Electron bunch position determination using a high frequency button beam position monitor in the AWAKE facility

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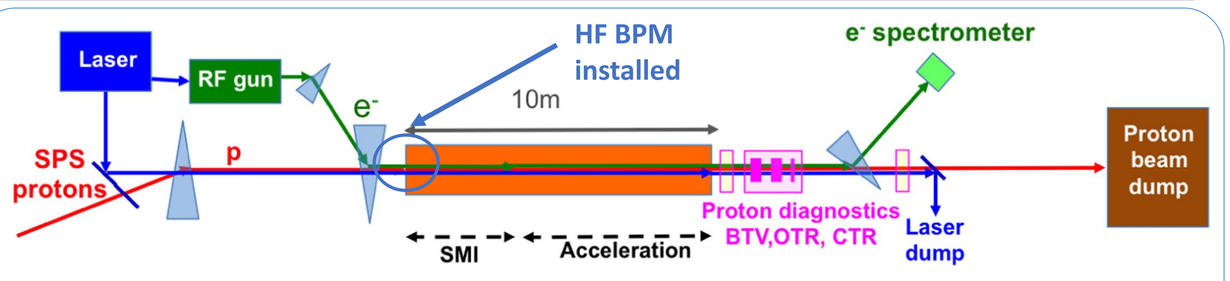
The AWAKE experiment

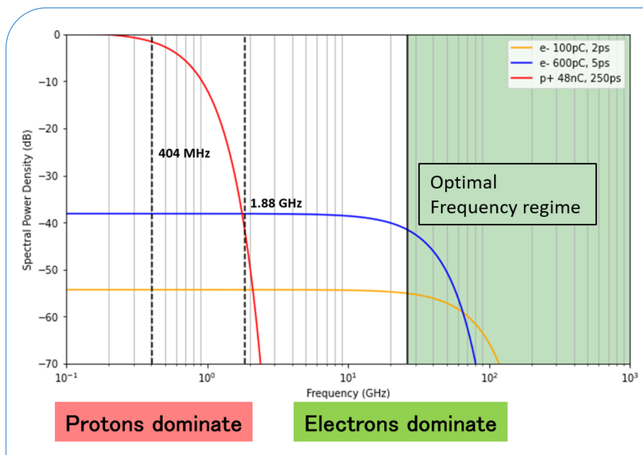


Setup of the AWAKE experiment [1].

The AWAKE experiment focuses on the acceleration of electrons using proton driven plasma wakefields [2].

- A **proton bunch** is extracted every 15-30 s from the Super Proton Synchrotron (SPS) at **400 GeV** and **bunch length 6-8 s**.
- **Laser beam** used to ionize the **Rb vapor** and seed the self-modulation process of the long proton bunch.
- A **20 MeV, 100-600 pC electron beam** co-propagating with the proton and laser beam travels through a **10 m Rb plasma cell**.

A High Frequency BPM



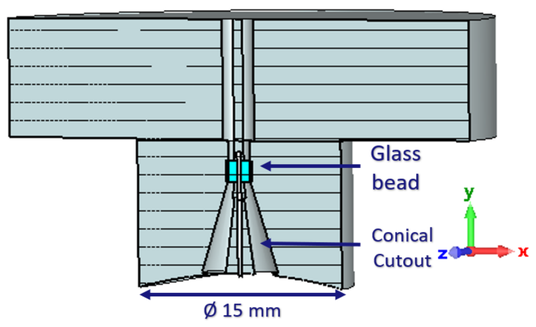
- The current electron BPMs in the common beam-line operate at $f_{readout}$ = 404 MHz where the electron signal is overshadowed by the proton signal.
- To measure the electrons in the presence of the more-intense proton bunches, requires a BPM to have a pass-band at frequencies higher than a few GHz.

Conical button BPM design by DESY [3]

- Designed as part of a bunch arrival-time monitor.
- High bandwidth with cut-off frequency > 40 GHz.

Electron Beam Studies

A simplified design of the HF BPM in CST, the button material is modelled with Aluminium, the beam pipe as a perfect vacuum, and the metallic conical pickup as a perfect electrical conductor (PEC).

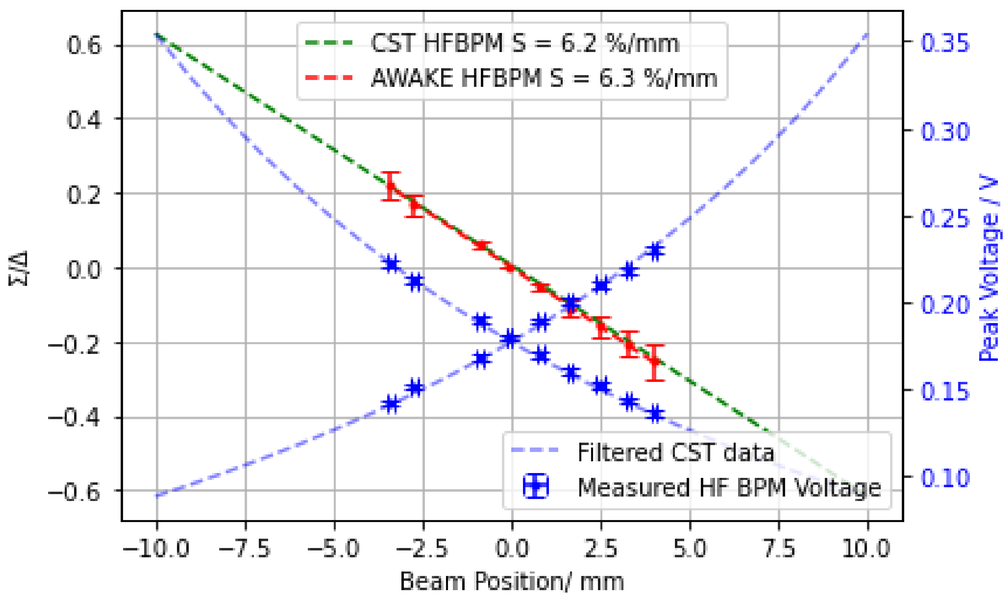


Electron beam measurements were conducted in parallel with numerical simulations. The Horizontal plane of the HF BPM was connected directly to an 8GHz Tektronix Oscilloscope via a series of coaxial cables.

$$x = \frac{1}{S_x}\frac{\Delta U_x}{\Sigma U_x} + \delta_x$$

The difference between the voltage from opposite radiators ΔUx = Uright − Uleft, and using a normalisation factor, here defined as the sum of the voltages, ΣUx = Uright + Uleft,

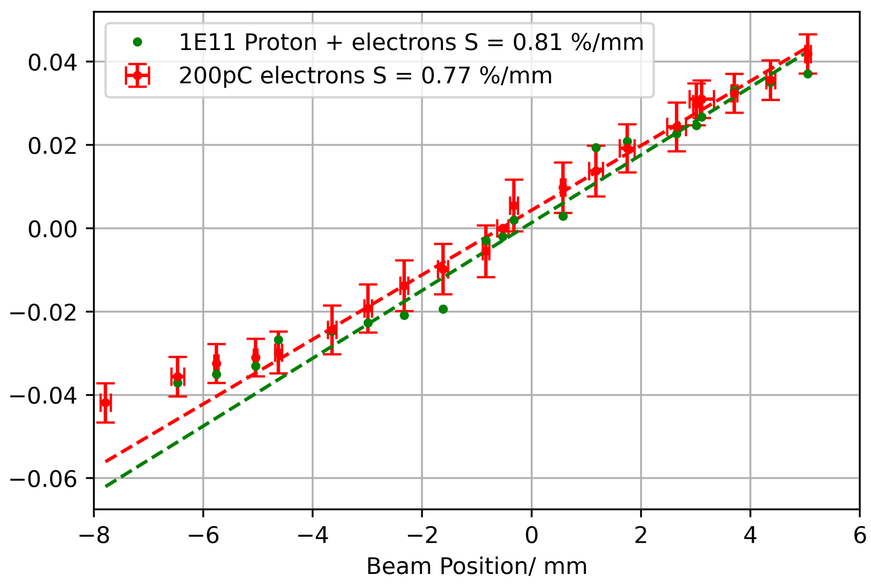
The constant Sx, also referred to as the position sensitivity, has units of [%/mm] and is an important characteristic of any BPM.

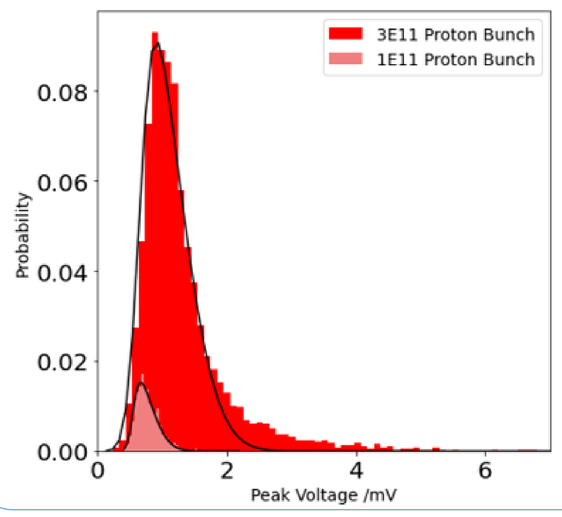


Simulated and measured response of the HF Button as a function of the electron beam position.

Combined Beam Studies

Position sensitivity of the HF BPM with 320 pC electrons only (red) and electrons and 1 × 10^{11} protons (green). The sensitivity is calculated between -5 and 5 mm.

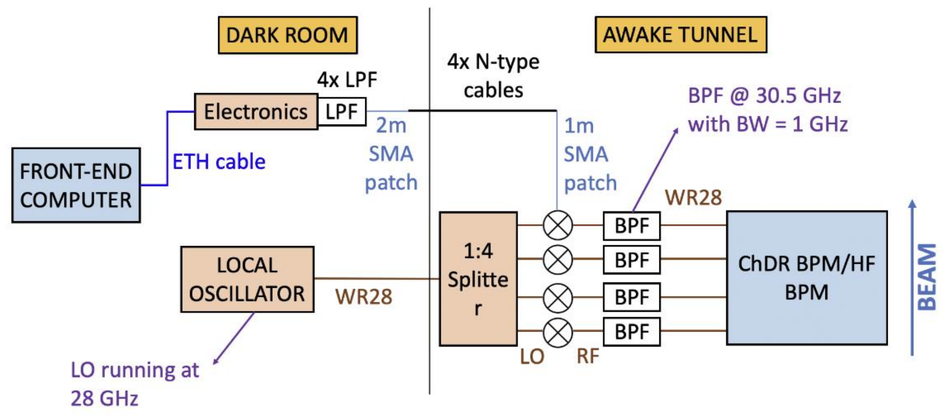




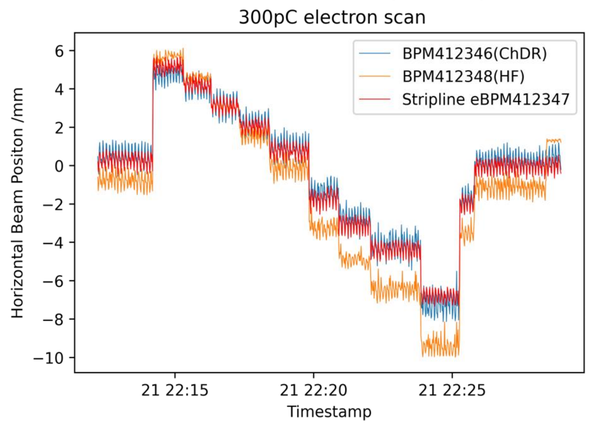
The distribution of the peak voltages recorded at the oscilloscope over a large number of proton shots represented with a histogram for low and high intensity proton bunches.

Voltage at the oscilloscope is greatly increased when the high intensity proton bunch is present,
The BPM is no longer insensitive to the proton signal.

Front-end Integration



- The HF BPM was connected to a pair of read-out electronics designed by TRIUMF [4].
- Detection chain – frequency downmixing, etc.



- HF BPM is sensitive to beam position following closely the response of the neighboring electron BPMs.
- Calibration was performed on both read-out electronics to remove the non-linear response of the diode detectors [5].

Outlook and Future plans

- HF pick-ups have large bandwidth which may also have impact for accelerators with short bunches
- Specifically at AWAKE, these could allow for beam distinction based on frequency discrimination
- More beam tests are required for the calibrated electronics and compared with beam trajectory

[1] E. Gschwendtner, et al.," AWAKE, The Advanced Proton Driven Plasma Wakefield Acceleration Experiment at CERN", Nuclear Instruments & Methods in Physics Research A (2016)
[2] E. Aldi *et al.*, "Acceleration of electrons in the plasma wakefield of a proton bunch", *Nature*, vol. 561, pp. 363-368, 2018
[3] A. Angelovski et. al., *High bandwidth pickup design for bunch arrival-time monitors for free-electron laser*, Physical Review Special Topics – Accelerators and Beams, **15**, 112803 (2012)
[4] S. Liu, et.al., The installation and commissioning of the AWAKE stripline BPM, 7th Int. Beam Instrumentation Conf.(IBIC 2018), Shanghai, China, September 9 - 13, 2018, pp.253-256
[5] C. Pakuza, in proceedings IBIC24, Beijing, China, 2024. this proceedings.