

# T-parity を課した littlest Higgs 模型における $\tau$ および $\mu$ の lepton flavor の破れ

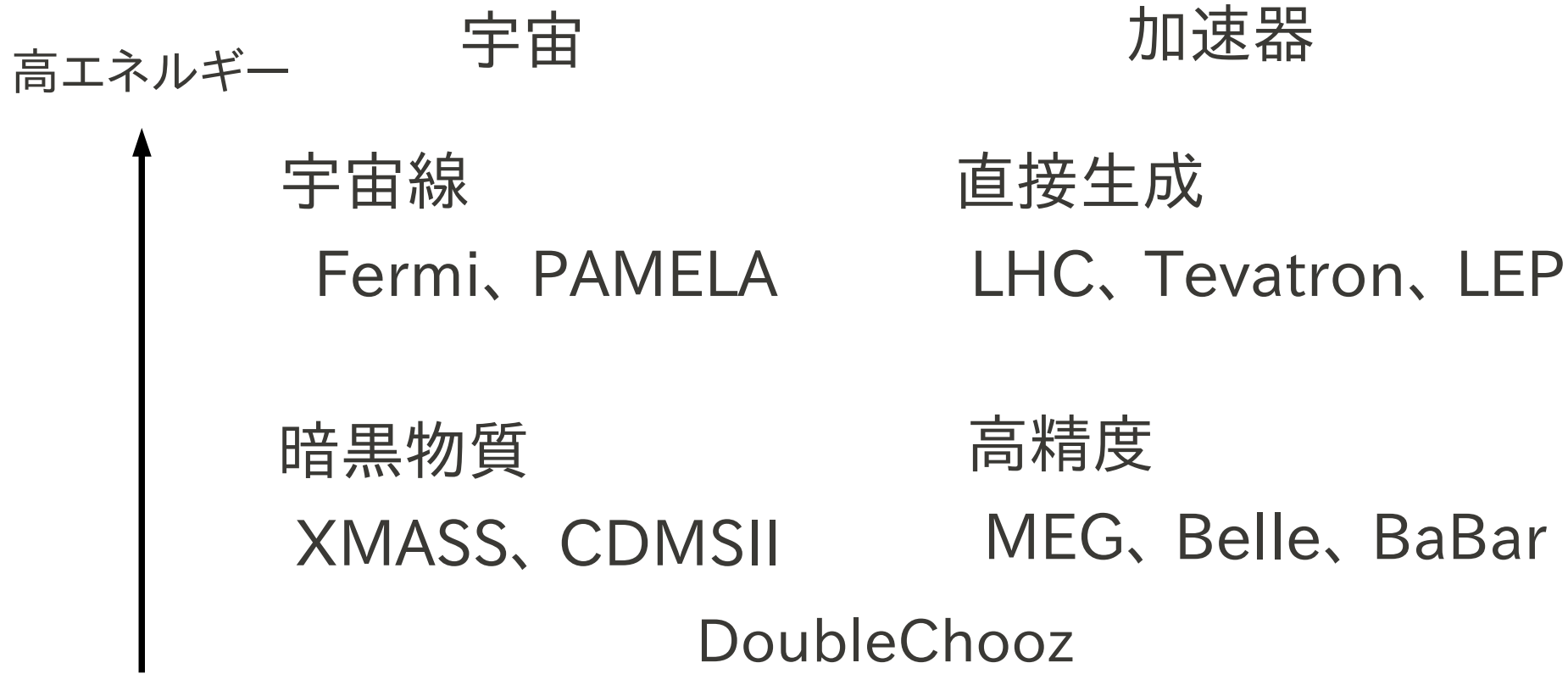
2011/03/10 @基研研究会 素粒子物理の進展

山本 康裕(総研大/KEK)

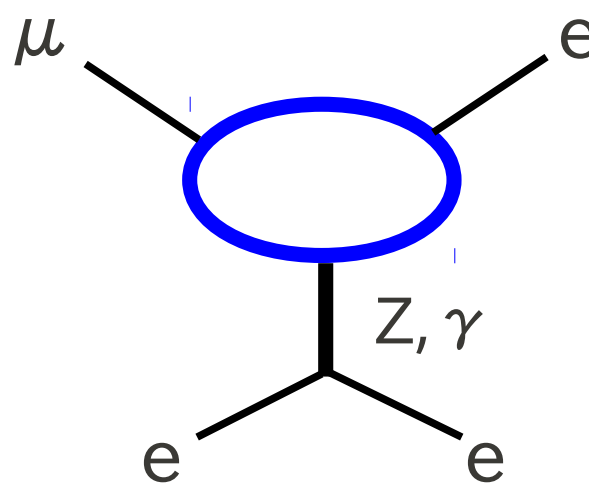
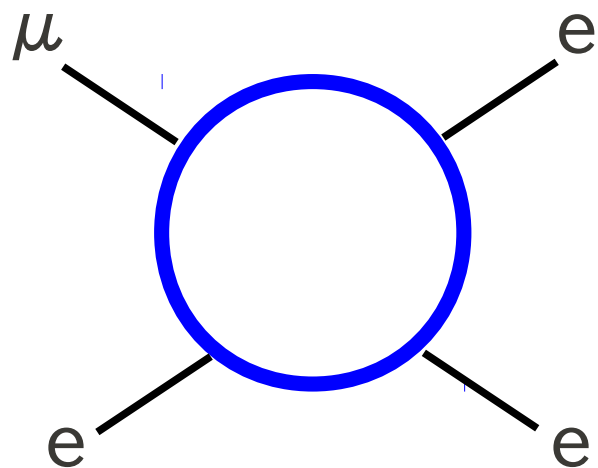
共同研究者: 後藤 亨(KEK)、岡田 安弘(KEK/総研大)

arXiv:1012.4385[hep-ph] に基づく。

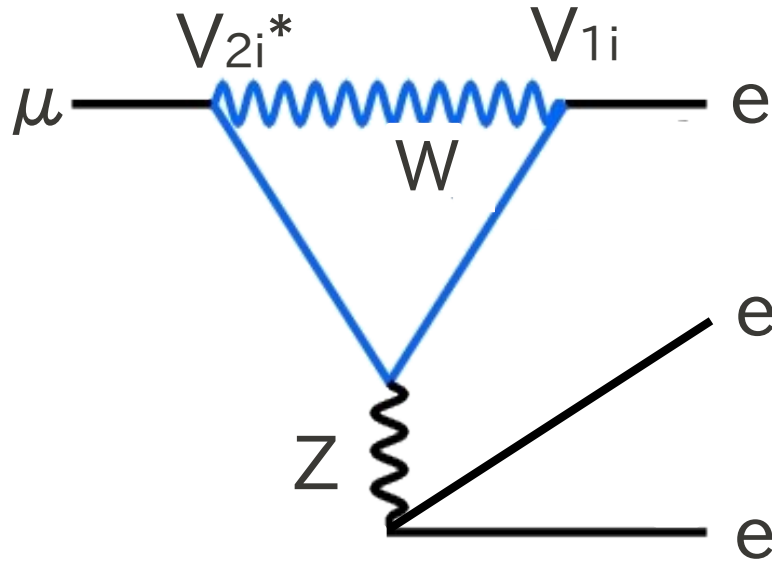
# 標準模型を越える物理の探索



# 標準模型を越える物理の探索



# Lepton flavor の破れ



$$\text{Br} \sim \left| \frac{g^2}{(4\pi)^2} \sum_i V_{2i} V_{1i}^* \frac{m_{\nu i}^2}{m_W^2} \right|^2 \sim \mathcal{O}(10^{-53})$$

標準模型の範囲では見えない。

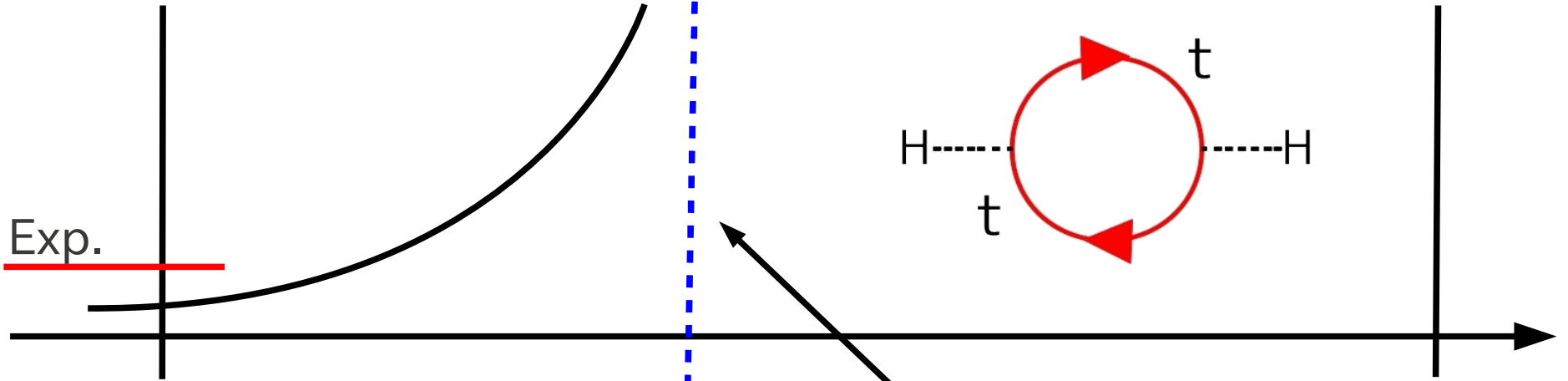
- ✓ 過程の観測が新しい物理の観測と同義。
- ✓ QCD の影響がないので見易い。

# Little Higgs 模型

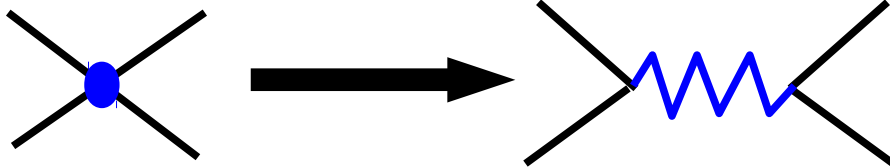
Hierarchy Problem

EW

$M_P$



新しい物理の scale  $\sim 5\text{TeV}$



$$\frac{\Delta m_H^2}{m_H^2} \sim \left( 0.3 \frac{\Lambda_{\text{cut off}}}{100\text{GeV}} \right)^2 > 200$$

不自然な階層性

'99 R.Barbieri, A.Strumia

Little Higgs 模型

相殺 @1-loop

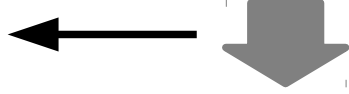


'01 N.Arkani-Hamed, A.G.Cohen, H.Georgi

# Littlest Higgs 模型

$$SU(5) \supset [SU(2) \times U(1)]_1 \times [SU(2) \times U(1)]_2$$

Higgs

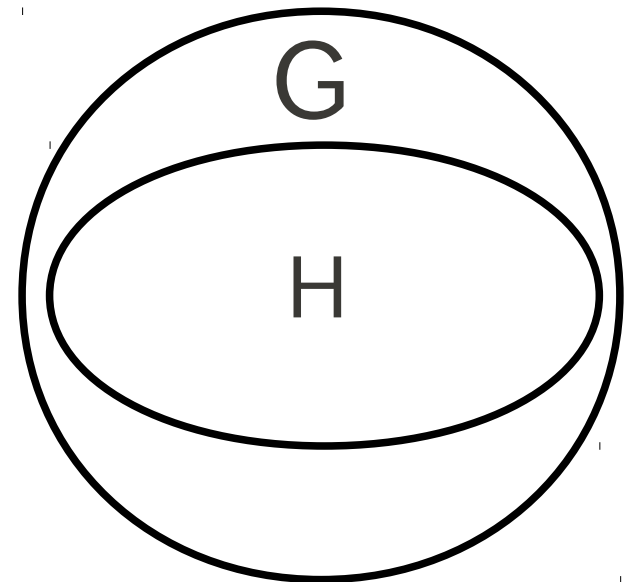


$$SO(5) \supset$$

$$SU(2)_L \times U(1)_Y$$

$SU(5) \rightarrow SO(5)$ : 14 NG bosons

$$\mathcal{L}_{NG} = \mathcal{L}_{G/H} + \mathcal{L}_{G1} + \mathcal{L}_{G2}$$

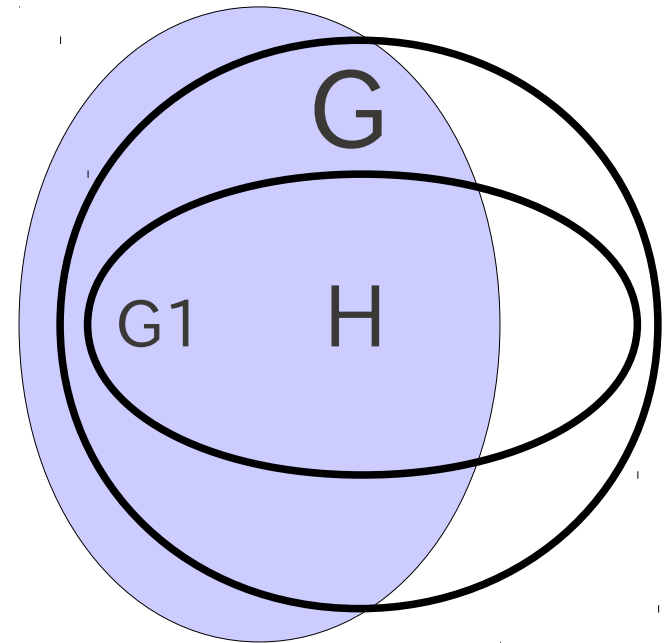


# Littlest Higgs 模型

$$\begin{array}{ccc} \text{Higgs} \leftarrow & \text{SU}(5) \supset [\text{SU}(2) \times \text{U}(1)]_1 \times [\text{SU}(2) \times \text{U}(1)]_2 & \\ & \downarrow & \downarrow \\ & \text{SO}(5) \supset & \text{SU}(2)_L \times \text{U}(1)_Y \end{array}$$

$\text{SU}(5) \rightarrow \text{SO}(5)$ : 14 NG bosons

$$\mathcal{L}_{NG} = \mathcal{L}_{G/H} + \mathcal{L}_{G1} + \mathcal{L}_{G2}$$



# Littlest Higgs 模型

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Higgs



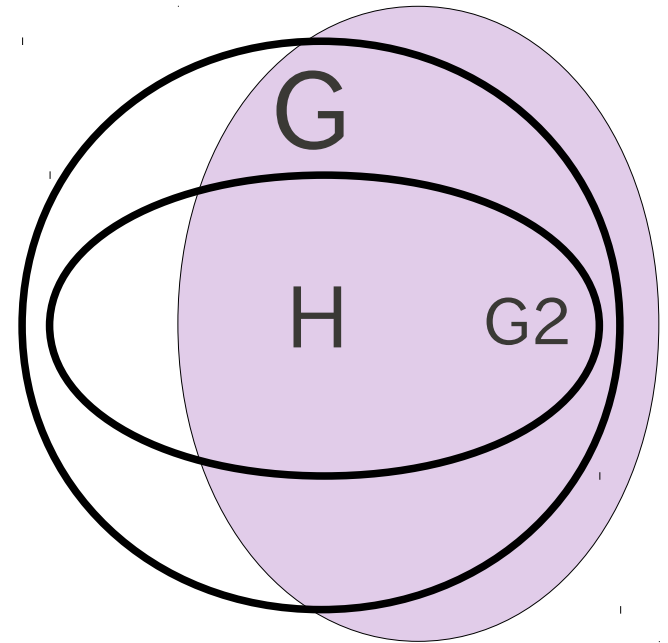
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# Littlest Higgs 模型

$$SU(5) \supset [SU(2) \times U(1)]_1 \times [SU(2) \times U(1)]_2$$

Higgs



$$SO(5) \supset$$



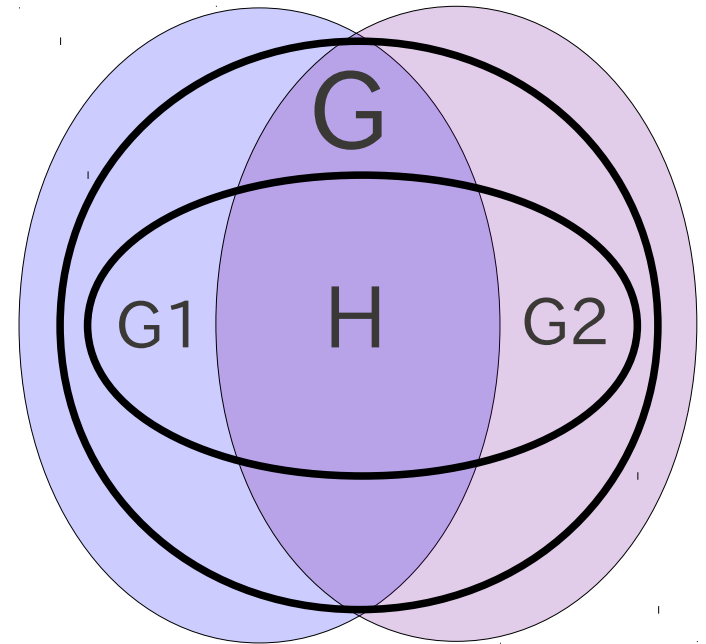
$$SU(2)_L \times U(1)_Y$$

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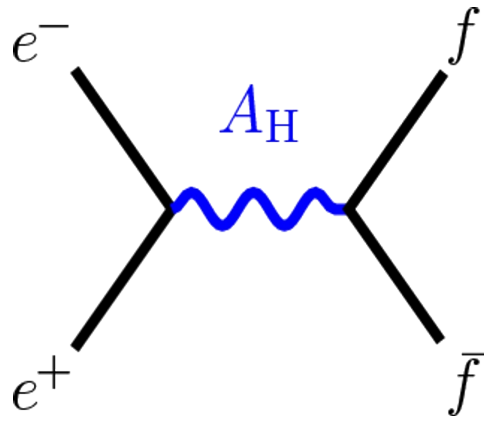
$$\mathcal{L}_{NG} = \mathcal{L}_{G/H} + \mathcal{L}_{G1} + \mathcal{L}_{G2}$$



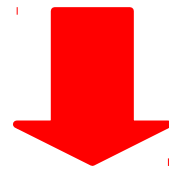
$$\mathcal{L}_{Hmass} = g_1 g_2 \langle O_1 O_2 \rangle H^\dagger H$$



# T-parity



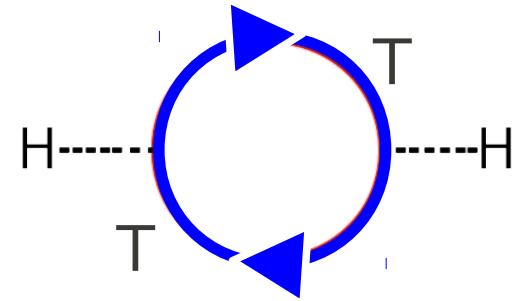
$$\simeq \frac{g'^2}{M_{AH}^2} (\bar{e}\gamma^\mu e)(\bar{f}\gamma_\mu f)$$



電弱精密測定より  $M_{AH} \rightarrow$  大

$$\Delta m_H \sim \underline{m_T} \ln \Lambda$$

デカ過ぎ!!



Z<sub>2</sub> 対称性 (T-parity) で禁止

'03 C.H.Chen, I.Low

✓ 新しい粒子、混合行列を導入

→ Flavor の signal からこのモデルの可能性を探る

中性中間子混合

'05 J.Hubisz, S.J.Lee, G.Paz

様々な FCNC 過程

'06~'09 M.Blanke, A.J.Buras, C.Tarantino et al.

$K \rightarrow \pi \nu \nu$

'08 T.Goto, Y.Okada, Y.Y.

$\mu$ -LFV

'08,10 F.del Aguila, J.I.Illana, M.D.Jenkins

arXiv: 1012.4385 [hep-ph]

- ✓ 偏極した  $\tau$  及び  $\mu$  の lepton flavor を破る崩壊。  
( $l \rightarrow l' \gamma, l \rightarrow l' l'' l''', l \rightarrow l' P, l \rightarrow l' V$ )
- ✓  $\mu$ -e conversion の原子番号依存性。

## ✓ Lepton Flavor の破れ

Angular と forward-backward asymmetries

## ✓ T パリティを課した Littlest Higgs 模型

対称性、新しい粒子と混合

## ✓ 数値計算

## ✓ まとめ

Tested: MEG @ PSI ( $\rightarrow 10^{-13}$ )

$$\mu^+ \rightarrow e^+ \gamma \leq 1.2 \times 10^{-11} \text{ by MEGA}$$

$$\mu^+ \rightarrow e^+ e^+ e^- \leq 1.0 \times 10^{-12} \text{ by SINDRUM}$$

$$\tau^+ \rightarrow \ell^+ \gamma \lesssim \mathcal{O}(10^{-8})$$

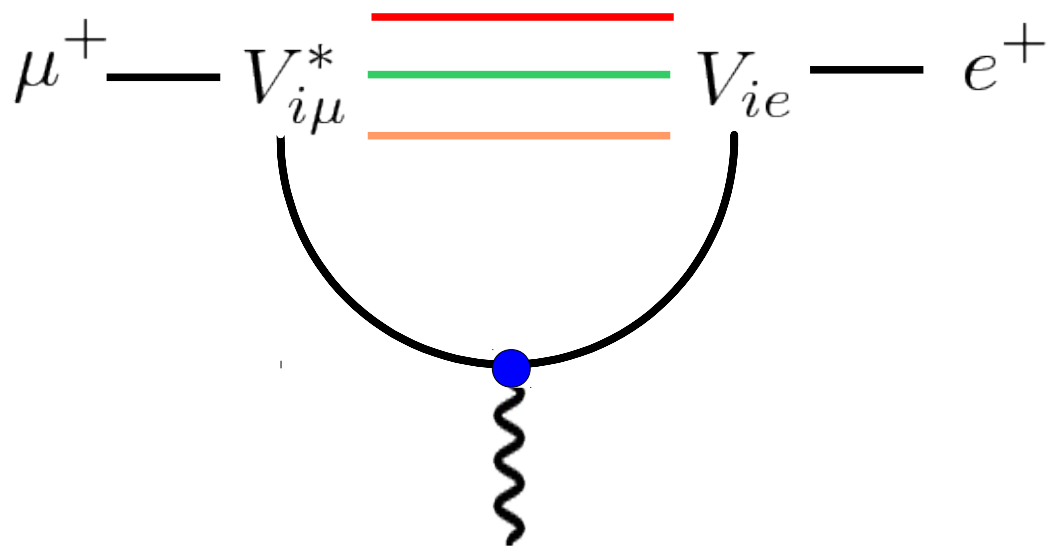
$$\tau^+ \rightarrow \mu^+ \mu^+ \mu^-, \tau^+ \rightarrow \mu^+ e^+ e^- \lesssim \mathcal{O}(10^{-8})$$

by Belle @ KEK and BaBar @ SLAC

Planned: Super B-factories @ KEK and INFN ( $\rightarrow 10^{-9}$ )

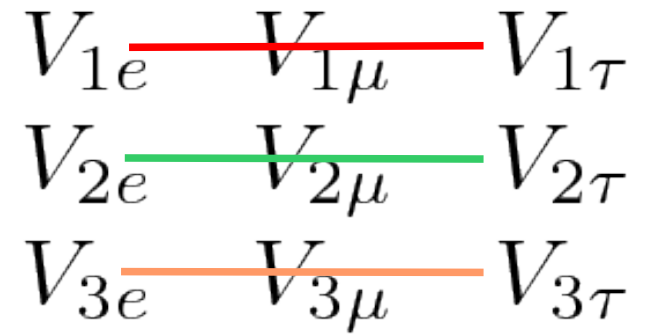
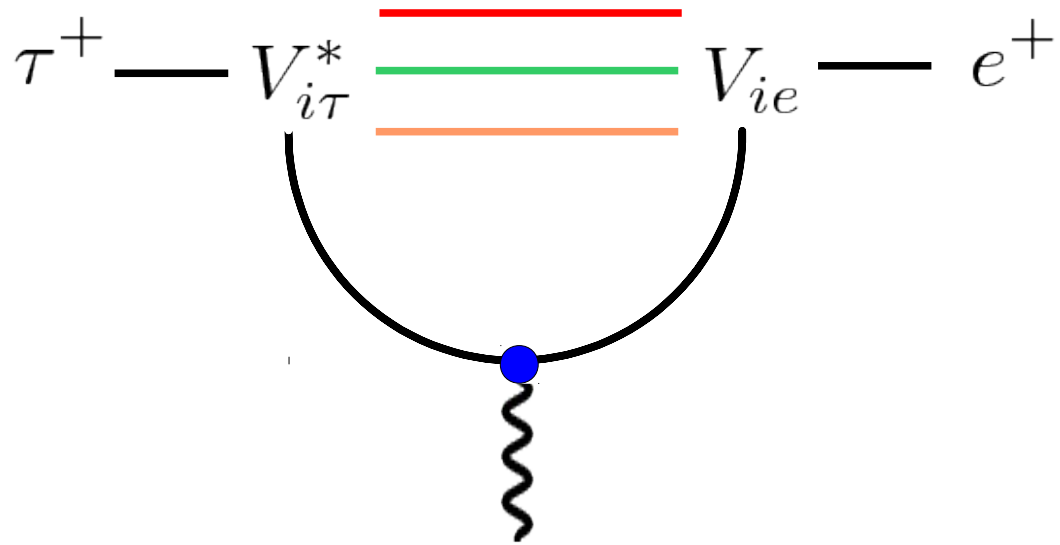
$\tau \rightarrow 3\mu$  can be tested @ LHC

# $\tau$ と $\mu$ の違い

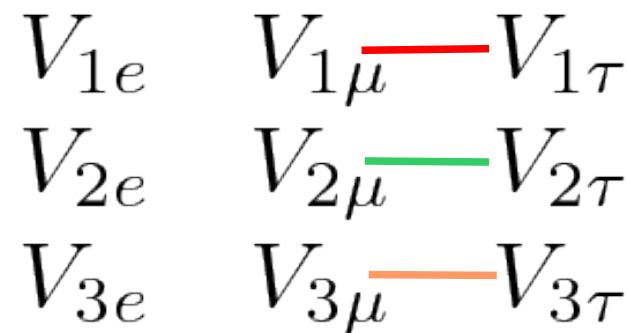
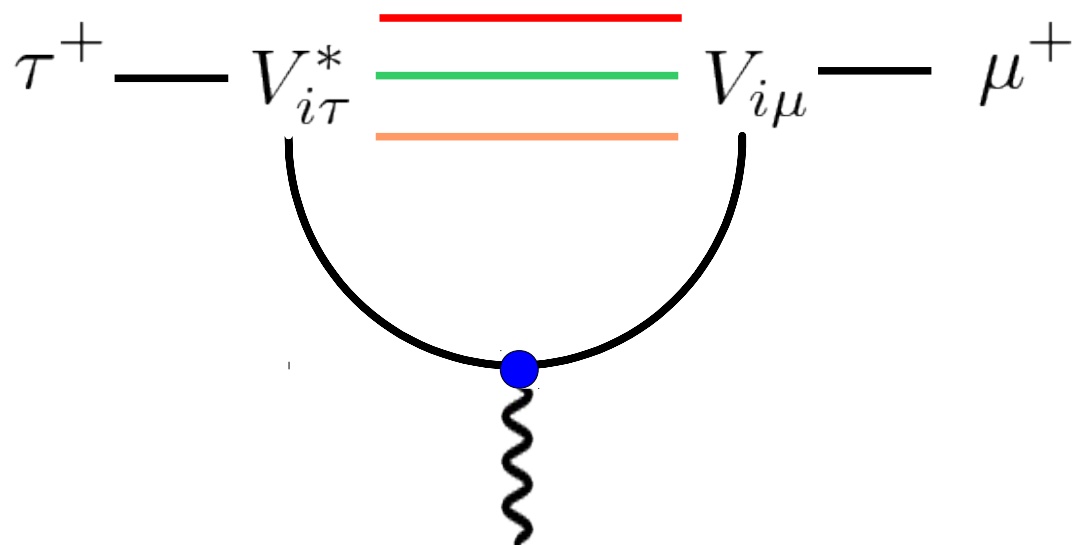


$V_{1e}$	$V_{1\mu}$	$V_{1\tau}$
$V_{2e}$	$V_{2\mu}$	$V_{2\tau}$
$V_{3e}$	$V_{3\mu}$	$V_{3\tau}$

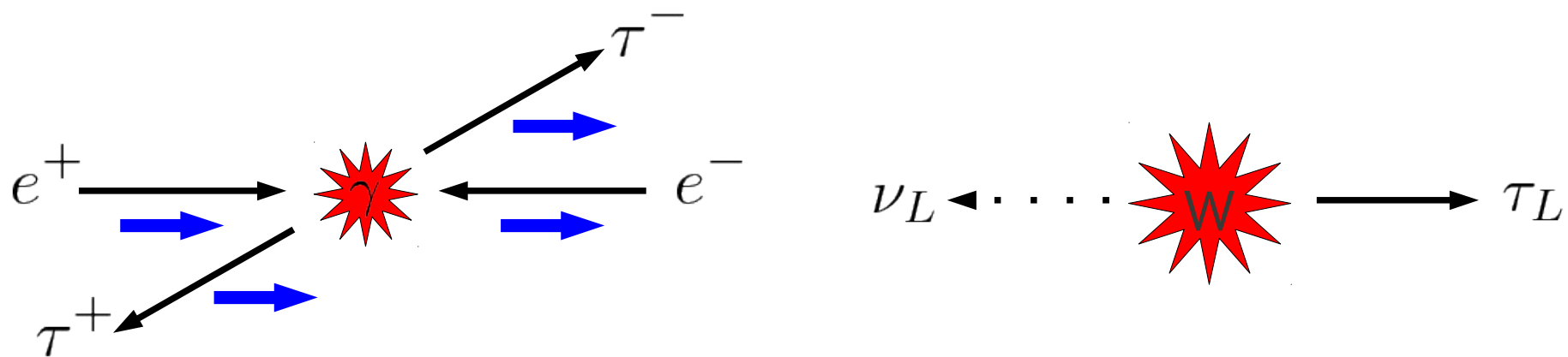
# $\tau$ と $\mu$ の違い



# $\tau$ と $\mu$ の違い



$\tau$  は spin の相関を持って生成される





# Asymmetry (2体)

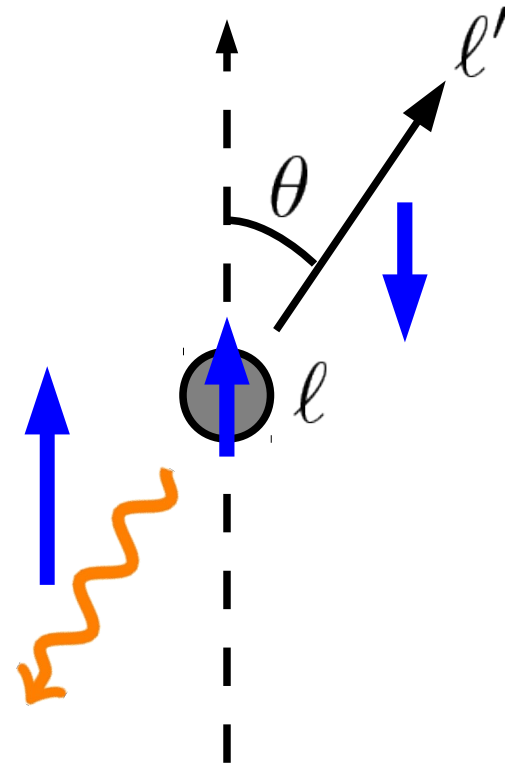
$$l \rightarrow l' \gamma$$

$$\mathcal{L}_\gamma = -\frac{4G_F}{\sqrt{2}} \left[ m_l A_R \bar{l}_R \sigma^{\mu\nu} l'_L F_{\mu\nu} + m_l A_L \bar{l}_L \sigma^{\mu\nu} l'_R F_{\mu\nu} \right],$$

$$\longrightarrow \frac{d\Gamma}{d\cos\theta} \propto |A_L|^2 (1 + \cos\theta) + |A_R|^2 (1 - \cos\theta),$$

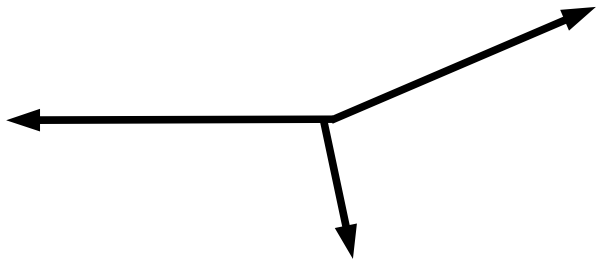
$$\underline{A_\gamma = \frac{1}{2} \frac{|A_L|^2 - |A_R|^2}{|A_L|^2 + |A_R|^2}}$$

: Parity Asymmetry



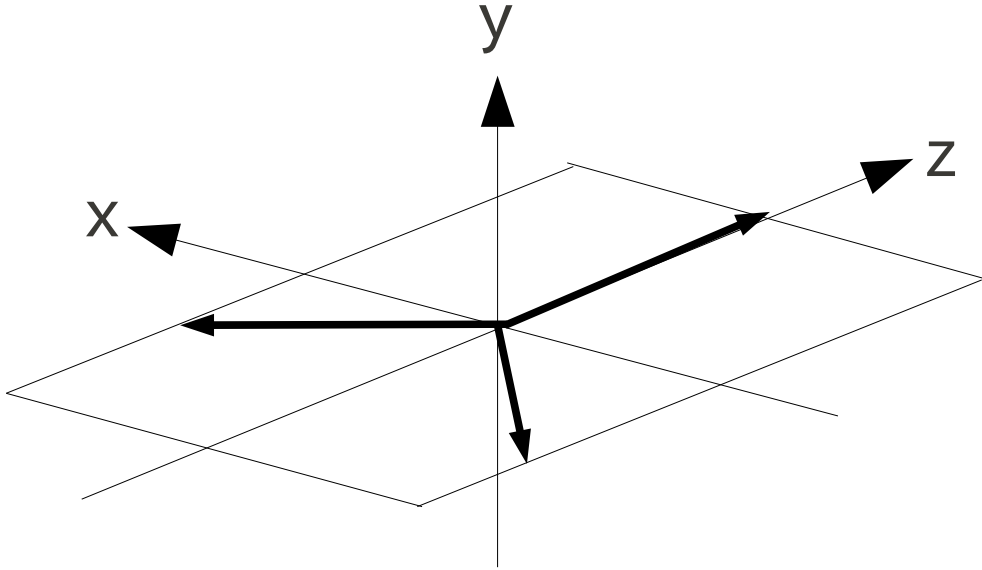
# Asymmetry (3体)

$$\tau^+ \rightarrow \mu^+ e^+ e^-$$



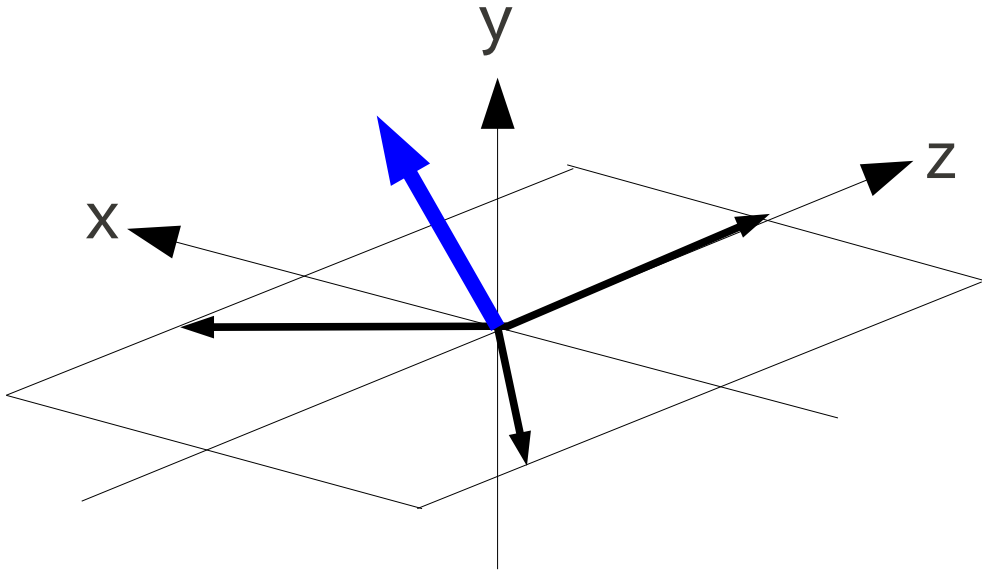
# Asymmetry (3体)

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$$\tau^+ \rightarrow \mu^+ e^+ e^-$$



$$\hat{z} : \cos \theta \sim \vec{s} \cdot \vec{p}_a$$

$$\hat{x} : \sin \theta \cos \phi$$

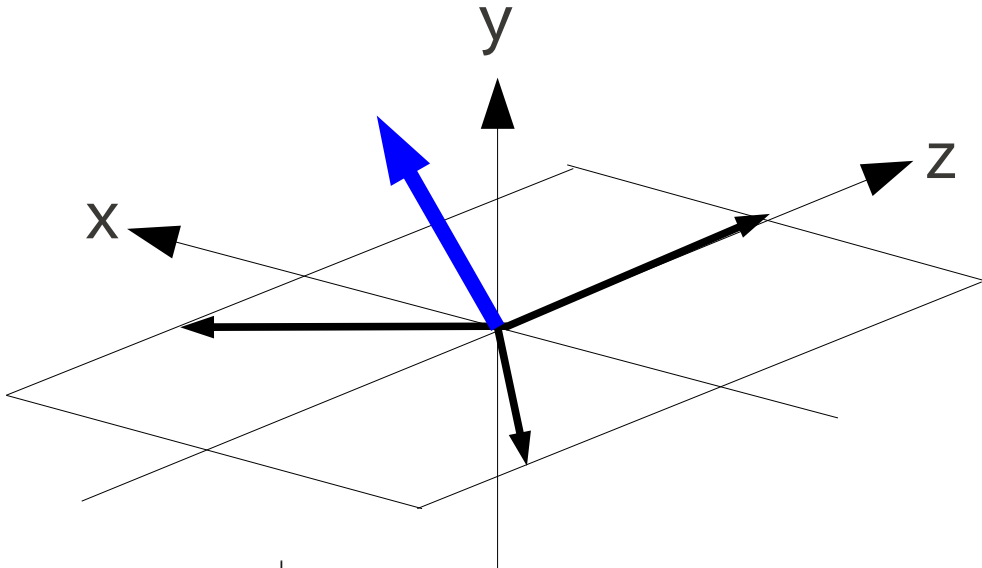
$$\sim \vec{s} \cdot ((\vec{p}_a \times \vec{p}_b) \times \vec{p}_a)$$

$$\hat{y} : \sin \theta \sin \phi \sim \vec{s} \cdot (\vec{p}_a \times \vec{p}_b)$$

'00 Y.Okada, K.Okumura, Y.Shimizu

# Asymmetry (3体)

$$\tau^+ \rightarrow \mu^+ e^+ e^-$$



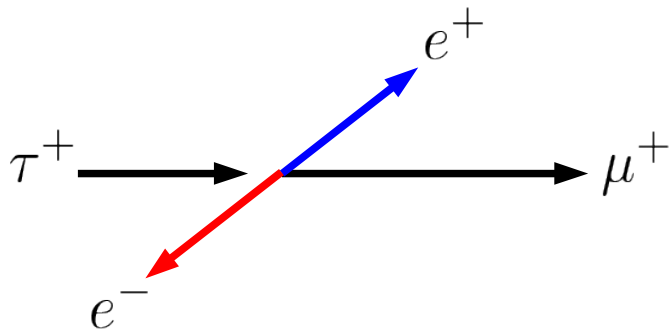
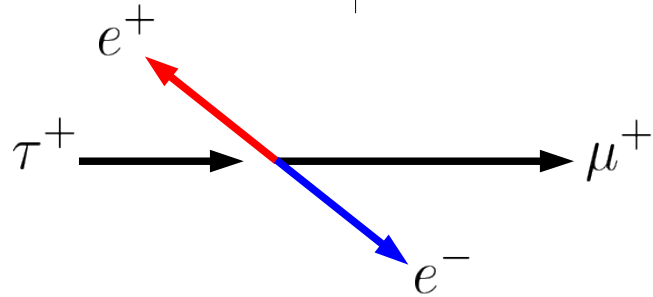
$$\hat{z} : \cos \theta \sim \vec{s} \cdot \vec{p}_a$$

$$\hat{x} : \sin \theta \cos \phi$$

$$\sim \vec{s} \cdot ((\vec{p}_a \times \vec{p}_b) \times \vec{p}_a)$$

$$\hat{y} : \sin \theta \sin \phi \sim \vec{s} \cdot (\vec{p}_a \times \vec{p}_b)$$

'00 Y.Okada, K.Okumura, Y.Shimizu



	Br	Ax	Ay	Az
<del>FB</del>	Br	Ax	Ay	Az
FB	A <sub>FB</sub>	A <sub>X,FB</sub>	A <sub>Y,FB</sub>	A <sub>Z,FB</sub>

# T-parity を課した Littlest Higgs 模型

$$SU(5) \supset [SU(2) \times U(1)]_1 \times [SU(2) \times U(1)]_2$$

Higgs

$$SO(5) \supset$$

$$SU(2)_L \times U(1)_Y$$

T-even

T-odd

$$\begin{matrix} \gamma & W^\pm & Z & h \\ \nu_i & e_i & u_i & d_i & T_+ \end{matrix}$$

$$\begin{matrix} V_{Hu} & V_{Hd} \\ V_{H\nu} & V_{H\ell} \end{matrix}$$

$$\begin{matrix} A_H & W_H^\pm & Z_H & \Phi \\ \nu_{Hi} & e_{Hi} & u_{Hi} & d_{Hi} & T_- \end{matrix}$$

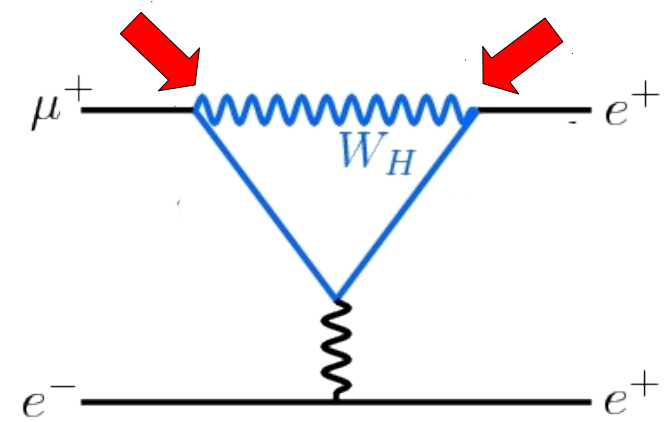
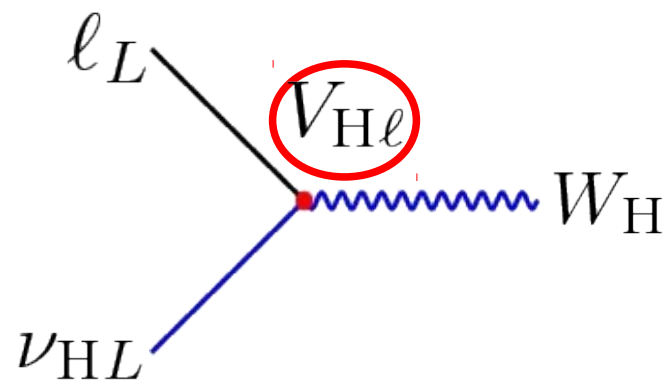
$$\begin{matrix} V_{CKM} \\ V_{MNS} \end{matrix}$$

3 angles  
1 phase

3 angles  
3 phases

'05 J.Hubisz, S.J.Lee, G.Paz

'08 M.Blanke, A.J.Buras, C.Tarantino et al.



$$\mathcal{L}_{\text{LHT}} = -\frac{4G_F}{\sqrt{2}} \left[ m_\tau A_R \bar{\tau}_R \sigma^{\mu\nu} \mu_L F_{\mu\nu} + g_{Ll} (\tau_L \gamma^\mu \mu_L) (\mu_L \gamma_\mu \mu_L) \right. \\ \left. + g_{Lr} (\tau_L \gamma^\mu \mu_L) (\mu_R \gamma_\mu \mu_R) + \text{H.c.} \right]$$

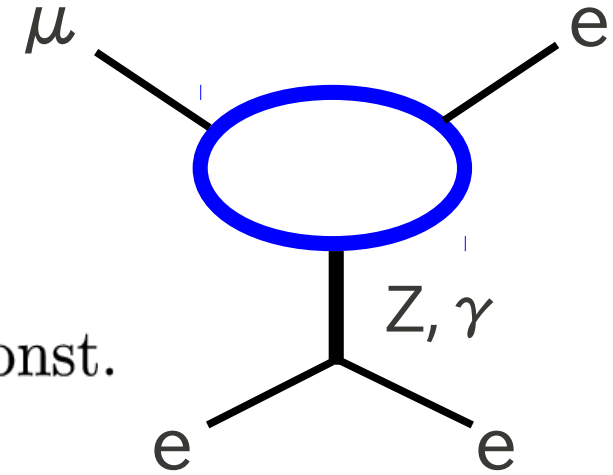
$$\frac{g_{Lr}}{eA_R} = -z, \quad \frac{g_{Ll}}{eA_R} = -z + \Delta$$

$$\frac{\text{Br}_{3l}}{\text{Br}_\gamma} \propto |z|^2 + 2|-z + \Delta|^2 + 8\text{Re}[-3z + 2\Delta] + \text{const.}$$

$$\frac{A_{Z3l}}{\text{Br}_\gamma} \propto \frac{1}{6}|z|^2 - |-z + \Delta|^2 - 4\text{Re}[-z + 2\Delta] + \text{const.}$$

$$\frac{A_{X3l}}{\text{Br}_\gamma} \propto \frac{1}{12}|z|^2 - \text{Re}[-z + 3\Delta] + \text{const.}$$

$$\frac{A_{Y3l}}{\text{Br}_\gamma} \propto \text{Im}[-z + 3\Delta]$$



10個の新しい parameter が関与

✓ 崩壊定数 (1):  $f = 500 \text{ GeV}$

✓ T-odd lepton の質量 (3):  $m_{H\ell}^i$   
 $100 \text{ GeV} \leq m_{H\ell}^i \leq 1 \text{ TeV}$

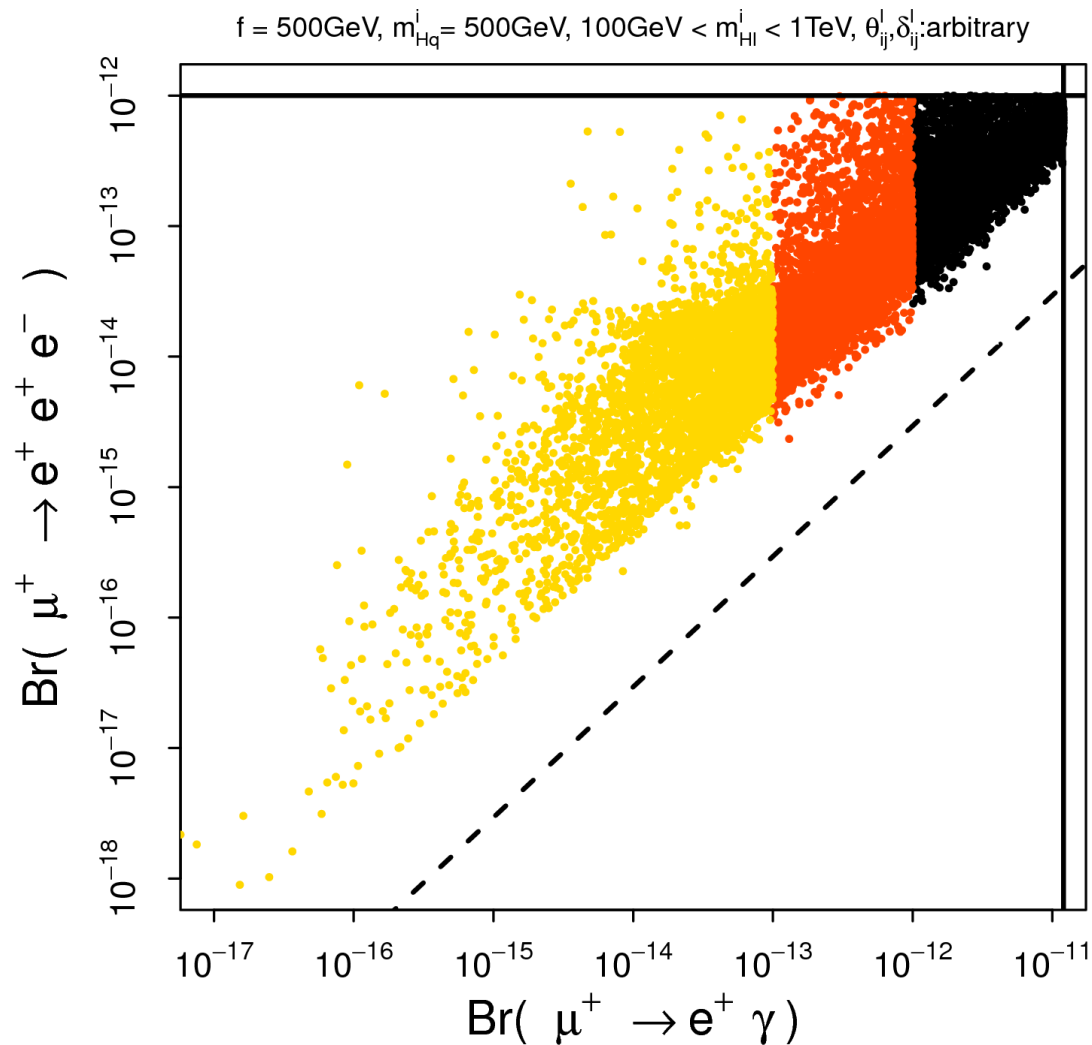
✓ 新しい混合の angle と phase (6):  $\theta_{ij}^\ell, \phi_{ij}^\ell$   
 $0 \leq \theta_{ij}^\ell, \phi_{ij}^\ell < 2\pi$

➡ 7 parameter での散布図

$$\text{Br}(\mu \rightarrow e \gamma) < 10^{-13} < \text{Br}(\mu \rightarrow e \gamma) < 10^{-12} < \text{Br}(\mu \rightarrow e \gamma) < 1.2 \times 10^{-11}$$



# 数值計算 ( $\mu \rightarrow e \gamma$ )

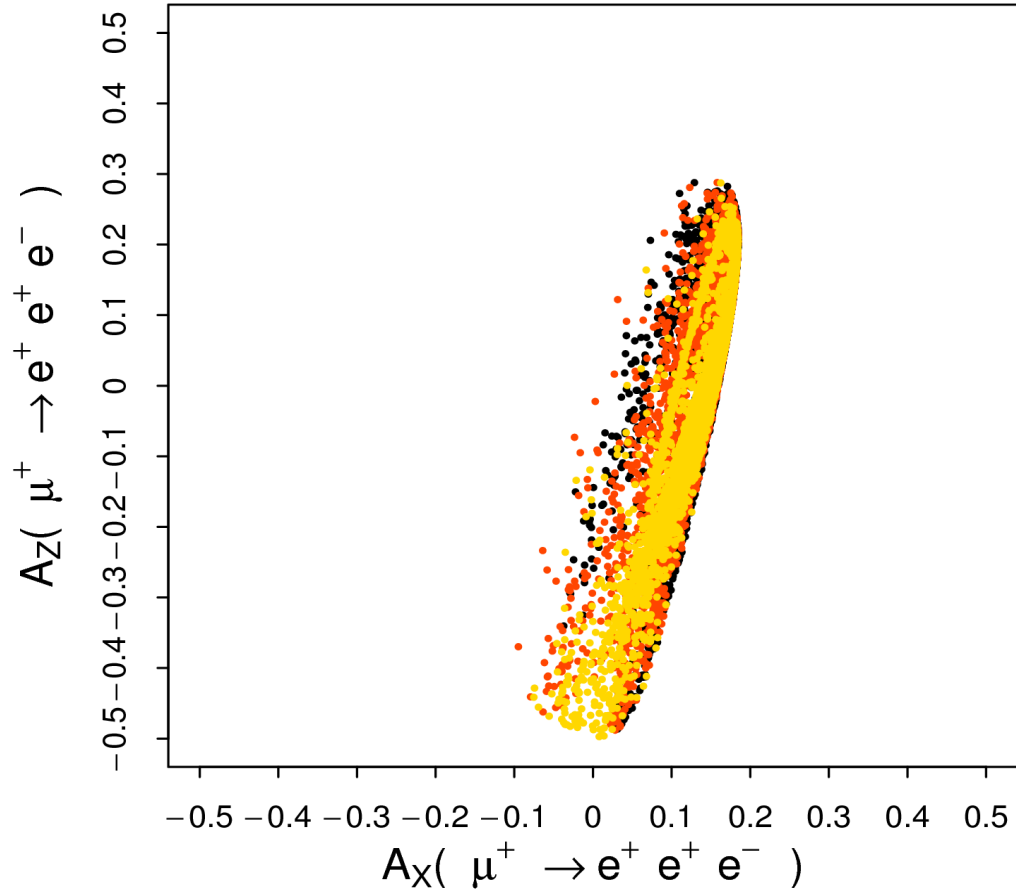


'08 M.Blanke, A.J.Buras, C.Tarantino et al.

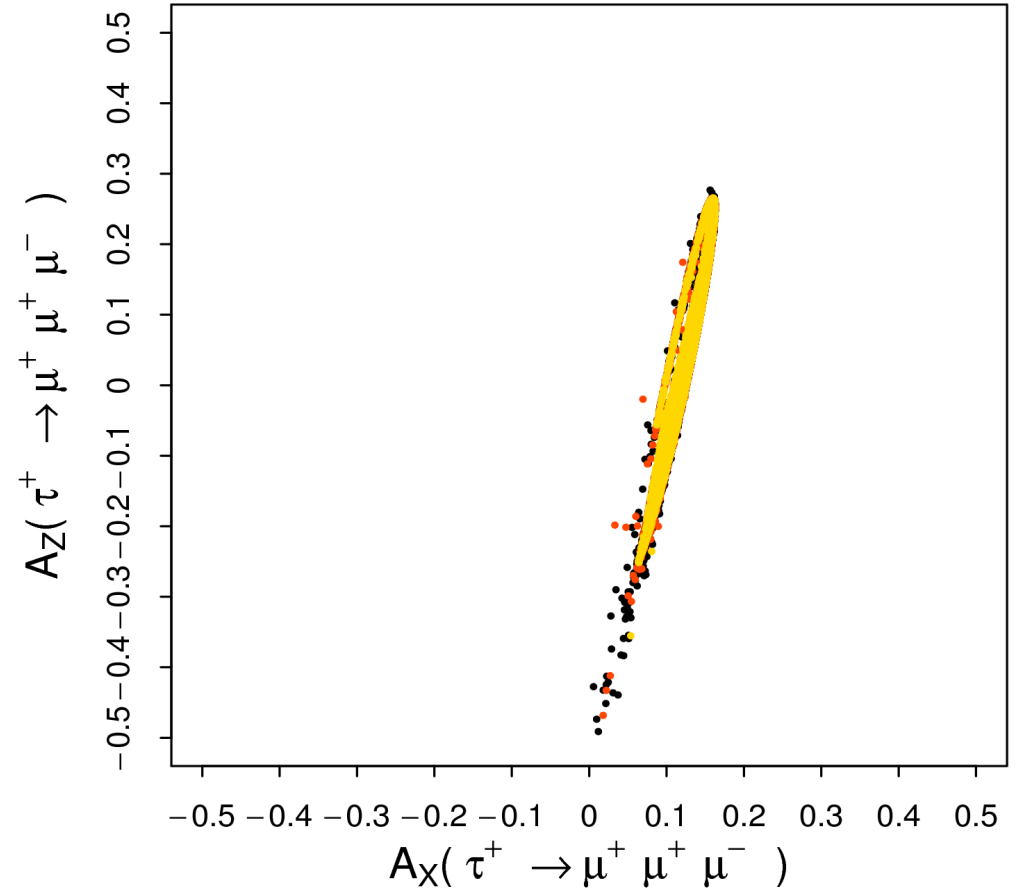
$$A_\gamma(\ell \rightarrow \ell' \gamma) = -1/2,$$

# 数值計算 (Parity Asymmetry)

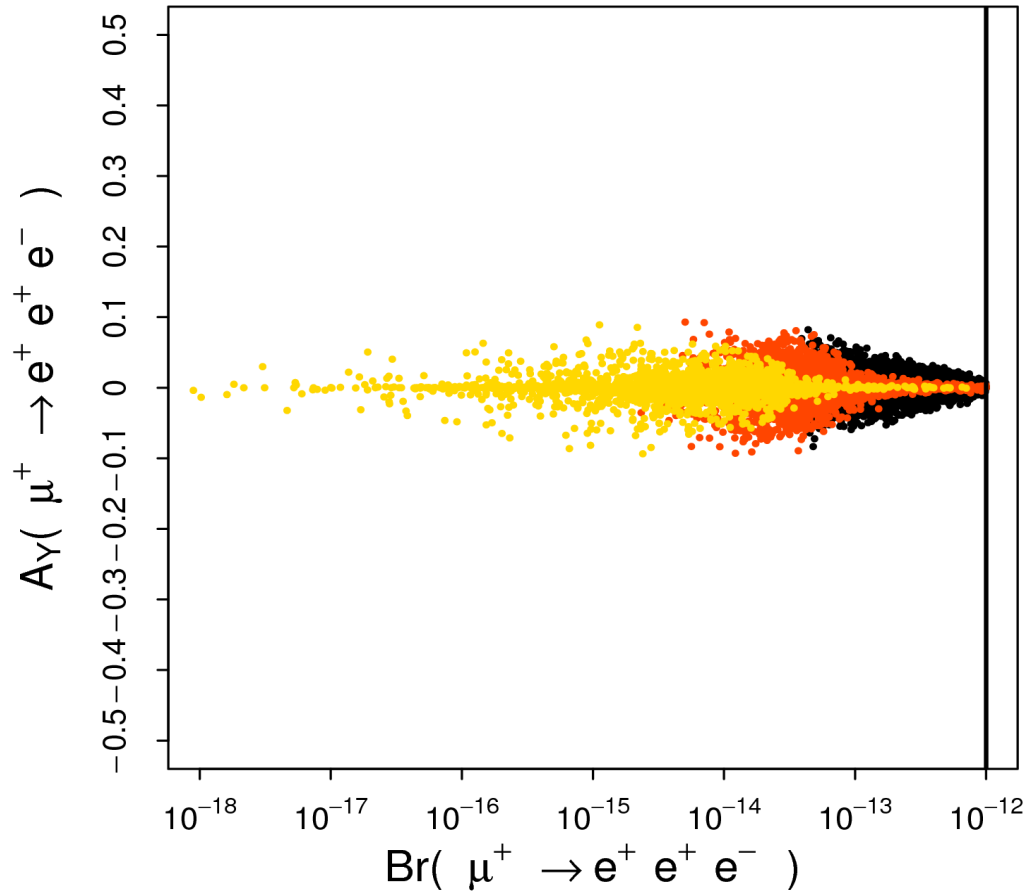
$f = 500\text{GeV}$ ,  $m_{Hq}^i = 500\text{GeV}$ ,  $100\text{GeV} < m_{Hl}^i < 1\text{TeV}$ ,  $\theta_{ij}^l, \delta_{ij}^l$ : arbitrary



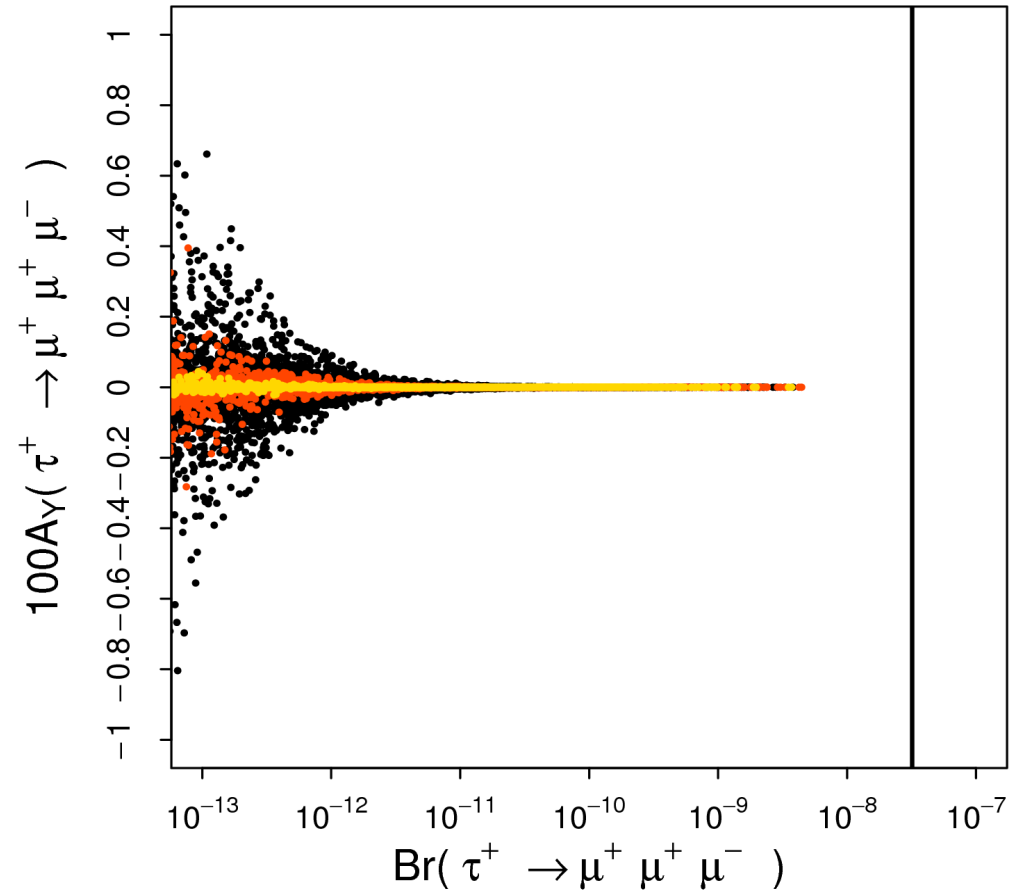
LHT ( $f = 500\text{GeV}$ ,  $m_{Hq}^i = 500\text{GeV}$ ,  $100\text{GeV} < m_{Hl}^i < 1\text{TeV}$ ,  $\theta_{Hl}^i, \phi_{Hl}^i$ : arbitrary)



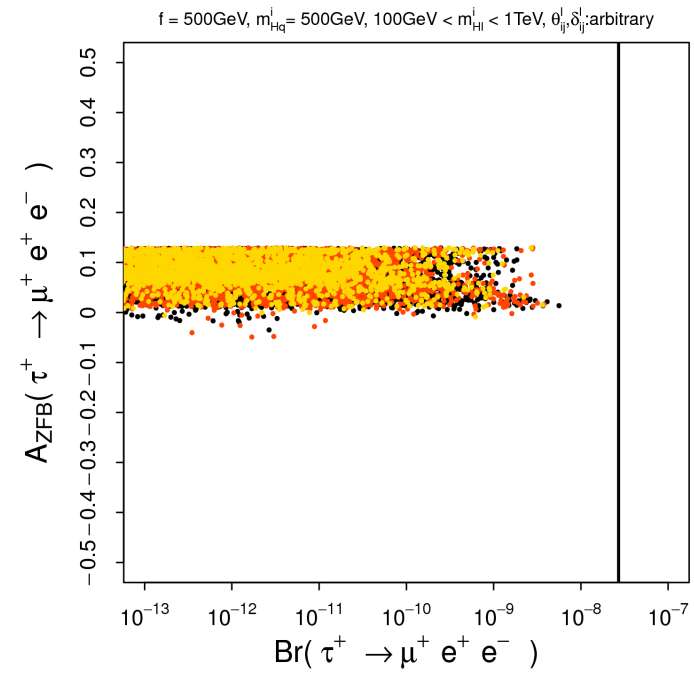
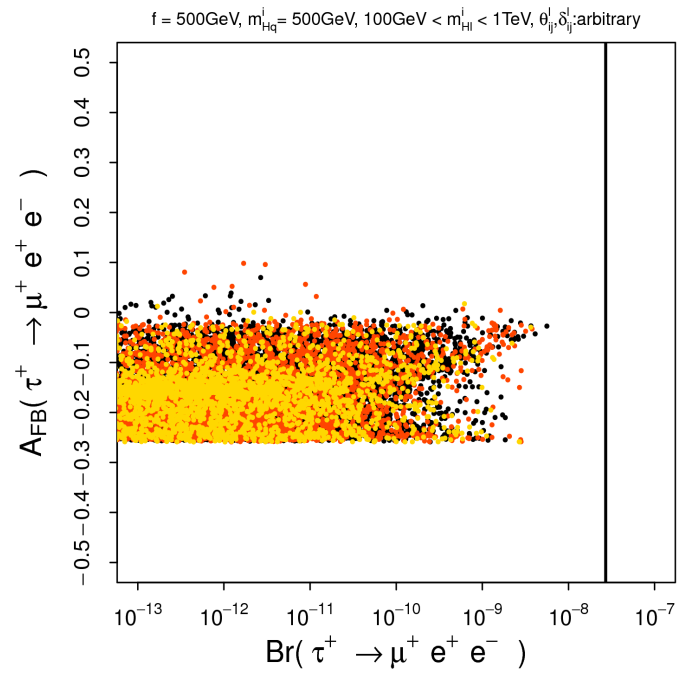
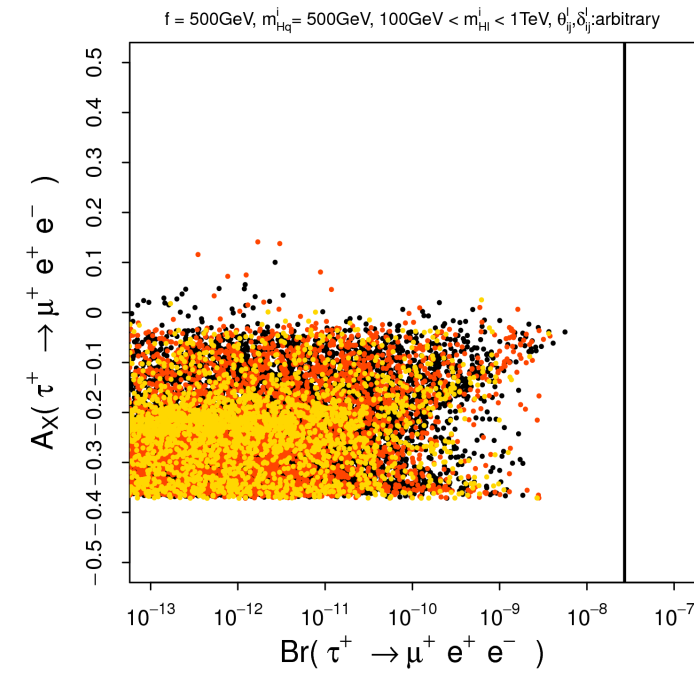
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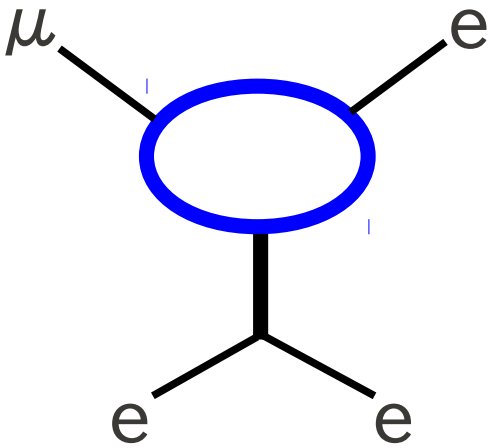
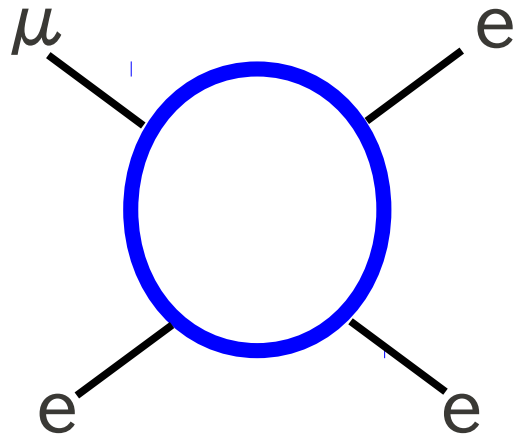
$f = 500\text{GeV}$ ,  $m_{Hq}^i = 500\text{GeV}$ ,  $100\text{GeV} < m_{Hl}^i < 1\text{TeV}$ ,  $\theta_{ij}^l, \delta_{ij}^l$ : arbitrary



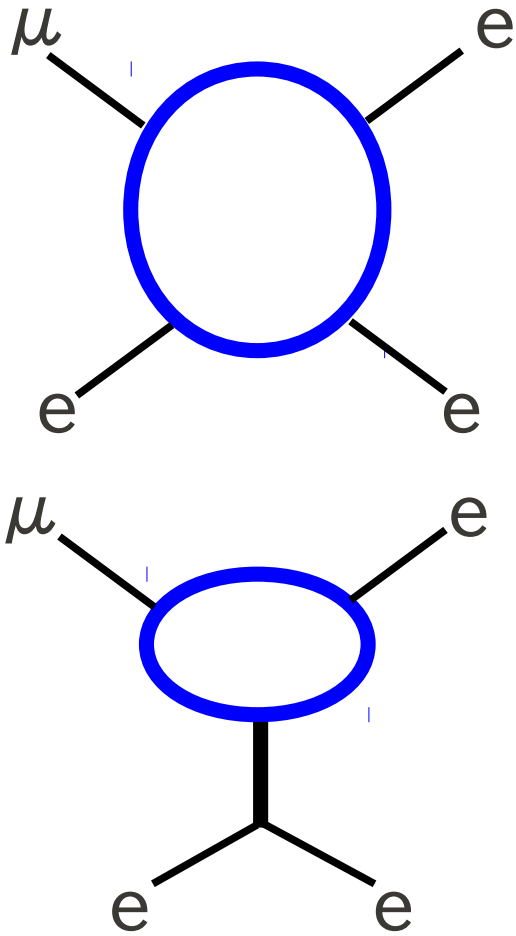
$$A_X(\tau^+ \rightarrow \mu^+ e^+ e^-) : A_{FB} : A_{Z,FB} = -\frac{4\pi}{35} : -\frac{1}{4} : \frac{1}{8}.$$



# Process x Model



LFV x Model



T-even

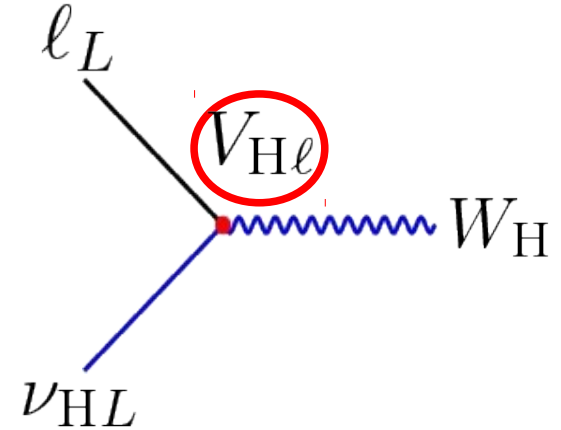
$\gamma$   $W^\pm$   $Z$   $h$   
 $\nu_i$   $e_i$   $u_i$   $d_i$   $T_+$

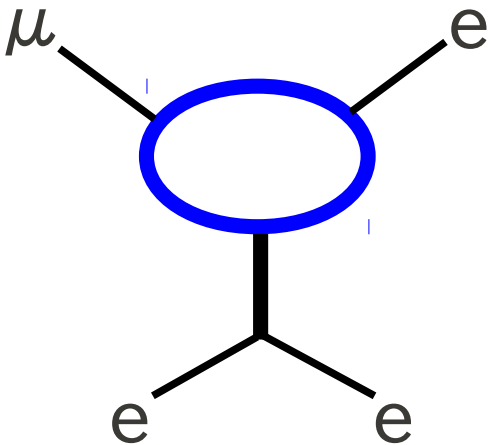
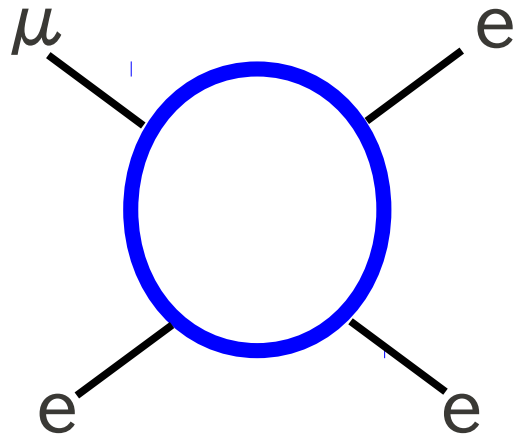
$V_{Hu}$   $V_{Hd}$   
 $V_{H\nu}$   $V_{H\ell}$

T-odd

$A_H$   $W_H^\pm$   $Z_H$   $\Phi$   
 $\nu_{Hi}$   $e_{Hi}$   $u_{Hi}$   $d_{Hi}$   $T_-$

LFV x LHT





T-even

- $\gamma$
- $W^\pm$
- $Z$
- $h$
- $\nu_i$
- $e_i$
- $u_i$
- $d_i$
- $T_+$

- $V_{Hu}$
- $V_{Hd}$
- $V_{H\nu}$
- $V_{H\ell}$

T-odd

- $A_H$
- $W_H^\pm$
- $Z_H$
- $\Phi$
- $\nu_{Hi}$
- $e_{Hi}$
- $u_{Hi}$
- $d_{Hi}$
- $T_-$

LFV x LHT

+ Asymmetry

