CERN

Alessandra Valloni

LHeC workshop

Test Facility- Stages and Optics

Chavannes-de-Bogis, 20th-21st January

Workshop on the LHeC

Electron-proton and electron-ion collisions at the LHC

CERN

Outline

1. **STAGES OF BUILDING DESIGN**
   - LAYOUTS
   - BASELINE PARAMETERS

2. **ARC OPTICS ARCHITECTURE**

3. **TEST FACILITY FOR SC MAGNET TESTS**

Goal

- Test facility for superconducting RF cavities and modules
- Test facility for beam dynamics in ERLs
- Test facility for controlled quench tests of next generation superconducting magnets

TARGET PARAMETER*	VALUE
Injection Energy [MeV]	5
Final Beam Energy [MeV]	1000
Normalized emittance $\gamma\varepsilon_{x,y}$ [µm]	50
Beam Current [mA]	10
Bunch Spacing [ns]	25 (50)
Bunch Population	$2*10^9$

*in few stages

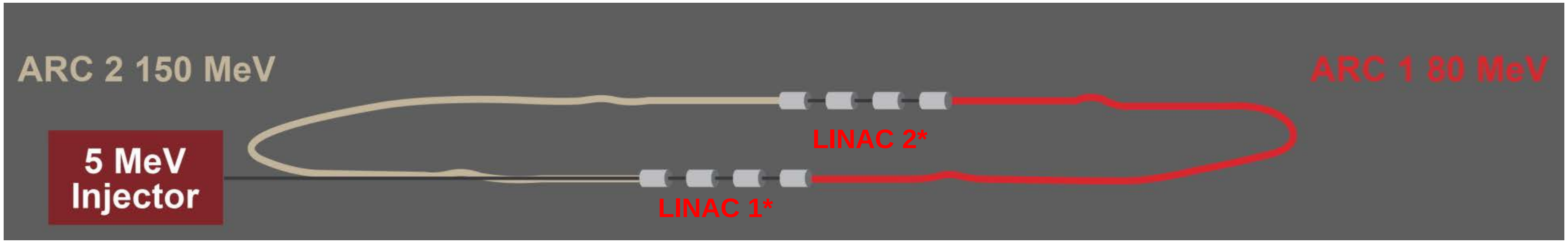
Planning for each stage

STEP 1

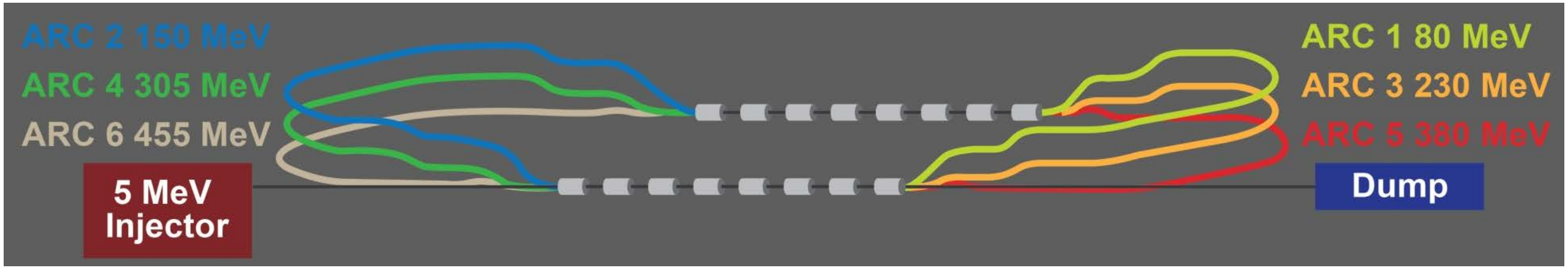
SC RF cavities, modules and e$^-$ source tests

- Injection at 5 MeV
- 1 turn
- 75 MeV/linac
- Final energy 150 MeV

ARC	ENERGY
ARC 1	80 MeV
ARC 2	155 MeV



*4 SRF 5-cell cavities at 802 MHz



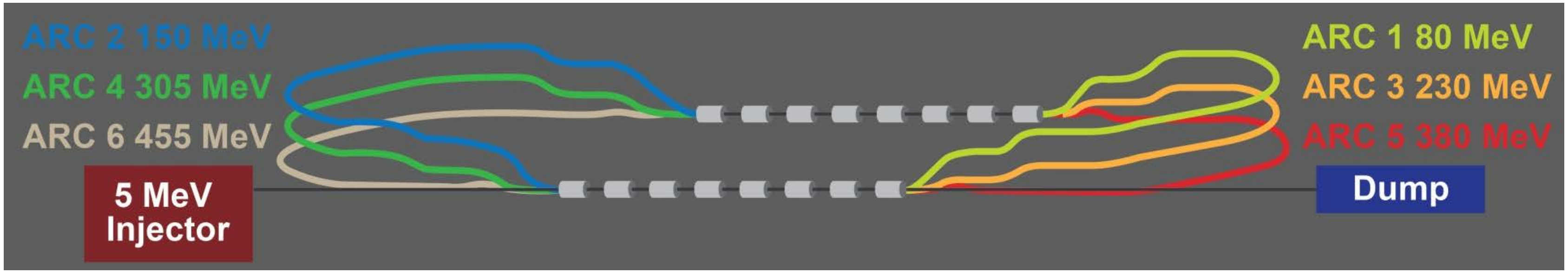
Planning for each stage

STEP 2

Test the machine in Energy Recovery Mode

- Injection at 5 MeV
- 3 turns
- 75 MeV/linac
- Final energy 450 MeV

ARC	ENERGY
ARC 1	80 MeV
ARC 2	155 MeV
ARC 3	230 MeV
ARC 4	305 MeV
ARC 5	380 MeV
ARC 6	455 MeV



Recirculation realized with vertically stacked recirculation passes

Planning for each stage

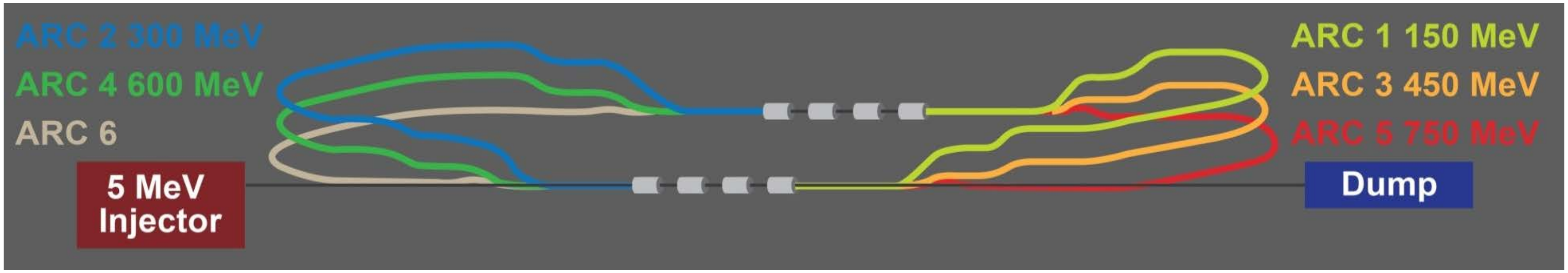
STEP 3

Additional SC RF modules test

Full energy test in Energy Recovery Mode

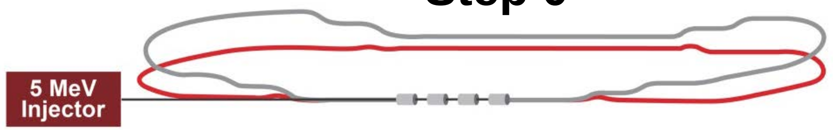
- Injection at 5 MeV
- 3 turns
- 150 MeV/linac
- Final energy 1 GeV

ARC	ENERGY
ARC 1	150 MeV
ARC 2	300 MeV
ARC 3	450 MeV
ARC 4	600 MeV
ARC 5	750 MeV
ARC 6	900 MeV

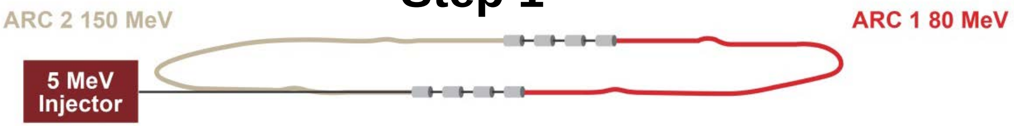


Planning for each stage

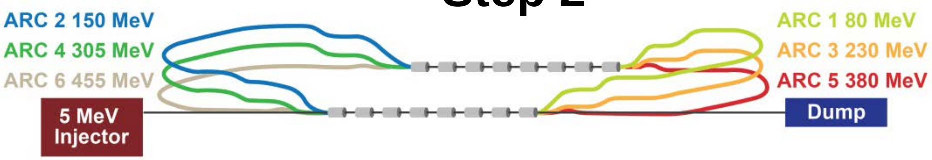
Step 0



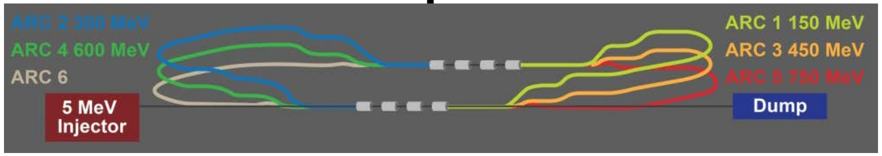
Step 1



Step 2



Step 4



ARC	Step 0	Step 1	Step 2	Step 3
ARC 1	80 MeV	80 MeV	80 MeV	150 MeV
ARC 2	155 MeV	155 MeV	155 MeV	305 MeV
ARC 3			230 MeV	455 MeV
ARC 4			305 MeV	605 MeV
ARC 5			380 MeV	755 MeV
ARC 6			455 MeV	905 MeV

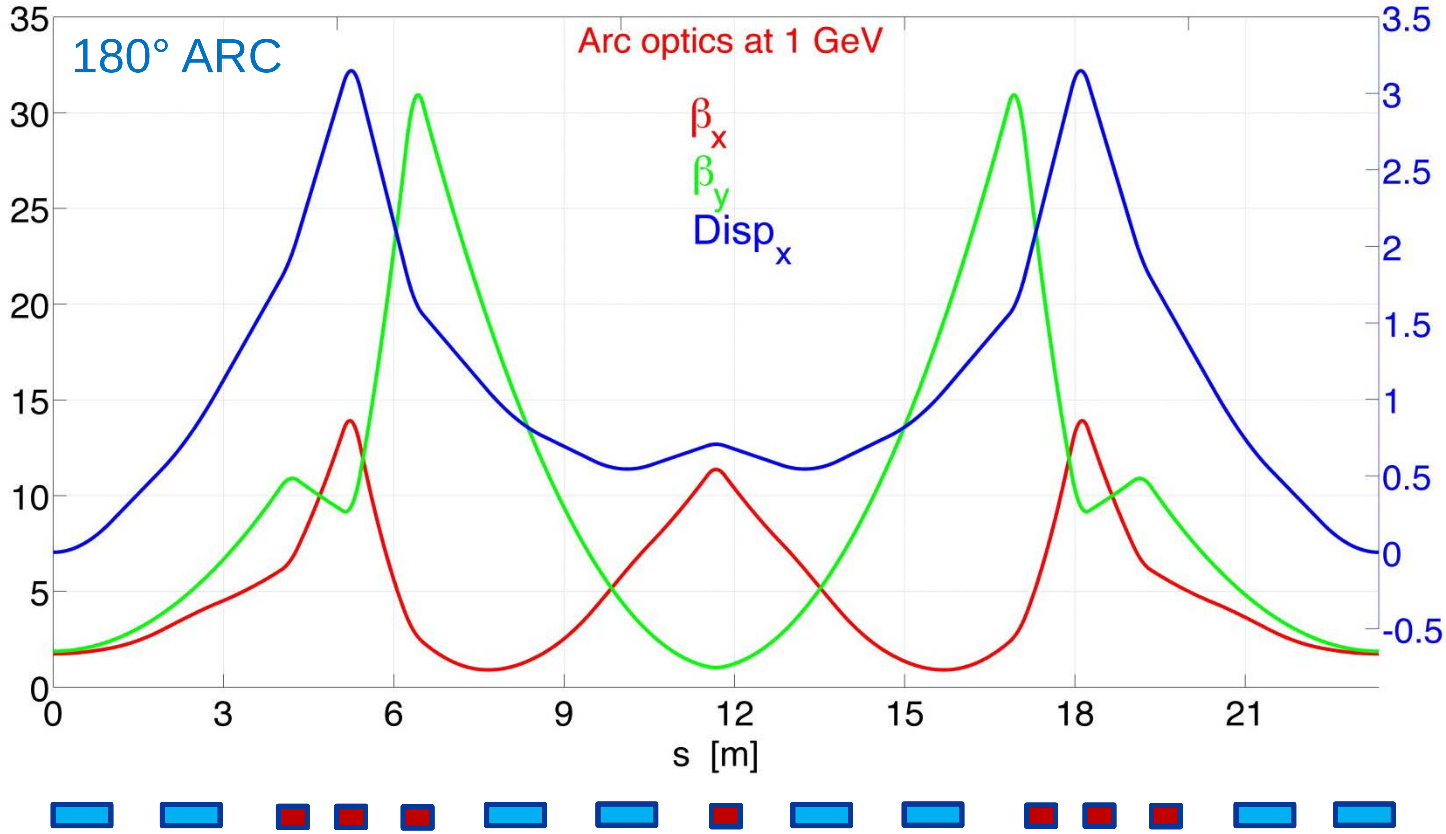
Outline

1. STAGES OF BUILDING DESIGN
    - LAYOUTS
    - BASELINE PARAMETERS

2. ARC OPTICS ARCHITECTURE

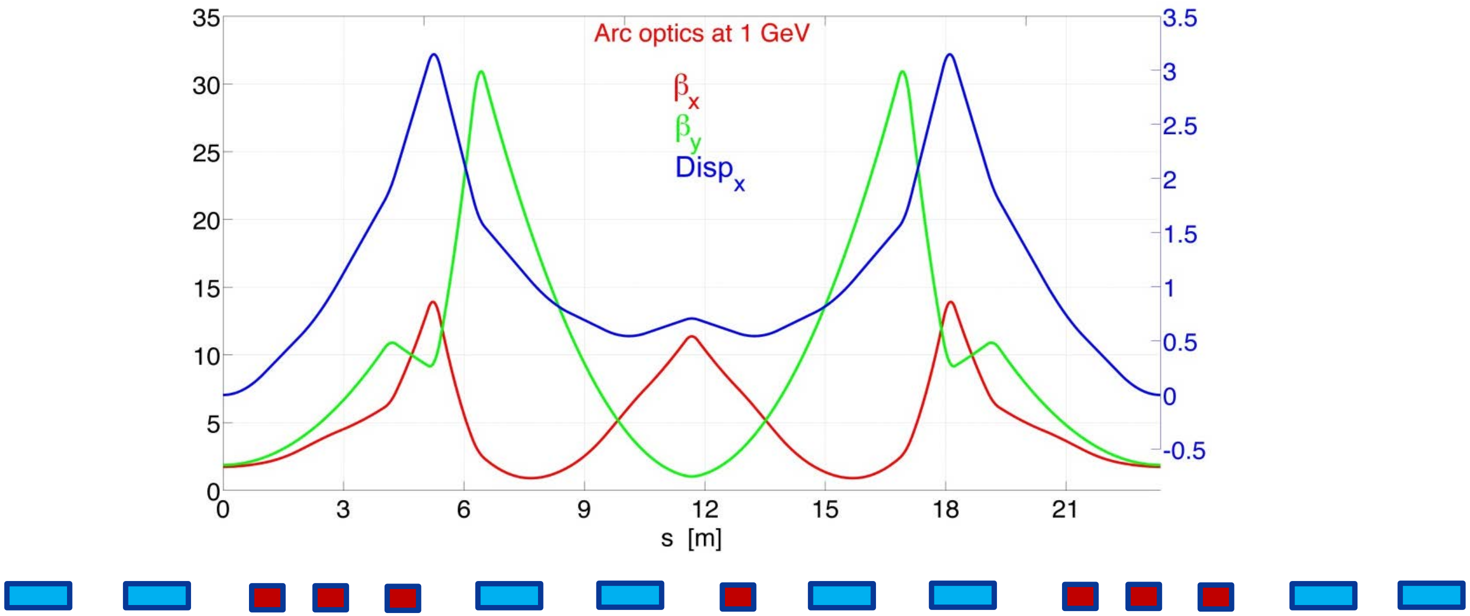
3. TEST FACILITY FOR SC MAGNET TESTS

Arc optics at 1 GeV



Arc length = 23.3 m

Arc optics at 1 GeV



Arc dipoles :

8×22.5^0 bends

Ldip = 100.6 cm

B = 13.02 kGauss

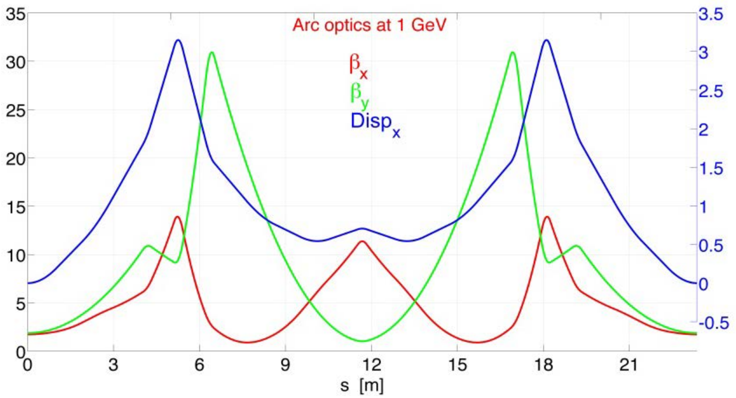
ρ = 256.3 cm

Arc quadrupoles :

Lquads = 30 cm

qQ1 G[kG/cm]=-0.338 qQ2 G[kG/cm]= 0.973
qQ3 G[kG/cm]=-0.698 qQ4 G[kG/cm]= 0.400

Arc optics at 1 GeV



$\varepsilon_{norm} = 50\ \mu m$

$\varepsilon_{geom} = 25\ nm$

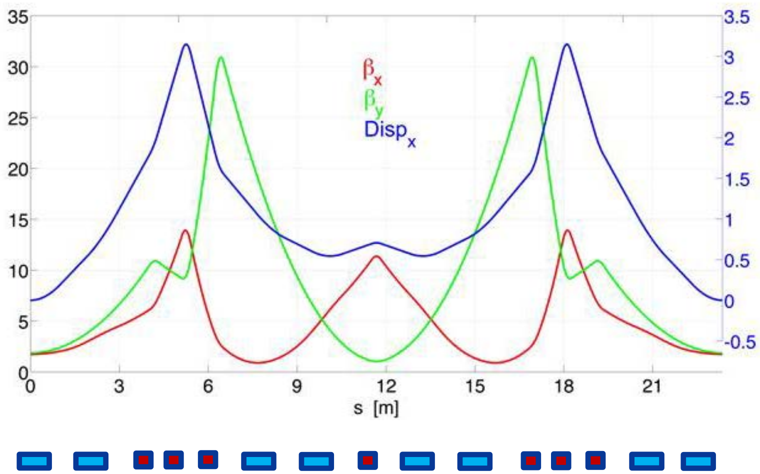
$\Delta p/p = 3*10^{-4}$

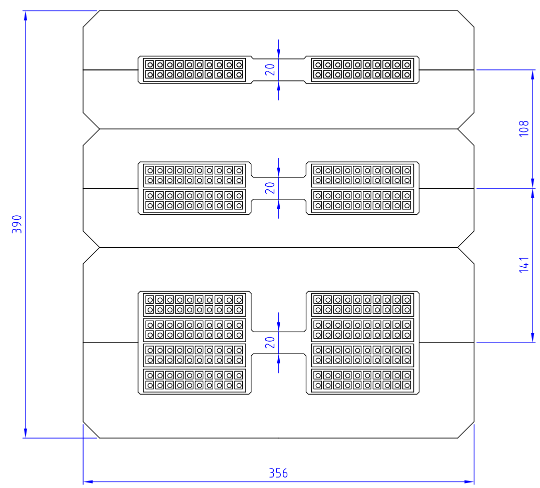
$$\text{Aperture} = 6\sigma + D\frac{\Delta p}{p} + 1\ mm + 2mm\sqrt{\frac{\beta}{\beta_{MAX}}}$$

	DIPOLE 1	DIPOLE 2	DIPOLE 3	DIPOLE 4
Max βx [m]	2.04	4.41	1.74	7.52
Max βy [m]	2.42	6.40	16.18	5.66
σx [μm]	228	335	210	438
σy [μm]	248	404	642	380
Dx [m]	0.19	1.06	0.99	0.57
Aperture_x [mm]	3.32	4.64	2.96	4.9
Aperture_y [mm]	3.20	4.59	6.14	4.36

Arc optics

SAME OPTICS LAYOUT FOR THE ARCS AT 750/600/450/300/150 MeV





3 DIPOLES
ON TOP OF
EACH OTHER

*Warm magnets
for LHeC / Test Facility arcs
Attilio Milanese

Arc dipoles :

8×22.5^0 bends

Ldip = 100.6 cm

ρ = 256.3 cm

	1GeV	750MeV	600MeV	450MeV	300MeV	150MeV
B FIELD	1.30 T	0.97 T	0.78 T	0.58 T	0.39 T	0.19 T

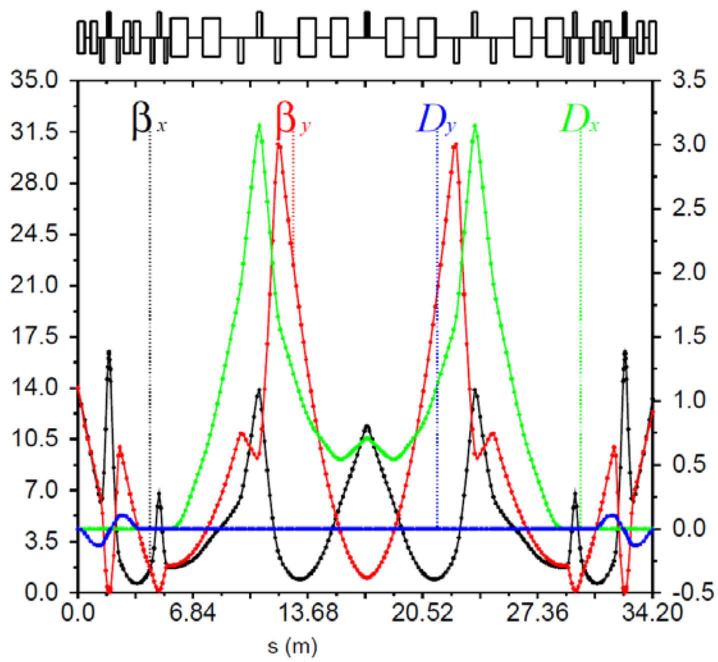
Arc quadrupoles

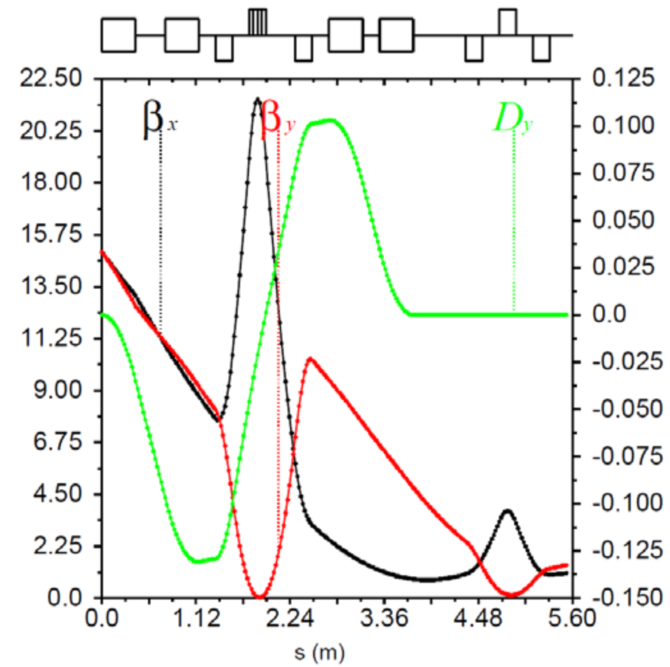
Lquads = 30 cm

	Q1	Q2	Q3	Q4
Kq[m^{-2}]	-1.01	2.91	2.09	1.19

Complete Arc architecture at 750 MeV

180° ARC + VERTICAL SWITCHYARDS





Path length
92 x λrf = 34.4 m

Spreader dipoles :

4×10^0 bends

Ldip = 40 cm

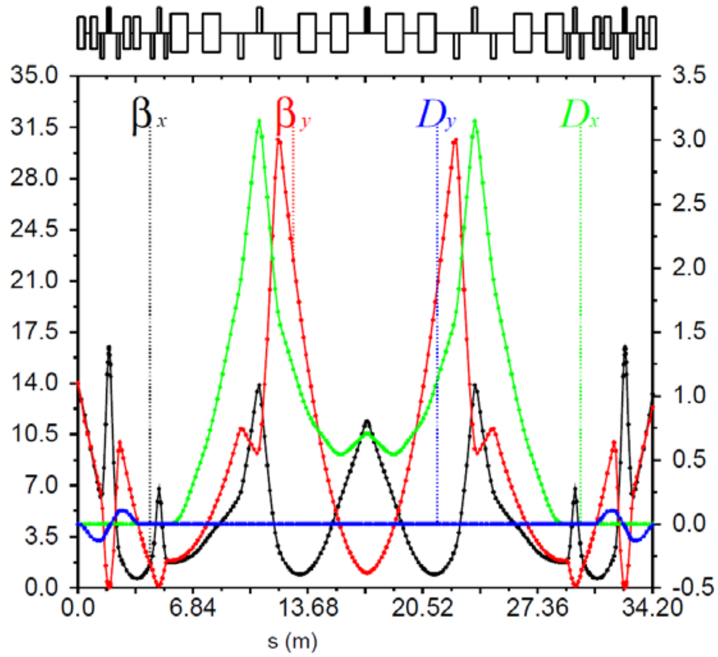
B = 10.8 kGauss

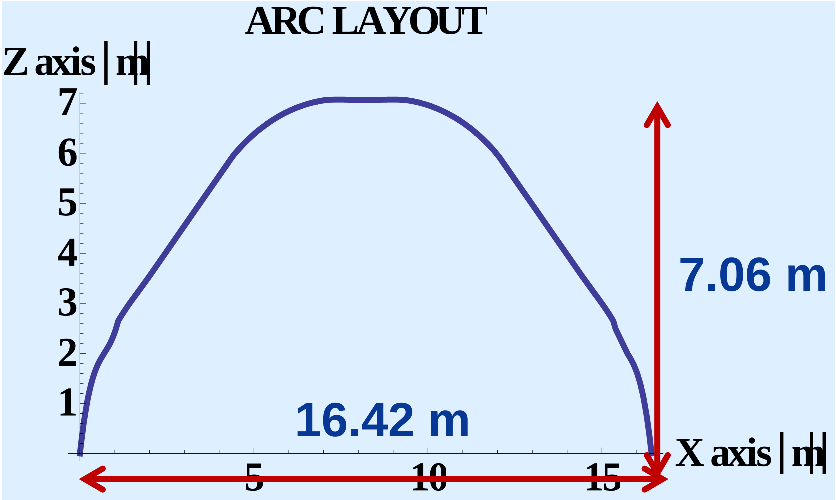
Spreader quads Lquads = 20 cm

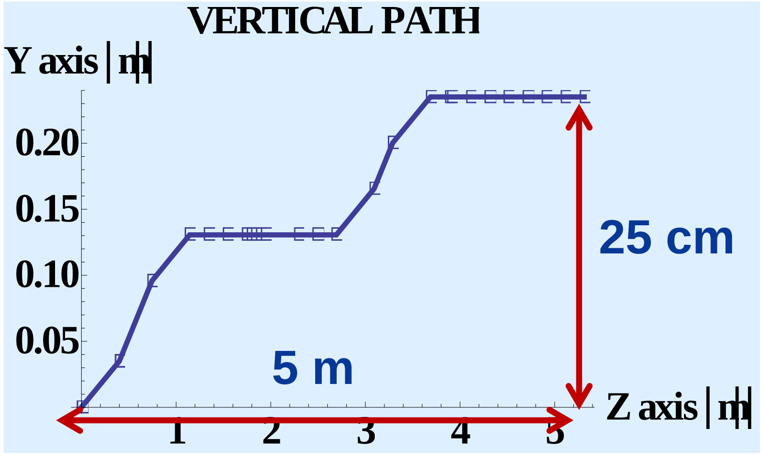
qQs1	kqs1 =	-11.087
qQs2	kqs2 =	12.28
qQs3	kqs3 =	-11.33
qQs4	kqs4 =	-7.79
qQs5	kqs5 =	13.91
qQs6	kqs6 =	-11.91

Complete Arc architecture

180° ARC + VERTICAL SWITCHYARDS







Path length
92 x λrf = 34.4m

Incoherent Synchrotron radiation in return arcs

ARC	E [MeV]	ΔE [keV]	σE/E [%]
1	150	0.0087	0.00000387
2	300	0.139	0.00002199
3	450	0.708	0.0000621
4	600	2.239	0.000132
5	750	5.467	0.00024
6	900	11.337	0.00039
7	750	5.4667	0.00052
8	600	2.239	0.00066
9	450	0.708	0.00089
10	300	0.139	0.00135
11	150	0.0087	0.0027

- Beam Energy loss $\Delta E = \int P_\gamma dt = P_\gamma \frac{\pi\rho}{\beta c}$ $\Delta E(GeV) = C_\gamma \frac{E^4}{\rho}\frac{1}{2}$
- Beam Energy Spread $\frac{\sigma_E}{E} = \sqrt{1.4397 * 10^{-27} \frac{\pi\gamma^5}{\rho^2}}$

Outline

1. STAGES OF BUILDING DESIGN
   - LAYOUTS
   - BASELINE PARAMETERS

2. ARC OPTICS ARCHITECTURE

3. TEST FACILITY FOR SC MAGNET TESTS

Controlled quench tests of SC magnets

WE ARE INVESTIGATING THE POSSIBILITY OF USING THE TEST FACILITY FOR SC MAGNET TESTS

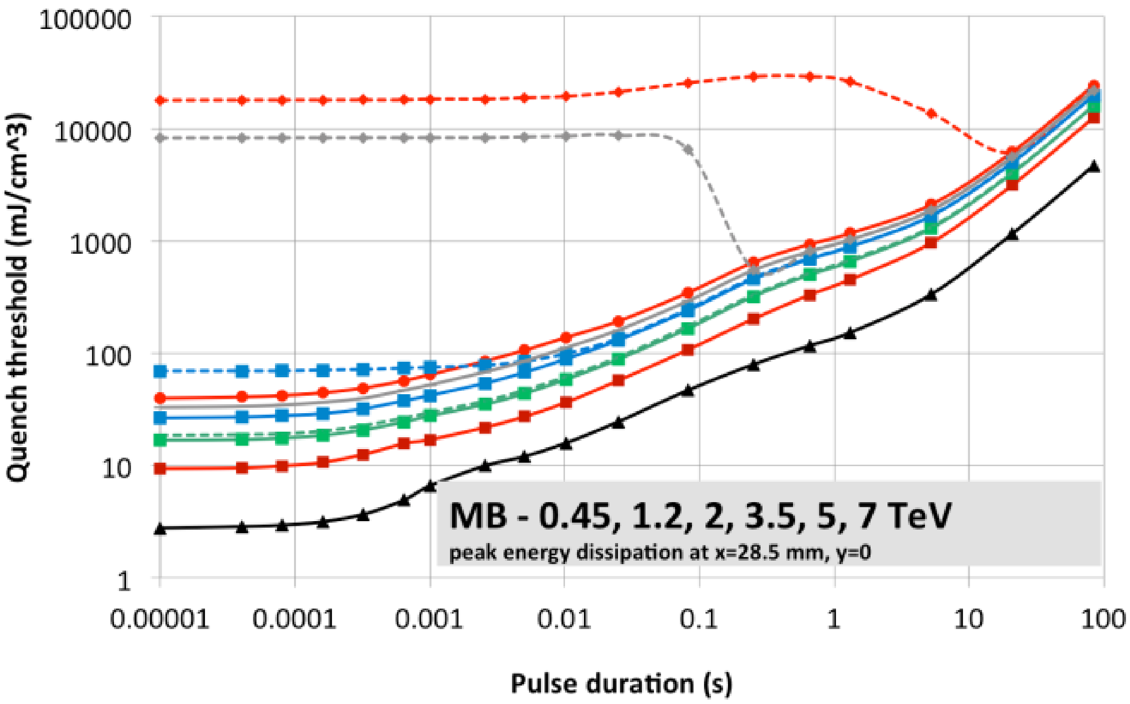
Requirements in terms of:

- Beam energy, intensity and pulse length (energy deposition)
- Space for the magnets installation (possible tests of cable samples and full cryo magnets)
- Cryo requirements
- Vacuum requirements
- Powering needs

Controlled quench tests of SC magnets

Study beam induced quenches (quench thresholds, quenchino thresholds) at different time scales for:

- SC cables and cable stacks in an adjustable external magnetic field
- Short sample magnets
- Full length LHC type SC magnets



Quench limits of LHC dipole as expected from QP3 simulations for different pulse durations

Courtesy A. Verweij

CABLE STACK / SHORT SAMPLES IN A ADJUSTABLE EXTERNAL MAGNETIC FIELD

- SC split coil or dipole magnet (as Fresca / Fresca 2)
- Advantages:
  - Flexibility in sample preparation
  - Defined experimental conditions
  - Instrumentation easily applicable
  - Homogeneous magnetic field profile on cable
  - ~5000 liter liquid helium for cool down
  - ~6 g/s liquid helium during continuous operation
  - Power supplies (14-25kA, 5V)
  - Smaller space requirements
- Disadvantages:
  - Maybe difficult to reproduce beam impact conditions in LHC

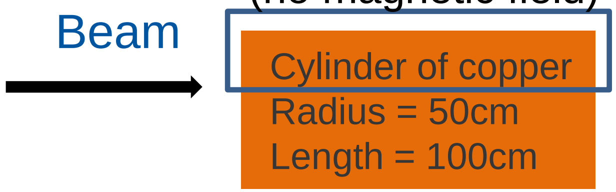
FULL LENGTH MAGNET TEST STAND

- Like SM18 horizontal bench
- Advantages:
  - Real magnet under real conditions tested
  - Beam experiences magnetic field of magnet as in LHC
  - No sample preparation or special cryostat for sample needed
  - One Power supply 14kA, 20V
- Disadvantages:
  - Relationship between B and I fixed due to design of magnet
  - Limited instrumentation
  - Impact angle can only be varied by beam optics not by sample rotation
  - ~10g/s liquid helium needed during continuous operation
  - ~10000 liter liquid helium buffer needed

Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS

Copper target
(no magnetic field)



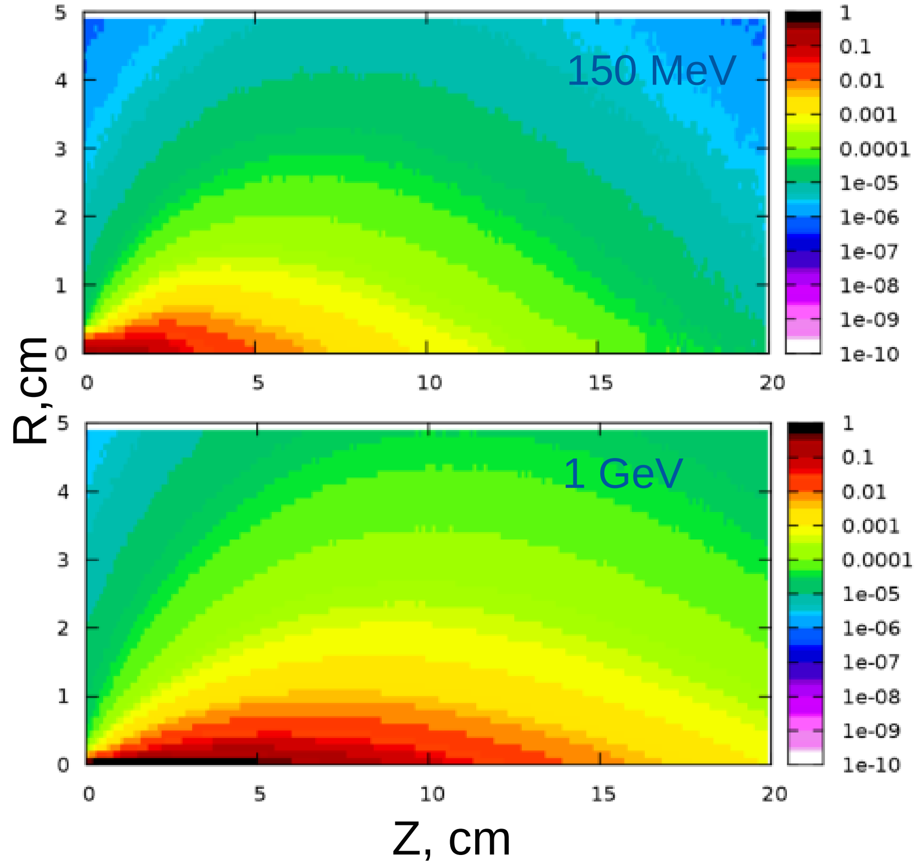
Beam parameters

Energy, MeV	Emittance, m	Sigma, cm	FWHM, cm
150	1.70E-07	0.092	0.22
300	8.52E-08	0.065	0.15
450	5.68E-08	0.053	0.13
600	4.26E-08	0.046	0.11
750	3.41E-08	0.041	0.10
900	2.84E-08	0.038	0.09
1000	2.55E-08	0.036	0.08

Results are given for half of bulky target because of symmetry

Binning: 1 mm^3 bins

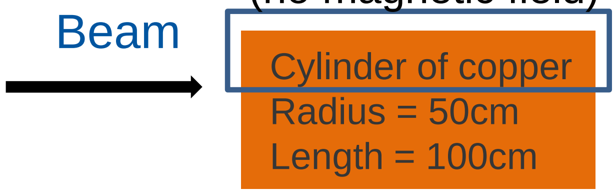
Energy deposition, $GeV/cm^3/e^-$



Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS

Copper target
(no magnetic field)



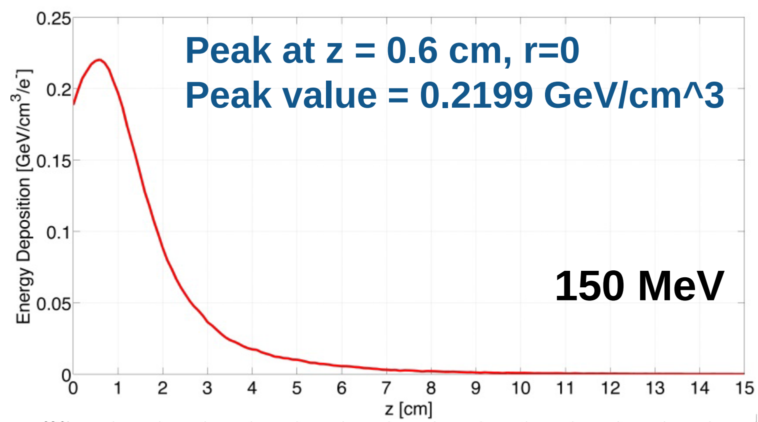
Beam parameters

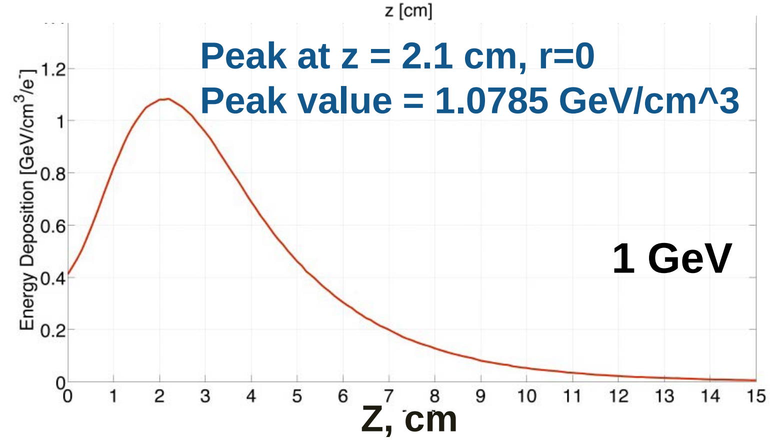
Energy, MeV	Emittance, m	Sigma, cm	FWHM, cm
150	1.70E-07	0.092	0.22
300	8.52E-08	0.065	0.15
450	5.68E-08	0.053	0.13
600	4.26E-08	0.046	0.11
750	3.41E-08	0.041	0.10
900	2.84E-08	0.038	0.09
1000	2.55E-08	0.036	0.08

Results are given for half of bulky target because of symmetry

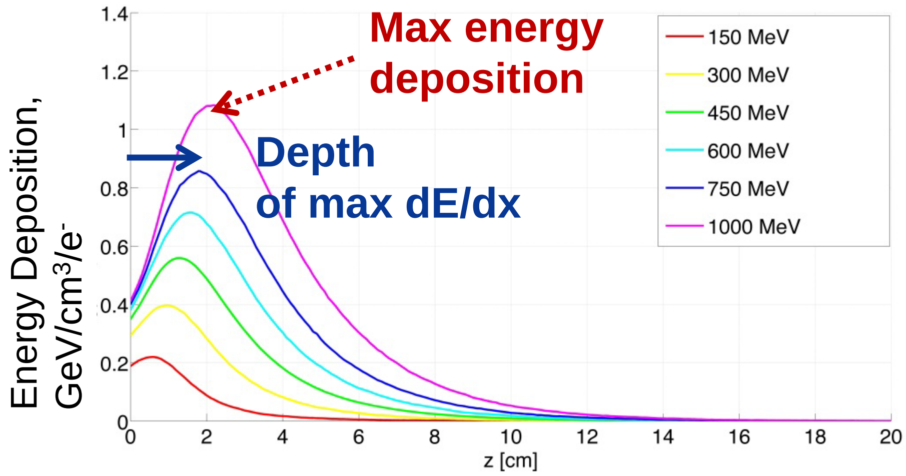
Binning: 1 mm^3 bins

Energy deposition, $GeV/cm^3/e^-$

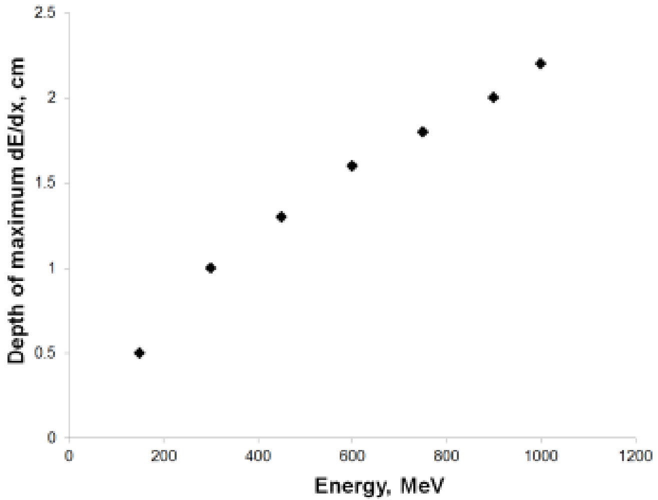




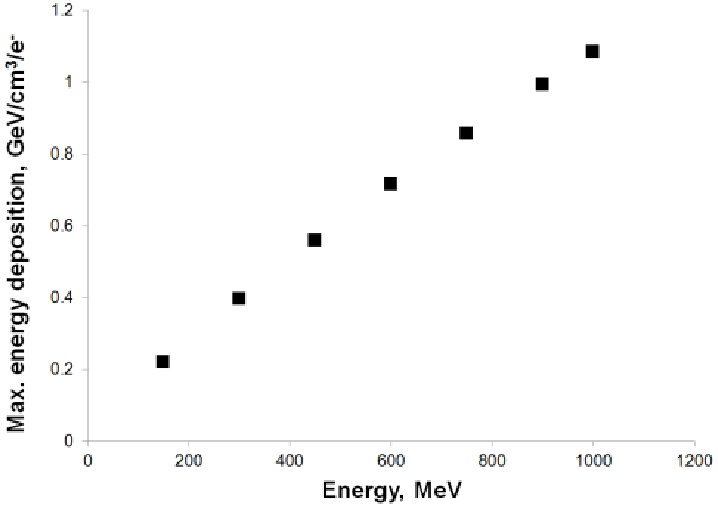
Beam parameters to generate a given amount of energy deposition



Depth of max dE/dx

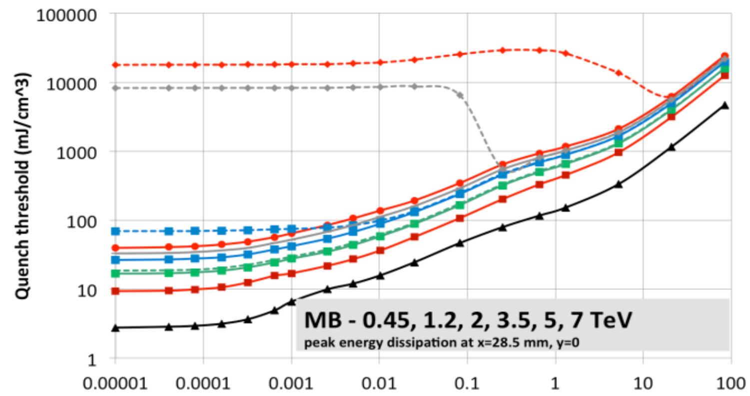


Max energy deposition

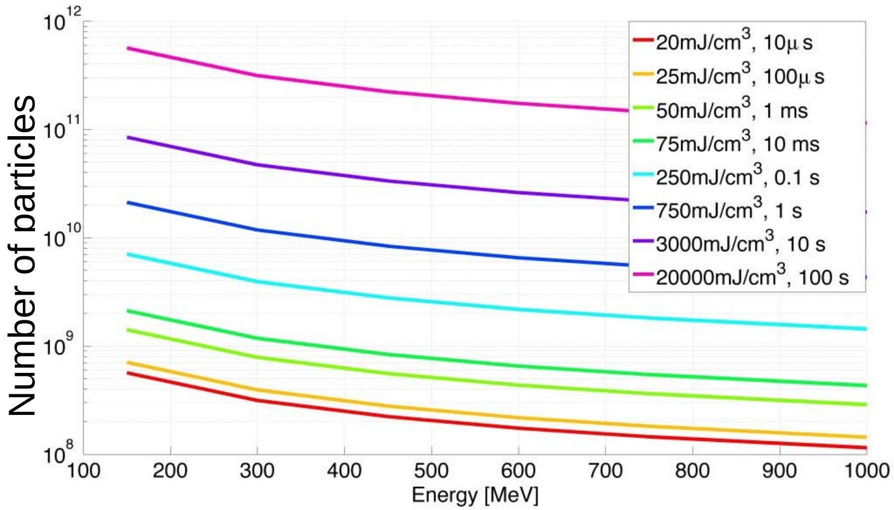


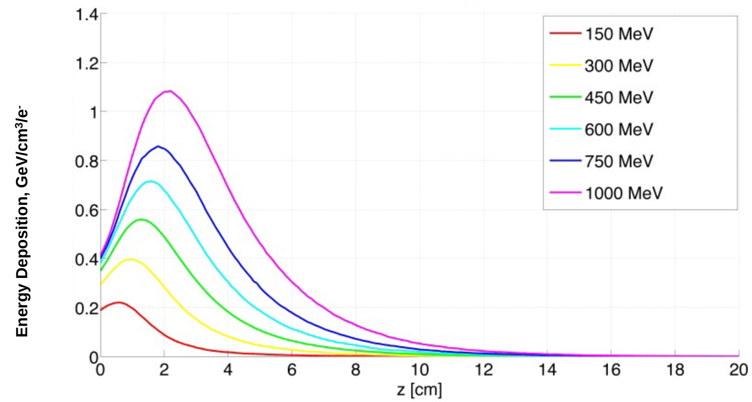
Beam parameters to generate a given amount of energy deposition

electrons needed to quench the magnet = Quench threshold / Maximum value for the energy deposition



MB quench limit 3.5 TeV





1 GeV = 1.602 x 10^{-7} mJ

MB quench limit 450 GeV is 140mJ/cm^3 in 10ms:

~2.2 x 10^9 e^- @ 1GeV necessary

MB quench limit 7 TeV is 16 mJ/cm^3 in 10ms:

~2.6 x 10^8 e^- @ 1GeV necessary

Summary

- The concept of the ERLTF is designed to allow for a staged construction with verifiable and useful stages for an ultimate beam energy in the order of 1 GeV

- A sketch of the ERLTF optics configuration is provided and other options are under investigation

- First analysis of having controlled quench tests of next generation superconducting magnets has been carried out. Beam parameters seem to match the requirements.

www.cern.ch