Prospects of LFV studies at Belle II

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Outline

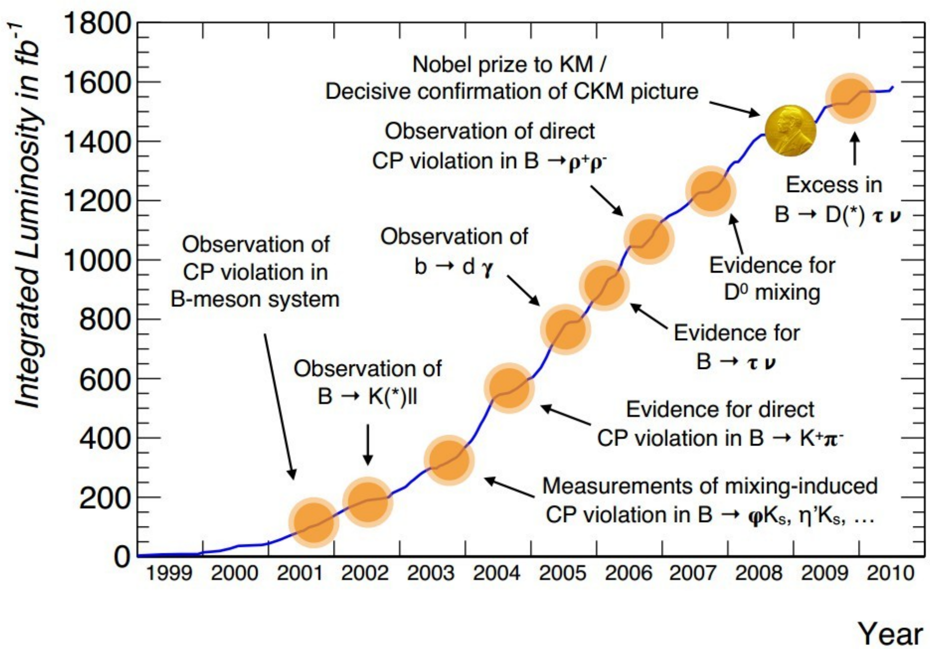
- Motivation
- Belle and Belle II
- LFV in τ-decays
- LUV in $B \longrightarrow D^{(*)}\tau\nu$ and $b \longrightarrow s\ell\ell$
- Status and schedule

Introduction

- After discovery of CP-violation in B-decays by Belle and BaBar in 2001 (Nobel prize in physics for Kobayashi and Maskawa in 2008) and Higgs boson by CMS and ATLAS in 2012 (Nobel prize in physics for Higgs in 2013) experimental grounds of the Standard model are complete.
- The Standard Model describes known processes quite well.
- However, there are indications that the Standard Model is not complete:
  - neutrino oscillations, baryon asymmetry, dark matter;
  - too many parameters, hierarchy problem.
- There should be something beyond the Standard Model – New Physics (NP).
- Actually experimental data hinting on NP is building up:
  - Deviations from the SM in angle distributions and differential branching ratios of $b \longrightarrow s\gamma^*$ decays ($B \longrightarrow K^{(*)}\ell^+\ell^-$ decays etc.) (~4σ);
  - Deviations from the SM in the branching ratios of $B \longrightarrow D^{(*)}\tau\nu_\tau$ decays (~4σ).

B-factories

- BaBar: PEP-II e^+e^- collider, SLAC, USA, 1999–2008.
- Belle: KEKB e^+e^- collider, KEK, Tsukuba, Japan, 1999–2010.
- Combined BaBar and Belle luminosity is ~1.5 ab^{-1} (1.25*10^9 $B\overline{B}$ pairs).
- Main focus: *CP*-violation (published in 2001)
  - Also B-decays, CKM parameters, charmonium(-like) states, charm- and τ-physics etc.
  - 500+ publications from BaBar, 500+ from Belle.
  - But still no definitive observation the New physics (NP)!



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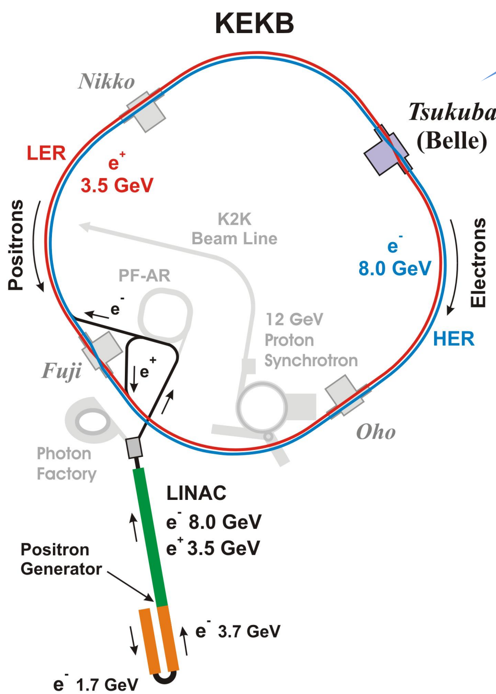
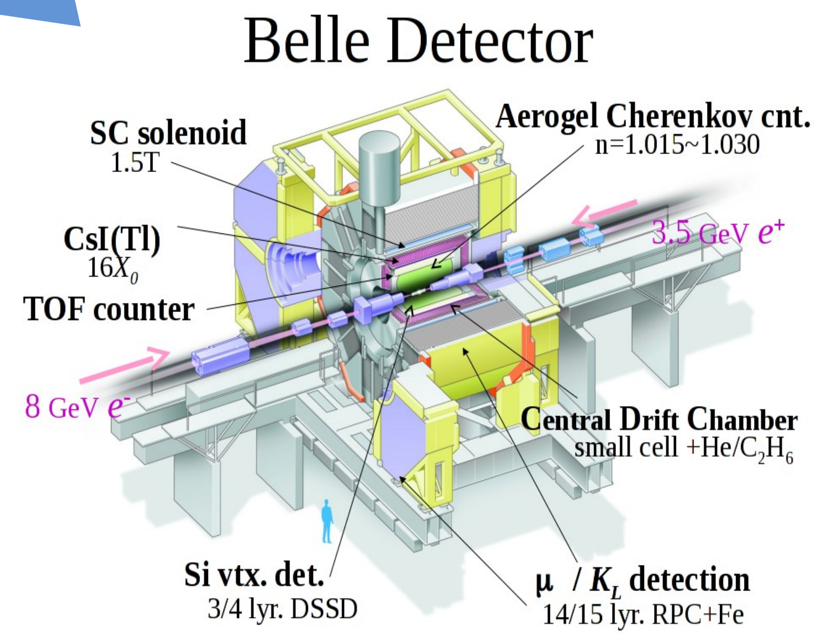
Belle experiment





- Located in KEK, Tsukuba, Japan
- KEKB is an asymmetric-energy e^+e^- collider 3.5GeV/8.0GeV,

$$c\bar{c}, q\bar{q}, \ell\ell \leftarrow e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B} \;, \quad \mathcal{L}_{peak} = 21nb^{-1}s^{-1}$$

Quest for high luminosity

- There are two ways to increase luminosity:
  - Increase beam currents
  - Decrease beam size
- SuperKEKB uses ~2x increase in currents and "nano-beams"
- 40x luminosity
- Beam energy changed to reduce beam background

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

Lorentz factor

Beam current

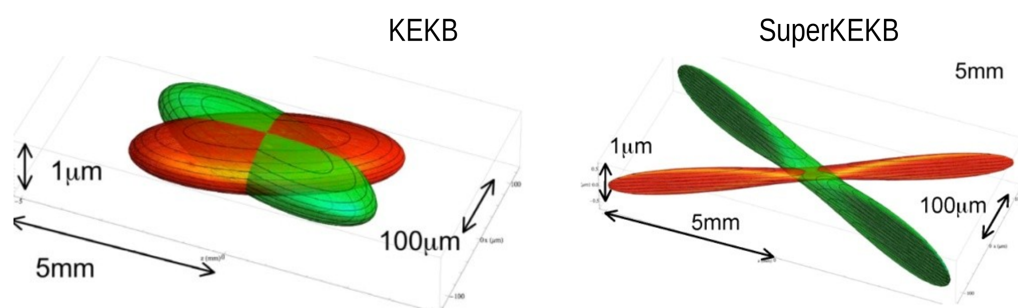
Beam-Beam parameter

Geometrical reduction factors (crossing angle, hourglass effect)

Beam aspect ratio at IP

Vertical beta function at IP

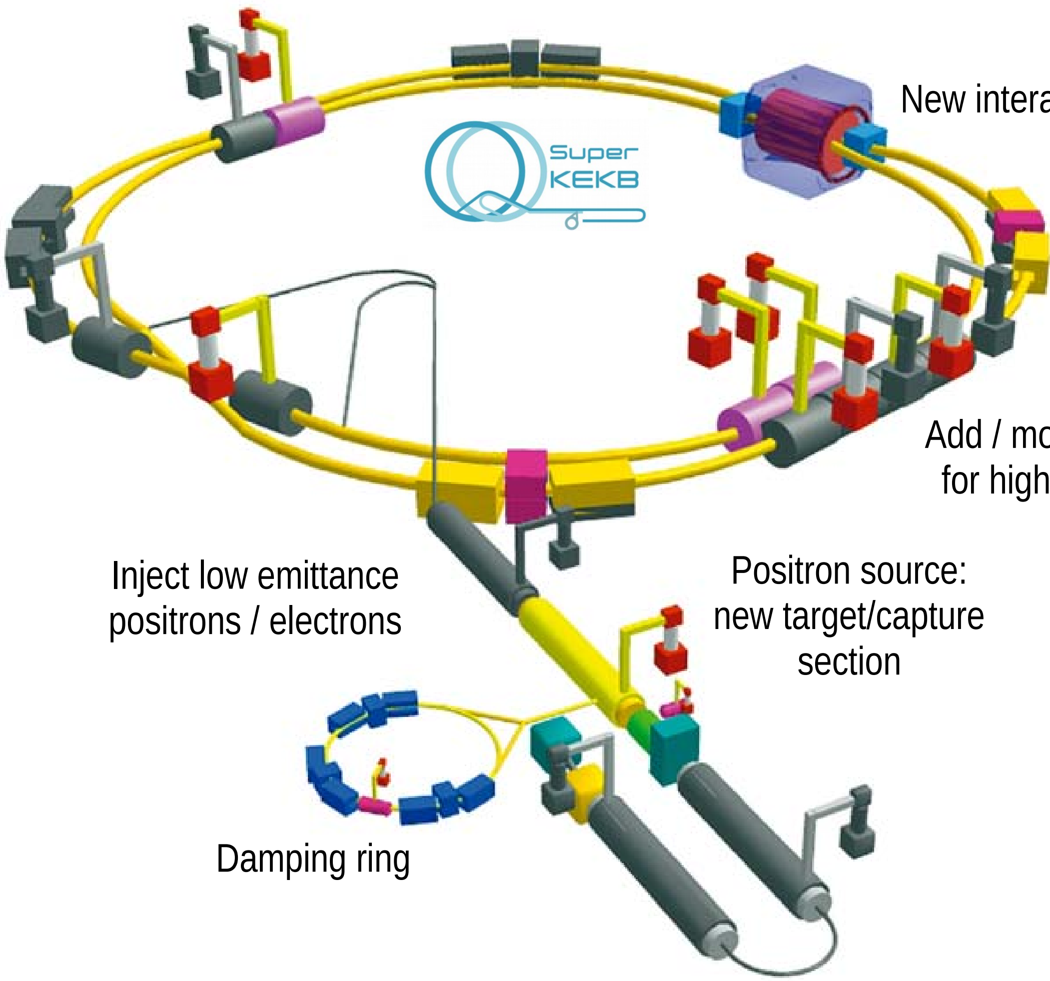
Minimum value is limited by hourglass effect



	E(GEV) HER/LER	β^*_y(mm) HER/LER	β^*_x(mm) HER/LER	2φ (mrad)	I(A) HER/LER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	22	1.6/1.2	$2.1x10^{34}$
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	83	3.6/2.6	$80x10^{34}$

SuperKEKB accelerator

A lot of modifications all around the accelerator.



New interaction region

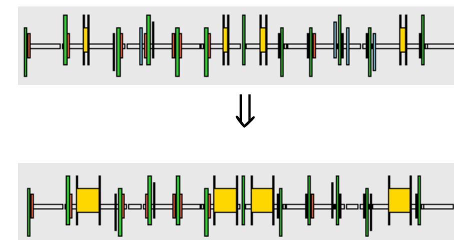
Add / modify RF systems
for higher beam current

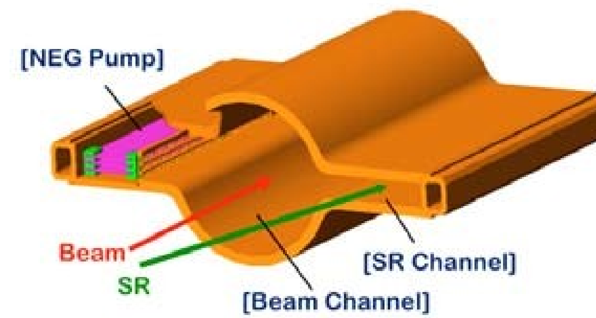
Inject low emittance
positrons / electrons

Positron source:
new target/capture
section

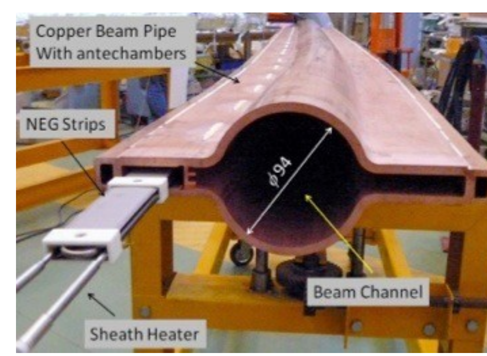
Damping ring

Replace short dipoles
with longer ones (LER)





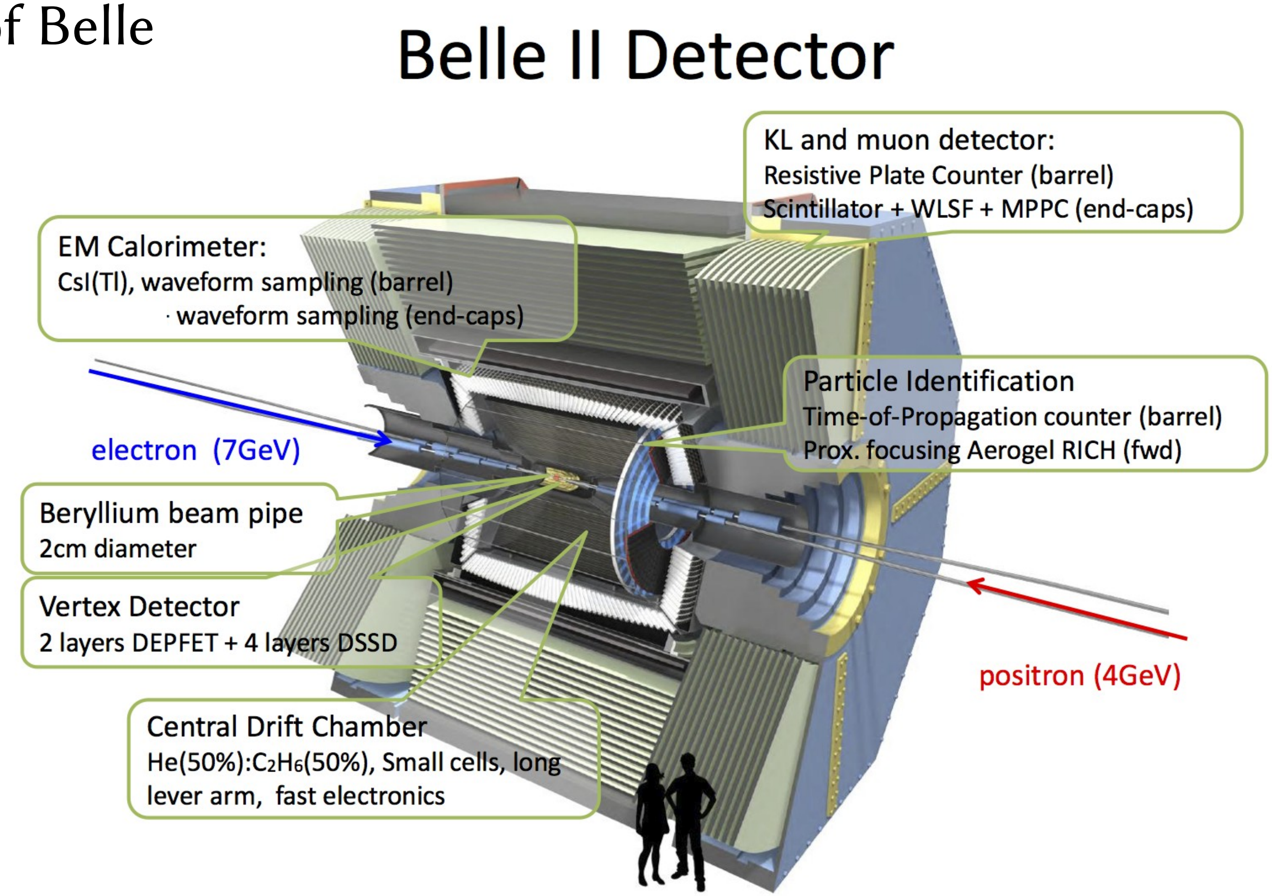
New
TiN-coated beam pipe
with antechambers



Belle II detector

Belle II is built on basis of Belle

- Main structure and magnet are reused;
- ECL and KLM are mostly reused;
- Vertex detector, drift chamber, PID, partially KLM are upgraded;
- All electronics is replaced.



Detector improvements

- Smaller beam pipe radius allows to place the innermost PXD layer closer to the Interaction point (r = 1.4cm)
  - Significantly improves the vertex resolution along z direction.
- Pixel part of the vertex detector, larger SVD and CDC
  - Increases K_S efficiency, improve vertex and timing resolution, better flavor tagging.
- PID: TOP and ARICH
  - Better K/π separation covering the whole range momentum.
- ECL and KLM
  - Less material in front of ECL;
  - Improvements in ECL and KLM to compensate for a larger beam background.
- Improved hermeticity.
- Improved trigger and DAQ.

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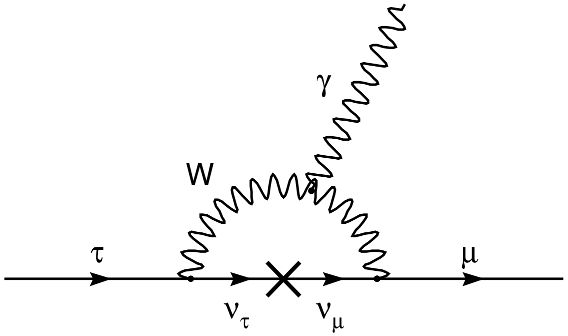
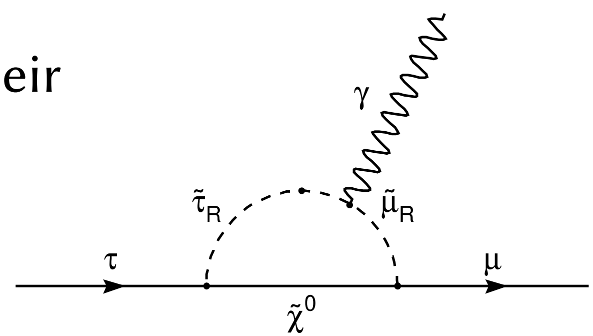
NP search with τ

- Lepton flavor is conserved in the SM
- If we take into account neutrino mass and neutrino oscillations,
  $\mathcal{B}(\tau\to\mu\gamma)\approx O(10^{-40})$ and $\mathcal{B}(\tau\to\mu\mu\mu)\approx O(10^{-14})$
  (Pham, XY. Eur. Phys. J. C (1999) 8: 513)



- Unobservable with current experiments!
- LFV is a clear signature of the New Physics
- Many extensions of the SM predict LFV decays and their BF may be enhanced to as high as $\mathcal{O}(10^{-8})$, which is within current experimental sensitivity



- τ is the heaviest lepton:
  - expect strong coupling to NP
  - many possible LFV decay modes. τ is ideal probe of NP.

NP search with τ (2)

- Ratios of BFs of τ LFV decays allow to discriminate NP models – need to measure LFV in as many modes as possible!

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

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

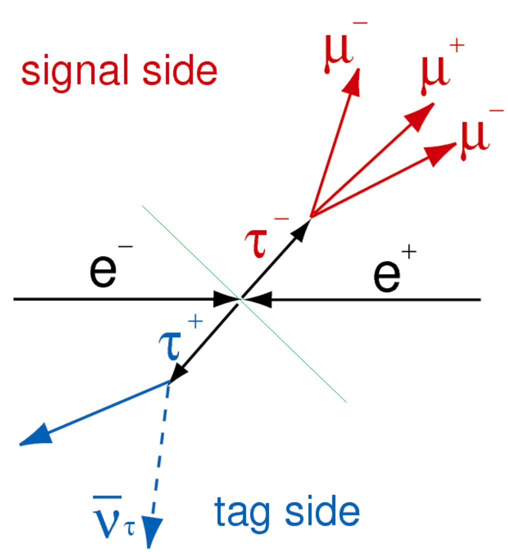
Reconstruction of τ-decays

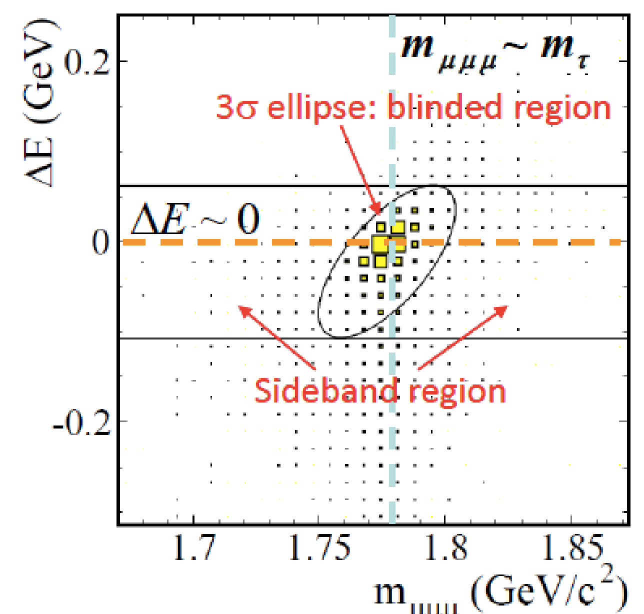
- $\sigma(e^+e^- \to \tau^+\tau^-) = (0.919 \pm 0.003)\,\mathrm{nb} \approx \sigma_{b\bar{b}}$ at $\sqrt{s} = 10.58$ GeV – *B*-factory is τ-factory!
- Due to Belle (II) hermeticity and clean environment we can reconstruct the whole event
- Divide event into two hemispheres by thrust
- Signal variables for neutrinoless LFV decays:

$$m_\tau = \sqrt{E_{sig}^2 - p_{sig}^2},$$

$$\Delta E = E_{sig}^{CM} - E_{beam}^{CM}$$

- Sidebands are used to evaluate expected background

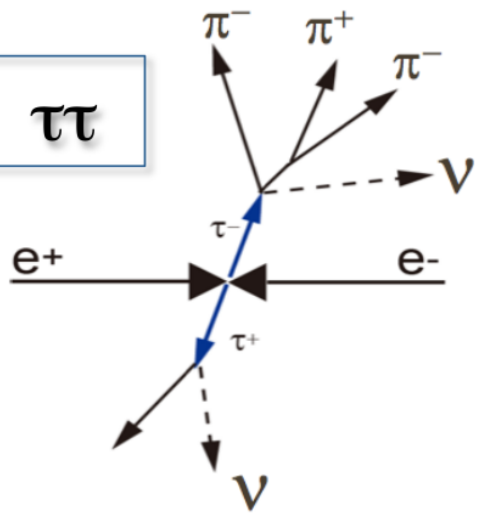




Backgrounds

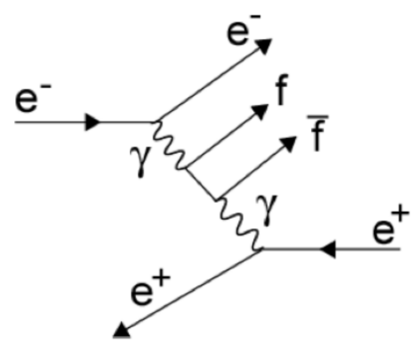
- Many backgrounds, but we have ways to mitigate them

ττ



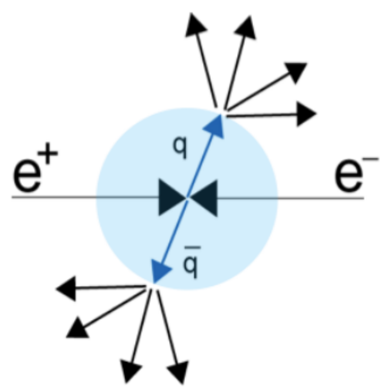
- Bkg for τ→μμμ, τ→eμμ
- Neutrinos on both sides
- Missing energy on signal side

two photon



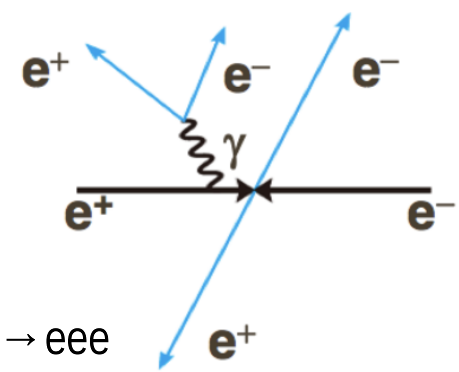
- f = leptons, quarks
- Bkg for τ→eμμ

qq



- Bkg for τ→μμμ
- Multiplicity

Radiative Bhabha

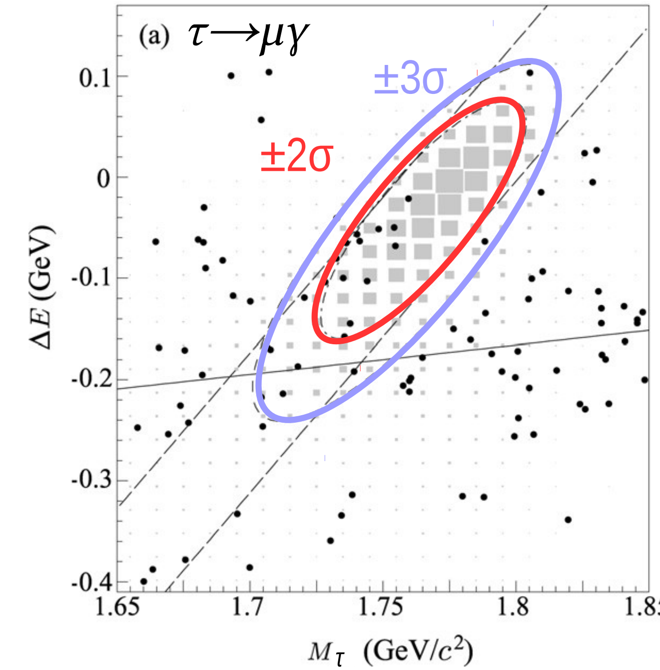


- Bkg for τ→eee
- Multiplicity

$\tau \longrightarrow \ell\gamma$

Our predictions for Belle II are based on Belle analyses. Examples follow.

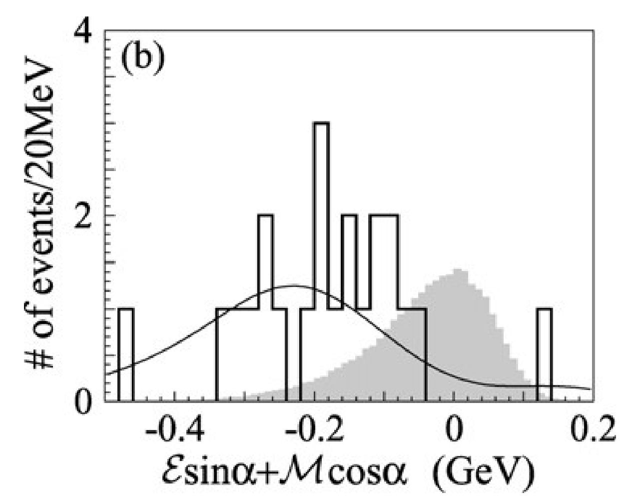
- Phys. Lett. B666, 16 (2008)
- 535 fb^{-1} sample, $4.77*10^{8}$ $\tau^{+}\tau^{-}$ events
- $\pm 3\sigma$ blinded
- $\pm 2\sigma$ for signal counting
- $\mathcal{B}(\tau^{-} \longrightarrow \mu^{-}\gamma) < 4.5*10^{-8}$ @90%CL
- $\mathcal{B}(\tau^{-} \longrightarrow e^{-}\gamma) < 12.0*10^{-8}$ @90%CL



$\mathcal{E} \equiv \Delta E - \Delta E^{(0)}$

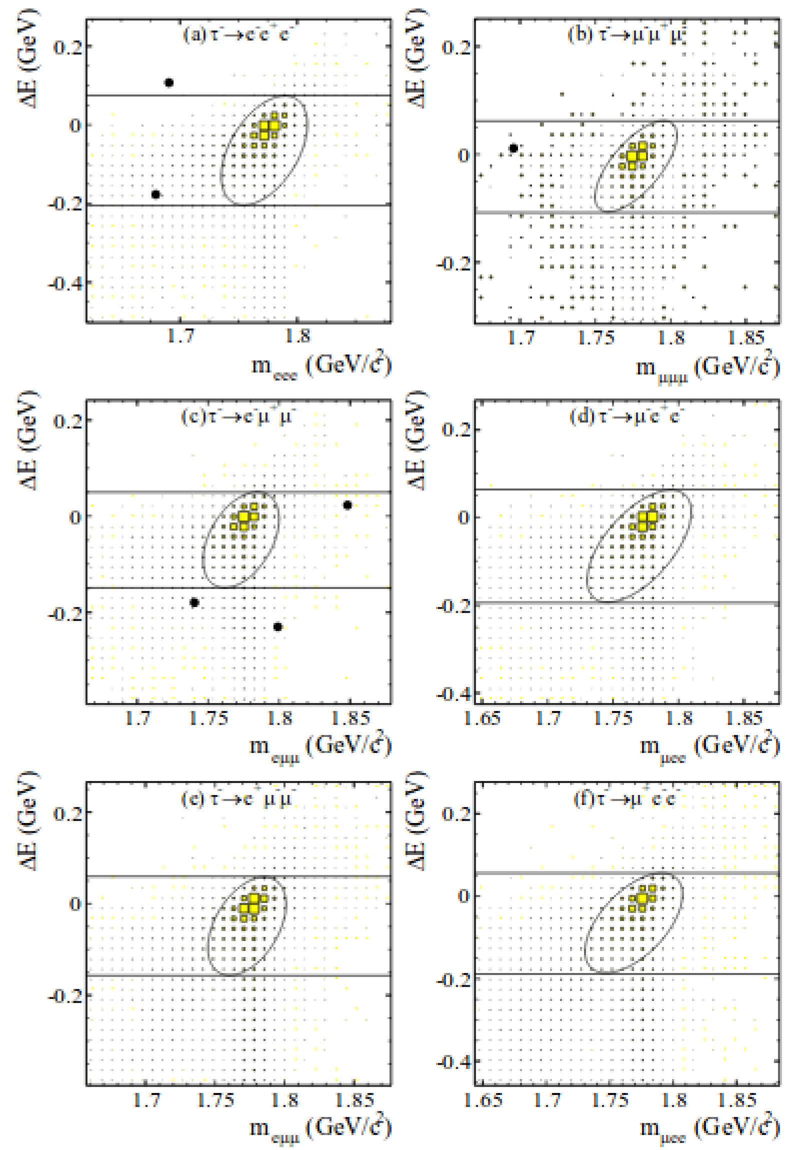
$\mathcal{M} \equiv 3.0*(M_\tau - M_\tau^{(0)})$

$\alpha = 46°$



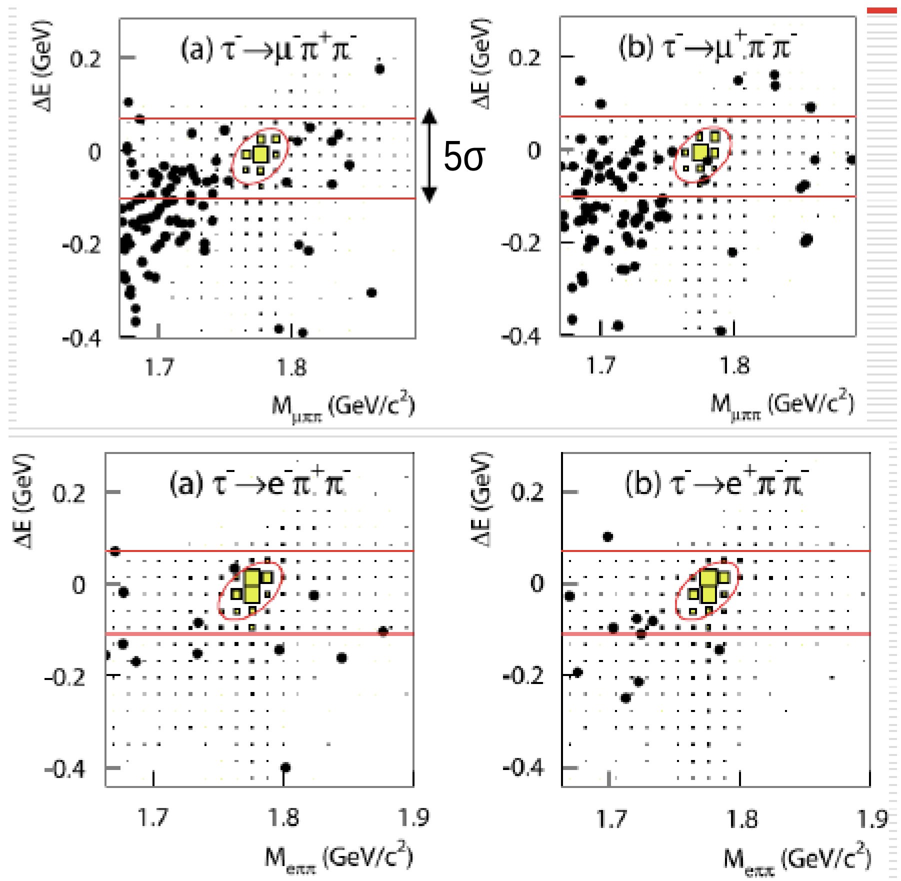
$\tau \longrightarrow \ell\ell\ell$

- 782 fb^{-1} sample, $7.19 * 10^8$ $\tau^+\tau^-$ events
- Phys.Lett.B687,139 (2010)
- No events found in signal region
- $\mathcal{B}<(1.5\text{-}2.7) * 10^{-8}$ @90%CL



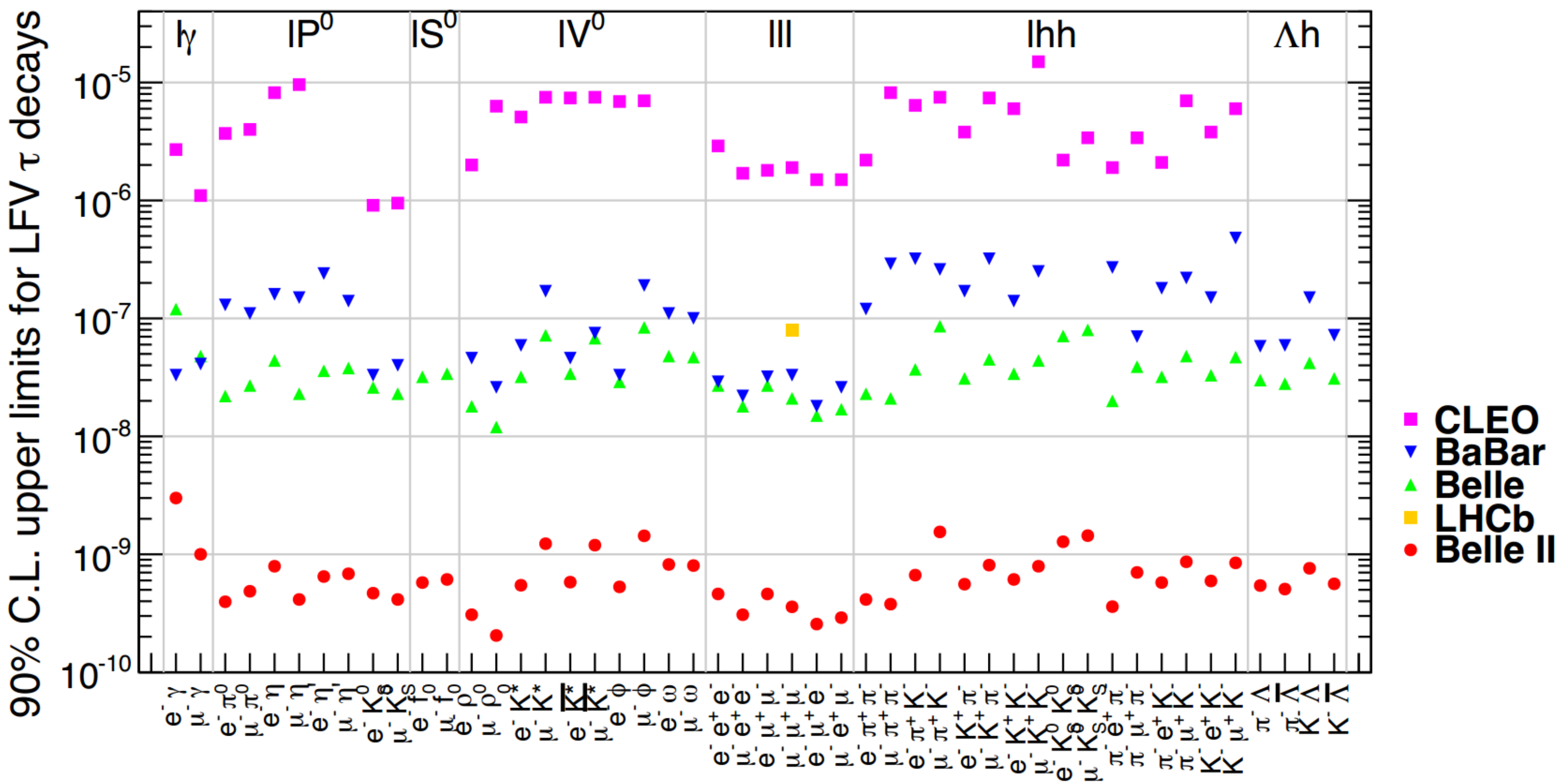
$\tau \to \ell h h'$

- 854 fb^{-1} sample
- Phys. Lett. B719, 346 (2013)
- 14 decay modes:
  - $h, h' = \pi^{\pm}, K^{\pm}$
  - $\tau^{-} \to \ell^{-} h^{+} h'^{-}$ (8 modes)
  - $\tau^{-} \to \ell^{+} h^{-} h'^{-}$ (6 modes) (LNV)
- $\mathcal{B}<(2.0\text{-}8.6)*10^{-8}$ @90%CL



Summary and prospects

- Belle (II) can study a whole spectrum of decays!
- Even with much higher beam background, the sensitivity is comparable to that of Belle, scaled by luminosity (B. Moore BELLE2-THESIS-2017-002)



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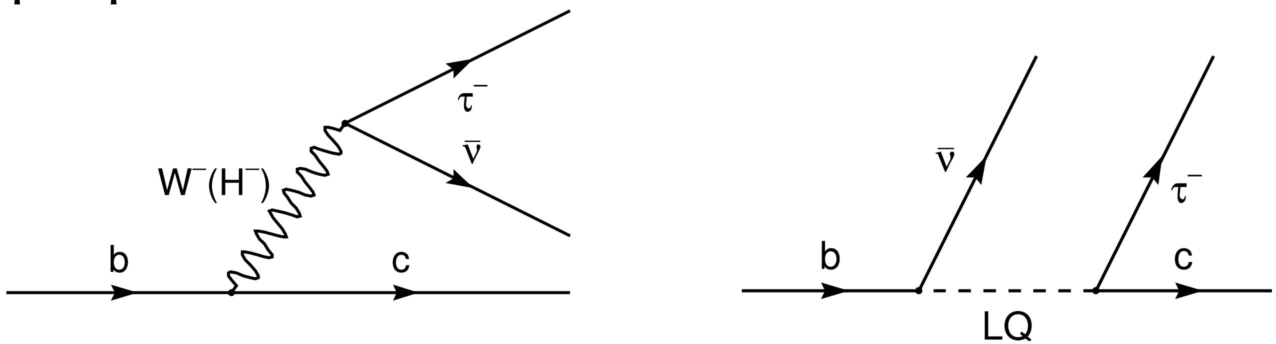
Study of $\overline{B} \longrightarrow D^{(*)}\tau^-\overline{\nu}_\tau$

- $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ decays are sensitive to New Physics models with charged Higgs and leptoquarks.



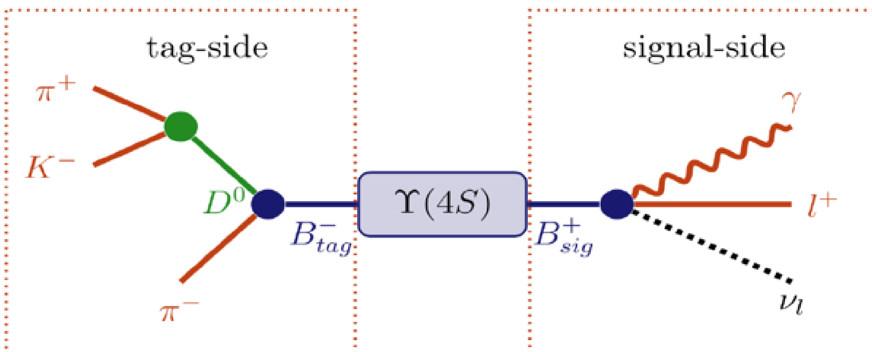
- Observed by Belle, also studied by BaBar and LHCb.
- To cancel experimental and theoretical uncertainties ratio of branching fractions is used:

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

Study of $\overline{B} \to D^{(*)}\tau^{-}\overline{\nu}_{\tau}$

- At Belle (II) events are clean are well separated from each other; we reconstruct the whole event:

$$e^+e^- \to \Upsilon(4S) \to B_{\mathrm{tag}} B_{\mathrm{sig}}$$



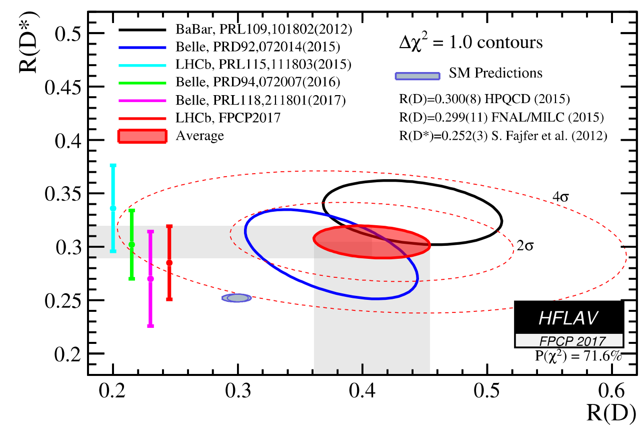
Purity

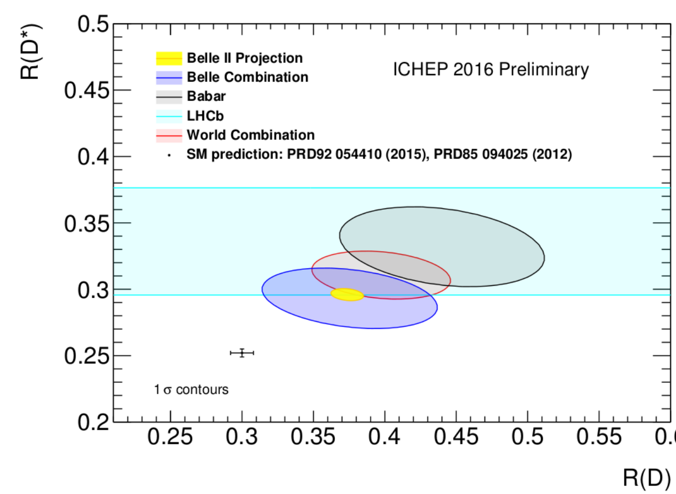
Efficiency

Inclusive	Semileptonic	Hadronic
$B \to$ anything	$B \to D^{(*)}\ell\nu$	$B \to$ hadrons
ε≈O(2%)	ε≈O(0.2%)	ε≈O(0.1%)
High background		Low background
		P(B)

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

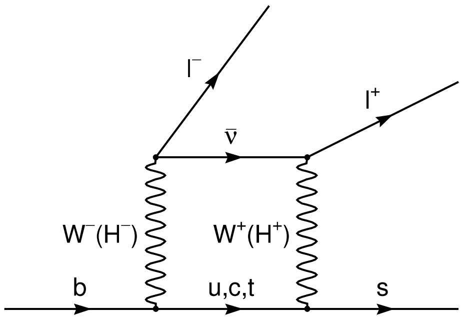
Now 4.1σ deviation from the SM



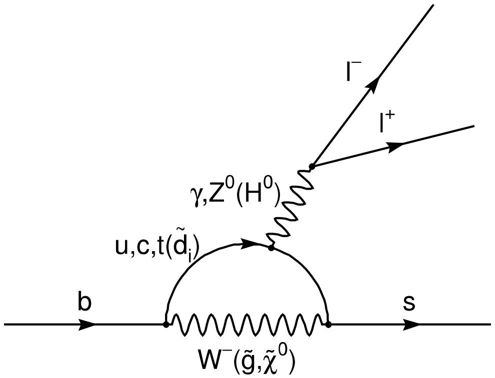


Penguin decays

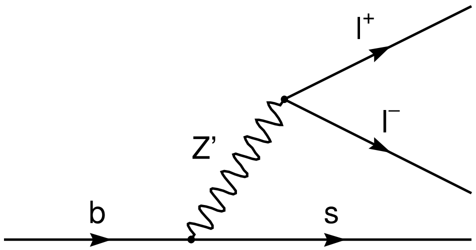
- Flavor changing neutral currents (FCNC) $b \longrightarrow s\ (d)$ are forbidden at tree level in the Standard model (SM) and happen through loops (penguins).
- New Physics (NP) particles may contribute to loop and box diagrams and change BF and angular observables.
- Make precise measurements of rare FCNC decays as precision tests of the SM.
- Make null tests of the SM, *e.g.* look for lepton flavor violation decays or lepton universality violation which are essentially forbidden in the SM.



Box diagram



Penguin diagram

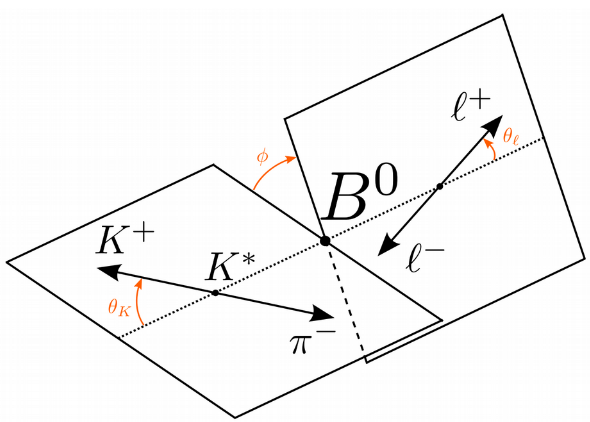


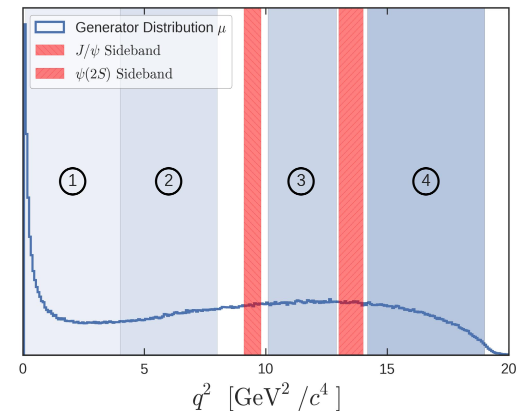
NP tree diagram

Angular analysis of $B \to K^* \ell^+ \ell^-$

- The decay is completely described by θ_ℓ, θ_K, φ and $q^2 = M_{\ell\ell}^2$.

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$





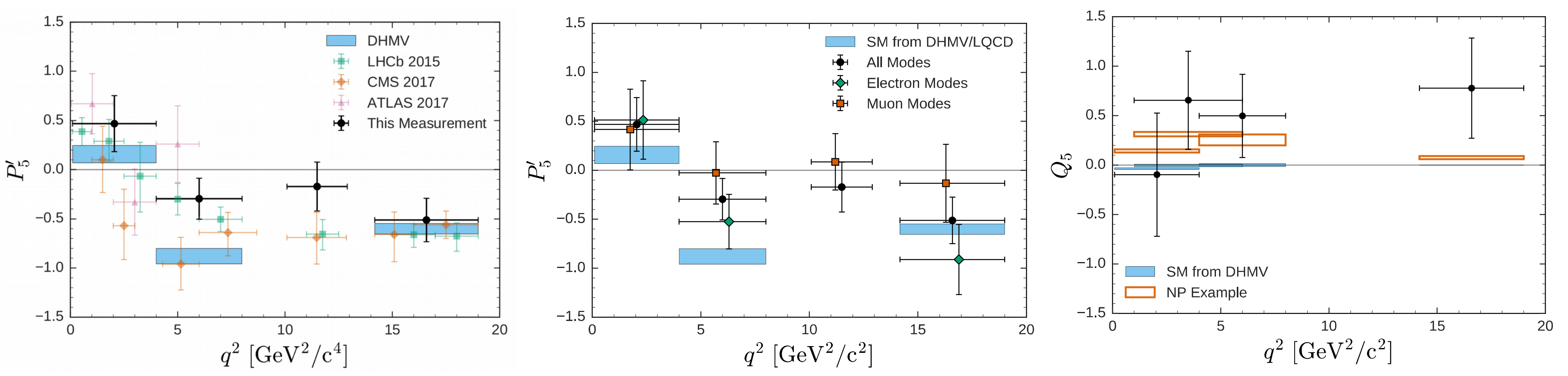
- The observables P_i' are considered to be largely free from form-factor uncertainties (S. Descotes-Genon *et al.*, JHEP 01, 048 (2013), JHEP 1305, 137 (2013)):

$$P'_{i=4,5,6,8} = \frac{S_{i=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

Anomalies in $b \to s\ell\ell$

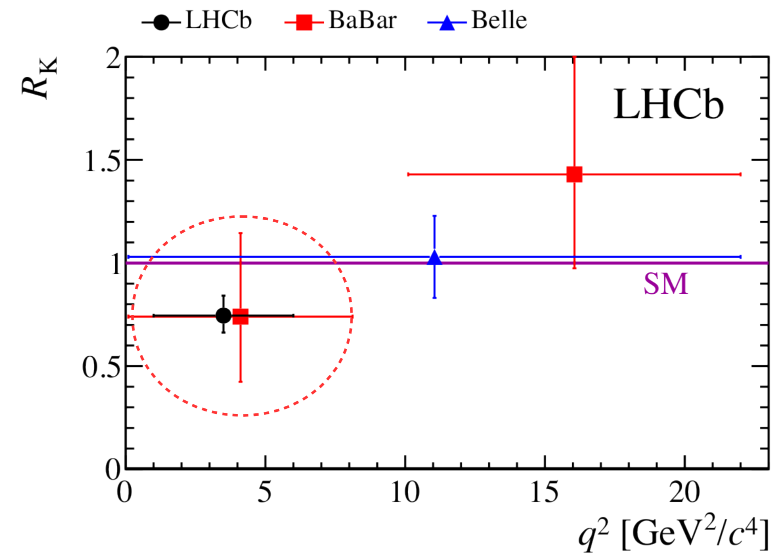
- Analysis of optimized angular observables P_i with reduced hadronic uncertainties
- 3.4σ (LHCb), 2.1σ (Belle) deviation from SM in P_5' in $4<q^2<8$ GeV²
- Belle also compared $b \to see$ and $b \to s\mu\mu$
- 2.6σ deviation for $P_5'^{\mu}$ versus 1.3σ deviation for $P_5'^{e}$
- Also seen in $Q_5 = P_5'^{\mu} - P_5'^{e}$ (= 0 in SM)

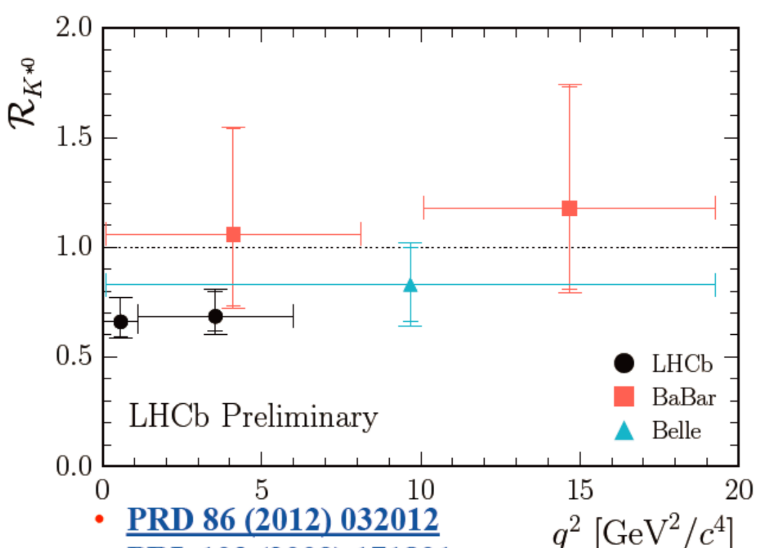
PRL 118, 111801 (2017)



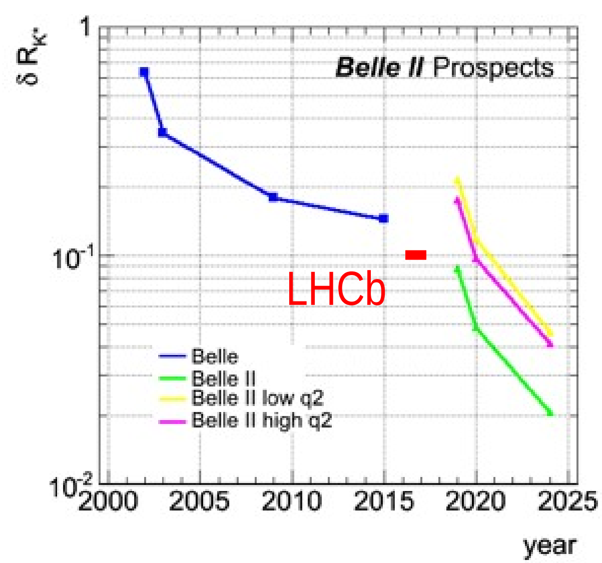
Lepton universality test: $R_{K^{(*)}}$

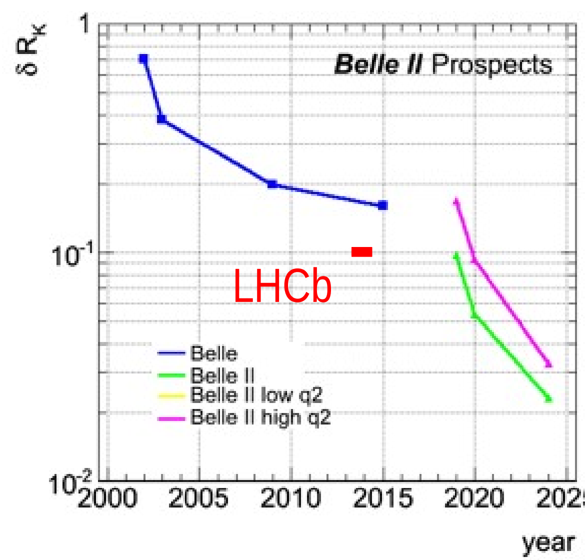
- $R_{K^{(*)}} = \mathcal{B}(B \to K^{(*)}\mu\mu)/\mathcal{B}(B \to K^{(*)}ee)$
  $= 1 \pm \mathcal{O}(10^{-3})$ (SM)
- A lot of uncertainties cancel in ratio
- 2.6σ deviation from SM
  (PRL 113, 151601 (2014))





- [PRD 86 (2012) 032012](#)
- [PRL 103 (2009) 171801](#)





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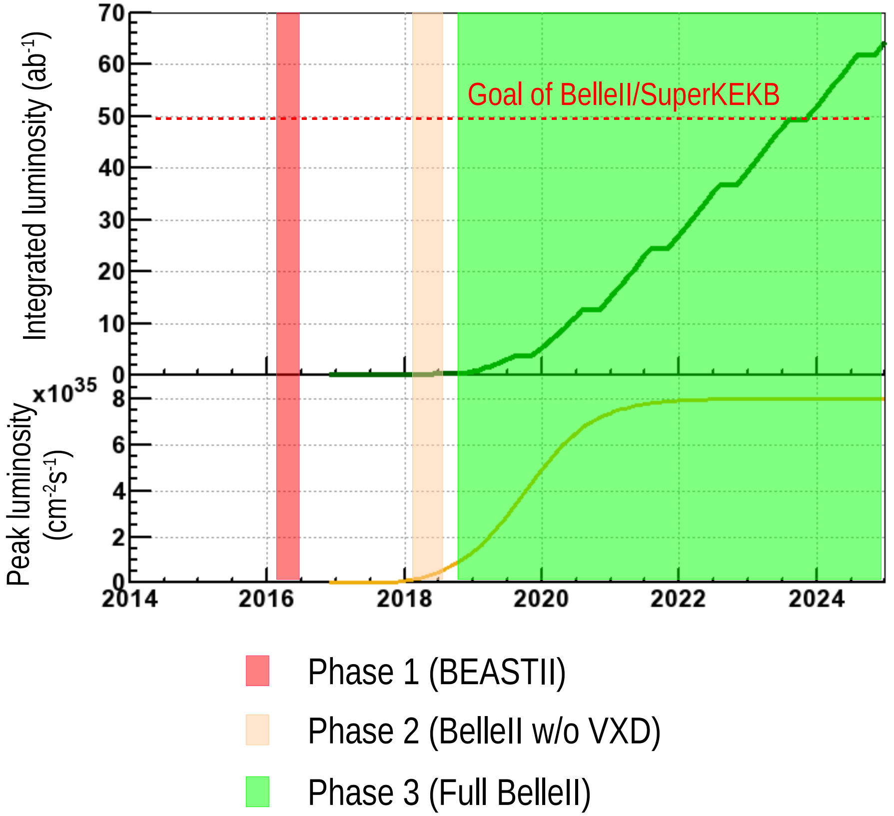
Schedule

- Accelerator Phase 1 successfully completed. SuperKEKB has been successfully switched on. It reached 1.01A current in the LER and 0.87A in the HER.
- BEAST II used as a commissioning detector
- CDC, TOP installed, ARICH ready for installation
- Belle II rolled in April 2017, global CRT
- February 2018 – ...
  - Phase 2 operation (Belle II w/o VXD)
- Summer – Autumn 2018
  - VXD installation
- End of 2018 – ...
  - Full Belle II detector, physics run

Expected running time:
9 months/year
20 days/month

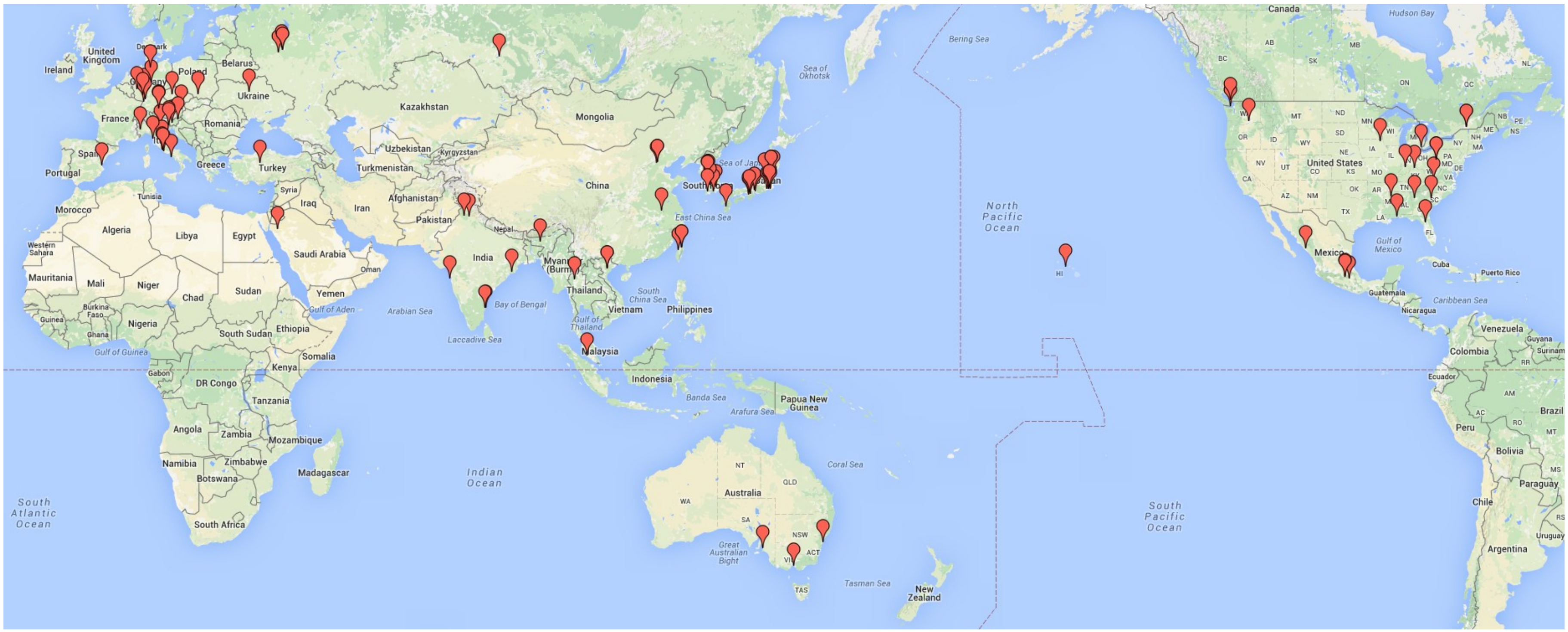


Summary

- Belle, being an e^+e^- B-factory experiment, is a τ-factory experiment at the same time.
- With nearly one billion $\tau^+\tau^-$ sample, Belle has obtained most stringent upper limits in most of the τ LFV, LNV and BNV decays, with 90% UL of $\mathcal{O}(10^{-8})$.
- With ~50 billion $\tau^+\tau^-$ events expected in the upgraded Belle II experiment, these searches will be greatly improved.
- For very clean modes (e.g. $\tau^+ \longrightarrow \ell^+\ell^-\ell^+$), the upper limit is expected to improve linearly with luminosity. And it will be a very powerful probe for new physics beyond the SM.
- In $B \longrightarrow K^{(*)}\ell^+\ell^-$ and $B \longrightarrow D^{(*)}\tau\nu_\tau$ decays hints of deviation from SM are seen; Belle II should make the picture clear.
  Also Belle II can study $B \longrightarrow K^{(*)}\nu\nu$ and $B \longrightarrow X_S\ell^+\ell^-$

Backup

Belle II collaboration



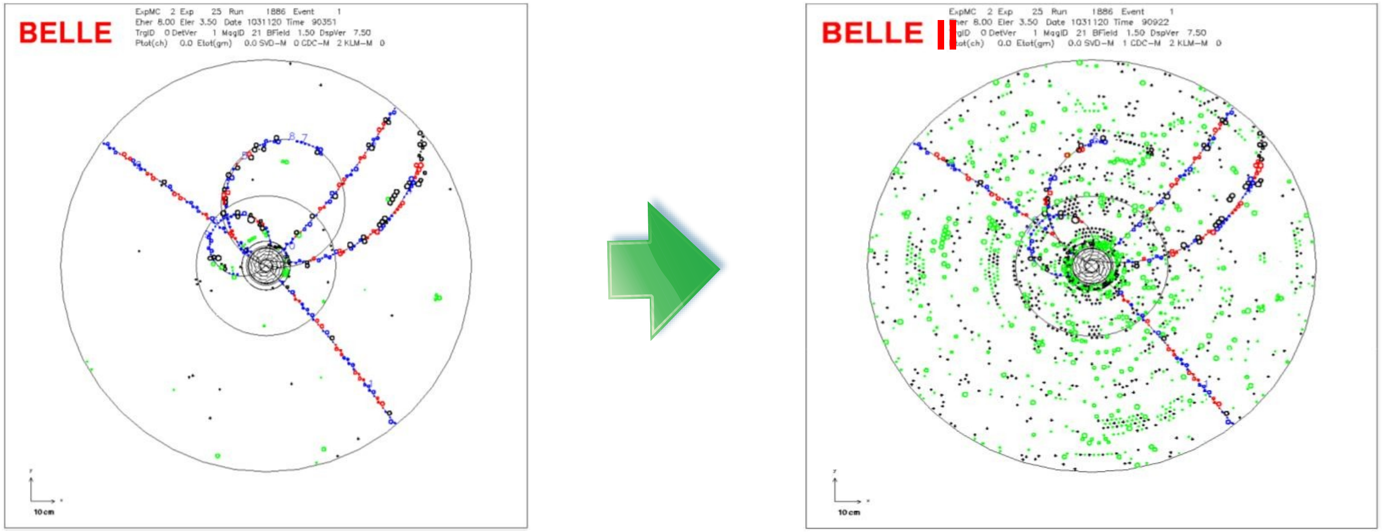
https://www.belle2.org

Formed in 2008 on basis of the Belle collaboration.

728 collaborators, 104 institutions, 24 countries/regions.

Requirements for detector

- Higher beam-related and QED backgrounds;
- L1 trigger rate 30kHz vs 500Hz for Belle:
  - Stability to high background; fast readout;
  - Better performance (vertex resolution, tracking, PID, esp. improve K/π separation);
  - Less material in front of ECL (for better performance).



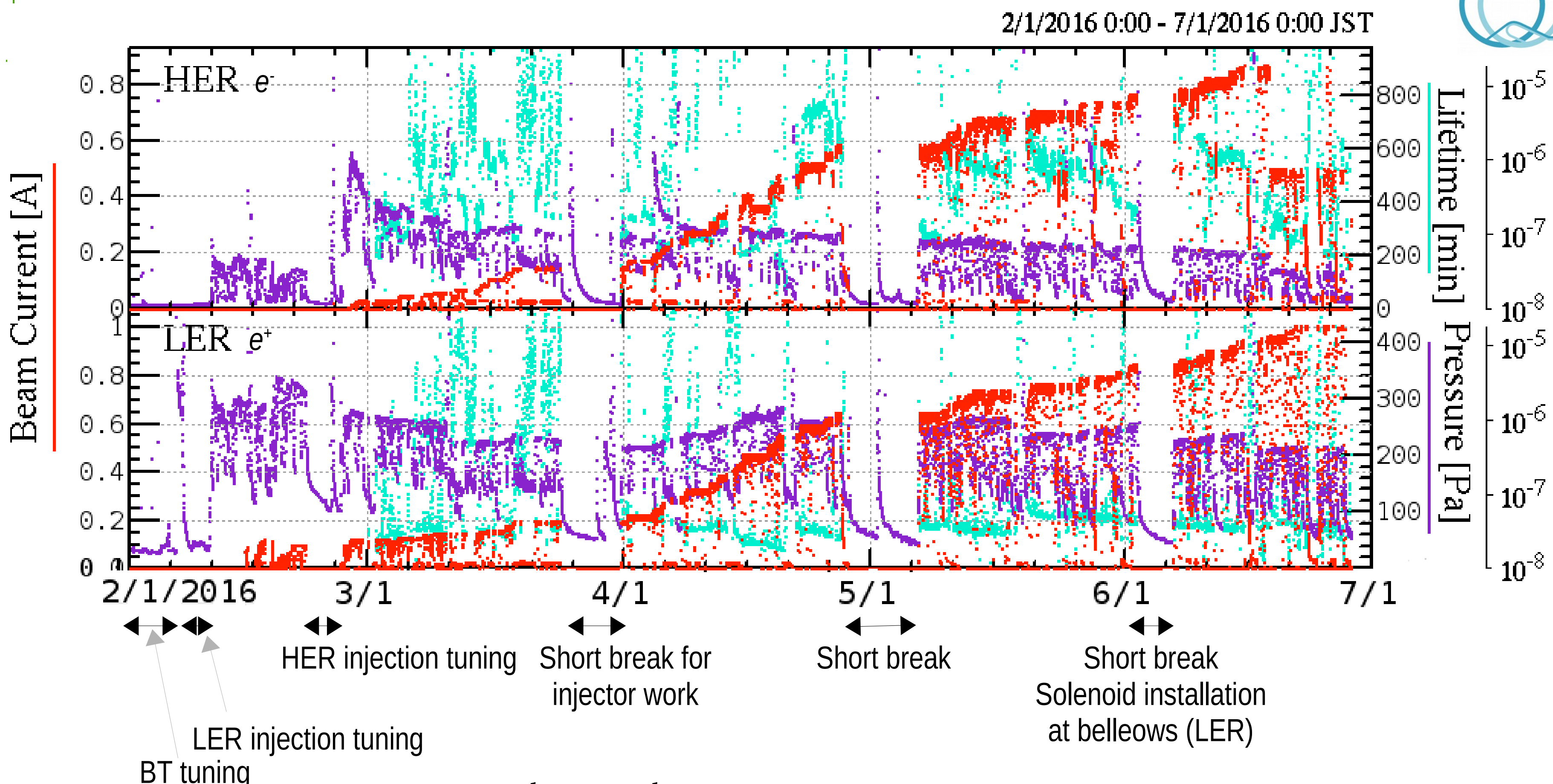
Not a simulation, just a naive illustration

SuperKEKB phase 1

SuperKEKB first started in February and worked until June (Phase 1).

- Startup of each hardware system
- Establish beam operation software tools
- Preparation for installation of Belle-II detector
  - Enough vacuum scrubbing
    - Request from Belle II group: ~1 month vacuum scrubbing with beam current of 0.5~1A (360~720Ah).
  - Beam background study with test detector (named BEAST)
- High beam current operation
  - Find and solve problems associated with high beam current operation
- Optics study w/o IR (no detector solenoid)
  - Low emittance tuning
- Other machine studies

SuperKEKB phase 1 history



Achieved currents:

HER: 870 mA, 5.7x10^{-8} Pa, ~200 min. (6/17)

LER: 1010mA, 4.7x10^{-7} Pa, ~60 min. (6/22)

SuperKEKB phase 1 results

- Faster startup than KEKB...
  - KEKB beam currents achieved after first 3 months

    LER: ~300mA, HER: ~200mA
  - SuperKEKB beam currents achieved after first 3 months

    LER: ~650mA, HER: ~590mA
- Compared with KEKB...
  - Each hardware component has been upgraded with experiences at KEK and has worked fine (RF, Magnet, Vacuum...)
  - The bunch-by-bunch feedback system has more effectively suppressed instabilities.
  - Operational tools (such as closed orbit correction system) has worked fine based on experiences at KEKB.
  - Less machine troubles than KEKB so far.

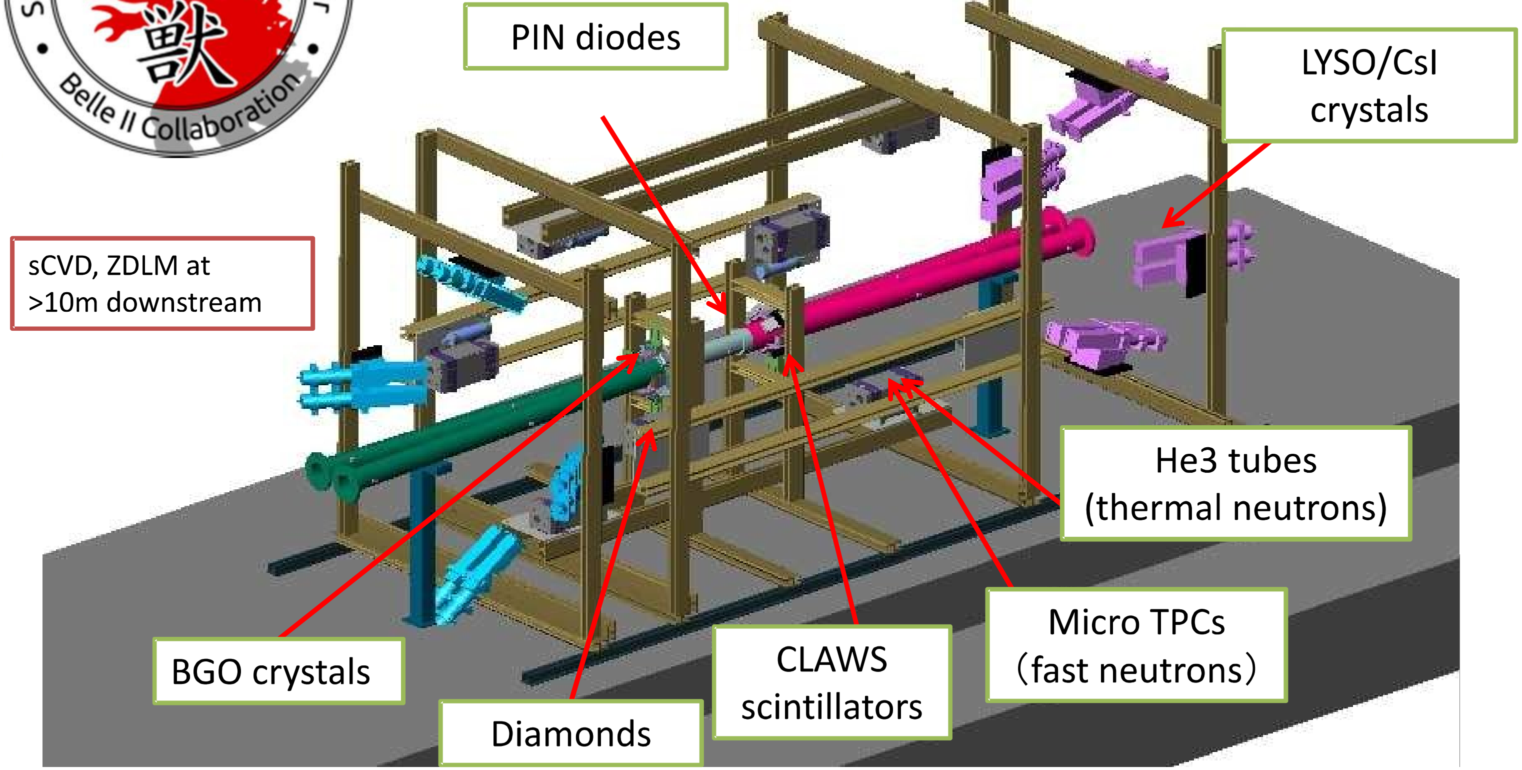
BEAST II

- Due to high beam currents, small beam size and higher luminosity, predicted SuperKEKB Beam background is 40 times higher than at KEKB.
- Background is reduced by installing moveable collimators and adding shielding near the final focus magnets.
- **B**eam **E**xorcism for a **S**table **E**xperimenT II (BEAST II): measure and characterize beam background for safe roll-in of Belle II.
- Provide feedback to SuperKEKB.
- First comparison of simulation with experimental data.
- Seven independent BEAST II sub-detectors to measure beam loss backgrounds

System	Number of detectors	Measurement
“CLAWS” scintillator	8	Injection background
Diamonds	4	Ionizing radiation dose
PIN Diodes	64	Neutral vs charged ionizing dose
BGO	8	Luminosity
Crystals	6 CsI(Tl) 6 CsI 6 LYSO	EM energy spectrum
He-3 tubes	4	Thermal neutron flux
Micro TPCs	2	Fast neutron flux

BEASTII schematic view

BEAST Phase1 sensors at IP



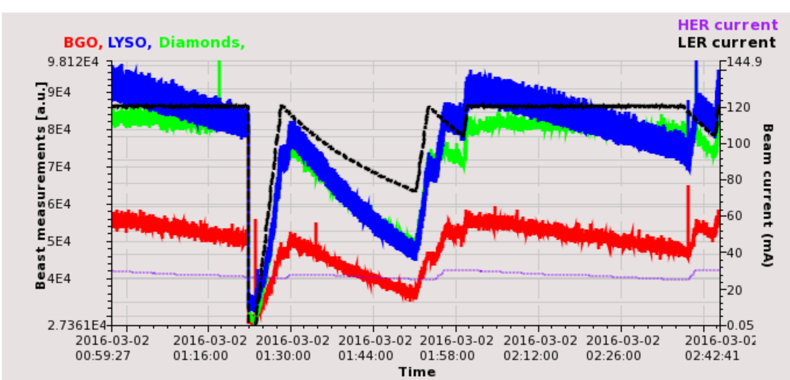
Various measurements (fast charged particle, high-energy photons, thermal/MeV neutron, dosimetry, etc..) to **validate beam loss simulation**

Hiroyuki Nakayama (KEK) 21th ARC (June. 13-15, 2016) 2

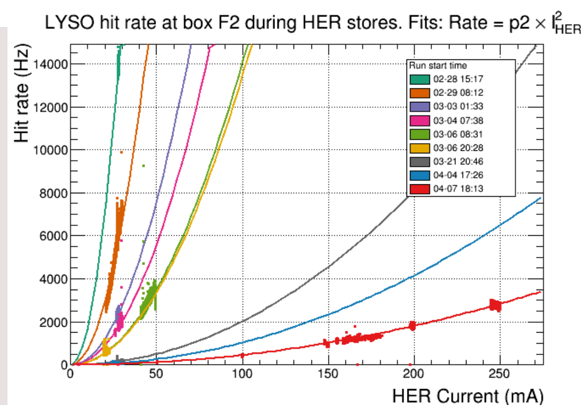
BEAST II results

- Early stage: LER/HER first turns seen by BEAST sensors.
- Vacuum scrubbing progress seen by BEAST sensors.
- "Vacuum burst"(dust capture) events seen by BEAST sensors.
- Provide "live" display of injection BG.
- Collimators are proven to reduce BEAST BG (incl. injection BG).
- Analysis of the results and comparison with simulation is ongoing.

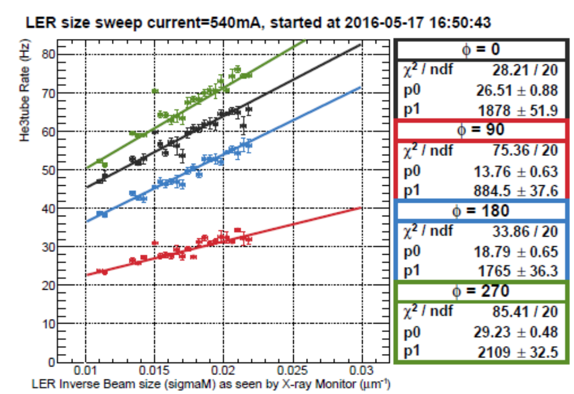
BEAST II Online monitor display



HER baking



LER Touschek study



Belle II and LHCb

Can Belle II compete with LHCb? Yes.

- Full solid angle detector and clean event environment and well defined initial state of e^+e^- experiment:
  - Missing energy modes are a strength of Belle II and the *B*-factories; powerful constraints on the charged Higgs;
  - Modes with neutrals (although not impossible at LHCb) are another strength of Belle II;
  - Belle II does inclusive modes ($B \to X_S \gamma$, $B \to X_S \ell^+ \ell^-$);
  - Belle II but not LHCb does modes with K_S mesons including a significant fraction of the $b \to s$ penguin modes.

Physics at Belle II

Since NP is not discovered yet, its manifestations are unknown. We should look everywhere. Our focus is on

- Precise CKM measurements,
- CPV in quarks and charged leptons,
- Missing energy studies:
  - $B \longrightarrow \ell\nu$,
  - $B \longrightarrow D^{(*)}\tau\nu$,
- Charged LFV: $\tau \longrightarrow \ell\gamma$, $\tau \longrightarrow \ell\ell\ell$, $\ell = e, \mu$,
- Quarkonium,
- Low multiplicity events.

Physics at 50 ab^{-1}

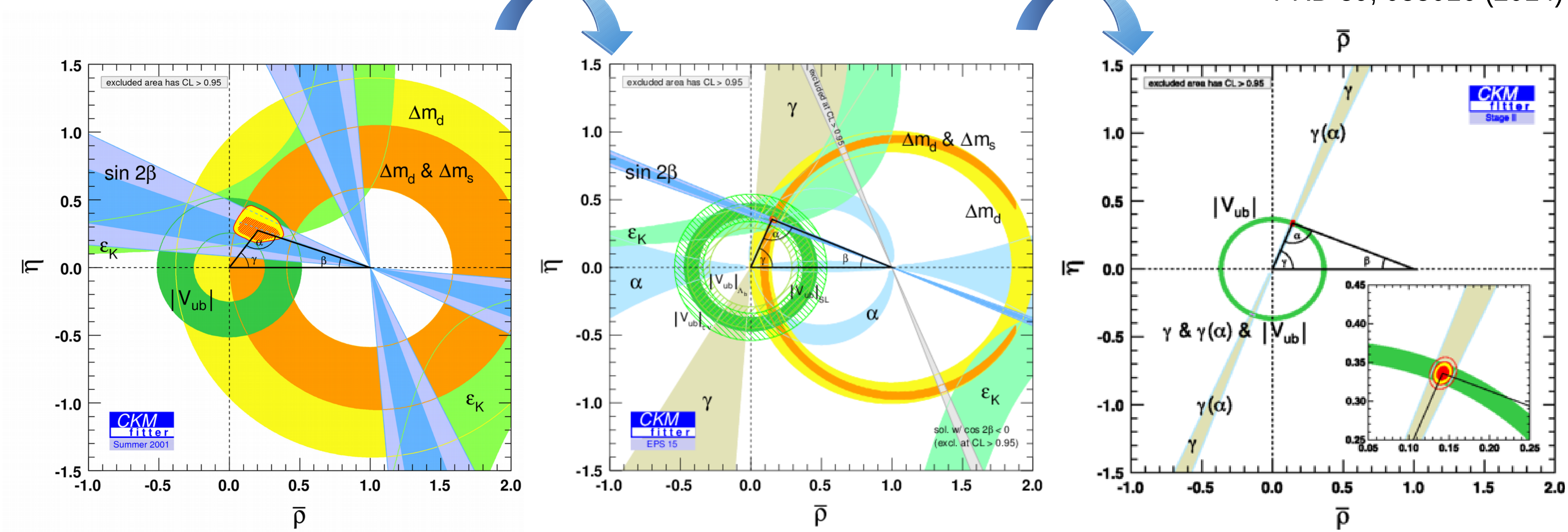
Belle II
Note 21
9th Belle PAC
P.Urquijo talk

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (1.4^\circ)$	0.7°	0.4°	1.6°	0.6°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)} K^{(*)})$	68 ± 14	6	1.5	4	1
	$2\beta_s (B_s \to J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\rm eff}(B_s \to \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03
	$\beta_s^{\rm eff}(B_s \to K^{*0} \bar{K}^{*0})$ [rad]	–			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		
UT sides	$\lvert V_{cb} \rvert$ incl.	$41.6 \cdot 10^{-3} (1 \pm 2.4\%)$	1.2%			
	$\lvert V_{cb} \rvert$ excl.	$37.5 \cdot 10^{-3} (1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$	1.8%	1.4%		
	$\lvert V_{ub} \rvert$ incl.	$4.47 \cdot 10^{-3} (1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$	3.4%	3.0%		
	$\lvert V_{ub} \rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3} (1 \pm 10.8\%)$	4.7%	2.4%		
Leptonic and Semi-tauonic	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96 (1 \pm 26\%)$	10%	5%		
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7	20%	7%		
	$R(B \to D\tau\nu)$ [Had. tag]	$0.440 (1 \pm 16.5\%)^\dagger$	5.6%	3.4%		
	$R(B \to D^*\tau\nu)^\dagger$ [Had. tag]	$0.332 (1 \pm 9.0\%)^\dagger$	3.2%	2.1%	...	
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4} (1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$2\beta_s^{\rm eff}(B_s \to \phi\gamma)$	–			0.13	0.03
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07		
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7	0.3	–		
Electroweak penguins	$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$ [10^{-6}]	< 40	< 15	30%		
	$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$ [10^{-6}]	< 55	< 21	30%		
	C_7/C_9 $(B \to X_s \ell\ell)$	~20%	10%	5%		
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2	–		
	$\mathcal{B}(B_s \to \mu\mu)$ [10^{-9}]	$2.9^{+1.1*}_{-1.0}$			0.5	0.2

Unitary triangle

- Unitary triangle changed dramatically in *B*-factories era.
- But is it really a triangle? Current $\alpha+\beta+\gamma = (175\pm9)^\circ$ (PDG), Belle II expects to improve the precision to $\alpha\sim0.3^\circ$, $\beta\sim1.0^\circ$, $\gamma\sim1.5^\circ$.
- Improvement in precision should help to resolve the tension between inclusive and exclusive measurements of $|V_{ub}|$ and $|V_{cb}|$.

PRD 89, 033016 (2014)



Physics at 50 ab^{-1}

Unitarity triangle in the presence of NP arXiv: 1309.2293

NP parameters in b→d box diagram arXiv:1011.0352