



L'esperienza Belle II a SuperKEKB



*Mario Merola (INFN Napoli)
per la Collaborazione Belle II
25 Settembre 2015*

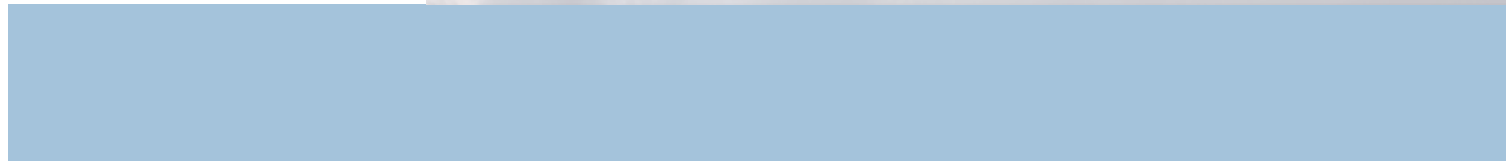


SOCIETÀ ITALIANA DI FISICA



IYL 2015

101°
CONGRESSO NAZIONALE
Roma, 21 - 25 settembre 2015





Physics Motivations



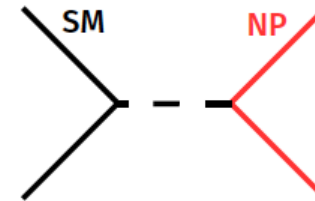
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Open issues in HEP, related to flavour

- **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



Physics Motivations



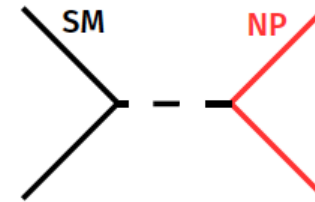
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Belle II

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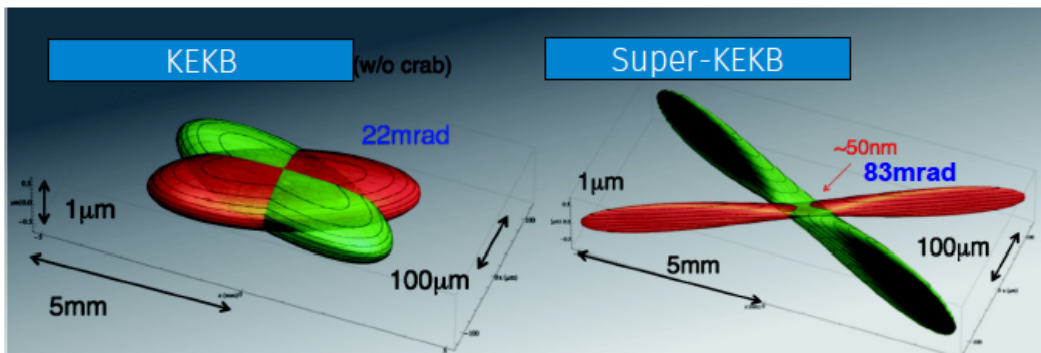
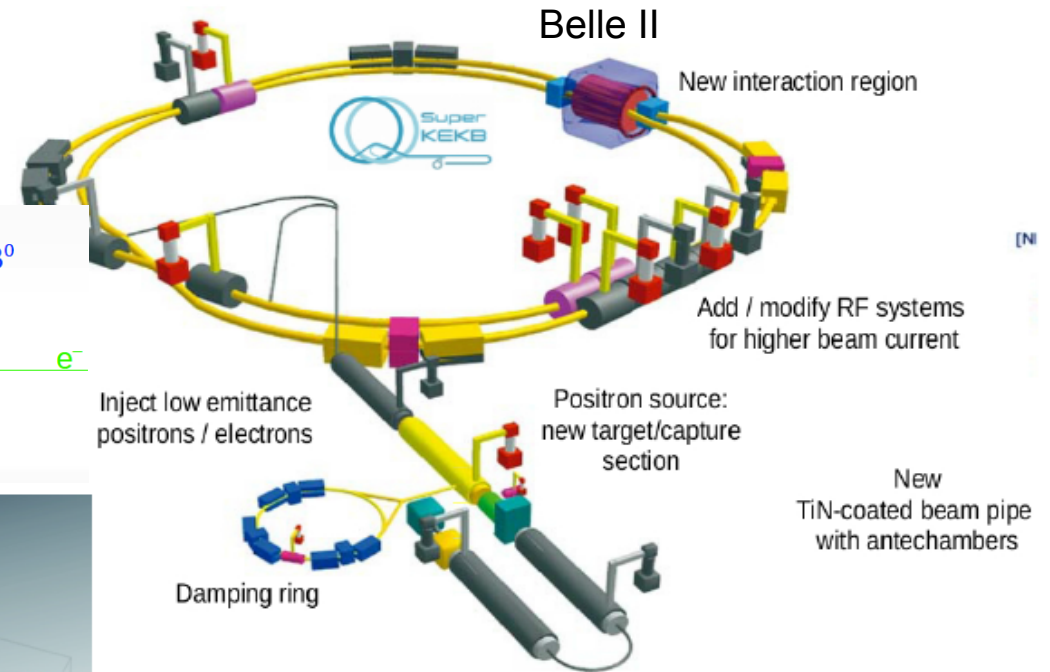
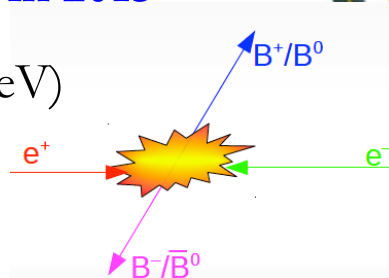


SuperKEKB



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- **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 ($\Upsilon(4S)$ resonance)



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

reduced boost $\sim 40-50 \times$ factor 20 factor 2-3

Luminosity
$$L = \frac{\gamma_{\pm}}{2 e r_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \frac{I_{\pm} \xi_{y_{\pm}}}{\beta_{y_{\pm}}} \frac{R_L}{R_{\xi_y}}$$
beam current
vertical beta function at IP

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



SuperKEKB



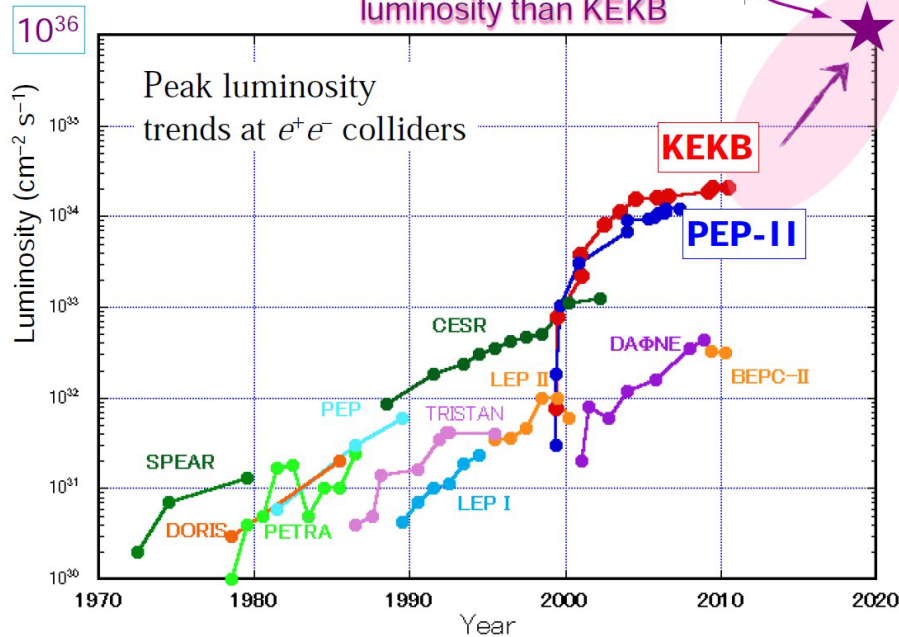
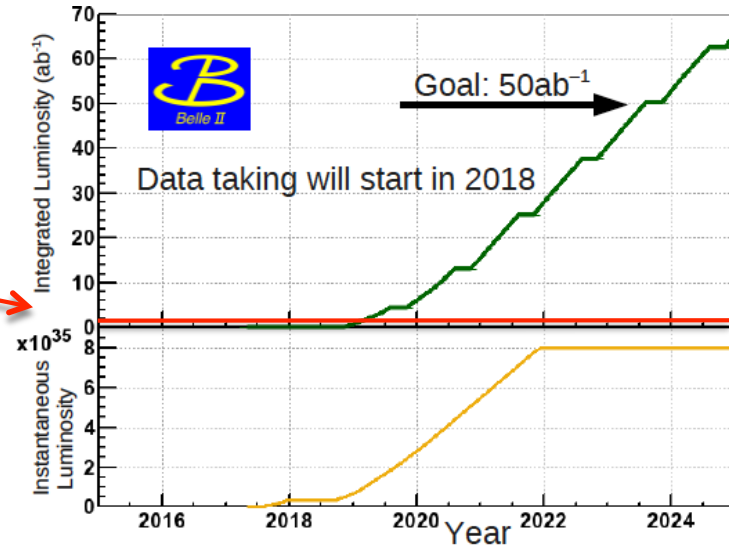
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Peak instantaneous luminosity: $\sim 0.8 \times 10^{36} \text{ cm}^{-2} \text{ s}^{-1}$

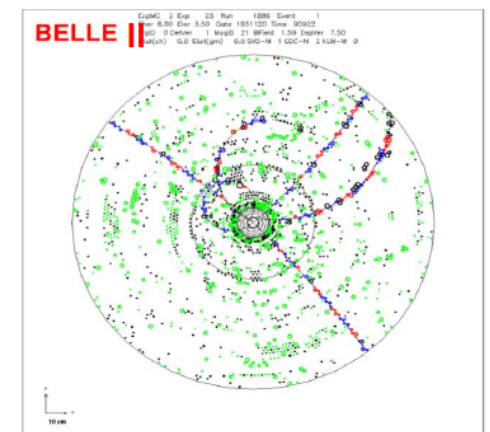
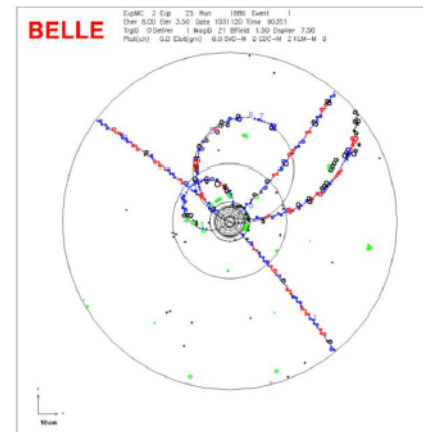
Belle II overall integrated luminosity: $\sim 50 \text{ ab}^{-1}$
 corresponding to 55×10^9 BB pairs (BaBar + Belle
 $\sim 1.5 \text{ ab}^{-1}$)

SuperKEKB is the intensity frontier

40x higher instantaneous
 luminosity than KEKB



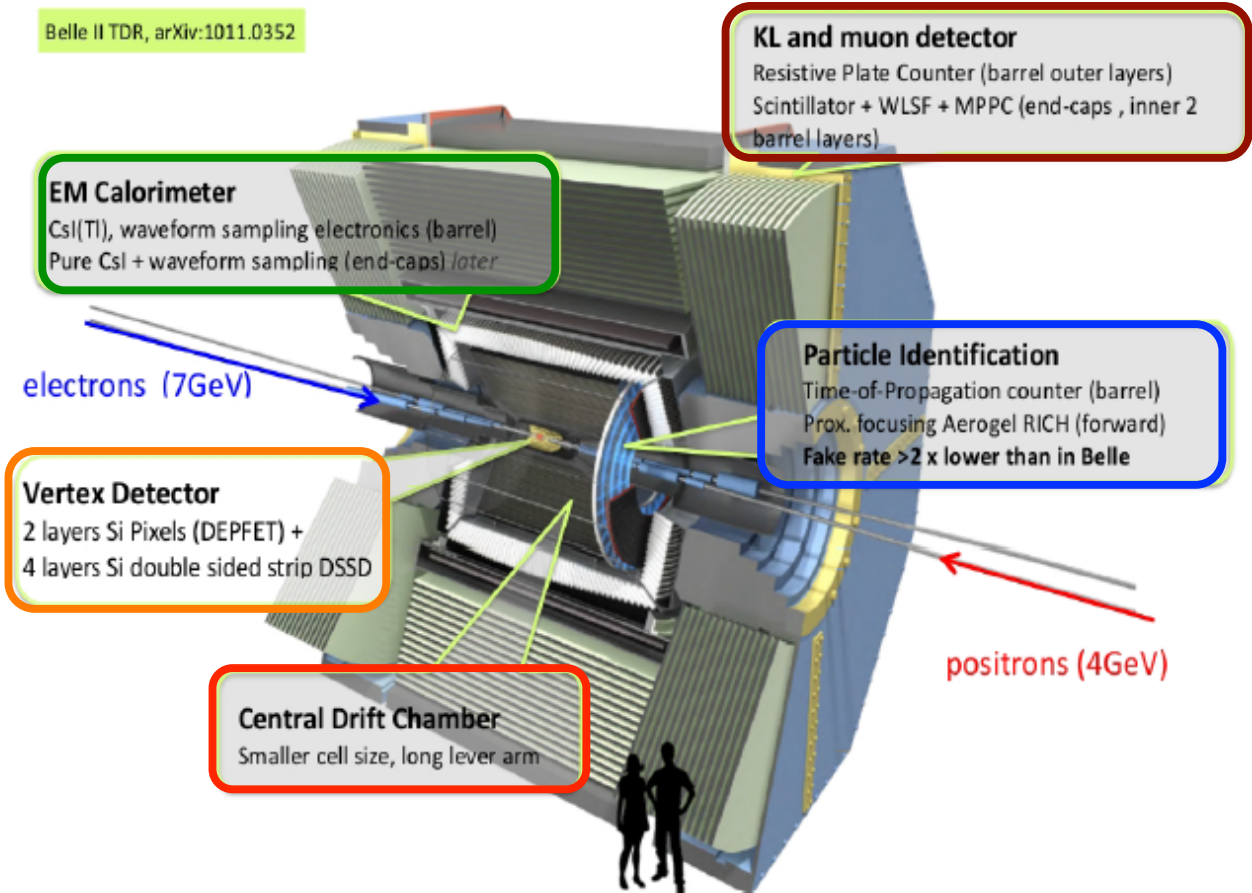
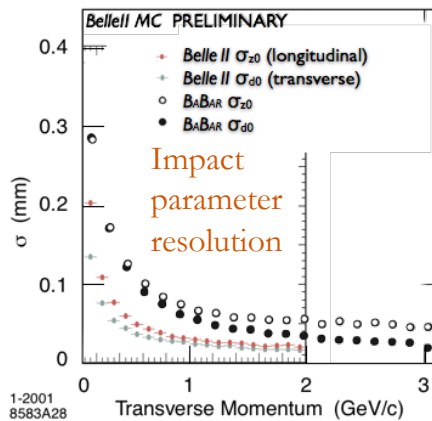
Higher beam background (10-20 x)



9/24/15

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 μ ID 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

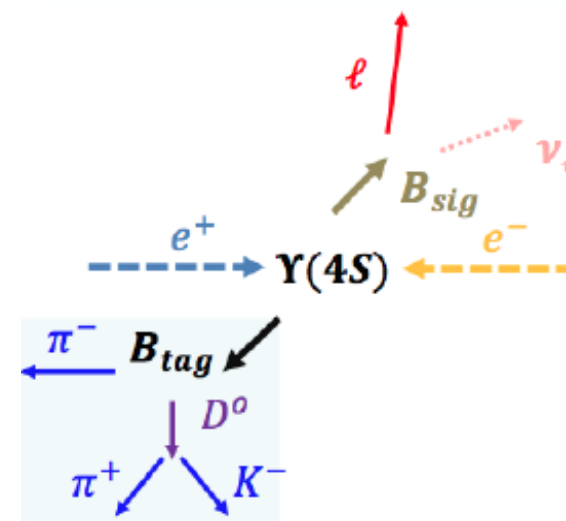


Unique capabilities of e^+e^- B factories - Belle II



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1. **Beam energy constraint** and adjusted for different resonances $\Upsilon(nS)$
2. **Clean experimental environment**, low track multiplicity and detector occupancy (w.r.t hadron collider)
 - high B, D, K, tau reconstruction efficiency
 - open trigger $\sim 99\%$ efficient
3. **Full reconstruction of one B (B_{tag})** constrains the 4-momentum of the other (B_{sig})
 - helpful in reconstruction of channels with missing energy
 - opposite side B tagging efficiency: $\sim 30\%$ ($\sim 2\%$ @LHCb)
4. **Excellent EM calorimetry performances**
 - high reconstruction efficiency of neutral final states





Physics program

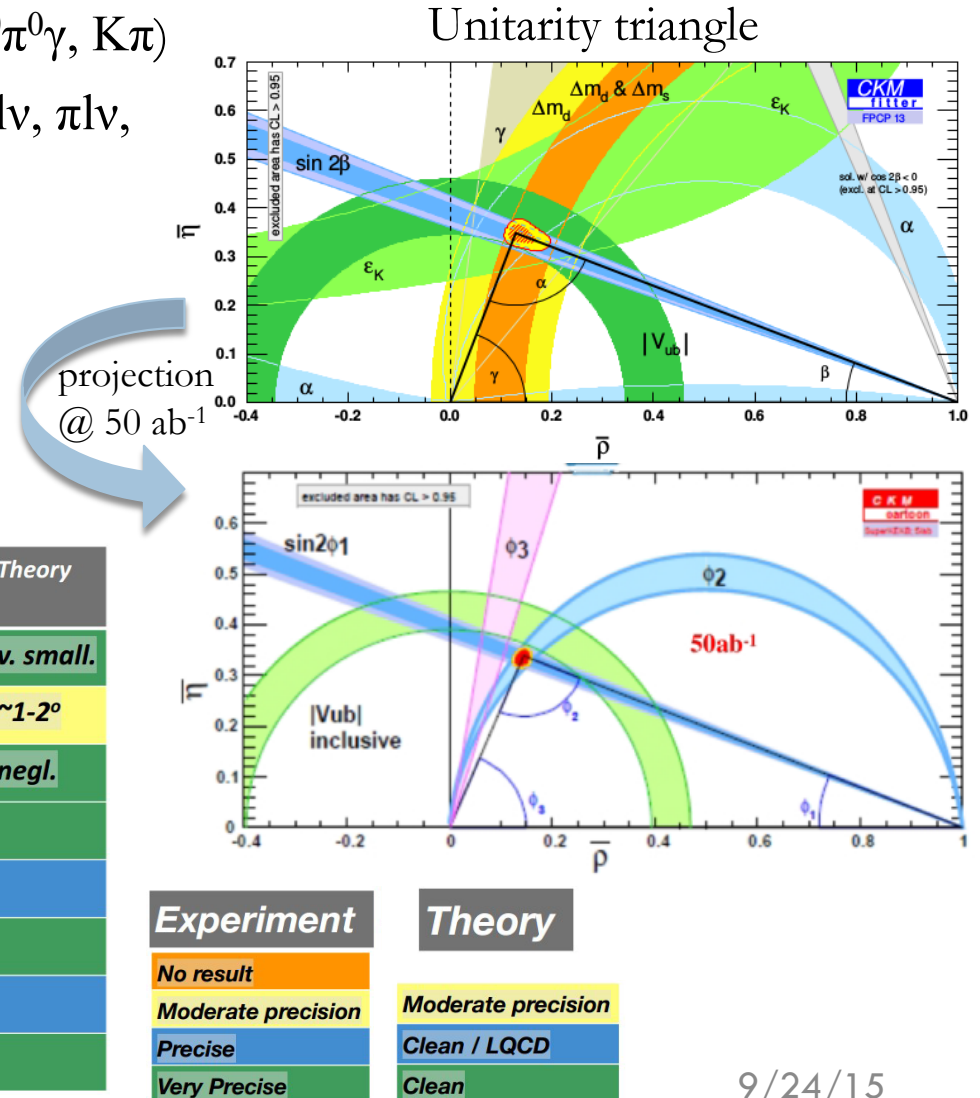


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- CPV in B decays, CKM angles ($B \rightarrow J/\psi K^0, K^0 \pi^0 \gamma, K\pi$)
- (Semi)leptonic B decays, CKM sides ($B \rightarrow D^{(*)} l \nu, \pi l \nu, \tau \nu, \mu \nu$)
- Rare B decays ($B \rightarrow K \nu \nu, X_s \gamma, X_s l l, \gamma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

	Belle	BaBar	Global Fit CKMfitter	LHCb Run-2	Belle II 50 ab^{-1}	LHCb Upgrade 50 fb^{-1}	Theory
$\varphi_1: ccs$	0.9°		0.9°	0.6°	0.3°	0.3°	v. small.
$\varphi_2: uud$	4° (WA)		2.1°		1°		~1-2°
$\varphi_3: DK$	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



9/24/15



Belle II – golden modes with 5 ab⁻¹

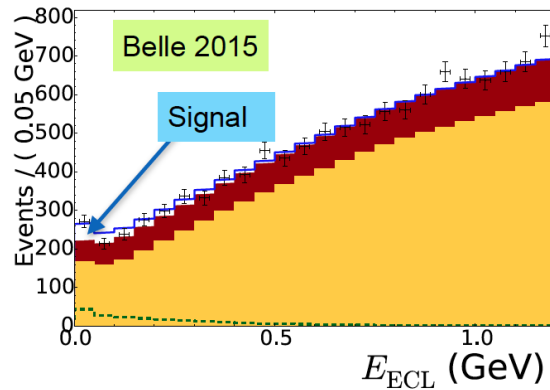
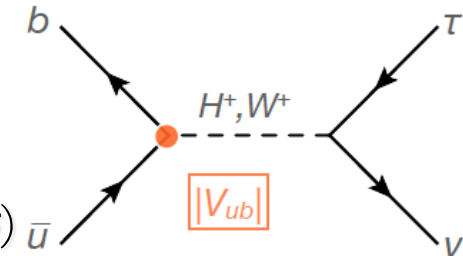


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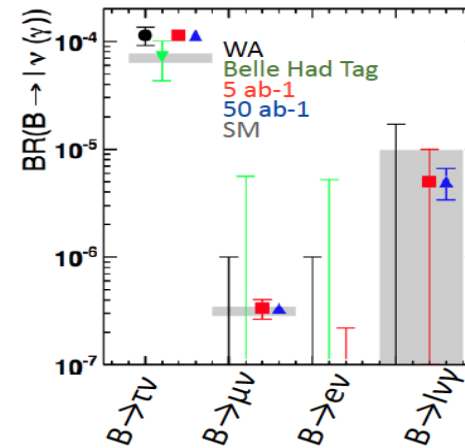
• B → τν

- 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 ($\sim 4.6 \sigma$)



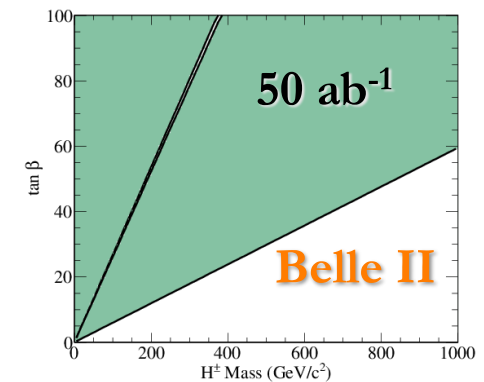
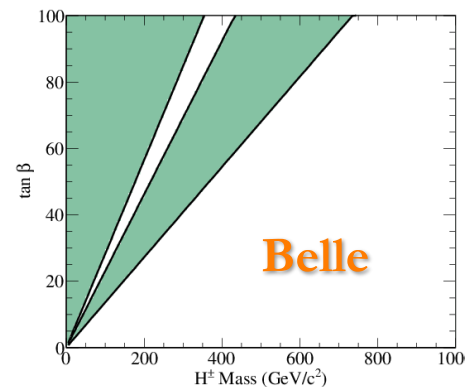
In agreement with SM expectations



Projections for B → lν(γ)

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

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





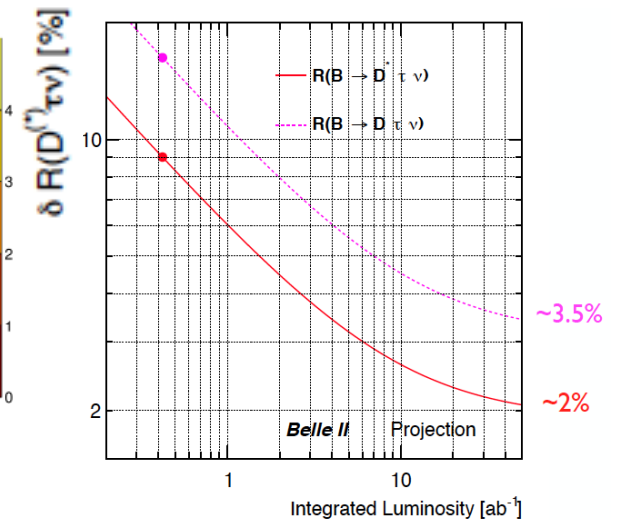
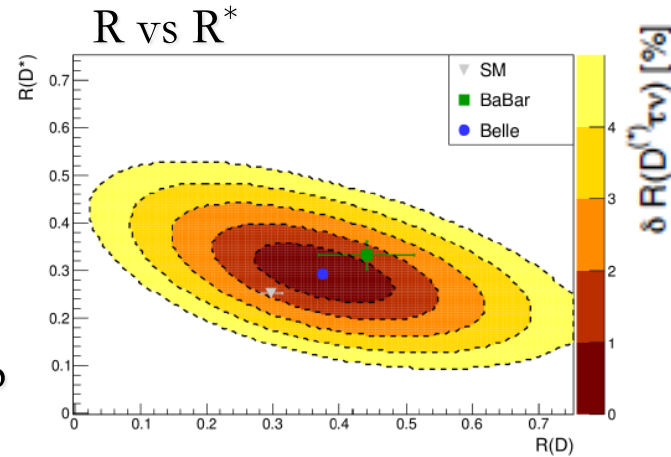
Belle II – golden modes with 5 ab⁻¹



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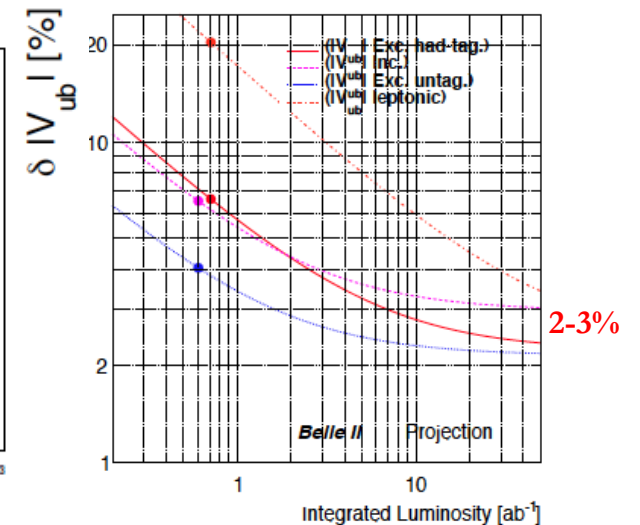
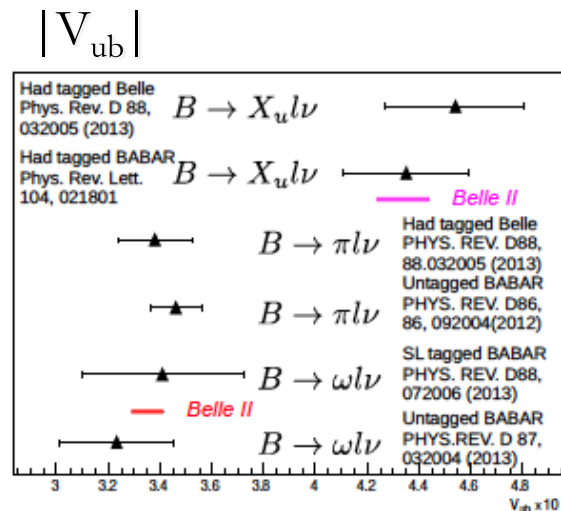
• $B \rightarrow D^{(*)} \tau \nu$

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



• $B \rightarrow X_u l \nu$

- Tension between inclusive and exclusive measurements of $|V_{ub}|$



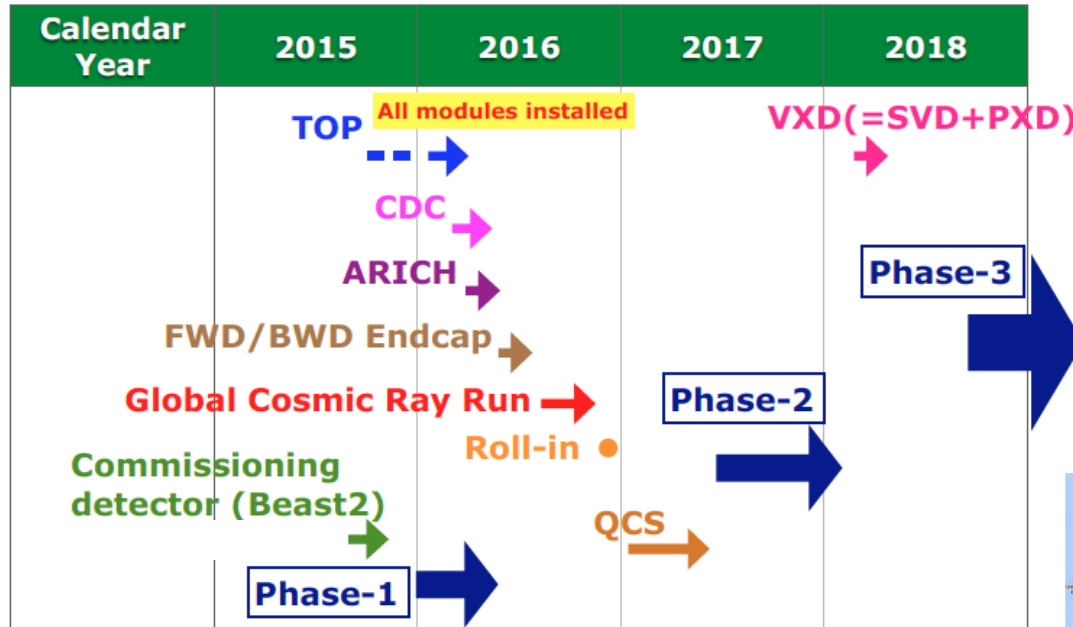
Projections for LFV in backup slides



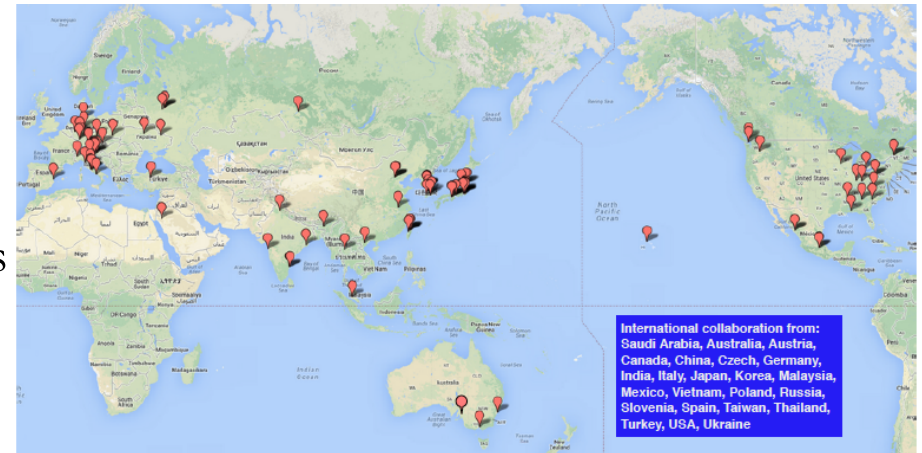
Belle II schedule: installation and commissioning



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BEAST (Beam Exorcism for A Stable 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



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- In the SuperKEKB B factory e^- and e^+ collisions will reach the unprecedented instantaneous luminosity of $\sim 10^{36} \text{cm}^{-2}\text{s}^{-1}$
- 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, 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 !

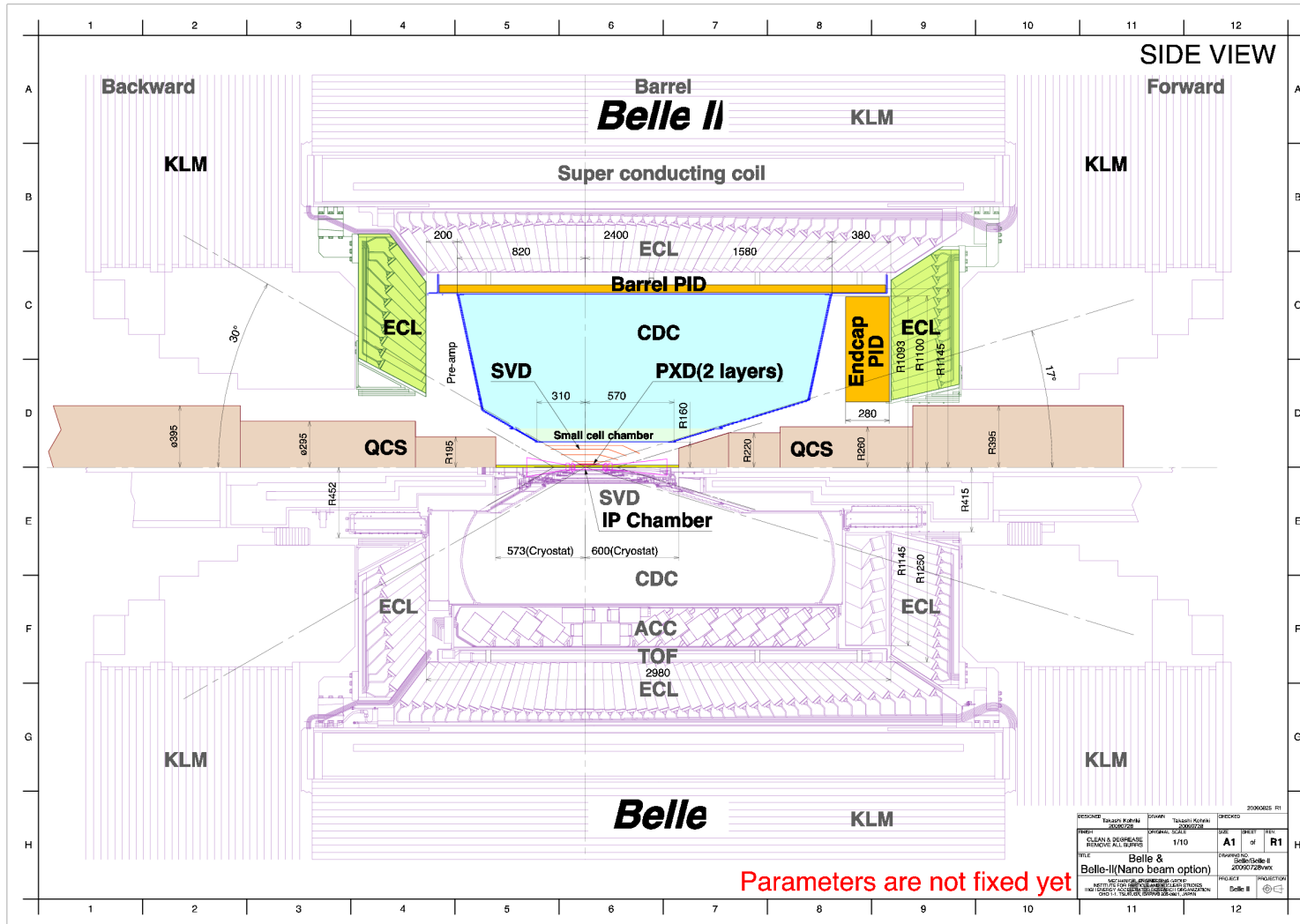


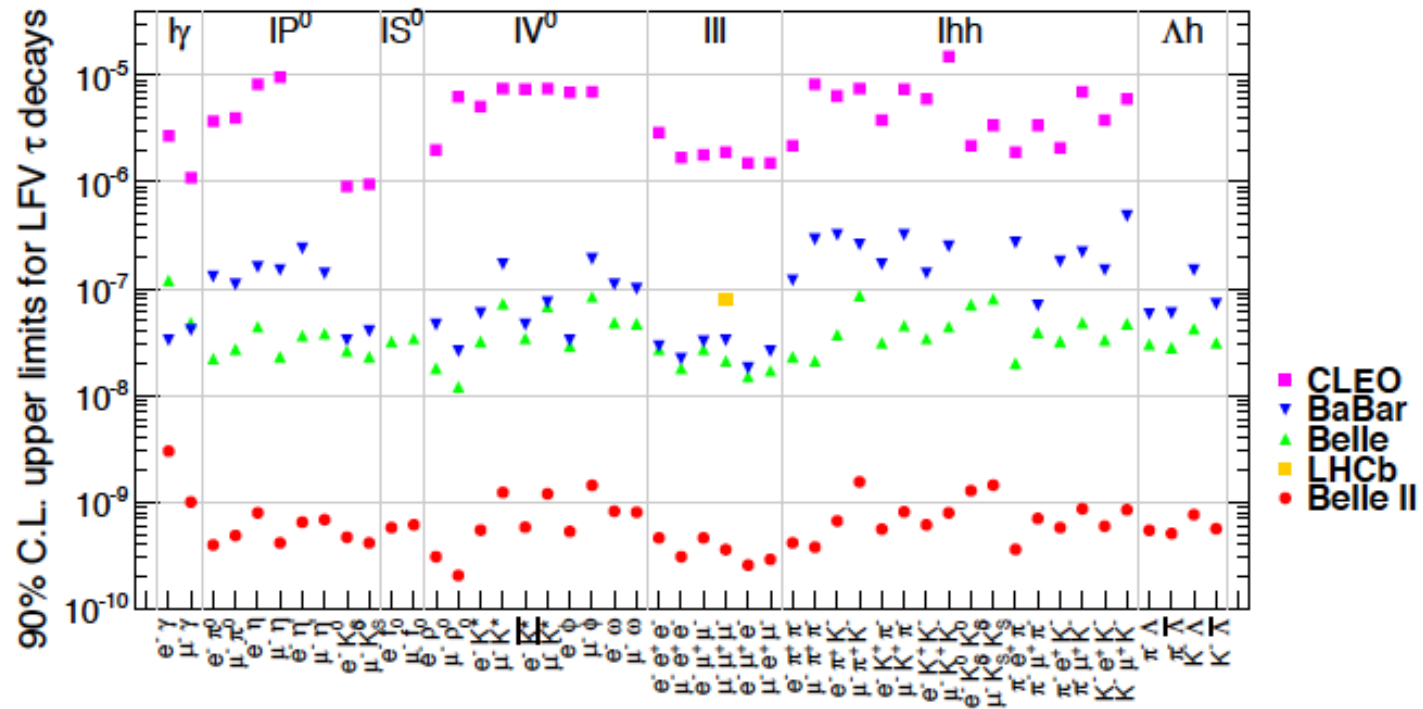
Backup





Belle II vs Belle







Physics prospects



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	Observables	Belle or LHCb*	Belle II		LHCb		Observables	Belle or LHCb*	Belle II		LHCb		
		(2014)	5 ab ⁻¹	50 ab ⁻¹	8 fb ⁻¹ (2018)	50 fb ⁻¹			(2014)	5 ab ⁻¹	50 ab ⁻¹	2018	50 fb ⁻¹
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012(0.9^\circ)$	0.4°	0.3°	0.6°	0.3°	Charm Rare	$B(D_s \rightarrow \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	α [°]	85 ± 4 (Belle+BaBar)	2	1				$B(D_s \rightarrow \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	γ [°] ($B \rightarrow D^{(*)}K^{(*)}$)	68 ± 14	6	1.5	4	1		$B(D^0 \rightarrow \gamma\gamma)$ [10 ⁻⁶]	< 1.5	30%	25%		
	$2\beta_s(B_s \rightarrow J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009		Charm CP	$A_{CP}(D^0 \rightarrow K^+K^-)$ [10 ⁻⁴]	$-32 \pm 21 \pm 9$	11	6	
Gluonic penguins	$S(B \rightarrow \phi K^0)$	$0.90_{-0.19}^{+0.09}$	0.053	0.018	0.2	0.04	$\Delta A_{CP}(D^0 \rightarrow K^+K^-)$ [10 ⁻³]		3.4*			0.5	0.1
	$S(B \rightarrow \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011			A_Γ [10 ⁻²]		0.22	0.1	0.03	0.02	0.005
	$S(B \rightarrow K_S^0 K_S^0 K_S^0)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033			$A_{CP}(D^0 \rightarrow \pi^0\pi^0)$ [10 ⁻²]		$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$\beta_s^{\text{eff}}(B_s \rightarrow \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03	$A_{CP}(D^0 \rightarrow K_S^0\pi^0)$ [10 ⁻²]	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03			
	$\beta_s^{\text{eff}}(B_s \rightarrow K^{*0}\bar{K}^{*0})$ [rad]	–			0.13	0.03	Charm Mixing	$x(D^0 \rightarrow K_S^0\pi^+\pi^-)$ [10 ⁻²]	$0.56 \pm 0.19 \pm_{0.13}^{0.07}$	0.14	0.11		
Direct CP in hadronic Decays	$A(B \rightarrow K^0\pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04				$y(D^0 \rightarrow K_S^0\pi^+\pi^-)$ [10 ⁻²]	$0.30 \pm 0.15 \pm_{0.08}^{0.05}$	0.08	0.05		
UT sides	$ V_{cb} $ incl.	$41.6 \cdot 10^{-3}(1 \pm 2.4\%)$	1.2%					$ q/p (D^0 \rightarrow K_S^0\pi^+\pi^-)$	$0.90 \pm_{0.15}^{0.16} \pm_{0.06}^{0.08}$	0.10	0.07		
	$ V_{cb} $ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\text{ex.}} \pm 2.7\%_{\text{th.}})$	1.8%	1.4%				$\phi(D^0 \rightarrow K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm_{5}^4$	6	4		
	$ V_{ub} $ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$	3.4%	3.0%			Tau	$\tau \rightarrow \mu\gamma$ [10 ⁻⁹]	< 45	< 14.7	< 4.7		
	$ V_{ub} $ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 10.8\%)$	4.7%	2.4%				$\tau \rightarrow e\gamma$ [10 ⁻⁹]	< 120	< 39	< 12		
Leptonic and Semi-tauonic	$B(B \rightarrow \tau\nu)$ [10 ⁻⁶]	96(1 ± 26%)	10%	5%				$\tau \rightarrow \mu\mu\mu$ [10 ⁻⁹]	< 21.0	< 3.0	< 0.3		
	$B(B \rightarrow \mu\nu)$ [10 ⁻⁶]	< 1.7	20%	7%									
	$R(B \rightarrow D\tau\nu)$ [Had. tag]	$0.440(1 \pm 16.5\%)^\dagger$	5.6%	3.4%									
	$R(B \rightarrow D^*\tau\nu)$ [Had. tag]	$0.332(1 \pm 9.0\%)^\dagger$	3.2%	2.1%	...								
Radiative	$B(B \rightarrow X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%									
	$A_{CP}(B \rightarrow X_{s,d}\gamma)$ [10 ⁻²]	$2.2 \pm 4.0 \pm 0.8$	1	0.5									
	$S(B \rightarrow K_S^0\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035									
	$2\beta_s^{\text{eff}}(B_s \rightarrow \phi\gamma)$	–			0.13	0.03							
	$S(B \rightarrow \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07									
	$B(B_s \rightarrow \gamma\gamma)$ [10 ⁻⁶]	< 8.7	0.3	–									
Electroweak penguins	$B(B \rightarrow K^{*+}\nu\bar{\nu})$ [10 ⁻⁶]	< 40	< 15	30%									
	$B(B \rightarrow K^+\nu\bar{\nu})$ [10 ⁻⁶]	< 55	< 21	30%									
	C_7/C_9 ($B \rightarrow X_s\ell\ell$)	~20%	10%	5%									
	$B(B_s \rightarrow \tau\tau)$ [10 ⁻³]	–	< 2	–									
	$B(B_s \rightarrow \mu\mu)$ [10 ⁻⁹]	$2.9_{-1.0}^{+1.1*}$			0.5	0.2							