L'esperimento Belle II a SuperKEKB

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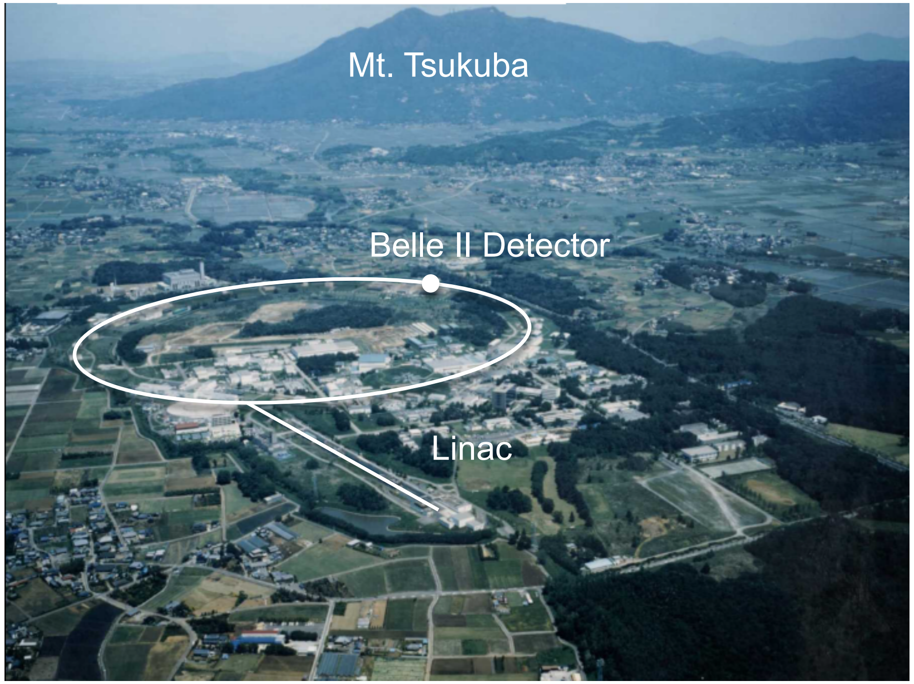
per la Collaborazione Belle II

25 Settembre 2015



Physics Motivations

Open issues in HEP, related to flavour

• **Baryon asymmetry in cosmology:** new sources of CPV

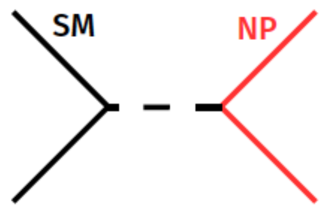
• **Quark and lepton hierarchy (mass and flavour), 19 free parameters in SM:** GUTs (SUSY) ?

• **Dark Matter:** hidden dark sector ?

• **Finite neutrino masses:** (charged) lepton flavour violation (tau) ?

Search for new physics (NP)

• **Energy frontier:** direct production of new particles - limited by beam energy (LHC - ATLAS, CMS)



• **Intensity frontier**: new particles in virtual loops, deviation from SM expectations (B factories, LHCb)

If NP is found in direct searches it is reasonable to expect NP effects in B, D, τ decays

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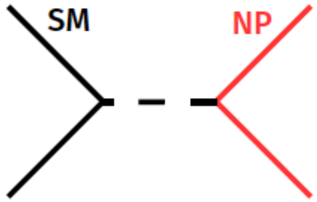

Belle II

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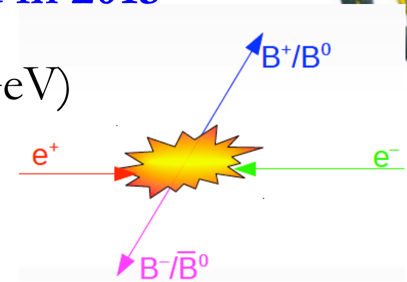
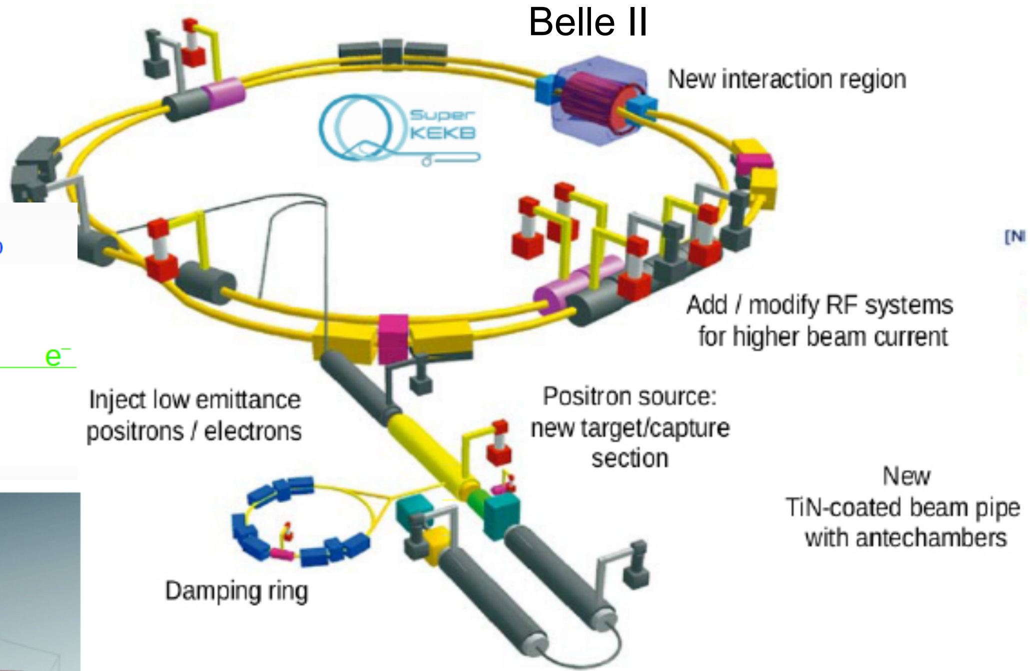
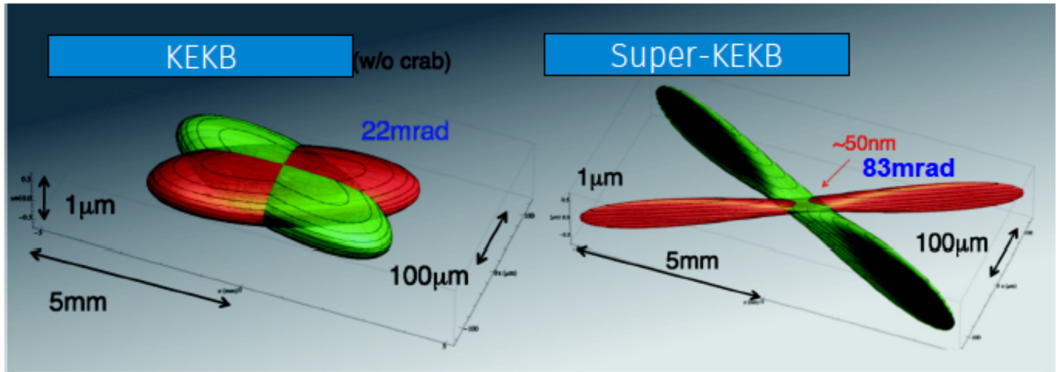
SuperKEKB

- **Electron-positron collider** situated at KEK (Tsukuba, Japan), upgrade of KEKB
- **Construction completed in 2015**
- $e^+e^- \rightarrow B\bar{B}$ (4 GeV + 7 GeV) mainly at $\sqrt{s^{cm}}$=10.58 GeV (Υ(4S) resonance)







	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

reduced boost

factor 20

factor 2-3

~ 40-50 x

beam current

Luminosity $$L=\frac{\gamma_\pm}{2 e r_e}\left(1+\frac{\sigma^*_y}{\sigma^*_x}\right)\frac{I_\pm \xi_{y\pm}}{\beta^*_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

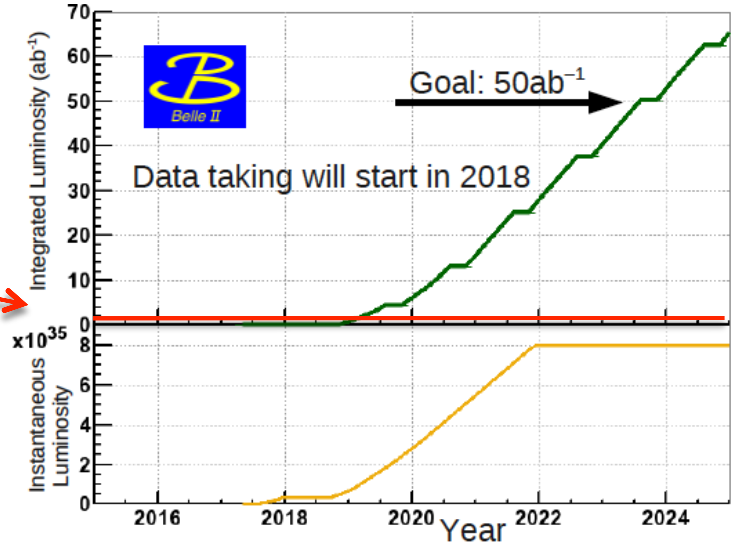
vertical beta function at IP

Nano-beam scheme firstly proposed by P. Raimondi for SuperB

SuperKEKB

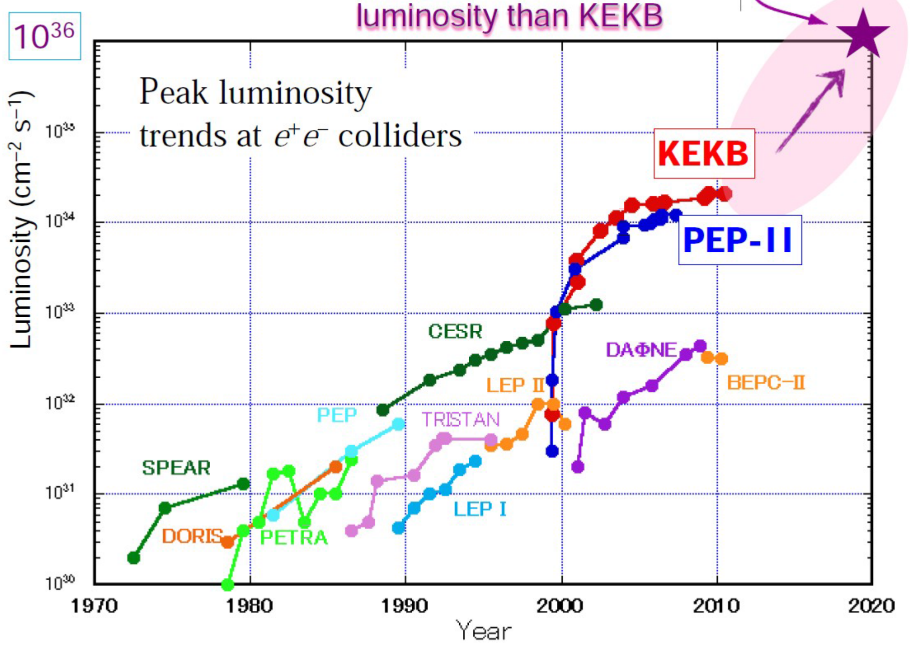
Peak instantaneous luminosity: ~0.8x10^{36} cm^{-2} s^{-1}

Belle II overall integrated luminosity: ~50 ab^{-1} corresponding to 55 × 10^9 BB pairs (BaBar + Belle ~ 1.5 ab^{-1})

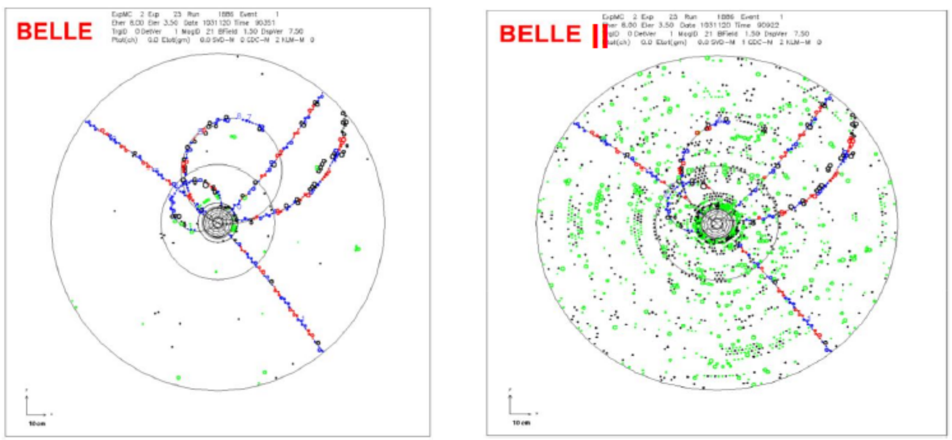


SuperKEKB is the intensity frontier

40x higher instantaneous luminosity than KEKB



Higher beam background (10-20 x)



From Belle to Belle II

Belle II upgrade:

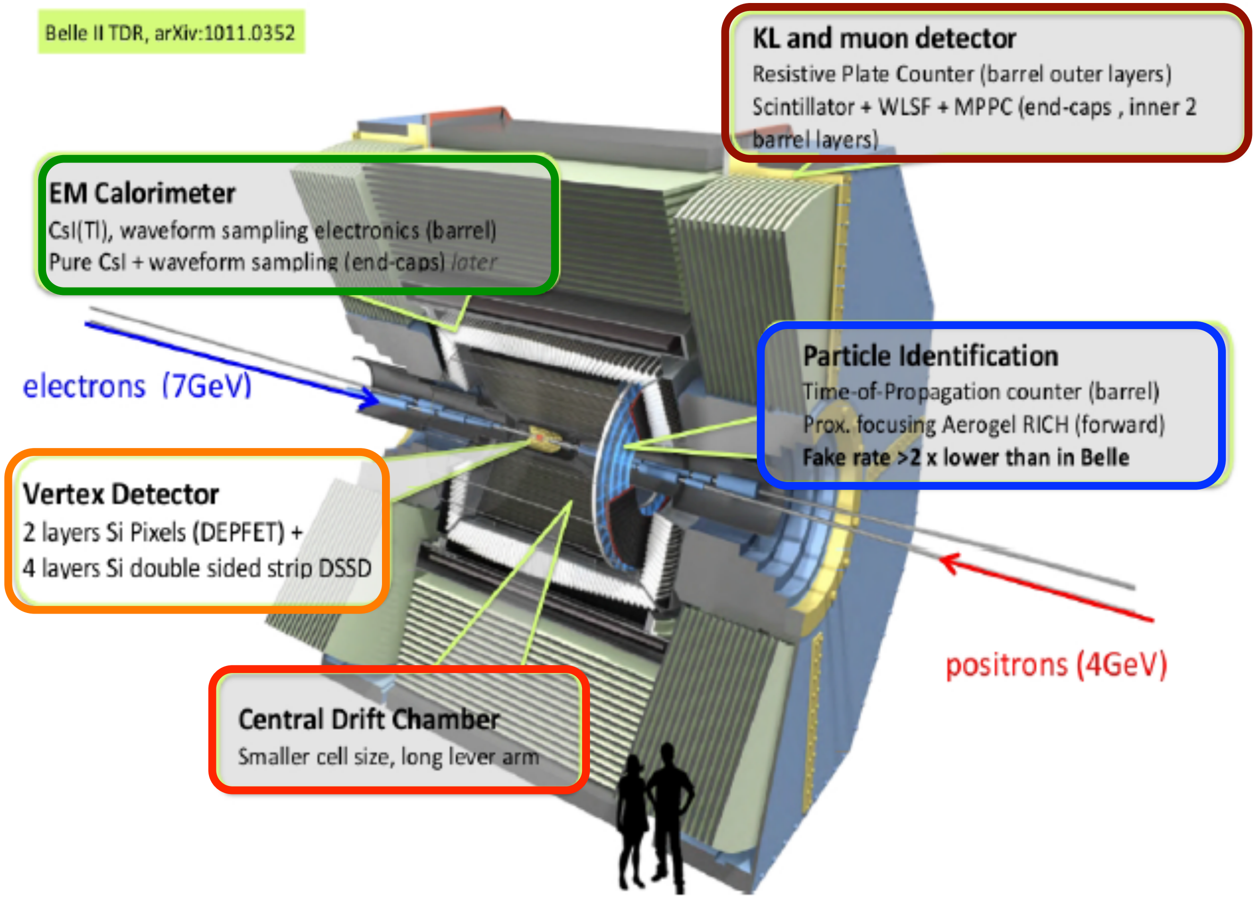
- **Extended VD region** (added pixel detector)

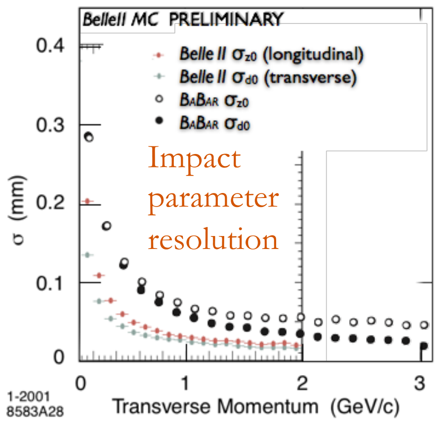
- **Extended Drift Chamber region**

- **New ECL electronics** (waveform sampling and fitting)

- **Better hermeticity** (adding PID and μID in the endcaps)

- **High efficiency KLM detector** (some RPCs layers substituted with scintillators)





- Better secondary vertex resolution
- Improved K/π separation and flavour tagging
- Increased K_s, π^0 and slow pion efficiency

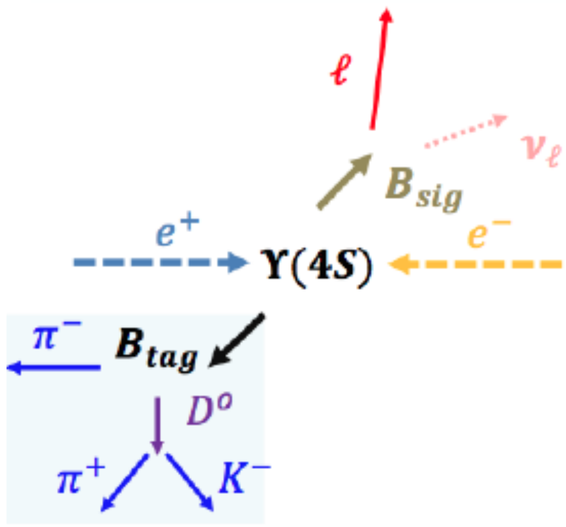
Unique capabilities of e^+e^- B factories - Belle II

1. **Beam energy constraint** and adjusted for different resonances ϒ(nS)

2. **Clean experimental environment**, low track multiplicity and detector occupancy (w.r.t hadron collider)
   - high B, D, K, tau reco. efficiency
   - open trigger ~99% efficient

3. **Full reconstruction of one B (B_{tag})** constraints the 4-momentum of the other (B_{sig})
   - helpful in reconstruction of channels with missing energy
   - opposite side B tagging efficiency: ~30% (~2%@LHCb)

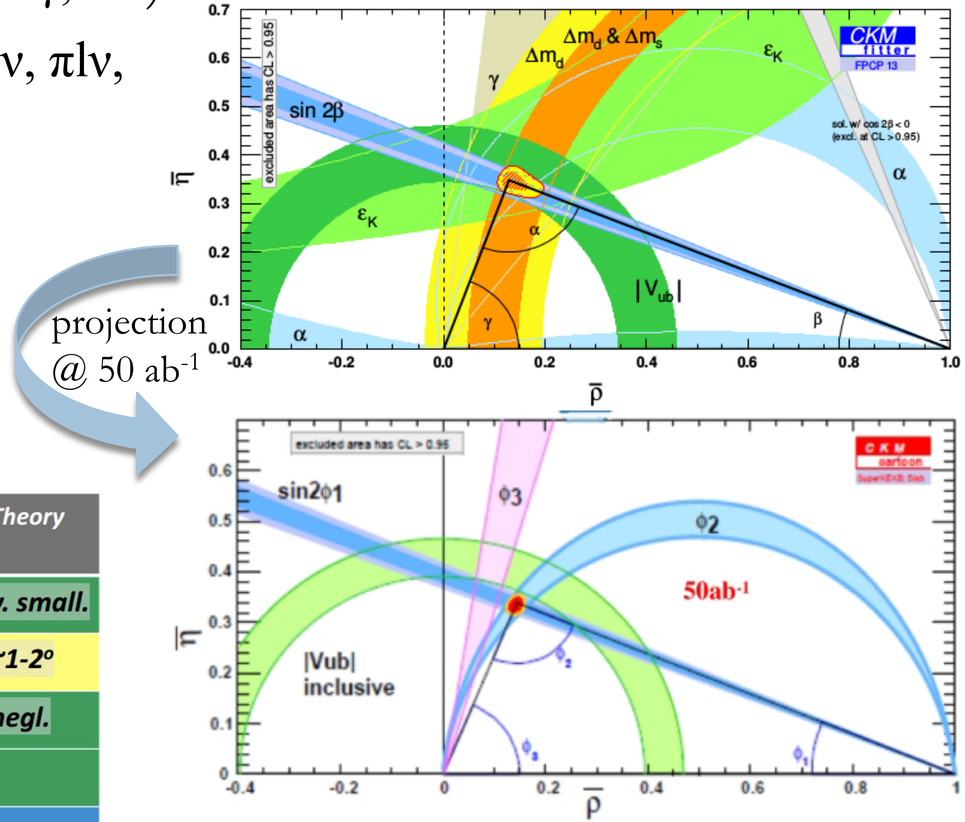
4. **Excellent EM calorimetry performances**
   - high reconstruction efficiency of neutral final states



Physics program

- CPV in B decays, CKM angles ($B \to J/\psi K^0, K^0\pi^0\gamma, K\pi$)
- (Semi)leptonic B decays, CKM sides ($B \to D^{(*)}l\nu, \pi l\nu, \tau\nu, \mu\nu$)
- Rare B decays ($B \to K\nu\nu, X_s\gamma, X_s ll, \gamma\gamma$)
- Charm physics ($D \to l\nu$, mixing, CPV)
- LFV tau decays ($\tau \to 3l, l\gamma$)
- Dark Sector, Spectroscopy

Unitarity triangle



	Belle	BaBar	Global Fit CKMfitter	LHCb Run-2	Belle II 50 ab^{-1}	LHCb Upgrade 50 fb^{-1}	Theory
φ_1: ccs	0.9°		0.9°	0.6°	0.3°	0.3°	v. small.
φ_2: uud	4° (WA)		2.1°		1°		~1-2°
φ_3: DK	14°		3.8°	4°	1.5°	1°	negl.
$\|V_{cb}\|$ inclusive	1.7%		2.4%		1.2%		
$\|V_{cb}\|$ exclusive	2.2%				1.4%		
$\|V_{ub}\|$ inclusive	7%		4.5%	7.2%	3.0%		
$\|V_{ub}\|$ exclusive	8%				2.4%		
$\|V_{ub}\|$ leptonic	14%				3.0%		

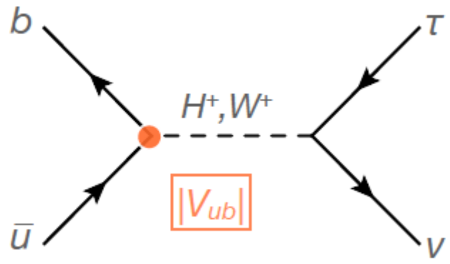
see backup for details on Belle2-LHCb comparison

Experiment
No result
Moderate precision
Precise
Very Precise

Theory
Moderate precision
Clean / LQCD
Clean

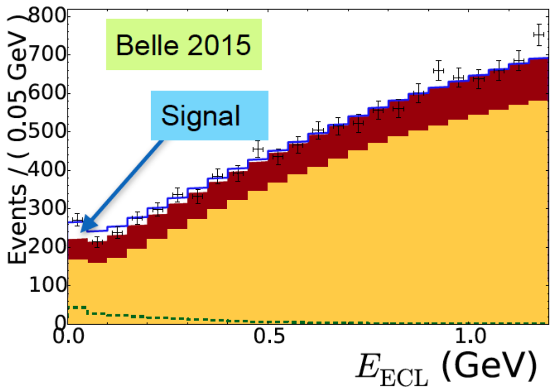
Belle II – golden modes with 5 ab^{-1}

- **B→τν**

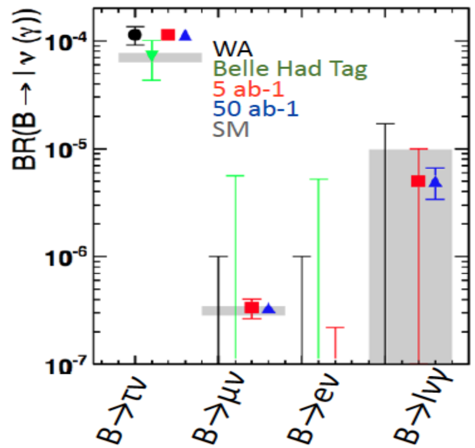


- Helicity suppressed. **BaBar and Belle found evidence**

$\mathcal{B} = [0.91 \pm 0.19(\text{stat.}) \pm 0.11(\text{syst.})] \times 10^{-4}$ Belle combination (~4.6 σ)



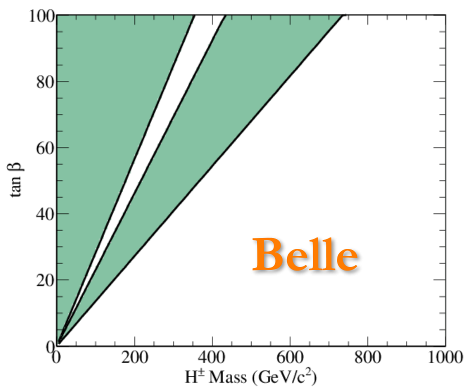
In agreement with SM expectations

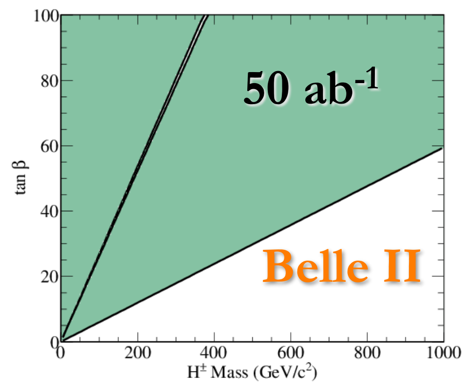


Projections for B→lν(γ)

- **NP, e.g. charged Higgs, enhances the branching ratio**. The 2-Higgs doublet model predicts

$$B = B_{SM} \times \left(1 - m_B^2 \frac{\tan^2 \beta}{m_{H^\pm}^2}\right)$$

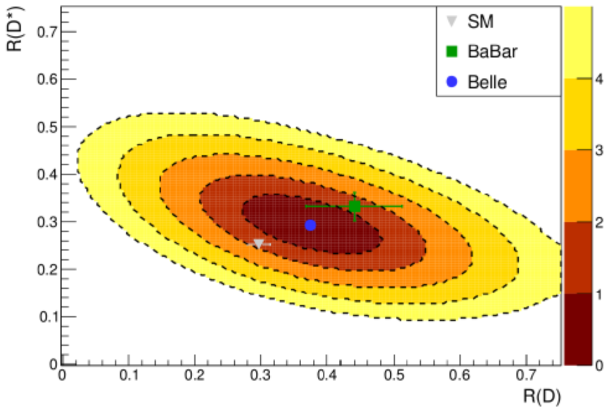


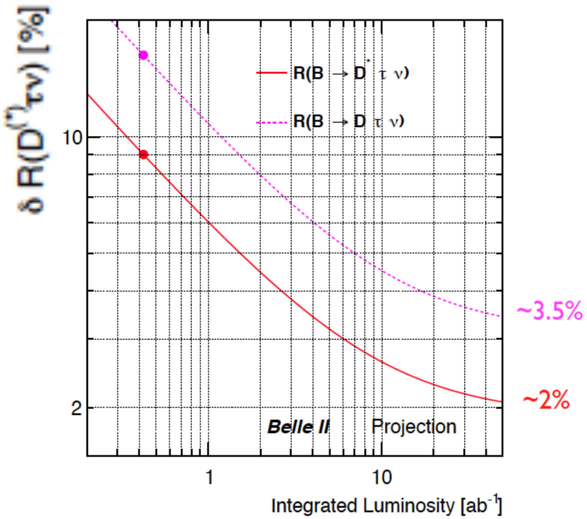


Belle II – golden modes with 5 ab^{-1}

- **$B \to D^{(*)}\tau\nu$**
  - Measurement of $R^{(*)}$ = BR $(B \to D^{(*)}\tau\nu)$ / BR$(B \to D^{(*)}l\nu)$
  - **BaBar**: 3.5 σ far from SM
  - **LHCb**: consistent with SM
  - **Belle**: consistent with both LHCb and BaBar

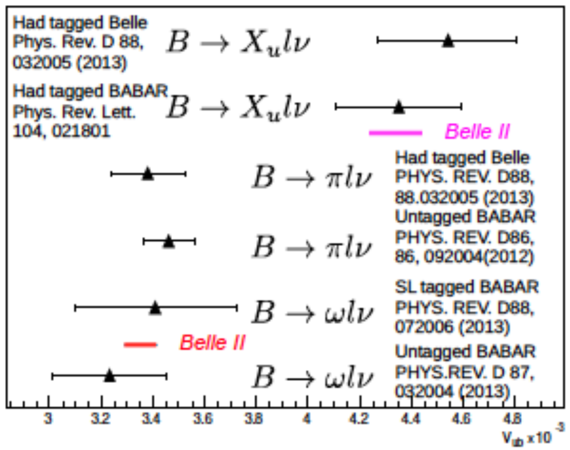
R vs R*

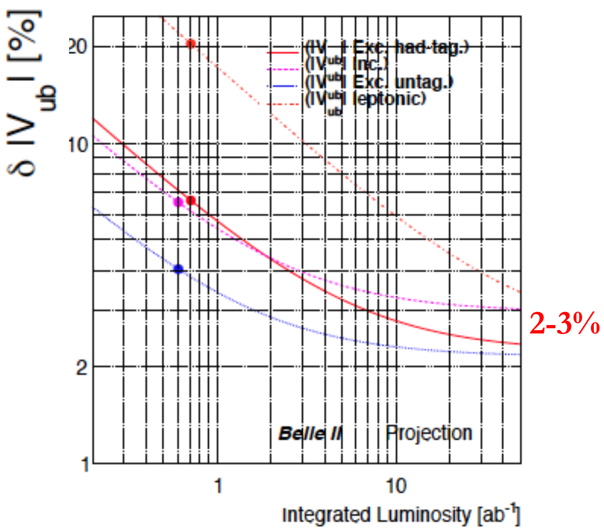




- **$B \to X_u l\nu$**
  - Tension between inclusive and exclusive measurements of $|V_{ub}|$

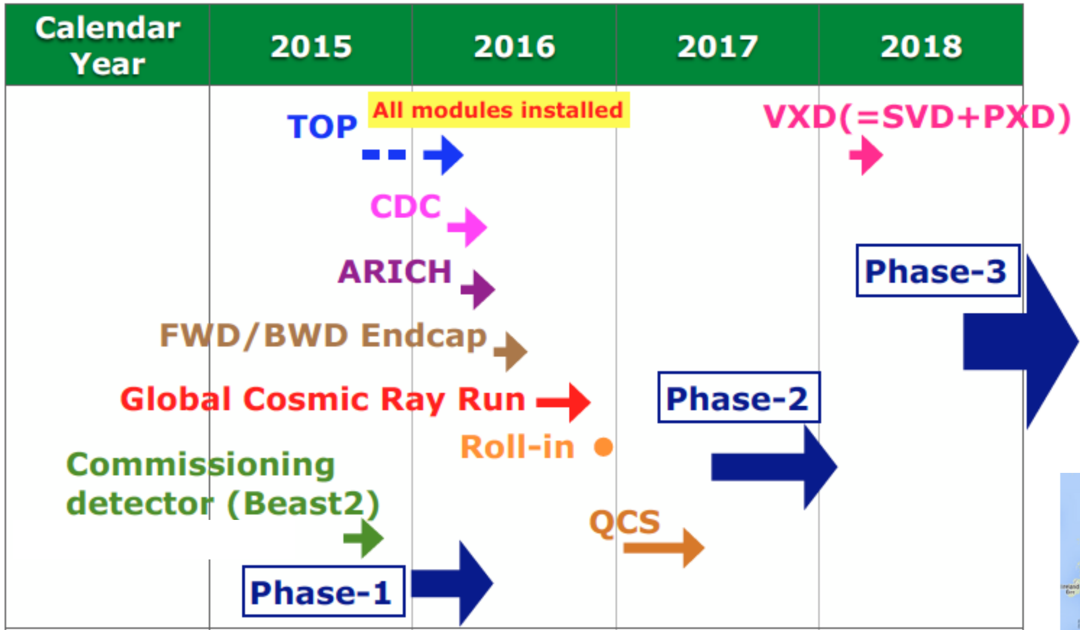
$|V_{ub}|$





Projections for LFV in backup slides

Belle II schedule: installation and commissioning

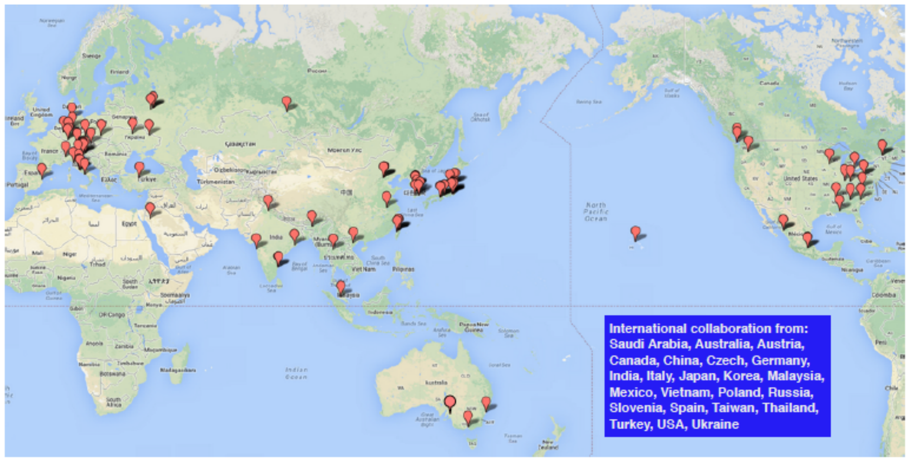


BEAST (**B**eam **E**xorcism for **A** **ST**able experiment): commissioning detector, aimed at studying beam induced backgrounds near the IP

BEAST phase 1 (2016): beam, no collisions, cosmics

BEAST phase 2 (2017-2018): collisions, complete Belle II detector except for Vertex Detector

Full physics (end 2018-2024): full Belle II detector



Belle II: ~650 collaborators, 99 institutions, 23 regions/countries

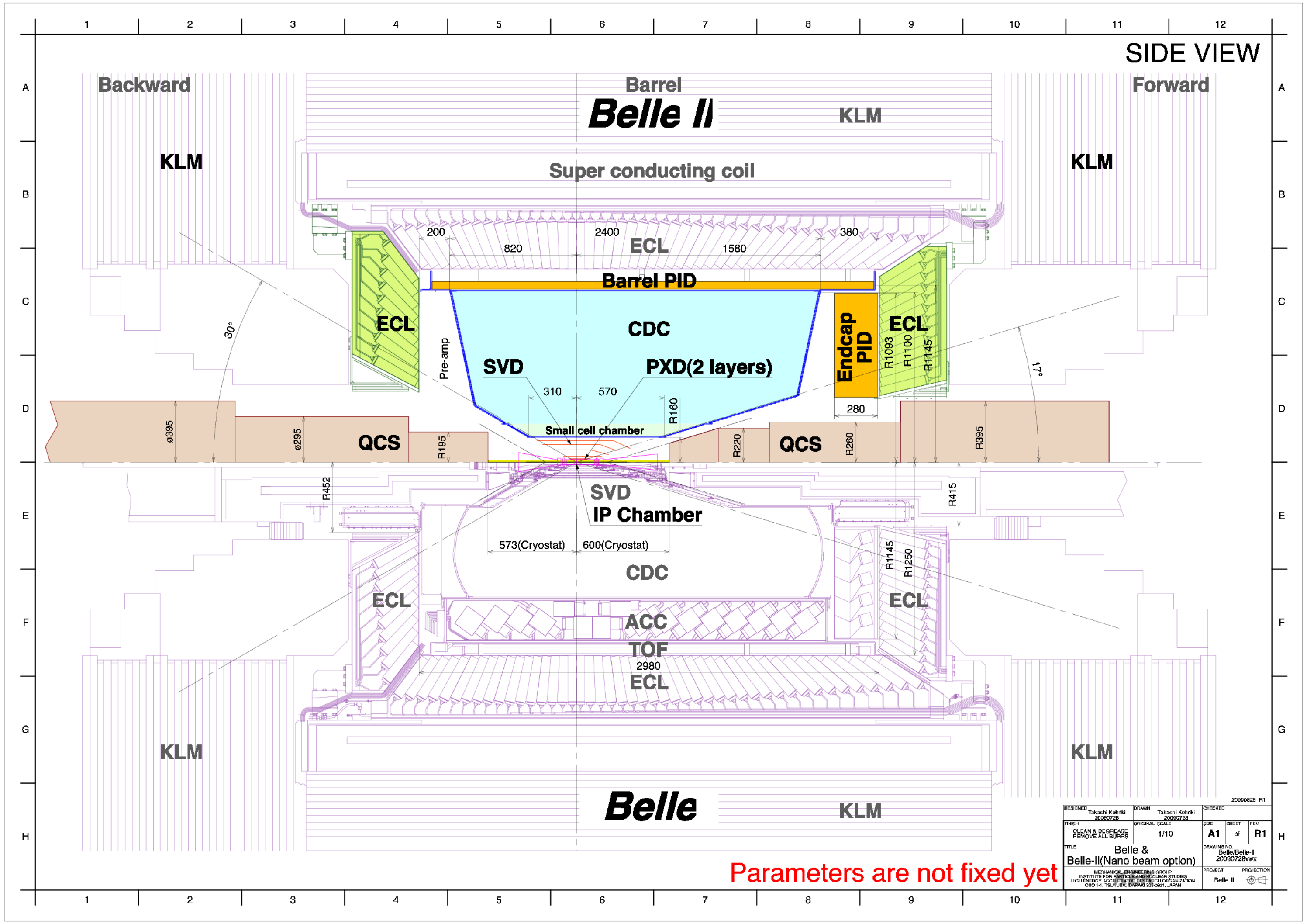
Summary

- In the SuperKEKB B factory e^- and e^+ collisions will reach the unprecedented instantaneous luminosity of $\sim 10^{36} cm^{-2} s^{-1}$
- The upgraded Belle II detector will face the higher level of backgrounds with improved tracking and PID
- The detector commissioning is starting in 2016 with first collisions in 2017 and full physics program in 2018
- The physics program includes the CP violation, (semi)leptonic B decays, rare B decays, LFV and charm physics, dark sector and spectroscopy
- With the full dataset of 50 / ab collected by 2024 Belle II will be able to shed light on the physics beyond the standard model

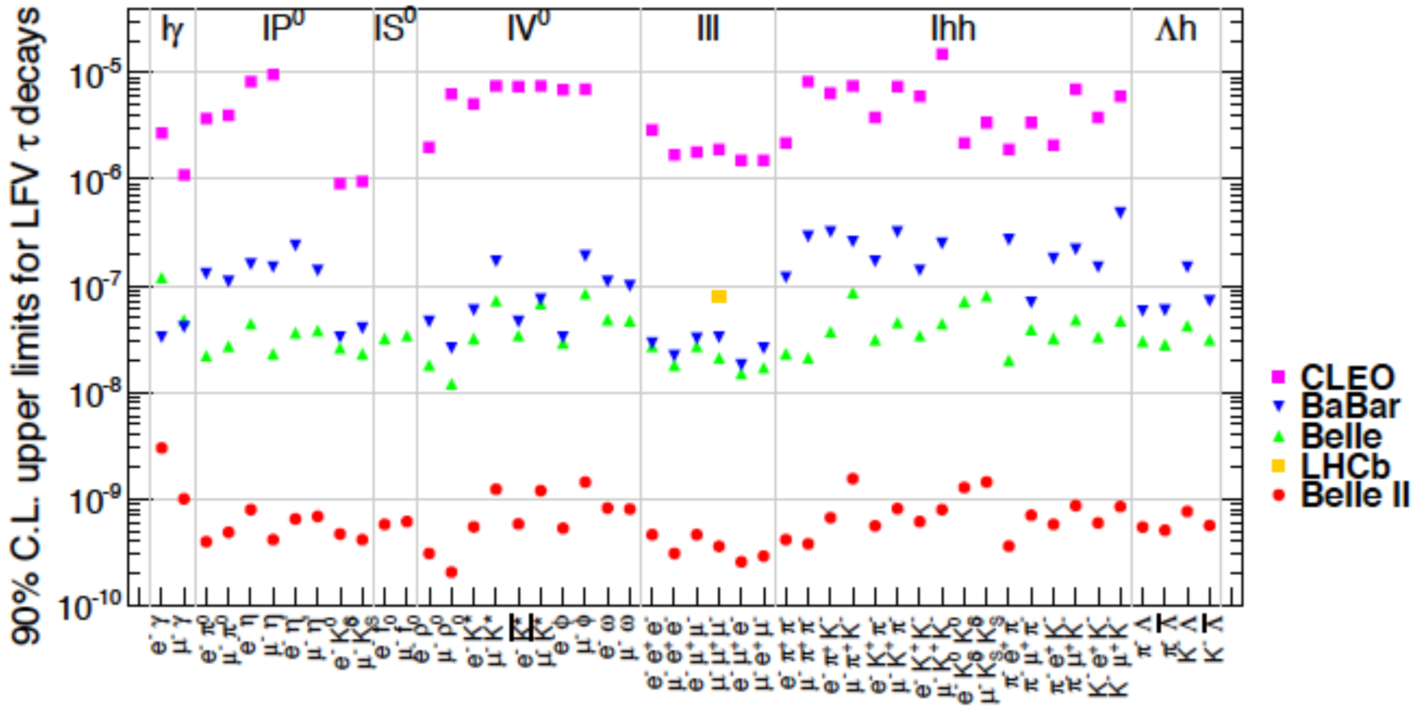
Thanks !

Backup

Belle II vs Belle



LFV


90% C.L. upper limits for LFV τ decays
lγ
lP0
lS0
lV0
lll
lhh
Λh
10-5
10-6
10-7
10-8
10-9
10-10
CLEO
BaBar
Belle
LHCb
Belle II

Physics prospects

	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	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (0.9°)$	0.4°	0.3°	0.6°	0.3°
	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		
	$\beta^{\rm eff}_s (B_s \to \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03
	$\beta^{\rm eff}_s (B_s \to K^{*0} \bar{K}^{*0})$ [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		
	$2\beta^{\rm eff}_s (B_s \to \phi\gamma)$	–			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

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 2018	LHCb 50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3} (1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3} (1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+ K^-)$ $[10^{-4}]$	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+ K^-)$ $[10^{-3}]$	3.4^*			0.5	0.1
	A_Γ $[10^{-2}]$	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0 \pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K^0_S \pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K^0_S \pi^+ \pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm ^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K^0_S \pi^+ \pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm ^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p \rvert (D^0 \to K^0_S \pi^+ \pi^-)$	$0.90 \pm ^{0.16}_{0.15} \pm ^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K^0_S \pi^+ \pi^-)$ [°]	$-6 \pm 11 \pm ^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ $[10^{-9}]$	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0	< 3.0	< 0.3		