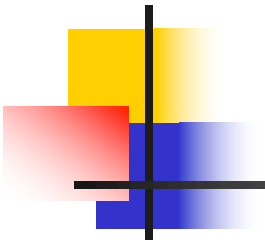

KIAS KOREA INSTITUTE FOR ADVANCED STUDY

Threshold corrections to the heavy Higgs decay

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Yuichiro Kiyo (Juntendo U) and HY, work in progress

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Introduction: Heavy Higgs Searches

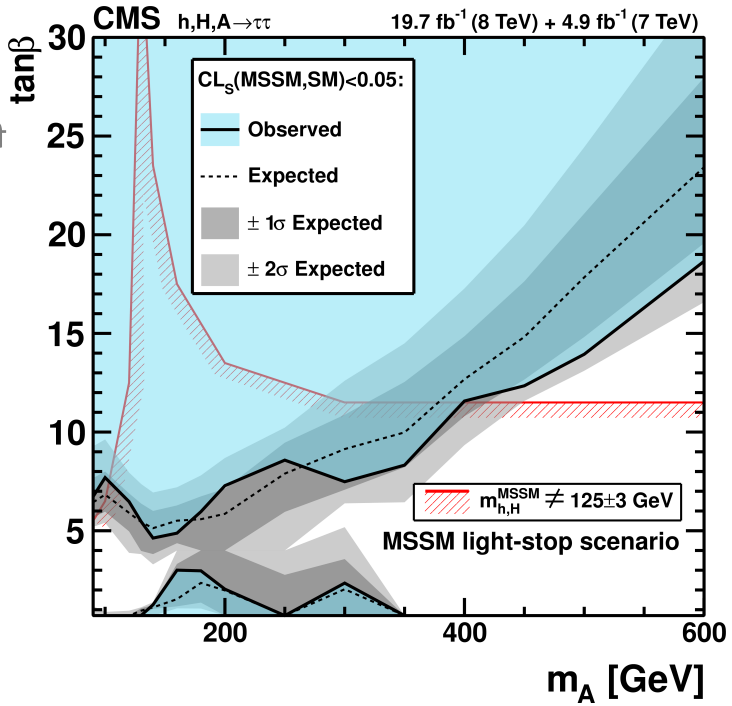
At the LHC experiments, we have found only the 125GeV Higgs so far. ~~2TeV diboson, 750GeV diphoton~~

Searches for heavy Higgs bosons in the extended Higgs sector (2HDM, HTM, HSM, …):

$$H,\ A,\ H^{\pm},\ H^{\pm\pm},\ S,,,$$

MSSM neutral Higgs searches in H/A→ττ mode
→ stringent bound in the m_A-tanβ plane.

m_A ~ 2m_t still open for tanβ ~ O(1)



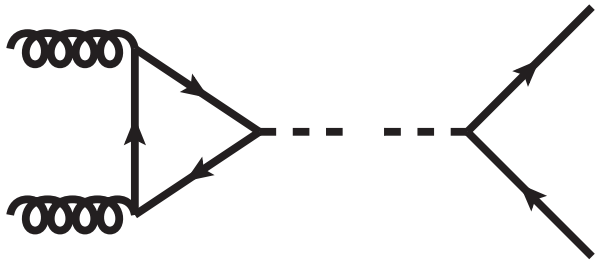
CMS-HIG-13-021, ATLAS-CONF-2016-085,,,

We study the threshold effects to the production and decays of neutral Higgs bosons with m_A ~ 2m_t.
[focus on pseudoscalar (S-wave), but neglect scalar (P-wave)]

Mixing of A and ttbar bound-states / interference effects in the production-decay are not implemented yet.

Drees,Hikasa(90) , talk by C. Zhang

Heavy Higgs Production & Decay



Production processes

- $gg \to A,$ **loop-induced, the largest**
- $q\bar{q} \to HA,$
- $q\bar{q}' \to H^{\pm}A,$
- $gg(q\bar{q}) \to q\bar{q}A,$
- $\cdots$

threshold corrections

Decay channels

- $A \to t\bar{t},$
- $A \to b\bar{b},$
- $A \to \tau^{-}\tau^{+},$

Yukawa couplings

- $A \to hZ,$ **gauge coupling [∝ cos(β-α)]**
- $A \to gg,$
- $A \to \gamma\gamma,$
- $A \to Z\gamma,$

loop-induced

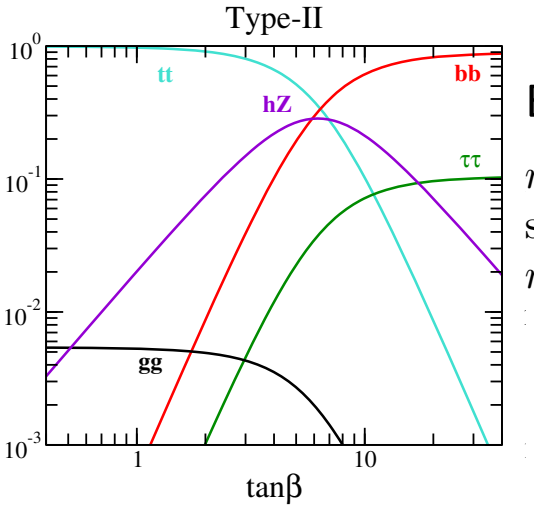
- $\cdots$

Yukawa interactions [in 2HDM]

$$\mathcal{L}_Y = \sum_f \xi_A^f \frac{y_f}{\sqrt{2}} \bar{f}[i\gamma_5] f\, A$$

$$\xi_A^t = \cot\beta,$$

(Type-II) $\quad \xi_A^{b,\tau} = \tan\beta$



Example:

$m_A = 400$ GeV,
$\sin(\beta-\alpha) = 0.99,$
$m_H,\ m_{H^{\pm}} \gtrsim m_A$

A→tt: Perturbative Calculations

$A \to t\bar{t}^{(*)}$

Important even below $m_A \sim 2m_t$ through off-shell top-quarks

$$\Gamma_{A\to t\bar{t}} \simeq \mathrm{Im}\left[\quad\right]$$

LO, **NLO** calc. for tt/bWbW

Drees,Hikasa(90); MG5_aMC@NLO

$$\Gamma_{A\to t\bar{t}} \simeq m_A \beta \left[1 + \frac{\alpha_s}{\pi} C_F \left(\frac{\pi^2}{2\beta} - 3 + \cdots\right) + \cdots\right]$$

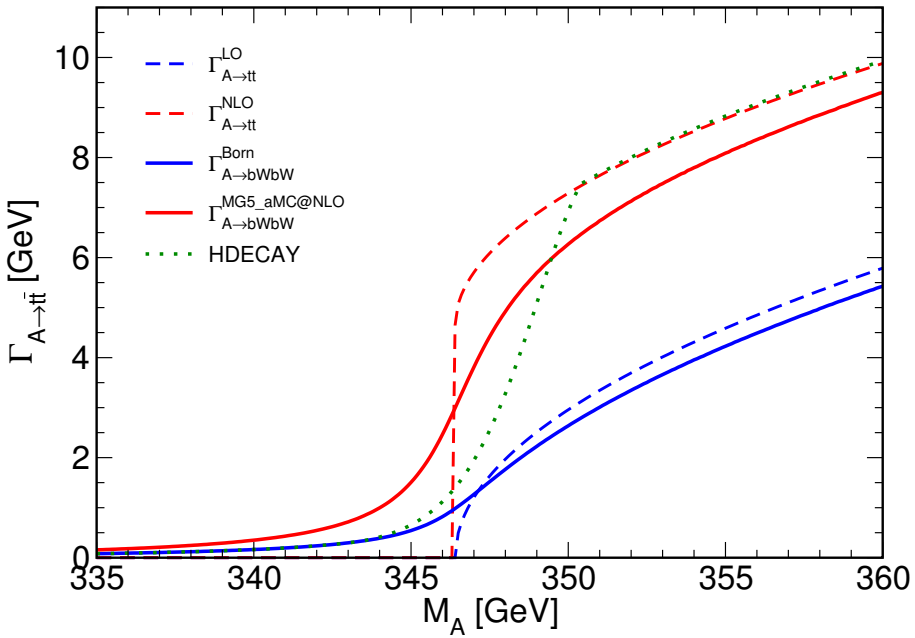
$$\beta = \sqrt{1 - \frac{4m_t^2}{m_A^2}}$$

HDECAY: (above thr.) tt@NLO

(below thr.) tbW@LO

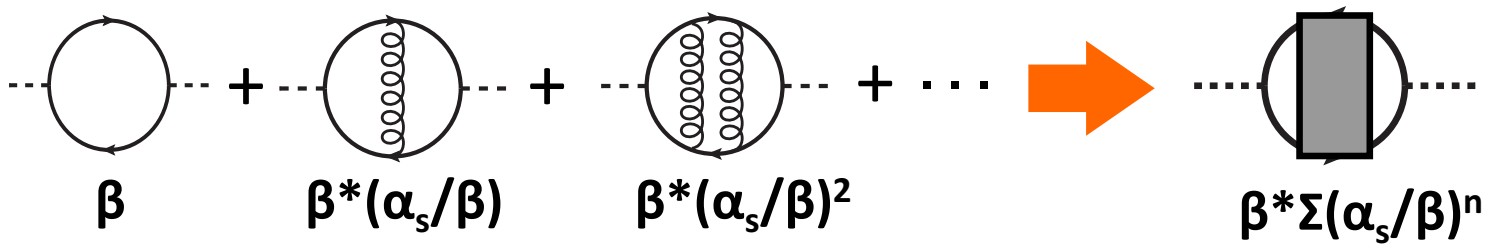
Djouadi,Kalinowski,Spira(97)

Large QCD correction near threshold, because of Coulomb singularity.



A→tt: Coulomb Resummation

Non-relativistic Green function $G(E) \simeq \frac{i}{2N_c} \int d^4x e^{iEt} \langle 0|T\{j_p(x) j_p(0)\}|0\rangle$



$$\Gamma_{A\to t\bar{t}} \simeq y_t^2 \mathrm{Im}[G(E)]$$

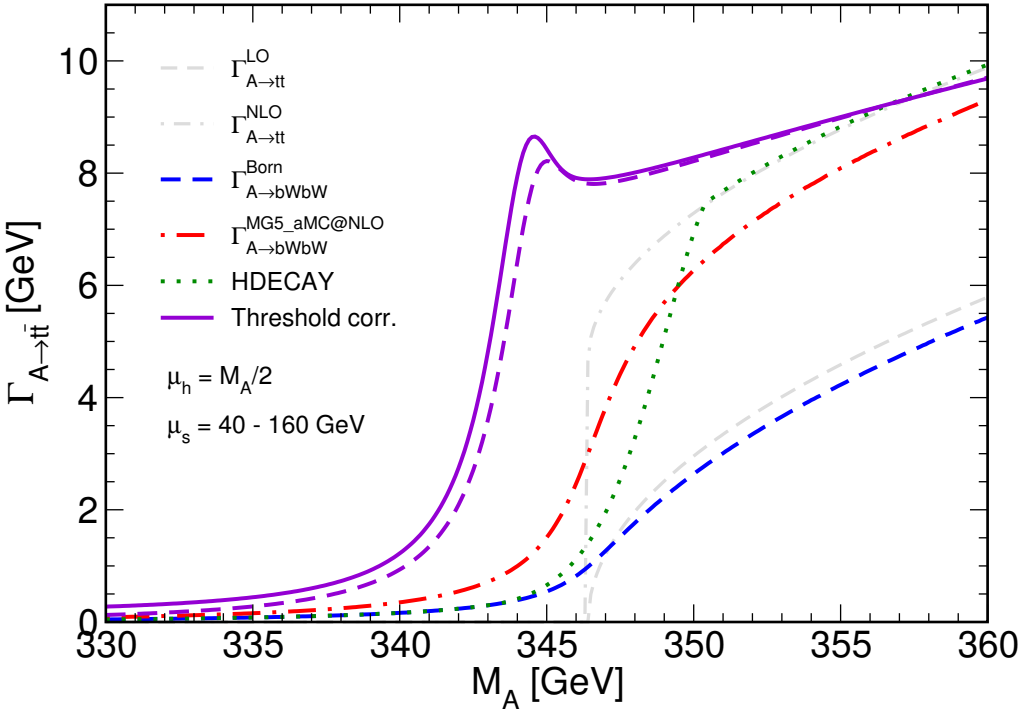
Schrodinger Eq. with QCD potential:

Fadin,Khoze (87,88)

$$\left[\left\{-\frac{\nabla^2}{m_t} + V(r)\right\} - \mathcal{E}\right] G_c(\vec{r}, \mathcal{E}) = \delta^3(\vec{r})$$

$$\mathcal{E} = E + i\Gamma_t$$

$$V(r) = -C_F \frac{\alpha_s}{r}\left[1 + \frac{\alpha_s}{4\pi}\{\cdots\} + \cdots\right]$$



Loop-induced decays

$A \to \gamma\gamma,\ gg,\ Z\gamma$

Spira,Djouadi,Graudenz,Zerwas(95);
Harlander,Kant(05);
Aglietti,Bonciani,Degrassi,Vicini(07);

1-loop/2-loop top-loop func.

γγ: analytic 2-loop correction known
gg/Zγ: 2-loop numerically (we use 1-loop amp.)

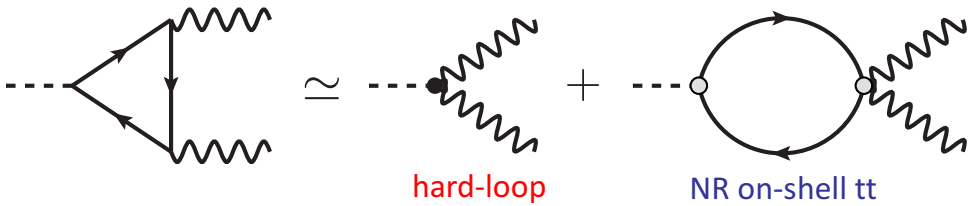
Re[*F*]

$$\mathcal{F}_{A\to\gamma\gamma,t}(v) = \mathcal{F}_t^{(0)}(v) + \frac{\alpha_s}{\pi}\mathcal{F}_t^{(1)}(v)$$

Im[*F*]

$$v = \sqrt{1-\tau},\ \tau = 4m_t^2/m_A^2$$

Threshold expansion → Coulomb summation



$$\mathcal{F}^{\rm NR}_{A\to\gamma\gamma,t}(v) = \mathcal{A}_t(\alpha_s) + \mathcal{B}_t(\alpha_s)G(E)$$

Melnikov,Spira,Yakovlev(94)

Numerical Results

$\Gamma^{\rm thr.}/\Gamma^{\rm pert.}$ for $A \to t\bar{t},\ \gamma\gamma,\ gg,\ Z\gamma$

thr./LO **thr./NLO**

Production: σ(gg→A) also roughly ×2~3

Summary and Outlook

- We studied the threshold corrections to the heavy Higgs decays and production for $m_A \sim 2m_t$.
- Near the heavy quark mass threshold, large Coulomb corrections arise, which have to be resummed to all orders in α_s.
- We formulated the threshold-correction based on NRQCD, and investigated a numerical impact of these corrections.

$$\frac{\Gamma^{\rm thr.}_{A\to t\bar{t}}}{\Gamma^{\rm pert.}_{A\to t\bar{t}}} \simeq 10-20 \qquad \frac{\Gamma^{\rm thr.}_{A\to \gamma\gamma,gg,Z\gamma}}{\Gamma^{\rm pert.}_{A\to \gamma\gamma,gg,Z\gamma}} \simeq 2-3 \qquad @\ m_A \sim 2m_t$$

- For a phenomenological application, both the production and decay have to be considered simultaneously.

  $\Rightarrow$ mixing of A & ttbar-state / large interference effects.