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The prospect of τ physics in the Belle II experiment

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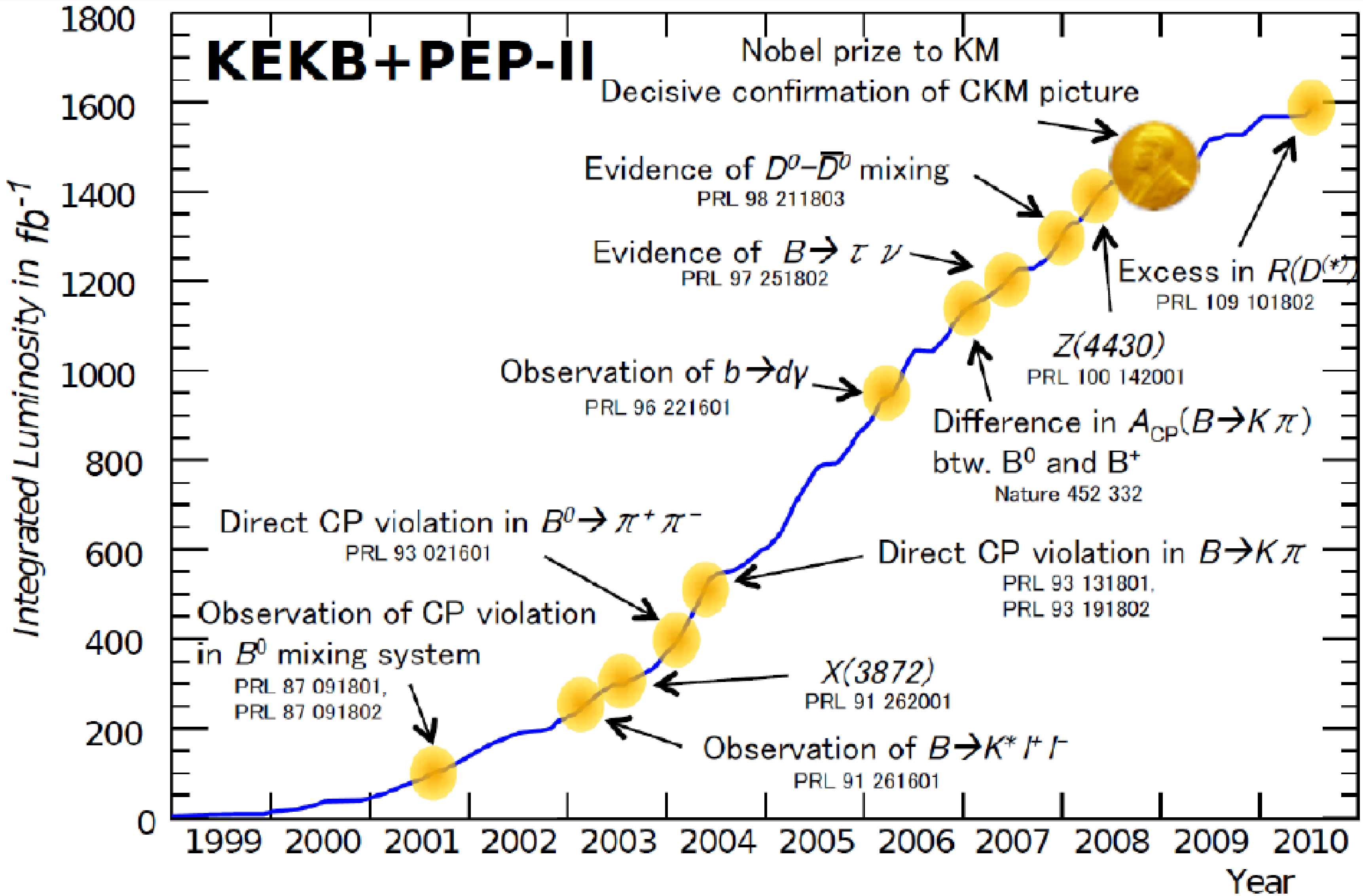
The 2nd International Workshop on High Intensity Electron-Positron Accelerator (HIEPA),
UCAS, March 19-21, 2018

Outline

- Introduction
- Studies of τ at B factories
- Belle II experiment
- Belle II schedule
- LFV τ decays at Belle II
- CPV in hadronic τ decays at Belle II
- B decays involving τ at Belle II
- Summary

The B Factory Legacy

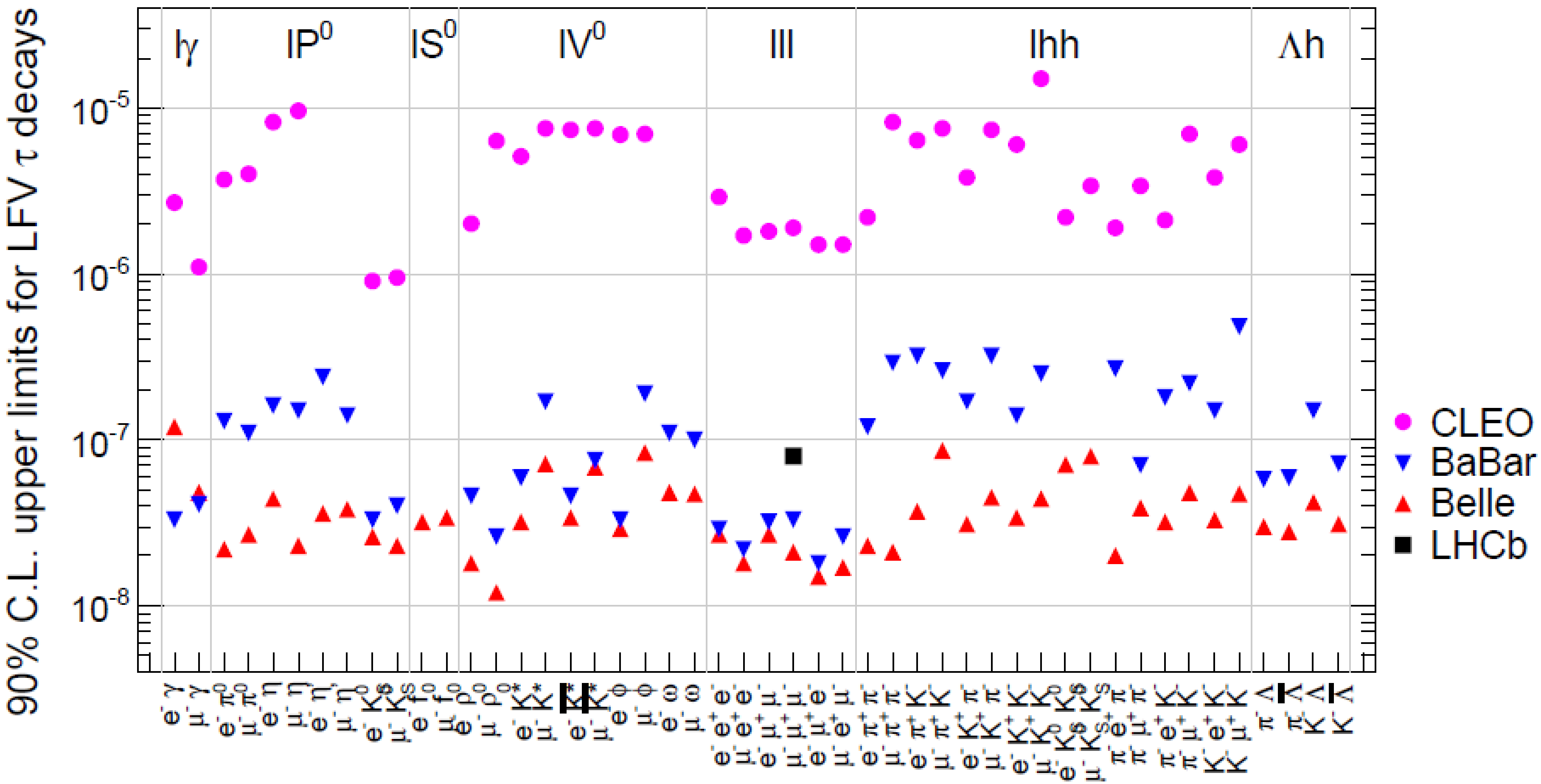


B factory is also a τ factory !

- The world largest statistics of τ leptons collected by e^+e^- B factories (Belle and *BABAR*) opens new era in the precision tests of the Standard Model (SM).
- Basic tau properties, like: lifetime, mass, couplings, electric dipole moment, anomalous magnetic dipole moment, etc. should be measured experimentally as precisely as possible in order to test SM and search for the effects of New Physics.
- In the SM τ decays due to the charged weak interaction described by the exchange of $W^\pm$ with a pure vector coupling to only left-handed fermions. There are two main classes of tau decays:
  - Decays with leptons, like: $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$, $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau \gamma$, $\tau^- \to \ell^- \ell'^+ \ell'^- \bar{\nu}_\ell \nu_\tau$; $\ell, \ell' = e, \mu$. They provide very clean laboratory to probe electroweak couplings, which is complementary/competitive to precision studies with muon (in experiments with muon beam). Plenty of New Physics models can be tested/constrained in the precision studies of the dynamics of decays with leptons.
  - Hadronic decays of τ offer unique tools for the precision study of low energy QCD.

Results of LFV decays of τ at B factories

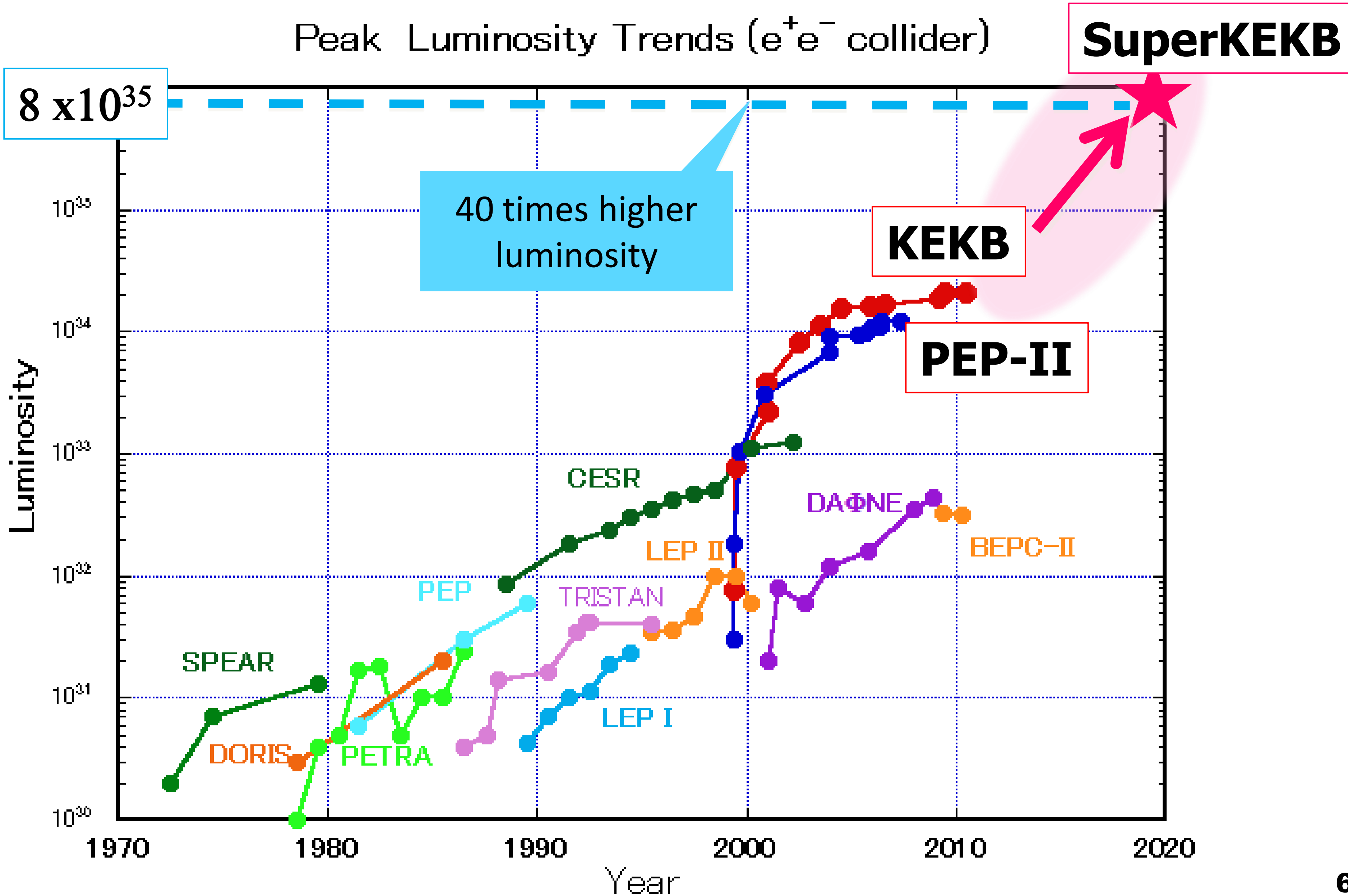
48 different LFV modes were studied at *B* factories



Next Generation SuperKEKB+ Belle II with > 50 ab^{-1}

➔ Discover (or constrain) new physics!

Need O(100x) more data →Next generation B-factories



High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathscr{L}$ = 8x10^{35} cm^{-2}s^{-1} (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP by 1/20

Lorentz factor

beam current

beam-beam parameter

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

geometrical reduction factors

beam aspect ratio at the IP

vertical beta-function at the IP

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1x10		8x10^{35}		cm^{-2}s^{-1}

High-Luminosity Asymmetric B Factory

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  - double beam currents
  - squeeze beams @

Lorentz factor

beam

beam-beam

$L = \frac{\gamma}{2e_e} \cdots$

beam aspect … at the IP

vertical beta-function at the IP

reduced CM boost

- reduced vertex separation, Δt resolution
- increased detector hermeticity

squeezed beams @ IP

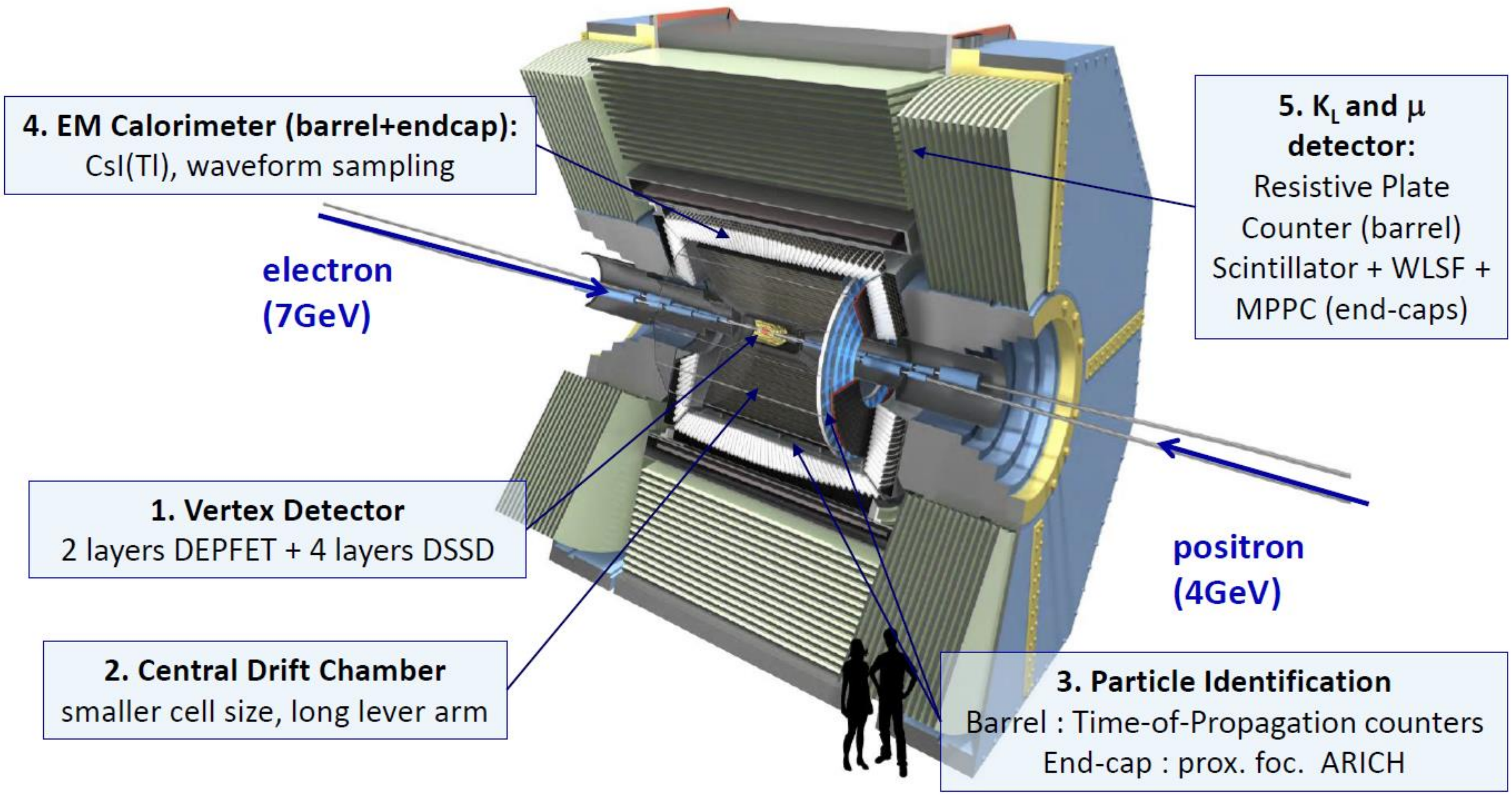
- greatly improved constraint for decay chain vertex fitting

paramet		LER		LER	HER	units
				SuperKEK		
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
h				41.5		mrad
ho			24	3.2	4.6	nm
			0.66	37	0.40	%
b			5.9	32/0.27	25/0.30	mm
			1.19	3.6	2.6	A
bea			90	0.0881	0.0807	
			2	10/0.059		μm
			0	8x10^{35}		cm^{-2}s^{-1}

x40 luminosity

- higher background rates (~10-20x)
  - detectors occupancy, radiation damage, fake hits, pile-up noise in the calorimeter
- higher event rate
  - higher trigger rate, DAQ, computing
- x40 produced signal events

Belle II Detector



- All sub-detectors are upgraded from Belle II:
  - Except for ECL crystals and a part of Barrel KLM

- Improved IP and secondary vertex resolution
- Better K/π separation and flavor tagging
- Higher Ks, π^0 and slow pion reconstruction efficiency

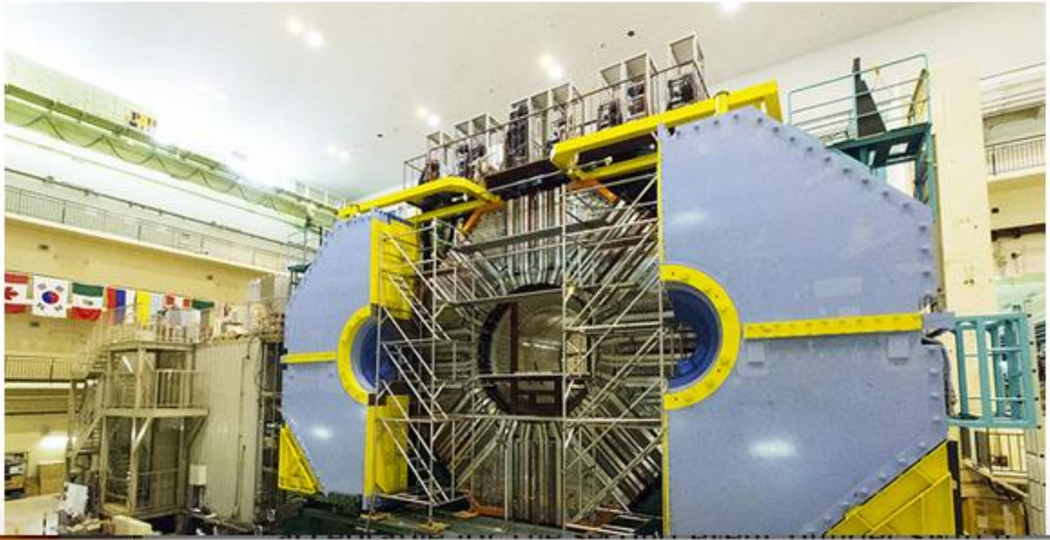
The world is waiting for us

NEWS · 12 JANUARY 2018

Revamped collider hunts for cracks in the fundamental theory of physics

Experiment smashes electrons into positrons to search for unseen particles and problems with overarching physics framework.

Elizabeth Gibney



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Transitions to Operations

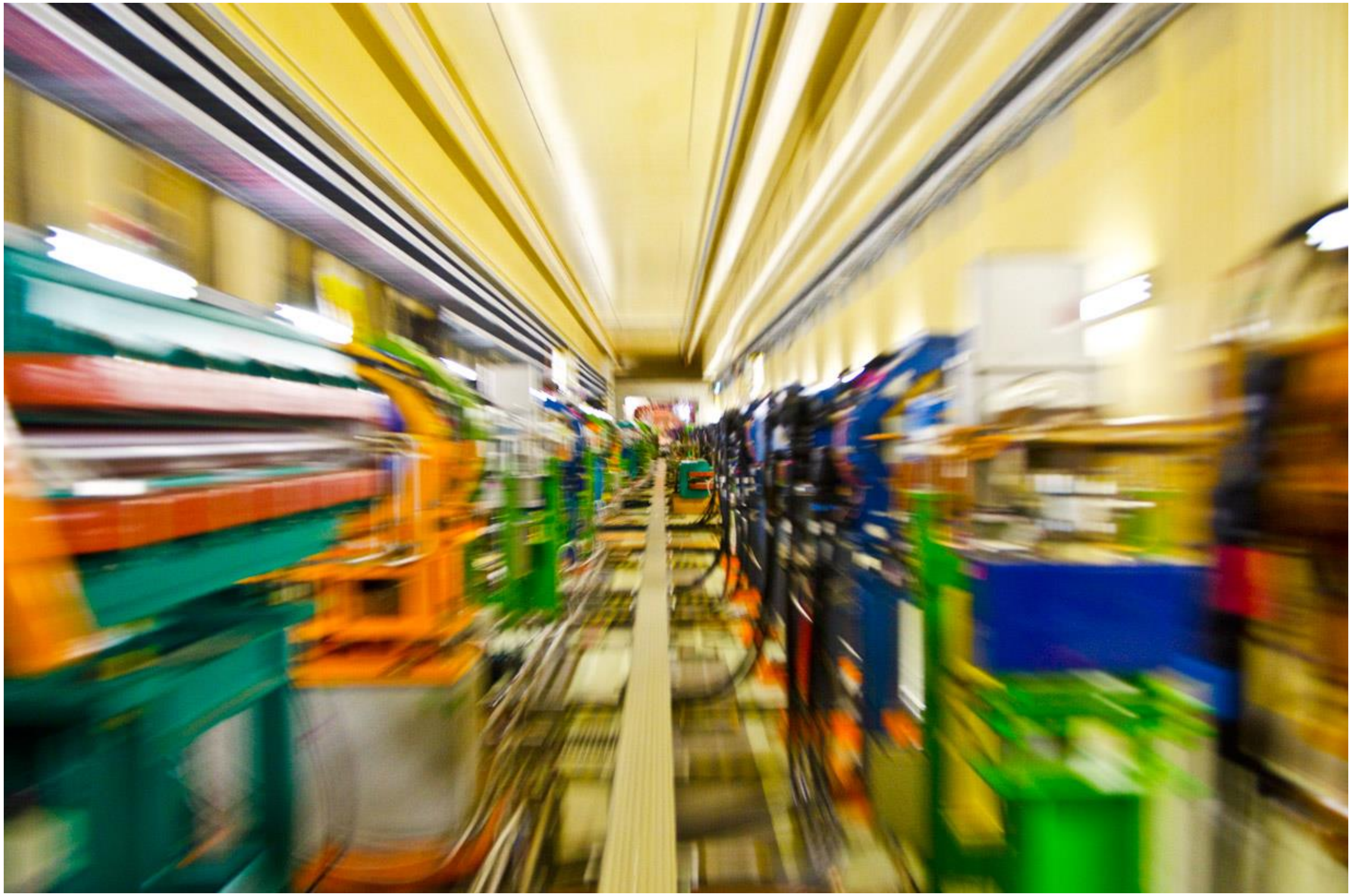
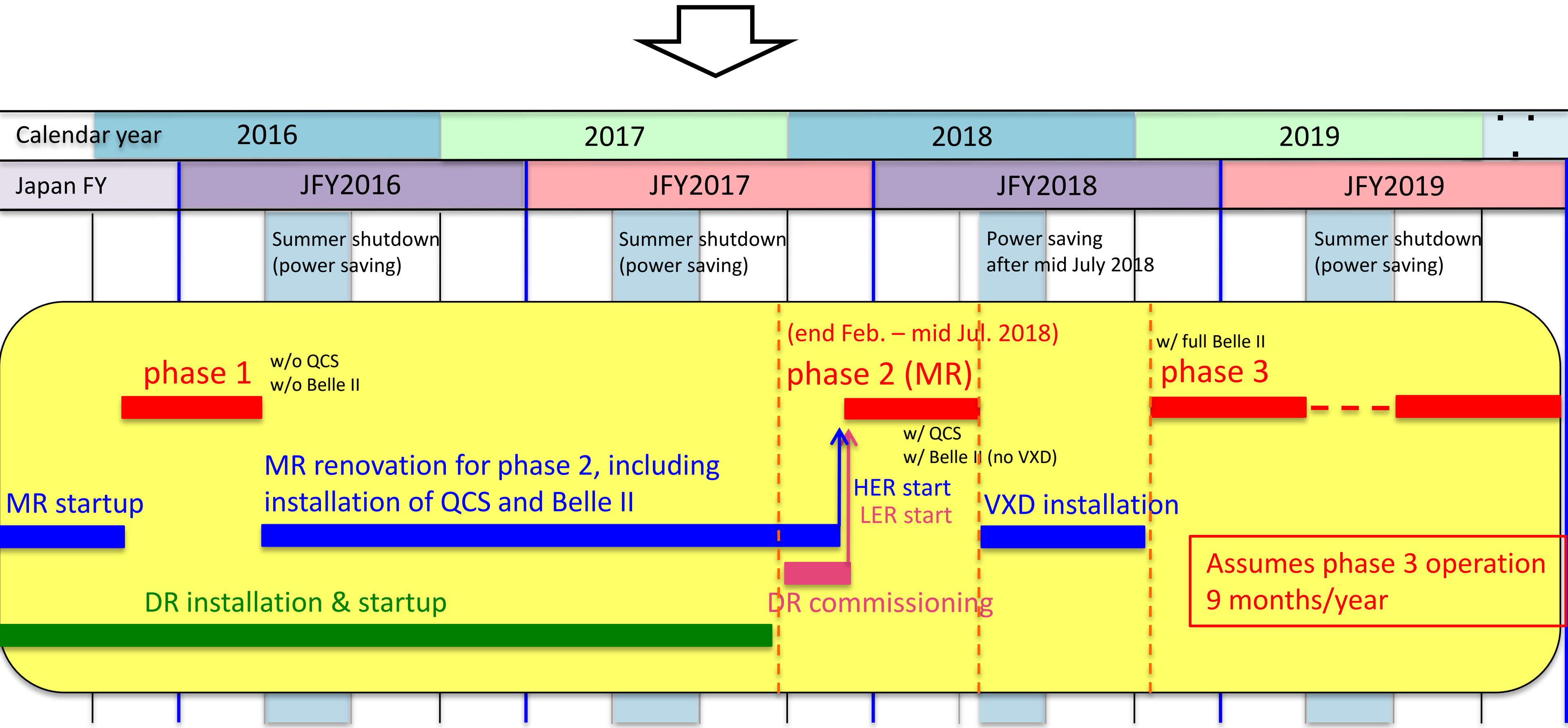


Photo credit: M. Friedl

SuperKEKB/Belle II schedule

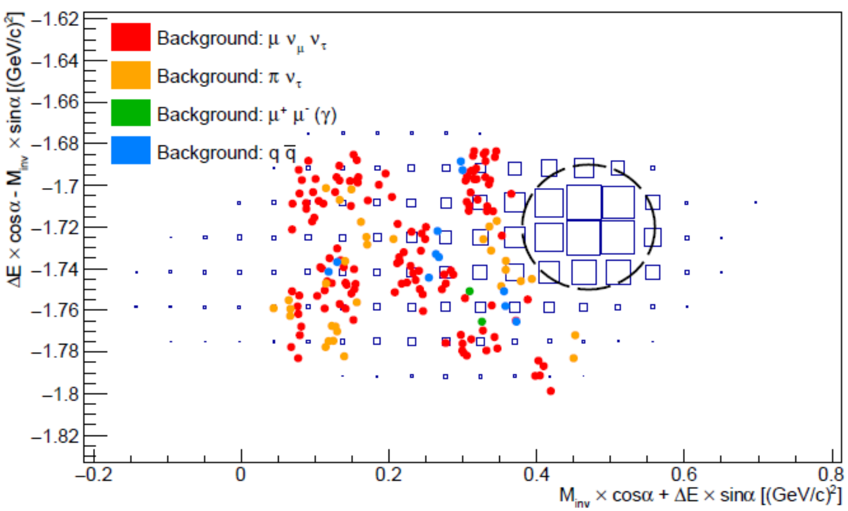
Oct. 2017



- Phase I: commissioning of the main ring; installation of outer detectors; vacuum scrubbing and beam bkg. studies
- Phase 2: start of the collisions, detector commissioning without vertex detector; first physics runs on Y(4S) and Y(6S) (~20±20 fb^{-1}) [now- July 2018]
- Phase 3: full detector operation in the end of 2018

Status of Belle II Physics Book

- Belle II physics book (>630 pages), to be printed by PTEP very soon
  https://confluence.desy.de/display/BI/B2TiP+ReportStatus
- The contents include Belle II detector, simulation, reconstruction. analysis software, B decays, CKM angles, charm, quarkonium(-like), τ, new physics, ….
- Some golden channels are given with Belle II MC simulations, theoretical discussions, sensitivity and systematic estimates

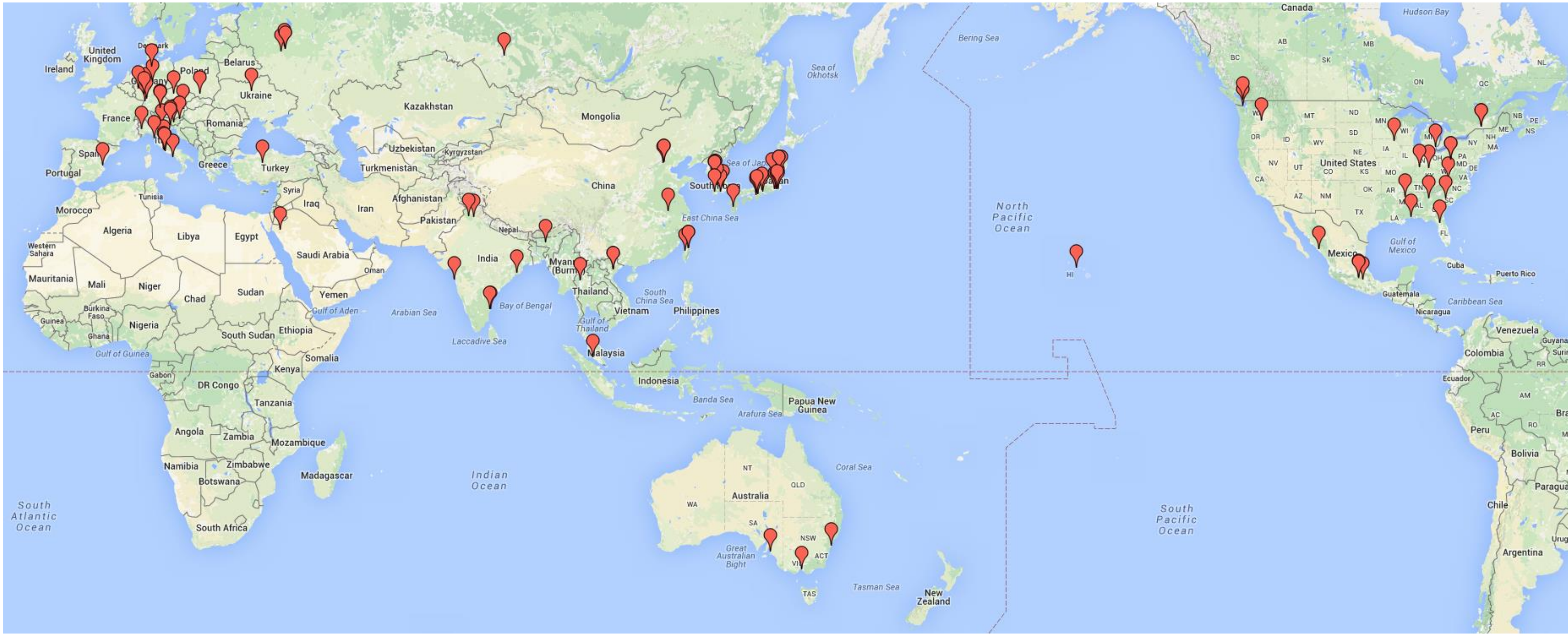


MC signal and background estimates for $\tau \to \gamma\mu$

1 ab^{-1}

Mode	Eff.(%)	N_{BG}^{exp}	UL (10^{-8})
$\mu\eta(\to\gamma\gamma)$	8.2	0.63 ± 0.37	3.6
$e\eta(\to\gamma\gamma)$	7.0	0.66 ± 0.38	8.2
$\mu\eta(\to\pi\pi\pi^0)$	6.9	0.23 ± 0.23	8.6
$e\eta(\to\pi\pi\pi^0)$	6.3	0.69 ± 0.40	8.1
$\mu\eta$(comb.)			2.3
$e\eta$(comb.)			4.4
$\mu\eta'(\to\pi\pi\eta)$	8.1	$0.00^{+0.16}_{-0.00}$	10.0
$e\eta'(\to\pi\pi\eta)$	7.3	0.63 ± 0.45	9.4
$\mu\eta'(\to\gamma\rho^0)$	6.2	0.59 ± 0.41	6.6
$e\eta'(\to\gamma\rho^0)$	7.5	0.29 ± 0.29	6.8
$\mu\eta'$(comb.)			3.8
$e\eta'$(comb.)			3.6
$\mu\pi^0$	4.2	0.64 ± 0.32	2.7
$e\pi^0$	4.7	0.89 ± 0.40	2.2

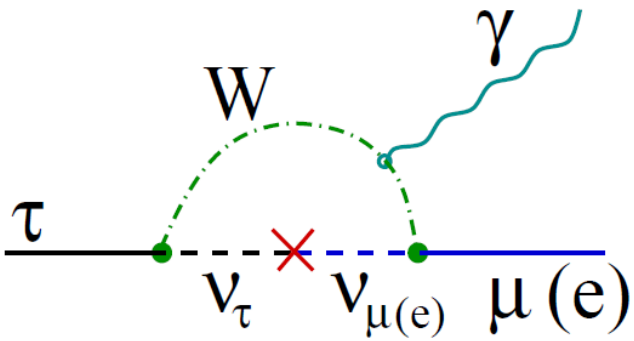
Belle II Collaboration



750 colleagues, 101 institutions, 23 countries/regions

国内单位：北航、北大、高能所、中科大、复旦

Lepton-flavor-violating (LFV) decays of τ



Model	Reference	τ→μγ	τ→μμμ
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{-14}
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}

- Probabililty of LFV decays of charged leptons is extremely small in the Standard Model, $\mathcal{B}(\tau \to l\gamma) = \frac{3\alpha}{32\pi}|\sum_i U^*_{\tau i}U_{\mu i}\frac{\triangle^2_{3i}}{m^2_W}|^2 \leq 10^{-53} \sim 10^{-49}$
- Many models beyond the SM predict LFV decays with the branching fractions up to $\lesssim 10^{-8}$. As a result observation of LFV is a clear signature of New Physics (NP).
- τ lepton is an excellent laboratory to search for the LFV decays due to the enhanced couplings to the new particles as well as large number of LFV decay modes
- Study of the different τ LFV decay modes allows us to test various NP models.

τ LFV in NP beyond SM

Ratios of τ LFV decay's BF's allow one to discriminate between new physics models

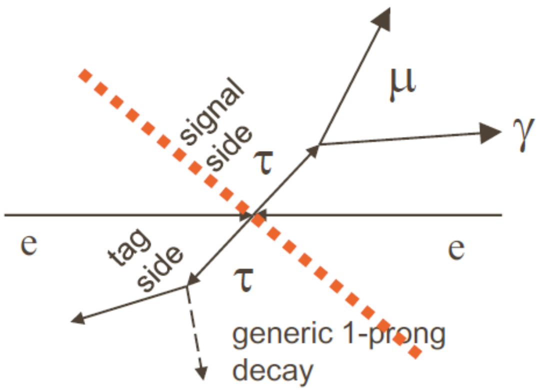
	SUSY+GUT (SUSY+Seesaw)	Higgs mediated	Little Higgs	non-universal Z'
$\frac{\mathcal{B}(\tau \to \mu\mu\mu)}{\mathcal{B}(\tau \to \mu\gamma)}$	~2 x 10^{-3}	0.06 - 0.1	0.4 - 2.3	~16
$\frac{\mathcal{B}(\tau \to \mu ee)}{\mathcal{B}(\tau \to \mu\gamma)}$	~1 x 10^{-2}	~1 x 10^{-2}	0.3 - 1.6	~16
$\mathcal{B}(\tau \to \mu\gamma)_{\mathrm{max}}$	$< 10^{-7}$	$< 10^{-10}$	$< 10^{-10}$	$< 10^{-9}$

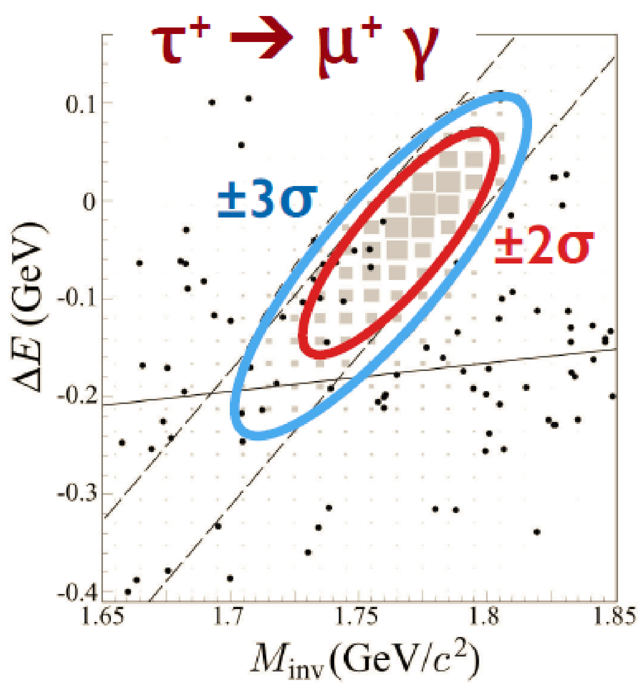
JHEP 0705, 013 (2007); PLB 547, 252 (2002)

$\therefore$ Good to measure LFV in as many modes as possible!

Past searches for $\tau \rightarrow \gamma\mu$ at Belle

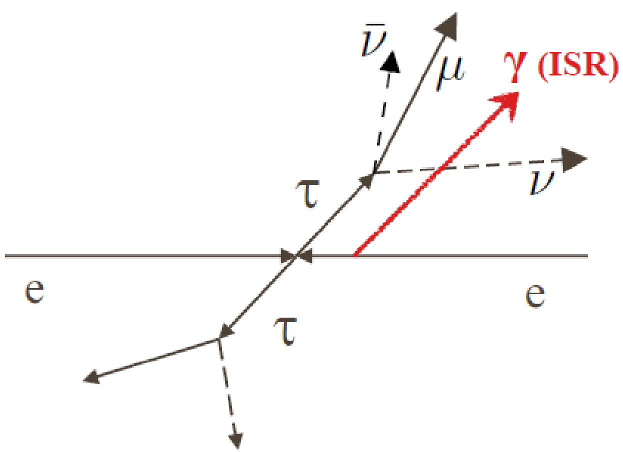
- Blinding box approach with BG evaluated outside the signal region
- Observables space: — $\mathbf{\Delta E} = E_{CM}^{(\mu+\gamma)} - E_{beam}/2$ (expected $\Delta E = 0$)
  — Signal-side $\mathbf{m_{inv}}$ (expected $m_{inv} = m_\tau = 1.777$ GeV/c^2)
- Signal regions after BG rejection cuts — data (points) and signal MC (shaded):





Irreducible background

- $\tau \rightarrow \ell\nu\nu$ with ISR



- $B(\tau^- \rightarrow \mu^-\gamma) < 4.5 \times 10^{-8}$
- $B(\tau^- \rightarrow e^-\gamma) < 12.0 \times 10^{-8}$ @ 90%CL

- $B(\tau^- \rightarrow \mu^-\gamma) < 4.4 \times 10^{-8}$
- $B(\tau^- \rightarrow e^-\gamma) < 3.3 \times 10^{-8}$

Belle: PLB 666,16(2008)

best limits, BaBar: PRL 104,021802(2010)

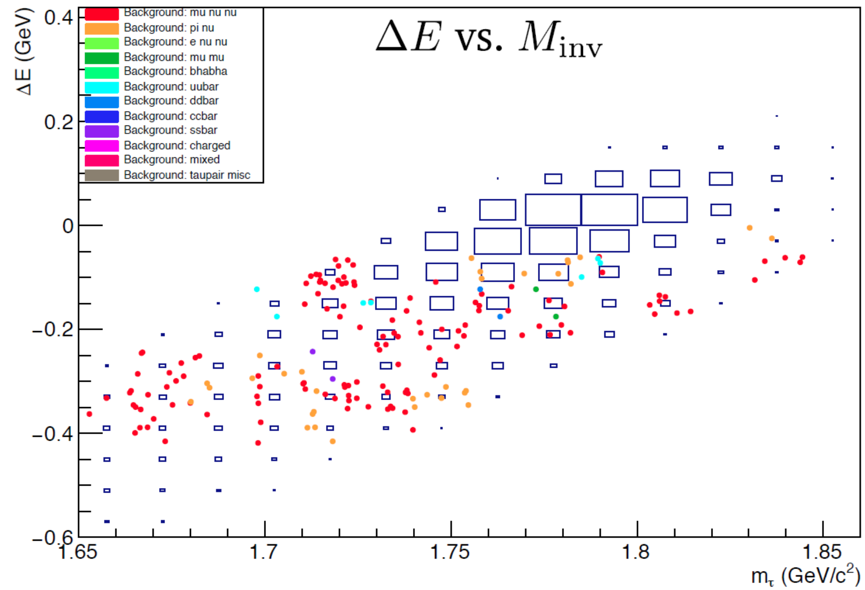
$\tau \to \gamma\mu$ at Belle II

sensitivity study using Belle II MC incl. beam background simulation

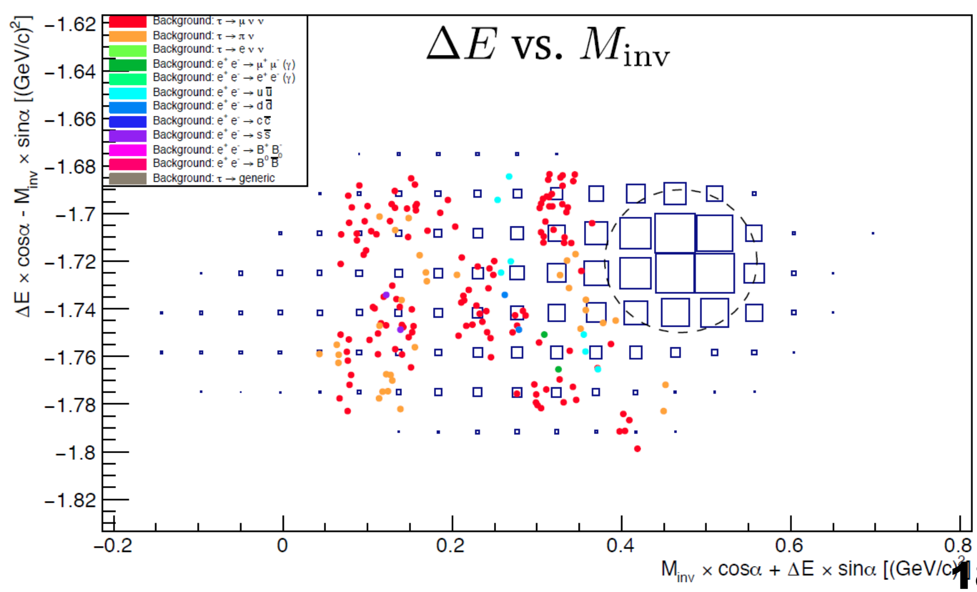
- for sensitivity comparison with Belle (with $\int \mathcal{L} dt = 1\ \mathrm{ab}^{-1}$)

Background:

$$\left.\begin{array}{l} - \tau \to \mu\nu\nu \\ - \tau \to e\nu\nu \\ - \tau \to \pi\nu \end{array}\right\} + \gamma \qquad \begin{array}{l} - ee \to ee/\mu\mu\ (\gamma) \\ - ee \to \text{hadronic} \end{array}$$



- rotating $(M_{\rm inv}, \Delta E)$ to minimize correlation



Background rejection by

- event shape variables — thrust, Fox-Wolfram moments, momentum flow distributions ("CLEO cones"), etc.

Signal extraction by $(\Delta E, M_{\rm inv})$

$\tau \to \gamma\mu$ sensitivity at Belle II

	Belle (535 fb^{-1})	**Belle II (1 ab^{-1})**
$\mathcal{L}$ (cm^2/s)	2.11 x 10^{34}	80 x 10^{34}
ε_{signal}	5.09%	4.59%
n_{BG}	10	-
$B_{90}(\tau \to \mu\gamma)$	**4.5 x10^{-8}**	**2.7 x10^{-8}**

→

Belle II (50 ab^{-1})
5.5 x10^{-10}

a naive extrapolation by luminosity

- First τ LFV sensitivity study at Belle II
  - even with much higher beam background, the sensitivity is comparable to that of Belle (scaled by luminosity)
  - signal region is background-free

Sci. Bull. (2016) 61(4):307–312
DOI 10.1007/s11434-016-0997-y

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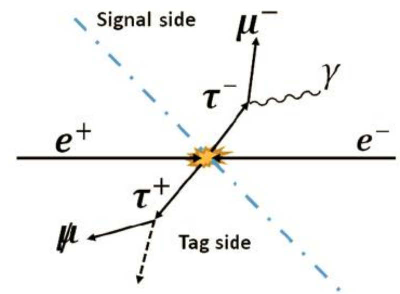
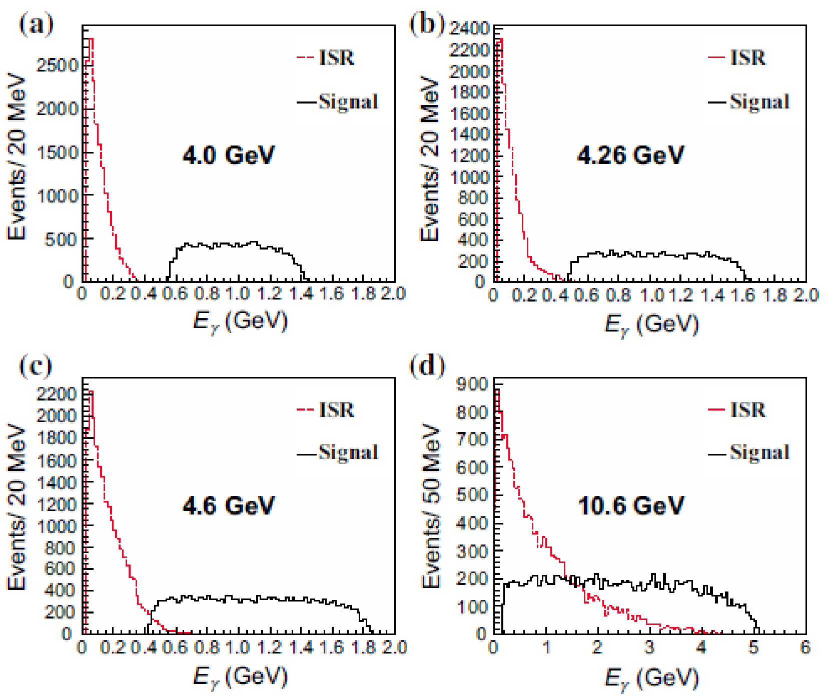
Article

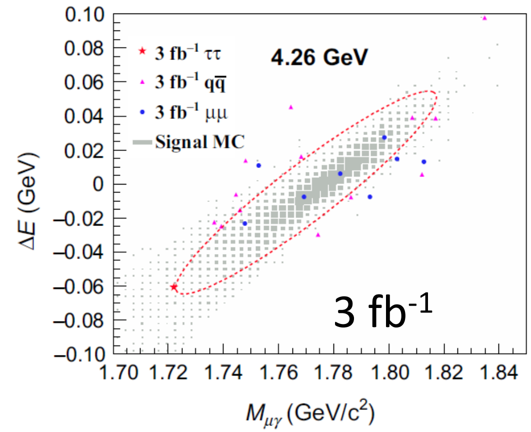
Physics & Astronomy

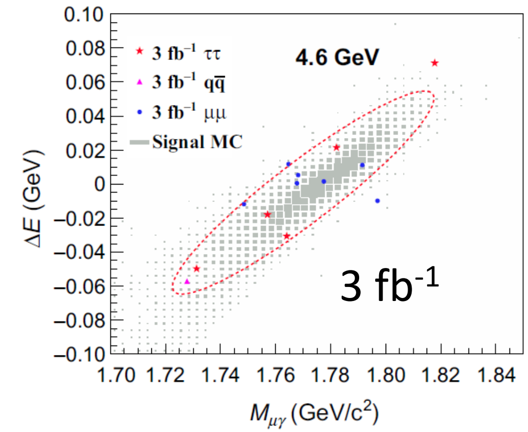
Sensitivity study of searching for $\tau^- \to \gamma\mu^-$ at HIEPA



Yu-Bo Li · Cheng-Ping Shen · Chang-Zheng Yuan



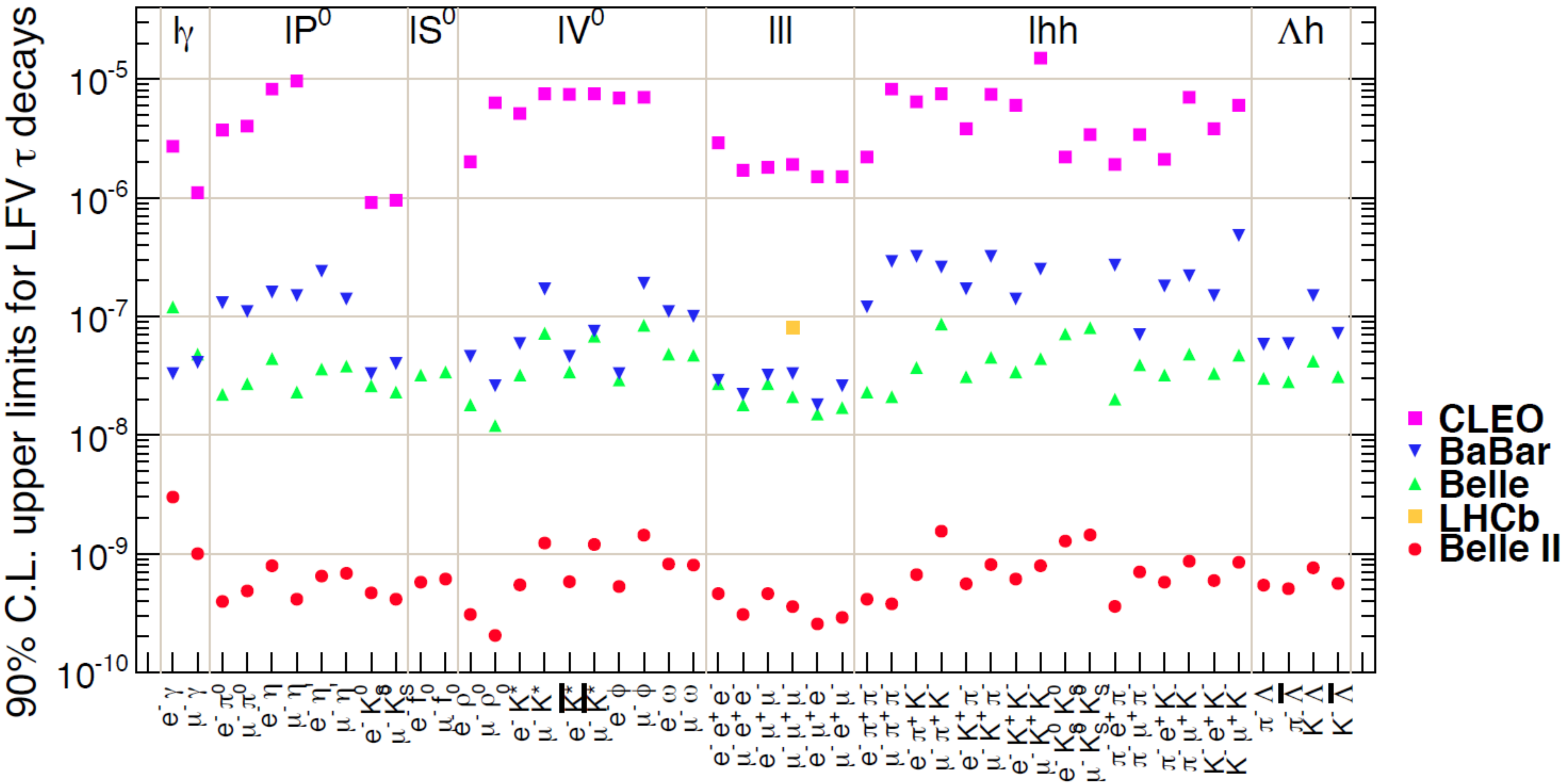




The advantage compared to B-factory is ISR $\tau^+\tau^-$ background can be neglected in lower CMS

1. The remaining backgrounds are due to μ/π misidentification based on BESIII simulation.
2. The expected μ/π separation power will Increase (>10 times) at HIEPA compared to BESIII.
3. If the backgrounds can be neglected, the upper limit can reach 10^{-9} with Lum=18.3ab^{-1} at 4.26 GeV.

τ LFV summary & prospects



HFAG summary plot for τ LFV decays,
overlaid with Belle II extrapolation to 50 ab^{-1} assuming zero background

CPV in hadronic τ decays

- CPV has never been observed in lepton decays
- It is strongly suppressed in the SM ($A^{CP} \leq 10^{-12}$) and observation of large CPV in lepton sector would be clear signal of NP, for example, minimum supersymmetric standard model [IHEP12,021;RMP80,577], multi-Higgs-doublet-models [PRL37,657;NPB426,355]
- τ lepton provides unique possibility to search for CPV effects, as it is the only lepton decaying to hadrons, so that the associated strong phases allow us to visualize CPV in hadronic τ decays
- The decays τ→$2\pi\nu$ [PRD50,4544], $K\pi\nu$[PLB398,407], $3\pi\nu$[PRD52,1614], K$\pi\pi\nu$, $KK\pi\nu$ [Z. Phys.G62,413; PRD78, 113008; PRD91, 073006]have been suggested to do CPV measurements.

Two ways to measure CPV in hadronic τ decays:

I: CPV in $\tau^- \to \pi^- K_s(\geq 0\pi^0)\nu_\tau$ at BaBar (PRD85, 031102(2012); 476 fb^{-1})

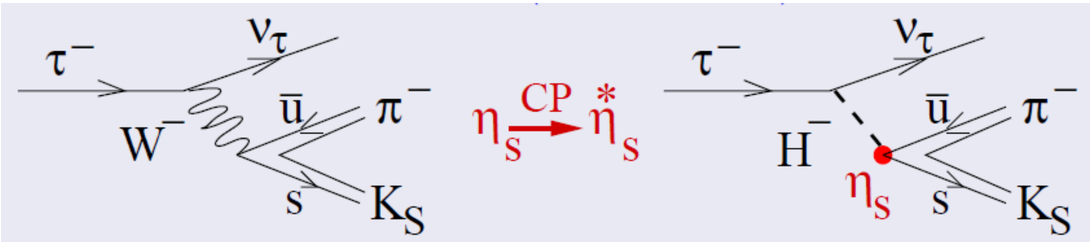
$$A_{cp} = \frac{\Gamma(\tau^+ \to \pi^+ K_s(\geq 0\pi^0)\bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_s(\geq 0\pi^0)\bar{\nu}_\tau)}{\Gamma(\tau^+ \to \pi^+ K_s(\geq 0\pi^0)\bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_s(\geq 0\pi^0)\bar{\nu}_\tau)} = (-0.36 \pm 0.23 \pm 0.11)\%$$

2.8σ deviation from the SM expectation: $A_{CP(SM)} = (+0.36 \pm 0.01)\%$

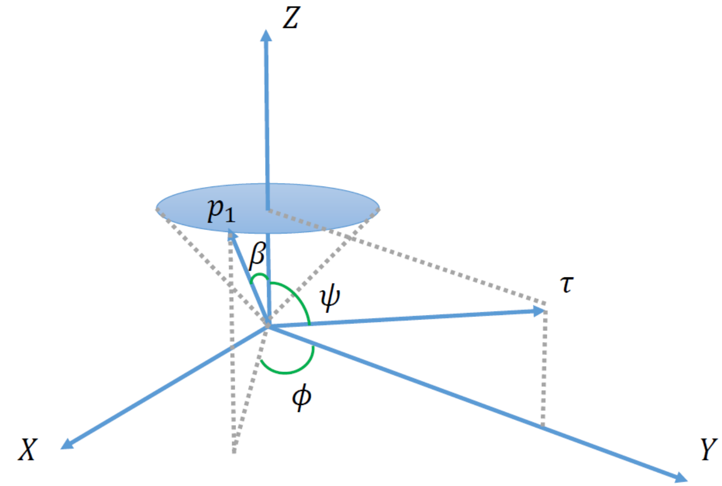
CPV in hadronic τ decays

II: CPV in $\tau^- \rightarrow \pi^- K_s \nu_\tau$ at Belle (PRL107, 131801(2011); 699 fb^{-1})

Angular distributions were analyzed, $A_{CP}(W = M_{Ks\pi})$ was measured

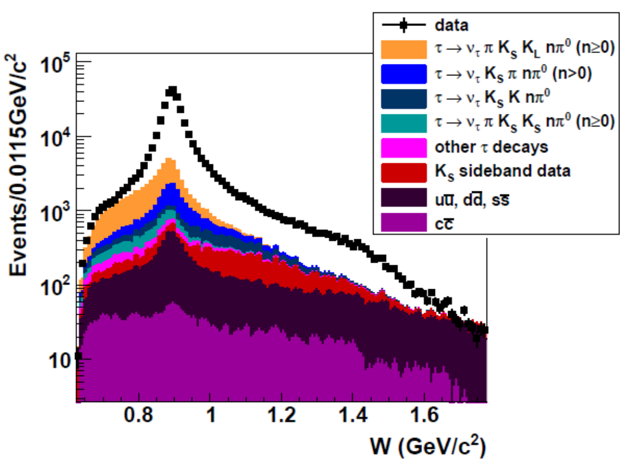


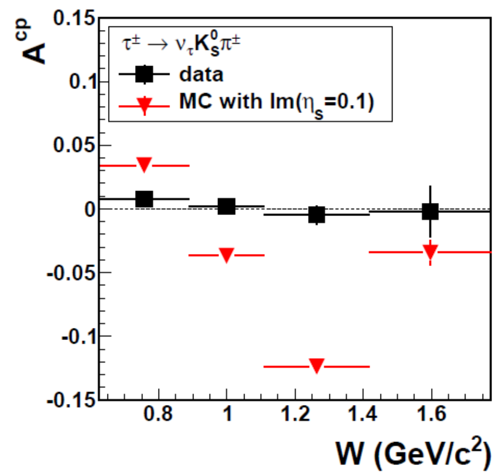
η_s is the dimensionless complex coupling constant



$$A_i^{CP} = \frac{\iint_{Q^2_{1,i}}^{Q^2_{2,i}} \cos\beta \cos\psi \left(\frac{d\Gamma_{\tau^-}}{d\omega} - \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}{\frac{1}{2} \iint_{Q^2_{1,i}}^{Q^2_{2,i}} \left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}$$

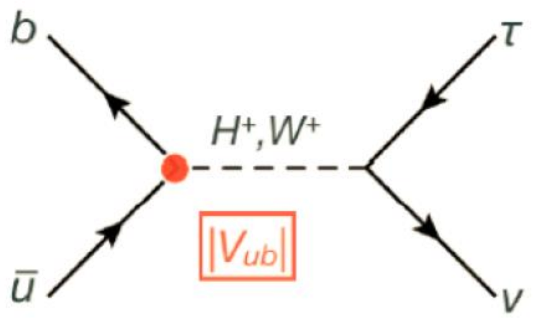
$$\simeq \langle \cos\beta \cos\psi \rangle^i_{\tau^-} - \langle \cos\beta \cos\psi \rangle^i_{\tau^+}, \quad d\omega = dQ^2 d\cos\theta d\cos\beta$$





With 50 ab-1 data at Belle II, we expect 70 times improvement, i.e., $|A^{CP}| < (0.5 - 3.8) \times 10^{-4}$, at 90% C.L. *assuming the central value* $A^{CP} = 0$

Search for NP in $B^+ \to \tau^+\nu_\tau$



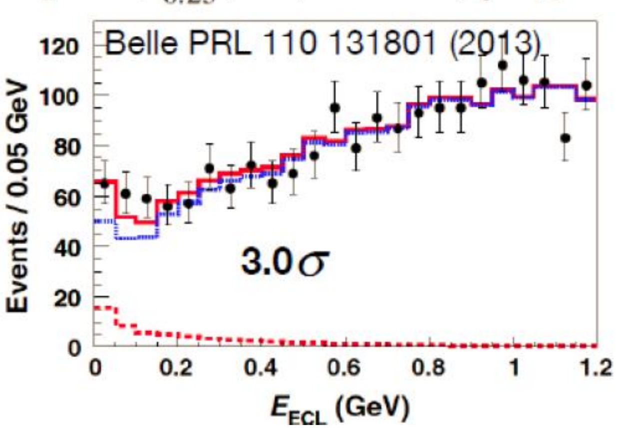
$$\mathcal{B}(B^+ \to \tau^+\nu_\tau)_{\rm SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}_{(B\to\tau\nu)} = \mathcal{B}_{SM} \times \left(1 - \tan^2\beta \frac{m_{B\pm}^2}{m_{H\pm}^2}\right)$$

- Branching ratio depends strongly on the mass of the lepton due to helicity suppression. Thus $B^+ \to \tau^+\nu_\tau$ is expected to have the largest leptonic branching fraction.
- NP could significantly suppress or enhance the branching ratio i.e. via exchange a charged Higgs boson from supersymmetry or from two-Higgs doublet models (2HDM).
- In the absence of NP, this channel provides a direct determination of the B decay constant f_B and the CKM matrix $|V_{ub}|$.

- Hadronic tagging
- dominate backgrounds: $B^- \to D^{(*)0}\ell^-\bar{\nu}_\ell$

$[0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}$.



tau decays:

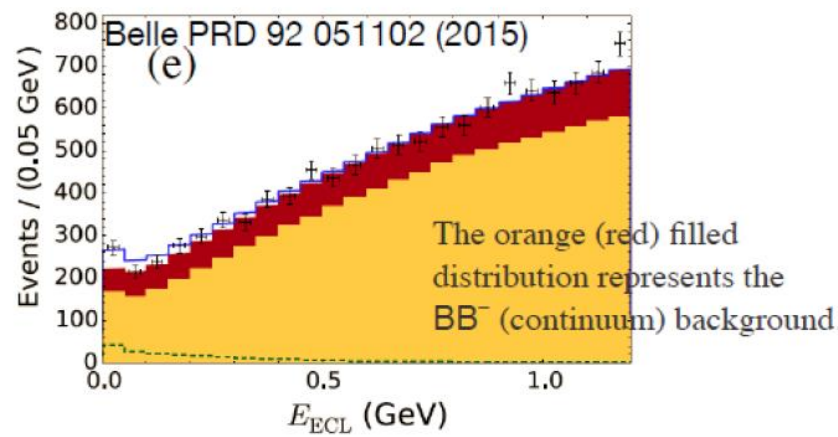
$\tau^- \to l^-\bar{\nu}_l\nu_\tau$

$\tau^- \to \pi^-\nu_\tau$

$\tau^- \to \rho^-\nu_\tau$

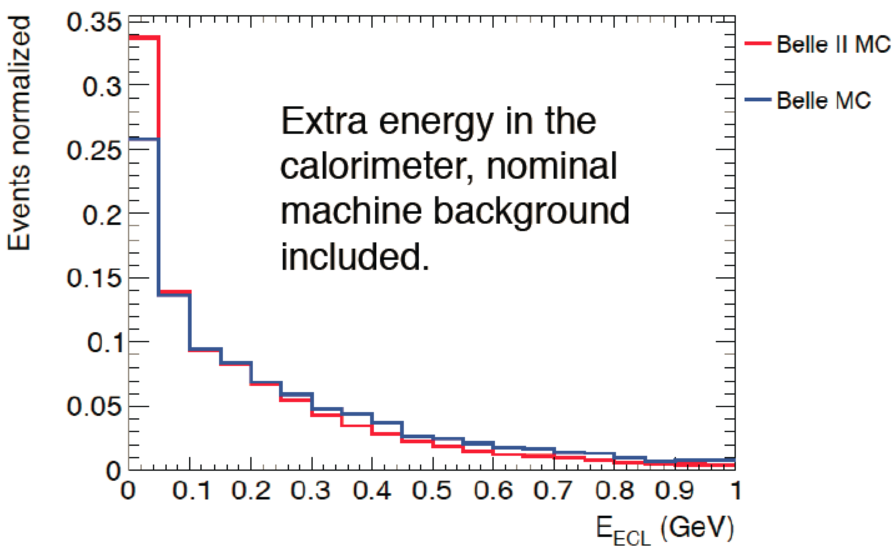
- Semi-leptonic tagging (agree with Had. tag and SM)

$\mathcal{B}(B^+ \to \tau^+\nu_\tau) = [1.25 \pm 0.28(\text{stat.}) \pm 0.27(\text{syst.})] \times 10^{-4}$



$B^+ \to \tau^+ \nu_\tau$ prospect at Belle II

- **Analysis on Belle II full simulation using hadronic B reconstruction.**
- **Signal yields extracted from fit to extra neutral energy.**
- **The extra energy resolution at Belle II is better than Belle despite the increased beam background.**



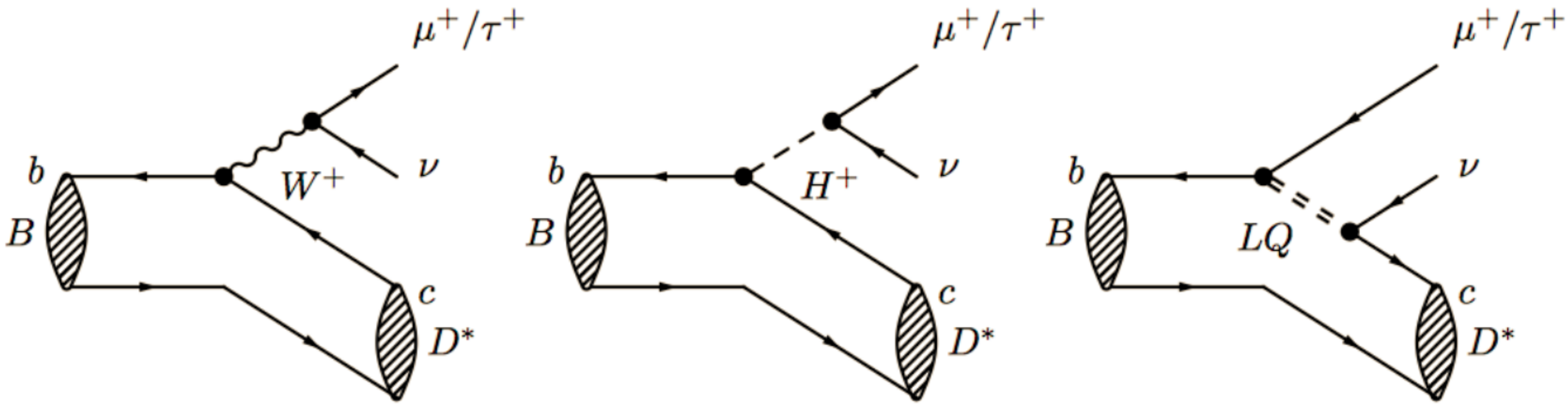
- **Comparison with Belle hadronic tag. 1 ab^{-1} equivalent statistics**

E_{ECL}		$< 0.25\,\mathrm{GeV}$
Belle II	# background events	1348
	# signal events	136
	signal efficiency (‰)	1.6
Belle	# background events	365
	# signal events	60
	signal efficiency (‰)	0.7

- **Extrapolation at full Belle II statistics**

	Integrated Luminosity (ab^{-1})	50
hadronic tag	statistical uncertainty (%)	4.1
	systematic uncertainty (%)	4.6
	total uncertainty (%)	6.2
semileptonic tag	statistical uncertainty (%)	2.7
	systematic uncertainty (%)	4.5
	total uncertainty (%)	5.3

Search NP in $B \to D^{(*)}\tau^+\nu_\tau$



- In the Standard Model (SM), the only difference between $B \to D^{(*)}\tau^+\nu_\tau$ and $B \to D^{(*)}\mu^+\nu_\mu$ is the mass of the lepton
- The ratio of them is sensitive to additional amplitudes, i.e. involving an intermediate charged Higgs boson.
- NP: type-II-2HDM (charged Higgs boson appears), Leptoquarks(LQ) model…
- NP could affect this decay topology in two ways:
  - Branching fraction
  - τ polarization

R(D$^{(*)}$) in $B \to D^{(*)}\tau^+\nu_\tau$

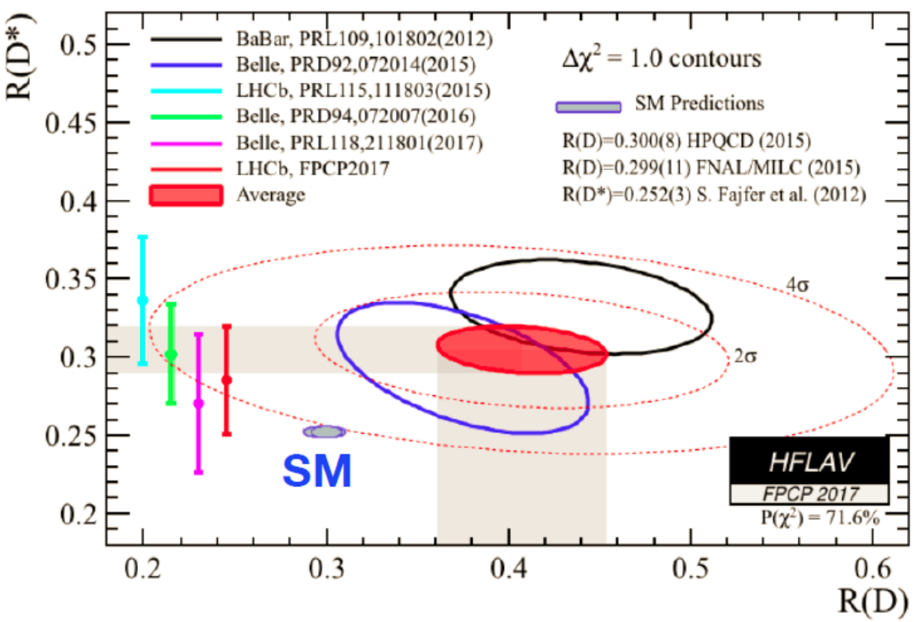
Test for lepton universality using the ratio typically:

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)} \quad (\ell = e, \mu).$$

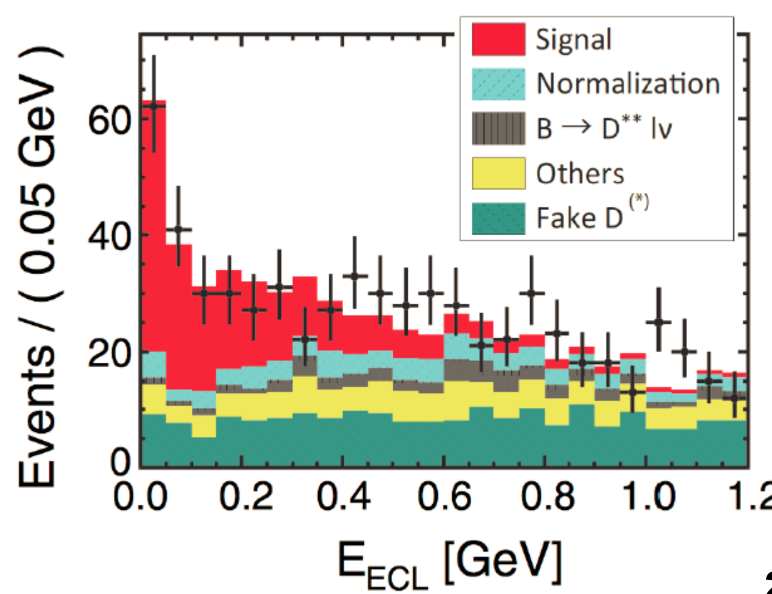
BaBar PRL 109 101802 (2012)
PRD 88 072012 (2013)
Belle PRD 92 072014 (2015)
PRD 94, 072007 (2016)
PRL 118, 211801 (2017)
arxiv1603.06711
LHCb PRL 115 111803 (2015)

SM: R(D) = 0.300 +- 0.008 Phys. Rev. D 92, 034506 (2015)
R(D*) = 0.252 +- 0.003 Phys. Rev. D 85, 094025 (2012)

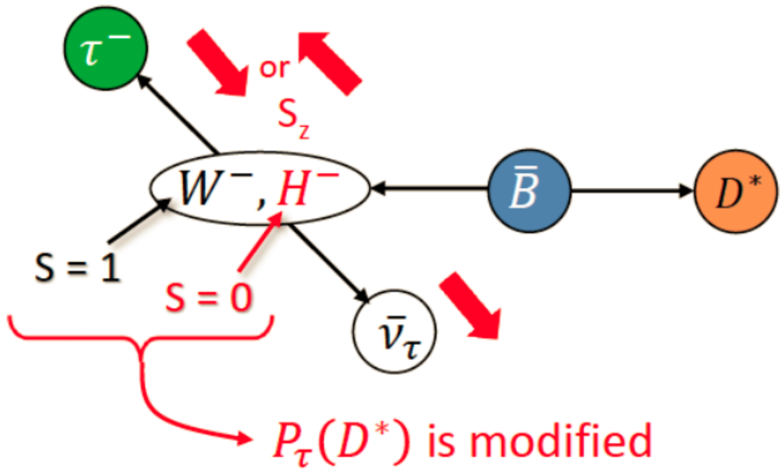
- Current world average for R(D$^{(*)}$) is in ~4.1σ tension with SM!



PRD 94 072007 (2016) SL tag



τ Polarization in $B \to D^{(*)}\tau^+\nu_\tau$



$$P_\tau(D^*) = \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-}$$

$\Gamma^{+(-)}$ for right-(left-)handed τ

$R(D^*)$ = 0.270 ± 0.035(stat.) $^{+0.028}_{-0.025}$ (syst.)

$\mathcal{P}_\tau(D^*)$ = −0.38 ± 0.51(stat.) $^{+0.21}_{-0.16}$ (syst.)

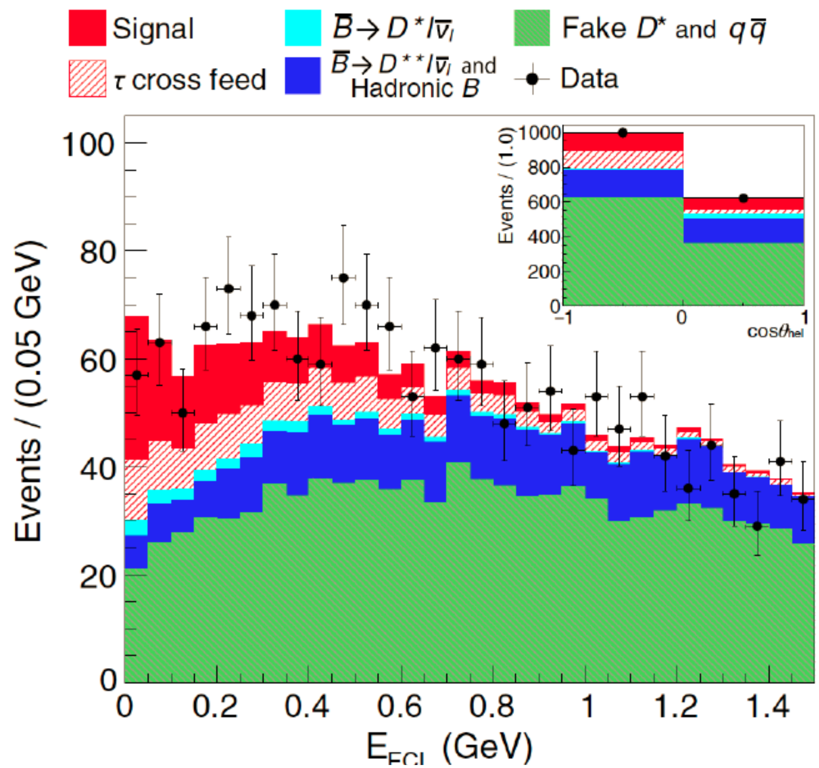
Compatibility with the SM.

$P_\tau(D^*)_{\rm SM} = -0.497 \pm 0.013$ Phys. Rev. D 87, 034028 (2013)

First measurement of the tau polarization in this decay.
First use tau had. decays in $B \to D^{(*)}\tau^+\nu_\tau$

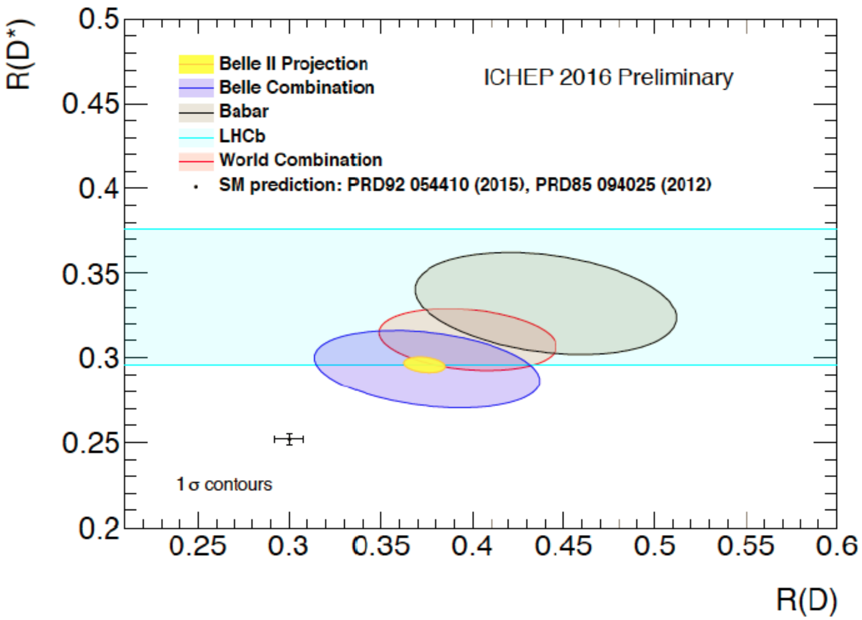
$\tau^- \to \pi^-\nu_\tau$ $\tau^- \to \rho^-\nu_\tau$

Belle PRL 118, 211801 (2017) had. tag

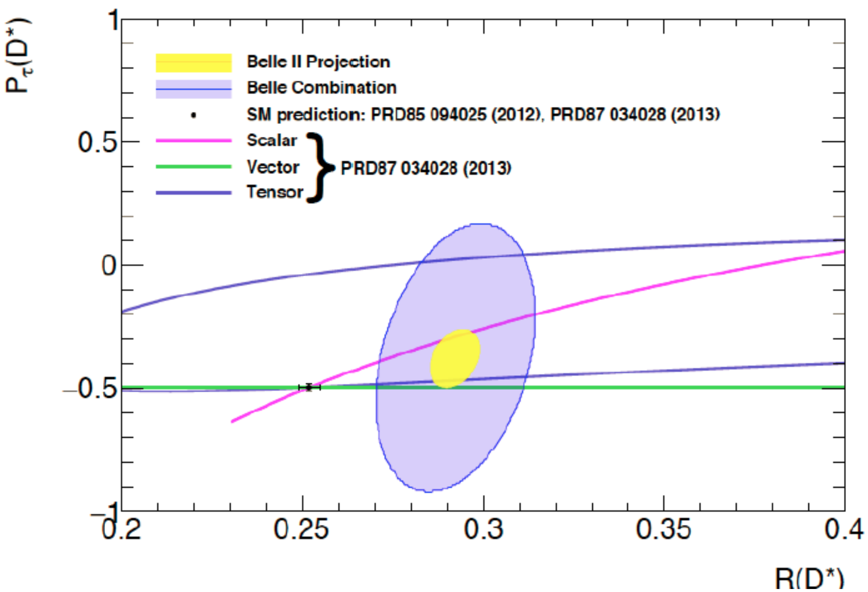


Signal significance of about 7σ

$B \to D^{(*)}\tau^+\nu_\tau$ prospect at Belle II



- Current measurements are statistically limited, dominant systematics from
  - limited MC -> larger at Belle II
  - limited knowledge of dominant bkg. (involving soft pions) —>dedicated studies with large data sample at Belle II
- With higher statistics, study polarization and q^2 distributions, essential to distinguish NP.



Uncertainties at Belle II

	$5\ \mathrm{ab}^{-1}$	$50\ \mathrm{ab}^{-1}$
R_D	$(6.0 \pm 3.9)\%$	$(2.0 \pm 2.5)\%$
R_{D^*}	$(3.0 \pm 2.5)\%$	$(1.0 \pm 2.0)\%$
$P_\tau(D^*)$	0.18 ± 0.08	0.06 ± 0.04

the first and the second values are the expected statistical and systematic errors.

Precise studies of τ at (Super)-B factories

- **Michel parameters in $\tau \to \ell\nu\nu$ (ρ, η, ξ, δ) at Belle**: arXiv:1409.4969
- **Study of the radiative leptonic decays $\tau \to \ell\nu\nu\gamma$:**

  BABAR: Measurement of $\mathcal{B}(\tau \to \ell\nu\nu\gamma)$; PRD 91, 051103(R) (2015)

  Belle(prelim.): $\bar{\eta} = -1.3 \pm 1.5 \pm 0.8$, $\xi\kappa = 0.5 \pm 0.4 \pm 0.2$; arXiv:1609.08280
- **Lepton universality with $\tau \to \ell\nu\nu$ and $\tau \to h\nu$ (h=π,K) at *BABAR*:**

  $\left(\frac{g_\mu}{g_e}\right)_\tau = 1.0036 \pm 0.0020$, $\left(\frac{g_\tau}{g_\mu}\right)_{\rm h} = 0.9850 \pm 0.0054$; PRL 105, 051602 (2010)
- **Tau lifetime:**

  Belle: $\tau_\tau = (290.17 \pm 0.53(\mathrm{stat}) \pm 0.33(\mathrm{syst}))$ fs; PRL 112, 031801 (2014)

  BABAR(prelim.): $\tau_\tau = (289.40 \pm 0.91(\mathrm{stat}) \pm 0.90(\mathrm{syst}))$ fs; Nucl. Phys. B 144, 105 (2005)
- Tau mass:

  Belle: $m_\tau = (1776.61 \pm 0.13(\mathrm{stat}) \pm 0.35(\mathrm{syst}))$ MeV/c^2; PRL 99, 011801 (2007)

  BABAR: $m_\tau = (1776.68 \pm 0.12(\mathrm{stat}) \pm 0.41(\mathrm{syst}))$ MeV/c^2; PRD 80, 092005 (2009)

  Accuracy comparable with the most precision measurements done by **BES** and **KEDR** at the $\tau^+\tau^-$ production threshold.
- Tau electric dipole moment (EDM):

  Belle: $\mathrm{Re}(d_\tau) = (1.15 \pm 1.70) \times 10^{-17}$ $e\cdot$cm, $\mathrm{Im}(d_\tau) = (-0.83 \pm 0.86) \times 10^{-17}$ $e\cdot$cm; PLB 551, 16 (2003) ($\int Ldt = 29.5$ fb^{-1}) We are working on EDM with full Belle statistics
- Hadronic contribution to a_μ ($\tau^- \to \pi^-\pi^0\nu_\tau$):

  Belle: $a_\mu^{\pi\pi} = (523.5 \pm 1.1(\mathrm{stat}) \pm 3.7(\mathrm{syst})) \times 10^{-10}$; PRD 78, 072006 (2008)

Summary

- Belle, being an e^+e^- B-factory experiment, is also a τ-factory experiment at the same time.
- With nearly 1 billion $\tau^+\tau^-$ sample, Belle has performed many precise measurements and obtained most stringent upper limits in most of the τ LFV, LNV and BNV decays, with 90% UL of $O(10^{-8})$.
- With ~50 billion $\tau^+\tau^-$ events expected at Belle II, these searches will be greatly improved.
- For very clean modes (for example $\tau \rightarrow lll$), the upper limits are expected to improve linearly with luminosity. New physics beyond SM can be searched for in these decays, and also in B decays with τ final states.

Michel parameters

In the SM charged weak interaction is described by the exchange of $W^{\pm}$ with a pure vector coupling to only left-handed fermions ("V-A" Lorentz structure). Deviations from "V-A" indicate New Physics. $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ ($\ell = e, \mu$) decays provide clean laboratory to probe electroweak couplings.
The most general, Lorentz invariant four-lepton interaction matrix element:

$$\mathcal{M} = \frac{4G}{\sqrt{2}} \sum_{\substack{N=S,V,T \\ i,j=L,R}} g_{ij}^N \left[\bar{u}_i(l^-)\Gamma^N v_n(\bar{\nu}_l)\right] \left[\bar{u}_m(\nu_\tau)\Gamma_N u_j(\tau^-)\right],$$

$$\Gamma^S = 1,\ \Gamma^V = \gamma^\mu,\ \Gamma^T = \frac{i}{2\sqrt{2}}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$$

Ten couplings g_{ij}^N, in the SM the only non-zero constant is $g_{LL}^V = 1$

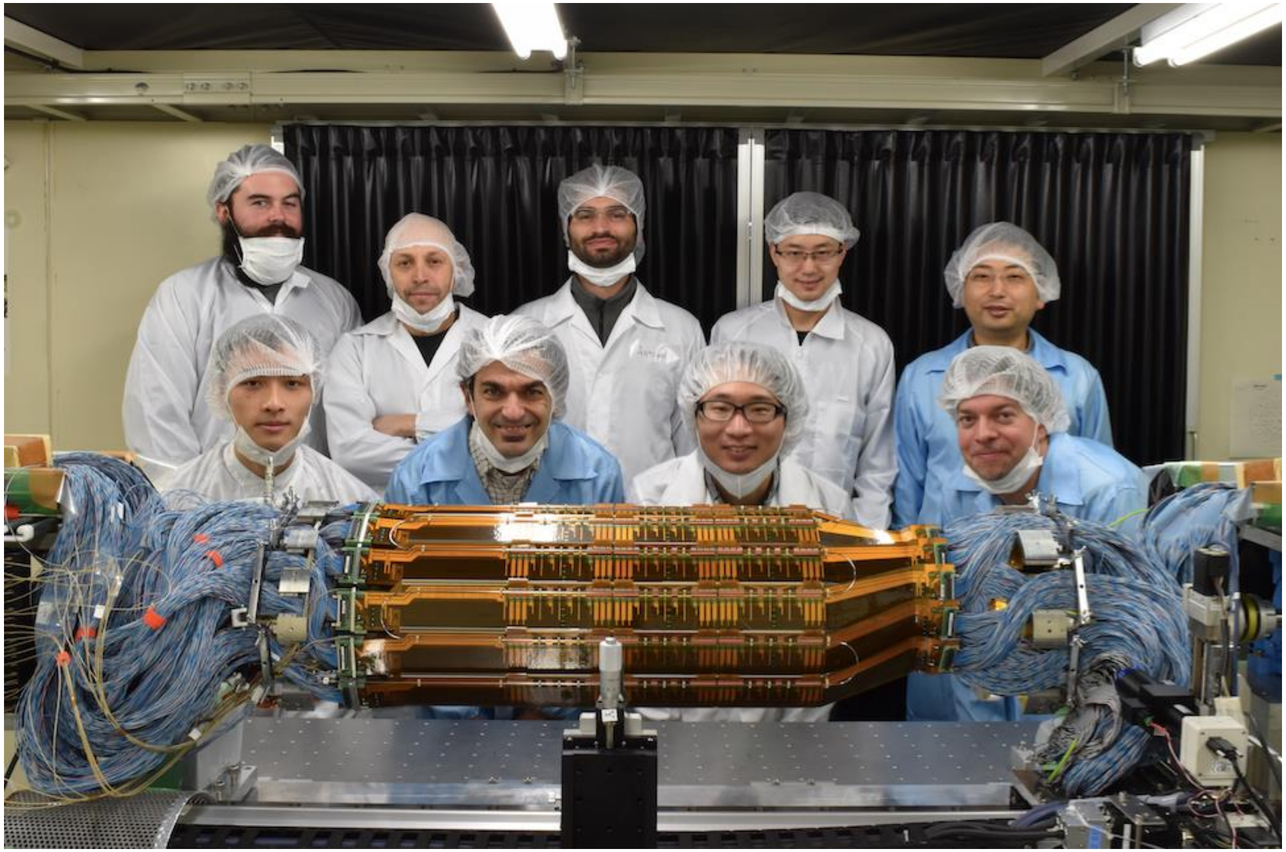
Four bilinear combinations of g_{ij}^N, which are called as Michel parameters (MP): ρ, η, ξ and δ appear in the energy spectrum of the outgoing lepton:

$$\frac{d\Gamma(\tau^\mp)}{d\Omega dx} = \frac{4G_F^2 M_\tau E_{\max}^4}{(2\pi)^4}\sqrt{x^2 - x_0^2}\Bigg(x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x)$$

$$\mp\frac{1}{3}P_\tau cos\theta_\ell \xi\sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\delta\left(4x - 4 + \sqrt{1 - x_0^2}\right)\right]\Bigg),\ x = \frac{E_\ell}{E_{\max}},\ x_0 = \frac{m_\ell}{E_{\max}}$$

In the SM: $\rho = \frac{3}{4}$, $\eta = 0$, $\xi = 1$, $\delta = \frac{3}{4}$

SVD ladder mount



- Jan 2018: Mount of the +X half shell was successfully completed

Beam Background Group

- [*First Measurements of Beam Backgrounds at SuperKEKB*](), submitted to NIMA, 101 pages
- Final experiment/simulation

$$LER\ beam - gas:\ 2.8^{+3.4}_{-2.3}$$

$$LER\ Touschek:\ 1.4^{+1.8}_{-1.1}$$

$$HER\ beam - gas: 108^{+180}_{-64}$$

$$HER\ Touschek:\ 4.8^{+8.2}_{-2.8}$$

- Phase 2 dedicated beam background detectors installed
  - VXD Volume: FANGS,CLAWS,PLUME
  - VXD dock space: TPCs, He-3 tubes
  - On QCS: PIN diodes, scintillators
- Next challenge: Phase 2 integration of DAQ and simulation

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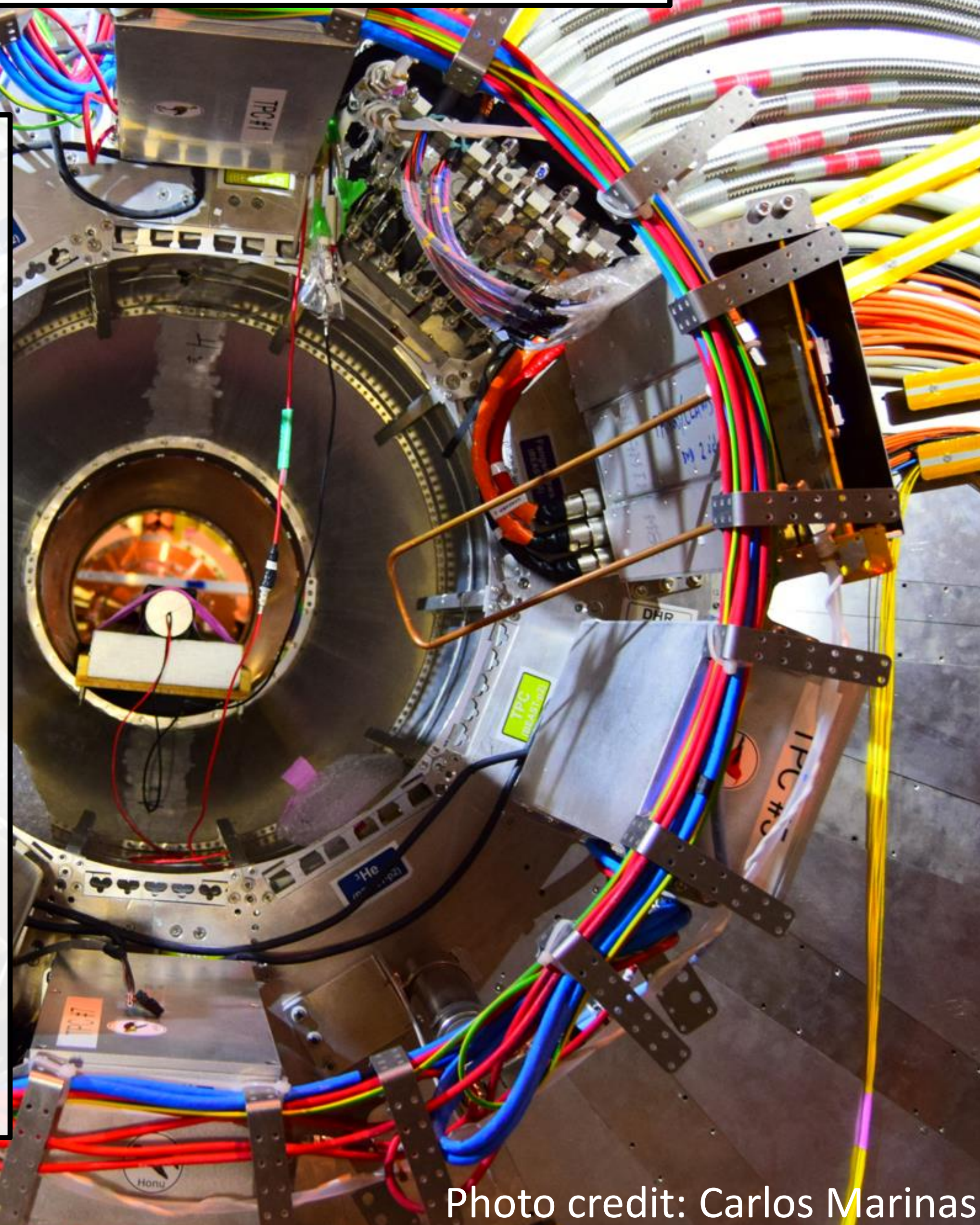


Photo credit: Carlos Marinas

Phase III:

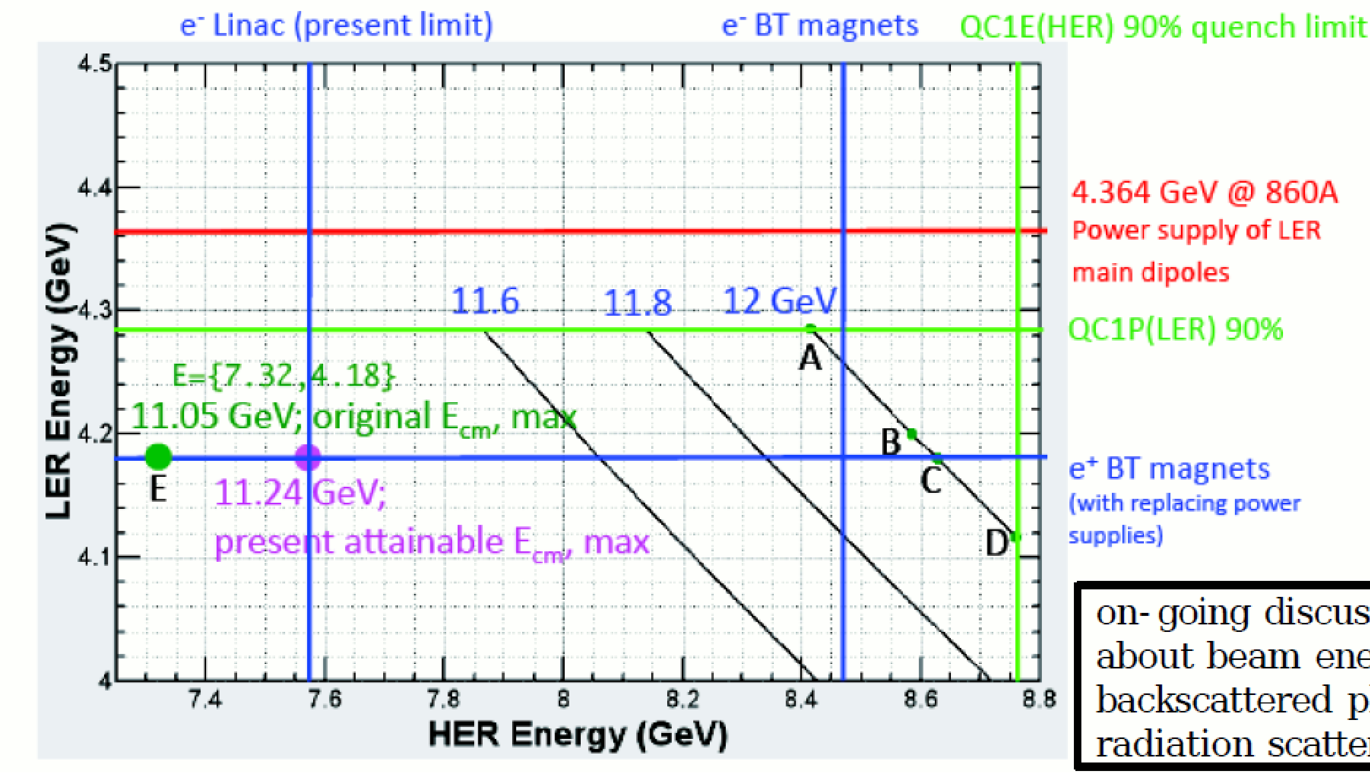
Milestone: Completion of +X clam-shell of the SVD on Jan 18, 2018

Higher energy run

from K. Akai, BPAC Feb 2012

- Design: original design maximum energy is 11.05 GeV at $\Upsilon(6S)$
- Possible higher energy run (11.5 GeV – 12 GeV)?
  - If any, higher energy run will be after several years running at $\Upsilon(4S) \sim \Upsilon(6S)$
  - **present max E_{cm} is 11.24 GeV**, limited by e^- Linac and e^+ BT magnets
  - In order to inject the electron beam to HER at the required energy for 12 GeV operation, there must be huge reinforcement of Linac (replacement of S-band with C-band, 7.571 → 8.6 GeV

11.24 GeV region: $\Lambda_b \overline{\Lambda}_b$ threshold



e.g. [arXiv:1211.0103]

on-going discussion with SuperKEKB people about beam energy measurement using backscattered photons produced by laser radiation scattered head-on the beams