IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

The Variant Axion Models at the LHC

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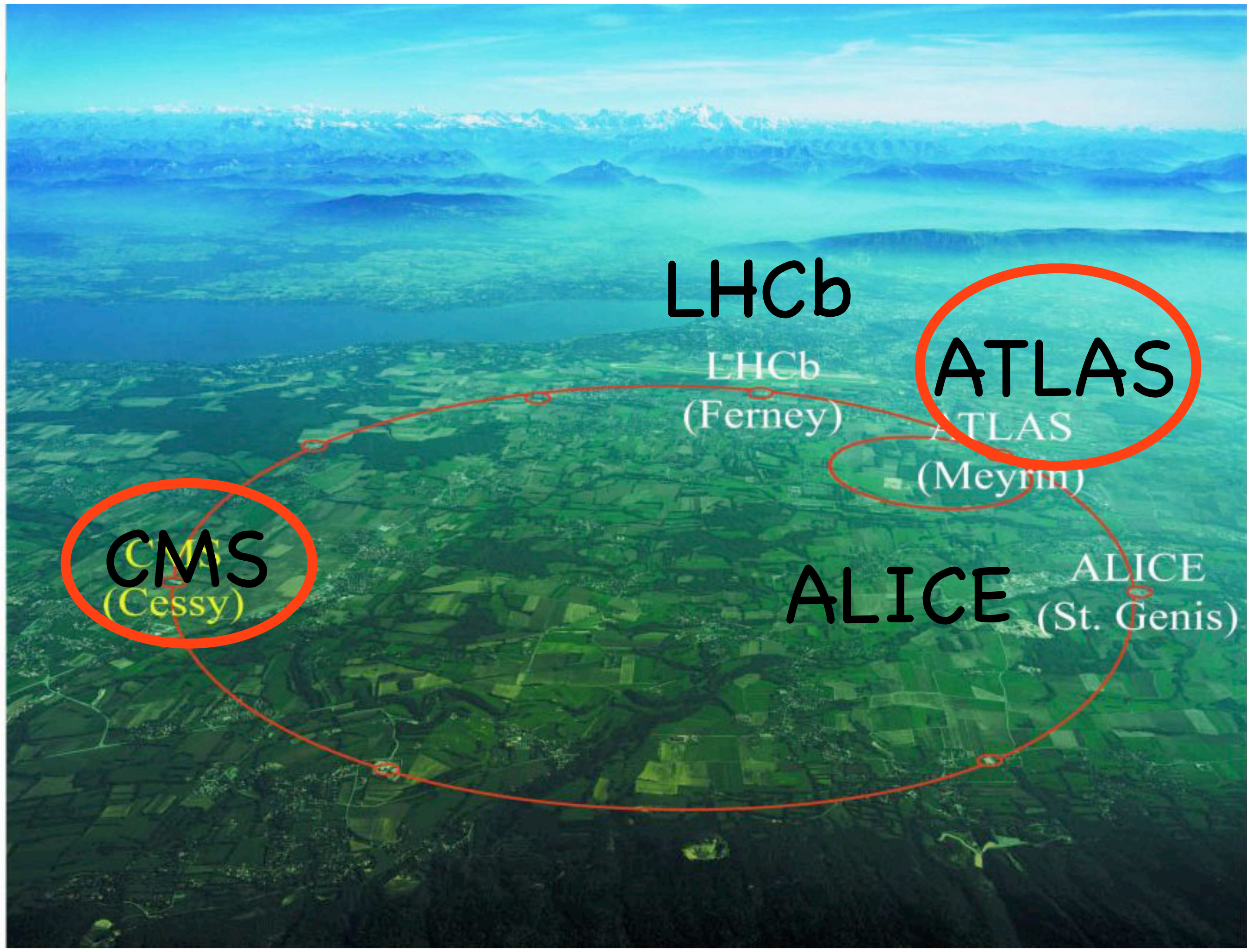
THE UNIVERSITY OF TOKYO

wpi World Premier International Research Center Initiative

Outline

- motivation and introduction
- variant axion models
- impact on Higgs boson search
  - $h \to \gamma\gamma$ and production
- Summary

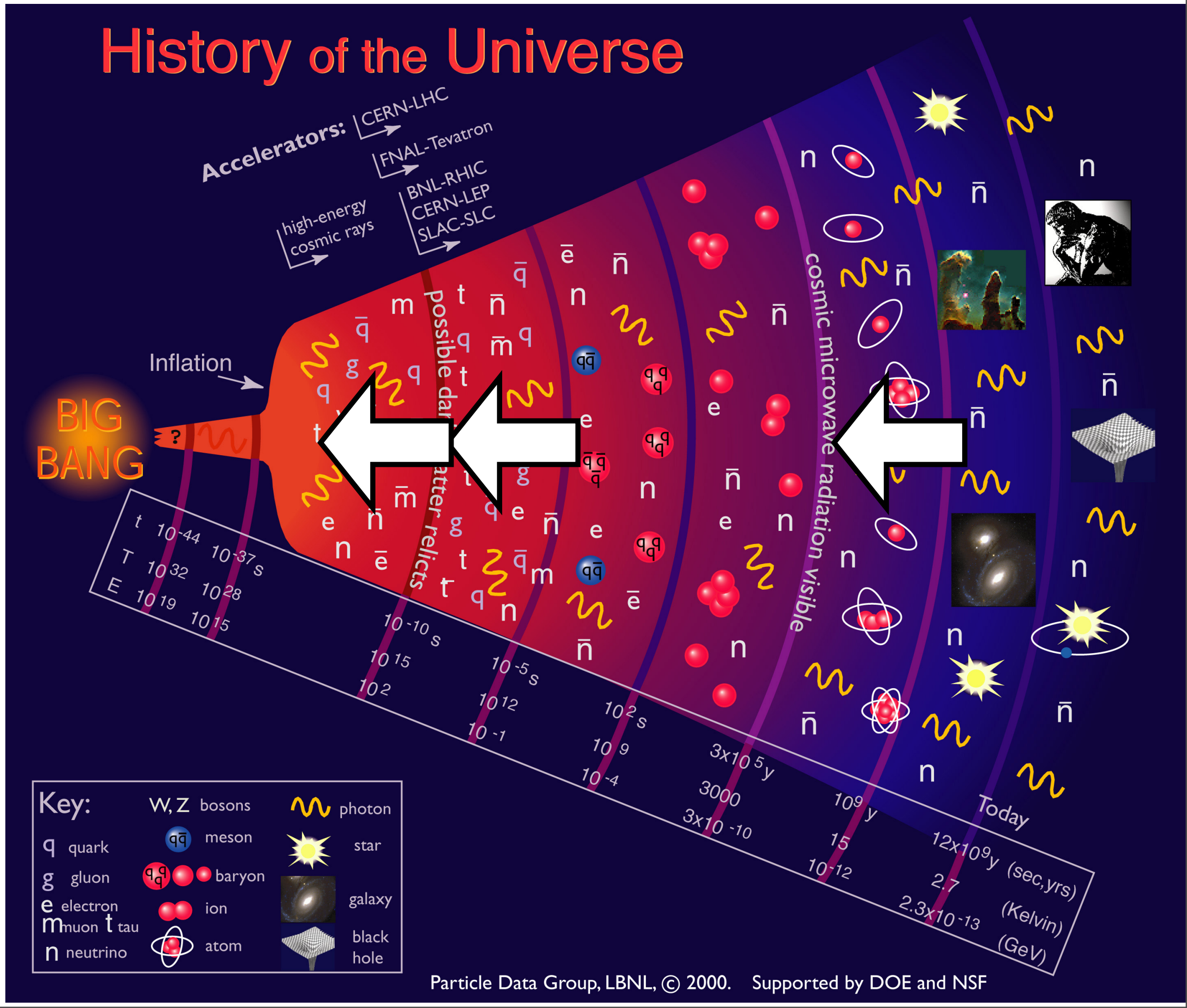
Motivation



LHC is running!

Physics of BSM will be found

Higgs boson will be discovered



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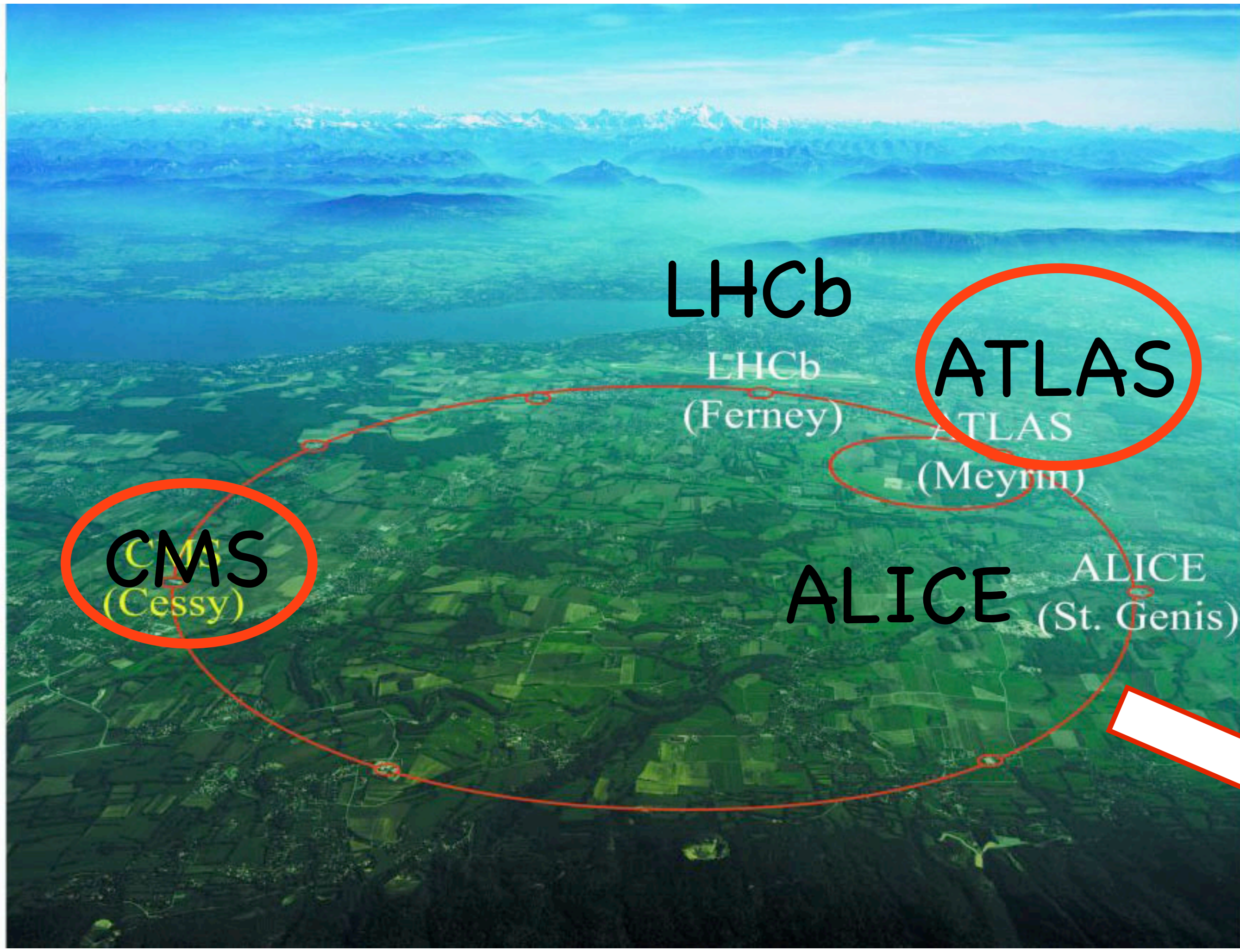

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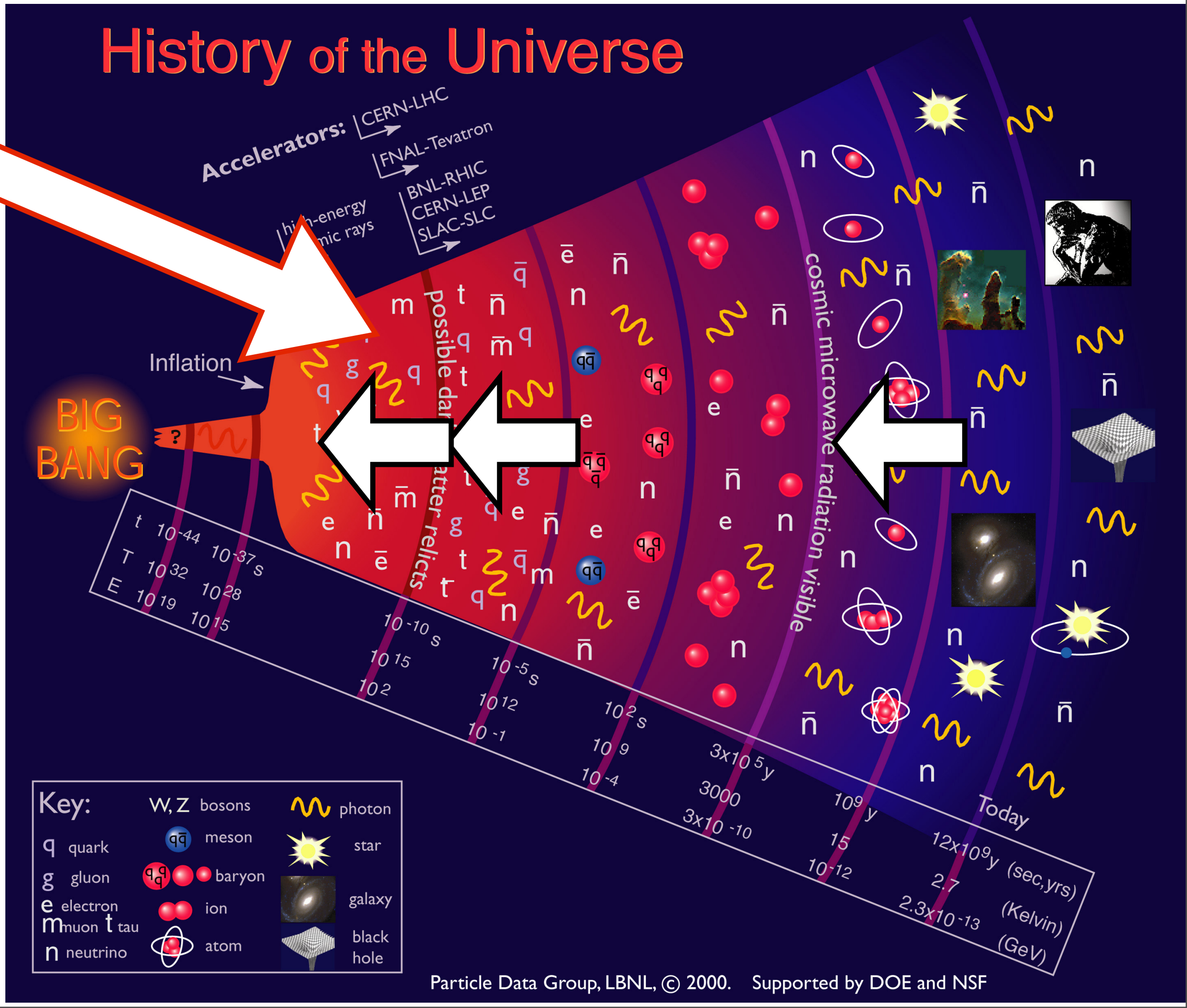
Can we cross check, test, probe the cosmology or its implications at the LHC?



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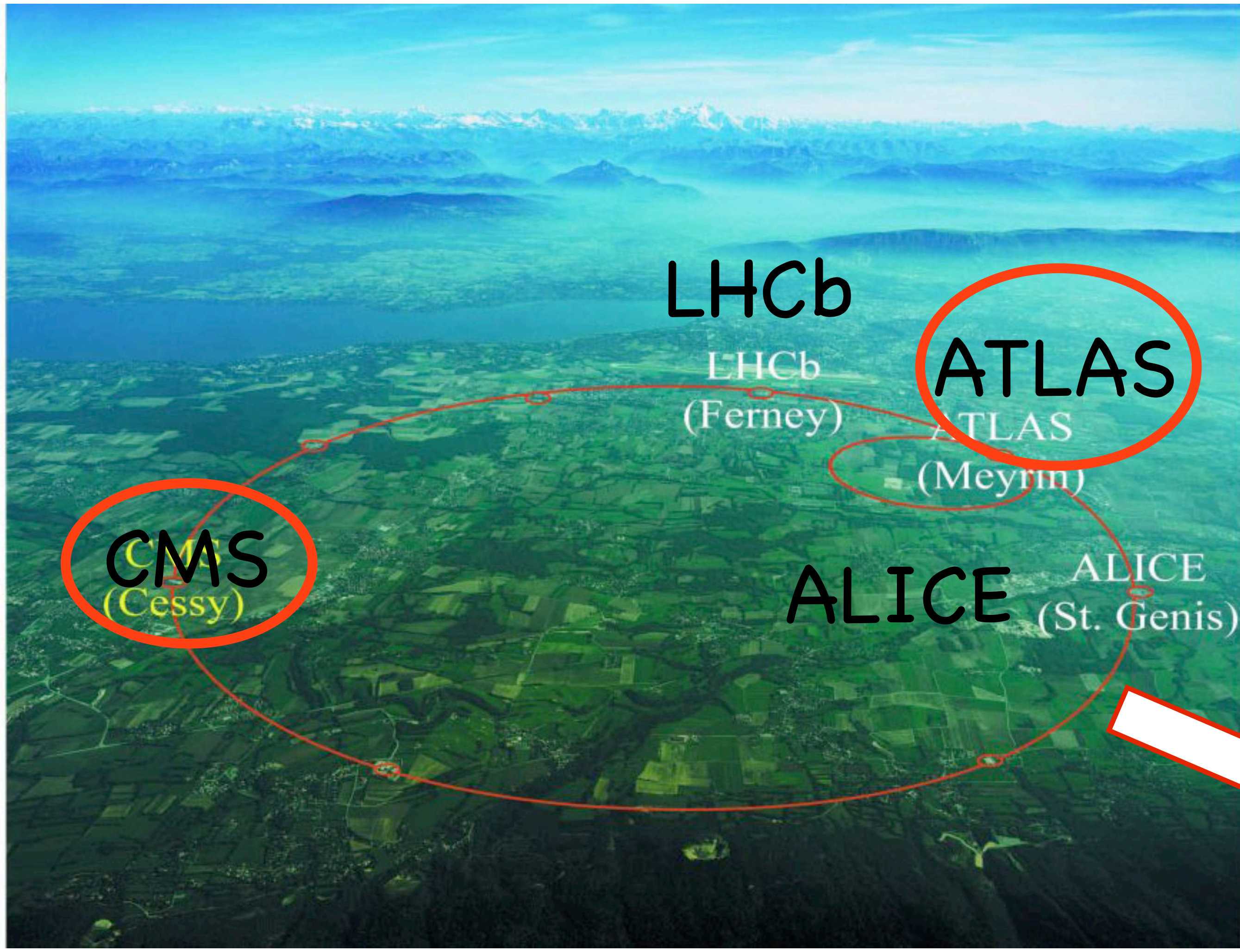

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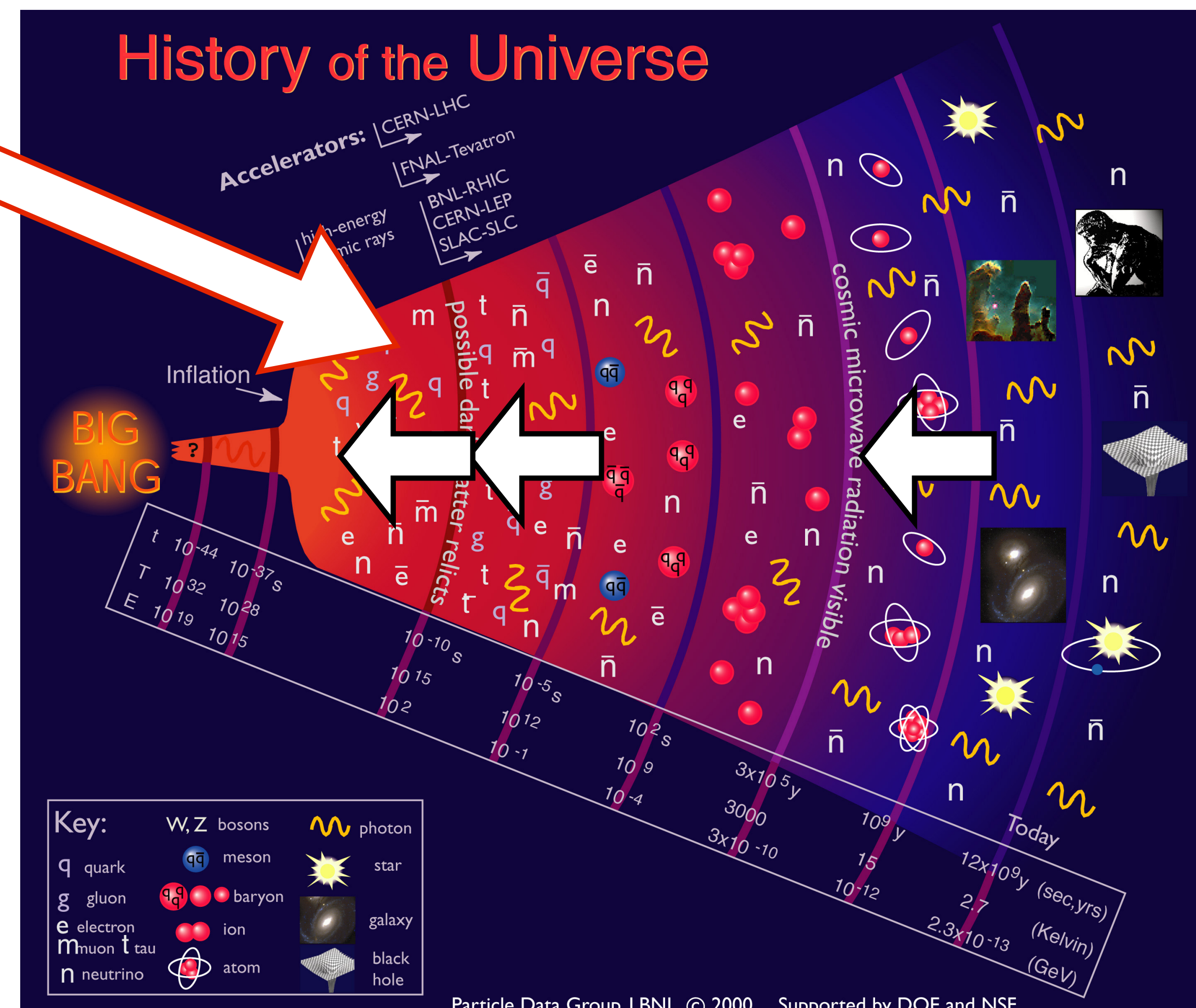

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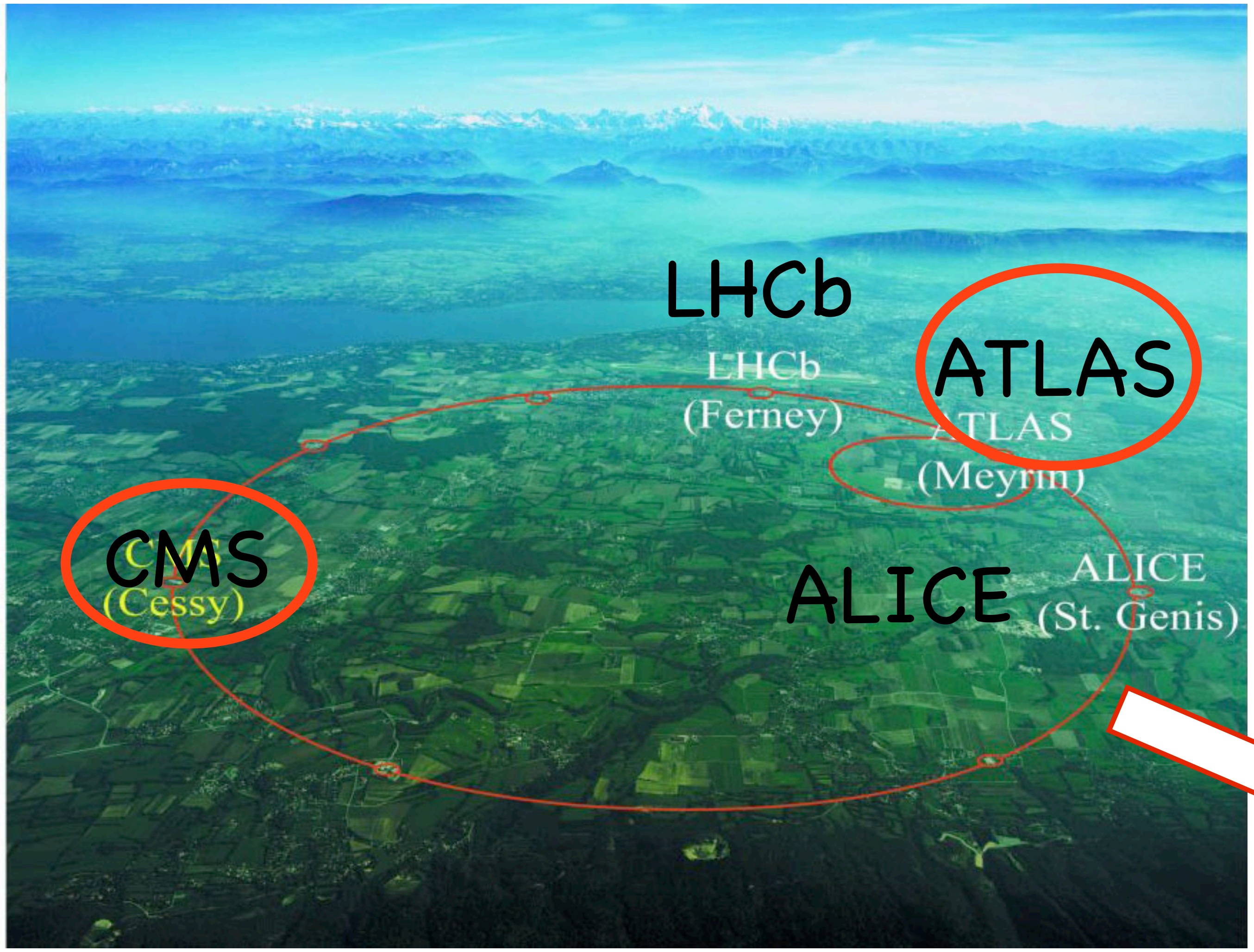

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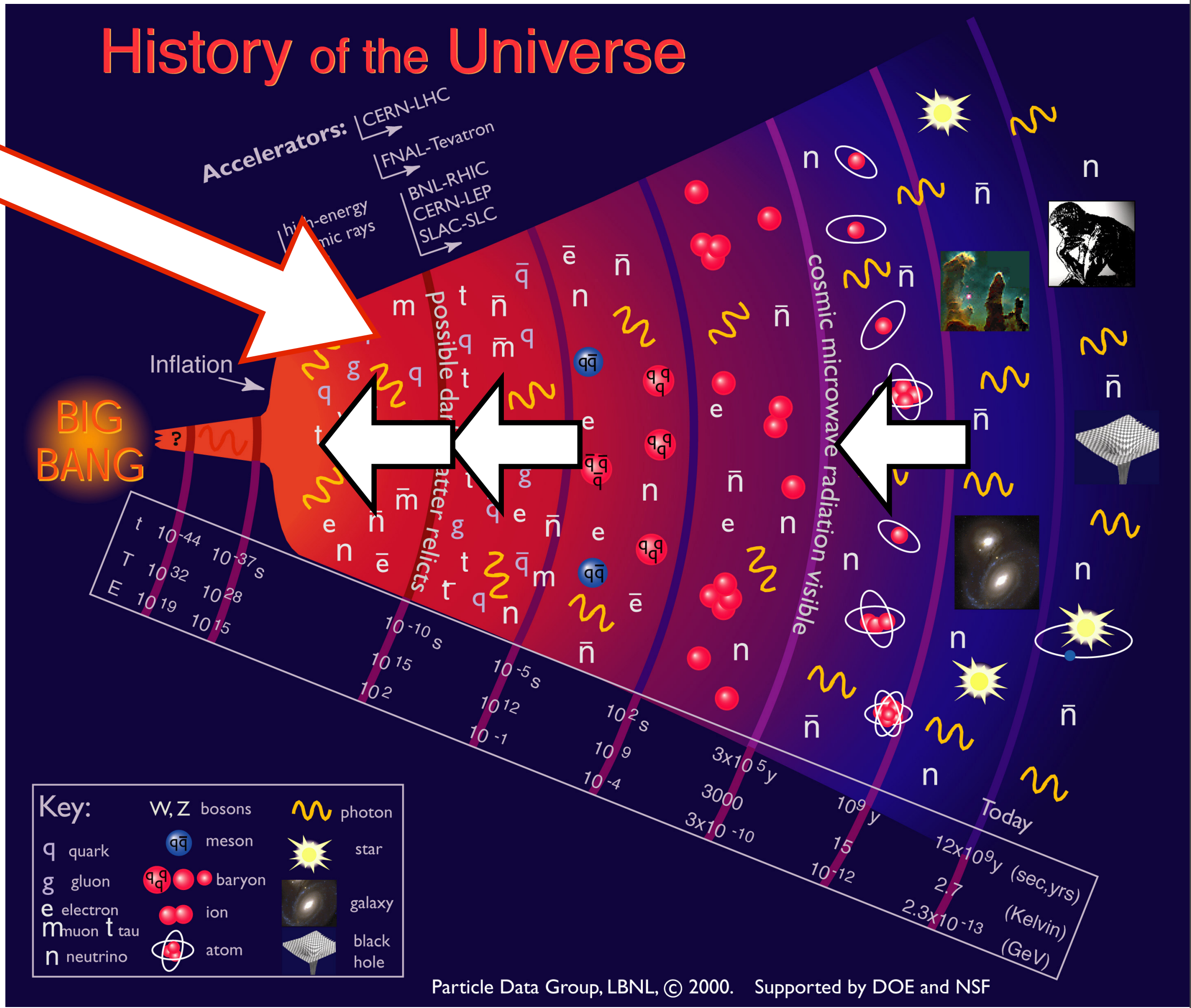

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DM $\boxed{\text{Axion models}}$

Introduction

❑ strong CP problem

from neutron EDM exp $\bar{\theta} \lesssim \mathcal{O}(10^{-9})$ Why so small?

Harris et al. PRL 82, 904 (1999)

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axion: very light, very weakly coupled (invisible axion)

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However → domain wall problem

Sikivie, PRL48, 1156 (1982)

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How to avoid DW problem?

1) low inflation scale, 2) explicit PQ symm breaking, **3) # of DW = 1**

variant axion models

Peccei, Wu, Yanagida PLB 172, 435 (1986),
Krauss, Wilczek PLB 173, 189 (1986)

- a two Higgs doublets + one singlet scalar (heavy)
  (Φ_1 , Φ_2) (σ)
- Φ_2 couples to **only** u or c or t quark
  (carries PQ charge)

N_{DW} = 1

NO domain wall problem !!

- couple to top quark (model T)
  PQ charge assignment:

Φ_1	Φ_2	t_R	other q's	σ
0	-1	-1	0	1

variant axion models

- model T

potential

$$
\begin{aligned}
V(\Phi_1, \Phi_2, \sigma) \;&=\; \lambda_1 \left(|\Phi_1|^2 - \frac{v_1^2}{2} \right)^2 + \lambda_2 \left(|\Phi_2|^2 - \frac{v_2^2}{2} \right)^2 + \lambda \left(|\sigma|^2 - \frac{v^2}{2} \right)^2 \\
&\quad + a\,|\Phi_1|^2|\sigma|^2 + b\,|\Phi_2|^2|\sigma|^2 + \left(m\,\Phi_1^\dagger \Phi_2 \sigma + \mathrm{h.c.} \right) \\
&\quad + d\,|\Phi_1^\dagger \Phi_2|^2 + e\,|\Phi_1|^2\,|\Phi_2|^2
\end{aligned}
$$

Yukawa

$$
\begin{aligned}
-\mathcal{L}_{\mathrm{Yukawa}} \;&=\; \boxed{y_{ij}^{(d)} \bar{Q}_{Li} \Phi_1 d_{Rj} + y_i^{(u)} \bar{Q}_{Li} \tilde{\Phi}_1 u_R + y_i^{(c)} \bar{Q}_{Li} \tilde{\Phi}_1 c_R} \\
&\quad \boxed{+ y_i^{(t)} \bar{Q}_{Li} \tilde{\Phi}_2 t_R,}
\end{aligned}
$$

VAM avoids DW problem

⇒ Yukawa couplings are different

⇒ can have signal of VAM at LHC??

variant axion models

- model T

Higgs bosons

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + h_1 + ig_1) \end{pmatrix}, \qquad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + h_2 + ig_2) \end{pmatrix}$$

$$\Longrightarrow \begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h_1 \\ h_2 \end{pmatrix},$$

$$\sin\alpha \to 0 \quad \Longrightarrow \quad H \sim h_1, h \sim h_2$$

couplings to SM particles

$\tan\beta \equiv v_2/v_1$ ⟹ larger/smaller than 1

variant axion models

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$\sin\alpha \to 0$ $\longrightarrow$ $H \sim h_1, h \sim h_2$

light

couplings to SM particles

$\tan\beta \equiv v_2/v_1$ $\longrightarrow$ $\boxed{\text{larger}}$/smaller than 1

variant axion models

- model T -- light Higgs couplings

to gauge bosons

$$hVV \ : \ \sin(\beta-\alpha)\, g_{\rm SM}^{hVV}$$ ⟶ SM like

tanβ large, sinα≈0

to quarks

$$hcc \ : \ -\frac{\sin\alpha}{\cos\beta} g_{\rm SM}^{hcc},$$

$$hbb \ : \ -\frac{\sin\alpha}{\cos\beta} g_{\rm SM}^{hbb},$$

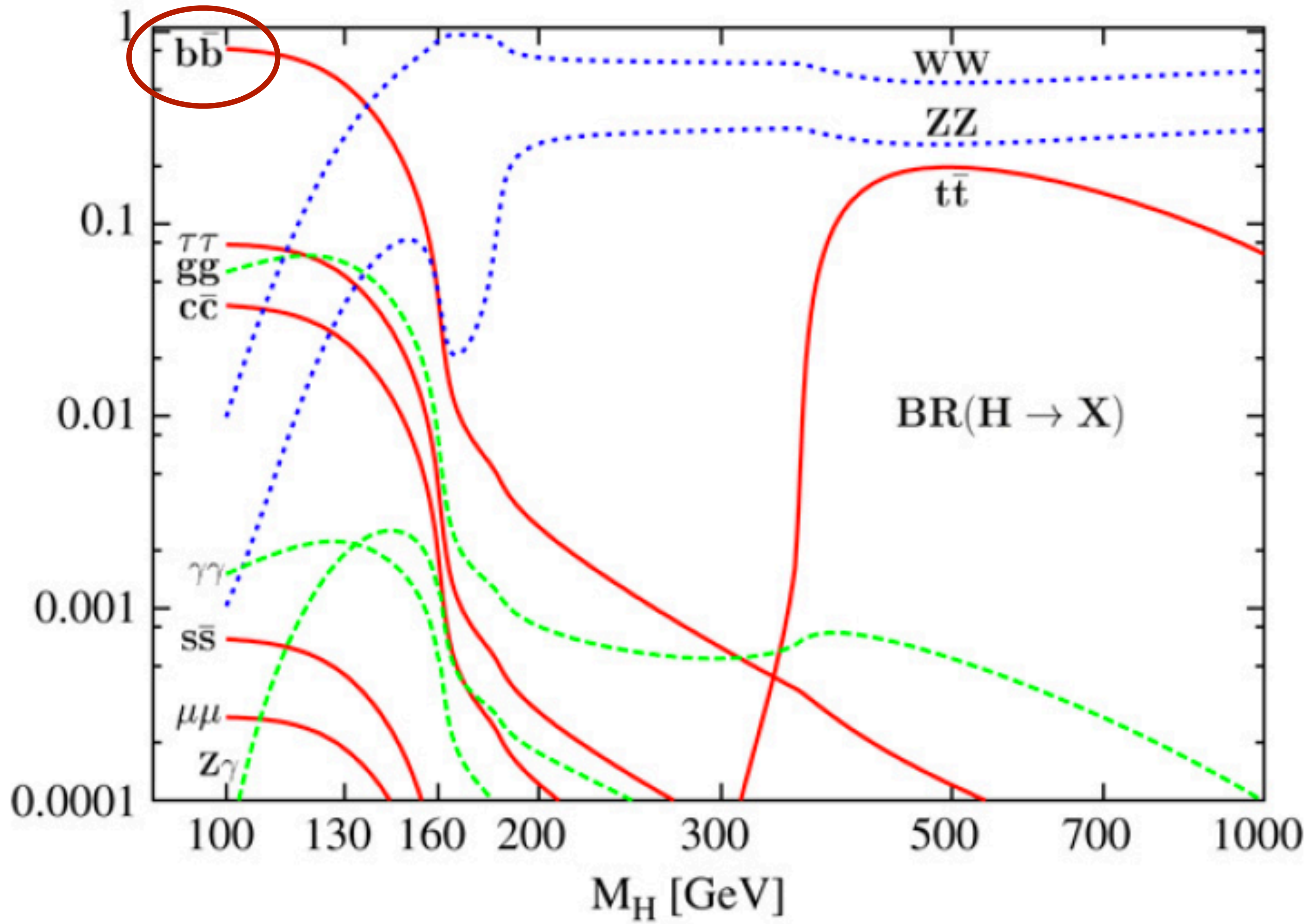
} suppressed if |sinα| < cotβ

$$htt \ : \ \frac{\cos\alpha}{\sin\beta} g_{\rm SM}^{htt}.$$ ⟶ SM like

- model U: t --> u ⟶ huu SM like
- model U: t --> c ⟶ hcc SM like

Higgs search

decay BRs in SM



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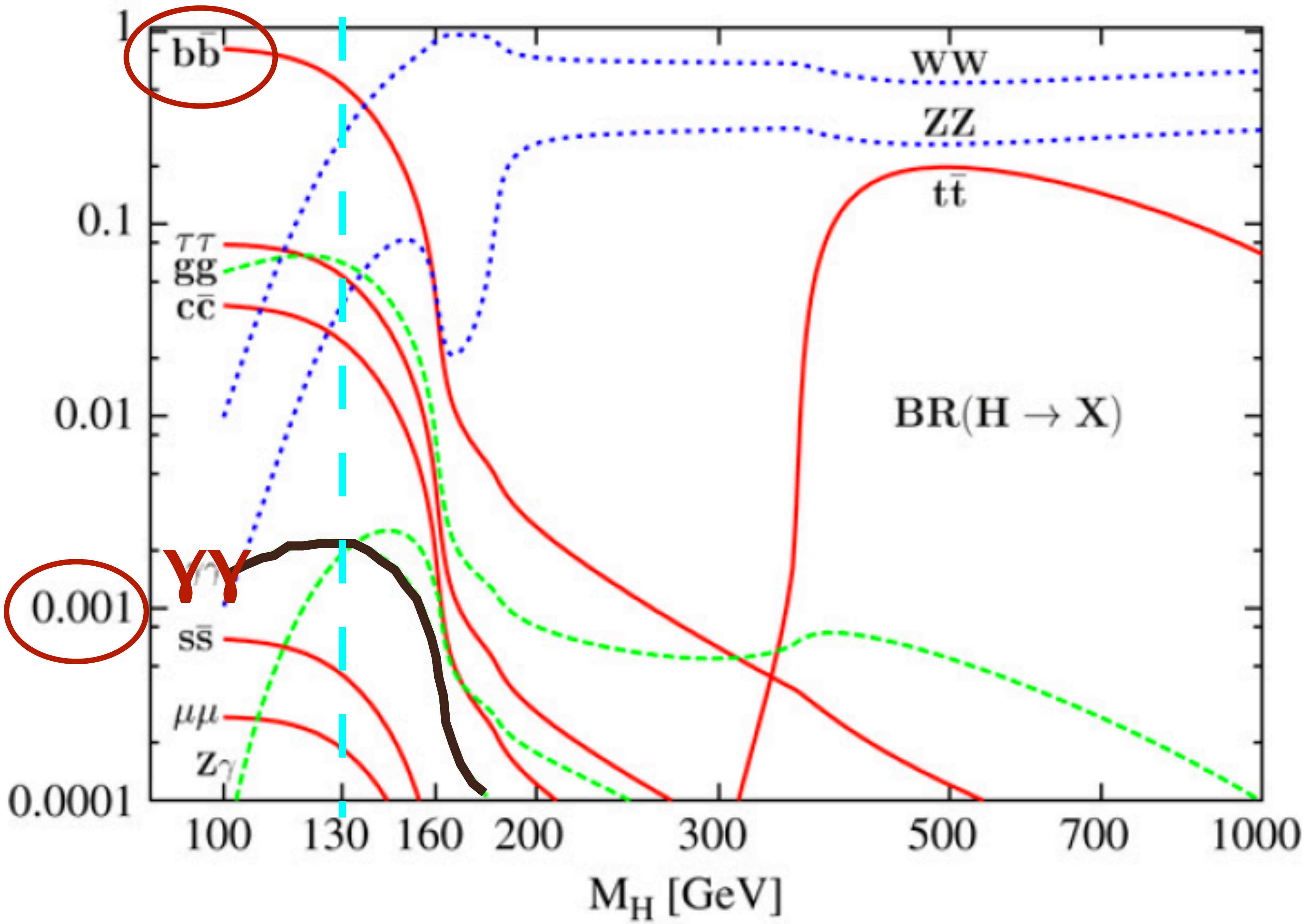

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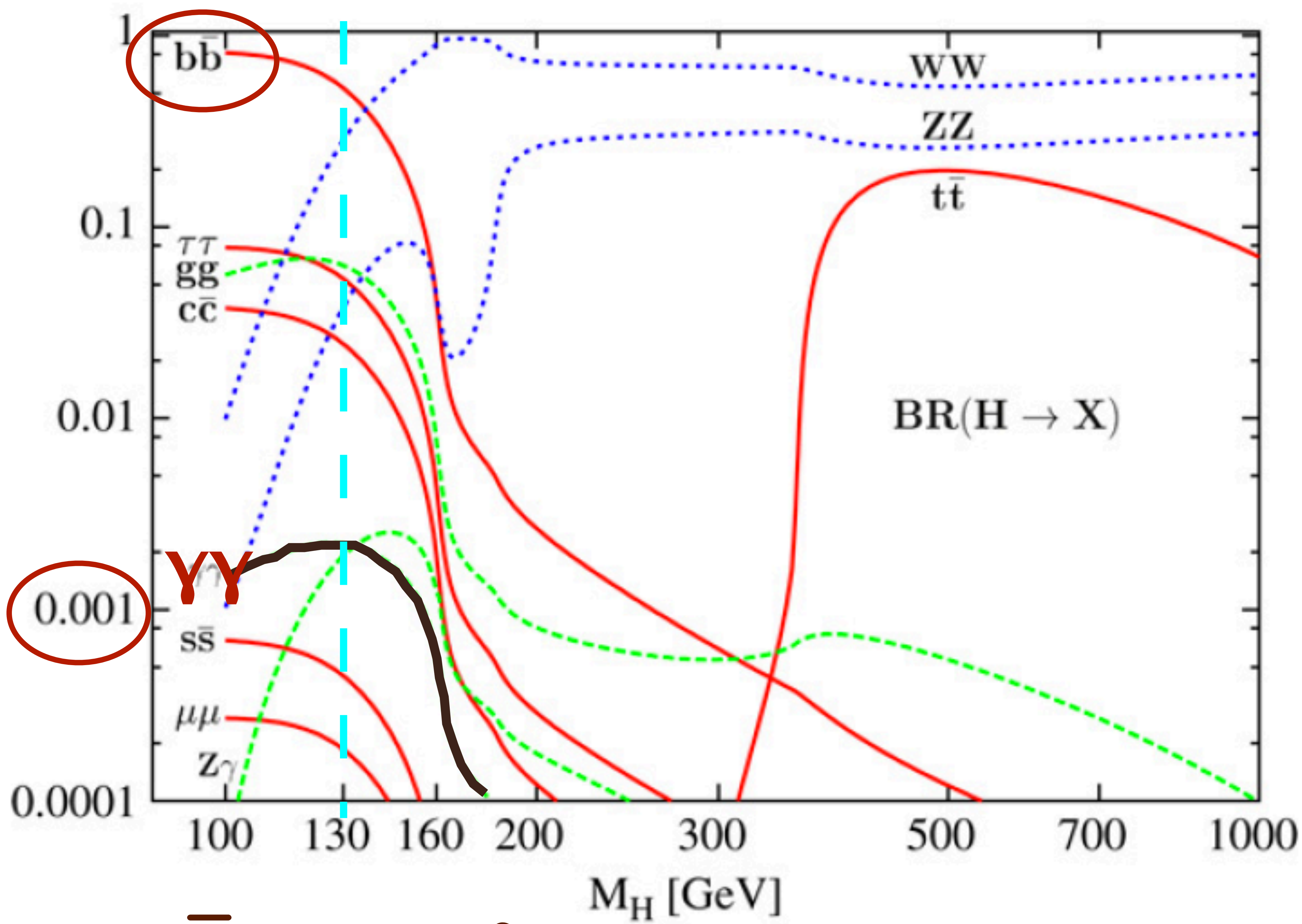
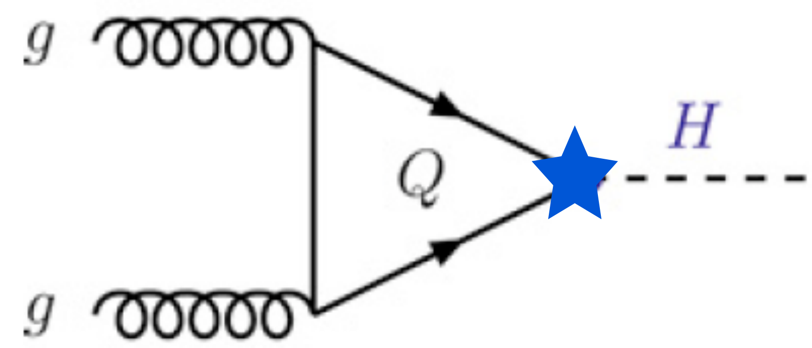
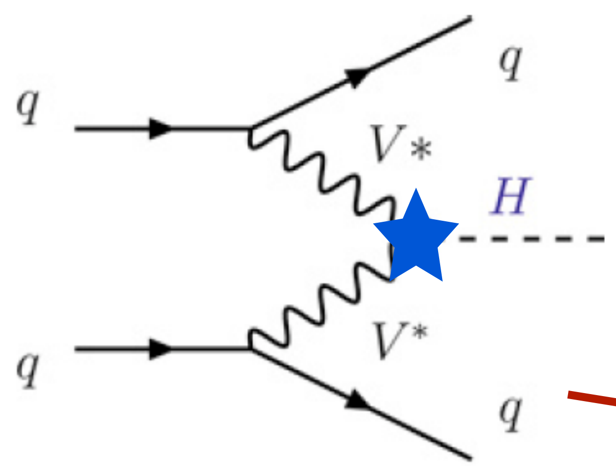


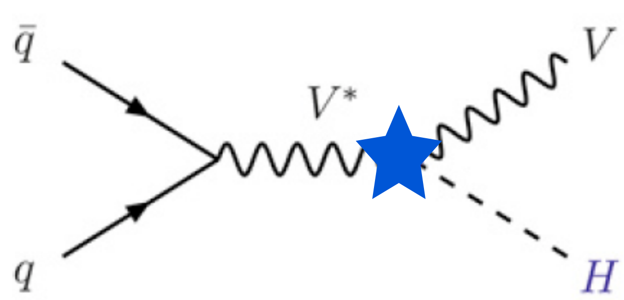
IF h--> $b\bar{b}$ is significantly reduced, h-->γγ can be enhanced!!

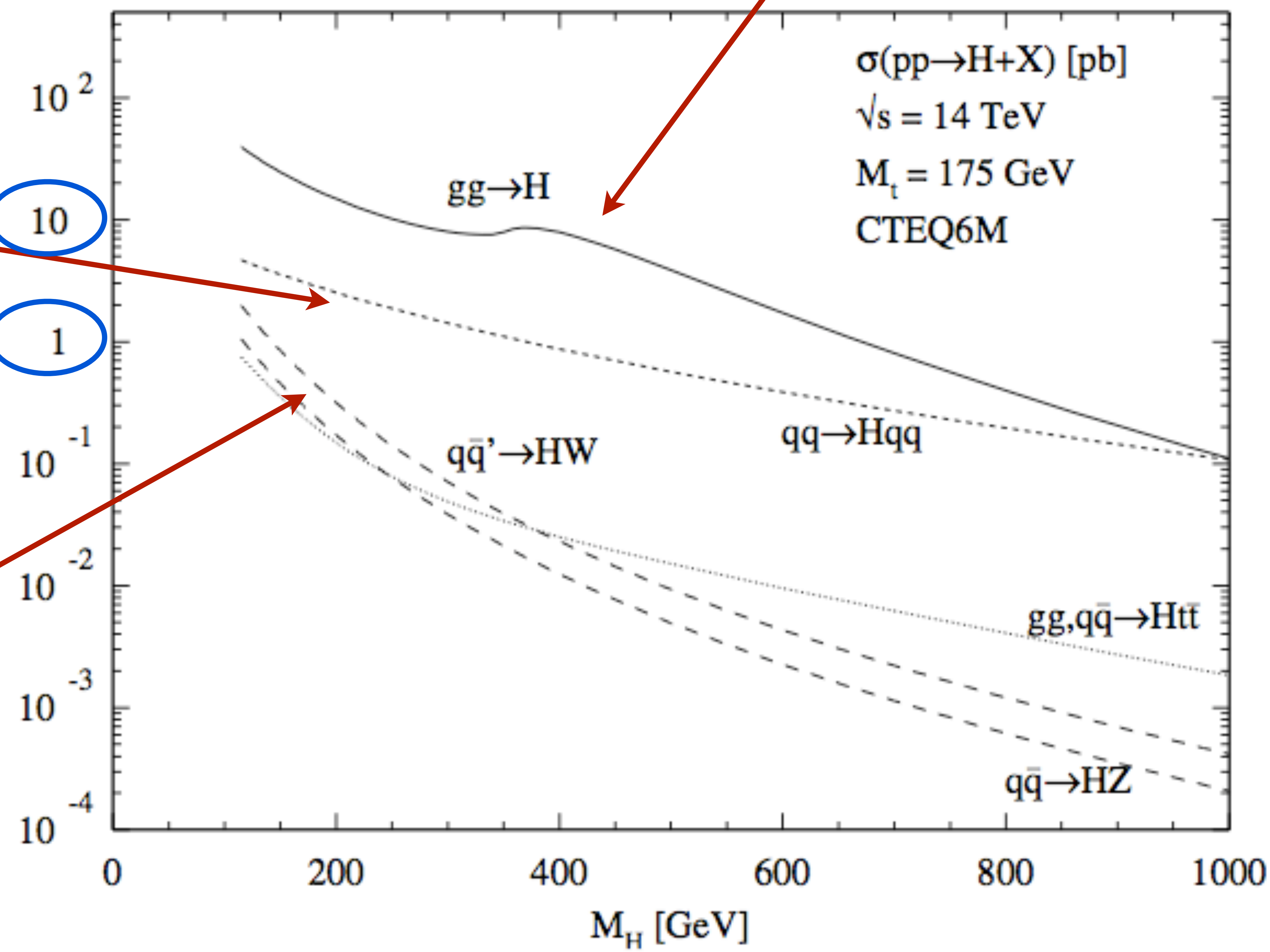
Higgs search

production in SM









Model U

$\tan\beta = 5$

$\sin\alpha = 0$

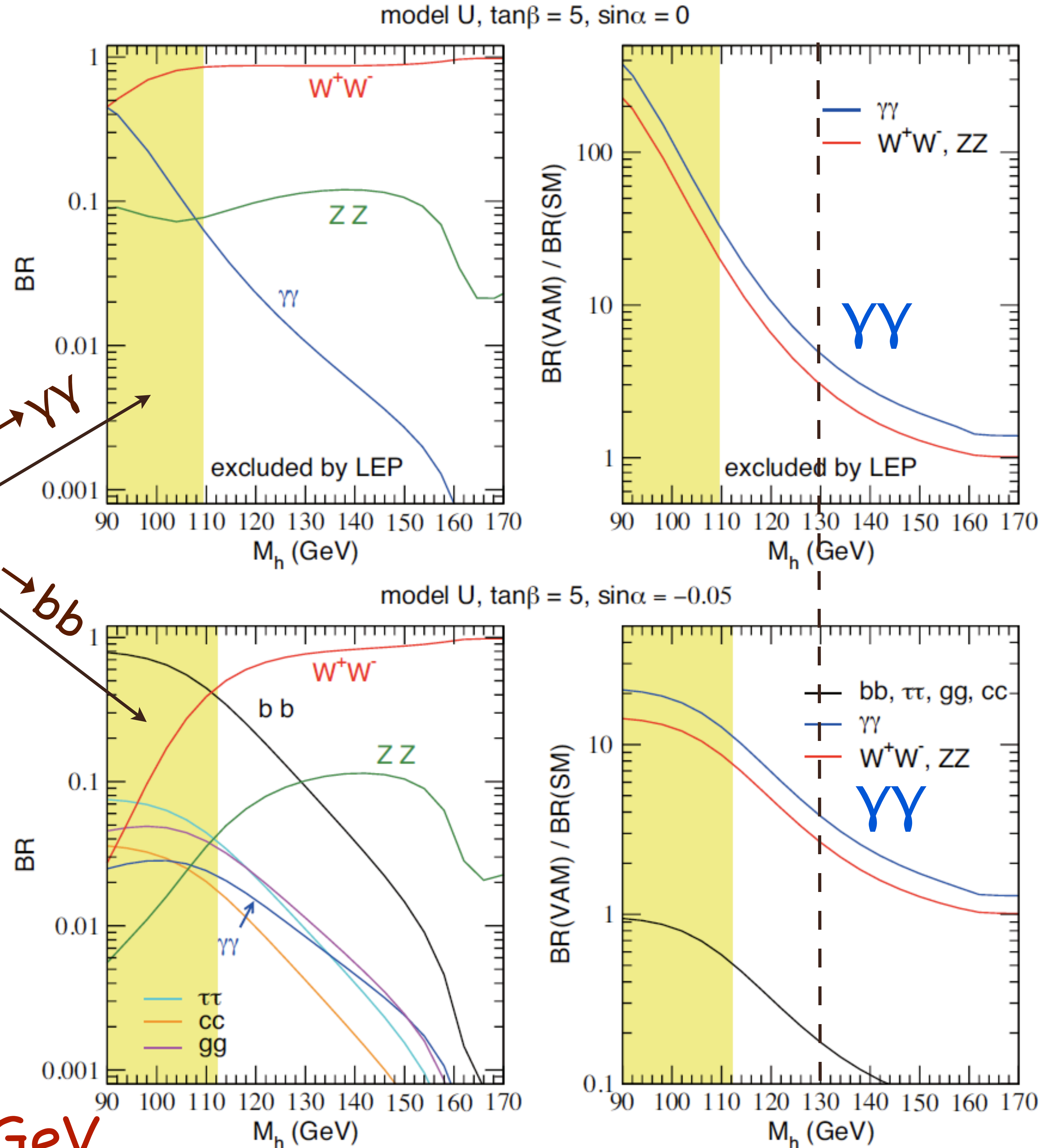
constrained by LEP

$h \to \gamma\gamma$

$h \to bb$

$\sin\alpha = -0.05$

a factor of 5 ~ 30 enhancement for $M_h \lesssim 130$ GeV



Model C

$\tan\beta = 5$

$\sin\alpha = 0$

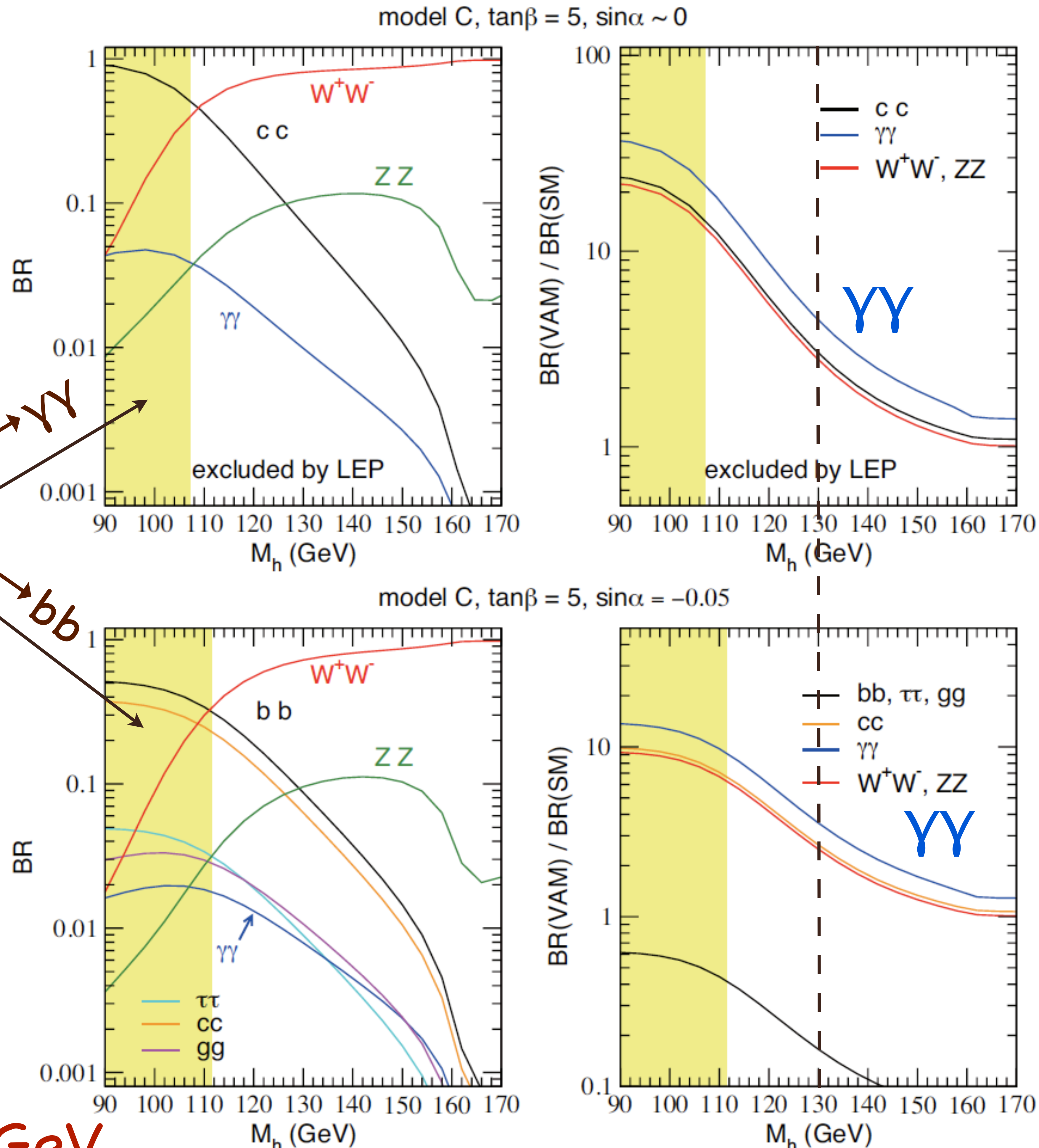
constrained by LEP

$h \to \gamma\gamma$

$h \to bb$

$\sin\alpha = -0.05$

a factor of $4 \sim O(10)$ enhancement for $M_h \lesssim 130$ GeV



Model T

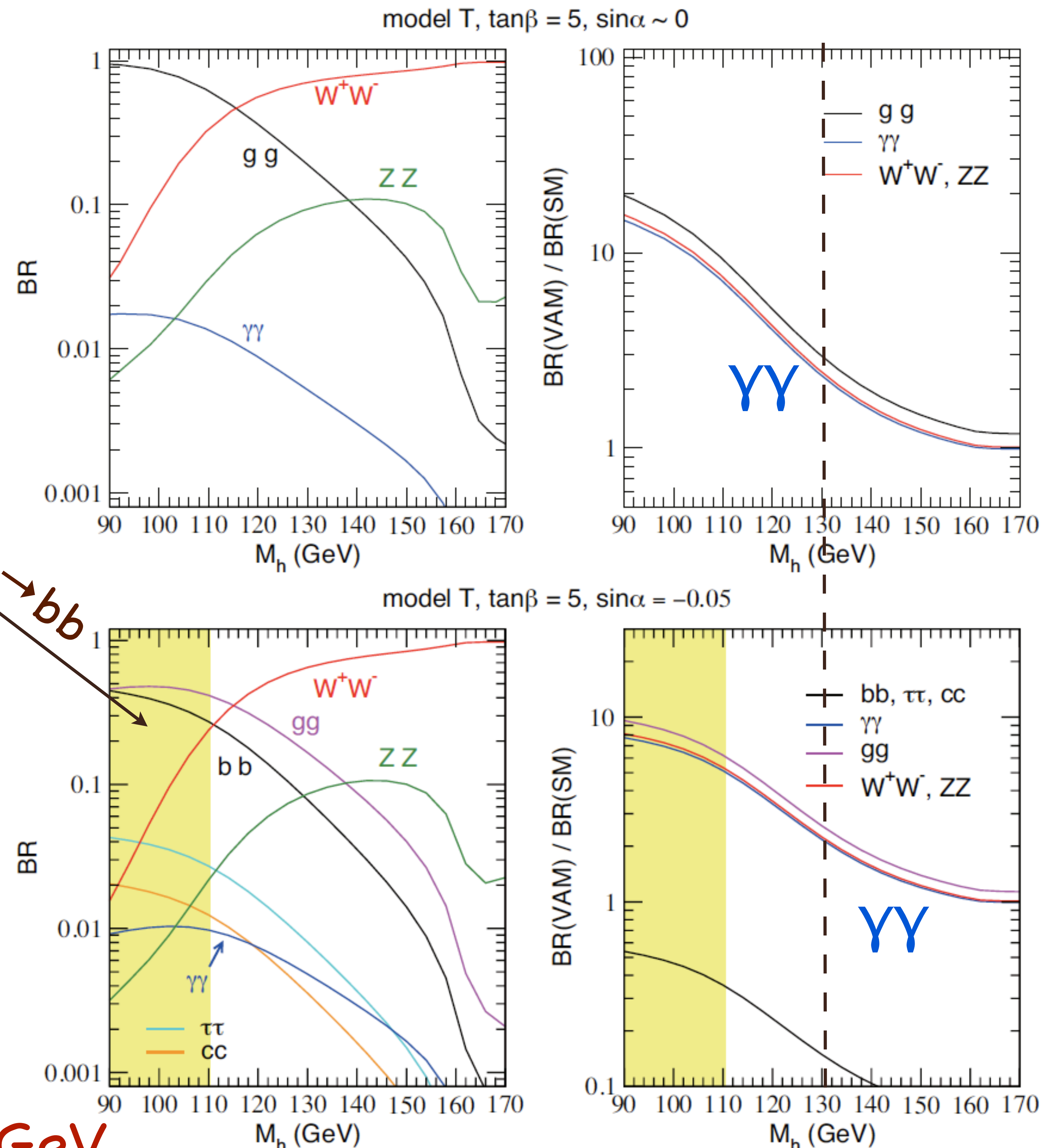
tanβ = 5

sinα = 0

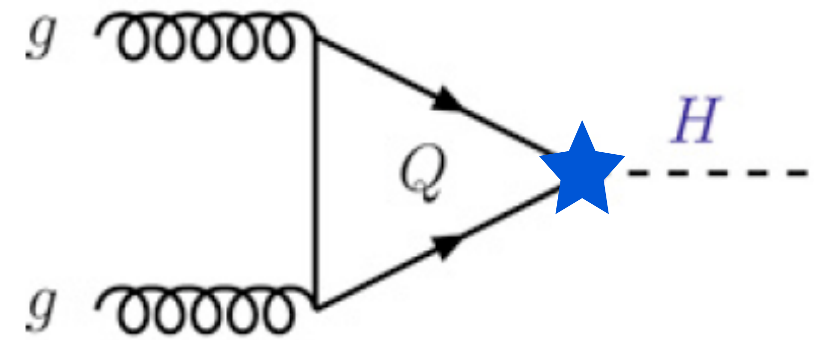
constrained by LEP

sinα = -0.05

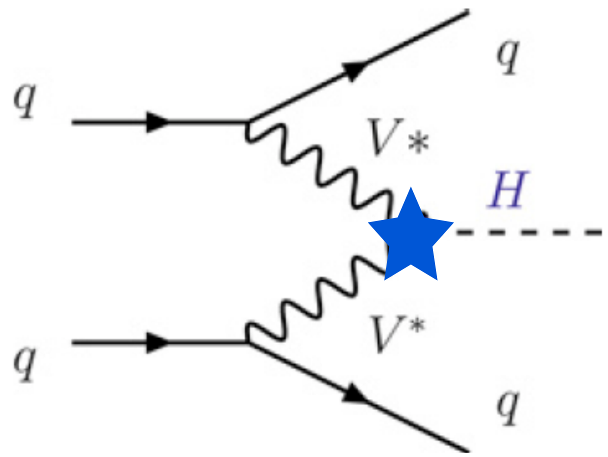
a factor of 2 ~ O(10) enhancement for $M_h \lesssim 130$ GeV

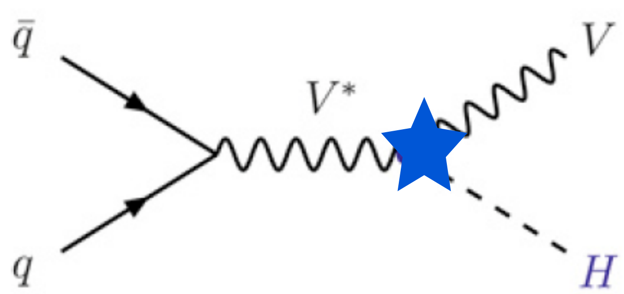


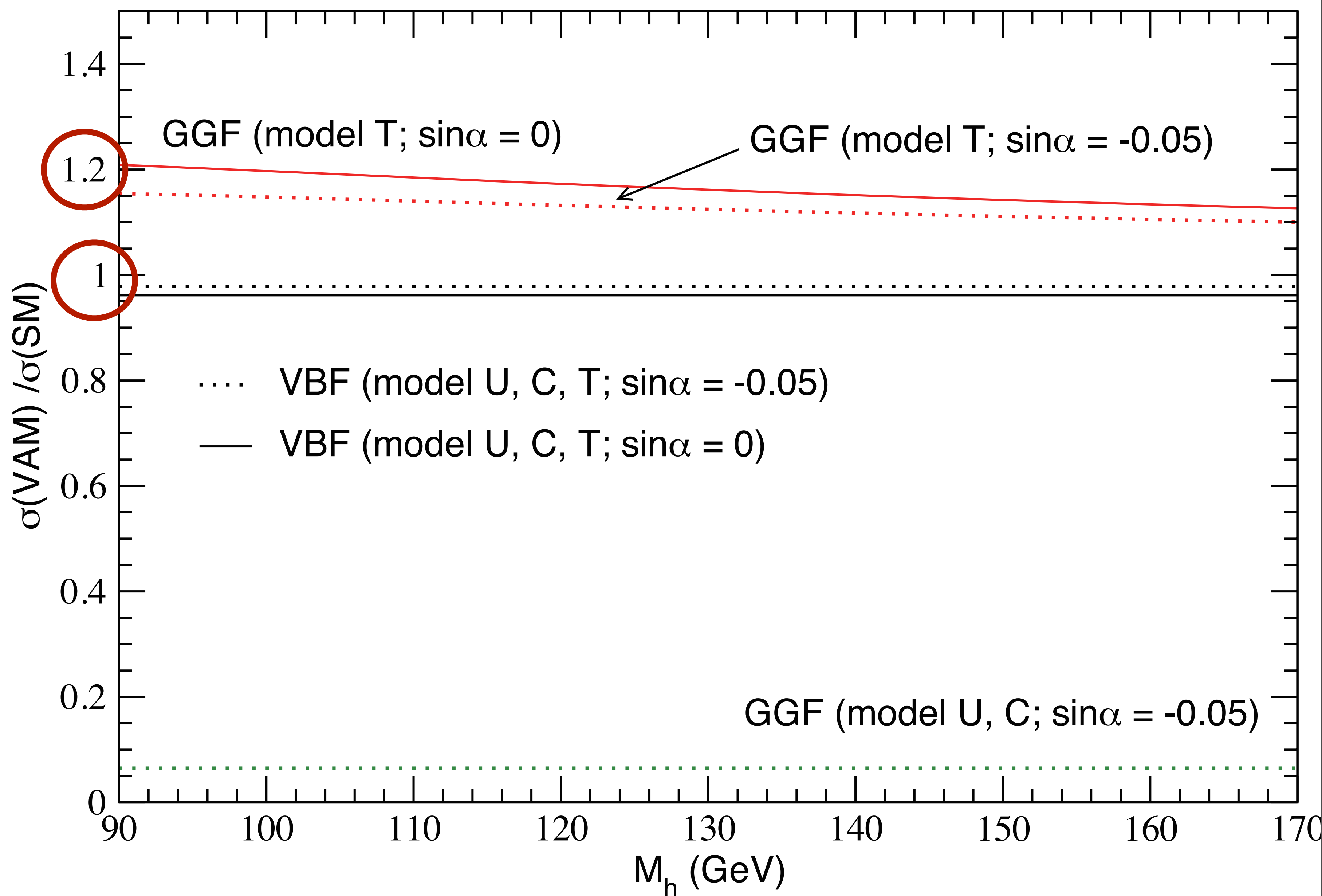
Higgs search



production cross sections







model U and C → VBF & VH

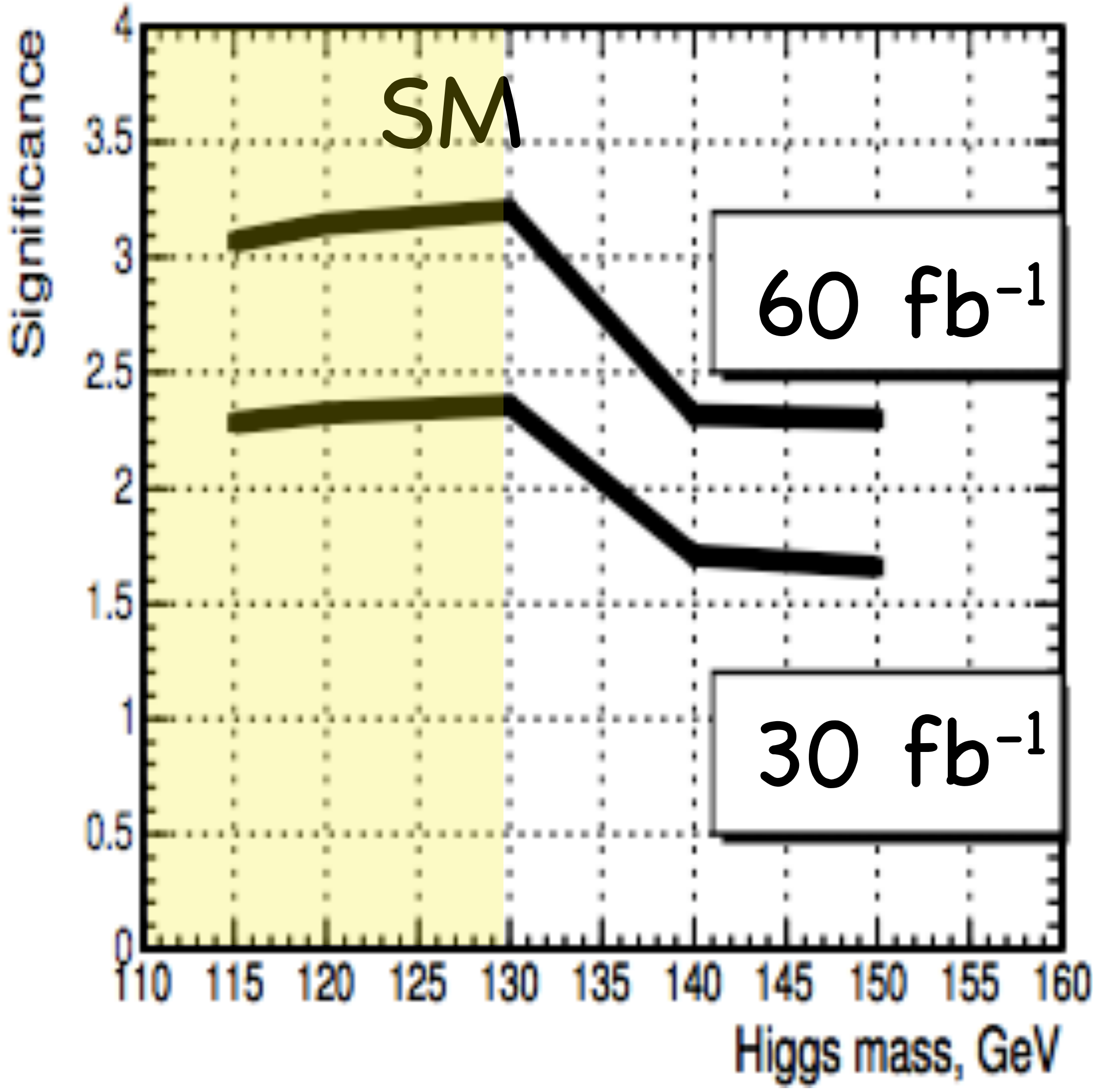
model T → GGF, VBF, VH

Higgs search

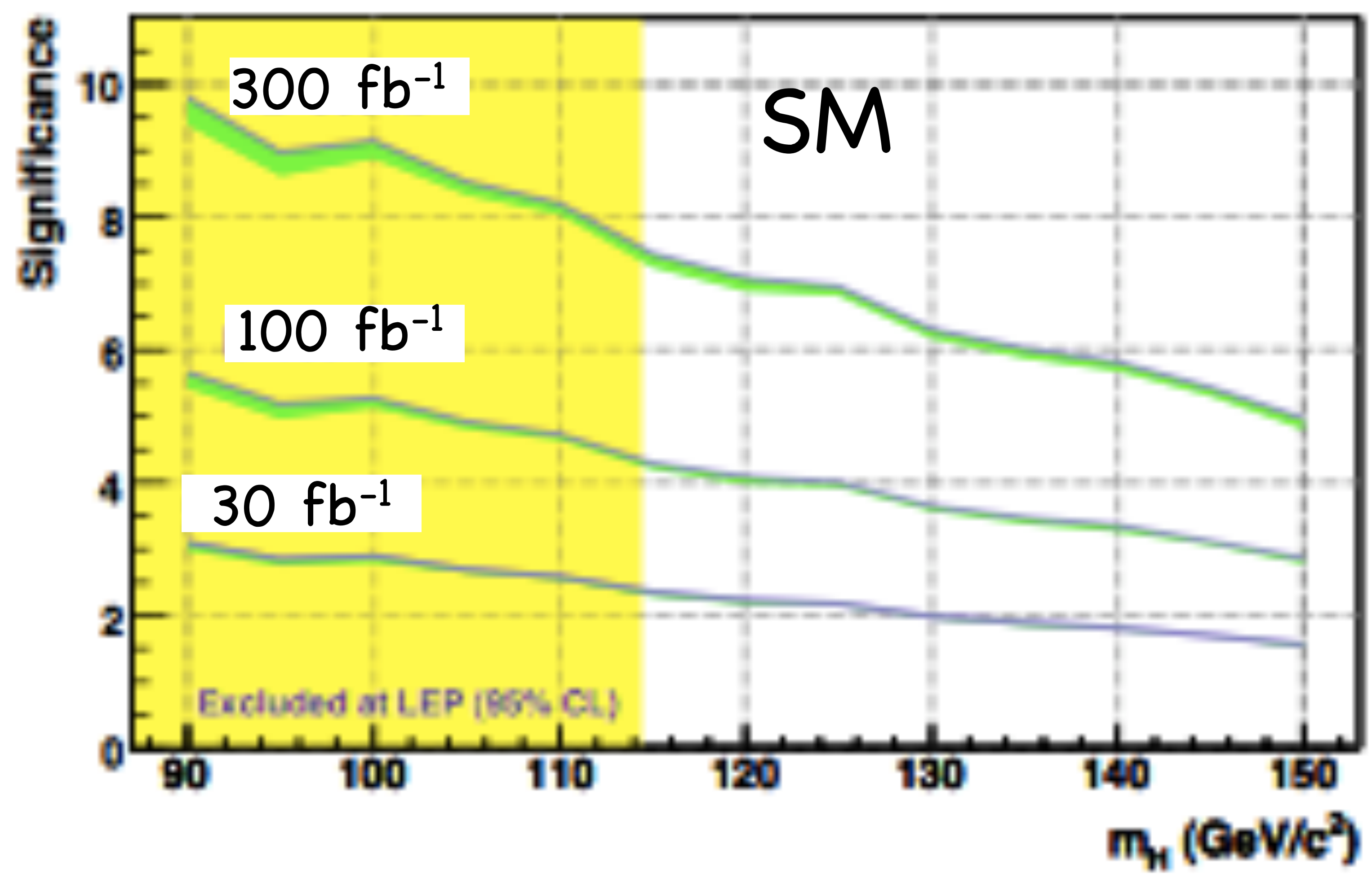
impacts

CMS, TDR

VBF, $h \to \gamma\gamma$



Vh, $h \to \gamma\gamma$



model U, C $\xrightarrow[M_h = 120 \text{ GeV}]{5\sigma \text{ w/}}$ ~ 3 fb^{-1} for $\sin\alpha = 0$

~ 10 fb^{-1} for $\sin\alpha = -0.05$

Higgs search

impacts

model T

↓

same production Xsection

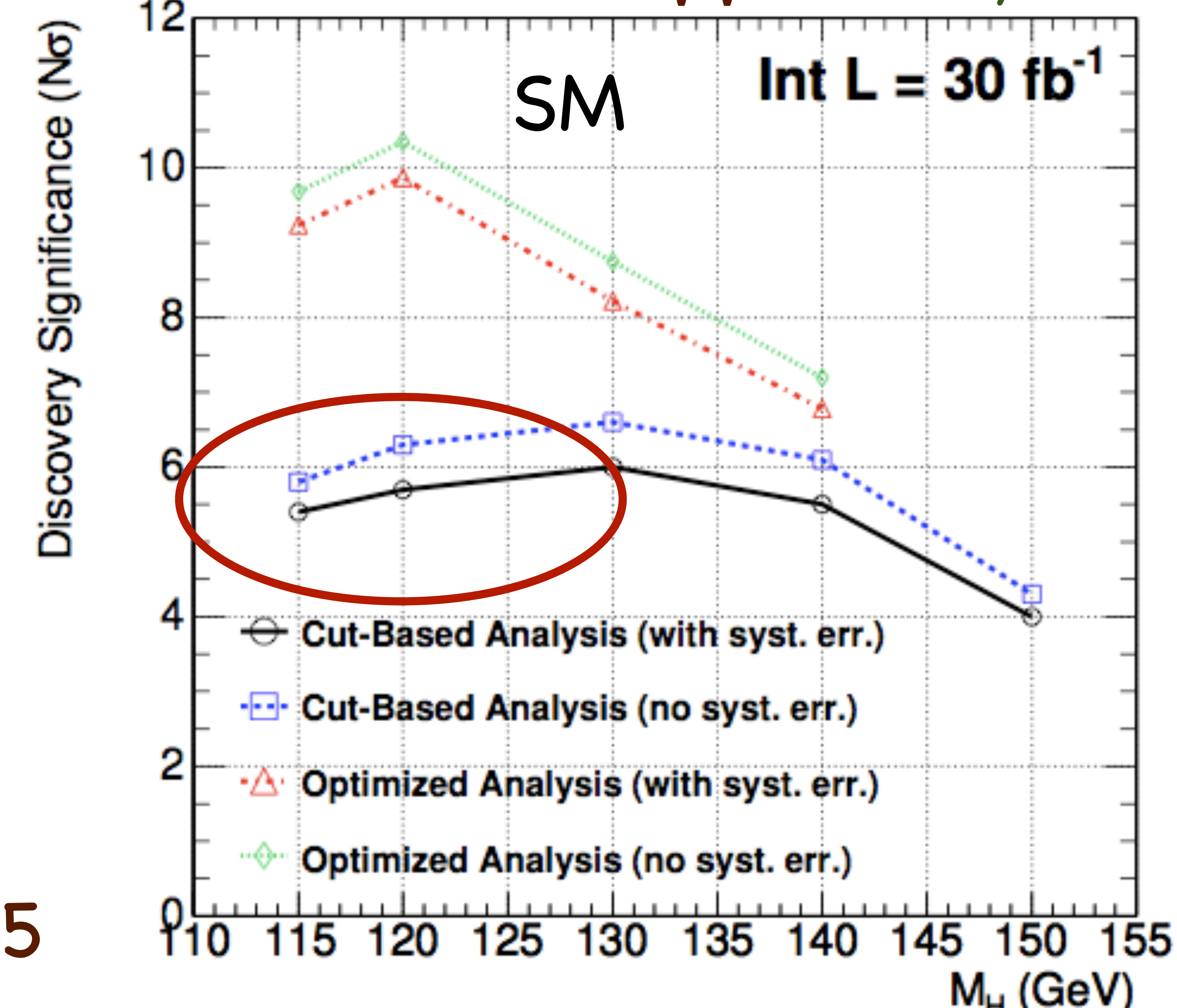
$\oplus$

larger BR($h \to \gamma\gamma$)

↓

can reach
3σ for $\sin\alpha = 0$
2σ for $\sin\alpha = -0.05$

inclusive $h \to \gamma\gamma$ CMS, TDR



w/ 7 TeV, 1 fb^{-1} LHC!! (early run; next year!!)

Summary

In variant axion models, which avoids the domain wall problem,

- branching ratio of light Higgs boson to two photons can be significantly enhanced.

- gluon-gluon fusion can be suppressed (U, C) or enhanced (T), VBF and VH are similar to SM.

- VBF, VH + $h \to \gamma\gamma$ can be more important at LHC.

- in model T (PQ Higgs couples to top only), LHC w/ 7 TeV may have evidence of the existence of light Higgs boson.