Machine Protection Strategy for the ESS Target Station

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Abstract

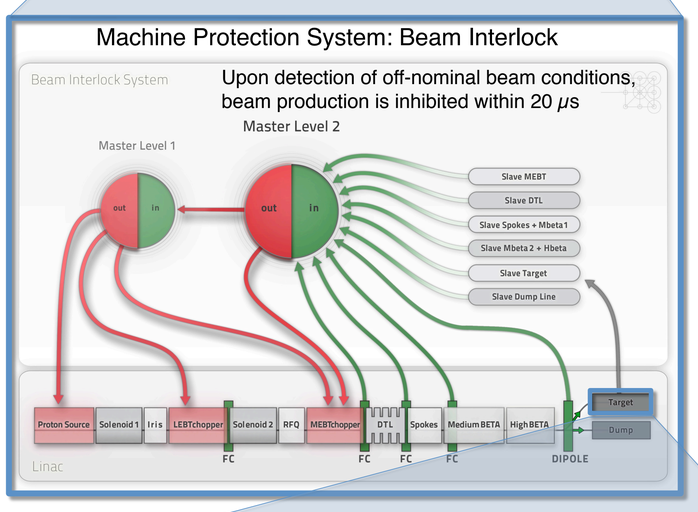
The ESS linear accelerator will deliver a 5 MW, low-emittance proton beam directly to the target station. To limit power density, a transport line expands this beam to centimetre scale and rasters this expanded beam across the target surface. This technique produces a reasonably uniform current density that enables a five year service life for the rotating tungsten target and a 6 month service life for the upstream proton beam window. Conversely, the beam's low emittance allows an errant spot size small enough to damage target station components within a single 2.86 millisecond pulse. A suite of instrumentation systems located within the target monolith and also upstream in the transport line will detect errant conditions and via the Beam Interlock System, suppress beam production. This presentation will introduce the primary causes of damaging beam properties, and describe the measurement techniques that will detect them promptly enough to mitigate component damage.

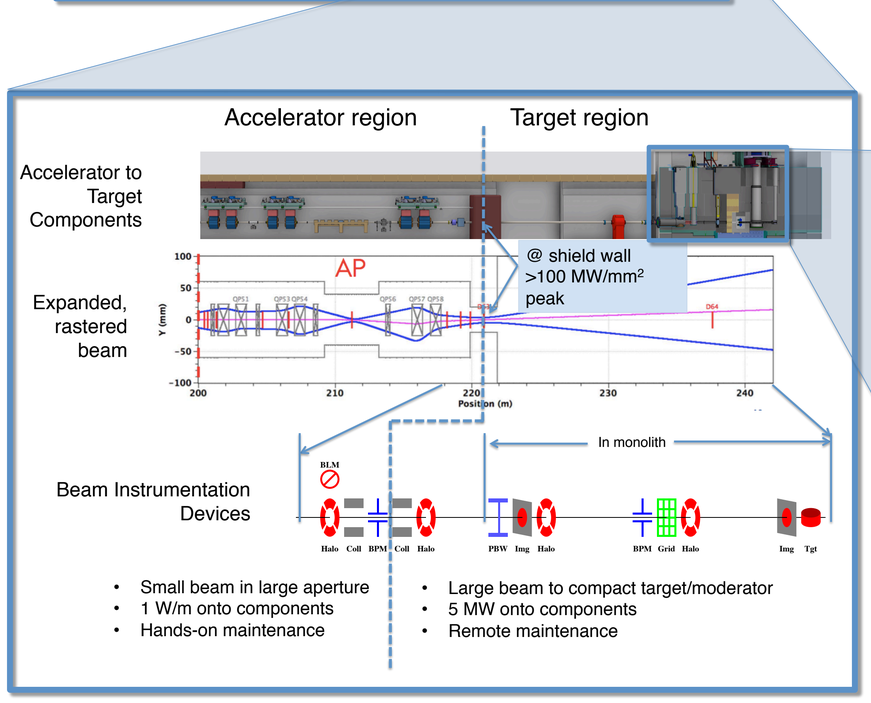
Graded Protection

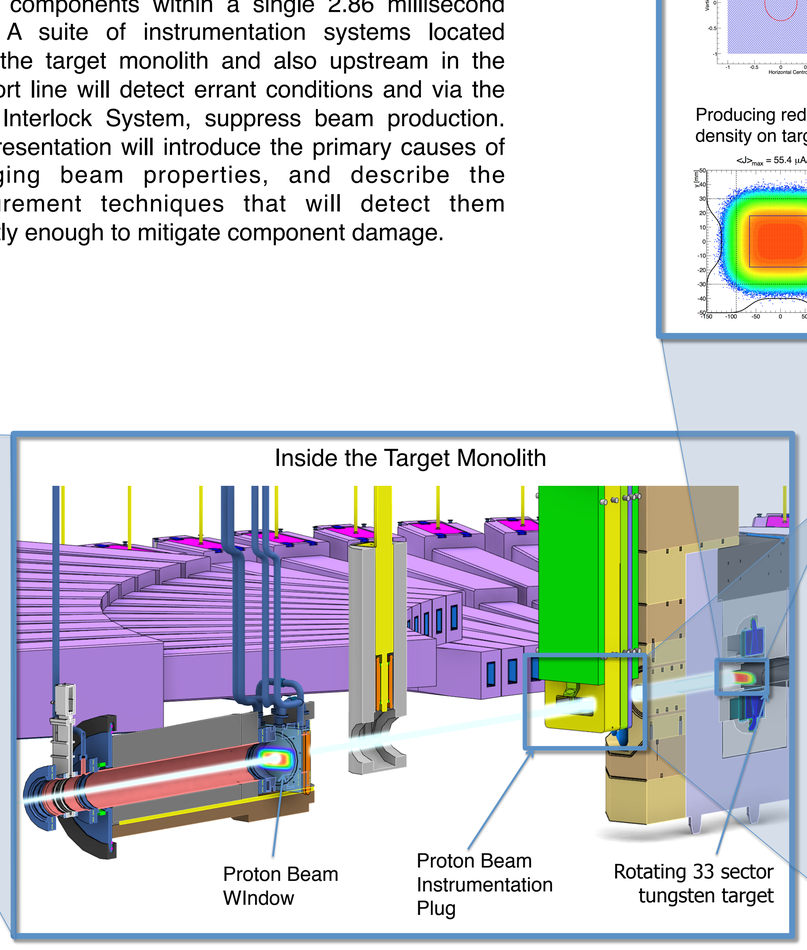
Target Safety System – Protect Public

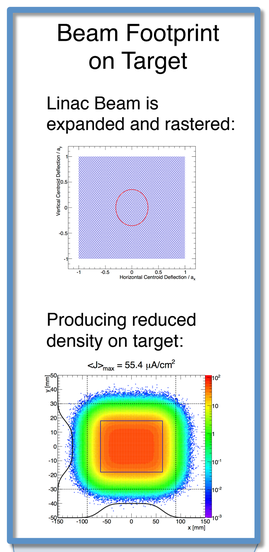
Machine Protection System – Protect the Facility

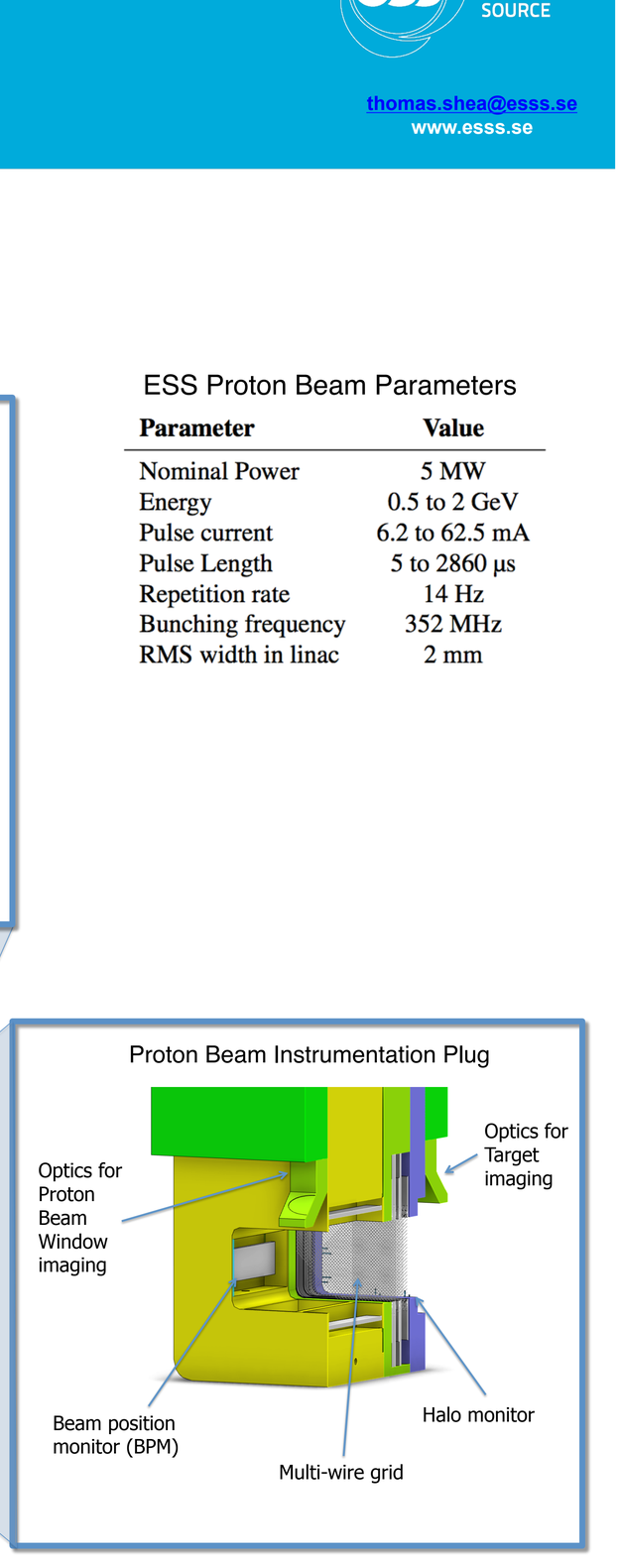
Control and Alarm System – Diagnose and Inform











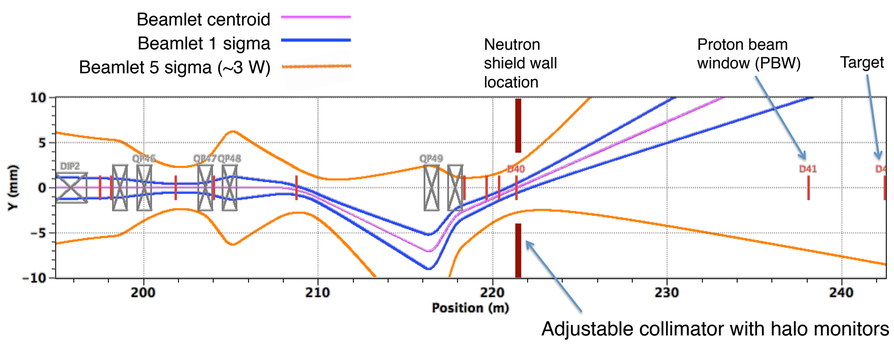
ESS Proton Beam Parameters

Parameter	Value
Nominal Power	5 MW
Energy	0.5 to 2 GeV
Pulse current	6.2 to 62.5 mA
Pulse Length	5 to 2860 μs
Repetition rate	14 Hz
Bunching frequency	352 MHz
RMS width in linac	2 mm

Example Beam Conditions

- These are examples of beam conditions that must be monitored by beam instrumentation systems
- Many other target stations properties are also monitored, including temperature, flow rates, vibration, etc.
- Target wheel position is also monitored for synchronization with the beam pulses

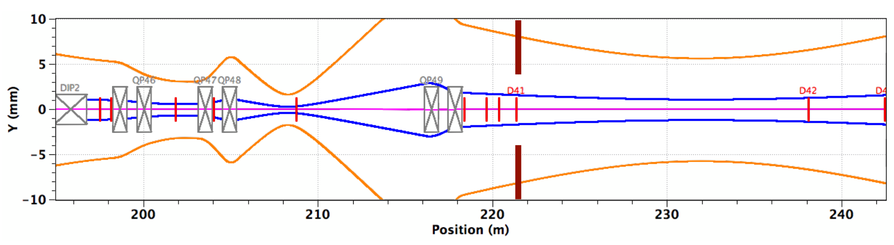
Nominal Beam



- Nominal beamlet size and nominal raster amplitude
- Beam is safely delivered to target.

- Collimator in neutron shield wall is adjusted to intercept of somewhat less than 1 W of beam.
- Thresholds on magnet system and instrumentation system readbacks are determined.

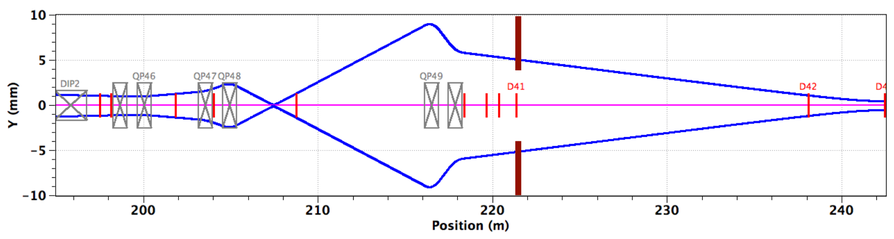
Mis-tuned beamlet



- DC magnets are at the wrong settings
- Reduced beamlet size on target
- With raster functioning, minimal impact
- With simultaneous raster failure, target components survive one pulse

- Window comparators on DC magnets and waveform templates on raster magnets detect cause of off-nominal beam.
- Beamlet misfocussing detected within pulse by adjustable collimator/ halo monitors.
- Beamlet misfocussing and failed raster detected before next pulse by imaging and grid systems
- Failed raster detected within one pulse by Beam Position Monitor (BPM)

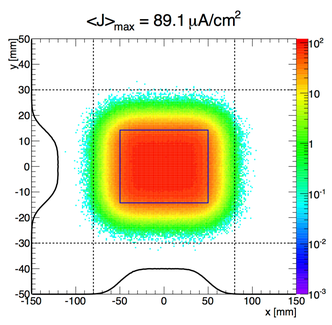
Worst case beamlet



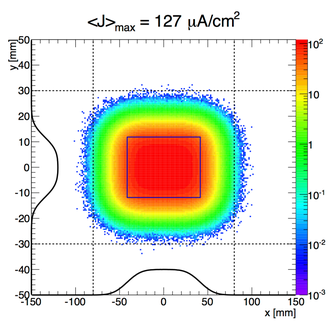
- DC magnets are set to focuss beam to sub-mm waist on target surface.
- With raster functioning, some shortened component lifetime
- With simultaneous raster failure, target components damaged within one pulse

- Window comparators on DC magnets and waveform templates on raster magnets detect cause of off-nominal beam.
- Beamlet misfocussing detected within pulse by adjustable collimator/halo monitors.
- Beamlet misfocussing by imaging and grid systems (failed raster also detected before next pulse, but this could be too late)
- Failed raster detected by within one pulse by Beam Position Monitor (BPM)

Mis-tuned raster



Nominal footprint on proton beam window (for comparison)



Reduced rastering amplitude would lead to a higher density footprint on the proton beam window

- As in Nominal Beam case above, but raster amplitude is low.
- Beam density is elevated and target component lifetime is reduced
- Related Case: over-expanded or mis-steered beam deposits too much power into components surrounding aperture.

- Window comparators on DC magnets and waveform templates on raster magnets detect cause of off-nominal beam.
- Beam Position Monitor (BPM) detects off-nominal raster amplitude within the pulse
- Grid and imaging systems detect off-nominal beam density after one pulse
- In case of over-expanded or mis-steered beam, thermocouple halo monitors detect elevated power deposition after many pulses