Search for flavour-changing neutral current couplings between the top quark and the Higgs boson in multilepton final states with the ATLAS detector

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on behalf of the ATLAS collaboration

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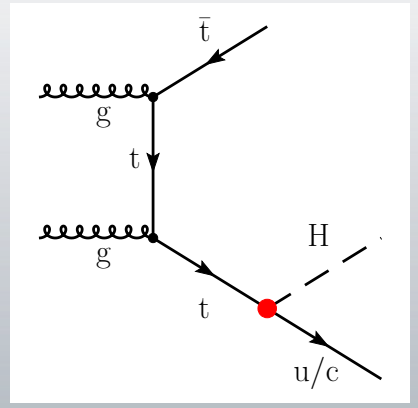
tHq FCNC Couplings in 2ℓSS and 3ℓ Final States

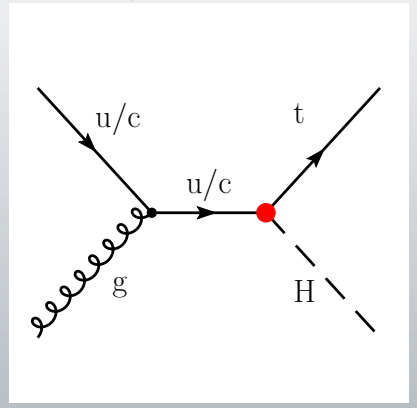
- FCNC processes **forbidden at tree-level** in the SM, higher orders suppressed by GIM mechanism → Any **observation** at the LHC indication of **new physics**
- **Model-independent** search using an **Effective Field Theory** (EFT) with the full ATLAS Run 2 dataset taken at $\sqrt{s} = 13$ TeV:

$$\mathcal{L}_{EFT} = \sum_{q=u,c} \frac{C_{u\phi}^{tq}}{\Lambda^2} \mathcal{O}_{u\phi}^{tq} + \frac{C_{u\phi}^{qt}}{\Lambda^2} \mathcal{O}_{u\phi}^{qt}; \qquad C_{u\phi}^{qt}, C_{u\phi}^{tq}: \text{Wilson coeff.}$$

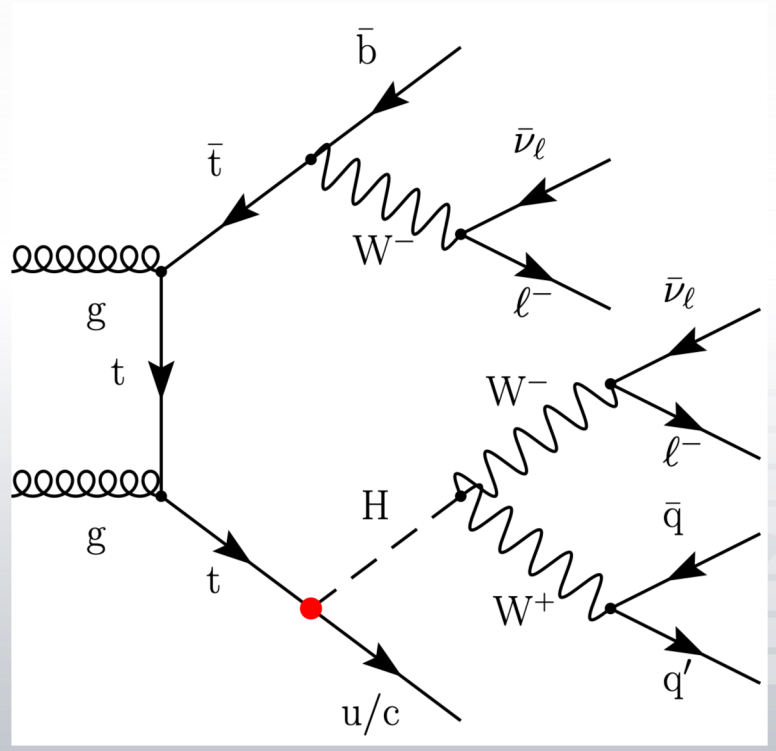
- Considering $t\bar{t}(t \to Hq)$ **decay** and $gq \to Ht$ **production processes**
- Search conducted in 2ℓ**SS and** 3ℓ **final states**
  - Small number of events, but high signal purity



$t\bar{t}(t \to Hq)$ decay



$gq \to Ht$ production

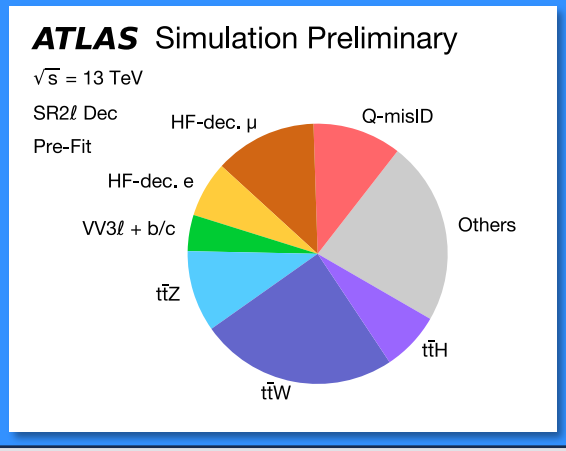


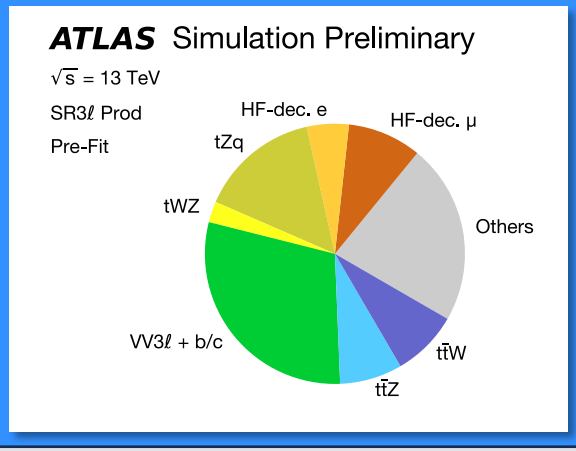
Example 2ℓSS Feynman diagram

Event Selection + Background Estimation

Signal Regions (SRs)

- 2 SRs per final state (4 in total)
- Each SR focused on either production or decay process
- $N_{b-\text{tags}} \geq 1$ based on signal signature

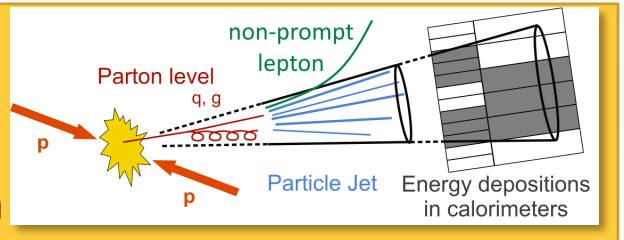




Q-misID Electrons (2ℓSS)

- Data-driven estimation
- Comparison of same-charge and opposite-charge ee events on $Z \rightarrow ee$ mass peak

Leptons from B-hadron decay (HF-decay e/μ)



- Free-floating normalisation
- 4 CRs defined (2 per final state)

$t\bar{t}W$/ $t\bar{t}Z$ production

- $t\bar{t}W$ cross-section measured 1.4 σ above prediction [arXiv:2401.05299]
- $t\bar{t}Z$ only measured for high N_{jets} while this analysis considers $N_{\text{jets}} \geq 1$ [arXiv:2312.04450]
- Free-floating normalisation for both processes with 3 CRs

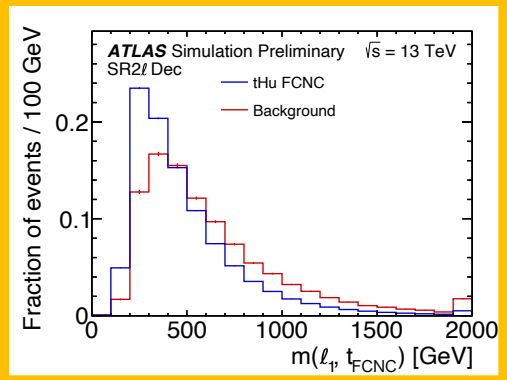
VV + HF production

- VV samples produced without additional b-quark → poor modelling in regions with $N_{b-\text{tags}} \geq 1$
- Splitting VV samples by number of leptons and jet flavour
- Largest template $VV3\ell + b/c$ left free-floating

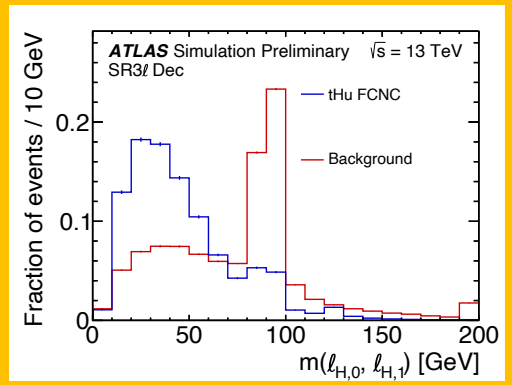
Reconstruction and Neural Networks (NNs) in SRs

Reconstruction Algorithms

- Multiple algorithms developed to separate signal and background
- **Recursive Jigsaw Reconstruction**



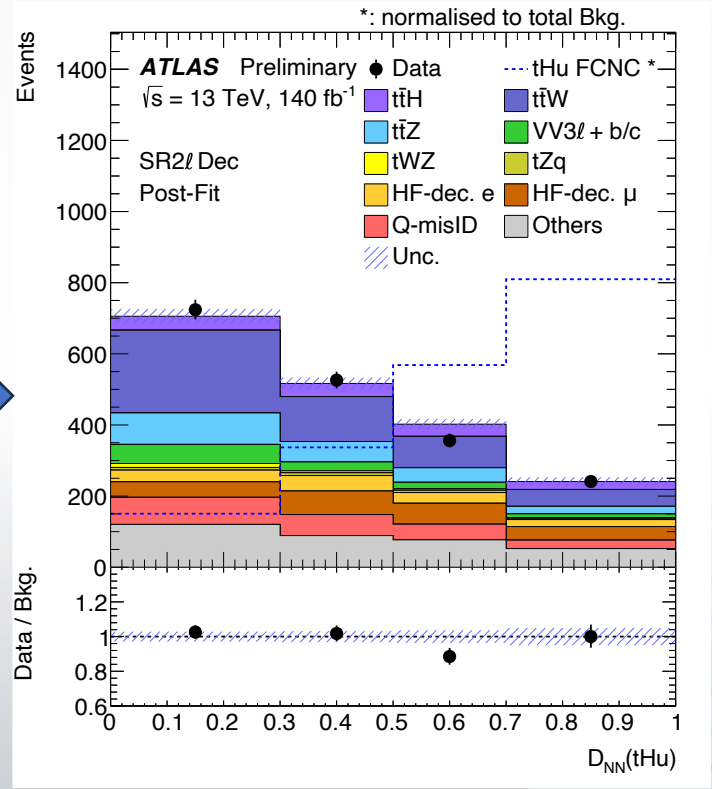
- **NICE-Reconstruction**



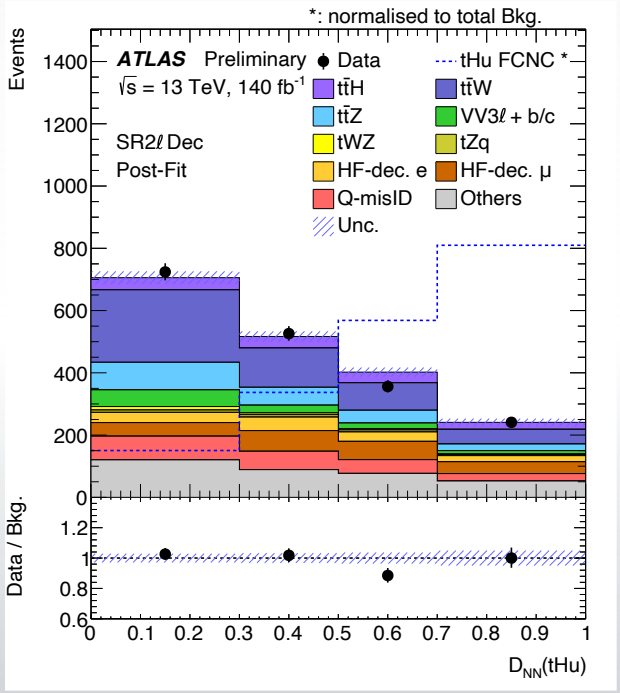
Variable preprocessing and NN training

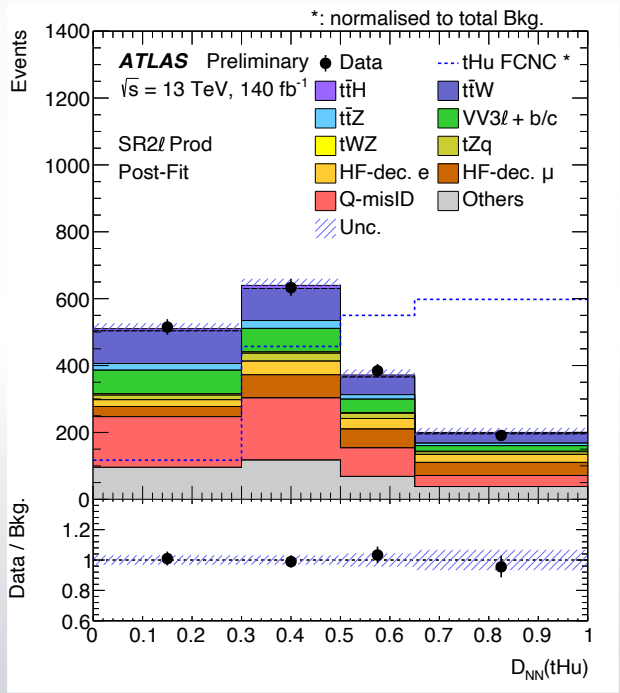
- Separation power of all variables combined using NNs
- Training one NN per signal process ($tHu/\ tHc$) and per SR
- Extensive **preprocessing**
  - ➢ *Variable selection* based on added significance
  - ➢ *Normalisation* ($\mu = 0, \sigma = 1$) and *decorrelation* of input variables
  - ➢ Transformation to *signal purity* S/B with *spline fit* to reduce statistical fluctuations

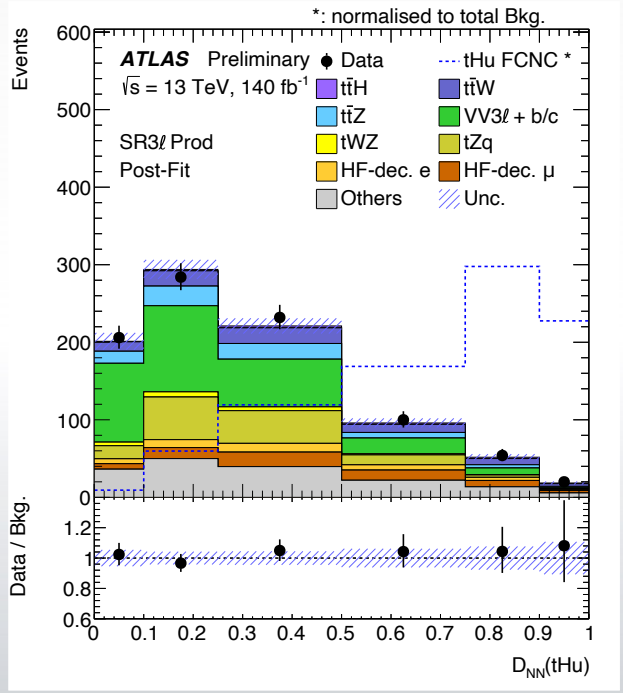
→ Allows for **NNs of very small size** (1 hidden layer)

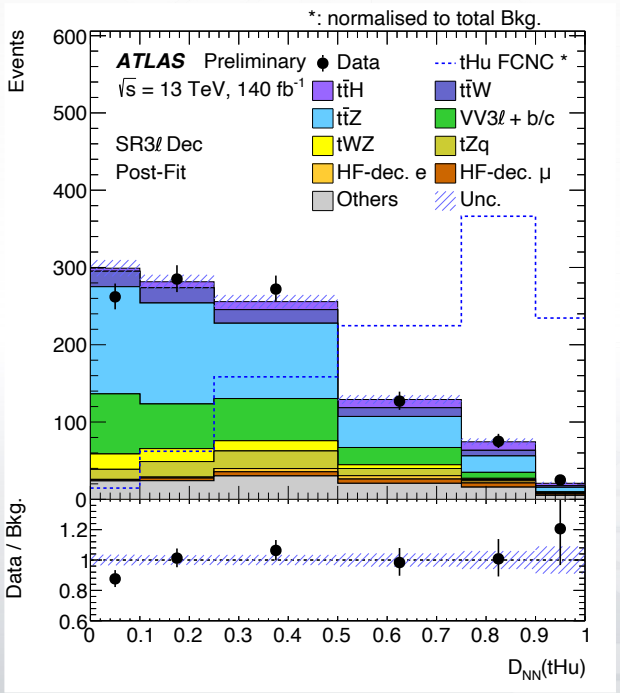


Results of the Profile-Likelihood Fit









Upper Exclusion Limits and Combination

- Signal normalisation compatible with zero
  → Observed (expected) upper limits on $\mathcal{B}(t \to Hq)$:

$$\mathcal{B}(t \to Hu) < 2.8\ (3.0) \times 10^{-4} \text{ and } \mathcal{B}(t \to Hc) < 3.3\ (3.8) \times 10^{-4}$$

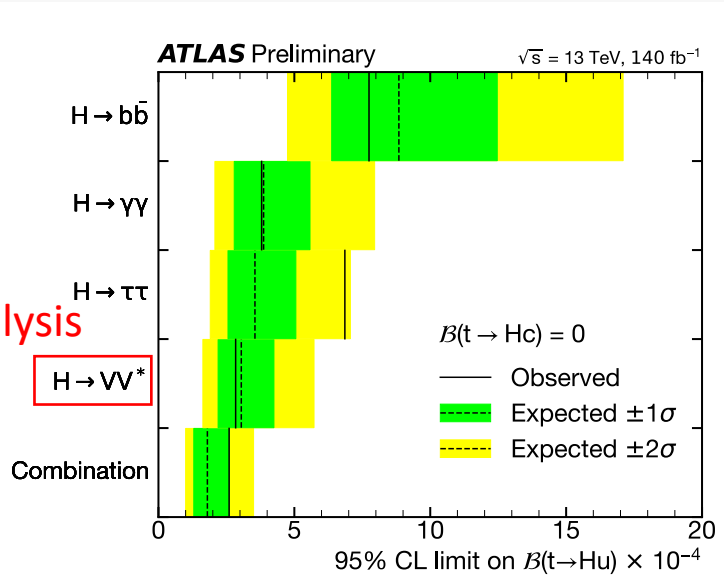
- Results are **combined** with **ATLAS tHq FCNC searches** in different Higgs-boson decay modes ($H \to \tau^+\tau^-$ [1], $H \to b\bar{b}$ [2] and $H \to \gamma\gamma$ [3])

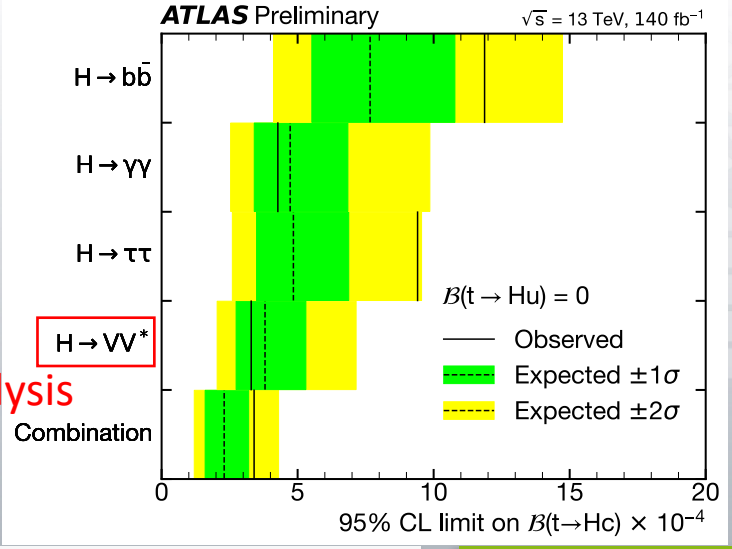
$$\mathcal{B}(t \to Hu) < 2.6\ (1.8) \times 10^{-4} \text{ and } \mathcal{B}(t \to Hc) < 3.4\ (2.3) \times 10^{-4}$$

- $\mathcal{B}(t \to Hq)$ BSM predictions are as high as 10^{-4}

- Combination is the most signal-sensitive tHq FCNC analysis and provides the strongest limits on the tHc process published to date

Thank you for your attention! ☺

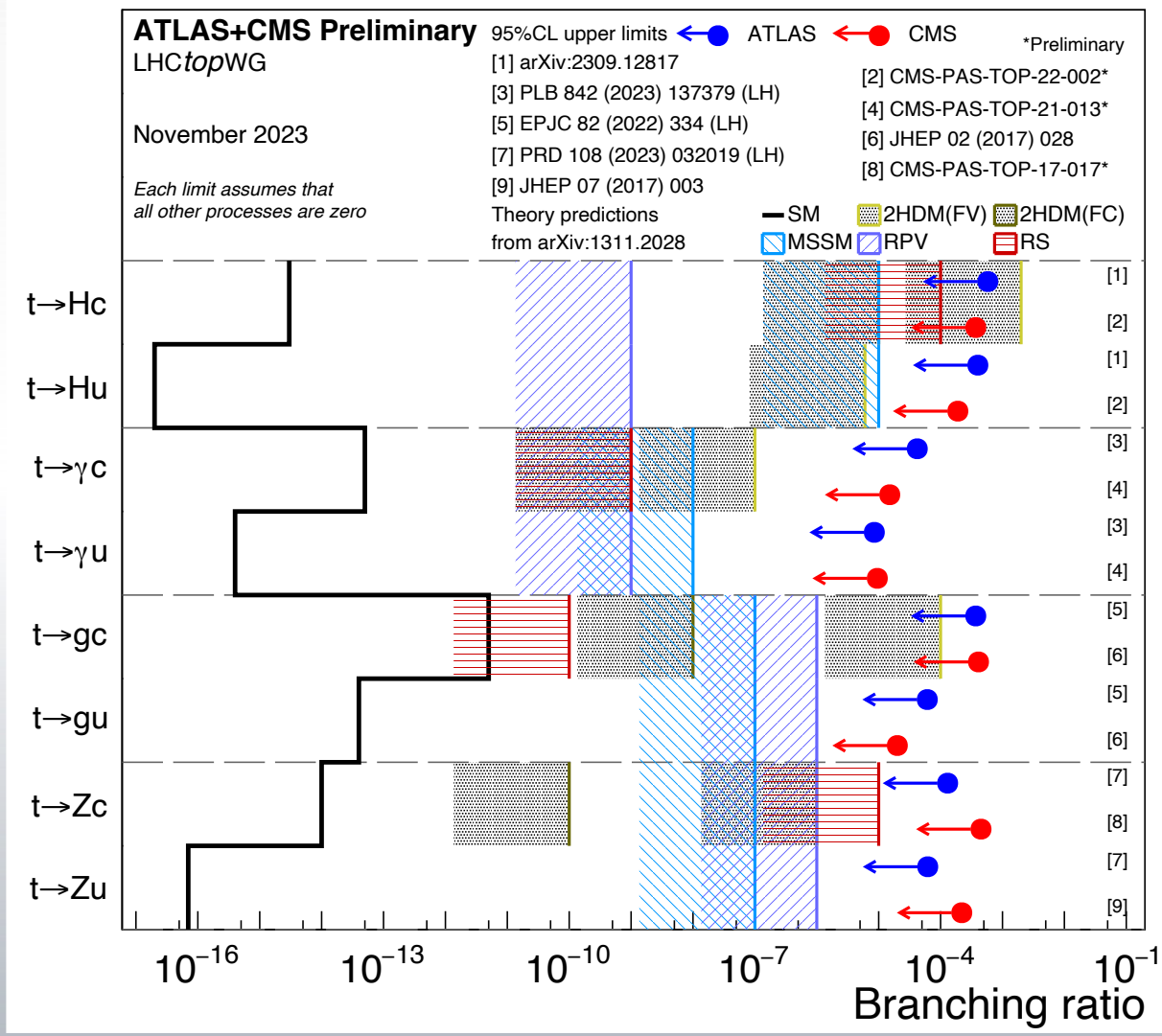




[1] JHEP 06 (2023) 155 [2] JHEP 07 (2023) 199 [3] JHEP 12 (2023) 195

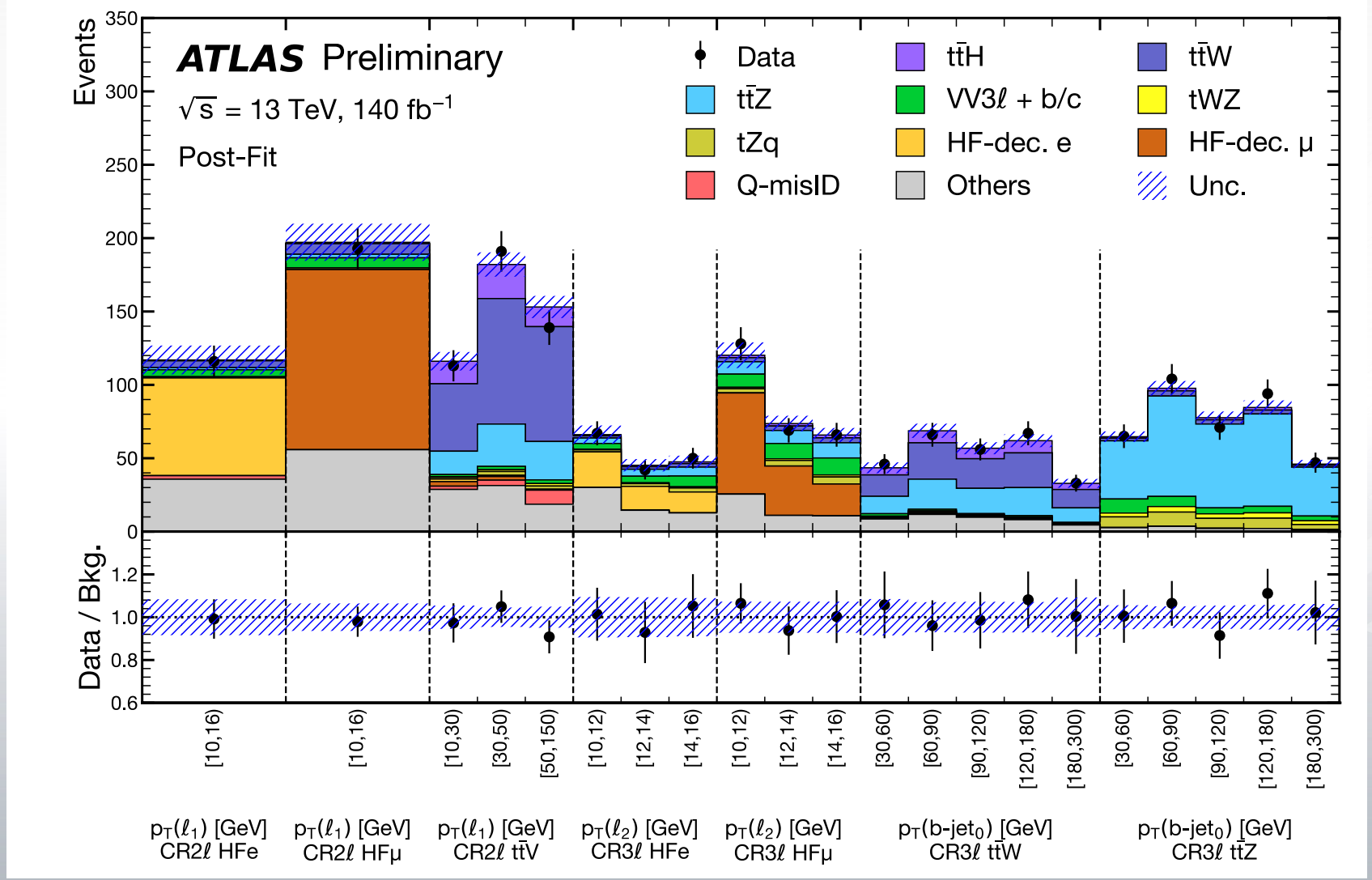
Backup

LHC Top working group FCNC summary Plot

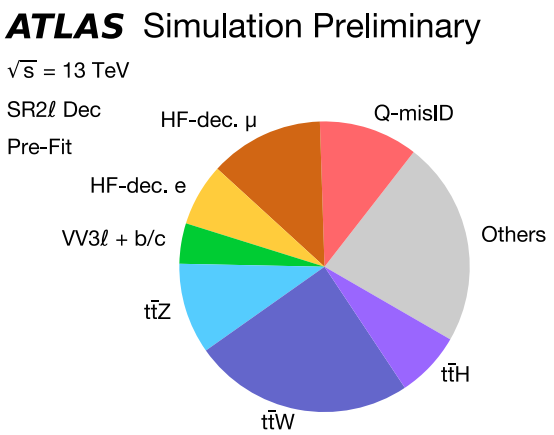


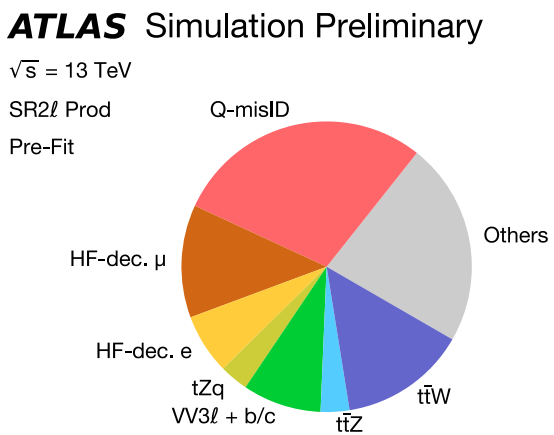
[Top WG Summary Plots]

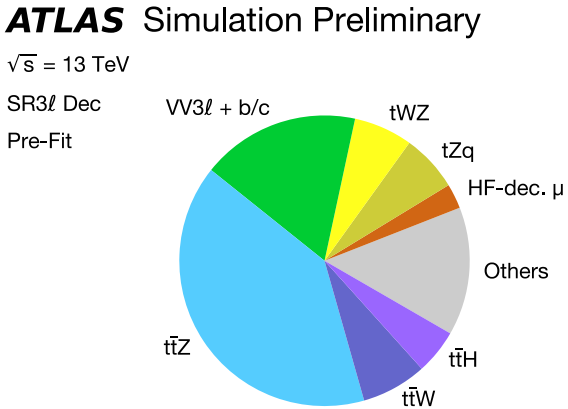
Results of the Profile-Likelihood Fit – CRs

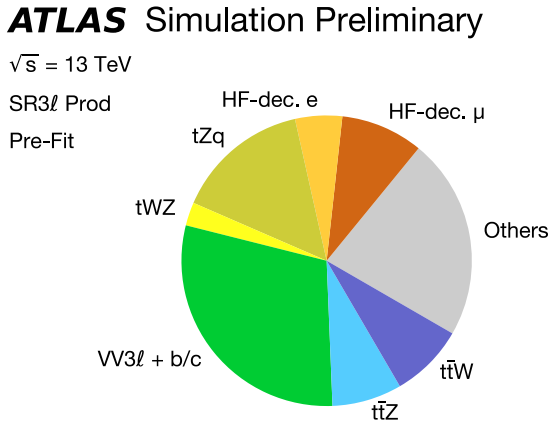


Background Composition of all Signal Regions









Basics on the Profile-Likelihood Fit

$$\mathcal{L} = \prod_{i=1}^{N_{bins}} \mathcal{P}\left(n_i \mid \mu \cdot S_i(\vec{\theta}) + B_i(\vec{\theta}, \vec{\beta})\right) \times \prod_{j=1}^{N_{NP}} \mathcal{G}(\theta_j^0 \mid \theta_j, \Delta\theta_j)$$

Signal contribution with normalisation μ

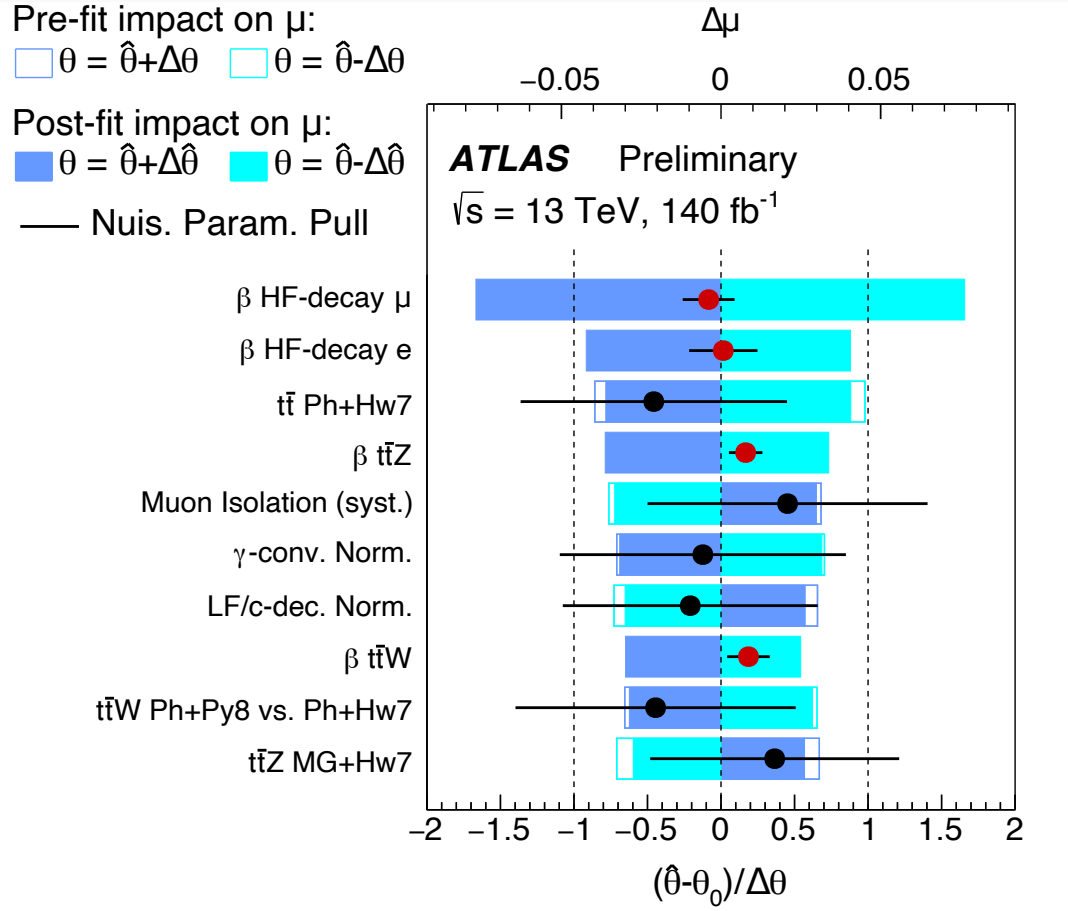
Background contribution of bin i:

$$B_i(\vec{\theta}, \vec{\beta}) = \sum_{k=1}^{N_{norm}} \beta_k \cdot B_i^{(k)}(\vec{\theta}) + B_i^{(rest)}(\vec{\theta})$$

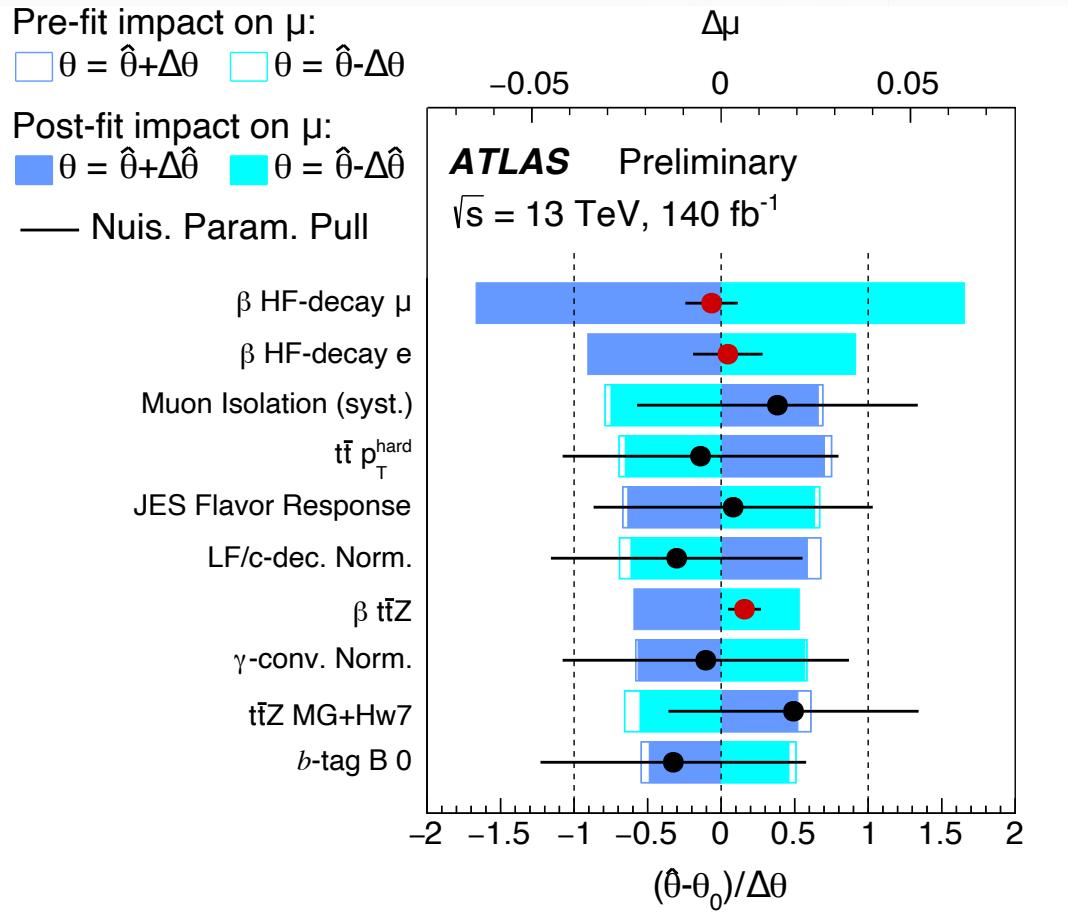
Gaussian distribution of nuisance parameters (1 parameter ≙ 1 systematic uncertainty)

Ranking of Systematic Uncertainties

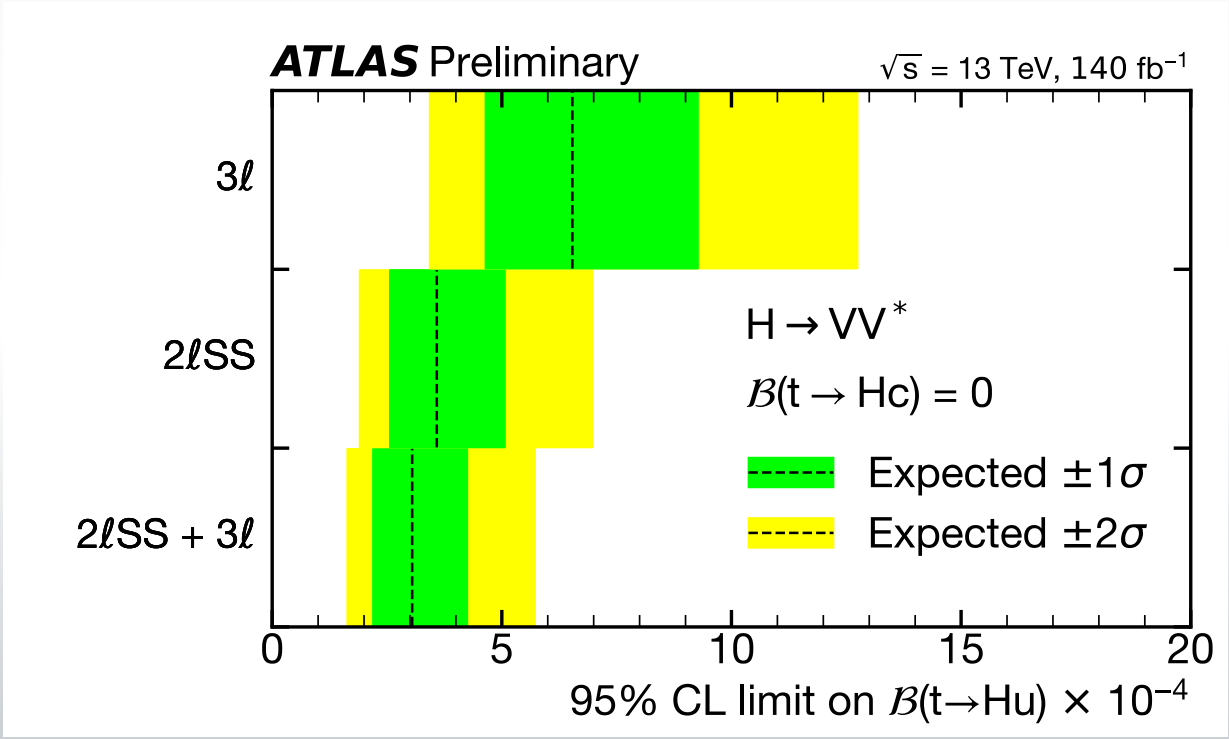
tHu Fit

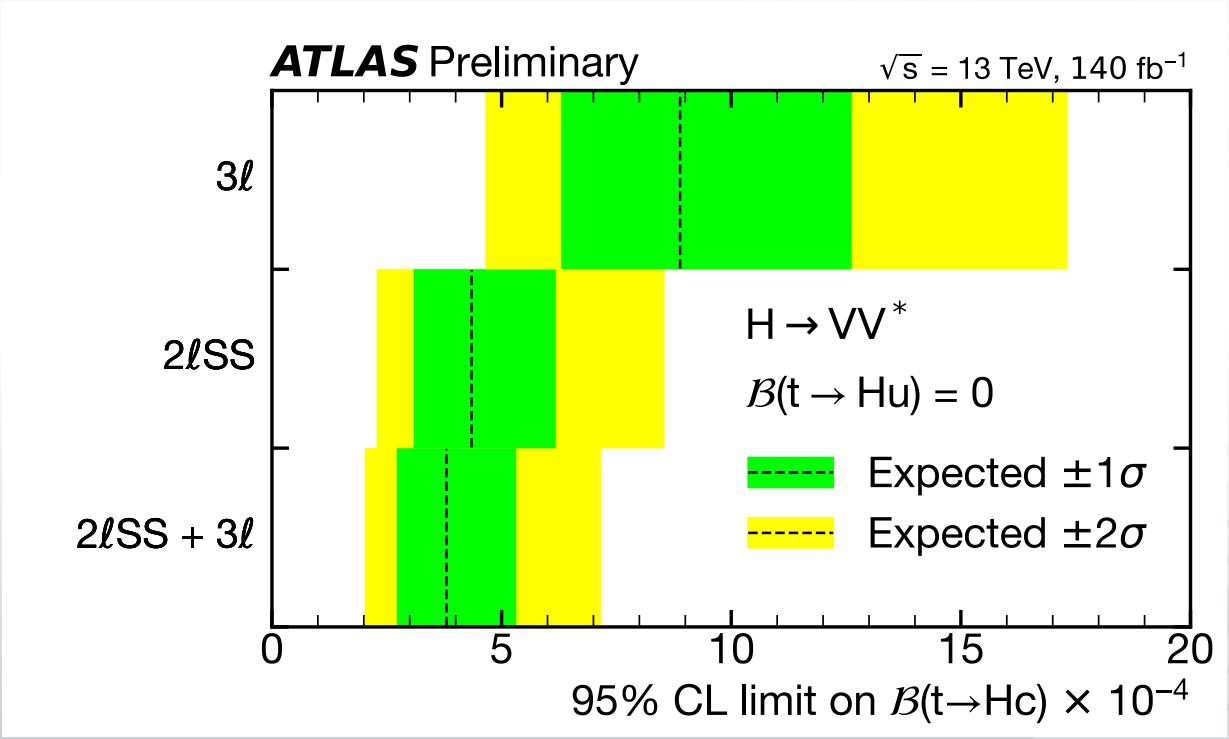


tHc Fit



Comparison of 2ℓSS and 3ℓ Final State Sensitivity





Combination Correlation Scheme

- **Signal modelling:** Treated differently by each analysis → *uncorrelated*
- **JES, JER:** The same treatment by all analyses → *correlated*
- **Electron, muon, photon, MET:** All related NPs (ID, isolation, calibration, …) are *correlated*
- **Luminosity, PRW:** The same treatment by all analyses → *correlated*
- **b-tagging:** Simplified scheme by $\gamma\gamma$ analysis → *only* $b\bar{b}$, $\tau^+\tau^-$, VV^* *correlated*
- **Background modelling:** Different processes and schemes by each analysis → *uncorrelated*