CERN

Availability Studies and Operating Cycle

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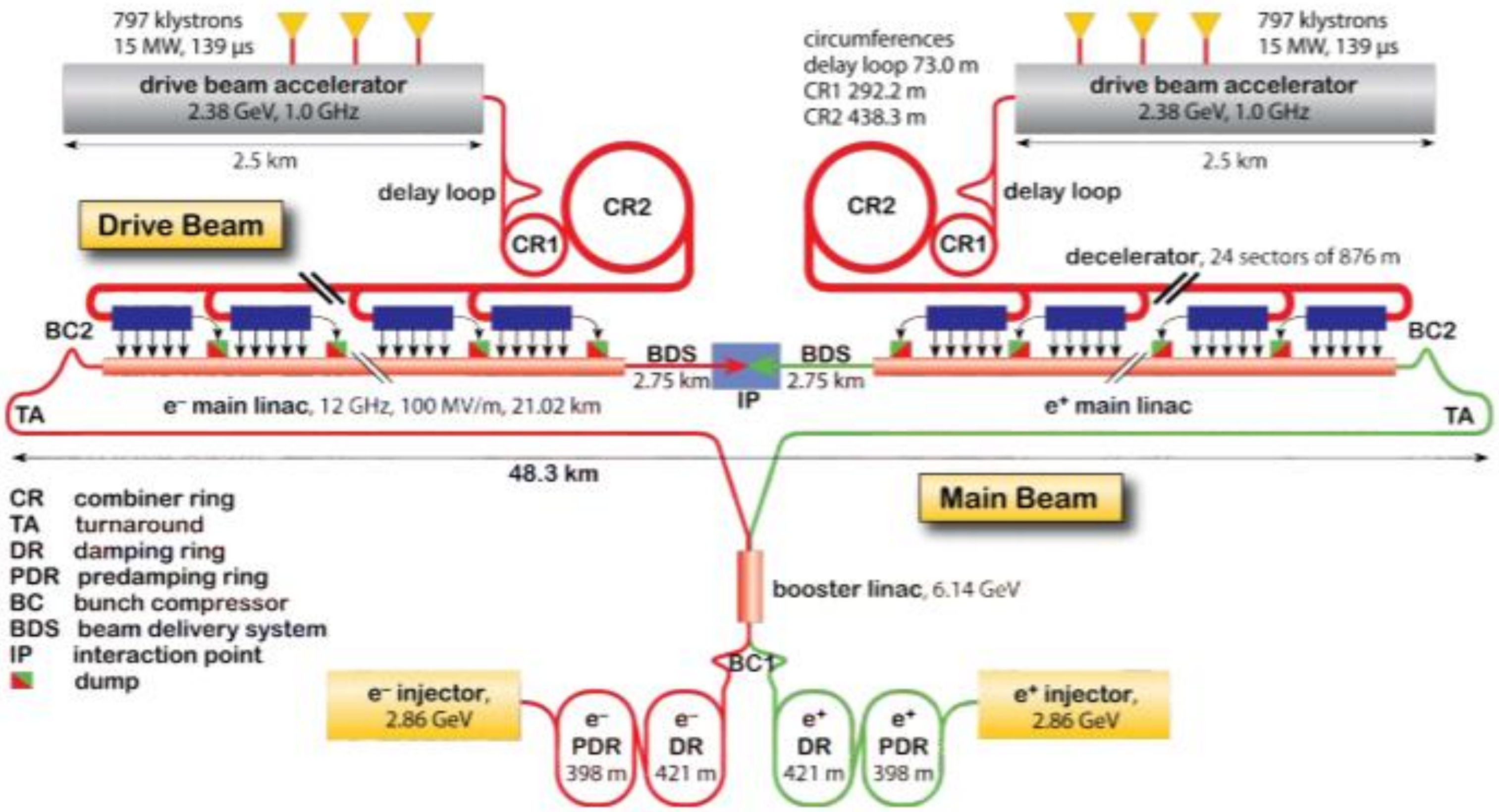
TE-MPE-PE Section Meeting, 22th of February 2018

The Compact Linear Collider (CLIC)

- Future accelerator project to collide electrons and positrons
- Particles are accelerated in two linear accelerator facing each other.
- Designed to be built in stages of increasing collision energy:

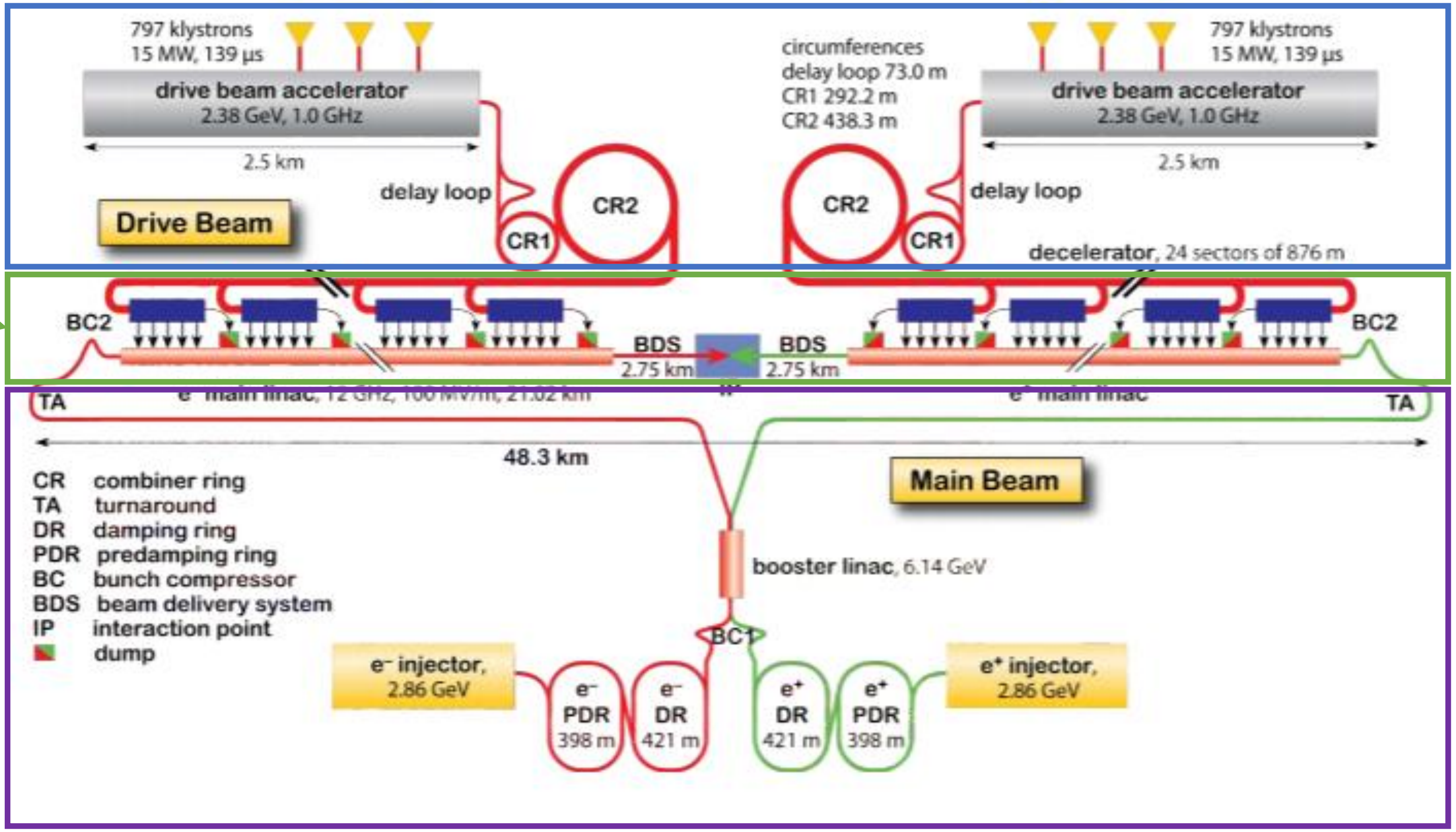
  360 GeV -> 1.4 TeV -> 3 TeV
- Accelerating gradient: 100 MV/m (20 times higher than the LHC)



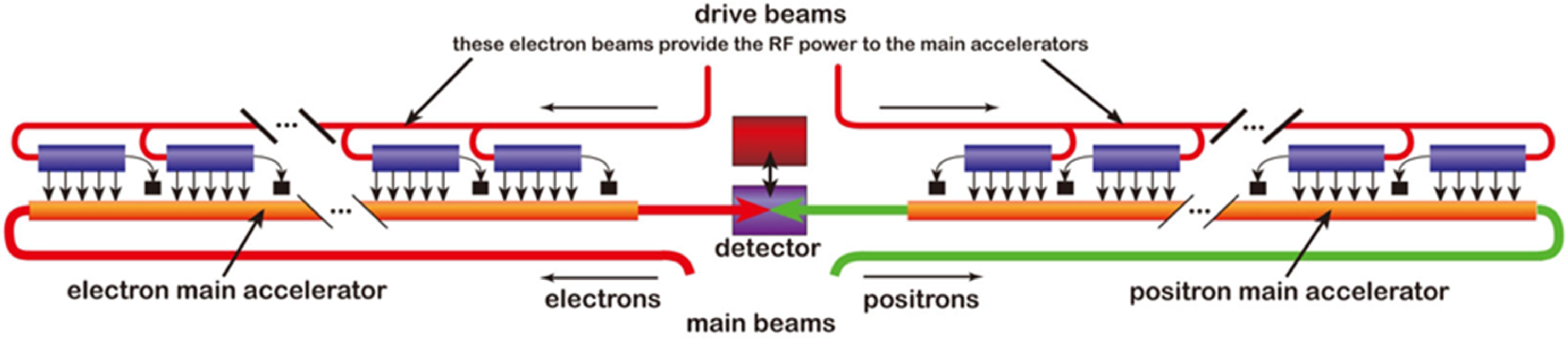
The Compact Linear Collider (CLIC)

Baseline

- Drive Beam Complex
- Two Beam modules
- Main Beam Complex



The Compact Linear Collider (CLIC)



Baseline

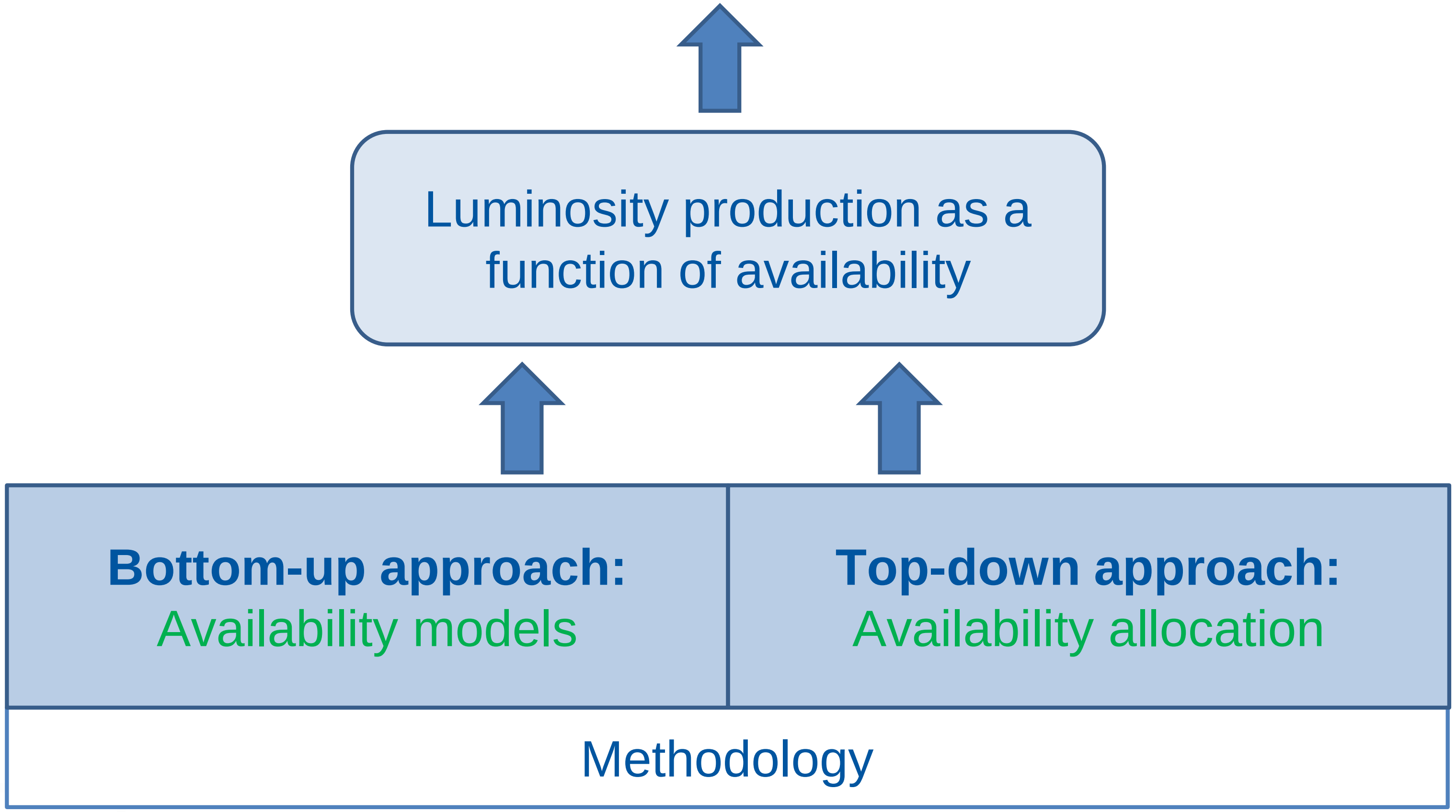
1. The **drive beam is decelerated** in special Power Extraction and Transfer Structures (PETS)

2. Accelerating structures are **powered by** the **generated RF power**

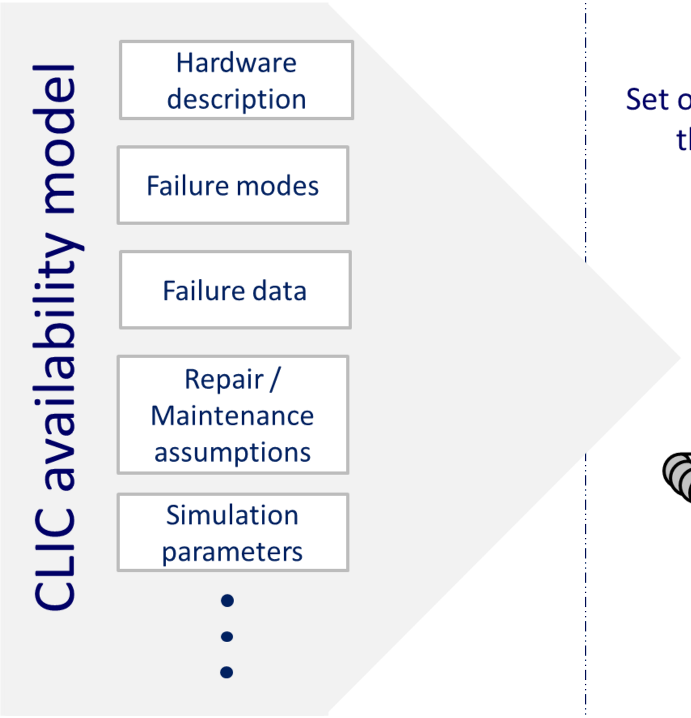
3. Main Beam is accelerated

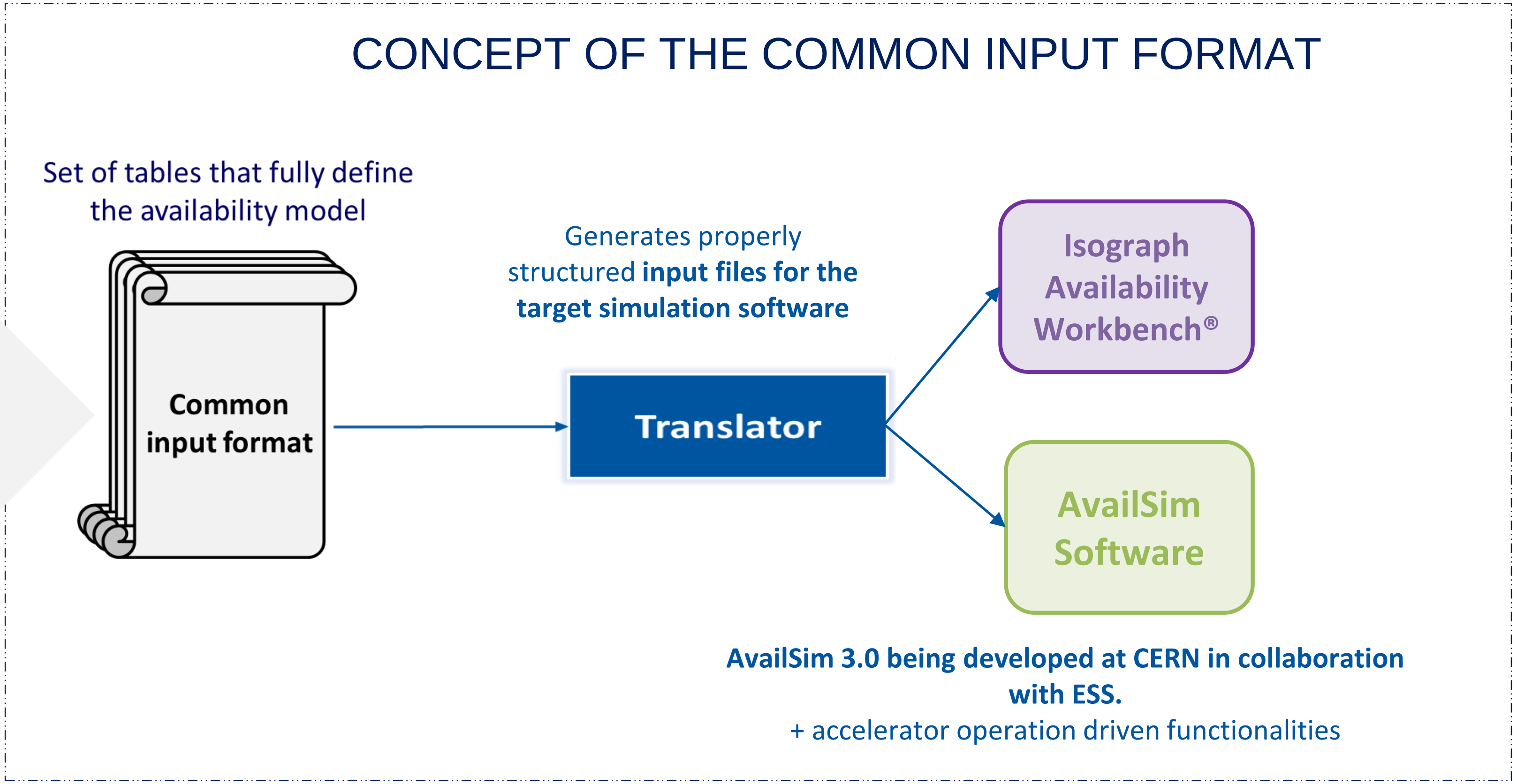
Goal of the study

- **Demonstrate** that CLIC availability requirements can be reached
- Identify the **key factors** that influence on failure effects
- Analyse possible **operational scenarios and machine designs**



CLIC Availability models





- + Modelling and running simulations in various software packages at the same time
- + Model definition once, avoids repetition
- + Model and results validation
- + Easy versioning of models

CLIC Availability models

Output -> Availability estimations

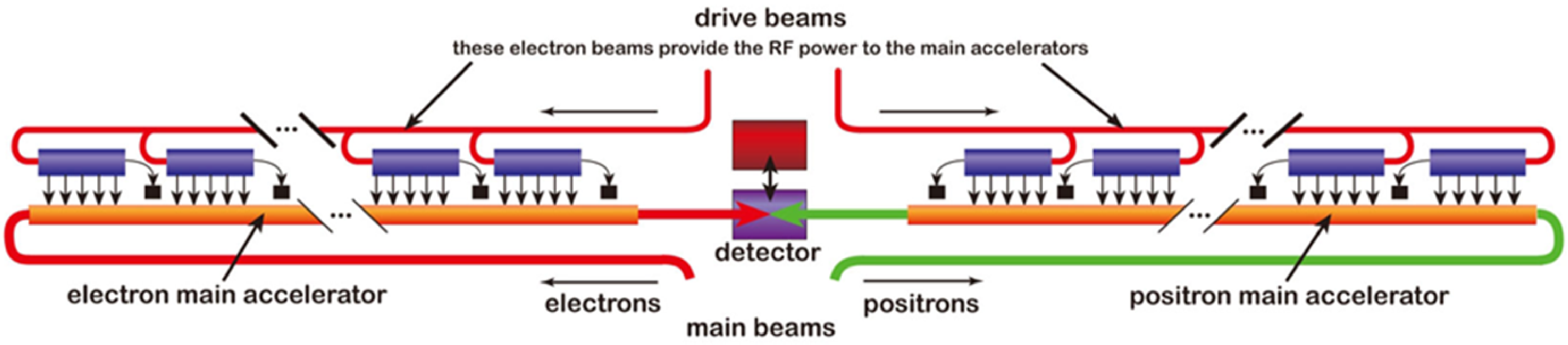
- How often do we expect CLIC to fail?
- How much time would we need to clean the system faults?
- Which are the systems contributing more to the failures? And to the fault time?
- Do we need to implement more redundancies?
- …

On-going studies

- Main Beam Linac RF powering schemes
- RTML and transfer lines
- Technical Infrastructures, cooling and ventilation

Main Beam Linac RF Powering

CLIC Availability models



Baseline

1. The **drive beam is decelerated** in special Power Extraction and Transfer Structures (PETS)

2. Accelerating structures are **powered by** the **generated RF power**

3. Main Beam is accelerated

Alternative for low collision energies

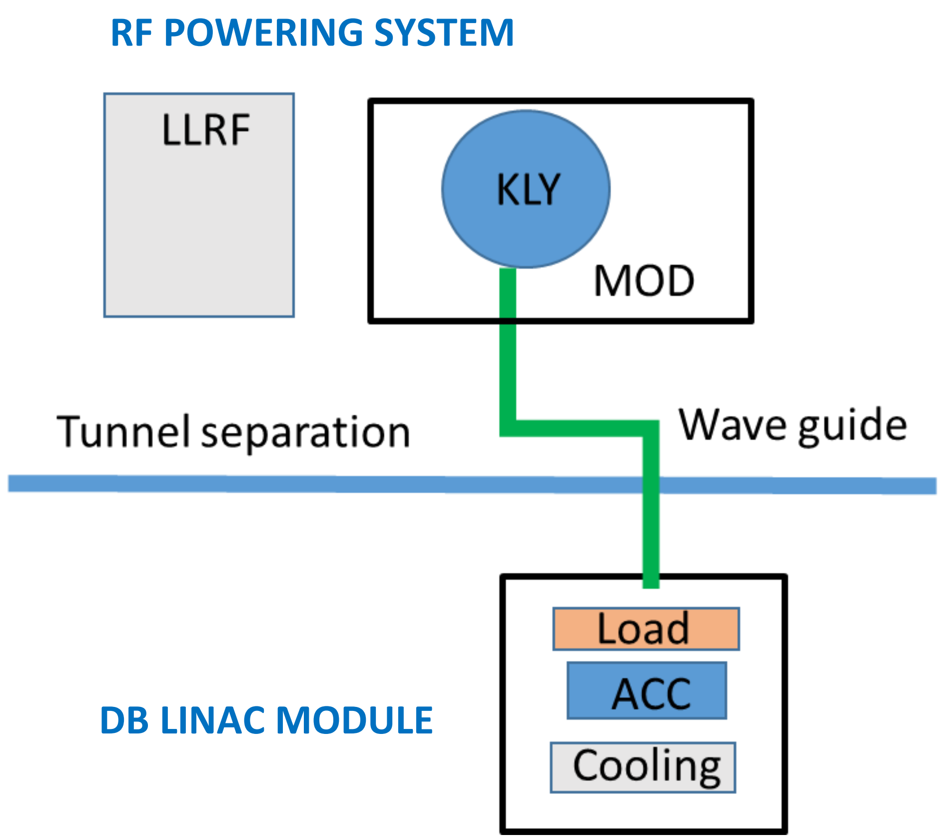
1. Accelerating structures are **powered by klystrons**

2. Main Beam is accelerated

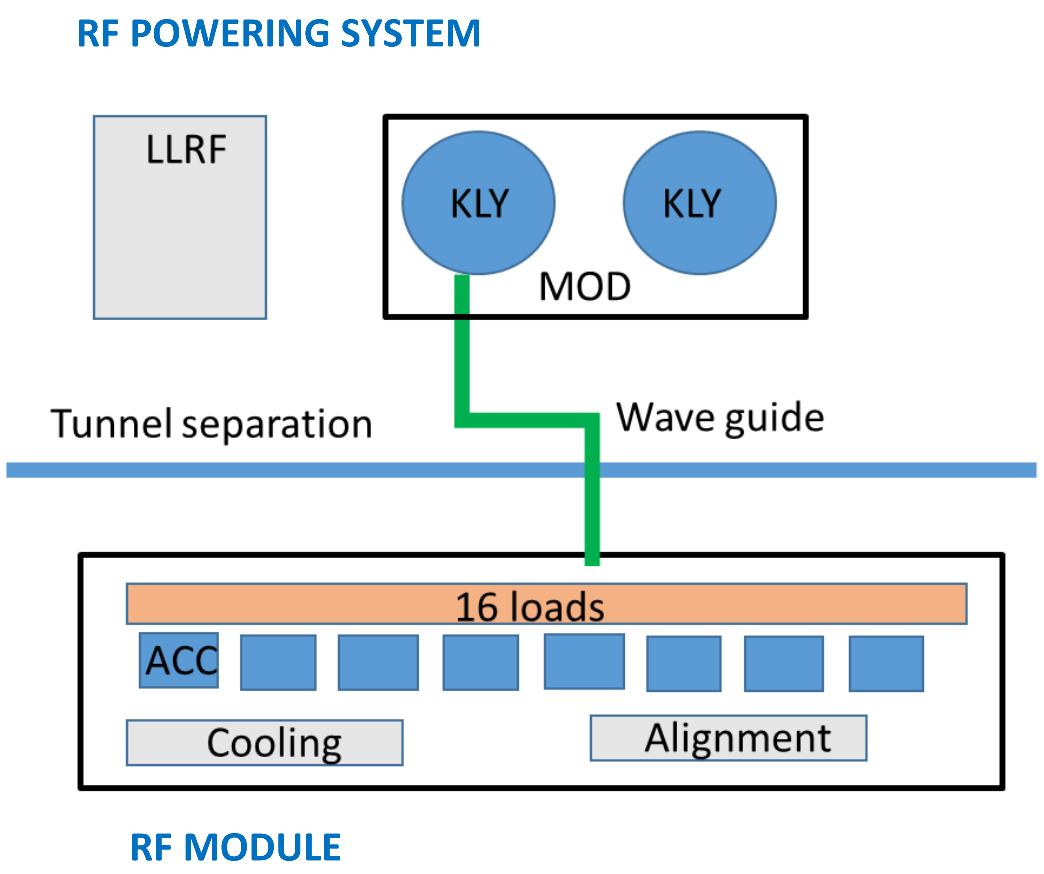
Main Beam Linac RF Powering

CLIC Availability models

BASELINE: DRIVE BEAM BASED



ALTERNATIVE: KLYSTRON BASED

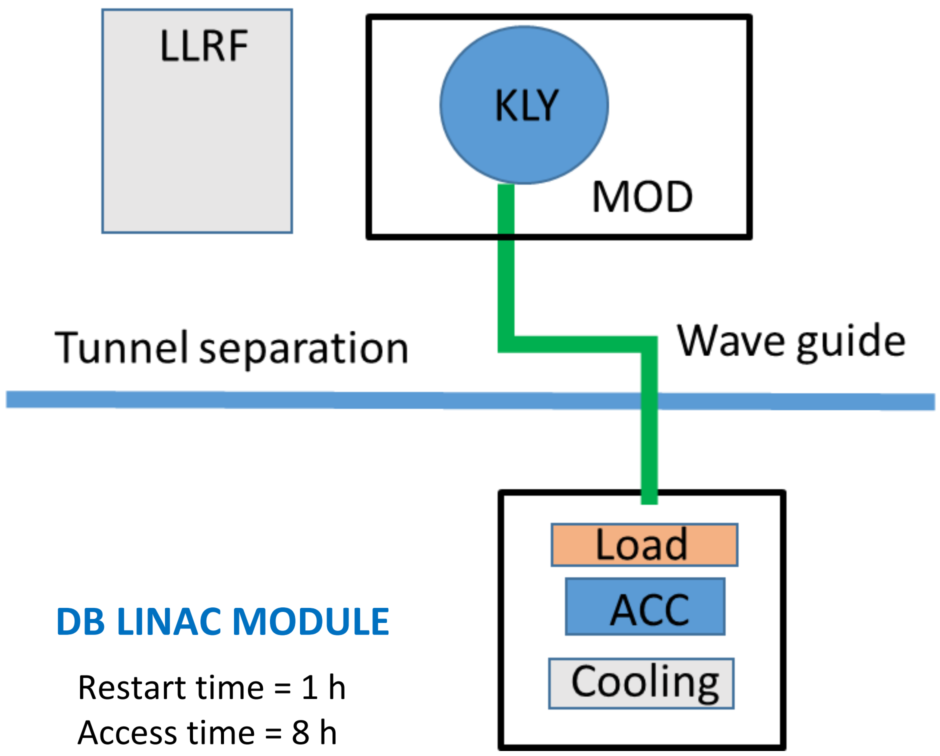


Main Beam Linac **Drive Beam based** RF Powering

CLIC Availability models

RF POWERING SYSTEM

Restart time = 1 h
Access time = 8 h



DB LINAC MODULE

Restart time = 1 h
Access time = 8 h

Each element can fail with a MTTF and then can be fixed with MTTR

One can define the consequence of the failure

Fix offline. Need to be exchanged/repaired in next shutdown

Total of 500 units (per linac)
50 hot spares

Does not include the Drive Beam accelerator (TBD)

Main Beam Linac **Drive Beam based** RF Powering

CLIC Availability models

Assumptions

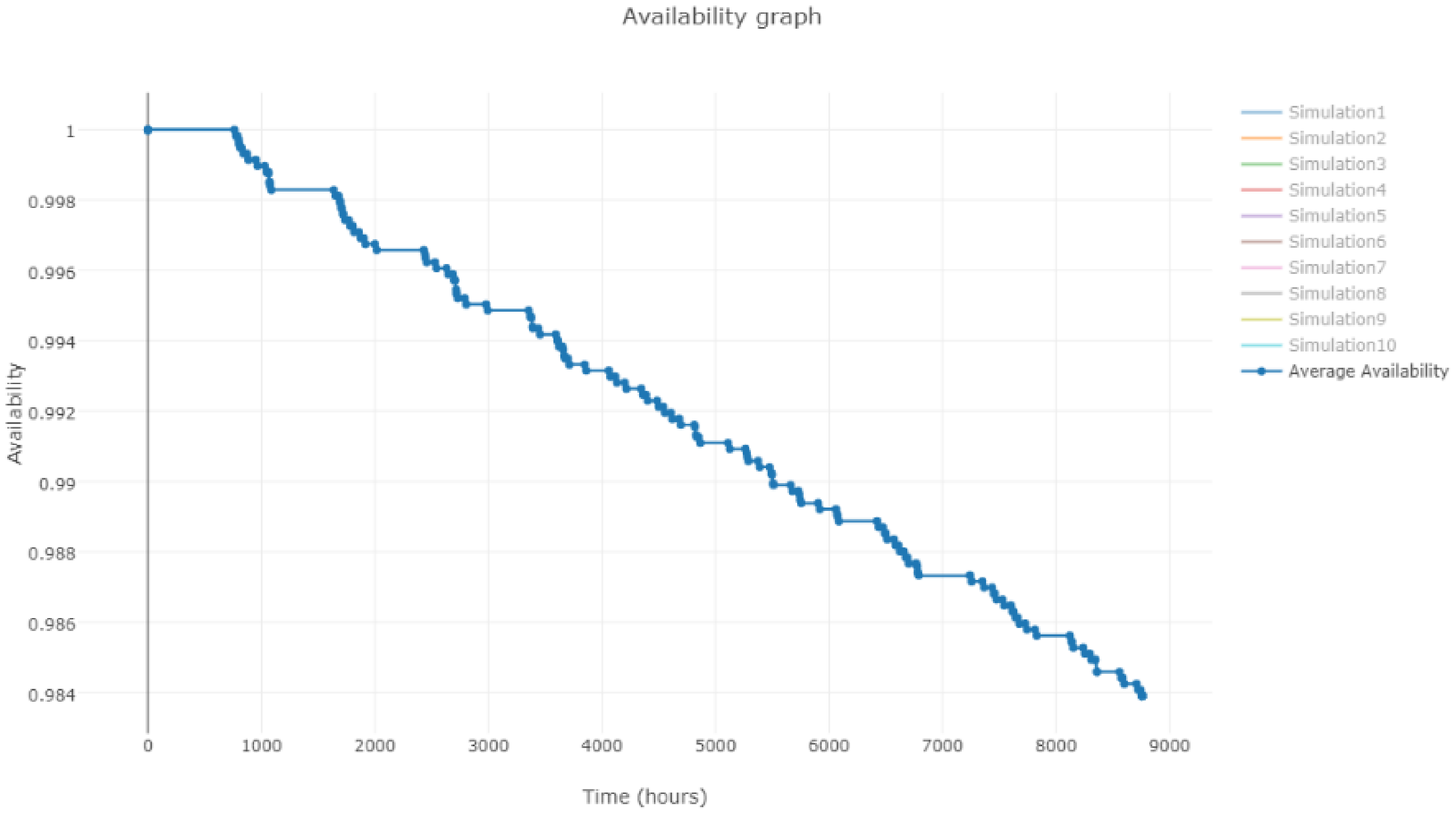
- Simulation period: 1 year (operation 24/7)
- Components failure behaviour follow an exponential distribution
- 50 Hot standby spares available every time operation (re)starts
- Maintenance/ repairs:
  - All failed components are repaired
  - Only repairs when the system is down due to components failures *
  - Repairs can be done simultaneously
  - All repairs must be finished before restating the system

- RF Breakdown can be fixed at the moment of failure if hot standby spares available

Main Beam Linac **Drive Beam based** RF Powering

CLIC Availability models

Availability	Times Down	Uptime (days)	Downtime (days)	Standard deviation	MTTR (h)	MTBF (h)
98.4%	**9.4**	359.1	5.9	0.001	**15**	**901.9**



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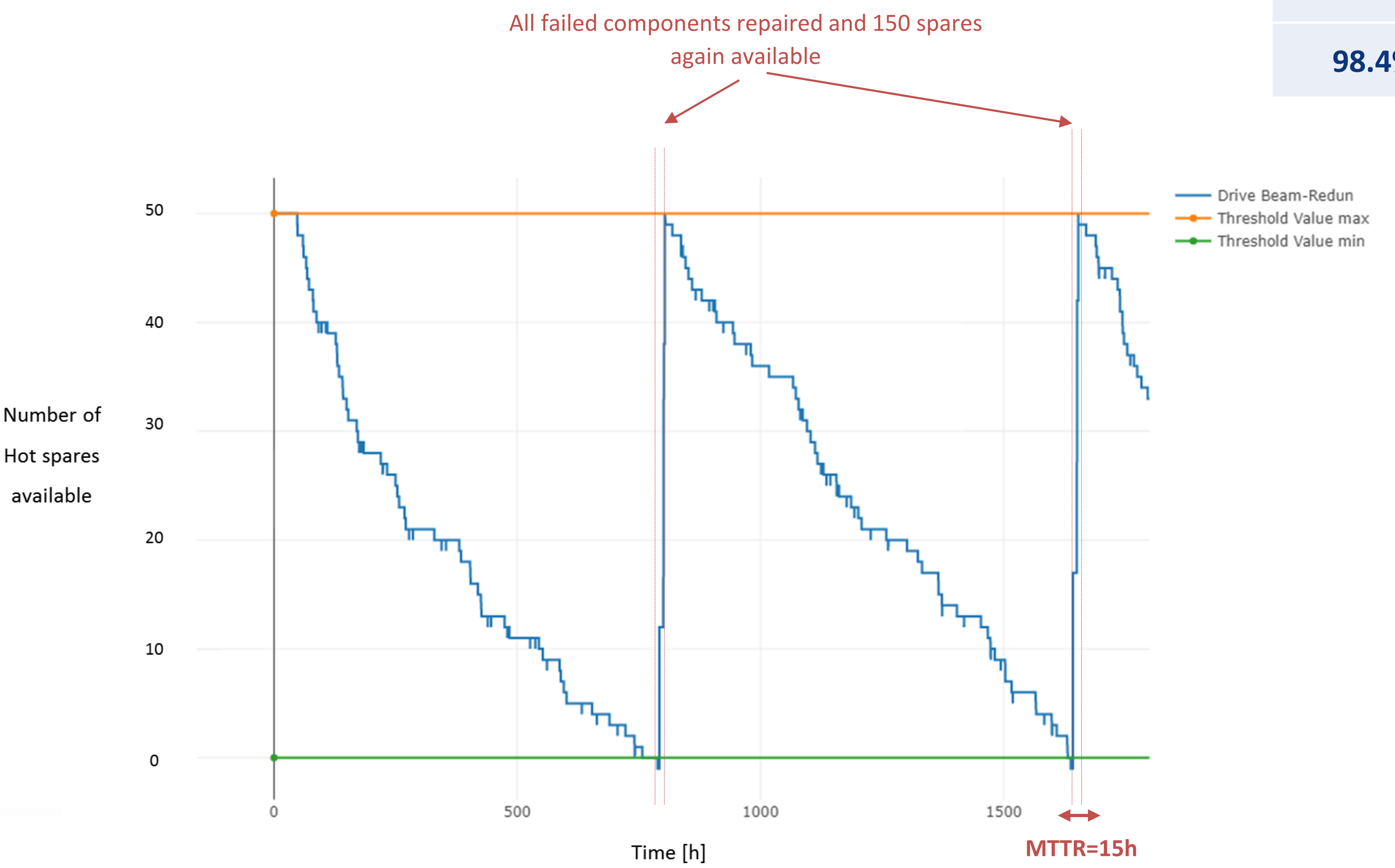
Main Beam Linac **Drive Beam based** RF Powering

CLIC Availability models

Availability	Times Down
98.4%	**9.4**



Main Beam Linac **Klystron based** RF Powering

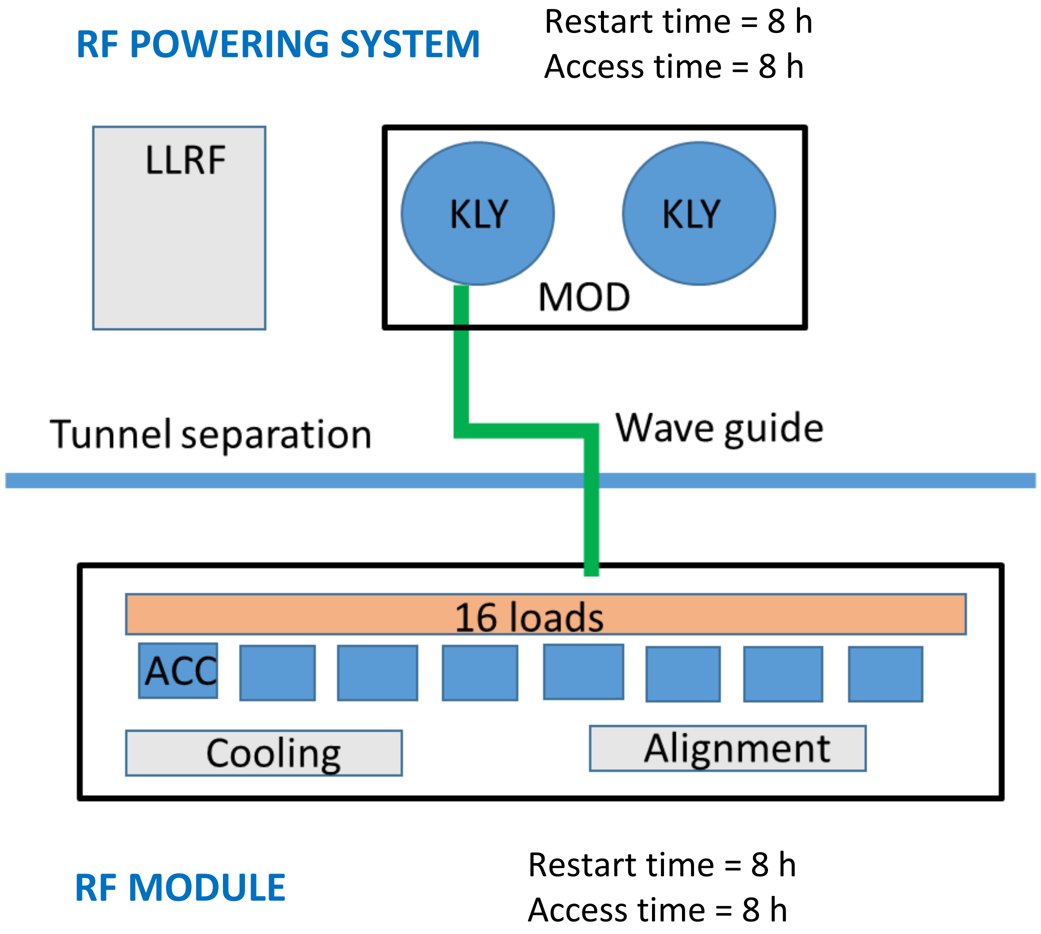
CLIC Availability models

Each element can fail with a MTTF and then can be fixed with MTTR

One can define the consequence of the failure

Fix offline. Need to be exchanged/repaired in next shutdown

Total of 1500 units (per linac)
150 hot spares



Main Beam Linac **Klystron based** RF Powering

CLIC Availability models

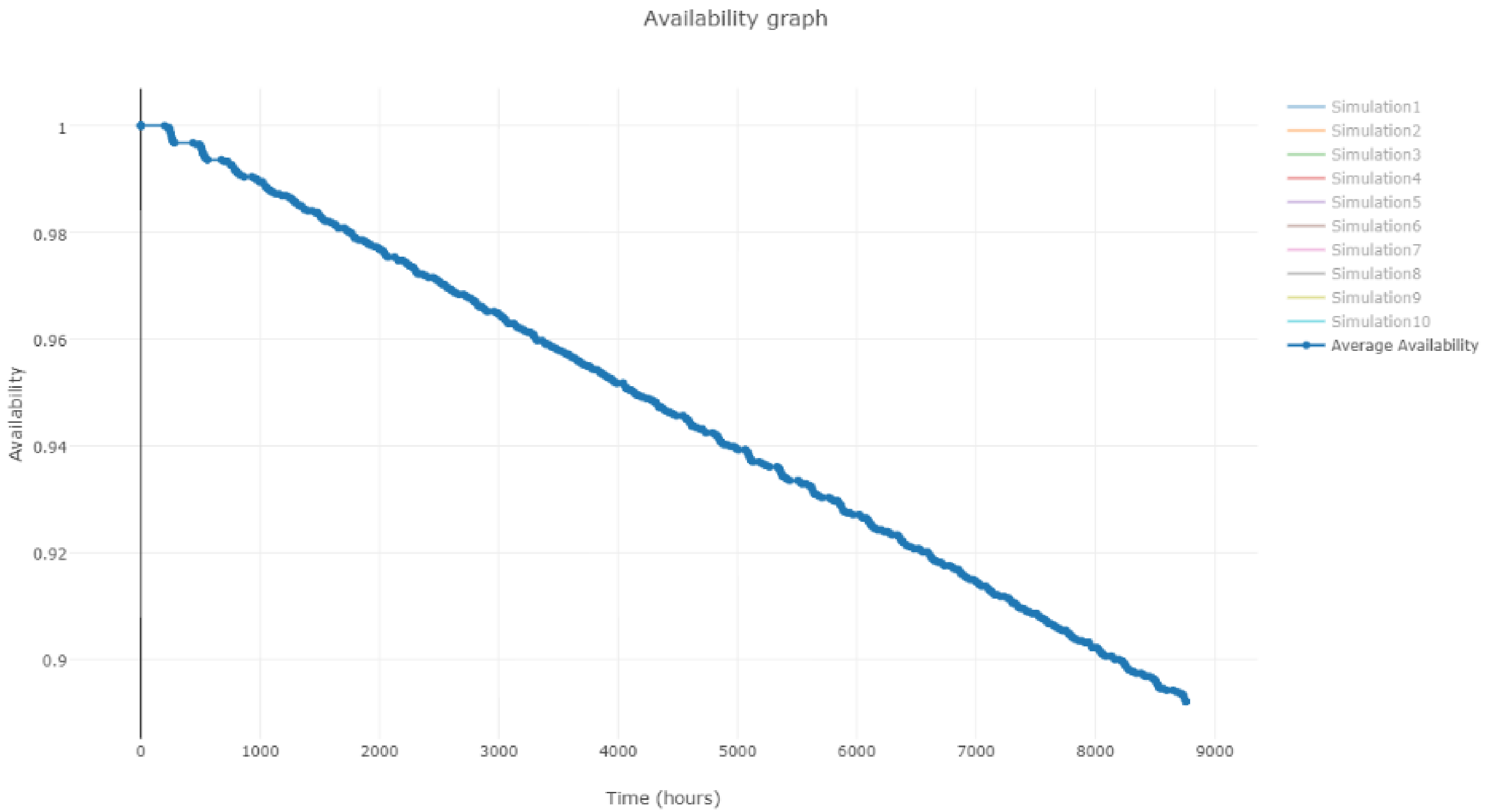
<u>Assumptions</u>

- ❑ Simulation period: 1 year (operation 24/7)
- ❑ Components failure behaviour follow an <u>exponential distribution</u>
- ❑ <u>150 Hot standby spares available</u> every time operation (re)starts
- ❑ Maintenance/ repairs:
  - All failed components are repaired
  - Only <u>repairs when the system is down</u> due to components failures *
  - Repairs can be done simultaneously
  - All repairs must be finished before restating the system
- ❑ RF Breakdown and Modulator failure 2 can be fixed at the moment of failure if hot standby spares available

Main Beam Linac **Klystron based** RF Powering

CLIC Availability models

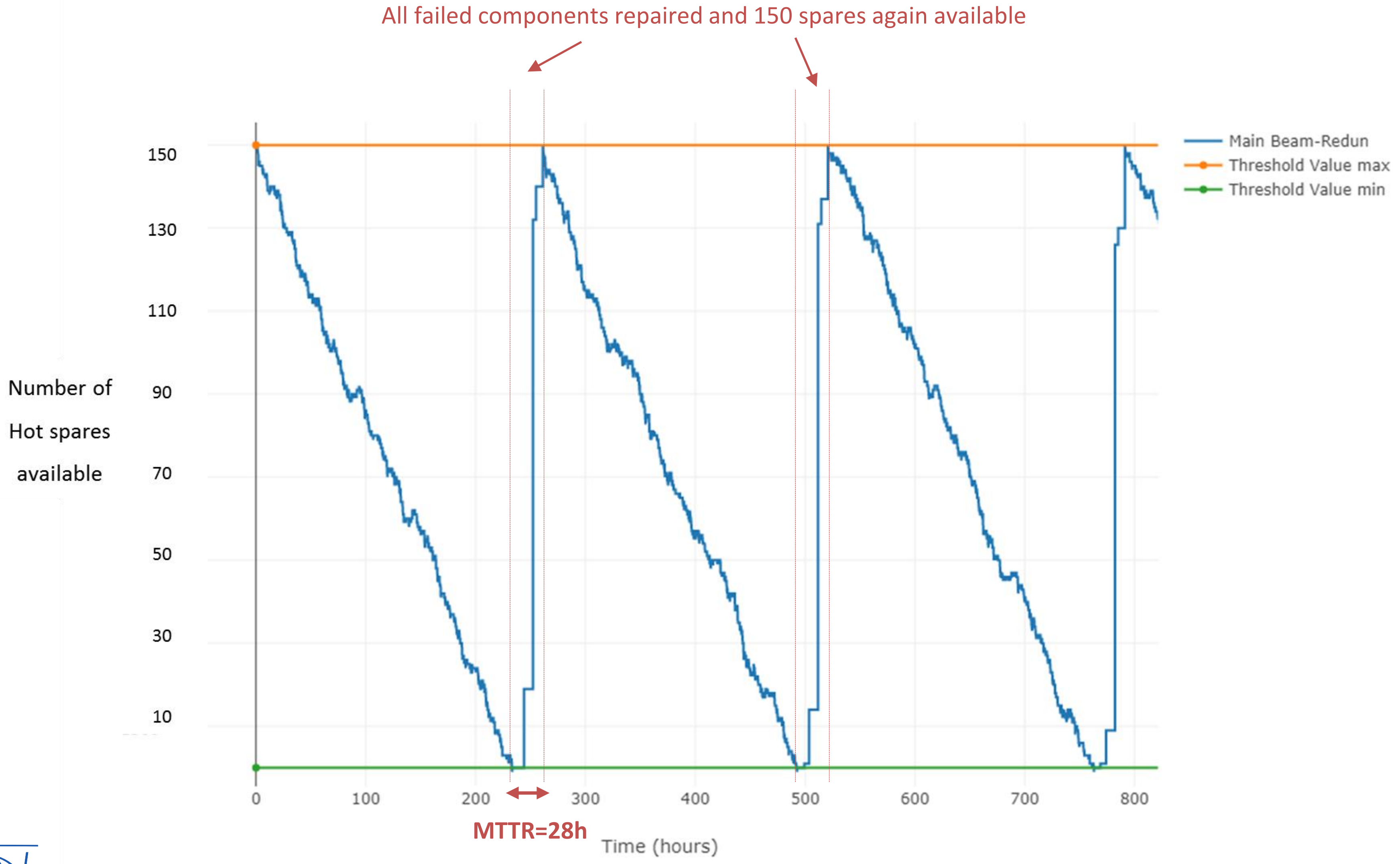
Availability	Times Down	Uptime (days)	Downtime (days)	Standard deviation	MTTR (h)	MTBF (h)
89.2%	**33.8**	325.6	39.4	0.001	**27.9**	**231.2**



Main Beam Linac **Drive Beam based** RF Powering

CLIC Availability models

Availability	Times Down
89.2%	**33.8**



Main Beam Linac **Drive Beam based** RF Powering

CLIC Availability models

Conclusions

Accuracy of the output results strongly depends on the quality of the input

- Only RF powering schemes compared, does not include other components

Drive Beam based powering

- Components with high failure frequency and repair time (cooling system, loads) are governing the system availability
- The powering system could operate around 600 hours before running out of spares

Klystron based powering

- The components in greater number (klystrons, loads) are governing the system availability
- The powering system could operate for around 231 hours before running out of spares

Availability allocation by complexity criteria

Output -> Availability requirements

- Allocate complexity to CLIC subsystems

  For each system i with allocated complexity C_i : $\sum C_i = 1$:

- Set target availability A_T
- Allocated availability for system i : $A_i = {A_T}^{C_i}$

Note that $\prod A_i = A_T$

How to measure complexity?

Experts evaluation

Determine scales of factors and the effects between systems

- No. of components
- Repair time
- Criticality
- State of art
- Performance time
- Environment

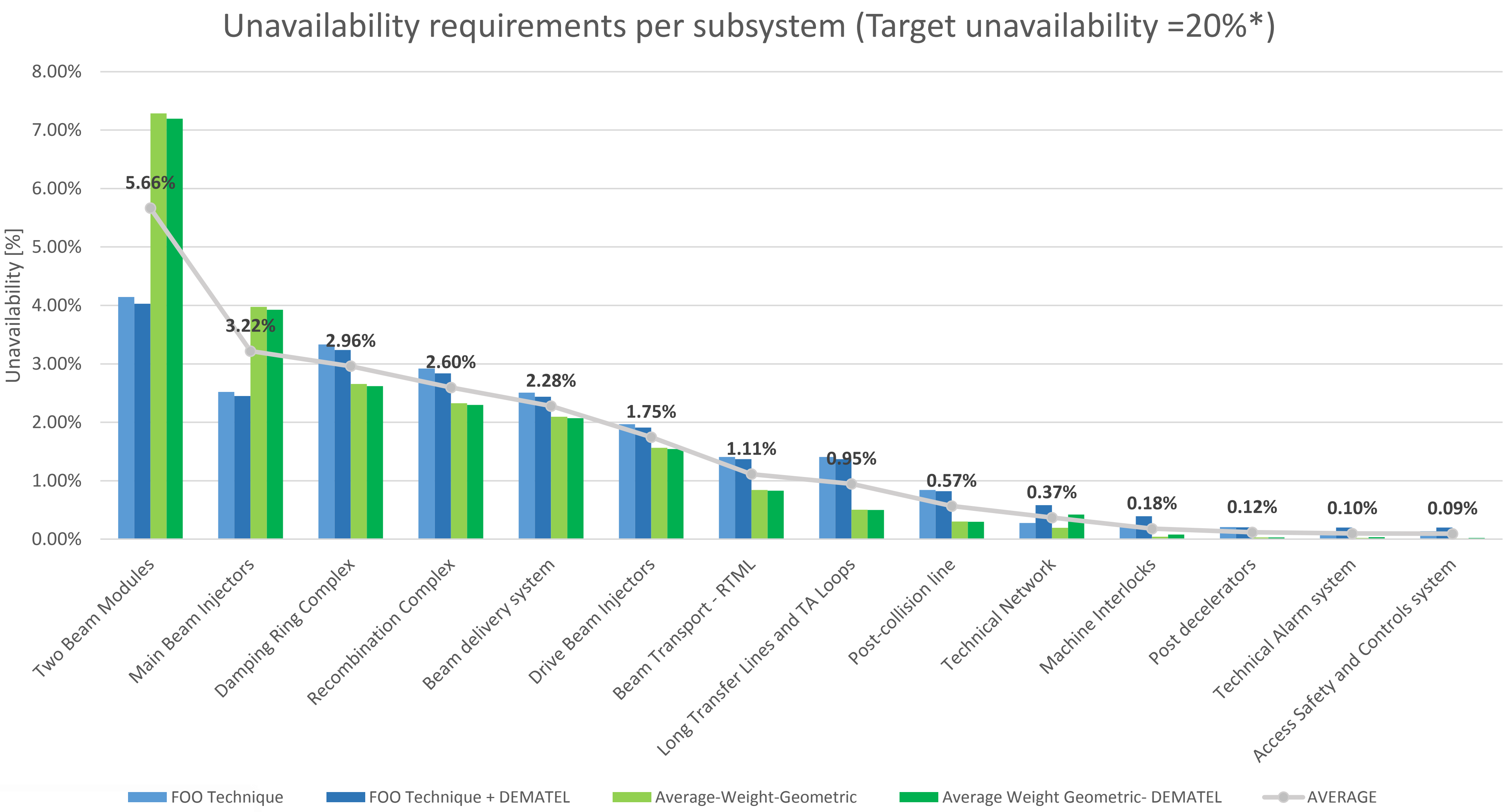
Availability allocation methods

Availability target

Availability requirements

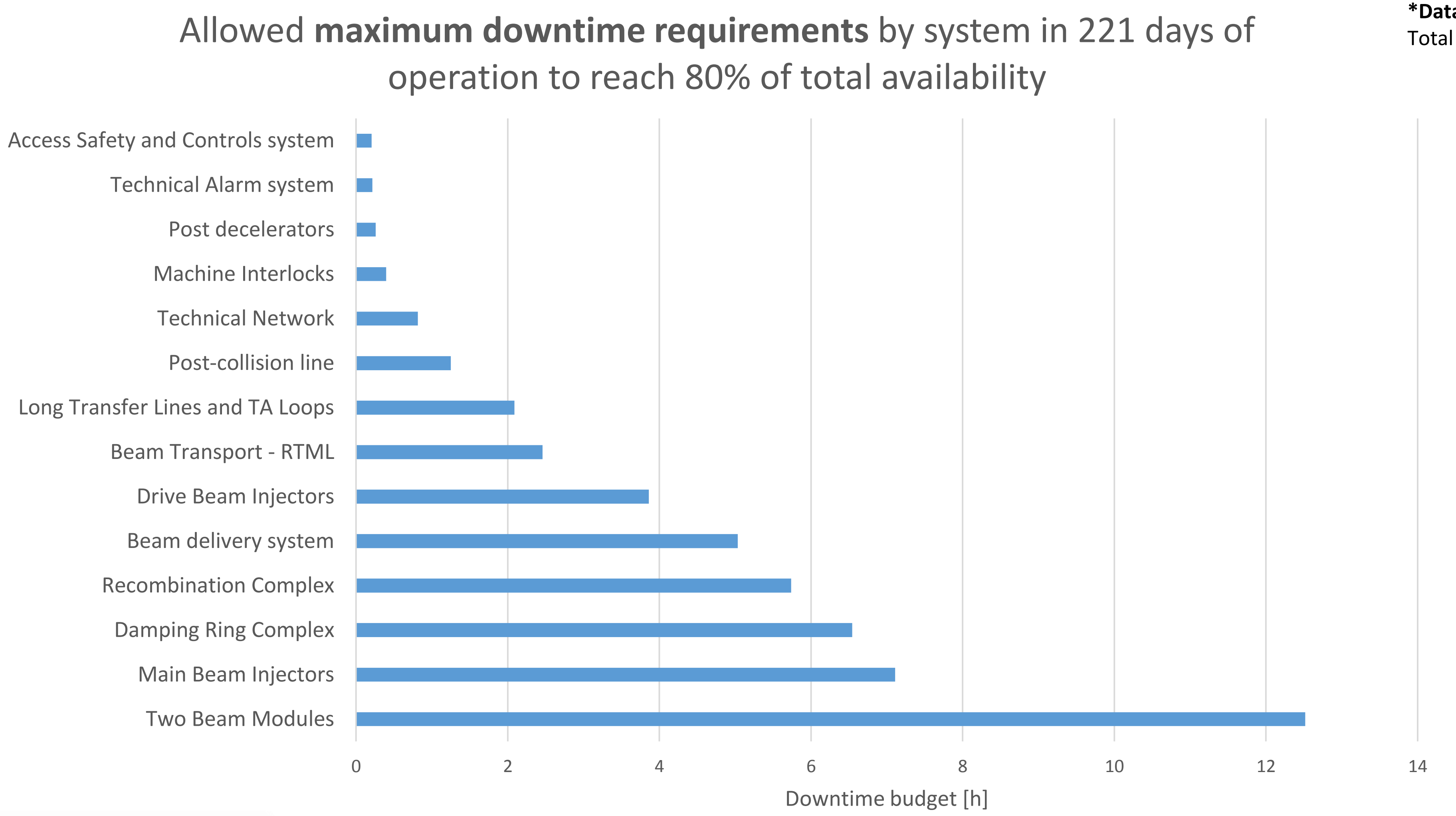
In line with the estimations from the Availability models?

Availability allocation by complexity criteria

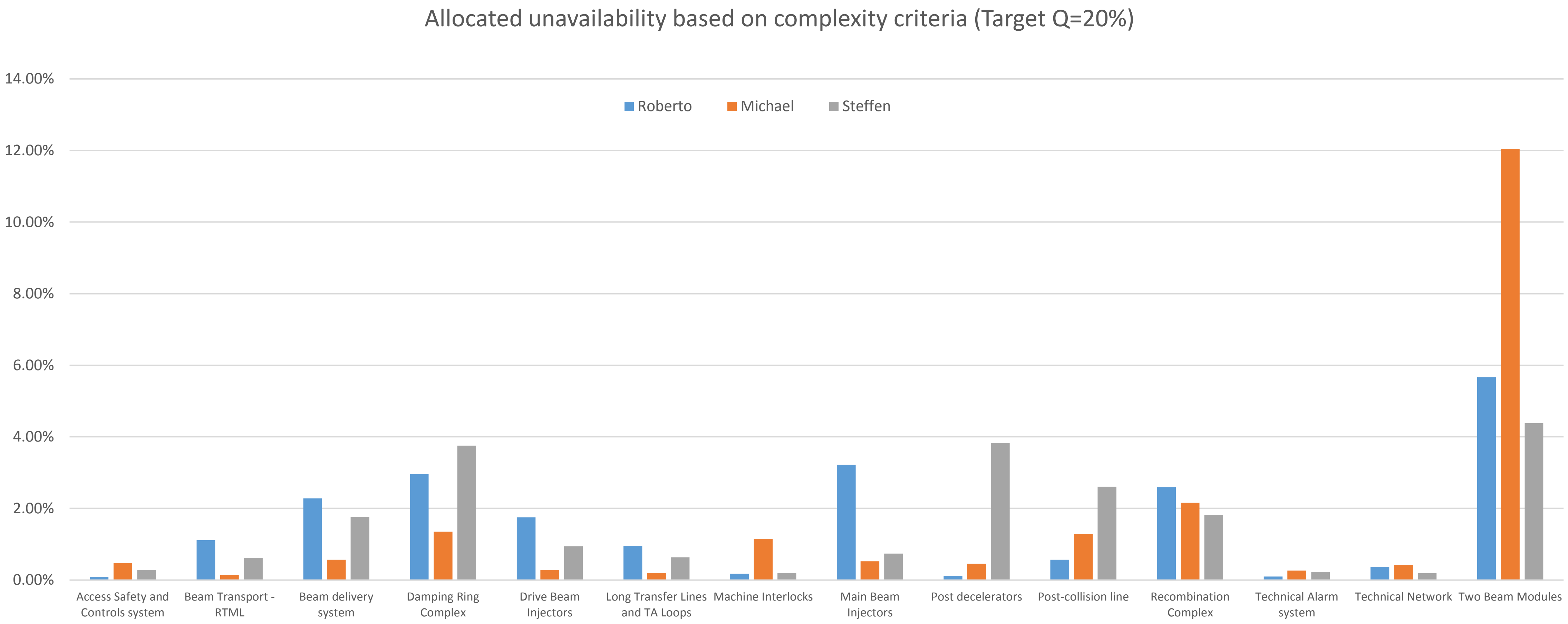


Availability allocation by complexity criteria

***Data from CLIC CDR vol. 3**
Total days in production=177
Production=221 days
Fault induced downtime=44 days



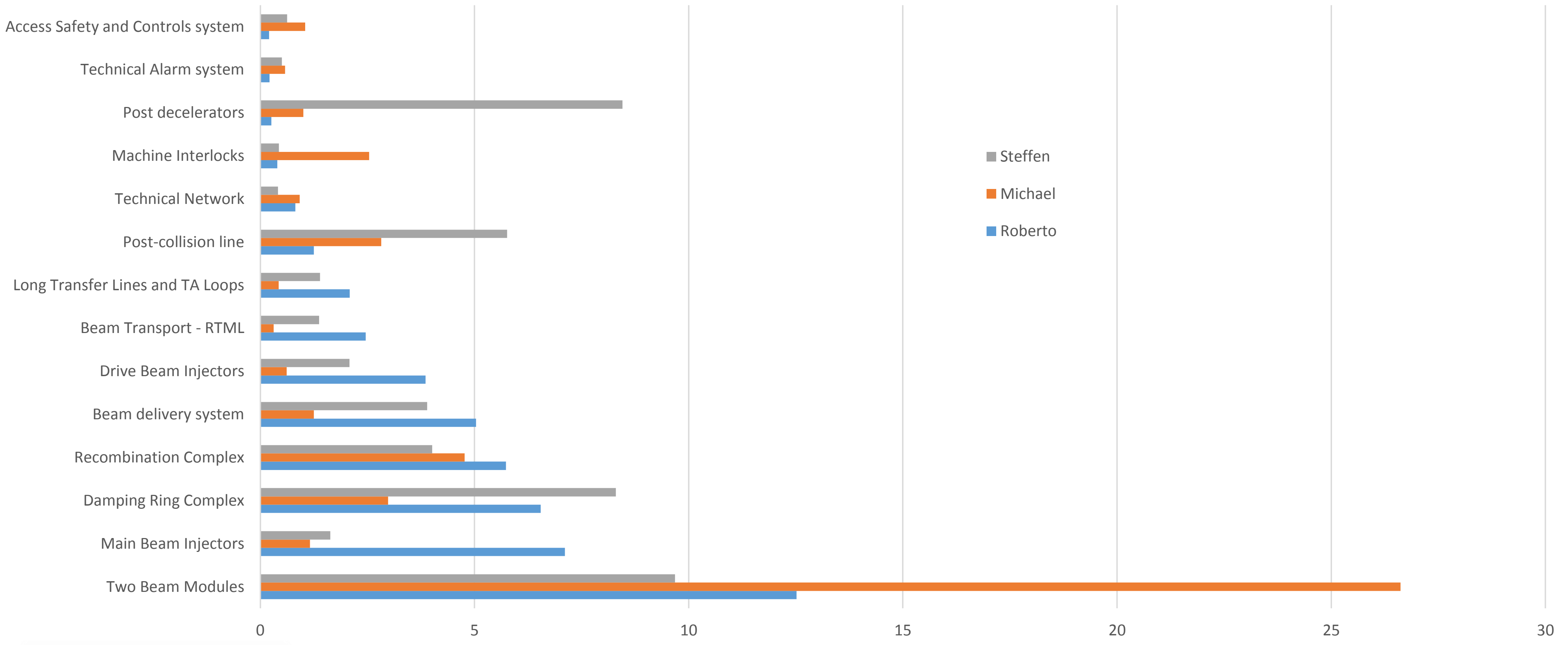
Availability allocation by complexity criteria



Availability allocation by complexity criteria

***Data from CLIC CDR vol. 3**
Total days in production=177
Production=221 days
Fault induced downtime=44 days

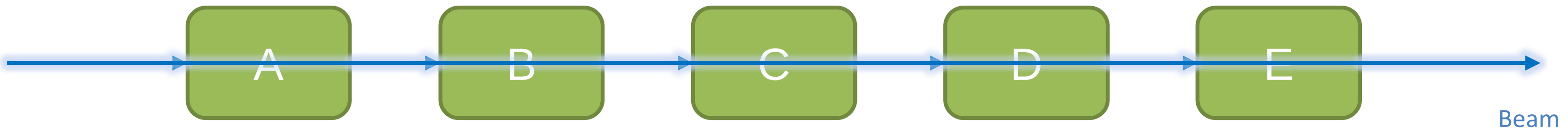
Allowed maximun downtime requirements by system in 221 days of operation to reach 80% of total availability



Integrated luminosity as a function of availability

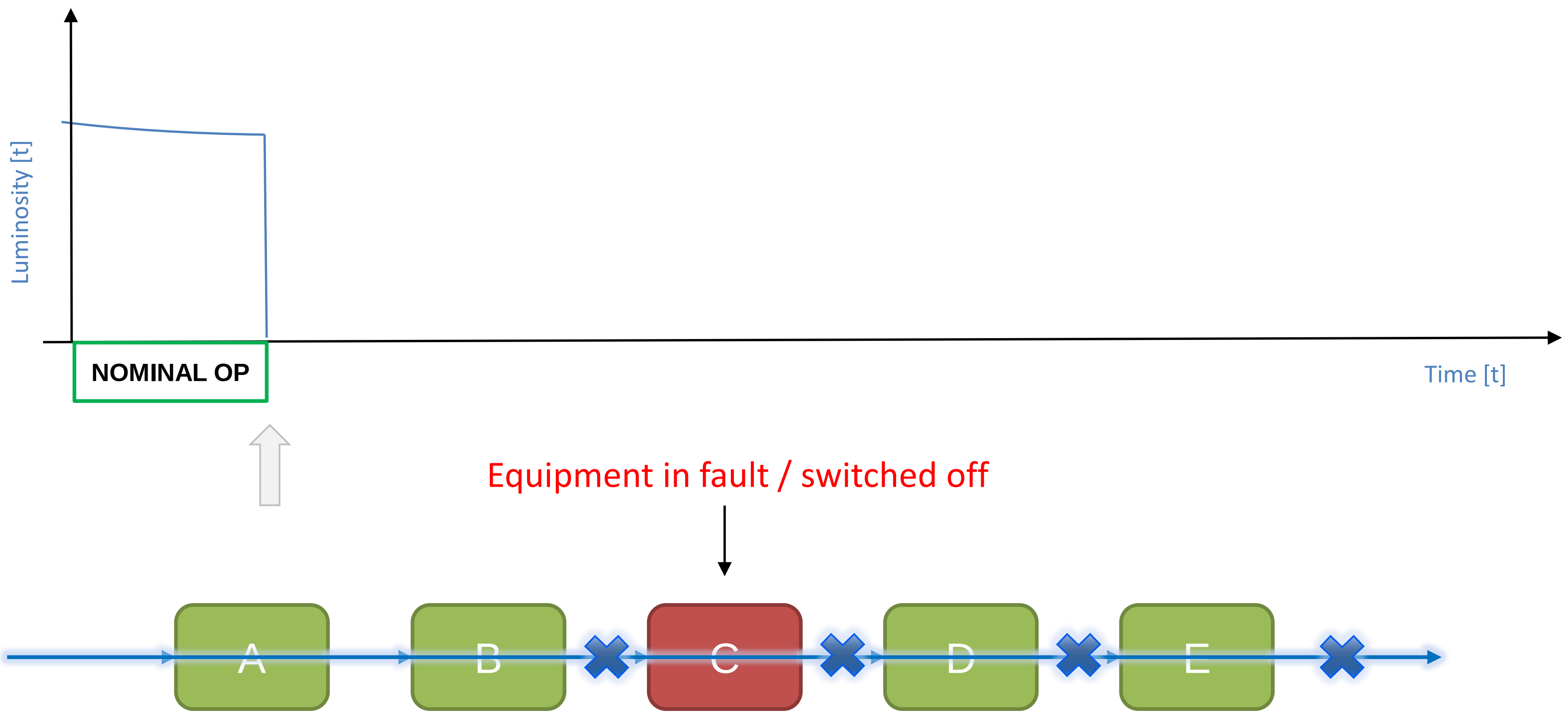
Understanding CLIC operating cycle

Successive subsystems in CLIC complex



Integrated luminosity as a function of availability

Understanding CLIC operating cycle



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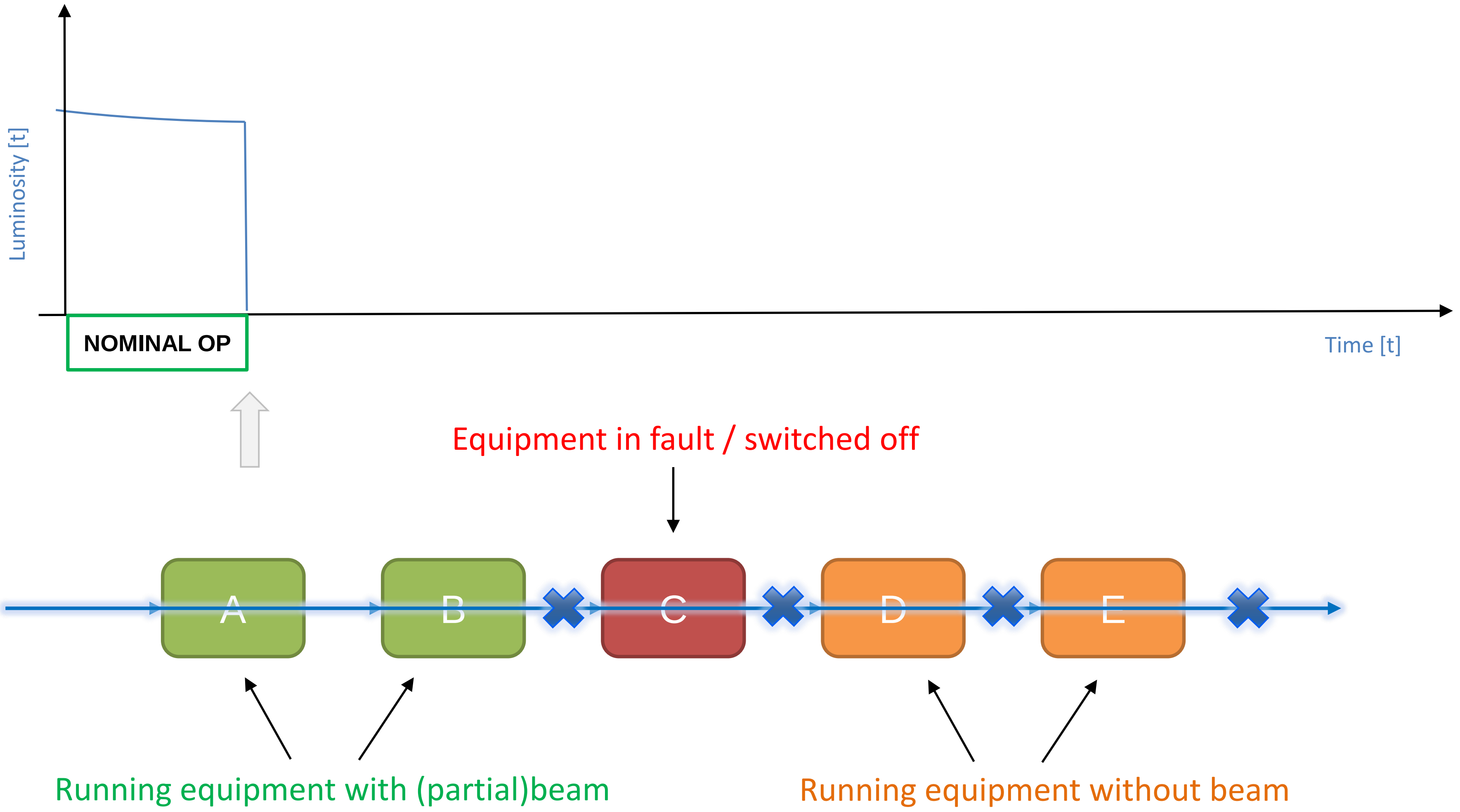

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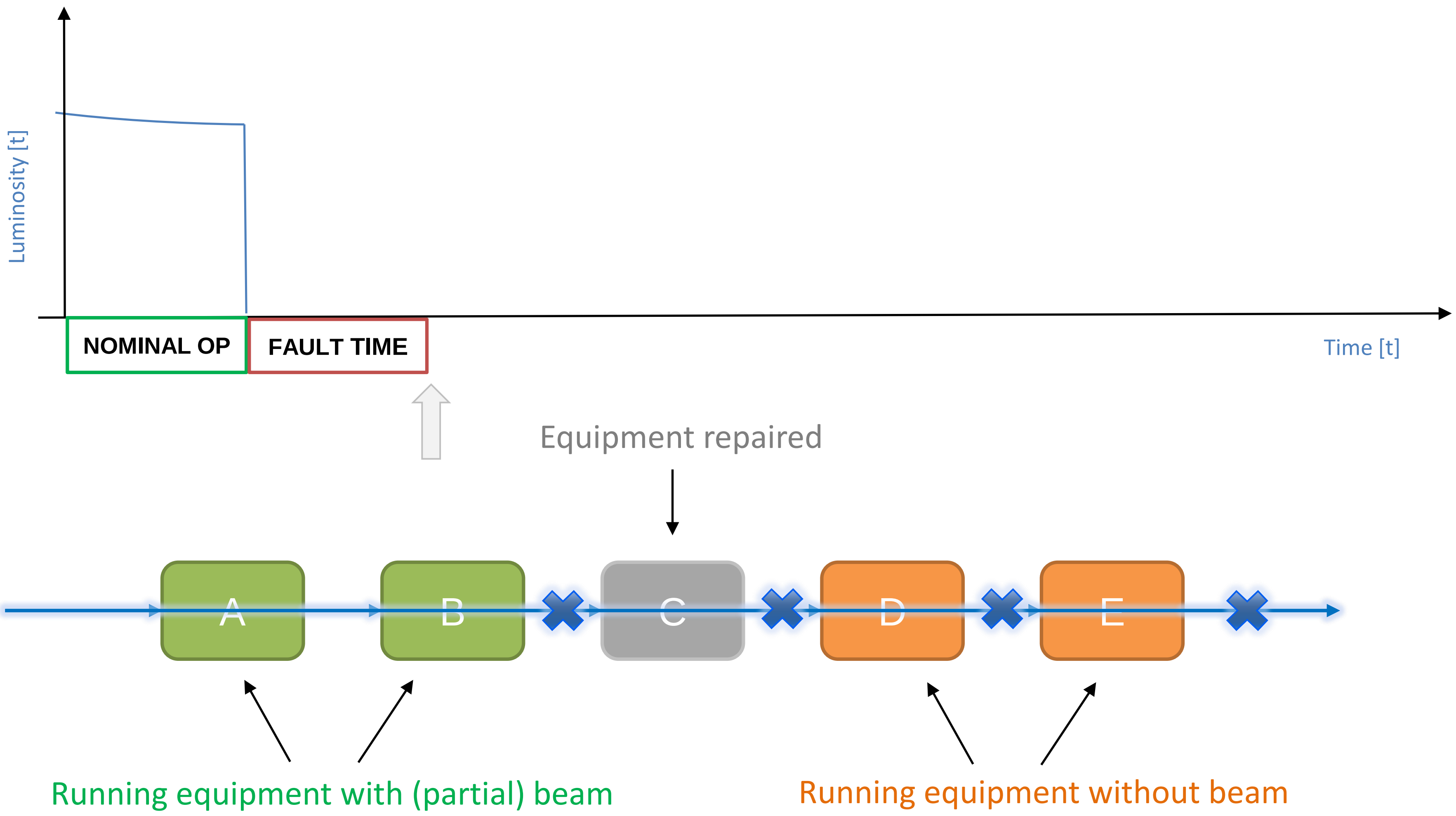

Integrated luminosity as a function of availability

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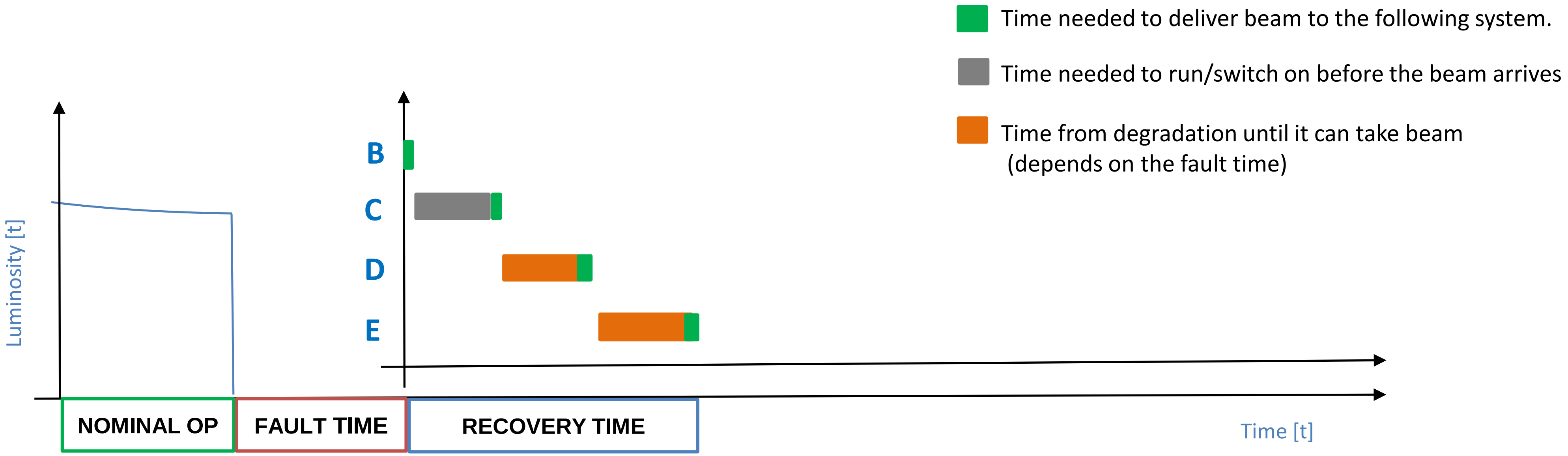
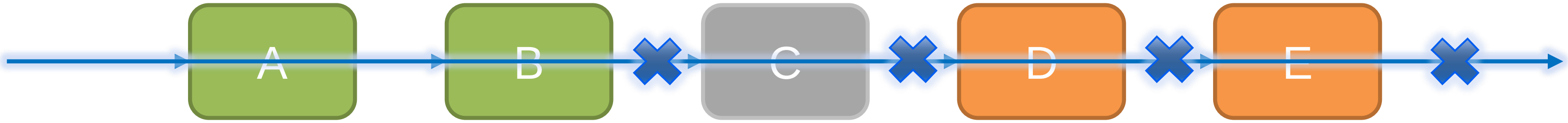
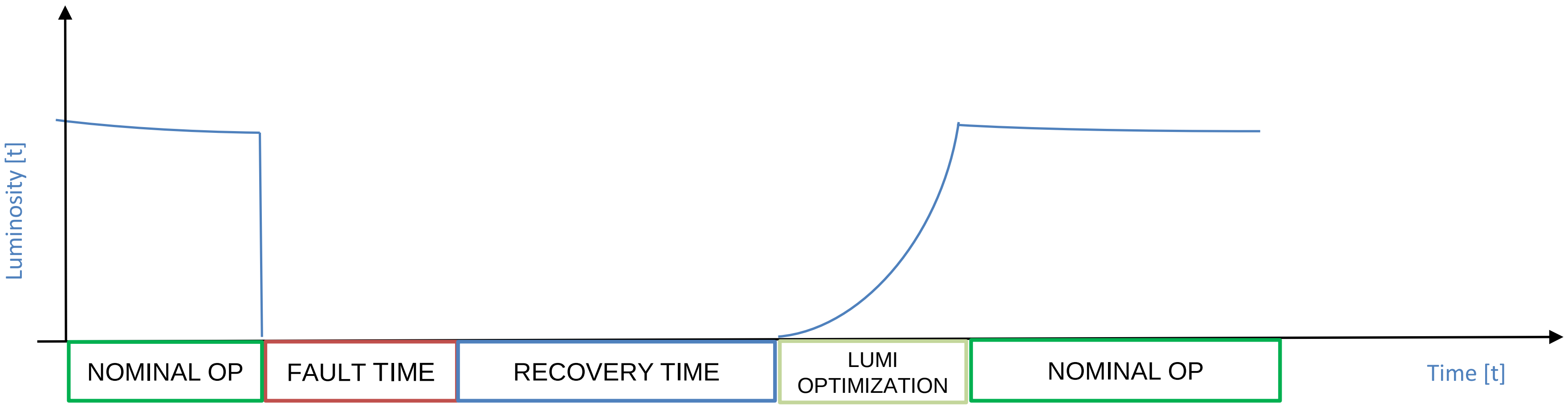
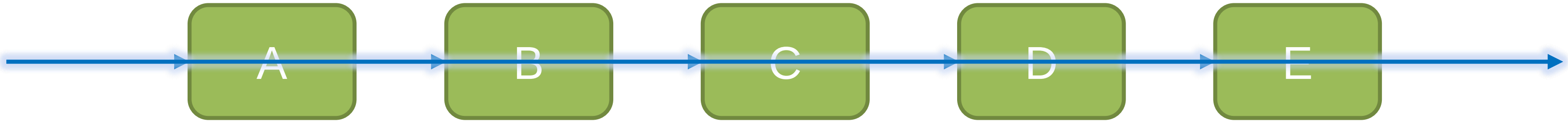




Integrated luminosity as a function of availability

Understanding CLIC operating cycle





- **Luminosity optimization:** Time to reach nominal operating conditions/ luminosity after the first collisions.
- **Nominal operation / Luminosity production**

CLIC failure scenarios

Failure effects

Failure \ Effect	MB source	MB injector	MB PDR	MB DR	MD Booster Linac	MB RTML	Main Linac	BDS	Collision/Inter action Point	Dump
MB source	out	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
MB injector	Standby with beam	Out	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
MB PDR	Standby with beam	Standby with beam	out	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
MB DR	Standby with beam	Standby with beam	Standby with beam	out	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
MD Booster Linac	Standby with beam	Standby with beam	Standby with beam	Standby with beam	out	Standby no beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
MB RTML	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	out	Standby no beam	Standby no beam	Standby no beam	Standby no beam
Linac	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	out	Standby no beam	Standby no beam	Standby no beam
BDS	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	out	Standby no beam	Standby no beam
Collision	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	out	Standby no beam
Dump	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Out
DB source	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
DB linac	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
DB CBR	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
DB transport	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby no beam	Standby no beam	Standby no beam	Standby no beam
DB decelerators	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby partial with beam	Standby no beam	Standby no beam	Standby no beam

Failure \ Effect	DB source	DB linac	DB CBR	DB transport	DB Post decelerators
MB source	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with reduced beam
MB injector	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with reduced beam
MB PDR	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with reduced beam
MB DR	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with reduced beam
MD Booster Linac	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with reduced beam
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Linac	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with reduced beam
BDS	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam
Collision	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam
Dump	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Standby with beam
DB source	out	Standby no beam	Standby no beam	Standby no beam	Standby no beam
DB linac	Standby with beam	out	Standby no beam	Standby no beam	Standby no beam
DB CBR	Standby with beam	Standby with beam	out	Standby no beam	Standby no beam
DB transport	Standby with beam	Standby with beam	Standby with beam	out	Standby no beam
DB decelerators	Standby with beam	Standby with beam	Standby with beam	Standby with beam	Partial Out

Summary & Outlook

Summary and Outlook

Availability models: Main Beam Linac RF Powering System

- Review failure data
- Estimate the number of spares needed to survive until certain point in time
- Sensitivity analysis of failure rates (DIMS)
- Further extension of models

Luminosity production model

- Agreement on the phases definition and failure scenarios
- Estimate recovery and tuning times
- Monte-Carlo Model implementation

Availability allocation by complexity criteria

- Exercise done at high level, intuitive results
- Next step: Allocation at lower level
- Complexity assessment by more than one expert

Thank you!

Special thanks to:

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CLIC failure scenarios

Operational Impact of faults, tuning and recover

Failure scenario	Beam kept?	Beam off time / Repair time	Consequence in Luminosity	Example	Recovery times by equipment state					
					Not affected	Standby with beam	Standby with reduced beam	Standby partial with beam	Standby no beam	Out
Short trips	yes	no	Minimal loss	RF Breakdown	x					
	yes	short	Short loss	Spurious machine protection interlocks	x					
Repair without access to the accelerator housing	Partial beam	short (~ 30 min)	No production	Equipment breakdown and swap with hot spare		x	x			
	Partial beam	long (< 4 h)	No production	Equipment breakdown requiring expert to come to change hardware (outside the accelerator housing)		x	x	x	x	
Repair with access to the accelerator housing	Partial beam	short (< ??)	No production			x	x	x	x	x
	No beam	long (>> ??)	No production							x

	Not affected	Standby with beam	Standby with reduced beam	Standby partial with beam	Standby no beam	Out
Description	Machine performance not affected	Running equipment with beam	Running equipment with partial beam	Running equipment with/ and without beam	Running equipment without beam	Faulty / Off equipment
Recovery = Time needed to…	None or Minor. Luminosity Optimization or Machine Validation	send beam to the following sytem	send beam to the following sytem		recover from degradation + send beam to following system	run before beam arrives + send beam to the following system

CLIC failure scenarios I

Operational Impact of faults, tuning and recover

- **Short trips without beam interruption** -> Minimal Luminosity loss

  Example: RF Breakdown

  Expected rate: every 100 pulses, i.e 100x20ms = 2 seconds.

  Recovery: None, occasionally a minor Luminosity Optimization could be needed.

- **Short trips with short beam interruption** -> Short Luminosity loss

  Example: Spurious machine protection interlocks, possibly due to glitches in the BLM, possibly caused by some of the RF breakdown

  Expected rate: every ~ 100^2 pulses, 5 minutes.

  Recovery: Short (2 second?) Machine Validation with luminosity interruption, but not affecting machine performance.

CLIC failure scenarios II

Operational Impact of faults, tuning and recover

➢ **Beam-off for repair without access to the accelerator housing**

- If the beam off time is short (**Fault time ~30 min**) -> **equipment running with (partial) beam** -> recovery will only require short tuning -> Recovery ≈ 0.5h (re-steering the golden orbits with some final IP tuning, machine validation)

  Example: Equipment breakdown and swap with hot spare (either remote controlled in the accelerator housing or on the surface by operator on duty.)

- If the beam off time is long enough (**30 min < Fault time < 4 h**)

  - **Running equipment with (partial) beam:** Unaffected systems -> recovery will only require short tuning -> Recovery = Time needed to deliver beam to the following system
  - **Running equipment without beam:** Affected systems -> equipment performance will be degraded-> Recovery = time from degradation until it can take beam (depends on the fault time) + time needed to deliver beam to the following system

  Example: Equipment breakdown requiring expert to come to change hardware (outside the accelerator housing).

CLIC failure scenarios III

Operational Impact of faults, tuning and recover

- **Beam-off for a repair with access to the accelerator housing (Fault time >4h)**

  - If **Fault time short < ?? h** -> Partial beam kept

    - **Running equipment with (partial) beam:** Unaffected systems -> recovery will only require short tuning -> Recovery = Time needed to deliver beam to the following system

    - **Running equipment without beam (**Affected systems) -> equipment performance will be degraded-> Recovery = time to recover from degradation until it can take beam (depends on the fault time) + time needed to deliver beam to the following system

    - **Faulty or off systems**: Equipment switched off without beam -> will be switched on when fault cleared-> Recovery= Time needed to run/switch on before the beam arrives + time needed to deliver beam to the following system

  - If **Fault time long>> ?? h** -> Beam is switched of to safe power comsumption

    - **Faulty or off systems**: Equipment switched off without beam -> will be switched on when fault cleared-> Recovery= Time needed to run/switch on before the beam arrives + time needed to deliver beam to the following system