TeV Scale Mirage Mediation with Vector-like Quark

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Problem of MSSM (1)

- In MSSM higgs quartic coupling is given by gauge coupling

$$\lambda_H = \frac{1}{8}\left(g^2 + g'^2\right)$$

- $\rightarrow$ at tree level, higgs mass is highly constrained

$$m_{h^0} < |m_Z \cos(2\beta)| \qquad m_Z = 91\,\text{GeV} \quad \tan\beta = \frac{\langle H_u^0 \rangle}{\langle H_d^0 \rangle}$$

- There are some quantum collection

$$m_{h^0}^2 \approx m_Z^2 \cos^2(2\beta) + \frac{3y_t^2 m_t^2}{4\pi^2} \ln\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right)$$
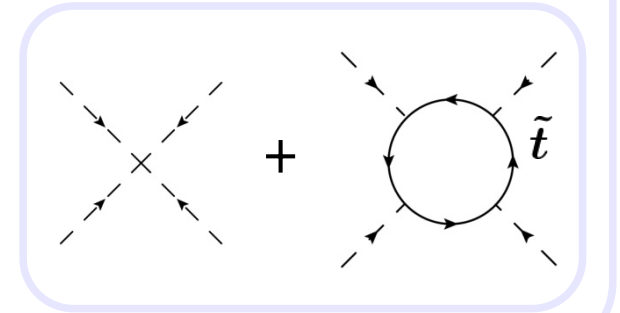
[Y.Okada, M.Yamaguchi and T.Yanagida, Prog. Theor. Phys. 85, 1 (1991)]

- BUT 125GeV Higgs boson mass is still difficult

Problem of MSSM (2)

- From potential minimization condition

$$m_Z^2 \approx -2\left(m_{H_u}^2 + |\mu|^2\right)$$

m_{H_u}: parameter rerated to SUSY breaking
$\rightarrow$ order of SUSY particle ($\sim$TeV) ?

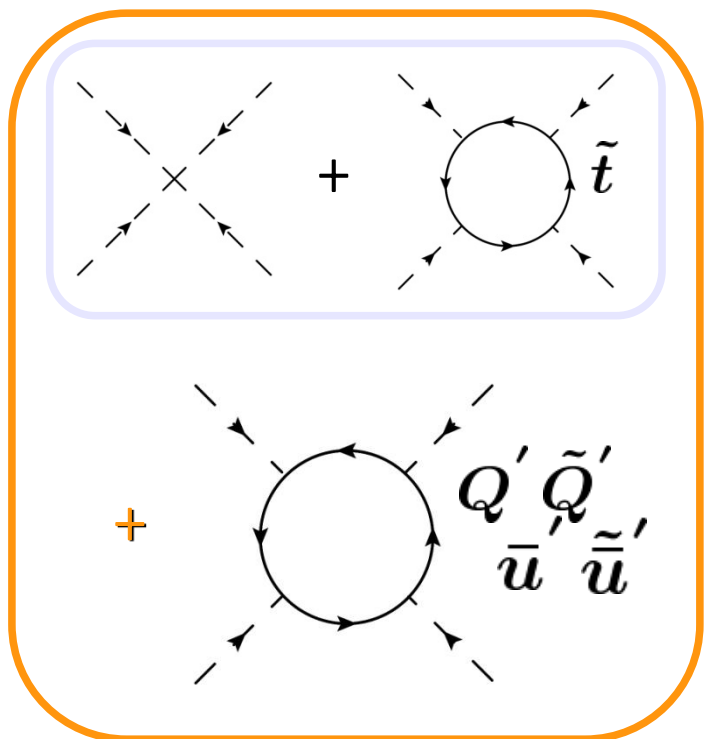μ : parameter which respects supersymmetry

Fine tuning between SUSY scale & EW scale is needed
(Little hierarchy problem)

Model

- MSSM + Vector-like quark [N.V.Krasnikov, Phys. Lett. B 312 133-136]

$$W = W_{\mathrm{MSSM}} + \underline{M\psi_{10}'\psi_{\overline{10}}'} + \underline{y'\bar{u}'Q'H_u} \qquad \psi_{10}' \supset (\bar{u}', Q', \bar{e}')$$

Mass term   Yukawa interaction

- **Higgs mass**
→ Quantum collection from new heavy quarks raise Higgs mass

Little hierarchy problem

⟹ Adopt Mirage Mediation to solve little hierarchy problem
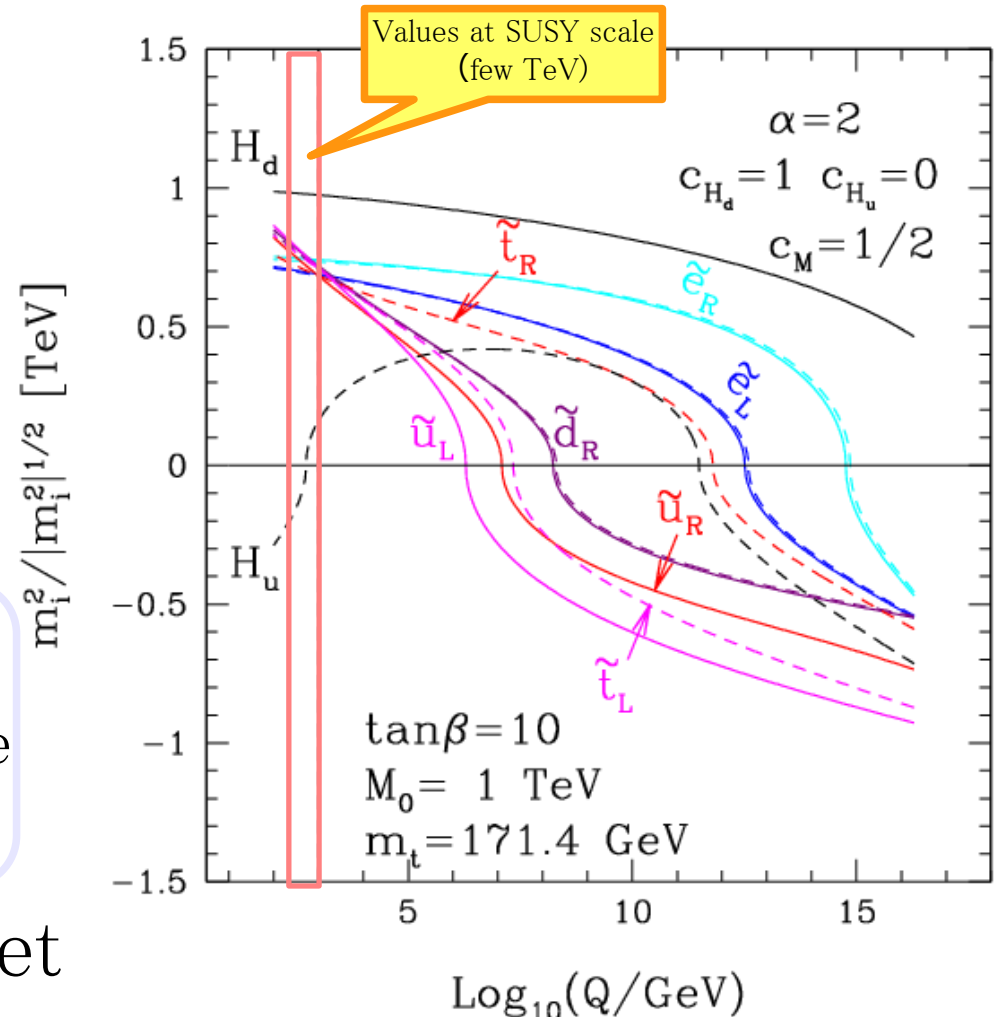
Mirage Mediation

- Mirage mediation
  Moduli mediation + Anomaly mediation

- Compressed mass parameters
- Small Higgs mass can be achieved
  → Natural explanation for
  little hierarchy problem

Requirement from mirage mediation

Masses of vector-like quarks should be
given by dimensionless parameter

→ vector-like quarks must get
their mass from singlet VEV

Values at SUSY scale
(few TeV)

$\alpha=2$
$c_{H_d}=1 \quad c_{H_u}=0$
$c_M=1/2$

$\tan\beta=10$
$M_0 = 1$ TeV
$m_t=171.4$ GeV

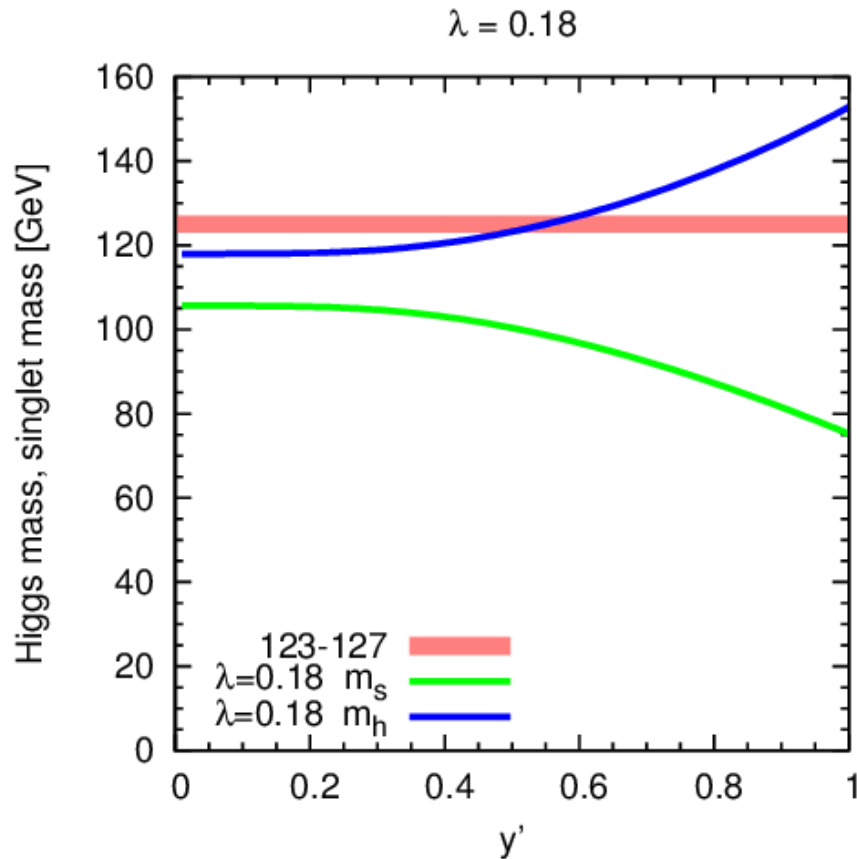[K.Choi, K.S.Jeong, K.Okumura, JHEP 09 (2005) 039]
[K.Choi, K.S.Jeong, T.Kobayashi, K.Okumura, Phys. Rev. D 75 095012]

$$W = W_{\mathrm{MSSM}} + \boxed{\lambda S \psi'_{10} \psi'_{\overline{10}}} + y' \bar{u}' Q' H_u + \boxed{\frac{\kappa}{3} S^3}$$
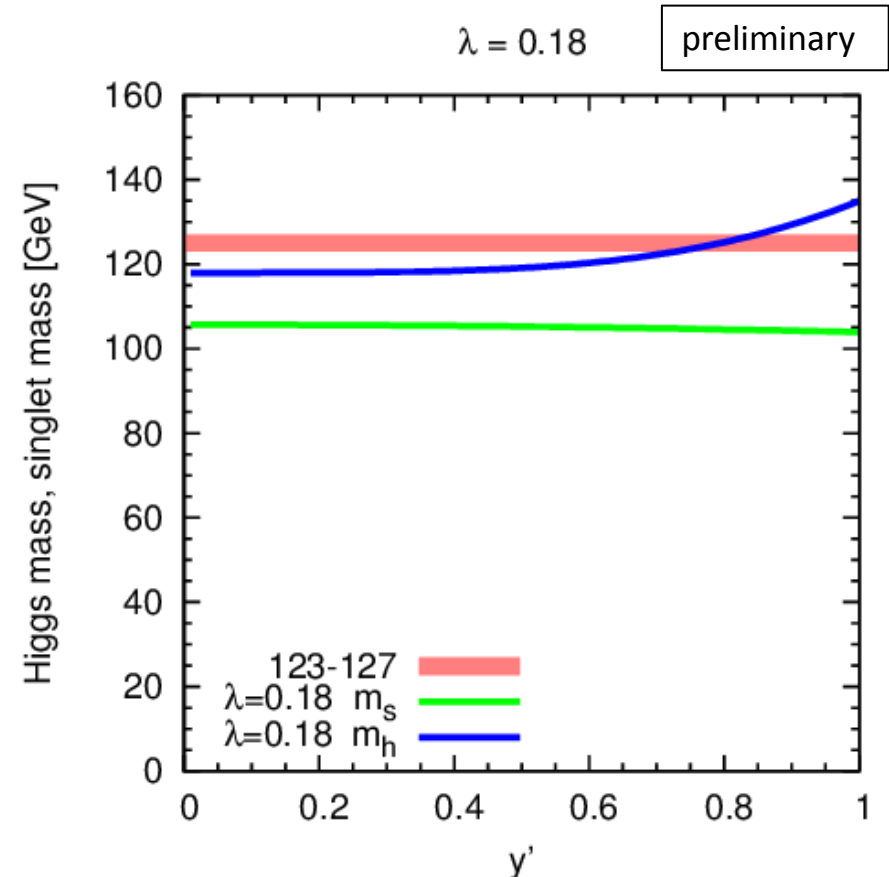
Analysis

- Set SUSY scale (2TeV)

- Determine singlet VEV $\langle S \rangle$ by 1-loop effective potential

- Calculate Higgs mass and vector-like quark mass at the vacuum

- Check some constraints (of Higgs sector) from collider experiments
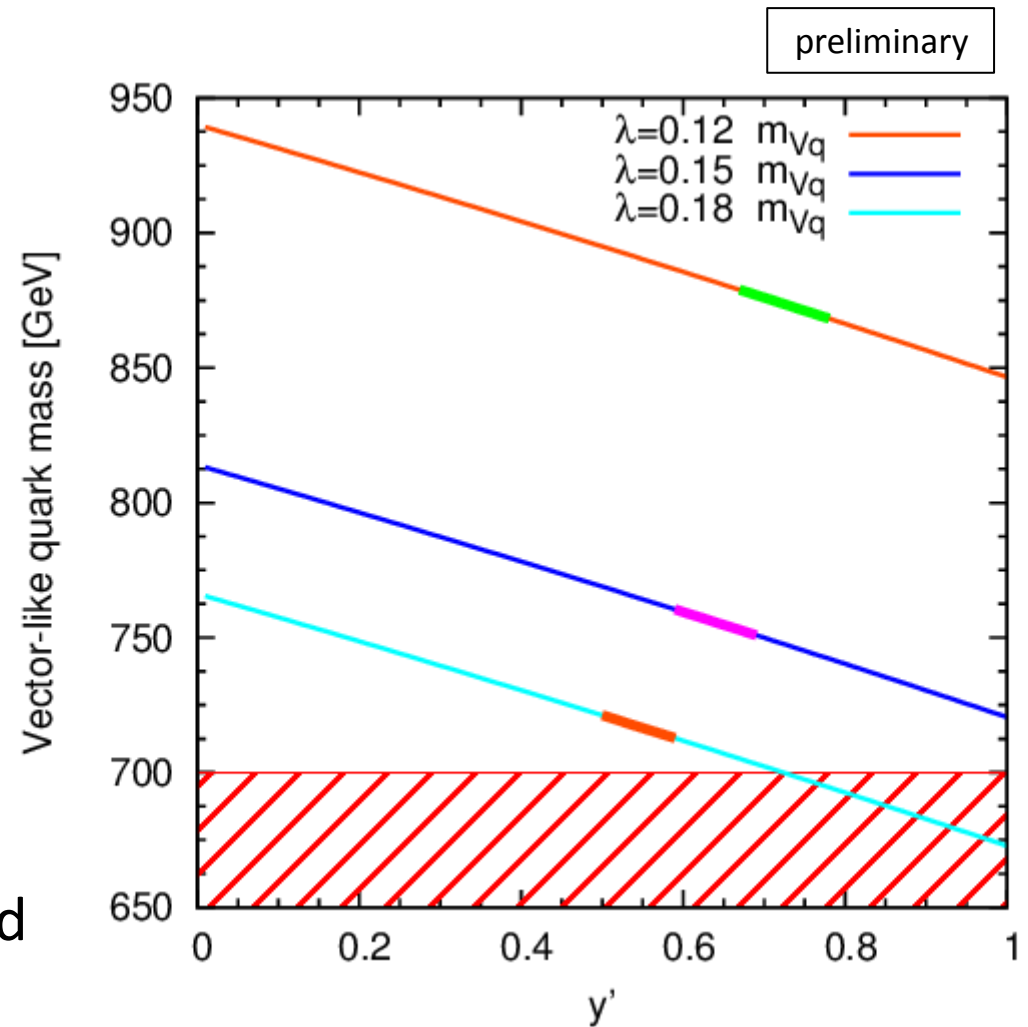
Higgs mass

With doublet-singlet mixing   Without the mixing

- SM-like higgs mass increase without higgs mixing

  : effect of vector-like quark

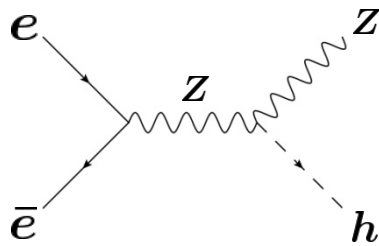- Mixing effect contribute higgs mass ～10GeV

Vector-like quark mass

- Showing lightest vector-like quark mass

- Red shaded area: rejected (lighter than 700GeV)

- Changed color region on the line : SM-like higgs mass is 125 ± 1 GeV

  $\rightarrow$ near the experimental bound

Vector-lilke quark can be discovered in near future

$Z^* \longrightarrow Z\, h$'
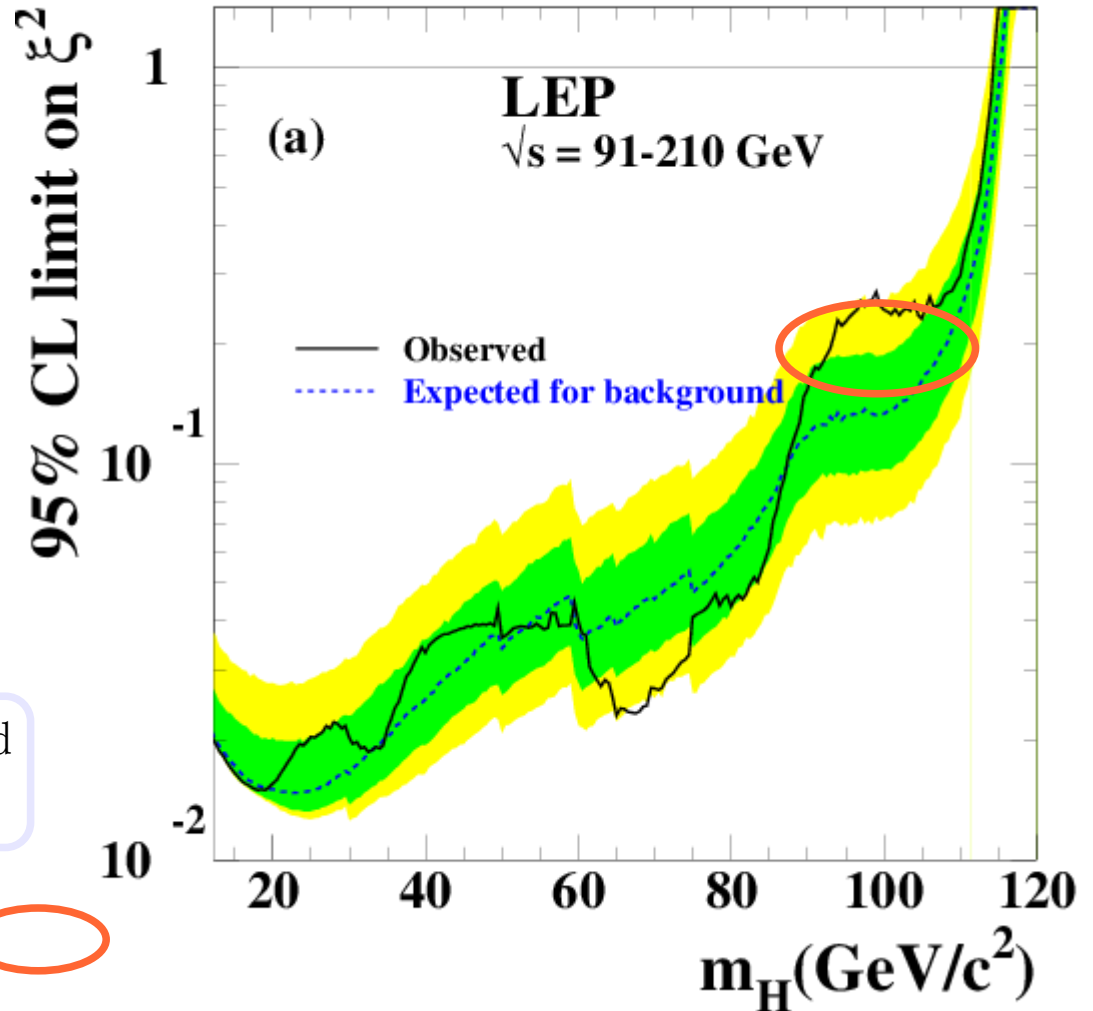
- Process of Higgs production at LEP

→depend on the coupling with Z

$$\frac{\Gamma(h_i \to ZZ)}{\Gamma(h_{\mathrm{SM}} \to ZZ)} = \xi_i^2 \text{ : experimental bound}$$

Dashed line : expected SM background
Solid line : observed value at LEP

difference to expected background at
→   new physics ?

[S. Schael et al. [ALEPH and DELPHI and L3 and OPAL Collaborations and LEP
Working Group for Higgs Boson Searches], Eur. Phys. J. C 47 (2006) 547 [arXiv:hep-ex/0602042]]

Z* → Z h'

•SM-like higgs mass
    : 125 ± 1 GeV
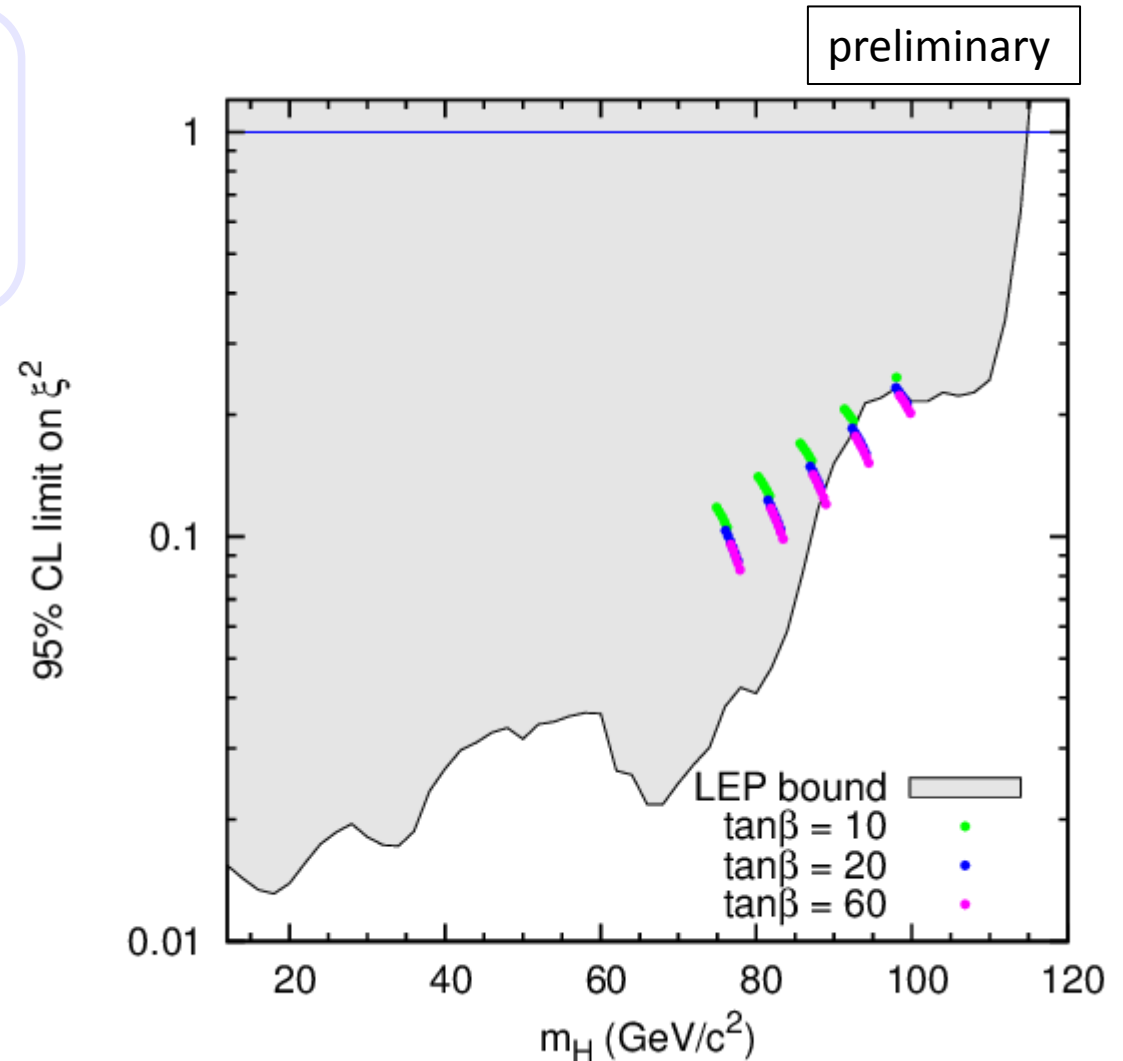•Lightest vector-like quark
    : over 700GeV

Relation between singlet-like
higgs mass and ξ^2

● : tan β = 10

● : tan β = 20

● : tan β = 60

Gray region : rejected

If singlet-like higgs is 90-100GeV,
the excess of LEP may be explained

preliminary

LEP bound
tanβ = 10
tanβ = 20
tanβ = 60

Summary

- 125GeV Higgs can be achieved with Vector-like quark

- Higgs mass is affected by not only quantum collection of new field but mixing effect with singlet

- Vector-like quark is 700-1000GeV and may be discovered near future

- Singlet-like higgs with mass 90-100GeV can explain the excess of Z* → Z h' at LEP experiment