ILC measurement of SUSY $(g\text{-}2)_\mu$

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Kavli IPMU, the University of Tokyo, JAPAN

21st Jul. 2014

ILC Summer Camp 2014 @ Sekigane Onsen

Reference)

M. Endo, K. Hamaguchi, SI, T. Kitahara, T. Moroi [1310.4496].

$$30 = 6 + 24$$

自己紹介

hep-ph

- 加速器実験
  - **LHC**
  - ILC
- 宇宙線観測

⇔

- 標準模型
- **SUSY**
- 暗黒物質の
  色々なモデル

hep-ph

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  - **LHC**
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- 標準模型
- **SUSY**
- 暗黒物質の
  色々なモデル

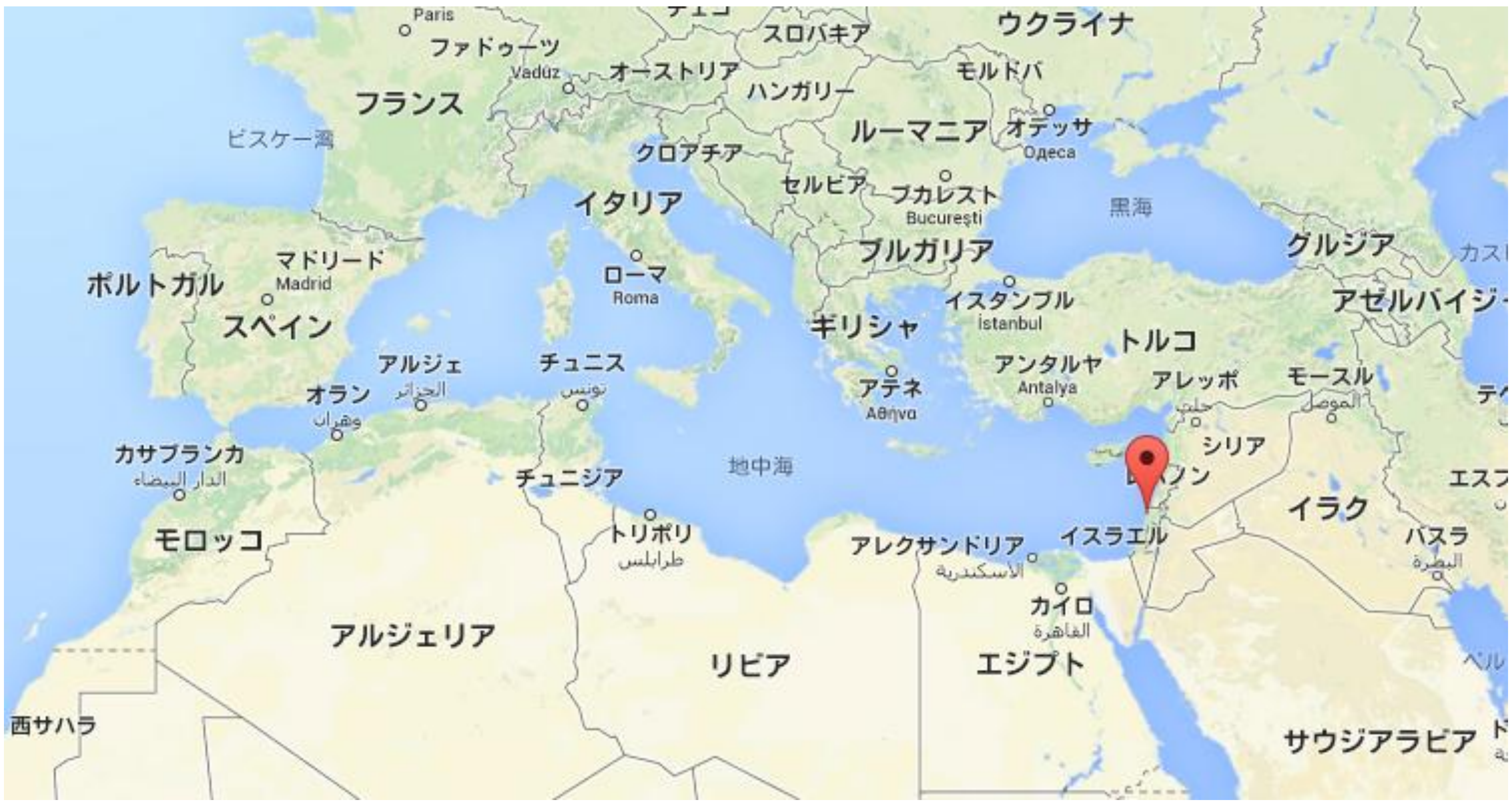
IPMU

2014秋

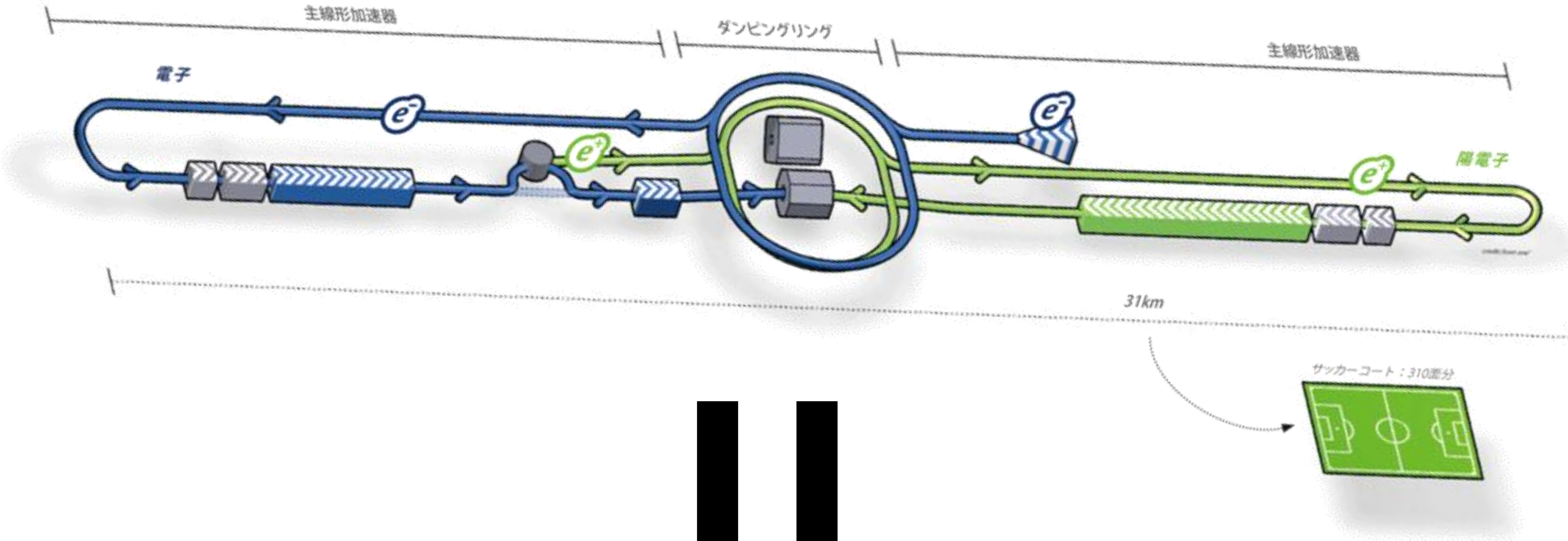
ISRAEL

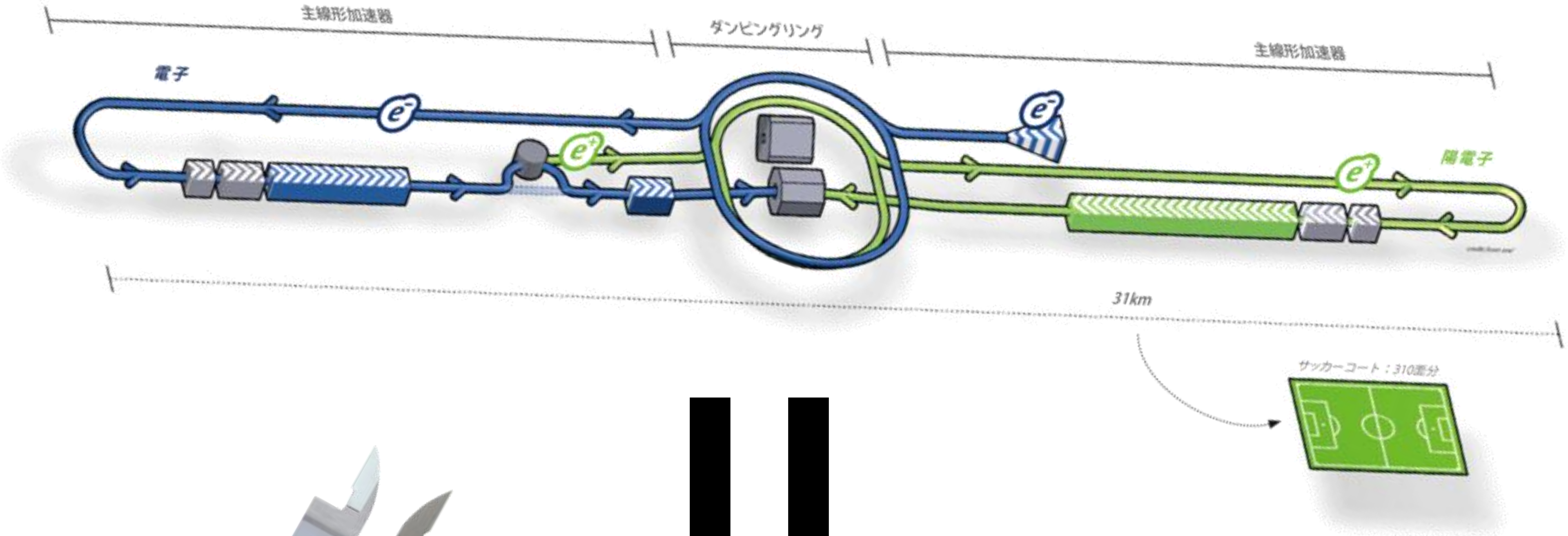
んおにくて

הטכניון
מכון טכנולוגי
לישראל



本編


主線形加速器
ダンピングリング
主線形加速器
電子
陽電子
e-
e+
31km
サッカーコート：310面分


主線形加速器
ダンピングリング
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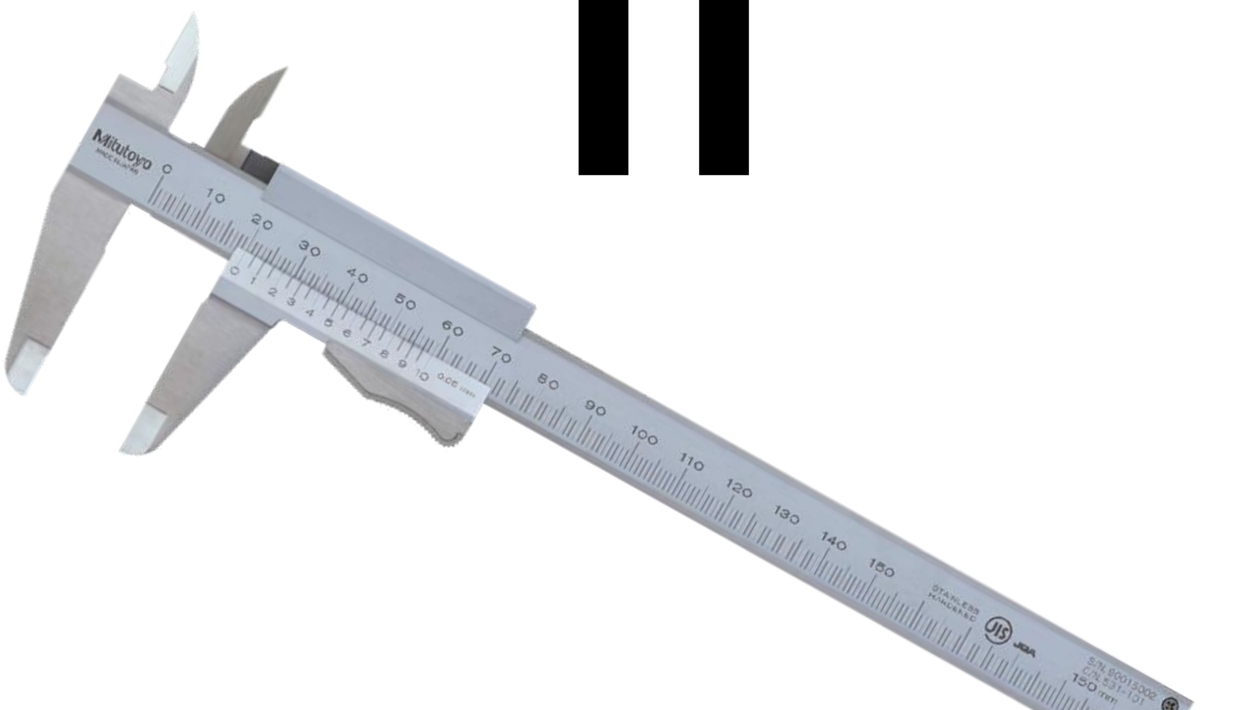

Mitutoyo

ILC＝測定器

↓

何を測る？

- Masses
- Mixings
- Couplings

- Masses
- Mixings
- Couplings
- $\Delta a_\mu^{\text{SUSY}}$

1. a_μ?
2. $\Delta a_\mu^{\mathrm{SUSY}}$?
3. Why measure?
4. How measure?

1. a_μ?
2. $\Delta a_\mu^{\mathrm{SUSY}}$?
3. Why measure?
4. How measure?

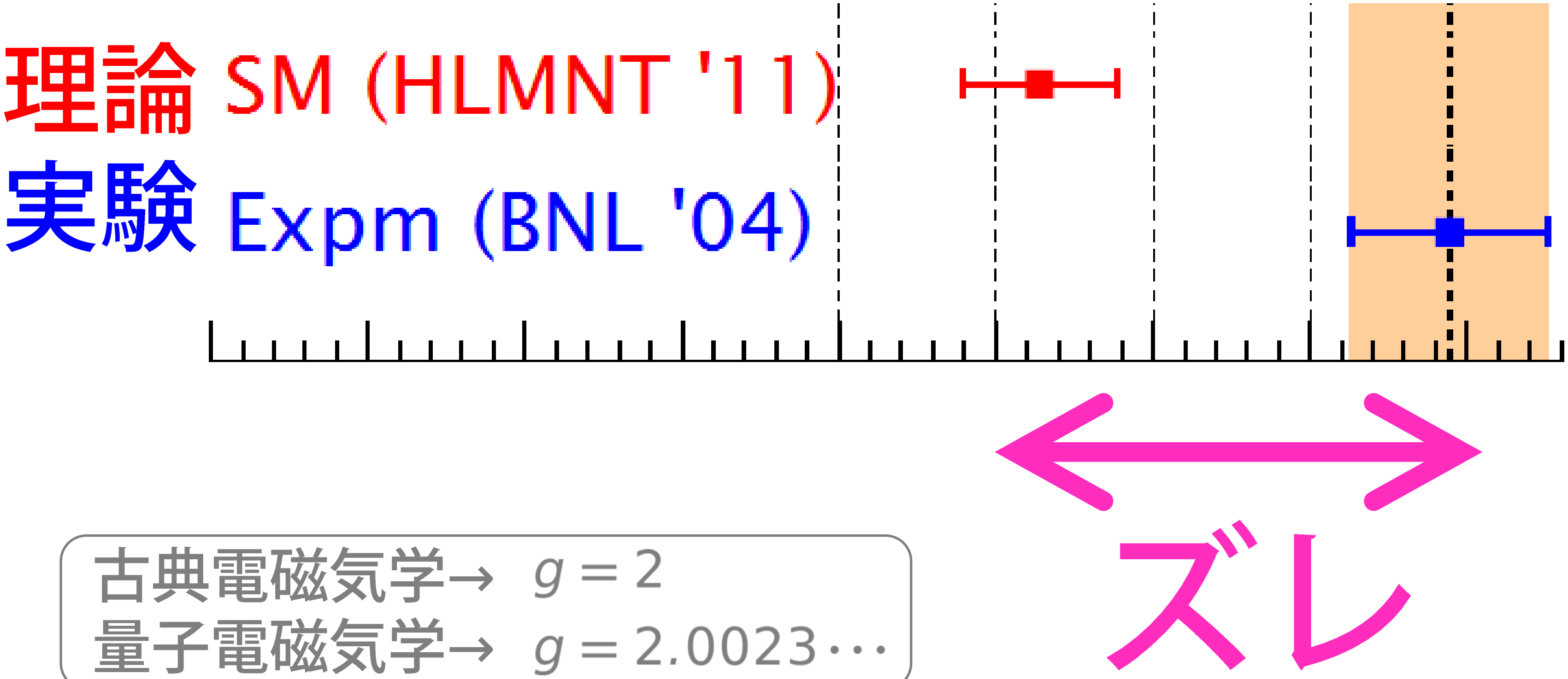
a_μ = μ粒子の異常磁気MOMENT $(g-2)$

超重要

古典電磁気学→ $g = 2$
量子電磁気学→ $g = 2.0023\cdots$

a_μ = μ粒子の異常磁気MOMENT $(g-2)$

超重要

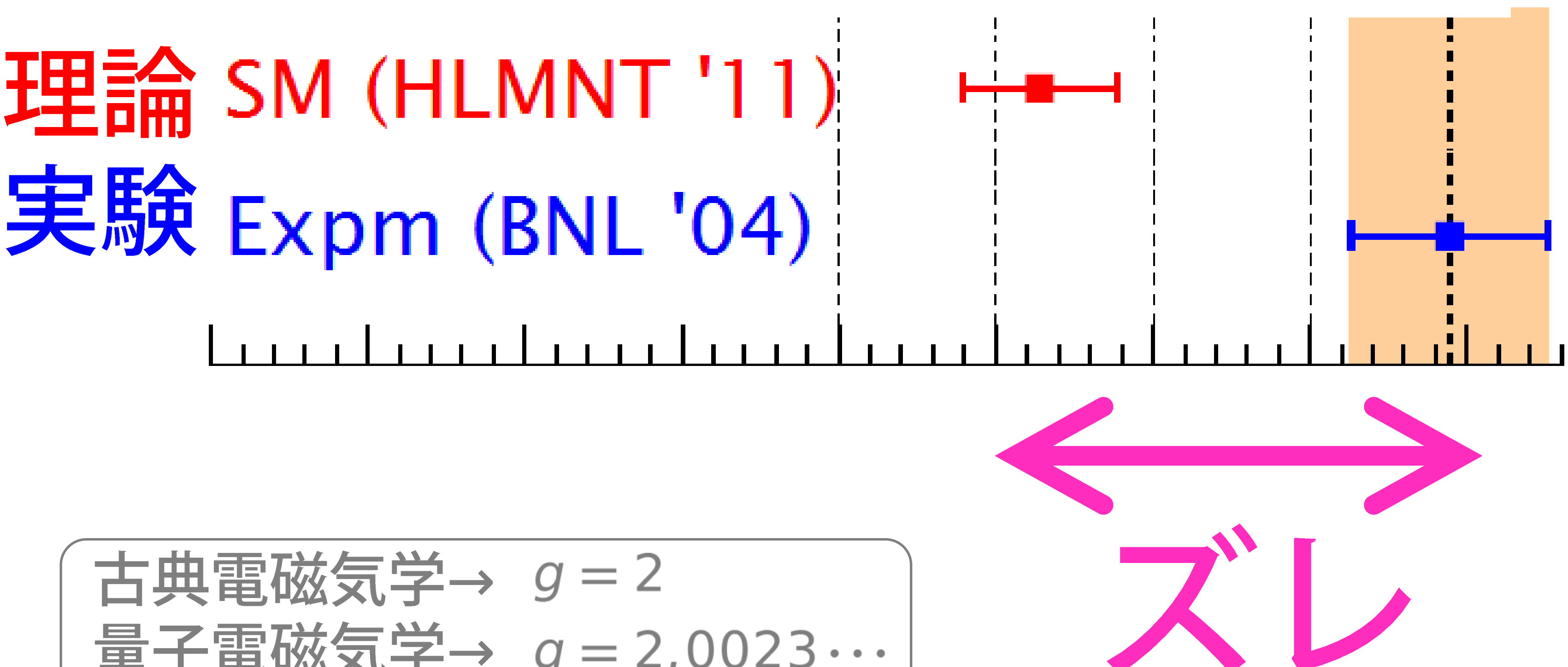


古典電磁気学→ $g=2$
量子電磁気学→ $g=2.0023\cdots$

a_μ = μ粒子の異常磁気MOMENT $(g-2)$

新物理の証拠

だったらいいなあ



古典電磁気学→ $g = 2$
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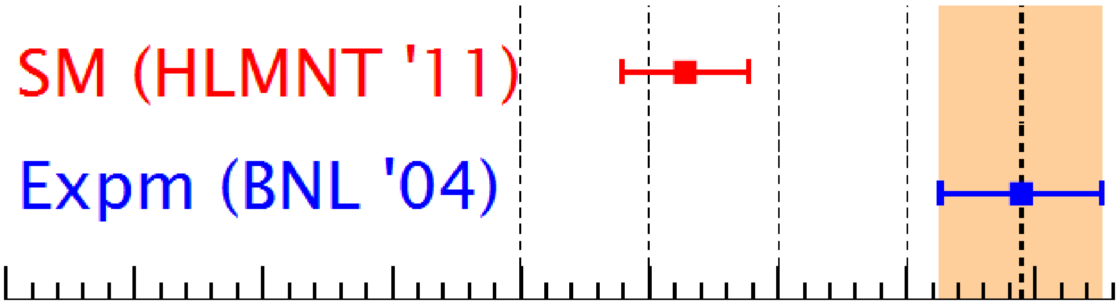
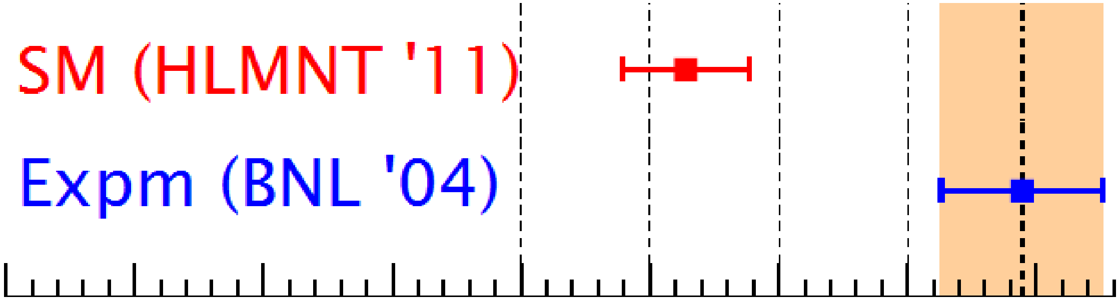
1. a_μ = 新物理の証拠？
2. $\Delta a_\mu^{\mathrm{SUSY}}$?
3. Why measure?
4. How measure?

このズレを説明する理論：



このズレを説明する理論：

超対称性 (SUSY)



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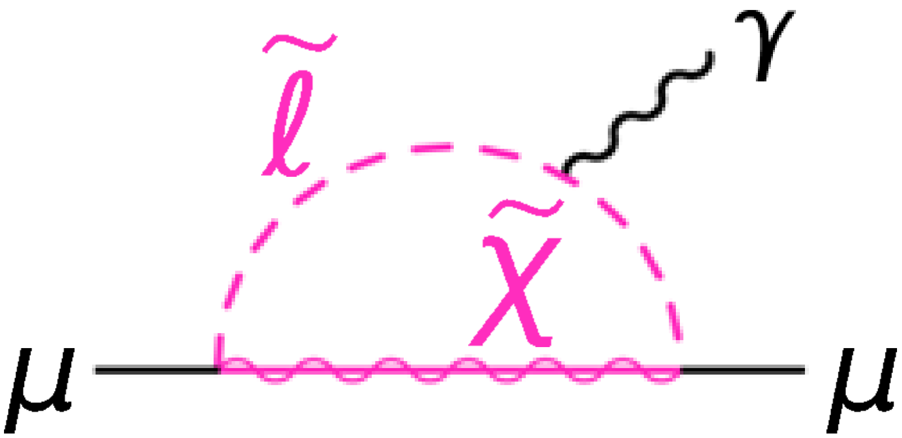
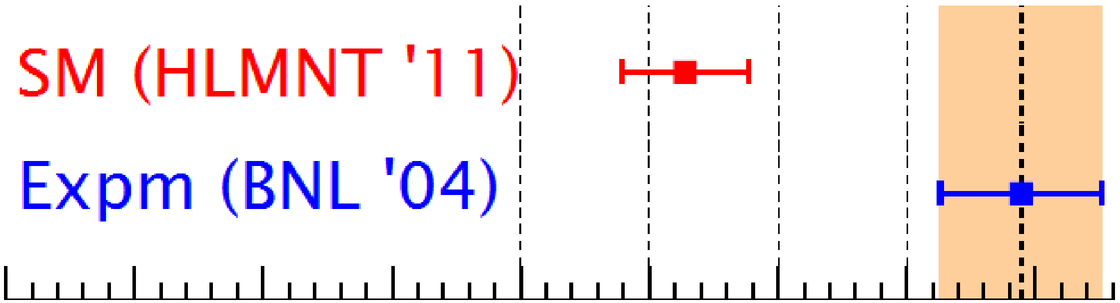
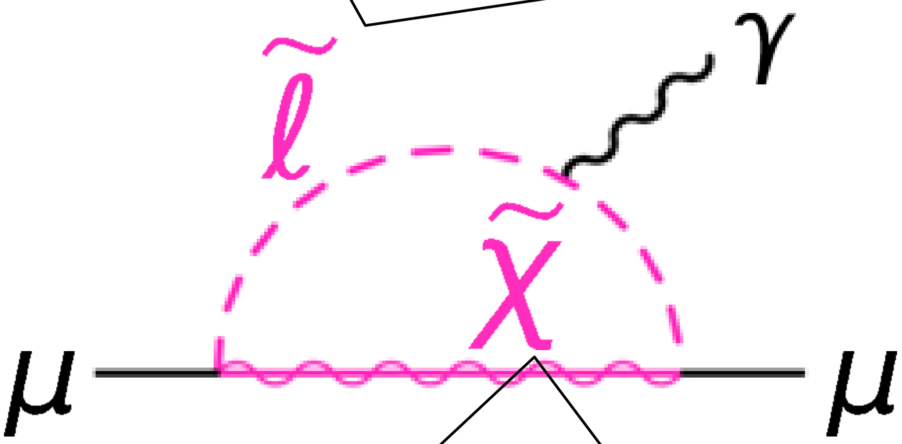




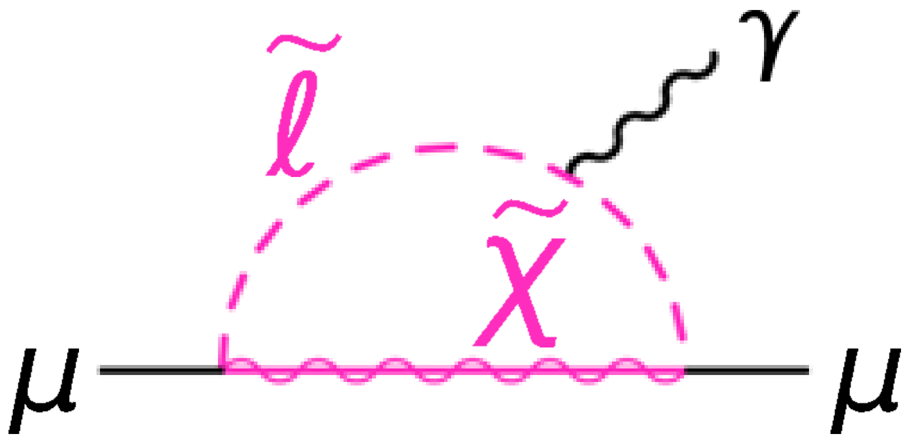
Scalar lepton (slepton)

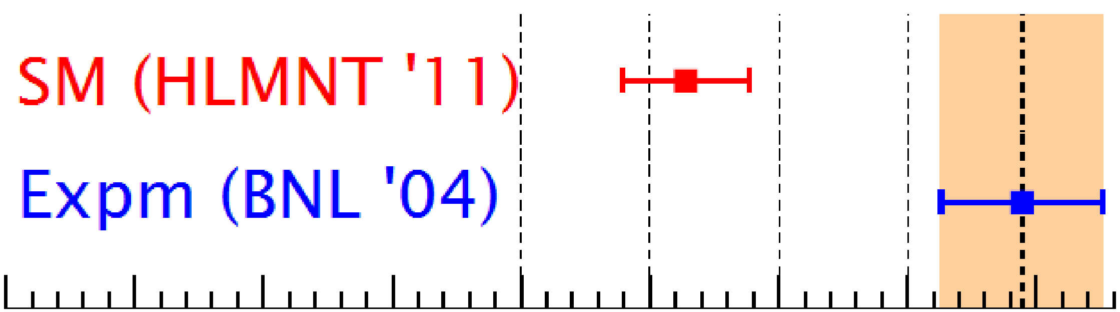
Lepton (e, μ, τ) の超対称 partner。
$\tilde{e}, \tilde{\mu}, \tilde{\tau}$ の 3 種類。



Neutralino。SUSY粒子。
電荷を持たないので，暗黒物質の候補の 1 つ。
なので，すごい。

このズレを説明する理論：





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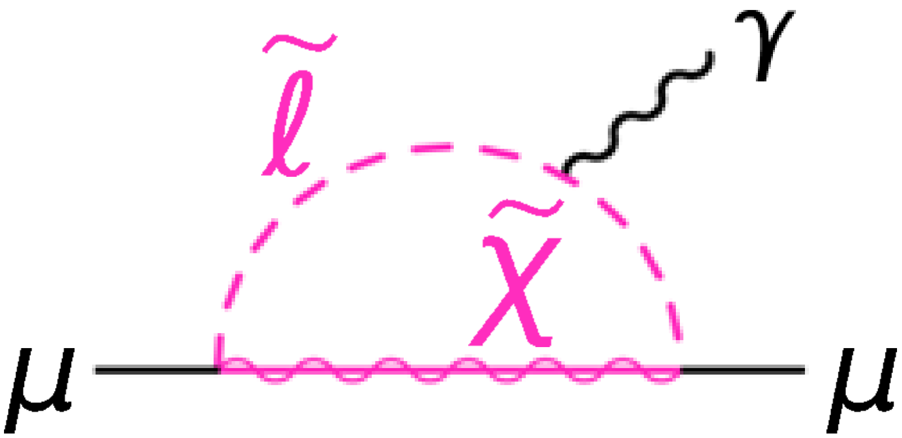
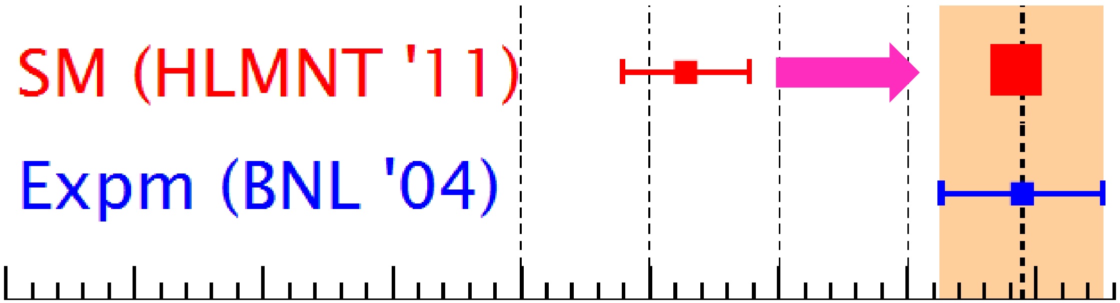


$\tilde{\ell}, \tilde{\chi} \sim O(100\,\mathrm{GeV})$ なら



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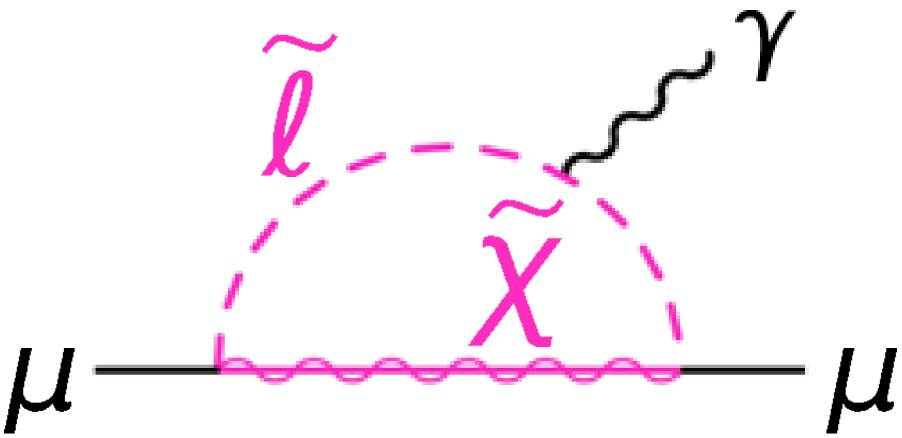

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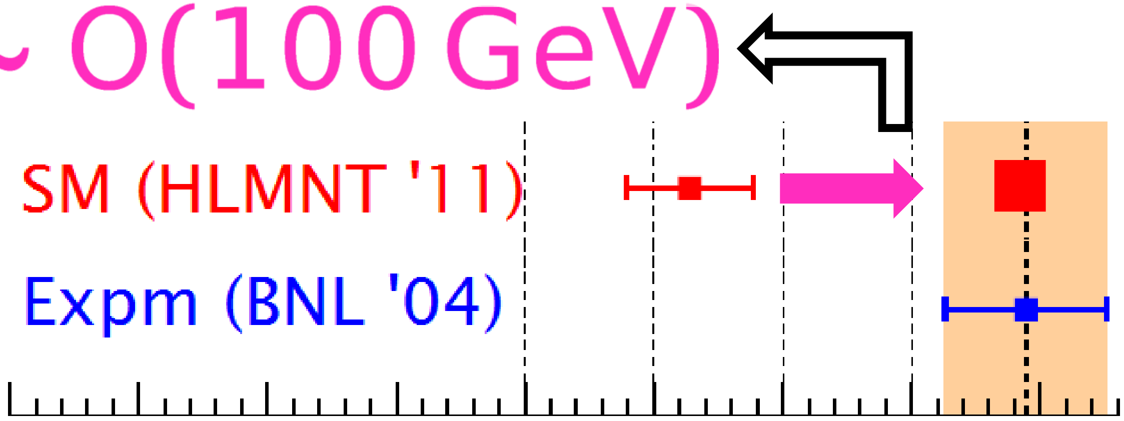


このズレを説明する理論：

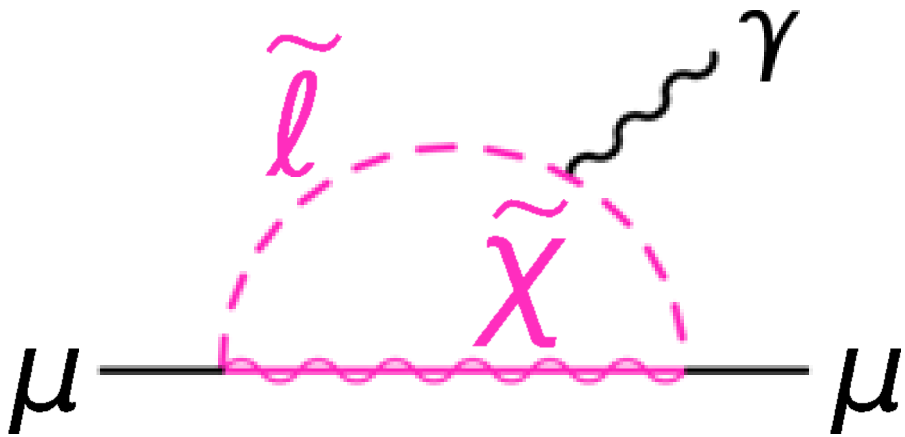
$\Delta a_\mu^{\mathrm{SUSY}}$ の見積もりが可能

⇧

ILCで見える！

かも

⇧



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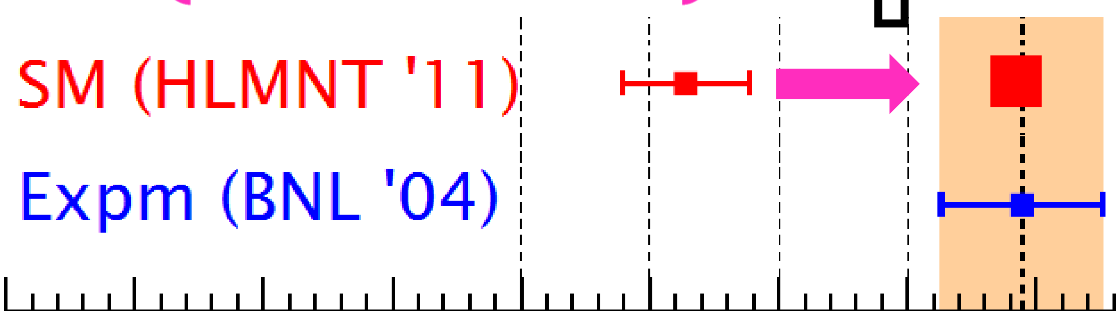
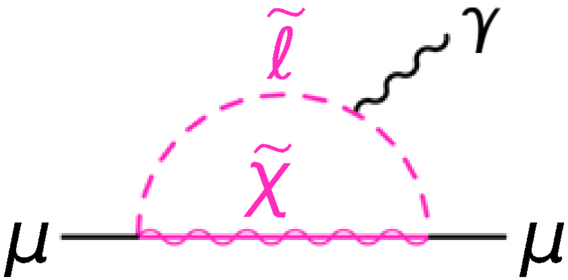


1. a_μ = 新物理の証拠？

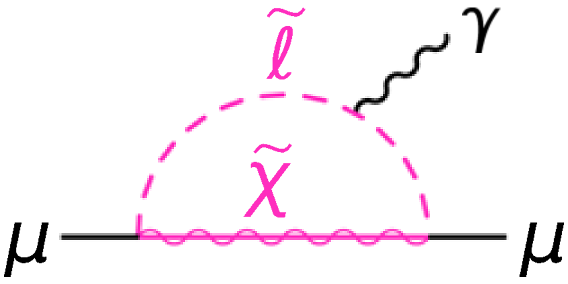
2. $\Delta a_\mu^{\mathrm{SUSY}}$ =



3. Why measure?

4. How measure?

1. $a_\mu \to \tilde{\ell}, \tilde{\chi}$ が見えるかも？

2. $\Delta a_\mu^{\mathrm{SUSY}} =$ 

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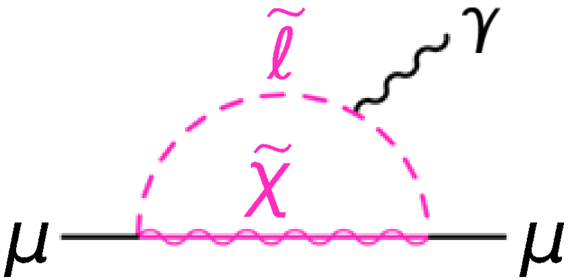
2. $\Delta a_\mu^{\mathrm{SUSY}} =$ 

3. Why measure?

そこに物理量があるから。

4. How measure?

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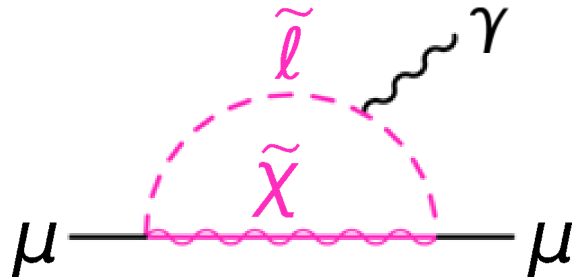
2. $\Delta a_\mu^{\mathrm{SUSY}} =$ 

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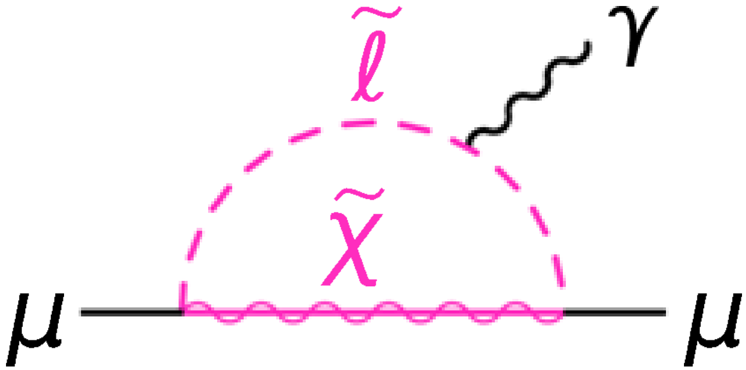
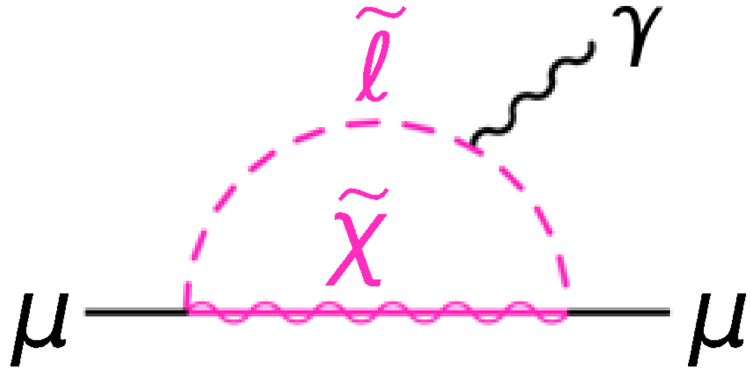
$$\Delta a_\mu^{\mathrm{SUSY}} =$$



これを”測る”　=　この diagram にでてくる量を測る

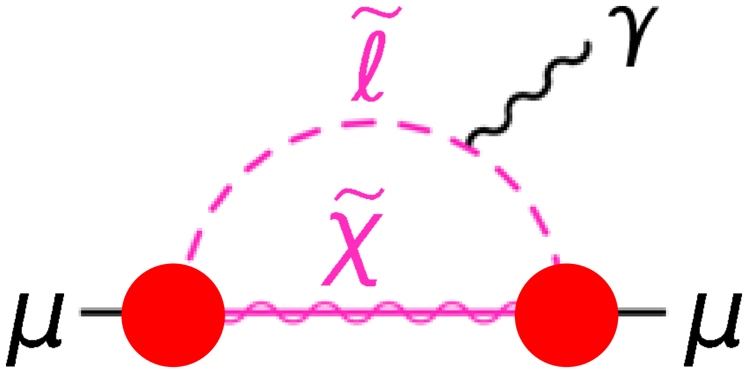
$$\Delta a_\mu^{\mathrm{SUSY}} =$$

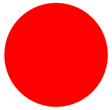


これを"測る"　=　この diagram にでてくる量を測る

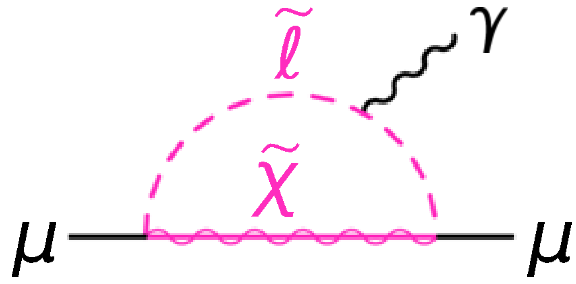
Masses, Mixings, Couplings を測る

$$\Delta a_\mu^{\text{SUSY}} =$$



- Mass of $(\tilde{\ell}, \tilde{\chi})$
- Mixing of $\tilde{\ell}_{\text{L}}$–$\tilde{\ell}_{\text{R}}$
- Coupling of 

$\Rightarrow \Delta a_\mu^{\text{SUSY}}$

1. $a_\mu \to \tilde{\ell}, \tilde{\chi}$ が見えるかも？
2. $\Delta a_\mu^{\mathrm{SUSY}} =$ 

3. Why measure?
そこに物理量があるから。
4. How measure?

→masses, mixings, couplings.

結論

$\Delta a_\mu^{\mathrm{SUSY}}$ は，測れます！

→masses, mixings, couplings.

ほんとの結論

大きな μ parameter によって$\Delta a_\mu^{\mathrm{SUSY}}$ を稼いでずれを説明するシナリオでは

$\tilde{e}_{\mathrm{L}}, \tilde{e}_{\mathrm{R}}, \tilde{\mu}_{\mathrm{L}}, \tilde{\mu}_{\mathrm{R}}, \tilde{\tau}_{\mathrm{L}}, \tilde{\tau}_{\mathrm{R}}, \tilde{\chi}_1^0$

が全てILCで見つかれば

$\Delta a_\mu^{\mathrm{SUSY}}$ の測定精度は約10%

→masses, mixings, couplings.

真・本編

ほんとの結論

大きな μ parameter によって$\Delta a_\mu^{\mathrm{SUSY}}$を稼いでずれを説明するシナリオでは

$\tilde{e}_\mathrm{L}, \tilde{e}_\mathrm{R}, \tilde{\mu}_\mathrm{L}, \tilde{\mu}_\mathrm{R}, \tilde{\tau}_\mathrm{L}, \tilde{\tau}_\mathrm{R}, \tilde{\chi}_1^0$ が全てILCで見つかれば

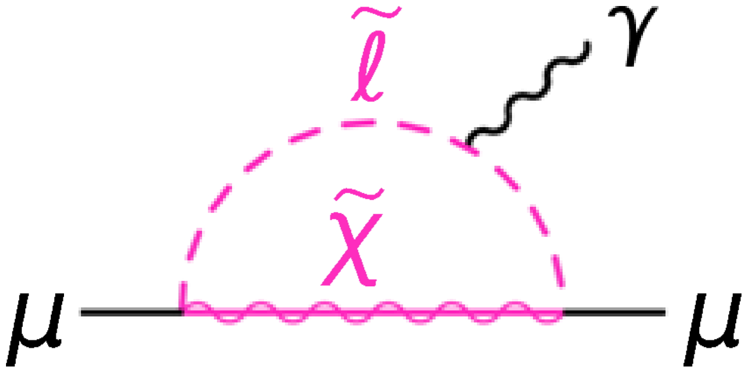
$\Delta a_\mu^{\mathrm{SUSY}}$ の測定精度は約10%

→masses, mixings, couplings.

μ parameter: SUSY の parameter の 1 つ。

小さい	μ parameter	**でかい**
かるい	$\widetilde{H}^0, \widetilde{H}^\pm$	**おもい**
小さい	$\widetilde{\ell}_\mathrm{L}$–$\widetilde{\ell}_\mathrm{R}$ mixing	**でかい**
いい	naturalness	**わるい**

$$\Delta a_\mu^{\text{SUSY}} =$$



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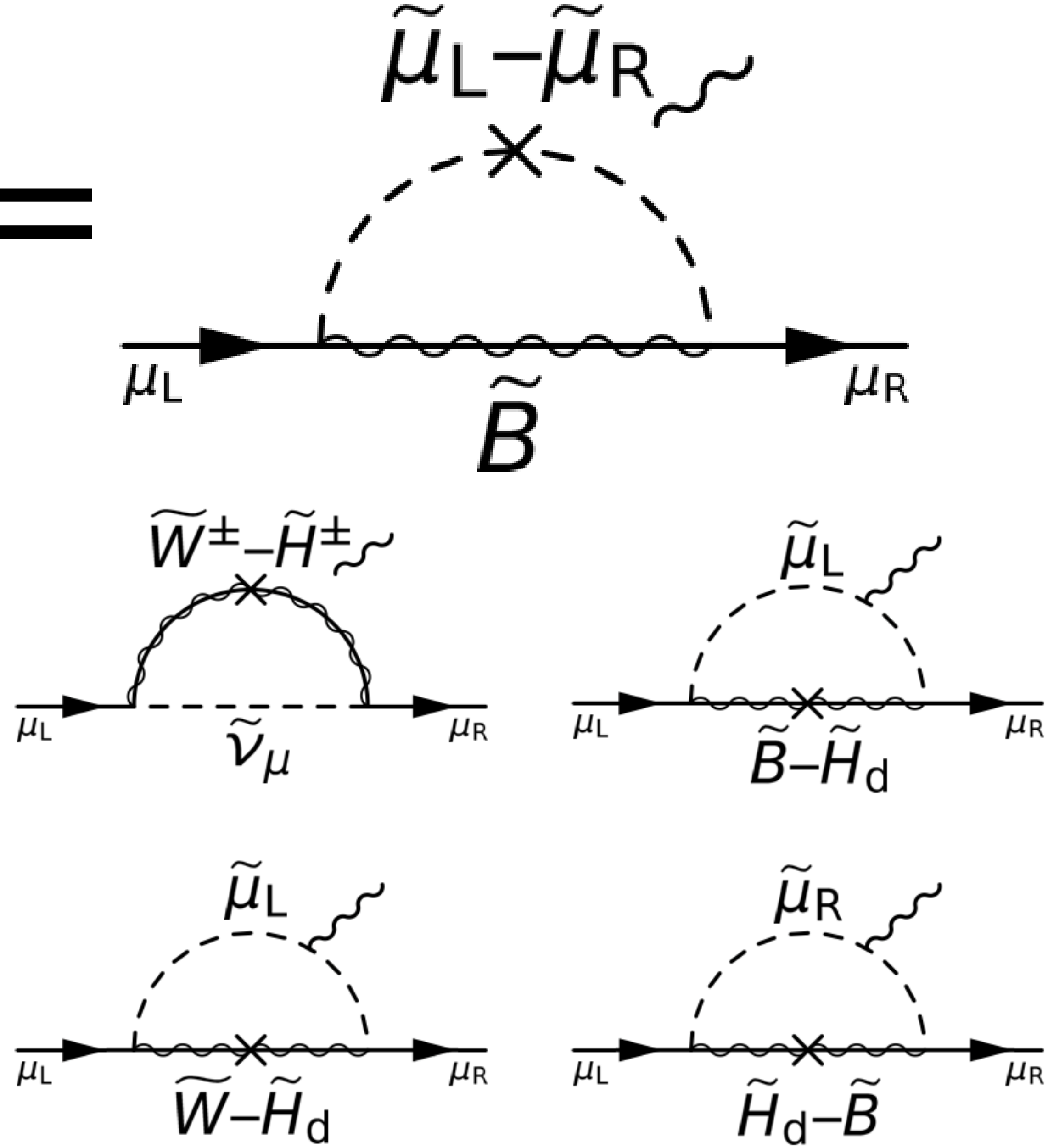
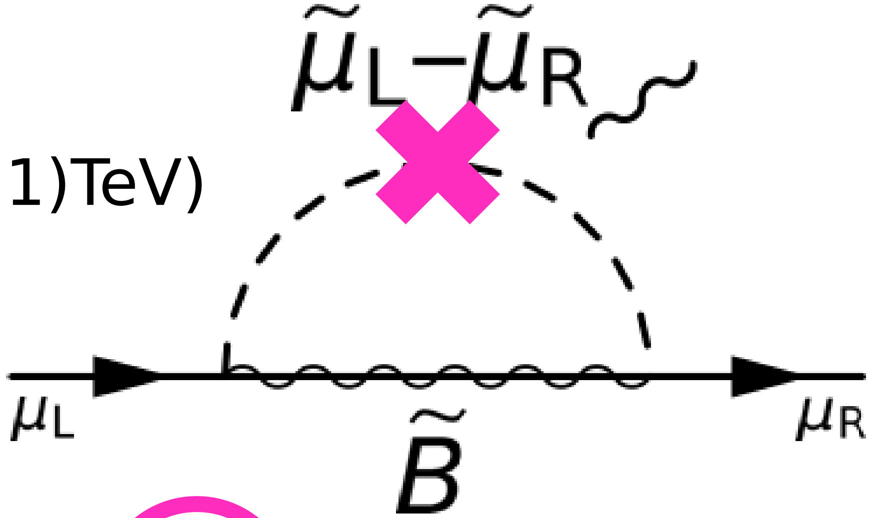


μ-param. が**でかい**(O(1)TeV)

→Mixing **でかい**

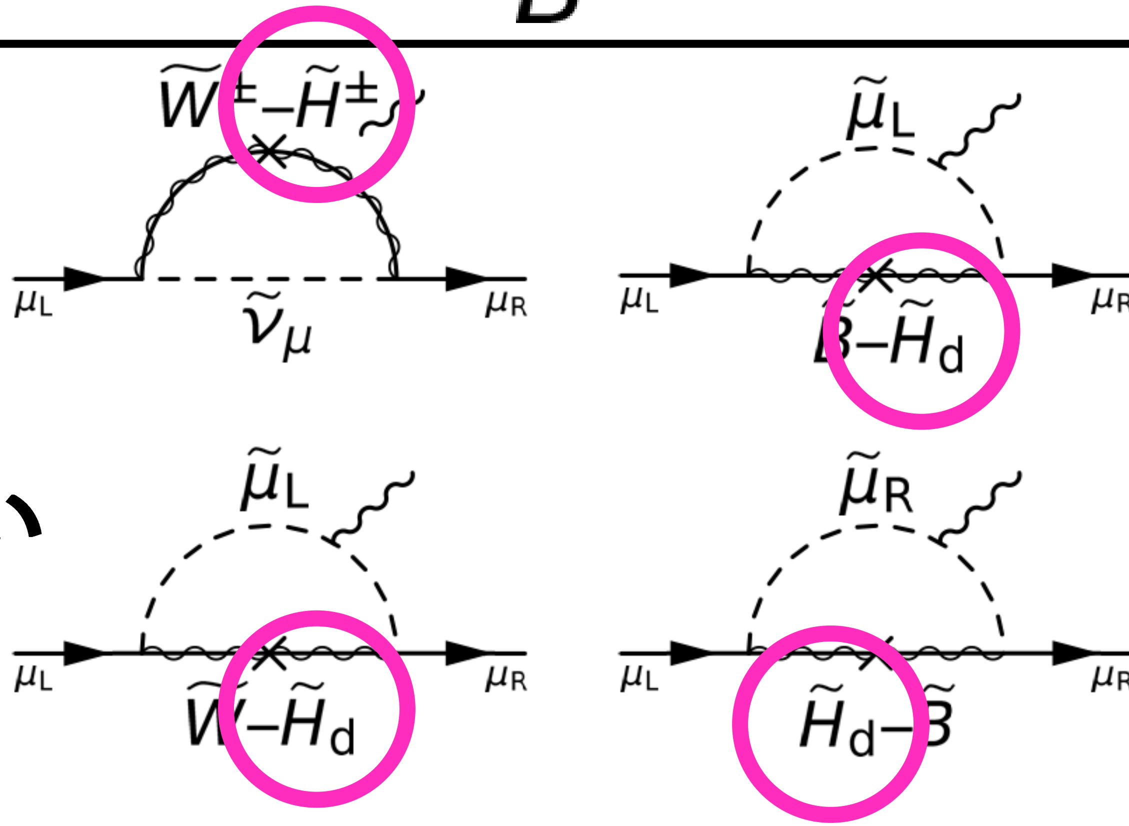
→この寄与が**でかい**



μ-param. が小さい
(O(100)GeV)

→ $\tilde{H}^0, \tilde{H}^\pm$ **軽い**

→この寄与が**でかい**



ほんとの結論

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$$\tilde{e}_\mathrm{L}, \tilde{e}_\mathrm{R}, \tilde{\mu}_\mathrm{L}, \tilde{\mu}_\mathrm{R}, \tilde{\tau}_\mathrm{L}, \tilde{\tau}_\mathrm{R}, \tilde{\chi}_1^0$$

が全てILCで見つかれば

$\Delta a_\mu^{\mathrm{SUSY}}$ の測定精度は約10%

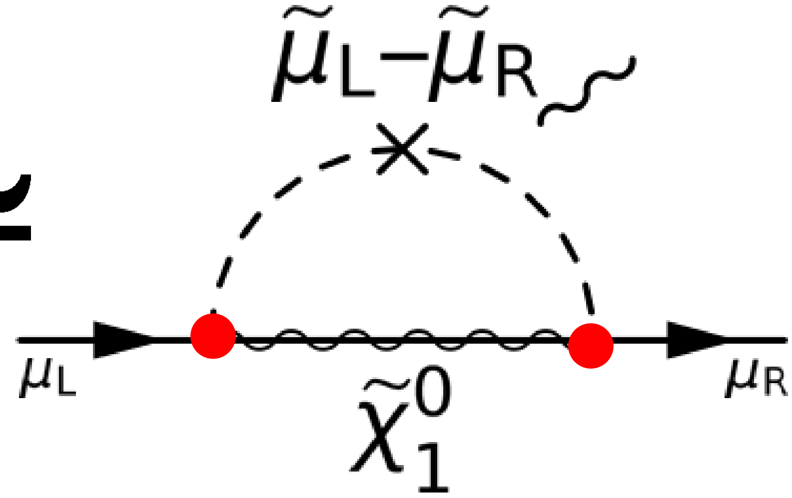
→masses, mixings, couplings.

1. $a_\mu \to \tilde{\ell}, \tilde{\chi}$ が見えるかも？
2. $\Delta a_\mu^{\mathrm{SUSY}} =$

3. Why measure?
   そこに物理量があるから。
4. How measure?
   →masses, mixings, couplings.

μ param. でかい場合,

$$\Delta a_\mu^{\mathrm{SUSY}} \simeq$$



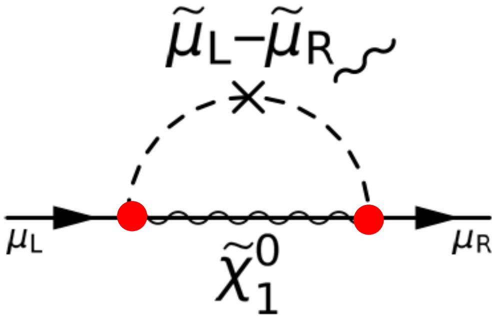
$\tilde{\mu}_1, \tilde{\mu}_2$

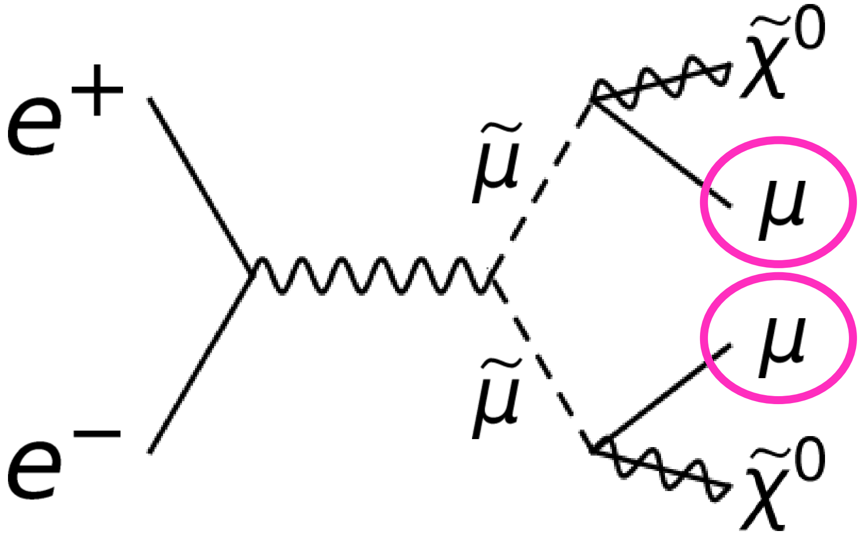
- Mass of $(\tilde{\mu}_L, \tilde{\mu}_R, \tilde{\chi})$
- Mixing of $\tilde{\mu}_L$–$\tilde{\mu}_R$
- Coupling of ●

⇒ $\Delta a_\mu^{\mathrm{SUSY}}$

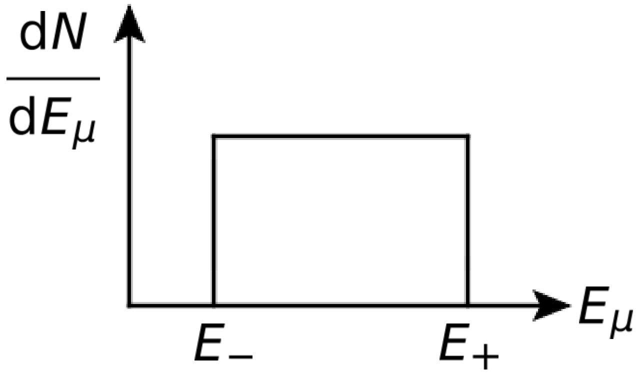
- Mass of $(\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\chi}_1^0)$

⇨ End-point analysis



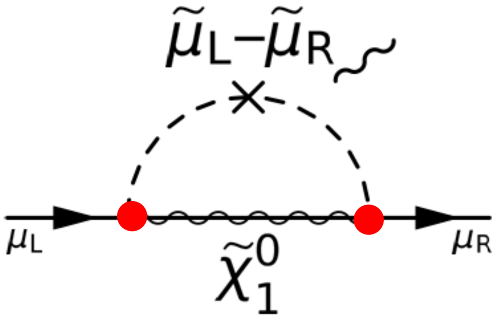


⇨



$$E_\pm = \frac{\sqrt{S}}{4}(1 \pm \beta)\left(1 - \frac{m^2}{M^2}\right); \quad \beta = \sqrt{1 - \frac{4M^2}{S}}.$$

- Mixing of $\tilde{\mu}_L$–$\tilde{\mu}_R$



⇨ Cross Section

$$\sigma(e^+e^- \to \tilde{\mu}_1\tilde{\mu}_2)$$

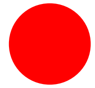
$$\propto \sin 2\theta_{\tilde{\mu}}$$

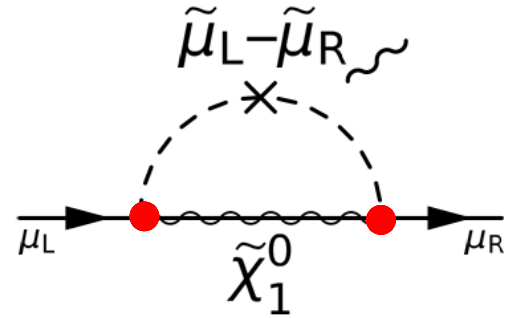
…小さすぎて見えない

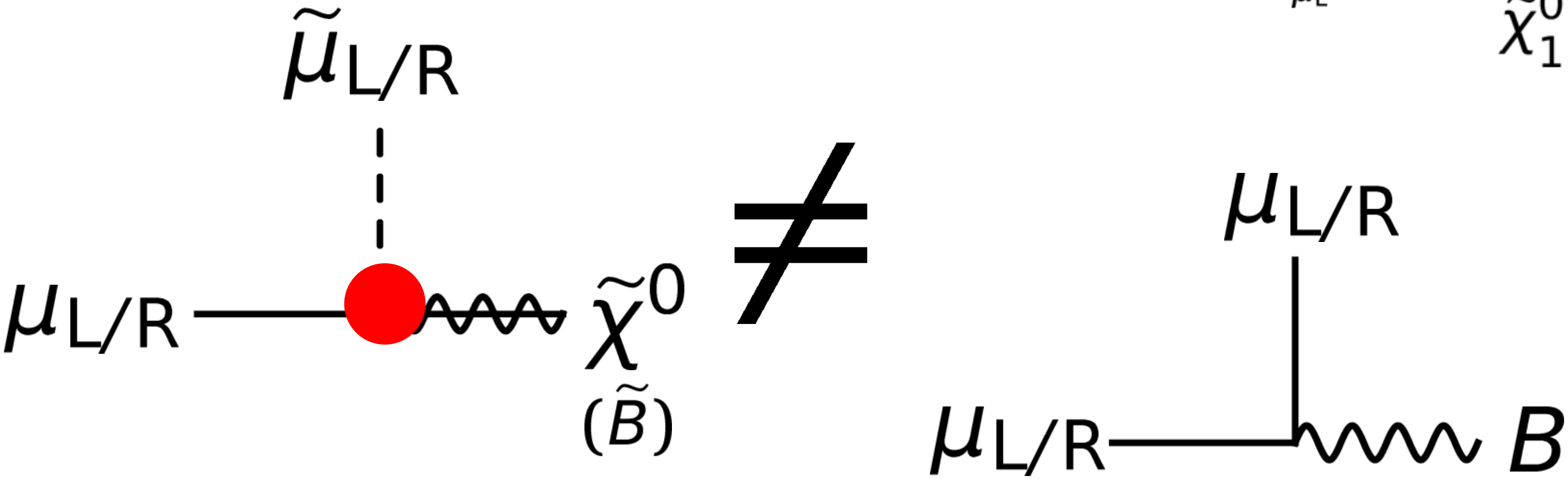
$(\theta_\mu = O(10^{-2}) \Rightarrow \sigma \sim O(0.1)\,\mathrm{fb})$

実は，だいたい $\theta_{\tilde{\ell}} \propto m_\ell$

⇨ $\sigma(e^+e^- \to \tilde{\tau}_1\tilde{\tau}_2)$ ⇨ $\theta_{\tilde{\tau}}$ ⇨ $\theta_{\tilde{\mu}}$

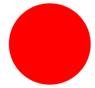
- Coupling of 

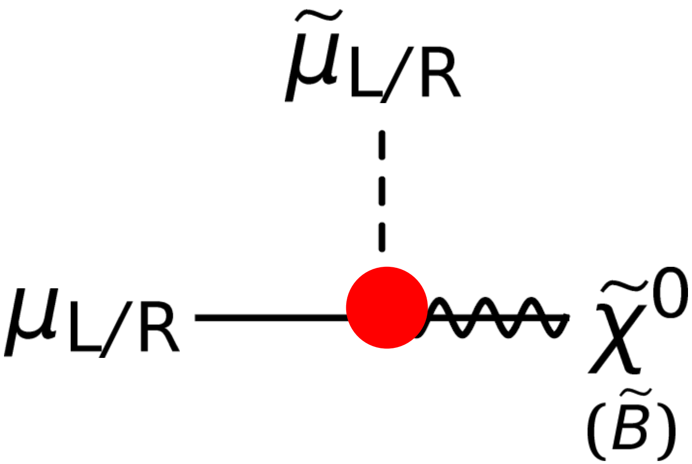




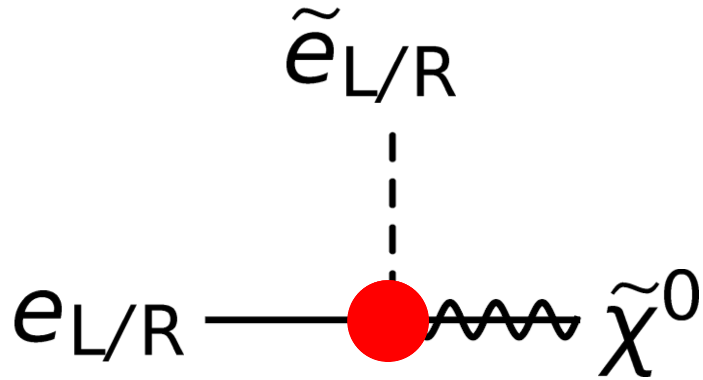
（∵他のSUSY粒子の量子効果）

→実験で測定すべき

- Coupling of 

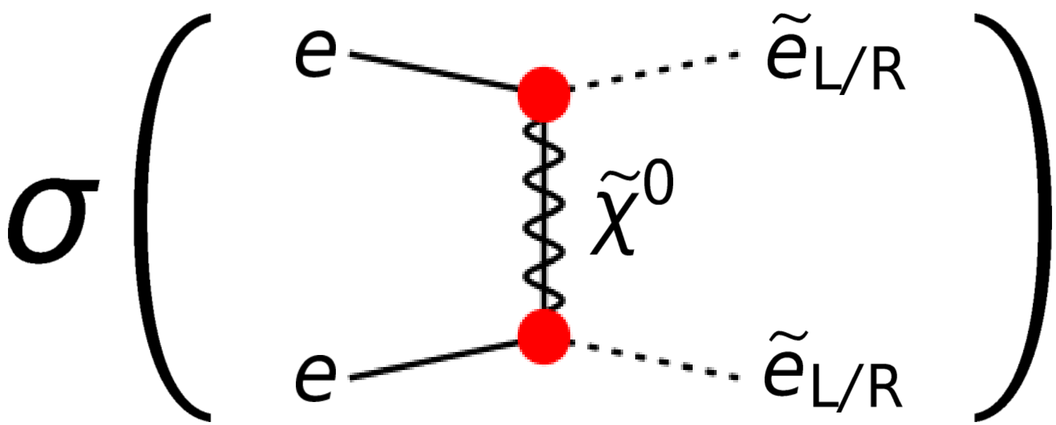


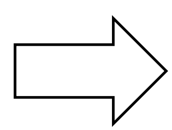
$\simeq$

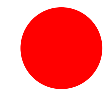


→測定できない

→測定できる







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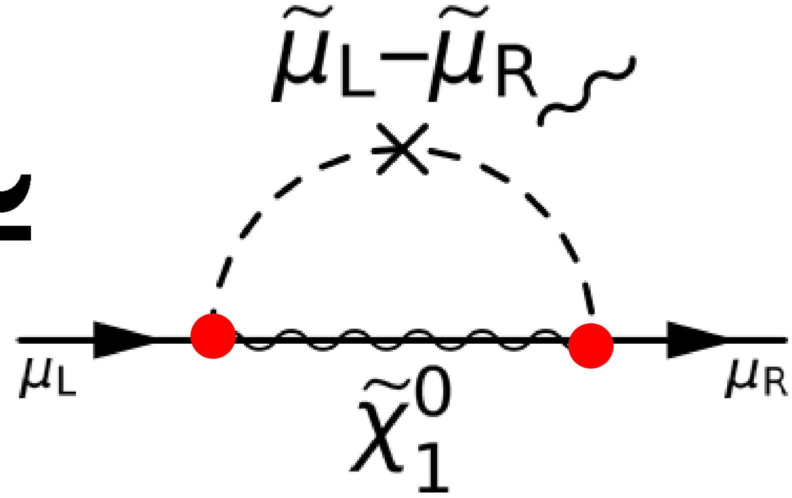


$\tilde{\mu}_1, \tilde{\mu}_2$

- Mass of $(\tilde{\mu}_L, \tilde{\mu}_R, \tilde{\chi}_1^0)$ → End-point analysis
- Mixing of $\tilde{\mu}_L$–$\tilde{\mu}_R$ → $\sigma(ee \to \tilde{\tau}_1 \tilde{\tau}_2) \Rightarrow \theta_{\tilde{\tau}}$
- Coupling of ● → $ee \to \tilde{e}\tilde{e}$ (t-channel)

ほんとの結論

大きな μ parameter によって $\Delta a_\mu^{\mathrm{SUSY}}$ を稼いでずれを説明するシナリオでは

$$\tilde{e}_\mathrm{L}, \tilde{e}_\mathrm{R}, \tilde{\mu}_\mathrm{L}, \tilde{\mu}_\mathrm{R}, \tilde{\tau}_\mathrm{L}, \tilde{\tau}_\mathrm{R}, \tilde{\chi}_1^0$$

が全てILCで見つかれば

$\Delta a_\mu^{\mathrm{SUSY}}$ の測定精度は約10%

- Mass of $(\tilde{\mu}_\mathrm{L}, \tilde{\mu}_\mathrm{R}, \tilde{\chi}_1^0)$ → End-point analysis
- Mixing of $\tilde{\mu}_\mathrm{L}$–$\tilde{\mu}_\mathrm{R}$ → $\sigma(ee \to \tilde{\tau}_1\tilde{\tau}_2) \Rightarrow \theta_{\tilde{\tau}}$
- Coupling of ● → $ee \to \tilde{e}\tilde{e}$ (t-channel)

ほんとの結論

大きな μ parameter によって $\Delta a_\mu^{\mathrm{SUSY}}$ を稼いでずれを説明するシナリオでは

実は $\sigma(ee \to \tilde{\tau}_1\tilde{\tau}_1)$ を用いた値

$\tilde{e}_L, \tilde{e}_R, \tilde{\mu}_L, \tilde{\mu}_R, \tilde{\tau}_L, \tilde{\tau}_R, \tilde{\chi}_1^0$

が全てILCで見つかれば

$\Delta a_\mu^{\mathrm{SUSY}}$ の測定精度は約10%

- Mass of $(\tilde{\mu}_L, \tilde{\mu}_R, \tilde{\chi}_1^0)$ → End-point analysis
- Mixing of $\tilde{\mu}_L$–$\tilde{\mu}_R$ → $\sigma(ee \to \tilde{\tau}_1\tilde{\tau}_2) \Rightarrow \theta_{\tilde{\tau}}$
- Coupling of ●

これを使えばもっと精度よく測れるはず！

Message

a_μ のずれ → 新物理（$\Delta a_\mu^{\mathrm{SUSY}}$）の示唆

- $\mu = \mathcal{O}(100)\,\mathrm{GeV}$
  $\rightarrow \mathcal{O}(100)\,\mathrm{GeV}\ \tilde{\chi}^+$

- $\mu = \mathcal{O}(1)\,\mathrm{TeV}$
  $\rightarrow$large $\tilde{\ell}$-mixing

$\Delta a_\mu^{\mathrm{SUSY}}$ は測れるかもしれません

a_μ のずれ → 新物理 ($\Delta a_\mu^{\mathrm{SUSY}}$) の示唆

- $\mu = \mathcal{O}(100)\,\mathrm{GeV}$
  $\rightarrow \mathcal{O}(100)\,\mathrm{GeV}\ \tilde{\chi}^+$

- $\mu = \mathcal{O}(1)\,\mathrm{TeV}$
  $\rightarrow$ large $\tilde{\ell}$-mixing

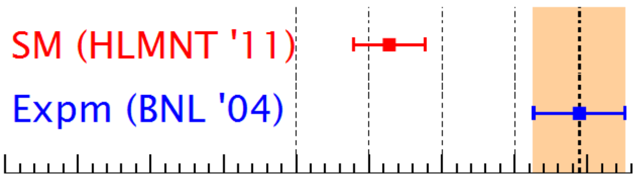
これを測るのおもしろそう！

$\Delta a_\mu^{\mathrm{SUSY}}$ は測れるかもしれません

BACKUP

$$\left(a_\mu := \frac{g_\mu - 2}{2}\right)$$

Muon *g*-2 (anomalous magnetic moment)



$$a_\mu^{\mathrm{SM}} = (116\,591\,828 \pm 49) \times 10^{-11}$$

$$a_\mu^{\mathrm{exp}} = (116\,592\,089 \pm 63) \times 10^{-11}$$

Hagiwara, Liao, Martin, Nomura, Teubner [1105.3149]

3.3σ discrepancy

New Physics?

can be explained with **SUSY**.

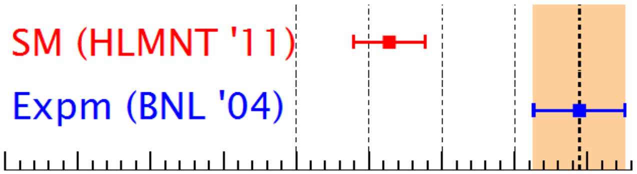
Lopez, Nanopoulos, Wang [ph/9308336]
Chattopadhyay, Nath [ph/9507386]
Moroi [ph/9512396]

SUSY!

- ✓ Dark matter problem,
- ✓ Hierarchy problem,
- ✓ Muon *g*-2 problem,
- ✓ Grand unification,
- ✓ **will be discovered at LHC.**

$$\left(a_\mu := \frac{g_\mu - 2}{2} \right)$$

Muon g-2 (anomalous magnetic moment)



Hagiwara, Liao, Martin, Nomura, Teubner [1105.3149]

$$a_\mu^{\rm SM} = (116\,591\,828 \pm 49) \times 10^{-11}$$

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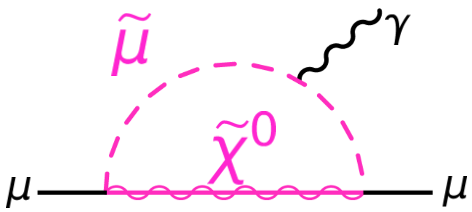
3.3σ discrepancy

New Physics?

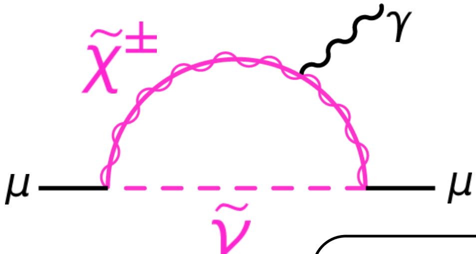
can be explained with **SUSY**.

Lopez, Nanopoulos, Wang [ph/9308336]
Chattopadhyay, Nath [ph/9507386]
Moroi [ph/9512396]

$$\left[\rightsquigarrow \ \left(\tilde\chi^0, \tilde\mu\right) \text{ or } \left(\tilde\chi^\pm, \tilde\nu\right) = \mathrm{O}(100)\mathrm{GeV} \right]$$



$$a_\mu^{\rm SUSY}\left(\tilde\chi^0, \tilde\mu\right) \approx \frac{g_Y^2}{(4\pi)^2} \frac{m_\mu^2}{m_{\rm soft}^2} \operatorname{sgn}(\mu) \tan\beta + \cdots,$$



$$a_\mu^{\rm SUSY}\left(\tilde\chi^\pm, \tilde\nu\right) \approx \frac{g_2^2}{(4\pi)^2} \frac{m_\mu^2}{m_{\rm soft}^2} \operatorname{sgn}(\mu) \tan\beta.$$

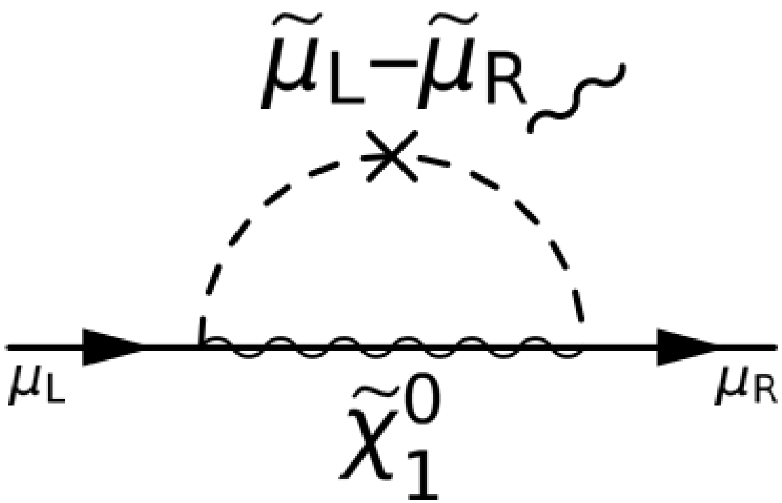
$W \ni \mu H_{\rm u} H_{\rm d}$ (Higgsino mass term), $\tan\beta = \dfrac{\langle H_{\rm u} \rangle}{\langle H_{\rm d} \rangle}$,

$m_{\rm soft}$: SUSY-particle mass-scale, g_i : Gauge couplings.

- Let's measure a_μ^{SUSY}!

What should be measured?

$a_\mu^{\mathrm{SUSY}} \simeq$



$$\left(\propto \frac{m_\mu \cdot M_{\mathrm{LR}}^2 \cdot \tilde{g}_\mathrm{L} \tilde{g}_\mathrm{R}}{(\mathrm{mass})^3} \right)$$

- Let's measure $a_\mu^{\rm SUSY}$!

What should be measured?

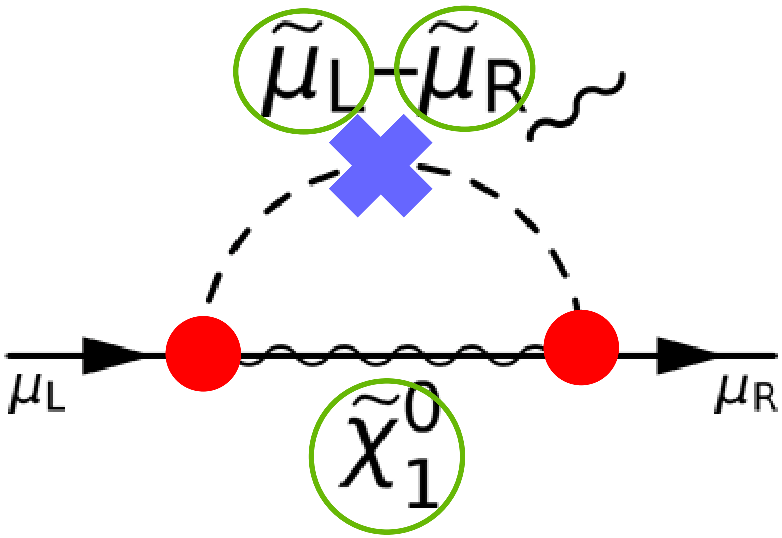
- Mass of $\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\chi}_0^1$
- Mixing $M_{\rm LR}^2$
- Coupling $\tilde{g}_{\rm L}, \tilde{g}_{\rm R}$

$$\mathcal{M}_{\tilde{\mu}}^2 = \begin{pmatrix} m_{\rm L}^2 & M_{\rm LR}^2 \\ M_{\rm LR}^2 & m_{\rm R}^2 \end{pmatrix}$$

$$\left(M_{\rm LR}^2 \simeq m_\mu \mu \tan\beta\right)$$

$$M_{\rm LR}^2 = -\frac{1}{2}\left(m_2^2 - m_1^2\right)\sin 2\theta$$

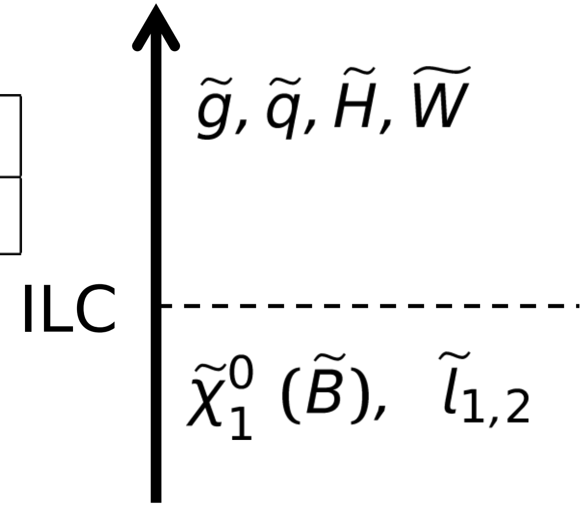
$\left(\neq g_Y \text{ because} \right.$
- ~~SUSY~~ effect.
- $\tilde{\chi}_1^0 \neq$ "pure" $\tilde{B}$. $\left.\right)$

$a_\mu^{\rm SUSY} \simeq$ 

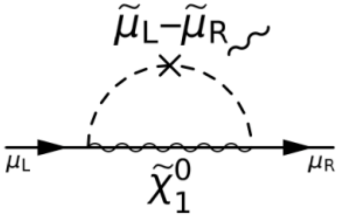
$$\left(\propto \frac{m_\mu \cdot M_{\rm LR}^2 \cdot \tilde{g}_{\rm L}\tilde{g}_{\rm R}}{(\text{mass})^3} \right)$$

$\tilde{e}_1, \tilde{\mu}_1$	$\tilde{e}_2, \tilde{\mu}_2$	$\tilde{\tau}_1$	$\tilde{\tau}_2$	$\tilde{\chi}_1^0$	$\mu \tan\beta$
126	200	108	210	90	6.1×10^3

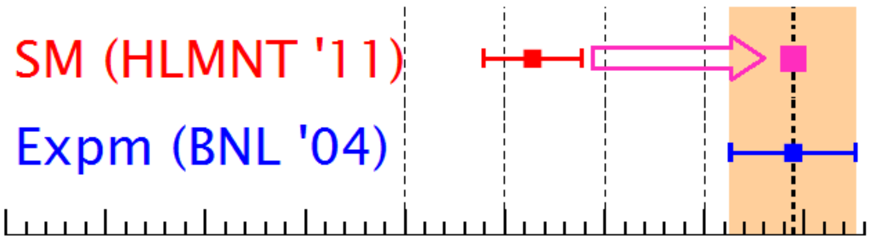
[in GeV]



$\rightsquigarrow \sin\theta_{\tilde{\mu}} = 0.027, \sin\theta_{\tilde{\tau}} = 0.36,$



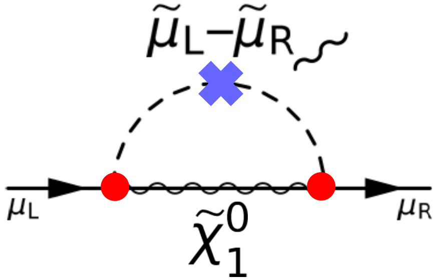
$\approx 2.6\times10^{-9}$



- Satisfies LEP/LHC constraints.
- Close to SPS1a(’)
  - → We can consult Previous works! Don’t call us lazy :)

How can we measure

- Mass of $\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\chi}_0^1$
- Mixing M^2_{LR}
- Coupling $\tilde{g}_\mathrm{L}, \tilde{g}_\mathrm{R}$ **?**



and How accurately?

How can we measure

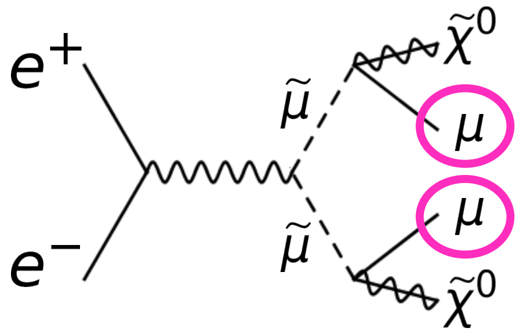
- Mass of $\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\chi}_0^1$

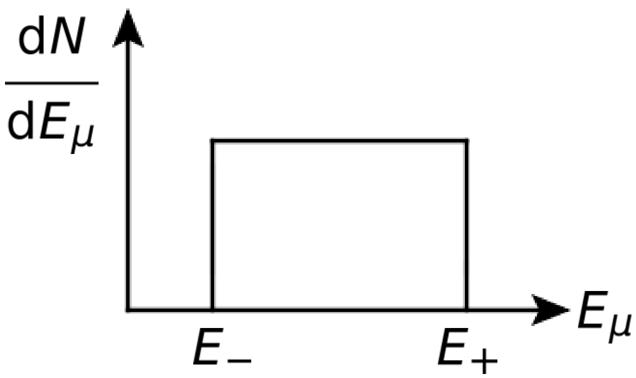
End-point analysis → $\Delta m_{\tilde{\mu}}, \Delta m_{\mathrm{LSP}} \sim 100\text{–}200\,\mathrm{MeV}$

(dominated by **stat.** unc.) $(\sim 0.1\%)$

$@\sqrt{s} = 500\,\mathrm{GeV}, \int \mathcal{L} = 500\,\mathrm{fb}^{-1}$

[ILC-TDR Vol.2 Sec.7.5.4]





$$E_\pm = \frac{\sqrt{S}}{4}(1 \pm \beta)\left(1 - \frac{m^2}{M^2}\right); \quad \beta = \sqrt{1 - \frac{4M^2}{S}}.$$

$\sin\theta_{\tilde{\mu}} = 0.027$, $\sin\theta_{\tilde{\tau}} = 0.36$, $M^2_{\mathrm{LR}} = -\frac{1}{2}\left(m_2^2 - m_1^2\right)\sin 2\theta$

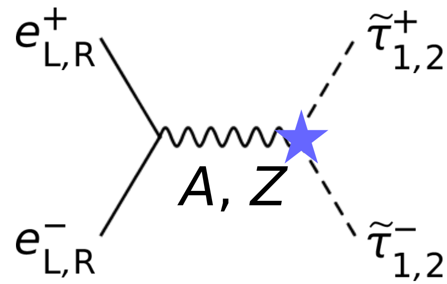
How can we measure

- Mixing M^2_{LR}

$$\mathcal{M}^2_{\tilde{\mu}} = \begin{pmatrix} m^2_{\mathrm{L}} & M^2_{\mathrm{LR}} \\ M^2_{\mathrm{LR}} & m^2_{\mathrm{R}} \end{pmatrix}$$

$\left(M^2_{\mathrm{LR}} \simeq m_\mu \mu \tan\beta\right)$

$\sigma(e^+e^- \to \tilde{\tau}^+_A \tilde{\tau}^-_B)$



$\Rightarrow$ $\tilde{\tau}$ mixing $M^2_{\mathrm{LR}}(\tilde{\tau})$ measured.

$\Rightarrow$ $M^2_{\mathrm{LR}} = \dfrac{m_\mu}{m_\tau} M^2_{\mathrm{LR}}(\tilde{\tau})$ (as long as $A_{\tilde{l}} \simeq 0.$)

$$\sigma(e^+e^- \to \tilde{\tau}_i\tilde{\tau}_j) = \frac{8\pi\alpha^2}{3s} v^3 \left[c^2_{ij} \frac{\Delta_Z^2}{\sin^4 2\theta_W} (\mathcal{P}_{-+}L^2 + \mathcal{P}_{+-}R^2) + \delta_{ij}\frac{1}{16}(\mathcal{P}_{-+} + \mathcal{P}_{+-}) + \delta_{ij} c_{ij} \frac{\Delta_Z}{2\sin^2 2\theta_W}(\mathcal{P}_{-+}L + \mathcal{P}_{+-}R) \right];$$

$$v^2 = [1 - (m_{\tilde{\tau}_i} + m_{\tilde{\tau}_j})^2/s][1 - (m_{\tilde{\tau}_i} - m_{\tilde{\tau}_j})^2/s], \quad \Delta_Z = s/(s - m_Z^2),$$

$$c_{11/22} = \frac{1}{2}\left[L + R \pm (L - R)\cos 2\theta_{\tilde{\tau}}\right], \quad c_{12} = c_{21} = \frac{1}{2}(L - R)\sin 2\theta_{\tilde{\tau}},$$

$$L = -\frac{1}{2} + \sin^2\theta_W, \quad R = \sin^2\theta_W.$$

$\sin\theta_{\tilde{\mu}} = 0.027,$ $\sin\theta_{\tilde{\tau}} = 0.36,$ $M^2_{\rm LR} = -\frac{1}{2}\left(m_2^2 - m_1^2\right)\sin 2\theta$

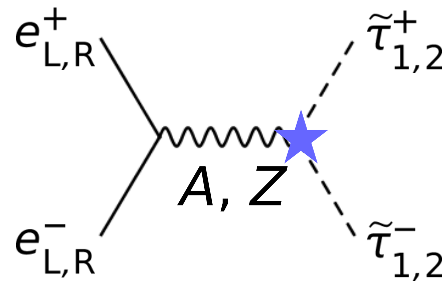
How can we measure

- **Mixing $M^2_{\rm LR}$**

$$\mathcal{M}^2_{\tilde{\mu}} = \begin{pmatrix} m^2_{\rm L} & M^2_{\rm LR} \\ M^2_{\rm LR} & m^2_{\rm R} \end{pmatrix}$$

$$\left(M^2_{\rm LR} \simeq m_\mu \mu \tan\beta\right)$$

$$\sigma(e^+e^- \to \tilde{\tau}^+_A \tilde{\tau}^-_B)$$



$\Rightarrow$ $\tilde{\tau}$ mixing $M^2_{\rm LR}(\tilde{\tau})$ measured.

$$\Rightarrow \quad M^2_{\rm LR} = \frac{m_\mu}{m_\tau} M^2_{\rm LR}(\tilde{\tau}) \qquad \left(\text{as long as } A_{\tilde{l}} \simeq 0.\right)$$

$$\sigma(\tilde{\tau}_A \tilde{\tau}_B) = \begin{cases} (\cdots) + (\cdots)\cos 2\theta + (\cdots)\cos^2 2\theta & (A = B) \\ (\cdots)\sin^2 2\theta & (A \neq B) \end{cases}$$

$\sin\theta_{\tilde{\mu}} = 0.027,$ $\sin\theta_{\tilde{\tau}} = 0.36,$ $M^2_{\rm LR} = -\frac{1}{2}\left(m_2^2 - m_1^2\right)\sin 2\theta$

$$\sigma(\tilde{\tau}_A\tilde{\tau}_B) = \begin{cases} (\cdots) + (\cdots)\cos 2\theta + (\cdots)\cos^2 2\theta & (A = B) \\ (\cdots)\sin^2 2\theta & (A \neq B) \end{cases}$$

How can we measure

- Mixing $M^2_{\rm LR}$

$$\sigma(e^+e^- \to \tilde{\tau}_A^+\tilde{\tau}_B^-)$$

$$\Rightarrow \quad \tilde{\tau} \text{ mixing } M^2_{\rm LR}(\tilde{\tau}) \text{ measured.}$$

$$\Rightarrow \quad M^2_{\rm LR} = \frac{m_\mu}{m_\tau} M^2_{\rm LR}(\tilde{\tau}) \qquad \left(\text{as long as } A_{\tilde{l}} \simeq 0.\right)$$

$$\Delta M^2_{\rm LR} = \Delta m_{\tilde{\tau}1} \oplus \Delta m_{\tilde{\tau}2} \oplus \Delta\sigma\left(\tilde{\tau}_A^+\tilde{\tau}_B^-\right)$$

$\Delta m_{\tilde{\tau}1}$ ↓ $\sim 0.1\%$ $\Delta m_{\tilde{\tau}2}$ ↓ $\sim 3\%$

$\left(@500\,\mathrm{GeV}, 500\,\mathrm{fb}^{-1}; \; (P_+, P_-) = (-0.3, +0.8)\right)$

ILC-TDR Vol.2 Sec.7.5.4 (and Bechtle, Berggren, et al. [0908.0876])

[All values are for the sample mass spectrum.]

$\sin\theta_{\tilde{\mu}} = 0.027,$ $\sin\theta_{\tilde{\tau}} = 0.36,$ $M^2_{\mathrm{LR}} = -\frac{1}{2}\left(m_2^2 - m_1^2\right)\sin 2\theta$

How can we measure

$$\sigma(\tilde{\tau}_A\tilde{\tau}_B) = \begin{cases} (\cdots) + (\cdots)\cos 2\theta + (\cdots)\cos^2 2\theta & (A = B) \\ (\cdots)\sin^2 2\theta & (A \neq B) \end{cases}$$

- Mixing M^2_{LR}

Not precise...

$$\Delta\sigma(\tilde{\tau}_1\tilde{\tau}_1) = \frac{1.8\,\mathrm{fb}}{54\,\mathrm{fb}} = 3.4\% \implies \Delta M^2_{\mathrm{LR}} = 12\%$$

(stat. dominated)

$$\Delta M^2_{\mathrm{LR}} = \Delta m_{\tilde{\tau}1} \oplus \Delta m_{\tilde{\tau}2} \oplus \Delta\sigma\left(\tilde{\tau}^+_A\tilde{\tau}^-_B\right)$$

$\Delta m_{\tilde{\tau}1}$: $\sim 0.1\%$

$\Delta m_{\tilde{\tau}2}$: $\sim 3\%$

(@500 GeV, 500 fb^{-1}; $(P_+, P_-) = (-0.3, +0.8)$)

ILC-TDR Vol.2 Sec.7.5.4 (and Bechtle, Berggren, et al. [0908.0876])

[All values are for the sample mass spectrum.]

$\sin\theta_{\tilde{\mu}} = 0.027,\quad \sin\theta_{\tilde{\tau}} = 0.36,\quad M^2_{\rm LR} = -\frac{1}{2}\left(m_2^2 - m_1^2\right)\sin 2\theta$

$$\sigma(\tilde{\tau}_A\tilde{\tau}_B) = \begin{cases}(\cdots) + (\cdots)\cos 2\theta + (\cdots)\cos^2 2\theta & (A = B)\\ (\cdots)\sin^2 2\theta & (A \neq B)\end{cases}$$

How can we measure

- Mixing $M^2_{\rm LR}$

Not precise...

$$\Delta\sigma(\tilde{\tau}_1\tilde{\tau}_1) = \frac{1.8\,\mathrm{fb}}{54\,\mathrm{fb}} = 3.4\% \implies \Delta M^2_{\rm LR} = 12\%$$

(stat. dominated)

$$\Delta\sigma(\tilde{\tau}_1\tilde{\tau}_2) = \frac{???\,\mathrm{fb}}{2.7\,\mathrm{fb}} = \cdots$$

→ should be studied!

$$\Delta M^2_{\rm LR} = \Delta m_{\tilde{\tau}1} \oplus \Delta m_{\tilde{\tau}2} \oplus \Delta\sigma\left(\tilde{\tau}^+_A\tilde{\tau}^-_B\right)$$

$\Delta m_{\tilde{\tau}1}$: $\sim 0.1\%$; $\Delta m_{\tilde{\tau}2}$: $\sim 3\%$

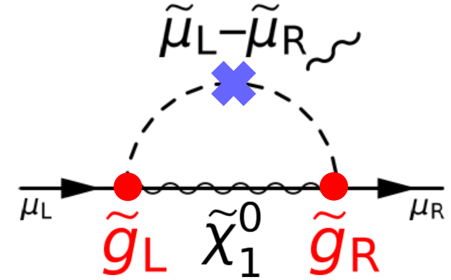
$\left(@500\,\mathrm{GeV}, 500\,\mathrm{fb}^{-1};\ (P_+, P_-) = (-0.3, +0.8)\right)$

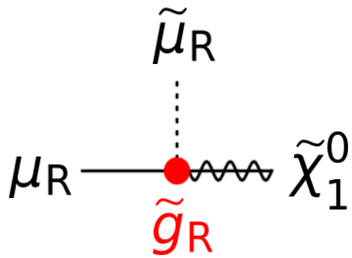
ILC-TDR Vol.2 Sec.7.5.4 (and Bechtle, Berggren, et al. [0908.0876])

[All values are for the sample mass spectrum.]

How can we measure

- Coupling $\tilde{g}_L, \tilde{g}_R$





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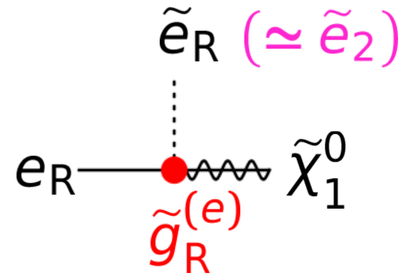
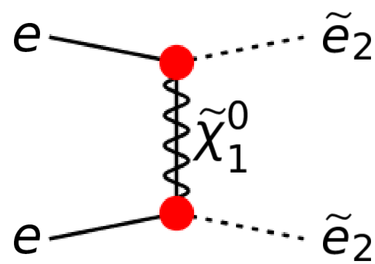


\+ $\tilde{H}^0$-contribution ($\propto Y_\mu$)

measured via



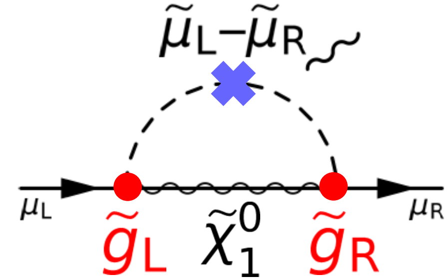
< 0.4% contrib. for $\tilde{H} > 500\,\mathrm{GeV}$

$$\Delta\sigma \sim \frac{4.7\,\mathrm{fb}}{316\,\mathrm{fb}} = 1.5\% \rightsquigarrow \Delta\tilde{g}^{(e)}_R \sim 0.4\%$$

$$\therefore \Delta\tilde{g}_R \lesssim 1\%$$

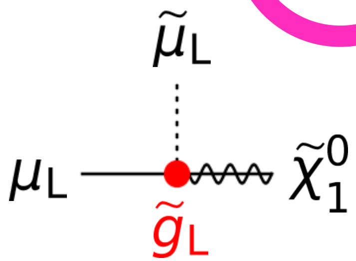
Freitas, Kalinowski, et al. [ph/0211108]
Freitas, Manteuffel, Zerwas [ph/0310382]
Kilian, Zerwas [ph/0601217]

(@500 GeV, 500 fb^{-1}; $(P_+, P_-) = (-0.3, +0.8)$)

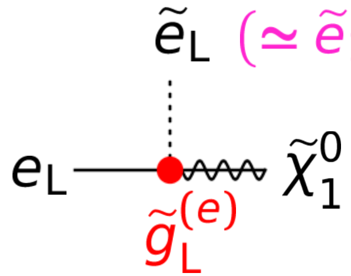


How can we measure

- Coupling $\tilde{g}_L, \tilde{g}_R$



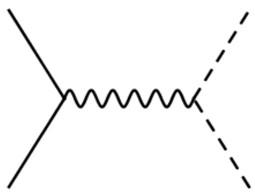
$=$



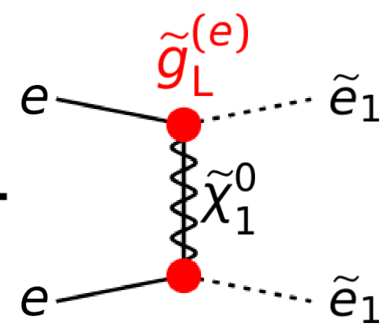
$+$ $\tilde{H}^0$-contribution $(\propto Y_\mu)$

However

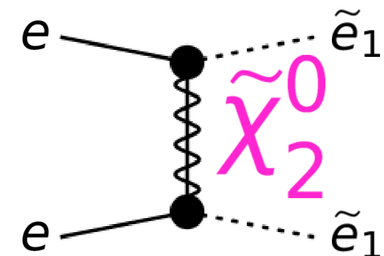
$\sigma(\tilde{e}_L\tilde{e}_L) \approx$



$+$



$+$



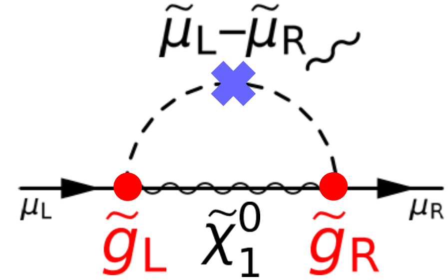
$(\simeq \tilde{W})$

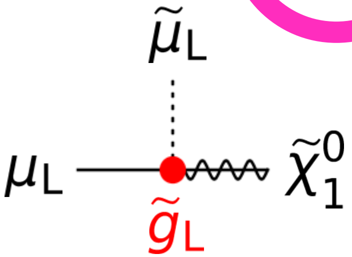
cannot be neglected.

We use $\sigma(\tilde{e}_L\tilde{e}_R)$.

How can we measure

- Coupling $\tilde{g}_L, \tilde{g}_R$





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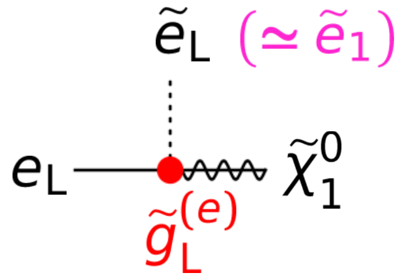
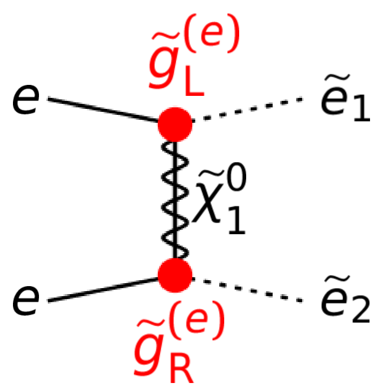


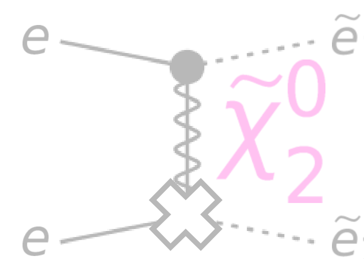
\+ $\tilde{H}^0$-contribution $(\propto Y_\mu)$

< 0.9% contrib. for $\tilde{H}, \widetilde{W} > 500\,\mathrm{GeV}$

$$\sigma(\tilde{e}_L \tilde{e}_R) \approx$$



\+

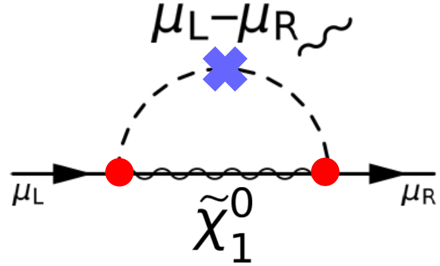


$\Delta\sigma \sim ???\%$ $(\sigma = 5.5\,\mathrm{fb})$

should be studied...

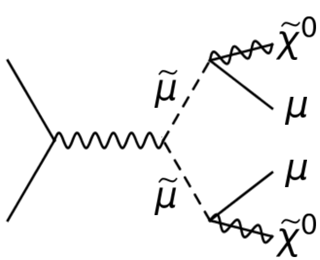
Here we use $\Delta\tilde{g}_L^{(e)} \sim$ a few%

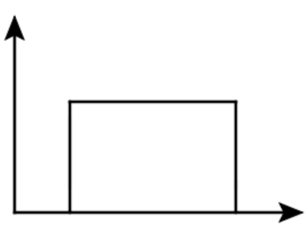
$\therefore \Delta\tilde{g}_L \sim 1 + \text{a few}\%$

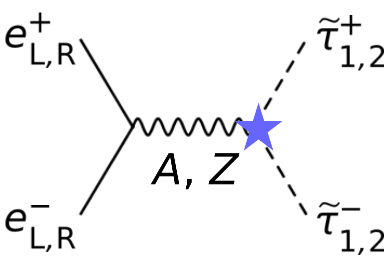
$a_\mu^{\rm SUSY} \simeq$ 

$\therefore \Delta a_\mu^{\rm SUSY} = 13\%$

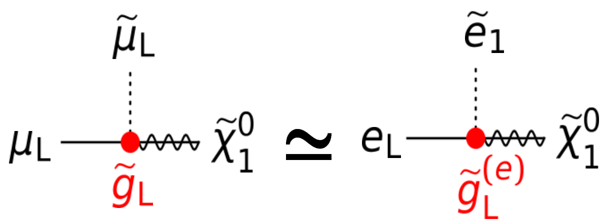
Mass of $\tilde\mu_1, \tilde\mu_2, \tilde\chi_0^1$	Mixing $M^2_{\rm LR}$	coupling $\tilde g_{\rm L}, \tilde g_{\rm R}$
$e^+e^- \to \tilde\mu^+\tilde\mu^-$ end-point	$\sigma(ee \to \tilde\tau_1\tilde\tau_1)$	$\sigma(ee \to \tilde e_R \tilde e_R)$, $\sigma(ee \to \tilde e_L \tilde e_R)$
→ ~0.1%	→ ~12%	→ R: ~1% L : (a few + 1)%

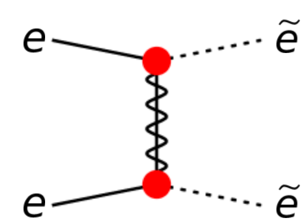






$$M^2_{\rm LR} \simeq m_\mu \mu \tan\beta \simeq \frac{m_\mu}{m_\tau} M^2_{\rm LR}(\tilde\tau)$$

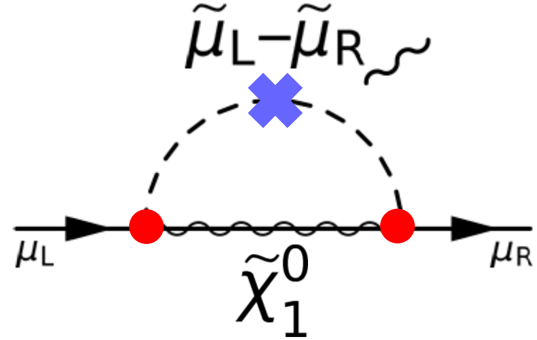




For the scenario

- $\tilde{g}, \tilde{q}, \widetilde{H}, \widetilde{W} \gg 100\,\text{GeV}$,
- $\tilde{e}, \tilde{\mu}, \tilde{\tau} <$ ILC reach,

$a_\mu^{\text{SUSY}} \simeq$



a_μ^{SUSY} **can reconstructed via**

Mass of $\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\chi}^1_0$	Mixing M^2_{LR}	coupling $\tilde{g}_L, \tilde{g}_R$
$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$ end-point	$\sigma(ee \to \tilde{\tau}_1\tilde{\tau}_1)$	$\sigma(ee \to \tilde{e}_R\tilde{e}_R)$, $\sigma(ee \to \tilde{e}_L\tilde{e}_R)$

with the precision 13% (at our sample point).

can be improved if we use $\sigma(ee \to \tilde{\tau}_1\tilde{\tau}_2)$.

Largely depends on mixing.