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# Hints for New Higgs Bosons at the LHC

**Sumit Banik**

**Based on: arXiv:2407.06267**

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# Motivation

## Hints for new Higgs Bosons

- Discovery of Higgs Boson in 2012 completes the SM
- SM is not the ultimate theory of nature
- Minimality of the scalar sector of the SM not guaranteed theoretically
- Hints for new Higgs Boson at 95 GeV and 152 GeV

# Motivation

## Hints for new Higgs Bosons

- ATLAS recently performed Model-Independent analysis of $\gamma\gamma + X$ for SM Higgs

**Full Run 2 Data**

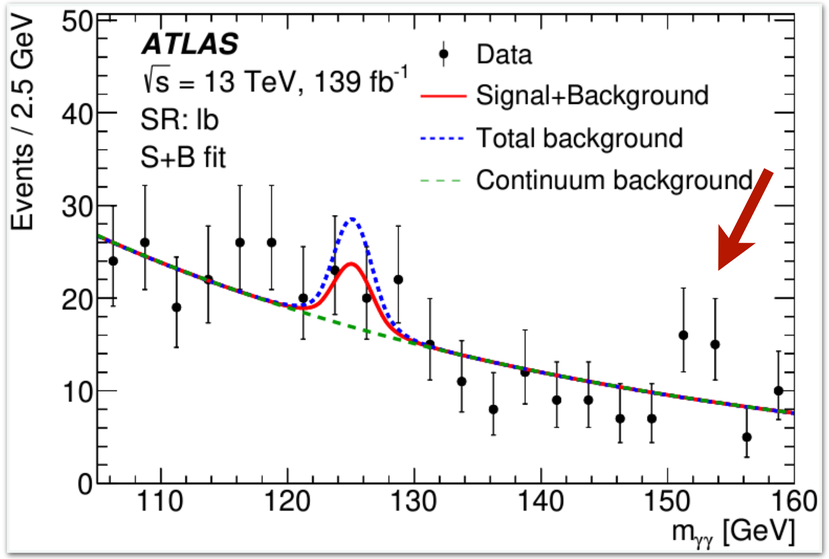
- Analysis involves 22 final states

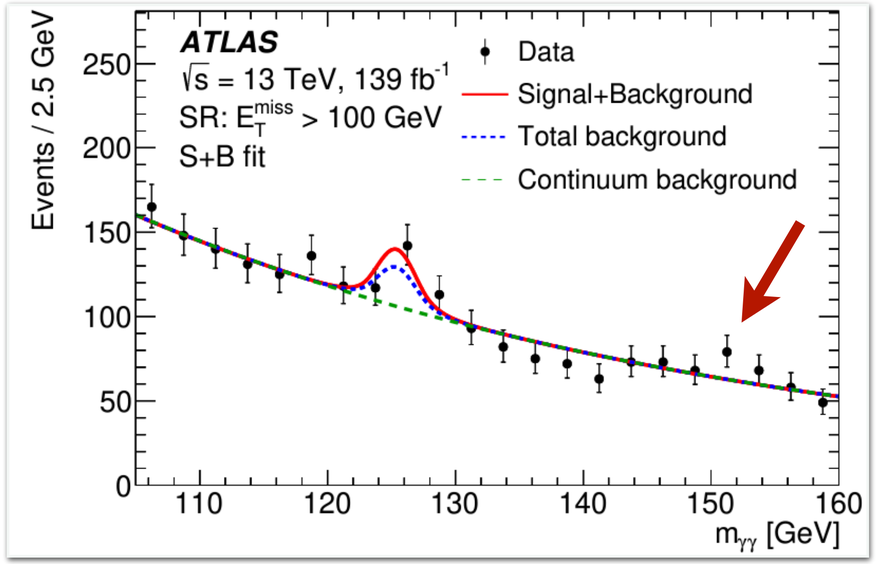
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SRs | $\geq 3b$ | $\geq 4b$ | $\geq 4j$ | $\geq 6j$ | $\geq 8j$ | $H_T > 500$ | $H_T > 1000$ | $H_T > 1500$ | $\ell b$ | $t_{\text{lep}}$ | $t_{\text{had}}$ |
| SRs | $\geq 1\ell$ | $2\ell$ | $2\ell - Z$ | SS$-2\ell$ | $\geq 3\ell$ | $E_{\text{miss}}^T > 100$ | $E_{\text{miss}}^T > 200$ | $E_{\text{miss}}^T > 300$ | $1\tau$ or $2\tau$ | $m_{\gamma\gamma}^{12}$ | $m_{\gamma\gamma}^{23}$ |

# Motivation

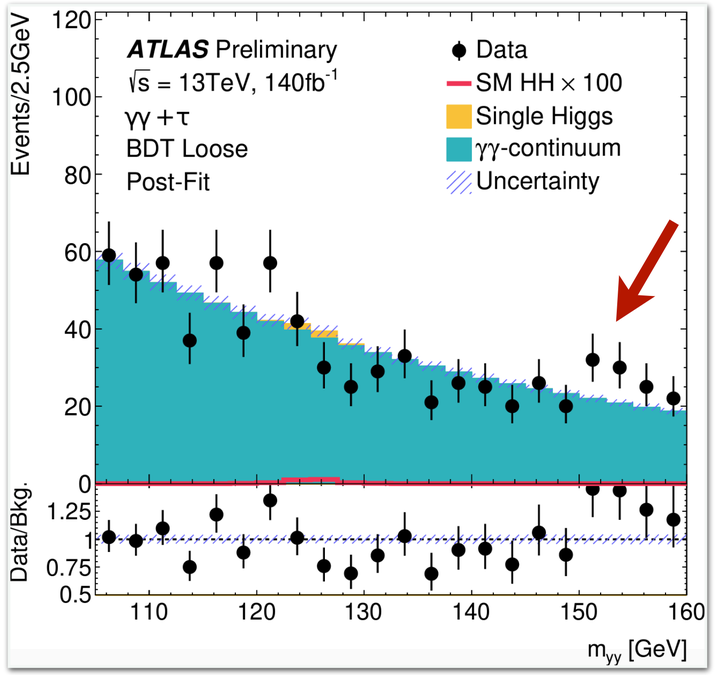
## Hints for new Higgs Bosons

- Excesses Most Pronounced: $\gamma\gamma + \ell b$, $\gamma\gamma + \text{MET}$, $\gamma\gamma + 1\tau$, $\gamma\gamma + 4j$, $\gamma\gamma + 1\ell$




[ATLAS: CERN-EP-2022-232]



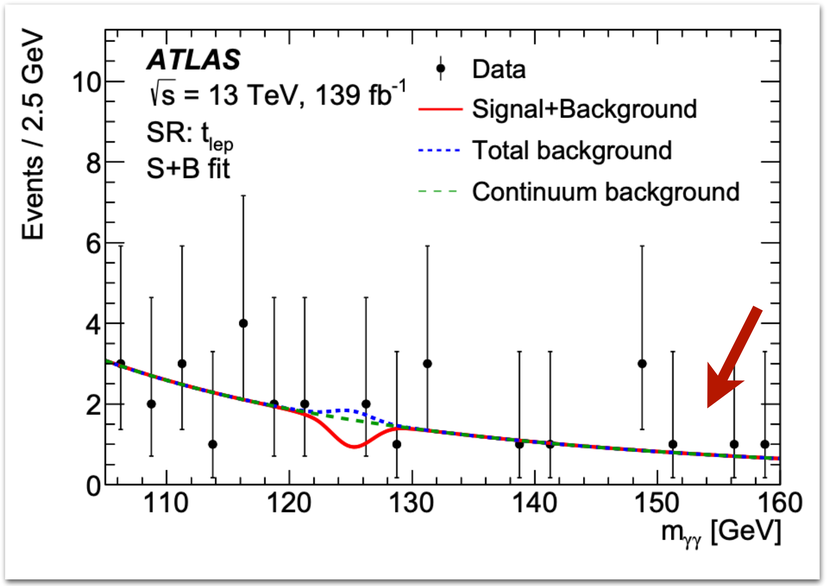

[ATLAS-CONF-2024-005]

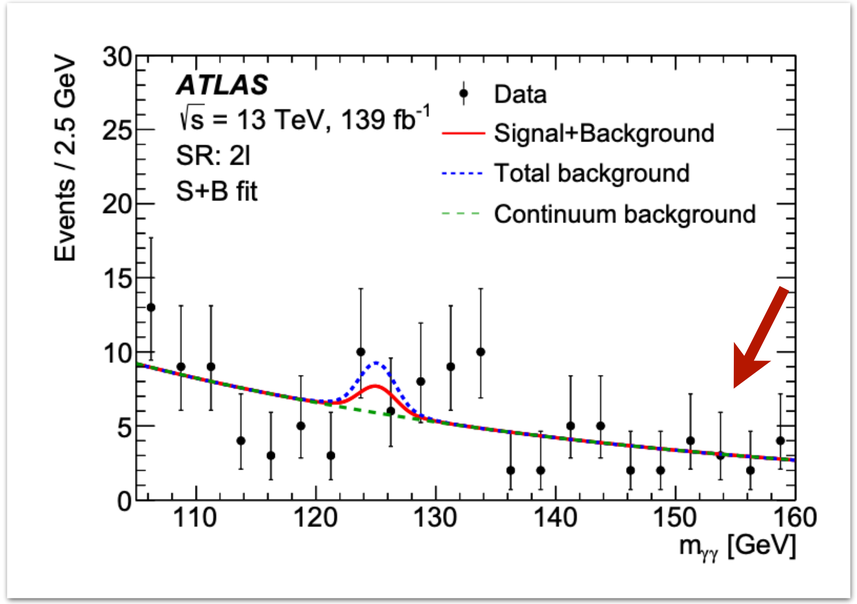
- Possible new Higgs Boson?

# Motivation

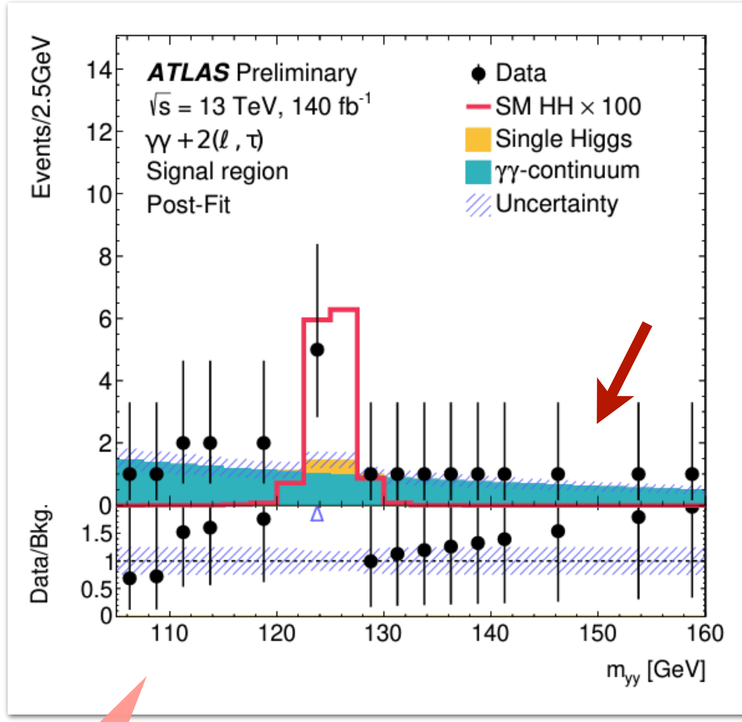
## Hints for new Higgs Bosons

- No Excesses at 152 GeV in SRs: $\gamma\gamma + t_{\text{lep}}$, $\gamma\gamma + 2\ell$, $\gamma\gamma + 2\tau$




[ATLAS: CERN-EP-2022-232]



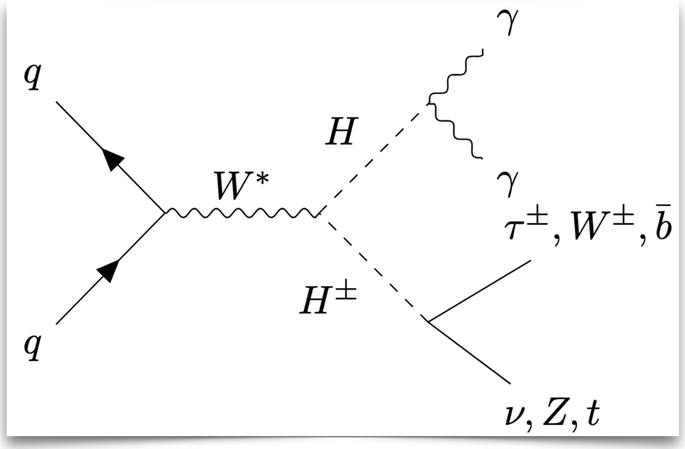

[ATLAS-CONF-2024-005]

**Point towards asssociated $H^{\pm}$**

# Motivation

## Hints for new Higgs Bosons

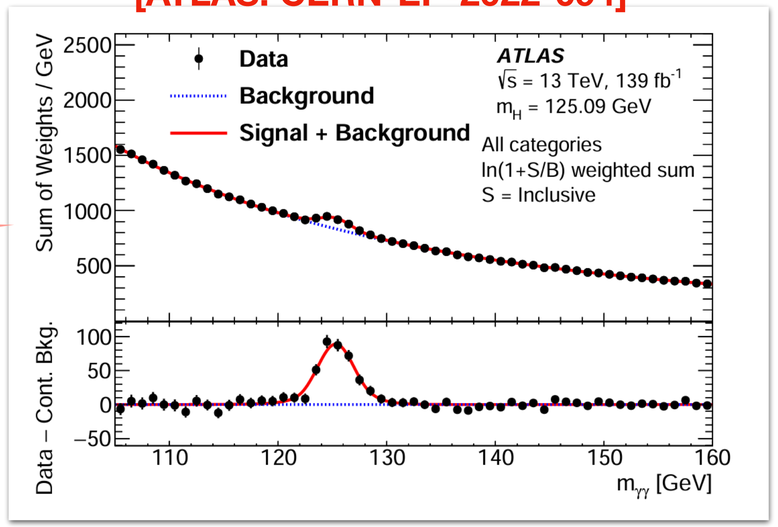
- Hints towards DY production of new Higgs at LHC




- No excess in Inclusive Searches

[ATLAS: CERN-EP-2022-094]

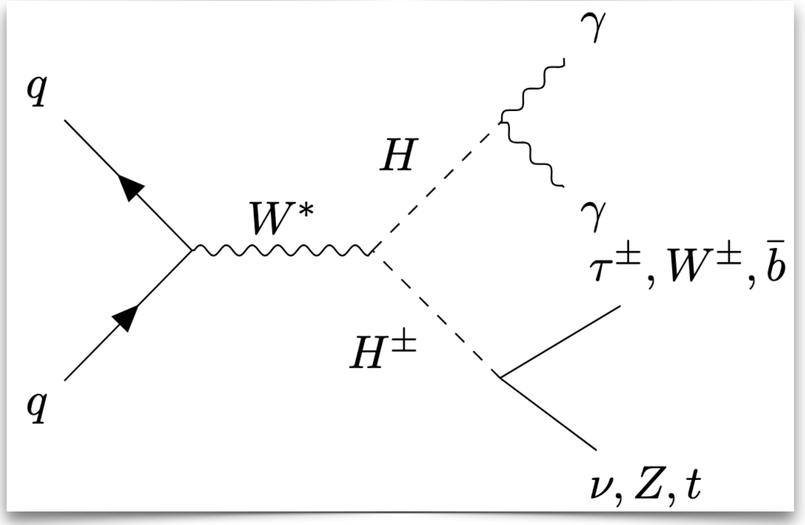
Full Run 2 Data



# Simplified Model

## Model Description

- Two New Particles: $H$, $H^{\pm}$
- $H$ produced only via DY process
- Dominant decays of $H^{\pm}$: $tb, \tau\nu, WZ$

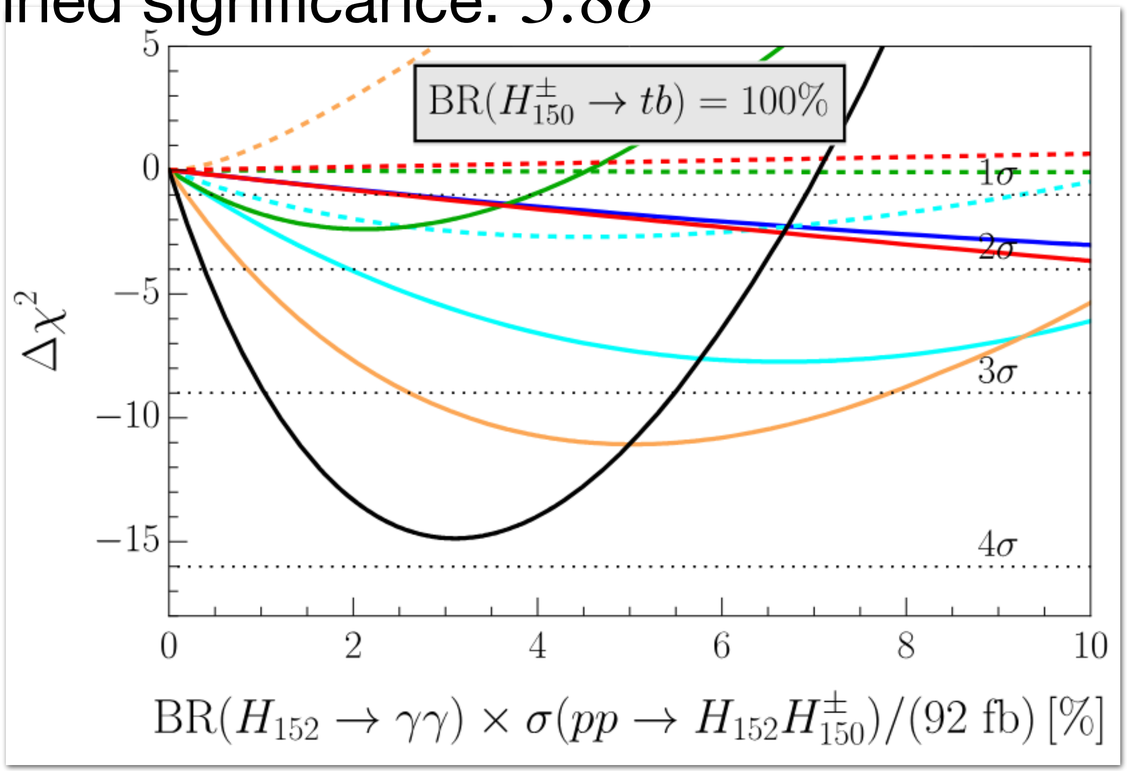



- Simulation Setup: MadGraph + Pythia + Delphes
- Log-Likelihood Fit performed using Poisson Statistics

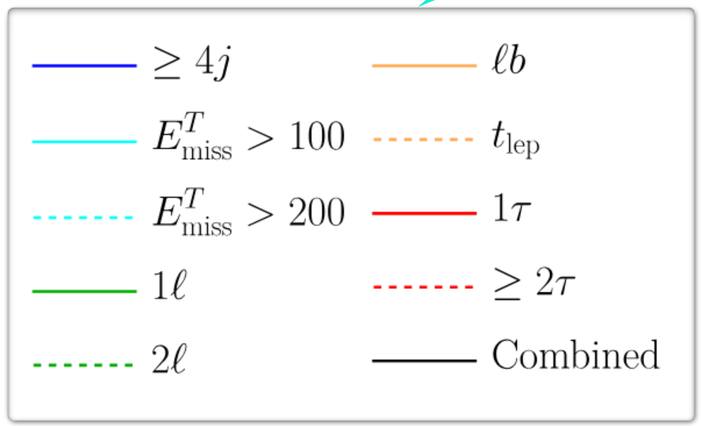
# Simplified Model

## Charged Higgs Decay

- BR($H^{\pm} \to tb \to bbW$) = 100 %
- Dominant Effect: $\gamma\gamma + \ell b, \gamma\gamma + MET, \gamma\gamma + 1\ell, \gamma\gamma + t_{\text{lep}}$
- Combined significance: $3.8\sigma$




Relevant SRs

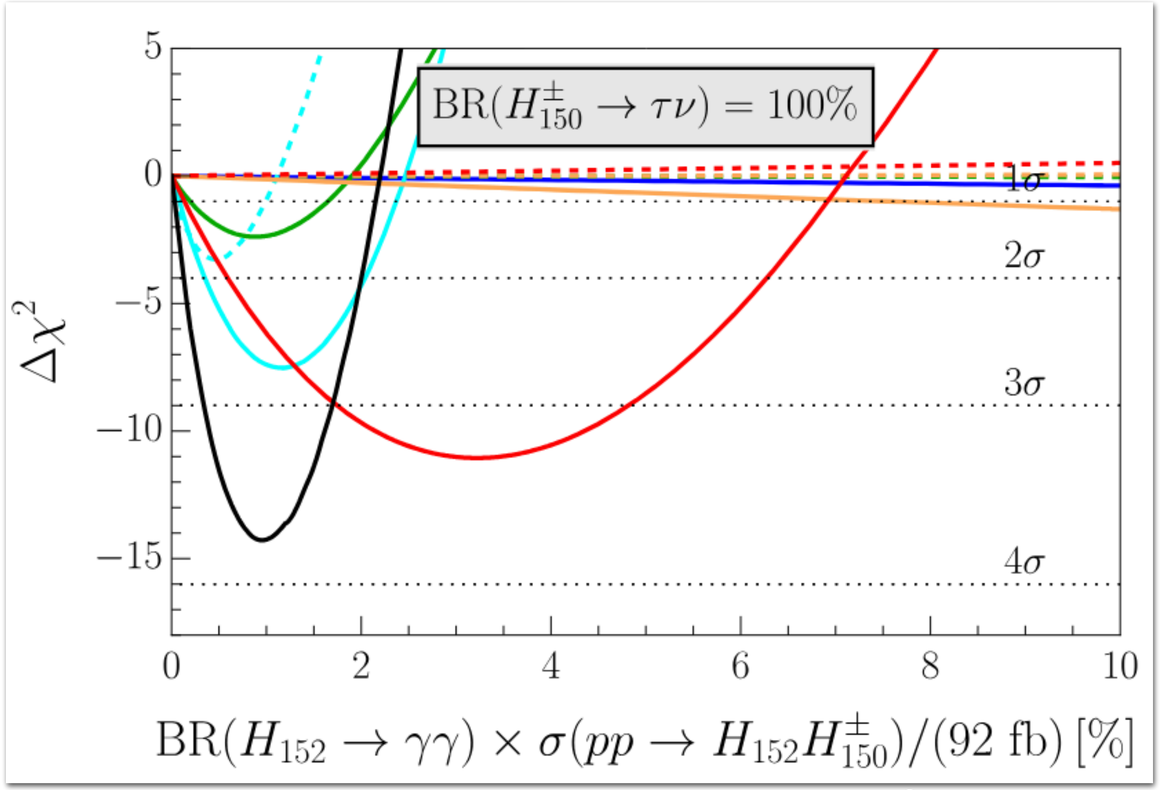


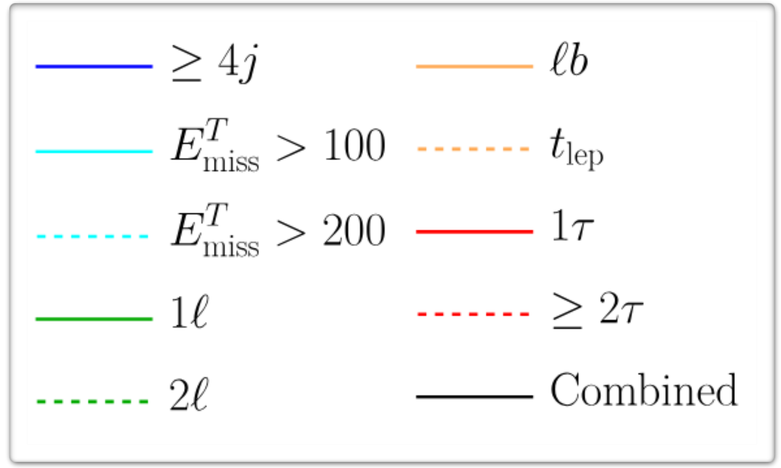

Cross-section Normalized to a $SU(2)_L$ doublet

# Simplified Model

## Charged Higgs Decay

- BR($H^{\pm} \to \tau\nu$) = 100 %
- Dominant Effect: $\gamma\gamma + MET, \gamma\gamma + 1\tau, \gamma\gamma + 1\ell$
- Combined significance: $3.8\sigma$



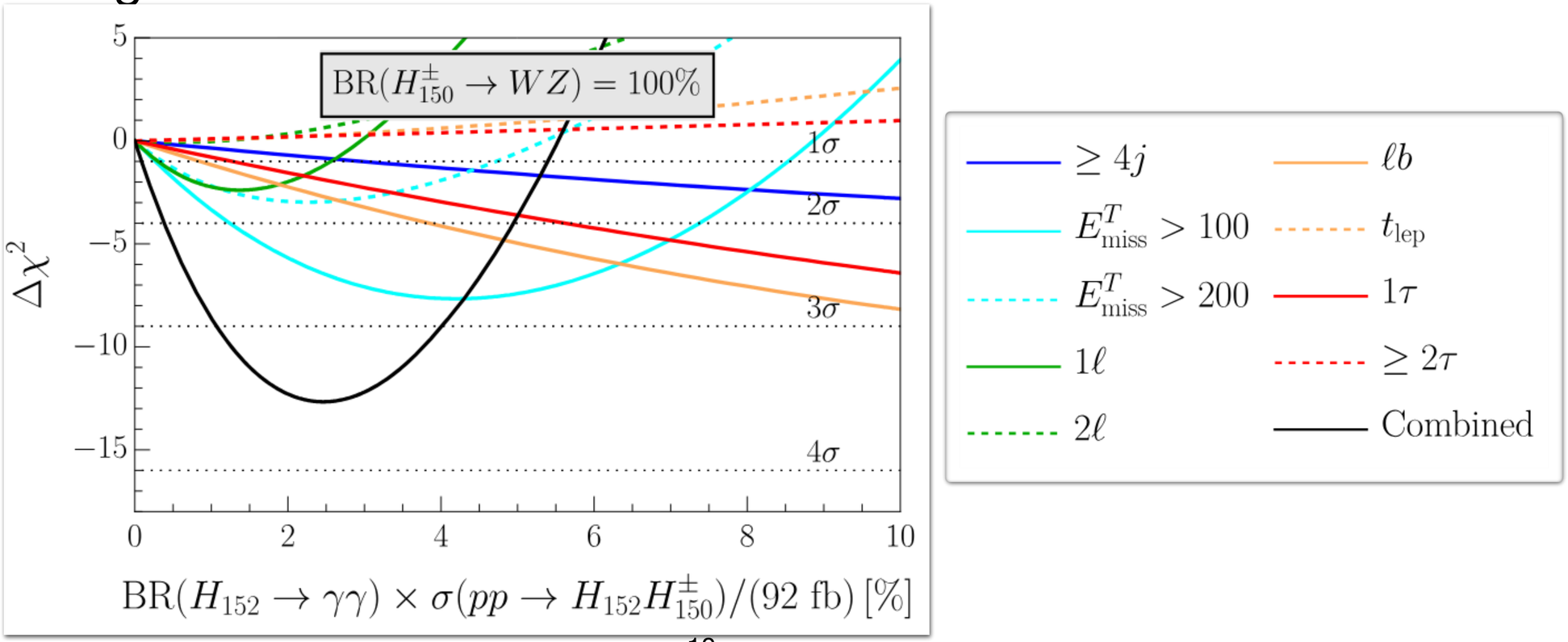



# Simplified Model

## Charged Higgs Decays

- BR($H^{\pm} \to WZ$) = 100 %
- Dominant Effect: $\gamma\gamma + MET$, $\gamma\gamma + 1\ell$, $\gamma\gamma + 2\ell$, $\gamma\gamma + 2\tau$
- Combined significance: $3.5\sigma$

**Dominant in Triplet Model (See Talk of G. Coloretti)**



# Model Building

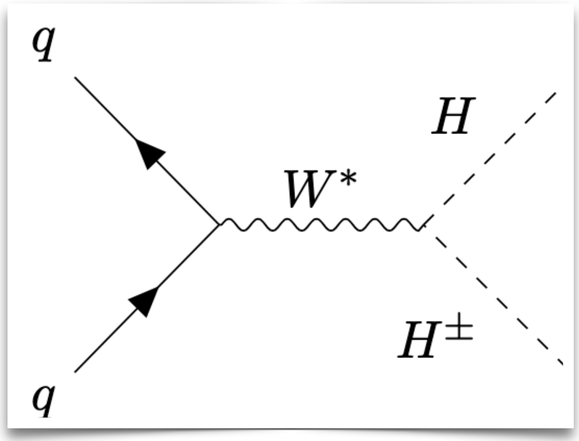
## Key Points

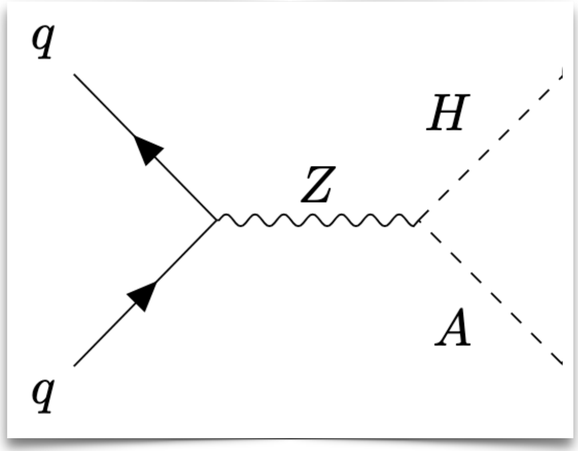
- Small total production cross-section
- Dominant DY production cross-section
- Large BR($H^{\pm} \to tb$) and BR($H^{\pm} \to \tau\nu$)
- Small BR($H^{\pm} \to WZ$) to avoid multiple leptons
- Sizable BR($H \to \gamma\gamma$)

# Explanation in 2HDM

## Description

- Two $SU(2)_L$ doublets: $\phi_1$ and $\phi_2$
- Scalar Particles: $h, H, A, H^{\pm}$
- Free Parameters: $m_h, m_H, m_A, m_{H^{\pm}}, m_{12}^2, \tan\beta = v_2/v_1, \alpha$
- Suppressed gluon-fusion, VBF, VH cross-section of $H$ for large $\tan\beta$ in Type 1




Small for large $m_A$

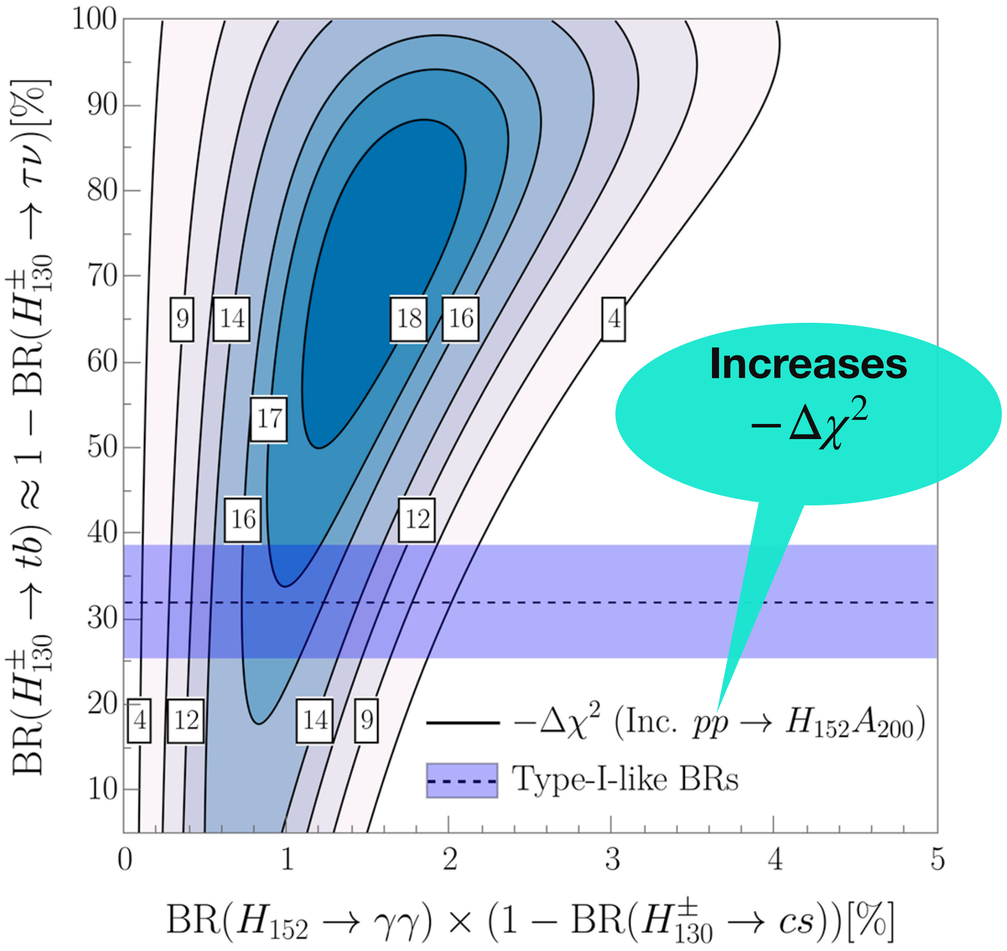
# Explanation in 2HDM

## Analysis

- Dominant decay modes of $H^{\pm}$: $\tau\nu$ , $tb$
- Considered Benchmark Point:

$$m_H = 152 \text{ GeV}, m_{H\pm} = 130 \text{ GeV}, \alpha - \beta \approx \pi/2$$
$$m_A = 200 \text{ GeV}, \tan\beta = 20, m_{12}^2 = 1100 \text{ GeV}$$

- Br($H \to \gamma\gamma$) required at the percent level
- Possible in Aligned 2HDM



# Summary & Outlook

- Model-Independent analysis by ATLAS of $\gamma\gamma + X$ in 22 SRs
- Excesses observed in some SRs
- Hints for associated production of Neutral Higgs Boson
- Explanation possible in 2HDM Type 1
- Large Br($H \to \gamma\gamma$) in general aligned 2HDM

# Thank you for your attention!