FCC

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MAGNET POWERING CIRCUITS

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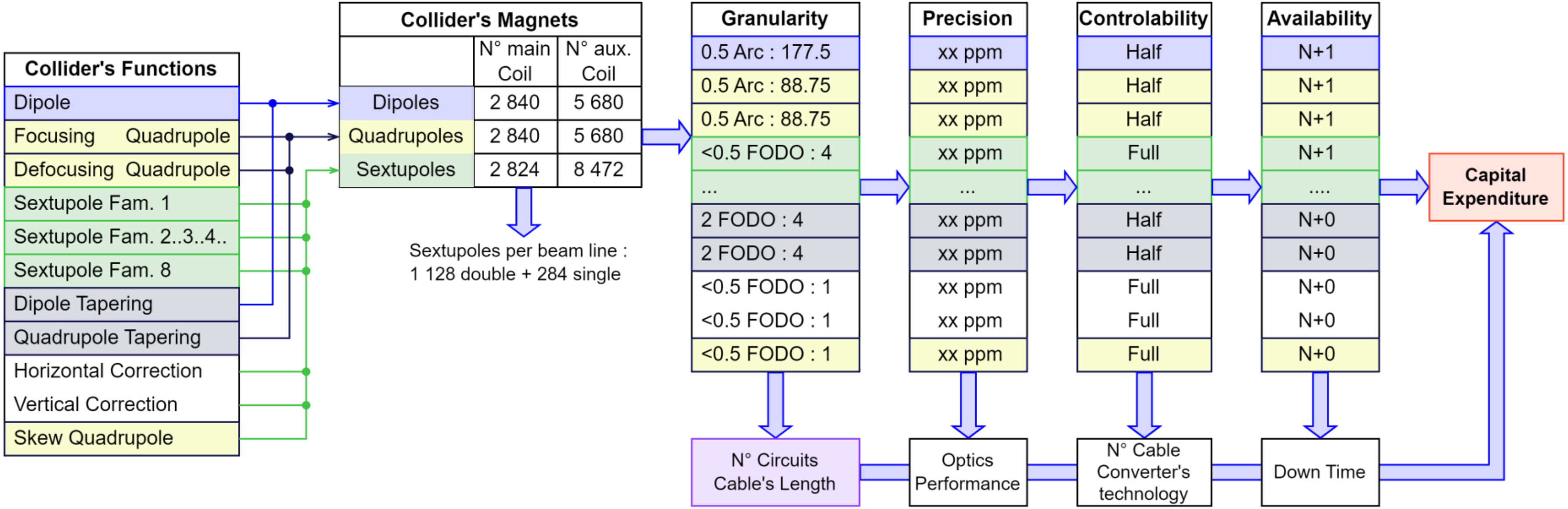
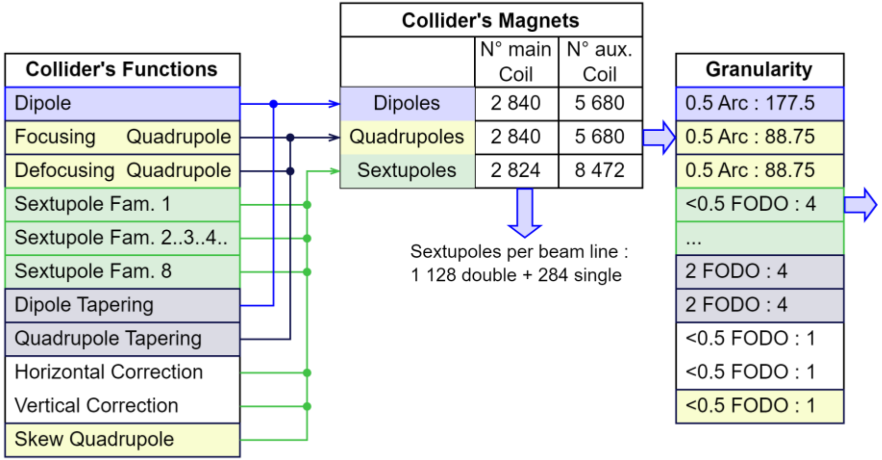
Introduction



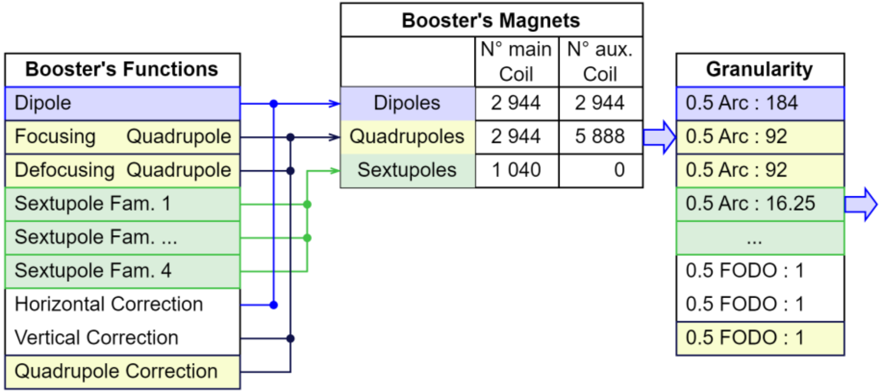
Parameters such as controllability, granularity and availability directly impact the number and performance of power converters powering the magnets. This presentation will illustrate the effect of each parameters.

Number of Circuit – Baseline



Collider Magnets	N° Magnets	N° Circuits
Dipole	2'840	16
Quadrupole	2'840	32
Sextupole	5'080	706
Sub-Total	10'760	754
Dipole Tapering	5'680	710
Quadrupole Tapering	5'680	710
Sub-Total	11'360	1'420
Horizontal Corrector	2'824	2'824
Vertical Corrector	2'824	2'824
Quadrupole Corrector	----	----
Skew Quadrupole	2'824	2'824
Sub-Total	8'472	8'472
Straight Section	?	?
Total	**30'592**	**10'646**

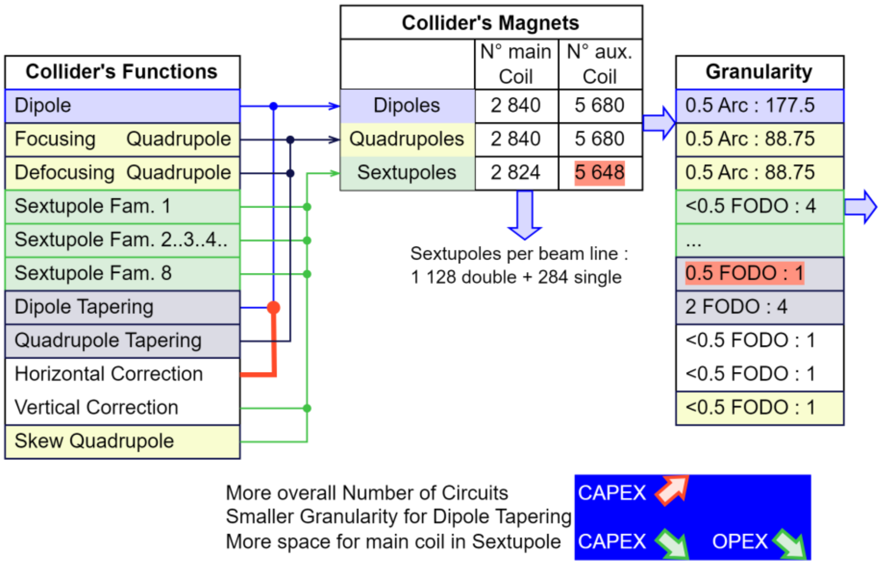
Number of Circuit – Baseline



Booster Magnets	N° Magnets	N° Circuits
Dipole	2 944	16
Quadrupole	2 944	32
Sextupole	1 040	64
Sub-Total	6 928	112
Dipole Tapering	----	----
Quadrupole Tapering	----	----
Sub-Total	----	----
Horizontal Corrector	? 2944 ?	2 944
Vertical Corrector	? 2944 ?	2 944
Quadrupole Corrector	? 2944 ?	2 944
Skew Quadrupole	----	----
Sub-Total	8 832	8 832
Straight Section	?	?
Total	**15 760**	**8 944**

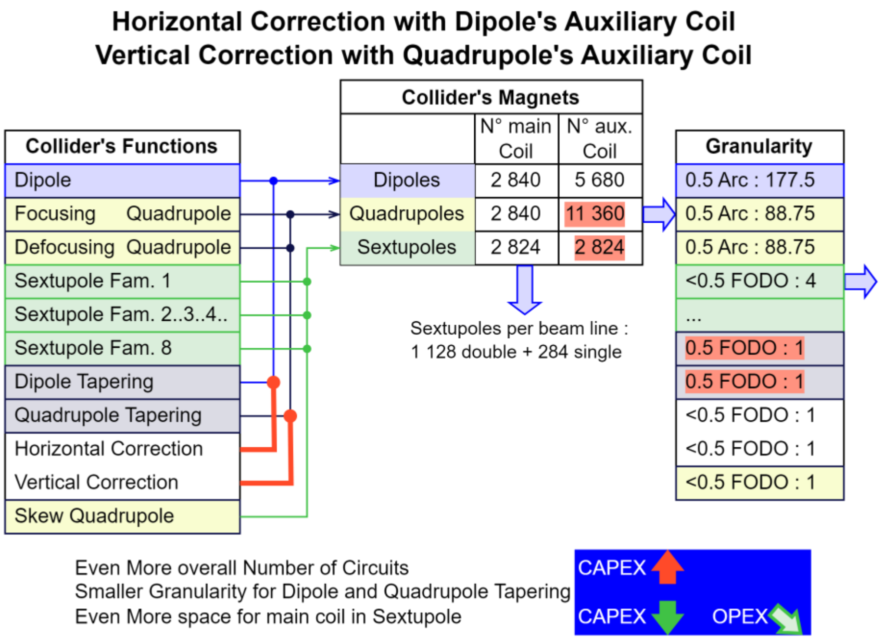
Number of Circuit – Collider's Alternative

Horizontal Correction with Dipole's Auxiliary Coil



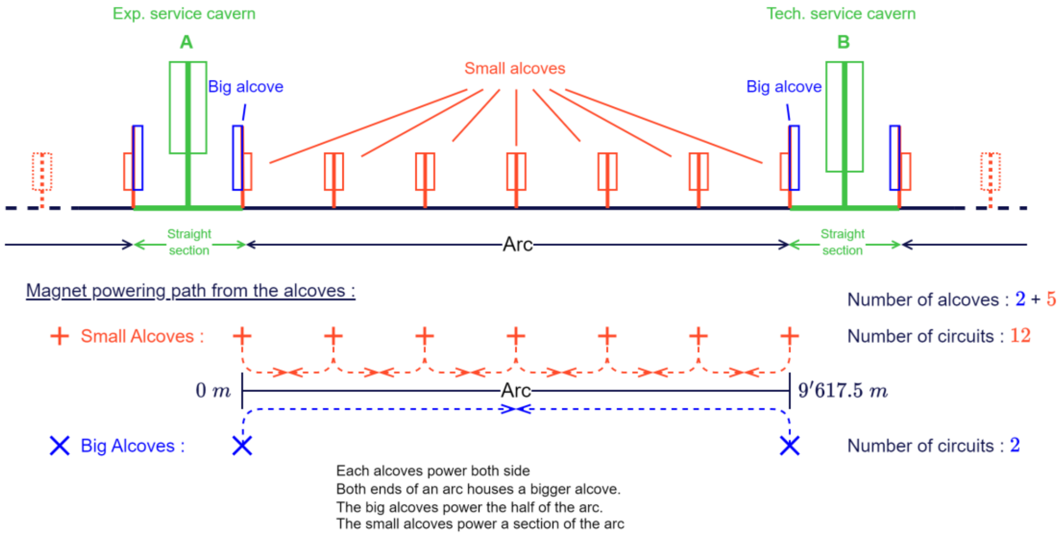
Collider Magnets	N° Magnets	N° Circuits
Dipole	2'840	16
Quadrupole	2'840	32
Sextupole	5'080	706
Sub-Total	10'760	754
Dipole Tapering	Achieved with Horizontal Corrector	
Quadrupole Tapering	5'680	710
Sub-Total	5'680	710
Horizontal Corrector	5'680	5'680
Vertical Corrector	2'824	2'824
Quadrupole Corrector	----	----
Skew Quadrupole	2'824	2'824
Sub-Total	11'328	11'328
Straight Section	?	?
Total	**27'768**	**12'792**

Number of Circuit – Collider's Alternative



Collider Magnets	N° Magnets	N° Circuits
Dipole	2'840	16
Quadrupole	2'840	32
Sextupole	5'080	706
Sub-Total	10'760	754
Dipole Tapering	Achieved with Horizontal Corrector	
Quadrupole Tapering	Achieved with Vertical Corrector	
Sub-Total	0	0
Horizontal Corrector	5'680	5'680
Vertical Corrector	11'360	11'360
Quadrupole Corrector	----	----
Skew Quadrupole	2'824	2'824
Sub-Total	19'864	19'864
Straight Section	?	?
Total	**30'624**	**20'618**

Granularity – Arc



Power converter's location impact the maximum granularity of a circuit :

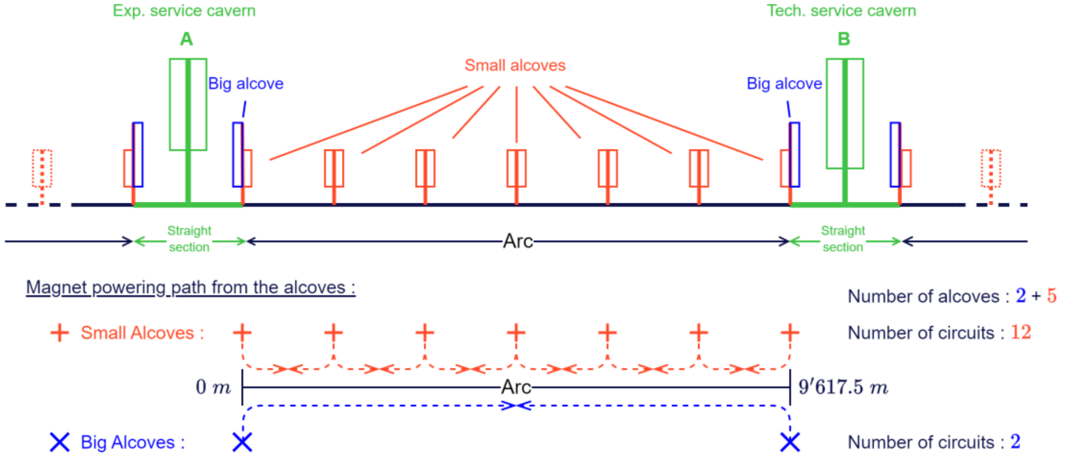
- **Big Alcoves**, can power up to a Half-Arc (4.8 km).
- **Small Alcoves**, can power up to a 12'th of an Arc (800 m).

For individually powered magnet, the best OPEX + CAPEX is from the Small Alcoves.

For magnet powered in series, the location will affect :

- Length of Cables **CAPEX/OPEX**
- Voltage of Converter **CAPEX/OPEX**
- Precision of Converters **CAPEX**

Granularity – Arc – Baseline

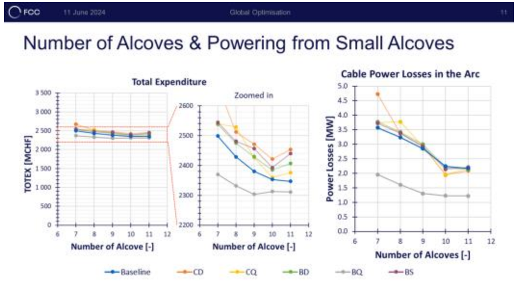


Each alcoves power both side
Both ends of an arc houses a bigger alcove.
The big alcoves power the half of the arc.
The small alcoves power a section of the arc

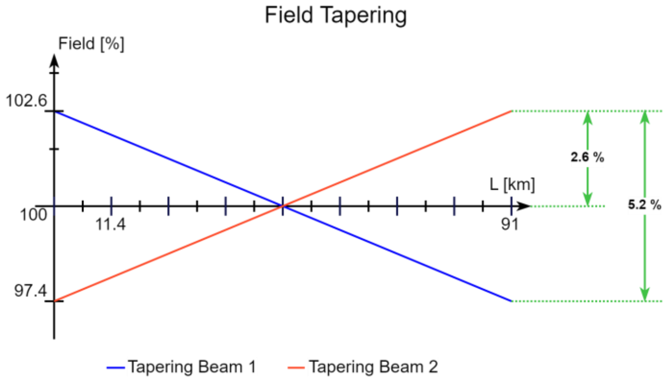
	Magnets powering emplacement	Big Alcoves	Small Alcoves
Collider	Dipoles	X	
	Quadrupoles	X	
	Sextupoles		+
	Horizontal Correctors		+
	Vertical Correctors		+
	Skew Quadrupoles		+
Booster	Dipoles	X	
	Quadrupoles	X	
	Sextupoles	X	
	Horizontal Correctors		+
	Vertical Correctors		+
	Quadrupole Correctors		+

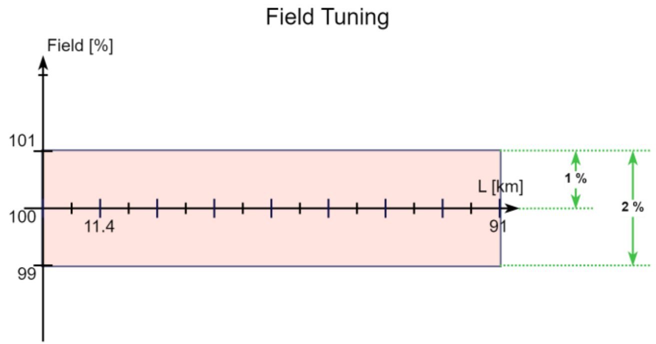
For scenario analysis see :

FCC Week 2024 – Global Optimisation
11th June – Room Elizabethan C



Granularity – Tapering and Tuning





Creating multiple families that power in steps from 2.6% to 0%, instead of having all magnet powering up to 2.6% :

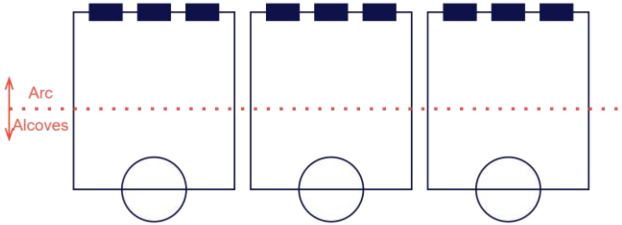
- Families of Converter + Magnet — CAPEX ↗
- Power of Converter — CAPEX ↘
- Precision of Converters — CAPEX ↗

Uniting both field Tapering and Tuning with the same circuit could further save in number of circuits.

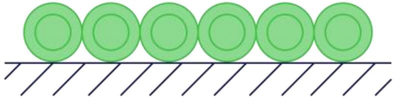
Controllability

Controllability : -100% to +100%

Polarity of group can be reversed during run



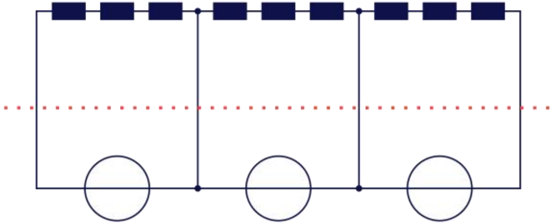
$$N_{cable} = 2N_{circ}$$



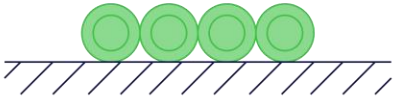
Power converters are too big to be put in the arcs.

Controllability : 0% to +100%

Polarity of group not reversed during run



$$N_{cable} = N_{circ} + 1$$

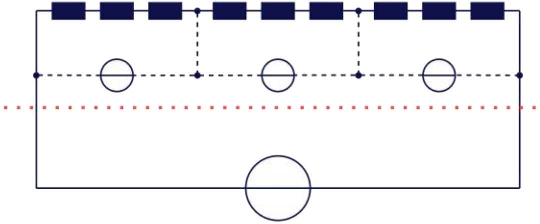


Close to half the space by using cable sharing.

CAPEX ↘
OPEX ↘

Controllability : 0% to +10%

Polarity of group not reversed during run
+ lower change percentage



$$N_{cable} = 2 \quad +(N_{circ} + 1)$$

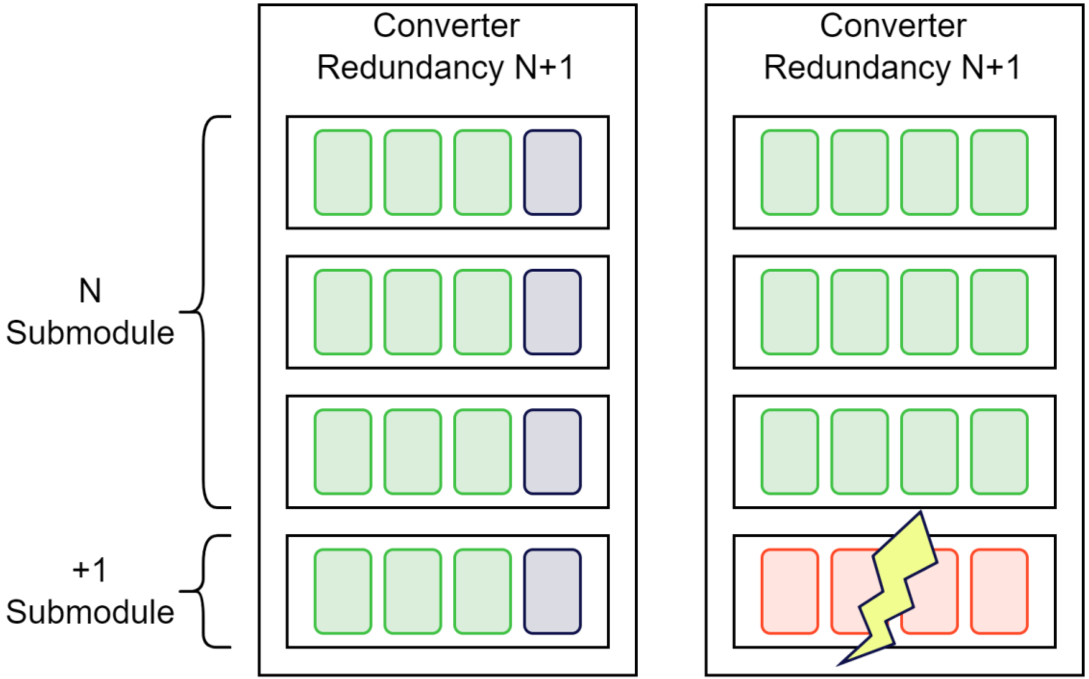
Only one converter in the alcoves.

The trimmers + cabling in the arc section, closest to magnets.

But need of Radiation hard trimmers

CAPEX ?
OPEX ↘

Availability – Redundancy of Converters

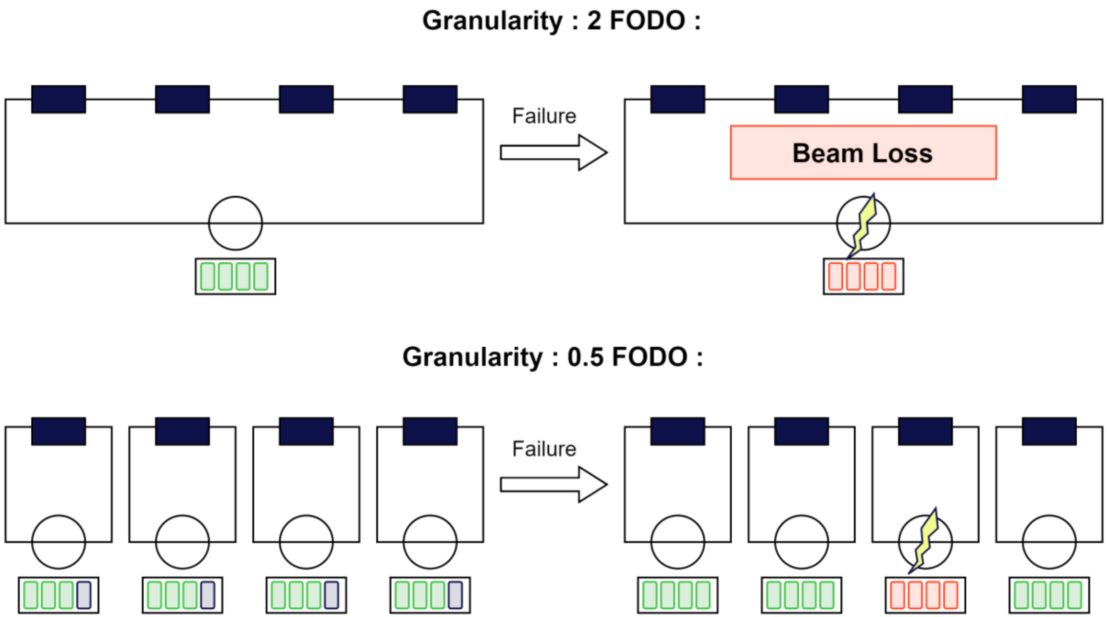


Redundancy is used to increase *Mean Time Between Failure* (**MTBF**).
The converter can suffer one submodule loss without Beam Loss.

During stops the faulty submodule can be replaced with a spare and the damaged can be repaired on the surface.

- N+1 redundancy level, great when accessible between runs. CAPEX ↗
- N+2 redundancy level, is almost safe by design. CAPEX ↑
- Less appealing for lower power, as it doubles the number of submodules N=1 → 1+1 = 2 CAPEX ↑

Availability – Redundancy of System



With a greater granularity allowance, we can choose a lower granularity to have redundancy of the circuit.

In case of a fault with a corrector the nearby corrector takes over and continue operation.

- Number of converters CAPEX ↑
- Power of converter CAPEX ↘

Precision

What parameter we need to define "precision"?

FCC-performance metrics shall follow metrology vocabulary – need for adopting metrics as done for HL-LHC (EPC reference document)

Accuracy classes per circuit need to be defined

PC REQUIREMENT SUMMARY - ACCURACY CLASSES	0	1	2	3	4
Resolution [ppm]	0.5	[illegible]	1.0	1.0	1.0
Initial uncertainty after cal [2xrms ppm] normal	2.0	[illegible]	3.0	7.0	10.0
Linearity [ppm] [max abs ppm] uniform	2.0	[illegible]	5.0	8.[illegible]	9.0
Stability during a fill (12h) [max abs ppm] uniform	0.7	[illegible]	5.0	[illegible]	9.5
Short term stability (20min) [2xrms ppm] normal	0.2	[illegible]	1.2	[illegible]	5.0
Noise (<500Hz) [2xrms ppm] normal	3.0	[illegible]0	7.[illegible]	15.0	19.0
Fill to fill repeatability [2xrms ppm] normal	0.[illegible]	[illegible].8	2.6	4.0	5.0
Long term fill to fill stability [max abs ppm] uniform	8[illegible]	8.0	19.0	40.0	45.0
Temperature coefficient [max abs ppm/C] uniform	[illegible]	1.2	2.5	5.5	6.5
12h Delta T for HL-LHC [max C] constant	[illegible]	1.0	5.0	5.0	5.0
1 y Delta T for HL-LHC [max C] constant	0.5	1.0	5.0	5.0	5.0

Up to 8

Hard & costly

Costly

Standard

Conclusion

- Number of circuits and their parameters impacts overall powering cost.
- Number of circuit is dependant of the number of optic functions and their granularity.
- Moving optics functions among magnets (existing for other functions or dedicated) have a huge cost consequences.
- Parameters such as Controllability, Availability, Precision drives the cost of the converter.
- All parameter requirements needs to be assessed in .

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