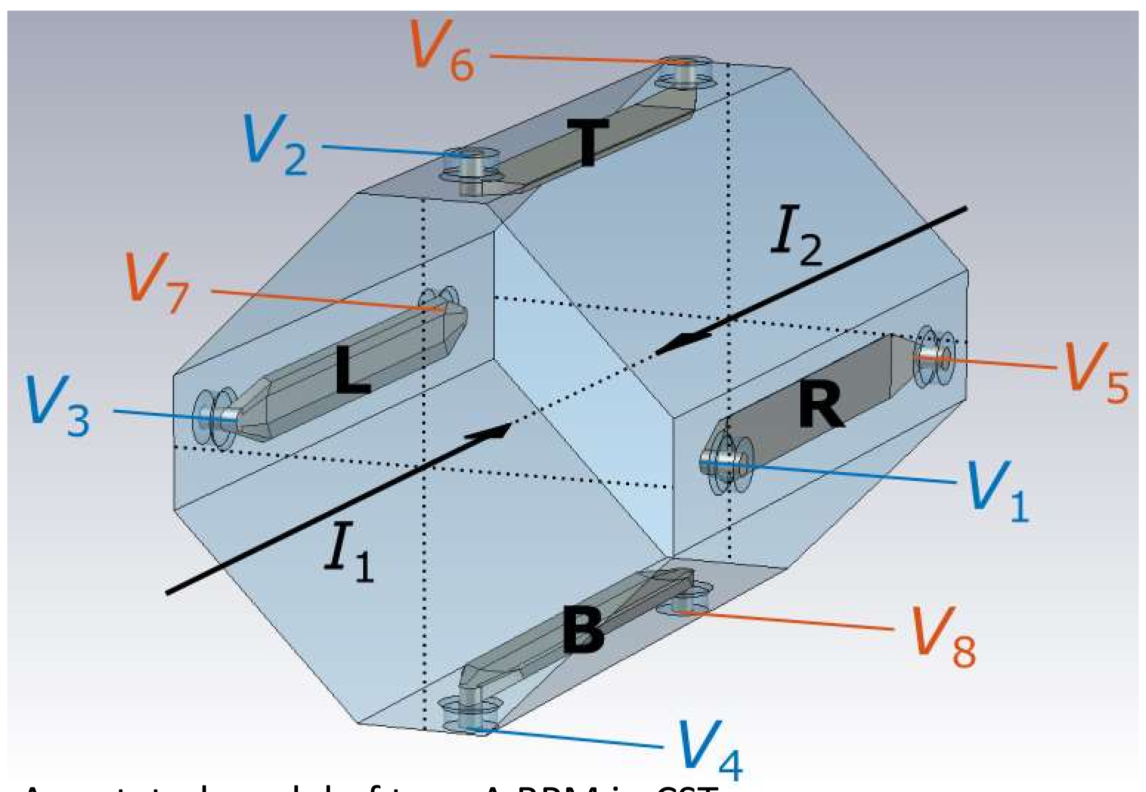
SIMULATION OF THE SIGNAL PROCESSING FOR THE NEW INTERACTION REGION BPMs OF THE HIGH LUMINOSITY LHC

IBIC'20 International Beam Instrumentation Conference
WEPP12

D. R. Bett
John Adams Institute for Accelerator Science, University of Oxford, UK
M. Wendt, M. Krupa, A. Boccardi
CERN, Geneva, Switzerland

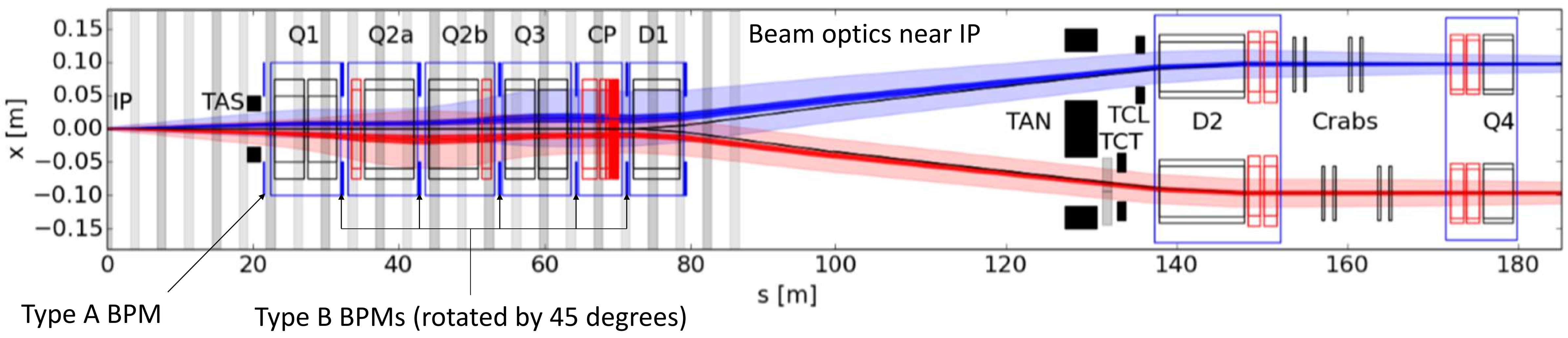
New stripline beam position monitors (BPMs) will be installed at the Interaction Regions of the ATLAS and CMS experiments as part of the High-Luminosity upgrade to the LHC. These BPMs will be located in sections of the beamline where the two counter-propagating proton beams co-exist within a single pipe, such that the signal observed on each output port is a combination of the signals generated by each beam. The use of the BPMs as the input for a possible luminosity feedback system places a demanding requirement on the long-term accuracy of the BPMs. Accurate measurement of the position of each beam requires a method for isolating the individual beam signals. A simulation framework has been developed covering all stages of the measurement process, from generation of the signals expected for beams of a given intensity and orbit through to digitization, and has been used to evaluate several candidate methods for extracting the position of each beam in the presence of the unwanted signal from the other.

Interaction region BPMs

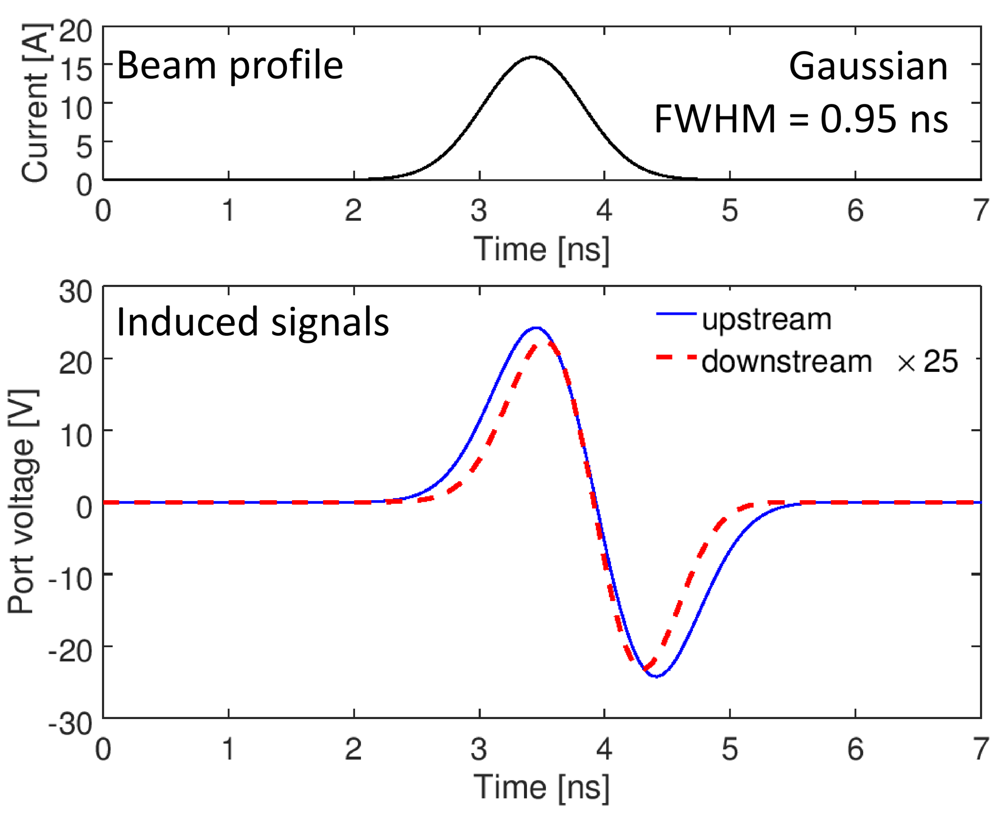


Annotated model of type A BPM in CST

CST Microwave Studio [2] was used to simulate the voltage induced at the upstream ports (V_1-V_4) and downstream ports (V_5-V_8) for a single beam travelling from upstream to downstream along the BPM axis (I_1).



The High Luminosity LHC is an upgrade of the LHC with a target luminosity five times larger than the current nominal value. Six new octagonal stripline BPMs of two different types will be installed either side of the IP [1] in interaction region 1 (ATLAS) and 5 (CMS). Close to the IP, the two beams travel within the same pipe and the BPMs must measure the position of both.

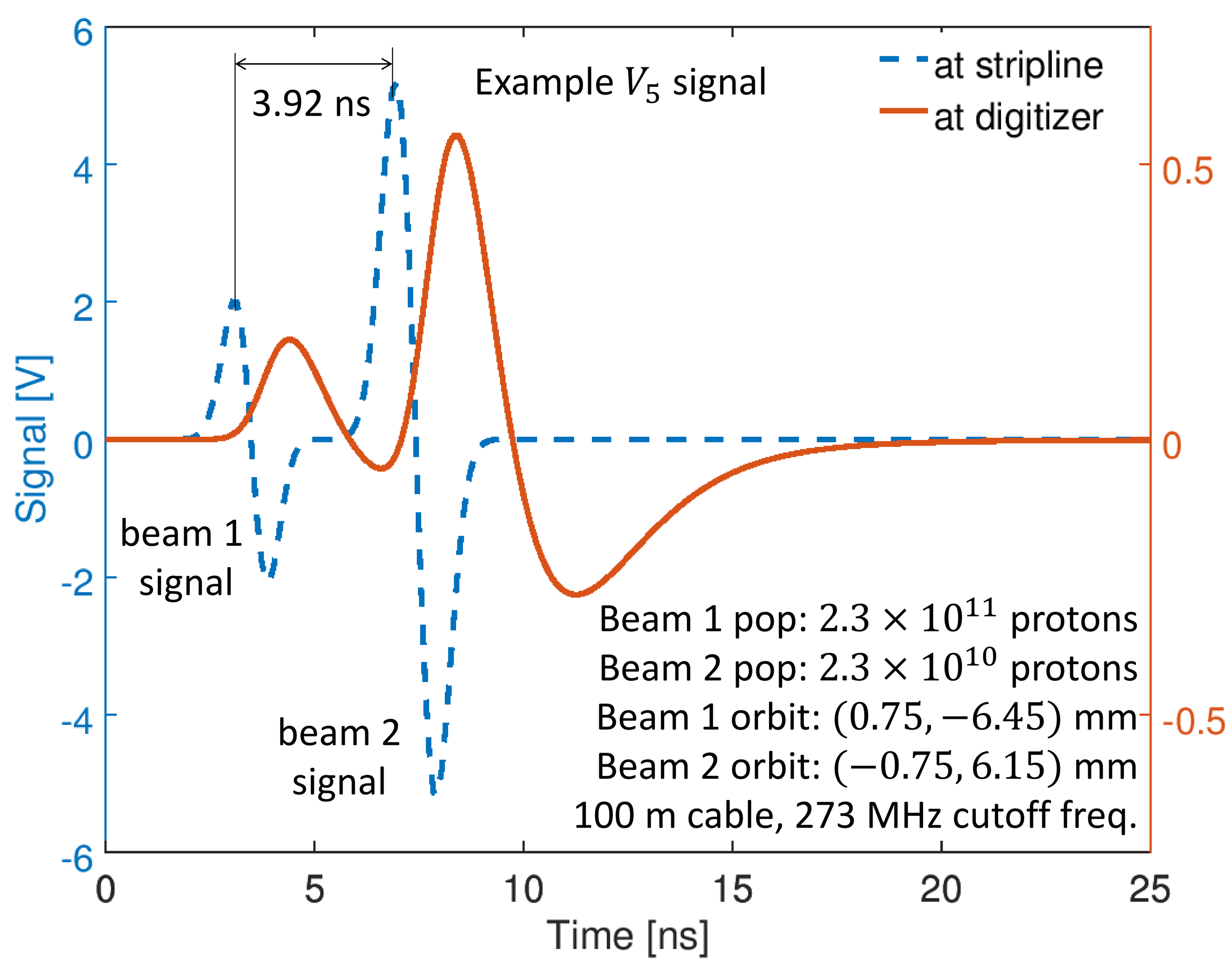


Simulation

GNU Octave [5] was used to simulate the process of obtaining beam position measurements from the stripline signals. The CST predictions are scaled according to the position and charge of each beam and the signals from beam 2 are delayed as appropriate in order to form the set of eight stripline signals.

The simulation models the effect of transporting the signals out of the high-radiation environment of the interaction region using long (>100 m) cables and then stretching them with a reflectionless low-pass filter [4].

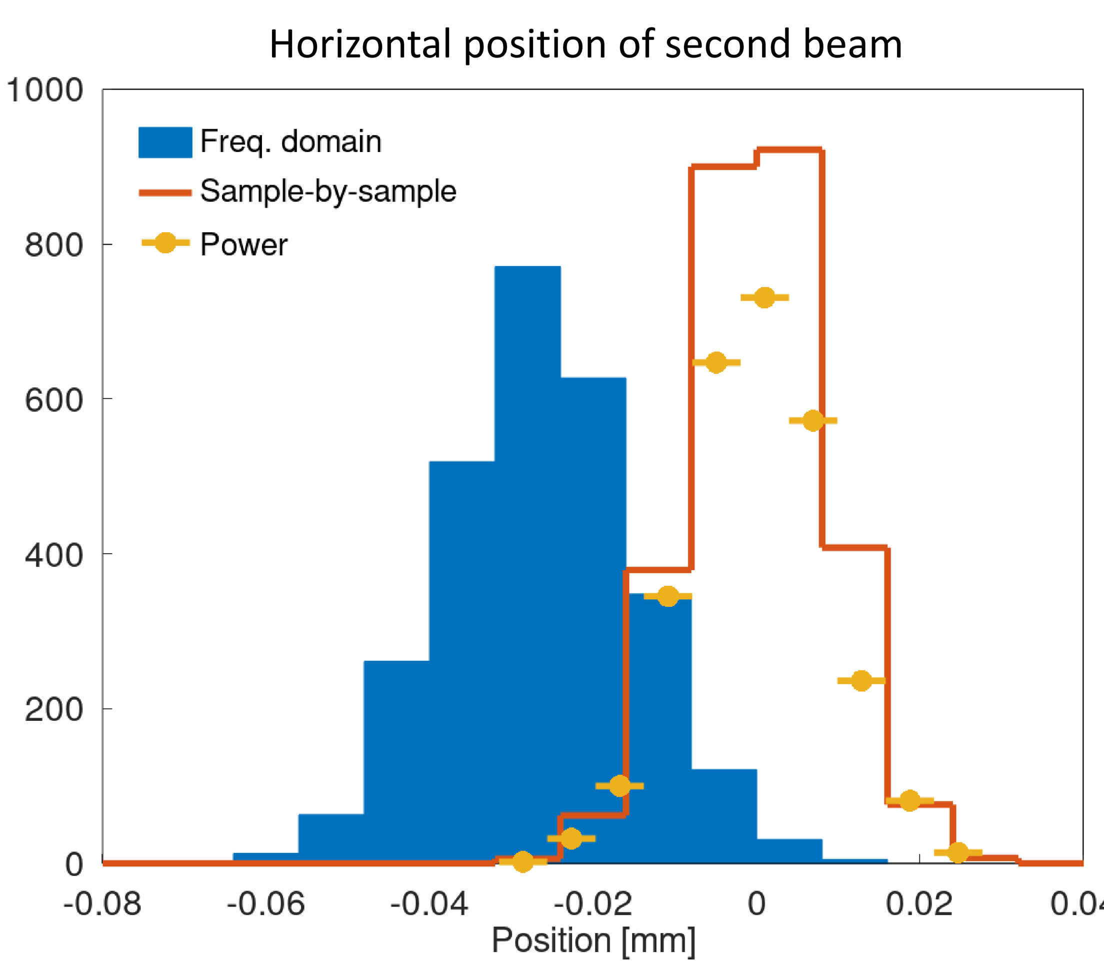
An ensemble of 2,760 pulses at the same position was generated by digitizing the set of eight stripline signal at 12-bit resolution with a 4 GHz sample clock. The clock phase varied uniformly and 1.5 bits of randomly distributed noise was added to each sample. Each set of eight waveforms was then used to perform a position measurement.



Compensation

Several methods of compensating the waveforms to account for the signal from the other beam were considered. These included explicit sample-by-sample subtraction of a reference waveform (scaled according to the observed amplitude of the waveform from the other end of the stripline) and a frequency domain approach that assumed the response of the BPM and the other hardware could be measured well enough to be able to recover the image current induced by each beam on each stripline.

The plot below shows histograms of the difference between the measured position and the ``ideal'' position of the stripline for three different methods. The frequency domain method clearly performs the worst as the mean apparent horizontal position of the second beam is offset by 25 µm from the ideal value compared to only 3 µm when no compensation is applied. Both sample-by-sample and power methods reduce this offset to less than half a micron. The single-pass error is approximately 10 µm regardless of whether compensation is performed or not. Power compensation is thus the preferred method as it requires by far the smallest amount of digital processing power.



Power compensation method

Consider the signal induced at the upstream end of the R stripline:

$$V_1 = \kappa_{1R} V_{1c} + \kappa_{2R} V_{2i}$$

- V_{1c} is the signal induced at the upstream end of each stripline by a reference beam 1 with some nominal intensity and bunch length that travels on axis
- V_{2i} is the signal induced by a reference beam 2 which has the same intensity and bunch length as the reference beam 1 and likewise travels on axis
- The κ scale factors set the amplitude of each term of the stripline signal according to the intensity of each beam and its position in the BPM; $\kappa_{ij} = \rho_{ij} \cdot q_i$ where q_i is the intensity of the actual beam i (expressed as a multiple of the intensity of the reference beam) and ρ_{ij} is the angle subtended by beam i on stripline j (expressed as a multiple of the angle subtended from the center of the BPM)

Taking the sum of the samples squared for both sides:

$$\underbrace{\sum V_1^2}_{\psi_1} = \kappa_{1R}^2 \underbrace{\sum V_{1c}^2}_{\psi_{1c}} + 2\kappa_{1R}\kappa_{2R} \underbrace{\sum V_{1c} \cdot V_{2i}}_{\chi_{1c2i}} + \kappa_{2R}^2 \underbrace{\sum V_{2i}^2}_{\psi_{2i}}$$

$$\kappa_{1R}^2 + 2\frac{\chi_{1c2i}}{\psi_{1c}} \kappa_{1R}\kappa_{2R} + \left(\frac{\psi_{2i}}{\psi_{1c}} \kappa_{2R}^2 - \frac{\psi_1}{\psi_{1c}}\right) = 0$$

By replacing κ_{2R} with $\sqrt{\psi_5/\psi_{2c}}$ the above becomes a quadratic equation whose coefficients are functions of scalars that are calculated in advance from the reference waveforms or calculated in real time from the measured waveforms:

$$\kappa_{1R}^2 + \left(2\frac{\chi_{1c2i}}{\psi_{1c}} \sqrt{\frac{\psi_5}{\psi_{2c}}}\right) \kappa_{1R} + \left(\frac{\psi_{2i}}{\psi_{1c}\psi_{2c}} \psi_5 - \frac{1}{\psi_{1c}} \psi_1\right) = 0$$

References

[1] R. De Maria, S. D. Fartoukh, and M. Fitterer, "HLLHCV1.1 Optics Version for the HL-LHC Upgrade", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 2090-2093. doi:10.18429/JACoW-IPAC2015-TUPTY037

[2] CST Microwave Studio, http://www.cst.com

[3] M. Wendt, "BPM Systems: A brief Introduction to Beam Position Monitoring," [arXiv:2005:14081 [physics.acc-ph]]

[4] M. Morgan, "Synthesis of a New Class of Reflectionless Filter Prototypes," [arXiv:1008.3502 [astro-ph.IM]].

[5] J. W. Eaton, D. Bateman, S. Hauberg, R. Wehbring "GNU Octave version 5.2.0 manual: a high-level interactive language for numerical computations" http://ww.gnu.org/software/octave/doc/interpreter