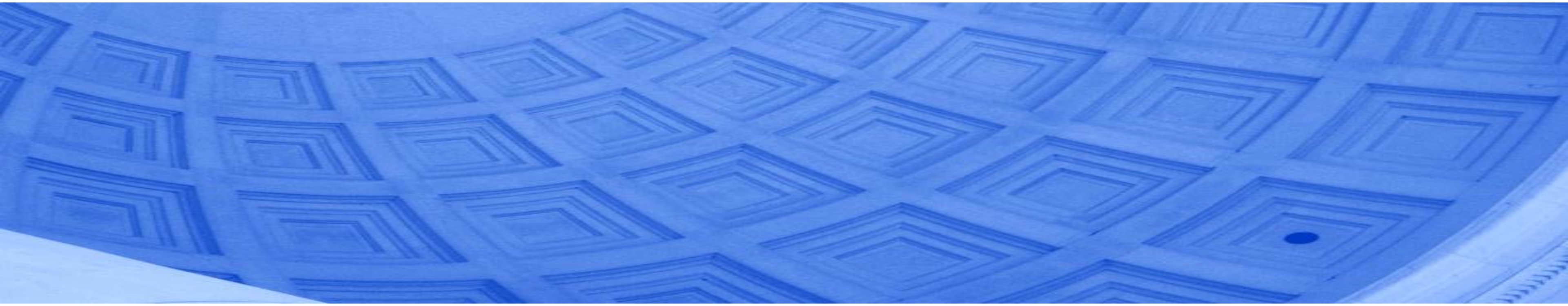
Alessandra Valloni

CIRCULAR ERL

FCC week 2015
First Annual Meeting of the Future Circular Collider study

22–27 March 2015
Washington DC, USA



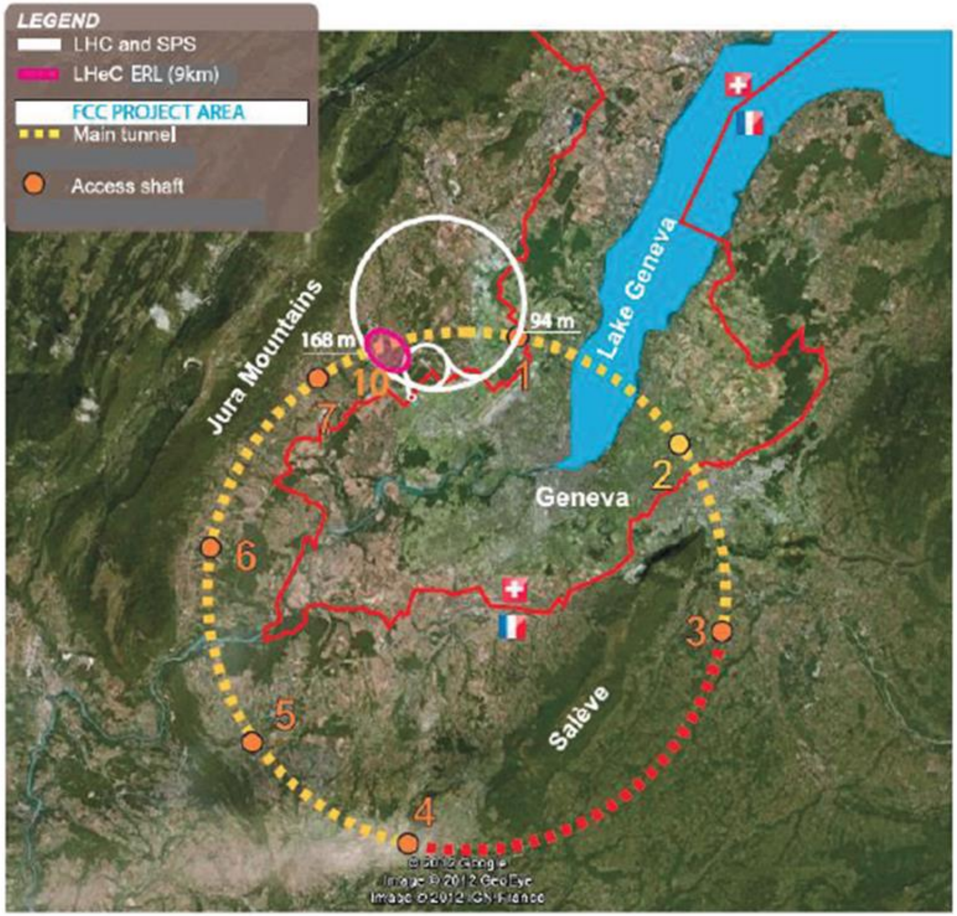
The Future Circular Collider_he

FCC-hh:
100 TeV *pp* collider as long-term goal

FCC-ee:
***e^+e^-* collider**, potential intermediate step

FCC-he:
integration aspects of *pe* collisions

Goal of this presentation
is to discuss a possible
option for the accelerator complex



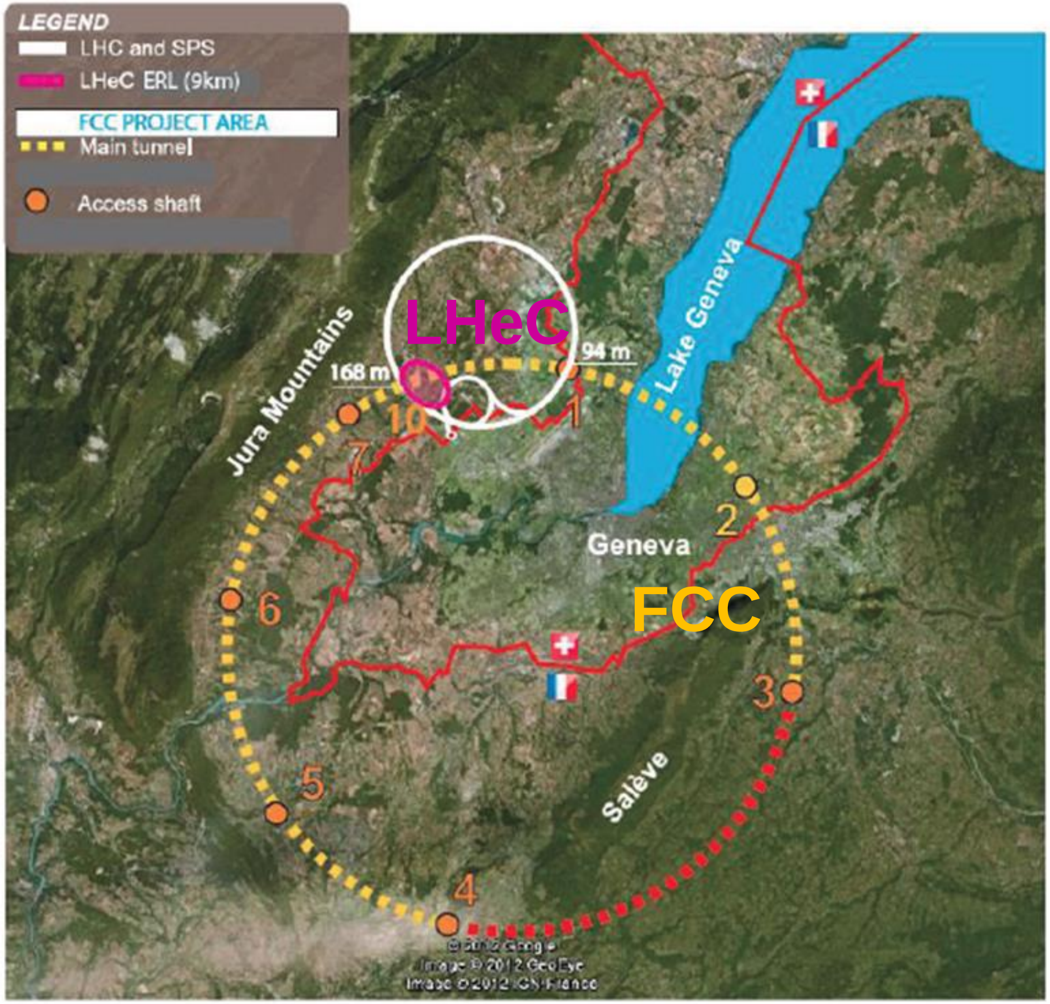
LHeC and the Future Circular Collider FCC_he

Two options for FCC_he

1. **e^- from LHeC or other ERL**
2. **e^- from FCC_ee**
   (if co-existing with FCC_hh)

Collide LHC proton beam
with LHeC electrons
Ep = 7 TeV <-> Ee= 60 GeV
√s = 1.3 TeV

Collide FCC proton beam
with LHeC electrons
Ep = 50 TeV <-> Ee= 60 GeV
√s = 3.5 TeV



LHeC and the Future Circular Collider FCC_he

Collide LHC proton beam with LHeC electrons

Ep = 7 TeV <-> Ee= 60 GeV

$\sqrt{s}$ = 1.3 TeV

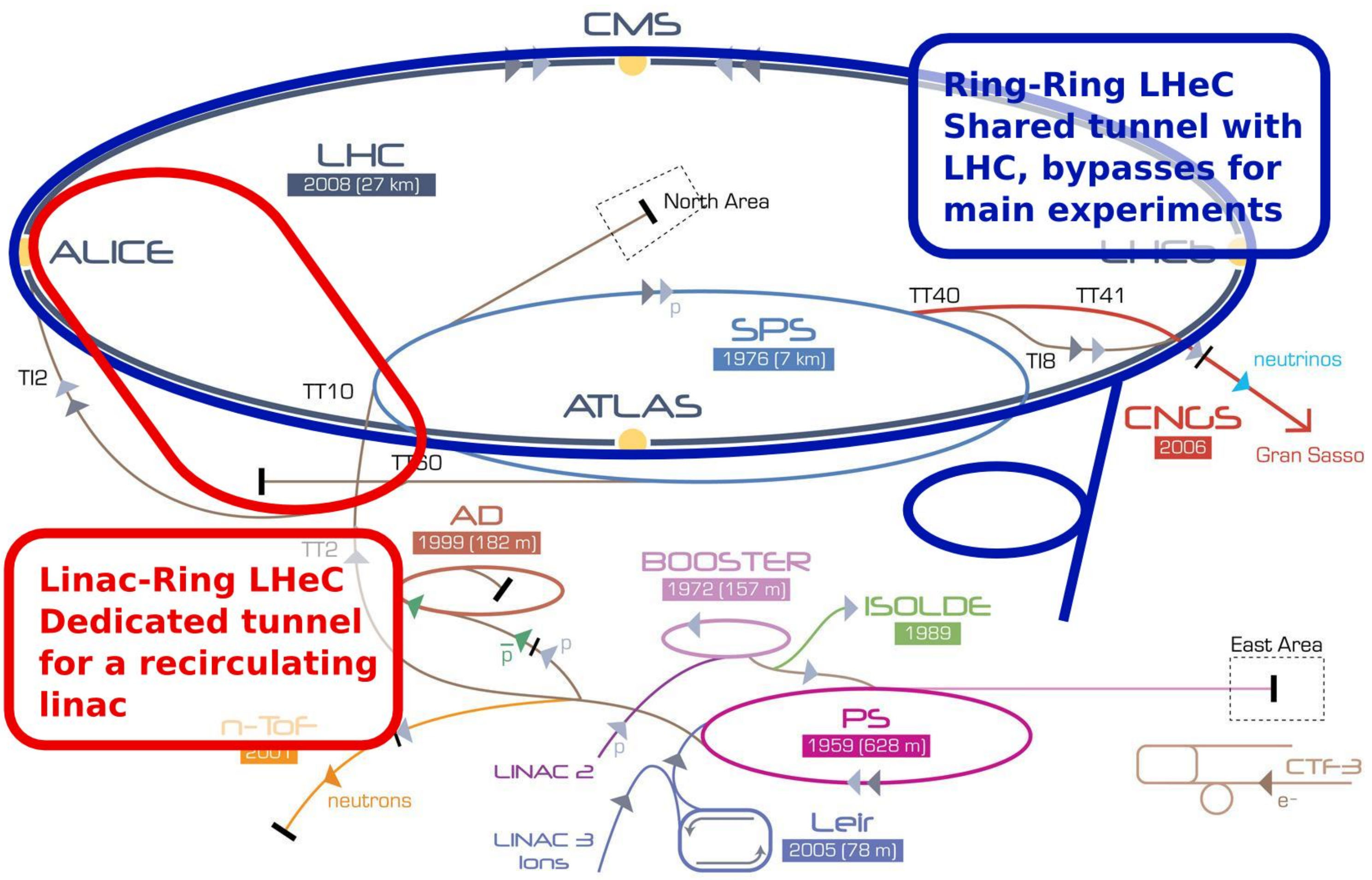
Collide FCC proton beam with LHeC electrons

Ep = 50 TeV <-> Ee= 60 GeV

$\sqrt{s}$ = 3.5 TeV

COLLIDER PARAMETERS	FCC PROTONS	LHeC ELECTRONS
Beam Energy [GeV]	50000	60
Luminosity $[10^{33} cm^{-2} s^{-1}]$	10	10
rms Emittance $\varepsilon n_{x,y}$ [μm]	2.2	20
IP Beta Function $\beta^*_{x,y}$ [m]	0.3	0.1
rms IP Spot size [μm]	3.5	3.5
Beam Current [mA]	500	25.6
Bunch Population	$1*10^{11}$	$0.04*10^{11}$

The LHeC Accelerator:
An energy recovery linac in a racetrack configuration



Why a multipass energy recovery linac in a racetrack configuration?

- **Installation fully decoupled from LHC operation**

- **A multipass energy recovery linac is appealing!**

  Multipass

  Reach the desired energy with a more compact and cost-effective design

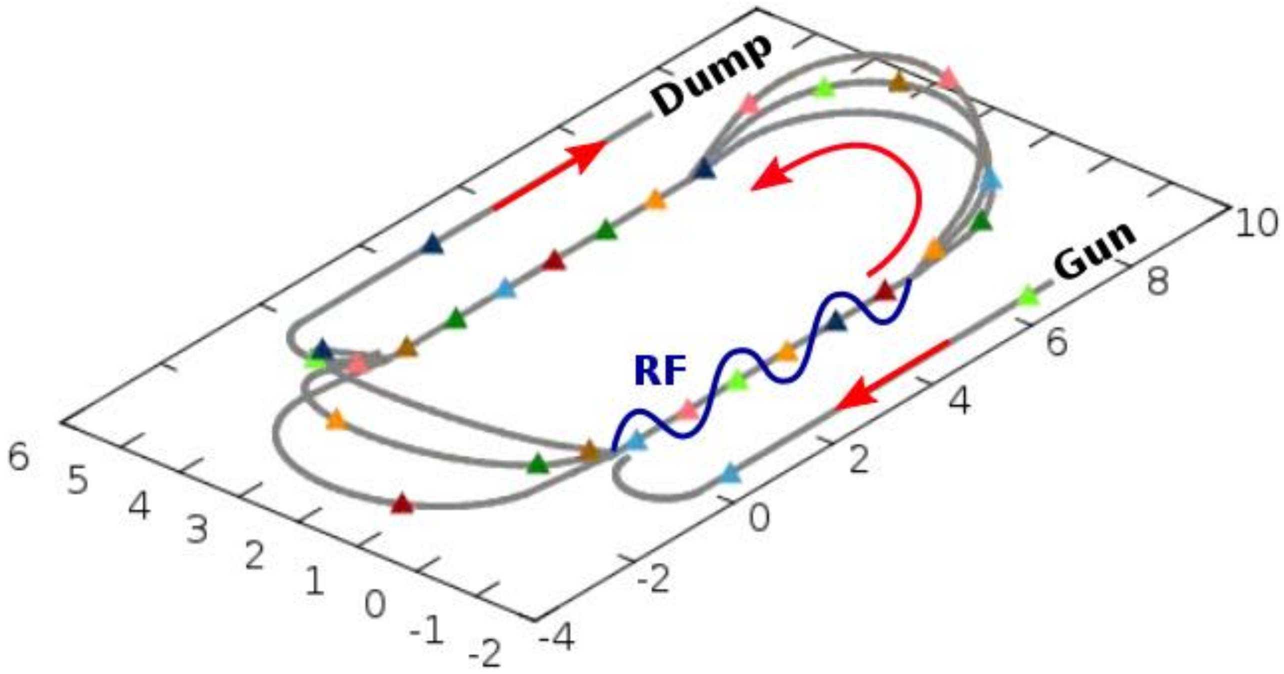
  Energy recovery:

  - Minimize the power consumption using the energy of the spent beam to accelerate a fresh one
  - Required RF power becomes nearly independent of beam current
  - Increases overall system efficiency
  - Reduces electron beam power to be disposed of at beam dumps

- **Power consumption for the ERL complex ≤ 100 MW**

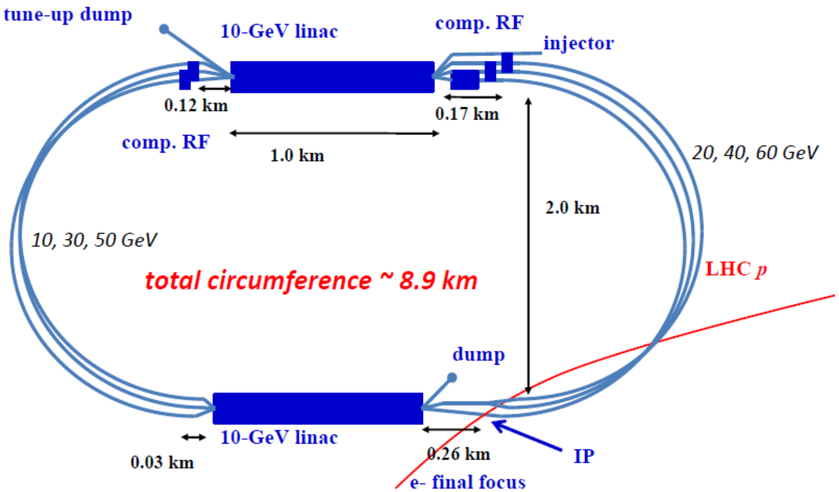
A conventional Linac would never fit into the power constraints

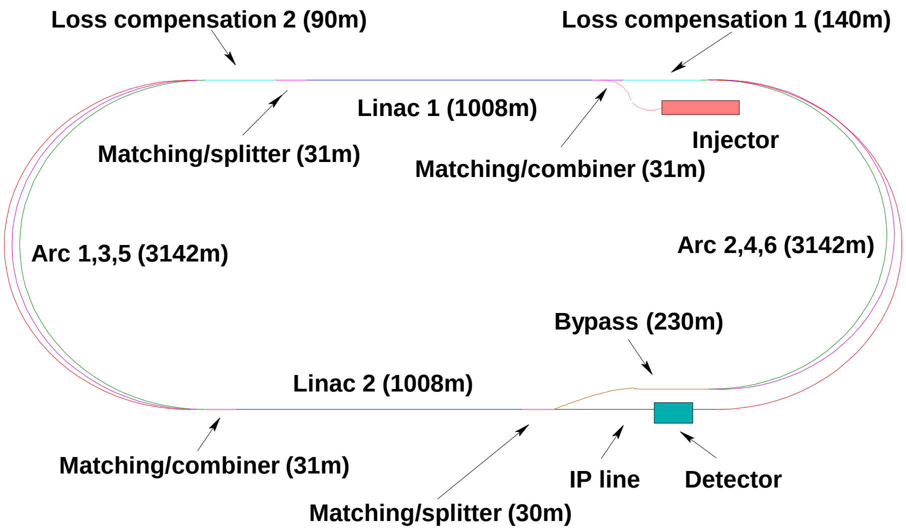
The LHeC Continuos Wave Operation



- New bunches are continuously injected and spent bunches are continuously dumped
- In the linac bunches at different turn numbers and energies are interleaved
  Decelerating bunches deliver their energy to the cavity fields

The LHeC Accelerator:
An energy recovery linac in a racetrack configuration





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

LHeC Recirculating Linear Accelerator Complex : 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 $\gamma\epsilon_{x,y}$ [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

ERL Facility

FUNDAMENTAL MOTIVATION:

- **Develop technologies to prepare for the next energy-frontier machine** (as SCRF cavities)

- **Validation of key LHeC Design Choices**

- **Proof validity of fundamental design parameters:**
  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

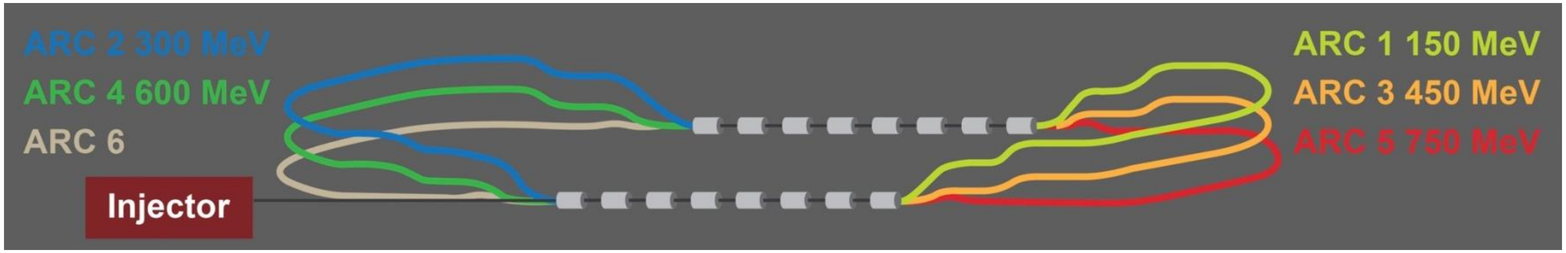
- **Build up expertise in the design and operation for a facility with a fundamentally new operation mode:**
  ERLs are circular machines with tolerances and timing requirements similar to linear accelerators (no 'automatic' longitudinal phase stability, etc.)

Goals of an ERL 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

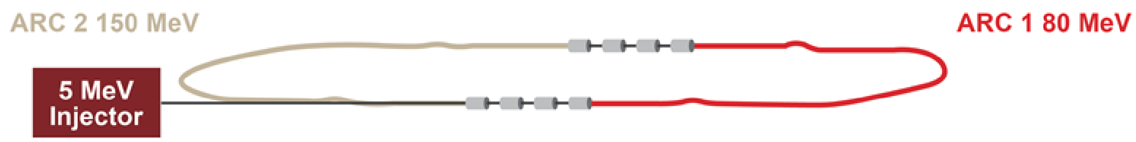


Planning for each stage

STEP 1

SC RF cavities, modules and e⁻ source tests

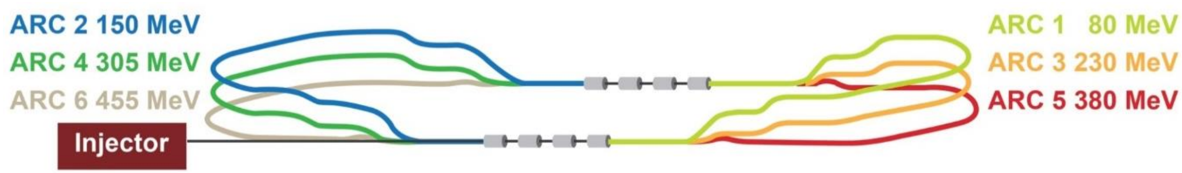
- Injection at 5 MeV
- 1 turn
- 75 MeV/linac
- Final energy 150 MeV



STEP 2

First tests in Energy Recovery Mode

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

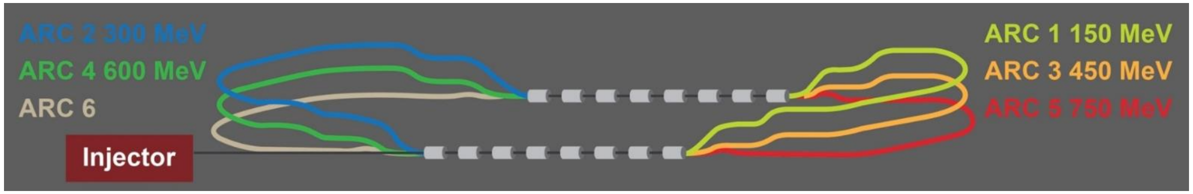


STEP 3

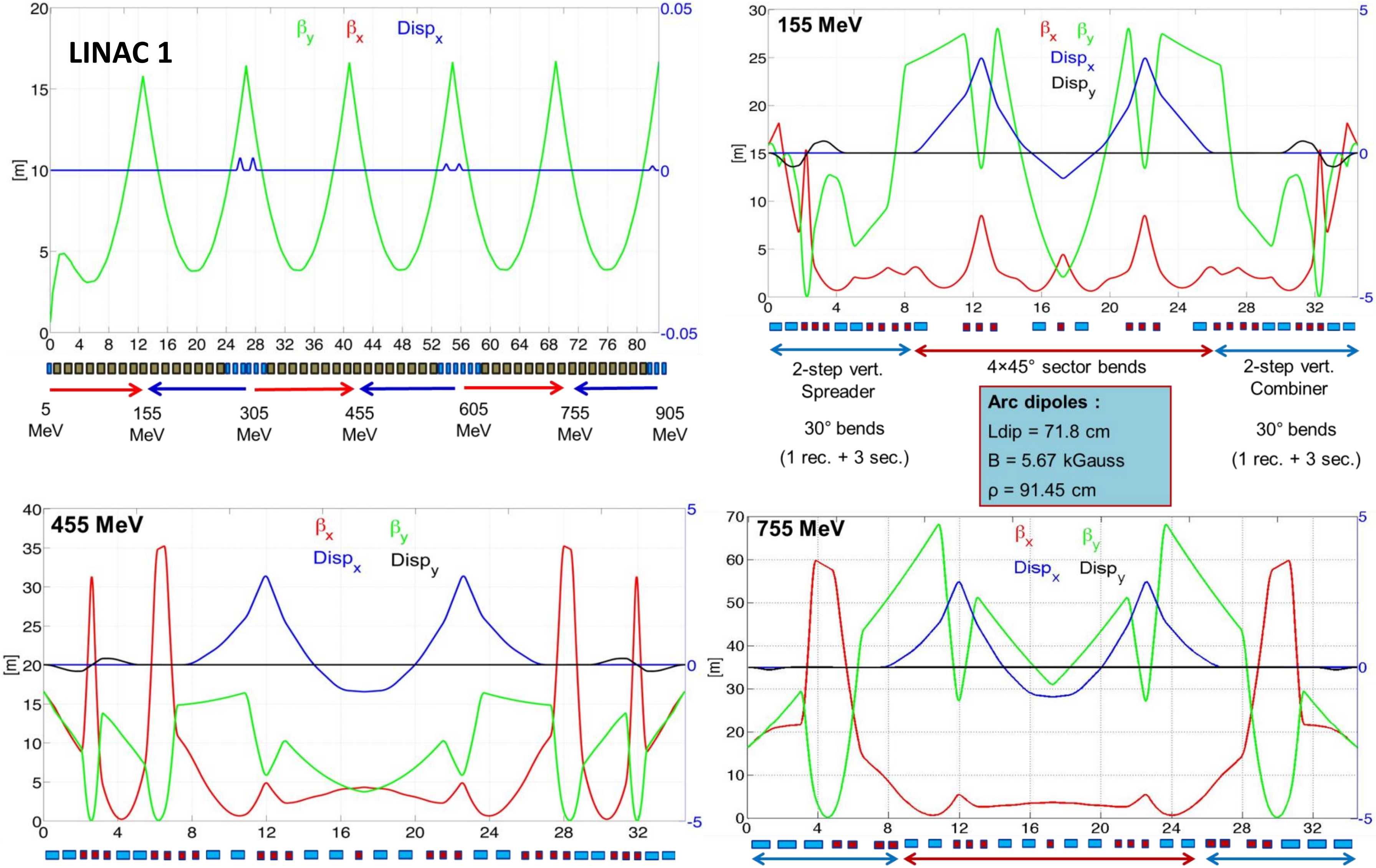
Additional SC RF modules test

Full energy test in Energy Recovery Mode

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

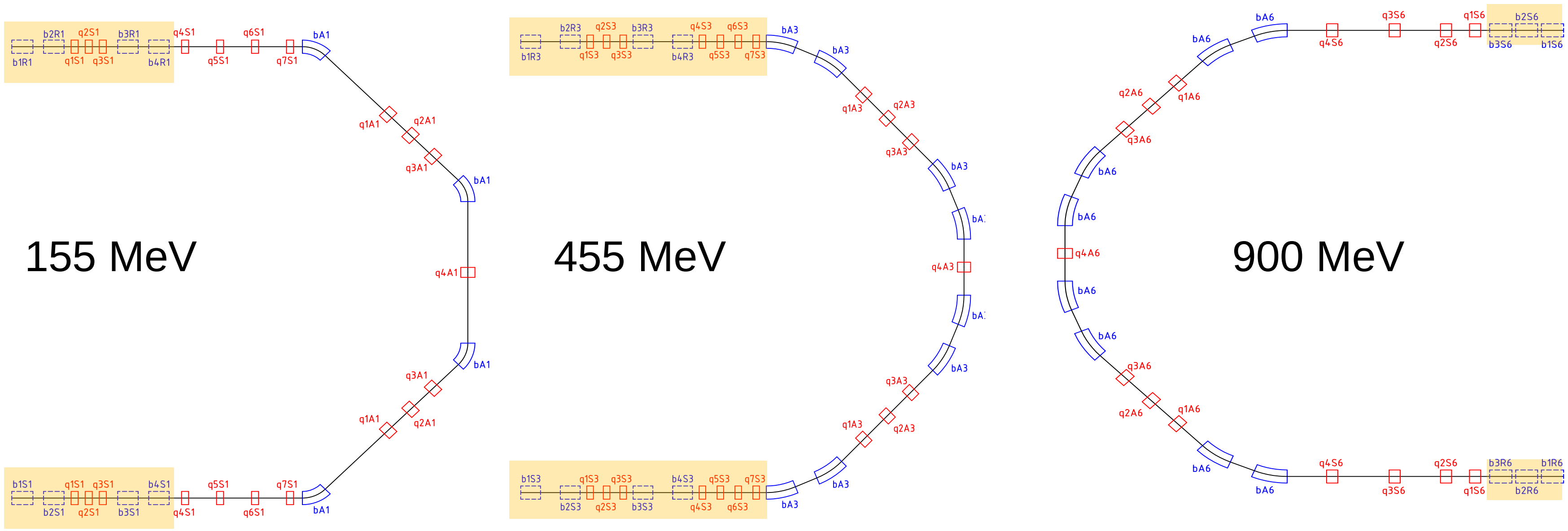


Lattice structure



CERN

Magnets inventory



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

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

Conventional iron-dominated resistive magnets can be used

ERL FACILITY CDR

In order to study and develop the technologies to prepare for the possible next energy-frontier machine

An ERL Facility could be a key tool

We have started this study and have started to establish collaborations

A preliminary Conceptual Design Report for the Energy Recovery Linac Facility will be delivered in June 2015

A. Introduction
[Overview, Purpose, Parameters]
B. Applications
1. Development of SCRF
2. Experiments
3. Technical Applications
4. Testbeams
5. LHeC Injector

C. Design
D. Components
1. Source
2. 802 MHz Cavity
3. Arc Magnets
4. Dumps and Transfer lines

E. Site Considerations
F. Cost estimate

Summary and Outlook

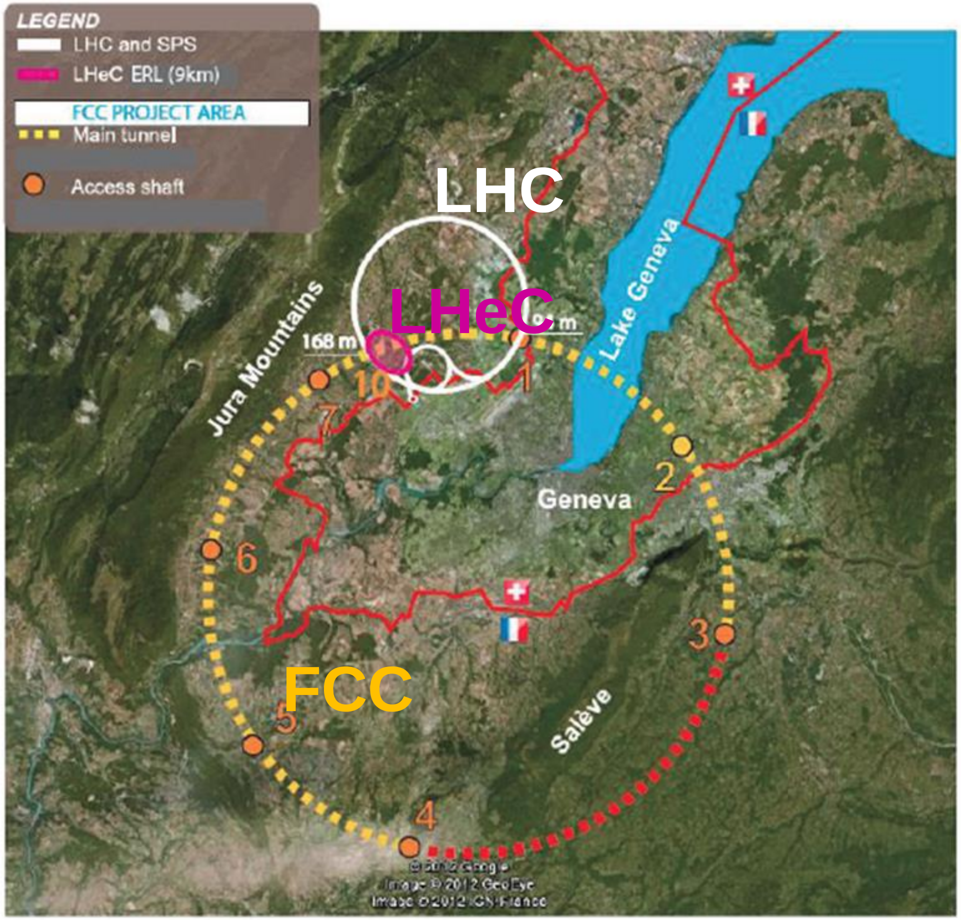
Two options for FCC_he

1. **e- from LHeC or other ERL**

1. **e- from FCC_ee**
   (if co-existing with FCC_hh)

The LHeC could
- be realized in parallel with HL-LHC
- potentially provide collisions with FCC-hh
- operate as an injector for FCC-ee

An ERL Facility could be a key tool



Thank you for your attention

...and thanks to the LHeC collaboration, in particular to
O. Bruning, M. Klein, A. Bogacz, A. Milanese, D. Pellegrini, F. Zimmermann

http://lhec.web.cern.ch

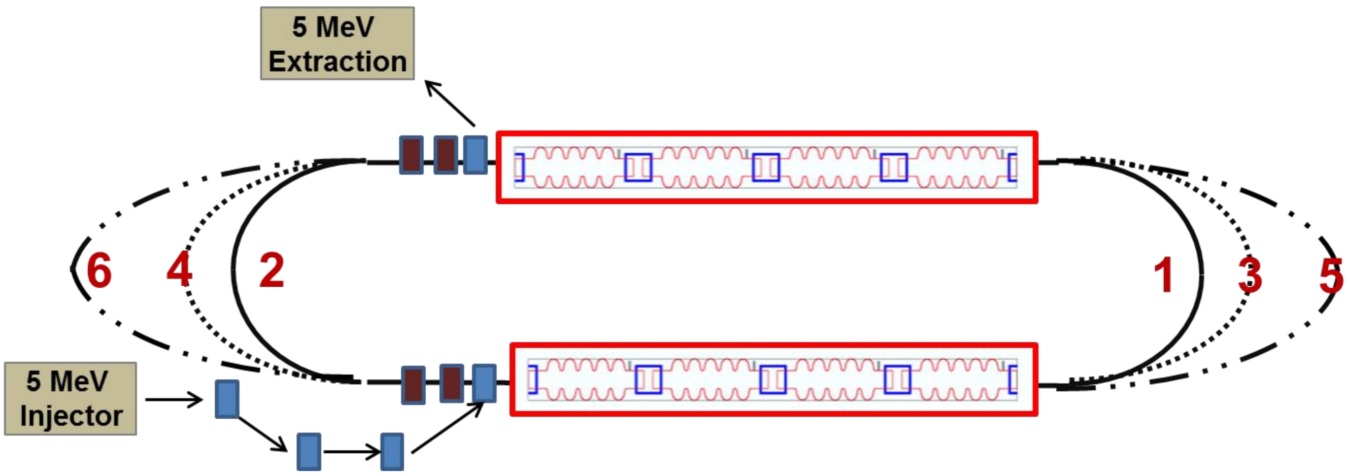
www.cern.ch

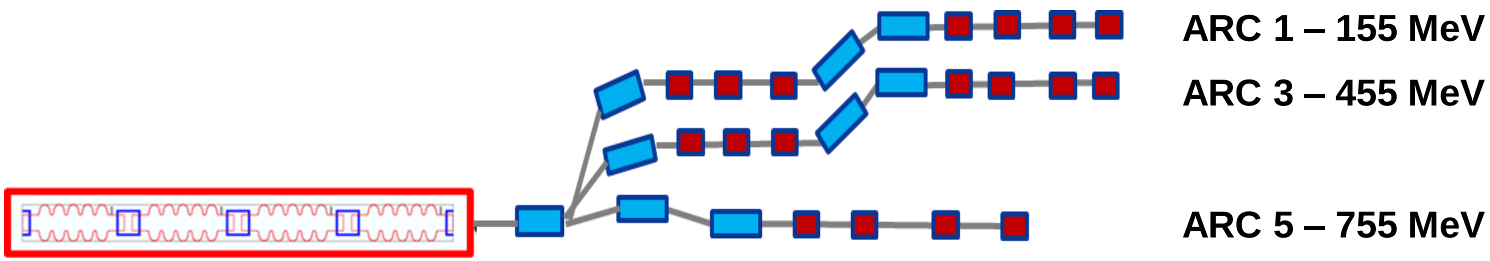
Backup slides

LHeC Recirculating Linear Accelerator Complex : IP parameters

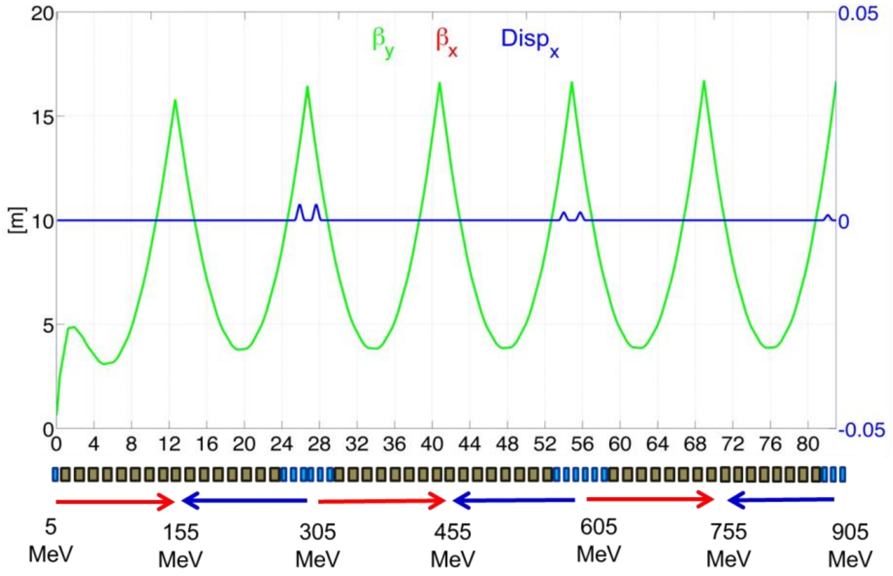
10^{33} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [10^{33}cm^{-2}s^{-1}]	1	1
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	3.75	50
Beta Function $\beta^*_{x,y}$ [m]	0.1	0.12
rms Beam size $\sigma^*_{x,y}$ [μm]	7	7
rms Beam divergence $\sigma'_{x,y}$ [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

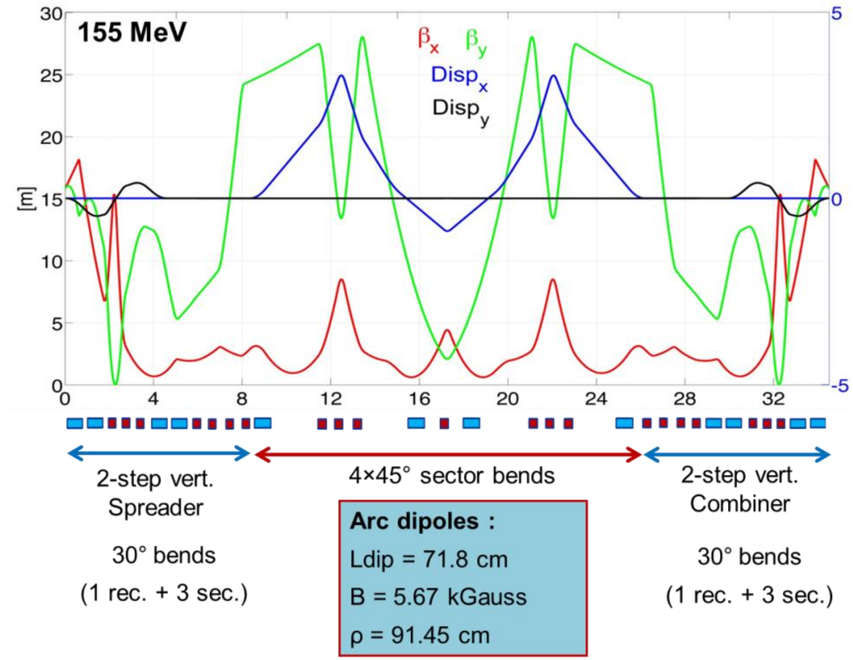
Layout

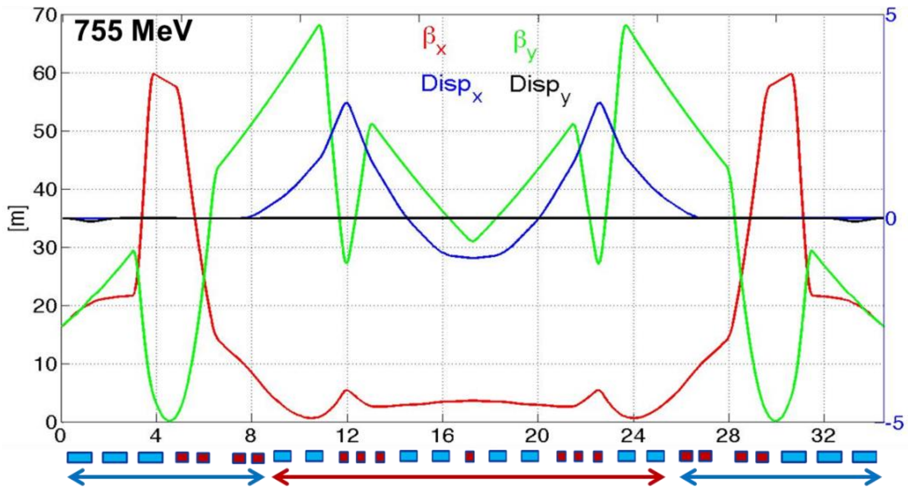

5 MeV
Extraction
6
4
2
1
3
5
5 MeV
Injector

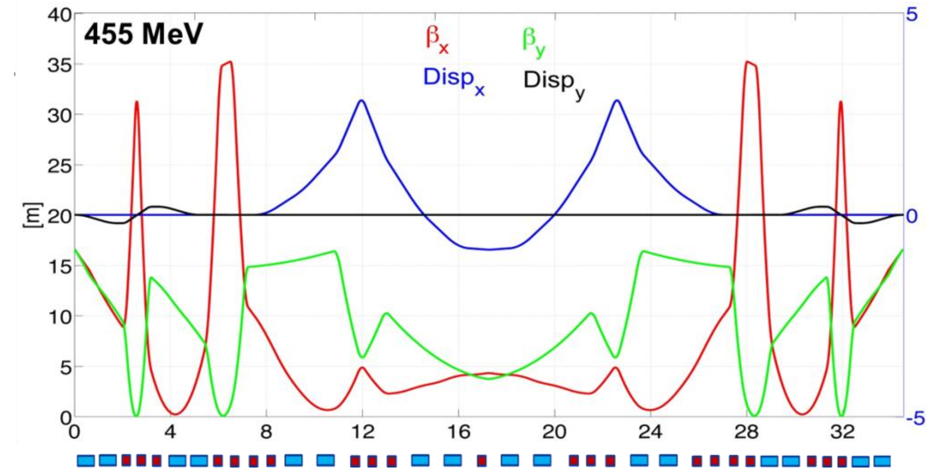

ARC 1 – 155 MeV
ARC 3 – 455 MeV
ARC 5 – 755 MeV

Optics layout







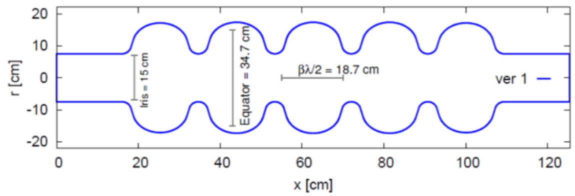


Superconducting RF

PARAMETER	VALUE
RF frequency	801.59 MHz
Acc. Voltage/cavity	18.7
# Cells/cavity	5
Cavity length	~ 1.2 m
# Cavities/cryomodule	4
RF power/cryomodule	< 50 MW
# Cryomodules	4*
Acceleration/pass	299.4 MeV*
Bunch repetition	36.44 MHz
Duty factor	CW

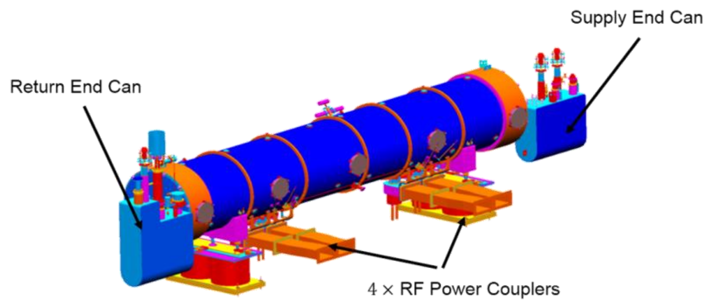
In order to make this facility work at the usual European frequencies (ESS, SPL,…), (LHC harmonic, SPS, LHeC, FCC,…)
(XFEL, ILC)
photocathode pulsed at

Initial Cavity Design (SPL, JLAB and BNL experience)

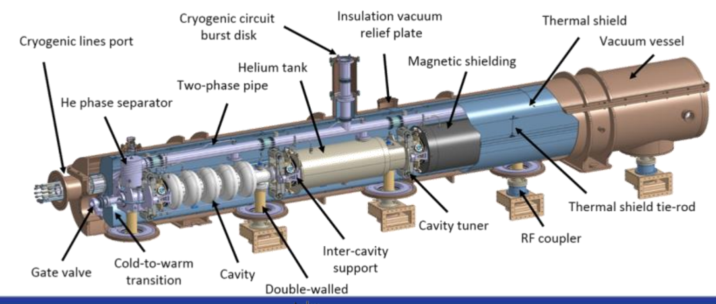


Cryomodule Design

JLAB had designed an 805 MHz cryomodule for SNS
(concept for the 802 MHz baseline design)



CERN is following for SPL (704 MHz) an alternative path using SS helium vessels and support by the power couplers



LTF Possible Site options

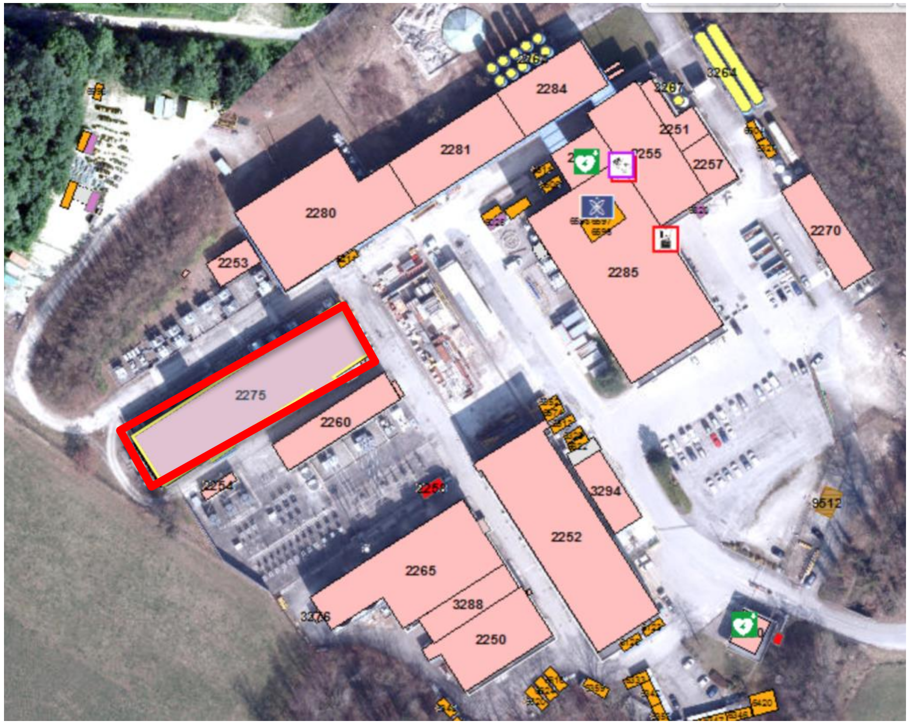
- Many site options presented @ January 2014 LHeC Workshop

- 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

LTF Possible Site Choice



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

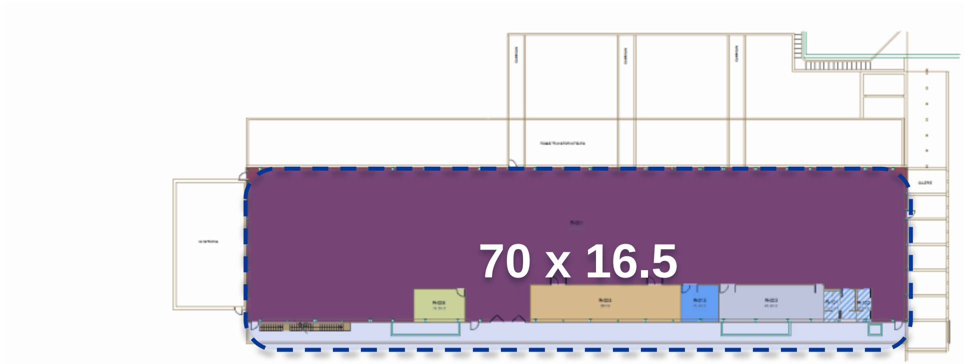
A suitable hall could be in **Building 2275, near LHC P2**

- Current use under investigation

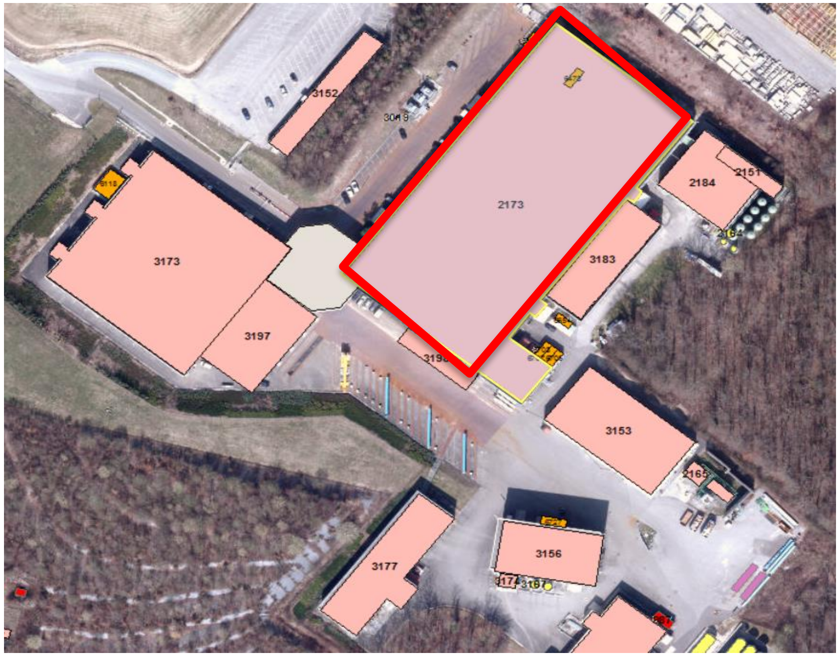
- Power converters already in place

- Geographically perfect as injector for LHeC ERL

- Slightly narrower than required Can it be extended?



LTF Possible Site Choice



A suitable hall could be in **Building 2173 (SM18)**

- Current use under investigation

- Powering infrastructure in place

- Cryogenics installation in place (capacity to be checked???)