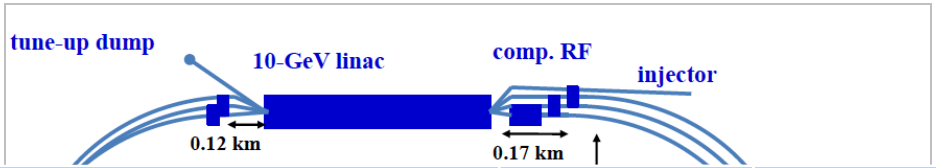
LHeC ERL Test Facility & SC RF:

Fundamental Goals and Motivation:

- Build up expertise in the design and operation for a facility with a fundamentally new operation mode:
  - ERLs are circular machines with tolerances and timing requirements similar to linear accelerators (no 'automatic' longitudinal phase stability etc.)
- Proof validity of fundamental design choices:
  - Multi-turn recirculation (other existing ERLs have only two passages)
  - Implications of high current operation (3 * [6mA – 12mA] > 30mA!!)
- Verify and test machine and operation tolerances before designing a large scale facility
  - Tolerances in terms of field quality of the arc magnets
  - Required RF phase stability (RF power) and LLRF requirements

LHeC: Baseline Linac-Ring Option

- Super Conducting Linac with Energy Recovery & high current (> 6mA)



Two 1 km long SC linacs in CW operation

10^{34} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60	7000	60
Luminosity [10^{33}cm^{-2}s^{-1}]	16	16	1	1
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	2.5	20	3.75	50
Beta Funtion $\beta^*_{x,y}$ [m]	0.05	0.10	0.1	0.12
rms Beam size $\sigma^*_{x,y}$ [μm]	4	4	7	7
rms Beam divergence σ□$^*_{x,y}$ [μrad]	80	40	70	58
Beam Current [mA]	1112	25	430 (860)	6.6 (3.3)
Bunch Spacing [ns]	25	25	25 (50)	25 (50)
Bunch Population	$2.2*10^{11}$	$4*10^{9}$	$1.7*10^{11}$	$(1*10^{9})$ $2*10^{9}$
Bunch charge [nC]	35	0.64	27	(0.16) 0.32

LHeC ERL RF Choices:

LHeC SC RF choice:

- ➔ Daresbury meeting on RF options January 2013:
  - ➔ no existing SC RF technology (ILC & ESS) fits perfectly to the LHeC
  - ➔ no synergy with existing RF power sources at CERN

- ➔ 800 MHz:
  - ➔ minimization of RF power a la Marhauser
  - ➔ lower frequency advantageous for beam stability (Wakefields)
  - ➔ Synergy with existing RF power sources @ CERN

➔ See presentation by Erk Jensen for more details

LHeC ERL Test Facility:

Validation of key LHeC Design Choices:

- ➔ Three re-circulations with high beam current:
  - ➔ Coherent Beam stability due to ions, and wake-fields when triggering transverse perturbations (a la beam-beam)
  - ➔ Pulse stability and reproducibility of beam parameters (intensity, position and size)
  - ➔ Energy spread and beam parameter stability at end of deceleration process
  - ➔ Study of transient ERL dynamics during current ramp-up
- ➔ SC RF Design validation via operation with beam
  - ➔ SC RF behavior with beam
  - ➔ Coupler validation
  - ➔ HOM tolerances and required HOM damping
  - ➔ Beam loading and implied RF controls

LHeC ERL Test Facility:

Validation and tests of auxiliary ERL components:

- ➔ Injector and gun
  - ➔ Choice of electron sources (Superconducting RF, DC High Voltage etc)
  - ➔ Injection energy and beam transfer, emittance requirements and preservation, etc.
- ➔ Required beam diagnostics:
  - ➔ Pulse by pulse diagnostics
  - ➔ Single pass beam size measurements etc.
- ➔ Injection line and beam dump tests
  - ➔ Momentum acceptance requirements
  - ➔ Beam extraction at different beam energies and machine protection aspects

LHeC ERL Test Facility:

Potential applications beyond an LHeC ERL Test Facility:

- ➔ Magnet and cable quench facility:
  - ➔ Vital for development of new cables and future high field SC magnets (e.g. FCC hh)
- ➔ Test facility for SC RF with beam
  - ➔ Very interesting for development of new SC RF components
  - ➔ e.g. Crab Cavities, SC RF for FCC ee, etc.
- ➔ Test beam for detector component developments
  - ➔ Beam lines with beam energies higher than 100 MeV/c [Peter Kostka]
- ➔ Dedicated Physics Facility
  - ➔ similar to MESA program but at higher energy

LHeC ERL Test Facility:

ERL Test Facility layout and parameters:

- ➔ Possibility for phased installation:
  - ➔ Energy range for each option
- ➔ Overall floor foot print
  - ➔ Requirements for ERL TF
  - ➔ Requirements for auxiliary applications
- ➔ Parameter overview

Planning for each stage

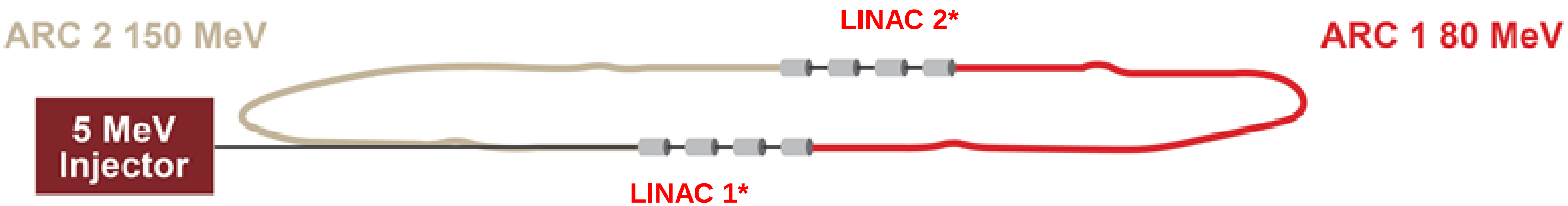
Courtesy of Alessandra Valloni

Phase 1:

ARC	ENERGY
ARC 1	80 MeV
ARC 2	155 MeV

SC RF cavities, modules and e^- source tests

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



*4 SRF 5-cell cavities at 802 MHz

Planning for each stage

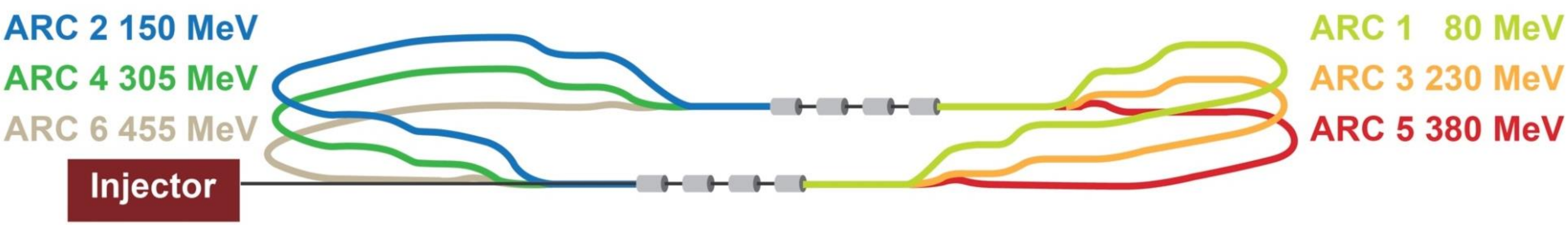
Courtesy of Alessandra Valloni

Phase 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

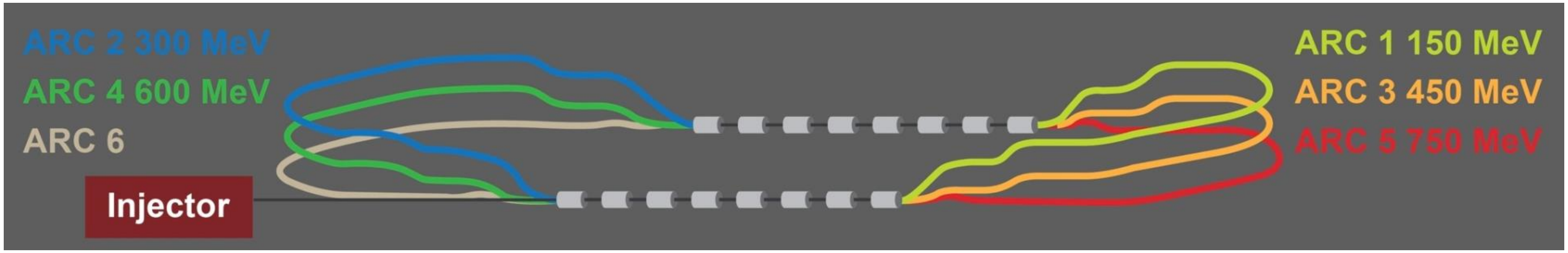
Courtesy of Alessandra Valloni

Phase 3:

Additional SC RF modules test
Full energy test in Energy Recovery Mode

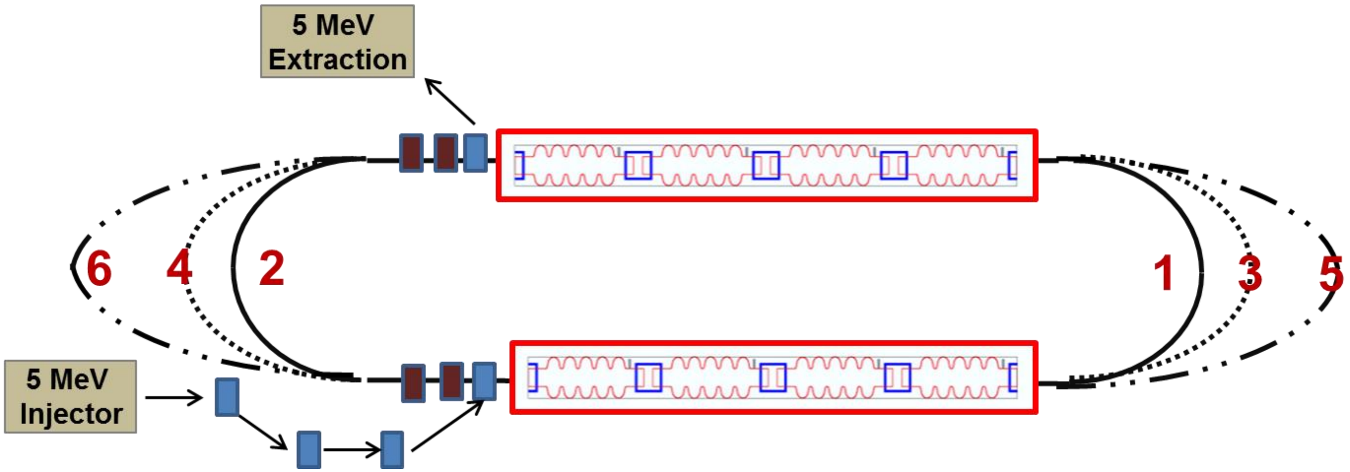
- Injection at 5 MeV
- 3 turns
- 150 MeV/linac
- Final energy 900 MeV

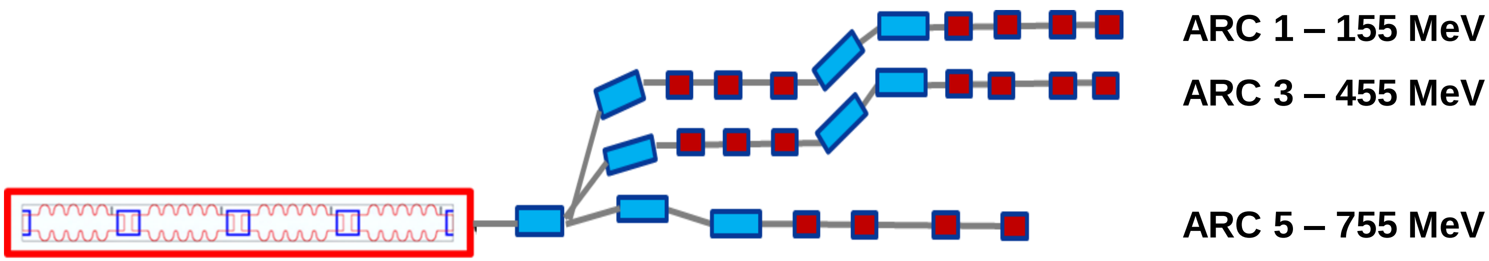
ARC	ENERGY
ARC 1	150 MeV
ARC 2	300 MeV
ARC 3	450 MeV
ARC 4	600 MeV
ARC 5	750 MeV
ARC 6	900 MeV



Layout:

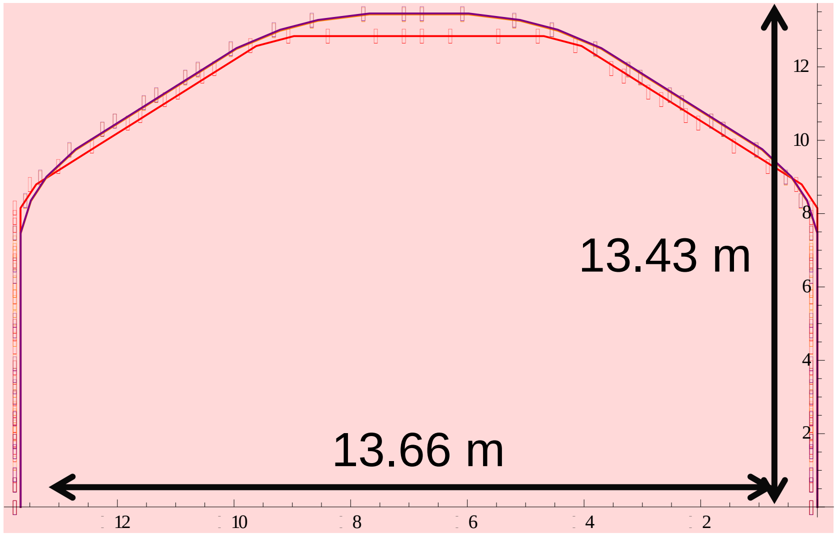
Courtesy of Alessandra Valloni



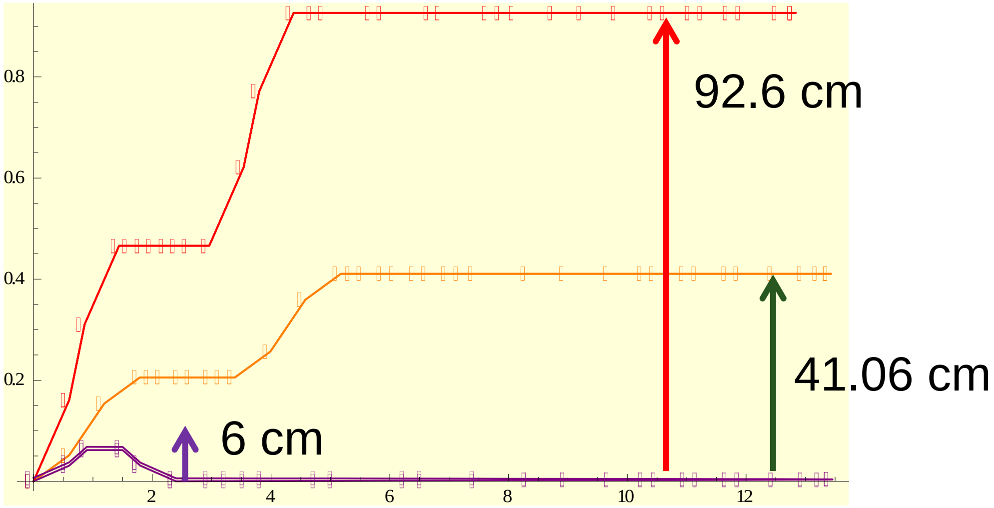


ARC I, III, IV Layout:

Courtesy of Alessandra Valloni



- Synchronous acceleration
  Isochronous arcs
- Achromatic arc
- FMC optics

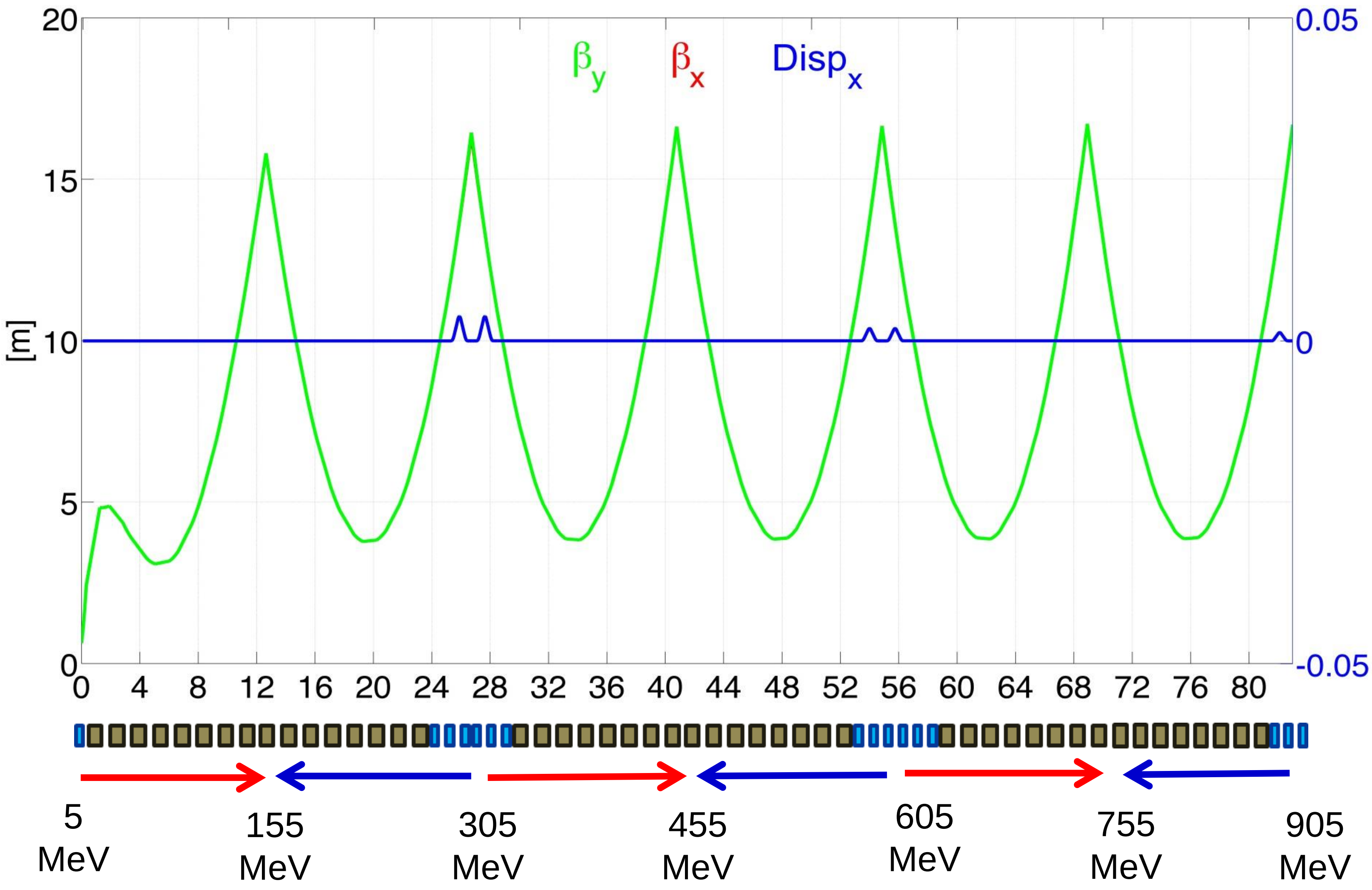


Total Arc length for Arc 1,2,3
34.5112 m
94 x λrf

For 6 arcs:
84 DIPOLES
114 QUADRUPOLES

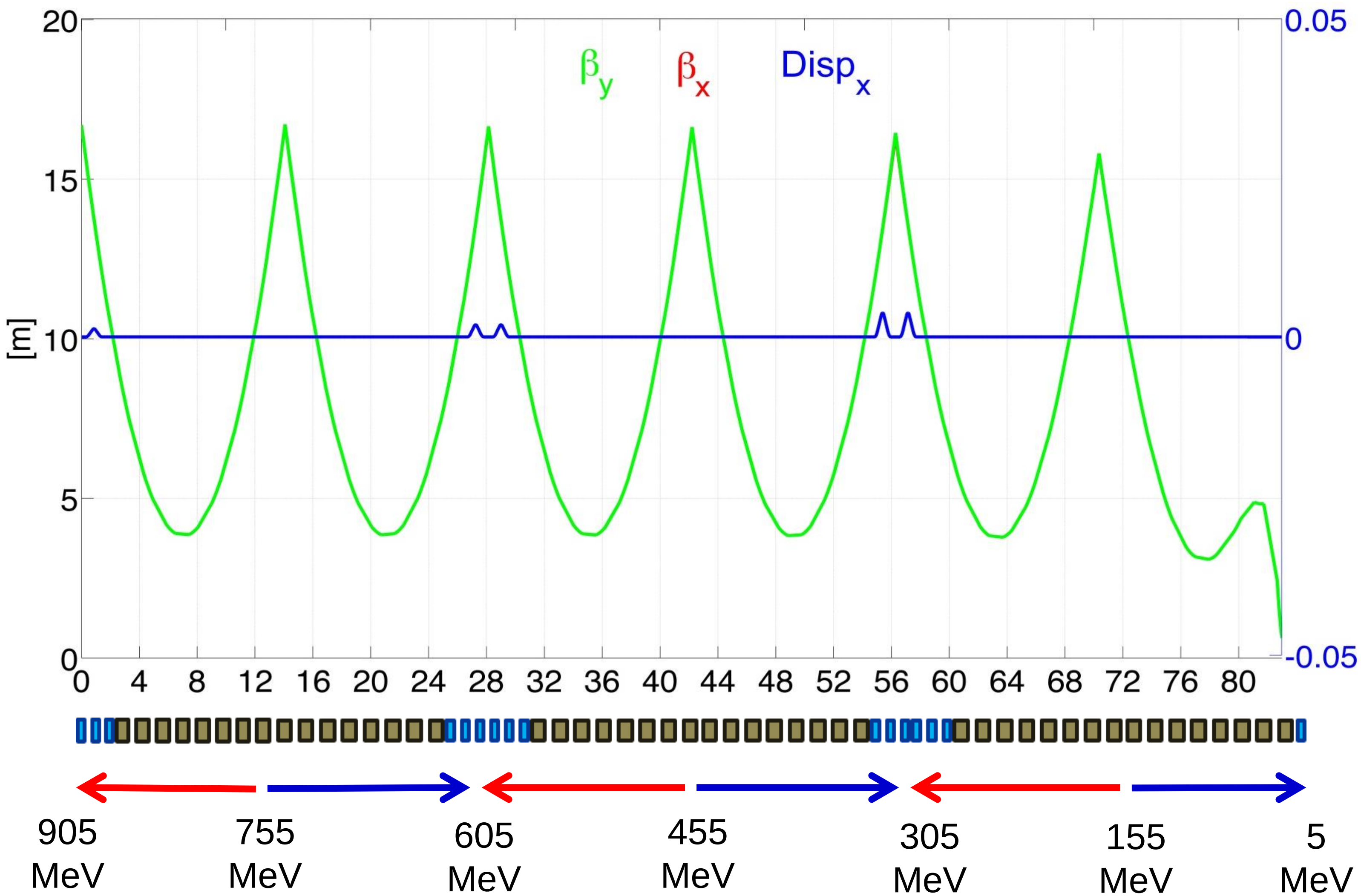
Linac I Multi-pass optics:

Courtesy of Alessandra Valloni



A. Valloni, A. Bogacz

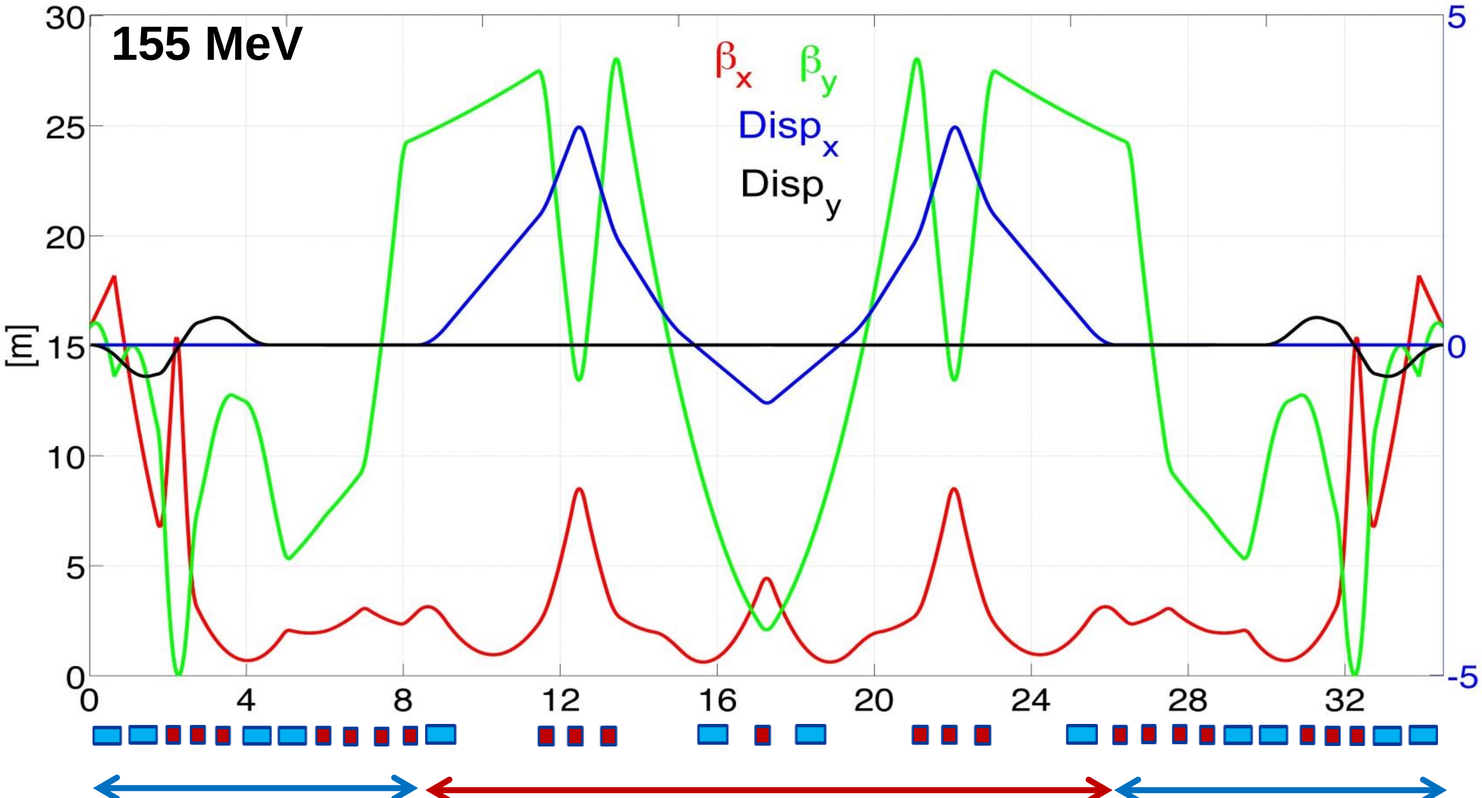
Linac II Multi-Pass Optics: Courtesy of Alessandra Valloni



A. Valloni, A. Bogacz

Optics Option I: Arc I:

Courtesy of Alessandra Valloni



30° bends

(1 rec. + 3 sec.)

Arc dipoles :

Ldip = 71.8 cm

B = 5.67 kGauss

ρ = 91.45 cm

30° bends

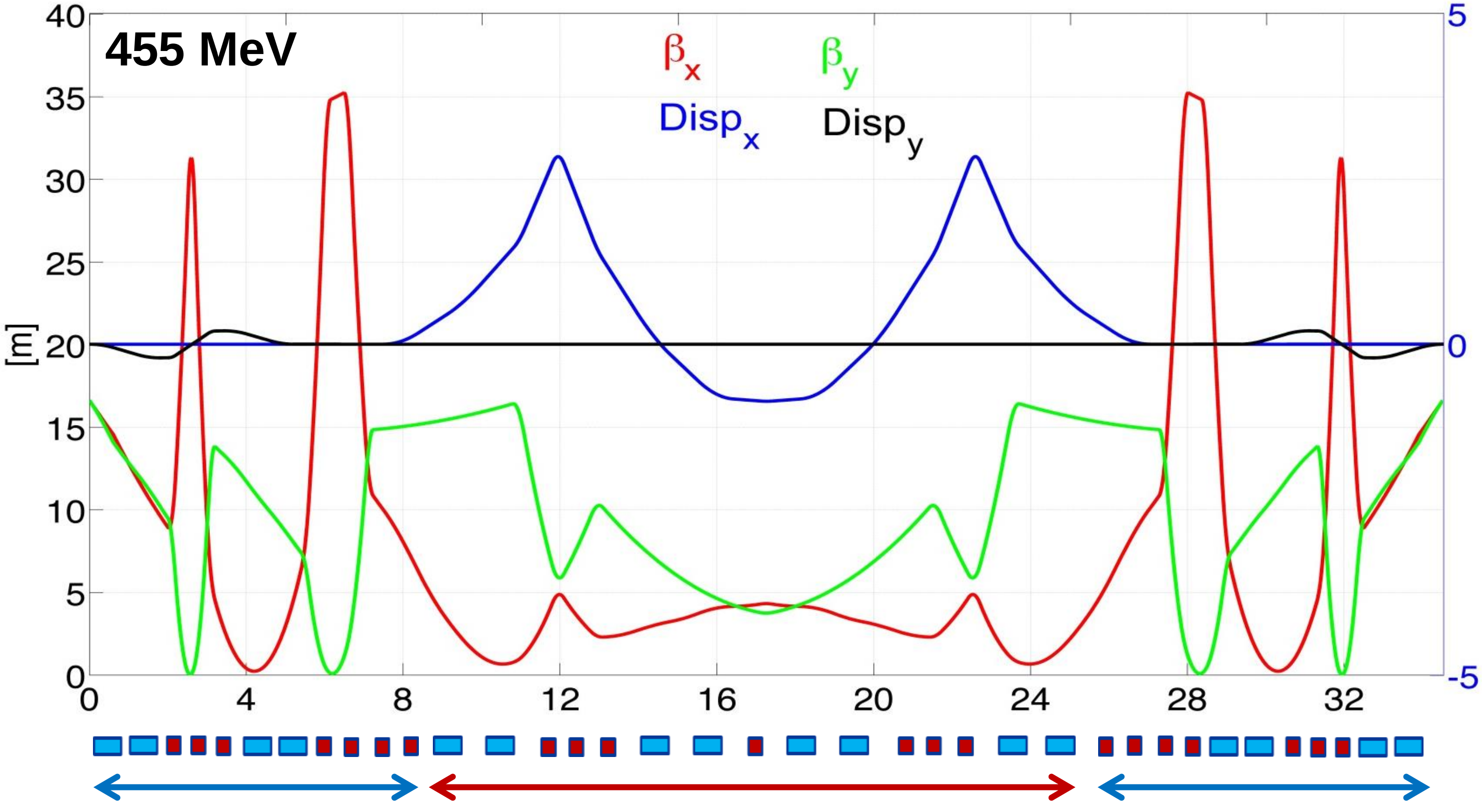
(1 rec. + 3 sec.)

FMC = Flexible Momentum Compaction

A. Valloni, A. Bogacz

Optics Option I: ARC III:

Courtesy of Alessandra Valloni



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

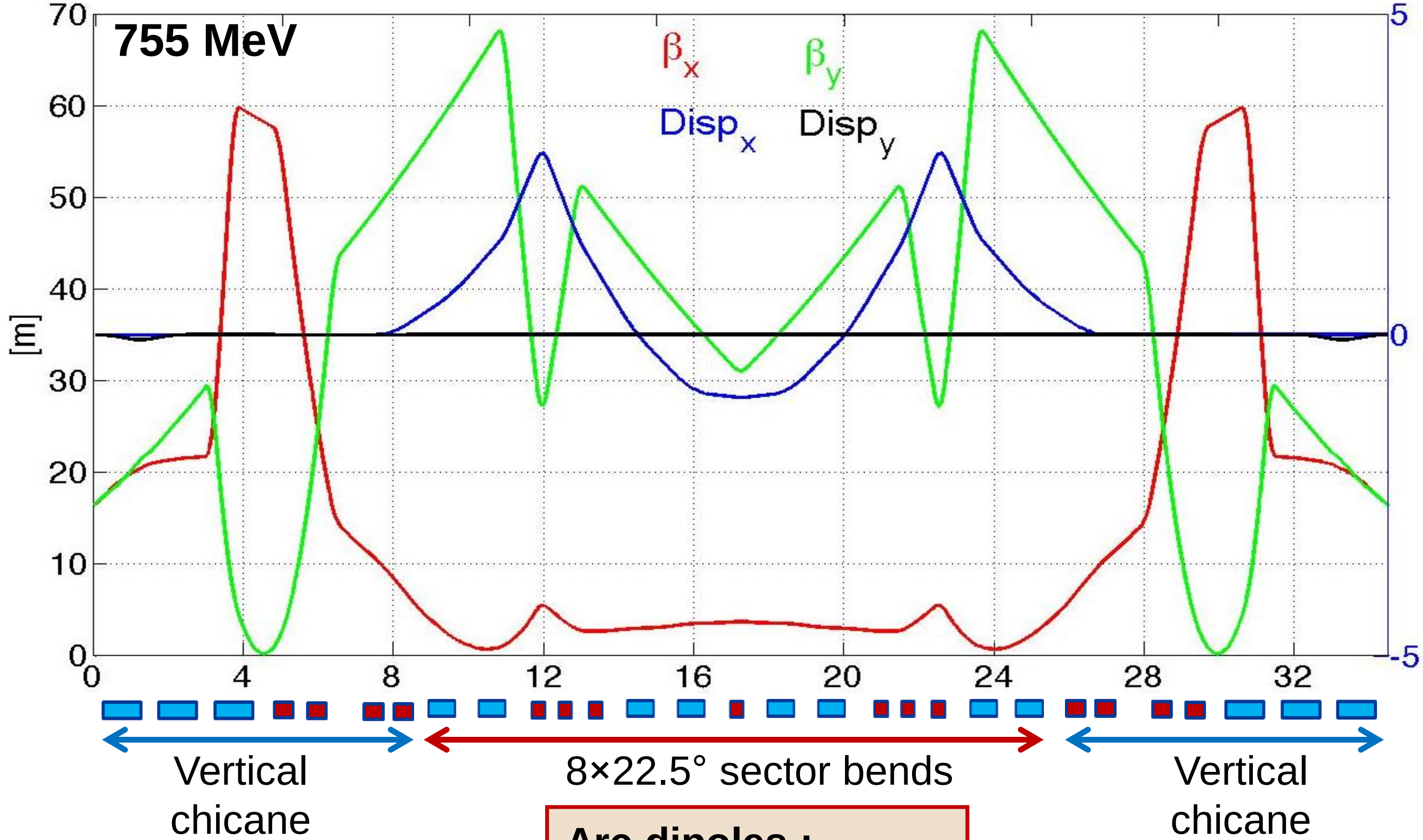
9.8° bends

(1 rec. + 3 sec.)

A. Valloni, A. Bogacz

Optics Option I: ARC V:

Courtesy of Alessandra Valloni



Arc dipoles :

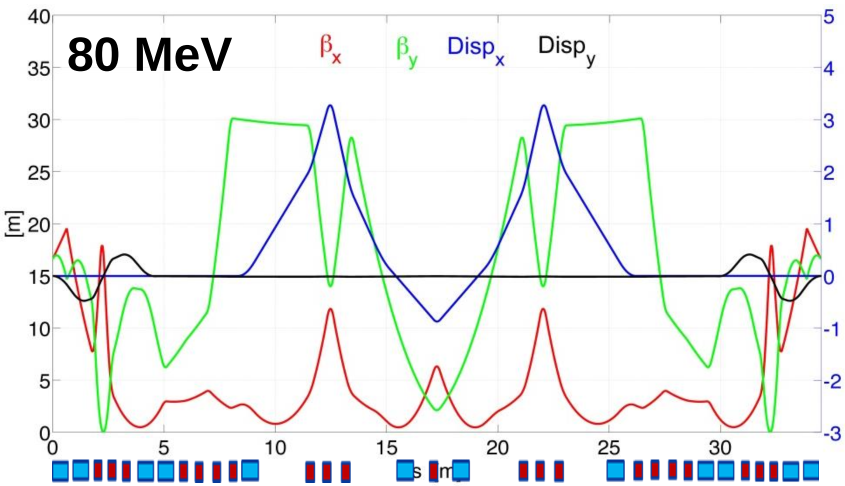
Ldip = 90.58 cm

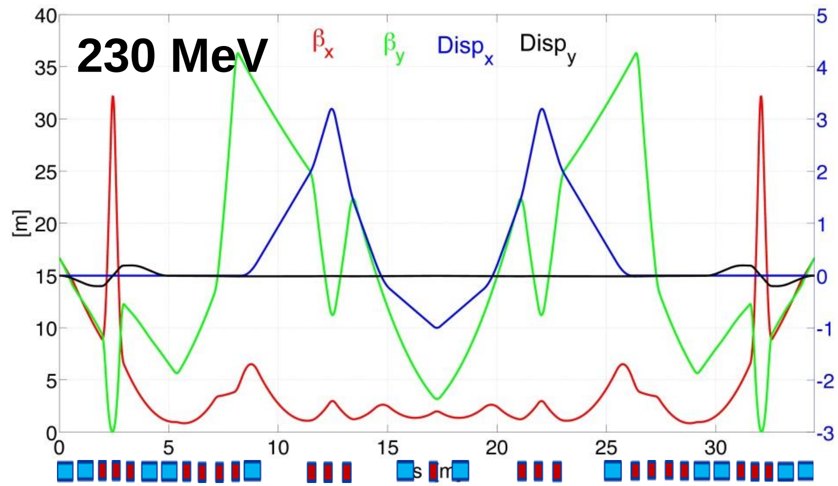
B = 10.92 kGauss

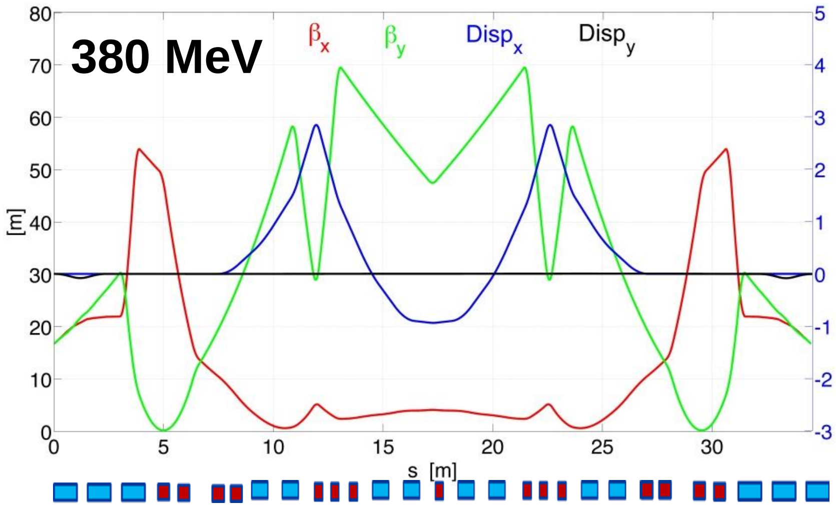
ρ = 230.66 cm

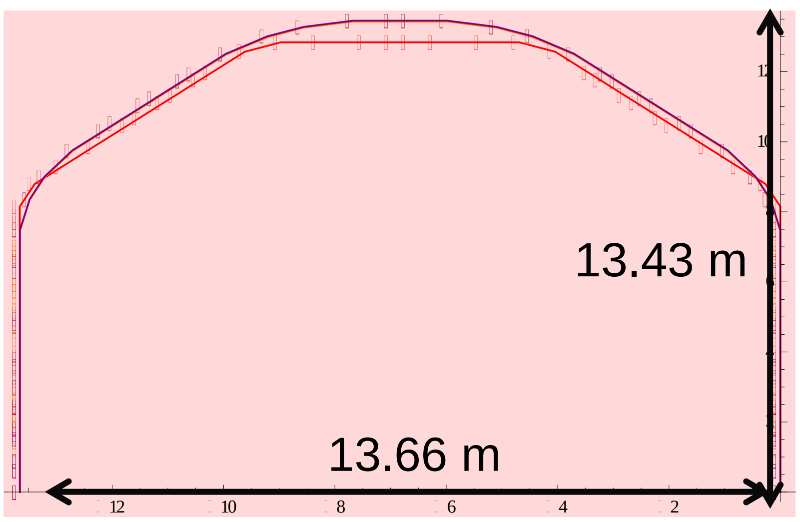
A. Valloni, A. Bogacz

Summary Option I Optics: Courtesy of Alessandra Valloni







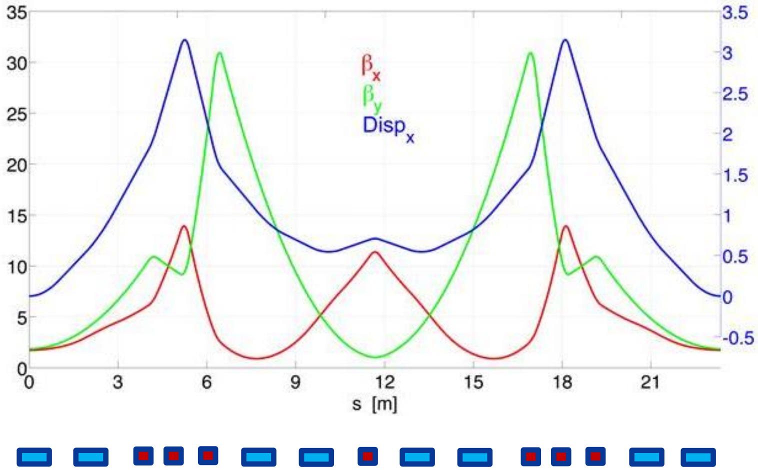


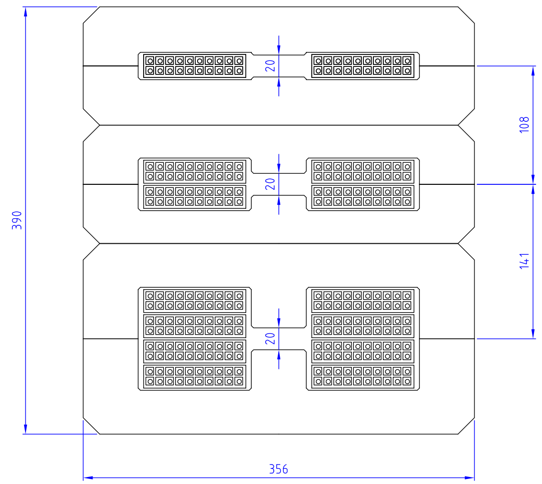
FMC = Flexible Momentum Compaction

ARC Optics Option II:

Courtesy of Alessandra Valloni

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

Arc quadrupoles

Lquads = 30 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

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

Synchrotron Radiation:

Courtesy of Alessandra Valloni

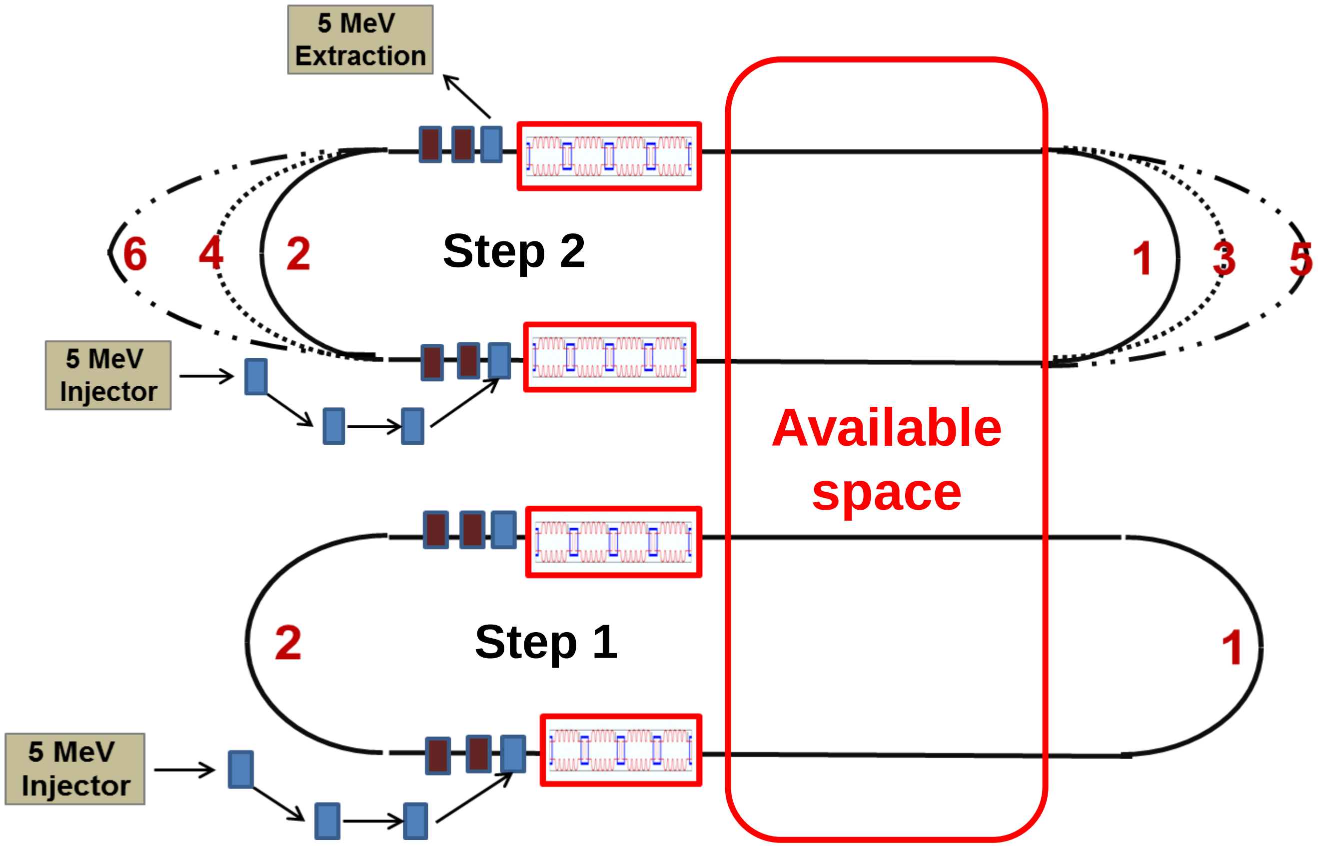
ARC	E [MeV]	ρ [cm]	ΔE [keV]	σE/E [%]
1	150	91.459	0.0280	1.17e-5
2	300	91.459	0.4191	6.42e-5
3	450	230.66	0.8230	8.13e-5
4	600	230.66	2.5726	1.53e-4
5	750	230.66	6.2394	2.73e-4
6	900	230.66	12.881	4.47e-4
7	750	230.66	6.2394	5.89e-6
8	600	230.66	2.5726	7.49e-6
9	450	230.66	0.8230	9.98e-6
10	300	91.459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

← maximum (ARC 6)

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

Next Steps Towards CDR: Courtesy of Alessandra Valloni

- Complete Step 2 and Step 1 configuration and optics layout



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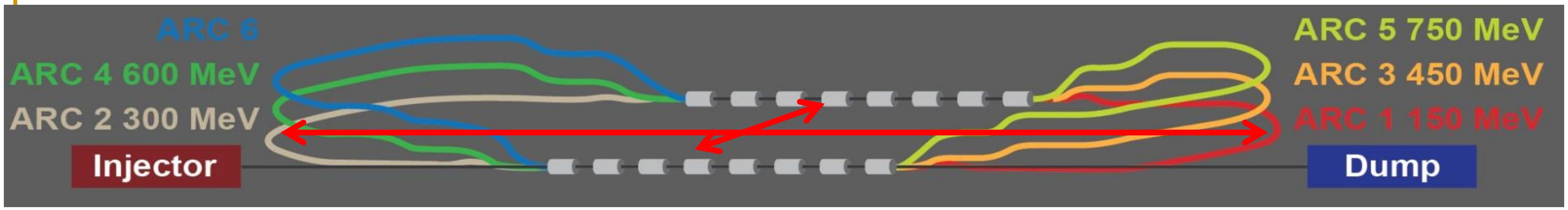
Floor Footprint:

Courtesy of Alessandra Valloni



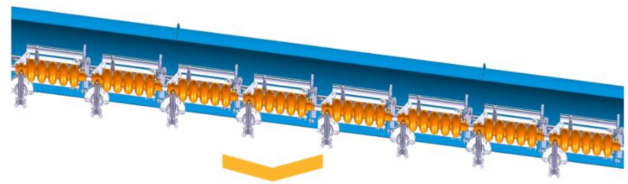
ARCS

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 4,5
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

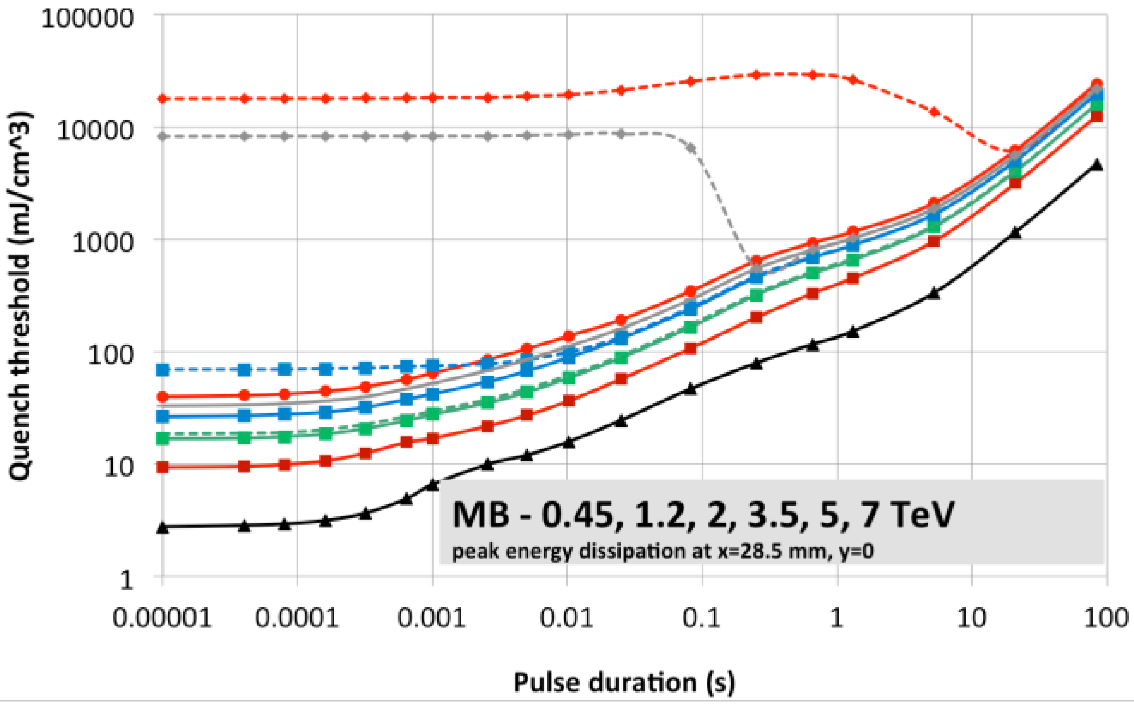
LHeC ERL Test Facility:

- Auxiliary Applications: SC Magnet Quench Facility

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



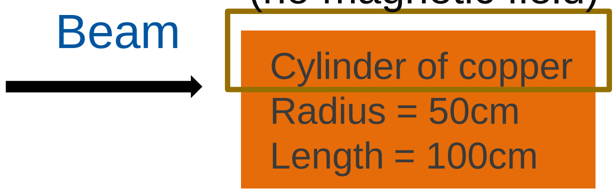
Courtesy of Daniel Wollmann
And Arijan Verweij

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

D. Wollmann

Beam parameters to generate a given amount of energy deposition CALCULATIONS AND FLUKA SIMULATIONS

Copper target
(no magnetic field)



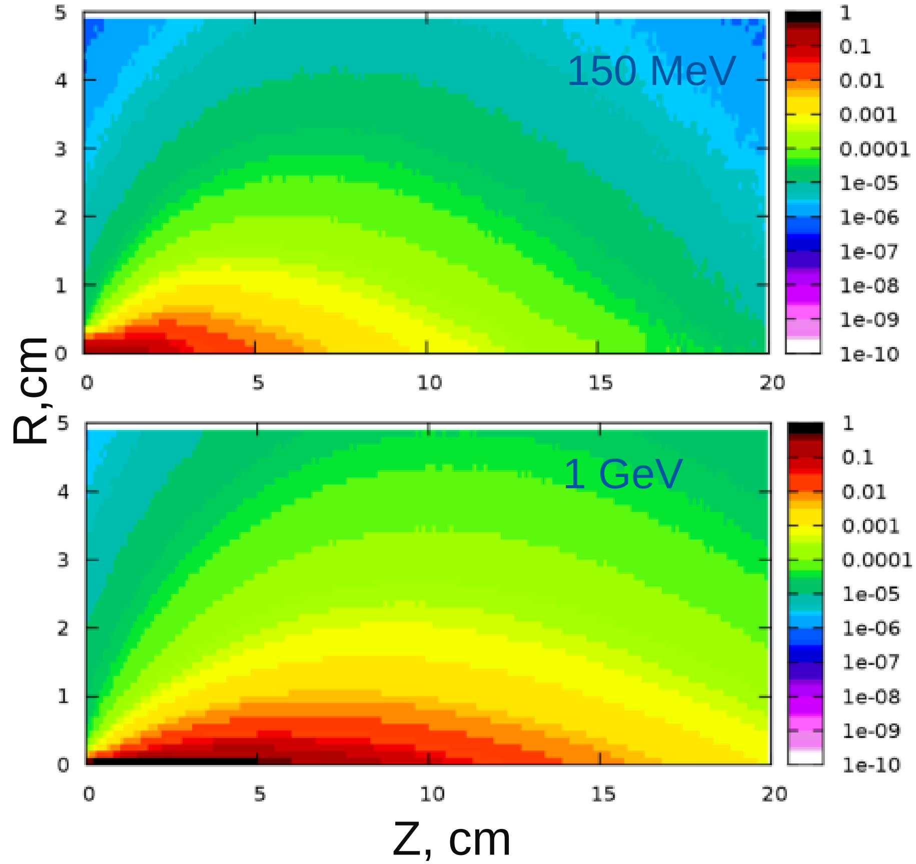
Beam parameters

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

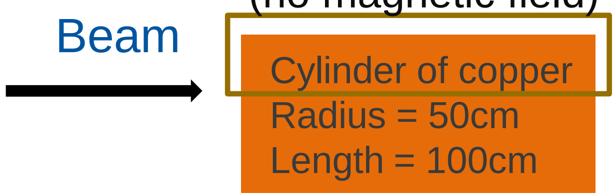
Binning: 1 mm^3 bins

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)



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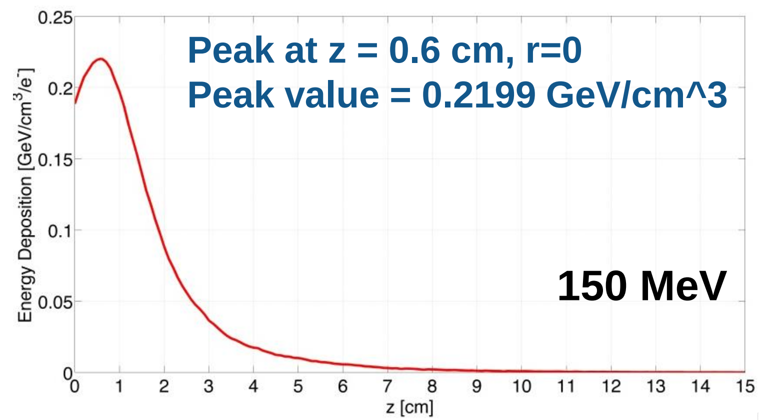
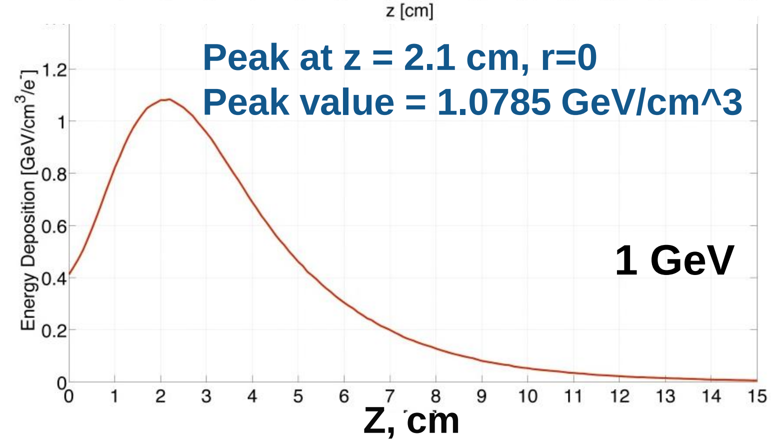
Energy deposition, $GeV/cm^3/e^-$

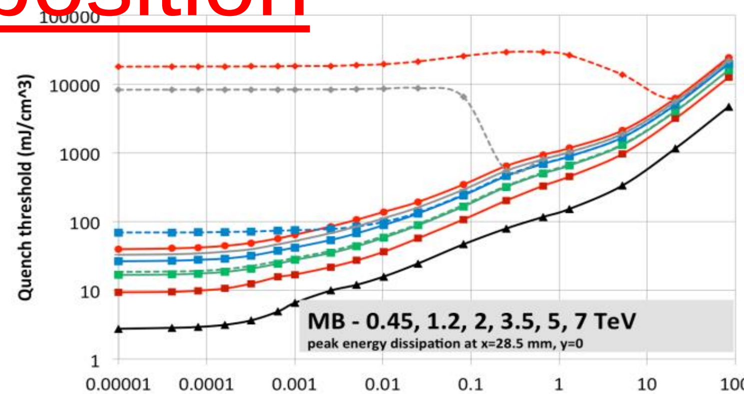




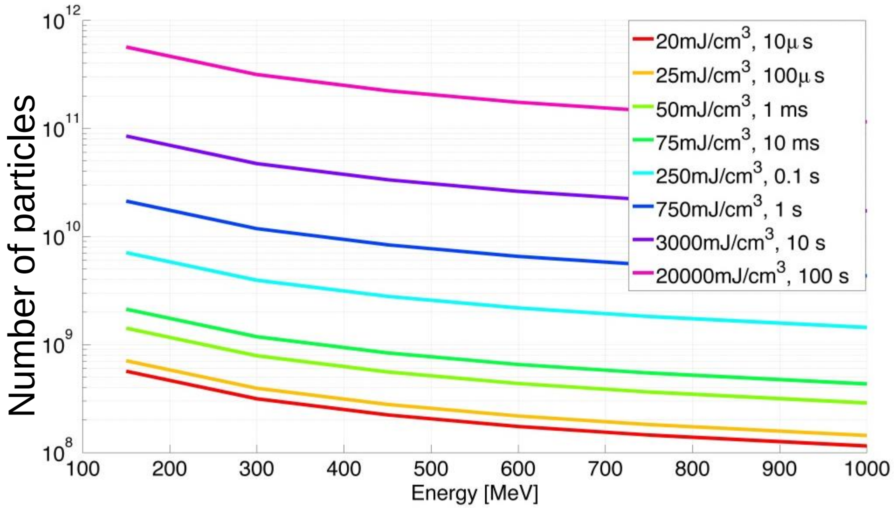
Beam parameters to generate a given amount of energy deposition

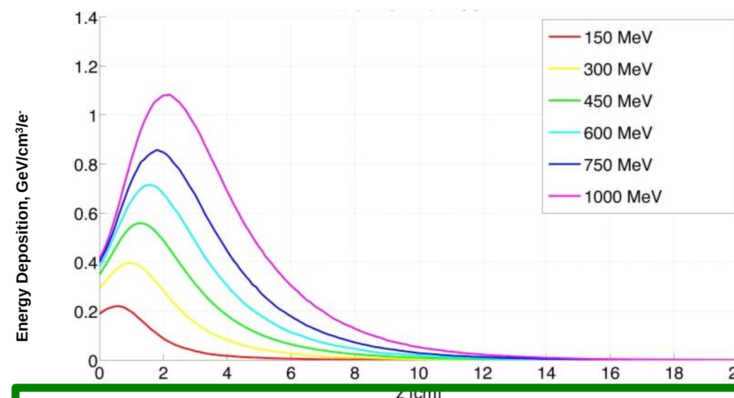
LHeC

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/cm³ in 10ms:

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

MB quench limit 7 TeV is 16 mJ/cm³ in 10ms:

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

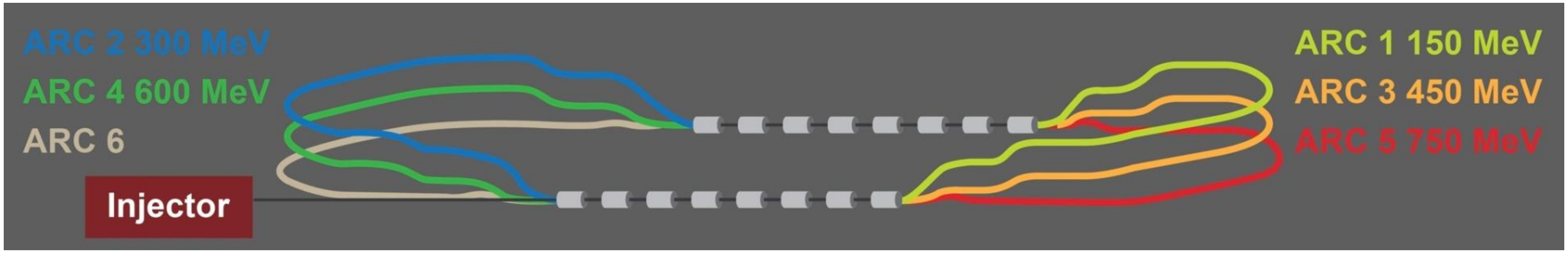
Summary ERL Test Facility

- Test facility for SCRF cavities and modules
- Test facility for multi-pass multiple cavity ERL
- Test facility for controlled SC magnet quench tests
- Injector studies: DC gun or SRF gun
- Study reliability issues, operational issues!
- Vacuum studies related to FCC
- Could it be foreseen as the injector to LHeC ERL and to FCC?

➔ ERL TF CDR by end 2015

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



LHeC ERL Test Facility:

Site options:

- ➔ Many site options presented @ January 2014 LHeC Workshop
- ➔ In Point 2 @ ALICE apparently not really a viable option (tbc)
- ➔ SM18:
  - ➔ Existing cryogenic installation
  - ➔ Existing powering infrastructure

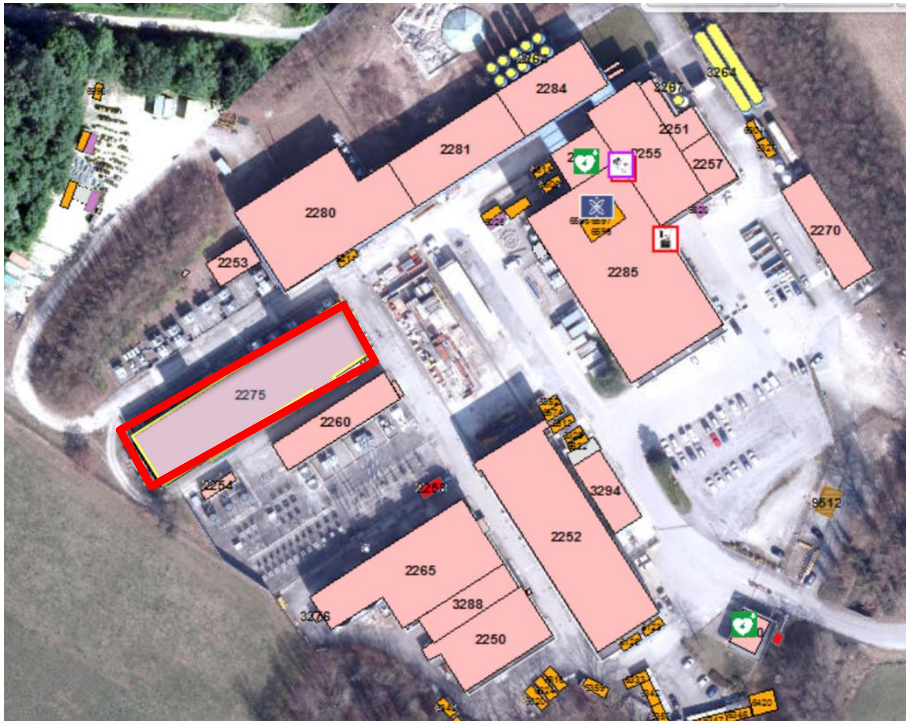
➔ Next step should be site specific studies for the ERL TF and auxiliary applications in preparation for the ERL TF CDR

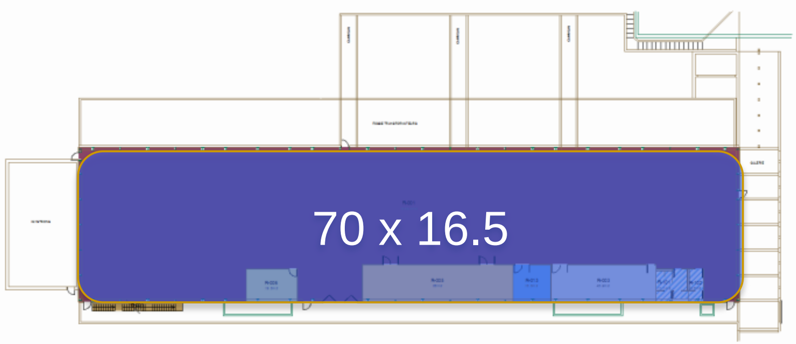
- B. 889 SPS Access point
- B. 897 Central Storage
- B. 867 Radioactive facility

B. 888 COMPASS
B. 887 North Hall
B. 890 EN-CV for North Hall

Nuria Catalan

ERL-TF possible sites: ALICE





We have started to look into possible existing buildings suited to host the ERL test facility.

A suitable hall could be in **Building 2275, near LHC P2**

- Current use under investigation

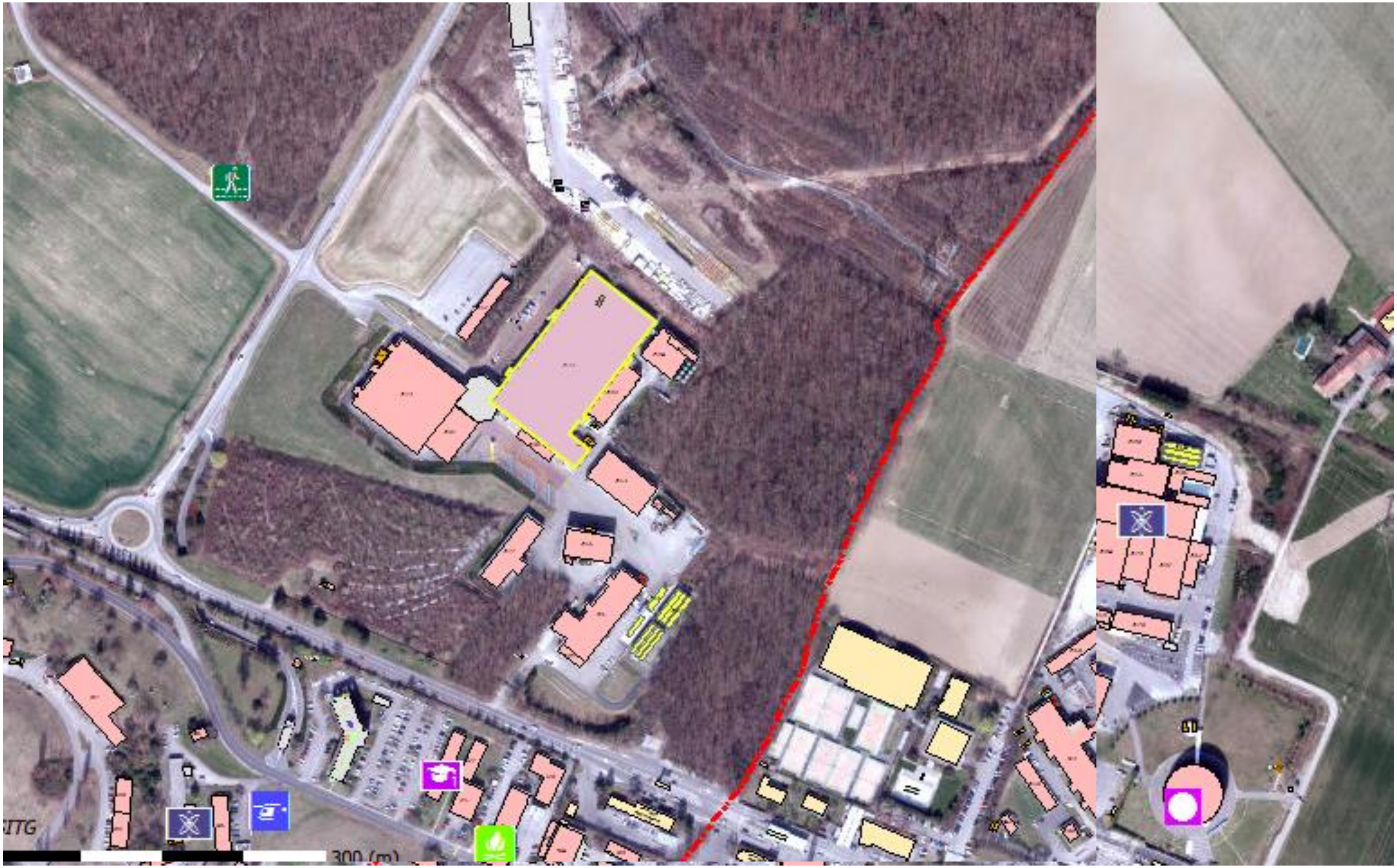
- Power converters already in place

- Geographically perfect as injector for LHeC ERL

- Slightly narrower than required
  Can it be extended?

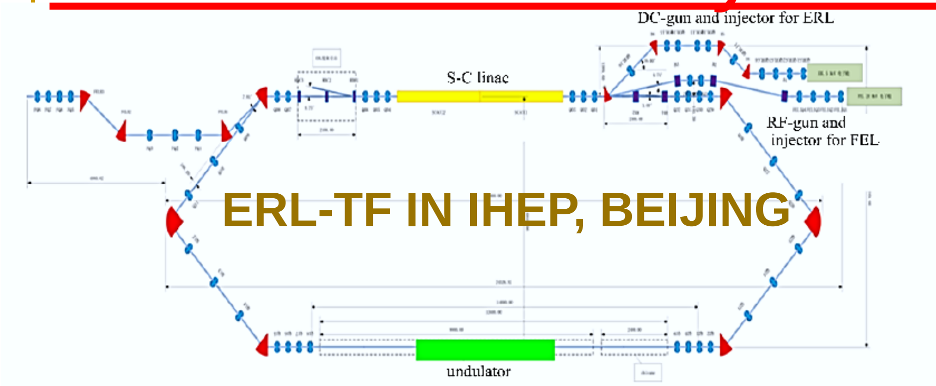
N. Catalan Lasheras

ERL-TF possible sites: SM18?

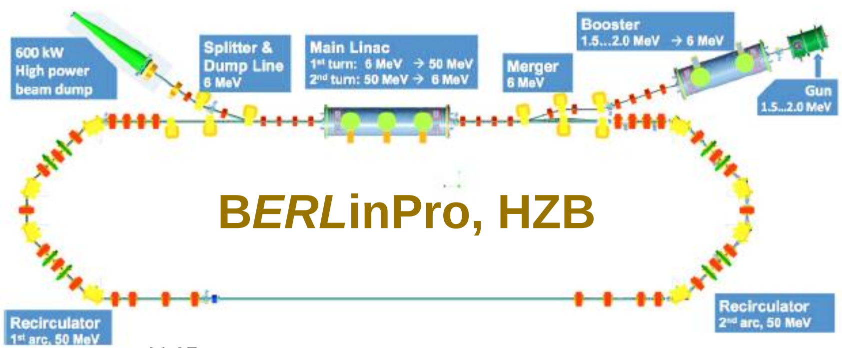


Reserve Transparencies:

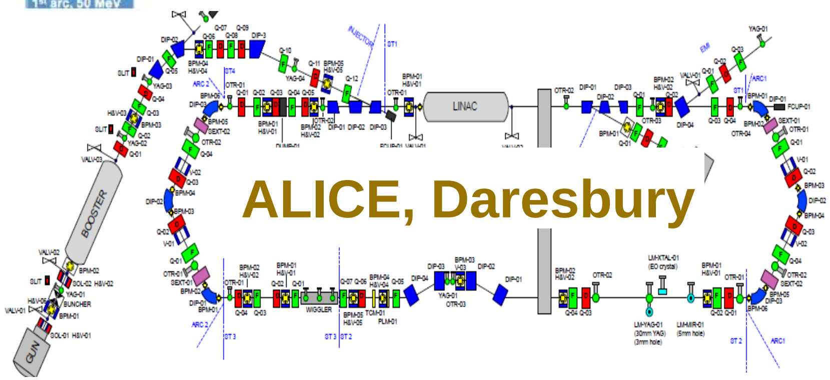
ERL Test Facility worldwide (1/2)



Beam Energy	35 MeV
Beam Current	10 mA
Bunch charge	77 pC
RF frequency	1300 MHz
Passes	1

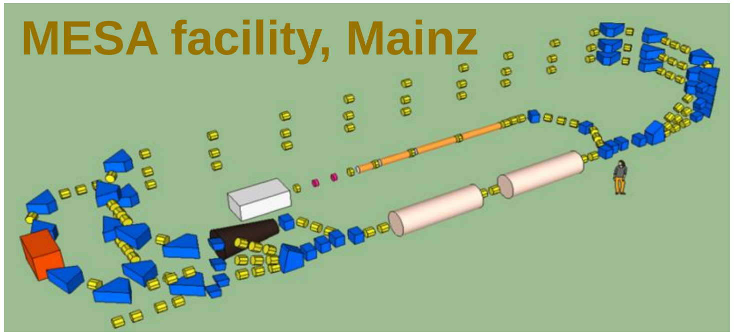


Beam Energy	50 MeV
Beam Current	100 mA
Bunch charge	77 pC
RF frequency	1300 MHz
Passes	1

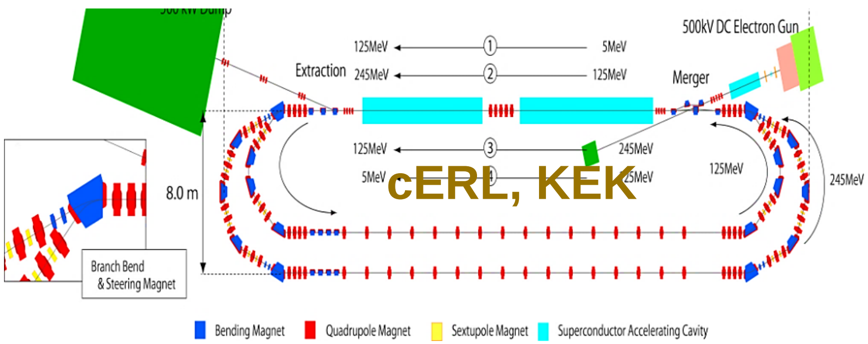


Beam Energy	12-26 MeV
Bunch charge	40-60-200 pC
RF frequency	1300 MHz
Passes	1

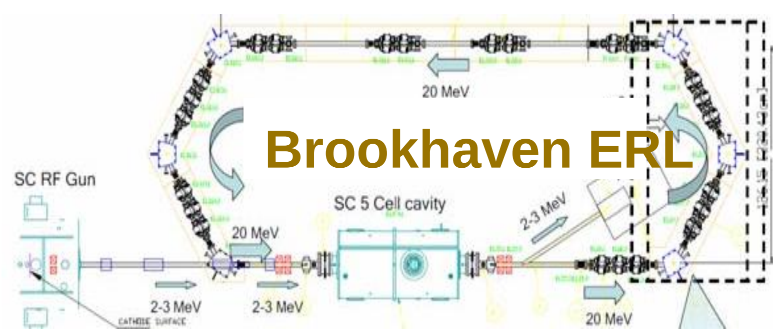
ERL Test Facility worldwide (2/2)



Beam Energy	105 MeV
Bunch charge	0.77 pC
RF frequency	1300 MHz
Passes	2-3



Beam Energy	35-125-250 MeV
Beam Current	10mA (100mA)
Bunch charge	7.7pC- 77pC
RF frequency	1300 MHz
Passes	1- 2



Beam Energy	20 MeV
Bunch charge	0.5-5 nC
Bunch current	300 mA
RF frequency	704 MHz
Passes	1