STATUS OF PERLE ARC MAGNETS DESIGN

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Powerful energy
recovery linac experiments

Overview

- Status of magnets with the first lattice parameters
  - Summary of magnet inventory
  - Requirements and constraints
  - Status of arc bending magnets
  - Status of quadrupoles
  - Status of Spreader/Combiner magnets
- Impacts of the new lattice :
  - Requirements and constraints changes
  - Improvements and issues
- Conclusion
  - Work Package progress
  - Short-term milestones

Summary of Magnet inventory – 1st lattice

6 arcs : 80, 155, 230, 305, 380, 455 MeV beams

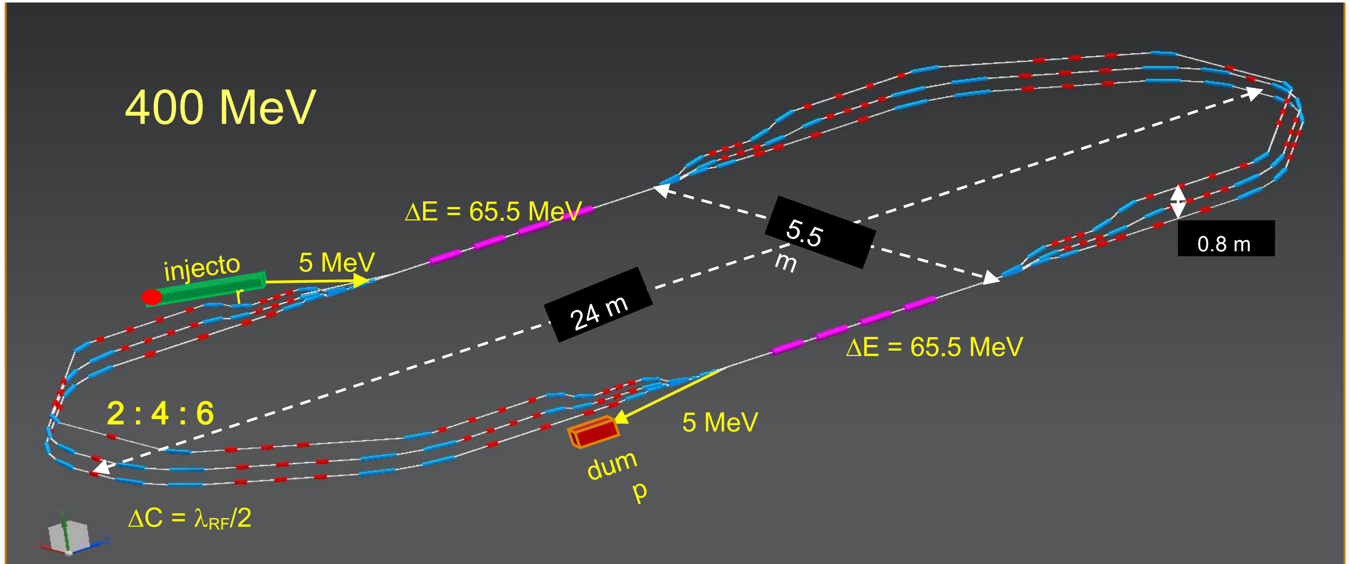
Each arc contains :

4 dipoles, powered in series within that arc ,

114 quadrupoles, which are powered individually.

46 spreader/combiner dipoles, which are powered individually.

184 magnets without sextupoles, correctors included and octupoles to be defined.



Courtesy to Alex Bogacz ERL'17, CERN, June 20, 2017

First Lattice

Arc Bending Magnets

Features of arc bending magnets		
Quantity	12 + 1 (pre-serie)	12 + 1 (pre-serie)
Rotation angle	45°	45°
Radius of curvature	1192 mm	596 mm
Main field B_0	1.25 - 1.3 T	1.25 - 1.3 T
Gap	40 mm	40 mm
Good field region	+/- 20mm	+/- 20mm
Mechanical length	936 mm	468 mm
Current max.	Not defined	Not defined
Beam energy	From 305 to 455 MeV	From 80 MeV to 230 MeV

- Iron-dominated resistive magnets preferred for improving tunability
- Engineering current density of 7-8 A/mm^2
- H design to reduce the height of magnet for stacking
- Homogeneous field as low as possible due to the use of one power supply per arc
- Cost minimization due to the quantity of magnets

Arc Quadrupoles

Features of quadrupoles magnets	
Quantity	114 + 1 (pre-serie)
Magnetic length	100 - 200 mm
Main gradient G_0	30T/m
Gap	40 mm
Good field region	+/- 20 mm
Height	250 mm
Beam energy	From 50 to 400 MeV

Bending magnet challenge :
Very compact bending magnet while keeping a reasonable current density for 6 arcs and especially using the same structure for Arc 1 up to 3 and for Arc 4 up to 6.

Arc bending magnet status – 1st lattice

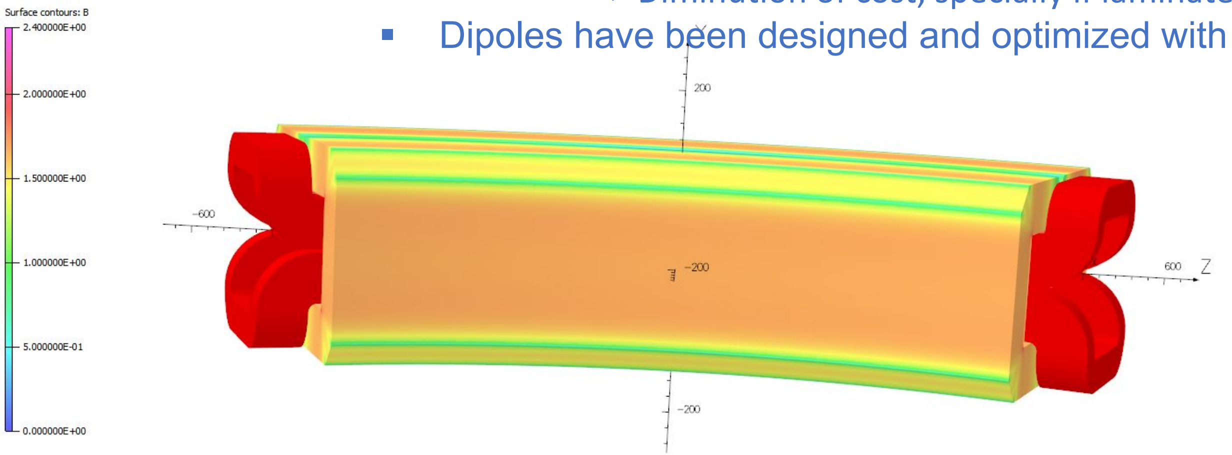
Main results :

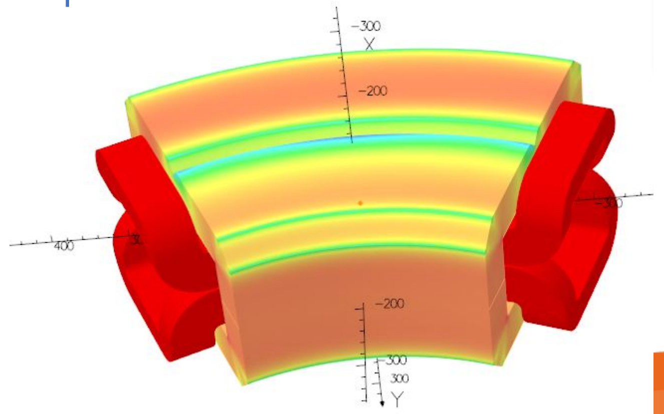
- 2D and 3D design done with the following changes :
  - Enlargement of the pole base width to desaturate iron : 50mm instead of 40mm
  - Add-on of 10mm shim width to improve the homogeneity of field
  - Design of coil height for stacking
- Optimization of the pole chamfer to get a similar magnetic length and a mechanical length :

  => Pole chamfer = 45mm for the longer BM and 51.1mm for the shorter BM
- Optimization of the pole width and the deepness shim to get a field homogeneity of 5.10^{-4} with the same shim thickness for higher energy arc :

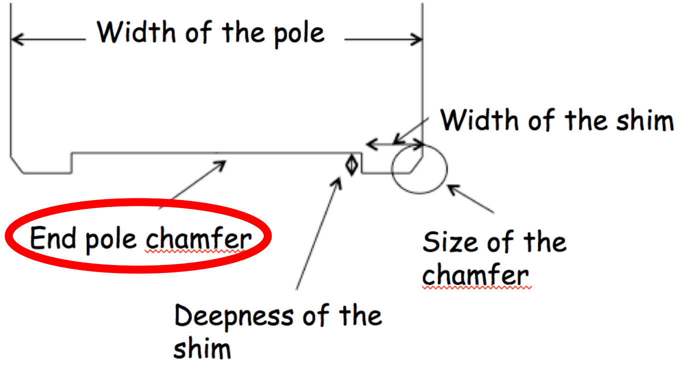
  => Pole width = 120mm and deepness shim = 1mm
- Feasibility was done for short and long radius with the same structure :

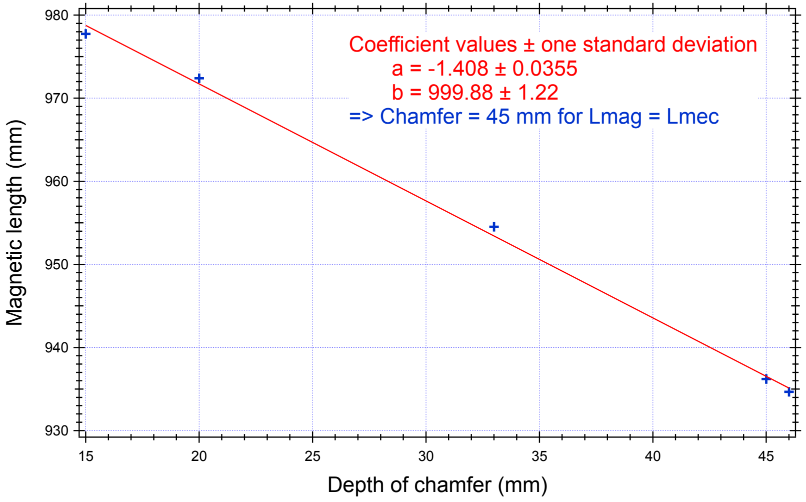
  => Diminution of cost, specially if laminated dipole used
- Dipoles have been designed and optimized with the first lattice parameters

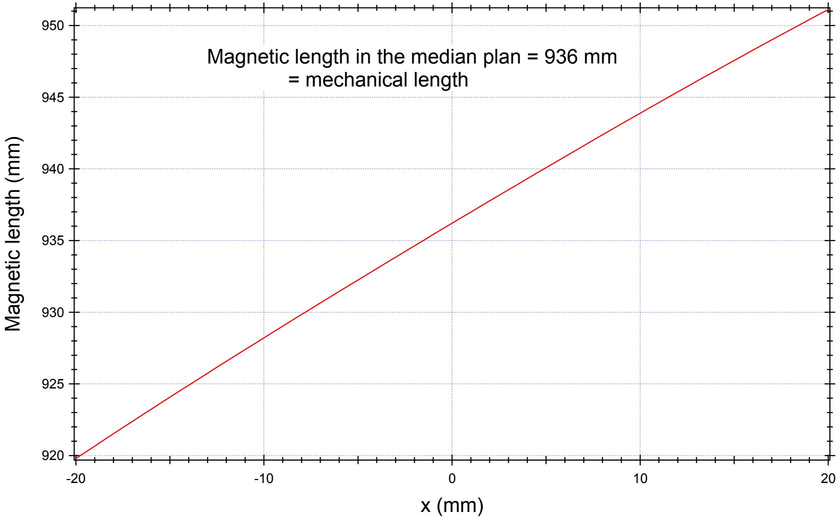




Arc bending magnet status - R = 1192mm



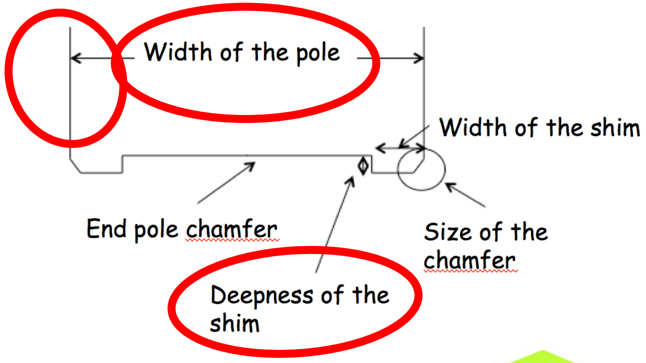




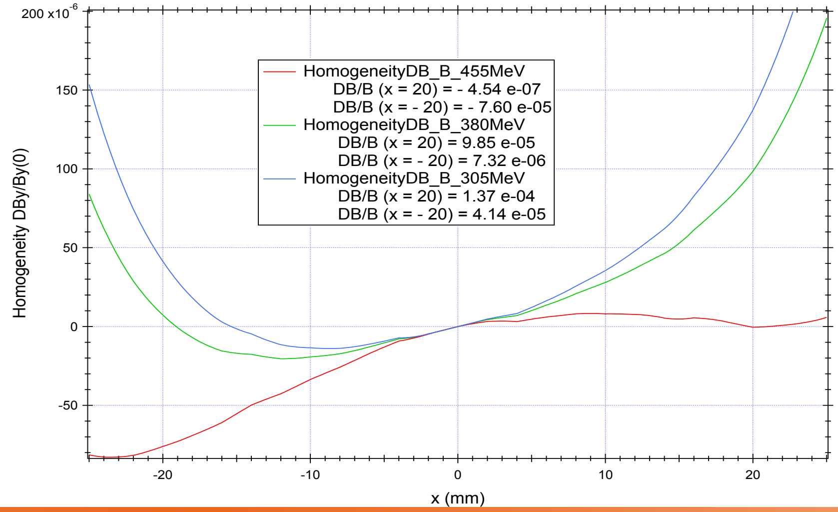
Magnetic length = mechanical length along the central trajectory with a chamfer of 45 mm

Arc bending magnet status - R = 1192mm

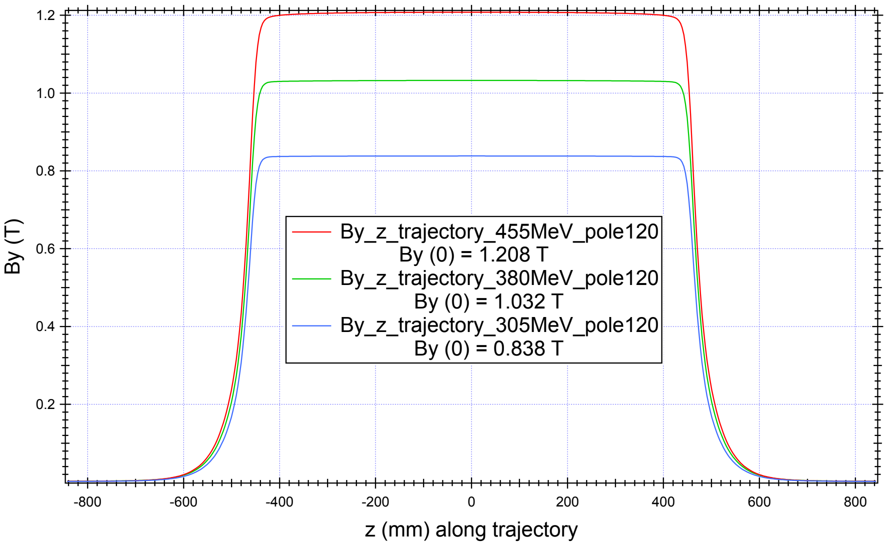
To keep the same shim for 3 energy arcs (305 – 380 - 455 MeV)
9 cases have been carried out:
- Width of pole : 90 – 105 – 120 mm
- Deepness of the shim : 1 – 2 – 3 mm

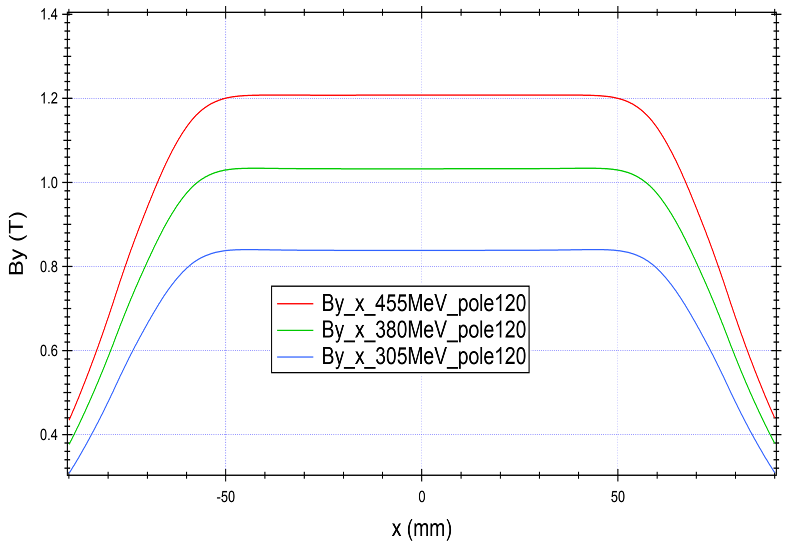


Depth shim (mm)	Homogeneity ($*10^{-4}$) with a pole width 90 mm			Homogeneity ($*10^{-4}$) with a Pole width 105 mm			Homogeneity($*10^{-4}$) with a pole width 120 mm		
	305 MeV	380 MeV	455 Mev	305 MeV	380 MeV	455 Mev	305 MeV	380 MeV	455 Mev
1	9.2	6.5	-2.5	3.5	2.5	-8	1.4	1	0
2	45	40.5	26	15	13	9	5	4.4	3
3	86	78	53	28	26	18	9	8	6



Arc bending magnet status - R = 1192mm



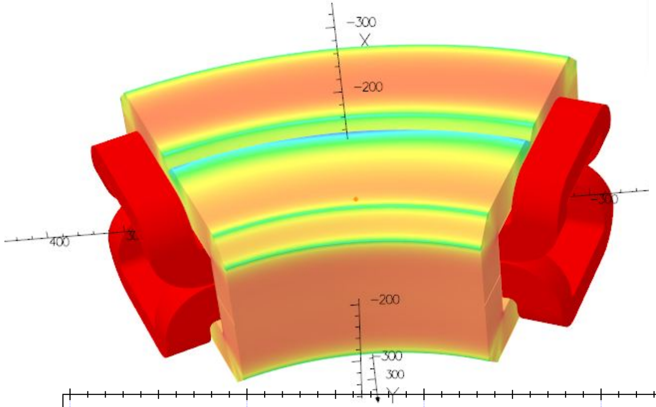


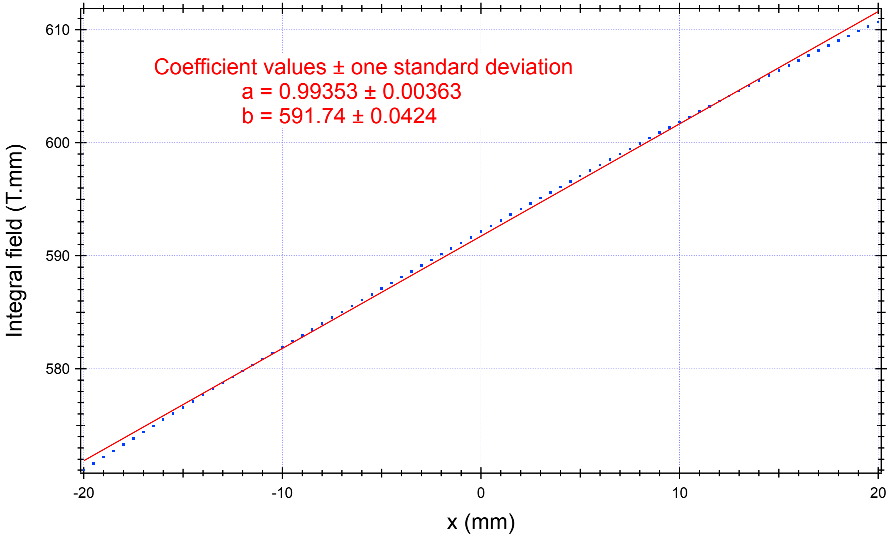
Shim was optimized for 3 energies to get a field homogeneity lower than $5.\ 10^{-4}$

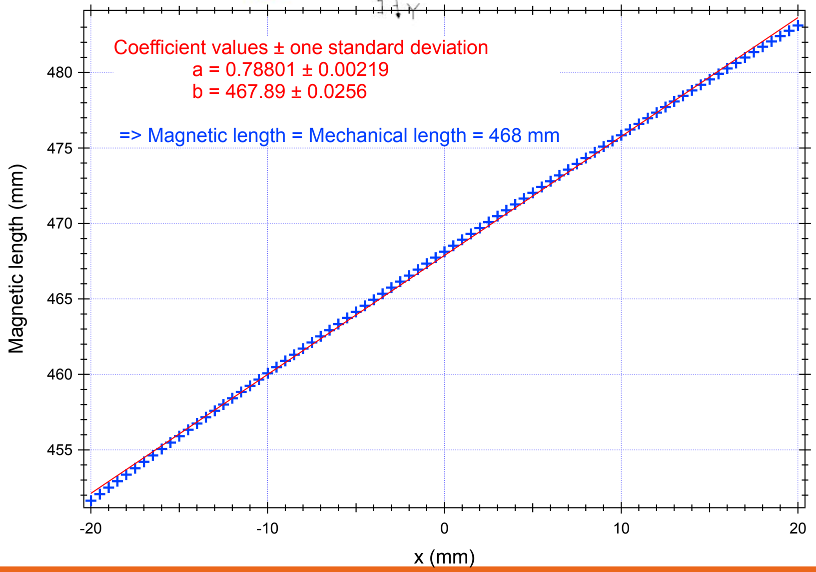
Magnetic design was finished for the arc bending magnet R=1192 mm

Arc bending magnet status – R = 596mm

Same way of design for R=1192 mm-V3 model.
Use of shims optimized for 455MeV (0.88 mm) and studies to optimize chamfer







Magnetic length = mechanical length along the central trajectory with a chamfer of 51.1 mm

Quadrupole status

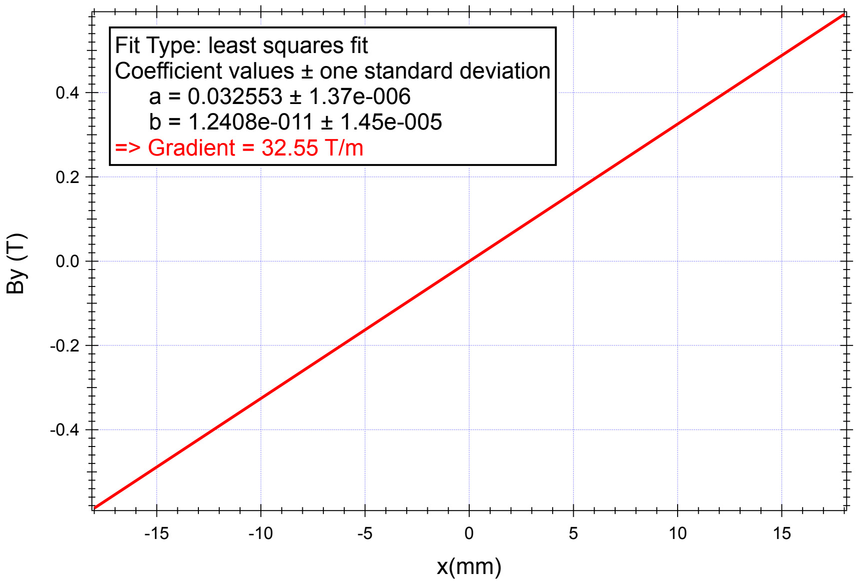
Main results :

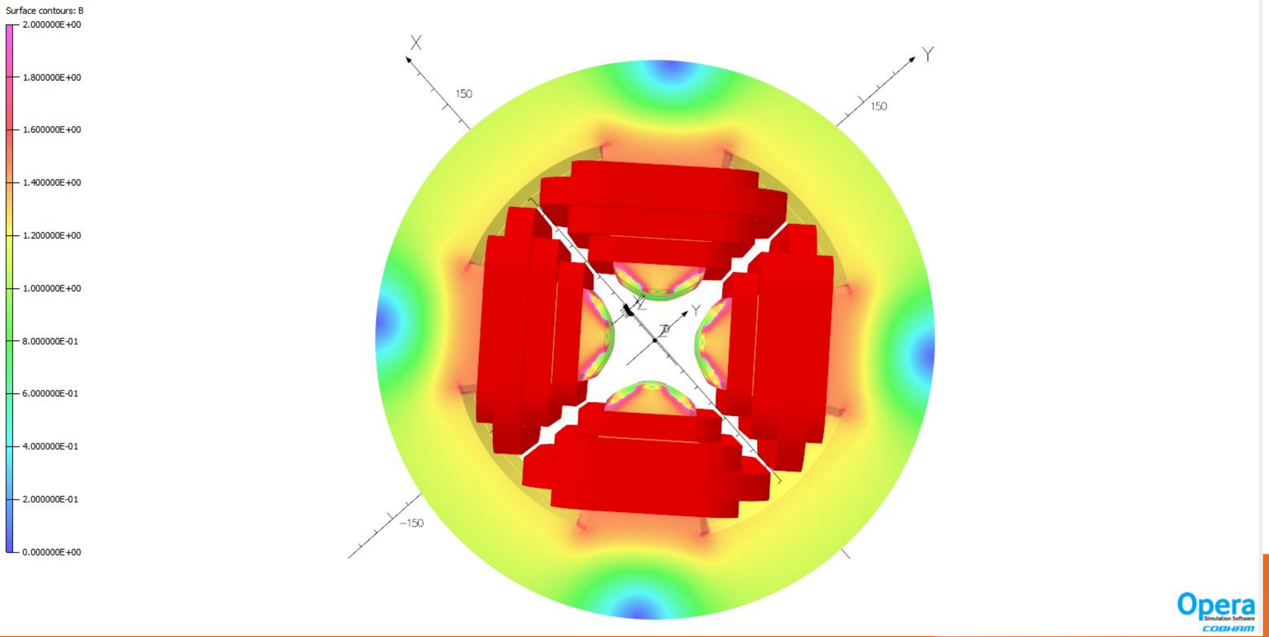
2D and 3D design

Feasibility has been done to get a gradient higher than 30 T/m (32.55 T/m) with a diameter of 250 mm

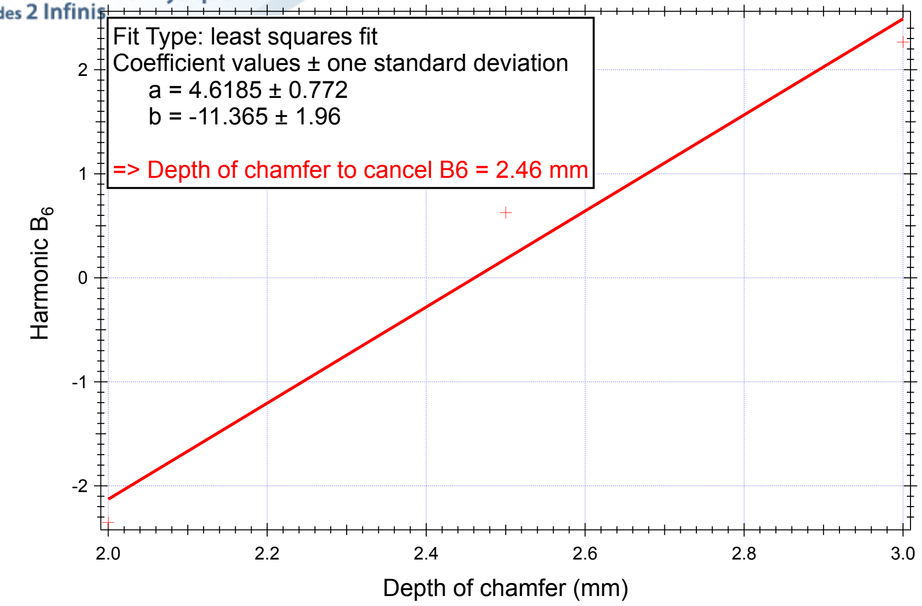
Cancellation of multipolar component is given with a chamfer of 2.46 mm depth

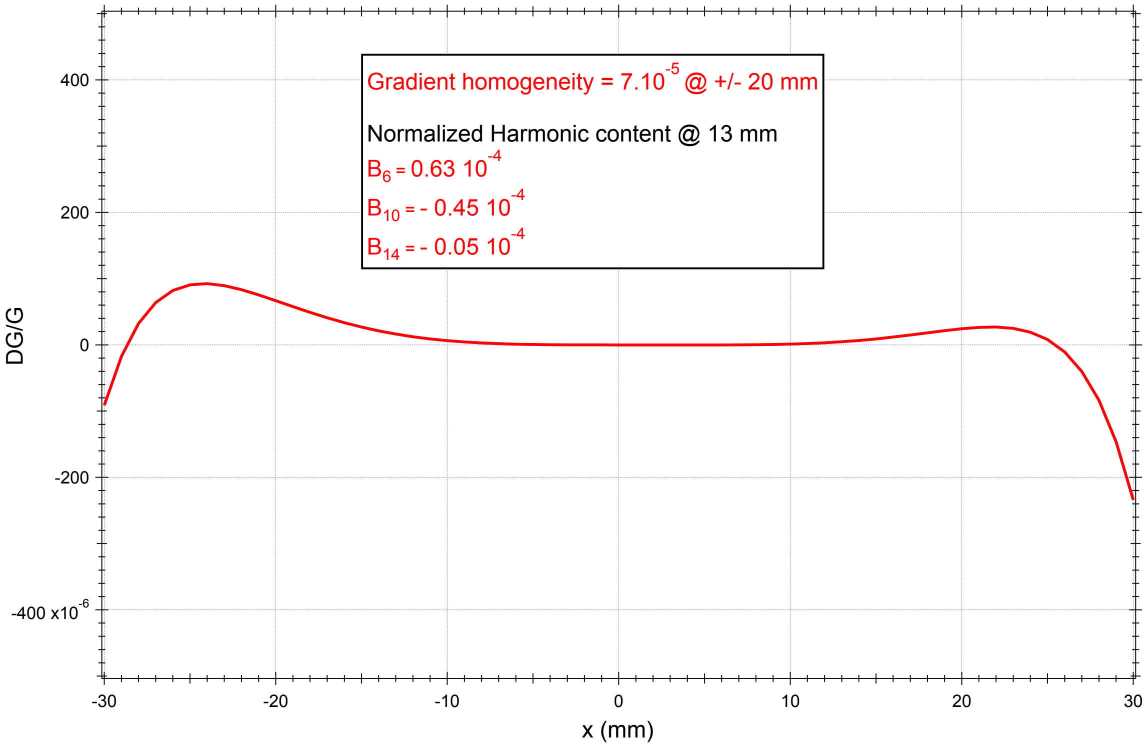
Quadrupoles designed and optimized with the first lattice parameters





Quadrupole status





	Harmonic @ 13 mm
B6/b2	**$0.63\ 10^{-4}$**
B10/b2	**$-0.45\ 10^{-4}$**
B14/b2	**$-0.05\ 10^{-4}$**
B18/b2	**$-0.003\ 10^{-4}$**

Switchyards magnet status

Requirements & Constraints :

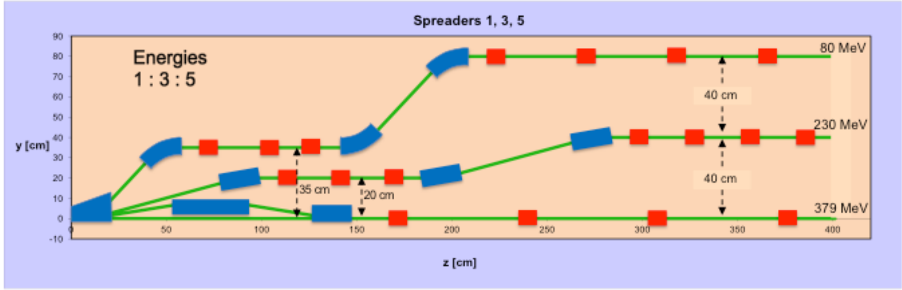
An H-magnet design was chosen for the dipoles in order to minimize stray fields given the close proximity of the four beamlines. The maximum field is restricted to 6 kG in order to limit flux leakage out of the central pole iron as for CBETA project.

Main results :

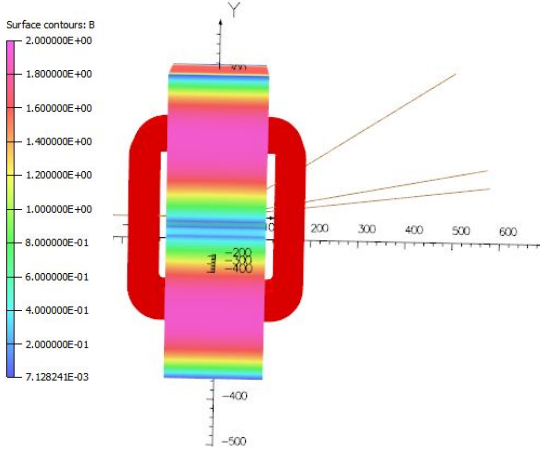
- 3D preliminary design
- Trajectory at 80 MeV – 230 MeV and 380 MeV is matched
- Feasibility is done but iron saturated.

  => Need to check if mechanical length can be increased.

  => Need to adjust magnetic length with mechanical lengh



	Energy (MeV)	Brho (T.m)	Angle (deg)	Bl (T.m)	Vertical coordinate of beam axis (mm) at z=400 (mm)/spreader	Distance between beams z=400 (mm)	Vertical coordinate of beam axis (mm) at z=500 (mm)/spreader	Distance between beams z=500	Vertical coordinate of beam axis (mm) at z=800 (mm)/spreader	Distance between beams z=800
Arc 1	80	0,269	41	0,19217	347,71		434,64		695,43	
Arc 3	230	0,769	14,32	0,19217	102,11	151,54	127,63	307,01	204,21	491,22
Arc 5	380	1,269	8,67	0,19217	61,03	43,90	76,29	51,35	122,06	82,15



New collaboration with BINP – Y. Pupkov, A. Starostenko - CremlinPlus project

Summary of Magnet inventory – New lattice

6 arcs : 80, 155, 230, 305, 380, 455 MeV beams

First lattice : Each arc contains :

4 dipoles, powered in series within that arc ,

114 quadrupoles, which are powered individually.

46 spreader/combiner dipoles, which are powered individually.

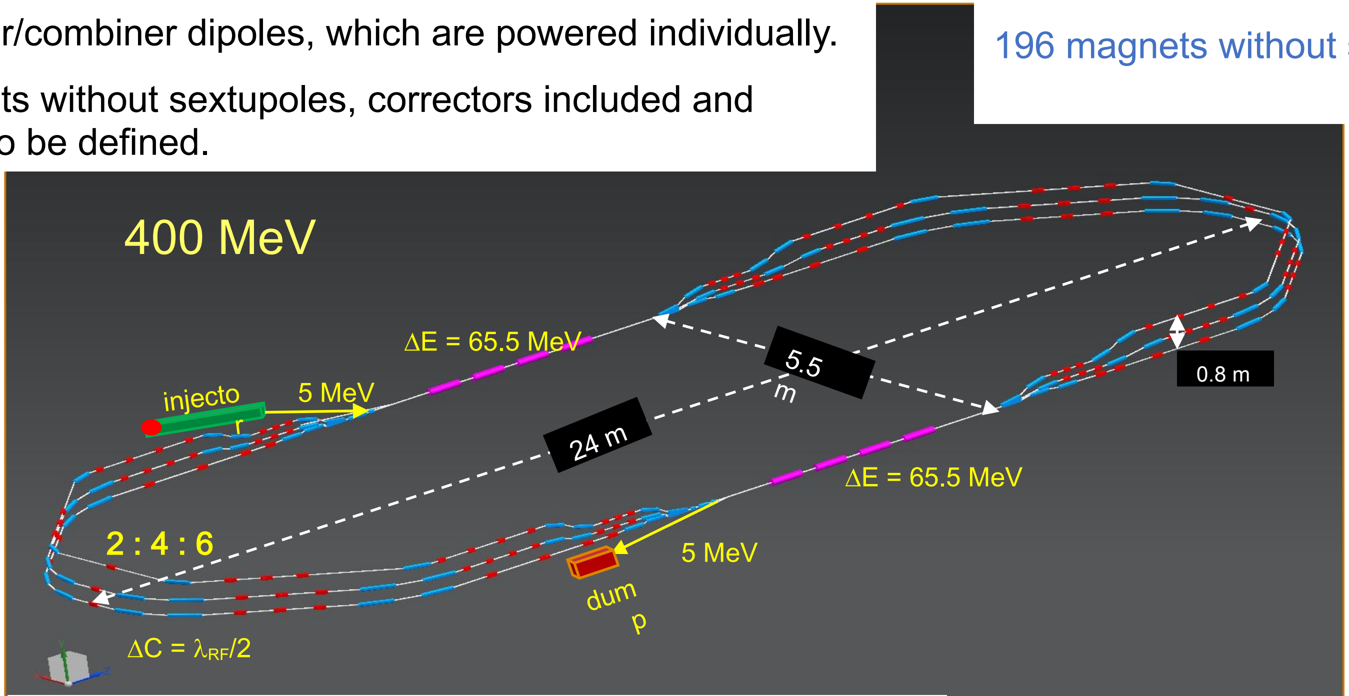
184 magnets without sextupoles, correctors included and octupoles to be defined.

New lattice : See Alex Bogacz presentation

6 dipoles/arc (30° vs 45°)

2B-Com magnets

196 magnets without sextupole and octupole magnets



Courtesy to Alex Bogacz ERL'17, CERN, June 20, 2017

Requirements and Constraints Change

New Lattice

Same constraints as the first lattice

Arc Bending Magnets

Features of arc bending magnets

Quantity	**18 + 1** (pre-serie)	**18 + 1** (pre-serie)
Rotation angle	**30°**	**30°**
Radius of curvature	1192 mm	596 mm
Main field B_0	1.25 - 1.3 T	1.25 - 1.3 T
Gap	40 mm	40 mm
Good field region	+/- 20mm	+/- 20mm
Mechanical length	660 mm	330 mm
Current max.	Not defined	Not defined
Beam energy	From 305 to 455 MeV	From 80 MeV to 230 MeV

No Critical Points to highlight, compared to the first lattice
If issues met to design with the 45° model, use of a model without curvature

Arc Quadrupoles

Features of quadrupoles magnets

Quantity	114 + 1 (pre-serie)
Magnetic length	100 - 200 mm
Main gradient G_0	**42T/m**
Gap	40 mm
Good field region	+/- 20 mm
Height	250 mm
Beam energy	From 50 to 400 MeV

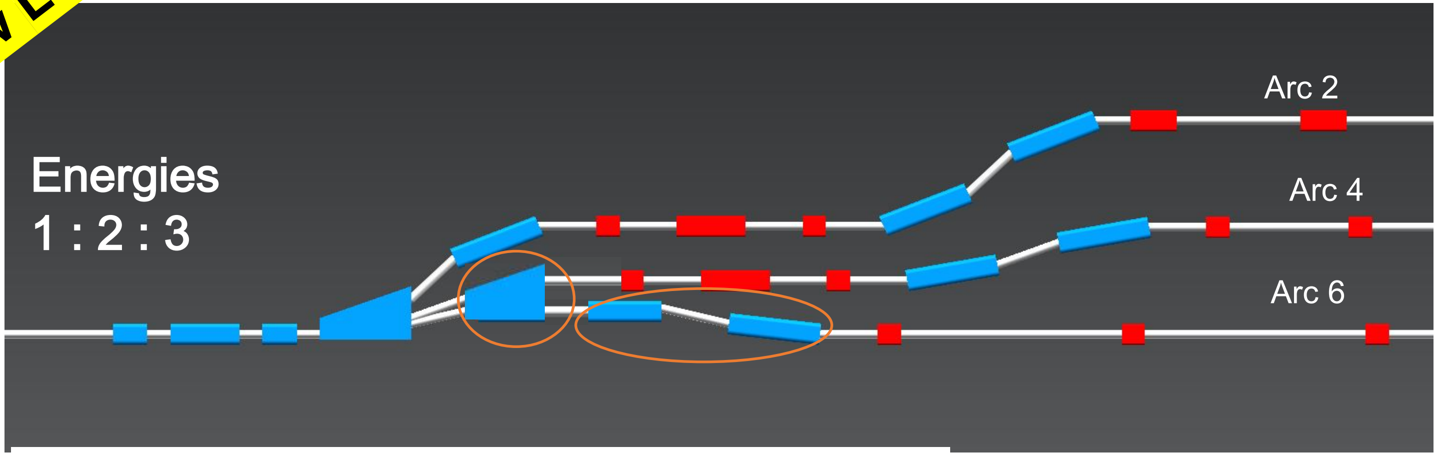
Critical Points : Gradient of 42 T/m

Solutions to study :

1) Increase the mechanical length => allow to increase current intensity
2) Increase the height => more space to insert coils and prevent saturation of the iron
3) Decrease the radius (15mm) only for the quadrupoles needing this high gradient

Requirement and Constraints

New Lattice



Courtesy to Alex Bogacz PERLE Monthly Meeting – 15 May 2020

- Use of a second B-com magnet
- Use of 2 steps Spread/Combiner configuration

⇒ Much better for magnet design in these region

Conclusion : WorkPackage Progress

WBS Level	WBS Description	Estimated status of completion (%)	Deliverable responsibles	Critical points	Response responsible
5.1	**Arc Magnet**		C. Vallerand (IJCLab) P.A Thonet (CERN)	Validate the new lattice (A. Bogacz) as the new baseline	Change Control Board
5.1.1	*Bending magnet*		CV, PAT		
5.1.1.1	Design (calculations)	100% - first lattice 0% - new lattice	CV, PAT	Check the possibility to use the 45° arc bending magnet design for the new angle deviation 30°	C. Vallerand
5.1.2	*Quadrupole*		CV, PAT		
5.1.2.1	Design (calculations)	100% - first lattice 60% - new lattice	CV, PAT	Check the possibility to reduce the gap to 30mm for only strong gradient quadrupoles (42T/m) and keep 40mm for others	A. Bogacz
5.2	**Spreaders & combiners magnets**		C. Vallerand (IJCLab) P.A Thonet (CERN) A. Starostenko (BINP)	Define features including homogeneity requirements (integrated homogeneity, flat field…)	A. Bogacz
5.2.1	*Splitter B-com*		CV, PAT, AS	Check the possibility to increase the magnetic length	A. Bogacz
5.2.1.1	Design (calculations)	20%	CV, PAT, AS		
5.2.2	*Chicane bending magnet*	0%	CV, PAT, AS	Define features	A. Bogacz
5.3	**Injection and Extraction magnets**	0%	P.A Thonet (CERN) C. Vallerand (IJCLab)	Define features	A. Bogacz
5.4	**Multipoles**	0%	C. Vallerand (IJCLab) P.A Thonet (CERN)	Define number and features	A. Bogacz

Conclusion : Short-term milestones for TDR in 2022

Description	Responsibles	Date
Validation of the new baseline	Change Control Board	T0
Calculation design complete for arc bending magnet (including cross-talk simulations, without including tolerance study results)	C. Vallerand, P. A Thonet	T0+2months
Calculation design complete for quadrupoles (without including tolerance study results)	C. Vallerand, P. A Thonet	T0+2 months
Requirement document complete for spreader/combiner magnets, multipole magnets and inj.extraction magnets	A. Bogacz	T1
Calculation design complete for switchyard magnet (2 B-com) - CremlinPlus	C. Vallerand, P. A Thonet, A. Starostenko	T1+4 months
Mechanical design complete for switchyard magnet - CremlinPlus	C. Vallerand, P. A Thonet, A. Starostenko	T1+6 months
Fabrication of one prototype - CremlinPlus	C. Vallerand, P. A Thonet, A. Starostenko	T1+20 months
Prototype magnetic measurements - CremlinPlus	C. Vallerand, P. A Thonet, A. Starostenko	T1+22 months
Calculation design complete for chicane bending magnets	C. Vallerand, P.A Thonet	T1+18months
Calculation design complete for multipoles	C. Vallerand, P.A Thonet	T1+18months
Calculation design complete for injection and extraction magnets	P.A Thonet, C. Vallerand	T1+24months
Calculation design complete for arc bending magnets and quadrupoles with tolerance study results	C. Vallerand, P. A Thonet	T1+24 months
Requirement document complete for all power supplies	P.A Thonet, C. Vallerand	T1+24 months
WP Risk Analysis	C. Vallerand, P. A Thonet	T1+24 months
Cost estimation complete	C. Vallerand, P.A Thonet	T1+24 months

Thank you for your attention

and

Thanks to Alex Bogacz

PERLE | Powerful energy recovery linac experiments