Future Prospects for Stau in Higgs Coupling to Di-photon

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University of Tokyo

SUSY2014: Higgs Phenomenology Session,

July 21, 2014, Manchester, England

Based on

T. K, JHEP 1211 (2012) 021 [arXiv:1208.4792]

T. K, T. Yoshinaga, **JHEP 1305** (2013) 035 [arXiv:1303.0461]

M. Endo, **T. K,** T. Yoshinaga, **JHEP 1404** (2014) 139 [arXiv:1401.3748]

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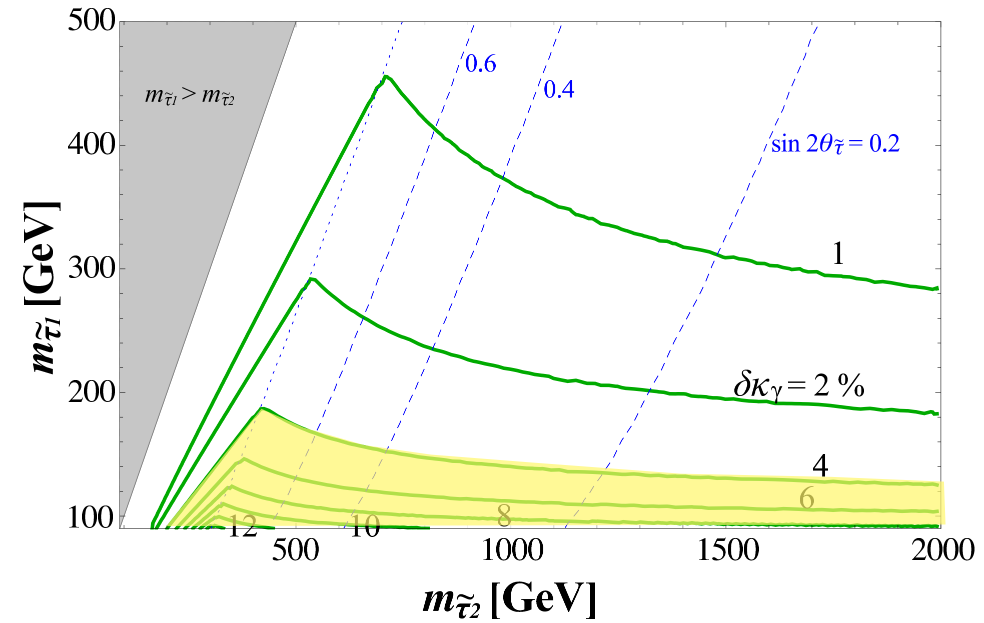
Main Conclusions

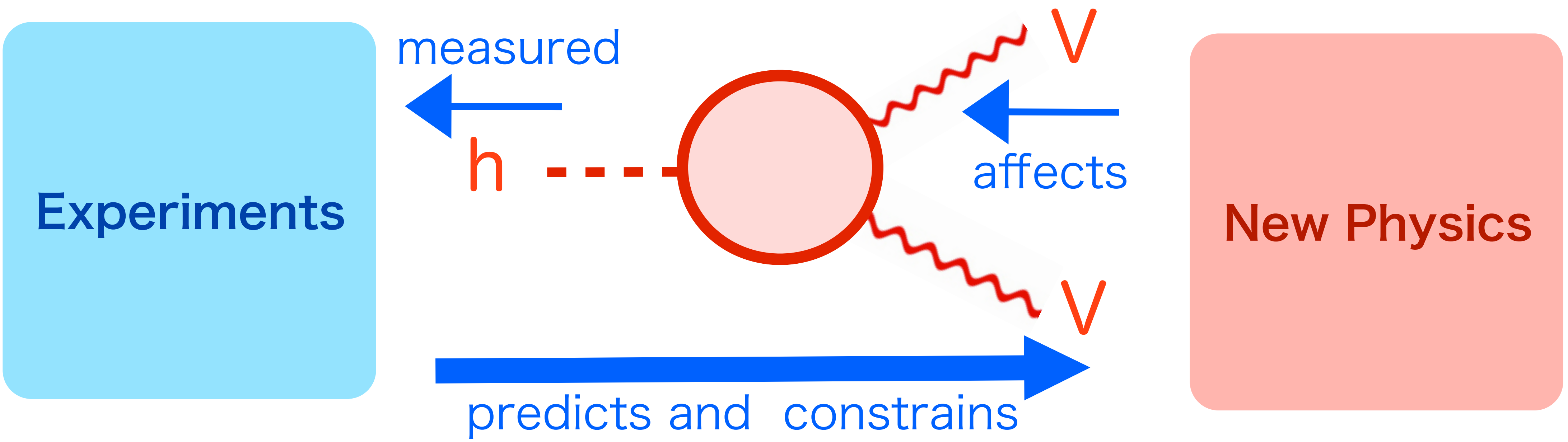
- If the excess of κ_γ **(= deviation of the Higgs to diphoton coupling)** is measured to **larger than 4%** **(= 2σ deviation) at the early stage of ILC,** the lightest stau is predicted to be **lighter than 200 GeV** in the MSSM.



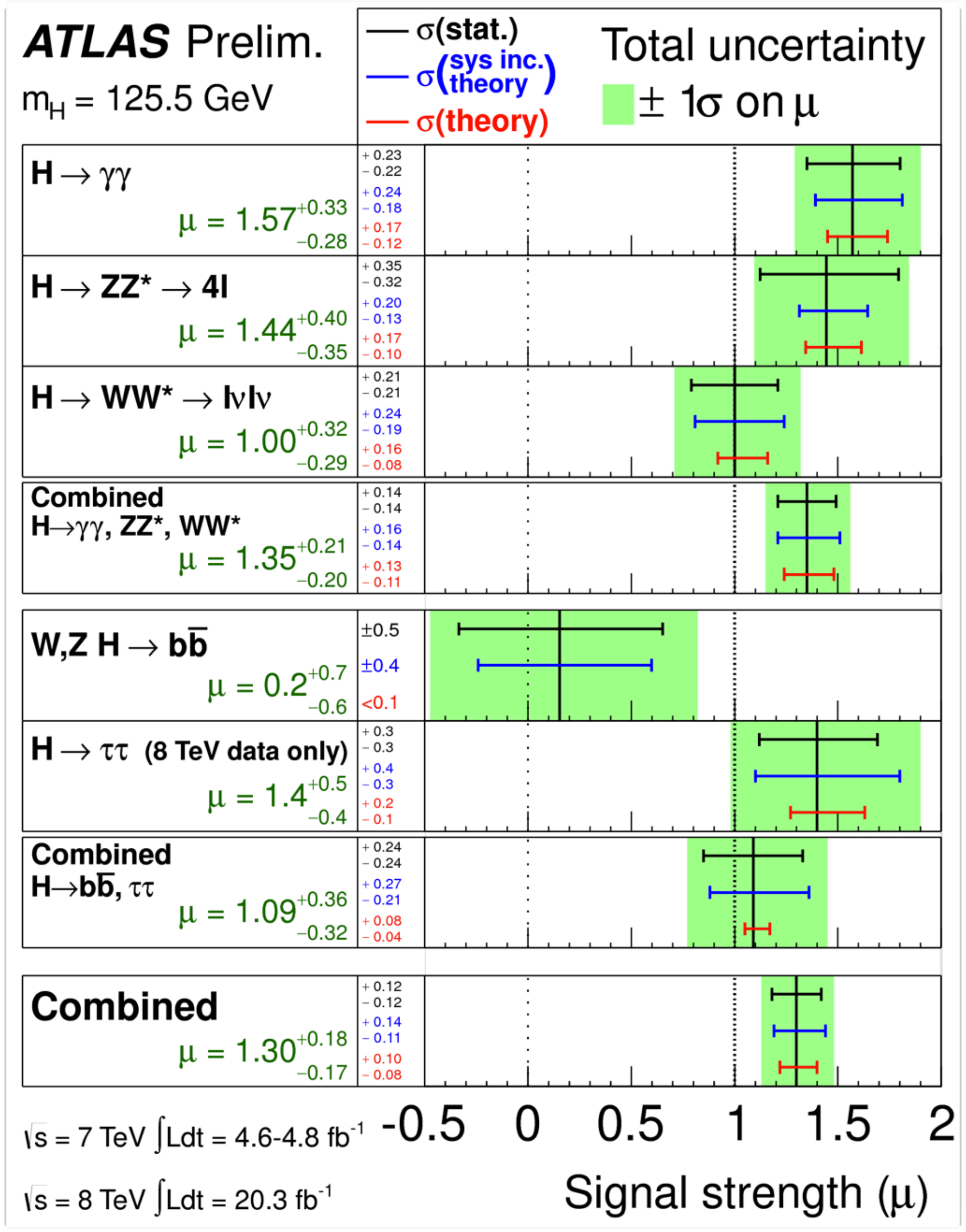
- If the excess of κ_γ and **the stau mixing angle** are measured at the early stage of ILC, it is possible to **predict the heaviest stau mass, even when it is not yet discovering.**

Higgs Oblique corrections

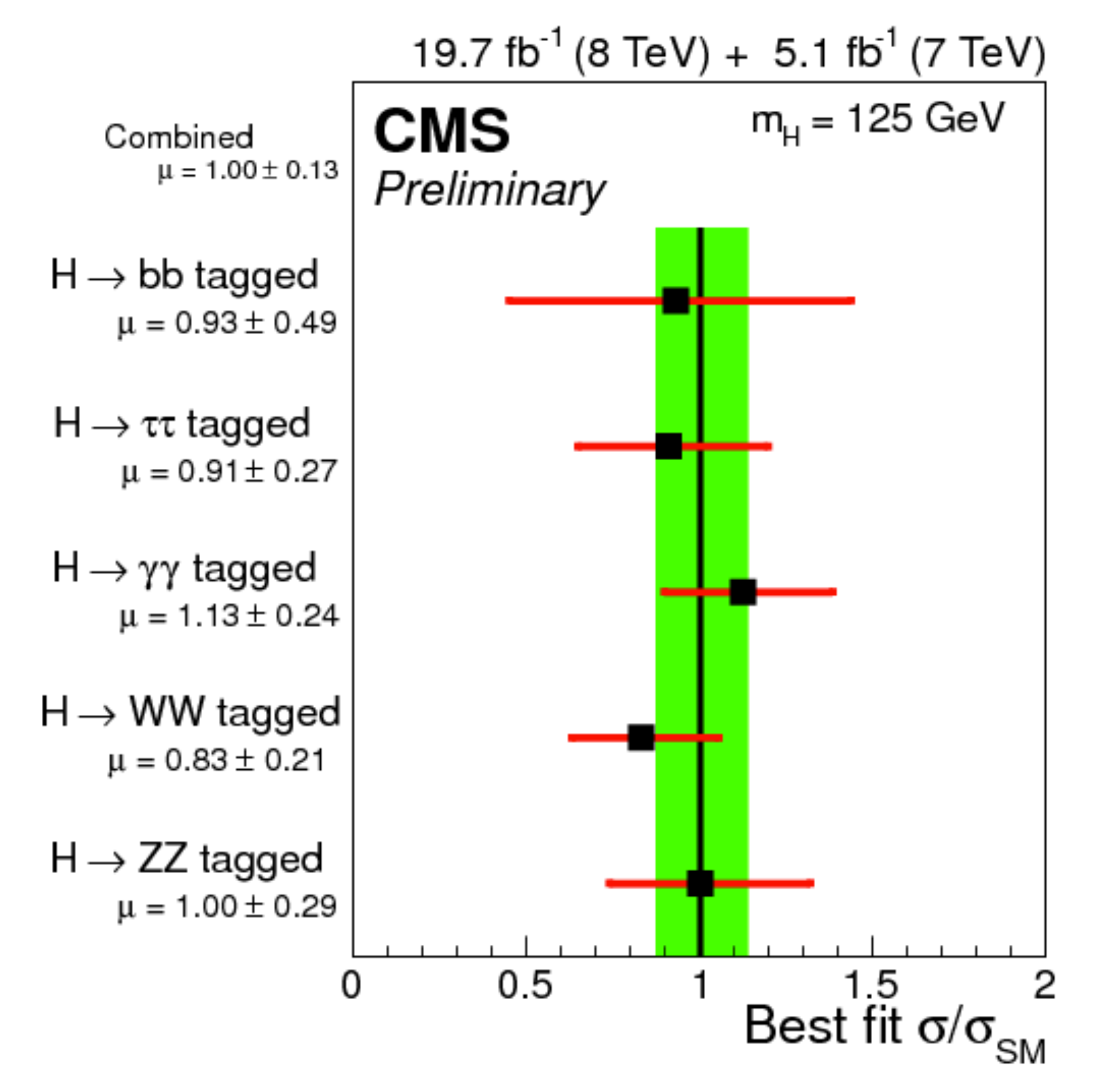
- “Higgs Oblique corrections”, which means loop-induced Higgs couplings (Higgs to digluon / **diphoton** / Z+photon), can also predict and constrain the new physics indirectly.
- Advantage: Since these loop-induced Higgs couplings do not emerge at the tree level and induced at radiative level, these diagrams are easily influenced by new physics.



Status of the Higgs couplings

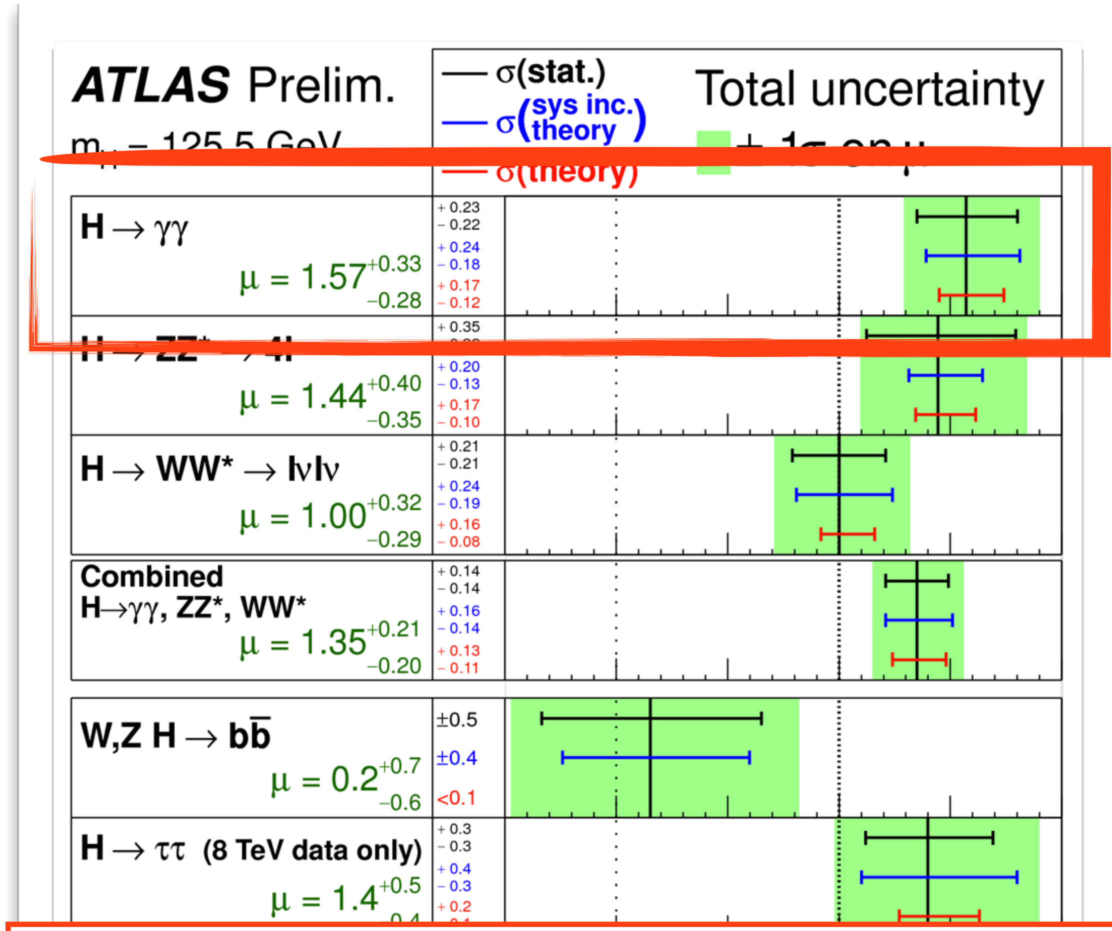


[ATLAS-CONF-2014-009 (2014)]

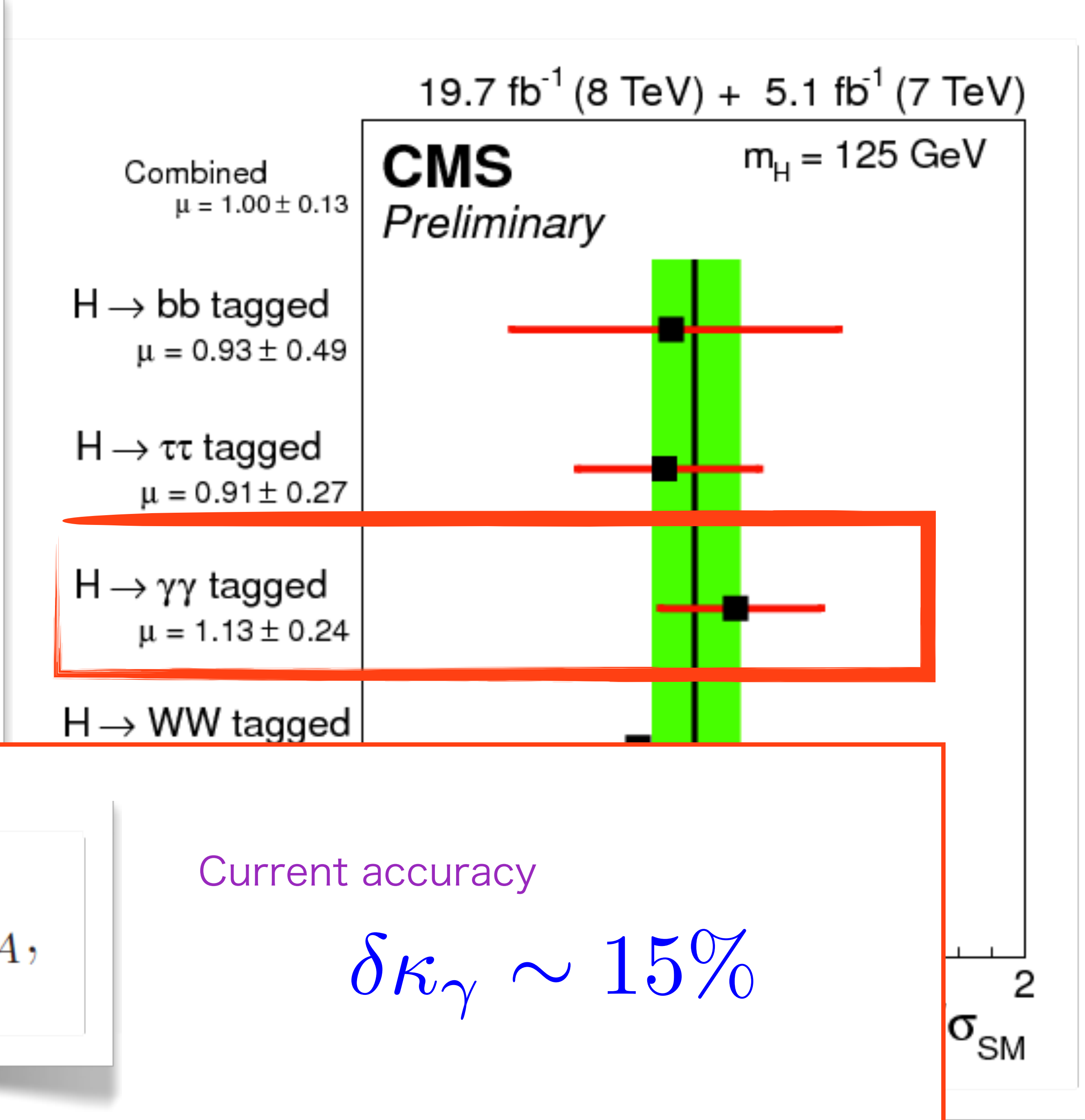


[CMS-PAS-HIG-14-009 (2014)]

Status of the Higgs couplings



[ATLAS-CONF-2014-009 (2014)]



[CMS-PAS-HIG-14-009 (2014)]

$$\kappa_A = \frac{g_{hAA}}{g_{hAA}(\mathrm{SM})} = 1 + \delta\kappa_A,$$

Current accuracy

$$\delta\kappa_\gamma \sim 15\%$$

Sensitivities of the Future colliders

[M. E. Peskin,1312.4974 (2013)]

$$\kappa_A = \frac{g_{hAA}}{g_{hAA}(\mathrm{SM})} = 1 + \delta\kappa_A,$$

future Systematic error
=
Current Values

Optimistic estimate

LHC Run2

300 fb^{-1}	Scenario 2		Scenario 1	
	7-param	9-param	7-param	9-param
γ	5.7	4.3	9.0	7.3
W	4.2	3.5	5.4	4.6
Z	5.7	5.0	8.5	6.6
g	4.9	4.1	6.9	6.3
b	11.4	7.6	14.9	10.2
t	17.3	17.3	20.5	20.6
τ	5.8	4.4	9.5	7.7
invis.	—	4.6	—	6.1

$\delta\kappa_\gamma \sim 4 - 9\%$

High Lumi -LHC

3000 fb^{-1}	Scenario 2		Scenario 1	
	7-param	9-param	7-param	9-param
γ	2.9	2.4	6.5	5.3
W	1.6	1.2	3.3	2.3
Z	2.8	2.2	6.3	4.3
g	2.3	2.0	4.8	4.4
b	4.2	2.9	8.5	6.0
t	5.7	5.6	12.9	12.8
τ	2.7	2.2	6.5	5.1
invis.	—	1.5	—	3.2

$\delta\kappa_\gamma \sim 3 - 6\%$

The error is dominated by systematic uncertainties (QCD theoretical error)

Sensitivities of the Future colliders

- The ILC sensitivity of Higgs to diphoton coupling is weaker than LHC one because the statistical error is larger than LHC.

$$\kappa_A = \frac{g_{hAA}}{g_{hAA}(\mathrm{SM})} = 1 + \delta\kappa_A,$$

ILC

	250	500	500up	1000	1000up
W	4.6	0.46	0.22	0.19	0.15
Z	0.78	0.50	0.23	0.22	0.22
g	6.1	2.0	0.96	0.79	0.60
γ	18.8	8.6	4.0	2.9	1.9
b	4.7	0.97	0.46	0.39	0.32
c	6.4	2.6	1.2	0.98	0.72
τ	5.2	2.0	0.89	0.79	0.65
invis.	0.54	0.52	0.22	0.22	0.21

[M. E. Peskin,1312.4974 (2013)]

Joint Analysis

[M. E. Peskin,1312.4974 (2013)]

- $Br(h \to \gamma\gamma)/Br(h \to ZZ^*)$ will be measured very precisely at HL-LHC because its theoretical error is alleviated.

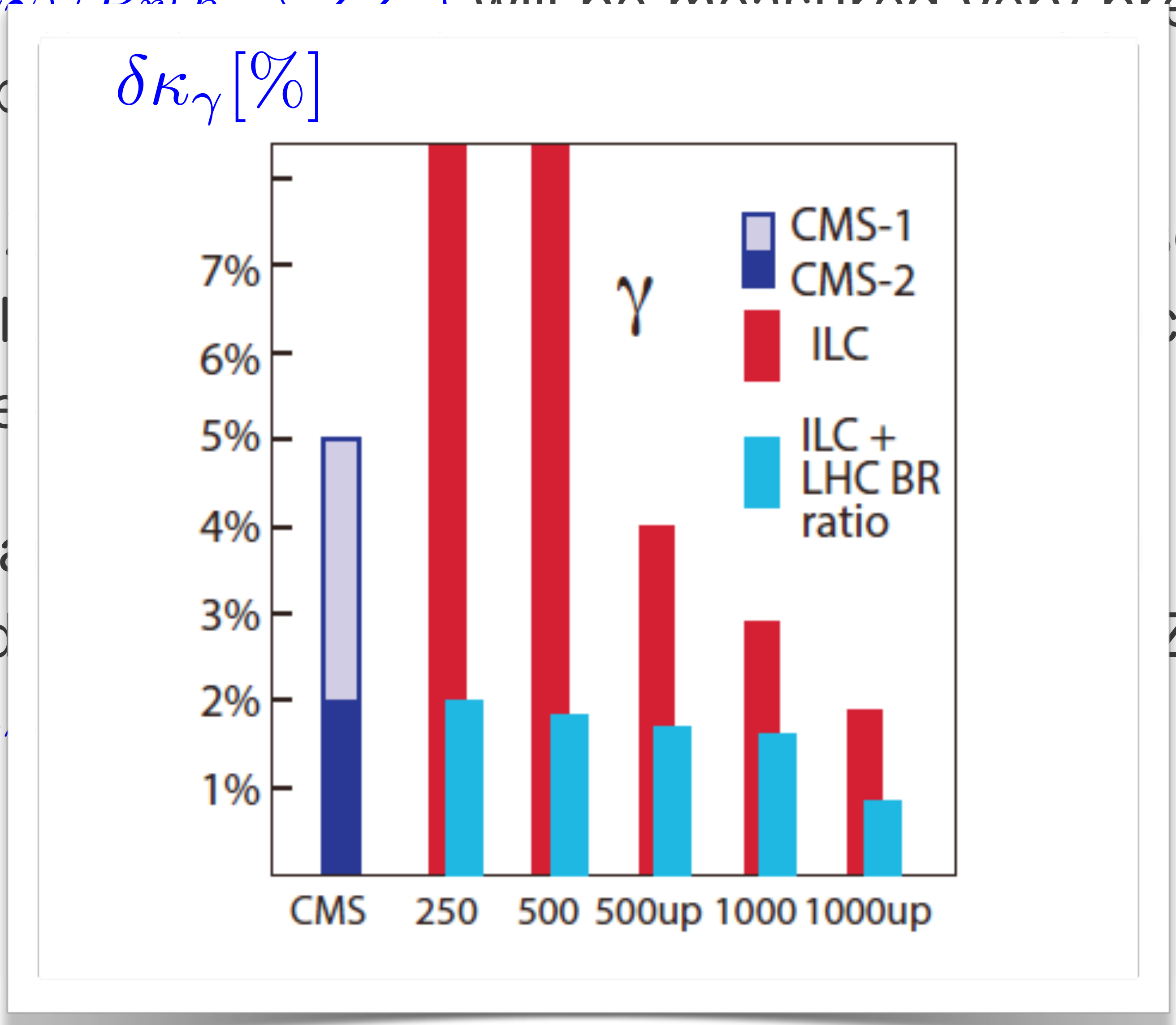
- Higgs to ZZ* coupling will be measured very precisely at ILC because ILC can measure associated Higgs production cross section (e+e- -> Z* -> Zh).

- If the measurement of $Br(h \to \gamma\gamma)/Br(h \to ZZ^*)$at HL-LHC is combined with the measurements of the Higgs to ZZ* coupling at ILC, κ_γ can be measured precisely.

Joint Analysis

[M. E. Peskin,1312.4974 (2013)]

- $Br(h \to \gamma\gamma)/Br(h \to ZZ^*)$ will be measured very precisely at HL-LHC b
- Higgs to ... ely at ILC because I ... ction cross section (e
- If the mea ... HL-LHC is combined ... ZZ* coupling at ILC, κ



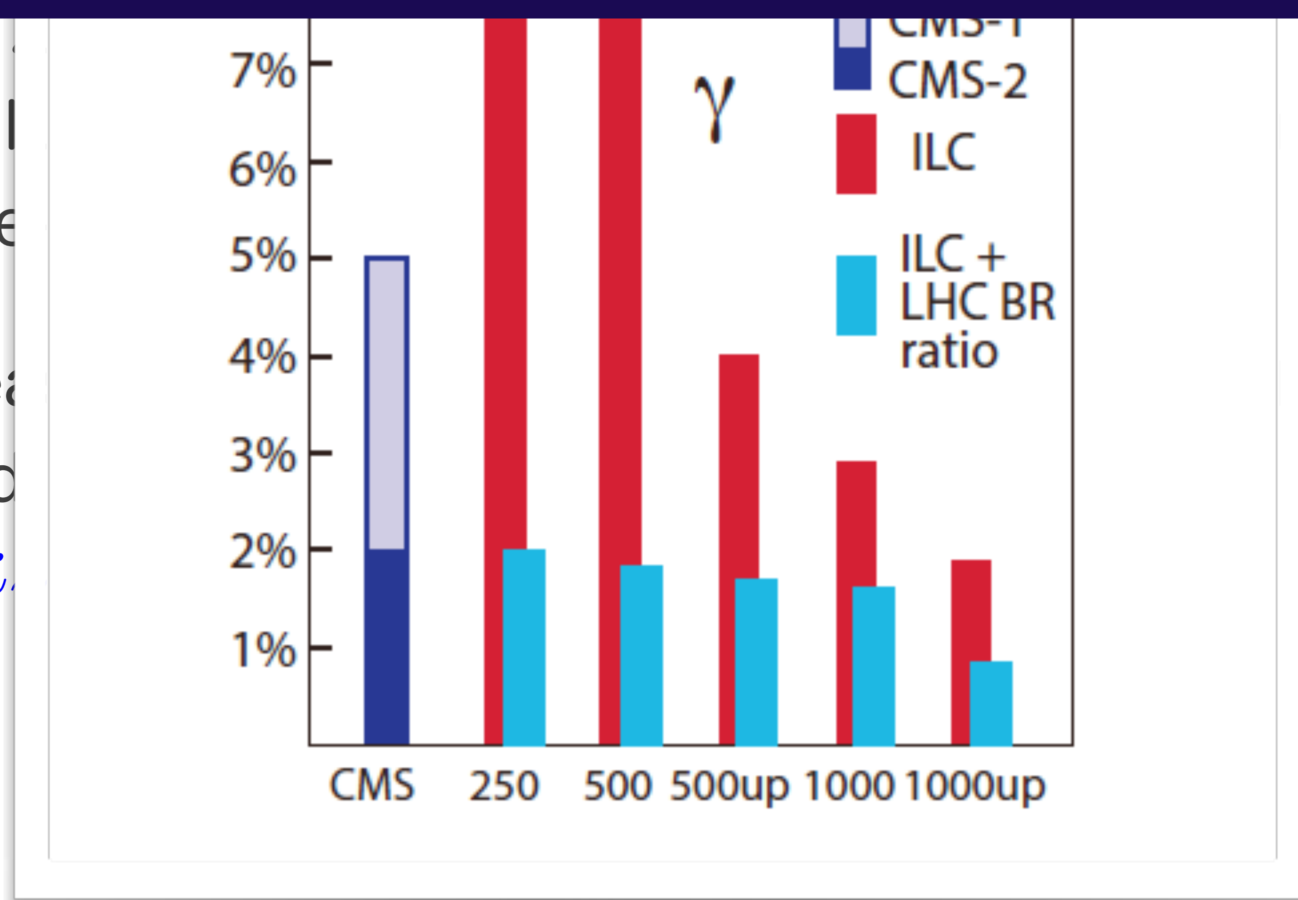
The uncertainty can be reduced to be $\delta\kappa_\gamma \sim 1 - 2\%$

Joint Analysis

[M. E. Peskin,1312.4974 (2013)]

We consider that how the accuracy of κ_γ predicts or constrains the new physics indirectly.

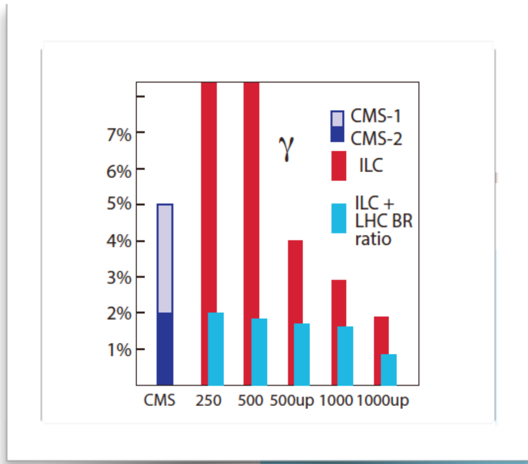
- Higgs to … ely at ILC because I… ction cross section (e…
- If the mea… HL-LHC is combined… ZZ* coupling at ILC, κ…

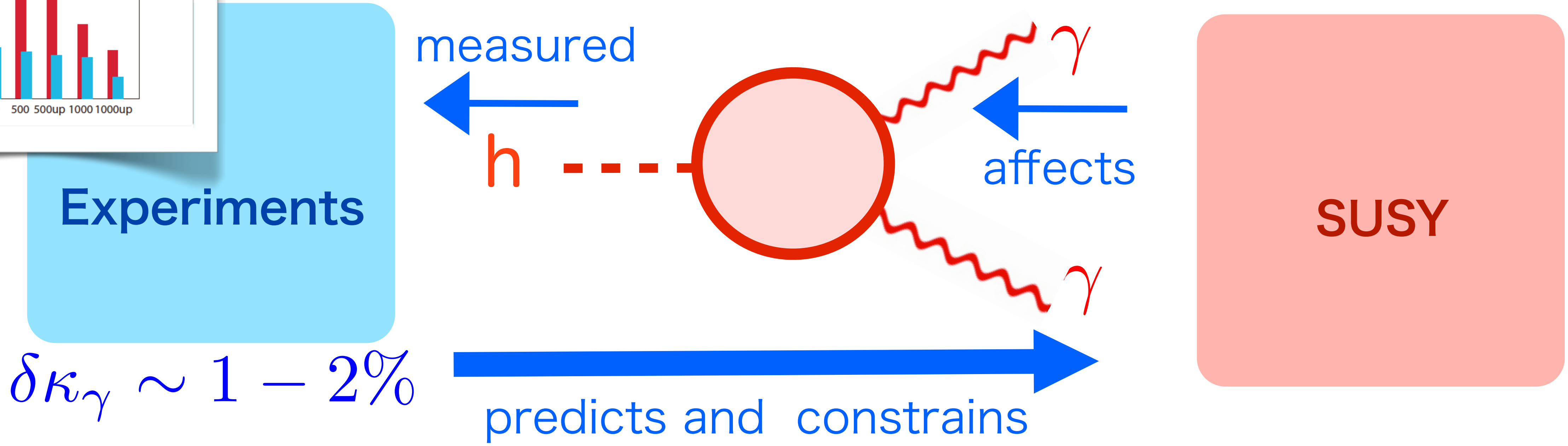


The uncertainty can be reduced to be $\delta\kappa_\gamma \sim 1 - 2\%$


GUT
No Hierarchy problem
Dark Matter
SUSY

SUSY Contributions to κ_γ



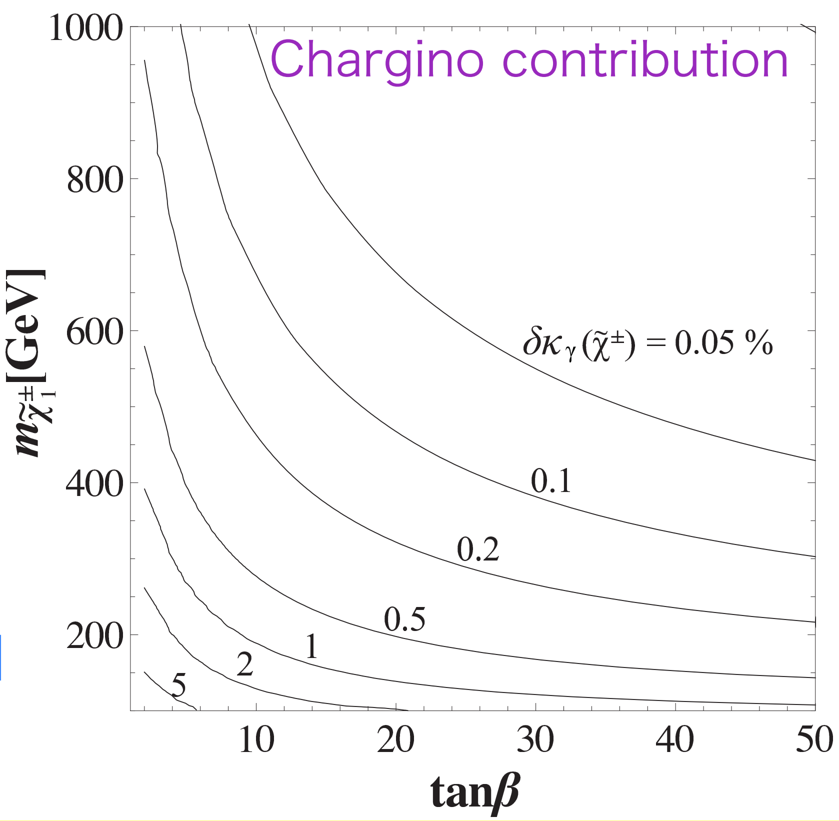


stop/sbottom..... We assume the colored particles are heavy (heavier than $\mathcal{O}(1\ \mathrm{TeV})$)

stau....This talk

chargino.... almost parameter regions chargino contributions are smaller than staus.

[M.Endo, **TK**, T.Yoshinaga, JHEP 1404 139 (2014)]



Stau Contributions to κ_γ

- I briefly review the stau contributions to κ_γ and the vacuum meta-stability condition.

$$M^2_{\tilde{\tau}} = \begin{pmatrix} m^2_{\tilde{\tau}LL} & m^2_{\tilde{\tau}LR} \\ m^2_{\tilde{\tau}LR} & m^2_{\tilde{\tau}RR} \end{pmatrix},$$

$$m^2_{\tilde{\tau}LL,RR} = \tilde{m}^2_{\tilde{\tau}L,R} + m^2_\tau + D_{\tilde{\tau}L,R}$$

$$D_{\tilde{\tau}} = m^2_Z \cos 2\beta (I^3_\tau - Q_\tau \sin^2\theta_W)$$

$$m^2_{\tilde{\tau}LR} = m_\tau (A_\tau - \mu_H \tan\beta)$$

$$U_{\tilde{\tau}} \mathcal{M}^2_{\tilde{\tau}} U^\dagger_{\tilde{\tau}} = \mathrm{diag}(m^2_{\tilde{\tau}_1}, m^2_{\tilde{\tau}_2})$$

$$U_{\tilde{\tau}} = \begin{pmatrix} \cos\theta_{\tilde{\tau}} & \sin\theta_{\tilde{\tau}} \\ -\sin\theta_{\tilde{\tau}} & \cos\theta_{\tilde{\tau}} \end{pmatrix}, \quad m^2_{\tilde{\tau}LR} = \frac{1}{2}(m^2_{\tilde{\tau}_1} - m^2_{\tilde{\tau}_2}) \sin 2\theta_{\tilde{\tau}}$$

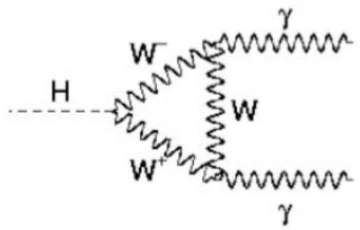
Staus are characterized by only **three parameters,** $m_{\tilde{\tau}_1}$, $m_{\tilde{\tau}_2}$, $\theta_{\tilde{\tau}}$

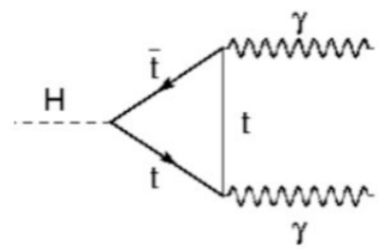
Stau Contributions to κ_γ

- The Higgs to diphoton decay rate

$$\Gamma(h \to \gamma\gamma) = \frac{\alpha^2 m_h^3}{1024\pi^3} |\mathcal{M}_{\gamma\gamma}|^2$$

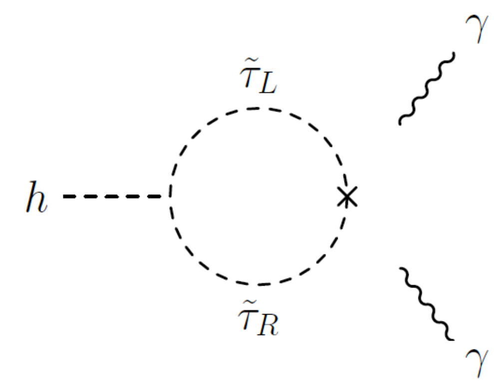
SM contributions





$$\mathcal{M}_{\gamma\gamma}(\mathrm{SM}) = \frac{g_{hWW}}{m_W^2} A_1^h(x_W) + \frac{2g_{htt}}{m_t}\frac{4}{3} A_{1/2}^h(x_t)$$

Stau contribution



$$\mathcal{M}_{\gamma\gamma}(\tilde{\tau}) = \sum_{i=1,2} \frac{g_{h\tilde{\tau}_i\tilde{\tau}_i}}{m_{\tilde{\tau}_i}^2} A_0^h(x_{\tilde{\tau}_i})$$

$$g_{h\tilde{\tau}\tilde{\tau}} \sim \frac{1}{v} m_{\tilde{\tau}LR}^2 \sin 2\theta_{\tilde{\tau}}$$

- The Higgs to diphoton coupling

$$\kappa_\gamma = \frac{|\mathcal{M}_{\gamma\gamma}(\mathrm{SM}) + \mathcal{M}_{\gamma\gamma}(\tilde{\tau})|}{|\mathcal{M}_{\gamma\gamma}(\mathrm{SM})|}$$

$$\delta\kappa_\gamma = \sum_{i=1,2} 0.03 \frac{m_\tau \mu_H \tan\beta}{m_{\tilde{\tau}_i}^2} \sin 2\theta_{\tilde{\tau}}$$

$$\sim \mathcal{O}(10\%)$$

always Constructive contribution to the SM

In the MSSM, the light staus with large stau mixing contribute to the Higgs to diphoton coupling at O(10%).

[Carena, Gori, Shah and Wagner[1112.3336]]

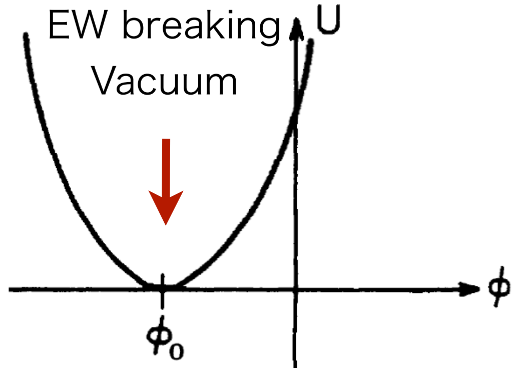
Vacuum Stability

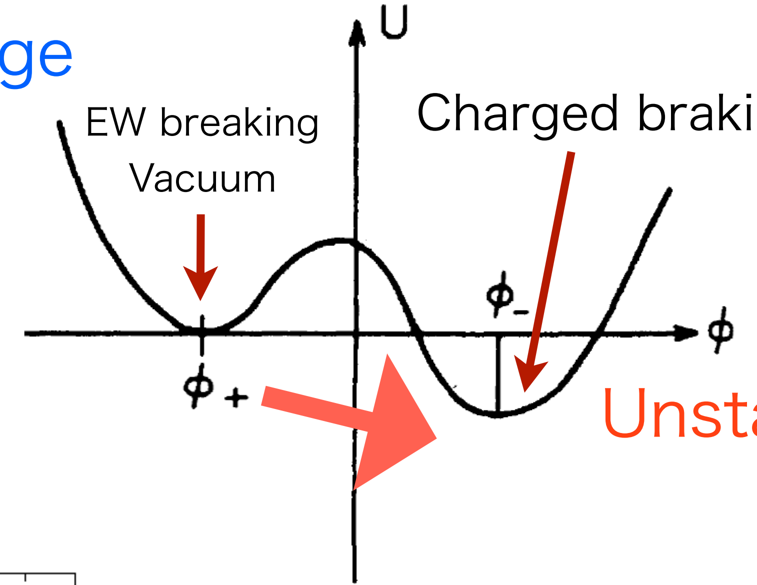
[**TK,** JHEP 1211 021 (2012)]
[**TK,** T.Yoshinaga, JHEP 1305 035 (2013)]

- The large $m^2_{\tilde{\tau}LR}$ increases trilinear couplings of the stau-Higgs potential and eventually makes the ordinary vacuum unstable.

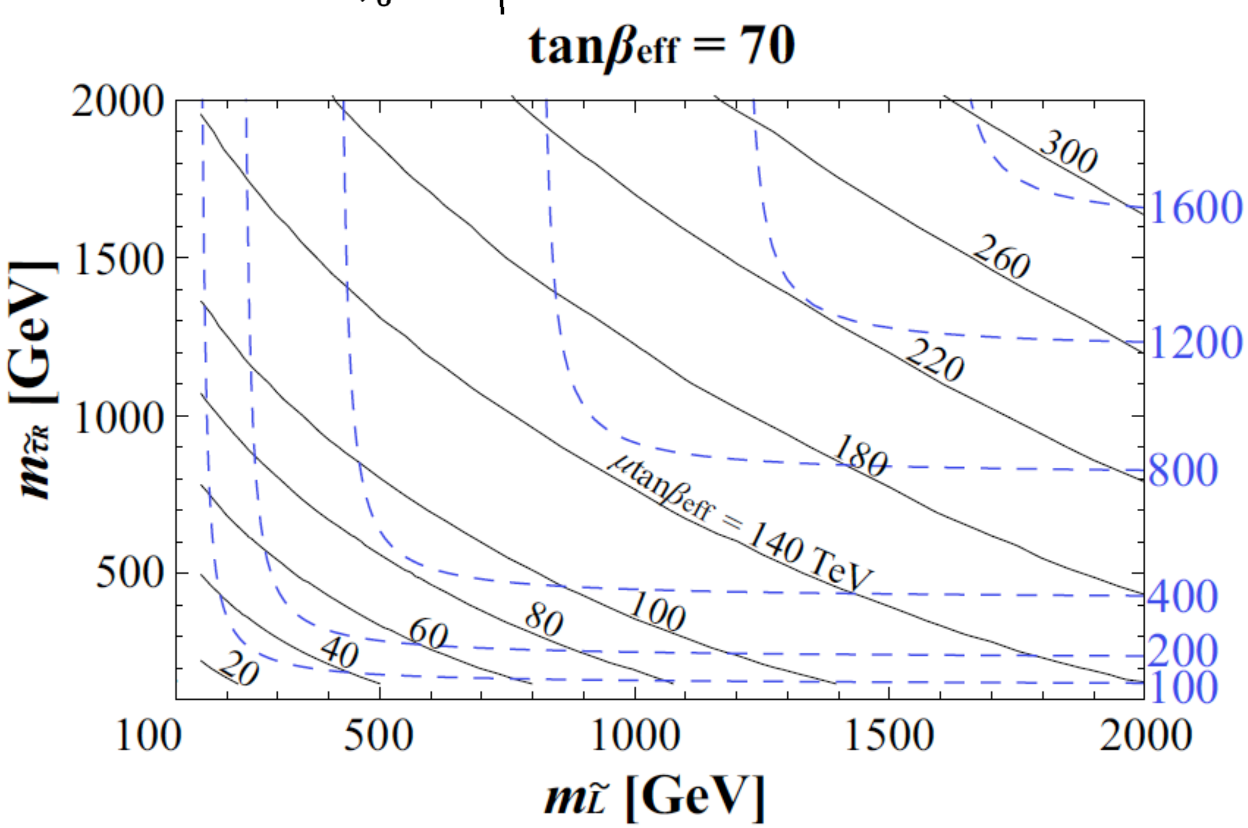
$$m^2_{\tilde{\tau}LR} = m_\tau (A_\tau - \mu_H \tan\beta) \longrightarrow \text{Large}$$

Stable Vacuum





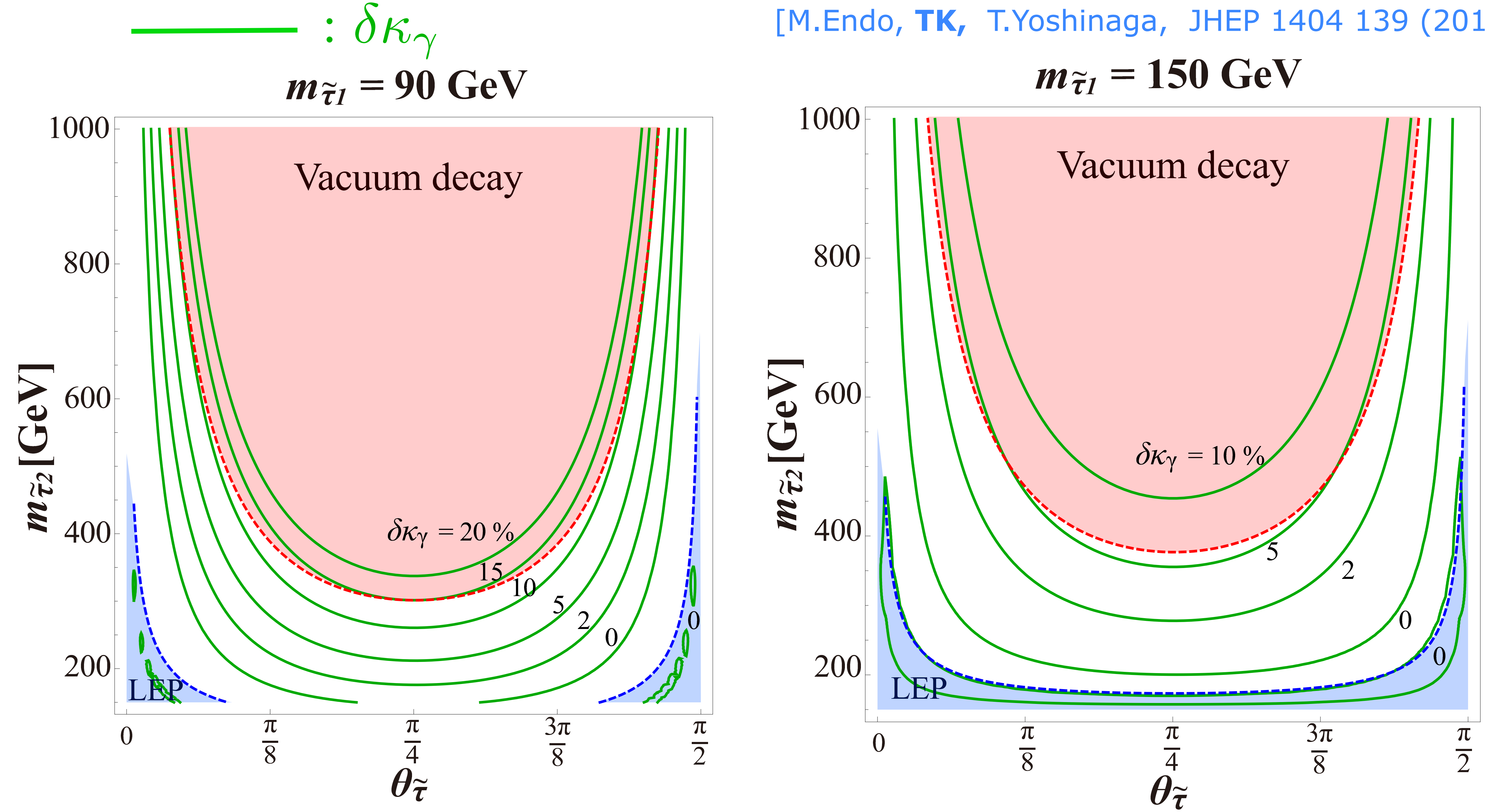
Unstable Vacuum



The vacuum stability gives the upper bound on left-right mixing of staus and κ_γ.

Stau Contributions to κ_γ

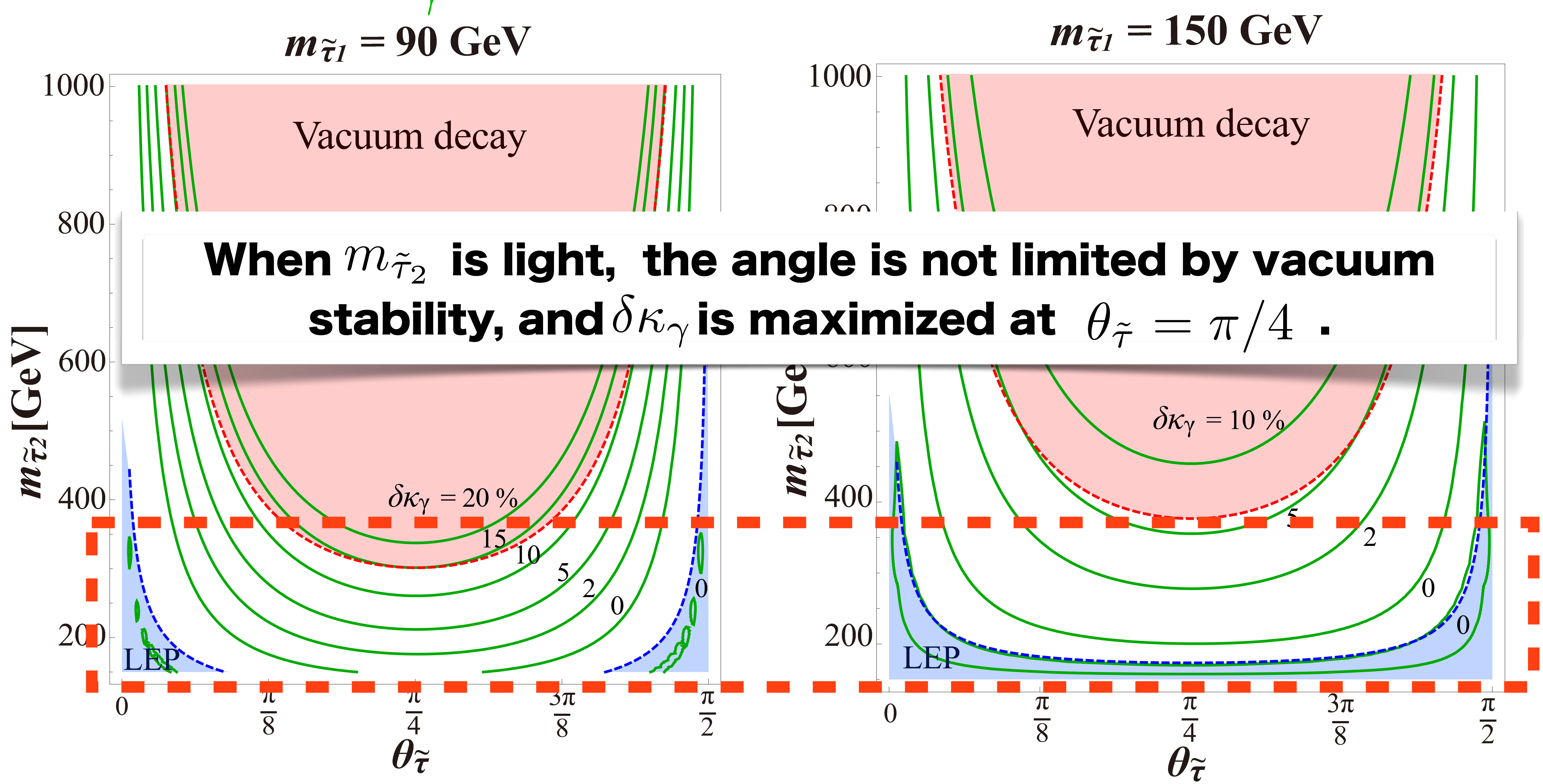
[M.Endo, **TK,** T.Yoshinaga, JHEP 1404 139 (2014)]



Large mixing angle provides significant contributions, but suffers from vacuum stability

Stau Contributions to κ_γ

—— : $\delta\kappa_\gamma$ [M.Endo, **TK,** T.Yoshinaga, JHEP 1404 139 (2014)]

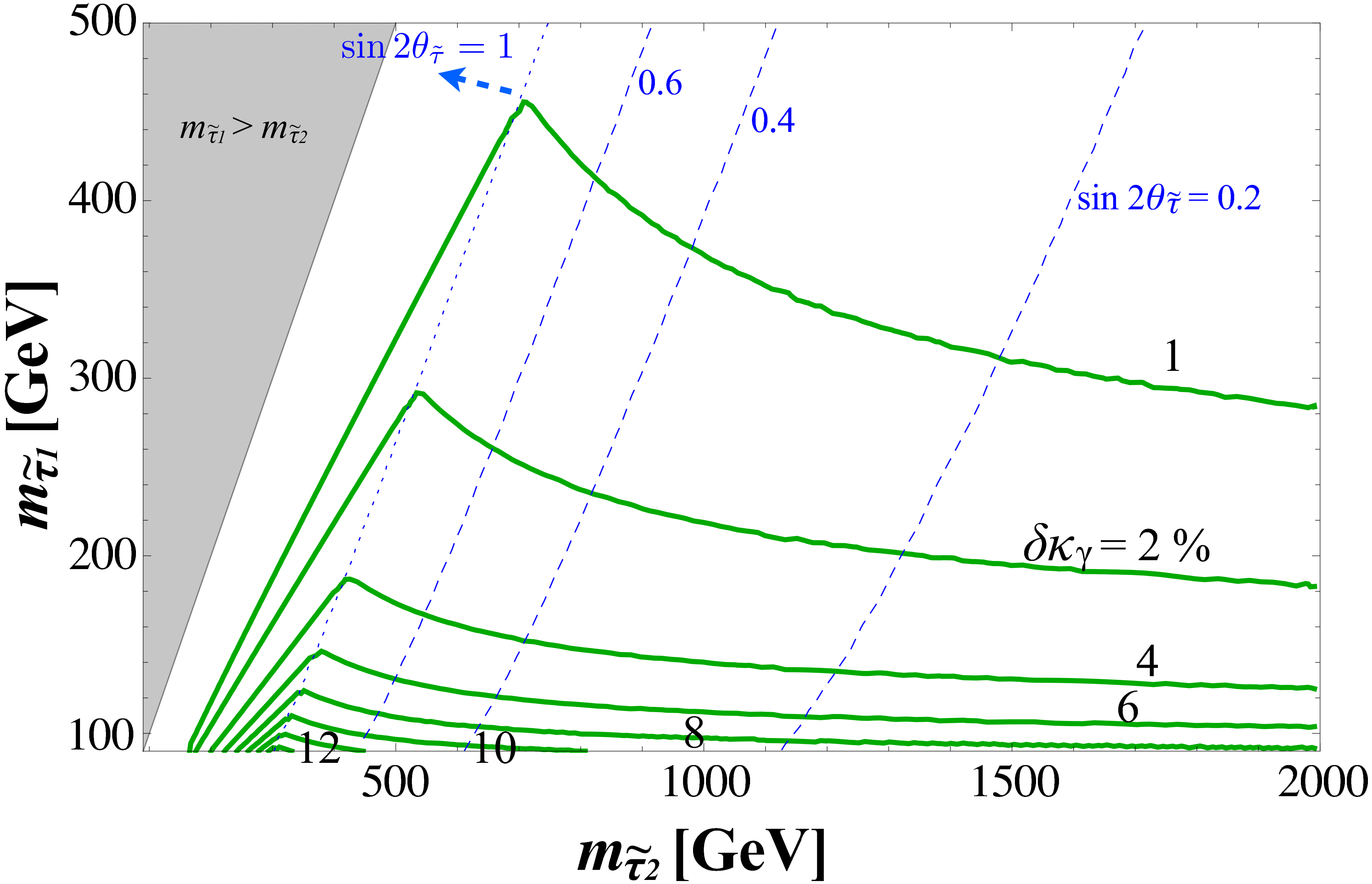


When $m_{\tilde{\tau}_2}$ is light, the angle is not limited by vacuum stability, and $\delta\kappa_\gamma$ is maximized at $\theta_{\tilde{\tau}} = \pi/4$.

Large mixing angle provides significant contributions, but suffers from vacuum stability

Upper bound on the lightest stau mass

The left-right mixing of staus is **maximized at each points under vacuum stability conditions.**



[M.Endo, **TK,** T.Yoshinaga, JHEP 1404 139 (2014)]

U… bound on the lightest stau mass

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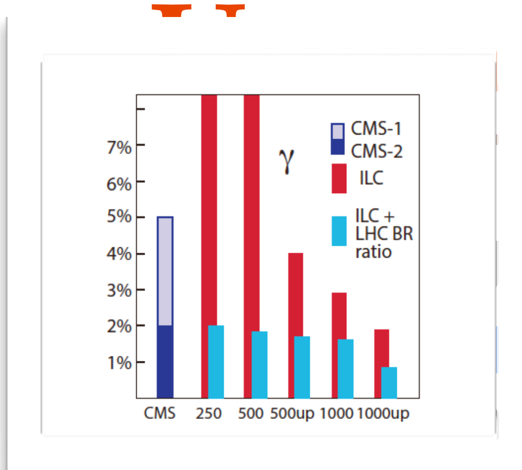
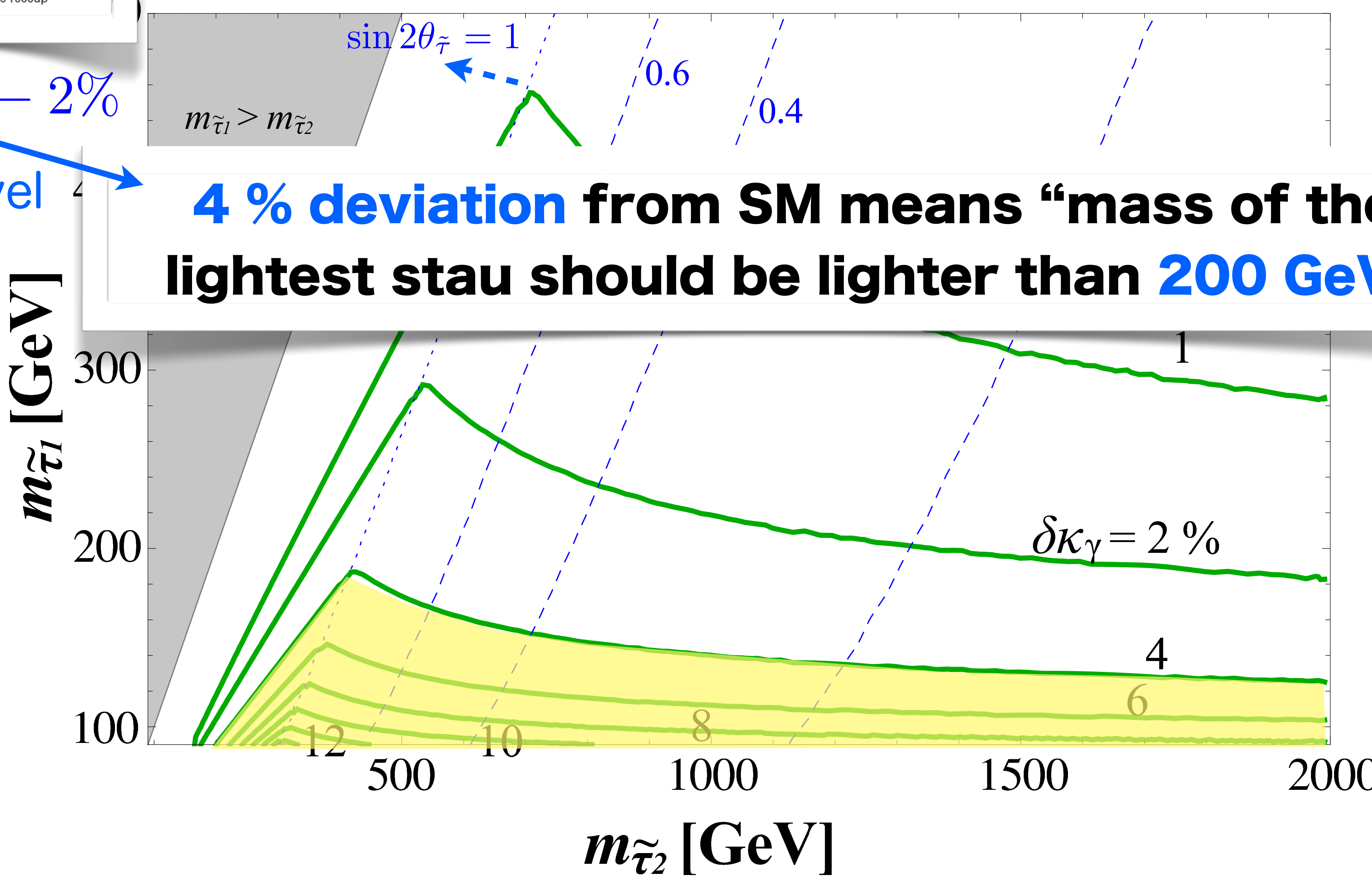


$\delta\kappa_\gamma \sim 1-2\%$

2σ level



4 % deviation from SM means "mass of the lightest stau should be lighter than 200 GeV"

[M.Endo, **TK,** T.Yoshinaga, JHEP 1404 139 (2014)]

Predict the heaviest stau mass

[Bechtle, Berggren, List, Schade, Stempel, Phys.Rev. D82 055016 (2010)]
[M.Endo, **TK,** T.Yoshinaga, JHEP 1404 139 (2014)]

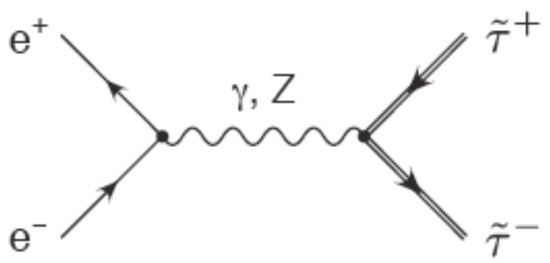
Stau properties are controlled **only three** parameters. $m_{\tilde{\tau}_1},\ m_{\tilde{\tau}_2},\ \theta_{\tilde{\tau}}$

Three observables at the early stage of ILC $m_{\tilde{\tau}_1},\ \theta_{\tilde{\tau}},\ \kappa_\gamma$

Our sample point

$m_{\tilde{\tau}_1}$	$m_{\tilde{\tau}_2}$	$\sin\theta_{\tilde{\tau}}$	$\delta\kappa_\gamma$
150 GeV	400 GeV	0.54	5.6%

true value



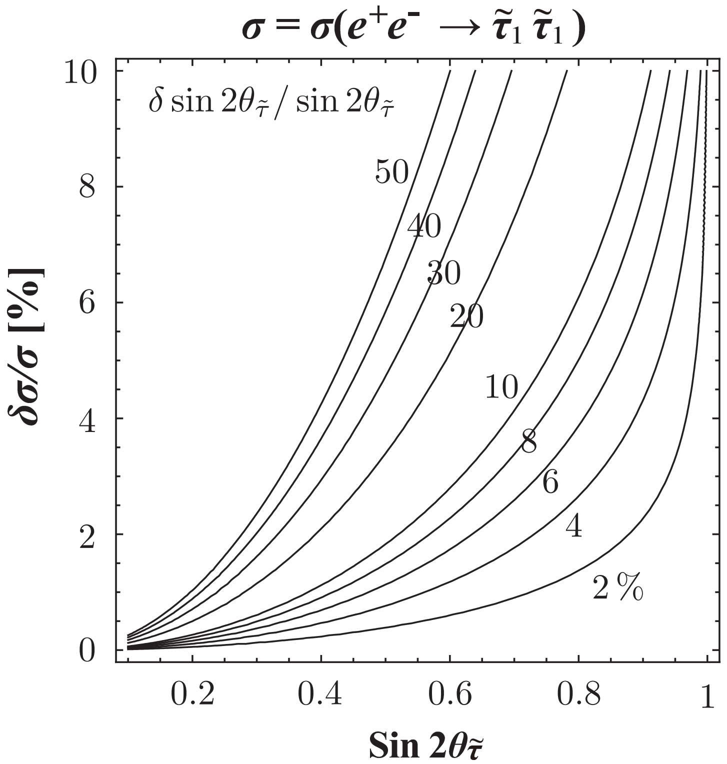
$\Delta\kappa_\gamma \sim 2\%$ by the joint analysis

$\Delta m_{\tilde{\tau}_1} \sim 0.1$ GeV, $\Delta\sigma(\tilde{\tau}_1) \sim 3\%$ at the ILC

We evaluated $\Delta \sin 2\theta_{\tilde{\tau}} \sim 2.5\%$

$m_{\tilde{\tau}_2}$ is predicted. ➡ $\boxed{m_{\tilde{\tau}_2} = 400 \pm 53 \text{ GeV}}$

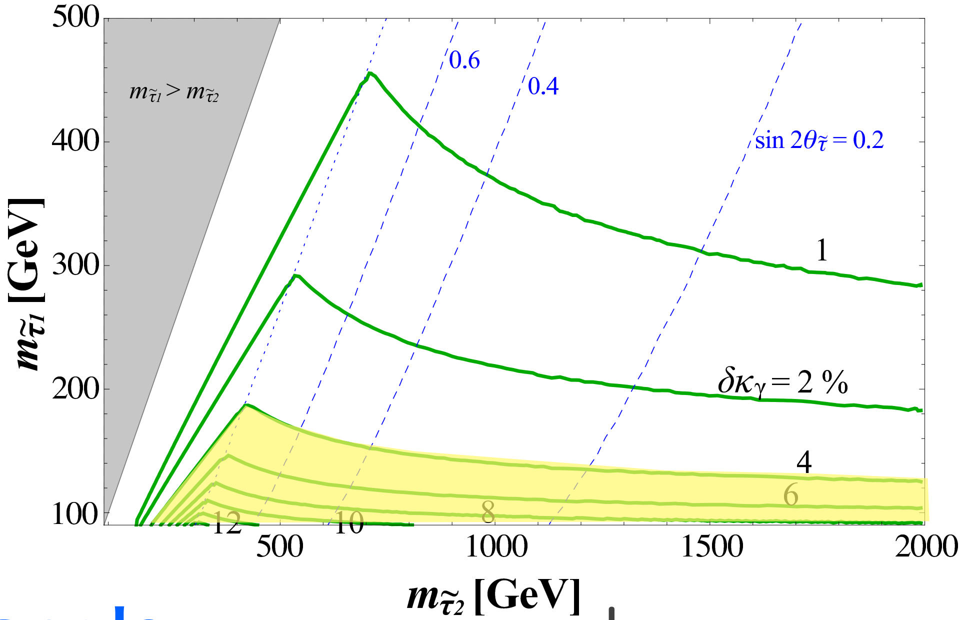
This proposal would be helpful for choosing the beam energy to search for $\tilde{\tau}_2$ at ILC.



Conclusions

- The coupling κ_γ will be measured **at percent levels by the joint analysis of HL-LHC and ILC**, and they enable us to probe the stau properties (mass, mixing) indirectly.

- **If the excess of κ_γ is measured to larger than 4% at the early stage of ILC, the lightest stau is predicted to be lighter than 200 GeV.**



- If the excess of κ_γ and **the stau mixing angle** are measured at the early stage of ILC, it is possible to predict the heaviest stau mass, even when it is not yet discovering.

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Backup Slide

Chargino Contributions to κ_γ

$$\mathcal{M}_{\gamma\gamma}(\tilde{\chi}^{\pm}) = \frac{4}{3}\frac{g^2 v \sin 2\beta}{M_2\mu_H - \frac{1}{4}g^2v^2\sin 2\beta}.$$

[M.Endo, **TK,** T.Yoshinaga, JHEP 1404 139 (2014)]