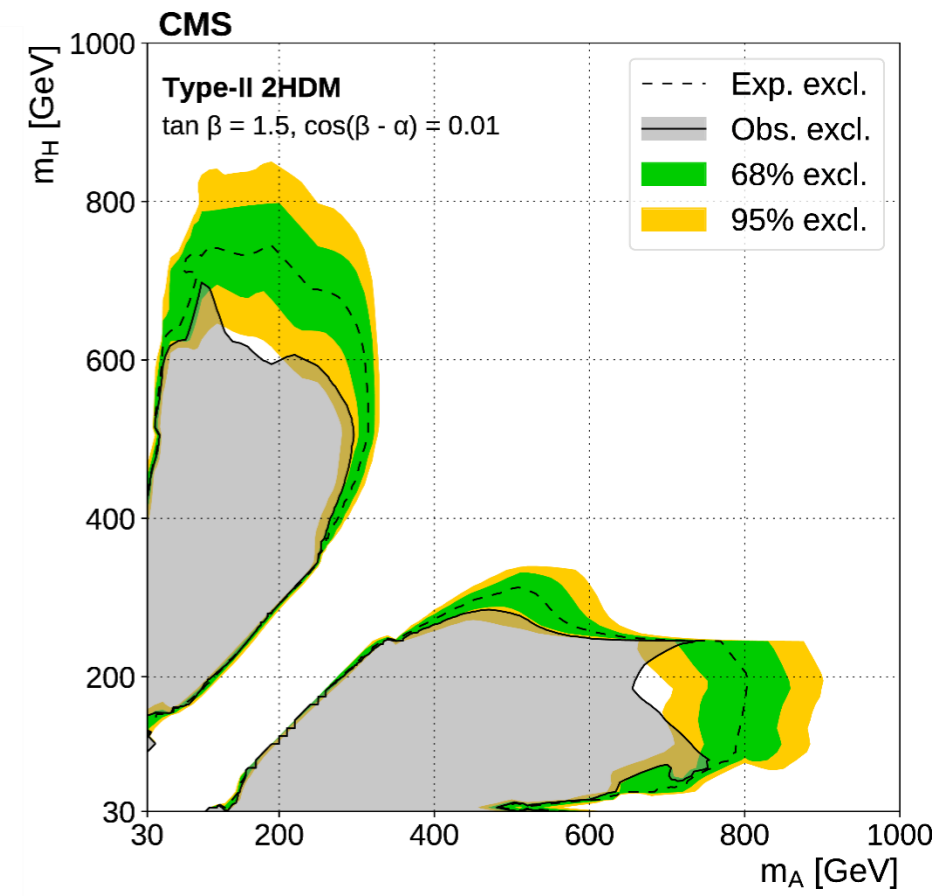
Interpretations in the context of 2HDM vs m_A, m_H and tanβ, in / near weak coupling limit

ATLAS-HDBS-2018-13
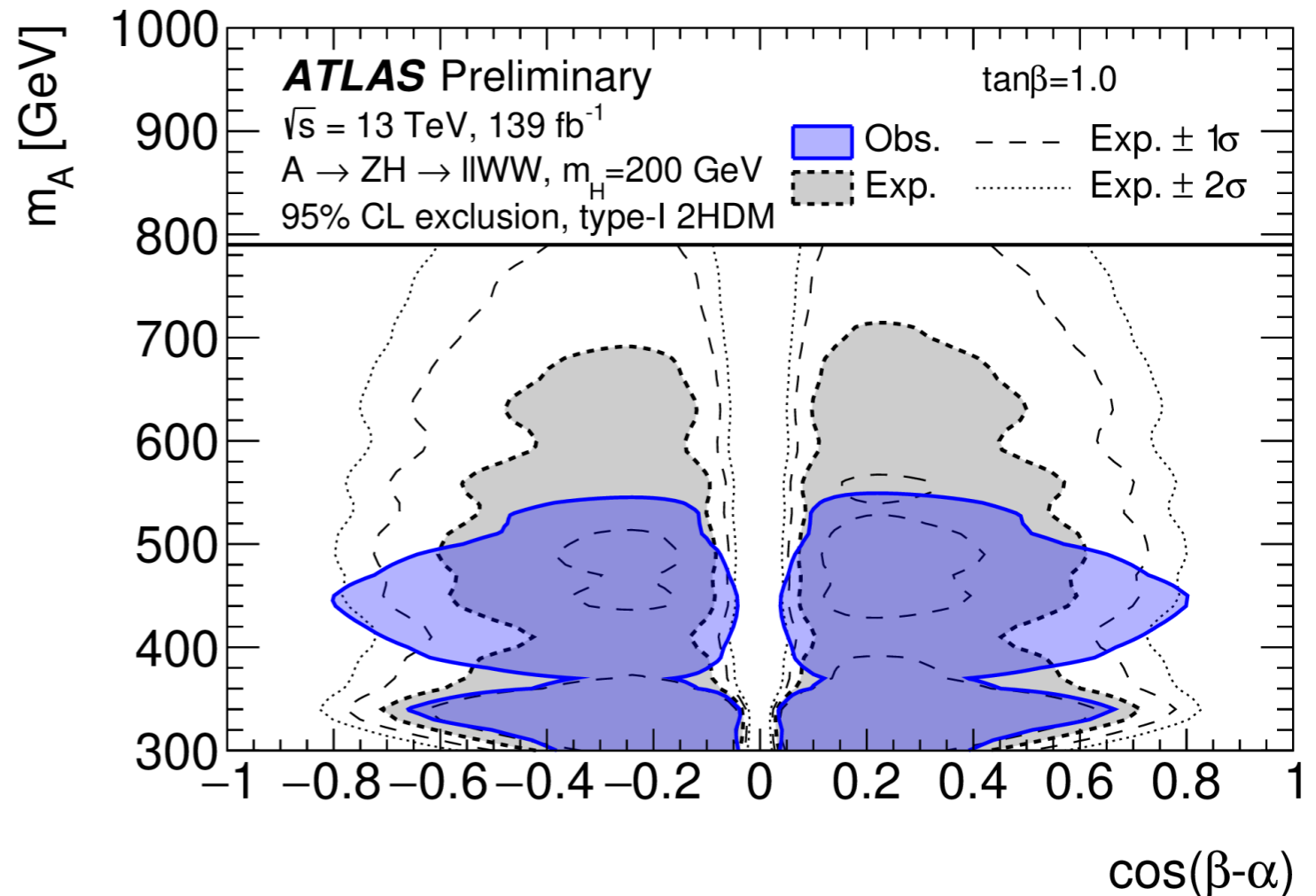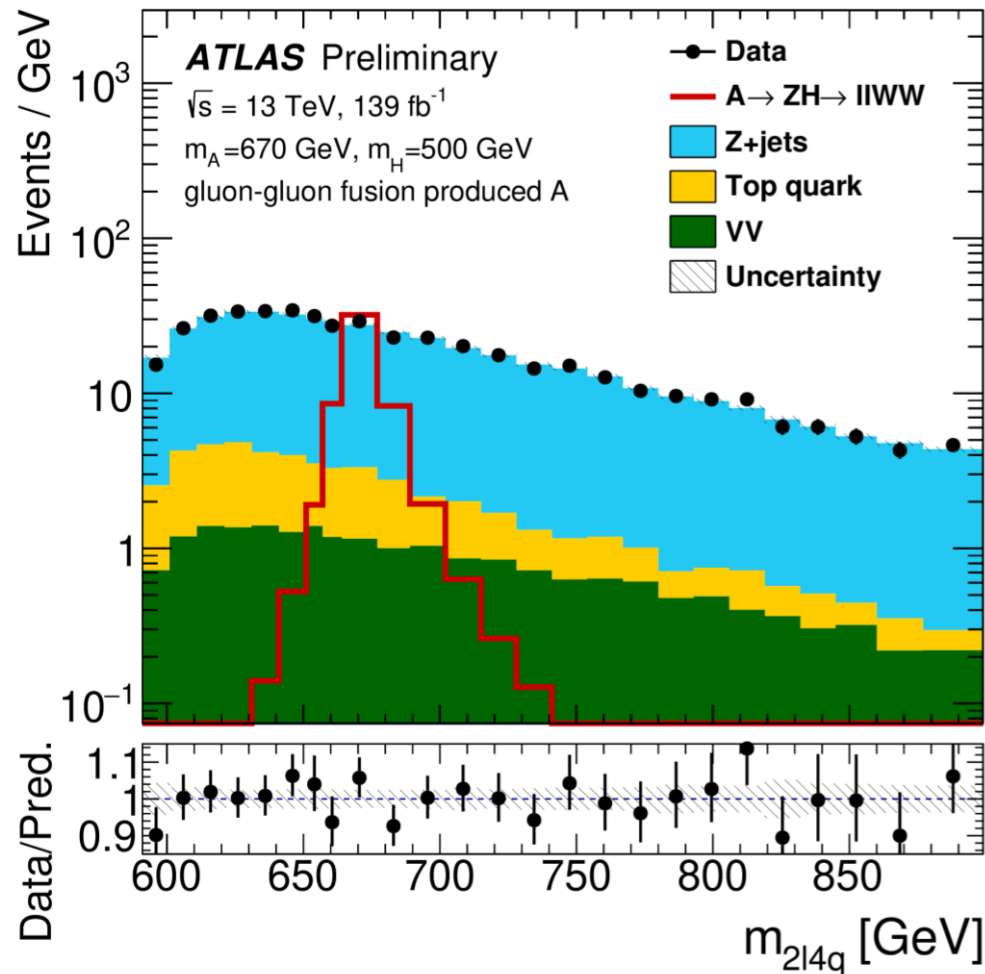
H→ZA, Z→2e/2μ, A →bb

Important channel in several scenarios such as 2HDM when $\cos(\beta - \alpha) \to 0$ (SM-like h)

Main discriminants are m_{jj} (2 b-tags) and m_{lljj}

Elliptical regions in m_{lljj} vs m_{jj} plane

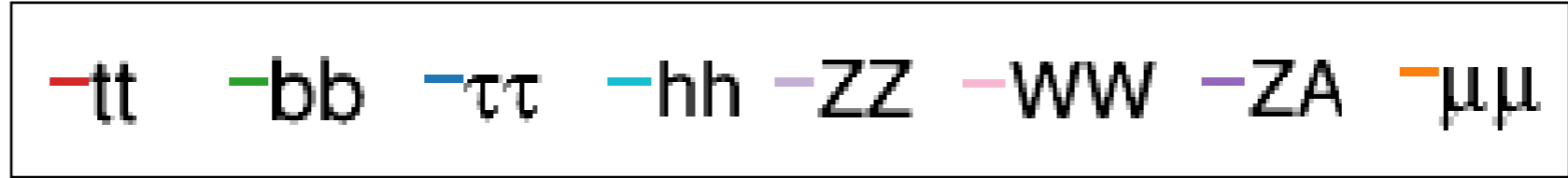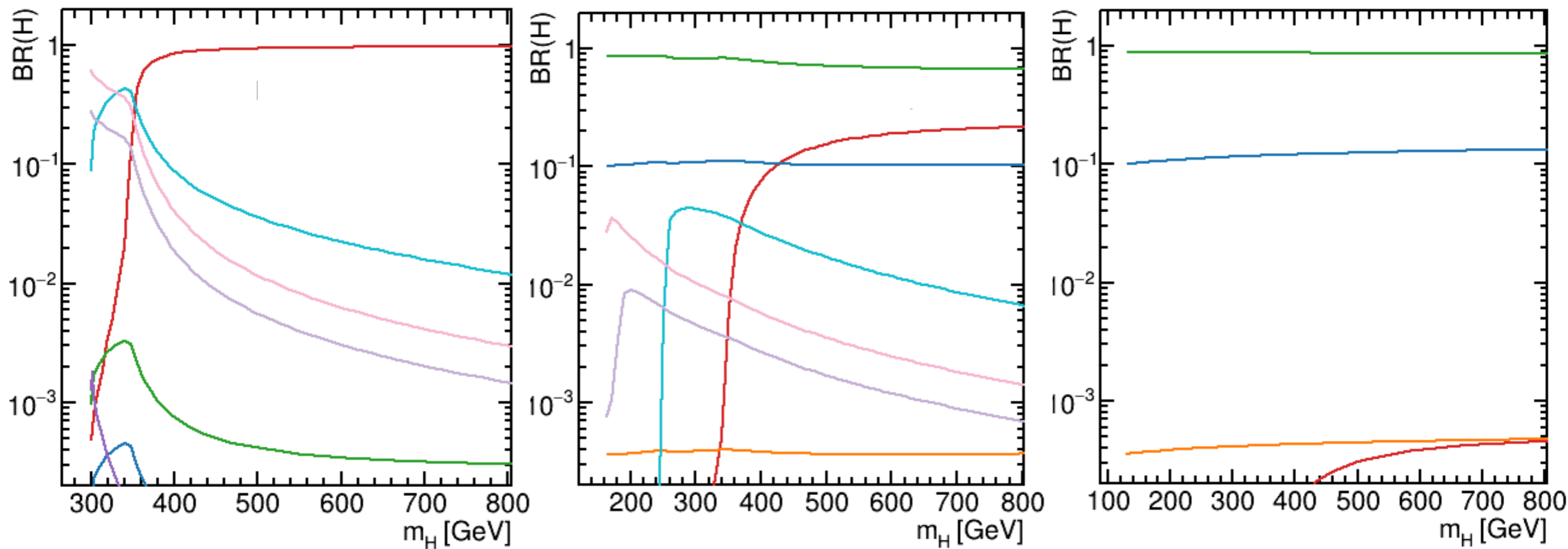Variable $\rho \sim 1\sigma$ of signal resolution
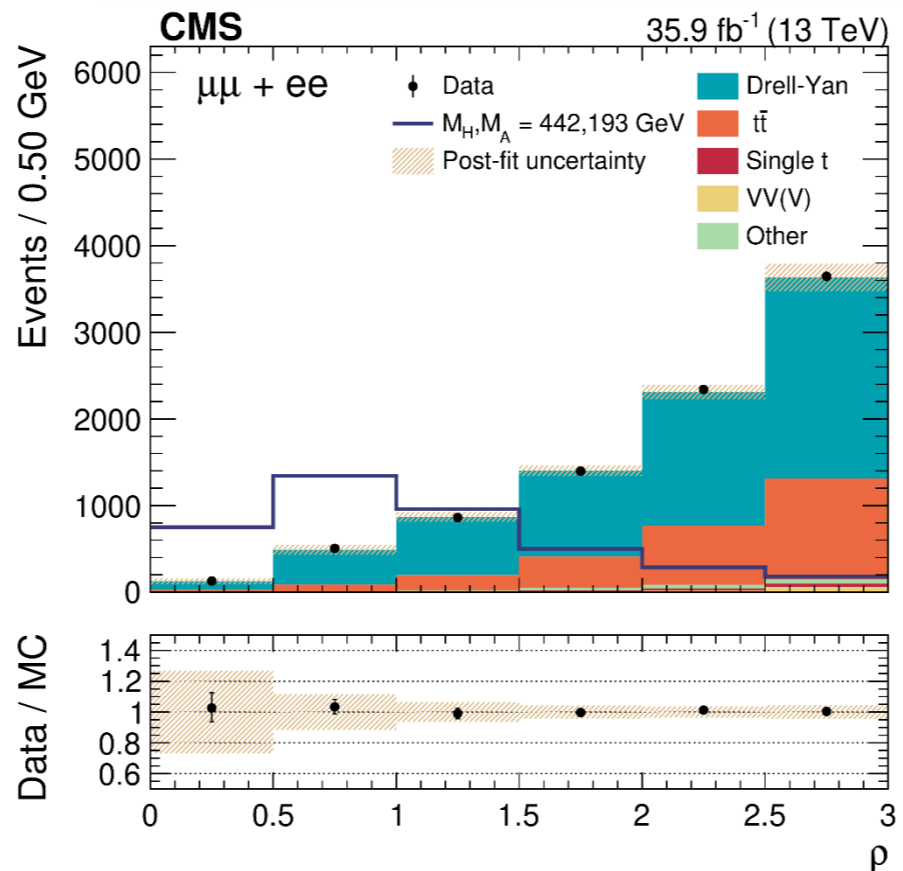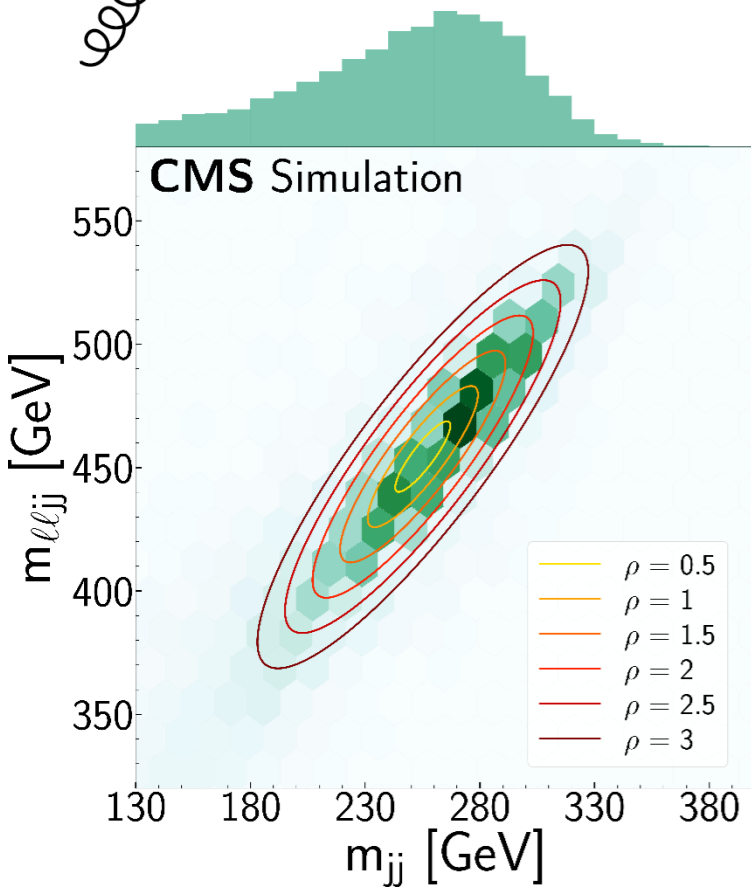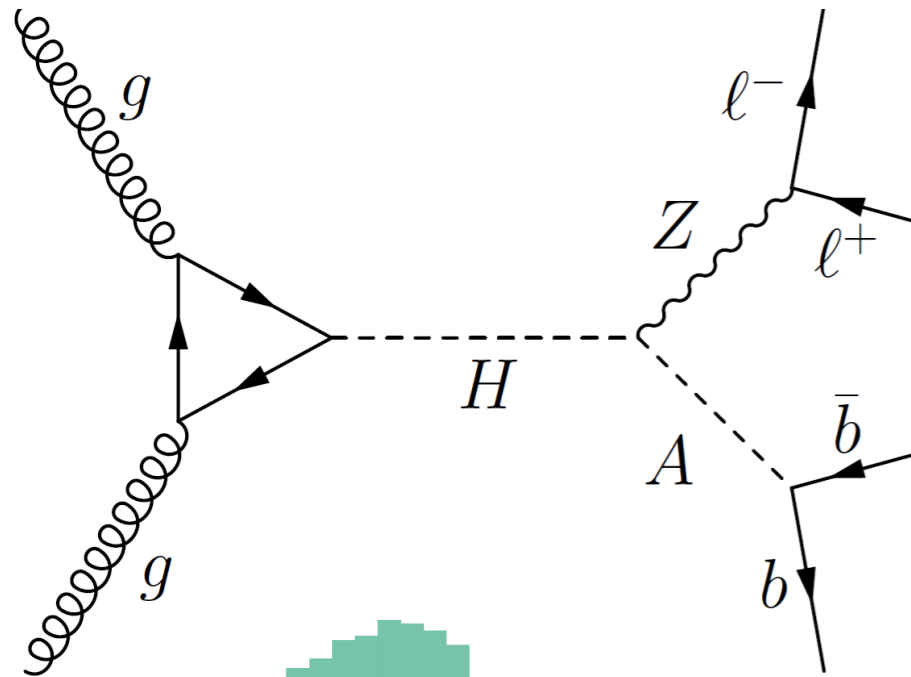
New Scalar Decay $BR(H)$

Rich phenomenology with several final states

Example benchmark hMSSM

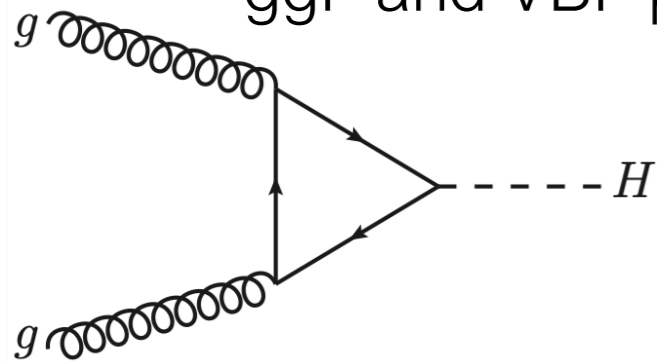$\tan\beta = 1$ $\tan\beta = 10$ $\tan\beta = 50$

Legend: —tt —bb —ττ —hh —ZZ —WW —ZA —μμ

H → WW → 2l2ν and lνqq

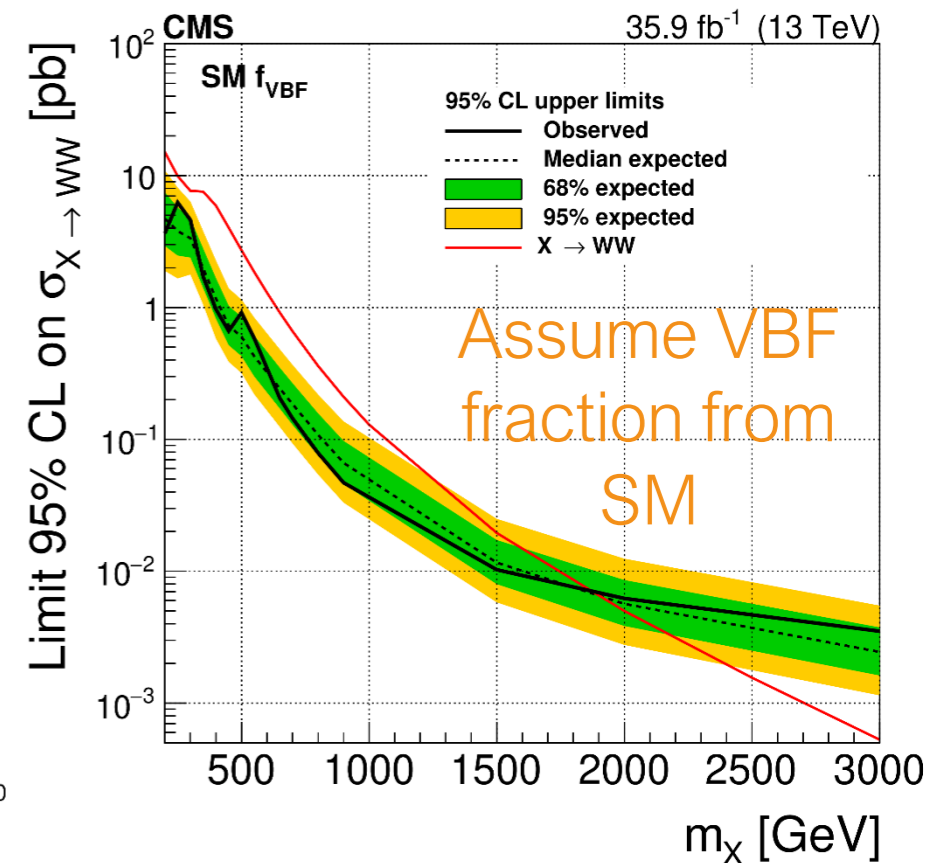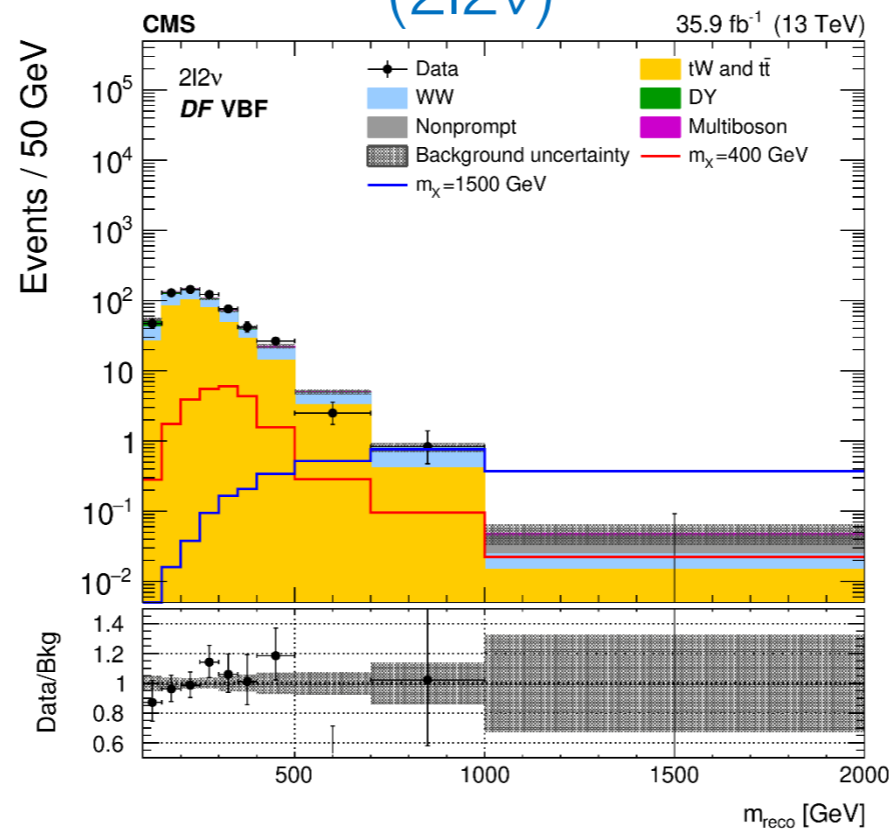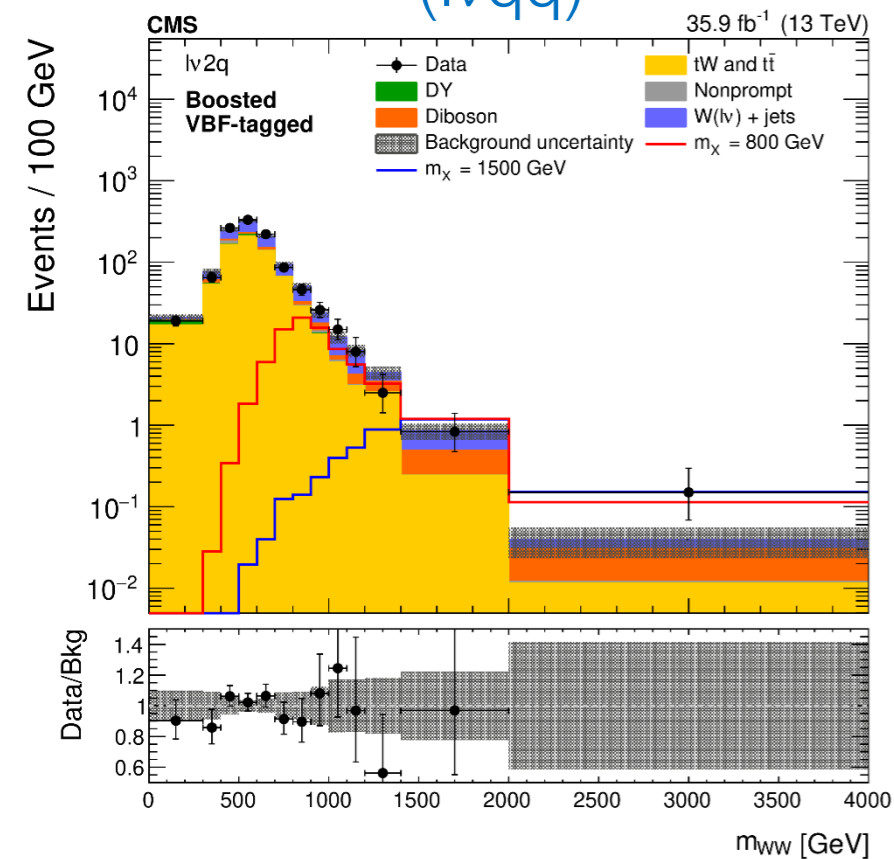ggF and VBF production – includes interference effects with background

Categorisation: ggF and VBF-like events
same-flavor (SF) & different-flavor (DF) 2l (2l2ν),
resolved & boosted hadronic W (lνqq)

H invariant mass m_{WW} (lνqq)

reconstructable mass m_{reco} (2l2ν)
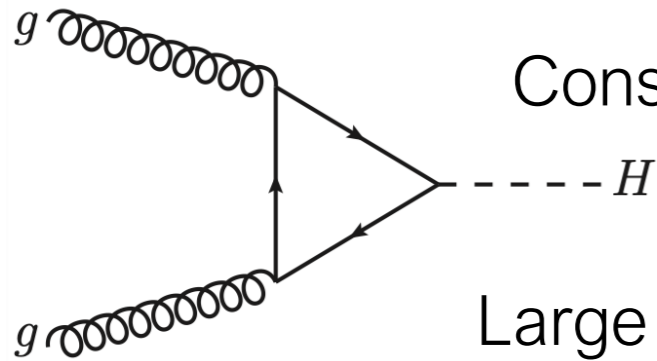

SM width up to TeV range

Assume VBF fraction from SM

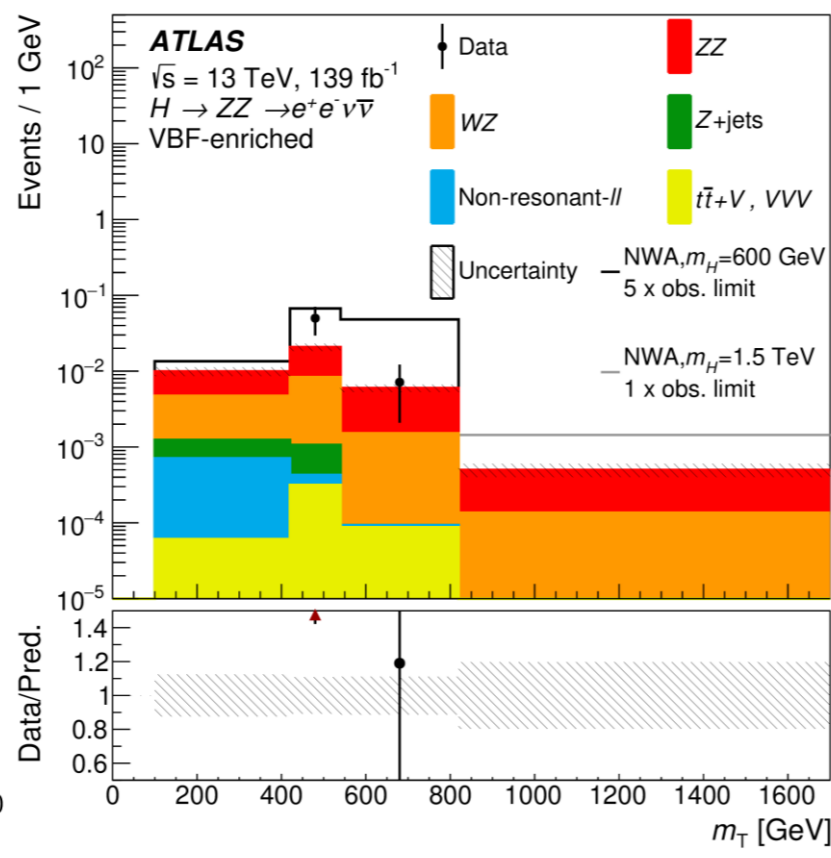# H→ ZZ → 4l and 2l2v

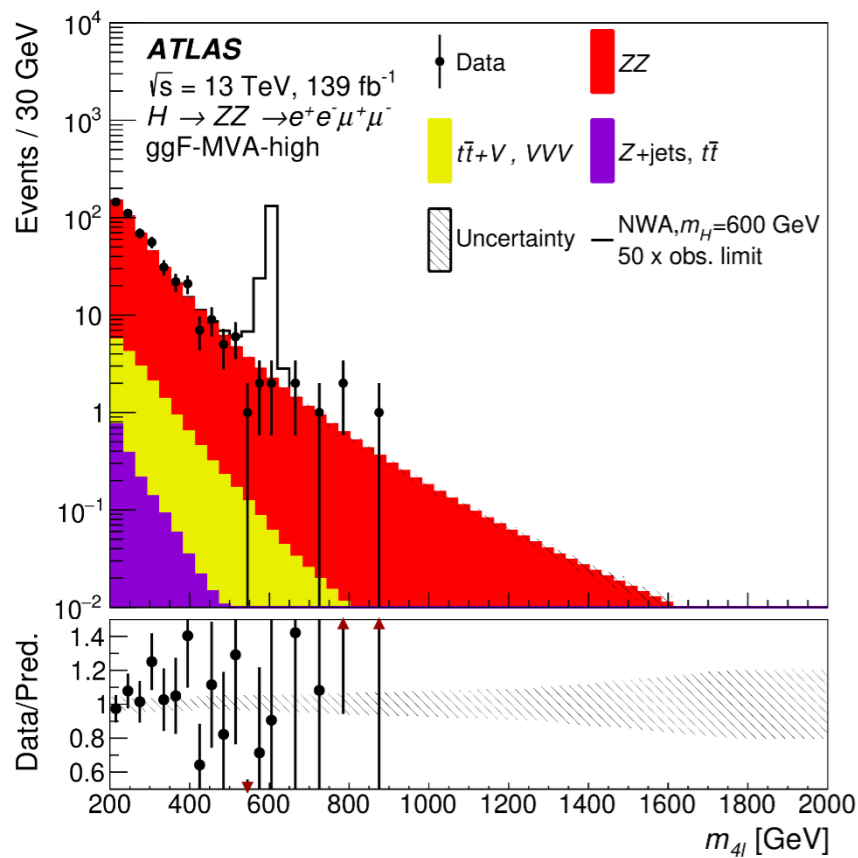ggF production of new heavy scalar decaying to ZZ

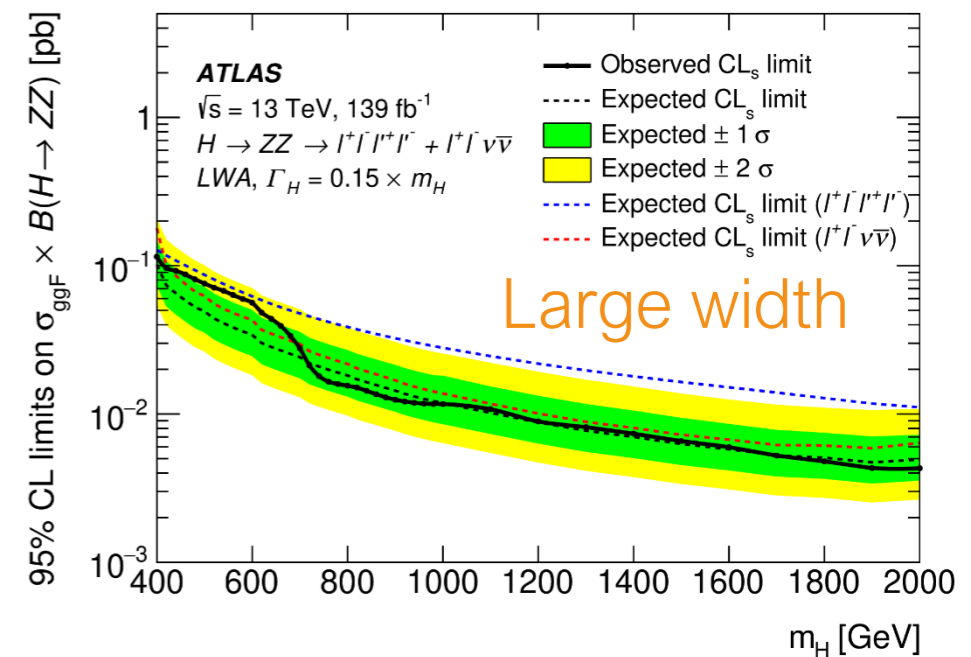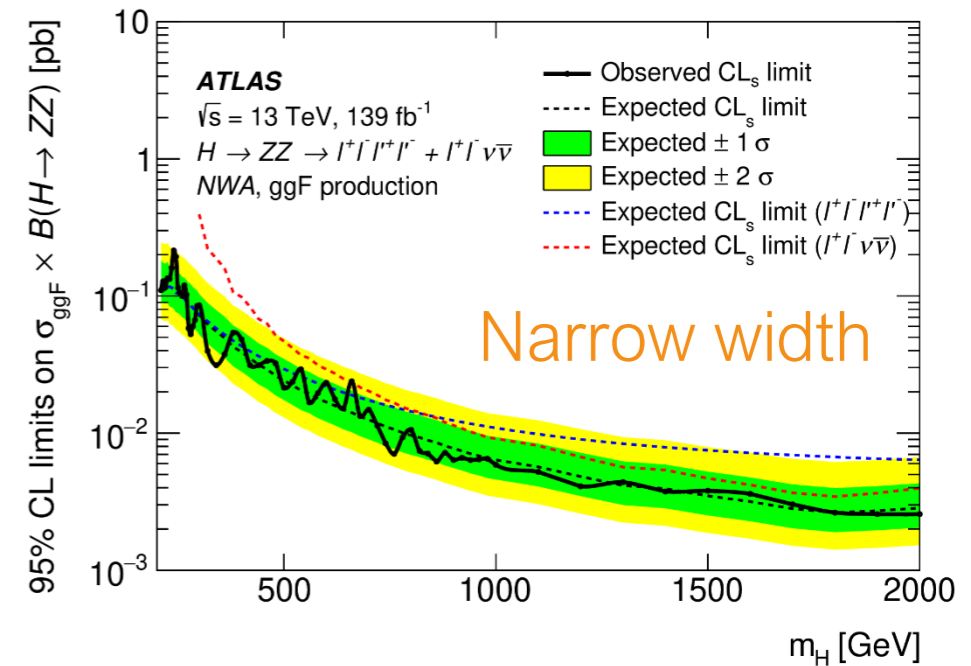Considers narrow and large widths, VBF included for narrow width

Large width search includes
interference effects with background

Invariant mass m$_{4l}$ (4l)

Transverse mass m$_T$ (2l2v)

Narrow width

Large width

$$m_T \equiv \sqrt{\left[\sqrt{m_Z^2 + \left(p_T^{\ell\ell}\right)^2} + \sqrt{m_Z^2 + \left(E_T^{miss}\right)^2}\right]^2 - \left|\vec{p}_T^{\,\ell\ell} + \vec{E}_T^{\,miss}\right|^2}$$
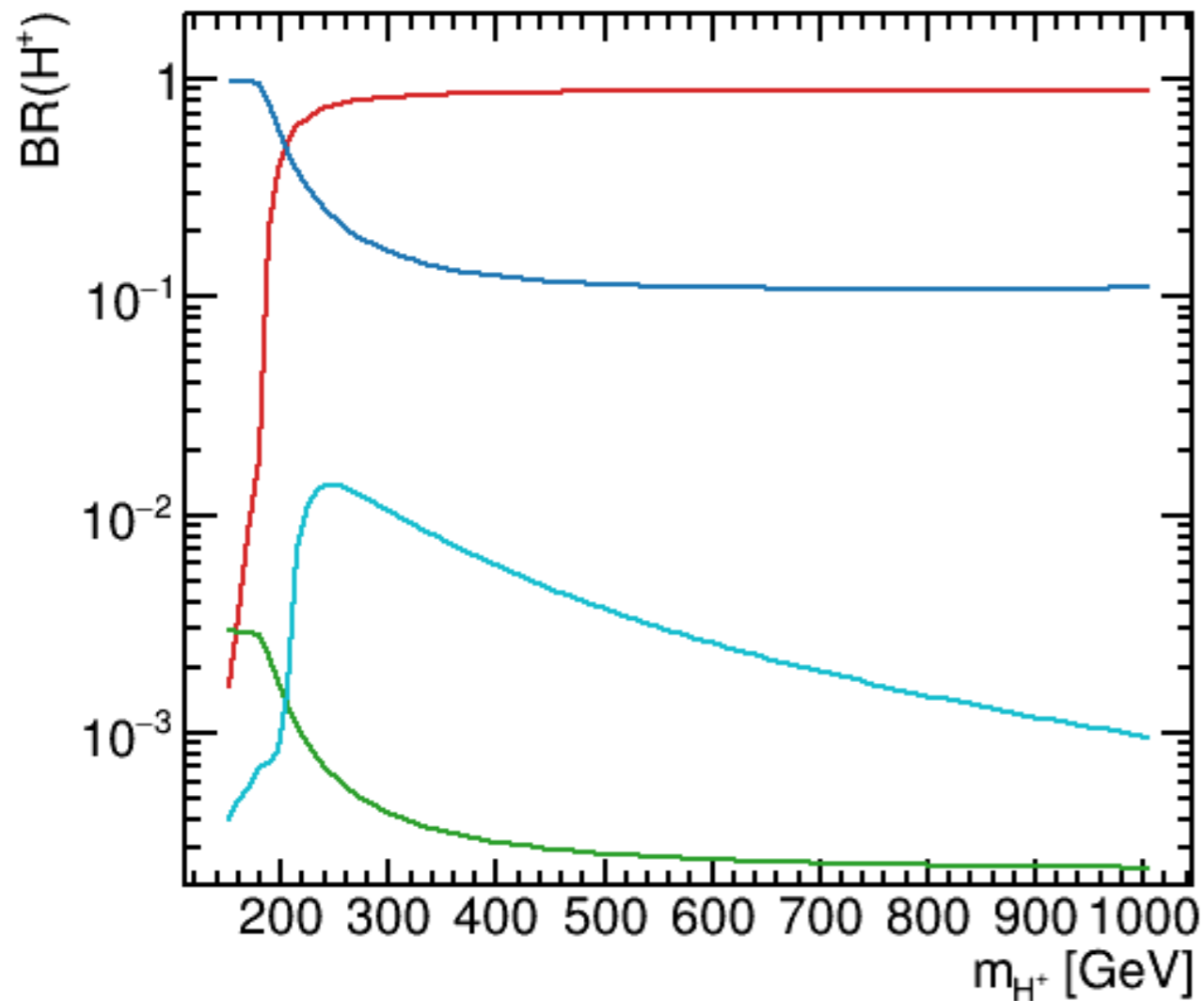
New Charged Higgs Decay $BR(H^{\pm})$

Rich phenomenology with several final states
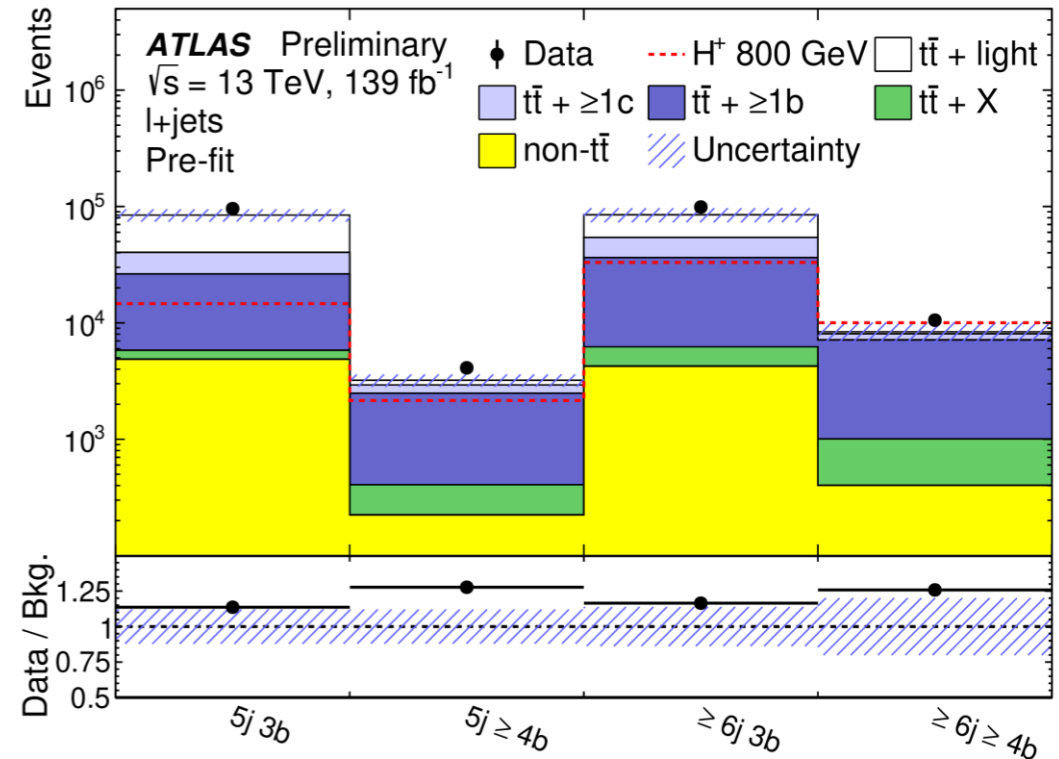
Example benchmark hMSSM

$\tan\beta = 10$

$\tan\beta = 50$

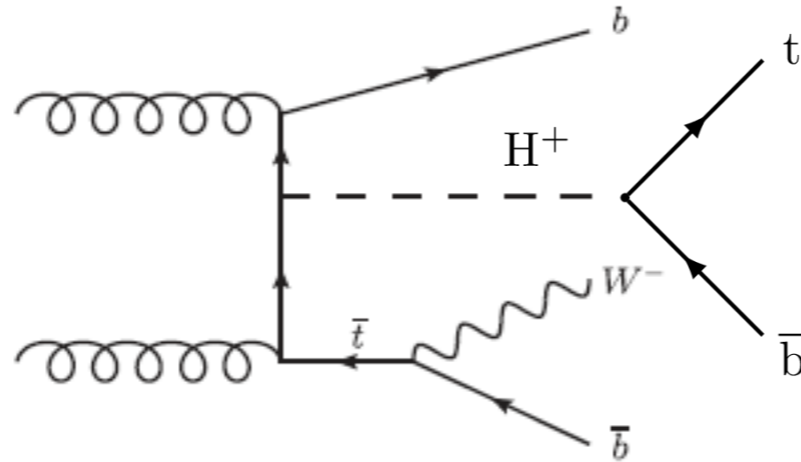Handbook of LHC Cross Sections: 4. Deciphering the Nature of the Higgs Sector
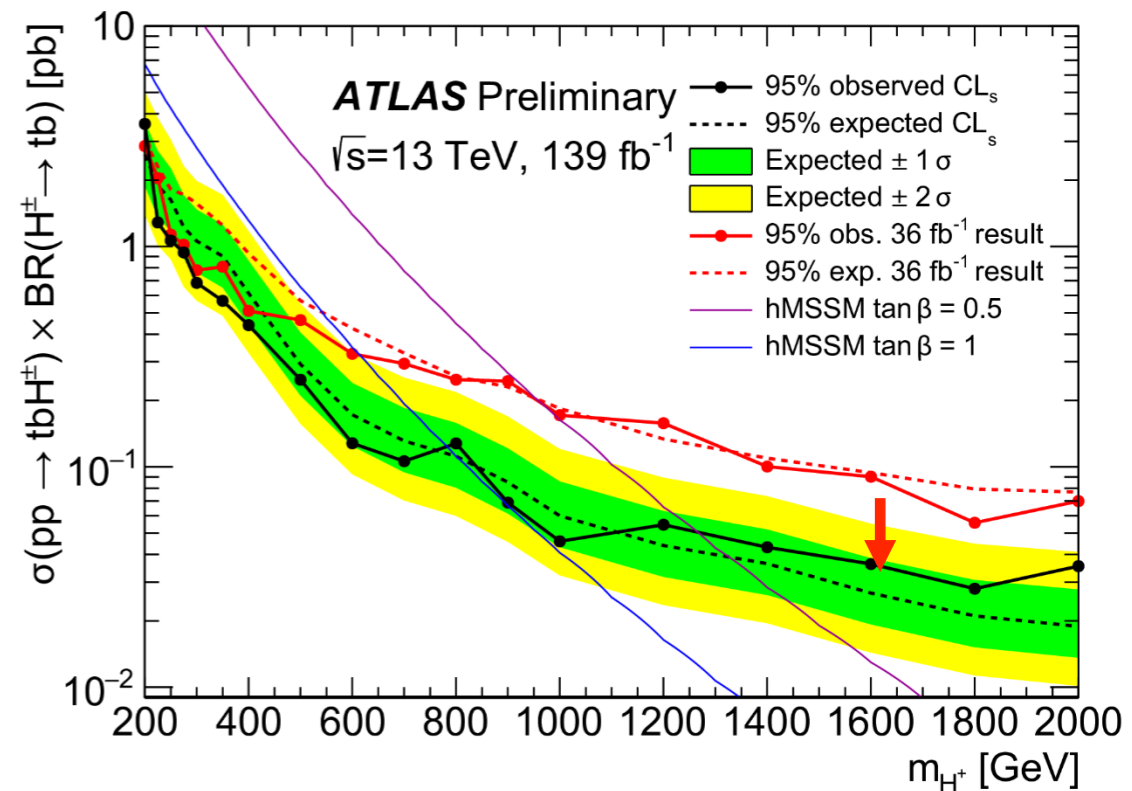Handbook of LHC Cross Sections: 3. Higgs Properties
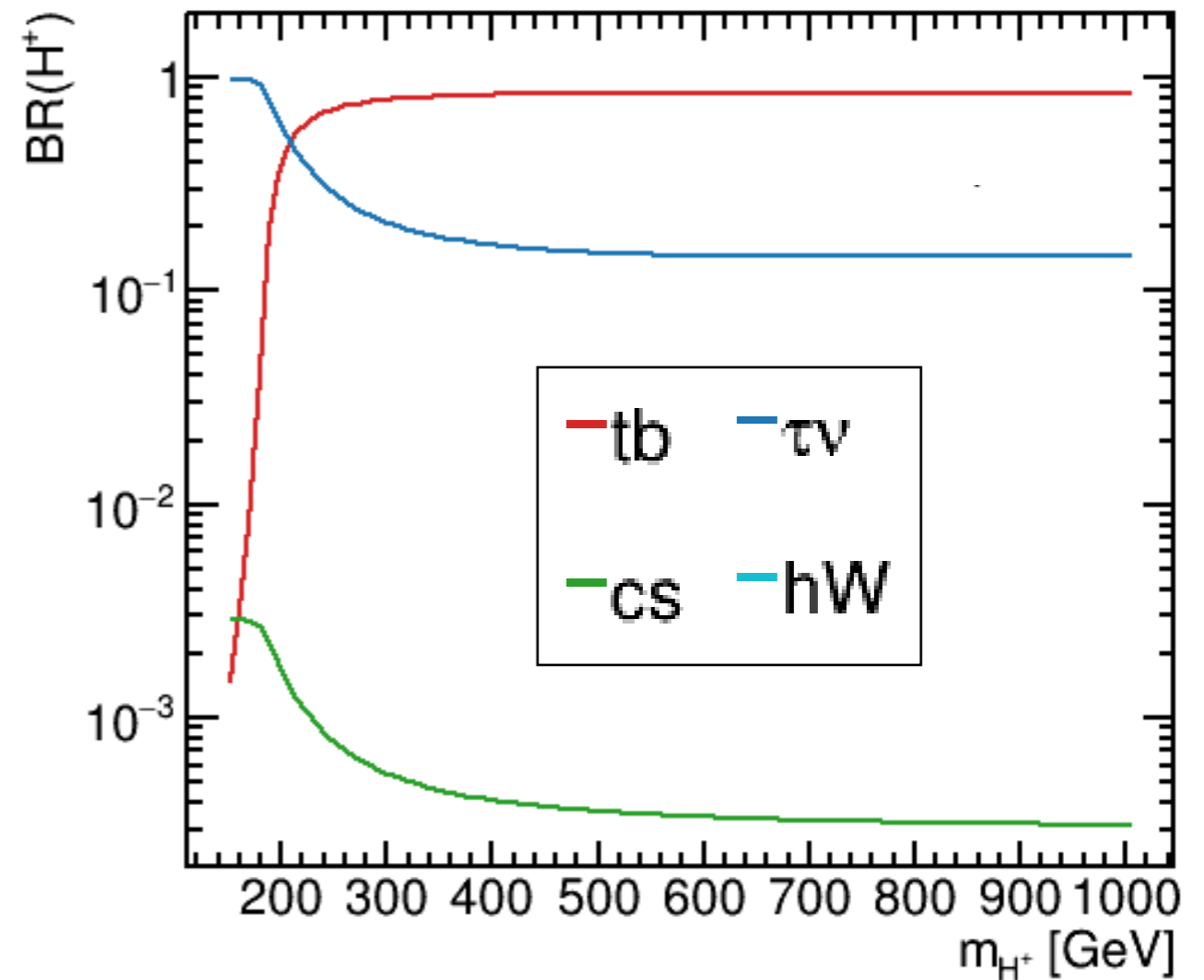
H⁺→tb in the 1 Lepton Channel
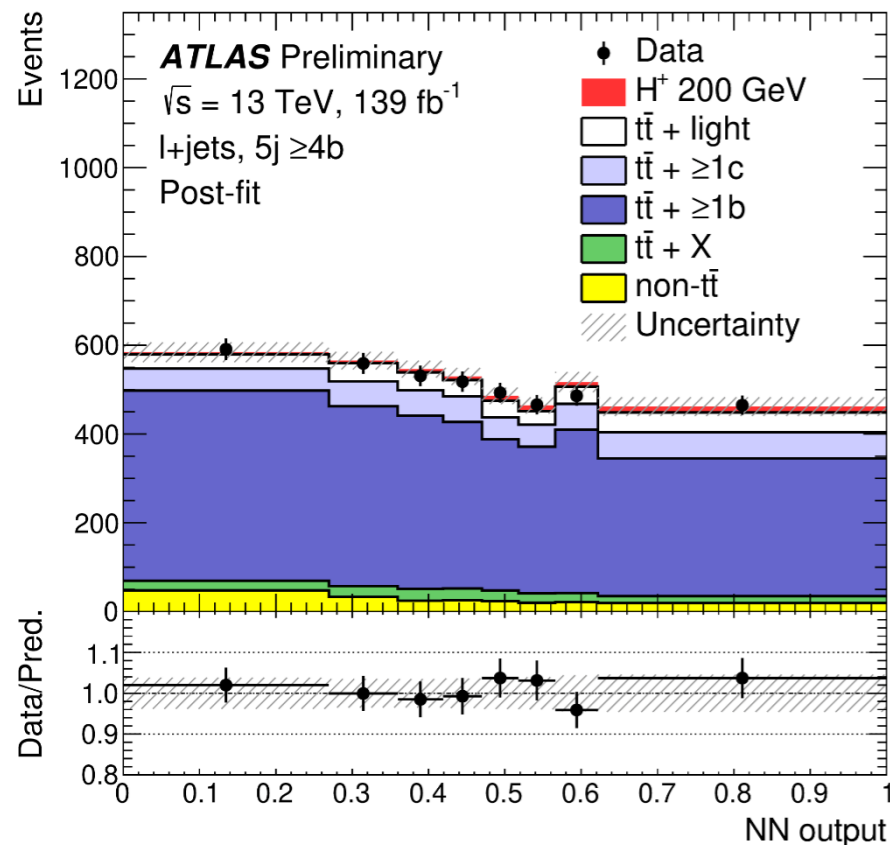
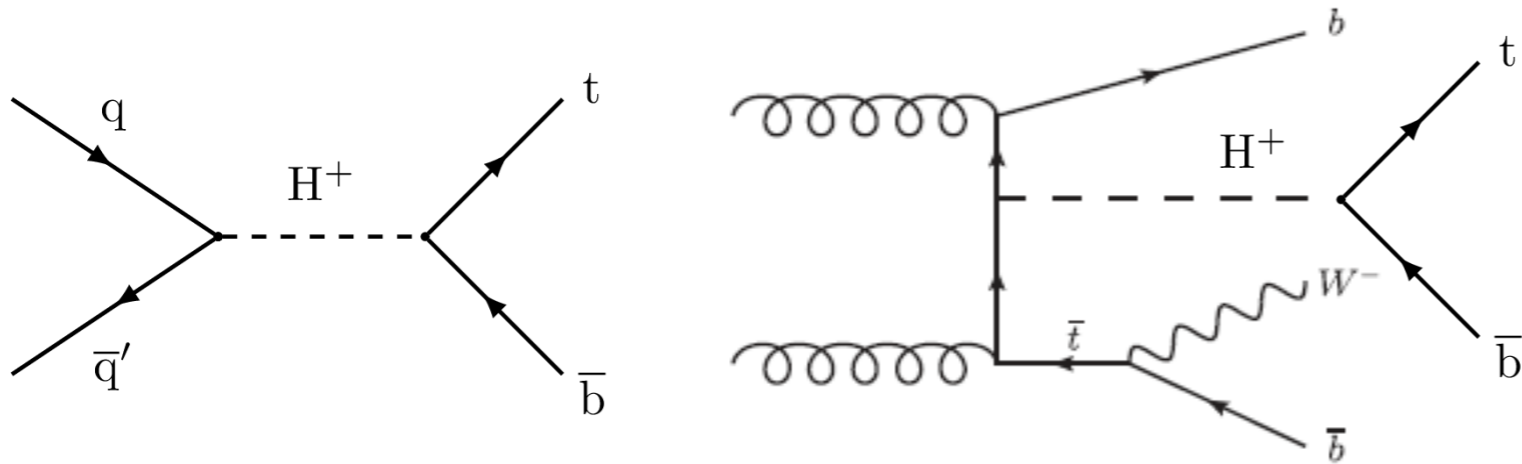Key channel in several new physics scenarios such as 2HDM (MSSM) at high H⁺ mass

Events 1 e/μ (trigger), ≥ 5 jets (≥2 b-jets)

Categories based on number of jets & b-jets
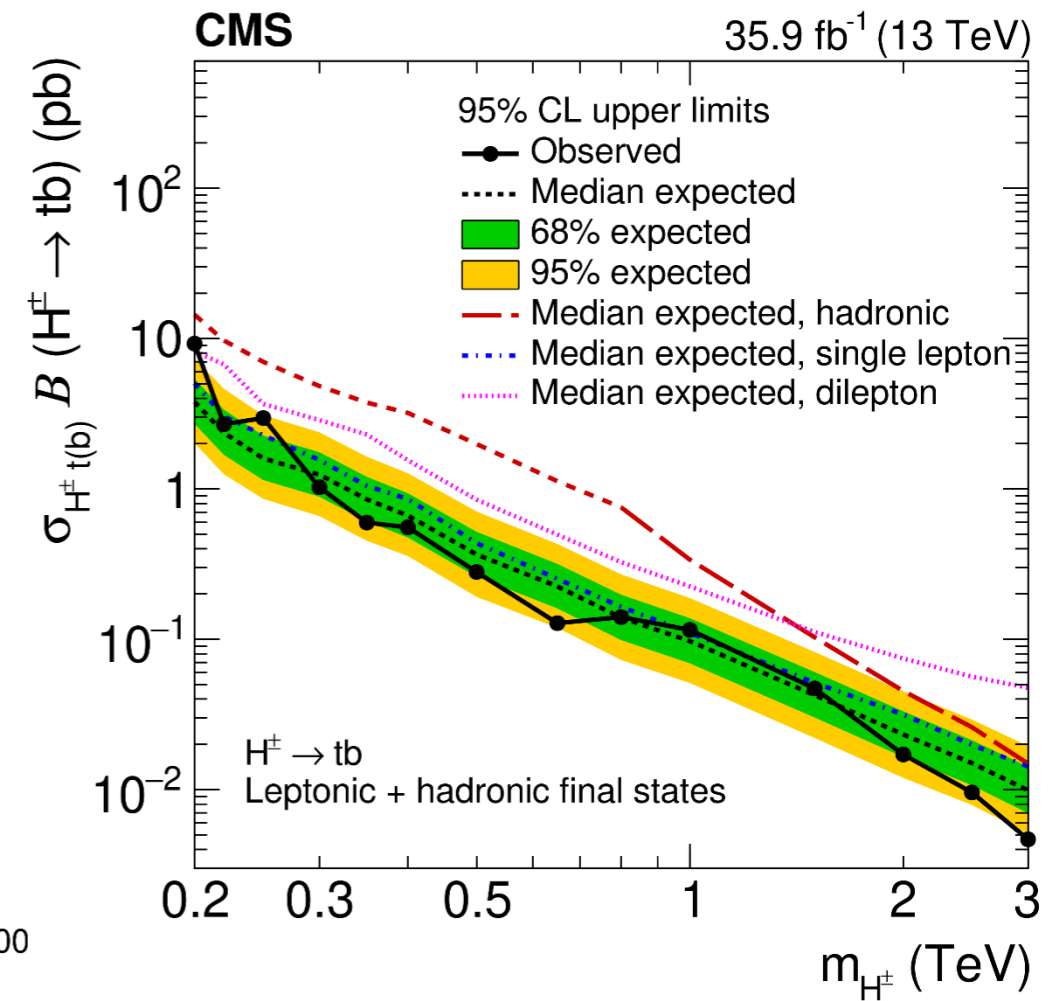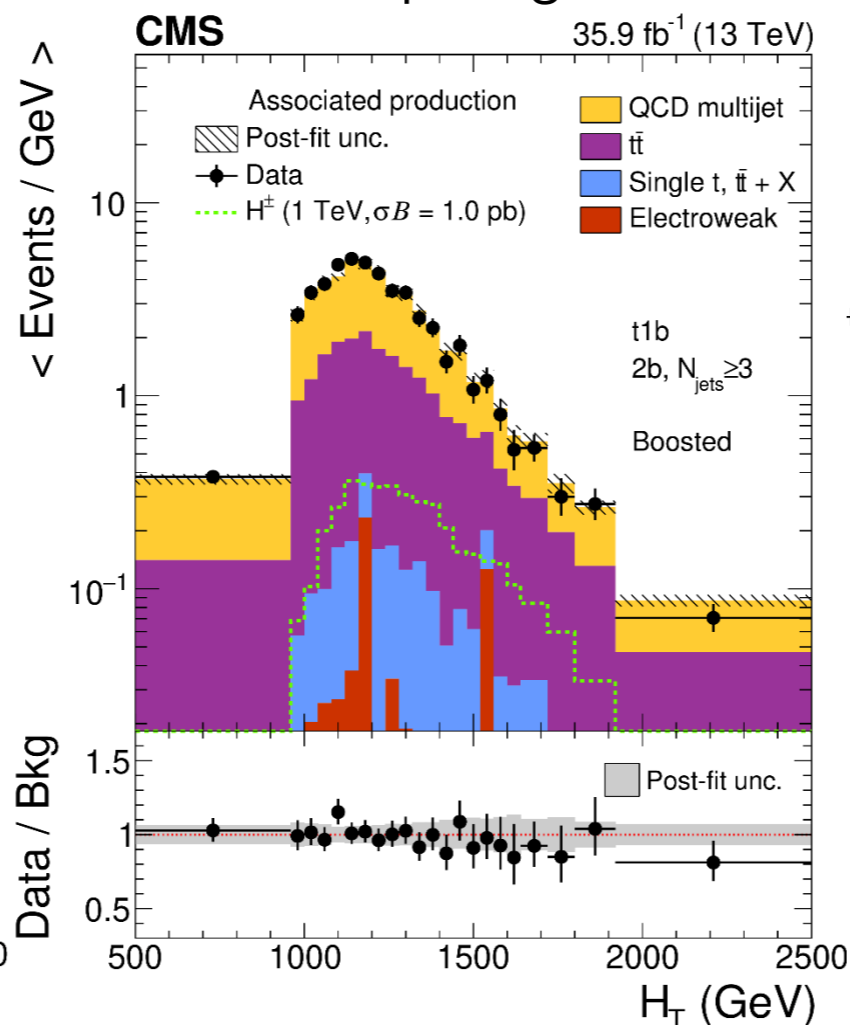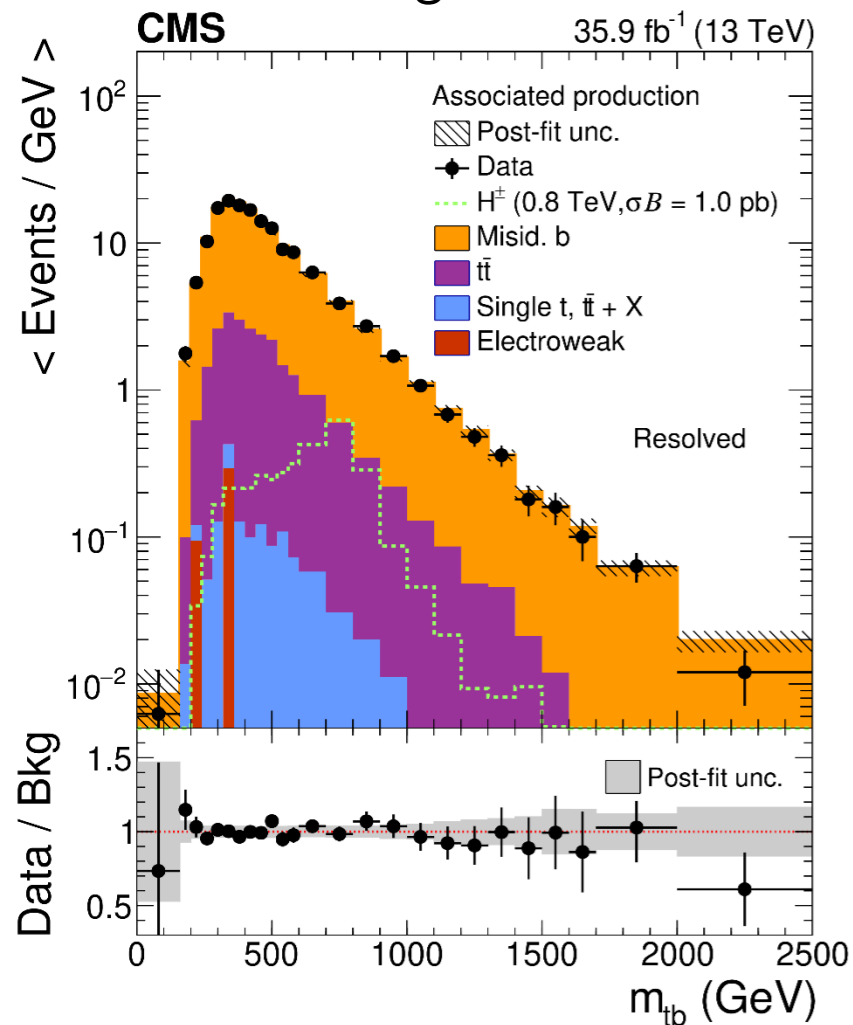
Parameterized Neural Network as final discriminant

Higher sensitivity due to larger dataset and improved analysis

H⁺→tb in the All-Hadronic Channel

Categorisation based on n-jets, boosted t/W and n b-tags

H_T (boosted) and m_{tb} (resolved) as final discriminants

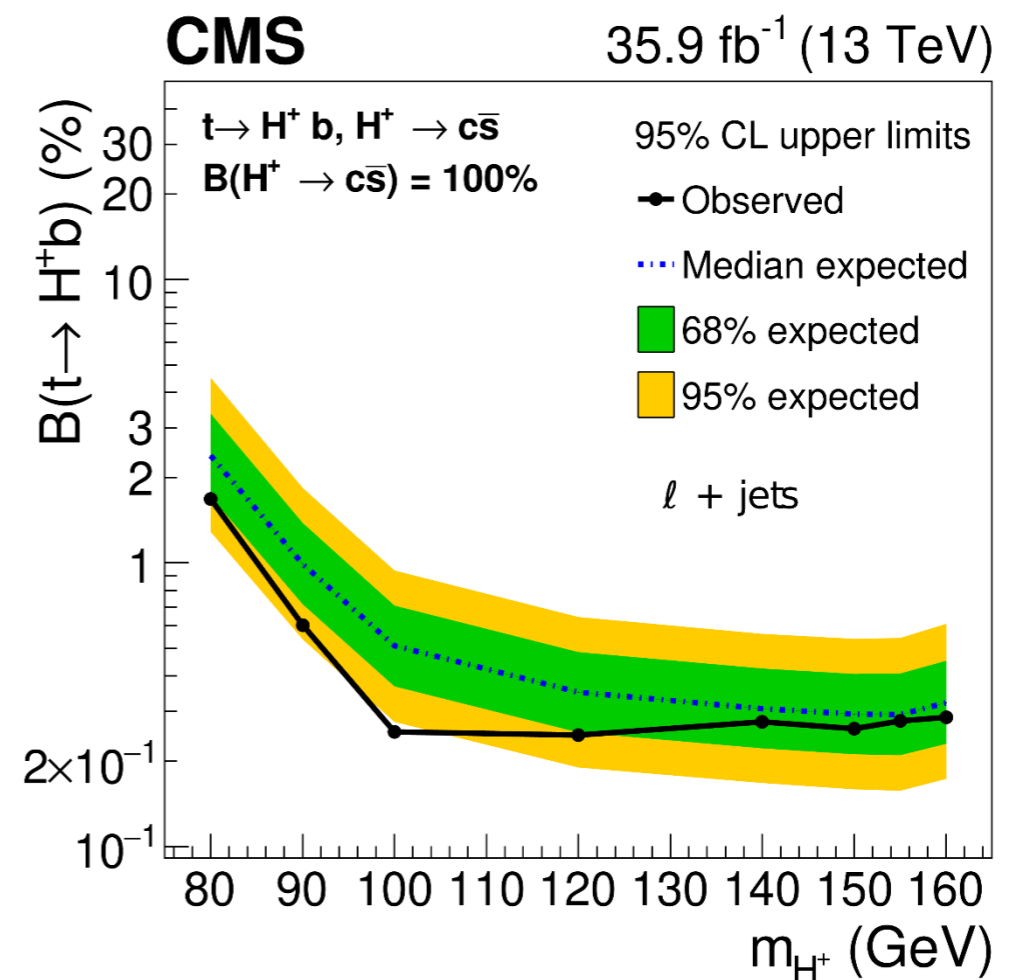Target resolved and boosted topologies

H$^+$→cs

Key channel in low tan β
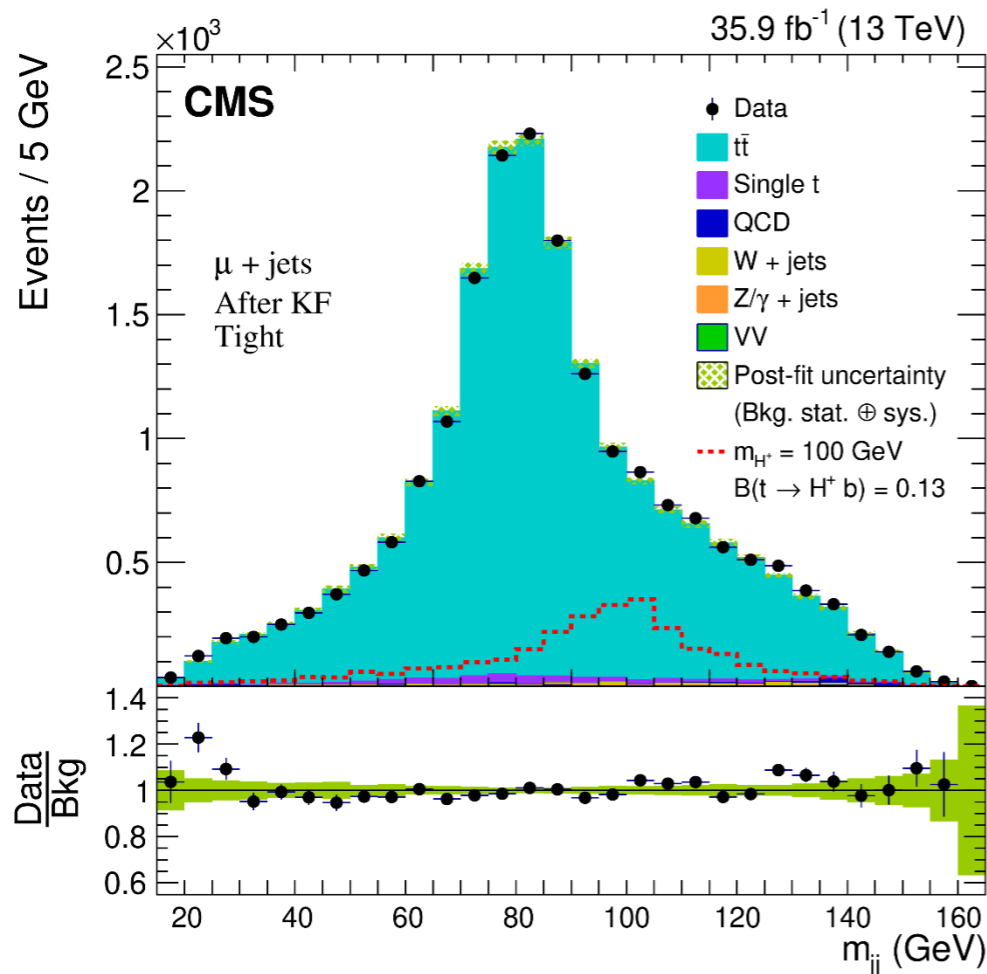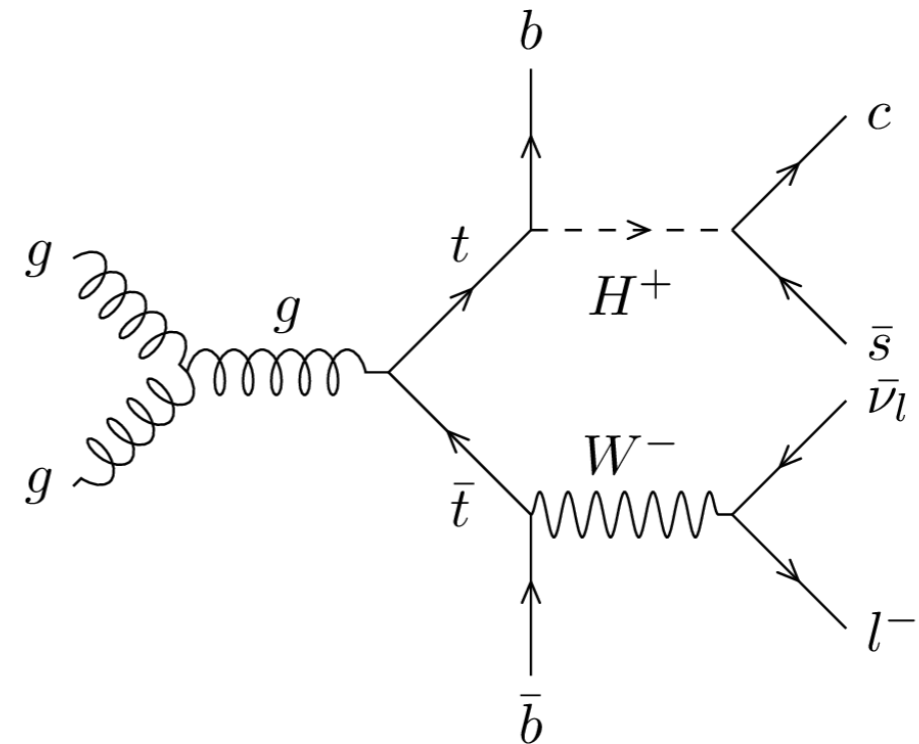Search in tt decays
1 e/μ, E_T^{miss}, ≥ 4 jets (≥2 b-jets)
Use kinematic fit with constraints on m_T
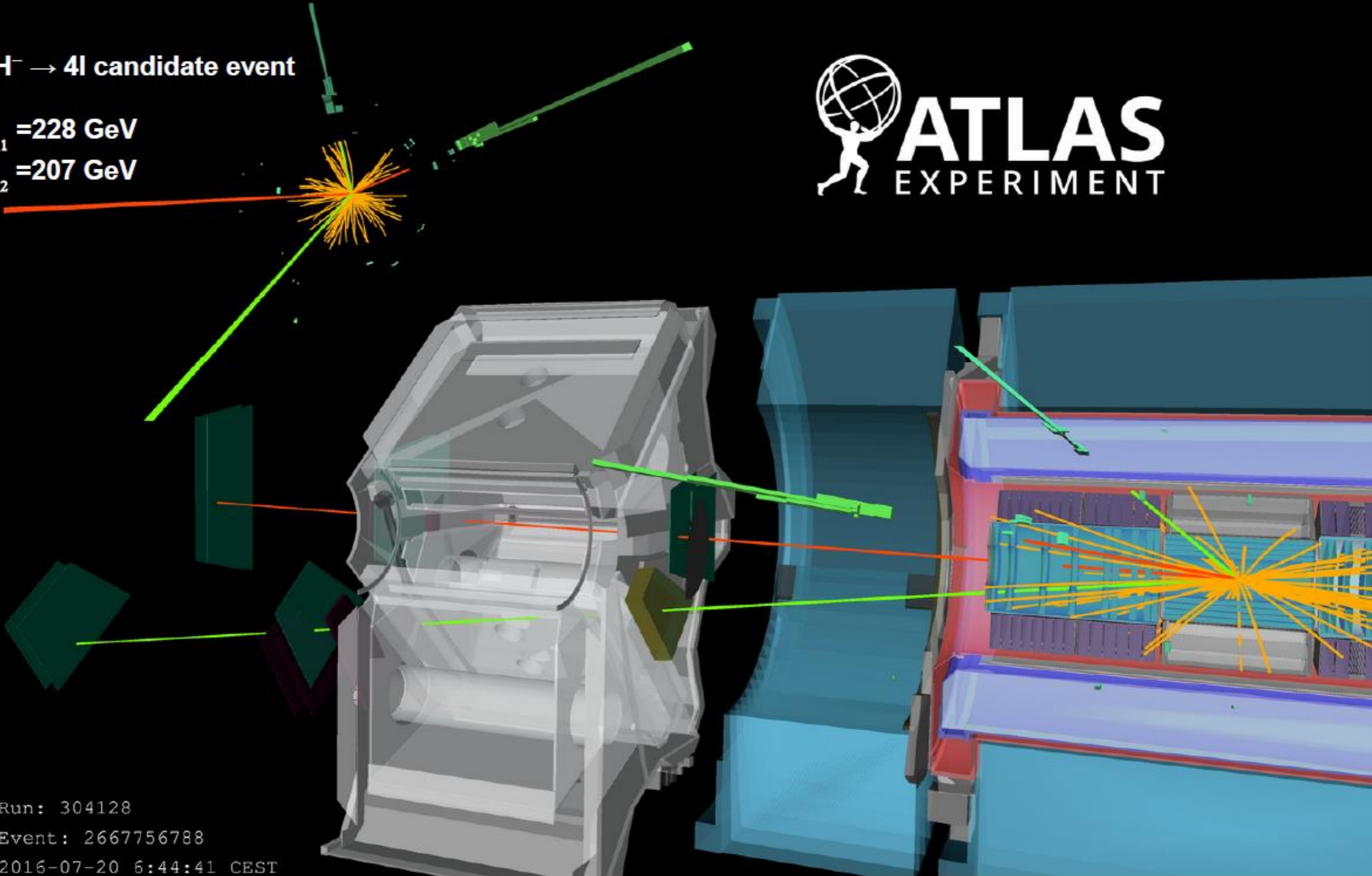m_{jj} of 2 non-b jets is final discriminant
Categories based on c-tagging

Other BSM Scenarios

H++H− → 4l candidate event

$m_{e\mu,1}$ = 228 GeV
$m_{e\mu,2}$ = 207 GeV

Run: 304128
Event: 2667756788
2016-07-20 6:44:41 CEST

NEW

$H^{++} \to W^+ W^+$

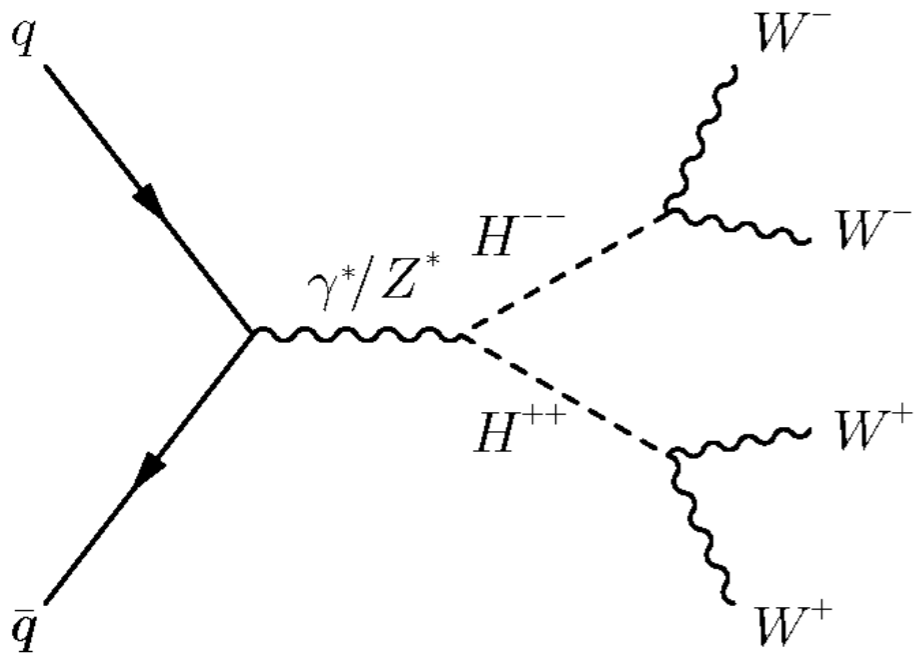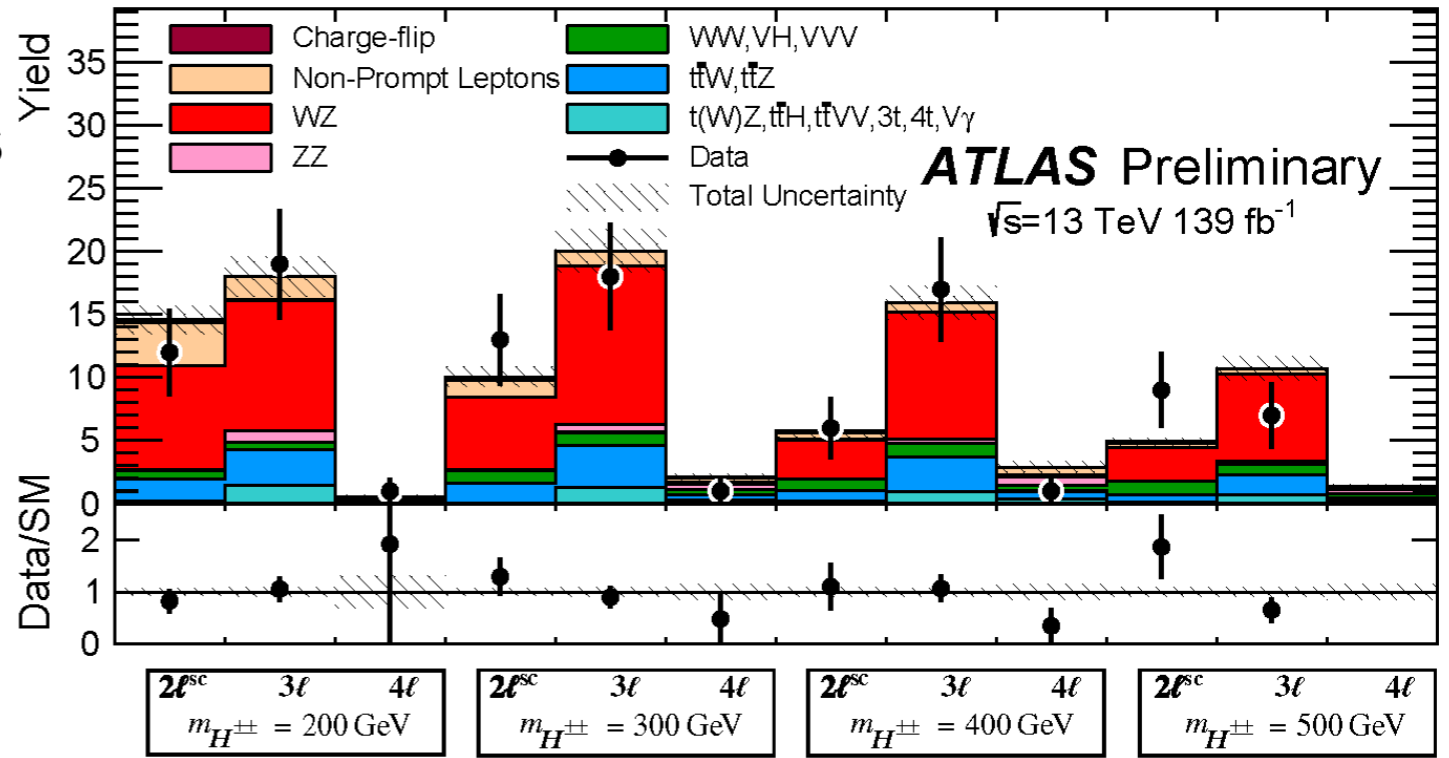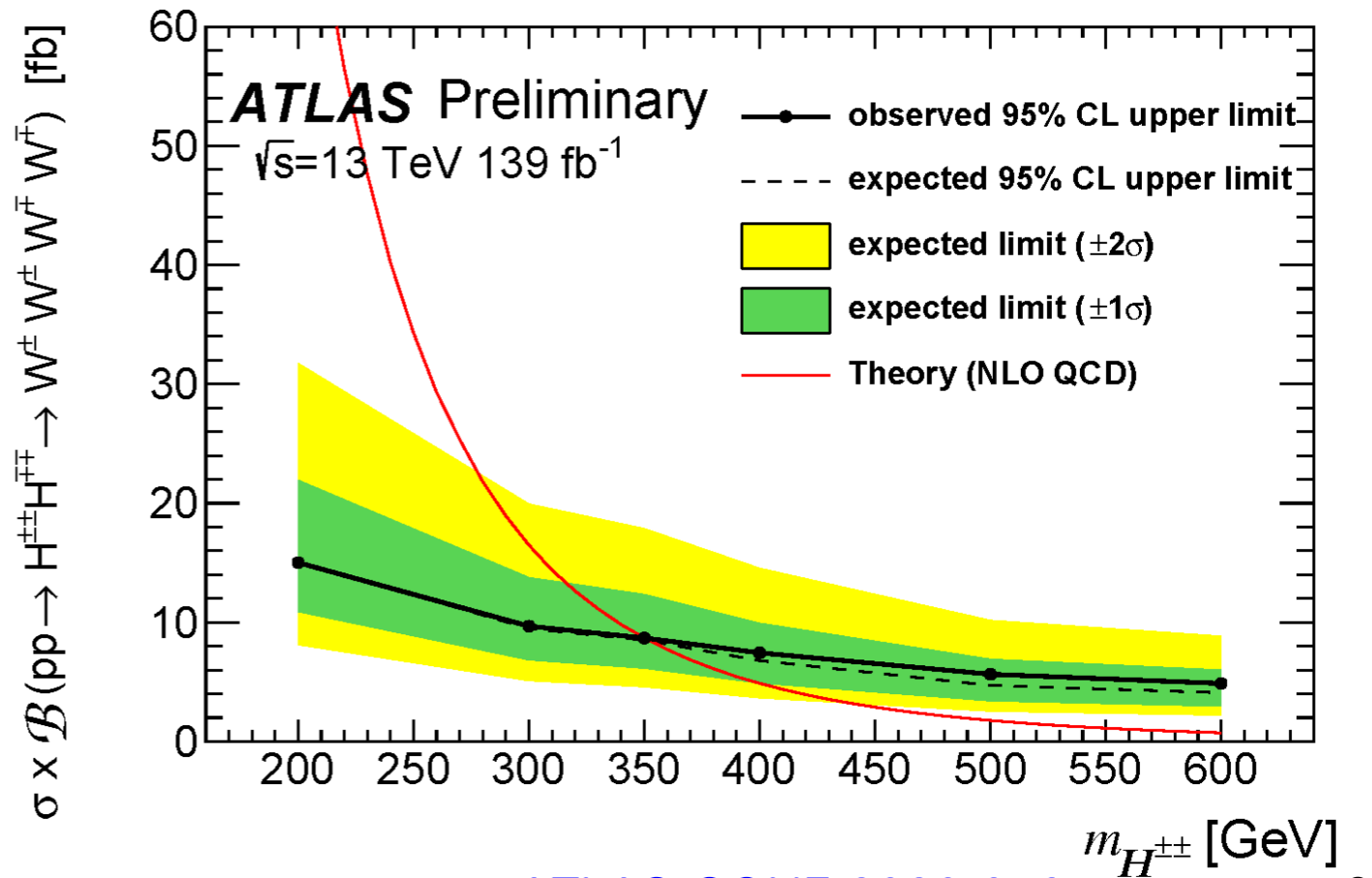Pair production of double charged Higgs bosons

Three channels: two same-sign charge, three or four leptons

Prompt lepton backgrounds from MC, non-prompt leptons from data

Sensitive to triplet vev $v_t \sim 100$ MeV

$H^{++} \to W^+ W^+$

Associated production of single charged
& double charged Higgs bosons

Three channels: two same-sign charge,
three or four leptons

Prompt lepton backgrounds from MC,
non-prompt leptons from data
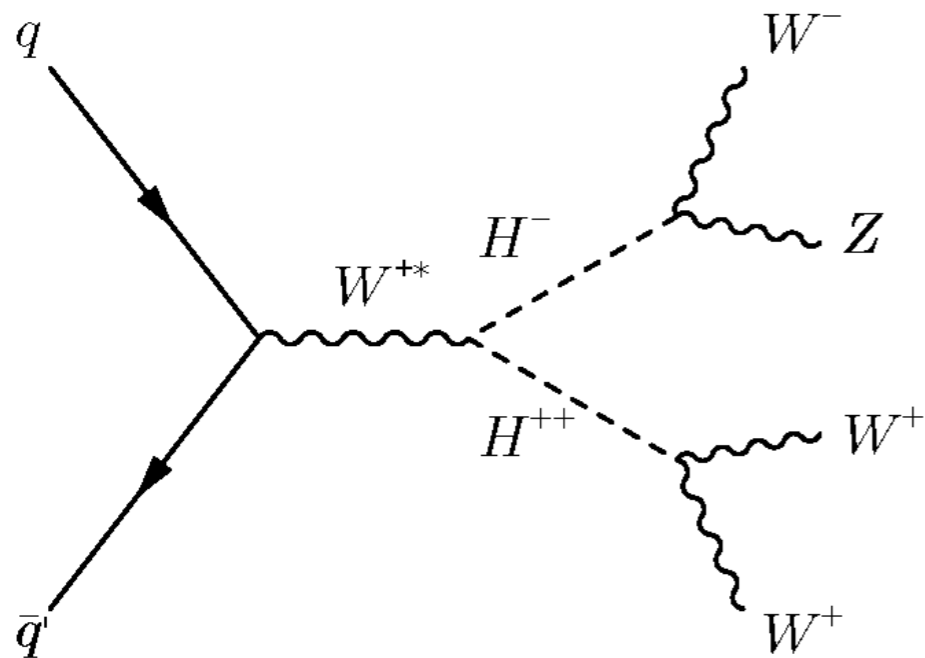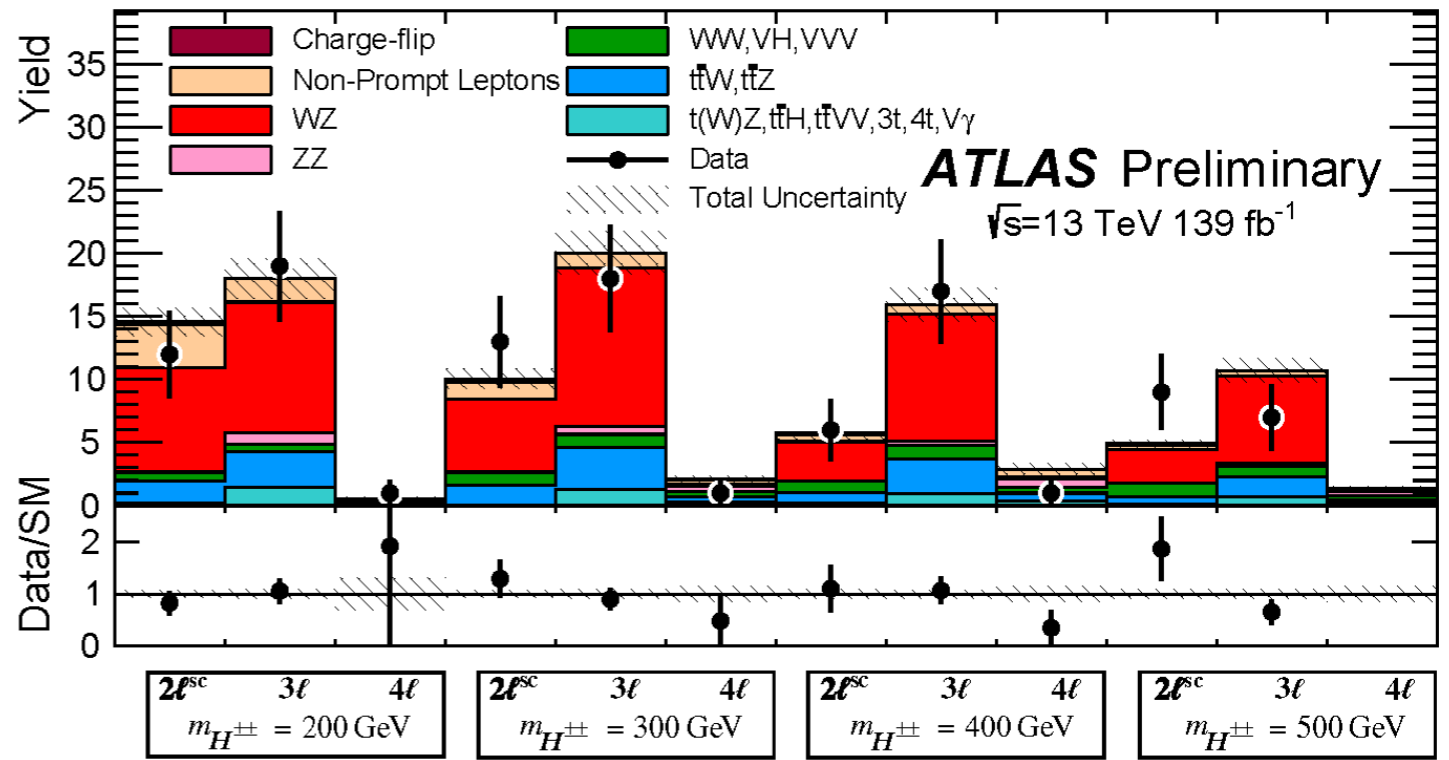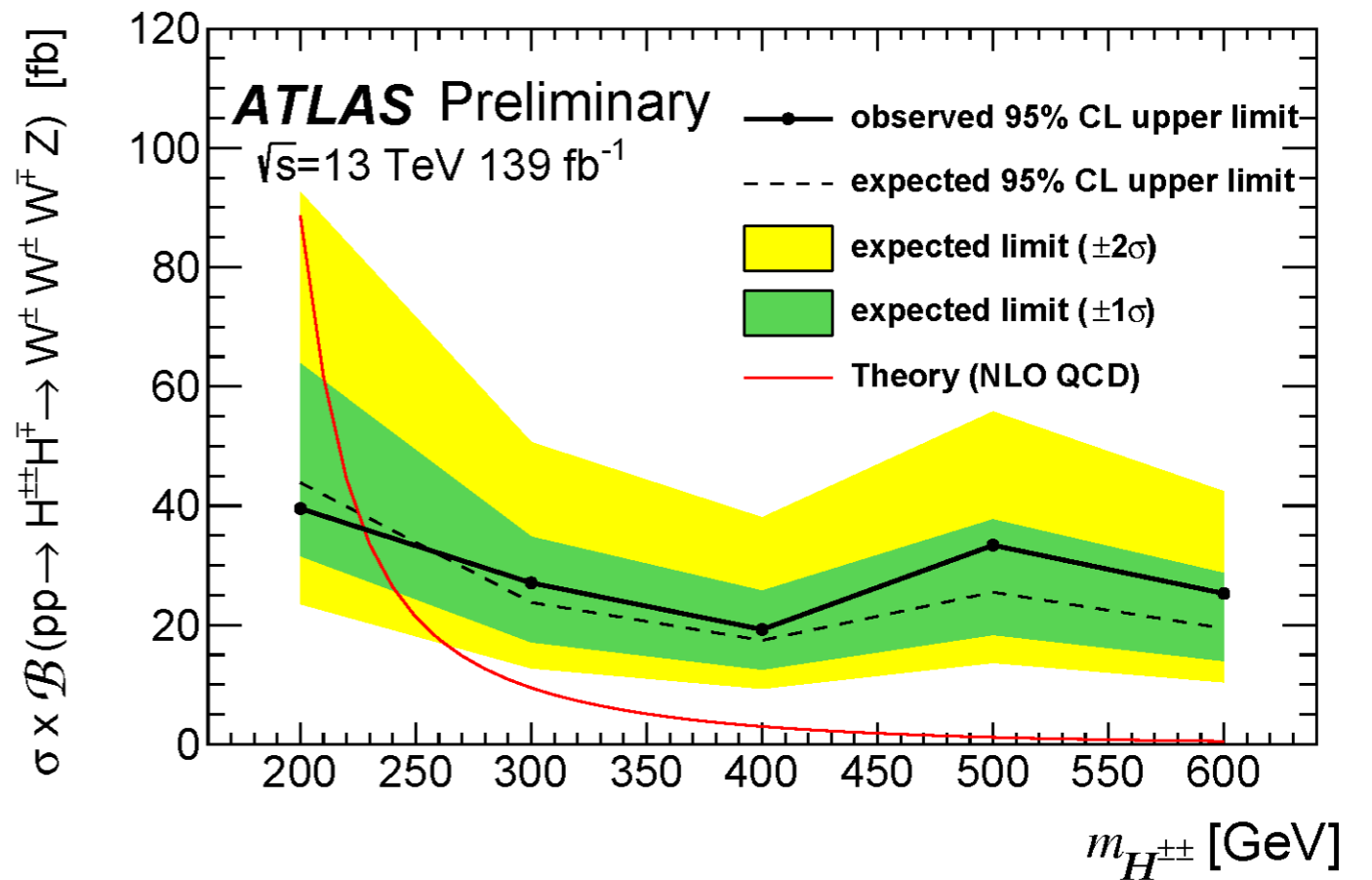
Sensitive to triplet vev $v_t \sim 100$ MeV
Targets range $|m_{H^{\pm\pm}} - m_{H^{\pm}}| < 5$ GeV

ATLAS-CONF-2020-056

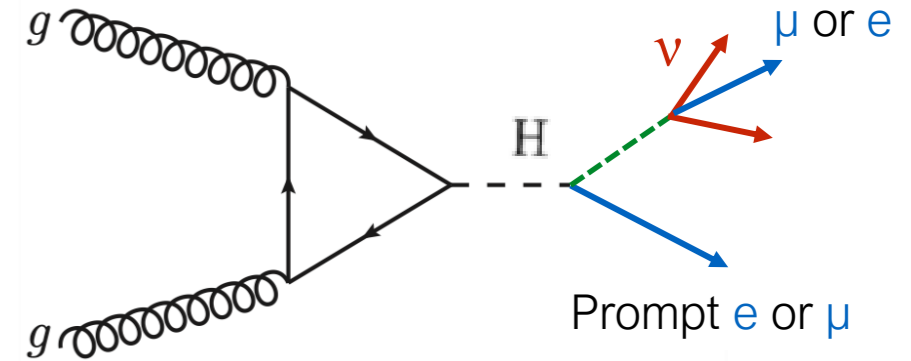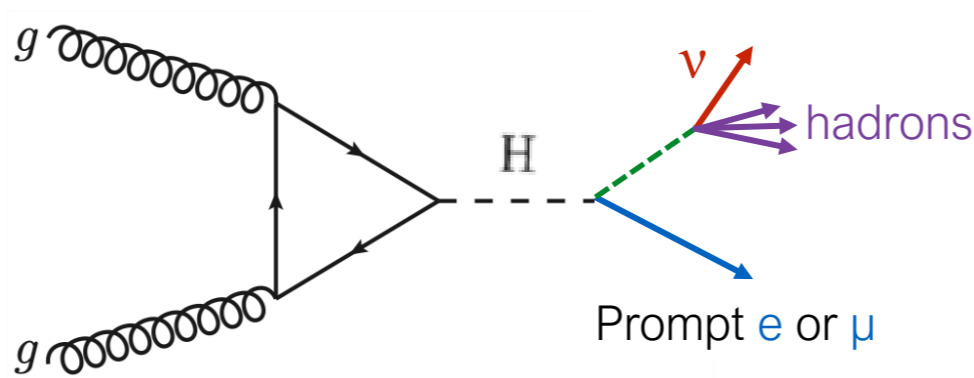# H → μτ and eτ

Search for lepton flavour violating decays

Four channels:

$\mu\tau_e$, $\mu\tau_{had}$, $e\tau_\mu$, $e\tau_{had}$

Collinear mass M_{Col} is final discriminant

Low mass selection
(m_H <450 GeV)

High mass selection
($m_H \geq$ 450 GeV)

low mass

high mass
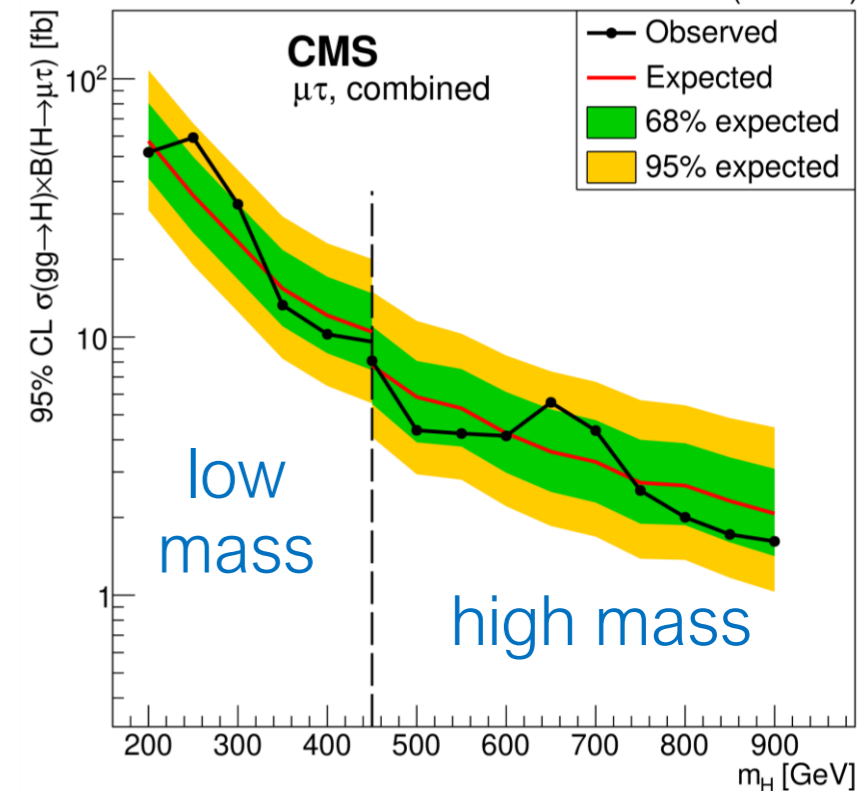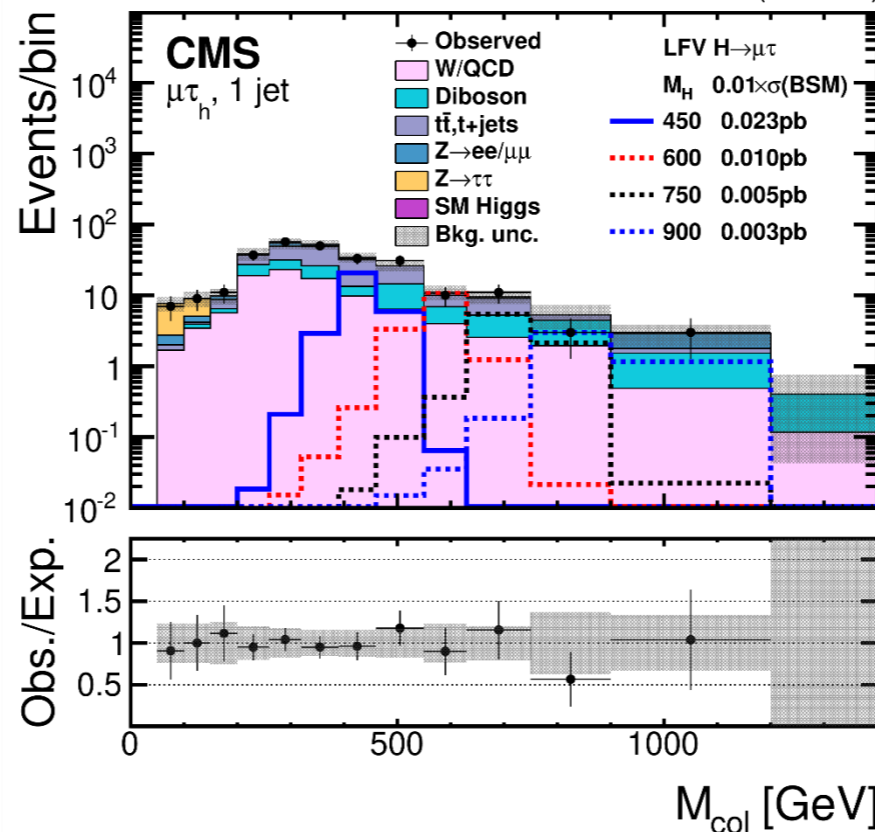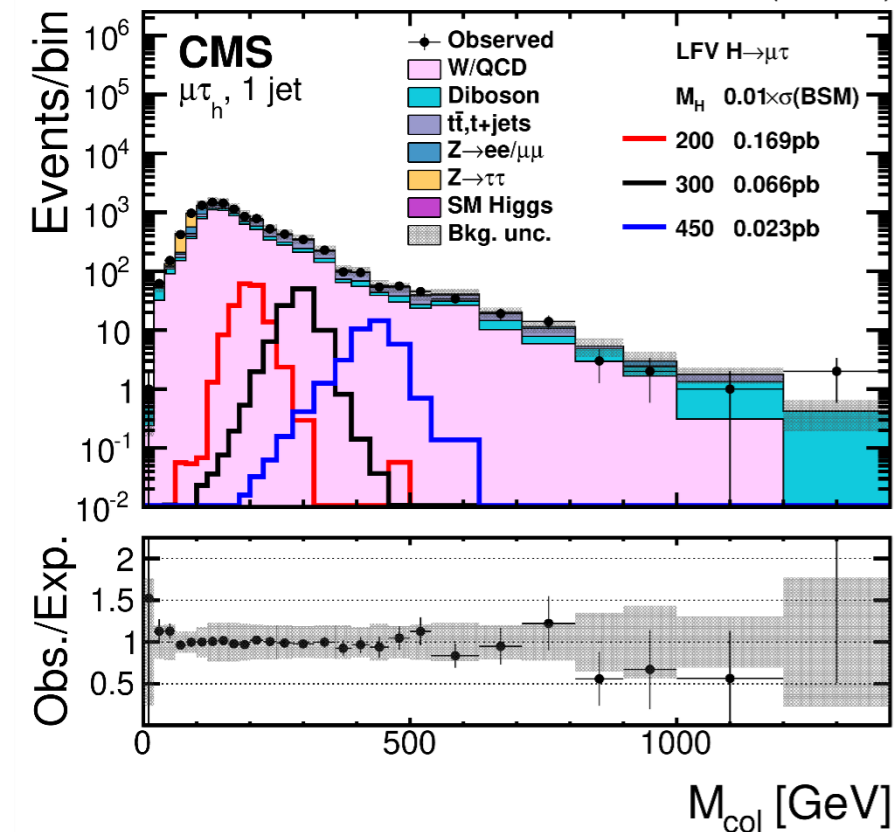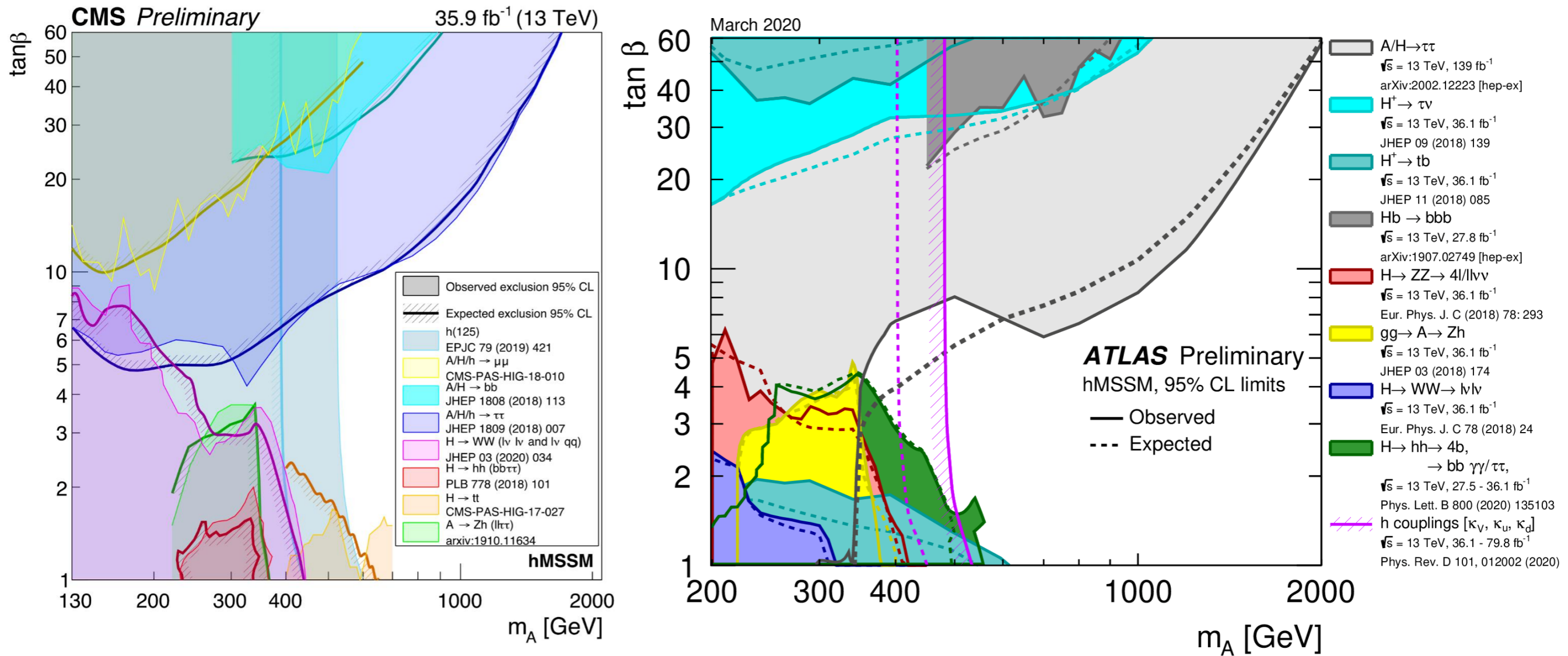
Summary of Results

Direct searches for heavy Higgs bosons and fits to observed Higgs boson production & decay rates constrain scenarios with extended Higgs sectors

Note: not all updated results included in summary plots

NEW

Reinterpretation of combination of Higgs measurements in several MSSM benchmark scenarios

Analysis		Integrated lumi (fb^{-1})
$H \to \gamma\gamma$	(all production modes)	139
$H \to ZZ^* \to 4\ell$	(all production modes)	139
$H \to b\bar{b}$	(VH)	139
$H \to WW^*$	(ggH, VBF)	36.1
$H \to \tau\tau$	(ggH, VBF)	36.1
$H \to b\bar{b}$	(VBF)	$24.5 - 30.6$
$H \to b\bar{b}$	$(t\bar{t}H)$	36.1
$H \to$ multilepton	$(t\bar{t}H)$	36.1
$H \to \mu\mu$	(all production modes)	139

M_h^{125} Scenario
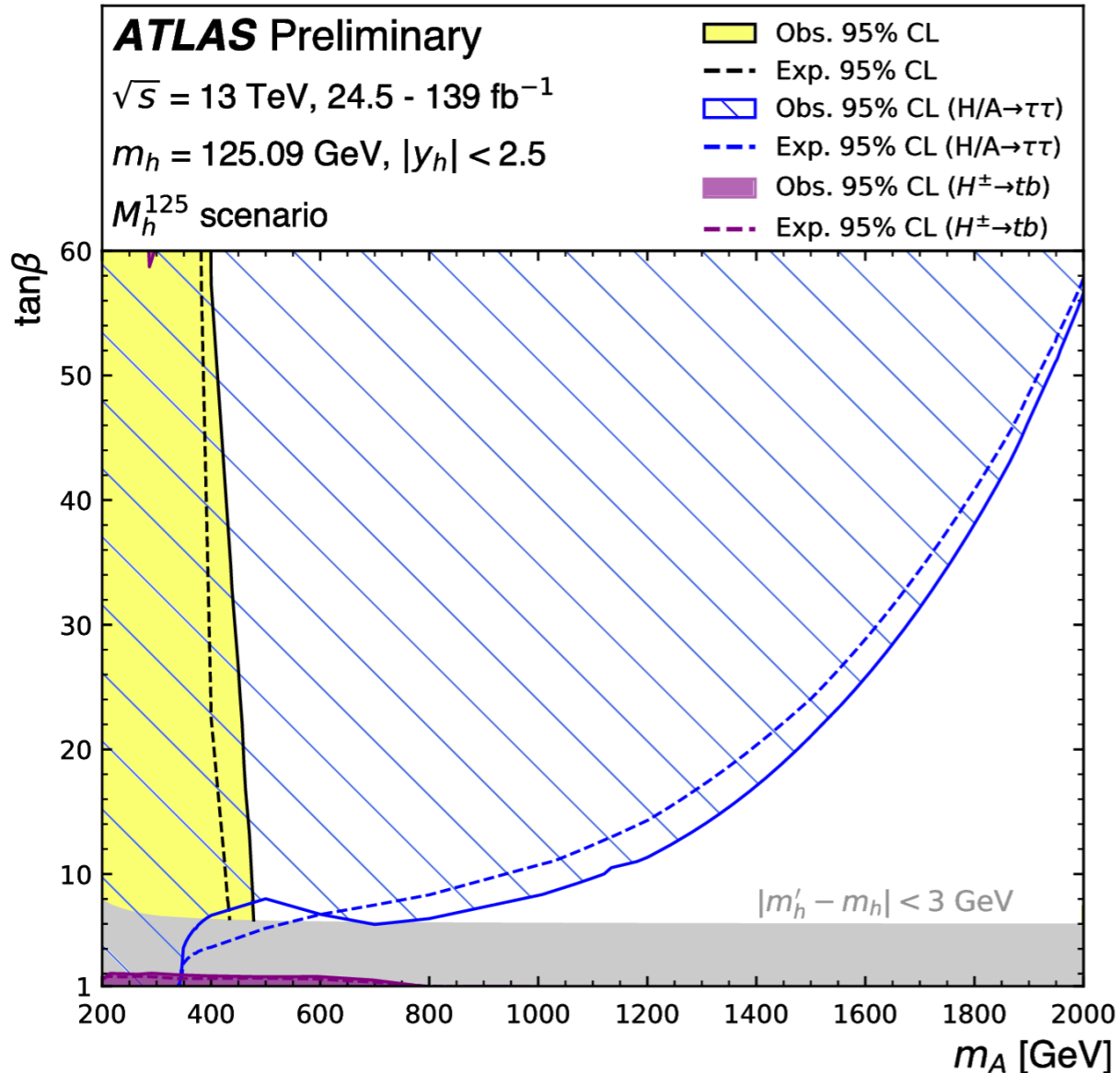
M_h^{125} (alignment) Scenario
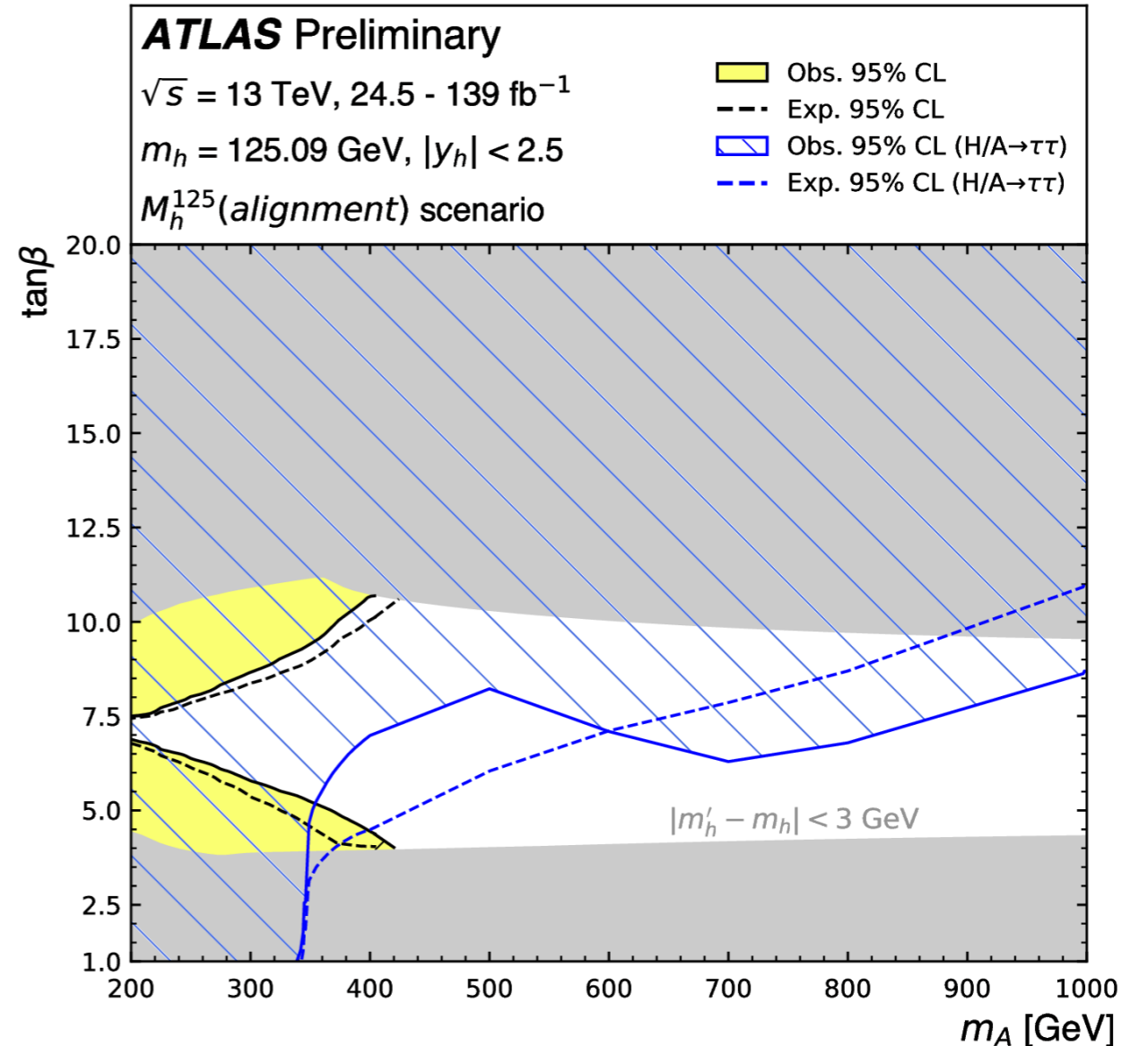
Summary and Conclusions

- Extensive program of searches for BSM Higgs bosons at the LHC
 - A few recent results shown here including first with full Run 2 dataset
- Searches extend the sensitivity to new regimes
  - Uncovered kinematics, both highest and lowest masses, new channels
  - Benefit from large dataset, improved reconstruction and analysis techniques that are increasingly sophisticated

Neutral Higgs
$H/A \to \tau\tau$
$H/A \to bb$
$H/A \to tt$
$H/A \to \mu\mu$
$H/A \to \gamma\gamma$
$A \to Zh$
$A \to ZH$
$H \to WW$
$H \to ZZ$
$H \to ZA$

Charged Higgs
$H^+ \to \tau\nu$
$H^+ \to tb$
$H^+ \to cs$
$H^+ \to WZ$

Double Charged Higgs
$H^{++} \to W^+ W^+$
$H^{++} \to \ell^+ \ell^+$

Lepton Flavor Violation
$H \to \mu\tau \ / \ e\tau$
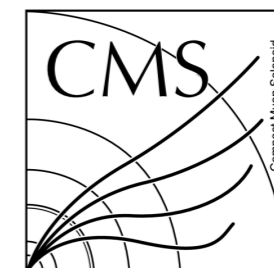
ATLAS Results Page

CMS Results Page

Stay tuned for many more results!