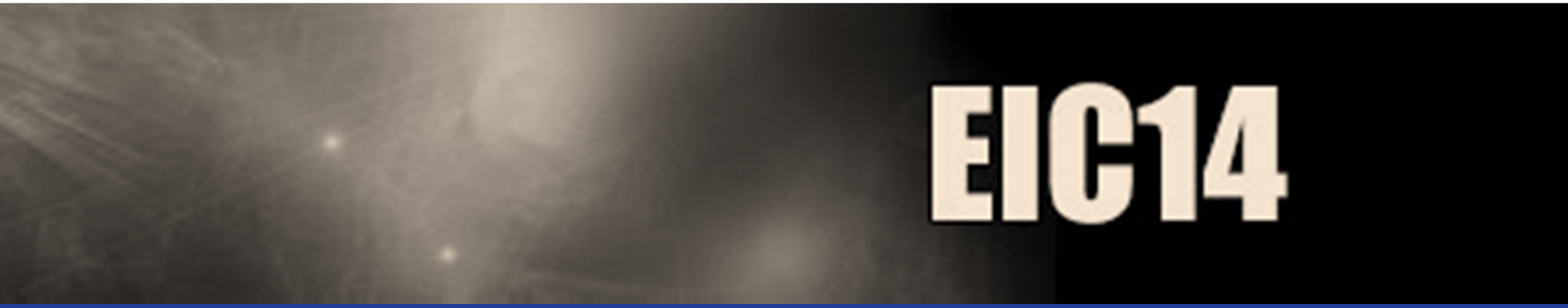
Alessandra Valloni

PRELIMINARY DESIGN OF THE CERN ERL TEST FACILITY

EIC14 Workshop on Accelerator Science and Technology for Electron-Ion Collider

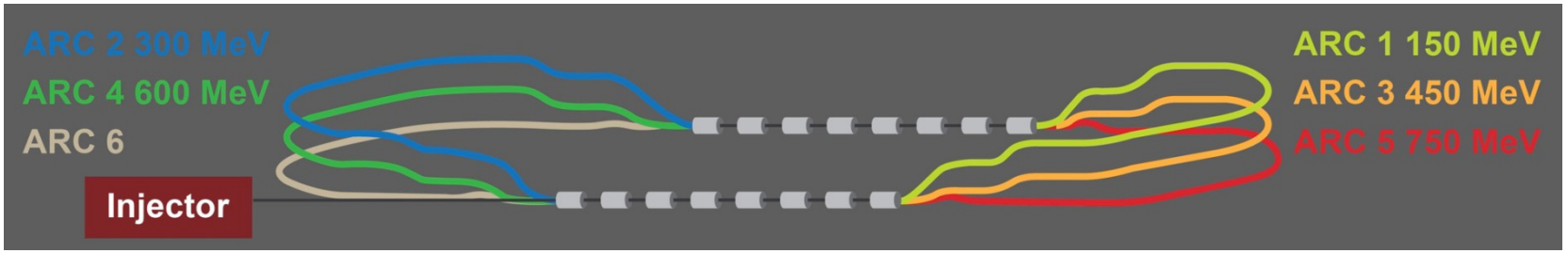
17–21 March 2014,

Thomas Jefferson National Accelerator Facility



Goals of a CERN ERL Test Facility

- Test facility for SCRF cavities and modules
- Test facility for multi-pass multiple cavity ERL
- Injector studies: DC gun or SRF gun
- Study reliability issues, operational issues!
- Vacuum studies related to FCC
- Test facility for controlled SC magnet quench tests
- Possible use for detector development, experiments and injector suggests ~1 GeV as final stage energy
- Could it be foreseen as the injector to LHeC ERL and to FCC?



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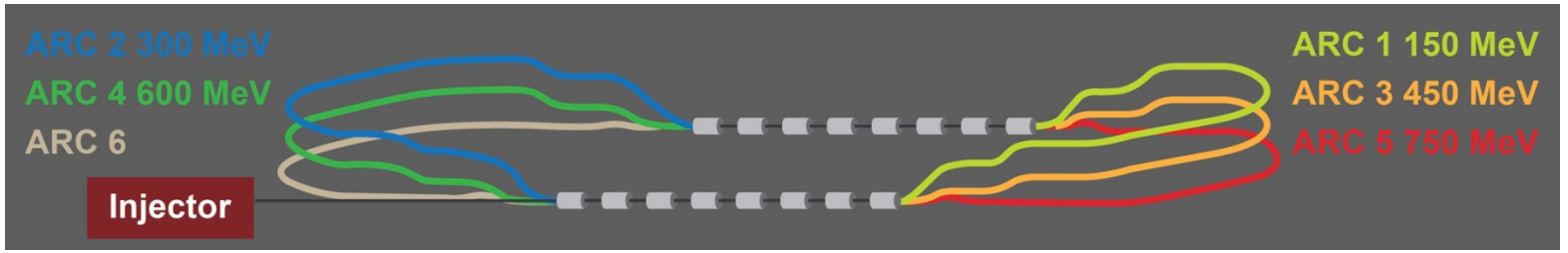
- Test facility for controlled SC magnet quench tests
- Could it be foreseen as the injector to LHeC ERL and to FCC?

TARGET PARAMETER*	VALUE
Injection Energy [MeV]	5
Final Beam Energy [MeV]	900
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	50
Beam Current [mA]	10
Bunch Spacing [ns]	25 (50)
Passes	3

*in few stages



Outline

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

2. **ARC OPTICS ARCHITECTURE**

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

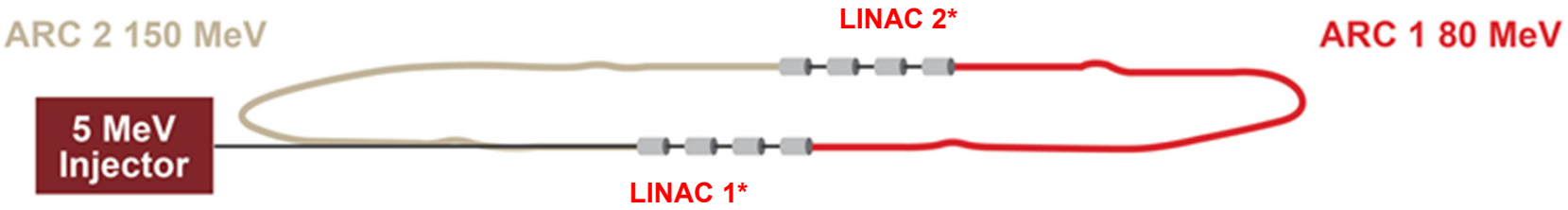
Planning for each stage

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

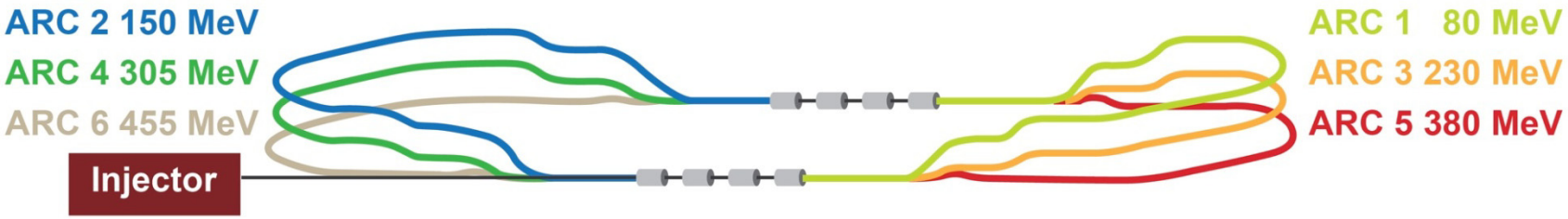
Planning for each stage

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

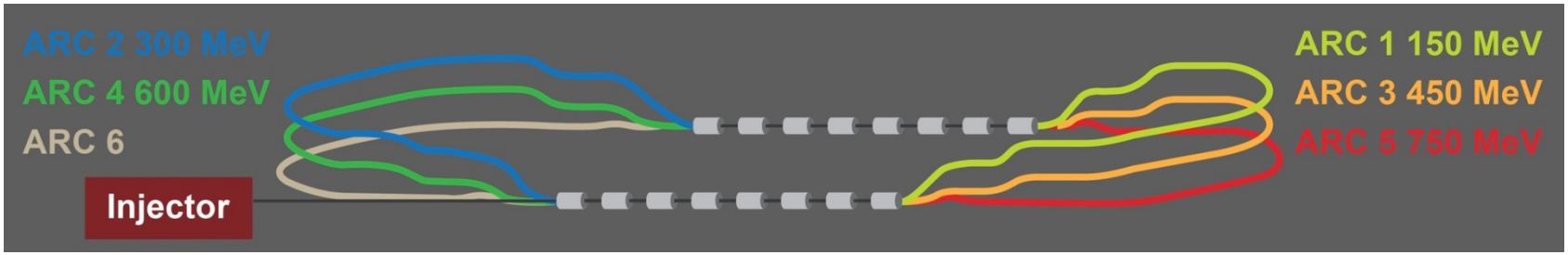
STEP 3

Additional SC RF modules test

Full energy test in Energy Recovery Mode

- Injection at 5 MeV
- 3 turns
- 150 MeV/linac
- Final energy 900 MeV

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



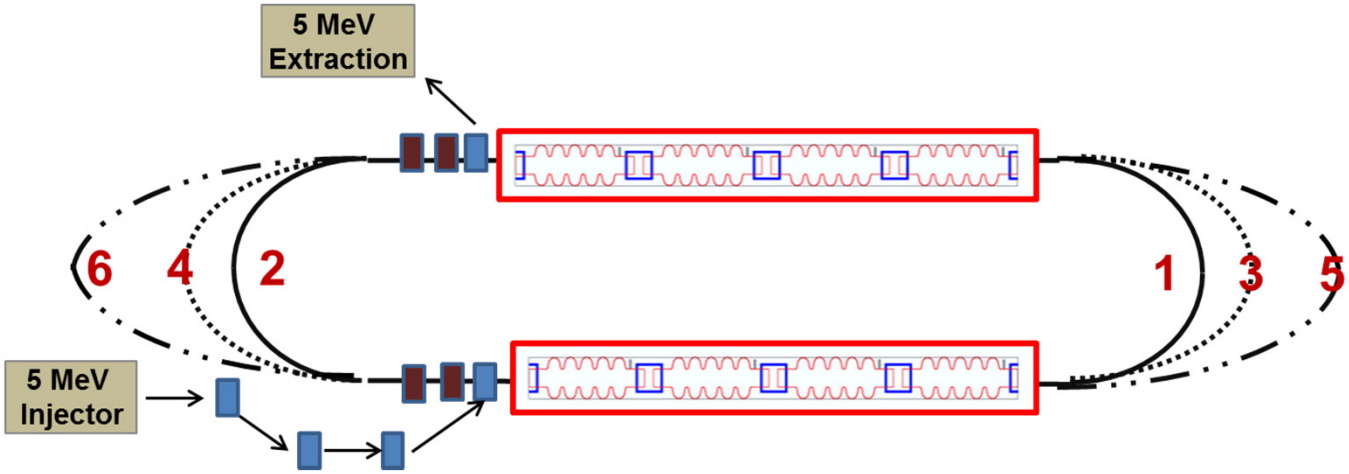
Outline

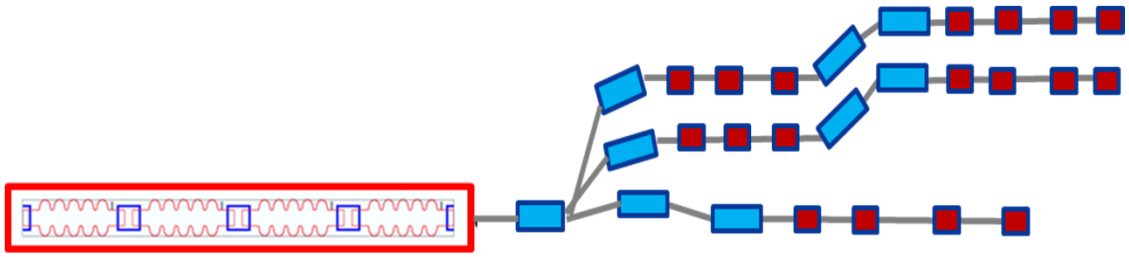
1. STAGES OF BUILDING DESIGN
   - LAYOUTS
   - BASELINE PARAMETERS

2. ARC OPTICS ARCHITECTURE FOR STEP 3

3. TEST FACILITY FOR SC MAGNET TESTS

Layout



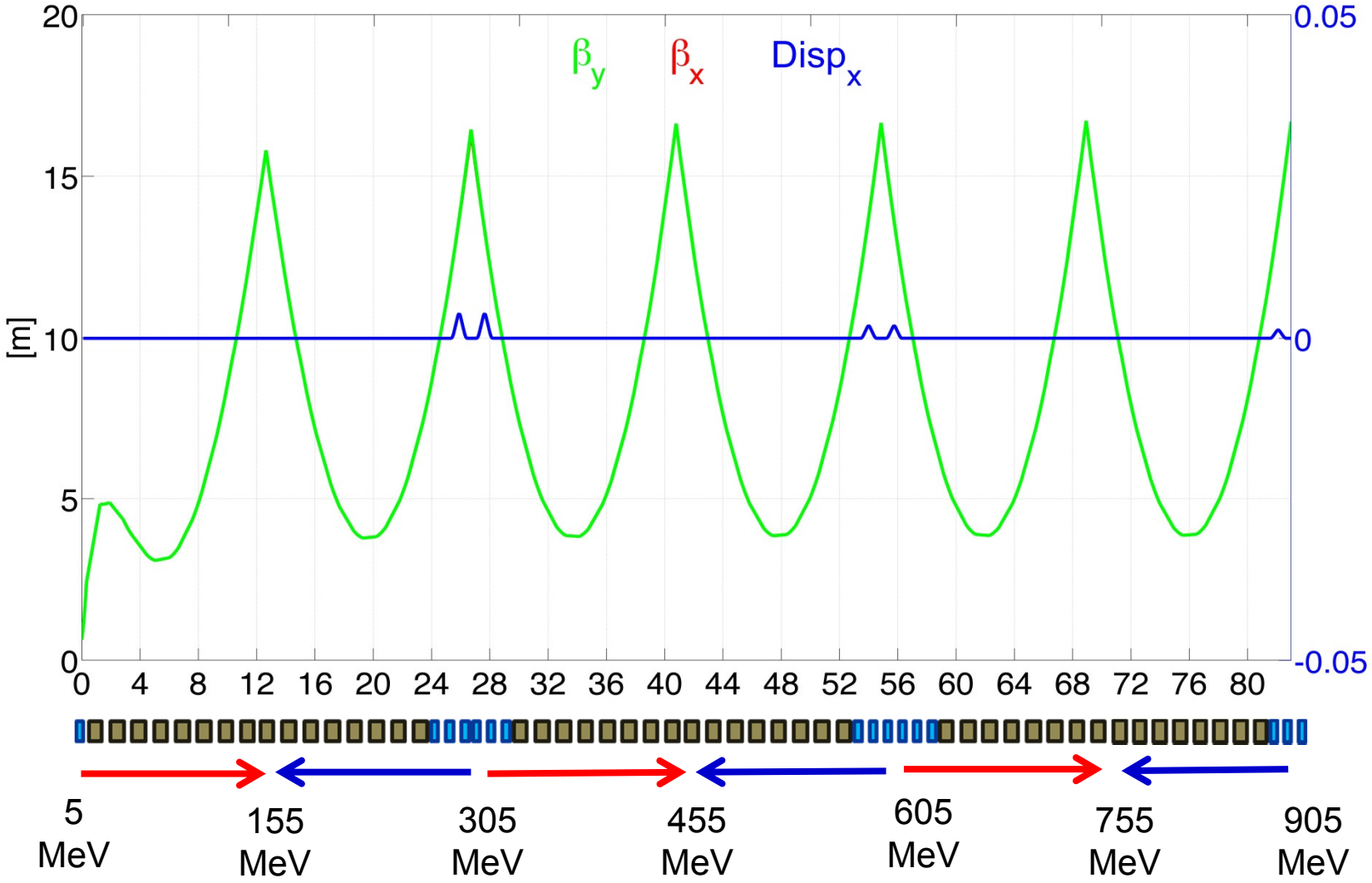


ARC 1 – 155 MeV

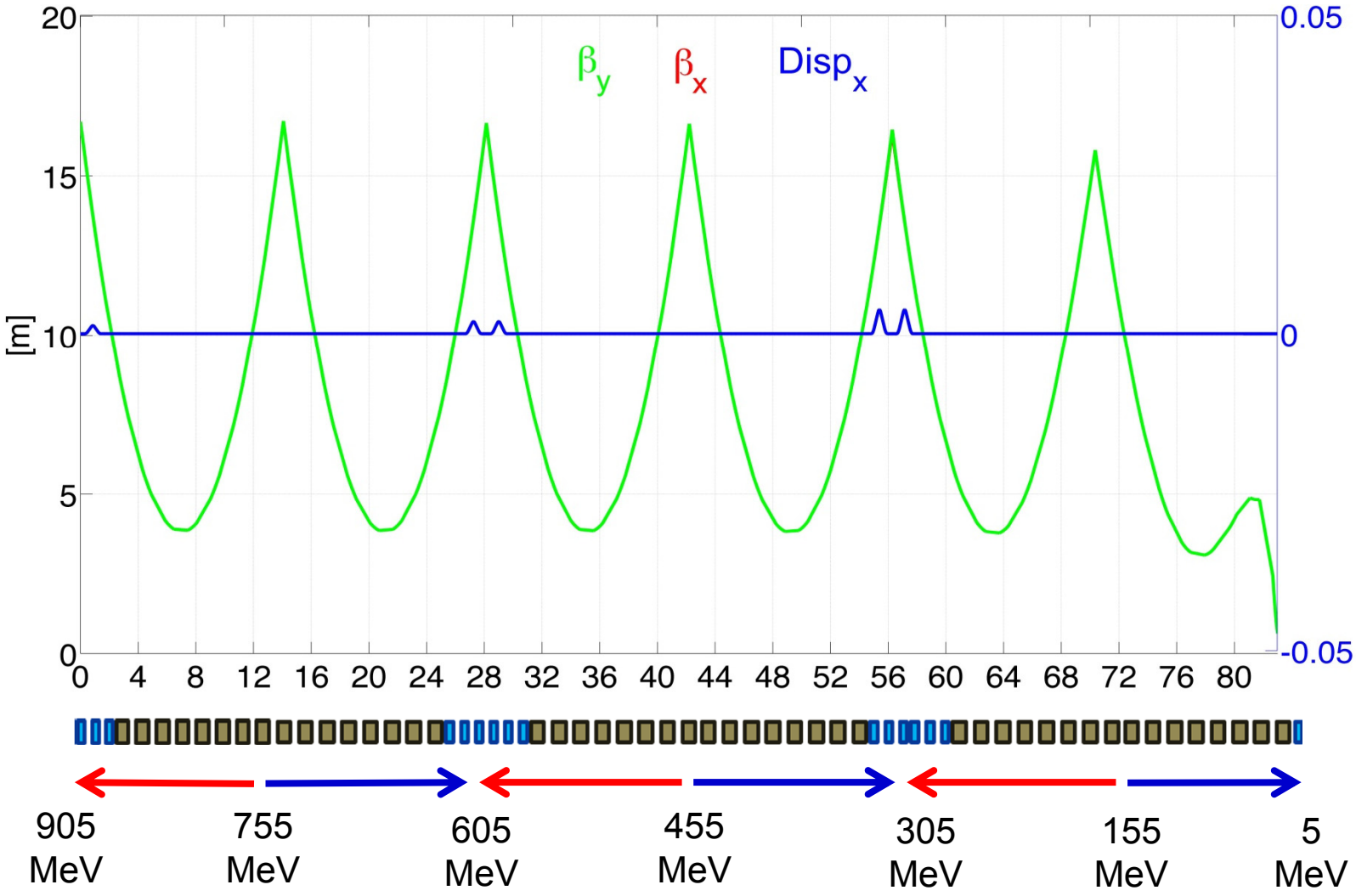
ARC 3 – 455 MeV

ARC 5 – 755 MeV

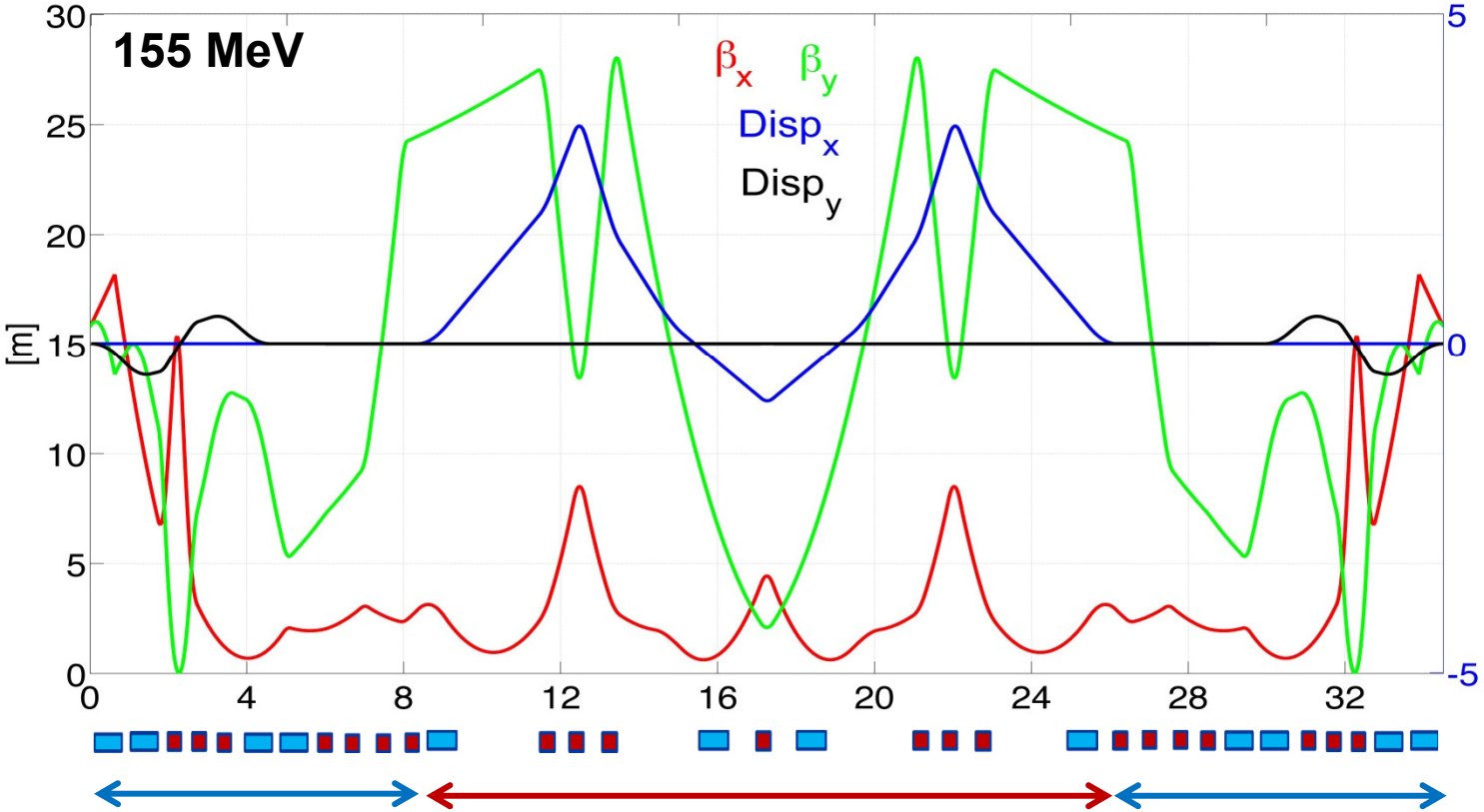
Linac 1 Multi-Pass Optics



Linac 2 Multi-Pass Optics



Arc 1 optics



2-step vert. Spreader

30° bends

(1 rec. + 3 sec.)

4×45° sector bends

Arc dipoles :

Ldip = 71.8 cm

B = 5.67 kGauss

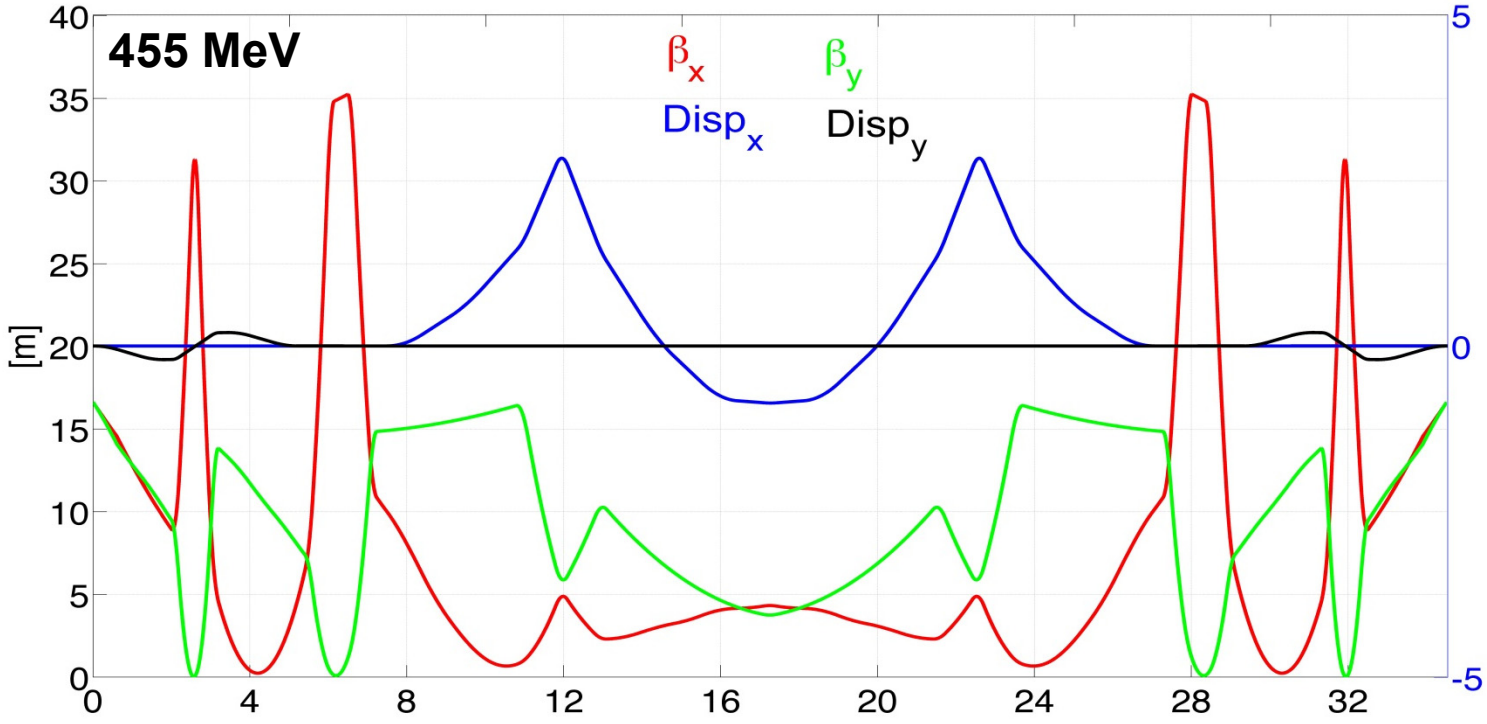
ρ = 91.45 cm

2-step vert. Combiner

30° bends

(1 rec. + 3 sec.)

Arc 3 optics



2-step vert. Spreader

9.8° bends

(1 rec. + 3 sec.)

8×22.5° sector bends

Arc dipoles :

Ldip = 90.58 cm

B = 6.58 kGauss

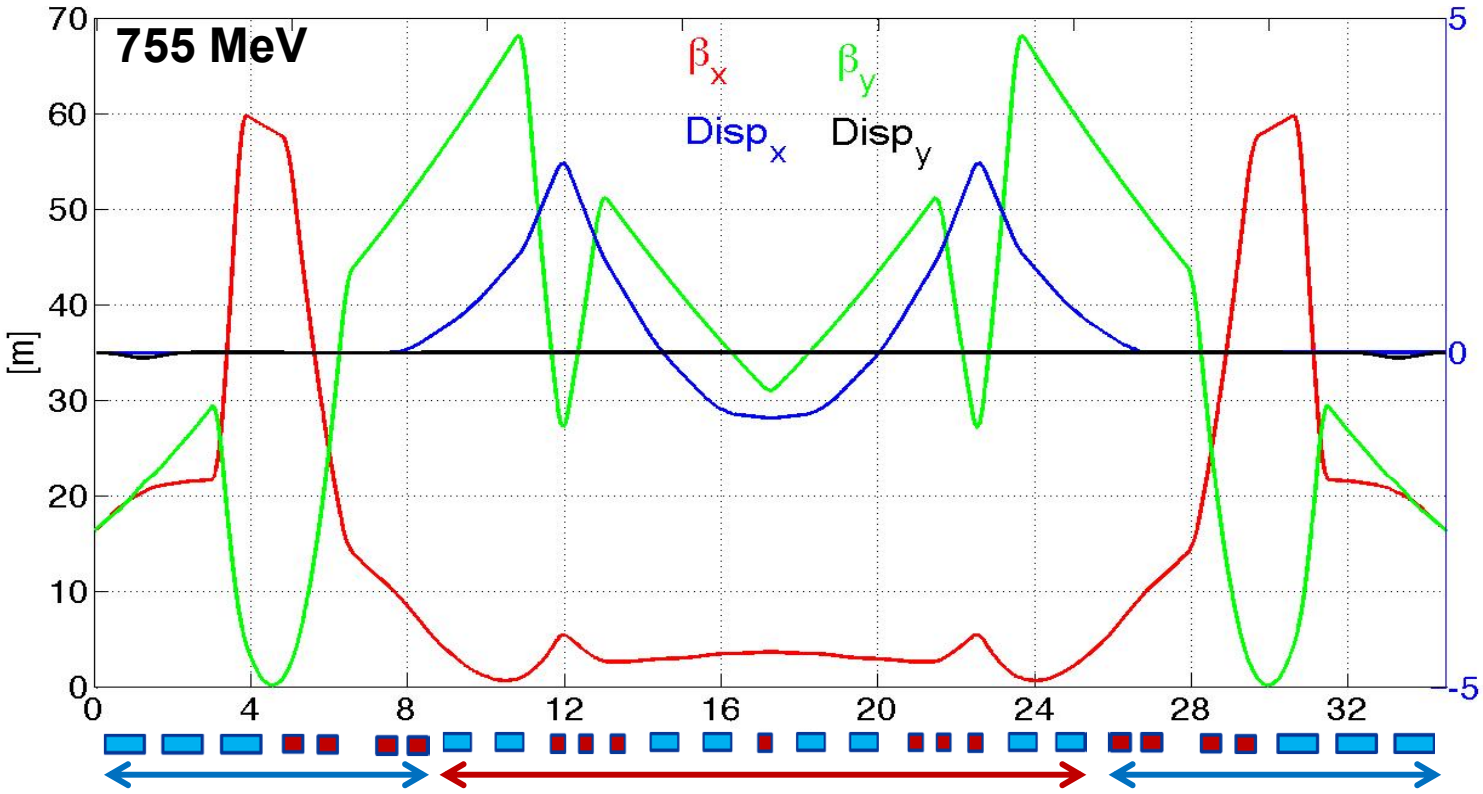
ρ = 230.66 cm

2-step vert. Combiner

9.8° bends

(1 rec. + 3 sec.)

Arc 5 optics



Vertical chicane

8×22.5° sector bends

Vertical chicane

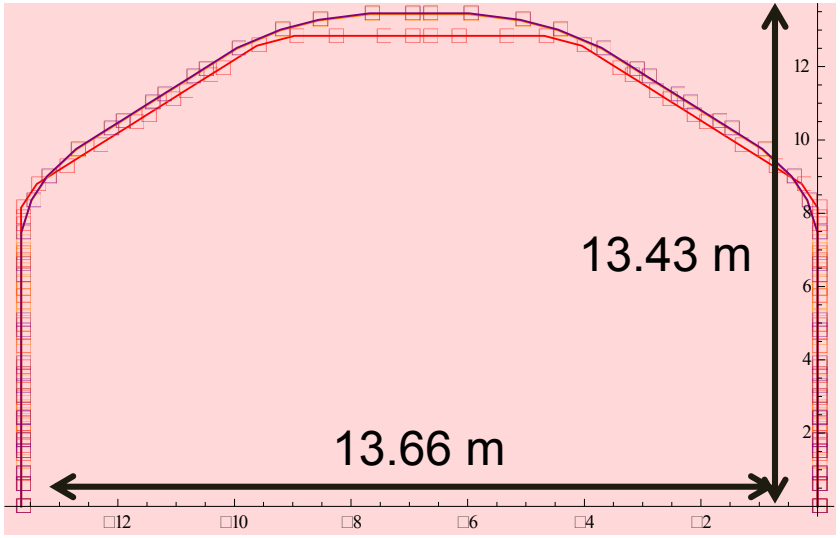
Arc dipoles :

Ldip = 90.58 cm

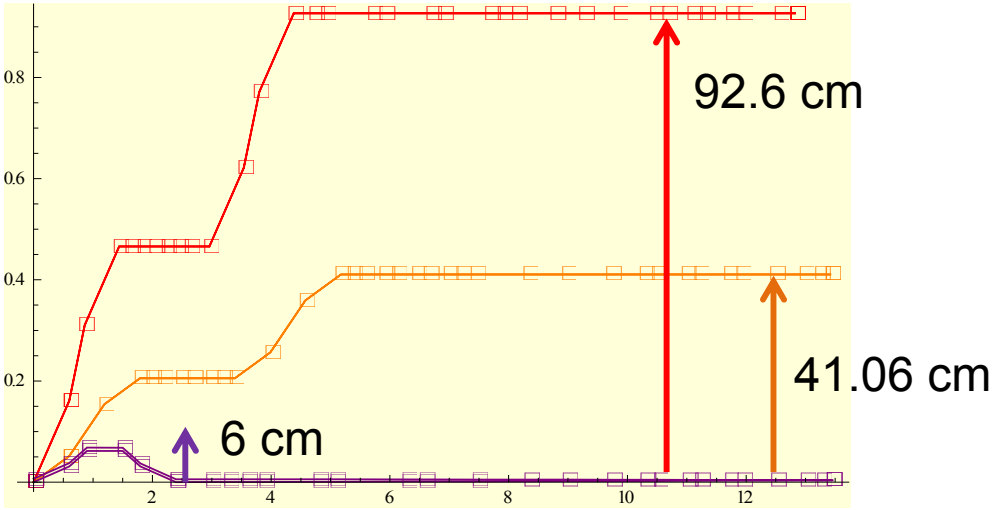
B = 10.92 kGauss

ρ = 230.66 cm

Arc 1,3,5 layout



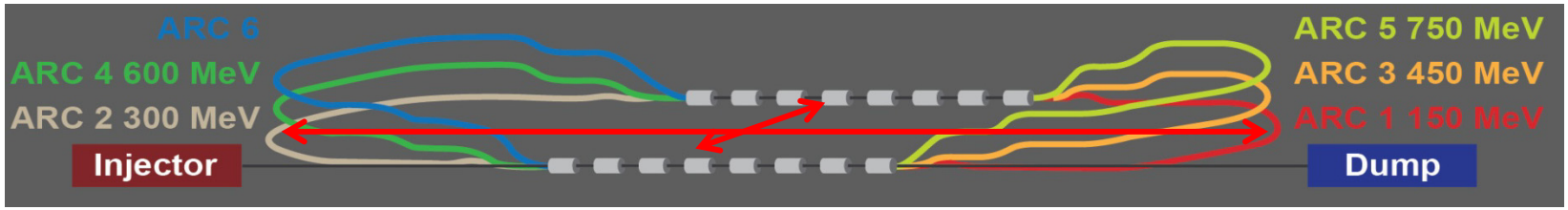
- Synchronous acceleration
  Isochronous arcs
- Achromatic arc
- FMC optics



Total Arc length for Arc 1,2,3
34.5112 m
94 x λrf

For 6 arcs:
84 DIPOLES
114 QUADRUPOLES

Footprint



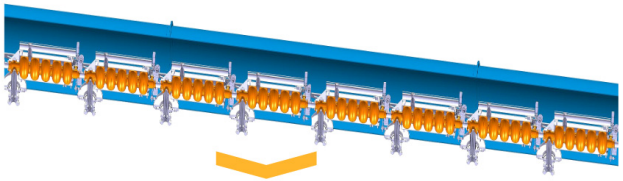
ARCS

Total length for Arc 1,2,3
34.5112 m
94 x λrf
(last cavity linac1 to first cavity linac 2)

Total length for Arc 2,4
34.2704 m
101 x λrf
(last cavity linac1 to first cavity linac 2)

Total length for Arc 6
34.4574 m
101.5 x λrf
(last cavity linac 1 to first cavity linac 2)

LINAC



ONE CRYOMODULE: 8 RF CAVITIES

PARAMETER	VALUE
Frequency	801.58 MHz
Wavelength	37.4 cm
Lcavity= 5λ/2	93.5 cm
Grad	20.02 MeV/m
ΔE	18.71 MV per cavity

Total length ~ 13 m

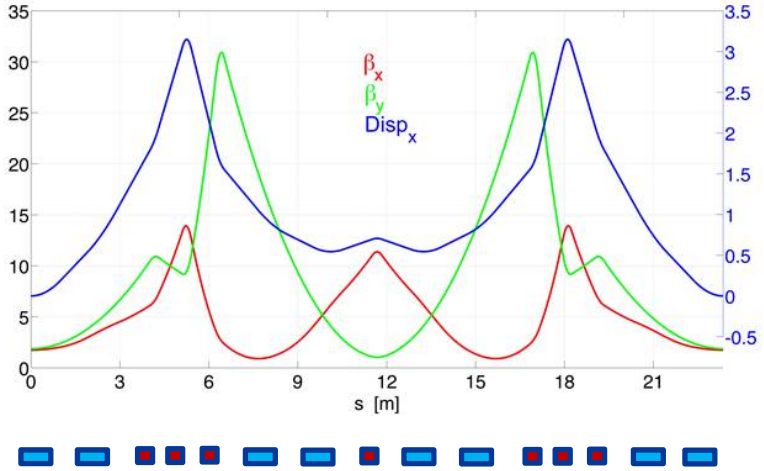
CHICANE INJ/EXTR

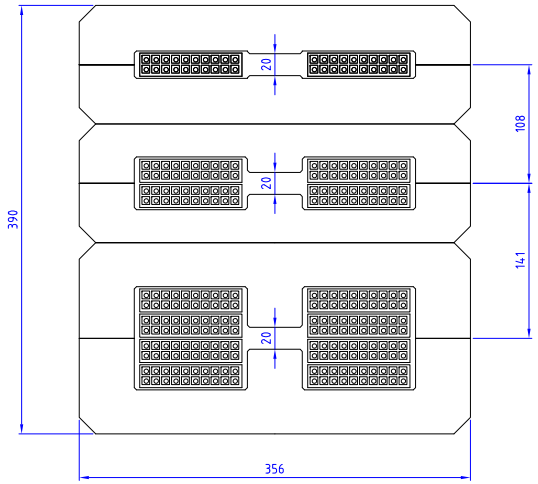
Length ~ 1.75 m

TOTAL DIMENSIONS
42 m x 13.7 m

Arc optics OPTION 2

SAME OPTICS LAYOUT FOR ALL THE ARCS 900/750/600/450/300/150 MeV





3 DIPOLES ON TOP OF EACH OTHER

*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

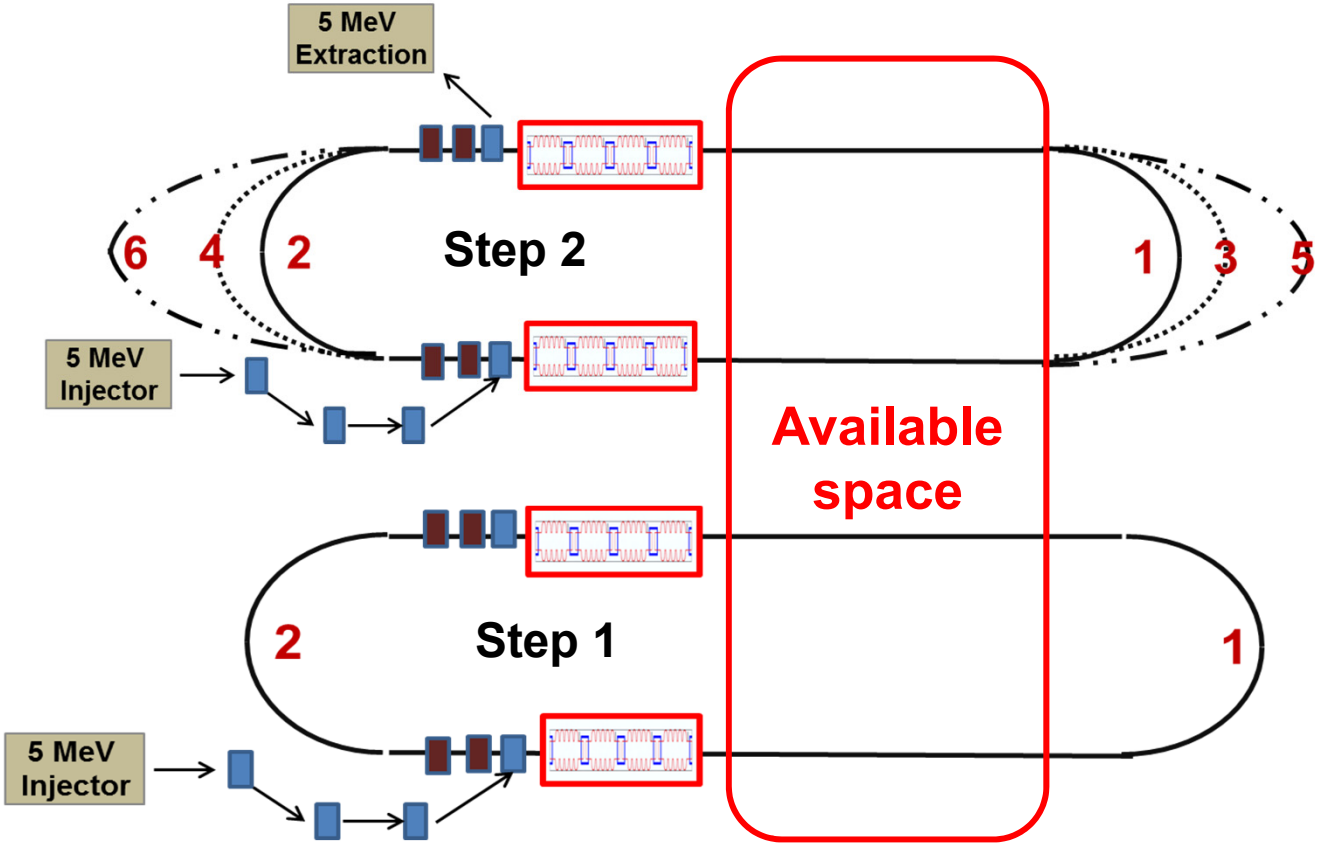
Incoherent Synchrotron radiation in return arcs

ARC	E [MeV]	ρ [cm]	ΔE [keV]	σE/E [%]
1	150	91.459	0.0280	1.17e-5
2	300	91.459	0.4191	6.42e-5
3	450	230.66	0.8230	8.13e-5
4	600	230.66	2.5726	1.53e-4
5	750	230.66	6.2394	2.73e-4
6	900	230.66	12.881	4.47e-4
7	750	230.66	6.2394	5.89e-6
8	600	230.66	2.5726	7.49e-6
9	450	230.66	0.8230	9.98e-6
10	300	91.459	0.4191	1.49e-6
11	150	91.459	0.0280	2.93e-3

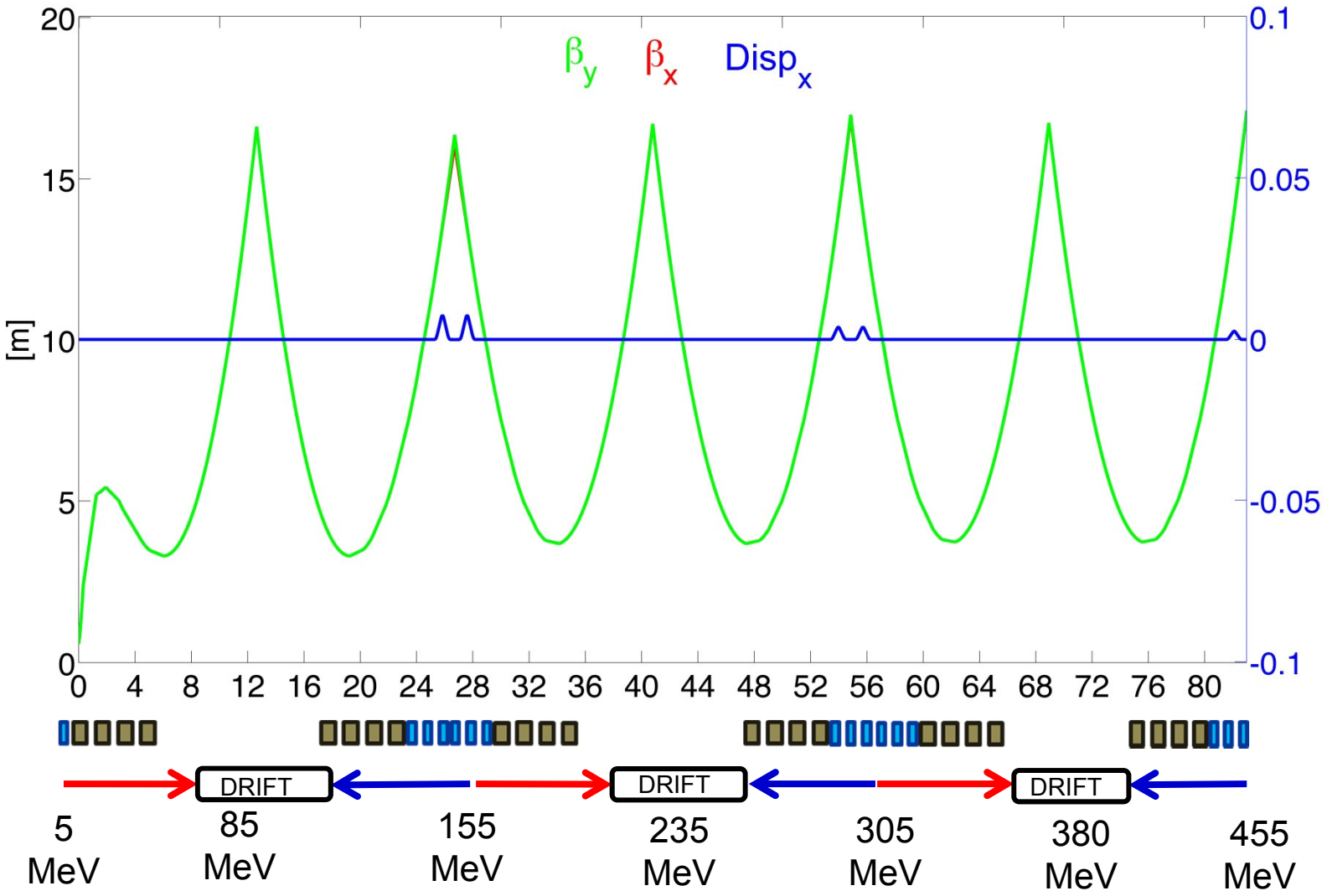
- Beam Energy loss $\Delta E = \int P_\gamma dt = P_\gamma \frac{\pi\rho}{\beta c}$ $\Delta E(GeV) = C_\gamma \frac{E^4}{\rho}\frac{1}{2}$
- Beam Energy Spread $\frac{\sigma_E}{E} = \sqrt{1.4397 * 10^{-27}\frac{\pi\gamma^5}{\rho^2}}$

Next steps

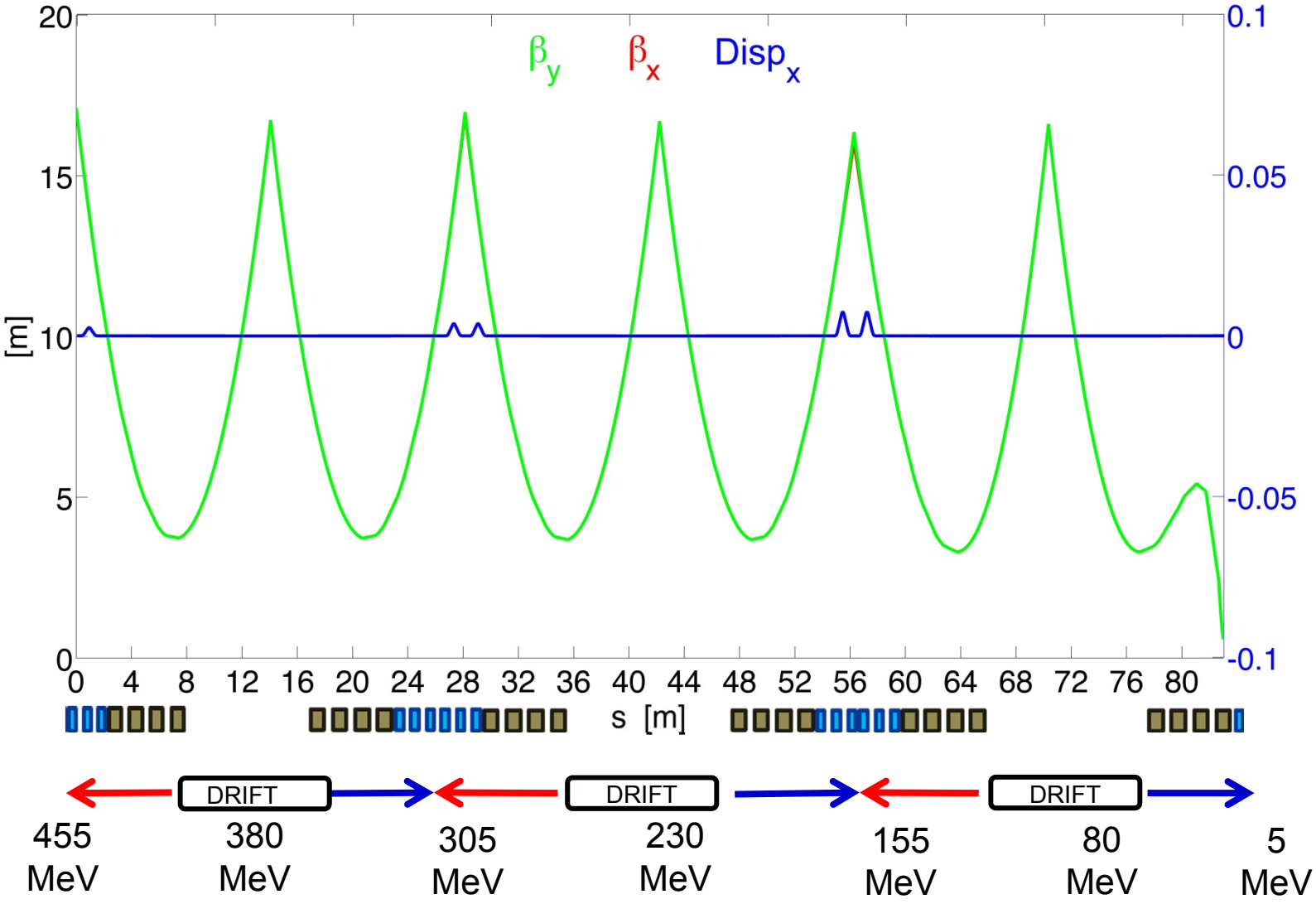
- Complete Step 2 and Step 1 configuration and optics layout



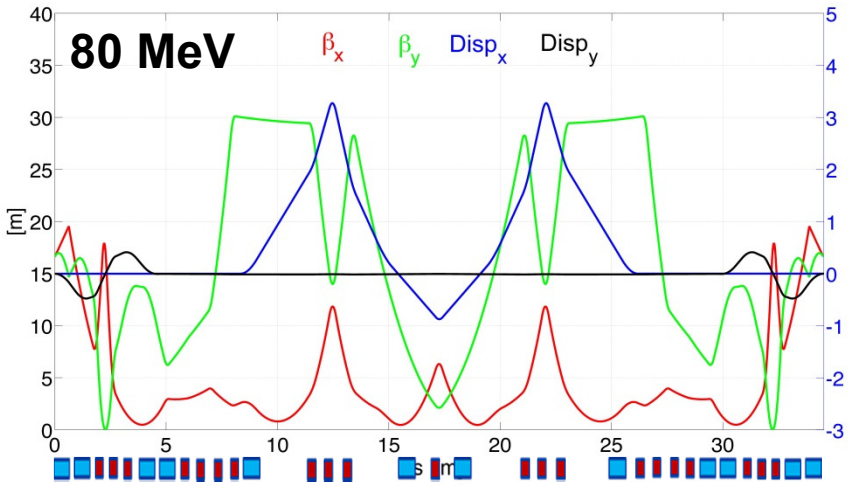
Linac 1 - Step 2

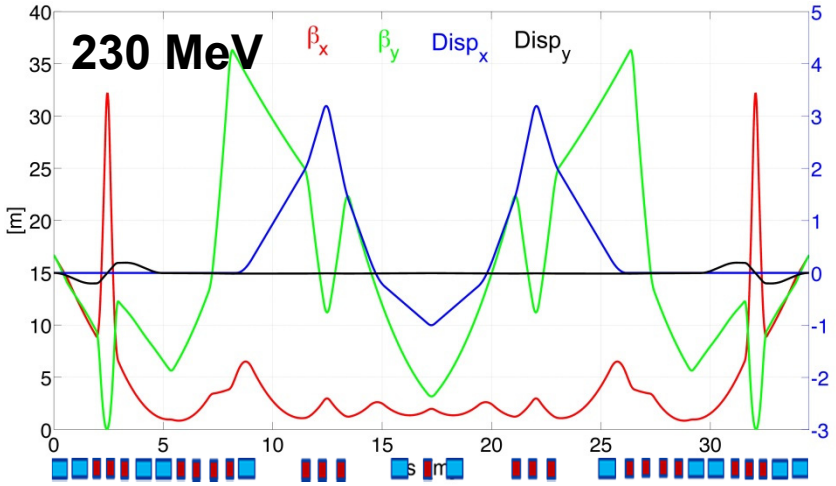


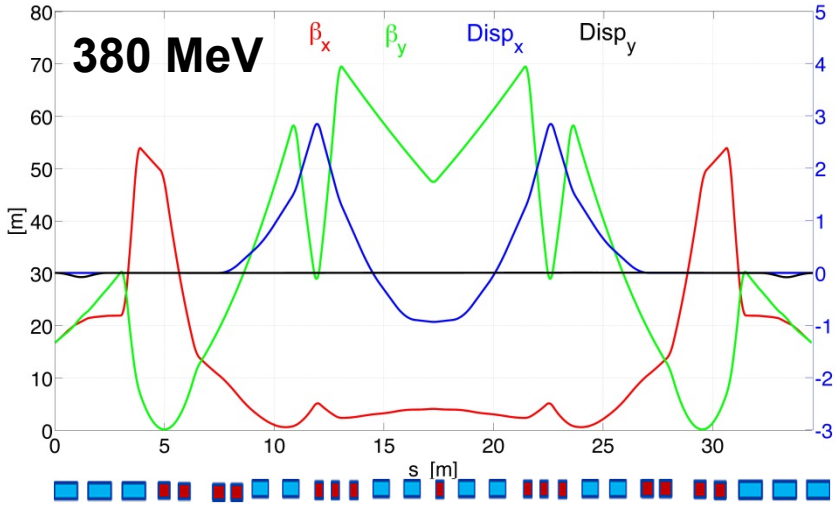
Linac 2 - Step 2

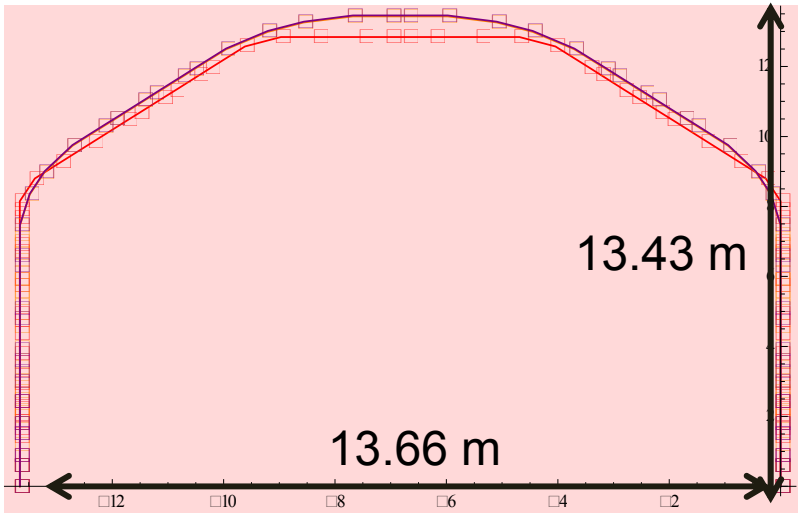


Step 2 optics









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Controlled quench tests of SC magnets

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

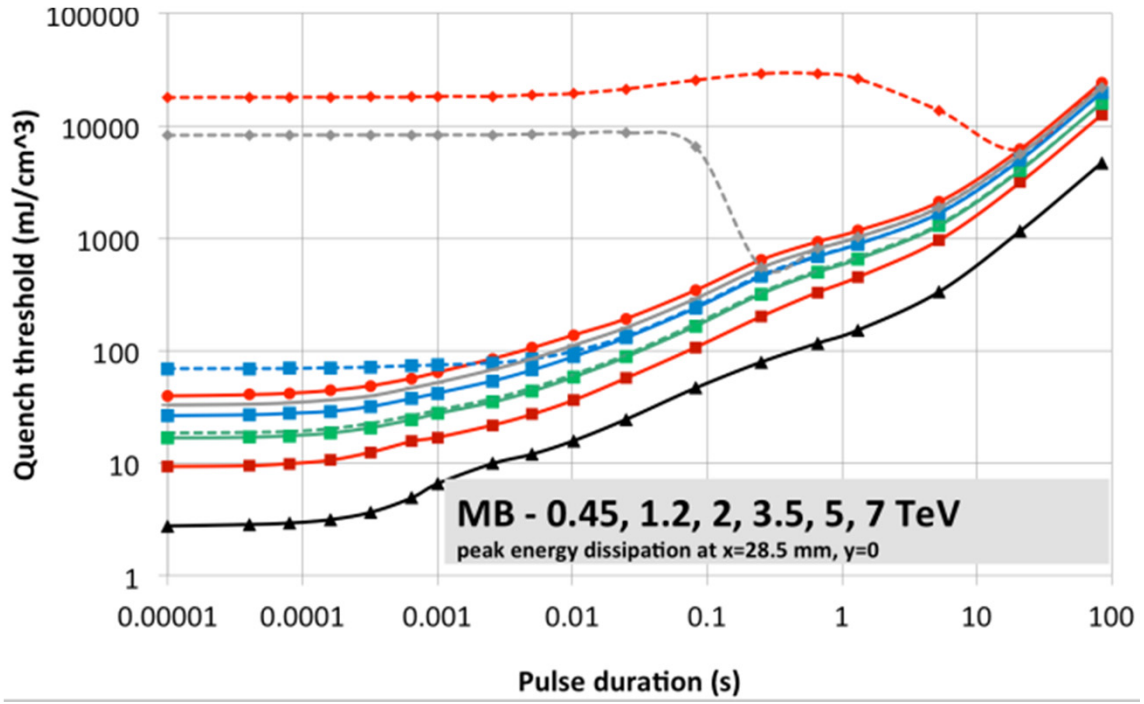
Requirements in terms of:

- 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

Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS

Beam

Copper target
(no magnetic field)

Cylinder of copper
Radius = 50cm
Length = 100cm

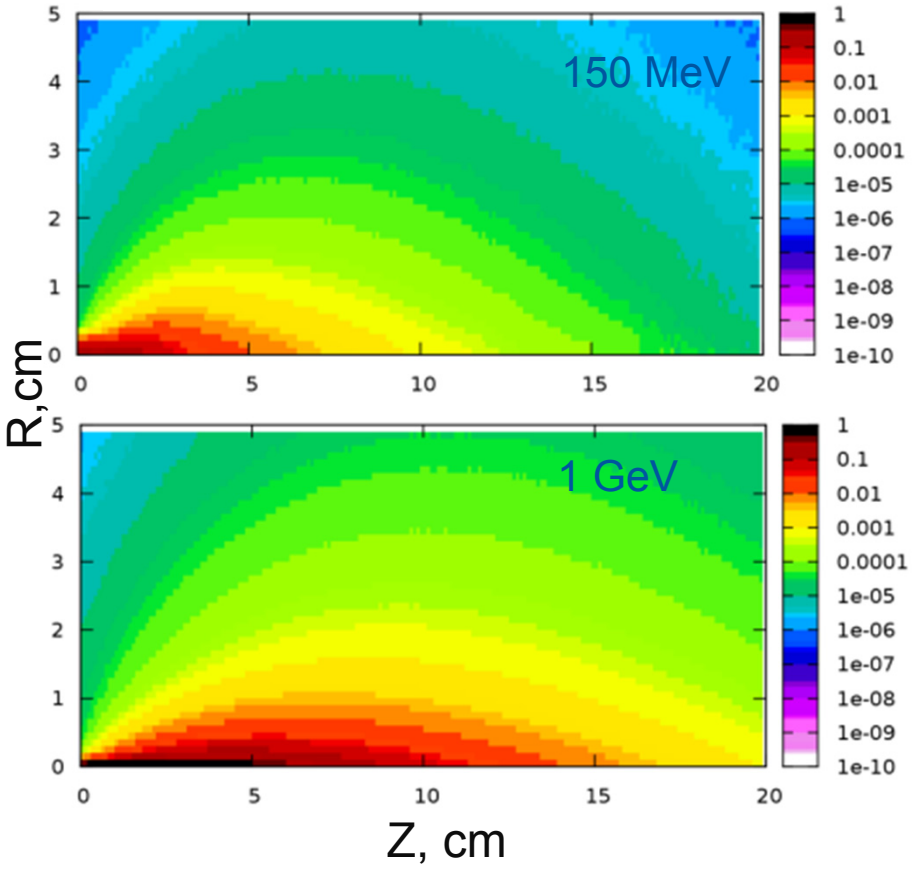
Beam parameters

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

Beam → Copper target (no magnetic field)

Cylinder of copper
Radius = 50cm
Length = 100cm

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
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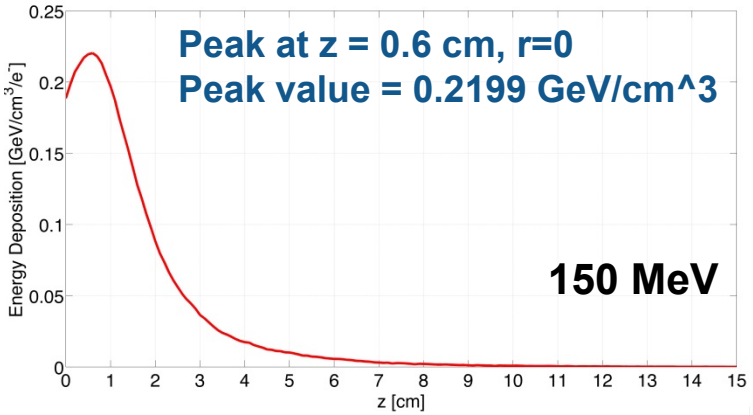
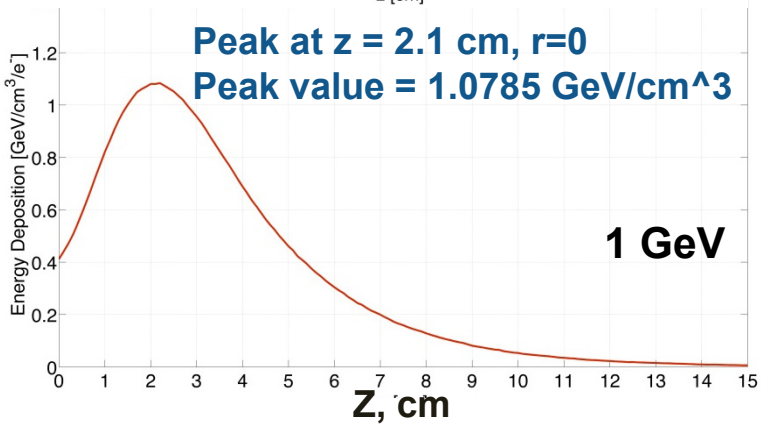
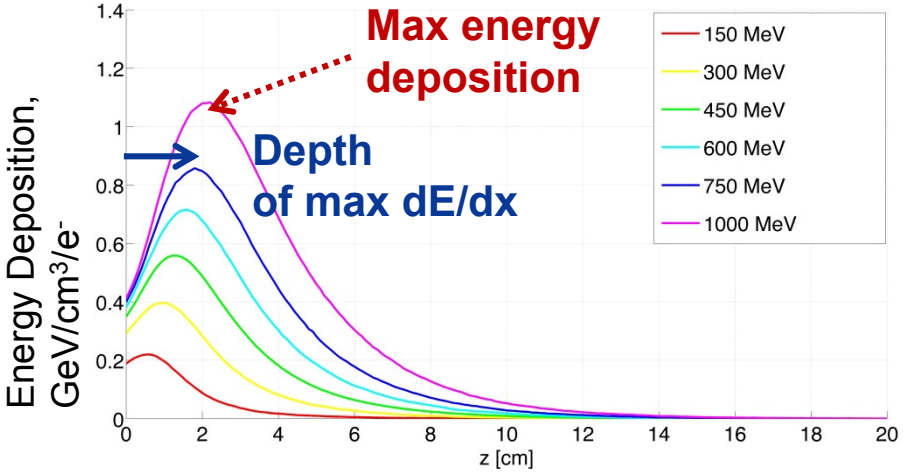
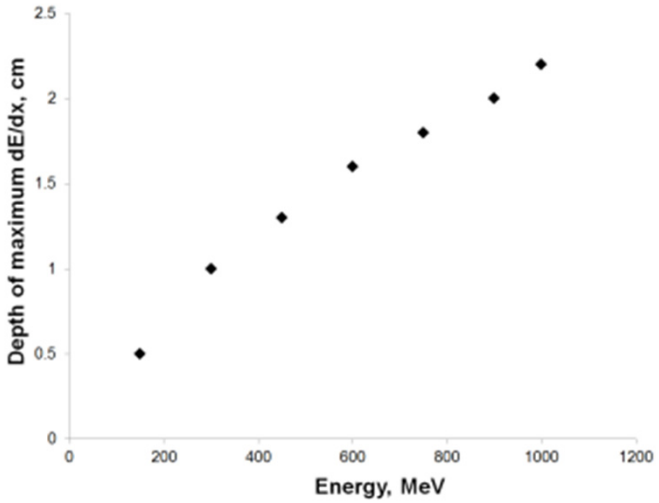




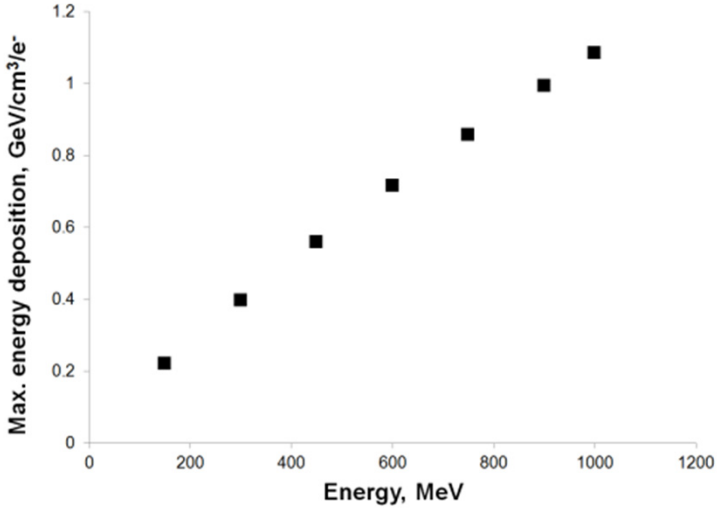
Beam parameters to generate a given amount of energy deposition



Depth of max dE/dx



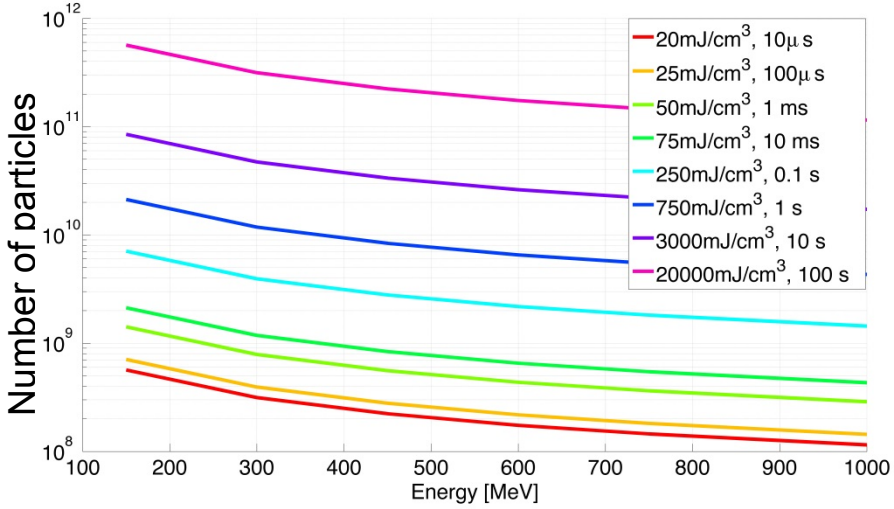
Max energy deposition

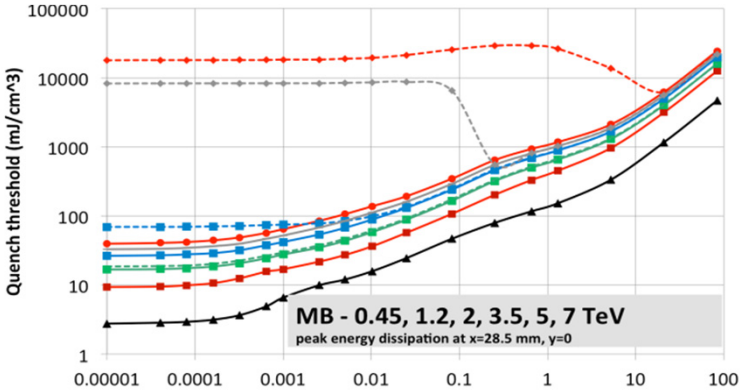


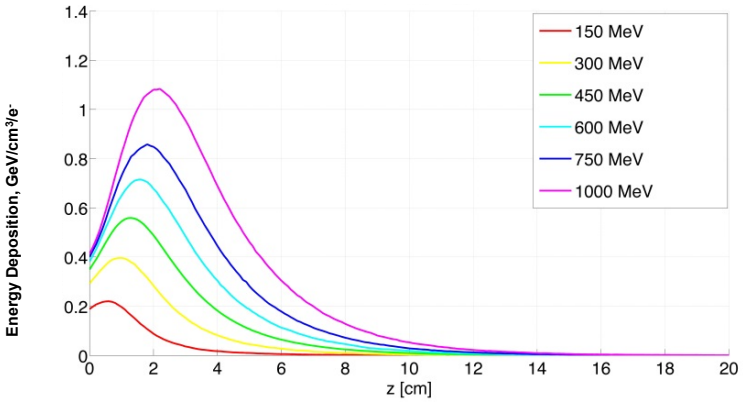
Beam parameters to generate a given amount of energy deposition

electrons needed to quench the magnet $=$ $\frac{\text{Quench threshold}}{\text{Maximum value for the energy deposition}}$

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.
- Design complementary to & synergetic with other proposals
- A Design Study of the ERL-TF has started (a sketch of the optics configuration is provided and other options are under investigation) in collaboration with other institutes (as JLAB)
- First analysis of having controlled quench tests of next generation superconducting magnets has been carried out. Beam parameters seem to match the requirements….further investigation is required!
- Completion of Conceptual design study of an ERL-TF at CERN by the end of 2015

Thank you for your attention

Many thanks to A. Bogacz , V. Chetvertkova, D. Wollmann, and the LHeC Study Group Collaboration