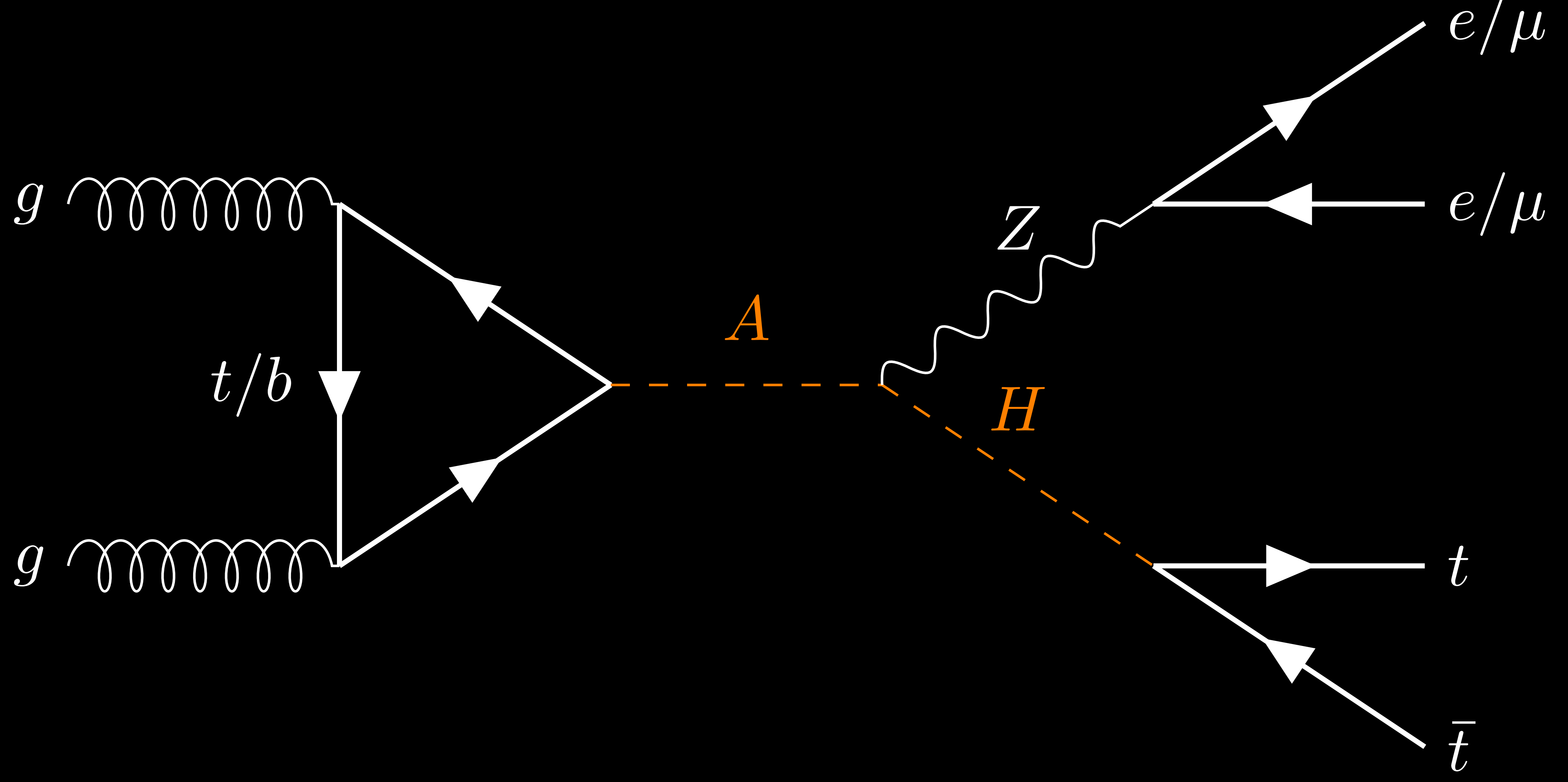
Search for $A \rightarrow ZH \rightarrow \ell\ell t\bar{t}$ at $\sqrt{s} = 13 TeV$ with the ATLAS detector

DPG Conference 2022



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DFG Deutsche Forschungsgemeinschaft

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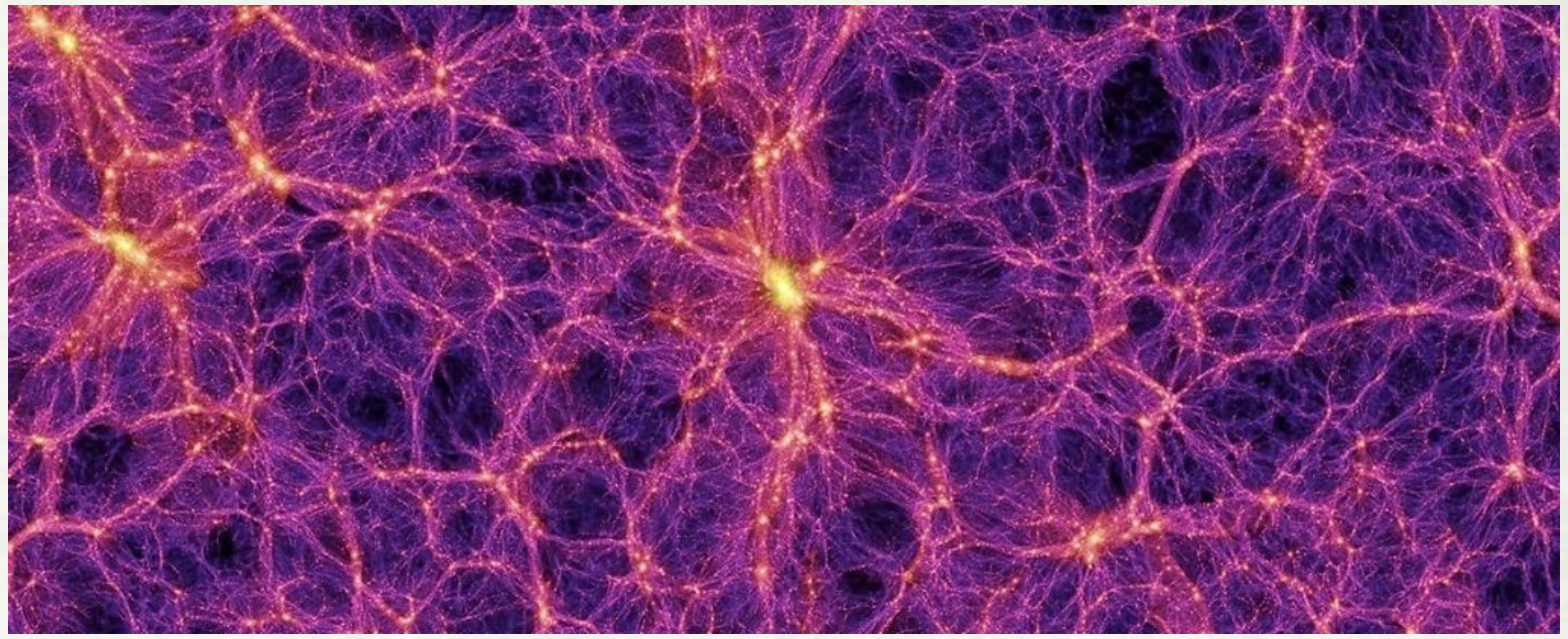
Motivation



hard-science

Observe huge matter-antimatter asymmetry in universe

Where is matter-antimatter asymmetry originating from?

conditions for Baryogenesis formulated in 1967 by Andrei Sakharov

- Sakharov Conditions

1. **C/CP violation**
2. **baryon number violation**
3. **interactions out of equilibrium**

} Standard Model does not fulfil all of these conditions

⇒Baryogenesis requires new physics!

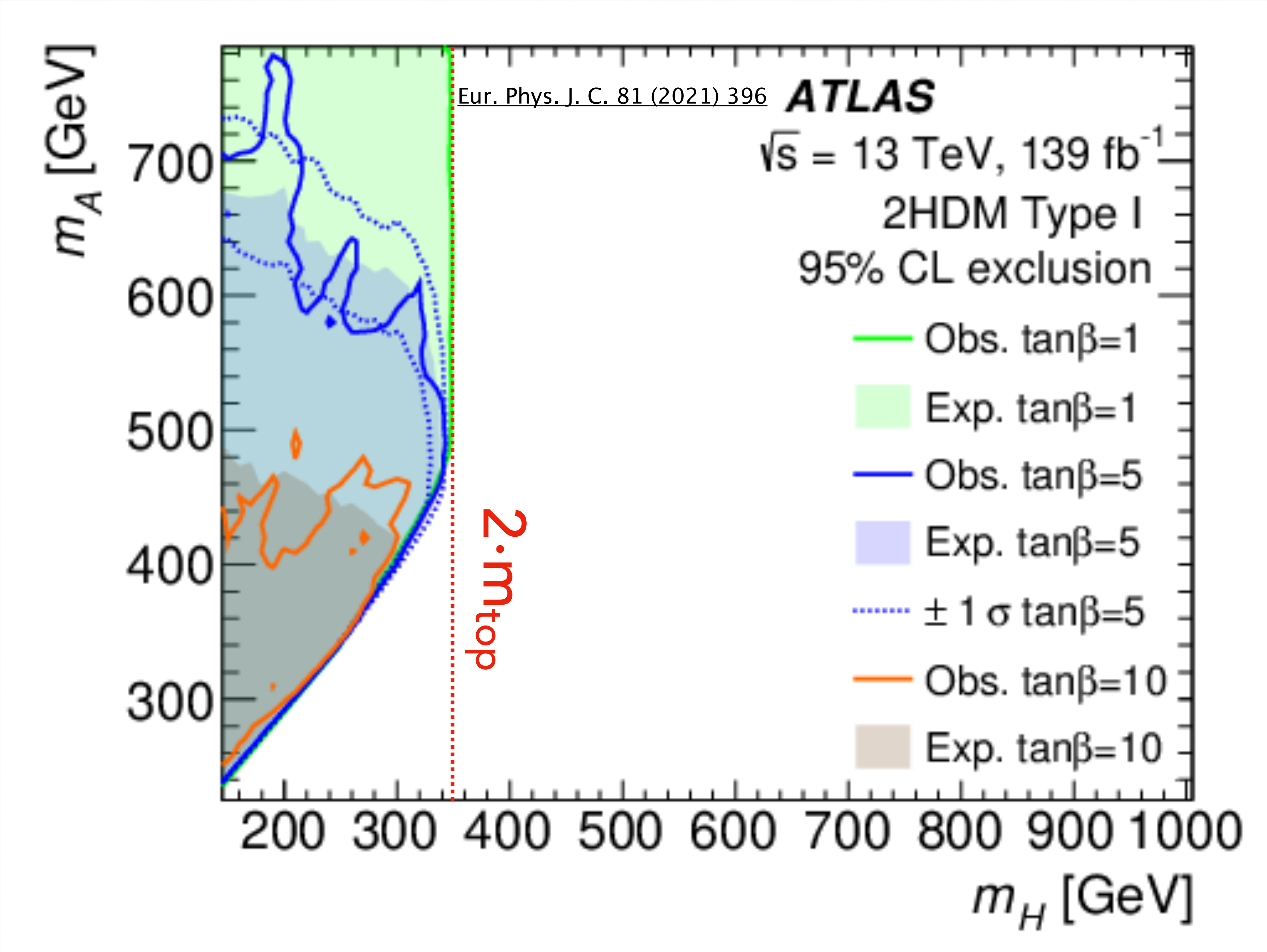
2HDM as a solution to Baryogenesis

$A \to ZH \to \ell\ell b\bar{b}$

one of the simplest extensions of standard model: addition of a second Higgs doublet
⇒8 fields, **BUT** 3 fields are absorbed by EWSB for electroweak interactions

⇒in total 5 physical Higgs bosons:
- 2 neutral CP even bosons (H, h)
- 1 neutral CP odd boson (A)
- 2 charged bosons ($H^{\pm}$)

2HDM can fulfil Sakharov conditions!!!

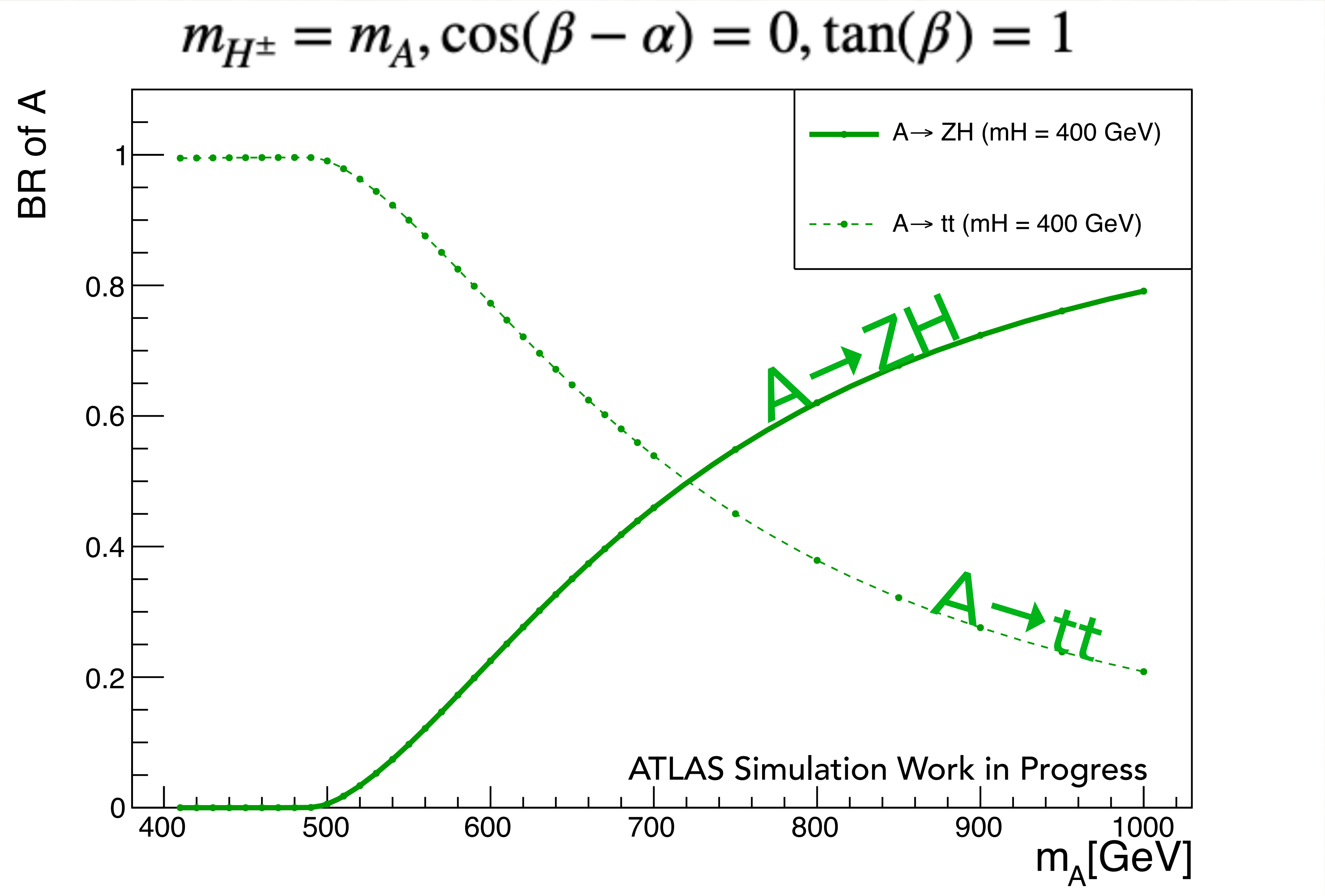


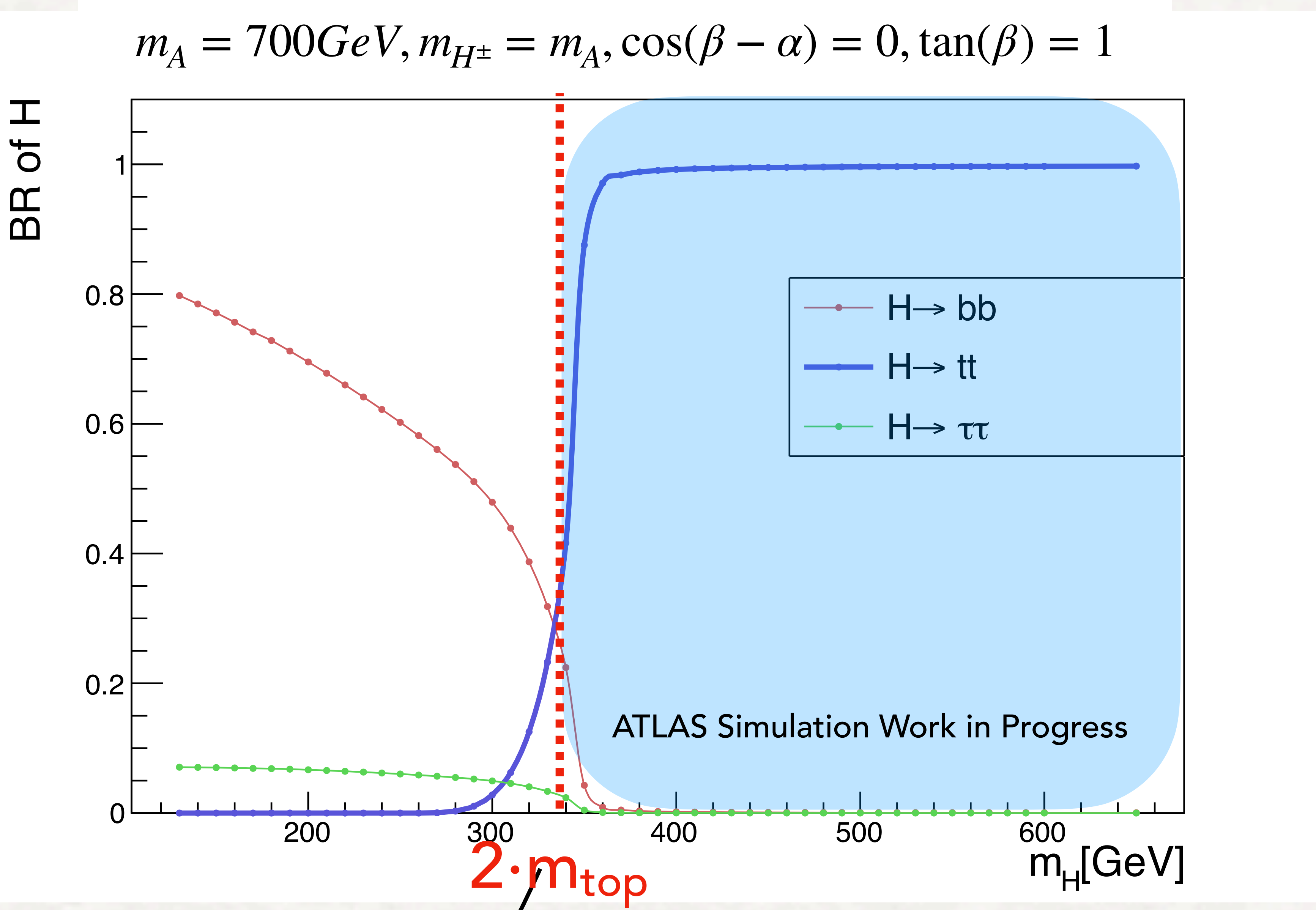
exclusion only for m_H < 350 GeV

Aim of this Analysis:

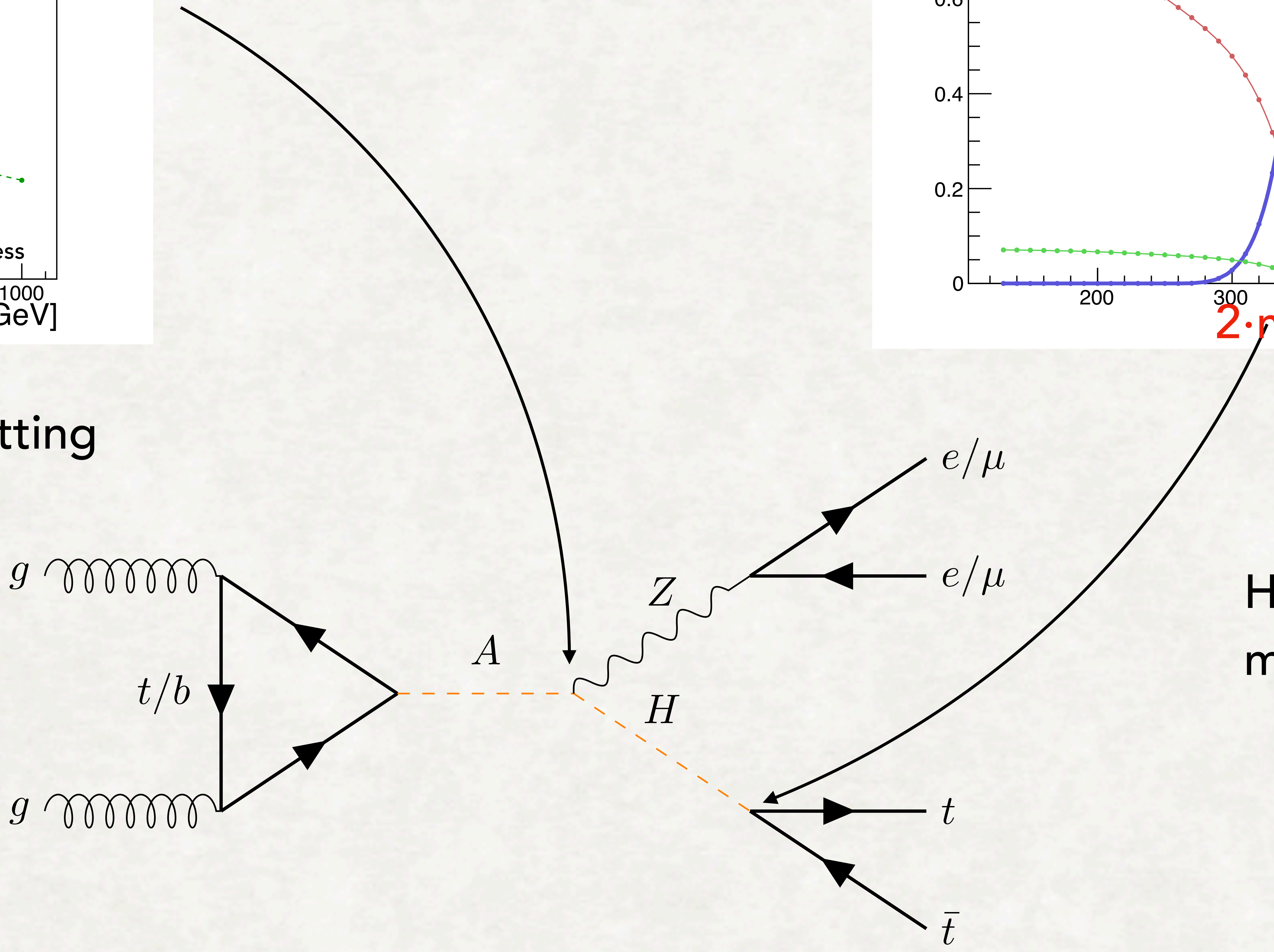
➡ Search for heavy scalars with large mass splitting
➡ extend mass region to m_H > 350 GeV

Branching Ratios of A & H:





$A \to ZH$ dominant for large mass splitting
($m_A > m_H$ +vev)

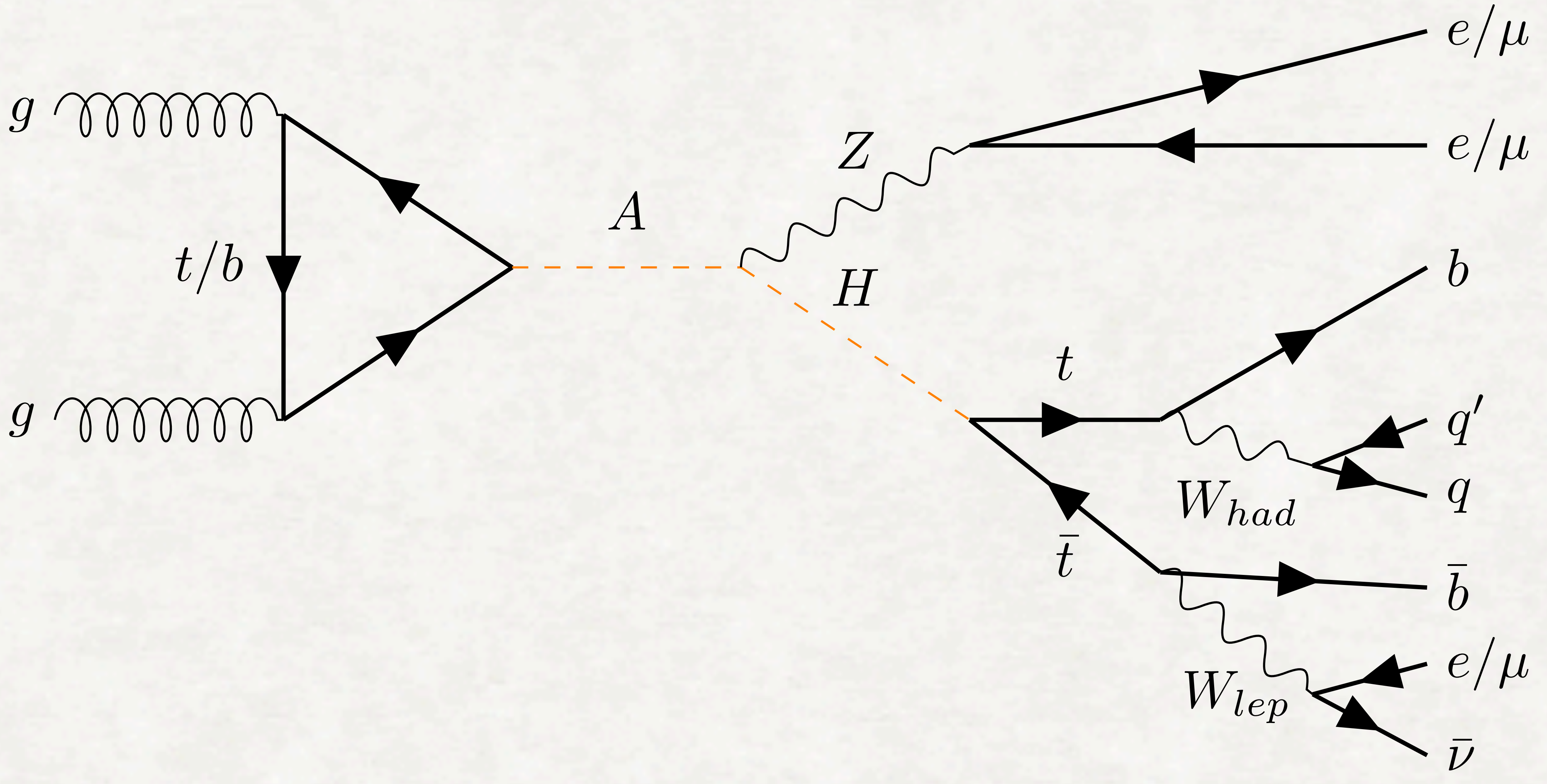


$H \to t\bar{t}$ dominant for
m_H > 350 GeV (ca 2*m_{top})

Selection & Reconstruction

Z Boson: decay to 2 leptons of **opposite charge, same flavour**
1 top: hadronic decay->1 **b-jet** + 2 **jets**
1 top: leptonic decay->1 **lepton** + 1 **b-jet**

⇒≥4 jets, exactly 2 b-jets, exactly 3 leptons



Z-Boson reconstruction:

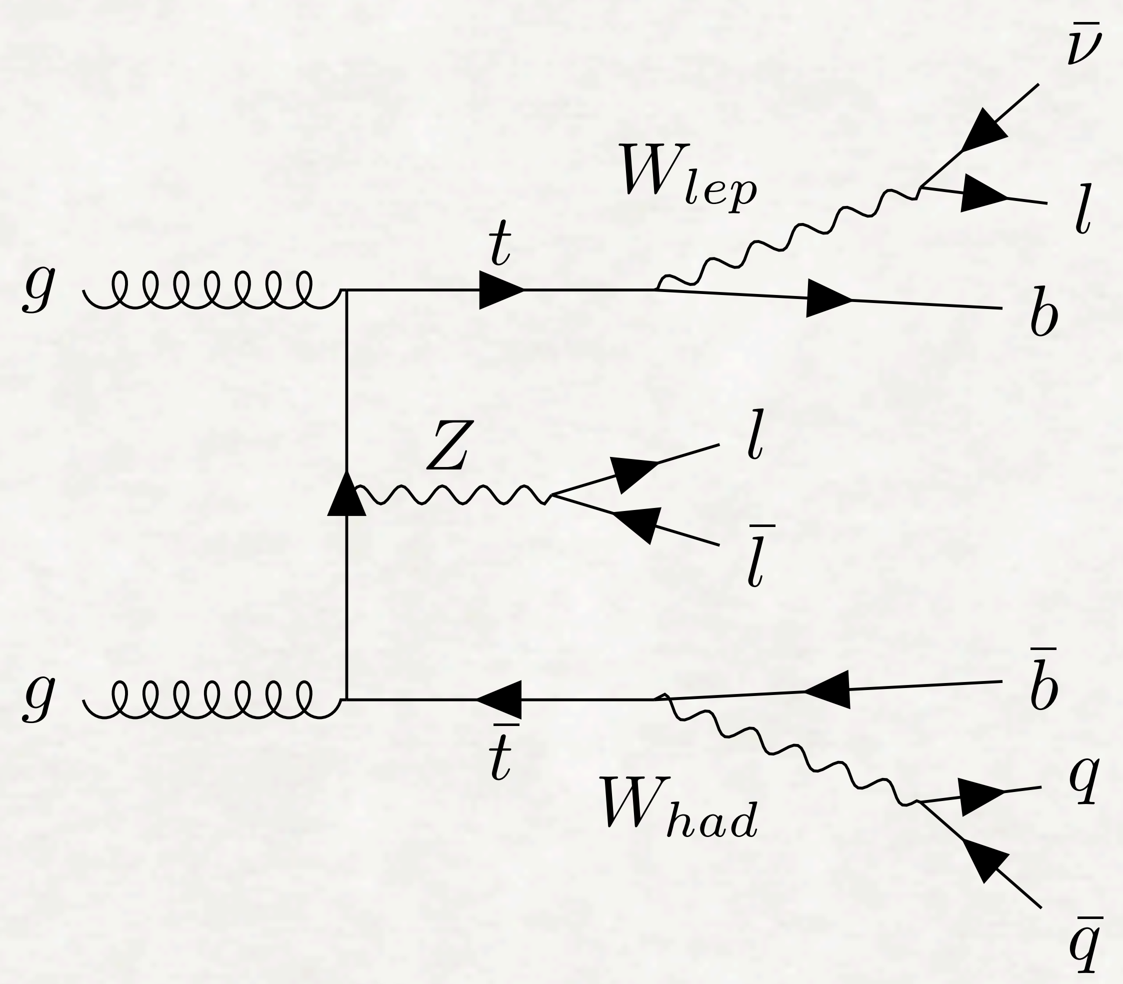
- oppositely charged leptons
- same flavour leptons
- if more than 1 possible pair(in $eee/\mu\mu\mu$):
  pair with mass closest to m_Z

$t\bar{t}$ reconstruction:

leptonic top $t \rightarrow l + \nu + b$	hadronic top $t \rightarrow q + q' + b$
• lepton not from Z • b-jet with min dR to this lepton	• 2 light jets with mass closest to m_W • b-jet not from leptonic top

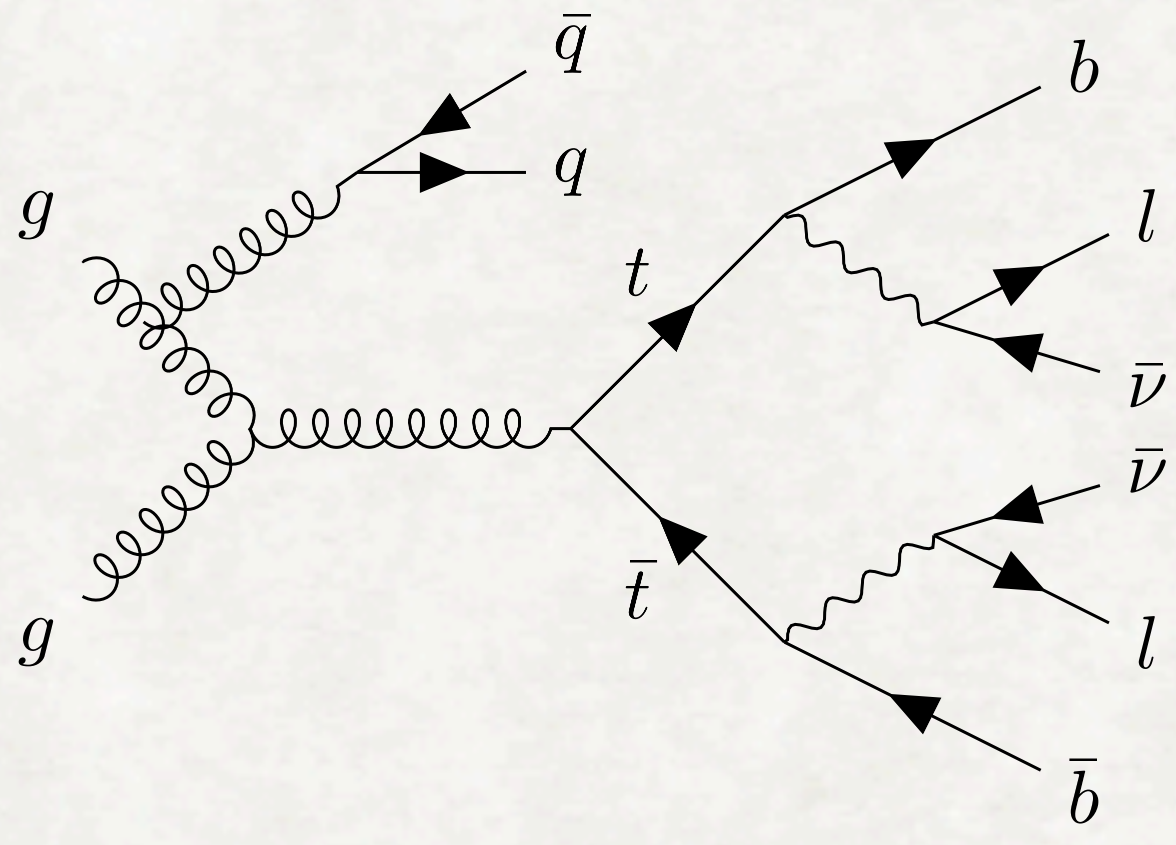
Main Backgrounds

ttZ



- irreducible
- softer leptons, different topology
- No resonance in m_{VH} expected

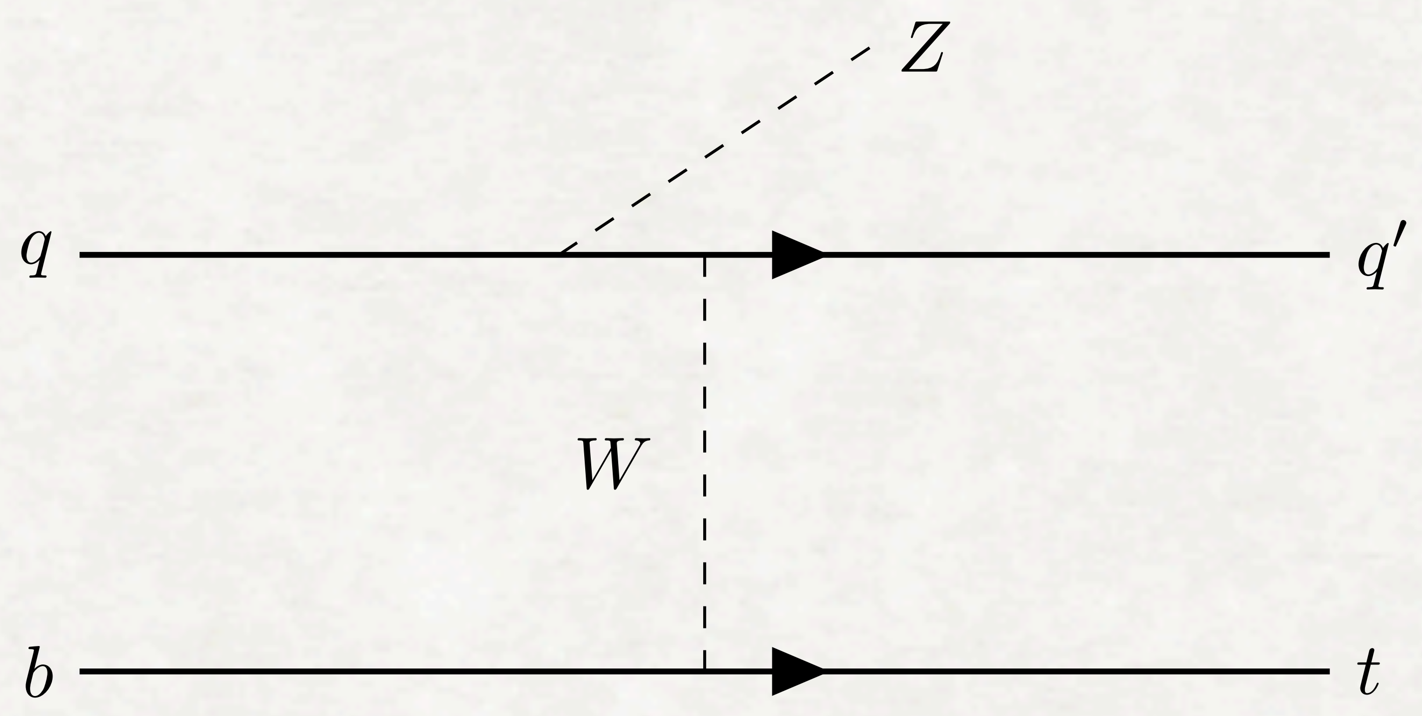
tt+fake lepton



- low rate, but cross section >200 higher than other bkgs
- $m_{jj} \neq m_W$, $m_{ll} \neq m_Z$
- fake lepton: something wrongly reconstructed as lepton (Pile Up,…)
- No resonance in m_Z expected

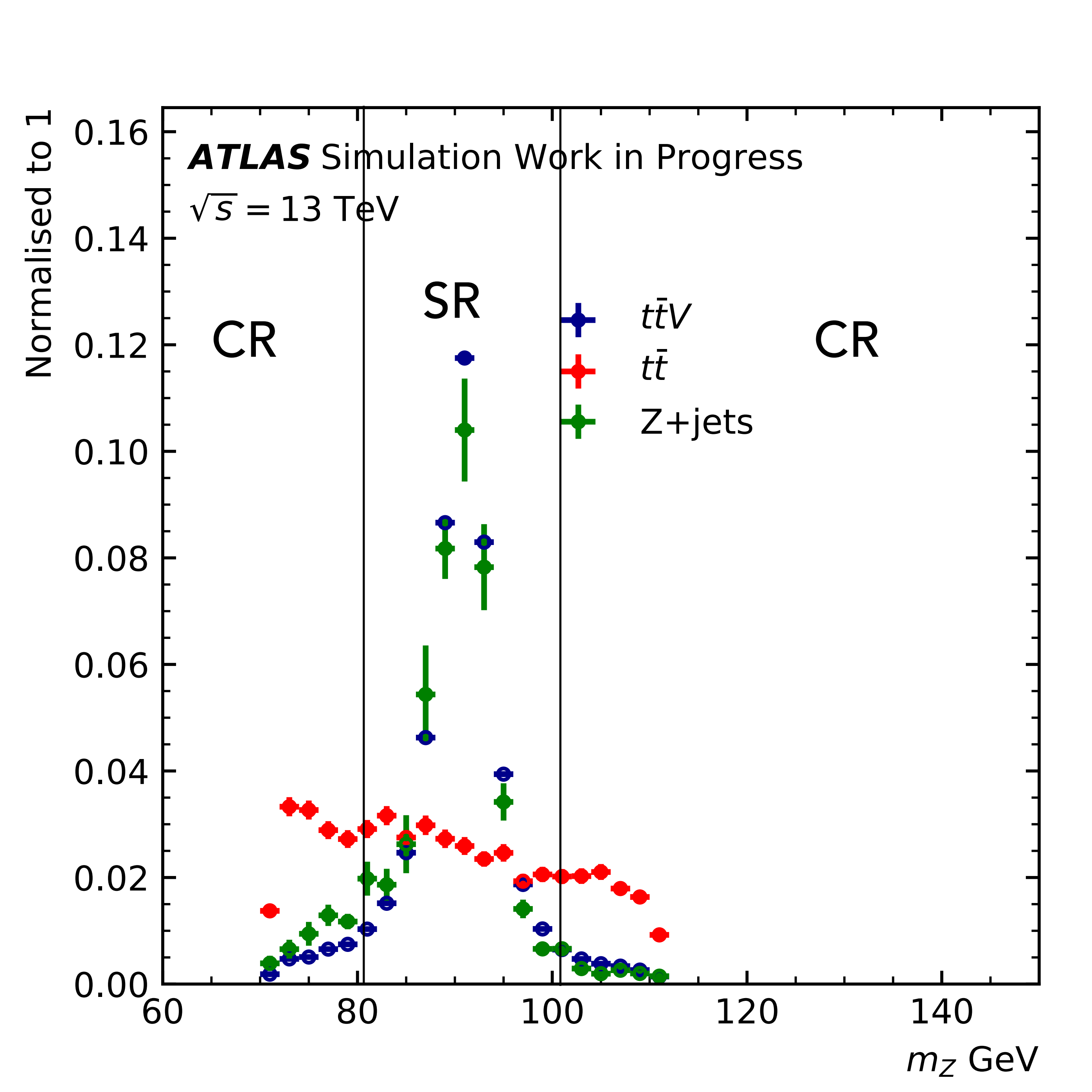
single top + Vector boson

- third dominant background
- no resonance expected in m_{VH}



Event Selection

	Signal Region	Control Region
Trigger	single-lepton-trigger	
$N_{b\text{-jets}}$	$= 2$	
N_{jets}	≥ 4	
$N_{Leptons}$	$= 3$	
Lepton optimisations	at least 1 opposite sign same flavour lepton pair	
b-tag Working Point	77% btag working point	
Jet optimisations	Muon in jet correction	
η (H) in ZH restframe	value is m_A/m_H dependent	
p_T l1/l2/l3	27/13/13 [GeV]	
m_Z window cut	$\|m_{ll} - m_Z\| < 10$ GeV	10 GeV $< \|m_{ll} - m_Z\| < 20$ GeV



CR rich in $t\bar{t}$ events

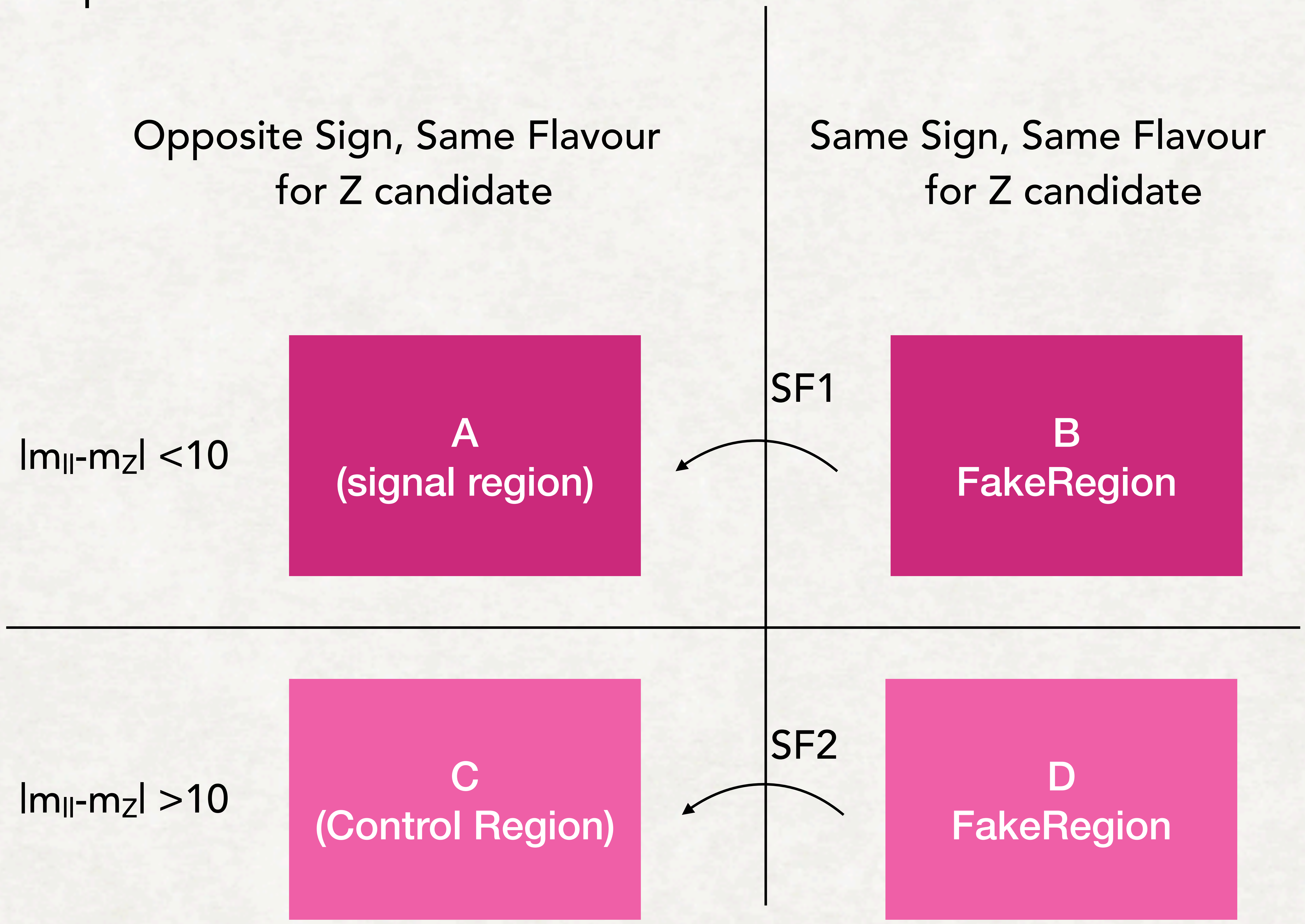
optimised cuts

Fake estimation

use Control Region to estimate ttbar+fake in signal region

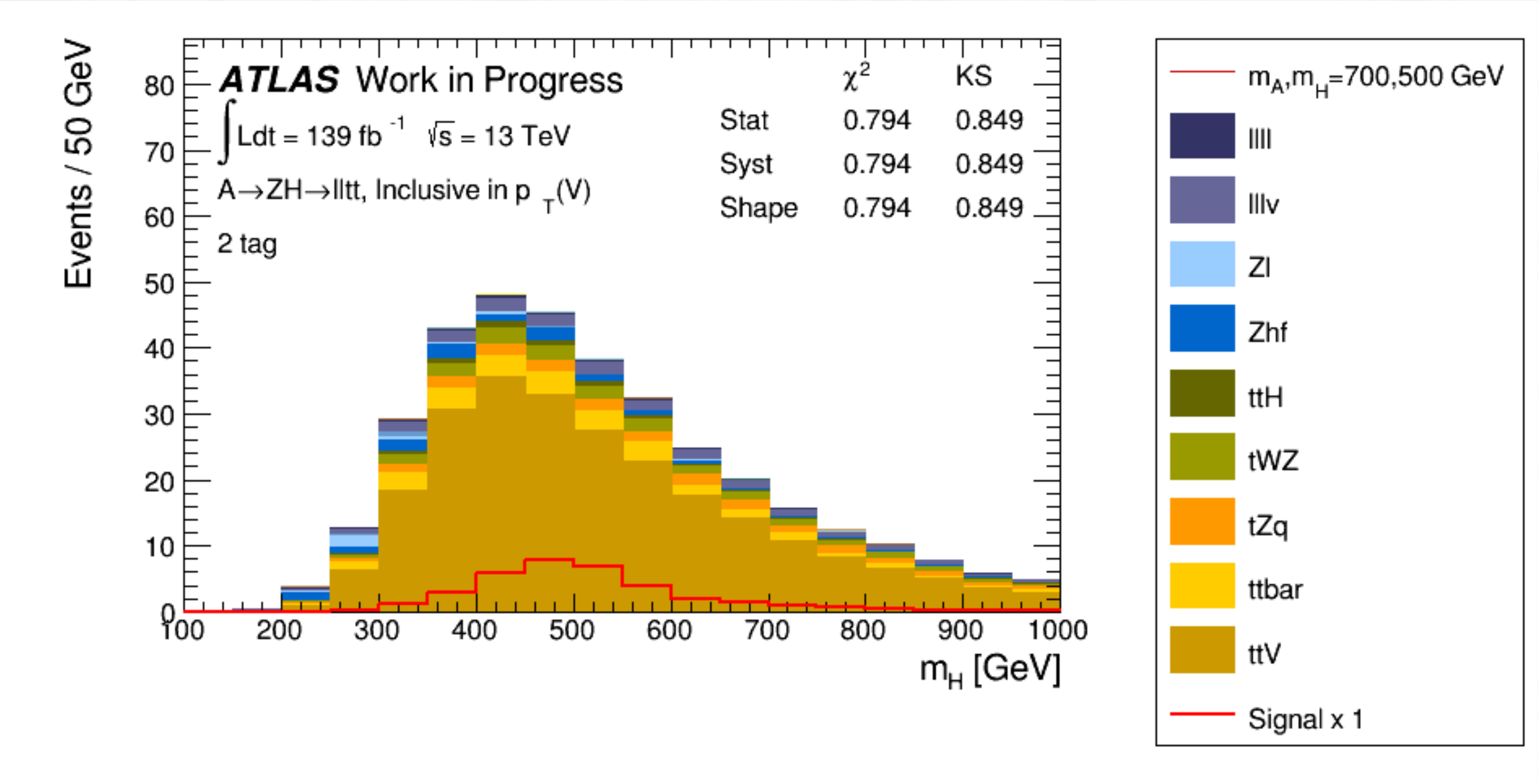
- B/C/D are regions with dominantly fake processes
- assume SF1≈SF2

$$\Rightarrow N_A \approx N_B \cdot \frac{N_C}{N_D}$$



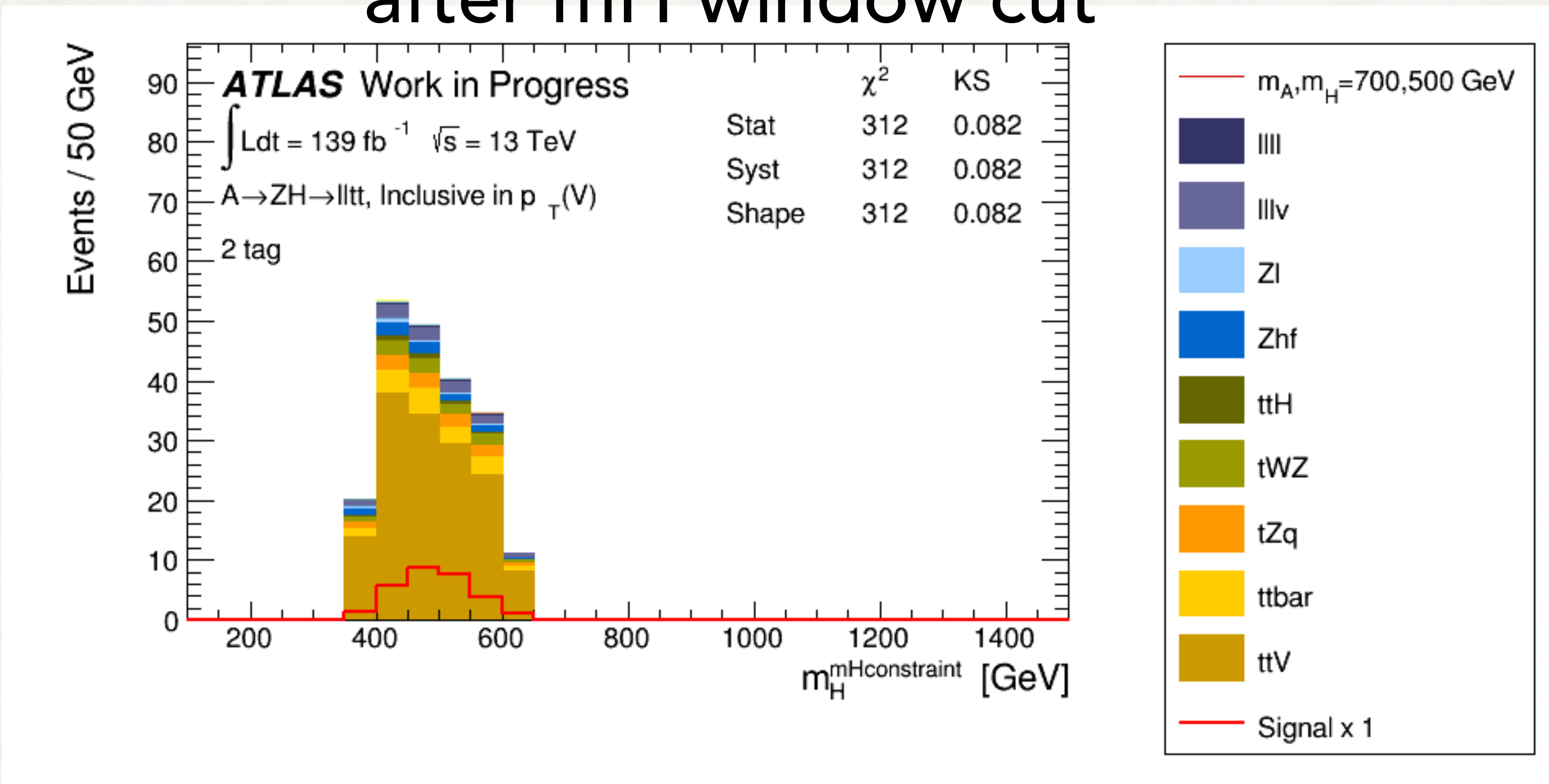
Rescaling of m_H

before mH window cut



- testing different mass hypotheses for mH
- rescaling of m_H , since m_H hypothesis is known

after mH window cut



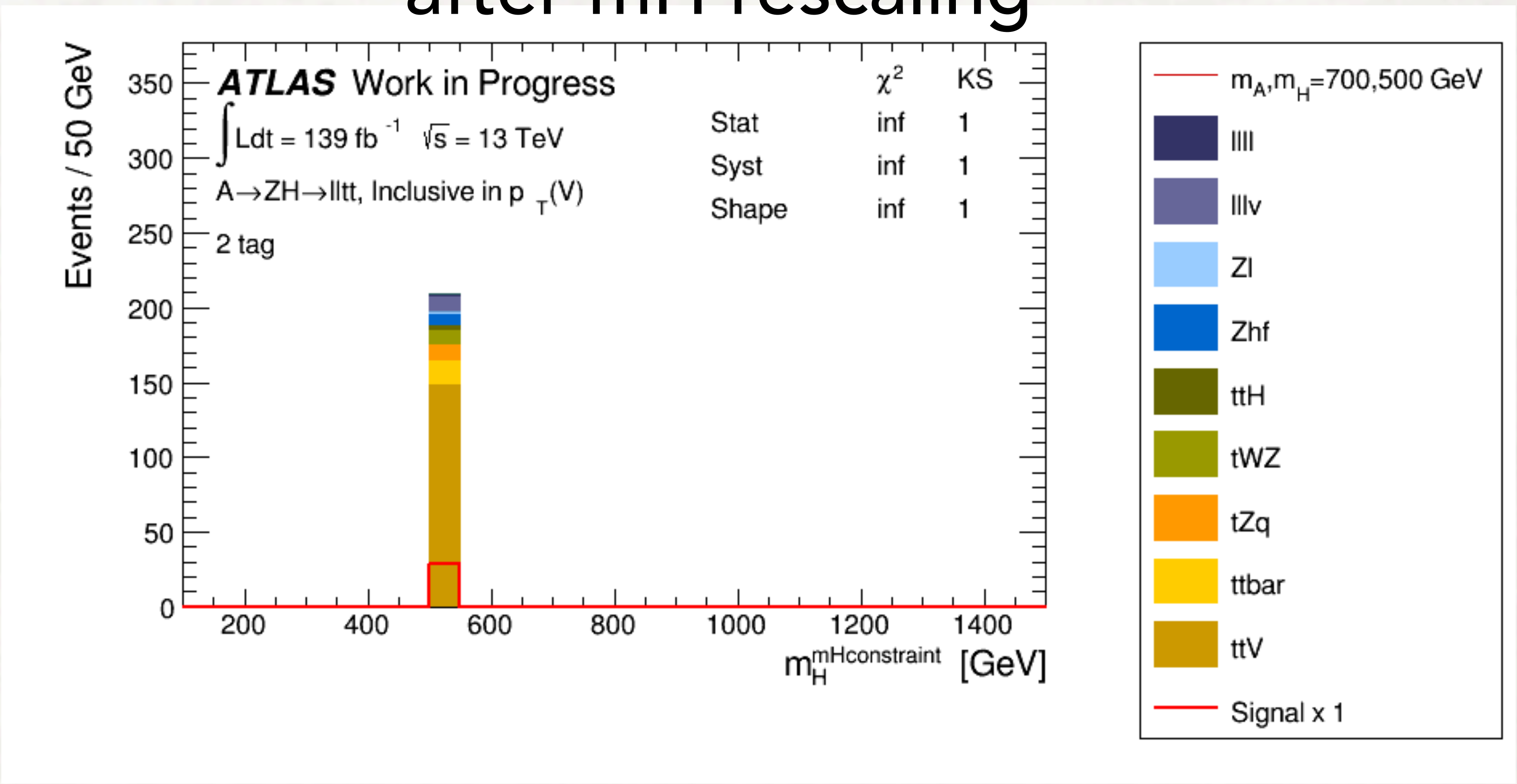
rescale Lorentz vector of H_{recon} to match m_H hypothesis

$$p(t\bar{t}_{1,2}) \rightarrow p(t\bar{t}_{1,2}) \cdot m_{H\ hypo} / m_{t\bar{t}}$$

apply window cut on m_H

$$|m_{reco} - m_{H\ hypo}| < \begin{cases} 1.5 \cdot \sigma(m_{reco}) & \text{if } m_{H\ hypo} < 500\ \text{GeV} \\ 2.0 \cdot \sigma(m_{reco}) & \text{if } m_{H\ hypo} \geq 500\ \text{GeV} \end{cases}$$

after mH rescaling

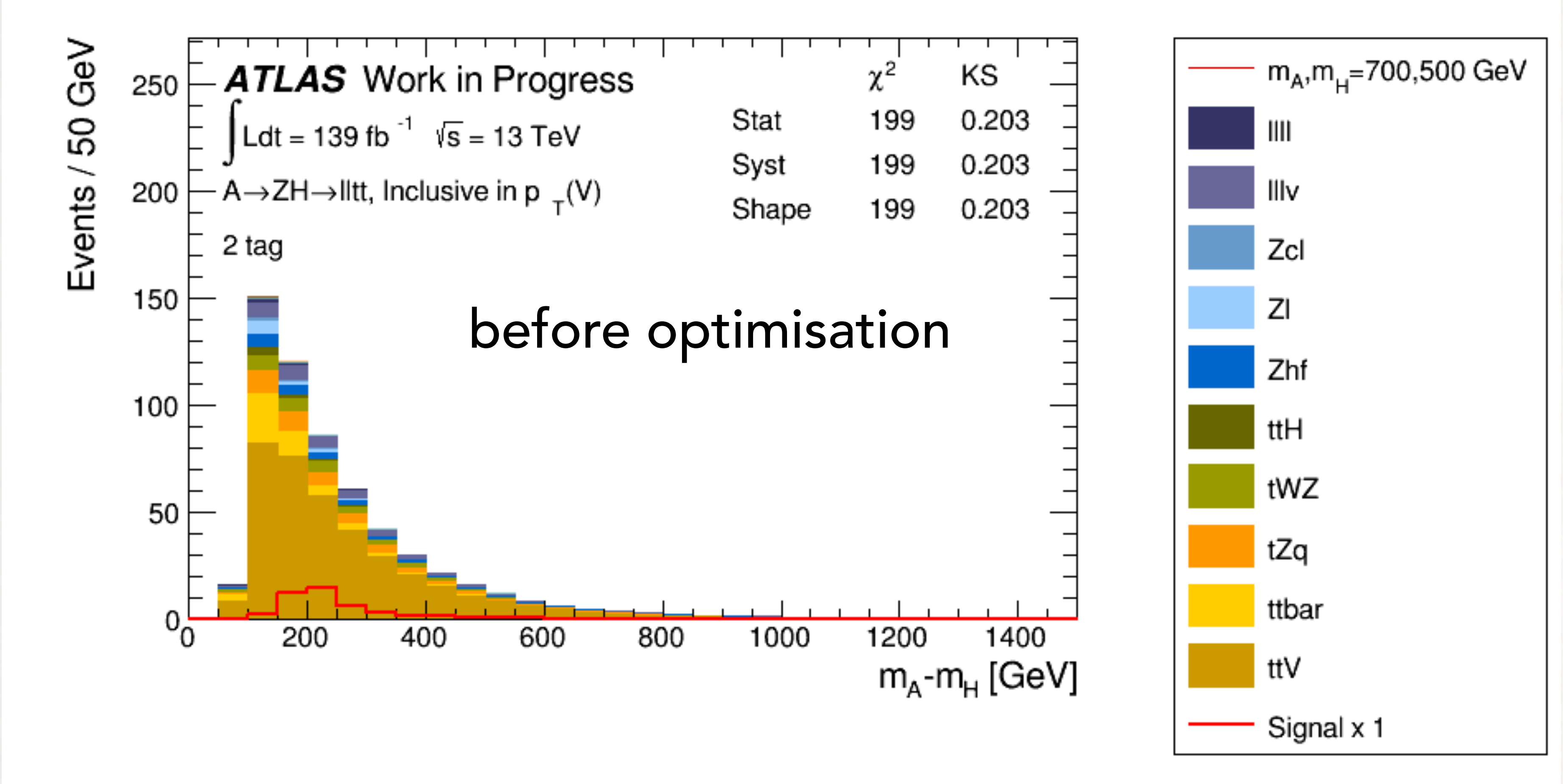


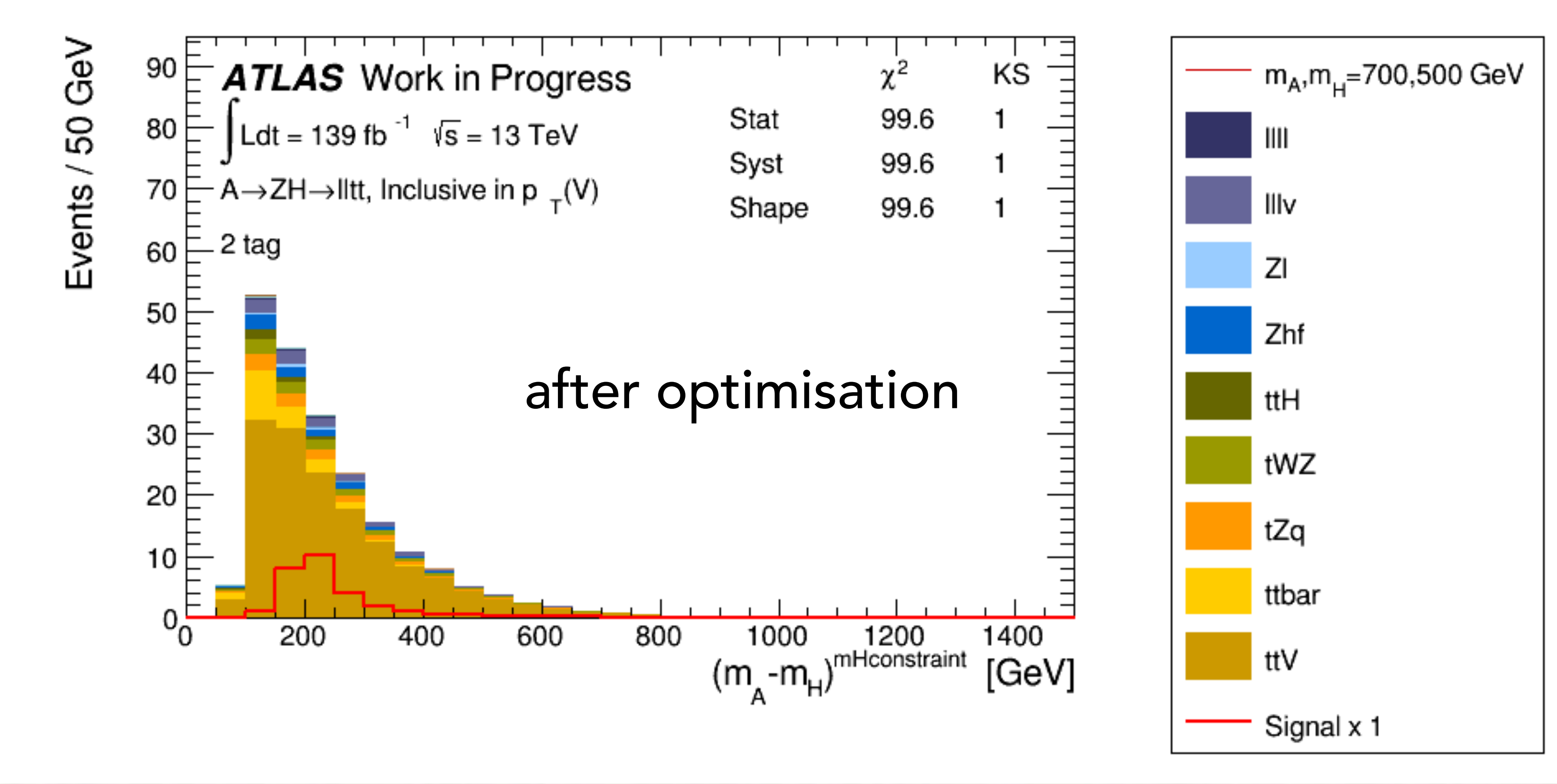
if signal is present, expect resonance in m_A , m_H & m_A - m_H

further information: arXiv:1807.07734

⇒ use m_A - m_H in bins of m_H

Significances



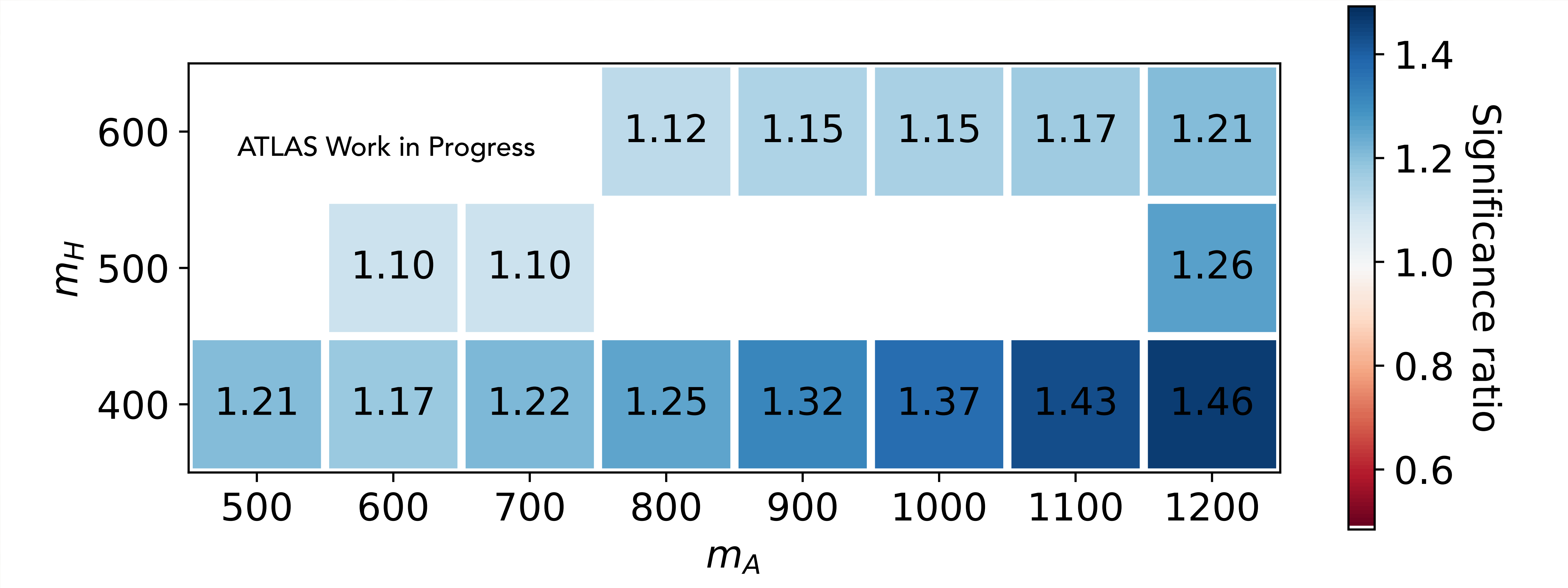


- significance calculated for variable m_A - m_H
- Asymptotic log-likelihood ratio formula

$$\Rightarrow S = \sqrt{\sum_{i=0}^{n=N_{bins}} \left(2[(s_i + b_i)\ln(1 + \frac{s_i}{b_i}) - s_i] \right)^2}$$

- significance ratio = $\dfrac{\text{significance after cut}}{\text{significance before cut}}$

- with optimised cuts significance increases up to 45%
- especially for high m_A - m_H splitting significance improved >= 20%



Future Steps & Outlook

Fitting:

- binned profile likelihood fit to data
- obtain upper limits on cross section for different signal hypotheses

Systematic uncertainties

include systematic uncertainties arising from

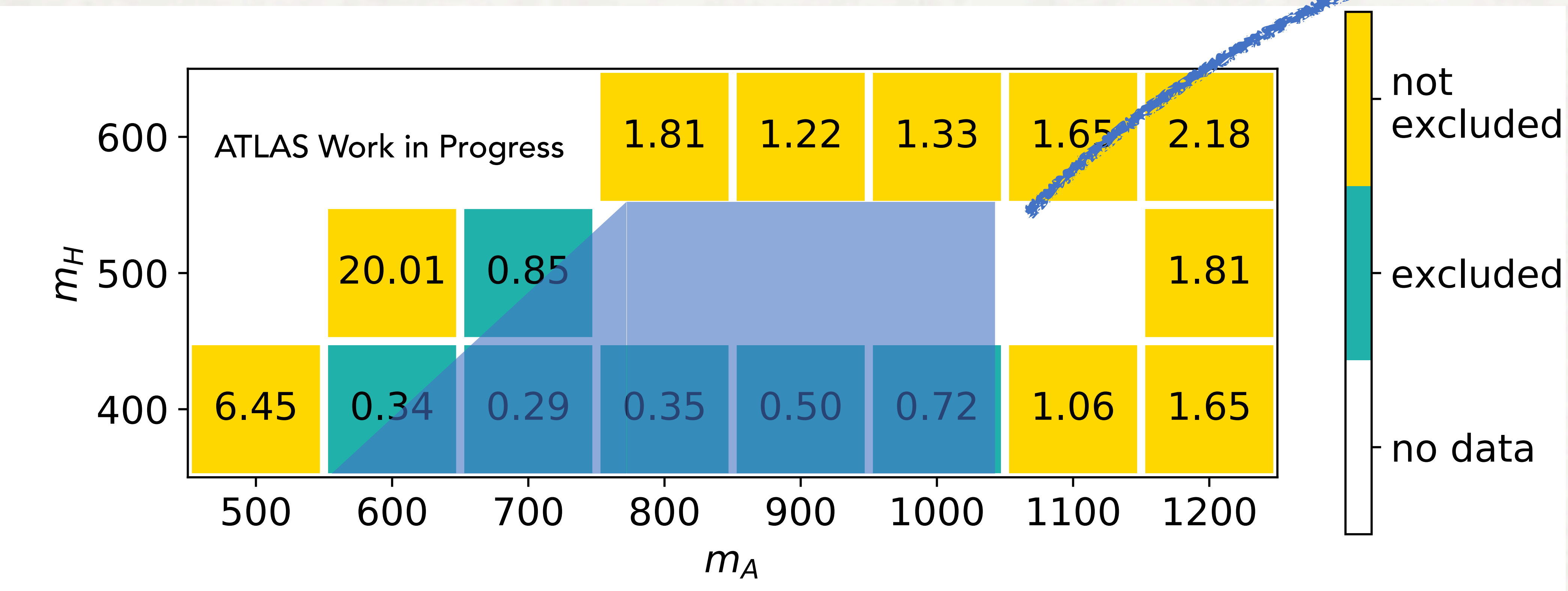
- detector
- theoretical uncertainties

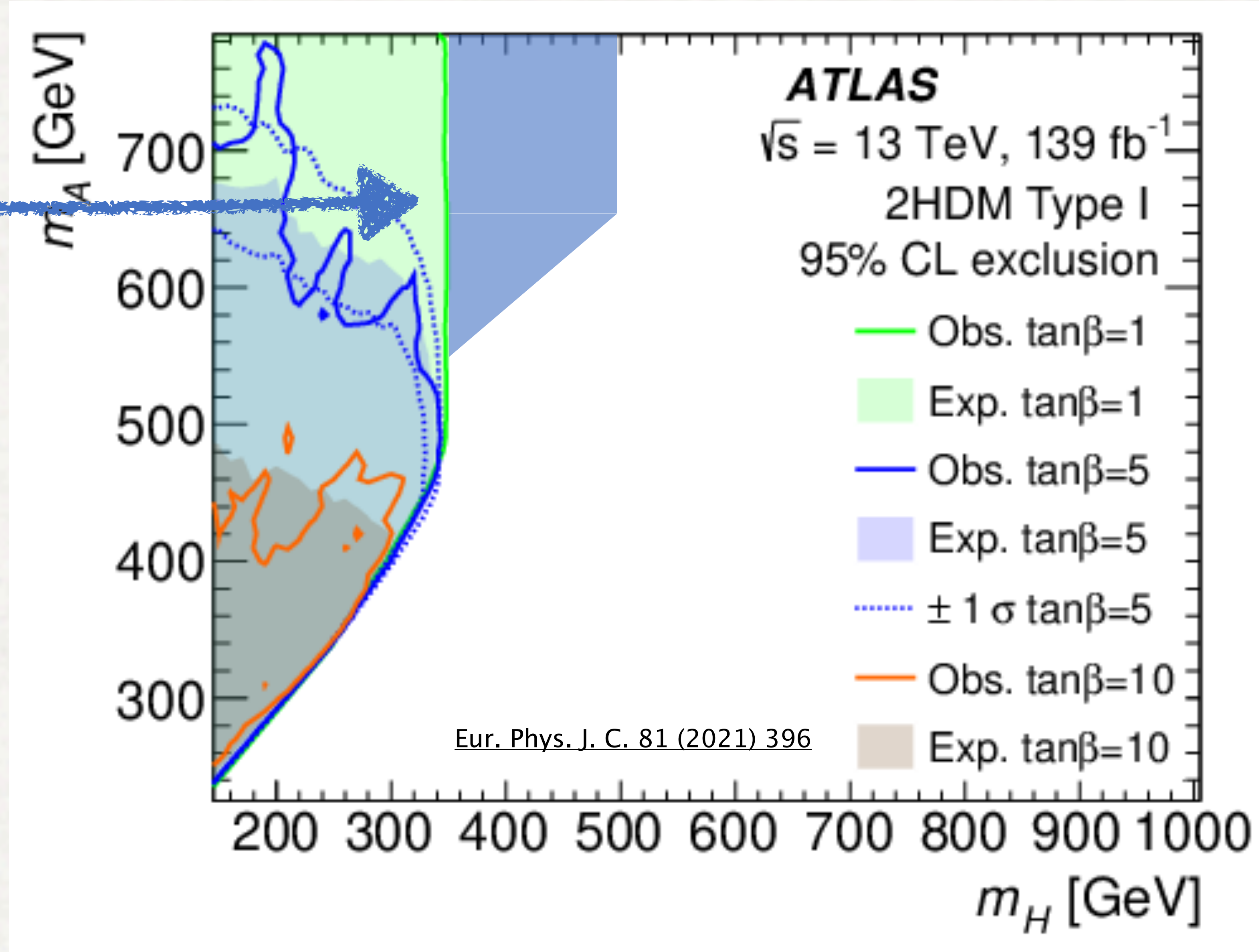
impact of uncertainties is under study

Aim:

test if signal is present, otherwise:

- put upper limits on $\sigma(A \rightarrow ZH \rightarrow \ell\ell t\bar{t})$



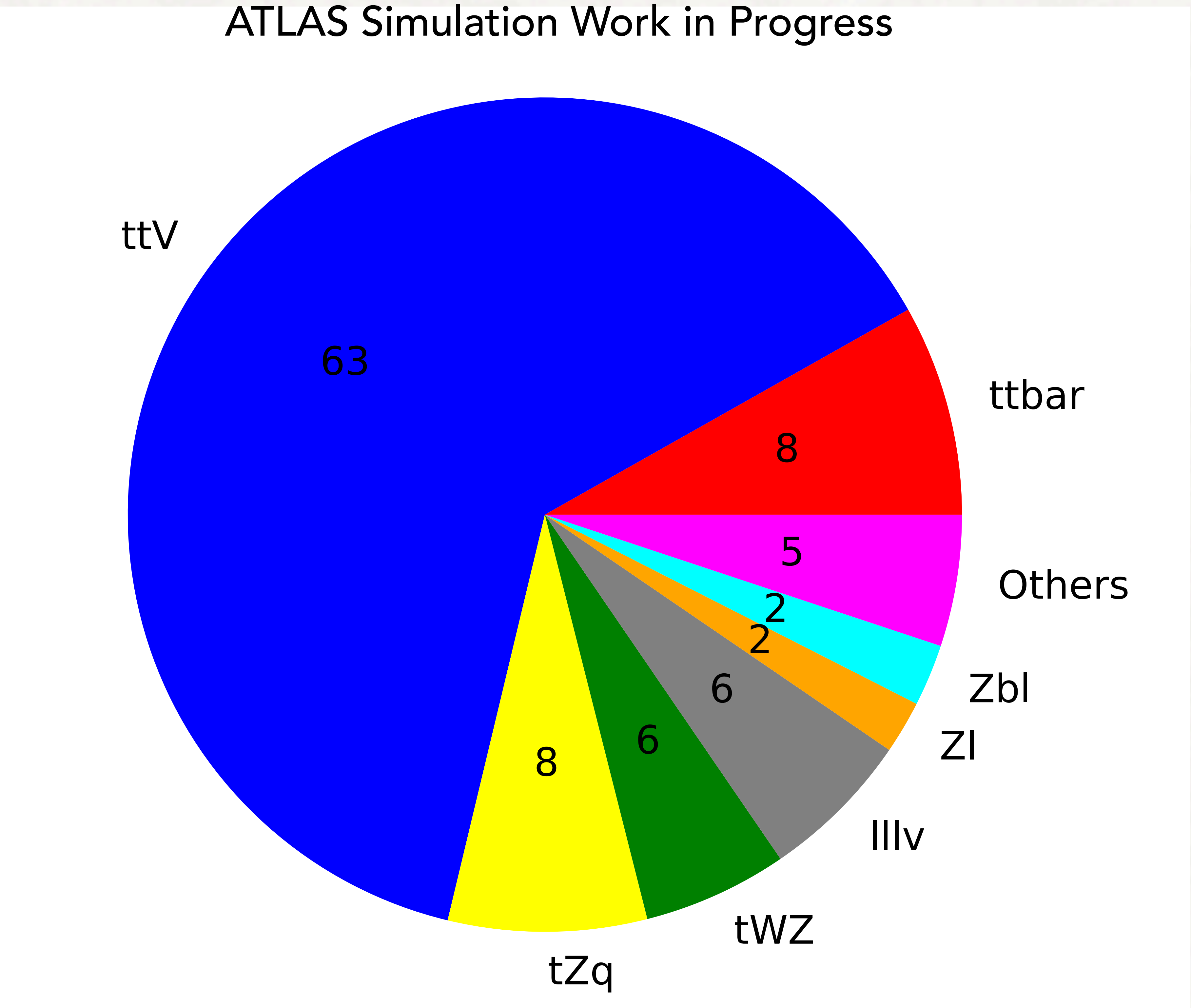


probe phase space so far unexplored with the LHC

— for a bridge between Particle Physics and Cosmology —

Back Up

Background composition



tWZ