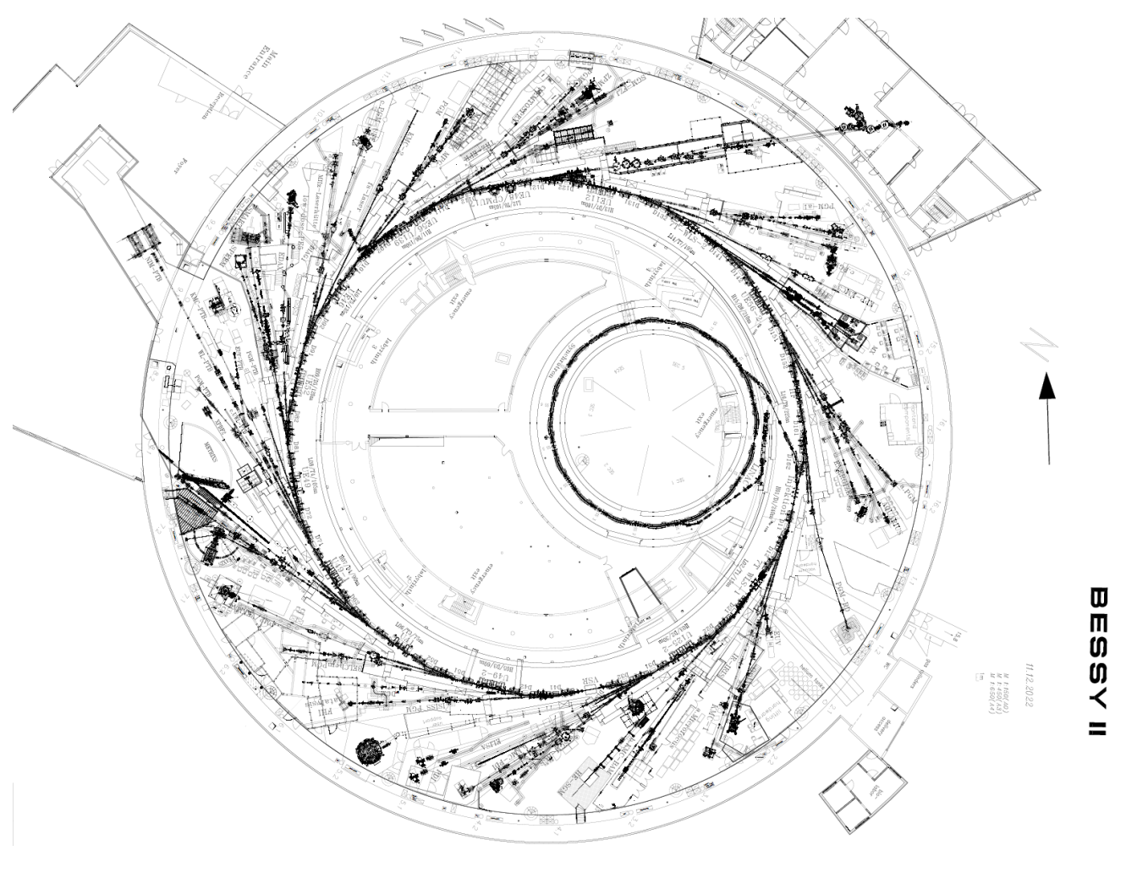
Transverse and Longitudinal optical beam diagnostics for the BESSY II Booster

M. Marongiu*, P. Ahmels, T. Atkinson, G. Rehm, M. Ries
Helmholtz Zentrum Berlin (HZB)

Abstract

This paper describes the optical beam diagnostics available at the BESSY II booster synchrotron. For the first time, diagnostics are established to investigate the distribution of the electron beam in all three dimension. A permanent installation of a source-point imaging system aided by a telescope optic depicts the transverse properties of the electron beam. Additionally, the bunch length is measured using a streak camera with a resolution in the picosecond range. Both systems can work in parallel and are able to observe the non-equilibrium beam dynamics over the entire booster ramp.

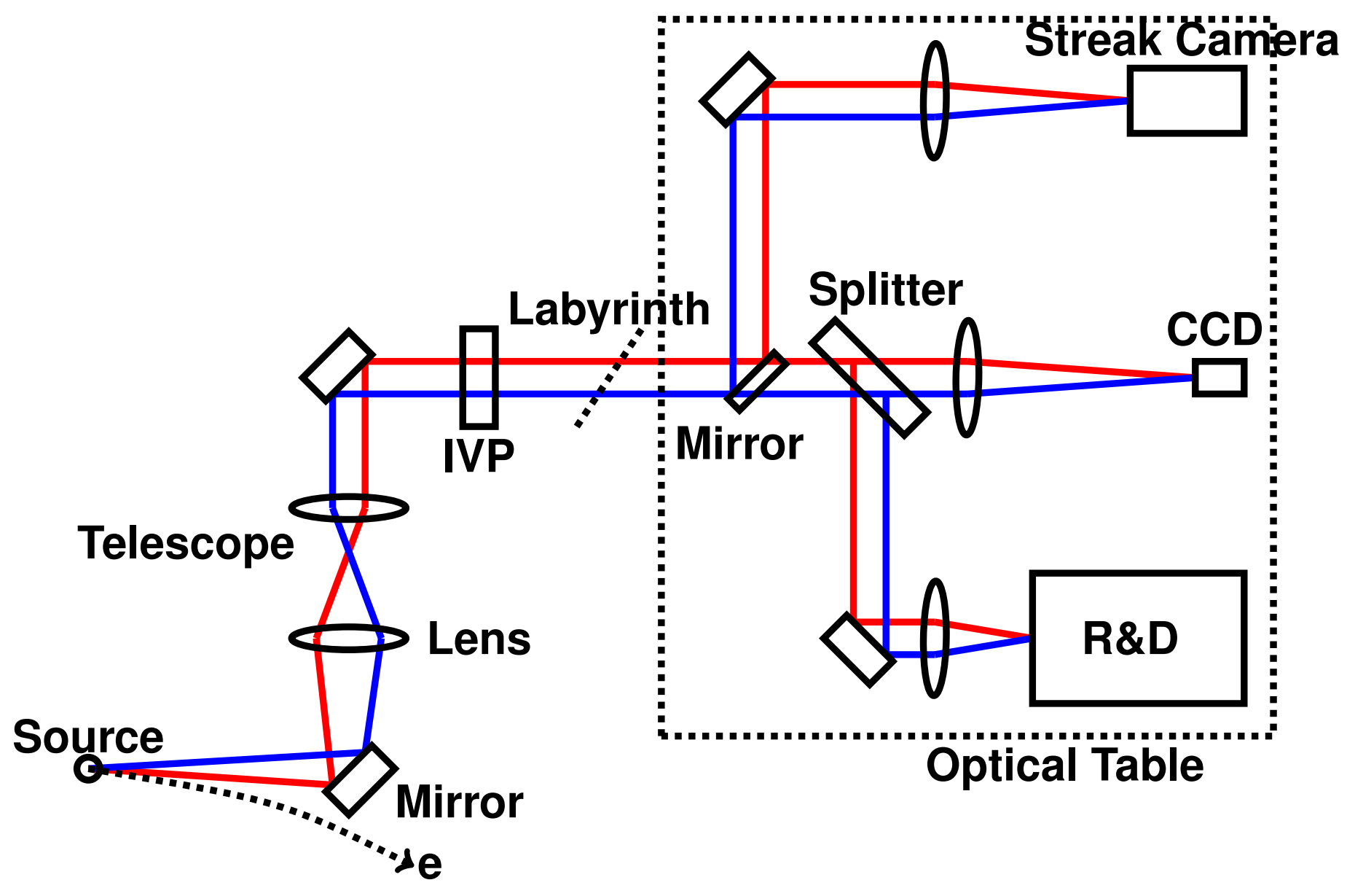
1. Introduction



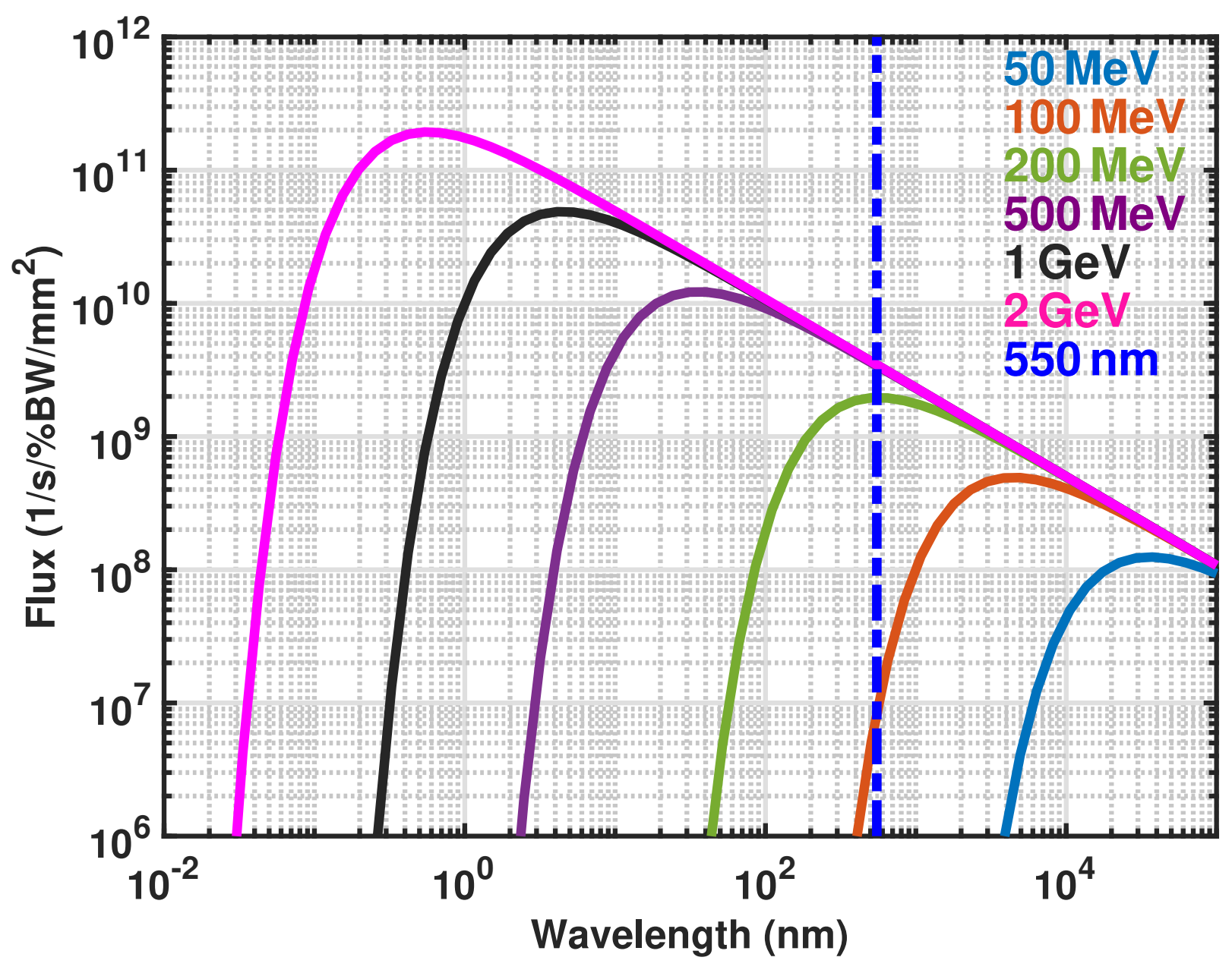
The BESSY II injector system consists of a 50 MeV Linac and a fast-ramping Booster synchrotron [1].
The system provides injection efficiencies into the Storage Ring well above 90%.
The 0.4 nC charged electron bunches leave the Linac and are transported along the long injection line into the Booster. This fast ramping synchrotron accelerates the bunches up to a final energy of 1.7 GeV.
One, three or five bunches of similar charge are commonly accelerated in the Booster during TopUp depending on the fill pattern requirements.
The incentive behind reducing the present bunch length is to optimise beam parameters ready for low-alpha Top-Up operation.
For this special optic, the bunch length over the whole booster cycle needs to be carefully diagnosed, controlled and tailored for high injection efficiency into the BESSY II storage ring.

Booster	Value
Beam Energy (GeV)	0.05 ... 1.7
Single Bunch Current (mA)	0.3 ... 1
Beam emittance (nm)	50
RF Frequency (MHz)	500
Circumference (m)	96

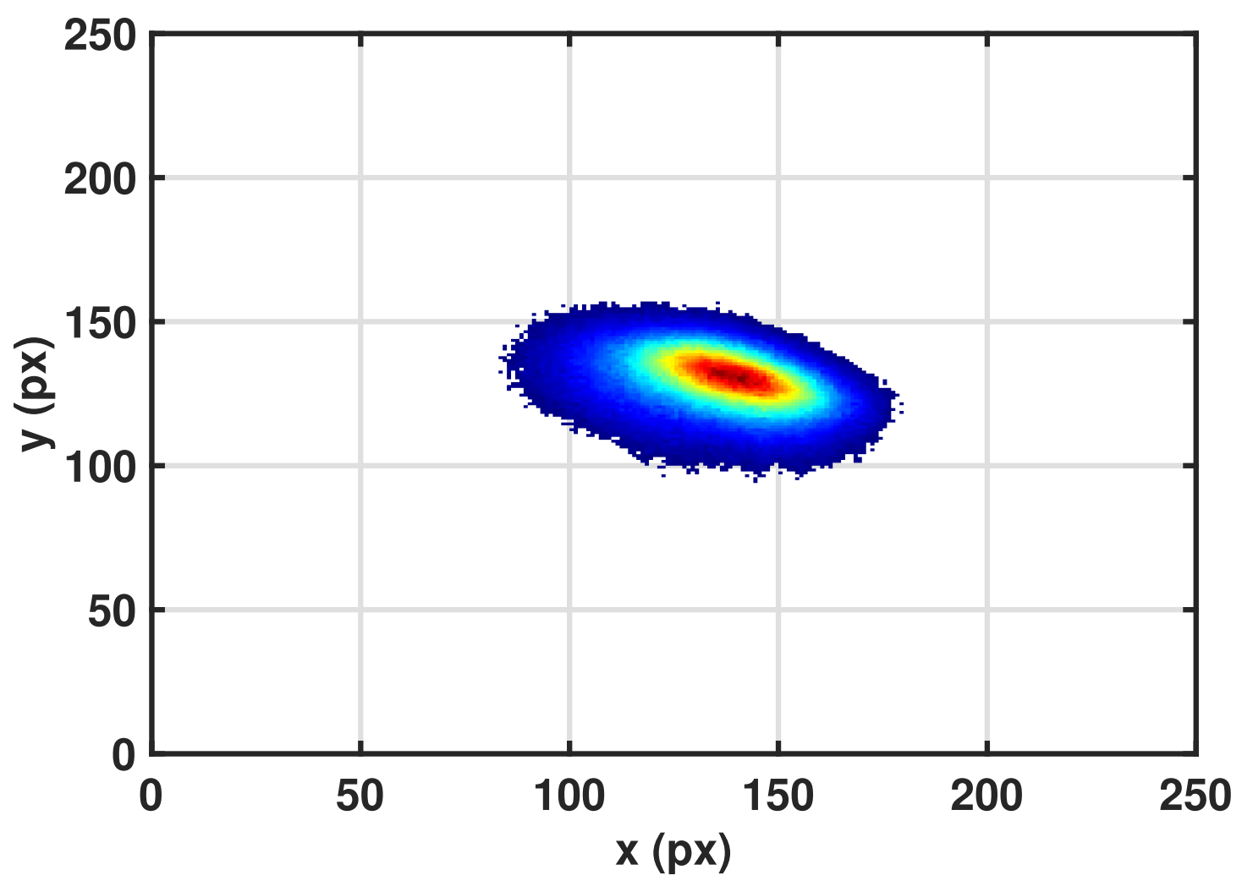
2. Beamline



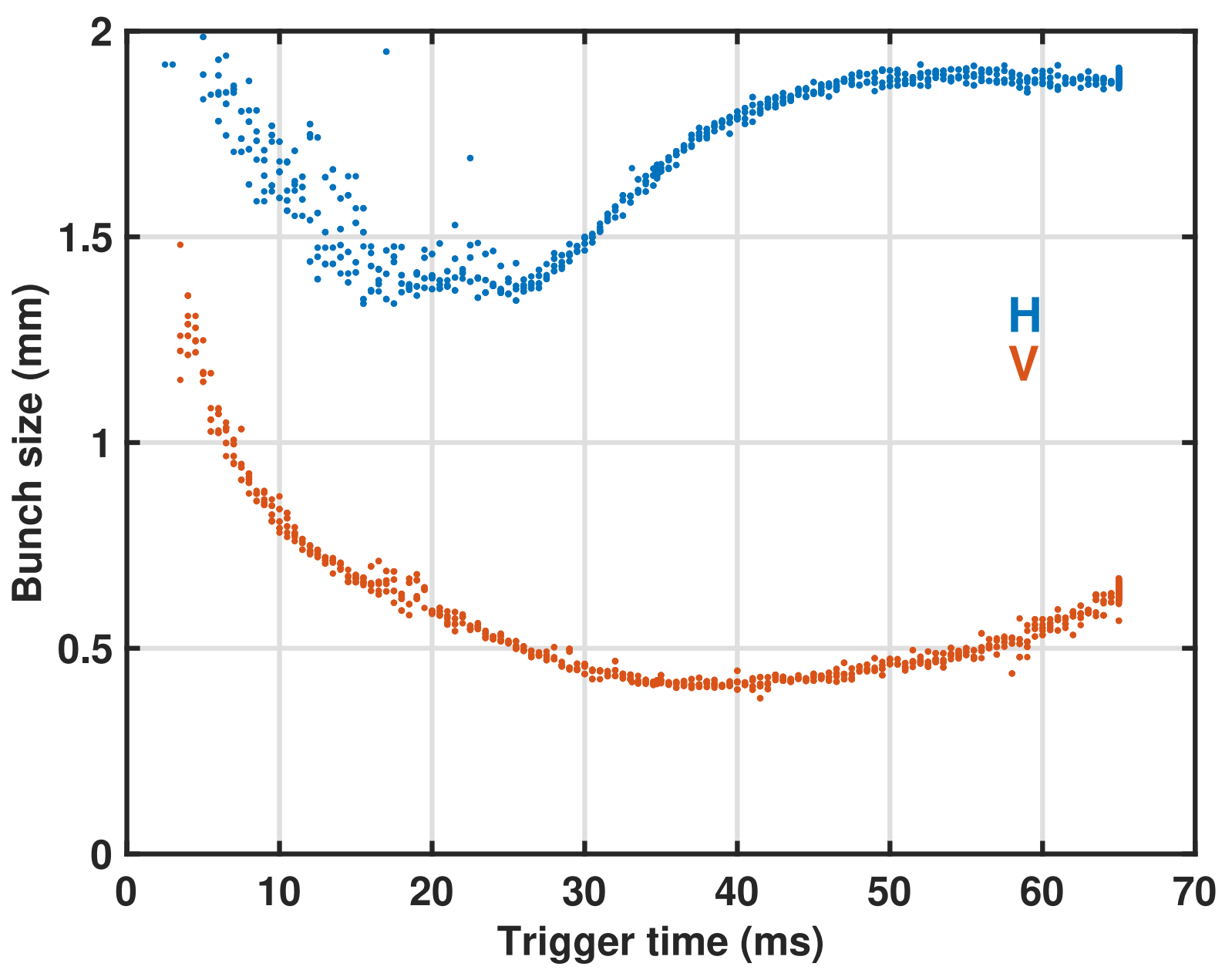
The beamline uses the synchrotron radiation. The divergence of the emitted light is corrected using refractive optics. First, the photons are transported through a wedged vacuum window to compensate the angular dispersion and protect the vacuum of the booster. Afterwards, the photons are reflected at a two-inch aluminium mirror into the tunnel system. The beam is collimated via a motorized achromatic telescope system consisting of 400 mm and 80 mm focal length lenses.
After exiting the labyrinth, the beam is reflected through two additional mirrors on to the optical table. The final outcome is three beamline branches: one for source point analysis of the electron beam size, the second for bunch length measurements via a streak camera and finally an R&D beamline for educational purposes [2].
The first branch is the source point analysis system. The beam is transported through a 500 mm achromatic lens mounted on a linear stage for fine-tuning the position and focused on a CCD camera. Presently installed into the set-up are three different filters: a polarized filter, a wavelength filter for 550 nm and a ND filter for protection of the camera.
On the second branch is installed a retractable mirror and Achromatic Doublet (300 mm), focusing on a streak camera for bunch length measurements.



3. Source-Point Imaging

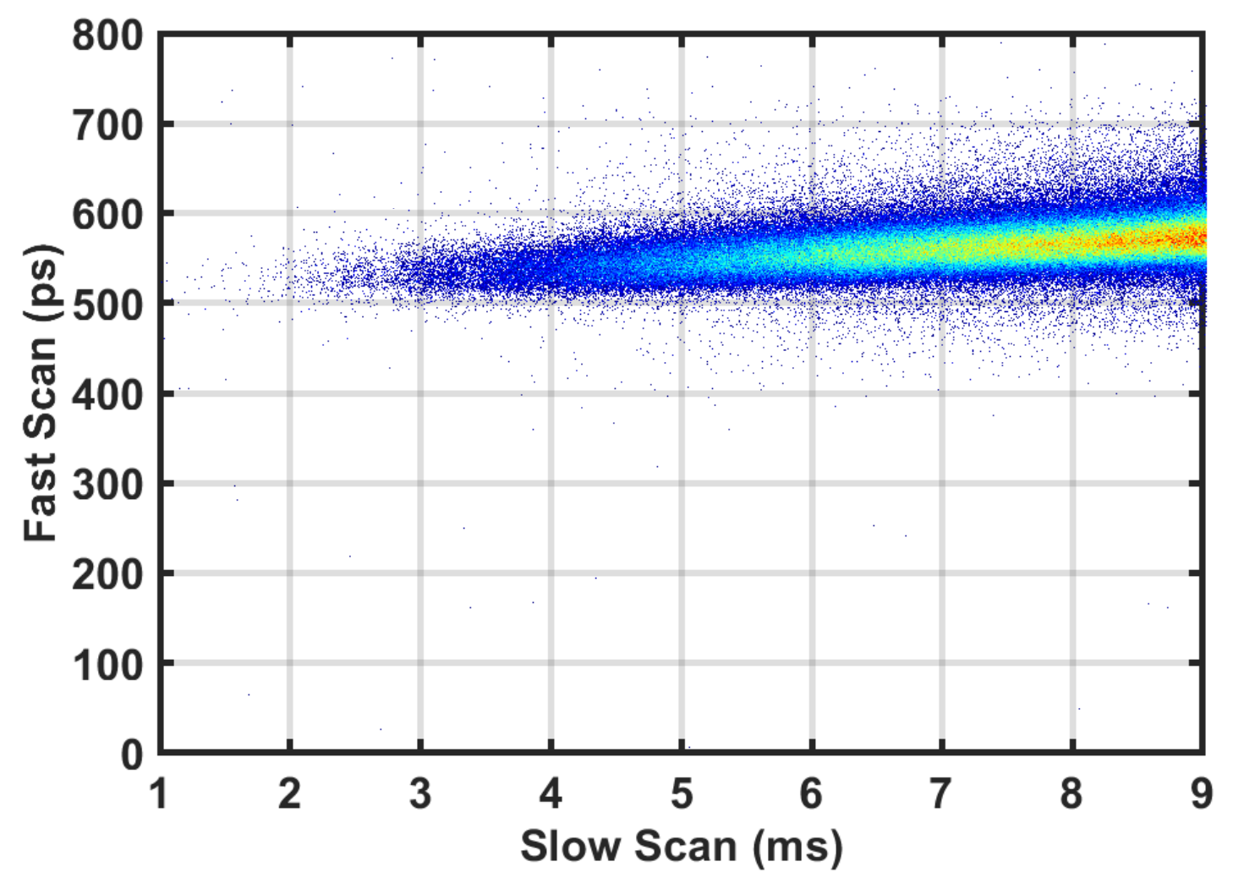


It presents live information of the position, the size and the profile in the vertical and horizontal plane of the beam. Important for the system is the high photon intensity in a defined region of interest, Gaussian beam profiles in both planes and beam stability over a long period of time.
To optimize the system, three main steps have to be performed in the following order. A good alignment for all mirrors is assumed. The first step is aligning the first two lenses, the telescope, to collimate the beam for high photon transmission. In order to do this, a 2D scan is realized, where the last lens is set near the presumed focus point. This measurement indicates region, where the photon count is maximized on the CCD camera. Zemax simulations confirm the optical setup [3]. It is important to note that mainly the relative position to each other is important, rather than the actual position of the lenses in the telescope system.
The final characterisation of the source point was to find a balance between staying close to the focus without limiting the resolution due to the pixel size, preserving the Gaussian properties of the beam spot and checking the working point is independent of the polarization.

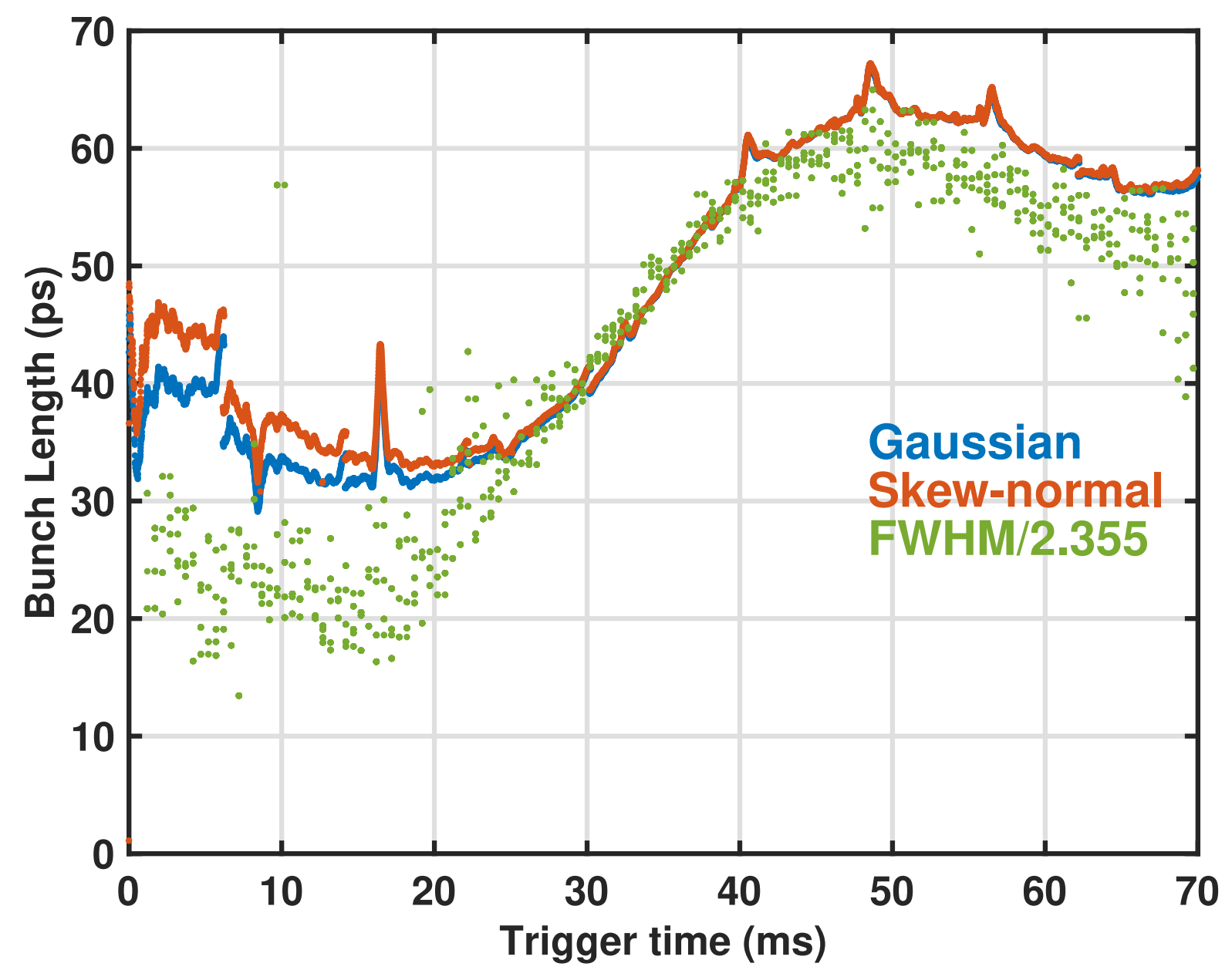


The source point imaging system has been found to be an essential diagnostic for daily operation. During an unwanted failure of a magnet power supply, the current in the coils drifted undetected by the electrical diagnostics. This caused a change in the booster orbit below the resolution of the BPM diagnostics and could only be observed at the high resolution imaging system on the optical table. The problem was readily addressed and repaired without any dark time in operation.
The beam energy increases on the up ramp to 2 GeV at 50 ms and decreases on the down ramp, without extraction. The diagnostics can then be triggered to characterize the whole 10 Hz energy ramp.
The measurements consist on the live readout of the horizontal and vertical Gaussian fit results performed while scanning the delay time of the trigger, to note the trigger is offset to injection at 0 ms (in reality injection is at 5 ms).
The results are in good agreement with the theoretical expectation with the horizontal size that grows from 1.5 mm to 1.7 mm (2 mm at 2 GeV without extraction) while the vertical size decrease from 0.7 mm to 0.4 mm (and then grows again to 0.7 mm).
For delay time below 20 ms, the results are not reliable due to the limited dynamic range of the camera. Also, in order to avoid saturation at high energies, a ND filter has been used, this then needs to be removed for low energy measurements.

4. Longitudinal Diagnostics



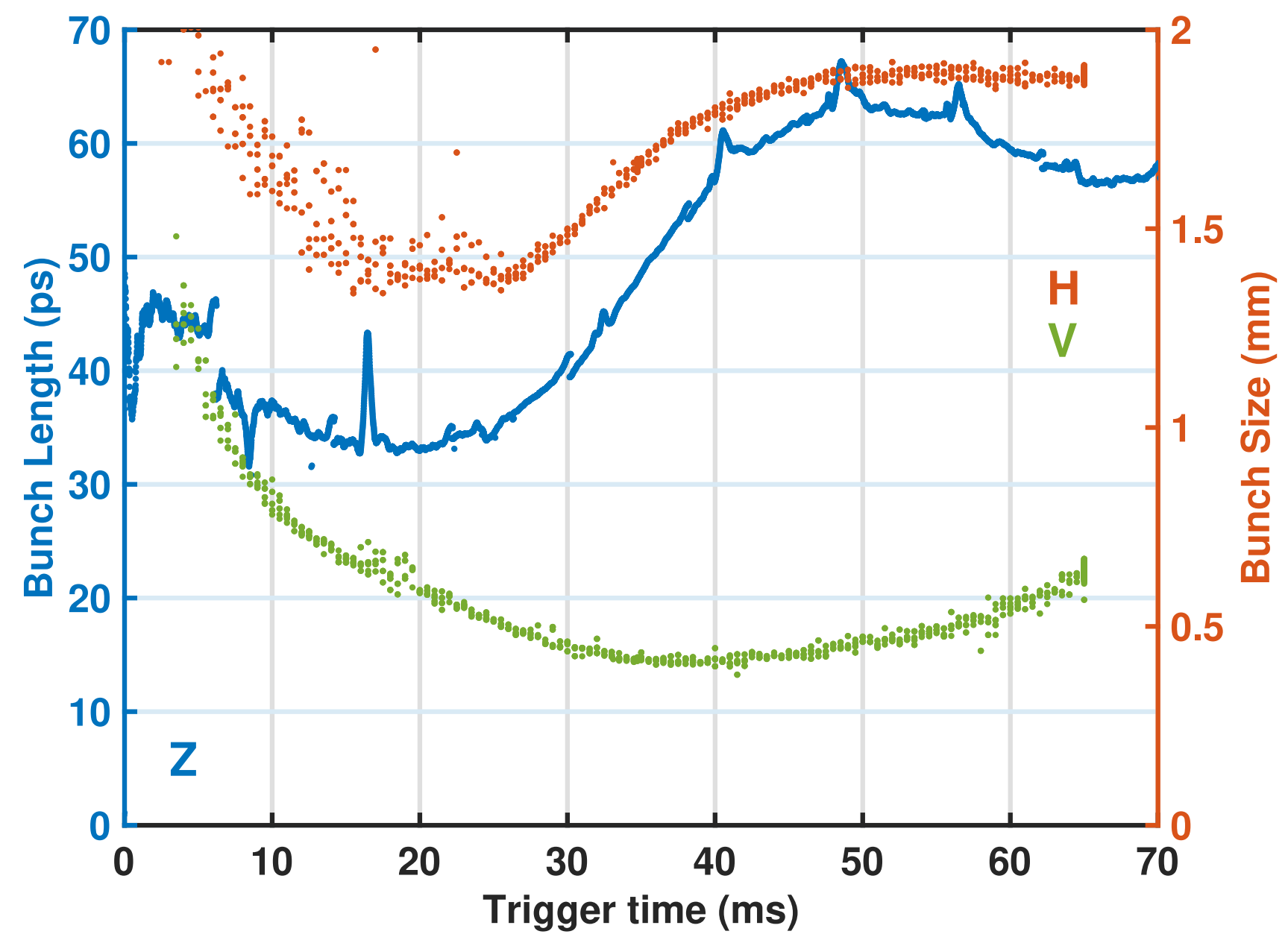
The study of the longitudinal properties of an electron beam in a synchrotron machine is typically done with a streak camera. One parameter (the so-called "Time Range") controls the fast scan and, hence, the bunch length resolution (and field of view). Another parameter (the "blanking amplitude") controls the slow scan, and it is therefore useful to determine the time window of observation: for instance, a small blanking amplitude like 100 ns allows to view the individual bunches, a value in the μs range allows to view multiple turns while a larger value (ms) allows to observe long range phenomena like the ramp up in electron-beam energy.
In a similar manner as above, the delay trigger can be scanned for the longitudinal studies. The streak camera was set to a Blanking Amplitude value of 10 ms: that means that each image shows a 10 ms evolution of the beam with the trigger delay value as a starting time. The measurement has been performed in single bunch configuration; this is due to the fact that in the high charge multi-bunch configuration (5 mA), electron beam instability is observed at lower energies. This makes the proper characterization of the injection phase challenging.
At first, the measurements were performed through the Hamamatsu native software that allows to remotely store the calculated FWHM in a specific ROI; however, this method is not robust and reliable when the Signal to Noise Ratio (SNR) become too low. This condition happens in the first bunch-turns in the booster when the electron energy is still close to the initial value of 50 MeV.



Therefore, an offline analysis has also been performed: images at different trigger delay has been saved and later analysed both evaluating the FWHM and by means of a Gaussian Fit.
For electron energy below 100 MeV (trigger time of 25 ms), the Gaussian fit and the Hamamatsu evaluation diverges and the latter is no longer reliable.
Furthermore, it should be also point out that in the first turns the electron bunch profile is not purely Gaussian, but it presents some asymmetry (close to a triangular profile): different fit functions rather than the Gaussian has been studied (i.e. skew-normal). The fit is improved from 0.9 to 0.92 (about 2 %) in the first 20 ms, and the corresponding bunch length is increased by 8 %. After this time, the two results do not differ significantly (less than 1 %).
Finally, the evolution in time of the bunch size in all the three planes is reported.

5. Conclusion

The beamline was brought into operation through careful planning without any dark time.
These improvements in the beamline were useful to perform a time resolved analysis of the bunches as they get accelerated in the booster before entering the storage ring.
The source-point imaging was used to study the transverse beam dynamics during the booster ramp, finding a good agreement with theoretical expectation.
A streak-camera was used to study the longitudinal evolution during the ramp: the best results have been obtained with an offline analysis and a skew-normal fit due to the asymmetric particle distribution at low energy (at the beginning of the ramp).
A fast live-mode scan was also implemented with the streak-camera, and with the source-point imaging as well, but this shows unreliable results for low energies (below 100 MeV) when the SNR is too high.
This is the first time that such a diagnostic tool has been used to show the evolution of the beam during a booster ramp. The facility now has the key-components to tailor beams from the pre-injector to the electron storage ring, preserving the high injection efficiency.



Reference

[1] T. Atkinson et al., Status and prospects of the bessy ii injector system, in 7th Int. Particle Accelerator Conf. (IPAC16), 2016.
[2] P. Ahmels et al., Advanced development beamline for the BESSY II Booster, presented at IBIC 2024, Beijing, China, September 2024, paper THP54, this conference.
[3] P. Ahmels, Inbetriebnahme des Aufbaus eines optischen Messinstruments zur Quellpunktabbildung am Vorbeschleuniger von BESSY II, Bachelor Thesis, Technical University Berlin, 2023.

IBIC2024 - 13th International Beam Instrumentation Conference - Beijing, China. September 9-13, 2024