Beam Physics Needs and Requirements for Target Imaging

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Thanks to Y.J. Lee, R. Miyamoto, M. Eshraqi

CDR for ESS Imaging Systems

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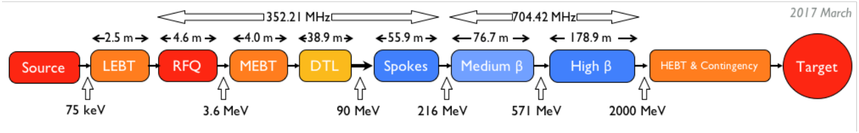
The ESS Linac



	Energy [MeV]	# modules	cav./mod.	$\beta\gamma$	Temp. [K]	Length [m]
Source	0.075	-	0	-	~ 300	-
LEBT	0.075	-	0	-	~ 300	2.4
RFQ	3.62	1	1	-	~ 300	4.6
MEBT	3.62	-	3	-	~ 300	4.0
DTL	90.0	5	-	-	~ 300	39
Spokes	216	13	2	-	~ 2	56
Med.-β	571	9	4(6C)	0.67	~ 2	77
High-β	2000	21	4(5C)	0.86	~ 2	179
HEBT	2000	-	-	-	~ 300	241

Introduction

- The proton beam is of very high intensity which can quickly damage components in the machine
- From the accelerator we are somewhat “blind” to what the target actually receives.
- E.g. incorrect/failing rastering of the beam, (too much) beam outside the beam entrance window (BEW), uneven painting on the BEW, ...
- The quality of the rastering (ie how evenly the beam is distributed on the BEW) is not visible to other beam diagnostics.
- Beam instrumentation that provide feedback on the beam optics and performance can be invasive (e.g. wirescanners), saturated or damaged if used at full beam power, or lacks redundancy.

Source

- 75 kV (so just under 75 keV protons)
- 6 ms pulse length
- Total current approx 90 mA, approx 74 mA proton beam

LEBT

- 2.4 m long
- 75 keV beam energy
- No acceleration, DC beam,
- 6-blade iris to transversally chop beam (control current)
- Chopper reduce pulse length 6 ms -> 2.88 ms

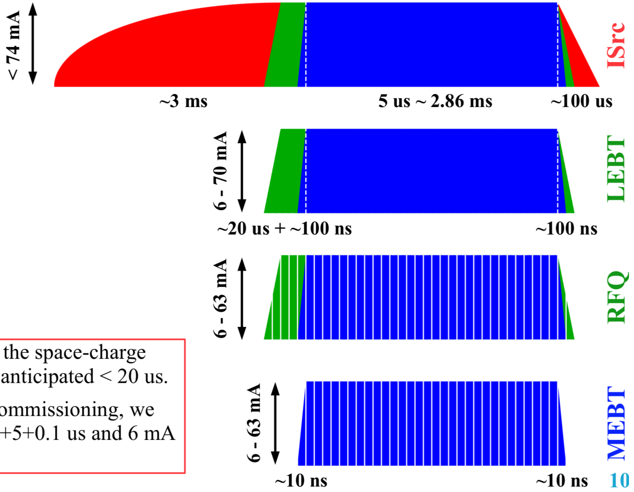
RFQ

- 4.6 m long
- Bunches the beam (allow for RF acceleration)
- Accelerates beam 75 keV -> 3.6 MeV

MEBT

- 4.0 m long
- No acceleration, match the beam for next section.
- Chops off a small part of the head/tail of pulse (cleaning) 2.88 ms -> 2.86 ms.
- MEBT chopper can "kick" for a maximum of 20 μs, twice with a 5 μs separation.
- Time MEBT+LEBT chopper accurately to get down to approx. 5 μs.

Chopping



- Build up time of the space-charge compensation is anticipated < 20 us.
- For the MEBT commissioning, we may also use 0.1+5+0.1 us and 6 mA out of LEBT.

R. Miyamoto

DTL

- 39 m long
- Acceleration to 90 MeV through 5 tanks.
- Technically we might be able to transport pilot beam if we manage to see it (BPM/debunching).

Spokes

- 56 m, superconducting cavities
- Acceleration to 216 MeV through 13x2 cavities.
- We expect to be able to transport this beam to target.

Elliptical cavities

- 256 m, superconducting cavities.
- Frequency jump 352 MHz -> 704 MHz, "longitudinal weak point"
- Acceleration to the full 2 GeV beam (570 MeV using only Mβ).
- Dogleg is only dispersive region of machine -> Energy acceptance on dump is high.
- Note, 2 GeV/570 MeV is the design energy, but depending on cavity performance and tuning we might end up with a lower energy on target.

HEBT/A2T

- Contingency space, dogleg, rastering, beam defocusing.
- Dogleg brings beam to target.

- Beam energy $\sim$ 200 MeV - 2 GeV.
- Pulse length 5 µs - 2.86 ms (longer if chopper timing fails?)
- Beam intensity 6 mA - 62.5 mA ($\pm$ 3% tolerance)

Requirements (presented by T. Shea at PDR)

Beam current density measurement locations	The proton beam current density map over the physical aperture, averaged over one pulse shall be determined at the locations of the proton beam window, the target wheel, and the tuning dump
Beam current density measurement range	The proton beam current density shall be measured in the range 0 - 160 $\mu A/cm^2$ at target; 0 - 60 $\mu A/cm^2$ at dump
Beam current density measurement error	The beam current density, averaged over one pulse, shall be measured with a total measurement error of less than $\pm 20\%$ in each point.
Beam current density measurement spatial resolution	The beam current density shall be measured with a spatial resolution of $\leq$ 2 mm.
Beam current density time resolution	The beam current density measurement time resolution, defined as the interval between independent reported measurement readouts, shall be once per pulse.
Damaging beam detection and mitigation	Beam conditions that are potentially damaging to machine components shall be detected by the instrumentation and reported fast enough so that the conditions can be mitigated before damage occurs.
Component measurement (interface requirement with target)	Relative transverse position of specified components shall be measured with an error of $\leq$ 1 mm.

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ESS TRM - Accelerator Technical Requirements - 10_A2T - Accelerator to Target Interface

Beam Limits on Target

ESS-0003310: Beam on Target Requirements

Max beam footprint enclosing 99% of beam at PBW	140mm H x 52mm V
Max beam footprint enclosing 99% of beam at BEW	160mm H x 60mm V
Max beam footprint enclosing 99.9% of beam at PBW	160mm H x 56mm V
Max beam footprint enclosing 99.9% of beam at BEW	160mm H x 64mm V
Nom. time-averaged peak current density at PBW	89 $\mu A/cm^2$
Nom. time-averaged peak current density at BEW	56 $\mu A/cm^2$
Max time-averaged peak current density at PBW	112 $\mu A/cm^2$
Max time-averaged peak current density at BEW	71 $\mu A/cm^2$
Max displacement of footprint from nominal at PBW	4mm H x 3mm V
Max displacement of footprint from nominal at BEW	5mm H x 3mm V
Min $\sigma_x \sigma_y$ at BEW	50
Min horizontal raster frequency	35 kHz

Beam Limits on Target

ESS-0003310: Revised version underway (Y.J. Lee)

- $\sim$3% of protons scattered on PBW -> Remove the 99% and 99.9% footprint req.
- Set rastering amplitude and tolerance individually
- Set minimal unrastered beam size based on assumption that a full unrastered nominal beam pulse could accidentally be sent to target (conservative?)
- Define max beam/minimum beam size required for first uncommissioned shot to target (ie. no rastering, unmatched beam optics and trajectory, hit anywhere on target wheel..)

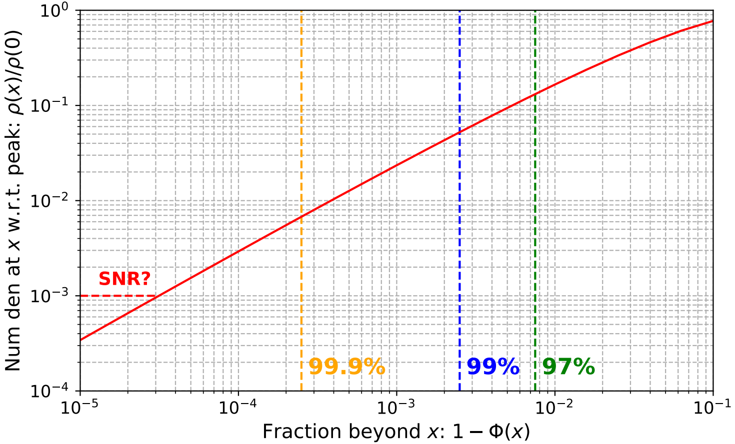
Comments from Beam Physics

- The 99.9% requirement can be challenging if we have a thick halo.
- During commissioning and studies, we might prefer (if possible) to defocus less -> We need to see that we obey minimum beam size requirements.
- The tolerance on current fluctuation is 3%, which equates to approx. 150 kW at full power. If the target limit is 5.2 MW then the margin is almost fully eaten up by the current fluctuation.
- First beam we send will be < 50 μs and 1 Hz unrastered, will need info about beam size& position on target to verify unrastered optics.
- Unrastered beam position at target (and PBW) is a concern for us, see BPM requirements next slide.

Beam Position Precision and Accuracy

Nominal beam	Accuracy ±0.2 mm, precision 20 µm
6.3 mA, pulse length of 5 µs	Accuracy ±0.4 mm, precision 200 µm
Low current, short pulse, debunched beam	Accuracy ±2 mm, precision 2 mm

Signal to Noise Ratio



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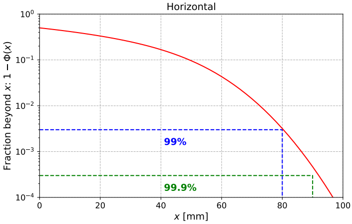
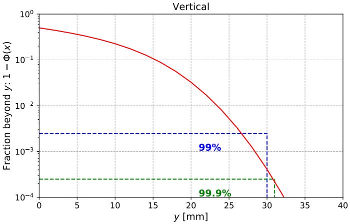
Integrated Halo Fraction





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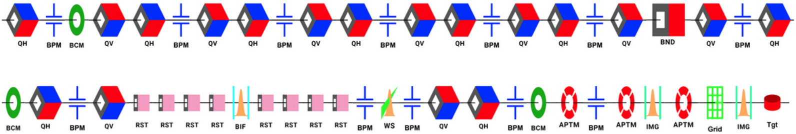
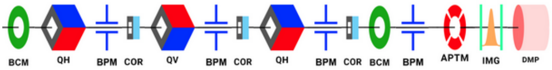
Synoptic - A2T



https://confluence.esss.lu.se/display/ALSV/

Synoptic - DumpL



https://confluence.esss.lu.se/display/ALSV/

Allowed Accelerator Mode Transitions

Origin mode / Destination mode	Shutdown	RF Power	Source	StudiesDump	StudiesTarget	StartUp Target Test	StartUp Low Power	StartUp Ramping	Production
Shutdown			↑	↑	✖	↑	✖	✖	✖
RF Power			↑	↑	✖	↑	✖	✖	✖
Source	↑	↑		↑	✖	↑	✖	✖	✖
StudiesDump	↑	↑	?		↑	↑	✖	✖	✖
StudiesTarget	↑	↑	?	↑		↑	↑	↑	↑
StartUp Target Test	↑	↑	?	↑	↑		↑	✖	✖
StartUp Low Power	↑	↑	?	↑	↑	↑		↑	✖
StartUp Ramping	↑	↑	?	↑	↑	↑	↑		↑
Production	↑	↑	?	✖	↑	↑	↑	↑	

Possible Beam Modes for each Accelerator Mode

Accelerator Mode / *Beam Mode*	None	Probe Beam	Fast Tuning	Slow Tuning	Long Pulse Verification	Shielding Verification	Production
Shutdown	1	0	0	0	0	0	0
RF Power	1	0	0	0	0	0	0
Source	1						
StudiesDump	1	1	1	1	1	0	0
StudiesTarget	1	1	1	1	1	1	1
StartUp Target Test	1	1	0	0	0	0	0
StartUp Low Power	1						
StartUp Ramping	1	1	1	1	1	1	
Production	1	0	0	0	0	0	1

Possible Destinations for each Accelerator Mode

Accelerator Mode \ *Destination*	LEBT	MEBT	DTL	Spokes	MBL	Dump	Target
Shutdown	0	0	0	0	0	0	0
RF Power	0	0	0	0	0	0	0
Source	1	0	0	0	0	0	0
StudiesDump	1	1	1	1	1	1	0
StudiesTarget	1	1	1	1	1	1	1
StartUp Target Test	1	1	1	1	1	1	1
StartUp Low Power	0	0	0	0	0	0	1
StartUp Ramping	0	0	0	0	0	0	1
Production	0	0	0	0	0	0	1

Possible Destinations for each Beam Mode

Beam Envelope Mode / *Destination*	LEBT	MEBT	DTL	Spokes	MBL	Dump	Target
None	1	1	1	1	1	1	1
Probe Beam	1	1	1	1	1	1	1
Fast tuning	1	1	1	1	1	1	1
Slow tuning	1	1	1	1	1	1	1
Long pulse verification	1	0	0	0	0	1	1
Shielding verification	1	0	0	0	0	0	1
Production	1	0	0	0	0	0	1