System Overview and Design Considerations of the BPM System of the ESS Linac

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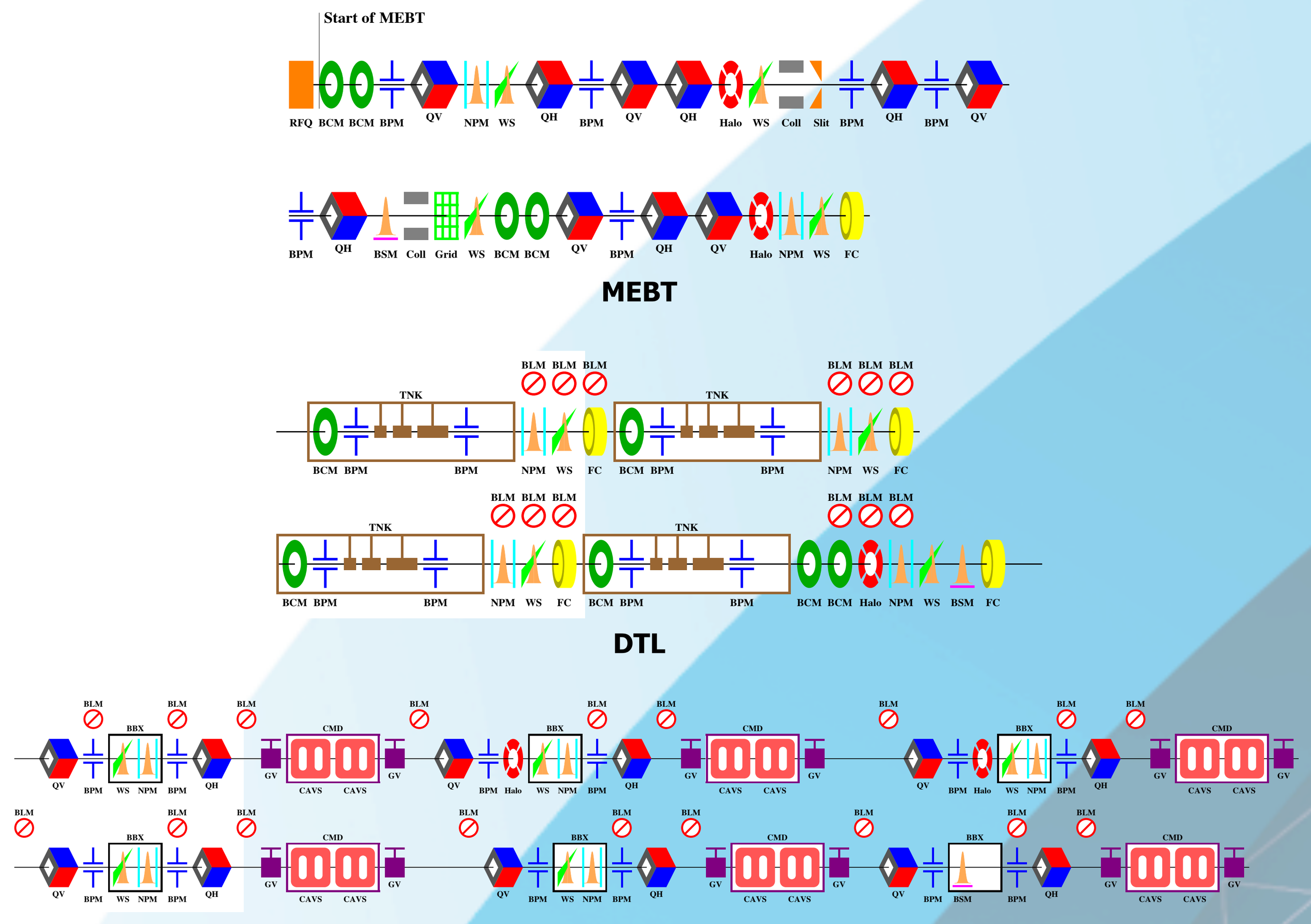
BPM System Overview

The ESS Linac will include in total more than 140 BPMs of various sizes and types. The BPMs will be mostly button type and will be mounted and centered in the quadrupole magnets. Several requirements have to be fullfilled in the design of the BPM detectors and the low-level electronics, being: equalization of the BPM voltages along the Linac, position/phase measurement of a debunched beam as well as a fast response and a wide aperture in particular for the rastering system. Meeting these requirements needs a careful design of the BPM detector and the front-end electronics. It is planned to use a custom analogue front-end combined with a commercial digitizer to detect the BPM signals and digitally process them for position, phase and intensity measurements. MTCA.4 standard is planned for the implementation of the electronics. A prototype MTCA.4 system has already been procured and successfully tested through external collaborations.

Diagnostics Layout



Beginning of the Spokes

Main Parameters

Beam parameters (subject to change)

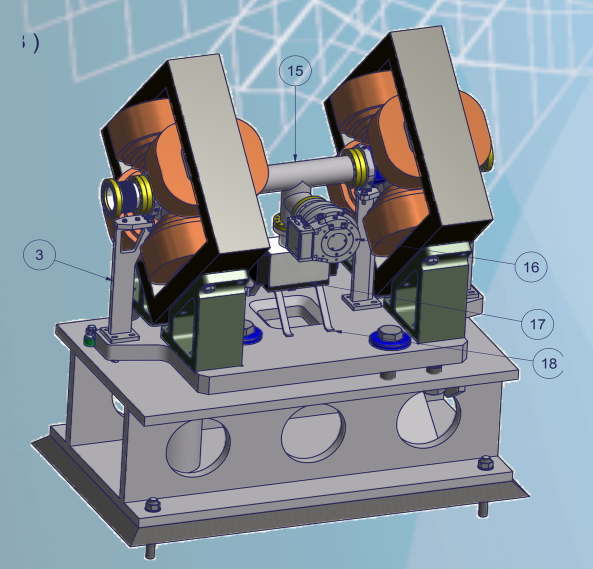
Parameter	Value	Unit
Particle type	Protons	
Max. beam energy	2	GeV
Average beam power	5	MW
Pulse repetition rate	14	Hz
Pulse duration	2.86	ms
Max. beam current (nominal beam)	62.5	mA
Min. beam current	6.25	mA
RF frequency	352, 704	MHz
Longitudinal bunch size (σ)	2–3	mm

BPM detector and electronics

Parameter	Value	Unit
Position measurement accuracy	100	µm
Position measurement resolution	20	µm
Phase measurement accuracy	1	°
Phase measurement resolution	0.2	°
Phase measurement range	±180	°
Beam pipe diameter	60, 100	mm
Measurement radius w.r.t. beam pipe	50	%
BPM cable length	~60	m
Electronics response time	1–2	µs
ADC sample rate	50–100	MSa/s
ADC bit number	16	bits

BPM quantity per Linac section

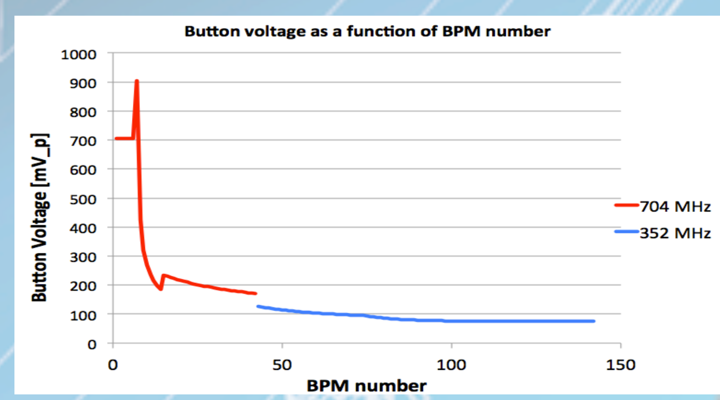
Linac section	BPM qty
LEBT	0
MEBT	6
DTL	8
Spokes	28
Medium-β	32
High-β	30
High-β upgrade	14
Accelerator to Target	15
Dumpline	8
Total	**141**



Most of the BPMs will be mounted and centered in the quadrupole magnets.

BPM Signal Level

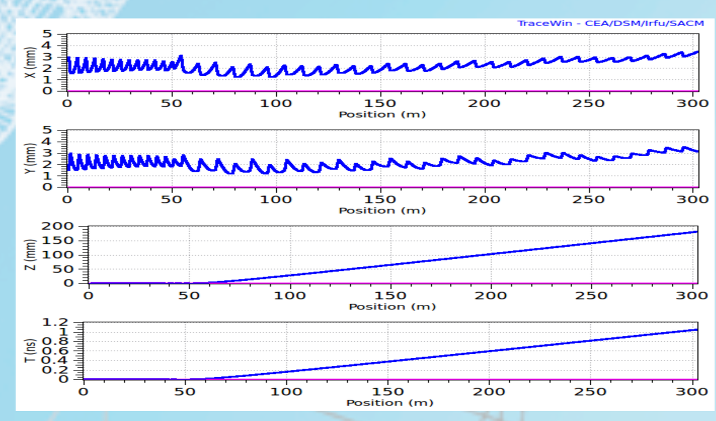
Calculations show that with a centered beam, the voltage induced on the BPM buttons ranges from less than 100 mV up to several hundred mV depending on the beam velocity and the beam pipe diameter. In the high-energy part of the Linac, an amplification factor of about 16 dB will be needed to utilize the full ±1 Vpp dynamic range of the ADC input. In the low-energy part, the BPM signal should be attenuated by as much as 14 dB in order not to saturate the ADC input.



Calculated BPM signal level along the Linac as a function of BPM number. The exponential-like decay is due to the increase of the beam velocity and the sharp changes are due to the differences of the beam pipe diameter and the button size.

Beam Debunching

The ESS BPM system needs to give at least a rough estimation of the position/phase of a debunched beam. This will be required, for example, during a cavity phase scan while the beam is being sent to the nearest beam dump. As in this case, all downstream cavities will be unpowered, the beam can become significantly debunched in the longitudinal direction. Nonetheless, it is important to know the beam phase and position to tune downstream cavities and dump the beam without facing a risk of damage to the Linac components.



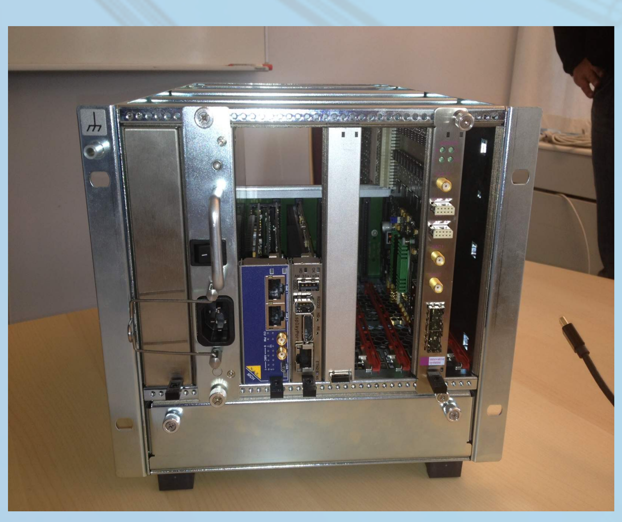
Simulated bunch size along the x, y, z and time axis with no powered cavity after the spokes. Simulation by: Ryoichi Miyamoto (ESS Beam Dynamics group).

BPMs for the Rastering System

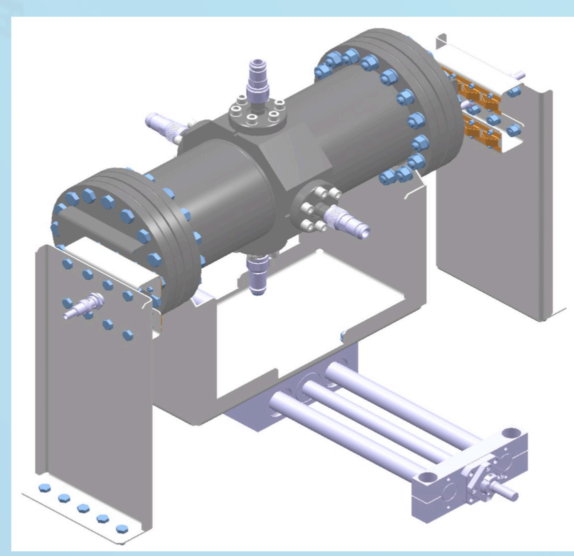
In order to avoid damages to the target wheel and increase its operational life, a series of quadrupole magnets combined with a rastering system will be used to uniformly enlarge the area where the proton beam hits the tungsten target (see **TUPC02** for details). The rastering system consists of two sets of dipole magnets powered by some ramping power supplies. The dipoles will move the beam horizontally and vertically so that it paints a rectangular area on the target wheel, thus spreading the power over a larger area. It is foreseen to use two BPMs in the target monolith for the rastering system. The two BPMs will measure the beam deviation from its expected path and send a beam abort request to the Beam Interlock System if the deviation exceeds a certain threshold. These BPMs need to measure the beam position within a large aperture of about 160 mm by 60 mm with a time resolution of 1 μs and accuracy of 1 mm. Furthermore, as they will be installed close to the target wheel, they need to work reliably under high radiation levels in addition to having a small size due to the limited space in the target monolith. Meeting these requirements simultaneously can be challenging due to the degraded S/N ratio caused by the high beam velocity, large aperture and significant BPM non-linearity with an off-centered beam. For those reasons, it may become necessary to use a different BPM type for the rastering system, or relax the rastering requirements.

BPM Electronics and Test Bench

The BPM electronics will be based on a MTCA.4 analogue RTM, combined with a commercial digitizer AMC. It is planned to develop the RTM through external collaborations. A prototype MTCA.4 crate including Struck SIS8900 and SIS8300 modules has already been procured and successfully tested at low RF frequencies. Also, a BPM test bench has been designed and will be used later on for testing the electronics and the BPM detector.



Picture of the prototype MTCA.4 system.



Layout of the BPM test bench (Drawn by Mikael Puls – ESS).