HITRI*plus*

Heavy Ion Therapy Research Integration

Work Package 7, task 7.3:
Operational modes, beam transport and instrumentation

M. Sapinski, HITRI*plus* WP7 meeting, 2021.11.19

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548

Deliverables

- D7.2: Report on operational modes, beam transport and instrumentation.

  - March 2024

- D7.4: Design of an optimised synchrotron with SC magnets and advanced features: high beam intensity, fast and slow extraction, multiple ion operation, optimised linac injector, optimised instrumentation and QA procedures:

  - July 2024

- It seems that we have plenty of time but the old wisdom says:

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Operational modes – To be developed

Requirements to be considered:

- Different use cases
  → beams for treatment vs. beams for research vs. beams for accelerator operation (e.g. machine development, commissioning) and QA

- Fast beam switching within the order of seconds
  → change in parameters, extraction mode and in destination

- Different control logics
  → User controlled beams vs. Operator controlled beams
  → Beam Delivery System controlled beams vs. Experiment controlled
  → Mixed scenarios

- Safety for patients under treatment:
  → validated beams only
  → sequence of beams and beam parameters in accordance to the treatment plan

- Safety under all scenarios !

To be continued...

by Peter Grübling

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Beam instrumentation (I)

The following has been done for the second DLR contract :

1. Survey of existing solutions (HIT, MedAustron, CNAO).
2. Adaptation to SEEIIST layout (numbers and preliminary location of devices).
3. Adaptation to FLASH therapy – proposal to use high dynamic range instruments in HEBT (the same device for slow and fast extractions).
4. Preliminary considerations for additional instrumentations to allow FLASH treatment based on better knowledge of machine state.

"Update on Accelerator Design resulting from new tasks 2.4 – 2.5 (March 2021)

Deliverable no. 2.3

As of: 31.07.2021

2. Accelerator Design: beam instrumentation requirements for the SEEIIST facility

2.1 Introduction

Beam instrumentation of an accelerator facility is a system of sensors which allows to measure various properties of the particle beam in numerous locations along the beam path. It is necessary in commissioning phase, for finding and correcting settings errors and faulty equipment as well as in daily operation to control and tune beam parameters.

(because feedback will not be fast enough to provide patient safety)

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Beam instrumentation (II)

Potential remaining subjects:

1. Check usability of continuous synchrotron emittance monitoring in the facility (MEE with RF-KO, assuring machine state before FLASH pulses).
2. Optimize scintillating screen design for normal and FLASH beam rates.
3. Other detectors for patient safety, e.g. dIdt?
4. Ideas…?

Table 2.3: Summary of diagnostic devices in various carbon therapy centers and comparison with the proposed devices for SEEIIST. The measured quantities are: I_b – beam current, x – beam position, σ – beam width, Q- synchrotron tune, Q'- chromaticity.

Part of complex	Device type	Measured quantity	Use case	Number of devices HIT	MedA	SEEIIST
Beam intensity						
Injector	Faraday cup	I_b	CO, QA	7	7	6
	DCT	I_b	CO, OP	4	0	3
	ACT	I_b	CO, OP	1	1	1
MEBT	Faraday cup	I_b	CO	2	4	2
	ACT	I_b	CO, OP	2	2	2
Synch	DCT	I_b	CO, OP	1	1	1
	ACT	I_b	CO, OP	1	1	1
HEBT	IC/SEM	I_b	CO, QA	11	0	15
	ACT	I_b	OP	0	0	2
Beam position and size						
Injector	Wire grid	x, σ	CO	8	1	10
	Wire scanner	x, σ	CO	0	11	1
	Slits	σ	CO	6	5	6
	pickups	x	OP	1	1	1
MEBT	pickups	x	CO, OP	3	1	3
	Wire grid	σ, x	CO	4	7	4
	Slits	σ	CO	2	3	2
Synch	pickups	x, Q, Q'	CO, OP	12	20	20
	IPM	σ, x	CO, OP	0	0	2
	Scint screens	σ,x	CO	2	2	2
HEBT	MWPC	σ,x	CO, QA	12	0	7
	Scint fiber hodoscopes	σ,x	CO, QA	0	30	0
	Scint Screens	σ,x	CO, QA	5	0	20
Other						
Synch	Shottky	Δp/p, Q	CO, OP	1	1	1
	BLMs	Beam loss	CO, OP	5	1	16

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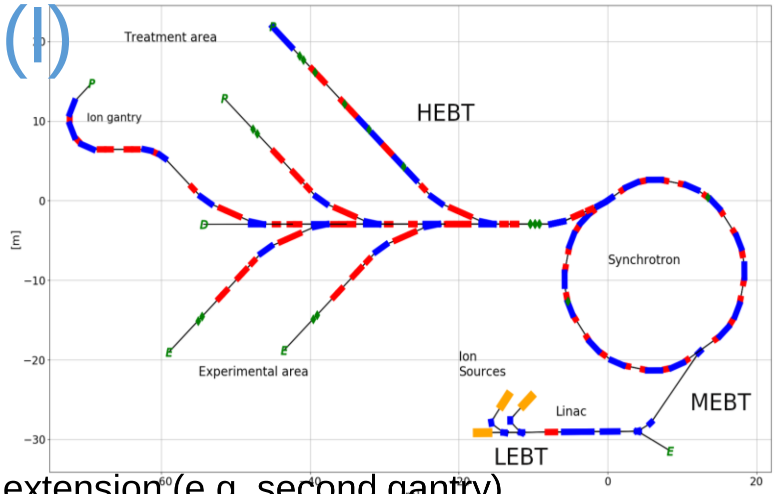
Transfer beam lines design (I)



We have done conceptual work in 2020,

but documented only general layout.

Main concepts:

1. Large, configurable experimental area well separated from medical area.
2. Three treatment rooms: H+V, H, gantry. Possibility of extension (e.g. second gantry).
3. Spacious treatment rooms (9.5 meter width, HIT only 5.5 meters) – for additional medical diagnostic devices.
4. Use of 22.5° dipoles, similar to the PIMMS synchrotron dipoles.
5. Horizontal beam size regulation by matching Twiss β_H and phase advance μ_H of the bar of charge and not only μ_H (PIMMS approach, which needs more quadrupoles).
6. Dispersion-free main transport line.

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Transfer beam lines design (II)

Done in frame of HITRIplus:

1. Survey of concepts in HIT, MIT, CNAO and MedAustron (PIMMS).
2. Tuning our design, correcting errors.
3. Coach IAEA fellow (M. Manojlovic) from Montenegro on the beam line design.
4. Documenting and writing a report (ready in early 2022).

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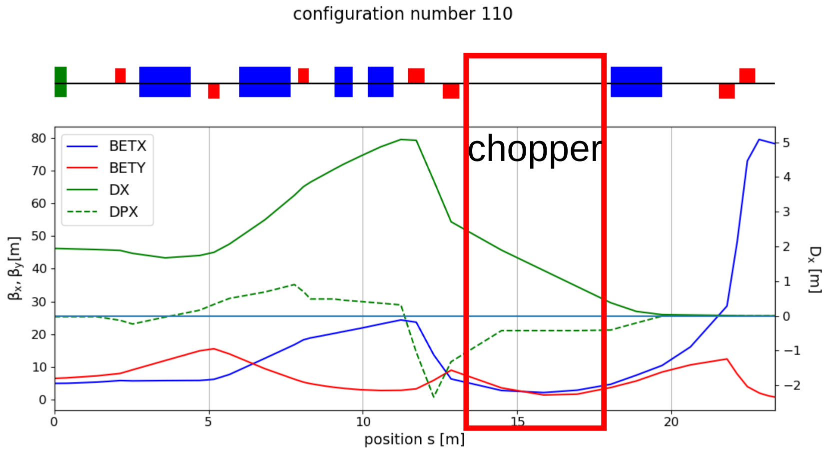
Transfer beam lines – key concepts

Dispersion suppressor:

1. First segment after extraction, brings beam dispersion (D_X and D'_X) to 0.
2. Not strictly necessary (e.g. not in HIT), but very helpful, especially if the beam branches to left and right downstream.
3. Zero-dispersion after extraction helps to transport the beam and allows for better beam measurements (so better understanding).
4. Proposed configuration features also large space (>6 m) for chopper.



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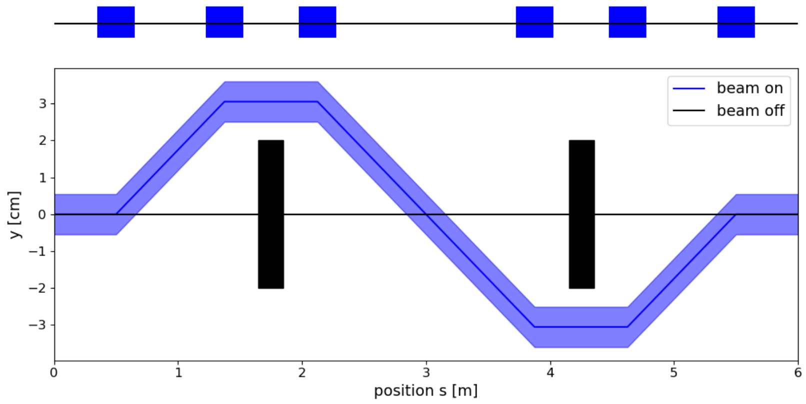
Transfer beam lines – key concepts

Beam chopper

1. Allows for fast (200 μs) beam abort – critical for patient safety.
2. This maybe not fast enough for FLASH

   (however, assuming 50 ms for FLASH it maybe only 0.4% of total dose)
3. Chopper based on double chicane and double dump could make beam abort faster by cutting the beam simultaneously on both sides (there is enough space).
4. The beam size in the chopper area is about 1-2 mm (vertical)
5. Vertical chopper is preferable as beam size is not affected by dispersion and the same for fast and slow extractions.



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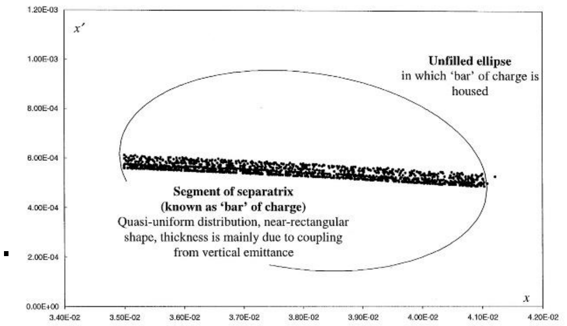
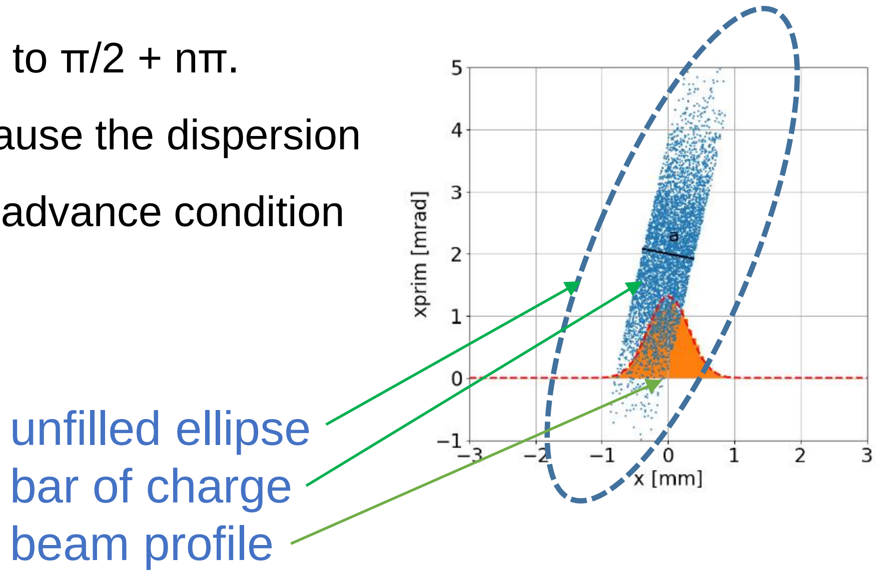
Transfer beam lines – key concepts

Beam chopper (II)

1. Even faster beam abort could be done using small thickness of the bar of charge; in this case chopper must be horizontal.
2. Dispersion should be 0 and phase advance wrt. Electrostatic Septum should be close to $\pi/2 + n\pi$.
3. This chopper needs more space because the dispersion must be closed upstream and phase advance condition must be matched.
4. Sub-mm beam size is reachable.
5. For fast extraction the dumps must be retracted (larger beam size).





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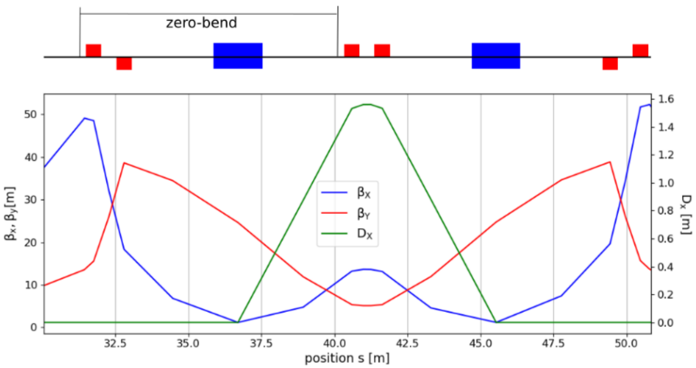
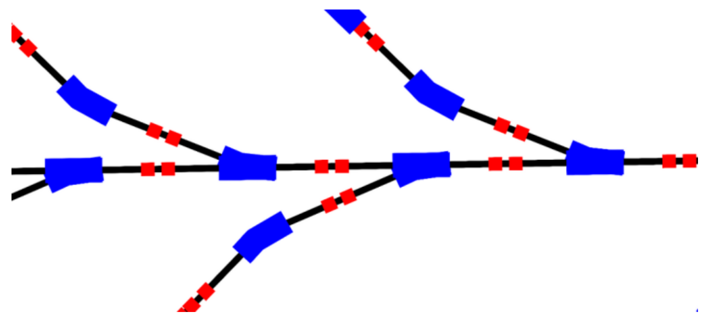
Transfer beam lines – key concepts

Double-bend achromat

1. To bend the beam and close dispersion a double-bend achromat is used.
2. Here a configuration with two quads in the middle is shown; it helps to simplify operation and optics calculations, but it is not necessary: space for optimization.





Optics should be fixed until end of DBA; final beam spot size regulated in the last (focusing) segment with 4 quadrupoles.

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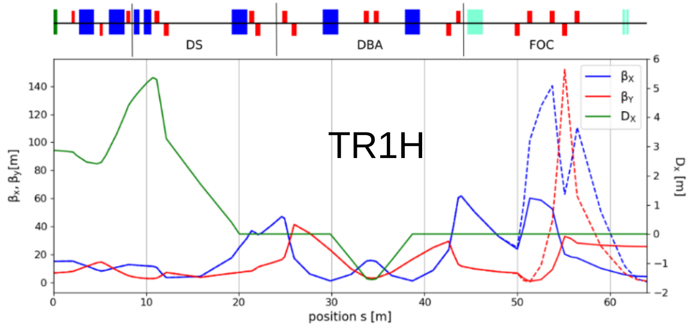
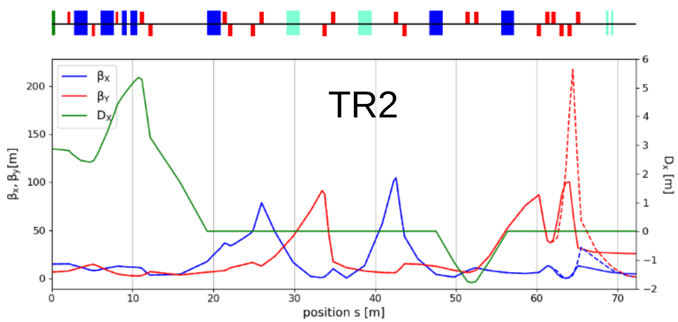
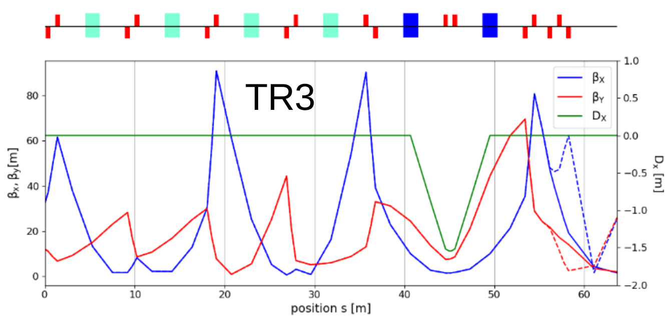
Transfer beam lines – optics and layout

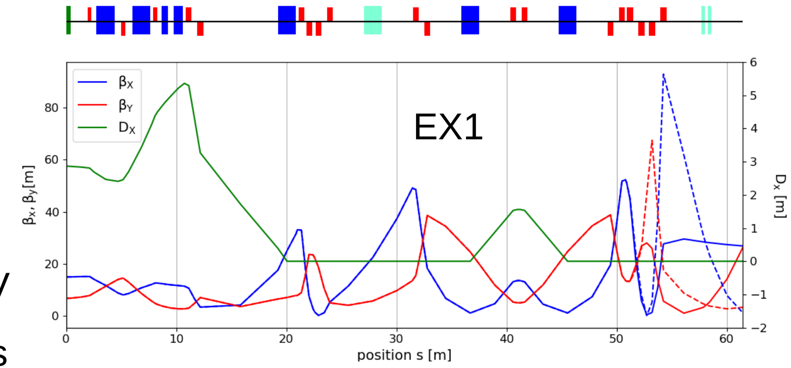


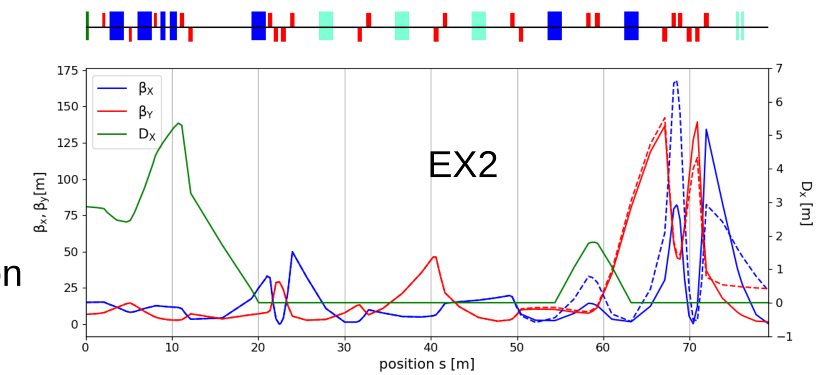




final focus for extreme cases:

- 2 mm beam spot for 60 MeV protons – this is sometimes difficult! Relax specification?
- 10 mm beam spot for Carbon at 430 MeV/u





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Transfer beam lines – what could still be done

1. Detailed location of steerers and instrumentation.
2. Reconsider treatment room width (maybe 7.5 meters is enough – mini version).
3. Redesign for helium facility (micro version).
4. Design Middle Energy Beam Transfer (MEBT).
5. Study different DBA concepts (e.g. single central quad)

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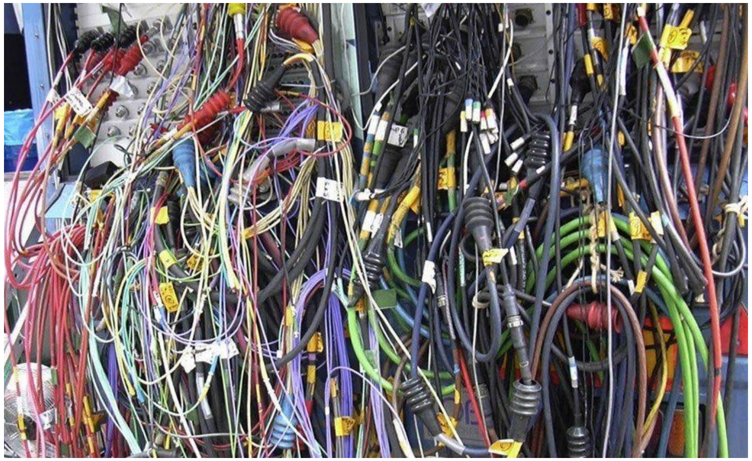
Conclusions

1. Work on operational modes still has to be done (Peter will coordinate).
2. Large part of work on beam instrumentation has been done and it is not very clear what should be added (more ideas are welcome).
3. Report on HEBT concept should be publishable (as NIMMS note), early 2022.
4. Additional works for transfer lines: MEBT, mini-HEBT, helium-HEBT, optimizations…
5. I have 10 working days left on the project until end of April 2022 and I will follow the above points. I hope I will be able to follow, to some degree, also after April.
6. Another person who could follow beam lines and instrumentation is needed.
7. We should have enough material for report in March 2024.



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