Input signals for error mitigation by interaction point fast feedback systems for FCC-ee

J. P. T. Salvesen[1,2], F. Zimmermann[1], P. N. Burrows[2]

1: CERN- Geneva, Switzerland, 2: John Adams Institute for Accelerator Science, Oxford, UK

Abstract

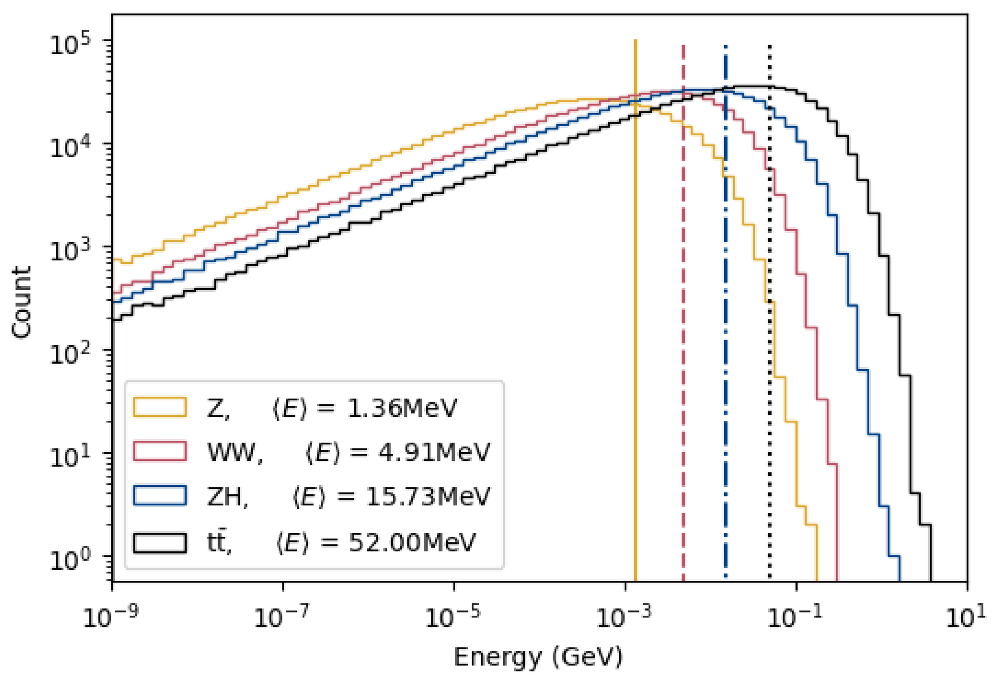
During operation, the Future Circular electron-positron Collider (FCC-ee) will be subject to vibrations from mechanical sources and ground motion, resulting in errors with respect to the closed orbit. To achieve physics performance, luminosity and beam lifetime must be kept to design specifications. To correct for errors at the interaction points (IPs), a fast feedback system is required. We present the tolerances for the allowable beam offsets at the IPs and propose a fast feedback system to address these errors, with the methods of detecting and correcting errors discussed.

Introduction and Simulation Description

The Future Circular electron-positron Collider (FCC-ee) *(1)* is a design study for a 91 km electron-positron collider based at CERN, Geneva. The collider is foreseen to operate with four Interaction Points (IPs), at four beam energies. The Interaction Region (IR) optics are based on a nano-beam, crab-waist collision scheme *(2)* with large Piwinski angle to allow β_y^* to be smaller than the bunch length without significant hourglass effect.

Running mode	Z	WW	ZH	tt
Beam energy [GeV]	45.6	80	120	182.5
Bunches /beam	11200	1780	440	60
Hor. emit. ε_x [nm]	0.71	2.17	0.71	1.59
Vert. emit. ε_y [pm]	1.9	2.2	1.4	1.6
Hor. IP beta β_x^* [mm]	110	220	240	1000
Vert. IP beta β_y^* [mm]	0.7	1	1	1.6
σ_z (BS) [mm]	15.5	5.41	4.70	2.17
Hor. BB ξ_x $[10^{-3}]$	2.2	13	10	73
Vert. BB ξ_y $[10^{-3}]$	97.3	128	88	134
Crab waist k [%]	70	55	50	40
Lumi. /IP $[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	141	20	5.0	1.25

To maintain luminosity, beams must be kept in collision to high accuracy. Errors due to magnet vibrations, induced by ground motion and other mechanical sources, must be suppressed. A fast IP feedback system is proposed to mitigate these errors.



Model Parameters

Single bunch crossings are simulated using GUINEA-PIG (GP) *(3)*. A large number of macroparticles (10^5) are used to suitably model the BS Spectrum. For each offset, 50 bunch crossings are simulated with different random seeds. Initial particle distributions are obtained by applying an analytic crab waist transform to a Gaussian bunch.

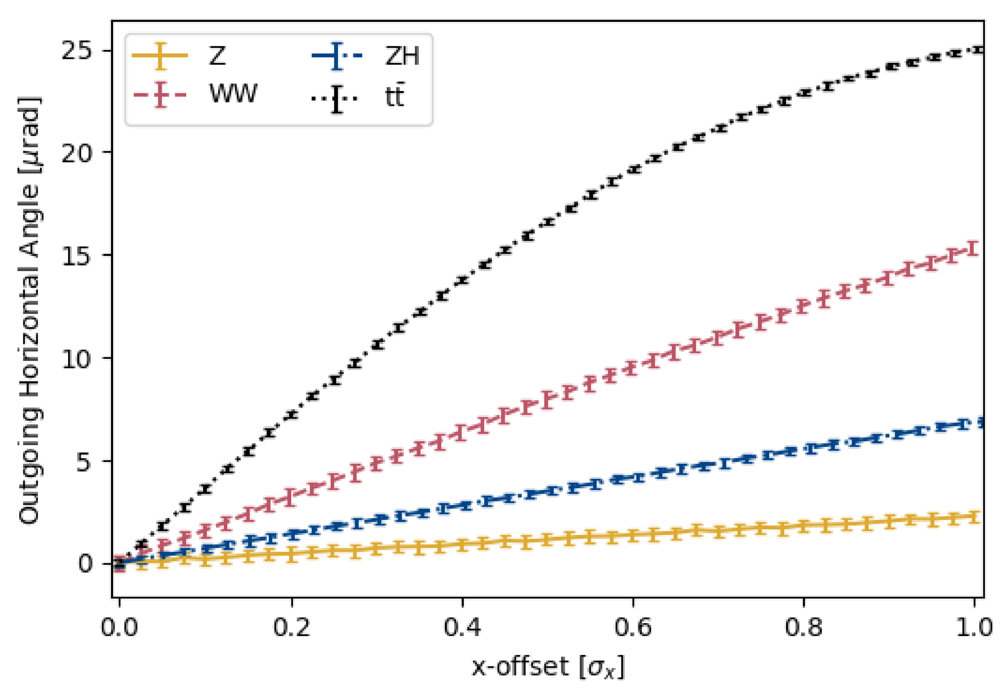
Performance Requirements

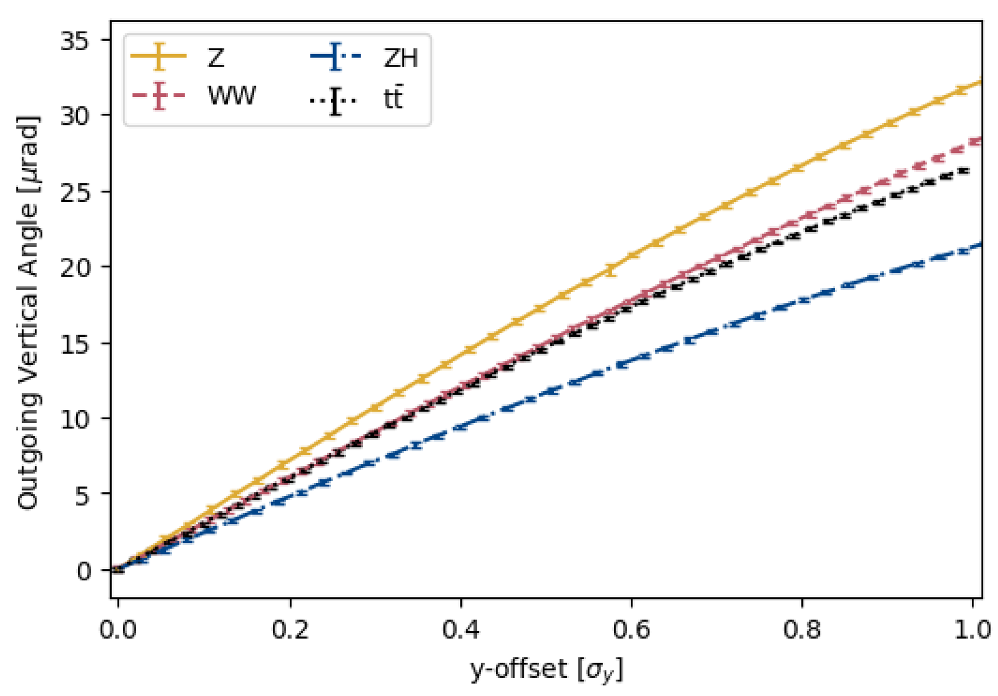
Offsets at the IPs not only reduce luminosity, but induce strong beam-beam deflections, negatively impacting the orbit, beam quality and lifetime. In particular, they lead to enhanced beamstrahlung and related longitudinal or transverse beam blow up. Offsets can also drive betatron resonances further disrupting the beam.

Previous studies, using CDR beam parameters, but assuming 4 IPs, at the Z working point concluded that a vertical orbit at IP should be maintained to within $0.05\sigma_y$ *(4)*. Refined studies for the current configuration are still being carried out; the tolerances are expected to be close to the past results.

Beam Position Monitor Signals

During the bunch crossing, the beams impart a beam-beam kick on each other's centroid motion dependant on the offset. For FCC-ee, the high vertical beam-beam tune shifts make a deflection measurement signal feasible at downstream Beam Position Monitors (BPMs). The influence of the experimental solenoid, nor of any subsequent compensation solenoid magnets or downstream quadrupoles was not included.



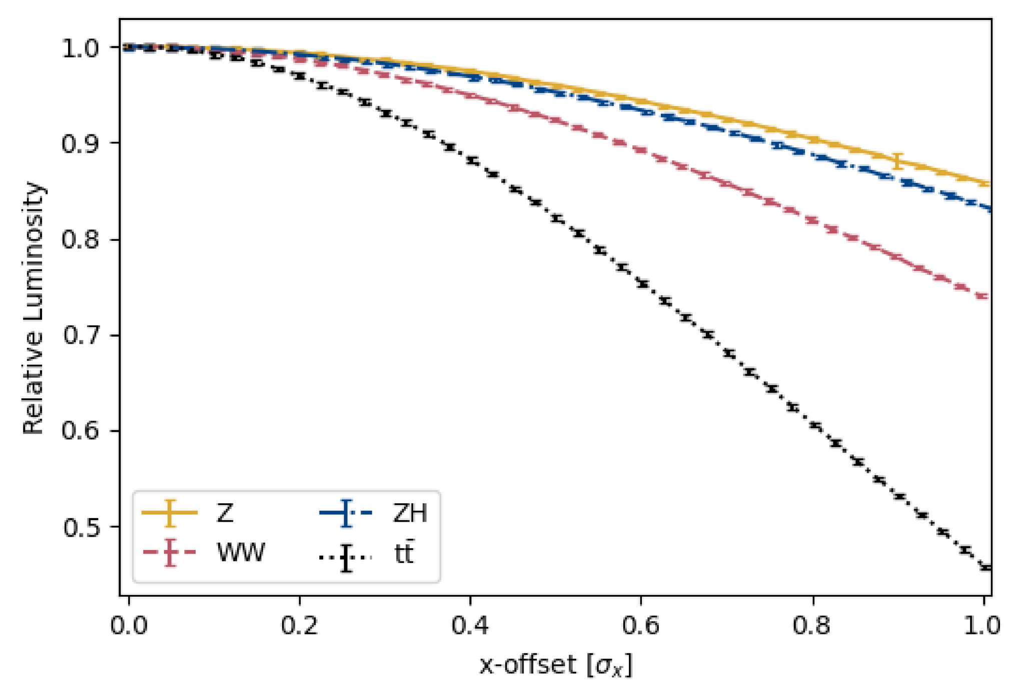


The leading choice of BPM for a fast feedback system is the "lumical" BPM at 1.1 m from the IP, on the shared elliptical beam-pipe within the solenoid field, prior to the final focus quadrupoles, and strongly mechanically linked with the IP. At only 1.1 m from the IP, resolving offsets of a few percent of the RMS beam size implies a requirement of sub-micron resolution for this BPM, which may represent a technical challenge, also taking into account impedance constraints.

Using BPMs further downstream relaxes the resolution requirement, but introduces potential errors from the final-focus quadrupoles.

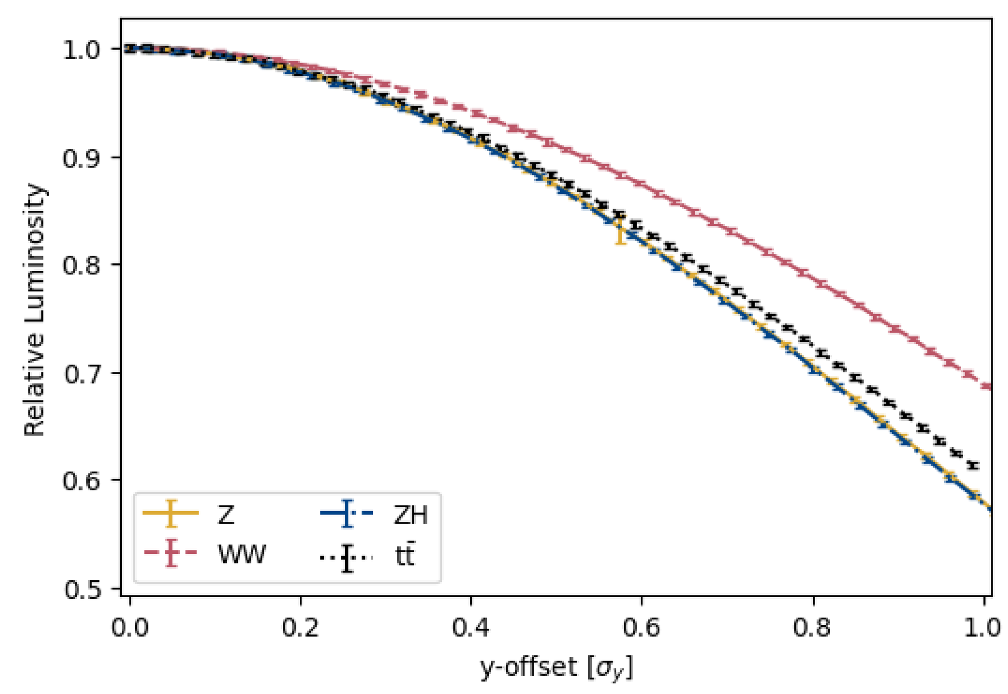
Luminosity Signal

Luminosity monitors ("lumicals") are situated at 1.1 m from the IP, on either side, with a target absolute measurement precision of 1×10^{-4} *(5)*.



Luminosity as measured by the lumical represents a relatively slow signal. To achieve the absolute luminosity reading, the calorimeter integrates over a number of crossings. Fast luminosity monitors, using the radiative Bhabha losses are under investigation. These may allow for bunch-by-bunch relative luminosity measurements, as operated at SuperKEKB *(6)*.

Luminosity also presents the challenge of being a scalar signal. As such, there is no direct information on which direction to drive the beam for correction. This directional information can be obtained from luminosity signals if the beam is driven: the dithering approach, currently employed at SuperKEKB in the horizontal plane *(7)* and previously at SLC in the vertical plane *(8)*. This approach however entails sacrificing luminosity by dithering the beam.

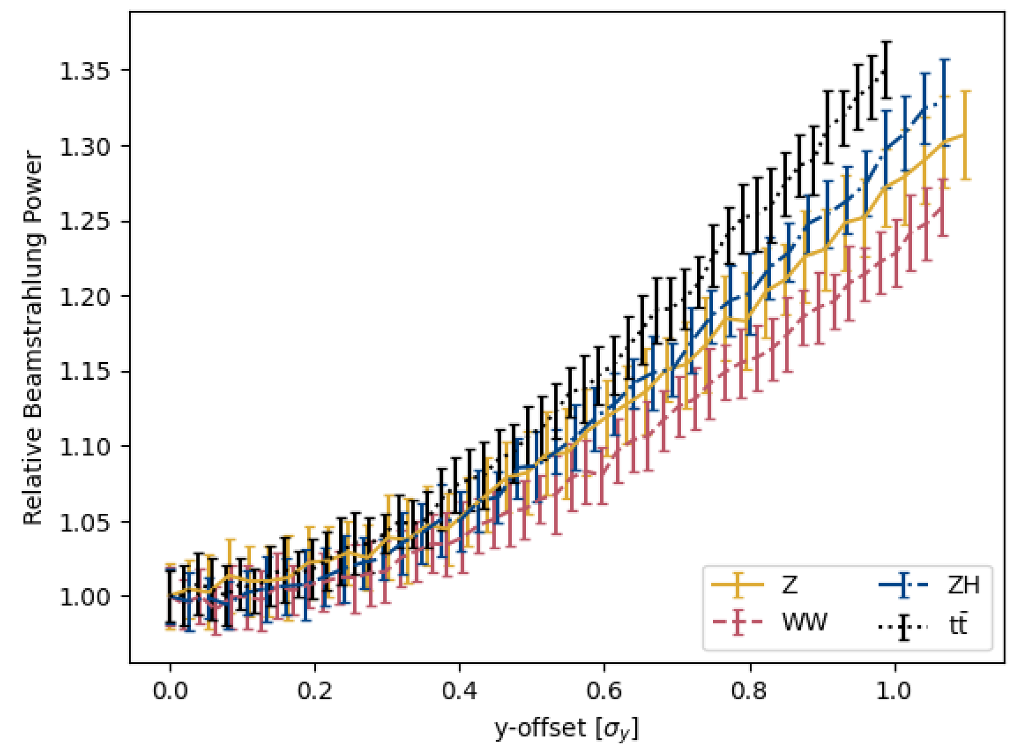


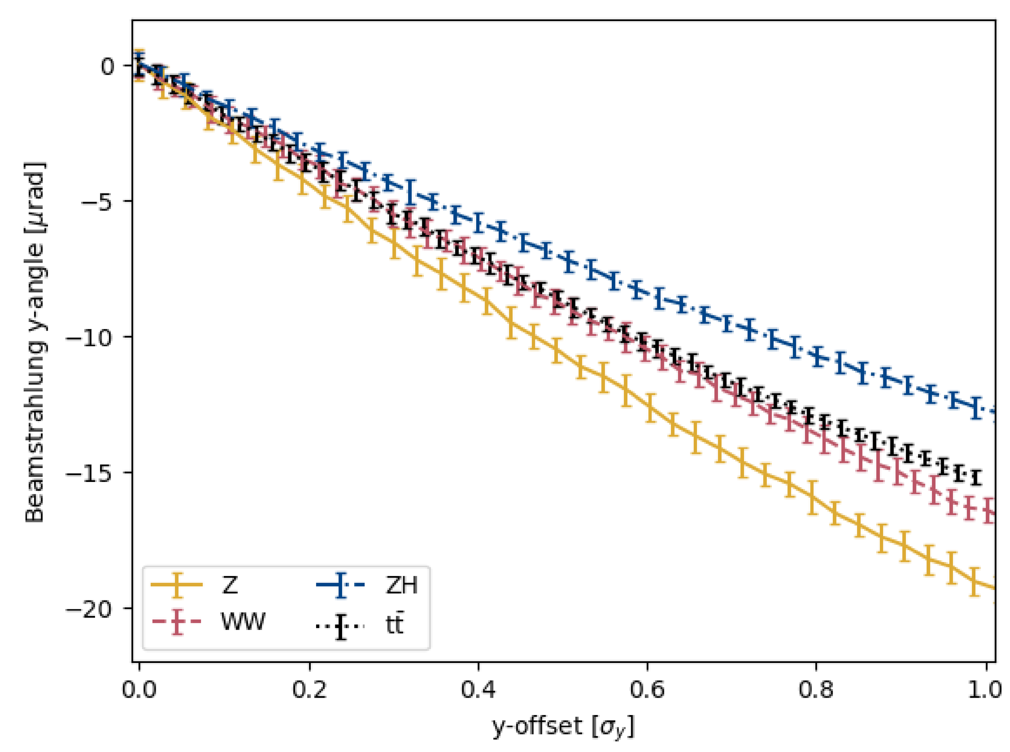
Beamstrahlung Photon Signals

A beamstrahlung (BS) dump is located 500 m downstream of the IP, and it is proposed to have a BS monitor along this photon line.

BS Power [kW]	Z	WW	ZH	tt
GP nominal	229	95.5	63.6	40.2
GP 1σ x-offset	239	94.0	63.4	29.0
GP 1σ y-offset	299	120.2	84.5	54.3

The use of beamstrahlung radiation is an enticing option, as the signal is a direct measure of the opposing beam, not a convolution of the separation of both beams. Both the position of the radiation (here described by the angle of emission) and the total power can be measured. However, this signal is difficult to measure due to the intense radiation power.





Beamstrahlung signals show much clearer trends with offset in the vertical plane, with the exception of the tt working point, where the much smaller Piwinski angle and high beam-beam tune shifts leads to significant changes in BS radiation with horizontal offset.

In the horizontal plane, the crab collision scheme with large crossing angle causes an energy dependence of the initial angle. At nominal collision the horizontal angles are 36.9, 18.8, 14.2 and 5.1 μrad for the Z, WW, ZH and tt working points respectively.

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