



Luminosity Monitoring at Belle II and FCC-ee

CERN, Switzerland
The University of Manchester, UK

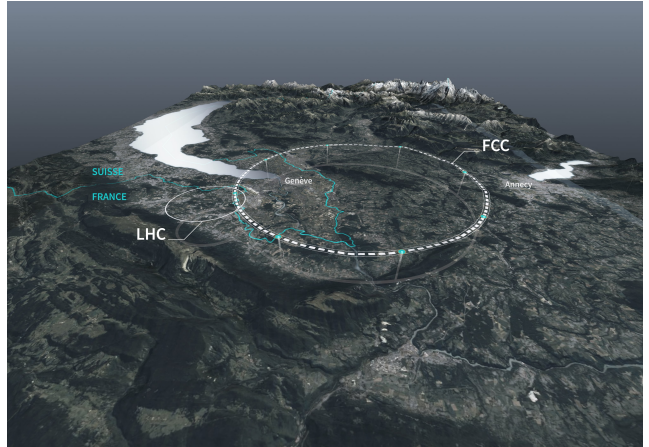
P. Mooney, R. Kieffer, S. Boogert

30th June

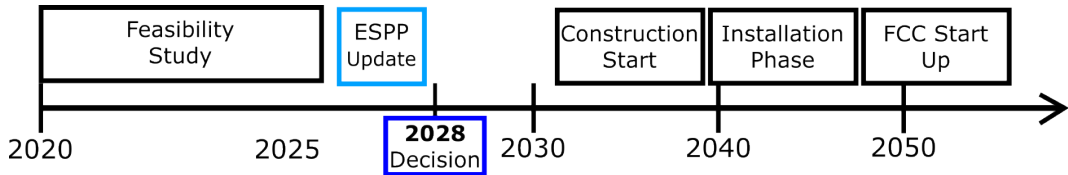
PAB 2026, Lancaster

Future Circular Collider

- The FCC is a proposed collider with a circumference of 91km
- Upon approval, it will begin operation in the late 2040s



FCC Status



Feasibility Report

Published in March 2025.
Covers Physics/Experiments,
Accelerators/Technical
Infrastructure, Civil
Engineering

Optics Decision 2026

Local Chromaticity Correction
(LCC) chosen over Global
Hybrid Correction (GHC)
1–6% less power demand

FCC Experiments

More detector concepts than
IPs (CLD, IDEA, ALLEGRO,
ALFA, ILD)
MAPS-based / silicon vertex
detector designs under
development

SuperKEKB

- Asymmetric e^+e^- collider at KEK, Tsukuba, Japan
- 3 km in circumference
- HER: 7 GeV (e^-), LER: 4 GeV (e^+)
- Collision energy at the $\Upsilon(4S)$ resonance (10.58 GeV)
- World record instantaneous luminosity: $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

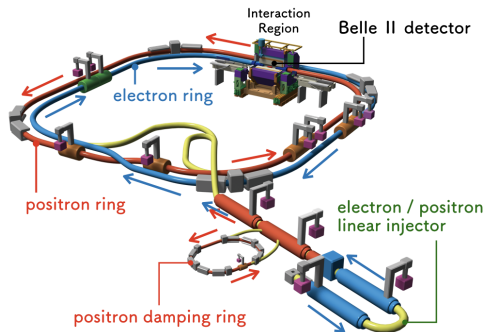


Figure 1: SuperKEKB accelerator complex, KEK.

1. Beamstrahlung Dump Monitor

Photon signal in the dump area sensitive to transverse beam separation

2. Large Angle Beamstrahlung Monitoring (LABM)

Beamstrahlung photons in the optical range used to monitor beam parameters

3. Radiative Bhabha Scattering

Scattering rate directly proportional to relative luminosity. Fast measurements are used to tune IP

Luminosity Monitors & IP Tuning

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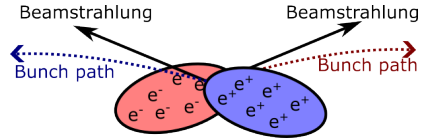


Figure 2: Beamstrahlung at IP

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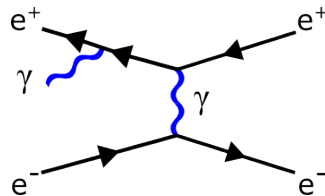
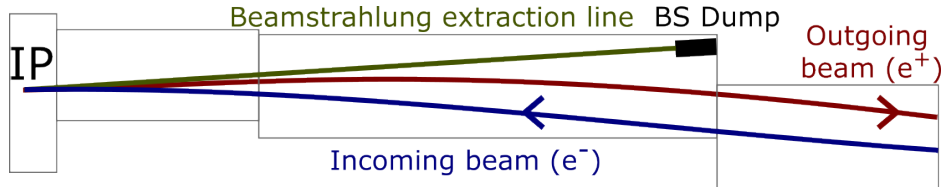


Figure 3: Feynman diagram for radiative Bhabha scattering

Beamstrahlung Dump Monitor

Beamstrahlung at FCC-ee

- Synchrotron radiation emitted by beam particles deflected in the electromagnetic field of the opposing bunch during collision
- At FCC-ee: 8 beamstrahlung dumps planned - 2 per interaction point
- Dump location not yet fixed; currently at ~ 500 m from IP
- Maximum beam thermal power: up to 500 kW per dump



Method

- Beamstrahlung signal in the dump area is being explored as a potential signal for transverse beam separation
- Calibration via van der Meer (vdM) scan: sweep beams transversely and record signal rate vs. separation
- This study aims to quantify the sensitivity of the beamstrahlung signal to beam separation at FCC-ee

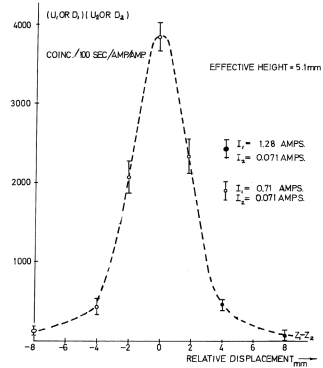


Figure 4: vdM scan at the CERN ISR (Intersecting Storage Rings, 1971). Monitor rate $R_y(\delta_y)$ vs. vertical beam separation δ_y .

Beamstrahlung Power vs. Beam Separation

Offset Signal

- Vertical separation strongly increases BS power
- Horizontal separation has minimal effect
- Vertical beam offset can be determined from the BS signal at the dump

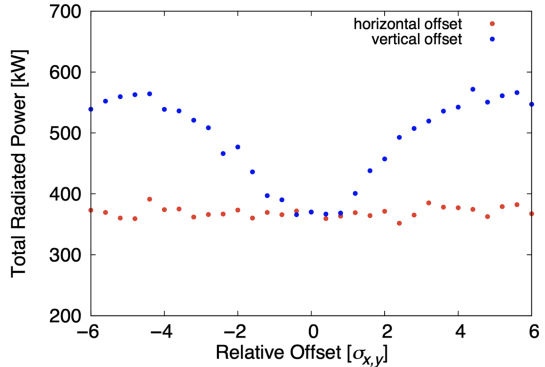


Figure 5: Total BS power versus relative bunch offset, horizontal (red) and vertical (blue). M. Boscolo & A. Ciarma.

Beamstrahlung Power vs. Beam Separation

Offset Signal

- Simulations using a 30mm hollow screen aperture
- 400m from the IP, 100m from the beam dump
- 1mm BS profile displacement corresponds to 5nm beam-beam offset

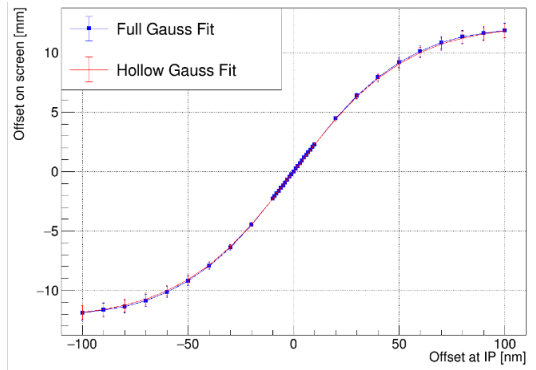


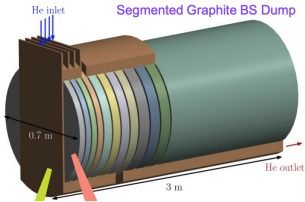
Figure 6: Screen offset (mm) versus IP offset (nm) at 400m from the IP

FCC-ee Beamstrahlung Dump Design

Images: S. Candido & L. Jorat, FCC Week 2026

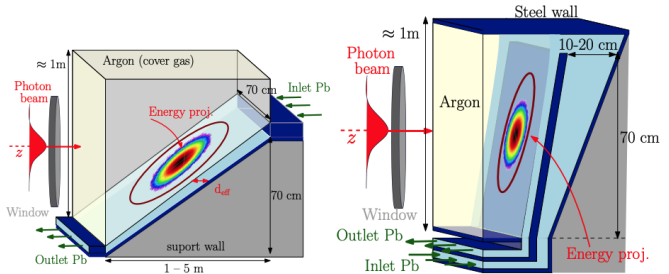
Segmented Graphite

- Helium-cooled absorber
- Issues: large He cooling station, erosion, complex beam window



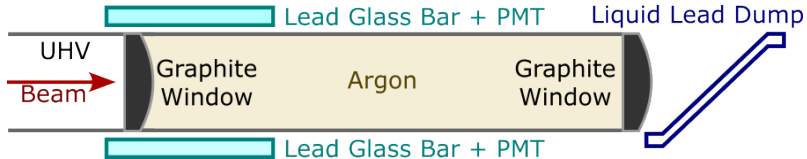
Liquid Lead Dump (Preferred)

- Free surface lead flow at 400°C, up to 500 kW beam power
- No thermal fatigue. Lead absorbs and shields



Beamstrahlung Dump Window

- Design of the dump means including monitoring of signal in the setup is very difficult due to spatial constraints and concrete shielding
- Beam windows separate the UHV from the dump environment
- Relatively thick low density Be/Graphite window
- This is an alternative location for a setup



Beamstrahlung Dump Window Simulation Framework

Geometry Model

- Constructed in Pyg4ometry and exported to GDML
- Imported into BDSIM
- Includes 8 lead glass bars surrounding the window
- Aim to assess the sensitivity of transverse beam separation

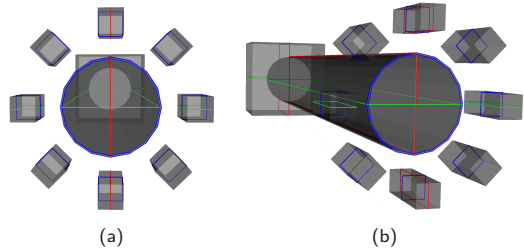


Figure 7: Pyg4ometry model of the beamstrahlung dump used in BDSIM simulations: (a) front view; (b) side view.

Beamstrahlung Dump Window Simulation Framework

Simulation Frameworks

- Simulation of this system in BDSIM was initially a voxel based scoring mesh
- Sub element scoring BDSIM development is ongoing
- This will allow per bar scoring/counting

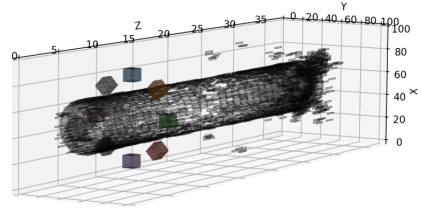


Figure 8: First voxel-based BDSIM simulation

Aims

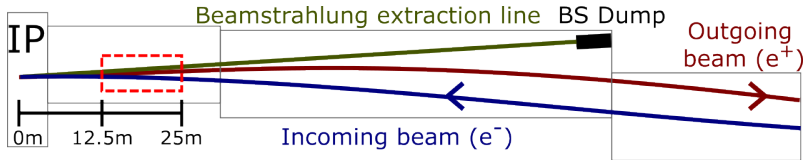
- Determine the sensitivity of this setup and variation when measuring transverse offset
- Create a framework along with XSuite and WarpX/GuineaPig to simulate from the IP per bunch crossing

Large Angle Beamstrahlung Monitoring (LABM)

Large Angle Beamstrahlung Monitoring

LABM at the FCC

- Determining the suitability of a LABM setup for BS photons in the optical range at the FCC
- Window available between 12.5m and 25m from the IP
- Optical setup currently at SuperKEKB



Large Angle Beamstrahlung Monitoring

Simulation

Code developed by S. Di Carlo for use at SuperKEKB
Simulates beamstrahlung radiation between two beams
Filters photons in optical range
Determines the number of photons passing through a mirror

Results

Mirror $2\text{ mm} \times 2\text{ mm}$ at 12.5 m has $\mathcal{O}(100)$ optical photons per bunch crossing for FCC parameters.
Optical photons on the order $\mathcal{O}(10)$ at SuperKEKB at the setup

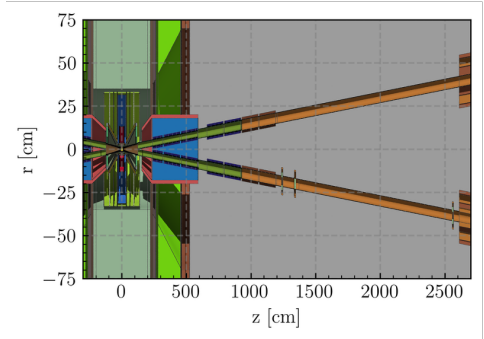


Figure 9: FCC IP Schematic

Radiative Bhabha Scattering

Radiative Bhabha Scattering

Luminosity from Bhabha Rate

- Bhabha scattering is a precisely calculable QED process enabling absolute luminosity determination
- Cross-section known to high accuracy from perturbative QED
- ECL at SuperKEKB provides absolute luminosity at 1Hz
- Luminosity directly proportional to the measured Bhabha rate
- Radiative Bhabha at SKB can be a gamma/electron/positron signal

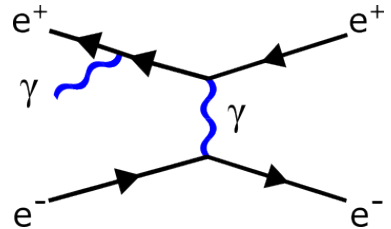


Figure 3: Feynman diagram for radiative Bhabha scattering

Fast Luminosity Monitoring

- Relative luminosity monitor for SuperKEKB
- Fast response, relative to ECL, enables real-time IP tuning using dithering feedback,
- In the 2024ab run, LumiBelle2 provided signal for tuning beams at the IP using $140\text{ }\mu\text{m}$ and $500\text{ }\mu\text{m}$ CIVIDEC sCVD sensors

CVD Diamond vs LGAD

- Low-Gain Avalanche Diodes (LGADs) provide superior timing performance for bunch-by-bunch luminosity measurements
- CVD diamond sensors offer greater radiation hardness and long-term stability

Property	CVD	LGAD
Intrinsic gain	None	$10\text{--}50\times$
Rise time	$\sim 350\text{ ps}$	$< 200\text{ ps}$
Timing resolution	$\sim 1\text{ ns}$	$< 25\text{ ps}$
Radiation hardness	High	Moderate
Cost	High	Lower

Table 1: CVD diamond vs. LGAD properties

CVD and LGAD



Figure 10: CIVIDEC CVD Diamond at SuperKEKB

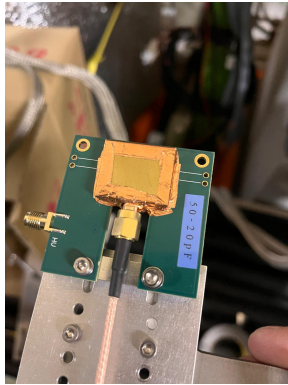


Figure 11: LGAD at SuperKEKB

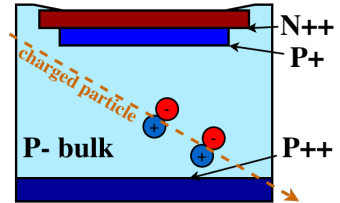


Figure 12: LGAD Schematic

LER Installation

- Two LGADs and one CVD diamond installed at 11m from the IP
- TIL (Train Integrated Luminosity) divided by ECL to obtain detector response
- Performance monitored over 5 weeks

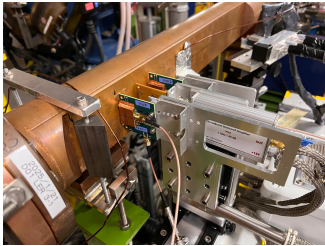


Figure 13: LER installation, March 2026

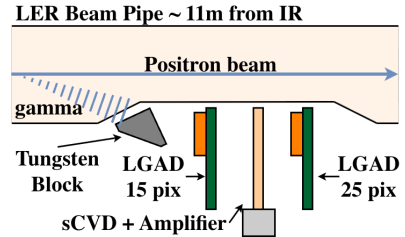


Figure 14: SKB LER setup, March 2026

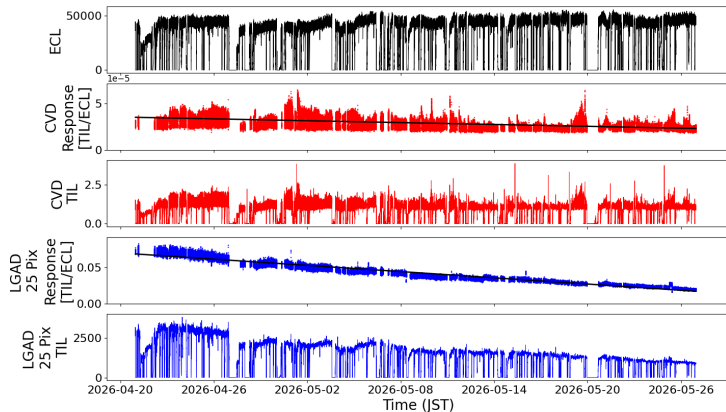


Figure 15: CVD and LGAD 25 Pix

Results

CVD much more resistant to radiation. LGAD degrades at a much quicker rate.

Sensor	Rate (%/day)
LGAD 15 pix	-3.697 ± 0.011
sCVD	-1.168 ± 0.018
LGAD 25 pix	-3.492 ± 0.010

Table 2: April-May Performance

LumiBelle2 Results

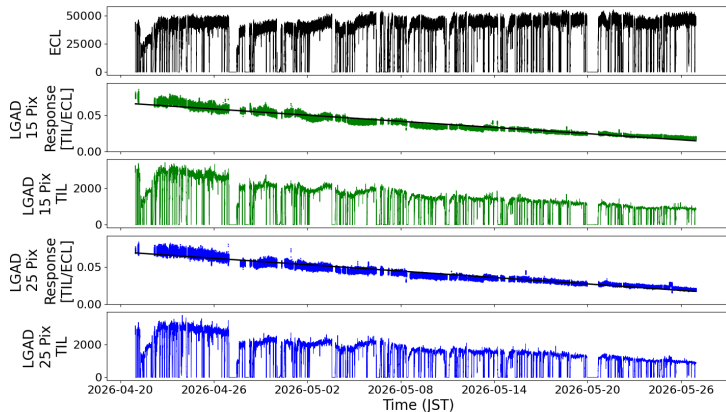
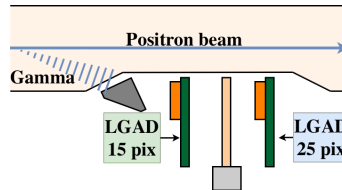


Figure 16: LGAD 15 Pix and LGAD 25 Pix

Results

Upstream LGAD shows higher degradation rate

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sCVD	-1.168 ± 0.018
LGAD 25 pix	-3.492 ± 0.010



Future Developments: SuperKEKB

- Install additional radiation monitor and temperature monitor
- Implement remote controlled heating for annealing studies for LGADs in the setup
- Test intrinsically radiation-hard LGADs

Future Developments: FCC

- Radiative Bhabha monitoring is scalable to FCC-ee luminosity regimes
- Optimise LGAD placement relative to beamline
- Benchmark simulations against SKB results

Thank you for your attention
