Higgs at ILC in Universal Extra Dimensions

in Light of Recent LHC Data

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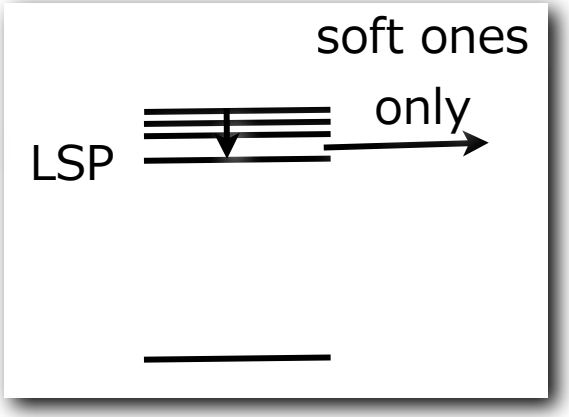
LHC!

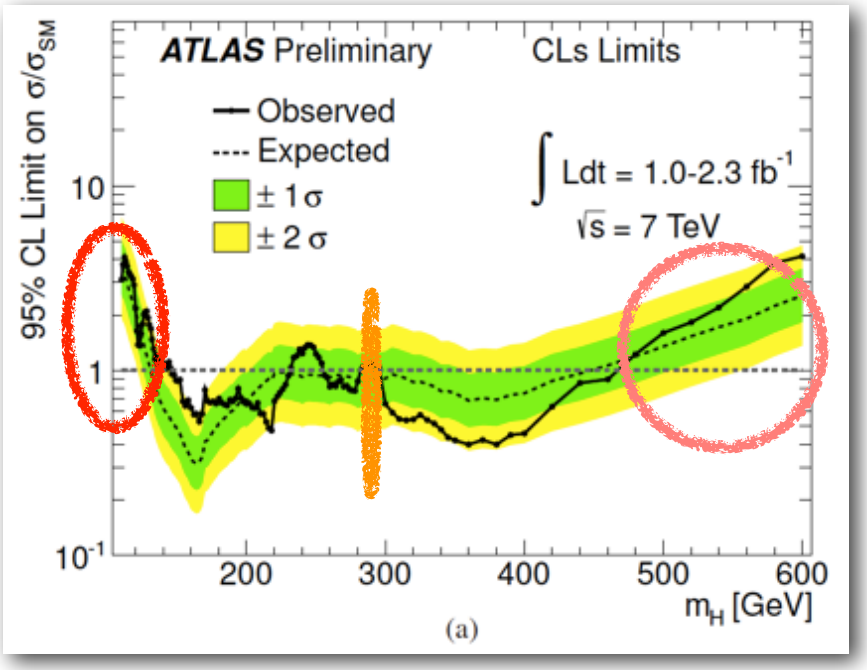
- Weak-scale SUSY (almost) dead.
  - ★ I would do light degenerate scenario ($\Delta M < \sim 100$GeV) if I was SUSY enthusiast.
    - ✳ Even more “natural” than ever.
    - ✳ Difficult to see at LHC. Ideal for ILC.

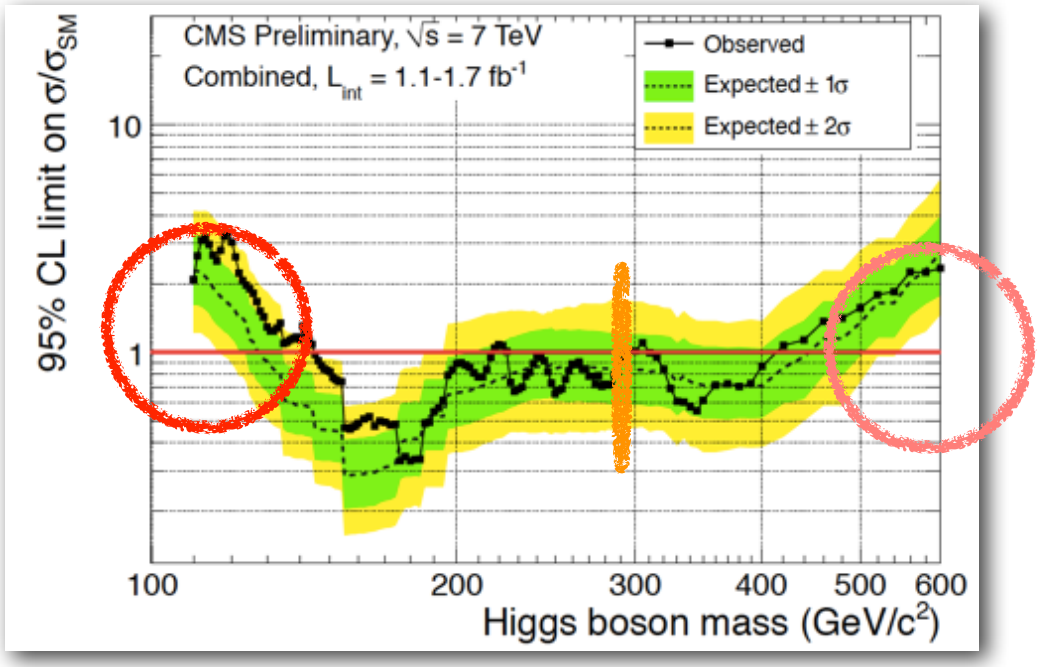


- Weak-scale UED provides similar situation.
  - ★ Would be of interest for SUSY clan too.
- What can we see in this situation?

Higgs!!

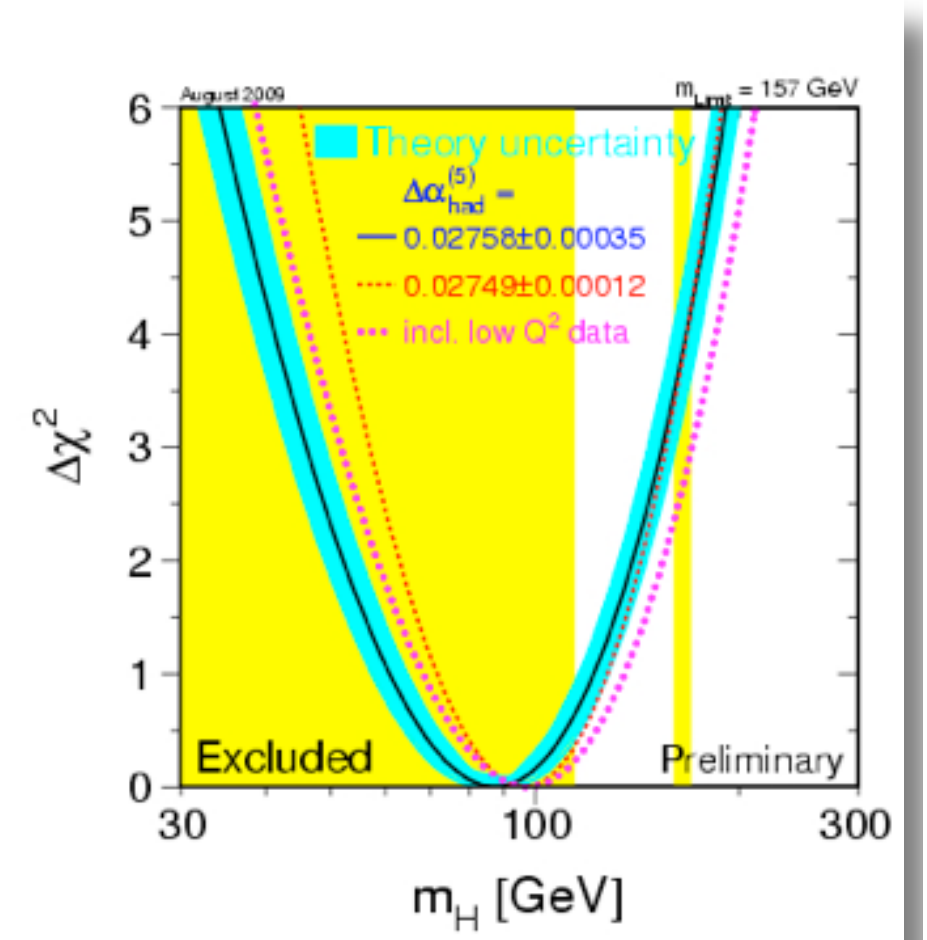
- We are about to see Higgs at LHC.
  - ★ Three regions left surviving:
    - ✳ Light **<~140GeV**, Middle **~290GeV**, Heavy **>~470GeV.**
- Note: Production can be enhanced from SM **by factor <~3**.
  - ★ (For light&heavy ones, and if decays like SM.)





Recall in SM, Higgs must be light

- Best fit value ~90GeV already excluded by direct search >114GeV.
  - ★ (Though still consistent.)
- Question: Why is Higgs heavier than expected from electroweak data?



[Fig. by others]

(Possible) Answer: Because there are KK modes!

- In Universal Extra Dimension (UED) models:
  - ★ Higgs tends to be heavy due to KK-top contributions. (shown later)
- UED's further virtues:
  - ★ Dark matter is provided as LKP (typically KK-photon).
    - ✳ Stable due to geometry, not by hand.
      - ✦ conservation of KK-parity, KK (angular) momentum, etc.
  - ★ Three families predicted (in 6D UED).
    - ✦ (From cancellation of $SU(2)_W$ global gauge anomaly [Dobrescu, Poppitz, 2001].)

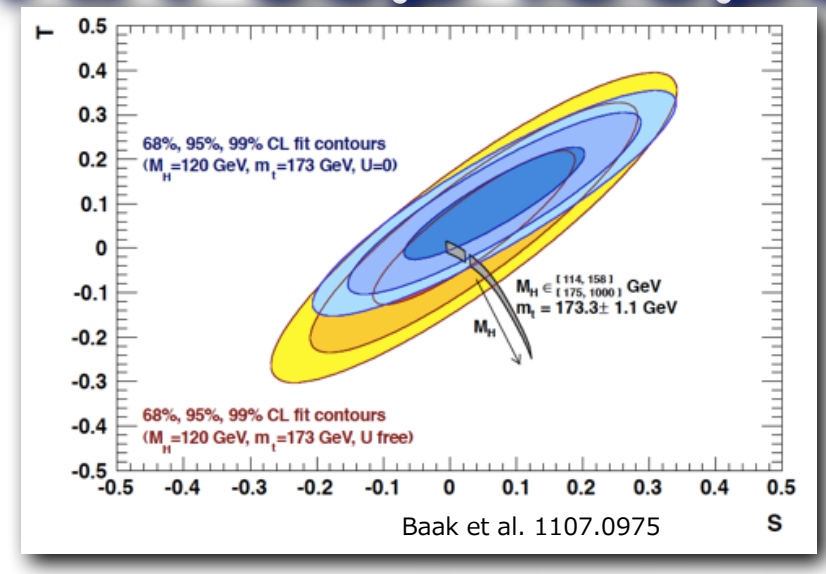
So what is UED?

- All SM fields live in higher dimensions.
  - ★ Compactified within ~am.
- Tower of KK modes for each SM mode.
  - ★ Different masses, same charges.
- Higgs as zero mode.
  - ★ EWSB by bulk Higgs potential.
    - ✳ (Except for Dirichlet Higgs model [Haba, KO, Takahashi, 11].)

Outline

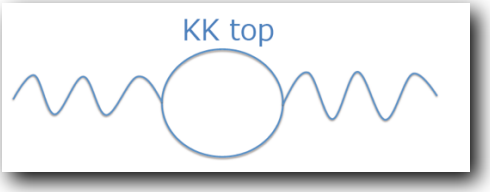
1. Higgs can be heavy >500GeV in UED, consistent with precision data.
2. Gluon fusion at LHC is enhanced by KK-top loops.
3. For light Higgs <140GeV, reduced BR($H \to \gamma\gamma$) can be measured at ILC.

KK-top loops in T-parameter



$S \propto \Pi_{33}' - \Pi_{3Q}'$

$T \propto \Pi_{11} - \Pi_{33}$



- KK-top contribution shift T-parameter positively.
  - ★ E.g. in 5D mUED on S^1/Z_2:

$$S \simeq \frac{1}{6\pi}\log\frac{m_H}{m_{H,\mathrm{ref}}} + \frac{1}{6\pi}\sum_{n=1}^{\infty}\frac{m_t^2}{n^2/R^2}$$

$$T \simeq -\frac{3}{8\pi c_W^2}\log\frac{m_H}{m_{H,\mathrm{ref}}} + \frac{m_t^2}{4\pi^2\alpha v_{\mathrm{EW}}^2}\sum_{n=1}^{\infty}\frac{m_t^2}{n^2/R^2}$$

0.15

0.05

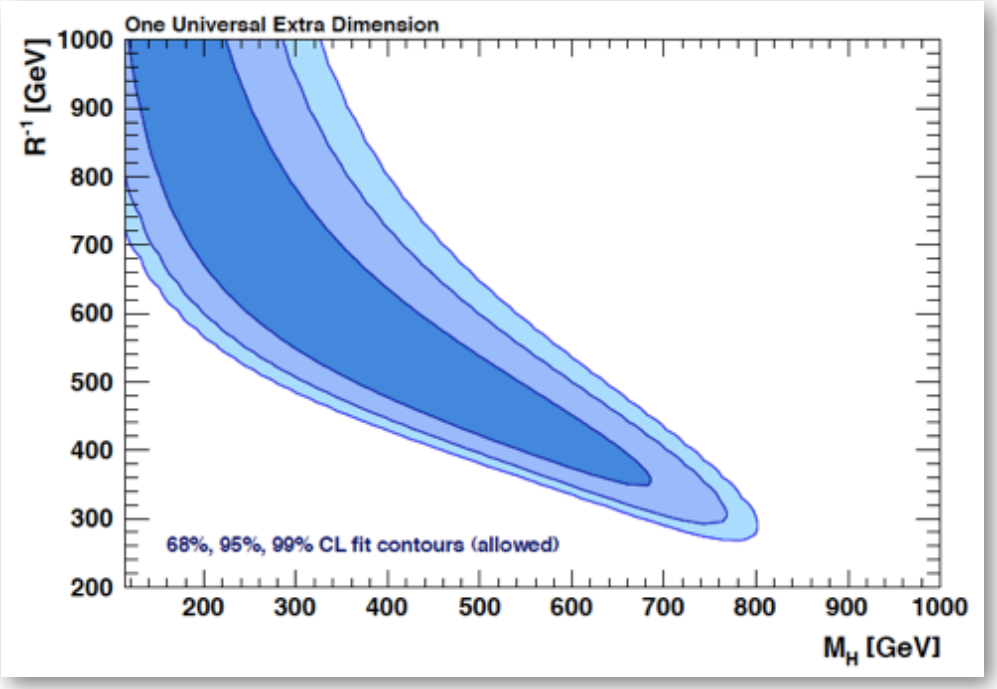
KK-top

KK-top

1.6

Higgs can be heavy in UED

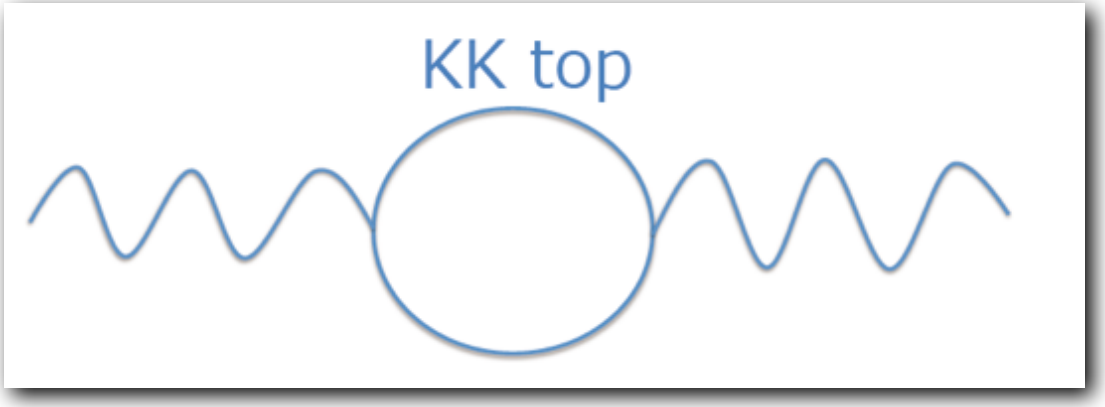
- E.g. even in the most constrained 5D mUED model.
  - ★ Assuming all boundary terms vanishing at UV cutoff.
- Higgs can be as heavy as 800GeV, if KK scale is light.
  - ✳ (Should be <~700GeV when triviality bound is taken into account.)

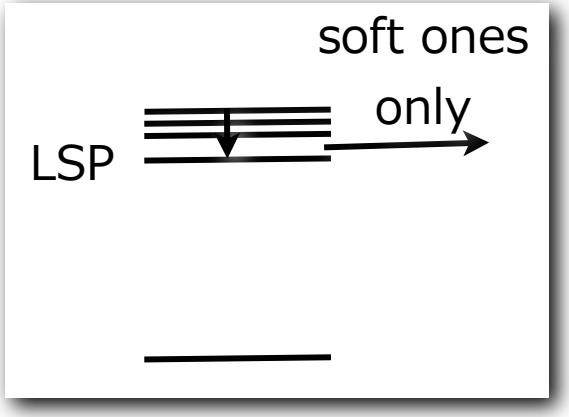


Baak et al.
1107.0975

Heavy Higgs in weak-scale UED

- This is a general tendency for light KK scale.
  - ★ KK top loops not only in 5D mUED.
  - ★ Insensitive to KK mass splitting & mixing: $M_n \to M_n + \delta M_n$.
    - ✦ (That comes from brane-localized Lagrangian.)
- In any case, Higgs signal is complementary to other signals: DM, $b \to s\gamma$ & direct KK search in which δM_n structure matters.





Outline

1. Higgs can be **heavy** >500GeV in UED, consistent with precision data.
2. Gluon fusion at LHC is enhanced by **KK-top loops**.
3. For light Higgs <140GeV, **reduced BR(H→γγ)** can be measured at ILC.

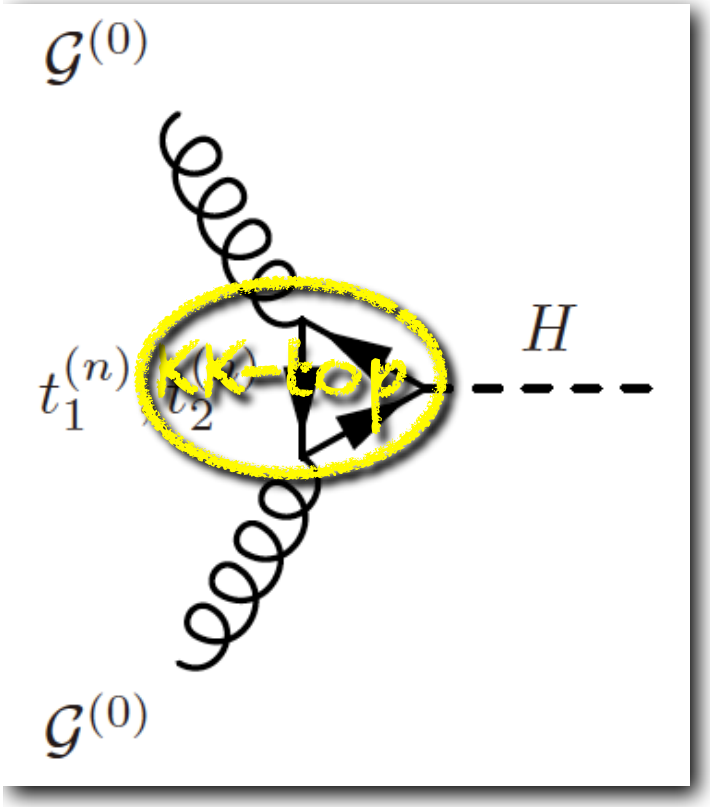
Rule of thumb

- If a process is loop-induced in SM,
- Corrections from KK-loops can be significant.

  ★(Loops cannot beat tree for perturbativity.)

UED Higgs at LHC

[Nishiwaki, **KO**, Okuda, Watanabe, 11]



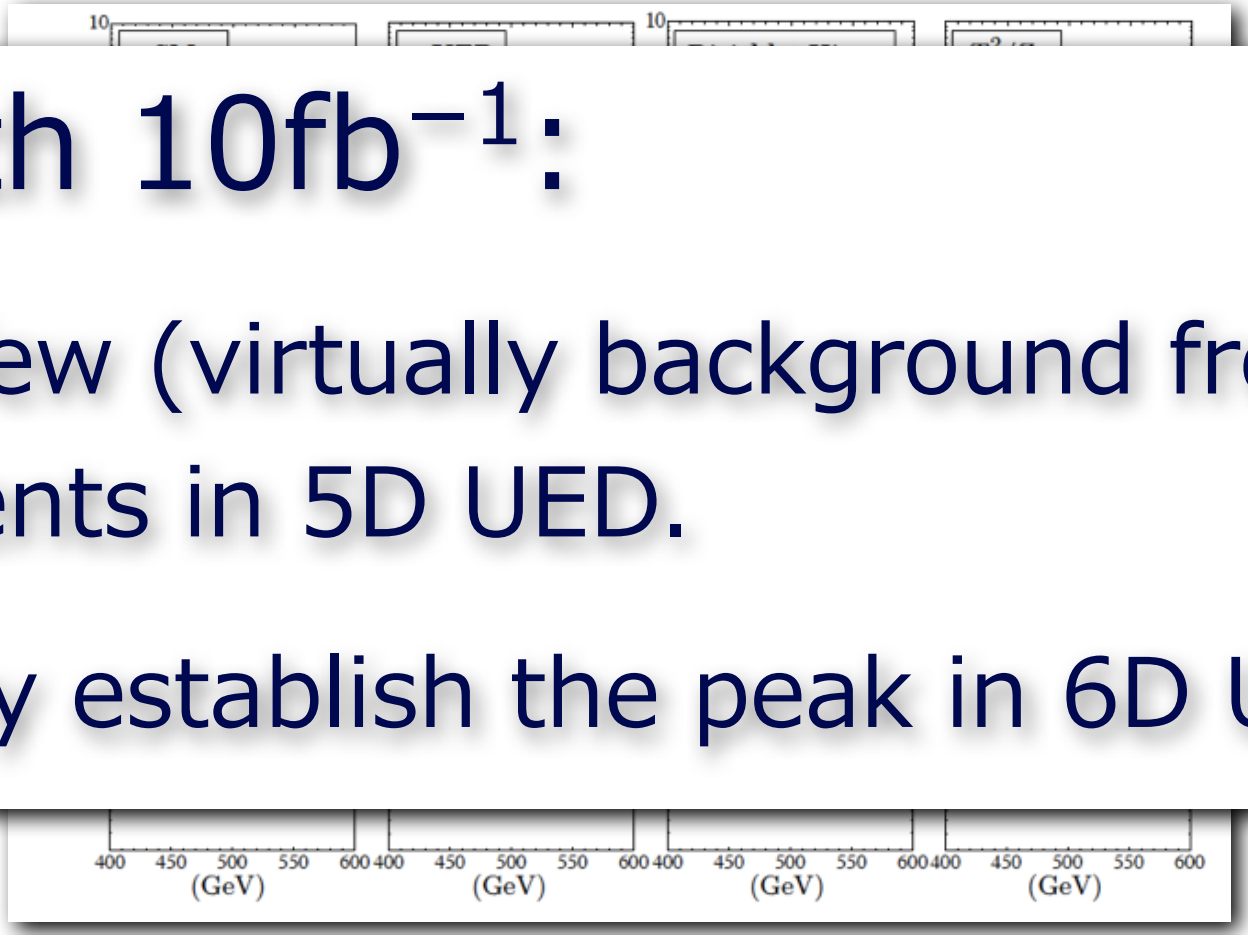
- Dominant gg→H production enhanced, since loop-produced in SM.
- Decays the same as in SM.
  - ★ H→WW, ZZ, tt, bb not much affected since there's tree coupling.
- We have computed:
  - ★ In 5D: S^1/Z_2 & Dirichlet Higgs [Haba, KO, Takahashi, 10].
  - ★ In 6D T^2-based:
    - ✳ T^2/Z_4, T^2/Z_2, $T^2/(Z_2\times Z_2')$ & RP^2.
  - ★ In 6D S^2-based:
    - ✳ S^2, S^2/Z_2 & Projective Sphere [Dohi, KO, 10].
      - ✤ Underlined ones are newly computed by ourselves.

Production can be greatly enhanced

- For example, $ZZ \to 4$ leptons for $M_H = 500$GeV

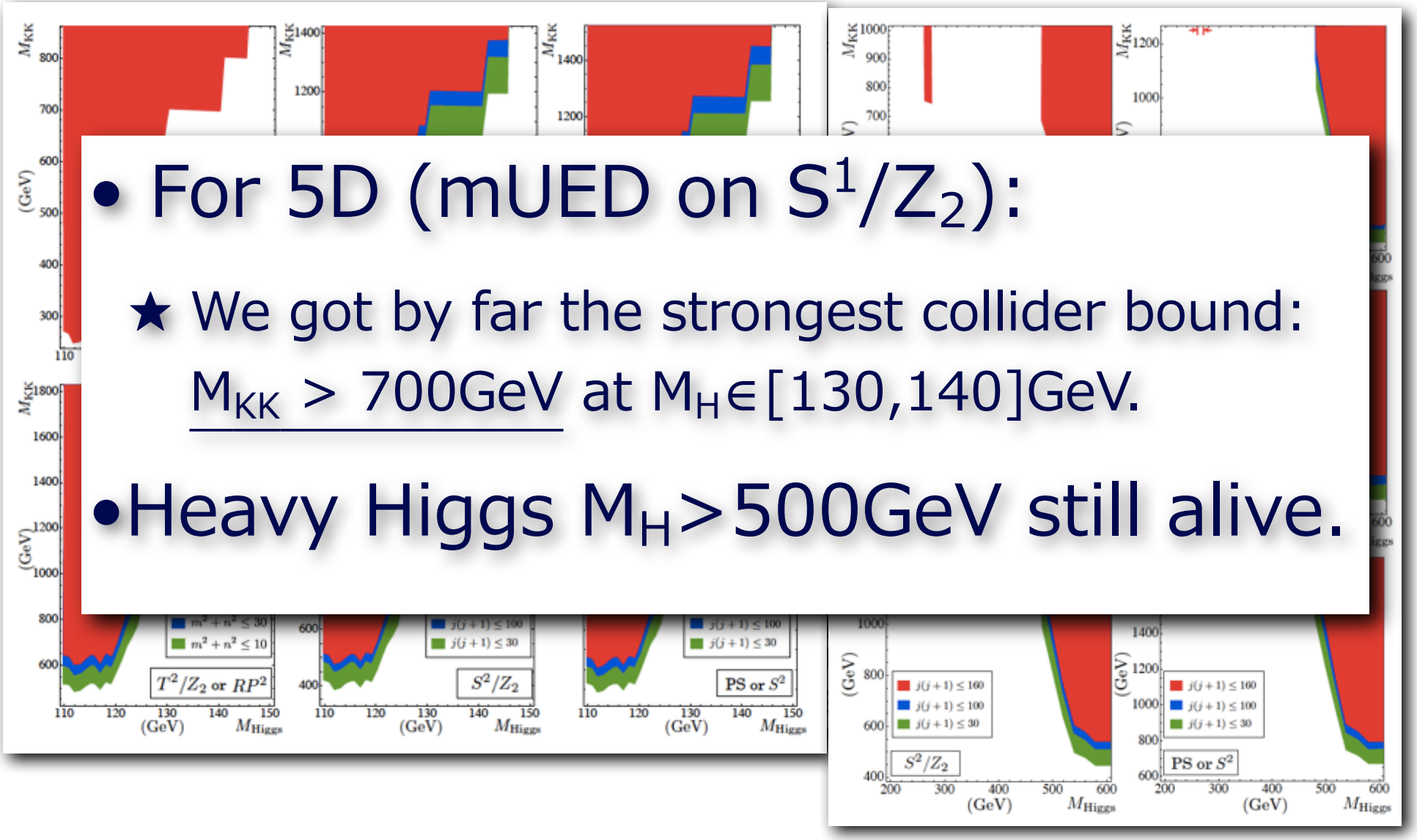
[Nishiwaki, **KO**, Okuda, Watanabe, 11]

  - ★ 7TeV, $1fb^{-1}$, per 25GeV bin.
  - ★ M_{KK}=200,400,600,800GeV (500GeV for DH).



- With $10fb^{-1}$:
  - ★A few (virtually background free) events in 5D UED.
  - ★May establish the peak in 6D UED.

Inclusive bound from Higgs production rate at CMS



- For 5D (mUED on S^1/Z_2):
  - ★ We got by far the strongest collider bound: $M_{KK} > 700$GeV at $M_H \in [130,140]$GeV.
- Heavy Higgs $M_H > 500$GeV still alive.

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H→γγ at ILC

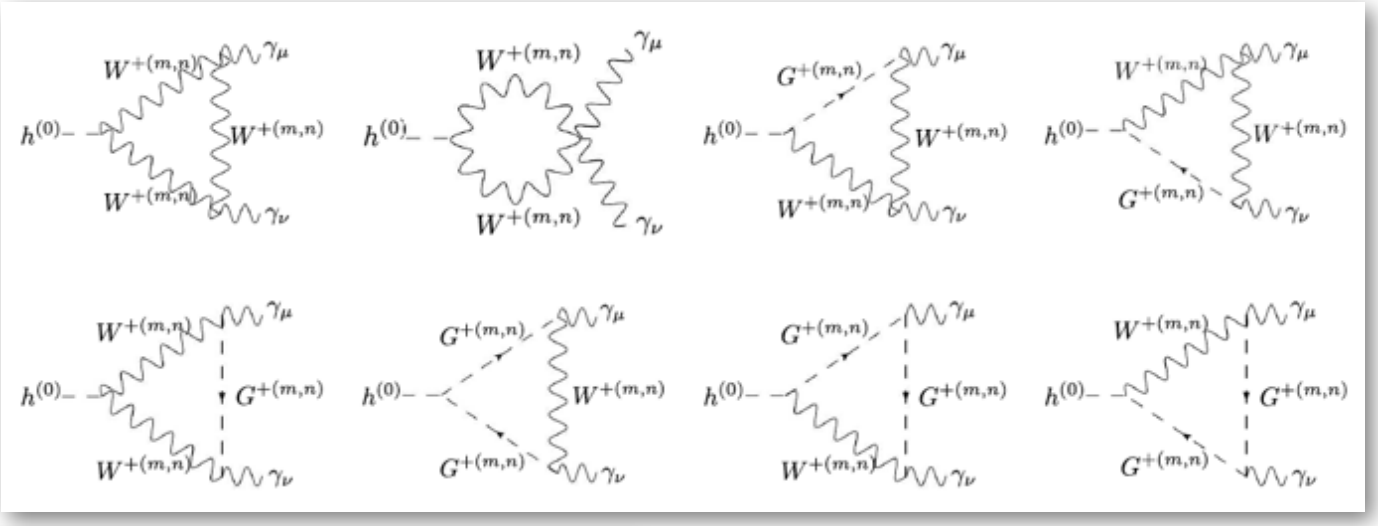
- Unlike LHC, Higgs is produced mainly via tree-level processes at ILC.
  - ★ Higgsstrahlung: ee→ZH.
  - ★ WW-fusion: ee→WWνν→Hνν.
- Therefore, production is not greatly affected by KK-loops.
- Still, modification of loop-induced decay H→γγ can be seen.

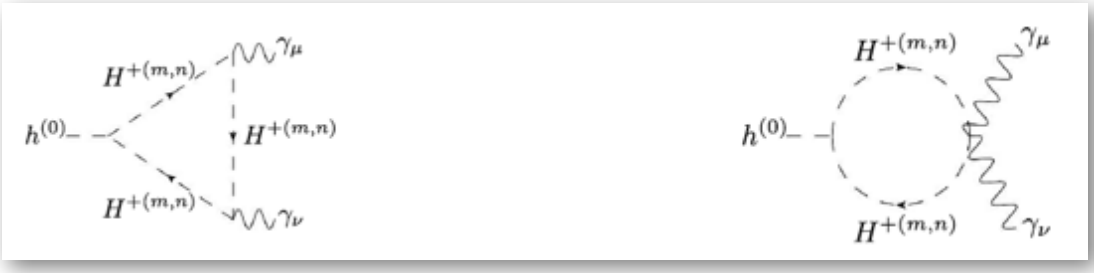
$H \to \gamma\gamma$

[Nishiwaki, 11]

- Reduced from SM due to KK-top loop.

★ (That is bigger than sum of many KK-boson loops.)

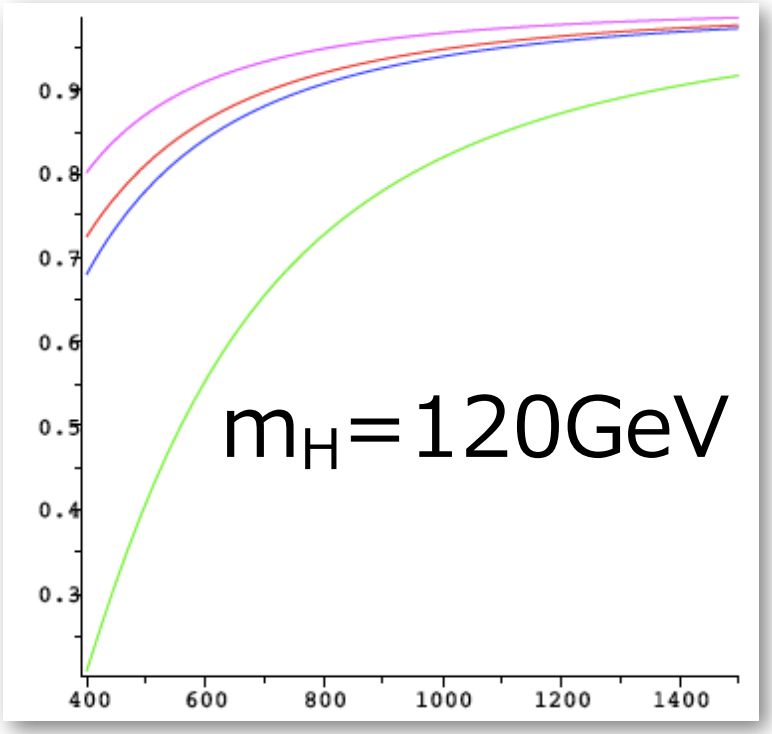




BR(H→γγ) reduced

[Nishiwaki 11]

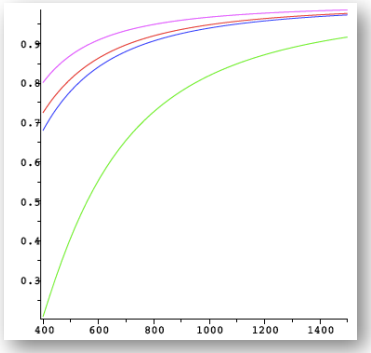
- 5D: mUED (S^1/Z_2)
- 6D: T^2/Z_4, S^2/Z_2, and **Projective Sphere (PS)** [Dohi, **KO,** 10].

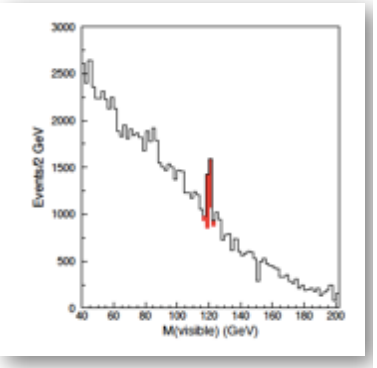


- BR(H→γγ) can be greatly reduced for 6D PS UED model.
- Reduction is up to 20(30)% for other 5D(6D) UED models.
- The lower the M_{KK}, the greater the reduction.
- (Enhancement of H→gg further reduces the BR(H→γγ).)

Measuring BR(H→γγ)

- Consider light Higgs: m_h=120GeV.
  - ★ ILC: $\sqrt{s}$=350GeV, 500fb^{-1} [Desch et al. 03]
    - ✳ BR(H→γγ) can be fixed within 23% accuracy.
    - ✳ 6D PS UED [Dohi, KO, 01] can be tested up to M_{KK}~800GeV.
  - ★ Superrich ILC: $\sqrt{s}$=1TeV, 1ab^{-1} [Barklow 03]
    - ✳ BR(H→γγ) can be fixed within 5% accuracy.
    - ✳ Even mUED can be tested up to M_{KK}~600GeV.





[Barklow 03]

Summary

- UED is nice: DM & 3 families (6D).

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★ $\gamma\gamma$-collider option for heavy Higgs?


Thank you!