Tau & Charm Physics

Toru Iijima

Nagoya University

November 7, 2009

HEC sub-committee for future planning

Talk Outline

- Charm Physics
- Tau Physics
- Run (machine) at tau-charm threshold ?

Super B factory is also

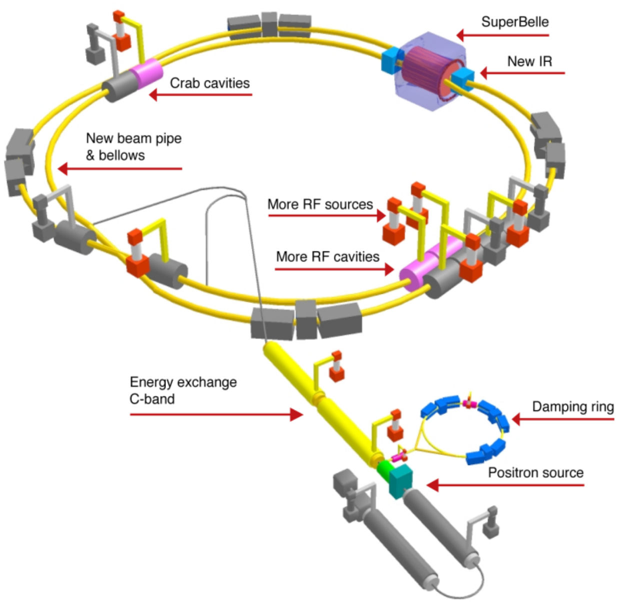
$$\sigma(e^+e^- \to B\bar{B}) \approx 1.1\text{nb}$$

Super Tau factory

$$\sigma(e^+e^- \to \tau^+\tau^-) \approx 0.91\text{nb}$$

Super Charm factory

$$\sigma(e^+e^- \to c\bar{c}) \approx 1.3\text{nb}$$

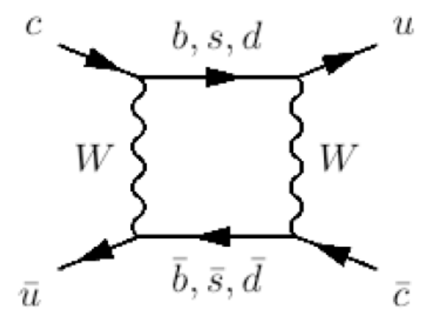


Physics with O(10^{10}) τ and charm / year

Target of Charm Physics 1

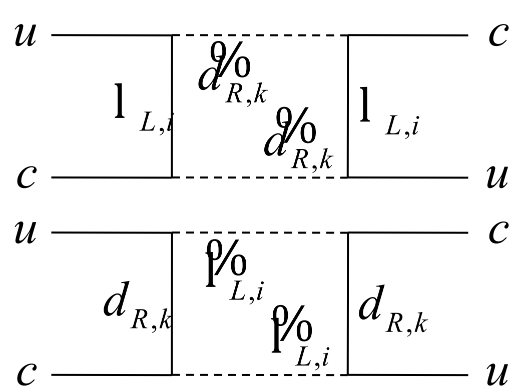
NP Search: DD-mixing and CPV

- Tiny in SM $O(10^{-2}) \to O(10^{-3})$
  - GIM cancellation $(m_s - m_d)/m_W \to 0$
  - Double Cabibbo suppressed $\sim \sin^2\theta_C$
  - CPV from phase of V_{cs} $\sim \eta A^2 \lambda^4 \sim O(10^{-3})$

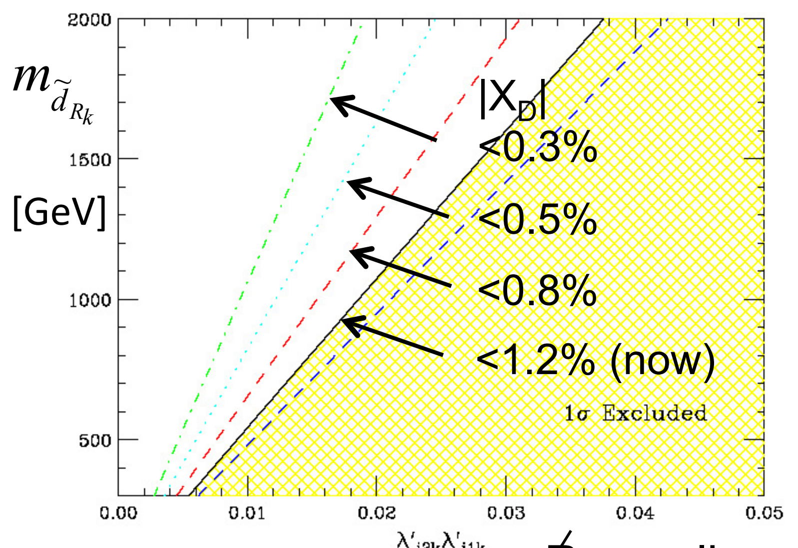


- If larger than expected → signal of NP
  - Unique probe for NP coupling to up-type quarks.

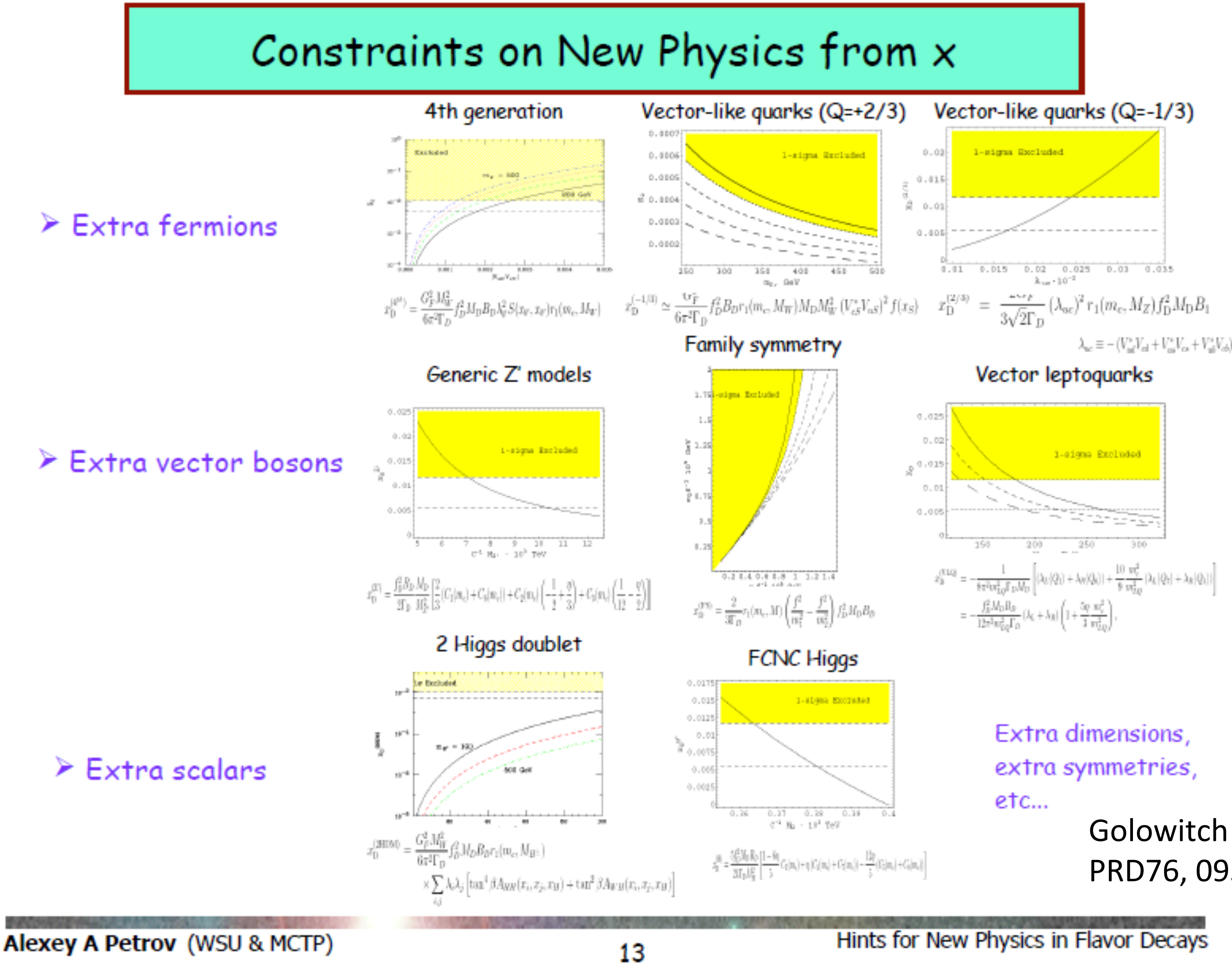
Example:
R-violating SUSY



Golowitch et al. PRD76, 095009 (2007)



NP and D-D mixing



Golowitch et al.
PRD76, 095009 (2007)

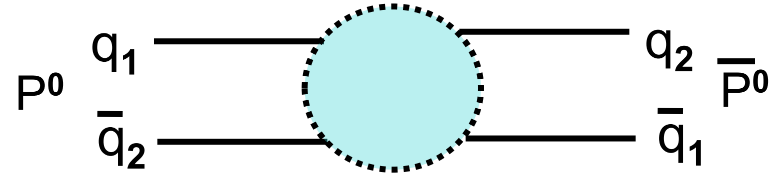
Phenomenology

- Time evolution by flavor states ≠ H_{eff} eigenstates:

(defined flavour) (defined $m_{1,2}$ and $\Gamma_{1,2}$)

$$\left|D_{1,2}\right\rangle = p\left|D^0\right\rangle \pm q\left|\overline{D}^0\right\rangle$$

$$x \equiv \frac{m_1 - m_2}{\Gamma}, \quad y \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$



$P^0 = K^0$, B_d^0, B_s^0 and D^0

$$\Rightarrow \left|D^0(t)\right\rangle = \left[\left|D^0\right\rangle \cosh\left(\frac{ix+y}{2}\overline{\Gamma}t\right) - \frac{q}{p}\left|\overline{D}^0\right\rangle \sinh\left(\frac{ix+y}{2}\overline{\Gamma}t\right)\right] e^{-i\overline{m}t - \frac{\overline{\Gamma}}{2}t}$$

$$\frac{dN(D^0 \to f)}{dt} \propto e^{-\overline{\Gamma}t}\left|\left\langle f\middle|D^0\right\rangle + \frac{q}{p}\frac{ix+y}{2}\left\langle f\middle|\overline{D}^0\right\rangle\right|^2$$

Decay time distribution of states accessible to D^0, D^0 is sensitive to x and y.

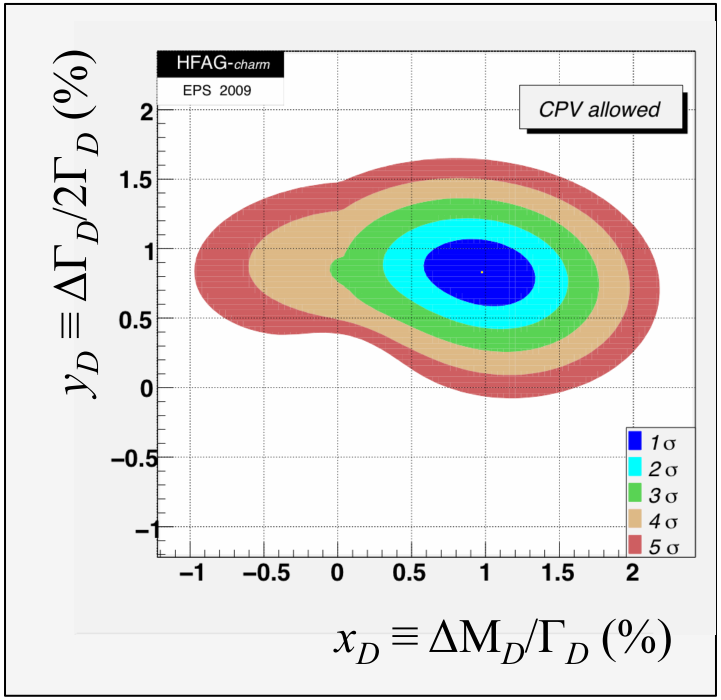
Measurements of D-D mixing

3 approaches

- Decays to CP eigen states:

  $D^0 \rightarrow K^+K^-/\pi^+\pi^-$ .vs. $K^-\pi^+$

- Wrong sign decays: $D^0 \rightarrow K^-\pi^+$
- Time-dep. Dalitz : $D^0 \rightarrow K^-\pi^-\pi^0$, $K_S\pi^+\pi^-$

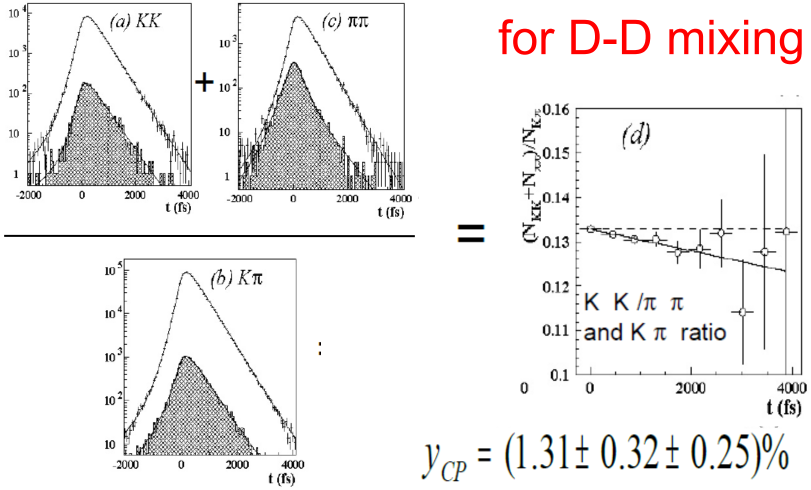


$$y_{CP} = y\cos\phi - \frac{A_M}{2} x\sin\phi$$

$$A_\Gamma = \frac{\tau(\bar{D}^0 \rightarrow K^-K^+) - \tau(D^0 \rightarrow K^+K^-)}{\tau(\bar{D}^0 \rightarrow K^-K^+) + \tau(D^0 \rightarrow K^+K^-)}$$

$$= \frac{A_M}{2} y\cos\phi - x\sin\phi$$

Belle, PRL 98, 211803 (2007), 540fb^{-1}



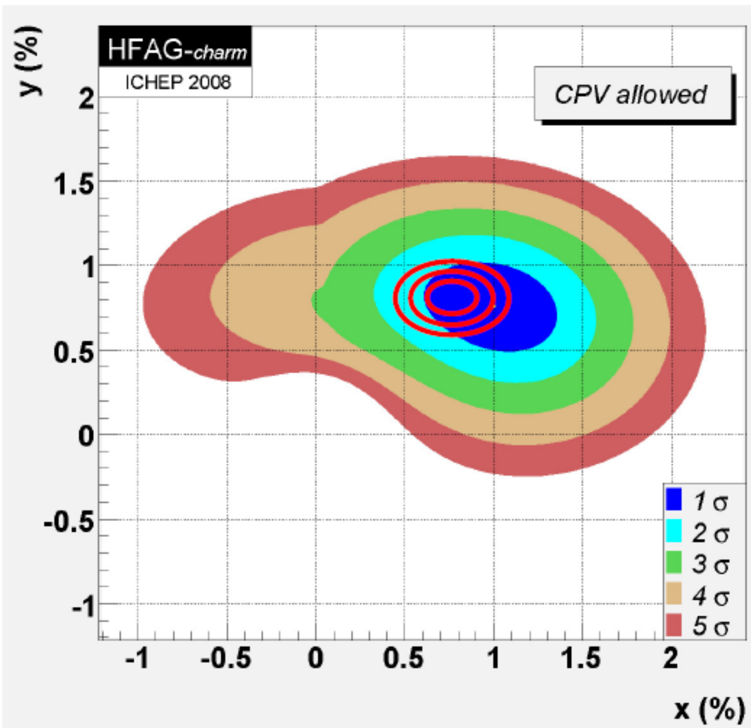
Evidence for D-D mixing !

$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$$

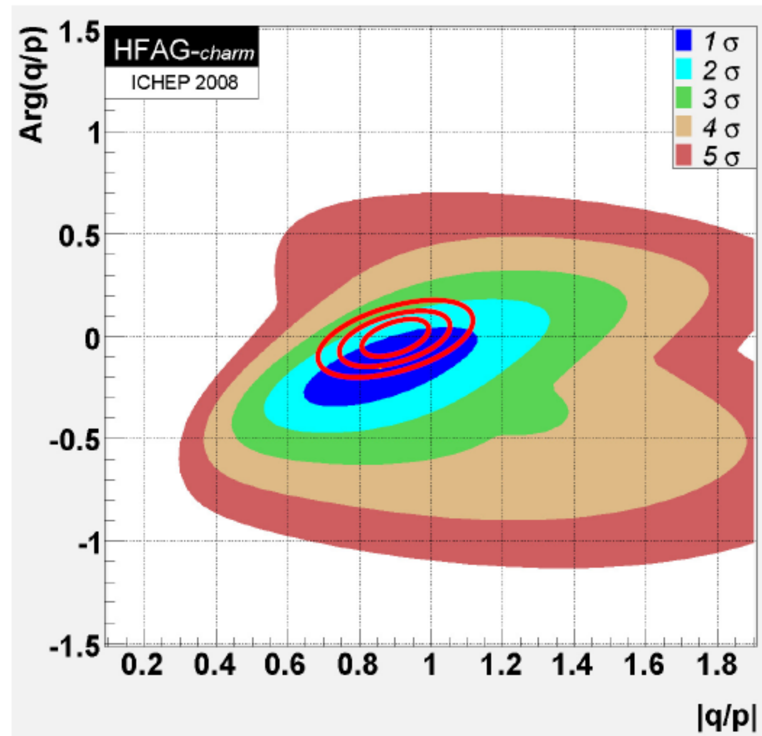
$$A_\Gamma = (0.01 \pm 0.30 \pm 0.15)\%$$

Prospect at Belle II

Expected constraints with $50ab^{-1}$



1, 2, 3 σ @ 50 ab

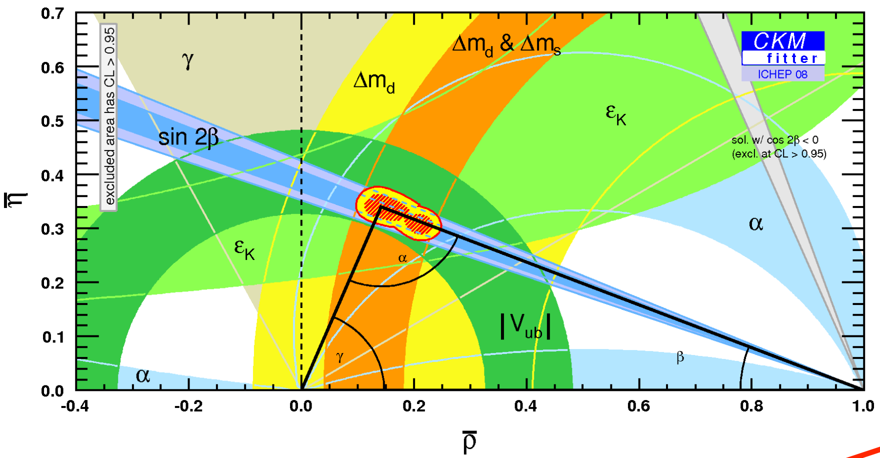


$\delta x = \pm 0.087\%$ (current:±0.25)
$\delta y = \pm 0.062\%$ (±0.18)
$\delta R_D = \pm 0.001\%$ (±0.01)

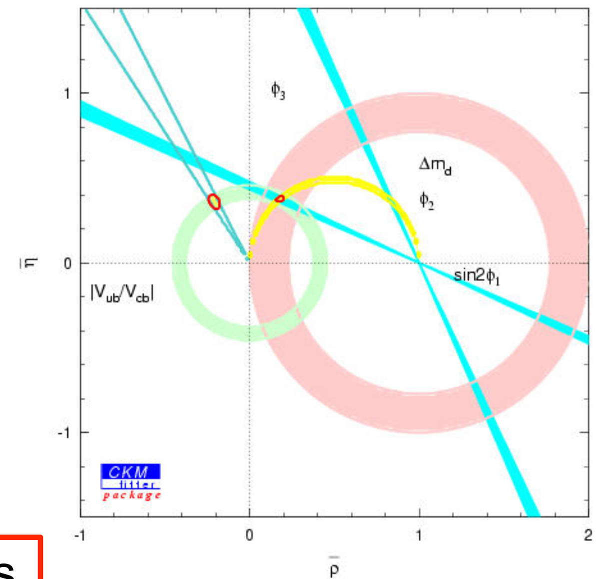
$\delta A_D = \pm 0.3\%$ (±2.4)
$\delta|q/p| = \pm 0.055$ (±0.16)
$\delta\phi = \pm 2.8°$ (±7.5°)

Target of Charm Physics 2

Precision CKM to over constrain NP together with B



Our dream



Not automatically reached by increasing the statistics

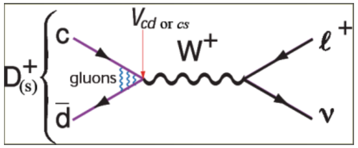
Need good understanding for fundamental parameters calculated by lattice QCD

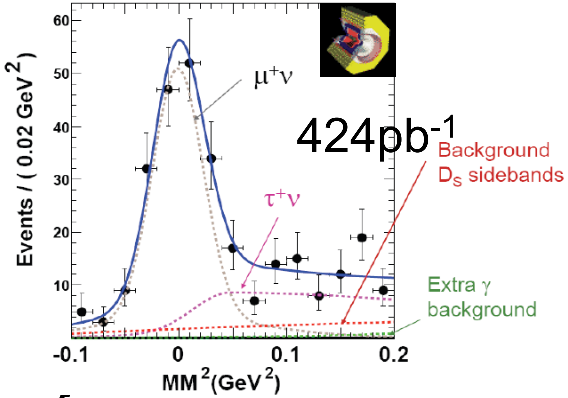
- B decay constant f_B
  V_{td} by B-B mixing, V_{ub} (or $H^{\pm}$)by $B\rightarrow\tau\nu$
- $B\rightarrow\pi$ form factor $f_{B\rightarrow\pi}$
  V_{ub} by $B\rightarrow\pi l \nu$

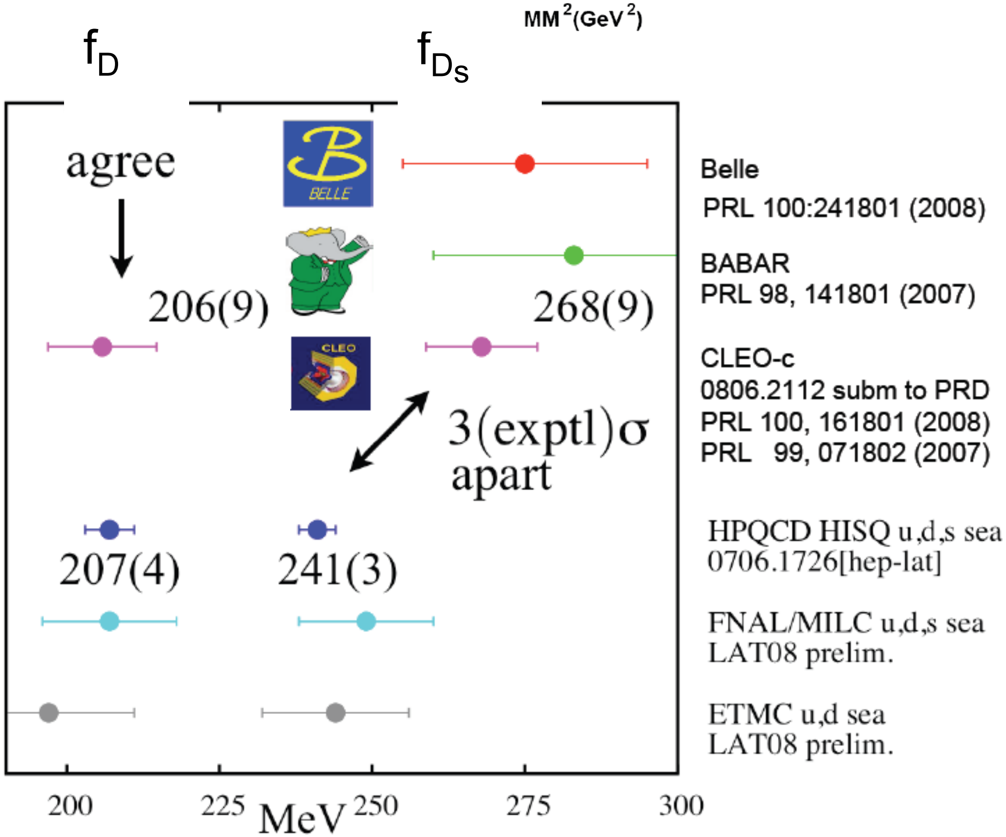
Precise measurements in D decays as calibration of lattice QCD

- f_D by $D\rightarrow\mu\nu$
- $f_{D\rightarrow\pi}$ by $D\rightarrow\pi l \nu$

D decay constant f_D / f_D







B→τ ν

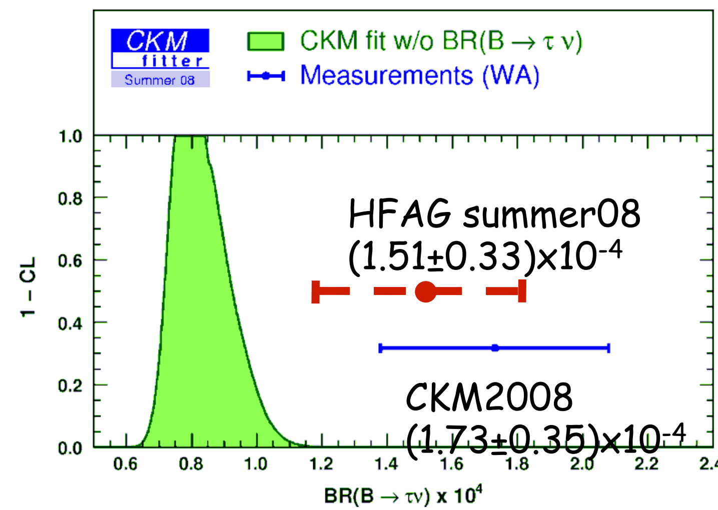
$$\mathcal{B}(B^- \to \ell^-\bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$Br_{SM}(\tau\nu) = [1.20 \pm 0.25] \times 10^{-4}$$

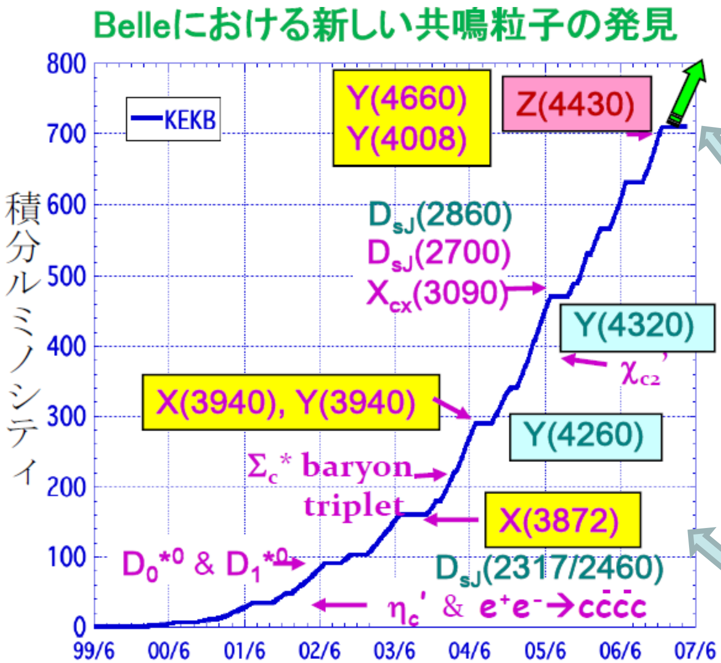
Based on fB from HPQCD and $|V_{ub}|$ from HFAG (BLNP, ICHEP08)

$$Br(\tau\nu)_{fit} = (0.786^{+0.179}_{-0.083}) \times 10^{-4}$$

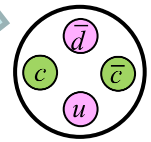
Based on CKM fitter
(τν is not included in the fit)

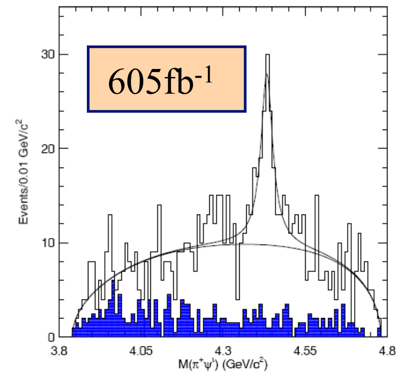


Target of Charm Physics - 3

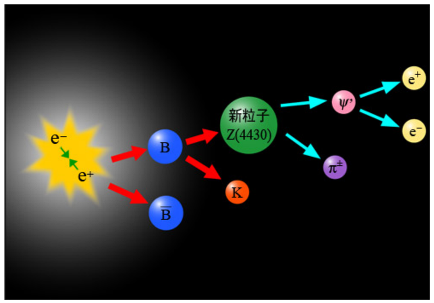


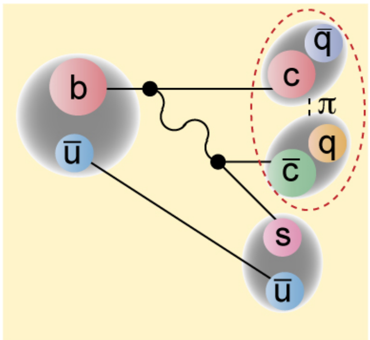
Z (4430)
荷電粒子



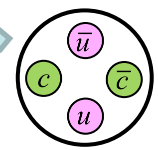


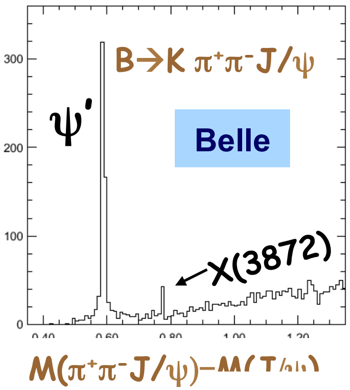
生成プロセス



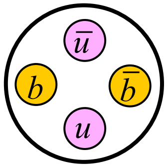


X (3872)
中性粒子





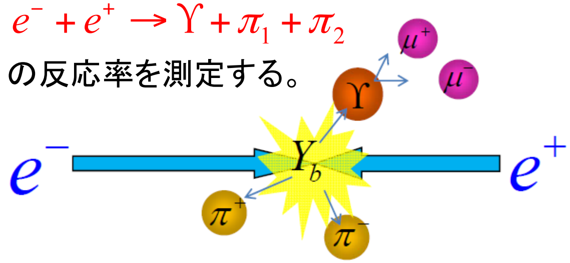
Y_b (10890)　　2008年8月
ボトムクォークを含んだエキゾチックハドロンの候補

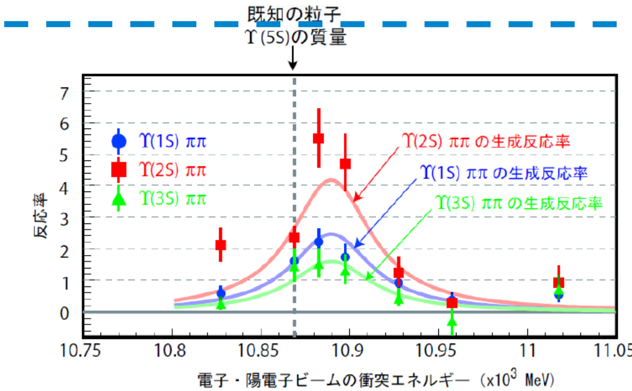


電子・陽電子の衝突エネルギーを変えながら、

$e^- + e^+ \rightarrow \Upsilon + \pi_1 + \pi_2$

の反応率を測定する。

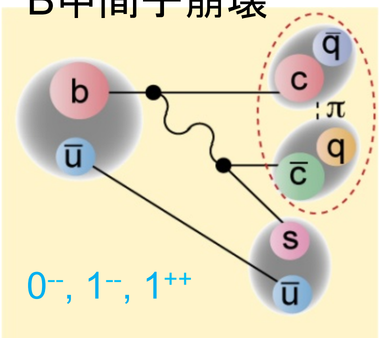




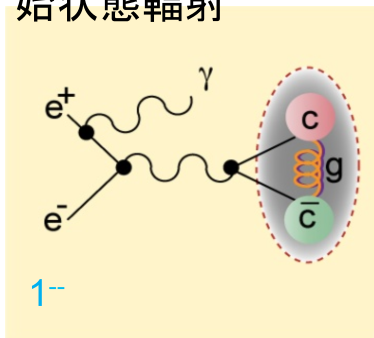
エキゾチックハドロン @ Belle II

- 様々な生成過程

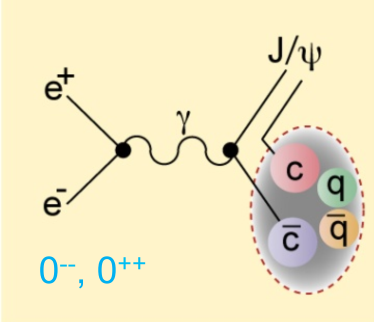
B中間子崩壊



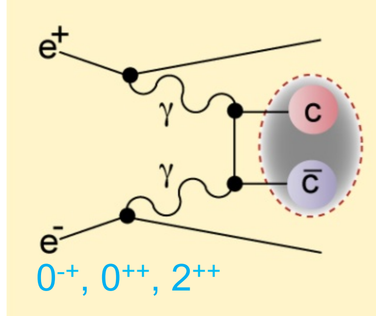
始状態輻射



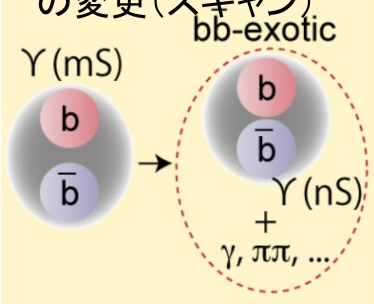
ダブルcc生成



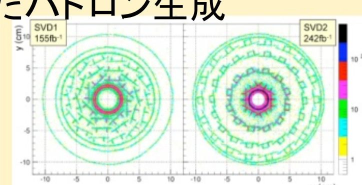
二光子衝突



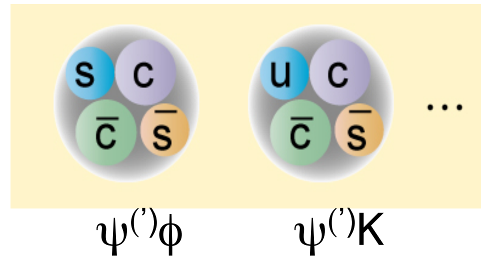
ビームエネルギーの変更(スキャン)



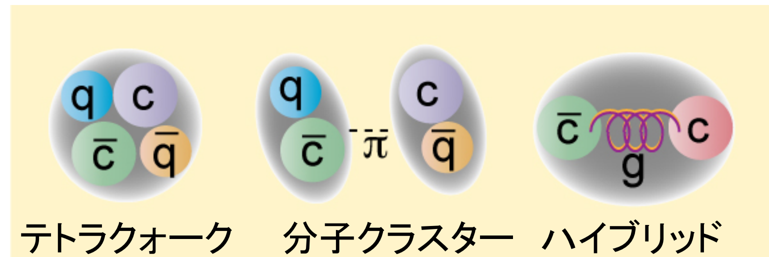
検出器物質を標的としたハドロン生成



新たなエキゾチック状態の探索



見つかった新粒子の性質(崩壊モード、スピン、パリティ)を測定し、状態の特定・理解を進める。



Super B-Factory では

新たなエキゾチックハドロン状態の探索(ccus、bbud など)。

エキゾチックハドロンの属性(スピン、パリティー)の測定。

Why do we want to study τ decays ?

τ = the heaviest lepton in the 3rd gen.

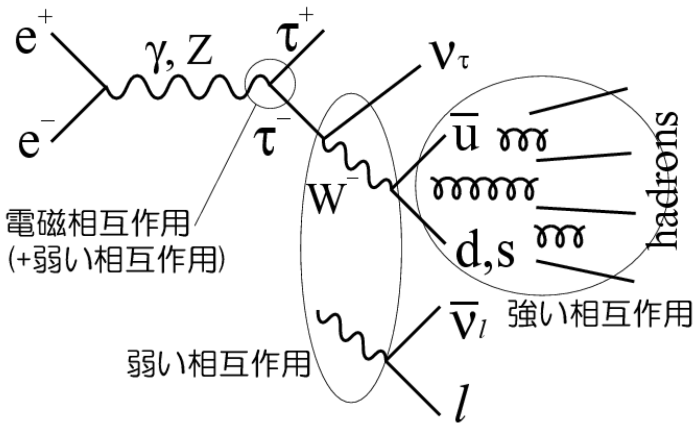
[m=1776.84±0.17 MeV/c^2, τ=(290.6±1.0)x10^{-15}s]

- Many physics involved in the production and decays.

  Goof probe for
  - Electromagnetic interaction
  - Weak interaction
  - Strong interaction

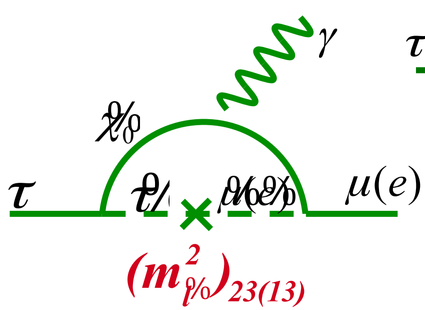
  Small theory errors

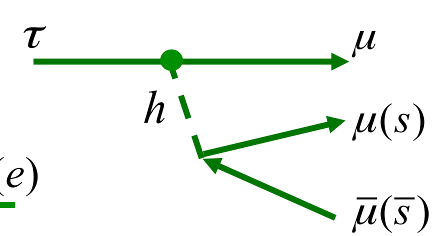
  Experimental sensitivity not limited by theory errors



And,

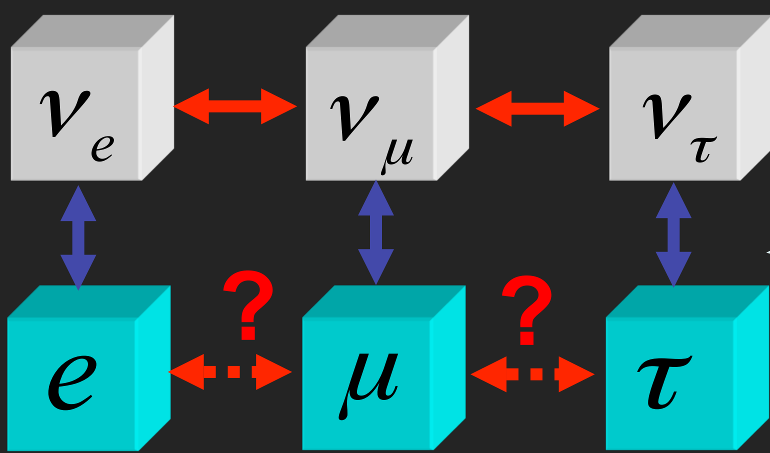
- Sensitive to New Physics
  - **Lepton Flavor Violation**
  - CP violation, EDM, lepton universality



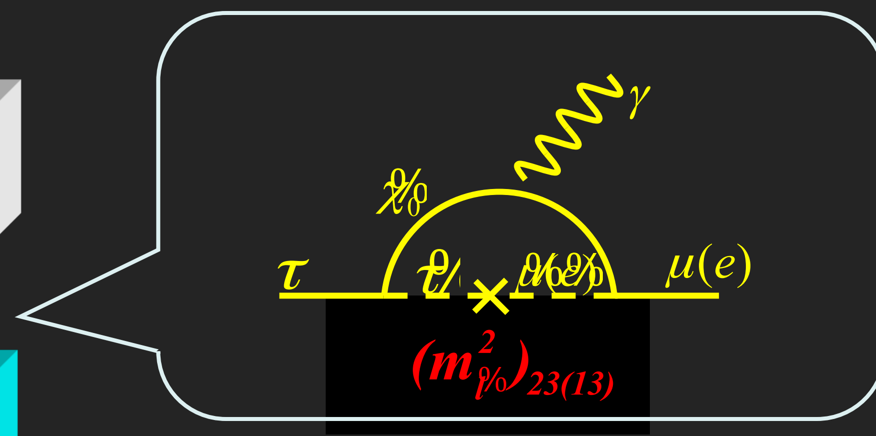


Lepton Flavor Violation

Quarks have flavor mixing.
Neutrino mixing has been found.
What about charged leptons ?



(Original figure by Dr. Kuno / Osaka Univ.)



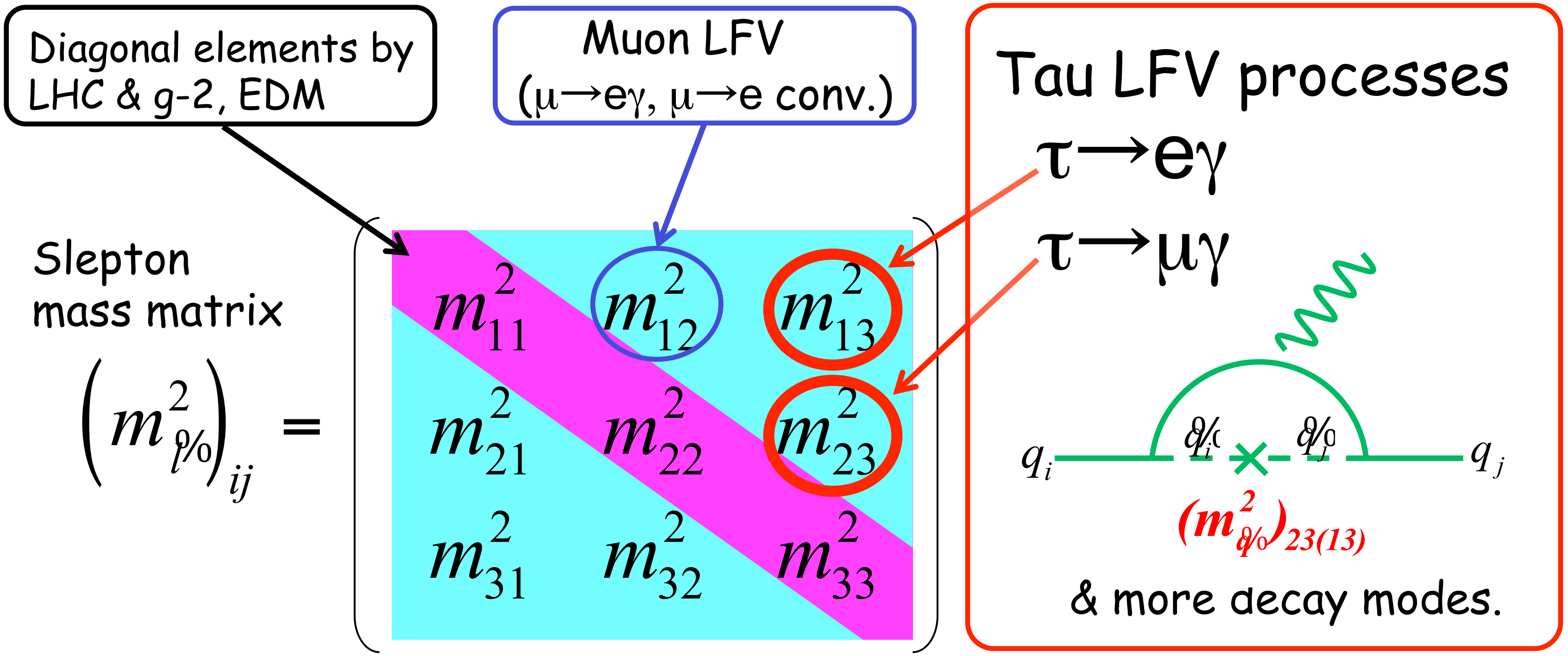
τ decays probe mixings between 3⇔2 and 3⇔1 generations.

B factory is also a tau factory

Role of LFV in τ decays

- In case of SUSY, LFV processes are induced by off-diagonal elements of the slepton mass matrix.

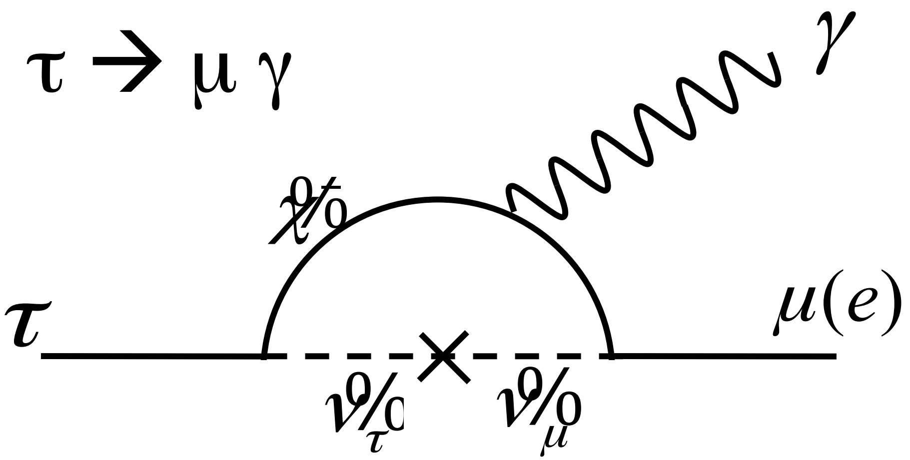
Sensitive to the SUSY breaking mechanism



LFV in τ decays probes NP flavor mixing bet. 3⇔1, 3⇔2 generations.

LFV in τ decays with NP

$\tau \rightarrow \mu \gamma$



In SM, negligibly small even including neutrino oscillation.

$$Br(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=1,2} U^*_{\tau i} U_{\mu i} \frac{\Delta m^2_{li}}{m^2_w}\right|^2 < 10^{-54}$$

U : MNS neutrino mixing matrix

$\Delta m^2_{ij} = m^2_{\nu i} - m^2_{\nu j}$

:Neutrino mass square difference

Example: SUSY + Seasaw (J.Hisano et. al., PRD60 (1999) 055008)

$$Br(\tau \to \mu\gamma) ; \ 3.0\times10^{-7} \times \left(\frac{\tan\beta}{60}\right)^2 \left(\frac{1\,TeV}{m_{SUSY}}\right)^4$$

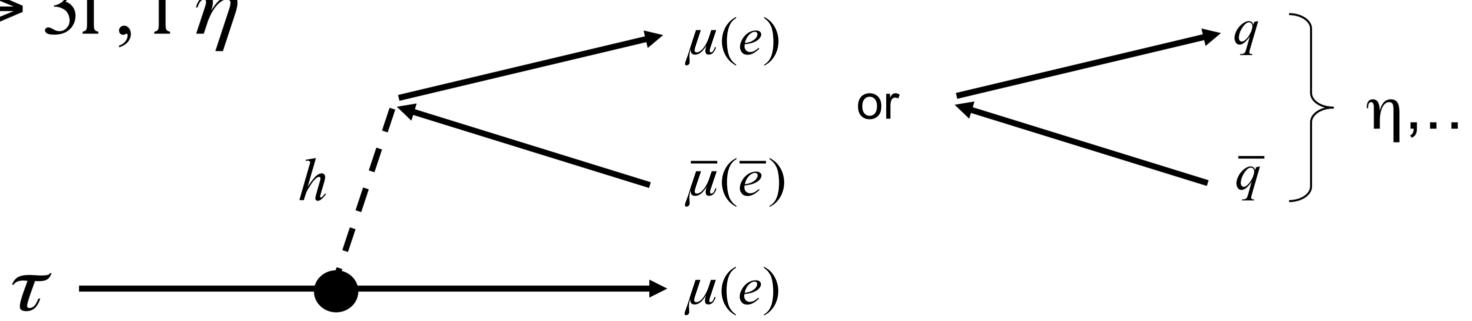
➡ $Br(\tau \rightarrow \mu\gamma) = O(10^{-7\sim9})$

- Many extensions of the SM predict LFV decays.
- Their branching fractions are enhanced as high as current and near future experimental sensitivity .

LFV is a clear signature of NP, if observed.

LFV in Higgs mediated model

$\tau \to 3l, l\eta$



These decays become important when sleptons are much heavier than weak scale

- τ→3μ (A.Brignole, A.Rossi, PLB 566 (2003) 217)

$$\mathcal{B}(\tau \to 3\mu) \sim 10^{-7} \left(\frac{\tan\beta}{50}\right)^6 \left(\frac{100\ \mathrm{GeV}/c^2}{m_A}\right)^4 \left(\frac{|50\Delta_L|^2 + |50\Delta_R|^2}{10^{-3}}\right)$$

- τ→μη (M.Sher, PRD 66 (2002) 057301)

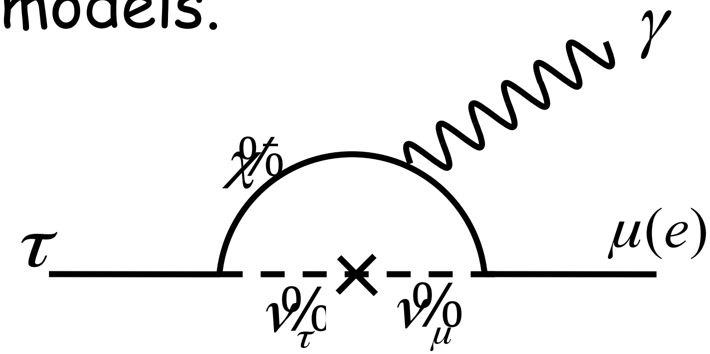
$$\mathcal{B}(\tau \to \mu\eta) \simeq 8.4 \times 10^{-7} \left(\frac{\tan\beta}{60}\right)^6 \left(\frac{100\ \mathrm{GeV}/c^2}{m_A}\right)^4$$

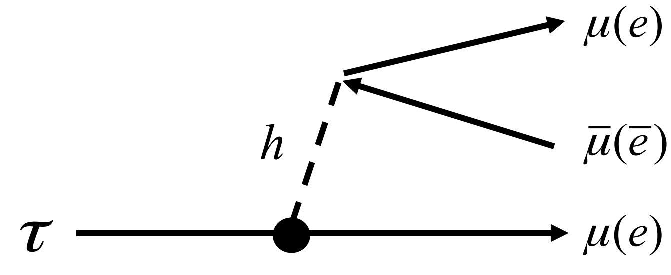
$\tau \to \mu\eta$ may be enhanced.

$$Br(\tau \to \mu\eta) : Br(\tau \to 3\mu) : Br(\tau \to \mu\gamma) :\ 8.4:1:1.5$$

NP signature in $\tau \to l\gamma, lll$

- The two decays have different sensitivity for different NP models.





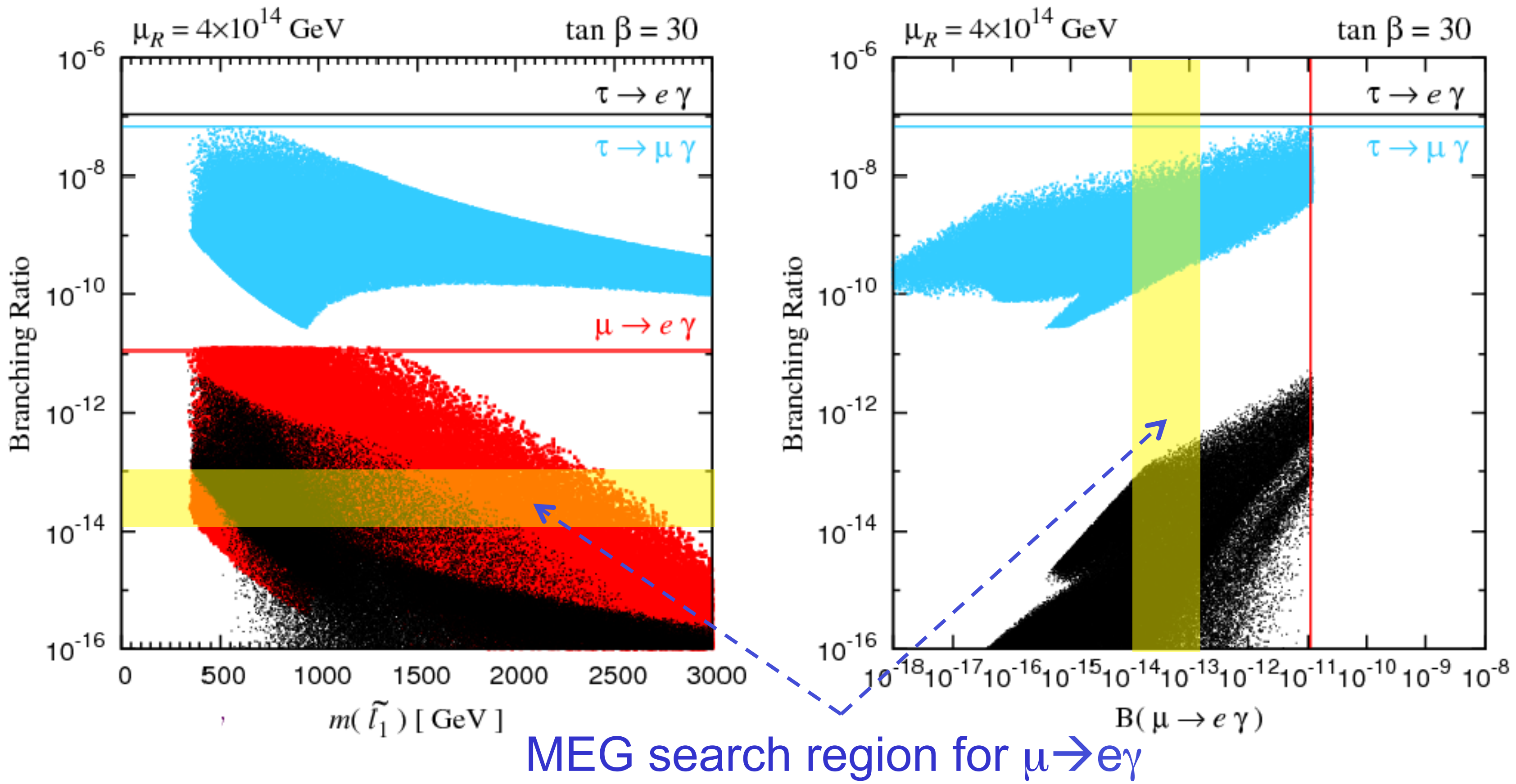
	Reference	τ◊μγ	τ◊μμμ
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}

Searches in various LFV modes help to discriminate NP models.

SUSY-GUT

Goto, Okada, Shindou & Tanaka
PRD77, 095010 (2008)

- SU(5)+ν_R, non-degenerate ν_R(I), normal Hierarchy



If MEG find $\mu \to e\gamma$ at ~10^{-13}, good chance to see also $\tau \to \mu\gamma$ at $10^{-8 \to -10}$
Even if MEG does not, still important to search for $\tau \to \mu\gamma$.

Muon g-2 & τ→μγ

- 3.4 σ discrepancy found in the muon g-2.

$$\delta a_\mu^{NP} = a_\mu^{\exp} - a_\mu^{SM} = (27.6 \pm 8.1)\times 10^{-10}$$

Fix the mass scale

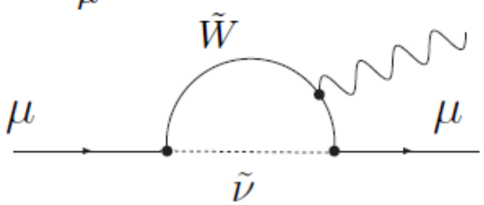
- Correlation to τ→μγ

$$BR(\tau \to \mu\gamma) \sim 10^{-8}\left(\frac{\delta a_\mu^{NP}}{10^{-9}}\right)\left(\frac{\theta_{\tau\mu}}{10^{-2}}\right)^2$$

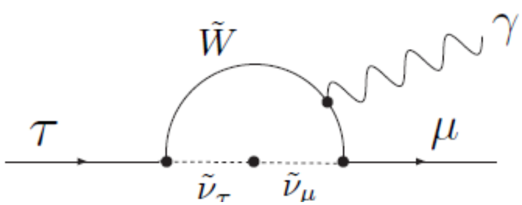
Their diagrams are similar except for the flavor mixing.

$$\frac{e}{2m_\mu}\delta a_\mu \bar{\mu}\sigma_{\alpha\beta}\mu F^{\alpha\beta}$$

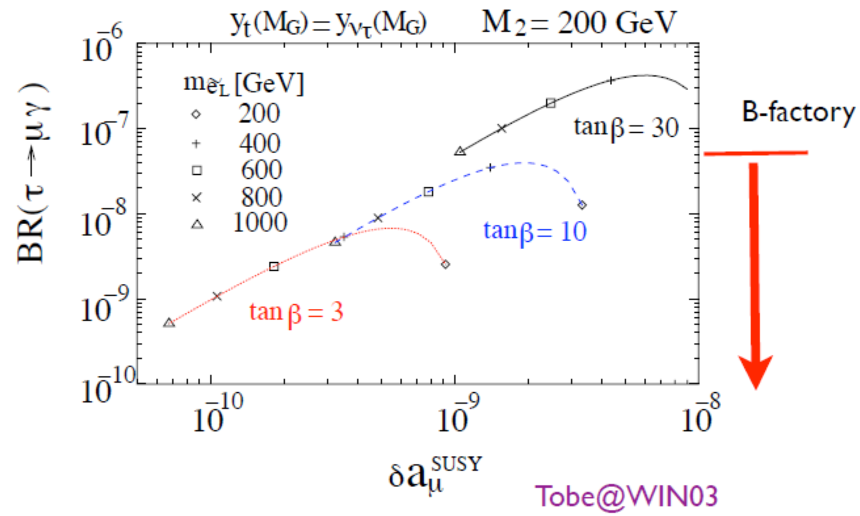
g-2



τ→μγ



SUSY + Seasaw



B-factoryで $\tau \to \mu\gamma$ が見つかっても不思議ではない

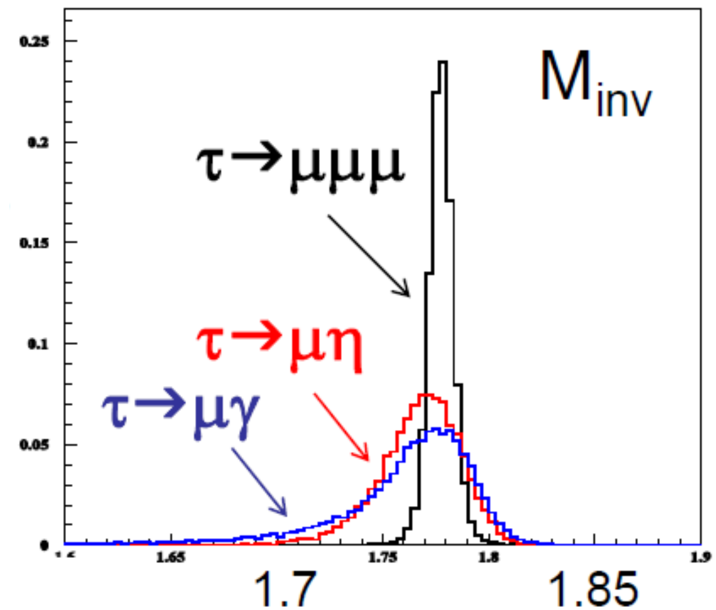
By Tobe-san at B physics WS in Hakone (Nov.2008)

Experiments

- LFV is forbidden in SM, therefore, very clear NP signal.
- Appearance is also very clear.

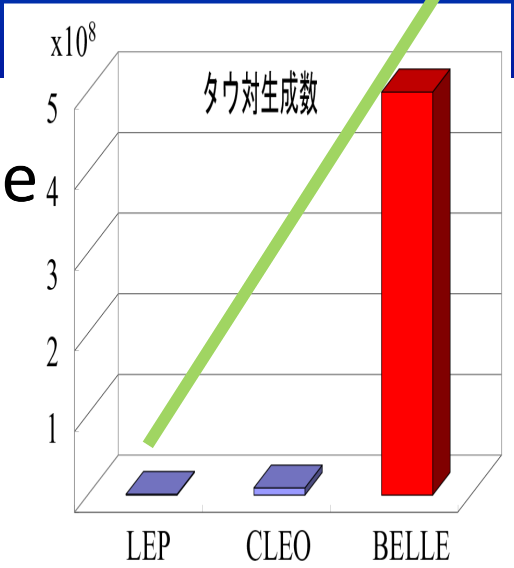
  Identified as a peak in M_{inv}.

- Considerations;
  - Statistics
  - Background
  - Resolution



Statistics

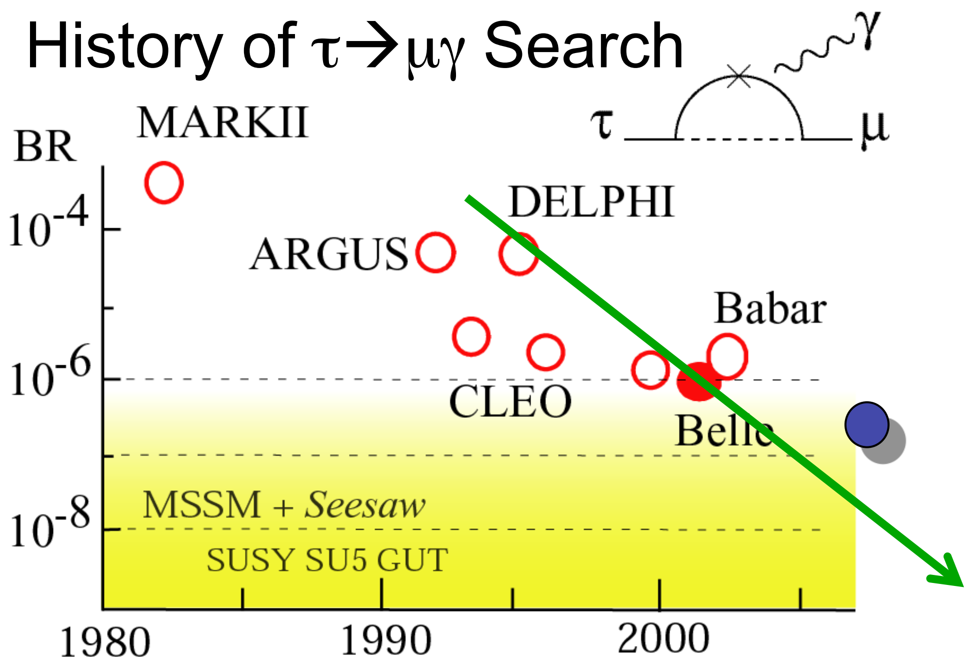
Much more at Super-KEKB !



- B-factory provides unprecedented large sample of τ leptons.

B-factory is τ-factory !

History of τ→μγ Search



Facility	# τ
CLEO	10^7
BES-III	10^8
B-factory	10^9
Super B factory	**10^{11}**

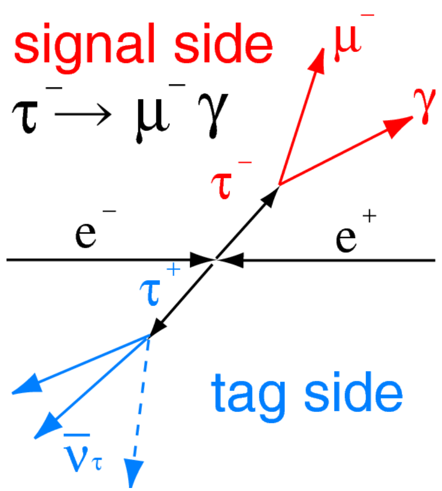
Super tau-charm (BINP) : a few x 10^{10} ($10^{35}cm^{-2}s^{-1}$)

(Super) B factories dominate the results

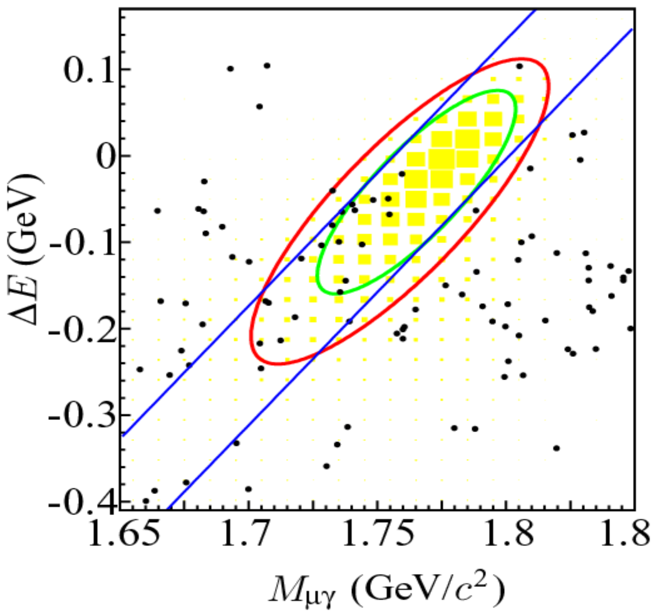
τ◊μγ, eγ

535 fb^{-1}

PLB666, 16(2008)

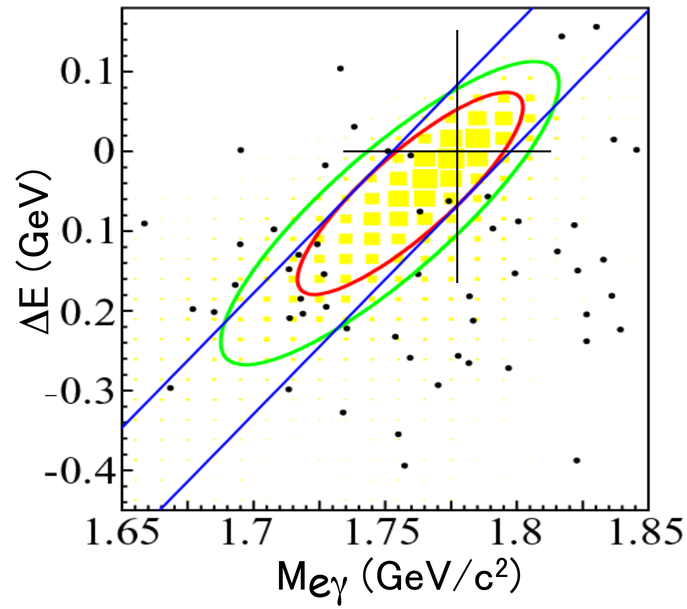


τ◊μγ



Br<4.5x10^{-8} at 90%C.L.

τ◊eγ



Br<1.2x10^{-7} at 90%C.L.

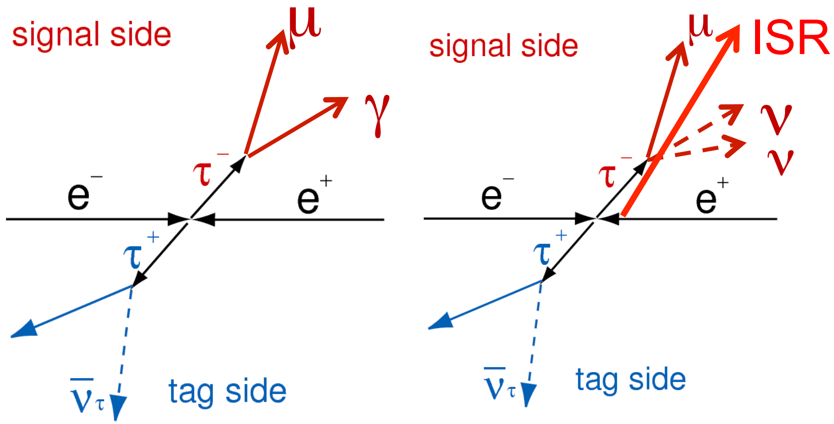
- Background: τ→μνν/eνν + ISR (or beam background)
- Small amount of μμ events in ΔE>0

$\tau \rightarrow \mu\gamma$ background

Background components

- $\tau^+\tau^-$

  Removed by missing mass vs P_{miss}.



Initial state radiation

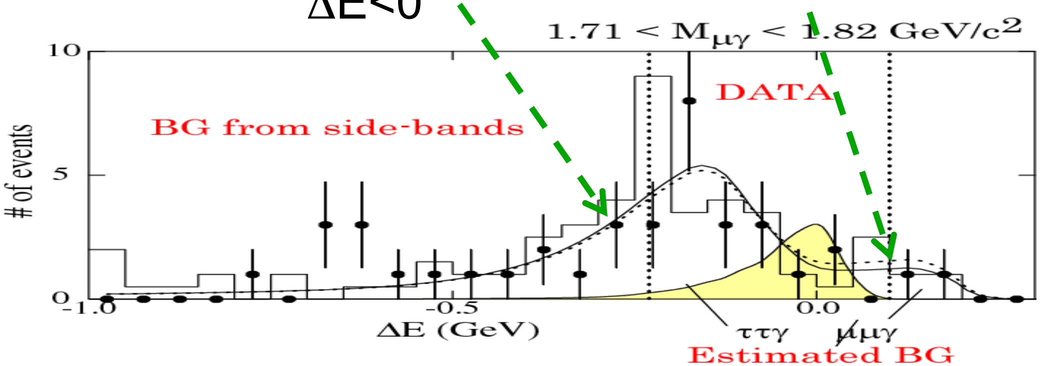
- $e^+e^- \rightarrow \tau^+\tau^-\gamma$ / $e^+e^- \rightarrow \mu^+\mu^-\gamma$

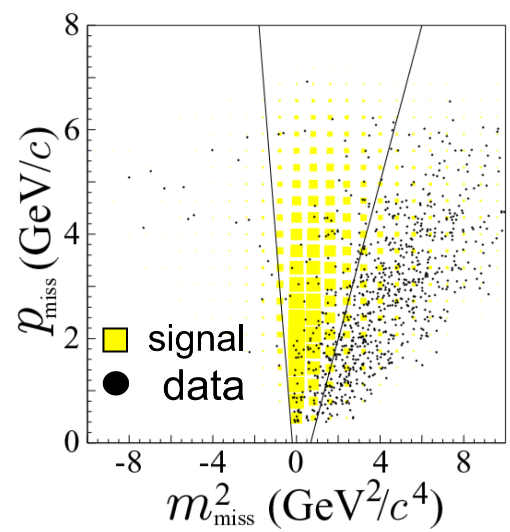
  ↳ $\mu\nu\nu$

Removed by requiring not μ for the tag side.

ΔE<0

15% of BG
ΔE>0

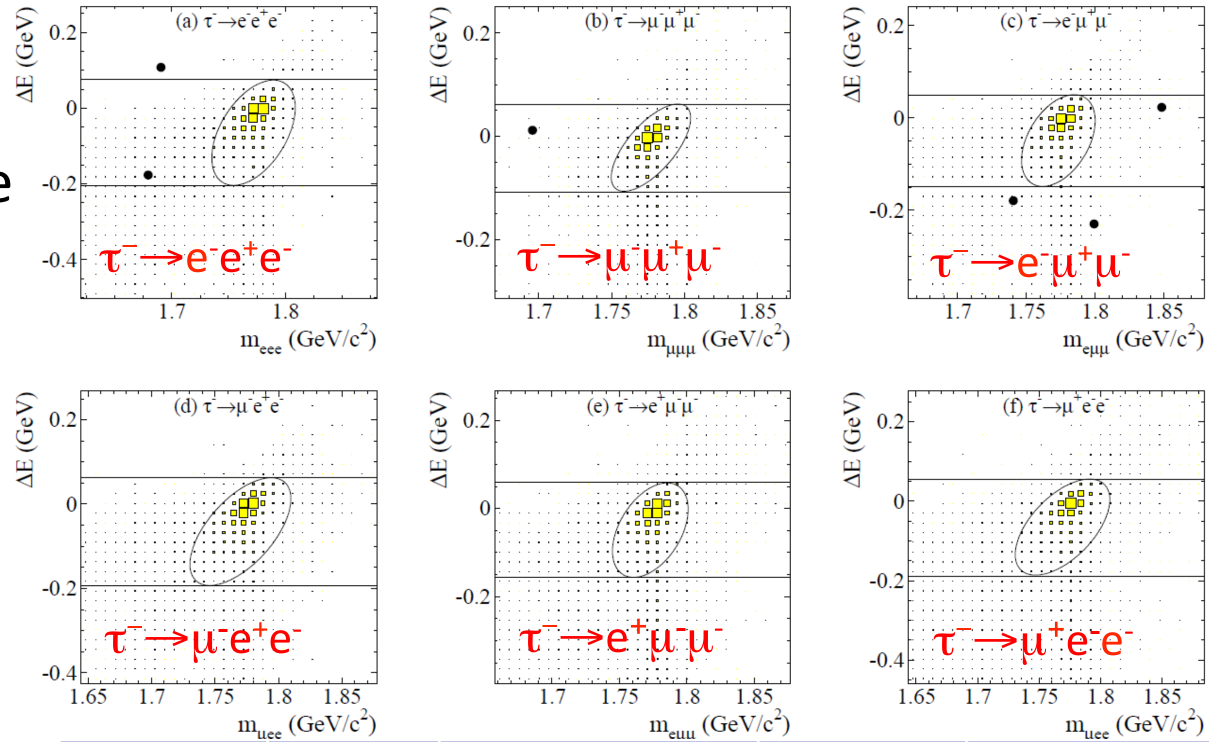




$\tau \rightarrow$ 3leptons from Belle

[EPS2009,Preliminary]

- Data: 782fb^{-1}
  - Prev.: 543fb^{-1}
- No event is found in the signal region.
- Dominant BG;
  Bhabha
  $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$
- $B<(1.5\text{-}2.7)\times10^{-8}$
  - Improved from (2.0-4.1) x10-8 @543fb-1



Mode	ε (%)	N_{BG}^{EXP}	σ_{syst} (%)	UL ($\times10^{-8}$)
$e^-e^+e^-$	6.0	0.21+-0.15	9.8	**2.7**
$\mu^-\mu^+\mu^-$	7.6	0.13+-0.06	7.4	**2.1**
$e^-\mu^+\mu^-$	6.1	0.10+-0.04	9.5	**2.7**
$\mu^-e^+e^-$	9.3	0.04+-0.04	7.8	**1.8**
$\mu^-e^+\mu^-$	10.1	0.02+-0.02	7.6	**1.7**
$e^-\mu^+e^-$	11.5	0.01+-0.01	7.7	**1.5**

The most stringent upper limits among LFV τ decays

Still a few background
→ Will be improved by $1/L_{int}$

$\tau \to l\eta, l\eta', l\pi^0$

Signal MC
• data

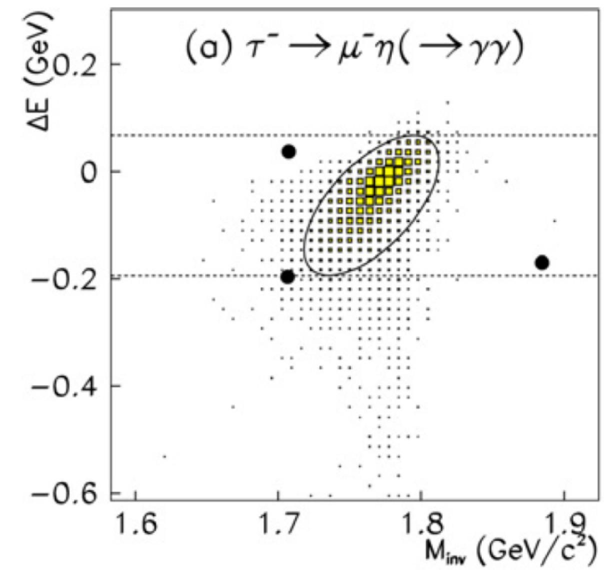
Belle

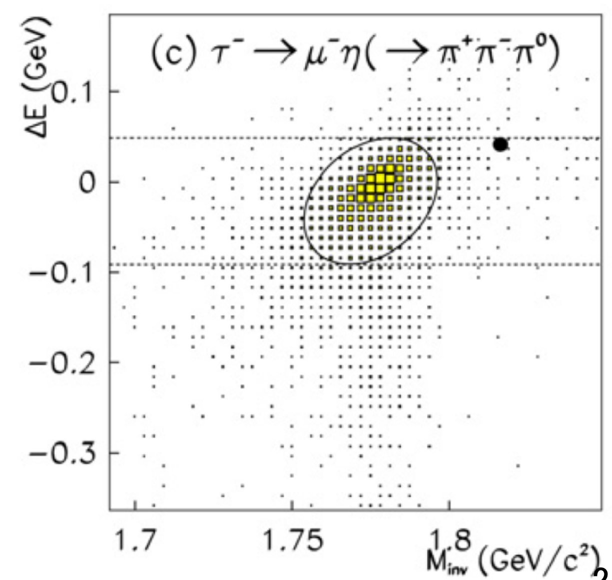
$\tau \to e/\mu + \eta, \eta', \pi^0$ @ 401fb^{-1}

(PLB648, 341 (2007))

$Br(\tau \to l\eta, l\eta', l\pi^0) < (6.5\text{-}16) \times 10^{-8}$ 90%C.L.

τ→	η/η’/ π⁰→	Eff(%)	N(exp)	N(obs)	N UL (90%CL)	Br UL (90%CL)	Combined
μη	$\pi^+\pi^-\pi^0$	6.8	0.24	0	2.2	20	6.5
	γγ	6.4	0.40	0	2.1	12	
eη	$\pi^+\pi^-\pi^0$	4.7	0.53	0	2.0	26	9.2
	γγ	4.6	0.25	0	2.2	17	
μh’	π+π-η	4.9	0	0	2.5	41	13
	ργ	5.4	0.23	0	2.2	19	
eh’	π+π-η	4.3	0	0	2.5	47	16
	ργ	4.8	0	0	2.5	25	
$\mu\pi^0$	γγ	4.5	0.58	1	3.8	12	
$e\pi^0$	γγ	3.9	0.20	0	2.2	8	

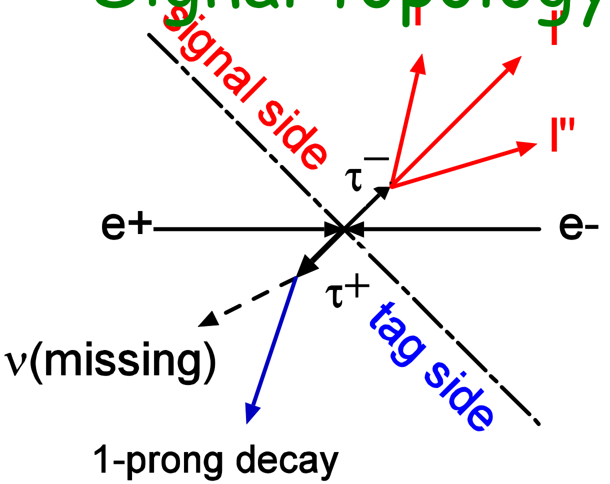




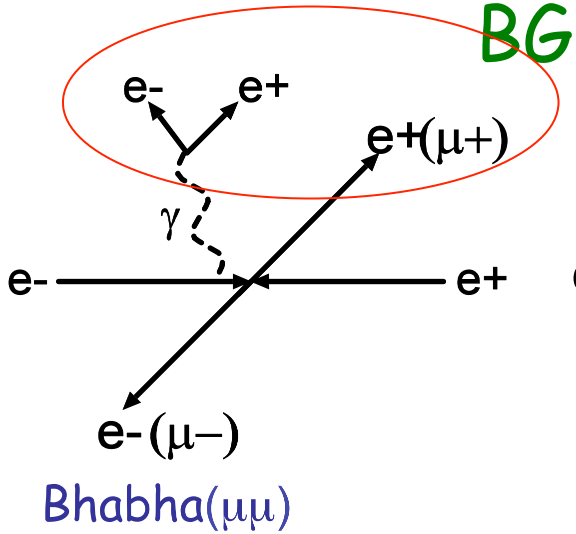
Only a few background
→ Will be improved by $1/L_{int}$

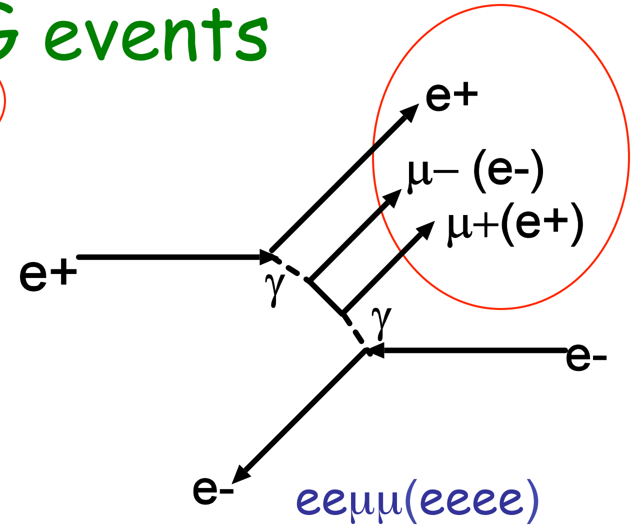
$\tau \rightarrow lll$: Background suppression

Signal topology



BG events





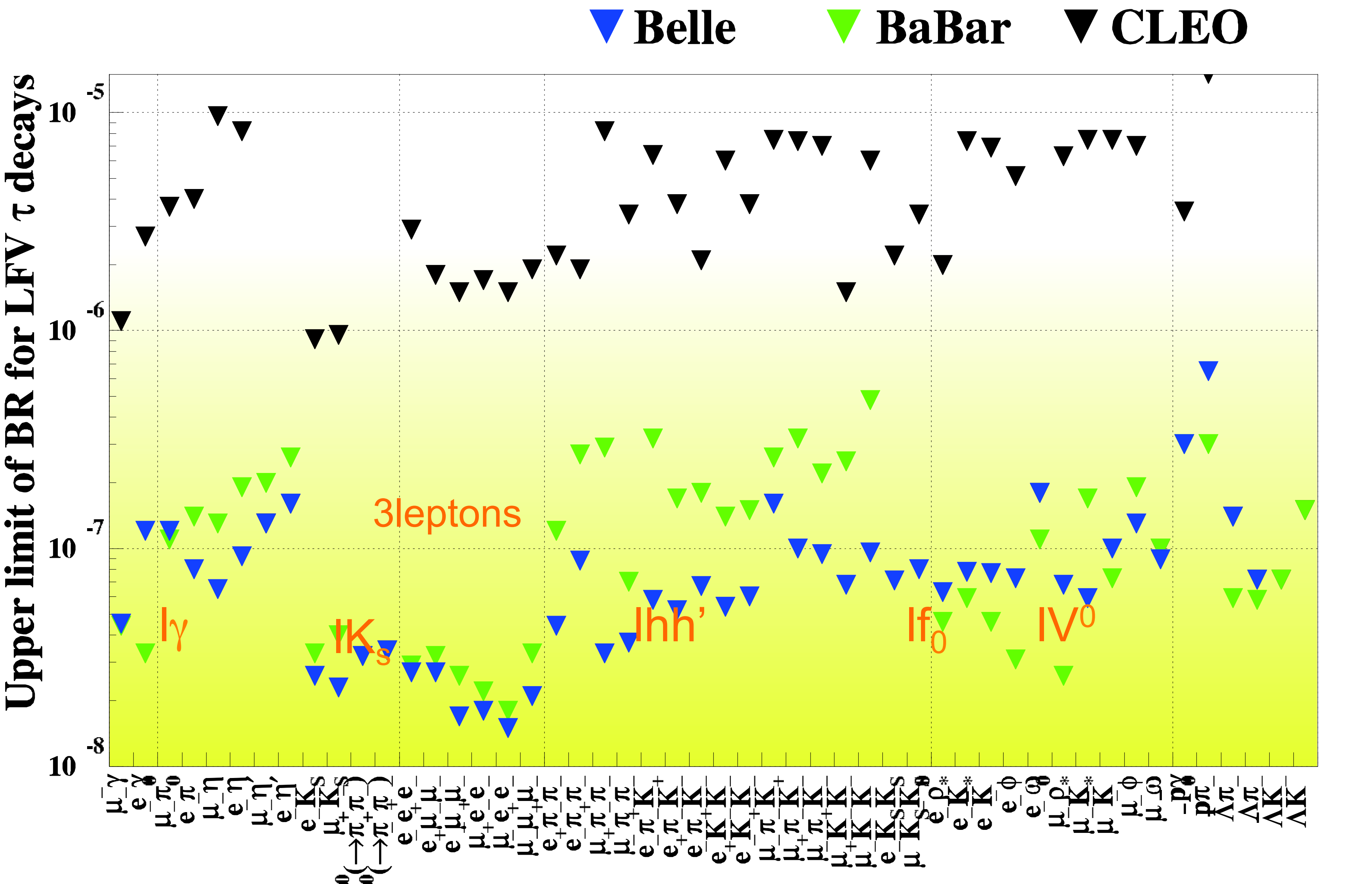
electron-veto on the tag-side
(e-e+e- and e-μ+μ-)

γ-conversion veto
(e-e+e- and μ-e+e-)

m^2_{miss} and p_{miss}
(e-e+e-, μ-μ+μ-,
e-μ+μ-, μ-e+e-)

mode	$\mu^-\mu^+\mu^-$	$e^-e^+e^-$	$\mu^-e^+e^-$ $e^-\mu^+\mu^-$	$\mu^+e^-e^-$ $e^+\mu^-\mu^-$
Dominant bkg.	ττ qq μμμμ	Bhabha eeee ττ	eeμμ ττ μμ	ττ qq

LFV results



- Reach the sensitivity of $O(10^{-8})$

Constraints on New Physics

- Constraints depend on NP models.
- Examples to illustrate the sensitivity
  - MSSM w/ seesaw

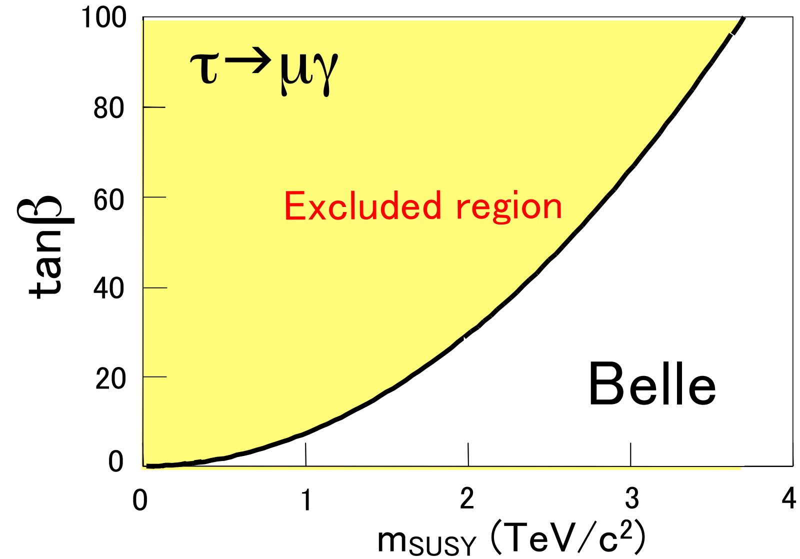
$$Br(\tau \to \mu\gamma) = 3.0\times10^{-6} \times \left(\frac{1\,TeV}{m_{SUSY}}\right)^4 \tan^2\beta$$

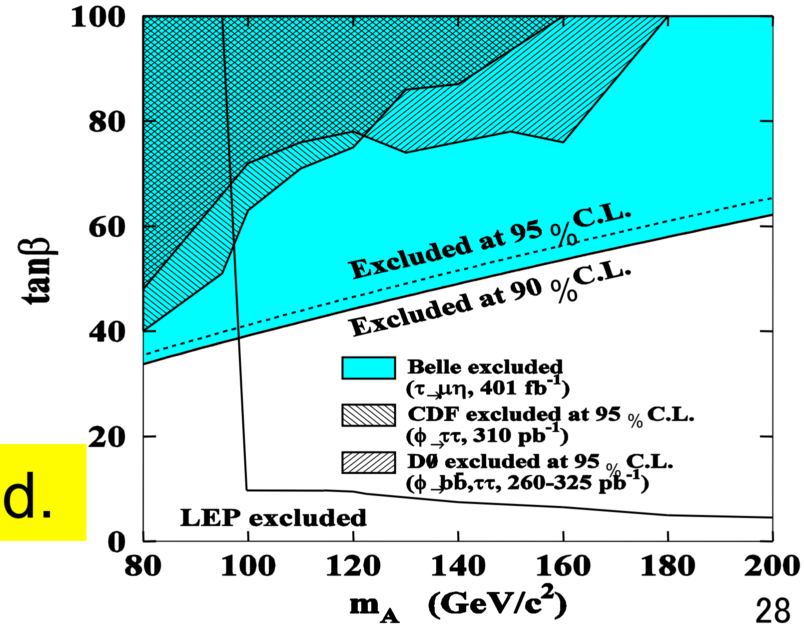
PRD60, 055008 (1998)

  - Higgs-mediated model

$$Br(\tau \to \mu\eta) = 8.4\times10^{-7} \times \left(\frac{\tan\beta}{60}\right)^6 \left(\frac{100GeV}{m_A}\right)^4$$

PRD66, 057301 (2002)





Useful information are being obtained.

Future Prospects

LFV sensitivity depends on the background level.

Sensitivity dependence on luminosity

- $\tau \to \ell\gamma$

  Sensitivity is currently limited due to background from $\tau\tau\gamma$ (ISR).

  $$\propto 1/\sqrt{L}$$

- $\tau \to 3\ell$, ℓ+M

  Negligible background at 1ab^{-1}.

  A few BG events at 10ab^{-1}.

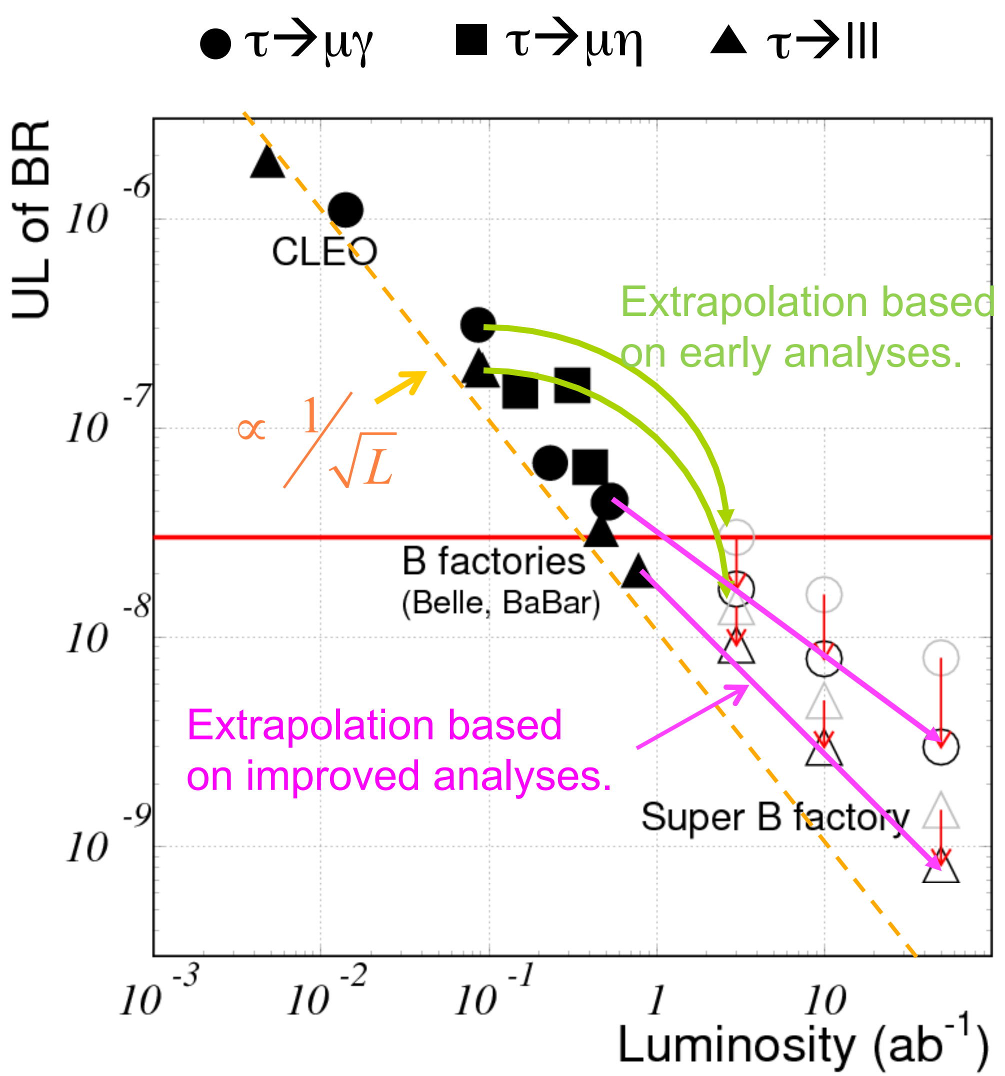
  $$\propto 1/L$$

  - Good PID
  - Mass restriction to select mesons.

Future prospects

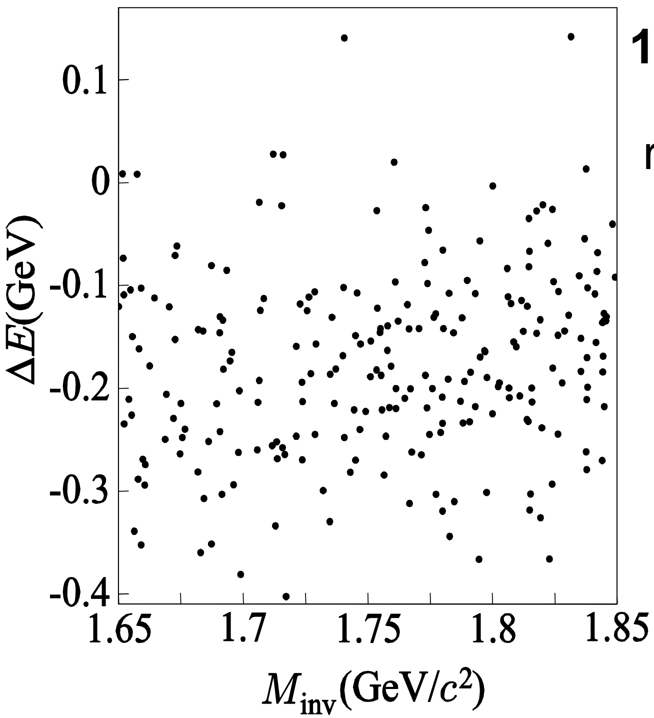
- Super B-factory:
  L_{int} = 10→50ab^{-1}
  N_τ = (1→5) x 10^{10}
- Recent improvement in the analysis
  - BG understanding
  - Intelligent selection
- At 50 ab^{-1}
  Br(τ→μγ) < O(10^{-9})
  Br(τ◊lll) < O(10^{-10})

Good chance to see NP !



ττγ BG events in τ→μγ analysis

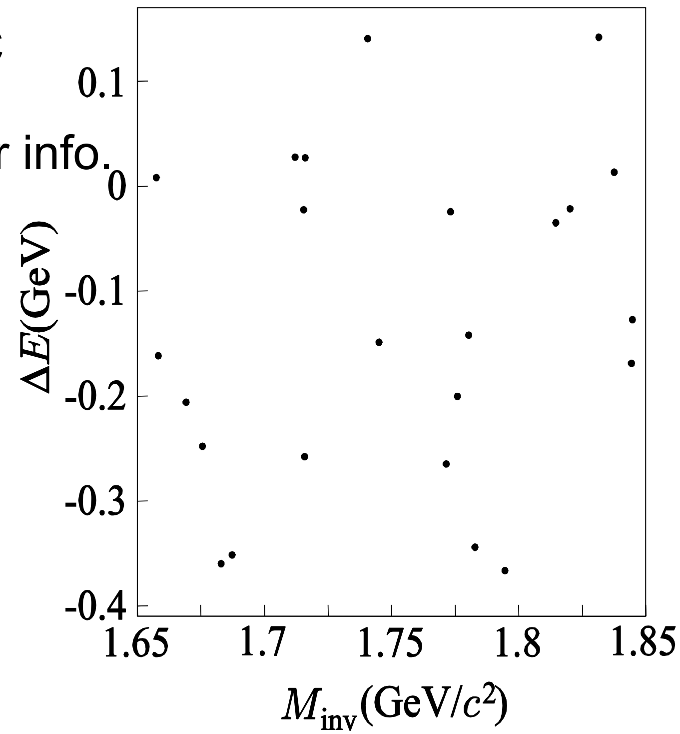
If we can remove BG events caused by ISR completely···



1.5 ab^{-1} generic ττ MC

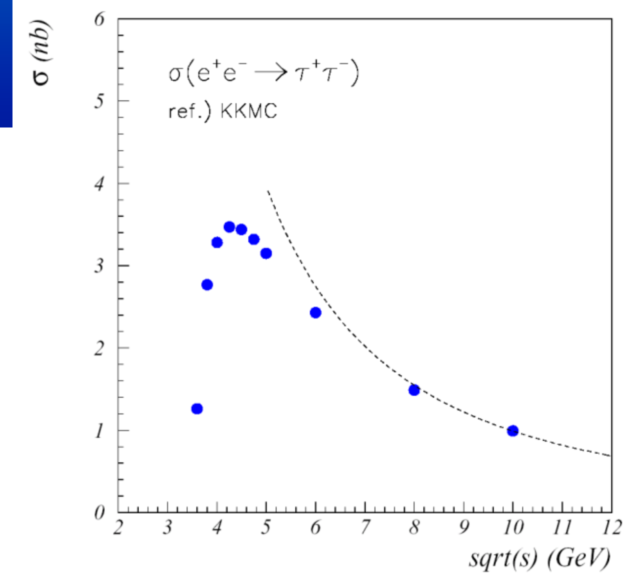
removed by generator info.

90% events removed!



When we run an accelerator with lower energy than Υ(4S),
Can we reduce these ISR BG events?

Low energy running



Operation near ττ threshold for τ→μγ search

Advantage

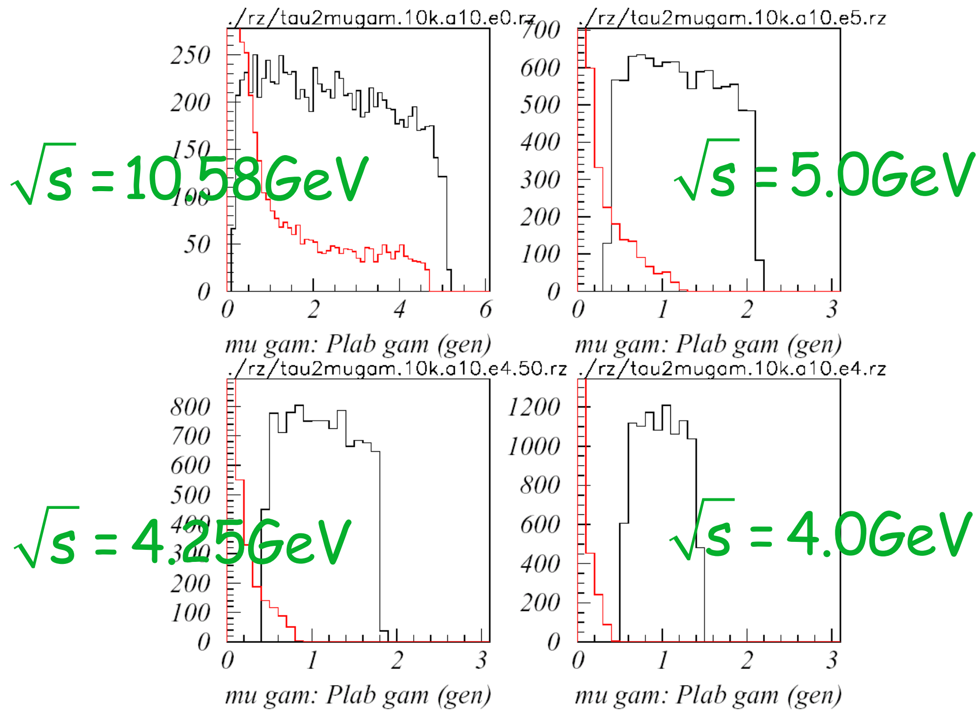
- Larger cross section

  max. at $\sqrt{s}$ = 4.25 GeV

  σ(ττ) ~3.6nb (x 4 wrt 4S)

- Dramatic reduction of ττγ background

  Eγ from ττγ is low, and separated from the signal region.



Eγ (CMS) from τ→μγ and ISR(ττγ)

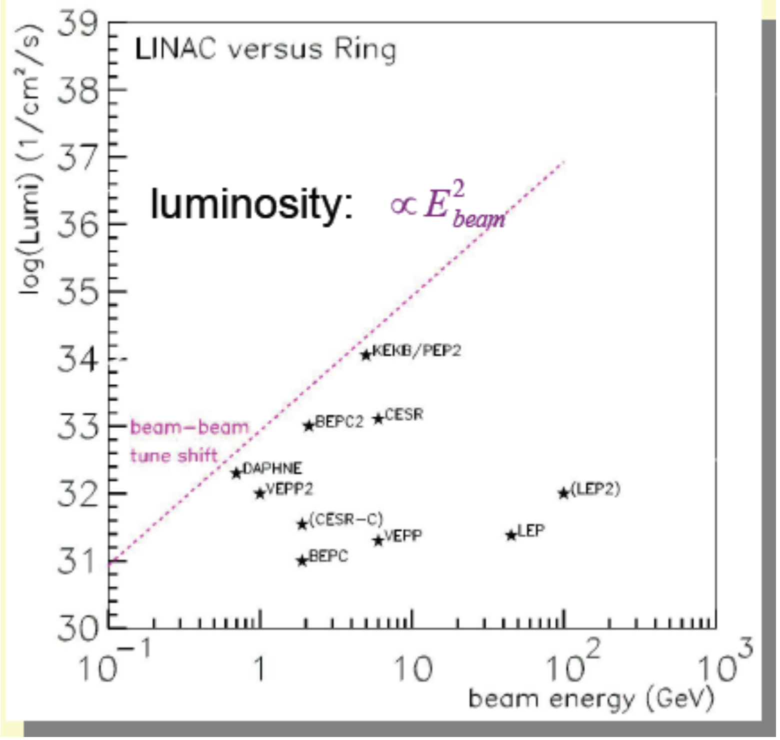
Cont'd

Disadvantage

- Lower luminosity ?
- Higher $\mu\mu\gamma$ background

  $\sigma(\tau\tau)$ ~3.6nb (x 4 wrt 4S)

  $\sigma(\mu\mu)$~6.4nb (x 6.2 wrt 4S)
- What about for $\tau \rightarrow 3\mu$
- Need more studies

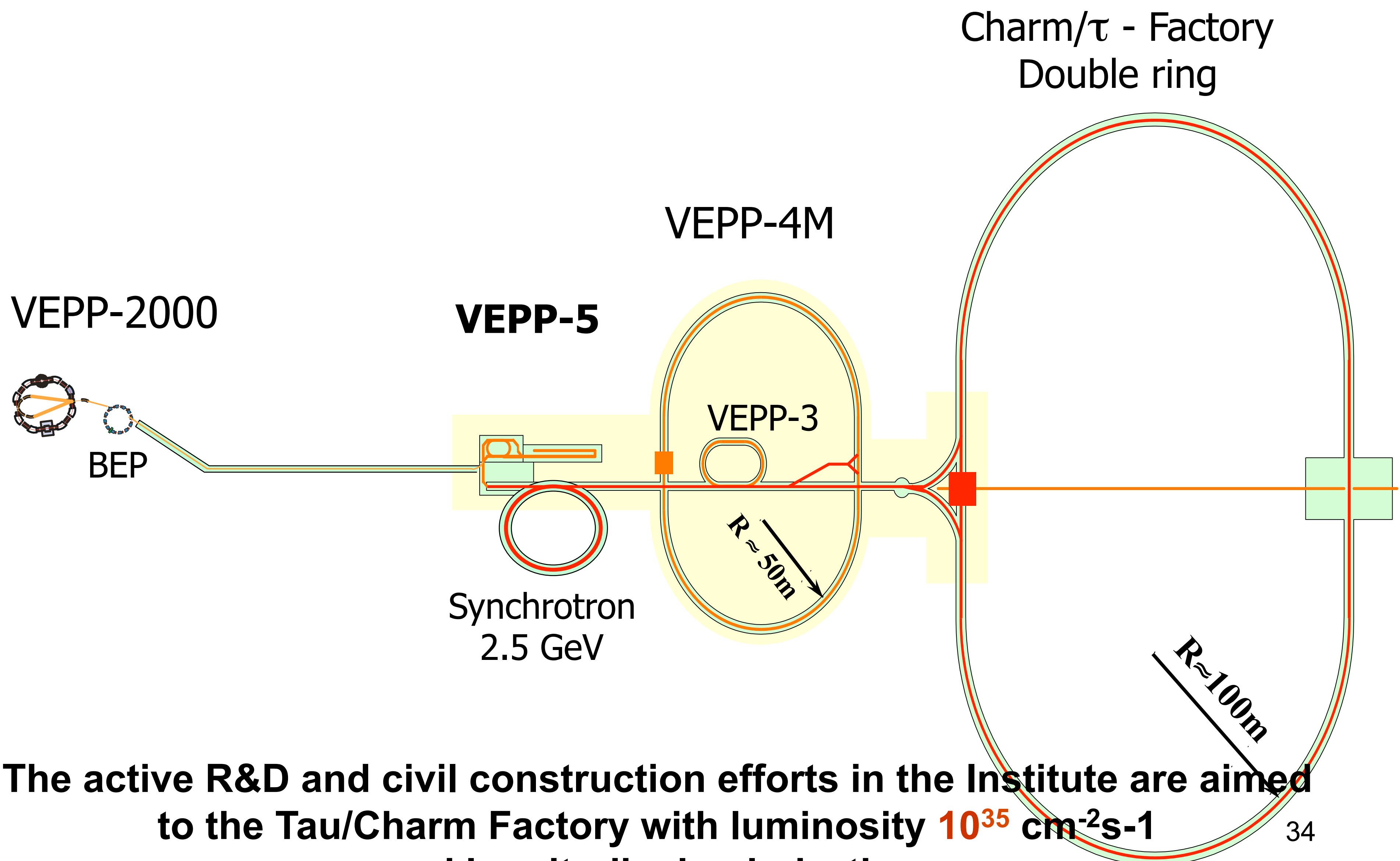


A.Shoning @ TAU06

Machine running near threshold w/ L > 10^{36} cm^{-2}s^{-1} would be interesting !

cf: Super Tau-Charm (BINP), INFN Super-B L = 10^{35} cm^{-2}s^{-1} near threshold.

Layout of injection using VEPP-5



The active R&D and civil construction efforts in the Institute are aimed to the Tau/Charm Factory with luminosity 10^{35} $cm^{-2}s^{-1}$ and longitudinal polarization.

Summary

- Super-B is also a Super Charm factory:
  - D-D mixing, CPV at sensitivity of $O(10^{-3})$.
  - Crucial tools for super-precise CKM.
  - Exotic hadrons.
- Super-B is also a Super Tau factory:
  - LFV search at $O(10^{-9}) \rightarrow O(10^{-10})$
  - Will become more & more important.
    - Especially when signals found at MEG, LHC…
    - Not limited by theory (hadronic uncertainty)
  - We must be ready for some options to maximize physics outputs.

Summary

- LFV is one of the front runners to find NP.

➔ If found, new paradigm of particle physics research
Tau provide rich physics programs there !

2010	2015	2020

LHC → Direct search

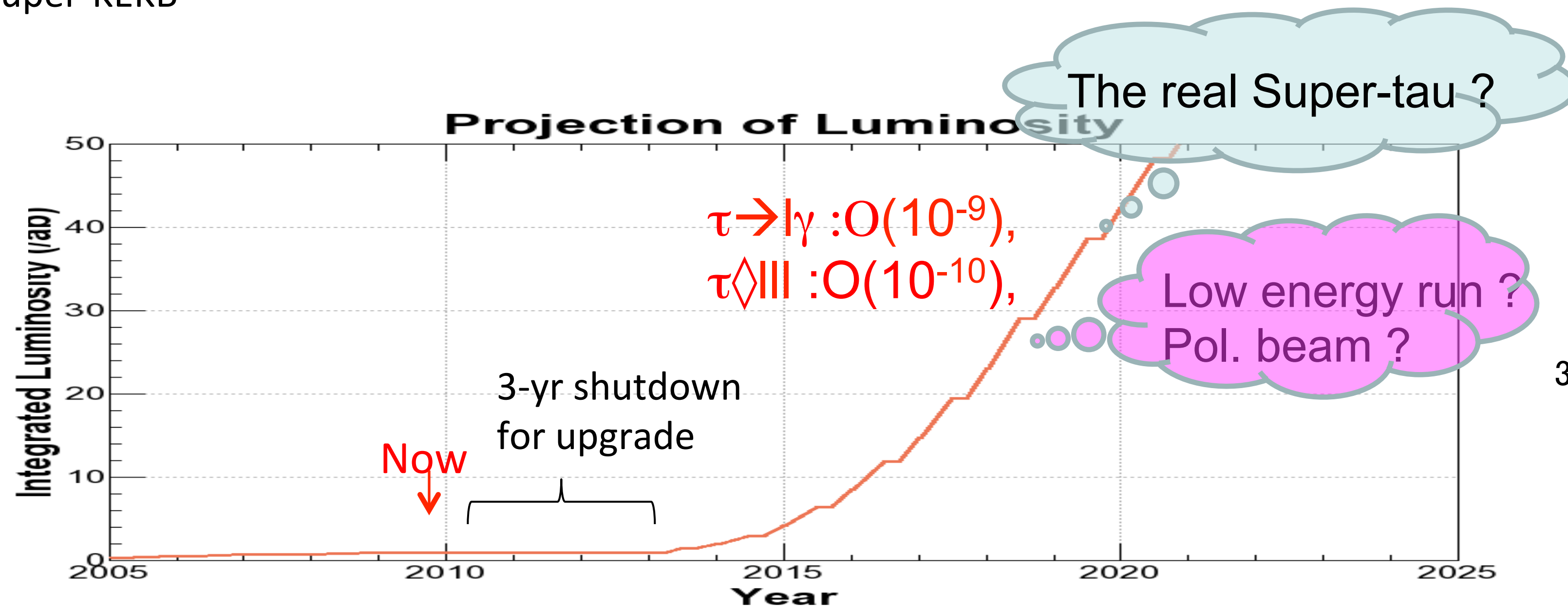
MEG → Br($\mu \rightarrow e\gamma$) ~10^{-13}

μ@J-PRC → $\mu \rightarrow e$ conv. 10^{-16}

Super-KEKB → $\tau \rightarrow l\gamma$, lll, $l\eta$, (~40 modes)

Plan of Super-KEKB

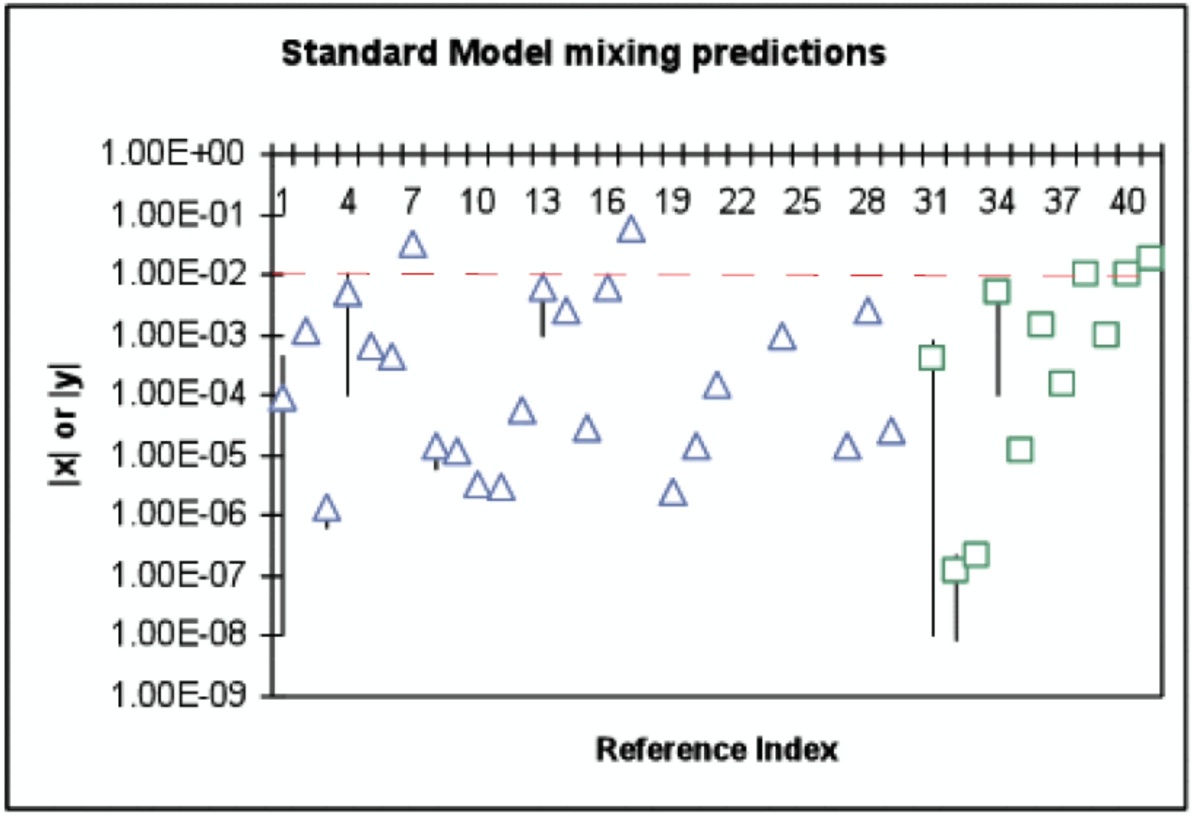
L_{int} (ab^{-1})
~x10^9 $\tau\tau$



Backup

D-D mixing in SM

Standard Model predictions of D^0-$\overline{D^0}$ mixing



- Prediction largely differs among models, but in recent models, x and y are expected to be ~1% in SM.

Prospect at Belle II

Estimated by B. Golob

- Statistical error scaled w/ L
- Systematic error
  - Scale component
    ex: Ratio of DCS/CF
    ← improved w/ L
  - Non-scale component
    ex: Model dependence,
    Detector resolution limit

3) t-dep. Dalitz:
$D^0 \to K_S\pi\pi$

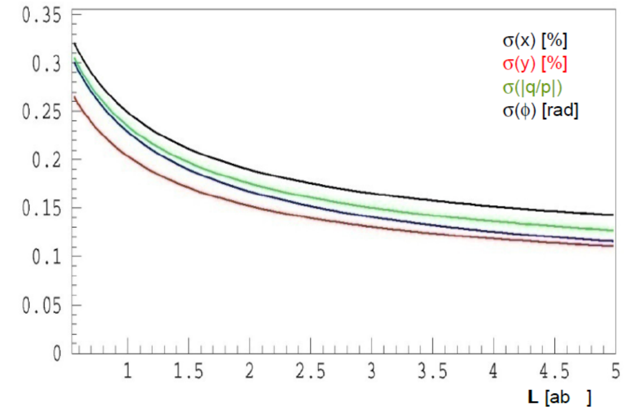
$$\sigma_x^2 = \left[\frac{0.31\%}{\sqrt{L/L_0}}\right]^2 + [0.10\%]^2$$

$$\sigma_y^2 = \left[\frac{0.26\%}{\sqrt{L/L_0}}\right]^2 + [0.07\%]^2$$

$$\sigma_{|q/p|}^2 = \left[\frac{0.30}{\sqrt{L/L_0}}\right]^2 + [0.08]^2$$

$$\sigma_\varphi^2 = \left[\frac{0.30\,rad}{\sqrt{L/L_0}}\right]^2 + [0.06\,rad]^2$$

L0=540 fb



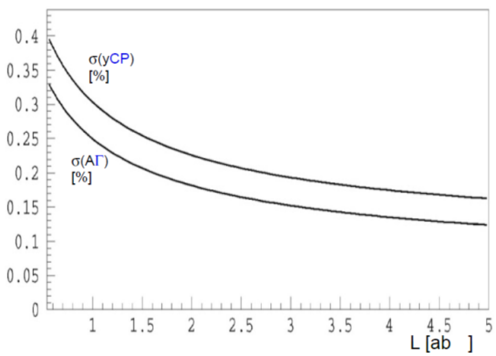
Saturation ($\sigma_{stat} = \sigma_{syst}$)
σ(x) at $5ab^{-1}$
σ(y) at $7ab^{-1}$
σ(|q/p|) at $7ab^{-1}$
σ(φ) at $13ab^{-1}$

1) CP eigen state: $D \to KK/\pi\pi$

$$\sigma_{yCP}^2 = \left[\frac{0.39\%}{\sqrt{L/L_0}}\right]^2 + [0.10\%]^2$$

$$\sigma_{A\Gamma}^2 = \left[\frac{0.33\%}{\sqrt{L/L_0}}\right]^2 + [0.06\%]^2$$

L_0=540 fb



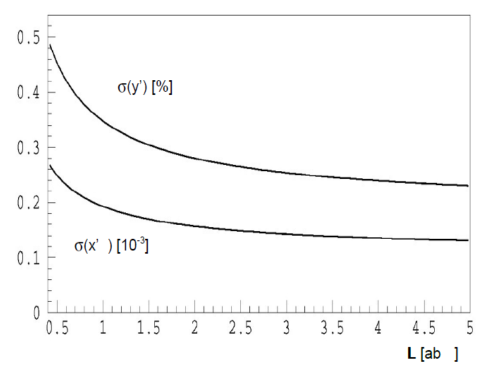
2) WS decay: $D \to K\pi$

$$\sigma_{x'2}^2 = \left[\frac{0.23\cdot 10^{-3}}{\sqrt{L/L_0}}\right]^2 + [0.09\cdot 10^{-3}]^2$$

$$\sigma_{y'}^2 = \left[\frac{0.42\%}{\sqrt{L/L_0}}\right]^2 + [0.16\%]^2$$

$$\sigma_{AD}^2 = \left[\frac{4.4\%}{\sqrt{L/L_0}}\right]^2 + [1.7\%]^2$$

L_0=400 fb

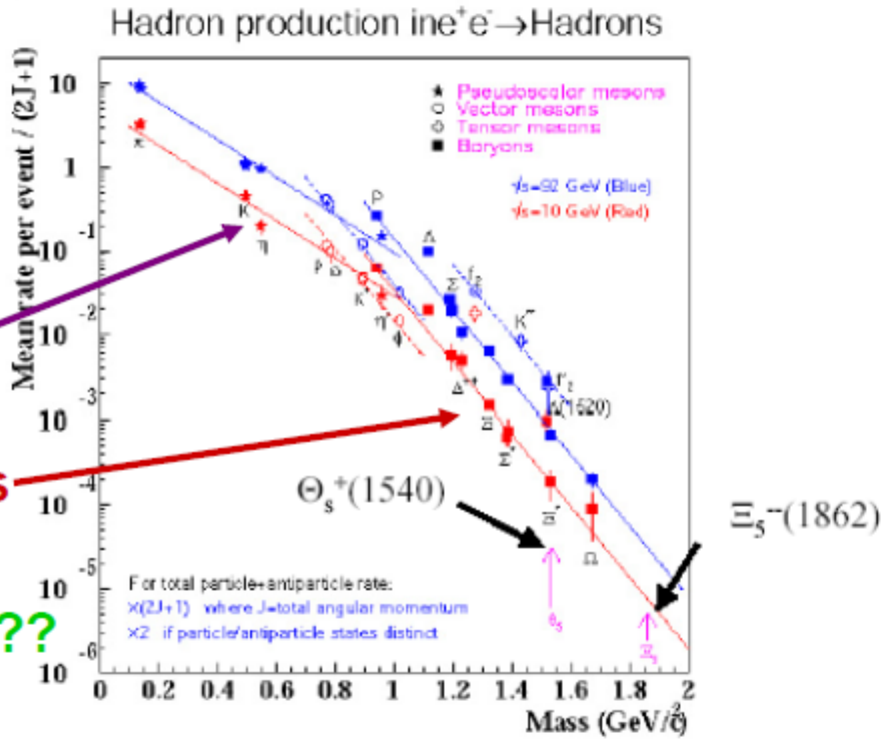


Hadron Rate in $e^+e^- \rightarrow$ Hadron

Slope for mesons

Slope for baryons

Slope for pentaquarks??

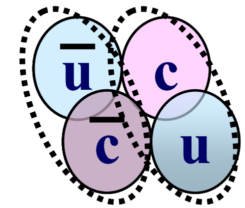


Assuming the Pentaquark production is the same as baryon production we expect the total production of Θ_s^+, Ξ_5^{--} per event continuum to be $\Theta_s^+ = 7 \times 10^{-4}$, $\Xi_5^{--} = 3. \times 10^{-5}$

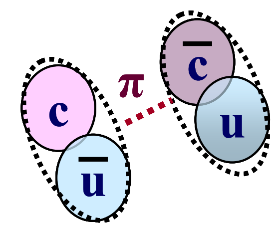
XYZ found at B-factories

State	M(MeV)	Γ(MeV)	J^{PC}	Decay	Production
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$\phi f_0(980)$	ISR
$X(3872)$	3871.4 ± 0.6	<2.3	1^{++}	$\pi^+\pi^- J/\psi, \gamma J/\psi$	B decay
$X(3875)$	3875.5 ± 1.5	$3.0^{+2.1}_{-1.7}$		$D^0\bar{D}^0\pi^0$	B decay
$Z(3940)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	Two-photon
$X(3940)$	3942 ± 9	37 ± 17	J^{P+}	$D\bar{D}^*$	Double-charm
$Y(3940)$	3943 ± 17	87 ± 34	J^{P+}	$\omega J/\psi$	B decay
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{-+}	$\pi^+\pi^- J/\psi$	ISR
$Z(4051)$	4051^{+24}_{-43}	82^{+51}_{-28}	?	$\pi^+\chi_{C1}$	B decay
$X(4160)$	4156 ± 29	139^{+113}_{-65}	J^{P+}	$D^*\bar{D}^*$	Double-charm
$Z(4248)$	4248^{+185}_{-45}	177^{+320}_{-72}	?	$\pi^+\chi_{C1}$	B decay
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$\pi^+\pi^- J/\psi$	ISR
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$\pi^+\pi^-\psi'$	ISR
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^+\psi'$	B decay
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$\pi^+\pi^-\psi'$	ISR
$Y_b(10890)$	10889.6 ± 2.3	$54.7^{+8.9}_{-7.6}$	1^{--}	$\pi^+\pi^-\Upsilon(nS)$	$e^+e^-\to Y_b$

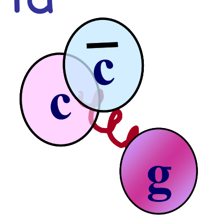
Tetraquark



D^(*)D^(*) Molecule



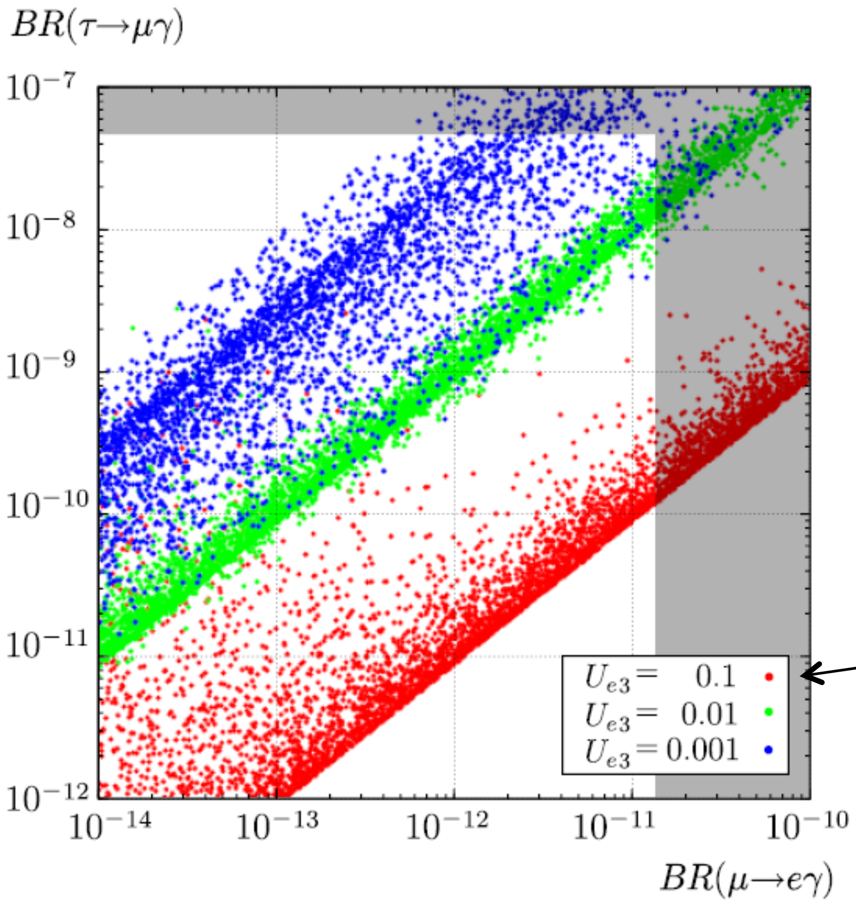
Hybrid



SUSY-GUT

Hisano, Nagai, Paradisi & Shimizu
arXiv: 0904.2080

SU(5)+ν_R



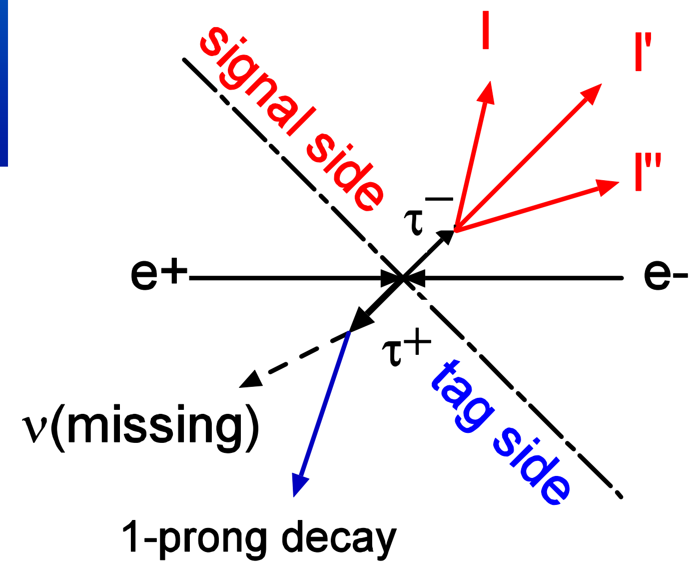
μ→eγ depends strongly on U_{e3}, but τ→μγ does not at all.

$$\left(m^2_{\tilde{L}}\right)_{ij} \simeq -\frac{(3m_0^2 + A_0^2)}{8\pi^2} U_{i3}U^*_{j3} \frac{m_{\nu_3}\bar{M}_3}{\langle H_u \rangle^2}$$

Close to the current experimental limit

If U_{e3} is tiny, τ→μγ still within the Super B factories reach, while μ→eγ could be too small to be seen by MEG.

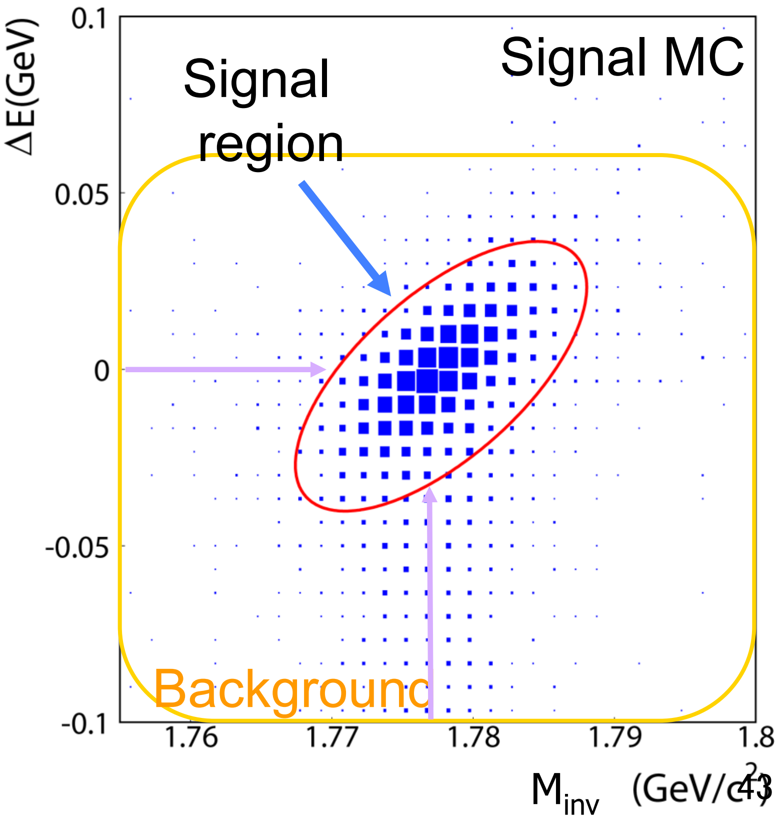
LFV analysis



- Signal side:
  τ → decay of interest
- Tag side:
  τ → 1 trk w/ n γ + missing
  - 1-prong decays occupy >80% of the τ decay.
  - Loose constraint on ν based on P_{miss}, M^2_{miss}.
- Background
  - ττ, continuum ($q\bar{q}$), μμ, ee, …
- Particle ID
- Signal evaluation based on $M_{inv} \sim M\tau$ & $\Delta E \sim 0$

$$\Delta E = E_{rec} - E_{beam}$$

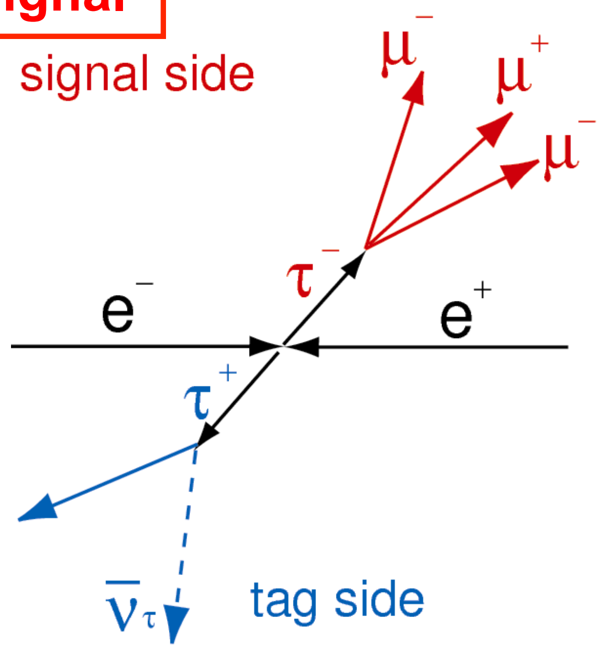
- Signal region is open after analysis cuts are finalized.



LFV τ decays; Signal and Background

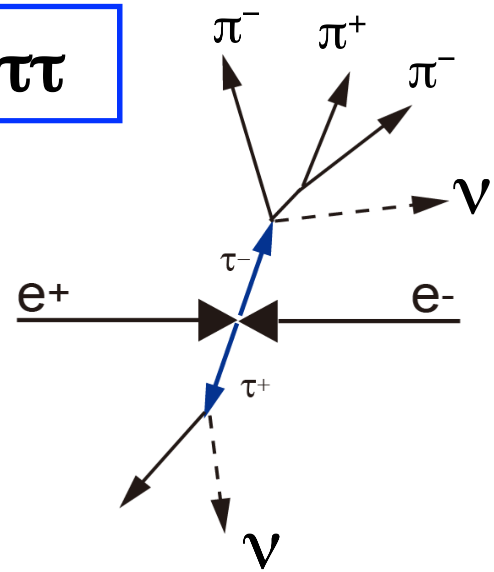
- $e^+e^- \rightarrow \tau^+\tau^-$
  - 1 prong tau decay (BR~85%)

signal



- Only tag side has neutrino(s).

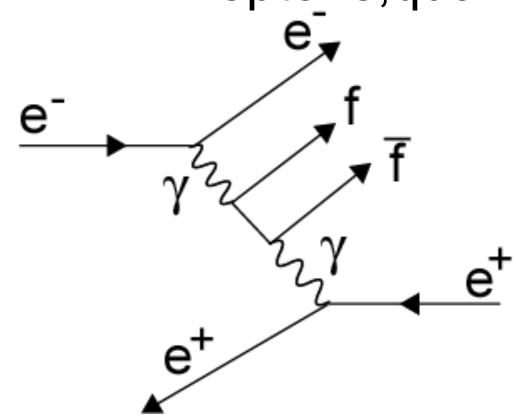
ττ



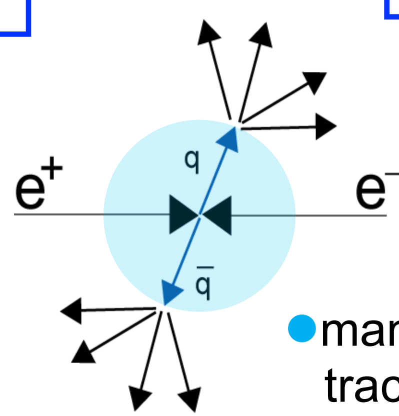
- Both sides have neutrino(s).

2photon process

f=leptons,quarks

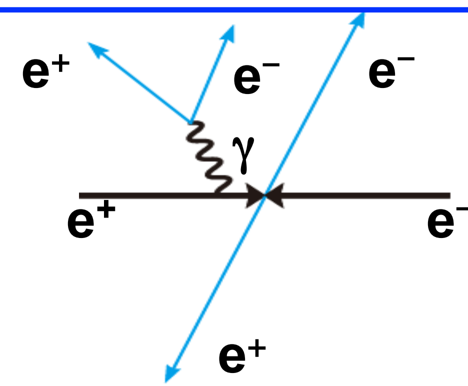


$q\bar{q}$



- many tracks

radiative Bhabha process



LFV results

	Belle UL (x10^{-8})	Lum(fb^{-1})	BaBar UL (x10^{-8})	Lum(fb^{-1})
$\tau \to \mu\gamma$	4.5	535	4.4	470+31+15
$\tau \to e\gamma$	12	535	3.3	470+31+15
$\tau \to \mu\eta$	6.5	401	15	339
$\tau \to e\eta$	9.2	401	16	339
$\tau \to \mu\pi^0$	12	401	11	339
$\tau \to e\pi^0$	8.0	401	13	339
$\tau \to \mu\eta'$	13	401	14	339
$\tau \to e\eta'$	16	401	24	339
$\tau \to \mu\mu\mu$	2.1	782	3.3	467
$\tau \to e\mu\mu$	2.7	782	3.2	467
$\tau \to \mu ee$	1.8	782	2.2	467
$\tau \to eee$	2.7	782	2.9	467
$\tau \to \mu e\mu$	1.7	782	2.6	467
$\tau \to e\mu e$	1.5	782	1.8	467
$\tau \to \mu\rho$	6.8	543	2.6	451
$\tau \to e\rho$	6.3	543	4.6	451
$\tau \to \mu K^*$	5.9	543	17	451
$\tau \to eK^*$	7.8	543	5.9	451
$\tau \to \mu K^*$	10	543	7.3	451
$\tau \to eK^*$	7.7	543	4.6	451
$\tau \to \mu\phi$	13	543	19	451
$\tau \to e\phi$	7.3	543	3.1	451
$\tau \to \mu\omega$	8.9	543	10	451
$\tau \to e\omega$	18	543	11	451

	Belle UL (x10^{-8})	Lum(fb^{-1})	BaBar UL (x10^{-8})	Lum(fb^{-1})
$\tau \to \mu Ks$	2.3	671	3.3	469
$\tau \to eKs$	2.6	671	4.0	469
$\tau \to \mu KsKs$	8.0	671		
$\tau \to eKsKs$	7.1	671		
$\tau \to \mu\pi\pi$	3.3	671	29	221
$\tau \to e\pi\pi$	4.4	671	12	221
$\tau \to \mu K\pi$	10	671	32	221
$\tau \to eK\pi$	5.2	671	17	221
$\tau \to \mu\pi K$	16	671	26	221
$\tau \to e\pi K$	5.8	671	32	221
$\tau \to \mu KK$	6.8	671	25	221
$\tau \to eKK$	5.4	671	14	221
$\tau \to \pi\mu\pi$	3.4	671	7.0	221
$\tau \to \pi e\pi$	8.8	671	27	221
$\tau \to \pi\mu K$	9.4	671	22	221
$\tau \to \pi eK$	6.7	671	18	221
$\tau \to K\mu K$	9.6	671	48	221
$\tau \to KeK$	6.0	671	15	221
$\tau \to \mu f_0$	3.4	671		
$\tau \to ef_0$	3.2	671		
$\tau \to \Lambda\pi$	7.2	154	5.8	237
$\tau \to \Lambda\pi$	14	154	5.9	237
$\tau \to \Lambda K$			15	237
$\tau \to \Lambda K$			7.2	237

No signal yet !

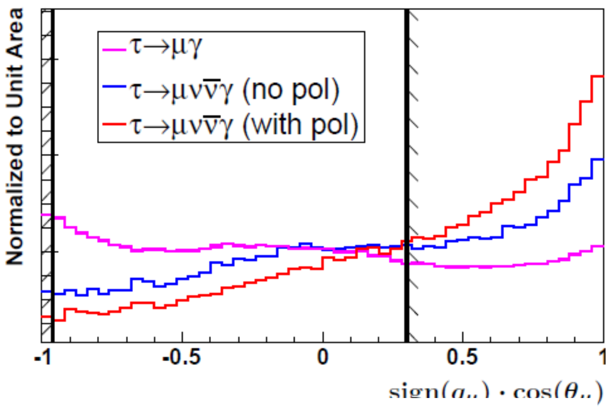
Too bad !

What about polarized beam ?

Longitudinally polarized beams help to reduce the ISR background.

(ISR emission flips the spin of e+/- beam)

arXiv:0810.1312 (study by INFN Super-B)



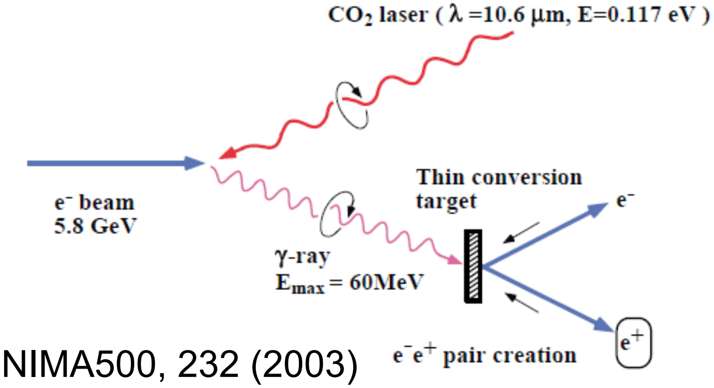
- Only one beam (electron)
  - Distribution of BKG shifted away from signal.
  - But, effect is not so significant ?

    Only 10% improvement in UL ?

- Both two beams
  - $\tau\tau\gamma$ events are inhibited.

    → dramatic suppression of BKG
  - Require polarized e+ beam

    R&D for ILC (synergy!)



T. Omori et al., NIMA500, 232 (2003)

After discovery of LFV, pol. beam is useful to investigate helicity nature of NP.

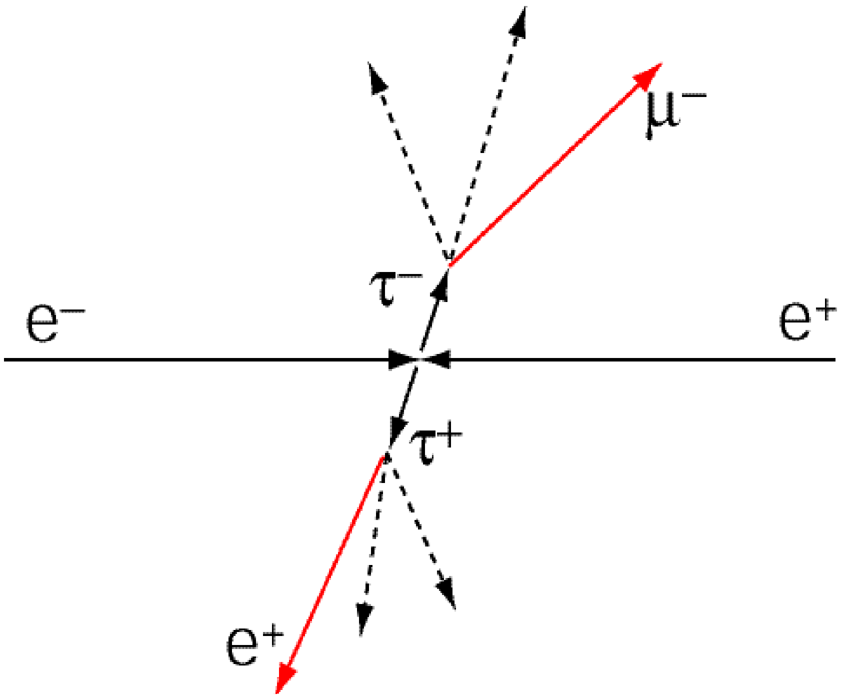
In any case, need polarized beams without loosing L !

Polarized beam

- Italian SuperB option

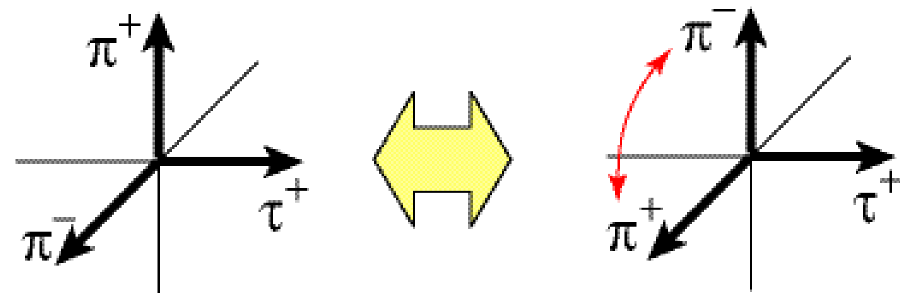
- Tau EDM, g-2
- Search for CP/T violation in tau decays
- Search for LFV
  - BG reduction
- LFV signature
  - Physics structure

How to measure EDM, g-2

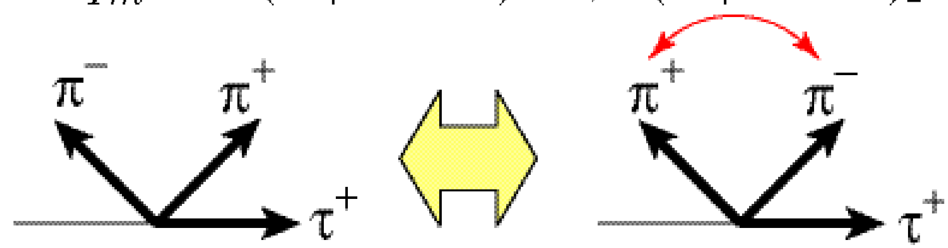


EDM

$$\mathcal{M}^2_{Re} \sim (\boldsymbol{S}_+ \times \boldsymbol{S}_-)\hat{\boldsymbol{k}} \quad , \quad (\boldsymbol{S}_+ \times \boldsymbol{S}_-)\hat{\boldsymbol{p}}$$

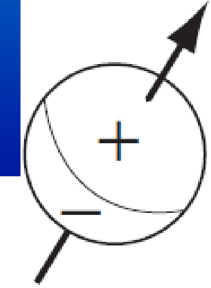


$$\mathcal{M}^2_{Im} \sim (\boldsymbol{S}_+ - \boldsymbol{S}_-)\hat{\boldsymbol{k}} \quad , \quad (\boldsymbol{S}_+ - \boldsymbol{S}_-)\hat{\boldsymbol{p}}$$



- Estimate tau spin direction from decay angles
- → Momentum correlation

Tau EDM



Belle ($30 fb^{-1}$)

$$-2.2 < Re(d_\tau) < 4.5\ (10^{-17}\, e\, \mathrm{cm}),$$
$$-2.5 < Im(d_\tau) < 0.8\ (10^{-17}\, e\, \mathrm{cm}).$$

	EDM (e cm)	
	Limit	SM [4]
e	$(0.18 \pm 0.12 \pm 0.10)\times 10^{-26}$	10^{-40}
μ	$(3.7 \pm 3.4)\times 10^{-19}$	10^{-38}
τ	L3/LEP: $\mid d_\tau \mid < 3.1 \times 10^{-16}$	10^{-37}
	ARGUS: $\mid Re(d_\tau) \mid < 4.6 \times 10^{-16}$	
	ARGUS: $\mid Im(d_\tau) \mid < 1.8 \times 10^{-16}$	
n	$6 - 10 \times 10^{-26}$	$10^{-(30-31)}$
Nuclei	2×10^{-24}	10^{-30}

- Polarized beam (P-odd)
  - Another correlation can be utilized.
    → Sensitivity improve by a factor of 4~5.

$$|\mathrm{Re}\{d_\tau^\gamma\}| \le 4.4\ 10^{-19}\ ecm, \text{ Babar + Belle at } 2ab^{-1}$$
$$|\mathrm{Re}\{d_\tau^\gamma\}| \le 1.6\ 10^{-19}\ ecm, \text{ SuperB/Flavor factory, 1 yr running, } 15ab^{-1}$$
$$|\mathrm{Re}\{d_\tau^\gamma\}| \le 7.2\ 10^{-20}\ ecm, \text{ SuperB/Flavor factory, 5 yrs running, } 75ab^{-1}\ (20)$$

G.A.Gonzalez-Sprinberg, arXiv:0707.1658

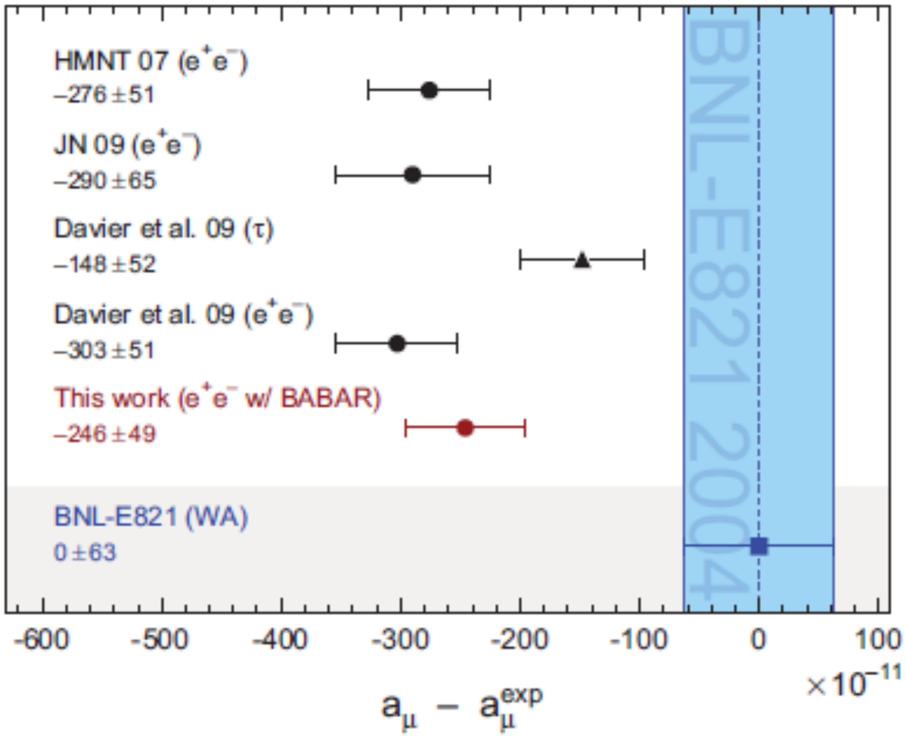
Tau g-2

- Muon g-2
  - O(10^{-9}) shift

~ m^2

- Tau g-2
  - O(10^{-6}) shift

M. Davier et al., arxiv:0908.4300



Current limit by Delphi (e+e-→e+e-τ+τ−)

$$-0.052 < a_\tau < 0.013 \quad (95\,\%\,C.L.)$$

SPS	1a	1b	2	3	4	5
$\Delta a_\mu \times 10^{-9}$	3.1	3.2	1.6	1.4	4.8	1.1
$\Delta a_\tau \times 10^{-6}$	0.9	0.9	0.5	0.4	1.4	0.3