Growing Evidence for a 150 GeV Higgs Triplet at the LHC

Saiyad Ashanujjaman

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(Going beyond) the Standard Model

A tale of theoretical and phenomenological success

- Several predictions confirmed by experiments at a persuasive level of accuracy: **neutral weak currents, massive vector bosons, Higgs boson**

Theoretical issues:

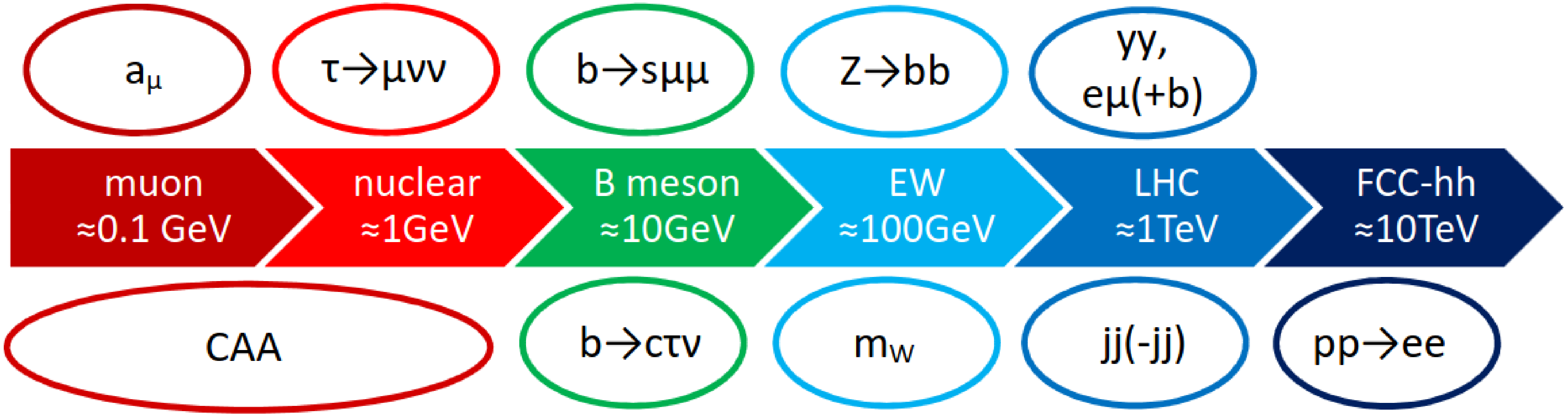
- Fermion mass and mixing hierarchies
- Electroweak vacuum instability
- Strong CP problem
- Naturalness problem

Experimental inconsistencies:

- Neutrino masses and mixings
- Anomalous magnetic moments of the electron and the muon
- B-anomalies
- Baryon asymmetry in the Universe
- Dark matter

Anomalies

- Extensive test of the SM: no discovery of any BSM particles yet
- Several ("Anomalies") : hints for new physics



- "Diphoton anomalies" at the LHC (95 GeV)
- "Multilepton anomalies" at the LHC

It is very unlikely that all these anomalies will be confirmed in the future, but it is ALSO unlikely that all of them are just statistical flukes.

Therefore, it is important to assess these anomalies in view of new physics.

Extension of the Standard Model

- Measured properties of the 125 GeV Higgs are consistent with the SM.
- No guiding principle or symmetry forbids the extension of the Higgs sector.
- Several anomalies can be explained by extending the SM Higgs sector.

  $\Rightarrow$ Extension of the SM Higgs Sector is motivated as long as their role in electroweak symmetry breaking is minute.
- A plethora of such models: SM + $SU(2)_L$ singlets/doublets/triplets, etc.
- Why a real Higgs Triplet?

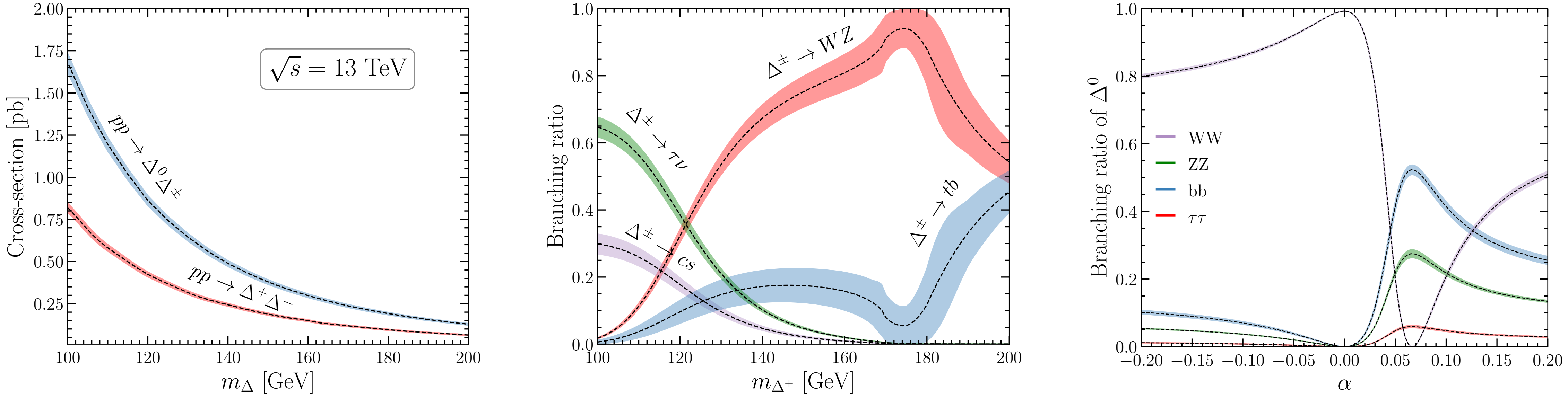
1. **"Multilepton anomalies": compatible with the production of a heavier Higgs decaying into a pair of ≈ 150 GeV Higgses which dominantly decay to WW. 1606.01674, 1711.07874, 1901.05300, 1912.00699, 2009.00032, 2302.07276, 2308.07953, 2312.17374**
2. **There is no excess in the $H \to ZZ^* \to 4\ell$ channel 2004.03447**
3. **Leads to a positive shift in the W-mass at tree-level, as preferred by the CDF-II measurement. (not so important!)**

A real Higgs triplet model

- SM + a $SU(2)_L$ triplet scalar with $Y = 0$

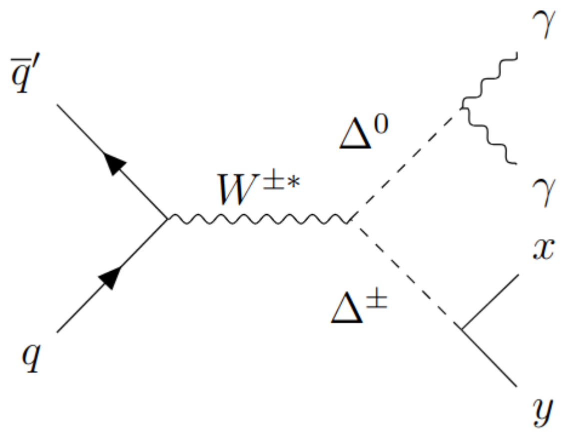
$$V = -\mu_\Phi^2 \Phi^\dagger \Phi + \frac{\lambda_\Phi}{4}\left(\Phi^\dagger\Phi\right)^2 - \mu_\Delta^2 \mathrm{Tr}\left(\Delta^\dagger \Delta\right) + \frac{\lambda_\Delta}{4}\left[\mathrm{Tr}\left(\Delta^\dagger\Delta\right)\right]^2 + A\Phi^\dagger\Delta\Phi + \lambda_{\Phi\Delta}\Phi^\dagger\Phi\mathrm{Tr}\left(\Delta^\dagger\Delta\right).$$

- **New states:** a neutral (Δ^0) and a charged Higgs ($\Delta^\pm$).
- Δ^0 procures a non-zero VEV $\Rightarrow$ a positive shift in m_W at tree-level, **EWPD** $\Rightarrow$ $v_\Delta \lesssim \mathcal{O}(1)$ GeV.
- (vacuum stability + perturbative unitarity + EWPD) $\Rightarrow$ Δ^0 and $\Delta^\pm$ are nearly mass-degenerate
- **Production & Decays of the Triplet Higgses:** Drell-Yan production ($W^*/\gamma^*/Z^*$ mediated)



Where to look for the evidence of a Triplet Higgs?

- **Final state:** diphoton + additional particles / missing p_T ($\gamma\gamma + X$)



- **Why $\gamma\gamma + X$?**
  1. smaller SM background
  2. Δ^0 can be reconstructed from the diphoton invariant mass
  3. experimental resolution for the reconstructed resonance mass is better
- **The most recent $\gamma\gamma + X$ searches by ATLAS/CMS**
  1. 2301.10486: 22 $\gamma\gamma + X$ signal regions (SRs), mild excesses in a few SRs
  2. 2405.20040: 3 $\gamma\gamma + X$ SRs

  They provide $m_{\gamma\gamma}$ distributions in the 105–160 GeV range, thereby covering part of the mass range of our interest.

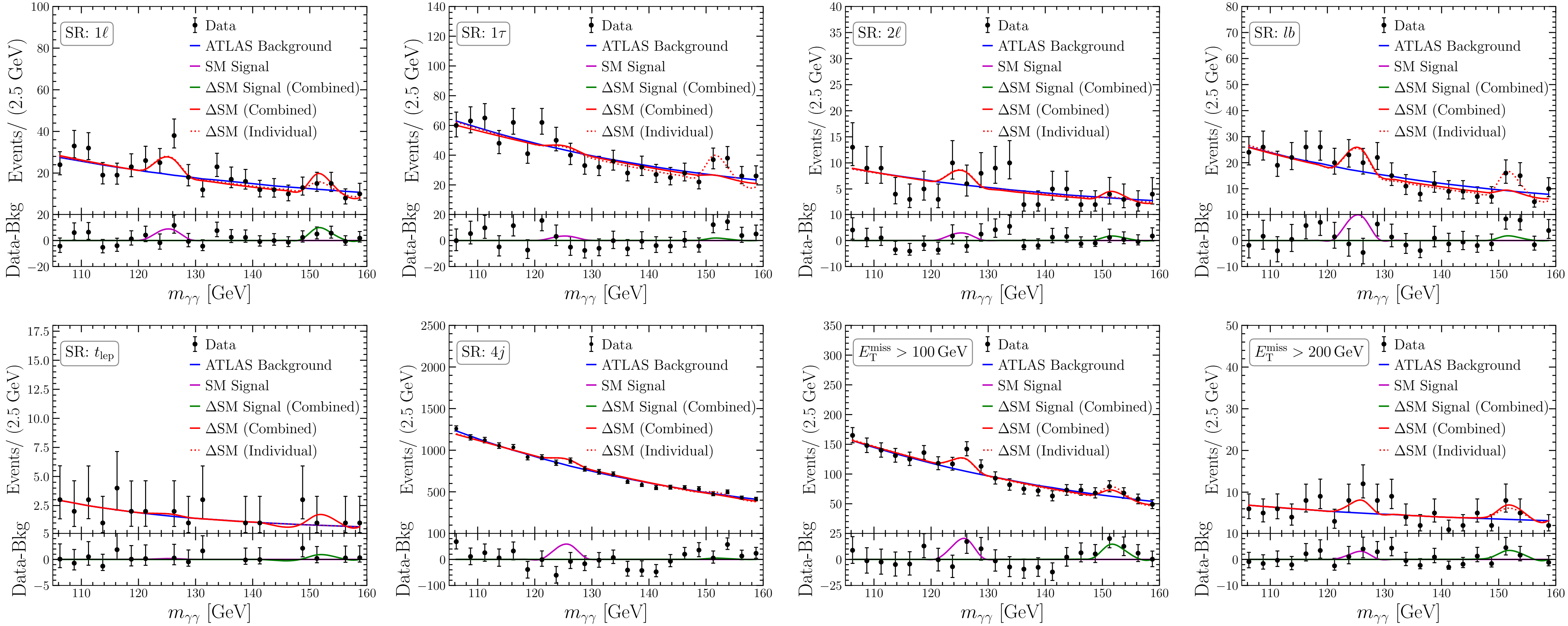
Analysing the $\gamma\gamma + X$ searches by ATLAS: Relevant SRs

- out of 25 SRs, only 10 SRs are relevant for our model

Target	Signal region	Detector level selections	Correlation
High jet activity [83]	$4j$	$n_{\text{jet}} \geq 4$, $\lvert\eta_{\text{jet}}\rvert < 2.5$	–
Top [83]	ℓb t_{lep}	$n_\ell \geq 1$, $n_{b\text{-jet}} \geq 1$ $n_{\ell=e,\mu} = 1$, $n_{\text{jet}} = n_{b\text{-jet}} = 1$	–
Lepton [83, 133]	2ℓ 1ℓ	ee, $\mu\mu$ or $e\mu$ $n_\ell = 1$, $n_{\tau_{\text{had}}} = 0$, $n_{b\text{-jet}} = 0$, $E_{\text{T}}^{\text{miss}} > 35$ GeV (only for e-channel)	$< 26\%$
Tau [133]	$1\tau_{\text{had}}$	$n_\ell = 0$, $n_{\tau_{\text{had}}} = 1$, $n_{b\text{-jet}} = 0$, $E_{\text{T}}^{\text{miss}} > 35$ GeV	–
$E_{\text{T}}^{\text{miss}}$ [83]	$E_{\text{T}}^{\text{miss}} > 100$ GeV $E_{\text{T}}^{\text{miss}} > 200$ GeV	$E_{\text{T}}^{\text{miss}} > 100$ GeV $E_{\text{T}}^{\text{miss}} > 200$ GeV	29%

Analysing the $\gamma\gamma + X$ searches by ATLAS: $m_{\gamma\gamma}$ spectra

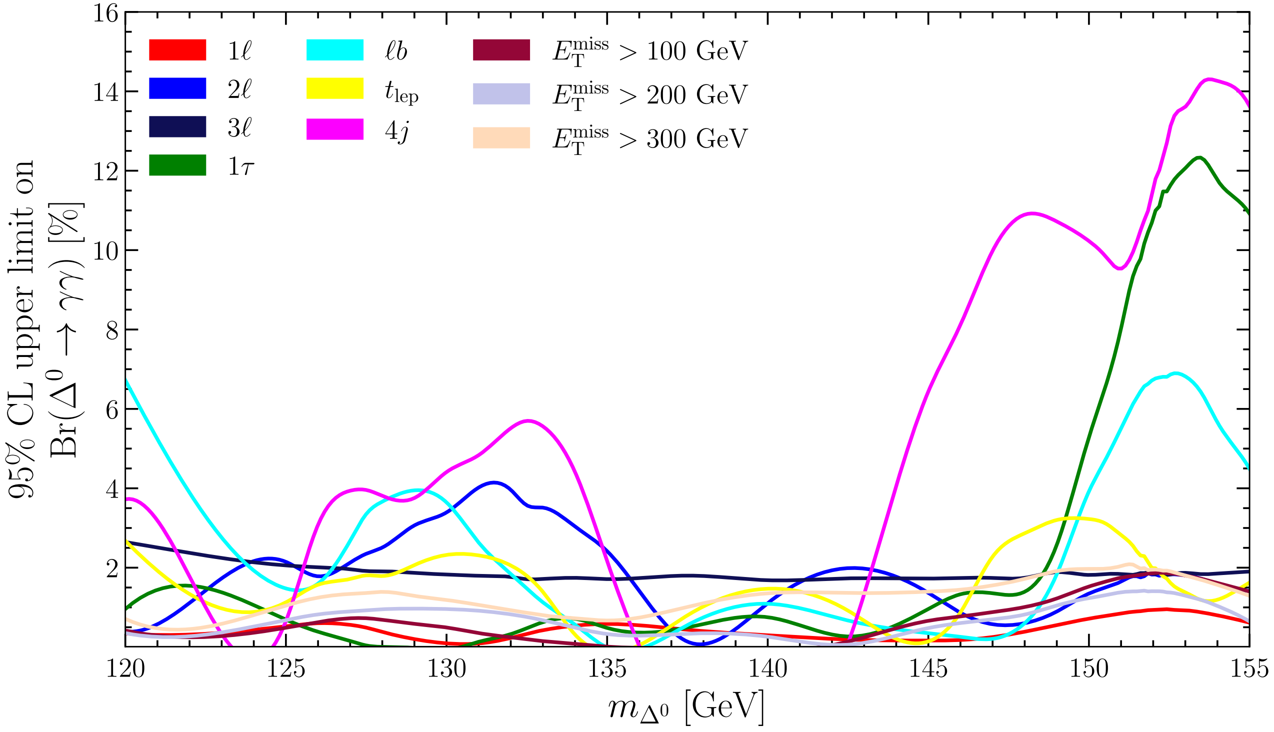
Refitting the continuum background: $\left(1 - \frac{m_{\gamma\gamma}}{\sqrt{s}}\right)^{b} \left(\frac{m_{\gamma\gamma}}{\sqrt{s}}\right)^{a_0 + a_1 \log(m_{\gamma\gamma}/\sqrt{s})}$



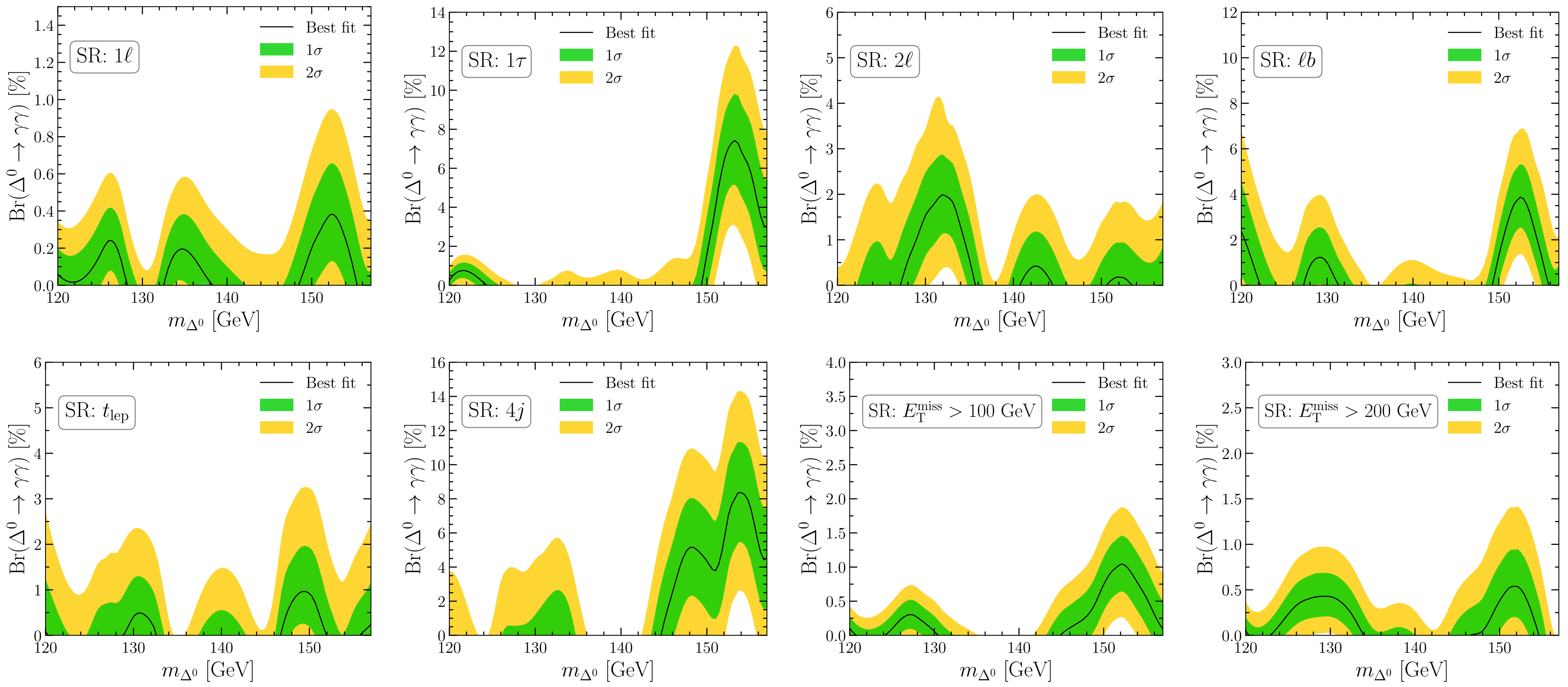
Analysing the $\gamma\gamma + X$ searches by ATLAS: Upper limits on diphoton BR

Assuming the bins as independent number-counting experiments $\mathcal{L}_{\rm SR}(\mu) = \prod_i \text{Poiss}\left(n^i | \mu s^i + b^i\right)$

Profile likelihood ratio test statistics $\Lambda_\mu = -2 \log \left(\frac{\mathcal{L}(\mu)}{\mathcal{L}(\hat{\mu})} \right)$

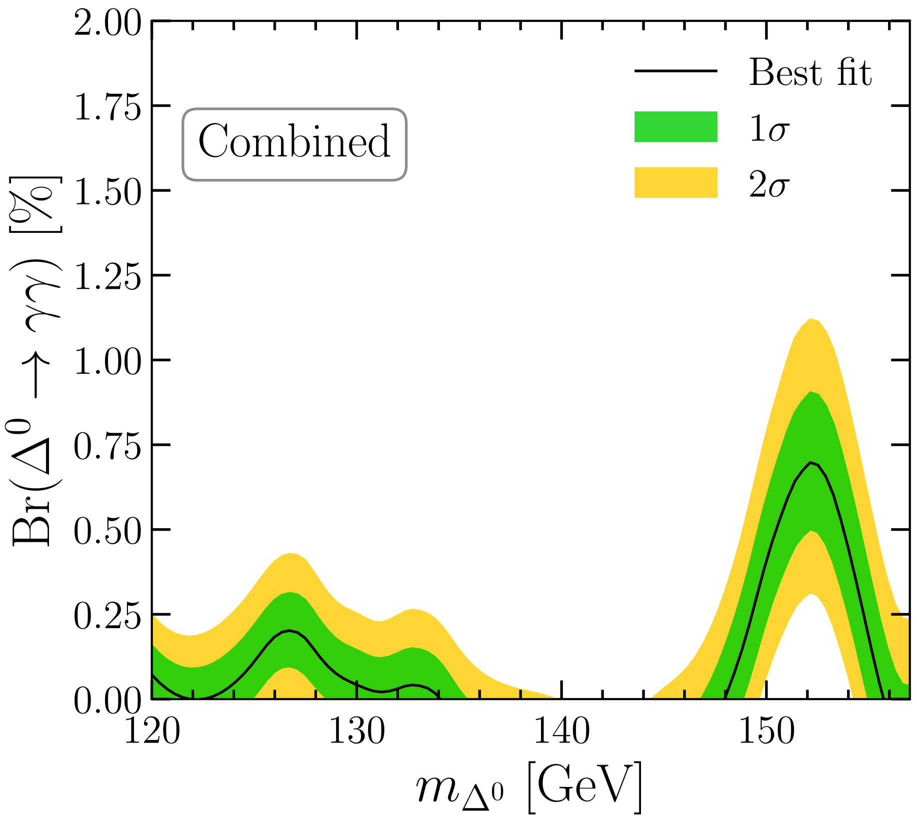


Analysing the $\gamma\gamma + X$ searches by ATLAS: Preferred diphoton BR



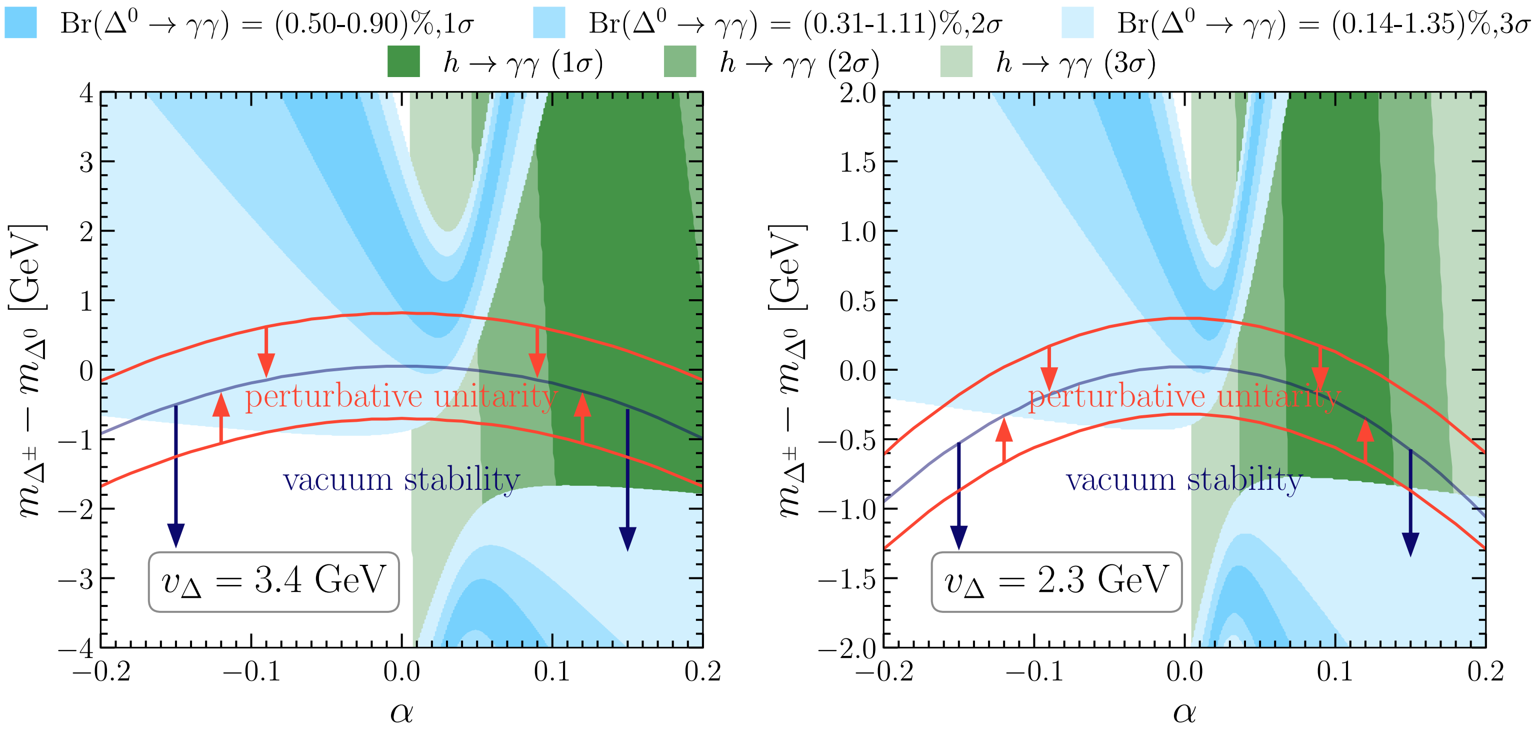
Analysing the $\gamma\gamma + X$ searches by ATLAS: Combinig all SRs

Combining all the relevant Signal Regions: $\mathcal{L}_{\mathrm{SR}}(\mu) = \prod_i \mathrm{Poiss}\left(n^i|\mu s^i + b^i\right)$



Data favors a Br($\Delta^0 \to \gamma\gamma$) $\approx 0.7\%$ at $m_{\Delta^0} \approx 152$ GeV with a significance of $\approx 4\sigma$

How well does this fit in the Higgs triplet model?



- The region preferred by the ATLAS $\gamma\gamma + X$ searches are in tension with the theoretical constraints.
- While we have growing evidence for a 152 GeV triplet-like Higgs, the model should be superseded with additional fields.

Thanks for your attention. **Any questions?**