Latest results on τ LFV and perspectives

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for Belle II Collaboration

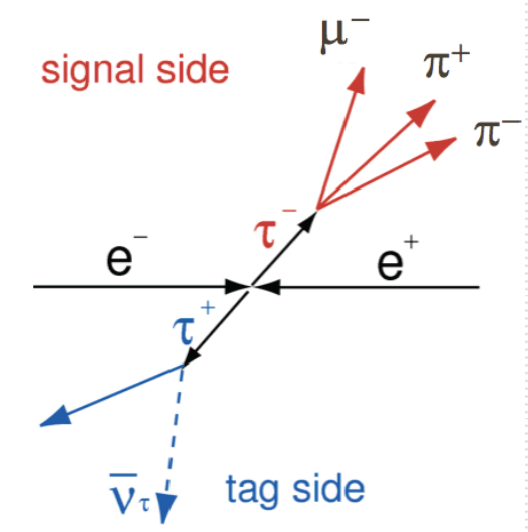
NuFACT 2013： 19-24 August , 2013, IHEP

Outline:

- Most of what we know about the τ comes from τ pair samples produced in e^+e^- annihilation
- τ decays provide an excellent laboratory for LFV studies. Even at current sensitivity, observed branching fraction patterns (or limits) serve to discriminate between New Physics models

I will discuss:

- A very brief introduction
- The Belle experiment
- τ LFV results from Belle
- The Belle II upgrade
- Prospects for τ LFV at Belle II

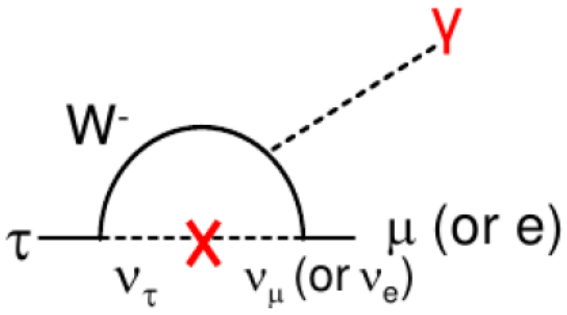


Motivation:

Probability for Lepton flavor violation (LFV) in charged leptons in the Standard Model (SM) ⇒ **negligible** even if neutrino oscillations are taken into account

$Br(\tau \rightarrow l\gamma)_{SM} < O(10^{-54})$ $Br(\tau \rightarrow lll)_{SM} < O(10^{-14})$

(PRL95 41802(2005), EPJC8 513(1999))



Many extensions of the SM predict LFV decays with enhanced branching fractions that could be measured at current experimental facilities with sensitivities ~10^{-8}

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

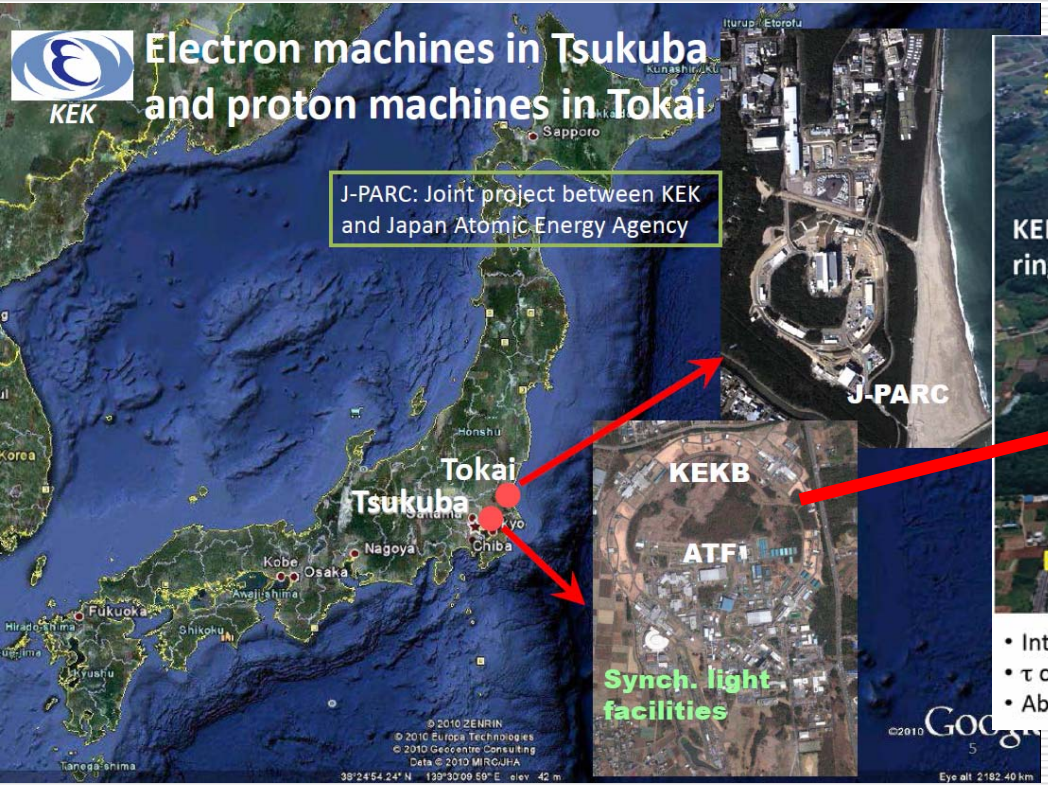
	Reference	τ→ μγ	τ →μμμ
SM + ν mixing	PRD 16(1977)1445, EPJ.C8,513(1999)	undetectable	
SM + heavy Majorana	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}

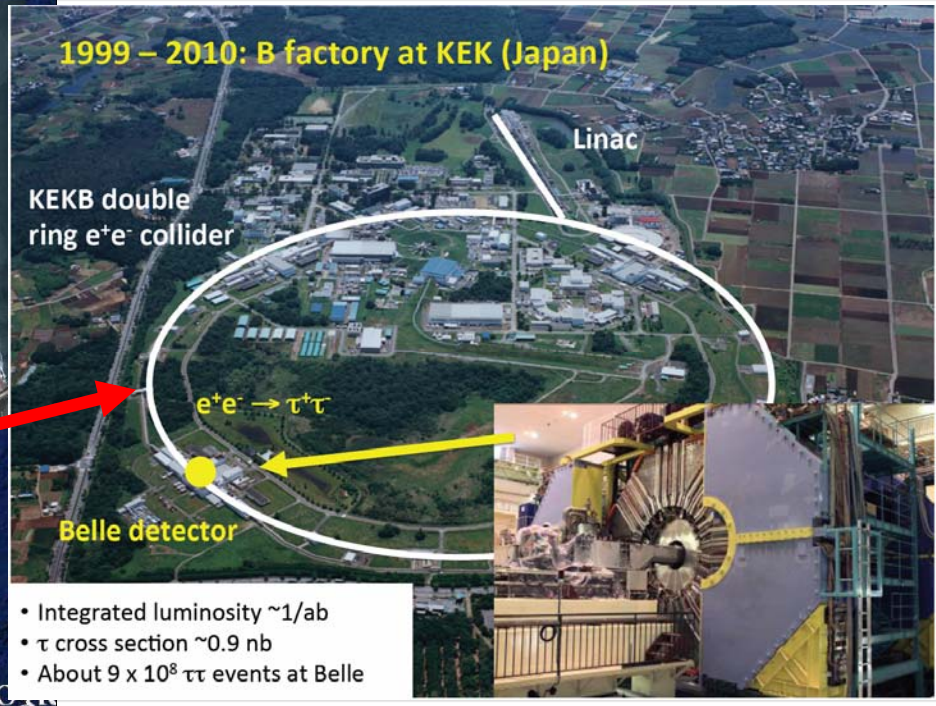
τ - the heaviest charged lepton

strong coupling to NP expected

It has many possible LFV decay modes ⇒ **Ideal to search for LFV**

KEKB/Belle


KEK
Electron machines in Tsukuba
and proton machines in Tokai
J-PARC: Joint project between KEK
and Japan Atomic Energy Agency
Sapporo
Tokai
Tsukuba
Nagoya
Kobe
Osaka
Chiba
Fukuoka
Honshu
Shikoku
Kyushu
KEKB
ATF
Synch. light
facilities
J-PARC


1999 – 2010: B factory at KEK (Japan)
Linac
KEKB double
ring e+e- collider
e+e- → τ+τ-
Belle detector
• Integrated luminosity ~1/ab
• τ cross section ~0.9 nb
• About 9 x 10^8 ττ events at Belle

KEKB/Belle

B–factory: E at CM = Υ(4S)

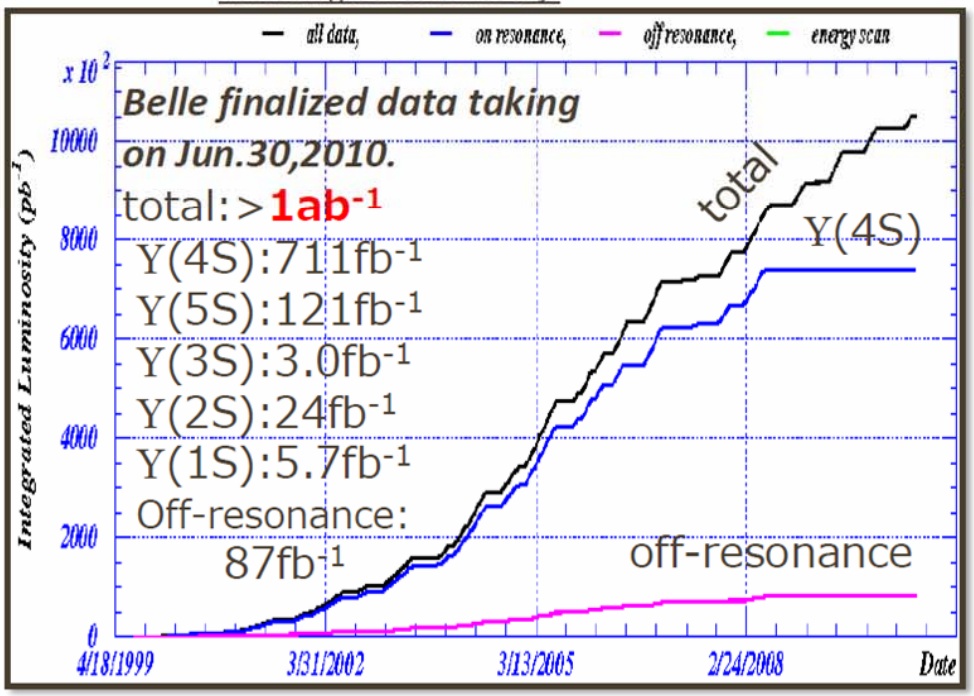
e^+(3.5 GeV) e^-(8 GeV)

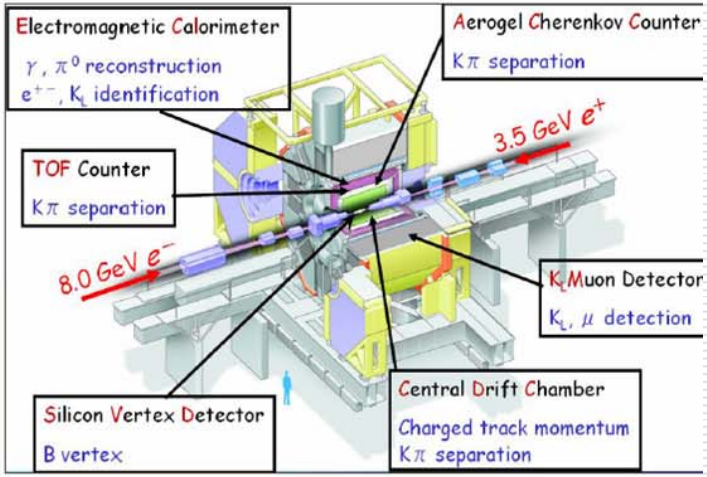
$\sigma(\tau\tau)\sim 0.9$nb, $\sigma(bb)\sim 1.1$nb

A B–factory is also a τ–factory!

Peak luminosity: 2.1×10^{34} $cm^{-2}s^{-1}$

World highest luminosity!





Belle Detector:

Good track reconstruction and particle identifications

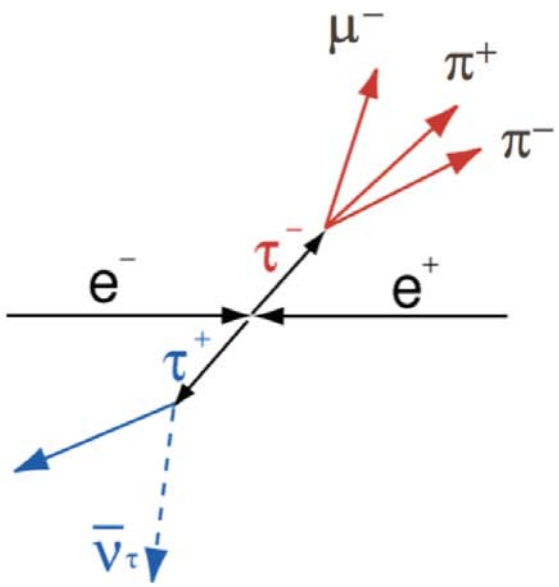
Lepton efficiency:90%

Fake rate : O(0.1) % for e

O(1)% for μ

~9×10^8 ττ at Belle

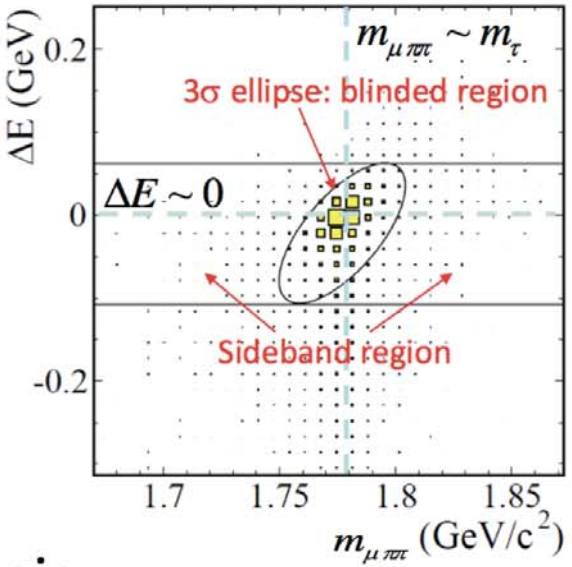
Analysis method



Signal side: extract signal from M_τ vs. ΔE plane

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

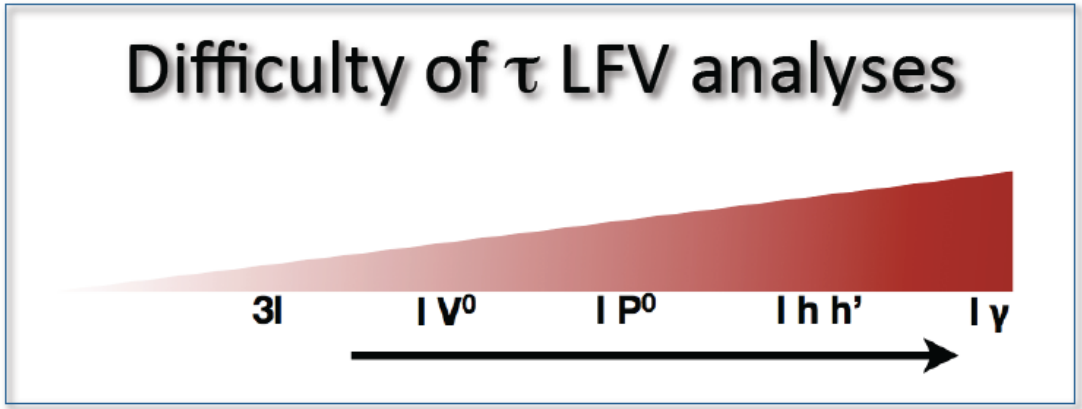
$$\Delta E = E^{CM}_{\mu\pi\pi\tau} - E^{CM}_{beam}$$



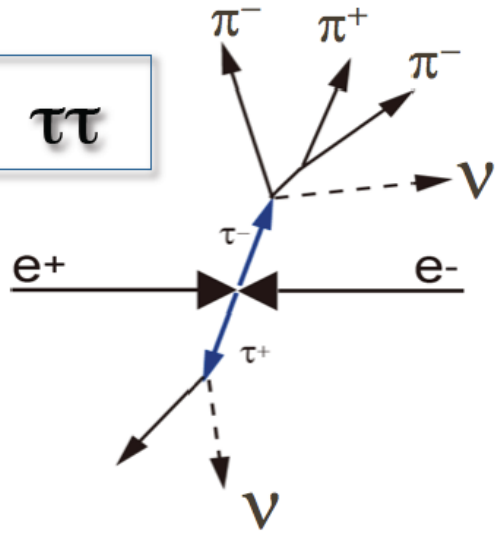
Tag side: select 1-prong decay ($\tau \to l\nu\nu$, $h\nu$, BR ~ 85%)

- Blind analysis (blinded signal region)
- Background estimated from sideband or MC simulation
- 90% C.L. upper limit set using **Feldman-Cousins** approach

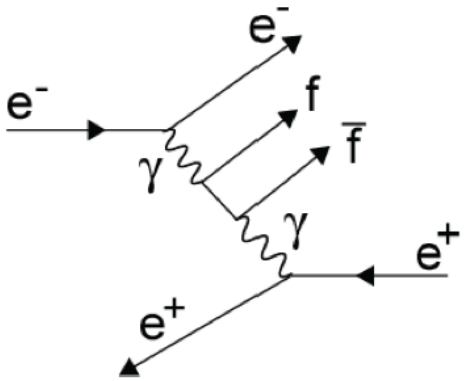
Background sources



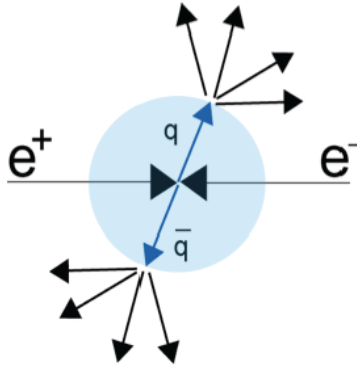
ττ



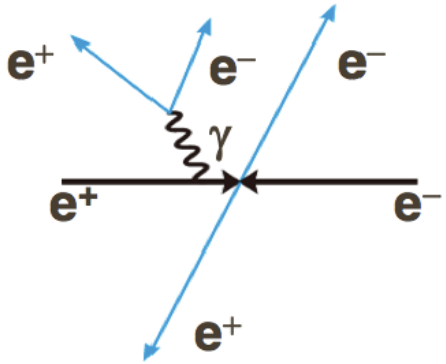
Two-photon



qq



Radiative Bhabha



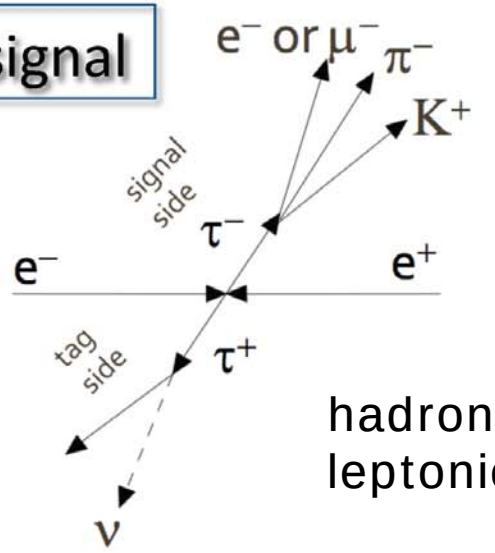
Phys. Lett. B719, 346 (2013)

$\tau \to l\ h\ h'$

For the updates, we have:
1. a larger data sample;
2. better method to reject specific backgrounds

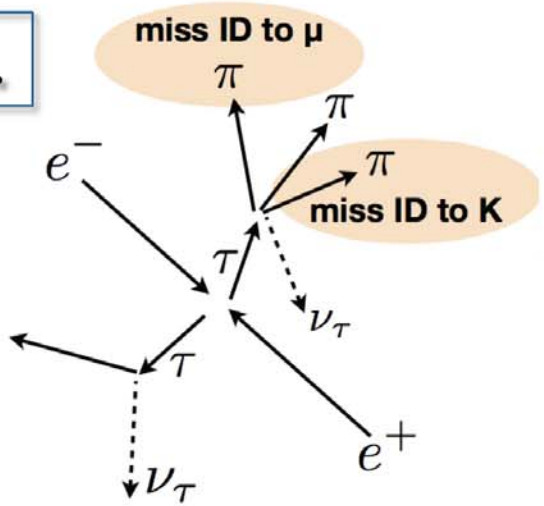
- Based on 854/fb of Belle data
- 14 modes are searched for (h, h' = π,K)
  - $\tau^- \to l^- h^+ h'^-$ (8 lepton flavour violating modes)
  - $\tau^- \to l^+ h^- h'^-$ (6 lepton number violating modes)

signal



hadronic tag or leptonic tag

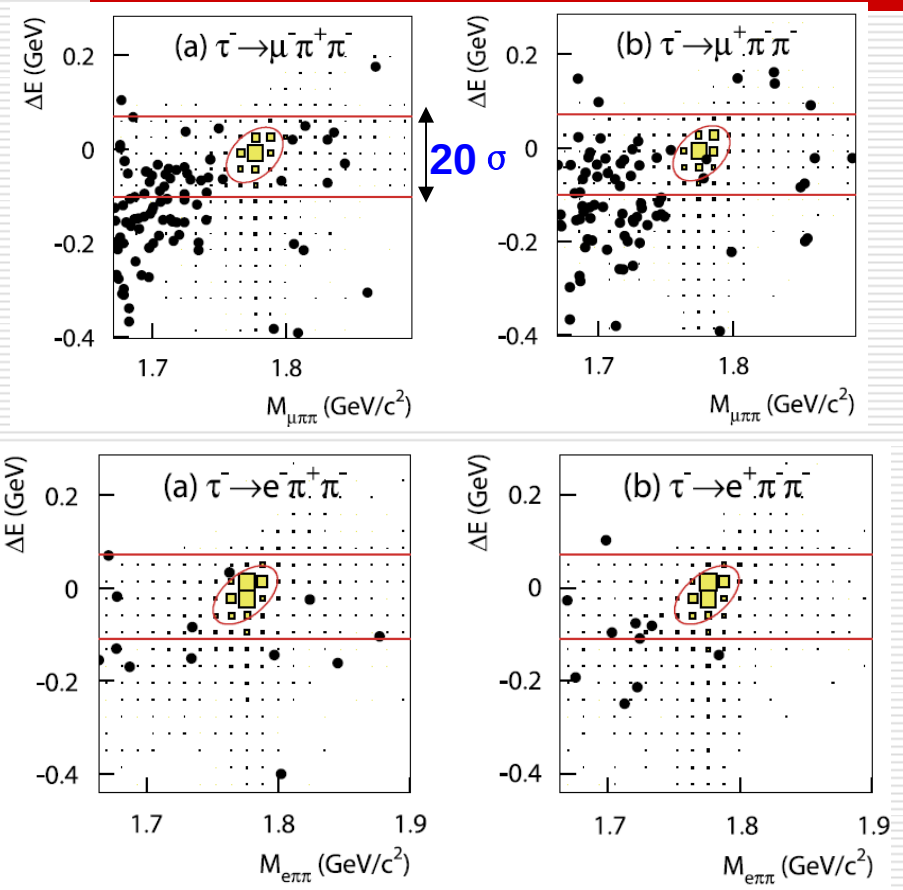
ττ bkgrd.



$\tau \rightarrow l\, h\, h'$ results

90% C.L. upper limits
$Br(\tau \rightarrow lhh') < (2.0\text{-}8.6) \times 10^{-8}$

These results improve upon our previous upper limits by factors of about 1.8 on average.



For other plots, please see **PLB719,346**

- In the signal window
  - 1 event in $\mu^+\pi^-\pi^-$ and $\mu^-\pi^+K^-$
  - Zero events in the other modes

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	$\mathcal{B}$ (10^{-8})
$\tau^- \rightarrow \mu^-\pi^+\pi^-$	5.83	0.63 ± 0.23	5.7	0	1.87	2.1
$\tau^- \rightarrow \mu^+\pi^-\pi^-$	6.55	0.33 ± 0.16	5.6	1	4.01	3.9
$\tau^- \rightarrow e^-\pi^+\pi^-$	5.45	0.55 ± 0.23	5.7	0	1.94	2.3
$\tau^- \rightarrow e^+\pi^-\pi^-$	6.56	0.37 ± 0.19	5.5	0	2.10	2.0
$\tau^- \rightarrow \mu^-K^+K^-$	2.85	0.51 ± 0.19	6.1	0	1.97	4.4
$\tau^- \rightarrow \mu^+K^-K^-$	2.98	0.25 ± 0.13	6.2	0	2.21	4.7
$\tau^- \rightarrow e^-K^+K^-$	4.29	0.17 ± 0.10	6.7	0	2.29	3.4
$\tau^- \rightarrow e^+K^-K^-$	4.64	0.06 ± 0.06	6.5	0	2.39	3.3
$\tau^- \rightarrow \mu^-\pi^+K^-$	2.72	0.72 ± 0.28	6.2	1	3.65	8.6
$\tau^- \rightarrow e^-\pi^+K^-$	3.97	0.18 ± 0.13	6.4	0	2.27	3.7
$\tau^- \rightarrow \mu^-K^+\pi^-$	2.62	0.64 ± 0.23	5.7	0	1.86	4.5
$\tau^- \rightarrow e^-K^+\pi^-$	4.07	0.55 ± 0.31	6.2	0	1.97	3.1
$\tau^- \rightarrow \mu^+K^-\pi^-$	2.55	0.56 ± 0.21	6.1	0	1.93	4.8
$\tau^- \rightarrow e^+K^-\pi^-$	4.00	0.46 ± 0.21	6.2	0	2.03	3.2

The lowest UL

The highest UL

$\tau \to \Lambda h,\ \bar{\Lambda} h$ (h= π , K)

$\tau^- \to \bar{\Lambda}\pi^-, K^-$, $\bar{\Lambda} \to \bar{p}\pi^+$

	τ^-	$\bar{\Lambda}$	π^-, K^-
B	0	-1	0
L	1	0	0
B-L	-1	-1	0

(B-L) conserving

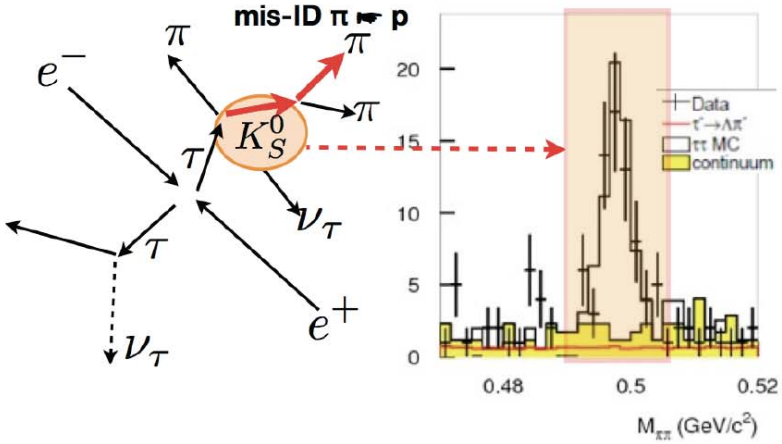
$\tau^- \to \Lambda\pi^-, K^-$, $\Lambda \to p\pi^-$

	τ^-	Λ	π^-, K^-
B	0	1	0
L	1	0	0
B-L	-1	+1	0

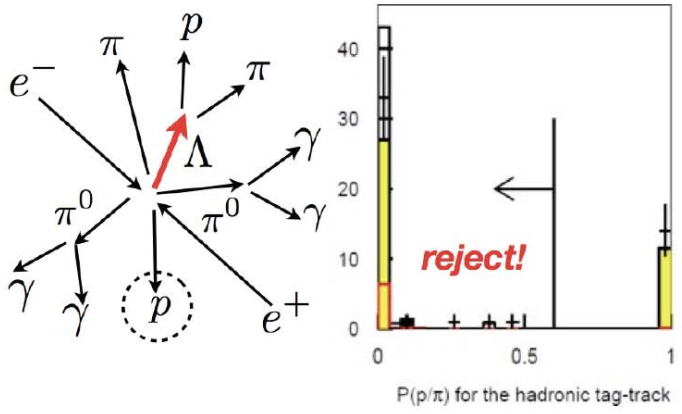
(B-L) violating

- Based on 904/fb of Belle data
- 4 modes are searched for
  - $\tau^- \to \bar{\Lambda} h^-$ (B-L conserving)
  - $\tau^- \to \Lambda h^-$ (B-L violating)
- Select three hadrons on signal side, require Λ vertex

K_S veto

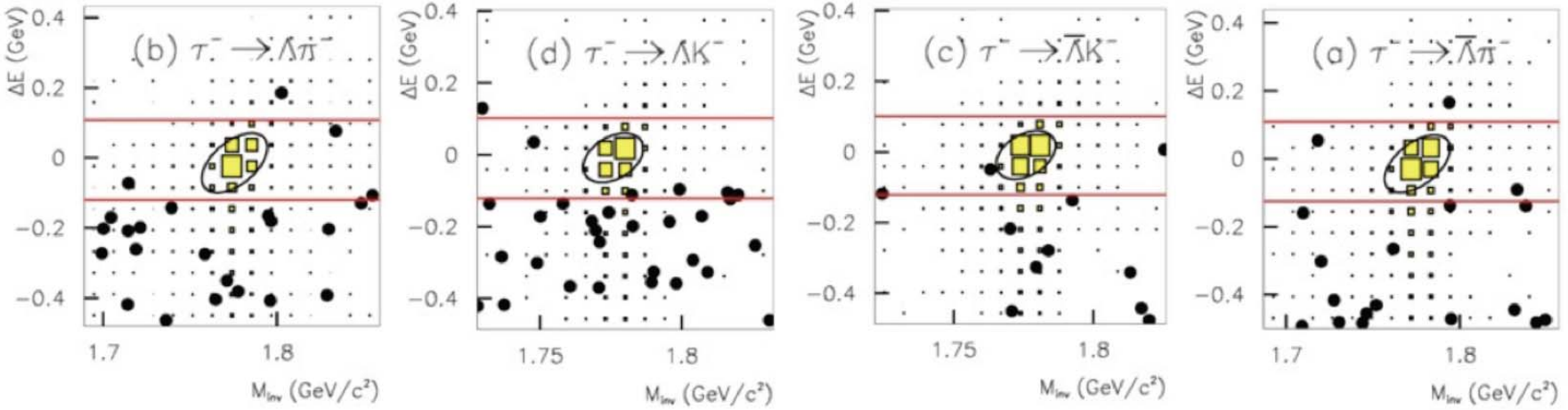


Proton veto tag side



$\tau \to \Lambda h, \bar{\Lambda} h$ results

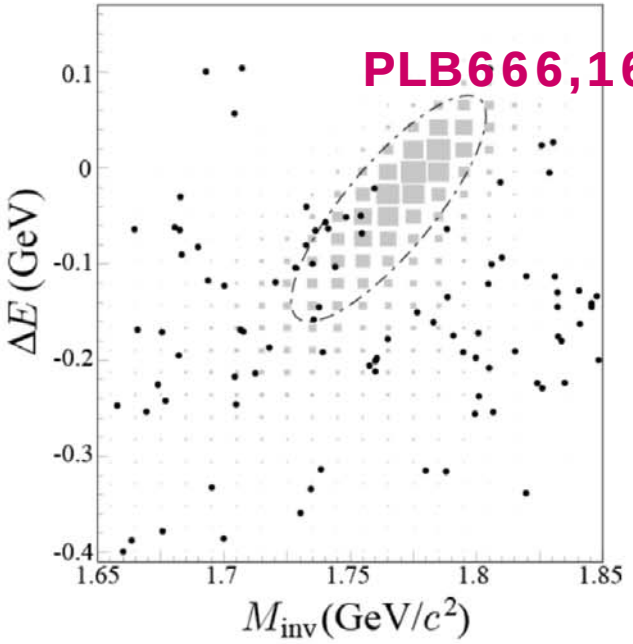
preliminary



	Mode	$\epsilon(\%)$	$N_{\rm BG}$	$\sigma_{\rm syst.}$	$N_{\rm obs}$	s_{90}	$\mathcal{B}(10^{-8})$
B-L conv.	$\tau^- \to \Lambda\pi^-$	4.80	0.21 ± 0.15	8.2	0	2.3	< 2.8
	$\tau^- \to \bar{\Lambda}K^-$	4.39	0.31 ± 0.18	8.2	0	2.3	< 3.1
B-L viol.	$\tau^- \to \bar{\Lambda}\pi^-$	4.11	0.31 ± 0.14	8.6	0	2.2	< 3.0
	$\tau^- \to \Lambda K^-$	3.16	0.42 ± 0.19	8.6	0	2.1	< 4.2

$\tau \rightarrow \mu\gamma$

- Based on 545/fb data
- Main backgrounds: $\tau \rightarrow \mu\nu\nu$ and dimuon events with ISR
- 94 events found in the 5σ signal region, while expecting (88 +/- 7)
- 90% C.L. upper limits
  - Expected: 7.8×10^{-8}
  - Observed: 4.5×10^{-8}



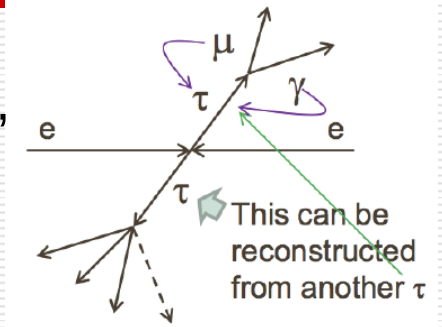
PLB666,16(2008)

545 fb^{-1}

Now updating to the full Belle dataset (980/fb)…

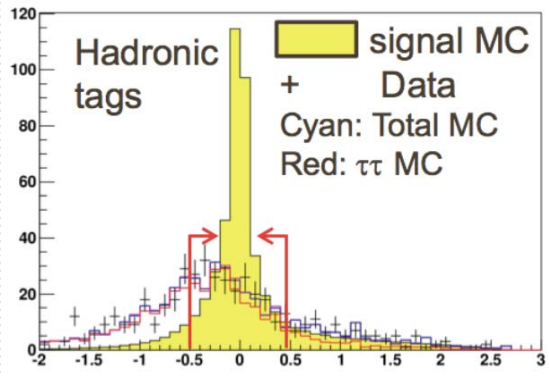
preliminary

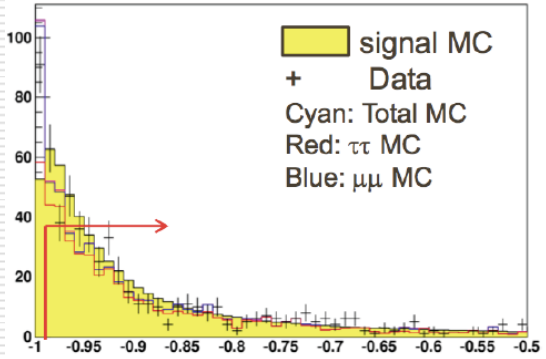
$\tau \rightarrow \mu\ \gamma$ results



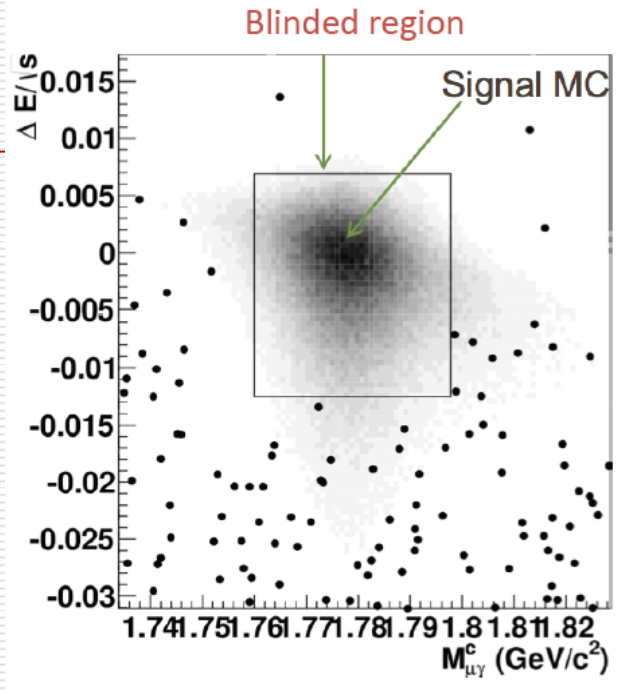
- To reduce $\tau\ \tau$ background, we used missing mass:

$$M^2_{miss} = (p_\tau - p_{tag})^2$$





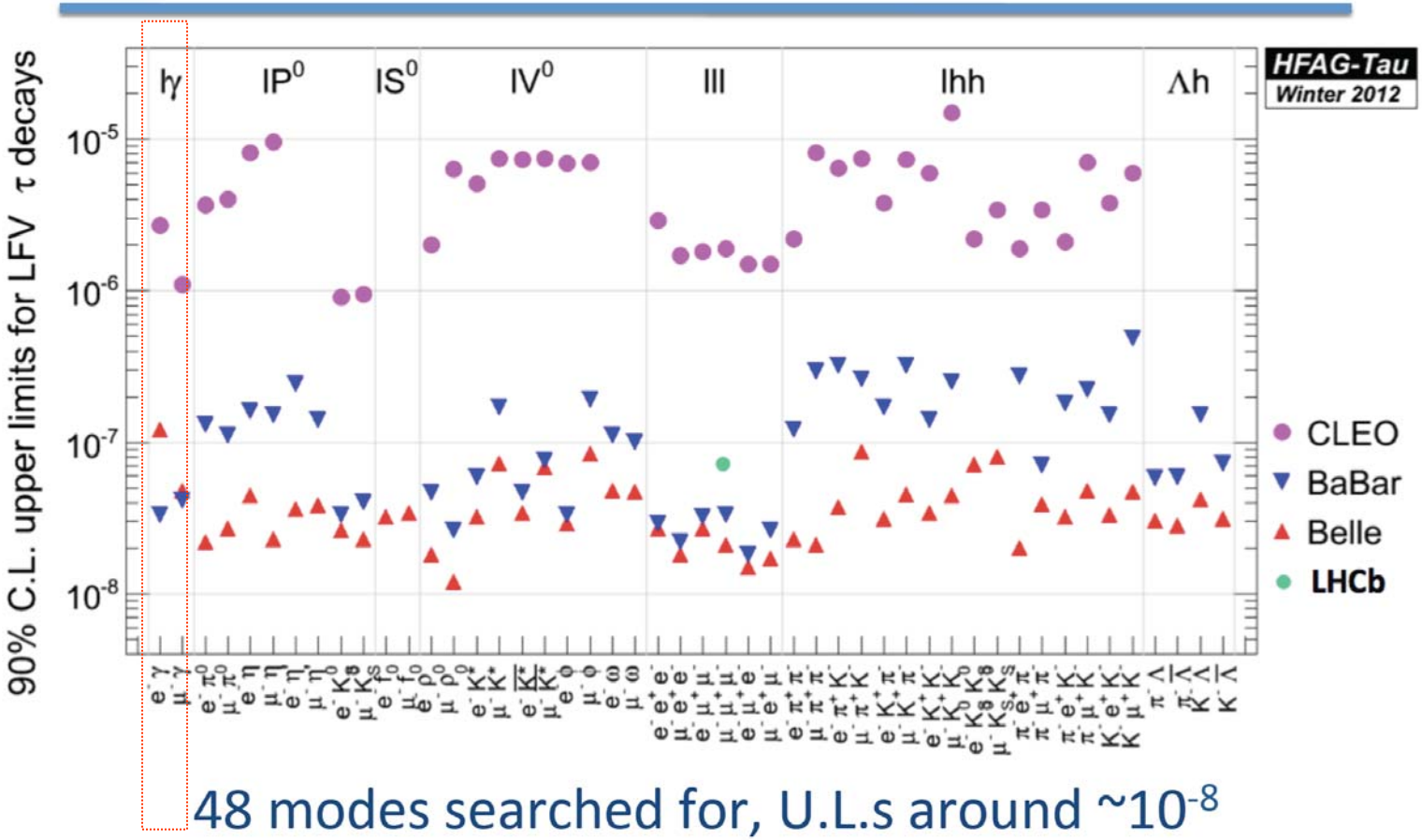
- To reduce ISR $\mu\ \mu$ background, we added a cut on the open angle between signal and tag-side tracks in γee CMS



- 6.5% efficiency
- 115 +/- 11 background events expected
- About a factor of 1.5 increase in sensitivity

Expected: 5.3×10^{-8}

Summary Belle τ LFV results



These results are under preparation with full data set

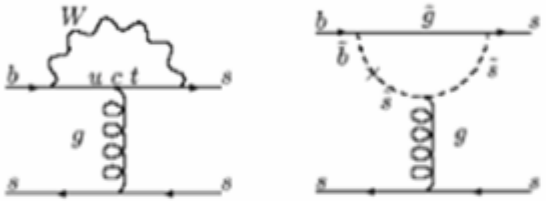
Future Facilities for τ LFV …

- Belle-II/Super-KEKB/KEK
- COMET+DeeMe/JPARC
- LHCb+ATLAS+CMS/LHC/CERN
- MEG+Mu3e/PSI
- Mu2e+Mu3e/Fermilab/Project-X
- NA62/SPS/CERN
- Super Tau-Charm (?)
- ……

Searching for New Physics with Belle II

Indirect searches for New Physics complement direct searches at LHC

Flavor changing neutral currents
(virtual contributions of new, heavy particles in loops)



Precision test of **CKM unitarity**
(search for new CP-violating phases)

New Physics ???

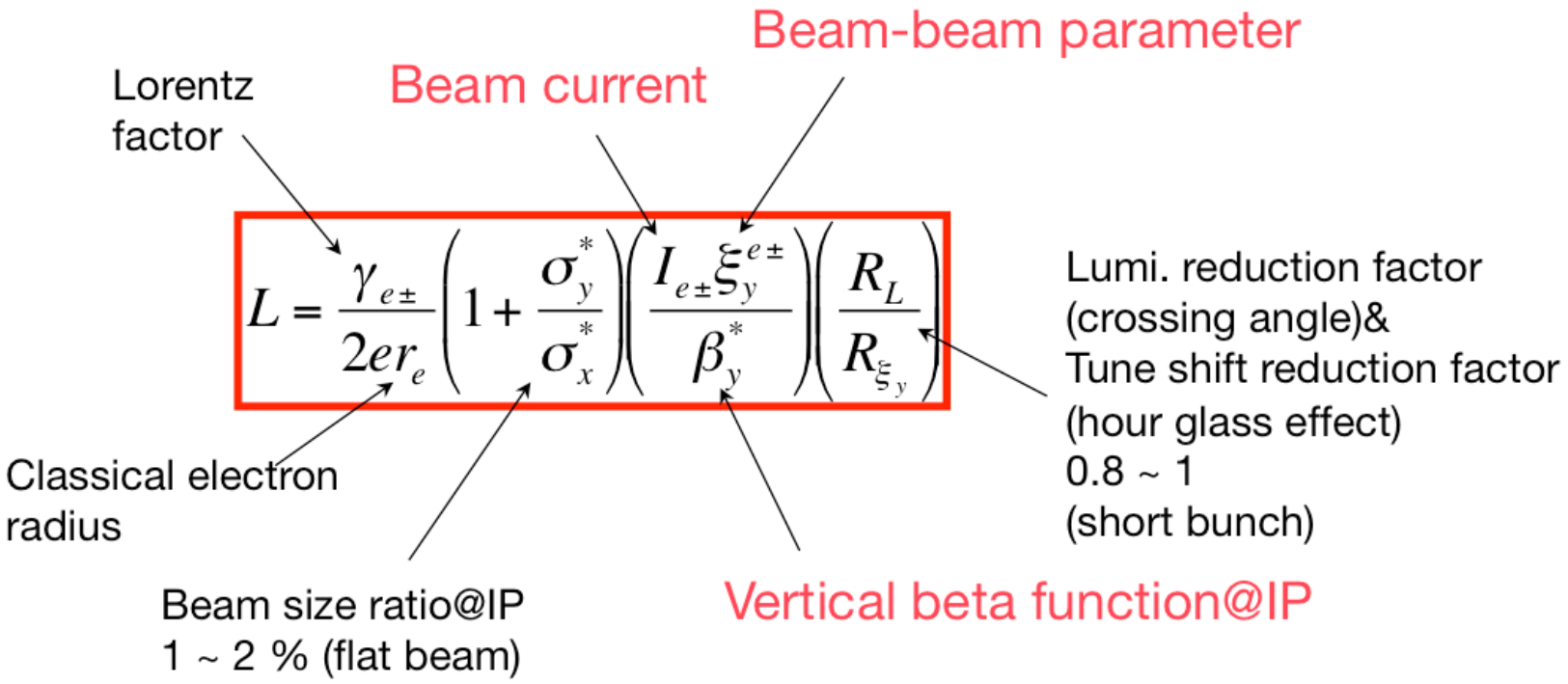
Search for **New Physics** in **B decays with τ leptons** (charged Higgs, ...)

Search for **lepton flavor violation** in **B and τ decays**

For sensitive New Physics searches, need **O(10²) times** more data

Belle / KEKB ⇒ Belle II / SuperKEKB

Strategies to increase luminosity



(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

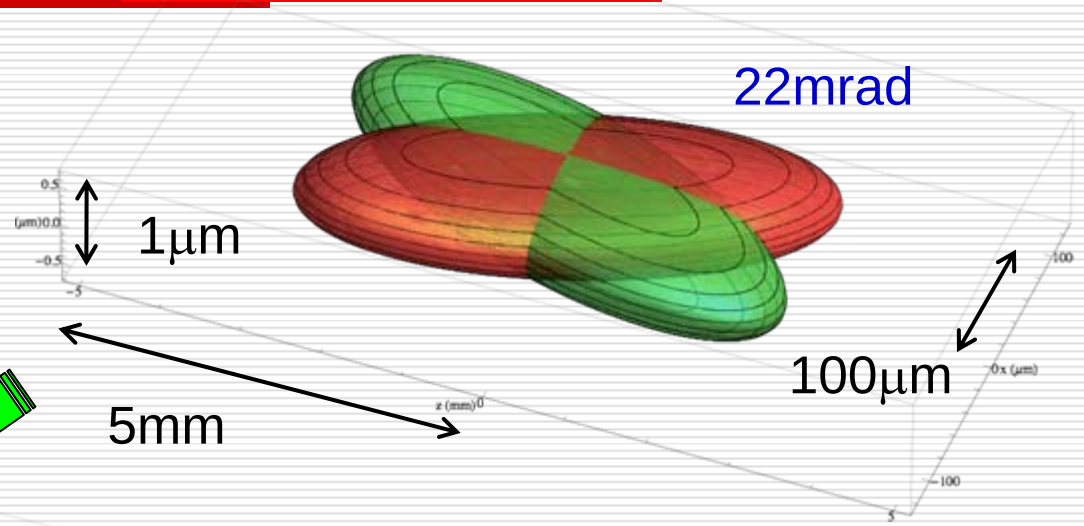
"Nano-Beam" scheme

Collision with very small spot-size beams

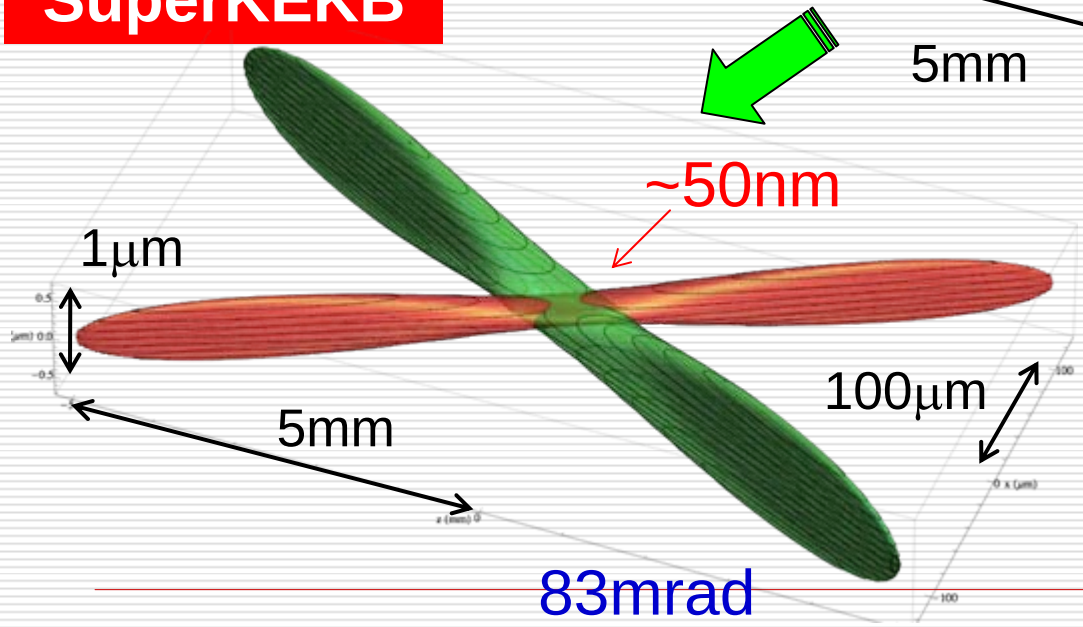
Invented by Pantaleo Raimondi for SuperB

Nano-Beam Scheme

present KEKB (w/o crab)



SuperKEKB

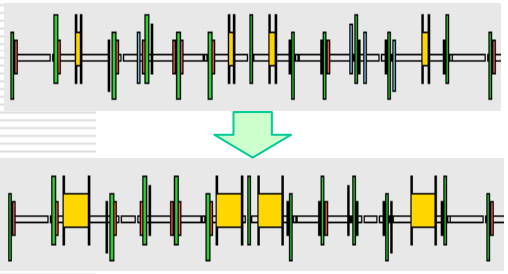


- **Small beam size & high current**
- **Large crossing angle**
- **Change beam energies**

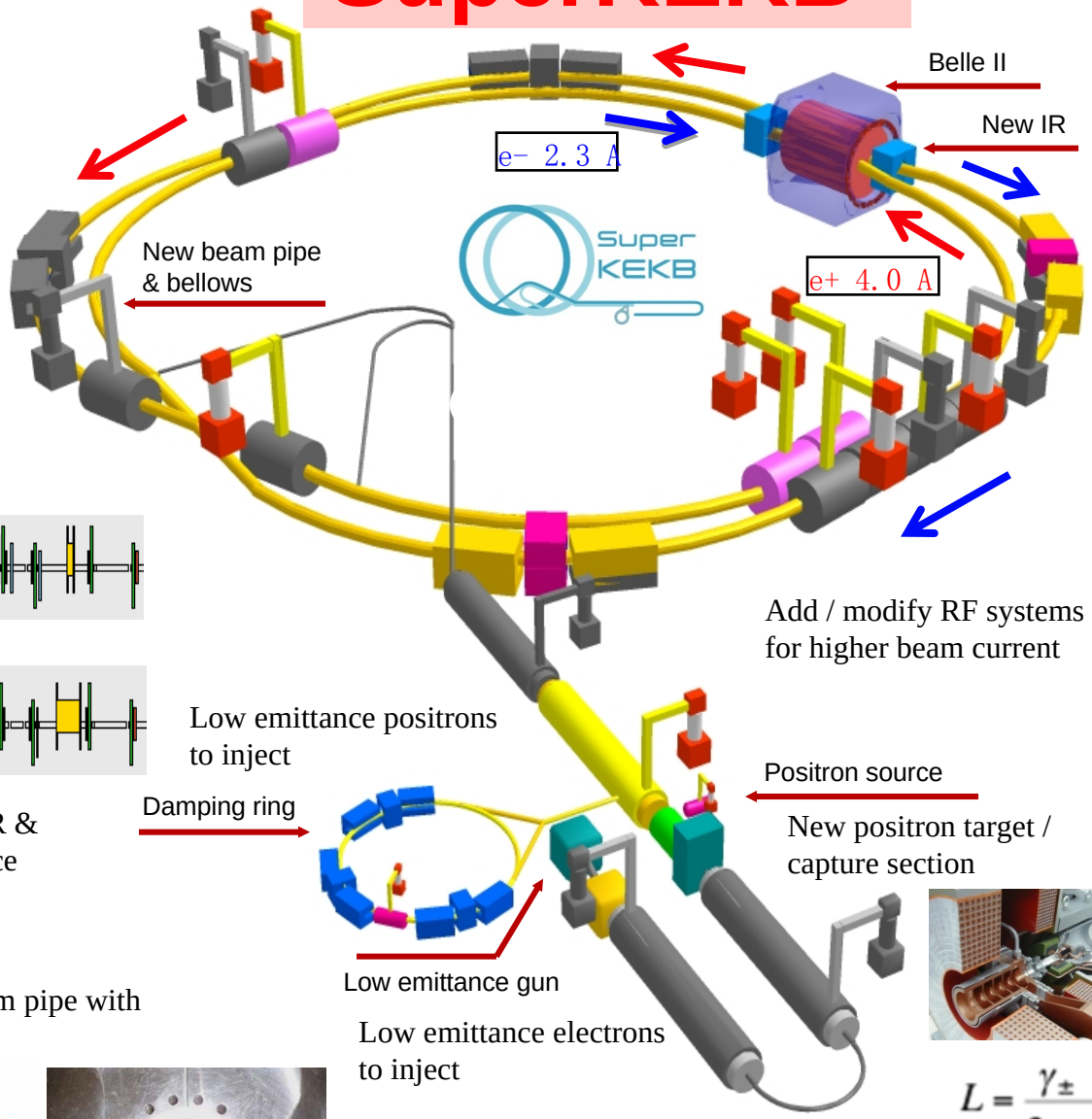
to solve the problem of LER short lifetime

SuperKEKB

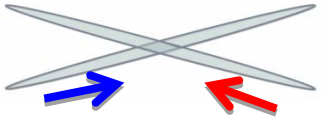
Replace short dipoles with longer ones (LER)



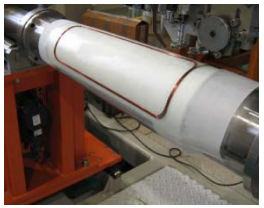
Redesign the lattices of HER & LER to squeeze the emittance



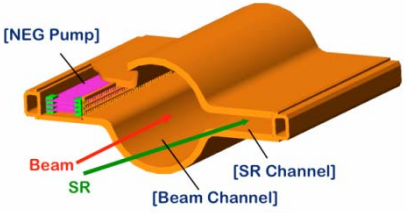
Colliding bunches

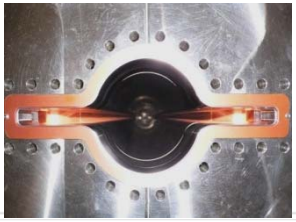


New superconducting /permanent final focusing quads near the IP



TiN-coated beam pipe with antechambers





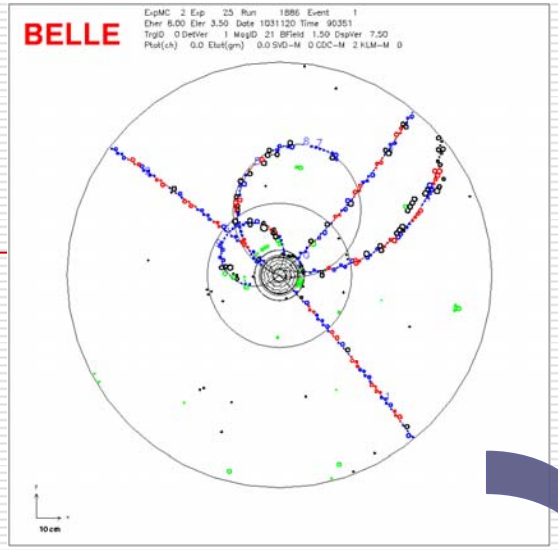
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

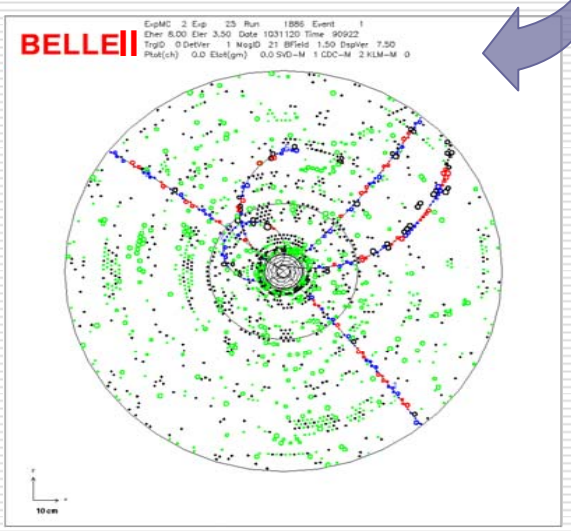
$L = 8 \cdot 10^{35}\ s^{-1}cm^{-2}$

x 40 Gain in Luminosity

Detector upgrade

TDR: arXiv:1011.0352





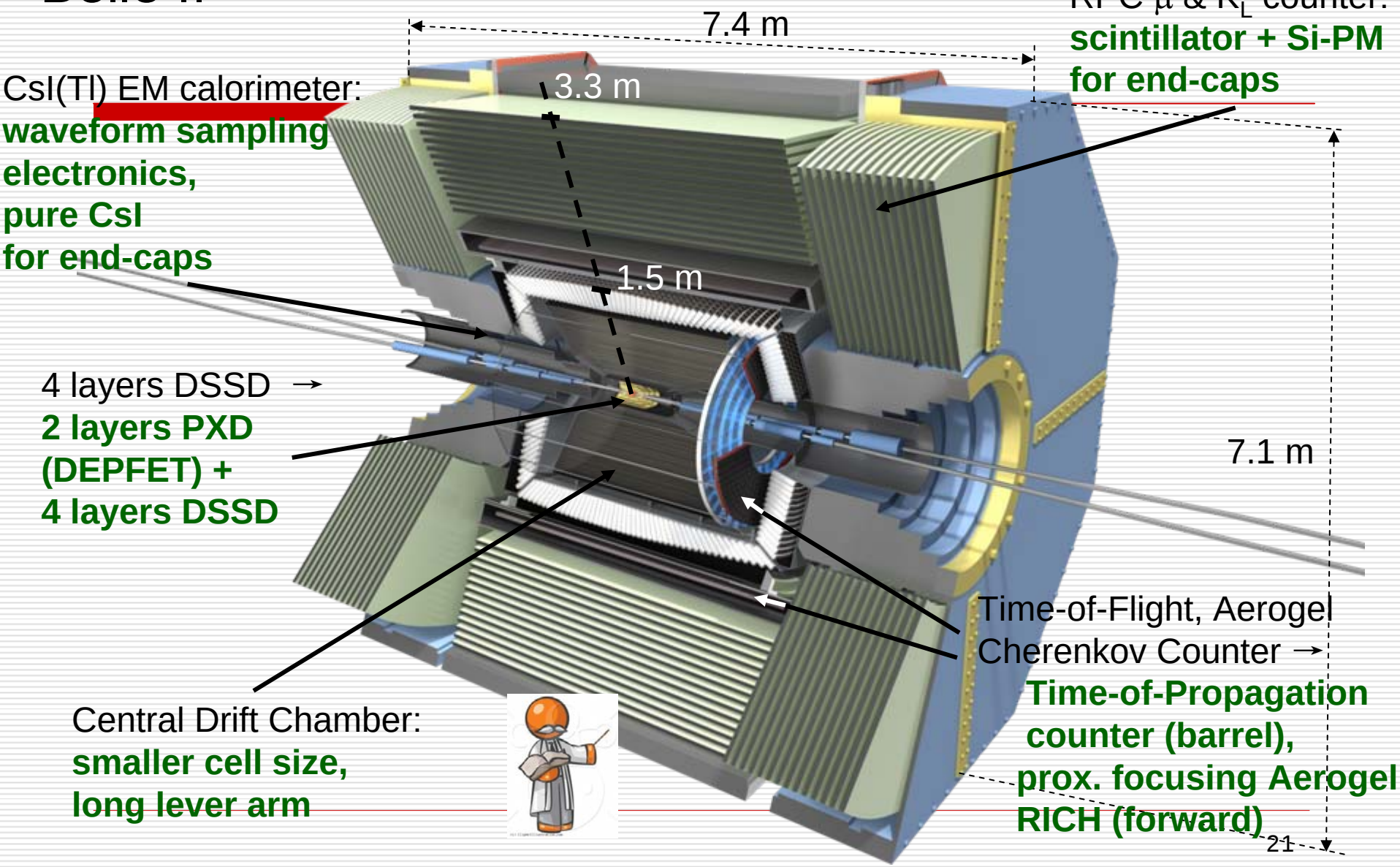
Critical issues at L= $8\times10^{35}/cm^2/s$:

- **Higher background (×10-20)**
  - **radiative Bhabha dominate**
  - **radiation damage and higher occupancy**
  - **fake hits and pile-up noise in EM calorimeter**
- **Higher event rates (×10)**
  - **higher rate trigger (L1 trigg. 0.5→30 kHz)**
  - **DAQ, computing**
- **Targeted improvements:**
  - **increase hermeticity**
  - **improve IP and secondary vertex resolution**
  - **improve K_s and π^0 efficiency**
  - **improve K/π separation**
  - **add μ-ID and PID in end-caps**

Higher luminosity ➡ higher background ➡ the **Belle** detector has to be upgraded

Belle II detector upgrade

Belle II



RPC μ & K_L counter:
scintillator + Si-PM for end-caps

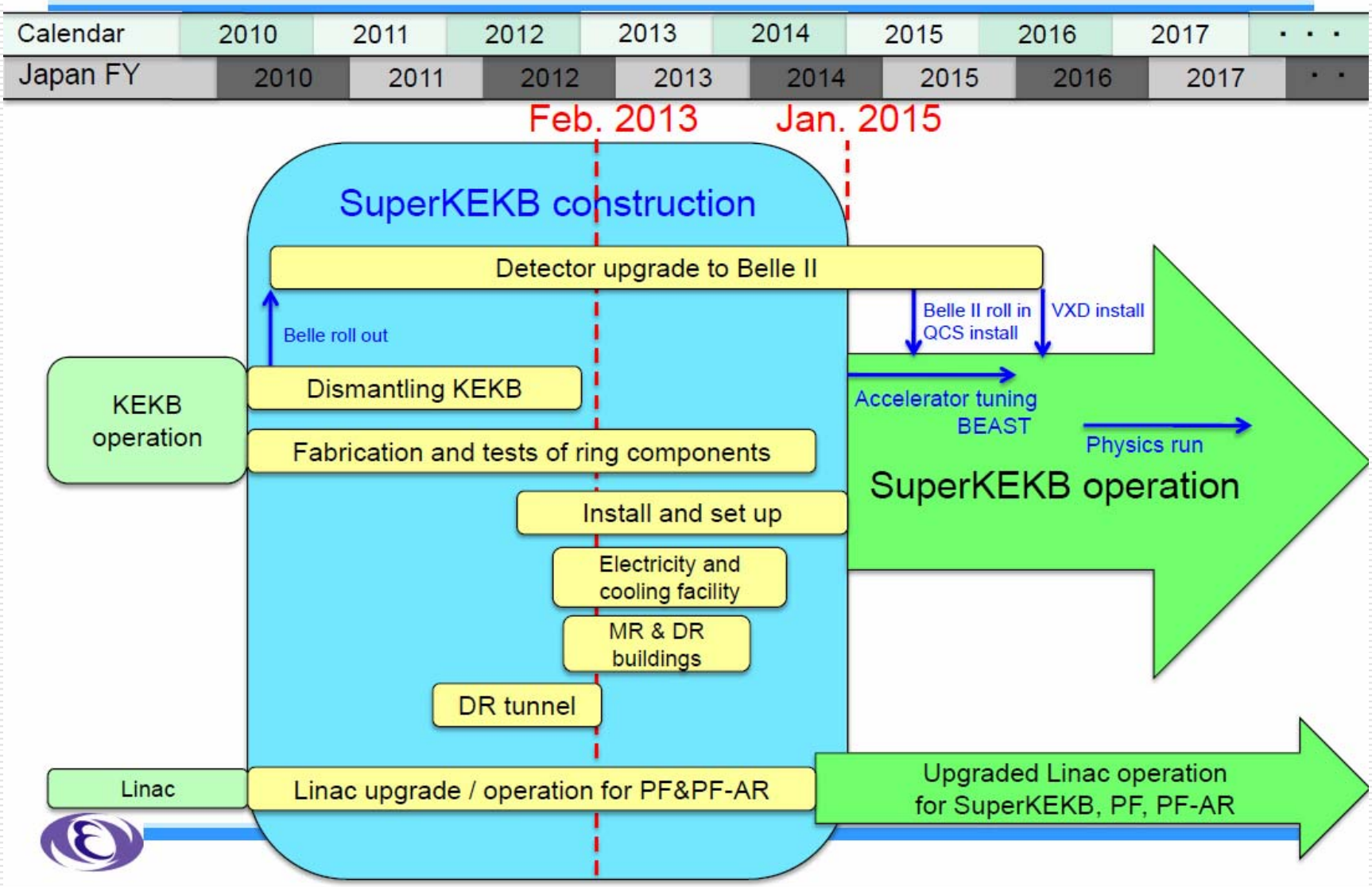
CsI(Tl) EM calorimeter:
waveform sampling electronics, pure CsI for end-caps

4 layers DSSD →
2 layers PXD (DEPFET) + 4 layers DSSD

Time-of-Flight, Aerogel Cherenkov Counter →
Time-of-Propagation counter (barrel), prox. focusing Aerogel RICH (forward)

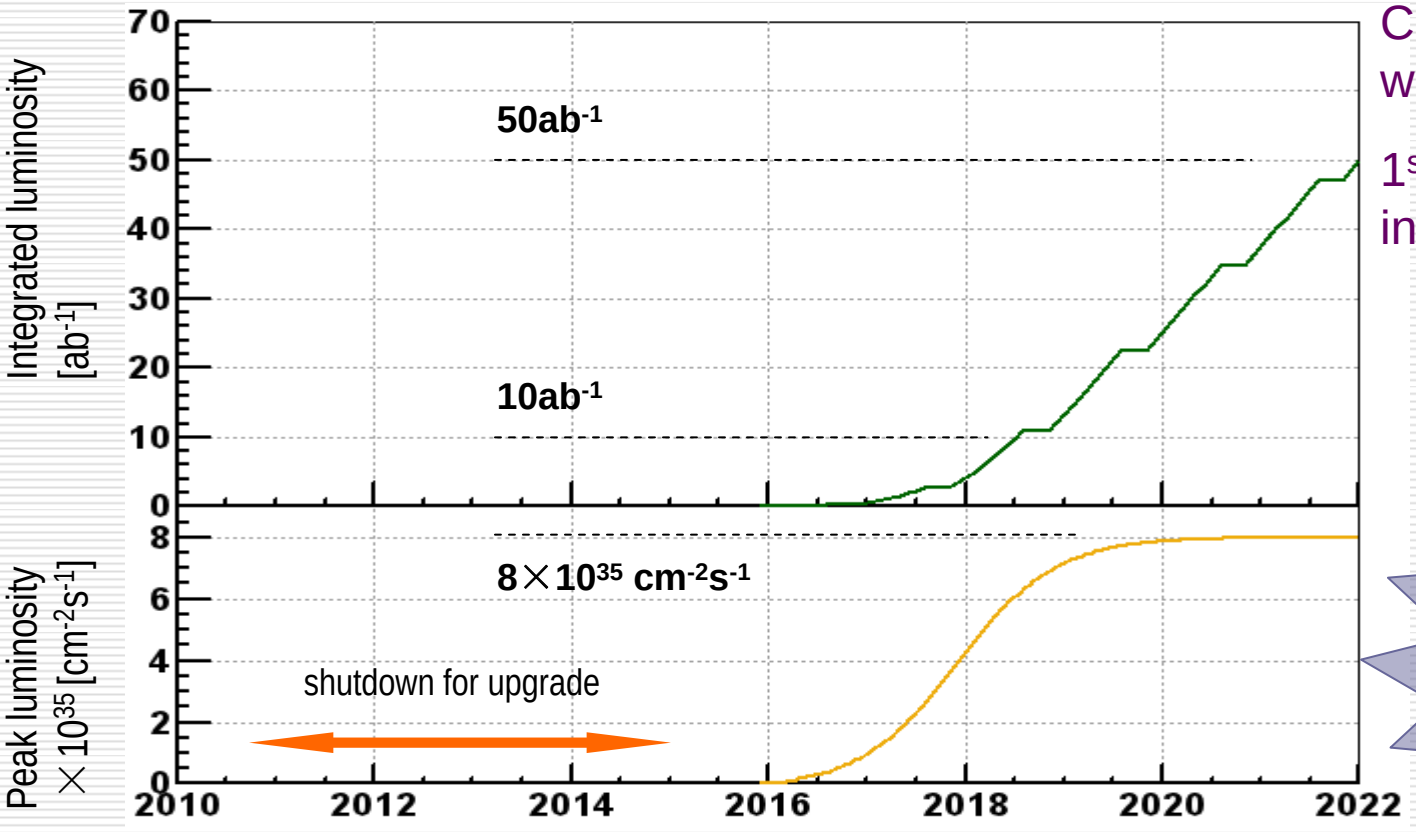
Central Drift Chamber:
smaller cell size, long lever arm

SuperKEKB/Belle II schedule



Sakai-san, KEK Roadmap Review April 2013

Luminosity prospects at SuperKEKB



Commissioning will start in early 2015

1st physics run in 2016

10 ab^{-1} in 2018
50 ab^{-1} in 2022

Belle II Collaboration

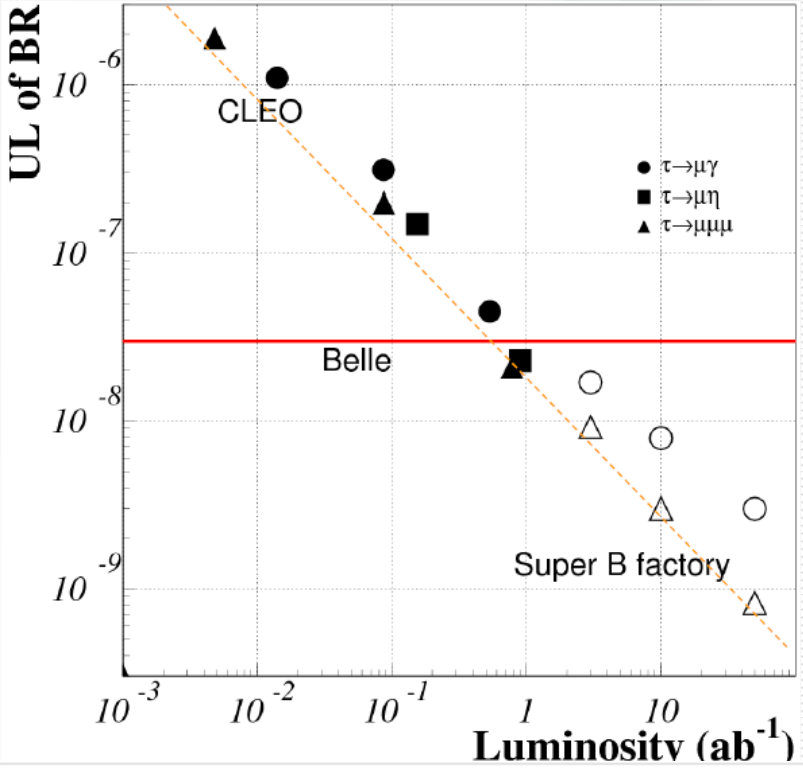
23 countries/regions, **94** institutions, **560** collaborators

We welcome new collaborators!

Latest collaboration meeting on July 4–7 at VT

Prospects for τ LFV at Belle II

experimental sensivity



- Belle II will collect ~10^{11} τ-leptons (50/ab)

Sensitivity depends on the BG level.

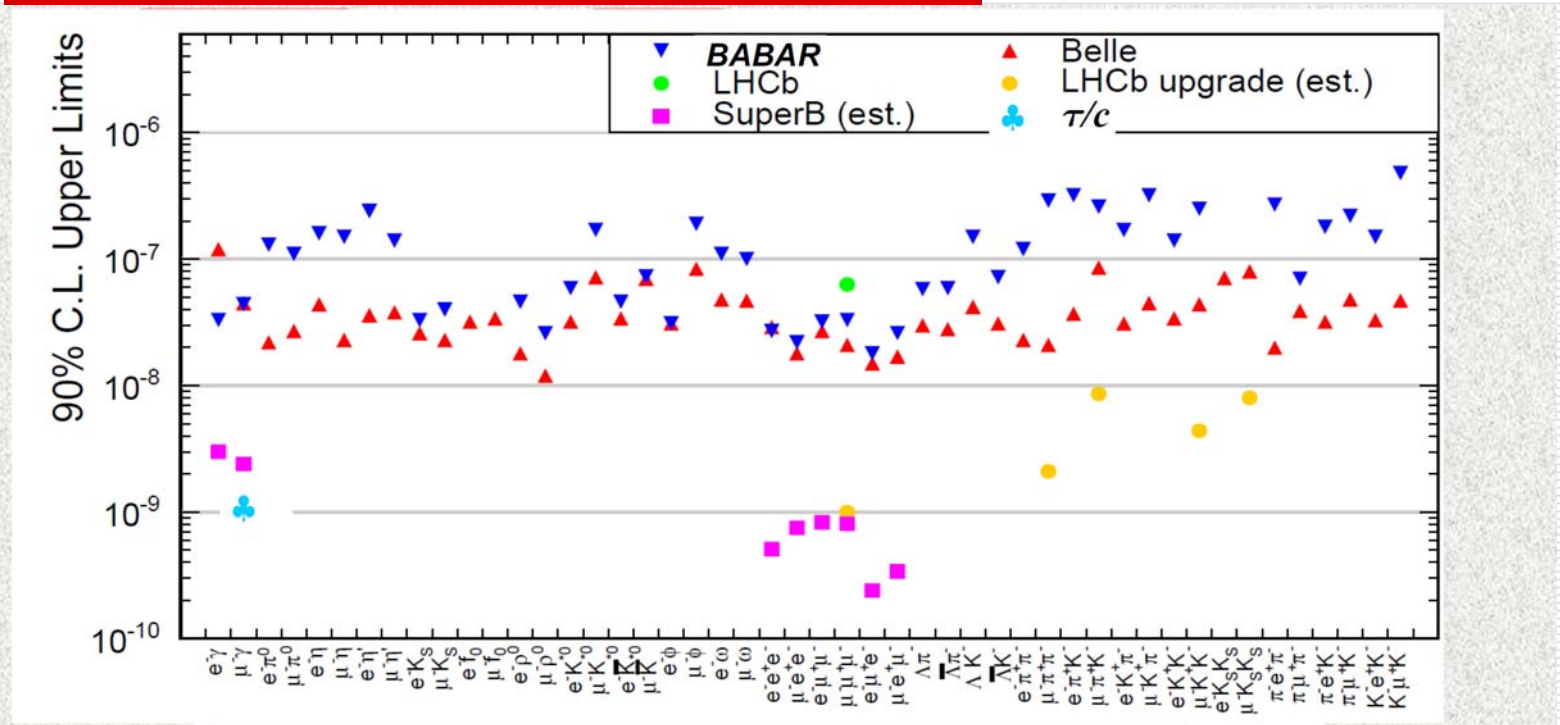
huge BG : $\tau \to l\gamma$; scaling ~$1/\sqrt{L}$

negligible BG at $1ab^{-1}$: $\tau \to 3l$, l+meson ; scaling ~$1/L$

mode	Br($\tau \to \mu\gamma$)	Br($\tau \to 3l$)
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY + SO(10)	10^{-8}	10^{-10}
SM + seesaw	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY + Higgs	10^{-10}	10^{-7}

The full range of τ LFV modes is only accessible at a Super B factory!

Super e^+e^- factory sensitivity of τ LFV



Mode	*BABAR* ($\times 10^{-8}$)	Belle ($\times 10^{-8}$)	Super$B$ ($\times 10^{-8}$)
$\tau^\pm \to e^\pm\gamma$	3.3	12	0.3
$\tau^\pm \to \mu^\pm\gamma$	4.4	4.5	0.2
$\tau^\pm \to \mu^\pm\mu^+\mu^-$	3.3	2.1	0.08
$\tau^\pm \to e^\pm e^+ e^-$	2.9	2.7	0.02

Summary

- Belle
  - Belle data sample contains ~10^9 τ -pairs, the world's largest sample
  - 48 τ LFV modes have been studied and 90% C.L. upper limits in the O(10^{-8}) have been set
  - The final analysis of $\tau \to e\gamma/\mu\gamma$ is ongoing and final results will come soon
- Belle II
  - Now the KEK B factory (KEKB and Belle) undergoes a major upgrade to become a Super B factory (SuperKEKB and Belle II)
  - The start of the physics run is foreseen for 2016, the luminosity goal is 50/ab by 2022, or ~5 x 10^{10} τ-pairs
  - This will allow to probe τ LFV at the level of O(10^{-9})

Background rejection

- μπK mode

  M^2_{miss} vs. p_{miss} 2d cut
  75% efficient while 75% of the BG is rejected

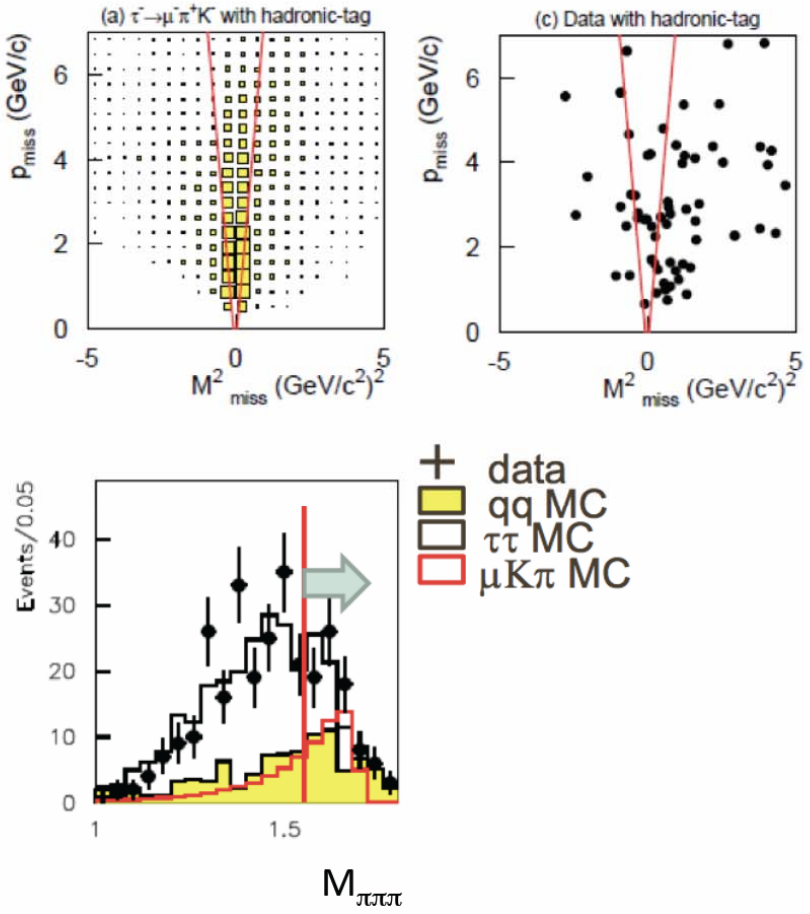
- ehh', μππ and μKK modes

  M^2_{miss} selection
  90% efficient while 50% of the BG is rejected

- πππν veto (for μπK mode)

  Assign ππ mass for selected events

  $M_{\pi\pi\pi}$ > 1.52 GeV/c2
  65% efficient, 65% of the BG rejected



Machine design parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	ϕ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.3-4.6	nm
Emittance ratio	K	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**