Status of Belle II experiment

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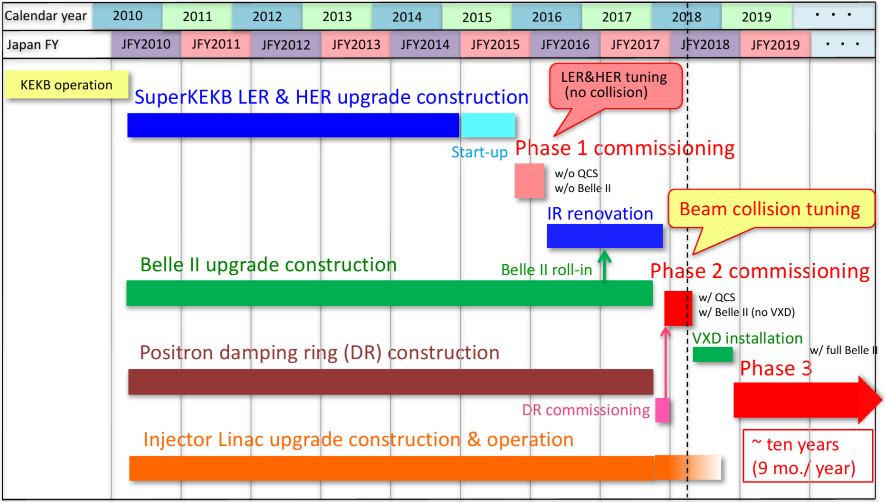
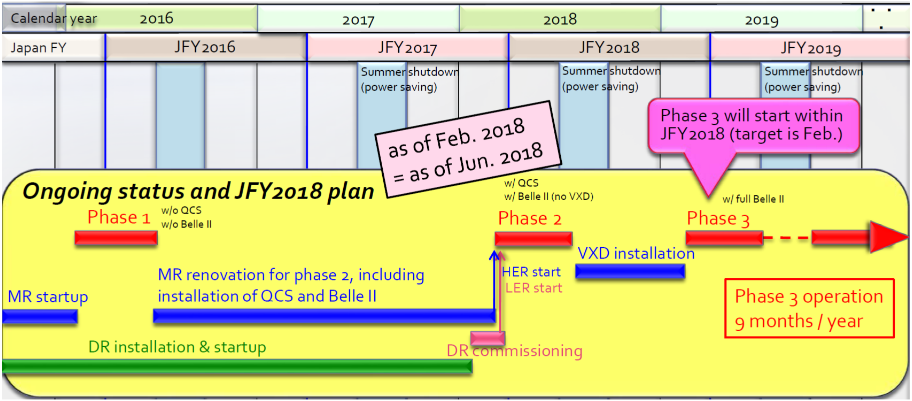
基本粒子和相互作用协同创新中心年会
暨 牡丹江合作组工作会议

济南大学，9月15日，2018

SuperKEKB/Belle II overall schedule

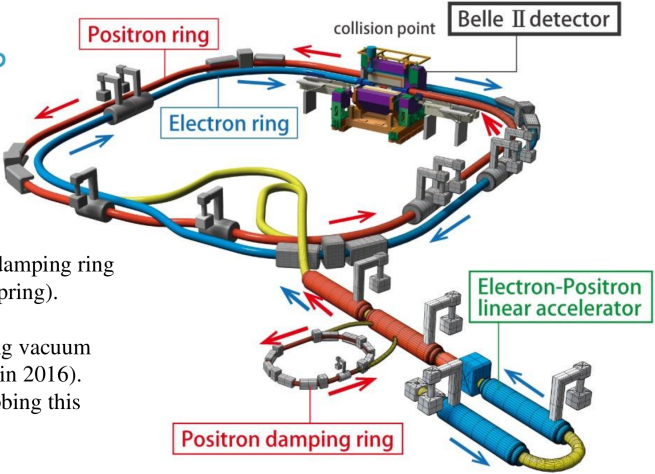


Current schedule



- 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

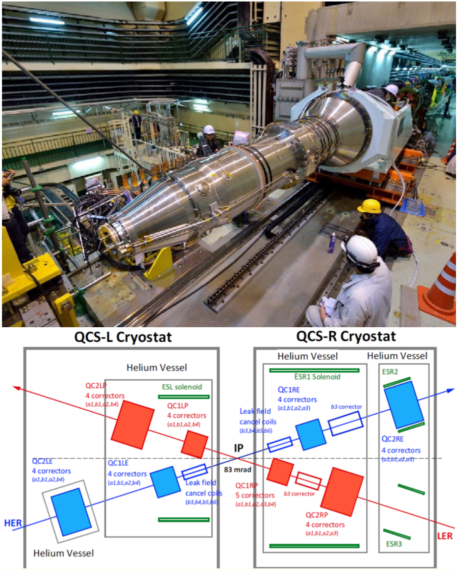


Some items to note:
1) Brand-new positron damping ring (commissioned this spring).

2) New 3 km positron ring vacuum chamber (commissioned in 2016). Optics and vacuum scrubbing this spring.

3) New complex superconducting final focus (commissioned this spring).

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



The superconducting final focus system

Large crossing angle nano-beams!

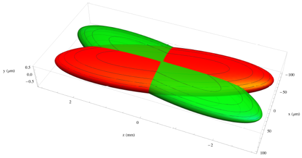


FIG. 1: Schematic view of Belle-I beam crossing at the interaction region. The spread of the z vertex distribution can be estimated as $\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x}$ where for Belle-I optics the horizontal emittance $\epsilon_x = 20 \times 10^{-6}$ mm, $\beta_x^* = 1200$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

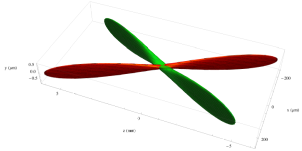
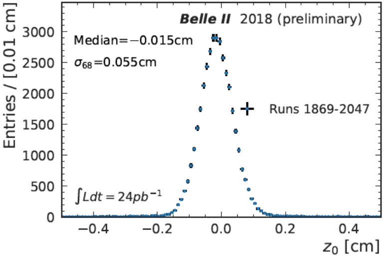


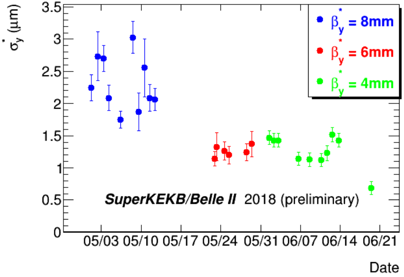
FIG. 2: Schematic view of Belle-II beam crossing at the interaction region. The spread of the z vertex distribution can be estimated as $\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x}$ where for Belle-II optics in phase 2 the horizontal emittance $\epsilon_x = 4 \times 10^{-6}$ mm, $\beta_x^*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

Method: Width of Luminosity scans with diamond detectors



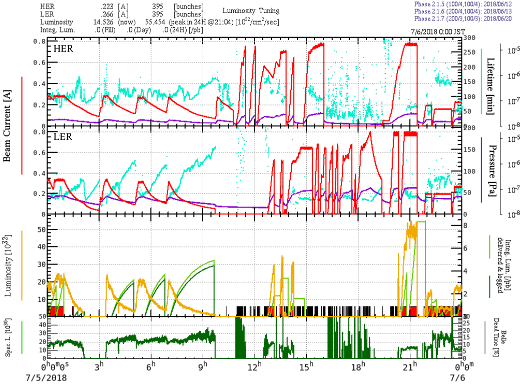
- When $L_{peak} = 0.5 \times 10^{34}\ cm^{-2}s^{-1}$ got during Phase II, the vertical spot is $\sim$ 700 *nm* high.
- There is still beam-beam blowup at high currents.
- At low currents, the vertical spot size is 330 *nm* high.
- The final goal is $\mathcal{O}(50\ nm)$ with full capability of the QCS system.

SuperKEKB achievements at Phase II

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

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

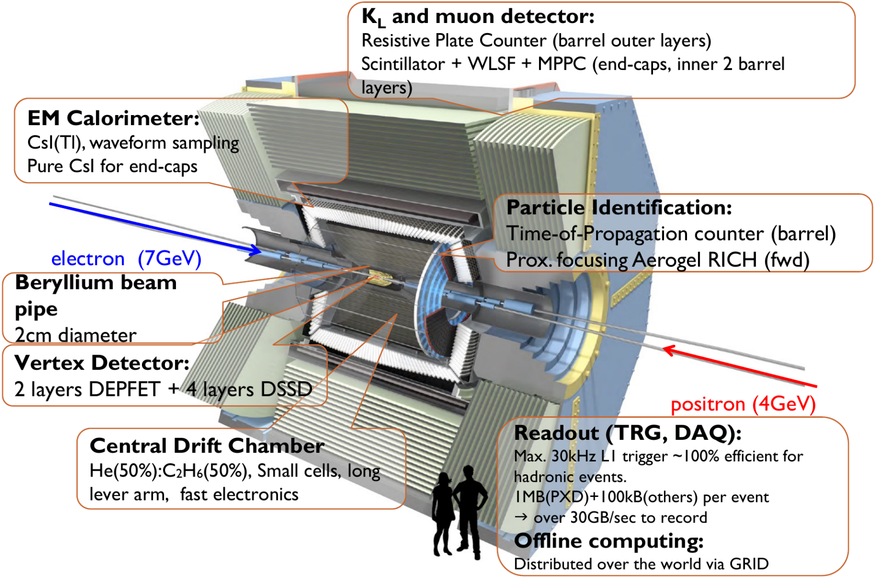
Phase 2,
July 2018



- 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 $L_{peak} = 2.2 \times 10^{34}\ cm^{-2}s^{-1}$ with $N_{bunch} = 1576$.
- $L_{max} = 2.1 \times 10^{34}\ cm^{-2}s^{-1}$ was recorded by KEKB.

Cut view of Belle II detector

$H = 7.1m$, $L = 7.4m$, $W = 1400ton$



K_L and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling
Pure CsI for end-caps

Particle Identification:
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

Vertex Detector:
2 layers DEPFET + 4 layers DSSD

Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

Readout (TRG, DAQ):
Max. 30kHz L1 trigger ~100% efficient for hadronic events.
1MB(PXD)+100kB(others) per event
→ over 30GB/sec to record

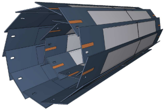
Offline computing:
Distributed over the world via GRID

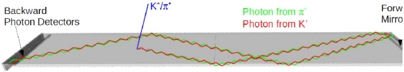
Advanced & Innovative Technologies used in Belle II

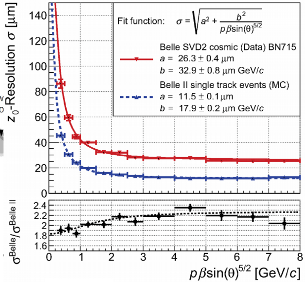
- Pixelated photo-sensors play a central role. Collaboration with Industry
  1. MCP-PMTs in the iTOP
  2. HARPDs in the ARICH
  3. SiPMs in the KLM
  4. DEPFET pixel sensors!
- Waveform sampling with precise timing is "saving our butts".
  Front-end custom ASICs (Application Specific Integrated Circuits) 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.

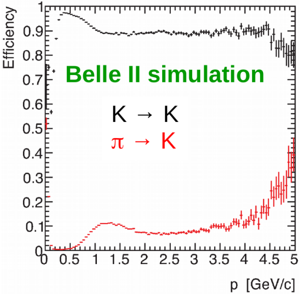
Detector highlights

PXD and iTOP









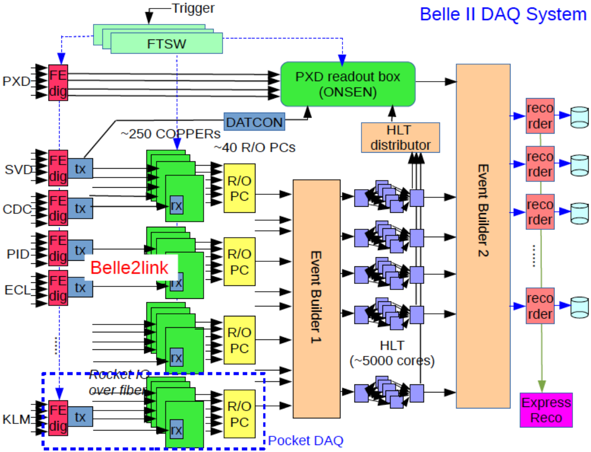
Vertex detectors:

- 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):

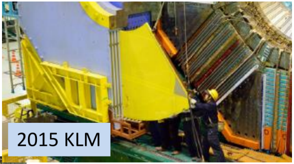
- $K - \pi$ separation is fundamental to distinguish among important final states and bkgs;
- crucial ingredient for B flavor tagger;
- expected performance: $K(\pi)$ efficiency $> 90\%$, with $\pi(K)$ fake rate $< 10\%$ for $p < 4$ GeV$/c$.

A modern DAQ and readout system

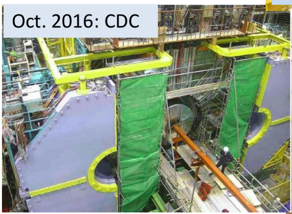


- Belle2link by IHEP; Dr. Chunhua Li (辽师大) is the previous convener of HLT group.
- Front-end readout electronics and Gb fiber optic link (Belle2link) to the back-end.
- ROI (Region of Interest) for PXD data volume.

Sub-detector installation


2015 KLM


May 2016: TOP


Oct. 2016: CDC


Jan. 2017 BWD ECL


Apr 2017
Belle roll-in

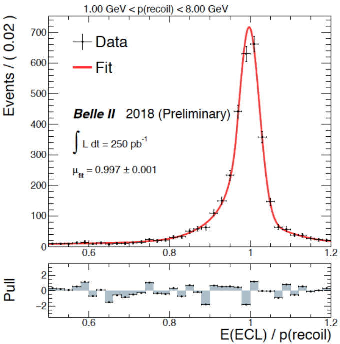

Aug.2017:ARICH


VXD: 2017 Nov.

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

Signals involving photons

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

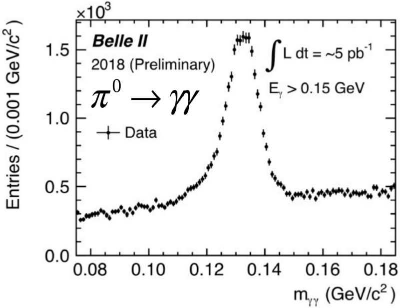


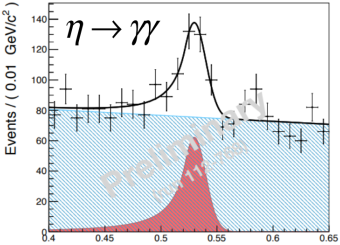
Single Photon Lines

Ready for the dark sector !

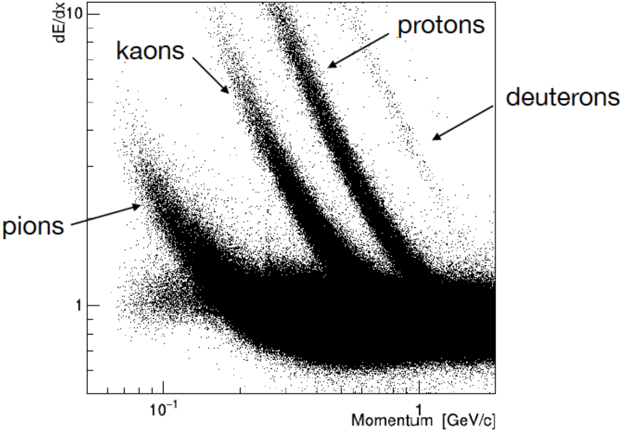
$$e^+e^- \to \gamma X$$

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



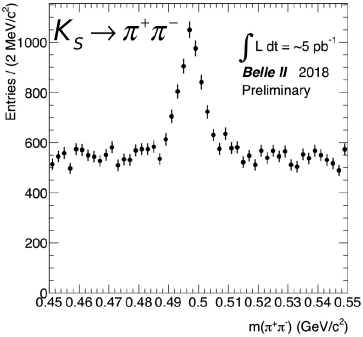


dE/dx from CDC for PID

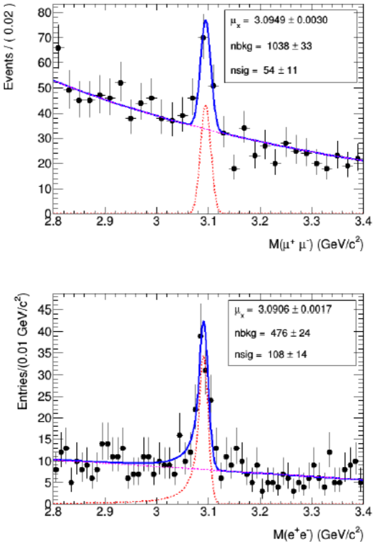


Extra cuts:
- |d0| < 1
- |dz| < 3
- # layers hit > 20

Signals involving charged tracks

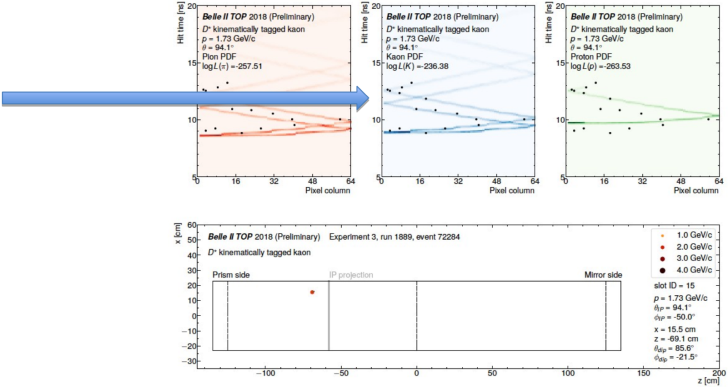


$J/\psi \to \mu^+\mu^-$, $J/\psi \to e^+e^-$



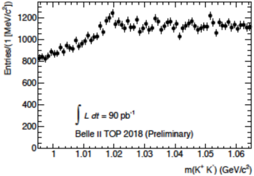
TOP for Particle Identification
$D^{*+} \to D^0 \pi_s^+; D^0 \to K^- \pi^+$

- 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):

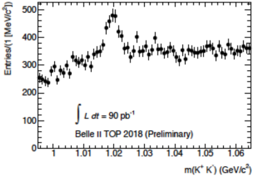


Inclusive $\phi \to K^+K^-$ with Kaon identification in TOP

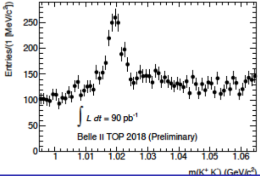
- No kaons identified:



- One kaon identified in the TOP:



- Both kaons identified in the TOP:



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

- Signals with no PID:

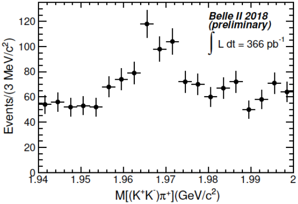


FIG. 1: This figure shows $M[(K^+K^-)\pi^+]$ distribution, which was produced using phase-II 366 pb^{-1} hadron skim data. No PID criteria are applied to any of the charged tracks ($K^\pm\pi^+$). Selection criteria and further details are described in the internal note BELLE2-NOTE-PH-2018-026.

- Signals with two identified charged kaons:

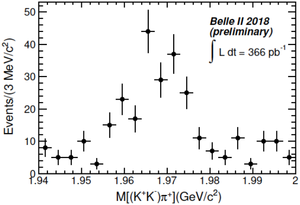


FIG. 2: This figure shows $M[(K^+K^-)\pi^+]$ distribution, which was produced using phase-II 366 pb^{-1} hadron skim data. Combined PID criteria, Prob(K:π) >0.5 for $K^\pm$ tracks and Prob(π:K) >0.5 for π^+ tracks are applied. Selection criteria and further details are described in the internal note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

R_2 distribution

- Fox-Wolfram moment:

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

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

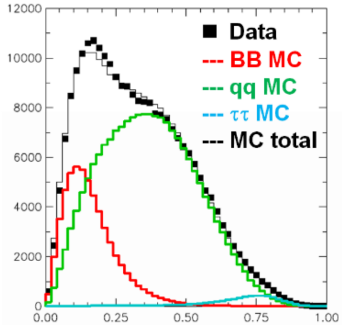


FIG. 1: R_2 distribution with Belle exp 5 data.

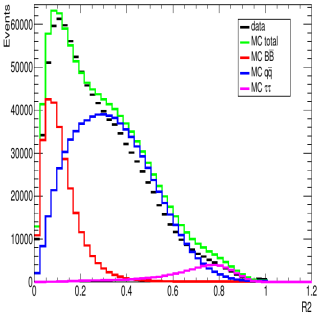


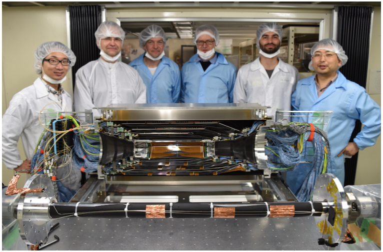
FIG. 9: R_2 distribution with Belle II exp 3 data (prod3 250 pb^{-1}).

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。复旦博士后刘清源即将参与PXD的工作。

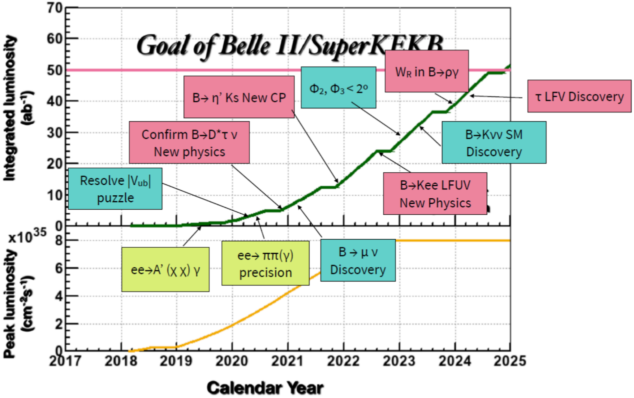
- SVD +x half-shell, Jan. 2018



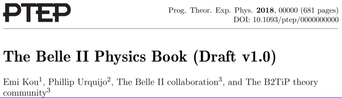
- SVD -x half-shell, July 2018

Luminosity and prospect

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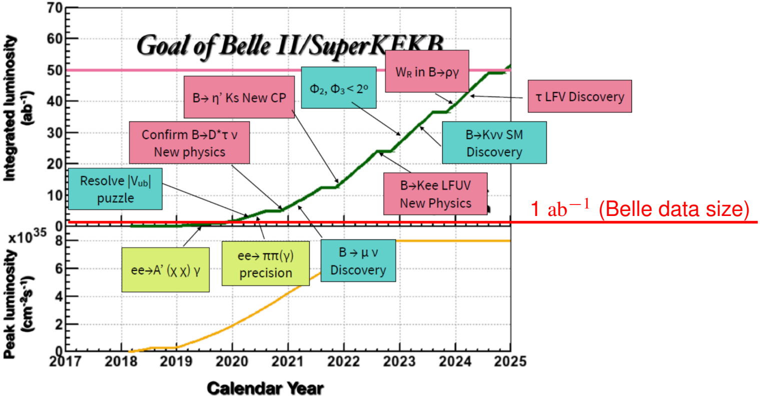

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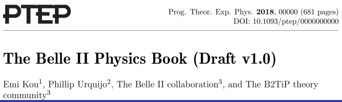
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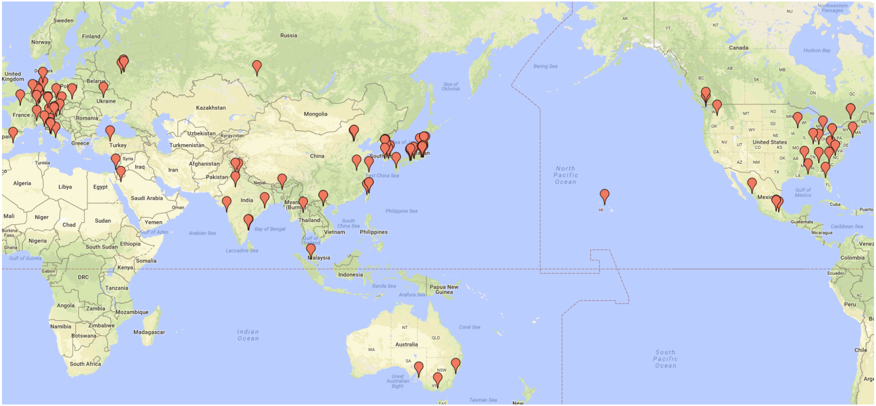
Belle II Collaboration



- Belle II Collaboration: 25 counties/regions, 110 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40名。
- 中国组网页: https://napp.fudan.edu.cn/belle2/

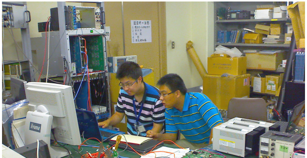
第一届Belle II中国组研讨会

欢迎加入Belle II中国组！

The China group at Belle II

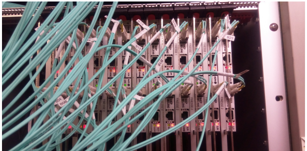
Past & now at Belle II

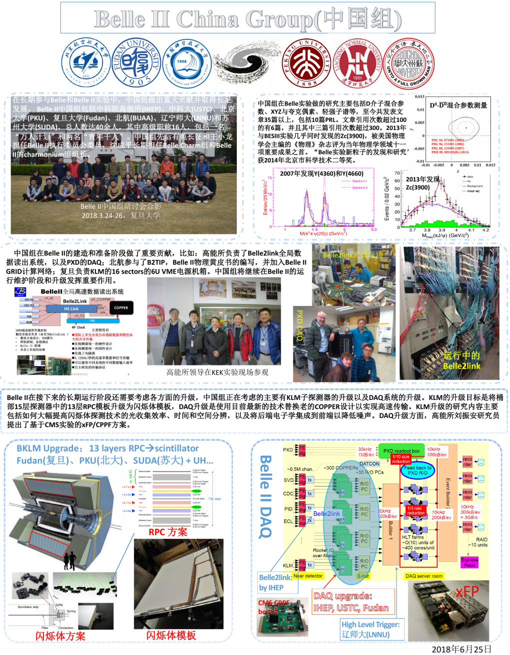
- China group made great contribution to Belle II
    - Belle2link (IHEP)
    - PXD DAQ (IHEP)
    - B2TIP — physics potential study (BUAA)
- China group is contributing more
    - Belle II maintenances and calibrations: CDC by IHEP, KLM by Fudan+USTC+SUDA, HLT by LNNU.
    - KLM detector (Fudan, SUDA)
    - 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?





Belle II China Group(中国组)

在长期参与Belle和Belle II实验中，中国组做出重大贡献并取得长足发展。Belle II中国组包括中科院高能所(IHEP)、中科大(USTC)、北京大学(PKU)、复旦大学(Fudan)、北航(BUAA)、辽宁师大(LNNU)和苏州大学(SUDA)，总人数达40余人，其中高级职称16人，包括一名“万人计划”和两名“青年千人”。中国组先后有苑长征和王小龙担任Belle II执行委员会委员，沈成平长期担任Belle Charm组和Belle II的charmonium组组长。

Belle II中国组研讨会合影
2018.3.24-26，复旦大学

中国组在Belle实验做的研究主要包括D介子混合参数、XYZ与夸克偶素、轻强子谱等，至今共发表文章35篇以上，包括10篇PRL。文章引用次数超过100的有6篇，并且其中三篇引用次数超过300。2013年与BESIII实验几乎同时发现的Zc(3900)，被美国物理学会主编的《物理》杂志评为当年物理学领域十一项重要成果之首。“Belle实验新粒子的发现和研究”获2014年北京市科学技术二等奖。

中国组在Belle II的建造和准备阶段做了重要贡献，比如：高能所负责了Belle2link全局数据读出系统，以及PXD的DAQ；北航参与了B2TIP，Belle II物理黄皮书的编写，并加入Belle II GRID计算网络；复旦负责KLM的16 sectors的6U VME电源机箱。中国组将继续在Belle II的运行维护阶段和升级发挥重要作用。

BelleII全局高速数据读出系统

2009底高能所受邀参加触发实验室负责（命名为Belle2Link）
- 整体方案设计、TDR撰写
- 样机研制、系统调试
- Belle II 联调
- 负责工作组的协调

主要特性有
- ■国际上率先实现告诉通路数据和慢控命令的共享传输
- ■各探测器统一的硬件设计
- ■各探测器统一的固件设计
- ■实现了电隔离
- ■3.125Gb/秒的高速率数据和信号传输
- ■可以兼容不同系统的不同数据输入速率
- ■自主研发的传输协议

高能所领导在KEK实验现场参观

Belle2link测试现场

PXD DAQ

运行中的Belle2link

Belle II在接下来的长期运行阶段还需要考虑各方面的升级，中国组正在考虑的主要有KLM子探测器的升级以及DAQ系统的升级。KLM的升级目标是将桶部15层探测器中的13层RPC模板升级为闪烁体模板，DAQ升级是使用目前最新的技术替换老的COPPER设计以实现高速传输。KLM升级的研究内容主要包括如何大幅提高闪烁体探测技术的光收集效率、时间和空间分辨，以及将后端电子学集成到前端以降低噪声。DAQ升级方面，高能所刘振安研究员提出了基于CMS实验的xFP/CPPF方案。

BKLM Upgrade：13 layers RPC→scintillator
Fudan(复旦)、PKU(北大)、SUDA(苏大) + UH...

RPC 方案

闪烁体方案

闪烁体模板

Belle II DAQ

Belle2link: by IHEP

DAQ upgrade: IHEP, USTC, Fudan

High Level Trigger: 辽师大(LNNU)

CMS CPPF board

xFP

2018年6月25日

2018年7月和8月，中科院和发改委领导访问KEK，并参观Belle II. 为此我们制作张贴于Belle II实验大厅的海报。

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.
- $0.8 \times 10^{36}\ cm^{-2}s^{-1}$ will make Belle II a luminosity revolution experiment, and open new windows for various physics topics.
- What can we do with the coming Belle II data?

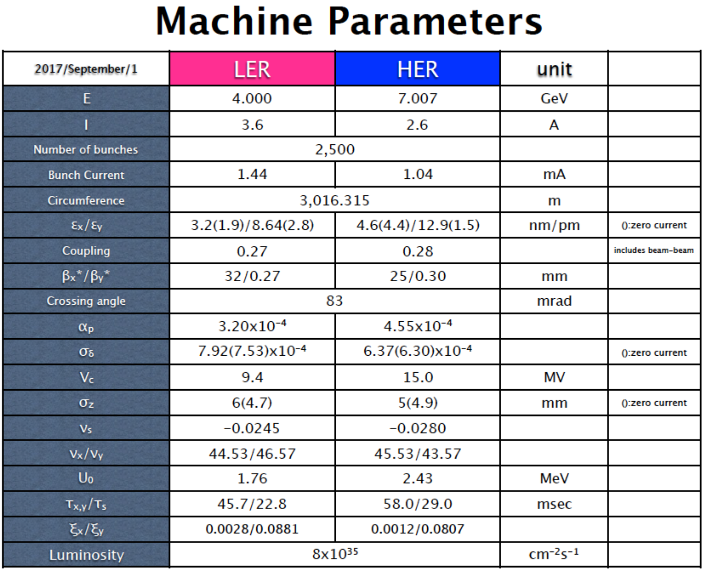
Thank you!

Back-up

From Belle to Belle II

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

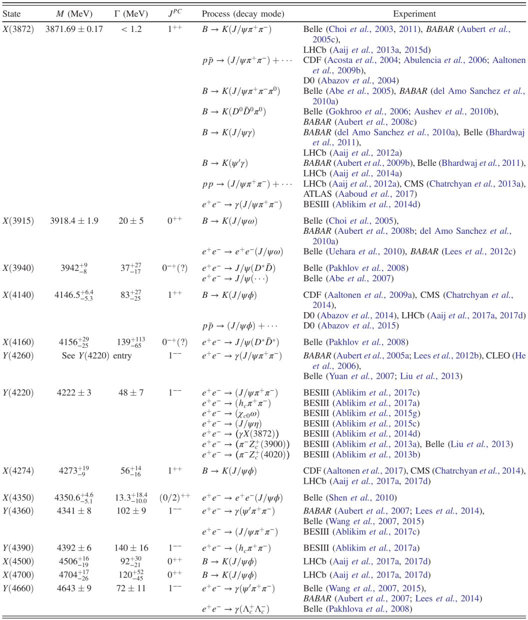
Machine Parameters



Machine Parameters

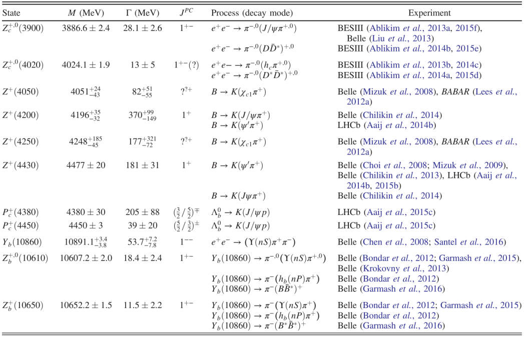
2017/September/1	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.20×10^{-4}	4.55×10^{-4}		
σ_δ	$7.92(7.53)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		():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	8×10^{35}		$cm^{-2}s^{-1}$	

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



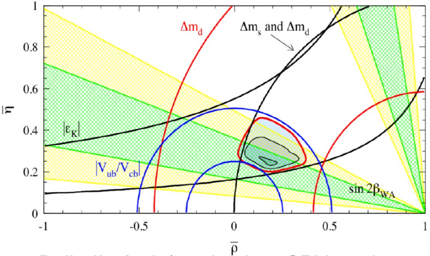
State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$Z_c^{+,0}(3900)$	3886.6 ± 2.4	28.1 ± 2.6	1^{+-}	$e^+e^- \to \pi^{-,0}(J/\psi\pi^{+,0})$	BESIII (Ablikim *et al.*, 2013a, 2015f), Belle (Liu *et al.*, 2013)
				$e^+e^- \to \pi^{-,0}(D\bar{D}^*)^{+,0}$	BESIII (Ablikim *et al.*, 2014b, 2015e)
$Z_c^{+,0}(4020)$	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)

- Belle is not just a *B* factory, but also a charm factory.
- High luminosity and high energy open the area of open-charm, which is quite different to light hadrons.
- There may be new hadrons out of quark model discovered: multi-quarks, molecule states, hadro-charmonium, glueball, ...
- China group contributes a lot: $Y(4008)$, $Y(4260)$, $X(4350)$, $Y(4360)$, $Y(4660)$, $Z_c(3900)^+$, ...

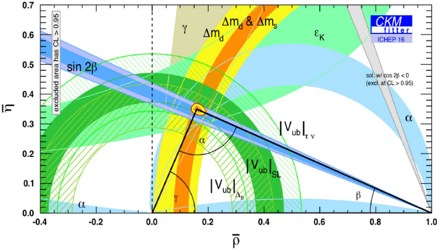
Pictorial Outlook

Before B-factories

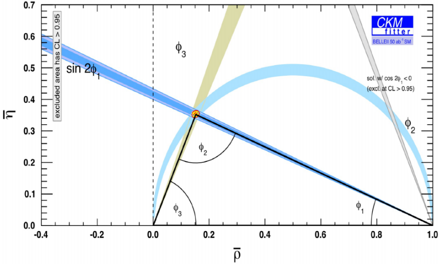
Eur.Phys.J.C21:225-259,2001



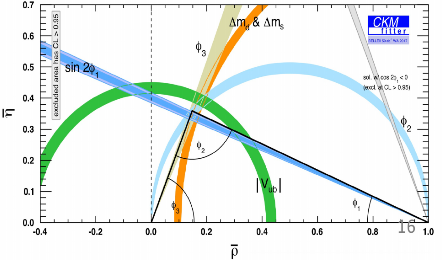
After B-factories



Belle II 50 ab^{-1} projection, CPV modes only



Belle II 50 ab^{-1} projection, all constraints



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
🟡	$B \to \pi \ell \nu_l$	$\|V_{ub}\|$	$\star\star\star$	10-20	$\star\star\star$	$\star\star\star$	$\star\star$	$\star$
🟡	$B \to X_u \ell \nu_\ell$	$\|V_{ub}\|$	$\star\star$	2-10	$\star\star\star$	$\star\star$	$\star\star\star$	$\star$
🟡	$B \to \tau \nu$	$Br.$	$\star\star\star$	$>$50 (2)	$\star\star\star$	$\star\star\star$	$\star$	$\star\star\star$
🟡	$B \to \mu \nu$	$Br.$	$\star\star\star$	$>$50 (5)	$\star\star\star$	$\star\star\star$	$\star$	$\star\star\star$
🟡	$B \to D^{(*)} \ell \nu_\ell$	$\|V_{cb}\|$	$\star\star\star$	1-10	$\star\star\star$	$\star\star$	$\star\star$	$\star$
🟡	$B \to X_c \ell \nu_\ell$	$\|V_{cb}\|$	$\star\star\star$	1-5	$\star\star\star$	$\star\star$	$\star\star$	$\star\star$
🟡	$B \to D^{(*)} \tau \nu_\tau$	$R(D^{(*)})$	$\star\star\star$	5-10	$\star\star$	$\star\star\star$	$\star\star\star$	$\star\star\star$
⚪	$B \to D^{(*)} \tau \nu_\tau$	P_τ	$\star\star\star$	15-20	$\star\star\star$	$\star\star\star$	$\star\star$	$\star\star\star$
⚪	$B \to D^{**} \ell \nu_\ell$	$Br.$	$\star$	-	$\star\star$	$\star\star\star$	$\star\star$	-

Time dependent CPV

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

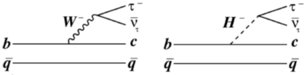
Some golden observables (II)

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_{CP}	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆
🟡	$B \to X_d\gamma$	A_{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	⋆⋆⋆	⋆	⋆	⋆⋆
⚪	$B_{d,(s)} \to \gamma\gamma$	$Br., A_{\mathrm{CP}}$	⋆⋆	$>$ 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

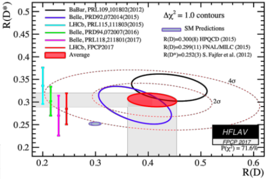
- Theoretically clean channel in SM
- Charged Higgs can contribute to the decay
- $R(D^{(*)})$ is sensitive parameter to BSM!

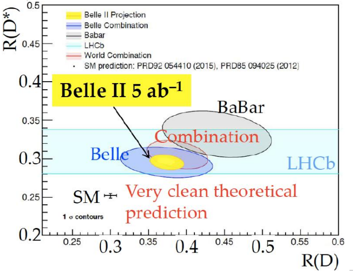


$$R(D^{(*)}) = \frac{\mathrm{Br}(B \to D^{(*)}\tau\nu)}{\mathrm{Br}(B \to D^{(*)}\mu\nu)}$$

	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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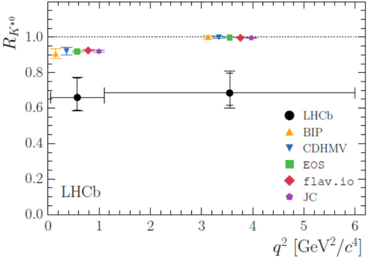
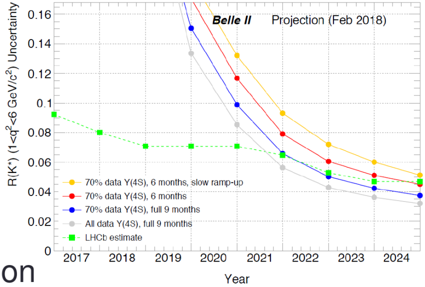


$$R(K^*) = \frac{BR(K^*\mu\mu)}{BR(K^*ee)}$$



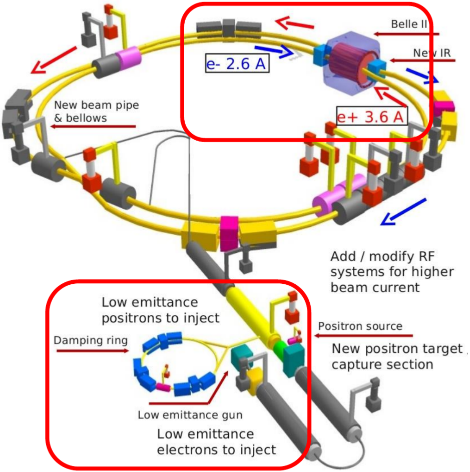
Note: LHCb value is extrapolated from run-1 result

- Belle II: good electron identification

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

SuperKEKB

- SuperKEKB is successor of former KEKB but refurbished with the new design



Belle II

New IR

e- 2.6 A

e+ 3.6 A

New beam pipe & bellows

Add / modify RF systems for higher beam current

Low emittance positrons to inject

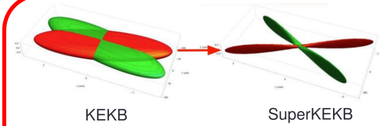
Damping ring

Positron source

New positron target capture section

Low emittance gun

Low emittance electrons to inject



“nano-beam” scheme

Beam squeezing: x20 smaller at IR

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

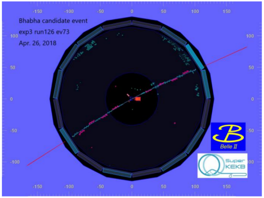
x2

X1/20

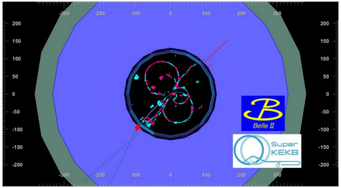
Target luminosity: 8x10^{35}cm^{-2}s^{-1}
KEKB x 40!

First collisions

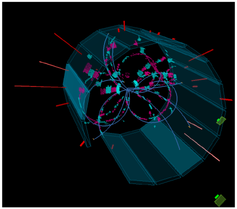
- First Belle II collisions on April 26, 2018 !!!
- Phase II ran until July 17.



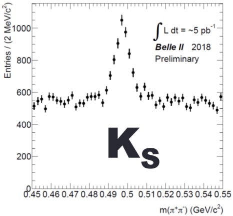
Bhabha event

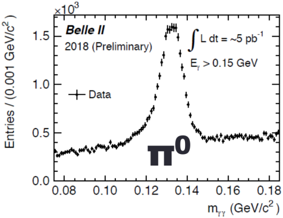


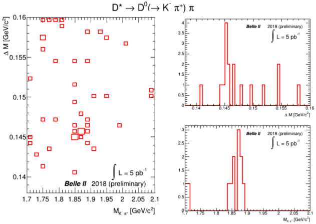
Hadronic event



$B\bar{B}$ like event







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