Heavy Higgs at LHC in UED

Kin-ya Oda (Osaka)

with

Kenji Nishiwaki (Kobe)

Naoya Okuda (Osaka)

Ryoutaro Watanabe (Osaka)

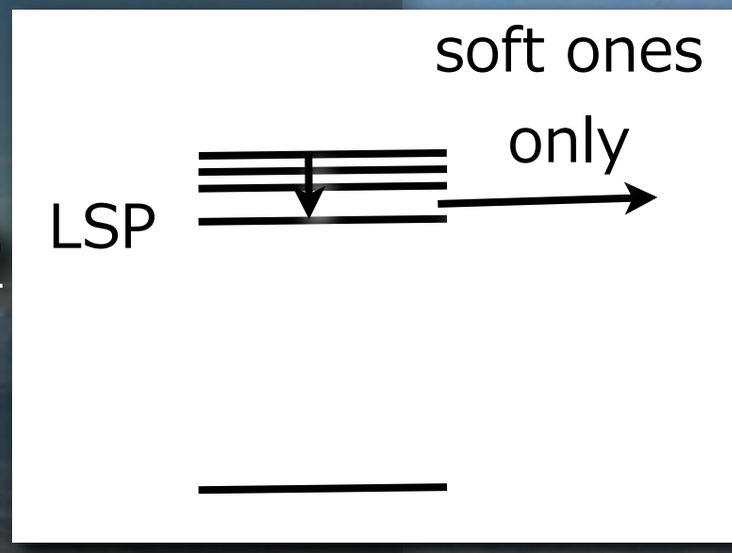
arXiv:1108.1764, 1108.1765

LHC!!

- We have not seen **weak-scale SUSY**.
  - ★ MSSM (almost) dead.
  - ★ I would do **light degenerate scenario** if I had bet on SUSY.
    - ✶ Natural but 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)]

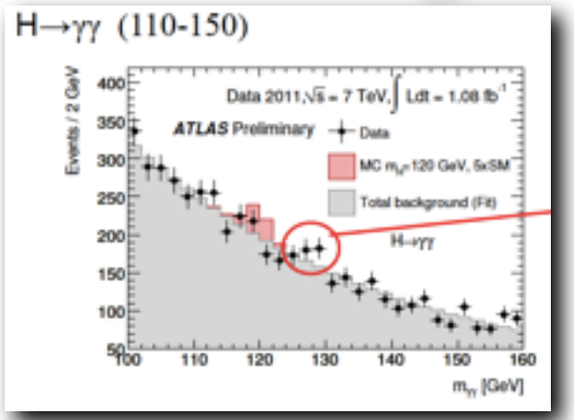
LHC!!

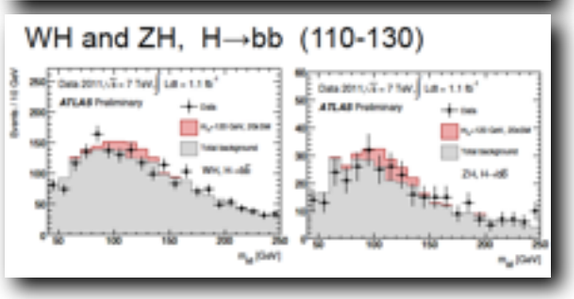
- We have not seen **weak-scale SUSY**.
  - ★ MSSM (almost) dead.
  - ★ I would do **light degenerate scenario** bet on SUSY.
    - ✶ Natural but challenging to observe.
    - ✶ Would be seen in events triggered by ISR.
- **Weak-scale UED** provides similar ISR signature in M_{T2}. [Murayama, Nojiri, Tobioka (2011)]

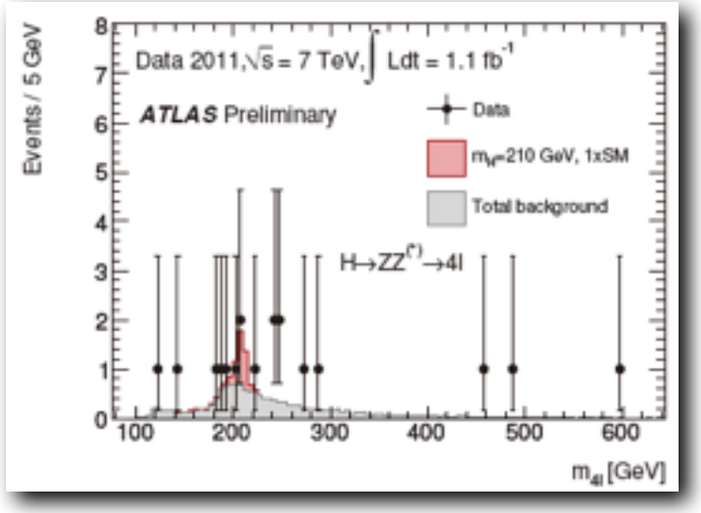


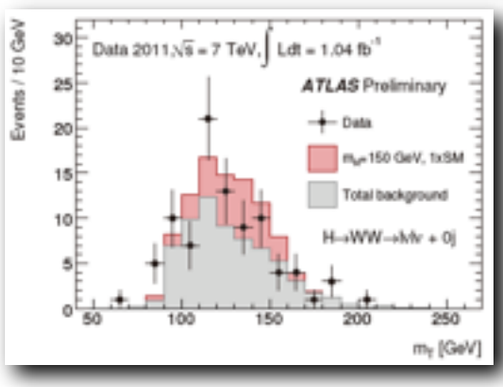
ヒッグス祭

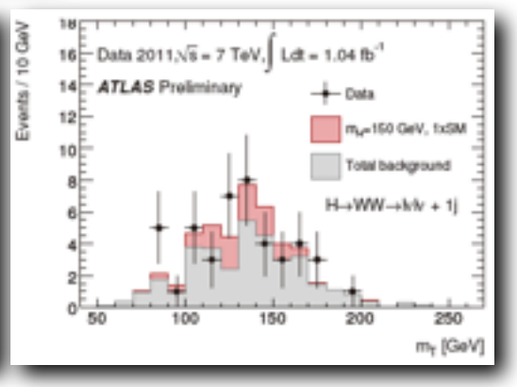
- Great step to prove that we are really living in a “superconducting” vacuum.

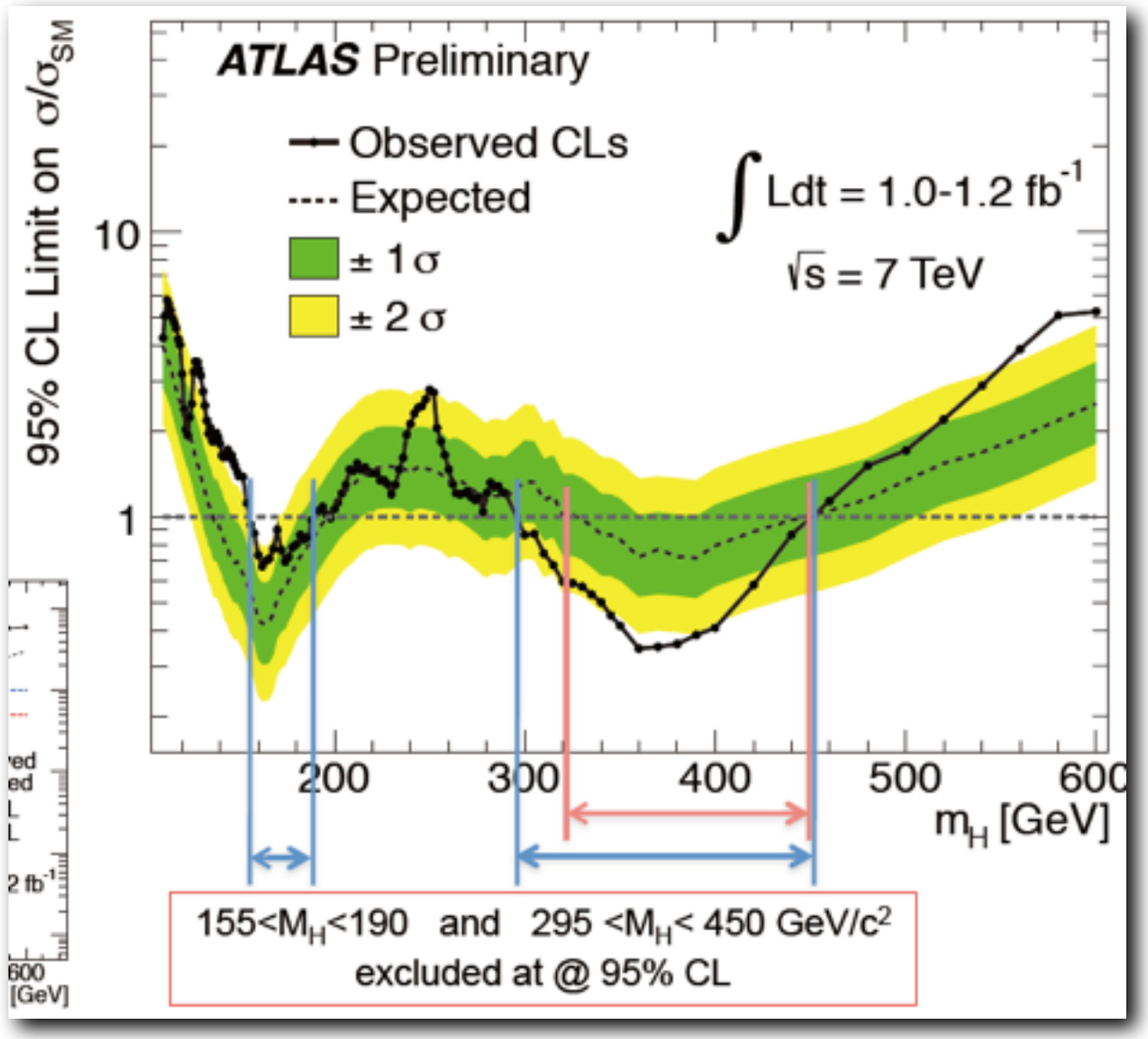






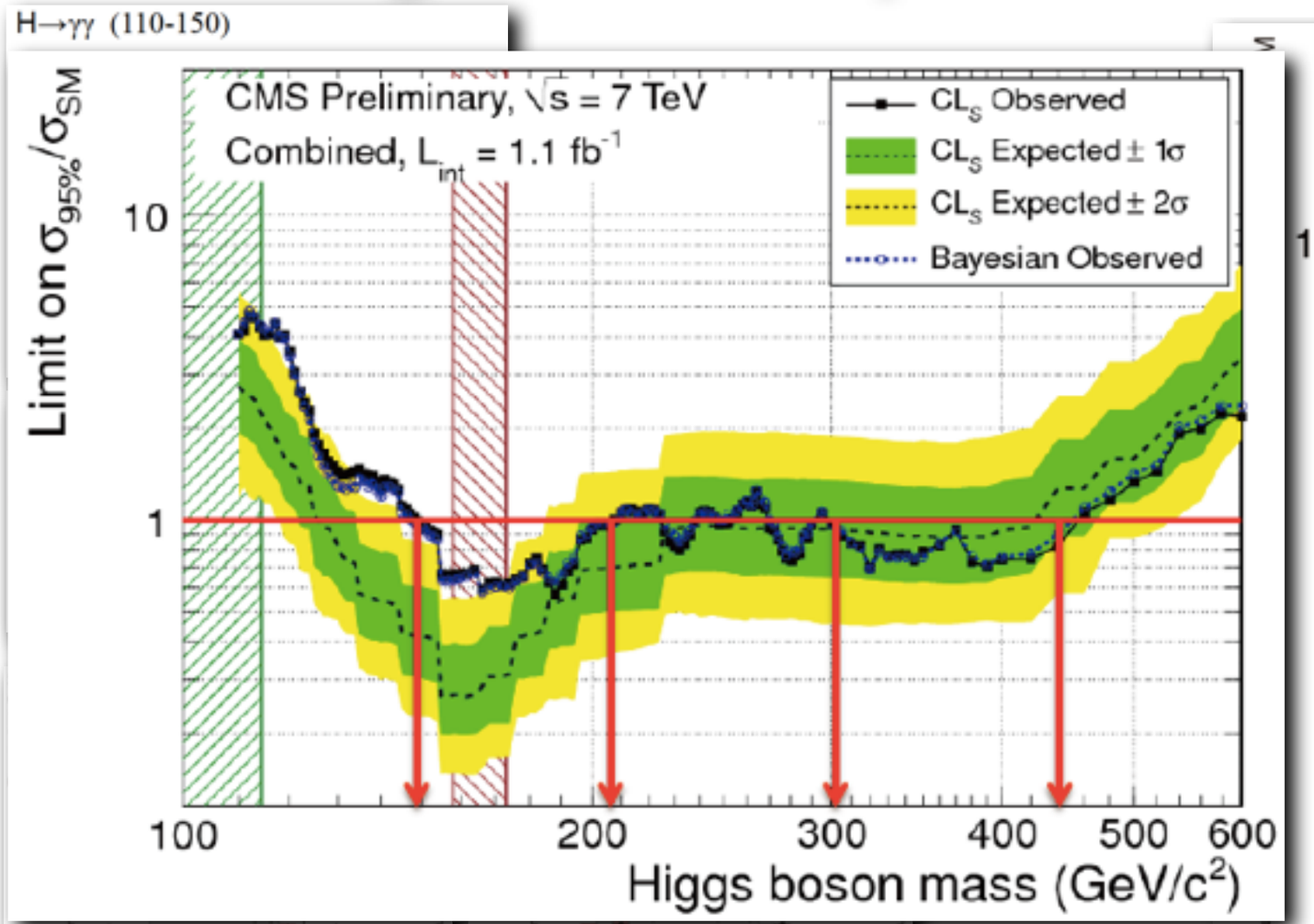


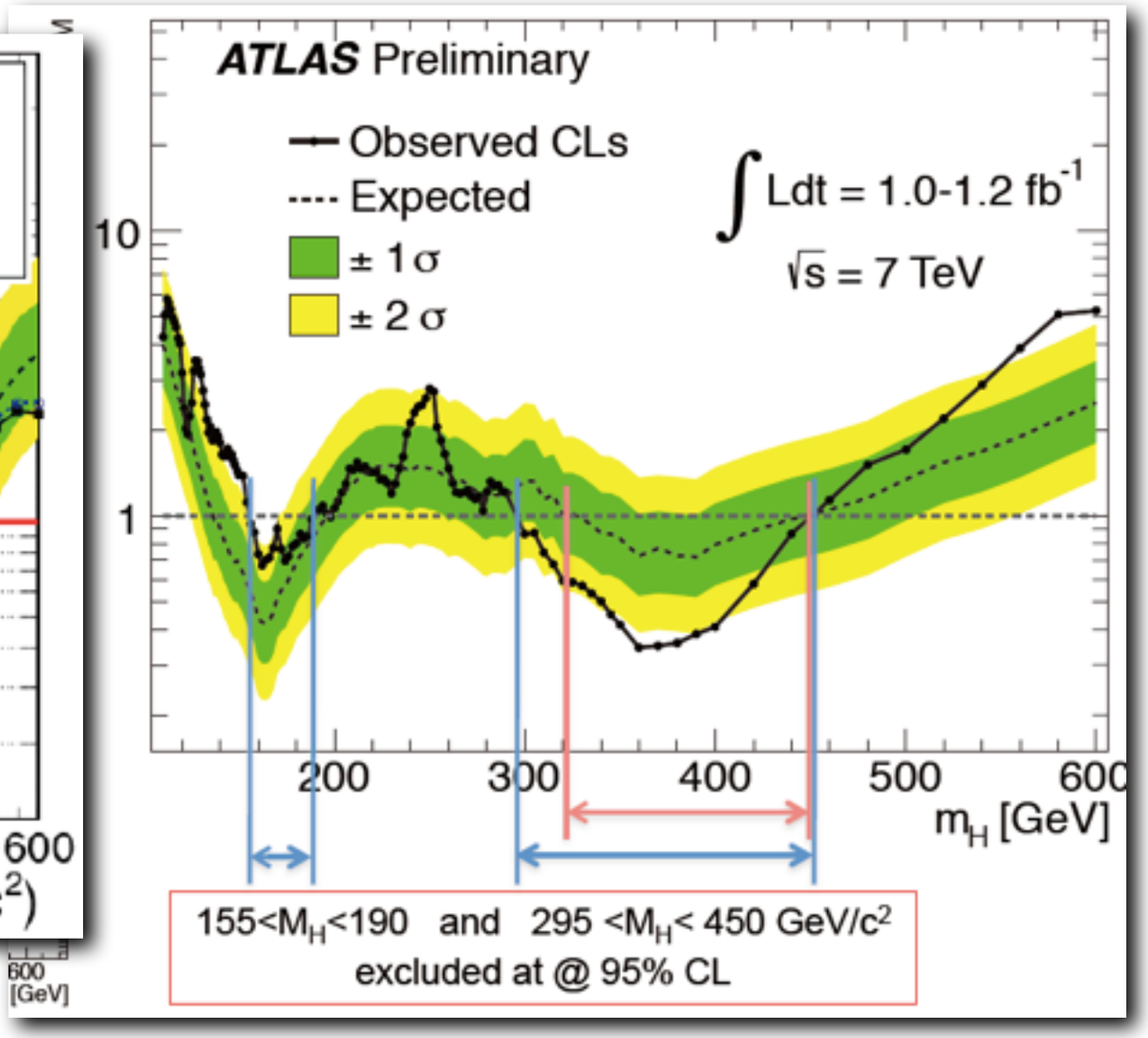




ヒッグス祭

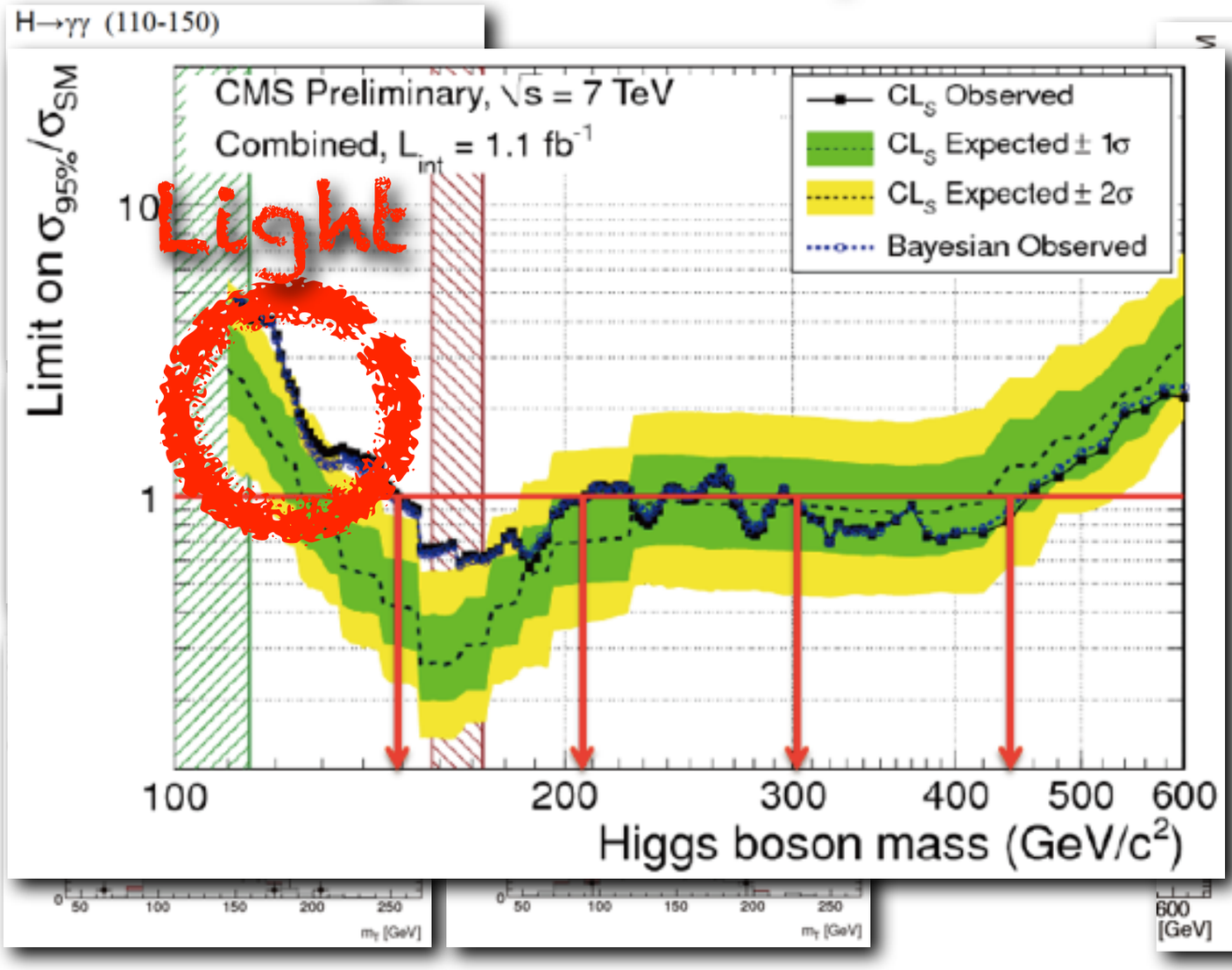
- Great step to prove that we are really living in a “superconducting” vacuum.

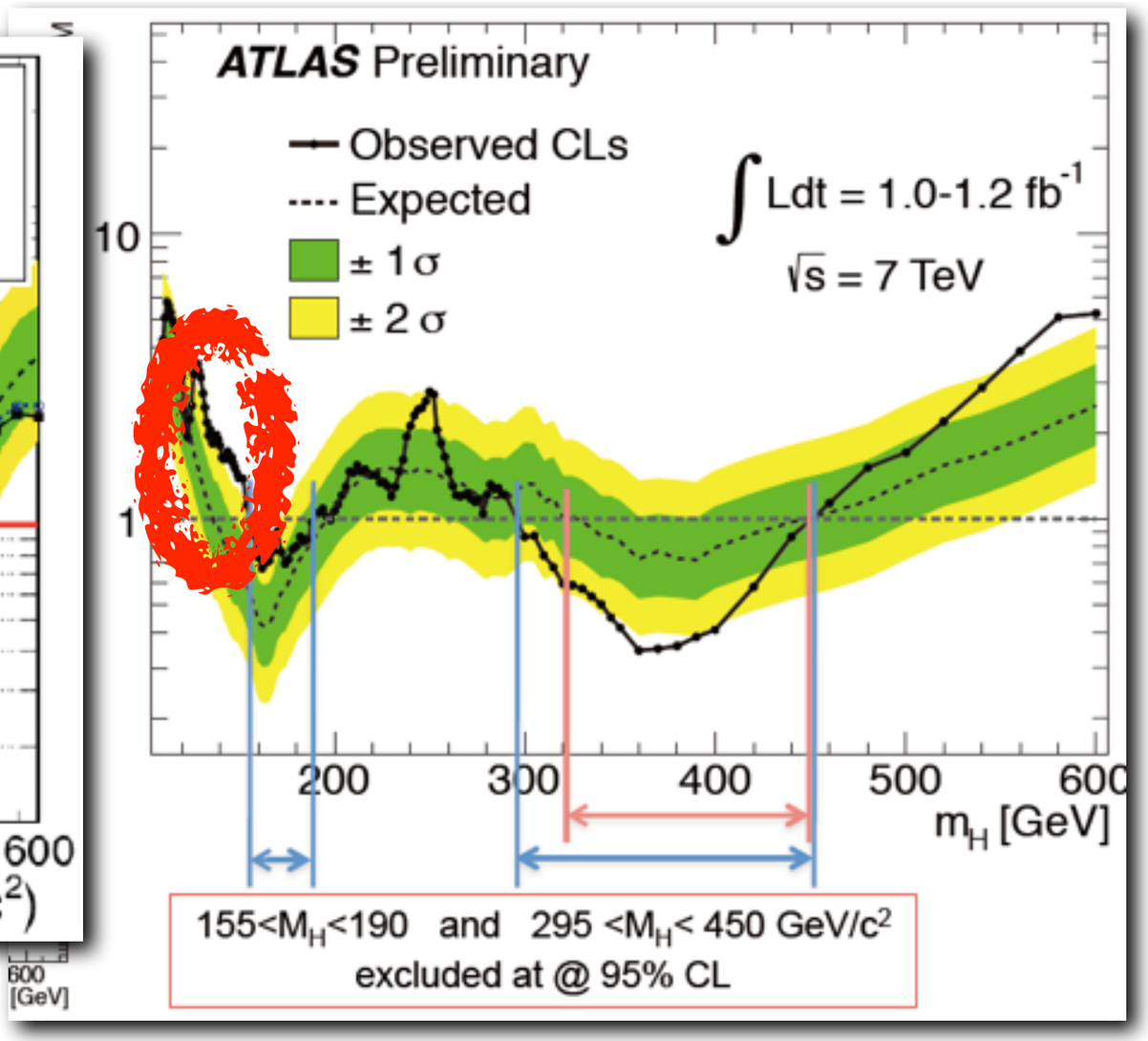




ヒッグス祭

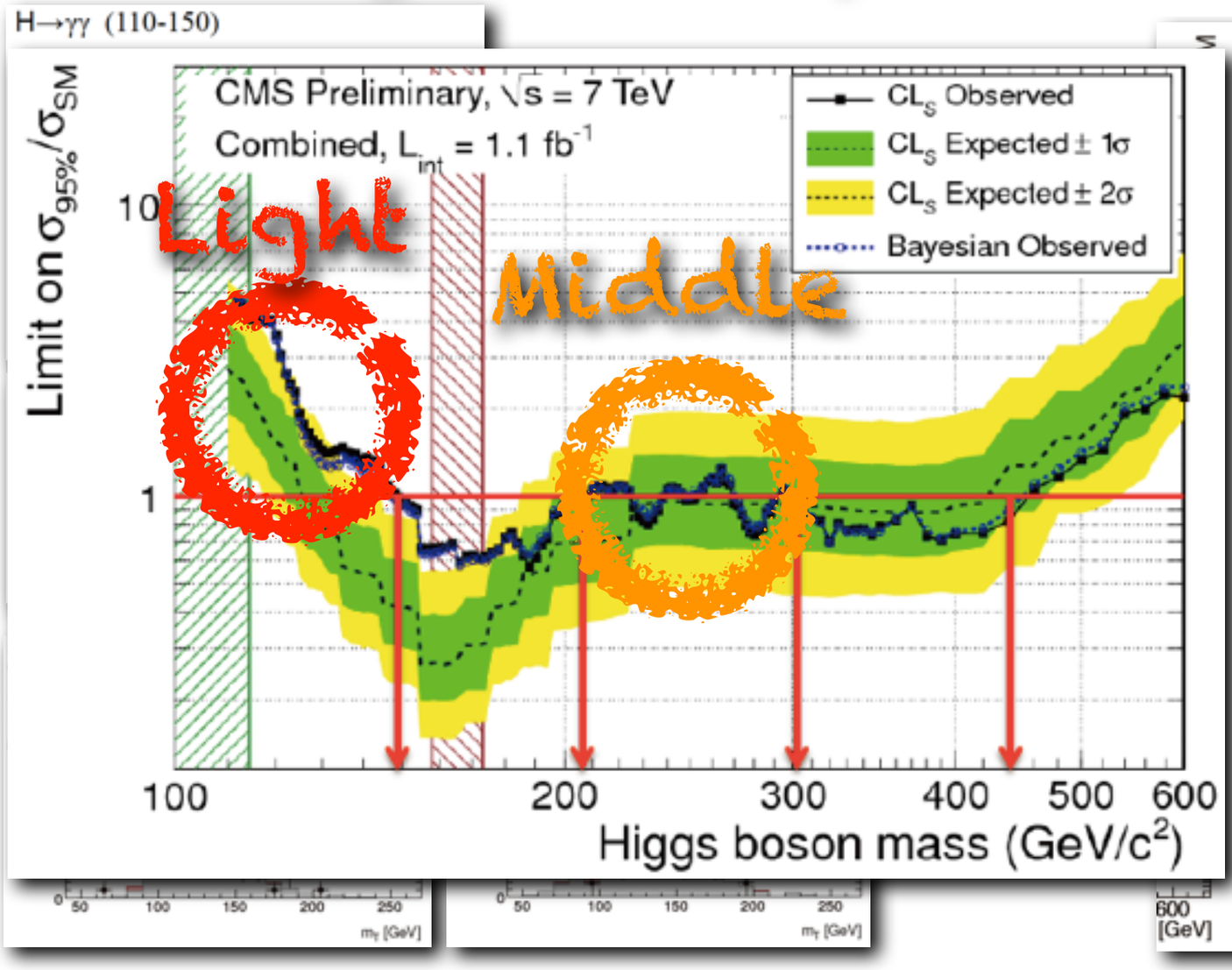
- Great step to prove that we are really living in a “superconducting” vacuum.

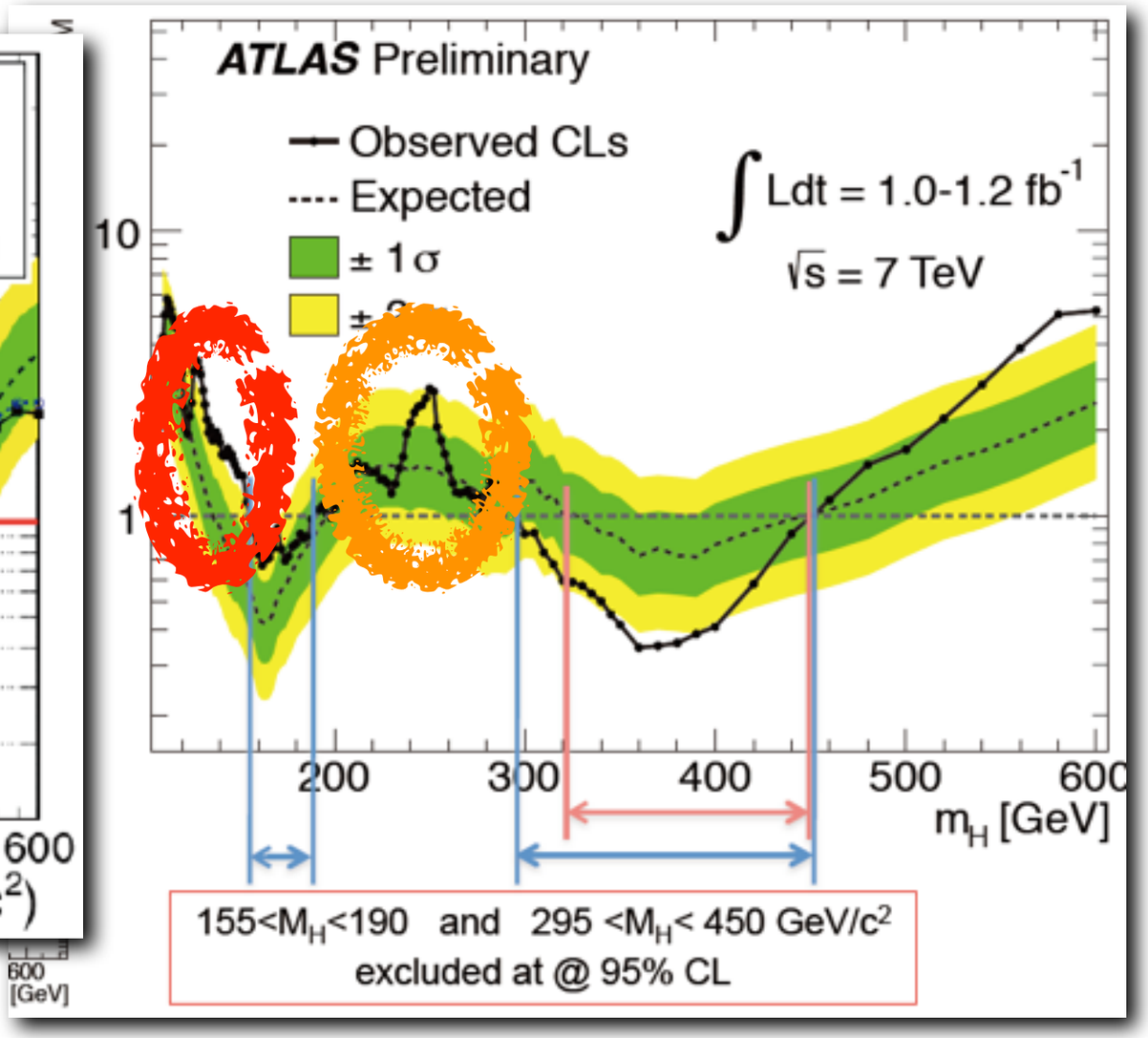




ヒッグス祭

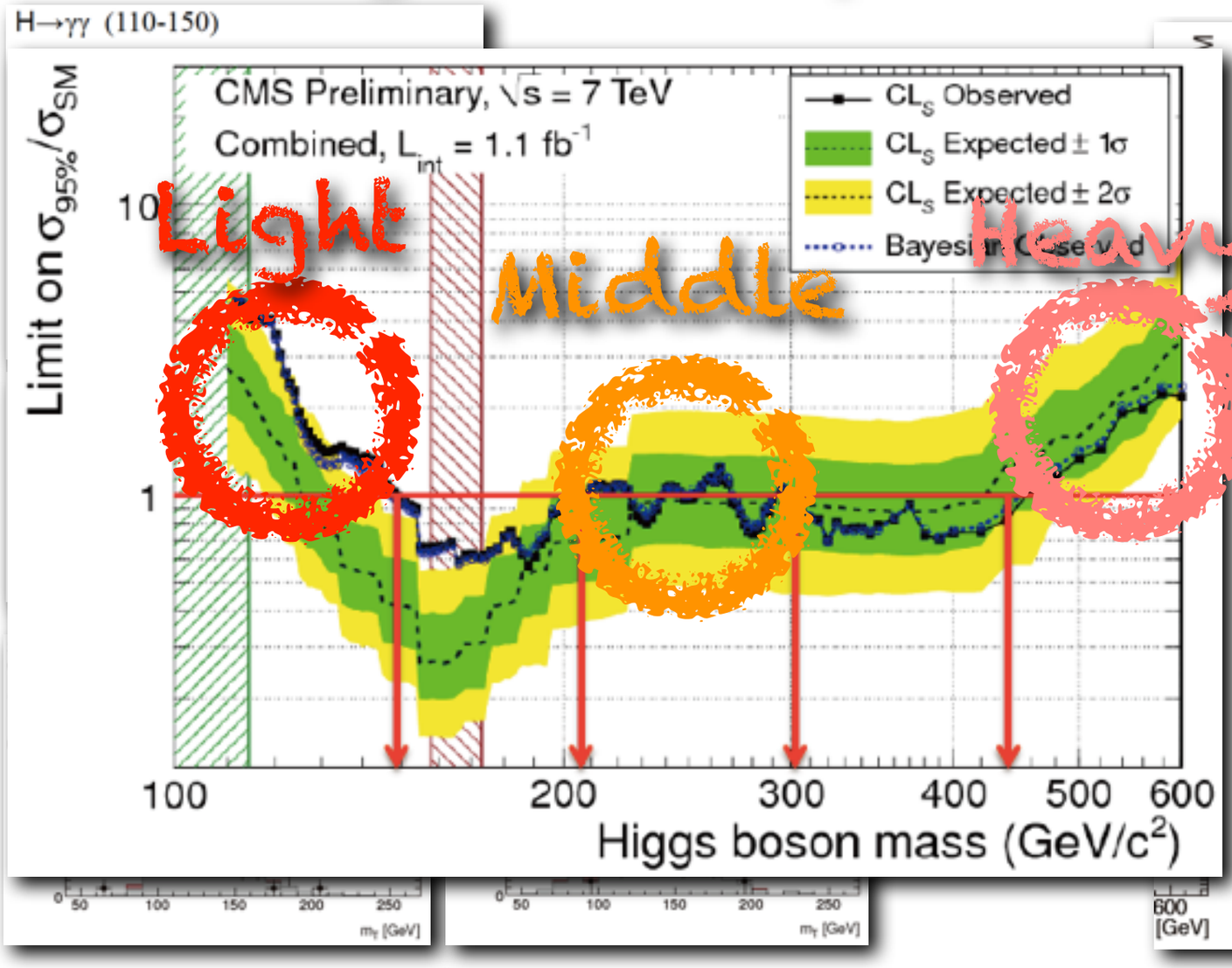
- Great step to prove that we are really living in a “superconducting” vacuum.

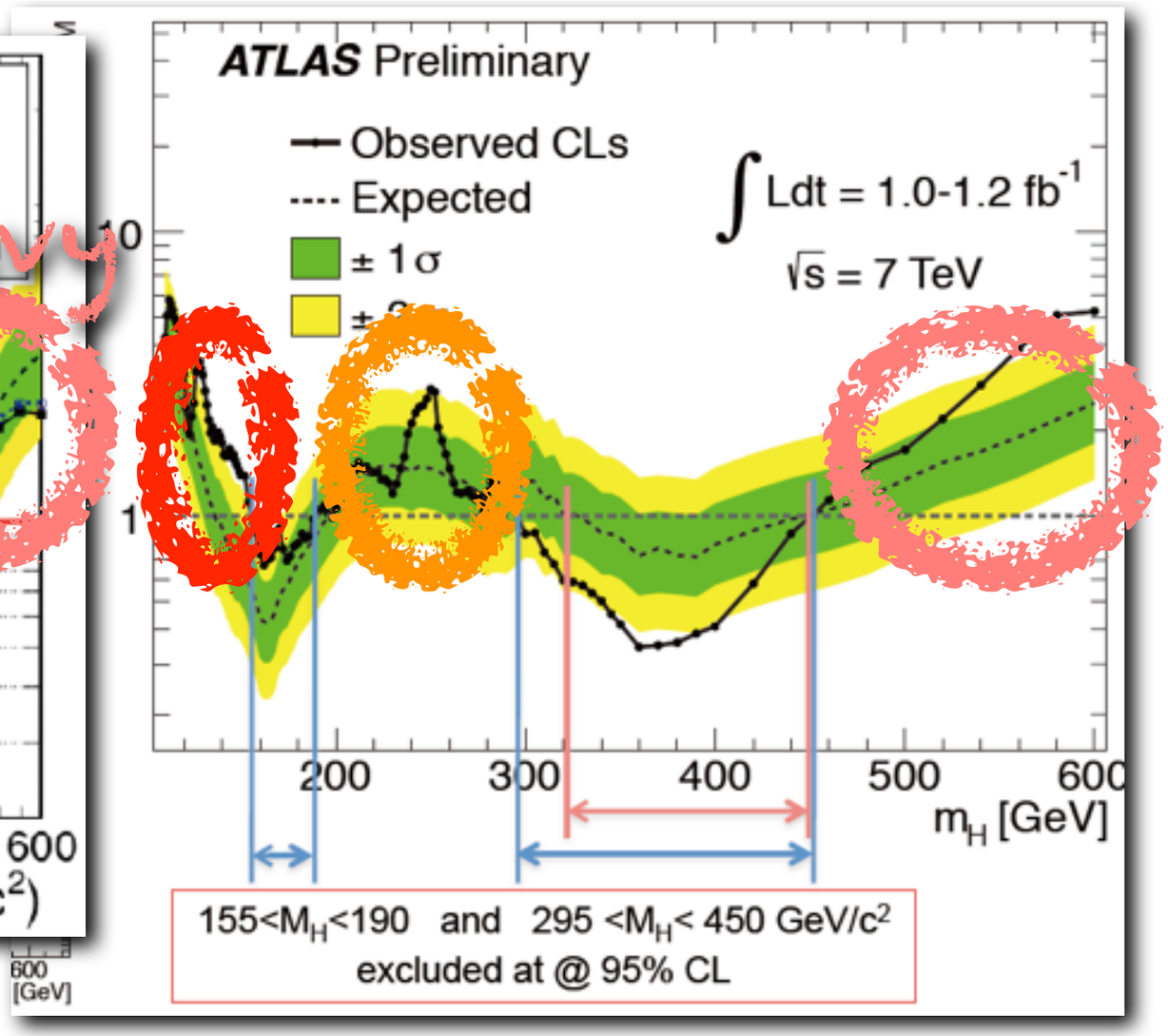




ヒッグス祭

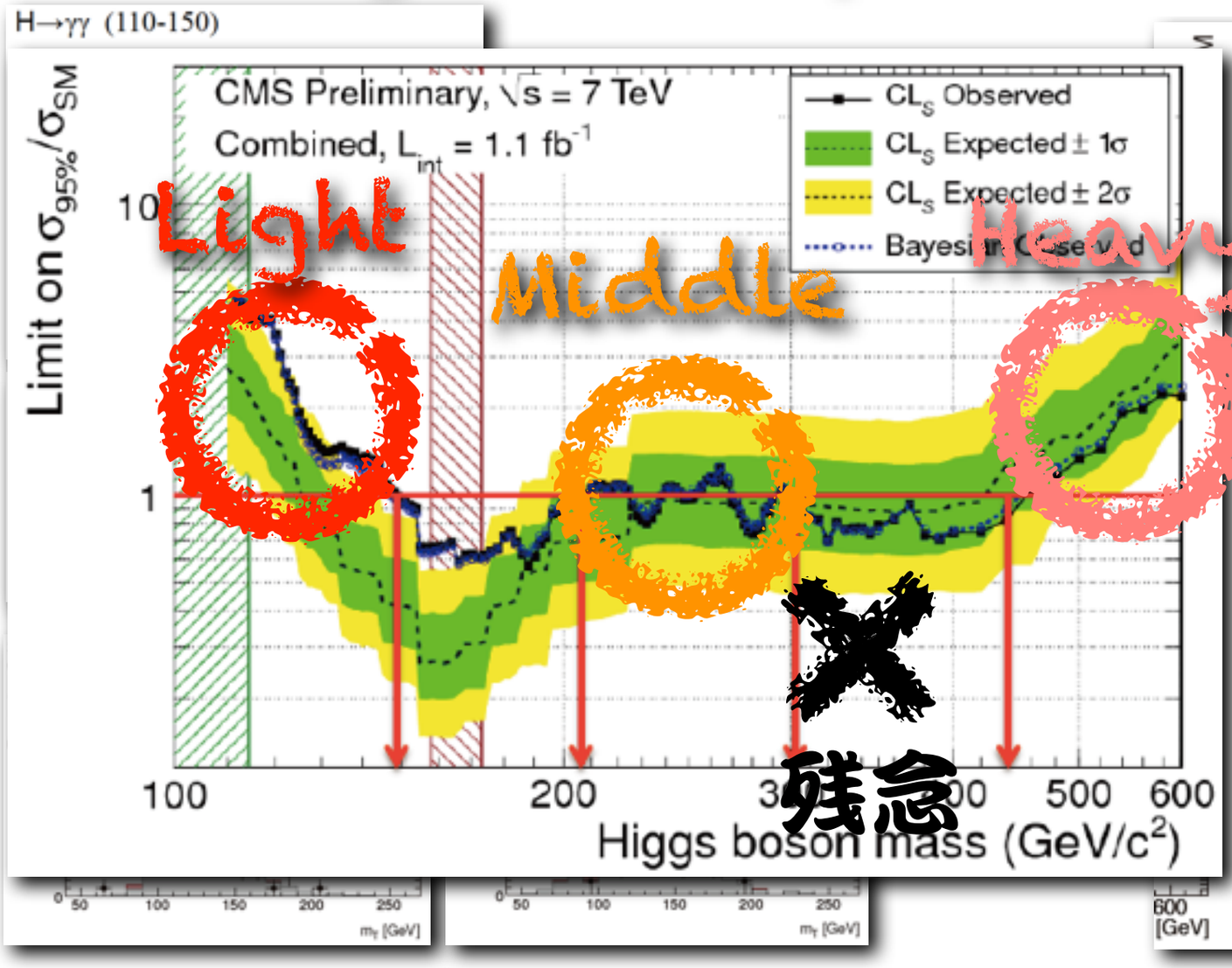
- Great step to prove that we are really living in a “superconducting” vacuum.

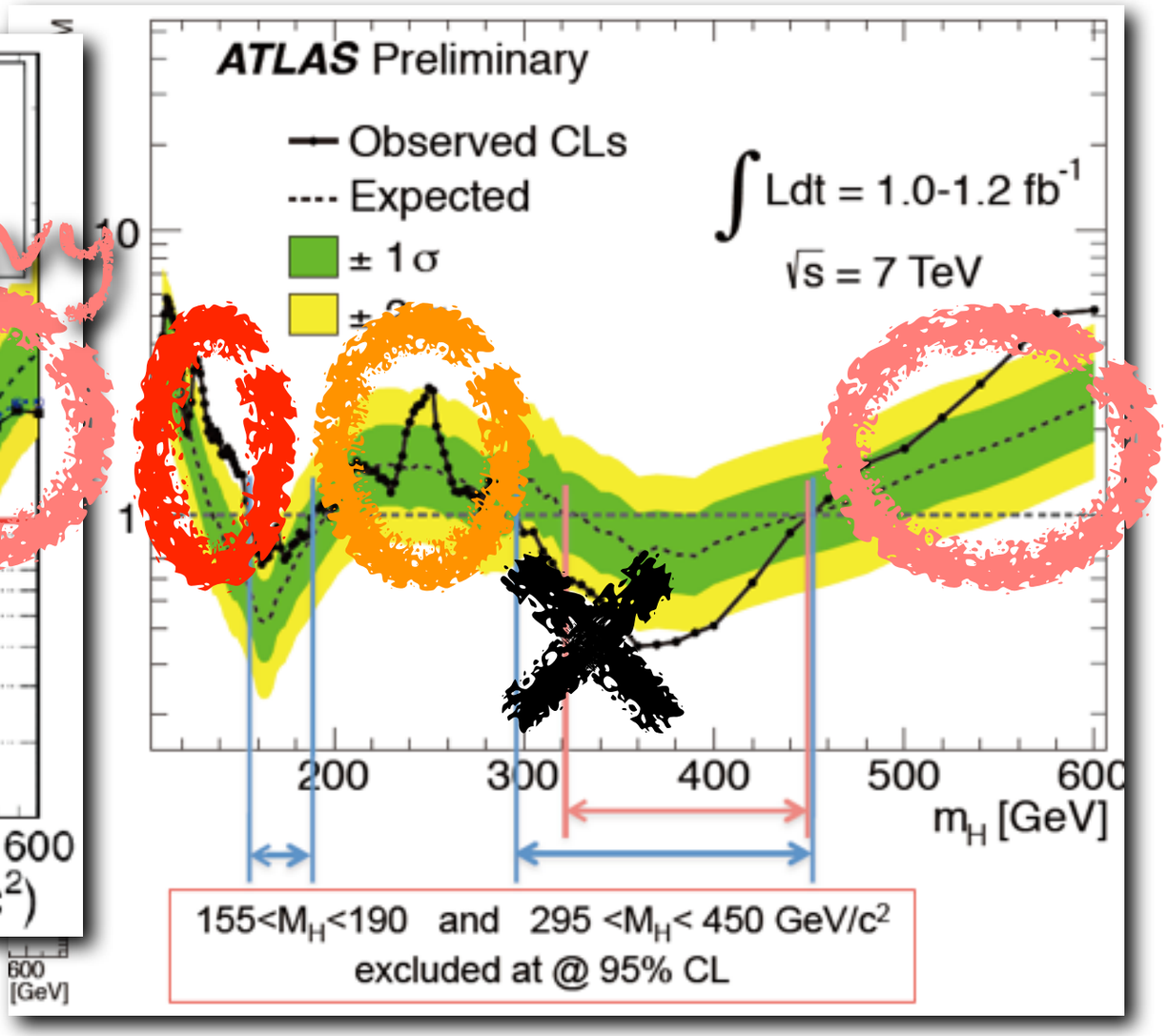




ヒッグス祭

- Great step to prove that we are really living in a “superconducting” vacuum.

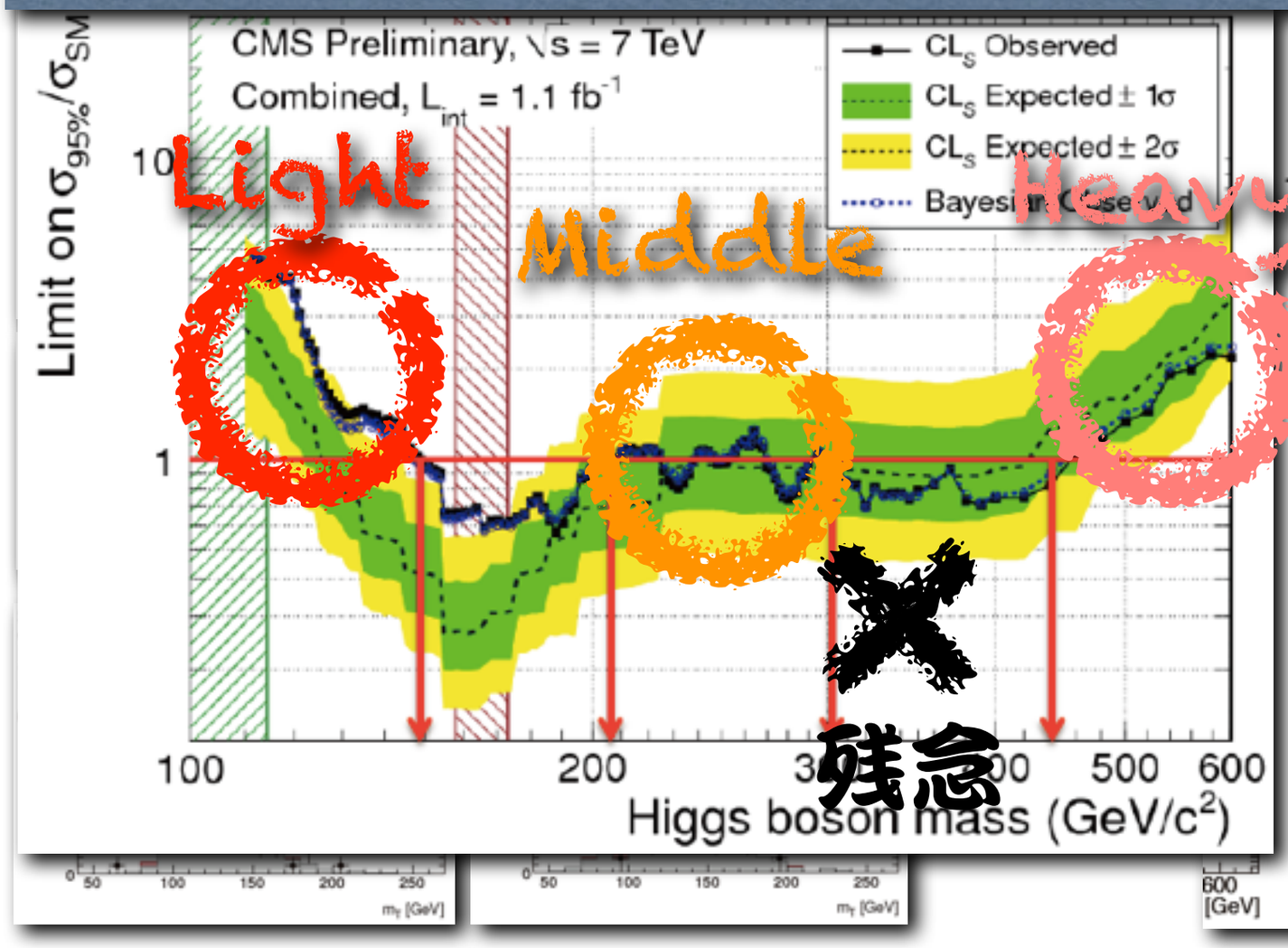


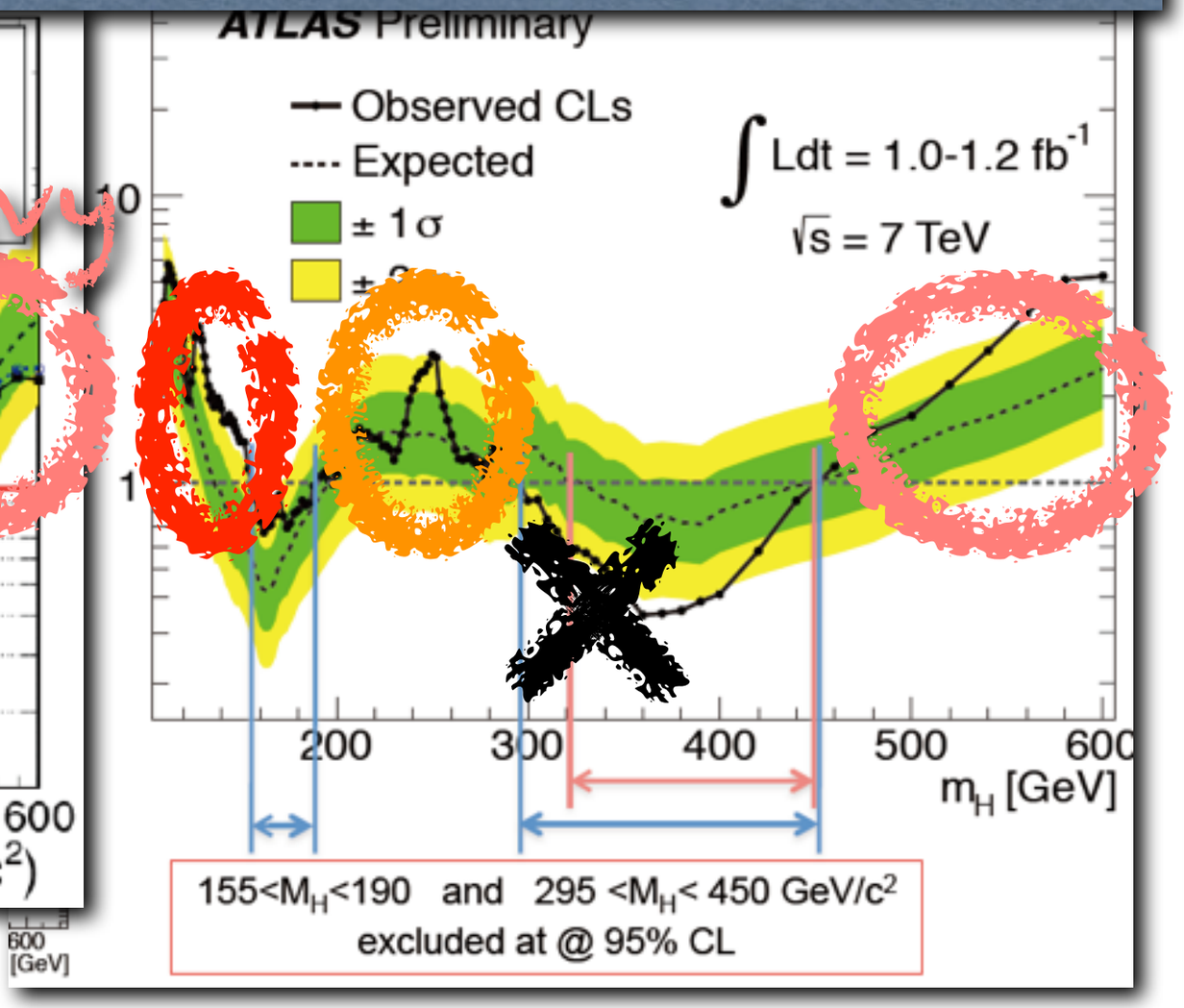


ヒッグス祭

We bet on middle & heavy regions:

200GeV < M_H < 300GeV, 500GeV < M_H





ヒッグス祭

We bet on middle & heavy regions:

$200\text{GeV} < M_H < 300\text{GeV}$, $500\text{GeV} < M_H$

(保険: For light Higgs, $M_H < 140\text{GeV}$, we got by far the strongest collider bound: $M_{KK} > 700\text{GeV}$ in mUED.)

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.)
- **Heavy Higgs** > 200GeV allowed (even favored).
  - ★ In weak-scale UED: $M_{KK} \sim v_{EW} = 246$GeV.
  - ★ Due to KK-top loops in T-parameter. (shown later)

So what is UED?

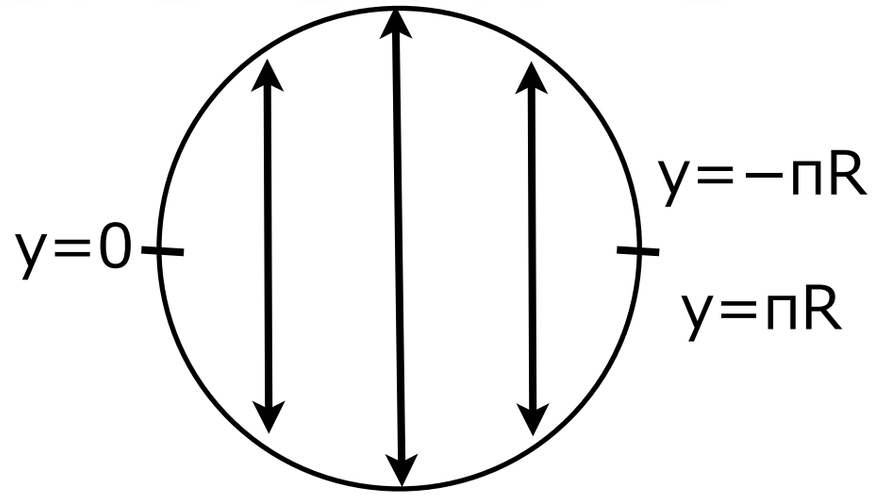
- All SM fields live in higher dimensions.
  - ★ Compactified within ~am.
- KK modes for each SM mode.
  - ★ Different masses, same charges.
- Higgs as zero mode.
  - ★ EWSB by bulk Higgs potential.
    - ✴ Except for Dirichlet Higgs model. [Haba, KO, Takahashi, 11]

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

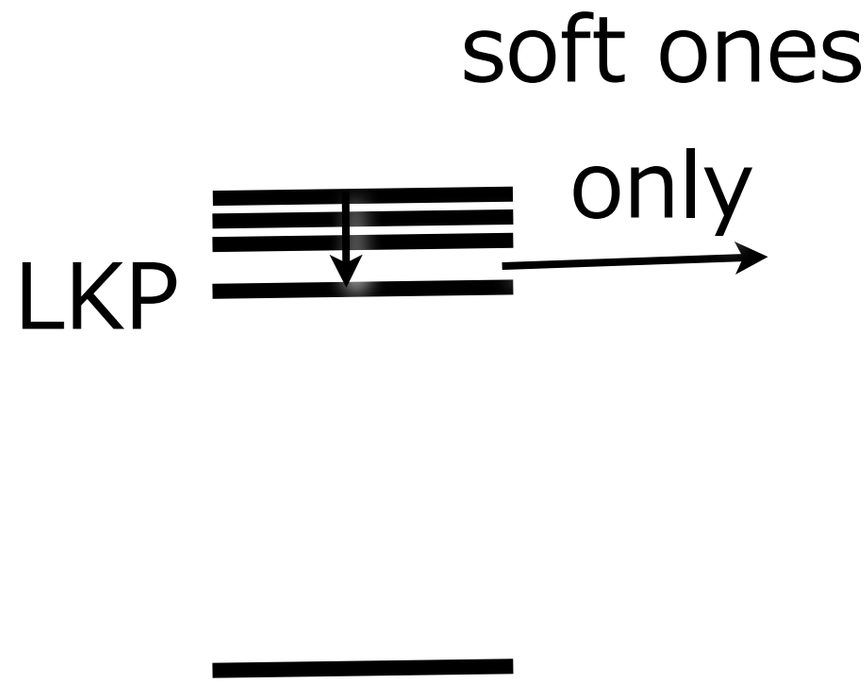
- Simple UEDs (of y~y+2πR type) require **orbifolding** (like −y~y) to have chiral fermions.



★ Resulting in orbifold **fixed point** (e.g. at y=0).

★ 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.

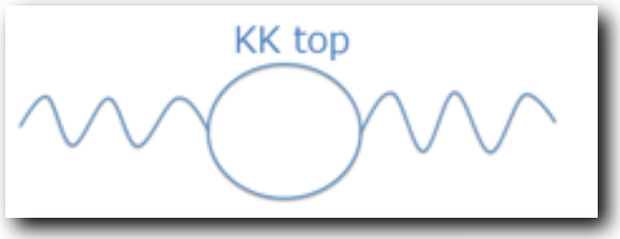
Can we have a UED signal independent of such detailed boundary structure?

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:

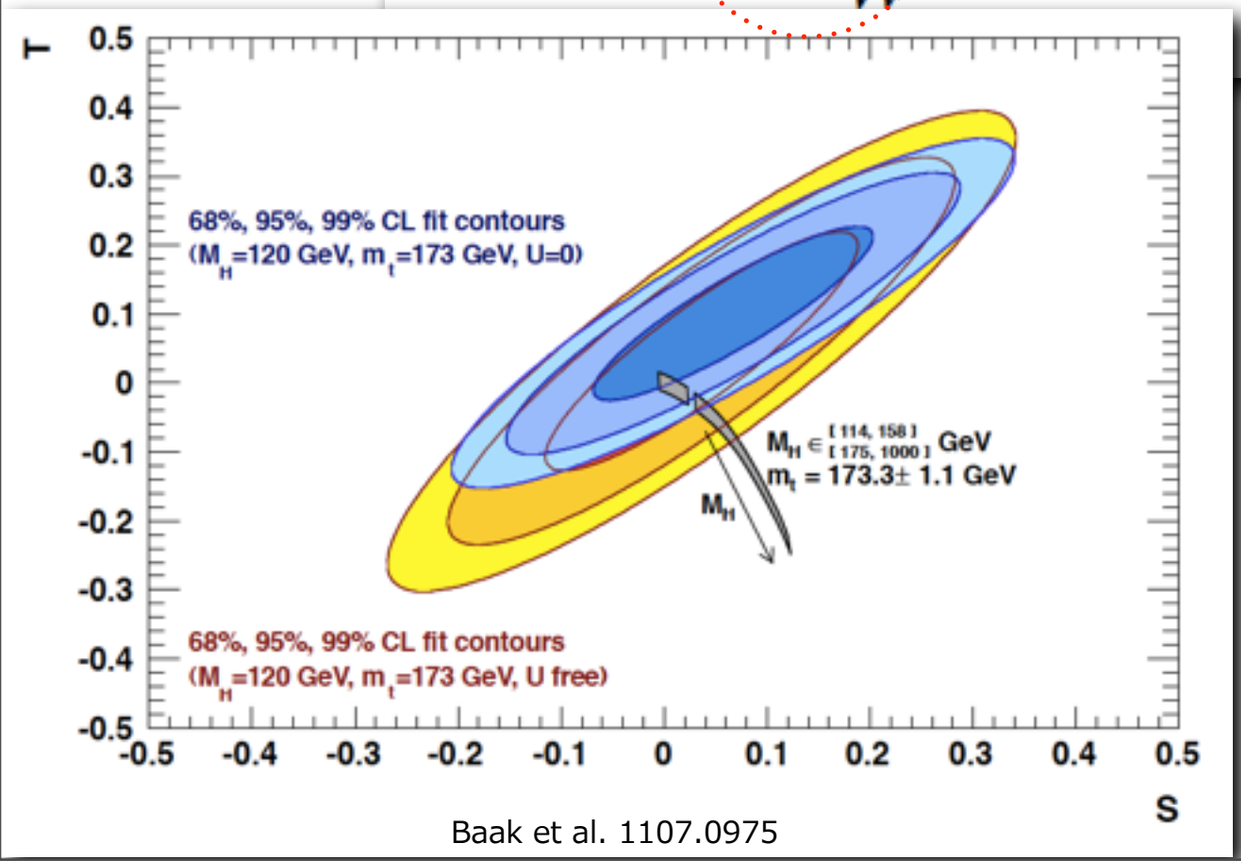
$$S \simeq \frac{1}{6\pi}\log\frac{m_H}{m_{H,\mathrm{ref}}} + \frac{1}{6\pi}\sum_{n=1}^{\infty}\frac{m_t^2}{n^2/R^2}$$

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



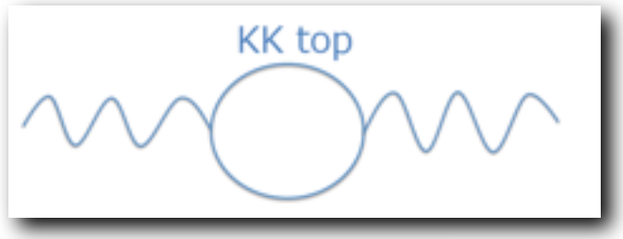
Baak et al. 1107.0975

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

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

KK-top loops in T-parameter

- KK-top contribution shift T-parameter positively.



★ E.g. in 5D mUED on S^1/Z_2:

0.05

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

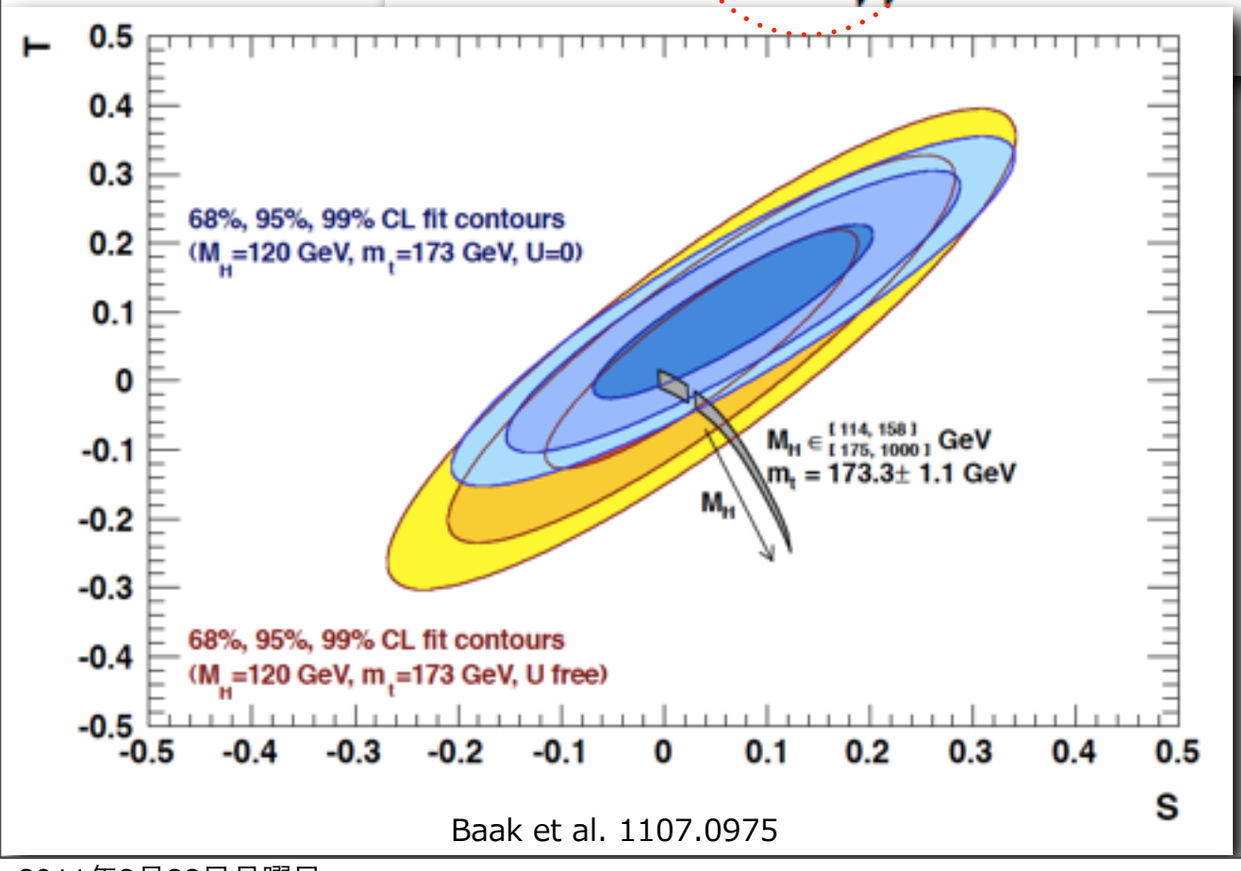
KK-top

0.15

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

KK-top

1.6



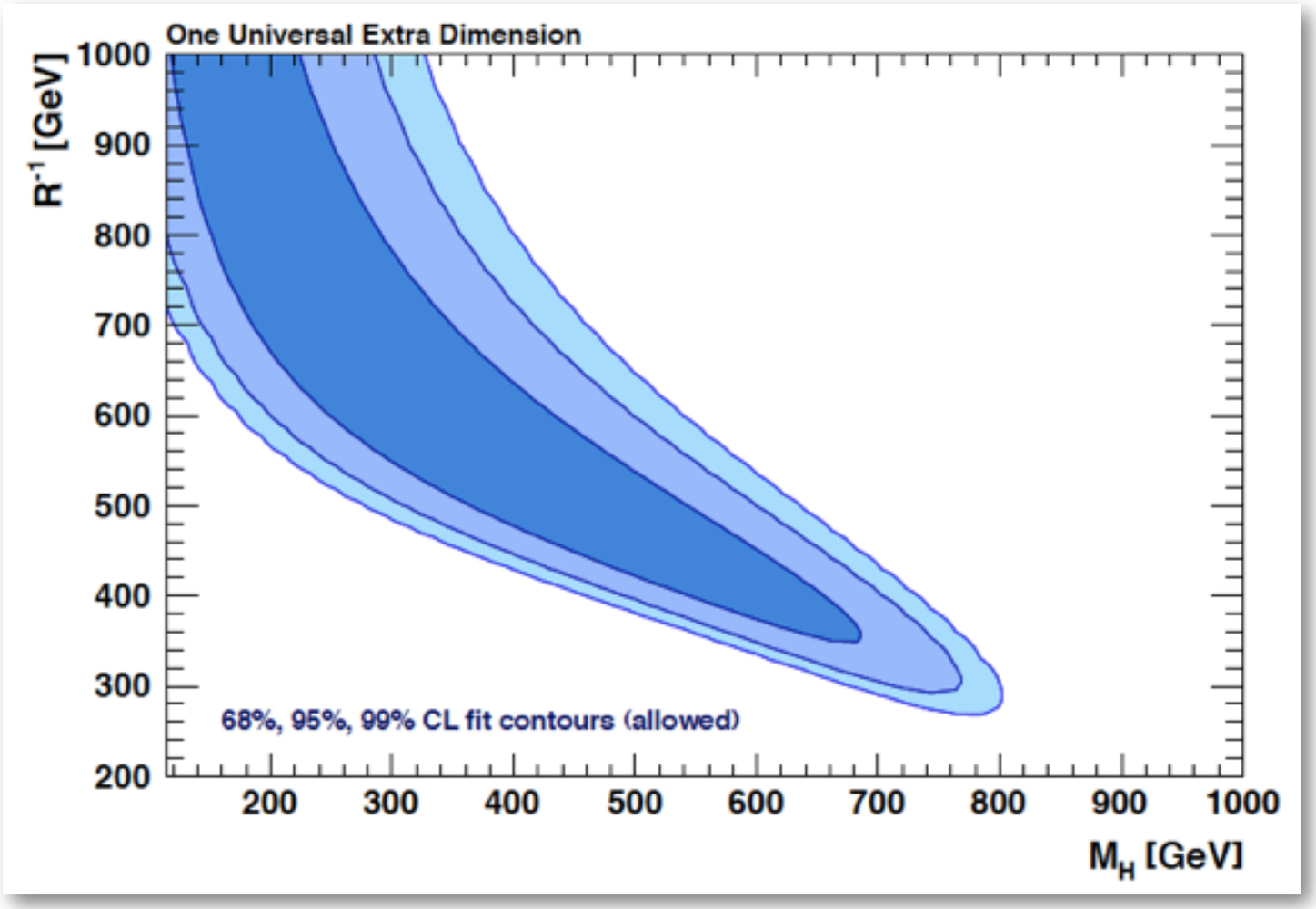
Baak et al. 1107.0975

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

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

Heavy Higgs favored in weak-scale UED

- E.g. in 5D mUED model on S^1/Z_2:



Baak et al.
1107.0975

- M_H>250GeV for M_{KK}<500GeV.

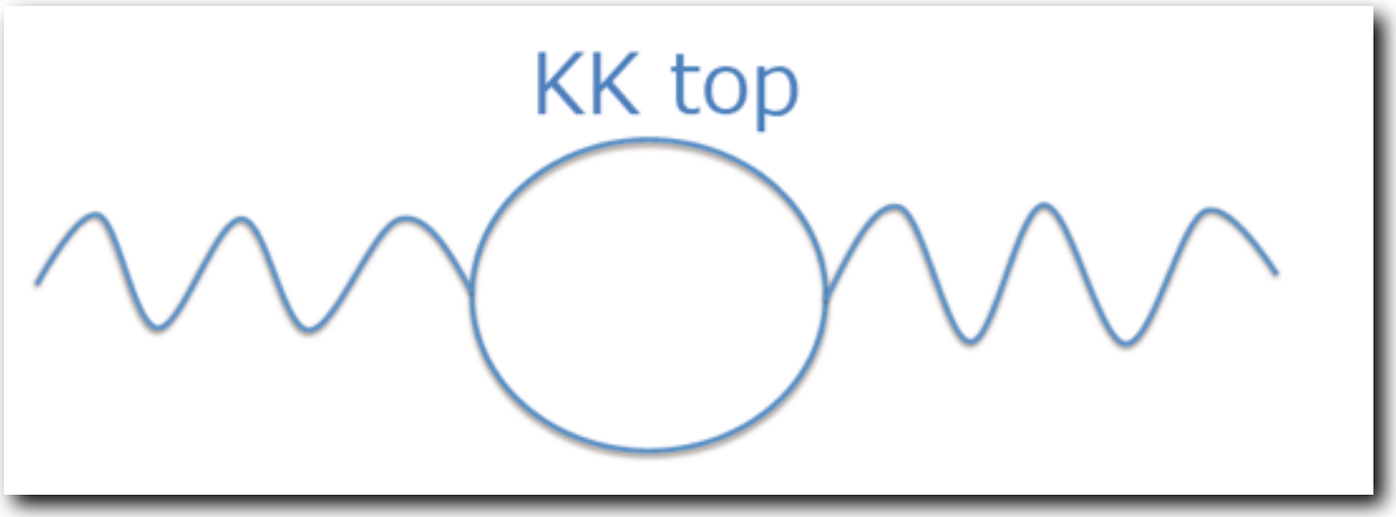
Heavy Higgs in UED models

- This is a general tendency.

★ KK top loops not only in 5D mUED.

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

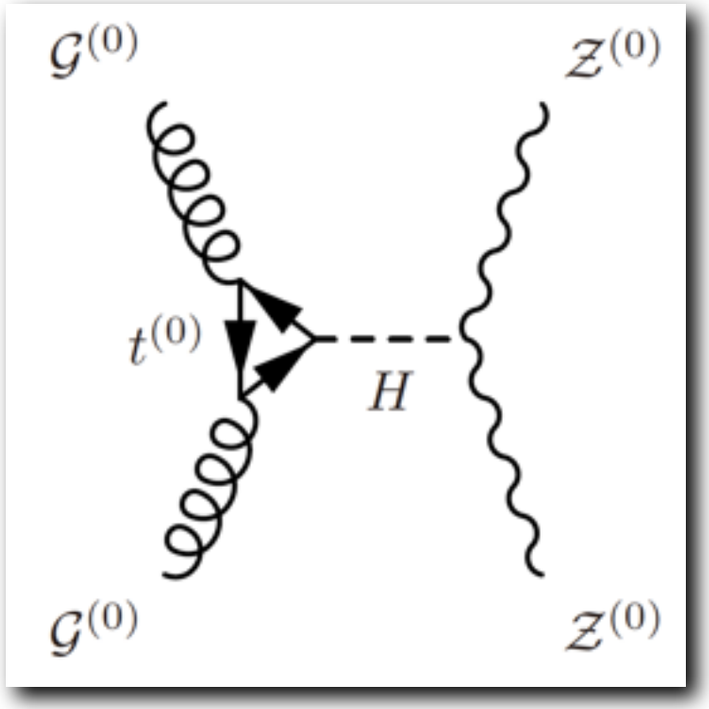
✴ (That comes from brane-localized Lagrangian.)



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**

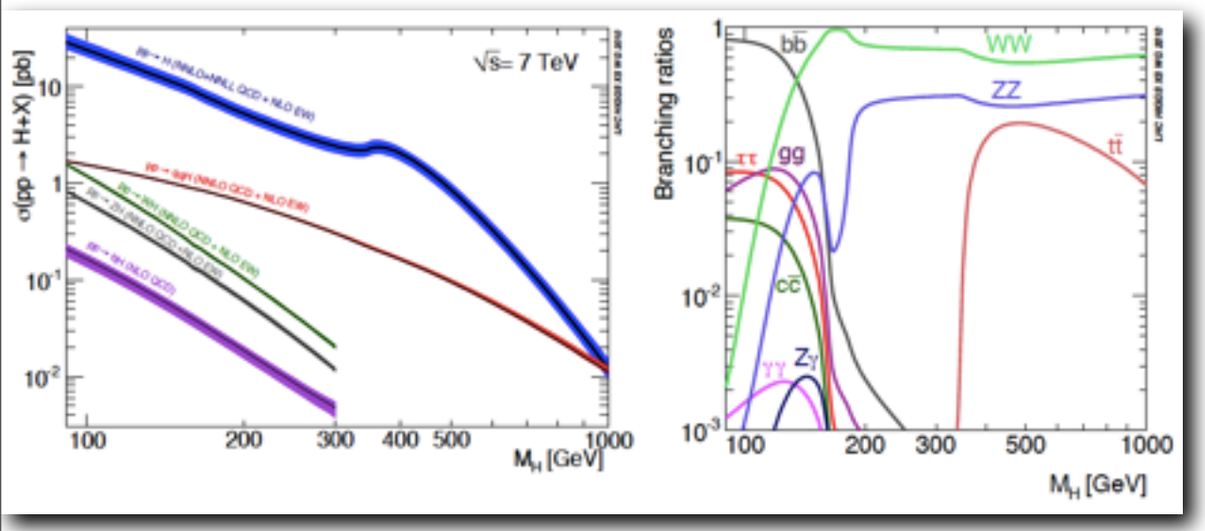
UED Higgs at LHC



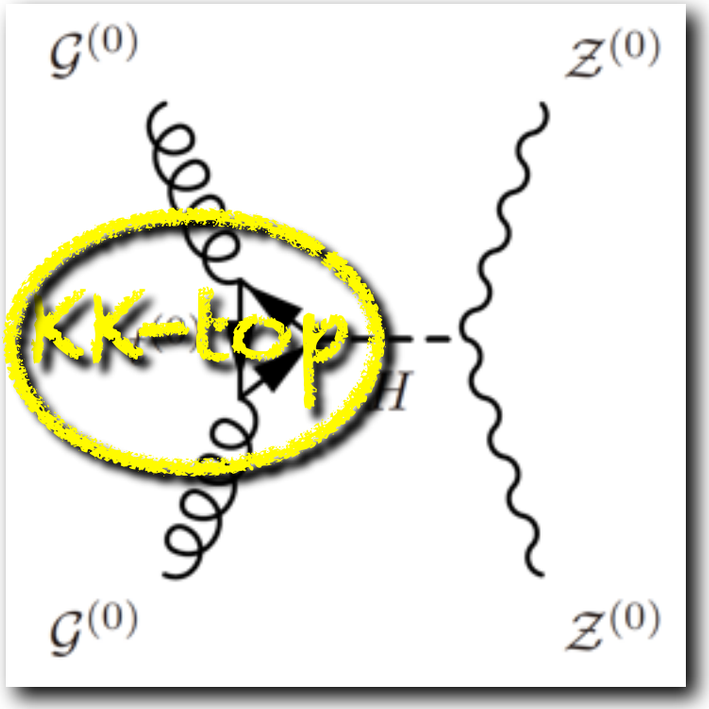
- gg→H production enhanced since **loop**-produced.

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

SM figures



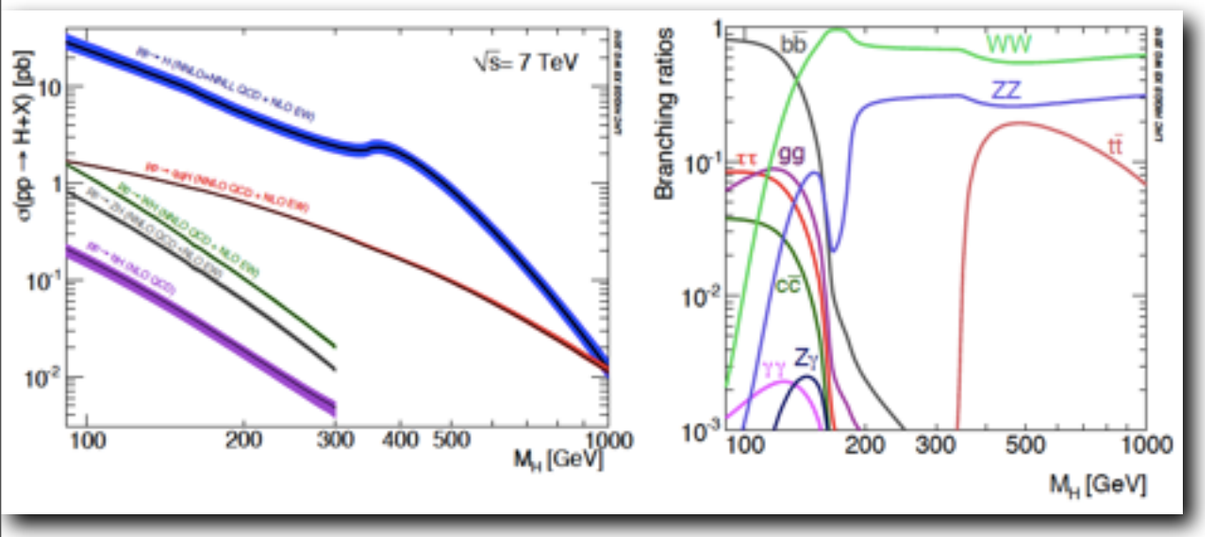
UED Higgs at LHC



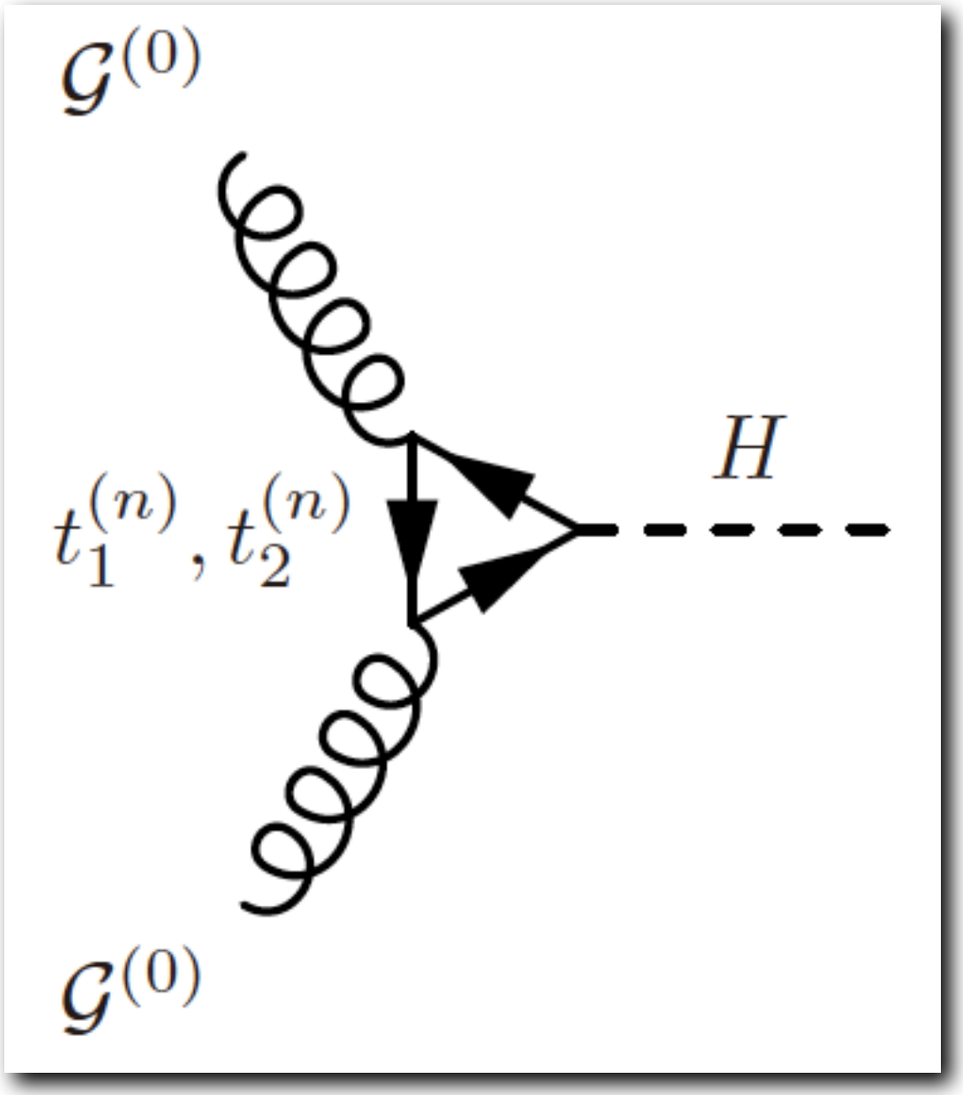
- gg→H production enhanced since **loop**-produced.

- Decay 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.

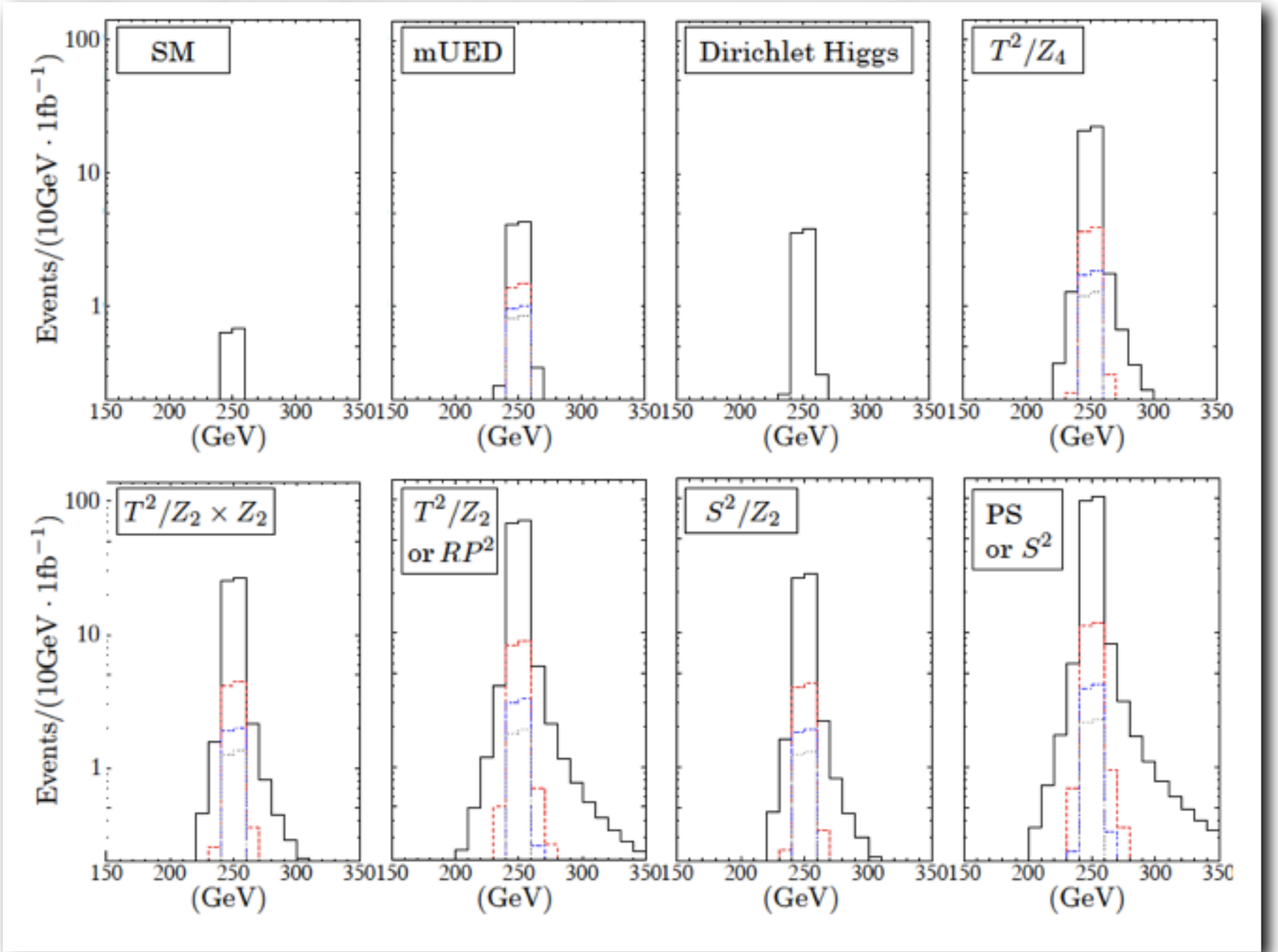
Results

2011年8月22日月曜日

$ZZ \to 4$ leptons
$M_H = 250$GeV

- 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).

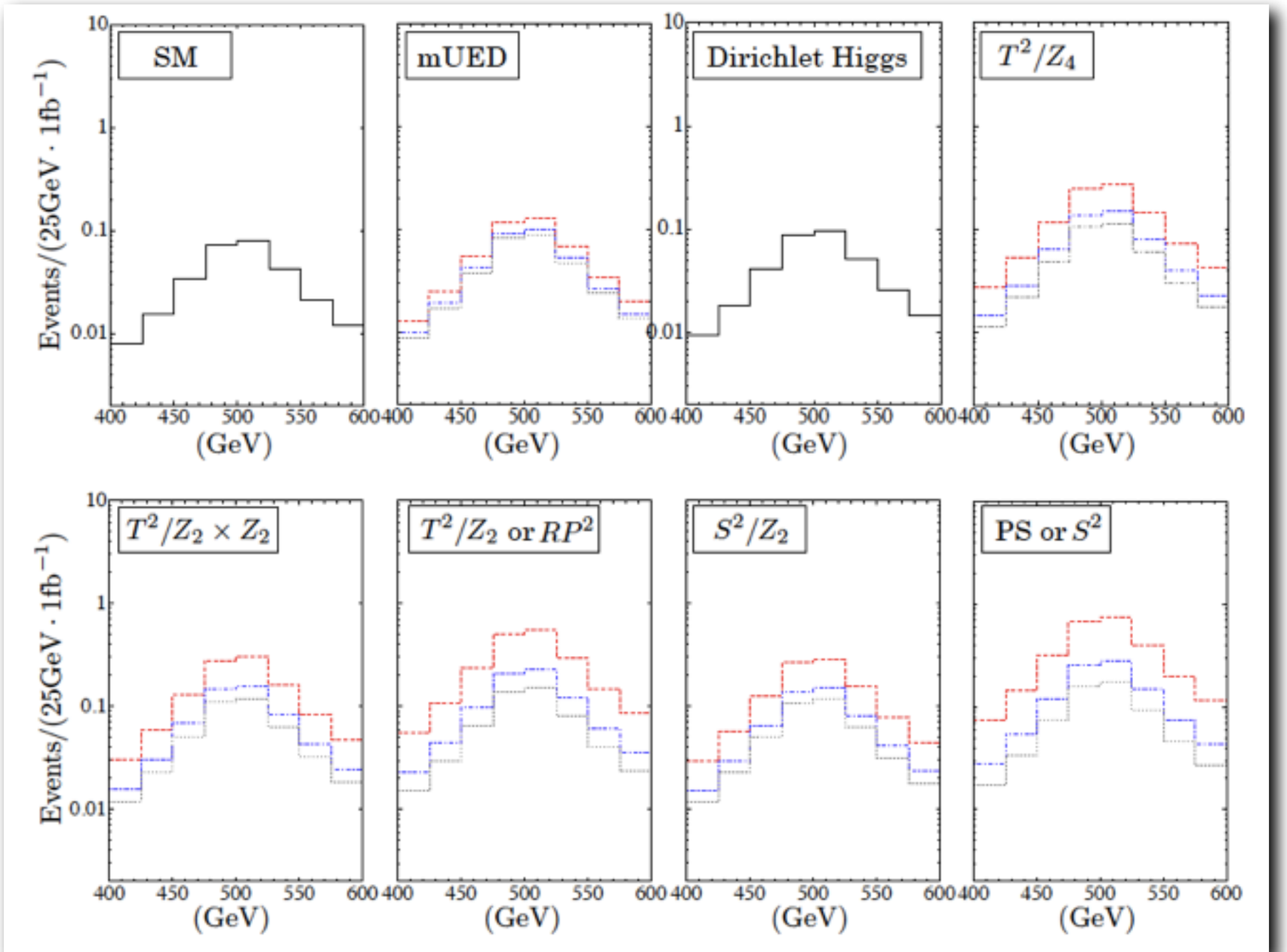
Nishiwaki, KO, Okuda, Watanabe
1108.1764

- 250GeV excess at ATLAS (consistent to CMS data) may be accounted for by UED.
- 10fb^{-1} would suffice to establish the resonance.

$ZZ \to 4$ leptons
$M_H = 500$GeV

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

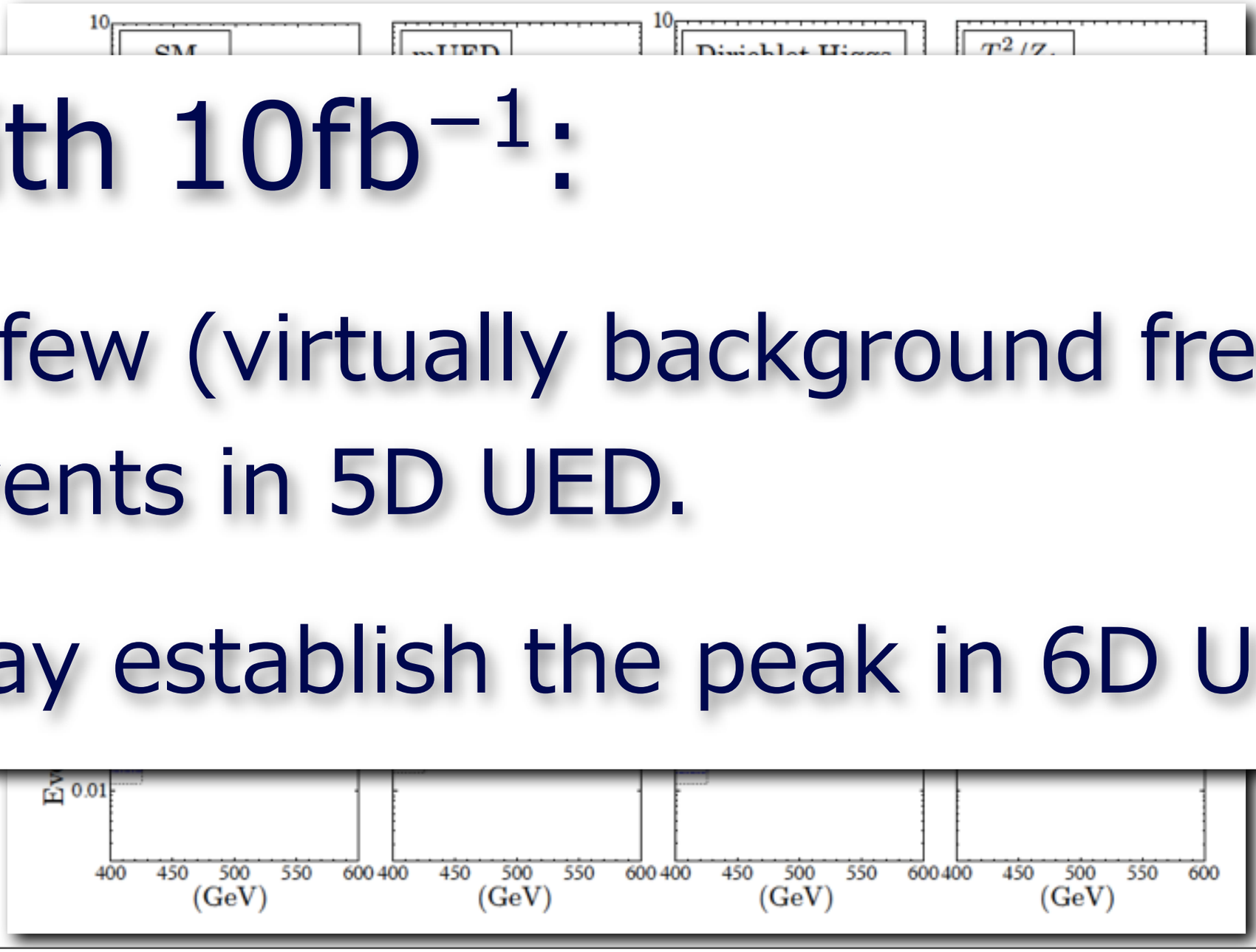
Nishiwaki, KO, Okuda, Watanabe
1108.1764



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



- With 10fb^{-1}:

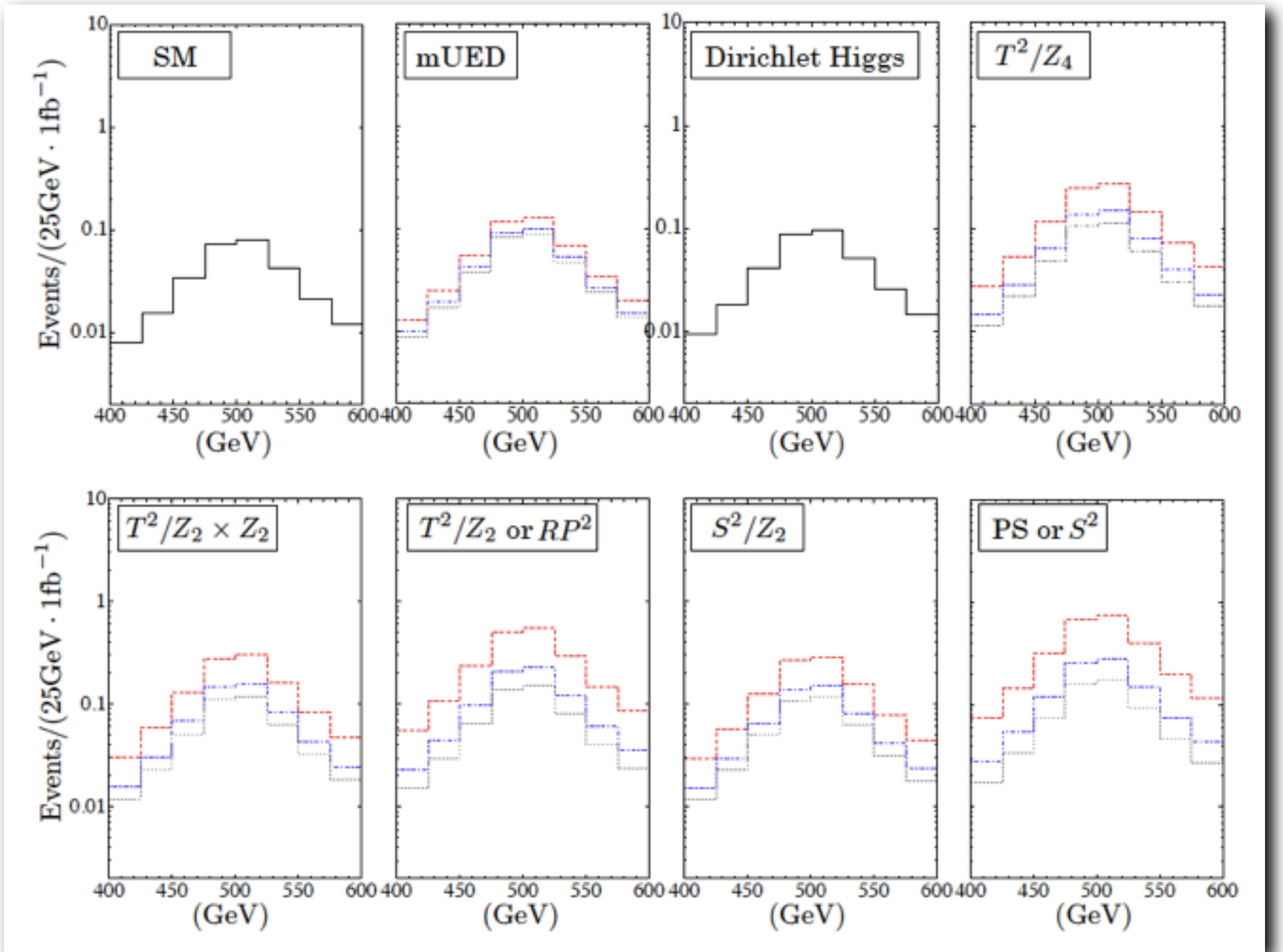
★A few (virtually background free) events in 5D UED.

★May establish the peak in 6D UED.

$ZZ \to 4$ leptons
$M_H = 700$GeV

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

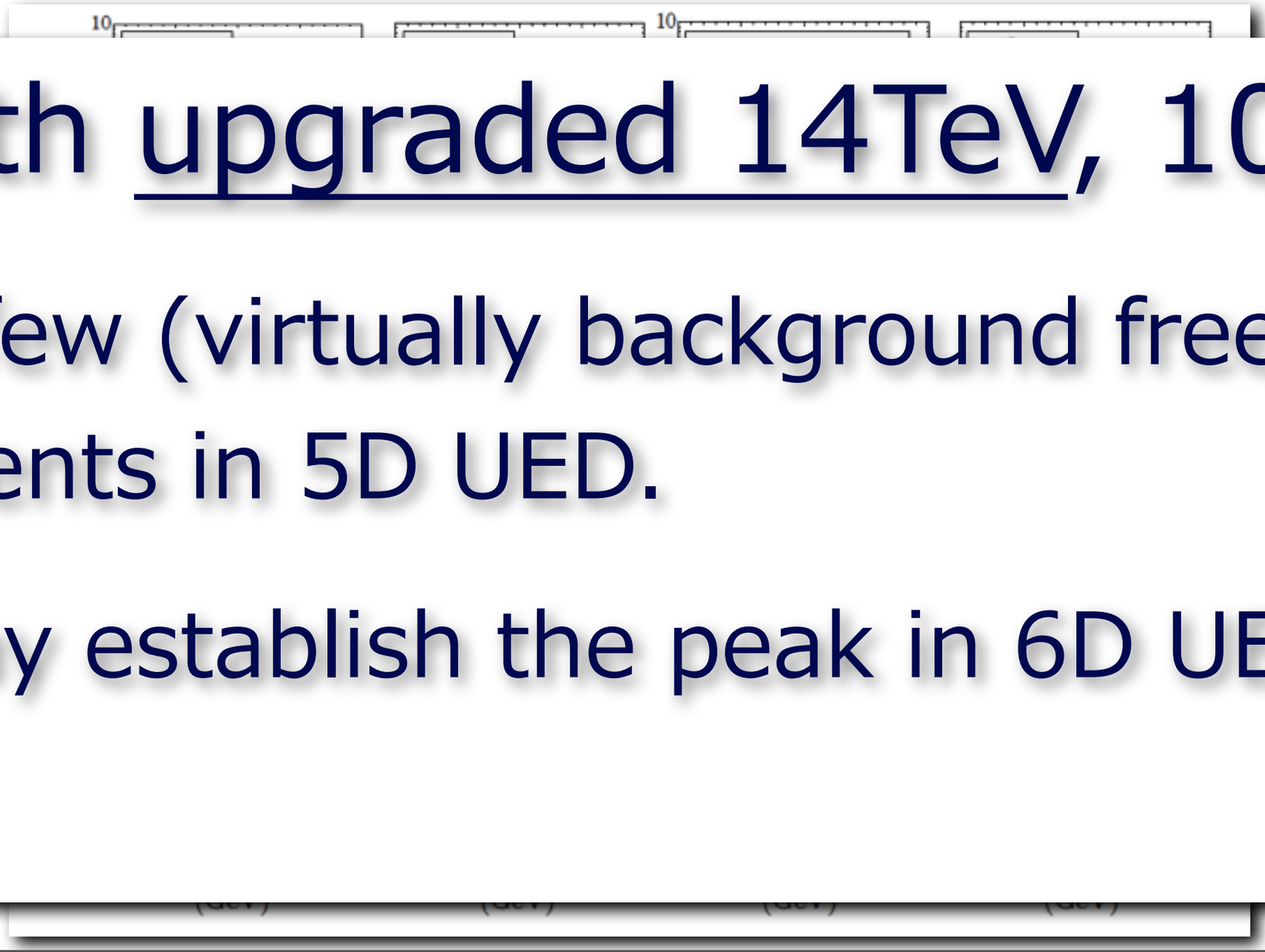
Nishiwaki, KO, Okuda, Watanabe
1108.1764



$ZZ \to 4$ leptons
$M_H = 700$GeV

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

Nishiwaki, KO, Okuda, Watanabe
1108.1764

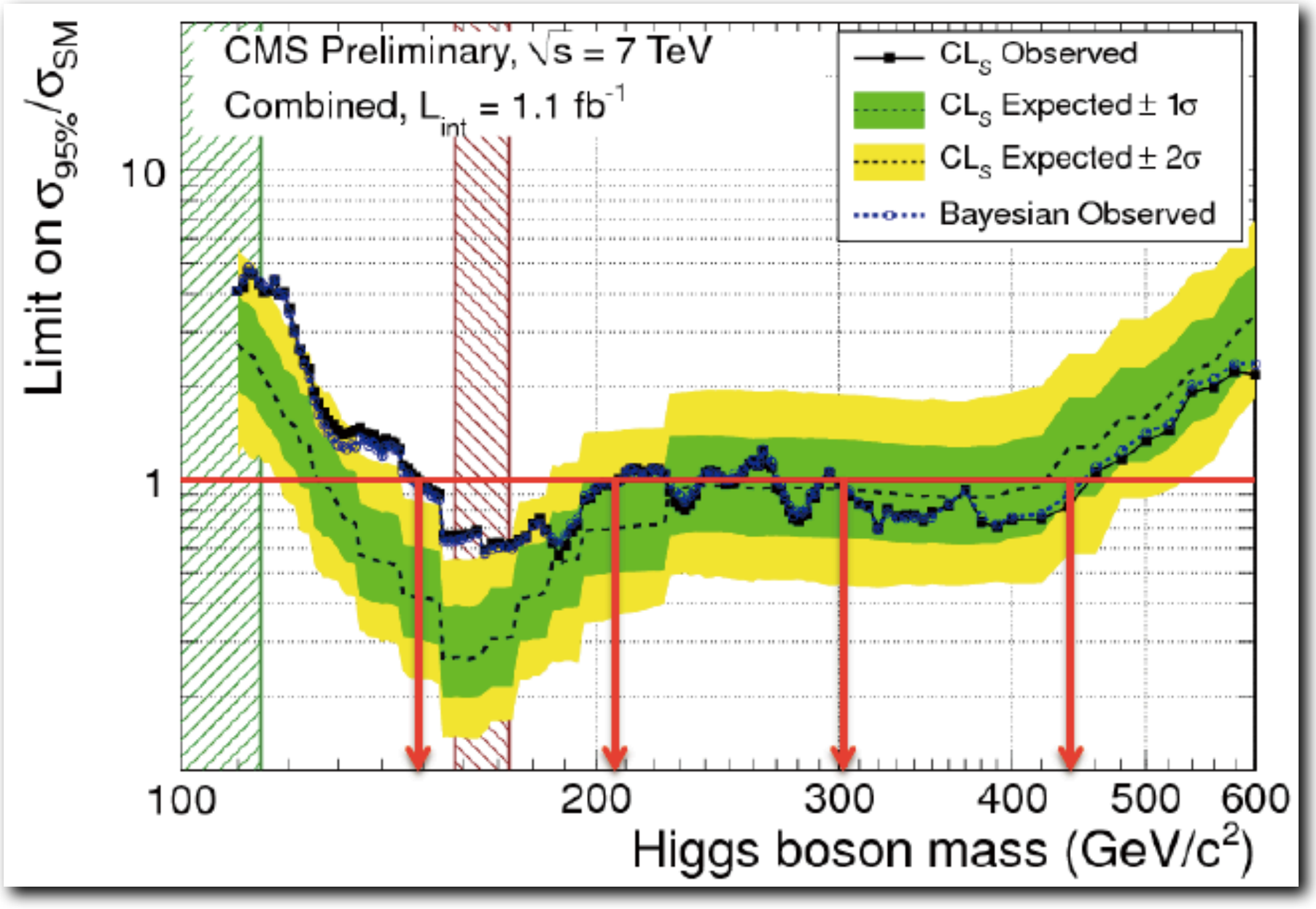


- With upgraded 14TeV, 10fb^{-1}:

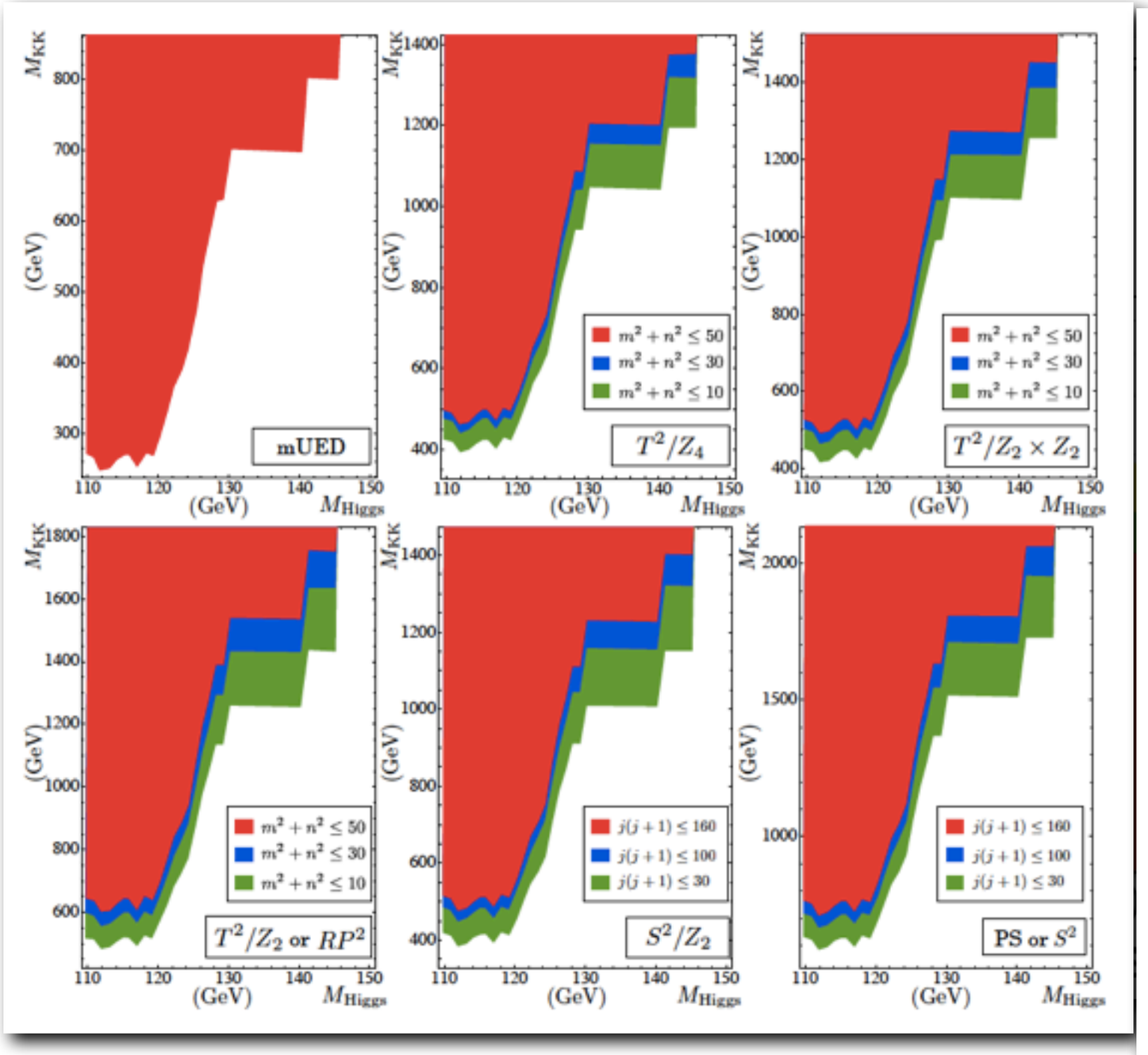
★A few (virtually background free) events in 5D UED.

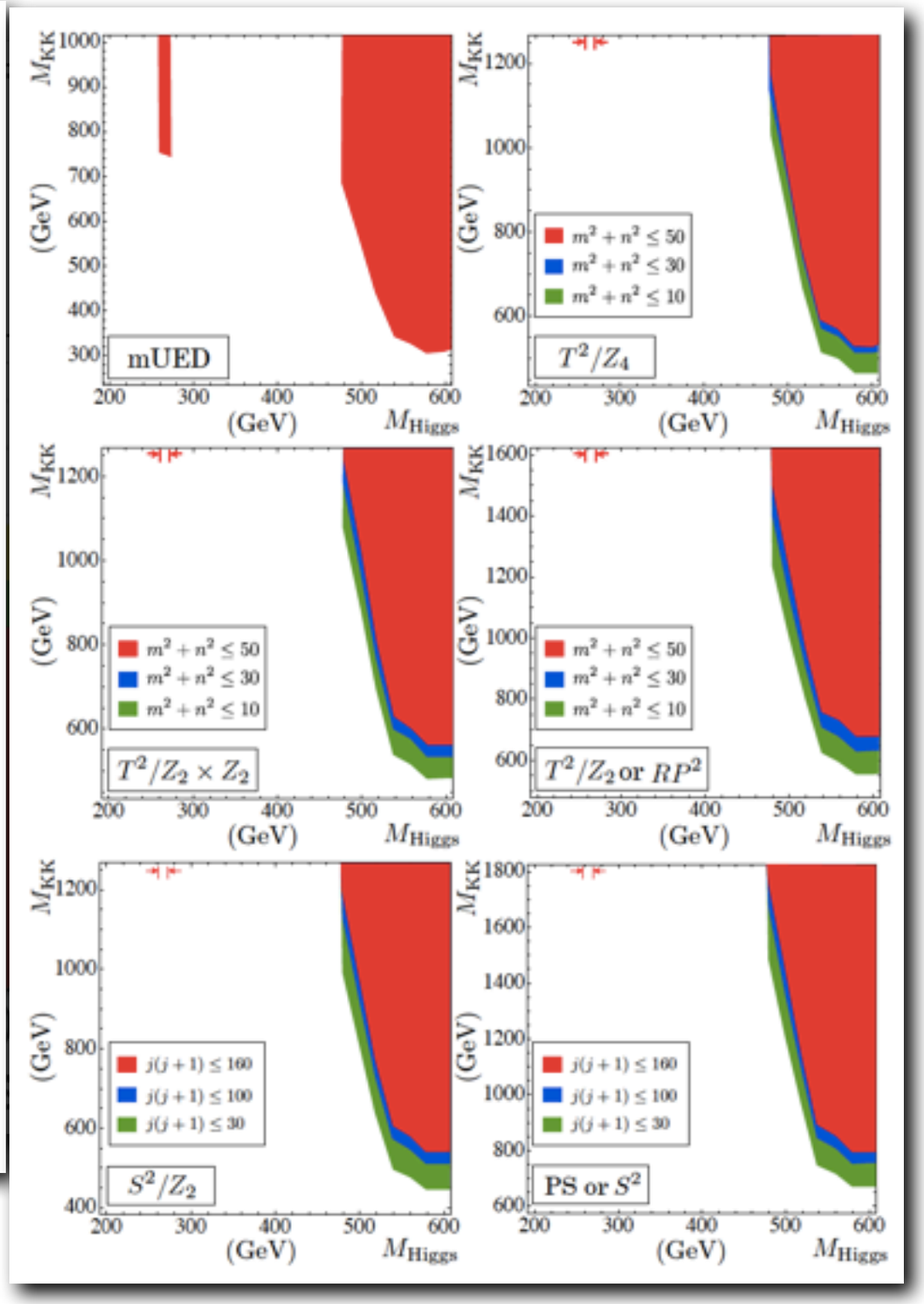
★May establish the peak in 6D UED.

Inclusive bound from Higgs production rate at CMS



Inclusive bound from Higgs production rate at CMS





Inclusive bound from Higgs production rate at CMS

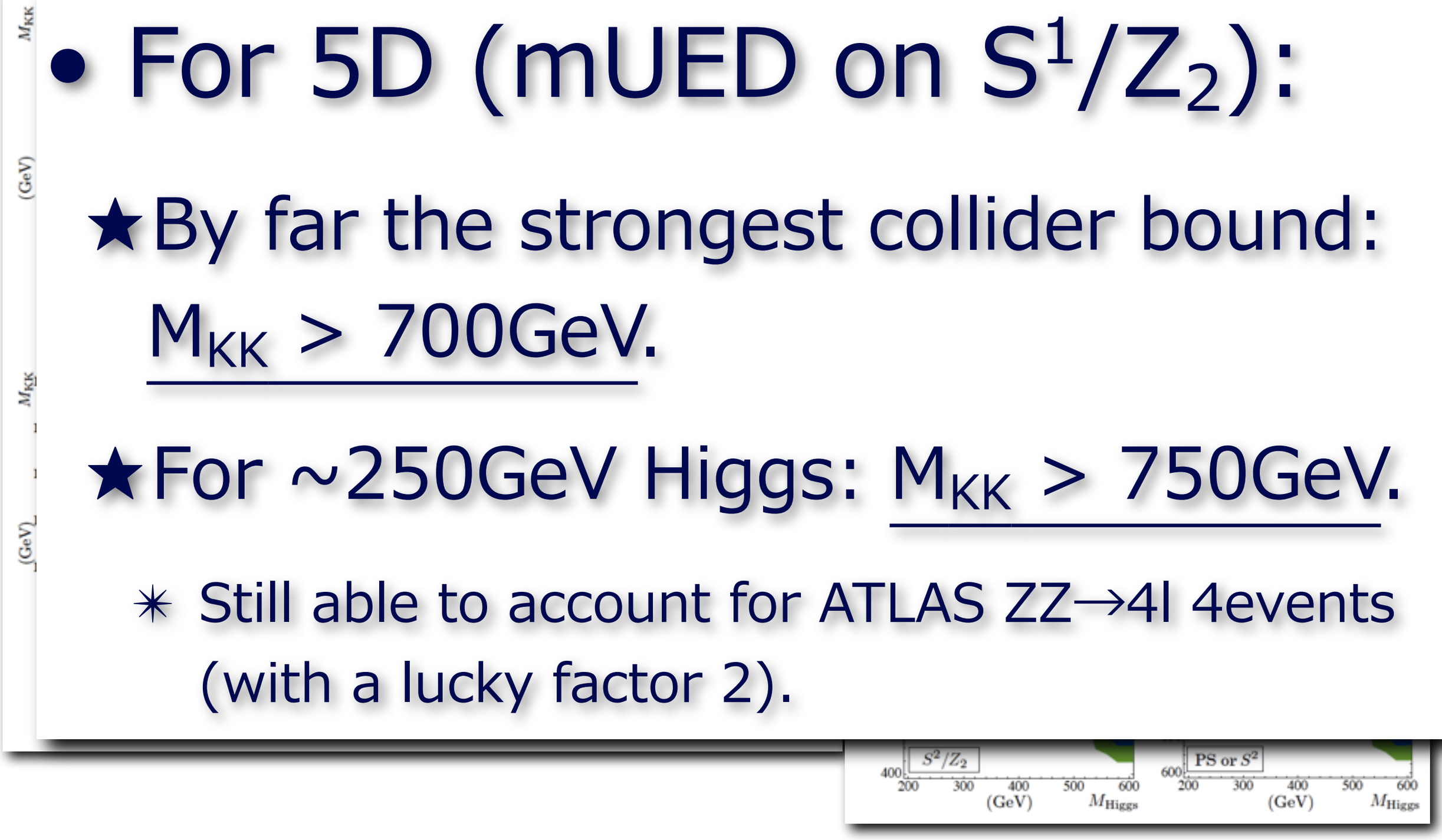
- For 5D (mUED on S^1/Z_2):

★By far the strongest collider bound:

$M_{KK} > 700GeV$.

★For ~250GeV Higgs: $M_{KK} > 750GeV$.

✳ Still able to account for ATLAS ZZ→4l 4events (with a lucky factor 2).



Inclusive bound from Higgs production rate at CMS

- Fo

★By

M_K

★Fo

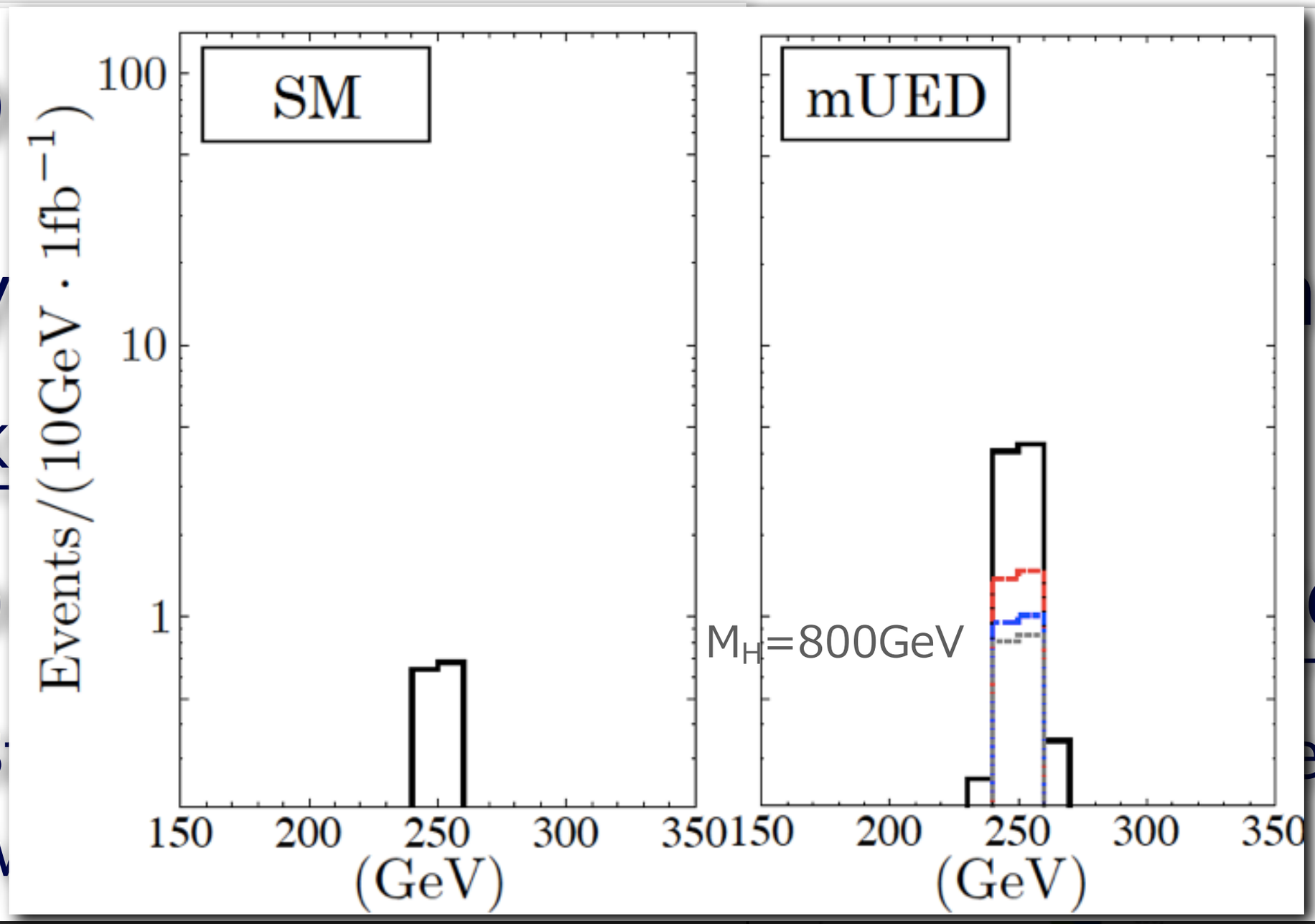
✳ S

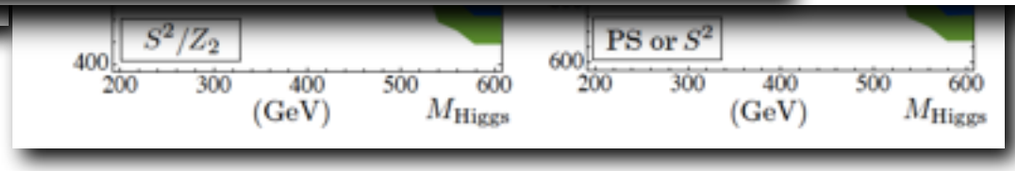
(v

d:

eV.

ents



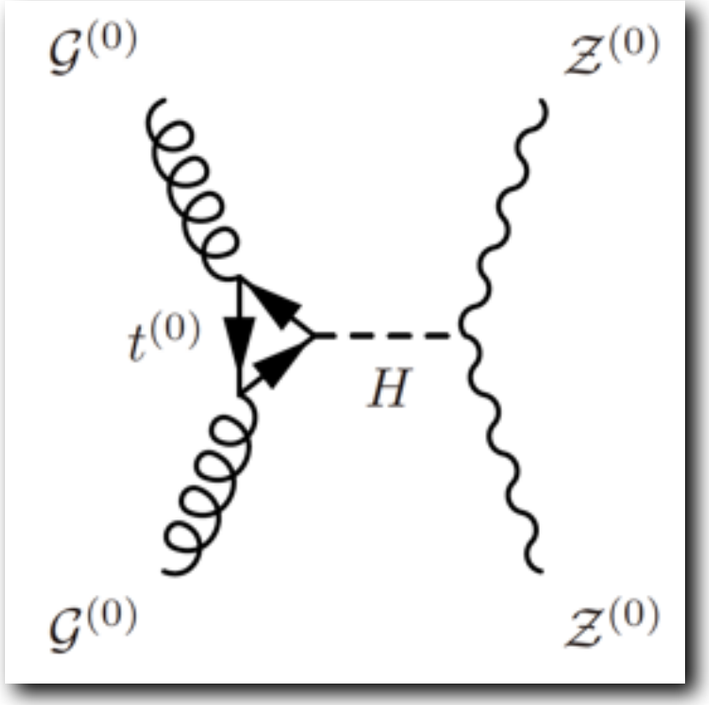


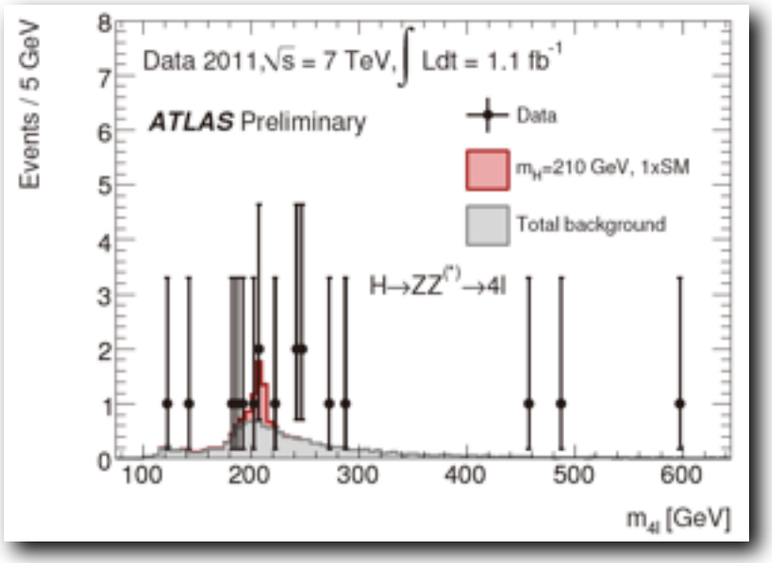
Summary

- 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, $M_H<140GeV$, (by far the strongest collider bound) $M_{KK}>700GeV$ is obtained for 5D mUED.
  - ★ Middle 250GeV UED Higgs may account for ATLAS ZZ→4l if lucky.
  - ★ Heavy 500 (700) GeV UED Higgs can be seen within $10fb^{-1}$ of data at 7 (14) TeV.

Discussion

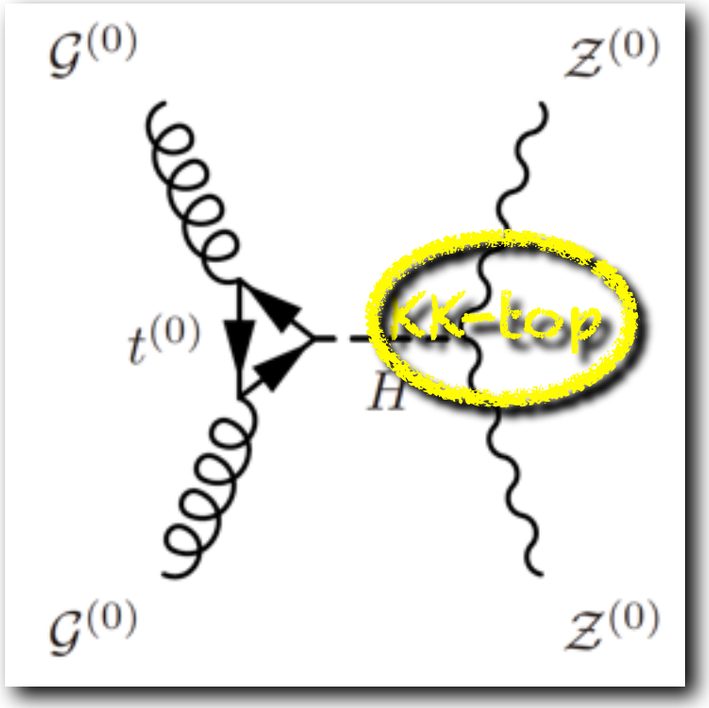
- Possible issues:
  - ★ KK top loops for H→WW,ZZ.
    - ✴ Might reduce events by ~O(10)%.
    - ✴ Same order as N(N)LO QCD corrections.
      - ✦ (NNLO PDF gives <~30% enhancement.)
  - ★ SM background?
- Todo:
  - ★ Combined analysis with H→WW.
  - ★ H→γγ is also enhanced.

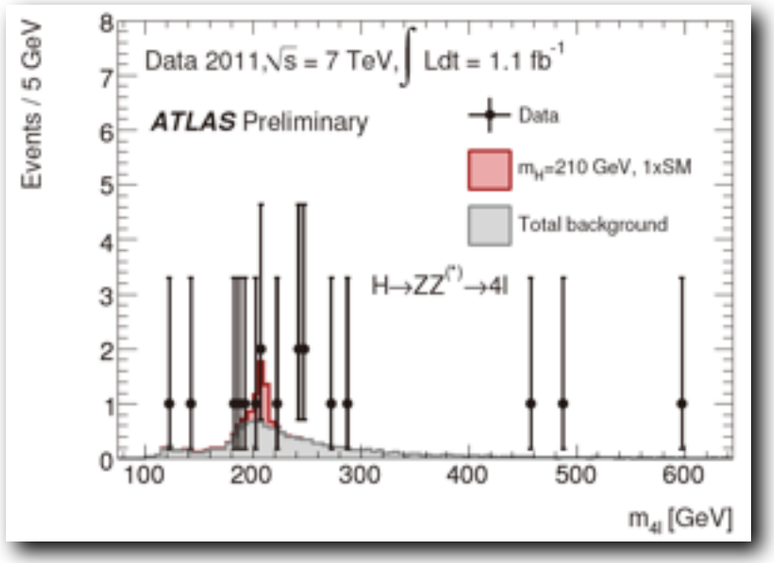




Discussion

- Possible issues:
  - ★ KK top loops for H→WW,ZZ.
    - ✴ Might reduce events by ~O(10)%.
    - ✴ Same order as N(N)LO QCD corrections.
      - ✦ (NNLO PDF gives <~30% enhancement.)
  - ★ SM background?
- Todo:
  - ★ Combined analysis with H→WW.
  - ★ H→γγ is also enhanced.





No matter what we will see,
finally, let us enjoy
the new era of
fundamental physics.

Thank you.