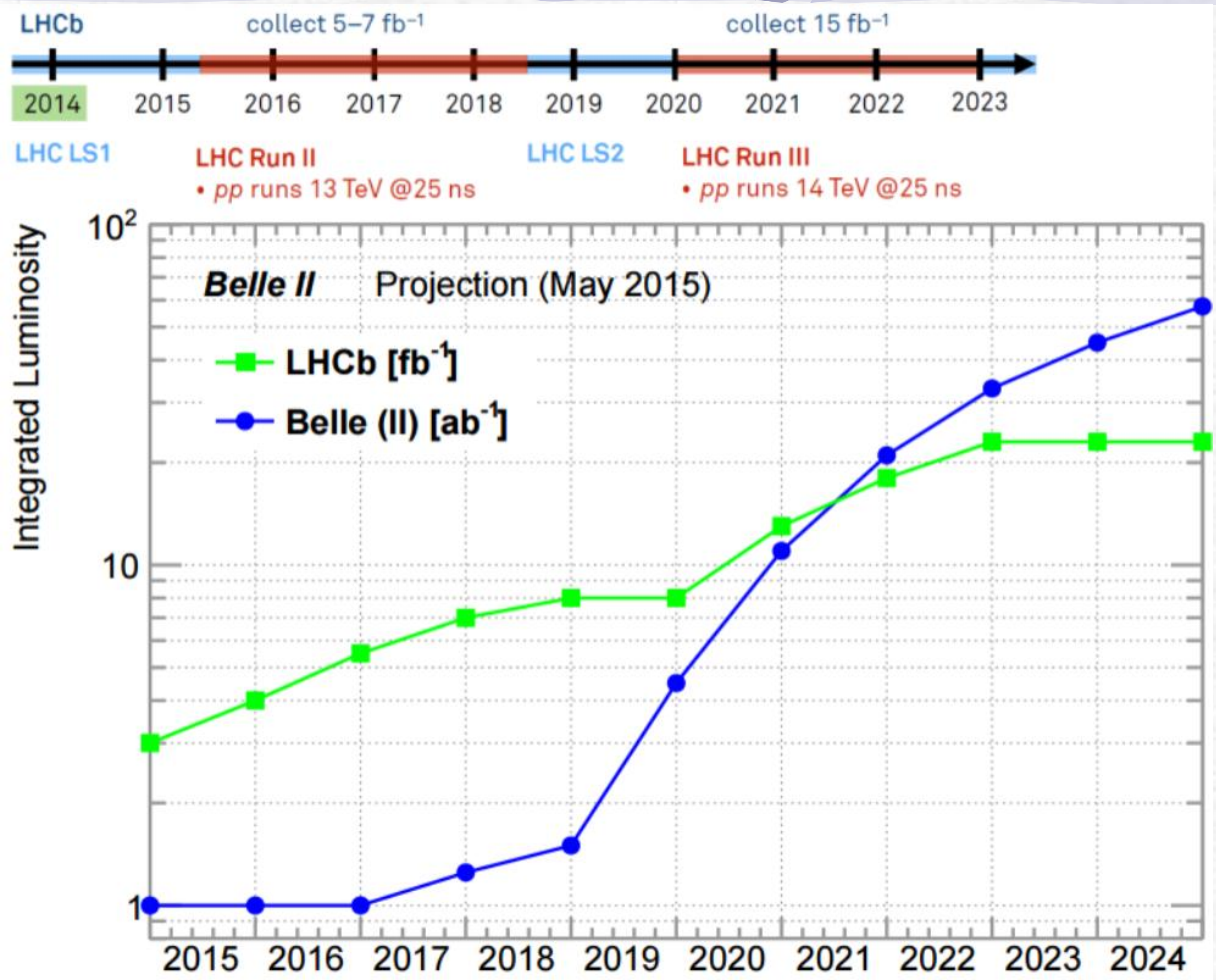
Future prospects for tau and low-multiplicity physics at Belle II

Kiyoshi Hayasaka

(Niigata Univ.)


LHCb
collect 5–7 fb-1
collect 15 fb-1
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
LHC LS1
LHC Run II
• pp runs 13 TeV @25 ns
LHC LS2
LHC Run III
• pp runs 14 TeV @25 ns
Integrated Luminosity
Belle II Projection (May 2015)
LHCb [fb-1]
Belle (II) [ab-1]
2015 2016 2017 2018 2019 2020 2021 2022 2023 2024

Our target

$$\begin{pmatrix} m_{ee}^2 & m_{e\mu}^2 & m_{e\tau}^2 \\ m_{\mu e}^2 & m_{\mu\mu}^2 & m_{\mu\tau}^2 \\ m_{\tau e}^2 & m_{\tau\mu}^2 & m_{\tau\tau}^2 \end{pmatrix}$$

Through the study of lepton flavor structure, find the New Physics

Our target

τLFV

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$$
\begin{array}{ccc}
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\tau\text{LFV} & & \tau\text{EDM/MDM}
\end{array}
$$

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μ g-2

τLFV

τEDM/MDM

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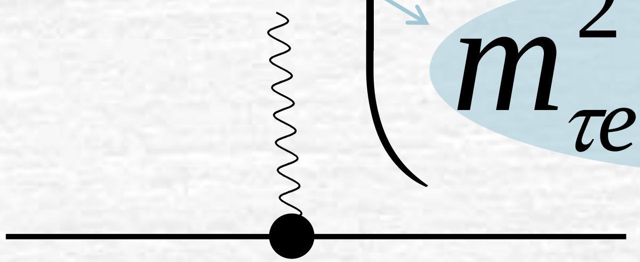

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μ g-2

τLFV

τEDM/MDM

?

Phase?
τ CPV

Through the study of lepton flavor structure, find the New Physics

B2TiP

- Belle II Theory Interface Platform

https://belle2.cc.kek.jp/~twiki/bin/view/B2TiP

Details will be introduced by Mishima-san later.

WG8:tau & low-multi group
→We care tau and low-multiplicity (events with small number of tracks (2-6)) physics

5 golden mode

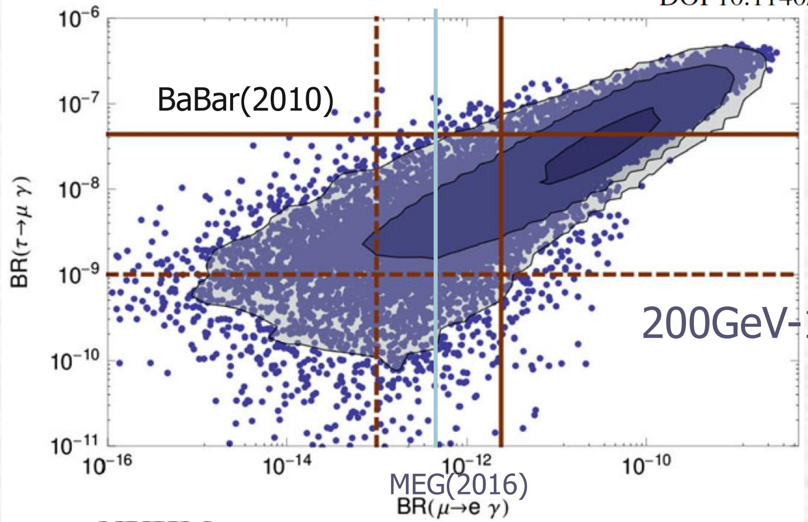
Tau WG page	$\mathcal{B}[10^{-9}]$	LFV $\tau \to \mu\mu\mu$
		CPV $\tau \to K_S \pi^0 \nu$
		Dark Photon to invisible
		$\pi^+\pi^-$ cross section
		π^0 TFF

tau Lepton Flavor Violation

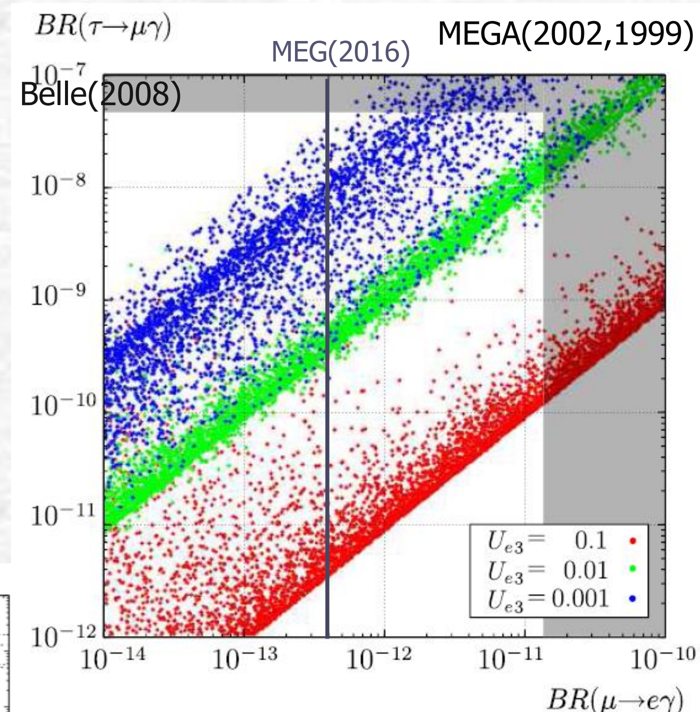
Gianluca Blankenburg[1,2], Gino Isidori[2,3,a], Joel Jones-Pérez[2,3]

Eur. Phys. J. C (2012) 72:2126
DOI 10.1140/epjc/s10052-012-2126-7

$U(3)^5$ flavor symmetry



SUSY SU(5) GUT with seesaw

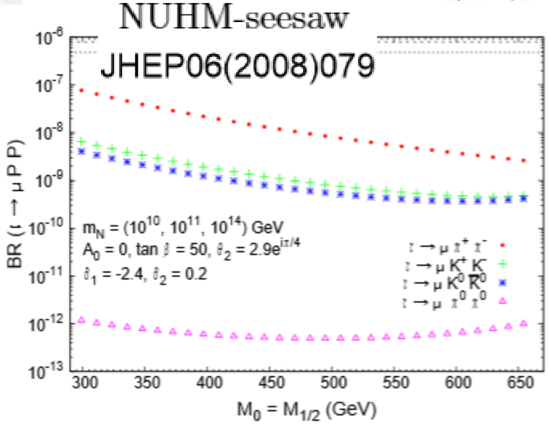


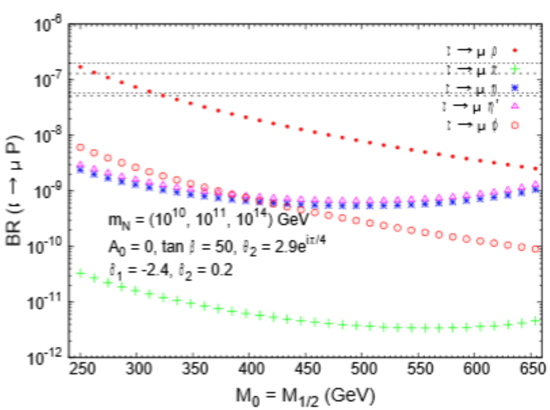
$m_0, M_{1/2} < 1\,\mathrm{TeV},\ |A_0| < 3m_0,\ 3 < \tan\beta < 50$

Junji Hisano *et al* JHEP12(2009)030 doi:10.1088/1126-6708/2009/12/030

NUHM-seesaw

JHEP06(2008)079

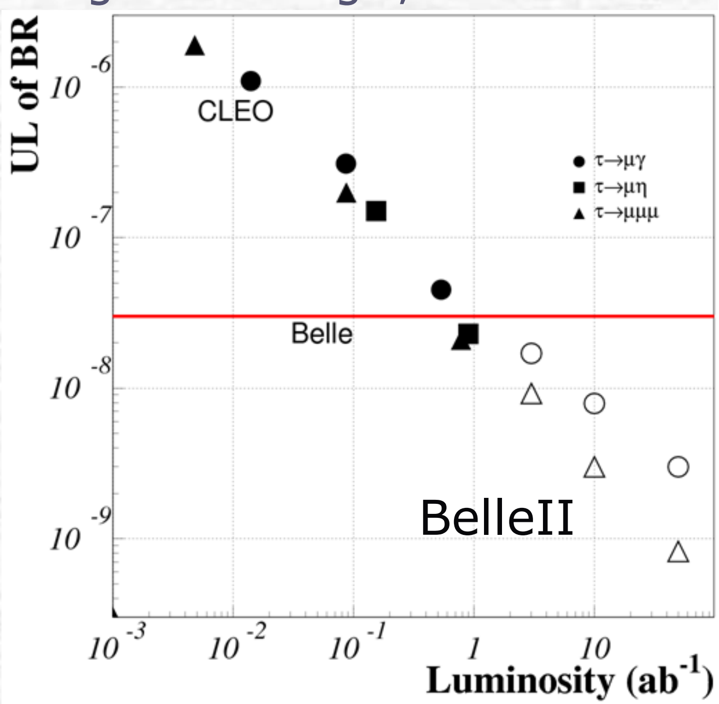


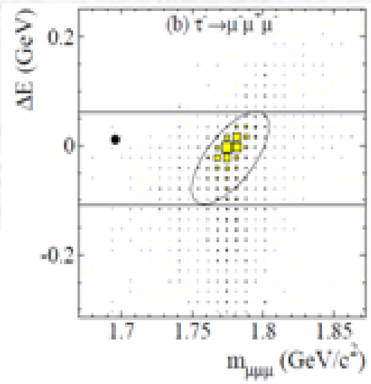


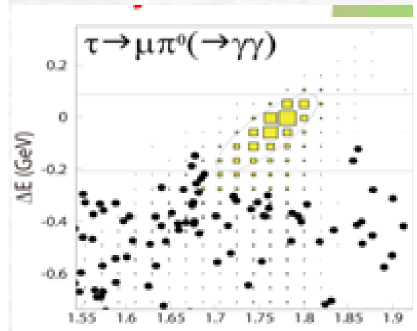
MEG(2011)= Phys. Rev. Lett. 107, 171801 (2011)
MEGA(2002)= Phys.Rev. D65, 112002 (2002)
MEGA(1999)= Phys.Rev.Lett. 83, 1521 (1999)
Belle(2008)= Phys. Lett. B666,16(2008)
BaBar(2010)=Phys. Rev. Lett. 104, 021802 (2010)

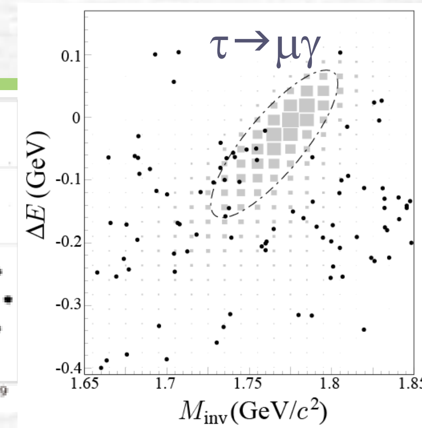
Tau LFV at Belle → Belle II

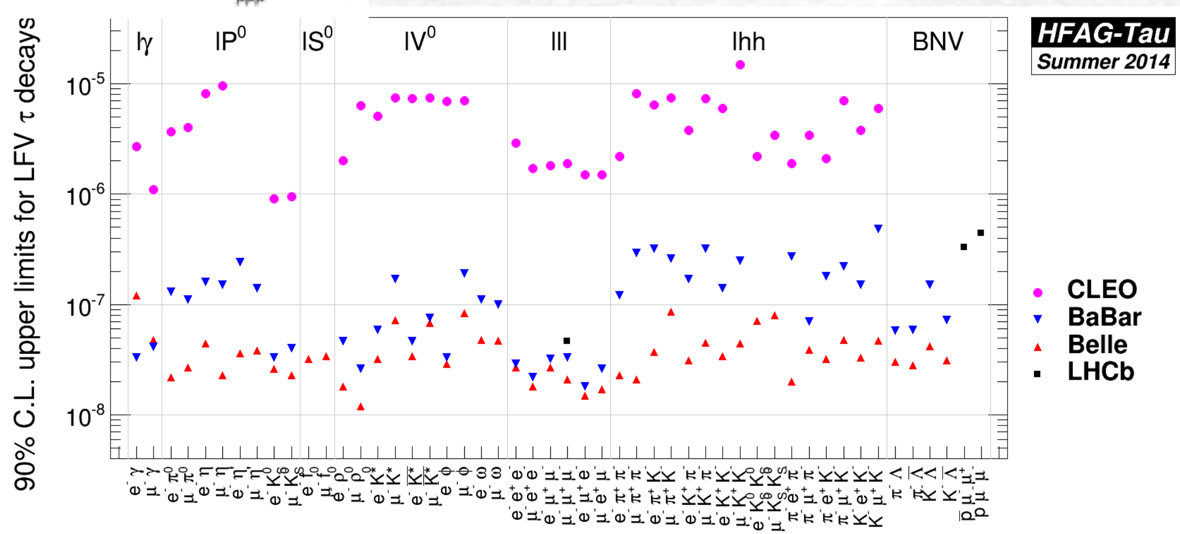
Around 50 tau LFV modes have been searched for at Belle with almost 1ab^{-1}. They were clean analyses (at most, 20 BGs.) But, when data sample gets x50 larger, …





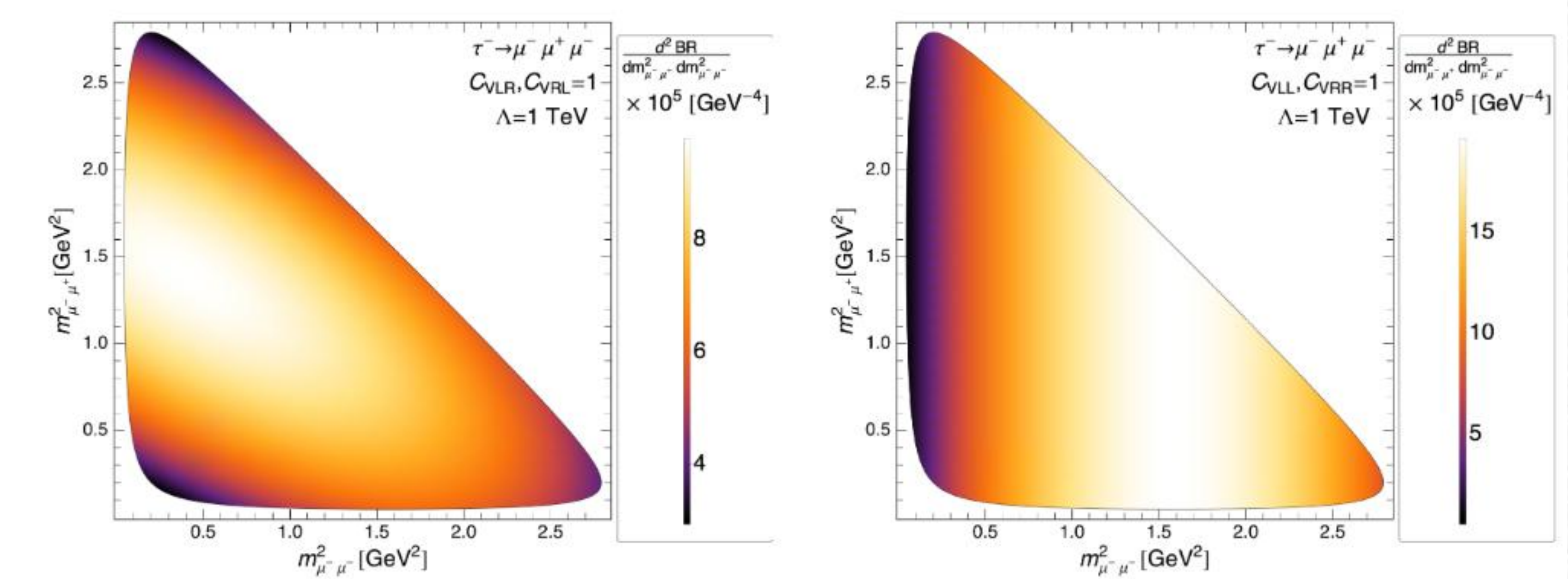






NP contribution for τ→μμμ

- Dalitz analysis is possible using 3μs.



$$
\begin{aligned}
\mathcal{L}_{\text{eff}}^{(4\ell)} = -\frac{1}{\Lambda^2}\{ & \mathrm{C}_{\mathrm{SLL}}(\bar{\mu}P_L\tau)(\bar{\mu}P_L\mu) + \mathrm{C}_{\mathrm{SRR}}(\bar{\mu}P_R\tau)(\bar{\mu}P_R\mu) \\
& + \mathrm{C}_{\mathrm{VLL}}(\bar{\mu}\gamma^\mu P_L\tau)(\bar{\mu}\gamma_\mu P_L\mu) \\
& + \mathrm{C}_{\mathrm{VRR}}(\bar{\mu}\gamma^\mu P_R\tau)(\bar{\mu}\gamma_\mu P_R\mu) \\
& + \mathrm{C}_{\mathrm{VLR}}(\bar{\mu}\gamma^\mu P_L\tau)(\bar{\mu}\gamma_\mu P_R\mu) \\
& + \mathrm{C}_{\mathrm{VRL}}(\bar{\mu}\gamma^\mu P_R\tau)(\bar{\mu}\gamma_\mu P_L\mu) + \mathrm{H.c.}\}. \qquad (2.8)
\end{aligned}
$$

10 signals may give some information.
(With 50ab^{-1}, det. eff.=7%,Br=2x10^{-9}→10 ev)

PHYSICAL REVIEW D **89,** 095014 (2014)

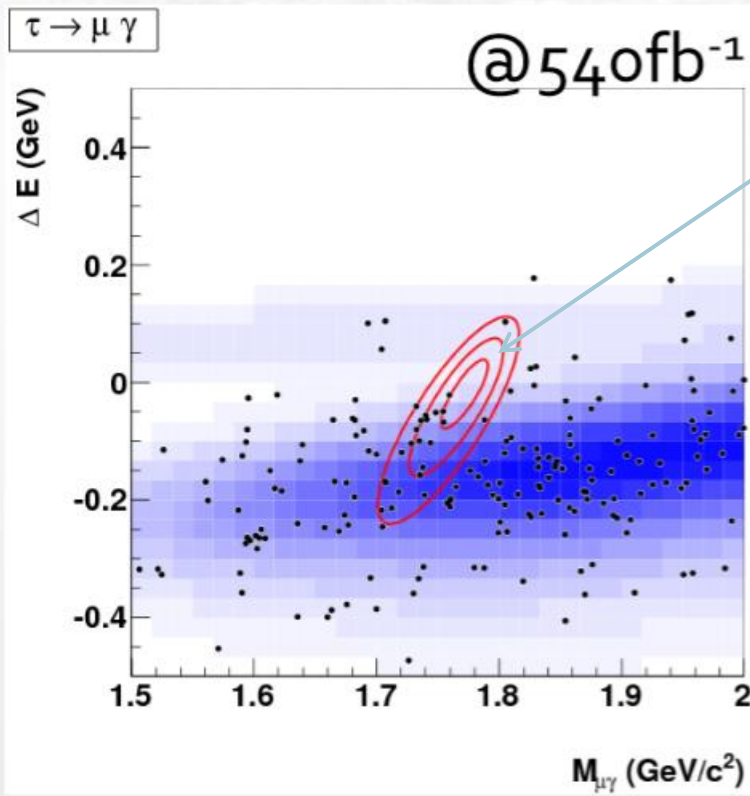
Model-discriminating power of lepton flavor violating τ decays

Alejandro Celis,[1,*] Vincenzo Cirigliano,[2,†] and Emilie Passemar[2,‡]

$\tau \rightarrow 3\mu$ on LHCb

- LHCb
  - At 14 TeV, 100x more tau will be produced.
  - Trigger efficiency will be doubled.
  - 20fb^{-1} data sample will be accumulated.
  - $\sqrt{1400}=40 \rightarrow 1.1\times10^{-9}$
- Belle II
  - x70 $(2.1\times10^{-8}) \rightarrow 3\times10^{-10}$

$\tau \rightarrow \mu\gamma$?



10 BGs in 2sigma elipse are found.
→with 50ab^{-1}, 1000 events will be…

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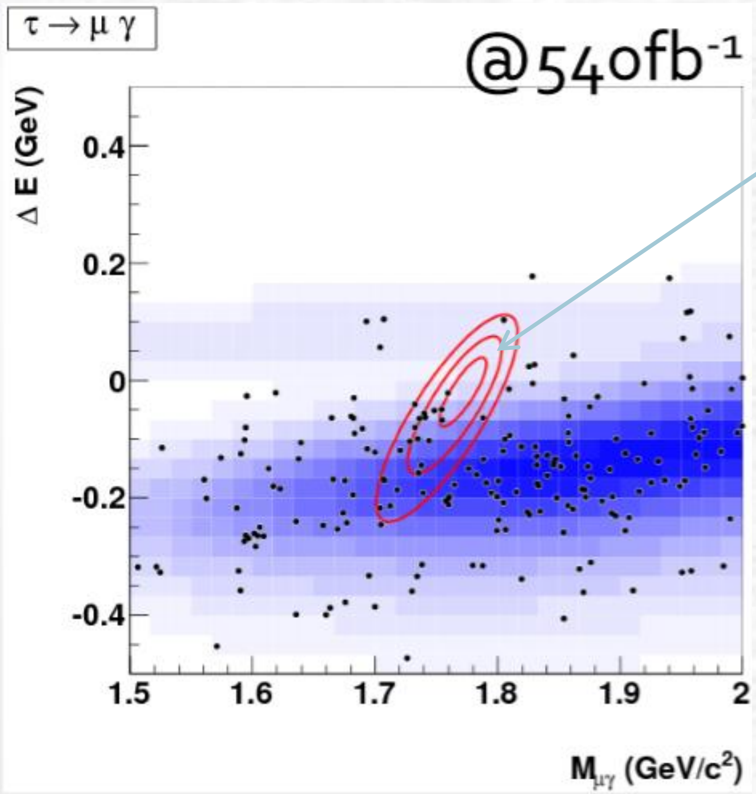

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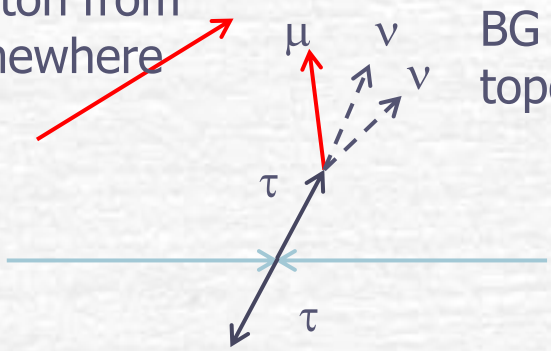
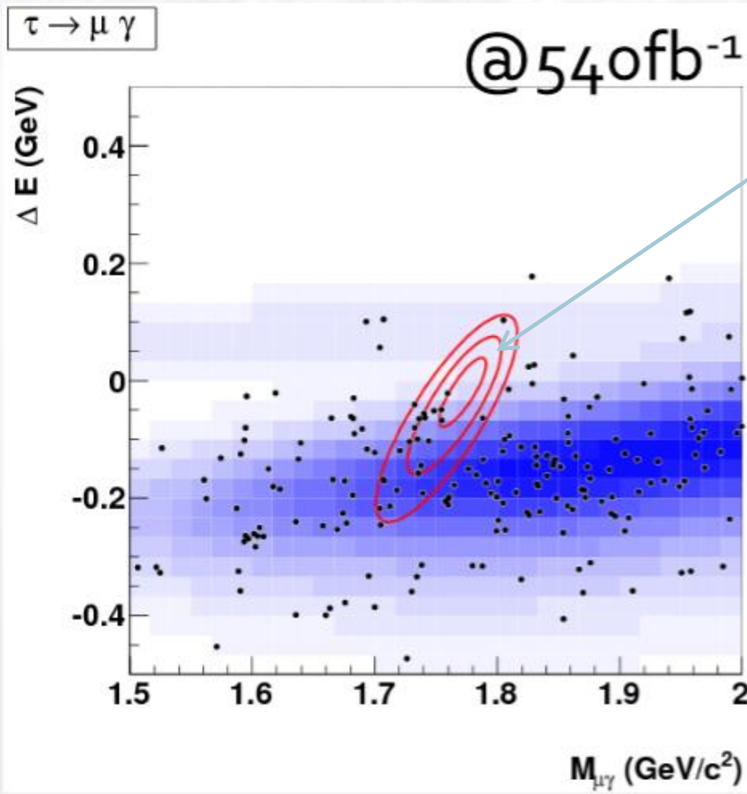
Photon from somewhere



BG event topology

$\tau \rightarrow \mu\gamma$?



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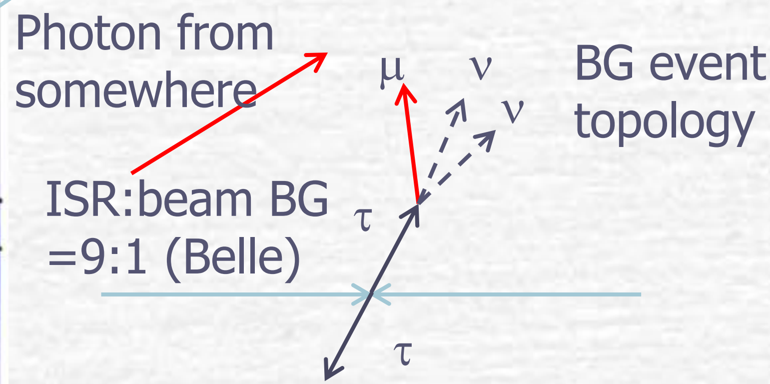

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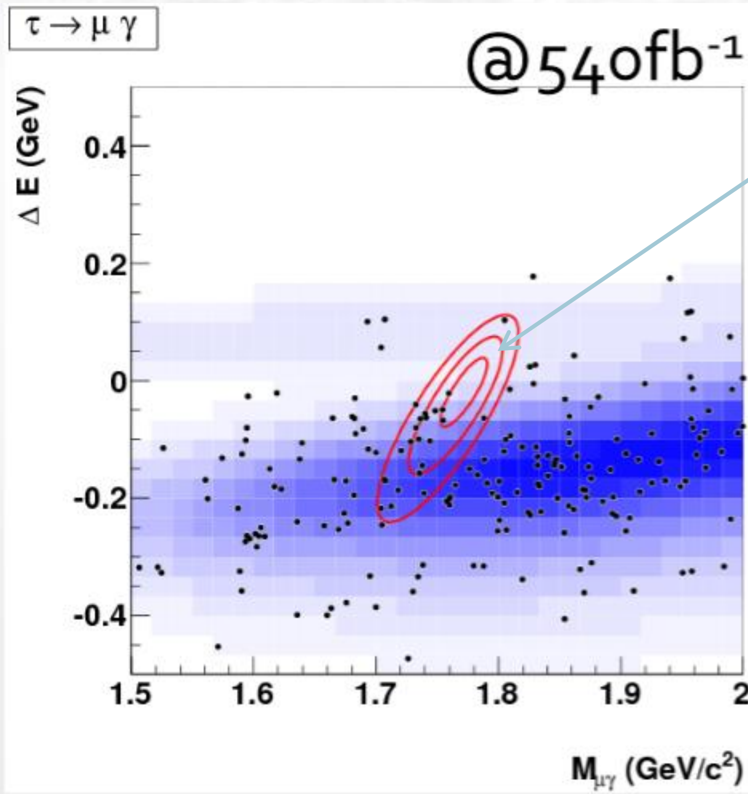

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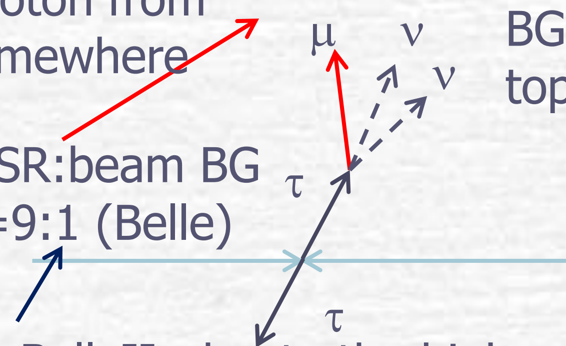
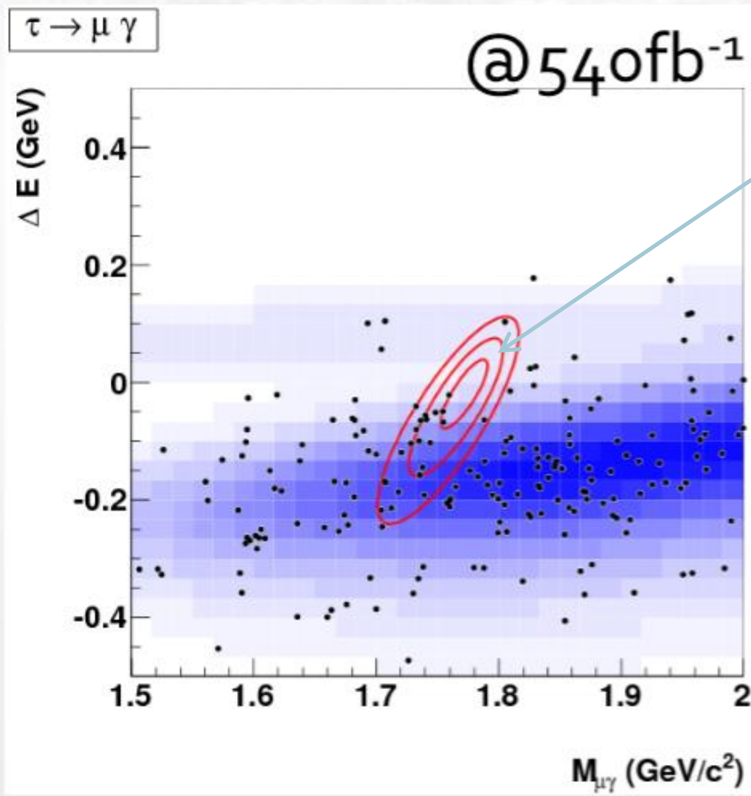


ISR:beam BG =9:1 (Belle)

At BelleII, due to the higher luminosity, this may get larger. With more realistic MC, this will be studied soon.

$\tau \to \mu\gamma$?



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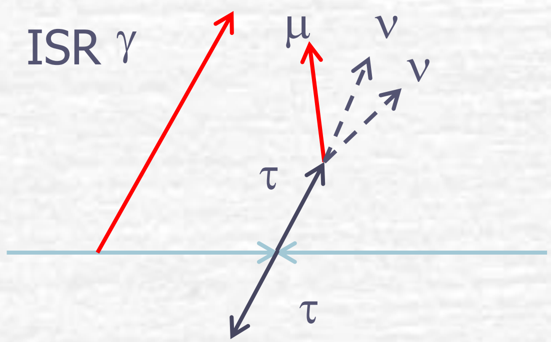
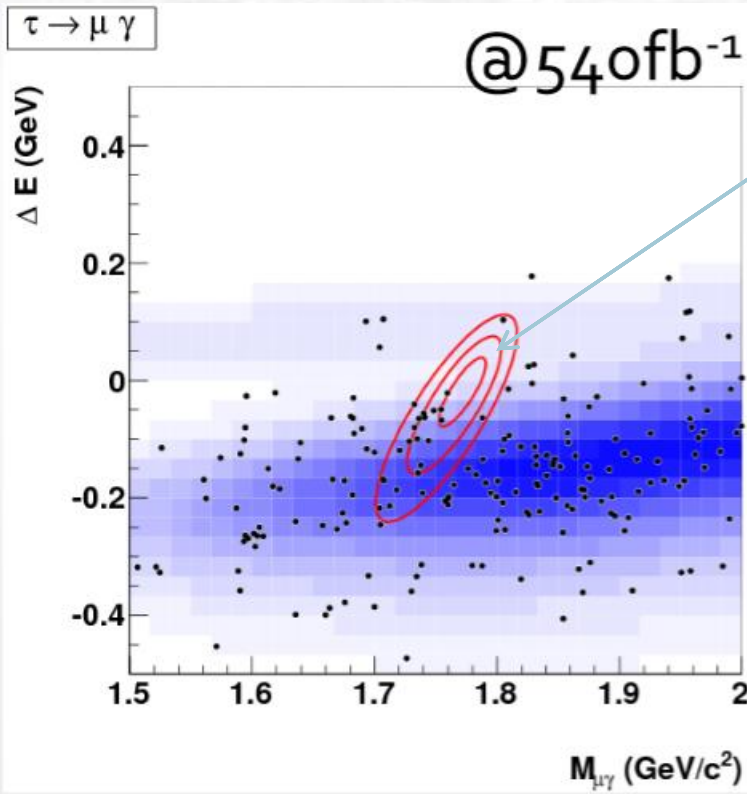


If main BG(ISR γ + SM leptonic decay) can be reduced, sensitivity is drastically modified.

$\tau \to \mu\gamma$?



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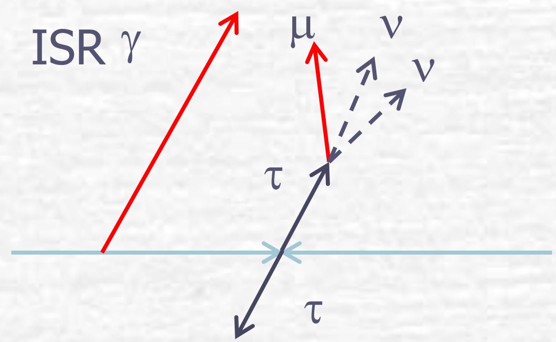
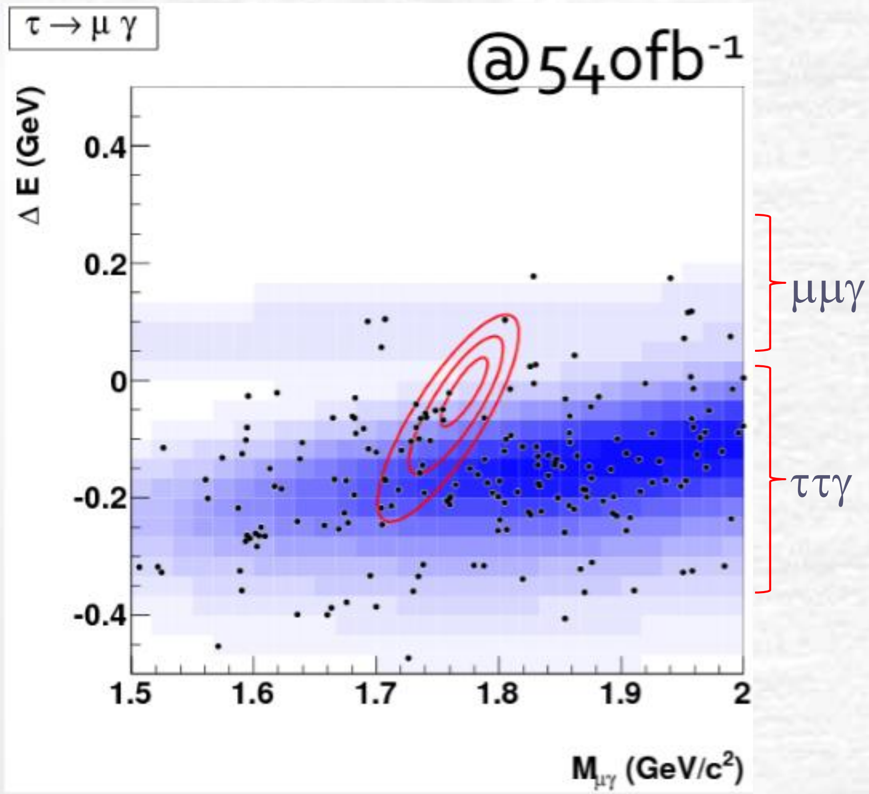


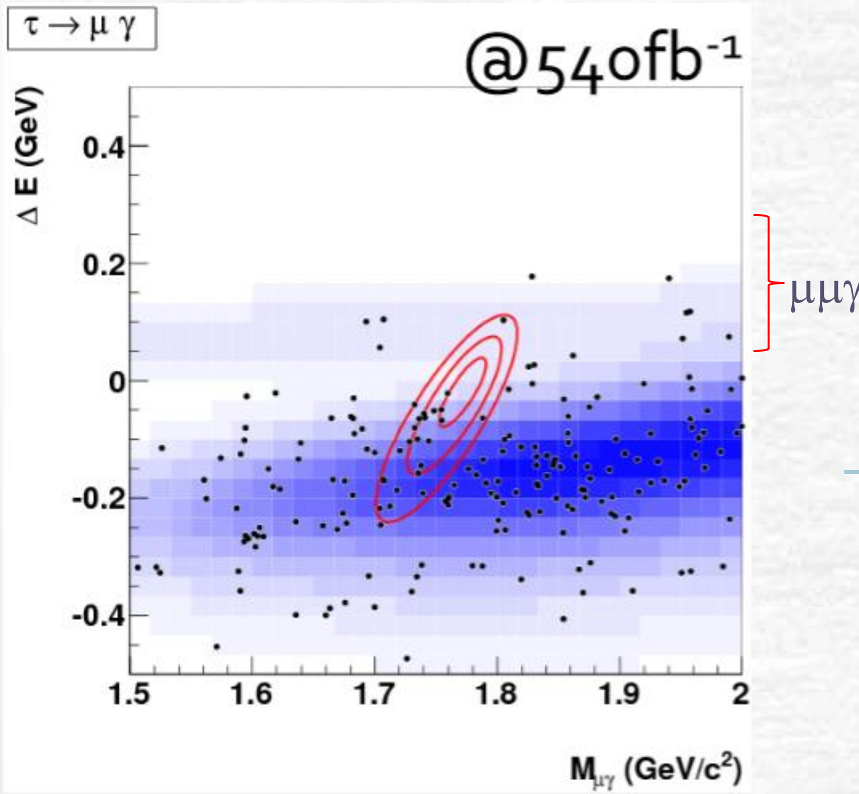
If main BG(ISR γ + SM leptonic decay) can be reduced, sensitivity is drastically modified. If you have any good idea possible to distinguish signal from this BG kinematically, please inform us! There, energy of system for tau-pair is lower than that of usual tau-pair due to ISR. But, we have no simple way to reconstruct tau-pair.

$\tau \rightarrow \mu\gamma$?



BG can be classified into 2 categories:

$\tau \to \mu\gamma$?



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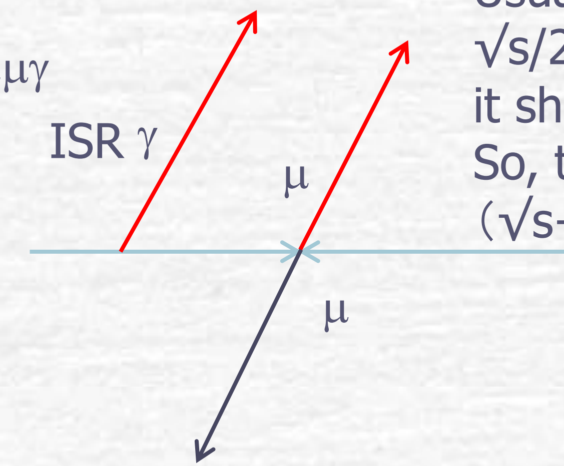

Usually E_μ should be $\sqrt{s}/2$ while, with ISR γ, it should be $(\sqrt{s}-E_\gamma)/2$.
So, the energy fake τ gets $(\sqrt{s}+E_\gamma)/2$

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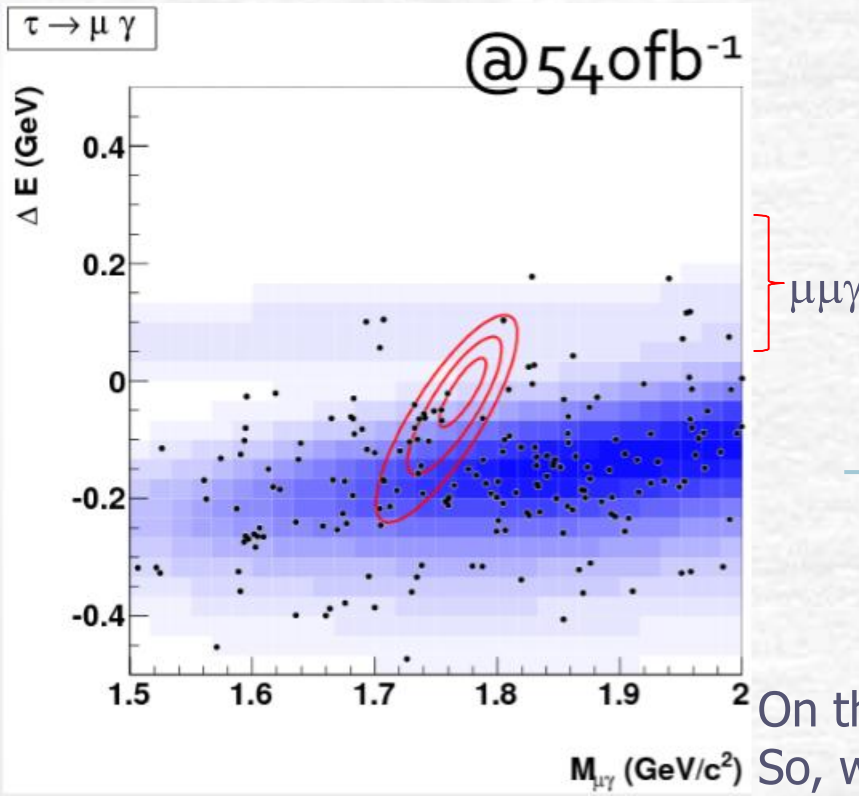

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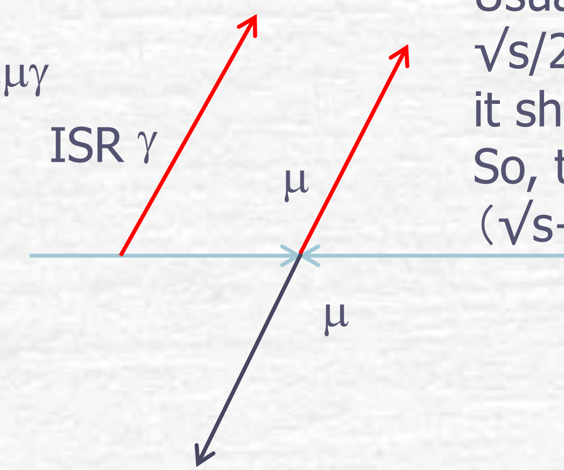

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On the upper half plane, less BGs are observed. So, when search area is focused on the UH plane, rather clean analysis is possible. But, the detection efficiency also becomes half. Thus, strategy of selection criteria should be changed to reduce $\mu\mu\gamma$.

$\tau \to e\gamma$?

- Main BG is very similar to that of $\tau \to \mu\gamma$ when $\tau \to \mu\nu\nu$ is replaced by $\tau \to e\nu\nu$.

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But the detection efficiency in the Belle analysis is lower than that of $\tau \to \mu\gamma$:

- $\tau \to \mu\gamma$:5%
- $\tau \to e\gamma$:3%

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- $\tau \to e\gamma$:3%

To veto Bhabha events, events dropping high energy into calorimeter are rejected by trigger at Belle. Some of $\tau \to e\gamma$ events are also rejected. At Belle II, more sophisticated trigger will be introduced and it gets similar to that of $\tau \to \mu\gamma$.

CPV in tau sector

- Similarly to charged LFV, CPV in the lepton sector has not been observed yet.

  →The observation indicates NP.

Some model where new scalar propagates similarly to W predicts CPV in lepton sector.

→$\tau^{\pm} \to \pi^{\pm} K_S{}^{0} \nu$ (Phys. Rev. Lett. 107, 131801 (2011))

- How to observe CPV?

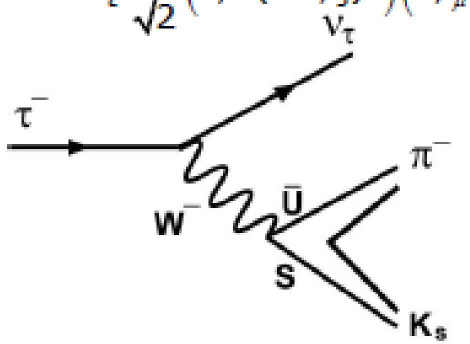
  →Evaluate decay angle from τ^{+} and τ^{-}.

CPV search in $\tau \to \pi K_S^0 \nu$

-Effective Hamiltonian

SM

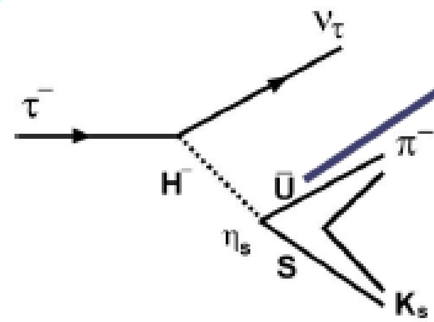
$$H_{SM} = \sin\theta_c \frac{G}{\sqrt{2}} \left(\bar{\nu}\gamma^\mu(1-\gamma_5)\tau\right)\left(\bar{s}\gamma_\mu(1-\gamma_5)u\right)$$



Scalar Boson

$$H_{NP} = \sin\theta_c \frac{G}{\sqrt{2}} \left(\bar{\nu}(1+\gamma_5)\tau\right)\left(\bar{s}(\eta_s + \eta_p\gamma_5)u\right)$$

Complex Coupling constant



NP

$$J_\mu^{K\pi} = \langle K(p_1)\pi(p_2) | \bar{s}\gamma_\mu u | 0 \rangle$$
$$= (p_1 - p_2)^\nu T_{\nu\mu} F(Q^2) + Q_\mu F_s(Q^2)$$

$$T_{\mu\nu} = g_{\mu\nu} - \frac{Q_\mu Q_\nu}{Q^2}$$

Form Factor：F （vector）
Fs（scalar）

$$F_s(Q^2) \to F_s(Q^2) = F_s(Q^2) + \frac{\eta_s}{m_\tau} F_H(Q^2)$$

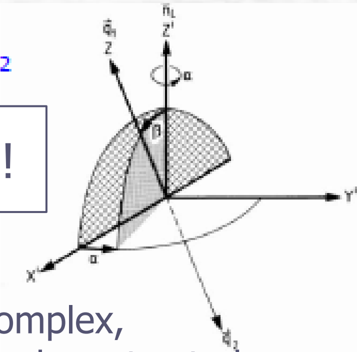
$$F_H(Q^2) \equiv \langle K(p_1)\pi(p_2) | \bar{s}u | 0 \rangle$$

Differential decay width and CPV

$$\frac{d\Gamma(\tau^-)}{dQ^2 d\cos\theta d\cos\beta} = \left[A(Q^2) - B(Q^2)(3\cos^2\Psi - 1)(3\cos^2\beta - 1)\right]\cdot |F|^2 + m_\tau^2 |F_s|^2$$

$$- C(Q^2)\cos\beta\cos\psi \cdot \mathrm{Re}(F F_s^*(\eta_s))$$

CPV appears here!



$Q^2 = M_{K\pi}^2$, $A(Q^2), B(Q^2), C(Q^2)$: known function.

β: direction of Ks in $K_s\pi$ rest frame

Ψ: direction of τ in the $K_s\pi$ rest frame.

(θ: direction of $K_s\pi$ system in the τ rest frame. Correlated with Ψ)

Since η is complex,
this term can be extracted.

$$A_i^{\mathrm{cp}} = \frac{\iiint_{Q_{1,i}^2}^{Q_{2,i}^2} \cos\beta\cos\psi \left(\frac{d\Gamma_{\tau^-}}{d\omega} - \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}{\frac{1}{2}\iiint_{Q_{1,i}^2}^{Q_{2,i}^2} \left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}$$

$$\simeq \langle\cos\beta\cos\psi\rangle_{\tau^-}^i - \langle\cos\beta\cos\psi\rangle_{\tau^+}^i$$

Values measured experimentally

with $d\omega = dQ^2 d\cos\theta d\cos\beta$.

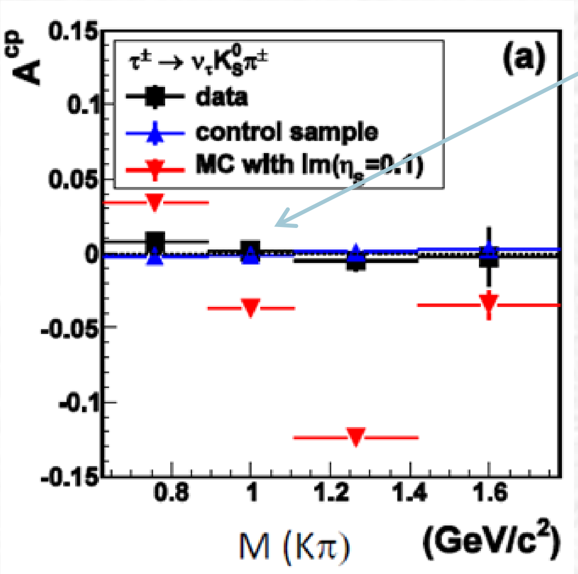
Belle result and prospect at Belle II

Data sample: 700fb^{-1}

$A_{cp} = (1.8 \pm 2.1(stat) \pm 1.4(sys))x10^{-3}$

$|Im(\eta_s)| <$ (0.012-0.026) at 90 %C.L.

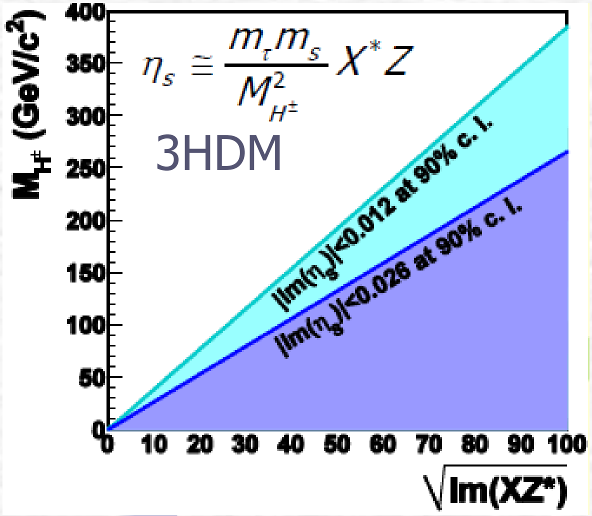
Corrected using control sample ($\tau \to \pi\pi\pi\nu$), since final state of $\tau \to \pi\pi\pi\nu$ is same as that of $\tau \to K_s^0\pi\nu$. Main contribution to systematics is the statistics of this control sample. So, it is expected that systematics is also scaled by luminosity.



Black: data

Blue: control sample ($\tau \to \pi\pi\pi\nu$)

Red: MC sample with (large) CPV



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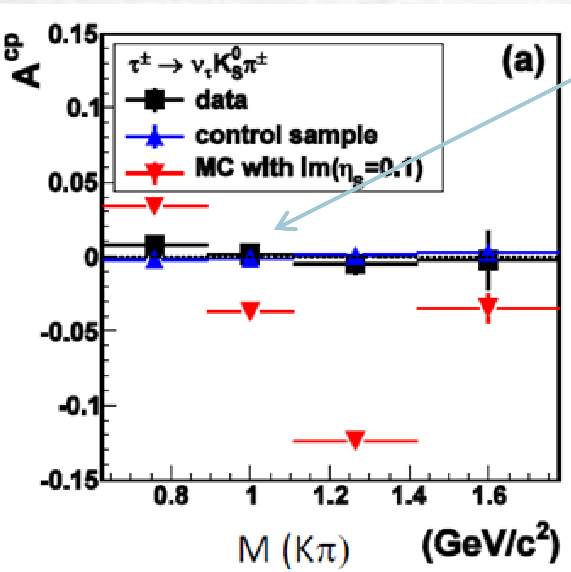

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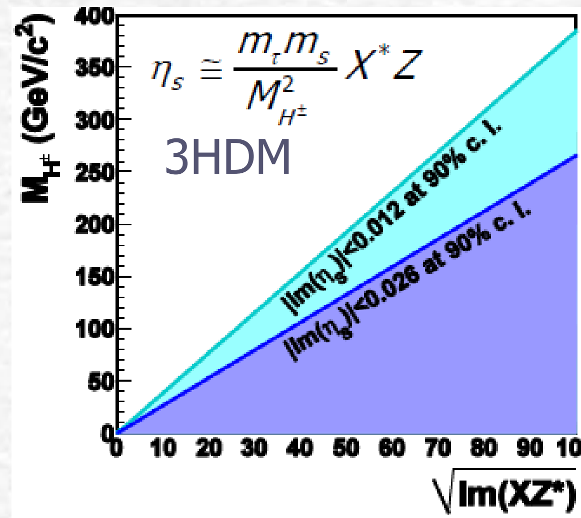
50ab^{-1}: x70

statistic 2.1→0.3

systematic 1.4→0.2



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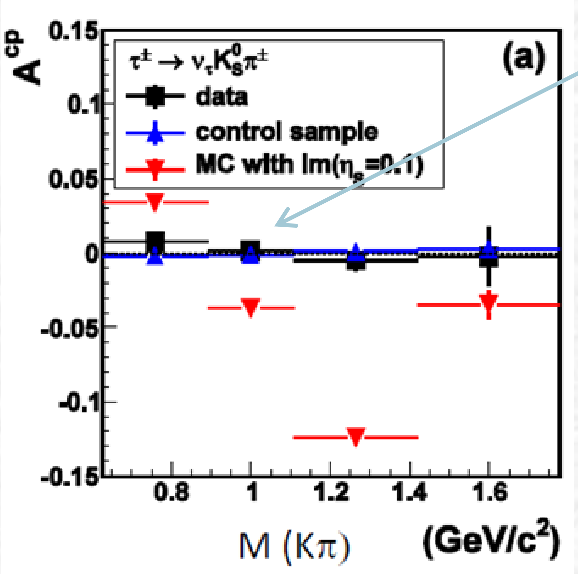

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$$A_{cp} = (1.8 \pm 2.1(stat) \pm 1.4(sys))x10^{-3}$$

|Im(η_s)|< (0.012-0.026) at 90 %C.L.

Corrected using control sample ($\tau \rightarrow \pi\pi\pi\nu$), since final state of $\tau \rightarrow \pi\pi\pi\nu$ is same as that of $\tau \rightarrow K_s^0\pi\nu$. Main contribution to systematics is the statistics of this control sample. So, it is expected that systematics is also scaled by luminosity.

Black: data

Blue: control sample ($\tau \rightarrow \pi\pi\pi\nu$)

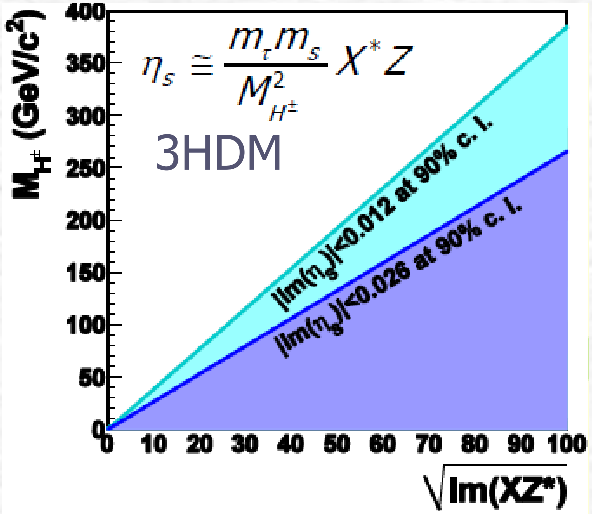
Red: MC sample with (large) CPV

50ab^{-1}: x70

statistic 2.1→0.3

systematic 1.4→0.2

We will obtain one order more sensitive result.



tau EDM/MDM

In SM, tau EDM is almost 0 while some BSMs predict sizable tau EDM. Most opportunistic prediction is $O(10^{-18})$. Belle's sensitivity is $O(10^{-17})$. At Belle II?

PHYSICAL REVIEW D **81,** 033007 (2010) Tarek Ibrahim[1,2] and Pran Nath[2]

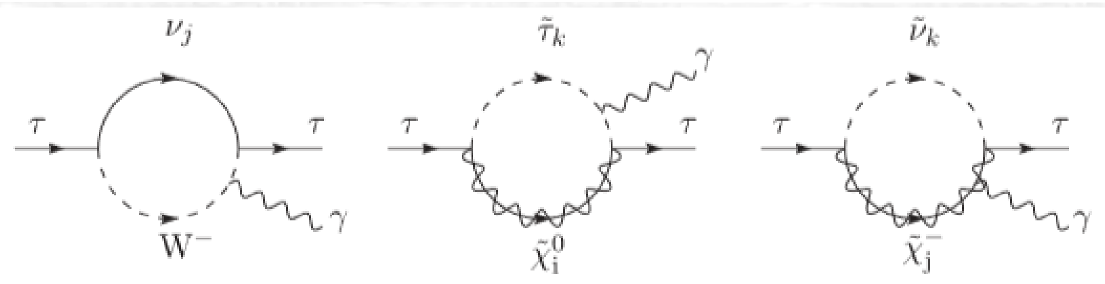
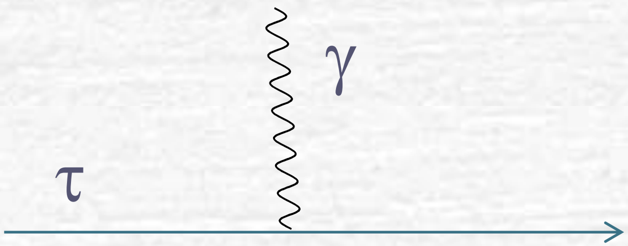


TABLE I. A sample illustration of the contributions to the electric dipole moments of ν_τ and τ. The inputs are as follows: $\tan\beta = 5$, $|f_3| = 90$, $|f_4| = 120$, $|f_5| = 75$, $m_0 = 150$, $|A_0| = 100$, $\tilde{m}_1 = 75$, $\tilde{m}_2 = 150$, $\mu = 130$, $\chi_3 = 1.0$, $\chi_4 = 0.6$, $\chi_5 = -0.8$, $\alpha_E = 0.3$ and $\alpha_N = 0.6$. All masses are in units of GeV and all angles are in radian.

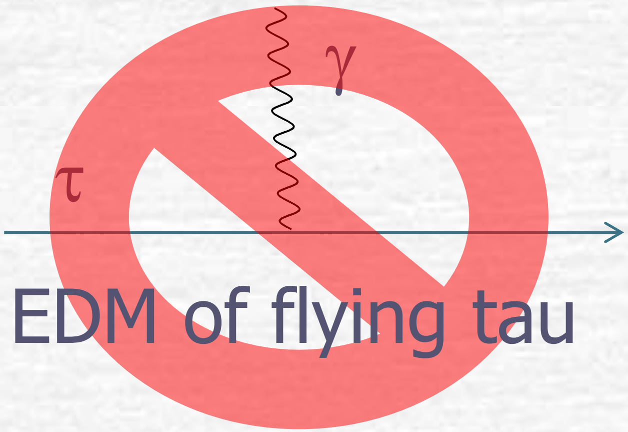
m_E(TeV)	m_N(TeV)	d_τ^W e · cm	$d_\tau^{\chi^+}$ e · cm	$d_\tau^{\chi^0}$ e · cm	d_ν^W e · cm	$d_\tau^{\chi^+}$ e · cm
0.1	0.2	6.5×10^{-18}	-3.4×10^{-18}	5.0×10^{-19}	3.7×10^{-18}	-2.4×10^{-18}
2.0	1.0	4.0×10^{-20}	-7.2×10^{-22}	3.0×10^{-23}	5.1×10^{-20}	-7.1×10^{-22}

Measurement of tau EDM/MDM



EDM of flying tau?

Measurement of tau EDM/MDM



EDM of flying tau

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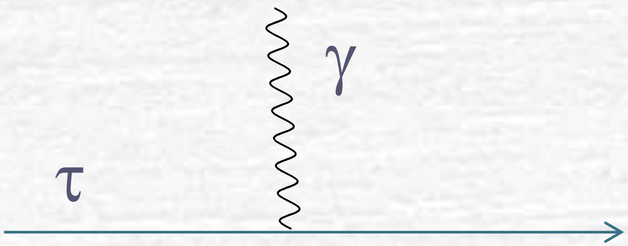
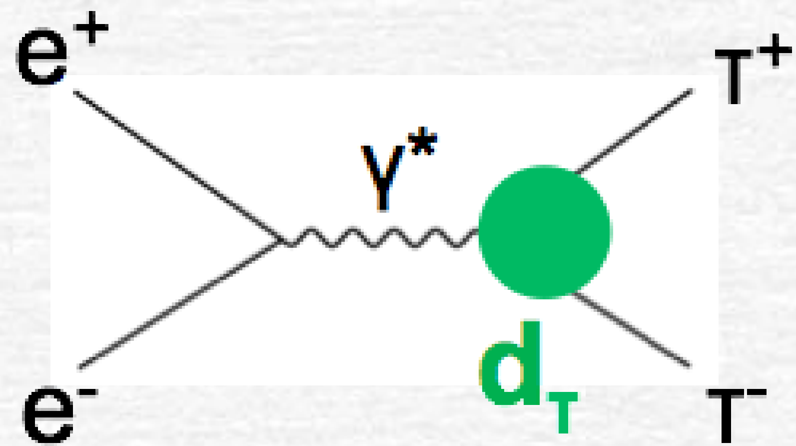
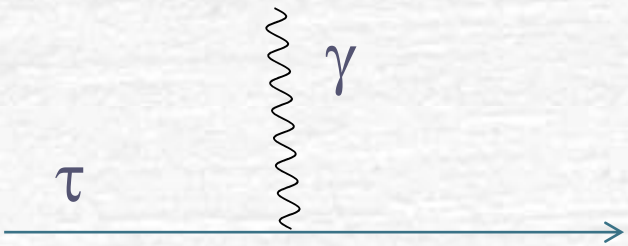


EDM of flying tau

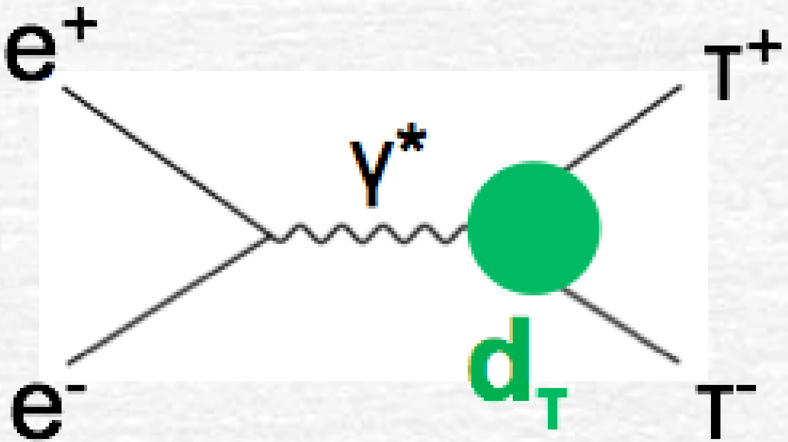


From tau-pair creation vertex, EDM/MDM will be measured.

Measurement of tau EDM/MDM

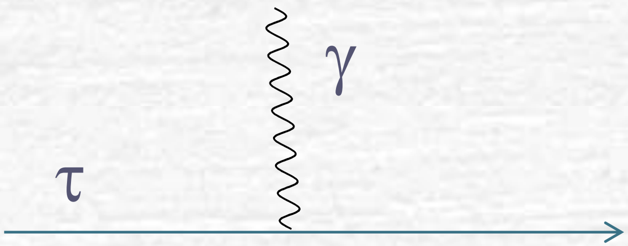


EDM of flying tau

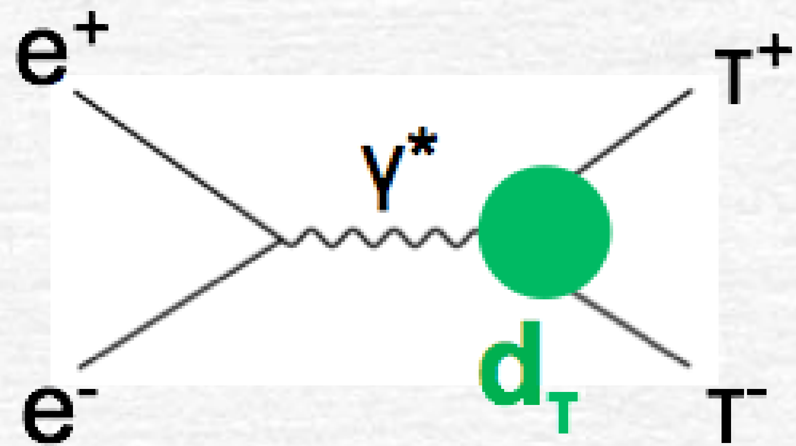


From tau-pair creation vertex, EDM/MDM will be measured via cross-section of tau-pair.

Measurement of tau EDM/MDM



EDM of flying tau



From tau-pair creation vertex,
EDM/MDM will be measured
via ~~cross-section of tau-pair.~~
via optimal observable.

Optimal observable

Amplitude for tau-pair creation:

$$\mathcal{M}^2_{prod} = \mathcal{M}^2_{SM} + Re(d_\tau)\mathcal{M}^2_{Re} + Im(d_\tau)\mathcal{M}^2_{Im}$$

$$\mathcal{M}^2_{SM} = \frac{e^4}{k_0^2}[k_0^2 + m_\tau^2 + |\mathrm{k}^2|(\hat{\mathrm{k}}\hat{\mathrm{p}})^2 - S_+S_-|\mathrm{k}|^2(1-((\hat{\mathrm{k}}\hat{\mathrm{p}})^2)]$$
$$+2(\hat{\mathrm{k}}S_+)(\hat{\mathrm{k}}S_-)(|\mathrm{k}|^2 + (k_0 - m_\tau)^2(\hat{\mathrm{k}}\hat{\mathrm{p}})^2)$$
$$-2k_0(k_0 - m_\tau)(\hat{\mathrm{k}}\hat{\mathrm{p}})((\hat{\mathrm{k}}S_+)(\hat{p}S_-) + (\hat{\mathrm{k}}S_+)(\hat{p}S_-))$$
$$+2k_0^2(\hat{p}S_+)(\hat{p}S_-)$$

$$\mathcal{M}^2_{Re} = 4\frac{e^3}{k_0}|\mathrm{k}|[-(m_\tau + (k_0 - m_\tau)(\hat{\mathrm{k}}\hat{p})^2)(S_+ \times S_-)\hat{k}$$
$$+k_0(\hat{\mathrm{k}}\hat{p})(S_+ \times S_-)\hat{p}]$$

$$\mathcal{L} = \bar{\tau}(i\partial\!\!\!/ - eA\!\!\!/)\tau - \frac{i}{2}d_\tau\bar{\tau}\sigma^{\mu\nu}\gamma_5\tau F_{\mu\nu} + O(d_\tau^2)$$

$p : e^+$ momentum

$k : \tau^+$ momentum

$S_\pm : \tau^\pm$ spin

By defining

$$\boxed{\mathcal{O}_{Re} = \frac{\mathcal{M}^2_{Re}}{\mathcal{M}^2_{SM}}}$$

$$\langle \mathcal{O}_{Re} \rangle \propto \int \mathcal{O}_{Re} d\sigma \propto \int \mathcal{O}_{Re}\mathcal{M}^2_{prod} d\phi$$

$$= \underbrace{\int \mathcal{M}^2_{Re} d\phi}_{\text{Offset}} + \underbrace{Re(d_\tau)}_{\text{EDM}} \underbrace{\int \frac{(\mathcal{M}^2_{Re})^2}{\mathcal{M}^2_{SM}} d\phi}_{\text{sensitivity}}$$

By extracting offset and sensitivity from MC, we can obtain d_τ.

Sensitivity at Belle and Belle II

PLB551, 16(2003)

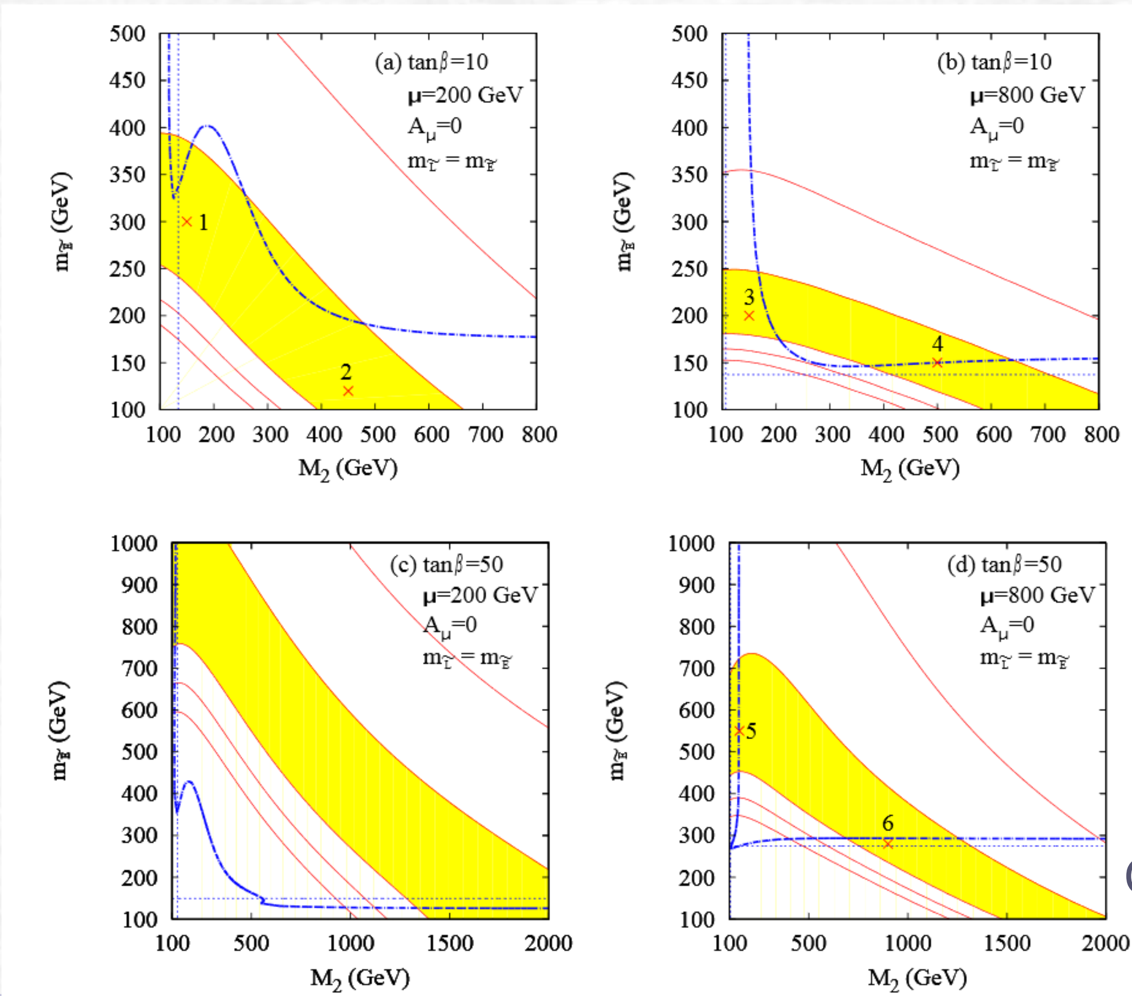
- At Belle, the result using 30fb^{-1} is published. Now, the new analysis using 825fb^{-1} is on-going.(x27 larger sample)

$$\mathrm{Re}(d_\tau)\times 10^{17} : 1.15 \pm 1.70\,(e\mathrm{cm}) \qquad \mathrm{Re}(d_\tau)\times 10^{17} : \pm 0.33\,(e\mathrm{cm})$$

$$\mathrm{Im}(d_\tau)\times 10^{17} : -0.83 \pm 0.86\,(e\mathrm{cm}) \qquad \mathrm{Im}(d_\tau)\times 10^{17} : \pm 0.30\,(e\mathrm{cm})$$

The total error of the real part is proportional to the square root of the data sample while systematics become dominant in the imaginary part.
This depends on the understandings of MC for tau decay.
So, we need to understand MC sample at Belle II deeply.

muon g-2 and New Physics



$$a_\mu^{exp} - a_\mu^{SM} = 29.2(8.9) \times 10^{-10} \Rightarrow 3.3\sigma$$

(TAU2014)

For example, MSSM can predict the allowed region for slepton, gaugino mass from the difference between the observed g-2 and SM prediction.

As Mibe-san reported,
at FNAL and J-PARC, experiments for 0.1ppm measurement of muon g-2 is on constructing.

Cho, Hagiwara, Matsumoto,Nomura
JHEP11(2011)068

Prediction of muon g-2 and budget of each contribution

QED contribution	11 658 471.808 (0.015) $\times 10^{-10}$	Kinoshita & Nio, Aoyama et al
EW contribution	15.4 (0.2) $\times 10^{-10}$	Czarnecki et al
Hadronic contribution		
LO hadronic	**694.9 (4.3)** $\times 10^{-10}$	HLMNT11
NLO hadronic	-9.8 (0.1) $\times 10^{-10}$	HLMNT11
light-by-light	10.5 (2.6) $\times 10^{-10}$	Prades, de Rafael & Vainshtein
Theory TOTAL	**11 659 182.8 (4.9)** $\times 10^{-10}$	
Experiment	**11 659 208.9 (6.3)** $\times 10^{-10}$	world avg
Exp − Theory	**26.1 (8.0)** $\times 10^{-10}$	**3.3 σ discrepancy**

(Numbers taken from HLMNT11, arXiv:1105.3149)

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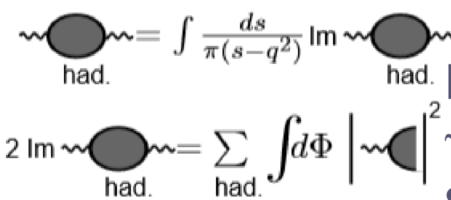

Experimentally $\gamma \rightarrow$hadrons should be evaluated.

(Numbers taken from HLMNT11, arXiv:1105.3149)

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(Numbers taken from HLMNT11, arXiv:1105.3149)

The largest uncertainty comes from the experimental measurement!

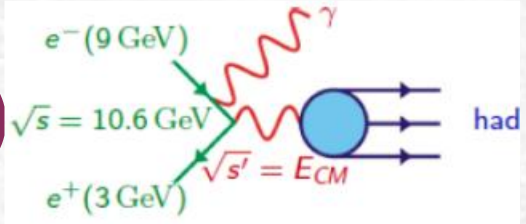
Content of LO Hadronic

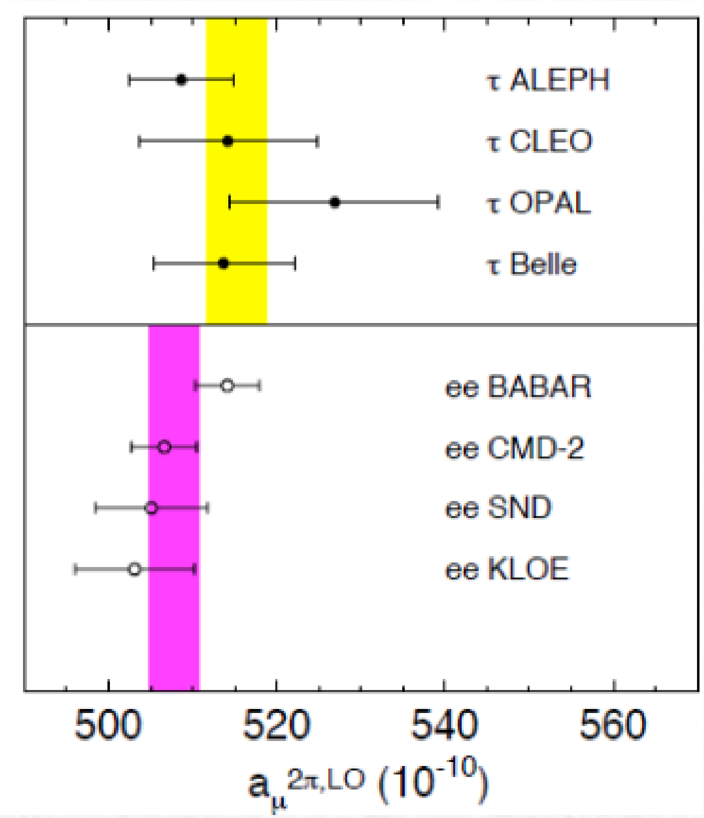
e^+e^- process	Contribution to $a_\mu^{had,\,LO}$ [$\times 10^{-10}$] val ± sta. ± process sys. ± common sys.	Total error
$\pi^+\pi^-$	507.80 ± 1.22 ± 2.50 ± 0.56	2.88
$\pi^+\pi^-\pi^0$	46.00 ± 0.42 ± 1.03 ± 0.98	1.48
K^+K^-	21.63 ± 0.27 ± 0.58 ± 0.36	0.73
$\pi^+\pi^-\pi^0\pi^0$	18.01 ± 0.14 ± 0.17 ± 0.40	0.46
$\pi^+\pi^-\pi^+\pi^-$	13.35 ± 0.10 ± 0.43 ± 0.29	0.53
$K_S^0K_L^0$	12.96 ± 0.18 ± 0.25 ± 0.24	0.39
$\pi^0\gamma$	4.42 ± 0.08 ± 0.13 ± 0.12	0.19
$K\bar{K}\pi$ (partly from isospin)	2.39 ± 0.07 ± 0.12 ± 0.08	0.16
$K\bar{K}\pi\pi$ (partly from isospin)	1.35 ± 0.09 ± 0.38 ± 0.03	0.39
$\pi^+\pi^-\eta$	1.15 ± 0.06 ± 0.08 ± 0.03	0.10
Total $a_\mu^{had,\,LO}$	$692.3 \pm 1.4 \pm 3.1 \pm 2.4 \pm 0.2_\psi \pm 0.3_{QCD}$	4.18

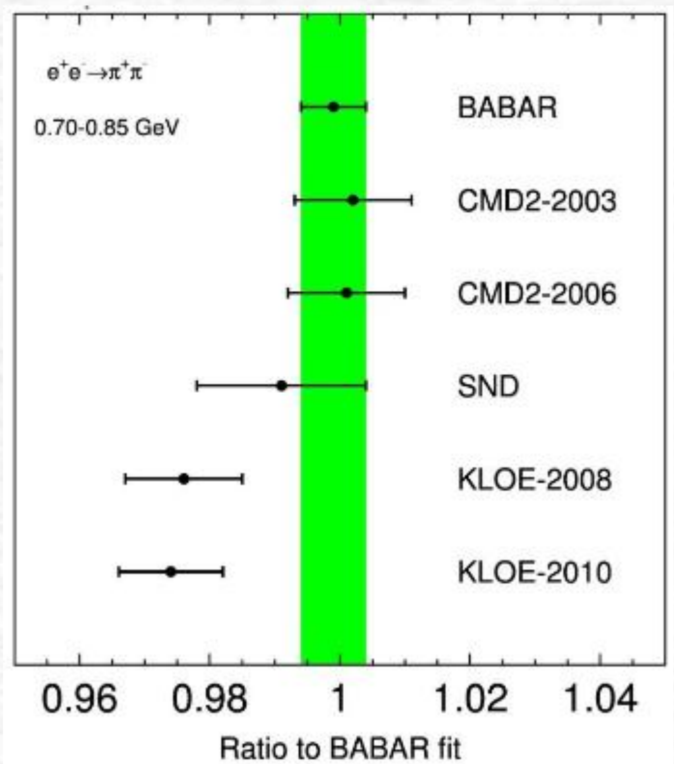
[1] M. Davier, A. Hoecker, B. Malaescu, Z. Zhang, Eur. Phys. J. C (2011) 71: 1515 [DOI 10.1140/epjc/s10052-010-1515-z].

Taken from Jason D. Crnkovic's TAU2012 talk

Recent status for ee→ππ(γ)

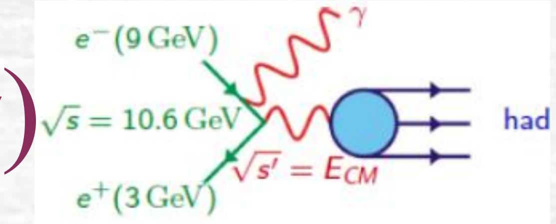


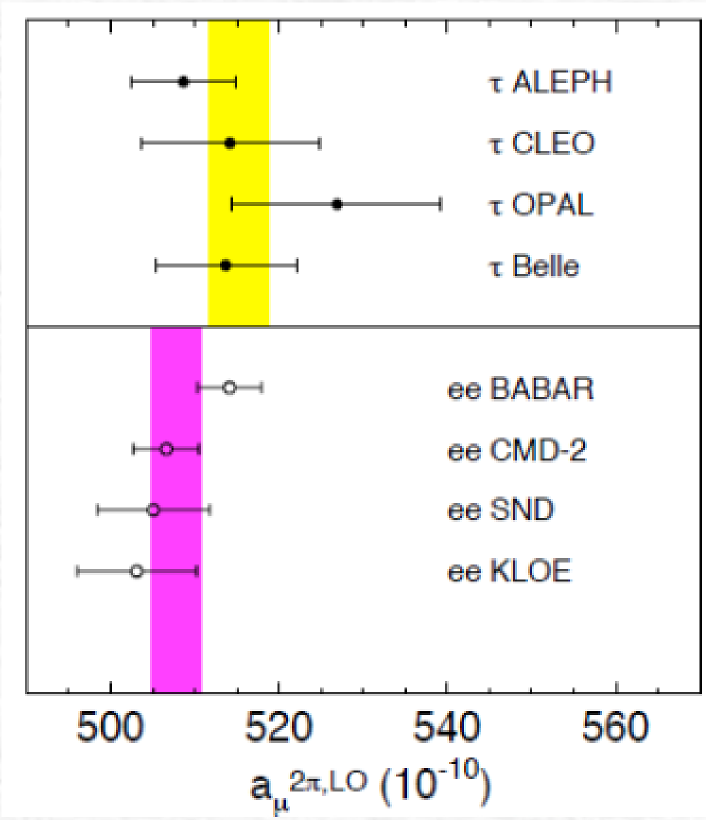


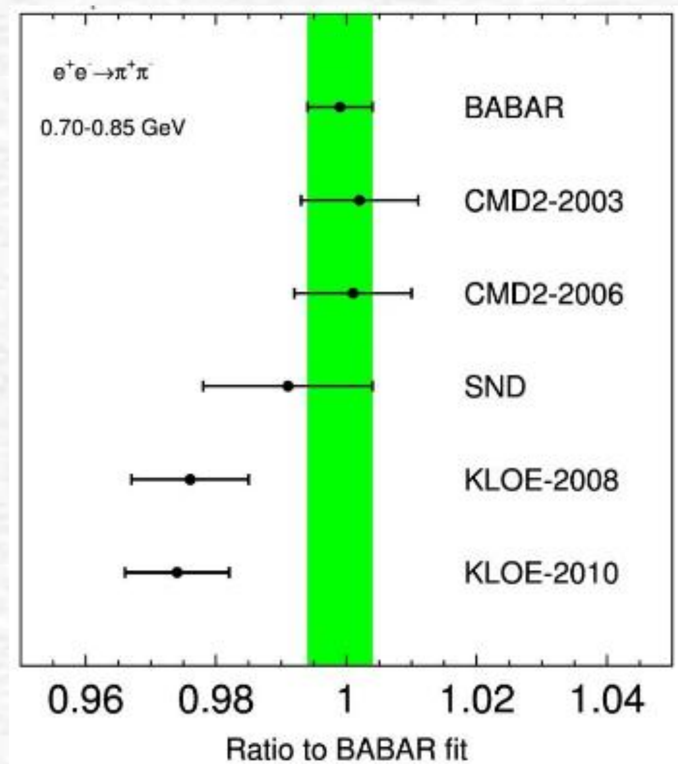


The recent big issue is the difference of the results on BaBar and KLOE.
Belle can not measure it since the trigger is not designed to measure it.

Recent status for ee→ππ(γ)

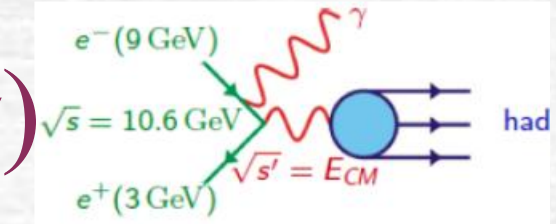


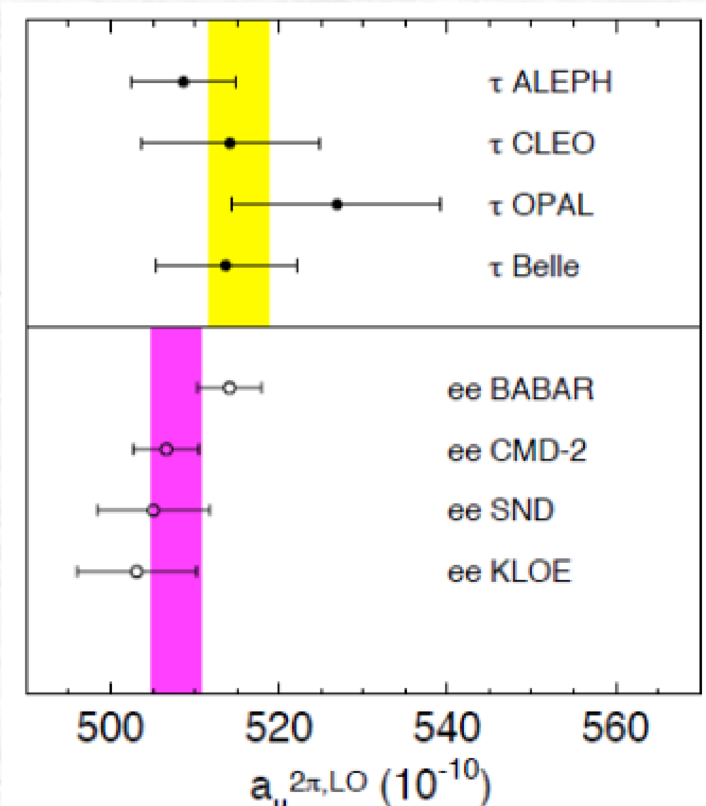


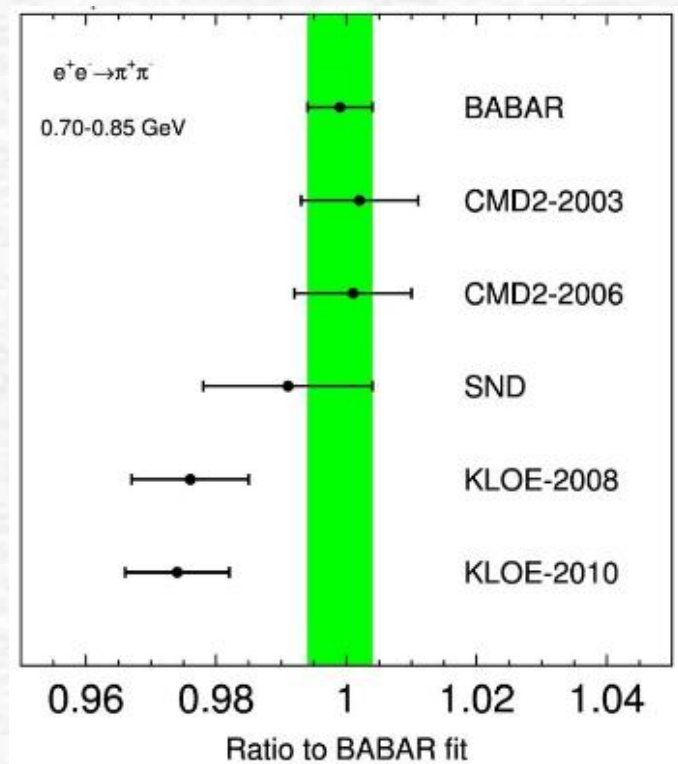


At Belle II, new trigger to keep relating events is designed.
We expect the similar accuracy as that of BaBar. → ~40% more accurate result?

Recent status for ee→ππ(γ)





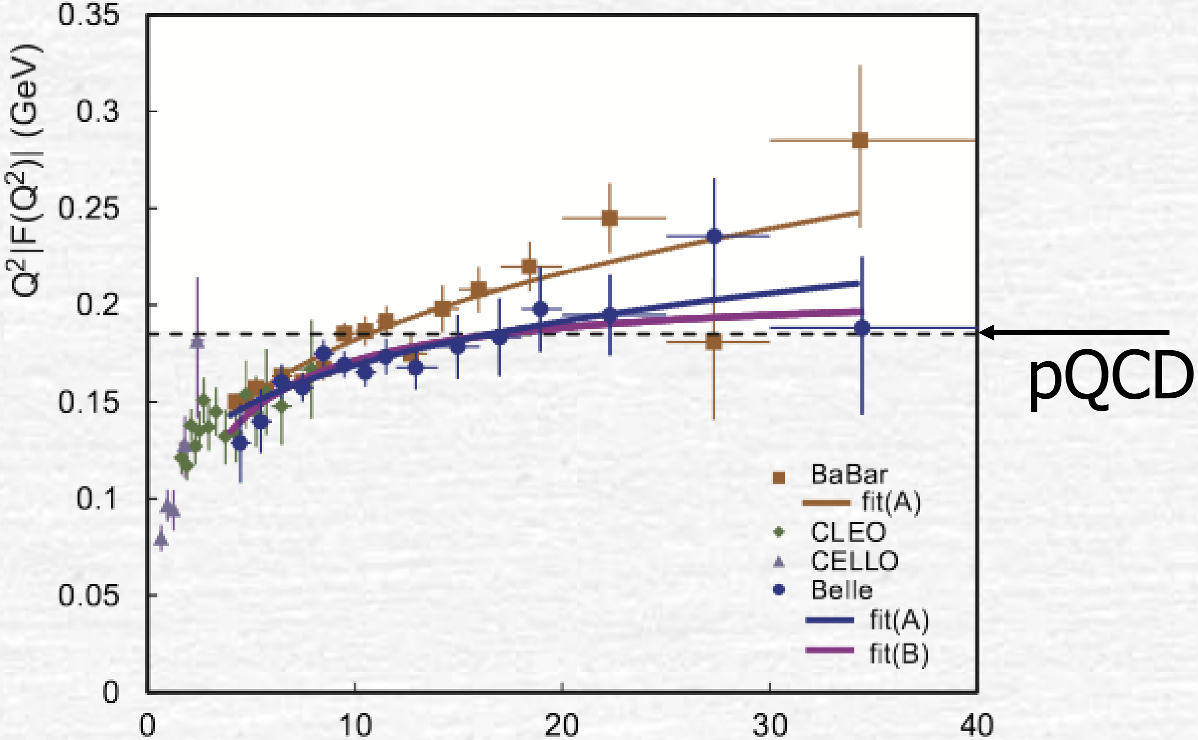


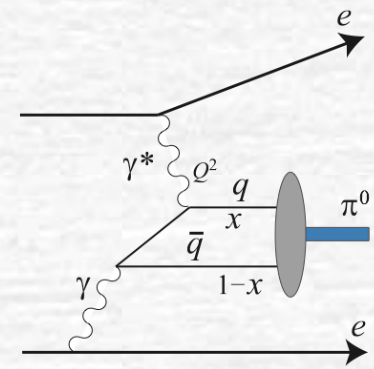
Not only $\pi\pi\gamma$ but also $\pi\pi\pi^0\gamma$, $KK\gamma$ should be.

At Belle II, new trigger to keep relating events is designed.
We expect the similar accuracy as that of BaBar. → ~40% more accurate result?

Two-Photon Process

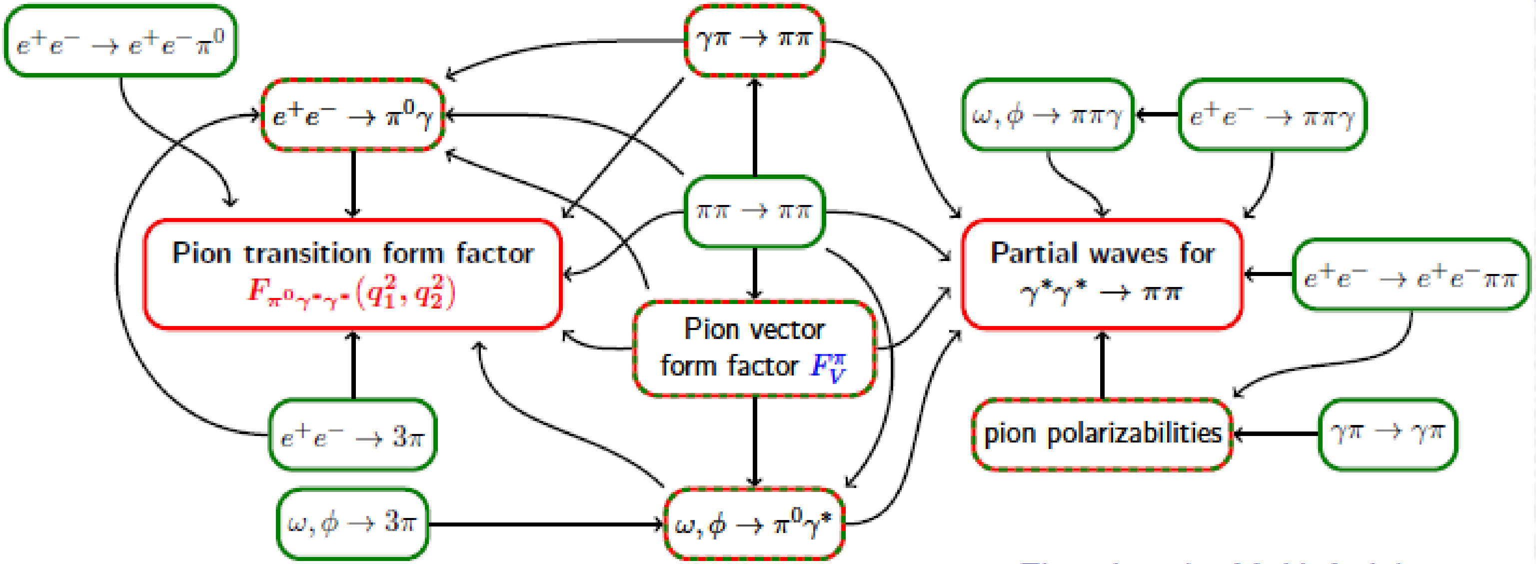
- Transition Form Factor using single tag process





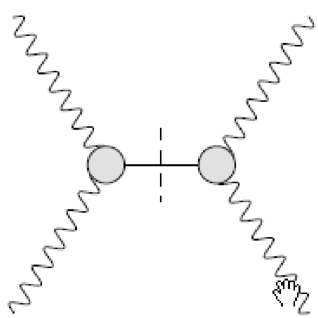
- BaBar data exceeds pQCD asymptotic limit
- Belle consistent with pQCD
- Up to 60 GeV^2 with 10 ab^{-1}
- BaBar also measured η, η′, and η_c from 4 to 40 GeV^2
- BhaBha veto reduces the efficieny at Belle.

A roadmap for HLbL



→ Flowchart by M. Hoferichter

Pion pole



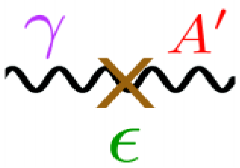
- input the doubly-virtual and singly-virtual pion transition form factors $\mathcal{F}_{\gamma^*\gamma^*\pi^0}$ and $\mathcal{F}_{\gamma^*\gamma\pi^0}$
- dispersive analysis of transition form factor:

→ Hoferichter et al., EPJC **74** (2014) 3180

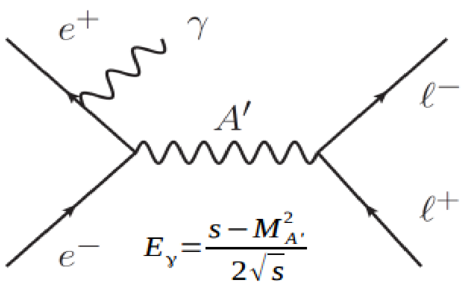
Dark Photon search

Introduction

- Dark Photon A’ motivated by Dark Matter, g-2, ..
- Minimal Dark Matter model: Dark Matter particle χ and a new scalar or gauge Boson A’ as s-channel annihilation mediator ($m_{A'} > 2m_{\chi}$)
- Additional U(1)’ symmetry → Kinetic mixing* of massive Dark Photon with the SM photon



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$



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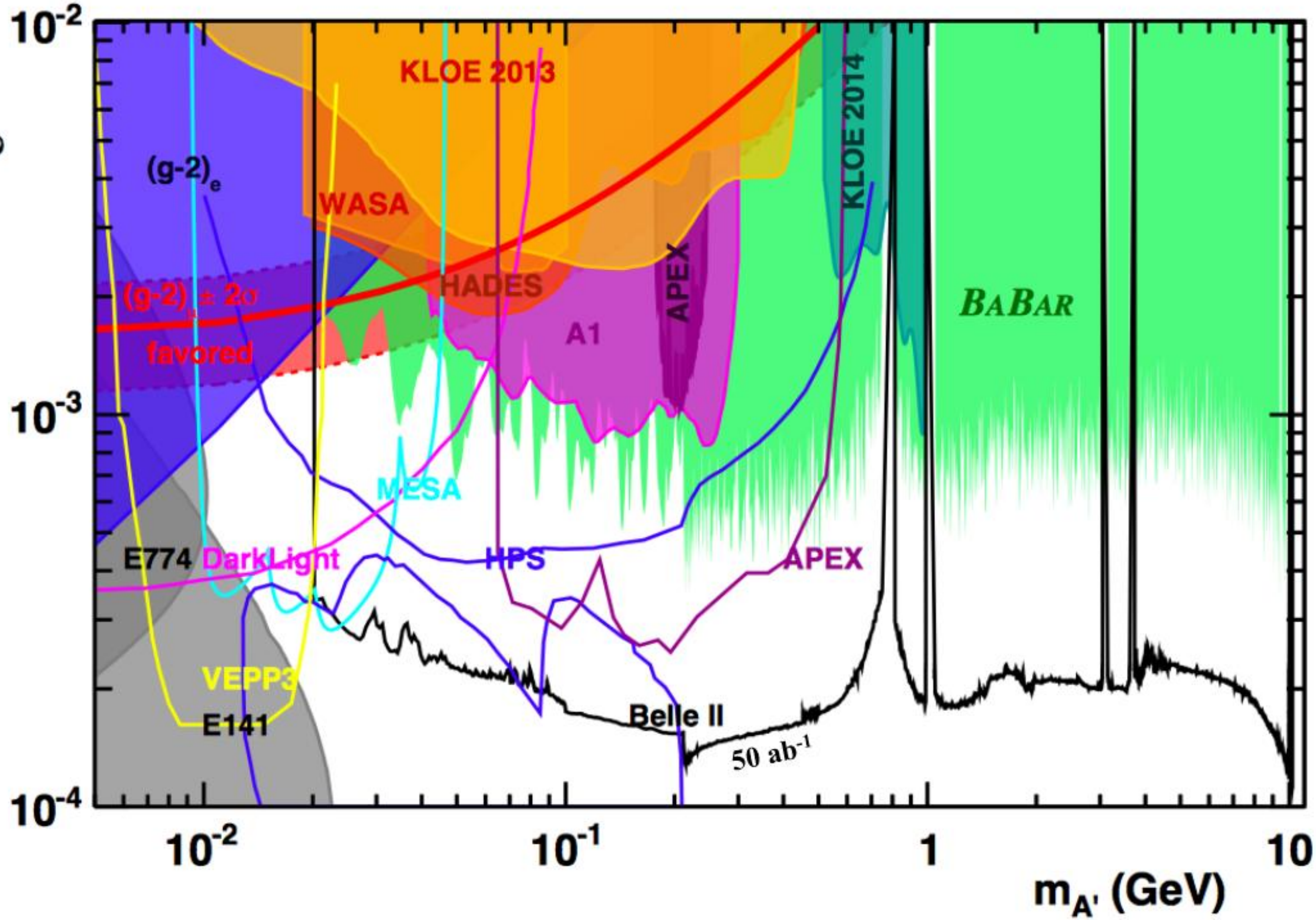
*Holdom, Phys. Lett B166, 1986

Reach in near future



Summary

- Utilizing Belle II data sample, we like to reveal lepton flavor structure (~1o years)
  - Off-diagonal: LFV
  - Diagonal: EDM/g-2
  - Complex component: CPV

We expect to peep the new physics world around several hundred GeV or a few TeV.

まとめ

- Belle IIのデータを利用して、レプトンのフレーバ構造を明らかにしていく(~10年)
  - 非対角要素はLFV
  - 対角要素はEDM/g-2
  - 複素成分はCPV

  ターゲットは数百～千GeV

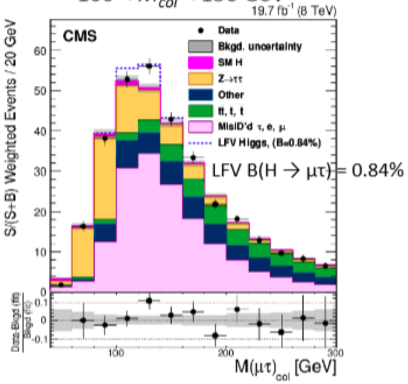
  もっと面白いアイディアがある！という方はB2TiPに来てください

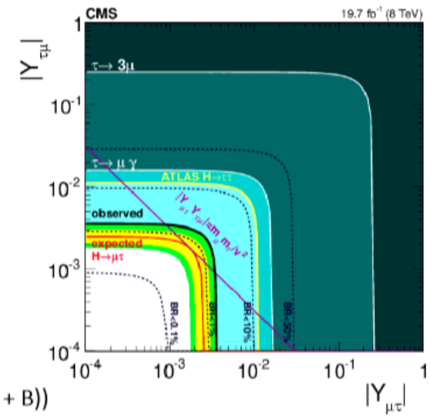
Higgs→τμ

Lepton Flavor Violating (LFV) decays
H→μτ_e, H→μτ_h (CMS)

Post-Fit M_{col}

$100 < M_{col} < 150$ GeV





All categories combined, each category weighted by significance (S/(S + B))

- A slight excess of signal events - still consistent within background uncertainties
  - significance of 2.4 standard deviations
- Best fit branching fraction
  - B(H → μτ) = (0.84 +0.39 -0.37)%
- Constraint on the branching fraction
  - B(H → μτ) < 1.51 (0.75)% at 95% CL

- BR limit <1.51% constrain the μ-τ Yukawa couplings $<3.6\times10^{-3}$
- It improves the indirect current bound by an order of magnitude.

H→eτ, H→eμ will be published soon!

Th. Lagouri, Yale Univ. EPS HEP (22-29 Jul 2015) 7

- For LFV Higgs and nothing else: LHC bound

→ $BR(\tau \to \mu\gamma) < 2.2\times10^{-9}$

$BR(\tau \to \mu\pi\pi) < 1.5\times10^{-11}$

By E.Passemar at TAU2014

ATLAS also has a result:

Best fit Br(H→μτ_{had}) = (0.77±0.62)%

No significant excess of data over SM BGs

95% CL Br(H→μτ_{had}) obs (exp.) < 1.85% (1.24 +0.50 -0.35)%

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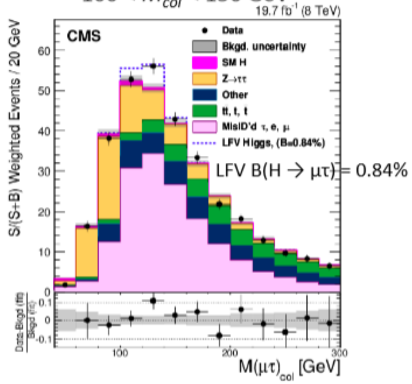
H→μτ_e, H→μτ_h (CMS)



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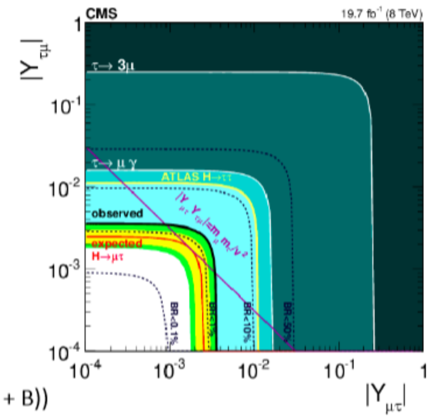

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95% CL Br(H→μτ_{had}) obs (exp.) < 1.85% (1.24 +0.50 -0.35)%

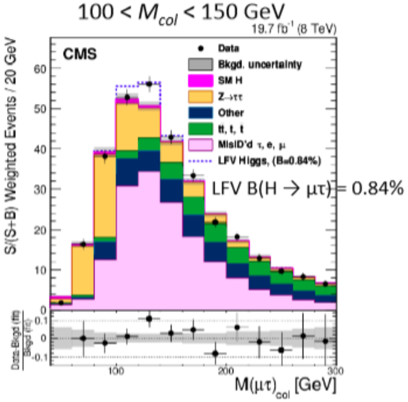
Weighted mean:
(0.82±0.32)%
and UL is also similar.

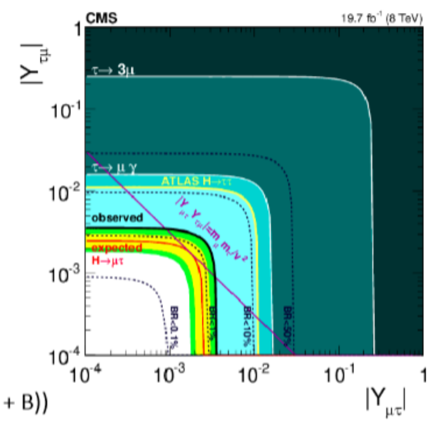
Higgs→τμ

Lepton Flavor Violating (LFV) decays
H→μτ_e, H→μτ_h (CMS)

Post-Fit M_{col}

100 < M_{col} < 150 GeV





All categories combined, each category weighted by significance (S/(S + B))

- A slight excess of signal events - still consistent within background uncertainties
  - significance of 2.4 standard deviations
- Best fit branching fraction
  - B(H → μτ) = (0.84 +0.39 -0.37)%
- Constraint on the branching fraction
  - B(H → μτ) < 1.51 (0.75)% at 95% CL

- BR limit <1.51% constrain the μ-τ Yukawa couplings <3.6x10^{-3}
- It improves the indirect current bound by an order of magnitude.

H→eτ, H→eμ will be published soon!

Th. Lagouri, Yale Univ. EPS HEP (22-29 Jul 2015) 7

- For LFV Higgs and nothing else: LHC bound

⇒ $BR(\tau \to \mu\gamma) < 2.2\times10^{-9}$

$BR(\tau \to \mu\pi\pi) < 1.5\times10^{-11}$

By E.Passemar at TAU2014

ATLASも出してきた

Best fit Br(H→μτ_{had}) = (0.77±0.62)%

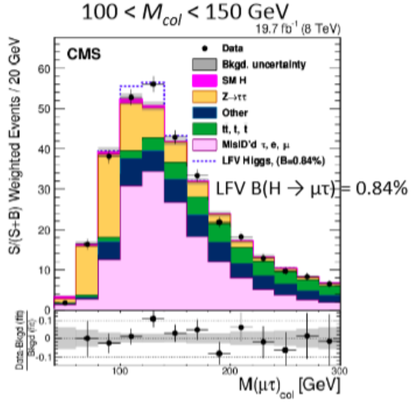
No significant excess of data over SM BGs

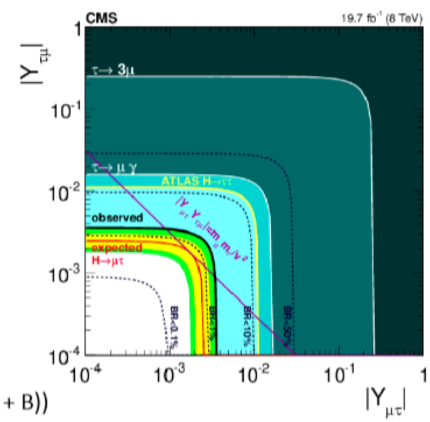
95% CL Br(H→μτ_{had}) obs (exp.) < 1.85% (1.24 +0.50 -0.35)%

注意点は:
τ→μγを使ってHiggs→τμを探索した場合Br<2x10^{-9}までいかないと同程度の探索にならないというだけの話

Higgs→τμ

Lepton Flavor Violating (LFV) decays
$H\to\mu\tau_e$, $H\to\mu\tau_h$ (CMS)





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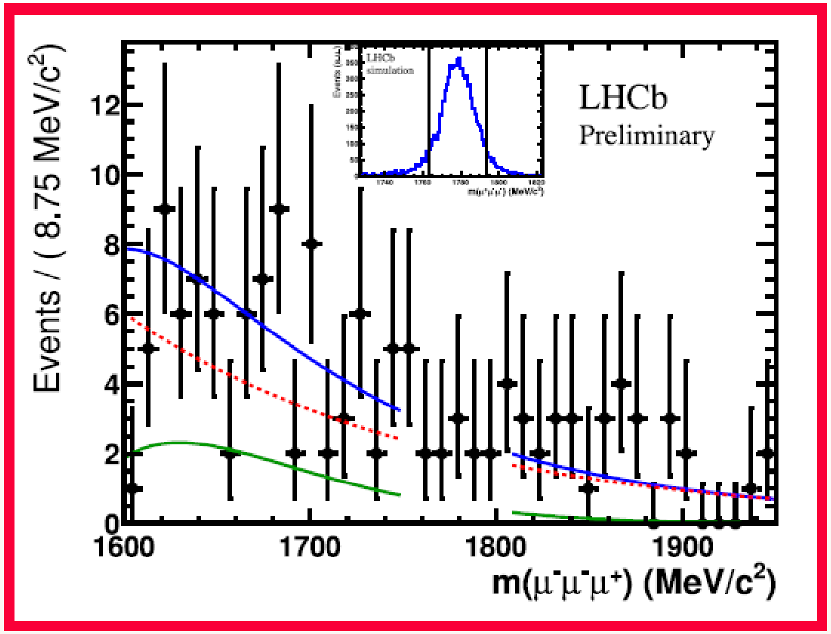
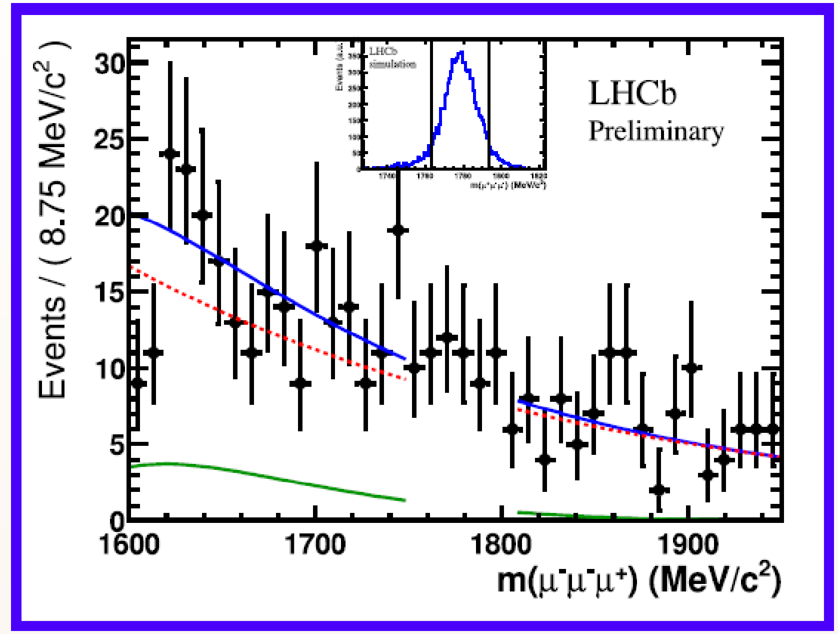
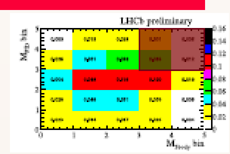
注意点は：
Higgs→τμ をLHCでやったら τ→μγの探索がBr<2x10^{-9}まで済んだという話では
決してありません。

observed events

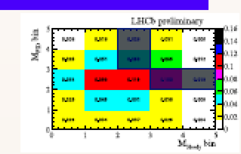




11 % of the signal
0.03 % of the background



21 % of the signal
0.14 % of the background



red dashed combinatorial background

green $D_s^+ \to \eta(\mu^-\mu^+\gamma)\mu^+\nu_\mu$

blue combined background

1 fb^{-1}

LHCb-CONF-2012-015

$\tau \rightarrow 3\mu$ on LHCb

- LHCb
  - At 14 TeV, 100x more tau will be produced.
  - Trigger efficiency will be doubled.
  - 20fb^{-1} data sample will be accumulated.
  - $\sqrt{1400}=40 \rightarrow 1.1\text{x}10^{-9}$
- Belle II
  - x70 ($2.1\text{x}10^{-8}$)$\rightarrow 3\text{x}10^{-10}$

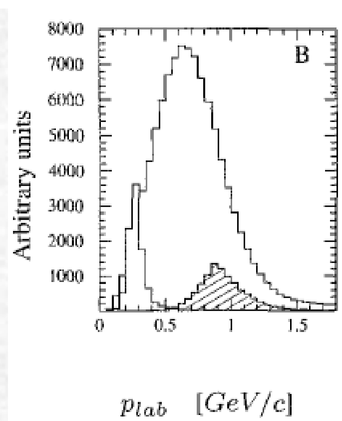
L_μ-L_τ?

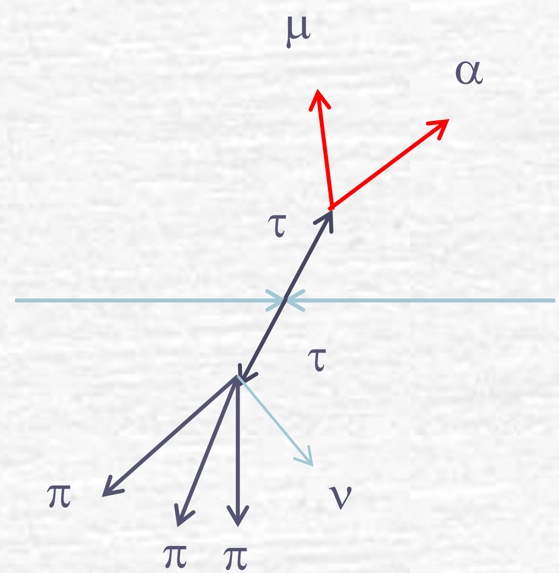
Z. Phys. C 68, 25–28 (1995)

A search for the lepton-flavour violating decays $\tau \to e\alpha$, $\tau \to \mu\alpha$

ARGUS Collaboration

472pb^{-1}





3π系をpseudo tauとして、
信号のtauの4 momentum を仮定
P_τ-P_μからP_αを評価
２体なのでmonochromatic
pseudoなので広がりがある

Trigger Efficiency at Belle

Y.Unno

	Bhabha(%)	Cosmic(%)	Physics(%)
$B^+ \to K^+\pi^-$	0 ± 0	0.06 ± 0.03	98.8 ± 0.2
$B^0 \to \pi^0\pi^0$	1.1 ± 0.2	0.2 ± 0.1	98.0 ± 0.2
$B^0 \to \rho^0\gamma$	0.04 ± 0.03	0.06 ± 0.03	99.2 ± 0.1
$B^+ \to \tau^+\nu$	0 ± 0	0.10 ± 0.04	97.7 ± 0.2
$\tau^+ \to \mu^+\gamma$	9.0 ± 0.4	4.5 ± 0.3	73.5 ± 0.6
$e^+e^- \to \mu^+\mu^-\gamma$	60.8 ± 0.7	11.0 ± 0.4	20.6 ± 0.6

@214MeV

- 60% vetoed by Bhabha trigger. Similar or worse for $\pi^+\pi^-\gamma$.
- Scale factor for the radiative $\mu\mu$ trigger makes it difficult that no. of the $\mu\mu\gamma$ events is correctly estimated.
- At Belle II, more sophisticated Bhabha trigger ensures high efficiency.