Probing the new physics through the exclusive decay of Higgs and Z boson

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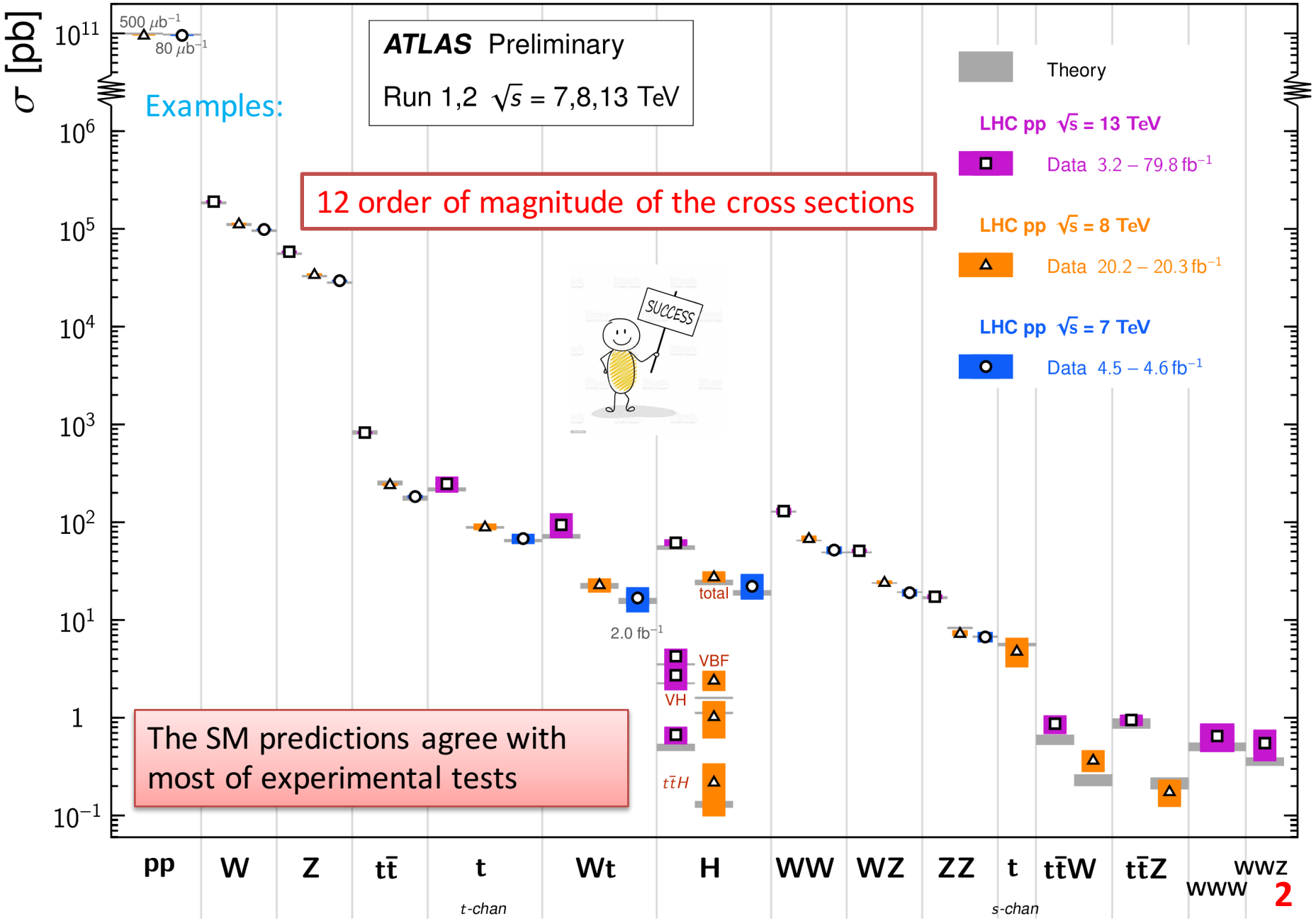
Institute of High Energy Physics

The 13th International Workshop on e+e- collisions from Phi to Psi
8-11, 2022

Hongxin Dong, Peng Sun, Bin Yan and C.-P. Yuan, PLB829(2022)137076
Hongxin Dong, Peng Sun and Bin Yan, arxiv: 220805153

Standard Model Total Production Cross Section Measurements

Status: May 2020



Why we need the New Physis?

Some open questions:

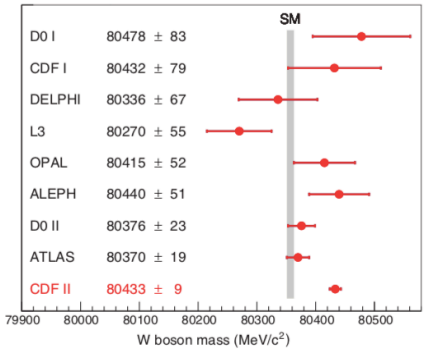
1. What is Dark Matter ?
2. What is the origin of the neutrino mass?
3. What is the nature of the electroweak symmetry breaking?
4. What is the nature of the Higgs boson (Composite or elementary particle)?
5. ……

New Physics Models and new measurements to answer these questions

The New Physics Signals?

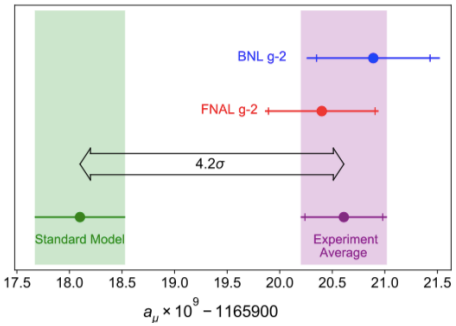
1. W-boson mass? 7σ

   CDF, Science 376(2022)6589



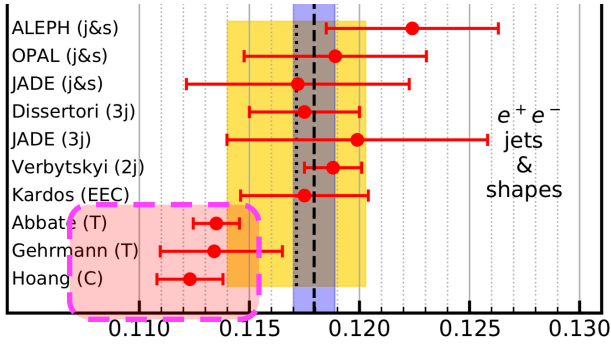
2. Muon g-2? 4.2σ

   PRL126(2021)14,141801



3. Strong coupling? $\sim 4\sigma$

   PDG2020



   G. Bell, C. Lee, Y. Makris, J. Talbert and Bin Yan, in preparation

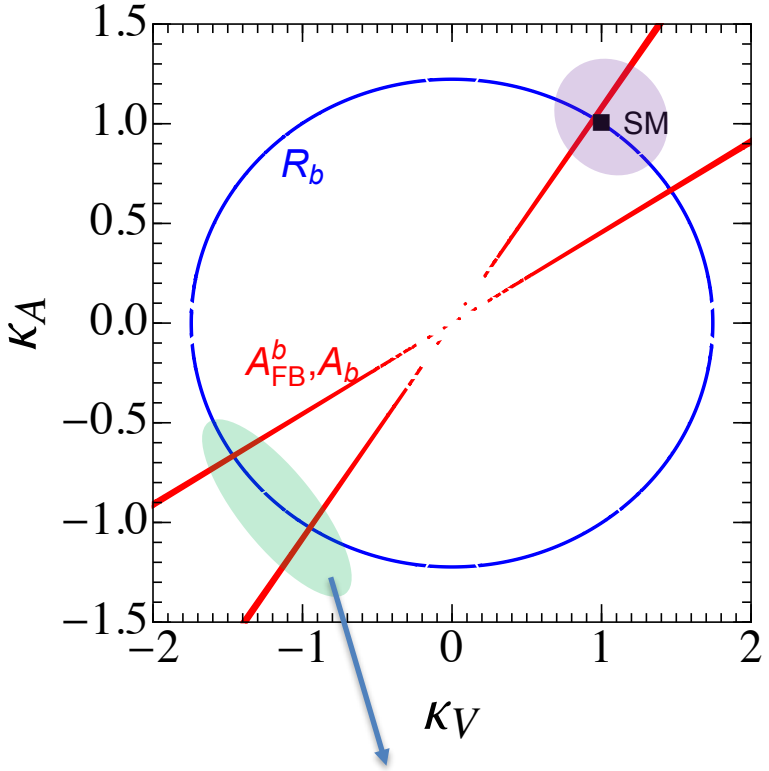
4. Forward-backward asymmetry of bottom quark @ LEP

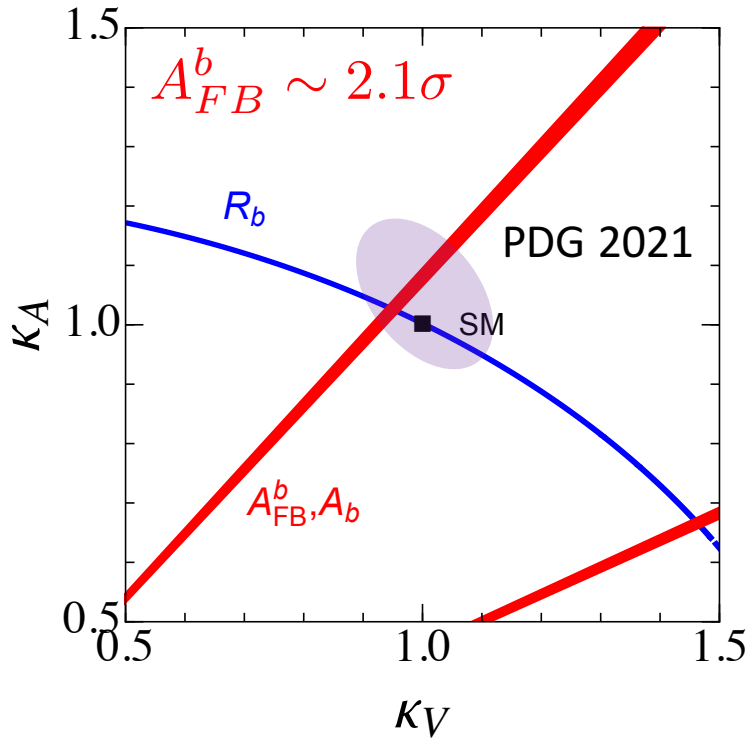
   PDG2020 2.1σ

5. Anomaly of B physics

Probing the Zbb coupling from Z boson exclusive decay

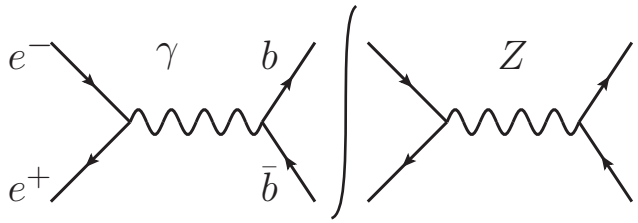
Status of Zbb couplings





Excluded by off-Z pole data

$$\mathcal{L} = \bar{b}\gamma_\mu(\kappa_V g_V - \kappa_A g_A \gamma_5) b Z_\mu$$



- *Large deviation* of the Zbb coupling
- The degeneracy of the Zbb coupling

Status of Zbb couplings

A. How to break the degeneracy of the Zbb coupling?

New experiments: CEPC (e+e- collider), etc.

B. How to explain the LEP data?

⇨ New Physics? Many new physics models

e.g. Custodial symmetry + heavy B' quark

K. Agashe, R. Contino, L. Rold, A. pomarol, 2006'

⇨ Statistical Fluctuation or Systematic error?

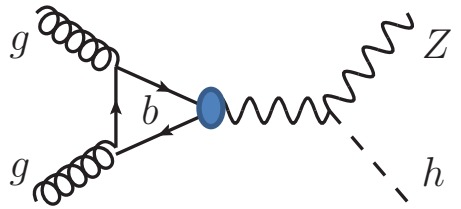
New experiments: e.g. CEPC

So…

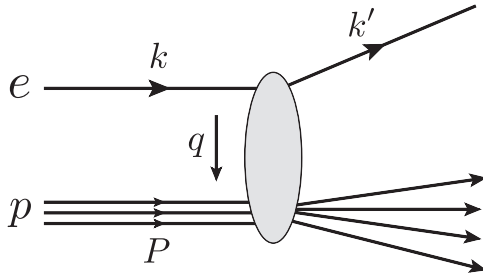
Should we just wait for the next generation lepton colliders?

Any possibility from LHC and other colliders?

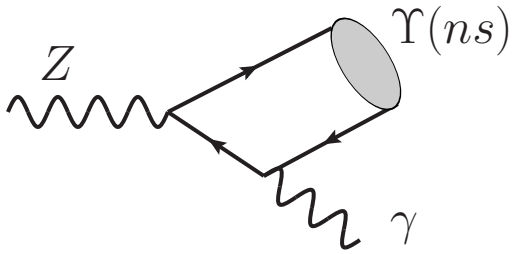
Zbb couplings@ LHC and EIC



Bin Yan, C.-P. Yuan, PRL127(2021)5,051801



Bin Yan, Zhite Yu and C.-P. Yuan, PLB822(2021)136697
Hai Tao Li, Bin Yan and C.-P. Yuan, PLB833(2022)137300



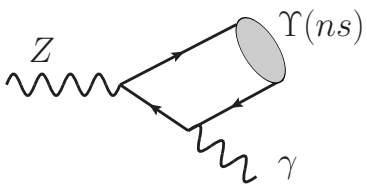
Hongxin Dong, Peng Sun, Bin Yan and C.-P. Yuan, PLB829(2022)137076

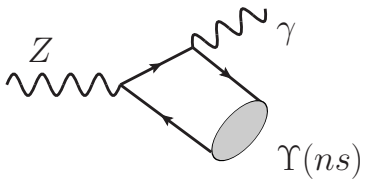
$$\Upsilon(ns) \to \ell^+\ell^- \qquad J^{PC}(\gamma, \Upsilon(ns)) = 1^{--}$$

charge conjugation invariance ⟹ axial-vector component of Zbb coupling

Exclusive Z boson decay@ NRQCD

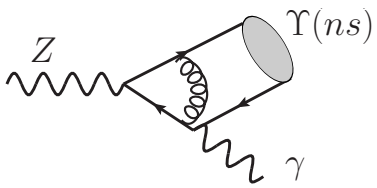
LO:

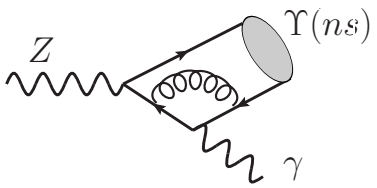


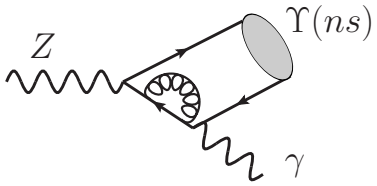


$\mathcal{O}(10^5)$ pb

NLO:







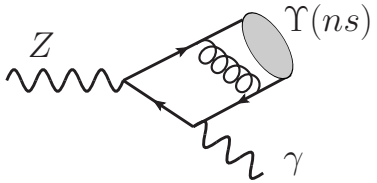


TABLE II. The branching ratios of $Z \to \Upsilon(ns) + \gamma$ at the LO and NLO in unites of 10^{-8} with renormalization scale $\mu = m_Z$.

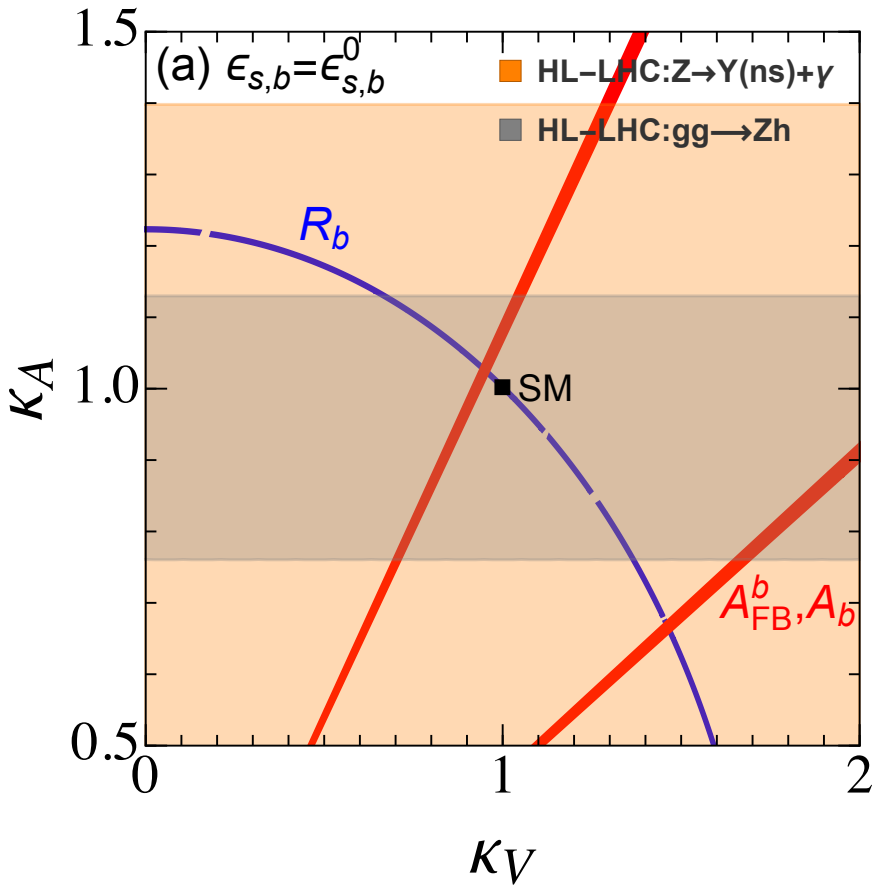
BR($Z \to \Upsilon(ns) + \gamma$)	$\Upsilon(1s)$	$\Upsilon(2s)$	$\Upsilon(3s)$
LO	3.83 ± 0.20	1.82 ± 0.21	1.32 ± 0.17
NLO	5.61 ± 0.29	2.66 ± 0.31	1.93 ± 0.25

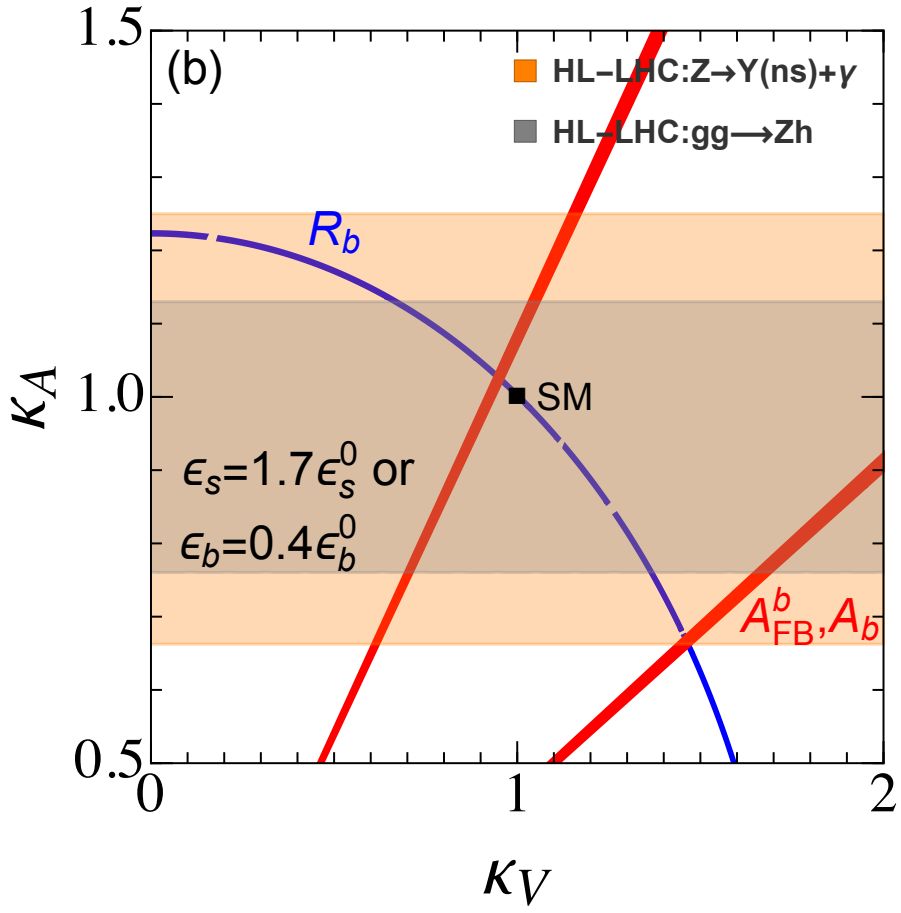
The relativistic correction is very small

T.- C. Huang and F. Petriello, PRD92,014007(2015)

Sensitivity @ HL-LHC

ATLAS+CMS $\quad \Upsilon(1s, 2s, 3s) \to e^+e^-, \mu^+\mu^-, \tau^+\tau^-$

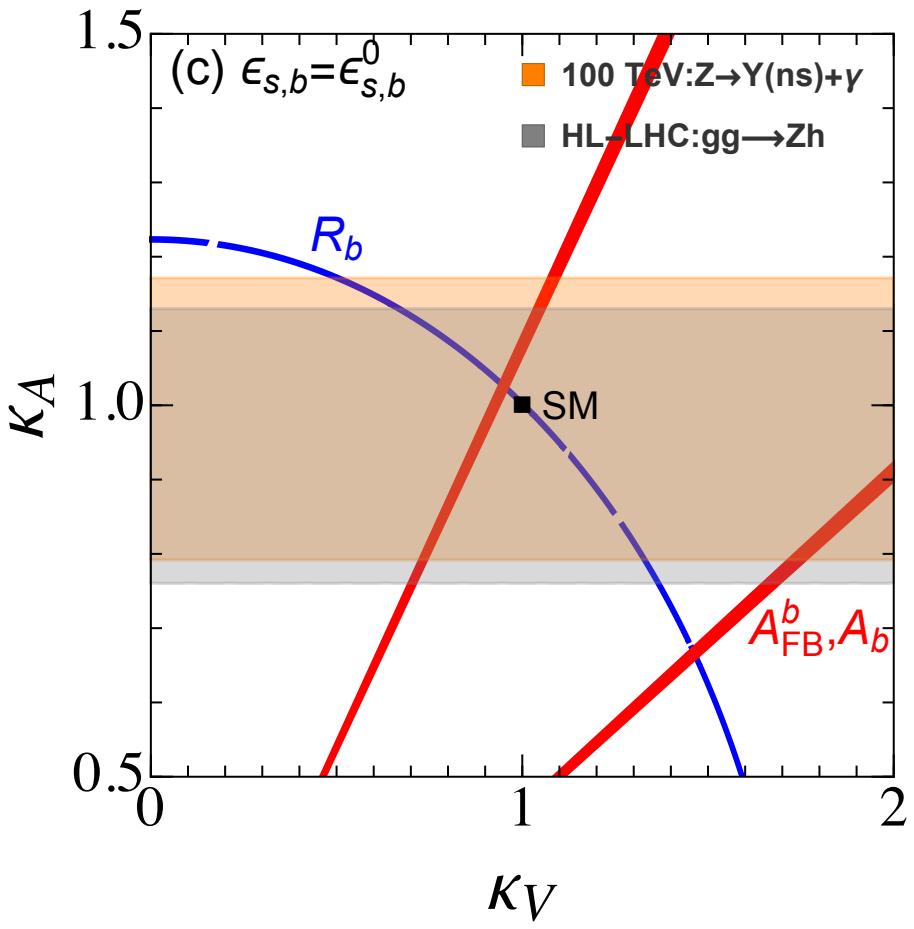


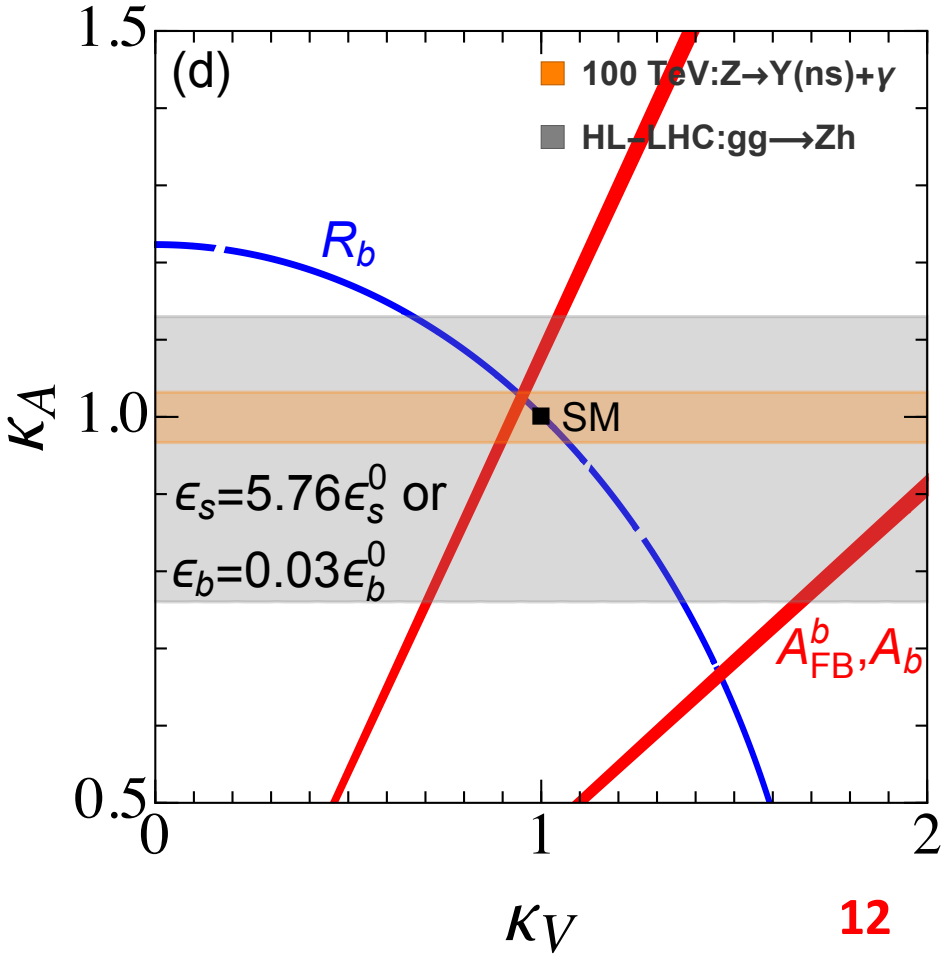


$$\mathcal{L} = \bar{b}\gamma_\mu(\kappa_V g_V - \kappa_A g_A \gamma_5) b Z_\mu$$

Sensitivity @ 100 TeV colliders

Same integrated luminosity and cut efficiencies as HL-LHC

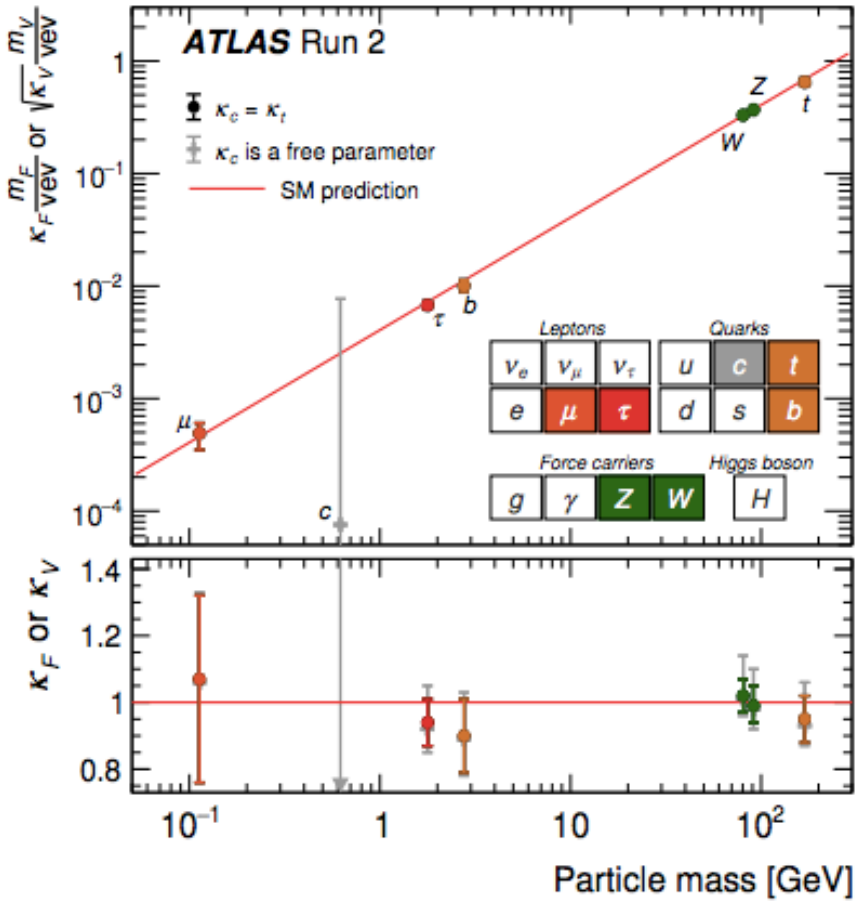


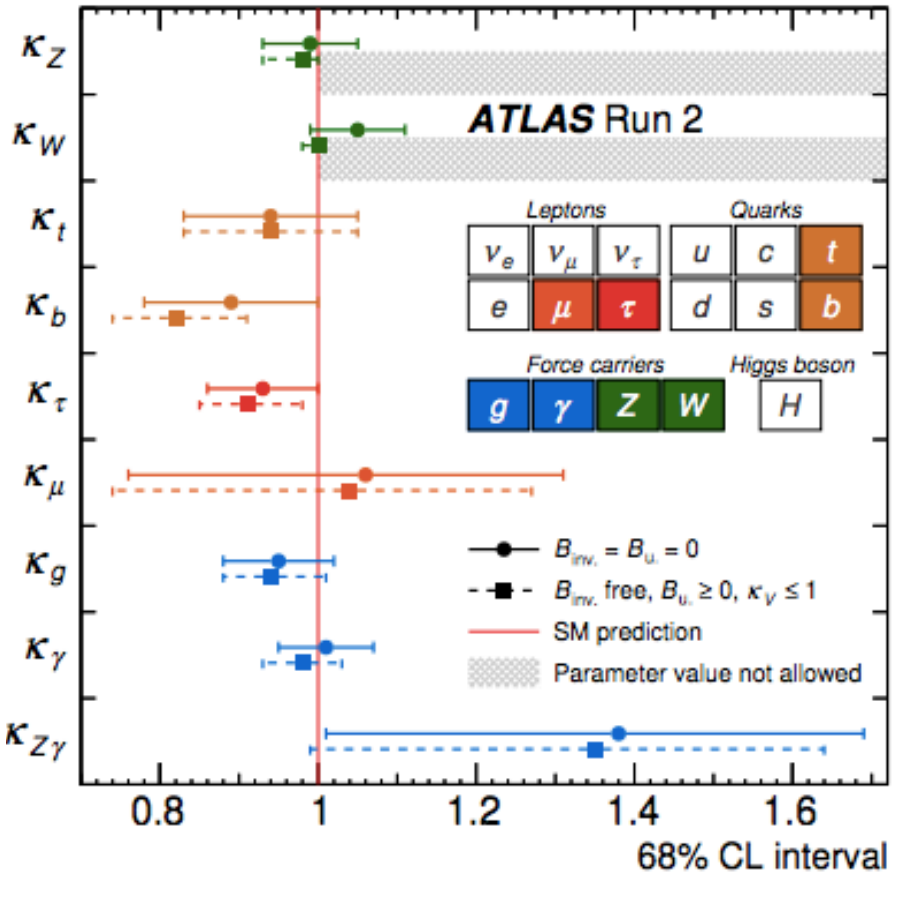


Probing the Higgs photon coupling from Higgs exclusive decay

Higgs couplings @LHC

Nature 607 (2022)7917,52-59





The data agrees with the SM prediction very well

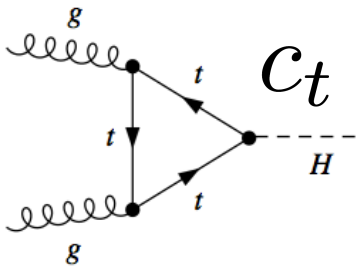
No new physics?

Faked no new physics scenario

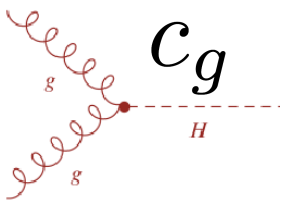
Example:

Q.-H.Cao, Bin Yan, D. M. Zhang, H. Zhang, PLB752(2016)285-290

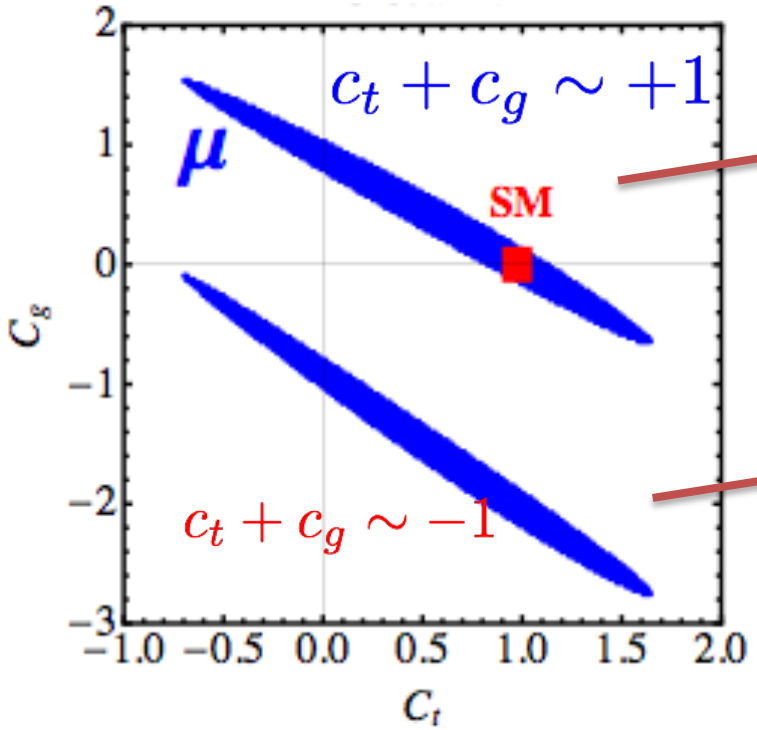
Higgs production



c_t



c_g



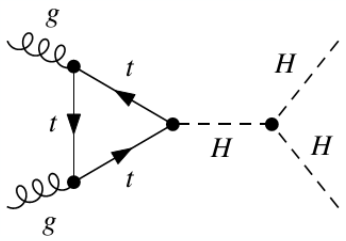
$$M_{\rm NP} + M_{\rm SM} \sim M_{\rm SM}$$

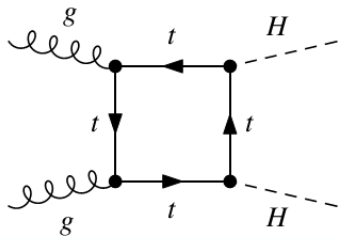
NP scale should be very high

$$M_{\rm NP} + M_{\rm SM} \sim -M_{\rm SM}$$

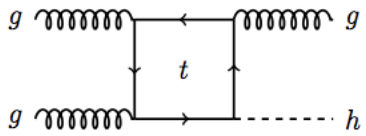
NP is hided under the SM

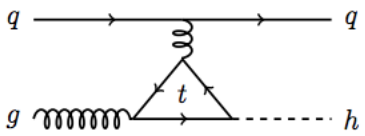
Faked no new physics scenario



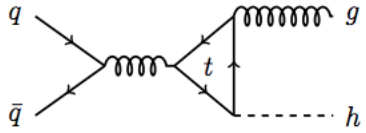


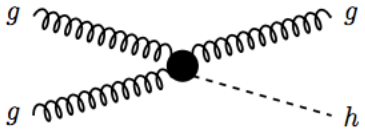
Q.-H.Cao, Bin Yan, D. M. Zhang, H. Zhang, PLB752(2016)285-290



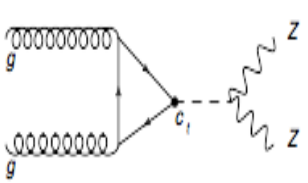


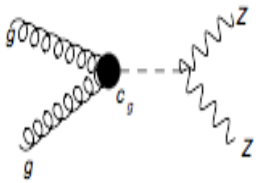
C.Grojean, E. Salvioni, M. Schlaffer, A. Weiler, JHEP05(2014)022

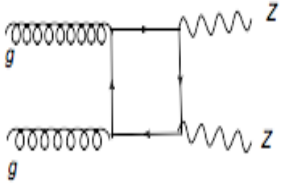




A.Azatov, A. Paul, JHEP 01(2014)014





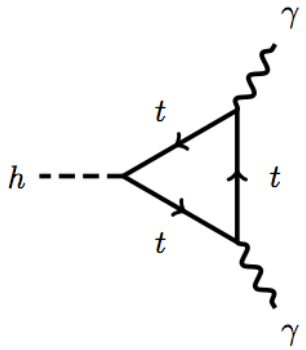


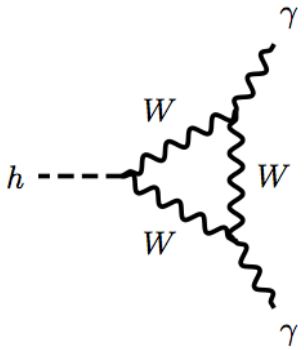
G. Cacciapaglia et al, PRL 113 (2014) 20,201802

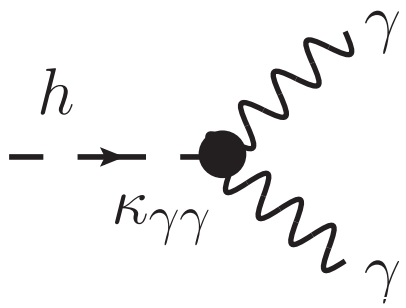
Faked no new physics scenario

How about the FNNP from Higgs decay?

$$\mathcal{L} = \frac{\alpha_{\rm em}}{4\pi v}\kappa_{\gamma\gamma} h A_{\mu\nu} A^{\mu\nu}$$







Two possible solutions:

$$-0.22 \leq \kappa_{\gamma\gamma} < 0.10,$$

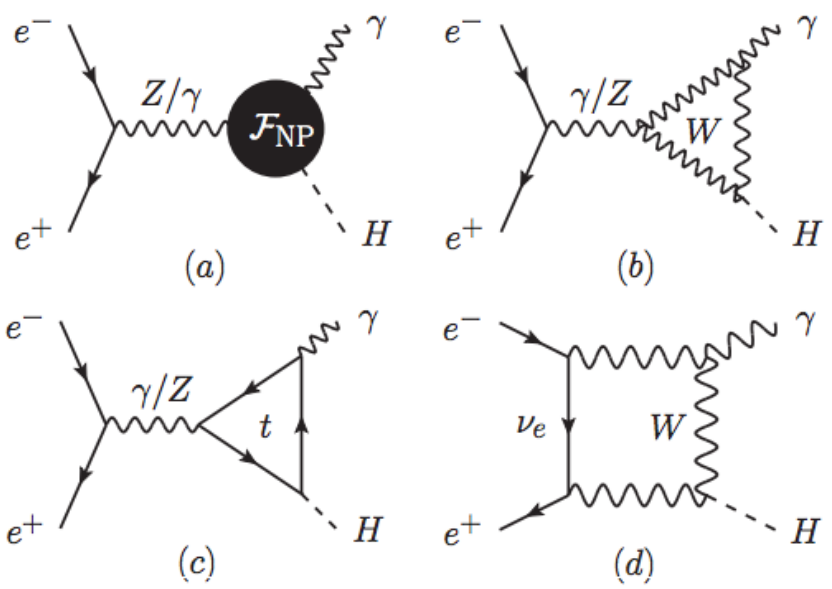
SM-like

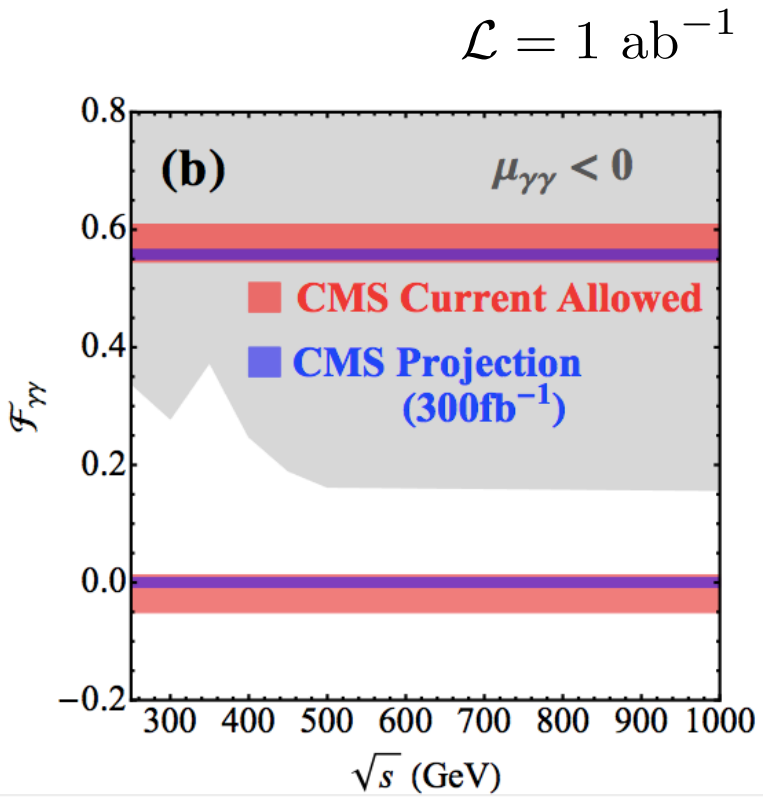
$$6.39 \leq \kappa_{\gamma\gamma} \leq 6.71$$

FNNP parameter space

Faked no new physics scenario

How to break the degeneracy?

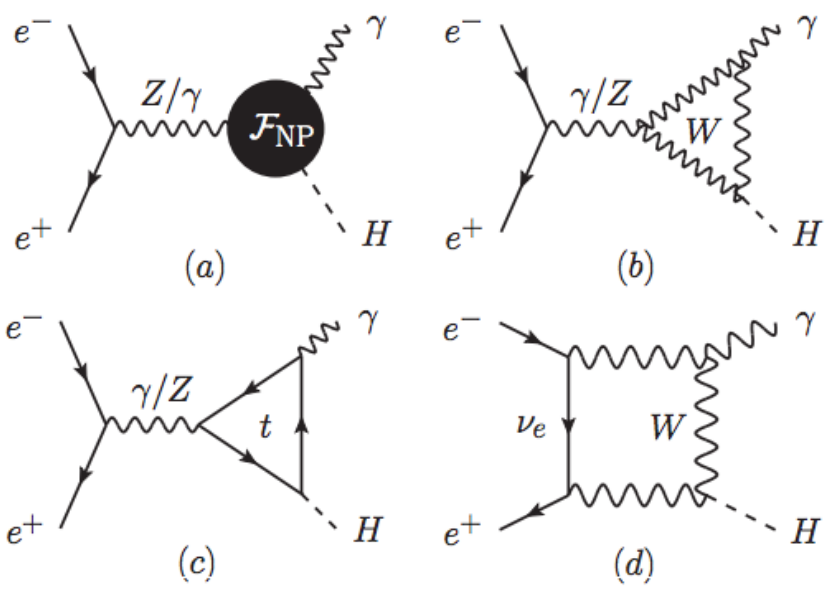


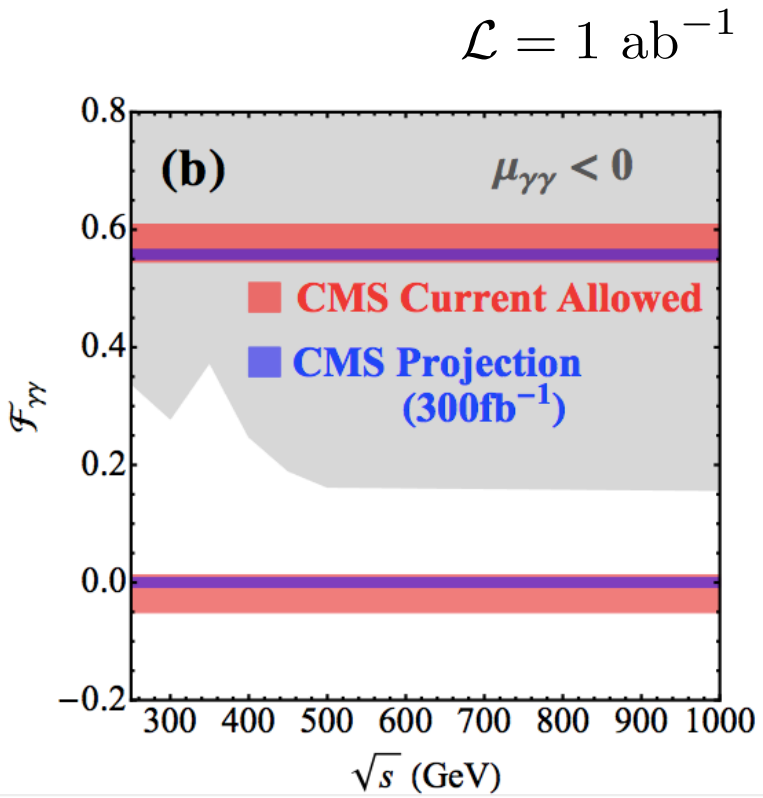


Q-H. Cao, H-R. Wang, Y. Zhang, 1503.05060, CPC39(2015)11,113102

Faked no new physics scenario

How to break the degeneracy?

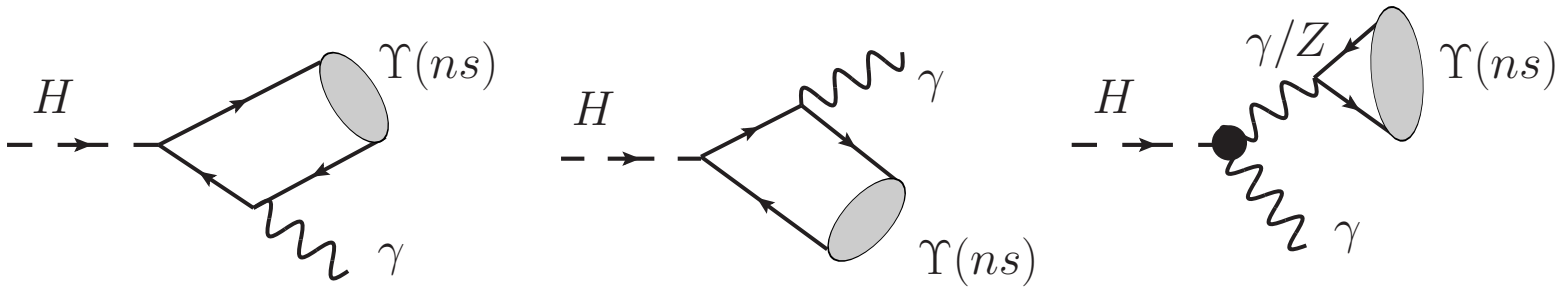




The conclusion depends on the assumption of the HZA coupling

Higgs photon couplings@LHC

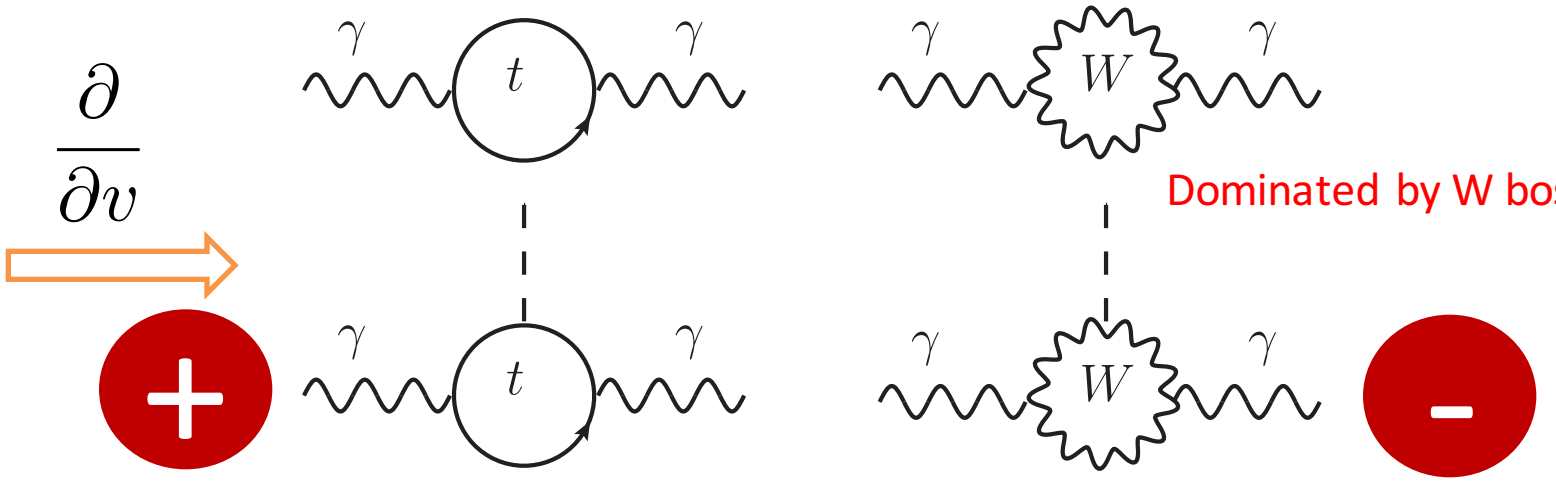
H.X. Dong, P. Sun and Bin Yan, 2208.05153



Direct production

Inirect production

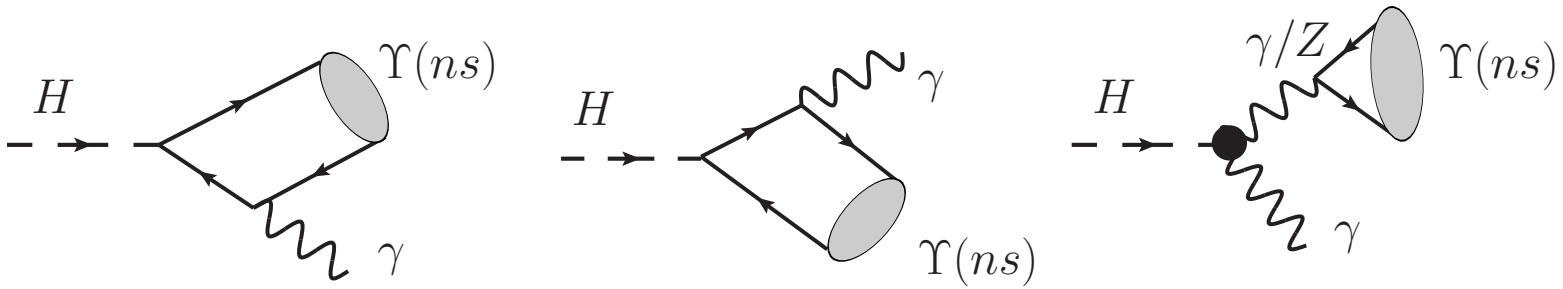
Low Energy Theorem: Dawson and Haber (1989)



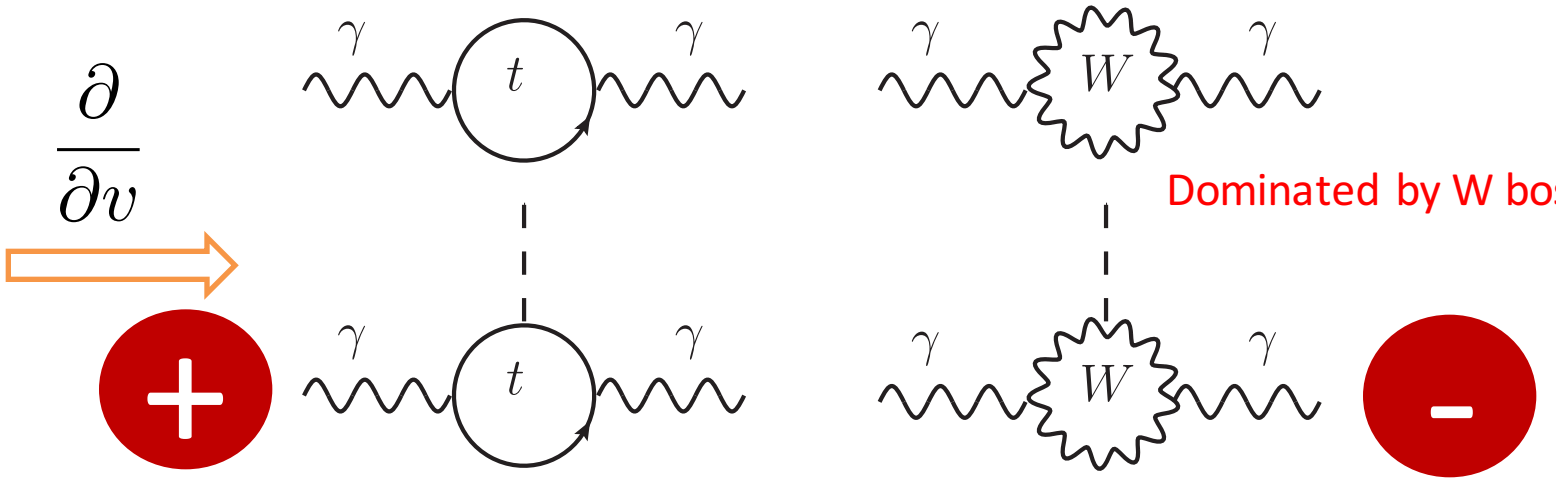
Dominated by W boson loop

Higgs photon couplings@LHC

H.X. Dong, P. Sun and Bin Yan, 2208.05153



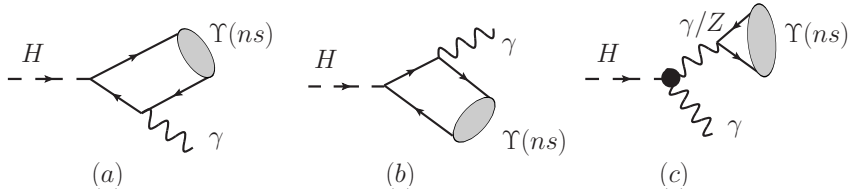
Destructive interference between the direct and indirect production=>Sensitive to the FNNP



Dominated by W boson loop

Exclusive Higgs decay@ NRQCD

LO:



NLO:

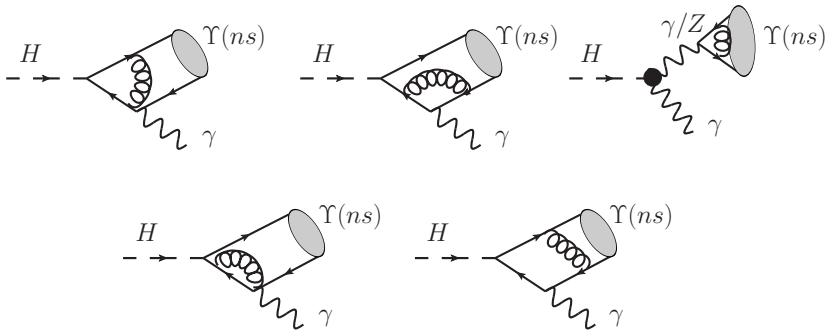


TABLE I. The branching ratios of $H \to \Upsilon(ns) + \gamma$ at the LO and NLO, respectively, in unites of 10^{-8}, with the renormalization scale $\mu = m_H$ and $\kappa_b = 1$.

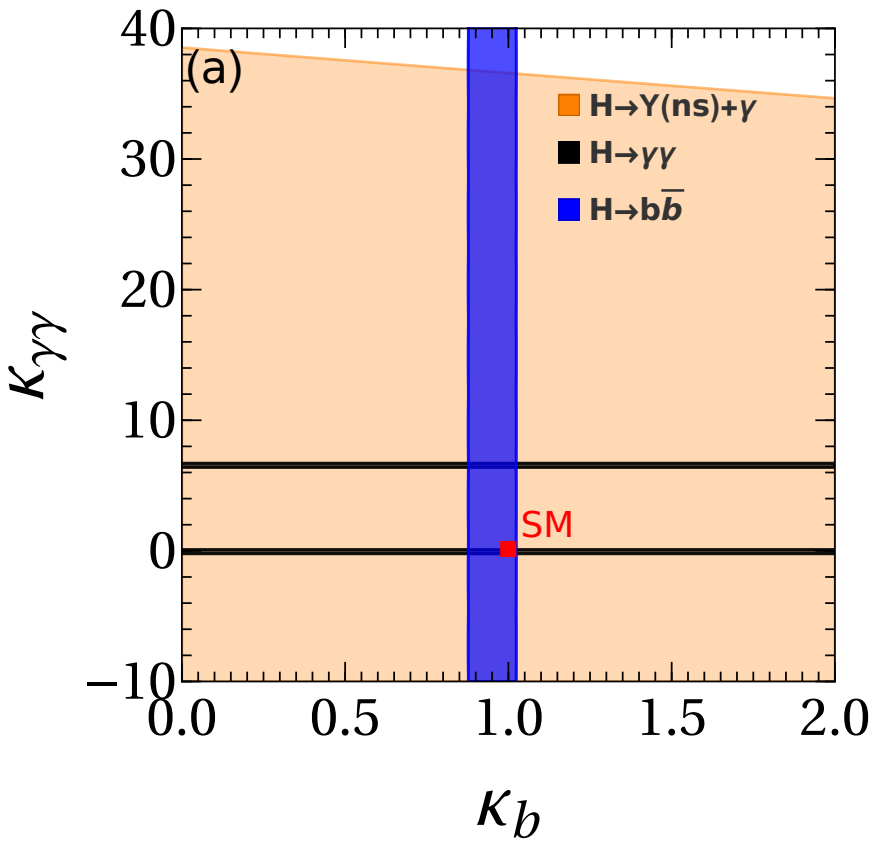
$\mathrm{BR}(H \to \Upsilon(ns) + \gamma)$	$\Upsilon(1s)$	$\Upsilon(2s)$	$\Upsilon(3s)$
LO ($\kappa_{\gamma\gamma} = 0$)	0.51	0.24	0.18
NLO ($\kappa_{\gamma\gamma} = 0$)	3.03	1.44	1.05
LO ($\kappa_{\gamma\gamma} = -2\kappa_{\gamma\gamma}^{\mathrm{SM}}$)	90.3	42.9	31.1
NLO ($\kappa_{\gamma\gamma} = -2\kappa_{\gamma\gamma}^{\mathrm{SM}}$)	83.6	39.7	28.8

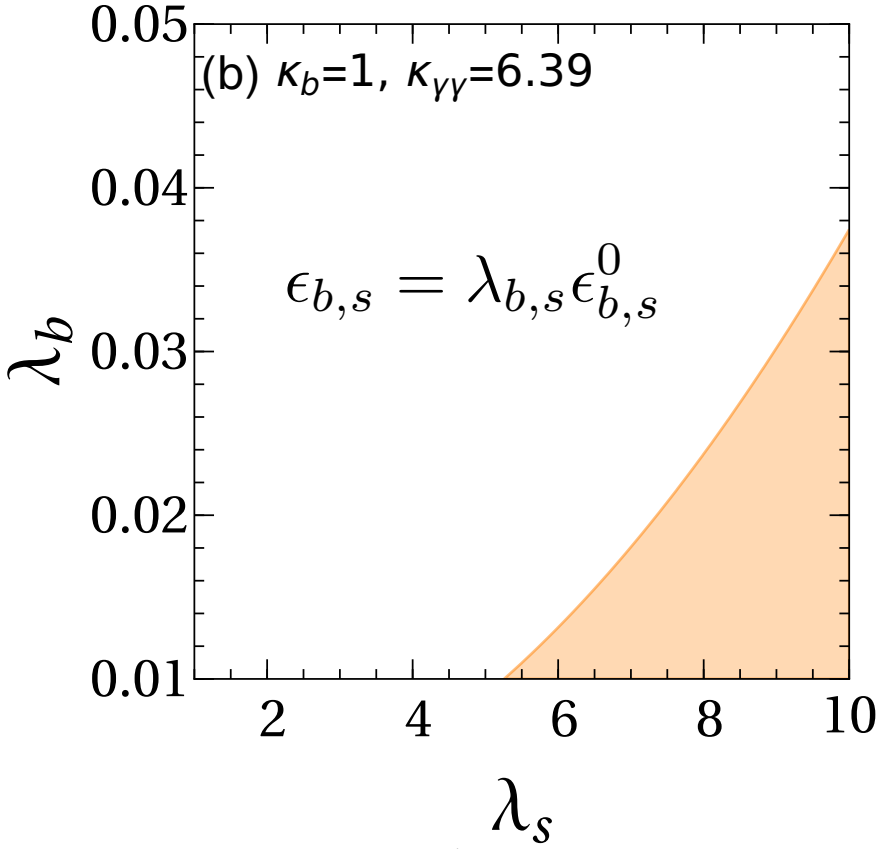
$\sigma(H) \sim 60$ pb

The branching ratios will be enhanced about one to two orders of magnitude

Higgs photon couplings@LHC

ATLAS+CMS $\Upsilon(1s, 2s, 3s) \to e^+e^-, \mu^+\mu^-, \tau^+\tau^-$





We rescale the events from the simulation of $H \to J/\Psi(\to \mu^+\mu^-) + \gamma$

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Summary

A. We proposed to use the exclusive decay of the Z and Higgs boson to probe the New Physics;

B. The rare decay of the Z boson is sensitive to the axial-vector Zbb coupling;

C. There is a strong cancelation between the direct and indirect production of quarkonium in Higgs decay;

D. The rare decay of the Higgs boson is hopeful to test the faked no new physics parameter space.

Thank you!