Natural Higgsino DM

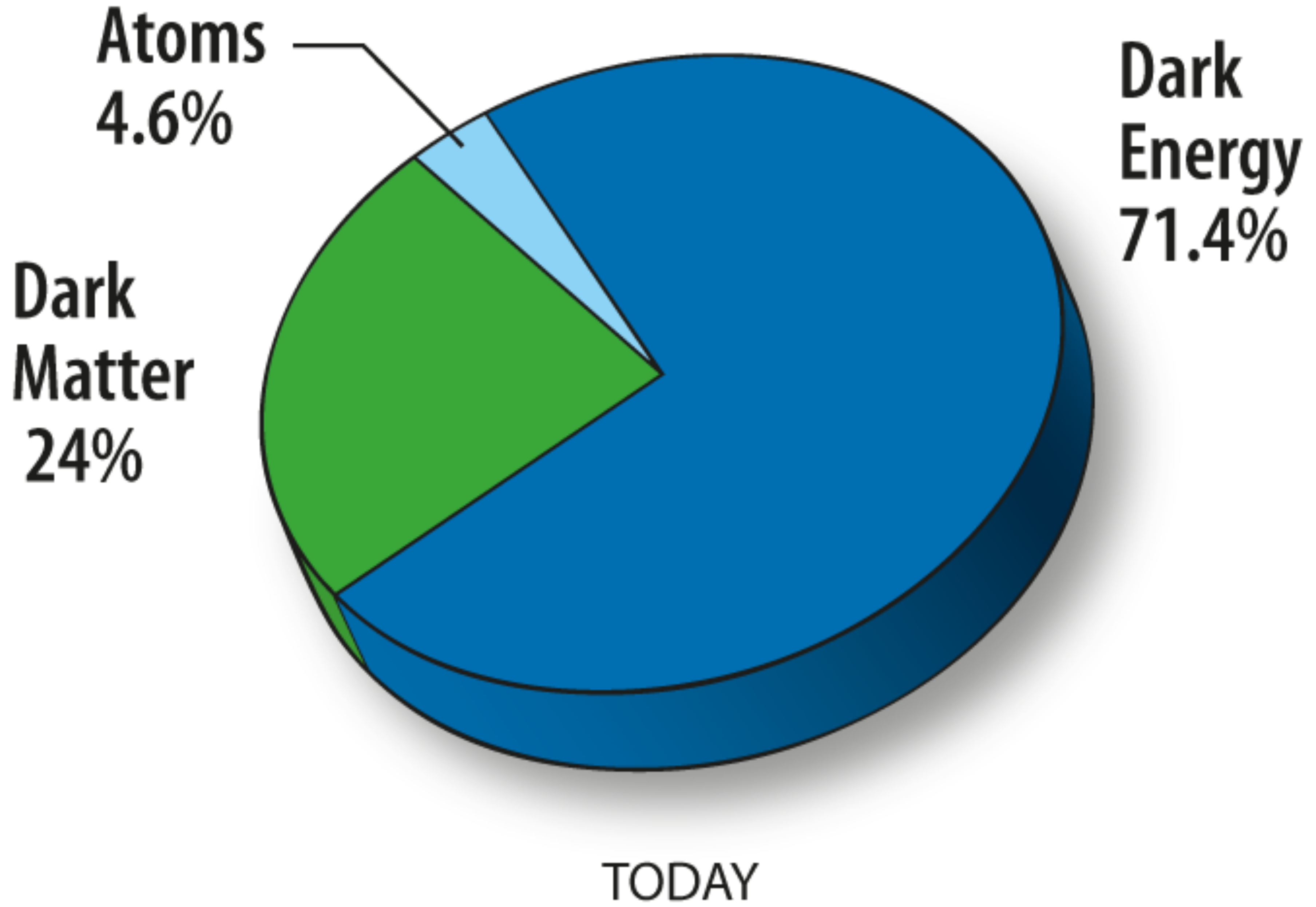
Antonio Delgado
University of Notre Dame

- Introduction: Higgsino DM
- The model: 5D with Scherk-Schwarz supersymmetry breaking.
- EWSB and Higgs mass condition
- Conclusion

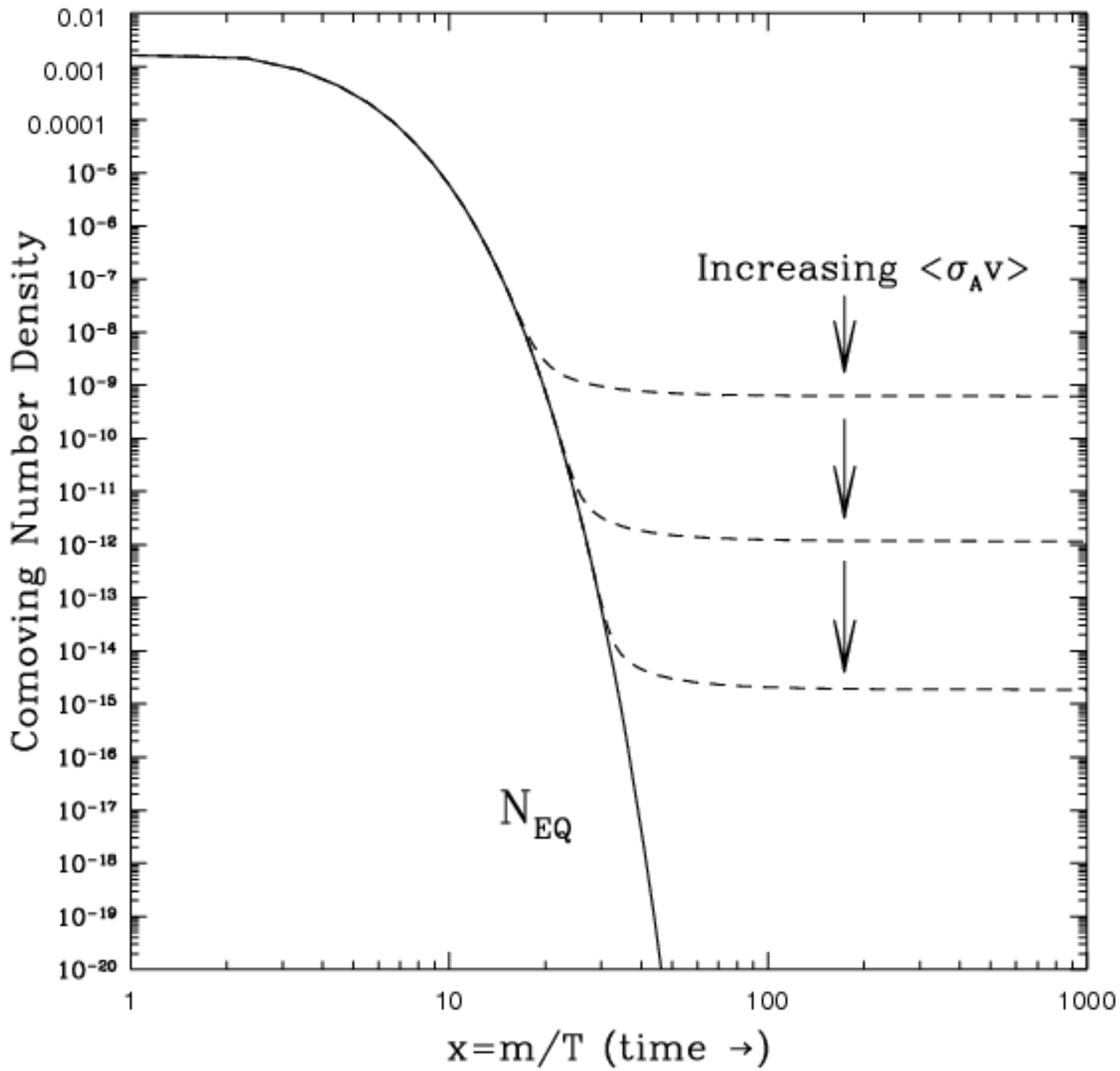
Based on arXiv: 1812.08019 with A. Martin and M. Quirós

In memoriam
Eduardo Pontón (1971-2019)

Introduction



- DM may be the most stablished reason for physics BSM

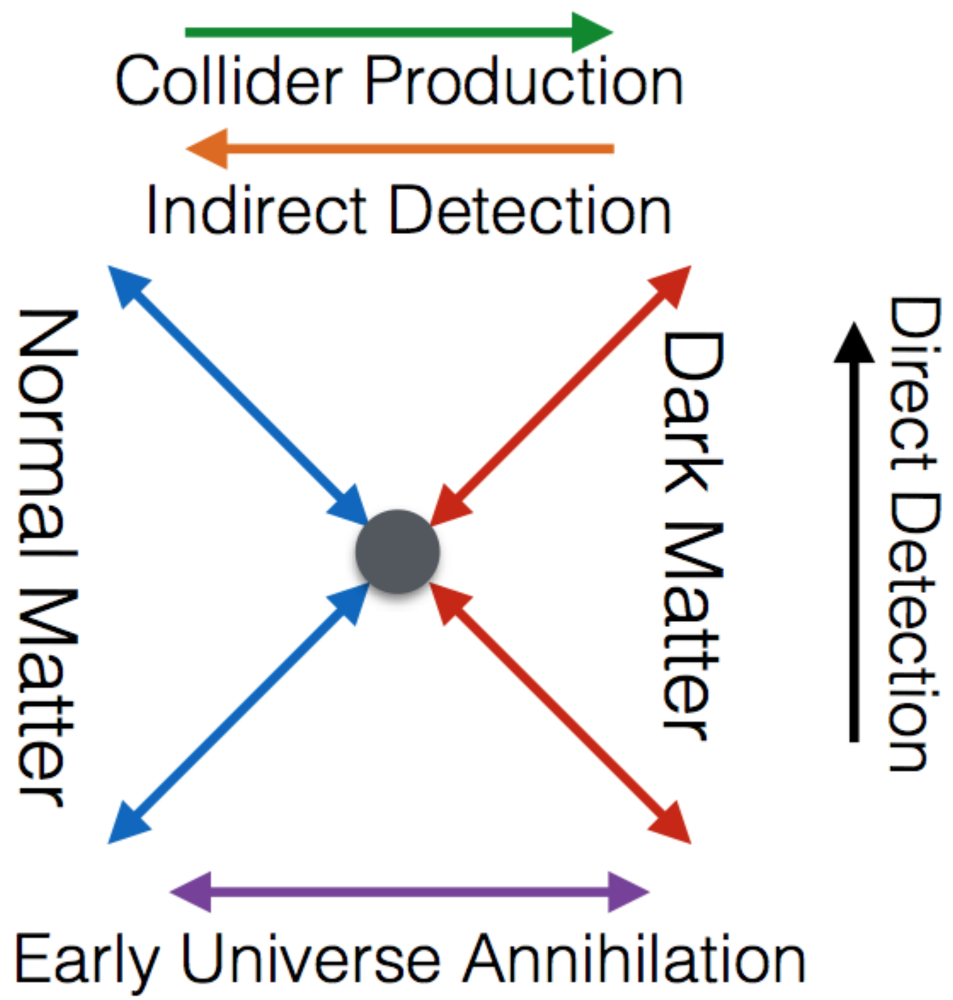


- The solution as a thermal relic it is very elegant as it depends very little on the details of the model.

- It turns out that a WIMP: a stable massive object with weak interactions and a mass around the EW scale reproduces the observed relic abundance.

$$\Omega h^2 \simeq 0.118$$

- It has interesting experimental consequences.



- On the other hand, the hierarchy problem, can be addressed with supersymmetry.

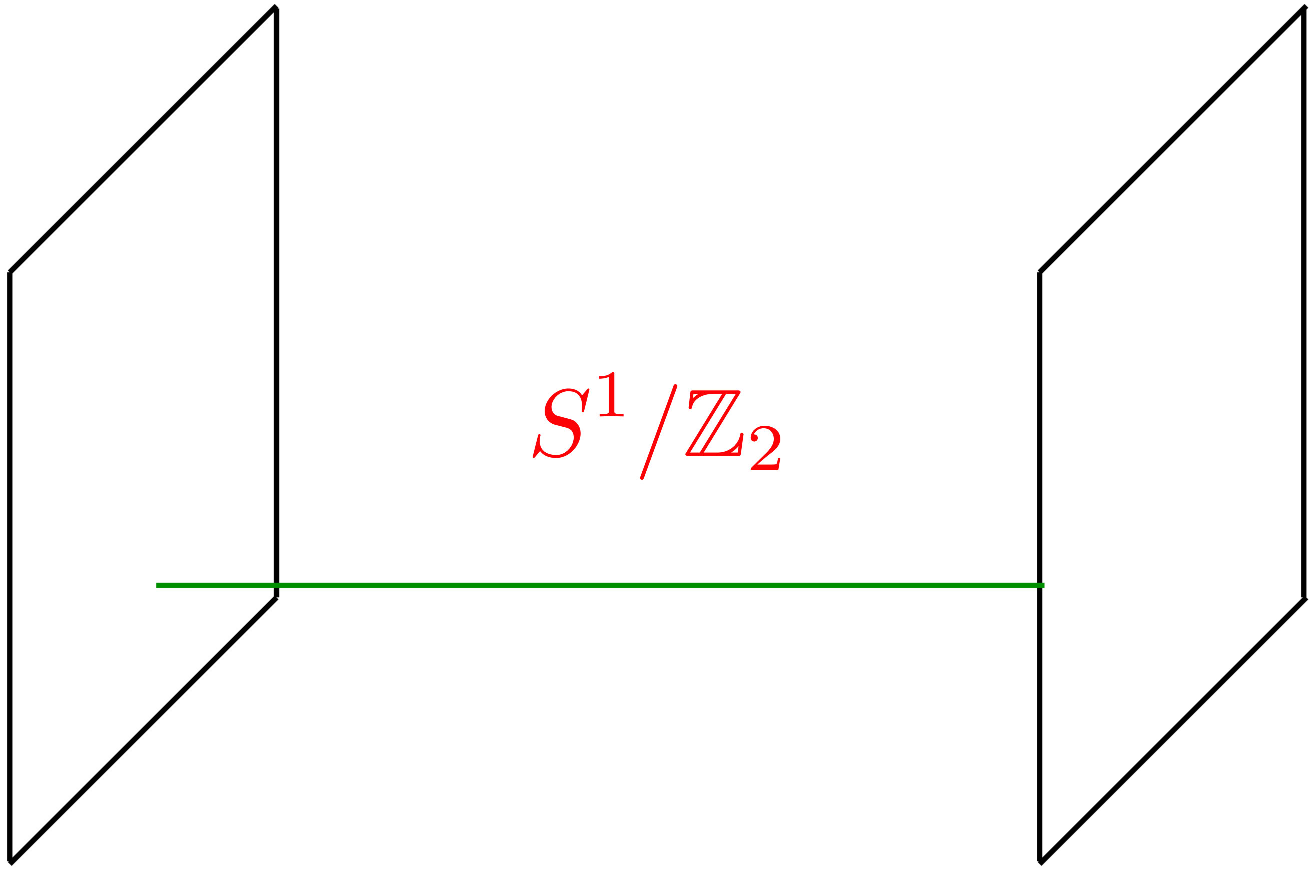
- Merging both ideas, SUSY & DM, is possible and quite exciting.

- Among the usual candidates for DM in the MSSM (neutralinos) the one with less constrains (specially from direct detections) is a pure Higgsino with mass ~1.1-1.2 TeV.

- In this talk I will build a model with just there free parameters that achieves the following:
    - Correct relic abundance with a (mostly pure) Higgsino
    - Correct EWSB
    - Correct mass of the Higgs
    - In agreement with all experimental bounds.

The model

- The model is 5D extension of the MSSM.
- The extra dimension of size πR is compactified on an orbifold S^1/Z_2
- The minimal supersymmetric content in 5D is equivalent to $N=2$
- The discrete symmetry Z_2 breaks half of the super symmetries making all fields either even/odd



- All fields live in the bulk and from N=2 representations
- Fields are decomposed in modes and ∂_5 terms become masses

- The theory in the bulk has a $SU(2)_R$ symmetry under which the gauginos in vector multiplets and scalars in hypermultiplets transforms non trivially.

- Like in the MSSM, there are 2 Higgs hypermultiplets which are related by a global $SU(2)_H$ symmetry

- By relating the boundary conditions in both end points of the orbifold using $SU(2)_R$ and $SU(2)_H$ one can generate masses for the, otherwise massless, zero mode that we will identify as the usual MSSM fields.

- This amounts for a non-trivial twist related to phases (q_R,q_H)

$$\mathbb{V} = (V_M, \Sigma, \lambda^i) \equiv (V_\mu, \lambda_L^1)^+ \oplus (\Sigma + iV_5, \lambda_L^2)^-$$

- Two Majorana gauginos $\lambda^{(\pm n)} = (\lambda_L^{1(n)} \pm \lambda_L^{2(n)})/\sqrt{2}$, with masses $|q_R \pm n|/R$.

Gauge bosons ($V^{(n)}$) with mass n/R

- Decomposition of Gauge multiplets

$$\mathbb{Q}_L = (\widetilde{Q}, \widetilde{Q}^c, q) \equiv (\widetilde{Q}, q_L)^+ \oplus (\widetilde{Q}^c, q_R)^-$$

two complex scalars $Q^{(\pm n)} = (\widetilde{Q}^{(n)} \pm \widetilde{Q}^{c(n)})/\sqrt{2}$ $\qquad (q_R \pm n)^2/R^2$

Chiral fermions ($q_L^{(n)}$) with mass n/R

- Decomposition for matter hypermultiplets

$$\mathbb{H}^1 \equiv (H_1^1, \Psi_R^1)^+ \oplus (H_2^1, \Psi_L^1)^-$$

$$\mathbb{H}^2 \equiv (H_2^2, \Psi_L^2)^+ \oplus (H_1^2, \Psi_R^2)^-$$

- Two Dirac Higgsinos $\tilde{H}^{(\pm n)} = (\Psi^{1(n)} \pm \Psi^{2(n)})/\sqrt{2}$, with masses $|q_H \pm n|/R$.
- Two Higgses $h^{(\pm n)} = \left[H_1^{1(n)} + H_2^{2(n)} \mp (H_2^{1(n)} - H_1^{2(n)}\right]/2$, with masses $|q_R - q_H \pm n|/R$.
- Two Higgses $H^{(\pm n)} = \left[H_1^{1(n)} - H_2^{2(n)} \mp (H_2^{1(n)} + H_1^{2(n)}\right]/2$, with masses $|q_R + q_H \pm n|/R$.

- Decomposition of Higgs hypermultiplets

$$W = \left(\widehat{h}_t \, \mathcal{Q}_L \, \mathcal{H}_2 \, \mathcal{U}_R + \widehat{h}_b \, \mathcal{Q}_L \, \mathcal{H}_1 \, \mathcal{D}_R + \widehat{h}_\tau \mathcal{L}_L \mathcal{H}_1 \mathcal{E}_R \right) \; \delta(y)$$

- In order to give masses to chiral fermions we need a N=1 superpotential in one of the branes.

- We are going to identify the physical Higgs with $h^{(0)}$ whose mass is $(q_R-q_H)/R$

- We have to make sure that there is no other scalar that could potentially get a vev. This is to make sure we are in the alignment limit.

- Since there is a periodicity we are going to assume that $q_R, q_H<1/2$

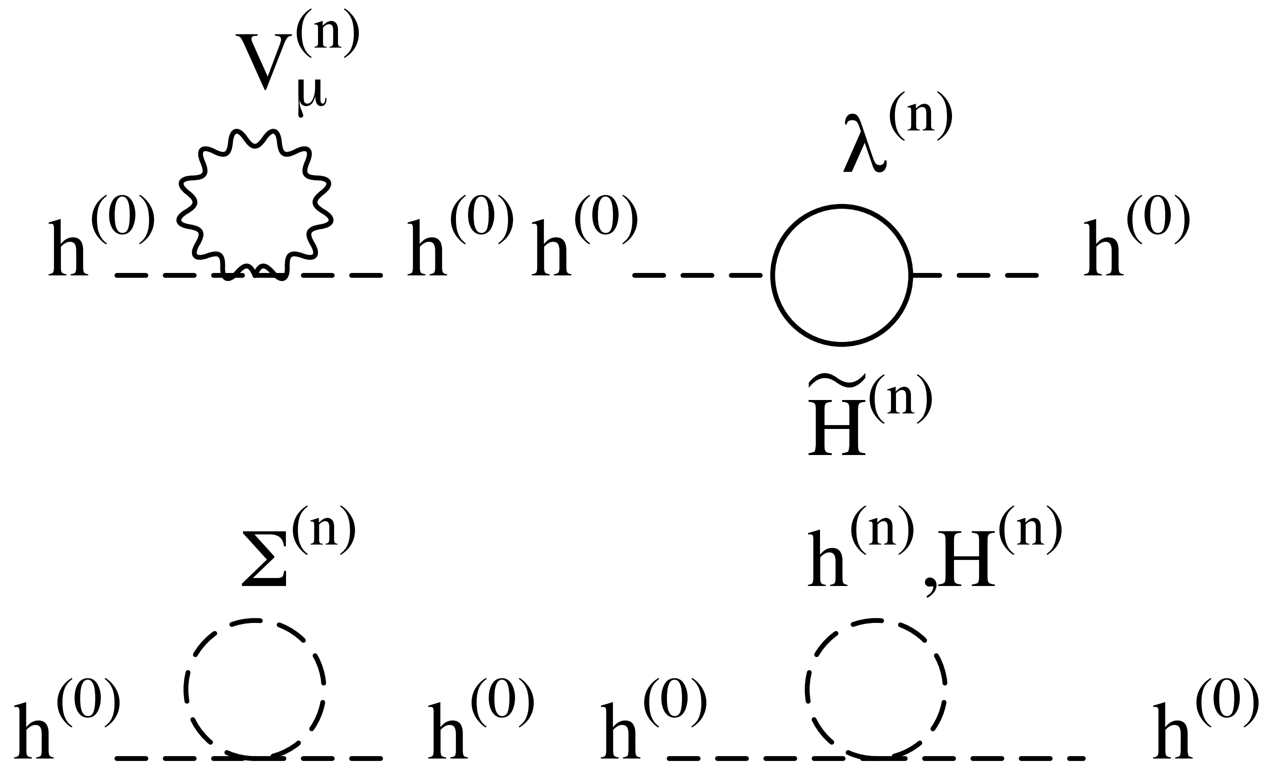
- We are going to fix q_H so that the mass of the Higgsino is equal to 1.1-1.2 TeV to reproduce the relic abundance.

- The other two free parameters q_R and R will be fixed by requiring correct EWSB and mass for the Higgs.

- In order to impose those conditions we have to calculate the one loop corrections to the Higgs potencial.

$$V = m^2|\mathcal{H}|^2 + \lambda|\mathcal{H}|^4$$

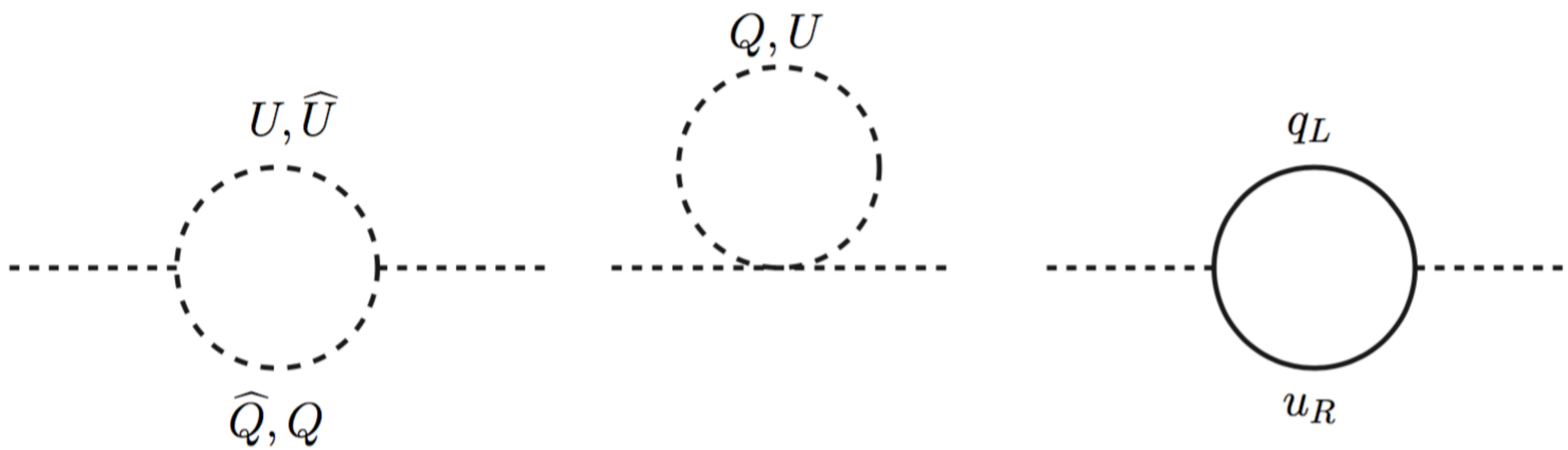
$$m_0^2 = (q_R - q_H)^2/R^2$$



$$\Delta_g m^2 = \frac{3g^2 + g_Y^2}{192\pi^4}\left[9\Delta m^2(0) + 3\Delta m^2(q_R \pm q_H) - 6\Delta m^2(q_R) - 6\Delta m^2(q_H)\right]$$

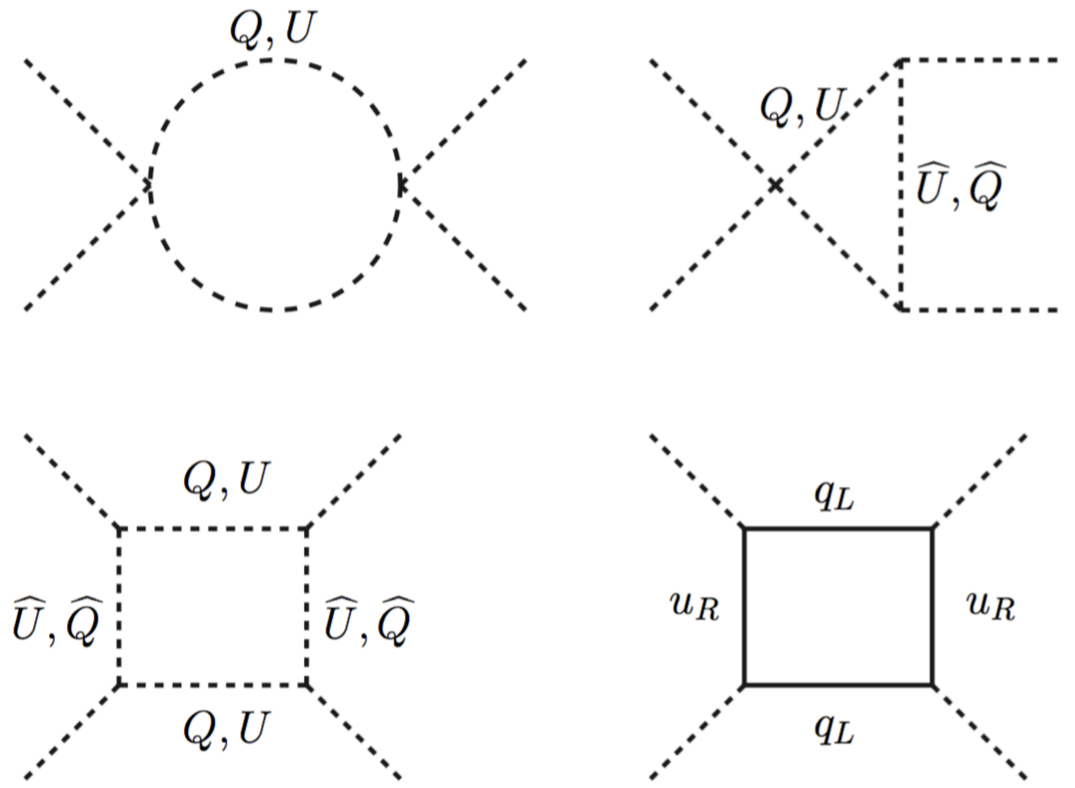
$$\Delta m^2(q) = \frac{1}{2R^2}[Li_3(e^{2\pi i q}) + h.c.]$$

- Gauge corrections



$$\Delta_t m^2 = \frac{3h_t^2(\mu)}{32\pi^4 R^2}\left[3Li_3(e^{2\pi i q_R}) - 3i\cot(2\pi q_R)Li_4(e^{2\pi i q_R}) - 2\zeta(3) + h.c.\right]$$

- Corrections from the Yukawa interaction



$$\Delta\lambda = \frac{3h_t^4(\mu)}{8\pi^2}\int_0^\infty p^7\left[s^4(p,0) - s^4(p,q_R)\right]dp$$

$$s(p,q) = \frac{\pi R \sinh(2p\pi R)}{p[\cosh(2p\pi R) - \cos(2\pi q)]}$$

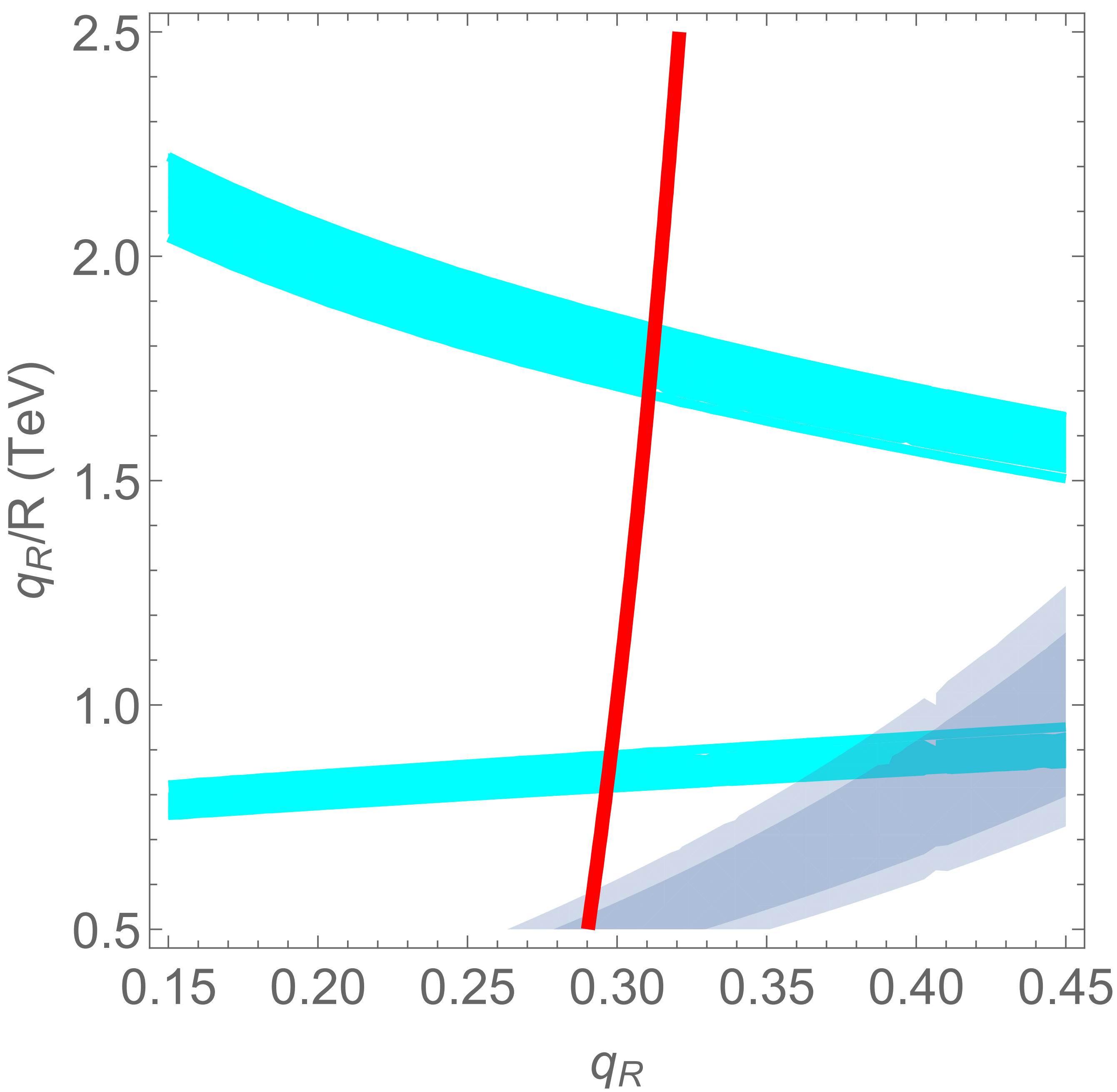
- Contribution to the quartic (analytical formula horrible!!!)

- The contributions to the mass are finite

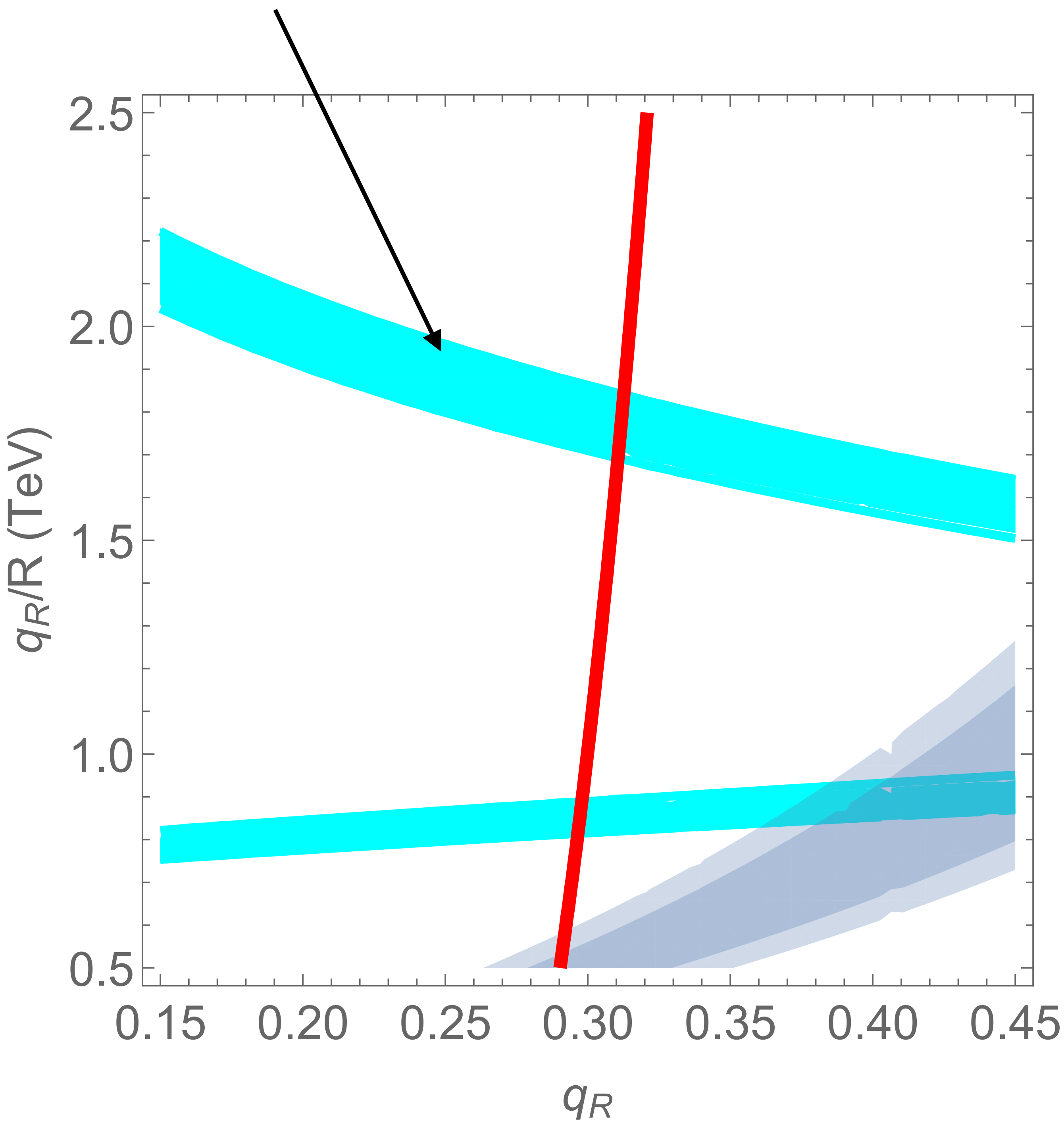
- The quartic coupling has an IR divergence related to the top quark

- We perform the matching of the SM to the new physics at q_R/R which is the mass of the squarks.

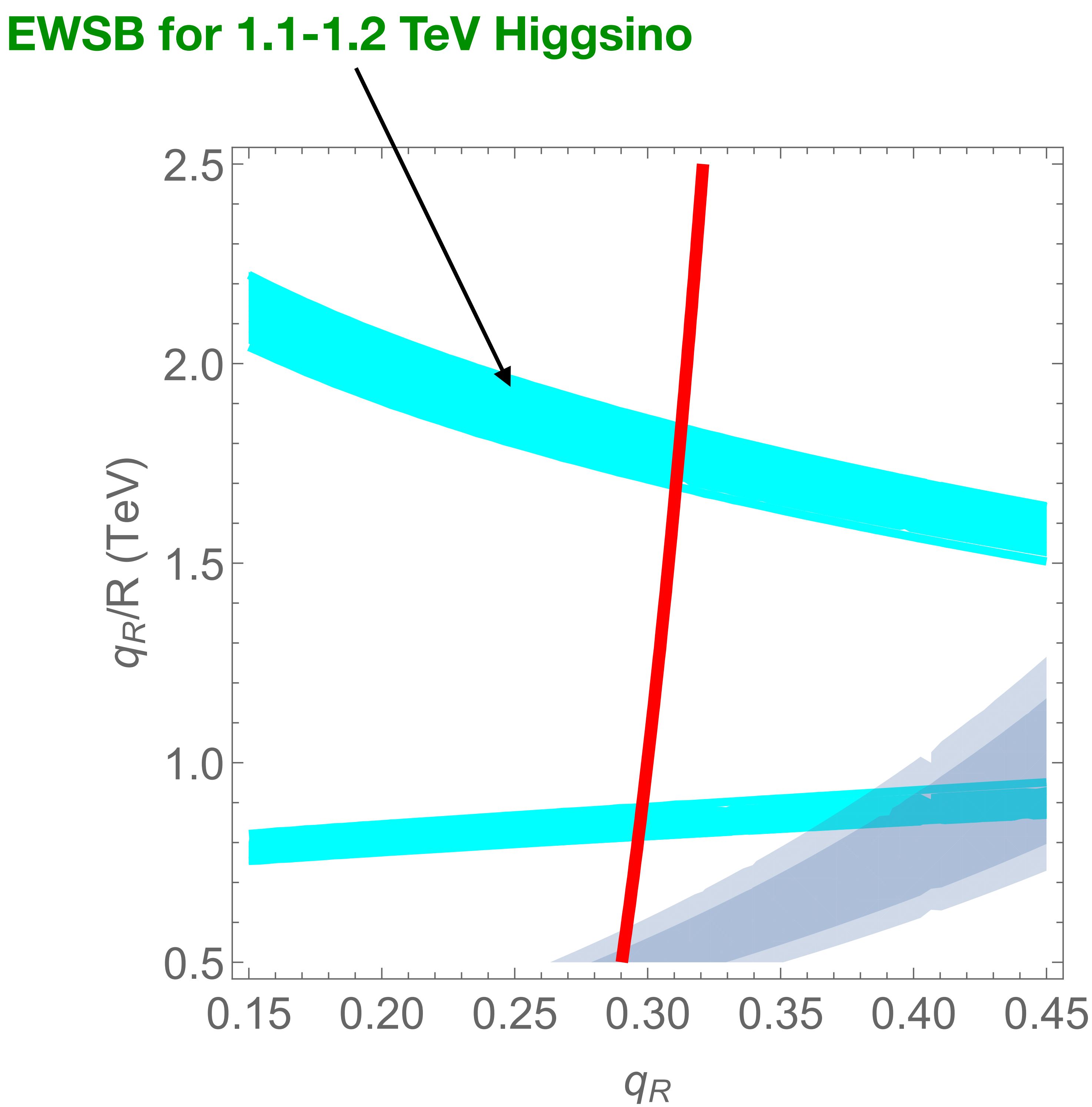
- There are two conditions, one on the mass to get EWSB and one on the quartic to reproduce the mass of the Higgs.



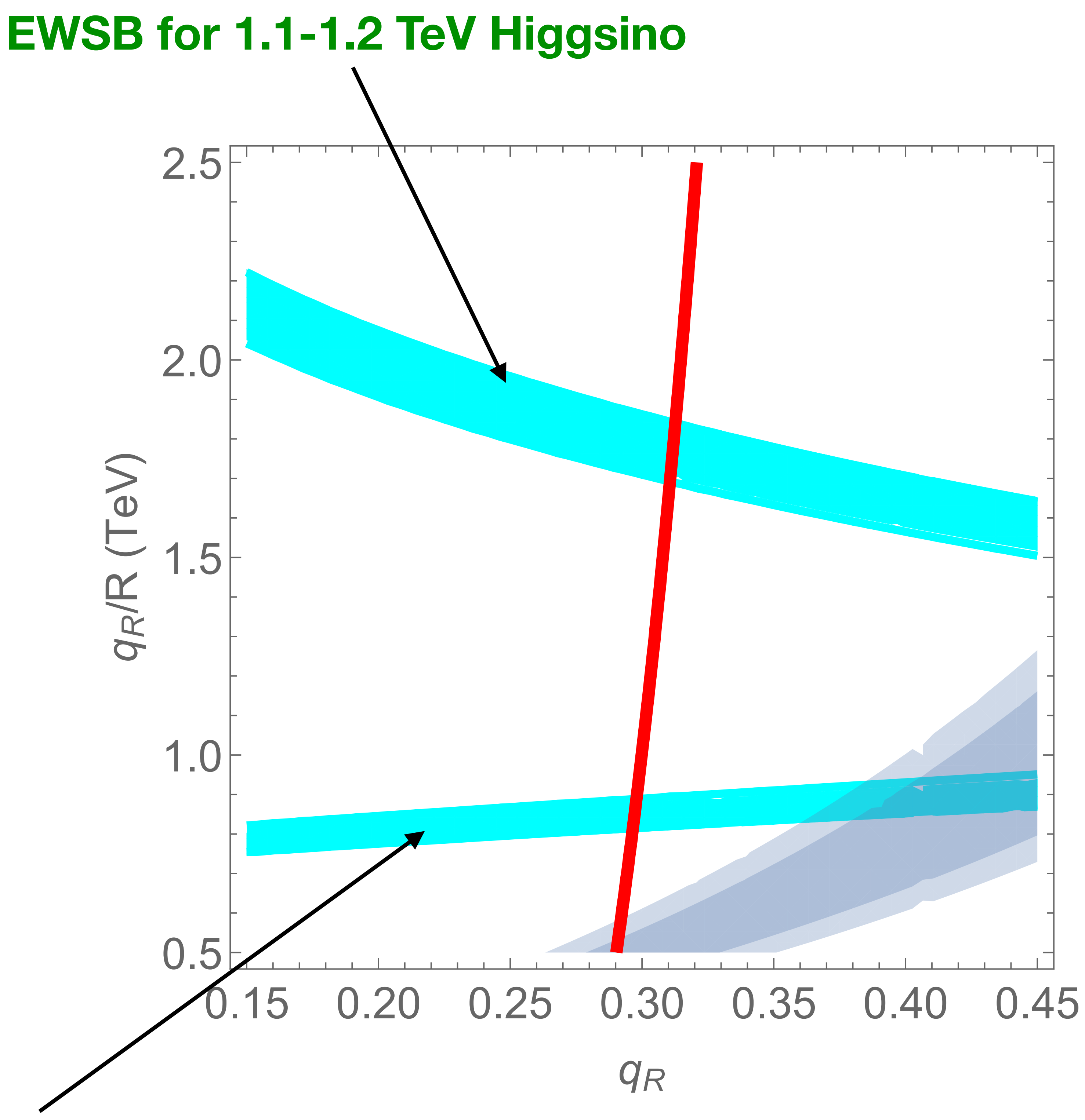
2.5
2.0
1.5
1.0
0.5
q_R/R (TeV)
0.15
0.20
0.25
0.30
0.35
0.40
0.45
q_R



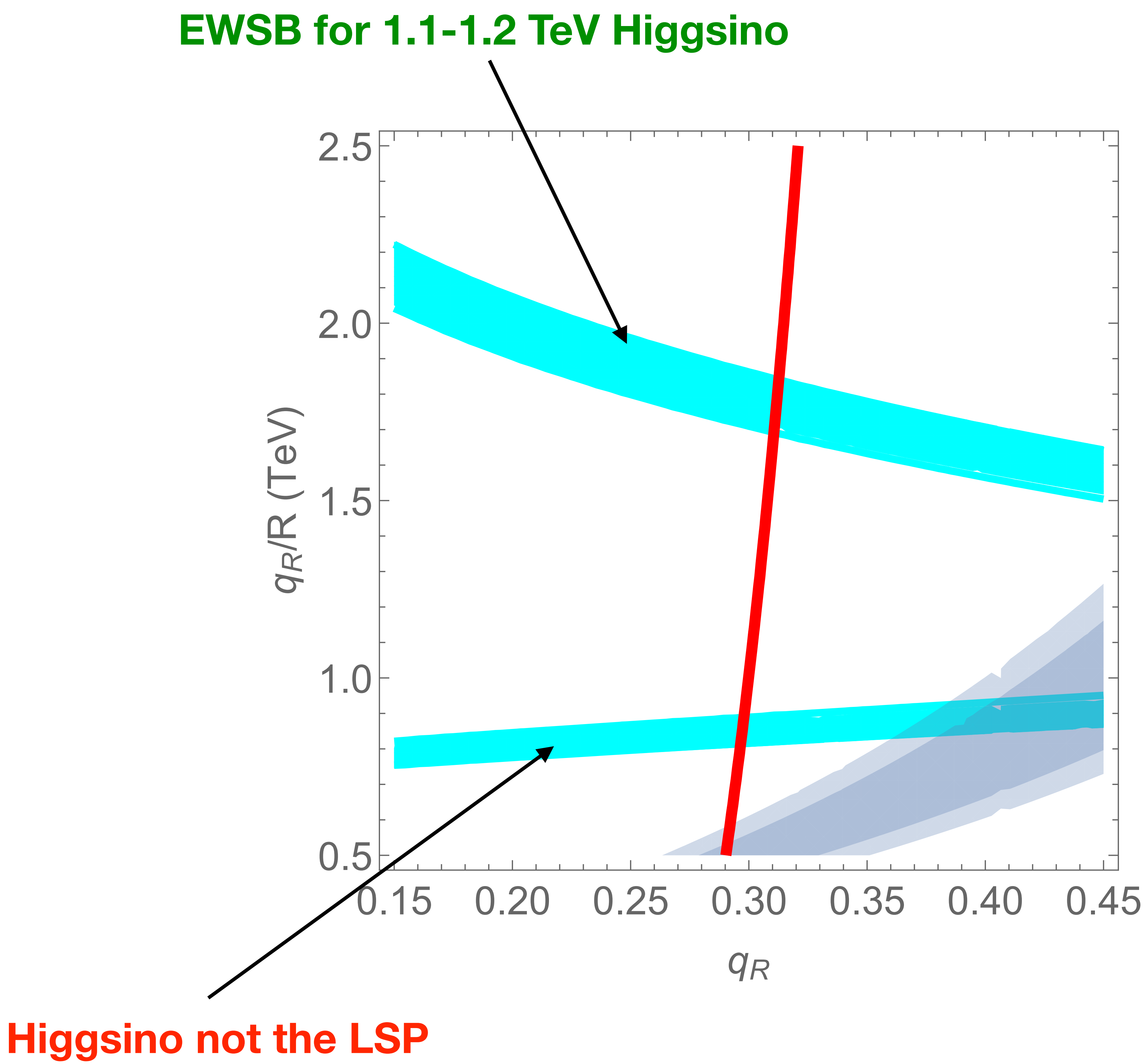
2.5
2.0
1.5
1.0
0.5
0.15
0.20
0.25
0.30
0.35
0.40
0.45
q_R/R (TeV)
q_R

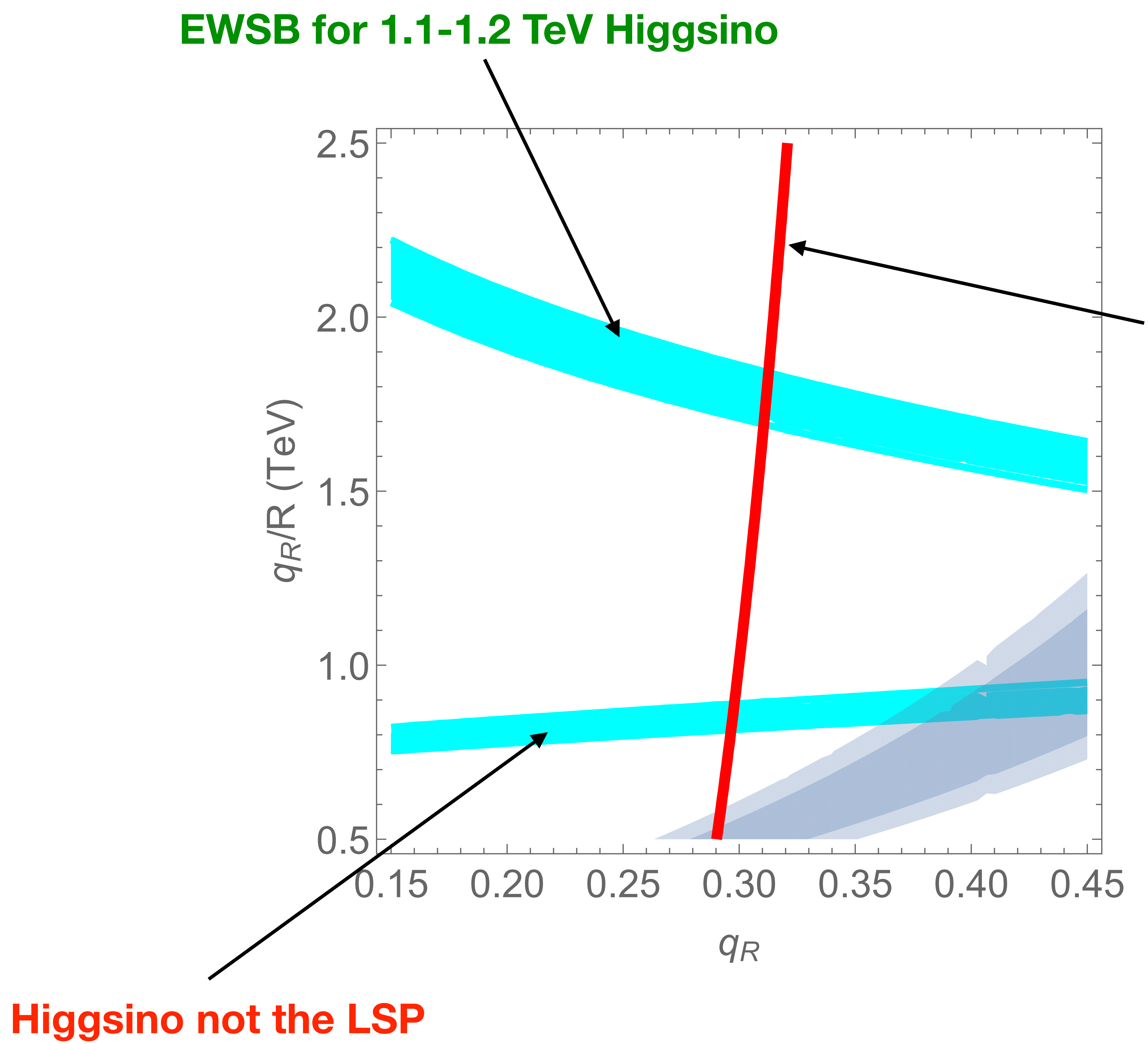


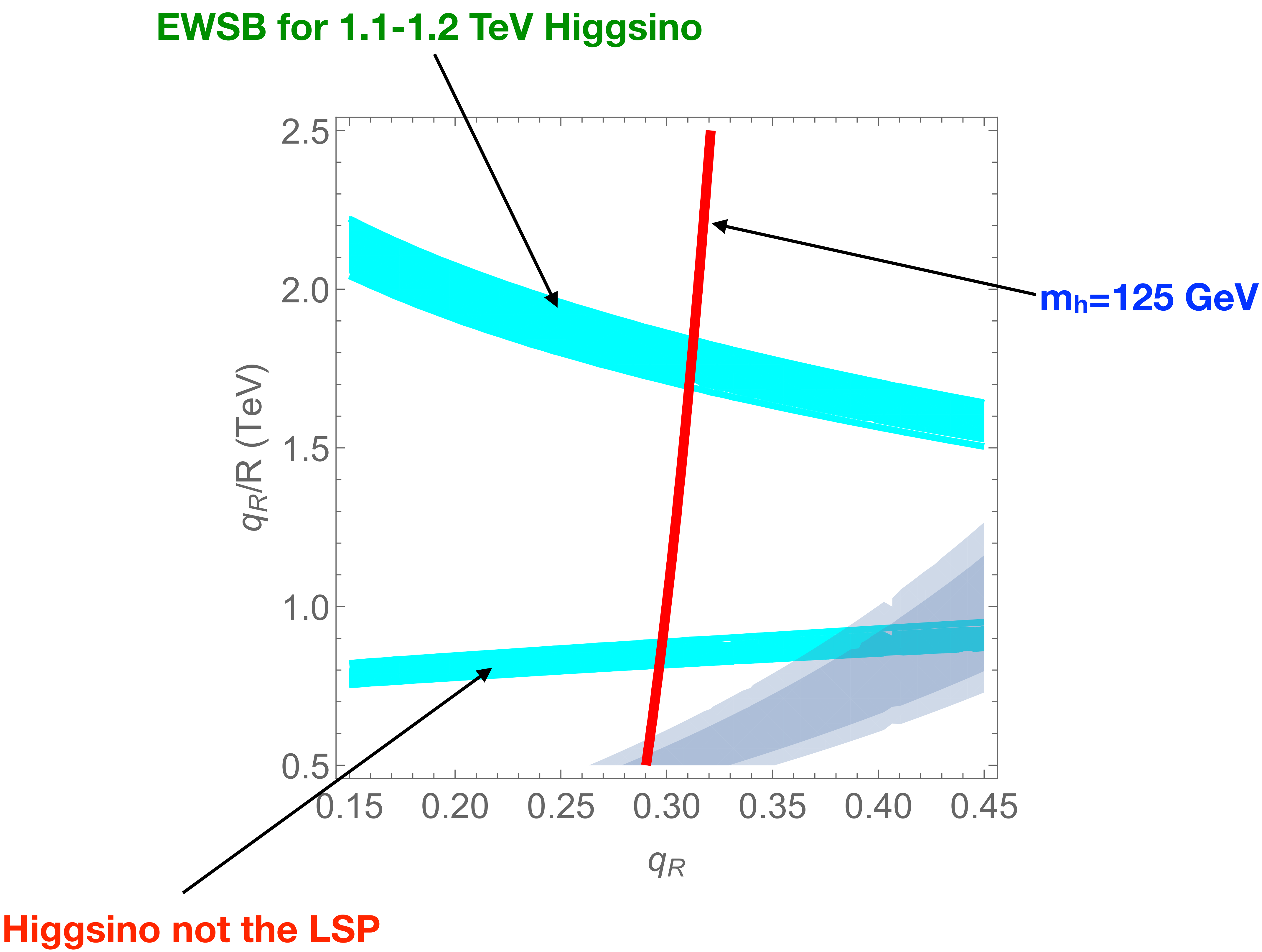
EWSB for 1.1-1.2 TeV Higgsino
2.5
2.0
1.5
1.0
0.5
q_R/R (TeV)
0.15
0.20
0.25
0.30
0.35
0.40
0.45
q_R



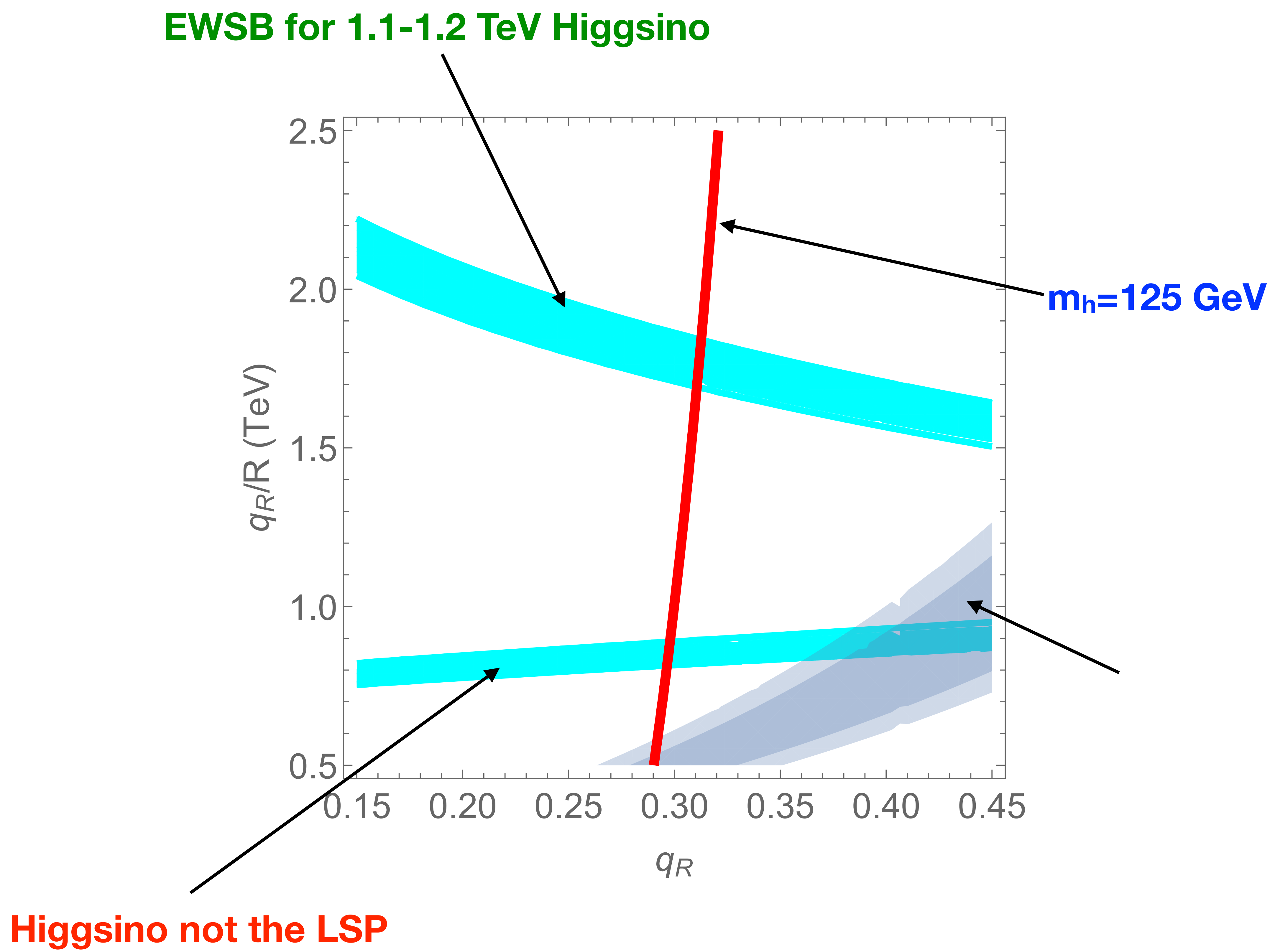
EWSB for 1.1-1.2 TeV Higgsino
2.5
2.0
1.5
1.0
0.5
0.15
0.20
0.25
0.30
0.35
0.40
0.45
q_R/R (TeV)
q_R


EWSB for 1.1-1.2 TeV Higgsino
2.5
2.0
1.5
1.0
0.5
q_R/R (TeV)
0.15
0.20
0.25
0.30
0.35
0.40
0.45
q_R
Higgsino not the LSP

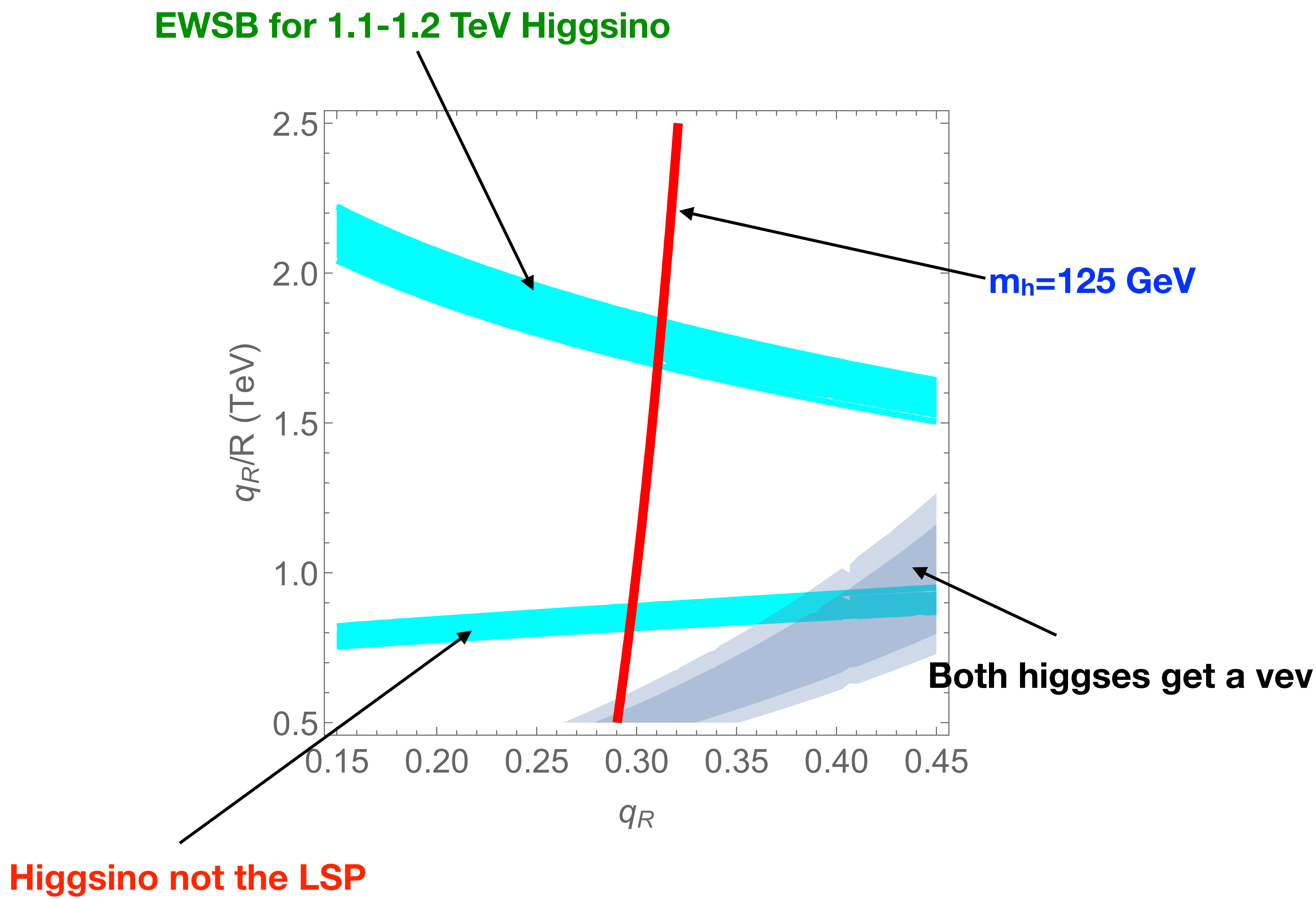

EWSB for 1.1-1.2 TeV Higgsino
2.5
2.0
1.5
1.0
0.5
q_R/R (TeV)
0.15
0.20
0.25
0.30
0.35
0.40
0.45
q_R
Higgsino not the LSP



EWSB for 1.1-1.2 TeV Higgsino
m_h=125 GeV
Higgsino not the LSP
q_R/R (TeV)
q_R
2.5
2.0
1.5
1.0
0.5
0.15
0.20
0.25
0.30
0.35
0.40
0.45



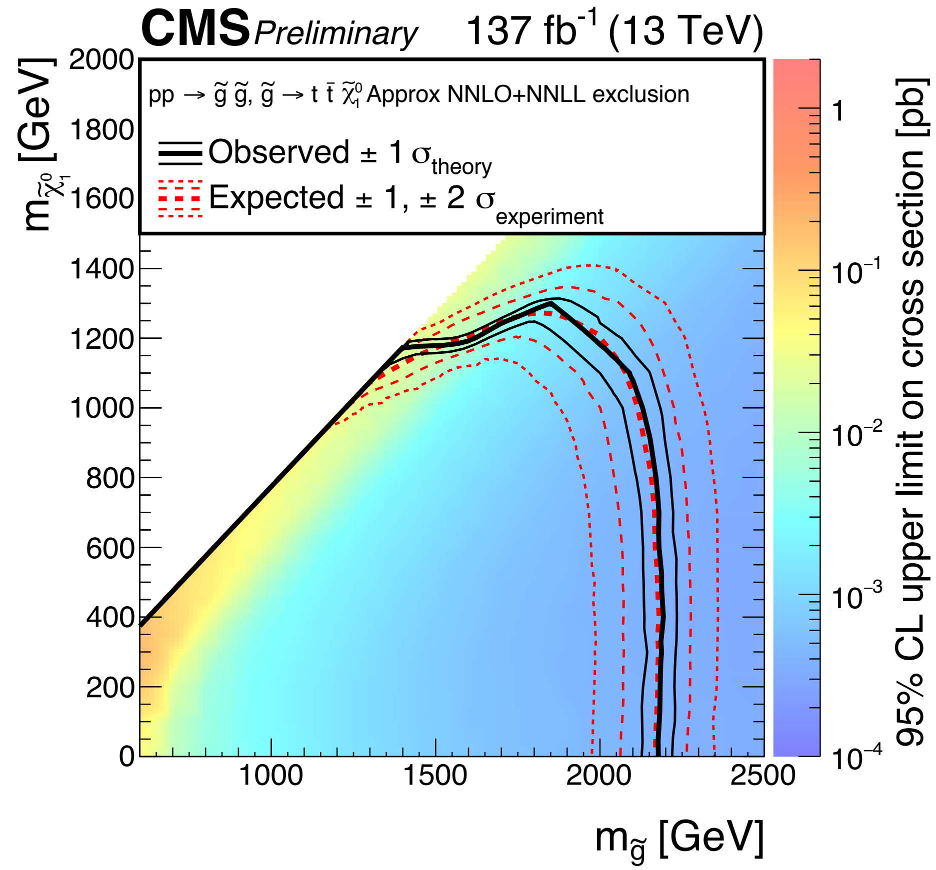
EWSB for 1.1-1.2 TeV Higgsino
m_h=125 GeV
Higgsino not the LSP
q_R/R (TeV)
q_R
2.5
2.0
1.5
1.0
0.5
0.15
0.20
0.25
0.30
0.35
0.40
0.45

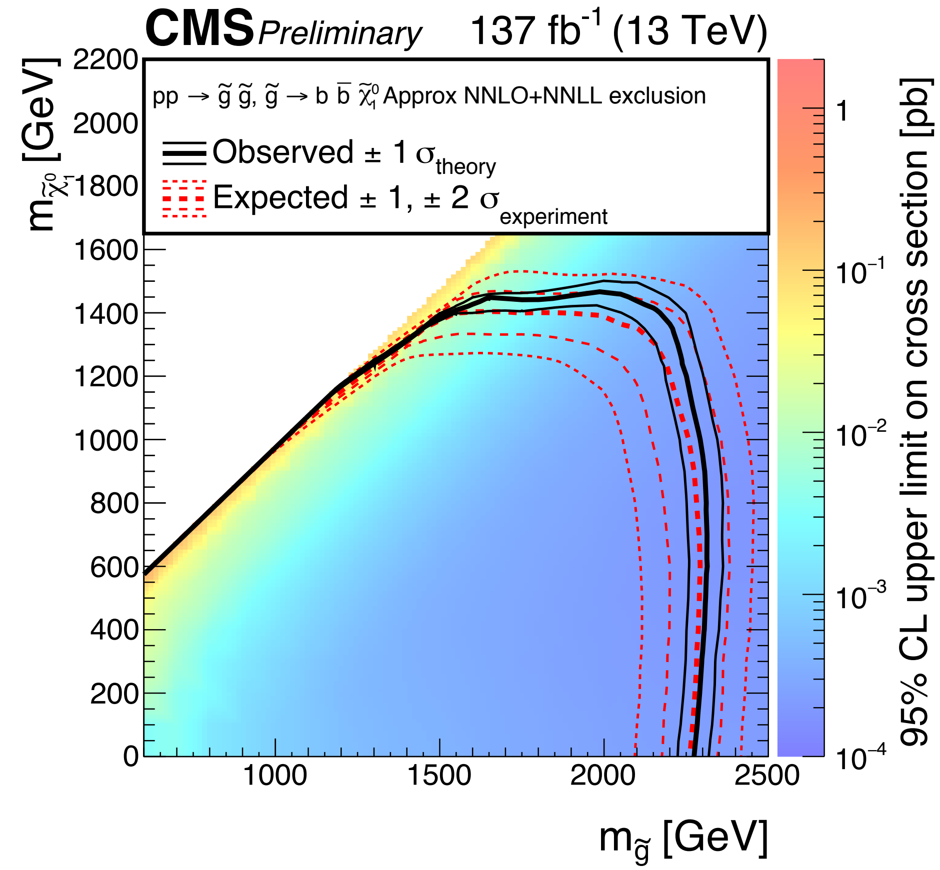


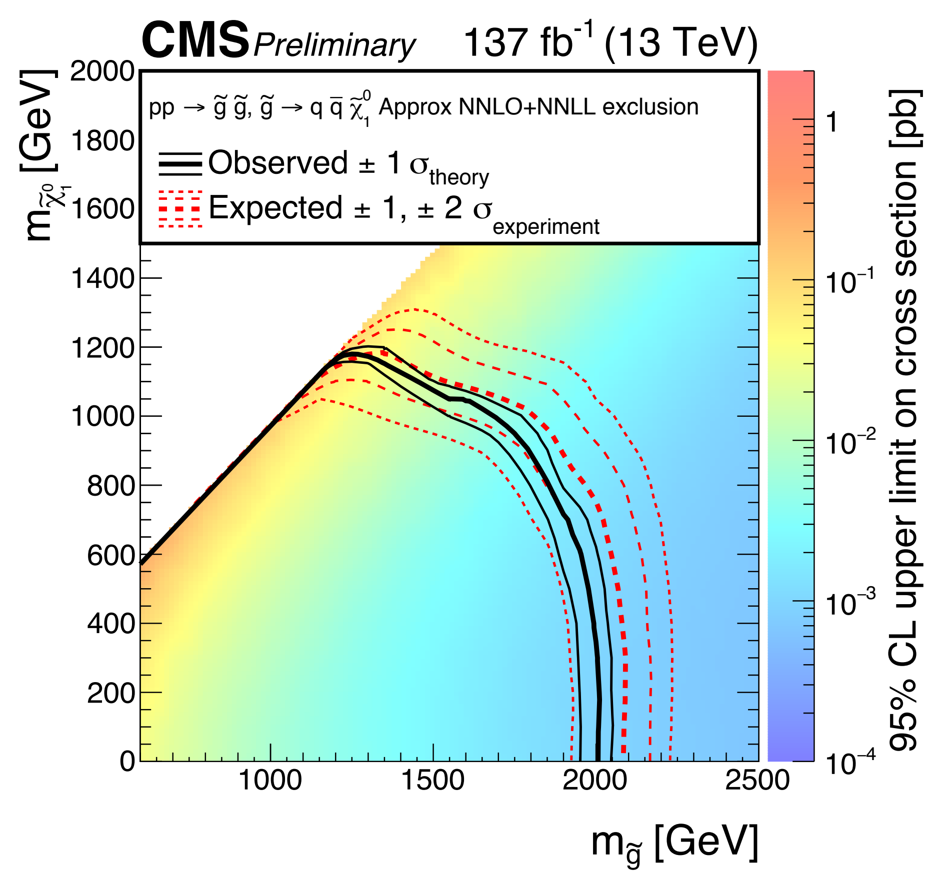
EWSB for 1.1-1.2 TeV Higgsino
m_h=125 GeV
Both higgses get a vev
Higgsino not the LSP
q_R/R (TeV)
q_R
2.5
2.0
1.5
1.0
0.5
0.15
0.20
0.25
0.30
0.35
0.40
0.45

Point	q_R	q_H	$1/R$ (TeV)	q_R/R (TeV)	q_H/R (TeV)	$M_{\tilde{g}}$ (TeV)	$m_{\mathcal{H}'}$ (TeV)
A	0.31	0.2	5.5	1.7	1.1	2.0	2.7
B	0.31	0.2	5.9	1.9	1.2	2.1	2.9

- Range of values for masses of the LSP between 1.1-1.2 TeV







- Experimental constrains from the LHC

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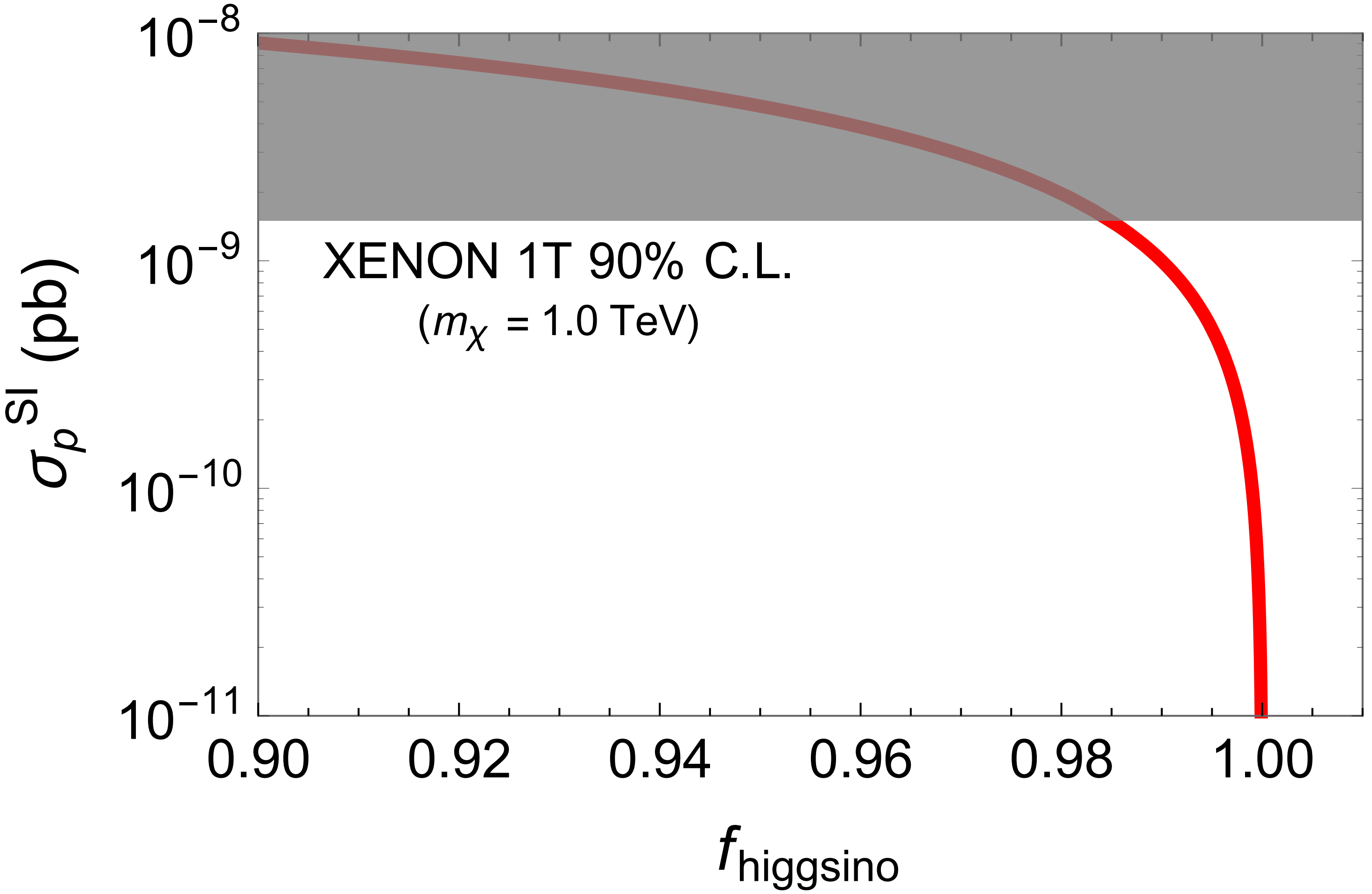

- The LSP is 99% Higgsino and has a cross section of 10^{-10} pb

- A 2 TeV gluino may need HL (~1 ab^{-1}) LHC
- The best chance to discover the Higgsino is in direct detection experiments like XENON-nT or LZ
- Fine tuning in this model is smaller than normal due to:
    - Low supersymmetry breaking scale
    - The electroweak scale depends linearly and not quadratically on the parameters

Conclusions

- In this talk we have built a 5D supersymmetric model with SS supersymmetry breaking (boundary conditions)
- The model is very predictive with just three free parameters (q_R,q_H,R)
- They are fixed by:
  - DM
  - EWSB
  - Higgs mass

- It is quite remarkable that one can find consistent solutions since it was not guaranteed.

- For a range of LSP between 1.1-1.2 TeV we find that the mass of the gluino is above 2 TeV, above the current experimental bounds from the LHC.

- The spectrum can be probed at the HL-LHC and in the next generation of direct detection experiments.