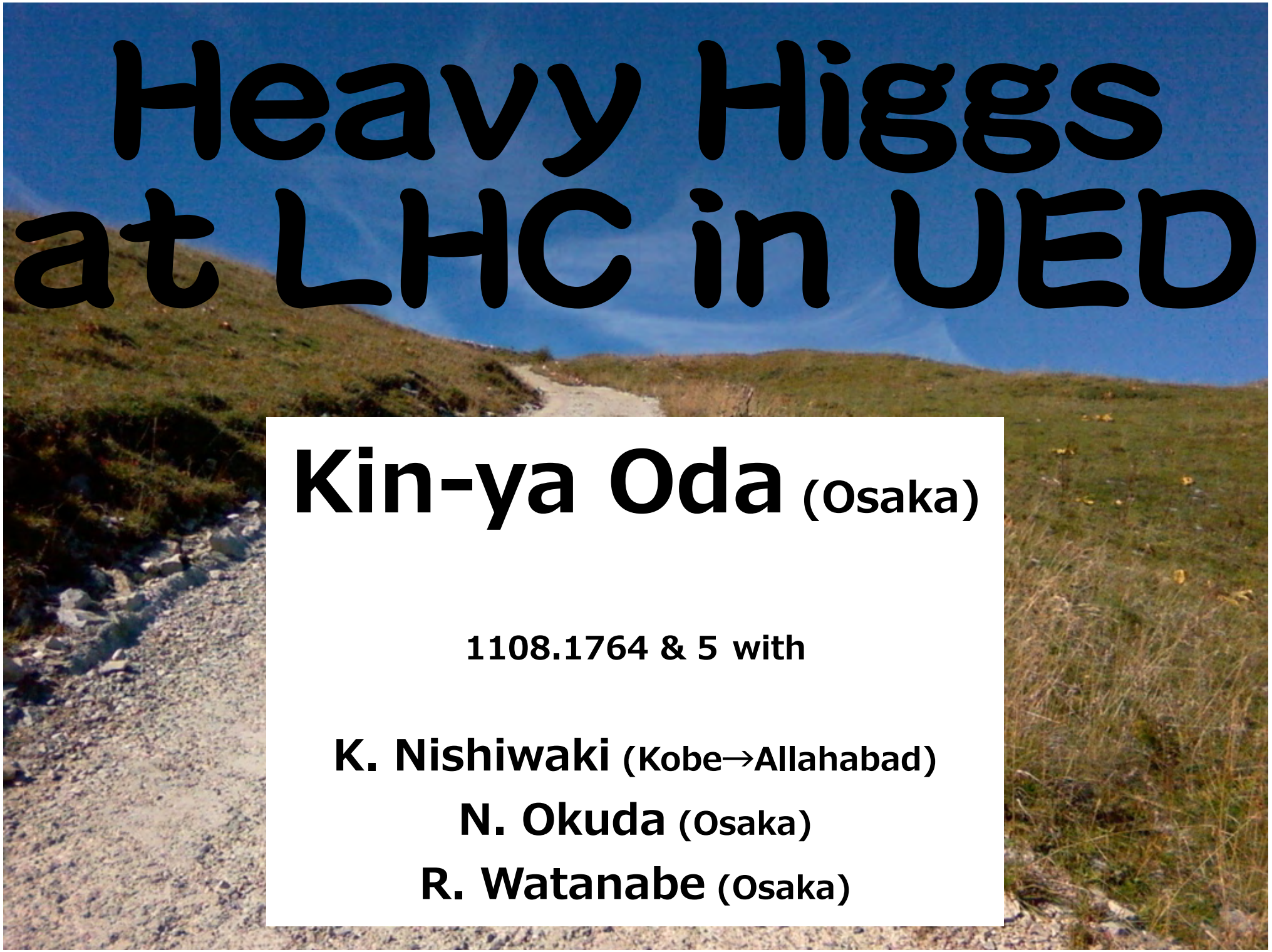


Heavy Higgs at LHC in UED

Kin-ya Oda (Osaka)

1108.1764 & 5 with

K. Nishiwaki (Kobe→Allahabad)

N. Okuda (Osaka)

R. Watanabe (Osaka)

LHC!!

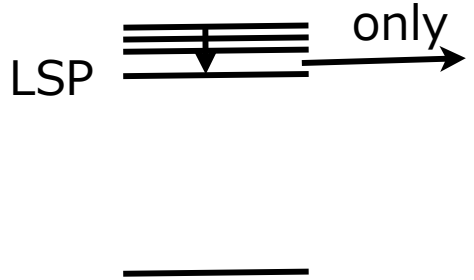
- **Weak-scale SUSY** (almost) dead.

  ★ I would do **light degenerate (ΔM<~100GeV) scenario** if I was SUSY enthusiast:

  ✳ Even more “natural” than ever.

  ✳ Difficult (well, challenging) to observe.

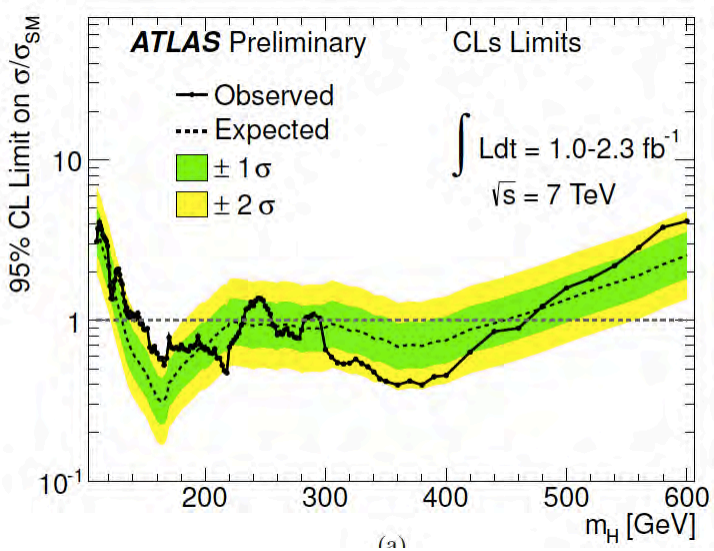
  ✳ Would be seen in events triggered by ISR.

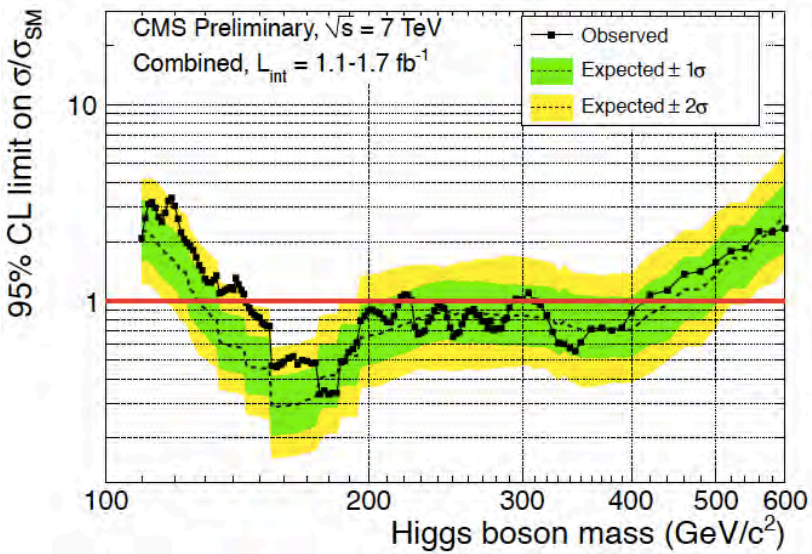


- **Weak-scale UED** provides similar ISR signature in M_{T2}. [Murayama, Nojiri, Tobioka, 2011]

  ✳ Would be of interest for SUSY clan too.

Higgs!!

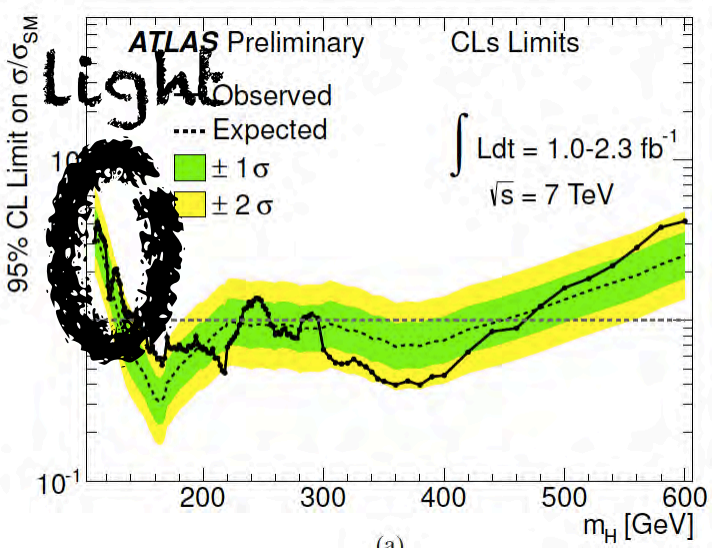


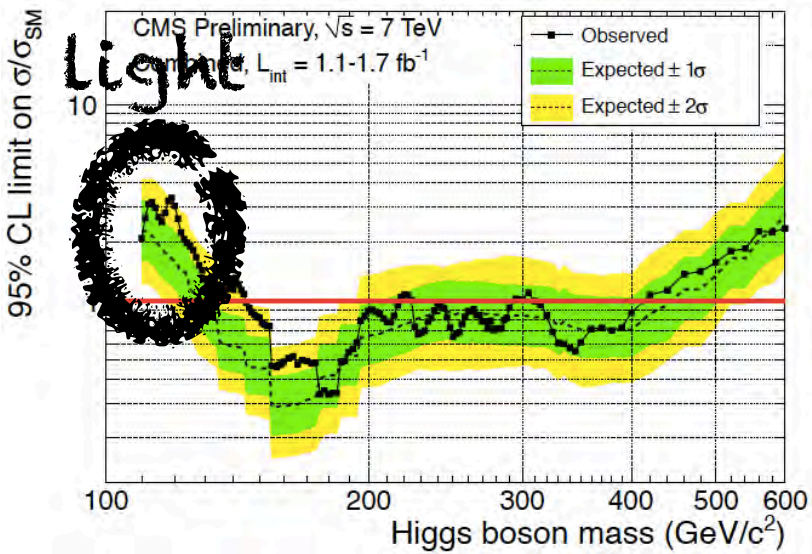


- Great step to prove that we are really living in a “superconducting” vacuum.
- We focus on middle (islands∈[200,300]GeV) and heavy (>460GeV) regions.

★ The >2σ excess at 130-140GeV in EPS ($1fb^{-1}$) is gone in LP ($2fb^{-1}$).

Higgs!!

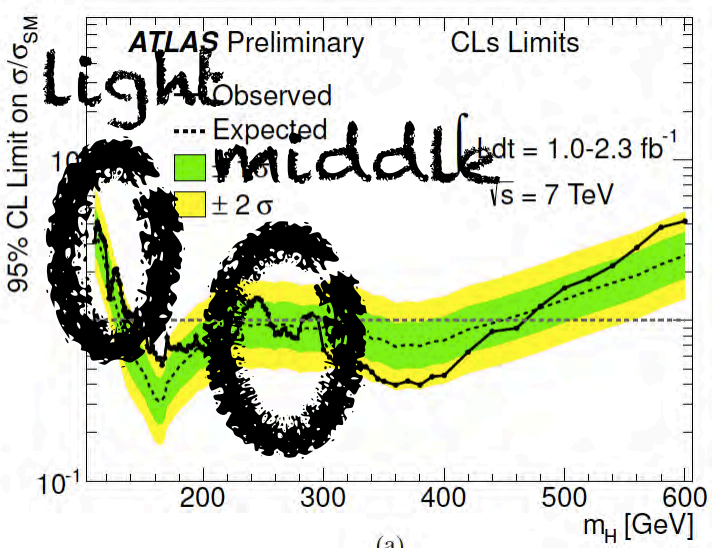


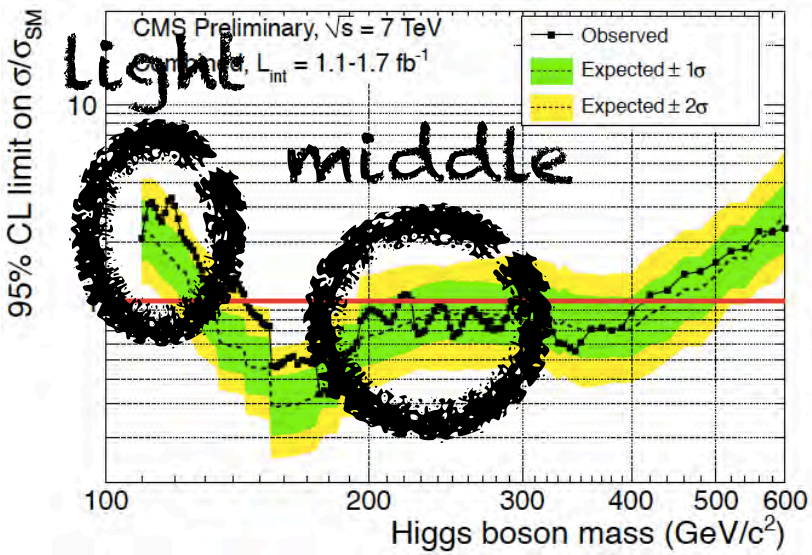


- Great step to prove that we are really living in a “superconducting” vacuum.
- We focus on middle (islands∈[200,300]GeV) and heavy (>460GeV) regions.

★ The >2σ excess at 130-140GeV in EPS ($1fb^{-1}$) is gone in LP ($2fb^{-1}$).

Higgs!!

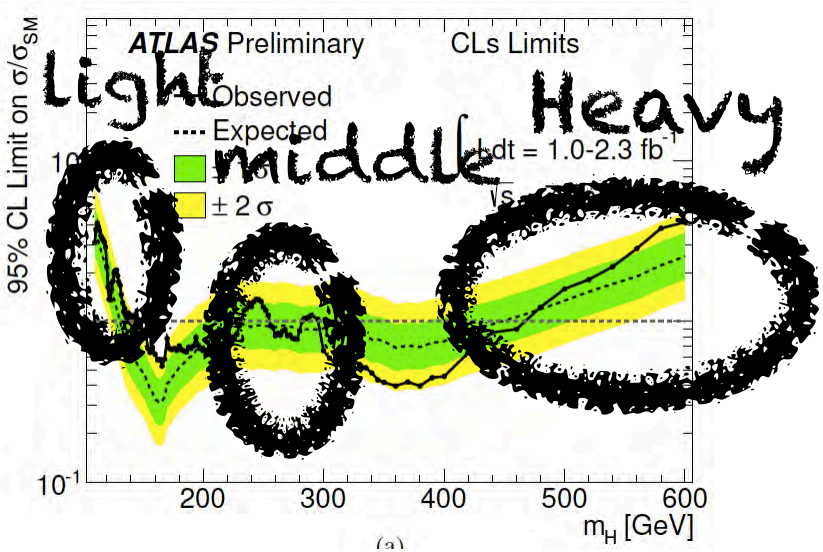


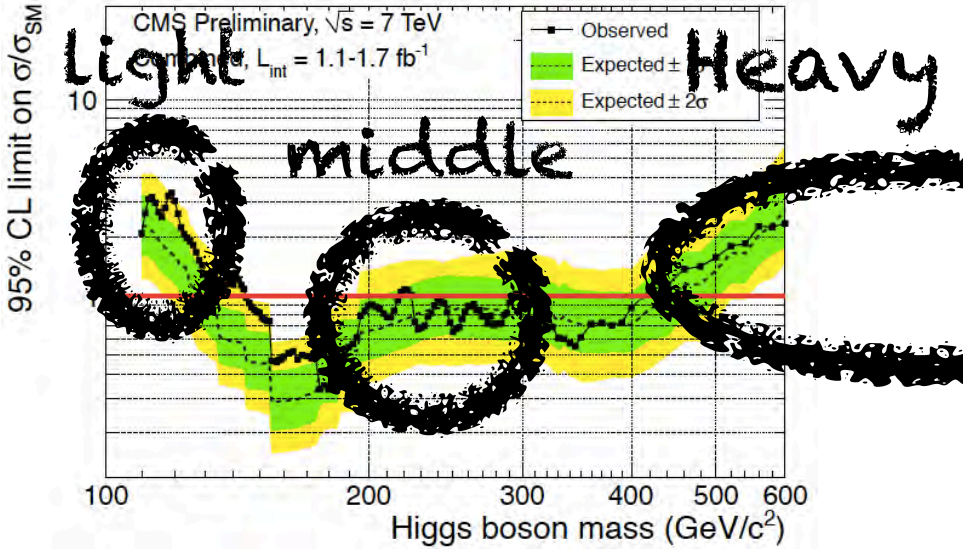


- Great step to prove that we are really living in a “superconducting” vacuum.
- We focus on middle (islands∈[200,300]GeV) and heavy (>460GeV) regions.

★ The >2σ excess at 130-140GeV in EPS ($1fb^{-1}$) is gone in LP ($2fb^{-1}$).

Higgs!!





- Great step to prove that we are really living in a “superconducting” vacuum.
- We focus on middle (islands∈[200,300]GeV) and heavy (>460GeV) regions.

★ The >2σ excess at 130-140GeV in EPS ($1fb^{-1}$) is gone in LP ($2fb^{-1}$).

Why UED?

- Provides LKP as **DM candidate**.
  - ★ Which is stable due to geometry, not by hand.
    - ✳ Conservation of KK parity, KK (angular) momentum, etc.
  - ★ From small number of free parameters.
- Predicts (multiple of) **three generations** in 6D.
  - ★ (From cancellation of $SU(2)_W$ global gauge anomaly [Dobrescu, Poppitz, 2001].)
- **Heavy Higgs** > 200GeV allowed (even favored).
  - ★ In weak-scale UED: $M_{KK} \sim v_{EW} = 246\text{GeV}$.
  - ★ Due to KK-top loops in T-parameter. (shown later)

So what is UED?

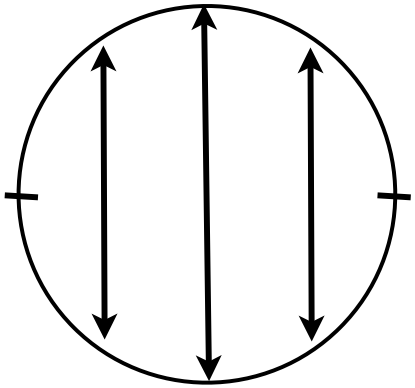
- All SM fields live in higher dimensions.
  - ★ Compactified within ~am.
- KK modes for each SM mode.
  - ★ Different masses, same charges.
- Higgs as zero mode.
  - ★ EWSB by bulk Higgs potential.
    - ✳ (Except for Dirichlet Higgs model. [Haba, KO, Takahashi, 11])

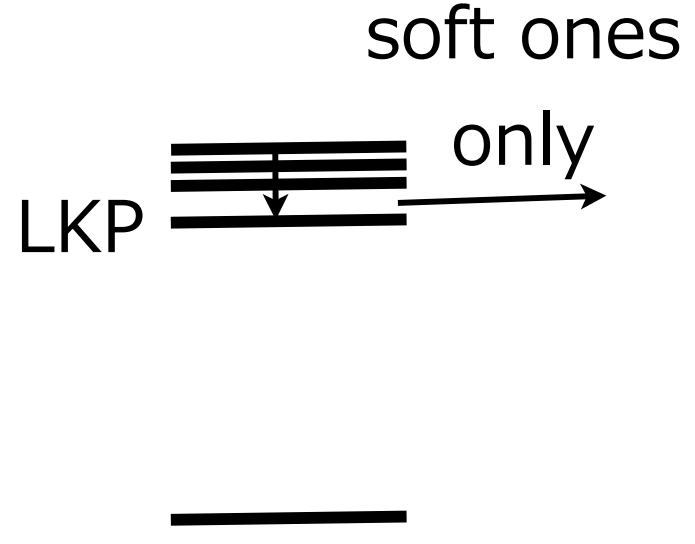
Outline:
UED Higgs at LHC

1. Want signal independent of detailed boundary structure
2. Heavy Higgs from **KK-top loops**
3. Enhanced gluon fusion from **KK-top loops**

Dependence on boundary structure

- UEDs require **orbifolding** to have chiral fermions.
  - ★ (Expept for S^2-based ones.)
  - ★ Resulting in orbifold **fixed point**.
  - ★ On which we can put **arbitrary** mass, mixing, and interaction (consistent to SM gauge symmetry).
- Especially **KK mass splitting** could be affected.
  - ★ All b→sγ, direct KK signals and DM relic abundance suffer from boundary structure.





Can we have a UED signal independent of such detailed boundary structure?

Outline:
UED Higgs at LHC

1. Want signal independent of detailed boundary structure
2. Heavy Higgs from **KK-top loops**
3. Enhanced gluon fusion from **KK-top loops**

KK-top loops in T-parameter

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

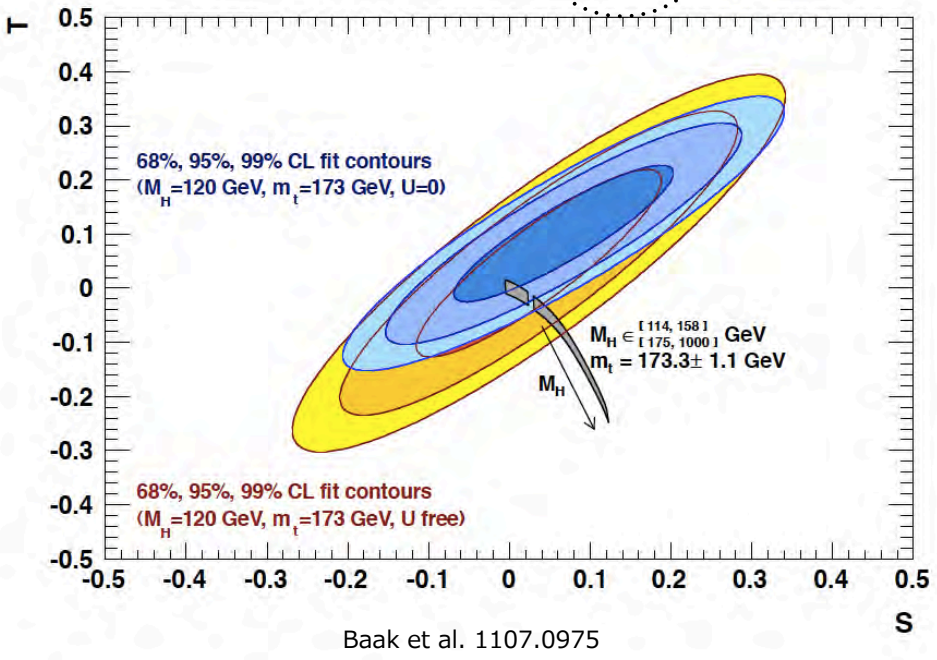
$$S \simeq \frac{1}{6\pi}\log\frac{m_H}{m_{H,\mathrm{ref}}} + \frac{1}{6\pi}\sum_{n=1}^{\infty}\frac{m_t^2}{n^2/R^2}$$

0.05

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

0.15

1.6



Baak et al. 1107.0975

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

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

KK-top loops in T-parameter

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

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

0.05

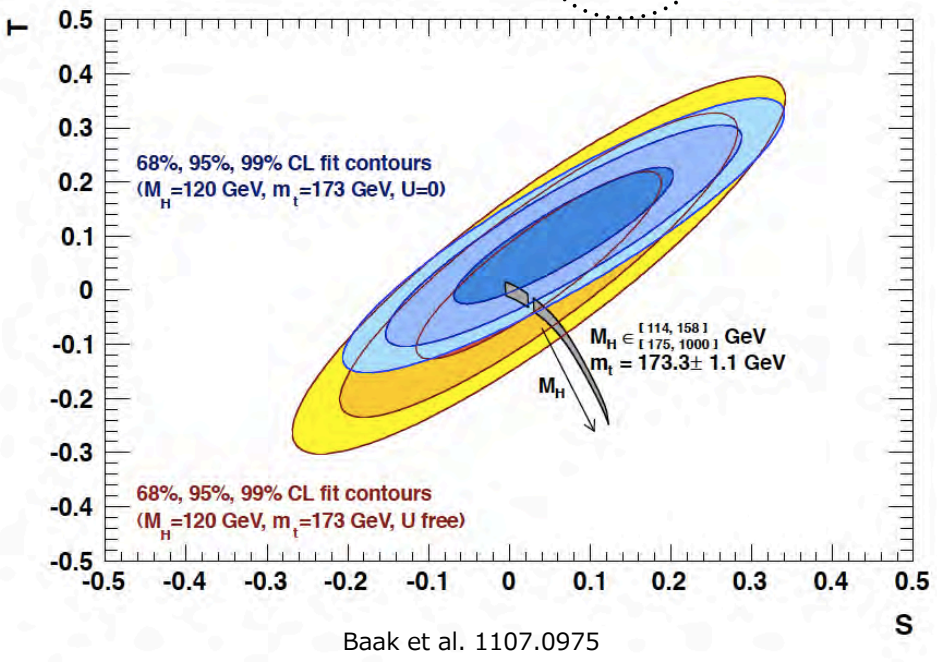
KK-top

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

0.15

KK-top

1.6



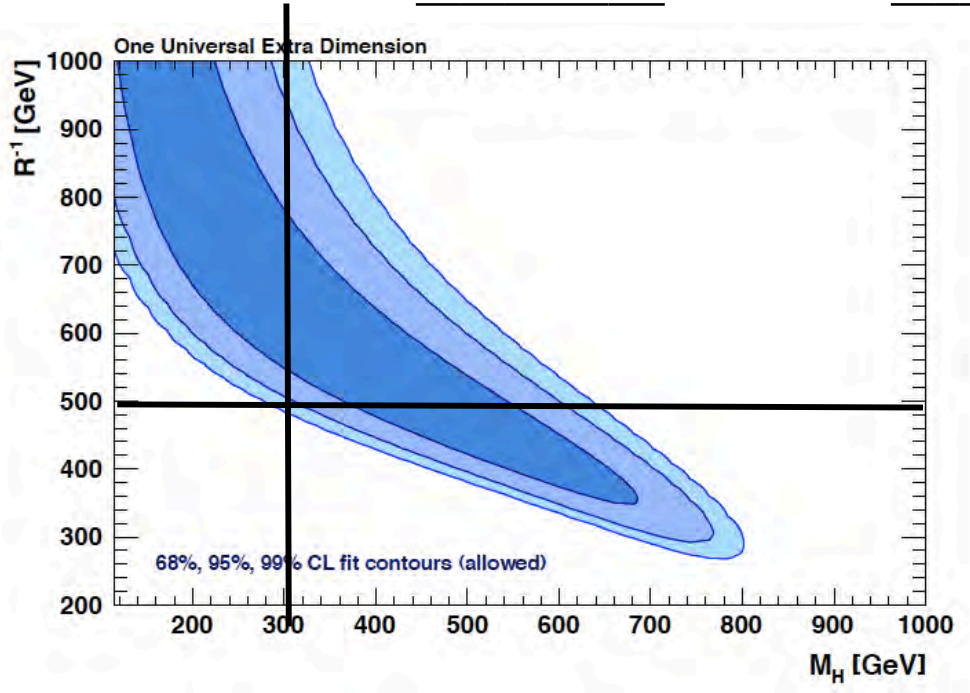
Baak et al. 1107.0975

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

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

Heavy Higgs favored in weak-scale 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**.
  - ★ For weak-scale UED, say $M_{KK}<2v_{EW}$, we get $M_H>300$GeV.



Baak et al.
1107.0975

Heavy Higgs in UED models

- This is a general tendency.

★ KK top loops not only in 5D mUED.

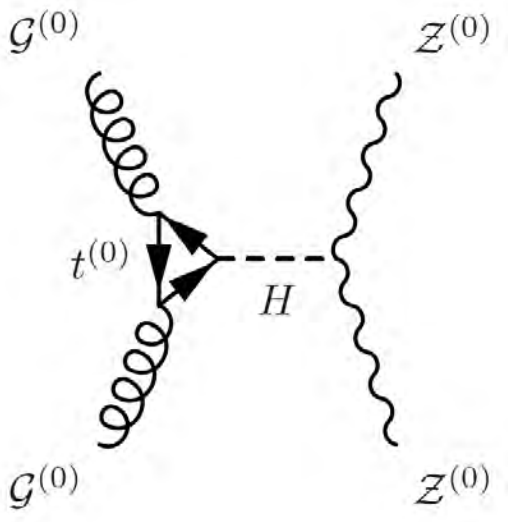
★ Insensitive to KK mass splitting $M_n \to M_n + \delta M_n$.

✳ (That comes from brane-localized Lagrangian.)

Outline:
UED Higgs at LHC

1. Want signal independent of detailed boundary structure
2. Heavy Higgs from **KK-top loops**
3. Enhanced gluon fusion from **KK-top loops**

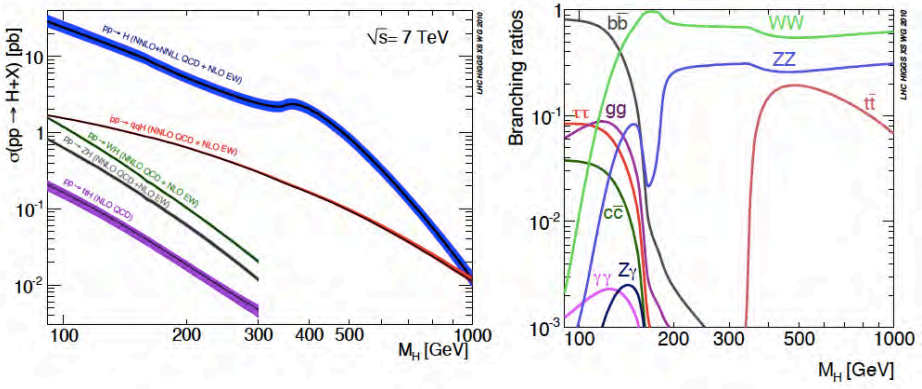
UED Higgs at LHC



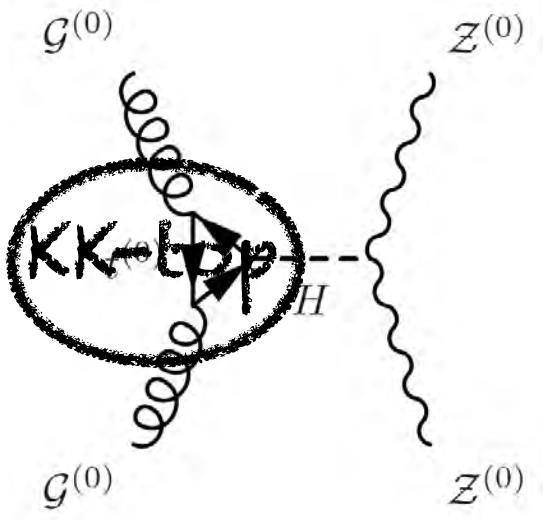
- gg→H production enhanced since **loop**-produced.
- Decays the same as in SM.

★ H→WW,ZZ,tt,bb not much affected since there's **tree** coupling.

SM figures



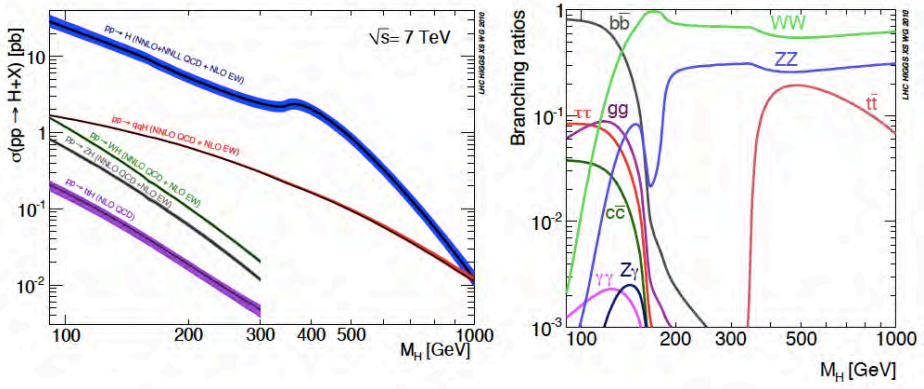
UED Higgs at LHC



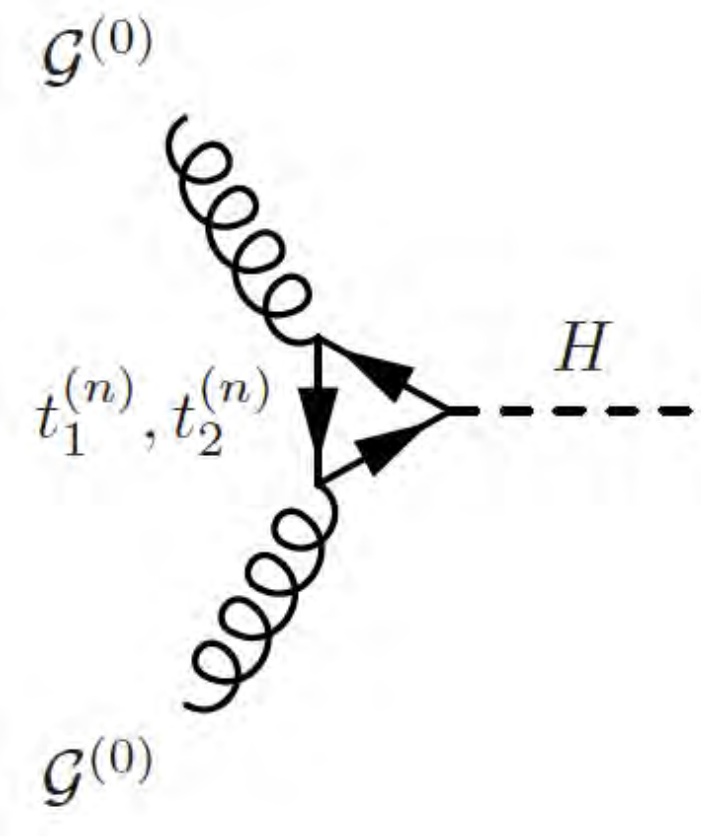
- gg→H production enhanced since **loop**-produced.
- Decays the same as in SM.

★ H→WW,ZZ,tt,bb not much affected since there's **tree** coupling.

SM figures



Gluon fusion in UED

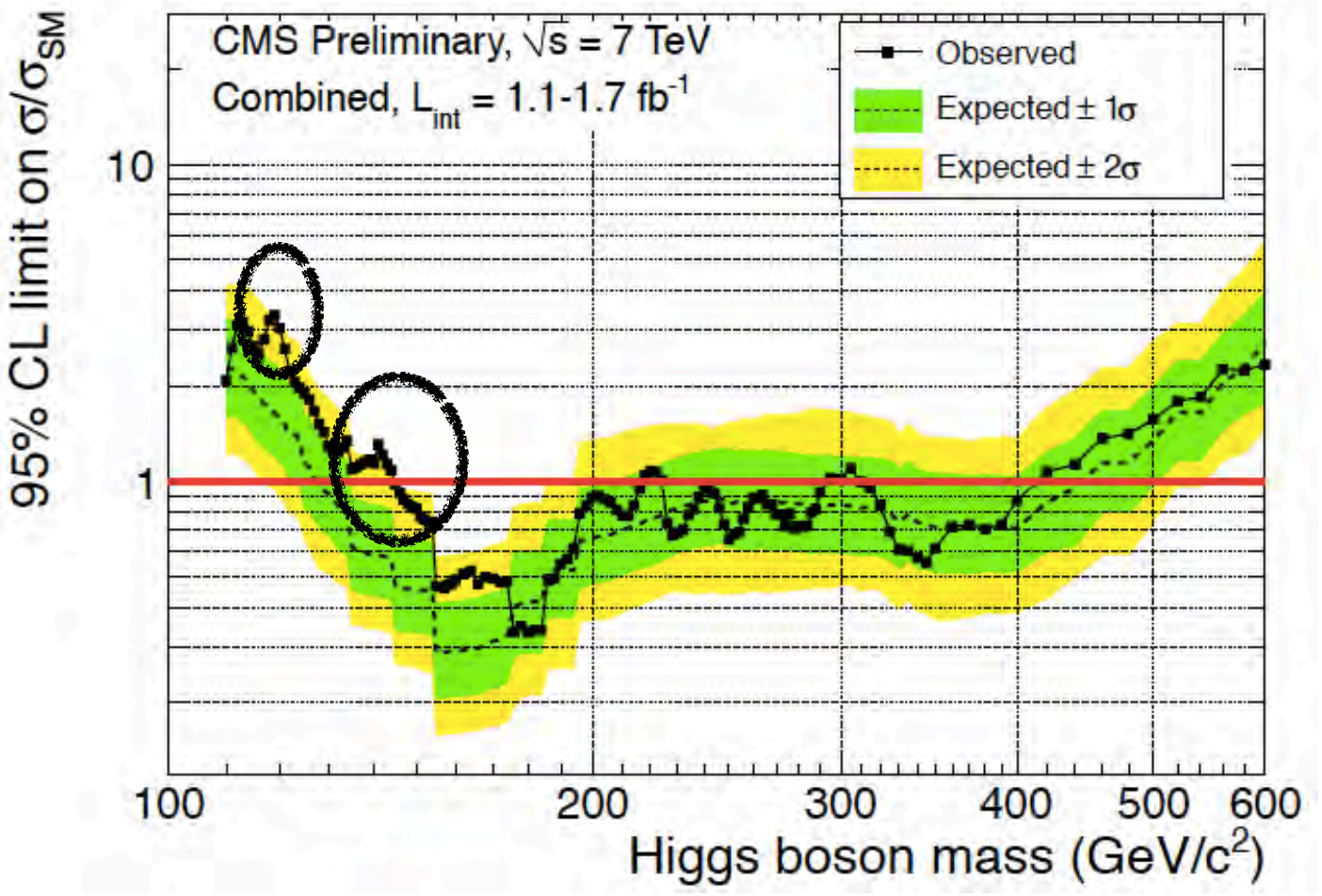


- Again, insensitive to detailed KK mass splitting.
- We have computed:
  - ★ In 5D:
    - ✳ S^1/Z_2 & **Dirichlet Higgs**.
  - ★ In 6D T^2-based:
    - ✳ T^2/Z_4, **T^2/Z_2**, **$T^2/(Z_2 \times Z_2')$** & **RP^2**.
  - ★ In 6D S^2-based:
    - ✳ **S^2**, S^2/Z_2 & Projective Sphere.
      - ✦ **Underlined ones** are newly computed by ourselves.


Decay

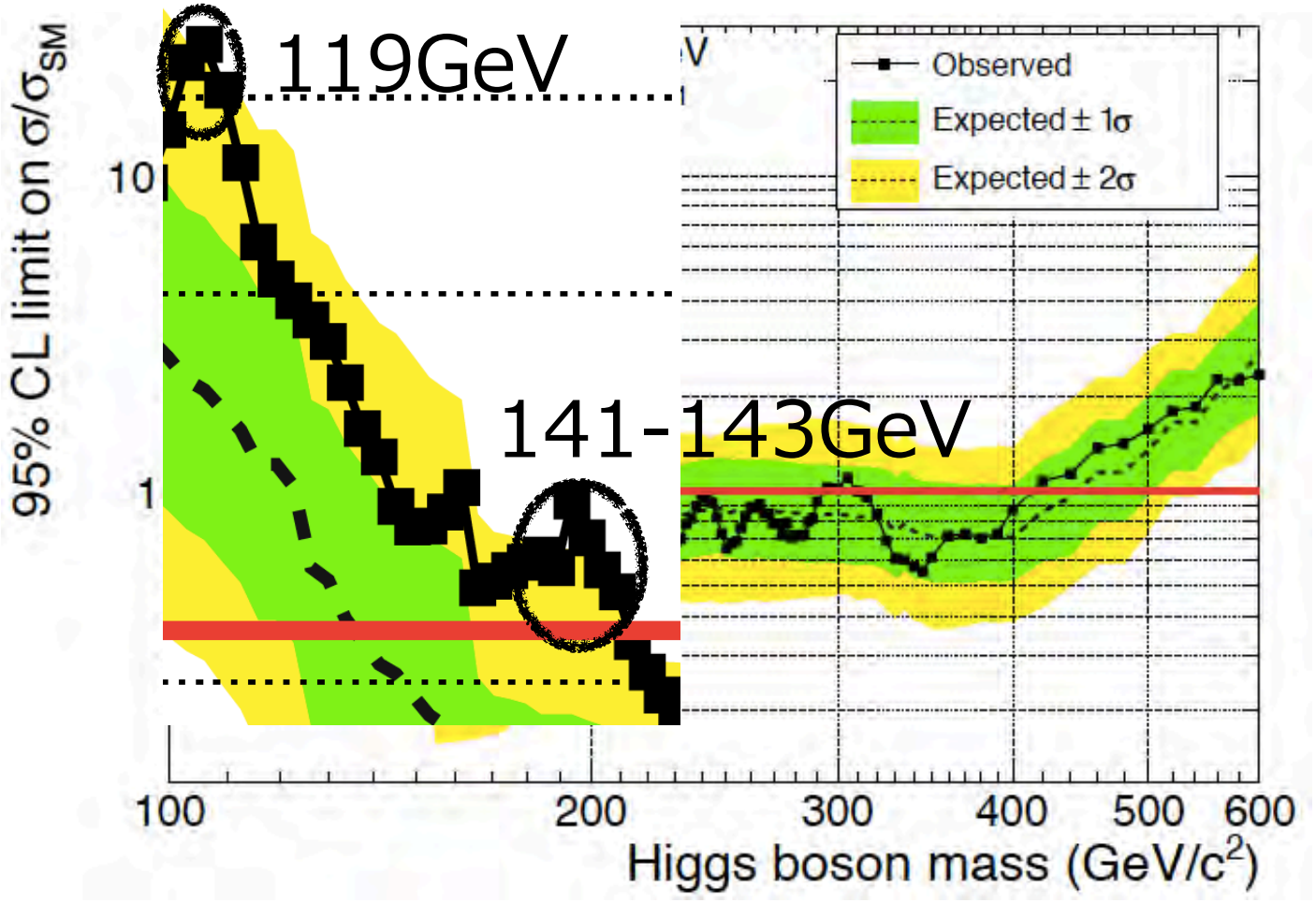
ZZ→4l is the golden channel.

- Essentially **all** the current >2σ bumps are due to ZZ→4l.



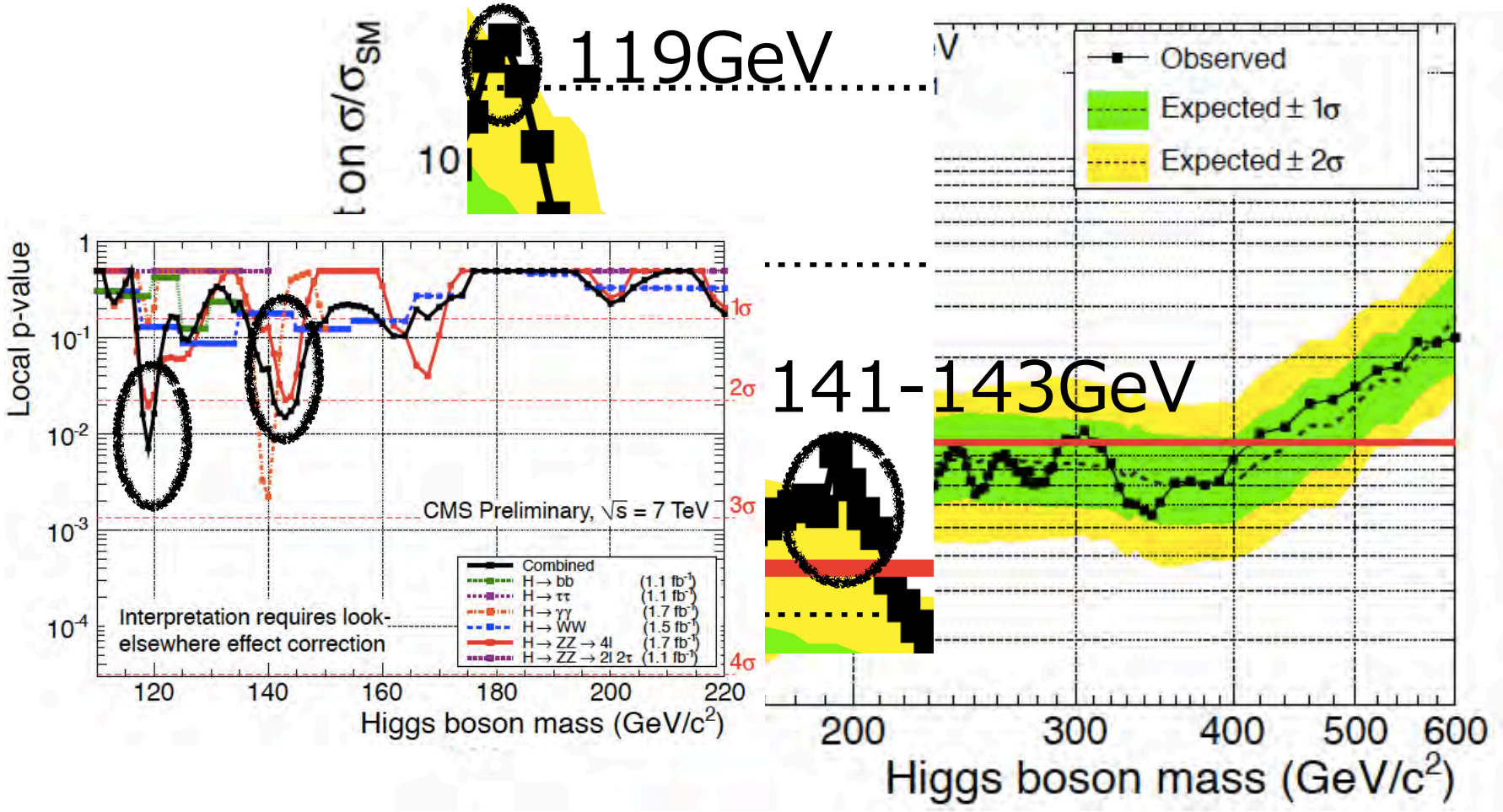
ZZ→4l is the golden channel.

- Essentially **all** the current >2σ bumps are due to ZZ→4l.



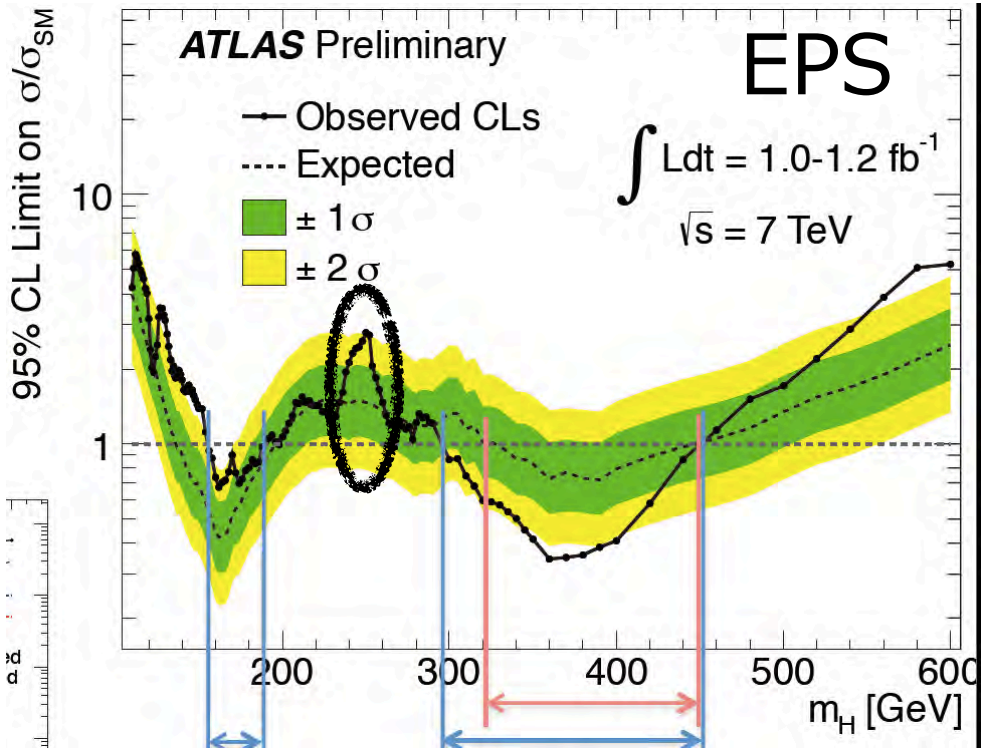
ZZ→4l is the golden channel.

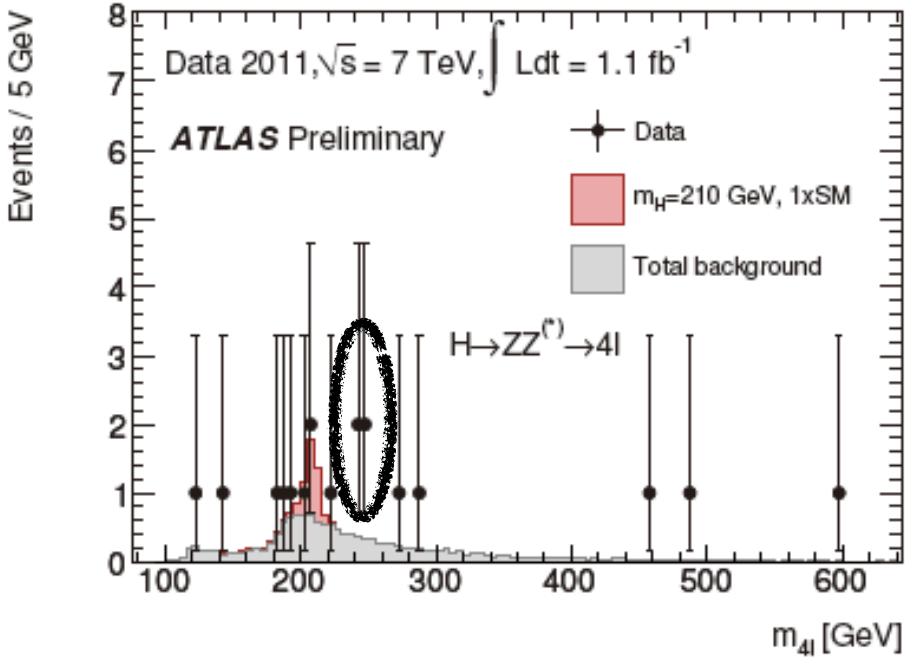
- Essentially **all** the current >2σ bumps are due to ZZ→4l.



ZZ→4l is the golden channel. (cont.)

- Also the case at ATLAS in EPS ($1fb^{-1}$) data.
- So clean that just few events suffice to make a bump in significance.



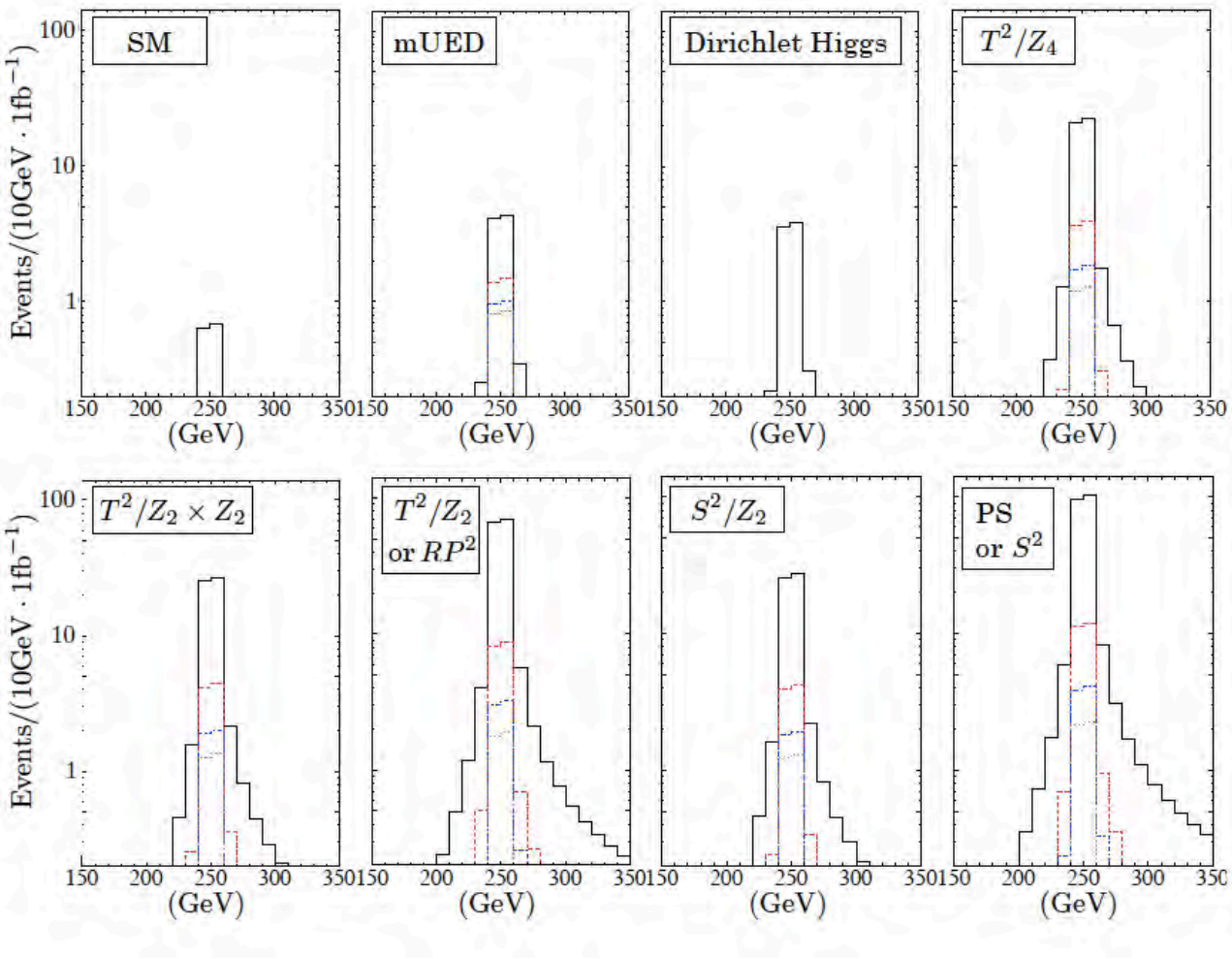



Results

22 → 4 leptons
M_H = 250GeV

- 7TeV, 1fb^{-1}, 10GeV bin.
- M_{KK}=200,400,600,800GeV (250GeV for DH).

Nishiwaki, KO, Okuda, Watanabe
1108.1764



ZZ → 4 leptons
M_H = 250GeV

- 7TeV, 1fb^{-1}, 10GeV bin.
- M_{KK}=200,400,600,800GeV (250GeV for DH).

Nishiwaki, KO, Okuda, Watanabe
1108.1764

- 250GeV excess at ATLAS may be accounted for by UED.

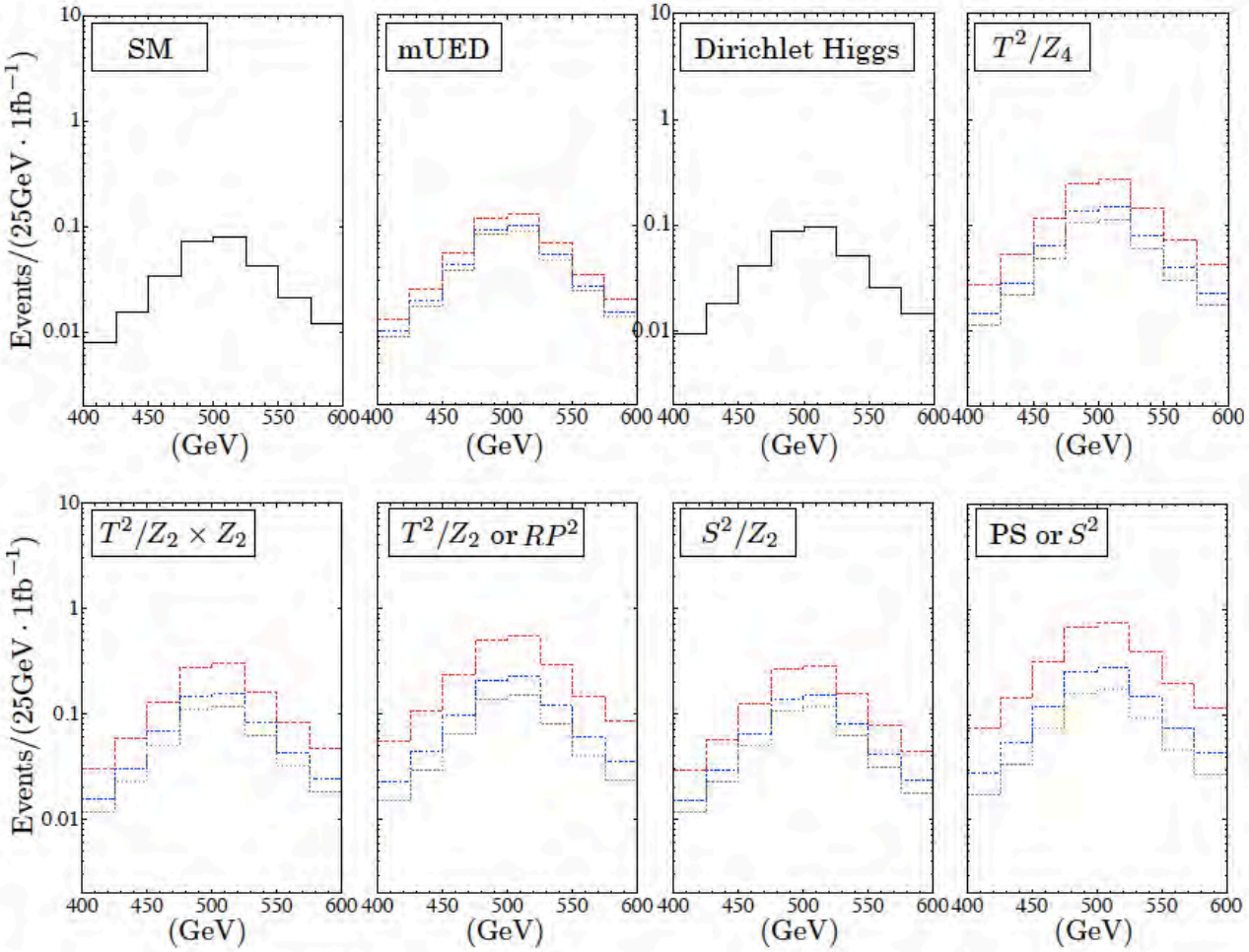
★Though became severer after LP (2fb^{-1}).

- 10fb^{-1} would suffice to establish the resonance.

ZZ → 4 leptons
M_H = 500GeV

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

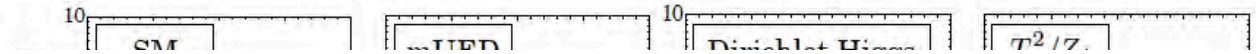
Nishiwaki, KO, Okuda, Watanabe
1108.1764



$ZZ \to 4$ leptons
$M_H = \underline{500}$GeV

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

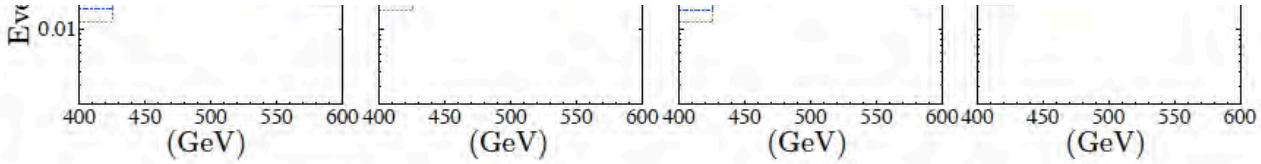
Nishiwaki, KO, Okuda, Watanabe
1108.1764



- With $10fb^{-1}$:

★A few (virtually background free) events in 5D UED.

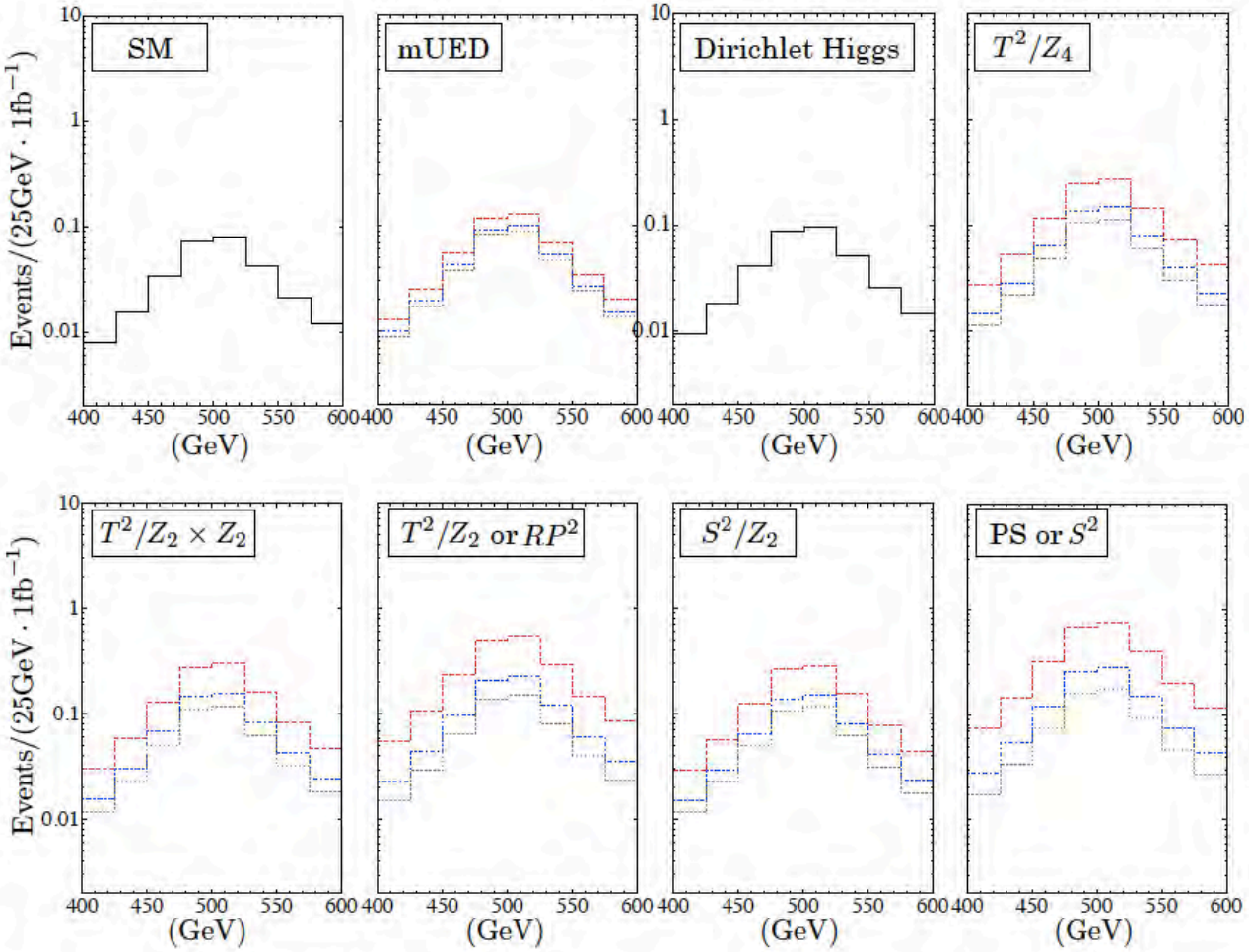
★May establish the peak in 6D UED.



ZZ → 4 leptons
M_H = 700GeV

- **14TeV**, 1fb^{-1}, 25GeV bin.
- M_{KK}=200,400,600,800GeV (700GeV for DH).

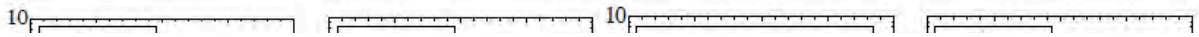
Nishiwaki, KO, Okuda, Watanabe
1108.1764



ZZ → 4 leptons
M_H = 700GeV

- **14TeV**, 1fb^{-1}, 25GeV bin.
- M_{KK}=200,400,600,800GeV (700GeV for DH).

Nishiwaki, KO, Okuda, Watanabe
1108.1764



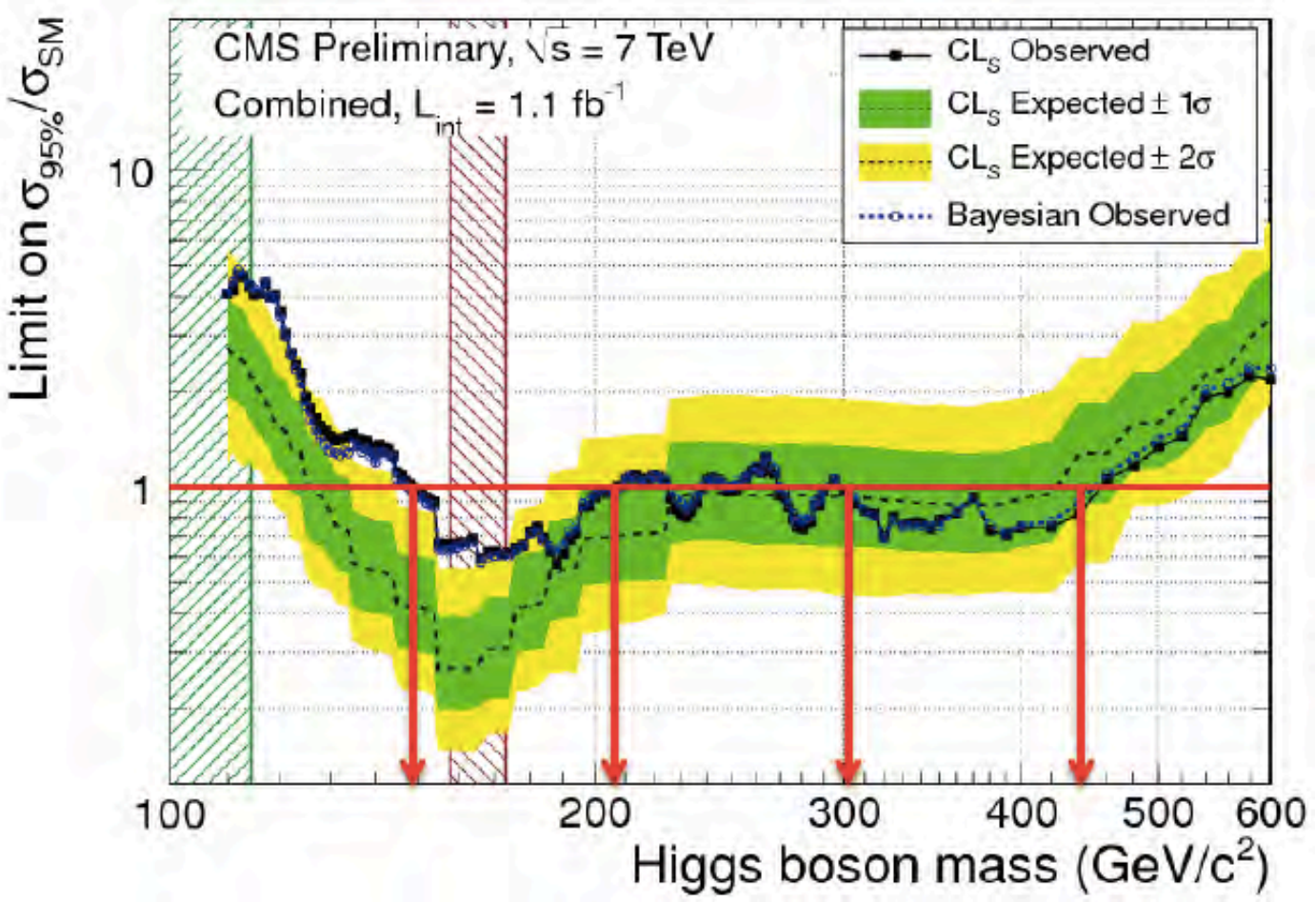
- With upgraded 14TeV, 10fb^{-1}:

★A few (virtually background free) events in 5D UED.

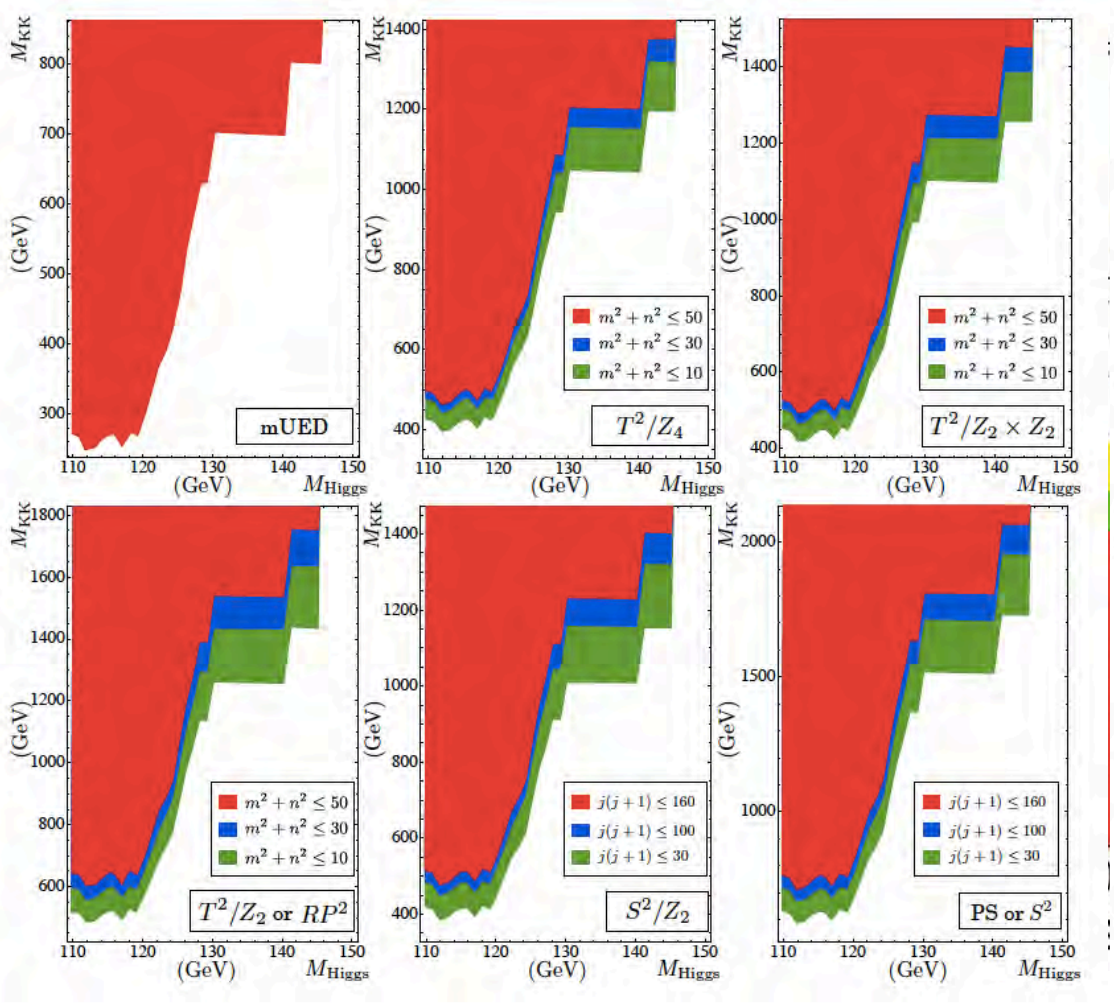
★May establish the peak in 6D UED.

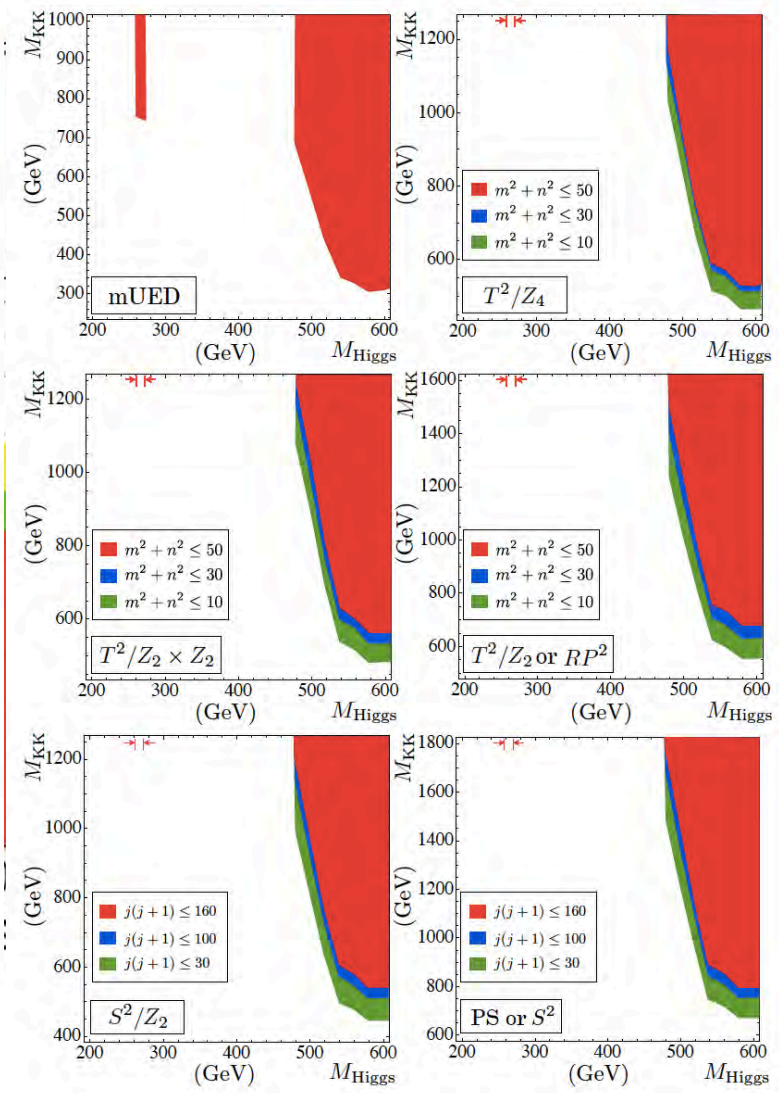

Furthermore,

Inclusive bound from Higgs production rate at CMS



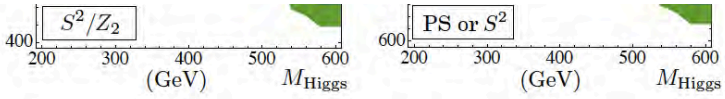
Inclusive bound from Higgs production rate at CMS





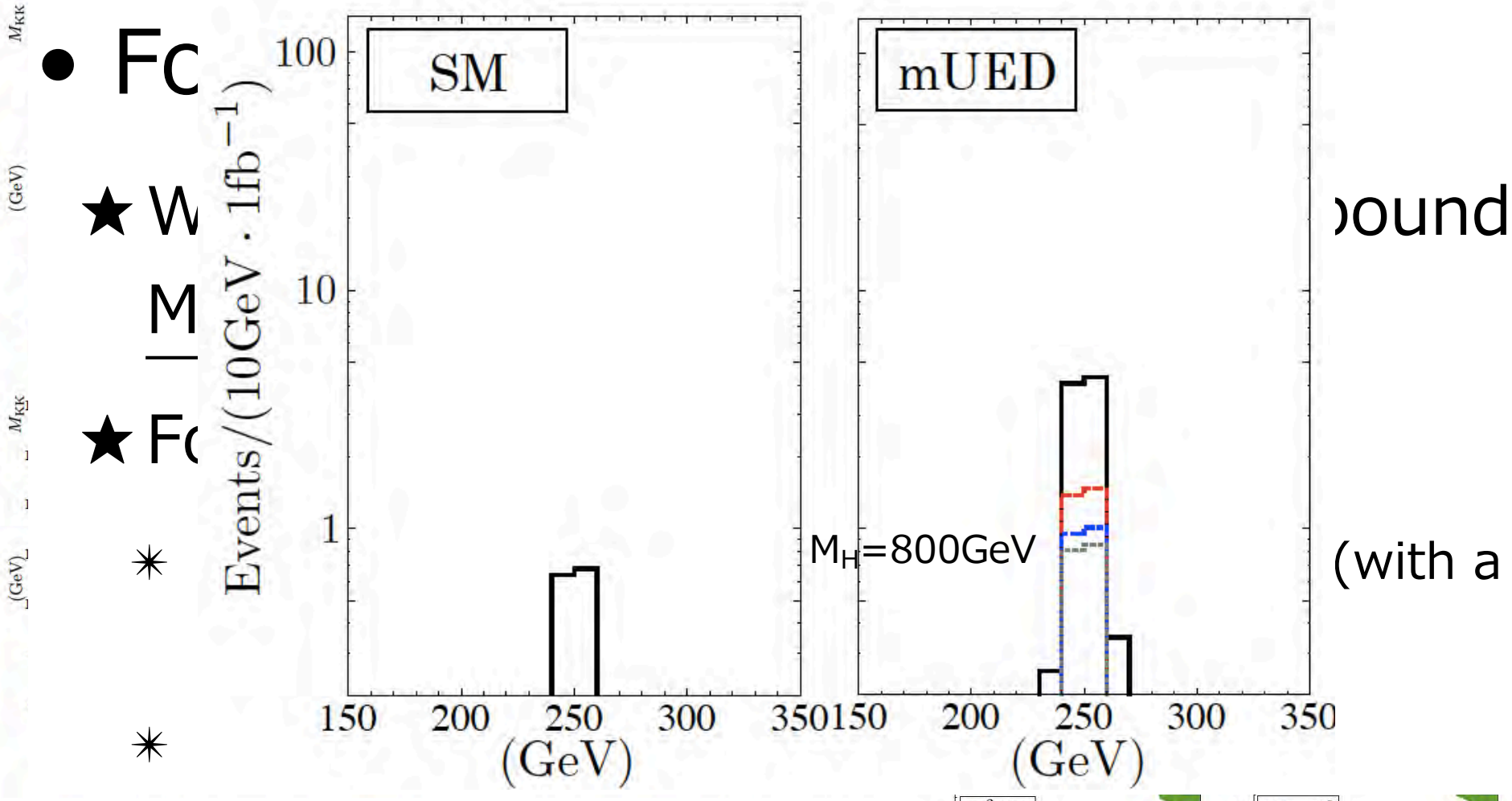
Inclusive bound from Higgs production rate at CMS

- For 5D (mUED on S^1/Z_2):
  - ★ We got by far the strongest collider bound: $M_{KK} > 700\text{GeV}$ at $M_H \in [130,140]\text{GeV}$.
  - ★ For ~250GeV Higgs: $M_{KK} > 750\text{GeV}$.
    - ✳ Still able to account for ATLAS ZZ→4l 4events (with a lucky factor 2) from EPS (1fb^{-1}).
    - ✳ Severer after LP (2fb^{-1}).



Inclusive bound from Higgs production rate at CMS

- Fc
  - ★ W
    M
  - ★ Fc
    - ✳
    - ✳



bound:

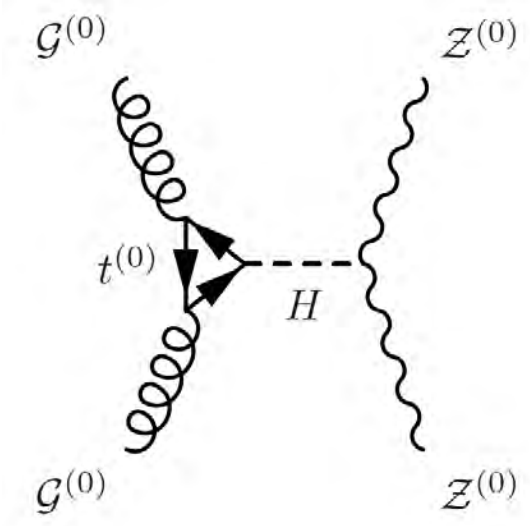
(with a

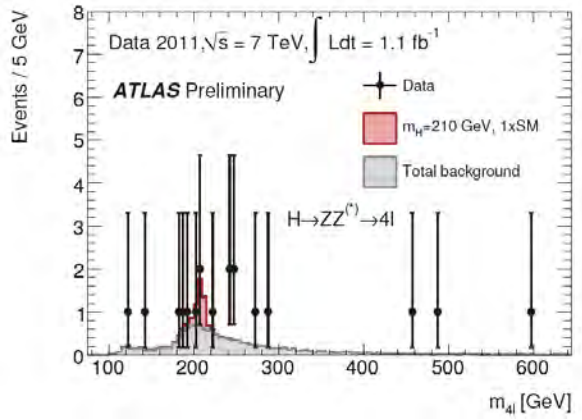
Summary

- UED is nice: DM & 3 families (6D).
- Due to **KK-top** loops:
  - ★ Weak-scale UED generically favors **heavy Higgs**.
  - ★ Higgs production **gg→H** is enhanced, which is:
    - ✳ **Insensitive** to KK mass splitting, and thus,
    - ✳ **Complementary** to other signatures.
- At LHC:
  - ★ When Higgs is light ∈[130,140]GeV, M_{KK}>700GeV is obtained for 5D mUED. (By far the strongest collider bound.)
  - ★ Middle 250GeV UED Higgs might account for ATLAS ZZ→4l. (Getting severer after LP.)
  - ★ Heavy 500 (700) GeV UED Higgs can be seen within 10fb^{-1} of data at 7 (14) TeV. (6D UED easier to see than 5D.)

Discussion

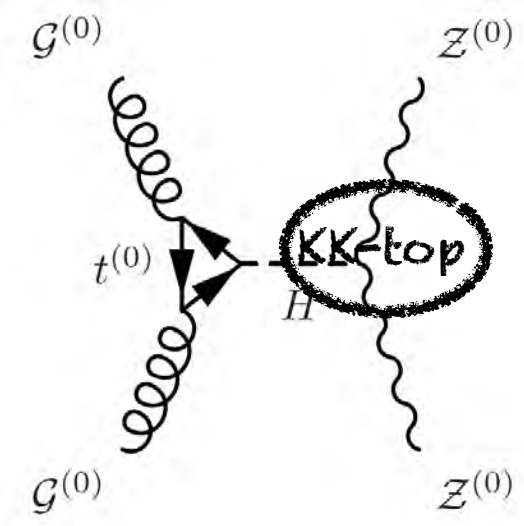
- Possible issues:
  - ★ KK top loops for H→WW,ZZ.
    - ✳ Might change events by ~O(10)%.
    - ✳ Same order as N(N)LO QCD corrections.
      - ✦ (NNLO PDF gives <~30% enhancement.)
  - ★ SM background?
- Todo:
  - ★ LP ($2fb^{-1}$) bound.
  - ★ Combined analysis with H→WW.
  - ★ H→γγ tends to be reduced due to interference.

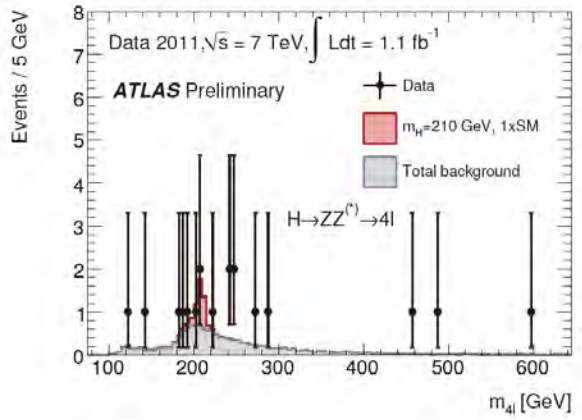


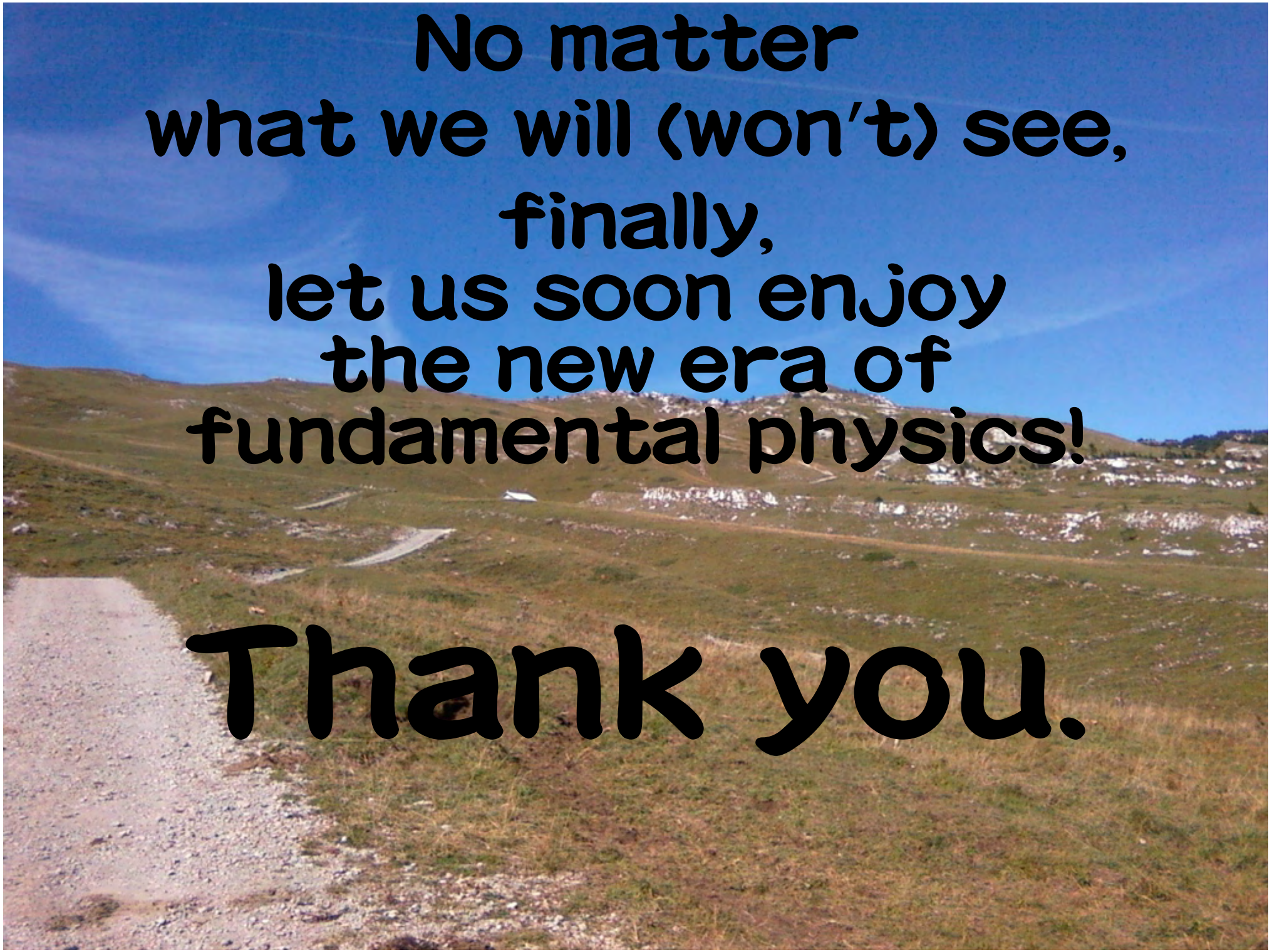


Discussion

- Possible issues:
  - ★ KK top loops for H→WW,ZZ.
    - ✳ Might change events by ~O(10)%.
    - ✳ Same order as N(N)LO QCD corrections.
      - ✦ (NNLO PDF gives <~30% enhancement.)
  - ★ SM background?
- Todo:
  - ★ LP ($2fb^{-1}$) bound.
  - ★ Combined analysis with H→WW.
  - ★ H→γγ tends to be reduced due to interference.






No matter
what we will (won't) see,
finally,
let us soon enjoy
the new era of
fundamental physics!
Thank you.