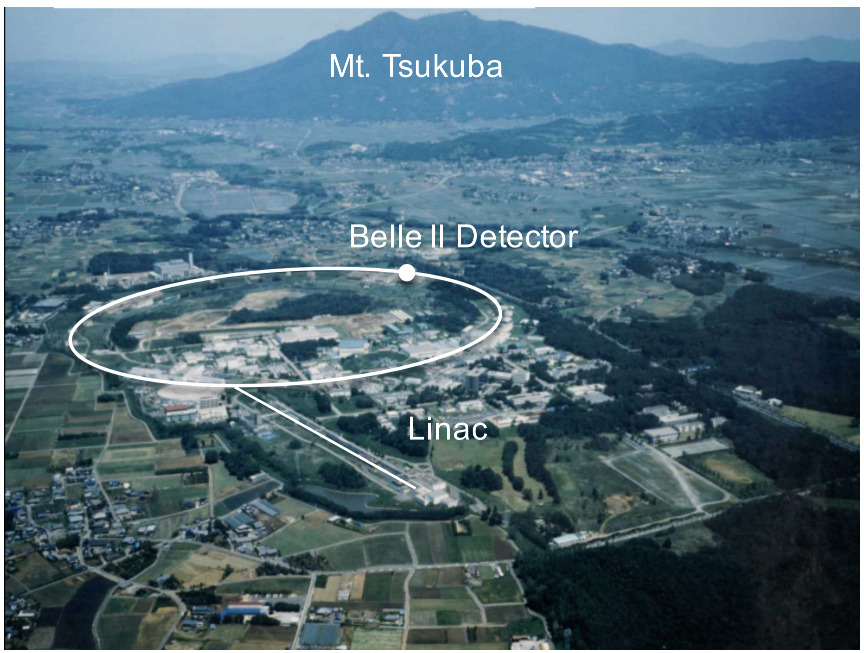
The Belle II experiment: status and physics prospects

Mario Merola (INFN Napoli)

On behalf of the Belle II Collaboration

PASCOS 2017, 19-23 June, Madrid



Physics Motivations

SM supported by experimental evidence at high level of precision, nonetheless tensions do exist

Open issues in HEP, related to flavour

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

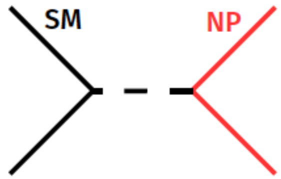
- **Quark and lepton hierarchy (mass and flavour):** GUTs (SUSY) ?

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

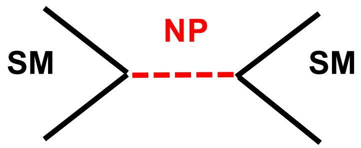
- **Finite neutrino masses:** (charged) lepton flavour violation (tau) ?

Search for new physics (NP)

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



- **Intensity frontier**: new virtual particles in loops/trees transitions, deviation from SM expectations (B factories, LHCb)



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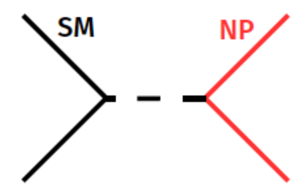

Belle II

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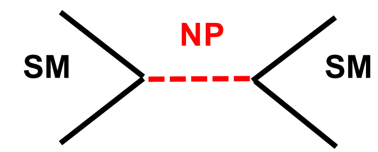

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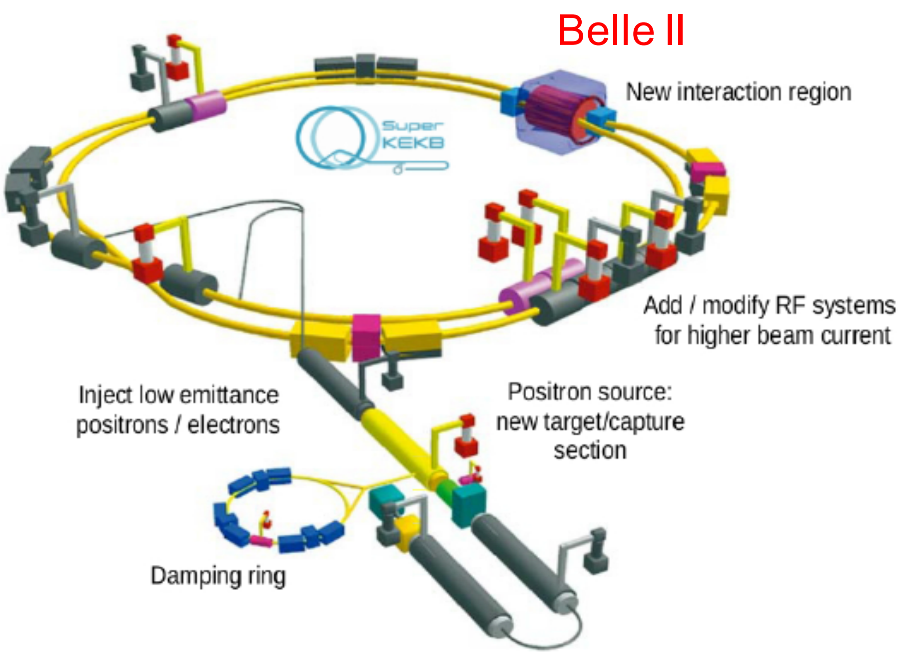
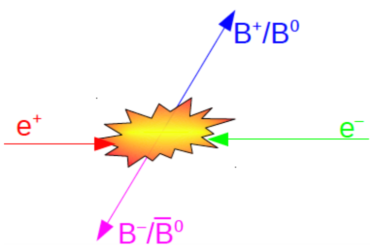
SuperKEKB

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





10^{10} BB pairs per year

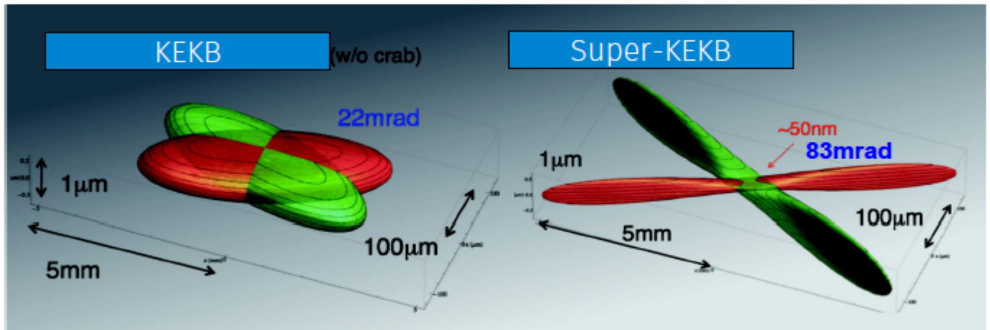
Expected data sample @ full luminosity

Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$ ϒ(4S)	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

assuming 100% running at each energy

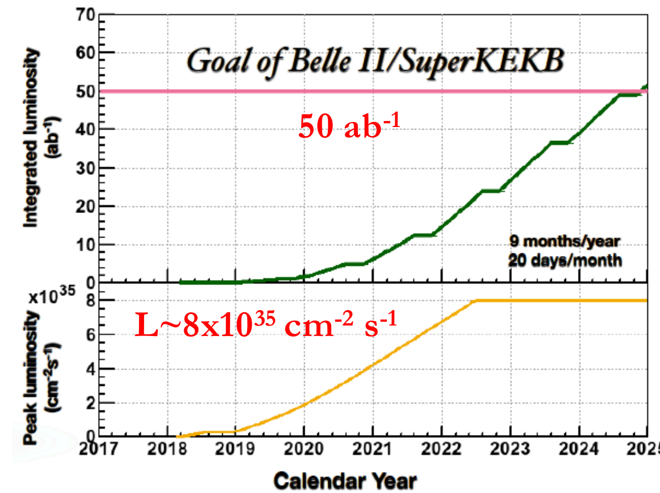
From KEKB to SuperKEKB

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



	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 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}

factor 20 factor 2-3



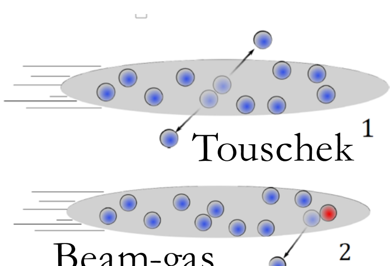
Factor ~ 40-50 in the luminosity

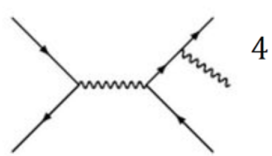
beam current

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

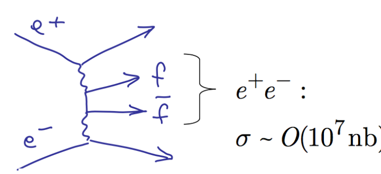
vertical beta function at IP

Higher backgrounds





Radiative Bhabha



2-photon-processes

- Radiation damage
- Occupancy in inner detectors
- Fake hits and pile-up

From Belle to Belle II

Belle Upgrade:

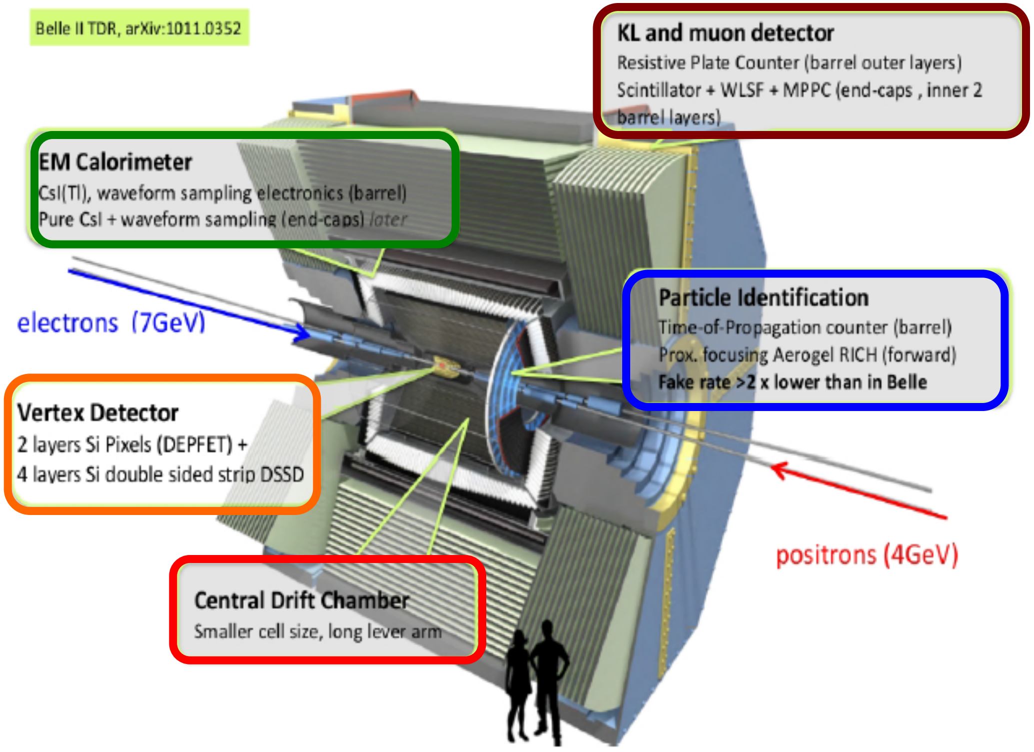
- **Extended VXD region** (added pixel detector)

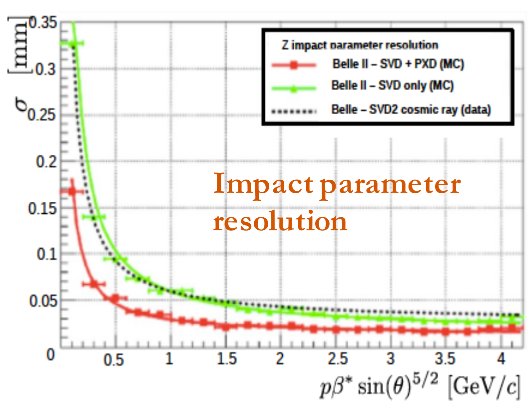
- **Extended Drift Chamber region**

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

- **New PID detector** in the forward region

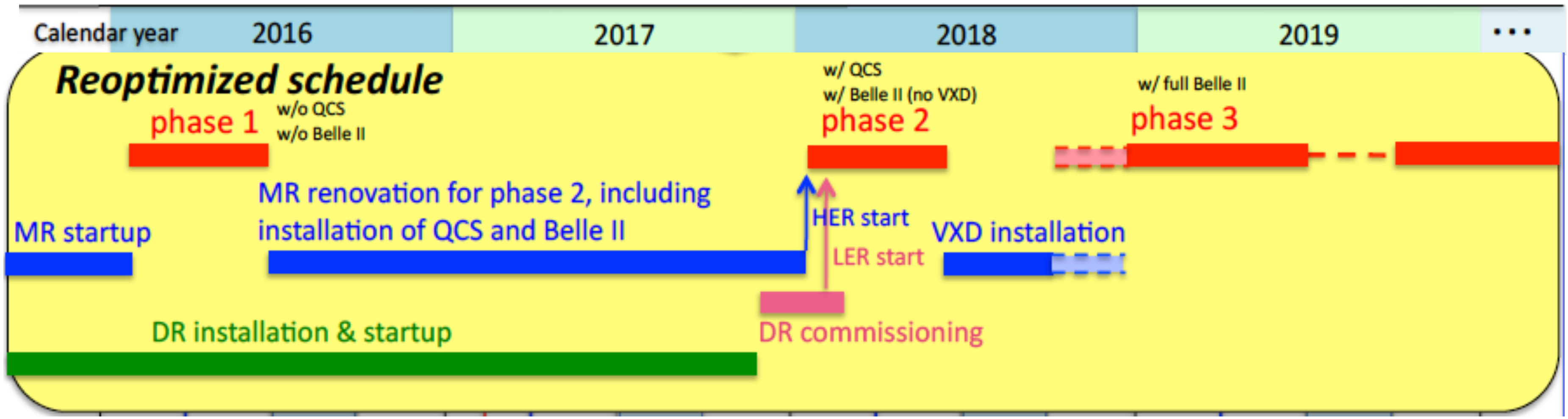
- **High efficiency KLM detector** (some RPCs layers substituted with scintillators to resist neutron background)





- improved IP and secondary vertex resolution
- better K/π separation and flavor tagging
- machine background rejection
- higher K_S, π^0 and slow pions reconstruction efficiency

Belle II schedule



Phase 1 (2016): beams, no collisions, cosmics

Phase 2 (2018): collisions, complete Belle II detector except for Vertex Detector

Phase 3 - Full physics (end 2018-2024): full Belle II detector

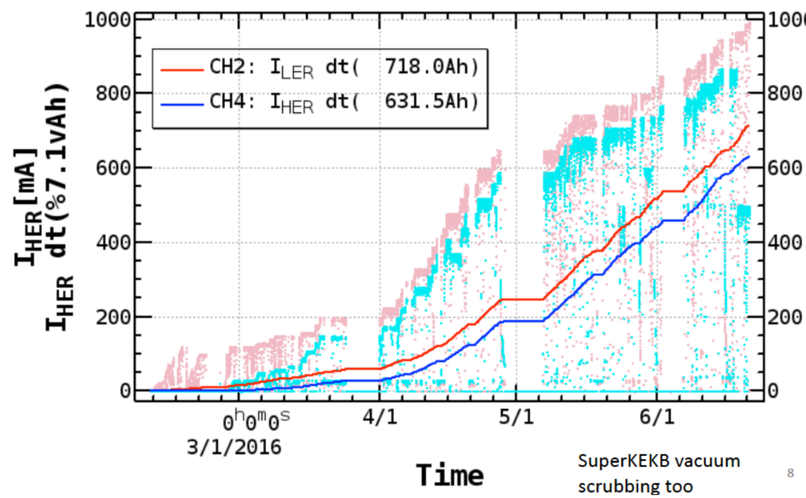
BEAST (**B**eam **E**xorcism for **A** **ST**able experiment): commissioning detector (during Phase 1 and 2), aimed at studying beam induced backgrounds near the IP

- w/o collisions: Touschek, beam-gas
- w collisions: rad Bhabha, two photons (very low momentum e^+e^-)

Important milestones in 2016/2017

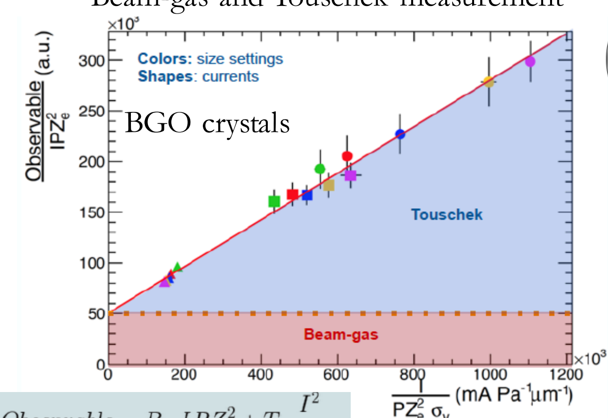
- First beams circulating in SuperKEKB at end of Feb 2016
- June 2016: 1 A current achieved
- First beam background measurements by BEAST
- April 2017: Belle II roll-in

June 21: LER beam current exceeded 1 Ampere



SuperKEKB vacuum scrubbing too

Beam-gas and Touschek measurement



$$Observable = B \cdot IPZ_e^2 + T \cdot \frac{I^2}{\sigma_y}$$

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 57 NUMBER 5 JUNE 2017

FACILITIES

Belle II rolls in

On 11 April, the Belle II detector at the KEK laboratory in Japan was successfully "rolled-in" to the collision point of the upgraded SuperKEKB accelerator, marking an important milestone for the international B-physics community. The Belle II experiment is an international collaboration hosted by KEK in Tsukuba, Japan, with related physics goals to those of the LHCb experiment at CERN but in the pristine environment of electron–positron collisions. It will analyse copious quantities of B mesons to study CP violation and signs of physics beyond the Standard Model (*CERN Courier* September 2016 p32).

"Roll-in" involves moving the entire 8 m-tall, 1400 tonne Belle II detector system from its assembly area to the beam-collision point 13 m away. The detector is now integrated with SuperKEKB and all its seven subdetectors, except for the innermost vertex detector, are in place. The next step is to install the complex focusing magnets around the Belle II interaction point. SuperKEKB achieved its first turns in February 2016, with operation of the main rings scheduled for early spring and phase-III "physics" operation by the end of 2018.

Compared to the previous Belle experiment, and thanks to major upgrades made to the former KEKB collider, Belle II will allow much larger data samples to be collected with much improved precision. "After six years of gruelling work with many unexpected twists and turns, it was a moving and gratifying experience for everyone on the team to watch the Belle II detector move to the interaction point," says Belle II spokesperson Tom Browder. "Flavour physics is now the focus of much attention and interest in the community and Belle II will play a critical role in the years to come."

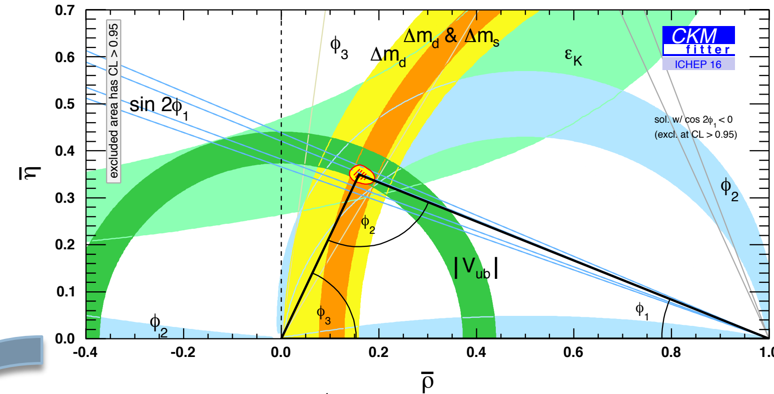
KEK

The Belle II detector is now in place at the SuperKEKB facility in Japan.

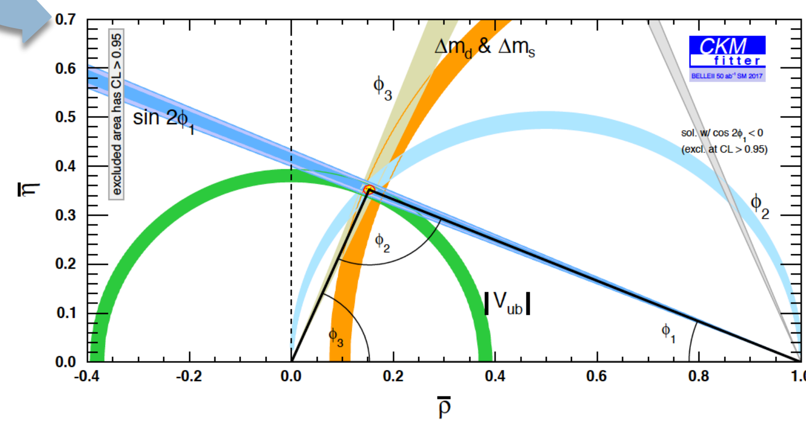
Physics program

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

Unitarity Triangle



projection @ 50 ab^{-1}



Observables	Expected exp. uncertainty	Facility (2025)
UT angles & sides		
ϕ_1 [°]	0.4	Belle II
ϕ_2 [°]	1.0	Belle II
ϕ_3 [°]	1.0	Belle II/LHCb
$\|V_{cb}\|$ incl.	1%	Belle II
$\|V_{cb}\|$ excl.	1.5%	Belle II
$\|V_{ub}\|$ incl.	3%	Belle II
$\|V_{ub}\|$ excl.	2%	Belle II/LHCb

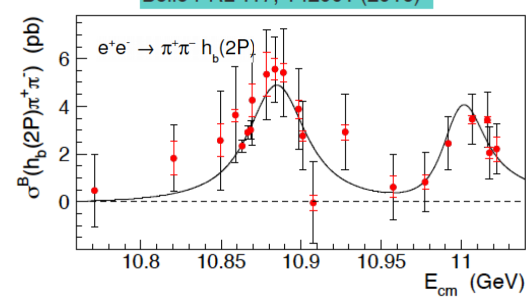
Further on Belle2 / LHCb projections in the backup

Highlights physics measurement perspectives

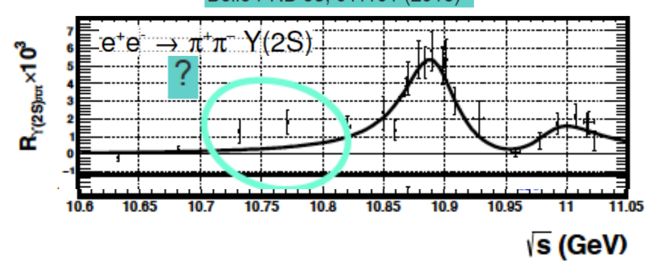
Phase II physics: quarkonium and dark sector

- **Collision energy scan** and data collected mainly at Υ(4S) peak (20-40 fb^{-1}): study of quarkonium transitions
- Unique dataset at Υ(6S) possibly - strong interaction studies
- Investigate **exotic meson states** (tetraquark, glueballs, hybrids)

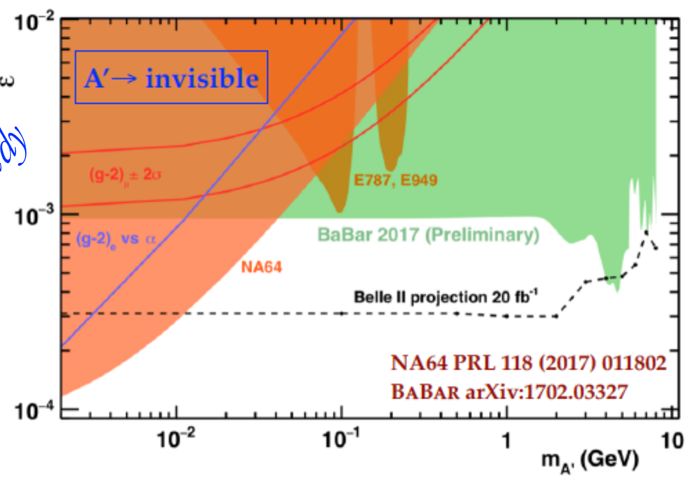
Belle PRL 117, 142001 (2016)



Belle PRD 93, 011101 (2016)

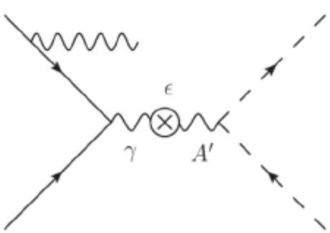


Belle II Full Simulation study



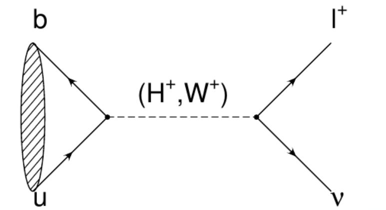
NA64 PRL 118 (2017) 011802
BABAR arXiv:1702.03327

- **Dark photon:** A’ ⟶ invisible + γ
- Challenging single photon triggers



Golden modes with 5 ab^{-1}: leptonic B decays

- **$B\to l\nu$:** helicity suppressed decays



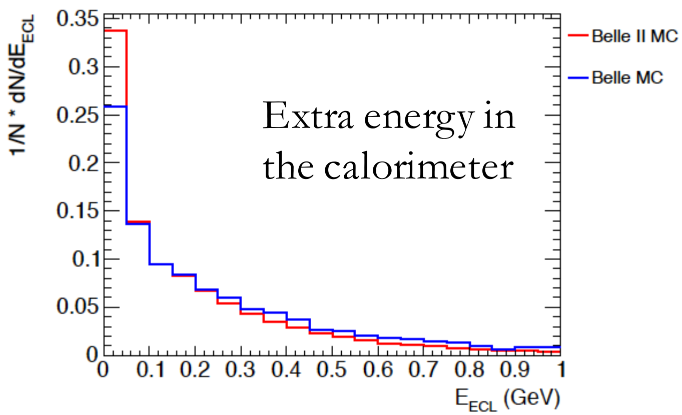
- NP, e.g. charged Higgs, enhances the branching ratio

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

- **$B\to\tau\nu$**
  - evidence at Belle and BaBar (Belle most recent ~4.6 σ level, PRD **92** 051102)
  - Belle II analysis
    - Observation at ~3 ab^{-1}
    - 5-6% uncertainty at 50 ab^{-1}
    - No E_{ECL} resolution degradation due to beam background

	Integrated Luminosity (ab^{-1})	1	5	50
hadronic tag	statistical uncertainty (%)	29.2	13.0	4.1
	systematic uncertainty (%)	12.6	6.8	4.6
	total uncertainty (%)	31.6	14.7	6.2
semileptonic tag	statistical uncertainty (%)	19.0	8.5	2.7
	systematic uncertainty (%)	17.9	8.7	4.5
	total uncertainty (%)	26.1	12.2	5.3

Projections at 1, 5 and 50 ab^{-1}

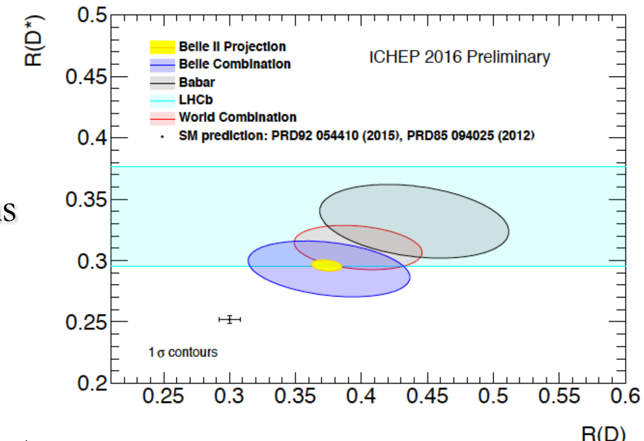


Belle II Full Simulation study

Golden modes with 5 ab^{-1}: semileptonic B decays

- **$B \to D^{(*)}\tau\nu$**
  - Measurement of $R^{(*)}$ = $BR(B \to D^{(*)}\tau\nu)$ / $BR(B \to D^{(*)}l\nu)$
  - Sensitive to charged Higgs bosons
  - **Measurements combination: 4.1 σ** far from the SM (including recent LHCb)
  - Belle II @ 50 ab^{-1}: 2-3% uncertainty

R(D) vs R(D*)



Most recent LHCb measurement of R(D*)

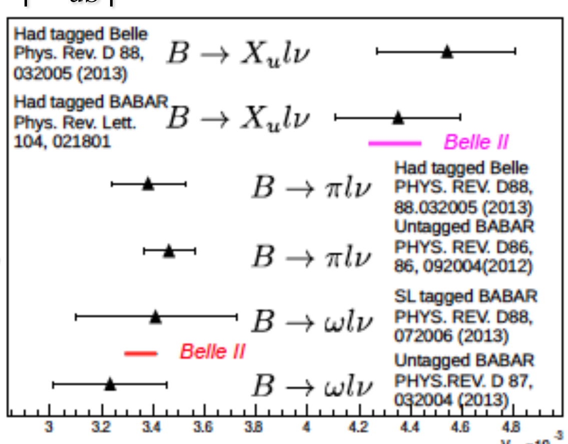
R(D*)=0.285±0.019(stat)±0.025(syst)

(LHCb-paper-2017-017 in preparation)

R(D*) average **0.306 ± 0.027**

- **$B \to X_u l\nu$**
  - Tension between inclusive and exclusive $|V_{ub}|$ measurements
  - Belle II @ 50 ab^{-1}: ~3% (inclusive) / ~1% (exclusive π l ν) uncertainty

$|V_{ub}|$



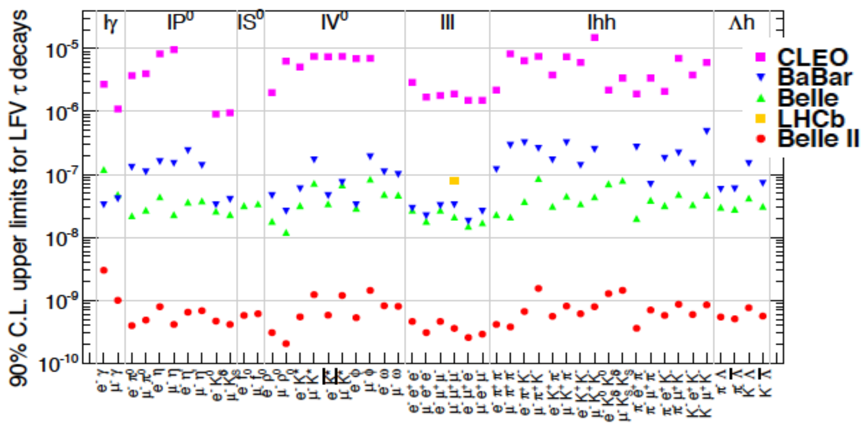
B → π l ν projections

$\mathcal{L}$ [ab^{-1}]		σ_B (stat±sys)	$\sigma_{LQCD}^{forecast}$	$\sigma_{V_{ub}}$
1	tagged	3.6 ± 4.4	current	6.2
	untagged	1.3 ± 3.6		3.6
5		1.6 ± 2.7	in 5 yrs	3.2
		0.6 ± 2.2		2.1
10		1.2 ± 2.4	in 5 yrs	2.7
		0.4 ± 1.9		1.9
50		0.5 ± 2.1	in 10 yrs	1.7
		0.2 ± 1.7		1.3

Belle II Full Simulation study

LFV and electroweak penguins

- LFV in tau decays is a **clear test of the SM**: expected BR $\sim 10^{-25}$ (**NP predicts BR up to 10^{-8}**)



- τ decays **studied at B-factories**
- precision improvement by **2 orders of magnitude**

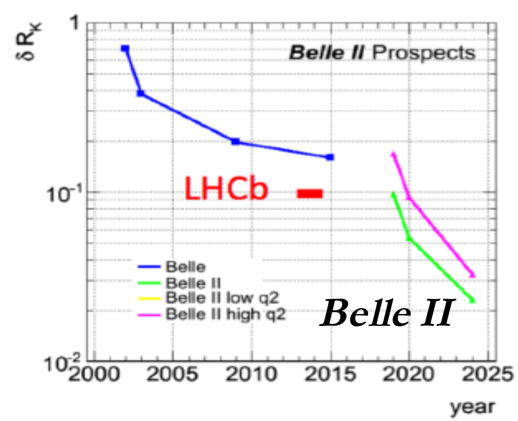
$B \rightarrow K^{(*)}\nu\nu$ (BR $\sim 10^{-6}$) not observed yet

Observables	Belle II 50 ab^{-1}
$\mathcal{B}(B^+ \to K^+ \nu\bar{\nu})$	12%
$\mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu})$	11%

NP contributions (BR x50):

- non standard Z-couplings (SUSY)
- new missing energy sources (DM, extra dim.)

$B \rightarrow K^{(*)}ll$: test of lepton universality



$$\mathcal{R}_K = \frac{\mathcal{B}(B \to K\mu\mu)}{\mathcal{B}(B \to Kee)} \sim 1$$

LHCb: 2÷2.5 σ deviation from SM

Belle II Full Simulation study

Conclusions

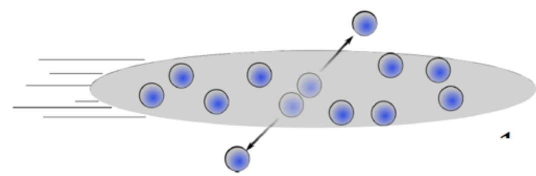
- In the SuperKEKB B factory e^- and e^+ collisions will reach the unprecedented instantaneous luminosity of $8 \times 10^{35} cm^{-2} s^{-1}$
- The upgraded Belle II detector will face the higher level of backgrounds with improved tracking and PID
- The detector commissioning has started in 2016 (phase I, no collisions) with first collisions expected in February 2018 (phase II, no VXD) and full physics program at the end of 2018 (phase III, full detector)
- 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 $50\ ab^{-1}$ collected by 2024 Belle II will be able to shed light on the physics beyond the Standard Model
- Belle II Physics Book to be published in 2017

Thanks !

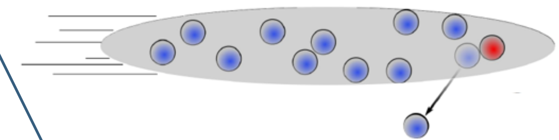
Backup

BEAST commissioning detector

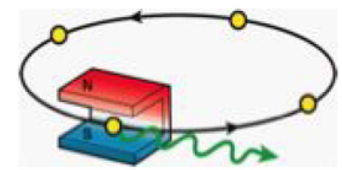
- Among the technical challenges at Belle2, there are beam backgrounds
- In Belle/KEKB, unexpected backgrounds burnt a hole in the beam pipe and damaged inner detectors
- Especially dangerous at SuperKEKB:
  - Temporary damage or faults in electronics
  - Obscure physics processes
  - Fake interesting physics signals
  - Rejecting fake signals also lowers efficiency
- This is where BEAST comes in…



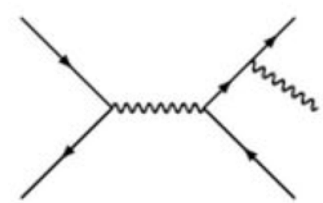
Touschek scattering



Beam-gas scattering



Synchroton radiation



Radiative Bhabha

BEAST Commissioning Detectors

Primary detectors in BEAST II* for phase I:

System	Institution	#	Unique measurement
PIN diodes	Wayne St.	64	Neutral vs. charged dose rate
Time Projection Chambers	U. Hawaii	4	Fast neutron flux and tracking
Diamonds	INFN Trieste	4	Beam abort
He3 tubes	U. Victoria	4	Thermal neutron rate
CsI(Tl) crystals	U. Victoria	6	EM energy spectrum, injection backgrounds
CsI+LYSO crystals	INFN Frascati	6+6	
BGO crystals	National Taiwan U.	8	Luminosity and EM rate
CLAWS plastic scintillators	MPI Munich	8	Fast injection backgrounds

Belle II Physics Book

- B2TiP Report (600p)
  - https://confluence.desy.de/display/BI/B2TiP+ReportStatus
- To be published in PTEP / Oxford University Press & printed.
  - Belle II Detector, Simulation, Reconstruction, Analysis tools
  - Physics working groups
  - New physics prospects and global fit code

PTEP
Prog. Theor. Exp. Phys. **2015**, 00000 (319 pages)
DOI: 10.1093/ptep/0000000000

The Belle II Physics Book

Emi Kou[1], Phillip Urquijo[2], The Belle II collaboration[3], and The B2TiP theory community[4]

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The report of the Belle II Theory Interface Platform is presented in this document.

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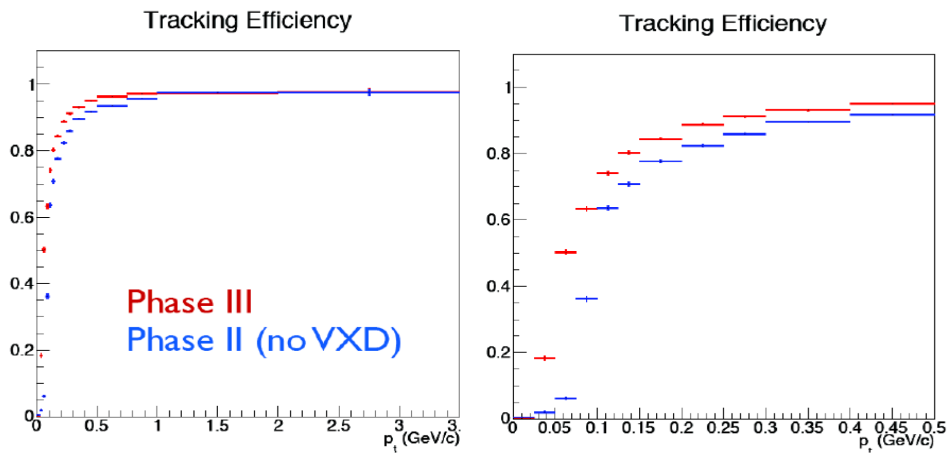
Phase II

Tracking without VXD



What can we do with phase II data ?

- Background studies
- Detector and trigger performance studies
- Simulation validation
- Exercising of calibration and alignment procedures
- Reconstruction algorithm tuning
- Physics measurements

Belle II Detector

Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	impact parameter resolution $\sigma_{z_0} \sim 20\ \mu$m (PXD and SVD)
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\leq z \leq$ 159 cm	14 k	$\sigma_{r\phi} = 100\ \mu$m, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}$ (with SVD)

component	background	generic $B\overline{B}$
PXD	10000 (580)*	23
SVD	284 (134)	108
CDC	654	810
TOP	150	205
ARICH	191	188
ECL	3470	510
BKLM	484	33
EKLM	142	34

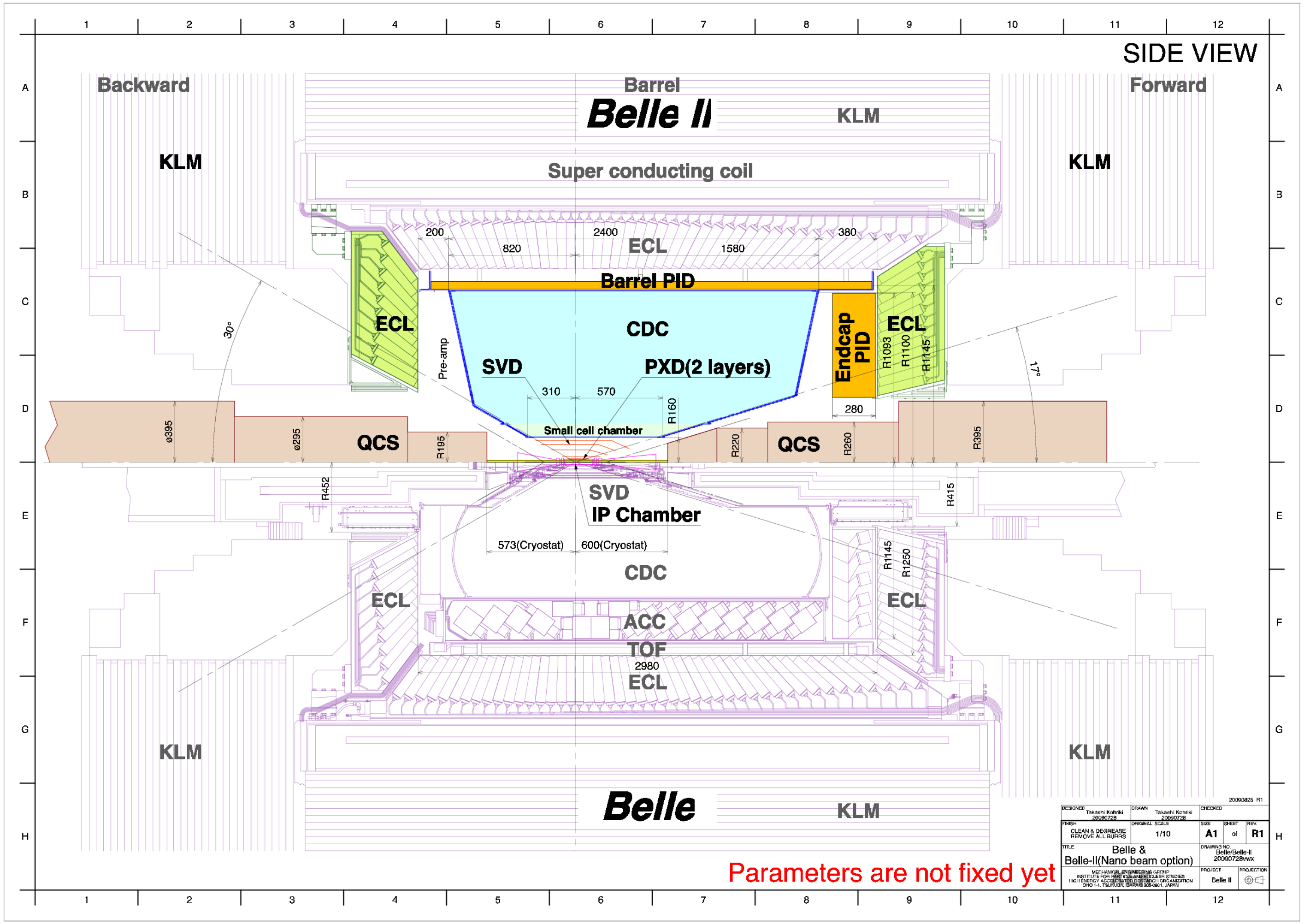
* in parentheses numbers without 2-γ QED

Total number of hits per event in each subdetector

Belle II / LHCb

Observables	Expected th. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	Belle II/LHCb
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb
CPV			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***	20%	Belle II
$R(B \to K^*\ell\ell)$	**	0.03	Belle II/LHCb

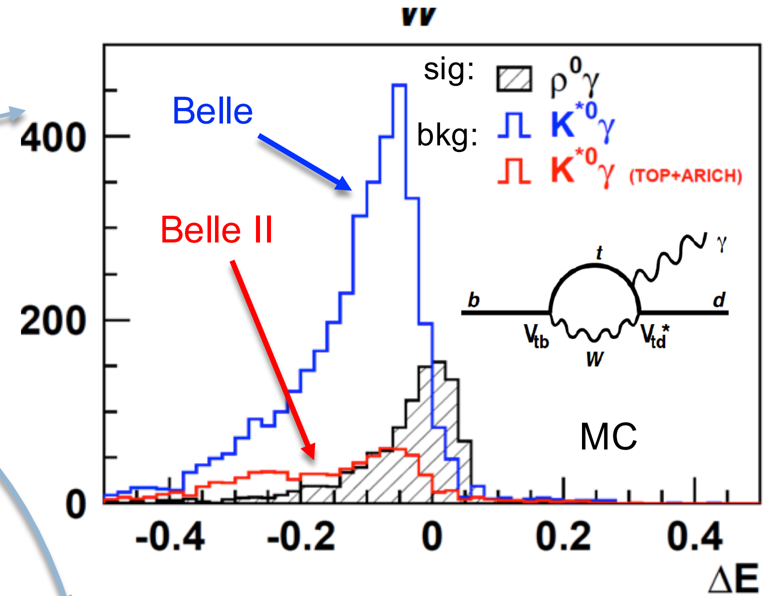
Belle II vs Belle

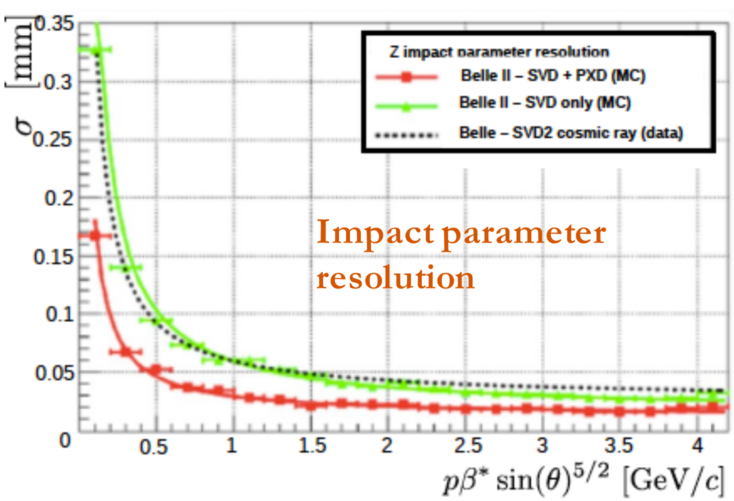


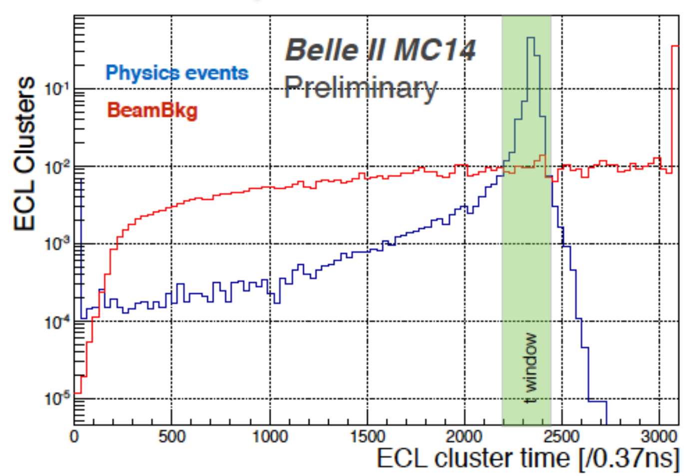
From Belle to Belle II

Improvements:

- IP and secondary vertex resolution
- K/π separation and flavour tagging
- machine background rejection
- K_S, π^0 and slow pions reconstruction efficiency





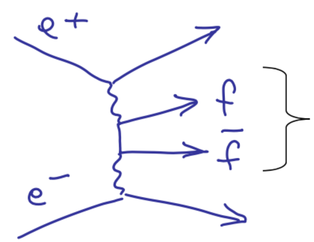


Physics processes cross sections at Belle II

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{lab} \geq 17°$)	44	350 [a]
$\gamma\gamma$ ($\theta_{lab} \geq 17°$)	2.4	19 [a]
2γ processes [b]	~ 80	~ 15000
Total	~ 130	~ 20000

[a] The rate is pre-scaled by a factor of 1/100.

[b] $\theta_{lab} \geq 17°$, $p_t \geq 0.1\text{GeV}/c$



e^+e^- : $\sigma \sim O(10^7\,\text{nb})$

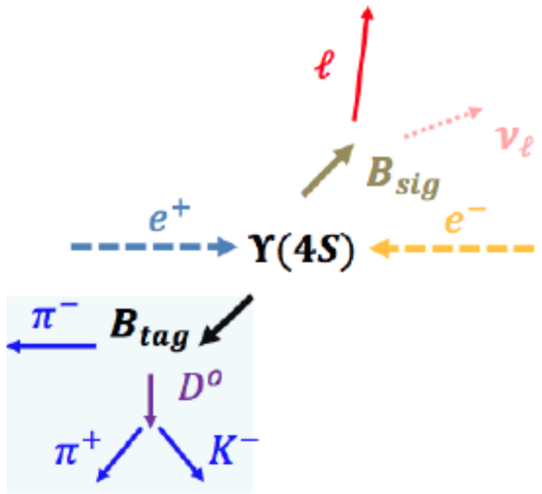
2-photon-processes

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 reconstruction efficiency
   - open trigger ~99% efficient

1. **Full reconstruction of one B (B_{tag})** constraints the 4-momentum of the other (B_{sig})
   - helpful in reconstruction of channels with missing energy



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

Early physics

Early Physics Topics on Belle II

Energy	Outcome	Lumi (fb^{-1})	Comments
$\Upsilon(1S)$ On	N/A	60+	-No interest identified for Phase 2 -Low energy
$\Upsilon(2S)$ On	N/A	200	-No interest identified for Phase 2
$\Upsilon(1D)$ Scan	Particle discovery	10-20	-Better Study needed for $\Upsilon(1D_2)$ -$\Upsilon(1D_{1,3})$ to be discovered
$\Upsilon(3S)$ On	Many topics	200+	-Known resonance -High luminosity needed: Phase 3
$\Upsilon(3S)$ Scan	Precision QED	~10	-Understanding of beam conditions needed
$\Upsilon(2D)$ Scan	Particle discovery	10-20	-$\Upsilon(2D)$ to be discovered
$\Upsilon(5S)$+ Scan	Particle discovery?	10+?	-Energy to be determined
Y(6S) On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required

Physics prospects: Belle II vs LHCb

Observables	Expected th. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	Belle II/LHCb
$\lvert V_{cb}\rvert$ incl.	***	1%	Belle II
$\lvert V_{cb}\rvert$ excl.	***	1.5%	Belle II
$\lvert V_{ub}\rvert$ incl.	**	3%	Belle II
$\lvert V_{ub}\rvert$ excl.	**	2%	Belle II/LHCb
CPV			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
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$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***	20%	Belle II
$R(B \to K^*\ell\ell)$	**	0.03	Belle II/LHCb

	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		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm ^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm ^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm ^{0.16}_{0.15} \pm ^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm ^{4}_{5}$	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		