Warm magnets for LHeC / Test Facility arcs

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Overview

1) CdR requirements and proposal for Linac-Ring arc magnets

2) Post-CdR concepts for combined multiple apertures dipoles

3) First ideas on ERL Test Facility arc magnets

4) Conclusions

LHeC arc magnets
CdR

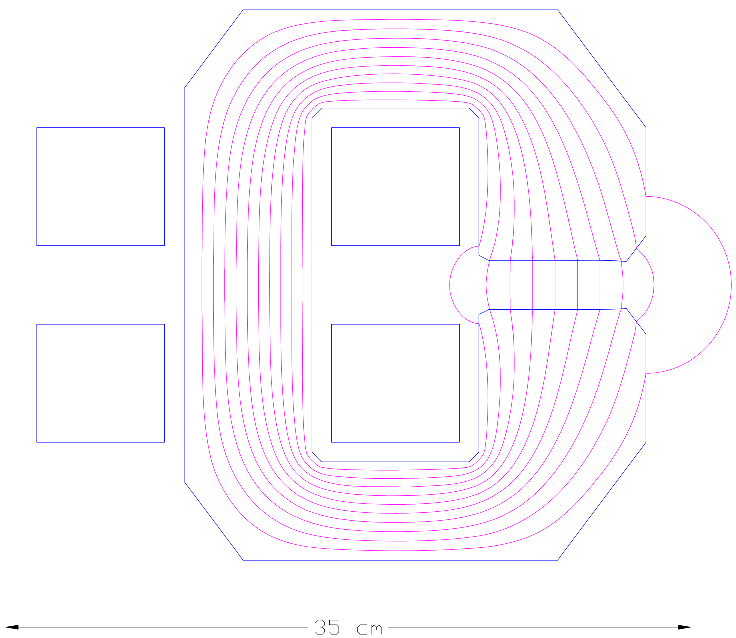
LR dipoles: requirements (CdR)

arc	energy [GeV]	number	field [T]	length [m]
#1	10.5	584	0.046	4.0
#2	20.5	584	0.089	4.0
#3	30.5	584	0.133	4.0
#4	40.5	584	0.177	4.0
#5	50.6	584	0.221	4.0
#6	60.5	584	0.264	4.0
	total	3504		

Proposed solution (CdR)

- one type of bending magnets for the six arcs, possibly with different conductors

LR dipoles: proposed CdR design



beam energy	10.5 to 60.5 GeV
field	0.046 to 0.264 T
magnetic length	4.0 m
vertical aperture	25 mm
pole width	80 mm
mass	2.0 t
number of magnets	6 × 584 = 3504
current @ 60.5 GeV	2700 A
number of turns per pole	1
current density @ 0.264 T	0.7 A/mm^2
conductor material	copper
power @ 60.5 GeV	585 W
total power 6 arcs	0.87 MW
cooling	air

<u>Proposed solution (CdR)</u>

- separate magnets for each energy
- rather compact
- simple coils / bus-bars

LR quadrupoles: requirements (CdR)

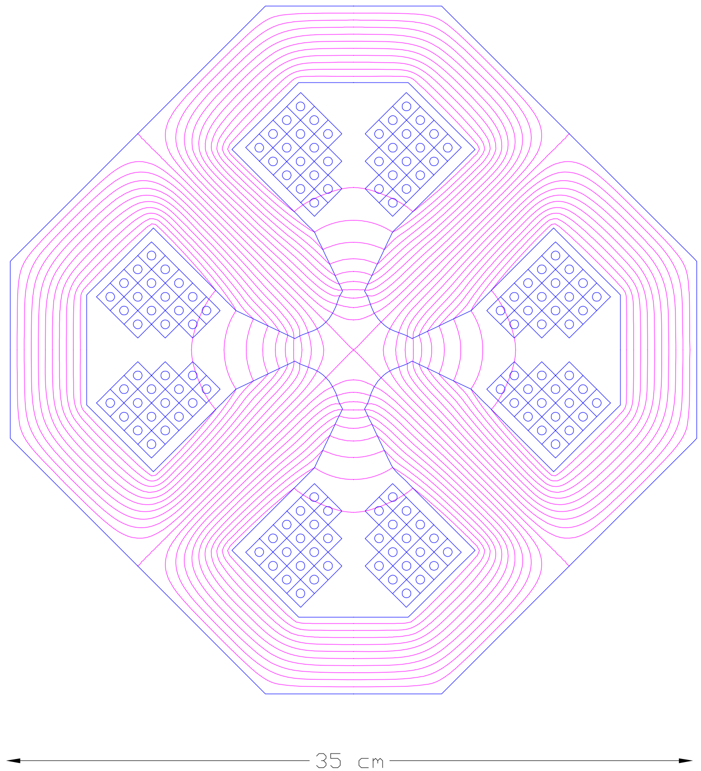
	Q0			Q1			Q2			Q3		
	#	G [T/m]	L [m]	#	G [T/m]	L [m]	#	G [T/m]	L [m]	#	G [T/m]	L [m]
LINAC 1	18	2.2	1.0				18	2.2	1.0			
LINAC 2	18	2.2	1.0				18	2.2	1.0			
Arc 1 (10.5 GeV)	60	3.2	1.0	60	10.5	1.0	60	11.1	1.0	60	10.5	1.0
Arc 2 (20.5 GeV)	60	6.2	1.0	60	20.5	1.0	60	21.6	1.0	60	20.6	1.0
Arc 3 (30.5 GeV)	60	12.4	1.0	60	17.5	1.0	60	24.6	1.0	60	17.9	1.0
Arc 4 (40.5 GeV)	60	16.5	1.0	60	23.2	1.0	60	32.6	1.0	60	23.8	1.0
Arc 5 (50.5 GeV)	60	29.2	1.0	60	28.9	1.0	60	40.8	1.0	60	29.7	1.0
Arc 6 (60.5 GeV)	60	35.0	1.0	60	34.6	1.0	60	48.9	1.0	60	35.5	1.0

Proposed solution (CdR)

- one type of quadrupoles for the Linacs
- one type of quadrupoles for the arcs in two different lengths

Q2	1.2 m
Q0, Q1 and Q3	0.9 m

LR quadrupoles: proposed CdR design



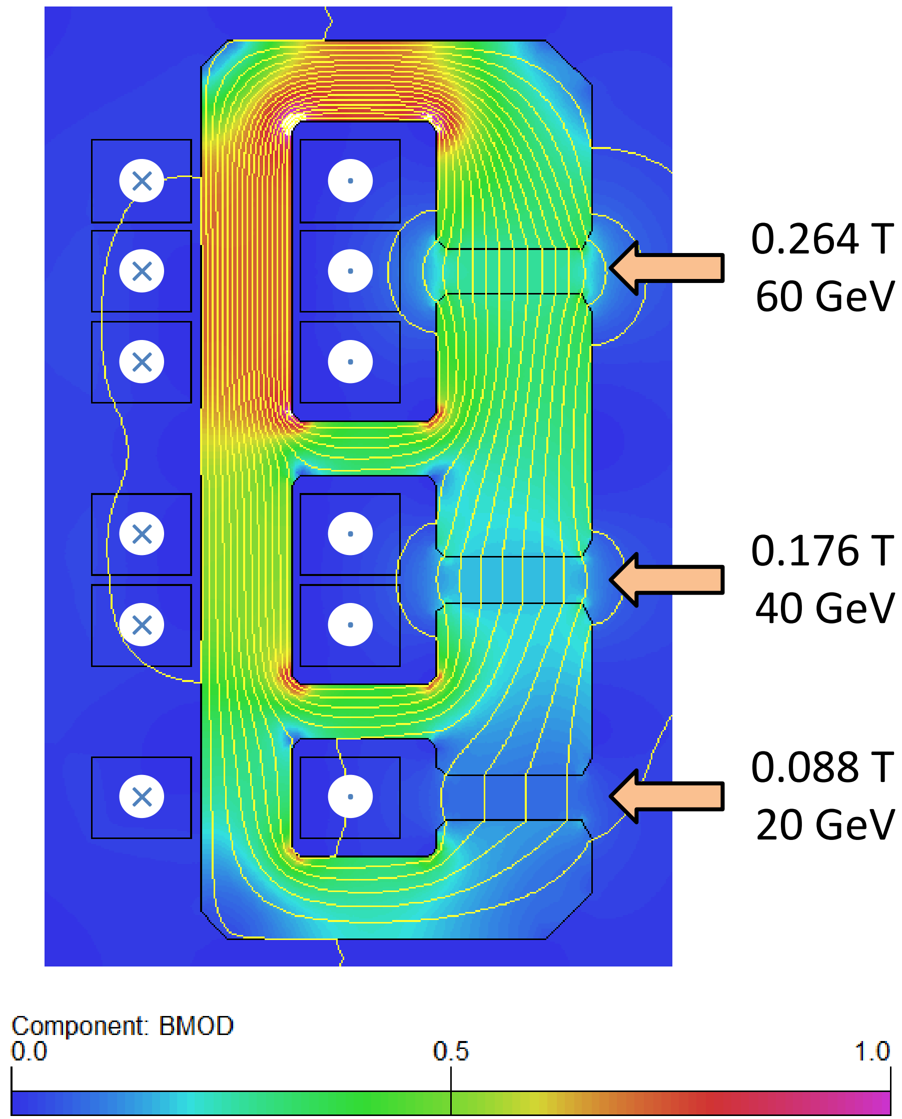
beam energy	10.5 to 60.5 GeV
field gradient (max)	41 T/m
magnetic length (short/long)	0.9 / 1.2 m
aperture radius	20 mm
pole root width	57 mm
mass (short/long)	0.8 / 1.0 t
number of magnets	6 × 240 = 1440
current @ 41 T/m	400 A
number of turns per pole	17
current density @ 41 T/m	4.8 A/mm^2
power @ 60.5 GeV (short/long)	4.8 / 6.4 kW
total power 6 arcs	3.17 MW
cooling	water

<u>Proposed solution (CdR)</u>

- separate magnets for each energy
- rather compact
- the power is higher than for the dipoles, but still limited in absolute

LHeC arc magnets post-CdR (conceptual cross-sections)

Dipoles in post-CdR



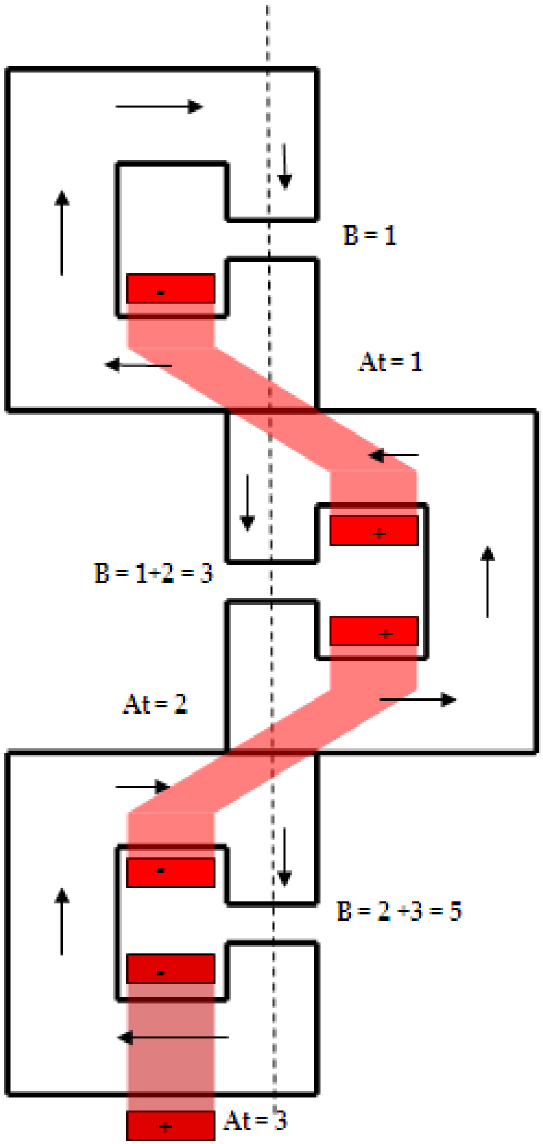
<u>Vertical stacking</u>

(2012 LHeC workshop)

- single dipoles for each arc for different energies: this saves 2/3 of the bending magnets (1168 vs. 3504 units)
- apertures stacked vertically
- same vertical gap, 25 mm
- simple coils / bus-bars, same powering circuit
- only some branches of the magnetic circuit serve two apertures
- the Ampere-turns are not "recycled"
- trim coils can be added for two of the apertures, to give some tuning

Dipoles in post-CdR

Values for bending field 'B' and coil excitation 'At' are for arc 1 (1:3:5), and are relative to the amplitudes in the lowest energy (top) dipole; arrows indicate the flux direction in each dipole's limb.

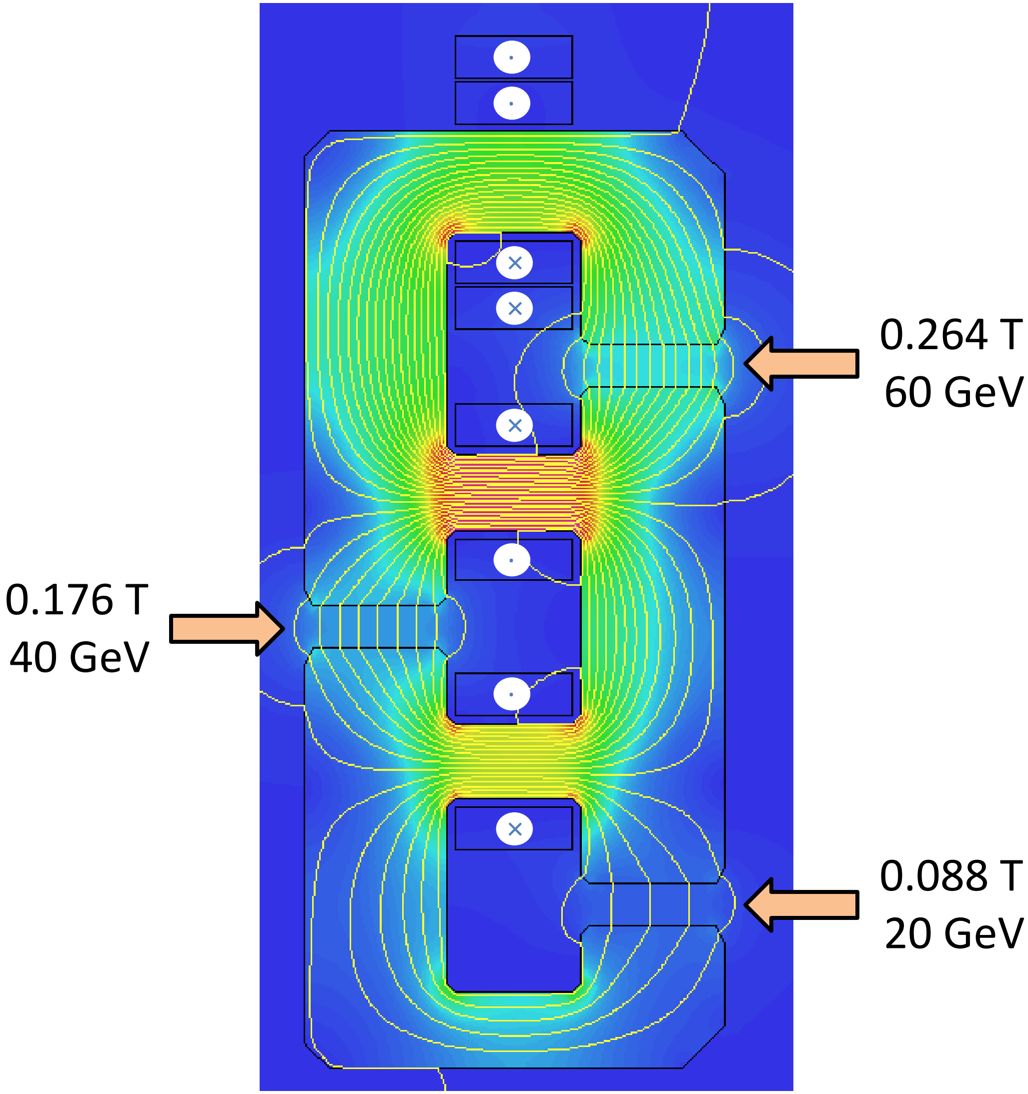


courtesy of Neil Marks

Alternative coil arrangement

- Neil Marks' suggestion: "recycle Ampere-turns"
- apertures stacked vertically
- same vertical gap
- simple coils / bus-bars, same powering circuit, though the Ampere-turns are "recycled", driving flux in different apertures
- 1/3 of the Ampere-turns can be saved in both the 10-30-50 and 20-40-60 GeV arcs
- the magnetic circuit has to be adapted to such a topology

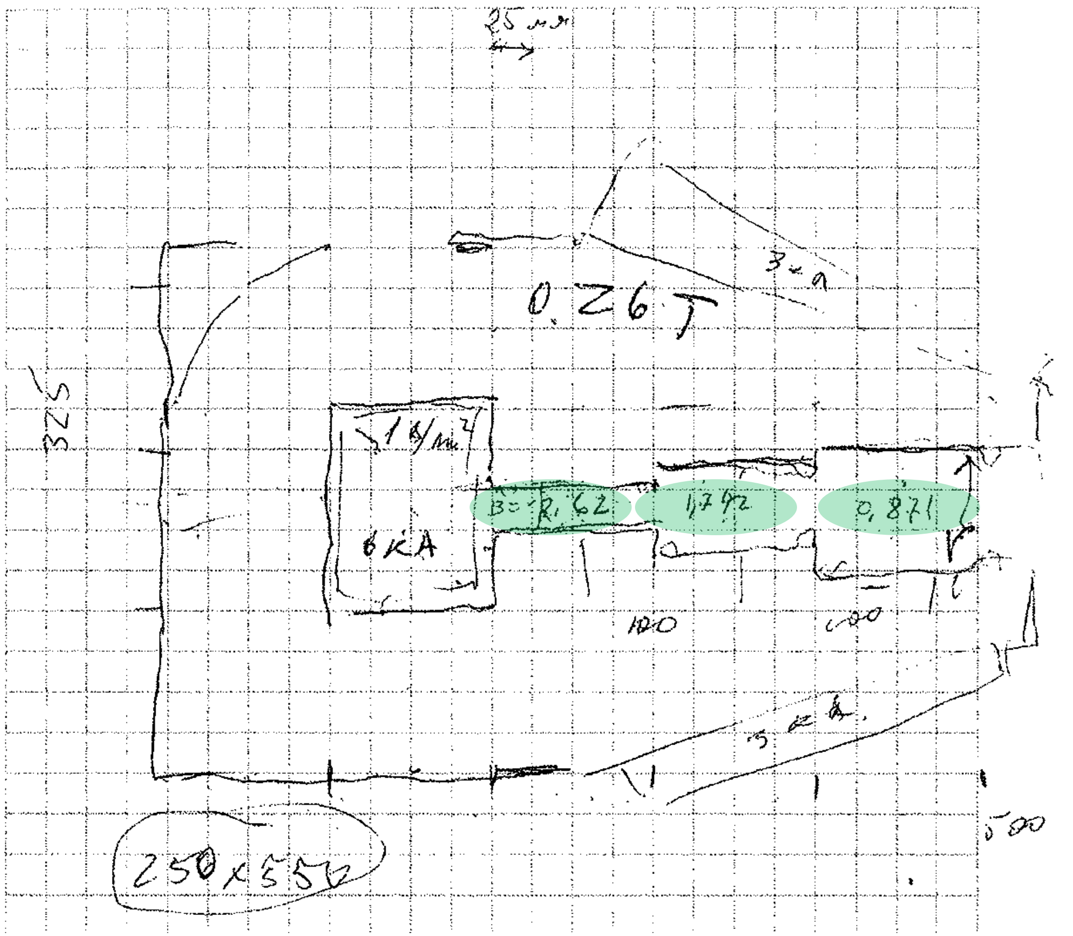
Dipoles in post-CdR



<u>Alternative coil arrangement</u>

- keep the idea of recycling Ampere-turns
- stack the apertures vertically but offset them also transversally
- same vertical gap, 25 mm
- simple coils / bus-bars, same powering circuit
- as before, trim coils can be added for two of the apertures, to give some tuning

Dipoles in post-CdR

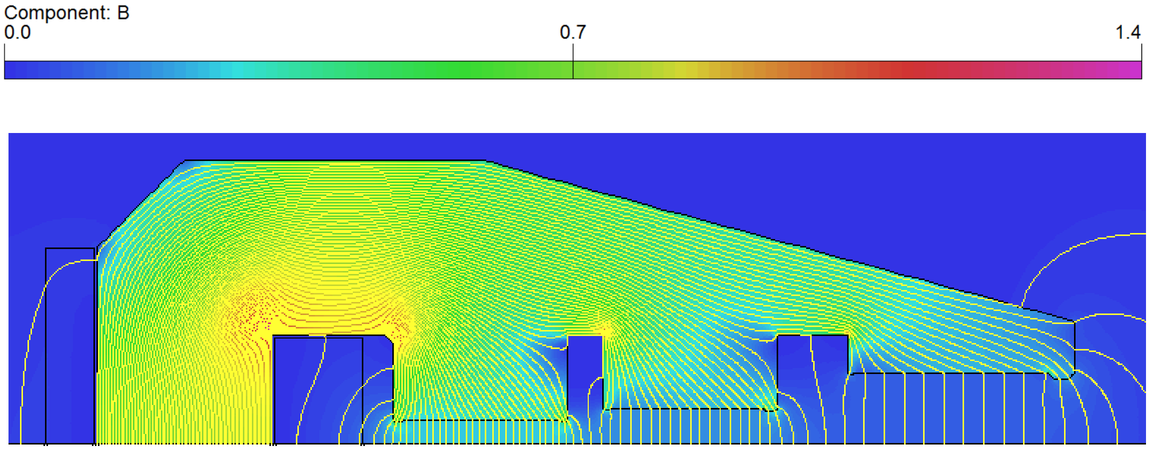


courtesy of Yury Pupkov

<u>Side-by-side concept</u>

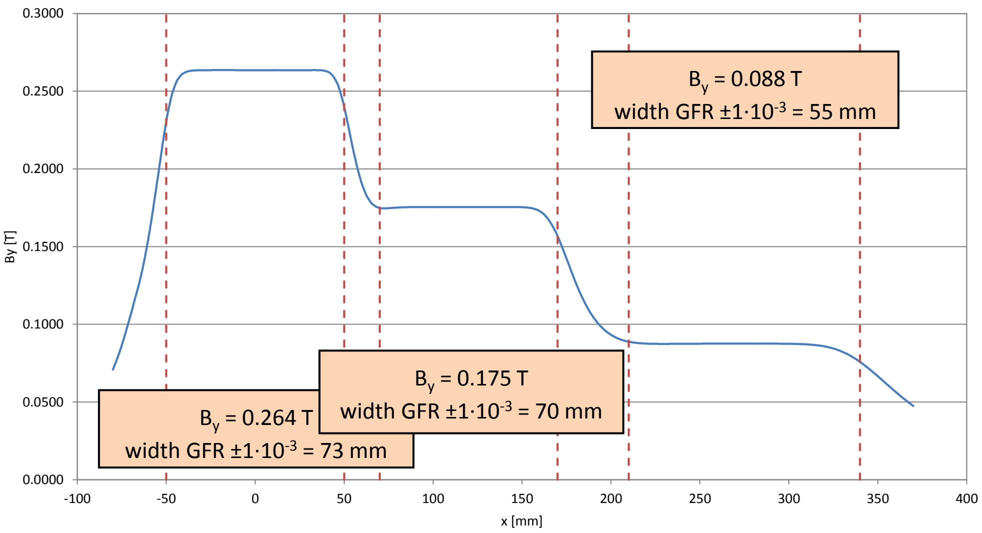
- Yury Pupkov's suggestion: "super-recycle Ampere-turns" by putting the three apertures side-by-side
- the three gaps vary in height
- a single vacuum chamber might be used for the three energies in the three gaps

Dipoles in post-CdR



(1/2 of the dipole shown)

field across the three apertures



<u>Side-by-side concept</u>

- needs some spacing between the apertures to keep a flat enough field distribution
- the Ampere-turns are fully recycled for the three energies
- trim coils can be added for two of the apertures, to give some tuning

ERL Test Facility
arc magnets

ERL TF dipoles requirements (tentative)

75 MeV per linac

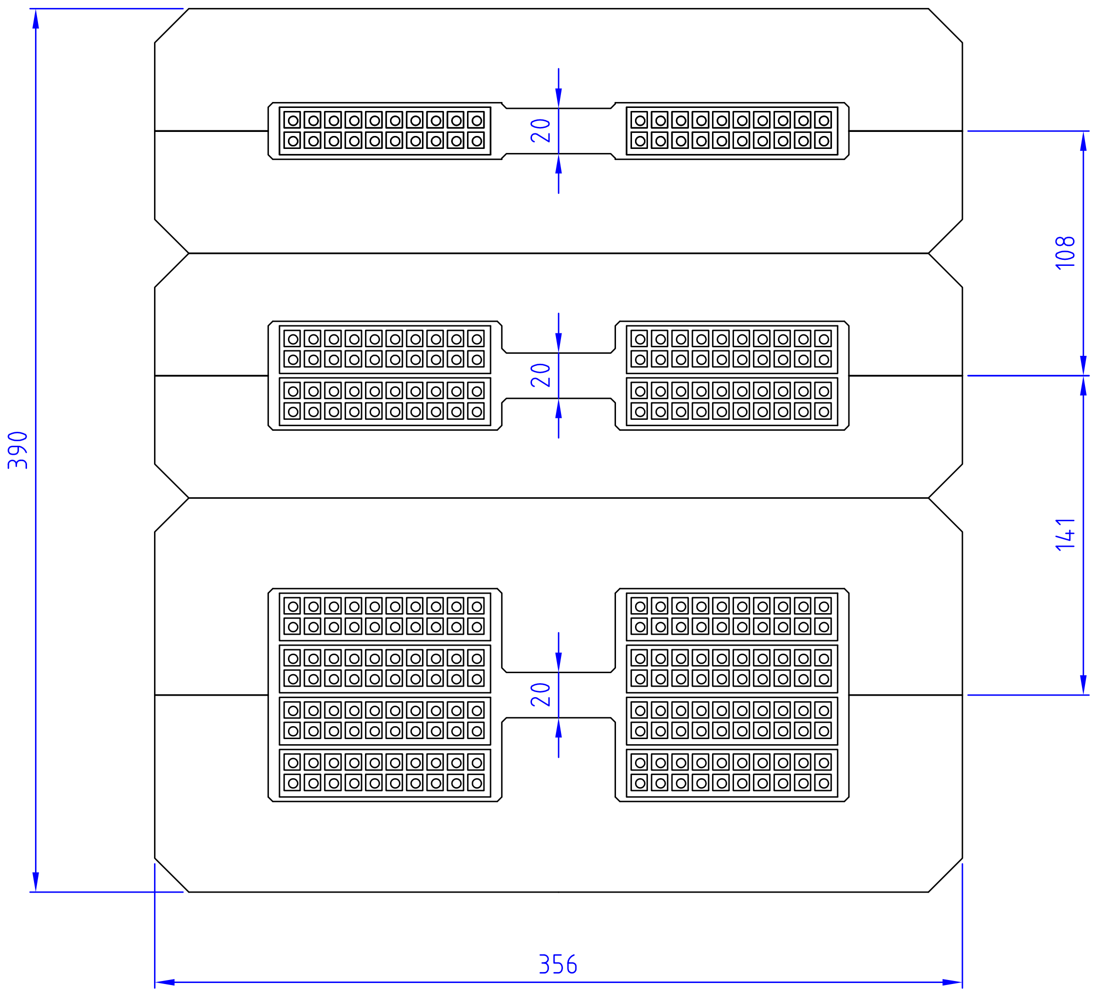
arc	energy [MeV]	number dipoles	field [T]	length [m]
#1	80	8	0.10	1.01
#2	155	8	0.20	1.01
#3	230	8	0.30	1.01
#4	305	8	0.40	1.01
#5	380	8	0.49	1.01
#6	455	8	0.59	1.01

150 MeV per linac

arc	energy [MeV]	number dipoles	field [T]	length [m]
#1	155	8	0.20	1.01
#2	305	8	0.40	1.01
#3	455	8	0.59	1.01
#4	605	8	0.79	1.01
#5	755	8	0.98	1.01
#6	905	8	1.18	1.01

- limited number of magnets, same optics throughout the passes
- apertures (horizontal and vertical) scale heavily with energy, a full vert. gap of 20 mm and a ±20 mm horiz. GFR seem good estimates
- synchrotron radiation not a constraint
- bending radius 2.56 m, bending angle 22.5°: edge effects important

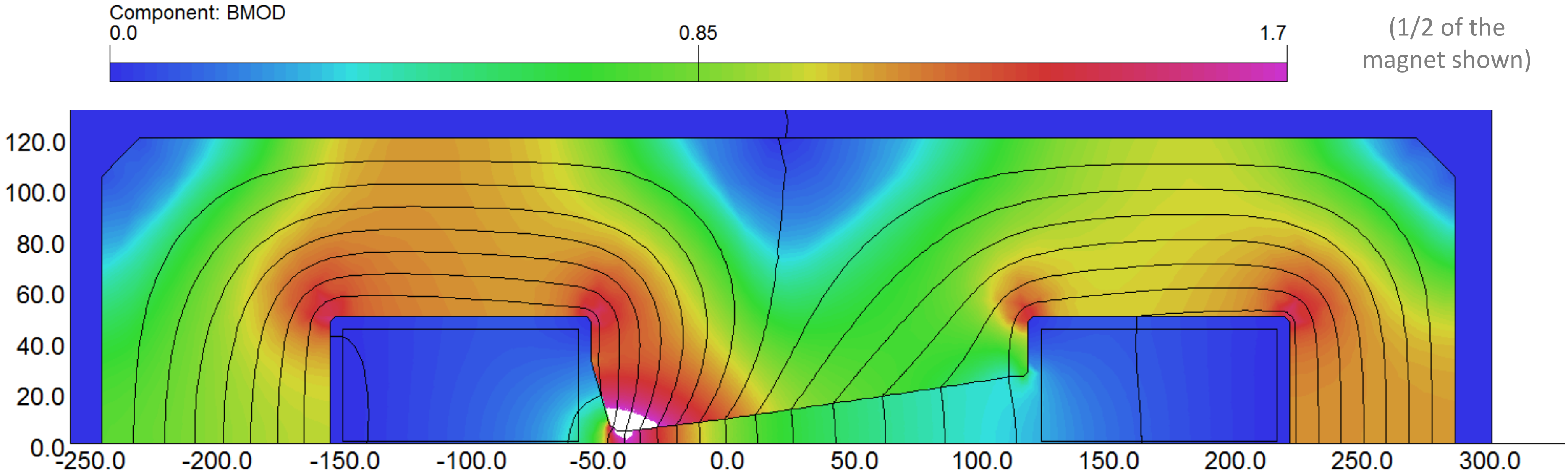
ERL TF dipoles: stack them on top

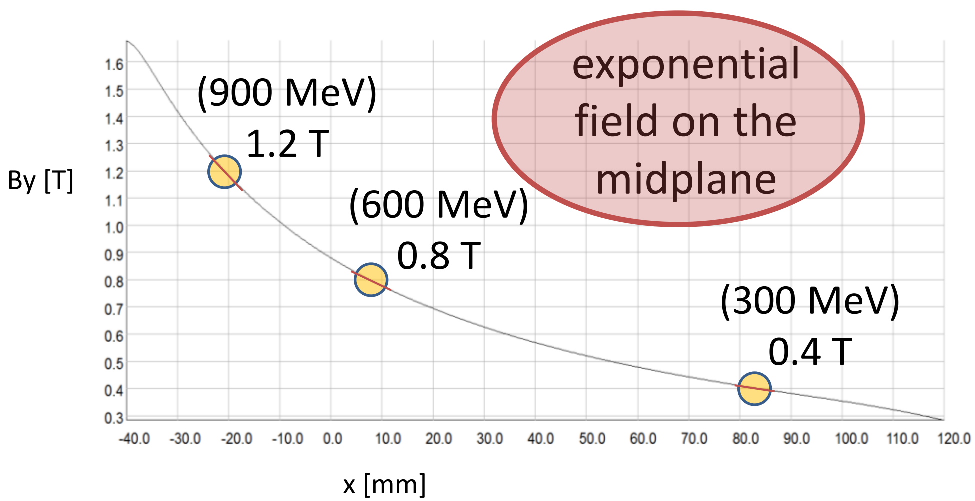


3 dipoles on top of each other

- conceptually they are separate magnetic circuits, that could be combined to have single units to handle
- same vertical gap in the different apertures
- the fields are controlled independently by separately powered coils
- water cooled coils since the fields are higher than in the full scale machine
- curved magnets, the sagitta would add about 50 mm on the pole width (and on some back legs as well)

ERL TF dipoles: (sort of) side by side





(Sort of) combined function magnet

- offset the transversal position of the beams for the different energies
- keep the same linear optics (to be anyway modified for the gradient)

$$B(x) = B_0 e^{\frac{G_0}{B_0}x} \qquad \mathrm{G}(x) = \frac{\mathrm{d}B}{\mathrm{d}x} = G_0 e^{\frac{G_0}{B_0}x}$$

$$\frac{B(x)}{G(x)} = \frac{B_0}{G_0} = \mathrm{const.}$$

to conclude

Conclusions

For the LHeC arcs

These magnets do not present particular technological challenges. However, a design involving stacked apertures – either vertically or transversally – would reduce the total number of units and decrease the capital and running costs.

For the Test Facility arcs

Although the design of the optics is still tentative, clearly we are in a region where we can comfortably use standard iron-dominated resistive magnets. It might be interesting also in this case to explore stacked apertures or combined function (exponential) bending magnets.

More exotic ideas?

The thing that hath been, it is that which shall be; and that which is done is that which shall be done: and there is no new thing under the sun. *Ecclesiastes 1:9*
Is there any thing whereof it may be said, See, this is new? it hath been already of old time, which was before us. *Ecclesiastes 1:10*

Method and apparatus for multi-pass return arc for recirculating linear accelerators

WO 2013043833 A1

ABSTRACT

In a particular embodiment, a device is disclosed that includes means for allowing a single multi-pass return arc for a recirculating linear accelerator (RLA) to return more than a single energy pass of a charged particle beam. The device also includes means for simplifying a design of the RLA and means for reducing a cost of the RLA. In another particular embodiment, a method is disclosed that includes steps for allowing a single multi-pass return arc for a recirculating linear accelerator (RLA) to return more than a single energy pass of a charged particle beam. The method also includes steps for simplifying a design of the RLA and means for reducing a cost of the RLA.

Publication number	WO2013043833 A1
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Inventors	Kevin BEARD, Alex BOGACZ, Vasiliy MOROZOV, Yves ROBLIN
Applicant	Muons, Inc.
Export Citation	BiBTeX, EndNote, RefMan

Patent Citations (1), Non-Patent Citations (4), Classifications (5), Legal Events (1)

External Links: Patentscope, Espacenet

SUMMARY FOR MEMBERS OF CONGRESS:

A multi-pass arc is a new type of magnetic channel capable of simultaneously transporting two or more particle beams of very different energies, where normally a separate string of magnets would be required for each individual energy. It has wide application in nuclear physics, high energy physics, and Free Electron Lasers (FELs).

? !

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Thank you.