The ESS front end

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Outline

Outline

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Introduction

Role of the front end

Generate and pre-accelerate a pulsed proton beam and shape the latter in a train of bunches

3 main components

- Ion source
- Low energy beam transport line (LEBT)
- Radio-frequency quadrupole (RFQ)

Outline

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Main performances to be achieved

- Output peak proton current from 10 mA to 90 mA
- Pollutant current is kept < 25 % of total current
- Pulse length up to 5 ms with a flat top duration > 3 ms
- Beam repetition rate between 0.1 and 14 Hz
- Flat top current jitter is $\pm$0.5 mA
- Output beam energy 75 $\pm$ 0.1 keV
- RMS Proton beam emittance 0.1 $\pi.\mu m$

VIS source at INFN Catania

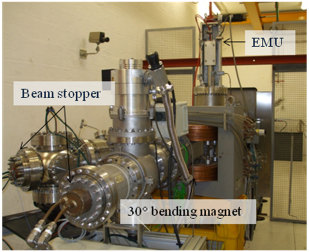

Figure: The VIS ion source.

See S. Gammino et al., THP116, LINAC'10

Achivements

- Electron enrichment investigations with passive methods
- Emittance measurements with typical ESS parameters

To be achieved

- Providing with realistic beam distributions (end-to-end simulations)
- Experimental demonstration of capabilities

THE IFMIF LEBT

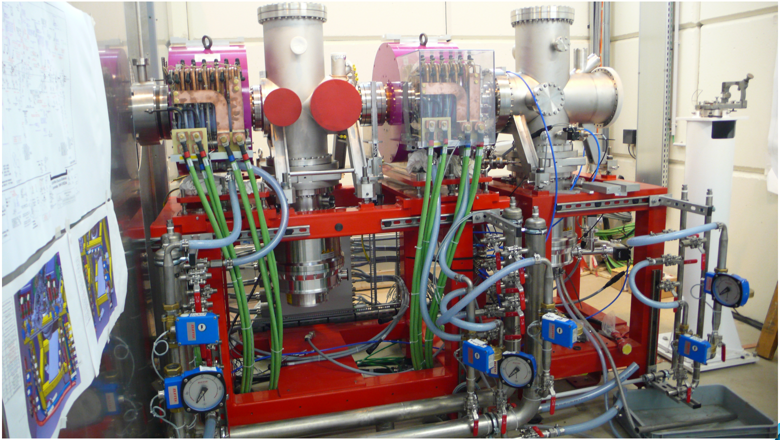

Figure: The IFMIF LEBT (side view).

THE IFMIF LEBT

Figure: The IFMIF LEBT (top view).

Preliminary simulations of the ESS LEBT

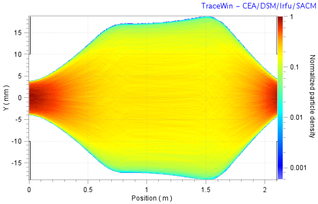

Figure: Beam profile in the LEBT.

IFMIF dual solenoid design can be used for the ESS LEBT purposes

See N.Chauvin et al., TH5PFP004, PAC'09

- Current: 50 mA
- Constant SCC: 90 %
- Input: Parallel WB

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Space Charge Compensation

Simulation of the SCC in SILHI LEBT (Equilibrium state)

(Loading movie...)

Questions

1. May I assume constant compensation?
2. Which tool can I use to perform more accurate simulations?

Chopper

5.2 kV electrostatic deflection to eliminate 1 ms source rise/fall time before/after the beam current has been stabilized

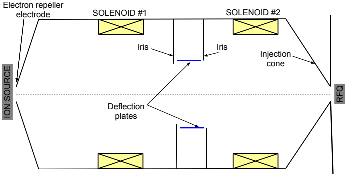

Figure: Chopper between solenoids.

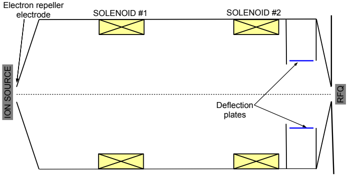

Figure: Chopper after 2nd solenoid.

Chopper

5.2 kV electrostatic deflection to eliminate 1 ms source rise/fall time before/after the beam current has been stabilized

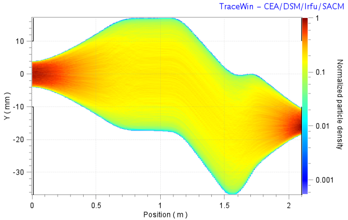

Figure: Chopper between solenoids.

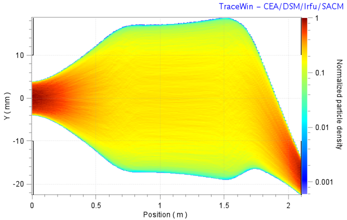

Figure: Chopper after 2nd solenoid.

Chopper

5.2 kV electrostatic deflection to eliminate 1 ms source rise/fall time before/after the beam current has been stabilized

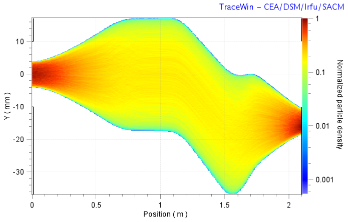

Figure: Chopper between solenoids.

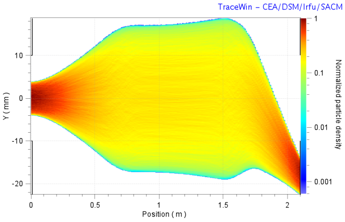

Figure: Chopper after 2nd solenoid.

$\longrightarrow$ Beam transient behavior (SCC)?

Outline

RFQ parameters

Parameters	unit	value
type		4-vanes
Output energy	MeV	3.0
Length	m	4.946531
RF frequency	MHz	352.21
Temperature	K	300
Elevtric field on axis, maximum	MV/m	2.123
Peak electric field on poles	Kilpatrick	1.8
Pole radius (R_0), minimum	mm	3.445
Pole radius (R_0), average	mm	4.09085
Pole radius (R_0), maximum	mm	4.7367
Minimum aperture (a), minimum	mm	2.972
Minimum aperture (a)	mm	3.482
Minimum aperture (a), maximum	mm	3.932
Intervane voltage, minimum	kV	80
Intervane voltage, maximum	kV	119.979
Radius of curvature: ρ	mm	3.0
Total length of vanes	m	4.92
Modulation factor, maximum		2.0412

Table: ESS RFQ parameters

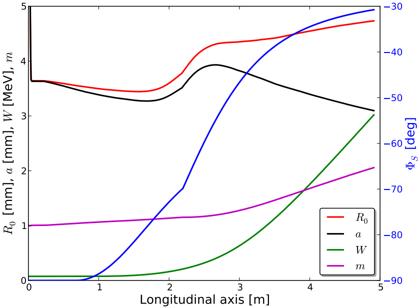

Figure: Evolution of some paramaters.

Requirements

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Requirements (1/2)

Long Name	Radio Frequency Quadrupole
Short Name	ACC.MS.RFQ
Stakeholders (actors)	Maintenance team, operators
Main Functions	1. Use EM wave to bunch and to focus the beam 2. Transfer EM wave energy to accelerate the beam
Performances	1. Cavity life time greater than 30 years 2. Protons > 2 MeV loss < 1W/m 3. Average pressure < 5 x10^{-7} HPa, Maximum pressure <10^{-6} HPa 4. Reflected power in the proton pulse < 30 % 5. Total beam loss < 10% 6. Output AC proton current up to 75 mA 7. Transverse rms emittance blow-up < 10 % 8. Longitudinal rms emittance < 0.15 deg.MeV 9. Output beam energy = 3 ± x % MeV 10. RF Pulse length < 3,6 ms 11. Repetition rate <= 14 Hz
Constraints	1. Use normal conductor (copper) for cavity 2. LEBT pressure < 2x10^{-5}HPa 3. MEBT pressure < 2x10^{-7} Hpa
Standards/regulations	1. ISO 3669 (vacuum) 2. NF-C 74-100 (X emitter)

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Requirements

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Requirements (2/2)

	Req ID	Flexibility	Source	Risk
Main Functions	1. 2.	N N	• Accelerator functional architecture • Accelerator functional architecture	L L
Performances	1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11.	L N L N M N L L M N N	• Facility maintenance • Safety • RF system • RF system • Proton source and LEBT • Upgrade plan • Beam physics group • Beam physics group • Beam physics group • Facility requirements • Facility requirements	L N L M M M H H L L L
Constraints	1. 2. 3.	N N N	• Facility requirements • LEBT system • MEBT system	L L L

(N= None, L = Low, M = Medium, H = High)

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Forewords

- ESS, LINAC 4, J-PARC, IPHI, THU
- TraceWin and Toutatis codes
- 50 (nominal), 75 (possible upgrade) and 90 mA (20 % margin)
- 1 000 000 macroparticles for emittance study and 250 000 macroparticles for the loss study
- 0.2 π.mm.mrad RMS transverse WB distribution input

Emittance and transmission

Output current: 50 mA

	ESS	LINAC 4	J-PARC	IPHI	THU
Tot. Trans.	0.9968	0.9731	0.9467	0.9999	0.9861
Ac. Trans.	0.9939	0.9604	0.9203	0.9998	0.9762
RMS Long. Em. (π.deg.MeV)	0.0985	0.1177	0.0986	0.1048	0.1397
Trans. Em. Blow up	1.0602	0.9736	1.1211	1.1217	1.2642

Table: Emittance and transmission for 50 mA

Emittance and transmission

Output current: 75 mA

	ESS	LINAC 4	J-PARC	IPHI	THU
Tot. Trans.	0.9948	0.9353	0.5738	0.9995	0.9440
Ac. Trans.	0.9914	0.9083	0.4722	0.9992	0.9326
RMS Long. Em. (π.deg.MeV)	0.1126	0.2421	0.1247	0.1254	0.1293
Trans. Em. Blow up	1.0330	1.0143	1.2500	1.1591	1.2440

Table: Emittance and transmission for 75 mA

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Emittance and transmission

Output current: 90 mA

	ESS	LINAC 4	IPHI	THU
Tot. Trans.	0.9879	0.8989	0.9983	0.8602
Ac. Trans.	0.9824	0.8541	0.9977	0.8489
RMS Long. Em. (π.deg.MeV)	0.1265	0.4109	0.1385	0.1264
Trans. Em. Blow up	1.0315	1.0586	1.1780	1.2260

Table: Emittance and transmission for 90 mA

Phase profile

Output current: 50 mA

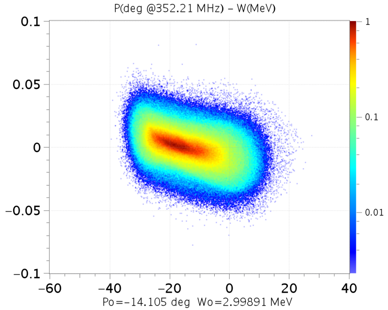

Figure: ESS longitudinal beam footprint at 50 mA.

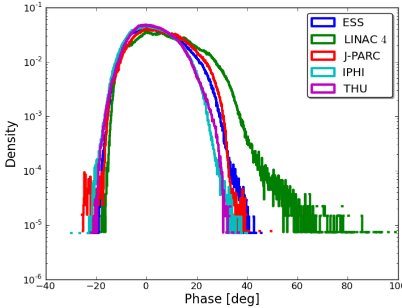

Figure: Phase profile for 50 mA.

Phase profile

Output current: 50 mA

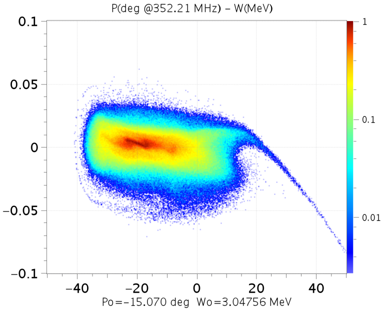

Figure: LINAC 4 longitudinal beam footprint at 50 mA.

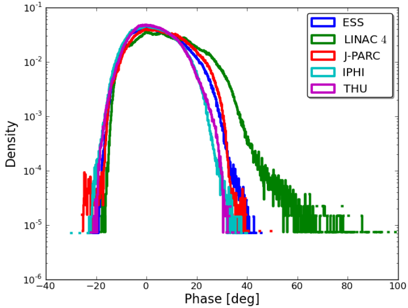

Figure: Phase profile for 50 mA.

Phase profile

Output current: 50 mA

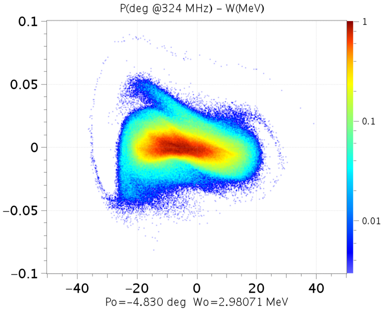

Figure: J-PARC longitudinal beam footprint at 50 mA.

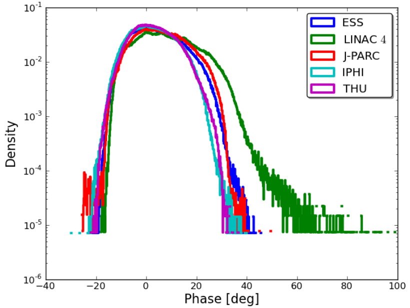

Figure: Phase profile for 50 mA.

Phase profile

Output current: 50 mA

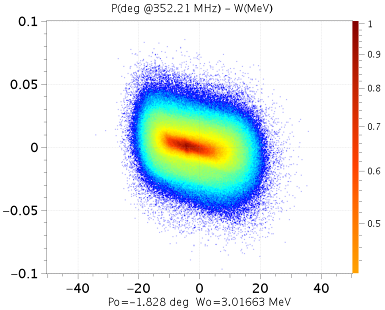

Figure: IPHI longitudinal beam footprint at 50 mA.

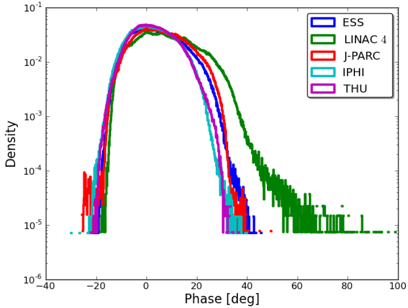

Figure: Phase profile for 50 mA.

Phase profile
Output current: 50 mA

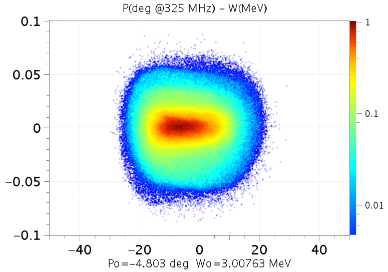

Figure: THU longitudinal beam footprint at 50 mA.

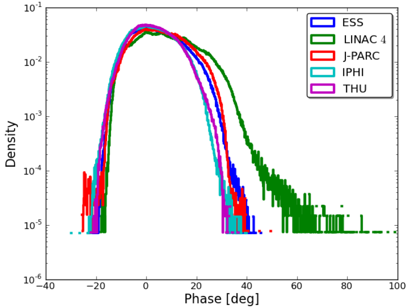

Figure: Phase profile for 50 mA.

Phase profile

Output current: 75 mA

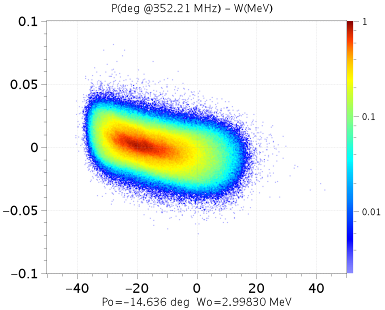

Figure: ESS longitudinal beam footprint at 75 mA.

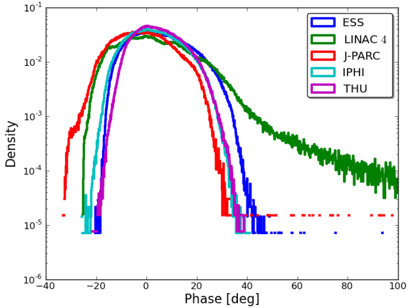

Figure: Phase profile for 75 mA.

Phase profile
Output current: 75 mA

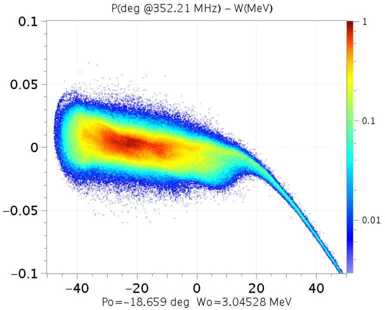

Figure: LINAC 4 longitudinal beam footprint at 75 mA.

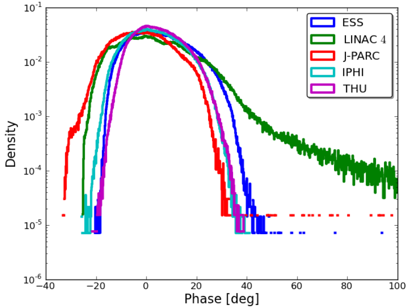

Figure: Phase profile for 75 mA.

Phase profile
Output current: 75 mA

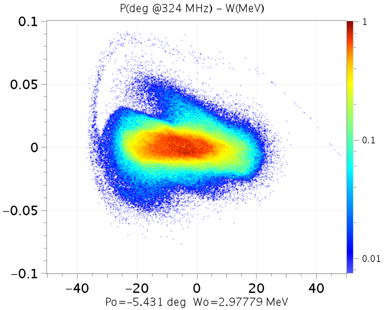

Figure: J-PARC longitudinal beam footprint at 75 mA.

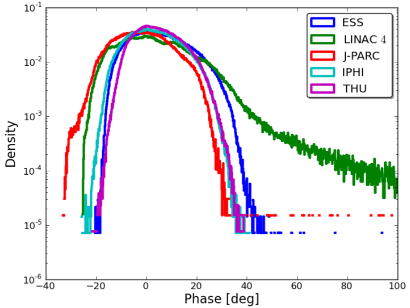

Figure: Phase profile for 75 mA.

Phase profile
Output current: 75 mA

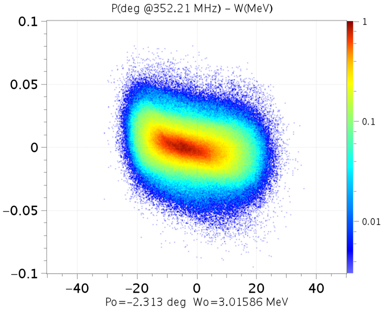

Figure: IPHI longitudinal beam footprint at 75 mA.

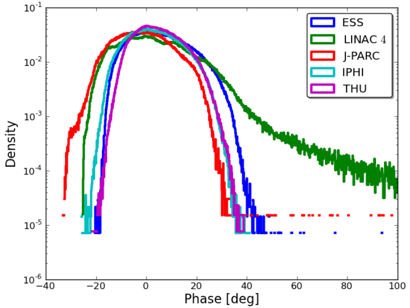

Figure: Phase profile for 75 mA.

Phase profile
Output current: 75 mA

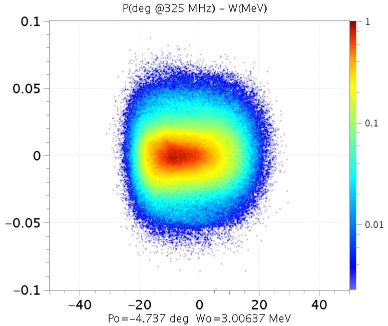

Figure: THU longitudinal beam footprint at 75 mA.

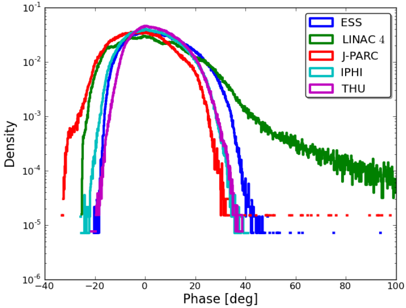

Figure: Phase profile for 75 mA.

Phase profile

Output current: 90 mA

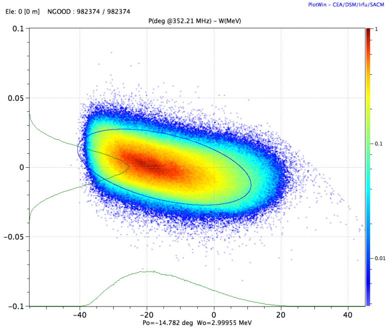

Figure: ESS longitudinal beam footprint at 90 mA.

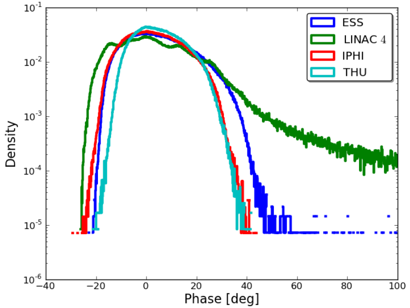

Figure: Phase profile for 90 mA.

Phase profile
Output current: 90 mA

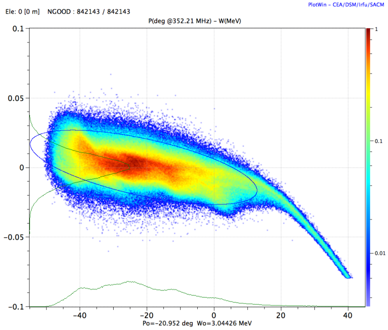

Figure: LINAC 4 longitudinal beam footprint at 90 mA.

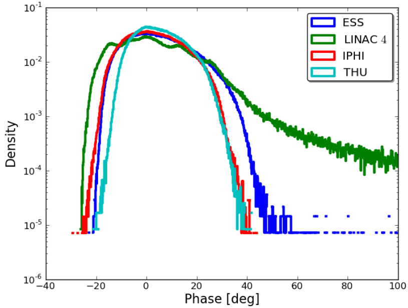

Figure: Phase profile for 90 mA.

Phase profile

Output current: 90 mA

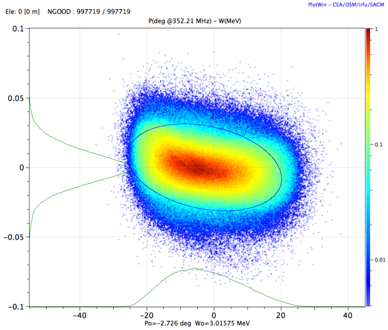

Figure: IPHI longitudinal beam footprint at 90 mA.

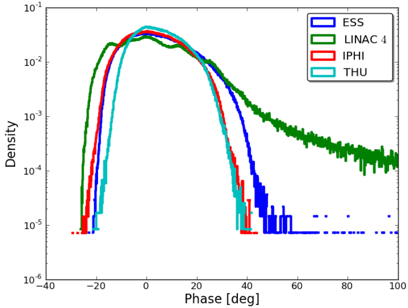

Figure: Phase profile for 90 mA.

Phase profile
Output current: 90 mA

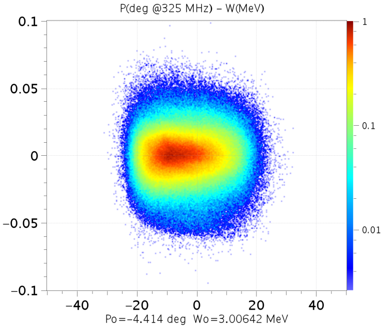

Figure: THU longitudinal beam footprint at 90 mA.

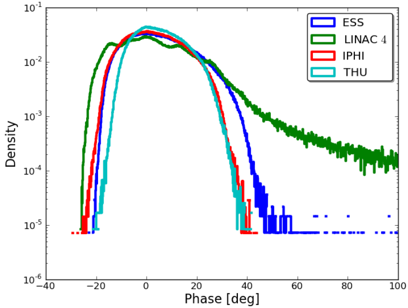

Figure: Phase profile for 90 mA.

Losses

ESS RFQ

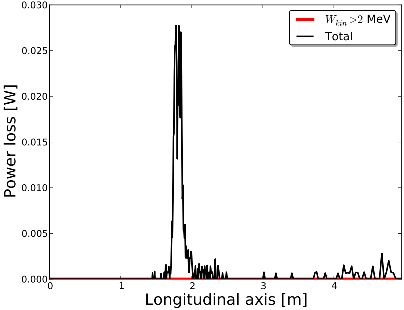

Figure: ESS RFQ losses at 50 mA.

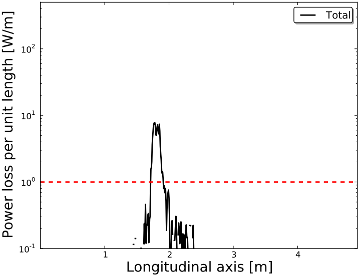

Figure: ESS RFQ losses per unit length at 50 mA.

Losses
ESS RFQ

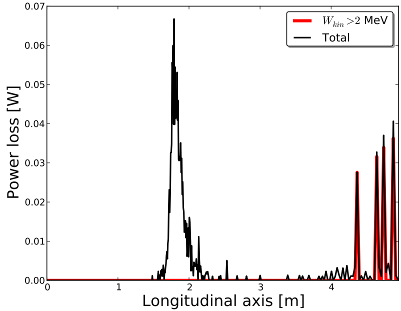

Figure: ESS RFQ losses at 75 mA.

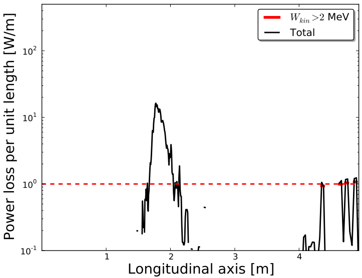

Figure: ESS RFQ losses per unit length at 75 mA.

Losses
ESS RFQ

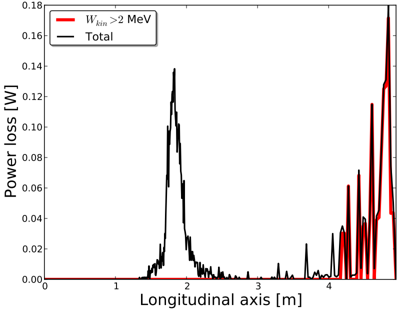

Figure: ESS RFQ losses at 90 mA.

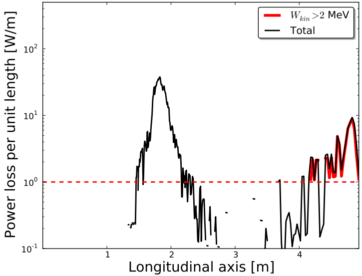

Figure: ESS RFQ losses per unit length at 90 mA.

Losses
THU RFQ

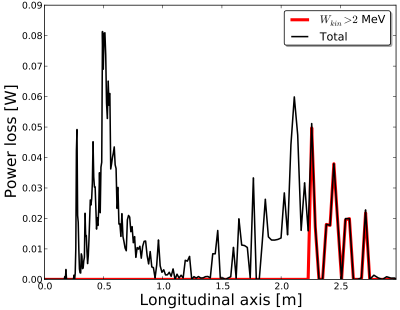

Figure: THU RFQ losses at 50 mA.

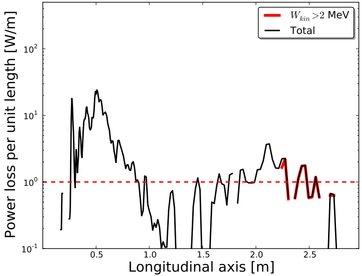

Figure: THU RFQ losses per unit length at 50 mA.

Losses
THU RFQ

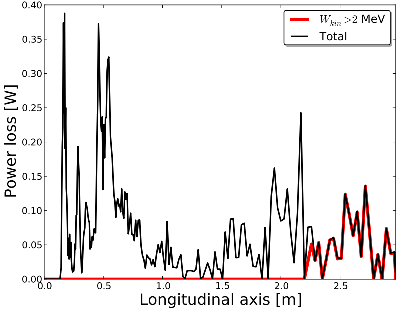

Figure: THU RFQ losses at 75 mA.

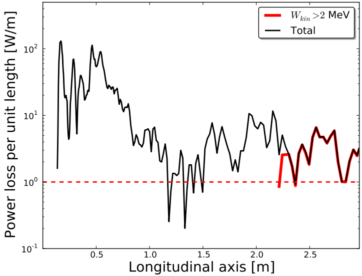

Figure: THU RFQ losses per unit length at 75 mA.

Losses
THU RFQ

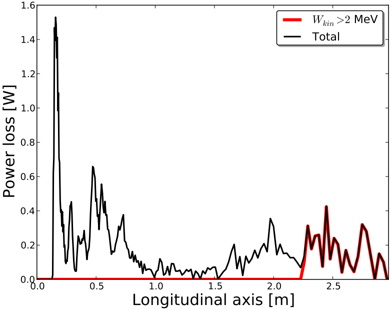

Figure: THU RFQ losses at 90 mA.

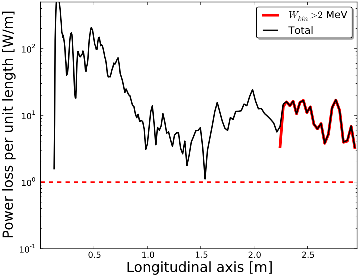

Figure: THU RFQ losses per unit length at 90 mA.

Losses for $W_{kin} > 2\,\mathrm{MeV}$

Output current: 50 mA

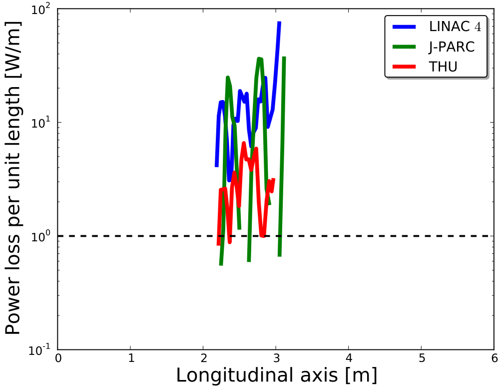

Figure: RFQ Losses per unit length at 50 mA.

Losses for $W_{kin} > 2\,\mathrm{MeV}$

Output current: 75 mA

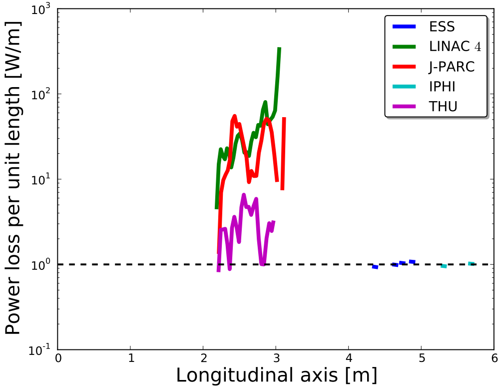

Figure: RFQ Losses per unit length at 75 mA.

Losses for $W_{kin} > 2\,\mathrm{MeV}$

Output current: 75 mA

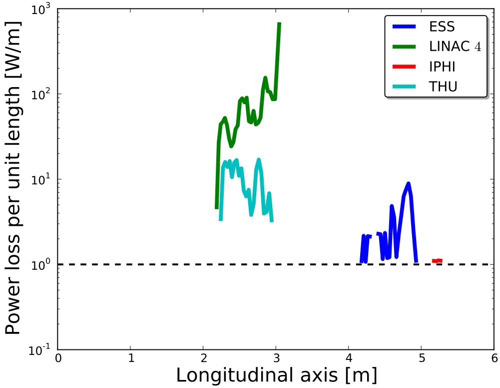

Figure: RFQ Losses per unit length at 90 mA.

Outline

Conclusions

1. Source:
   - VIS with minor modifications suitable for ESS
   - Experimental results to demonstrate its capabilities
2. LEBT:
   - Design closed to IFMIF's
   - Space charge compensation modelisation: an issue?
   - Location of the chopper and beam transient behavior to be adressed
3. RFQ:
   - No transverse emittance growth
   - Small longitudinal emittance
   - Very low loss
   - Meets all ESS requirements but the limit of 1 W/m seems difficult to achieve for 90 mA