CERN

Alessandra Valloni on behalf of the LHeC collaboration

KEK Seminar

Accelerator Development for LHeC and LTF

KEK, High Energy Accelerator Research Organization, 12th June

Alessandra Valloni on behalf of the LHeC collaboration

ありがとうございます

Thanks for your hospitality, time, help and support

KEK, High Energy Accelerator Research Organization, 12th June

Outline

1. THE LHeC : **BASELINE PARAMETERS AND CONFIGURATION**
   - GOALS
   - PHYSICS REQUIREMENTS

2. **GENERAL DESIGN CONSIDERATIONS**
   - LINAC-RING COLLIDER

3. **POST CDR PLANS**
   - AN ERL TEST FACILITY

4. **PLANNING AND TIMELINE**

5. **NEXT STEPS AND R&D ACTIVITIES**

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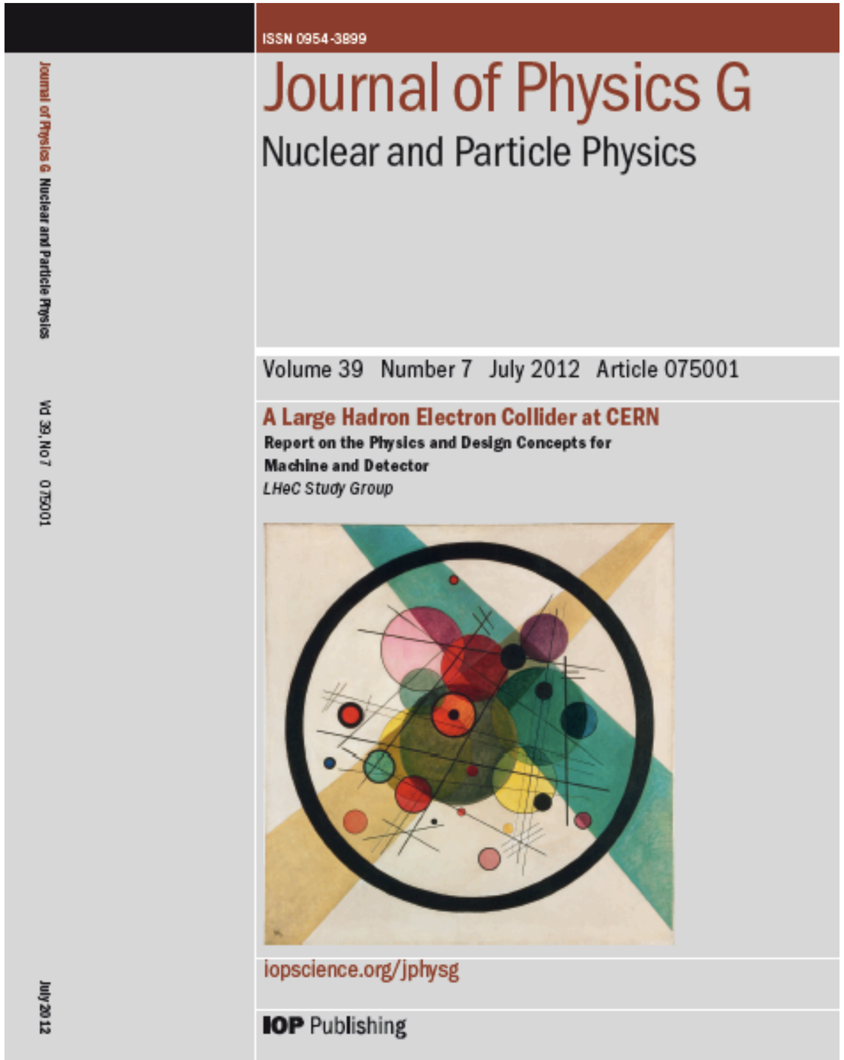
DE L'ACCÉLÉRATEUR
LINÉAIRE

...

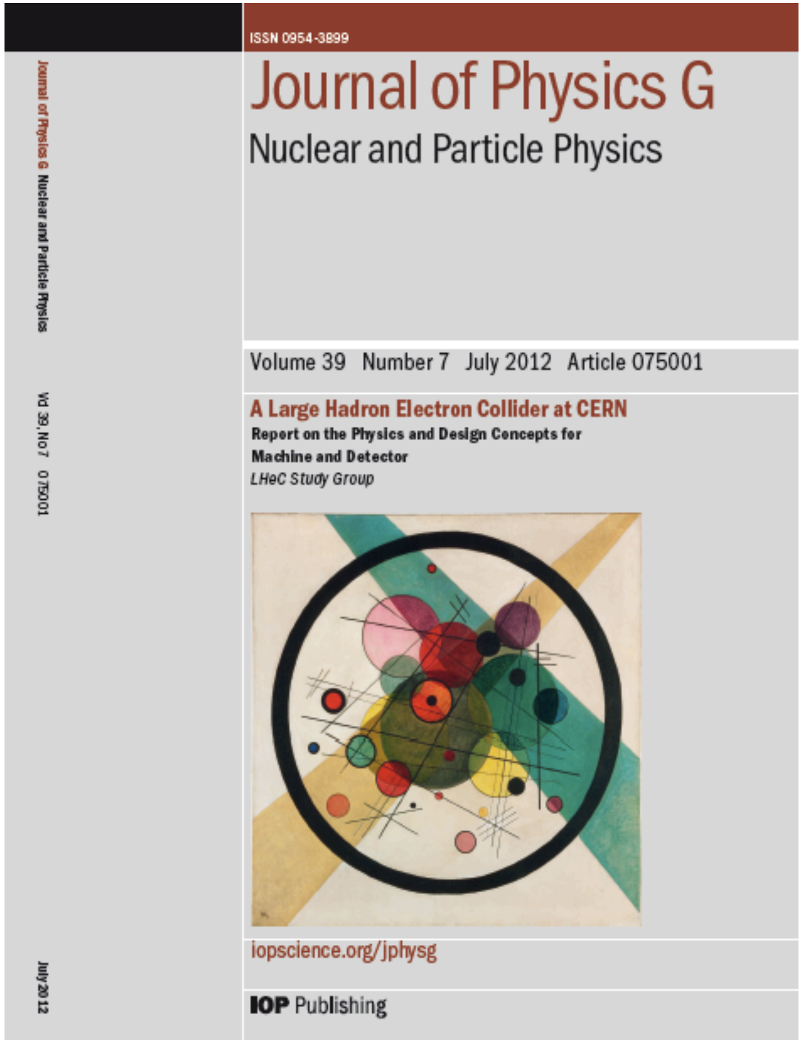
CERN

LHeC Overview



1. INTRODUCTION
2. PHYSICS
3. ACCELERATOR
4. DETECTOR
5. CONCLUSIONS

LHeC Overview



1. **INTRODUCTION**

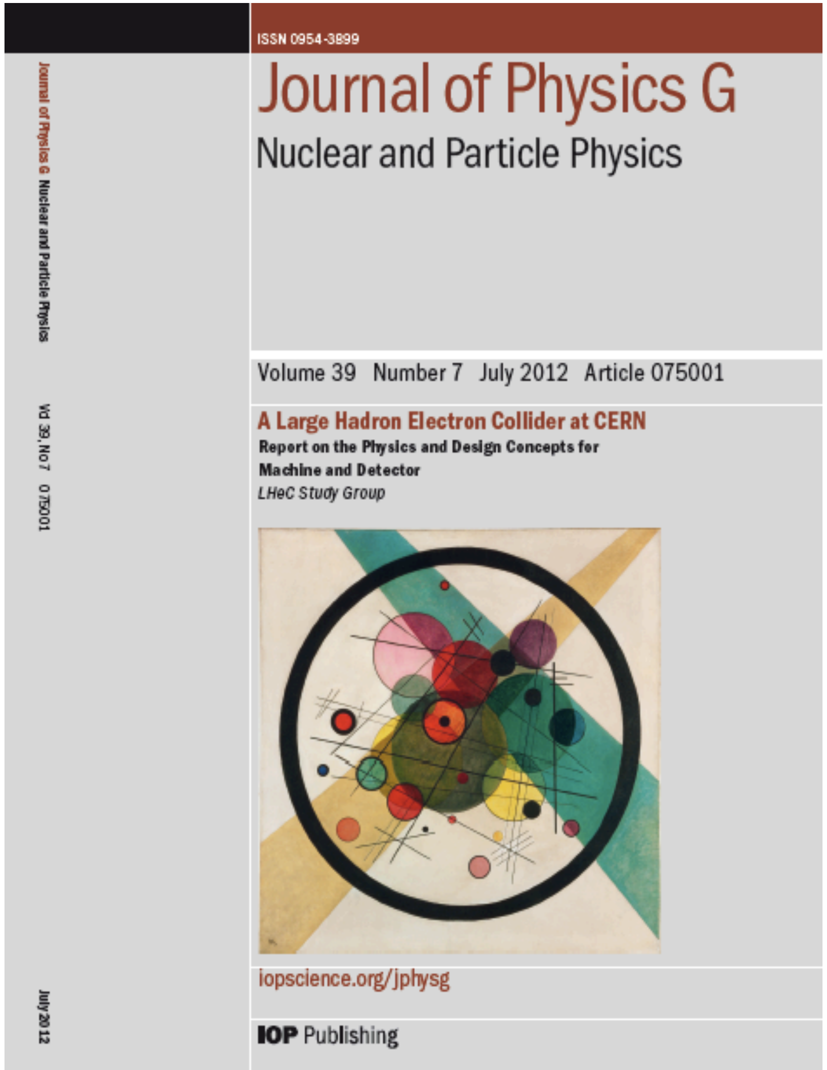
2. **PHYSICS**
   - Precision QCD and Electroweak Physics
   - Physics at High Parton Densities
   - New Physics at high energy

3. **ACCELERATOR**

4. **DETECTOR**

5. **CONCLUSIONS**

LHeC Overview



1. **INTRODUCTION**

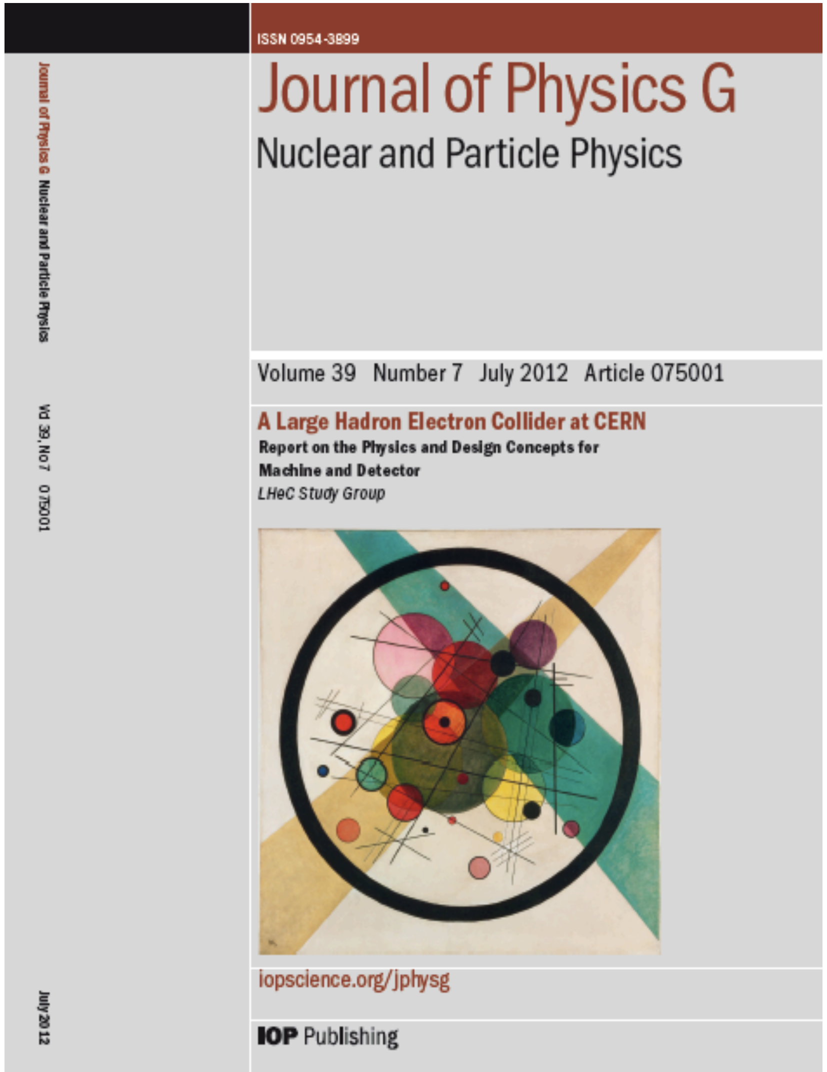
2. **PHYSICS**

3. **ACCELERATOR**
   - Ring-Ring Collider
   - Linac-Ring Collider
   - System Design
   - Civil Engineering and Services

4. **DETECTOR**

5. **CONCLUSIONS**

LHeC Overview



1. **INTRODUCTION**

2. **PHYSICS**

3. **ACCELERATOR**

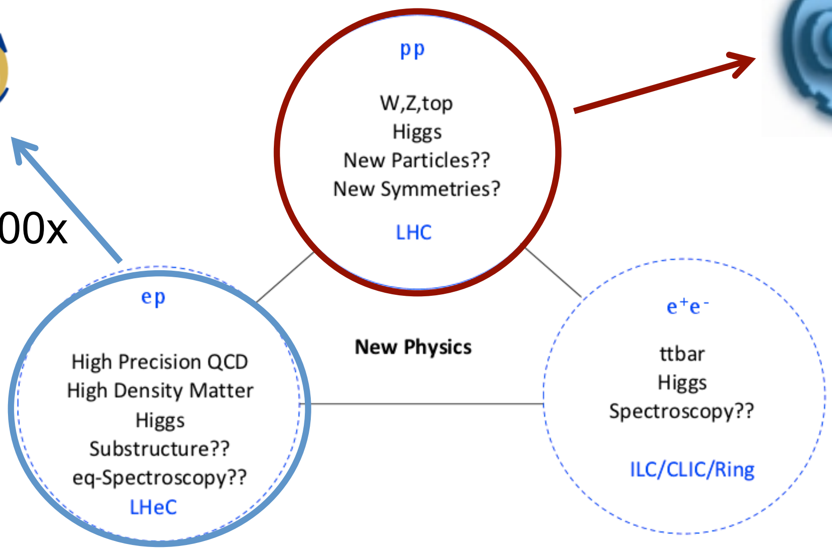
4. **DETECTOR**
   - Detector Requirements
   - Central detector
   - Forward and Backward Detectors

5. **CONCLUSIONS**

Physics Programme

LHeC is a new collider: the cleanest microscope of the world

Energy ($\sqrt{s}$= 1.2 TeV) 4x
luminosity (10^{33} $cm^{-2}s^{-1}$) 100x



High Luminosity LHC

Increase luminosity ($5x10^{34}$ $cm^{-2}s^{-1}$) in IP1 (ATLAS) and IP5 (CMS)

- Exploration of the energy frontier, complementing the LHC and its discovery potential for physics beyond the Standard Model with high precision deep inelastic scattering measurements
- Investigation of a variety of fundamental questions in strong and electroweak interactions
- Electron-deuteron and electron-ion scattering in a (Q^2, 1/x) range extended by 4 orders of magnitude as compared to previous lepton-nucleus DIS experiments
- Novel investigations of neutron's and nuclear structure, the initial conditions of Quark-Gluon Plasma formation and further quantum chromodynamic phenomena

LHeC Goal

COLLIDE LHC BEAM WITH ELECTRONS OR POSITRONS

- LHC hadron beams: $E_p = 7$ TeV
  CM collision energy: $E^2_{CM} = 4\ E_e * E_{p,A}$
  Required lepton energy 50 GeV to 150 GeV

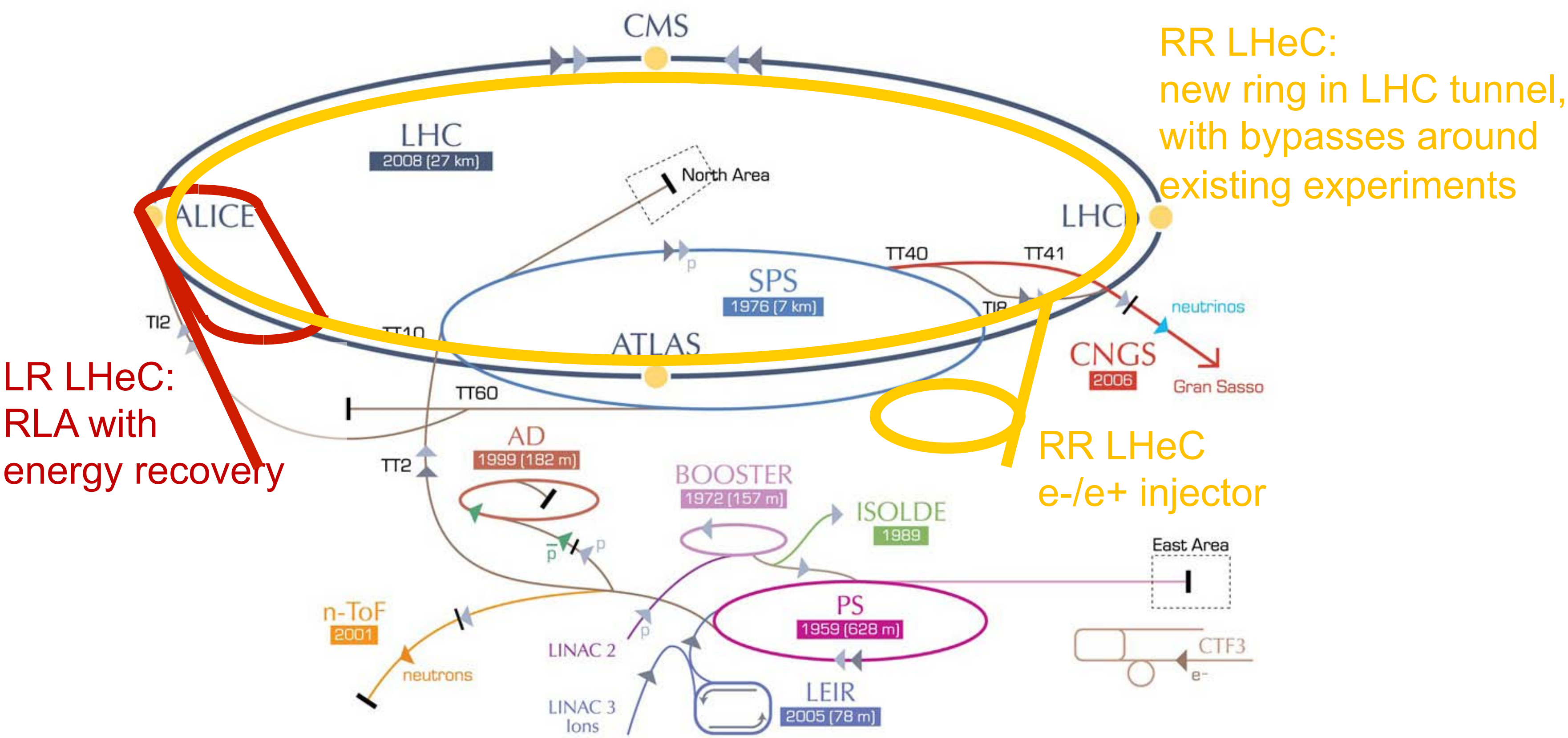
- Integrated $e^{\pm}p$: O(100) fb^{-1} ≈ 100 * L(HERA)
  Synchronous ep and pp operation

- Luminosity of ≈ $10^{33}cm^{-2}s^{-1}$ (proposal for $10^{34}cm^{-2}s^{-1}$ exists)
  Power consumption for lepton complex ≤ 100 MW
  Beam Power < 70 MW

- Polarisation

- No interference with pp physics

LHeC option: RR and LR



Study team provided CDR:

Ring-ring option, feasible but impact LHC operation during installation

Linac-ring option, the baseline

A solution exists, will now have to find the best solution

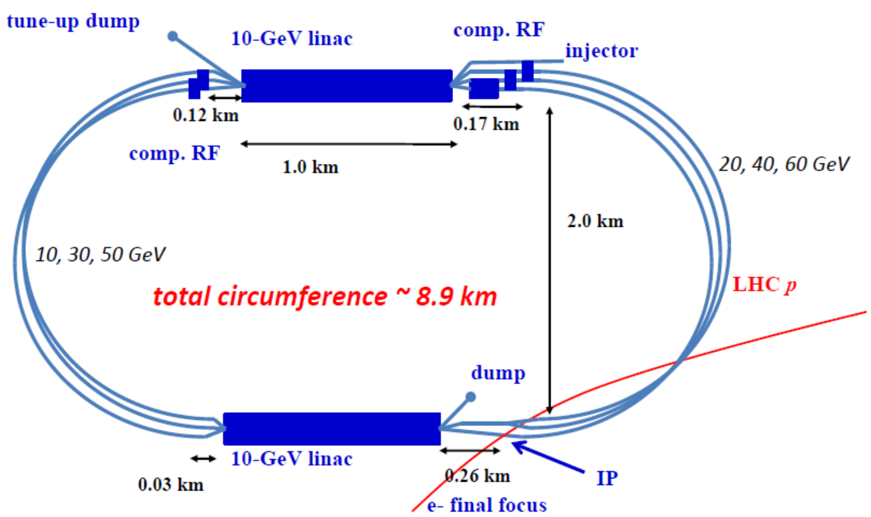
Already have a baseline and alternatives for some components

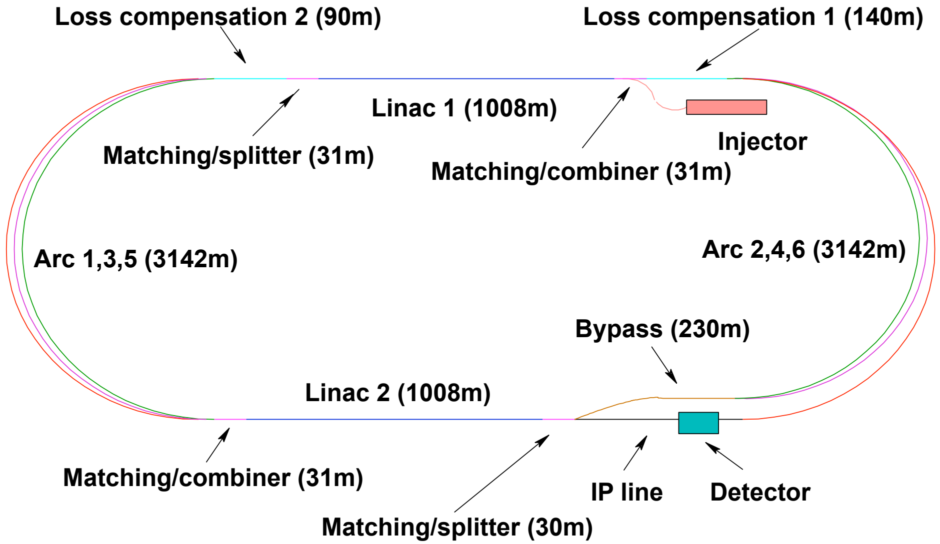
CERN Mandate (2012)

STUDIES AND PROTOTYPING OF THE FOLLOWING KEY TECHNICAL COMPONENTS:

- Superconducting RF system for CW operation in an ERL
- Superconducting magnet development of the insertion regions of the LHeC with three beams
- Studies related to the experimental beam pipes with large beam acceptance
- The design and specification of an ERL test facility for the LHeC
- The finalization of the ERL design for the LHeC (optics design, beam dynamics studies and identification of potential performance limitations)

Recirculating Linear Accelerator Complex : Schematic Layout





RECIRCULATOR COMPLEX

1. 0.5 Gev injector
2. A pair of SCRF linacs with energy gain 10 GeV per pass
3. Six 180° arcs, each arc 1 km radius
4. Re-accelerating stations to compensate energy lost by SR
5. Switching stations at the beginning and end of each linac
6. Matching optics
7. Extraction dump at 0.5 GeV

Linac-Ring layout: IP Parameters

10^{33} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [10^{33}cm^{-2}s^{-1}]	1	1
Normalized emittance $\gamma\varepsilon_{x,y}$ [µm]	3.75	50
Beta Function $\beta^*_{x,y}$ [m]	0.1	0.12
rms Beam size $\sigma^*_{x,y}$ [µm]	7	7
rms Beam divergence $\sigma'_{x,y}$ [µrad]	70	58
Beam Current [mA]	430 (860)	6.6
Bunch Spacing [ns]	25 (50)	25 (50)
Bunch Population	$1.7*10^{11}$	$(1*10^9)$ $2*10^9$
Bunch charge [nC]	27	(0.16) 0.32

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Energy **4** times
Luminosity **100** times
larger than HERA

Linac-Ring layout: IP Parameters

10^{34} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [$10^{33}cm^{-2}s^{-1}$]	16	16
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	2.5	20
Beta Function $\beta^*_{x,y}$ [m]	0.05	0.10
rms Beam size $\sigma^*_{x,y}$ [μm]	4	4
rms Beam divergence $\sigma'_{x,y}$ [μrad]	80	40
Beam Current [mA]	1112	25
Bunch Spacing [ns]	25	25
Bunch Population	$2.2*10^{11}$	$4*10^{9}$
Bunch charge [nC]	35	0.64

Linac-Ring layout: IP Parameters

10^{34} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
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Bunch Population	$2*10^{11}$	$4*10^{9}$
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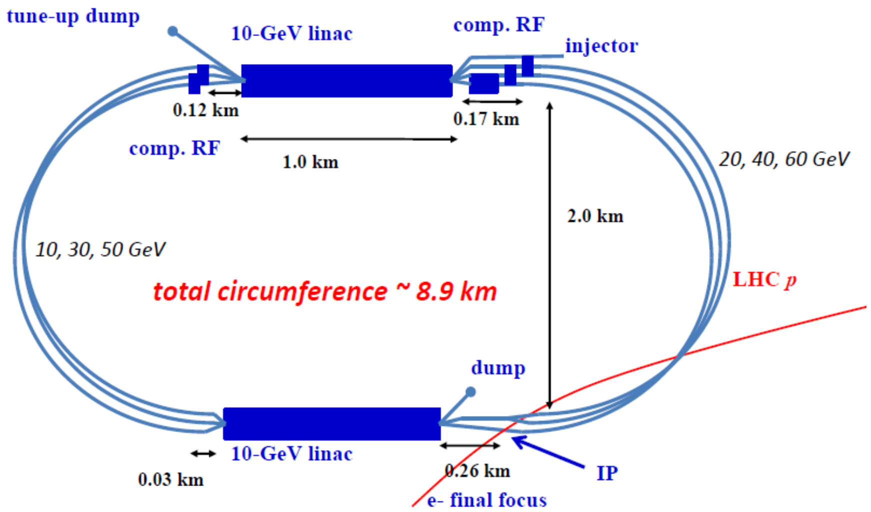
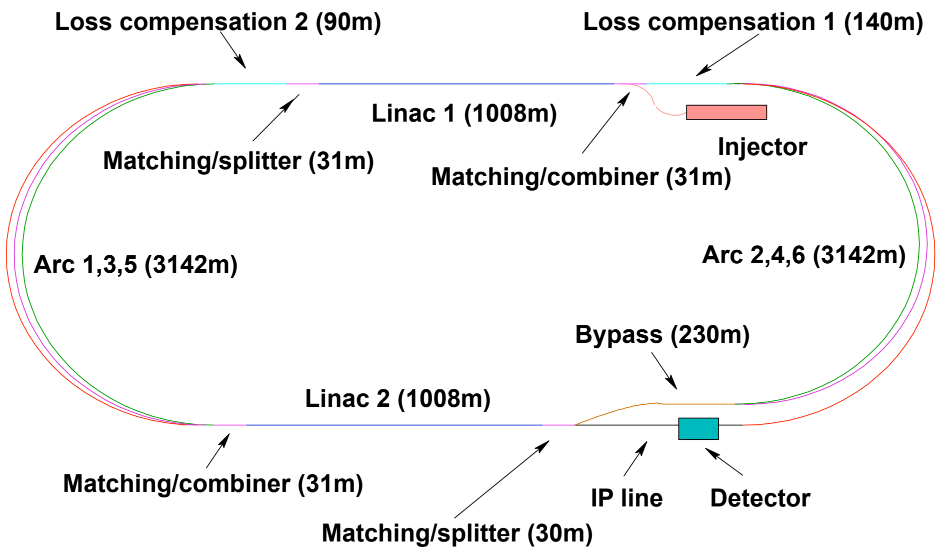
Luminosity 1000 times larger than HERA

Recirculating Linear Accelerator Complex : Schematic Layout





RECIRCULATOR COMPLEX

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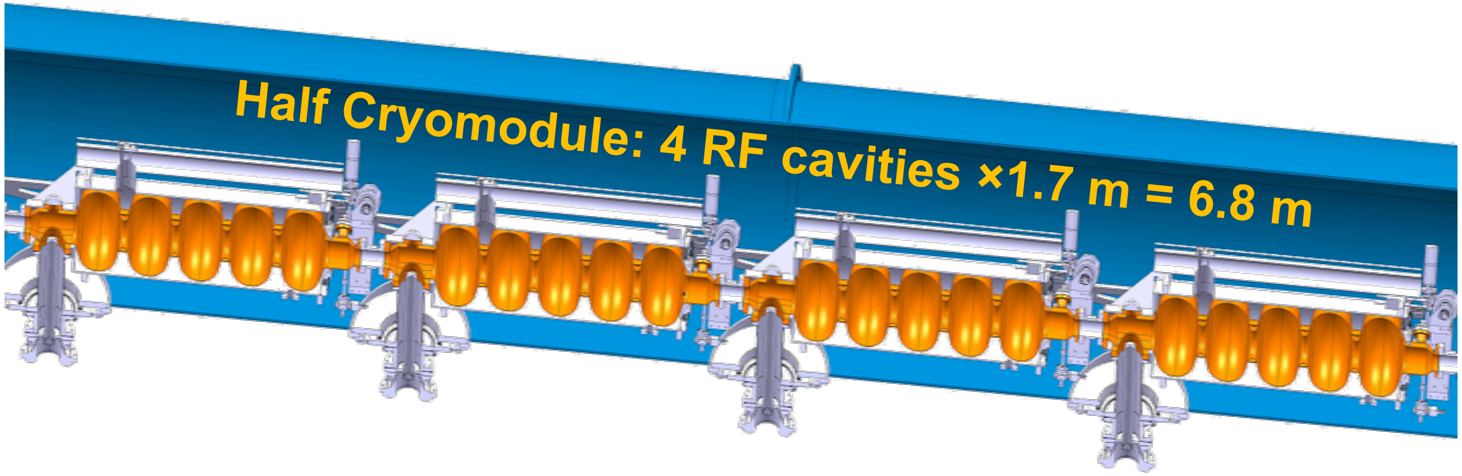
Linac Design

In **CDR**: 8 cavities per 14 m long module
Choice between O(720 MHz) and O(1.3 GHz) made in January 2013
~ 720 MHz had been baseline for CDR



HALF CRYOMODULE, 4 RF CAVITIES
721.4 MHz RF, 5-cell cavity
λ = 41.557 cm, L_c = 5l/2 = 103.89 cm
Grad = 18 MeV/m (18.7 MeV per cavity)
ΔE= 74.8 MV per Half Cryomodule

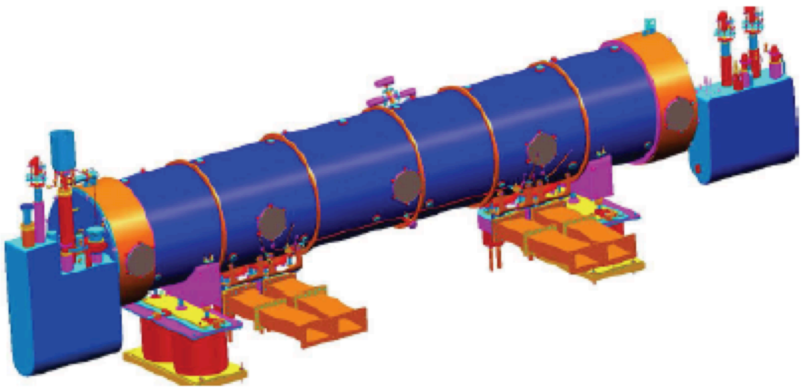
- $Q_0=2.5*10^{10}$ assumed,
- $R=1.43*10^{13}\,\Omega$ (ILC: $R=1.04*10^{13}\,\Omega$)
- 2 modules per quadrupole pack (2 m)
- ~ 60 modules per 1000 m long linac

Post CDR frequency choice

LHeC Meeting at Daresbury Laboratory, January 2013

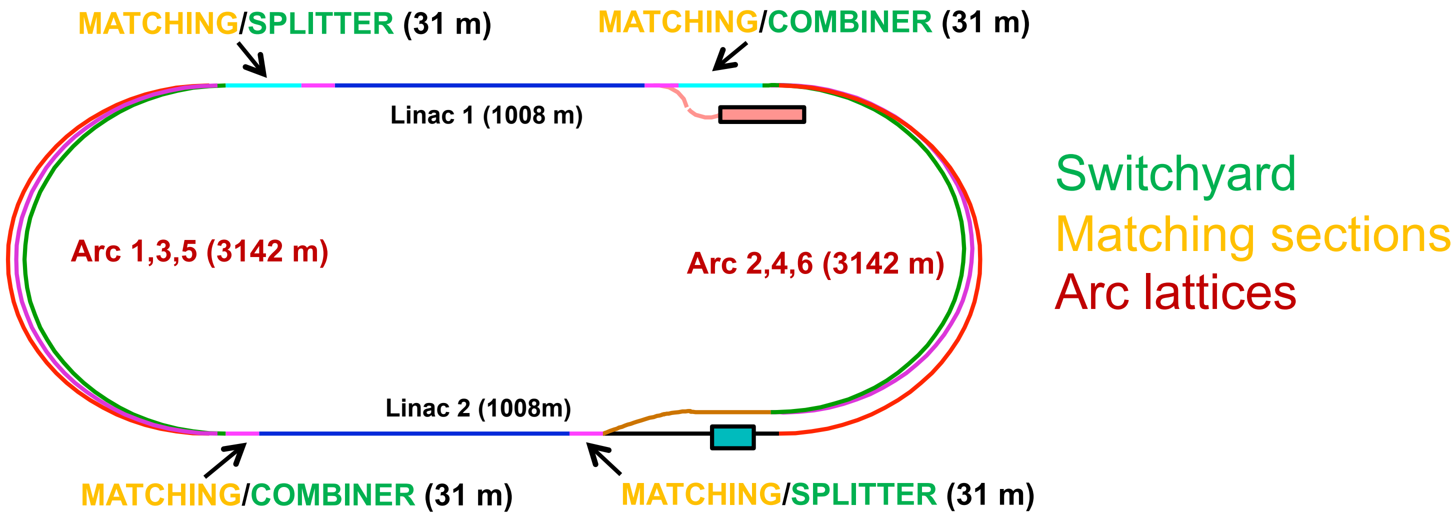
FINAL CHOICE: 801.58 MHz

- Frequency of a future LHC harmonic system



JLAB-CERN-Mainz 802MHz
Cavity cryo module under design
B.Rimmer, E.Jensen, K.Aulenbacher et al.

Return Arc Optics



- Arc-to-Linac Synchronization - Momentum compaction

  Quasi-isochronous lattices

  Choice of Arc Optics - Flexible Momentum Compaction

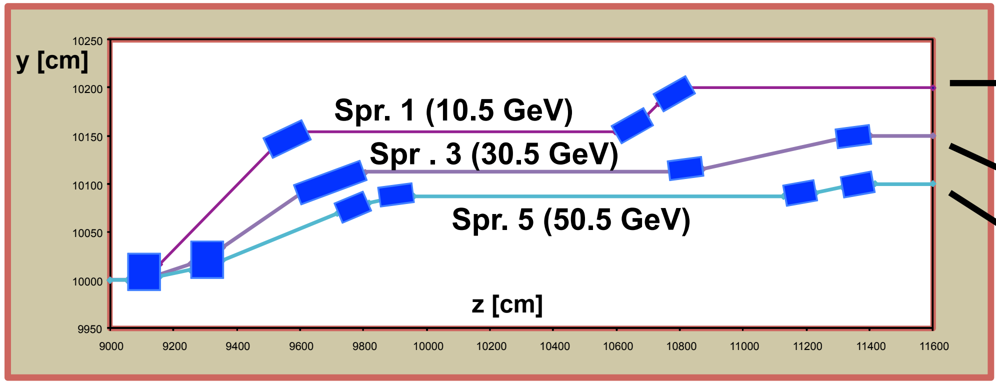
- Arc Optics Choice - Emittance preserving lattices

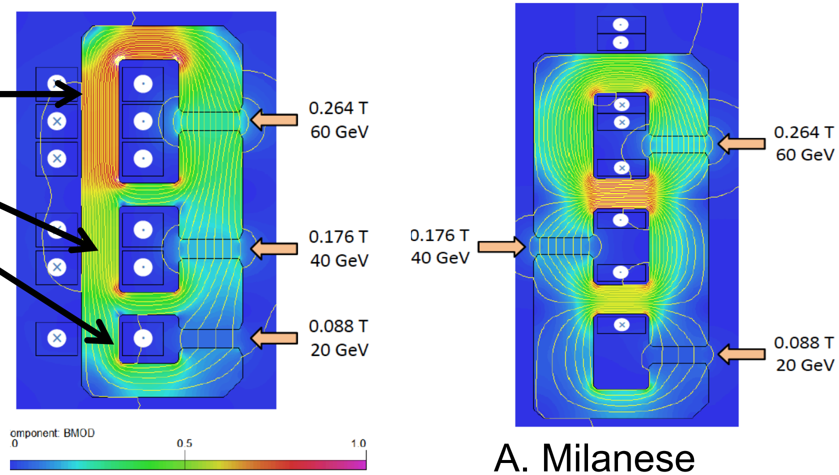
  Arcs based on variations of FMC optics (Im. γ_t, DBA, TEM)

- Acceptable level of emittance dilution and momentum spread

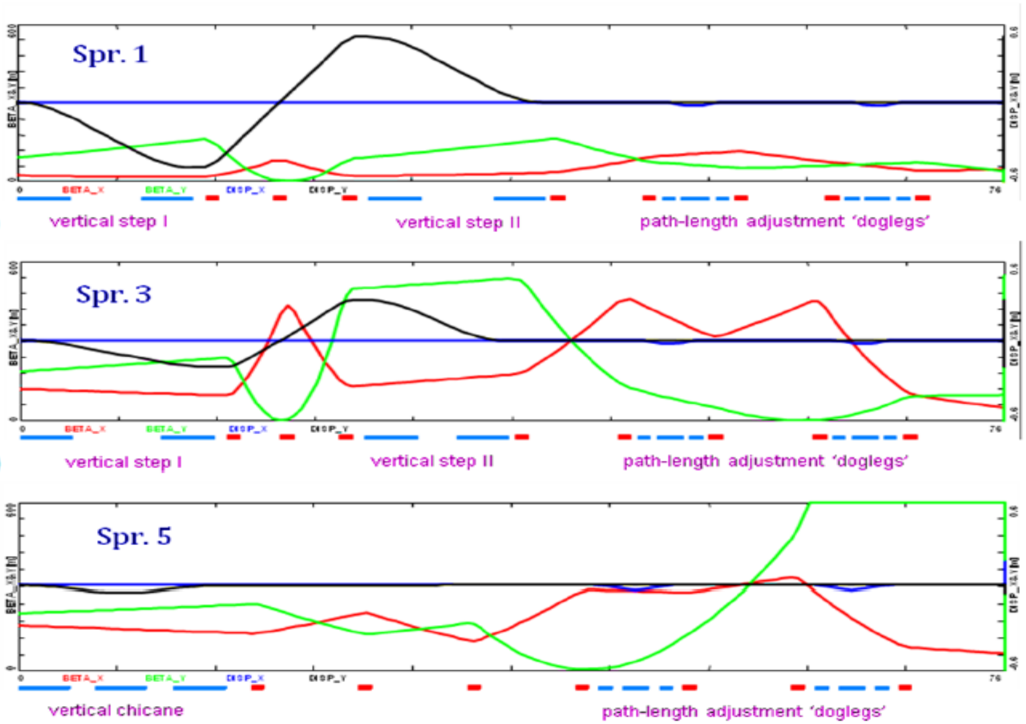
  Magnet apertures

Switchyards





A. Milanese

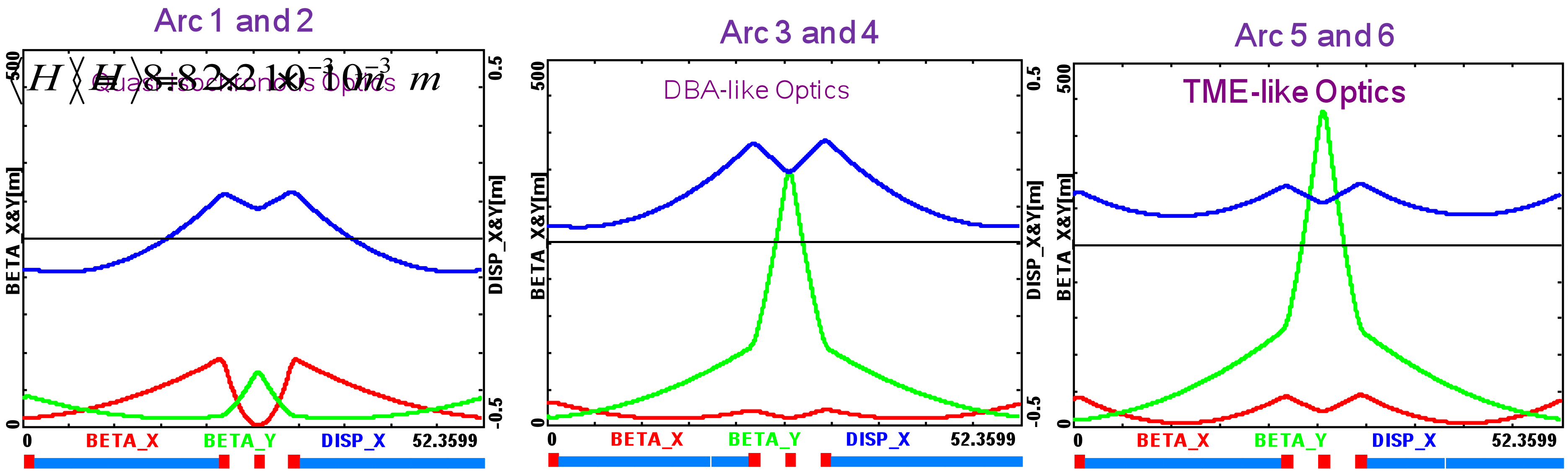


- Two-step-achromat spreaders and mirror symmetric recombiners
- Arcs are separated into 1m high vertical stack
- Very compact switchyard system (~20 m long)
- Horizontal doglegs used for path-length adjustment

Emittance Preserving Arc Optics

Proper lattice design in the arcs to address
the effect of SR on electron beam phase-space:
cumulative emittance and momentum growth due to quantum excitations

$$\Delta\varepsilon^N = \frac{2}{3} C_q \, r_0 \, \gamma^6 \langle H \rangle \frac{\pi}{\rho^2} \qquad H = \gamma D^2 + 2\alpha D D' + \beta D'^2$$



Various flavors of FMC Optics used

Emittance not exceeding 50 μrad required for the LHeC luminosity

Synchrotron radiation in return arcs (1/2)

- Energy loss due to synchrotron radiation in the arcs
- Integrated energy spread induced by synchrotron radiation

ARC	E [GeV]	ΔE [MeV]	σE/E [%]
1	10.4	0.678	0.00052
2	20.3	9.844	0.00278
3	30.3	48.86	0.00776
4	40.2	151.3	0.01636
5	50.1	362.3	0.02946
6	60	751.3	0.04829
7	50.1	362.3	0.06366
8	40.2	151.3	0.08065
9	30.3	48.86	0.10808
10	20.3	9.844	0.16205
11	10.4	0.678	0.31668
dump	0.500	0	6.66645

Total loss per particle about ~1.9 GeV → 12.2 MW beam power
Compensated by additional linacs
60% wall plug to beam efficiency → 20.3 MW

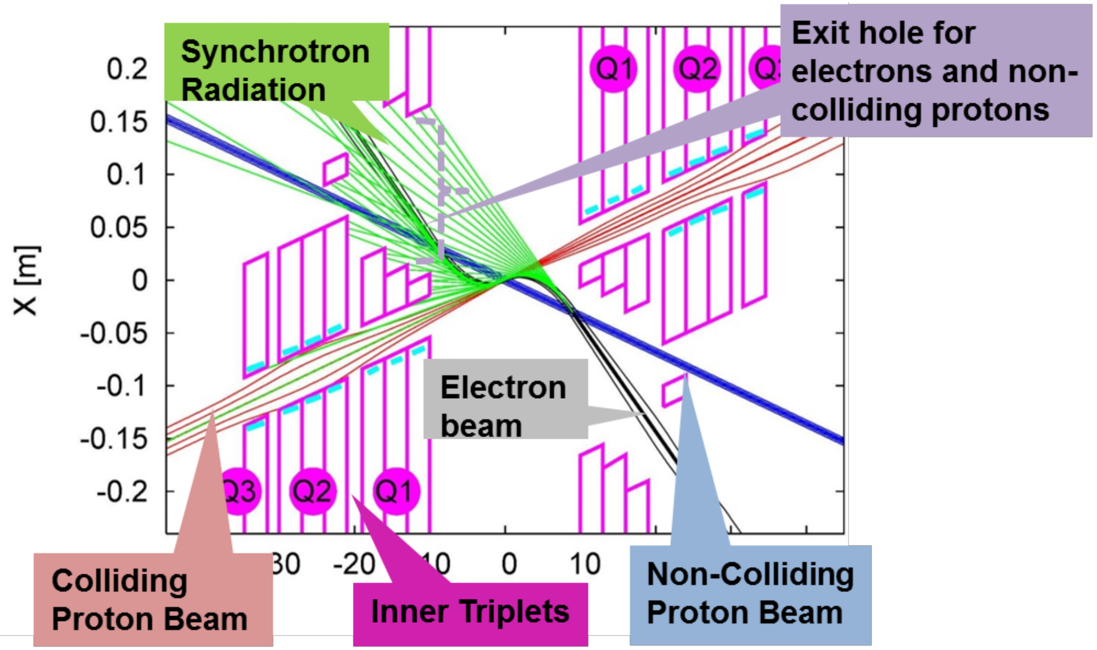
Synchrotron radiation in return arcs (2/2)

- Emittance growth in each individual arc*
- Integrated growth including all previous arcs

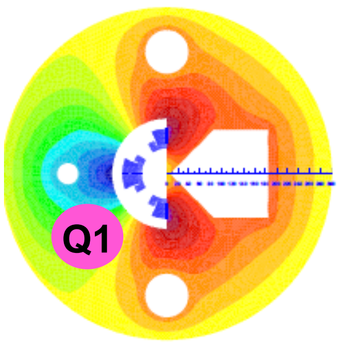
ARC	E [GeV]	$\Delta\varepsilon_{ARC}$ [μm]	$\Delta\varepsilon_t$ [μm]
1	10.4	0.0025	0.0025
2	20.3	0.140	0.143
3	30.3	0.380	0.522
4	40.2	2.082	2.604
5	50.1	4.268	6.872
6	60	12.618	19.490
5	50.1	4.268	23.758
4	40.2	2.082	25.840
3	30.3	0.380	26.220
2	20.3	0.140	26.360
1	10.4	0.0025	26.362

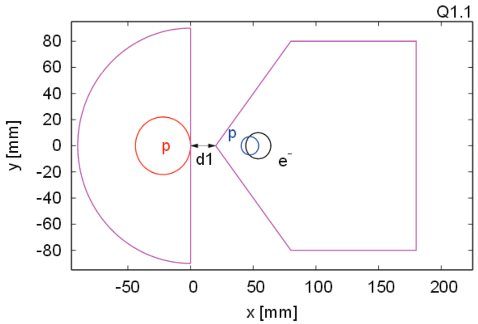
Before the IP a total growth of ~ 7 μm is accumulated
The final value is ~ 26 μm

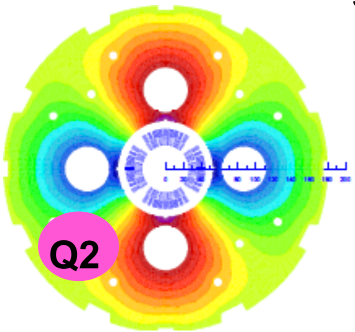
Interaction Region layout (CDR)



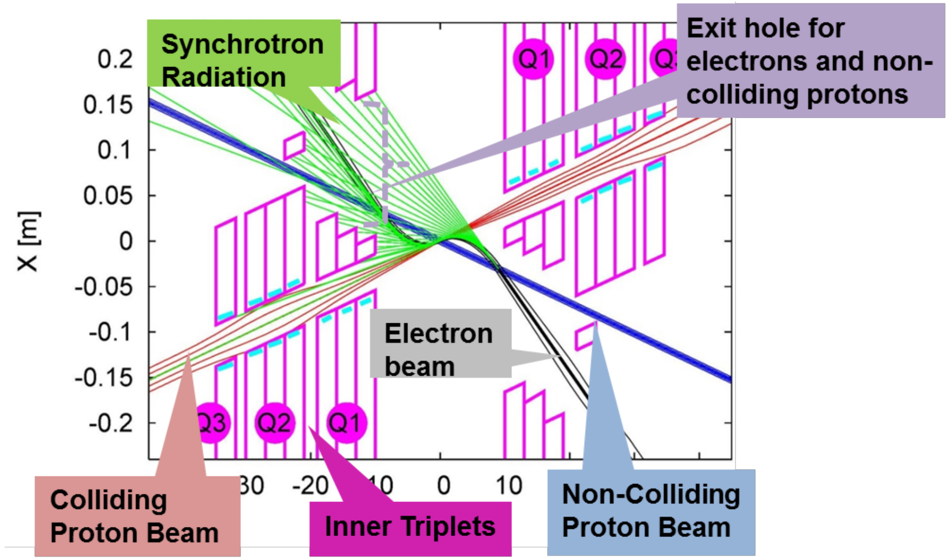
- β*of 0.1 m with proton triplets close to the IP to minimize chromaticity
- Head-on *p-e*⁻ collisions achieved by dipoles around the IP
- 6 mrad crossing angle between the non-colliding *p* beams
- Only the p beam colliding with the *e*⁻ is focused
- Mirror quadrupole design using Nb_3Sn technology







Interaction Region layout



Towards Luminosity ≥10^{33} $cm^{-2}s^{-1}$

$$L = \frac{1}{4\pi e}\frac{N_{b,p}}{\varepsilon_p}\frac{1}{\beta_p^*} I_e H_{hg} H_D$$

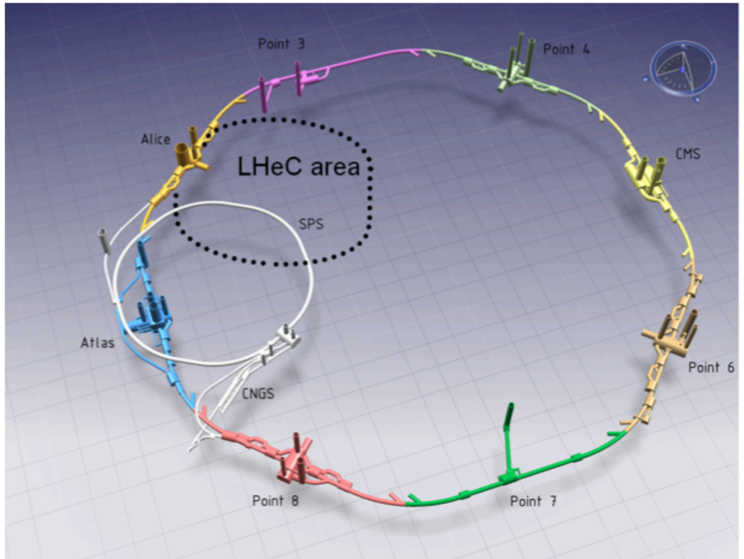
Minimize β* = More Luminosity!

Normal way.
Focus 26 quads in IR2 ❯ $\beta^*=0.3\ m$

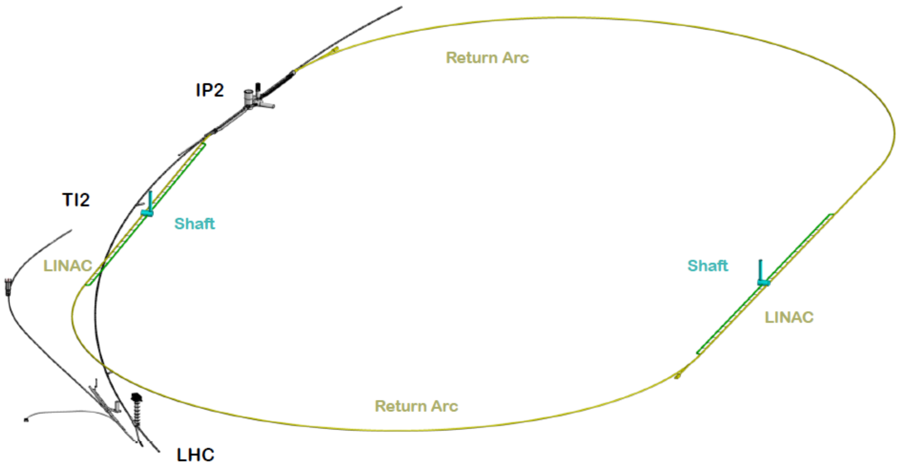
Limits quadrupole strengths
It causes huge chromatic aberrations

Achromatic Telescopic Squeezing
Focus 3x26 quads in IR1, IR2, IR3 ❯ $\beta^*=0.1\ m$

Civil Engineering Feasibility Studies



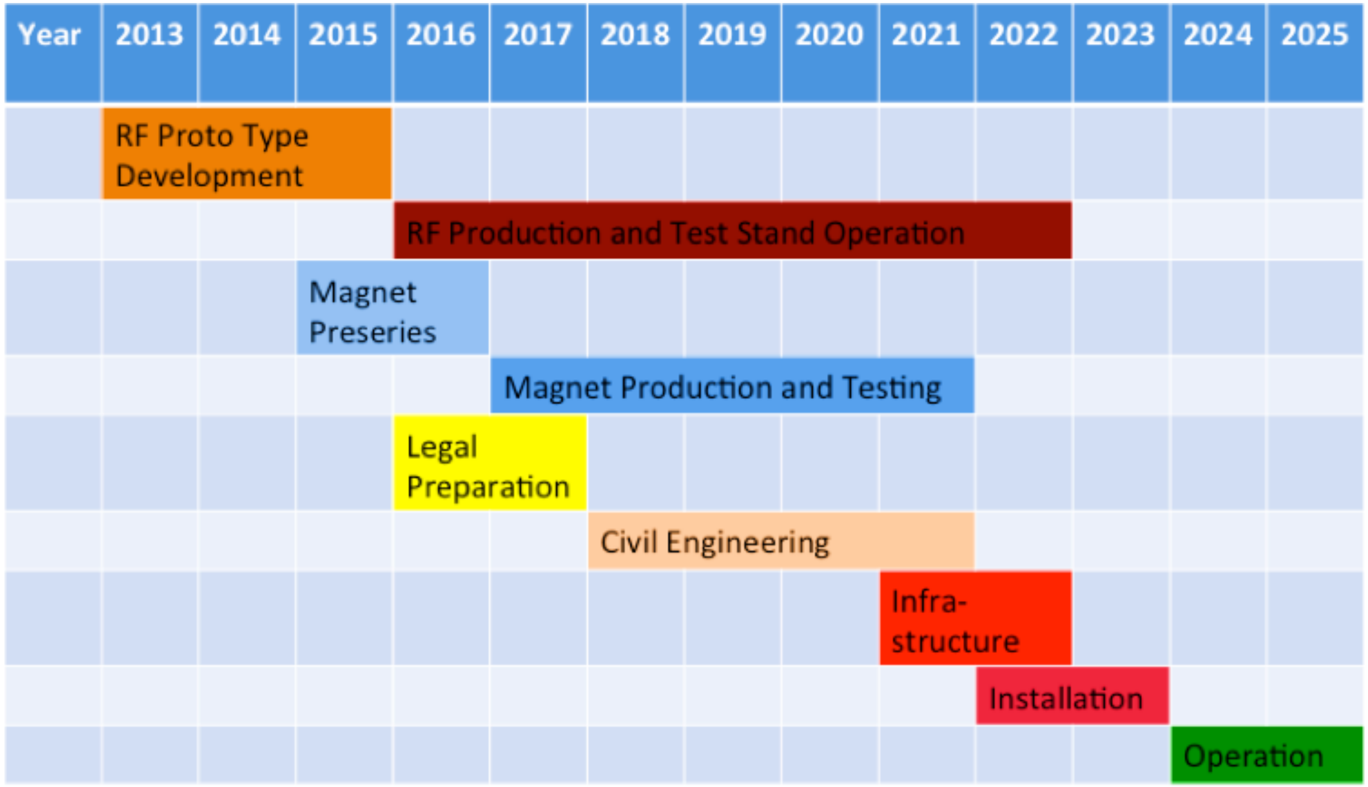
- ERL placed inside the LHC ring and tangential to IP2
- Two 1 km long LINACs; arcs have 1 km radius and are passed 3 times
- Whole racetrack ~9 km long (1/3 of the LHC length)



~ 960 cavities
~ 60 cryomodules per linac
~ 4500 magnets in the 2*3 arcs
~ 600 - 4 m long dipoles per arc
~ 240 - 1.2 m long quads per arc

LHeC Planning and Timeline

- Installation decoupled from LHC operation and shutdown planning
- Infrastructure investment with potential exploitation beyond LHeC

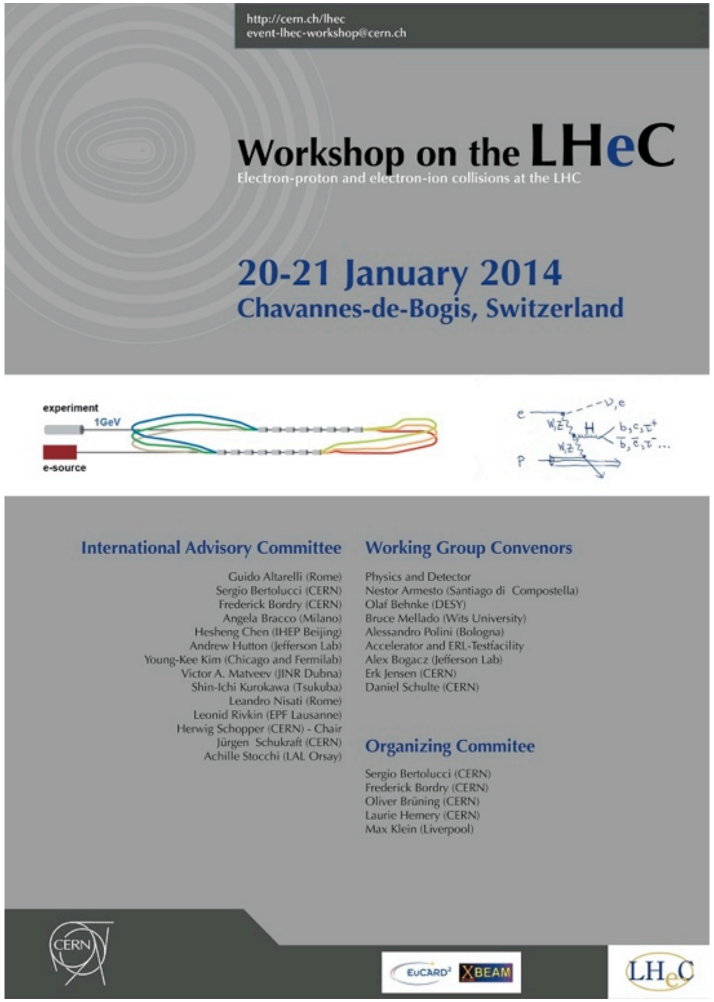


LHeC can be realised in about 10 years, as was for example HERA
The real installation plan will need to be agreed upon in the process of endorsing the project, it also depends on the LHC physics and time schedule

International Advisory Committee

H. Schopper (CERN)
G. Altarelli (Rome)
S. Bertolucci (CERN)
F. Bordry (CERN)
O. Brüning (CERN)
S. Brodsky (SLAC)
H. Chen (IHEP Beijing)
A. Hutton (JLab)
Y. Kim (Chicago)
M. Klein (Liverpool)
S. Kurokawa (KEK)
V. Matveev (JINR Dubna)
S. Kurokawa (Tsukuba)
A. Nisati (Rome)
L. Rivkin (EPFL)
J. Schukraft (CERN)
A. Stocchi (LAL-IN2P3)
J. Womersley (STFC)

First IAC meeting at the
LHeC 5th workshop, Switzerland, January 2014



Mandate of the IAC (2014-2017)

Advice to the LHeC Coordination Group and the CERN directorate by following the development of options of an ep/eA collider at the LHC and at FCC, especially with:

- Provision of scientific and technical direction for the physics potential of the ep/eA collider both at LHC and at FCC, as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an ERL test facility at CERN

- Assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects of the ep/eA collider.

Outline

1. THE LHeC : BASELINE PARAMETERS AND CONFIGURATION
    - GOALS
    - PHYSICS REQUIREMENTS

2. GENERAL DESIGN CONSIDERATIONS
    - LINAC-RING COLLIDER

3. THE ERL TEST FACILITY
    3A. STAGES OF BUILDING DESIGN
        - LAYOUTS
        - BASELINE PARAMETERS
    3B. ARC OPTICS ARCHITECTURE
    3C. TEST FACILITY FOR SC MAGNET TESTS

4. PLANNING AND TIMELINE

5. NEXT STEPS AND R&D ACTIVITIES

LHeC test facility

THE NEXT MAJOR STEP OF THE LHeC R&D IS A DEMONSTRATOR AT CERN OF AN ENERGY RECOVERY LINAC

- **The test facility would consist of SC linacs, recirculation and energy recovery**

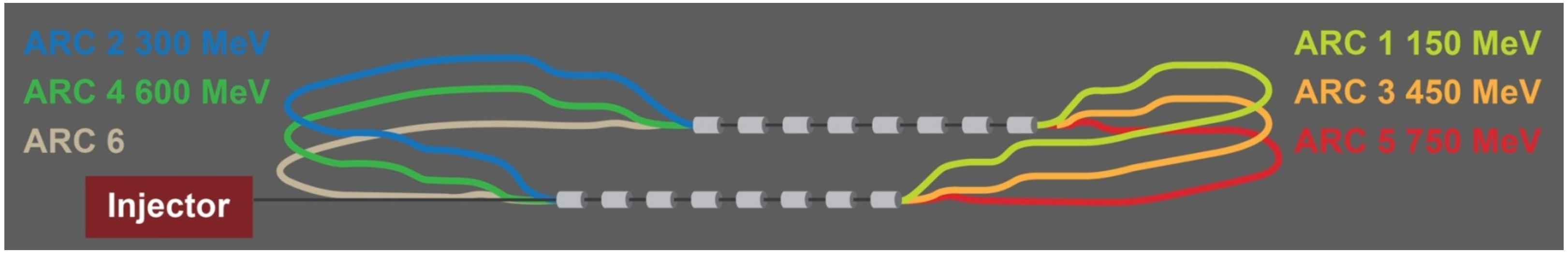
- **Among the purposes of this test facility are**
  1. Demonstrating the feasibility of the LHeC ERL design
     - Study behaviour of a high energy multi-pass multiple cavity ERL for LHeC
     - Optics, RF power, synchronization & delay issues …
     - HOMs and HOM couplers, cryogenics, instrumentation, controls, LLRF …
  2. Injector studies (DC or SRF gun)
  3. Study real SCRF cavities with beam
  4. Analyzing electron beam dynamics challenge
  5. Reliability issues, operational issues
  6. Beam facility for controlled SC magnet quench tests
  7. Beam facility for HEP detector R&D
  8. Demonstrator and study facility for e-cooling
  9. Could it be foreseen as the injector to LHeC ERL ?

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
- Possible use for detector development, experiments and injector suggests ~1 GeV as final stage energy
- 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



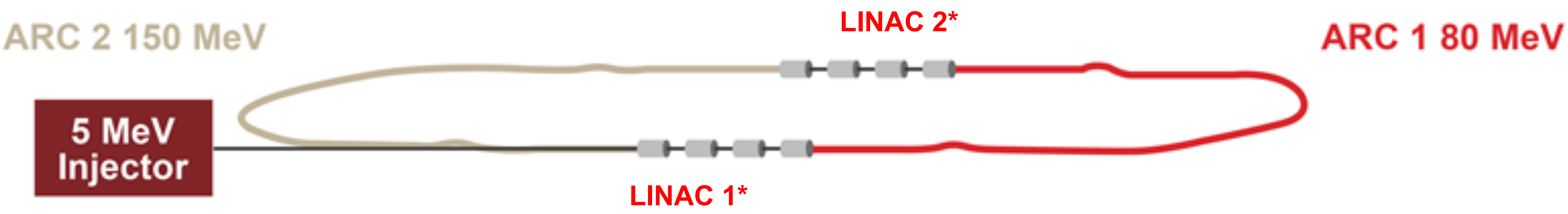
Planning for each stage

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

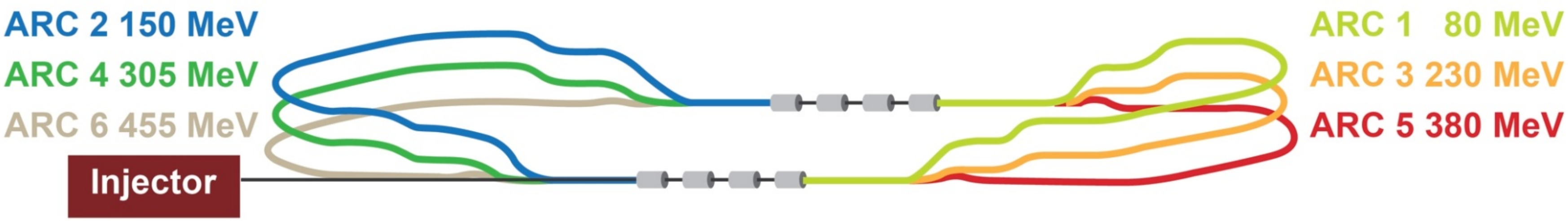
Planning for each stage

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

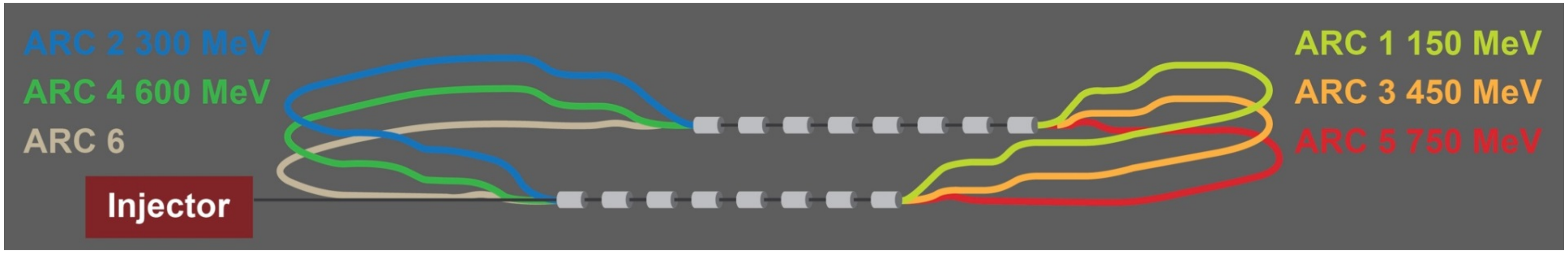
STEP 3

Additional SC RF modules test

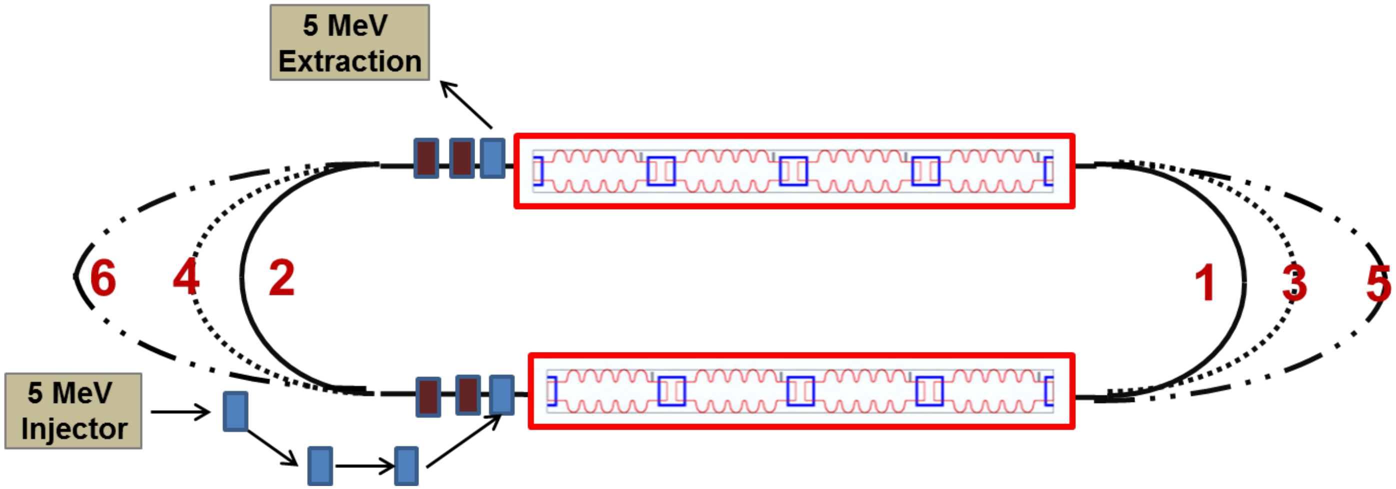
Full energy test in Energy Recovery Mode

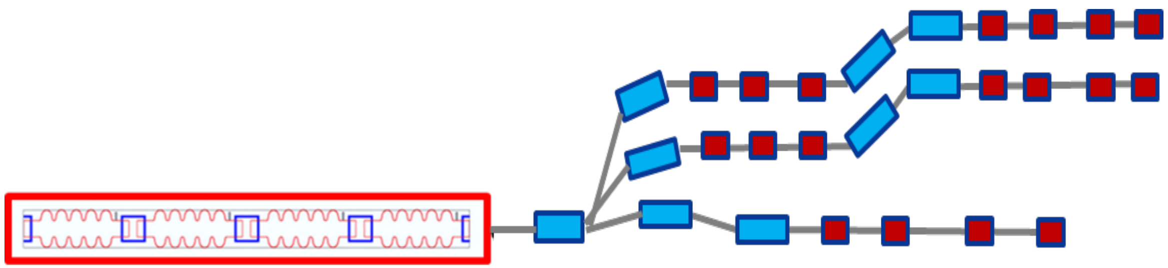
- Injection at 5 MeV
- 3 turns
- 150 MeV/linac
- Final energy 900 MeV

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



Layout



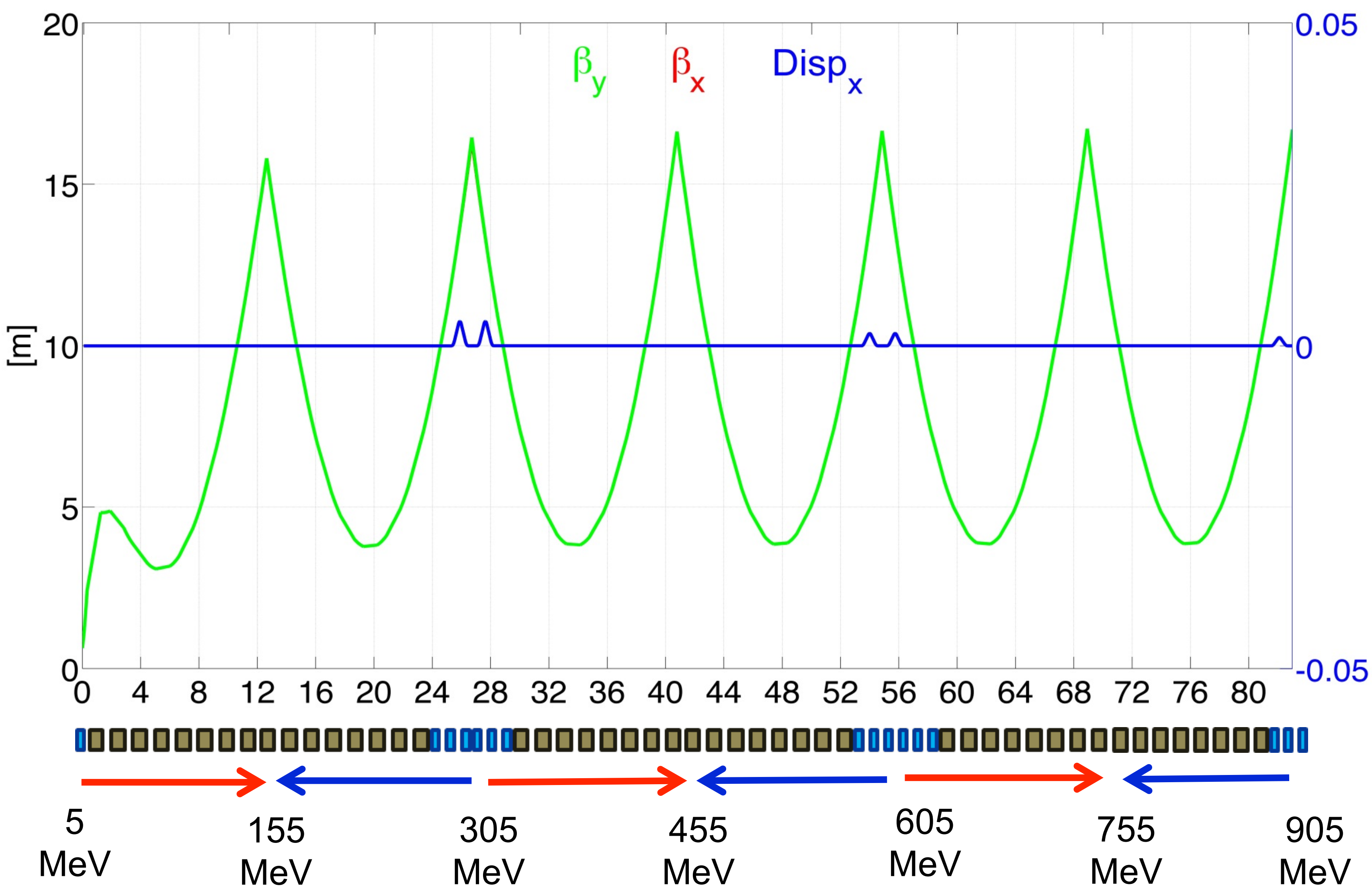


ARC 1 – 155 MeV

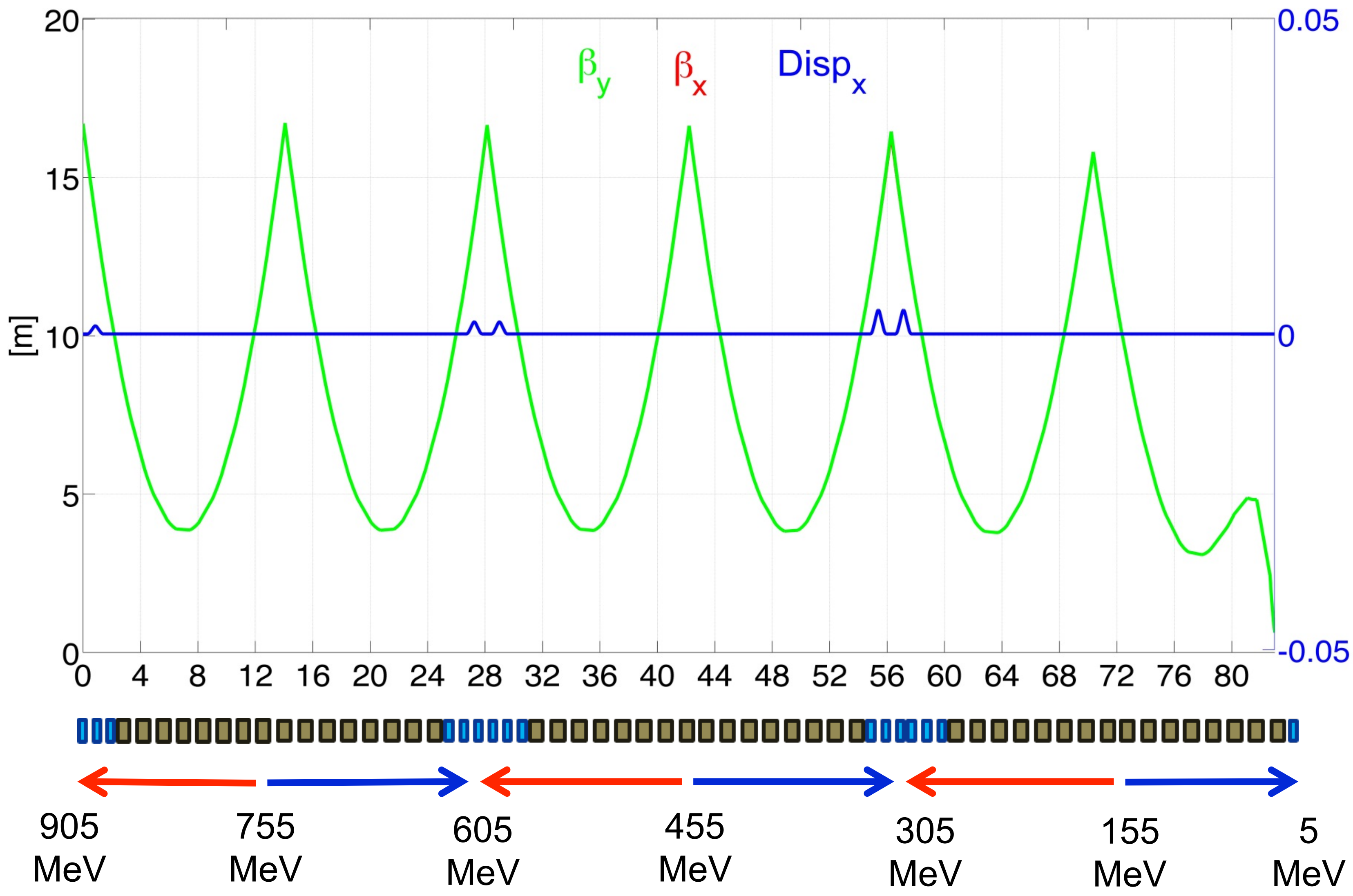
ARC 3 – 455 MeV

ARC 5 – 755 MeV

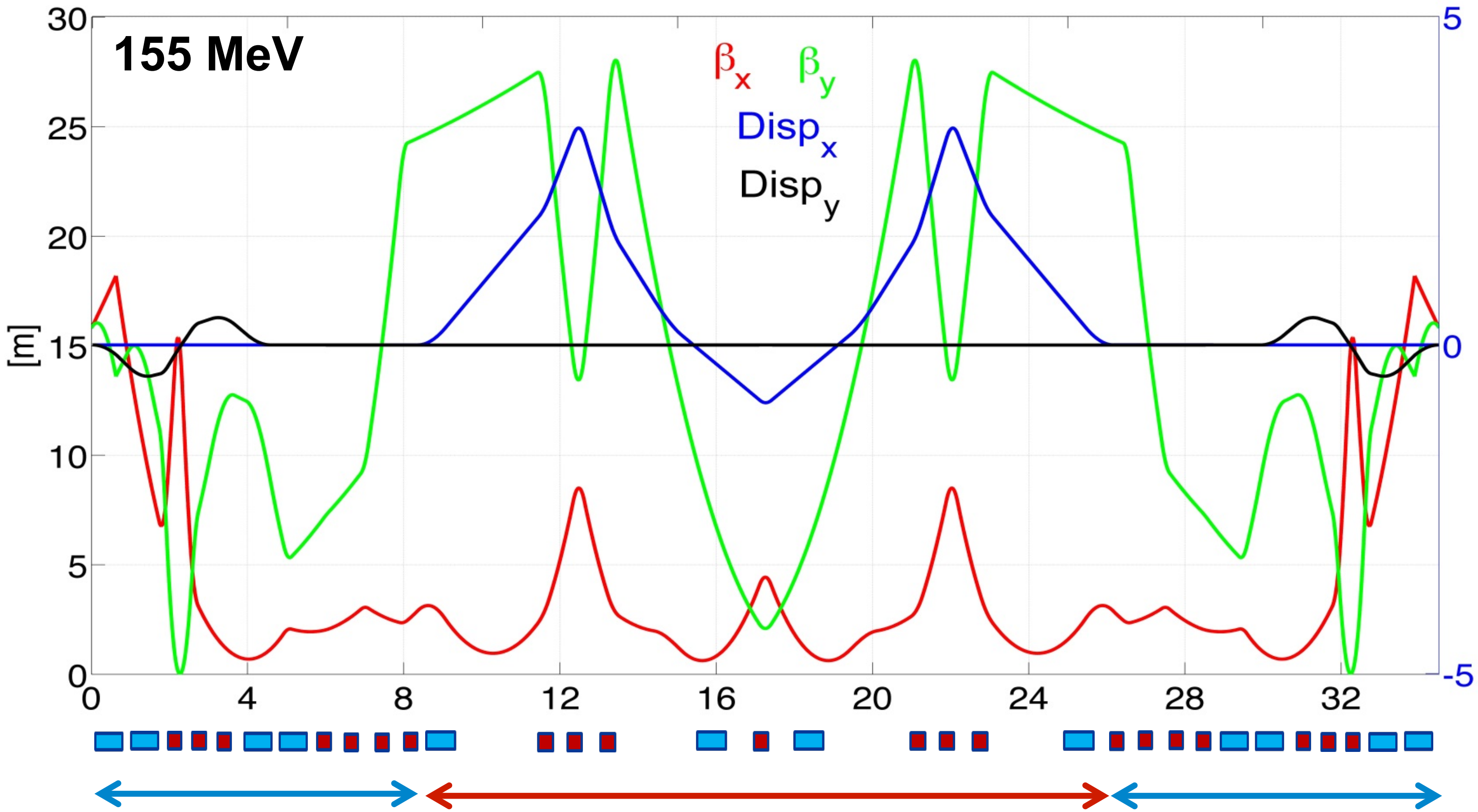
Linac 1 Multi-Pass Optics



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

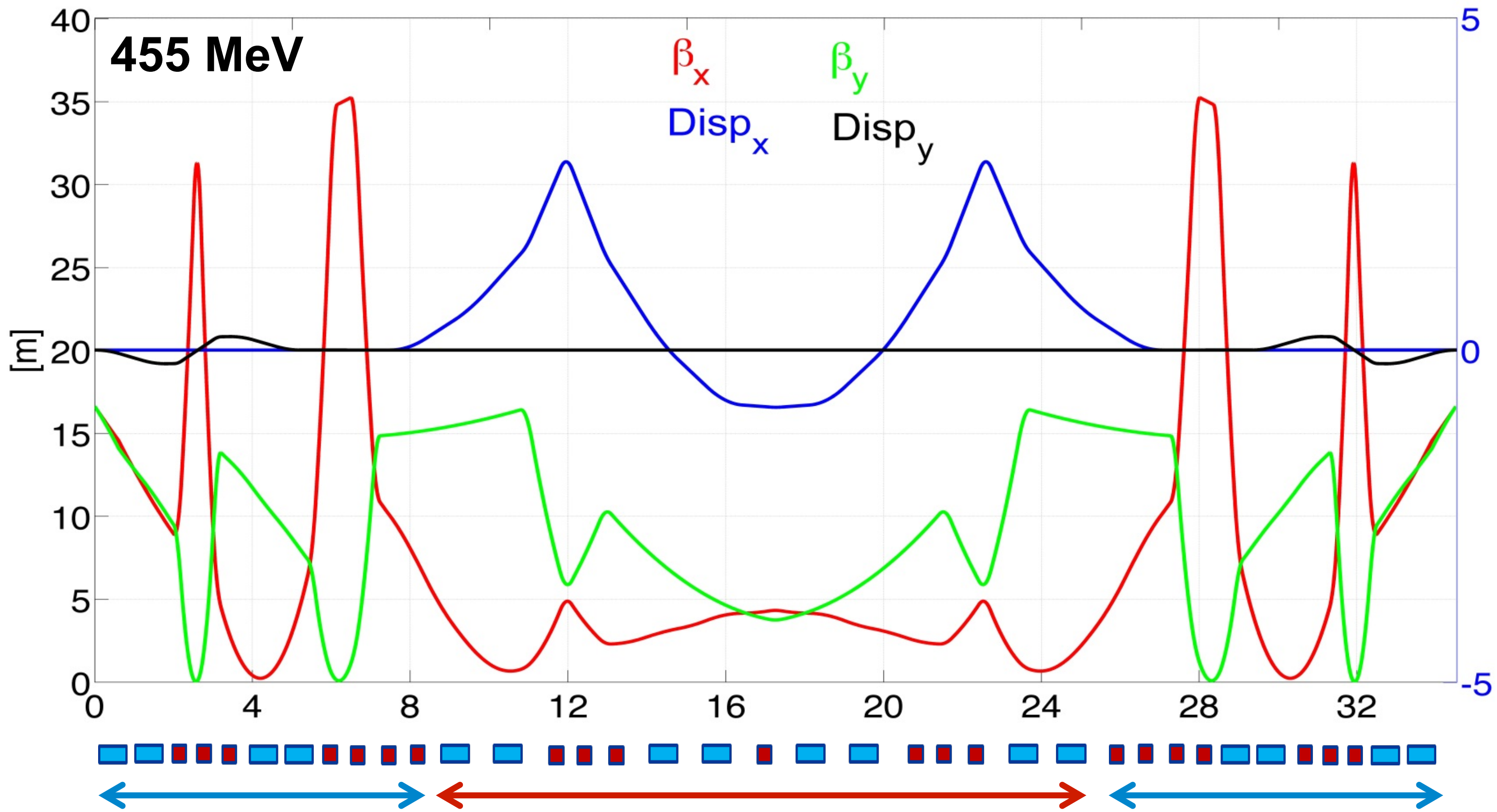
ρ = 91.45 cm

2-step vert.
Combiner

30° bends

(1 rec. + 3 sec.)

Arc 3 optics



9.8° bends

(1 rec. + 3 sec.)

Arc dipoles :

Ldip = 90.58 cm

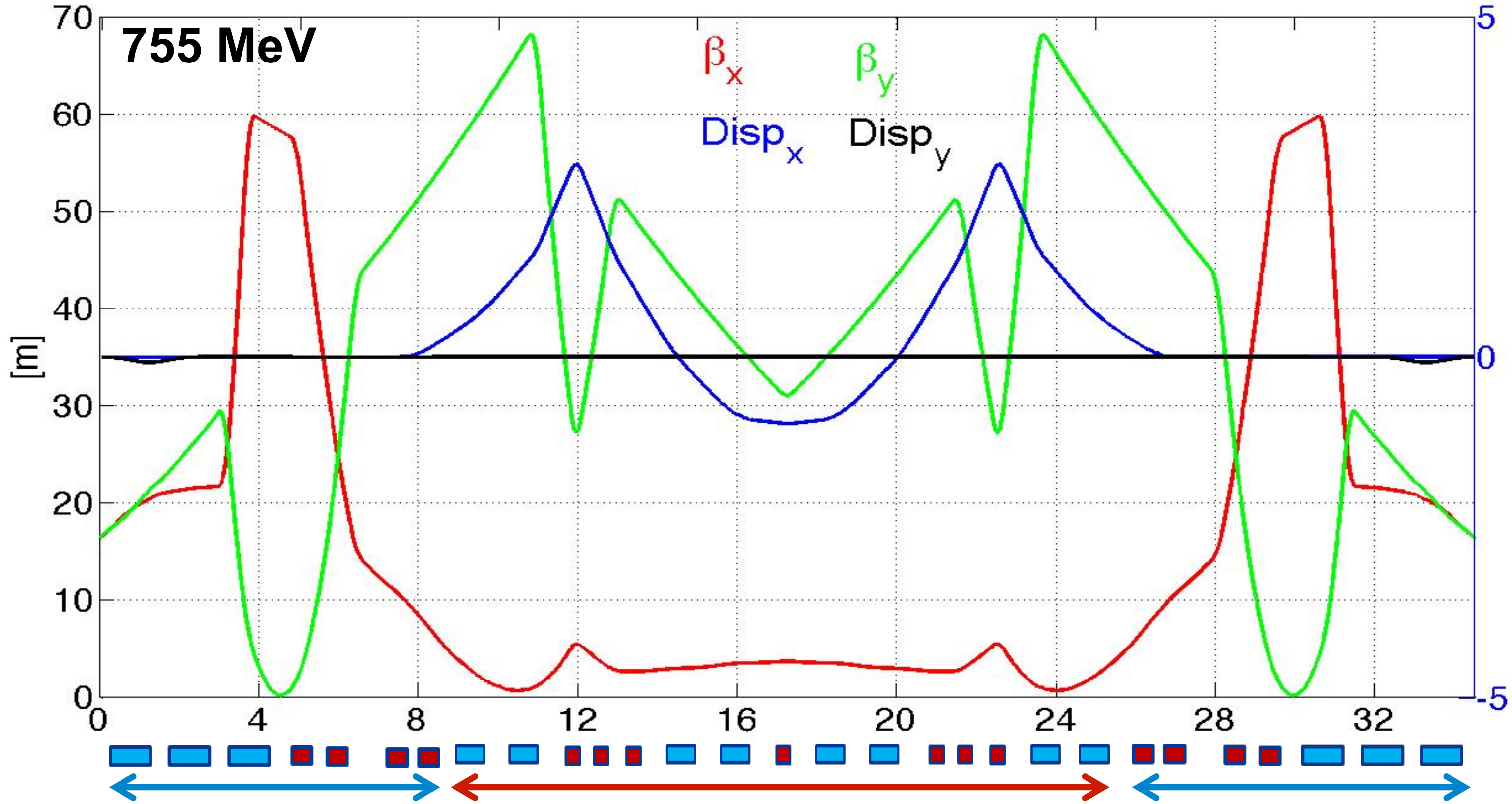
B = 6.58 kGauss

ρ = 230.66 cm

9.8° bends

(1 rec. + 3 sec.)

Arc 5 optics



Vertical chicane

8×22.5° sector bends

Vertical chicane

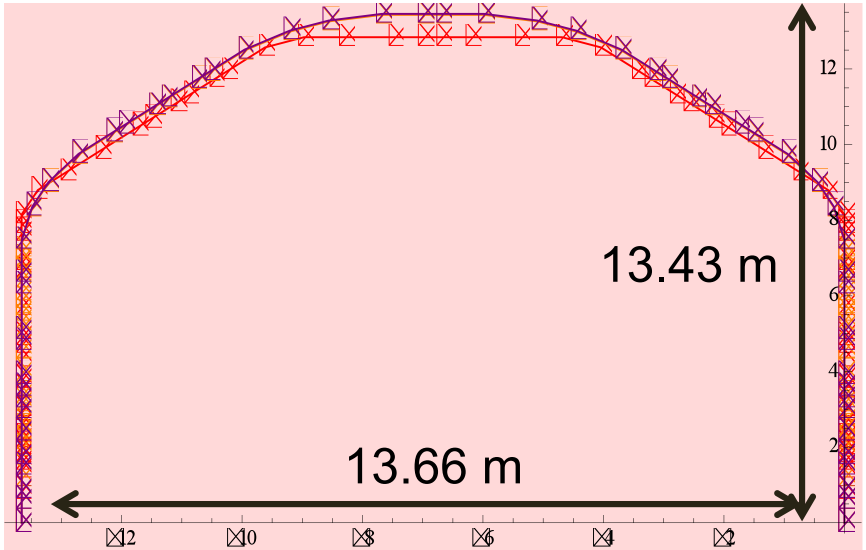
Arc dipoles :

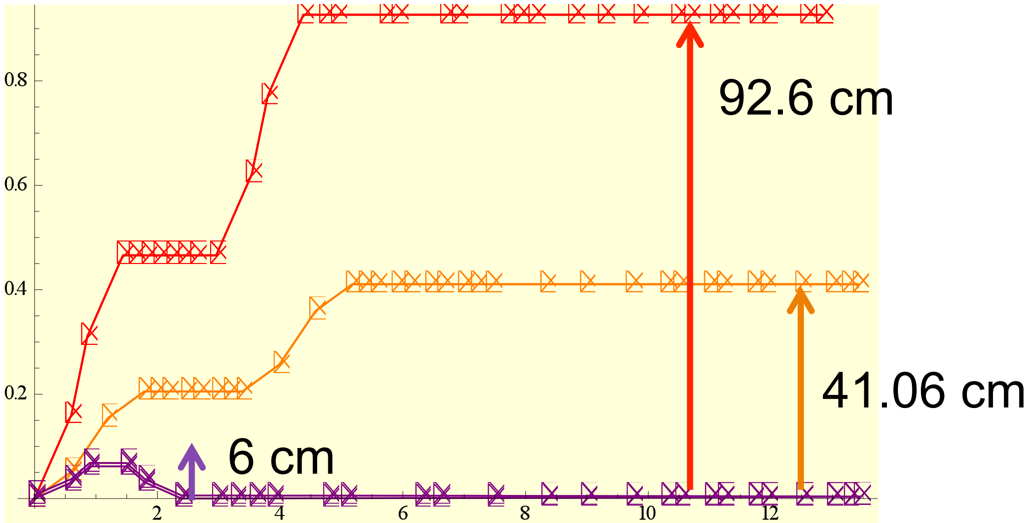
Ldip = 90.58 cm

B = 10.92 kGauss

ρ = 230.66 cm

Arc 1,3,5 layout



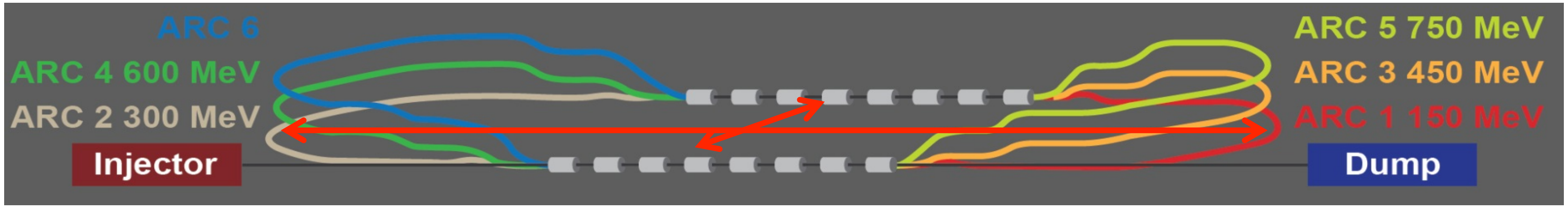


- Synchronous acceleration
  Isochronous arcs
- Achromatic arc
- FMC optics

Total Arc length for Arc 1,3,5
34.5112 m
94 x λrf

For 6 arcs:
84 DIPOLES
114 QUADRUPOLES

Footprint



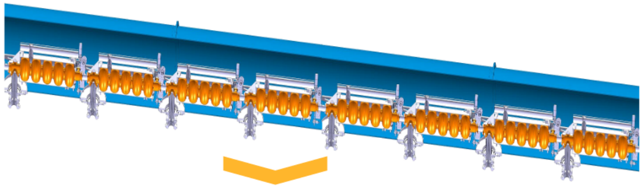
ARCS

Total length for Arc 1,3,5
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

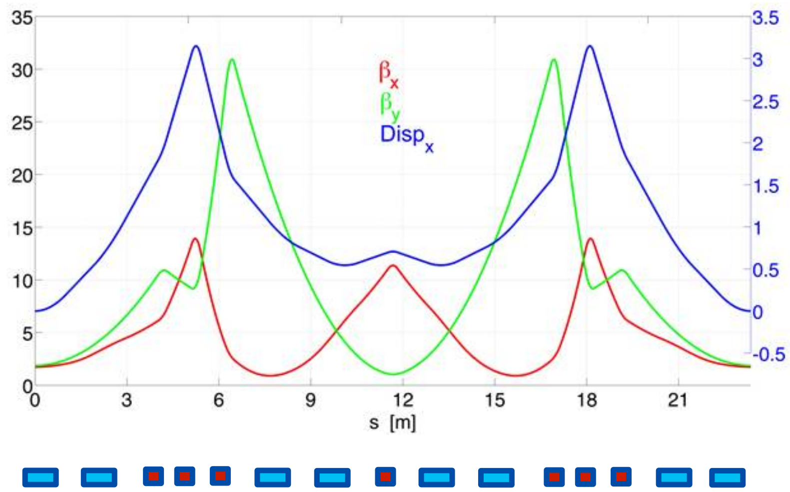
CHICANE INJ/EXTR

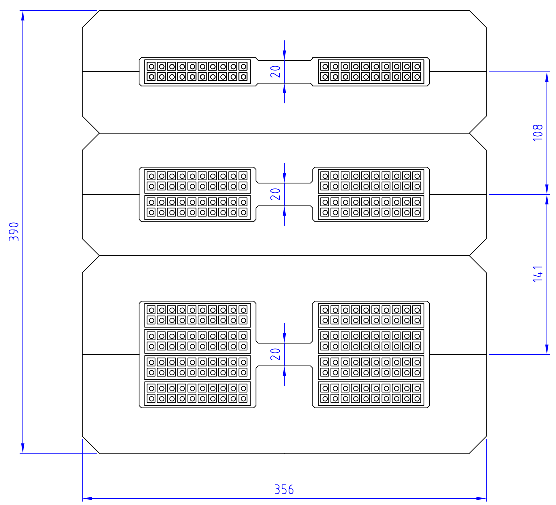
Length ~ 1.75 m

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

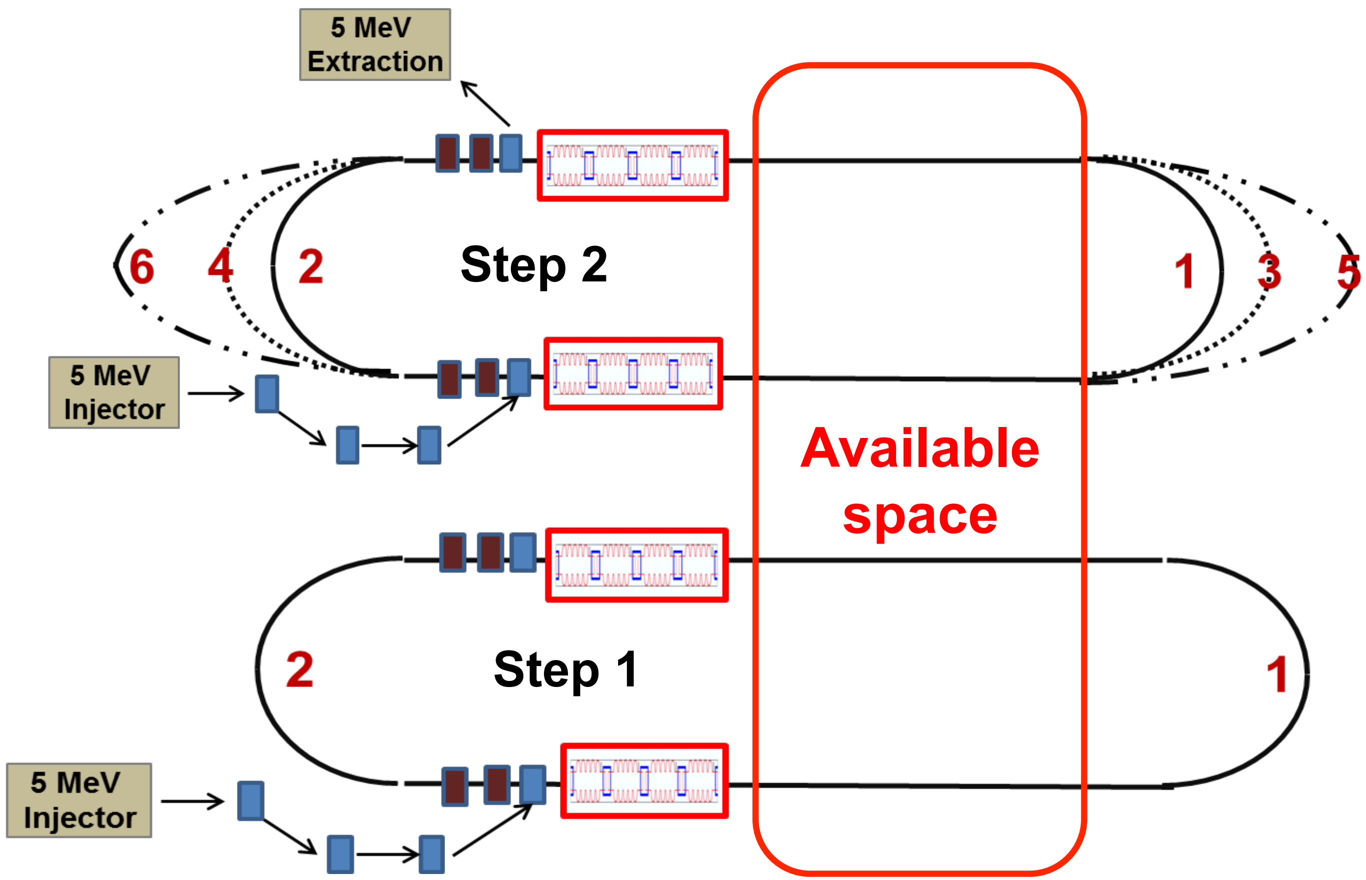
Incoherent Synchrotron radiation in return arcs

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

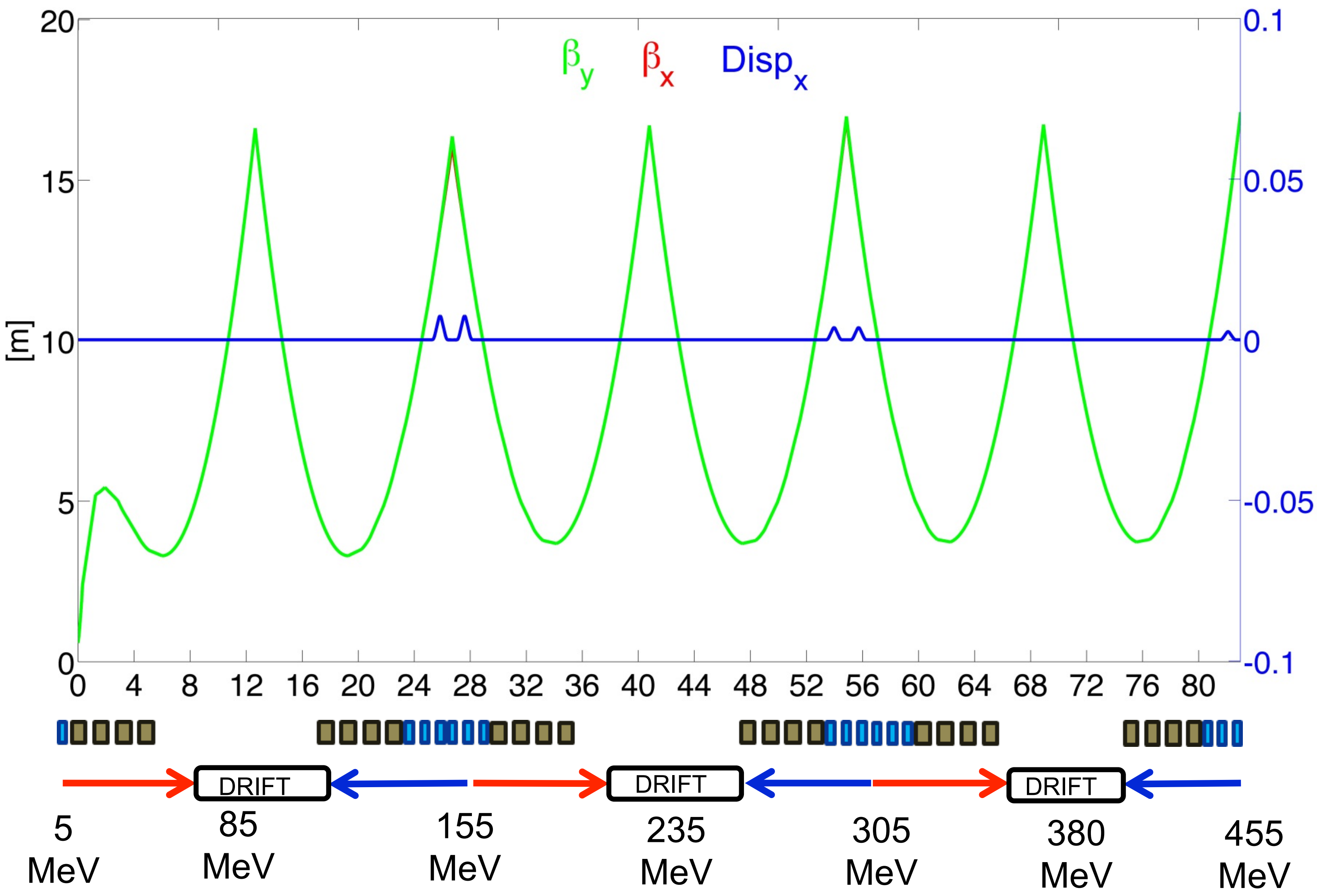
- Beam Energy loss $\Delta\mathrm{E} = \int P_\gamma dt = P_\gamma \frac{\pi\rho}{\beta c}$ $\Delta\mathrm{E}(GeV) = C_\gamma \frac{E^4}{\rho} \frac{1}{2}$
- Beam Energy Spread $\frac{\sigma_E}{E} = \sqrt{1.4397 * 10^{-27} \frac{\pi\gamma^5}{\rho^2}}$

Next steps

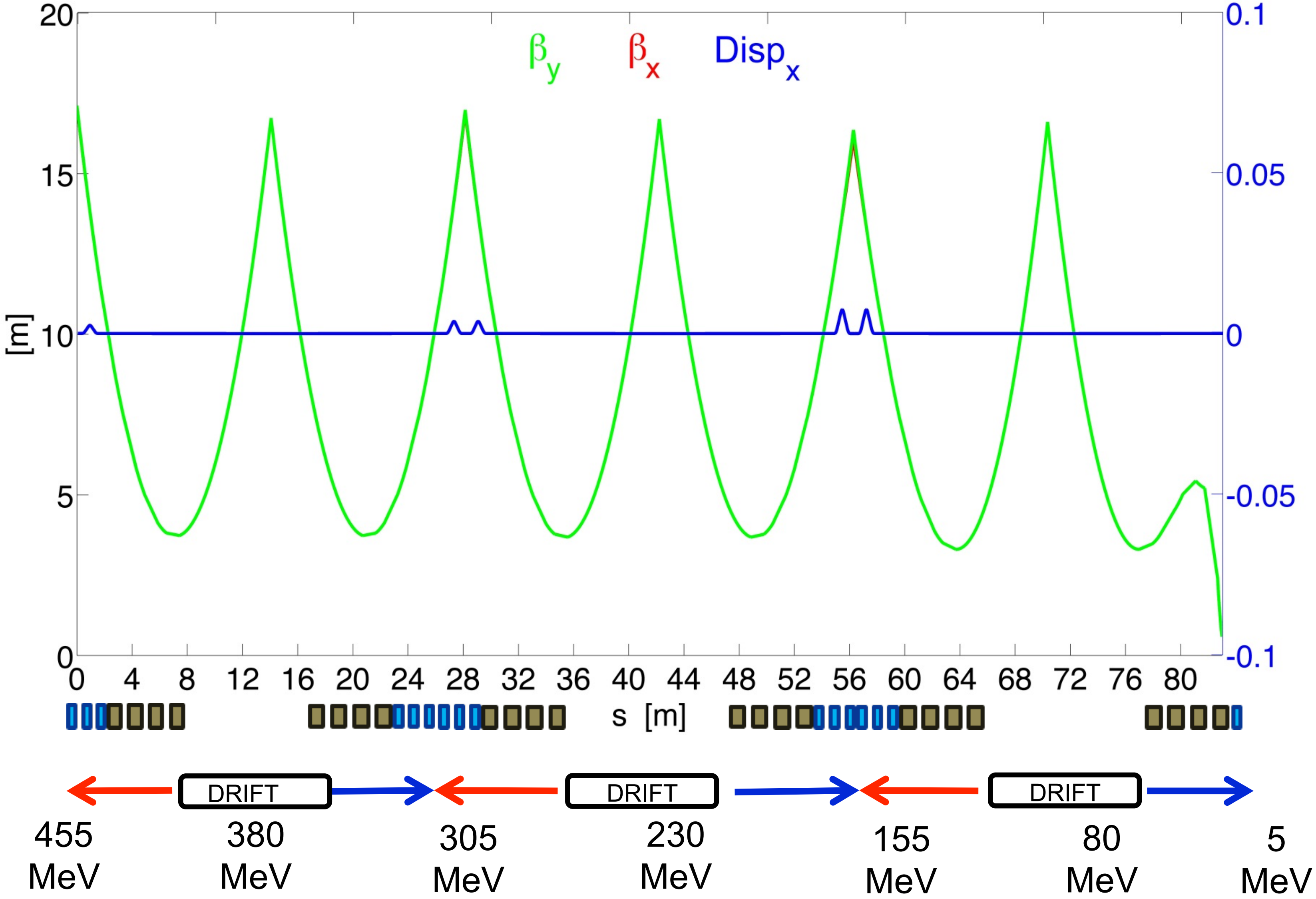
- Complete Step 2 and Step 1 configuration and optics layout



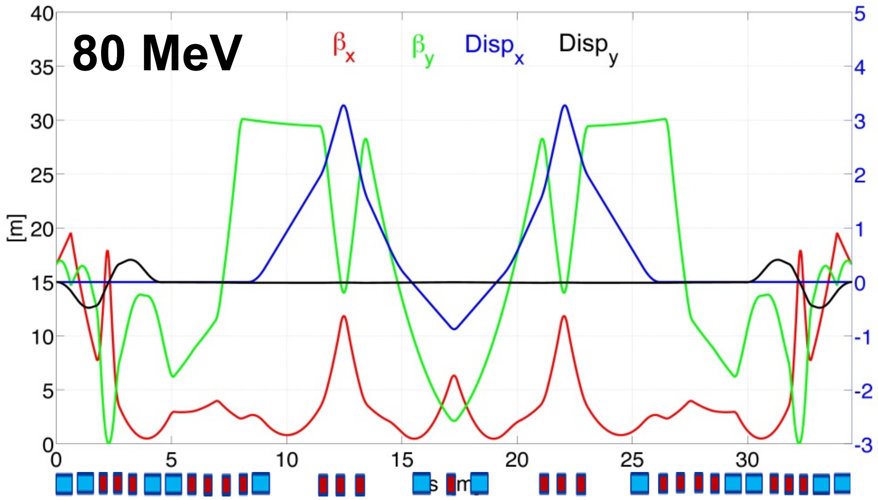
Linac 1 - Step 2

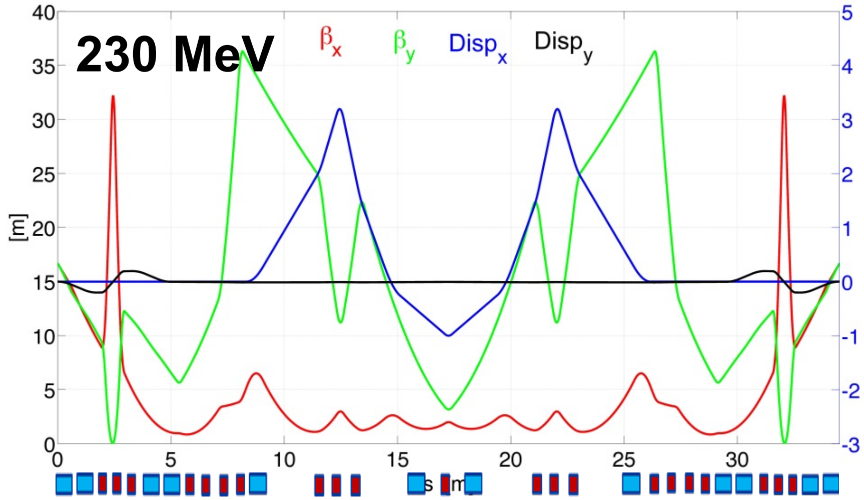


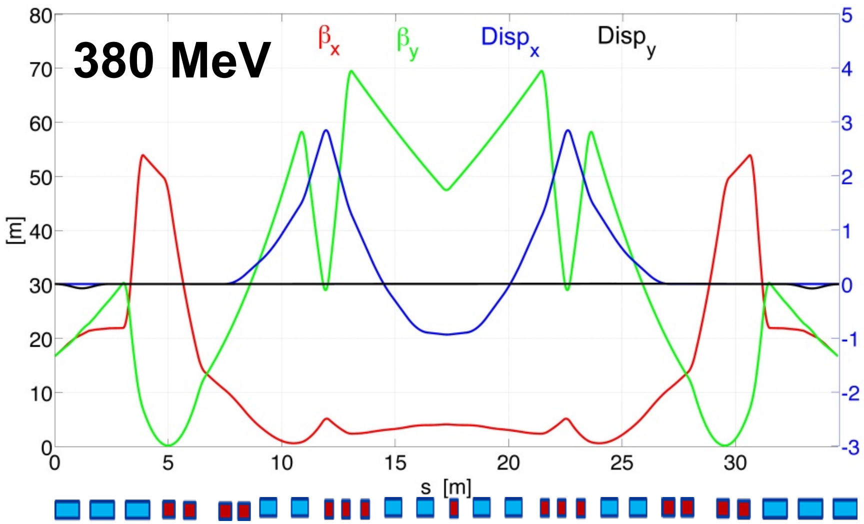
Linac 2 - Step 2

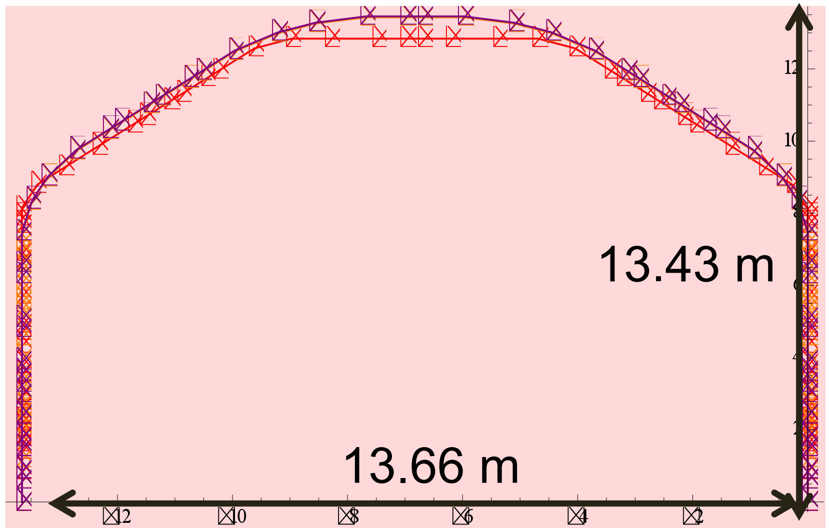


Step 2 optics

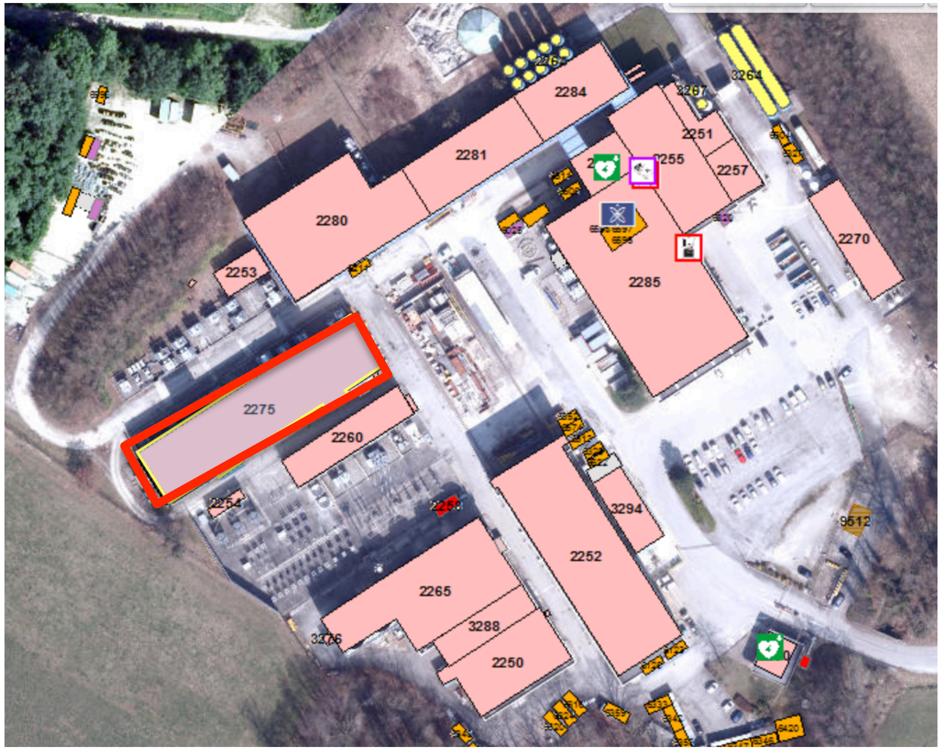








LTF Possible Site Choice



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?

Controlled quench tests of SC magnets

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

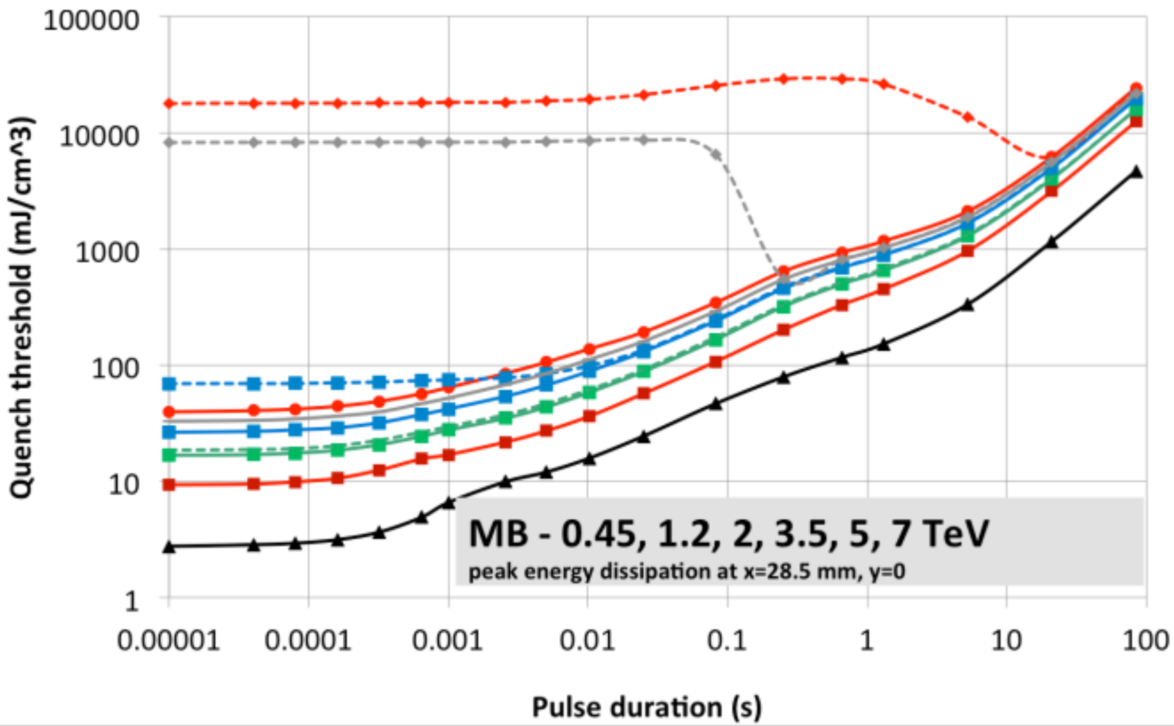
Requirements in terms of:

- Beam energy, intensity and pulse length (energy deposition)
- Space for the magnet 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

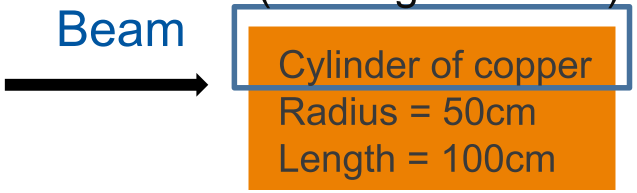


Quench limits of LHC dipole as expected from QP3 simulations for different pulse durations

Courtesy A. Verweij

Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS



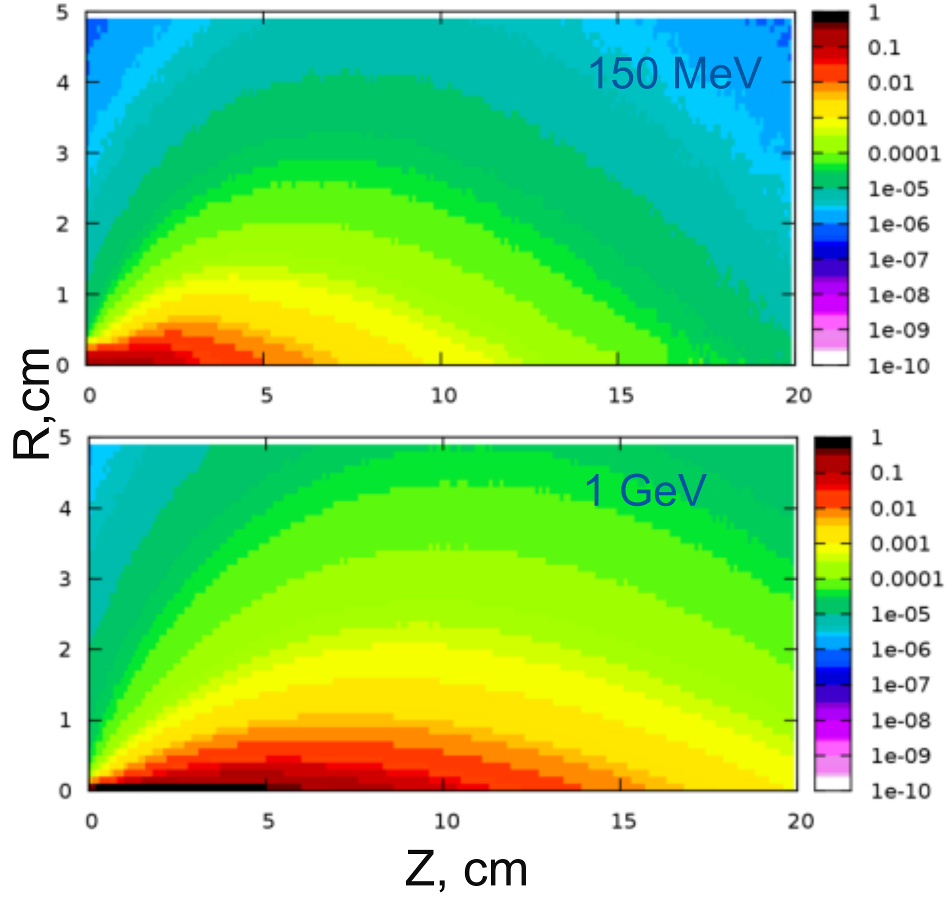
Beam parameters

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

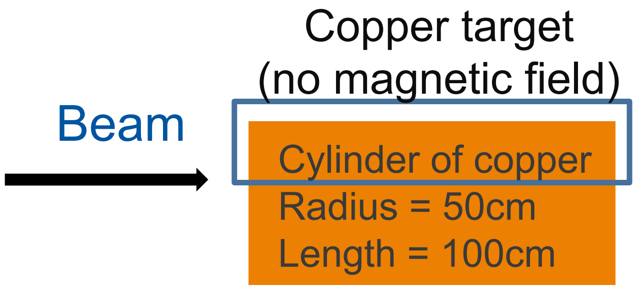
Binning: 1 mm^3 bins

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



Beam parameters to generate a given amount of energy deposition

CALCULATIONS AND FLUKA SIMULATIONS



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Results are given for half of bulky target because of symmetry

Binning: 1 mm^3 bins

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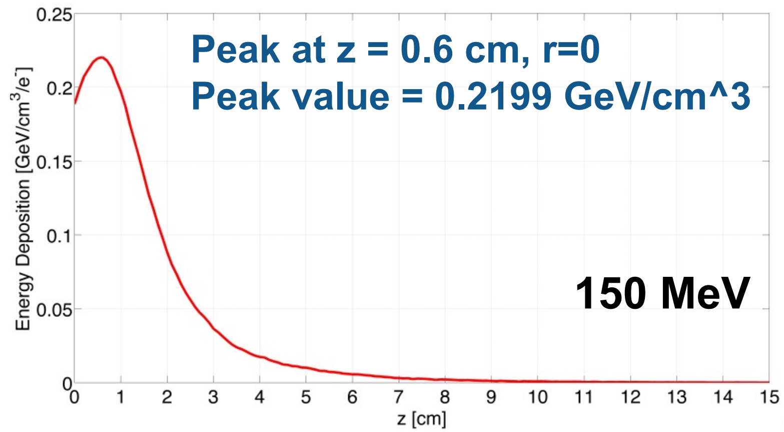
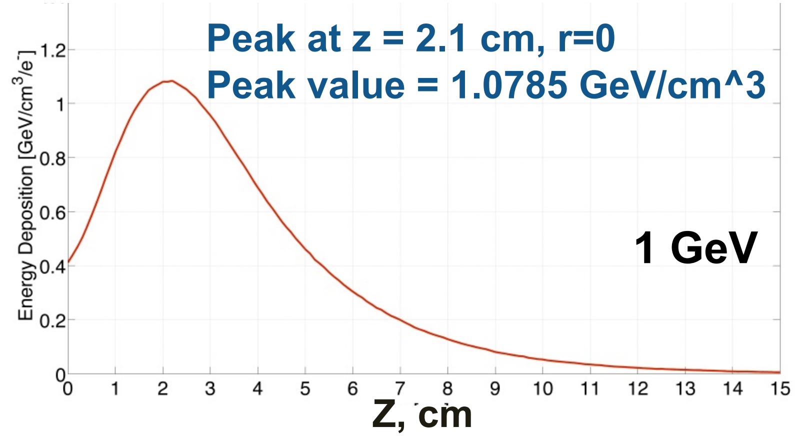
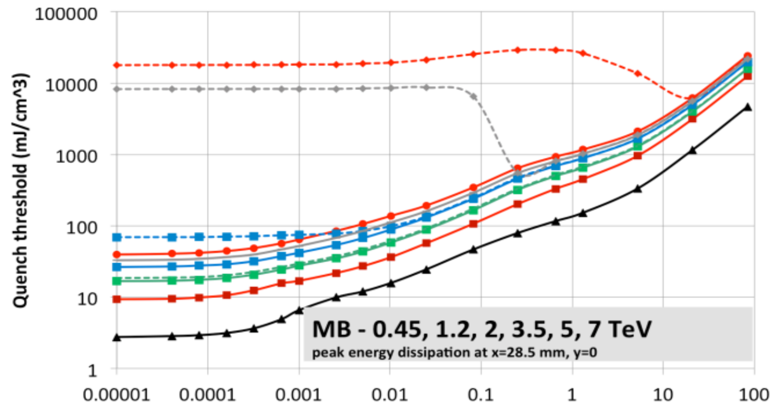


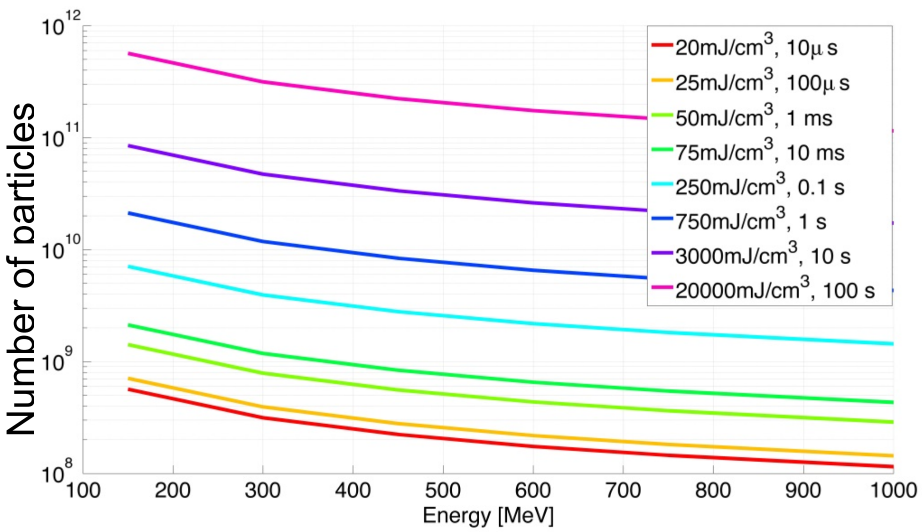


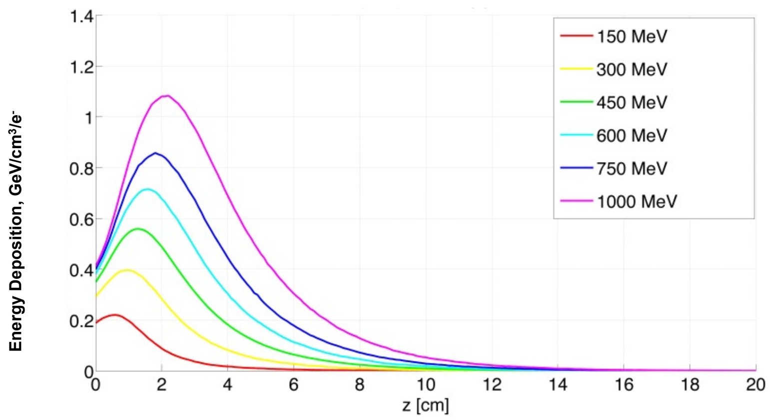
Beam parameters to generate a given amount of energy deposition

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 and Outlook

LHeC appears feasible and can be realized in parallel with HL-LHC

- Significant room for optimization in design
  - Choice of RF frequency has now been done
  - Basic parameter choice has been reviewed for further improvements (higher luminosity)

- Future plans
  - R&D on individual components
  - Ongoing parameter studies for cost optimization (slightly lower beam energy for significantly lower circumference)
  - Preparation of a TEST FACILITY proposal
    Some (potential) international partners have declared large interest (JLAB, Mainz, ASTeC and others).
  - Completion of Conceptual design study of an ERL-TF at CERN by the end of 2015

Some References

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6. M. Klein et al. , LHeC Design Report, J.Phys. G39 (2012) 075001 [arXiv:1206.2913]
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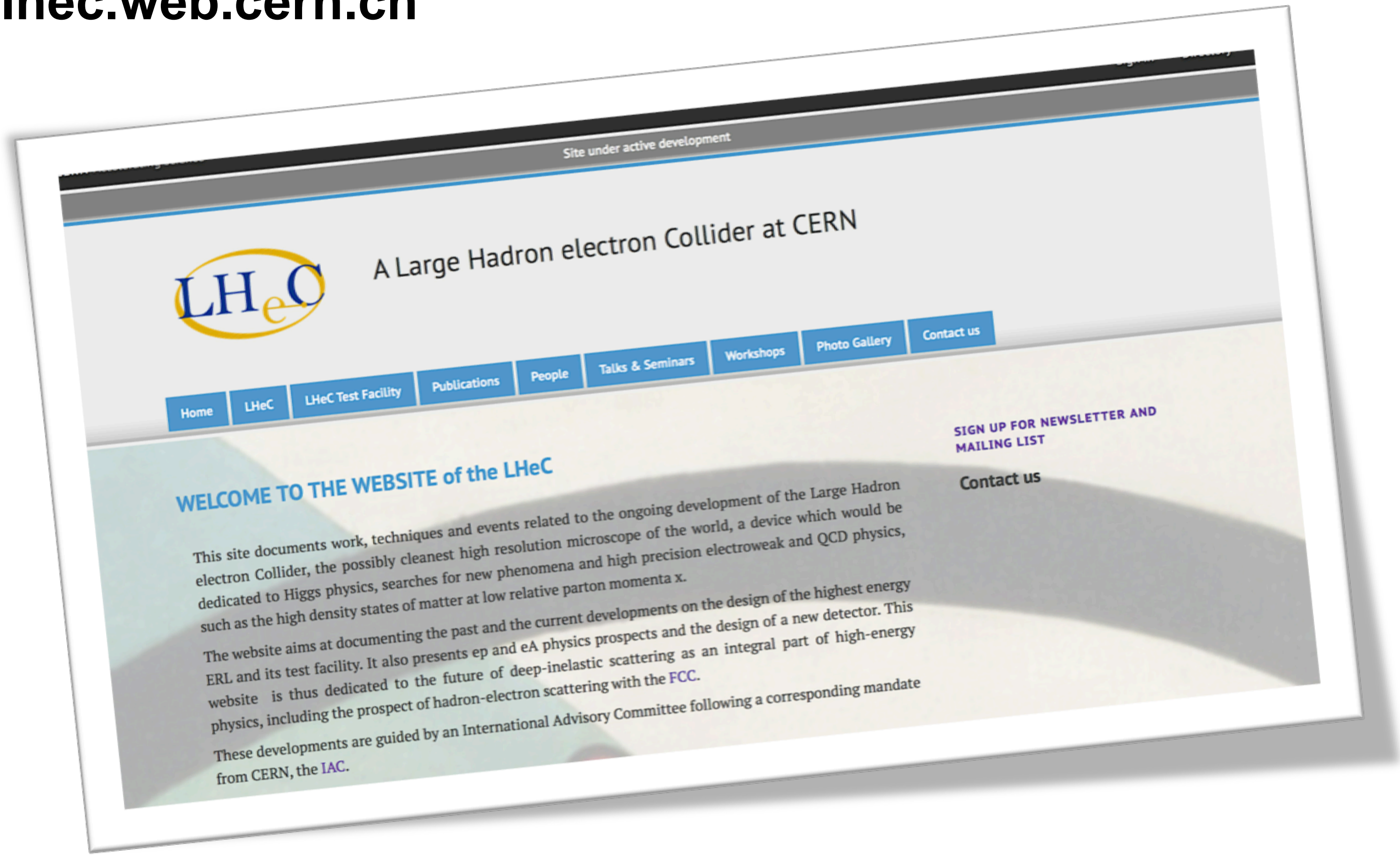
10. LHeC IR Optics Design Integrated into the HL-LHC Lattice, *M. Korostelev et al.,* MOPWO063
11. The LHeC as a Higgs Boson Factory, *F. Zimmermann et al.*, MOPWO054
12. A Proposal for an ERL Test Facility at CERN, *R.Calaga et al.,* WEPWO049
13. Strawman Optics design for the LHeC ERL Test Facility, *A. Valloni et al.,* TUPME055
14. Electrons at the LHC: a new beginning, *Max Klein and Herwig Schopper* CERN Courier, June 2014
15. LHeC meetings https://indico.cern.ch/category/1874/

Some more References

A complete list of Papers, Proceedings, Articles, Talks and Seminars can be found at
http://lhec.web.cern.ch



Please fill out the “Contact us” form to sign up for the LHeC Newsletter and Mailing List

Alessandra Valloni on behalf of the LHeC collaboration

ありがとうございます

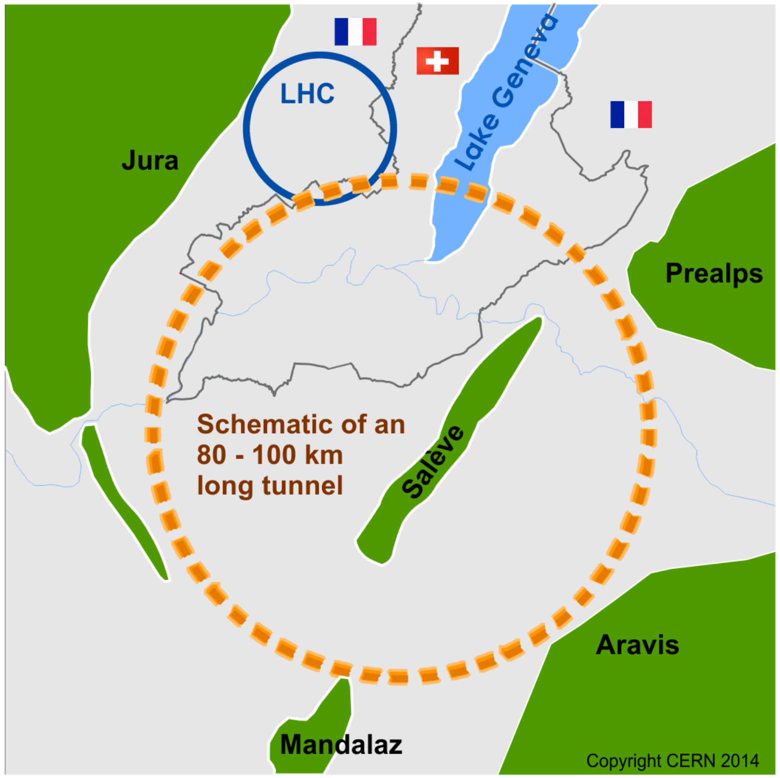
Thanks for your hospitality, time, help and support

KEK, High Energy Accelerator Research Organization, 12th June

www.cern.ch

Future Circular Collider Study
CDR and cost review for the next ESU (2018)

- 80-100 km tunnel infrastructure in Geneva area
- *pp*-collider (*FCC-hh*) defining the infrastructure requirements
- e^+e^- collider (*FCC-ee*) as potential intermed. step and ***p-e (FCC-he)*** option
- international collaboration hosted by CERN

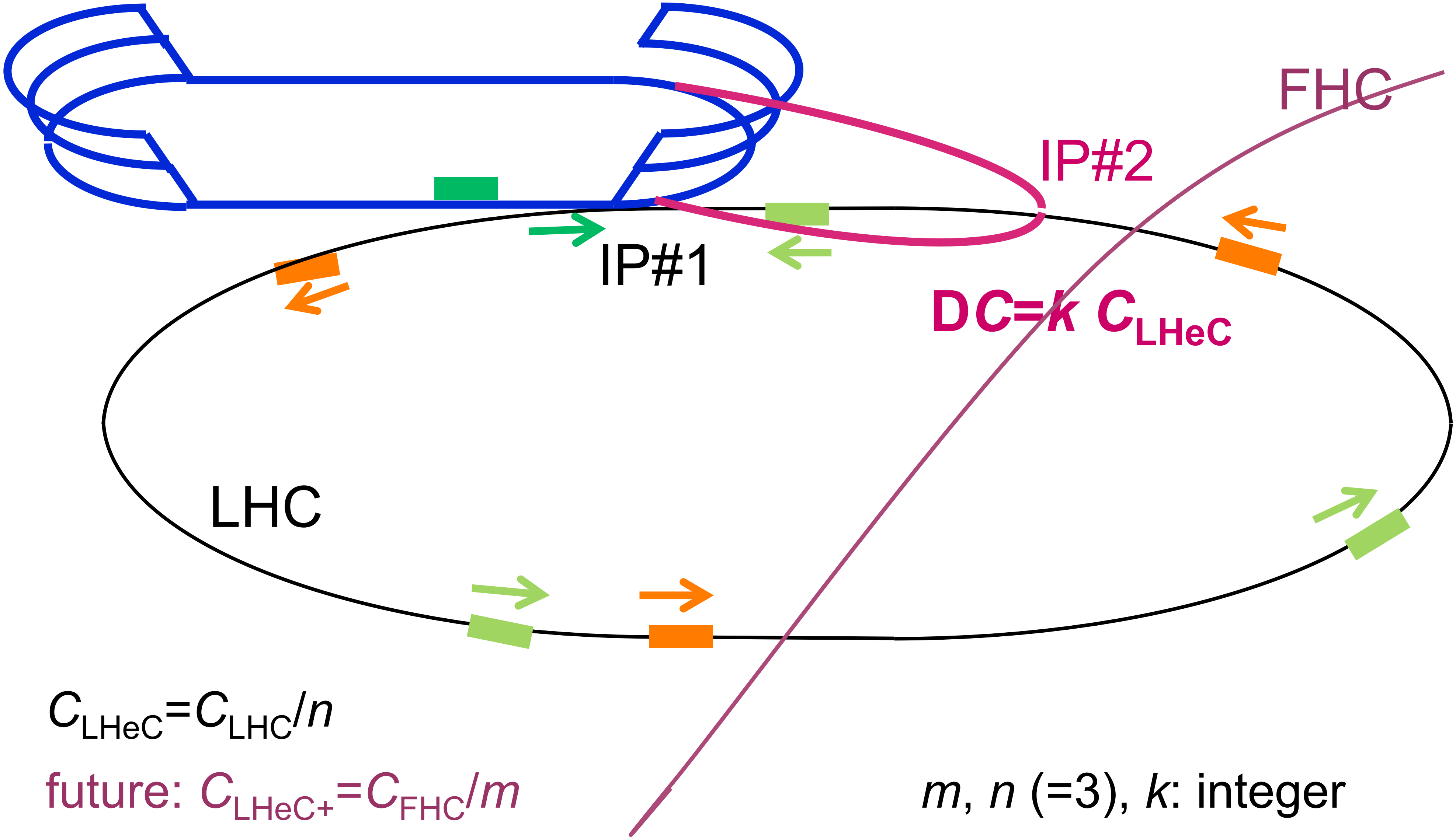


~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

Preliminary parameters for FCC-he-ERL w/o FCC-ee

Parameter [unit]		
species	*e-*	*p*
beam energy (/nucleon) [GeV]	60	50000
bunch spacing [ns]	25	25
bunch intensity (nucleon) [10^{10}]	0.4	10
beam current [mA]	25.6	500
normalized rms emittance [mm]	20	2.0
geometric rms emittance [nm]	0.17	0.04
IP beta function $b_{x,y}^*$ [m]	0.10	0.4
IP rms spot size [mm]	4.0	4.0
lepton *D* & hadron x	32	0.0002
hourglass reduction factor H_{hg}	0.94	
pinch enhancement factor H_D	1.35	
luminosity / nucleon [10^{33} cm^{-1}s^{-1}]	6.4	

LHeC - ion gaps & circumference



$C_{LHeC}=C_{LHC}/n$

future: $C_{LHeC+}=C_{FHC}/m$

m, n (=3), k: integer

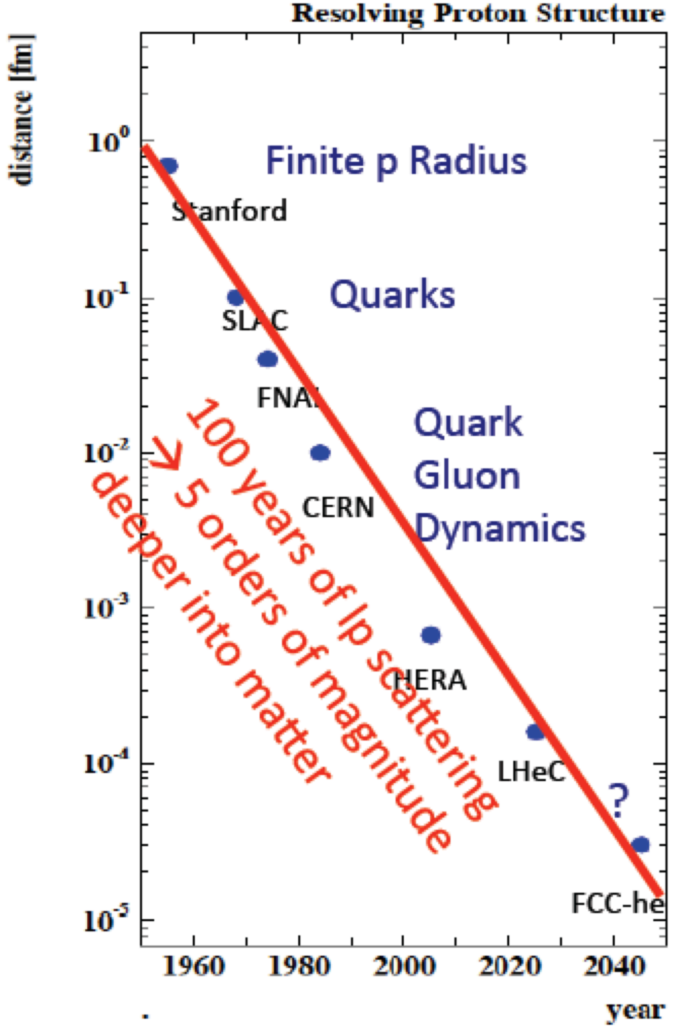
CERN has begun a study for a
100 TeV pp collider with an integrated ep facility. This has two options:

a) the ERL of the LHeC (60 GeV) coupled with the 50 TeV proton machine in synchronous ep and pp mode.
b) the FCC electron and proton rings colliding which increases the energy available.

Both options are under study.
In terms of physics the FCC_he complex leads for example
-- to accessing the Higgs self coupling (under study),
-- to lepto-quark access up to ~4TeV and
-- to Bjorken x as low as 10^-7/8 (which is of direct interest for ultra high energy neutrino scattering).

The vision of the LHeC followed by the FCC_he promises a 4 decade unique physics program

HERA-LHeC-FCC-eh: finest microscope
with resolution varying like 1/√Q²



High Q²

Rutherford backscattering
of dozens of TeV e- energy