Lepton flavor violation including $\tau\to\mu\mu\mu$

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on behalf of Belle Collaboration

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Outline

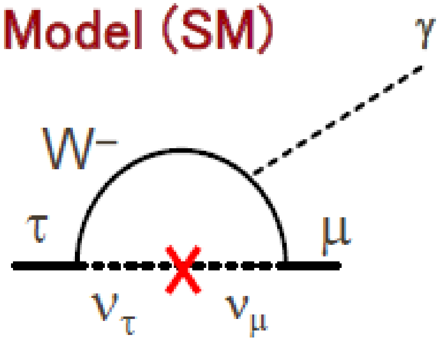
- Motivation
- LFV results from Belle and BaBar
- Result on $\tau \to \mu\mu\mu$ from LHCb
- Conclusion

Motivation

- Lepton flavor violation (LFV) in charged leptons

⇒negligibly small probability in the Standard Model (SM) even including neutrino oscillations:

→ $\mathcal{B}(\tau \to \mu\gamma) < O(10^{-54})$

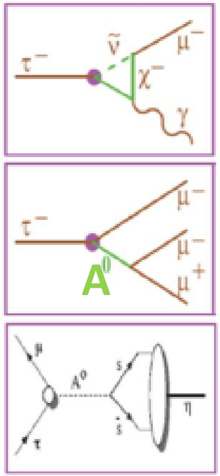


Observation of LFV is a clear signature of New Physics (NP)

- Many extensions of the SM predict LFV decays.
  - These branching fractions could be enhanced as high as current experimental sensitivity. (~10^{-8})

- Tau lepton = The heaviest charged lepton
  - Expected strong coupling to NP
  - Many possible LFV decay modes

Illustrations

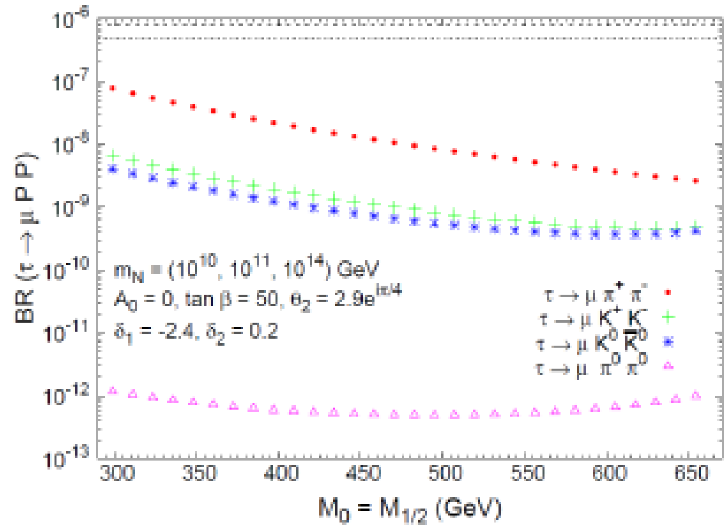


New Physics and τ LFV

We would like to find LFV and New Physics (NP)
as well as to learn what NP induces LFV

Ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{\mathcal{B}(\tau^-\to e^-e^+e^-)}{\mathcal{B}(\tau\to e\gamma)}$	$0.4\ldots2.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{\mathcal{B}(\tau^-\to \mu^-\mu^+\mu^-)}{\mathcal{B}(\tau\to \mu\gamma)}$	$0.4\ldots2.3$	$\sim 2\cdot10^{-3}$	$0.06\ldots0.1$
$\frac{\mathcal{B}(\tau^-\to e^-\mu^+\mu^-)}{\mathcal{B}(\tau\to e\gamma)}$	$0.3\ldots1.6$	$\sim 2\cdot10^{-3}$	$0.02\ldots0.04$
$\frac{\mathcal{B}(\tau^-\to \mu^-e^+e^-)}{\mathcal{B}(\tau\to \mu\gamma)}$	$0.3\ldots1.6$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{\mathcal{B}(\tau^-\to e^-e^+e^-)}{\mathcal{B}(\tau^-\to e^-\mu^+\mu^-)}$	$1.3\ldots1.7$	~ 5	$0.3\ldots0.5$
$\frac{\mathcal{B}(\tau^-\to \mu^-\mu^+\mu^-)}{\mathcal{B}(\tau^-\to \mu^-e^+e^-)}$	$1.2\ldots1.6$	~ 0.2	$5\ldots10$

NUHM JHEP06(2008)079

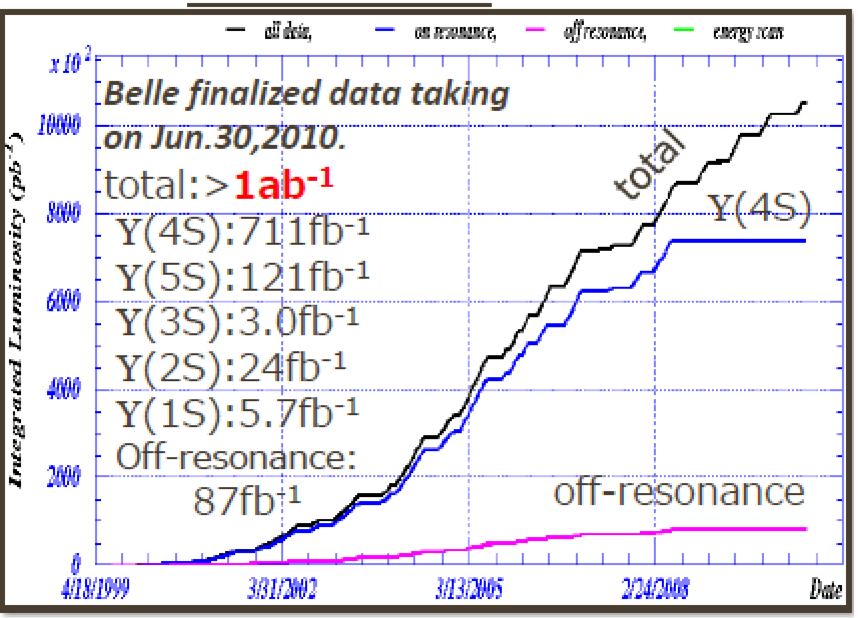


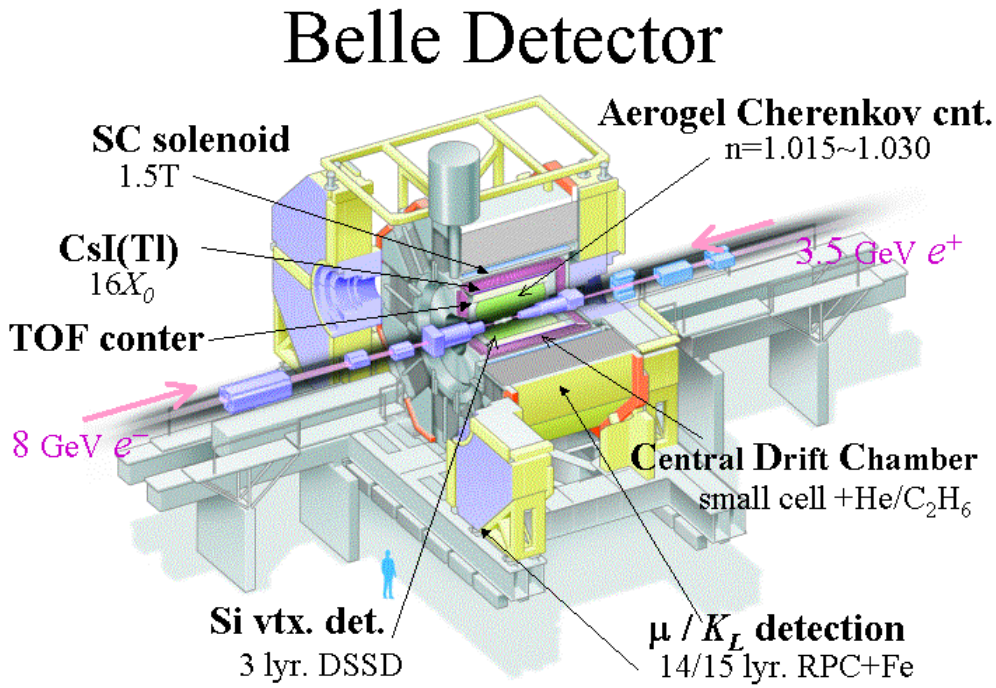
Various LFV searches are important because they can distinguish NP models even if one LFV decay has been observed.

It is strong advantage that τ has many kinds of LFV decays.
Using Belle/BaBar data, we search for τ LFV decays.

KEKB/Belle (1999-2010)

B-factory: E @ CM = 10.58 GeV
e^-(8 GeV) e^+(3.5 GeV)
$\sigma(\tau\tau) \approx 0.9$ nb, $\sigma(bb) \approx 1.1$ nb
B-factory is also τ-factory
Peak Luminosity is $2.1 \times 10^{34} cm^{-2} \cdot s^{-1}$
World highest luminosity



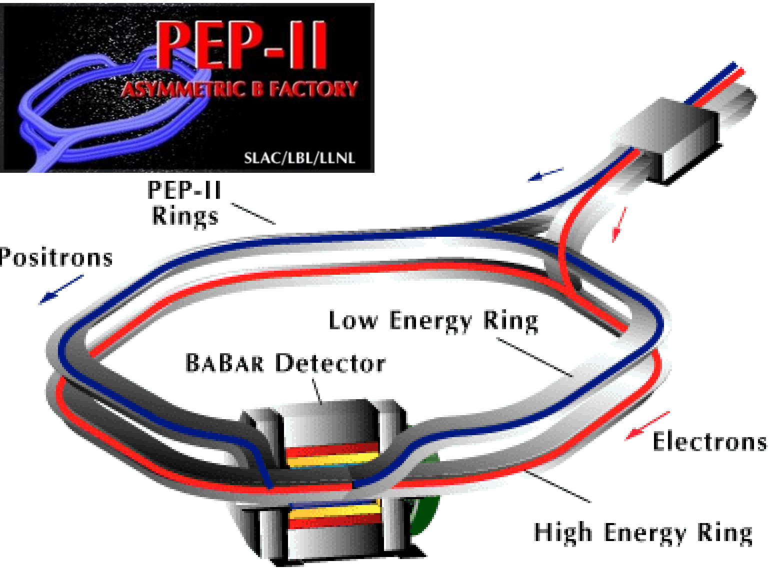


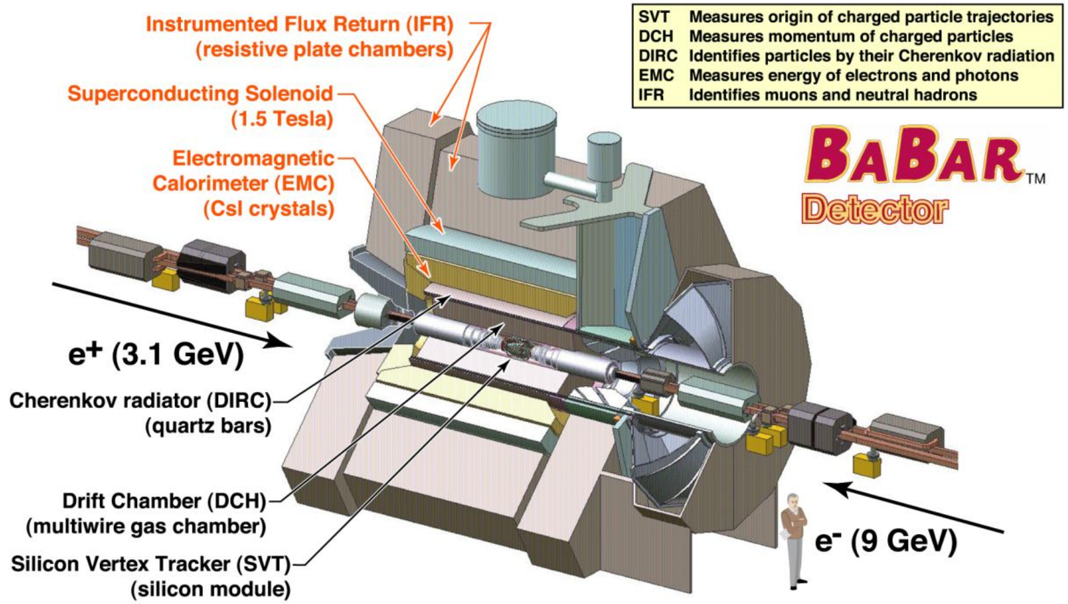
Belle detector:

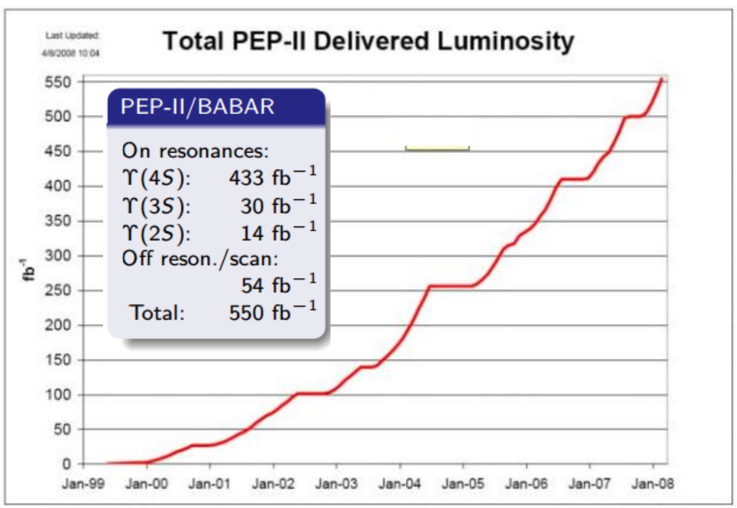
- Good track reconstruction and particle identification
- Lepton efficiency = 90%
- Fake efficiency: O(0.1)% for electrons, O(1)% for muons

9×10^8 $\tau\tau$ pairs at Belle

PEP-II/BaBar (1999-2008)







SVT: 97% efficiency, 15 μm z hit resolution

SVT+DCH: $\sigma(p_T)/p_T = 0.13\,\% \times p_T + 0.45\,\%$

DIRC: K-π separation 4.2 σ @ 3.0 GeV/c → 2.5 σ @ 4.0 GeV/c

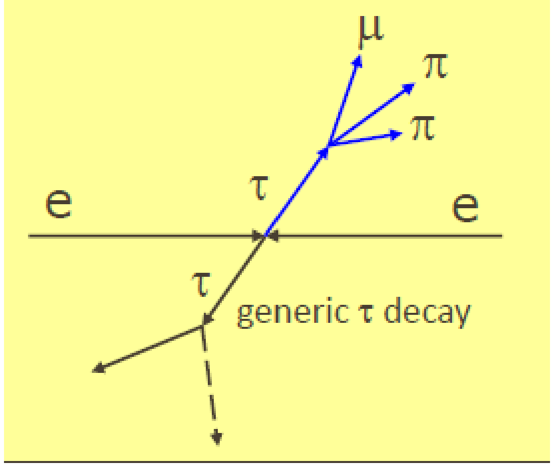
EMC: $\sigma_E/E = 2.3\,\% \cdot E^{-1/4} \oplus 1.3\,\%$

495M τ decays @ BaBar

Analysis procedure

- $e^+e^- \to \tau^+\tau^-$ Br~85%
  - τ^- → 1 prong + missing (tag side)
  - τ^+ → $\mu\pi\pi$ (signal side)

Fully reconstructed



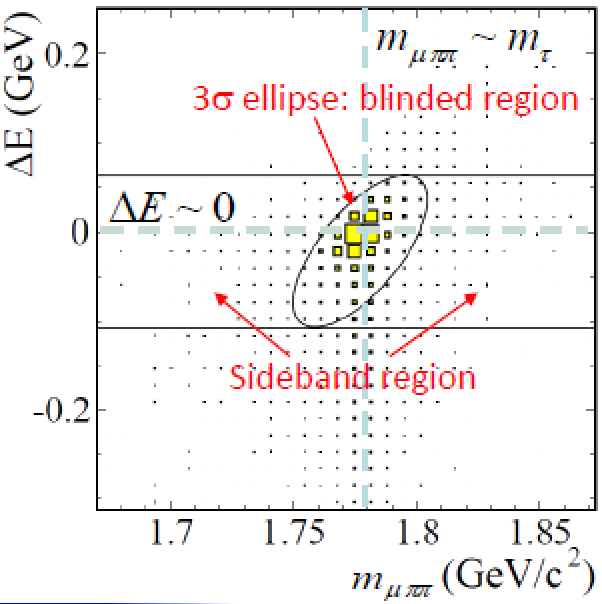
Signal extraction: $m_{\mu\pi\pi}$–ΔE plane

$$m_{\mu\pi\pi} = \sqrt{(E^2_{\mu\pi\pi} - p^2_{\mu\pi\pi})}$$

$$\Delta E = E^{CM}_{\mu\pi\pi} - E^{CM}_{beam}$$

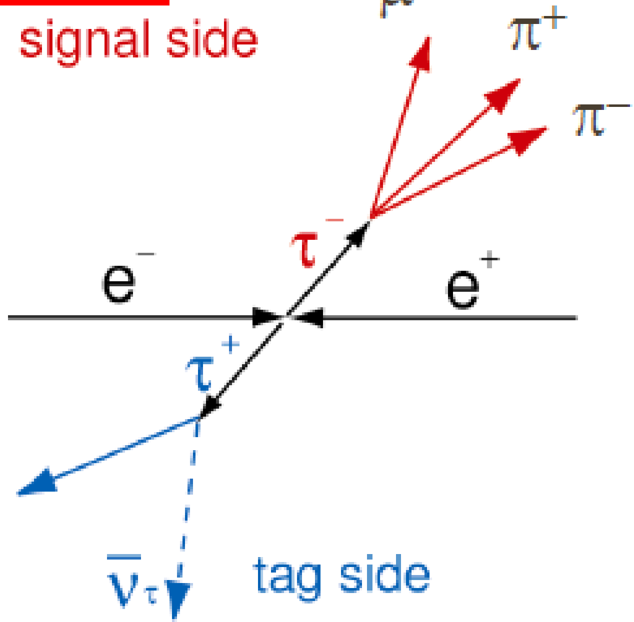
Blind analysis ⇒ Blind signal region

Estimate number of BG events in the signal region using sideband data and MC



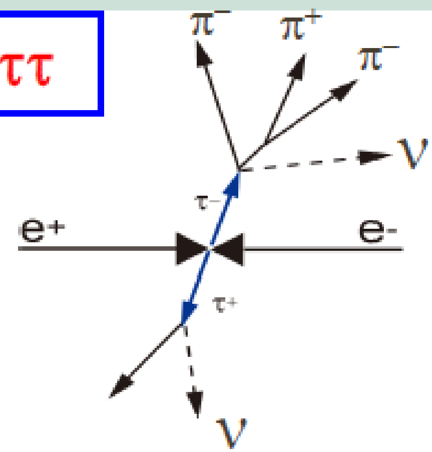
LFV τ decays: Signal and background

signal



- Neutrino(s) in tag side
- Particle ID
- Mass of mesons

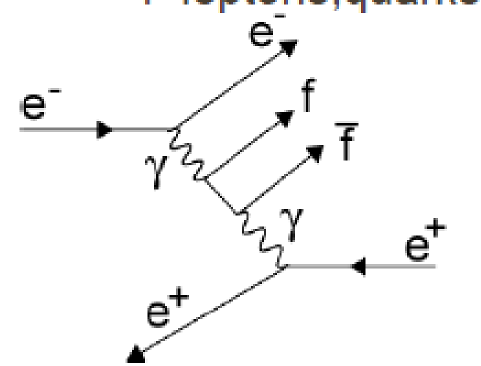
ττ



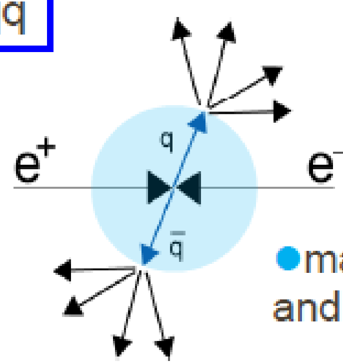
- ❑ **Neutrinos in both sides**
- ❑ **Missing energy in signal side**

2photon process

f=leptons,quarks

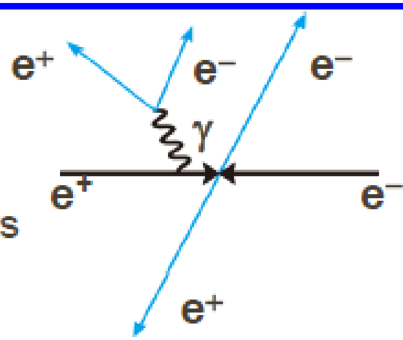


qq̄



- many tracks and photons

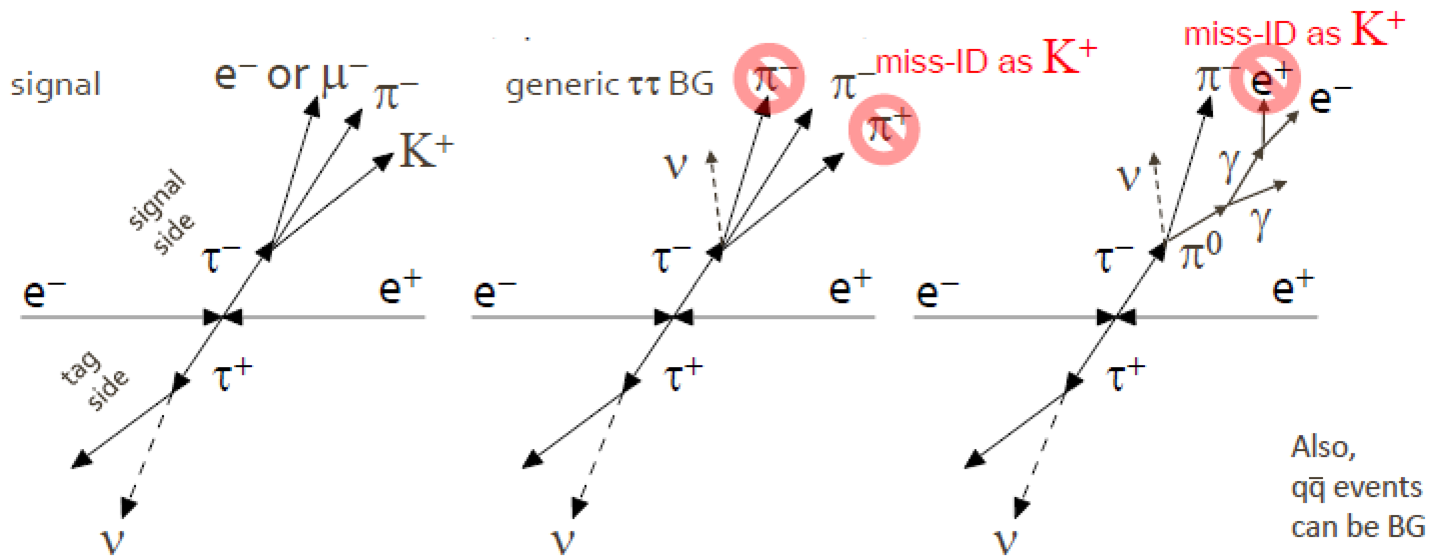
radiative Bhabha process



Search for $\tau \to lhh'$

PLB 719, 346 (2013)

- NUHM favors $\tau^- \to l^- \pi^+ \pi^-$ while doubly charged higgs induces $\tau^- \to l^+ \pi^- \pi^-$
- Update with 854 fb^{-1}
- 14 modes were investigated ($h, h' = \pi^\pm, K^\pm$):
  - $\tau^- \to l^- h^+ h'^-$ 8 modes (lepton flavor violation)
  - $\tau^- \to l^+ h^- h'^-$ 6 modes (lepton number violation)



Missing momentum can help to reject this kind of BG since signal has ν on tag side only

BG rejection for $\tau \rightarrow lhh'$

To reduce $\tau\tau$ and qq BG

- $\mu\pi K$ mode

$\Rightarrow m_{miss}^2$ -- p_{miss} correlation

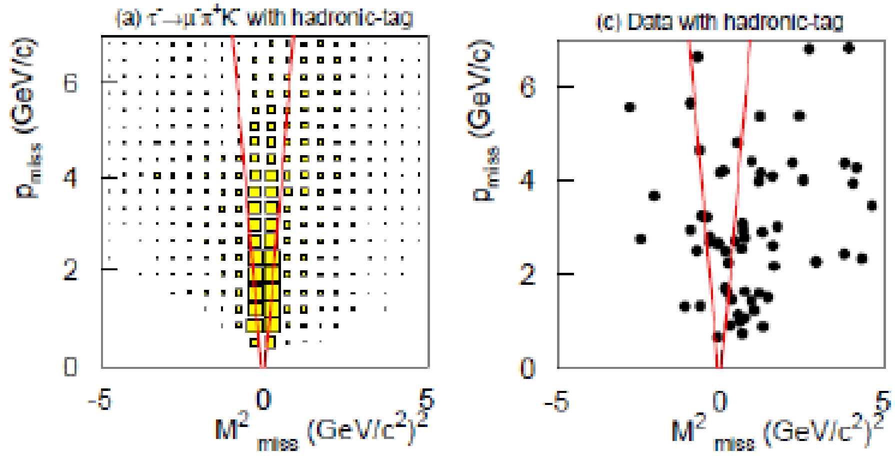
2d selection

75% of eff. is kept while 75% of BG is rejected.

- ehh', $\mu\pi\pi$ and μKK modes

$\Rightarrow m_{miss}^2$ selection

90% of eff. is kept while 50% of BG is rejected.



To reduce $\tau\tau$ BG

- $\mu\pi K$ mode

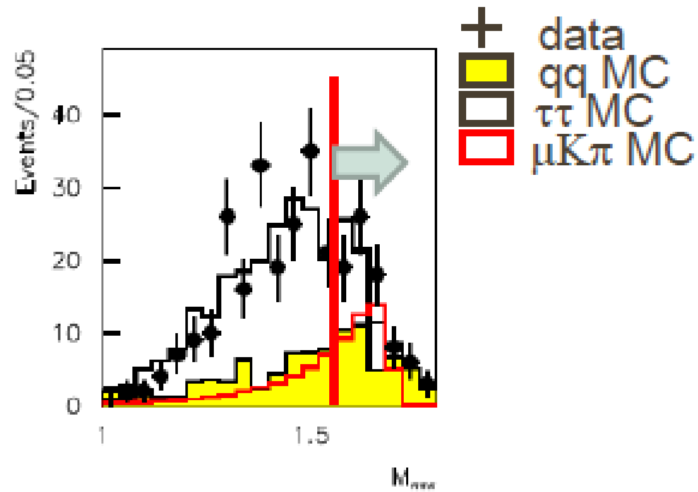
Dominant BG is from $\tau \rightarrow \pi\pi\pi\nu$ with a $\pi\pi$ combination misidentified as $K\mu$.

$\Rightarrow M_{\mu\pi K}$ is shifted into the τ-mass signal region while the original $M_{\pi\pi\pi}$ will be below the τ-mass due to the missing neutrino.

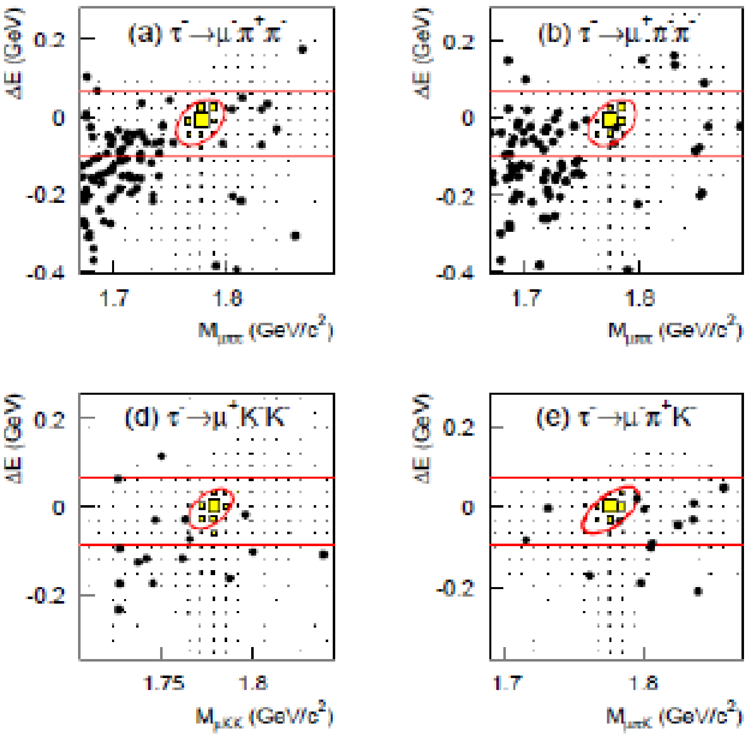
Assign $\pi\pi\pi$ mass for selected events

$\Rightarrow M_{\pi\pi\pi} > 1.52$ GeV/c^2

65% of eff. is kept while 65% of BG is rejected.



Result for $\tau \rightarrow lhh'$



In the signal region

1event : in $\mu^+\pi^-\pi^-$ and $\mu^-\pi^+K^-$

no events: in other modes

⇒ no significant excess/Expected # of BG: 0.06-0.72

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	UL,10^{-8}
$\tau^- \rightarrow \mu^-\pi^+\pi^-$	5.83	0.63 ± 0.23	5.3	0	1.87	2.1
$\tau^- \rightarrow \mu^+\pi^-\pi^-$	6.55	0.33 ± 0.16	5.3	1	4.02	3.9
$\tau^- \rightarrow e^-\pi^+\pi^-$	5.45	0.55 ± 0.23	5.4	0	1.94	2.3
$\tau^- \rightarrow e^+\pi^-\pi^-$	6.56	0.37 ± 0.18	5.4	0	2.10	2.0
$\tau^- \rightarrow \mu^-K^+K^-$	2.85	0.51 ± 0.18	5.9	0	1.97	4.4
$\tau^- \rightarrow \mu^+K^-K^-$	2.98	0.25 ± 0.13	5.9	0	2.21	4.7
$\tau^- \rightarrow e^-K^+K^-$	4.29	0.17 ± 0.10	6.0	0	2.28	3.4
$\tau^- \rightarrow e^+K^-K^-$	4.64	0.06 ± 0.06	6.0	0	2.38	3.3
$\tau^- \rightarrow \mu^-\pi^+K^-$	2.72	0.72 ± 0.27	5.6	1	3.65	8.6
$\tau^- \rightarrow e^-\pi^+K^-$	3.97	0.18 ± 0.13	5.7	0	2.27	3.7
$\tau^- \rightarrow \mu^-K^+\pi^-$	2.62	0.64 ± 0.23	5.6	0	1.86	4.5
$\tau^- \rightarrow e^-K^+\pi^-$	4.07	0.55 ± 0.31	5.7	0	1.97	3.1
$\tau^- \rightarrow \mu^+K^-\pi^-$	2.55	0.56 ± 0.21	5.6	0	1.93	4.8
$\tau^- \rightarrow e^+K^-\pi^-$	4.00	0.46 ± 0.21	5.7	0	2.02	3.2

Set upper limits at 90%CL:

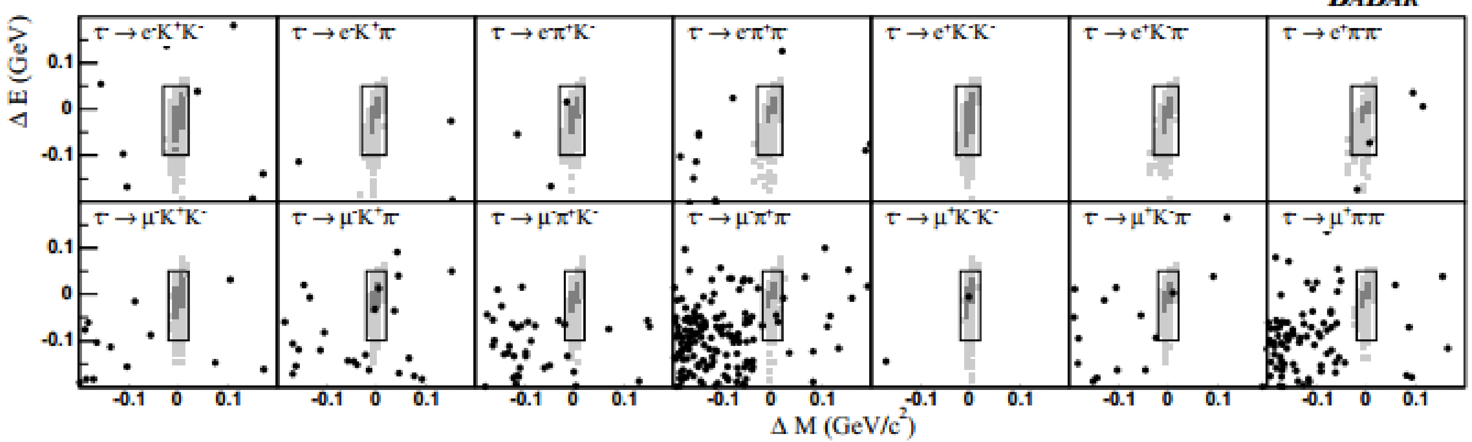
Br($\tau \rightarrow \ell hh'$)< (2.0-8.6)x$10^{-8}$

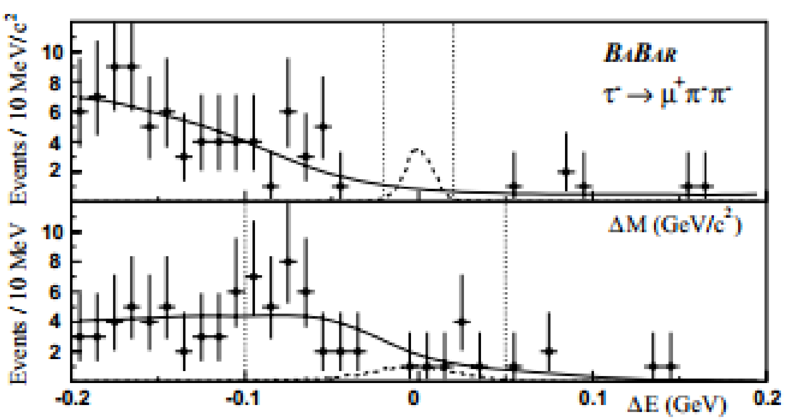
→most sensitive results

Search for τ→ lhh'

Results based on 221 fb^{-1}

PRL 95 (2005) 191801

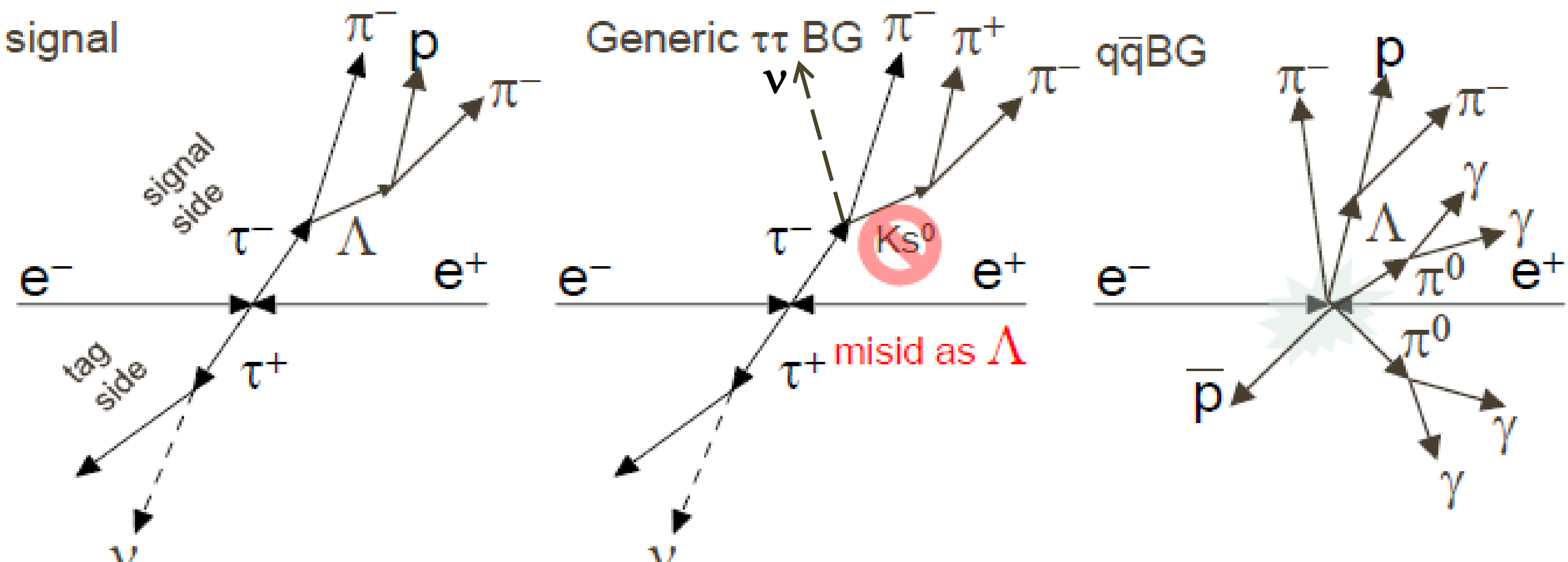




Mode	Efficiency [%]	N_{bgd}	N_{obs}	UL at 90% CL
$e^-K^+K^-$	3.77 ± 0.16	0.22 ± 0.06	0	$1.4 \cdot 10^{-7}$
$e^-K^+\pi^-$	3.08 ± 0.13	0.32 ± 0.08	0	$1.7 \cdot 10^{-7}$
$e^-\pi^+K^-$	3.10 ± 0.13	0.14 ± 0.06	1	$3.2 \cdot 10^{-7}$
$e^-\pi^+\pi^-$	3.30 ± 0.15	0.81 ± 0.13	0	$1.2 \cdot 10^{-7}$
$\mu^-K^+K^-$	2.16 ± 0.12	0.24 ± 0.07	0	$2.5 \cdot 10^{-7}$
$\mu^-K^+\pi^-$	2.97 ± 0.16	1.67 ± 0.29	2	$3.2 \cdot 10^{-7}$
$\mu^-\pi^+K^-$	2.87 ± 0.16	1.04 ± 0.18	1	$2.6 \cdot 10^{-7}$
$\mu^-\pi^+\pi^-$	3.40 ± 0.19	2.99 ± 0.41	3	$2.9 \cdot 10^{-7}$
$e^+K^-K^-$	3.85 ± 0.16	0.04 ± 0.04	0	$1.5 \cdot 10^{-7}$
$e^+K^-\pi^-$	3.19 ± 0.14	0.16 ± 0.06	0	$1.8 \cdot 10^{-7}$
$e^+\pi^-\pi^-$	3.40 ± 0.15	0.41 ± 0.10	1	$2.7 \cdot 10^{-7}$
$\mu^+K^-K^-$	2.06 ± 0.11	0.07 ± 0.10	1	$4.8 \cdot 10^{-7}$
$\mu^+K^-\pi^-$	2.85 ± 0.16	1.54 ± 0.25	1	$2.2 \cdot 10^{-7}$
$\mu^+\pi^-\pi^-$	3.30 ± 0.18	1.46 ± 0.27	0	$0.7 \cdot 10^{-7}$

Search for $\tau \to \Lambda h / \bar{\Lambda} h$

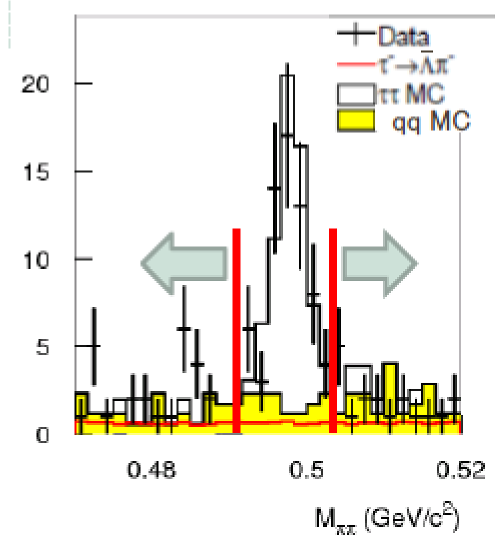
- GUT allows $\tau^- \to \bar{\Lambda} h^-$ while more complicated model is required for $\tau^- \to \Lambda h^-$
- Search with 904 fb^{-1} data sample
  - Select three hadrons
  - Require Lambda vertex
- 4 modes are searched for ($h = \pi, K$)
  - $\tau^- \to \bar{\Lambda} h^-$: (B-L) conserving decay
  - $\tau^- \to \Lambda h^-$: (B-L) violating decay



BG rejection for $\tau \to \Lambda h / \bar{\Lambda} h$

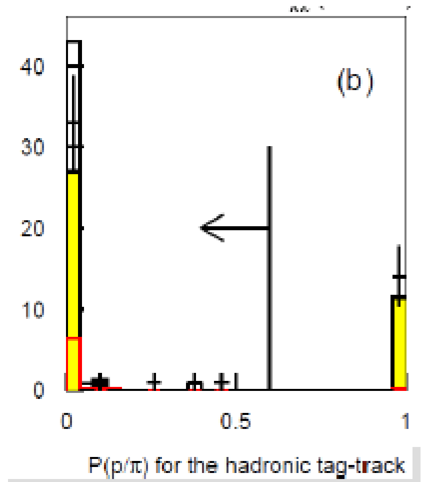
To reduce $\tau\tau$ BG including K_S^0
$\Rightarrow$ reconstruct K_S^0 and reject events that are likely to be K_S^0

85% of eff. is kept while
75% of Ks^0 BG events is rejected.

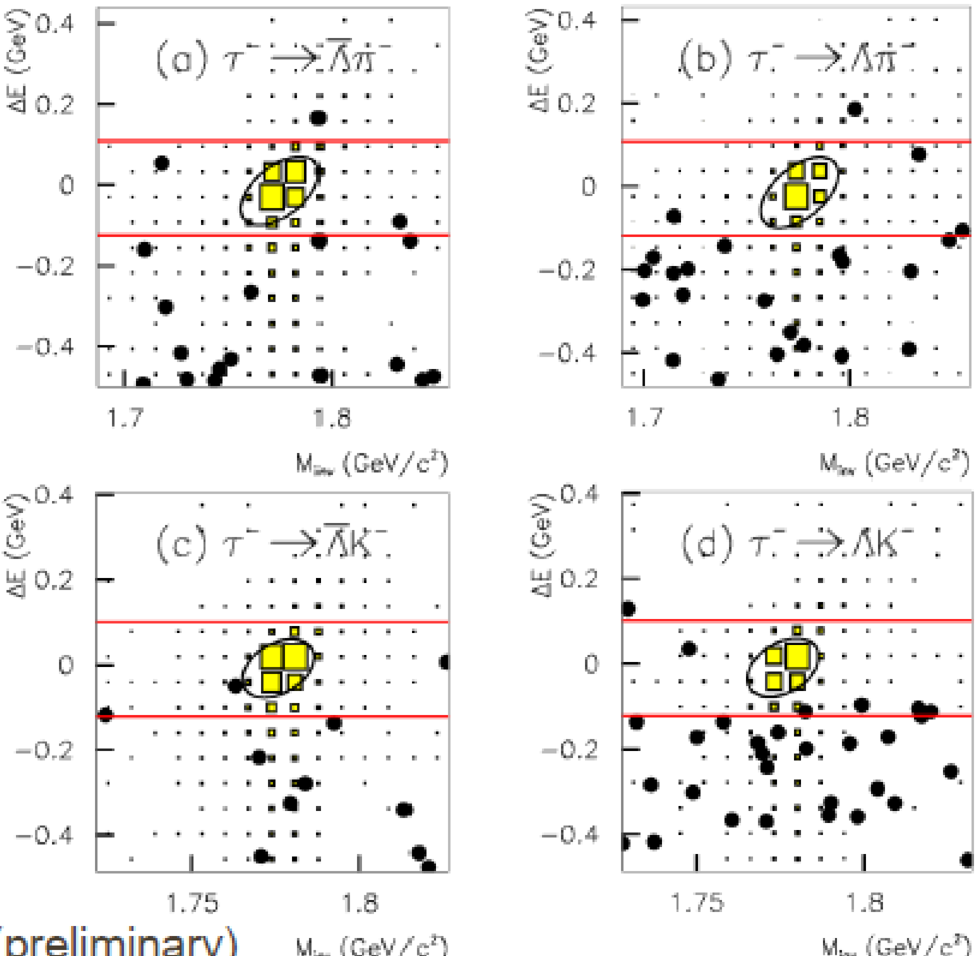


To reduce $q\bar{q}$ BG including Λ
$\Rightarrow$ reject events with a proton in tag side (due to BN conservation, the events including a Λ tend to have baryon on tag side.)

One third of $q\bar{q}$ BG events are rejected while a loss of eff. is negligibly small.



Results for $\tau \to \Lambda h / \bar{\Lambda} h$



(preliminary)

In the signal region:

no candidate events are found

⇒ no significant excess

•Expected # of BG: (0.21-0.42)

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}
$\tau^- \to \bar{\Lambda}\pi^-$	4.80	0.21 ± 0.15	8.2	0	2.3
$\tau^- \to \Lambda\pi^-$	4.39	0.31 ± 0.18	8.2	0	2.2
$\tau^- \to \bar{\Lambda}K^-$	4.11	0.31 ± 0.14	8.6	0	2.2
$\tau^- \to \Lambda K^-$	3.16	0.42 ± 0.19	8.6	0	2.1

Set upper limits@90%CL:

$Br(\tau^- \to \bar{\Lambda}\pi^-) < 2.8\times10^{-8}$
$Br(\tau^- \to \bar{\Lambda}K^-) < 3.1\times10^{-8}$ (B-L) cons.

$Br(\tau^- \to \Lambda\pi^-) < 3.0\times10^{-8}$
$Br(\tau^- \to \Lambda K^-) < 4.2\times10^{-8}$ (B-L) viol.

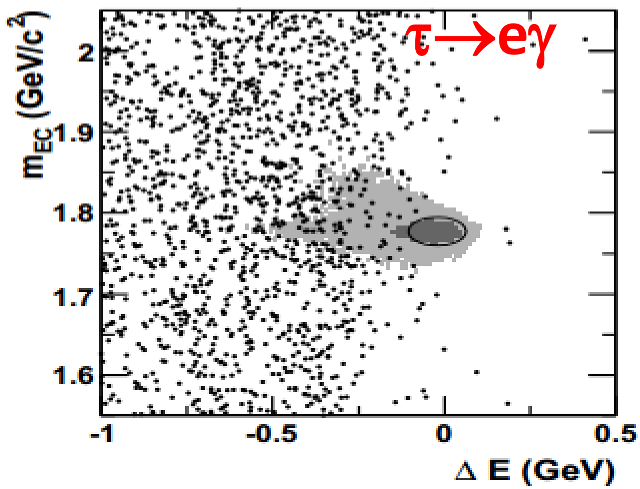
(preliminary)

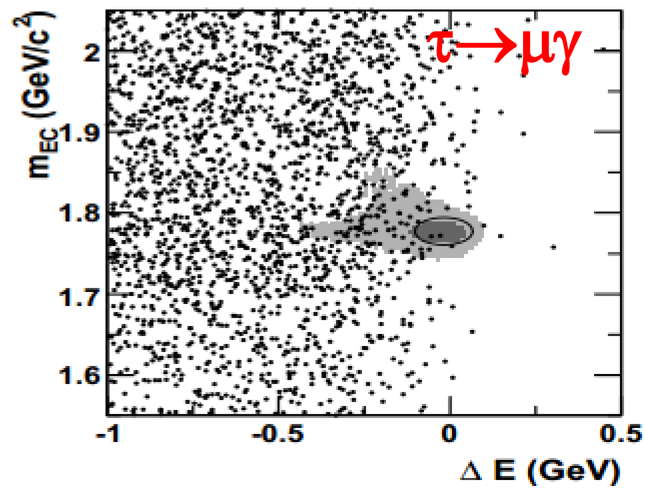
→most sensitive results

Search for $\tau \to e\gamma$ and $\tau \to \mu\gamma$

Phys. Rev. Lett. 104 (2010) 021802

Final BABAR result based on 467 fb^{-1}





		-9σ	-5σ	$+5\sigma$	$+9\sigma$	sum
$\tau^\pm \to e^\pm\gamma$	obs	2	1	2	2	7
	exp	1.2±0.2	1.4±0.2	1.9±0.3	2.1±0.3	6.6±0.5
$\tau^\pm \to \mu^\pm\gamma$	obs	3	1	4	6	14
	exp	2.8±0.3	3.1±0.3	4.2±0.4	4.8±0.5	14.9±0.8

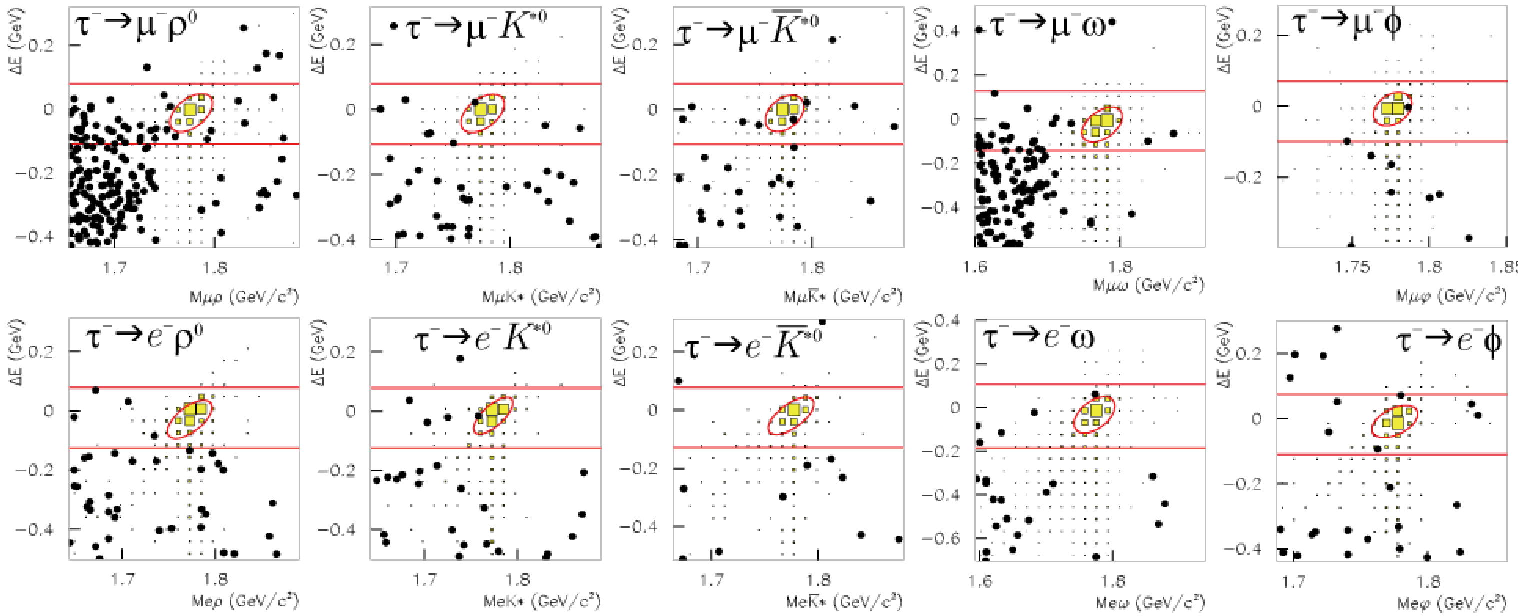
Mode	UL^{exp},10^{-8}	UL^{meas},10^{-8}
$\tau \to e\gamma$	9.8	3.3
$\tau \to \mu\gamma$	8.2	4.4

Search for $\tau \to \ell V^0$ $(=\rho^0, K^{*0}, \overline{K^{*0}}, \omega, \phi)$

Data:854fb^{-1}

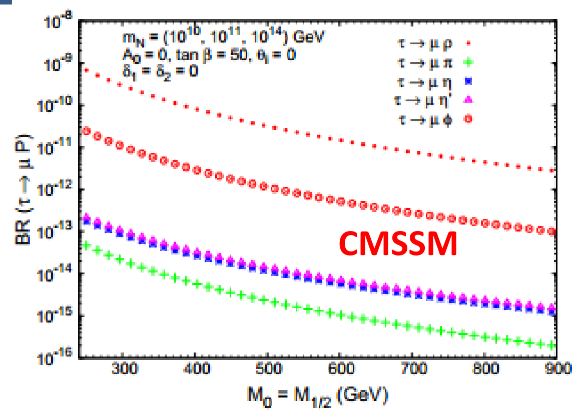
PL B699 (2011) 251

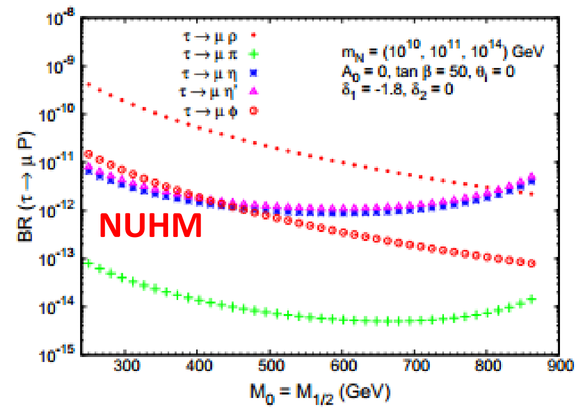
$\mathcal{B} < (1.8\text{-}8.4)\times10^{-8}$ @90% CL



$\tau^- \to$	Eff.	N_{BG}^{exp}	UL,10^{-8}	$\tau^- \to$	Eff.	N_{BG}^{exp}	UL,10^{-8}
$e\text{-}\rho^0$	7.6%	0.29 ± 0.15	**1.8**	$e\text{-}K^{*0}$	4.4%	0.39 ± 0.14	**3.2**
$\mu^-\rho^0$	7.1%	1.48 ± 0.35	**1.2**	μ^-K^{*0}	3.4%	0.53 ± 0.20	**7.2**
$e\text{-}\phi$	4.2%	0.47 ± 0.19	**3.1**	$e\text{-}K^{*0}$	4.4%	0.08 ± 0.08	**3.4**
$\mu^-\phi$	3.2%	0.06 ± 0.06	**8.4**	μ^-K^{*0}	3.6%	0.45 ± 0.17	**7.0**
$e\text{-}\omega$	2.9%	0.30 ± 0.14	**4.8**	$\mu^-\omega$	2.4%	0.72 ± 0.18	**4.7**

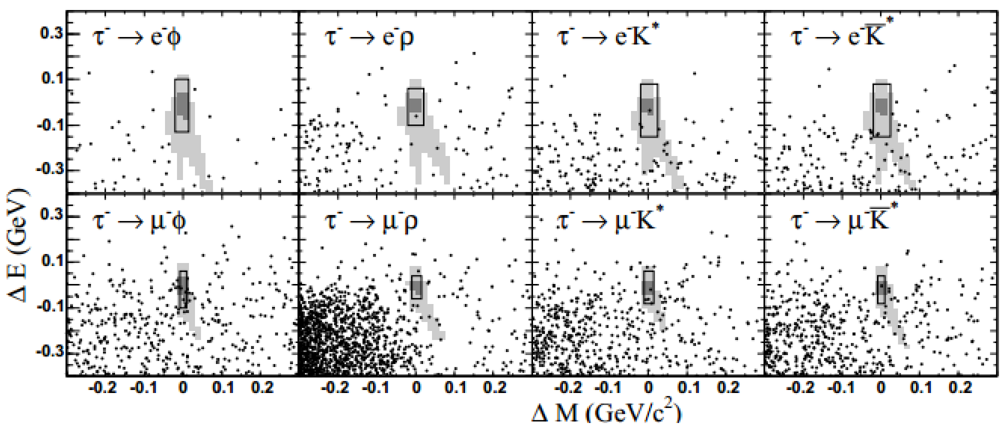
Search for $\tau \to \ell\phi, \ell\rho, \ell K^*, \ell\bar{K}^*$





Phys.Rev.Lett. 103 (2009) 091801

Data: 451 fb^{-1}



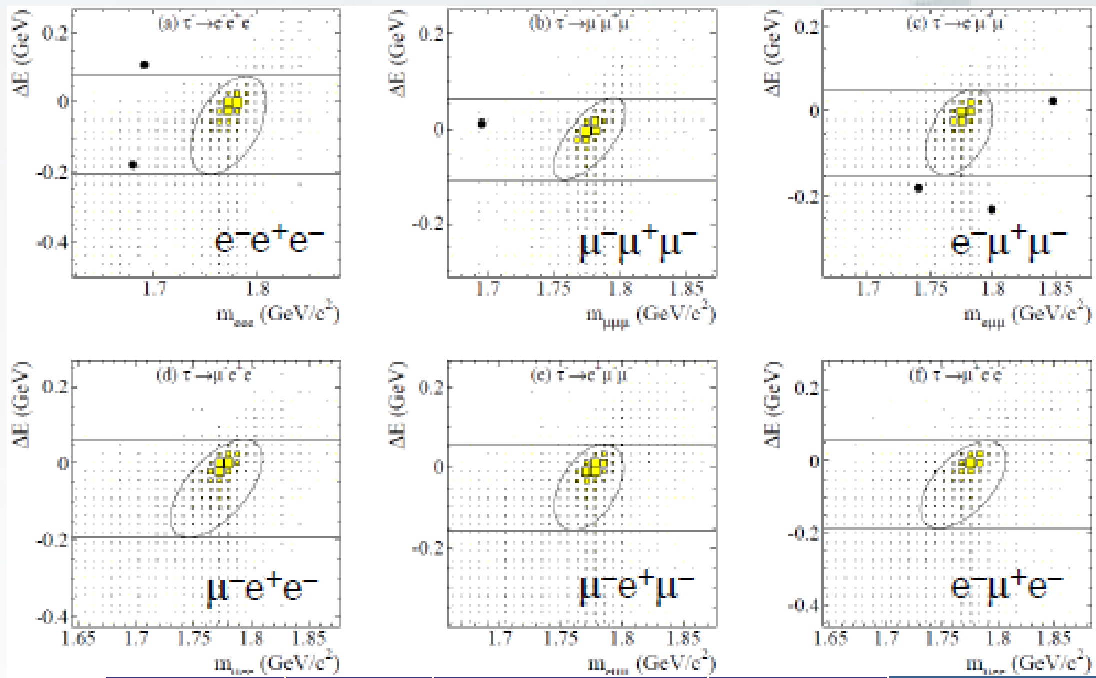
Mode	Eff., %	N_{bkg}	N_{obs}	UL, 10^{-8}
$e\phi$	6.43	0.68±0.12	0	3.1
$\mu\phi$	5.18	2.76±0.16	6	19
$e\rho$	7.31	1.32±0.17	1	4.6
$\mu\rho$	4.52	2.04±0.19	0	2.6
eK^*	8.00	1.65±0.23	2	5.9
μK^*	4.57	1.79±0.21	4	17
$e\bar{K}^*$	7.76	2.76±0.28	2	4.6
$\mu\bar{K}^*$	4.11	1.72±0.17	1	7.3

Search for $\tau \to \ell\ell\ell$

- Data: 782fb^{-1}
- No event is found in the signal region.
- **Almost BG free**
  - Expected # of BG: 0.01-0.21
  - Because of good lepton ID
- Br<(1.5-2.7)x10^{-8} at 90%CL.

→most sensitive results

Phys.Lett.B 687,139 (2010)



Mode	ε (%)	N_{BG}^{EXP}	σ_{syst} (%)	UL(10^{-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**

Search for $\tau \to lll$

Update analysis 376 $fb^{-1} \to$ 477 fb^{-1}

Phys. Rev. D81 (2010) 111101

Improve lepton ID eff.

- μ: 66%→77%
- e: 89%→91%

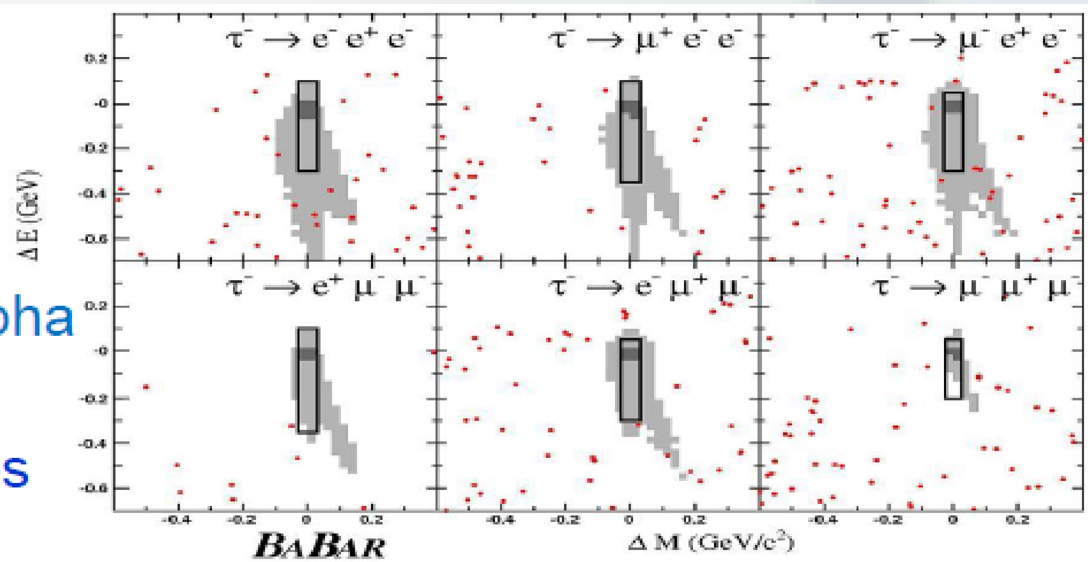
→Better BG rejection

BG : two-photon Bhabha

no events in signal region for all modes

Br<(1.8-3.3)x10^{-8}

Improved by a factor of 2-3 from previous results

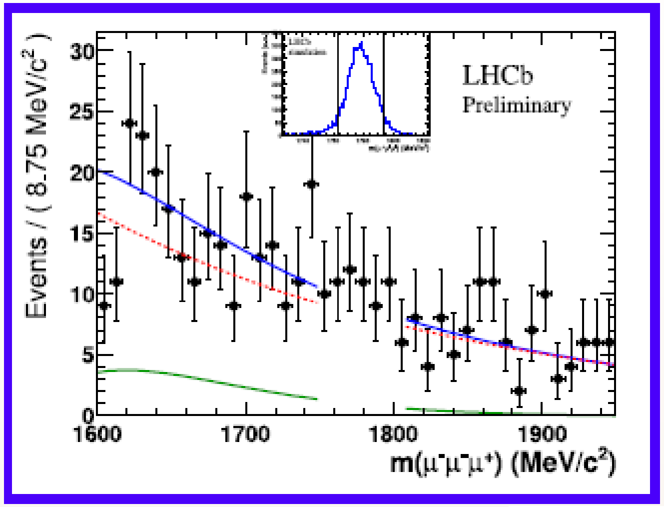


Channel	Efficiency (%)	N_{bgd}	Exp. UL	N_{obs}	UL
$e^+e^-e^+$	8.6 ± 0.2	0.12 ± 0.02	3.4×10^{-8}	0	2.9×10^{-8}
$e^+e^-\mu^+$	8.8 ± 0.5	0.64 ± 0.19	3.7×10^{-8}	0	2.2×10^{-8}
$e^+e^+\mu^-$	12.6 ± 0.7	0.34 ± 0.12	2.2×10^{-8}	0	1.8 x 10^{-8}
$e^+\mu^-\mu^+$	6.4 ± 0.4	0.54 ± 0.14	4.6×10^{-8}	0	3.2×10^{-8}
$e^-\mu^+\mu^+$	10.2 ± 0.6	0.03 ± 0.02	2.8×10^{-8}	0	2.6×10^{-8}
$\mu^+\mu^-\mu^+$	6.6 ± 0.6	0.44 ± 0.17	4.0×10^{-8}	0	3.3×10^{-8}

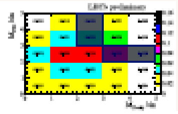
Search for $\tau \to lll$ at LHCb

The result is based on 1 fb^{-1} collected in 2011 at $\sqrt{s}$ = 7 TeV

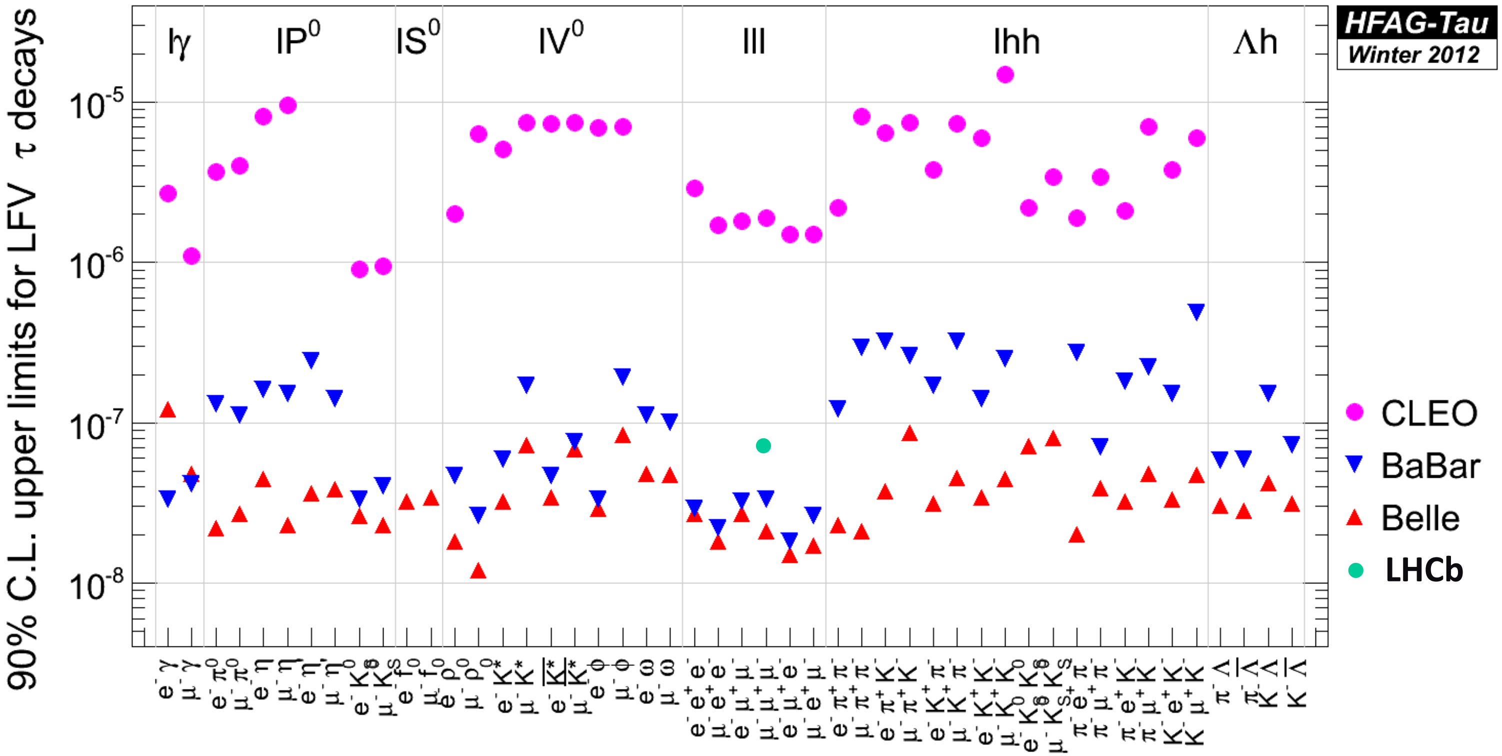
- 7.9×10^{10} τ produced (mainly from $D_s \to \tau\nu$)
- τ-tag is impossible
- Main BG is from $D_s \to \eta(\mu\mu\gamma)\mu\nu$
- The decay $D_s \to \phi(\mu\mu)\pi$ was used for calibration
- $\mathcal{B}(\tau \to \mu\mu\mu) < 6.3 \times 10^{-8}$ @ 90%CL
- Data sample of about 1.5 fb^{-1} is expected this year



21 % of the signal
0.14 % of the background



Summary of LFV study



Searches include: Lepton Flavor Violation

Lepton Number Violation

Baryon Number Violation

Conclusion

- Data samples, collected with Belle and BaBar detectors, allowed to perform study of 48 τ LFV decay modes.
- UL for almost all modes reach $O(10^{-8})$.
  - This corresponds to 100x more sensitive results than CLEO's
- Analysis of $\tau \to \mu/e\gamma$ processes is on going and final results will come soon.
- First results on LFV study are coming from LHCb experiment

Thank You!

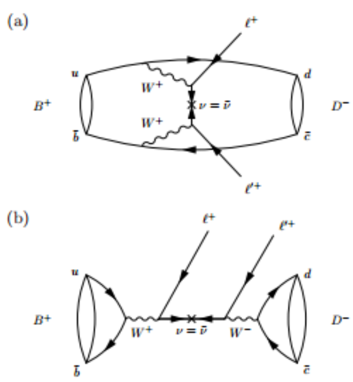
Backup slides

LFV in B-meson decays

$B^+ \to D^- l^+ l'^+$ (first measurement)

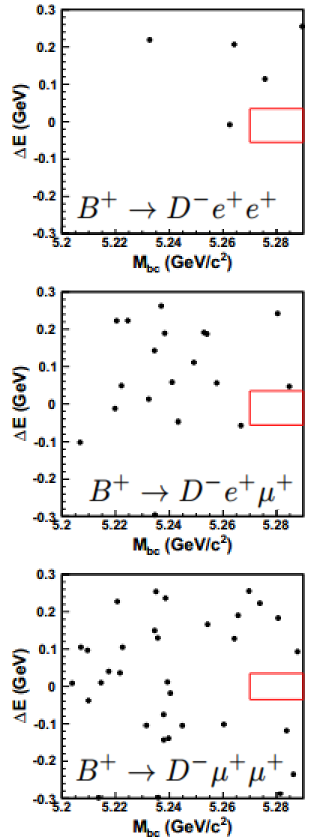
Phys. Rev. D84 (2011) 071106

Theory: $\mathcal{B}(B^+ \to D^- l^+ l'^+) > 10^{-7}$



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

$$M_{bc} = \sqrt{E_B^2 - p_B^2}$$

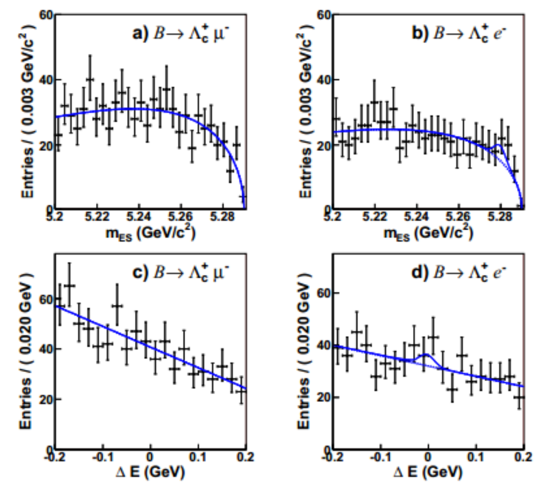


Mode	ϵ [%]	N_{obs}	N_{exp}^{bkg}	U.L. [10^{-6}]
$B^+ \to D^- e^+ e^+$	1.2	0	0.18±0.13	< 2.6
$B^+ \to D^- e^+ \mu^+$	1.3	0	0.83±0.29	< 1.8
$B^+ \to D^- \mu^+ \mu^+$	1.9	0	1.44±0.43	< 1.0

$B^0 \to \Lambda_c^+ l^-$, $B^- \to \Lambda l^-$, $B^- \to \bar{\Lambda} l^-$ (first measurement)

Phys. Rev. D83 (2011) 091101

Calculations: From non-observation of proton decay $\to \mathcal{B}(B^0 \to \Lambda_c^+ l^-) = 4\times10^{-29}$

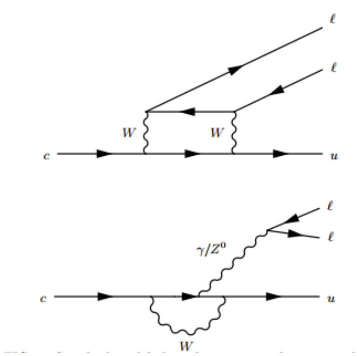


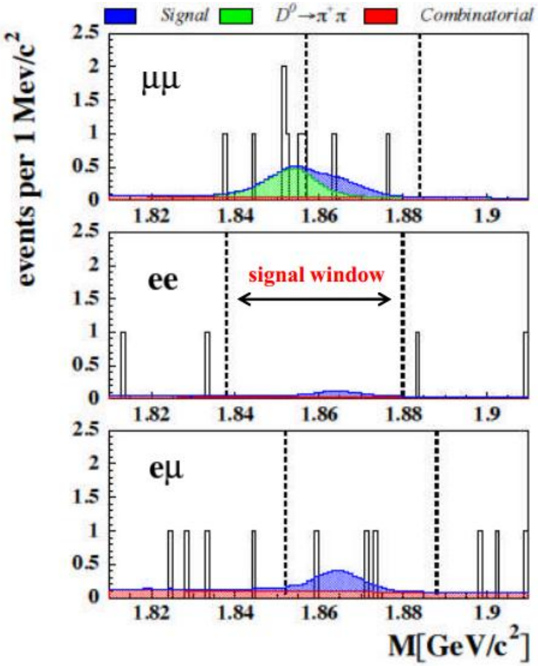
Decay mode	N_{cand}	$\mathcal{B}$ ($\times10^{-8}$)	ϵ (%)	$\mathcal{B}_{90\%}$ ($\times10^{-8}$)
$B^0 \to \Lambda_c^+ \mu^-$	814	-4^{+71}_{-56}	26.3 ± 0.9	180
$B^0 \to \Lambda_c^+ e^-$	651	190^{+130}_{-90}	25.7 ± 0.7	520
$B^- \to \Lambda \mu^-$	320	$-2.3^{+3.5}_{-2.5}$	28.7 ± 0.9	6.2
$B^- \to \Lambda e^-$	194	$1.2^{+3.7}_{-2.6}$	27.2 ± 0.6	8.1
$B^- \to \bar{\Lambda} \mu^-$	192	$1.5^{+2.6}_{-1.7}$	31.3 ± 1.0	6.1
$B^- \to \bar{\Lambda} e^-$	74	$-0.9^{+0.7}_{-0.0}$	30.0 ± 0.6	3.2

LFV in D-meson decays

$D^0 \to l^+ l'^-$

PR D81 (2010) 091102R





No evidence for signal observed!

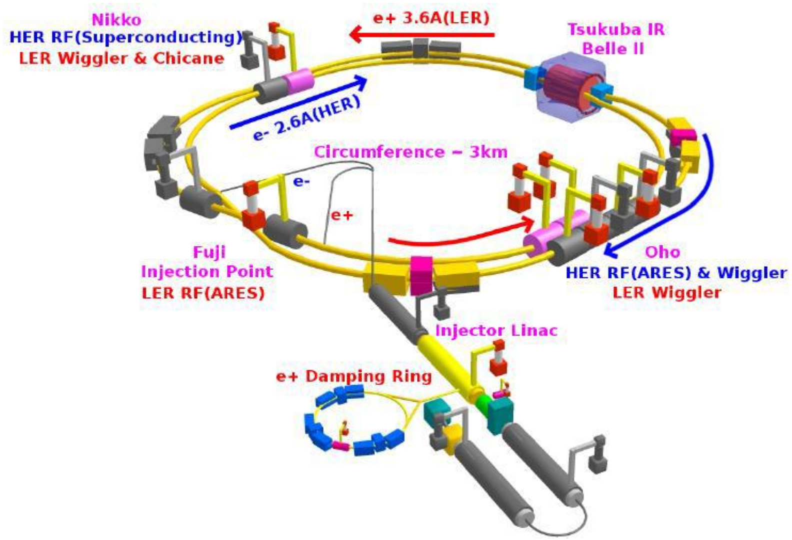
	$D^0 \to \mu^+\mu^-$	$D^0 \to e^+e^-$	$D^0 \to e^\pm\mu^\mp$
N_{bkg}	3.1 ± 0.1	1.7 ± 0.2	2.6 ± 0.2
N	2	0	3
$\epsilon_{\ell\ell}[\%]$	7.02 ± 0.34	5.27 ± 0.32	6.24 ± 0.27
$\epsilon_{\pi\pi}[\%]$	12.42 ± 0.10	10.74 ± 0.09	11.22 ± 0.09
$f[10^{-8}]$	$4.84(1 \pm 5.3\%)$	$6.47(1 \pm 6.4\%)$	$5.48(1 \pm 4.8\%)$
UL $[10^{-7}]$	1.4	0.79	2.6

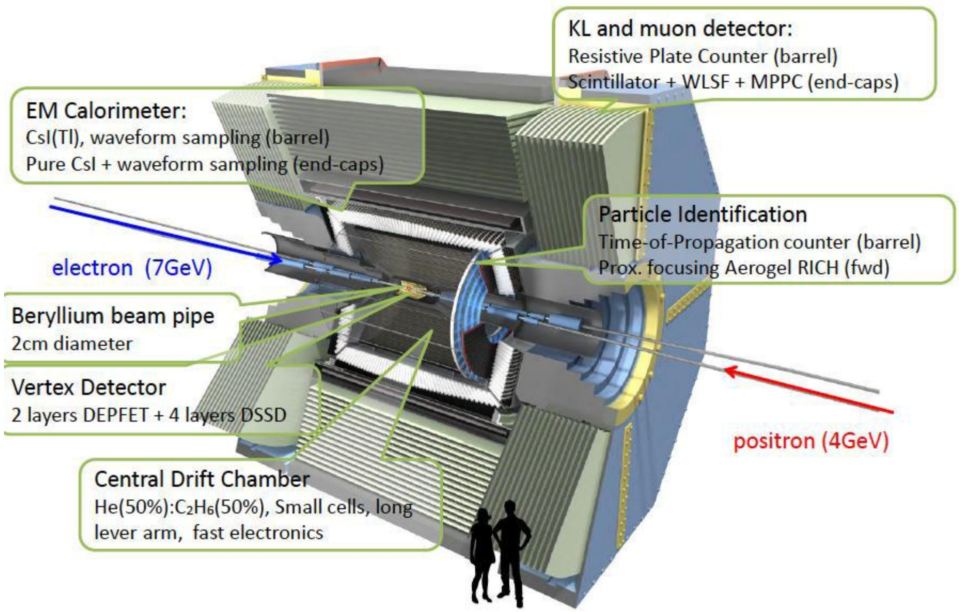
$D^+ \to h^+ l^+ l^{(\prime)-}$

PR D84 (2011) 072006

Decay mode	Yield (events)	Eff. (%)	BR UL 90% CL (10^{-4})	BF UL 90% CL (10^{-6})
$D^+ \to \pi^+e^+e^-$	$-3.9 \pm 1.6 \pm 1.7$	1.56	3.9	1.1
$D^+ \to \pi^+\mu^+\mu^-$	$-0.2 \pm 2.8 \pm 0.9$	0.46	24	6.5
$D^+ \to \pi^+e^+\mu^-$	$-2.9 \pm 3.4 \pm 2.4$	1.21	11	2.9
$D^+ \to \pi^+\mu^+e^-$	$3.6 \pm 4.3 \pm 1.3$	1.54	13	3.6
$D_s^+ \to \pi^+e^+e^-$	$8 \pm 34 \pm 8$	6.36	5.4	13
$D_s^+ \to \pi^+\mu^+\mu^-$	$20 \pm 15 \pm 4$	1.21	18	43
$D_s^+ \to \pi^+e^+\mu^-$	$-3 \pm 11 \pm 3$	2.16	4.9	12
$D_s^+ \to \pi^+\mu^+e^-$	$9.3 \pm 7.3 \pm 2.8$	1.50	8.4	20
$D^+ \to K^+e^+e^-$	$-3.7 \pm 2.9 \pm 3.3$	2.88	3.7	1.0
$D^+ \to K^+\mu^+\mu^-$	$-1.3 \pm 2.8 \pm 1.1$	0.65	16	4.3
$D^+ \to K^+e^+\mu^-$	$-4.3 \pm 1.8 \pm 0.6$	1.44	4.3	1.2
$D^+ \to K^+\mu^+e^-$	$3.2 \pm 3.8 \pm 1.2$	1.74	9.9	2.8
$D_s^+ \to K^+e^+e^-$	$-5.7 \pm 5.8 \pm 2.0$	3.20	1.6	3.7
$D_s^+ \to K^+\mu^+\mu^-$	$4.8 \pm 5.9 \pm 1.2$	0.85	9.1	21
$D_s^+ \to K^+e^+\mu^-$	$9.1 \pm 6.0 \pm 2.8$	1.74	5.7	14
$D_s^+ \to K^+\mu^+e^-$	$3.4 \pm 6.4 \pm 3.5$	2.08	4.2	9.7
$D^+ \to \pi^-e^+e^+$	$4.7 \pm 4.7 \pm 0.5$	3.16	6.8	1.9
$D^+ \to \pi^-\mu^+\mu^+$	$-3.1 \pm 1.2 \pm 0.5$	0.70	7.5	2.0
$D^+ \to \pi^-\mu^+e^+$	$-5.1 \pm 4.2 \pm 2.0$	1.72	7.4	2.0
$D_s^+ \to \pi^-e^+e^+$	$-5.7 \pm 14. \pm 3.4$	6.84	1.8	4.1
$D_s^+ \to \pi^-\mu^+\mu^+$	$0.6 \pm 5.1 \pm 2.7$	1.05	6.2	14
$D_s^+ \to \pi^-\mu^+e^+$	$-0.2 \pm 7.9 \pm 0.6$	2.23	3.6	8.4
$D^+ \to K^-e^+e^+$	$-2.8 \pm 2.4 \pm 0.2$	2.67	3.1	0.9
$D^+ \to K^-\mu^+\mu^+$	$7.2 \pm 5.4 \pm 1.6$	0.80	37	10
$D^+ \to K^-\mu^+e^+$	$-11.6 \pm 4.0 \pm 3.1$	1.52	6.8	1.9
$D_s^+ \to K^-e^+e^+$	$2.3 \pm 7.9 \pm 3.3$	4.10	2.1	5.2
$D_s^+ \to K^-\mu^+\mu^+$	$-2.3 \pm 5.0 \pm 2.8$	0.98	5.3	13
$D_s^+ \to K^-\mu^+e^+$	$-14.0 \pm 8.4 \pm 2.0$	2.26	2.4	6.1

SuperKEKB/Belle II





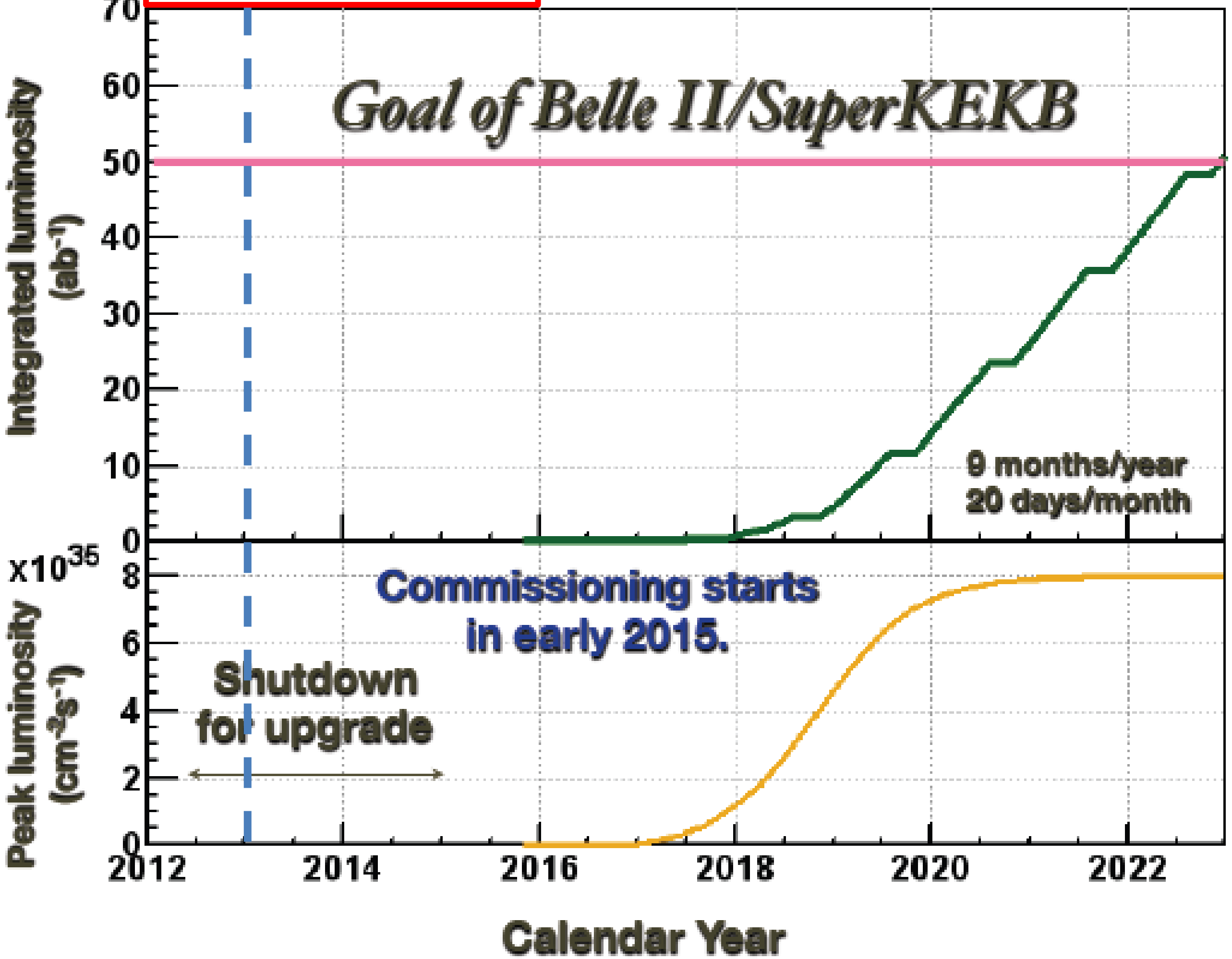
	KEKB		superKEKB	
Vertical β function:	5.9 mm	→	0.27/0.30 mm	(x20)
Beam current:	1.7/1.4 A	→	3.6/2.6 A	(x2)

→ $L = 2\times10^{34}\ \mathrm{cm^{-2}s^{-1}} \rightarrow 8\times10^{35}\ \mathrm{cm^{-2}s^{-1}}$ (x40)

SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Expected luminosity @ SuperKEKB

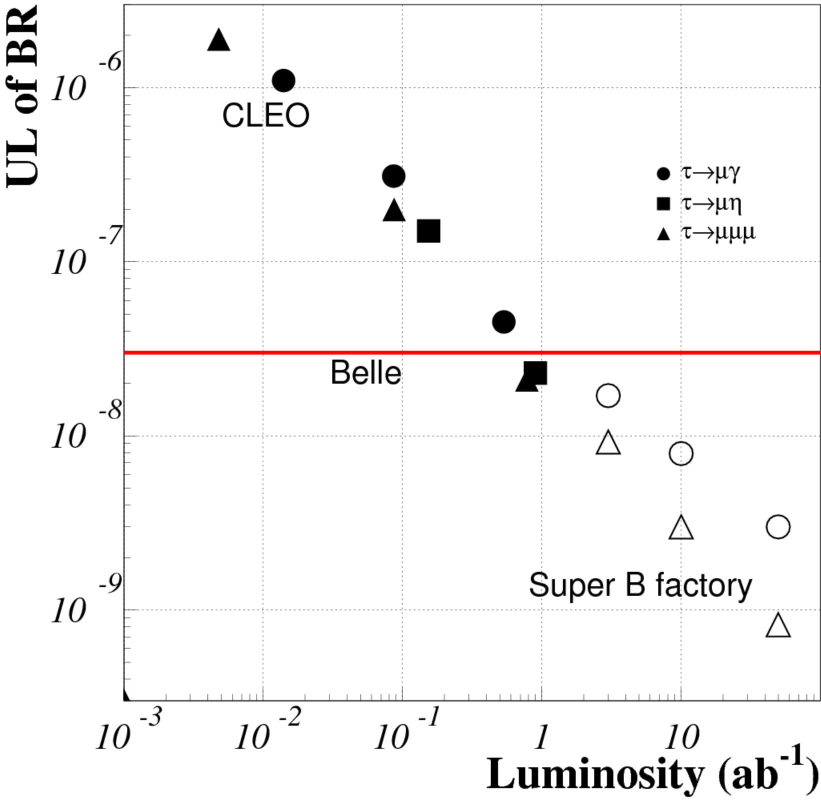
We are now here



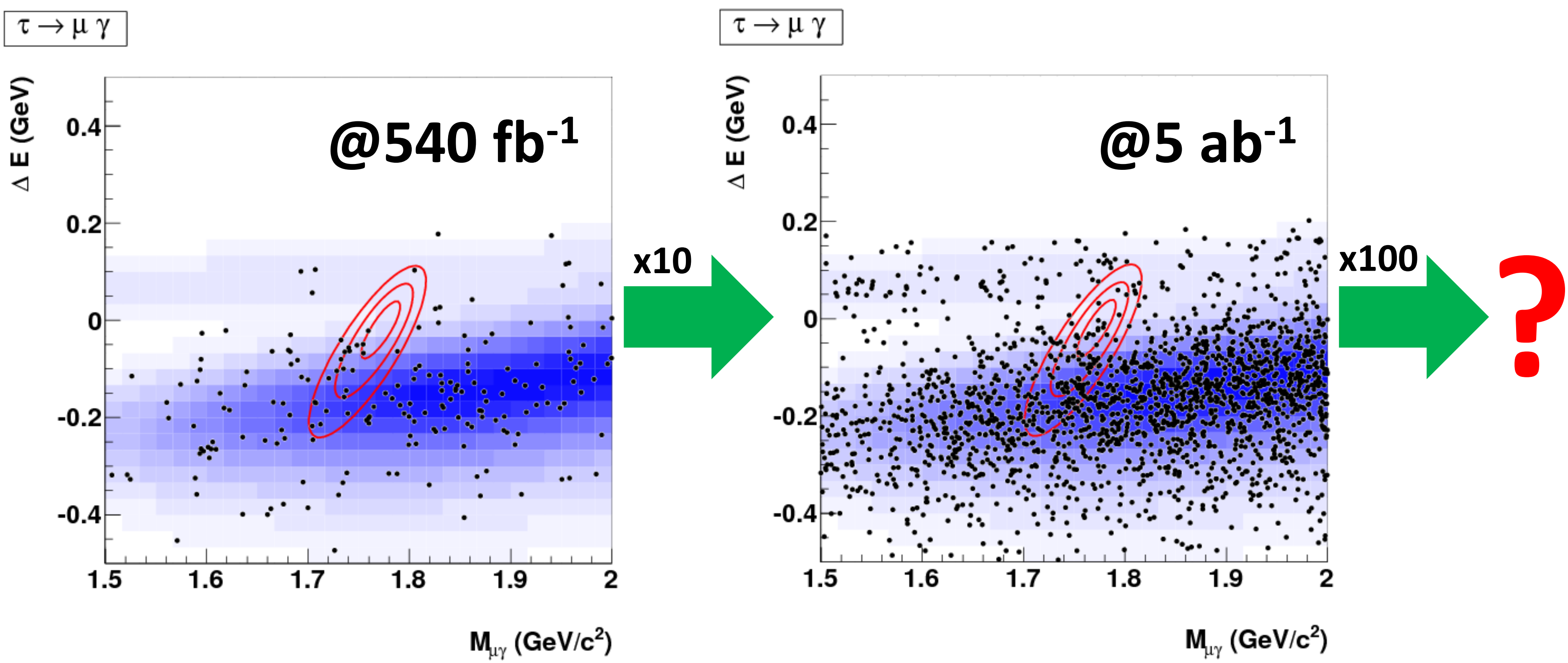
50 ab^{-1} by the end of 2022

Prospects for study LFV @ Belle II

- Belle-II will collect $\sim 10^{11}$ tau leptons. (=50ab^{-1})
- Sensitivity depends on BG level.
  - Recent improvement of the analysis (BG understanding, intelligent selection)
    → Improve achievable sensitivity
- **UL($\tau \to \mu\gamma$)~1/√L→O(10^{-9}) and UL($\tau \to \mu\mu\mu$) ~1/L →O(10^{-10}) at 50 ab^{-1}**
  - Improvement of BG reduction is important.
    - Beam BG
    - Signal resolution



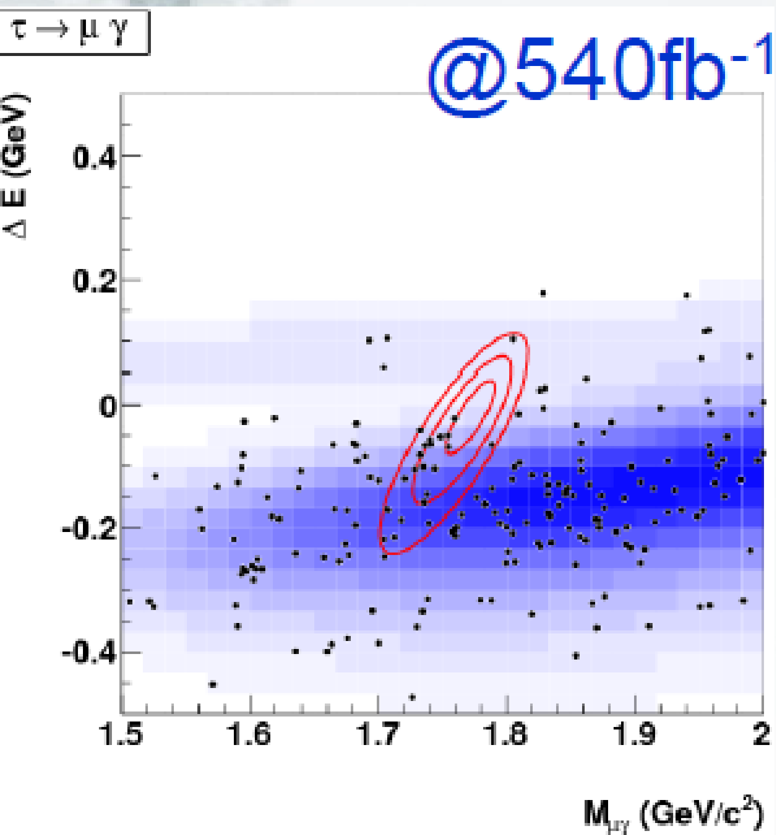
$\tau \to \mu\gamma$ @ 5 ab^{-1}, 50 ab^{-1}

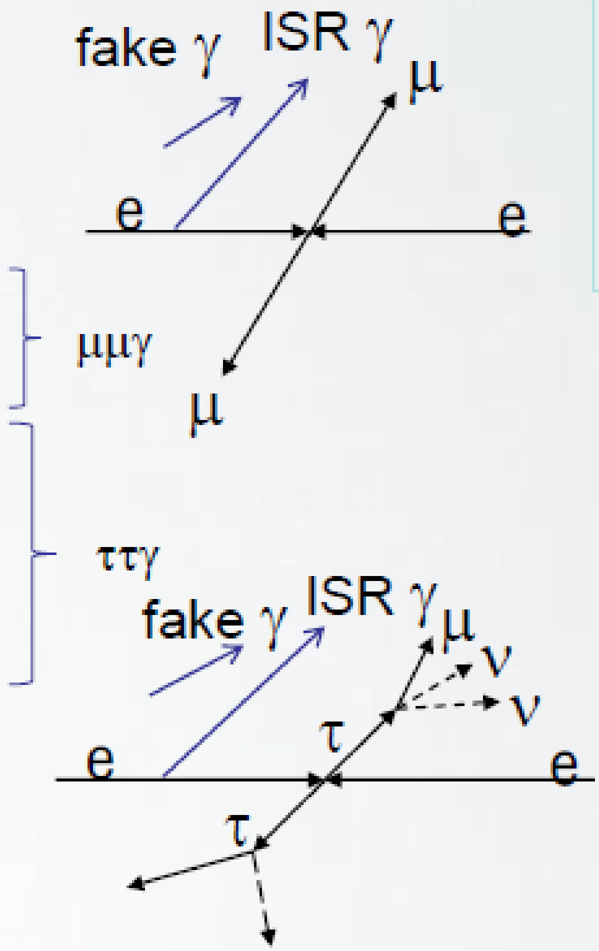


180 BG events in total

1800 BG events in total

$\tau \to \mu\gamma$ BG components





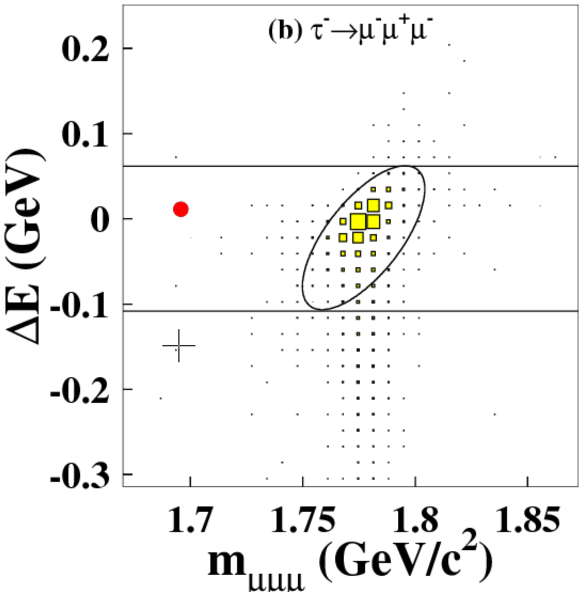
unapplied effective selection remains & μID inefficiency will decrease
→possible to reduce

upper half ellipse will be main signal-search field @ Belle II

particleID works well but remains.
almost all kinematical selection applied.
→hard to reject

$\tau \to \mu\mu\mu$ @ 50 ab^{-1}

> 780 fb^{-1}

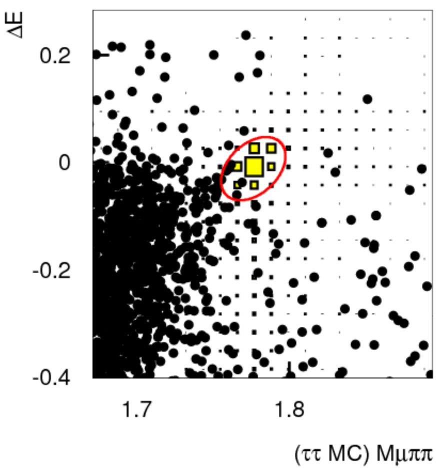


x70

~50 ab^{-1} but 70 events do not distribute flatly because main BG comes from $\tau \to \pi\pi\pi\nu$

Still clean!

In $\tau \to \mu\pi\pi$ search $\tau \to \pi\pi\pi\nu$ is also main BG. We have already found effective rejection



$\tau \to \pi\pi\pi\nu$ distribution in $\tau \to \mu\pi\pi$ selection at 5 ab^{-1}