Constraining the Higgs boson width from Higgs-top Yukawa coupling at the ATLAS experiment

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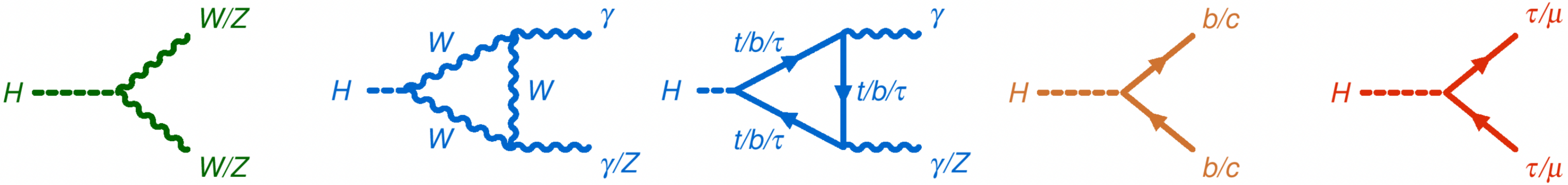
Based on Phys. Lett. B 861 (2025) 139277

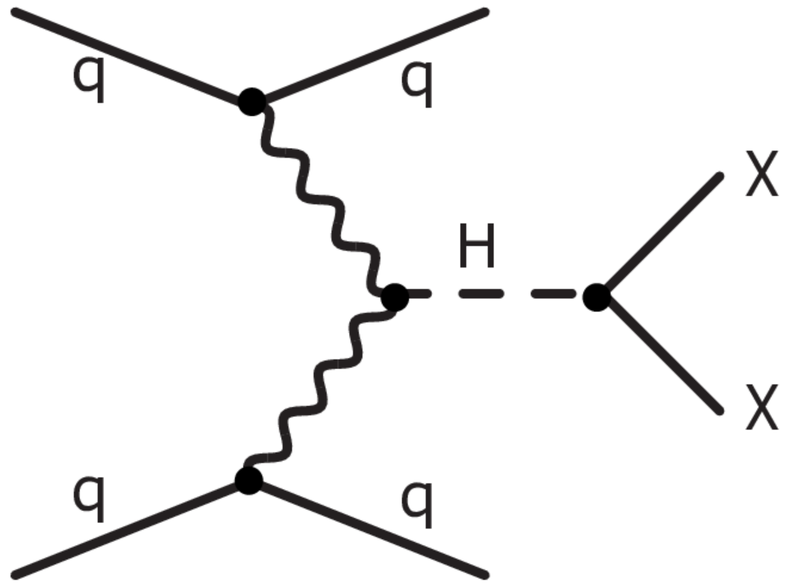
Introduction

- Higgs width:
  - Predicted as 4.1 MeV in SM for a 125 GeV Higgs boson
  - Includes the Higgs boson coupling to the known SM particles
    - No BSM effects assumed



→ Deviation from predicted value will indicate new physics

Such as the composite Higgs model and Higgs invisible decay into light dark matter



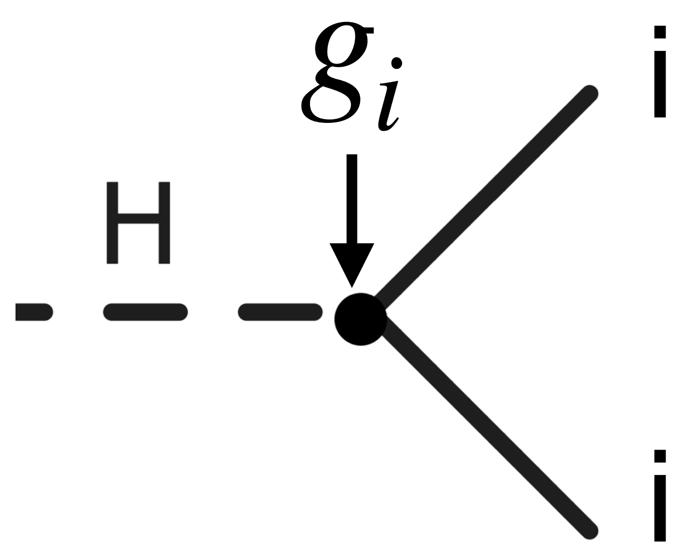
Experimental measurement of the Higgs boson width is important

Indirect Method to Measure Higgs Width

- 4.1 MeV is too small compared to O(GeV) detector resolution for a direct measurement
- Indirect method:
  - Combining on- and off-shell measurements
  - Assumes the same κ for on- and off-shell Higgs coupling

$\rightarrow$ allows us to measure κ and Higgs width simultaneously

Kappa modifier: $\kappa_i = \dfrac{g_i}{g_{i,SM}}$



$$\frac{d\sigma}{dm^2} \sim \frac{g_{i,SM}^2 g_{f,SM}^2 \kappa_i^2 \kappa_f^2}{(m^2 - m_H^2)^2 + m_H^2 \Gamma_H^2}$$

On-shell ⇩

$$R_\Gamma = \frac{\Gamma_H}{\Gamma_{H,SM}}$$

⇩ Off-shell

$$\mu_{i \to H \to f} = \frac{\kappa_i^2 \kappa_f^2}{R_\Gamma}$$

Depend on Higgs width

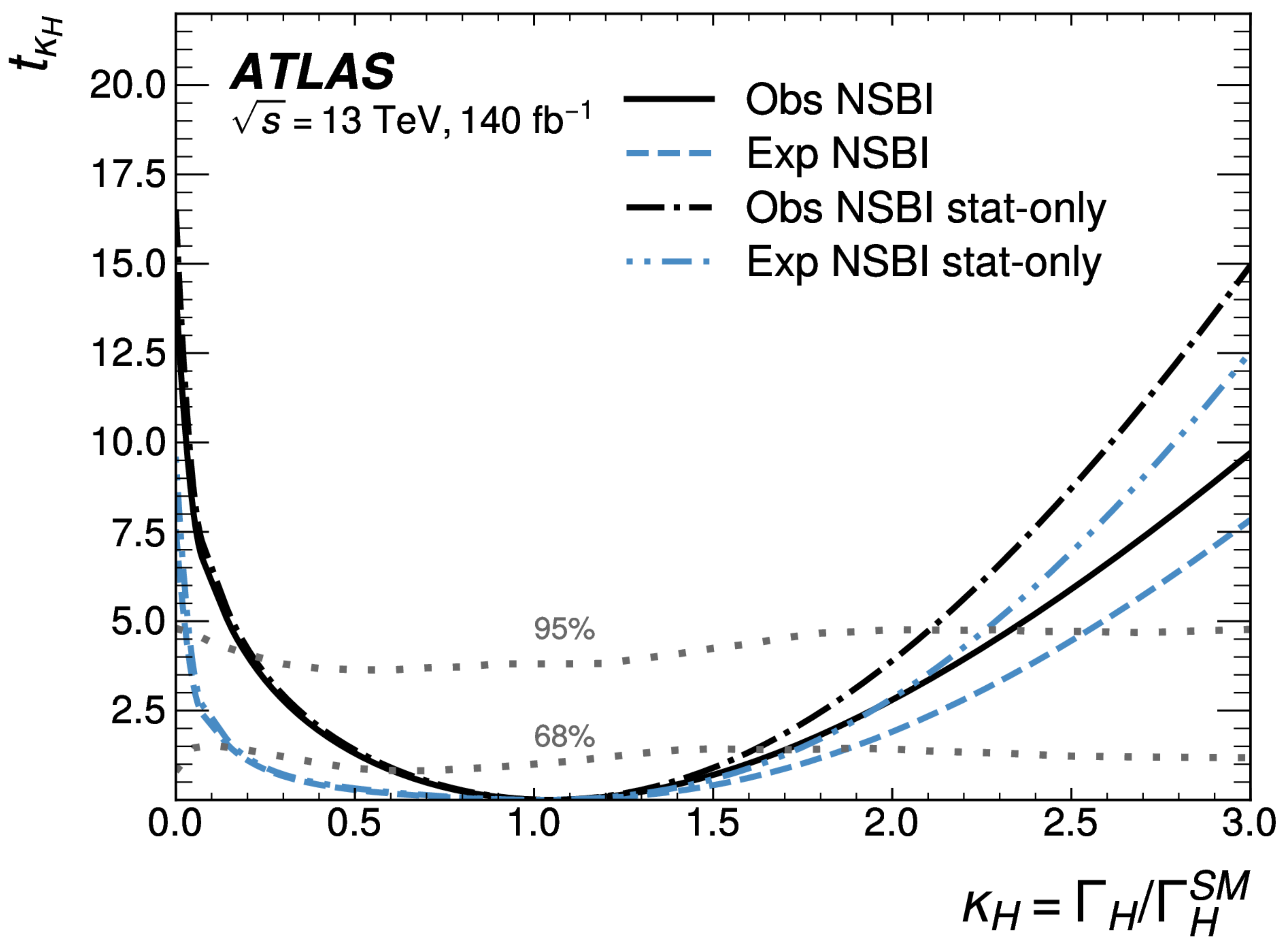
$$\mu_{i \to H \to f} = \kappa_i^2 \kappa_f^2$$

Independent of Higgs width

Γ_H from κ_V

- Decay channels of $H \to ZZ/WW$ has been used to constrain Higgs width since Run1

ATLAS $H \to ZZ$ channel



$\Gamma_H = 4.3^{+2.7}_{-1.9}$ MeV

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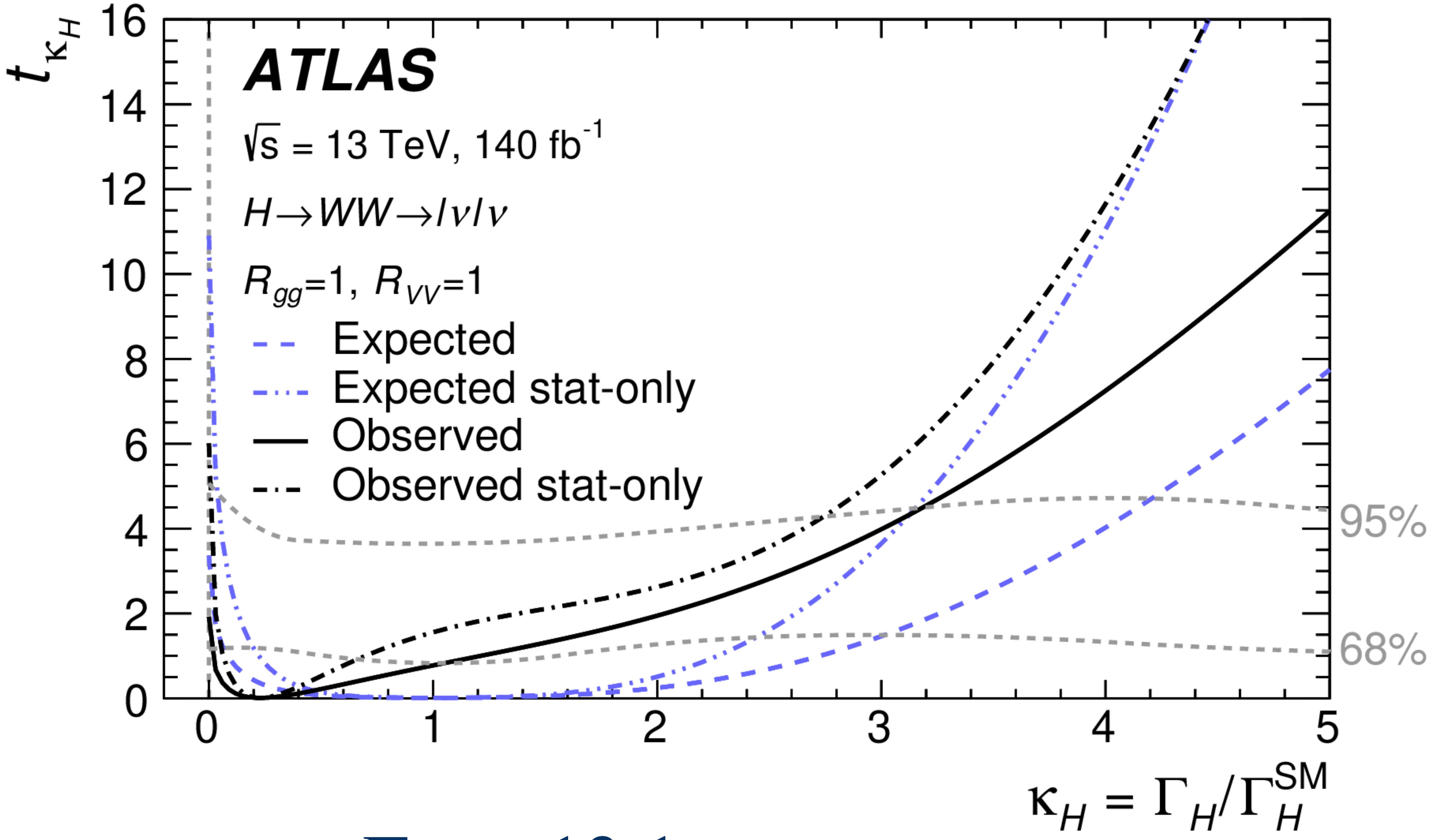
ATLAS $H \to WW$ channel



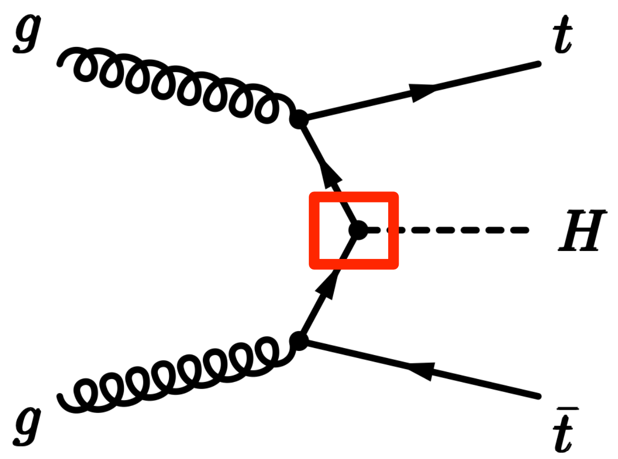
$\Gamma_H < 13.1$ MeV at 95% CL

HIGP-2024-05

- CMS $H \to ZZ$: Phys. Rev. D 111 (2025) 092014, $\Gamma_H = 3.0^{+2.0}_{-1.5}$ MeV

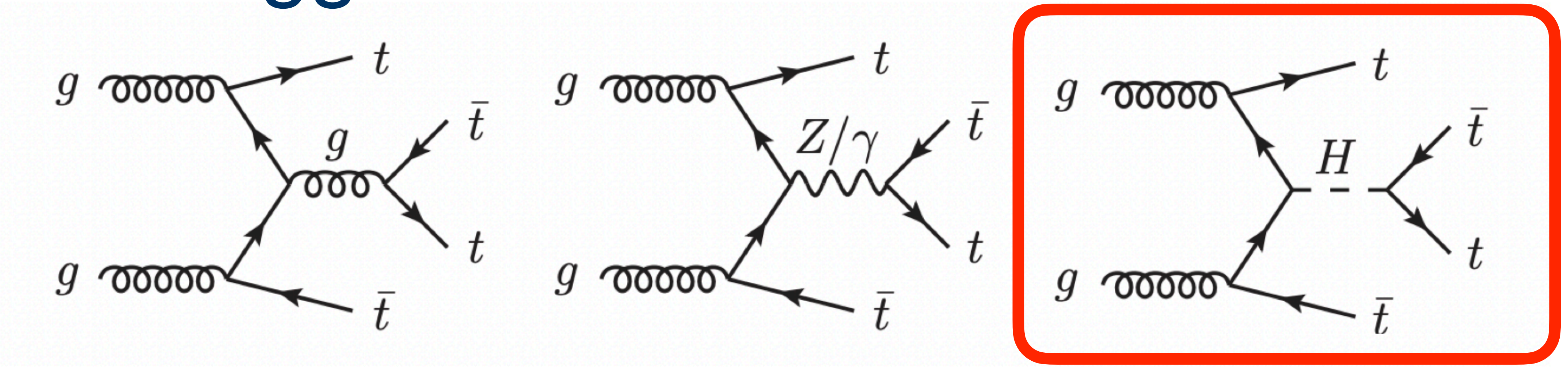
Γ_H from κ_t with Four-Top and On-Shell Higgs

- Different from the previous analysis, we rely on **direct Higgs-Top Yukawa coupling**
  - Not affected by the presence of unknown colored particles
- On-shell measurement has constraints from $t\bar{t}H$ production



Higgs-top vertex

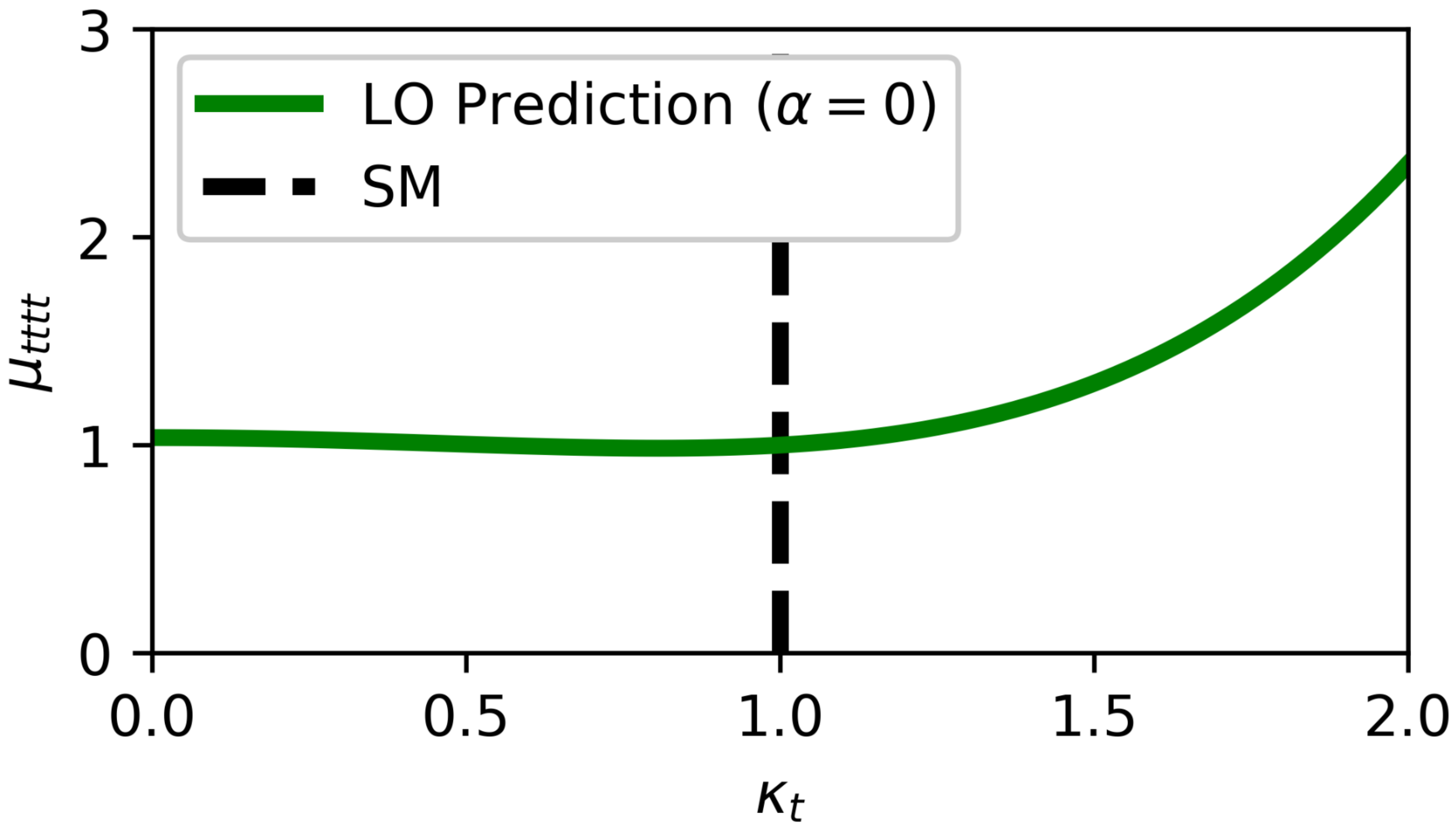
- Four-top cross-section depends on κ_t due to off-shell Higgs contribution



Pure *H* contribution is quartic, interference is quadratic

Inclusive normalized four-top cross-section parameterized as a function of κ_t:

$$\mu_{t\bar{t}t\bar{t}} = 1.04 - 0.16\kappa_t^2 + 0.12\kappa_t^4$$



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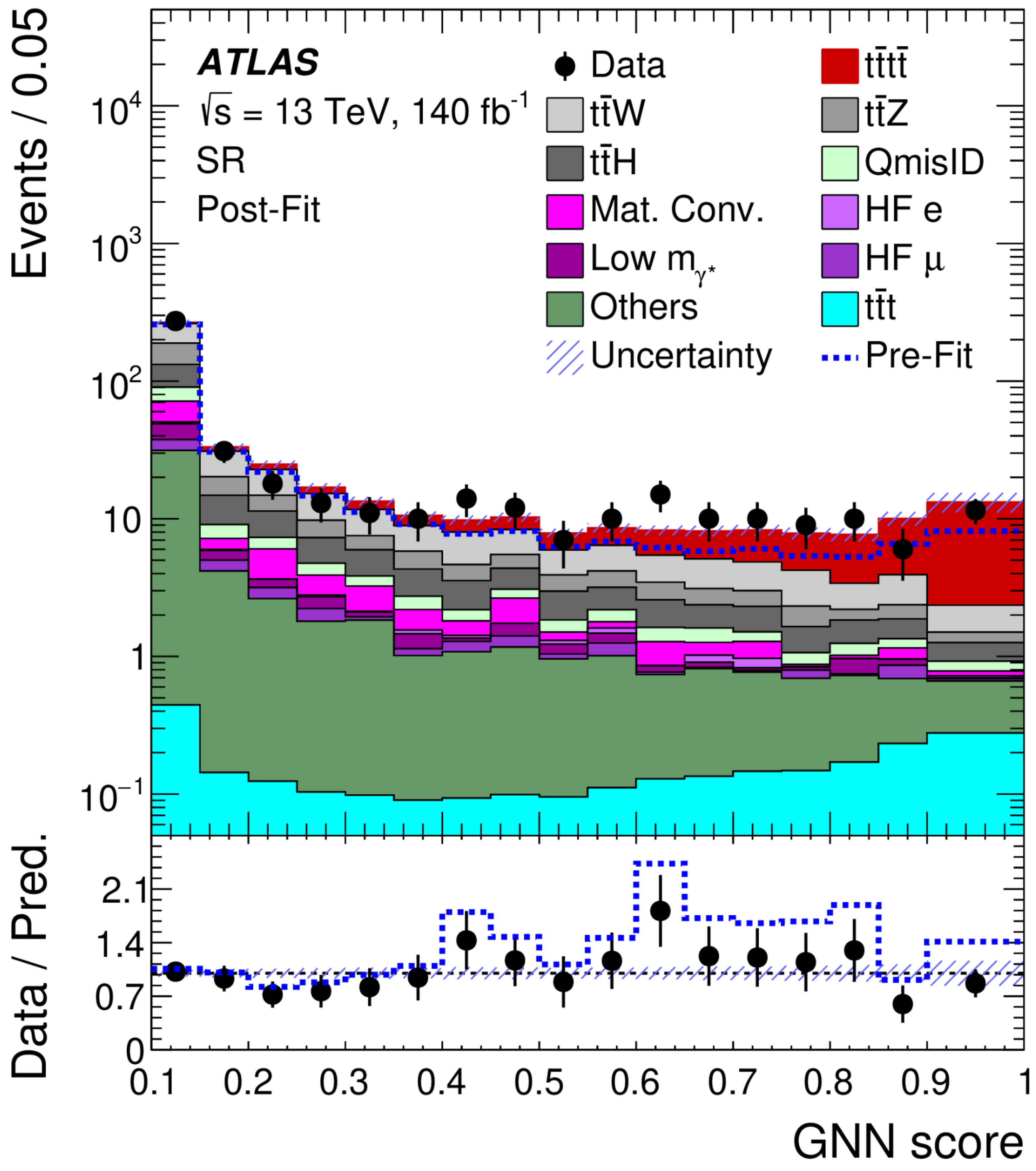
Off-shell part: Four-Top

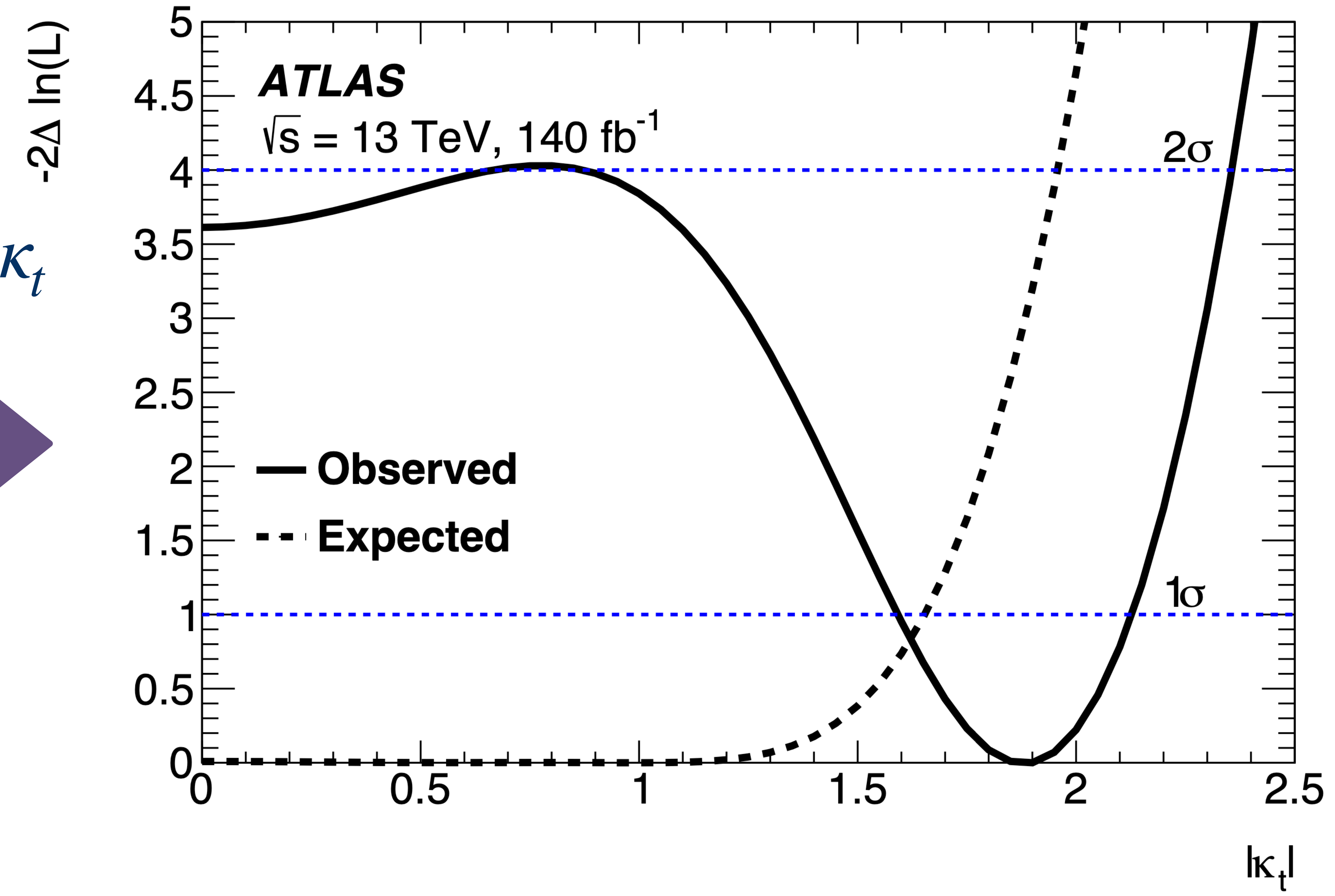
- Analysis targets at Multi-lepton final state
- Graph Neural Network used to separate signal and background processes



Interpreted into κ_t measurement

Eur. Phys. J. C 83 (2023) 496

On-shell ttH yield profiled to data

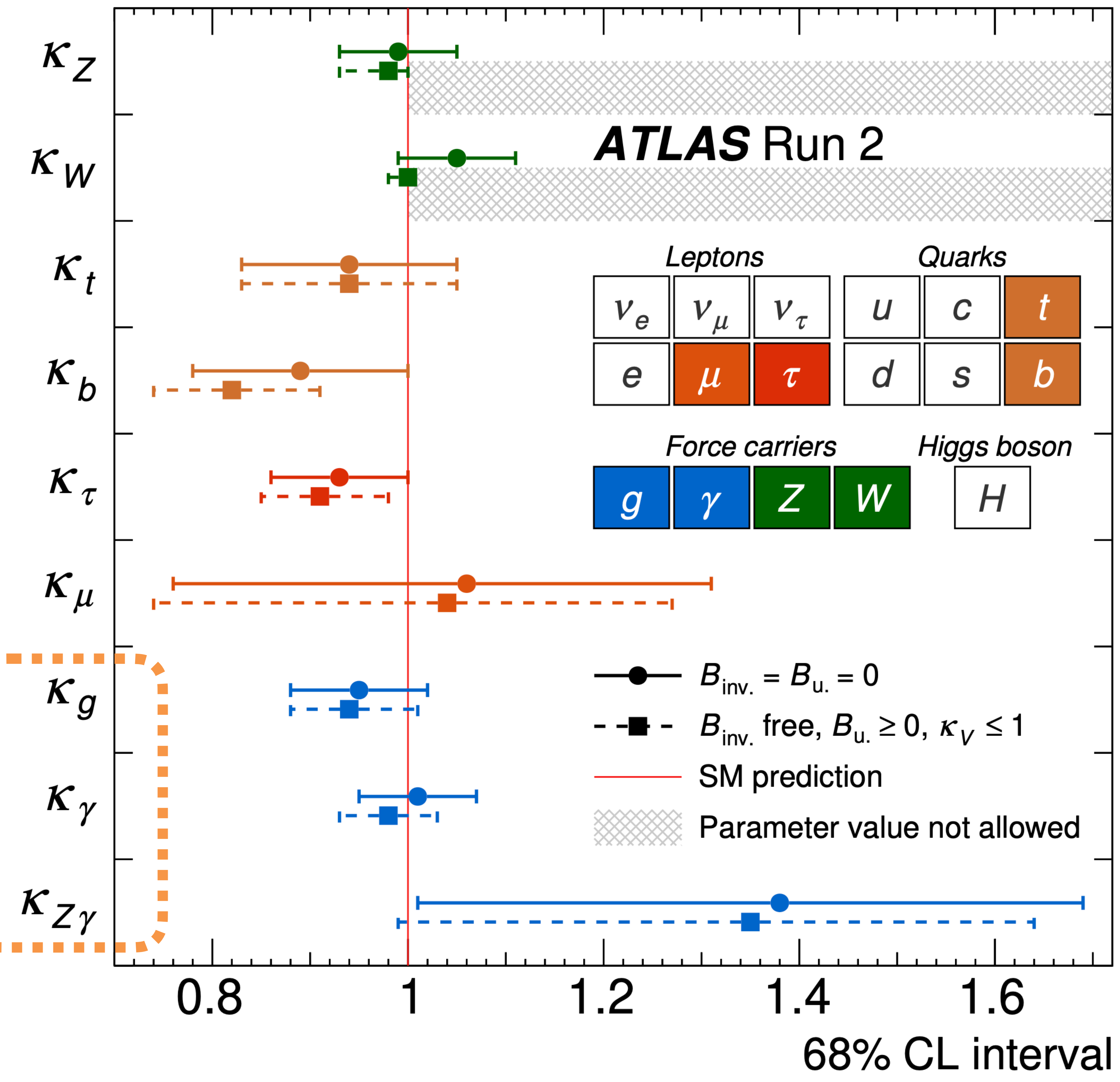


95% CL upper limit: 2.3

First observation with 6σ significance!

On-shell part: Run2 Higgs Coupling Combination

- Covering all major Higgs production and decay modes at LHC. Nature 607 52 (2022)



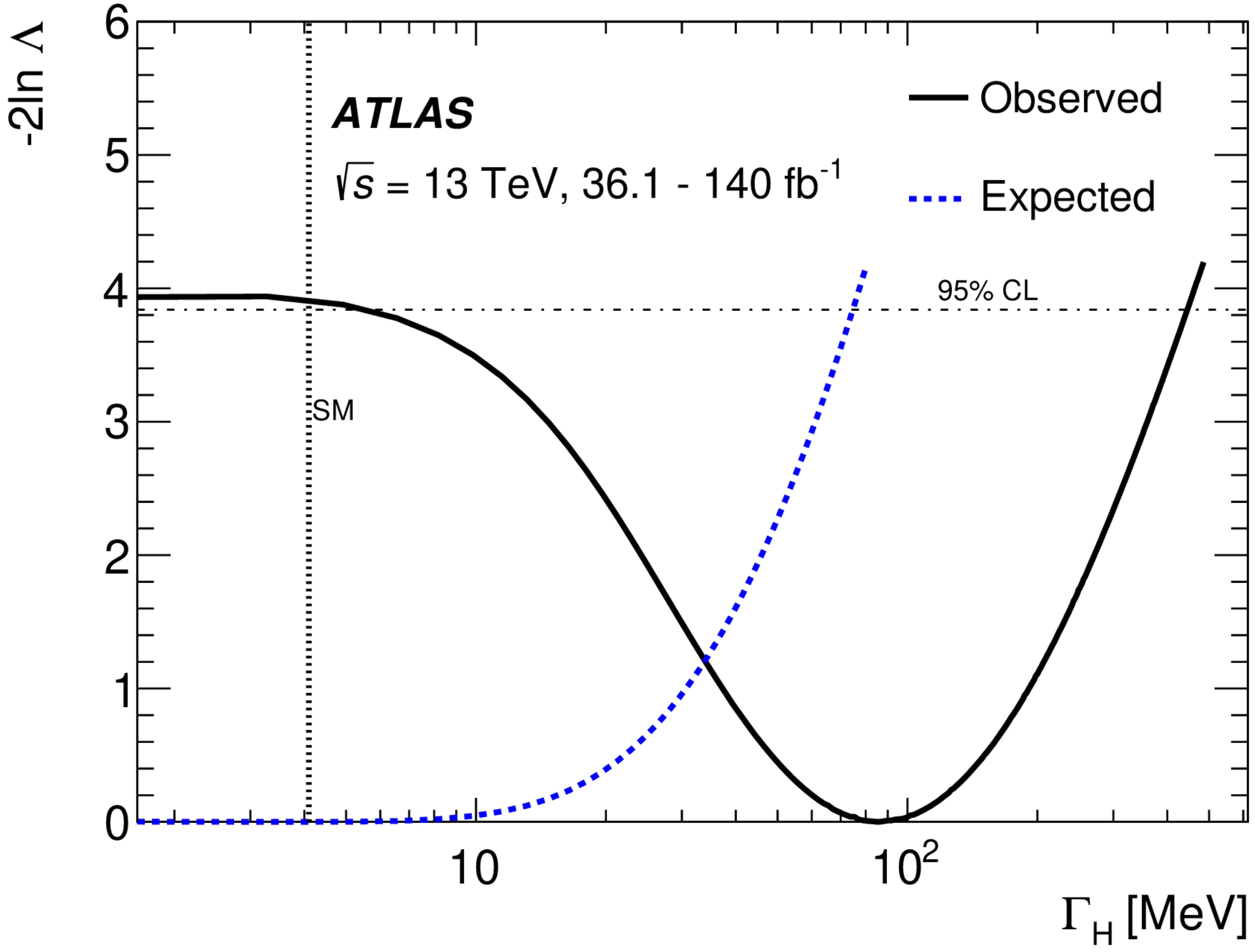
Loop-induced, BSM particles can enter the loops

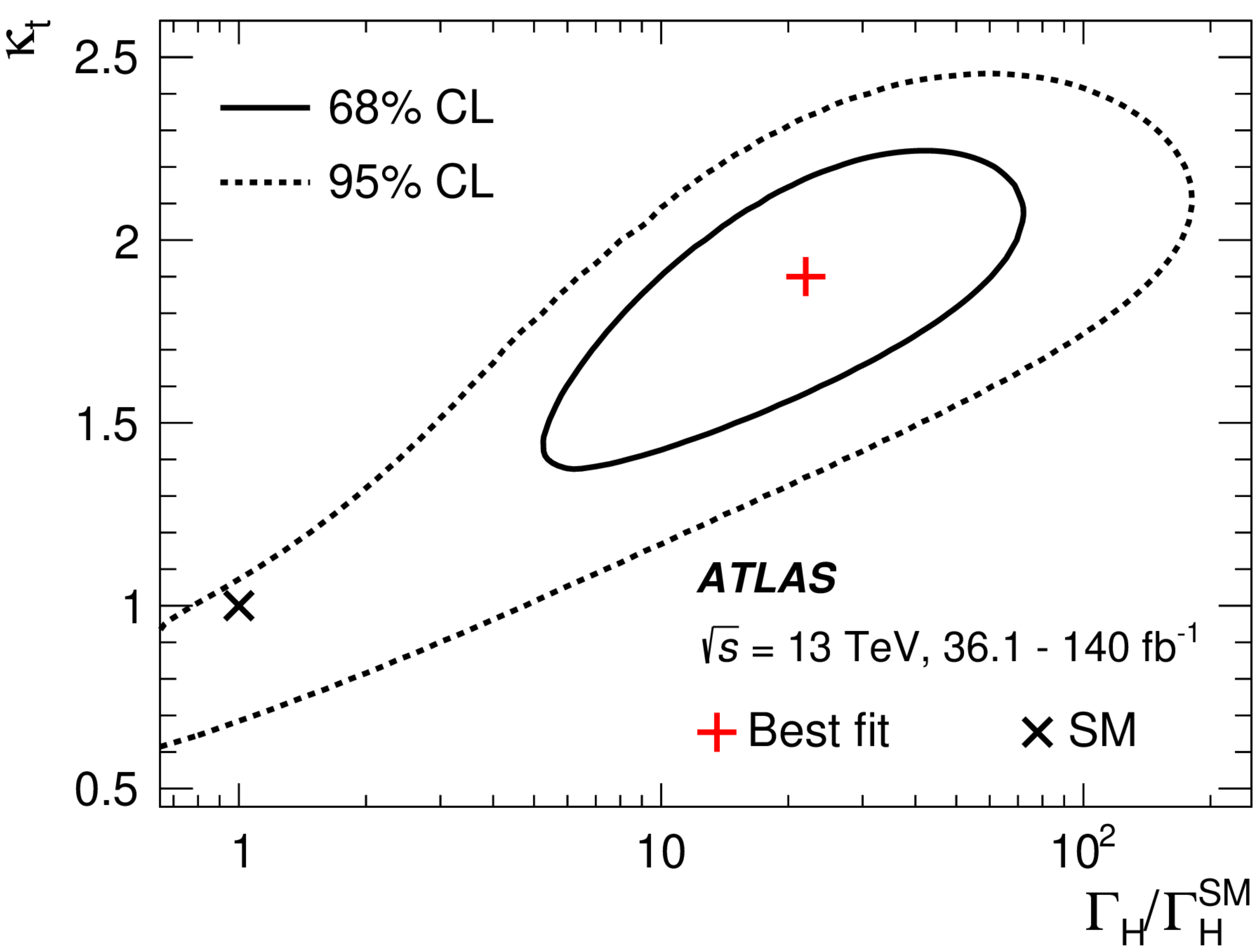
On-shell measurements	
Production	Decay
ggF, VBF, WH, ZH, $t\bar{t}$H, tH	$H \to \gamma\gamma$
$t\bar{t}$H + tH	$H \to b\bar{b}$
WH, ZH	$H \to b\bar{b}$
VBF	$H \to b\bar{b}$
ggF, VBF, WH + ZH, $t\bar{t}$H + tH	$H \to ZZ$
ggF, VBF	$H \to WW$
WH, ZH	$H \to WW$
ggF, VBF, WH + ZH, $t\bar{t}$H + tH	$H \to \tau\tau$
ggF + $t\bar{t}$H + tH, VBF + WH + ZH	$H \to \mu\mu$
Inclusive	$H \to Z\gamma$

*To combine with four-top measurement, $t\bar{t}H \to$ Multi-lepton channel is removed from the on-shell part due to non-trivial overlap between them

Upper limit on Γ_H

- Loop-induced $\kappa_g, \kappa_\gamma, \kappa_{Z\gamma}$ are profiled to data simultaneously with other κ





	Observed	Expected
95% CL upper limit [MeV]	450	75

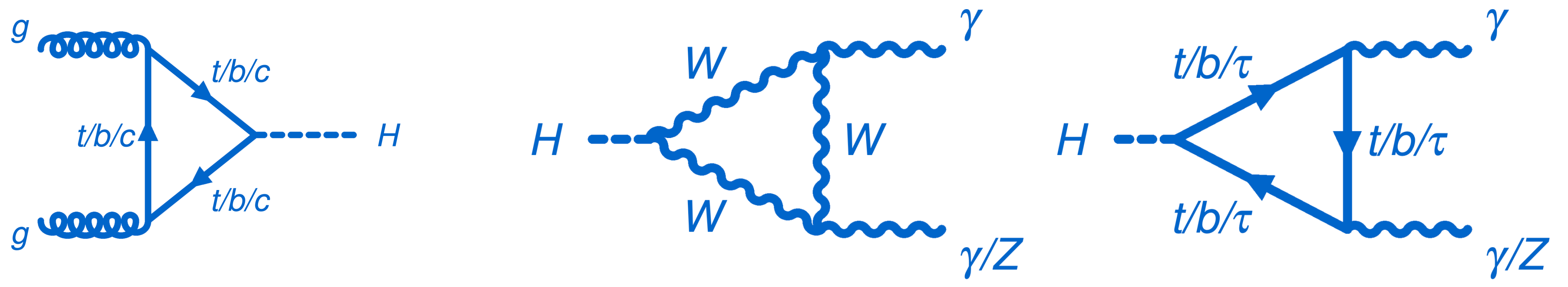
Impact of systematic uncertainties

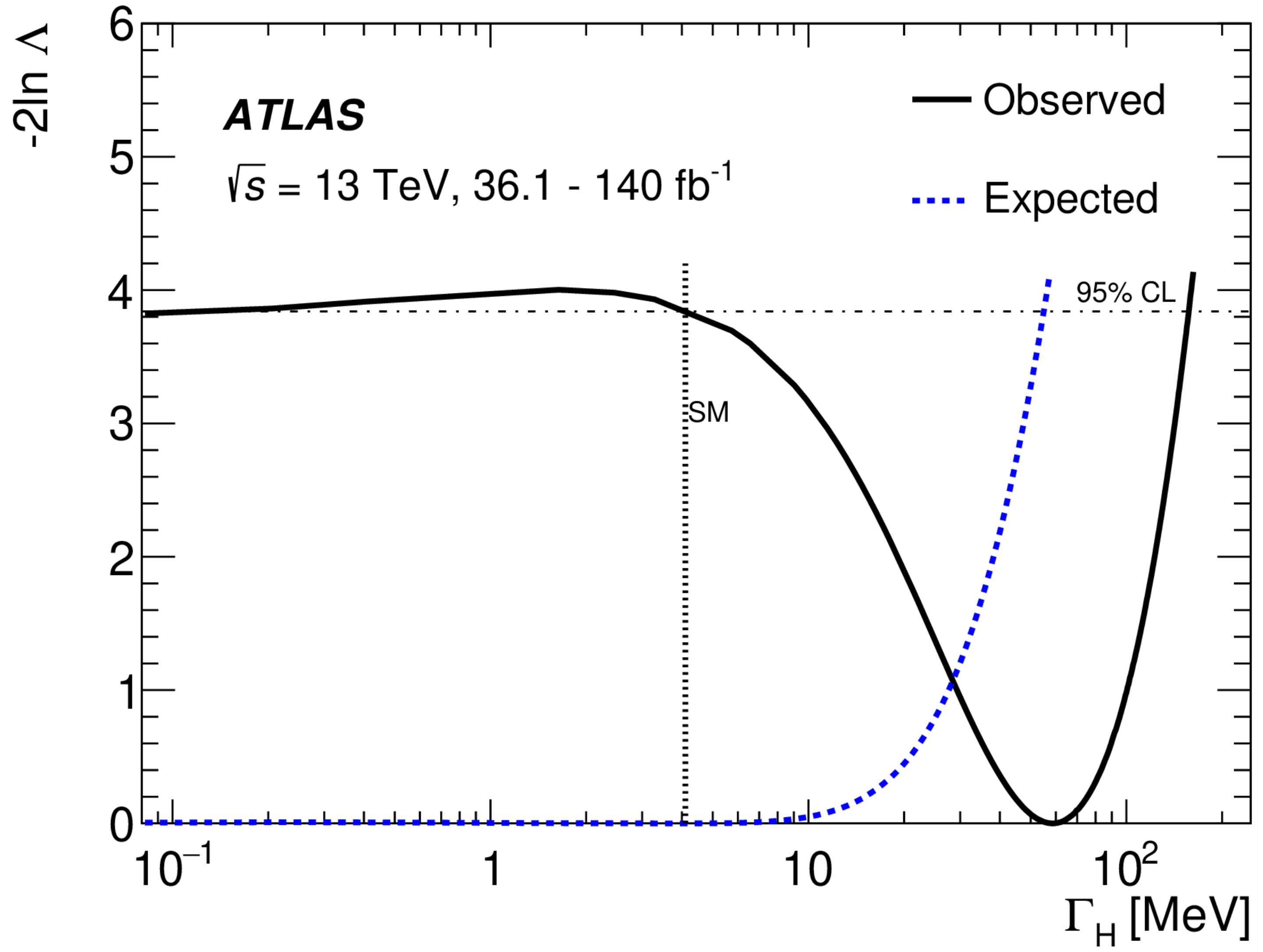
Systematic uncertainty	Impact on 95% CL upper limit of Γ_H Expected [%]	Observed [%]
Theory	37	33
$t\bar{t}t\bar{t}$ theory	25	13
Higgs boson theory	5	6
Other theory	10	16
Experimental	2	2
Jet flavor tagging	2	1
Jet and missing transverse energy	< 1	< 1
Leptons and photons	< 1	< 1
All other systematic uncertainties	< 1	< 1

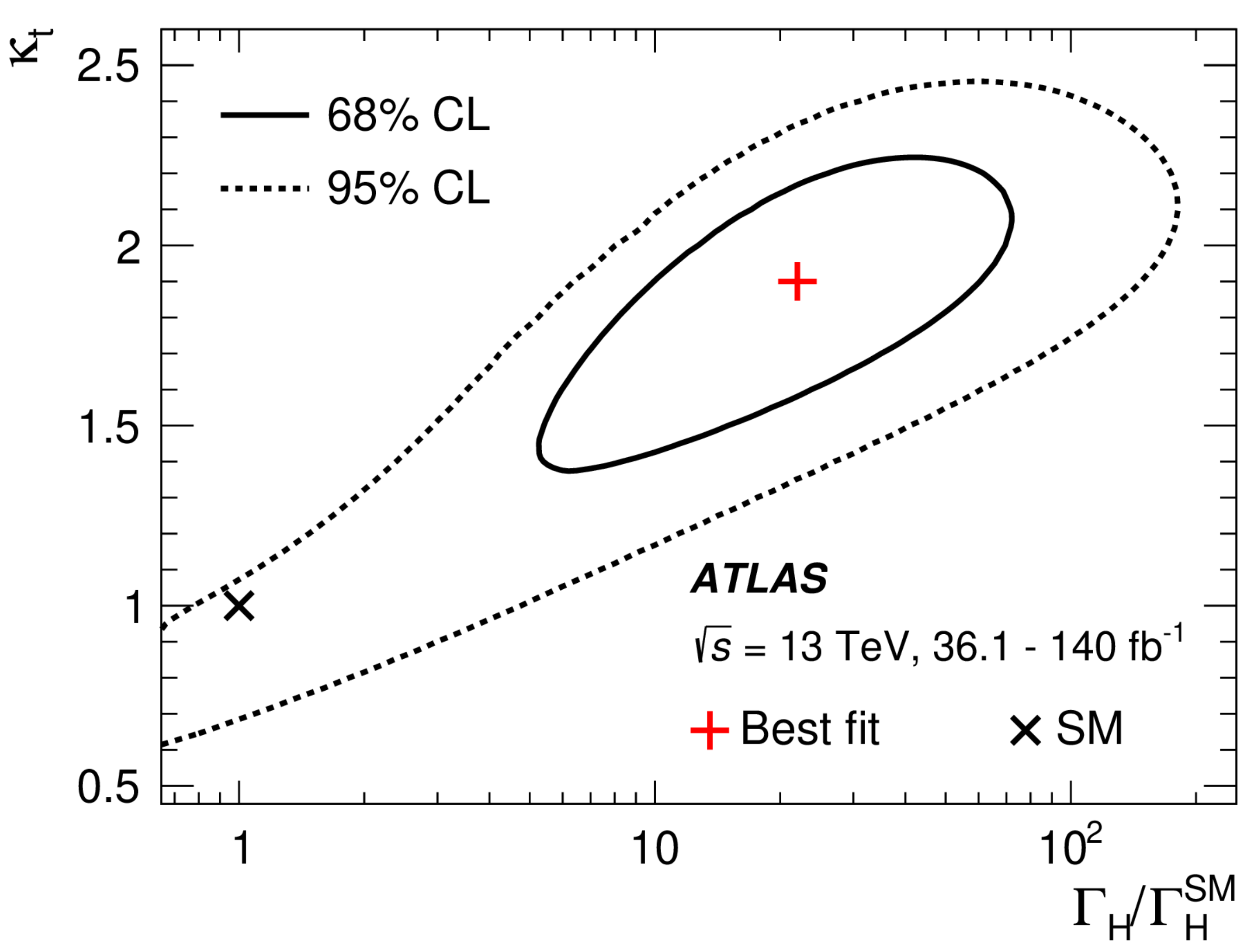
Results with loops resolved

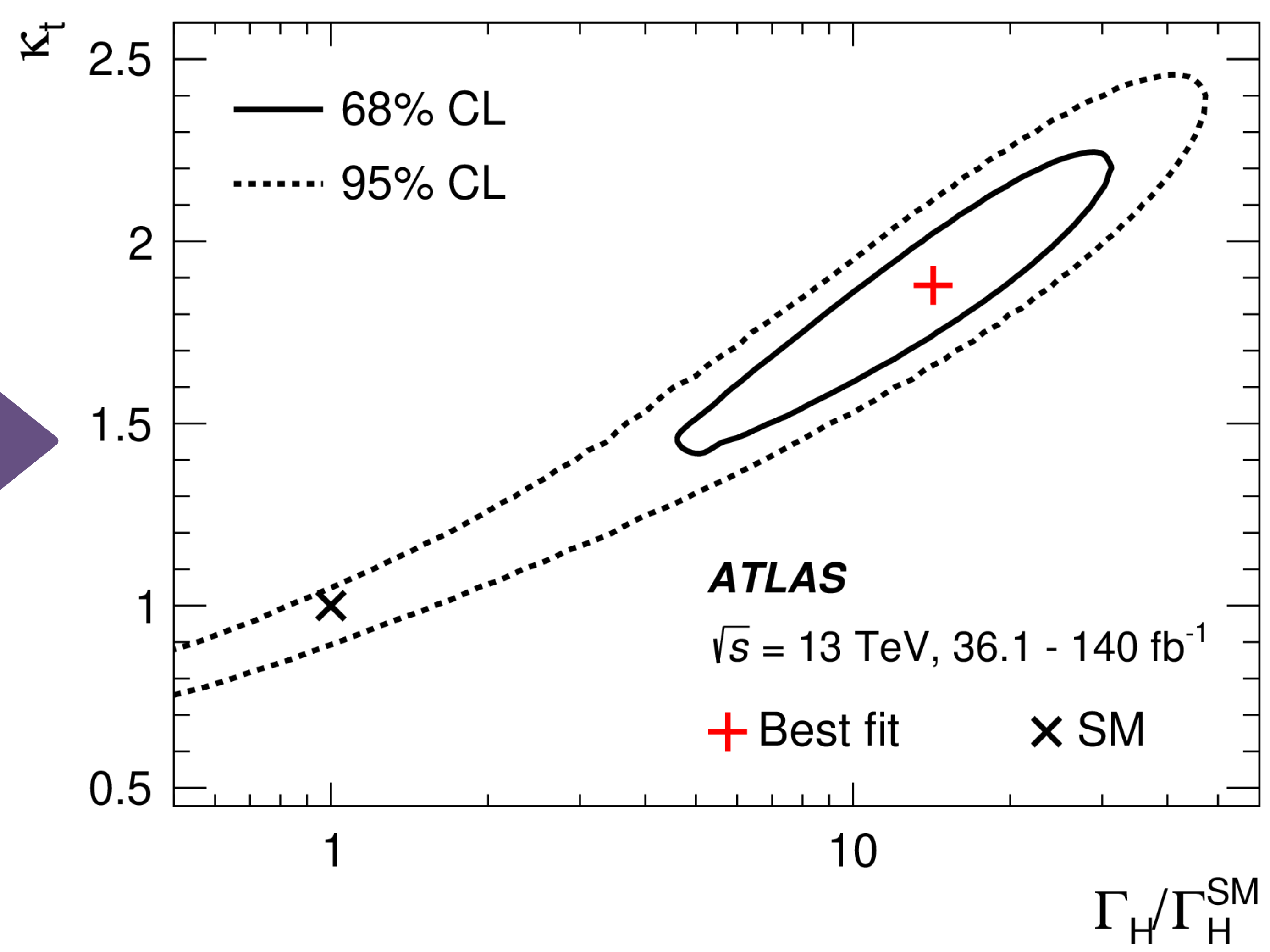
- ggF, $H \to \gamma\gamma$ and $H \to Z\gamma$ loops contain the contribution from top-quark
  - Parameterized them into couplings with SM particles
  - Applied stronger assumptions

$\rightarrow$ The observed (expected) 95% CL upper limit decreases from 450 (75) MeV to 160 (55) MeV after resolving the loops









The 2D contour's shape shrinks in the κ_t direction as expected

Summary

- A first measurement of the Higgs boson width based on direct Higgs-top Yukawa coupling has been performed (Phys. Lett. B 861 (2025) 139277)
    - The observed (expected) 95% CL upper limit for Γ_H is 450 (75) MeV
    - If the loops are parameterized, the observed (expected) 95% CL upper limit for Γ_H is 160 (55) MeV
- Outlook:
    - Improvement of four-top measurement from Run3 and HL-LHC will bring significant benefits
    - Can potentially add $t\bar{t}$ measurement to further constrain off-shell κ_t, and $t\bar{t}H, H \to$ Multi-lepton for on-shell κ_t

Back up