PERLE

Powerful energy recovery linac experiments

Alessandra Valloni

ERL FACILITY: DESIGN AND PARAMETERS

Workshop on the LHeC
24-26 June 2015

Outline

1. **DESIGN STAGES AND PARAMETERS**

2. **MACHINE DESIGN: LAYOUT AND OPTICS**
   MAGNETS INVENTORY
   TRACKING SIMULATIONS

3. **APPLICATIONS**

Goals of the ERL Facility

Dedicated Accelerator physics studies and R&D:

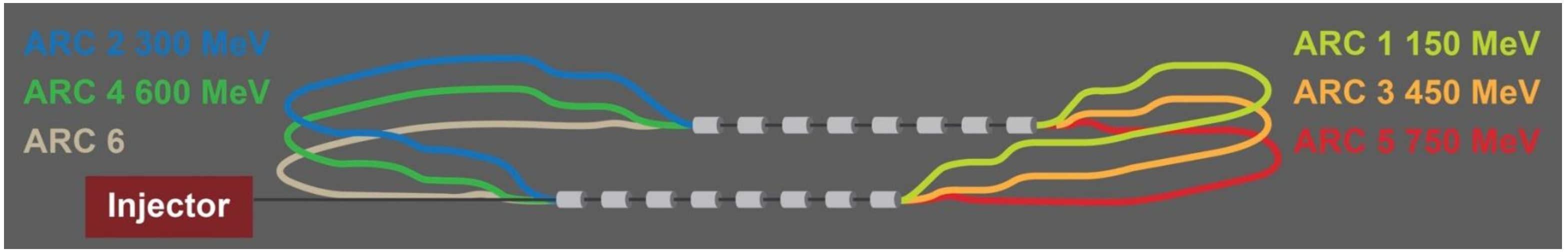
- Injector studies
- Beam diagnostics developments and testing with beam
- SCRF

Scientific and technical applications:

- Possible use for detector development
- Controlled quench and damage test for SC magnets
- Generation of gamma-ray beams via Compton backscattering

TARGET PARAMETER*	VALUE
Injection Energy [MeV]	5
Final Beam Energy [MeV]	905
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	<25
Delivered Beam Current [mA]	12.8 (6.4)
Bunch Spacing [ns]	25 (50)
Passes	3

*in few stages



Planning for each stage

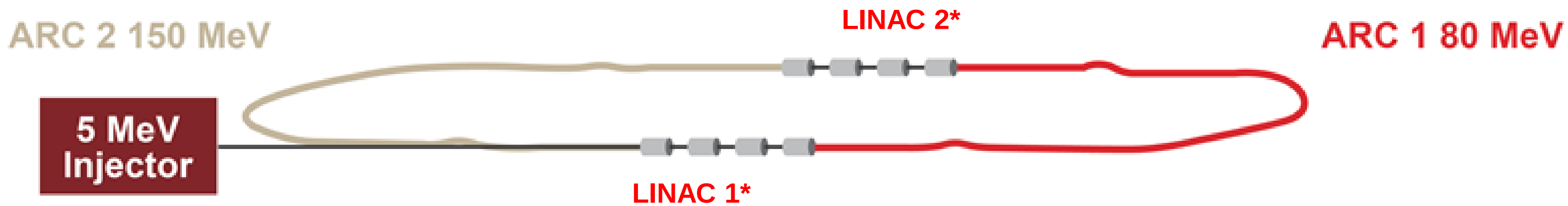
STEP 1

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

Two cryomodules with 4 SRF 5-cell cavities at 801.58 MHz.
Clear path already established in collaboration with JLab to obtain a prototype.



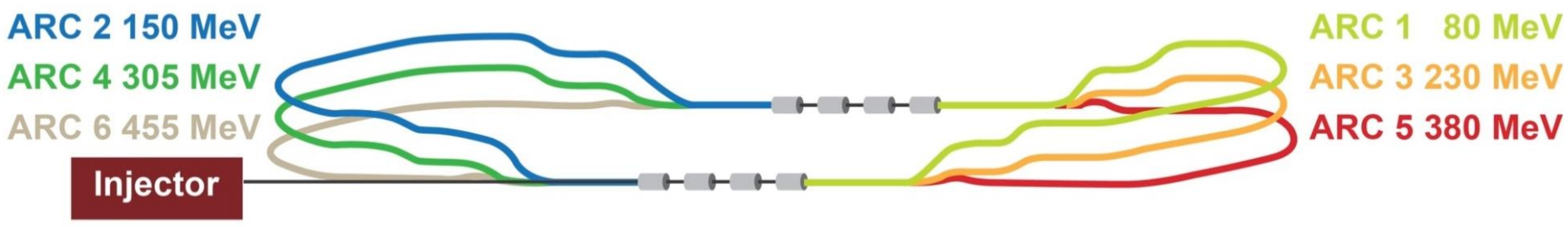
Planning for each stage

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

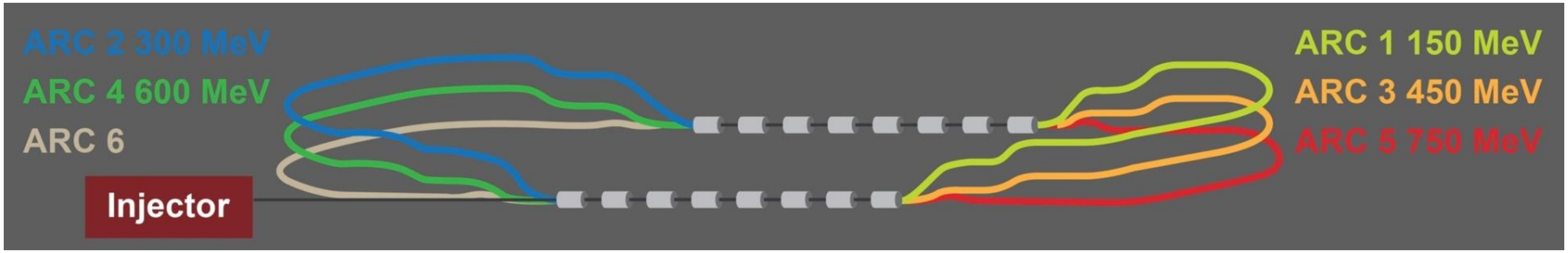
STEP 3

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



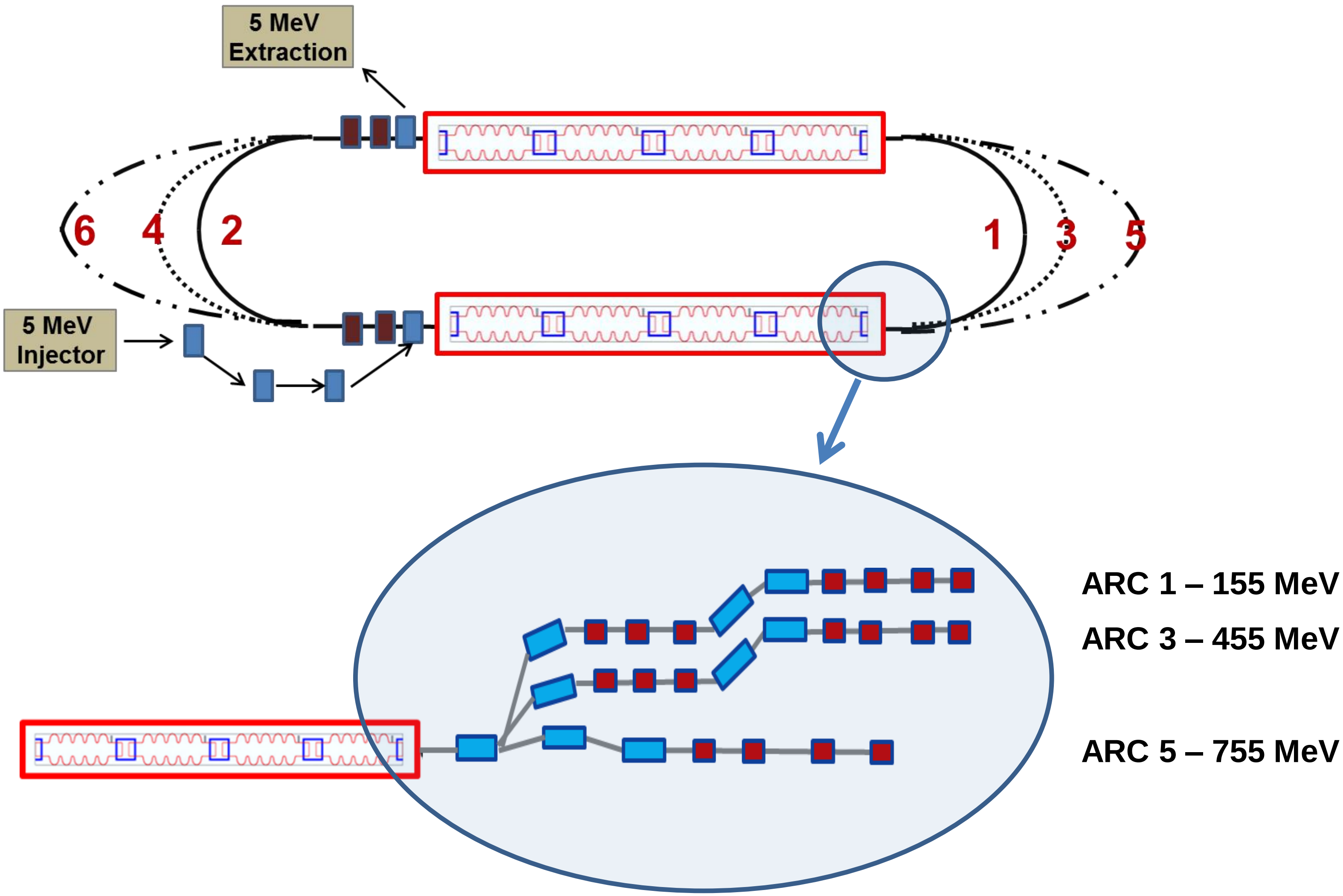
Outline

1. DESIGN STAGES AND PARAMETERS

2. MACHINE DESIGN: LAYOUT AND OPTICS
MAGNETS INVENTORY
TRACKING SIMULATIONS

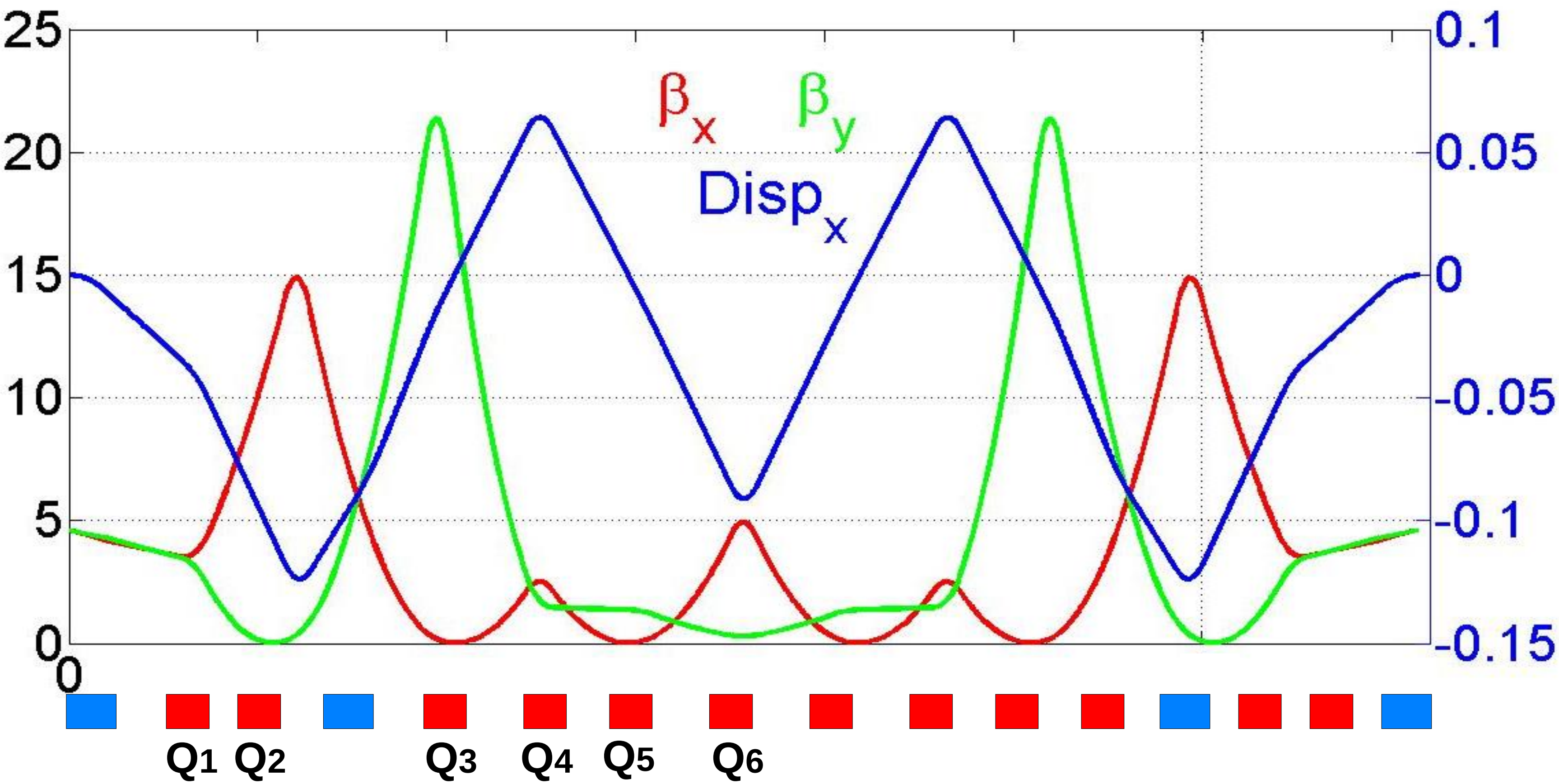
3. APPLICATIONS

Layout



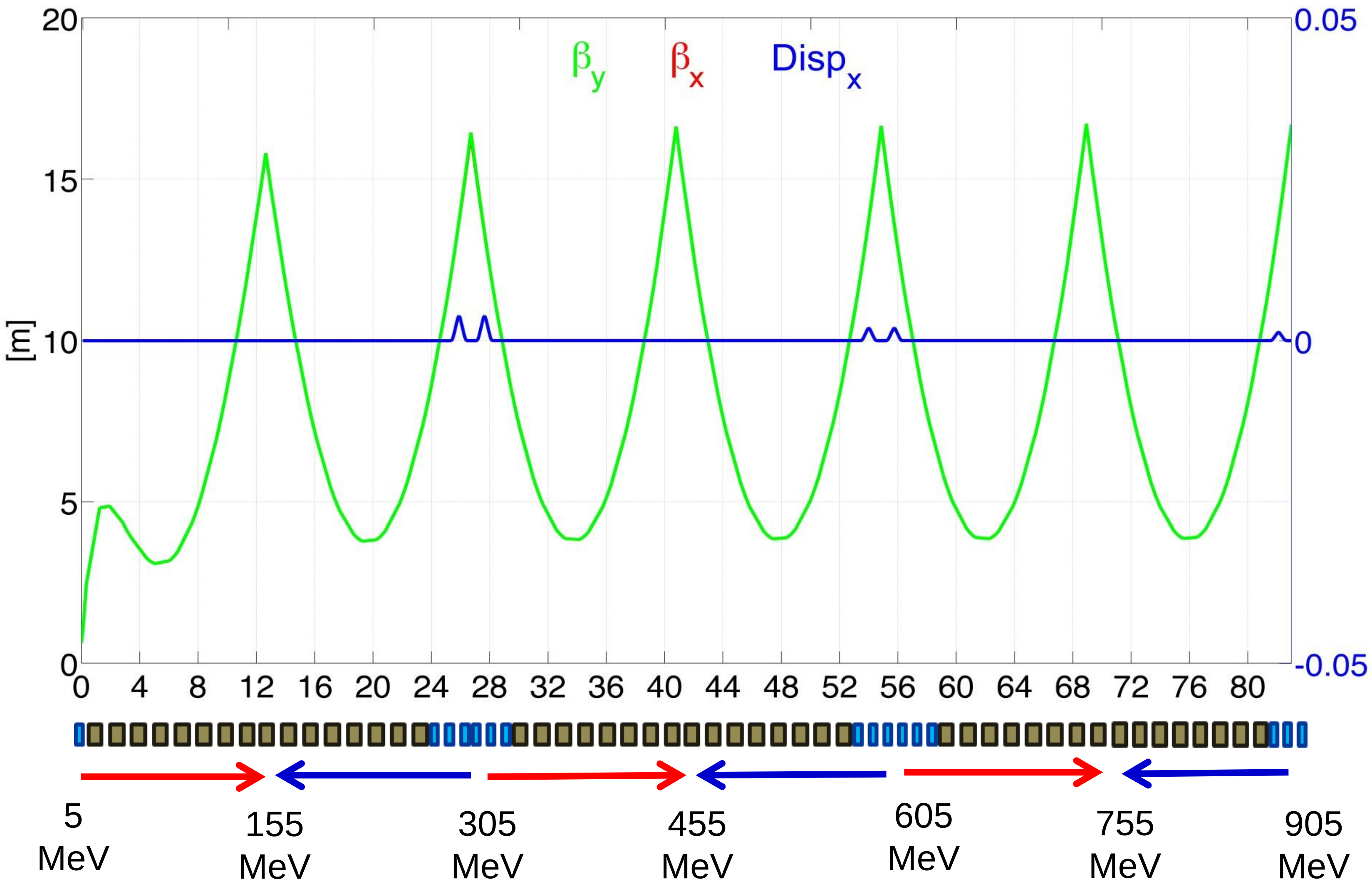
5 MeV Extraction
5 MeV Injector
6
4
2
1
3
5
ARC 1 – 155 MeV
ARC 3 – 455 MeV
ARC 5 – 755 MeV

Injection rectangular chicane

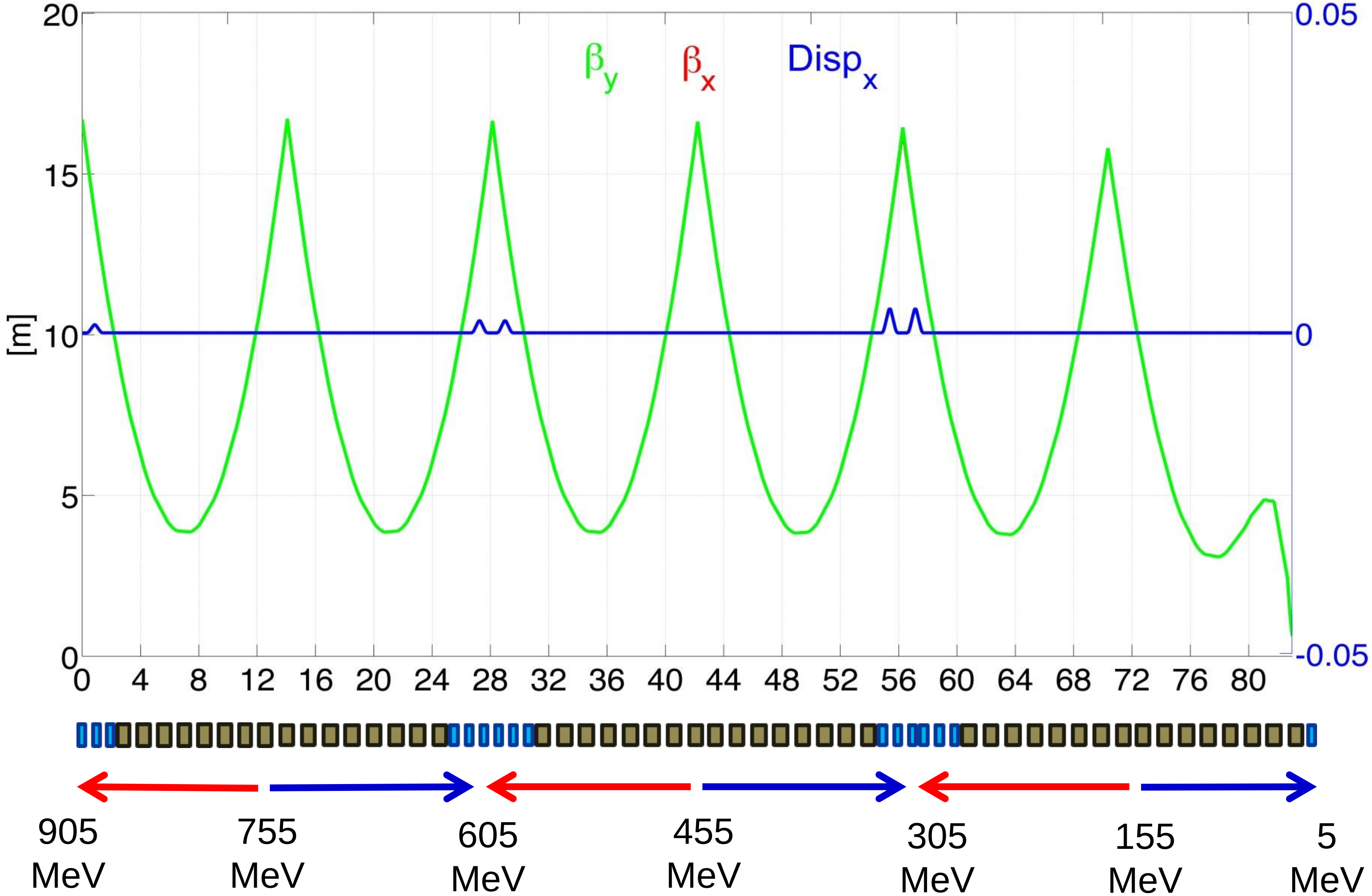


The chicane optics features a horizontal achromat with tunable momentum compaction to facilitate bunch-length control and with Twiss functions matched to the specific values required by the linac

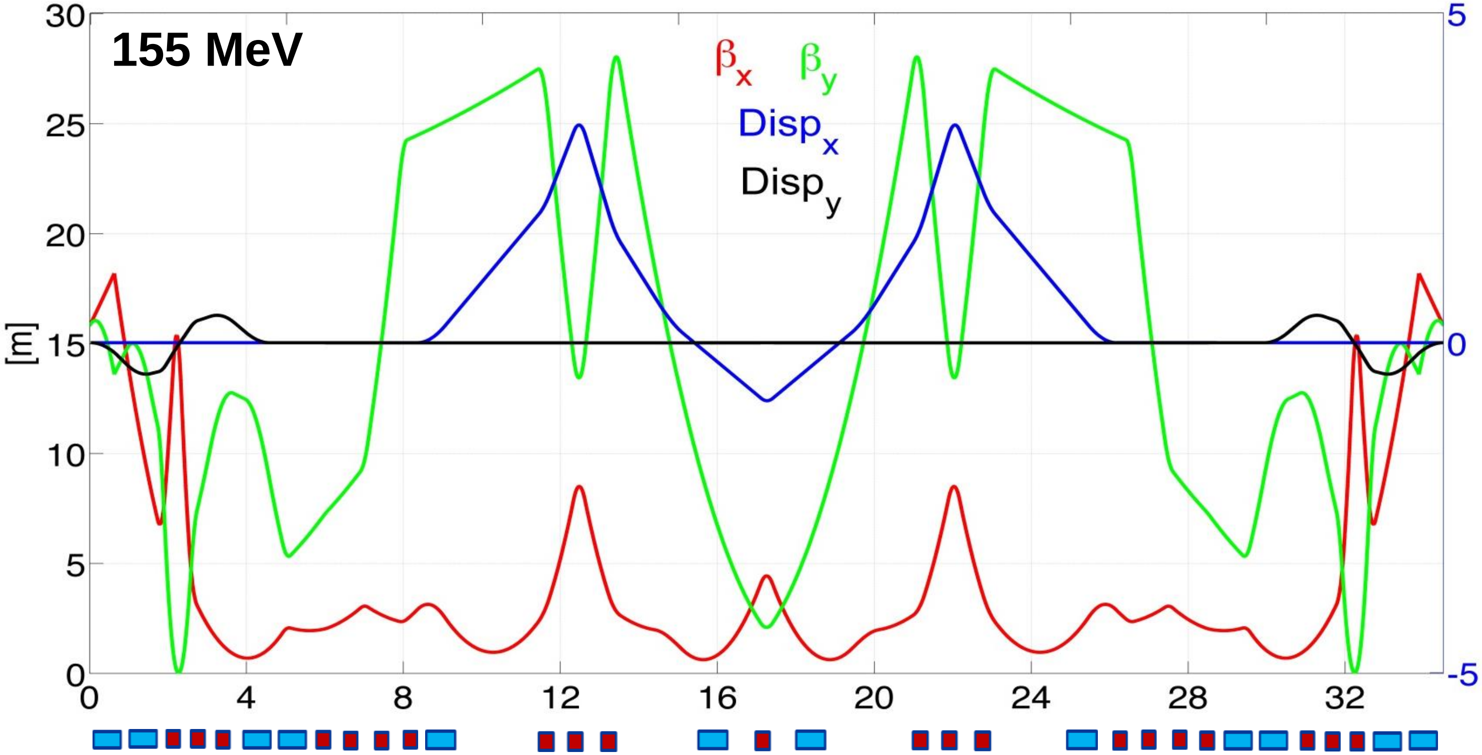
Linac 1 Multi-Pass Optics



Linac 2 Multi-Pass Optics



Arc 1 optics



2-step vert. Spreader

4×45° sector bends

2-step vert. Combiner

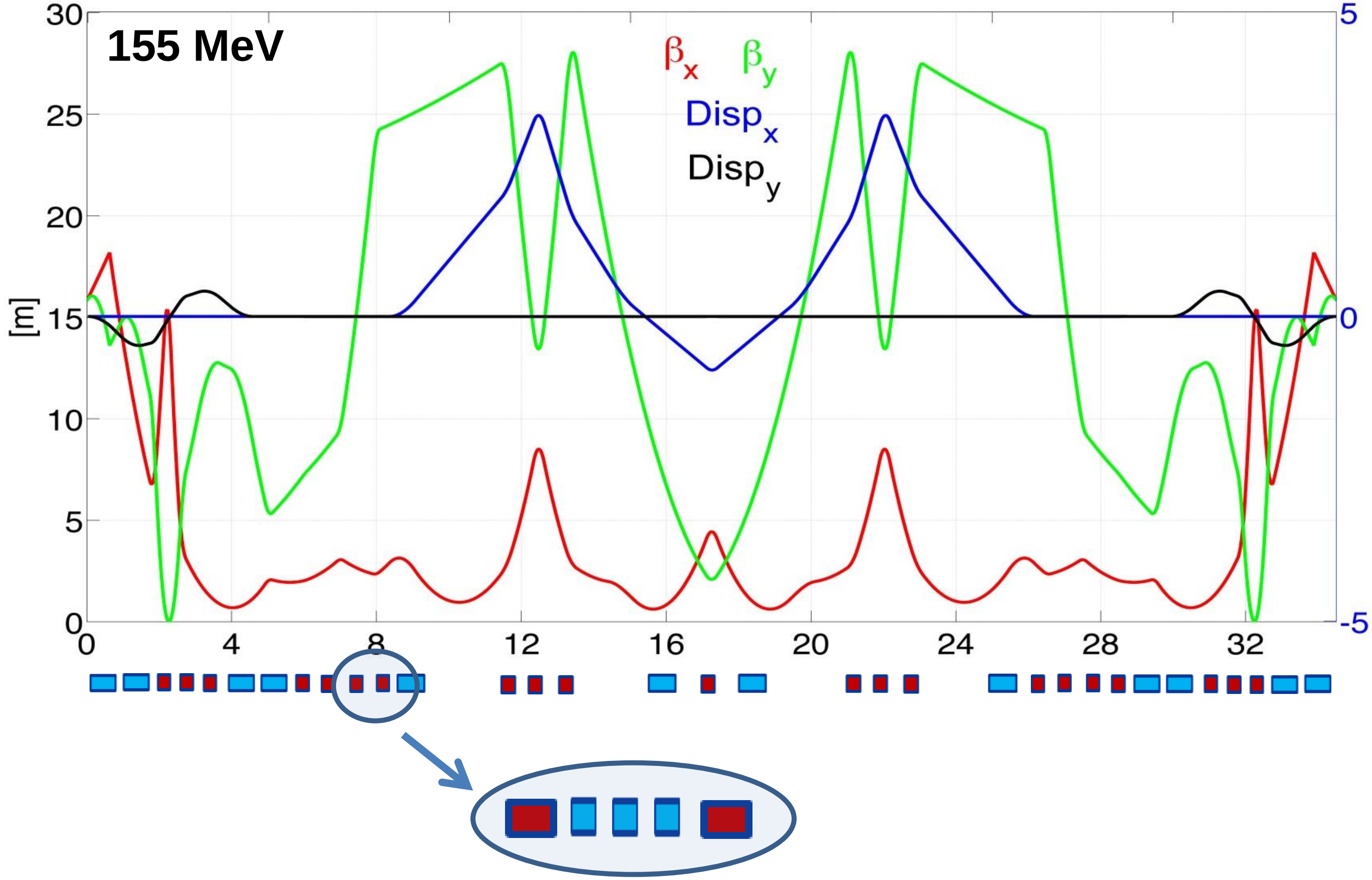
Arc dipoles :

Ldip = 71.8 cm

B = 5.67 kGauss

ρ = 91.45 cm

Arc 1 optics

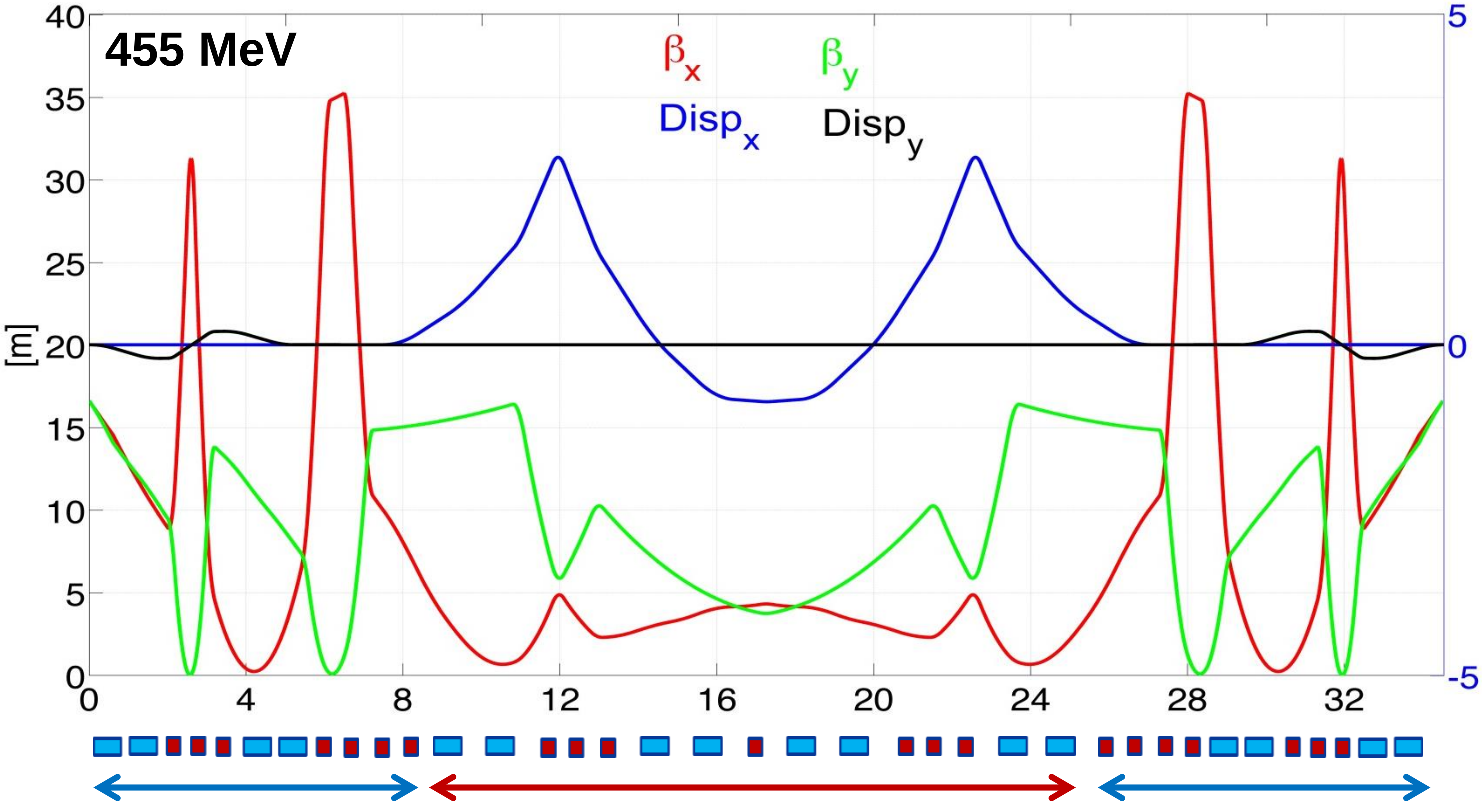


A horizontal dogleg, used for path length adjustment

3-13 cm long dipoles

Fine tuning → tunability of ±1 cm (10°of RF)

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

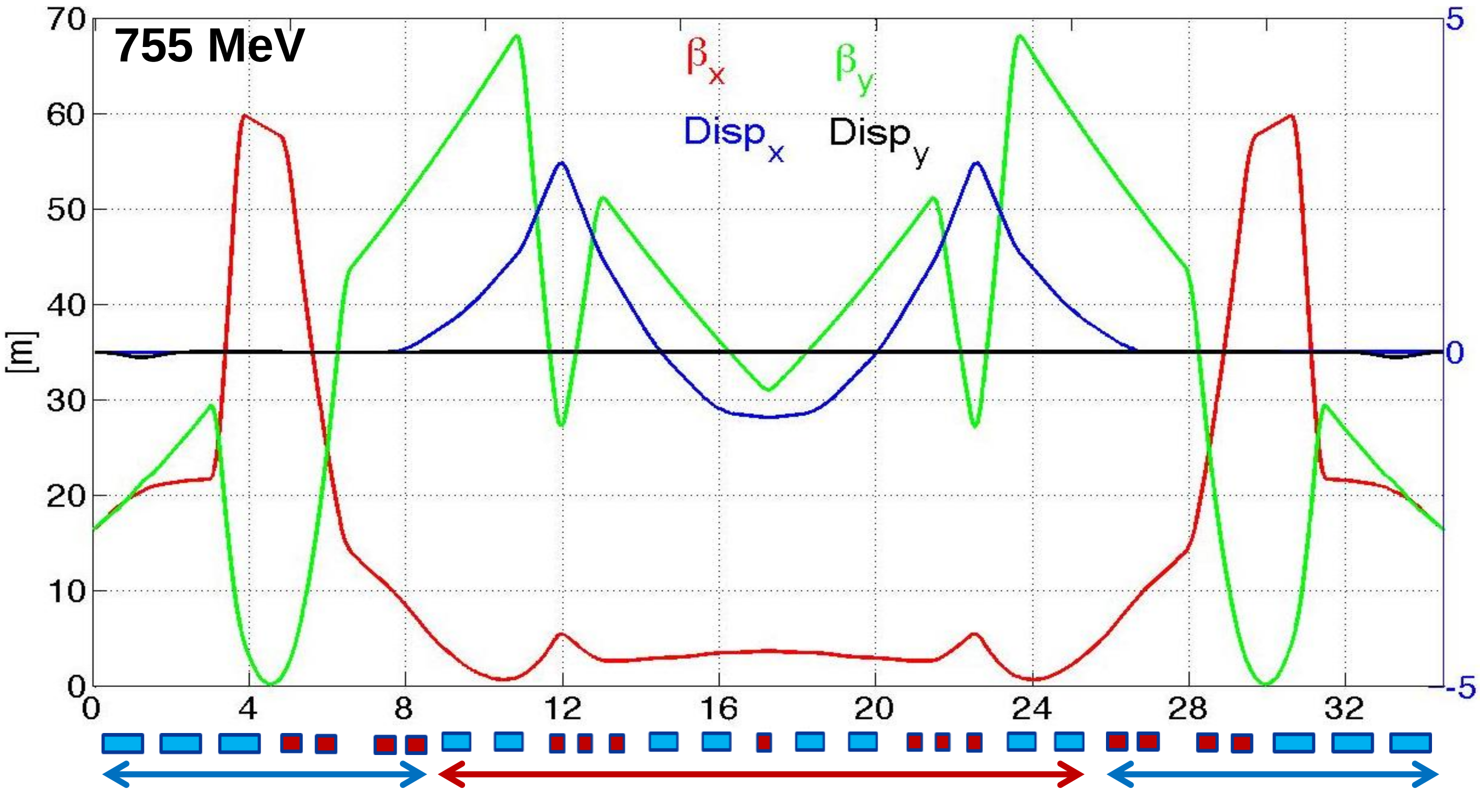
ρ = 230.66 cm

2-step vert. Combiner

9.8° bends

(1 rec. + 3 sec.)

Arc 5 optics



Vertical chicane

8×22.5° sector bends

Vertical chicane

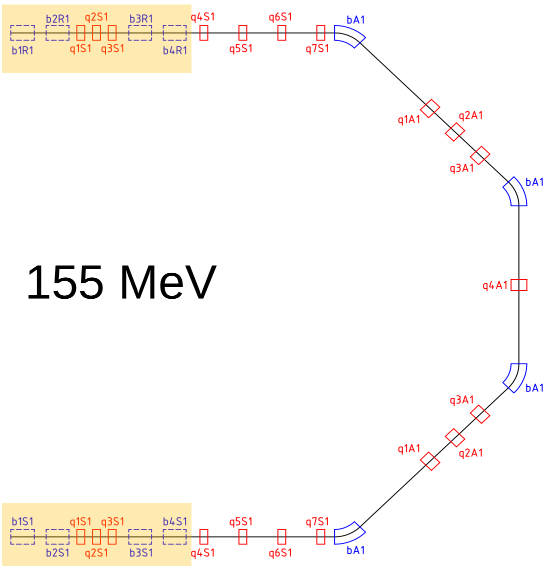
Arc dipoles :

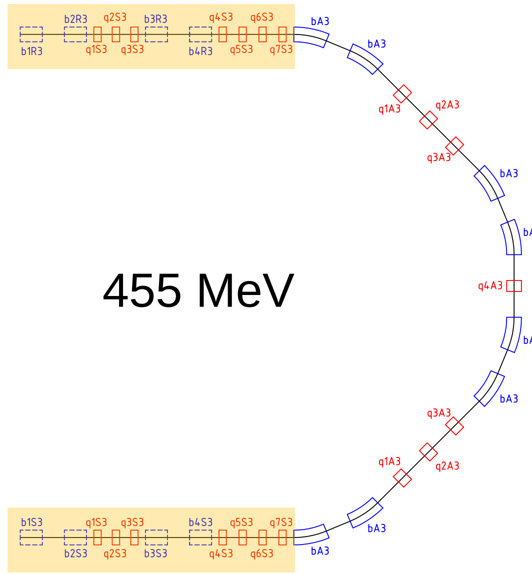
Ldip = 90.58 cm

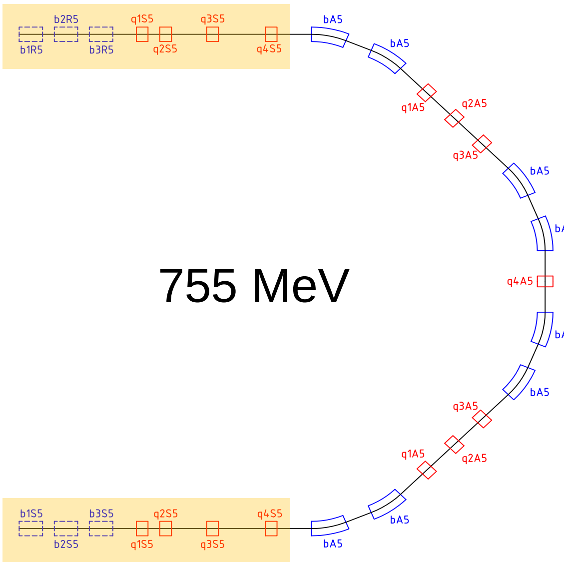
B = 10.92 kGauss

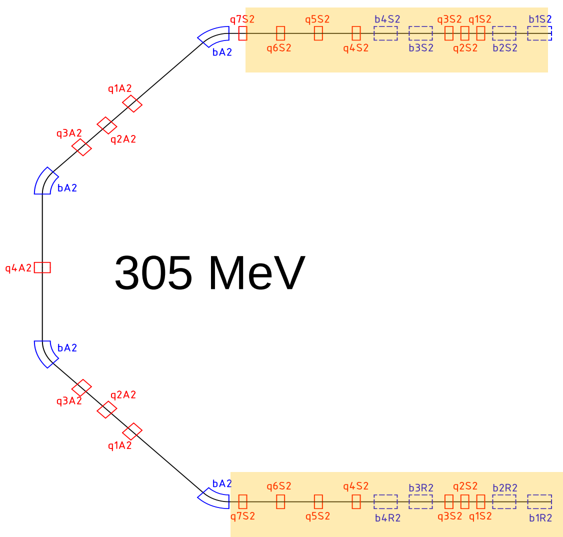
ρ = 230.66 cm

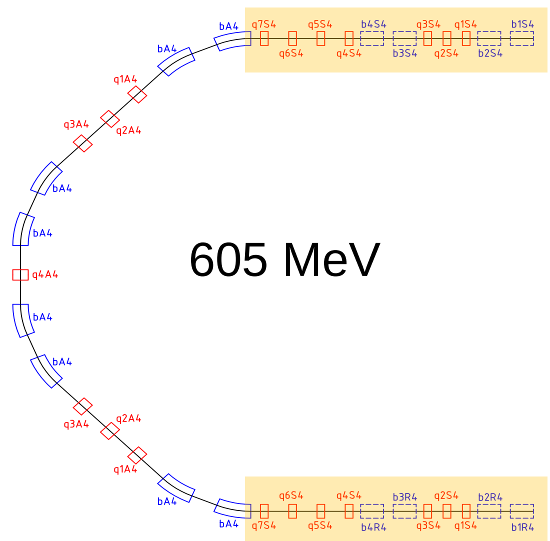
Magnets inventory

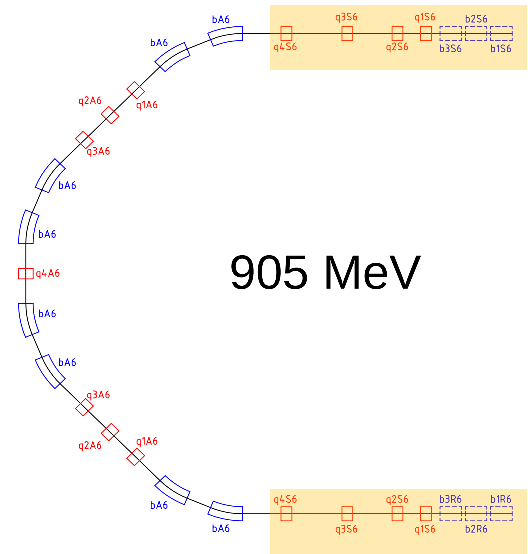












Summary of magnets inventory

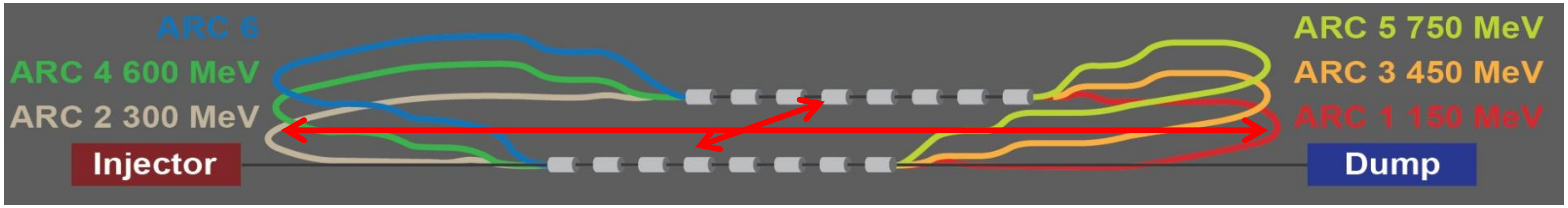
A preliminary inventory of the magnets of the ERL Facility lists:

- 40 bending magnets (vertical field)
- 36 bending magnets (horizontal field) in the spreaders / combiners
- 114 quadrupole magnets
- a few magnets in the injection / extraction parts

Conventional iron-dominated resistive magnets can be used

ARC	ENERGY	LENGTH	# QUADS	# DIPOLES
ARC 1	150 MeV	35.98 m	21	12
ARC 2	300 MeV	35.74 m	21	12
ARC 3	450 MeV	35.61 m	21	14
ARC 4	600 MeV	35.74 m	21	14
ARC 5	750 MeV	35.98 m	15	12
ARC 6	900 MeV	34.43 m	15	12
TOTAL		297.9 m	114	76

Footprint



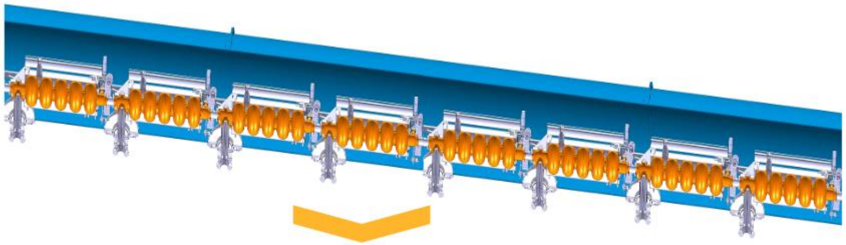
ARCS

Total length for Pass 1
99.86 m
267 x λrf = 20*n* λrf +7*λrf

Total length for Pass 2
99.48 m
266 x λrf = 20*n* λrf +6*λrf

Total length for Pass 3
98.55 m
263.5 x λrf = 20*n* λrf +**3.5***λrf

LINAC

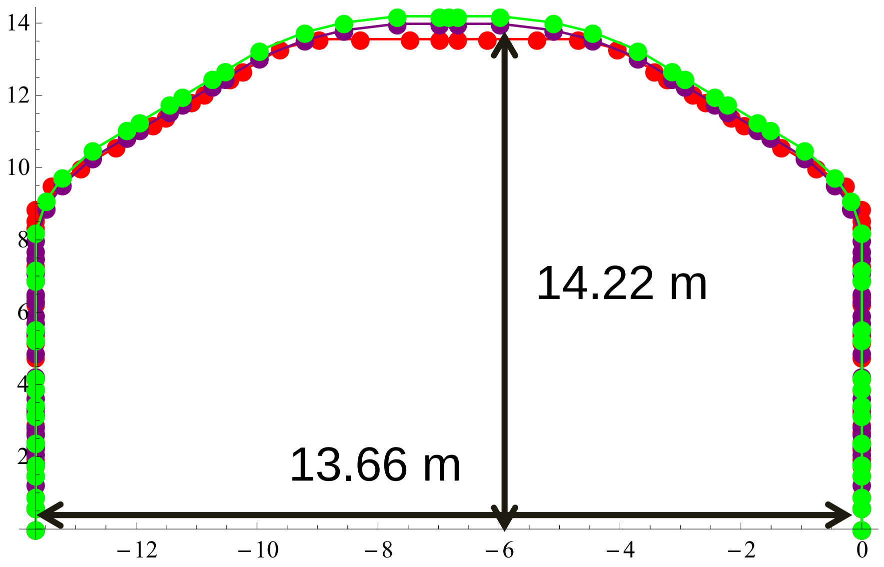


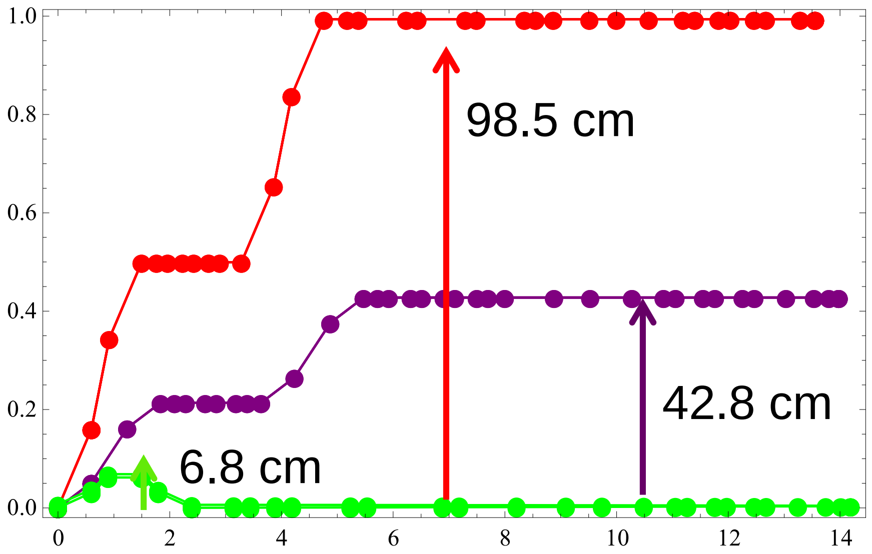
ONE CRYOMODULE: 8 RF CAVITIES

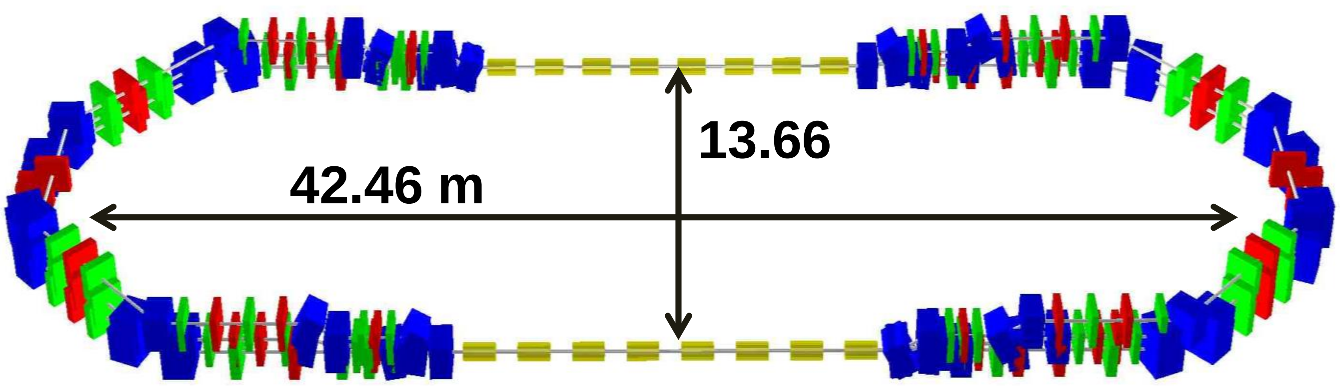
Linac length ~ 12.6 m
Chicane inj/extr length ~ 1.42 m
F= 801.58 MHz
λrf = 37.4 cm

Total length for 3 passes
297.9 m

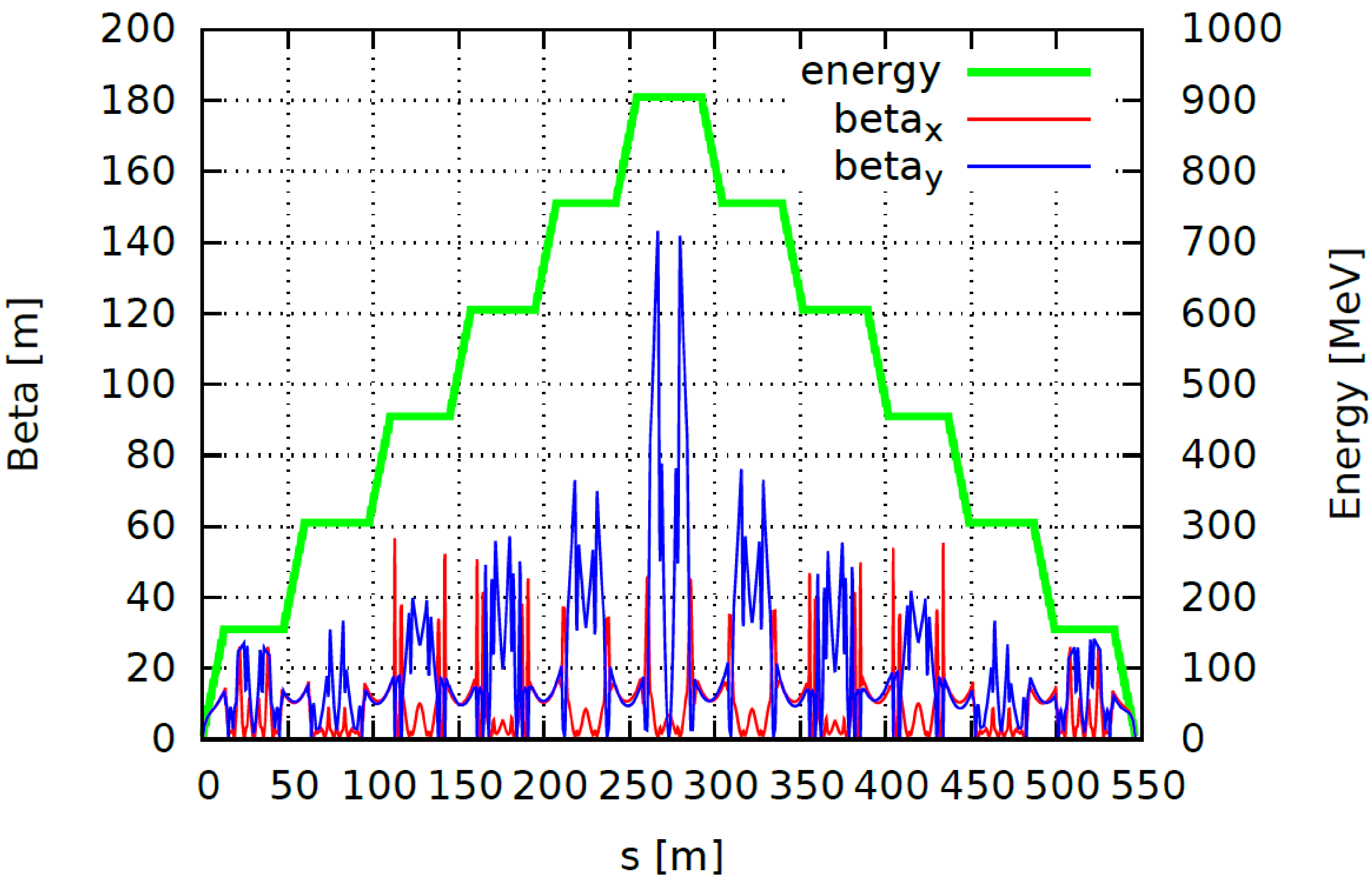
Arc layout





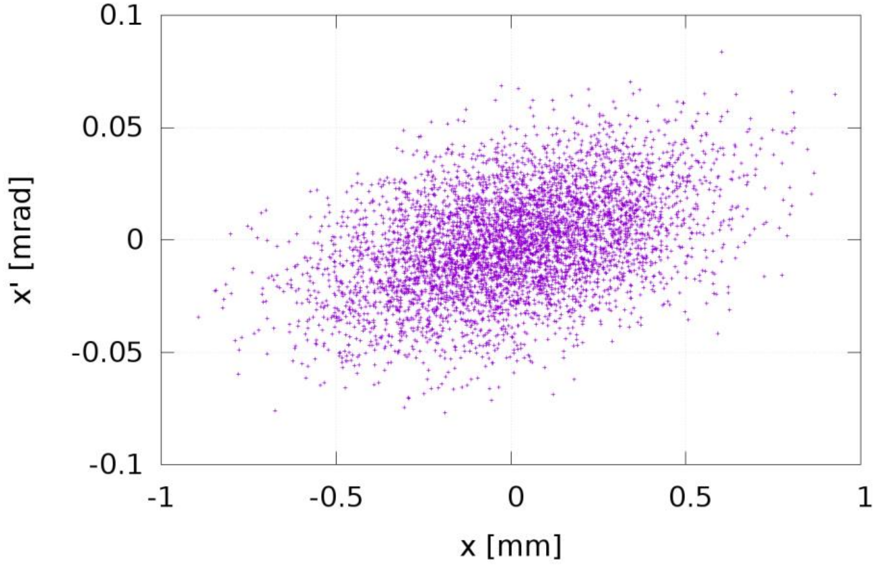


Start-to-end Optics with PLACET2*

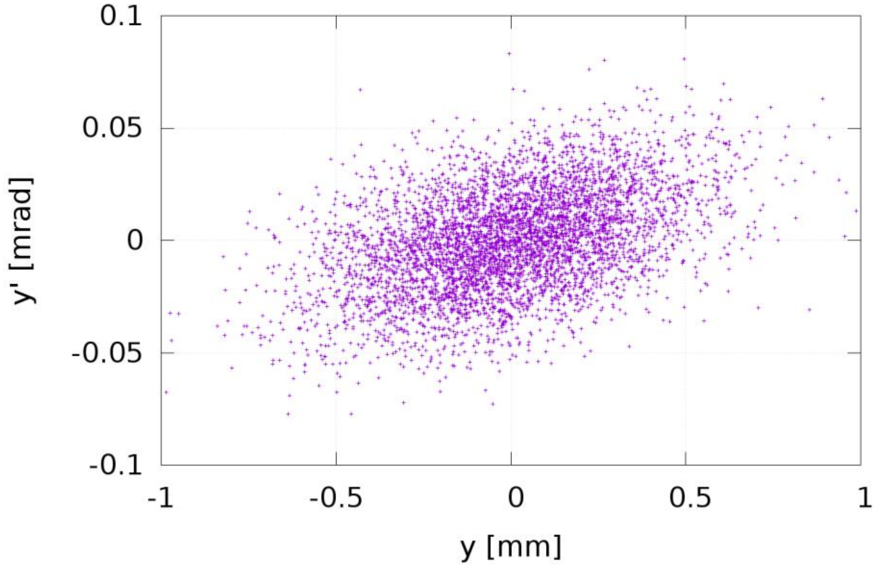


Transverse Phase space at 900 MeV
(PLACET2 – only optics)

Horizontal phase space
at 900 MeV



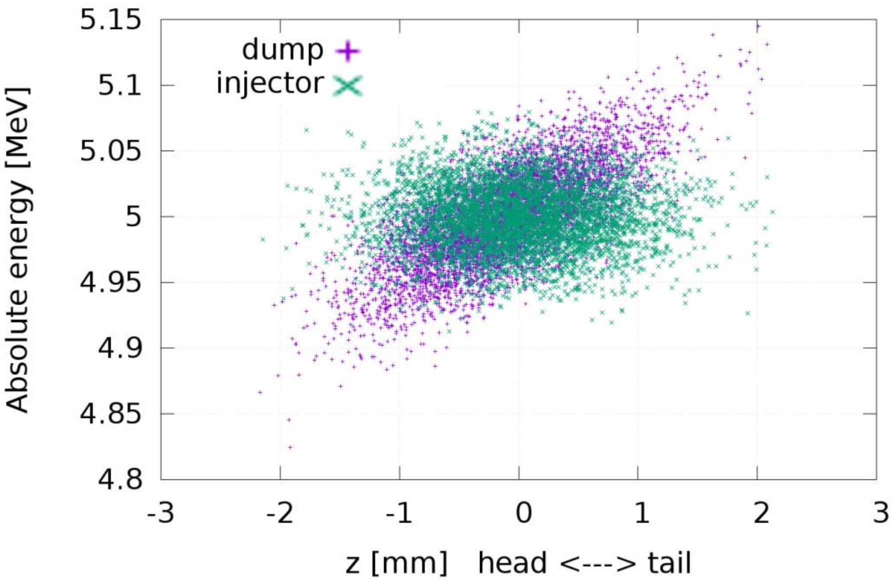
Vertical phase space
at 900 MeV

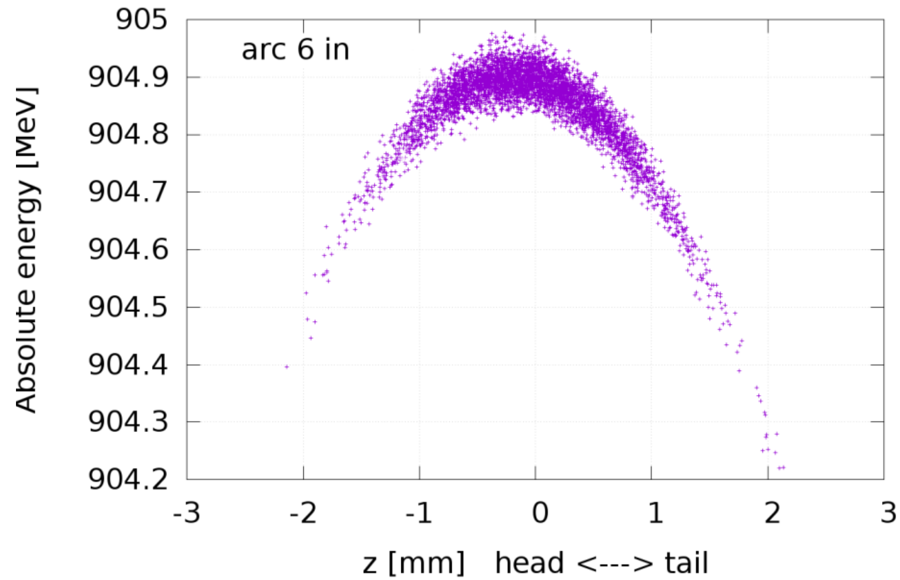


Very well preserved phase space and transverse emittance at 900 MeV and down to the dump

Small impact of (coherent) synchrotron radiation verified with Elegant
Small impact of short-range wakefields expected (to be futher investigated)

Longitudinal Phase Space
(PLACET2 – only optics)



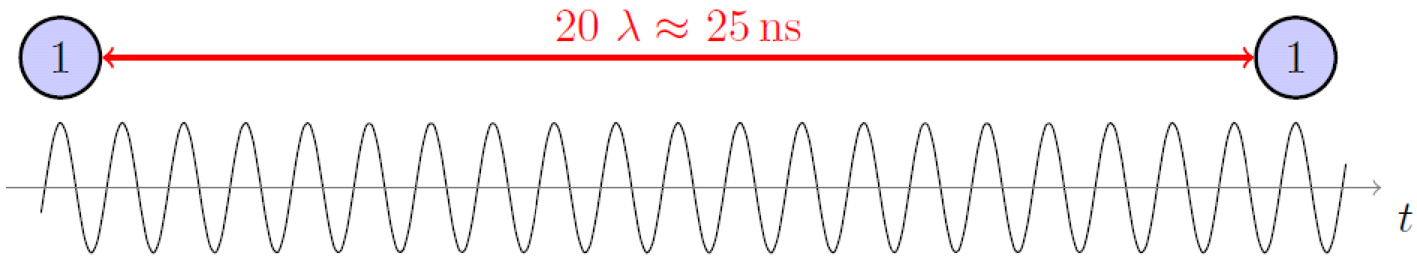


Bunch length preservation down to dump (very good isochronicity)
Some energy chirp at dump -> requires fine tuning of the arc lengths

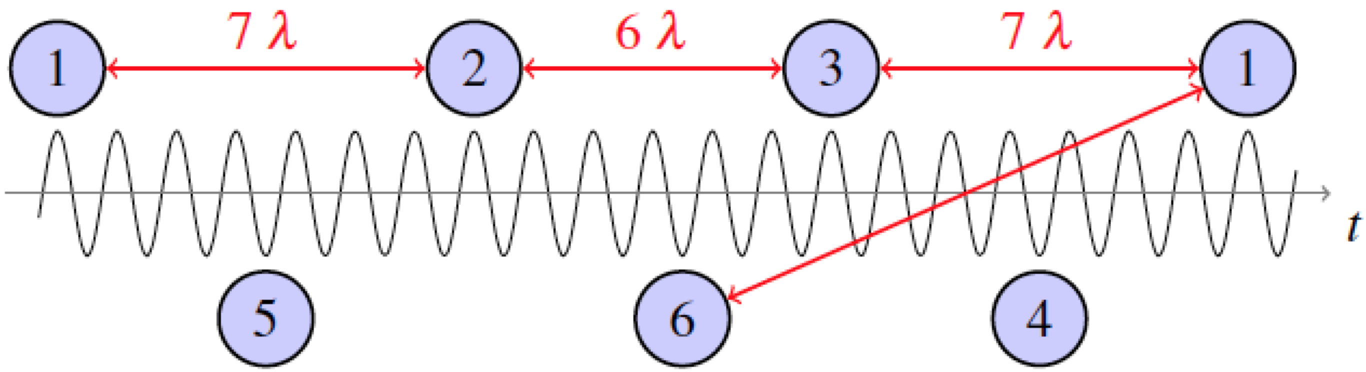
With 6 mm long bunches, the RF curvature can be seen at high energy,
still extremely small energy spread: 5 ‰ at injector -> 0.1 ‰ at 900 MeV

Possibility to introduce enegy chirp and tune the arcs R_{56} to manipulate the phase space

Recombination Pattern

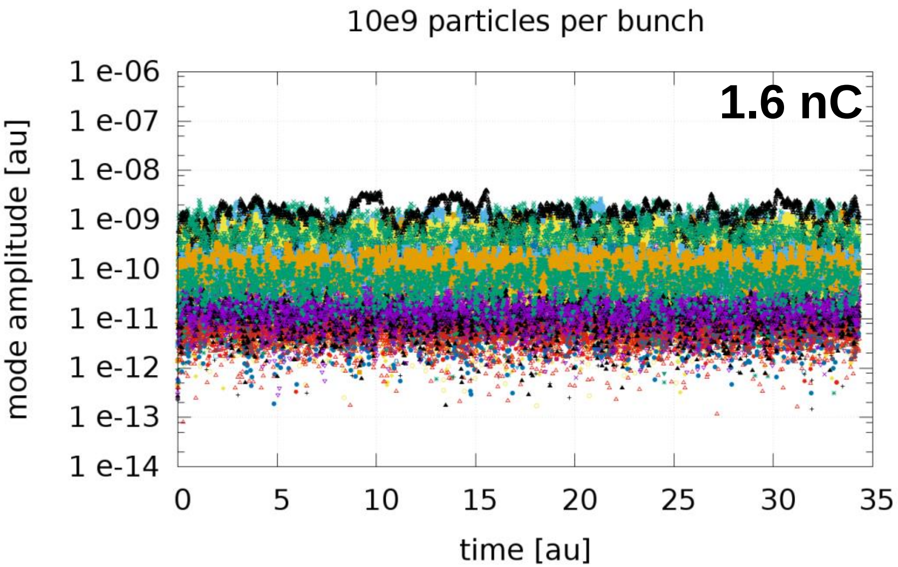


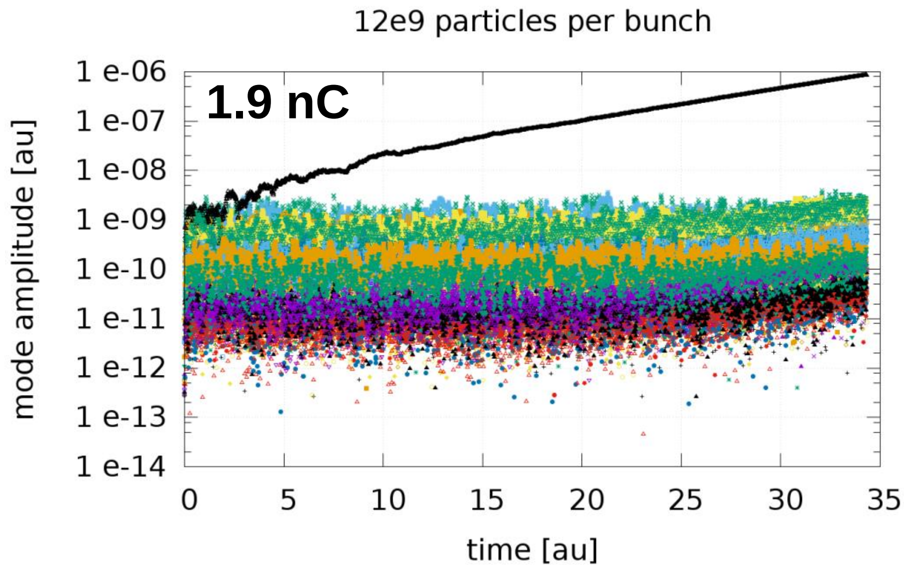
Arc's lengths tuned to avoid bunches in the same bucket
Lattice adjusted to achieve a nearly constant bunch spacing



Long Range Wakefields Threshold Current

Multi-bunch tracking simulations with PLACET2 and optimal recombination pattern
26 dipole modes of the SPL cavity scaled to 802 MHz
100 particles per bunch – BBU triggered by statistical fluctuations of the centroid





Offending mode builds up in the vertical plane (coupling between a specific mode frequency, time of flight and the vertical betatron tune).

Threshold current >5 times higher than the nominal (2e9 particles per bunch)

Outline

1. DESIGN STAGES AND PARAMETERS

2. MACHINE DESIGN

3. APPLICATIONS

ERL Facility at CERN for Applications

- Facility for testing quench and damage levels of SC wires and SC magnets
  - Intensities and repetition rates
  - Space, powering and other requirements

- Generation of high-energy monochromatic polarized photons via Compton backscattering of laser light from relativistic electrons for nuclear physics research*
  - Investigate the maximum energy and flux of the gamma-beam generated
  - Define the laser requirements according to the electron beam parameters

*Photon Beam Generation, F. Zomer
Photonuclear reactions, N. Pietralla

Controlled quench and damage tests

MOTIVATION
FACILITY FOR TESTING QUENCH AND DAMAGE LEVELS
OF SC WIRES AND SC MAGNETS

Advantages comparing to the existing at CERN facilities:

- Beam will directly hit a sample (straightforward calculation of loss distribution, no need to account for the beam dynamics over the turns as in case of a circulating beam)
- SC wires, magnets/prototypes could be tested (not only the magnets that are already in the machine)
- With the ERL facility the whole time range (ns - several s) losses would be available to test - e.g. HiRadMat maximum length of losses is 7us every ~40s.

Question:
Are the intensities at extraction and repetition rates sufficient for the tests?

Quench threshold level depends on

- Current
- Cooling
- Energy deposition
- Pulse duration

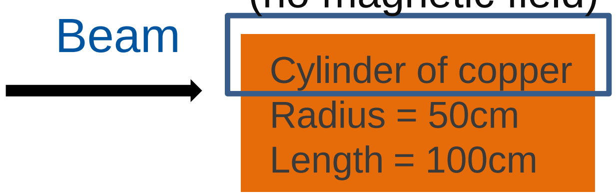
Damage threshold depends on

- Cooling
- Material
- Impact duration
- Beam size (the volume that needs to be melted to qualify as a damage)

Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS

Copper target
(no magnetic field)



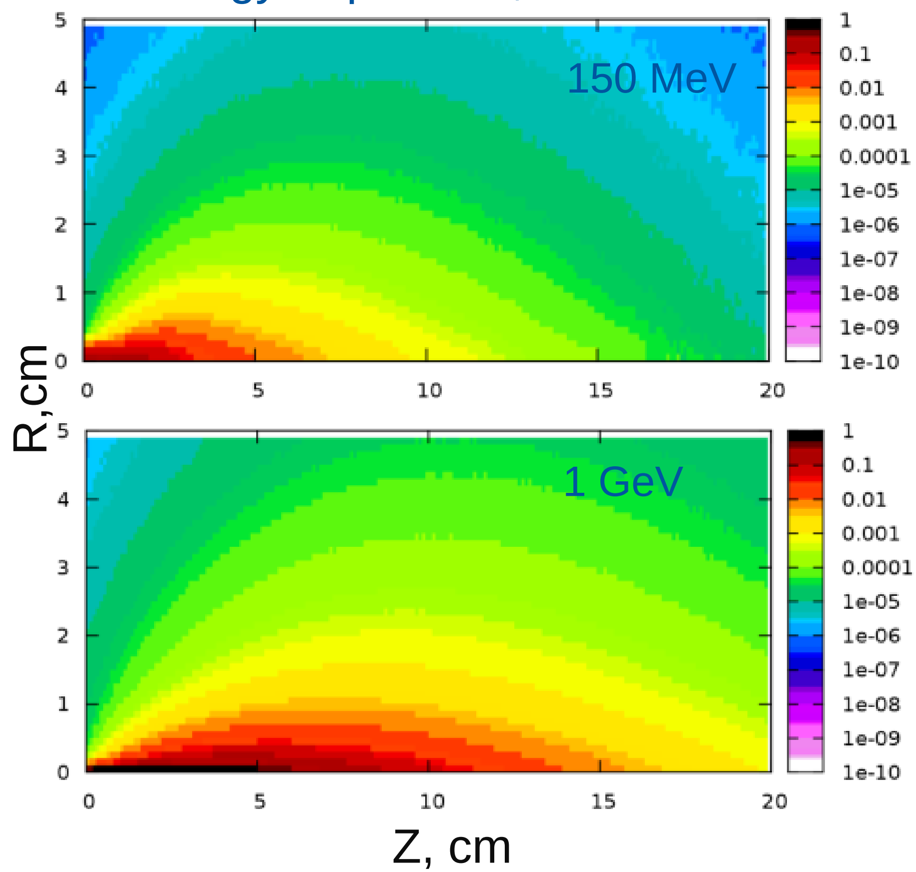
Beam parameters

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

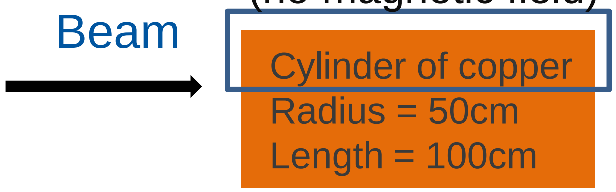
Energy deposition, $GeV/cm^3/e^-$



Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS

Copper target
(no magnetic field)



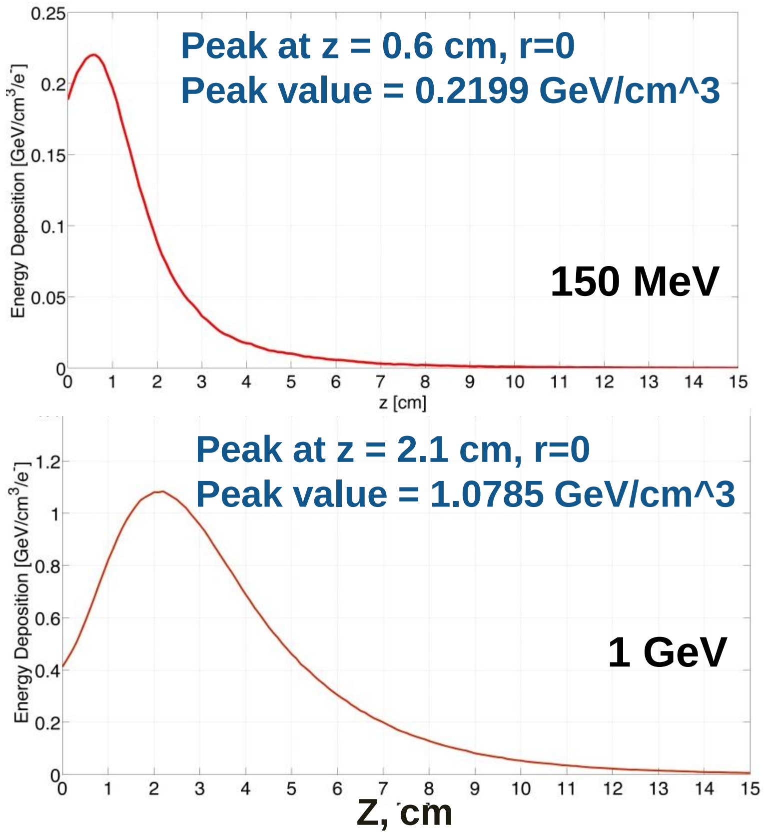
Beam parameters

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

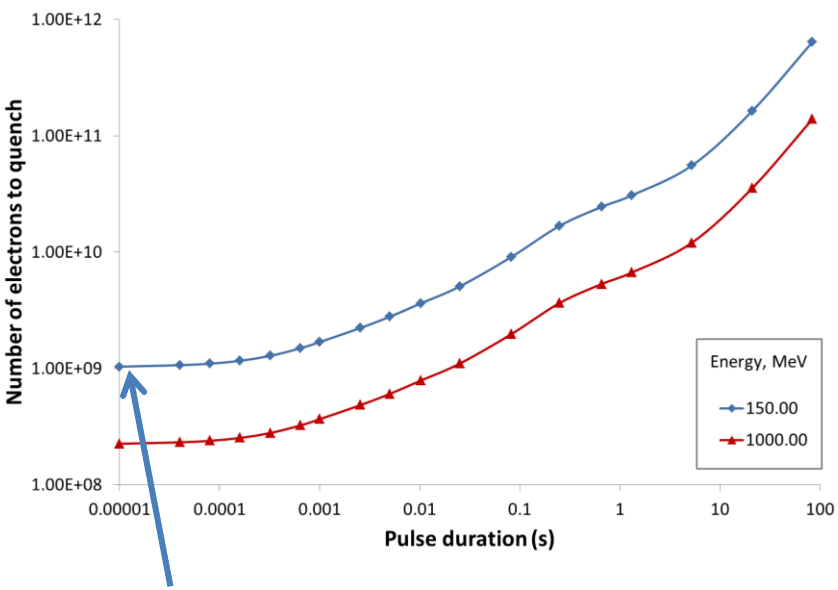
Energy deposition, GeV/cm^3/e$^-$



Quench & Damage

For **quenching** an LHC MB (main dipole magnet) a certain amount of energy should be deposited in $1mm^3$

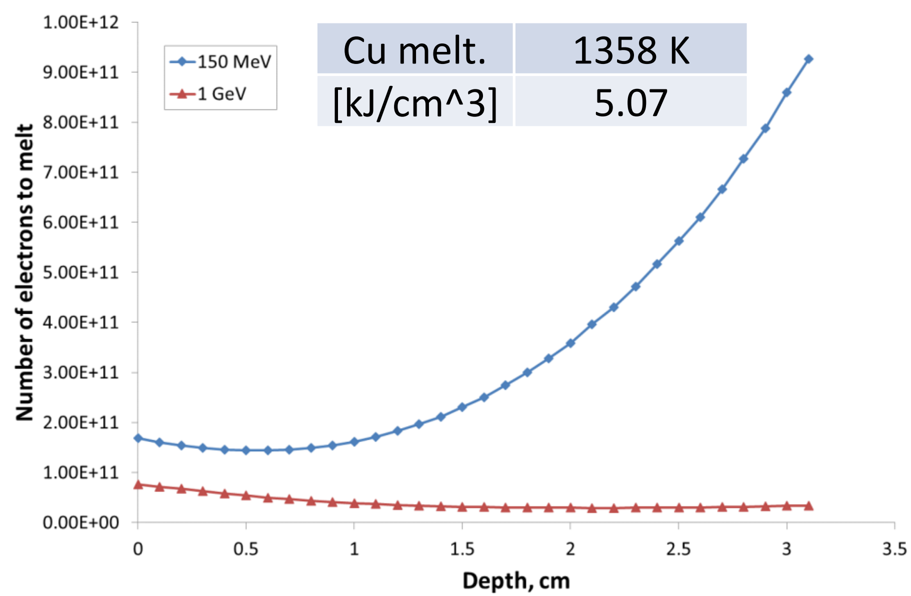
$$\#\text{ electrons needed to quench the magnet} = \frac{\text{Quench threshold}}{\text{Maximum value for the energy deposition}}$$



Can easily quench with a single bunch at 150MeV
Bunch charge 2e9 > quench threshold 1e9

Damage limit in present studies is defined as a number of electrons needed for melting 1 mm^3 of Cu

Number of electrons for melting Cu should be delivered to the target within <u>several hundreds ms</u> in order to avoid heat transfer



Cu melt.	1358 K
[kJ/cm^3]	5.07

2e11 electrons required over 0.1 s to melt 1 mm^3
8e15 electrons accelerated over 0.1 s
(can extract few bunches with a fast kicker)

Summary

- **An ERL platform is being pursued at CERN to validate the LHeC key design choices along with dedicated physical and technical applications**

- The concept of the ERL Facility is designed to allow for a staged construction with verifiable and useful stages for an ultimate beam energy in the order of 900 MeV

- An optics design study of the ERLF has been completed and start-to-end analysis are on going

- Design complementary to & synergetic with other proposals worldwide

- Collaborations with other institutes have been started

- Preliminary Conceptual design report ready!!!!

Thank you for your attention

...and thanks to the LHeC collaboration, in particular to

A. Bogacz, O. Bruning, V. Chetvertkova, *E. Jensen, M. Klein,* D. Pellegrini

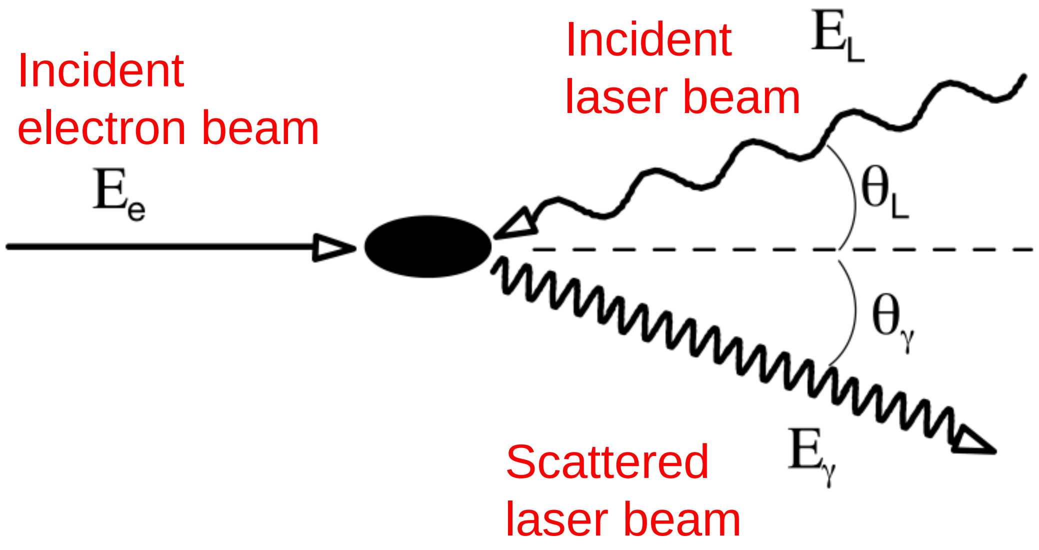
http://lhec.web.cern.ch

PERLE

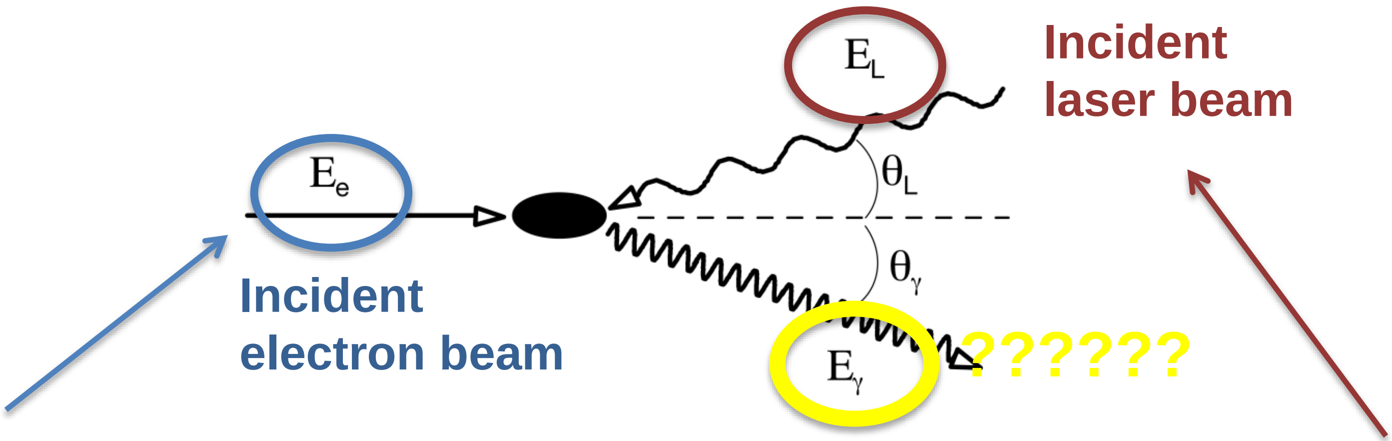
Powerful energy recovery linac experiments

Gamma beams at the ERL Facility

GOAL: Generation of high-energy monochromatic polarized photons via Compton backscattering of laser light from relativistic electrons for nuclear physics research



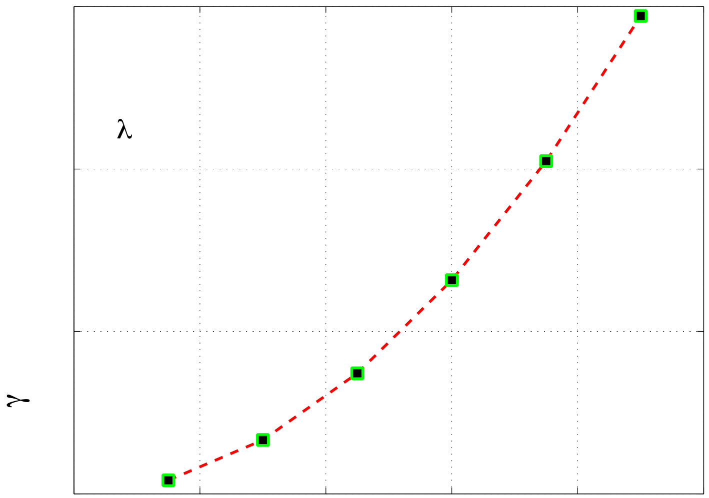
Gamma beams at the ERL Facility: input parameters

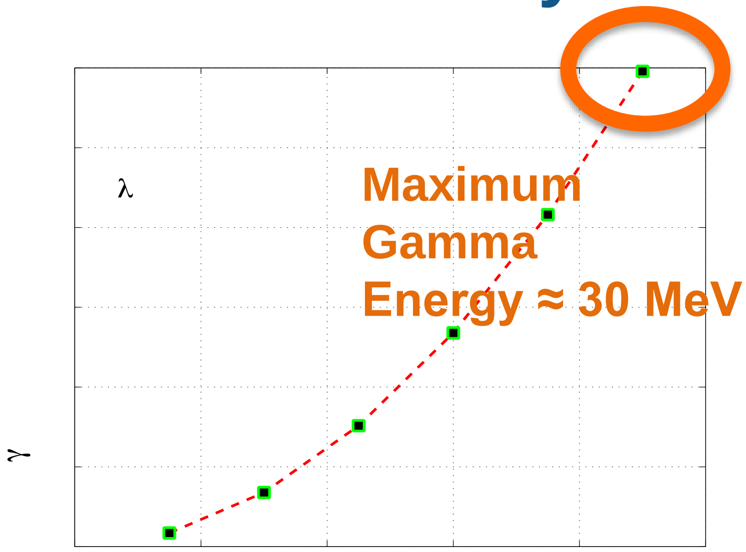


ELECTRON BEAM PARAMETERS	
Energy	900 MeV
Charge	320 pC
Bunch Spacing	25 ns
Spot size	30 um
Norm. Trans. Emittance	5 um
Energy Spread	0.1 %

LASER BEAM PARAMETERS	
Wavelength	515 nm - 1030 nm
Average Power	300kW - 600 kW
Pulse length	3 ps
Pulse energy	7.5mJ - 15 mJ
Spot size	30 um
Bandwidth	0.02 %
Repetition Rate	40 MHz

Gamma beam properties at the ERL facility





GAMMA BEAM PARAMETERS	
Energy	30 MeV
Spectral density	$9*10^{4}$ ph/s/eV
Bandwidth	< 5%
Flux within FWHM bdw	$7*10^{10}$ ph/s
ph/e^{-} within FWHM bdw	10^{-6}
Peak Brilliance	$3*10^{21}$ ph/s*mm^{2}*mrad^{2} 0.1%bdw