PERLE | Powerful energy recovery linac experiments

Preliminary studies : Quadrupoles & Arc - Splitter dipoles

P.A THONET (CERN) - C. VALLERAND (LAL)

27th June 2018

CERN

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

PERLE Powerful energy recovery linac experiments

Overview

- **Summary of magnet inventory**

- **<u>Arc region :</u>**
  - **Quadrupole magnets :**
    - Requirements & constraints
    - 3D design
  - **Arc bending magnets :**
    - Requirements & constraints
    - 3D design

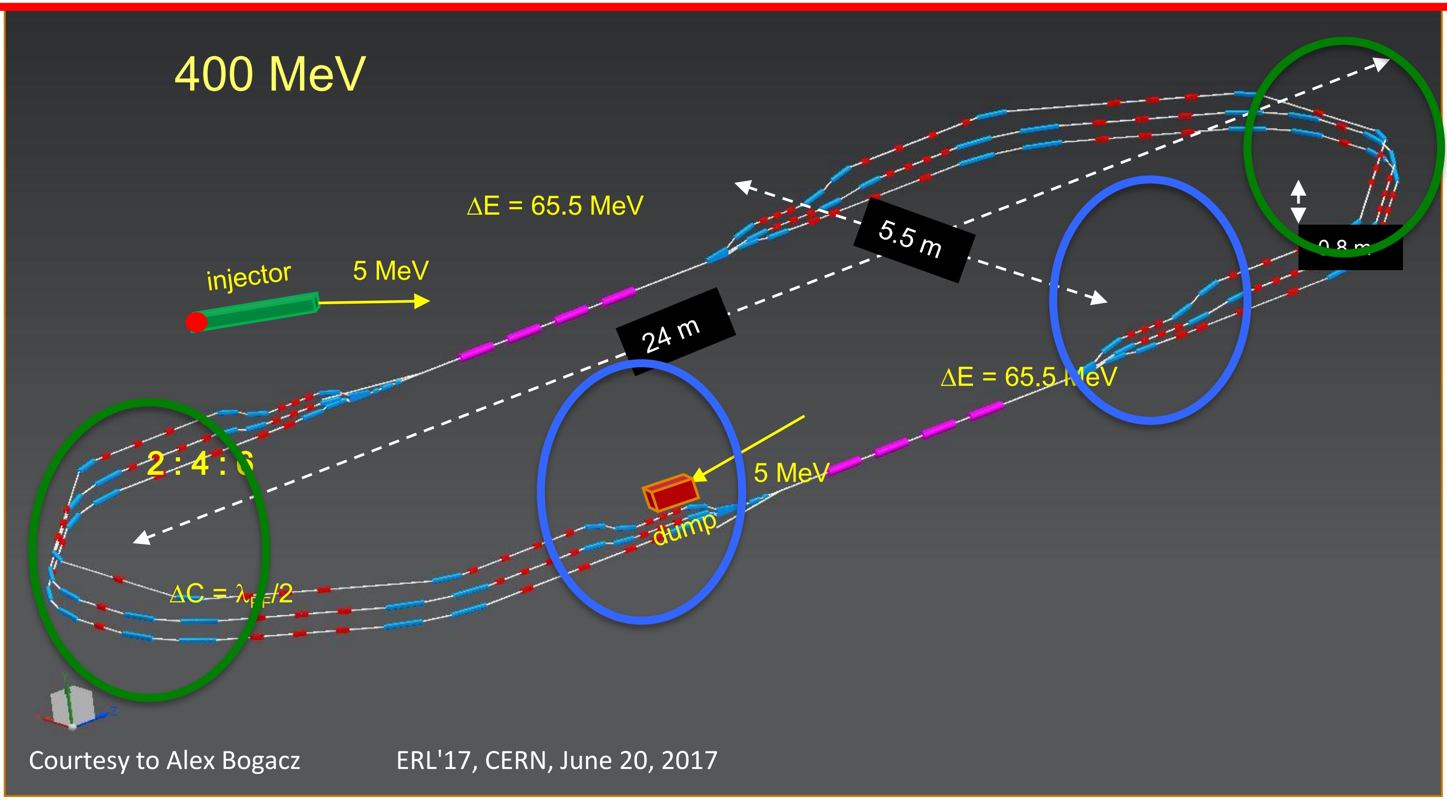
- **<u>Spreader region :</u>**
  - **Splitter magnet**
    - Requirements & constraints
    - 3D preliminary design

- **Points to be highligthed**

Summary of magnet inventory

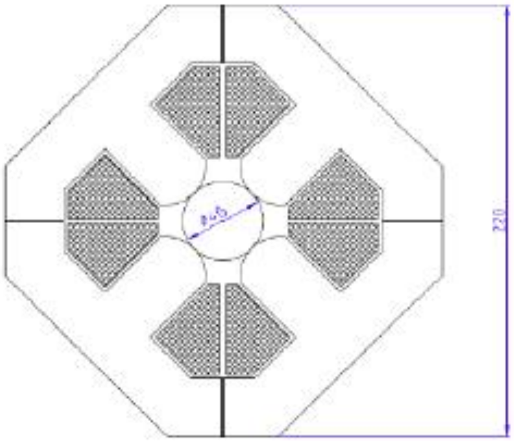
- 6 arcs, one each for 80, 155, 230, 305, 380, 455 MeV beams.
- Each arc contains : 4 dipoles, powered in series within that arc
  114 quadrupoles, which are powered individually
  Number of sextupoles and correctors to be defined
- 4 splitters and 46 spreader/recombiner dipoles are placed at each end of the linacs in order to provide/suppress the vertical separation between the beams at different energies.

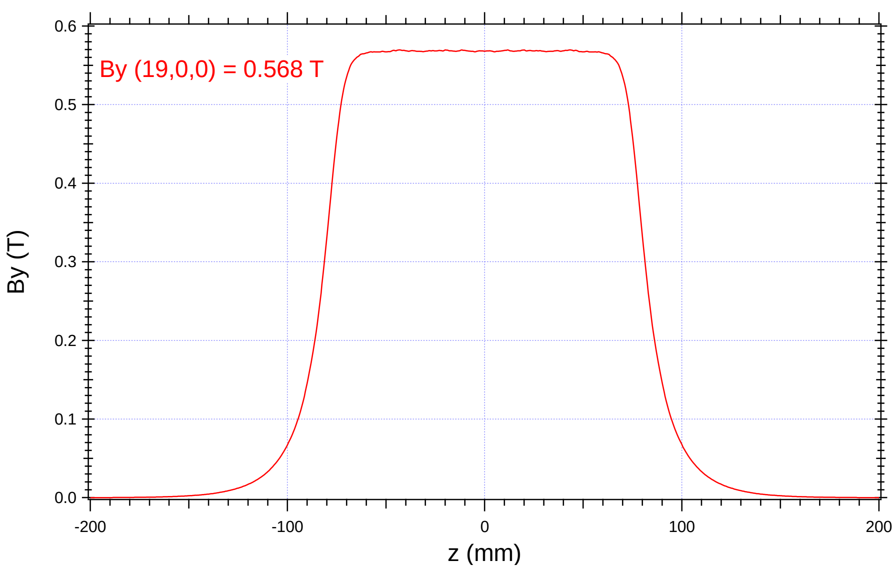
168 magnets without including sextupoles with correctors
=> Need to optimize design of magnets by considering cost and dimensions as a key parameter

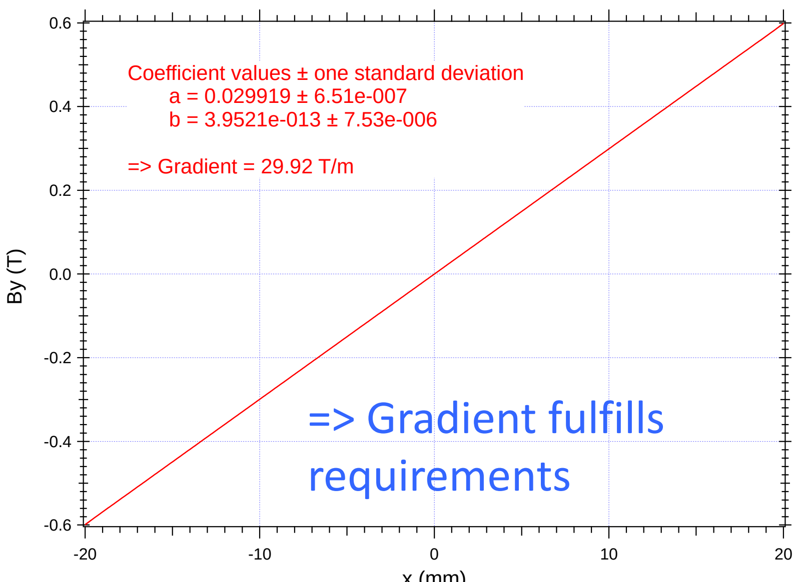


Quadrupoles of arc : features and requirements

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	+/- 20mm
Beam energy	From 50 to 400 MeV



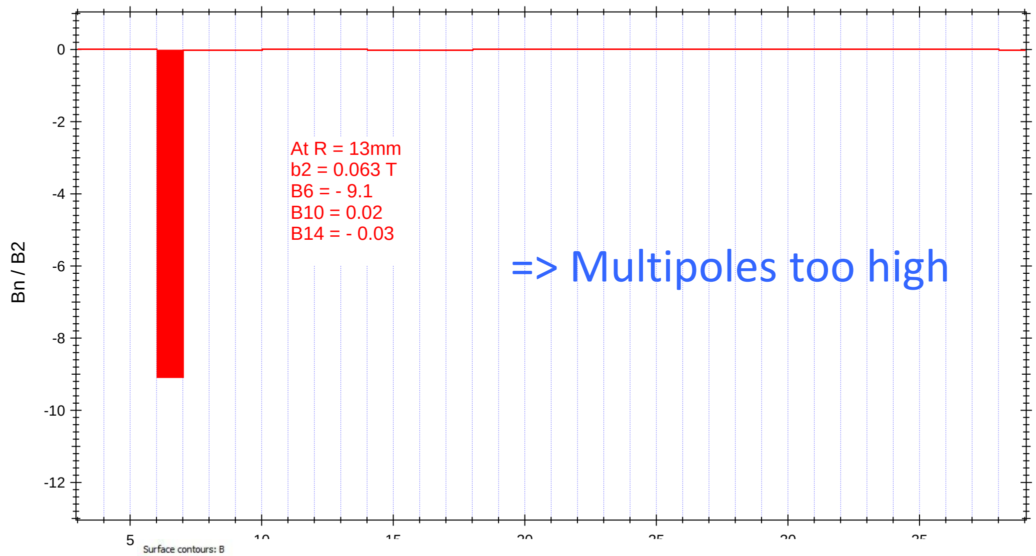


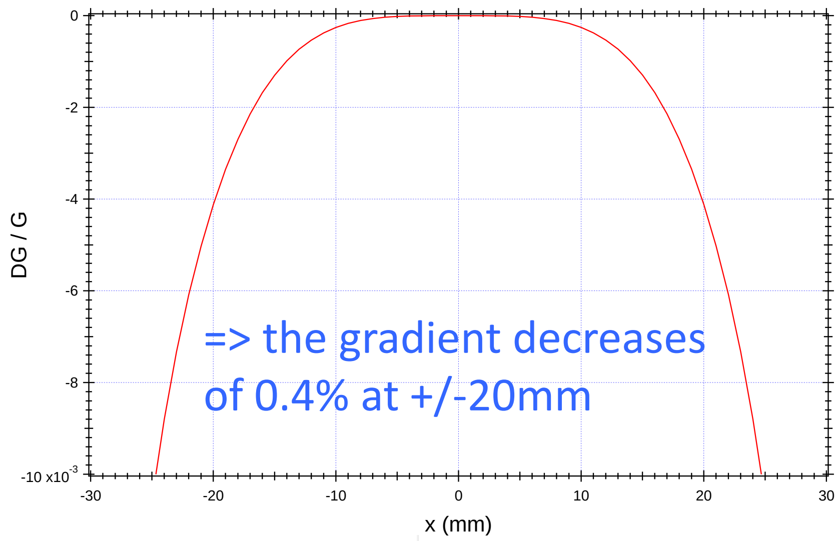


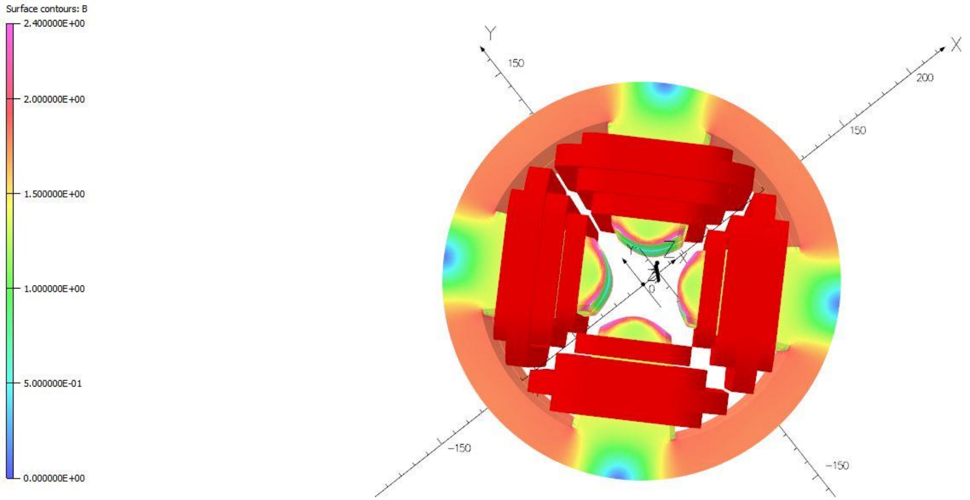
=> Gradient fulfills requirements

Preliminary design Qpole Diameter = 220 mm

- **BUT**

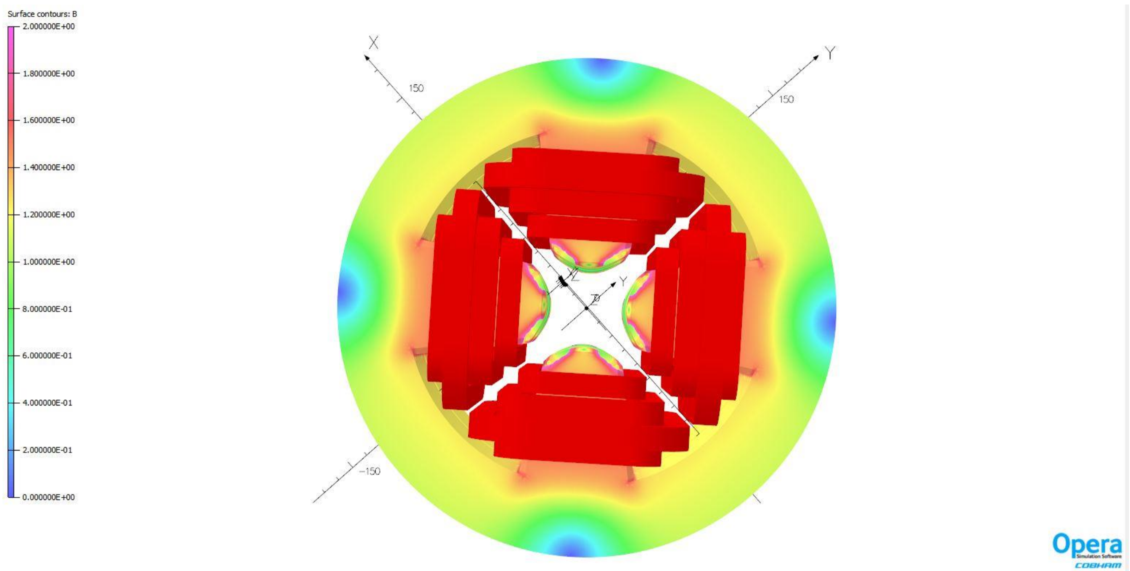


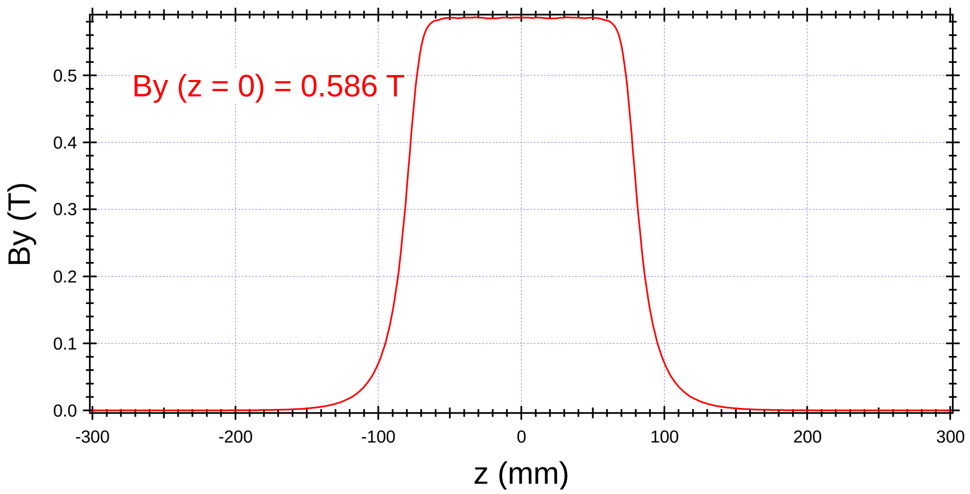


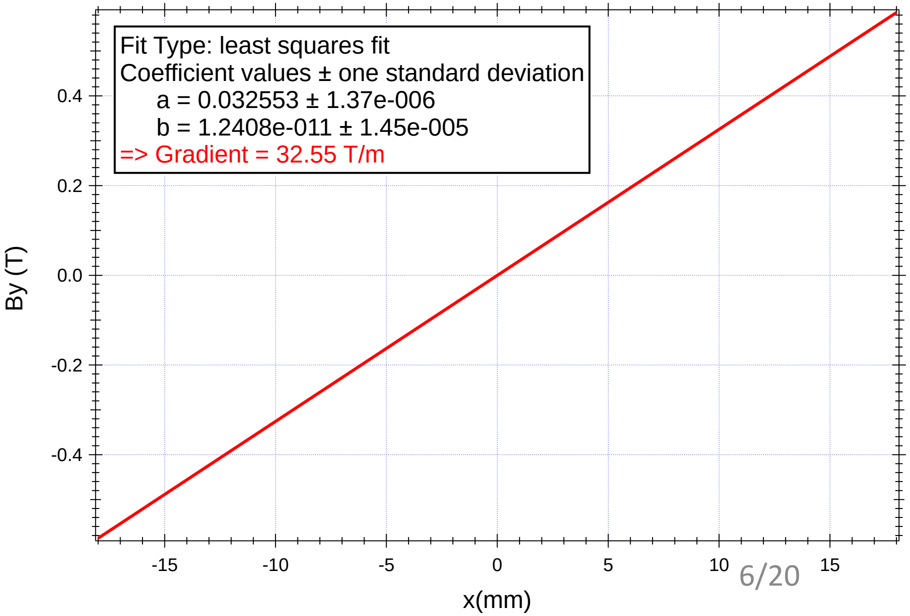


=> Iron totally saturated

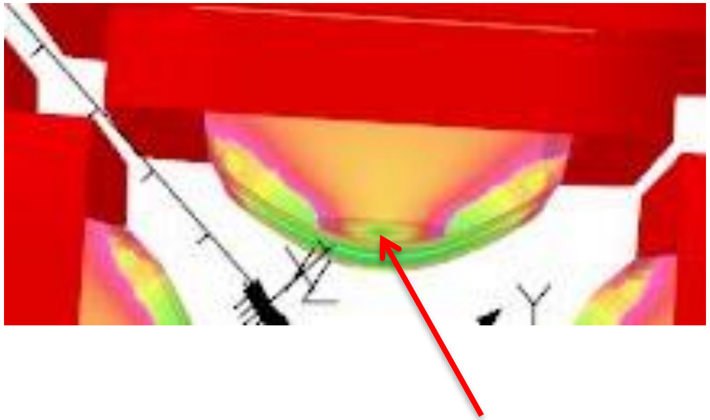
Optimisation Qpole with Diameter = 250 mm



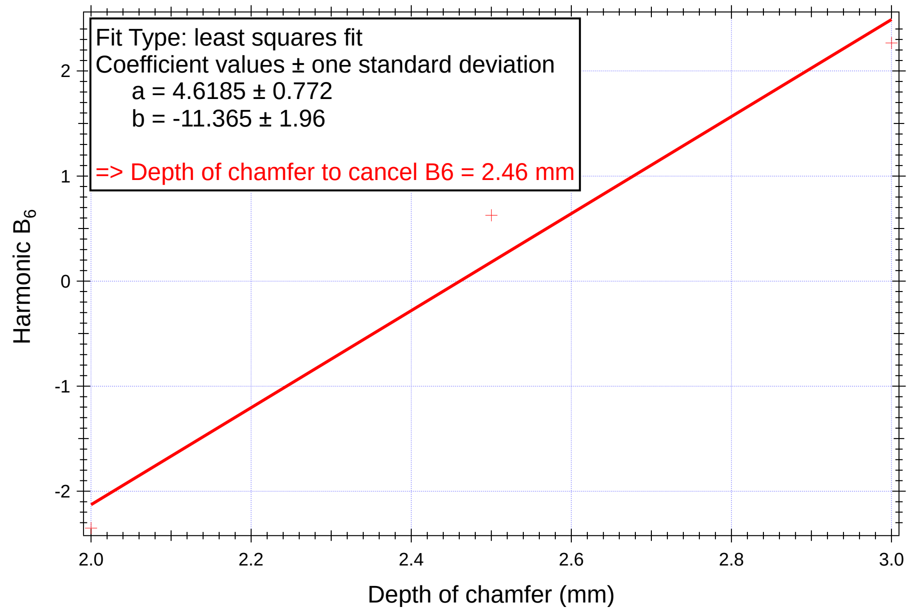




Optimisation Qpole with Diameter = 250 mm



Study of the chamfer deepness
at the entrance/exit of the pole



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

Conclusion :

Quadrupoles are designed and optimized :
- **By (0) = 0.586 T**
- **Gradient = 32.55 T/m > 30 T/m**
- **Harmonic content << 5.10^{-4}**

IF
diameter can be 250 mm instead of 220mm

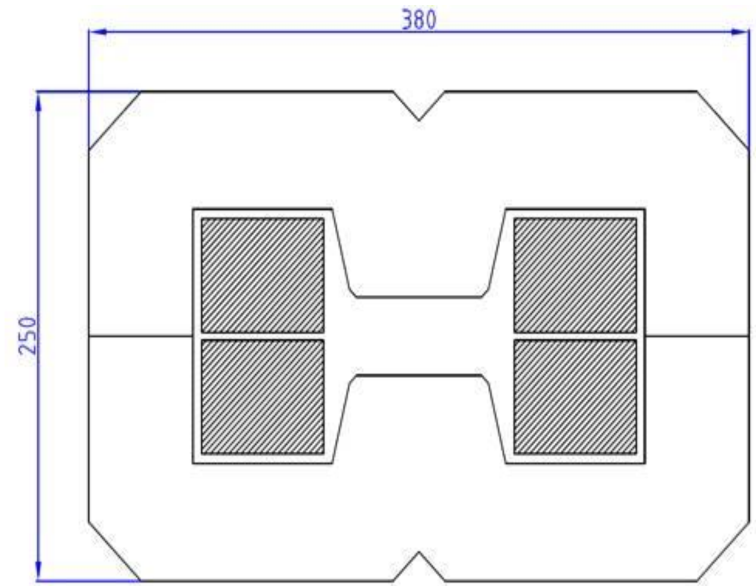
Arc bending magnets : Requirements & constraints

- 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 by [illegible]
- Cost minimization with a design of the arc magnets coupled to st[illegible] converters, the vacuum system and cooling as well as [illegible] with a 45° deflection

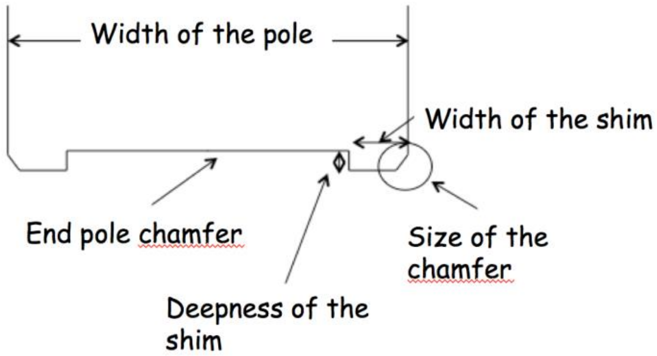
Challenge to highlight : Very compact bending magnet while keeping a reasonable current density for 6 arcs and using the same structure for Arc 1 up to 3 and for Arc 4 up to 6.

Features of arc bending magn[illegible]

Quantity	[illegible]	[illegible] 1 (pre-serie)
Ro[illegible]	[illegible]	45°
[illegible]	1192 mm	596 mm
[illegible]ain 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

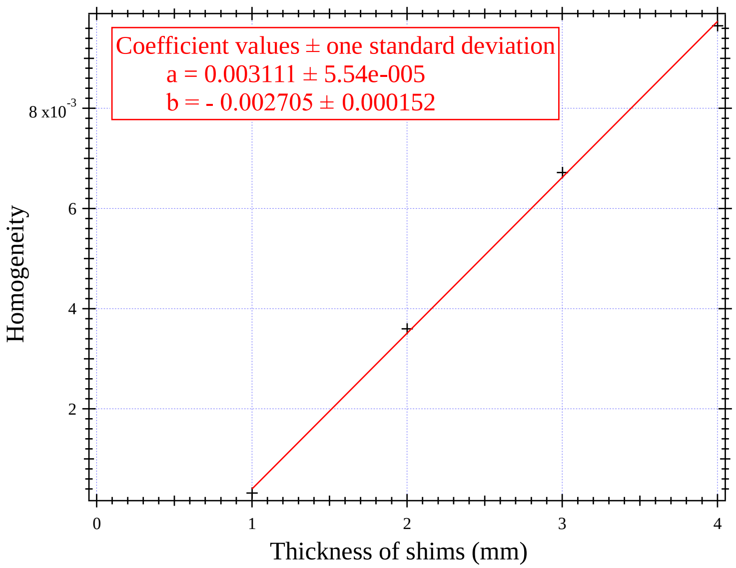


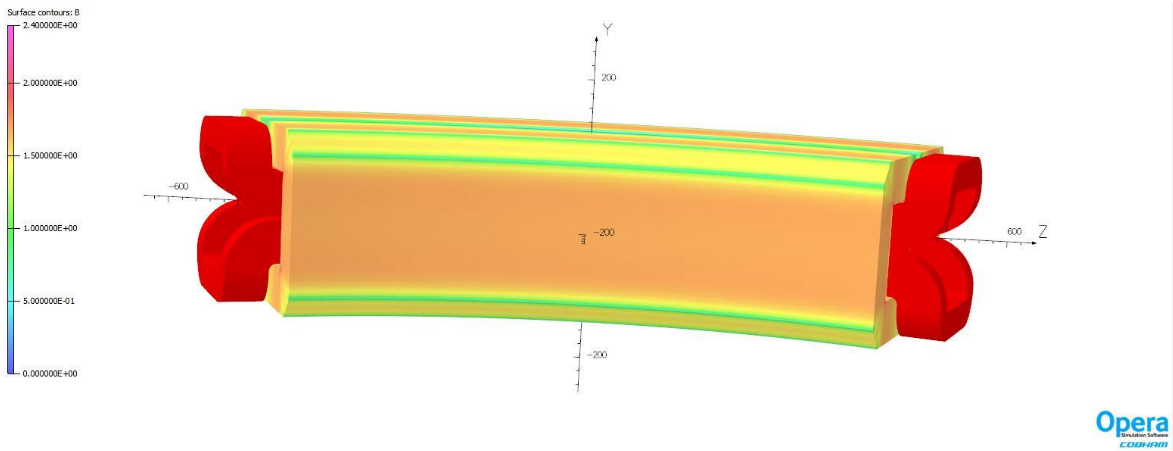
Preliminary results for R 1192mm



Improvements :

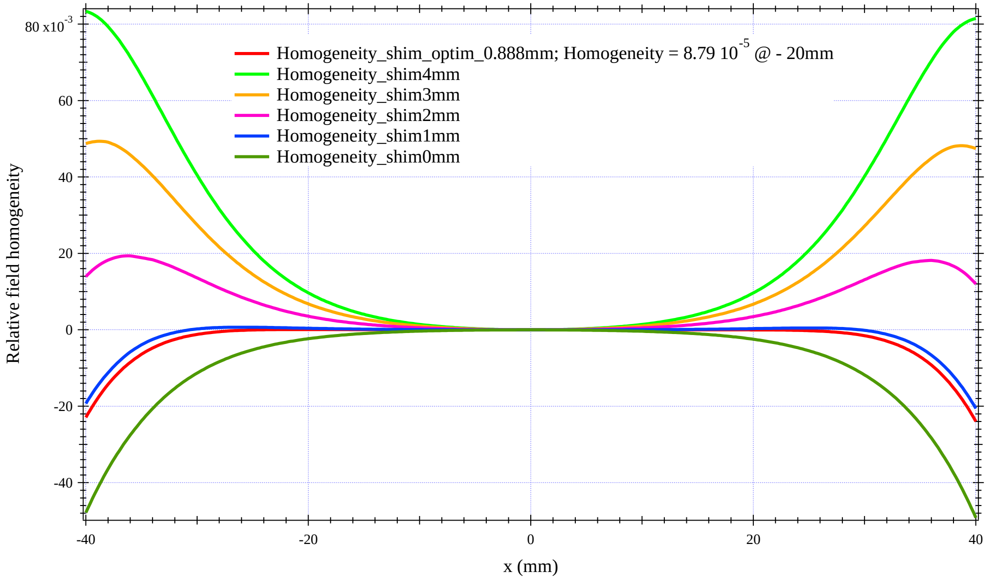
- Enlargement of the pole base width (50mm instead of 40mm) to desaturate iron
- Add-on of shims (10mm) to improve the homogeneity of field
- Height of coils allowing superposition
- Use of bedstead coils to get j < 7 A/mm^2

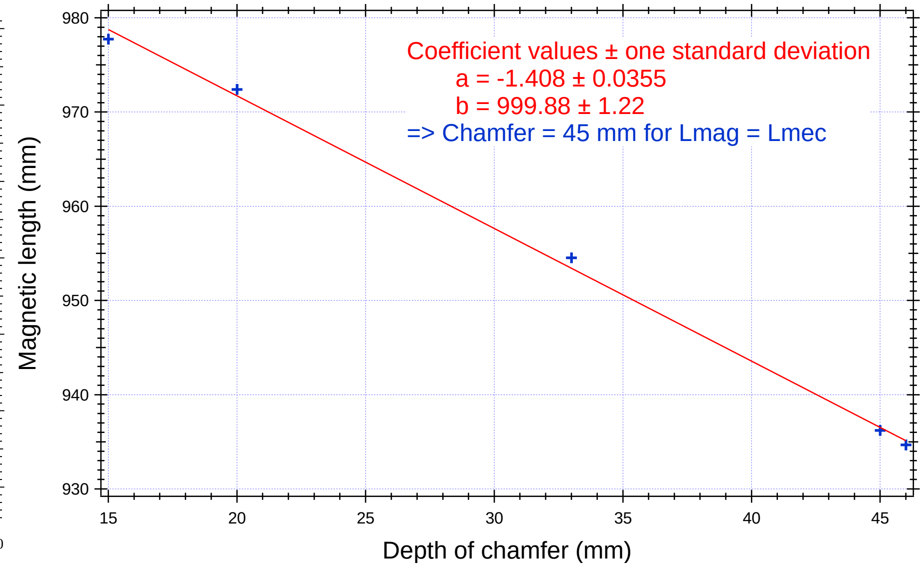


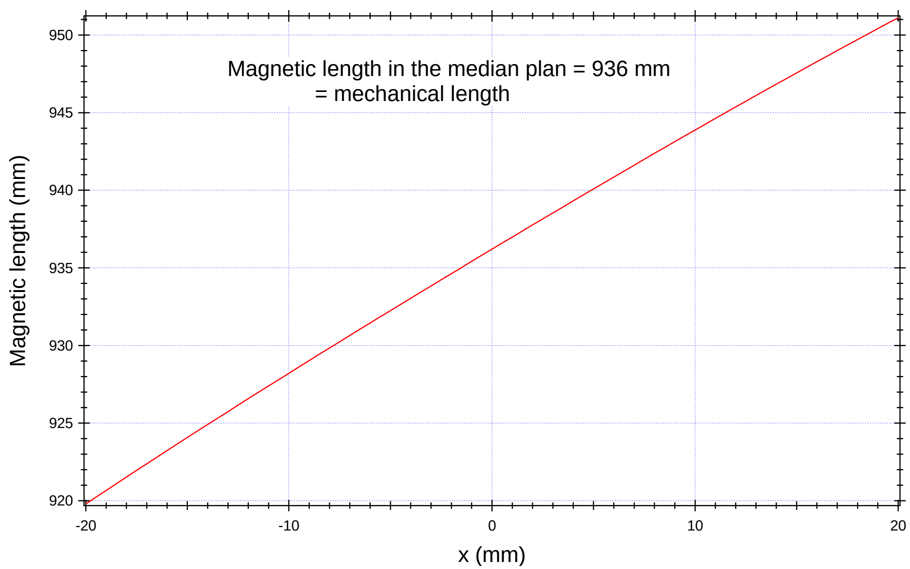


Simulation results with 4 thickness of shims to obtain a field homogeneity of 5.10^{-4} expected
By fitting, we obtained a thickness of 0.888mm

Preliminary results for R1192 @ 455 MeV







Conclusion in January :

Magnetic field = 1.26 T

Homogeneity 8.8 10^{-5} with a shim 0.88 mm < 5.10-4

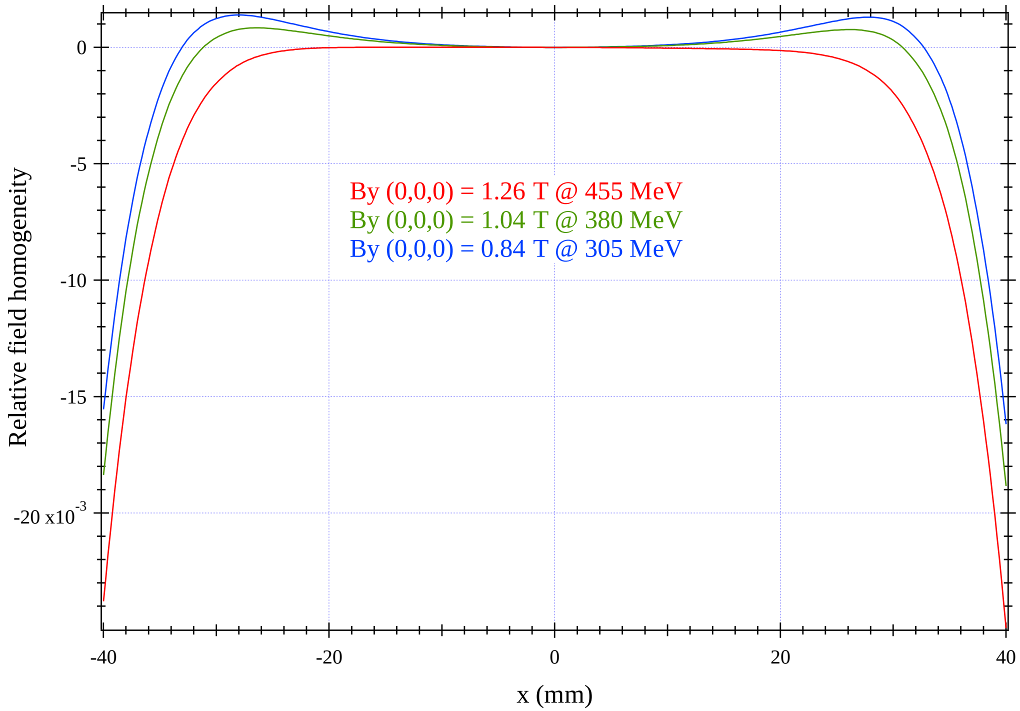
Magnetic length = Mechanical length = 936mm

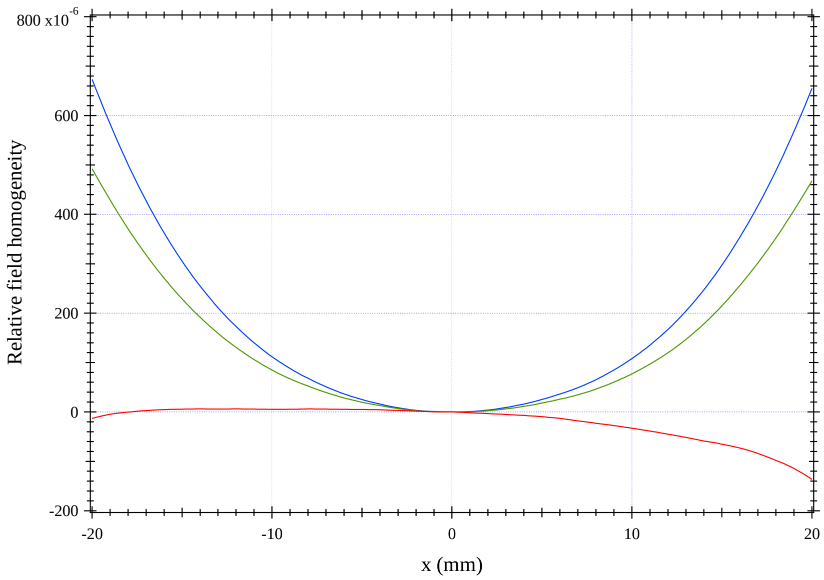
J = 5.5 A/mm^2

⇒ **Feasibility has been proved for using same structure for long radius**

Preliminary design for R = 1192 mm with shim 0.88 mm

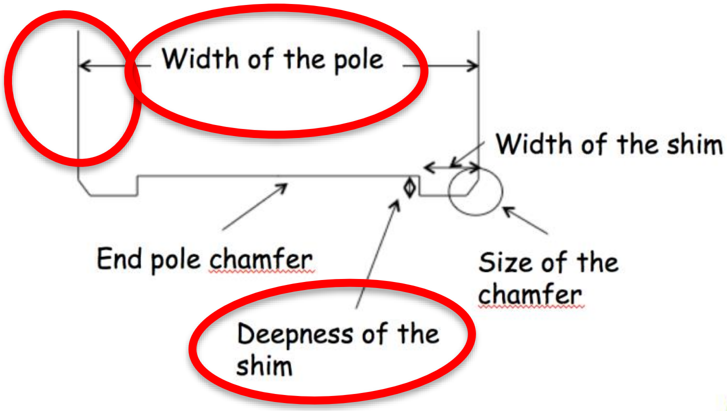
- **BUT :** Homogeneity of By(x) for 3 last arcs with the shim optimized for 455 MeV

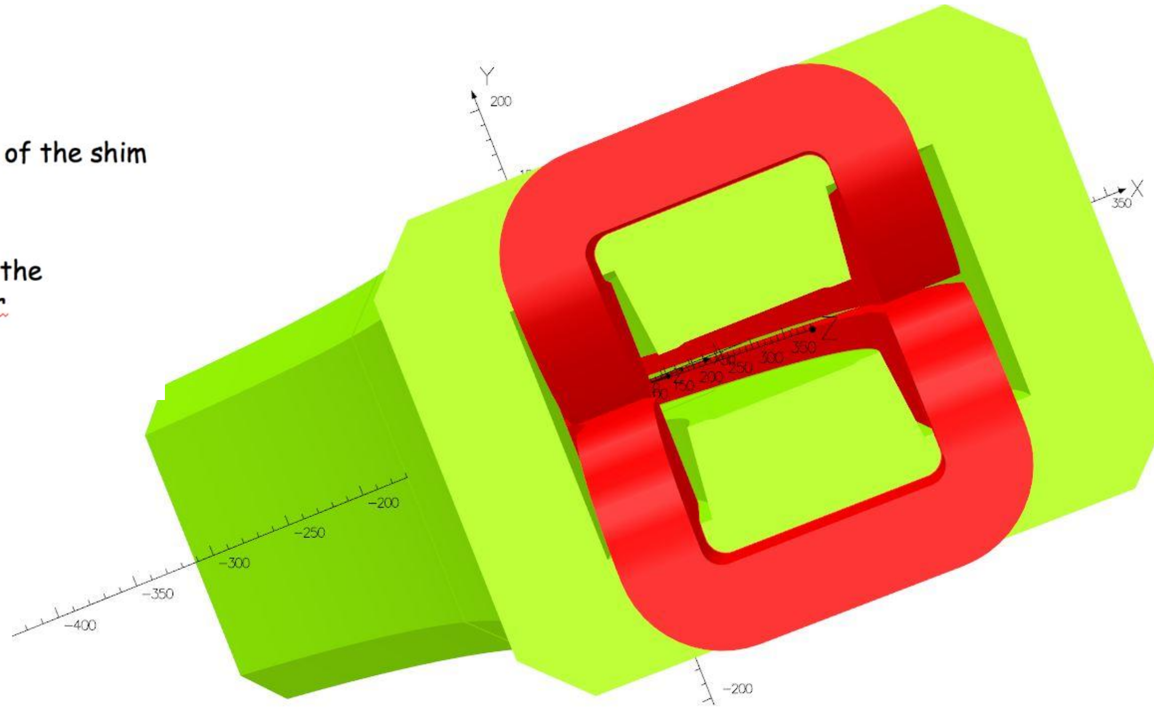




Shim optimized for 455 MeV doesn't match for others energies with this design of magnet.
$\Rightarrow$ Need to adjust shims for each beam energy or change the design to use a same shim.

Optimisation for keeping same shims





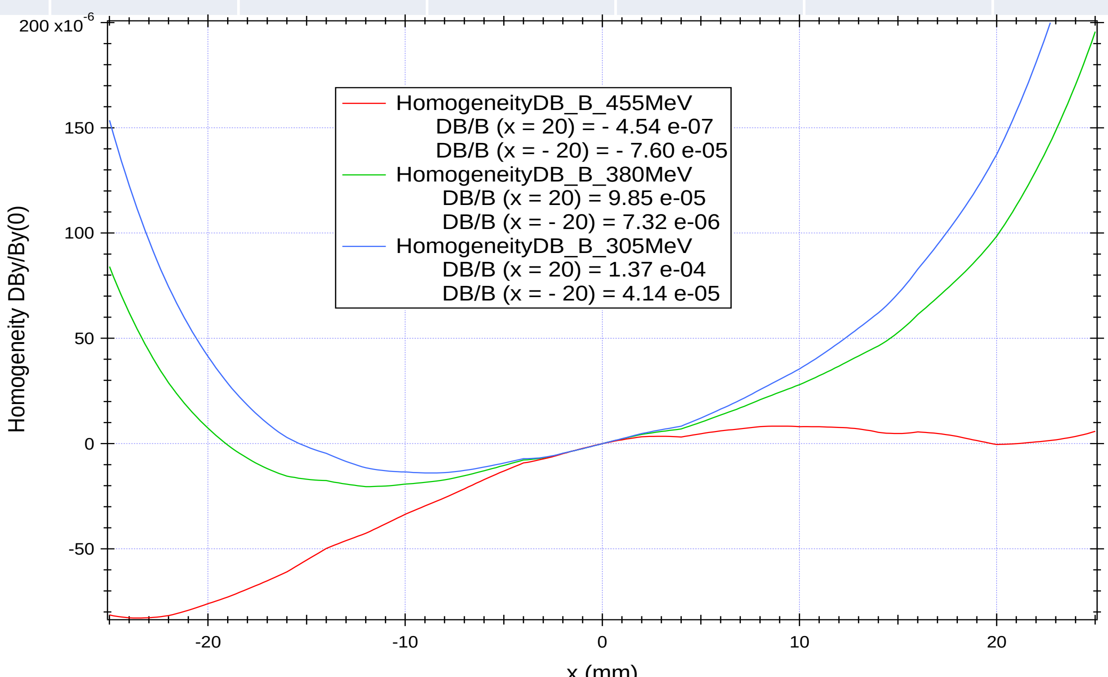
9 cases have been carried out for 3 energies 305 – 380 - 455 MeV :

- **Width of pole : 90 – 105 – 120 mm**
- **Deepness of the shim : 1 – 2 – 3 mm**

Optimisation for keeping same shims

- Results for 3 energies of homogeneity results vs depth shim

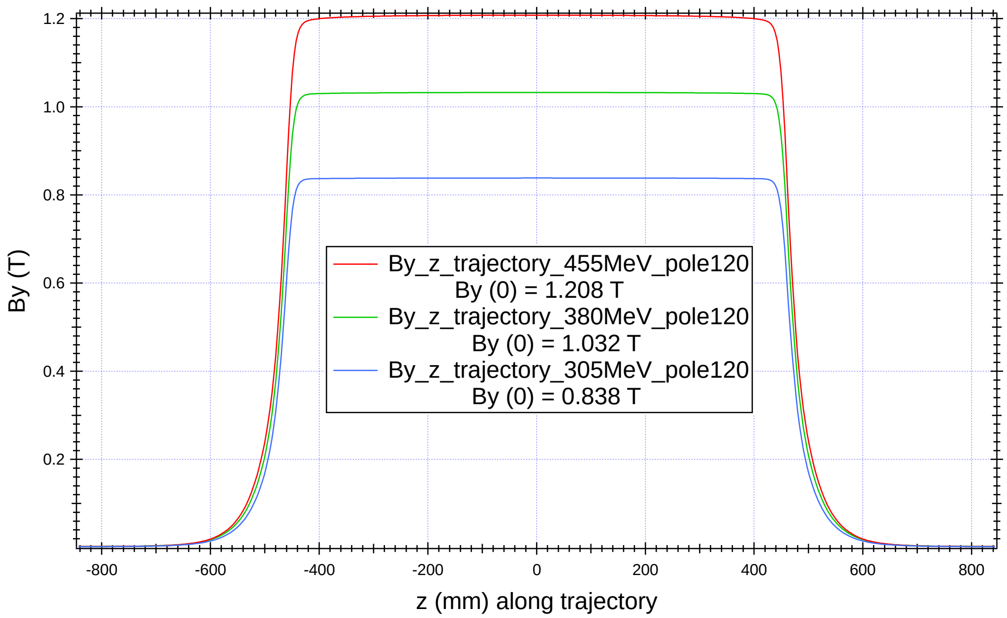
Depth shim (mm)	Homogeneity (*10^{-4}) with a pole width 90 mm @ 20mm			Homogeneity (*10^{-4}) with a Pole width 105 mm @ 20 mm			Homogeneity(*10^{-4}) with a pole width 120 mm @ 20 mm		
	305 MeV	380 MeV	455 Mev	305 MeV	380 MeV	455 Mev	305 MeV	380 MeV	455 Mev
1	9.2	6.5	-2.5	3.5	2.5	-8	1.4	1	0
2	45	40.5	26	15	13	9	5	4.4	3
3	86	78	53	28	26	18	9	8	6

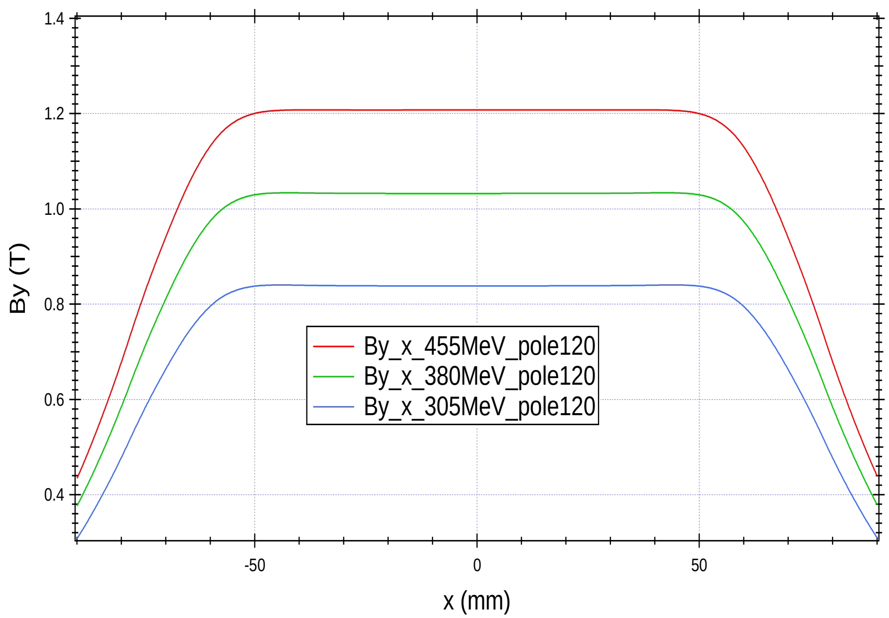


With a shim of 1 mm, Homogeneity << 5.10-4 for 3 higher energies

Optimisation for keeping same shims

- By(z) along the trajectory and By (x) for R 1192 mm with a shim =1 mm





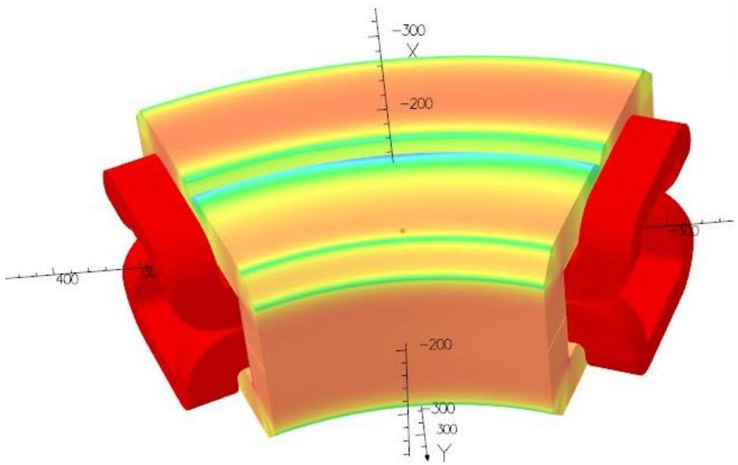
Conclusion :

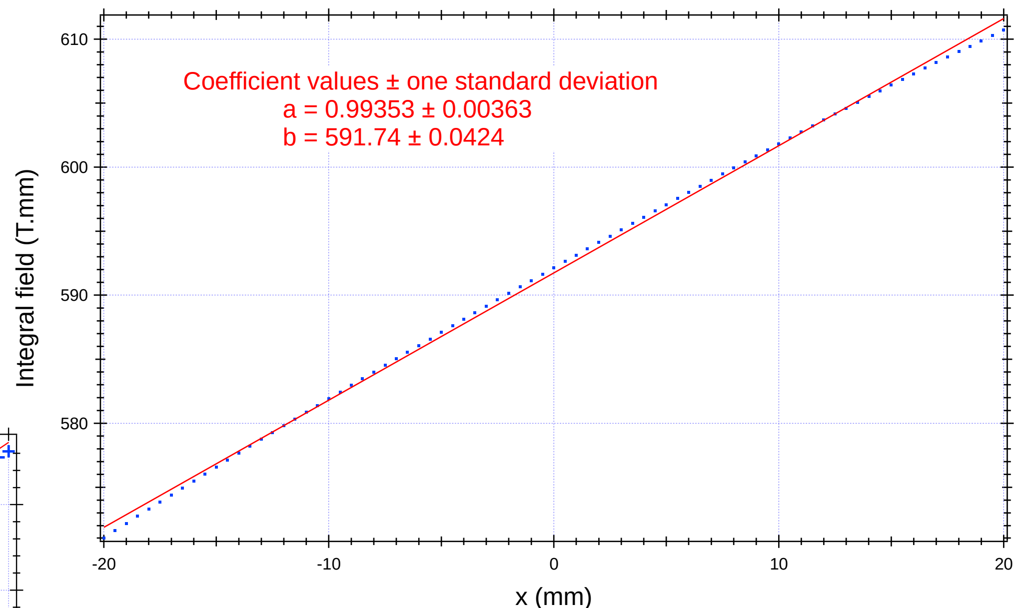
Shim is optimized for 3 energies to get a field homogeneity lower than 5. 10^{-4}

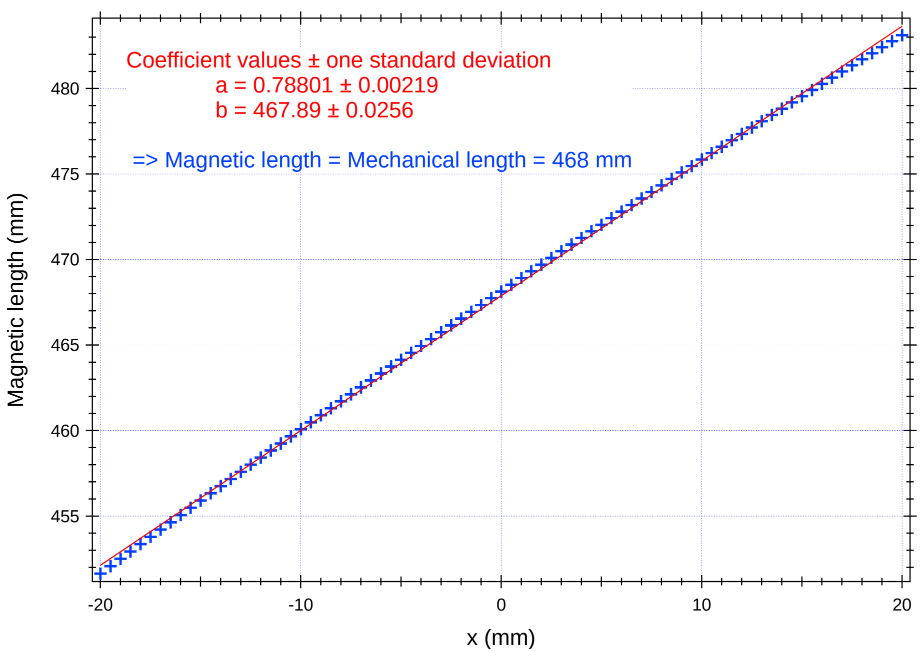
Magnetic design is done for the arc bending magnet R1192 mm

Preliminary design for R = 596 mm

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





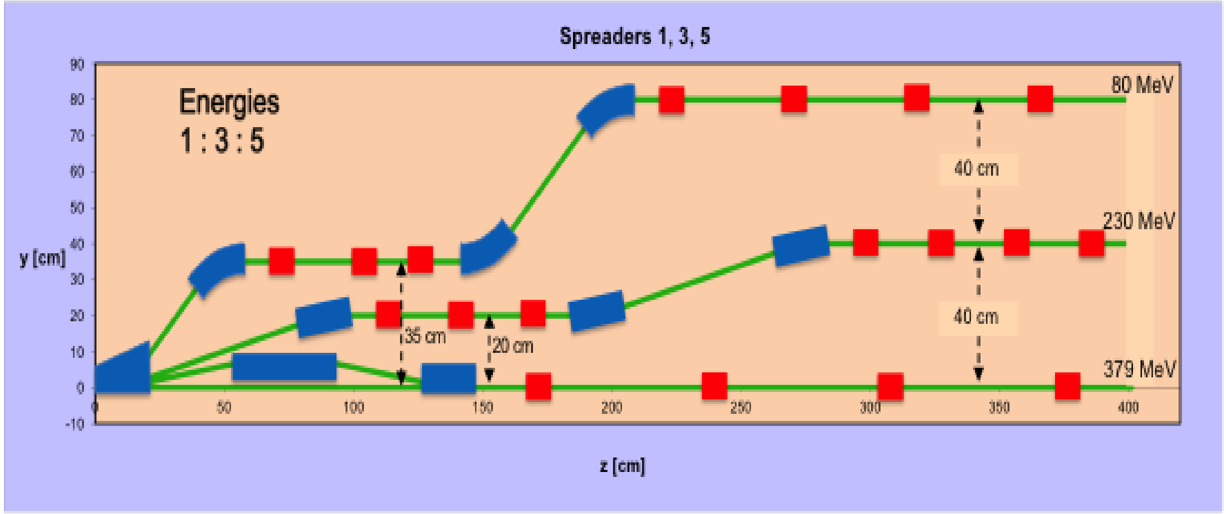


With a chamfer of 51.1 mm :
Magnetic length = mechanical length along the central trajectory
⇒ 1st model optimized for short radius
⇒ Need to check that shim 1mm is right for 3 lower energies

Remind : Spreader / Combiner dipole roles

- The spreaders and recombiners separate the bunches at different energies coming from the linac, in order to route them to the corresponding arc, and recombine them to the same orbit before entering the next linac.

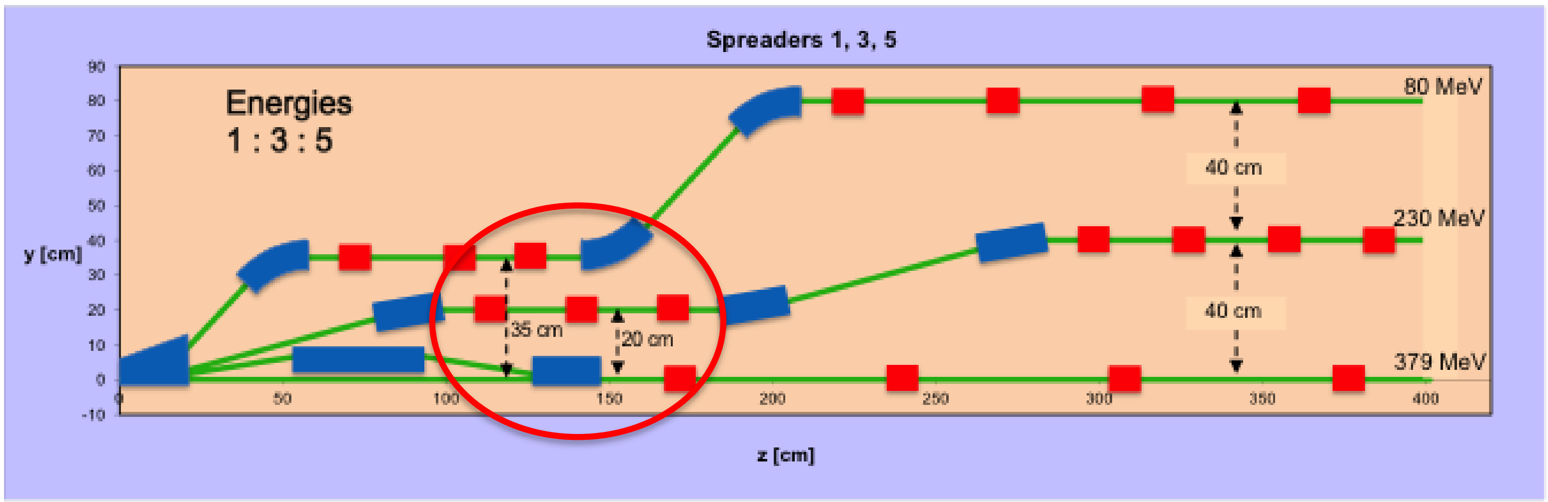
- The spreader consists of a vertical bending magnet that initiates the separation.



- The highest energy, at the bottom, is brought back to the horizontal plane with a chicane.
- The lower energies are captured with two-steps vertical bendings.

Spreader Requirements

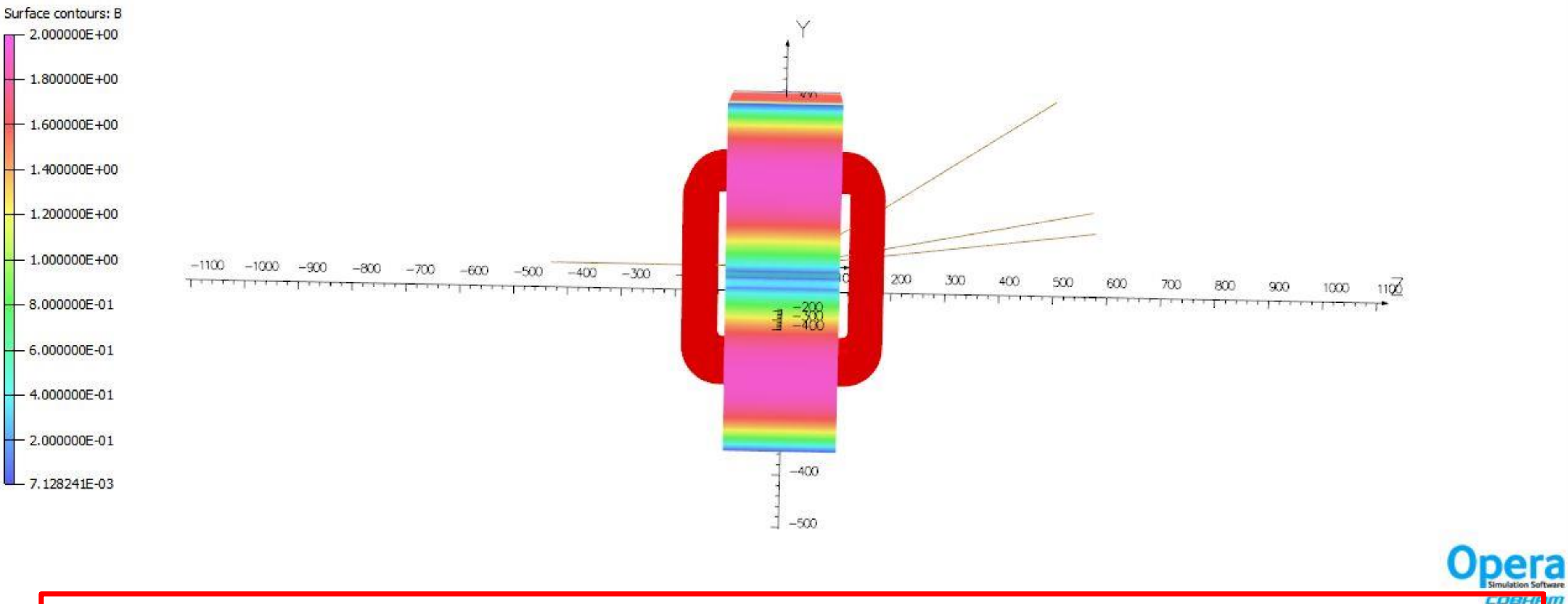
An H-magnet design was chosen for the dipoles in order to minimize stray fields given the close proximity of the four beamlines. The maximum field is restricted to 6 kG in order to limit flux leakage out of the central pole iron as for CBETA project.



	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

PERLE Powerful energy recovery linac experiments

Preliminary results for Spreader dipole



=> Trajectory at 80 MeV – 230 MeV and 380 MeV is correct.

⇒ Feasibility is done but need to go ahead simulations due to

- the saturation of the iron.
- the necessity to improve magnetic field homogeneity (1.10^{-3})
- the necessity to assure the design of following dipoles with these angles

PERLE Powerful energy recovery linac experiments

Conclusion

- Magnetic design of arc quadrupoles is optimized
- Magnetic model for long radius arc bending magnets is optimized
- Feasibility of splitter is done

What remains to do

- Finalization of short radius bending magnet design : 1 day if shim 1mm is adapted – 4 days
- Simulation of the cross-talk between arc magnets : 4 days
- Finalization of the spreader design : 15 days
- Design of combiner magnets : 4 months
- Need sextupoles with integrated correctors ? Design of these sextupoles : 8 weeks

What we need to know to go ahead

- Arc bending magnets :
  - Homogeneity requirements : integrated homogeneity, flat field…
- If sextupoles and octupoles :
  - Strength, Homogeneity
- Spreader/Combiner magnets :
  - Deflection angle possibilities, Size of the beams, Homogeneity
  - Possibility to envisage septa solution ?

Thank you for your attention

Thank you to Fabrice Marteau from SOLEIL