Prompt searches in ATLAS

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On behalf of the ATLAS collaboration

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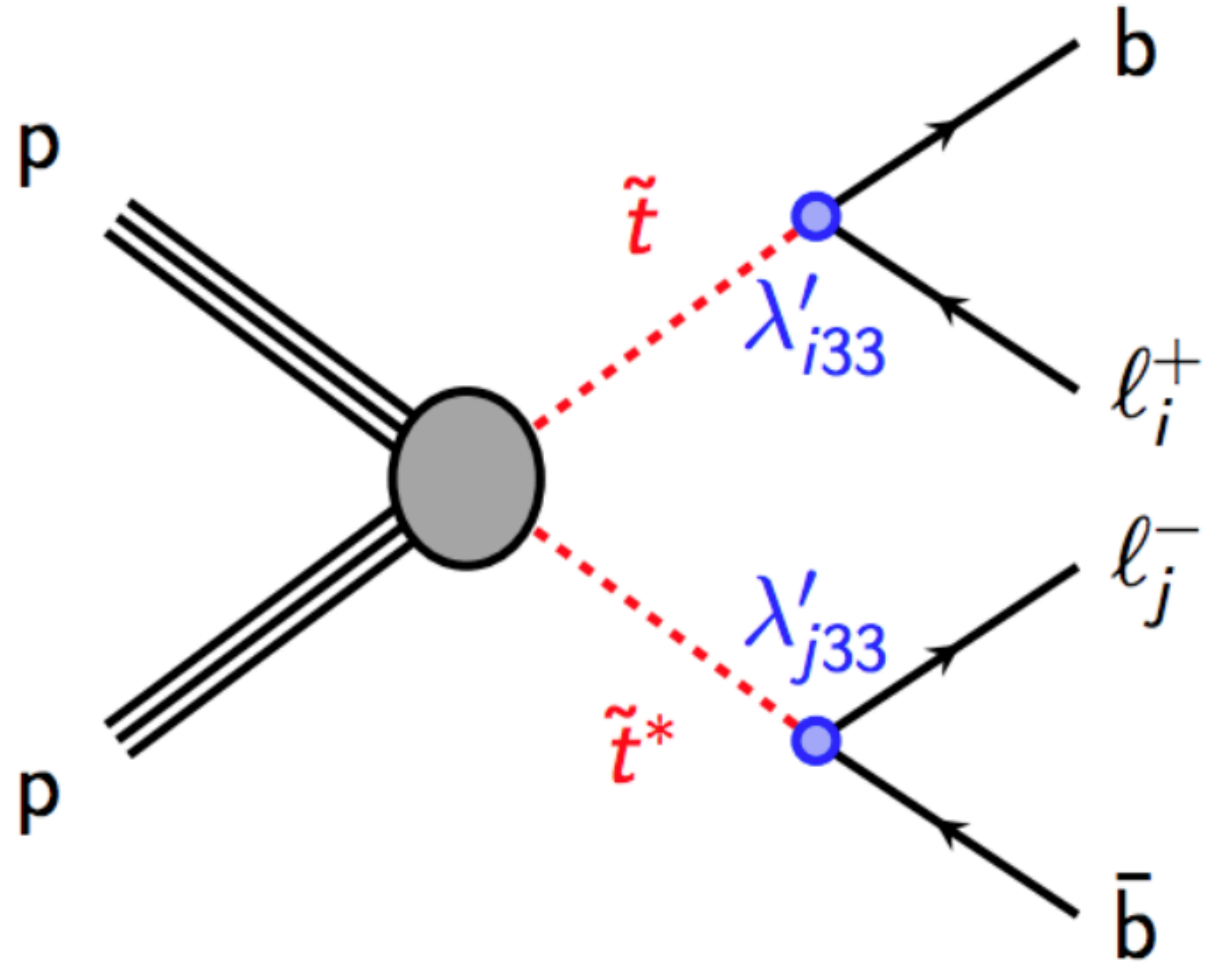
Introduction

- > Despite its success in describing a wide variety of phenomena, many questions/problems are left unanswered by the SM
  - What is the nature of Dark Matter?
  - Why is the EW scale much smaller than the Planck scale? (Hierarchy problem)
- > Many BSM theories try to solve these problems
- > ATLAS collaboration pursues an extensive BSM search program
  - New gauge vector bosons
  - Additional scalar particles
  - Supersymmetry (SUSY)
- > Presenting a selection of latest results
  - More public results

R-parity violating $\tilde{t} \rightarrow b\ell$

Introduction

- R-parity conservation is often invoked in SUSY to
  - Prevent violation of barion (B) and lepton (L) numbers
  - Ensure proton stability
- R-parity-violating theories can also achieve these requirements
  - B-L-conserving theories are theoretically well motivated (arXiv:1401.7989)
- B-L theories
  - stop squark $\tilde{t}$ is the lightest SUSY particle
  - $\tilde{t}$ can decay to SM particles
- Search for $\tilde{t}\tilde{t}* \rightarrow \ell^+\ell^-b\bar{b}$



R-parity violating $\tilde{t} \to b\ell$

Strategy

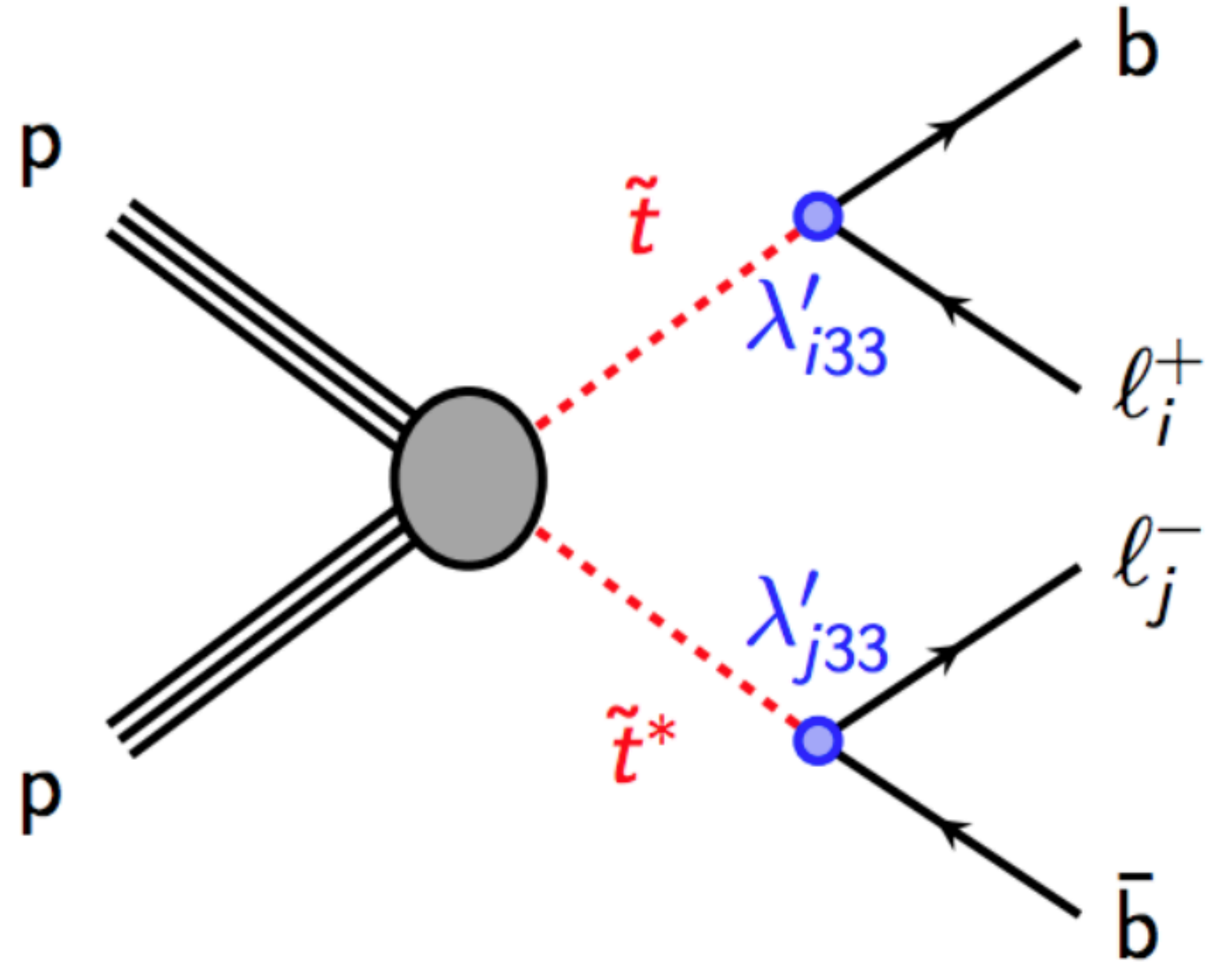
> Event selection

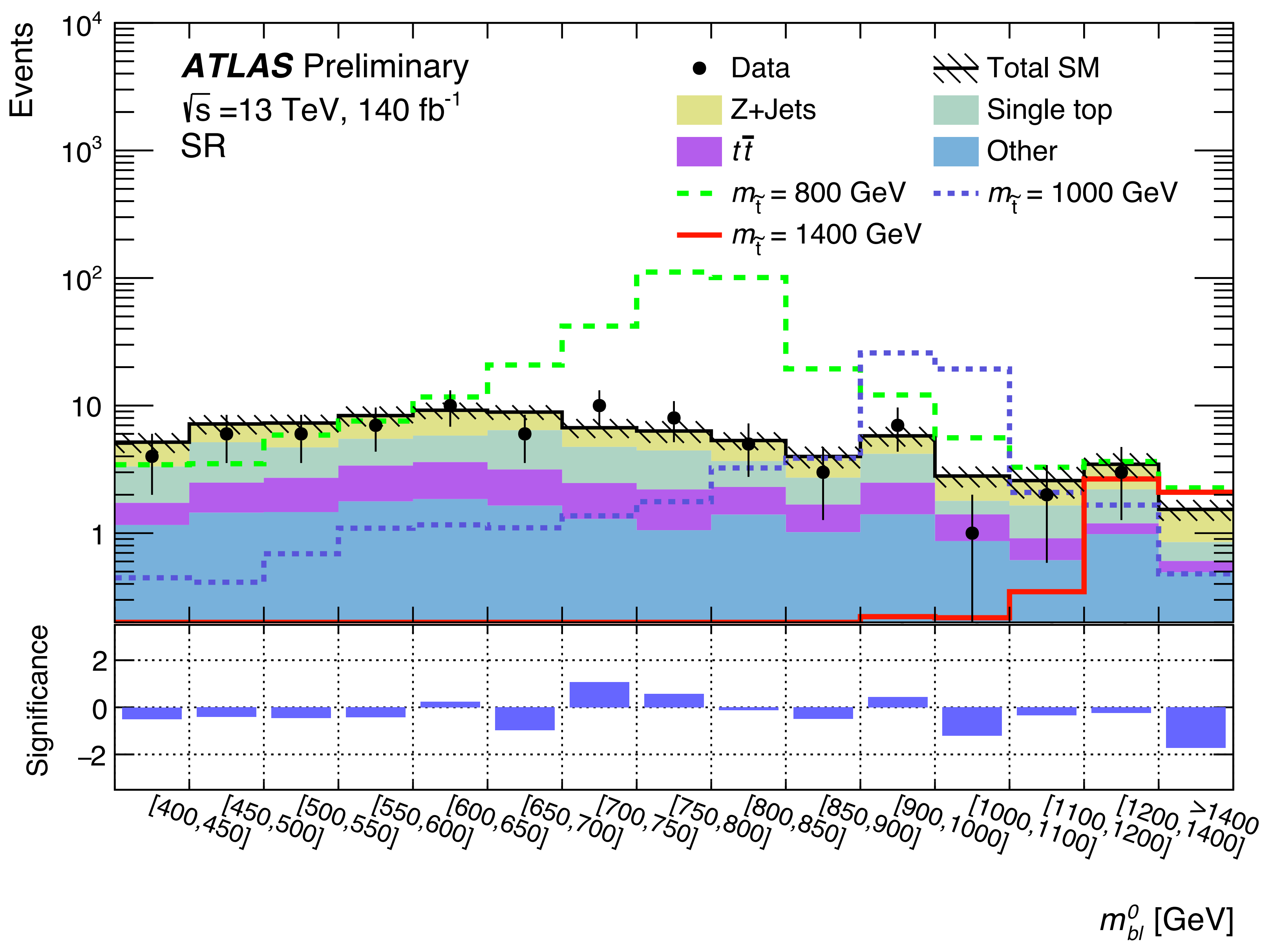
- ≥ 2 leptons (e, μ)
- ≥ 2 jets (≥ 1 b-tag)

> 2 possible $b - \ell$ pair assignments

- Correct assignment chosen minimising mass asymmetry $\dfrac{m^0_{b\ell} - m^1_{b\ell}}{m^0_{b\ell} + m^1_{b\ell}}$

> Search for resonance on distribution of largest jet+ℓ mass

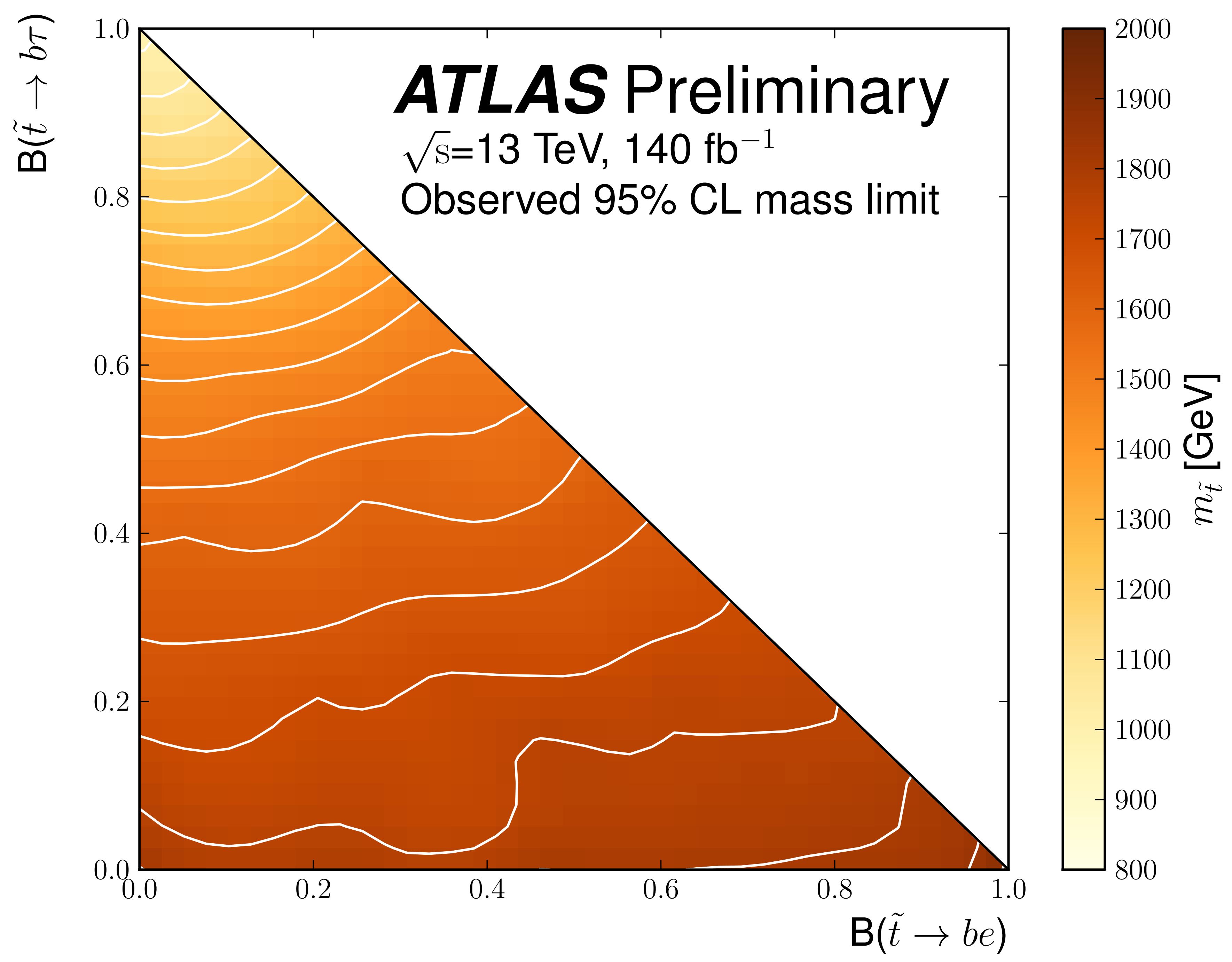




R-parity violating $\tilde{t} \to b\ell$

Results

- Upper limits on stop mass
- 2 limits calculated for each choice of BR
  - From lepton-flavour-agnostic fit
    - Best performance for $B(\tilde{t} \to be) \approx B(\tilde{t} \to b\mu)$
  - From lepton-flavour-aware fit
    - Best performance for $B(\tilde{t} \to be) \neq B(\tilde{t} \to b\mu)$
- Strictest limits used for final results



$$B(\tilde{t} \to be) + B(\tilde{t} \to b\mu) + B(\tilde{t} \to b\tau) = 1$$

$W' \to \tau\nu$ — arXiv:2402.16576

Introduction

> Search for spin-1 resonance W' in τ+Missing E_T (MET) final state

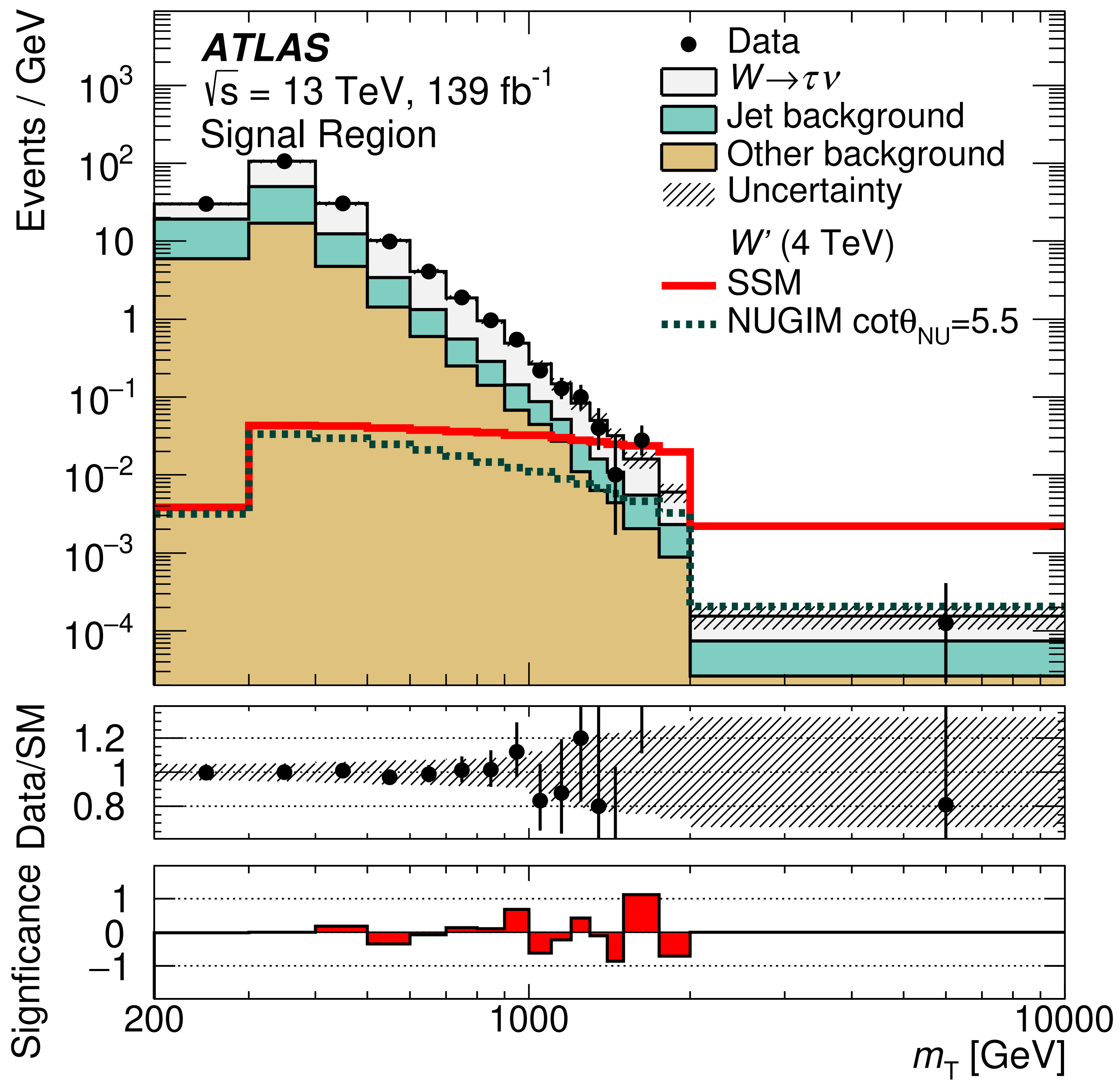
> Motivated by models predicting additional vector gauge bosons

- SSM: SM-like couplings, preserves lepton flavour universality (LFU)
- NUGIM: Not LFU-preserving
  - Parameter θ_{NU} regulates coupling to third generation of fermions

$W' \to \tau\nu$ — arXiv:2402.16576

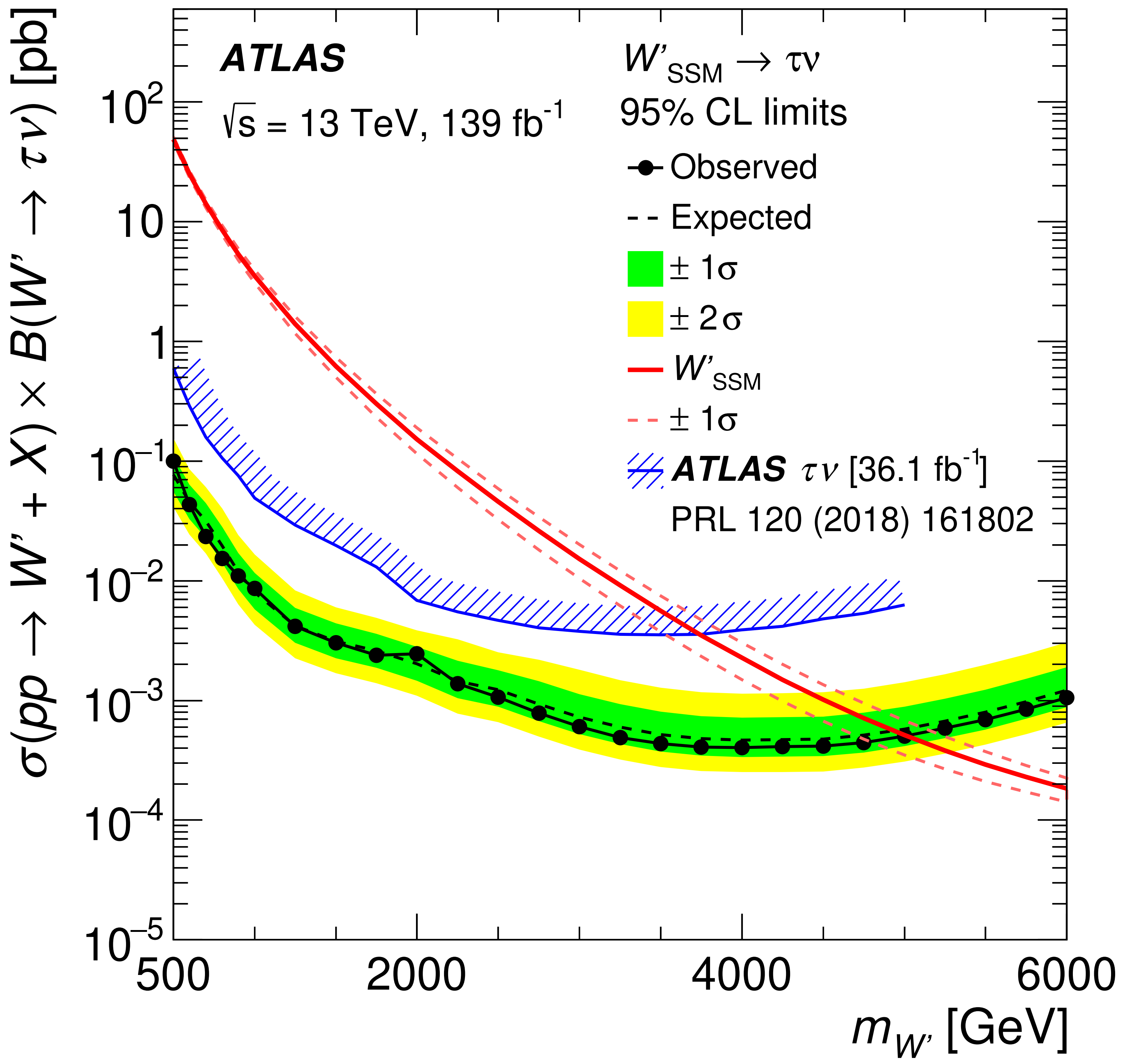
Strategy

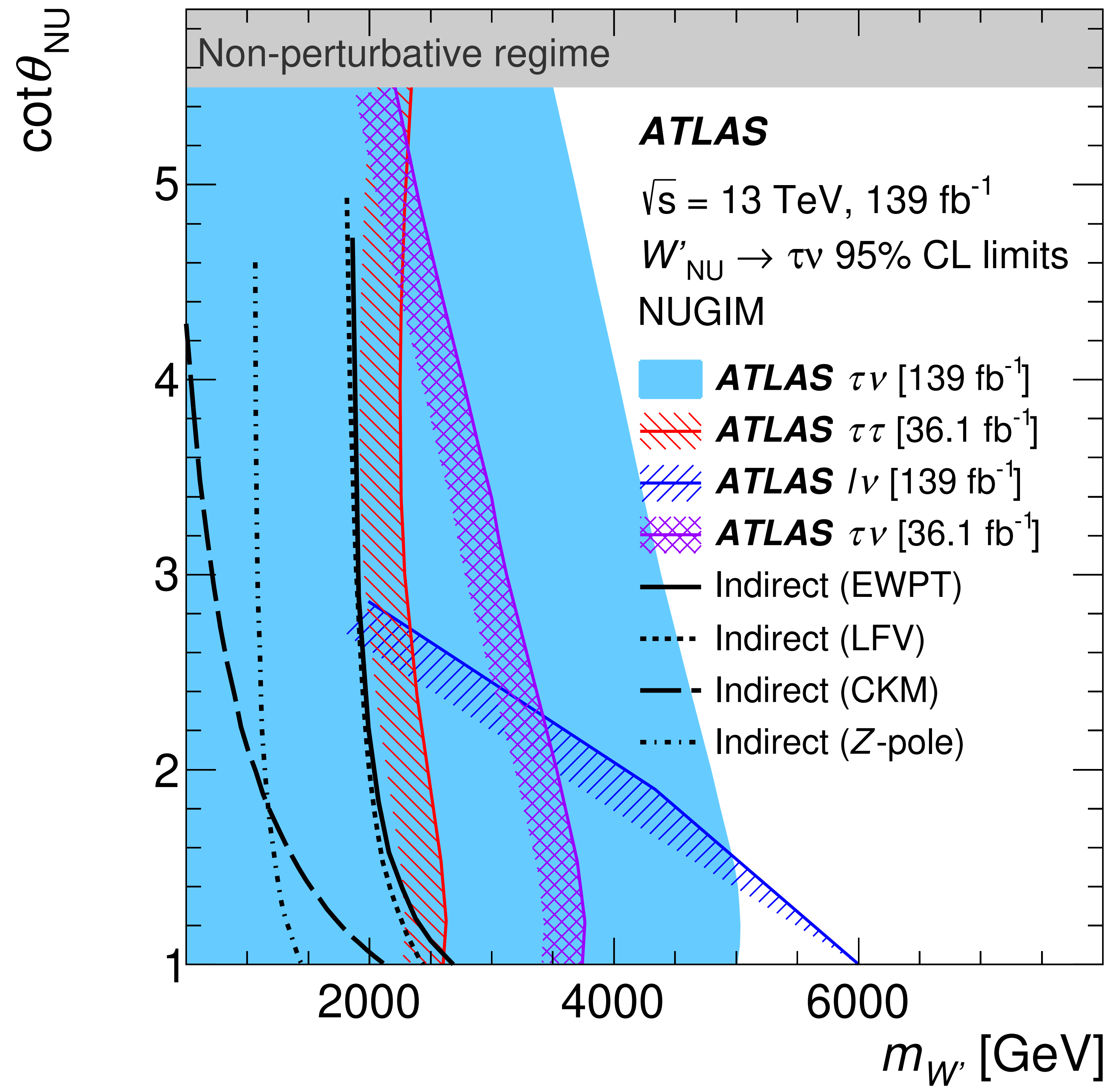
- Event selection via Missing E_T triggers
- Targeting only hadronic τ decays
- BDT-based classification of tracks in the core of the reconstructed τ
  - Improves the reconstruction efficiency and rejection of jets faking τ
- Statistical analysis based on transverse mass
  - $$m_T = \sqrt{2E_T^{\text{miss}} p_T^{\tau_{\text{had-vis}}} \left(1 - \cos \Delta\phi_{\text{had-vis},E_T^{\text{miss}}}\right)}$$



$W' \to \tau\nu$ — arXiv:2402.16576

Results



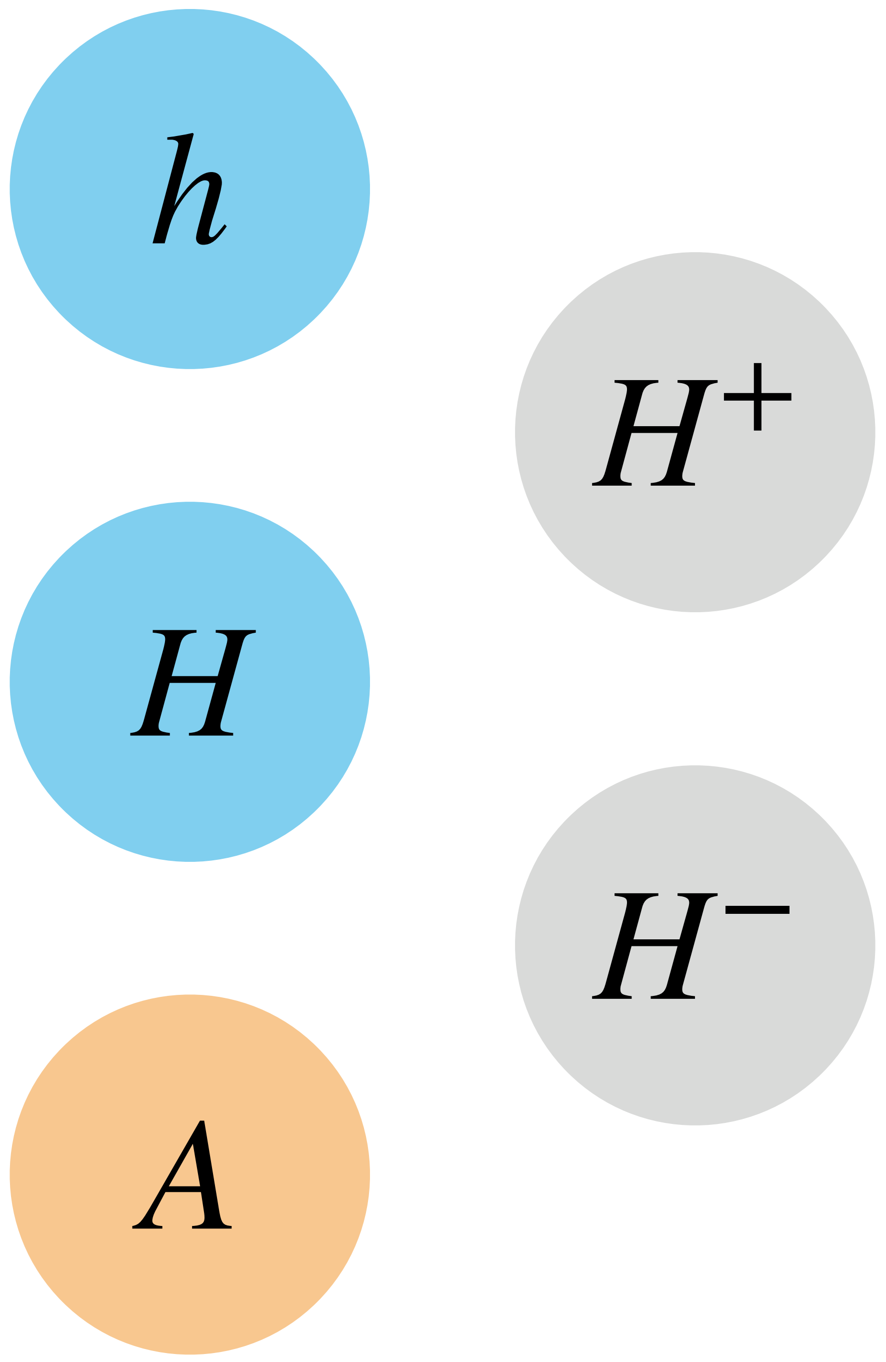


Upper limit on x-section X BR SSM

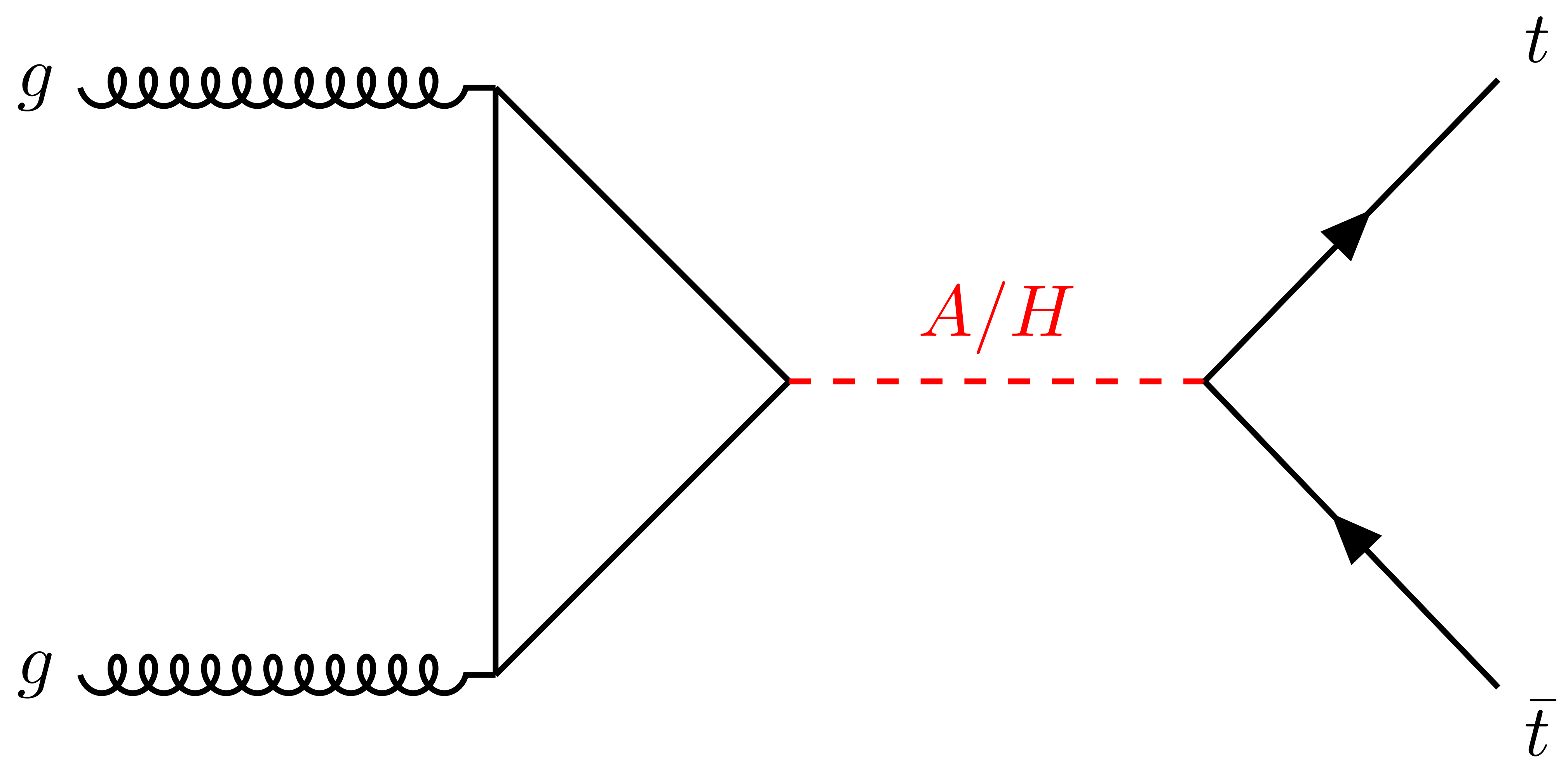
Excluded region in $m_{W'} - \cot\theta_{NU}$ plane NUGIM

Searches for additional scalars

- Many BSM models include extended Higgs sectors
- Simple extensions consistent with constraints: 2HDM
  - Predict additional Higgs doublet
  - Total of 5 scalar particles
- 2HDMs fit in more complex theories
  - SUSY (e.g. hMSSM)
  - WIMP DM models (2HDM+a, pseudo scalar mediator to DM)
- Relevant parameters
  - m_A, m_H, Higgs VEV ratio $\tan\beta$
    - At low $\tan\beta$, heavy Higgs couples preferentially to top quarks



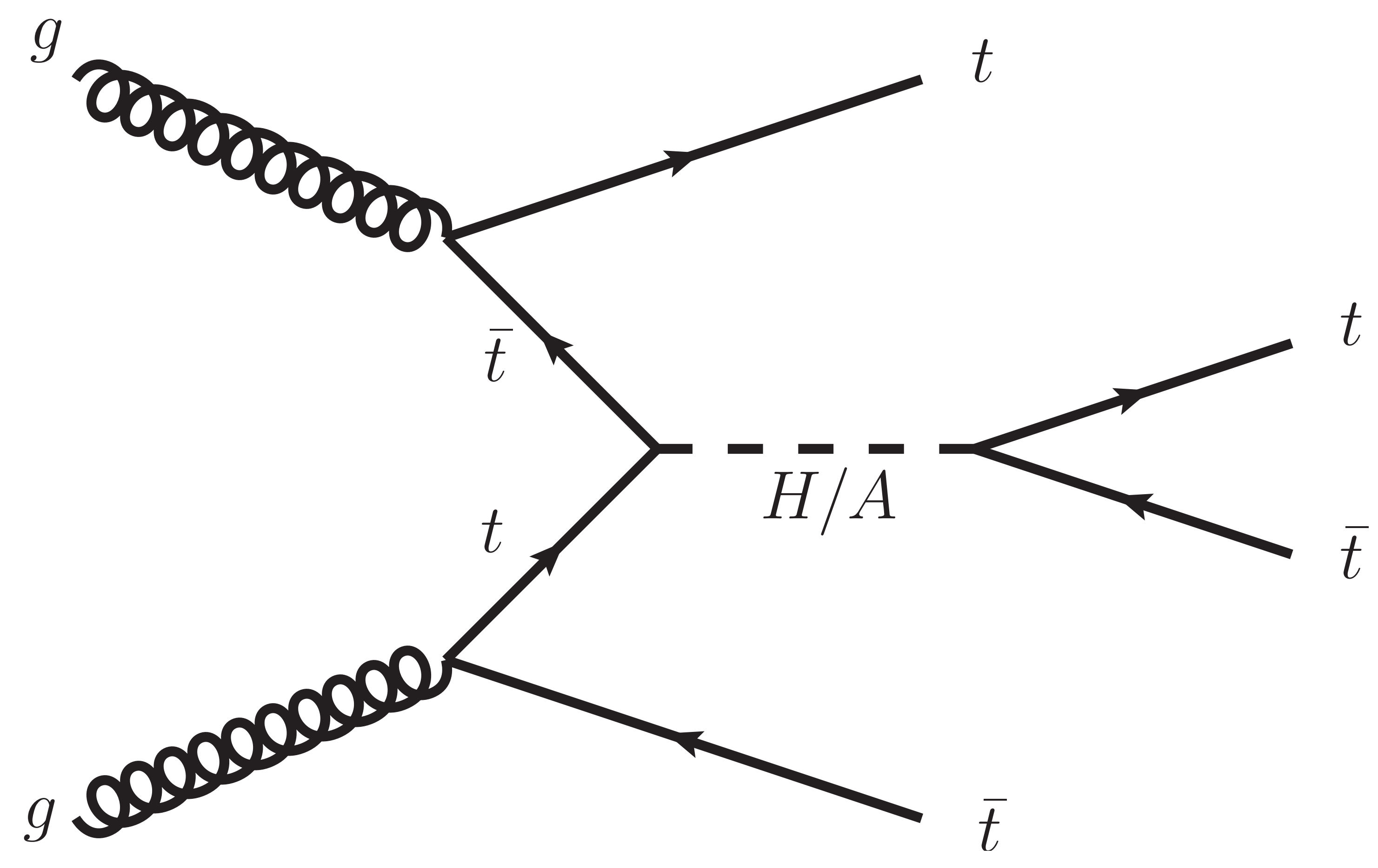
Signal processes in 2HDM @ LHC



$A/H \to t\bar{t}$

Dominant mode
gluon-gluon fusion (2 top quarks)
Strong interference with SM $t\bar{t}$

arXiv:2404.18986



$t\bar{t}A/H \to t\bar{t}t\bar{t}$

Subdominant mode
Top-associated production (4 top quarks)
Negligible interference with SM $t\bar{t}t\bar{t}$

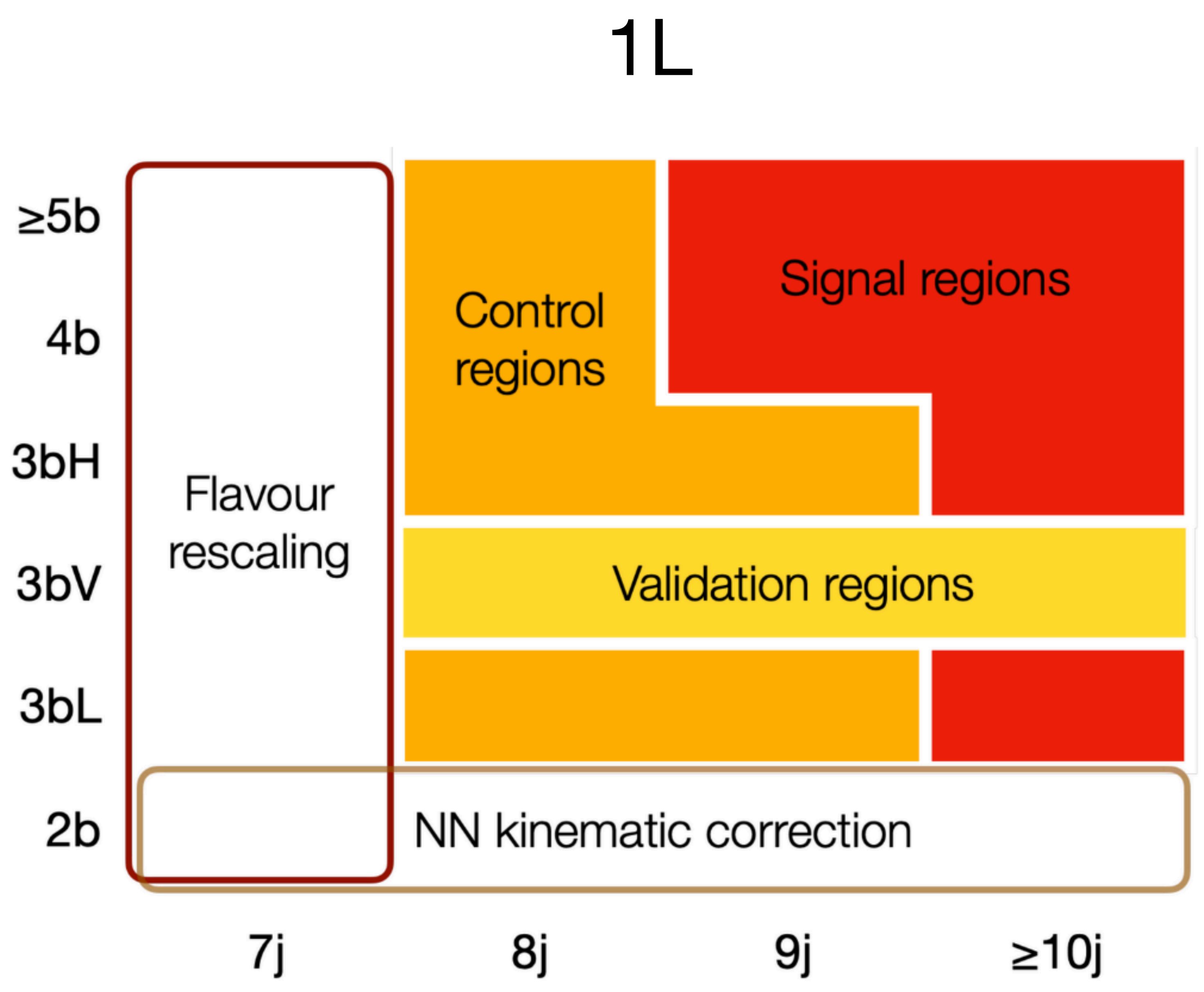
ATLAS-CONF-2024-002

$t\bar{t}A/H \rightarrow t\bar{t}t\bar{t}$

Strategy (1)

- Motivated by excess in $t\bar{t}t\bar{t}$ x-section measured by ATLAS and CMS
- Two orthogonal channels
  - 1L, $\geq$10 jets, 4 b-jets
  - 2L OS, $\geq$8 jets, $\geq$4 b-jets
- Dominant backgrounds
  - $t\bar{t}$+jets
  - SM $t\bar{t}t\bar{t}$
- Events categorisation based on jet and b-jet multiplicity
  - Useful to correct and validate $t\bar{t}$+jets estimate

Combination with SS2L + 3L search JHEP 07 (2023) 203



Name	$N_b^{60\%}$	$N_b^{70\%}$	$N_b^{85\%}$
2b	-	= 2	-
3bL	≤ 2	= 3	-
3bH	= 3	= 3	> 3
3bV	= 3	= 3	= 3
≥4b (2LOS)	-	≥ 4	-
4b (1L)	-	= 4	-
≥5b (1L)	-	≥ 5	-

$t\bar{t}A/H \rightarrow t\bar{t}t\bar{t}$

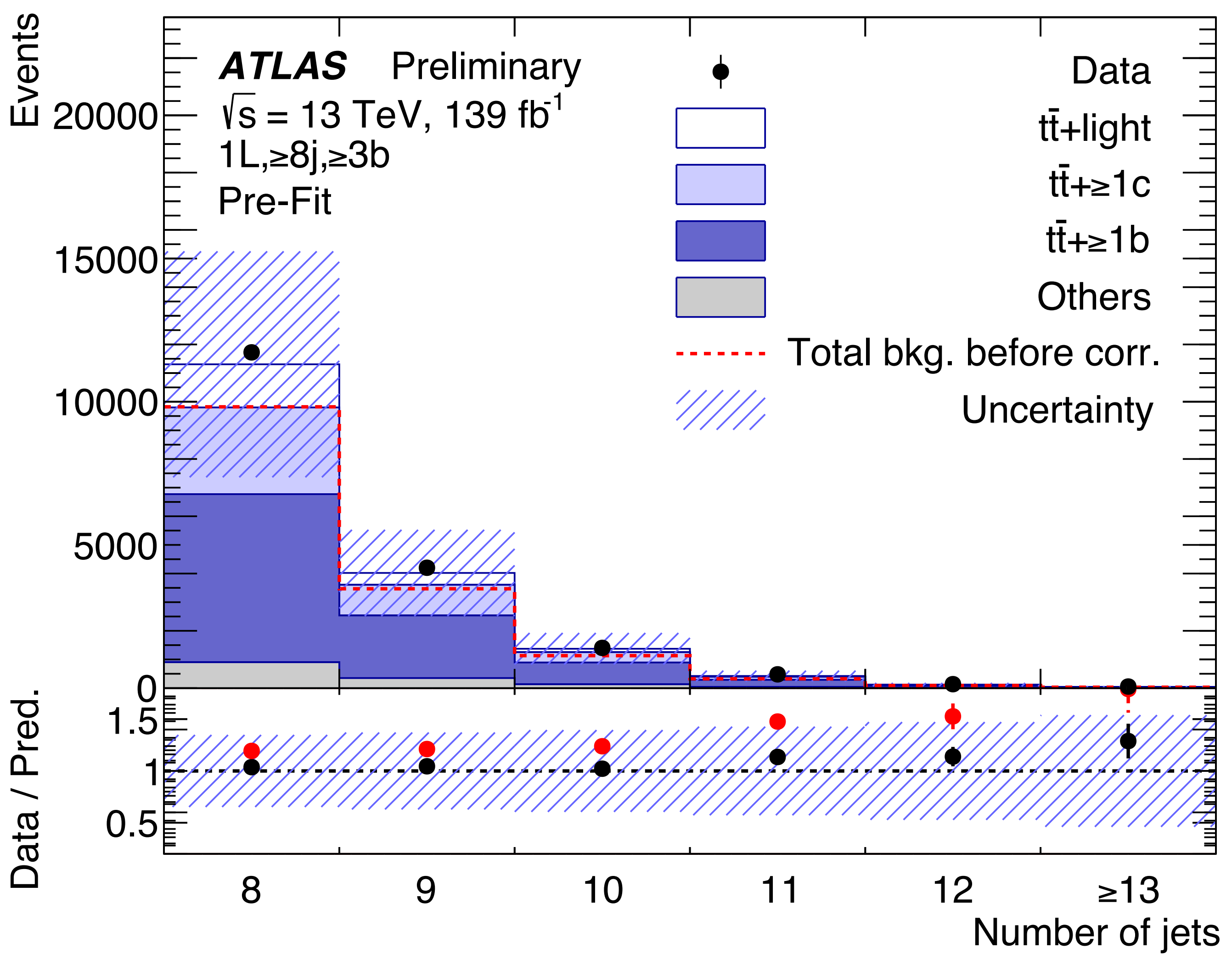
Strategy (2)

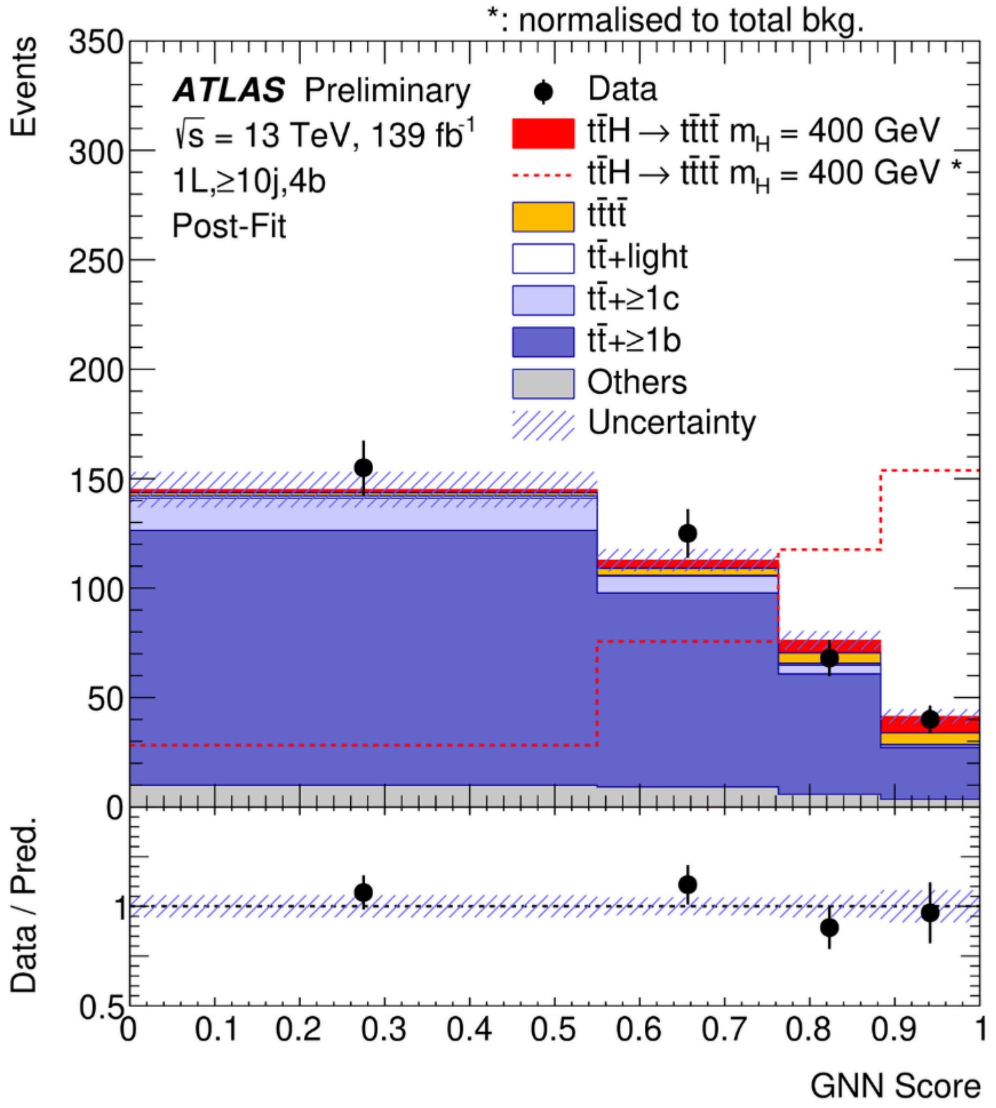
> $t\bar{t}$+jets background corrections

- Flavour rescaling
  - Fits to data in CRs to correct fractions of $t\bar{t}$+light $t\bar{t}+\geq 1c$, $t\bar{t}+\geq 1b$ events
- NN reweighting to improve modelling of kinematic variables
  - DNN trained to distinguish between MC and data in CRs
  - DNN score used to reweight MC in SR

> GNN to discriminate signal and background

- Statistical analysis on GNN score

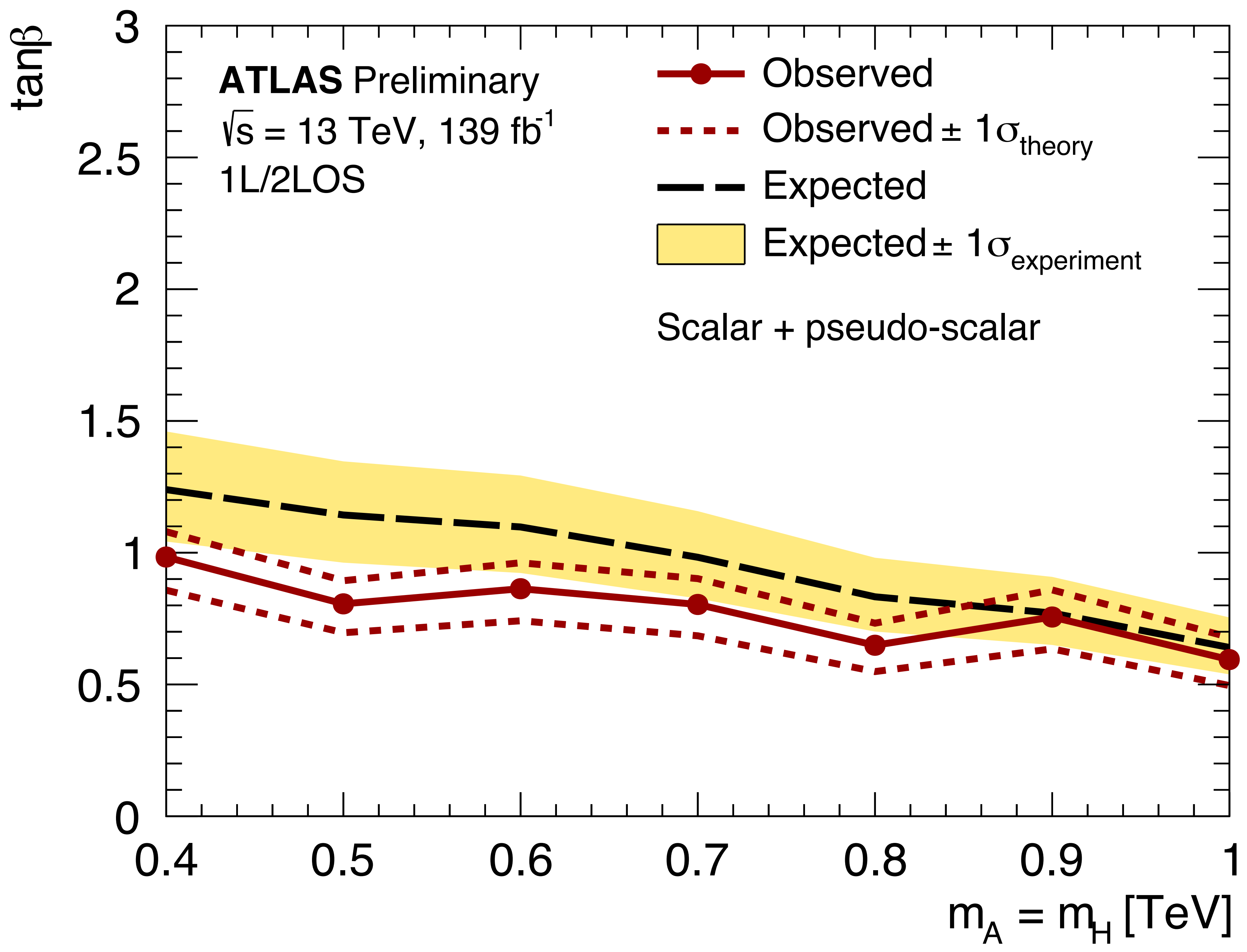




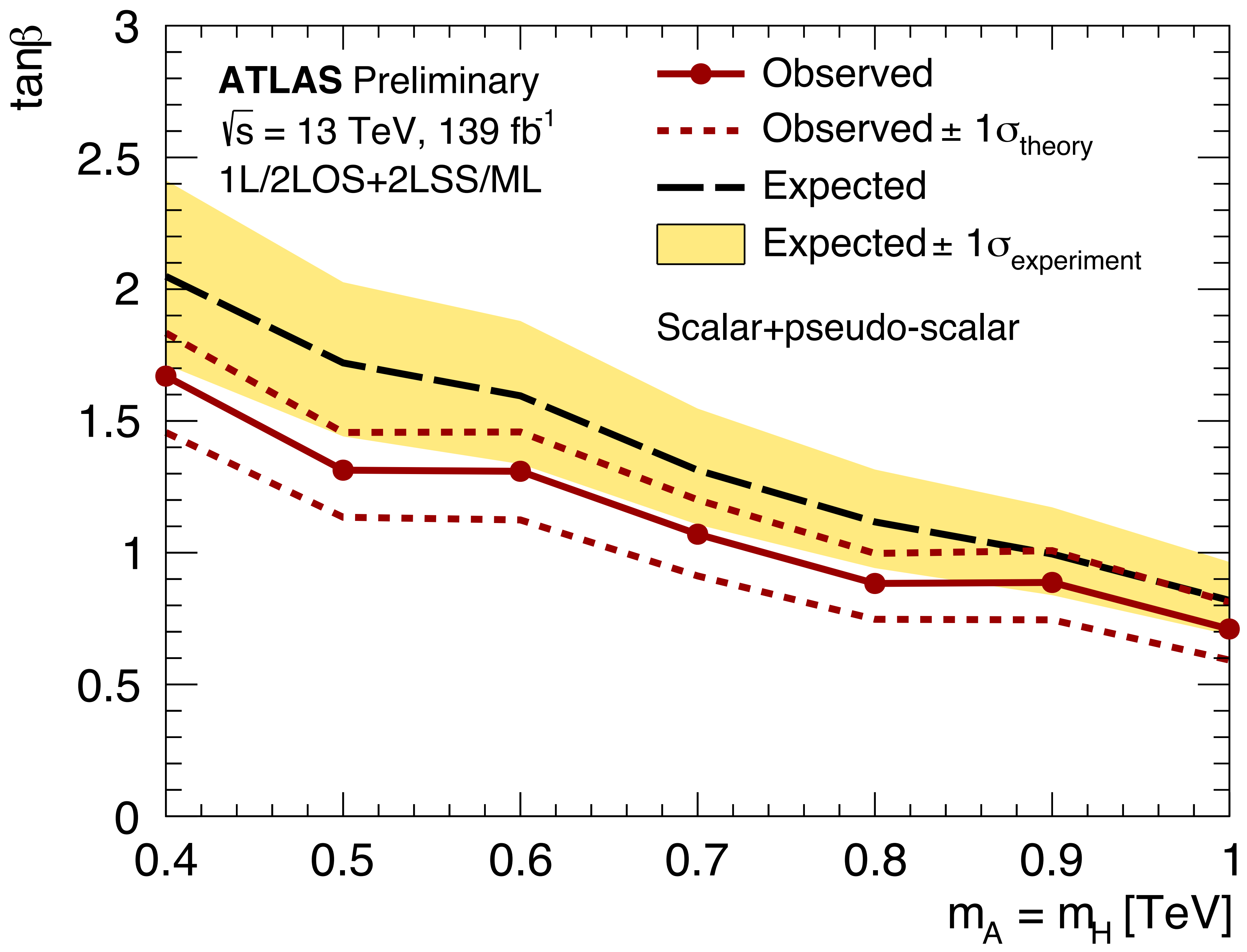
$t\bar{t}A/H \to t\bar{t}t\bar{t}$

Results — Excluded regions in $m_A - \tan\beta$ plane

Largest deviation from SM in the search stage:
$m_A = m_H = 500$ GeV, at 2.1σ



1L/2LOS



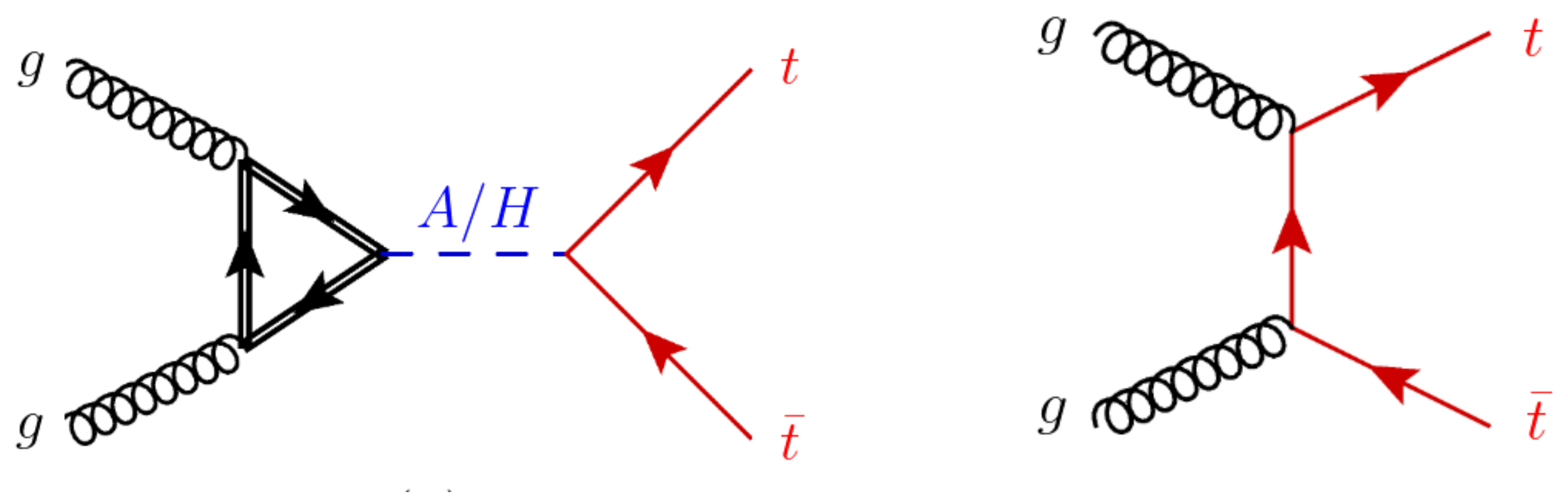
Combination 1L/2LOS + 2LSS/3L

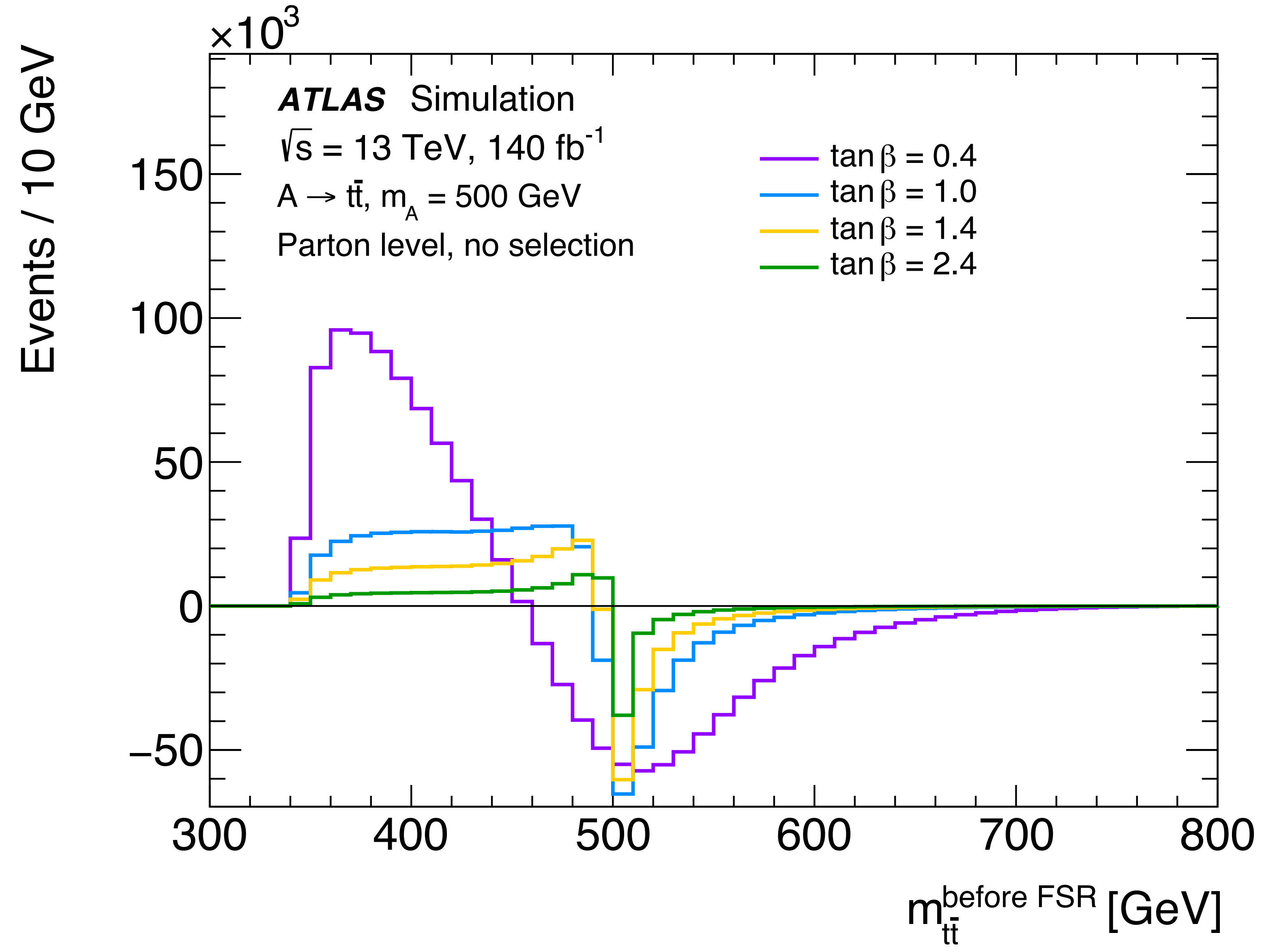
$A/H \to t\bar{t}$

Strategy

> Signal-background interference effect

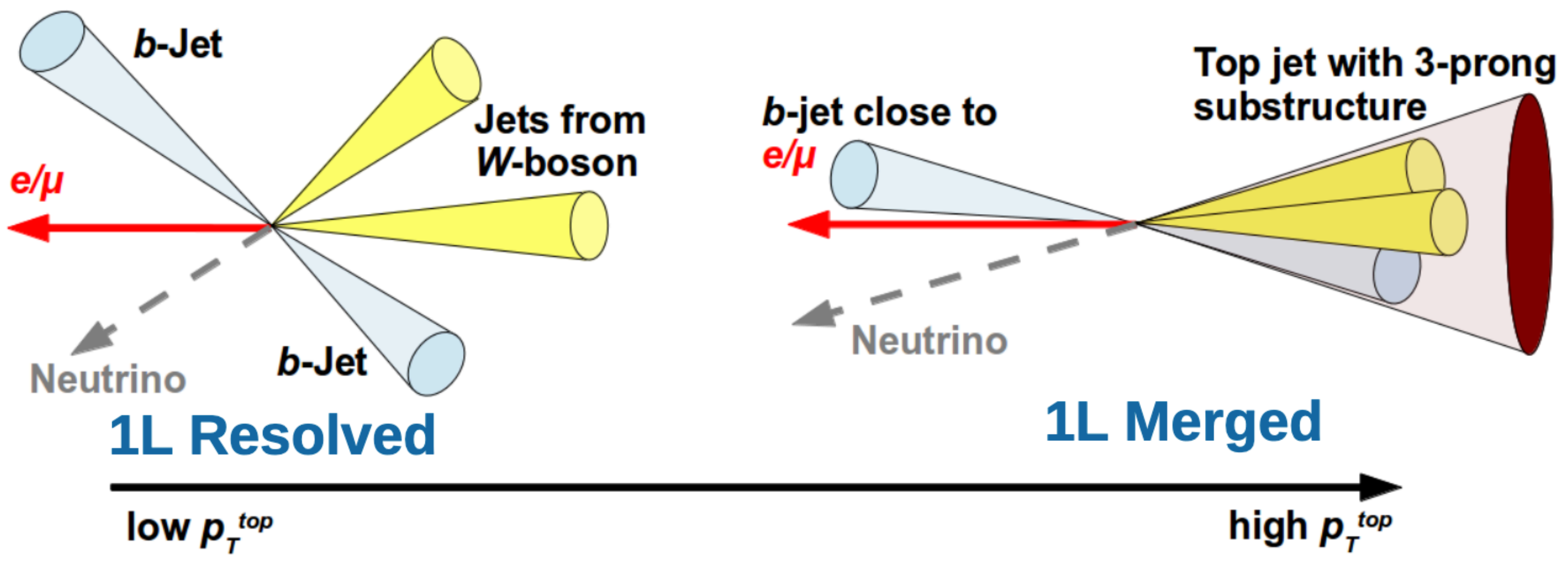
- Model-dependent peak-dip structure in $m_{t\bar{t}}$ spectrum





> Two orthogonal channels

- 2-leptons
  - Fits on $m_{\ell\ell bb}$
- 1-lepton
  - Resolved+Merged topologies
  - Fits on $m_{t\bar{t}}$

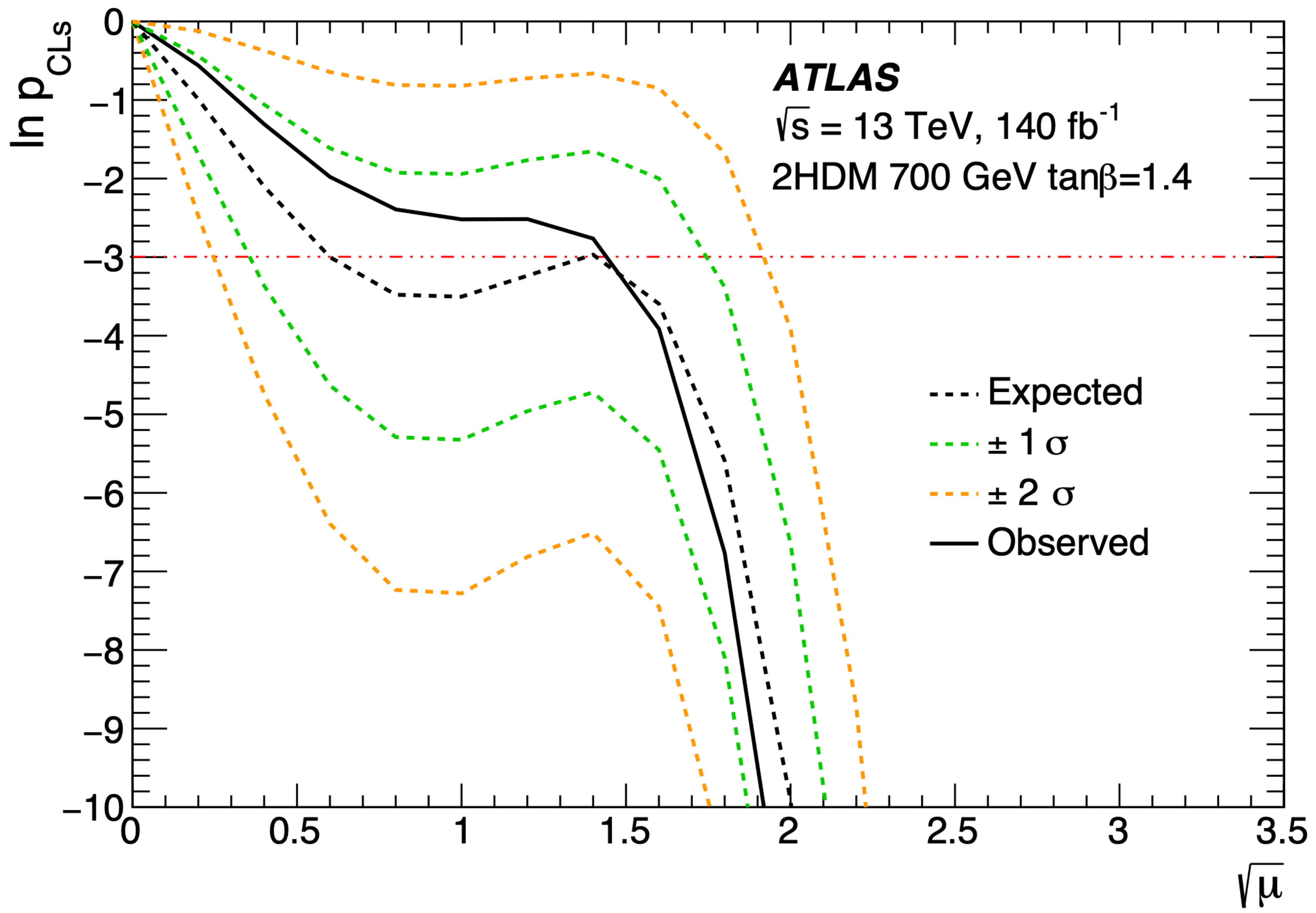


$A/H \to t\bar{t}$

Statistical analysis with interference

> Quadratic dependence of the bin content expectation from POI $\sqrt{\mu}$

- $\nu = \mu \cdot S + \sqrt{\mu} \cdot I + B = (\mu - \sqrt{\mu}) \cdot S + \sqrt{\mu} \cdot (S + I) + B$
- Interference shape changes with $\sqrt{\mu}$
- Double minima can appear in CLs scan
  - Upper limits on $\sqrt{\mu}$ not well defined



> Requires special statistical treatment

- Choice of test statistics
  - Search stage: quantify deviation from SM $\sqrt{\mu}$=0 hypothesis
  - Exclusion stage: reject BSM hypothesis $\sqrt{\mu}$=1 in favour of SM $\sqrt{\mu}$=0

$$q_0 = -\ln \frac{\mathcal{L}\left(\sqrt{\mu} = 0, \hat{\hat{\theta}}_0\right)}{\mathcal{L}\left(\hat{\sqrt{\mu}}, \hat{\theta}\right)}$$

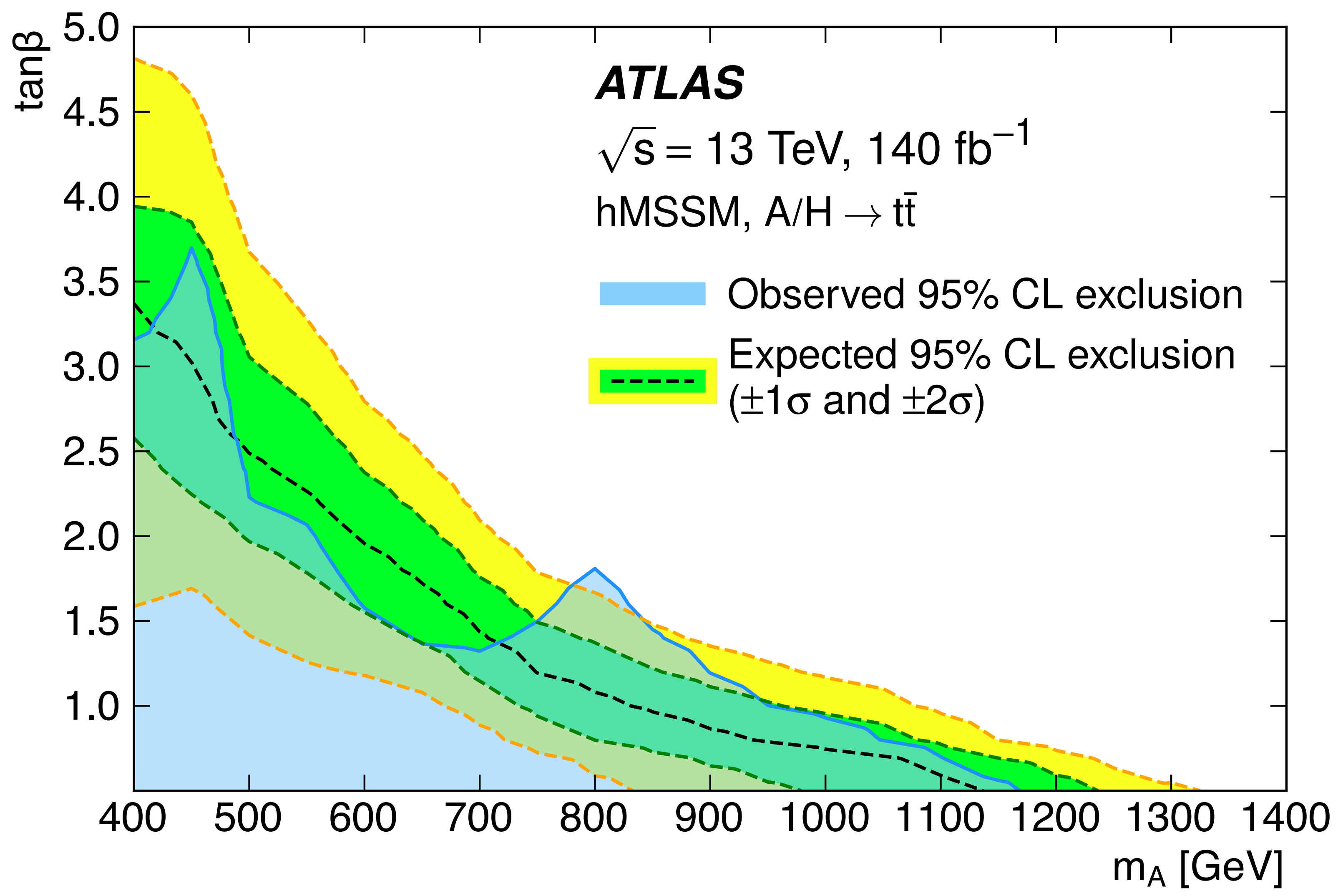
$$q_{1,0} = -\ln \frac{\mathcal{L}\left(\sqrt{\mu} = 1, \hat{\hat{\theta}}_1\right)}{\mathcal{L}\left(\sqrt{\mu} = 0, \hat{\hat{\theta}}_0\right)}$$

$A/H \to t\bar{t}$

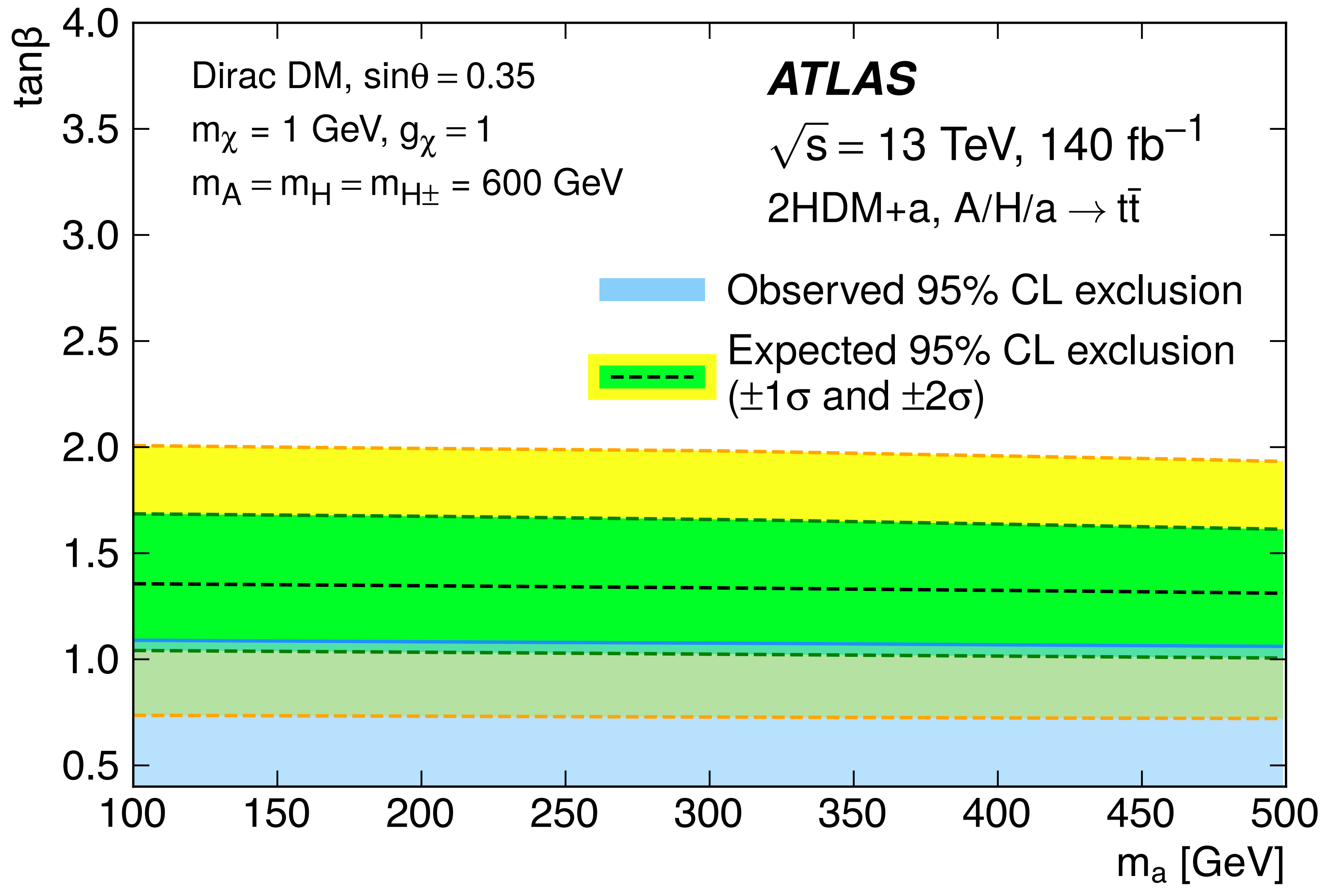
Results — Excluded regions

Largest deviation from SM in the search stage:
$m_A = 800$ GeV, $m_A/\Gamma_A = 10\%$ at 2.3σ

hMSSM $m_A - \tan\beta$ plane



2HDM+a $m_a - \tan\beta$ plane



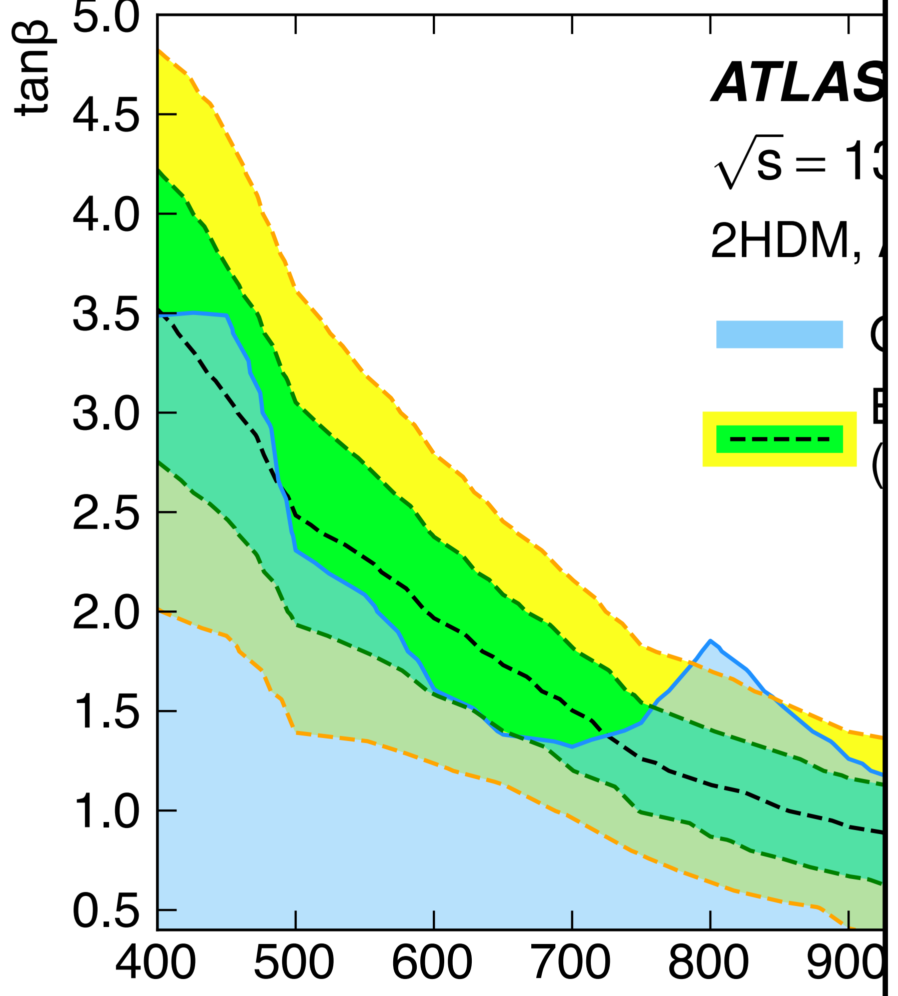
Benchmark scenario 3a in LHC DM WG recommendations

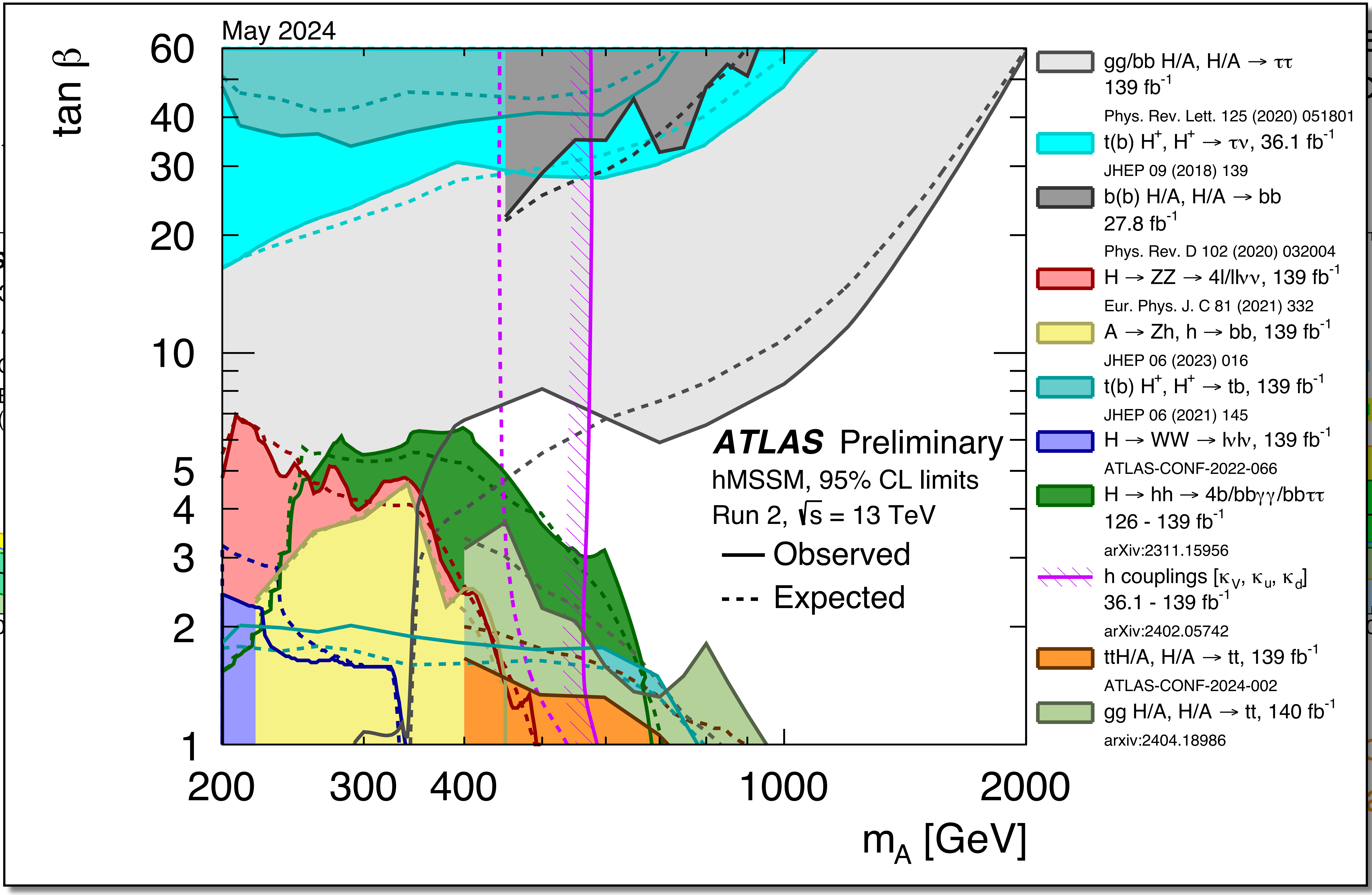
Strongest constraint from neutral scalar search!

$A/H \rightarrow t\bar{t}$

Results — Excluded regions

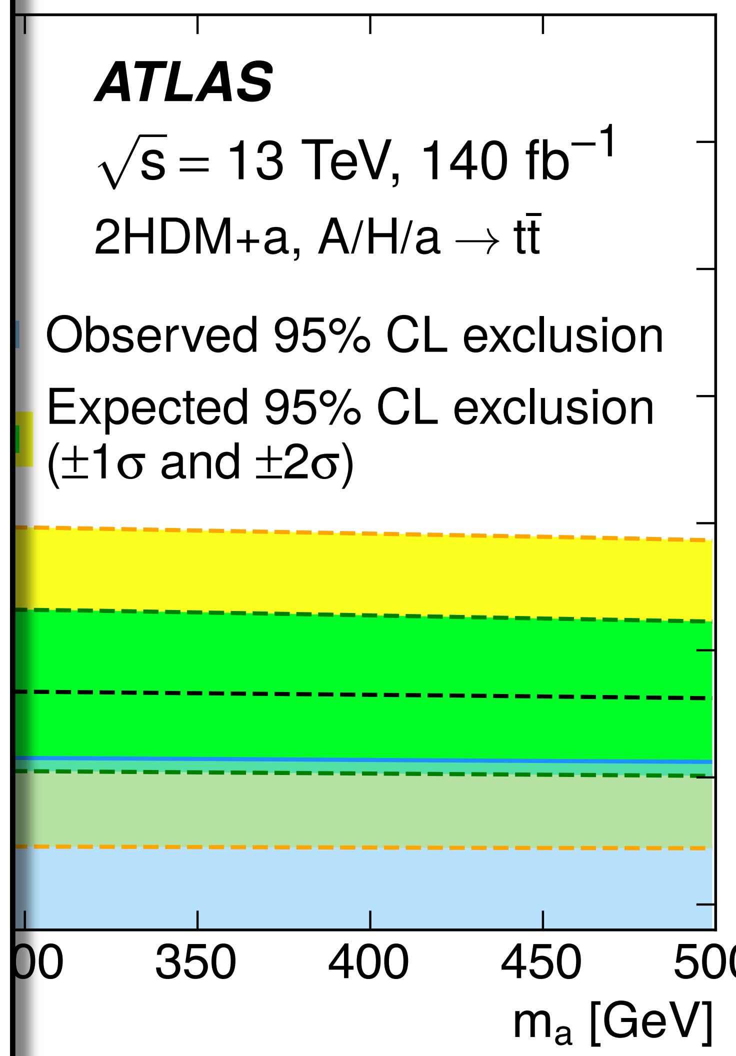
2HDM m_A –





enario 3a in LHC
ommendations

– $\tan\beta$ plane



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alar search!

Conclusions

- ATLAS has a very diverse BSM programme
- Run-2 has provided us with a wide variety of searches, with exotics signatures and novel techniques
- Various searches presented today, constraining parameter space of different models
- No BSM physics found but the quest continues!
- LHC Run-3 is in progress
  - New and exciting results await us