Measurements and calibration of the stripline BPM for the ELI-NP facility with the stretched wire method

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A methodology has been developed to perform electrical characterization of the stripline BPMs for the future Gamma Beam System (GBS) of the ELI Nuclear Physics (ELI-NP) facility in Romania.

Several prototype BPM units are extensively benchmarked and the results are presented in this work. The mechanical offset and sensitivity functions are determined using a uniquely designed motorized test bench with a stretched wire for measuring the BPM response maps.

The electrical offset is obtained using S-parameter measurements with a Network Analyzer via the *"Lambertson"* method and is referenced to the mechanical offset.

Table 1: Main characteristics of the ELI-NP Linac.

Linac energy E_e	700 MeV
Linac length	90 m
Number of bunches	32
Bunch spacing	16 ns
Charge/bunch	[25 - 400] pC
Bunch size, σ_x	100-200 μm
Bunch size, σ_y	100-200 μm
Bunch length, σ_z	3-4 ps

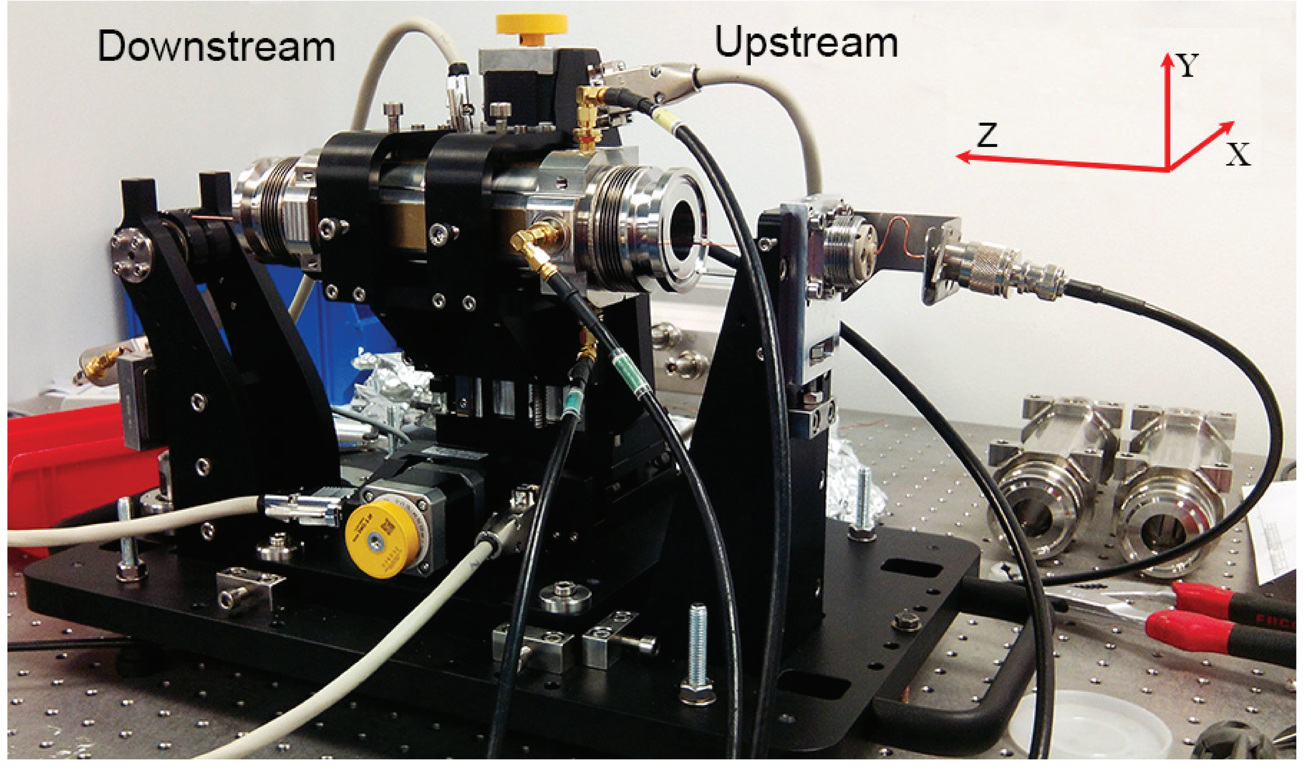
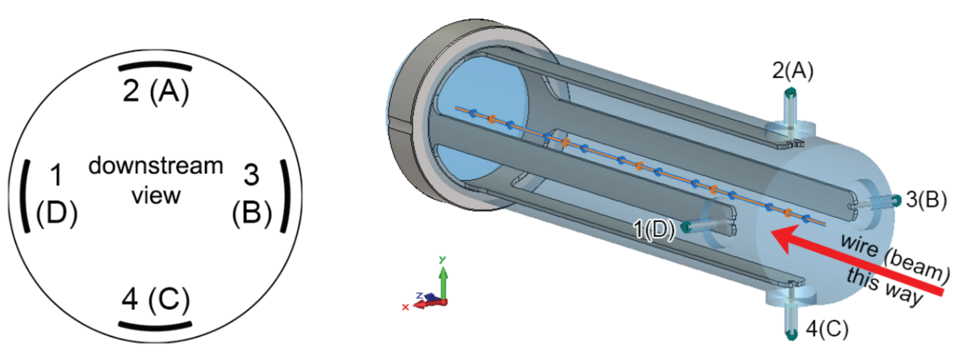


Fig. 2. Photo of the ELI-NP stripline BPM in the lab, mounted on the test bench for wire mapping.

Introduction and setup



(a) cross-section. (b) 3D BPM Model.

Figure 1: Naming convention and 3D BPM Model.

The stripline BPMs for the GBS of ELI-NP are designed by INFN/LNF in Frascati, produced by *Comeb* (Italy), and measured in ALBA for electrical characterization and alignment. In total there will be 32 BPM units, all of them lambda/4 stripline type working at ~500 MHz, shorted on the downstream port, Fig. 1.

This work summarizes the methodology followed to characterize the stripline BPMs and find their offsets using different techniques.

Simulations of exciting the wire or the electrode reveal different patterns of periodic notches, which are due to the electrode geometry or the excitation type.

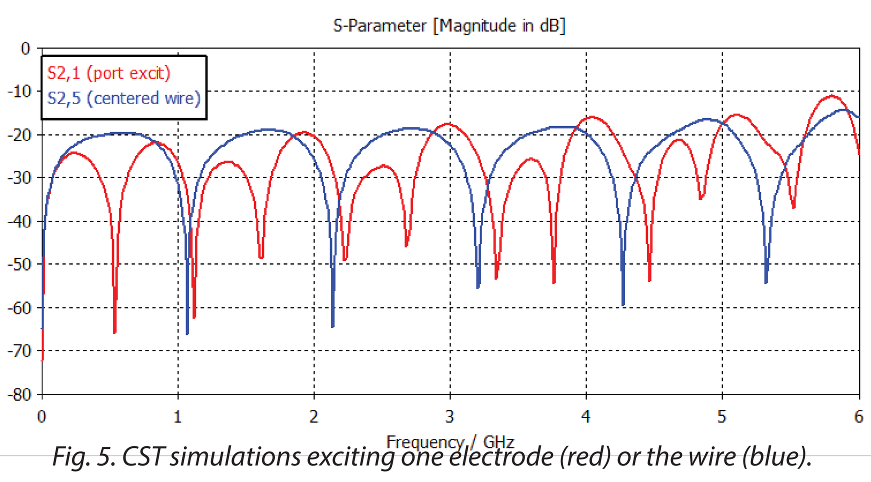


Fig. 5. CST simulations exciting one electrode (red) or the wire (blue).

Electrical offset measurement

The electrical offset (*Xe,Ye*) is obtained using the *"Lambertson"* method, which is used to analyze the asymmetries among BPM electrodes. The electrical offset measured this way is not affected by any systematic error due to the test bench or BPM positioning on it.

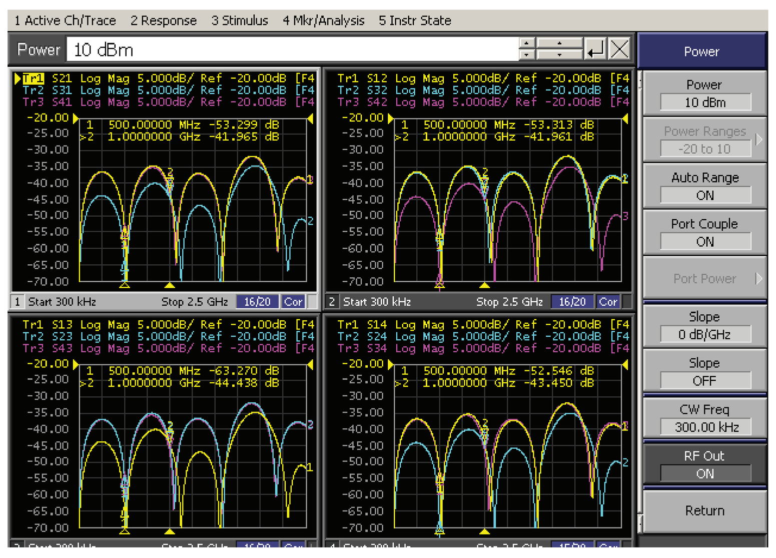


Fig. 3. Sample snapshot of the S-parameter measurement by a Network Analyzer.

This method uses the coupling between buttons/electrodes to determine the gain factors *gi* of each electrode; the ratios between gain factors then provide the difference between mechanical and electrical centers.

$$x_e = k_x \times \frac{g_3 - g_1}{g_3 + g_1}, \quad y_e = k_y \times \frac{g_2 - g_4}{g_2 + g_4}$$

In total there are 3 possible asymmetries of each electrode with respect to the others:

$$2 * 50 * g_1^2 = \frac{V_{21}V_{14}}{V_{42}} \times \frac{G_{13}}{G_{12}G_{23}} = \frac{V_{12}V_{31}}{V_{32}} \times \frac{G_{23}}{G_{12}G_{13}} = \frac{V_{41}V_{31}}{V_{43}} \times \frac{G_{12}}{G_{23}G_{13}}$$

In practice, the BPM electrical offset is obtained by measuring S-parameter matrix of the 4 electrodes with a Network Analyzer (Fig. 3) and transforming it from dB to linear readings.
Since the normalized voltage *Vij* is equal to the transmission coefficient *Sij*, e.g. the *Xe* position is:

$$x_e = k_x \frac{\sqrt{10^{S_{x,ijm}/20}} - \sqrt{10^{S_{x,npq}/20}}}{\sqrt{10^{S_{x,ijm}/20}} + \sqrt{10^{S_{x,npq}/20}}}$$

where one of the three combinations for Xe, Ye is

$$\text{(a)} \quad \begin{cases} S_{x,ijm} = S_{32} + S_{42} - S_{43} \\ S_{x,npq} = S_{14} + S_{42} - S_{21} \end{cases} \quad \text{and} \quad \begin{cases} S_{y,ijm} = S_{41} + S_{31} - S_{43} \\ S_{y,npq} = S_{32} + S_{31} - S_{21} \end{cases}$$

Figs. 6 show the hor and ver offsets for a range of frequencies [0.2-2500] MHz. The periodic notches are in agreement with the CST simulations in Fig 5.

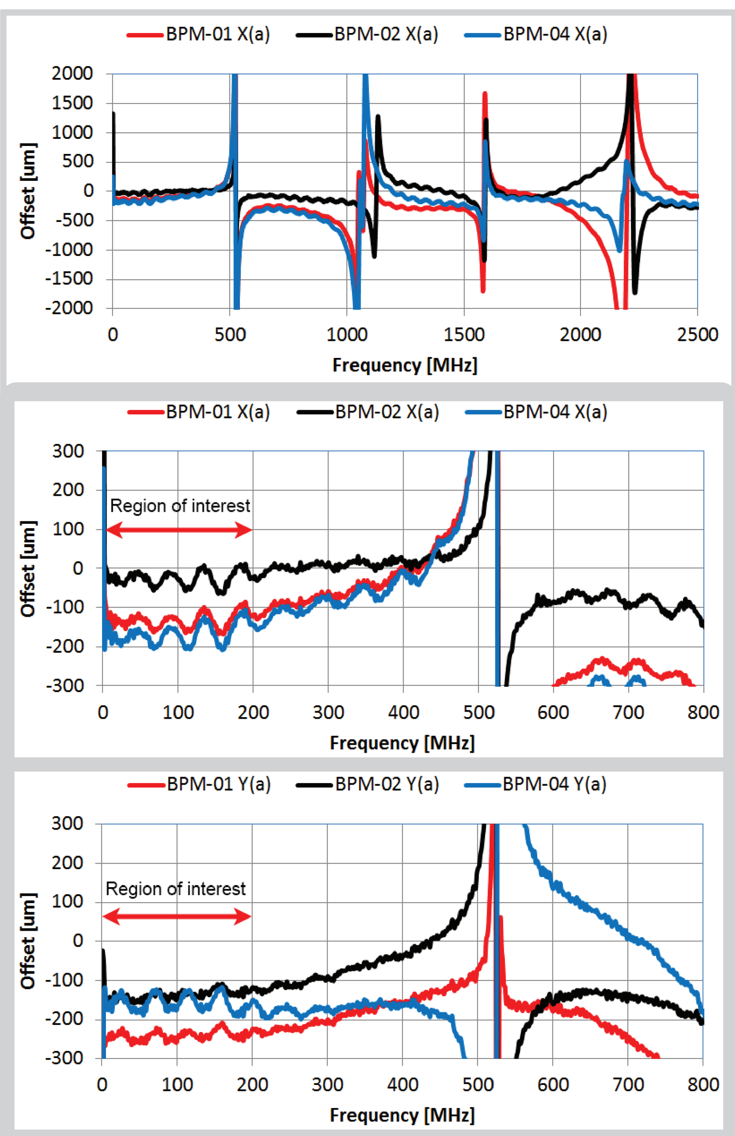


Fig. 6. Measurement of the electrical offset of each plane and zoom-ins (one of the 3 combinations for each

The measured offsets of the 3 striplines do not show flat behavior at their working frequency. It therefore makes sense to take an average value for offsets in both planes between [20-200] MHz (Table 2).

Table 2: Electrical offsets measured using the external "Lambertson" method.

	$x_e, \mu m$	$y_e, \mu m$
BPM-01	132 ± 0	-238 ± 8.5
BPM-02	25 ± 0.15	-134 ± 10.4
BPM-04	165 ± 0.7	-157 ± 10

BPM test bench and its fiducialization

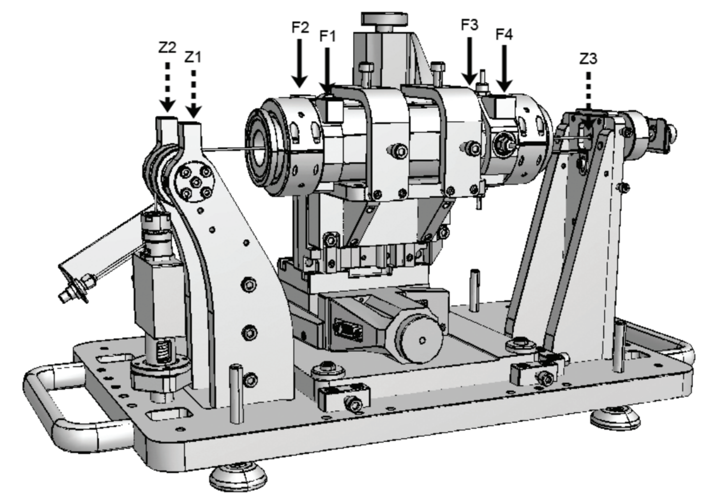


Figure 8: A complete 3D model of the test bench for ELI BPM measurements.

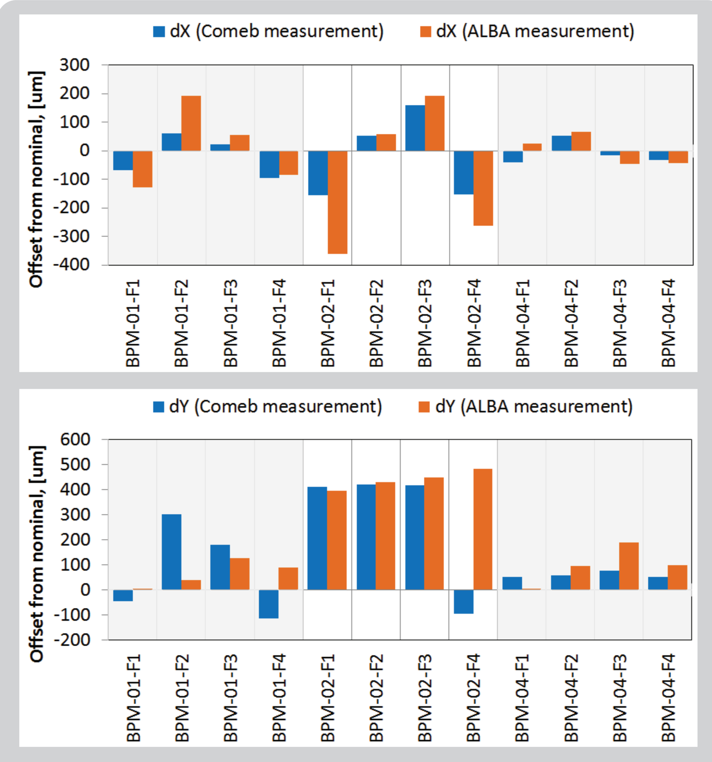


Fig. 9. Fiducial position deviations from nominal in X and Y.

The ALBA engineering department has designed an ad-hoc test bench to mechanically hold the stripline BPMs for stretched wire measurements, Fig. 8.

The bench is equipped with 2 motors for hor and ver movement and ensures reproducibility of within 20 um between BPM-to-BPM measurements.

The BPM fiducials' (F1, F2, F3, F4) positions with respect to the wire are measured by the alignment team of ALBA and compared to factory values. Large mismatches are discovered in particular cases, Fig. 9.

The stretched wire is considered as the *homing position* where (x,y) = [0,0]. The wire position is referenced by the three fiducials on the test bench (Z1, Z2, Z3). A BPM is placed on an L-shaped motor-controlled platform touching it with its two reference surfaces whose positions are known within 20 um, Fig. 10.

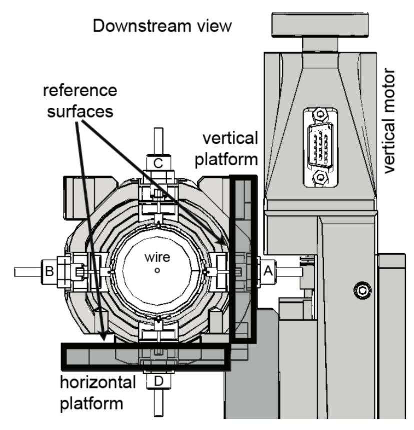
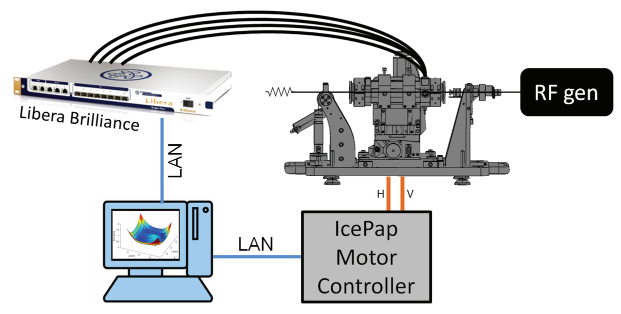


Figure 10: Positioning a BPM on an L-shaped platform by touching it with 2 reference surfaces.

Mechanical offset by wire scanning



The wire scan is emulated by scanning the BPM transversely around the stretched wire to obtain the sensitivity factors (*kx,ky*) and the mechanical offset (*Xw,Yw*):

$$x_0 = k_x \frac{V_3 - V_1}{V_3 + V_1} - x_w$$
$$y_0 = k_y \frac{V_2 - V_4}{V_2 + V_4} - y_w$$

The wire (1 mm, Cu) is fed by an RF signal generator (CW 499.654 MHz) and is terminated by 50 Ohm. The electrode signals are read by the *Libera Brilliance* electronics with averaging over 1024 samples. The bench motors are controlled by a standard *IcePap* controller from a remote PC.

One result of such scan is shown in Fig. 11. These offsets, referenced with respect to BPM's fiducials, are due to all possible mechanical and electrical effects:

-- positioning errors of the BPM on the test bench;
-- electrical offset due to geometrical manufacturing imperfections;
-- electrical offset due to cable differences and reading electronics.

The measured mechanical offsets (Table 4) will be taken into account when installing the BPM units in the GBS Linac.

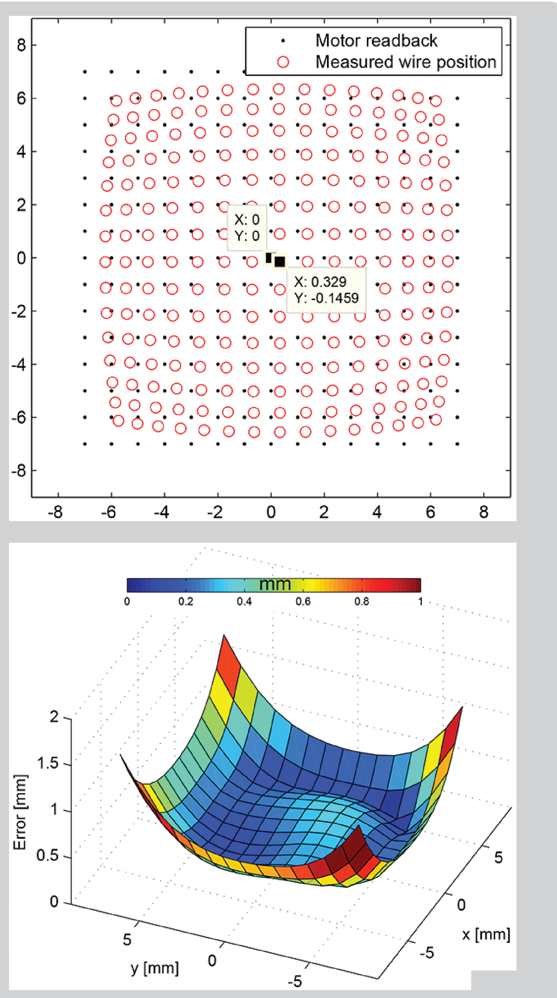


Fig. 11. BPM response map an its error, measured by wire scanning, with respect to motor positions.

Table 4: Offsets measured using the wire scan.

	k_x	k_y	$x_w, \mu m$	$y_w, \mu m$
BPM-01	9.57	9.51	146 ± 39	-19 ± 16
BPM-02	9.47	9.45	114 ± 14	-210 ± 48
BPM-04	9.57	9.54	256 ± 16	-139 ± 34

REFERENCES
[1] G.R. Lambertson, "Calibration of Position Electrodes using external measurements", LSAP Note-5, LBL, 1987.
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[3] A. Olmos, M. Alvarez and F. Perez, "BPM characterization for ALBA", TUPSM075, Proceedings of BIW10, 2010.