Status and prospects of the Belle II experiment

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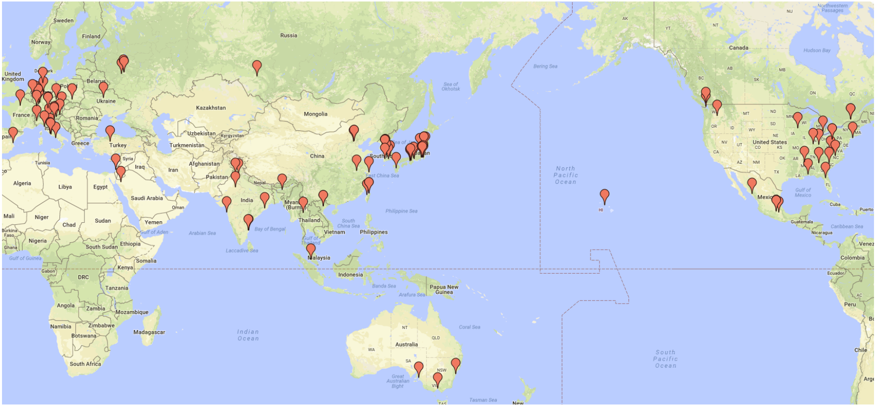
Belle II Collaboration

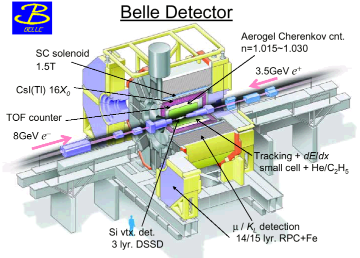


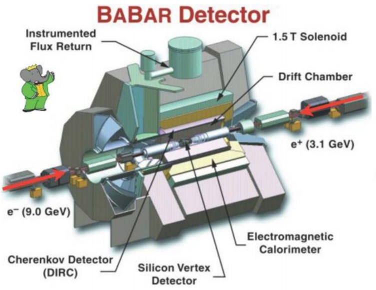
- Belle II Collaboration: 26 counties/regions, 113 institutions, > 800 collaborators.
- Belle II China Group: 高能所, 中科大, 北大, 北航, 复旦, 辽宁师大，以及苏州大学. 成员超过45名。
- 中国组网页: https://napp.fudan.edu.cn/belle2/

From Belle to Belle II

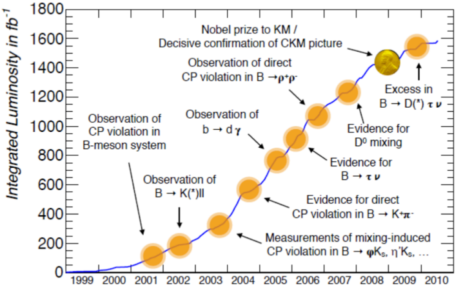
- Accelerator: KEKB→SuperKEKB, $\mathcal{L} \times 40$!
- Detector: Belle→Belle II, a new detector with great improved performance.

Achievements from B factories for Flavor Physics





- Two e^+e^- B factories: Belle/KEKB at KEK and BaBar/PEP-II at SLAC
- Very successful physics programs with a total recorded sample over 1.5 ab^{-1} (1.25×10^9 $B\bar{B}$).
- Experimental confirmation of CKM mechanism as source of CPV in the SM.

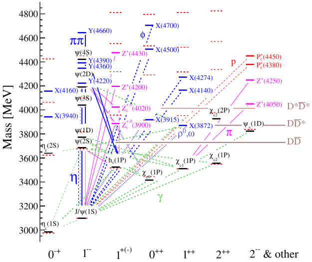


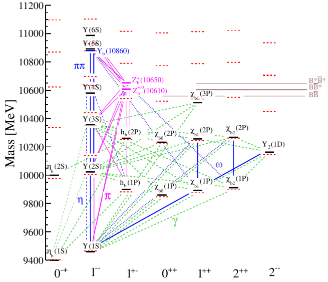
A lot list of charmonium-like states

State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$X(3872)$	3871.69 ± 0.17	< 1.2	1^{++}	$B \to K(J/\psi\pi^+\pi^-)$	Belle (Choi *et al.*, 2003, 2011), *BABAR* (Aubert *et al.*, 2005c), LHCb (Aaij *et al.*, 2013a, 2015d)
				$p\bar{p} \to (J/\psi\pi^+\pi^-) + \cdots$	CDF (Acosta *et al.*, 2004; Abulencia *et al.*, 2006; Aaltonen *et al.*, 2009b), D0 (Abazov *et al.*, 2004)
				$B \to K(J/\psi\pi^+\pi^-\pi^0)$	Belle (Abe *et al.*, 2005), *BABAR* (del Amo Sanchez *et al.*, 2010a)
				$B \to K(D^0\bar{D}^0\pi^0)$	Belle (Gokhroo *et al.*, 2006; Aushev *et al.*, 2010b), *BABAR* (Aubert *et al.*, 2008c)
				$B \to K(J/\psi\gamma)$	*BABAR* (del Amo Sanchez *et al.*, 2010a), Belle (Bhardwaj *et al.*, 2011), LHCb (Aaij *et al.*, 2012a)
				$B \to K(\psi'\gamma)$	*BABAR* (Aubert *et al.*, 2009b), Belle (Bhardwaj *et al.*, 2011), LHCb (Aaij *et al.*, 2014a)
				$pp \to (J/\psi\pi^+\pi^-) + \cdots$	LHCb (Aaij *et al.*, 2012a), CMS (Chatrchyan *et al.*, 2013a), ATLAS (Aaboud *et al.*, 2017)
				$e^+e^- \to \gamma(J/\psi\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2014d)
$X(3915)$	3918.4 ± 1.9	20 ± 5	0^{++}	$B \to K(J/\psi\omega)$	Belle (Choi *et al.*, 2005), *BABAR* (Aubert *et al.*, 2008b; del Amo Sanchez *et al.*, 2010a)
				$e^+e^- \to e^+e^-(J/\psi\omega)$	Belle (Uehara *et al.*, 2010), *BABAR* (Lees *et al.*, 2012c)
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$0^{-+}(?)$	$e^+e^- \to J/\psi(D^*\bar{D})$	Belle (Pakhlov *et al.*, 2008)
				$e^+e^- \to J/\psi(\cdots)$	Belle (Abe *et al.*, 2007)
$X(4140)$	$4146.5^{+6.4}_{-5.3}$	83^{+27}_{-25}	1^{++}	$B \to K(J/\psi\phi)$	CDF (Aaltonen *et al.*, 2009a), CMS (Chatrchyan *et al.*, 2014), D0 (Abazov *et al.*, 2014), LHCb (Aaij *et al.*, 2017a, 2017d)
				$p\bar{p} \to (J/\psi\phi) + \cdots$	D0 (Abazov *et al.*, 2015)
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$0^{-+}(?)$	$e^+e^- \to J/\psi(D^*\bar{D}^*)$	Belle (Pakhlov *et al.*, 2008)
$Y(4260)$	See $Y(4220)$ entry		1^{--}	$e^+e^- \to \gamma(J/\psi\pi^+\pi^-)$	*BABAR* (Aubert *et al.*, 2005a; Lees *et al.*, 2012b), CLEO (He *et al.*, 2006), Belle (Yuan *et al.*, 2007; Liu *et al.*, 2013)
$Y(4220)$	4222 ± 3	48 ± 7	1^{--}	$e^+e^- \to (J/\psi\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017c)
				$e^+e^- \to (h_c\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017a)
				$e^+e^- \to (\chi_{c0}\omega)$	BESIII (Ablikim *et al.*, 2015g)
				$e^+e^- \to (J/\psi\eta)$	BESIII (Ablikim *et al.*, 2015c)
				$e^+e^- \to (\gamma X(3872))$	BESIII (Ablikim *et al.*, 2014d)
				$e^+e^- \to (\pi^- Z_c^+(3900))$	BESIII (Ablikim *et al.*, 2013a), Belle (Liu *et al.*, 2013)
				$e^+e^- \to (\pi^- Z_c^+(4020))$	BESIII (Ablikim *et al.*, 2013b)
$X(4274)$	4273^{+19}_{-9}	56^{+14}_{-16}	1^{++}	$B \to K(J/\psi\phi)$	CDF (Aaltonen *et al.*, 2017), CMS (Chatrchyan *et al.*, 2014), LHCb (Aaij *et al.*, 2017a, 2017d)
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$(0/2)^{++}$	$e^+e^- \to e^+e^-(J/\psi\phi)$	Belle (Shen *et al.*, 2010)
$Y(4360)$	4341 ± 8	102 ± 9	1^{--}	$e^+e^- \to \gamma(\psi'\pi^+\pi^-)$	*BABAR* (Aubert *et al.*, 2007; Lees *et al.*, 2014), Belle (Wang *et al.*, 2007, 2015)
				$e^+e^- \to (J/\psi\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017c)
$Y(4390)$	4392 ± 6	140 ± 16	1^{--}	$e^+e^- \to (h_c\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017a)
$X(4500)$	4506^{+16}_{-19}	92^{+30}_{-21}	0^{++}	$B \to K(J/\psi\phi)$	LHCb (Aaij *et al.*, 2017a, 2017d)
$X(4700)$	4704^{+17}_{-26}	120^{+52}_{-45}	0^{++}	$B \to K(J/\psi\phi)$	LHCb (Aaij *et al.*, 2017a, 2017d)
$Y(4660)$	4643 ± 9	72 ± 11	1^{--}	$e^+e^- \to \gamma(\psi'\pi^+\pi^-)$	Belle (Wang *et al.*, 2007, 2015), *BABAR* (Aubert *et al.*, 2007; Lees *et al.*, 2014)
				$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$	Belle (Pakhlova *et al.*, 2008)

A lot list of charged charmonium-like states

State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$Z_c^{+,0}(3900)$	3886.6 ± 2.4	28.1 ± 2.6	1^{+-}	$e^+e^- \to \pi^{-,0}(J/\psi\pi^{+,0})$	BESIII (Ablikim *et al.*, 2013a, 2015f), Belle (Liu *et al.*, 2013)
				$e^+e^- \to \pi^{-,0}(D\bar{D}^*)^{+,0}$	BESIII (Ablikim *et al.*, 2014b, 2015e)
$Z_c^{+,0}(4020)$	4024.1 ± 1.9	13 ± 5	$1^{+-}(?)$	$e^+e- \to \pi^{-,0}(h_c\pi^{+,0})$	BESIII (Ablikim *et al.*, 2013b, 2014c)
				$e^+e^- \to \pi^{-,0}(D^*\bar{D}^*)^{+,0}$	BESIII (Ablikim *et al.*, 2014a, 2015d)
$Z^+(4050)$	4051^{+24}_{-43}	82^{+51}_{-55}	$?^{?+}$	$B \to K(\chi_{c1}\pi^+)$	Belle (Mizuk *et al.*, 2008), *BABAR* (Lees *et al.*, 2012a)
$Z^+(4200)$	4196^{+35}_{-32}	370^{+99}_{-149}	1^+	$B \to K(J/\psi\pi^+)$	Belle (Chilikin *et al.*, 2014)
				$B \to K(\psi'\pi^+)$	LHCb (Aaij *et al.*, 2014b)
$Z^+(4250)$	4248^{+185}_{-45}	177^{+321}_{-72}	$?^{?+}$	$B \to K(\chi_{c1}\pi^+)$	Belle (Mizuk *et al.*, 2008), *BABAR* (Lees *et al.*, 2012a)
$Z^+(4430)$	4477 ± 20	181 ± 31	1^+	$B \to K(\psi'\pi^+)$	Belle (Choi *et al.*, 2008; Mizuk *et al.*, 2009), Belle (Chilikin *et al.*, 2013), LHCb (Aaij *et al.*, 2014b, 2015b)
				$B \to K(J\psi\pi^+)$	Belle (Chilikin *et al.*, 2014)
$P_c^+(4380)$	4380 ± 30	205 ± 88	$(\frac{3}{2}/\frac{5}{2})^{\mp}$	$\Lambda_b^0 \to K(J/\psi p)$	LHCb (Aaij *et al.*, 2015c)
$P_c^+(4450)$	4450 ± 3	39 ± 20	$(\frac{5}{2}/\frac{3}{2})^{\pm}$	$\Lambda_b^0 \to K(J/\psi p)$	LHCb (Aaij *et al.*, 2015c)
$Y_b(10860)$	$10891.1^{+3.4}_{-3.8}$	$53.7^{+7.2}_{-7.8}$	1^{--}	$e^+e^- \to (\Upsilon(nS)\pi^+\pi^-)$	Belle (Chen *et al.*, 2008; Santel *et al.*, 2016)
$Z_b^{+,0}(10610)$	10607.2 ± 2.0	18.4 ± 2.4	1^{+-}	$Y_b(10860) \to \pi^{-,0}(\Upsilon(nS)\pi^{+,0})$	Belle (Bondar *et al.*, 2012; Garmash *et al.*, 2015), Belle (Krokovny *et al.*, 2013)
				$Y_b(10860) \to \pi^-(h_b(nP)\pi^+)$	Belle (Bondar *et al.*, 2012)
				$Y_b(10860) \to \pi^-(B\bar{B}^*)^+$	Belle (Garmash *et al.*, 2016)
$Z_b^+(10650)$	10652.2 ± 1.5	11.5 ± 2.2	1^{+-}	$Y_b(10860) \to \pi^-(\Upsilon(nS)\pi^+)$	Belle (Bondar *et al.*, 2012; Garmash *et al.*, 2015)
				$Y_b(10860) \to \pi^-(h_b(nP)\pi^+)$	Belle (Bondar *et al.*, 2012)
				$Y_b(10860) \to \pi^-(B^*\bar{B}^*)^+$	Belle (Garmash *et al.*, 2016)

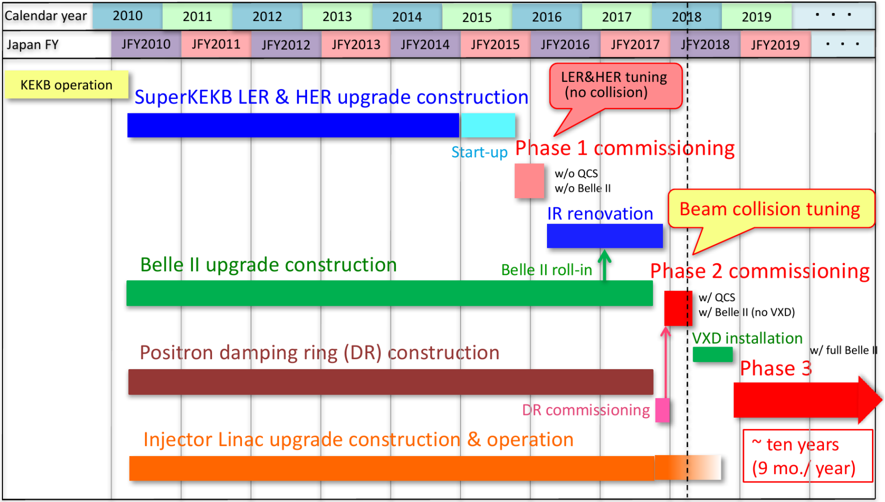




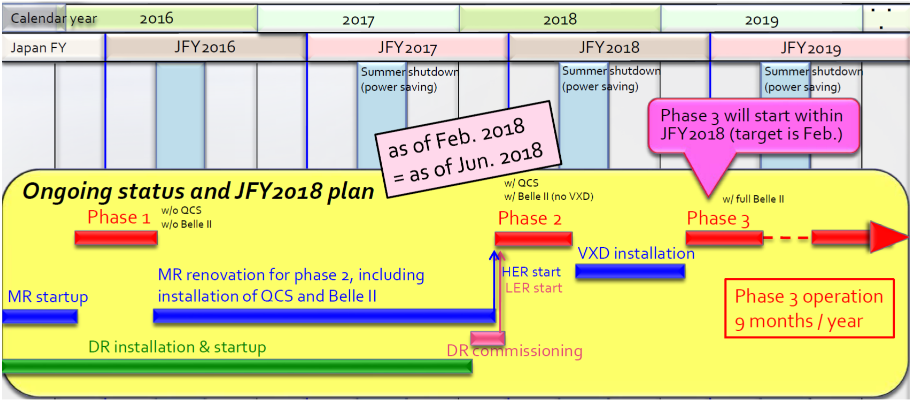
S. Olsen, T. Skwarnicki and D. Zieminska: Rev. Mod. Phys. 90, 015003(2018)

- Rough summary of XYZ discoveries:
  - Belle: $X(3872)$, $X(3915)$, $X(3940)$, $Y(4160)$, $Y(4350)$, $Y(4660)$, $Y(4630)$, $Z_c(3900)$, $Z(4050)$, $Z(4200)$, $Z(4250)$, $Z(4430)$, $Z_b(10610)$, $Z_b(10650)$, $X(3860)^*$
  - BaBar: $Y(4260)$, $Y(4360)$ ($Y(4324)$).
  - BESIII: $Z_c(3900)$, $Y(4220)$.
  - LHCb: $P_c(4380)$, $P_c(4450)$, $X(4700)$.
- China group contributions: $Y(4008)$, $Y(4260)$, $X(4350)$, $Y(4360)$, $Y(4660)$, $Z_c(3900)$, ...

SuperKEKB/Belle II overall schedule



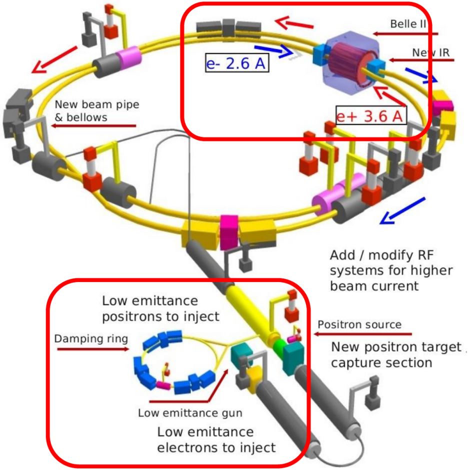
Current schedule

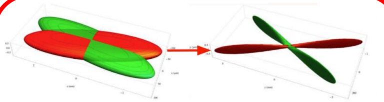


- First collisions on 4/26/2018, 8 years after KEKB and Belle being shut down.
- Phase 2 until July 17th.
- On the way to Phase III: Physics Run.

The SuperKEKB

A lot of new designs





"nano-beam" scheme

Beam squeezing: x20 smaller at IR

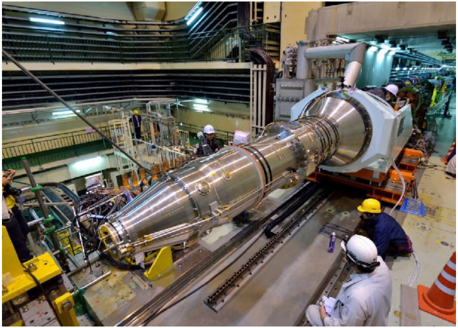
x2

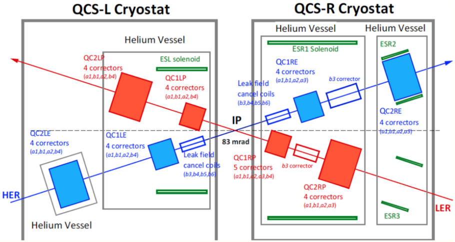
$$\text{Luminosity} = \frac{\gamma_{\pm}}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\zeta_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

X1/20

Target luminosity: $8\text{x}10^{35}\text{cm}^{-2}\text{s}^{-1}$
KEKB x 40!

The final focus: Key of achieving the goal of $L = 0.8 \times 10^{36}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$





The superconducting final focus system

Large crossing angle nano-beams!

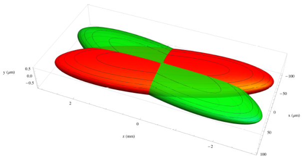


FIG. 1: Schematic view of Belle-I beam crossing at the interaction region. The spread of the z vertex distribution can be estimated as $\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x}$ where for Belle-I optics the horizontal emittance $\epsilon_x = 20 \times 10^{-6}$ mm, $\beta_x^* = 1200$ mm, and the crossing angle $\phi_x = 11$ mrad leading to expected $\sigma_z = 1$ cm.

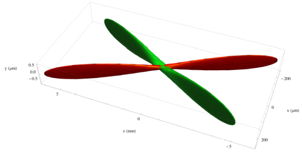
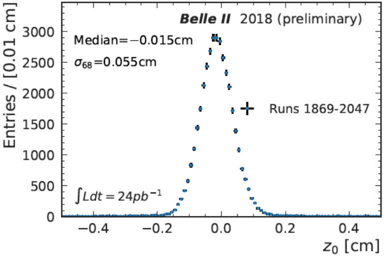
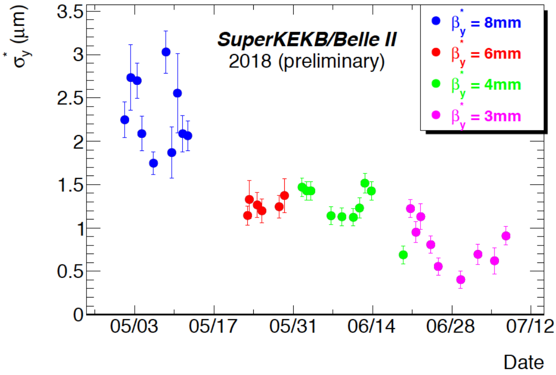


FIG. 2: Schematic view of Belle-II beam crossing at the interaction region. The spread of the z vertex distribution can be estimated as $\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x}$ where for Belle-II optics in phase 2 the horizontal emittance $\epsilon_x = 4 \times 10^{-6}$ mm, $\beta_x^* = 200$ mm, and the crossing angle $\phi_x = 41$ mrad leading to expected $\sigma_z = 0.049$ cm.

- As expected, the effective bunch length is reduced from $\sim$ 10 mm (KEKB) to 0.5 mm (SuperKEKB).
- Measured the bunch length in two track events in Belle II data.



Measure the vertical height of nanobeams



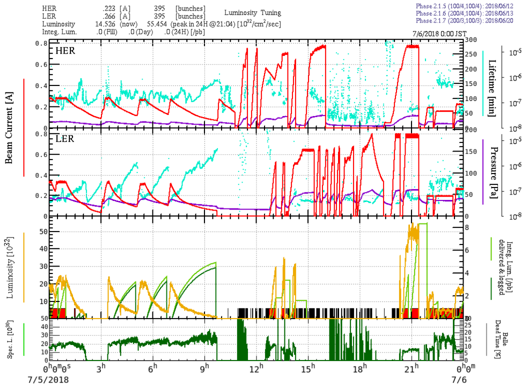
- When $L_{peak} = 0.5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ got during Phase 2, the vertical spot $\sim$ 700 nm high.
- For early Phase 3, we will continue with $\beta^* = 3$ mm. The goal is $\beta^* \sim 0.3$ mm.
- The record the vertical spot size is 400nm and beam currents of only ~ 15 mA.
- Heading downwards but still struggling with beam-beam blow-up, a major issue for Phase3.
- The final goal is $\mathcal{O}(50\ \mathrm{nm})$ with full capability of the QCS system.

SuperKEKB achievements at Phase II

Keep on squeezing the two beams with the superconducting final focus $\beta_y^* = 3$ mm.

$$L_{peak} = 5.5 \times 10^{33} / cm^2 / sec$$

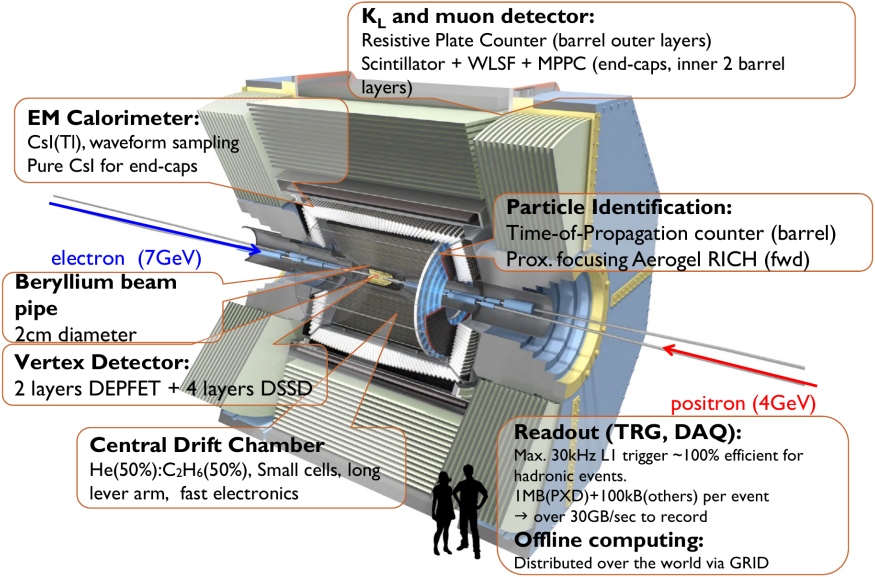
Phase 2,
July 2018



- N.B. still a long way to go with the superconducting final focus (one order of magnitude in β_y^*)
- Luminosity tuning has priority. When accelerator physicists become tired, Belle II takes data (usually owl shift). Only able to record 0.5 fb^{-1}.
- Note $N_{bunch} = 395$ here, one expects $L_{peak} = 2.2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ with $N_{bunch} = 1576$.

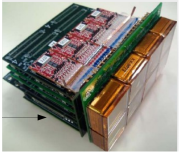
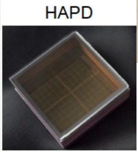
Cut view of Belle II detector

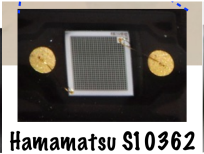
$H = 7.1\text{m}, L = 7.4\text{m}, W = 1400\text{t}$



Advanced & Innovative Technologies used in Belle II

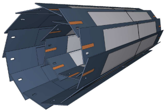
- Pixelated photo-sensors play a central role. Collaboration with Industry
  1. MCP-PMTs in the iTOP
  2. HAPDs in the ARICH
  3. SiPMs in the KLM
  4. DEPFET pixel sensors!
- Waveform sampling with precise timing. Front-end custom ASICs (Application Specific Integrated Circuits) for all subsystems.
  1. KLM: TARGETX ASIC
  2. ECL: New waveform sampling backend with good timing
  3. TOP: IRSX ASIC
  4. ARICH: KEK custom ASIC
  5. CDC: KEK custom ASIC
  6. SVD: APV2.5 readout chip adapted from CMS
- DAQ with high performance network switches, large HLT software trigger farm
- a 21^{th} century HEP experiment.

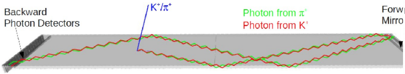



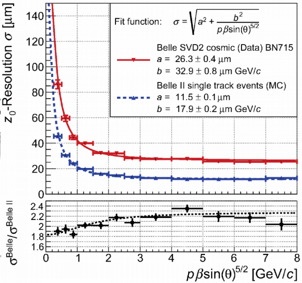


Detector highlights

PXD and iTOP

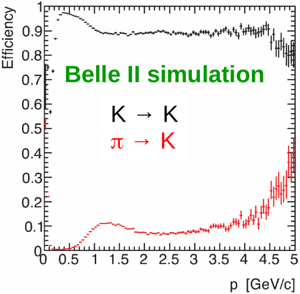






Vertex detectors:

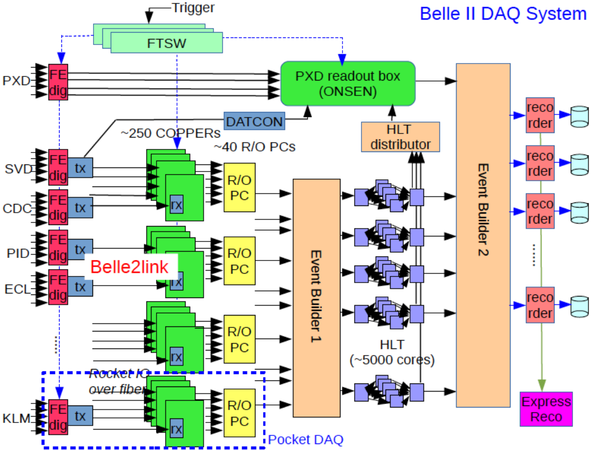
- spatial resolution has a factor $\sim$ 2 than Belle;
- despite lower Lorentz boost, $O(30\%)$ improvement in separating the B decay vertices!
- $\sim 30\%$ larger acceptance for K_s reconstruction



Particle Identification (PID):

- $K - \pi$ separation is fundamental to distinguish among important final states and bkgs;
- crucial ingredient for B flavor tagger;
- expected performance: $K(\pi)$ efficiency $> 90\%$, with $\pi(K)$ fake rate $< 10\%$ for $p < 4$ GeV$/c$.

A modern DAQ and readout system



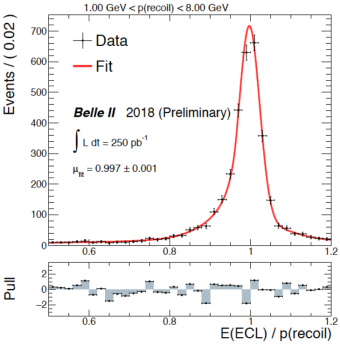
- Belle2link by IHEP; Dr. Chunhua Li (辽师大) is the previous convener of HLT group.
- Front-end readout electronics and Gb fiber optic link (Belle2link) to the back-end.
- ROI (Region of Interest) for PXD data volume.

Sub-detector installation

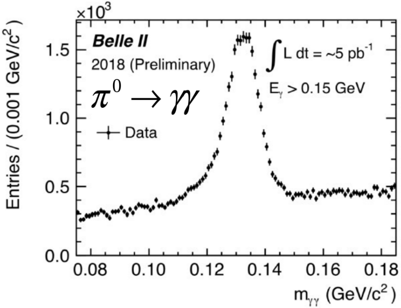
Most of the Belle II detector subsystems are working well now!

Signals involving photons (ECL)

$$e^+e^- \to \mu^+\mu^-\gamma$$



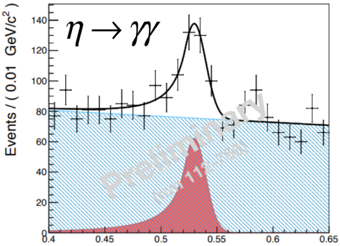
Single Photon Lines



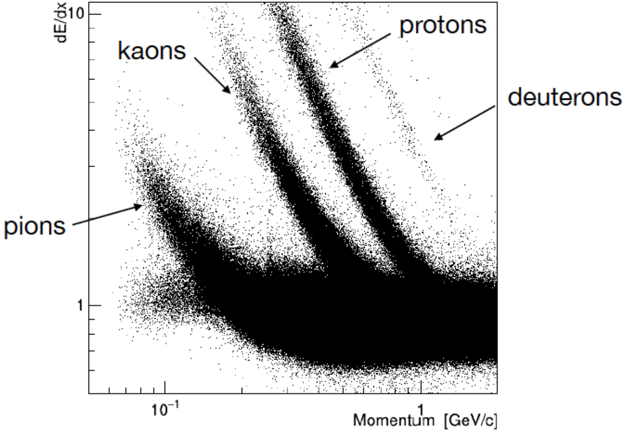
Ready for the dark sector !

$$e^+e^- \to \gamma X$$

$$e^+e^- \to \gamma ALPS \to \gamma(\gamma\gamma)$$



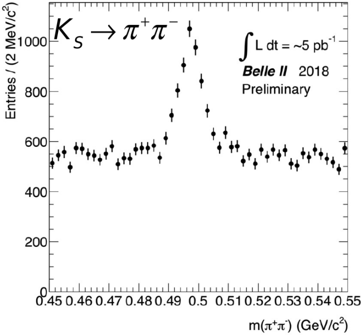
$\frac{dE}{dx}$ from CDC for PID



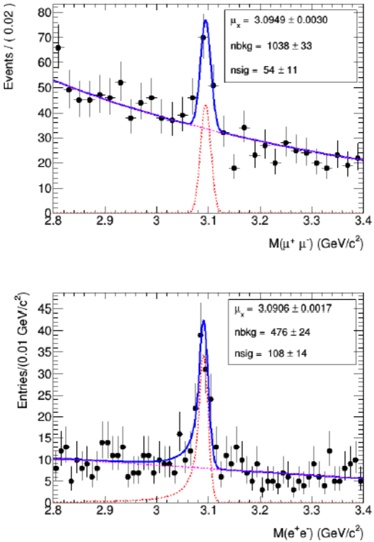
Extra cuts:

- |d0| < 1
- |dz| < 3
- # layers hit > 20

Signals involving charged tracks

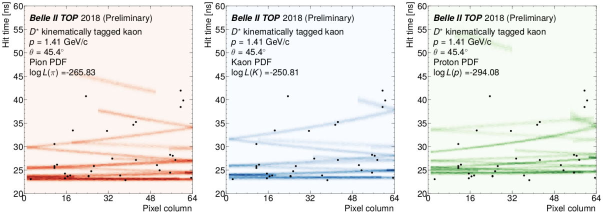


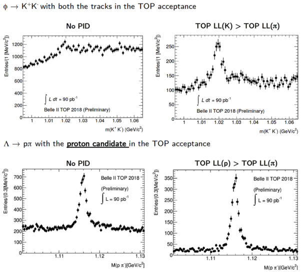
$J/\psi \to \mu^+\mu^-$, $J/\psi \to e^+e^-$

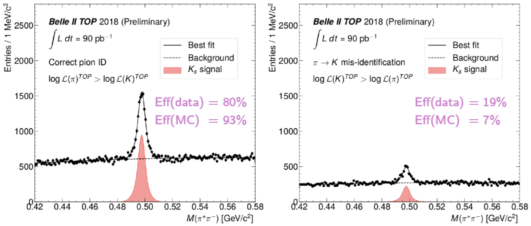


TOP for Particle Identification: $K^{\pm}$, p and $\pi^{\pm}$

- The charged correlation with the slow pion determines which track is the kaon (or pion)
- Kinematically identified kaon from a D^{*+} in the TOP.
- Cherenkov x vs. t pattern (mapping of the Cherenkov ring):







$K_S^0 \to \pi^+\pi^-$

Rediscovery of $D_s \to \phi\pi^+$ with $\phi \to K^+K^-$

- Signals with no PID:

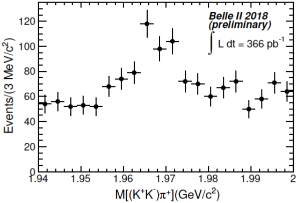


FIG. 1: This figure shows M[$(K^+K^-)\pi^+$] distribution, which was produced using phase-II 366 pb^{-1} hadron skim data. No PID criteria are applied to any of the charged tracks ($K^\pm\pi^+$). Selection criteria and further details are described in the internal note BELLE2-NOTE-PH-2018-026.

- Signals with two identified charged kaons:

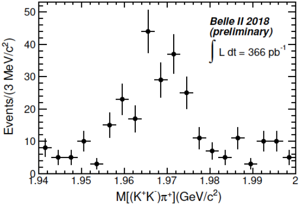


FIG. 2: This figure shows M[$(K^+K^-)\pi^+$] distribution, which was produced using phase-II 366 pb^{-1} hadron skim data. Combined PID criteria, Prob(K:π) >0.5 for $K^\pm$ tracks and Prob(π:K) >0.5 for π^+ tracks are applied. Selection criteria and further details are described in the internal note BELLE2-NOTE-PH-2018-026.

R_2 distribution

- Fox-Wolfram moment:

$$H_l = \sum_{ij} |p_i||p_j|P_l(\cos\theta_{ij}) \tag{1}$$

- $R_2 = H_2/H_0$ is very powerful in distinguishing $B\bar{B}$ component from others.

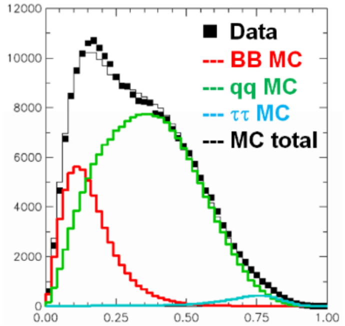


FIG. 1: R_2 distribution with Belle exp 5 data.

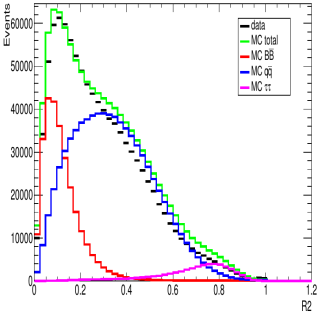
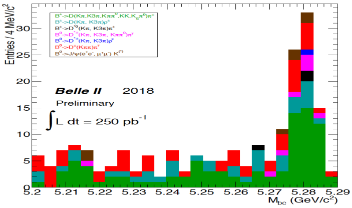


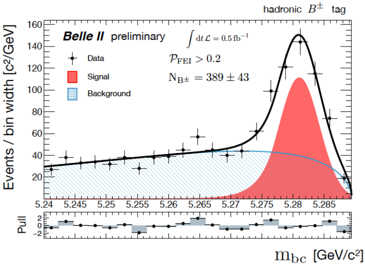
FIG. 9: R_2 distribution with Belle II exp 3 data (prod3 250 pb^{-1}).

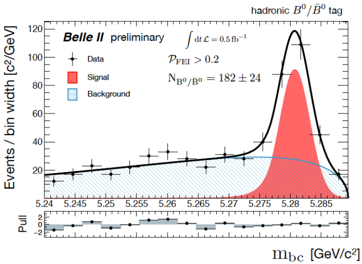
B mesons from Belle II

- Rediscovery of B mesons in June, shown at ICHEP2018.



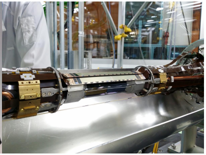
- Use the full Phase 2 dataset and apply the FEI (Full Event Interpretation) technique based on boosted decision trees (BDTs, a machine learning technique).





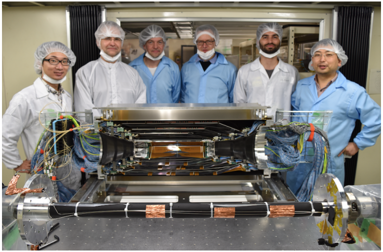
Onwards to Phase 3 and the Physics Run

- VXD = PXD+SVD
- PXD installation ongoing well at KEK.



叶桦(DESY)正在KEK负责相关工作。复旦博士后刘清源也正在DESY参与PXD的工作。

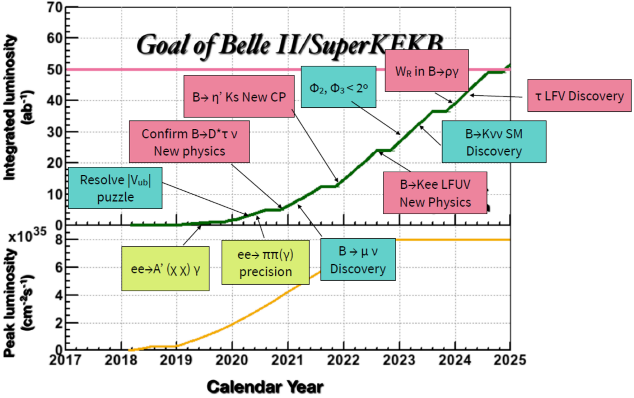
- SVD installation, finished in July, 2018



- Successful marriage of the PXD and SVD, current highlight of Belle II.

Luminosity and prospects

- 2020: about twice of the Belle data sample.
- 2021: $\sim 5\ \mathrm{ab}^{-1}$, enough for searching new signals, especially for XYZ!
- 2022: $10 - 15\ \mathrm{ab}^{-1}$, ≥ 10 Belle experiments.



Book of Belle II Physics is available at arXiv:1808.10567

PTEP
Prog. Theor. Exp. Phys. **2018**, 00000 (681 pages)
DOI: 10.1093/ptep/0000000000

The Belle II Physics Book (Draft v1.0)

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

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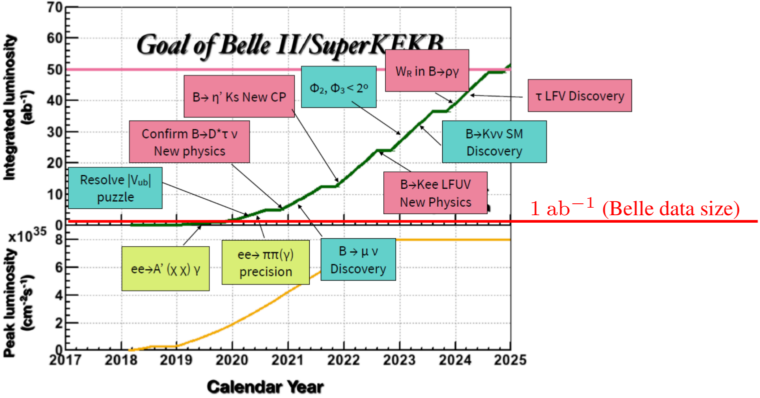

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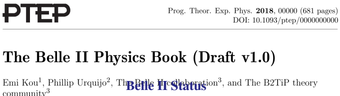
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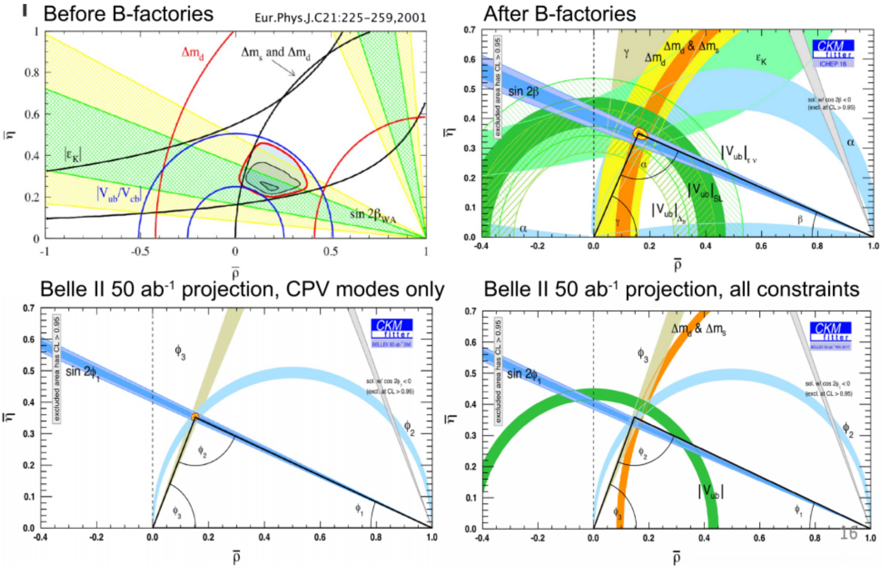
Prospects of CPV



Processes for XYZ

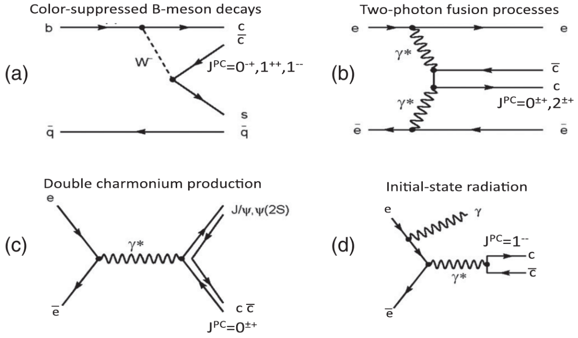


FIG. 12. Processes that produce $c\bar{c}$ pairs in e^+e^- collisions near $E_{\mathrm{c.m.}} = 10.6$ GeV: (a) $B \to K(c\bar{c})$ decays, (b) two-photon fusion processes, (c) e^+e^- annihilation into $c\bar{c}c\bar{c}$, and (d) initial state radiation.

And: $\Upsilon(1, 2, 3S)$ decays, continuum productions...

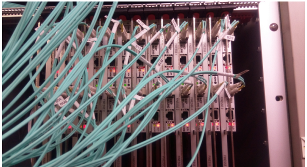
The China group at Belle II

Past & now at Belle II

- China group made great contribution to Belle II
  - Belle2link (IHEP)
  - PXD DAQ (IHEP)
  - B2TIP — physics potential study (BUAA)
- China group is contributing more
  - Belle II maintenances and calibrations: CDC by IHEP, KLM by Fudan+USTC+SUDA, HLT by LNNU.
  - KLM detector (Fudan, SUDA)
  - Computing (BUAA, Fudan)
  - PXD, SVD, Trigger/DAQ, B-field mapping, ...
  - Generator, Data validation, IP profile, luminorsity, ...
  - DAQ upgrade: IHEP, USTC, Fudan

Future at Belle II

- Hardware, electronics, computing
  - Fudan: hardware lab based on KLM, computing
  - IHEP: Belle II trigger, DAQ upgrade
  - BUAA: computing cluster joining Belle II GRID
  - DAQ upgrade: Fudan, USTC, IHEP
- Physics
  - Where China group has advantage
    - $D\bar{D}$-mixing and CPV
    - Exotics: XYZ & quarkonium, T_{cs}, T_{cc}, $D^*(2380)$,...
  - New idea, new method
    - Lepton universality (R_K, R_D, R_{D^*})
    - Semileptonic decays using the B decay vertex
    - Dark sector
  - What are the hot topics of heavy flavor physics? What can China group do?



Summary

- Belle II has finished the detector construction.
- Belle II had the first collisions on April 26, 2018, and the Phase 2 was until July 17th.
- The Phase 2 got very impressive results from both the SuperKEKB accelerator and the Belle II detector.
- $L_{peak} = 0.55 \times 10^{34}$ cm^{-2}s^{-1} was achieved with a quarter of the number of bunches.
- The nano-beam scheme is working well and the Belle II detector has very good performance!
- Belle II is going to start physics running in 2019, coming back the game.
- 0.8×10^{36} cm^{-2}s^{-1} will make Belle II a luminosity revolution experiment, and open new windows for various physics topics.
- What can we do with the coming huge Belle II data?

Welcome to join Belle II !

Thank you!

Back-up

Machine Parameters

Machine Parameters

2017/September/1	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	$3.20\text{x}10^{-4}$	$4.55\text{x}10^{-4}$		
σ_δ	$7.92(7.53)\text{x}10^{-4}$	$6.37(6.30)\text{x}10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6(4.7)	5(4.9)	mm	():zero current
ν_s	-0.0245	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.76	2.43	MeV	
$\tau_{x,y}/\tau_s$	45.7/22.8	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	$8\text{x}10^{35}$		$cm^{-2}s^{-1}$	

Some golden observables (I)

Pure-leptonic and semi-leptonic B decays

Process	Observable	Theory	Sys. limit (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	NP
$B \to \pi \ell \nu_l$	$\lvert V_{ub} \rvert$	★★★	10-20	★★★	★★★	★★	★
$B \to X_u \ell \nu_\ell$	$\lvert V_{ub} \rvert$	★★	2-10	★★★	★★	★★★	★
$B \to \tau \nu$	$Br.$	★★★	>50 (2)	★★★	★★★	★	★★★
$B \to \mu \nu$	$Br.$	★★★	>50 (5)	★★★	★★★	★	★★★
$B \to D^{(*)} \ell \nu_\ell$	$\lvert V_{cb} \rvert$	★★★	1-10	★★★	★★	★★	★
$B \to X_c \ell \nu_\ell$	$\lvert V_{cb} \rvert$	★★★	1-5	★★★	★★	★★	★★
$B \to D^{(*)} \tau \nu_\tau$	$R(D^{(*)})$	★★★	5-10	★★	★★★	★★★	★★★
$B \to D^{(*)} \tau \nu_\tau$	P_τ	★★★	15-20	★★★	★★★	★★	★★★
$B \to D^{**} \ell \nu_\ell$	$Br.$	★	-	★★	★★★	★★	-

Time dependent CPV

$B \to J/\psi K_S$	ϕ_1	★★★	5-10	★★	★★	★	★
$B \to \phi K_S$	ϕ_1	★★	>50	★★	★★★	★	★★★
$B \to \eta' K_S$	ϕ_1	★★	>50	★★	★★★	★	★★★
$B \to J/\psi \pi^0$	ϕ_1	★★★	>50	★	★★★	–	–
$B \to \rho^\pm \rho^0$	ϕ_2	★★★	–	★	★★★	★	★
$B \to \pi^0 \pi^0$	ϕ_2	★★	>50	★★★	★★★	★★	★★
$B \to \pi^0 K_S$	S_{CP}	★★	>50	★★★	★★★	★★	★★

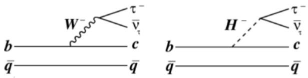
Some golden observables (II)

Radiative and electroweak penguin B decays

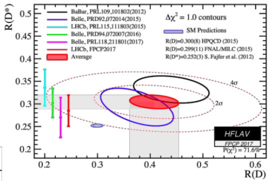
	Process	Observable	Theory	Sys. limit (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	NP
●	$B \to K^{(*)}\nu\nu$	$Br., F_L$	★★★	>50	★★★	★★★	★	★★
●	$B \to X_{s+d}\gamma$	$A_{\rm CP}$	★★★	>50	★★★	★★★	★	★★
●	$B \to X_d\gamma$	$A_{\rm CP}$	★★	>50	★★★	★★★	-	★★
●	$B \to K_S\pi^0\gamma$	$S_{K_S\pi^0\gamma}$	★★	>50	★★	★★★	★	★★★
●	$B \to \rho\gamma$	$S_{\rho\gamma}$	★★	>50	★★★	★★★	-	★★★
●	$B \to X_s l^+l^-$	$Br.$	★★★	>50	★★★	★★	★★	★★★
●	$B \to X_s l^+l^-$	R_{X_s}	★★★	>50	★★★	★★★	★★	★★★
●	$B \to K^{(*)}e^+e^-$	$R(K^{(*)})$	★★★	>50	★★	★★★	★★★	★★★
●	$B \to X_s\gamma$	$Br.$	★★	1-5	★★★	★	★	★★
●	$B_{d,(s)} \to \gamma\gamma$	$Br., A_{\rm CP}$	★★	> 50(5)	★★	★★	-	★★
●	$B \to K^*e^+e^-$	P_5'	★★	>50	★★★	★★	★★★	★★★
●	$B \to K\tau l$	$Br.$	★★★	>50	★★	★★★	★★	★★★

$B \to D^{(*)} l\nu$: challenge to lepton universality

- Theoretically clean channel in SM
- Charged Higgs can contribute to the decay
- $R(D^{(*)})$ is sensitive parameter to BSM!

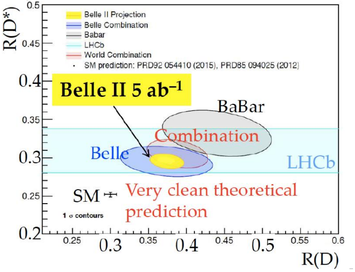


$$R(D^{(*)}) = \frac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}\mu\nu)}$$



	Exp	SM
$R(D^*)$	0.304±0.013±0.007	0.252±0.003
$R(D)$	0.407±0.039±0.024	0.300±0.008

4.1σ away from the SM



Belle II should be able to confirm the excess with ~5ab^{-1} data

$B \to K^* \ell^+ \ell^-$: yet another smoking gun

- Interesting discrepancy as well as measured in P5'

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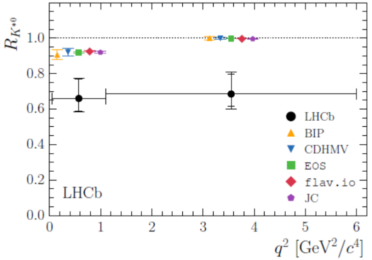
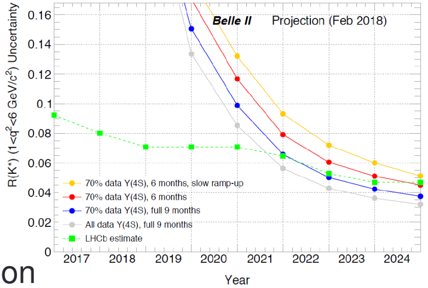


$$R(K^*) = \frac{BR(K^* \mu\mu)}{BR(K^* ee)}$$



- Belle II: good electron identification

K*ee: ~200 events/ab^{-1}
K*μμ: ~280 events/ab^{-1}

Note: LHCb value is extrapolated from run-1 result

Compare to KEKB

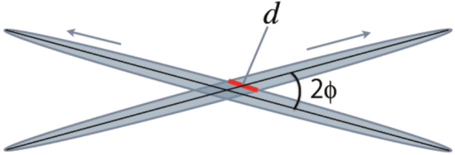


Figure 2.1: Schematic view of beam collision in the Nano-Beam scheme.

	KEKB Achieved	SuperKEKB
Energy (GeV) (LER/HER)	3.5/8.0	4.0/7.0
ξ_y	0.129/0.090	0.090/0.088
β_y^* (mm)	5.9/5.9	0.27/0.41
I (A)	1.64/1.19	3.60/2.62
Luminosity ($10^{34}\text{cm}^{-2}\text{s}^{-1}$)	2.11	80

Table 2.1: Fundamental parameters of SuperKEKB and present KEKB.

Nano-beam parameters of SuperKEKB

		LER (e+)	HER (e-)	units
Beam Energy	E	4	7	GeV
Half Crossing Angle	ϕ	41.5		mrad
Horizontal Emittance	ε_x	3.2(2.7)	2.4(2.3)	nm
Emittance ratio	$\varepsilon_y/\varepsilon_x$	0.40	0.35	%
Beta Function at the IP	β_x^*/β_y^*	32 / 0.27	25 / 0.41	mm
Horizontal Beam Size	σ_x^*	10.2(10.1)	7.75(7.58)	μm
Vertical Beam Size	σ_y^*	59	59	nm
Betatron tune	ν_x/ν_y	45.530/45.570	58.529/52.570	
Momentum Compaction	α_c	2.74×10^{-4}	1.88×10^{-4}	
Energy Spread	σ_ε	$8.14(7.96) \times 10^{-4}$	$6.49(6.34) \times 10^{-4}$	
Beam Current	I	3.60	2.62	A
Number of Bunches/ring	n_b	2503		
Energy Loss/turn	U_0	2.15	2.50	MeV
Total Cavity Voltage	V_c	8.4	6.7	MV
Synchrotron Tune	ν_s	-0.0213	-0.0117	
Bunch Length	σ_z	6.0(4.9)	5.0(4.9)	mm
Beam-Beam Parameter	ξ_y	0.0900	0.0875	
Luminosity	L	8×10^{35}		$\mathrm{cm^{-2}s^{-1}}$

Table 2.2: Machine Parameters of SuperKEKB. Values in parentheses denote parameters at zero beam currents.