FAST FAULT RECOVERY SCENARIOS FOR THE JAEA-ADS LINAC

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Goal

The **main** challenge of a **ADS accelerator** is the **high-reliability** demanded.

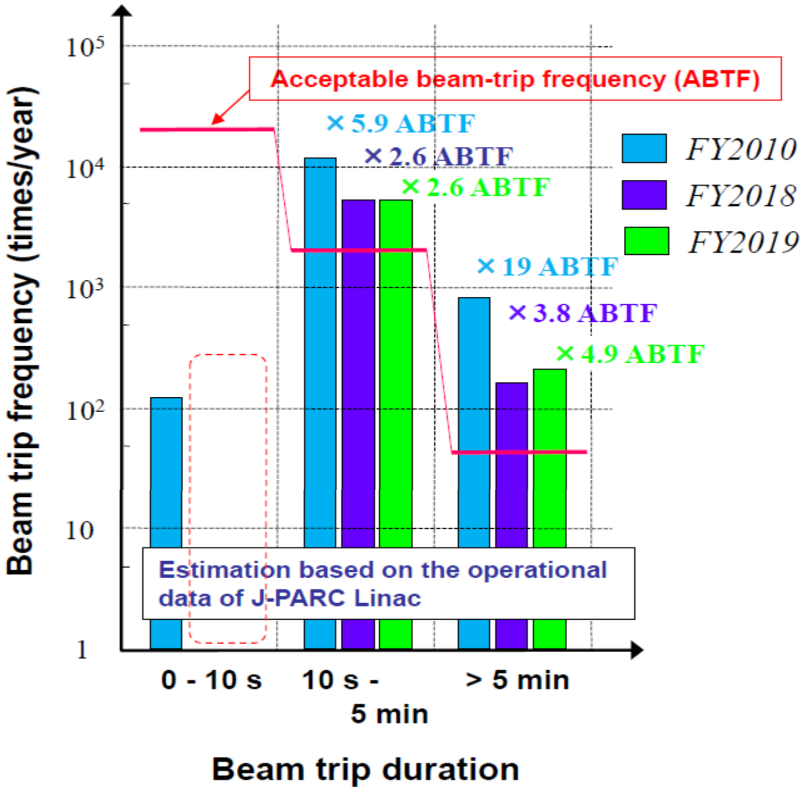


Fig.1: Beam trips requirements for the JAEA-ADS project [1].

The performance is higher than the achieved in present operation linacs such as J-PARC linac.

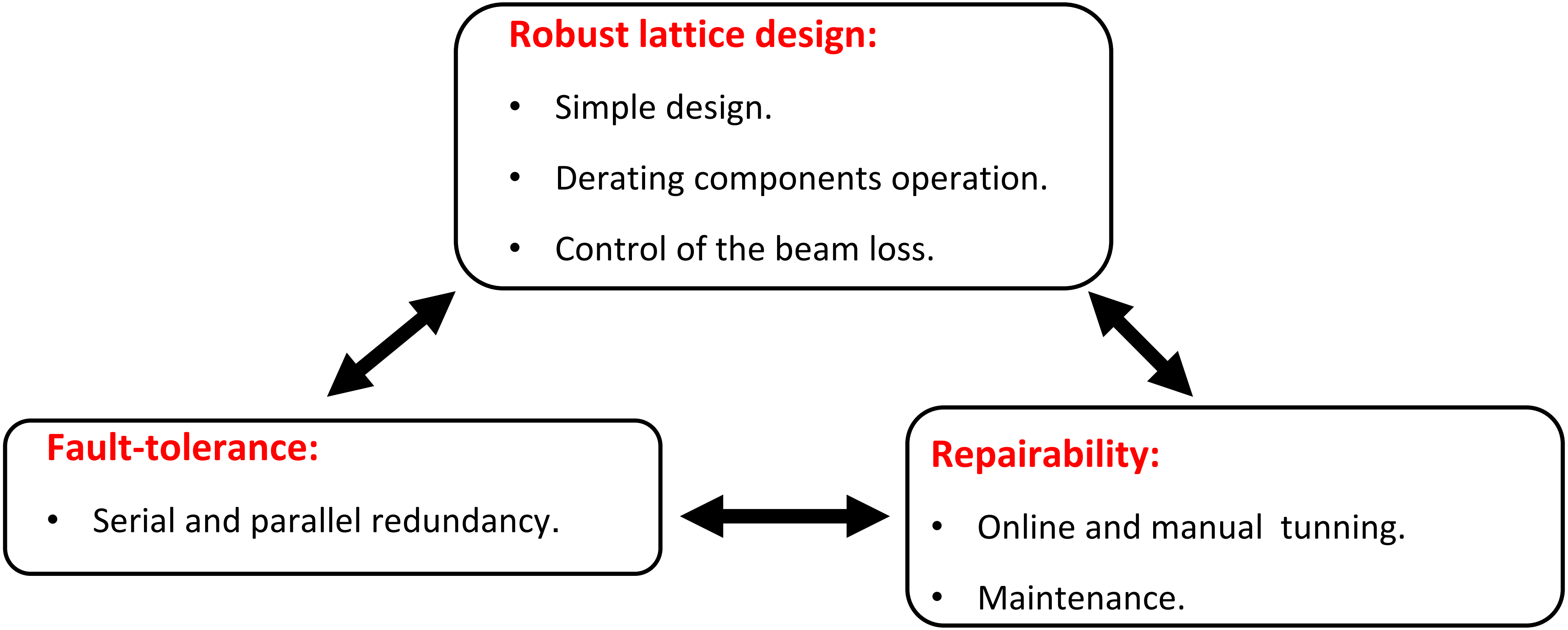
To this end, a **reliability-oriented ADS linac** design is **mandatory.**

This work investigated the Fault-tolerance compensation schemes (**FTCS**) for SRF cavity or magnet failures to achieve a **fast recovery** operation.

[1] H. Takei, *Study of accelerator reliability, TAC2021.*

Introduction

- **Reliability** is the probability that a system will perform its intended function under a specified work condition for a specific time[1].



Robust lattice design:

- Simple design.
- Derating components operation.
- Control of the beam loss.

Fault-tolerance:

- Serial and parallel redundancy.

Repairability:

- Online and manual tunning.
- Maintenance.

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[1] J.L. Biarrotte, *Reliability and fault-tolerance in the European ADS project,* CERN Yellow Report CERN-2013-001, pp.481-494 .

JAEA-ADS linac design

A strong optics design has been developed (and continue...)

- Equipartitioning condition (EP).
- Derating operation of the cavities.
- Control of the beam lost.

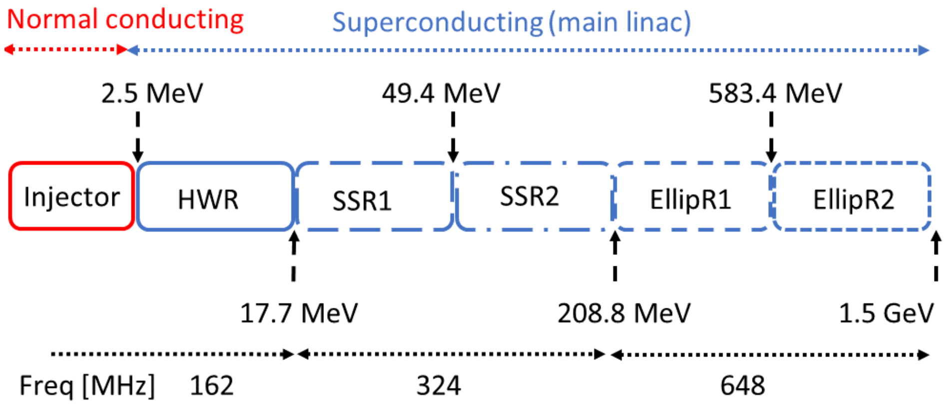
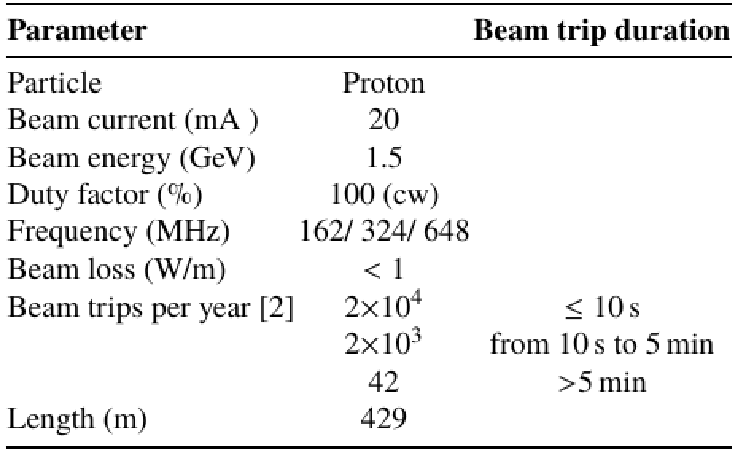


Fig. 2: Layout of the JAEA-ADS.

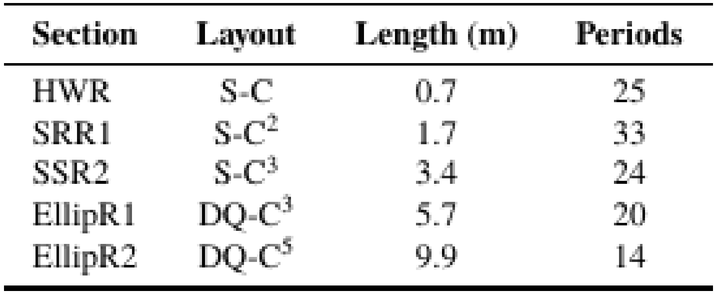
- Half-Wave Resonator (HWR) section
- Single Spoke Resonator (SSR) sections
- Elliptical Resonator (EllipR) sections

Table 1: Main characteristics of the JAEA-ADS accelerator.



Parameter		Beam trip duration
Particle	Proton	
Beam current (mA)	20	
Beam energy (GeV)	1.5	
Duty factor (%)	100 (cw)	
Frequency (MHz)	162/ 324/ 648	
Beam loss (W/m)	< 1	
Beam trips per year [2]	2×10^4	≤ 10 s
	2×10^3	from 10 s to 5 min
	42	>5 min
Length (m)	429	

Table 2: Lattice configuration in the main linac.



Section	Layout	Length (m)	Periods
HWR	S-C	0.7	25
SRR1	S-C^2	1.7	33
SSR2	S-C^3	3.4	24
EllipR1	DQ-C^3	5.7	20
EllipR2	DQ-C^5	9.9	14

Fault-tolerance

The **ability to operate** the accelerator with an **acceptable** beam performance in the presence of undesired behavior of machine components, the so-called **Fault-tolerance**[1].
Two approaches (or a combination of both) are considered:

Parallel redundancy

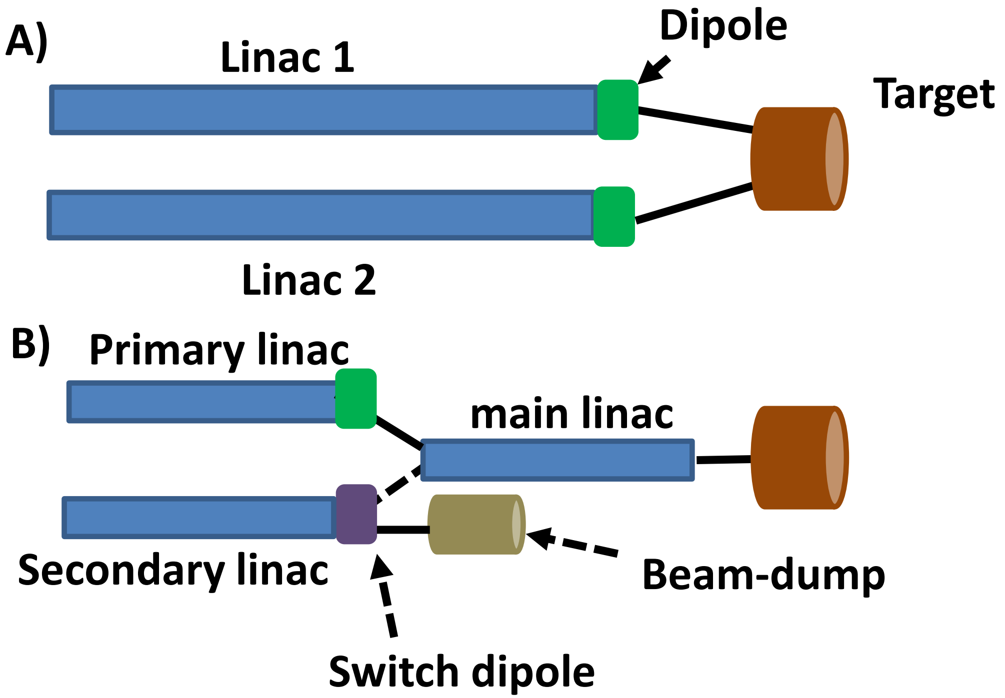


Fig. 3: Fault-tolerance using full (A) and partially (B) parallel redundancy.

Serial redundancy

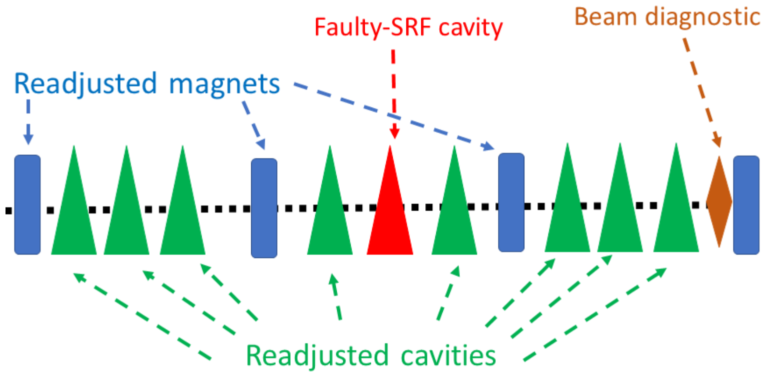


Fig. 4: Fault-tolerance using serial redundancy.

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[1] J. L. Biarrote et al, "Beam Dynamics Studies for the Fault Tolerance Assessment of the PDS-XADS Linac Design", in Proc. 9th European Particle Accelerator Conf. (EPAC'04), Lucerne, Switzerland, Jul. 2004.

Fault-tolerance strategy

The general strategies is the follows:

few seconds

1) Fast detection of abnormal element:

- Machine learning prediction (Fast , accuracy depends of the training).
- MPS and beam loss monitor (robust, slow)

2) Fast faulty-element detuning:

- Cold tuner for SRF cavities.

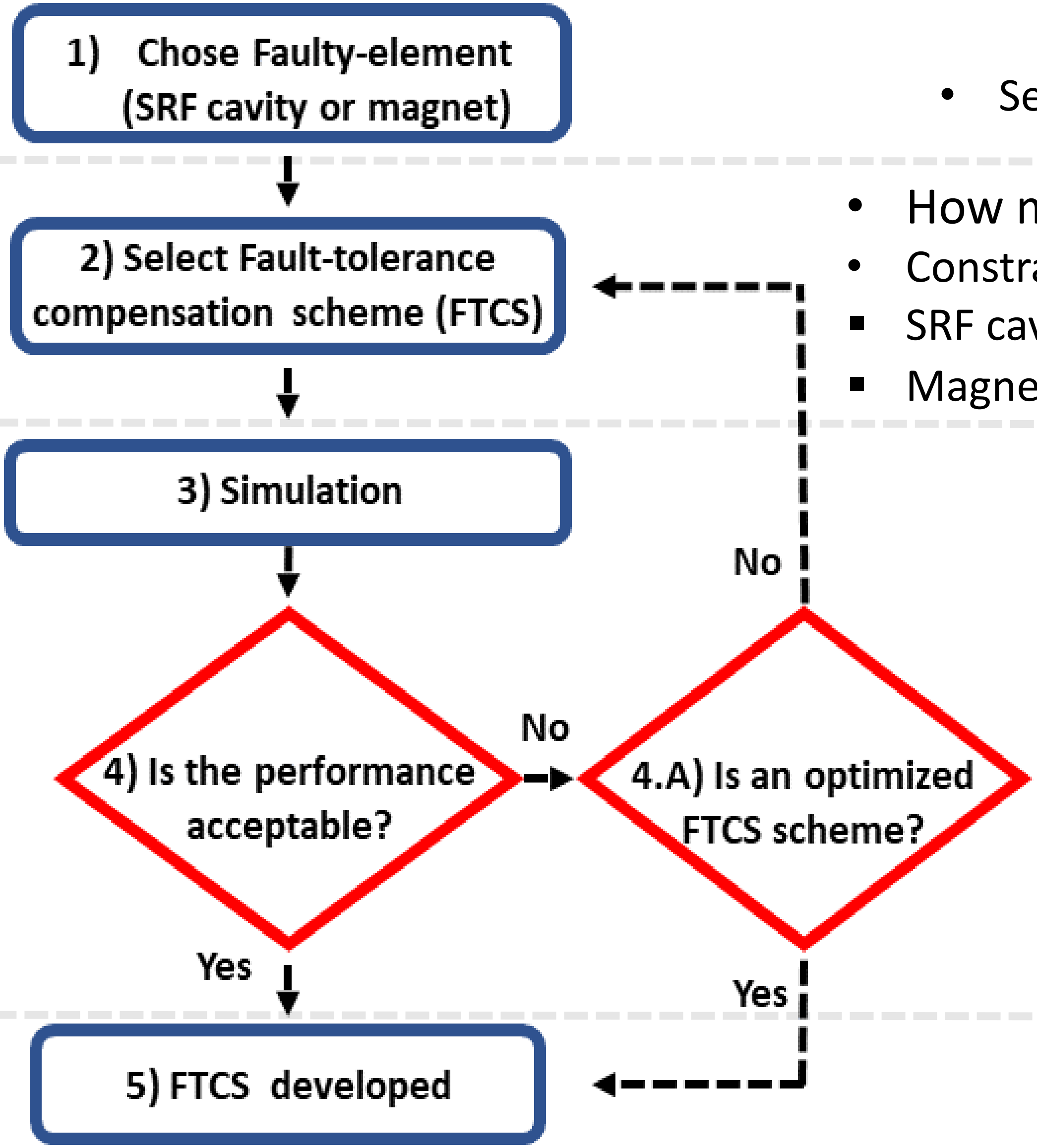
3) Beam operation is stopped:

4) Pre-calculated compensation setting are uploaded:

- During the beam commission is required to estimate these parameters.
- Update the base according the element performance.

5) Beam operation is resumed:

FTCS flow chart



1) Chose Faulty-element (SRF cavity or magnet)

2) Select Fault-tolerance compensation scheme (FTCS)

3) Simulation

4) Is the performance acceptable?

No

4.A) Is an optimized FTCS scheme?

No

Yes

Yes

5) FTCS developed

- Selection: Which one?

- How many elements?
- Constraints:
- SRF cavity: $\Delta\phi_s = \pm 50\%$, $\Delta E_{acc} = 20\%$ ($E_{pk} \lesssim$ 36 MV/m)
- Magnets : $\Delta B = 20\%$

- Two steps to speed up:
  - local
  - To the end of the linac

- Design goal:
  - Beam loss < 1 W/m
  - $\frac{\Delta E}{E_0} < \pm 1\%$
  - $\frac{\Delta \varepsilon}{\varepsilon_0} <$ double
  - $M < 0.2$

SRF cavity failures

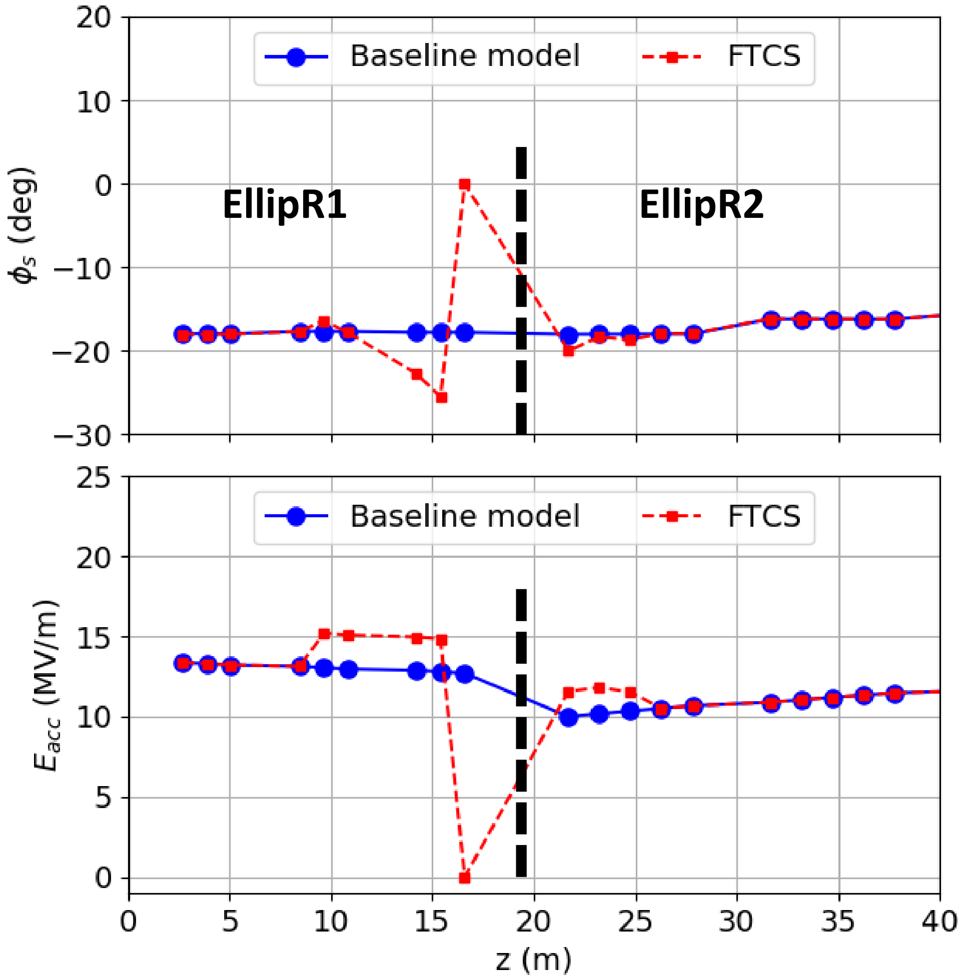
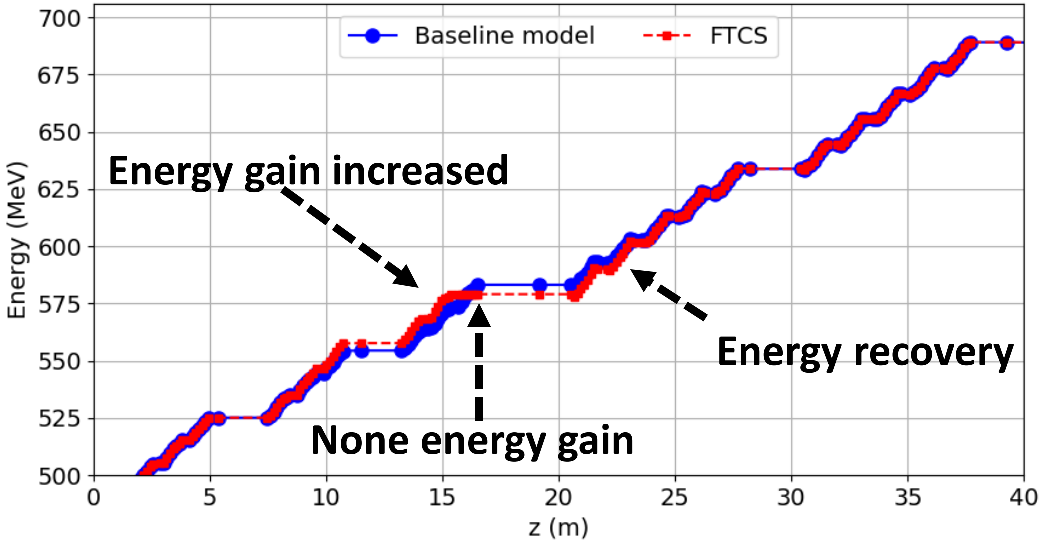


Fig. 5: ϕ_s and E_{acc} adjustment for FTCS SRF cavity.



Energy gain increased

Energy recovery

None energy gain

Fig. 6: Energy compensation for the FTCS SRF cavity.

Table 3: Summary for the worst SRF cavity's FTCS.

Parameters	**SSR1**	**SSR2**	**EllipR1**	**EllipR2**
$(\Delta\epsilon/\epsilon_0)_t$ (%)	12.2	1.9	3.5	0.4
$(\Delta\epsilon/\epsilon_0)_l$ (%)	35.8	7.8	4.5	1.4
M_t	0.03	0.06	0.03	0.04
M_l	0.06	0.04	0.09	0.12
$\Delta E/E_0$ (%)	0.00	0.01	0.01	0.00
Max E_{pk}(MV/m)	32.6	35.9	35.4	35.9
Max B_{pk}(mT)	48.3	51.9	66.1	69.3

Several SRF cavity failures

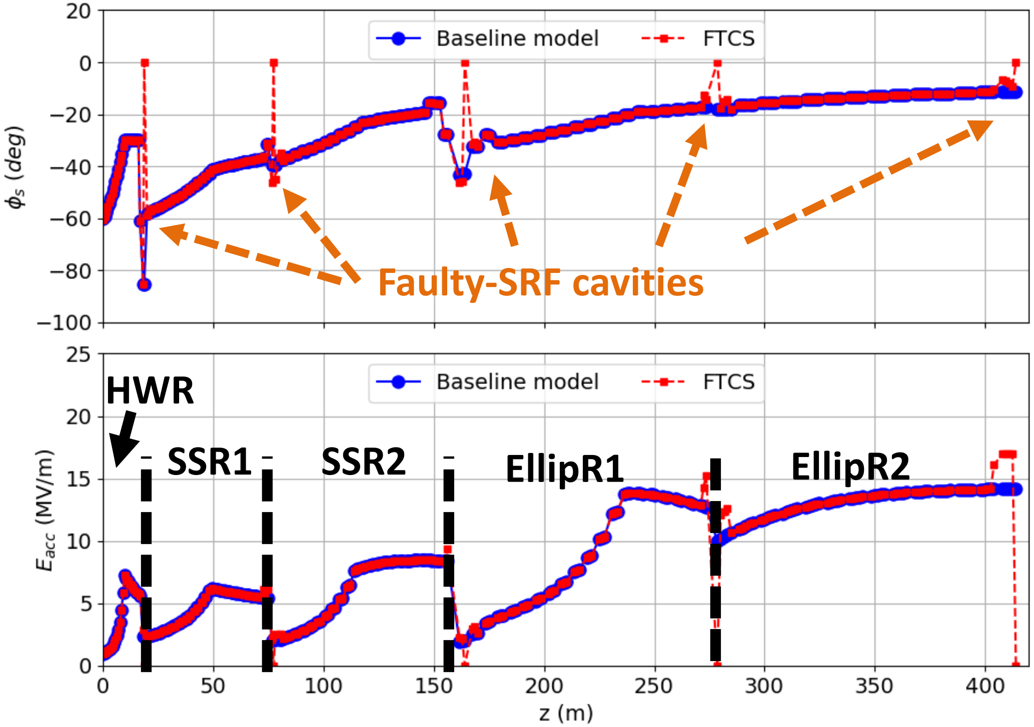


Fig. 7: Multiple SRF cavity (MSRFC) failures.

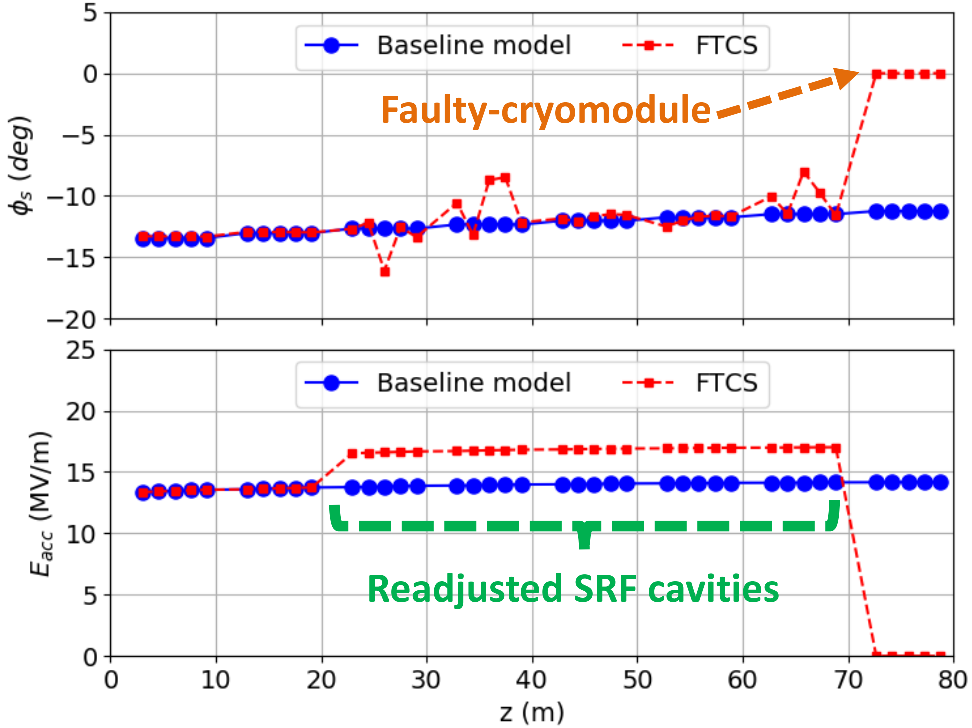


Fig. 8: Faulty-cryomodule (FCRYO).

Table 4: Summary of multiples SRF cavity failures.

Parameters	**MSRFC**	**FCRYO**
$(\Delta\epsilon/\epsilon_0)_t$ (%)	9.2	1.3
$(\Delta\epsilon/\epsilon_0)_l$ (%)	50	-2.5
M_t	0.04	0.16
M_l	0.16	0.64
$\Delta E/E_0$ (%)	0.01	0.03
Max E_{pk}(MV/m)	35.9	35.9
Max B_{pk}(mT)	69.3	69.3

FTCS magnets

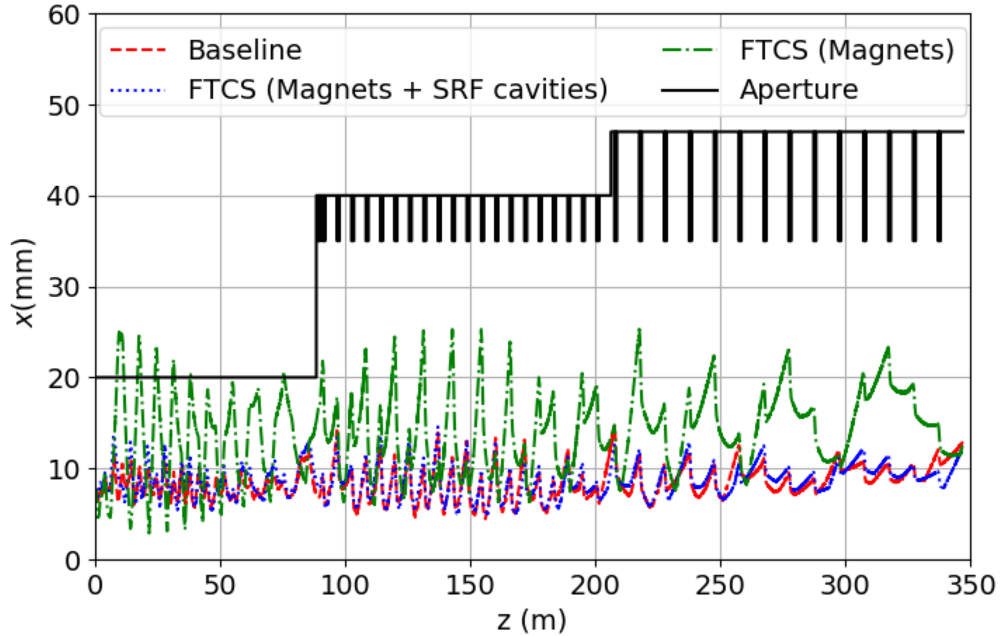


Fig. 9: Horizontal beam envelopes for different models.

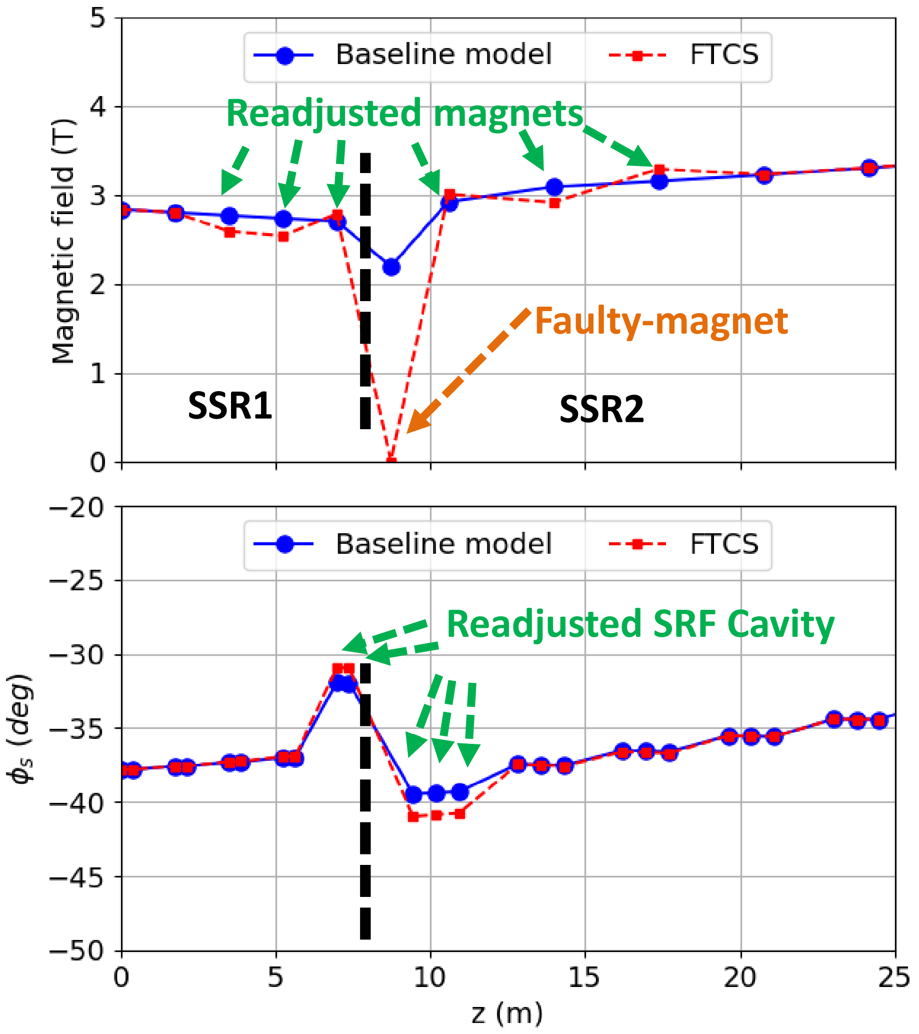


Fig. 10: Magnets compensation failures.

Table 5: Summary of beam optics performance for the worst magnet compensation case in each section.

Parameters	**SSR1**	**SSR2**	**EllipR1**	**EllipR2**
$(\Delta\epsilon/\epsilon_0)_t$ (%)	63.7	8.2	22.1	35.8
$(\Delta\epsilon/\epsilon_0)_l$ (%)	63.1	10.1	4.6	7.5
M_t	0.08	0.04	0.06	0.12
M_l	0.17	0.04	0.03	0.16
$\Delta E/E_0$ (%)	-0.04	-0.01	0.01	0.00

Conclusions

- **Serial redundancy** can be applied **from the SSR1** section until the end linac **without** a severe **beam degradation**.
- The linac could **operate** in the presence of **multiples Faulty-SRF cavities** and even in the case of a **full cryomodule failure**.
- Thus, it shows the possibility of **fast recovery** after a **failure** of a principal component: **cavity** or **magnet**.
- Nevertheless, the main limitation comes from the engineering side to **reduce the time** of:
  - **Detection** of an abnormal element behavior
  - **Detuning** the element
  - **Application** the compensation setting.
- We require a large R&D effort to overcome these difficulties.