Exploring Matter-Antimatter Asymmetry: The Belle Experiment

천병구(한양대)

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Contents

- Heavy Flavor Physics
- Belle & Belle II experiments
- Legacy of prof. Sun Kee Kim
- Photos of the memories @ Belle

Heavy Flavor Physics

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, …

Leptons spin =1/2

Flavor	Mass GeV/c²	Electric charge
ν_L lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e electron	0.000511	−1
ν_M middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ muon	0.106	−1
ν_H heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ tau	1.777	−1

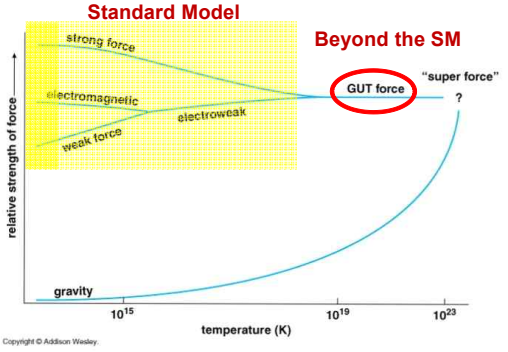
Quarks spin =1/2

Flavor	Approx. Mass GeV/c²	Electric charge
u up	0.002	2/3
d down	0.005	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	173	2/3
b bottom	4.2	−1/3

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

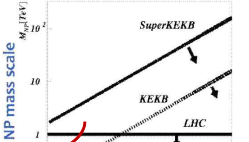
Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60



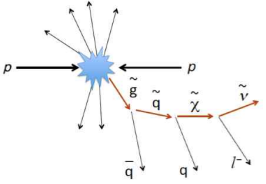
- Precision test of the Standard Model
- Search for New Physics beyond the SM

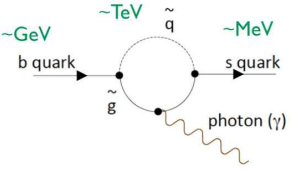
LHC *vs* SuperKEKB

- New Physics beyond the Standard Model
  - -- Direct new particle production : LHC/ ATLAS,CMS
  - -- Indirect new particle production : SuperKEKB/ Belle II
- Two collider experiments are complementary.
  - -- LHC vs SuperKEKB



실험과 Belle II 실험의 상보성

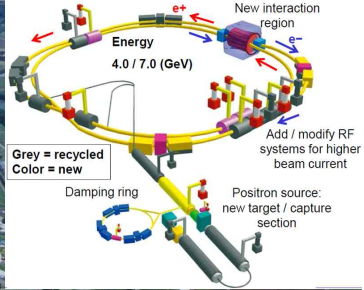




LHC : Energy Frontier
ATLAS,CMS

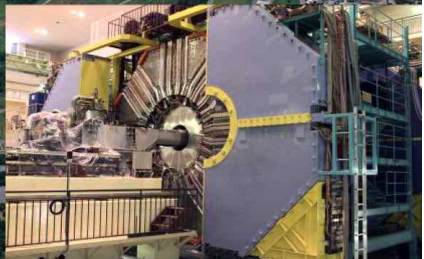
SuperKEKB: Luminosity Frontier
Belle II

일본 KEK 연구소

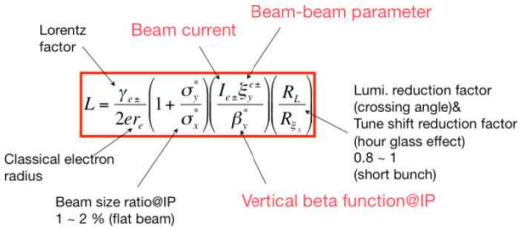


4.0GeV e^+

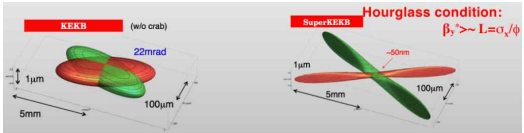
7.0GeV e^-



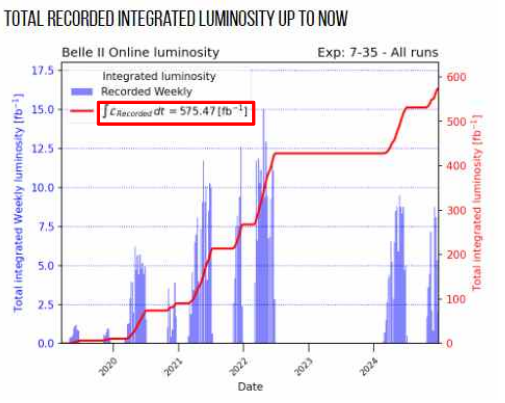
Instantaneous Luminosity

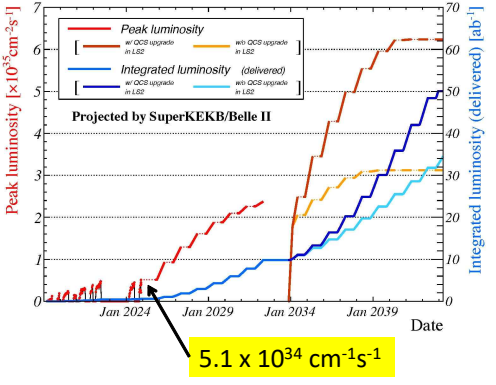


	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

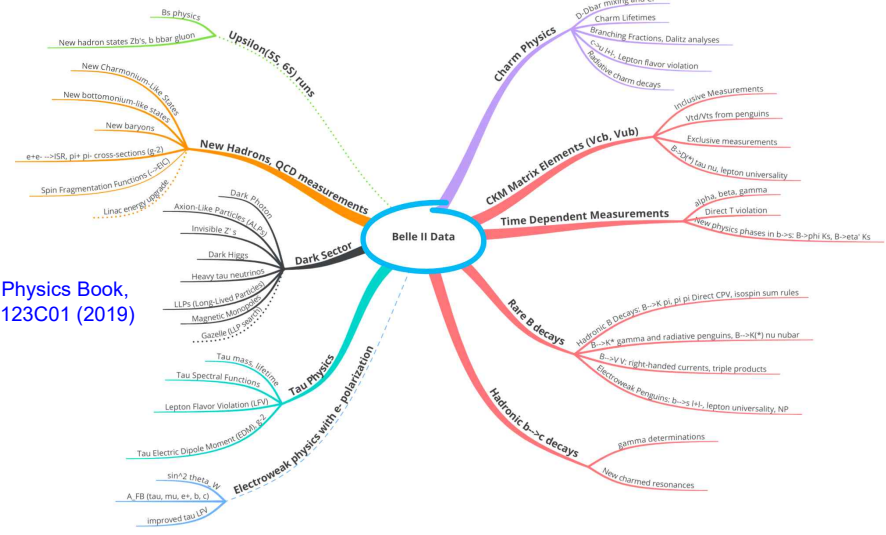


SuperKEKB/Belle II Luminosity





Belle II Physics Program



The Belle II Physics Book,
PTEP 2019, 123C01 (2019)

Belle & Belle II

Belle & Belle II milestones

- 1980 KEK B-factory 논의 시작
- 1994 일본 정부 승인
- 1999 Belle physics run w/ full detector
- **2001 B 중간자 CP 대칭성 깨짐 발견!**
- 2003 X(3872) 발견
- 2007 D^0 mixing 최초 증거
- 2008 B → Kπ CPV [Nature (2008)]
- **2008 고바야시&마스카와 노벨상 수상**
- Belle Data : ~ 1 ab^{-1} (10억개 B-pairs)
- ~650 Journal papers

- 2011 SuperKEKB & Belle II 건설 시작
- 2016 SuperKEKB commissioning
- 2019 Belle II physics run w/ full detector
- Belle II Data : 575.47 fb^{-1}
- Up to now ~75 Journal papers

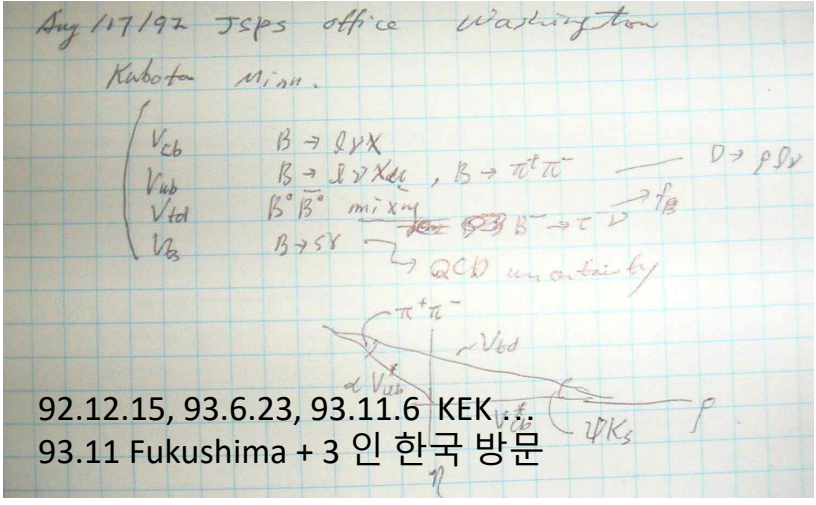
한국 BELLE 그룹의 태동과 초기 활동

- Based on SKK's personal memory & logbook

김선기
서울대학교 물리천문학부

AMY 실험 후속으로
Belle 실험에 참여

Pre-History



92.12.15, 93.6.23, 93.11.6 KEK ...

93.11 Fukushima + 3 인 한국 방문

3 77,860 2191

Minutes of B-factory collaboration general meeting

Date: Jan. 25-26, 1994
Place: Nara Women's University

Jan.25 ==========

[1] Report of ad. hoc. committee

At the last group meeting held at KEK in November, it was decided that the interim steering committee (sewa-nin-kai) appoints ad. hoc. committee to select 3 spokespersons (1 from KEK, 1 from Japanese Univ. and 1 from Oversea).

Appointed ad. hoc. committee members were:
F.Takasaki, M.Yamauchi, T.Matsuda, K.Abe, M.Fukushima (KEK),
Y.Watanabe (TIT), H.Yuta (Tohoku), S.Noguchi (Nara),
S.Suzuki (Nagoya), J.Haba (Osaka), T.J.Wang (Beijing), S.Olsen (Hawaii),
B.Shwarts (BINP, Novosibirsk), S.K.Kim (Seoul National U.)

The committee had a meeting at Dec 22 at KEK (Present: Takasaki, Yamauchi, Shwarts, Abe, Fukushima, Watanabe, Noguchi, Suzuki, Haba, Wang, Olsen). Summary is as follows:

* Three spokespersons are nominated.
  S.Olsen (Hawaii Univ.)
  S.Suzuki (Nagoya Univ.)
  F.Takasaki (KEK)
  Those should get approval at the general meeting.
* Terms of the spokespersons are two years and renewable. To get new one, institutional board will form a nominating committee.
* Spokespersons will select executive board members, 3 from KEK, 3 from Universities in Japan, 2-3 from Universities out side Japan, and 2-3 at large. (+ 3 spokespersons)

[2] Approval of spokespersons
Three spokespersons nominated by ad. hoc. commitee were approved.

[3] Approval of

Jan. 26 ==========

[6] Vote for group name.

Group members present had two votes.
Following is the list of names and number of votes.

APHRODITE	3	DARUMA	9
BANKO	9	DRAGON	6
BEAST	7	KOTORI	2
BEAT	10	MIMI	2
BEE	9	OBI	3
BELLE	15	PEACE	15
BFK	7	SACRA	8
B-FAK	0	TAMI	4
BOTANY	3		

Next step is to select two names among the top three
"BEAT, BELLE, and PEACE" by E-mail vote.

[7] Short talks on the various topics;

Electronics Readout Issues	D. Marlow
RICH Counter Works at Pronceton	E. Prebys
Plan of Crystal Fabrication in China	D.S. Yan
Activities at Novosibirsk	V. A. Sidorov
Activity at Cracow	K. Rybicki

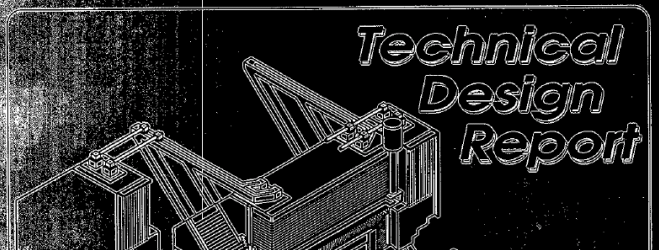
[8] Critical issues of Accelerator was discussed by S. Kurokawa

[9] Mechanics for the communication among the group

Experi... collaboration was presented by A. Breakstone.
...viewed by Y. Sa...

KEK Report 95-1
April 1995
H

A Study of CP Violation in B Meson Decays



Technical Design Report

BELLE Collaboration

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Chuo Univers

N. Katayama

Y. Tamagawa

A. Breakston
University of

M. Asai, *Hirc*

J. Z. Bai, H.S
T.J. Wang, X
Institute for

X.L. Fang, S.
Joint Crystal
52 Sanlihe ro

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H. Sagawa, M
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Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061

J.H. Kang and S.M. Pahk, *Yonsei University, Seoul, 120-749*

==========

From : Byung Gu Cheon (bgcheon@hep1.snu.ac.kr)
To : Korean BELLE Group Members
Subject : 2nd Korean BELLE Meeting

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Dear Collaborators,

1995

The 2nd regular Korean BELLE Group Meeting is scheduled on Jun 10th (Sat.)
at Seoul National University (25Dong-313Ho). Here is a tentative agenda
that I propose, but please let me know if you have any comment or
like to give a talk.

14:30-14:40 S.K.Kim : BELLE Status
14:40-15:00 B.G.Cheon : CsI Calorimeter status
15:00-15:15 I.C.Park : FPGA/Xilinx in LeCroy 2366 Module

15:15-15:30 Coffee break

15:30-15:50 S.S.Myung : V_td measurement / BELANL usage
15:50-16:00 G.Y.Kim : V_u measurement in BELLE experiment
16:00-16:15 T.W.Hur : BELANL install on Alpha-station

16:15-16:30 Coffee break

16:30-17:10 Discussion Session
S.K.Kim : Korean Group Status at BELLE experiment
J.S.Kang : KUHEP Status
J.H.Kang : YSUHEP Status

한국 BELLE 그룹의 방향
-for discussion

제2회 KBELLE meeting
1995년 6월 10일
서울대학교
김 선 기

*** Current Activities**

*At KEK

김 동영(고대) : ECL Front End Electronics : Preamplifier, Shaper, Digitizer(FASTBUS Q-to-T + TDC)
안 호석(서울대): R&D on pure CsI crystal for Endcap ECL option
이 무현(KEK) - Special member of KBELLE Group : ECL Assembly

*고대

명 성숙 / 윤 형호 Simulation study of Vtd measurement

*연대

Warming up

*서울대

허 태웅 : Trigger simulation
박 인철 : Xilinx Chip logic design

천 병구 : Overall orgnization of ECL trigger
김 근영 : Simulation study of Vub measurement

*** 어떻게 진행할 것인가 ?**

1. Concentrate only on ECL (KU+YU+SNU)
2. Separate main efforts of institutions and make some efforts together.
   eg. KU : Computing
   YU : SVD vertex detector
   SNU: ECL calorimeter

Comparison of shorts and longs

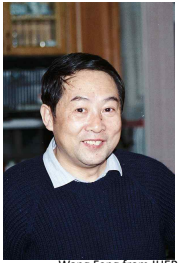
	1	2
Advantages	.make an unified effort .share resources efficiently	.develop expertise in several parts of the experiment .do not need strong organization .flexibility in group expansion
Disadvantages	.activities are to localized .need a strong organization .hard to expand group	.rather difficult to make an unified effort .resource sharing may be somewhat difficult

1997

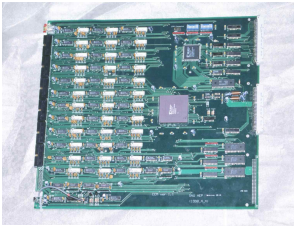
Agenda for KBELLE meeting on Nov. 29, 1997
Morning Session Chair : Youngil Choi
10:00 : Sun Kee Kim, Opening
10:10 : Young Joon Kwon, Belle gerneral meeting summary
10:20 : Hong Joo Kim, Status of the ECL trigger
10:30 : Hee Jong Kim, Logic design of ECL trigger master
10:40 : ByungSub Ahn, Test of Q/T module
10:50 : Sangryul Ro, MC Study of Hadron Effect in BTOF Counters
11:00 : Dounguk Kim, Study of dE/dx in BTOF
11:10 : HeeJong Kim, Measurement of Time Resolution with TOF Counters
11:20 : Soo Kyung Choi, Status of EFC
11:30 : Jiwoo Nam, Searching of B_s in LEP ALEPH
11:40 : Jiwoo Nam, Simulation Study of B -> pipi
11:50 : Chawon Park, Progress Report of B-->rhopi
12:00 - 13:30 Lunch
Afternoon Session Chair : Soo Kyung Choi
13:30 : Byoungsup Ahn, Progress Report of B-->D*D*
13:40 : Sung-Min Pahk, Feasibility at Y(5s)? Bs -> K+ K-
13:50 : Dong Wook Jang, b -> s l+ l- inclusive
14:00 : So-Myoung Choi, Continuum background and other thoguhts
on B -> K* l+ l-
14:10 : Eunil Won, Comments on K*l+l-
14:20 : Hong Joo Kim, Comments on s nu nu,...
14:30 : Seong Sook Myung, Development of analysis utilities in C++
14:40 : Eunil Won, SP2, the prospect
14:50 : Joo Sang Kang, Concluding remark
15:00 - 16:00 Executive session
16:00 - 17:30 B-workgroup meeting

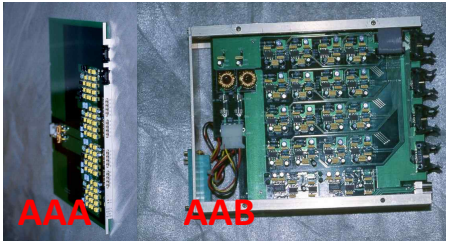
KBELLE 의 기여 : ECL Construction

KBELLE의 독자적인 기여
– ECL Trigger



Wang Feng from IHEP
Stayed at SNU
1996.8.1 -1997.

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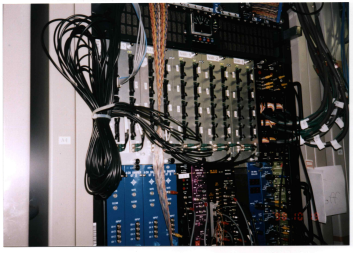
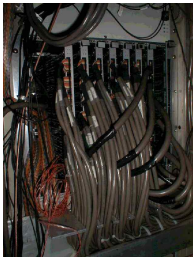
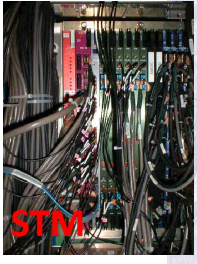
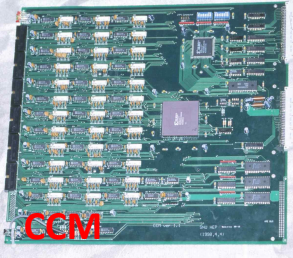
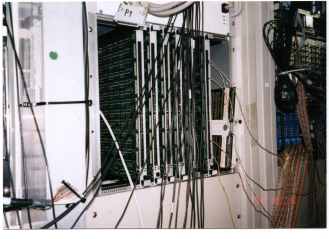
AAB






STM


CCM

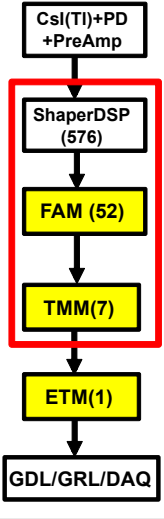


Belle 서울대 졸업생

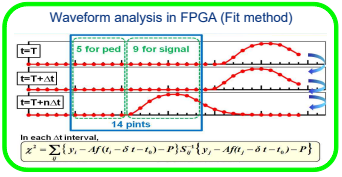
- 박사 (12): 박철수, 장현기, 이상희, 양혜영, 이상은, 이명재, 류수, 이재용, 문태진, 김봉호, 양성배, 주창우

- 석사 (8): 안호석,허태웅, 김근영, 박인철, 장현기, 김창환, 이상희, 노재준

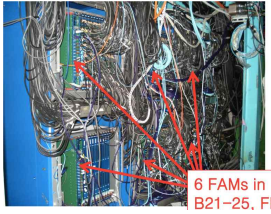
Belle II Calorimeter Trigger System

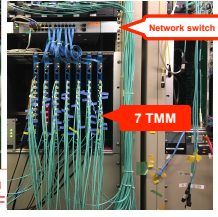


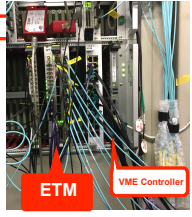
- FAM (FADC Analysis Module)
  - Measure TC Energy & Timing
  - Waveform analysis
  - Apply TC threshold > 100 MeV
- TMM (Trigger Merger Module)
  - Merge FAM data and send to ETM
- ETM (ECL Trigger Master)
  - Perform ECL trigger decision (Physics & Bhabha)



- All of ShaperDSP/FAM/TMM electronics boards mass-produced in Korea.
- This system fully working at Phase II operation.







Belle II Experiment

- 전세계 28개국 123개기관, ~1200연구자
- 한국 10개기관 41 연구자
- 해외대형연구시설활용연구지원사업 수행 (PI: 이명재)
- SuperKEKB: 전자 7GeV / 양전자 4GeV 충돌 가속기
- CPV 연구를 통한 우주의 물질-반물질 비대칭성 연구
- 다양한 Intensity-Frontier 입자물리학 실험 연구

Belle 시절 KEK 추억 사진들


10
2


박상원
원은익
김현우


'99 3 26

I met Professor Sun Kee Kim when I was a young post-doc joining the Belle experiment, was his colleague there during a decade.
He made significant and essential contributions to the ECL detector and the trigger system.

A big part of the success of our experiment !

Congratulations on your well-deserved retirement !

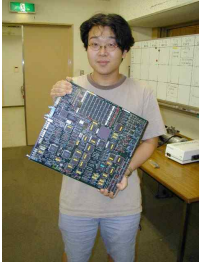
Karim Trabelsi
(Belle II spokesperson 2023-2025)

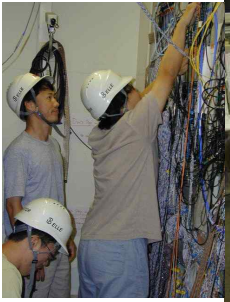
Backup

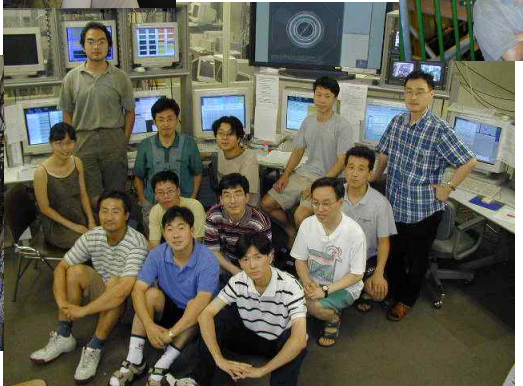
~ 1995
Flower Park near
Tsukuba-san

BELLE calorimeter members after a beam test ending party at dormitory.(June 17th 1995)

Korean BELLE members on the Top of hill where a B physics summer school was held. (~ 1995) With Hayashii san of Nara.

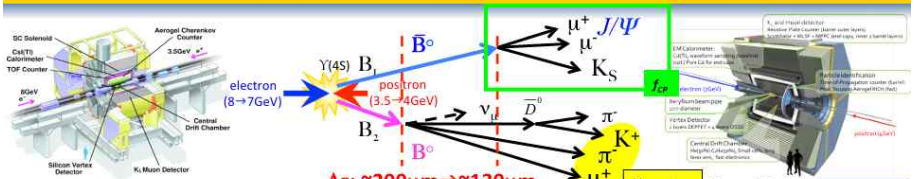




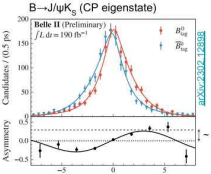


93 94 95 96 97 98 overflow

Challenges toward Belle II Experiment



- **High beam background**
  - Fine segmentation and fast readout → occupancy reduction
  - Replacement of detectors
- **Improve detection efficiency for neutral particles**
  - Larger VXD outer radius → Improvement on K_S detection efficiency
  - New scintillators in KLM → Improvement on K_L detection efficiency
- **Smaller Lorentz boost (for lower beam emittance and longer beam life)**
  - Smaller VXD inner radius → Improvement on vertex position resolution



Belle II *vs* LHCb

Property	LHCb	Belle II
$\sigma_{b\bar{b}}$ (nb)	~150,000	~1
$\int L\,dt$ (fb^{-1}) by ~2024	~25	~50,000
Background level	Very high	Low
Typical efficiency	Low	High
π^0, K_S reconstruction	Inefficient	Efficient
Initial state	Not well known	Well known
Decay-time resolution	Excellent	Very good
Collision spot size	Large	Tiny
Heavy bottom hadrons	B_s, B_c, b-baryons	Partly B_s
τ physics capability	Limited	Excellent
B-flavor tagging efficiency	3.5 - 6%	36%

Belle II physics potential

“The Belle II Physics Book” arxiv:1808.10567

Process	Observable	Theory	Sys. limit [Discovery] [ab^{-1}] vs LHCb	vs Belle	Anomaly	NP
$B \to \pi l \nu_l$	$\|V_{ub}\|$	⋆⋆⋆	10-20	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆
$B \to X_u l \nu_l$	$\|V_{ub}\|$	⋆⋆	2-10	⋆⋆⋆	⋆⋆	⋆⋆⋆	⋆
$B \to \tau\nu$	$Br.$	⋆⋆⋆	>50 (2)	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$B \to \mu\nu$	$Br.$	⋆⋆⋆	>50 (5)	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$B \to D^{(*)} l \nu_l$	$\|V_{cb}\|$	⋆⋆⋆	1-10	⋆⋆⋆	⋆⋆	⋆⋆	⋆
$B \to X_c l \nu_l$	$\|V_{cb}\|$	⋆⋆⋆	1-5	⋆⋆⋆	⋆⋆	⋆⋆	⋆⋆
$B \to D^{(*)} \tau \nu_\tau$	$R(D^{(*)})$	⋆⋆⋆	5-10	⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆
$B \to D^{(*)} \tau \nu_\tau$	P_τ	⋆⋆⋆	15-20	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆⋆
$B \to D^{**} l \nu_l$	$Br.$	⋆	-	⋆⋆	⋆⋆⋆	⋆⋆	-
$B \to K^{(*)} \nu\nu$	$Br., F_L$	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆
$B \to X_{s+d} \gamma$	A_{CP}	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆
$B \to X_s \gamma$	A_{CP}	⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	-	⋆⋆
$B \to K^0_S \pi^0 \gamma$	$S_{K^0_S \pi^0 \gamma}$	⋆⋆	>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	⋆⋆⋆	⋆	⋆	⋆⋆
$B_{d,(s)} \to \gamma\gamma$	$Br., A_{CP}$	⋆⋆	>	⋆⋆	⋆⋆	-	⋆⋆
			50(5)				
$B \to K^* e^+ e^-$	P_4'	⋆⋆	>50	⋆⋆⋆	⋆⋆	⋆⋆⋆	⋆⋆⋆
$B \to K \tau l$	$Br.$	⋆⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆⋆
$B \to J/\psi K^0_S$	ϕ_1	⋆⋆⋆	5-10	⋆⋆	⋆⋆	⋆	⋆
$B \to \phi K^0_S$	ϕ_1	⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$B \to \eta' K^0_S$	ϕ_1	⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$B \to J/\psi \pi^0$	ϕ_1	⋆⋆⋆	>50	⋆	⋆⋆⋆	-	-
$B \to \rho^\pm \rho^\mp$	ϕ_2	⋆⋆⋆	-	⋆	⋆⋆⋆	⋆	⋆
$B \to \pi^0 \pi^0$	ϕ_2	⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆
$B \to \pi^0 K^0_S$	S_{CP}	⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆

Process	Observable	Theory	Sys. limit [Discovery] [ab^{-1}] vs LHCb	vs Belle	Anomaly	NP
GGSZ	ϕ_3	⋆⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆
GLW	ϕ_3	⋆⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆
ADS	ϕ_3	⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
Time-dependent	$\phi_3 - \phi_2$	⋆⋆	-	⋆⋆	⋆⋆	⋆	⋆
$B \to \pi^0 K^0$	$A_{CP}, I_{K\pi}$	⋆⋆	-	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆⋆
$B \to \rho K$	$A_{CP}, I_{K\rho}$	⋆	-	⋆⋆	⋆⋆⋆	-	⋆⋆
$B \to b\gamma$	λ_B	⋆⋆	-	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆
$B \to \rho K^*$	γ polari.	⋆⋆	-	⋆⋆	⋆⋆	-	⋆⋆⋆
$B \to K^+ K^- / \pi^+ \pi^-$	$Br., A_{CP}$	⋆⋆	-	⋆	⋆⋆⋆	⋆⋆	⋆⋆
$B \to K\pi\pi, KKK$	A_{CP}	⋆⋆	-	⋆	⋆	⋆⋆⋆	⋆
$B_s \to K^0 \bar{K}^0$	lifetime	⋆	-	⋆⋆	⋆⋆⋆	-	⋆⋆
$D^0 \to K^0_S K^0_S$	A_{CP}	⋆⋆⋆	-	⋆⋆⋆	⋆⋆	⋆	⋆
$D^+ \to \pi^+ \pi^0$	A_{CP}	⋆⋆⋆	-	⋆⋆⋆	⋆⋆	⋆	⋆⋆
$D_s \to \ell^+ \nu$	f_{D_s}	⋆⋆⋆	-	⋆⋆⋆	⋆	-	⋆⋆
$D^0 \to V\gamma$	A_{CP}	⋆	-	⋆⋆	⋆⋆	⋆⋆	⋆⋆
$D^0 \to \gamma\gamma$	$Br.$	⋆	-	⋆⋆	⋆⋆	⋆⋆	⋆⋆
$D^0 \to \nu\bar{\nu}$	$Br.$	⋆⋆⋆	-	⋆⋆⋆	⋆⋆	⋆⋆⋆	⋆⋆⋆
$D \to \ell^+ \nu$	f_D	⋆⋆⋆	-	⋆	⋆	-	⋆⋆
$\tau \to \mu\gamma$	$Br.$	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$\tau \to lll$	$Br.$	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$\tau \to K\pi\nu$	A_{CP}	⋆⋆⋆	-	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆
$e^+e^- \to \gamma A'(\to \text{invisible})$	σ	⋆⋆⋆	-	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$e^+e^- \to \gamma A'(\to \ell^+\ell^-)$	σ	⋆⋆⋆	-	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
π form factor	$g-2$	⋆⋆	-	⋆⋆⋆	⋆⋆	⋆⋆	⋆⋆⋆
ISR $e^+e^- \to \pi\pi$ g-2	$g-2$	⋆⋆	-	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆⋆