Mihoko Nojiri, JGRG 22(2012)111203

"The Standard model and beyond after LHC at 8 TeV"

RESCEU SYMPOSIUM ON

GENERAL RELATIVITY AND GRAVITATION

JGRG 22

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Higgs discovery and BSM

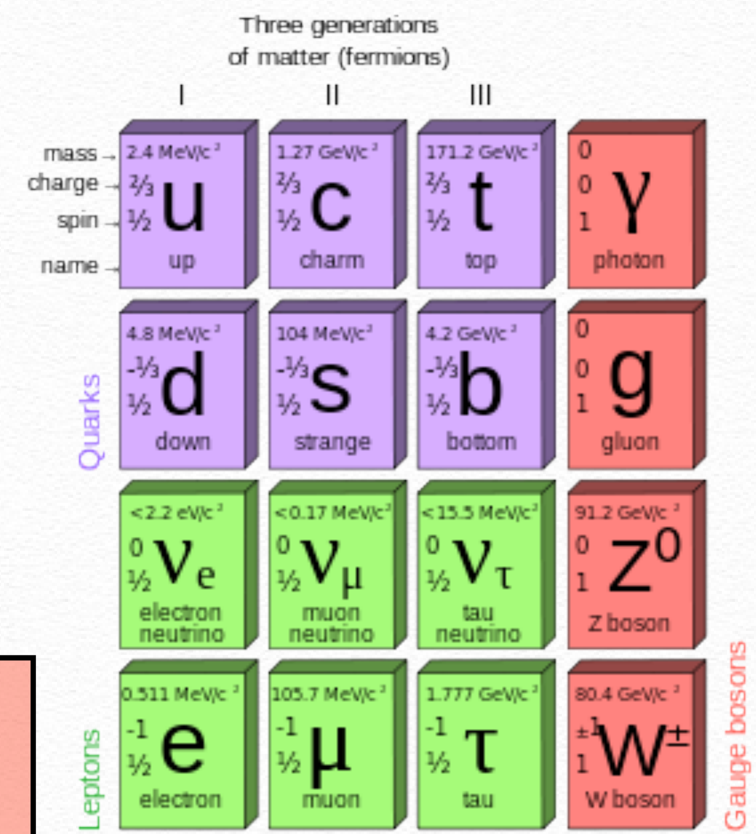
Mihoko M. Nojiri

Higgs discovery at the LHC

- Higgs boson: The Last missing particle of the SM particles
- Probably starting point of “the Beyond the stard model”
- why we think so, and how it conflicts with data

Standard model of particle physics history

- Discover the symmetry “SU(3)xSU(2)xU(1)” out from interactions involving mesons, leptons, and baryons
- finding “the three generation in the matter sector”



- The SM identify “universal forces” to the gauge symmetry, representation (charge) difference leads interaction difference.
- putting origin of the symmetry breaking (“mass”) to nature of the spin 0 sector (Higgs boson).

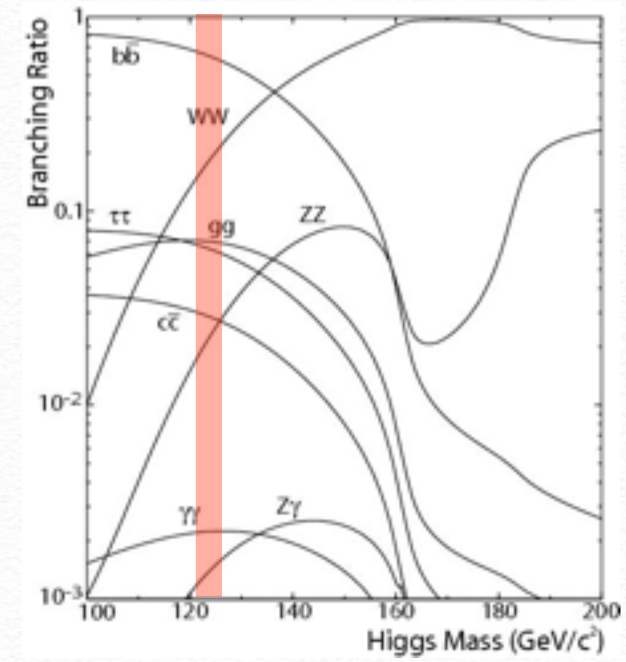
?

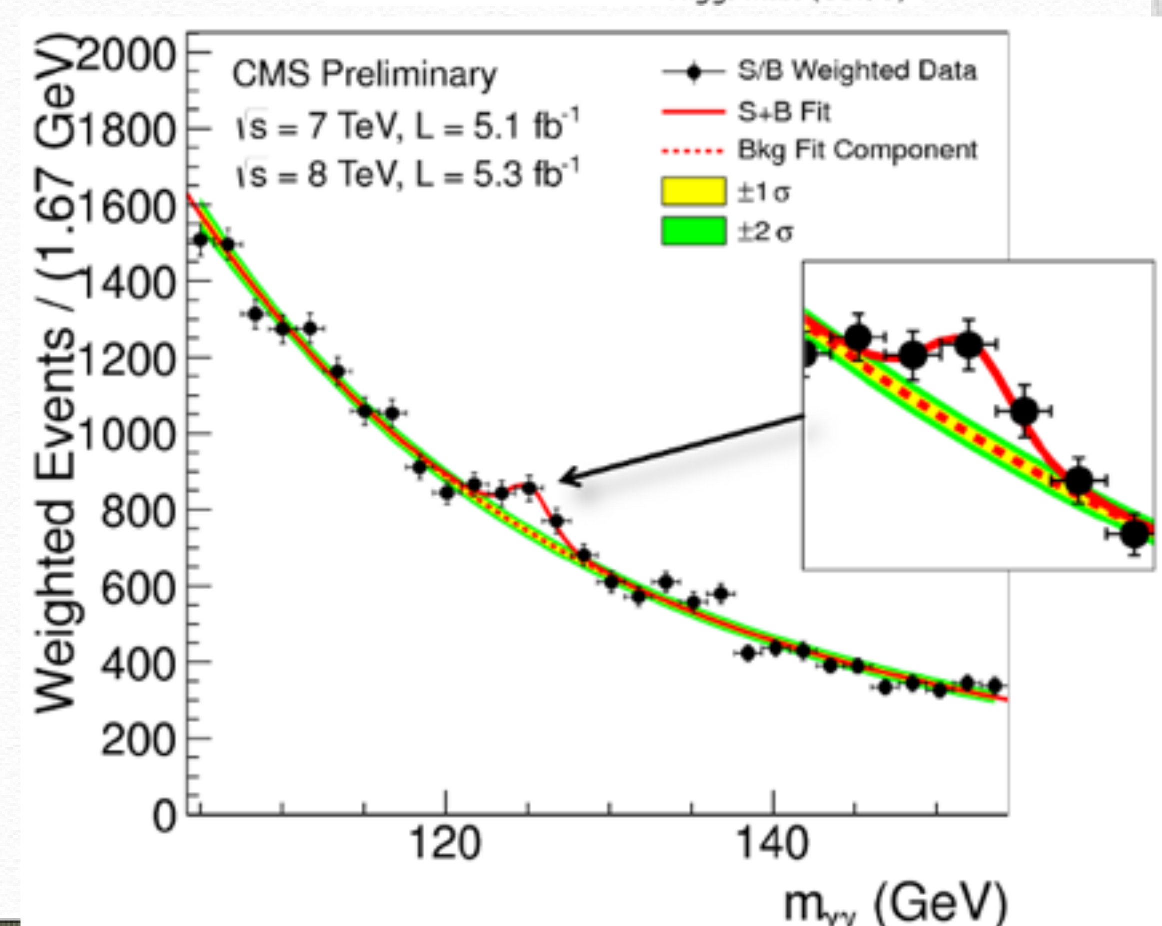
discovery summary

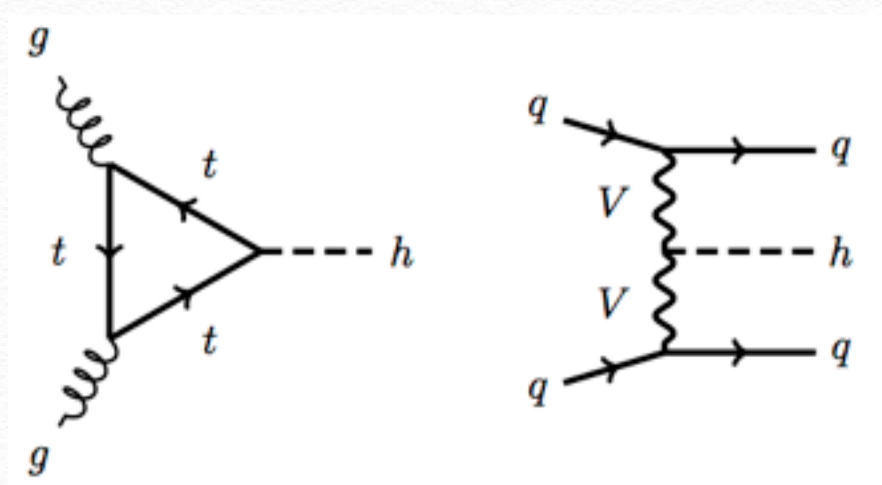
- Higgs couples to massive objects in the tree level, tt, bb, ZZ, WW...

- discovery in photon and lepton channel H→γγ H→ ZZ and H→ WW. We can only measure (procution) x (branching ratio) at LHC.

- production gg→ H dominant, subdominant WW, ZZ→ H contribution is seen. The two process overlap significantly.

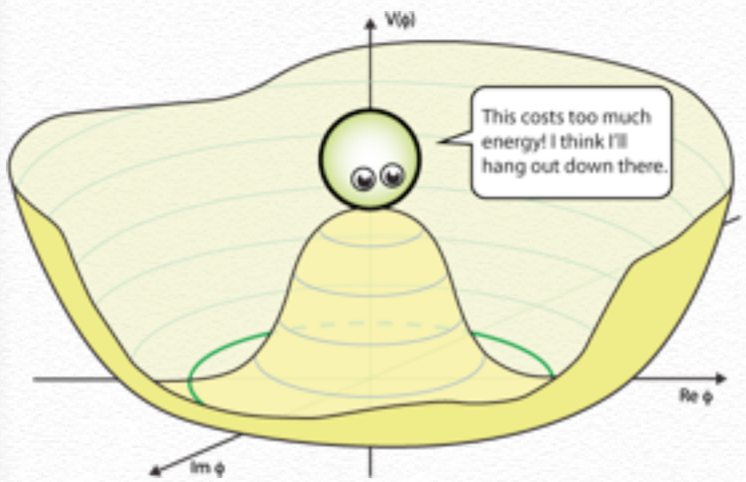






question on the mass value

Are we in meta stable vacuum or there are new physics in between? is this consistent with cosmology?



$V(\varphi)=-m2\varphi2+\lambda\varphi4$

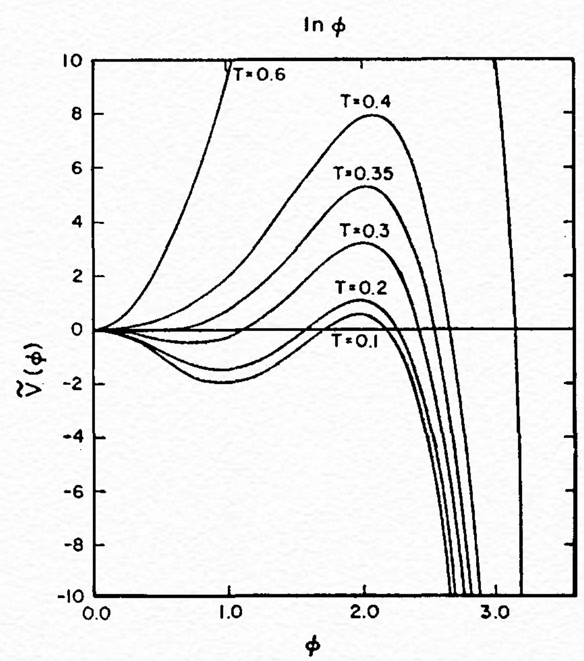
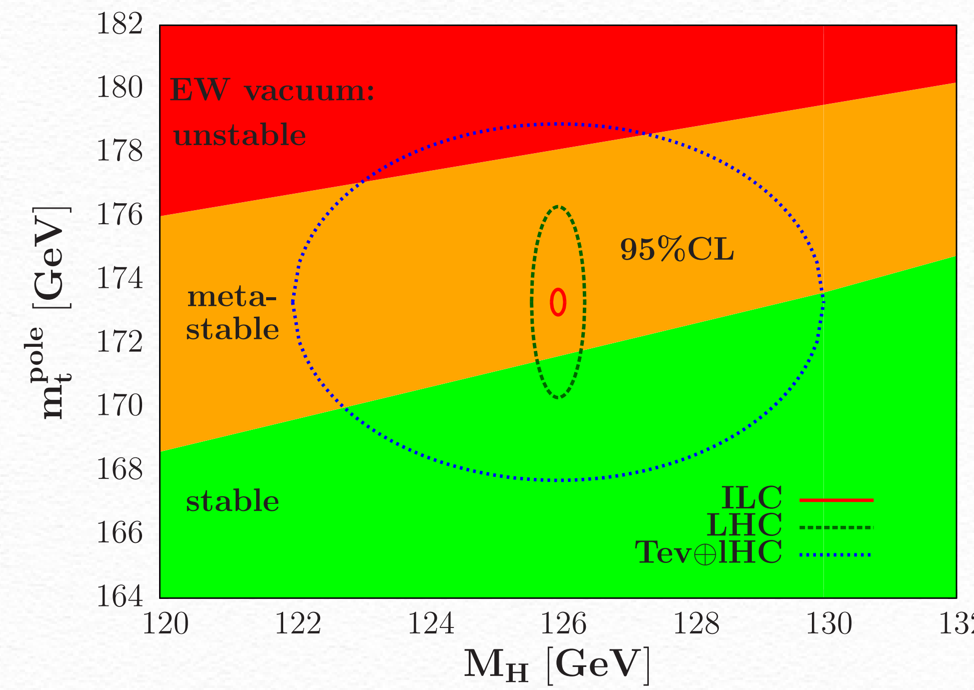


Fig. 18. The temperature dependent potential for $m_{Higgs} = 50$ GeV and for $m_t = 240$ GeV. Here, $\tilde{V} = 8V/m^2_{Higgs}$ and units of $\sigma = 1$ are used.



but λ get negative correction at large φ

We are on the meta stable vacuum?

or there is something between 100GeV to 10^{19}GeV

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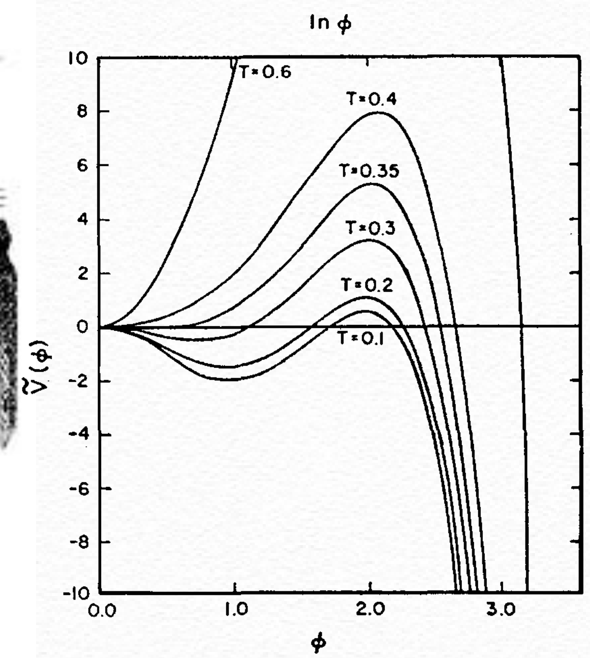

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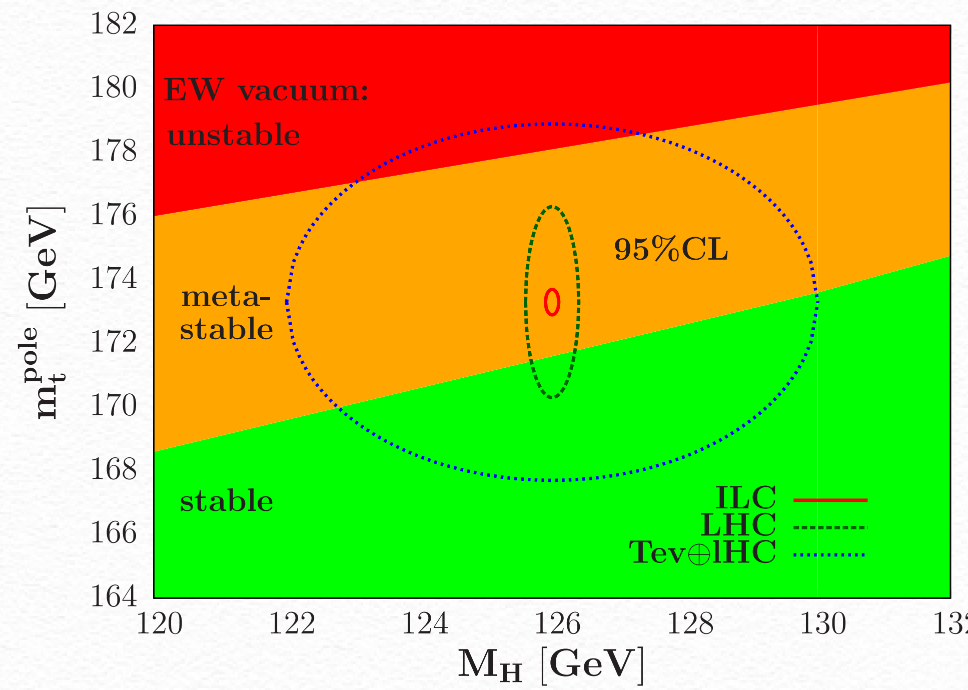

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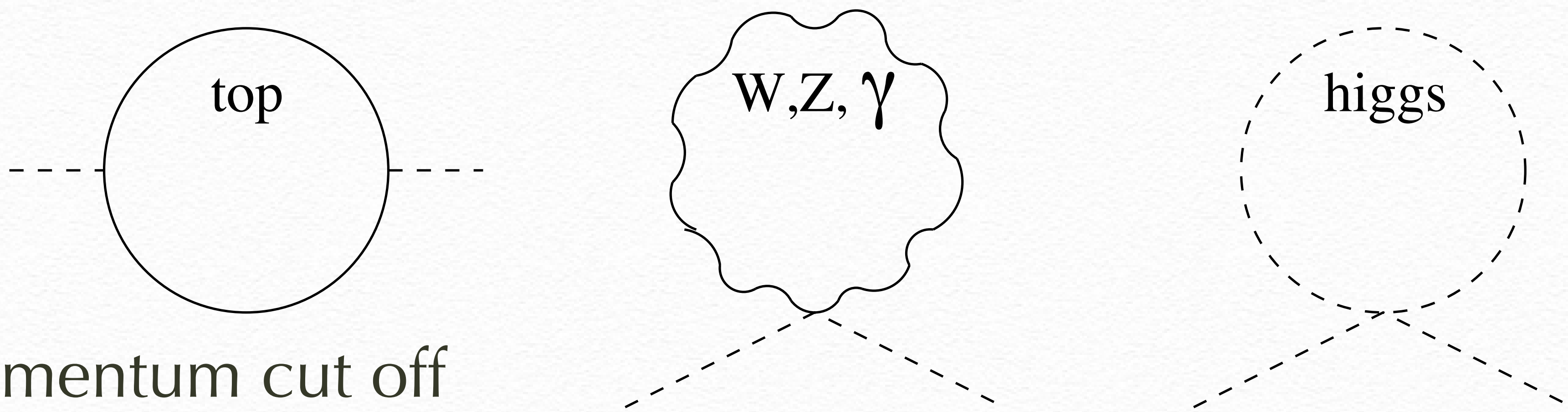
New Physics, Clue

Fine tuning in the Higgs sector



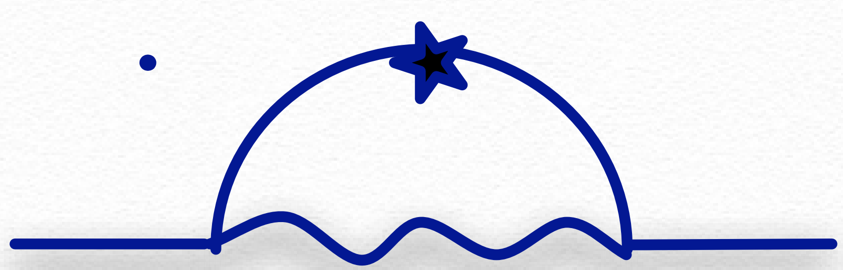
if scale of momentum cut off
Λ =5TeV

$$
\begin{array}{rll}
\text{top loop} & -\frac{3}{8\pi^2}\lambda_t^2\Lambda^2 & \sim -(2\ \text{TeV})^2 \\
SU(2)\ \text{gauge boson loops} & \frac{9}{64\pi^2}g^2\Lambda^2 & \sim (700\ \text{GeV})^2 \\
\text{Higgs loop} & \frac{1}{16\pi^2}\lambda^2\Lambda^2 & \sim (500\ \text{GeV})^2.
\end{array}
$$

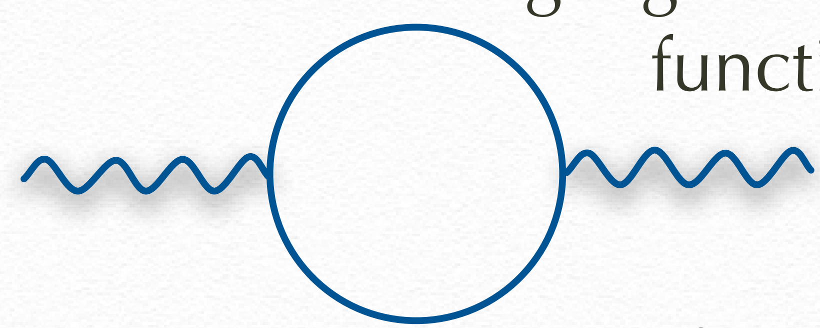
Others are reasonable

Why Higgs vev is O(200) GeV??

$m_f \log \Lambda$ fermion mass



gauge two point function



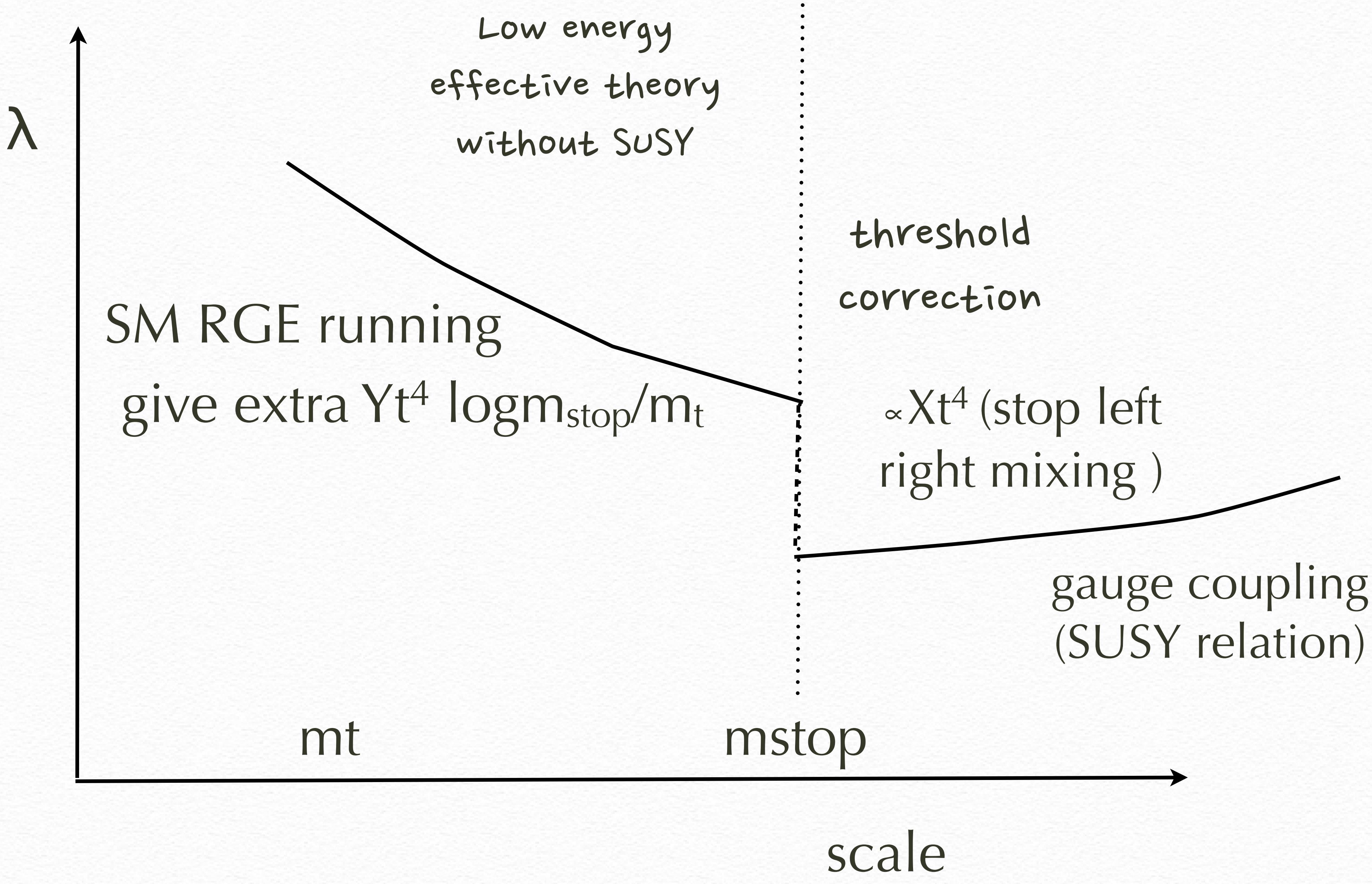
$$\Pi_{\mu\nu} = (g_{\mu\nu}p^2 - p_\mu p_\nu)\Pi$$

Classic Solution:Supersymmetry

- exchange boson and fermion. $\phi \leftrightarrow \psi$
  - sfermions(0), gaugino(1/2), higgsinos(1/2)
- boson and fermion are in the same multiplet; chiral symmetry extended to bosons. No quadratic divergence
- No new dimensionless coupling and no quadratic divergence
- Higgs 4 point coupling is written by gauge coupling. (no negative 4 point coupling.)
- gauge coupling unification
- R parity in MSSM . New stable particle→ DM candidate.

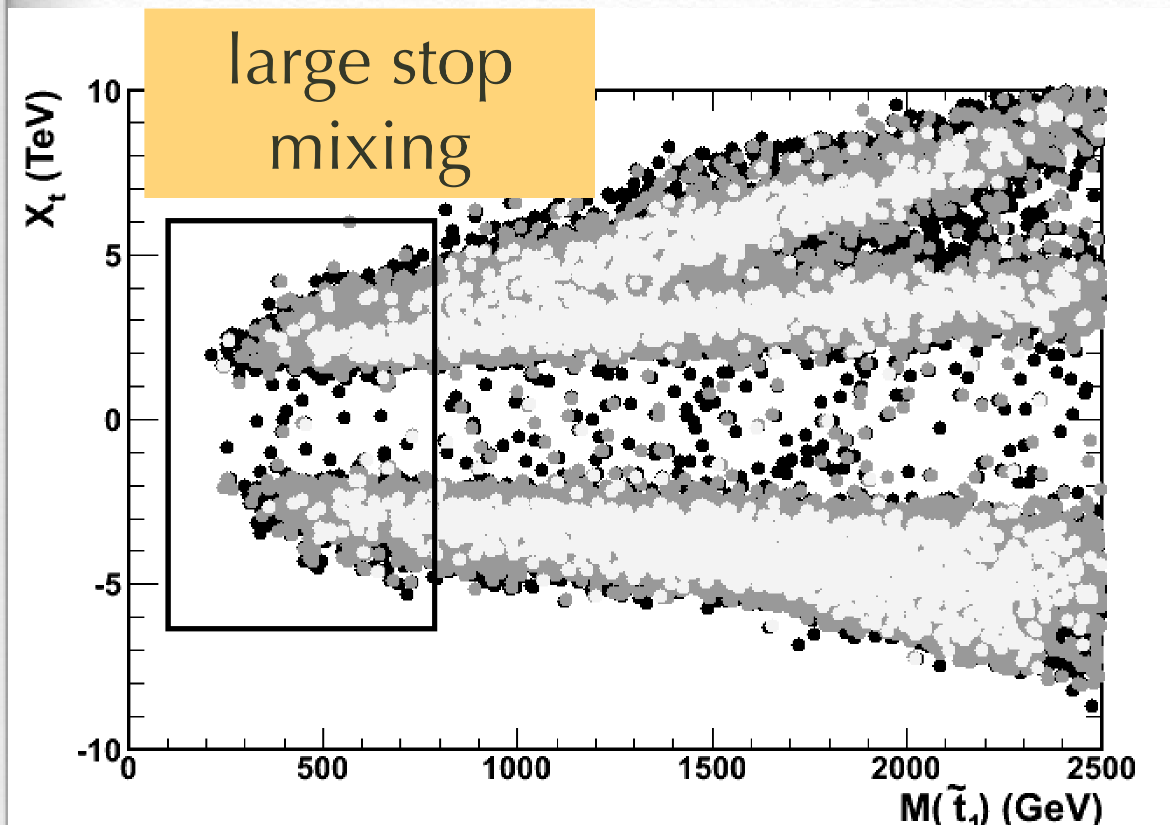
Higgs 4 point coupling at low energy

tree level Higgs mass < mZ + additional correction to from stop sector



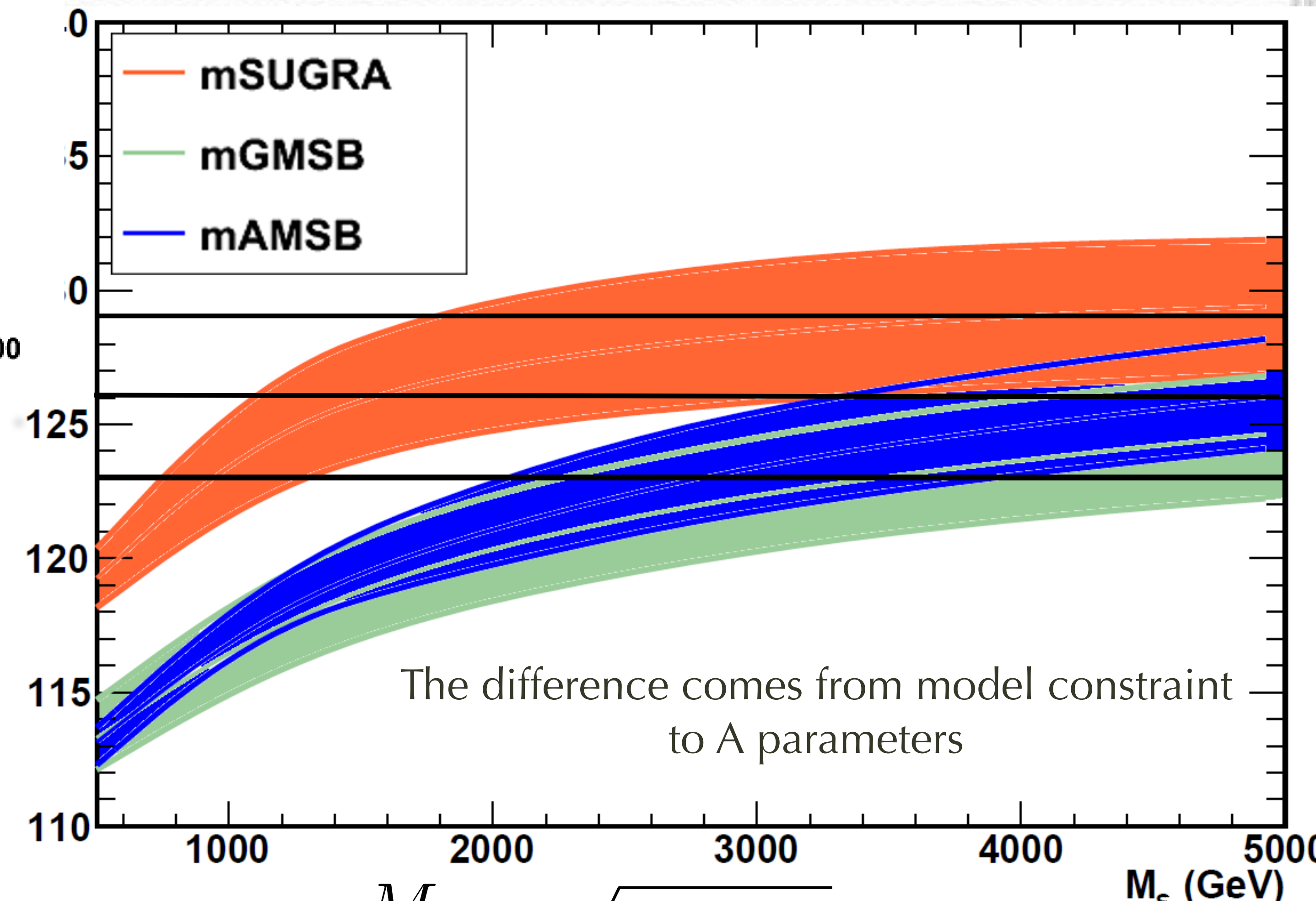
off diagonal part

Higgs mass vs SUSY



large stop mixing required for light stop mass in model independent approach

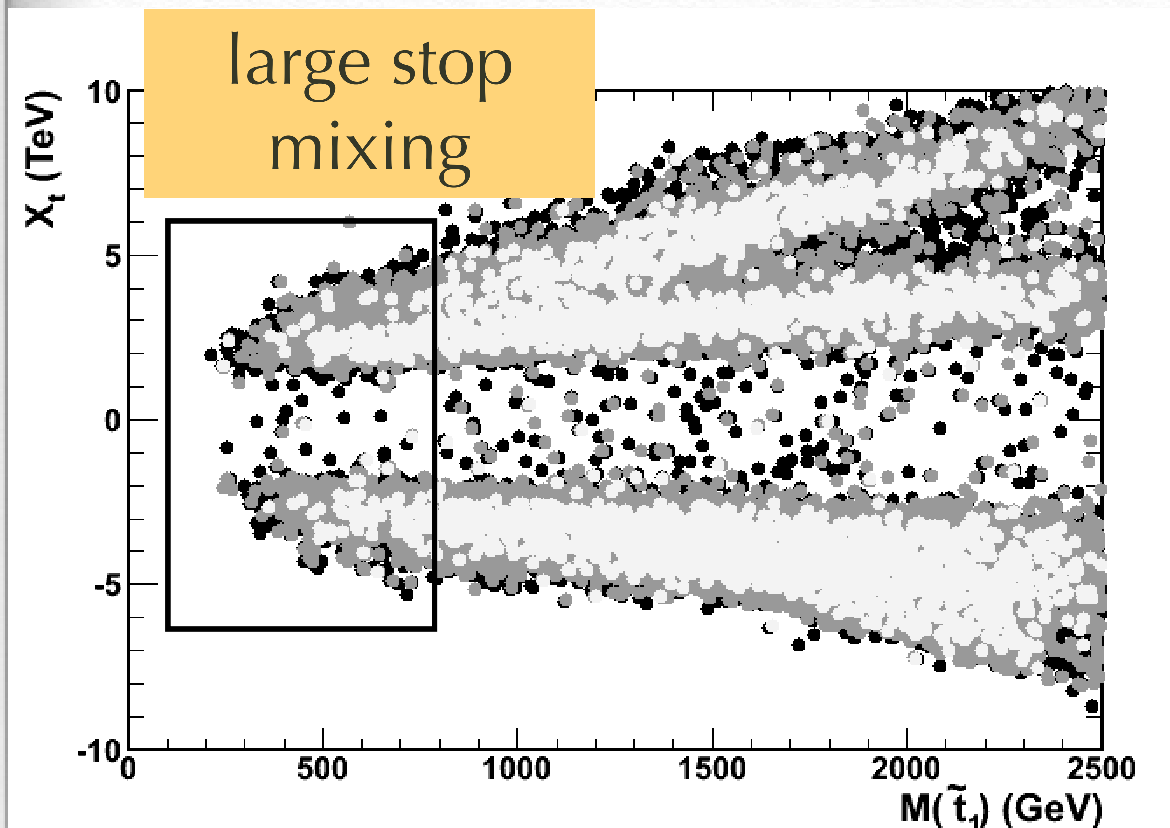
large SUSY scale required in simple gauge and anomaly mediation
=> Huge Tension



$$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Higgs mass vs SUSY

off diagonal part



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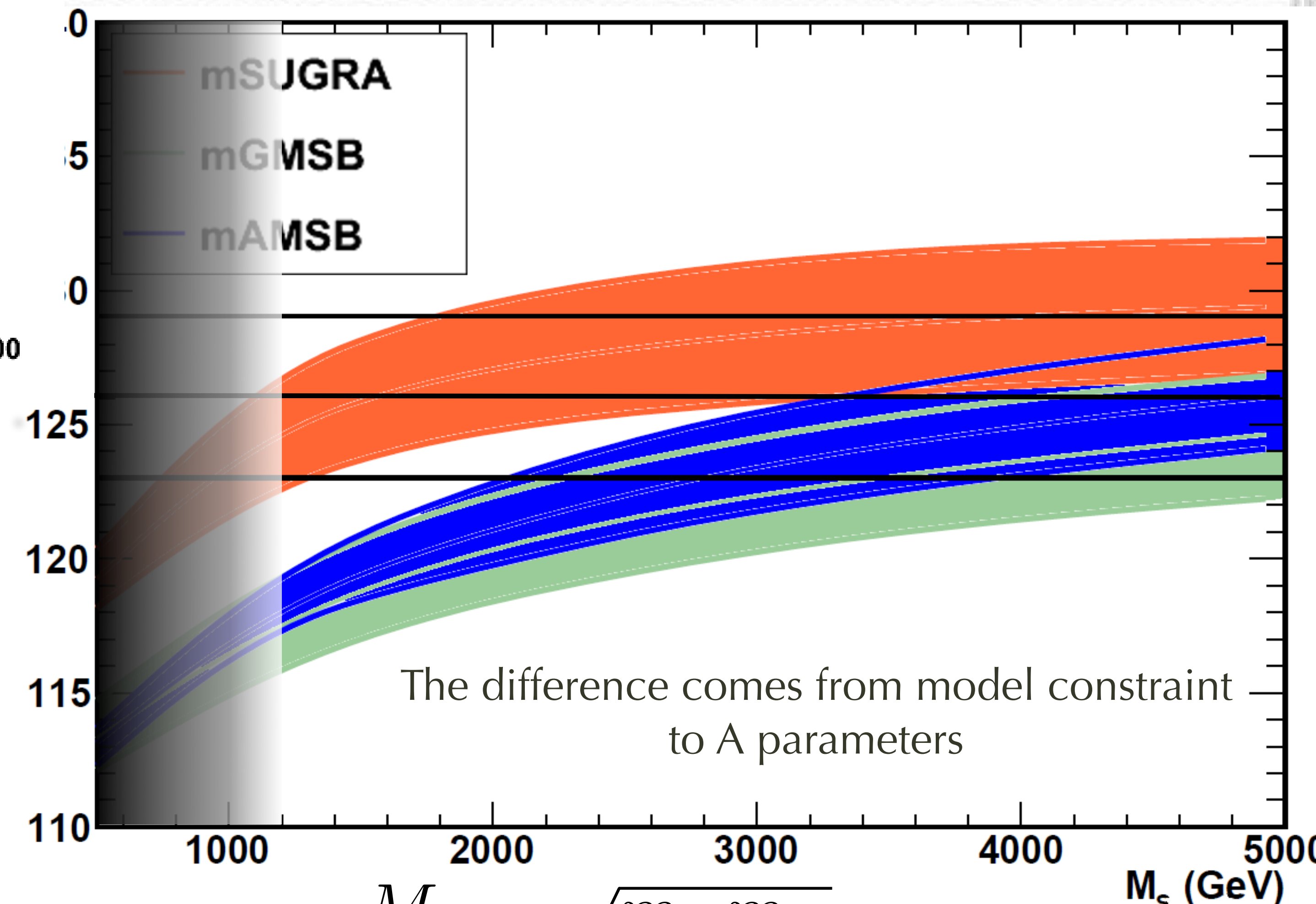
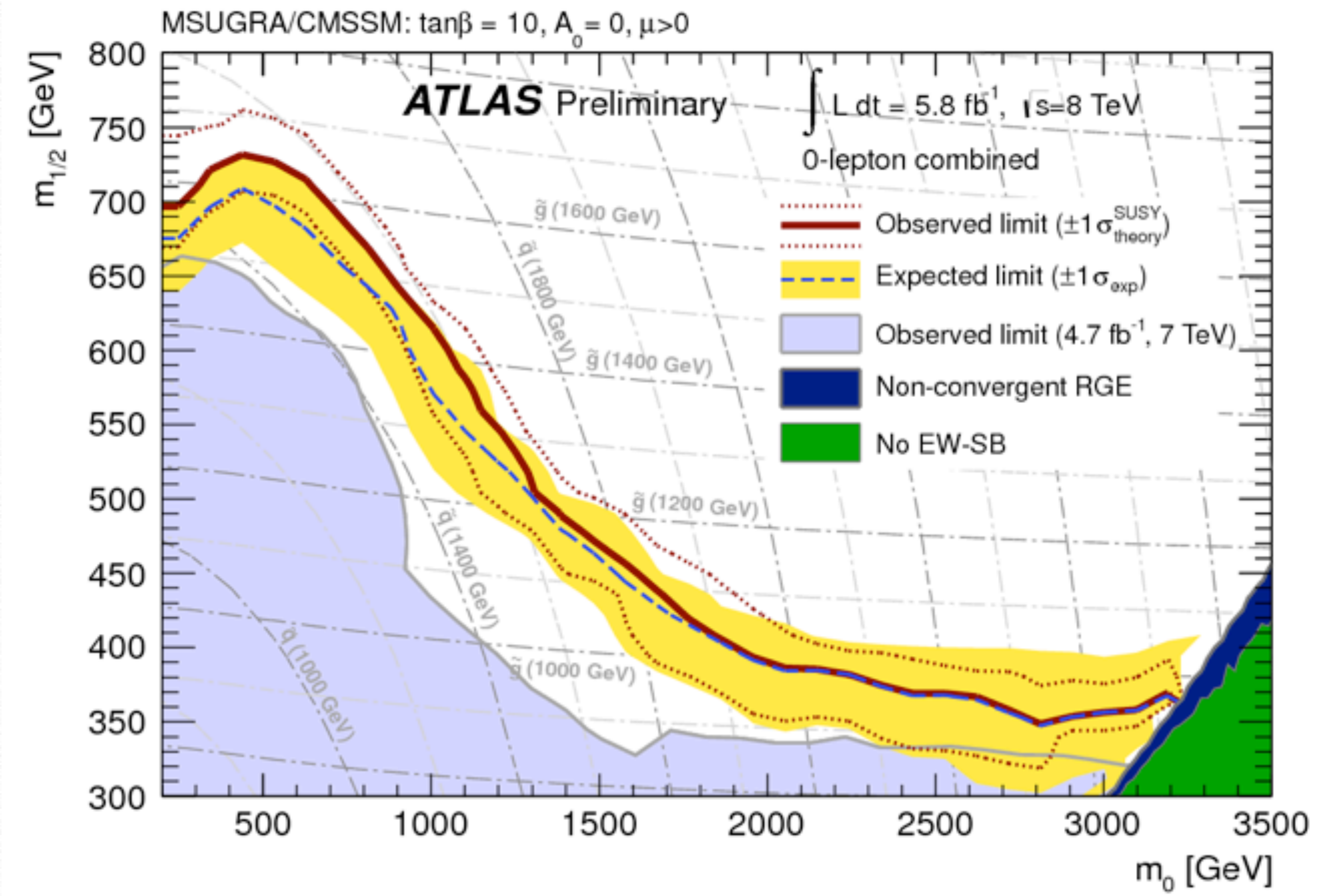


$$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

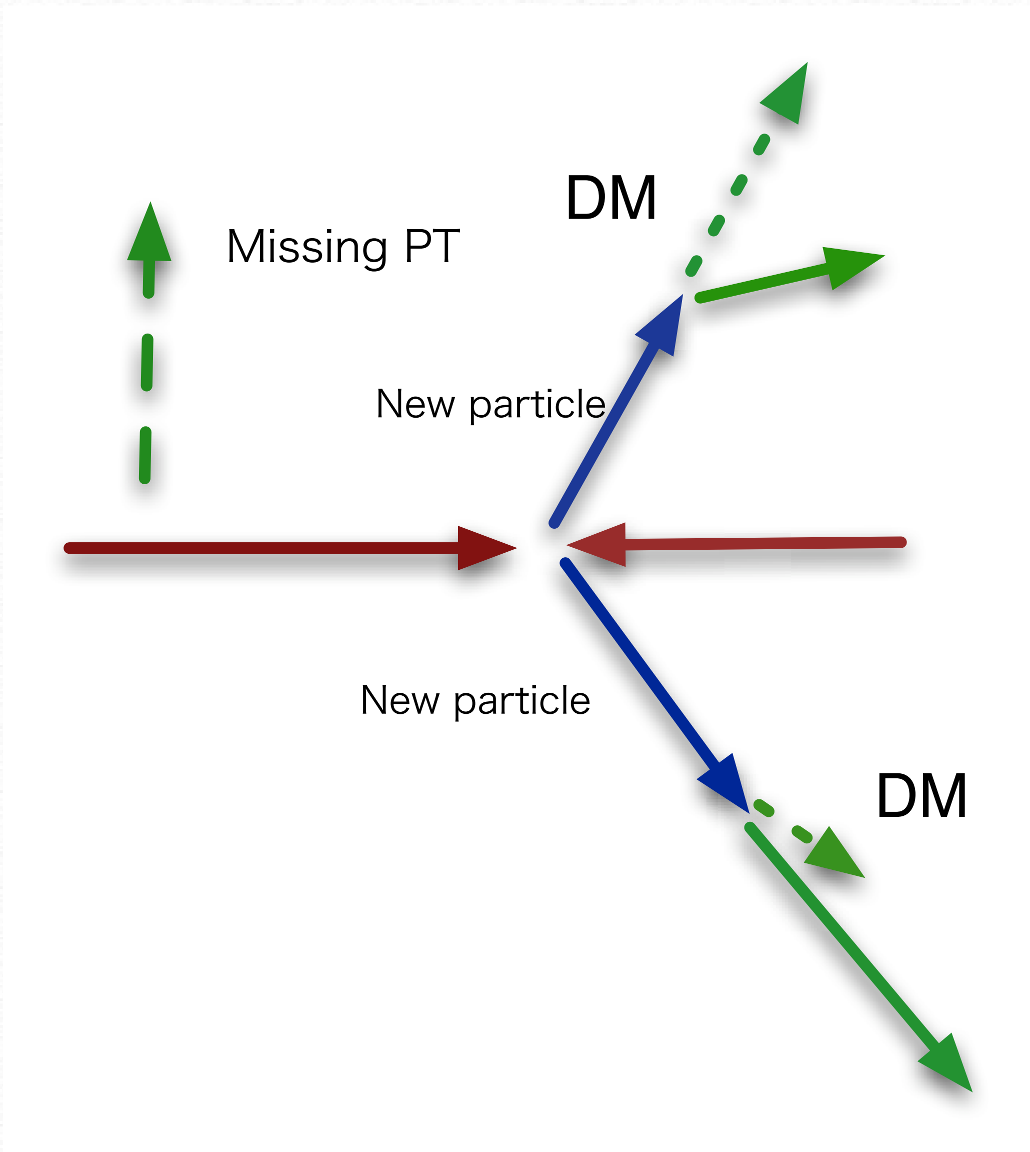
limit at 8TeV (from recent ATLAS)

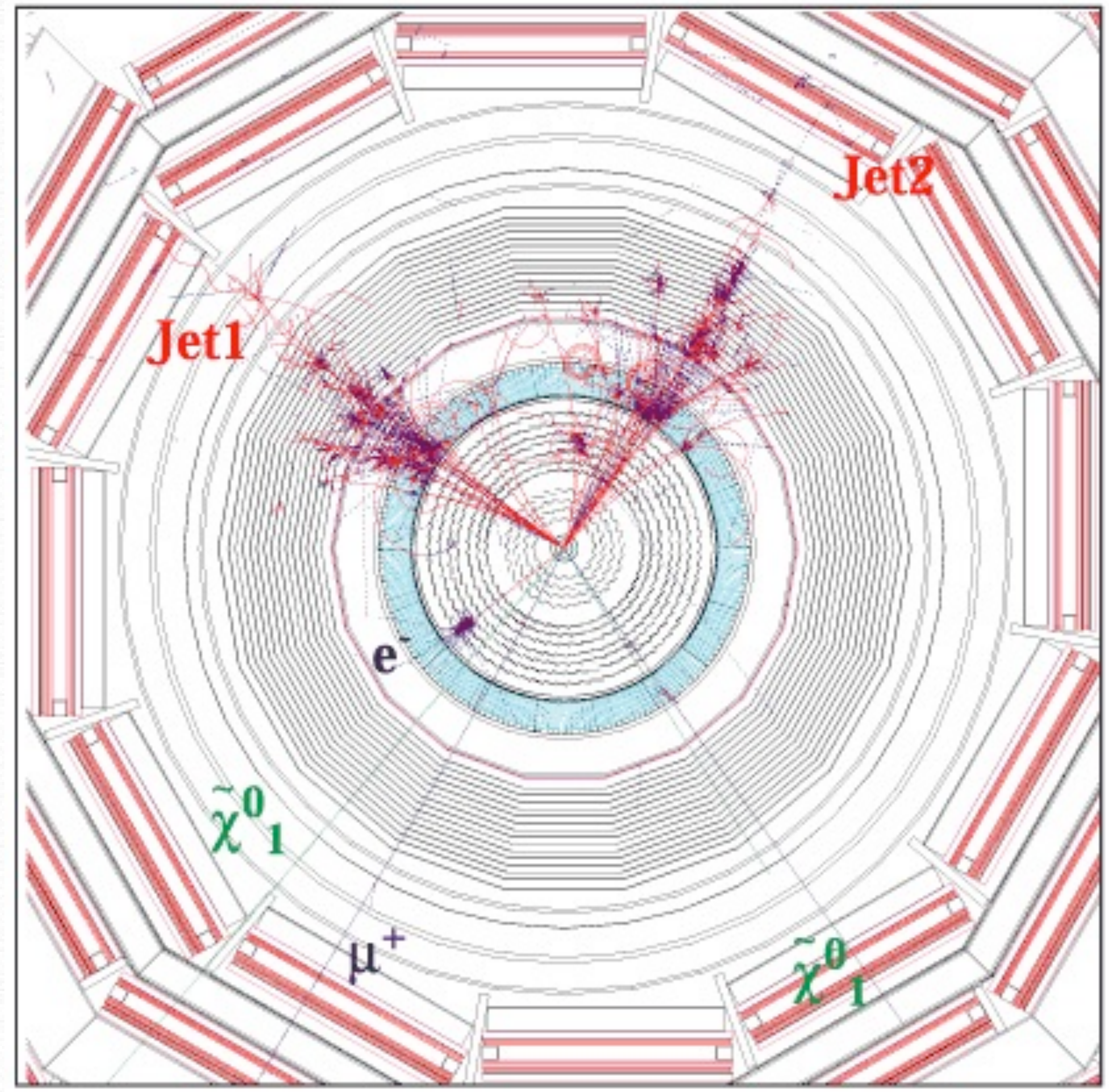


SUSY > (or maybe >>) 1TeV, Does this cause fine turning?

under the assumption of **universal SUSY breaking**(MSUGRA) , sleptons are much above 300 GeV

Basic collider objects and supersymmetry





really SUSY particles are so heavy?

- Too large fine turning? Correction to the higgs mass exceed higgs mass
  - Is this such a big problem? GUT/weak scale fine turning has been solved. We have fine turning in vacuum energy anyway..
- By extending model to **Next Minimal SUSY**, higgs masses upper limit increase→ allowing light SUSY particles.
- contribution from 4th generation can also contribute

$$W = Y' H_u Q' U' + M'(Q'\bar{Q}' + U'\bar{U}')$$

$$\Delta m_h \simeq \frac{3v^2}{4\pi^2} Y'^4 \ln \frac{m_S^2}{m_F^2} + \dots$$

$m_{S(F)}$: vector scalar(fermion) mass

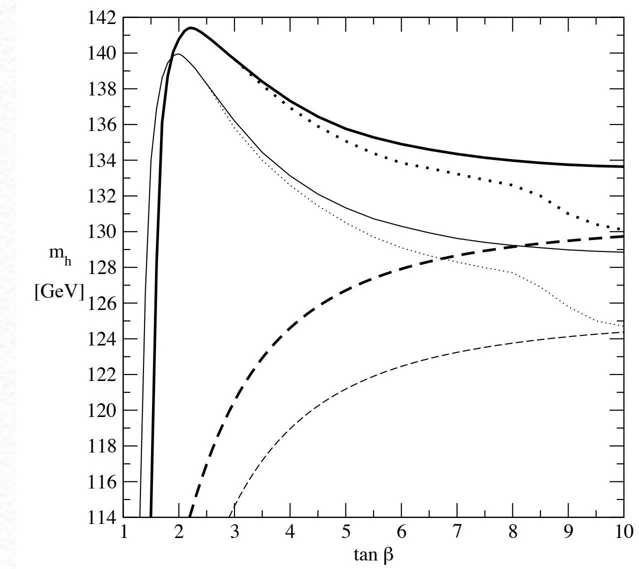
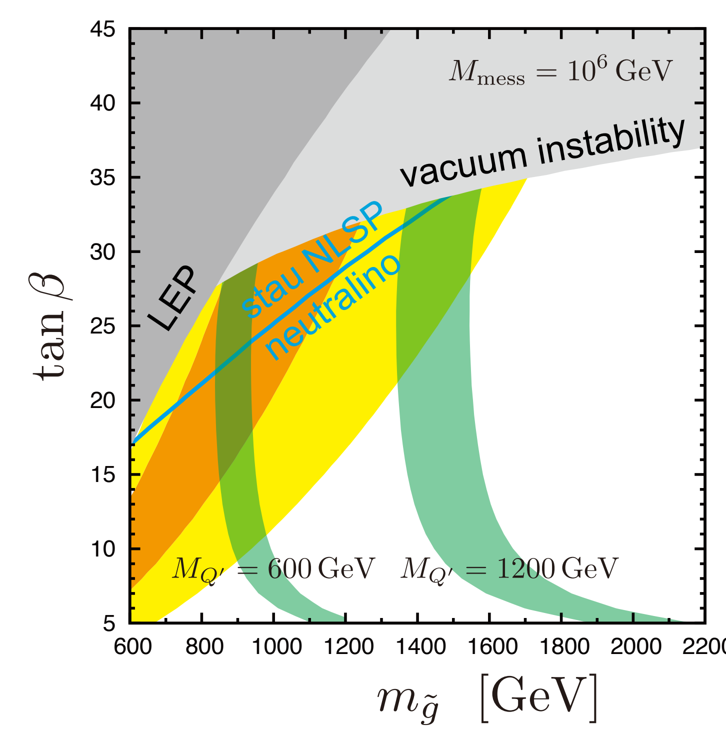
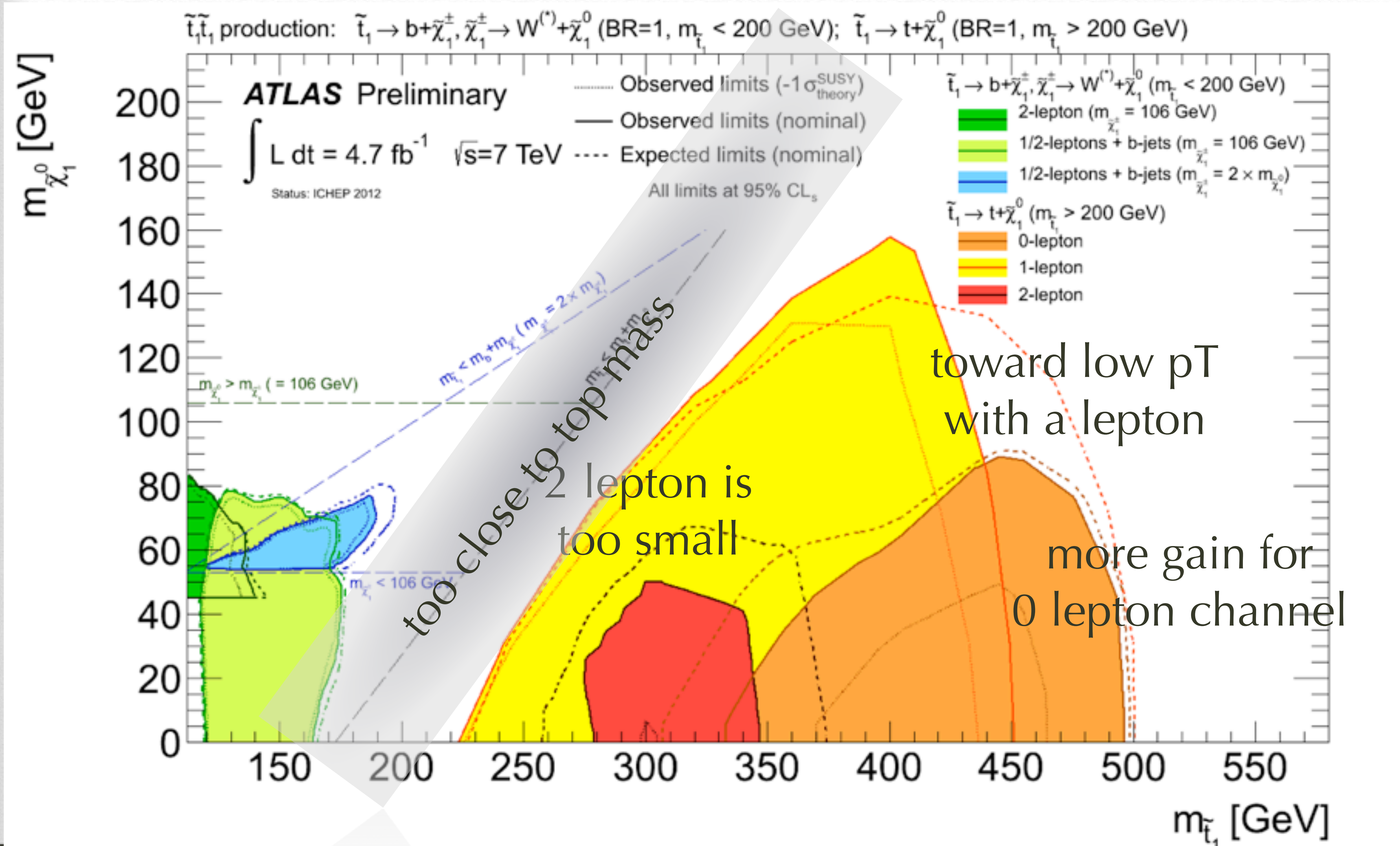


Figure 1: Upper bound on the lightest Higgs mass in the NMSSM for $m_{top} = 178$ GeV (thick full line: m_A arbitrary, thick dotted line: $m_A = 1$ TeV) and $m_{top} = 171.4$ GeV (thin full line: m_A arbitrary, thick dotted line: $m_A = 1$ TeV) and in the MSSM (with $m_A = 1$ TeV) for $m_{top} = 178$ GeV (thick dashed line) and $m_{top} = 171.4$ GeV (thin dashed line) as obtained with NMHDECAY as a function of $\tan\beta$. Squark and gluino masses are 1 TeV and $A_{top} = 2.5$ TeV.



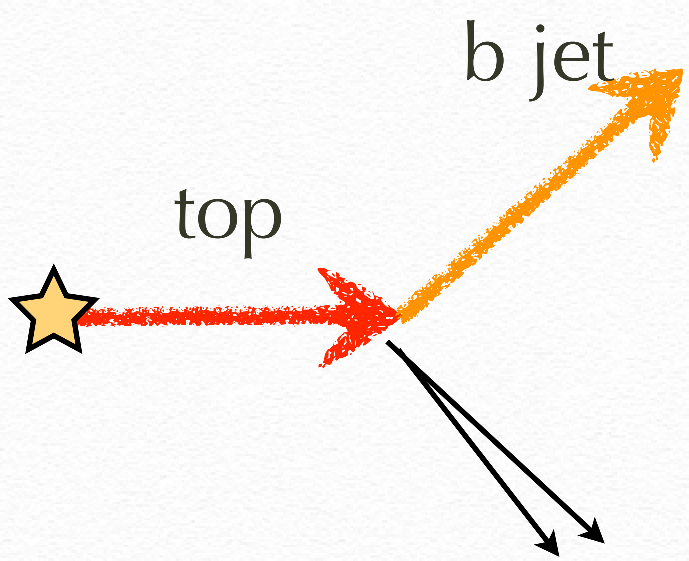
stop search

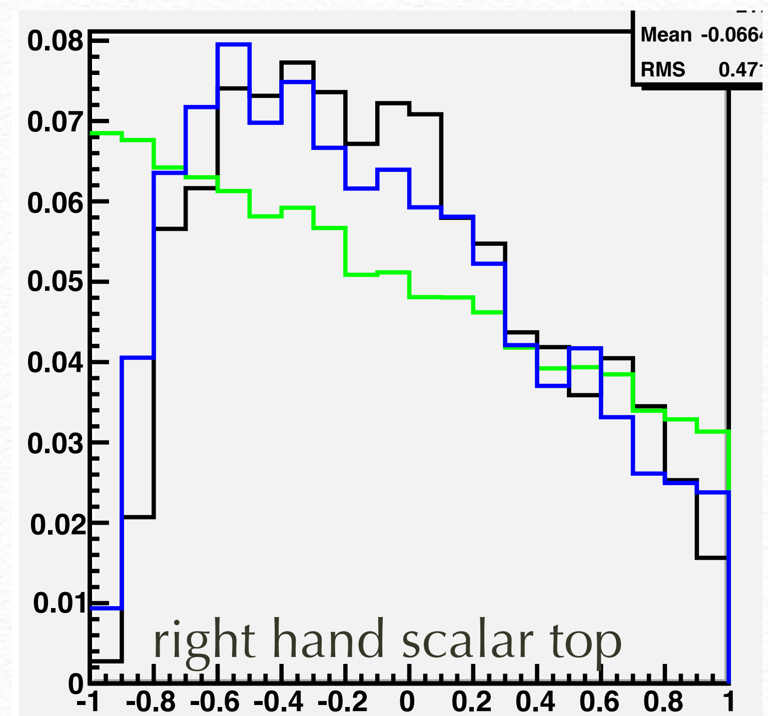
Direct search limit are actually not so strong
allows for relatively light stop for NMSSM

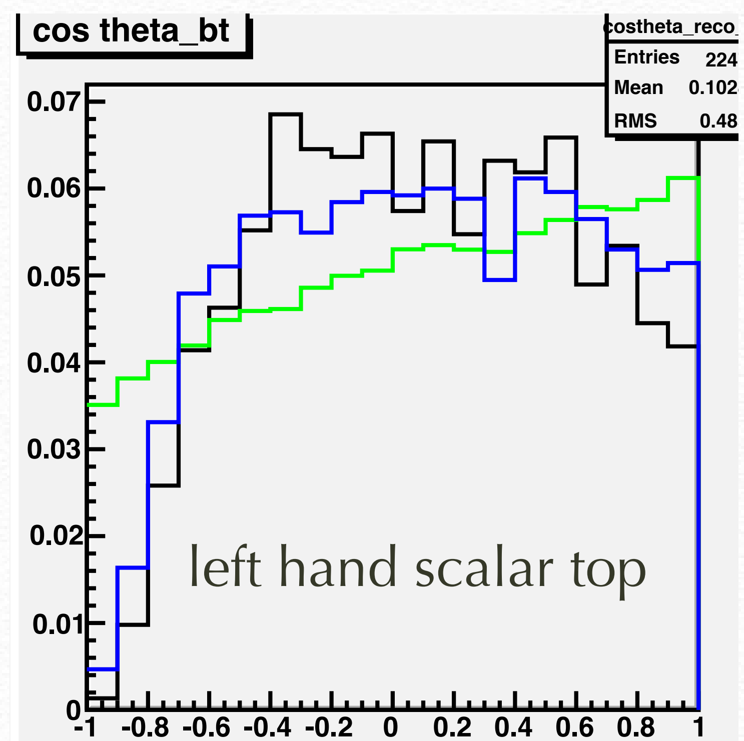


if light stop is found

- stop mixing makes the lighter stop light
- model is NMSSM so that stop is need not to be light.
- stop mixing → top polarization from stop decay(visible at LHC)







Biplob Bhattacherjee Sourav K Mandal Mihoko.M Nojiri in preparation

Limit for degenerate SUSY

The previous plot assumes universal
scalar and gaugino mass at GUT scale.
=> large mass splitting between QCD and EW SUSY particles

model independent gluino and squark mass could be
much lighter (stop still needs to be heavy in MSSM)

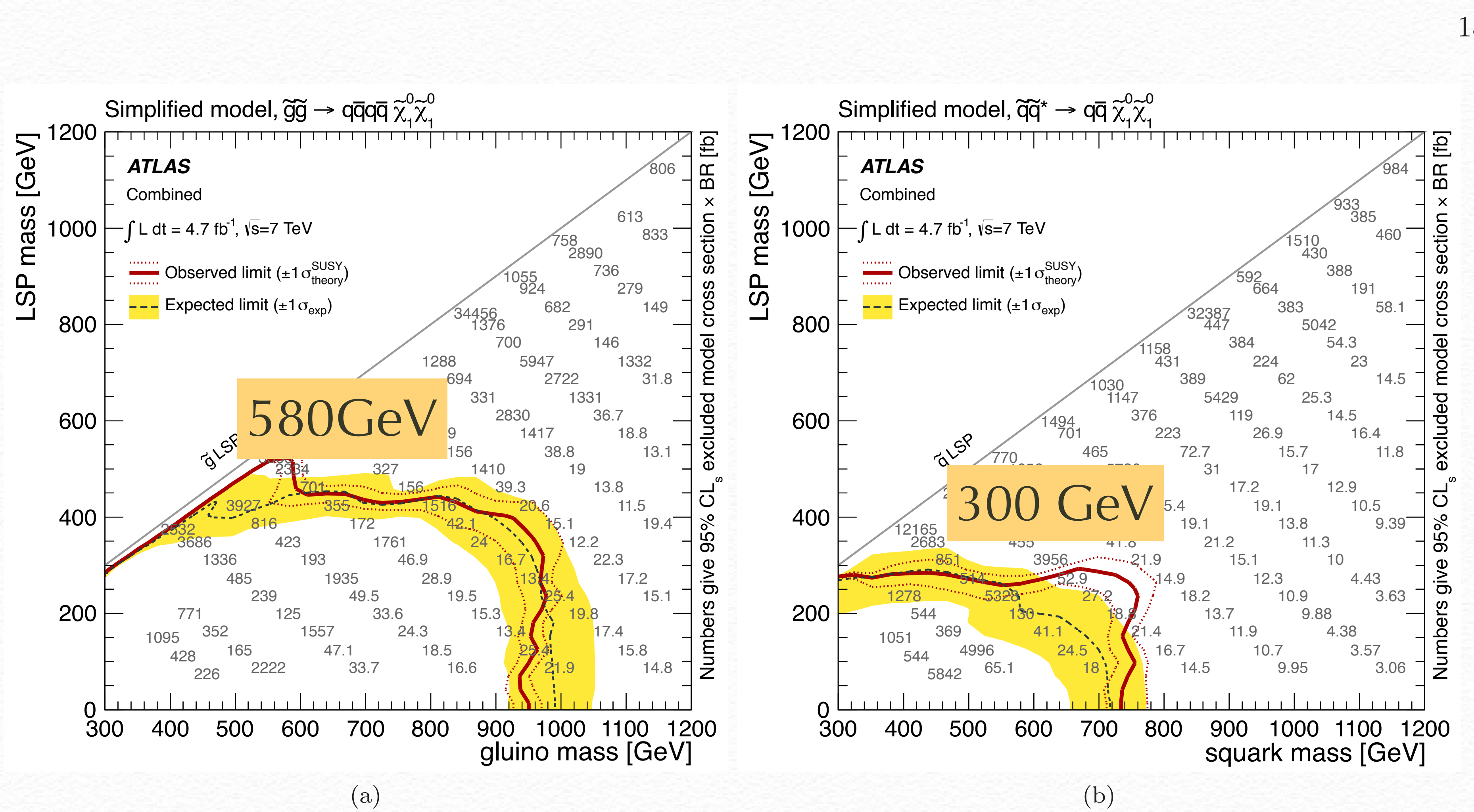
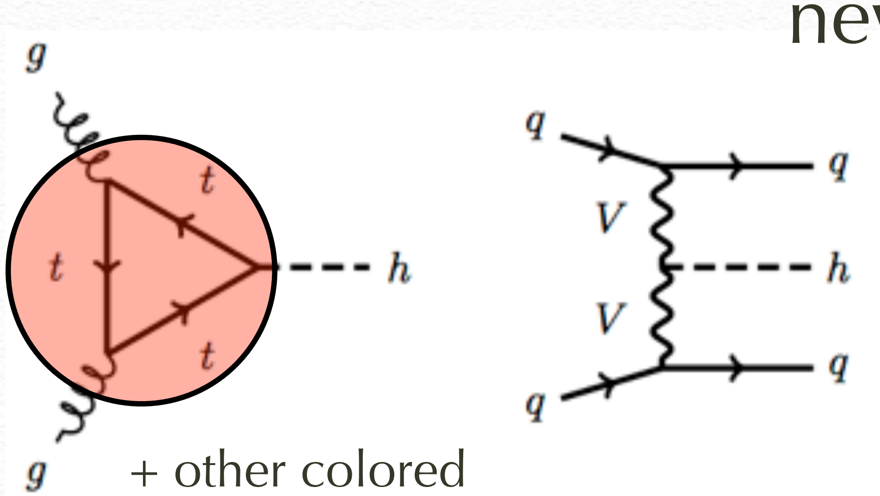


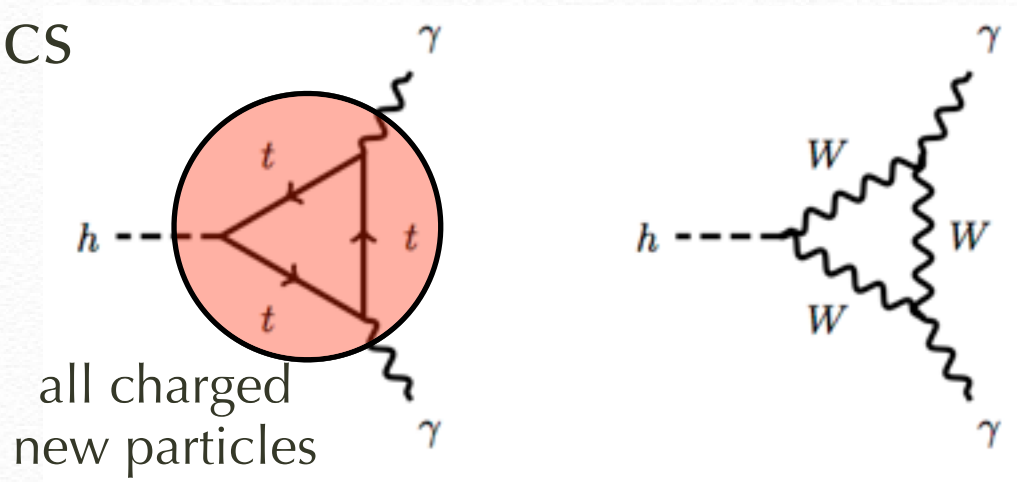
FIG. 12: The 95% CL exclusion limits on simplified models assuming direct production of (a) gluino pairs with decoupled

How about the EW SUSYparticle ?

this is a window to
new physics



+ other colored
new particles



all charged
new particles

production of
Higgs boson

very light stau O(100GeV)
or scalar top generation may
change Higgs branches up
to 20%

NMSSM can account for
deviations from SM

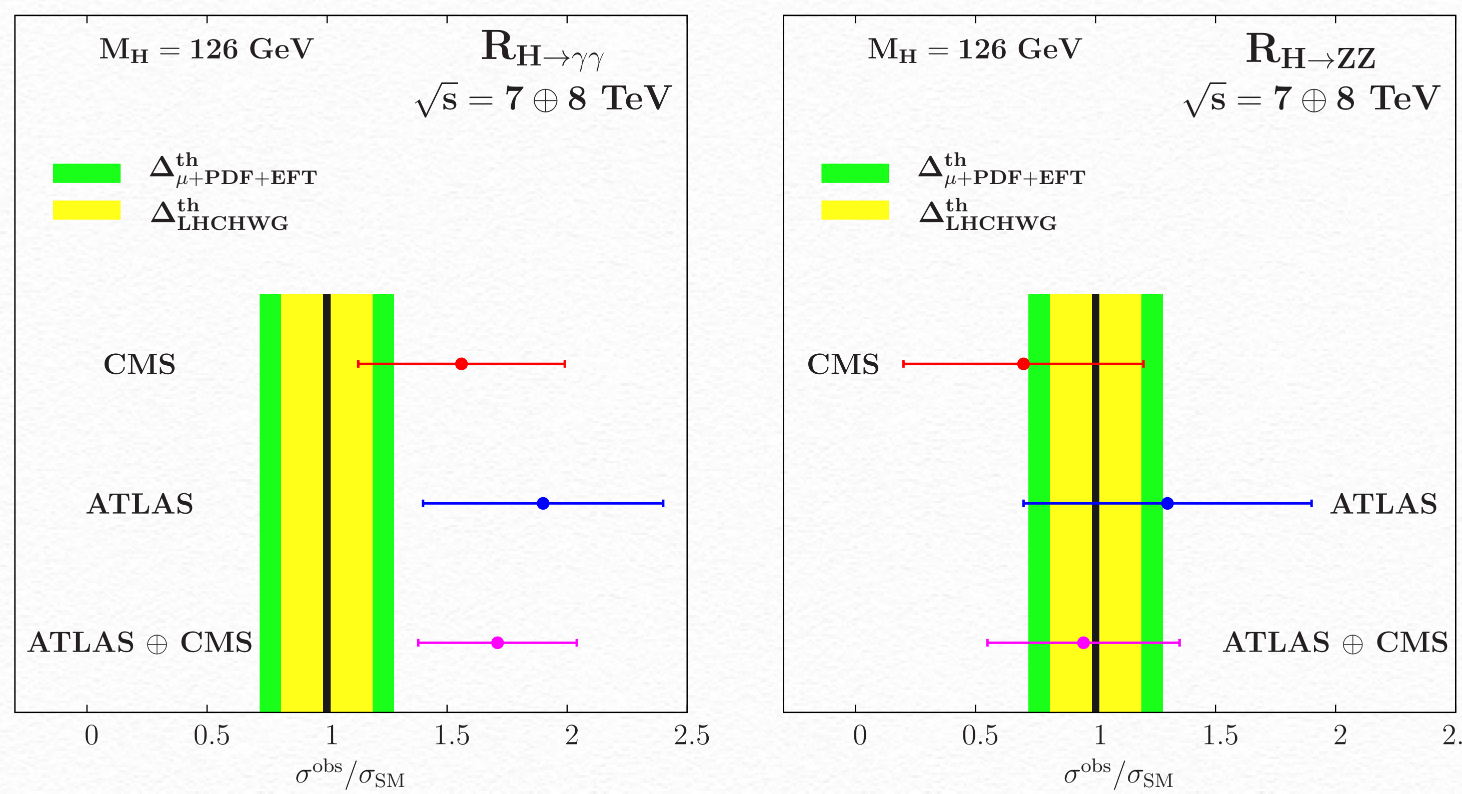


Figure 2: The value of R_{XX} for the $H \to \gamma\gamma$ and ZZ final states given by the ATLAS and CMS collaborations, as well as their combination, compared to the theoretical uncertainty bands.

How about the EW SUSYparticle ?

this is a window to
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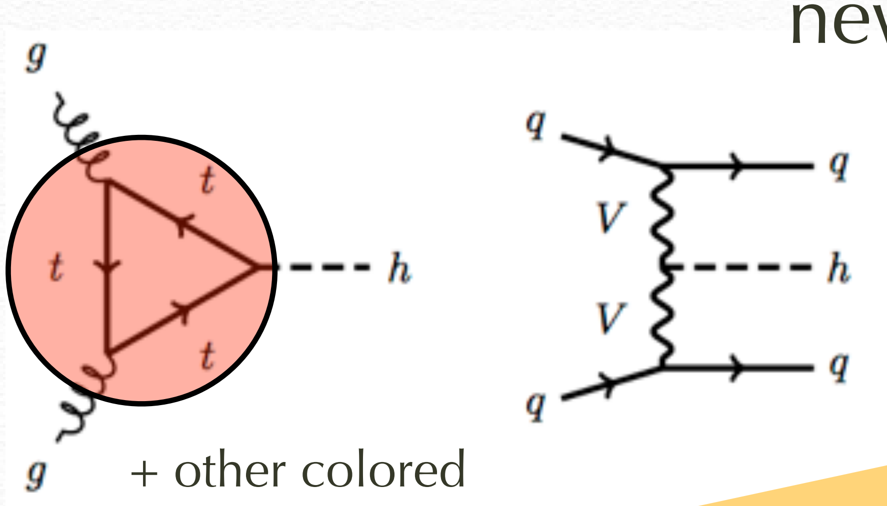

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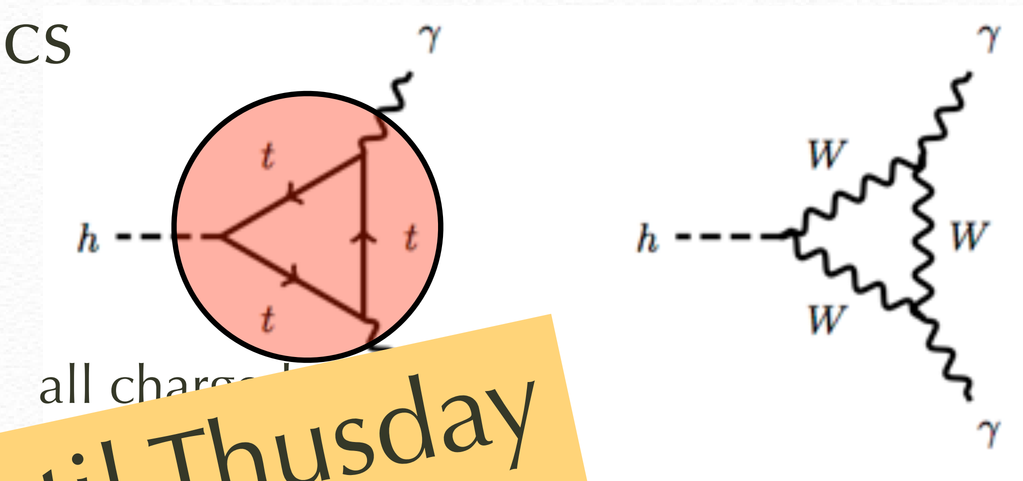

all charg

Need to wait until Thusday
this week

production
Higgs boson

very light stau O(100GeV)
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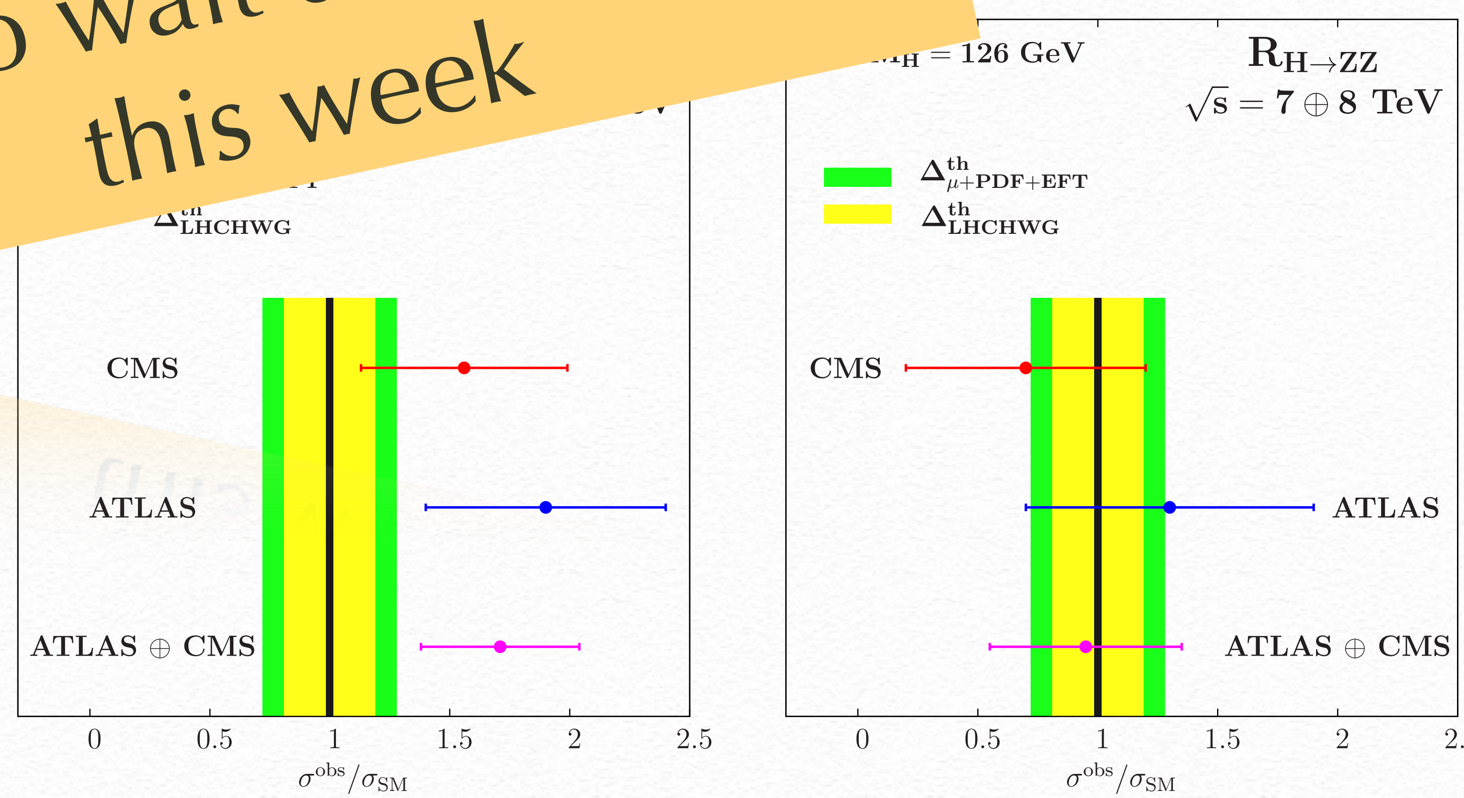
NMSSM can account for
deviations from SM



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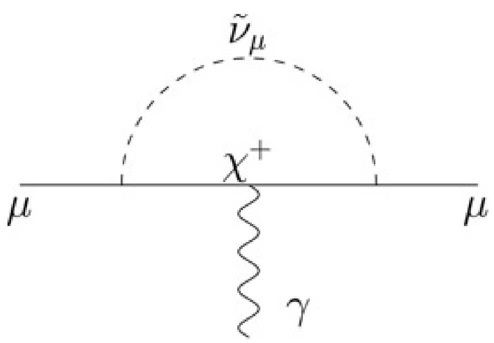
12年11月12日月曜日

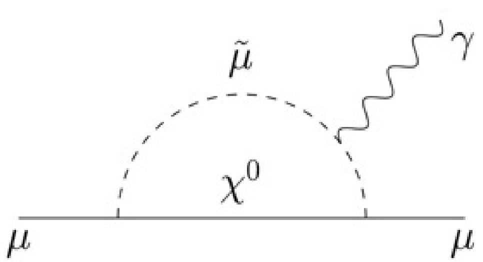
Maybe sleptons are light at least?
muon g-2

a_μ^{exp} = 116 592 089 (63) [10^{-11}]

$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (26.1 \pm 8.0) \cdot 10^{-10}$$ > 3σ deviation



chargino-sneutrino



neutralino-smuon

need light EW SUSY particle

Endo, Hamaguchi, Iwamoto, Nakayama Yokozaki

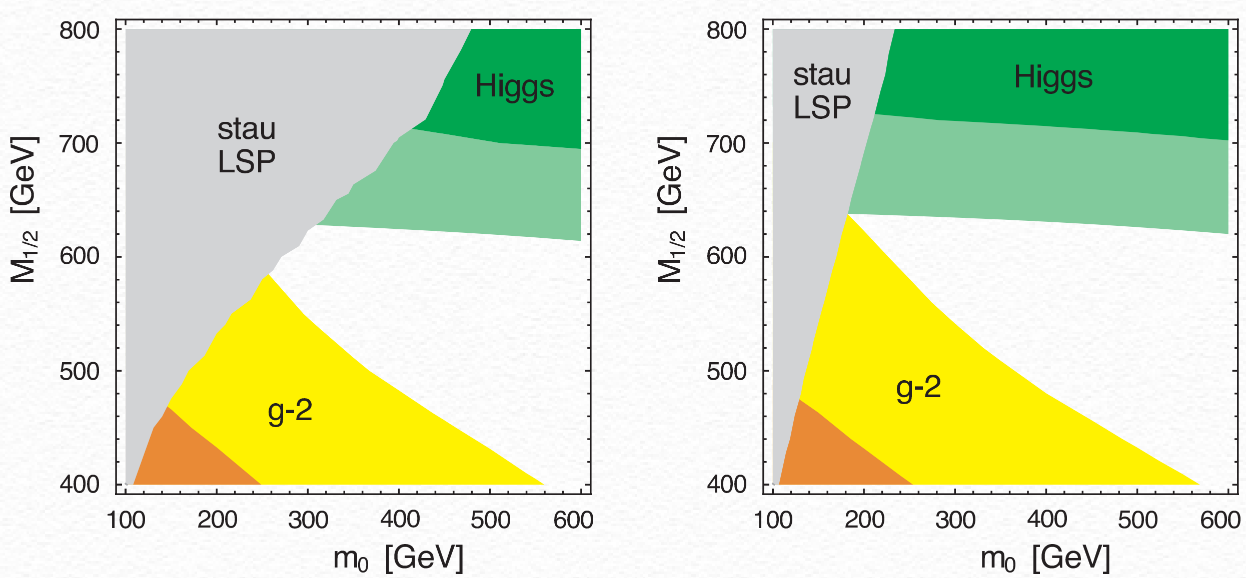
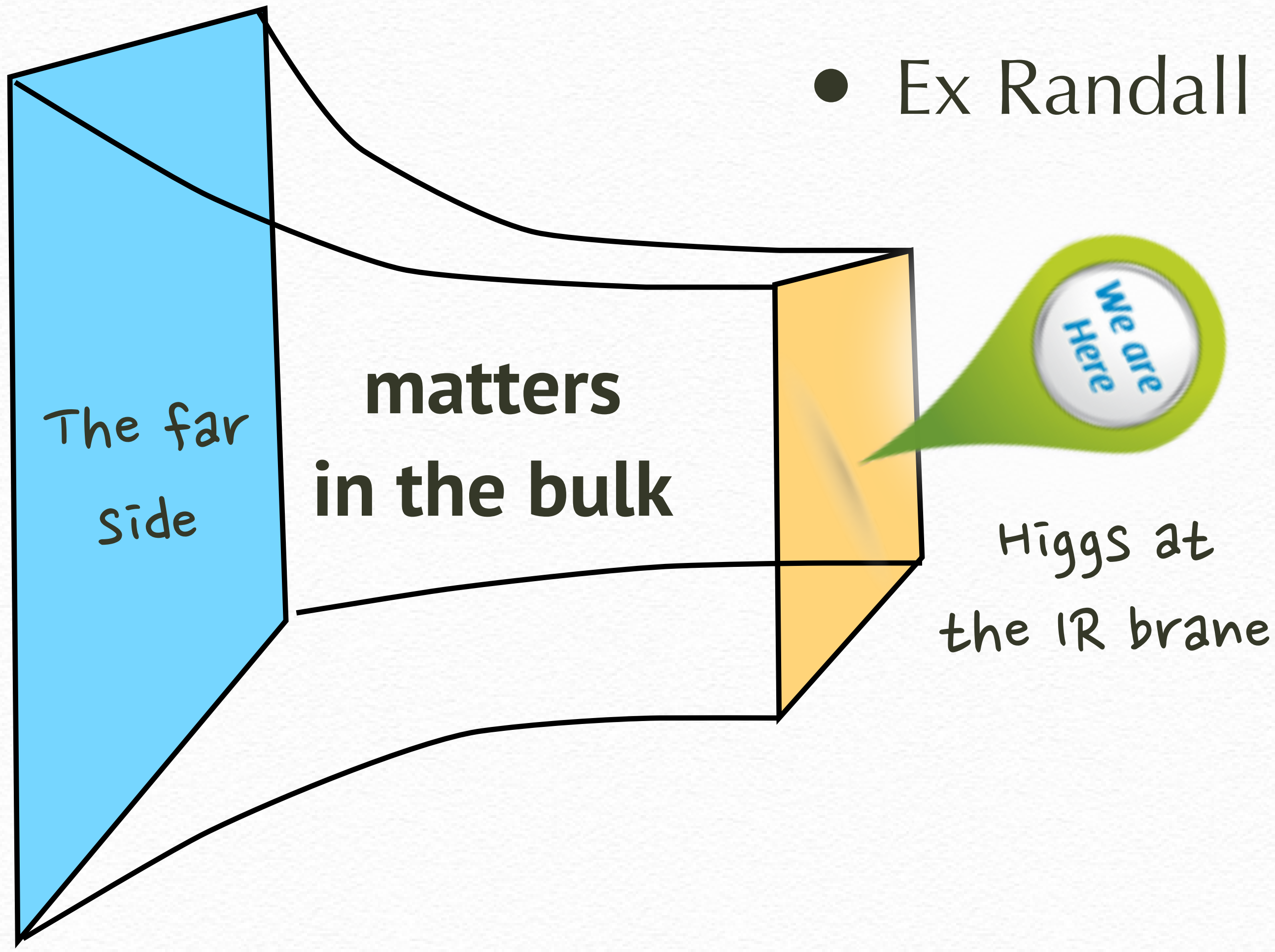
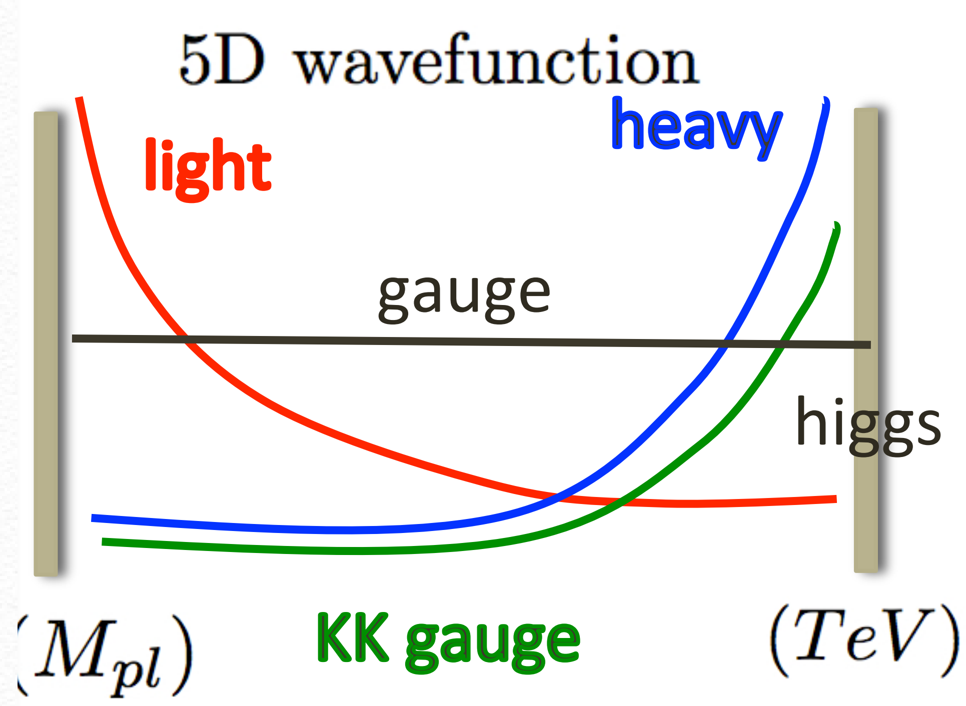


Figure 3: Contours of the Higgs mass and the muon $g-2$ are shown. The Higgs mass are maximized by choosing A_0 and A_u appropriately under the Br($\bar{B} \to X_s\gamma$) constraint in the CMSSM models (left) and the extension (right), respectively ("m_h-max scenario"). In the dark green region, the Higgs mass is 124 – 126 GeV, and it becomes larger than 124 GeV in the light green region once the uncertainties are included. In the orange (yellow) regions, the muon $g-2$ is explained at the 1σ (2σ) level. The LSP is the (lighter) stau in the upper-left shaded region, while the lightest neutralino in the rest.

Other new physics?

- Ex Randall Sundrums model

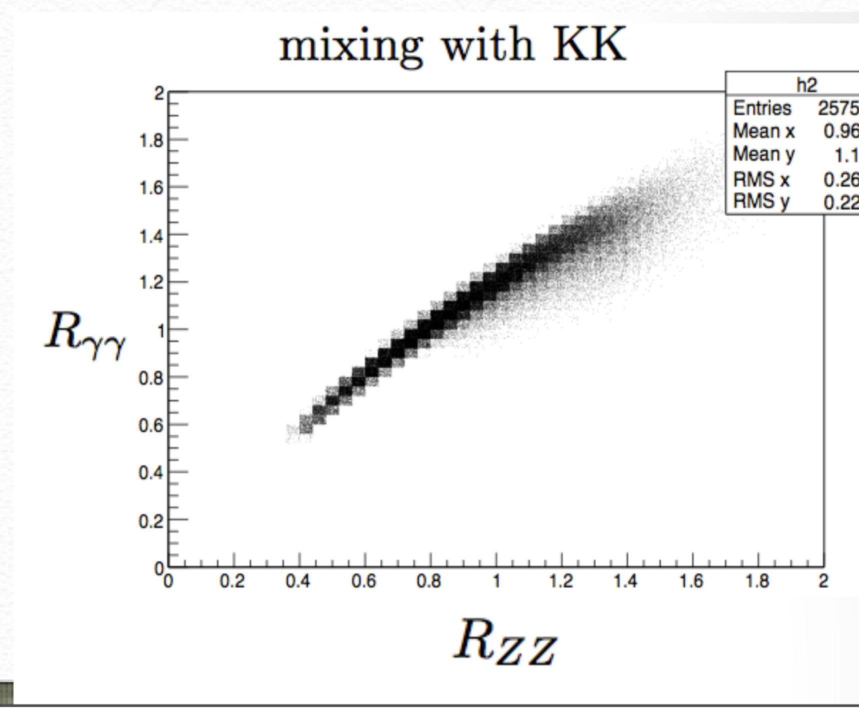




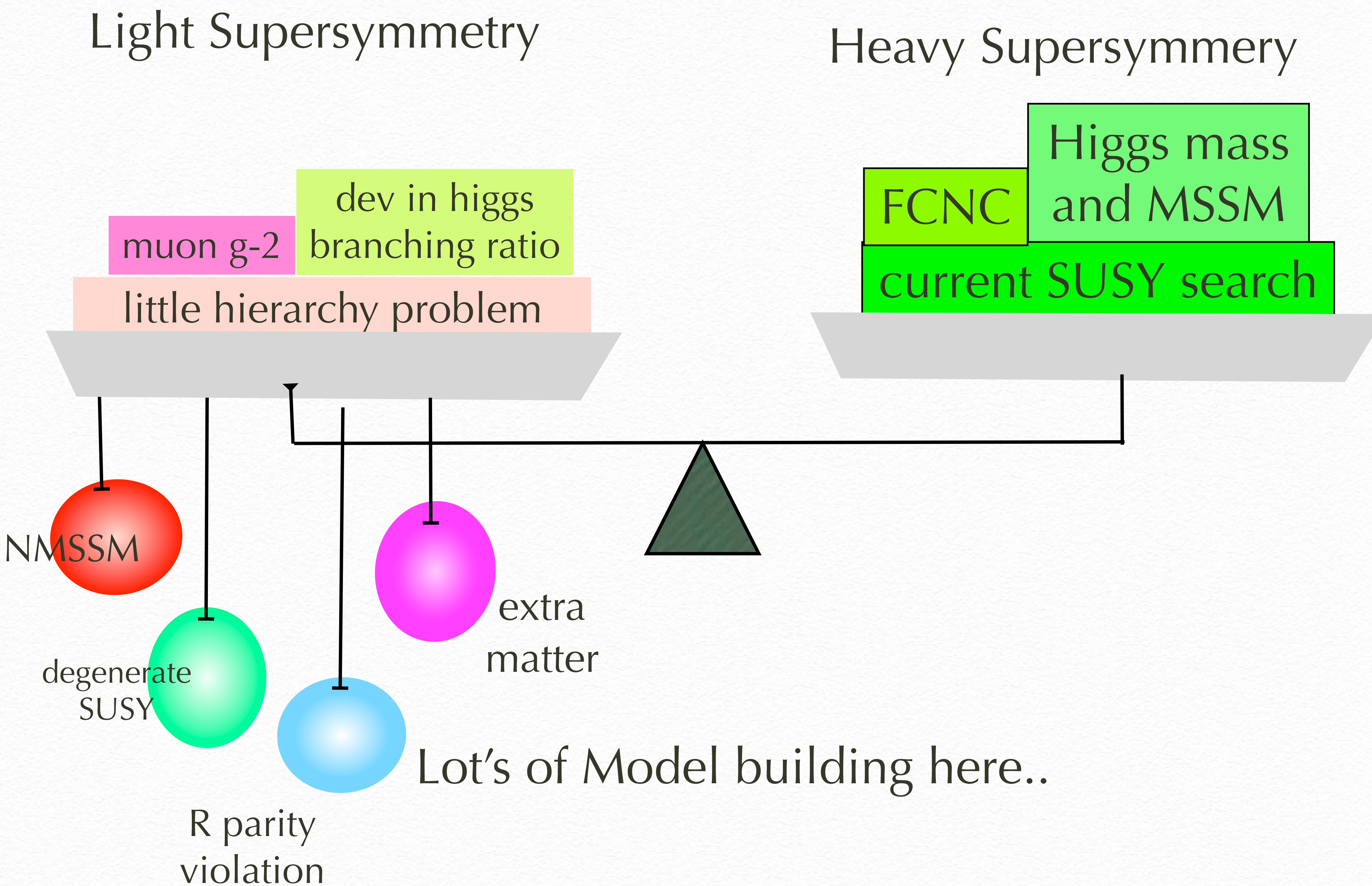
huge contribution to gg→h and h→γγ process

+mixing between radion(the 5th direction mode) and higgs boson

$$\mathcal{L}_\xi = \sqrt{g_{\rm ind}}\,\xi R(g_{\rm ind}) H^\dagger H$$



Mind of some theorists



“really nothing so far
(except the SM higgs boson) ”

“Is this a dead end of particle physics?”

My impression is different

Hadron collider searches:past and now

- To calculate SUSY background, we need to know W, t, Z with multiple jets in the final state. In 90's: we did not know how to calculate the processes appropriately for the hadron collider. "I do not trust hadron collider physics" was typical attitudes in e^+e^-collider funs.
  - It took very long time to get limit from hadron collider data, and there were fake discovery as well (famous SPS1a...)

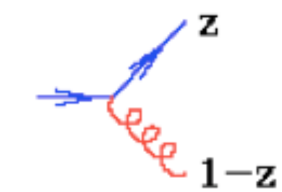
photo 1972

- **Progress in "Matching" and NLO,** we have better background prediction now.
- We can "exclude" the model parameters rather convincingly , and we do not "discover" much unless we comes to **the point to discover**.

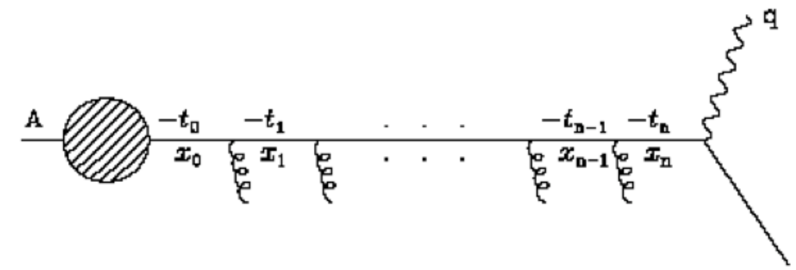
Parton shower and hard process

- MC simulation for hadron collider roughly divided into three parts

$$d\sigma_{n+1} = d\sigma_n \frac{dt}{t} dz \frac{\alpha_s}{2\pi} \widehat{P}_{ba}(z)$$

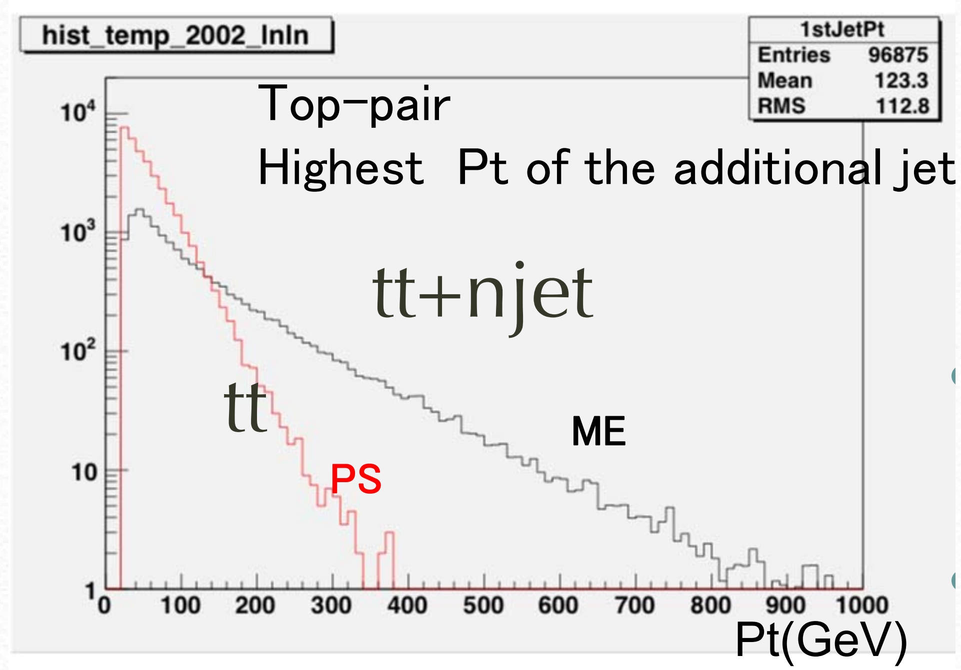


  - "hard process" gg→H, gg, qq→SUSY..



  - Initial/final state radiation: multiple emission of **collinear gluon and quarks**. often treated by parton shower approximation (multiple emission summed.

- Background: QCD process with multiple **hard jets**. ex: process of W+n hard parton: some of the hard partons overlap with parton showers. "double counting problem"

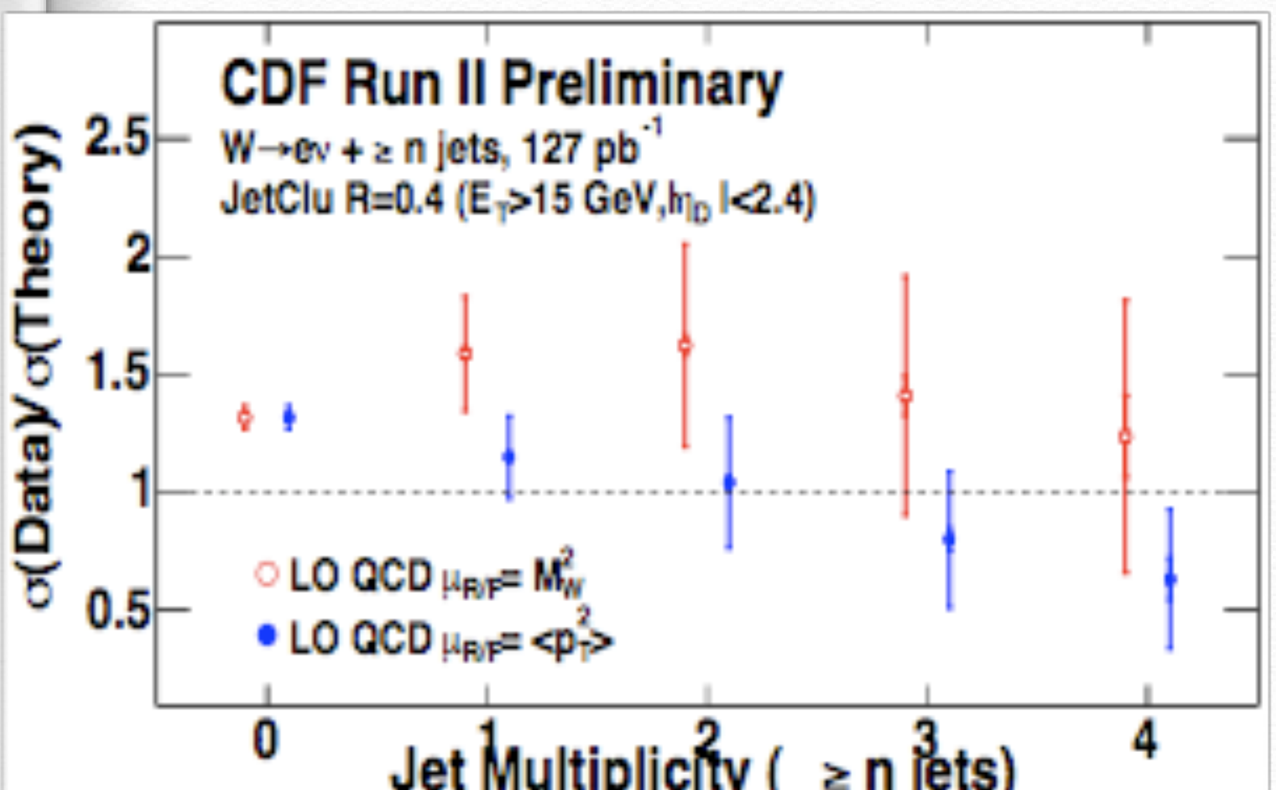


- "Maching" is a consitent treatment to veto the overlap between hard and soft process.

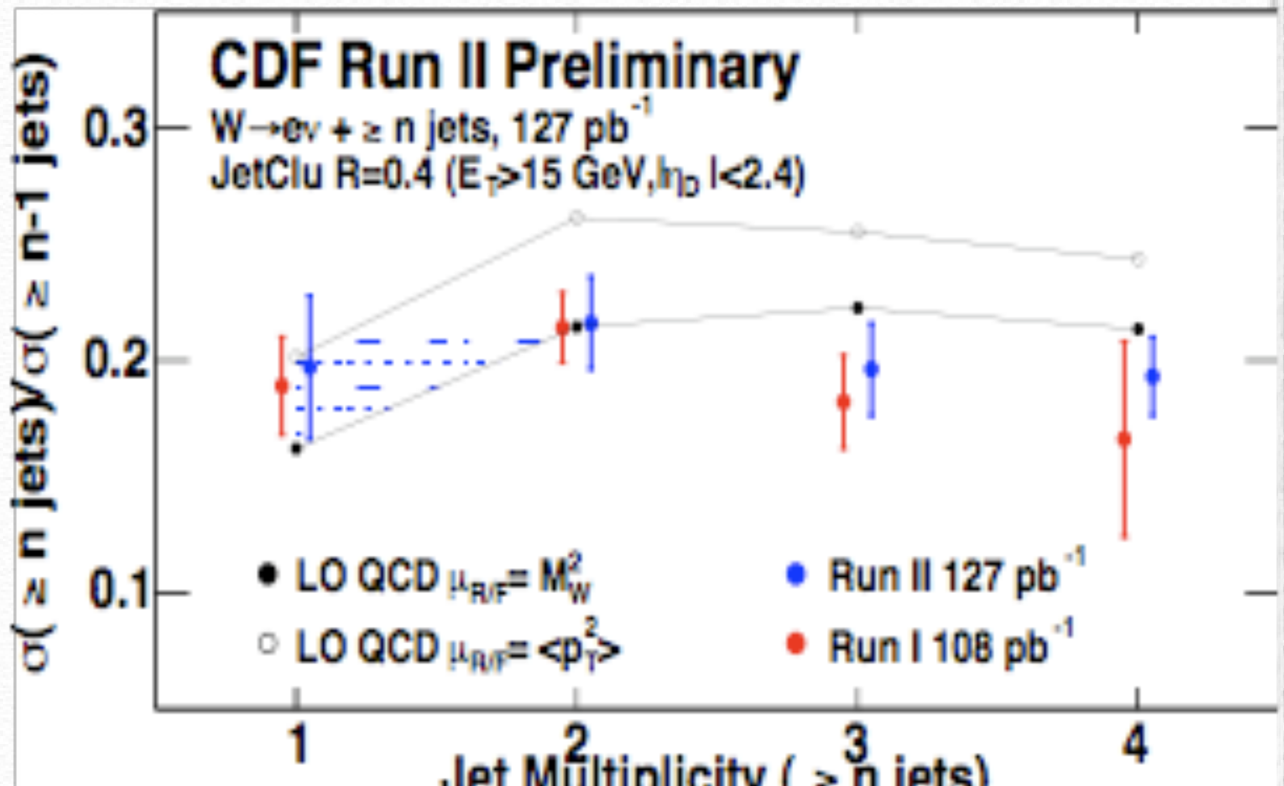
W+jets (leading SUSY BG at 7TeV)

Data vs Theory in 2003

Data vs Theory



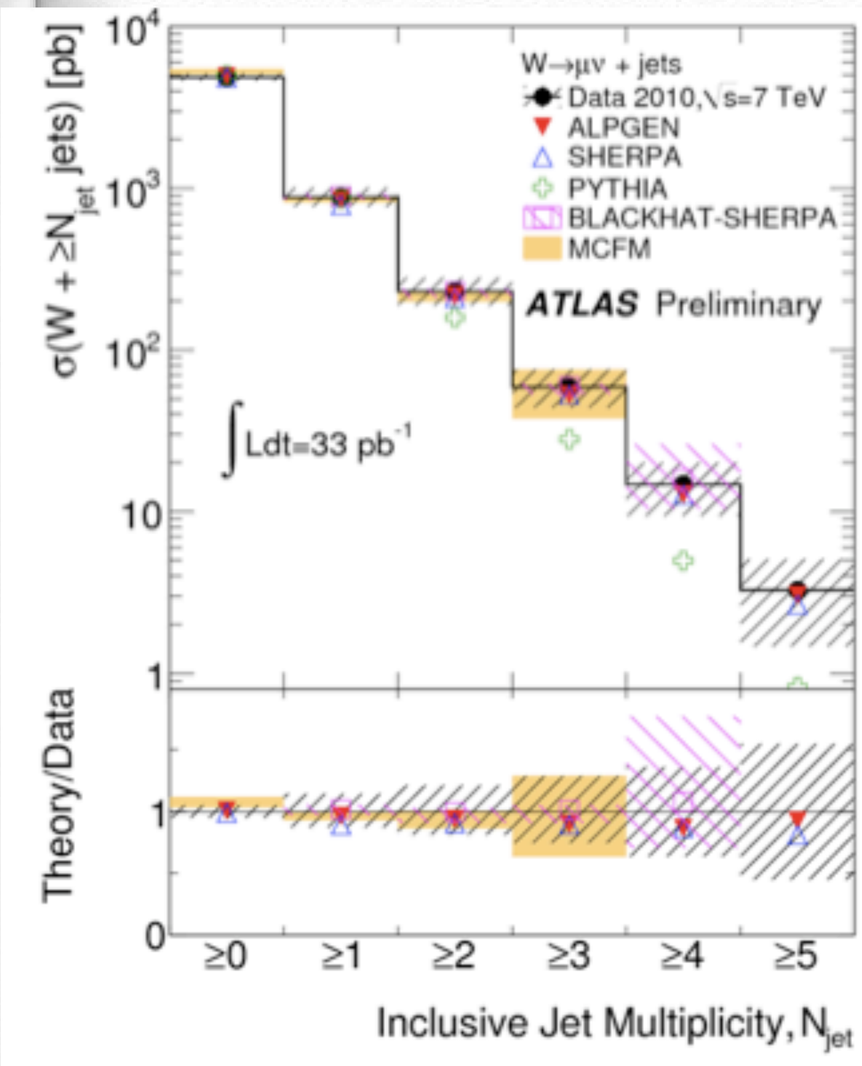
Ratio of Cross-sections

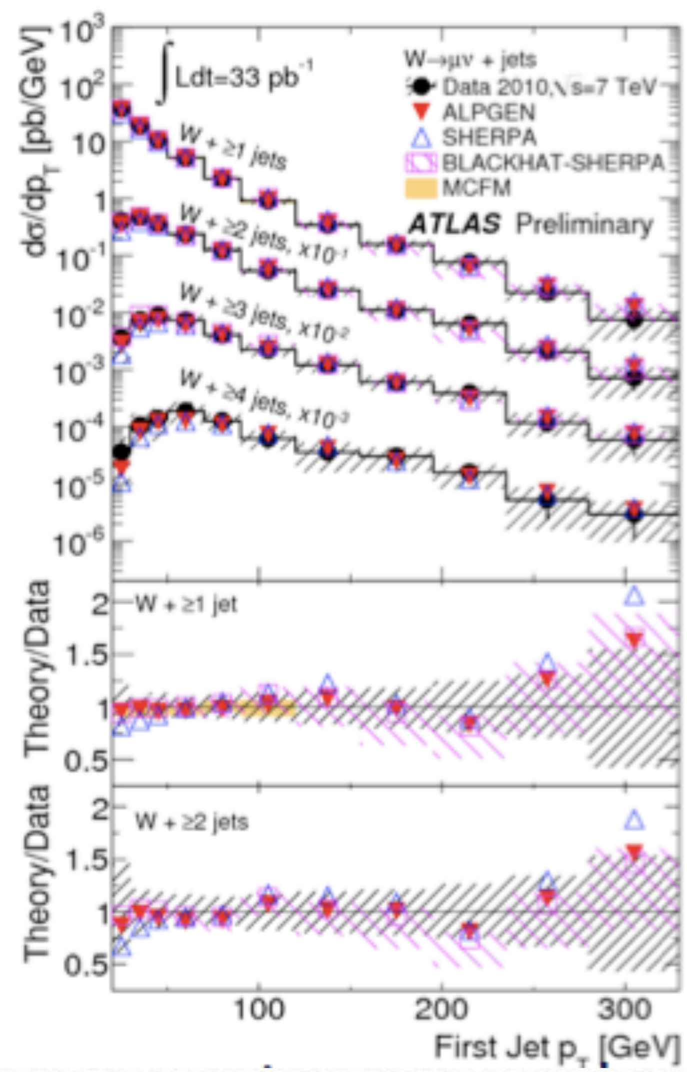


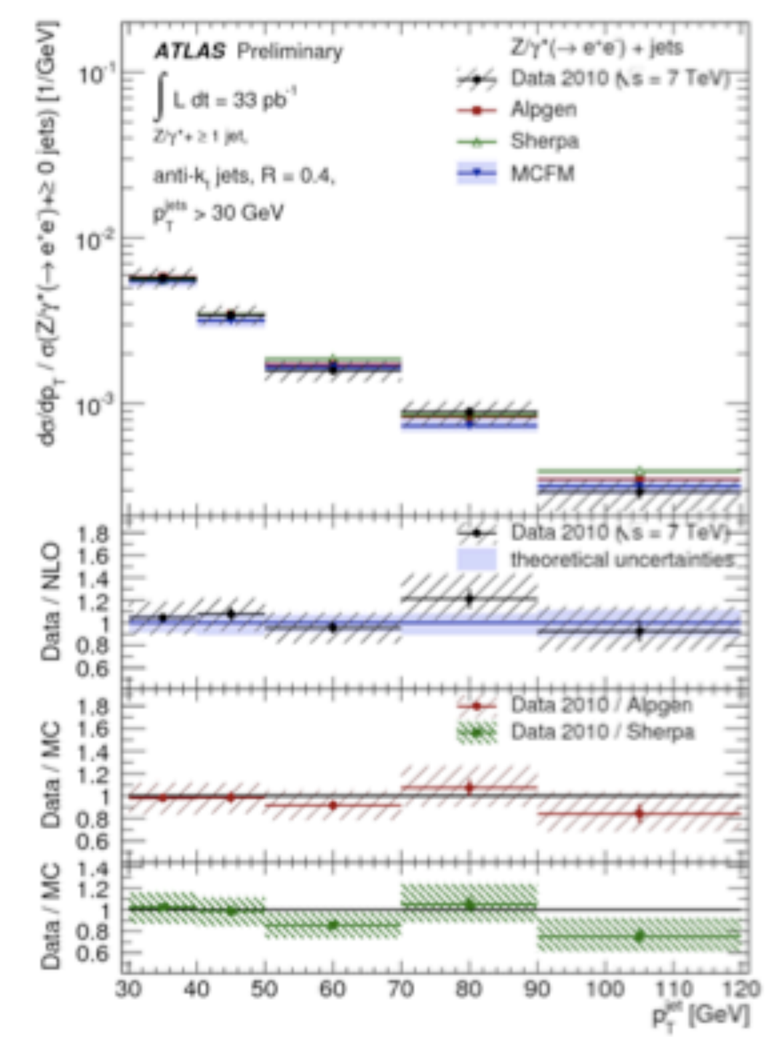
This allows estimate of background with "confidence "

W+jets (leading SUSY BG at 7TeV)

Data vs Theory in 2011

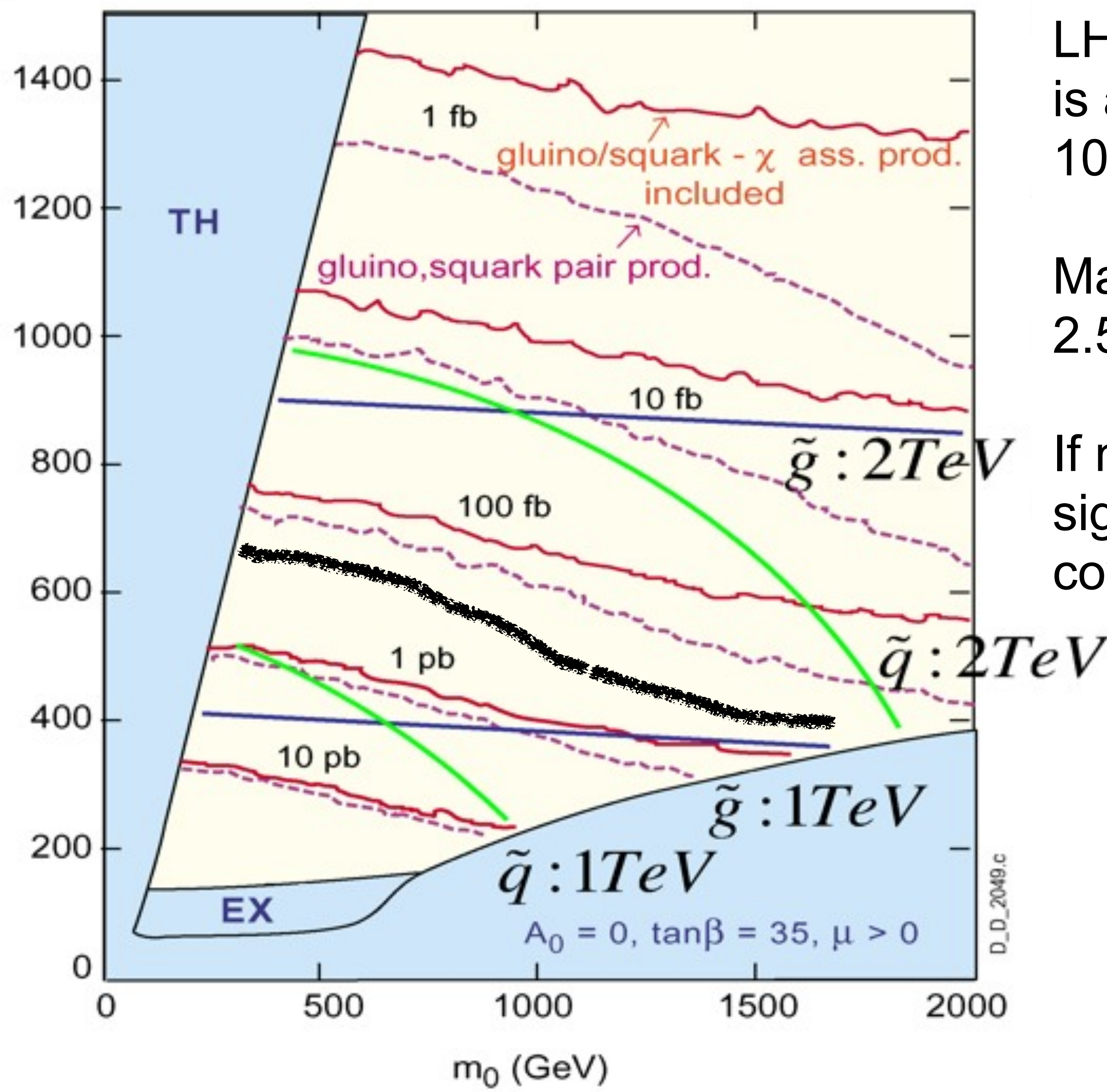






This allows estimate of background with "confidence "

cross section at 13TeV run



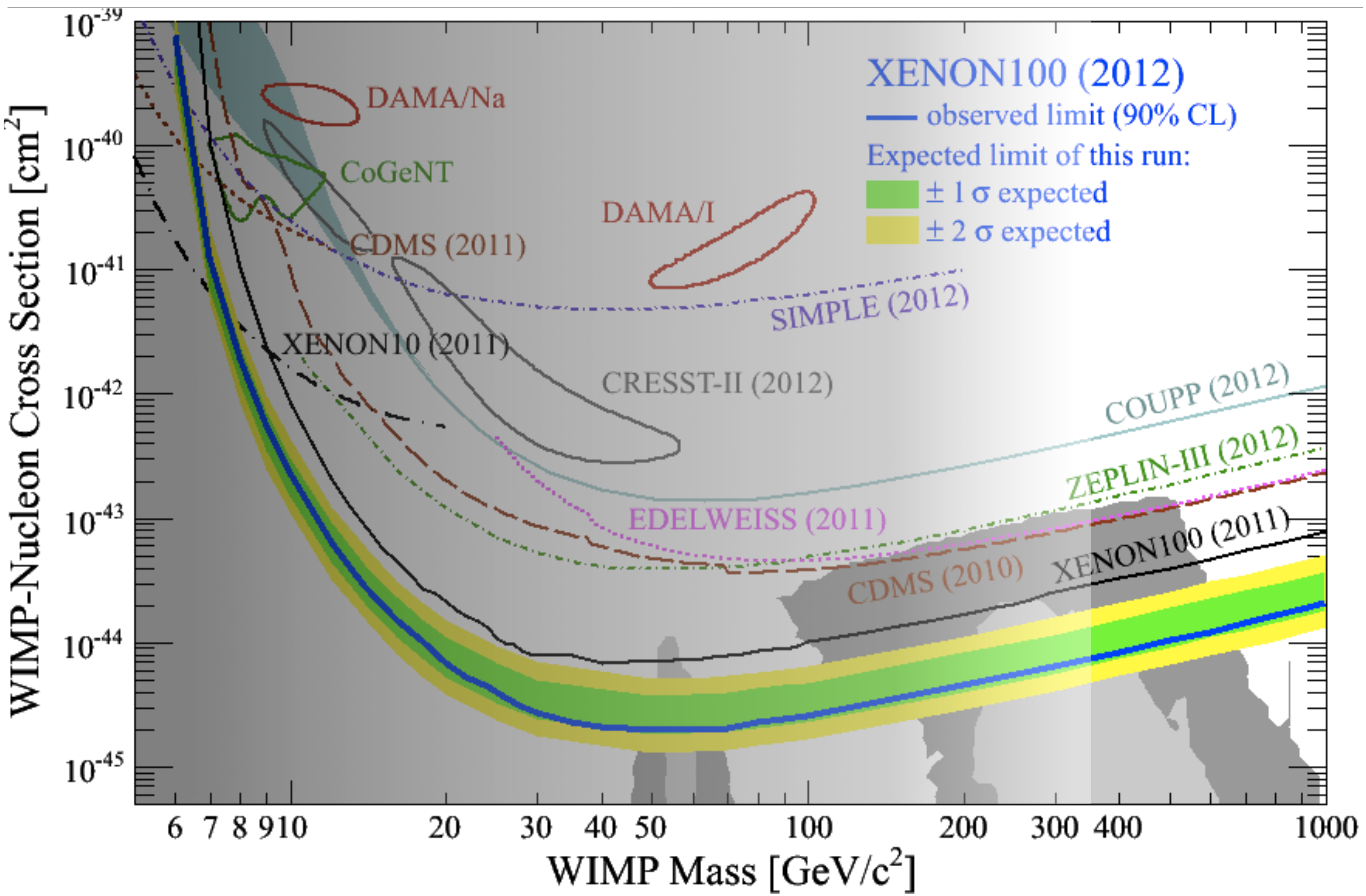
LHC at 13TeV max total cross section is around
100 fb-1→1000 events

Max reach will be around 10fb to 1fb
2.5TeV

If nature takes supersymmetry, significant parameter space will be covered by the 13TeV run

Study of Higgs sector is also very important O(10%) measurement of Branches
e+e- collider O(1%)

Direct search will be serious constraint this year



Upper Limit (90% C.L.) is 2 x 10^{-45} cm^2 for 55 GeV/c^2 WIMP waiting for new data to decide the direction

with LHC at 13TeV, it will have a great fall ...

To where?

waiting for new data to decide the direction

with LHC at 13TeV, it will have a great fall ...

To where?