Implication of the 95GeV di-tau and di-photon excesses

Teppei Kitahara

Institute of Theoretical Physics, Chinese Academy of Sciences

with: Syuhei Iguro, Yuji Omura, Hantian Zhang

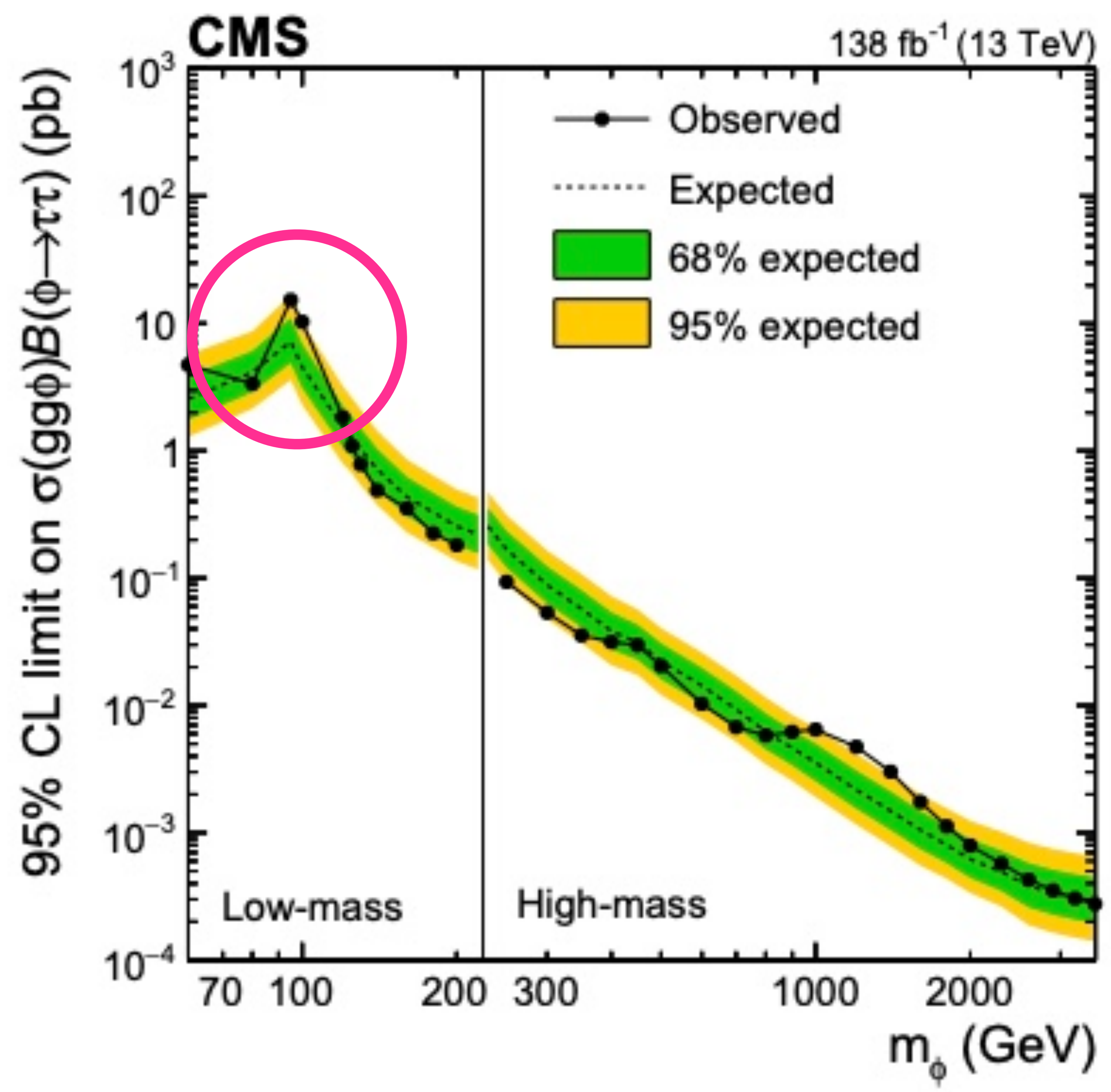
Refs: 2205.03187, 2211.00011

Higgs 2023, IHEP, Beijing

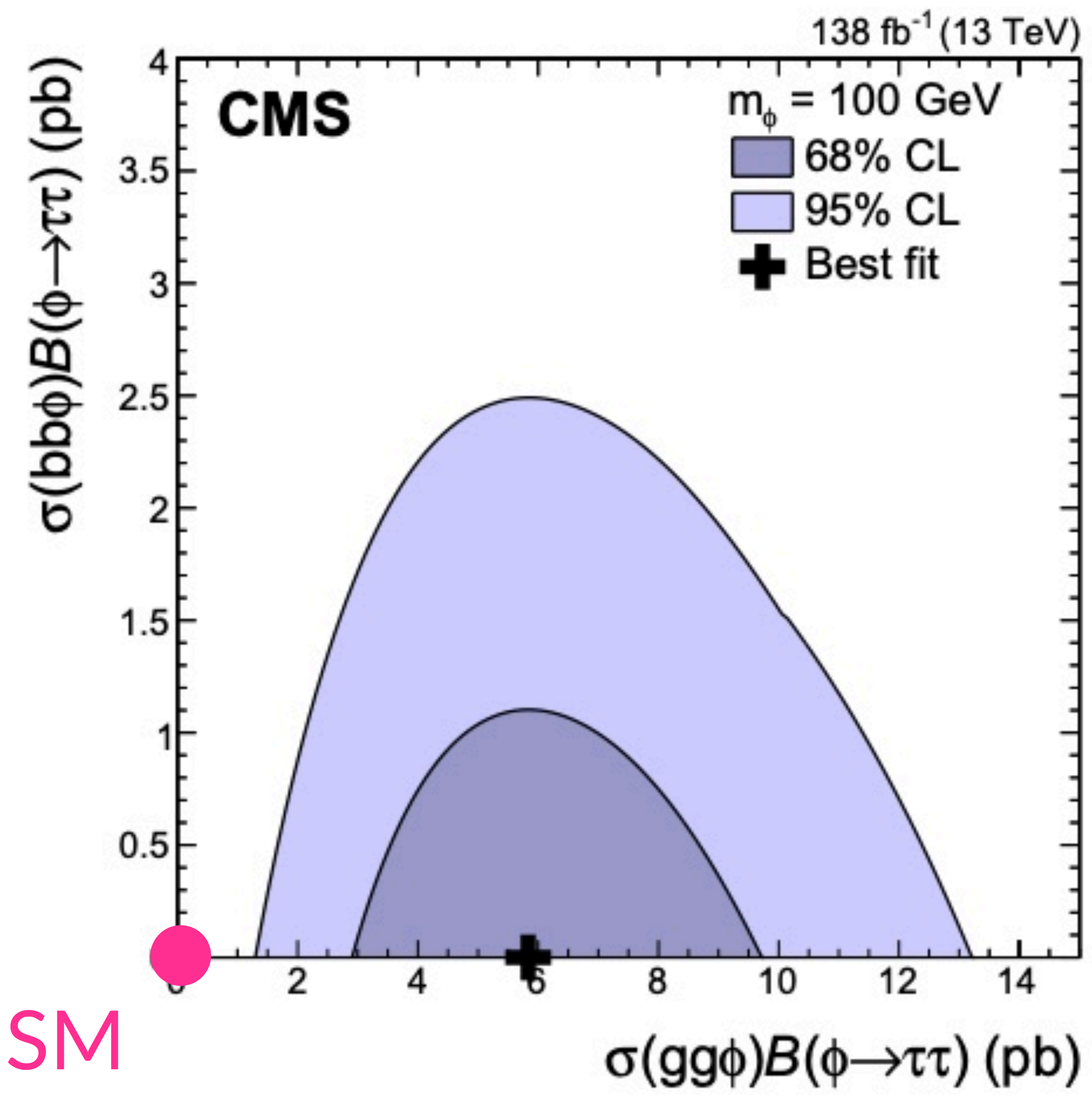
November 28, 2023

95GeV di-tau excess

- ~95GeV di-tau excess: CMS Run-2 result CMS-PAS-HIG-21-001, 2208.02717



bottom-associate channel



SM

gluon fusion channel

local (global) $m_\phi = 95$GeV, 2.6σ (2.3σ), $m_\phi = 100$GeV, 3.1σ (2.7σ)

$$\sigma(gg\to\phi)\times \mathrm{BR}(\phi\to\tau\bar\tau) = 7.7^{+3.9}_{-3.1}\ \mathrm{pb}$$

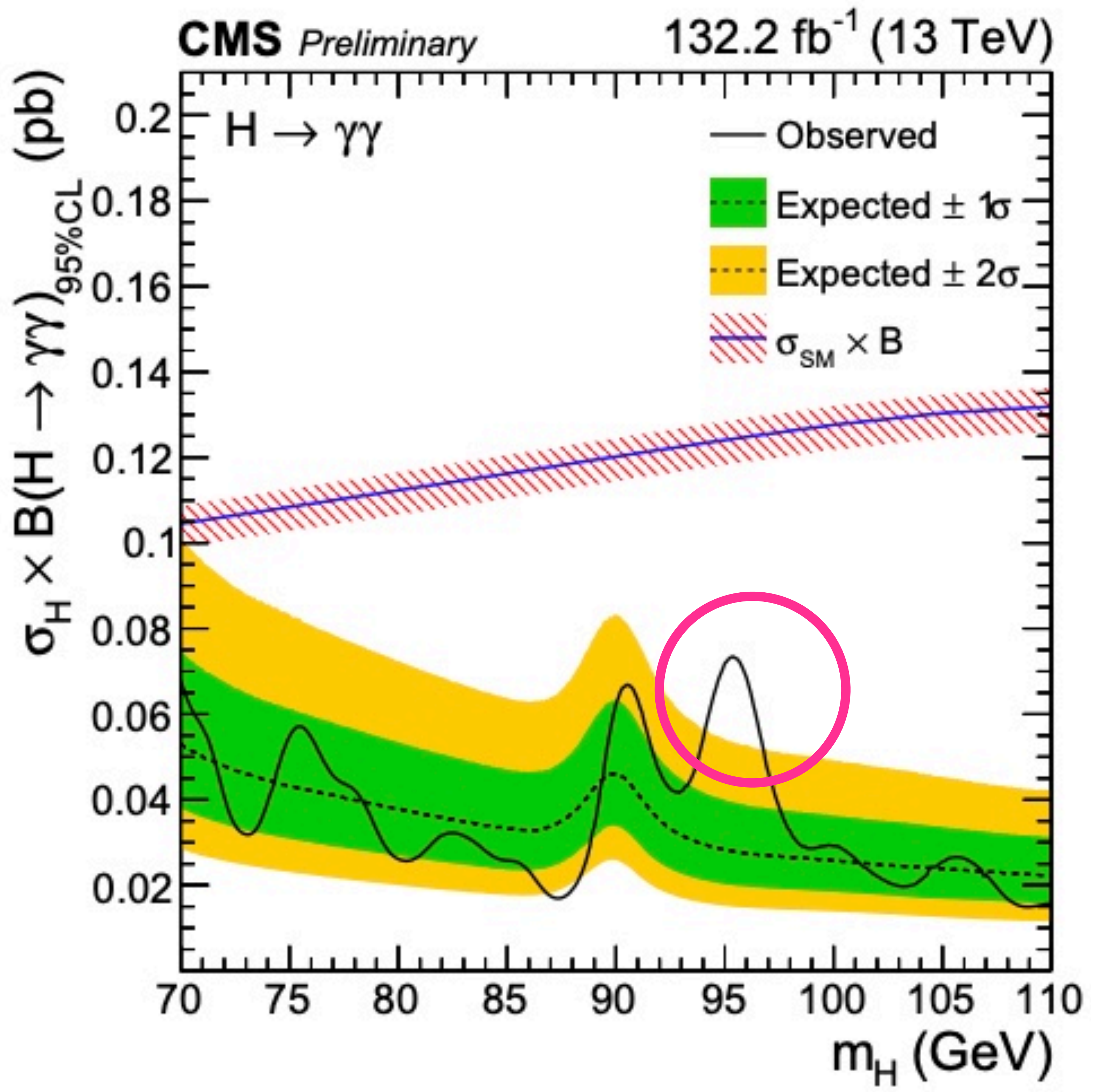
for $m_\phi = 95\,\mathrm{GeV}$

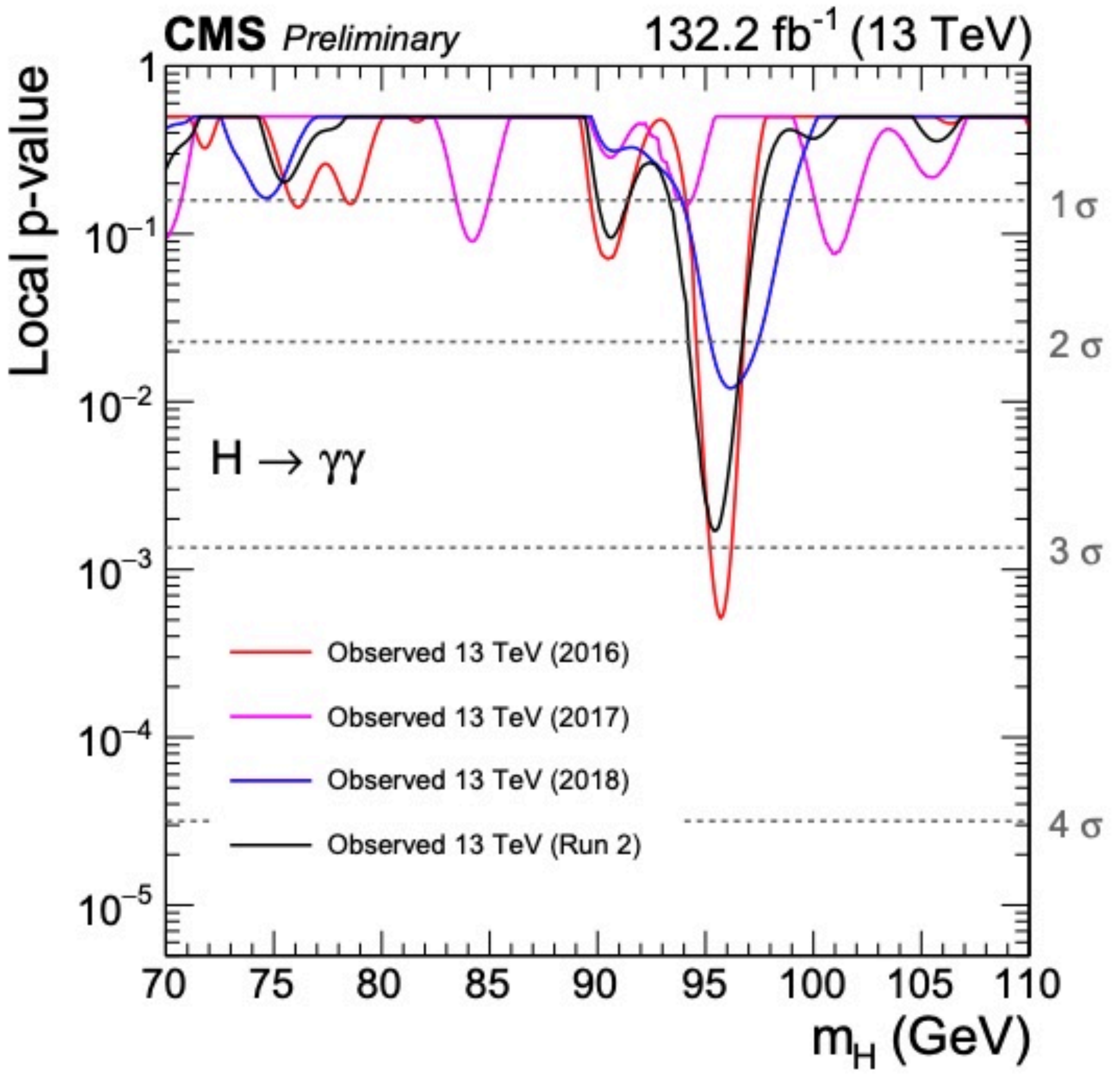
consistent with ATLAS $h_{\rm SM}\to\tau^+\tau^-$ data $\sigma \lesssim 11$pb

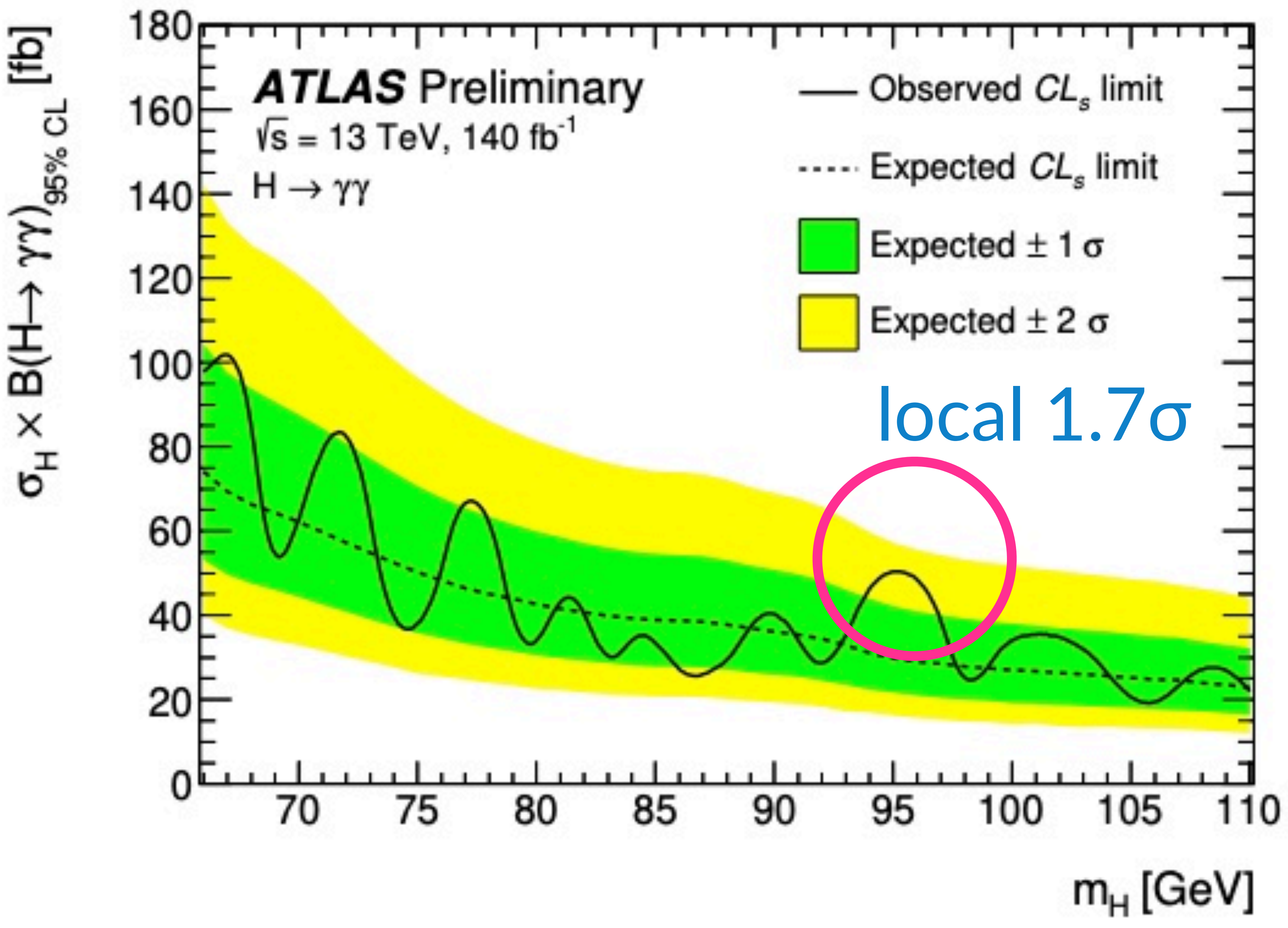
[Iguro, TK, Omura, 2205.03187]

95 GeV di-photon excess

- ~95GeV di-photon excess: CMS Run-2 result and ATLAS Run-2







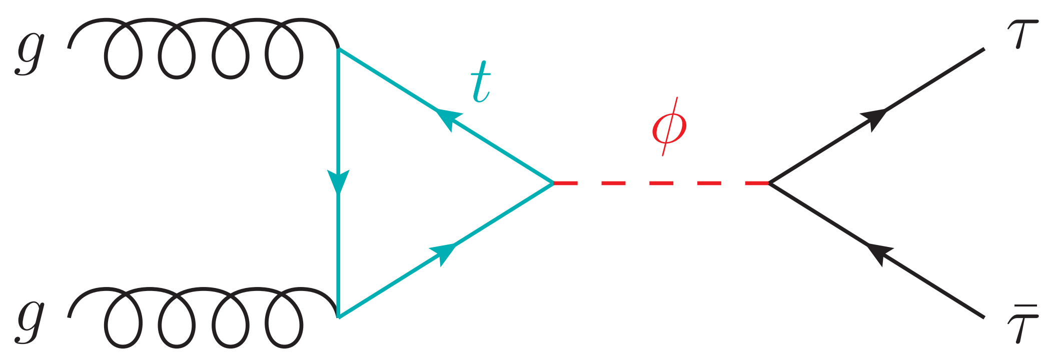
ATLAS-CONF-2023-035

CMS-PAS-HIG-20-002 local (global) $m_\phi = 95$GeV, 2.9σ (1.3σ)

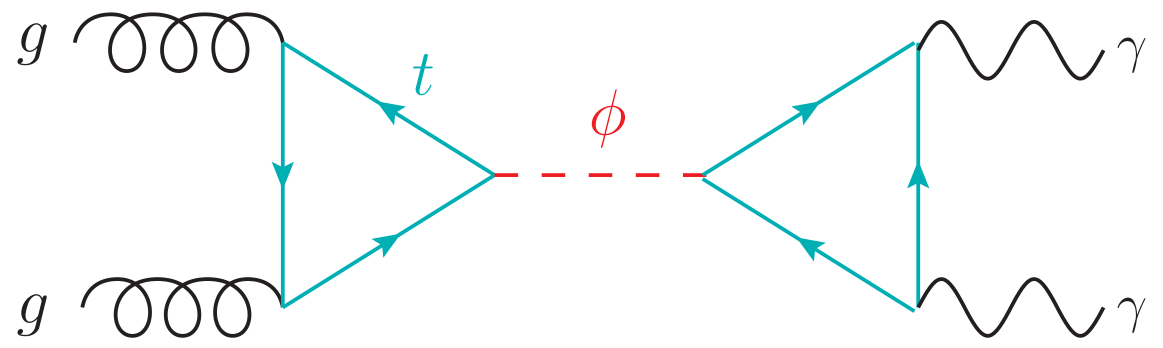
CMS+ATLAS = 3.1σ
[Biekötter, et al, 2306.03889]

Introduction

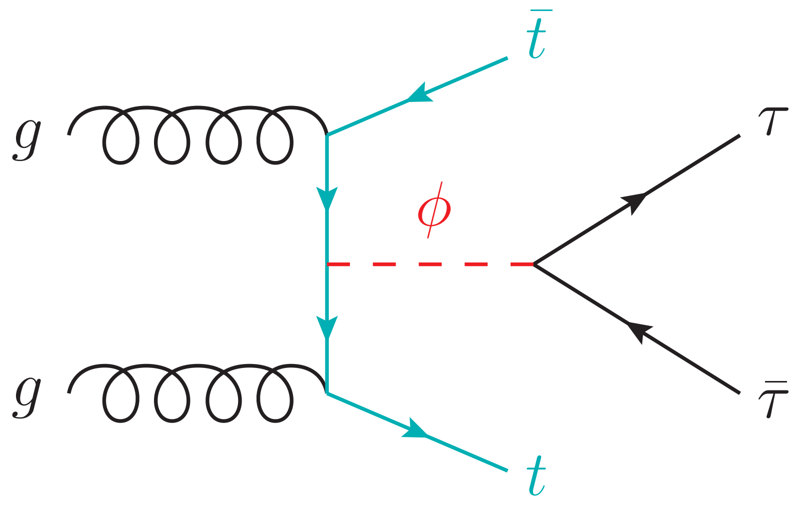
- The di-photon decay can be interpreted as spin 0 or 2 resonance (Landau–Yang theorem)
- Our assumption: 95GeV di-tau and di-photon excesses are interpreted by spin-0 scalar ϕ.
  The gluon fusion amplitude is dominated by the top-quark loop.
- Question: How about the CP-state of ϕ? Is there any way to confirm this anomaly?

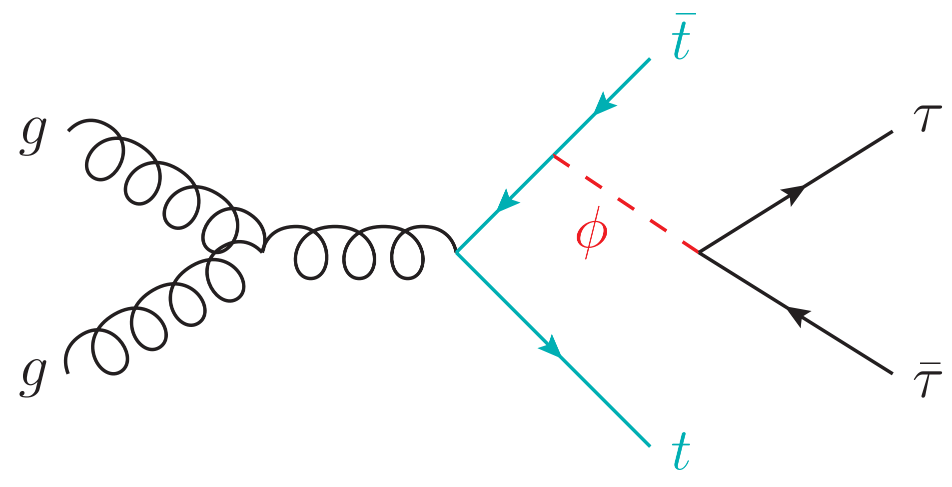


95GeV excess



95GeV excess





Minimal setup

- CP-even H or CP-odd A are considered

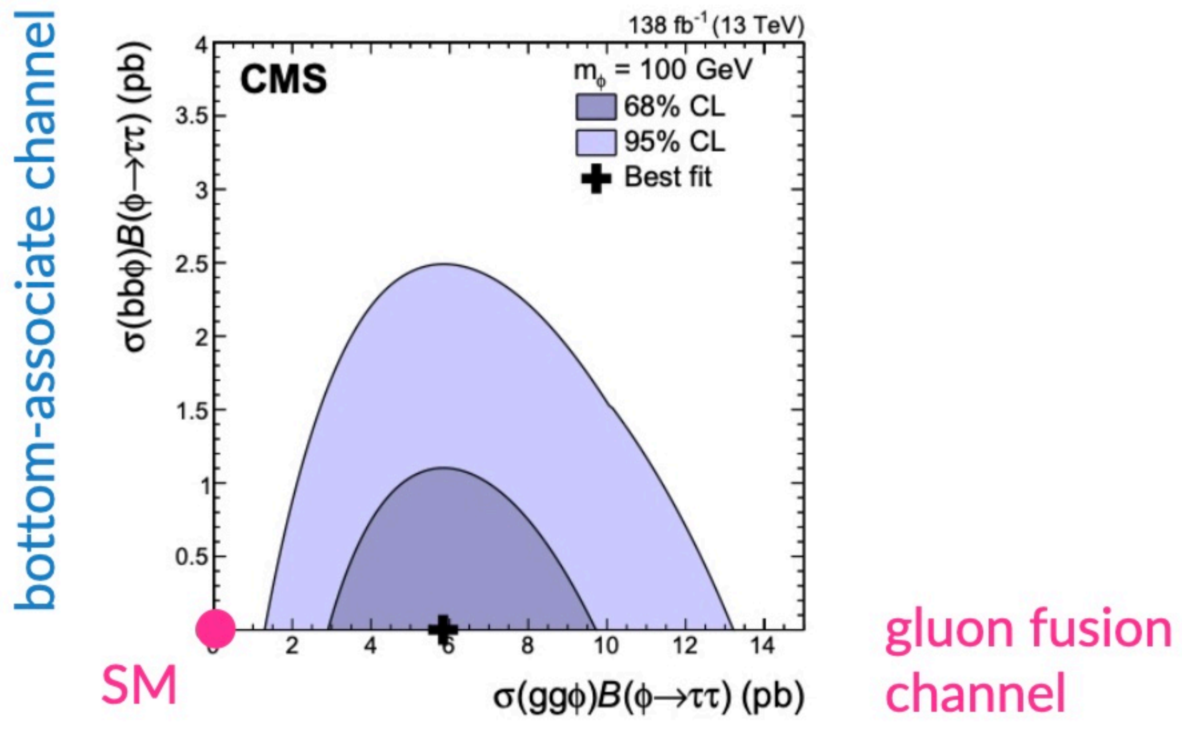
$$-\mathcal{L}_{\text{eff}} = \frac{\rho_{tt}^{H}}{\sqrt{2}}\bar{t}Ht + \frac{\rho_{\tau\tau}^{H}}{\sqrt{2}}\bar{\tau}H\tau \pm i\frac{\rho_{tt}^{A}}{\sqrt{2}}\bar{t}A\gamma_5 t + i\frac{\rho_{\tau\tau}^{A}}{\sqrt{2}}\bar{\tau}A\gamma_5\tau$$

The bottom-coupling is supposed to be small:

1. To amplify BR($\phi \to \tau^+\tau^-$)

   $\tau\tau$, bb, gg, $\gamma\gamma$ and $Z\gamma$

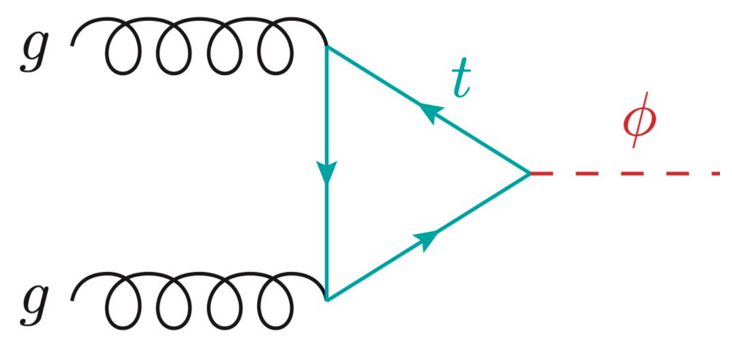
2. There is no excess in b-associated $\tau\tau$ signal region



Sign of ρ_{tt}^{A} depends on UV theory, but no impact on our study

CP-even scenario

- We obtained the following theoretical predictions for CP-even 95GeV H

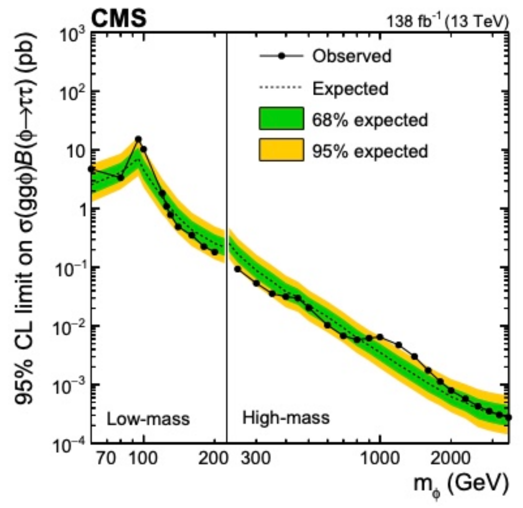


gluon-fusion production

$$\sigma(pp \to gg \to H) = 87.2\,(\rho_{tt}^H)^2 \text{ pb} \quad \text{for } m_H = 95\,\text{GeV}$$

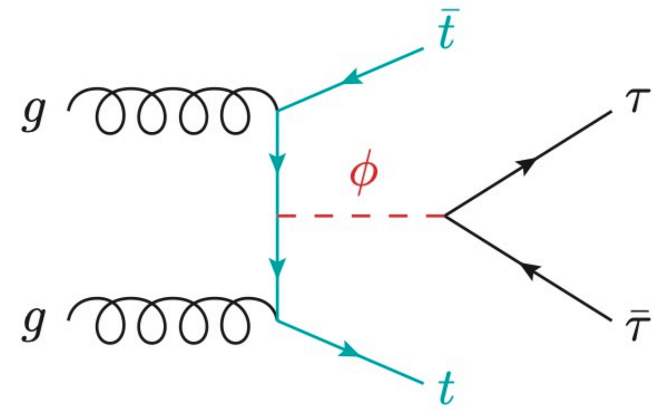
NNLO @SusHi

N3LO < 3%



di-tau excess

$$\rho_{tt}^H \sqrt{\text{BR}(H \to \tau\bar{\tau})} = 0.30 \pm 0.07$$



top-associated production

$$\sigma(pp \to t\bar{t} + H) = 1.07\,(\rho_{tt}^H)^2 \text{ pb}$$

$$\sigma(pp \to t\bar{t} + H) \times \text{BR}(H \to \tau\bar{\tau}) = [0.056, 0.094, 0.14] \text{ pb}$$

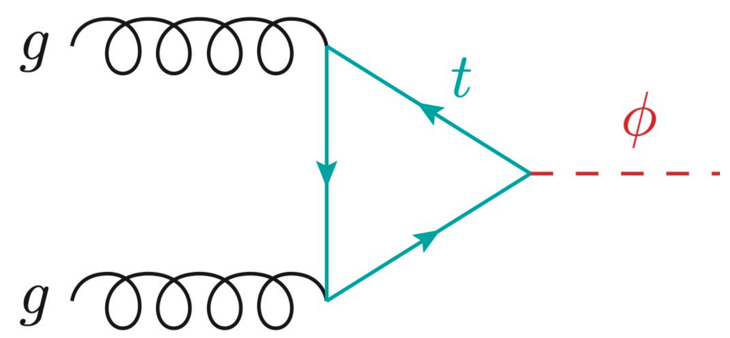
NLO @MadGraph5+K-factor [Frixione, et al, 1407.0823]

larger than SM: $\sigma(pp \to t\bar{t} + h_{\text{SM}}) \times \text{BR}(h_{\text{SM}} \to \tau\bar{\tau}) \simeq 0.03\text{pb}$

$\sigma(pp \to t\bar{t} + Z) \times \text{BR}(Z \to \tau\bar{\tau}) \simeq 0.03\text{pb}$

CP-odd scenario

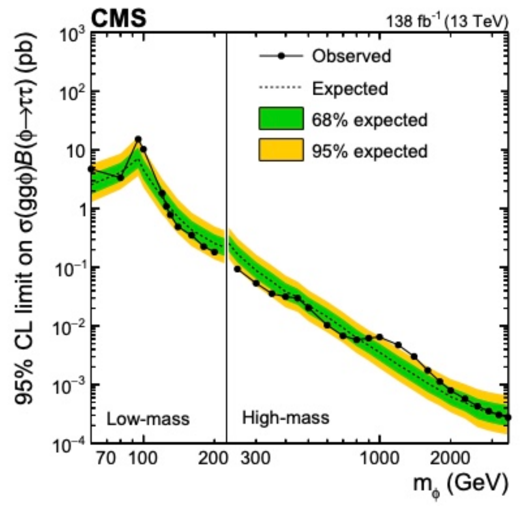
- We obtained the following theoretical predictions for CP-even 95GeV A



gluon-fusion production

$$\sigma(pp \to gg \to A) = 201.7\,(\rho_{tt}^{A})^2\,\text{pb} \quad \text{for } m_A = 95\,\text{GeV}$$

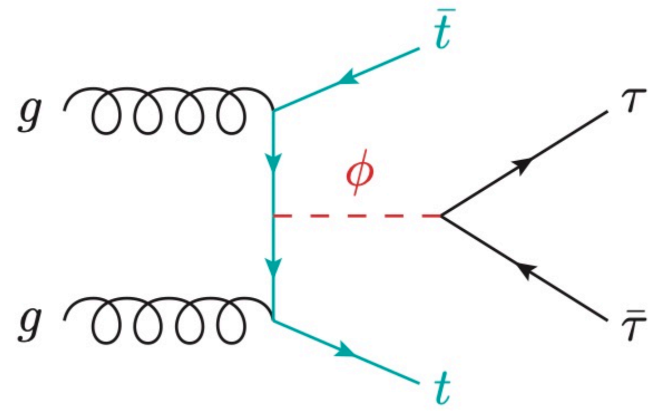
NNLO @SusHi



di-tau excess

$$\rho_{tt}^{A}\sqrt{\text{BR}(A \to \tau\bar{\tau})} = 0.20 \pm 0.04$$

top-associated production



$$\sigma(pp \to t\bar{t} + A) = 0.30\,(\rho_{tt}^{A})^2\,\text{pb}$$

$$\sigma(pp \to t\bar{t} + A) \times \text{BR}(A \to \tau\bar{\tau}) = [0.007, 0.011, 0.017]\,\text{pb}$$

NLO @MadGraph5+K-factor
[Frixione, et al, 1407.0823; Frederix, et a, 1104.5613]

smaller than SM: $\sigma(pp \to t\bar{t} + h_{\text{SM}}) \times \text{BR}(h_{\text{SM}} \to \tau\bar{\tau}) \simeq 0.03\text{pb}$

$\sigma(pp \to t\bar{t} + Z) \times \text{BR}(Z \to \tau\bar{\tau}) \simeq 0.03\text{pb}$

Comparisons

CP-even H

$$\sigma(pp \to gg \to H) = 87.2\,(\rho_{tt}^H)^2\ \mathrm{pb}$$

$$\sigma(pp \to t\bar{t} + H) = 1.07\,(\rho_{tt}^H)^2\ \mathrm{pb}$$

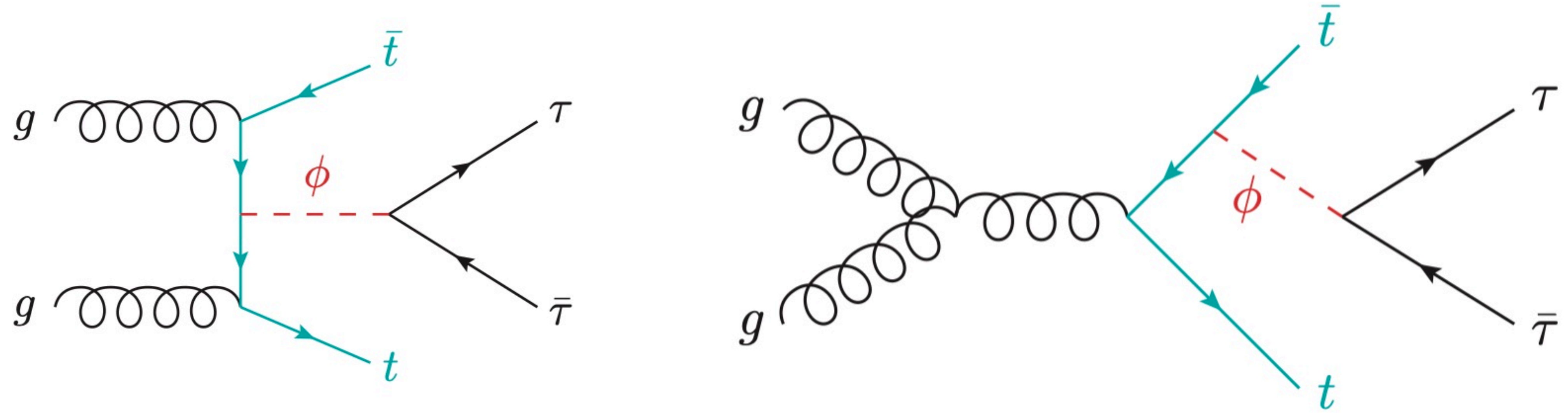
Three times larger

CP-odd A

$$\sigma(pp \to gg \to A) = 201.7\,(\rho_{tt}^A)^2\ \mathrm{pb}$$

Two times larger

$$\sigma(pp \to t\bar{t} + A) = 0.30\,(\rho_{tt}^A)^2\ \mathrm{pb}$$



Constructive/destructive interference and sensitive to γ_5

[Djouadi, hep-ph/0503173; Frederix, et a, 1104.5613; Dolan, et al, 1606.00019]

$$\sigma(pp \to t\bar{t} + H) \times \mathrm{BR}(H \to \tau\bar{\tau}) = [0.056, 0.094, 0.14]\ \mathrm{pb}$$

$$[0.007, 0.011, 0.017]\ \mathrm{pb}$$

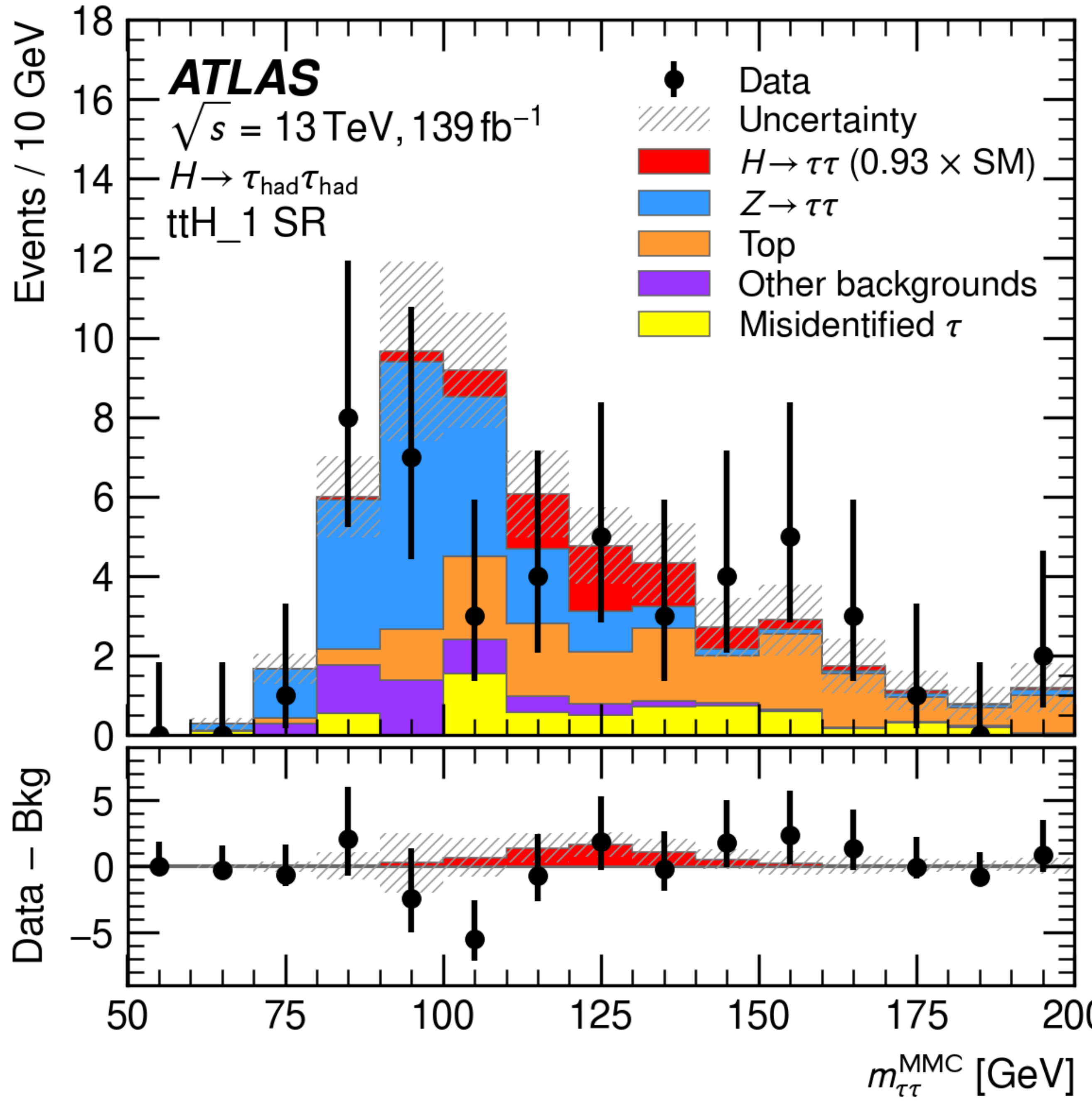
As a result, predicted $\sigma(pp \to t\bar{t}\tau^+\tau^-)$ differs by an order of magnitude. Angular distribution also differs

Comparison to ATLAS $tt+\tau\tau$ search

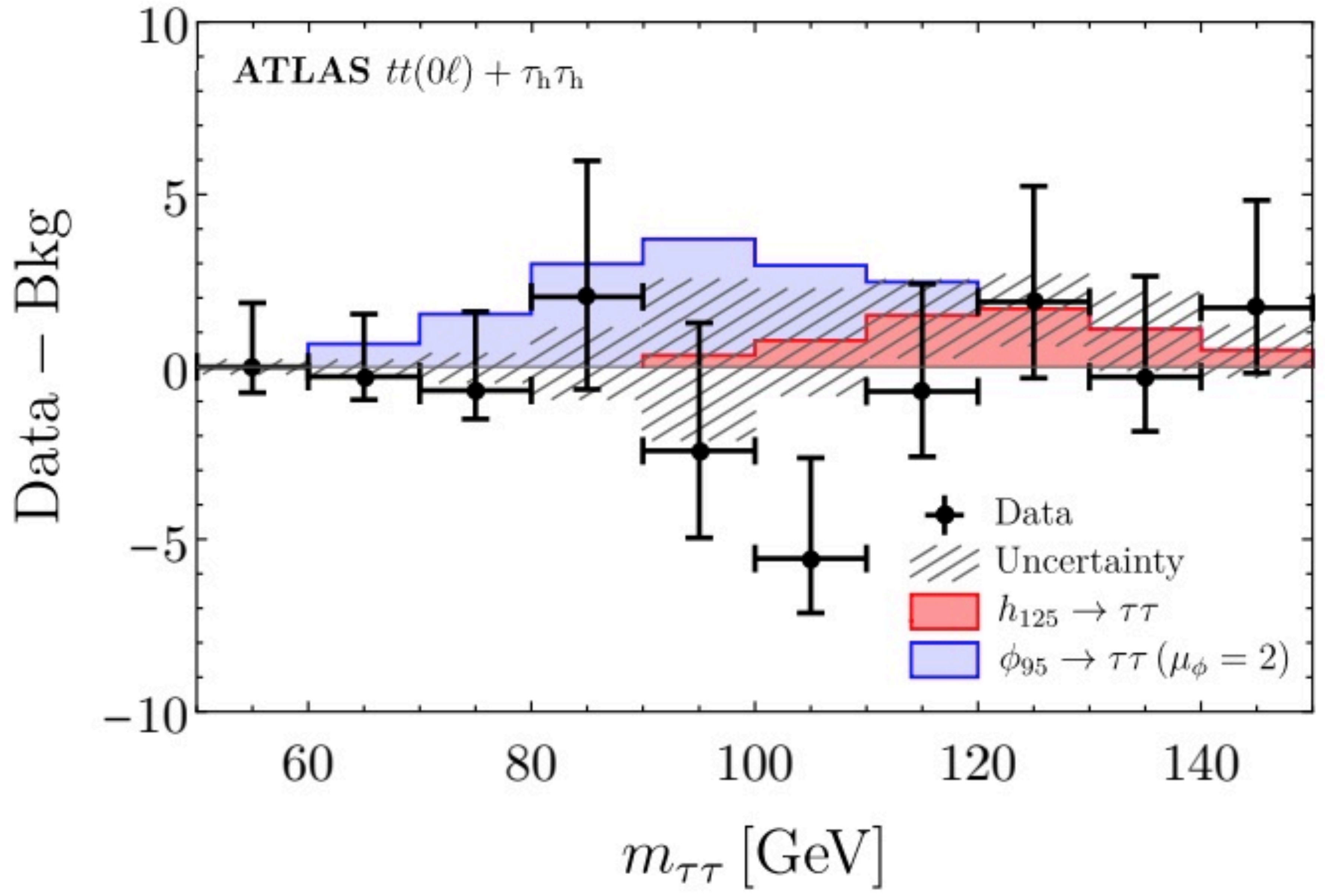
- We estimate the sensitivity to probe $t\bar{t}\phi \to t\bar{t}\tau^+\tau^-$, assuming that the $m_{\tau\tau}$ distribution of under the BDT is similar to the SM Higgs (red)

[Iguro, TK, Omura, 2205.03187]

ATLAS Run-2
$t\bar{t}h, h \to \tau^+\tau^-$
search



[ATLAS 2201.08269, hepdata]



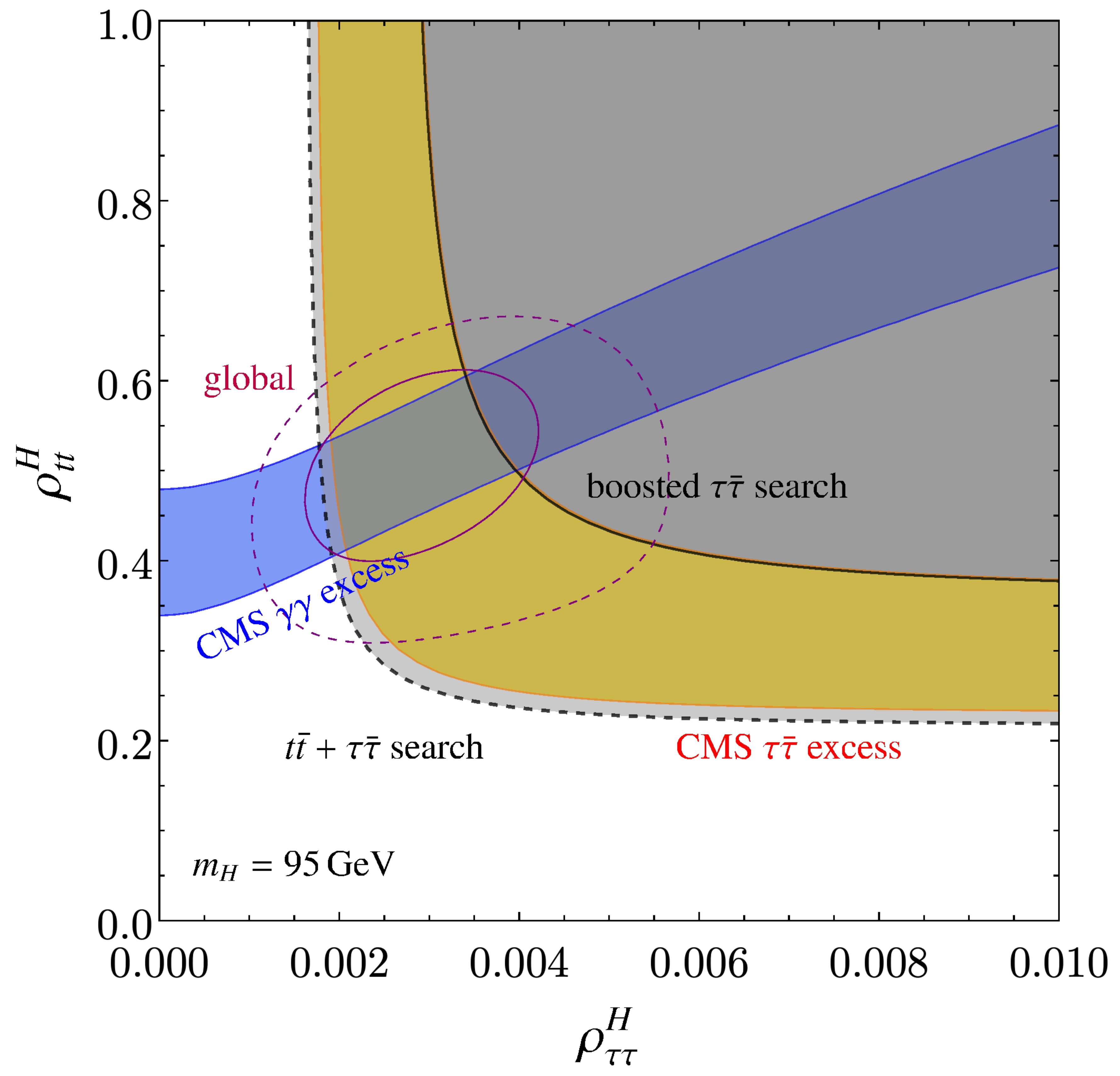
χ^2 analysis (reproducing correct μ_h bound) figures out

$\sigma(pp \to t\bar{t} + \phi) \times \mathrm{BR}(\phi \to \tau\bar{\tau}) < 0.050\,\mathrm{pb}$ (95%CL)

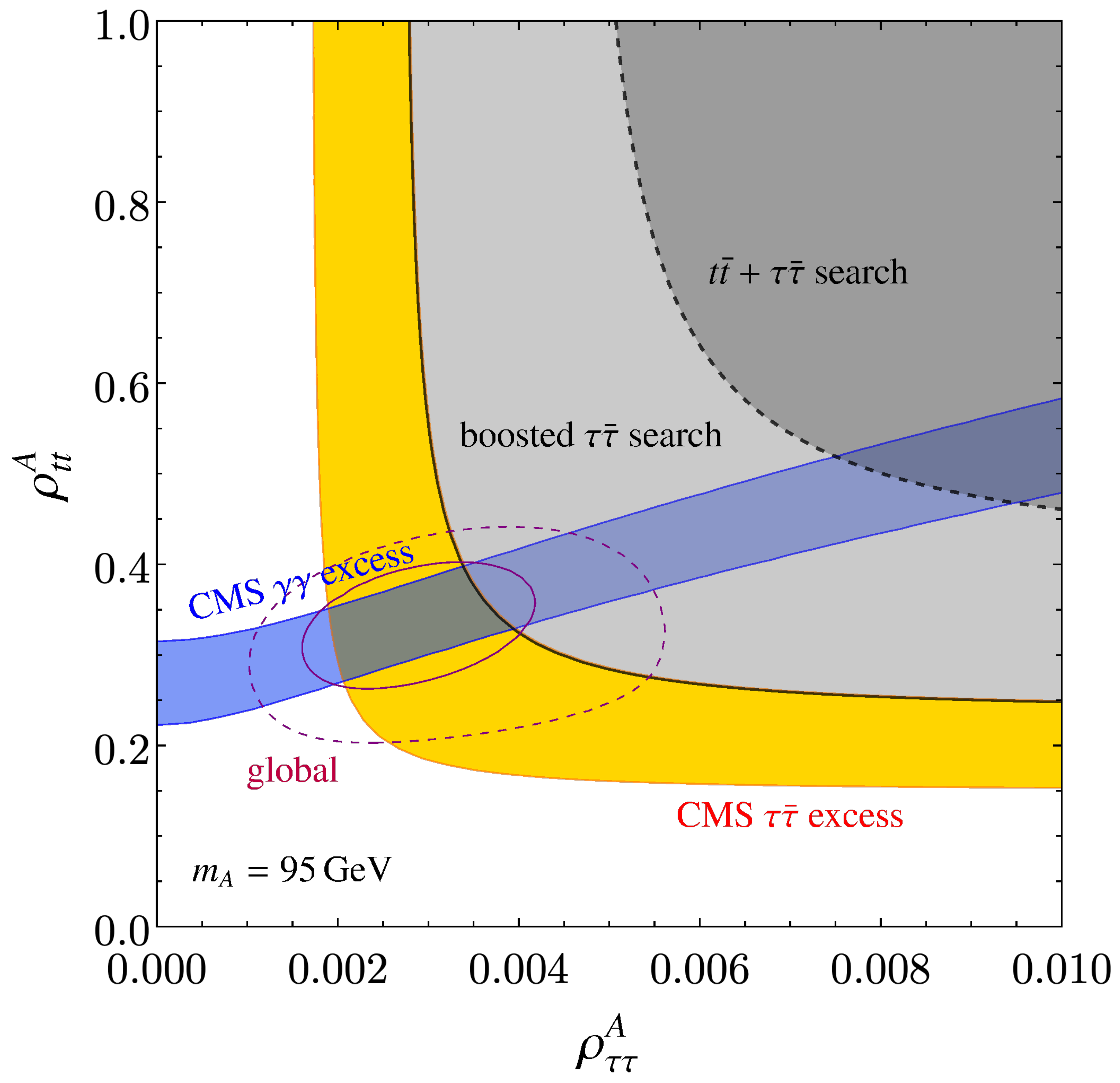
Results

[Iguro, TK, Omura, 2205.03187]

CP-even H



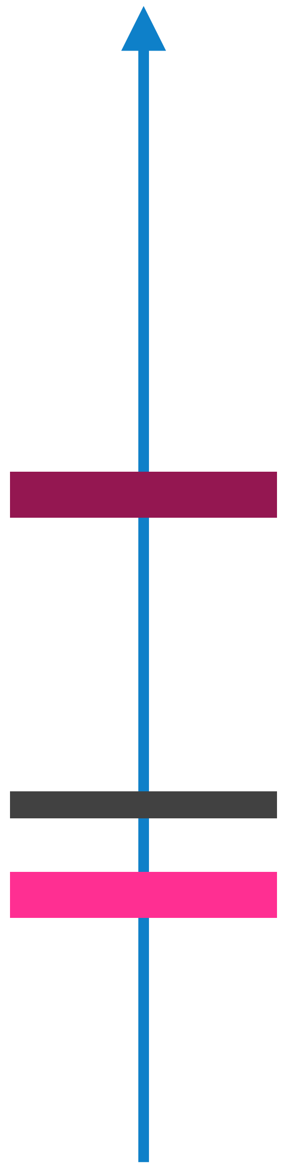
CP-odd A



CP-even H interpretation is disfavored by the ATLAS Run-2 data of $t\bar{t}\tau^+\tau^-$ search

Test of 95GeV CP-odd A within general 2HDMs

- How to probe the 95GeV CP-odd A particle? → We propose di-Higgs (hA) search
- Let us assume the following mass spectrum within general 2HDMs



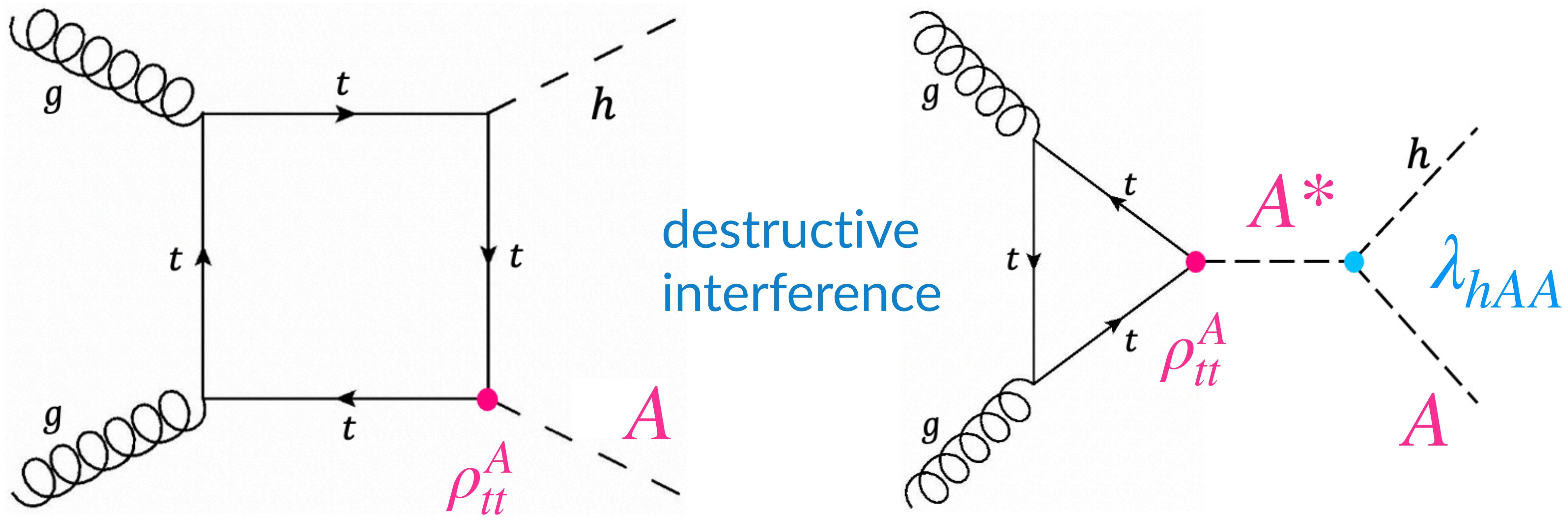
+ Higgs alignment limit assumption
for Higgs precision tests

$m_H = m_{H^\pm}$ for EWPO

$m_{h_{\rm SM}}$
$m_A = 95\text{GeV}$ for di-tau di-photon

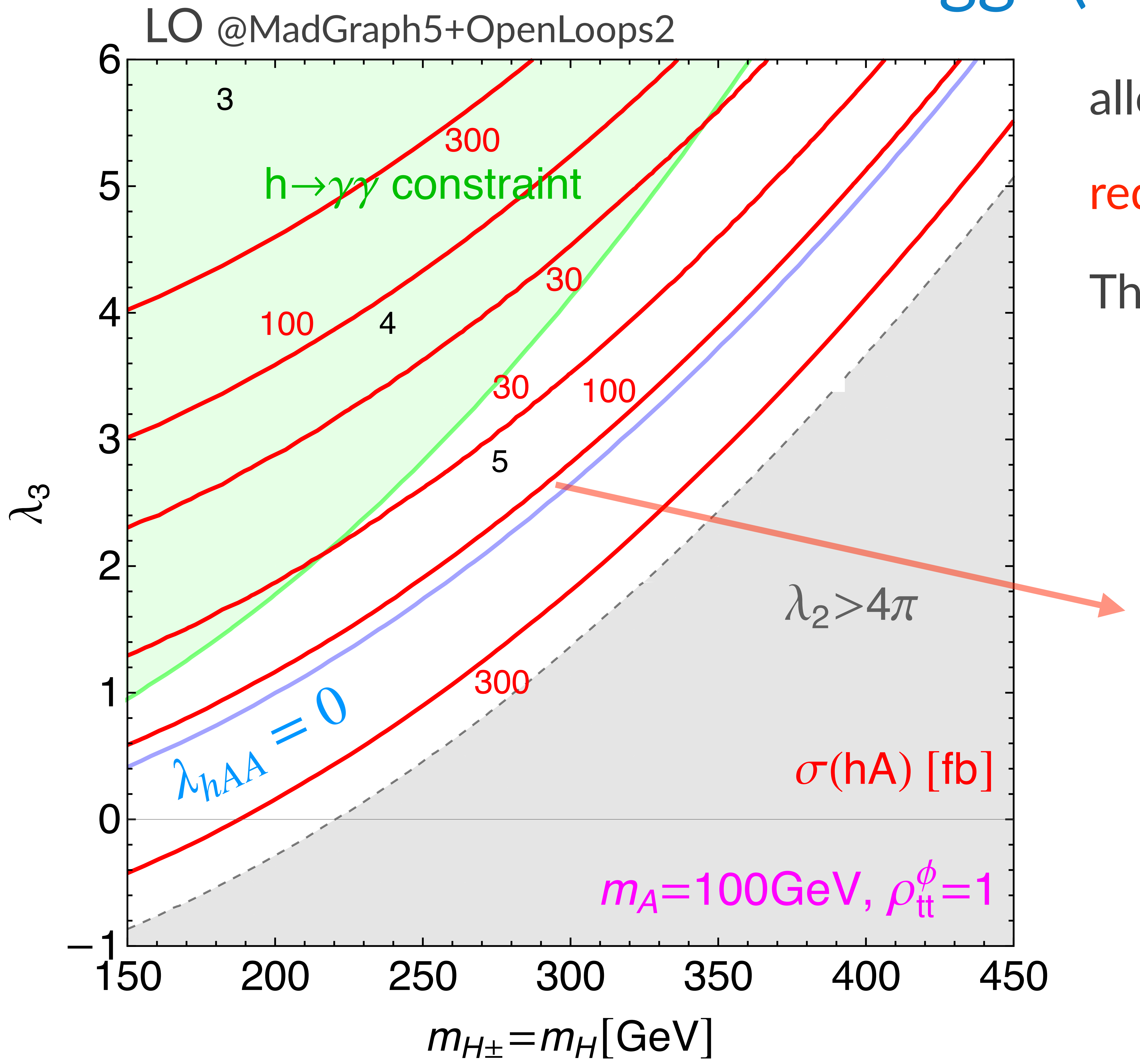
Non-alignment case, DY process
$q\bar{q} \to Z^* \to hA$ exists

In this setup, production cross section of di-Higgs (hA) depends on only three-parameter (heavy scalar mass, two couplings; ρ_{tt}^A, λ_{hAA}) [Iguro, TK, Omura, Hantian, 2211.00011]



irreducible contributions to di-Higgs production

Di-Higgs (hA) production [Iguro, TK, Omura, Hantian, 2211.00011]



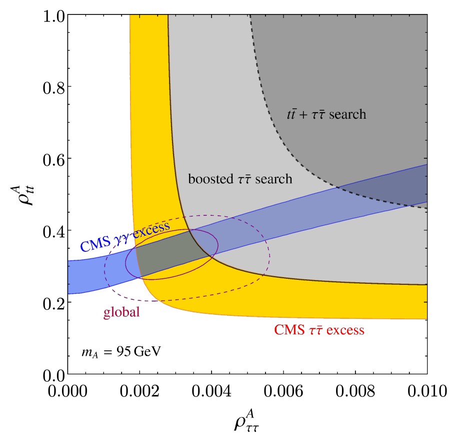
allowed region is in White

red contor is $\sigma(gg \to hA)/(\rho_{tt}^A)^2$ [fb]

The NLO K-factor $\simeq 2$ is not included in this plot

See [Abouabid, et al, 2112.12515]

95GeV excesses prefer $\rho_{tt}^A \sim 0.4$



$\sigma(gg \to hA \to b\bar{b} + \tau^+\tau^-) \simeq 5$ fb

Current LHC sensitivity [CMS, 2206.09401]

$$\sigma(pp \to 2h \to b\bar{b}\tau^+\tau^-) < 7.5 \text{ fb}$$

$$\sigma(pp \to 2h \to b\bar{b}\tau^+\tau^-)_{\rm SM} = 2.3 \text{ fb}$$

Such a mass spectrum in 2HDMs could be tested by $b\bar{b}\tau^+\tau^-$ channel in near future

Conclusions

- We investigated CP-even/odd scalar interpretations of the 95GeV excesses in di-tau and di-photon modes

- CP-even H interpretation of di-tau excess is disfavored by the ATLAS Run-2 data of $t\bar{t}\tau^+\tau^-$ search, while CP-odd A is allowed

- The 95GeV CP-odd A scenario could be tested within the 2HDMs by $gg \to hA \to b\bar{b}\tau^+\tau^-$, whose cross section can be larger than $\sigma(pp \to 2h \to b\bar{b}\tau^+\tau^-)_{\rm SM}$