

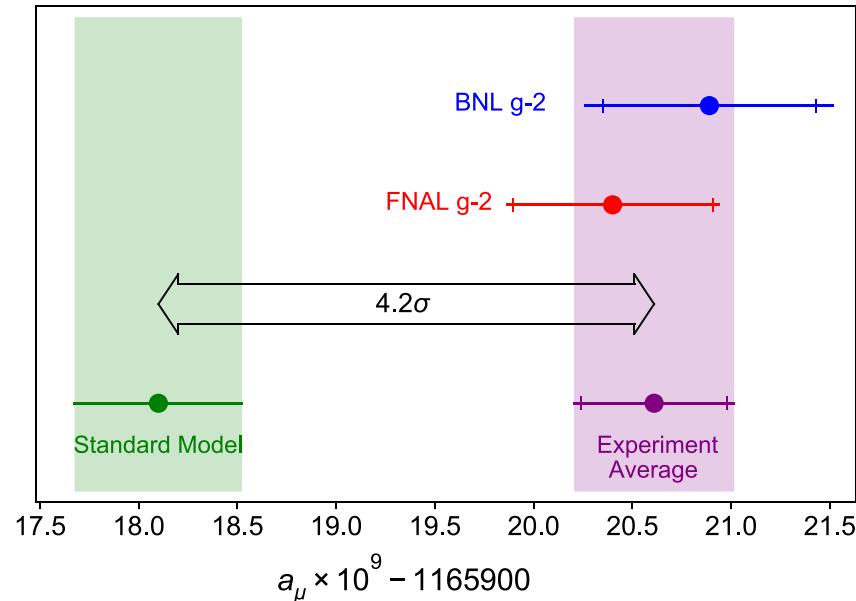
The Muon $g - 2$ Anomaly and Supersymmetry

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1. Introduction

Muon $g - 2$ anomaly



[Muon $g - 2$ Collaboration ('21)]

$$a_\mu^{(\text{exp})} = (11\,659\,206.1 \pm 4.1) \times 10^{-10}$$
$$a_\mu^{(\text{SM})} = (11\,659\,181.0 \pm 4.3) \times 10^{-10}$$

[Aoyama et al. ('20)]

$$a_\mu = \frac{1}{2}(g_\mu - 2)$$

$$a_\mu^{(\text{exp})} - a_\mu^{(\text{SM})} = (25.1 \pm 5.9) \times 10^{-10}$$

⇒ There exists 4.2σ discrepancy

⇒ This may indicate a physics beyond the SM

The muon $g - 2$ anomaly may be due to SUSY contribution

⇒ I discuss implications of the muon $g - 2$ anomaly to the SUSY phenomenology

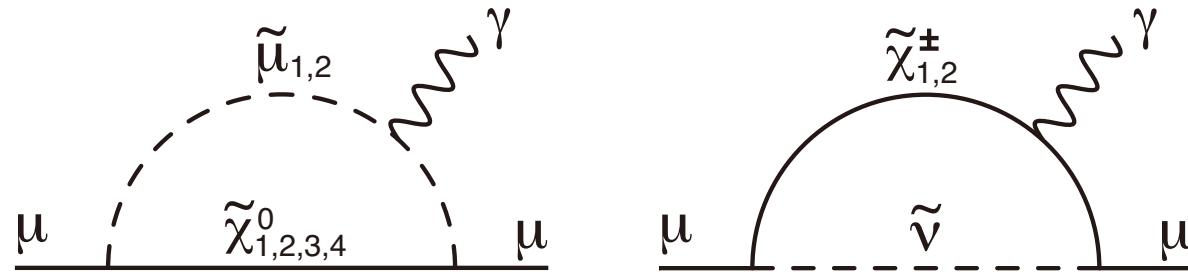
Outline

1. Introduction
2. Muon $g - 2$ in the Minimal SUSY SM (MSSM)
3. Muon $g - 2$ Anomaly and Vacuum Stability
4. Reconstruction of the SUSY Contribution to a_μ using ILC
5. Summary

2. Muon $g - 2$ in the MSSM

SUSY contribution $a_\mu^{(\text{SUSY})}$

[Lopez, Nanopoulos & Wang ('93); Chattopadhyay & Nath ('95); TM ('95)]



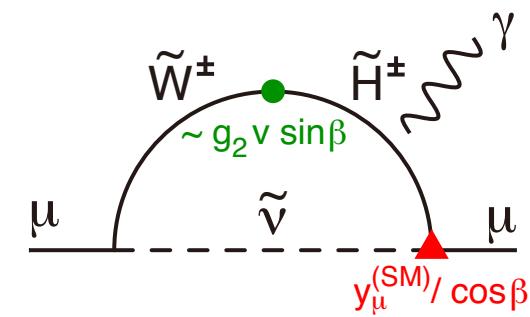
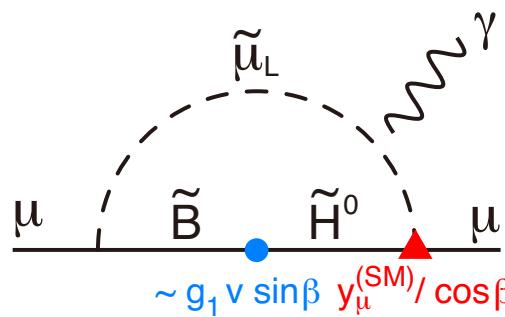
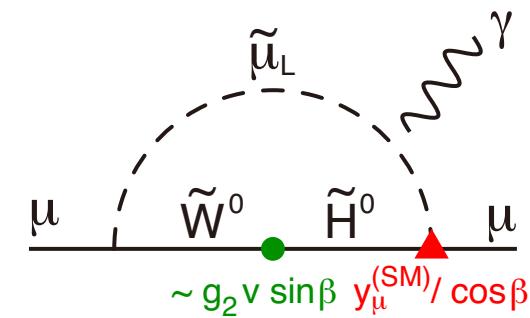
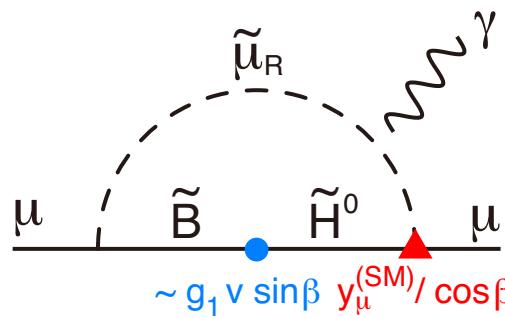
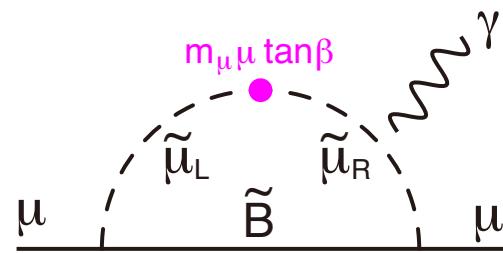
$$\Rightarrow a_\mu^{(\text{th})} = a_\mu^{(\text{SM})} + a_\mu^{(\text{SUSY})}$$

$a_\mu^{(\text{SUSY})}$ is enhanced when $\tan \beta$ is large

$$\tan \beta = \frac{\langle H_u \rangle}{\langle H_d \rangle} \Leftrightarrow y_\mu^{(\text{MSSM})} \simeq \frac{y_\mu^{(\text{SM})}}{\cos \beta}$$

$\tan \beta \lesssim 50 - 60$ for perturbativity

$\tan\beta$ enhanced diagrams (with mass insertion)



μ : Higgsino mass

If all the SUSY particles are degenerate:

$$a_\mu^{(\text{SUSY})} \simeq \frac{5g_2^2}{192\pi^2} \frac{m_\mu^2}{m_{\text{SUSY}}^2} \tan\beta$$

$\Rightarrow m_{\text{SUSY}} \lesssim 700 \text{ GeV}$ for $a_\mu^{(\text{SUSY})} \gtrsim 13.3 \times 10^{-10}$ and $\tan\beta \lesssim 50$

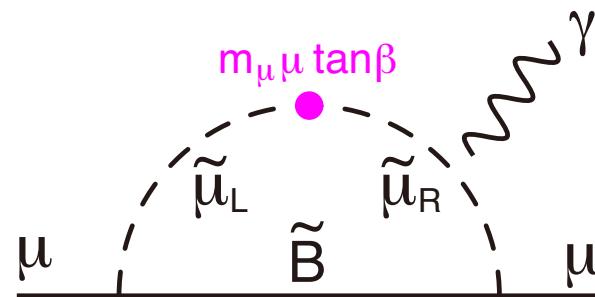
3. Muon $g - 2$ Anomaly and Vacuum Stability

Ref:

Chigusa, TM, Shoji, 2203.08062 [PLB 831 ('22) 137163]

Upper bound on the superparticle masses to solve the anomaly

⇒ Bino-smuon diagram is important



⇒ It is enhanced in large μ limit

The $\tilde{\mu}_L$ - $\tilde{\mu}_R$ mixing is due to H - $\tilde{\mu}_L$ - $\tilde{\mu}_R$ trilinear interaction

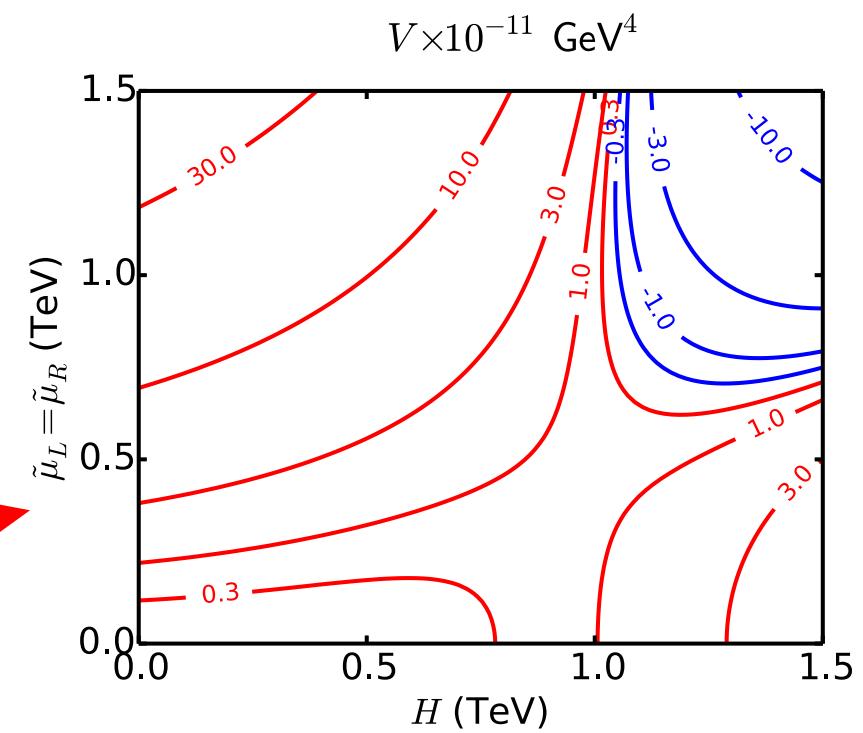
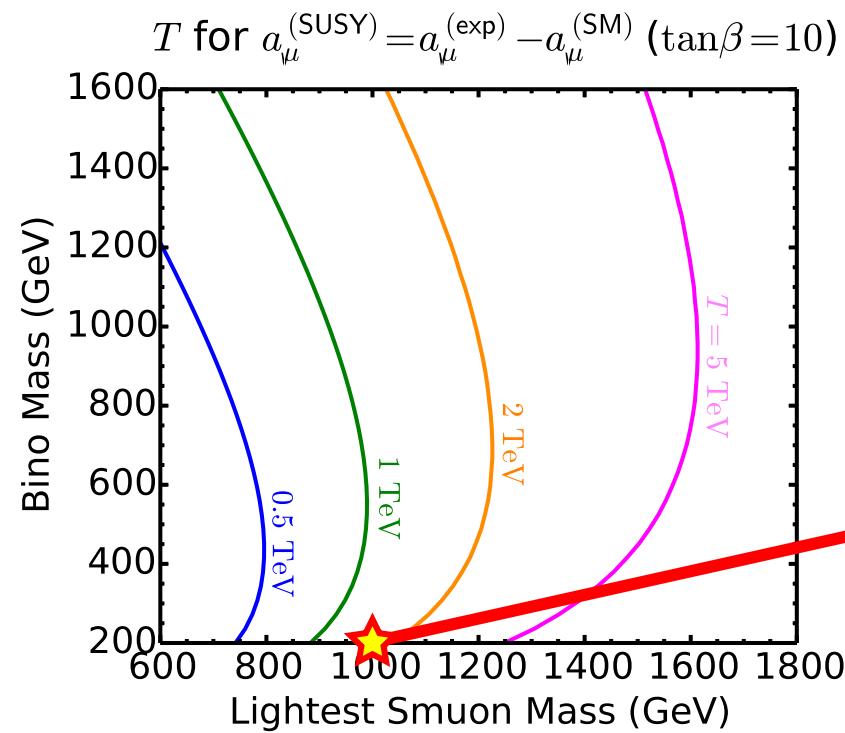
⇒ A large trilinear coupling makes the EW vacuum unstable
[Frere, Jones & Raby ('83); Gunion, Haber & Sher ('88); Kusenko, Langacker & Segre ('96)]

Stability of the EW vacuum is important in studying $a_\mu^{(\text{SUSY})}$

[Endo, Hamaguchi, Kitahara & Yoshinaga ('13); Endo, Hamaguchi, Iwamoto & Kitahara ('21)]

$$V \simeq V_H + m_L^2 |\tilde{\ell}_L|^2 + m_R^2 |\tilde{\mu}_R|^2 - T(H_{\text{SM}}^\dagger \tilde{\ell}_L \tilde{\mu}_R^\dagger + \text{h.c.}) + \dots$$

$$T \simeq y_\mu^{(\text{SM})} \mu \tan \beta$$



Decay rate per unit volume can be calculated with “bounce”
[Coleman ('77); Callan & Coleman ('77)]

$$\gamma \equiv \mathcal{A} e^{-\mathcal{B}} \text{ with } \mathcal{B} = \text{Bounce action}$$

We have performed a full one-loop calculation of \mathcal{A}

$$\mathcal{A} \simeq \frac{1}{VT} \times \left| \frac{\text{Det} \mathcal{M}^{(\text{Bounce})}}{\text{Det} \mathcal{M}^{(\text{EW})}} \right|_{\text{Bosons}}^{-1/2} \times \left| \frac{\text{Det} \mathcal{M}^{(\text{Bounce})}}{\text{Det} \mathcal{M}^{(\text{EW})}} \right|_{\text{Fermions}}$$

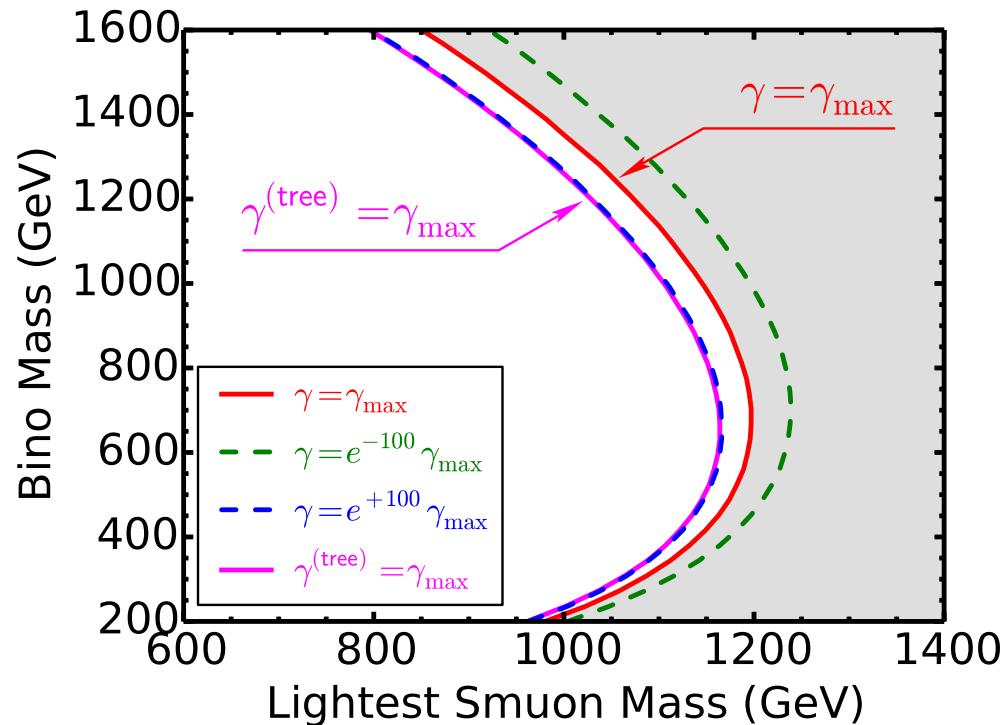
$$\mathcal{M}_{ij}(x, y) \equiv \frac{\delta^2 S_E}{\delta \Phi_i(x) \delta \Phi_j(y)} : \text{Fluctuation operator}$$

Fields included:

- $H_{\text{SM}}, \tilde{\ell}_L, \tilde{\mu}_R$
- t, γ, Z, W^\pm

Stability of the EW vacuum (taking $m_L = m_R$)

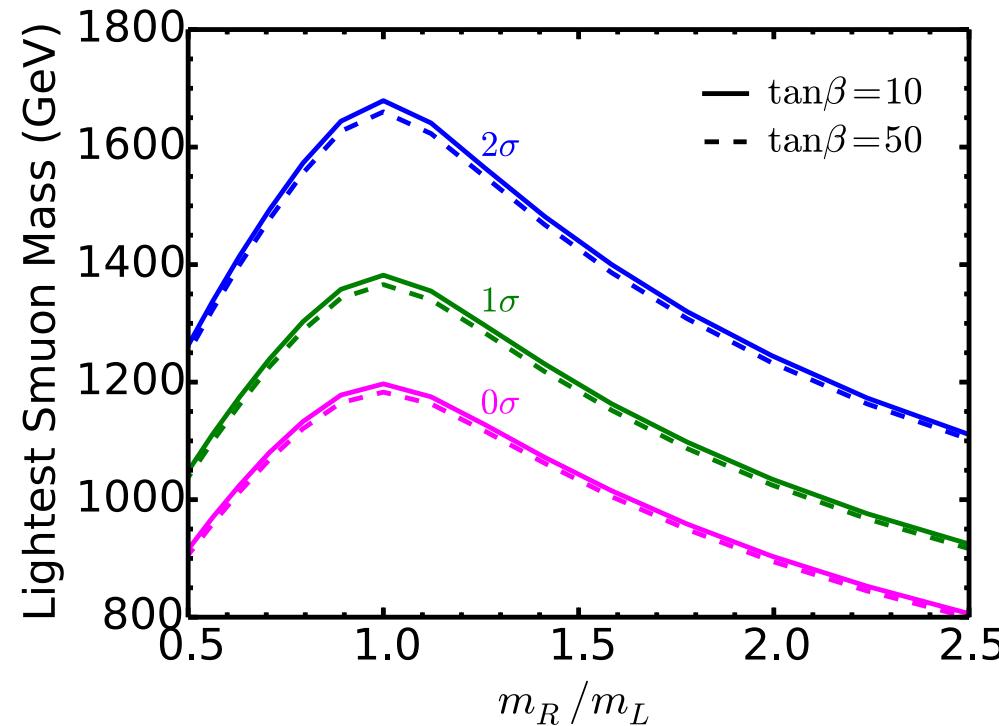
$$\gamma < \gamma_{\max} \equiv (V_{\text{horizon}} t_{\text{now}})^{-1} \sim 0.0002 \text{ Gyr}^{-1} \text{Gpc}^{-3}$$



- $a_\mu^{(\text{SUSY})} = 25.1 \times 10^{-10}$
- T is tuned to realize $a_\mu^{(\text{SUSY})}$
- $\tan \beta = 10$
- $\gamma^{(\text{tree})} \equiv \langle H_{\text{SM}} \rangle^4 e^{-\mathcal{B}}$

⇒ Decay rate becomes larger as the smuons become heavier

Upper bound on the lightest smuon mass



	0σ	1σ	2σ
$\tan\beta = 10$	1.20 TeV	1.38 TeV	1.68 TeV
$\tan\beta = 50$	1.18 TeV	1.37 TeV	1.66 TeV

4. Reconstruction of $a_\mu^{(\text{SUSY})}$ with the ILC

Refs:

Endo, Hamaguchi, Iwamoto, Kitahara & TM, 1310.4496 [PLB 728 ('14) 274]

Endo, Hamaguchi, Iwamoto, Kawada, Kitahara, TM & Suehara, 2203.07056

Superparticles may be within the reaches of future colliders

⇒ $a_\mu^{(\text{SUSY})}$ may be reconstructed

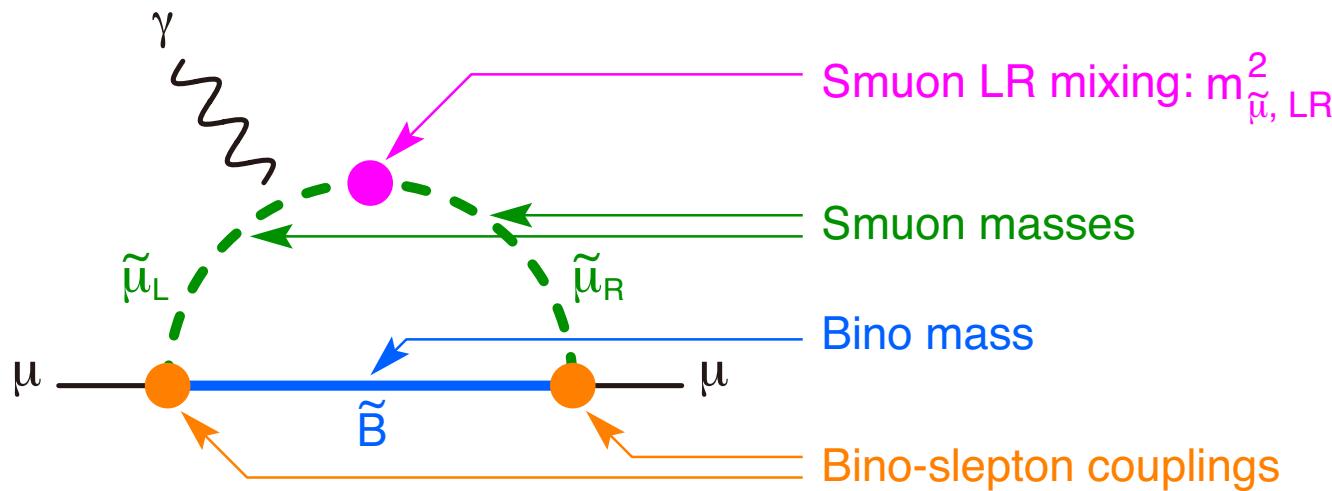
Let us consider how and how well we can reconstruct $a_\mu^{(\text{SUSY})}$

- International e^+e^- Linear Collider (ILC) with $\sqrt{s} = 500$ GeV

$m_{\tilde{\tau}_1}$	113.2 GeV	$\tan \beta$	4.84
$m_{\tilde{\tau}_2}$	189.8 GeV	μ	1324 GeV
$\cos \theta_{\tilde{\tau}}$	0.703	$m_{\tilde{\mu}_1}$	154.0 GeV
$m_{\chi_1^0}$	99.3 GeV	$m_{\tilde{\mu}_2}$	158.5 GeV
		$a_\mu^{(\tilde{B})}$	27.5×10^{-10}

- Sleptons and the lightest neutralino are within the reach
- Other superparticles are (much) heavier

Bino-smuon contribution to $a_\mu^{(\text{SUSY})}$



- Bino and smuon masses are obtained from endpoints
- Bino-slepton couplings can be determined by measuring $\sigma(e^+e^- \rightarrow \tilde{e}^*\tilde{e})$ and $\sigma(e^+e^- \rightarrow \tilde{\nu}_e^*\tilde{\nu}_e)$
[Nojiri, Fujii & Tsukamoto ('96); Nojiri, Pierce & Yamada ('97); Cheng, Feng & Polonsky ('97)]
- Direct measurement of $m_{\tilde{\mu}, \text{LR}}^2$ is difficult since $m_{\tilde{\mu}, \text{LR}}^2 \ll m_{\tilde{\mu}_{1,2}}^2$

We may use $\tilde{\tau}$'s to determine $m_{\tilde{\mu},LR}^2$

$$m_{\tilde{\ell},LR}^2 \simeq m_\ell \mu \tan \beta \Rightarrow m_{\tilde{\mu},LR}^2 \simeq \frac{m_\mu}{m_\tau} m_{\tilde{\tau},LR}^2$$

$m_{\tilde{\tau},LR}^2$ is related to observables as

$$m_{\tilde{\tau},LR}^2 = \frac{1}{2} (m_{\tilde{\tau}_1}^2 - m_{\tilde{\tau}_2}^2) \sin 2\theta_{\tilde{\tau}} \quad w/ \begin{pmatrix} \tilde{\tau}_1 \\ \tilde{\tau}_2 \end{pmatrix} = \begin{pmatrix} \cos \theta_{\tilde{\tau}} & \sin \theta_{\tilde{\tau}} \\ -\sin \theta_{\tilde{\tau}} & \cos \theta_{\tilde{\tau}} \end{pmatrix} \begin{pmatrix} \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix}$$

We consider: $e^+ e^- \rightarrow \tilde{\tau}_i \tilde{\tau}_j^*$, followed by $\tilde{\tau} \rightarrow \tau \tilde{B}$

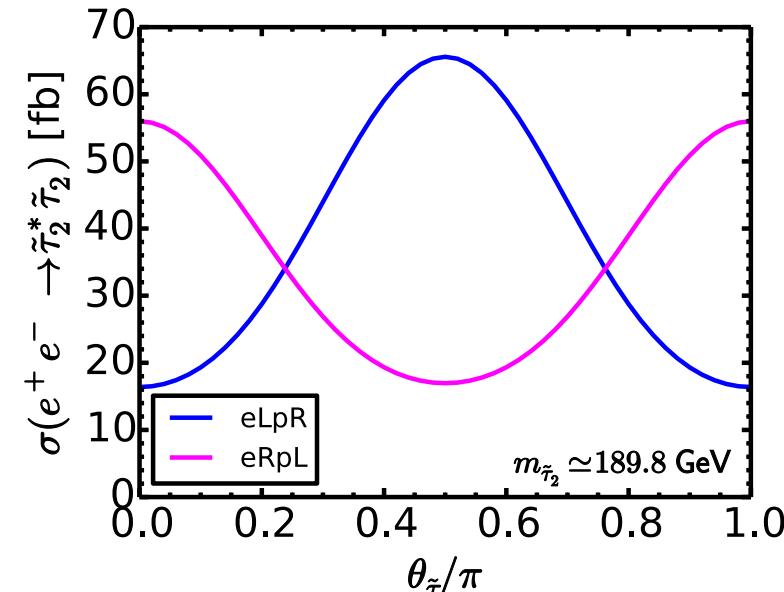
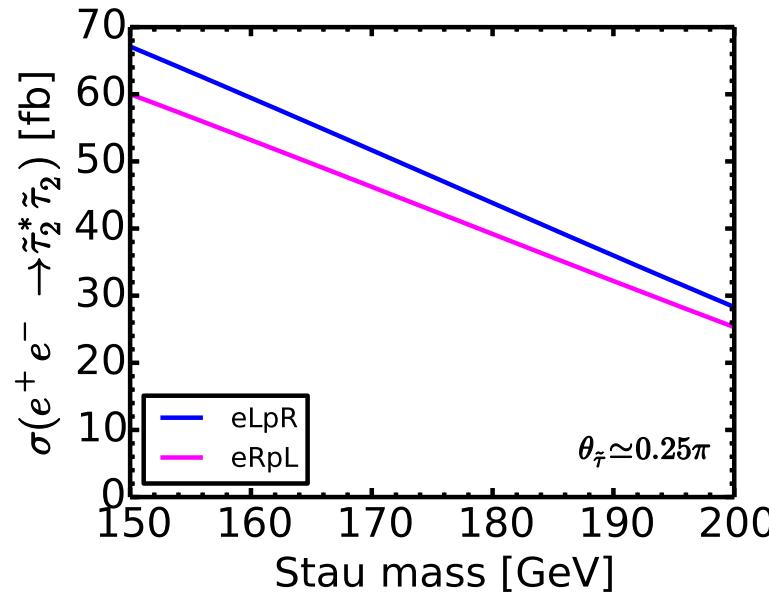
[Earlier works: Nojiri ('95); Nojiri, Fujii & Tsukamoto ('96); Bechtle et al. ('10)]

- Two hadronic tau candidates with opposite charges
- No isolated leptons
- (+ Additional cuts)

\Rightarrow SM and SUSY bkgs can be made sub-dominant

We can use cross-section and endpoint information

- Cross sections depend on stau masses and mixing angle

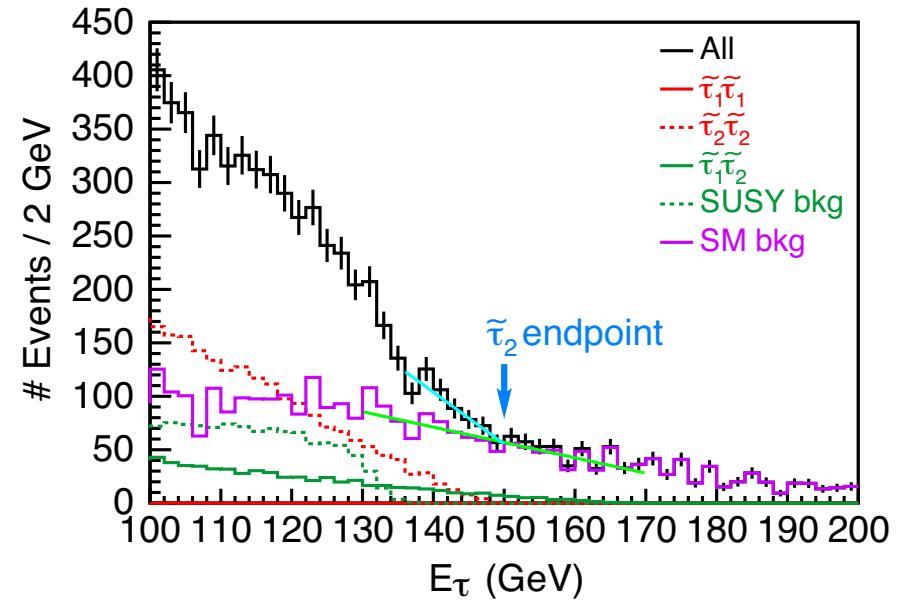
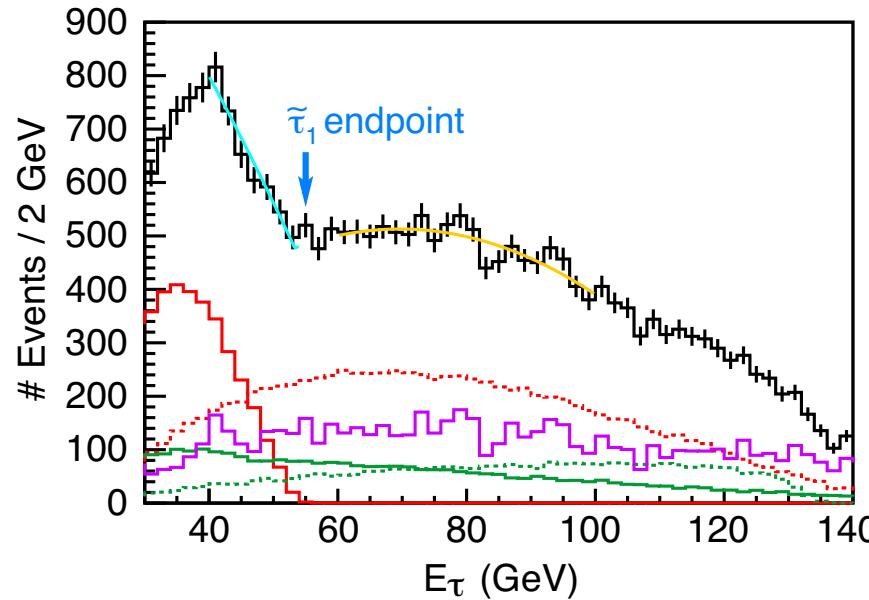


$$\text{eLpR / eRpL: } (P_{e^-}, P_{e^+}) = (-80\%, +30\%) / (+80\%, -30\%)$$

- Endpoint of the energy distribution of τ -jets

$$E_\tau < \frac{m_{\tilde{\tau}}^2 - m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{\tau}}^2} \left(E_{\tilde{\tau}} + \sqrt{E_{\tilde{\tau}}^2 - m_{\tilde{\tau}}^2} \right)$$

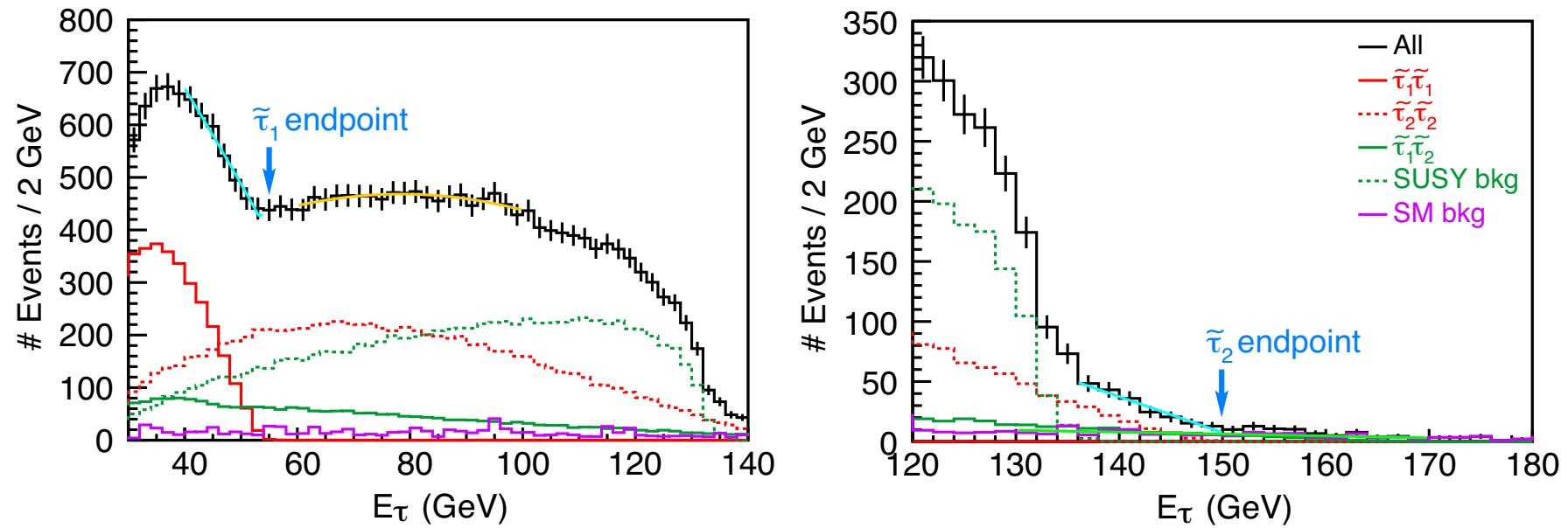
Energy distribution of the leading τ -jet: eLpR w/ 1.6 ab^{-1}



	Fit	True
$\tilde{\tau}_1$ endpoint	$53.31 \pm 0.55 \text{ GeV}$	54.5 GeV
$\tilde{\tau}_2$ endpoint	$149.5 \pm 1.7 \text{ GeV}$	149.9 GeV

- We extract the cross-section information using the number of events with $60 < E_\tau < 150 \text{ GeV}$

Energy distribution of the leading τ -jet: eRpL w/ 1.6 ab^{-1}



	Fit	True
$\tilde{\tau}_1$ endpoint	$53.17 \pm 0.67 \text{ GeV}$	54.5 GeV
$\tilde{\tau}_2$ endpoint	$150.4 \pm 1.2 \text{ GeV}$	149.9 GeV

- We extract the cross-section information using the number of events with $60 < E_\tau < 150 \text{ GeV}$

Results of likelihood analysis using cross section and endpoint

	Fit	True
$m_{\tilde{\tau}_1}$ [GeV]	112.8 ± 0.8	113.2
$m_{\tilde{\tau}_2}$ [GeV]	$189.9^{+0.8}_{-0.7}$	189.8
$\cos \theta_{\tilde{\tau}}$	0.703 ± 0.010	0.703
$-m_{\tilde{\tau},LR}^2$ [GeV 2]	$(1.17 \pm 0.01) \times 10^4$	11606
$-m_{\tilde{\mu},LR}^2$ [GeV 2]	693^{+9}_{-8}	690.1
$m_{\tilde{\mu}_1}$ [GeV]	(154.0 ± 0.2)	154.0
$m_{\tilde{\mu}_2}$ [GeV]	(158.5 ± 0.2)	158.5
$m_{\chi_1^0}$ [GeV]	(99.3 ± 0.1)	99.3
$a_\mu^{(\tilde{B})}$ [10^{-10}]	27.5 ± 0.4	27.5

Smuon and Bino results are taken from earlier works
 [Martyn ('04); Freitas et al. ('04); Baer et al. ('13)]

$$\Rightarrow \delta a_\mu^{(\text{SUSY})} \Big|_{\text{ILC}} \sim \text{a few \%}$$

5. Summary

The muon $g - 2$ anomaly can be due to SUSY contributions

⇒ Rich phenomenology

Stability of the EW vacuum constrains the mass spectrum

⇒ $m_{\tilde{\mu}} \lesssim 1.4 - 1.7$ TeV (for $1 - 2\sigma$ consistency of $a_\mu^{(\text{th})}$ and $a_\mu^{(\text{exp})}$)

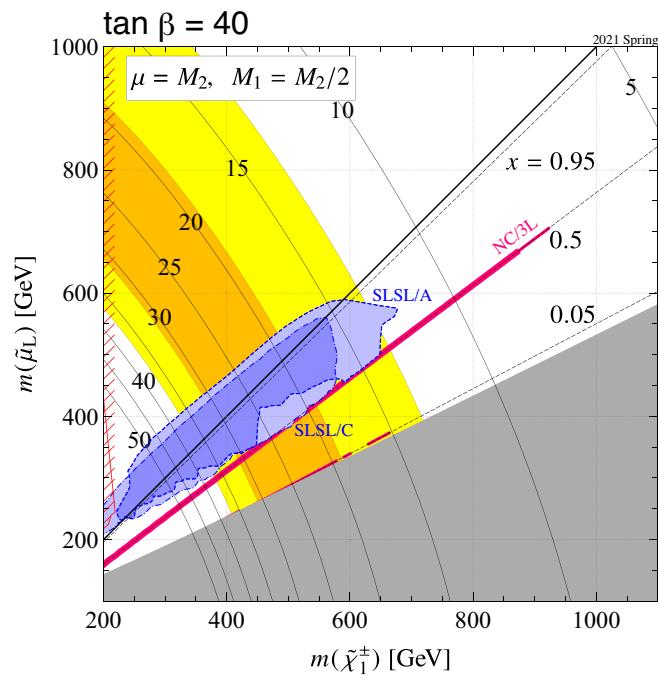
ILC can help reconstructing the SUSY contribution to a_μ

⇒ $\delta a_\mu^{(\text{SUSY})} \Big|_{\text{ILC}} \sim \text{a few \%}$ (for our sample point)

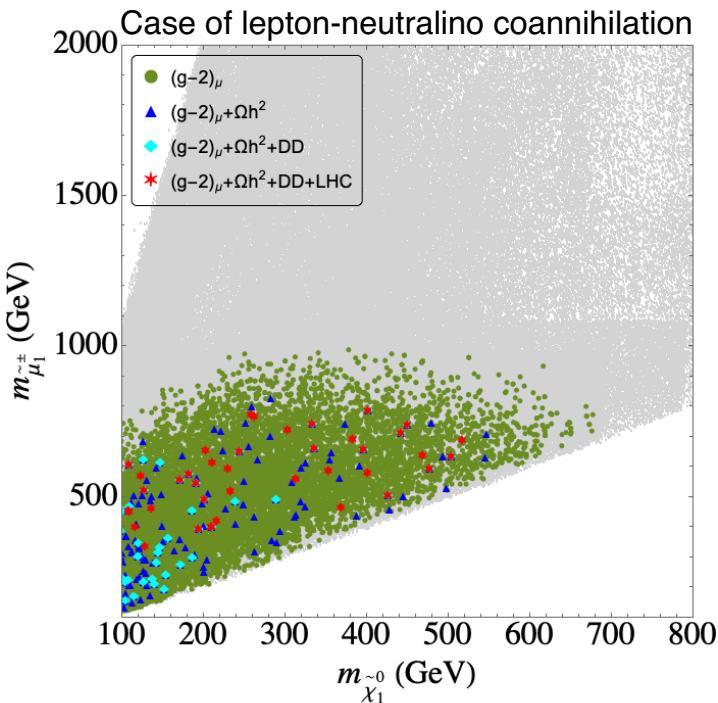
Backup: Muon $g - 2$, LHC, and DM in the MSSM

SUSY interpretation of the muon $g - 2$ anomaly is possible

↔ Parameter region remains after imposing LHC and/or DM constraints



[Endo, Hamaguchi, Iwamoto & Kitahara, 2104.03217]



[Chakraborti, Heinemeyer & Saha, 2104.03287]

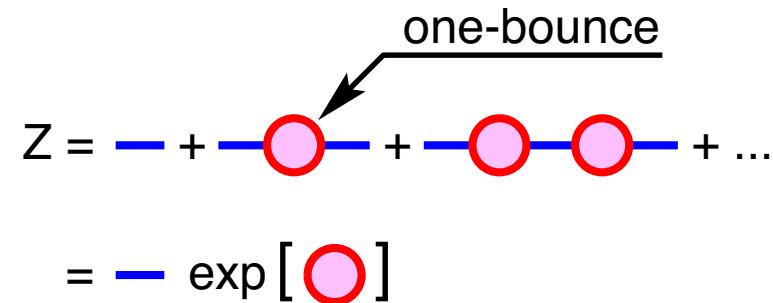
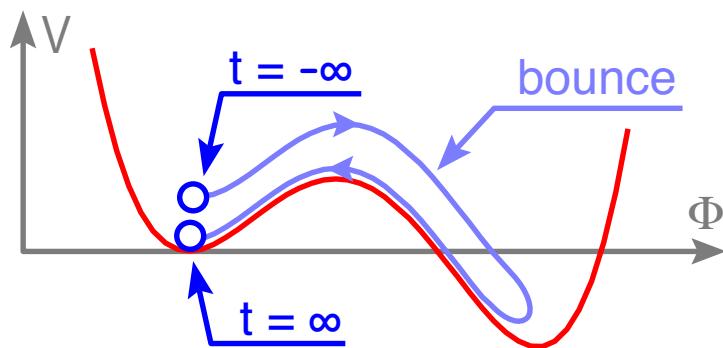
⇒ Let us discuss implications of the muon $g - 2$ anomaly

Backup: Calculation of $\text{Det}\mathcal{M}$ (Bosonic Case)

Calculation of the decay rate of the false vacuum with bounce

[Coleman ('77); Callan & Coleman ('77)]

$$Z = \langle \text{FV} | e^{-HT} | \text{FV} \rangle \propto \exp(i\gamma VT)$$



$$\gamma \simeq \frac{1}{VT} \text{Im} \left[\frac{\int_{1\text{-bounce}} \mathcal{D}\Psi e^{-S_E}}{\int_{0\text{-bounce}} \mathcal{D}\Psi e^{-S_E}} \right] \equiv \mathcal{A}e^{-\mathcal{B}} \quad \text{with } \mathcal{B} = S_E[\bar{\phi}] - S_E[v]$$

Prefactor \mathcal{A}

$$\mathcal{A} \simeq \frac{1}{VT} \times \left| \frac{\text{Det}\mathcal{M}^{(\text{Bounce})}}{\text{Det}\mathcal{M}^{(\text{EW})}} \right|_{\text{Bosons}}^{-1/2} \times \left| \frac{\text{Det}\mathcal{M}^{(\text{Bounce})}}{\text{Det}\mathcal{M}^{(\text{EW})}} \right|_{\text{Fermions}}$$

$$\mathcal{M}_{ij}(x, y) \equiv \frac{\delta^2 S}{\delta \Phi_i(x) \delta \Phi_j(y)} : \text{Fluctuation operator}$$

For the calculation of \mathcal{A} , we need

- Path integral around the false vacuum
- Path integral around the bounce

⇒ We use Gelfand-Yaglom theorem to calculate the functional determinant

[Gelfand & Yaglom ('59); Dashen, Hasslacher & Neveu ('74); Coleman ('85); Kirsten & McKane ('03)]

Calculation of $\text{Det}\mathcal{M}$: bosonic case

$$\mathcal{L} \ni \frac{1}{2} \Psi \left[-\partial_\mu \partial_\mu + V''(\bar{\phi}) \right] \Psi = \frac{1}{2} \Psi \mathcal{M} \Psi$$

Expansion of Ψ w.r.t. 4D spherical harmonics \mathcal{Y}_{J,m_A,m_B}

$$\Psi(x) = \sum_{J,m_A,m_B,n} c_{n,J,m_A,m_B} \mathcal{G}_{n,J}(r) \mathcal{Y}_{J,m_A,m_B}(\hat{\mathbf{r}})$$

$$J = 0, 1/2, 1, 3/2, \dots$$

$\mathcal{G}_{n,J}$: n -th radial mode function

c_{n,J,m_A,m_B} : expansion coefficient

Define the path integral as:

$$\int \mathcal{D}\Psi \rightarrow \int \prod_{n,J,m_A,m_B} dc_{n,J,m_A,m_B}$$

Fluctuation operator for angular-momentum eigenstates:

$$\mathcal{M}_J \equiv -(\Delta_J - V'') \equiv -\left[\partial_r^2 + \frac{3}{r}\partial_r - \frac{4J(J+1)}{r^2} - V''\right]$$

Radial mode function $\mathcal{G}_{n,J}$

- $\mathcal{M}_J \mathcal{G}_{n,J}(r) = \omega_{n,J} \mathcal{G}_{n,J}(r)$
 $\omega_{n,J}$: n -th eigenvalue of \mathcal{M}_J
- $\mathcal{G}_{n,J}(r = 0) < \infty$
- $\mathcal{G}_{n,J}(r \rightarrow \infty) = 0$

The ratio of the fluctuation operators:

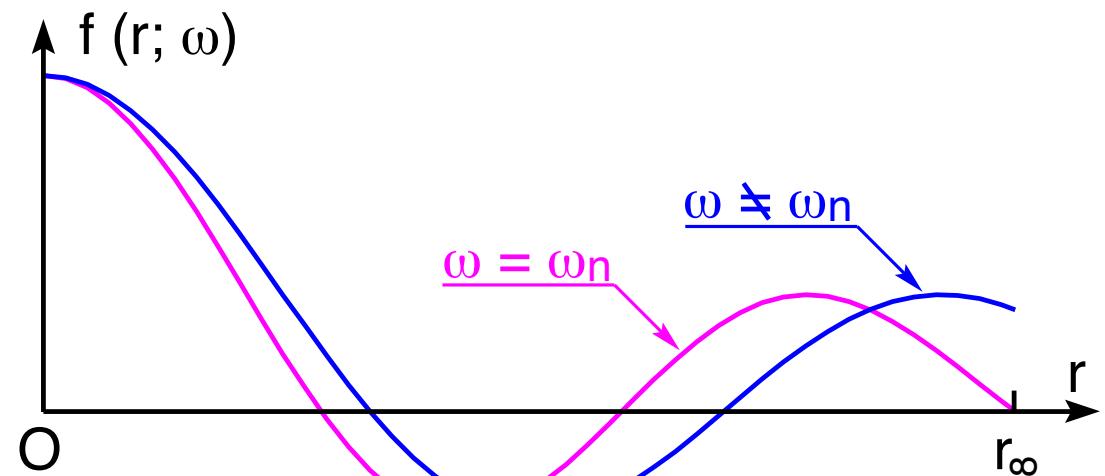
$$\frac{\text{Det} \mathcal{M}}{\text{Det} \widehat{\mathcal{M}}} = \prod_J \left[\frac{\text{Det} \mathcal{M}_J}{\text{Det} \widehat{\mathcal{M}}_J} \right]^{(2J+1)^2} \simeq \prod_{n,J} \left[\frac{\omega_{n,J}}{\widehat{\omega}_{n,J}} \right]^{(2J+1)^2}$$

Functional determinant for operators defined in $0 \leq r \leq r_\infty$

$$\text{Det} \mathcal{M}_J \simeq \prod_n \omega_n \text{ with } \begin{cases} \mathcal{M}_J \mathcal{G}_n = -[\Delta_J + V''(r)] \mathcal{G}_n = \omega_n \mathcal{G}_n \\ \mathcal{G}_n(0) < \infty \\ \mathcal{G}_n(r_\infty) = 0 \end{cases}$$

We introduce a function f_J : $\mathcal{M}_J f_J(r; \omega) = \omega f_J(r; \omega)$

- $f_J(r = r_\infty; \omega)|_{\omega=\omega_n} = 0$
- $\text{Det}(\mathcal{M}_J - \omega)|_{\omega=\omega_n} = 0$



Gelfand-Yaglom theorem

$$\frac{\text{Det}(\mathcal{M}_J - \omega)}{\text{Det}(\widehat{\mathcal{M}}_J - \omega)} = \frac{f_J(r = r_\infty; \omega)}{\widehat{f}_J(r = r_\infty; \omega)} \quad \text{with} \quad \begin{cases} \mathcal{M}_J f_J(r; \omega) = \omega f_J(r; \omega) \\ \widehat{\mathcal{M}}_J \widehat{f}_J(r; \omega) = \omega \widehat{f}_J(r; \omega) \\ f_J(r = 0) = \widehat{f}_J(r = 0) \end{cases}$$

⇒ Notice: LHS and RHS have the same analytic behavior

- LHS and RHS have same zeros and infinities
- LHS and RHS becomes equal to 1 when $\omega \rightarrow \infty$

We can use:

$$\frac{\text{Det}\mathcal{M}_J}{\text{Det}\widehat{\mathcal{M}}_J} = \frac{f_J(r = \infty; 0)}{\widehat{f}_J(r = \infty; 0)} \quad \text{with} \quad \mathcal{M}_J f_J(r; 0) = \widehat{\mathcal{M}}_J \widehat{f}_J(r; 0) = 0$$

Backup: Scale Dependence of γ

Toy model 1: a model with a real scalar field Φ

$$V(\Phi) = -\xi\Phi + \frac{1}{2}m_\Phi^2\Phi^2 - \frac{1}{2}T\Phi^3 + \frac{1}{8}\lambda\Phi^4$$

\Rightarrow With large T (and $\xi = 0$), $\Phi = 0$ is false vacuum

Coupling constants depend on the renormalization scale Q

$$\frac{d\xi}{d \ln Q} = \frac{3}{16\pi^2} T m_\Phi^2$$

$$\frac{dm_\Phi^2}{d \ln Q} = \frac{3}{16\pi^2} (\lambda m_\Phi^2 + 3T^2)$$

$$\frac{dT}{d \ln Q} = \frac{9}{16\pi^2} \lambda T$$

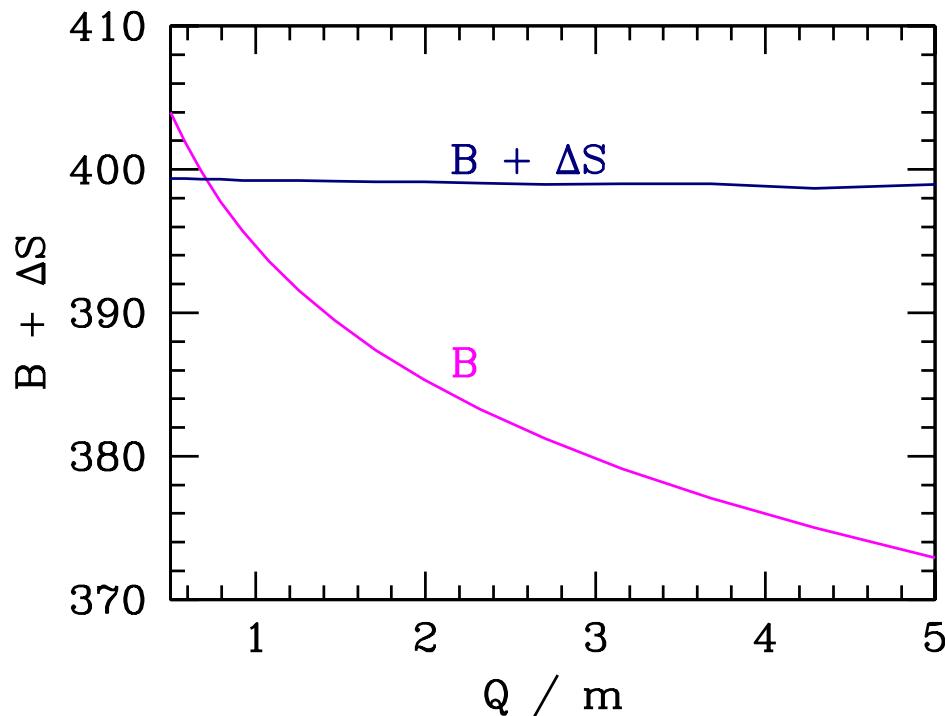
$$\frac{d\lambda}{d \ln Q} = \frac{9}{16\pi^2} \lambda^2$$

The bounce action depends on Q

$$\Rightarrow \mathcal{B} \simeq \int d^4x \left[\mathcal{L}_{\text{kin}} - \xi(Q)\bar{\phi} + \frac{1}{2}m_\Phi^2(Q)\bar{\phi}^2 - \frac{1}{2}T(Q)\bar{\phi}^3 + \frac{1}{8}\lambda(Q)\bar{\phi}^4 \right]$$

$\Rightarrow Q$ dependence disappears from $\gamma = \mathcal{A}e^{-\mathcal{B}}$

[Endo, TM, Nojiri & Shoji ('15)]

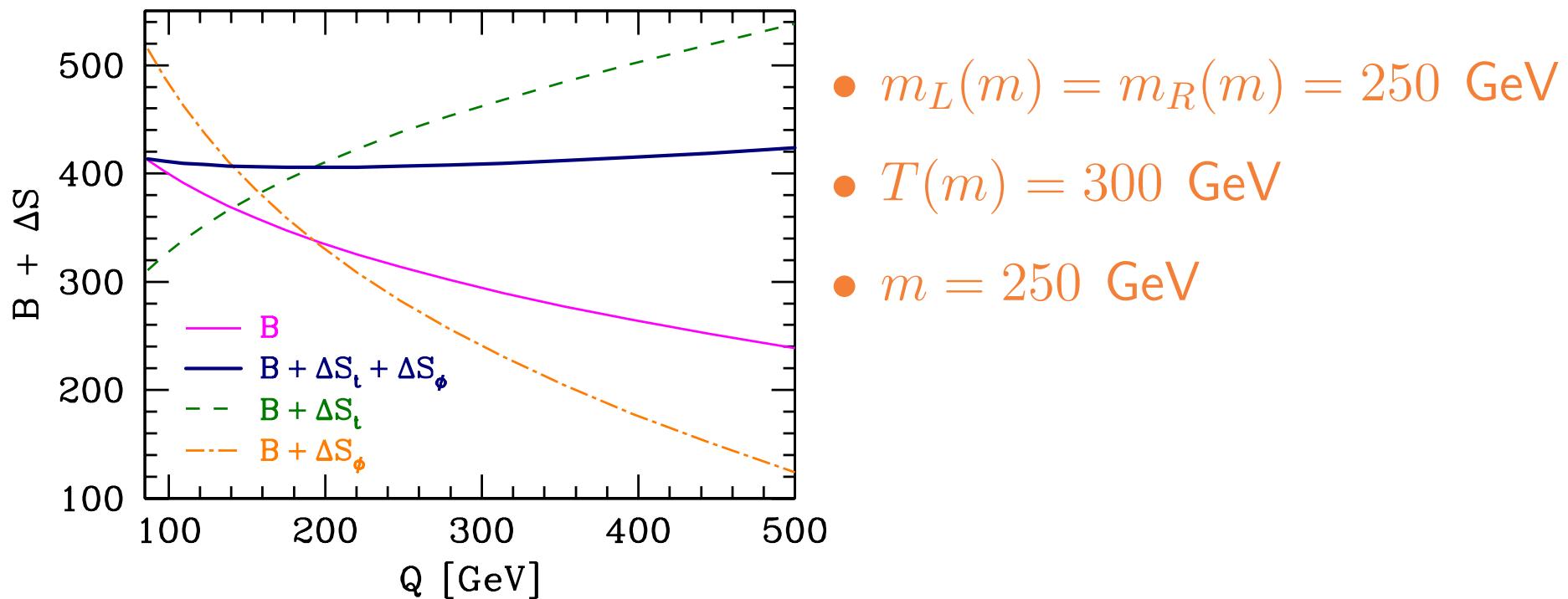


$$\gamma = m^4 e^{-\mathcal{B} - \Delta S}$$

- $m_\Phi^2(m) = m^2$
- $T(m) = m$
- $\lambda(m) = 0.6$

Toy model 2: MSSM-like model

- The model is like our EFT, but no gauge interaction
- Scalar and top loops are included



Backup: Stau Study at the ILC

ILC parameters we adopt:

- $\sqrt{s} = 500$ GeV
- eLpR / eRpL: $(P_{e^-}, P_{e^+}) = (-80\%, +30\%) / (+80\%, -30\%)$

Event generation: SUSY events

- WHIZARD 2.8.5 + TAUOLA 2.7 + DELPHES 3.5.0

Event generation: SM bkgs

- We use the ILD fully simulated samples of $2f - 6f$ and Higgs SM events
- $\gamma\gamma \rightarrow \bar{f}f$ is simulated with the SGV fast detector

Preselections

1. Require exactly two reconstructed hadronic taus with opposite charge
2. Remove events with one or more isolated electrons or muons
3. Require two reconstructed taus to have, in total, at least one photon or at least three charged particles
4. Remove events with two or more tracks, or six or more neutral particles, that are not included in the tau candidate jets

Cuts 1 – 6

- Cut 1: $\theta_{\text{acop}}/\pi > 0.05$
- Cut 2: $20 < E_{\text{vis}} < 300 \text{ GeV}$
- Cut 3: $M_{\text{inv}} > 200 \text{ GeV}$
- Cut 4: $|\cos \theta_{\text{miss}}| < 0.9$
- Cut 5: missing $P_t > 20 \text{ GeV}$
- Cut 6: $|\cos \theta_{\tau^\pm}| < 0.9$

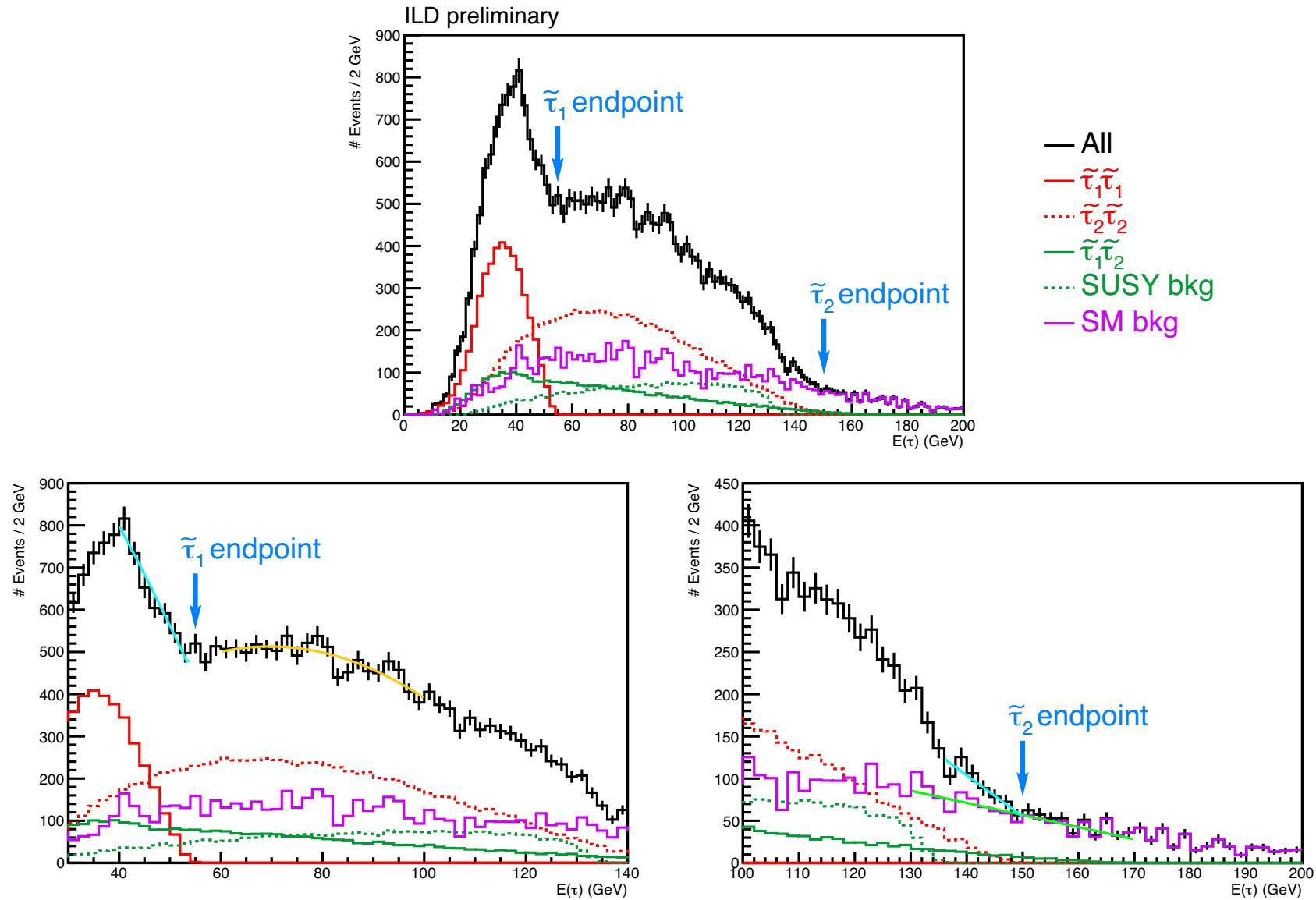
Cut table: eLpR

	$\tilde{\tau}_1 \tilde{\tau}_1$	$\tilde{\tau}_2 \tilde{\tau}_2$	$\tilde{\tau}_1 \tilde{\tau}_2$	SUSY bkg	SM bkg
no cuts	1.488×10^5	4.647×10^4	2.621×10^4	5.539×10^5	8.770×10^7
preselection	2.157×10^4	1.340×10^4	5176	4653	1.209×10^5
cut 1	1.703×10^4	1.230×10^4	4536	4284	4.131×10^4
cut 2	1.608×10^4	1.229×10^4	4499	4284	2.585×10^4
cut 3	1.608×10^4	1.229×10^4	4499	4284	2.080×10^4
cut 4	1.475×10^4	1.141×10^4	4141	3882	1.368×10^4
cut 5	4798	1.091×10^4	3675	3760	1.151×10^4
cut 6	4456	9457	3397	2961	7681

Cut table: eRpL

	$\tilde{\tau}_1 \tilde{\tau}_1$	$\tilde{\tau}_2 \tilde{\tau}_2$	$\tilde{\tau}_1 \tilde{\tau}_2$	SUSY bkg	SM bkg
no cuts	1.386×10^5	4.211×10^4	2.075×10^4	1.286×10^6	4.727×10^7
preselection	2.004×10^4	1.213×10^4	4128	1.380×10^4	7.292×10^4
cut 1	1.581×10^4	1.113×10^4	3616	1.268×10^4	1.916×10^4
cut 2	1.493×10^4	1.112×10^4	3584	1.268×10^4	8032
cut 3	1.493×10^4	1.112×10^4	3584	1.268×10^4	4954
cut 4	1.369×10^4	1.032×10^4	3301	1.154×10^4	2119
cut 5	4396	9868	2930	1.117×10^4	1439
cut 6	4091	8564	2706	8940	1001

Energy distribution of the leading τ -jet: eLpR w/ 1.6 ab^{-1}



Energy distribution of the leading τ -jet: eRpL w/ 1.6 ab^{-1}

