FCC

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GLOBAL OPTIMISATION

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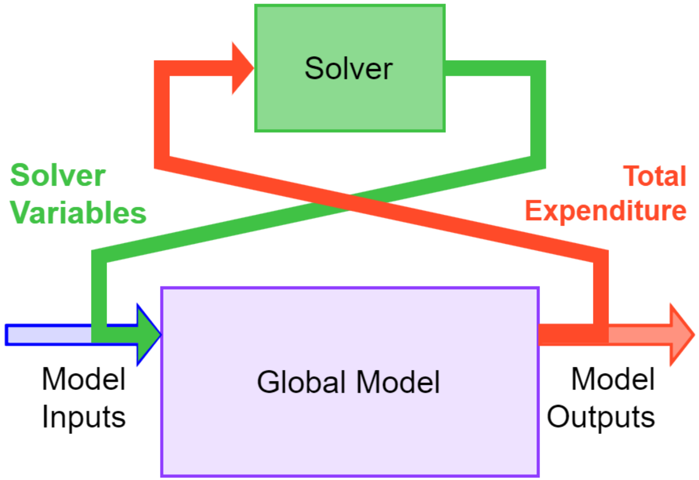
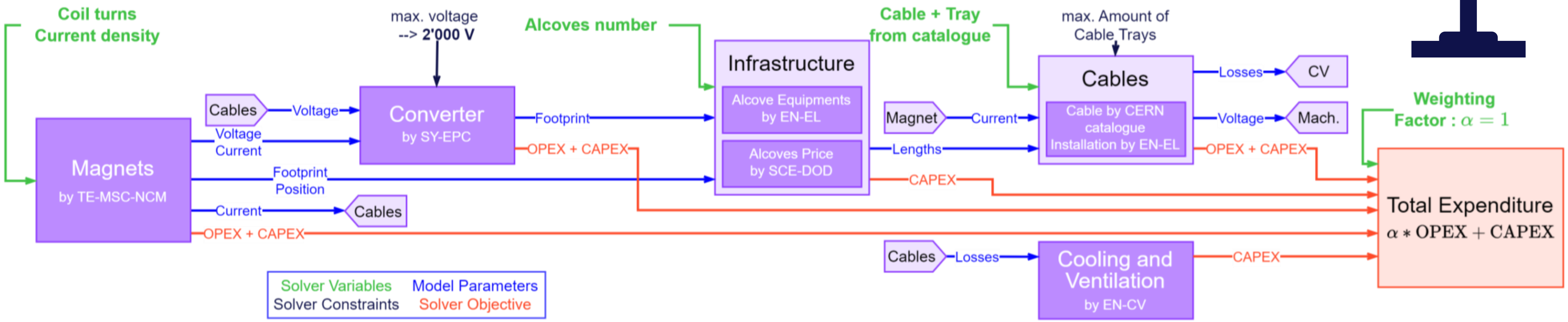


Submodels of Global Model

The global model is composed of multiple interconnected sub-models, each intricately linked. Every sub-model is tailored to represent a distinct segment of the broader system.

The **Total Expenditure** is the **Sum** of the **Capital** and **Operational Expenditure** of each submodels :

- ❑ **Magnets** — **TE-MSC-NCM** — with script modelling MSC's magnets.
- ❑ **Power Converters** — **SY-EPC** — with existing converters + adjustment to FCC's need.
- ❑ **Cables** + **Cable-Trays** — **EN-EL** — with CERN Catalogue.
- ❑ **Alcoves** — **SCE-DO** — with Mid Term Review's data given by SCE.
- ❑ **Electrical Equipment** — **EN-EL** — with EN-EL Catalogue.
- ❑ **Cooling and Ventilation** — **EN-CV** — with Mid Term Review's data given by CV.

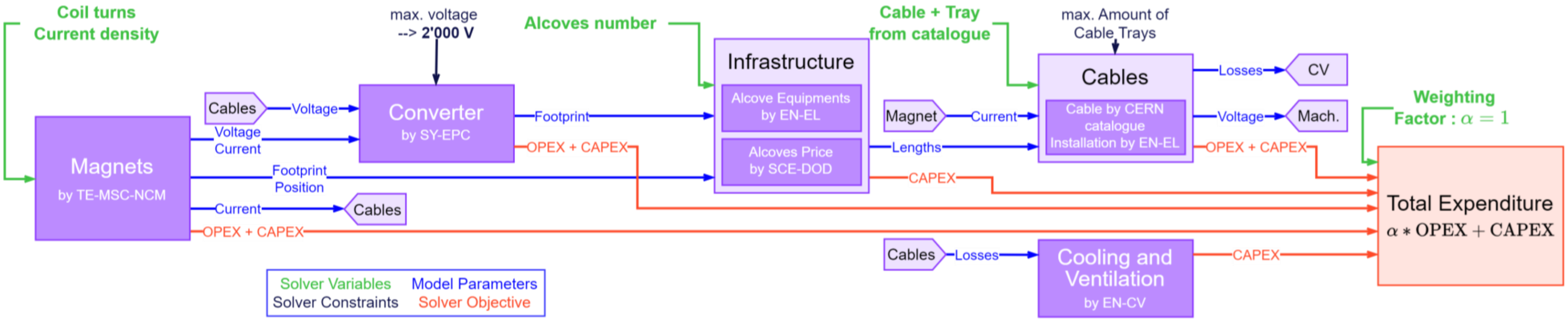


Parameter Consideration of Global Model

Parameters taken into account :

- **Magnets** : Material, Power Losses
- **Power Converters** : Material, Power Losses
- **Cables** + **Cable-Trays** : Material, Power Losses, Installation
- **Alcoves** : Volume, Schedule change
- **Electrical Equipment** : Material in Alcoves
- **Cooling and Ventilation** : Equipment upgrade needed to accommodate Cable's power losses

More parameters/submodels can and **will** be implemented.
The current submodels were chosen as most representative of **current input parameters**.



Price Consideration and Constraints of Global Model

Price consideration taken in the global model :

- **Electricity cost for 15 years of operation**, integrated energy level considering machine OP cycles.
- **Booster Mean power** as OPEX.
- Length of cable for each circuit is considered as CAPEX and OPEX.
- **Alcove volume and schedule change** are considered as CAPEX.
  - Schedule change has other impact beyond cost.

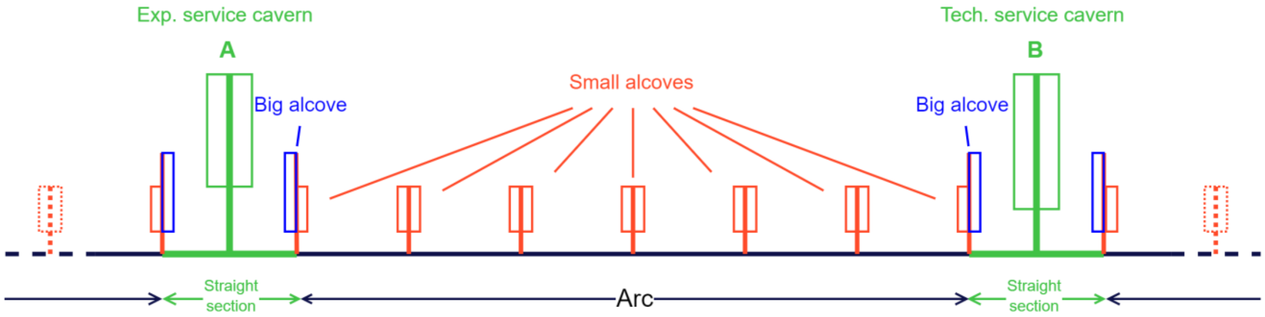
Constraints accounted for :

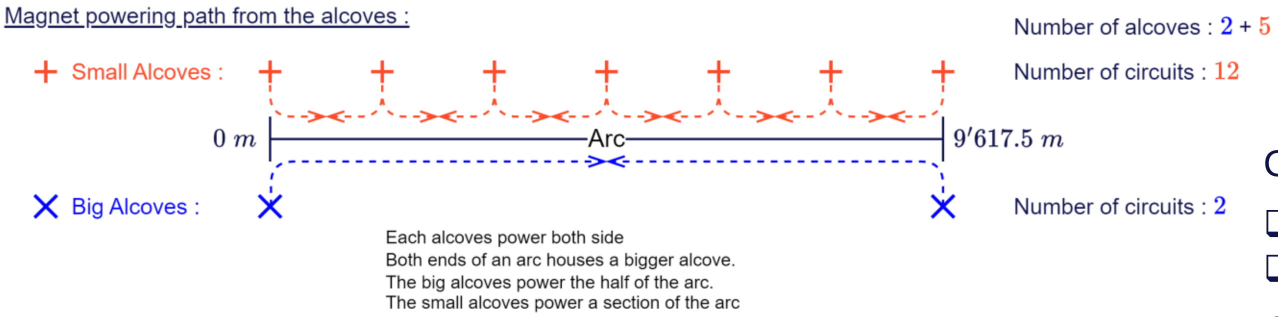
- **Space taken in the cable trays**.
- **Number of alcoves**.
- **Power losses in the air** for cooling limits.
- **Maximum voltage** for cable isolation.
- **Water cooling performance** of magnet design.

Pricing Model **Not** Accounted for :

- Uninstallation of equipment
- Operational Expenditure of Cooling and Ventilation
- Radiation protection
- …

Small and Big Alcoves in the Arcs





	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		+

Circuits can be powered from :

- ❑ Big Alcoves at the end of the arc
- ❑ Small Alcoves in the arc

Choosing the alcoves impacts greatly the expenditures.

Magnet Powering Circuits

Collider Magnets	N° Magnets	N° Circuits	Booster Magnets	N° Magnets	N° Circuits
Dipole	2 840	16	Dipole	2 944	16
Quadrupole	2 840	32	Quadrupole	2 944	32
Sextupole	5 080	706	Sextupole	1 040	64
Sub-Total	10 760	754	Sub-Total	6 928	112
Dipole Tapering	5 680	710	Dipole Tapering	----	----
Quadrupole Tapering	5 680	710	Quadrupole Tapering	----	----
Sub-Total	11 360	1 420	Sub-Total	----	----
Horizontal Corrector	2 824	2 824	Horizontal Corrector	? 2944 ?	2 944
Vertical Corrector	2 824	2 824	Vertical Corrector	? 2944 ?	2 944
Quadrupole Corrector			Quadrupole Corrector	? 2944 ?	2 944
Skew Quadrupole	2 824	2 824	Skew Quadrupole	0	
Sub-Total	8 472	8 472	Sub-Total	8 832	8 832
Straight Section	?	?	Straight Section	?	?
Total	**30 592**	**10 646**	**Total**	**15 760**	**8 944**

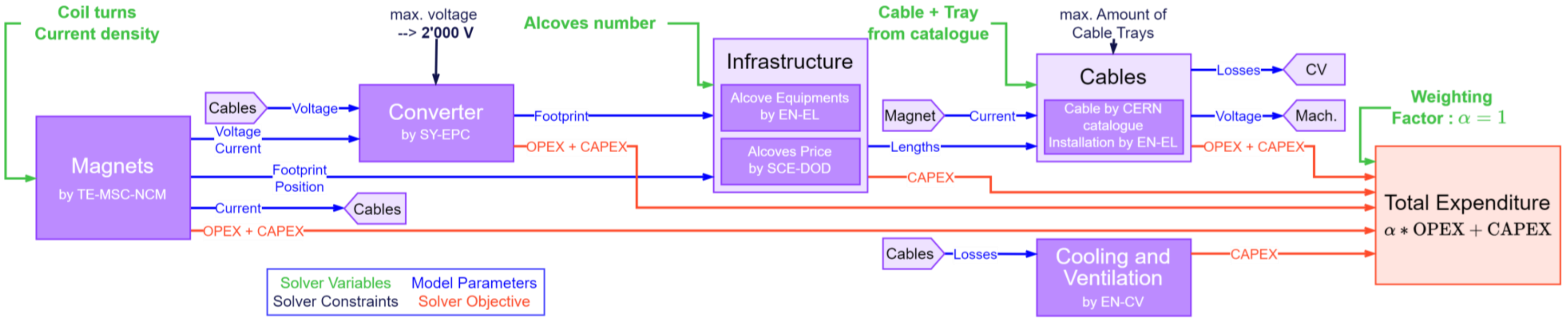
Global Optimisation Solving for Best TOTEX

Following slides present optimised solutions, with varying constraints.
The objective being: reaching the **minimum Total Expenditure** while complying with constraints.

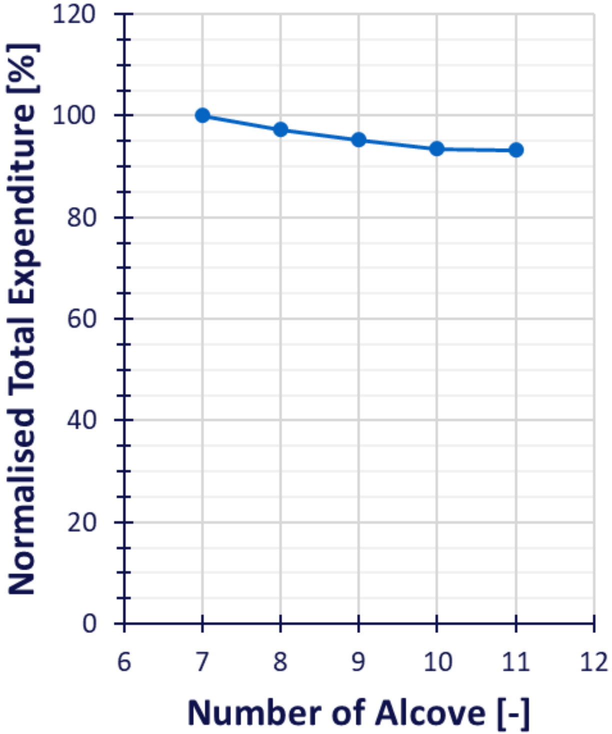
Solver's evolutionary optimisation algorithm identify the most likely optimal solution, meaning the best solution found within the given time frame.

Weighting Factor set to **1** so far, meaning that Operation and Capital Expenditure have the same weight when optimising.

$$TOTEX = \alpha * OPEX + CAPEX, \alpha = 1$$



Increasing Number of Alcoves



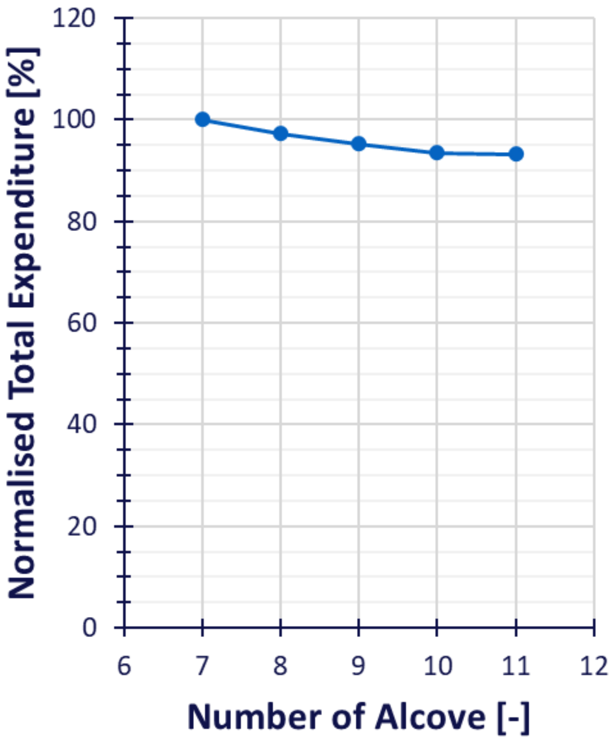
Cost increase incurred by having more Alcoves is **outweighed** by the benefits of :

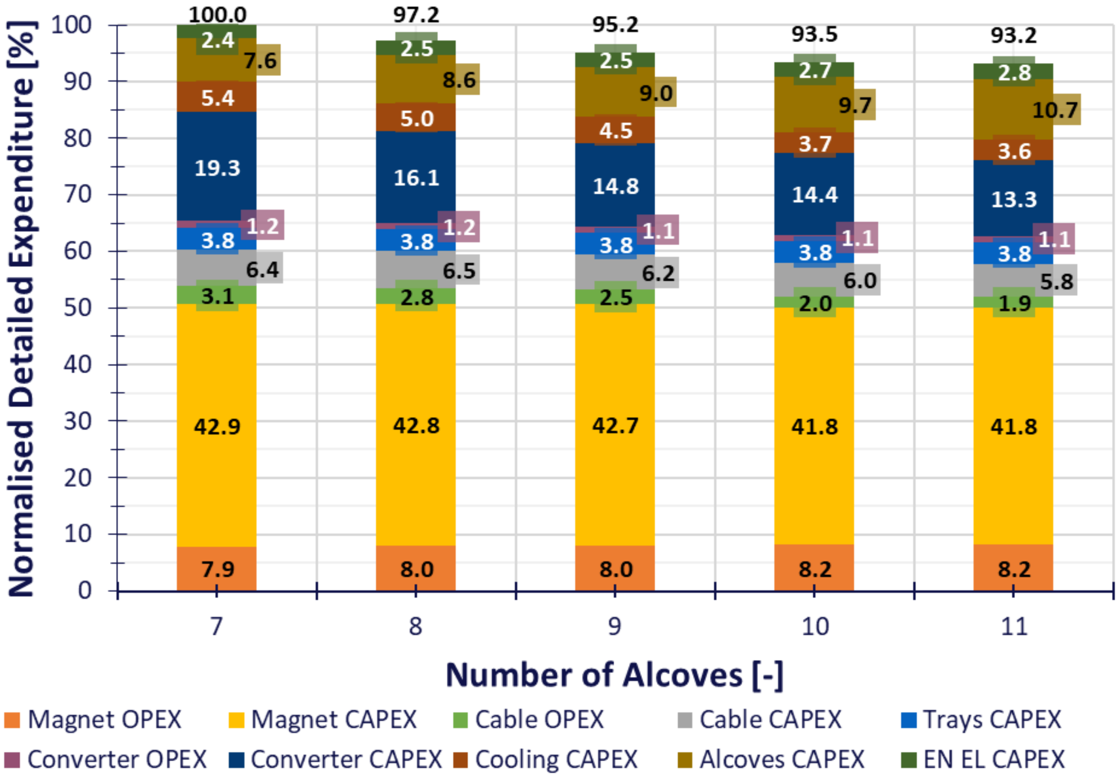
- Less cable length in the arc :
  - Lower voltage drop.
  - Lower converter power rating.
- Fewer cable numbers in the cable trays :
  - More room for bigger cable.

→ Lower Total Expenditure.

	CAPEX	OPEX
More **Alcoves** and Schedule Change	↑	
More **Electrical Equipment**	↗	
Reduced **Cable** length	↓	↓
Reduced **Converter** power rating	↘	↘
Reduced **Cooling** in the arc	↘	

Increasing Number of Alcoves





Optimising Collider Magnet Parameters

Collider Magnets	Current Density [A/mm^2]		Number of Turns [-]	
	FCC Week 23	Optimised Model	FCC Week 23	Optimised Model
Dipole	1.010	1.845	1	1
Quadrupole	2.150	2.475	25	36
Sextupole	5.100	5.581	14	53
Dipole Tapering	1.000	0.907	5	19
Quadrupole Tapering	1.000	0.980	5	43
Horizontal Corrector	1.400	3.625	48	10
Vertical Corrector	1.200	3.050	48	22
Skew Quadrupole	2.600	3.314	24	22

Best Magnet parameters found by the global optimisation at 9 Alcoves.

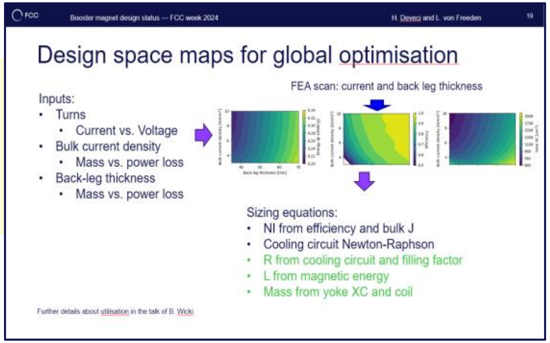
The global model optimisation tends to :

- ❑ Decrease current (higher number of turns) as it affects Cables and Converters.
- ❑ Increase iron vs copper as it directly affect CAPEX of magnets.

For Magnet analysis see :

FCC Week 2024 – Collider magnet design status

12th June – Room Elizabethan B



Optimising Cable Trays Integration

When trying different Cable Trays, **the more space we have the better**, as it allow for bigger cables.

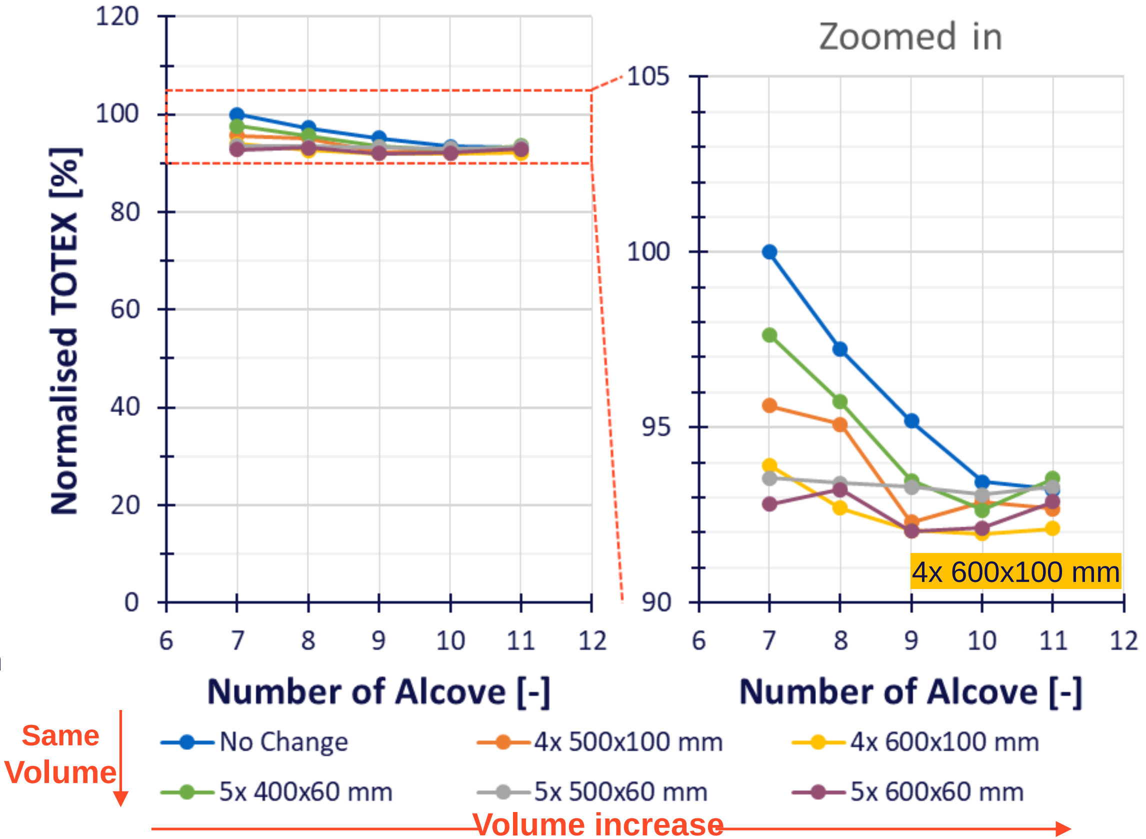
→ Lower Total Expenditure

When comparing same volume scenarios, the TOTEX changes due to **Cable Tray rules**.

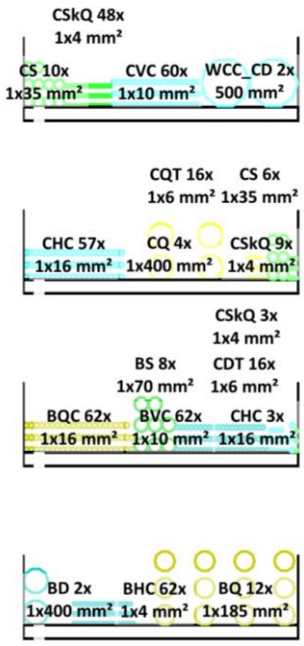
NB : the total height allocation doesn't change (with overhang = 150 mm)

$$5x(60+150) \approx 4x(100+150)$$

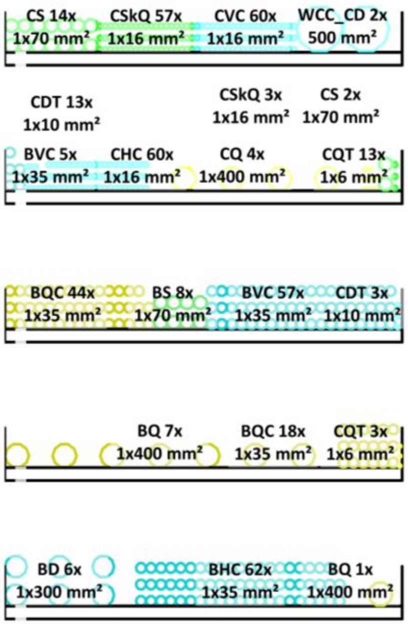
Only the width changes ; 400, 500 or 600 mm



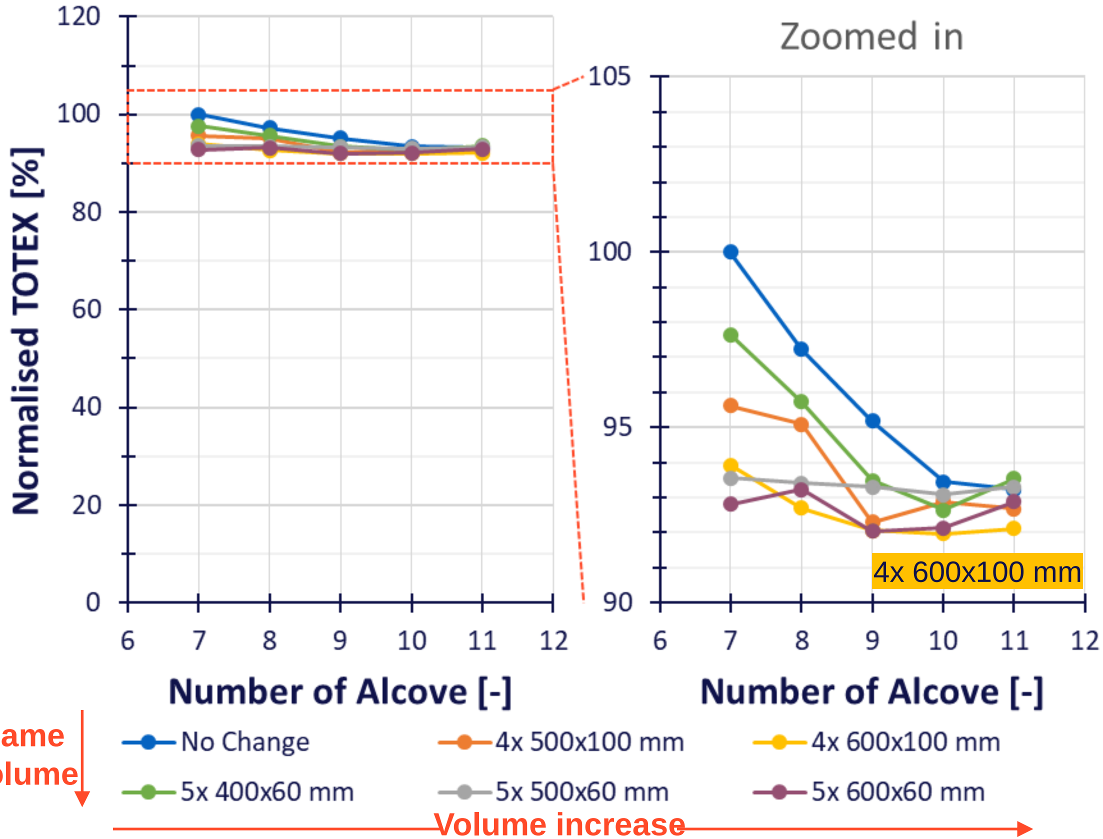
Optimising Cable Trays Integration



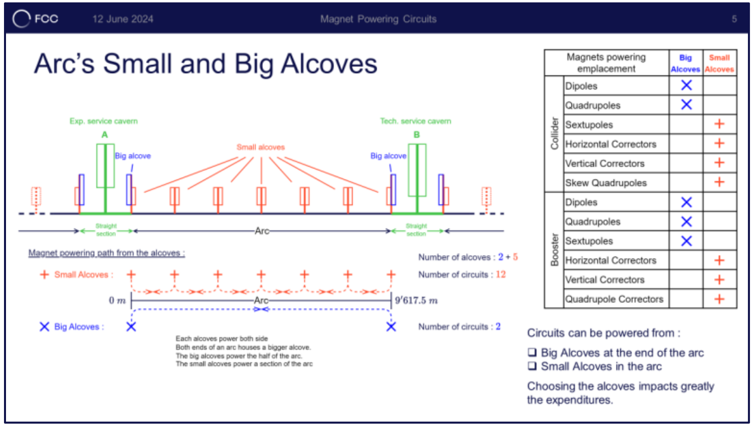
4x 400x100 mm
7 Alcoves



5x 600x60 mm
7 Alcoves



Powering from Small or Big Alcoves ?



Arc's Small and Big Alcoves

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

Circuits can be powered from :

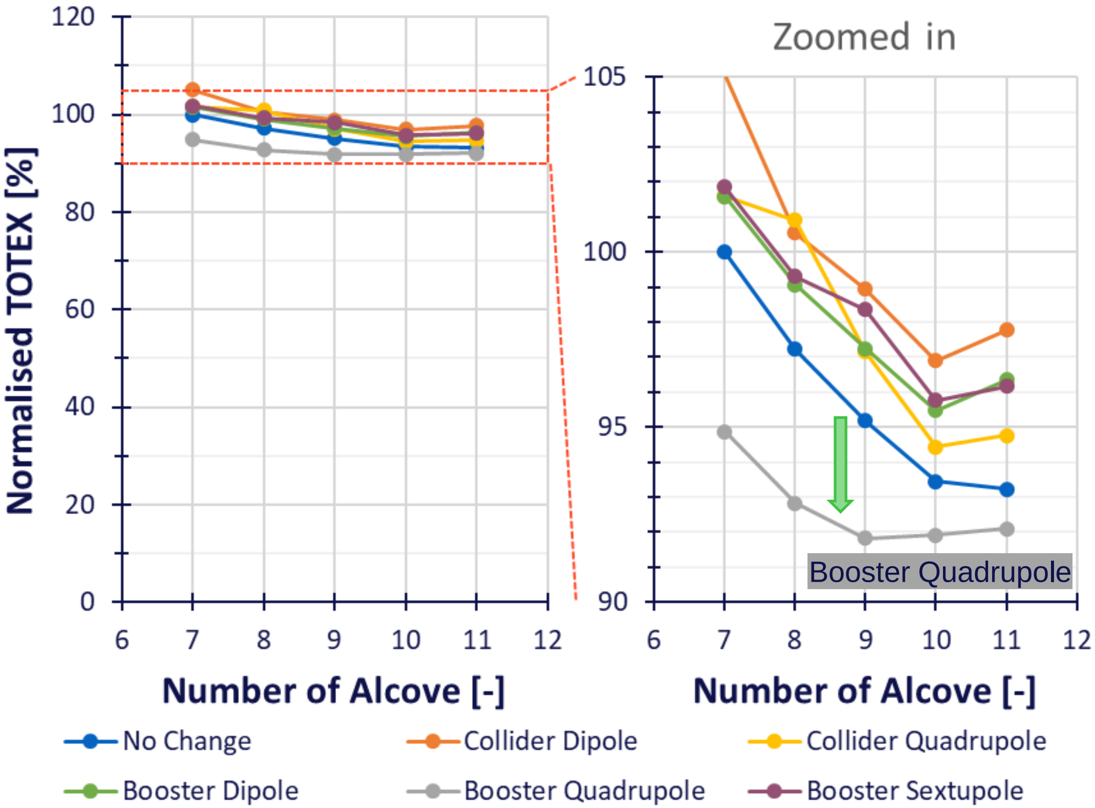
- ❑ Big Alcoves at the end of the arc
- ❑ Small Alcoves in the arc

Choosing the alcoves impacts greatly the expenditures.

When the Booster Quadrupole is powered from the small alcoves, the **BQ's voltage constraint is relaxed**

→ Lower Total Expenditure

Another solution could be a different Magnet/Optic specification.



Choosing Aluminium VS Copper Coils

When using aluminium coils instead of copper, aluminium is **less expensive in all cases except for the Collider Sextupole**.

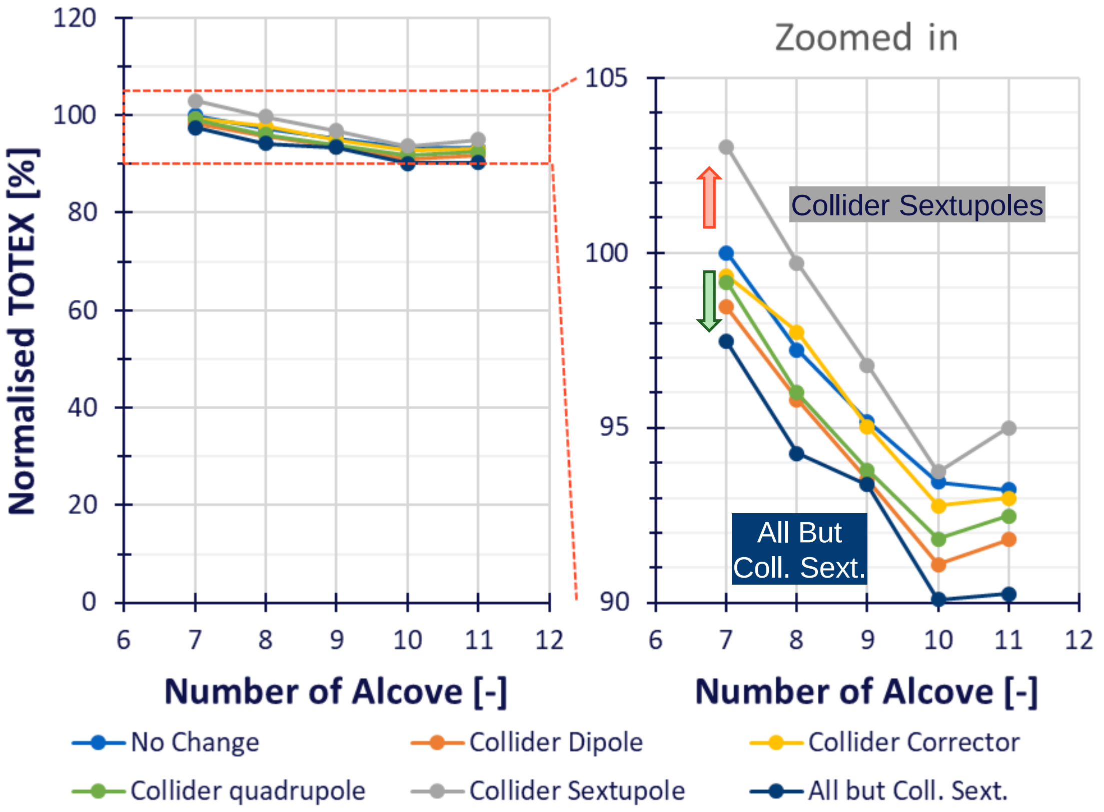
Aluminium is :

- **~3x cheaper**
- **~1.6x** less electrically conductive,
  for the same power, the coil is ~1.6x bigger.
- **Shield less radiation.**

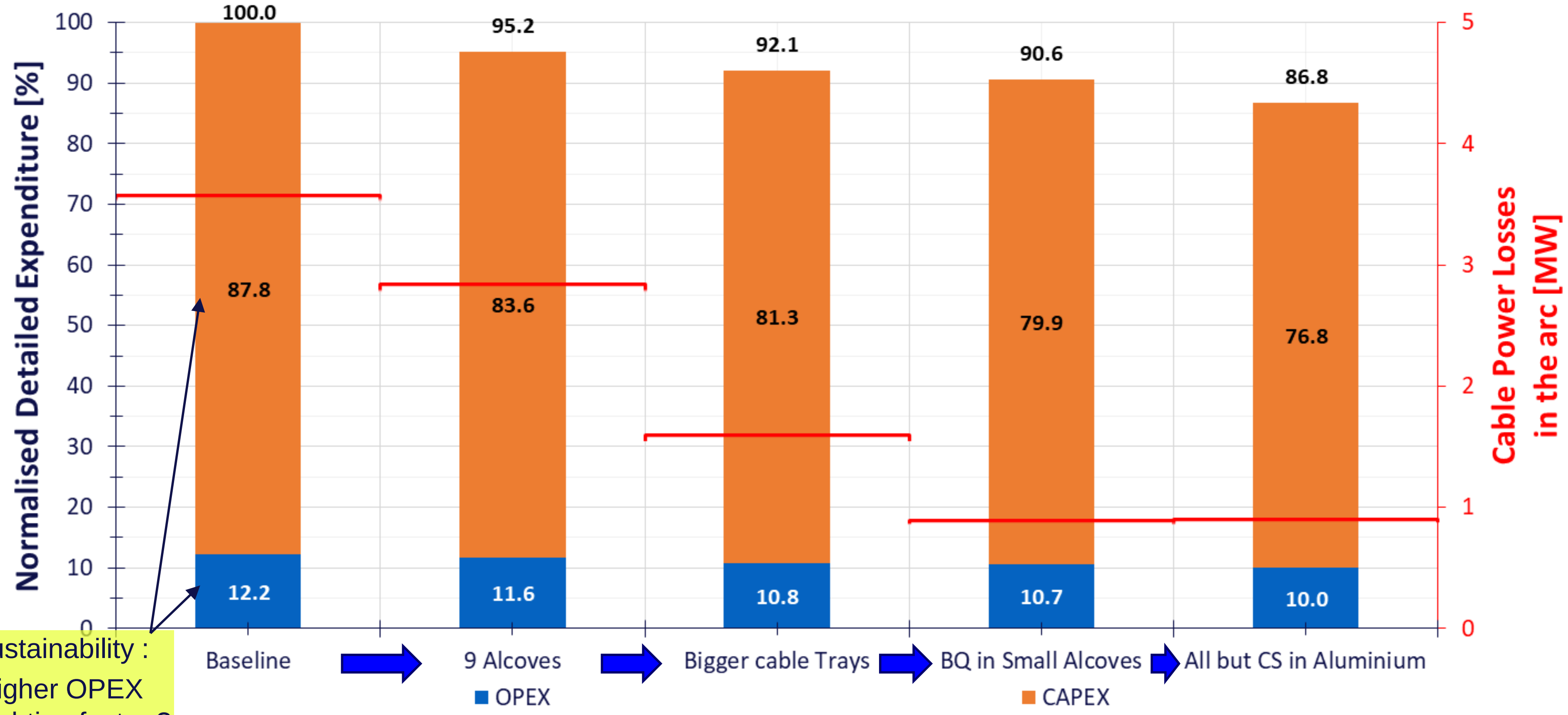
The **Collider Sextupole** is already **over constrained by its footprint** and cannot be bigger.

→ Higher Total Expenditure

NB: Aluminium Cable not yet considered

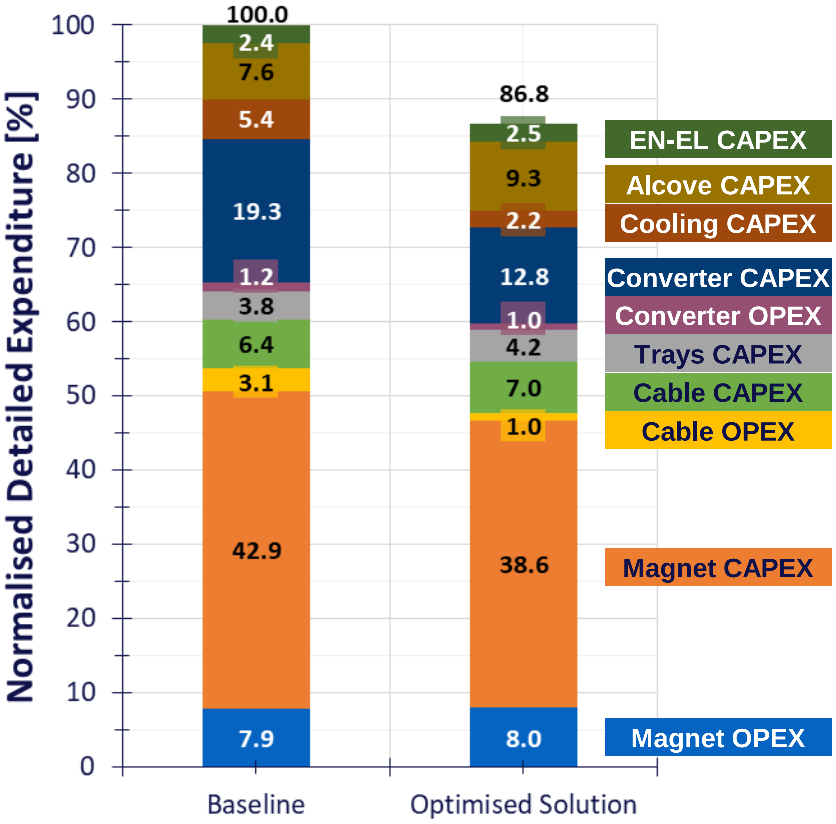


Comparing All Scenarios



Sustainability :
Higher OPEX
Weighting factor ?

Conclusion – Optimised Solution



The Global Model found an optimised solution by considering **Capital** and **Operational Expenditures**.

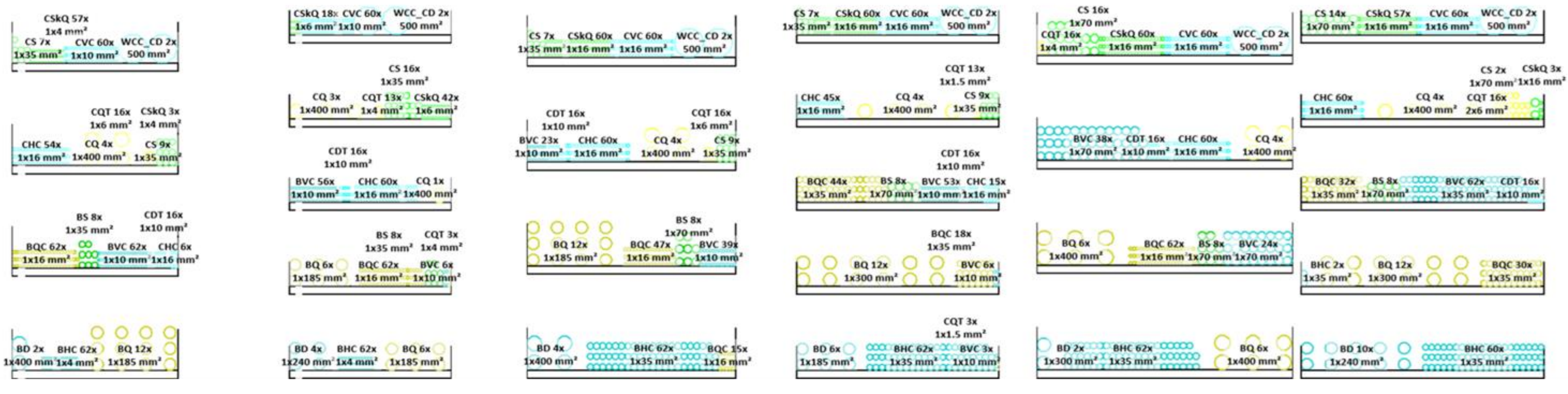
Preliminary global optimisation results shows that:

- **≥9 alcoves** per arc seems to be optimal
- **Bigger cable Trays** needed.
- Booster Quadrupole powered from Big Alcoves.
- Collider Dipole, Quadrupole and Corrector in aluminium coil.

What's next :

- Booster Magnet model with TE-MSC.
- Assessing certainty.
- Refining certain submodels.
- Fixing Optics parameters.
- Radiation Protection
- ...

Cable Trays Comparison



4x 400x100 mm | 5x 400x60 mm | 4x 500x100 mm | 5x 500x60 mm | 4x 600x100 mm | 5x 600x60 mm