^{3}He neutron detectors in Belle II

Caleb Miller , Samuel de Jong , Micheal Roney

University of Victoria

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Introduction

- Motivation
  - SuperKEKB
  - Understanding Simulation with BEAST II
- ^{3}He as a neutron detector
- Phase 1 commissioning of SuperKEKB
  - Beam Gas and Touschek Scattering
  - Calibration of ^{3}He tubes
  - Implications for Belle-II
- Phase 2 commissioning of SuperKEKB
  - Plans and status

Motivation

- SuperKEKB will deliver e^+e^- collisions with 10.58 GeV COM energy
  - e^+ at 4 GeV
  - e^- at 7 GeV
- The luminosity goal of SuperKEKB is $8 \times 10^{35} cm^{-2} s^{-1}$
  - 40x the luminosity of KEKB
- Commissioning of the accelerator will take place in three separate phases
  - Phase 1: Beam gas and Touschek studies, no collisions (Completed 2016)
  - Phase 2: Collisions begin with Belle-II in place, no vertex detectors (February 2018)
  - Phase 3: Vertex detectors installed, Physics runs begin (Late 2018)
- Simulations for the running of Belle II and SuperKEKB were made with a combination of SAD and GEANT4
  - SAD: Strategic Accelerator Design

Motivation

- During the running of Belle II high energy collisions will produce a range of particles including neutrons
- Neutrons in particular can be hard on silicon based electronics

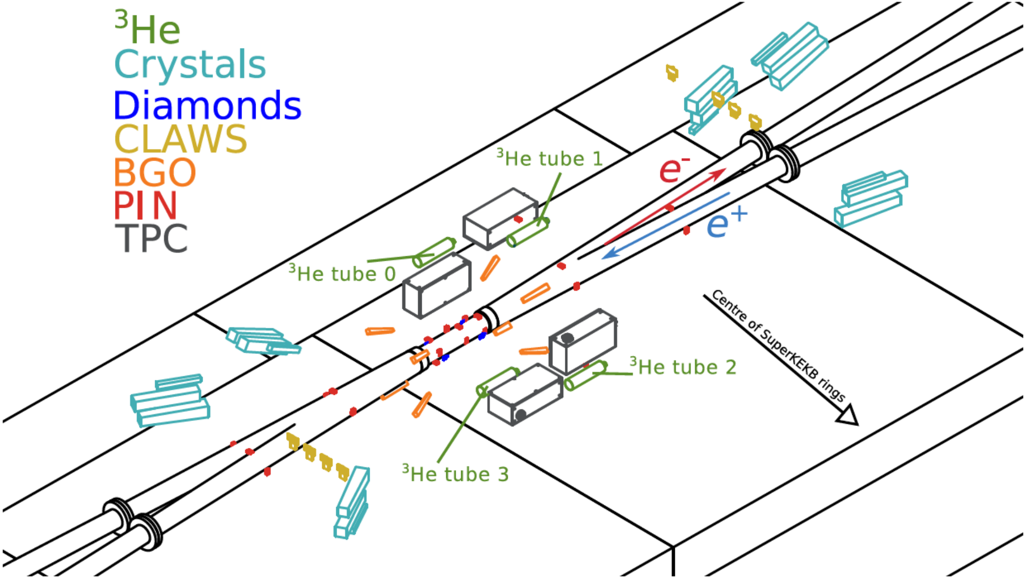
$$^{30}\mathrm{Si} + n \rightarrow ^{31}\mathrm{Si} + \gamma \rightarrow ^{31}\mathrm{P} + \beta^{-} + \gamma \tag{1}$$

- Introduction of phosphorus increases n-doping which changes the response of detectors
- Neutron rate measured with thermal neutron detectors and compared to simulation

BEAST II

- In order to test the accuracy of the simulations a group of small detectors were designed for deployment during beam commissioning and make corrections as needed
- Collectively the group is know as BEAST II
  - Beam Exorcism for A Stable experimenT
- BEAST II was deployed in phase 1 with a variety of detectors and is being deployed in phase 2 with a new set of detectors

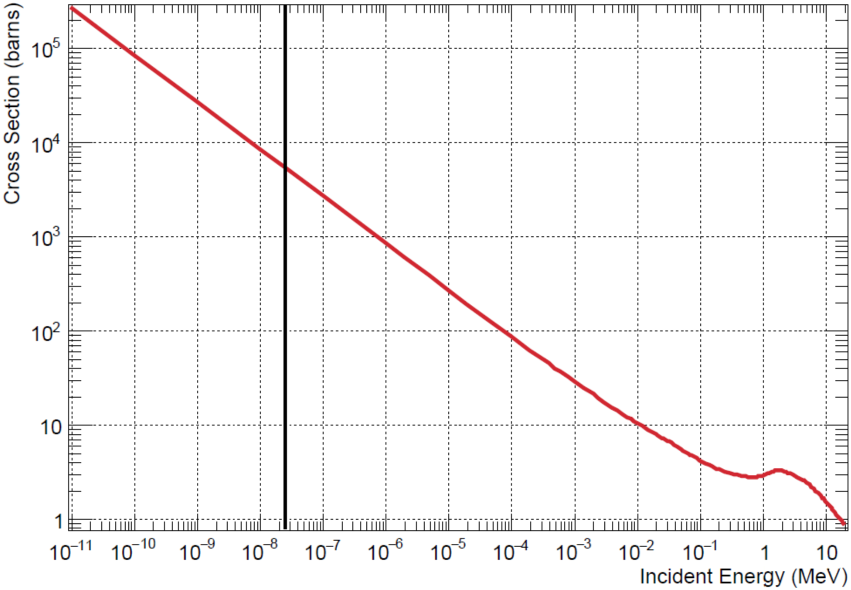
BEAST II in Phase 1



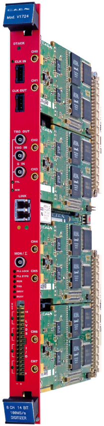
^{3}He Tubes

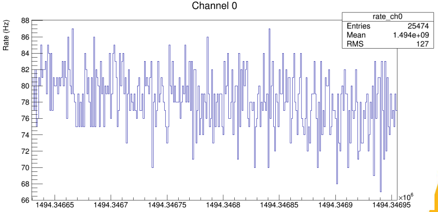
$$^3\text{He} + n \rightarrow ^3\text{H} + ^1\text{H} + 764 keV \quad (2)$$

Neutron Capture Cross-Section



Signal Extraction





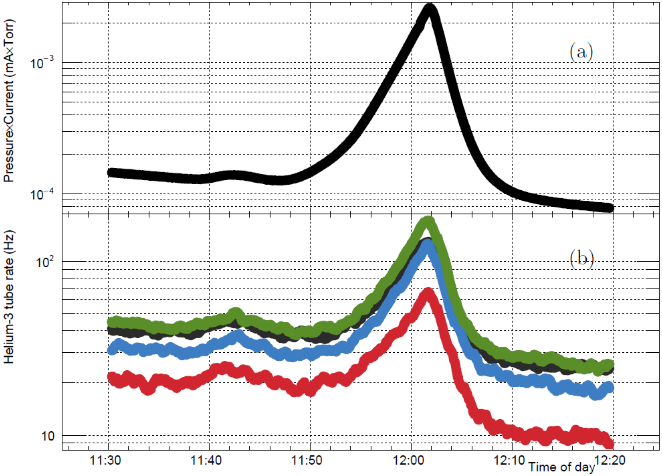
- A preamp is attached directly to each tube.
- Signal is then sent ∼30m from the tubes to a receiver module
- The analog signal is then digitized with CAEN V1724 and sent to the control room

Beam Gas and Touschek Scattering

- During the running of SuperKEKB various backgrounds are produced
- The main contributions to neutrons are:
  - Interactions with residual gases in the beam pipe
  - Interaction within beam bunches causes Touschek scattering
  - e^+e^- interactions release radiative Bhabhas (not present in phase 1)
- When scattered electrons or photons hit the beam pipe wall, showering events occur
- Phase 1 studies compared neutron rates from beam gas and Touschek contributions to simulated rates

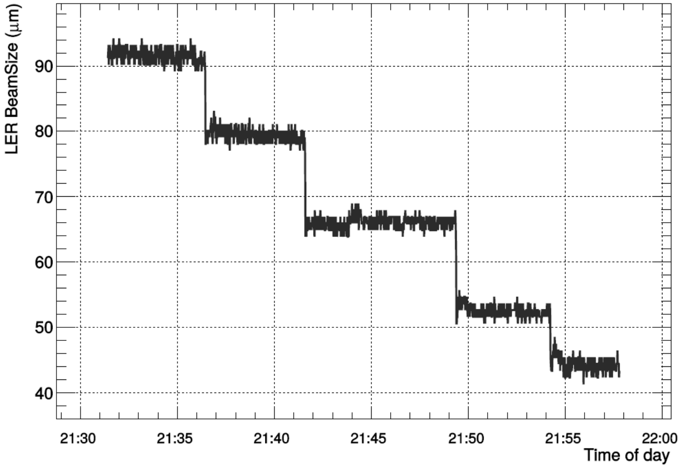
Pressure Bumps during Phase 1

- Gasses adsorbed on getter pumps were released in a controlled manner into the beam line on several occasions for dedicated measurements
- These bumps were ideal for studying the beam gas contribution to neutron rate



Beam Size Scan

- In order to study the Touschek contribution to backgrounds various beam diameters were sent through BEAST II



GEANT and Calibration

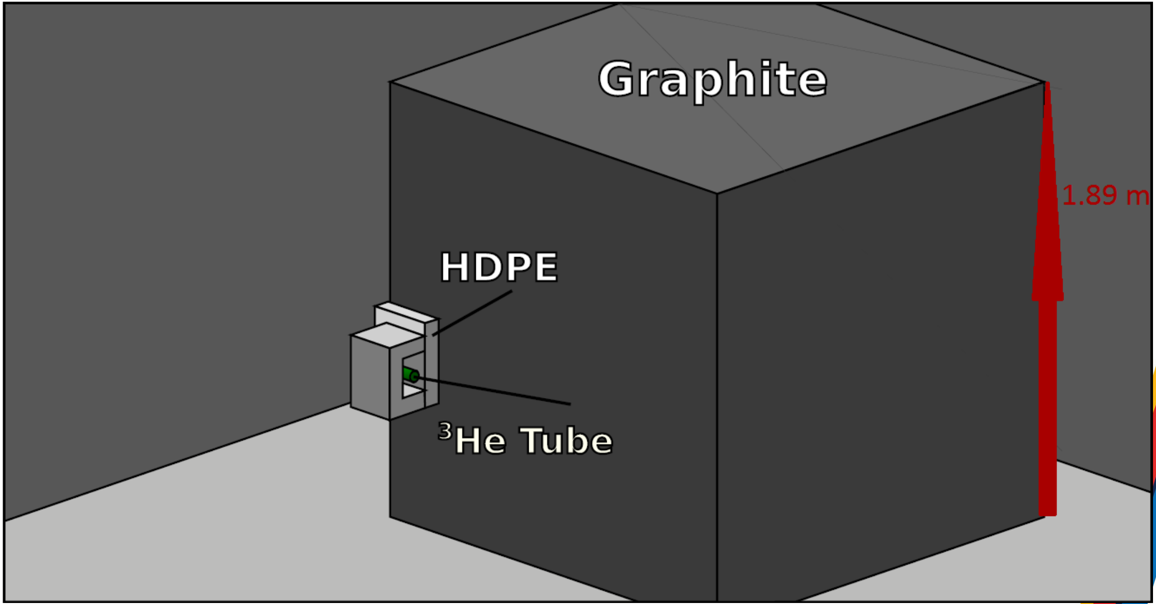
- After phase 1 the tubes were returned to UVic for final calibration
- UVic has a 168 GBq AmBe source encased in a cube of graphite 1.89m/side

$$^{241}\mathrm{Am} \rightarrow ^{237}\mathrm{Np} + ^{4}\mathrm{He} + \gamma \tag{3}$$

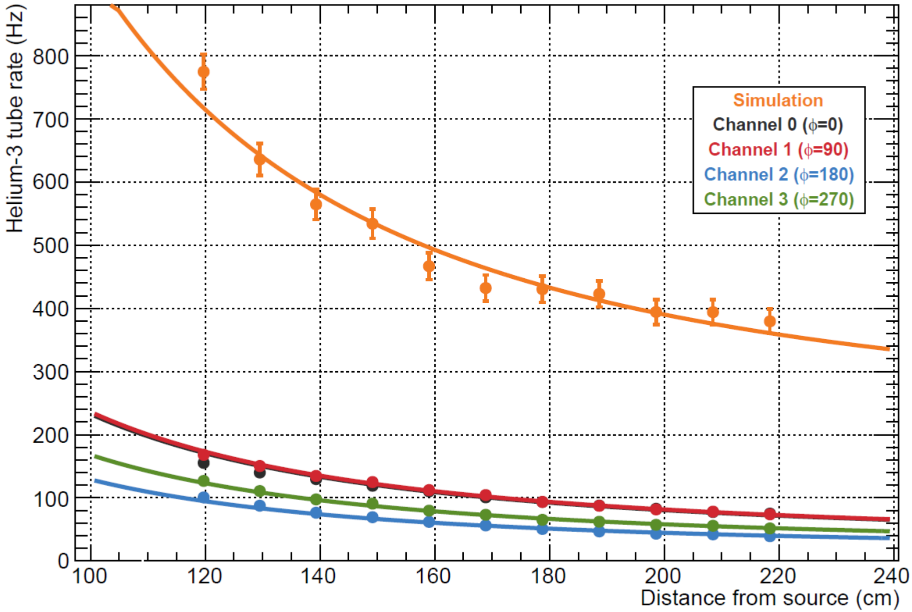
$$^{9}\mathrm{Be} + ^{4}\mathrm{He} \rightarrow ^{12}\mathrm{C} + n + \gamma \tag{4}$$

- Thermal rates were measured with the full system used at KEK and compared to a GEANT simulation

GEANT



Calibration Results



Phase 1 Measured Rates divided by Simulation

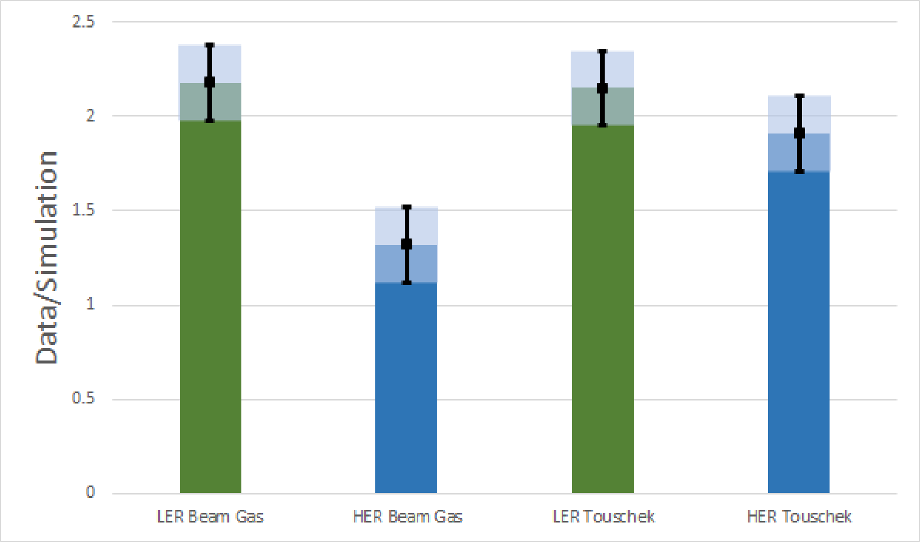
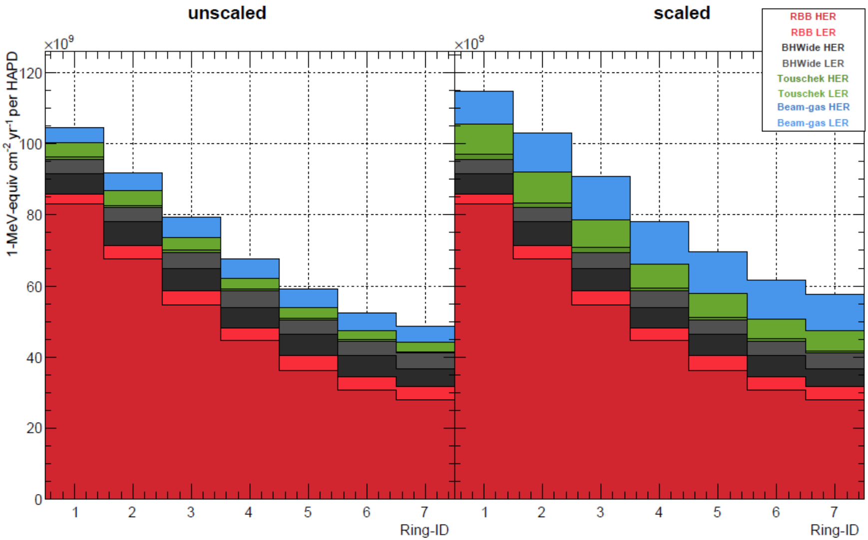


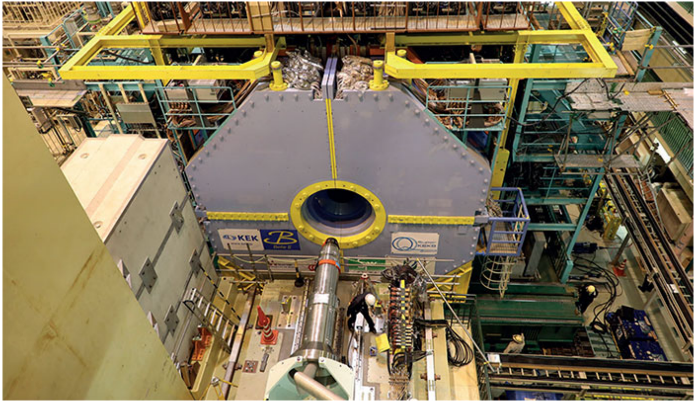
Figure: ratio of rates detected vs simulated rates

Effect of Correction in Neutron Sensitive Detector



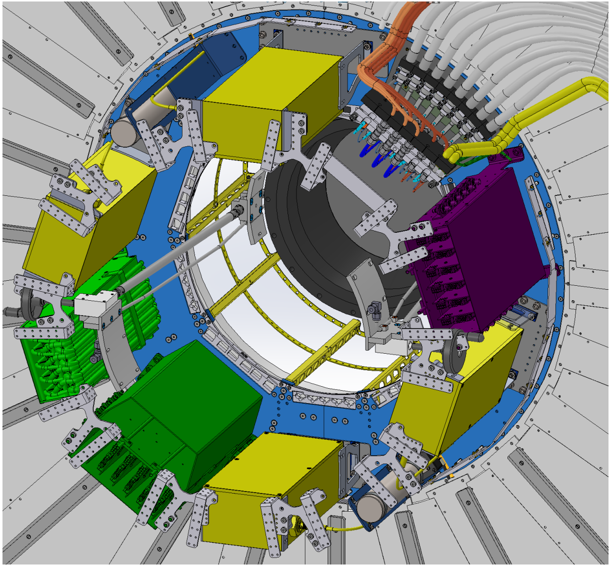
SuperKEKB Phase 2

- Belle-II was rolled onto the beam line in April
- Phase 2 e^+e^- collisions without vertex detectors will begin next year



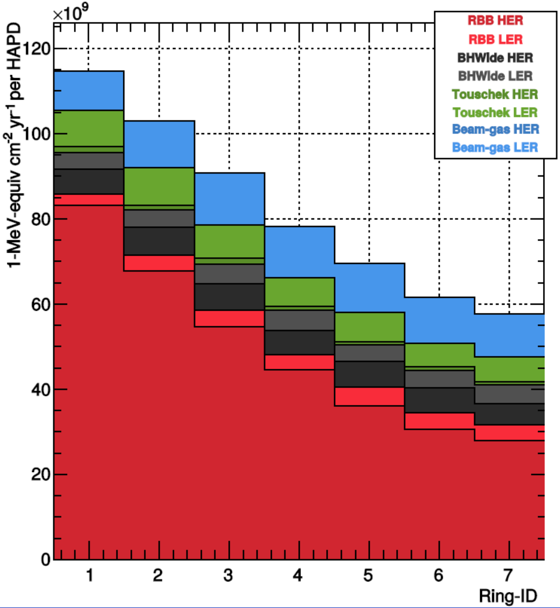
The return of BEAST

- ^{3}He
- TPC
- CLAWS
- FANGS
- PLUME
- PIN
- Diamonds
- PXD
- SVD



Phase 2 plans

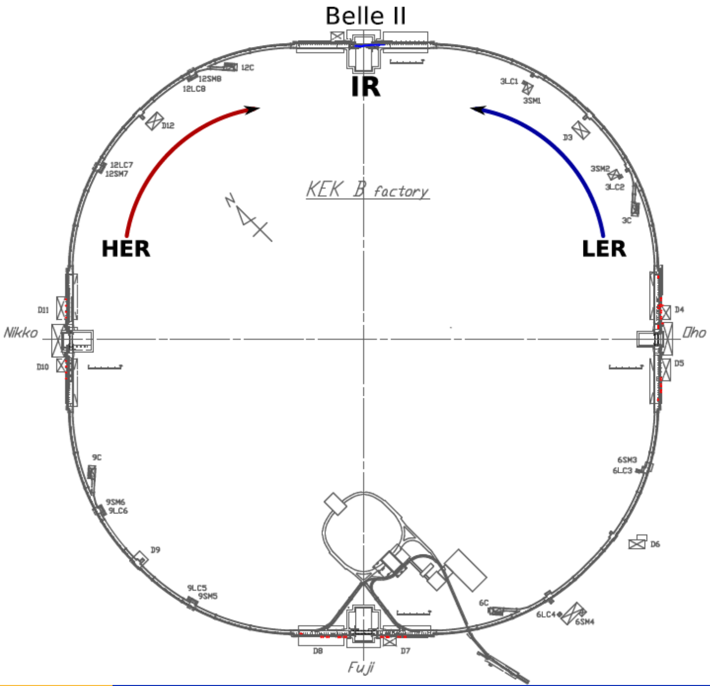
- Upgrade cabling to LSZH requirements
- Make use of radiative Bhahbas to determine if simulation error is present in SAD or GEANT4
- Confirm neutron rates are acceptable for installation of vertex detector



Conclusions

- ^{3}He neutron detectors were able to successfully measure beam backgrounds in Phase 1 commissioning and correct simulation
- Preparations for Phase 2 are on track
  - Components start shipping end of June
  - Installation begins end of October
- ^{3}He will continue to provide unique insight into the SuperKEKB beam conditions

Backup Slides



Belle II
IR
KEK B factory
HER
LER
Nikko
Oho
Fuji
N
12C
12SM8
12LC8
D12
12LC7
12SM7
3LC1
3SM1
D3
3SM2
3LC2
3C
D11
D10
D4
D5
9C
9SM6
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6SM4
D8
D7

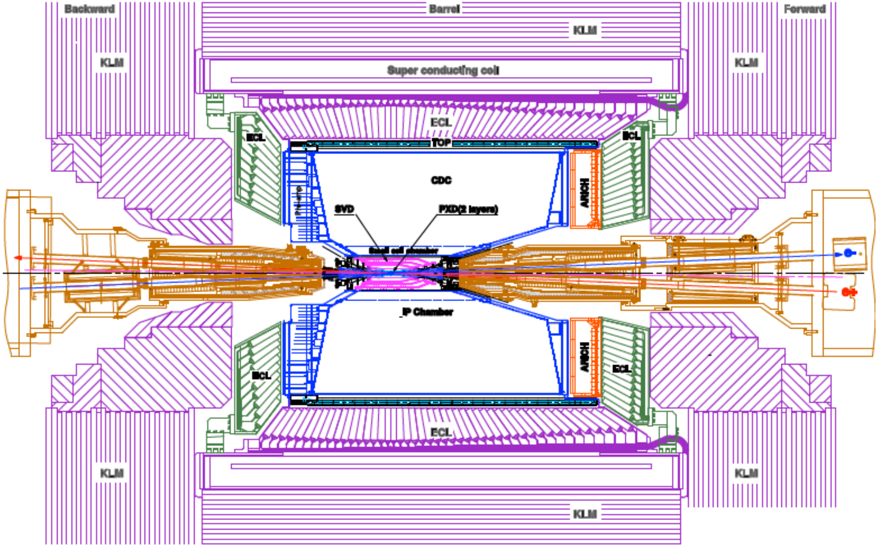
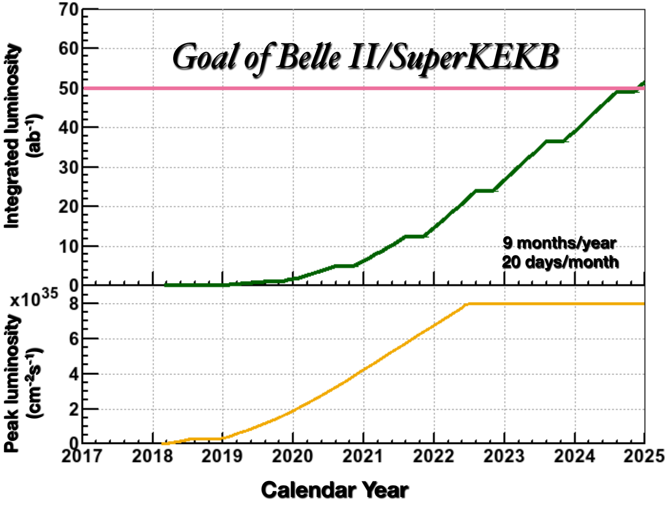


Figure 2.3: Cross section of the Belle II detector. The forward direction is on the right, and is the direction the electron beam travels. The whole detector is 5 m tall, and approximately symmetric in ϕ [3].

Machine Parameters

2013/July/29	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	3.18×10^{-4}	4.53×10^{-4}		
σ_δ	$8.10(7.73) \times 10^{-4}$	$6.37(6.30) \times 10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6.0(5.0)	5(4.9)	mm	():zero current
ν_s	-0.0244	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.86	2.43	MeV	
$\tau_{x,y}/\tau_s$	43.2/21.6	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	

SuperKEKB luminosity projection



Enter the BEAST

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 had its own BEAST

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BEAST II: the commissioning detector

Primary detectors in BEAST II for phase **II**:

System	Institution	#	Unique measurement
PIN diodes	KEK	64	Neutral vs. charged dose rate
"Micro" Time Projection Chambers	U. Hawaii	~~4~~8	Fast neutron flux and tracking
Diamonds	INFN Trieste	~~4~~8	Ionizing radiation rate
He3 tubes	U. Victoria	4	Thermal neutron rate
CLAWS plastic scintillators	MPI Munich	~~8~~2 ladders	Fast injection backgrounds

...continued

BEAST II: the commissioning detector

Primary detectors in BEAST II for phase **II**:

System	Institution	#	Unique measurement
Belle II PXD	U. Bonn	2 ladders	Radiation tolerance for final physics runs
Belle II SVD	KEK	4 ladders	Radiation tolerance for final physics runs
FANGS	U. Bonn	15	Silicon pixel sensors (synchrotron x-ray spectrum)
PLUME	Strasbourg	2 ladders	Silicon pixel sensors (collimator adjustment)