CERN

Availability Studies for CLIC

Odei Rey Orozco

Availability studies for CLIC

- Key performance indicator ->> Integrated luminosity ->> Availability
- Availability target for CLIC -> 75% in 185 days of scheduled operation

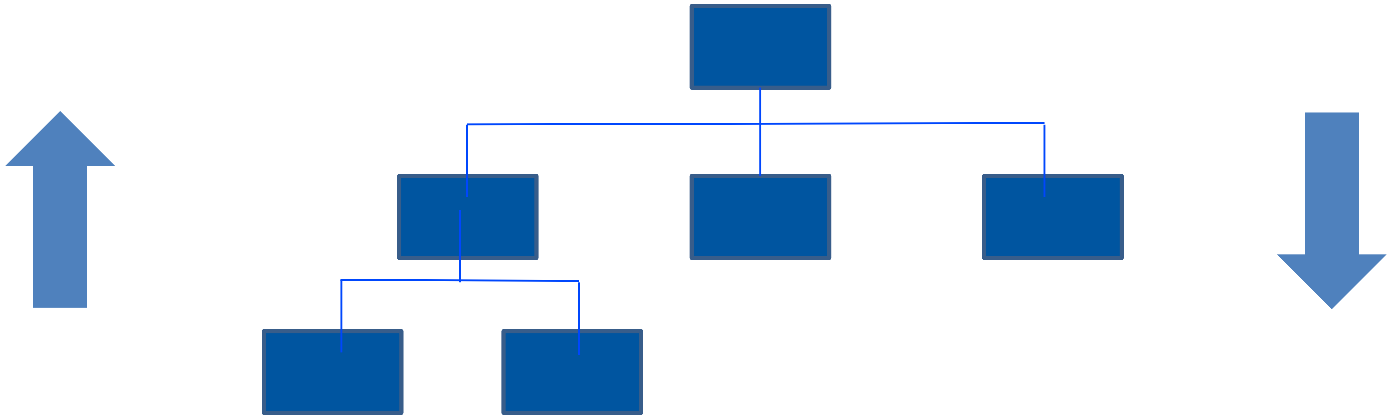
Goals:

- ➢ Demonstrate that CLIC availability requirement of 75 % can be reached.
- ➢ Identify the key accelerator systems and components that drive availability.
- ➢ Investigate the impact of failures on machine operation and recovery.
- ➢ Optimise the design with the best balance between availability and cost.
- ➢ Find the optimal technical stops and operational schedule that maximizes availability.
- ➢ Provide guidelines for availability-driven improvements of system and component designs.

Availability studies for CLIC

Bottom-up approach:
Availability models

Top-down approach:
Availability requirements



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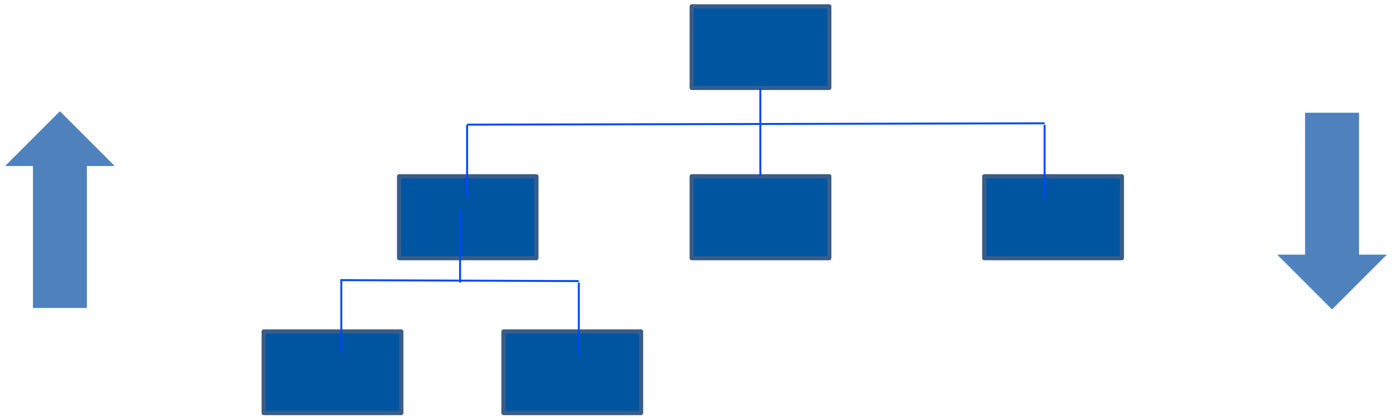

CLIC Failure scenarios and Operational impact

Failure scenario	Beam kept?	Beam off time / Repair time	Consequence in Luminosity	Example	Recovery times of faulty system
Hardware failures that do not require an interlock	yes	**no**	Minimal loss / Negligible	RF Breakdown	**No recovery**
Short beam interruptions due to spurious interlocks.	yes	**Short (~400s)**	Short loss / Small	Simultaneous RF breakdowns	**Short recovery Ramp-up**
Short hardware failure	Partial beam	**Short**	No production	Simultaneous breakdowns, requiring minor changes of the machine configuration Equipment breakdown and swap with hot spare	**Short recovery Ramp-up**
Failure requiring a hardware intervention	Partial beam	**long (< 4 h)**	No production	Equipment breakdown requiring expert to come to change hardware (outside the accelerator housing)	**Long recovery**
Repair with access to the accelerator housing	Partial beam / No beam	**short (< 4h)**	No production	Failure requiring a hardware intervention under controlled access in some areas of the machine	**Long recovery**
	No beam	**long (>> ??)**	No production		**Very long recovery / Restart**

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CLIC Availability models

- Use of component reliability data to estimate overall machine availability
- Focus on most critical systems of CLIC
  - Main LINAC and Drive Beam LINAC RF powering systems (@380 TeV and 3TeV)
  - Main Linac Magnets powering
  - RTML and transfer lines (on-going)
  - Technical Infrastructures, cooling and ventilation (on-going)

Assumptions

- The simulation period corresponds to the CLIC scheduled operation time: 175 days.
- Components failure behaviour follow an exponential distribution.
- Failed components are repaired only when the system is down due to components failures, unless otherwise defined.
- All repairs must be finished before restarting operation, including spare part repairs.

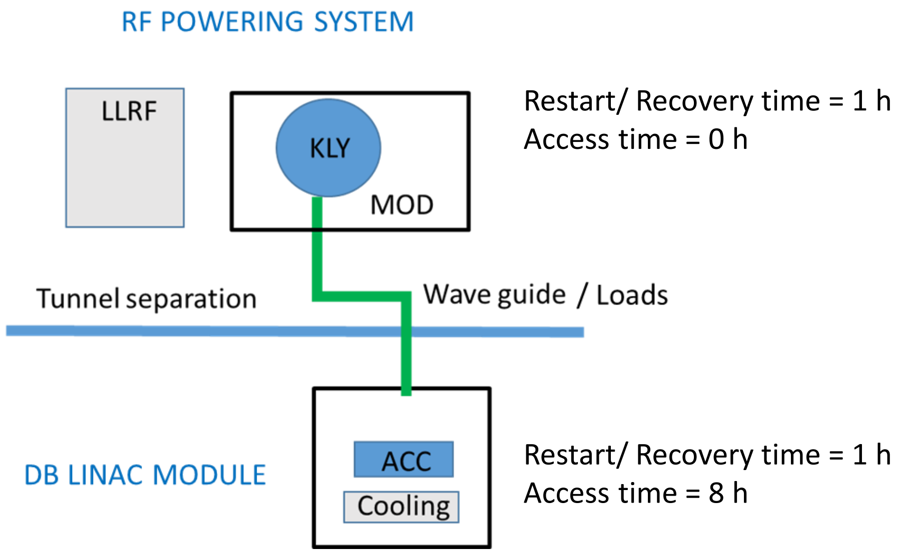
Simulation tool

- AvailSim Availability simulation software (Monte Carlo simulations)

Main Linac Drive Beam based RF Powering System @380TeV

CLIC Availability models

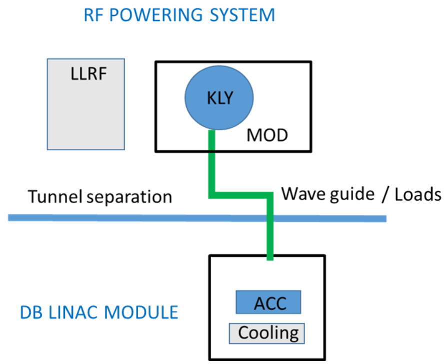
@380TeV	Availability	Times Down	Downtime (h)	MTTR (h)	MTTF (h)
472 modules + 12 standby spares	**98.2%**	**5**	75	**15**	**822**



Major contributors to	
# Failures	**Downtime**
Cavity breakdown (41%)	Cooling system (64%)
LLRF (20%)	Wave guides (17%)
Cooling system (15%)	Klystrons (8%)
Klystrons (9%)	LLRF(6%)

Main Linac Drive Beam based RF Powering System @380TeV

CLIC Availability models

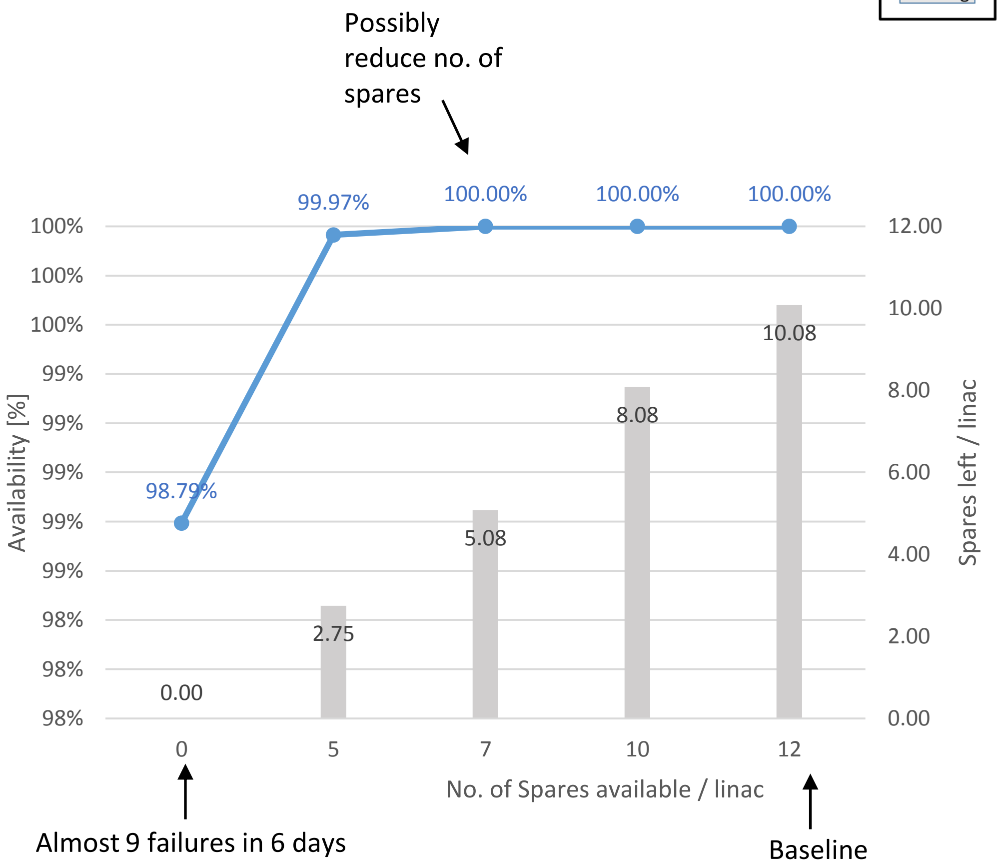


If planned Maintenance each 6 days of operation…

- Continuous machine operation for 6 days (Availability = 100%)
- Maximum 2 standby spares in use before PM
- Component failures:

	Failures / system	Time Spent Repairing [h] (during Operation)
RF Structure	4.7	0.16
Klystrons	1.3	16.3
LLRF	2.6	10.2
Modulators	0.61	7.7
Cooling System	1.05	0
Wave guides	0.7	0

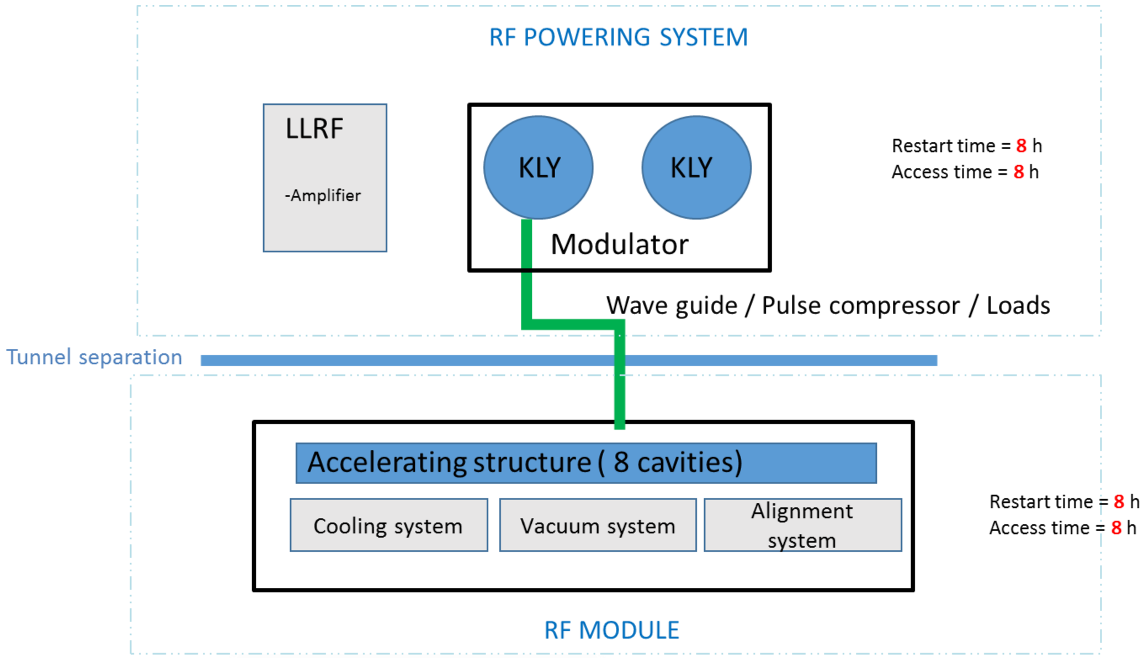
Components to be repaired during PM ~ 15h



Main Linac Klystron based RF Powering System @380TeV

CLIC Availability models

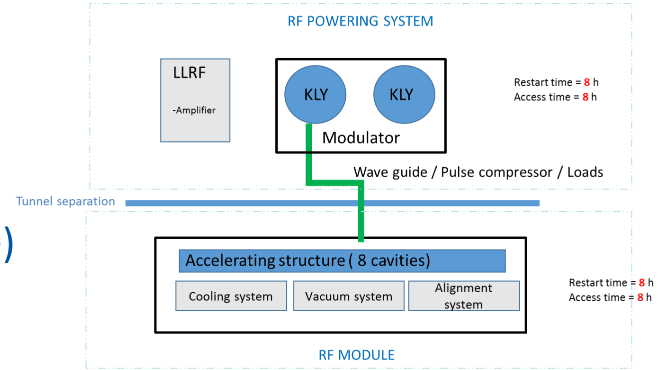
@380TeV	Availability	Times Down	Downtime (h)	MTTR (h)	MTTF (h)
1500 units / linac + 150 standby spares	**93.5 %**	**6.8**	272	**40**	**577.7**



Major contributors to	
# Failures	**Downtime**
Vacuum system (62%)	Vacuum system (62%)
Accelerating structure (15%)	Klystrons (24%)
Modulators (12%)	Modulators (5%)
Klystrons (4.4%)	Cooling system (5%)

Main Linac klystron based RF Powering System @380TeV

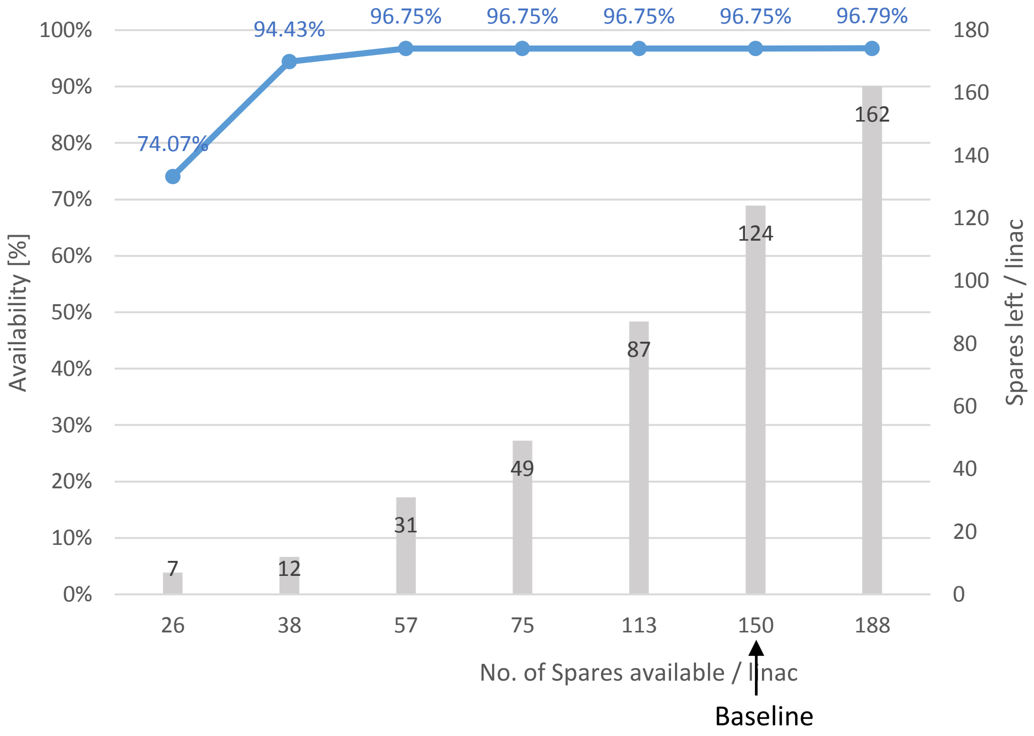
CLIC Availability models



If planned Maintenance each 6 days of operation…

- Availability = 96.75% (12% of prob. of a vacuum failure to interrupt operation of the machine)
- Maximum 26 standby spares in use / linac before PM
- Component failures:

	Failures / system	Caused downtime
Alignment system	3.82	0
Accelerating structures	47.61	0
Cooling system	9.77	0
Vacuum	0.12	0.12
Klsytrons	13.45	0
LLRF	15.85	0
Modulators	45.37	0
Wave guides	4.54	0



Main Linac Drive Beam Magnets powering @3TeV

CLIC Availability models

48 sector (24 sector / linac)

860 QD magnets / Sector = 41280 QD

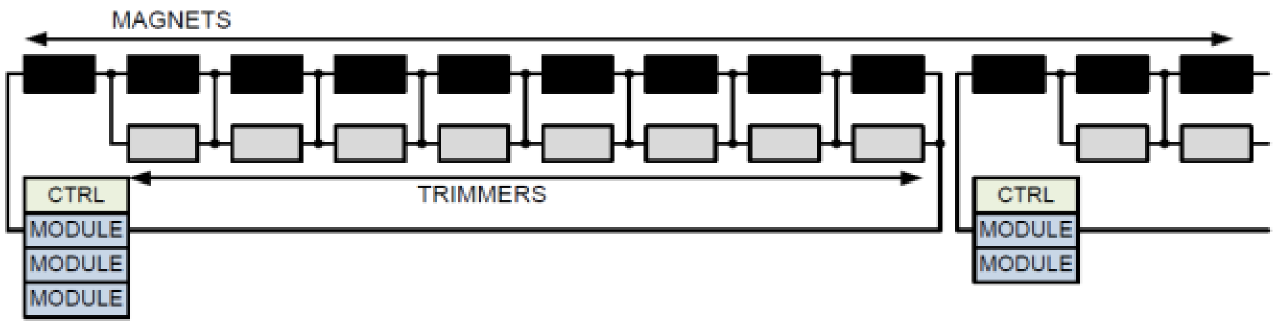
Magnet strings powered in series using trimmers to decrease current

830 trimmers / Sector – 20 failure tolerance

100 power converter modules / sector
- 12 PC of 4 modules
- 16 PC of 3 modules
- 2 PC of 2 modules

N+1 redundancy in Power converters modules

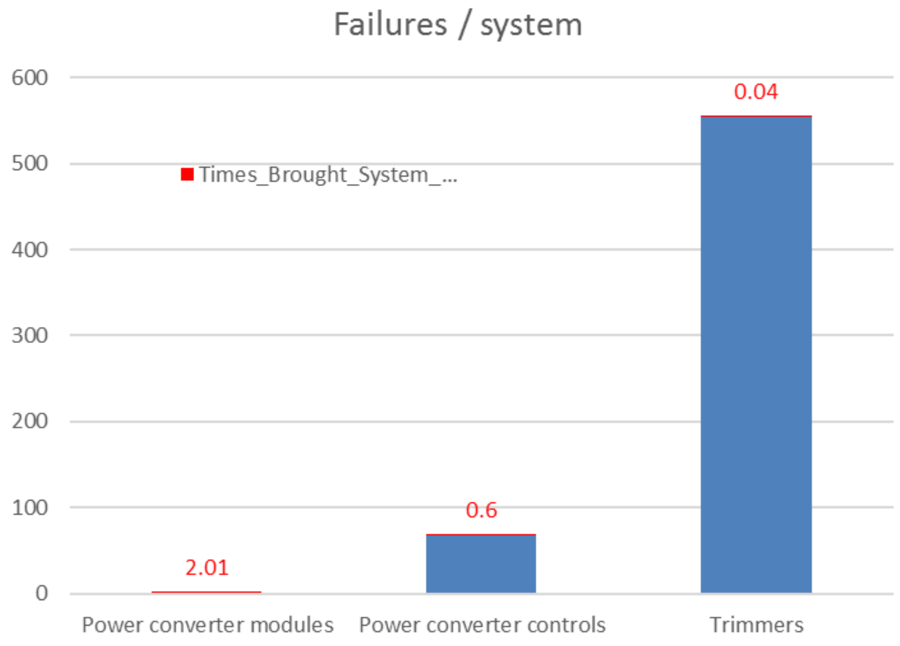
1 controller per PC (30 /sector)



Main Linac Drive Beam Magnets powering @3TeV

CLIC Availability models

Availability	Times Down	Downtime (h)	MTTR (h)	MTTF (h)
99.7	**2.7**	10.6	**3.99**	**1575**



- Failure of magnets powering caused by PC **Modules**
- **If no redundancy in PC, availability = 93.9%**
- Trimmers failures do not cause system failure due to implemented redundancy.
- **If Planned Maintenance each 6 days of operation**, minimum failure tolerance not to suffer from trimmers failure -> 2/830

Main Linac Main Beam Magnets powering @3TeV

CLIC Availability models

Dipoles

- Powered individually
- Failure tolerance: 1%

Quadrupoles

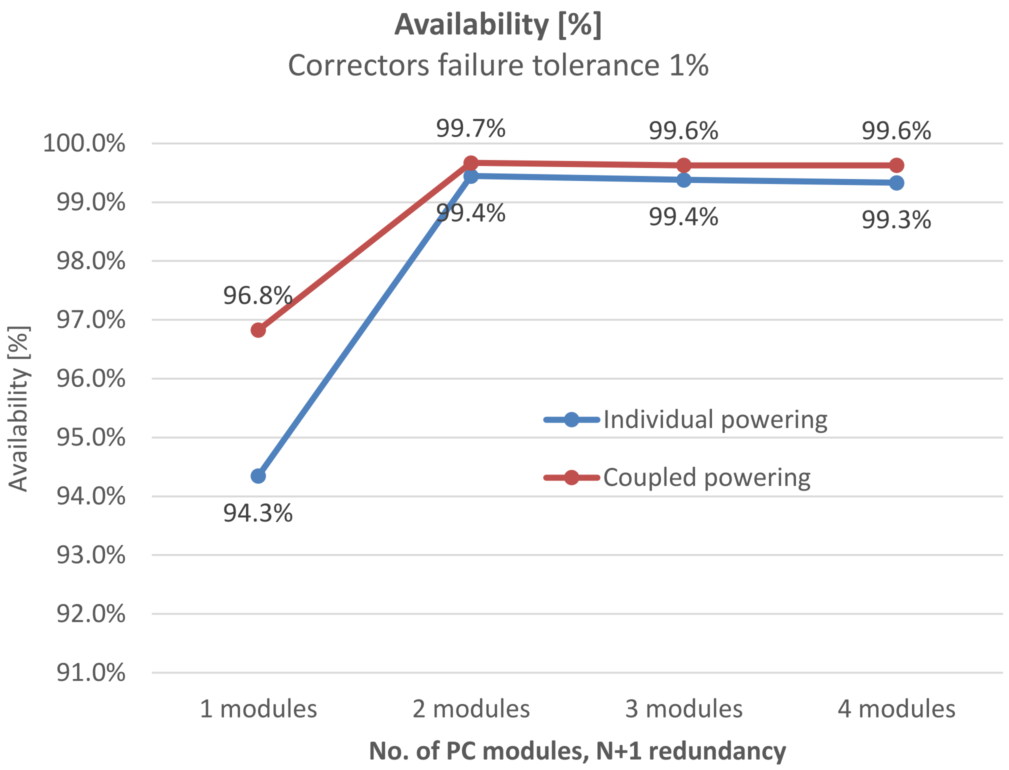
- Powering strategy: individually OR in couples but 7 / sector individually
- N+1 redundancy in Power converters modules (N=1, 2 OR 3)

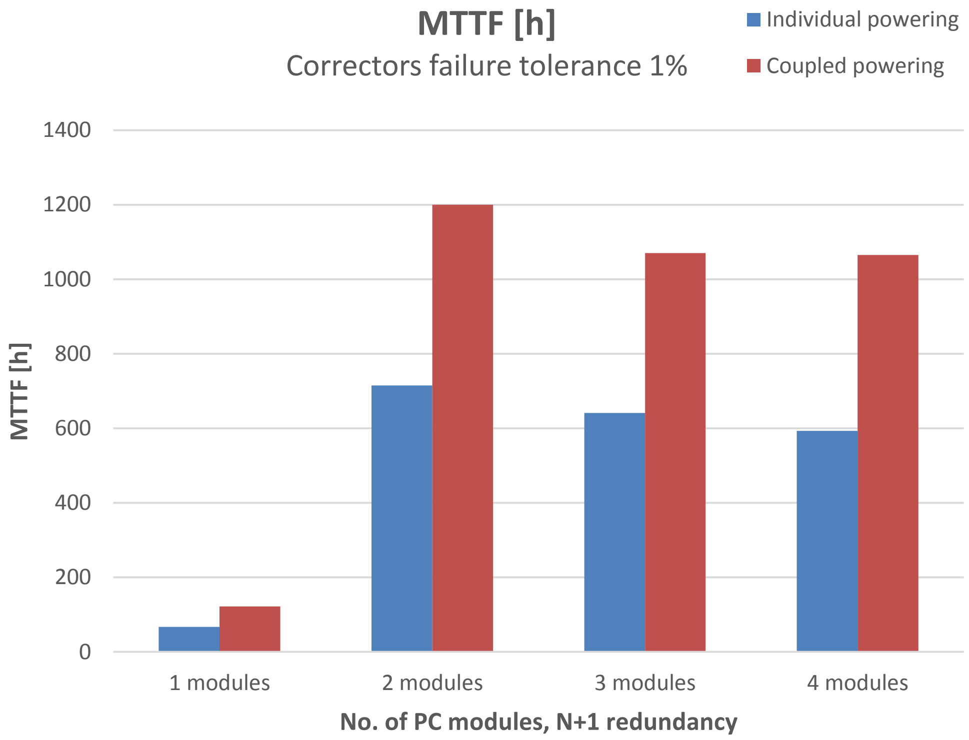
	Magnets	Magnets /linac	7 QD/ sector Powered individually	Powered in couples	PC for individual powering	PC for QD in couples + individual
Quadrupoles	4142	2071	168	952	2071	1120
Dipoles	3996	1998	-	-	1998	1998

Main Linac Main Beam Magnets powering @3TeV

CLIC Availability models

- Coupled powering higher lifetime
- Best option (in terms of availability): Coupled powering + PC of 2 modules -> **99.7%** (match with powering requirements)





Main Linac Main Beam Magnets powering @3TeV

CLIC Availability models

AVAILABILITY [%]		PC modules , N+1 redundancy			
Failure tolerance in correctors	**Powering strategy**	**1 modules**	**2 modules**	**3 modules**	**4 modules**
0%	Individual powering	89.48%	93.84%	94.06%	94.10%
	Coupled powering	91.53%	94.18%	94.23%	94.21%
1%	Individual powering	94.34%	99.45%	99.38%	99.33%
	Coupled powering	96.83%	**99.67%**	99.63%	99.63%
2%	Individual powering	94.3%	99.45%	99.39%	99.33%
	Coupled powering	96.66%	**99.68%**	99.64%	99.62%

Main Linac Main Beam Magnets powering @3TeV

CLIC Availability models

MTTF [h]		**PC modules , N+1 redundancy**			
Failure tolerance in correctors	**Powering strategy**	**1 modules**	**2 modules**	**3 modules**	**4 modules**
0%	Individual powering	33.97	60.89	63.33	63.81
	Coupled powering	43.19	64.69	65.26	65.01
1%	Individual powering	66.63	715.18	641.17	592.59
	Coupled powering	121.87	**1199.44**	1070.17	1064.72
2%	Individual powering	66.63	720.14	648.18	595.14
	Coupled powering	115.80	**1227.67**	1104.19	1051.29

Planned maintenance each 6 days (MTTF >144 h)

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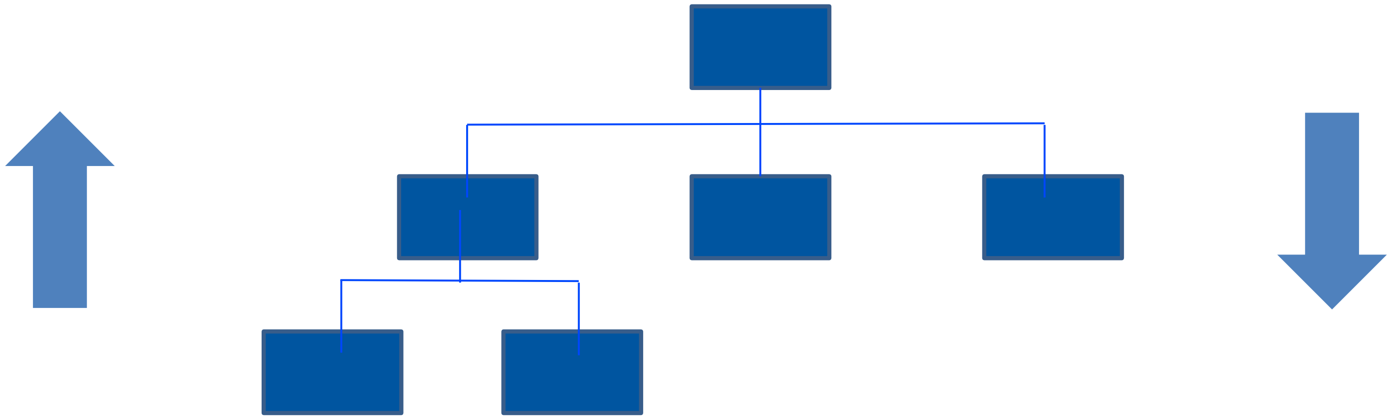


Availability allocation by complexity criteria

- An **availability requirement** based on the complexity is assigned to each subsystem **to meet the CLIC 75% requirement**
- Experts assess the **complexity** of each subsystem **based on influential factors**
- The **more complex** a subsystem is, the **less available** is required to be

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

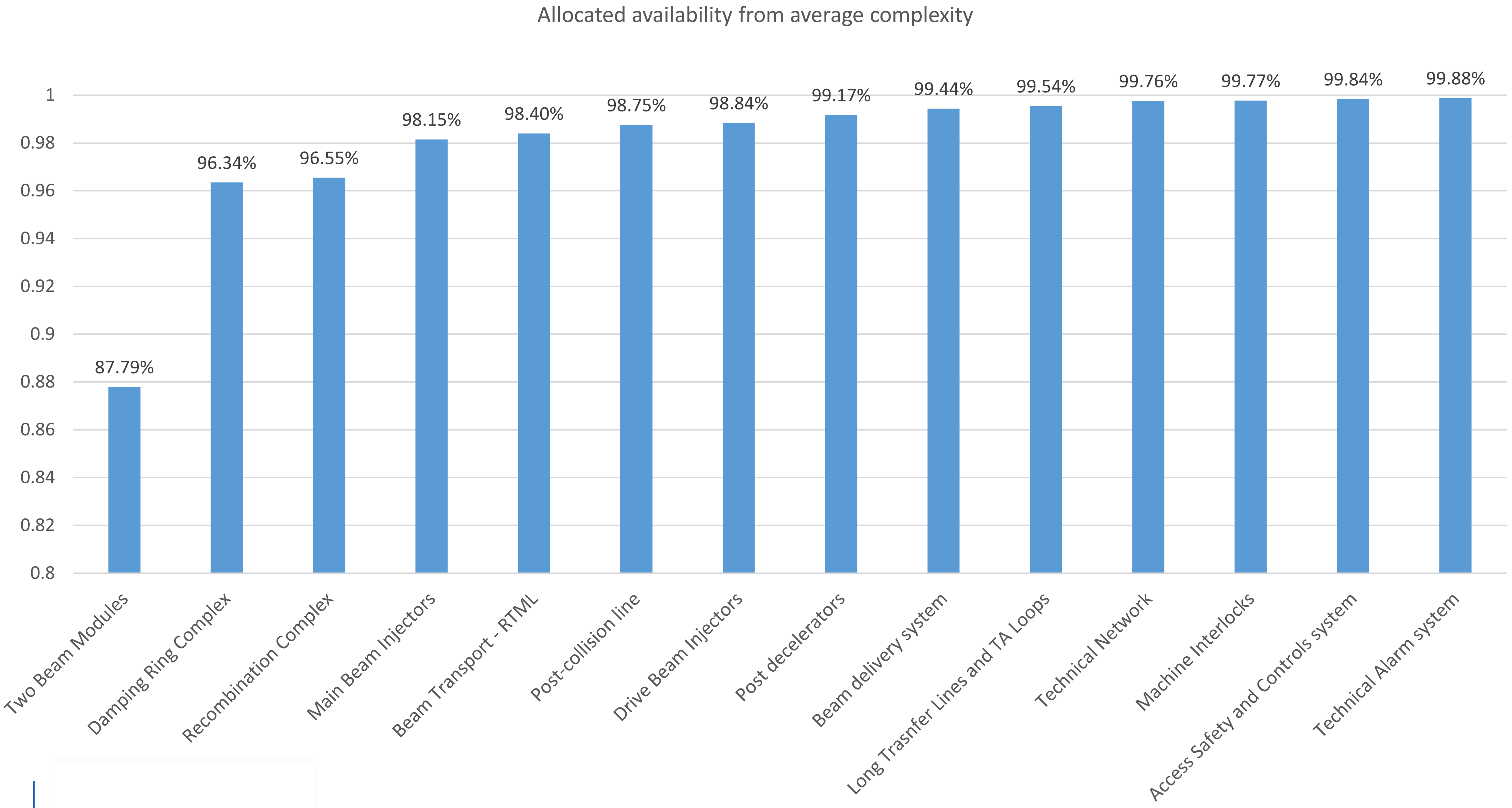
75%

Availability requirements

$$\prod A_i = 75\%$$

In line with the estimations from the Availability models?

Availability allocation by complexity criteria



Summary & Outlook

CLIC Availability studies

Summary & Outlook

- The investigated key failures do not compromise the operation of CLIC thanks to the implemented redundancy and hot-standby spares.
- Further studies are required to include a more complete list of failures and to optimise the design for robustness.
- Recovery times will be included as a function of downtime to understand the impact of failures on operation
- A maintenance schedule will be developed with optimised length and frequency of technical short stops.

- The availability allocation method shows intuitive results

- A luminosity production model could be developed taking as input the results from the availability models

Thank you!

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