LHeC
Accelerator Developments

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ASTeC, STFC Daresbury Laboratory

LHeC meeting, 8th May 2013, University of Liverpool

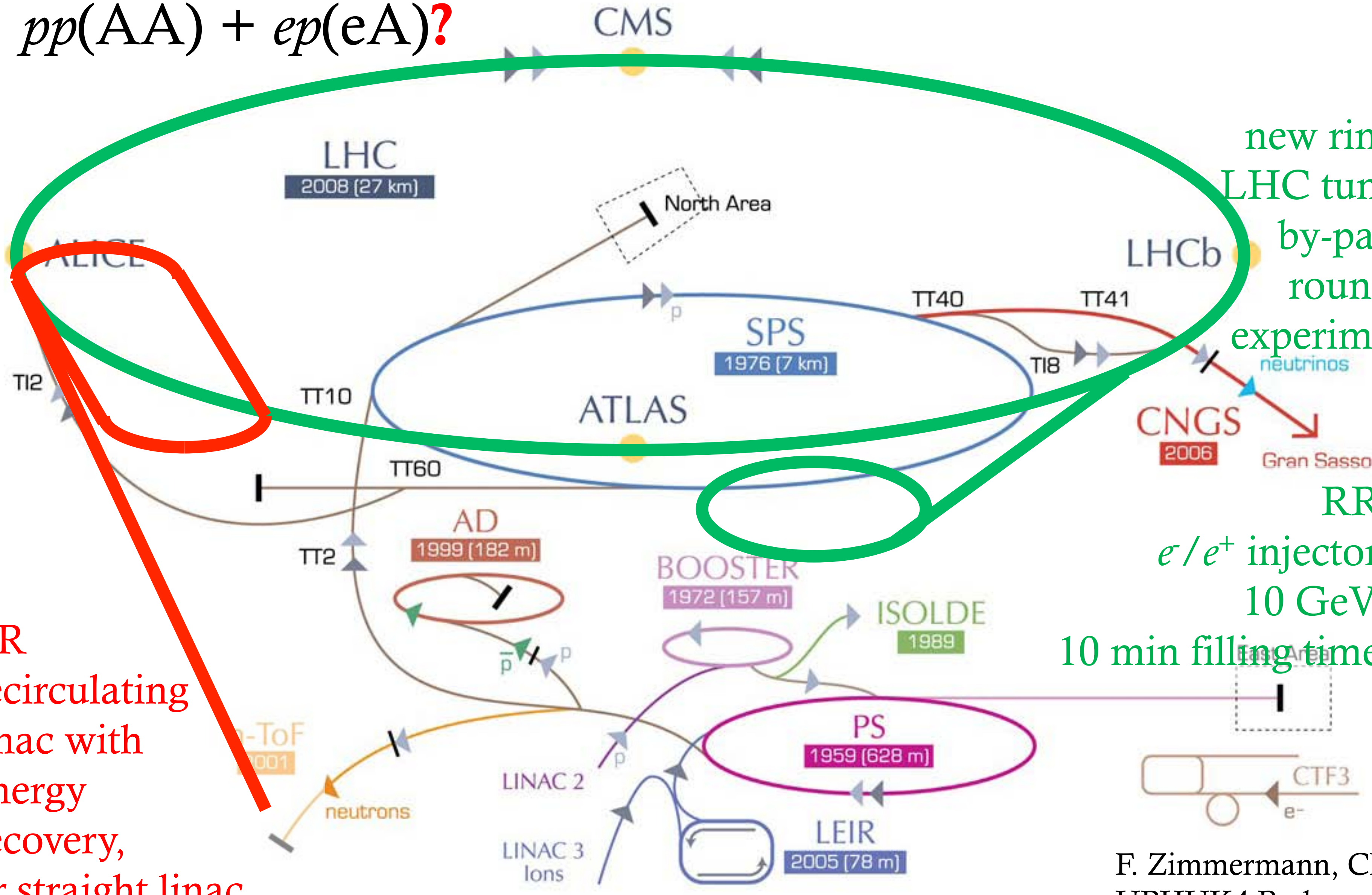
Outline

- LHeC Accelerator Updates
  - O. Bruning, DIS2013
- Interest from ASTeC/CI
  - ERL experience
  - Possible contributions to LHeC and the Test Facility
- Present status

Measurement @ the Terascale

upgrade LHC?

pp(AA) + *ep*(eA)?



RR
new ring in LHC tunnel, by-passes round *pp* experiments

RR
e^-/e^+ injector
10 GeV,
10 min filling time

LR
recirculating linac with energy recovery,
or straight linac

F. Zimmermann, CERN
UPHUK4 Bodrum 2010

Design Parameters

electron beam	RR**	LR	LR*
e- energy at IP[GeV]	60	60	[illegible]
luminosity [10^{32} cm^{-2}s^{-1}]	0.9	10	[illegible]
polarization [%]	40	[illegible]	[illegible]
bunch population [10^9]	20	[illegible]	[illegible]
e- bunch length [mm]	[illegible]	[illegible]	[illegible]
bunch interval [ns]	[illegible]	[illegible]	[illegible]
transv. emit. $\gamma\varepsilon_{x,y}$ [illegible]	[illegible]	[illegible]	[illegible]
rms IP beam [illegible]	[illegible]	[illegible]	[illegible]
e- IP be[illegible]	[illegible]	[illegible]	[illegible]
fu[illegible]	[illegible]	[illegible]	[illegible]
geo[illegible]	[illegible]	[illegible]	[illegible]
repet[illegible]	[illegible]	[illegible]	[illegible]
beam p[illegible]	[illegible]	[illegible]	5
ER efficie[illegible]	[illegible]	[illegible]%	N/A
average cu[illegible]	[illegible]	6.6	5.4
tot. wall plug [illegible]	100	100	100

*) pulsed, but high e[illegible] impossible; **) 1° acceptance optics

	LR
[illegible]	1.7
[illegible]	3.75
[illegible]	[illegible]

...servative

... also for deuterons
...ew) and lead (exists)

RR= Ring – Ring
LR =Linac –Ring

Ring uses 1° as baseline : L/2
Linac: clearing gap: L*2/3

Final parameter set to be developed as we gain experience with LHC operational (beam-beam, spacing etc)

The goal here is to demonstrate that realistic sets exist for both LHeC versions

LHeC Options: Executive Summary

Ring-Ring option:

-We know we can do it: → LEP 1.5

-Challenge 1: integration in tunnel and co-existence with LHC HW

-Challenge 2: installation within LHC shutdown schedule

Linac-Ring option:

-Installation decoupled from LHC operation and shutdown planning

-Infrastructure investment with potential exploitation beyond LHeC

-Challenge 1: technology → high current, high energy SC ERL

-Challenge 2: Positron source

LHeC Planning and Timeline

LHeC

- We assume the LHC will reach end of its lifetime with the end of the HL-LHC project:

  -Goal of integrated luminosity of 3000 fb^{-1} with 200fb^{-1} to 300fb^{-1} production per year ➔ ca. 10 years of HL-LHC operation

  -Current planning based on HL-LHC start in 2022

  ➔ end of LHC lifetime by 2032 to 2035

- LHeC operation:

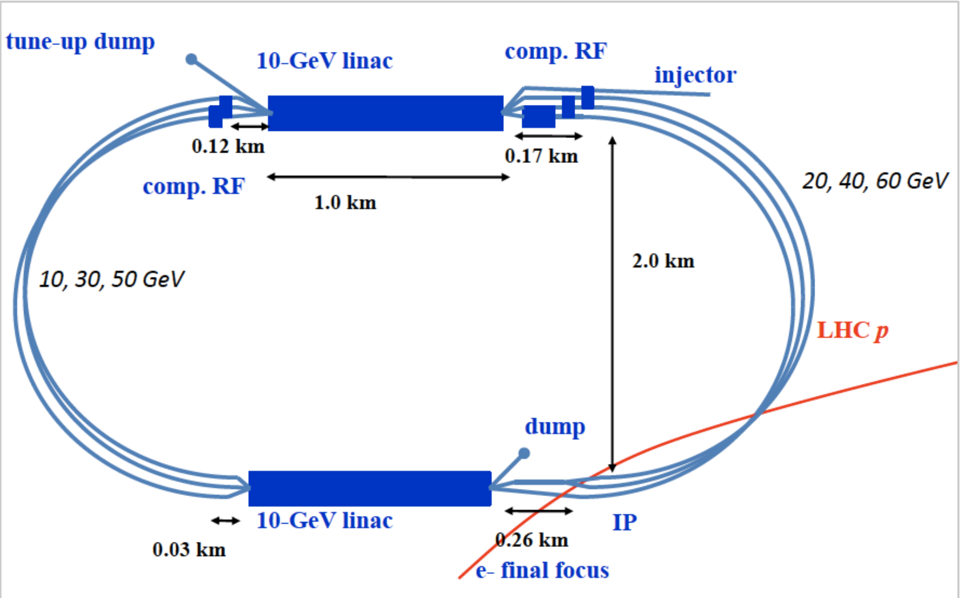
  -Luminosity goal based on ca. 10 year exploitation time (➔100fb^{-1})

  -LHeC operation beyond or after HL-LHC operation will imply significant operational cost overhead for LHC consolidation

LHeC: Baseline Linac-Ring Option

LHeC

- Challenge 1: Super Conducting Linac with Energy Recovery & high current (> 6mA)



Two 1 km long SC linacs in CW operation ($Q > 10^{10}$)

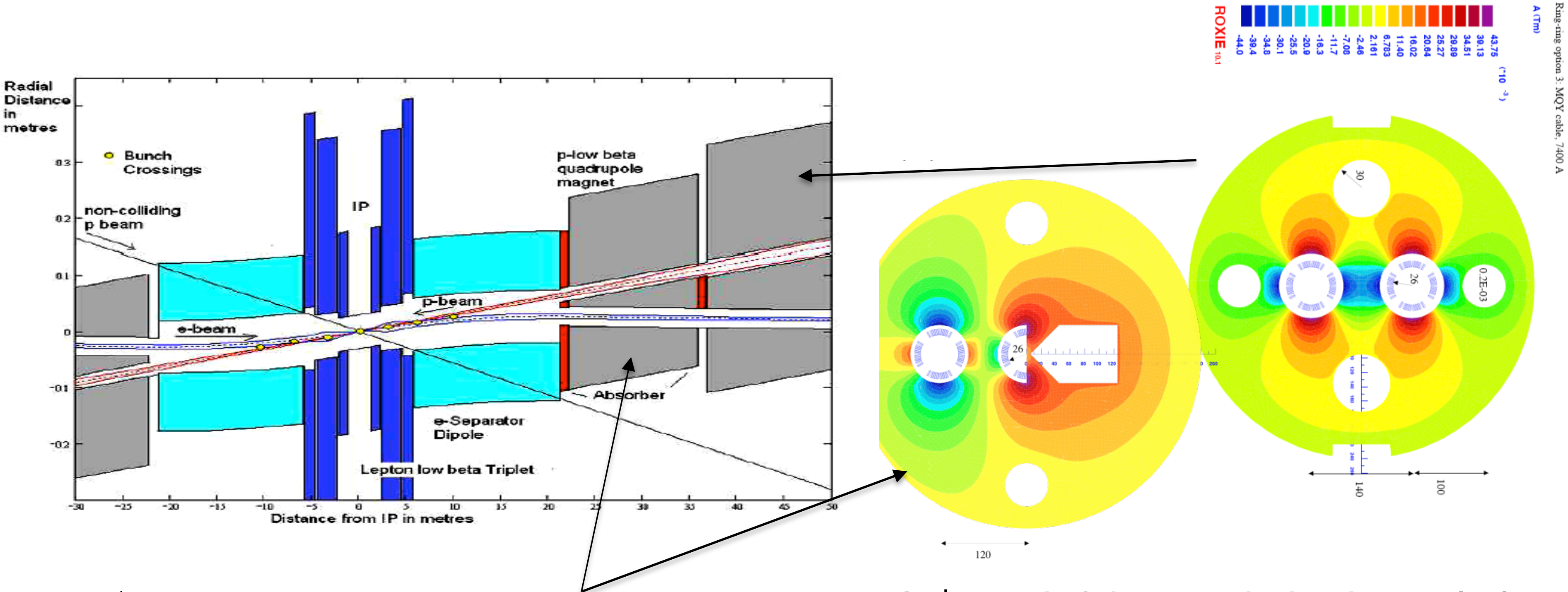
➔ requires Cryogenic system comparable to LHC system!

- Challenge 2: Relatively large return arcs
  - ➔ ca. 9 km underground tunnel installation
  - ➔ total of 19 km bending arcs
  - ➔ same magnet design as for RR option: > 4500 magnets

Interaction Region: Accommodating 3 Beams

Small crossing angle of about 1mrad to avoid first parasitic crossing (L x 0.77)
(Dipole in detector? Crab cavities? Design for 25ns bunch crossing [50ns?]
Synchrotron radiation –direct and back, absorption … recall HERA upgrade…)

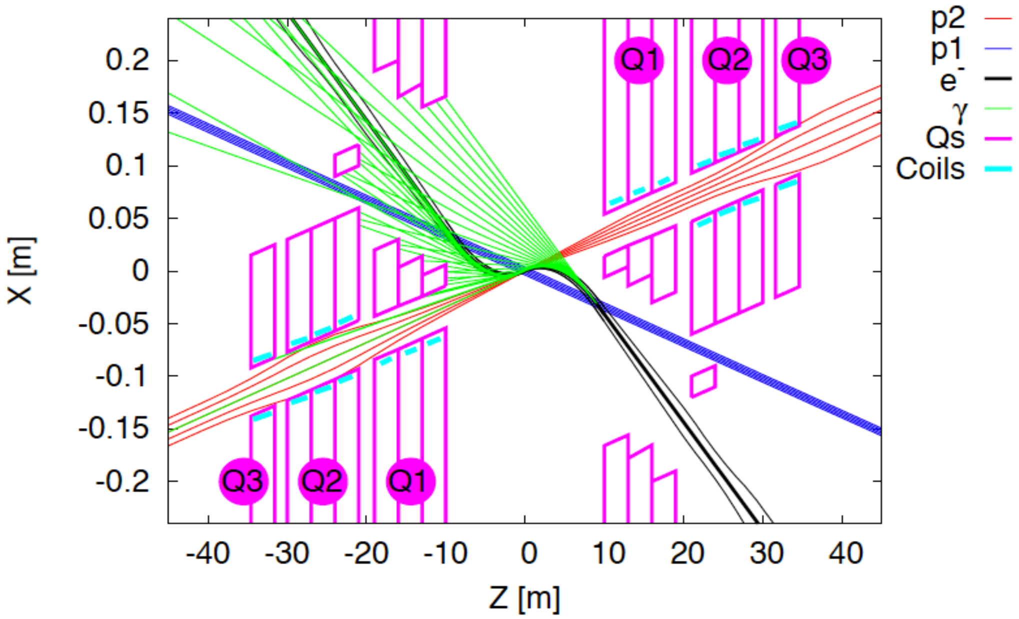
Focus of current activity



1st sc half quad (focus and deflect)
separation 5cm, g=127T/m, MQY cables, 4600 A

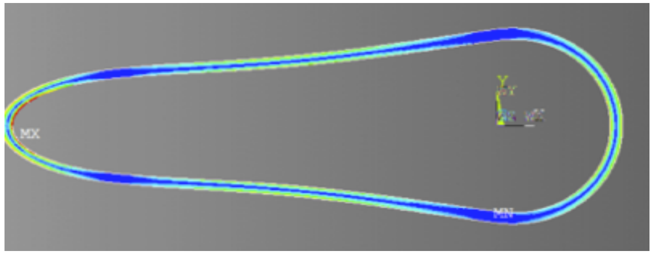
2nd quad: 3 beams in horizontal plane
separation 8.5cm, MQY cables, 7600 A

Next Steps: Interaction Region Design



Beam pipe: in CDR 6m, Be, ANSYS calculations

Composite material R+D, prototype, support..
→ Essential for tracking, acceptance and Higgs



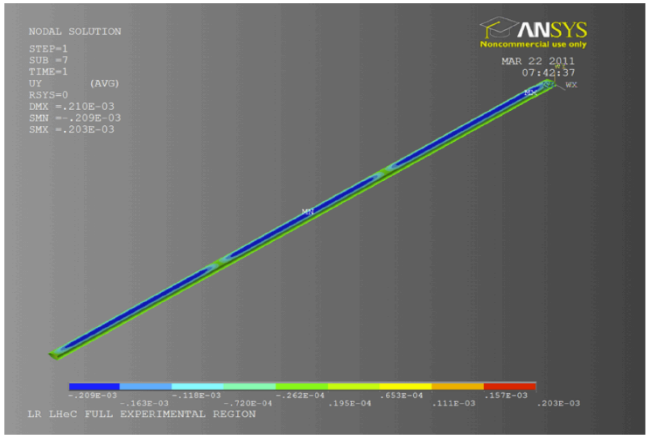


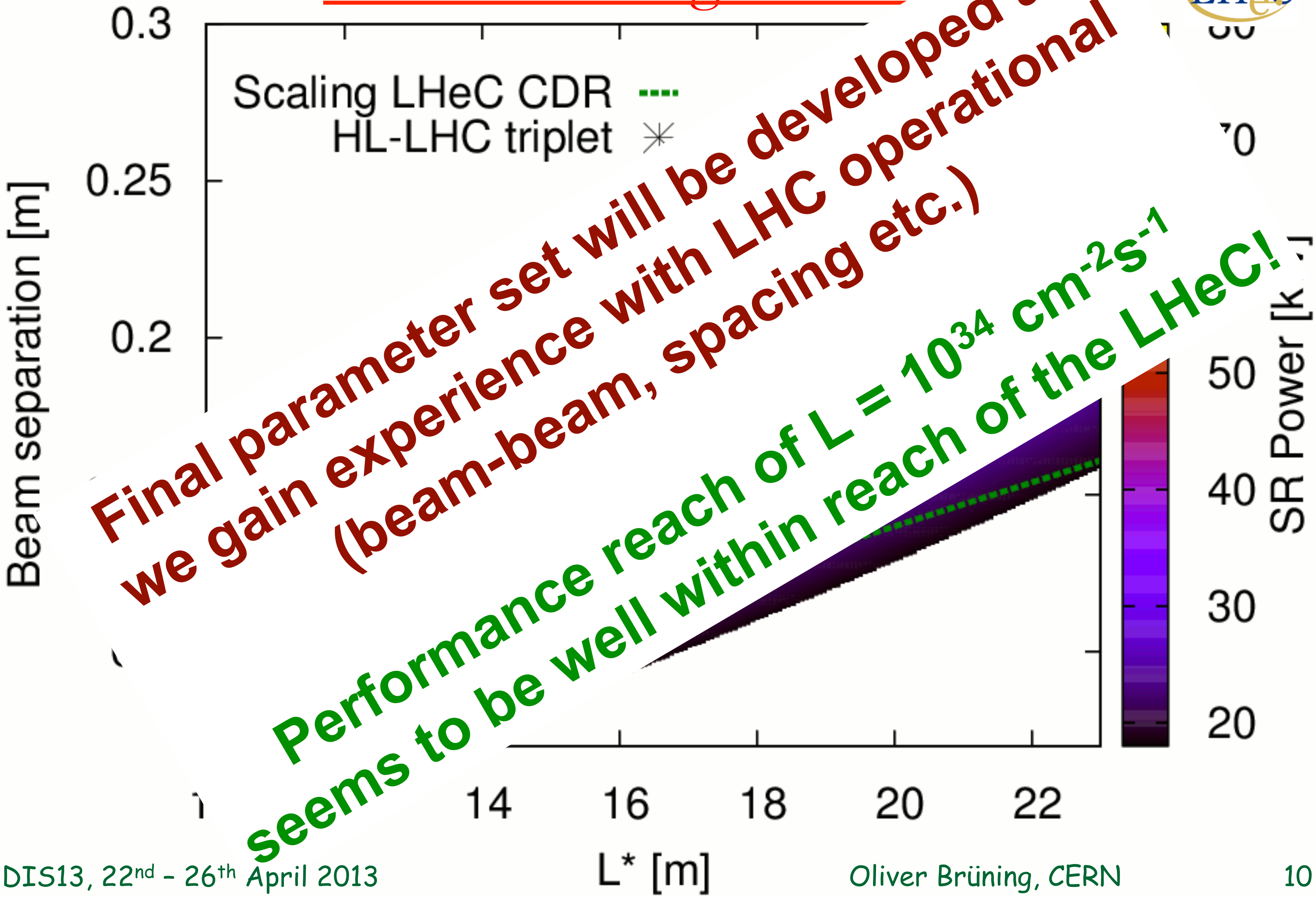
Figure 9.32: 3-D view of the LR geometry showing contours of bending displacement [m].

Have optics compatible with LHC ATS optics and β*=0.1m
Head-on collisions mandatory →
High synchrotron radiation load, dipole in detector

Adapt LHeC to LHC ATS optics
Specification of Q1 – NbTi prototype

Revisit SR (direct and backscattered),
Masks+collimators
Beam-beam dynamics and 3 beam operation studies

Interaction Region Desi[...]



Final parameter set will be developed as we gain experience with LHC operational (beam-beam, spacing etc.)

Performance reach of L = 10^{34} $cm^{-2}s^{-1}$ seems to be well within reach of the LHeC!

LHeC IR OPTICS DESIGN INTEGRATED INTO THE HL-LHC LATTICE

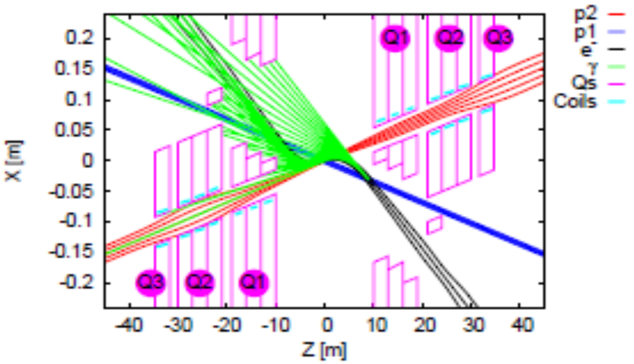
O. Brüning, R. Tomás, CERN, Switzerland
M. Korostelev, E. Cruz-Alaniz, D. Newton, A. Wolski, Univ. Liverpool/Cockcroft Institute, UK

Abstract

The two main drivers for the CDR LHeC IR design were chromaticity and synchrotron radiation. Recently it has been proposed that the LHeC IR proton optics could make use of the Achromatic Telescopic Squeeze (ATS) scheme, which benefits from higher arc beta functions for the correction of chromaticity. In this scenario the distance between the IP and the proton triplet can be increased allowing for a reduction of the IR dipole field and the synchrotron radiation. First feasibility considerations and more in-depth studies of the synchrotron radiation effects are presented in this paper.

INTRODUCTION

A first conceptual design of the LHeC linac-ring Interaction Region (IR) is presented in the LHeC Conceptual Design Report [1]. The merits of the design are a very low β^* of 0.1 m with proton triplets as close as possible to the IP to minimize chromaticity. Head-on proton-electron collisions are achieved by means of dipoles around the Interaction Point (IP). A crossing angle of 6 mrad between the non-colliding proton beams allows enough separation to place the proton triplets. Only the proton beam colliding with the electrons is focused. In the IR2 configuration the electrons are injected parallel to the LHC beam 1 and collide head-on with beam 2, see Fig. 1.



Bending dipoles around the IP are used to make the electrons collide head-on with beam 2 and to safely extract the disrupted electron beam. The required field of these dipoles is determined by the L^* and the minimum separation of the electron and the focused beam at the first quadrupole (Q1). A 0.3 T field extending over 9 m allows for a beam separation of 0.07 m at the entrance of Q1. This separation distance is compatible with mirror quadrupole designs using Nb_3Sn technology. A transverse section of the Q1 quadrupole is shown in Fig. 2. The electron beam radiates 48 kW in the IR dipoles. The impact of the back-scattered synchrotron radiation in the detector needs to be carefully evaluated, while reducing the total SR power is highly recommended.

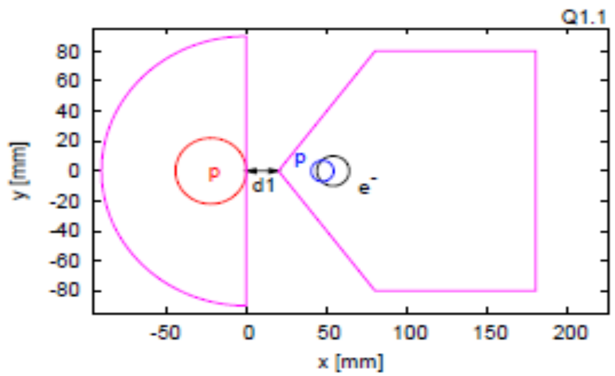


Figure 2: Transverse section of the first Q1 block showing the face closest to the IP.

After matching this triplet to the LHC and correcting linear chromaticity the chromatic β-beating at dp/p=0.001 is about 100% [1]. This is intolerable regarding collimation and machine protection issues. Therefore an appropriate chromatic correction scheme is required. The HL-LHC optics uses beta-beating waves in the arcs in order to accomplish achromatic β^* squeeze by increasing the beta-

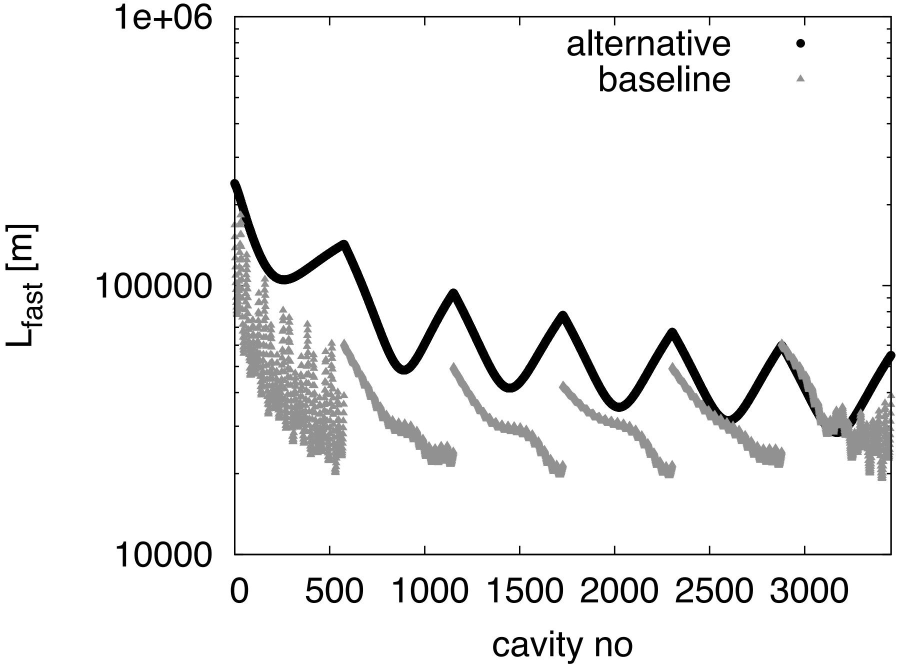
IPAC2013

Integration of an LHeC IR into the HL-LHC lattice (including implementation of the ATS optics) – low level effort from Liverpool in collaboration with CERN.

LINAC: Beam Dynamics Issues

- Has been studied for the linacs only
  - Arcs need to be included
  - Only analytics estimates used
- Continuous beam would trap ions in the linacs
  - This would lead to unstable beam
- One 10μs long gap in beam prevents long-term trapping
  - Rise time of instability during the train between gaps seems to be acceptable (10 turns)

- Full study needed
  - Arcs will make instability worse
  - Ions are not completely lost during one passage of the gap
  - But the frequency of the induced instability varies along the machine, which helps



Post CDR Studies: ERL Beam Dynamics

LHeC

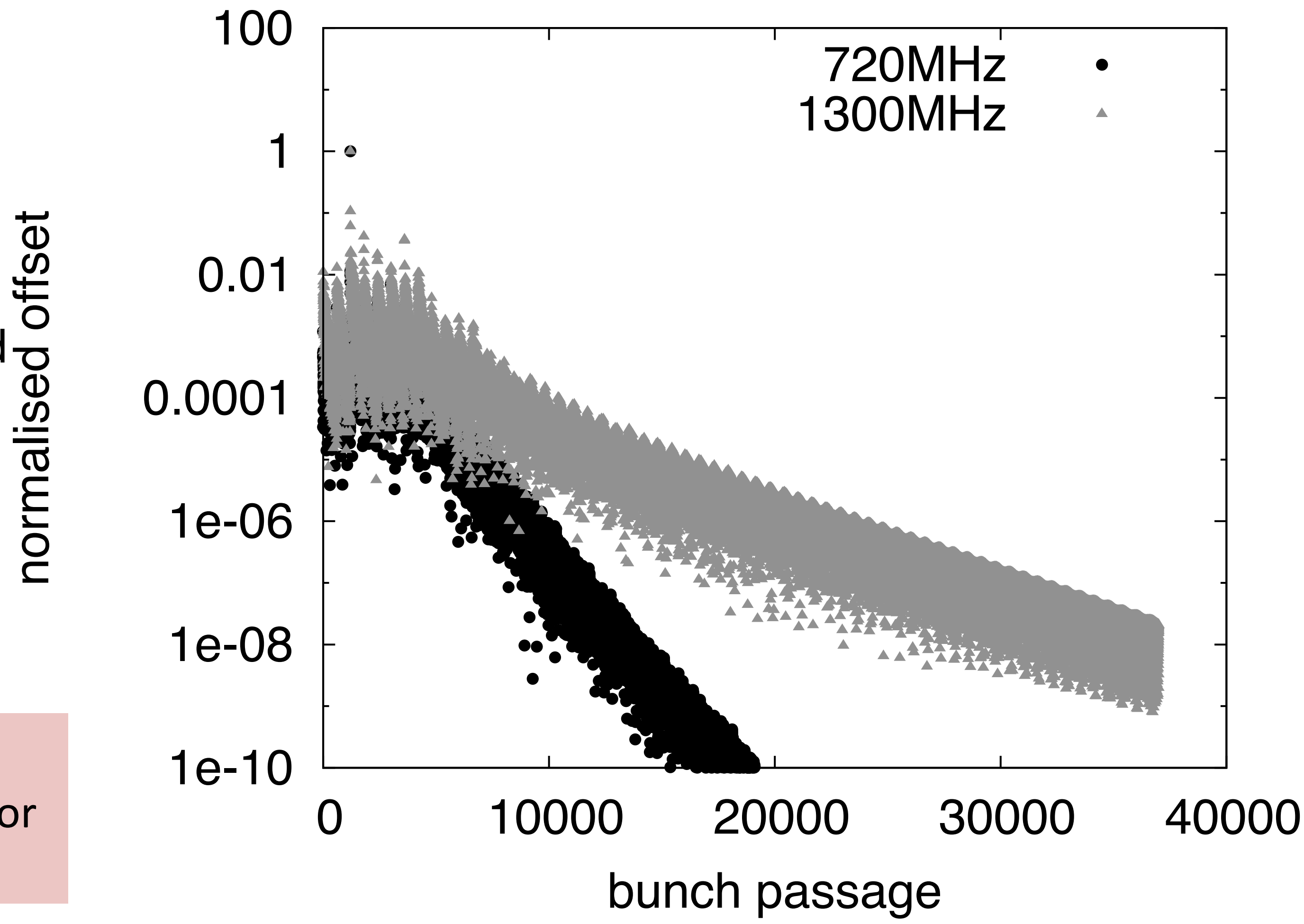
Beam Instabilities:

Daniel Schulte @ LHeC Seminar 12. March 2013

Increased bunch charge
To allow for ion-clearing gaps
$N = 3\ 10^9$

Note: bunches were placed in the gaps

F_{rms}=1.05 for ILC cavity
F_{rms}=1.001 for SPL cavity



Beam is stable for both cases but more margins for lower RF frequency

→ Optimum choice for LHeC RF frequency?

Post CDR Studies: ERL Beam Dynamics

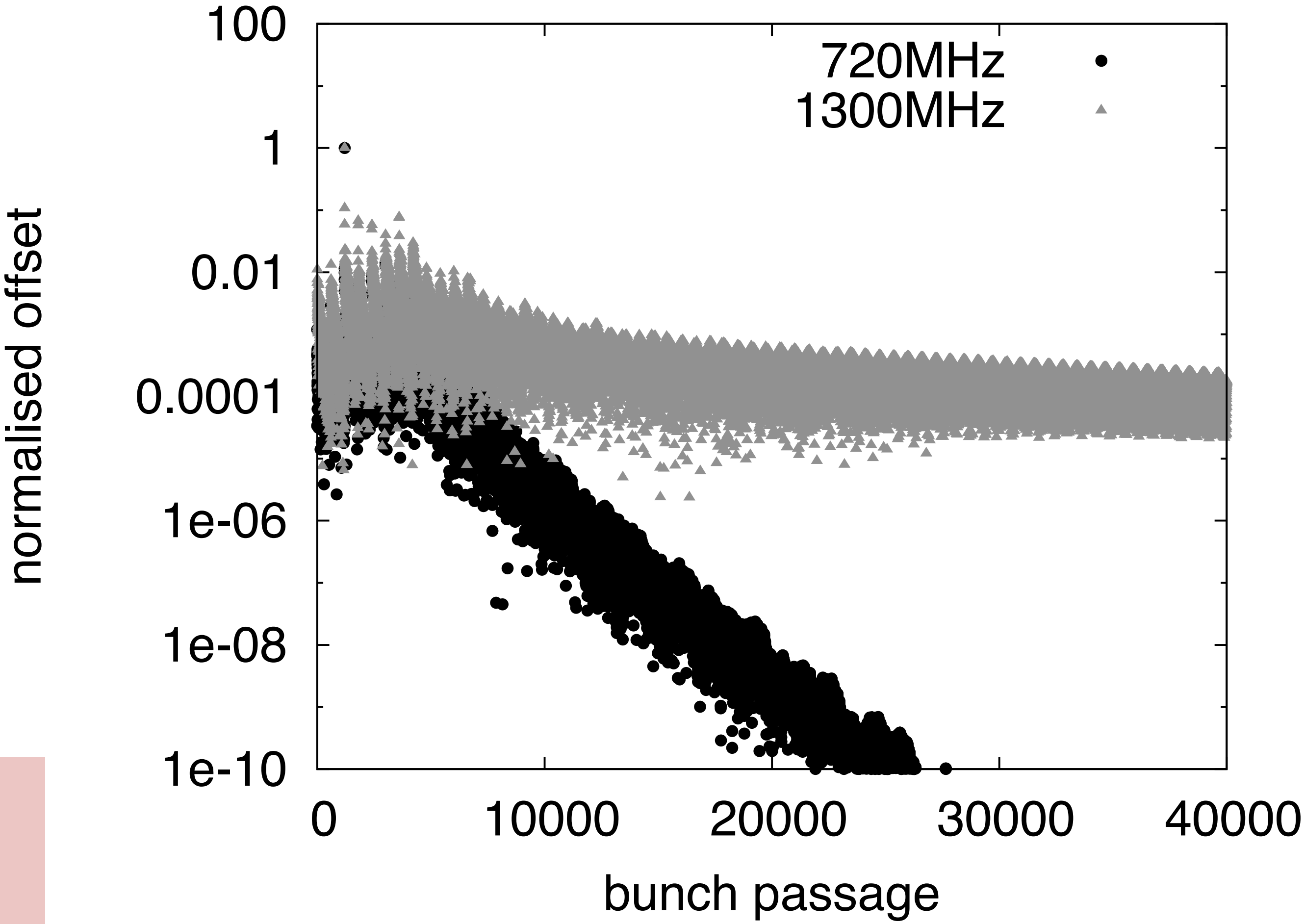
Beam-Beam effects:

Daniel Schulte @ LHeC Seminar 12. March 2013

$N=3\ 10^9$
Beam-beam effect included as linear kick

Result depends on seed for frequency spread
“worst” of ten seed shown

$F_{rms}=1.135$ for ILC cavity
$F_{rms}=1.002$ for SPL cavity



Beam is stable but very small margin with 1.3GHz cavity

➔ Optimum choice for LHeC RF frequency?

Post CDR Studies: RF Frequency

LHeC

- Review of the SC RF frequency:

  -HL-LHC bunch spacing requires bunch spacing with multiples of 25ns (40.079 MHz)

Frequency choice: *h* * n* 40.079 MHz

Symmetry in ERL: n=3 ➔ h * 120.237 MHz

h=6: 721 MHz or h=11: 1.323GHz

SPL & ESS: 704.42 MHz; ILC & XFEL: 1.3 GHz

Frequencies are slightly different (20MHz) from existing technologies!
But having the harmonic number be a multiple of the ERL symmetry is not a strong requirement ➔ asymmetric bunch patterns

Outcome of Daresbury meeting

- Frequency choice:

Low frequency	high frequency
BBU, HOMs, BCS	RF power needs & cost

- Gradient choice:

Low frequency	high frequency
20 MV/m	17 MV/m

- Cost:

Low frequency	high frequency
RF system 30% more expensive (overall ~10%?)	

- Conclusion:

  Lower frequency clearly preferred. 800 MHz true, exploitable synergy with other systems.

LHeC: Post CDR Plans

LHeC

- Launch SC RF and ERL R&D and Establish collaborations:

  -SC RF R&D has direct impact on cryo power consumption

  -Synergy with HL-LHC and TLEP!

  -ERL is a hot topic with many applications

  -Synergy with national research plans: e.g. MESA

- Magnet R&D activities:

  -Normal conducting compact magnet design ✔

  -Superconducting IR magnet design

  ➔ Detailed magnet design depends on IR layout and optics

  ➔ Optics & IR magnet design influence experimental vacuum beam pipe

LHeC: Post CDR Plans

- Develop an ERL test facility @ CERN:
  - -Beam Dynamics for ERL operation → develop expertise at CERN
  - -Synergy with other research plans: SC RF and TLEP

ERL Test Facility at CERN

CERN-LHeC-Note-2012-006 ACC

October 17, 2012

Rama.Calaga@cern.ch

Proposal for an LHeC ERL Test Facility at CERN [1]

R. Calaga, E. Ciapala, E. Jensen
CERN, Geneva, Switzerland

Keywords: electron-hadron collider, energy recovery linac, test Facility

Summary

An energy recovery linac at 300-400 MeV is proposed as a test facility using a two-pass double cryomodule concept. This facility will be designed to serve as a validation and a test bench for the electron linac with energy recovery foreseen for the LHeC. Furthermore, the test facility can be used as the injector to the main linac in future. Some aspects of the test facility RF system are outlined.

1 Introduction

A 60 GeV superconducting energy recovery linac (SC-ERL) is presently considered as the baseline for a future electron-hadron collider, the LHeC [1]. It should be noted that only 96% of the energy is recovered in the LHeC from synchrotron radiation. Relevant beam parameters and RF layout for the LHC, LHeC and the proposed ERL test facility are listed in Table 1 and Table 2 respectively.

Table 1: Some relevant parameters for the protons in the LHC and the electrons in the LHeC compared to the proposed ERL test facility.

Parameter	LHC	LHeC	ERL-TF
Species	Protons	Electrons	
Inj energy [MeV]	4.5×10^5	400	5
Max energy [GeV]	7.0×10^6	60	0.3-0.4
Beam current [mA]	500	40	40-100
Charge/Bunch [p/e]	1.7×10^{11}	2.0×10^9	
N. Emitt [μm]	2.5	50	50
Bunch length [mm]	75.5	0.3	0.3-2.0
Duty Factor	CW	CW	CW
Energy recovery eff	-	96%	> 99.95 %

STRAWMAN OPTICS DESIGN FOR THE LHeC ERL TEST FACILITY

A. Valloni*, O. Bruning, R. Calaga, E. Jensen, M. Klein, R.Tomas, F. Zimmermann,
CERN, Geneva, Switzerland
A. Bogacz, D. Douglas, Jefferson Lab, Newport News Virginia

Contribution to IPAC13

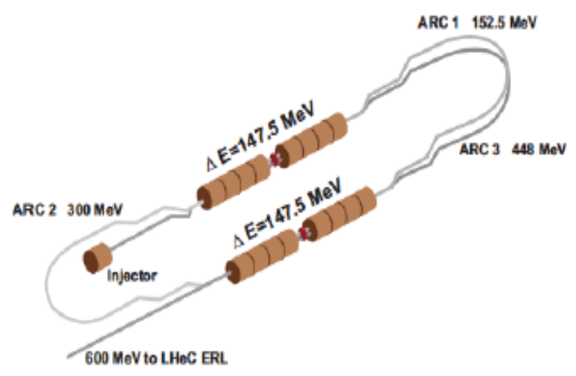


Figure 2: Consequent upgrade to LHeC pre-accelerator. By modifying the machine backleg to include a second full cryomodule, the recirculator can deliver higher beam energy of 600 MeV.

IPAC2013

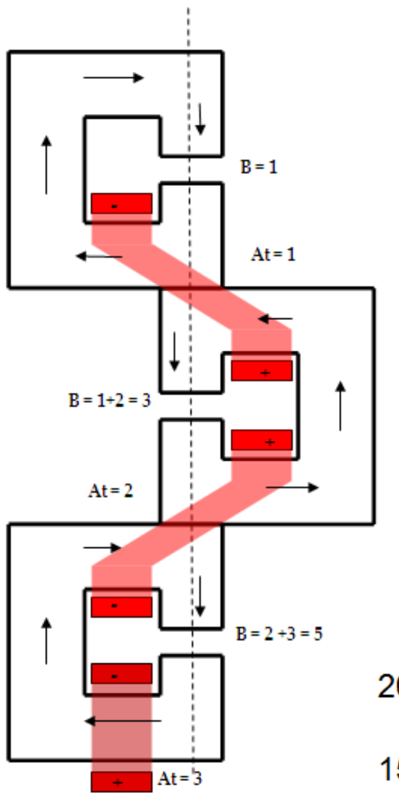
Next Steps: RF Prototype and Test Facility

- Develop 2 RF Cryomodule Prototypes over the nest 3 years
  - -LHeC RF frequency choice driven by power considerations
    - → Choice of ERL RF frequency: 801.58 MHz
    - → Synergy with HL-LHC and Higher Harmonic RF system!
- Design an ERL test facility @ CERN:
  - -Optimize magnet design for ERL return arcs
- Optimize and Iterate on LHeC ERL layout:
  - -Optimization of linac configuration & of number of passages
  - -Optimization of Civil Engineering layout
  - -Optimization of Interaction Region (L^*) and Synchroton Light

Next Steps: Test Facility and Magnets

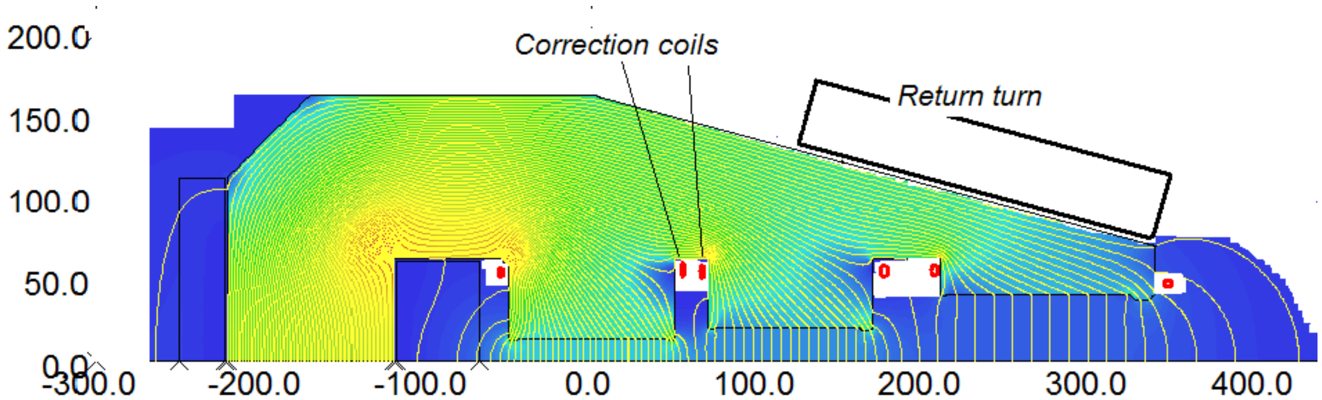
Intend to build Collaboration of CERN Magnet Group for the dipole and possibly further arc magnets for the Test Facility (two turns) and the LHeC.

Initial designs for Linac magnets in CDR and further discussions/thoughts from Daresbury, CERN and BINP colleagues.



Neil Marks 7/12

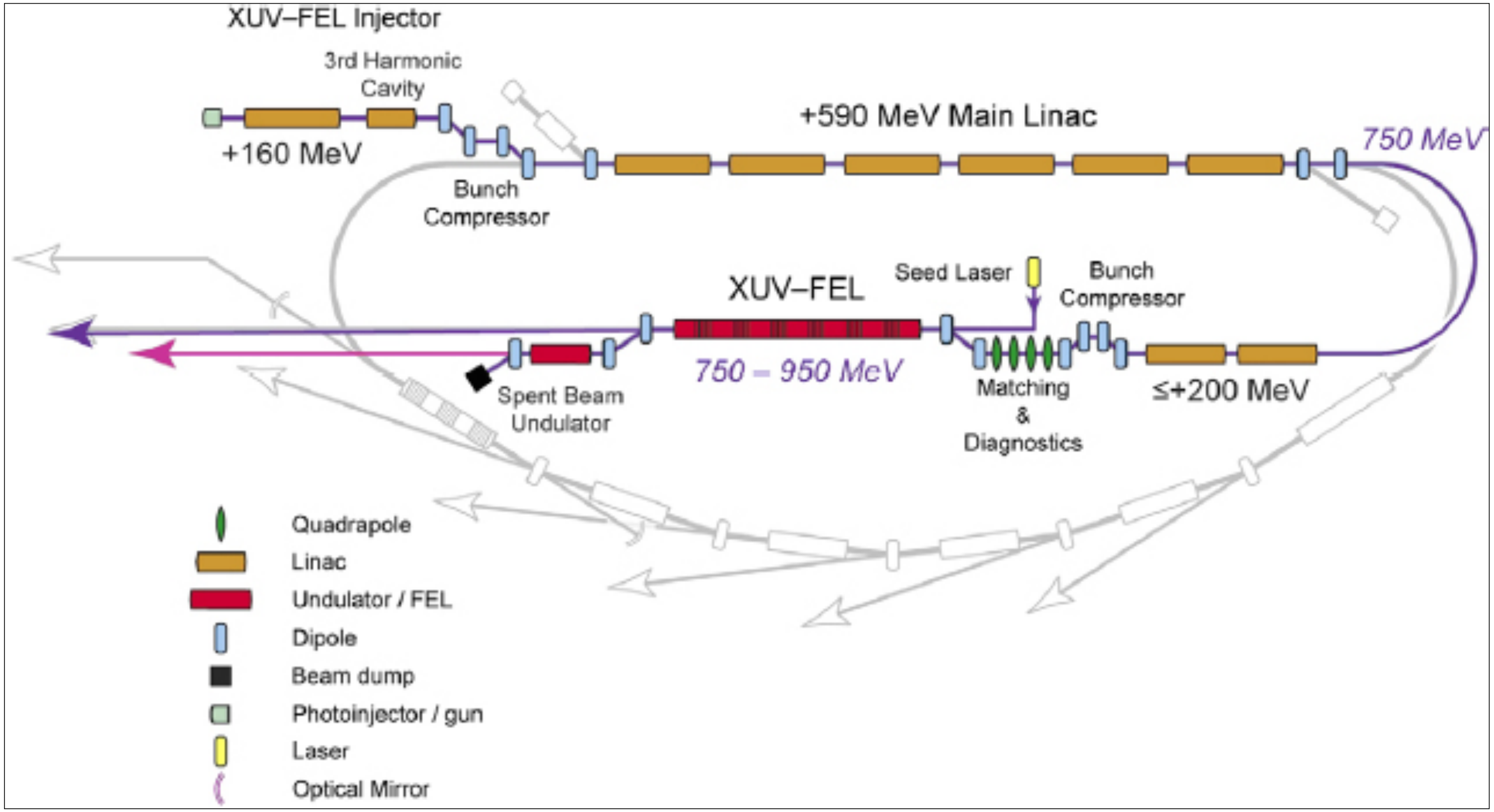
Attilio Milanese and Yuri Pupkov 11/12



Why ASTeC/CI interest in LHeC?

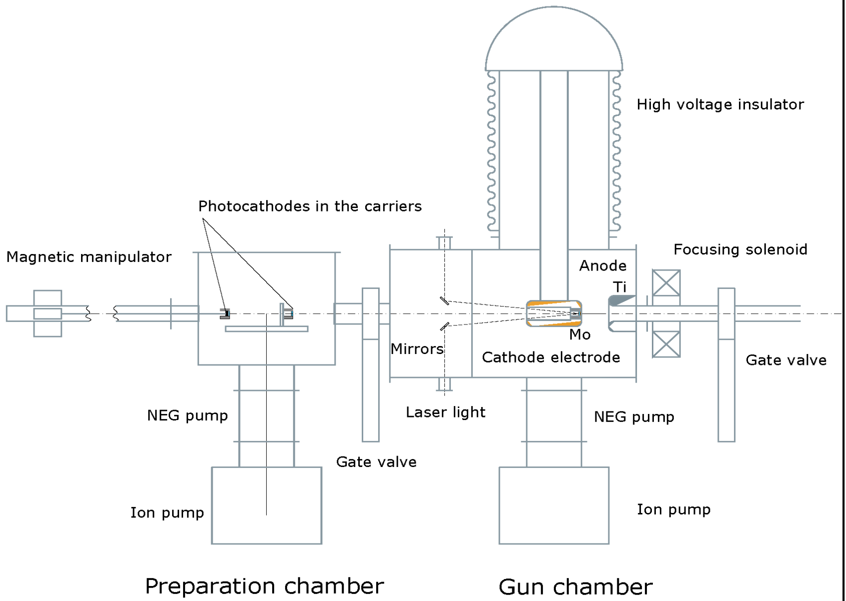
4GLS Project (2004-2008)

- 4th Generation Light Source (sub-GeV; CW, 100mA ERL)
- A host of new (to the UK, at least) technologies :
  SC RF & cryogenics; photoelectron guns; FEL; ERL specific physics.
- Expertise build-up needed → ERLP → ALICE
- 4GLS has not been realised but ALICE remains

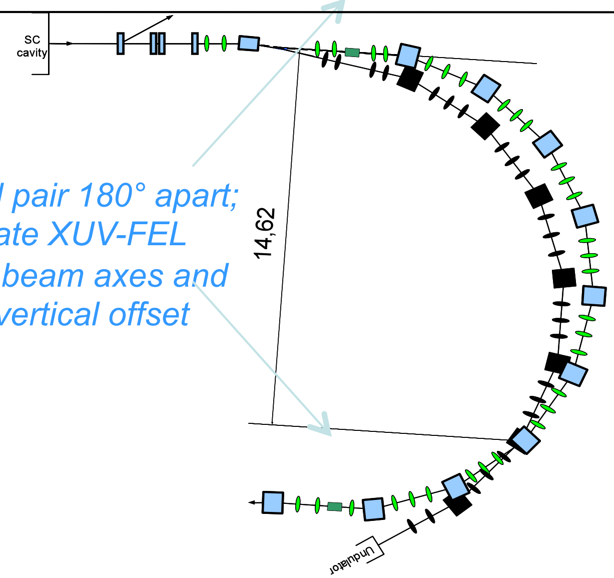


4GLS Project (2004 - 2008)

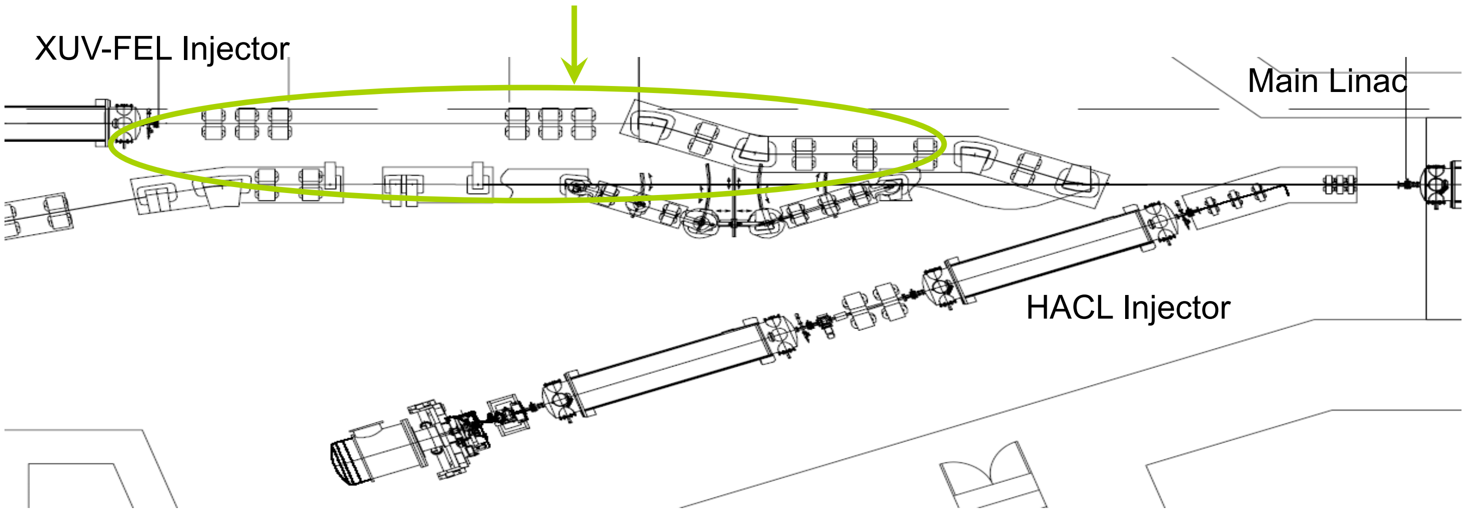
High Average Current DC Gun



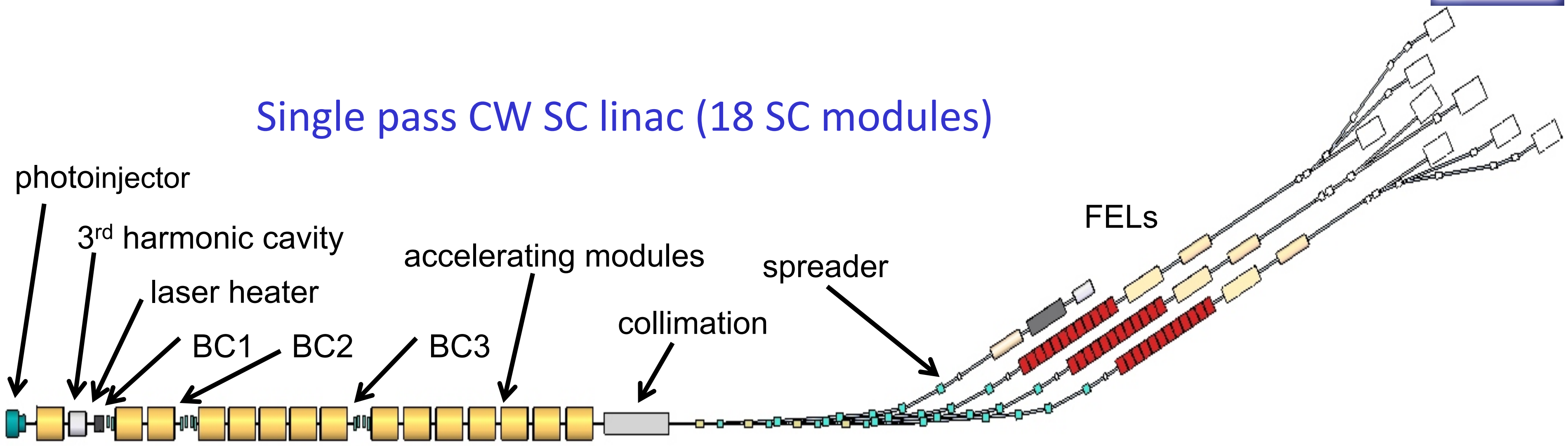
HACL and XUV-FEL Arc Schematic

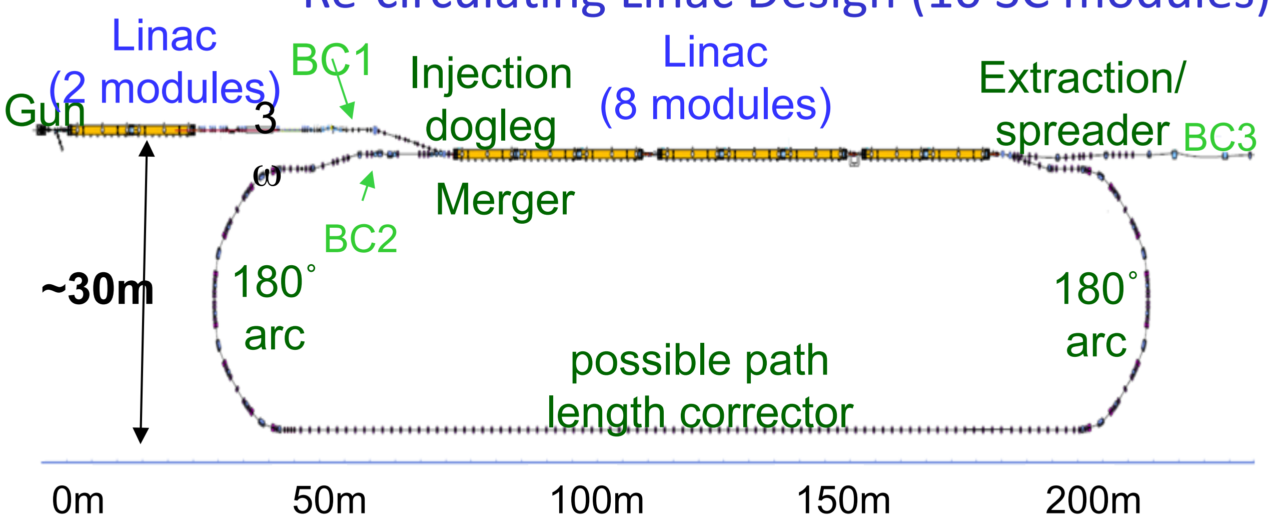


Final Decompression Chicane and Path Length Correction Moving Doglegs



NLS Project (2008 – 2010)



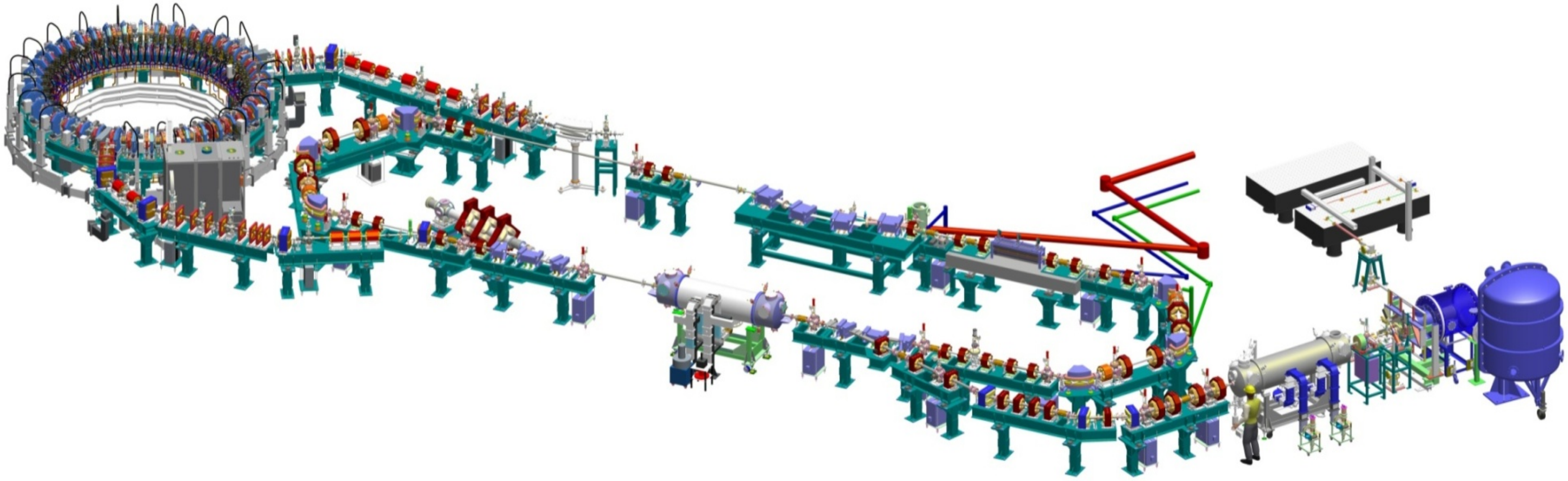


Inject at ~200 MeV, two passes through 1 GeV

Concept and design of SCRF based linac capable of operating at 1 MHz (stage II)

Start-to-end simulations
SCRF cost and optimisation
Outline Design and CDR with full costing.

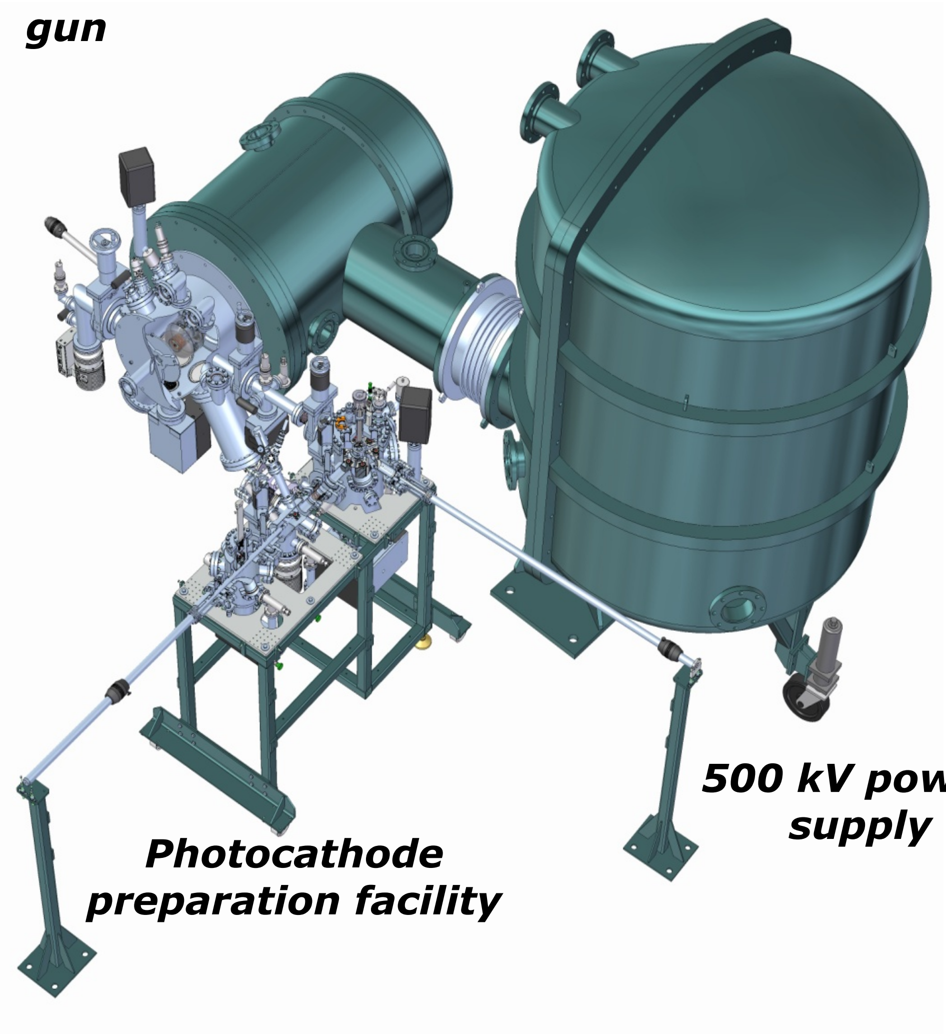
ERLP/ALICE (2004 – 2012)



~A decade of investment in ALICE at Daresbury. Expertise acquired in design and simulations, experimental operational expertise in DC photoguns, GaAs photocathodes, XHV, PI laser, SRF and cryogenics, LLRF and advanced instrumentation.

ALICE is one of very few currently operational ERLs and the only one in Europe till date (few coming up - BERLinPRO, MESA ….).

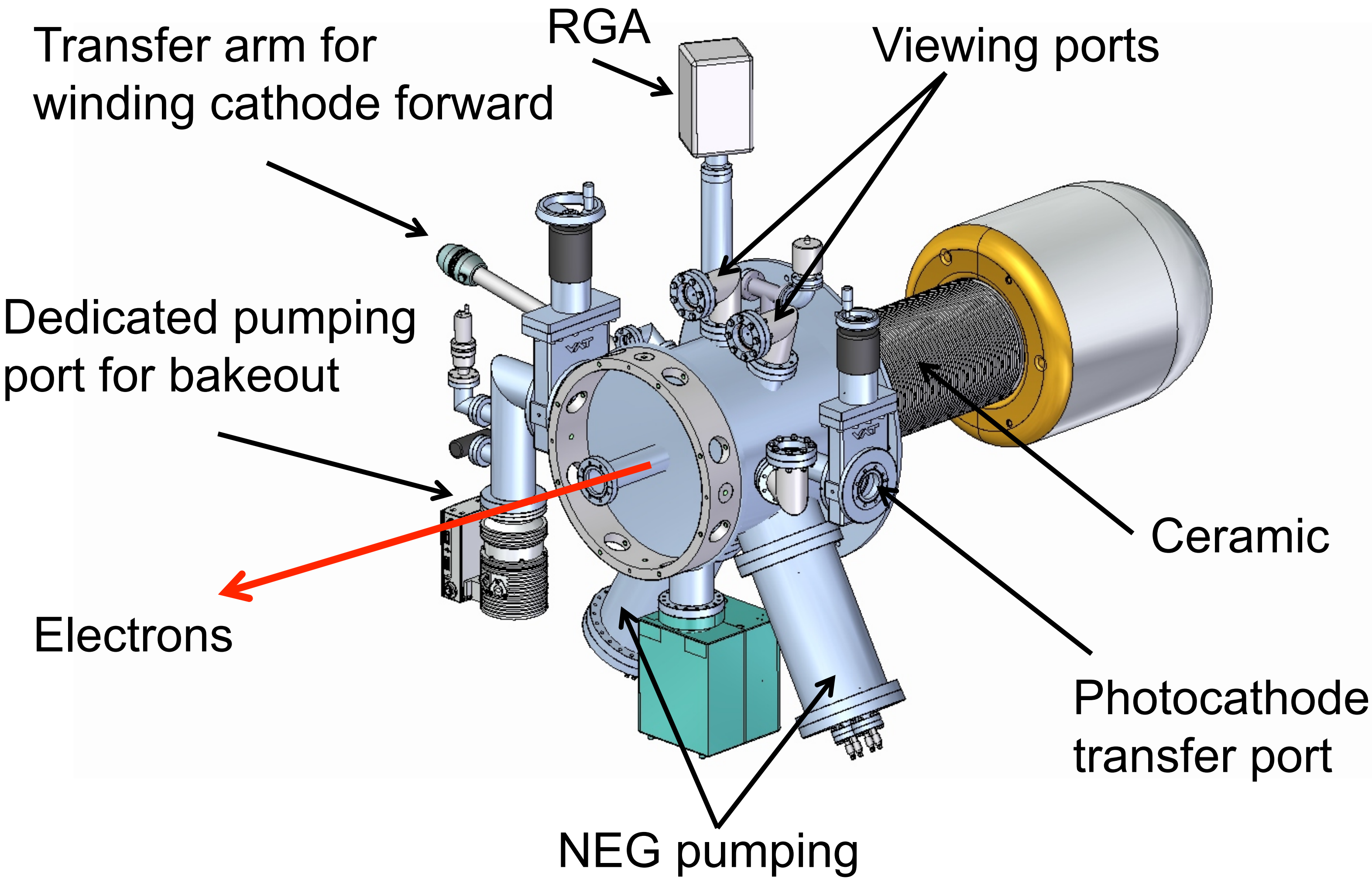
ALICE DC photocathode gun upgrade



Upgrade of the gun allows

- Reduce the down time required for activation of the photocathode and allows ALICE for operation with higher bunch charge.
- Remove activation/caesiation procedure out of the gun
  - Improve vacuum in the gun
  - Reduce contamination of the high voltage electrodes with Cs and other products of photocathode preparation
- Make photocathode activation more controllable
- Allows for experiments with different types of photocathodes

ALICE gun upgrade-Gun vacuum chamber

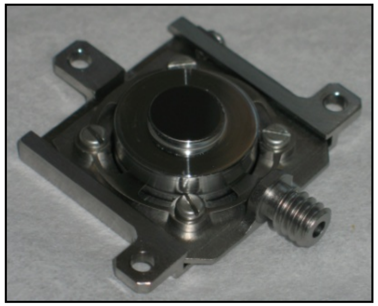


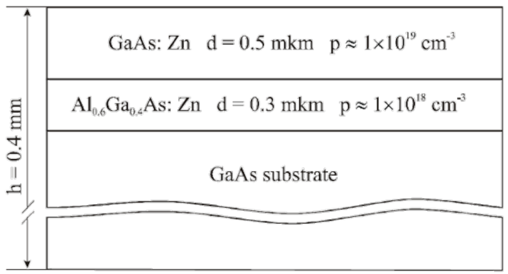
GaAs photocathode preparation facility

Due to ASTeC priorities on projects, decision was taken to not to implement PPF on ALICE. The developed technology and facilities will be used for wide range of R&D experiments to understand physics and performance of photocathodes.

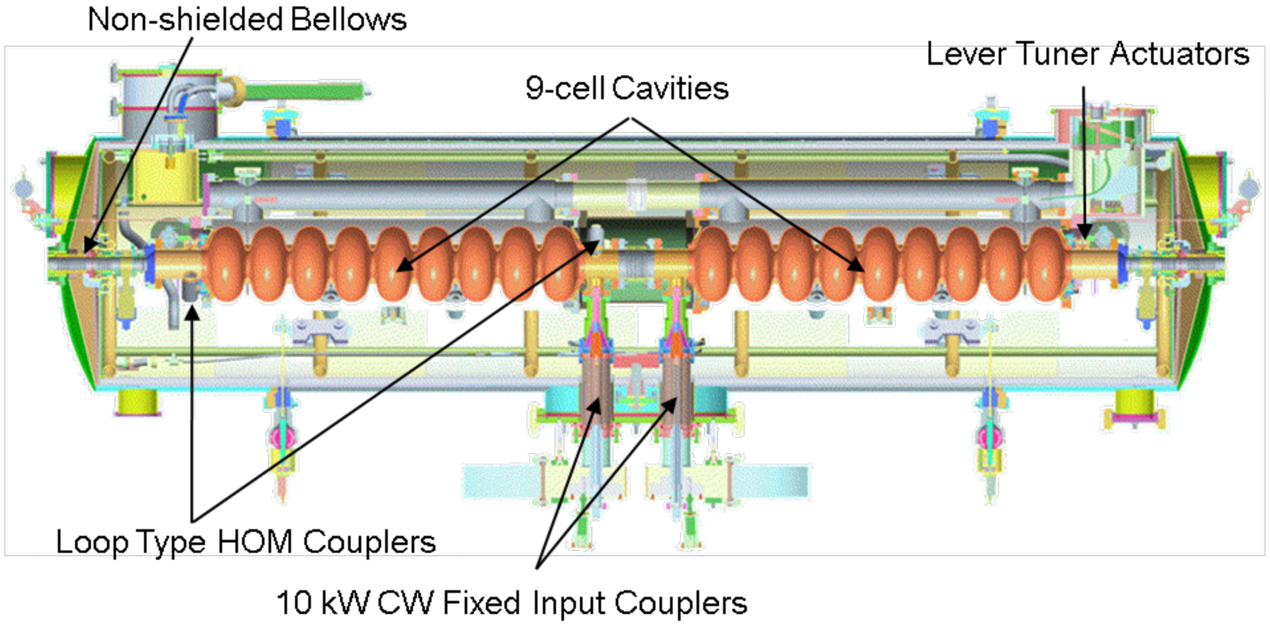
The PPF itself and parts of the mock gun are in place, which will allow to built another gun rather quickly (will be similar to ALICE gun).

High average current GaAs photocathodes



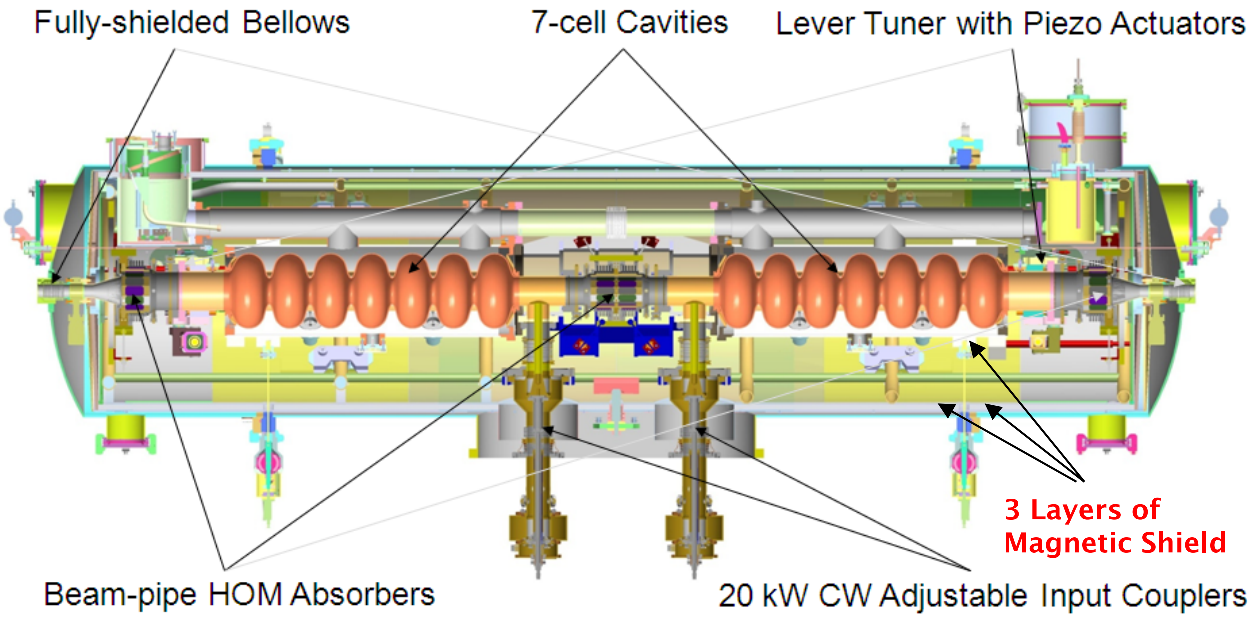


Cryomodule Design Evolution



Existing ALICE CM

New CM



DICC Collaboration Team

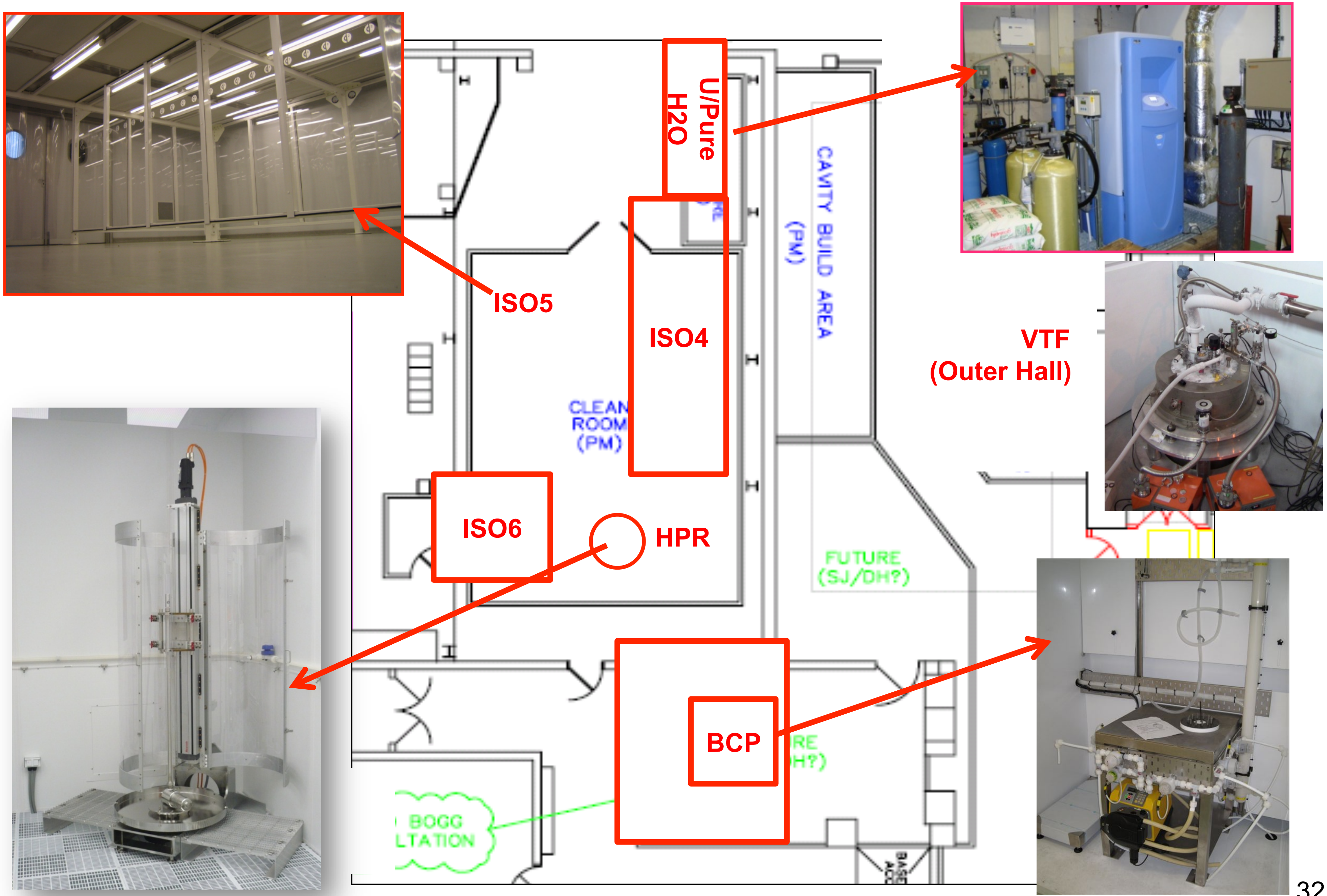
Target Cryomodule Specification

Parameter	**ALICE**	**Target**
Frequency (GHz)	1.3	1.3
Number of Cavities	2	2
Number of Cells/Cavity	**9**	**7**
Cavity Length (m)	1.038	0.807
Cryomodule Length (m)	3.6	3.6
R/Q (Ω)	1036	762
E_{acc} (MV/m)	**12 - 15**	**>20**
CM Energy Gain (MeV)	**27**	**>32**
Q_o	**$<5 \times 10^9$**	**$>10^{10}$**
Q_{ext}	**4×10^6**	**$4 \times 10^6 - 10^8$**
Max Cavity FWD Pwr (kW)	**10 SW**	**20 SW**

- International collaboration initiated in early 2006:
  - ASTeC (STFC)
  - Cornell University
  - DESY
  - FZD-Rossendorf
  - LBNL
  - Stanford University
  - TRIUMF (2009)
- Fabricate new cryomodule and validate with beam.
- Dimensioned to fit on ALICE:
  - Same CM footprint
  - Same cryo/RF interconnects
  - ‘Plug Compatible’

- **With new cryomodule, ALICE can reach design beam energy of 35MeV (currently operation at 26.0 MeV)**
- **New cryomodule installation and commissioning in 2013, looking at characterisation with beam ~July2013.**
- **ALICE will then run for science in 2014 for limited duration.**

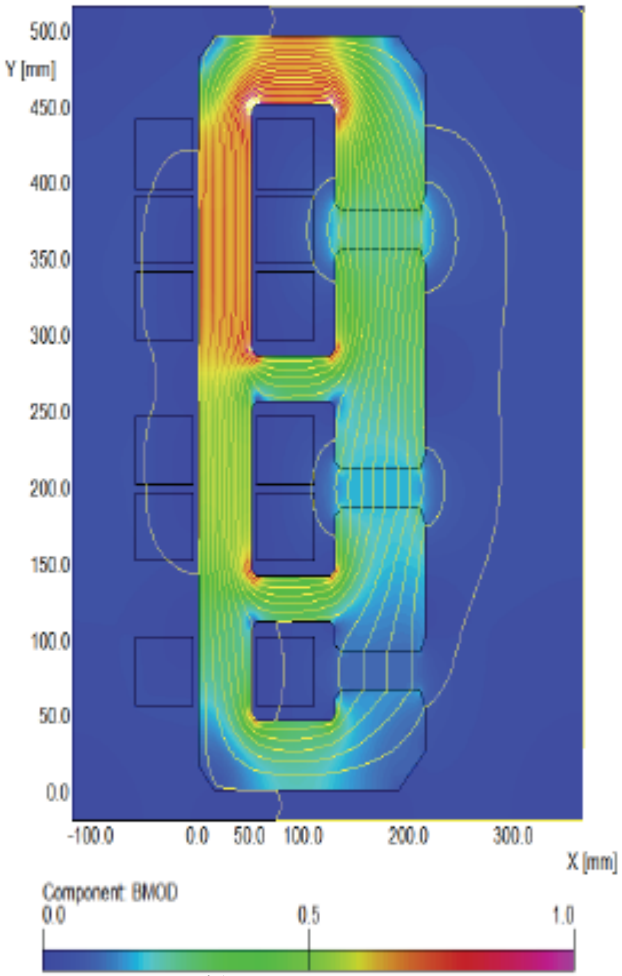
SRF Infrastructure



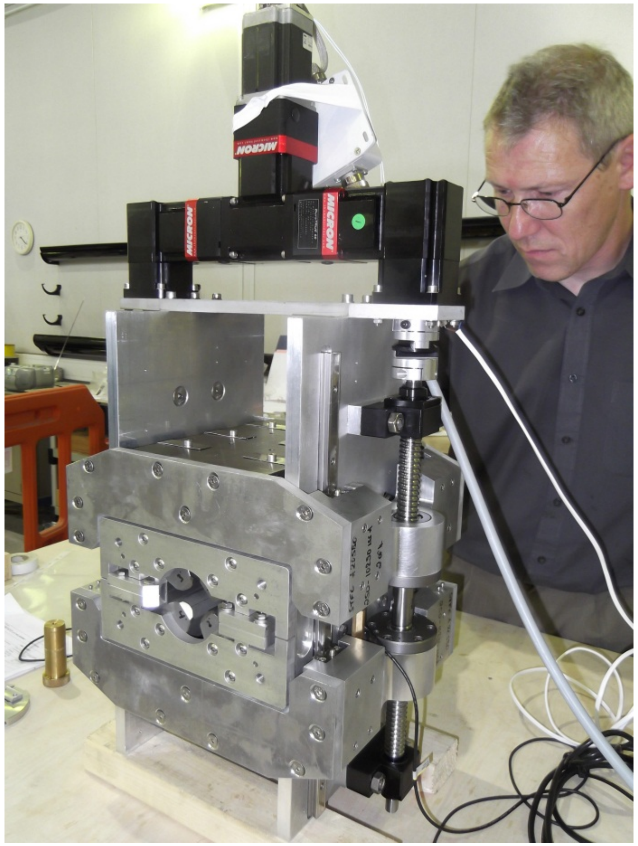
Novel Magnets

ERL re-circulator dipoles and quadrupoles : new requirements (aperture, field)? Combined apertures/functions? *ASTeC has suggested an efficient powering scheme for arc dipoles.*

Linac quadrupoles : more compact magnets – PM/SC?



A. Milanese, CERN



CLIC drive beam PM quadrupole prototype. ASTeC and Technology in collaboration with CERN

ASTeC/CI Interest

- Following discussion within CI after Chavannes workshop, list of areas of interest, possible deliverables and required resources was outlined.
  - **Test Facility**
  - **Polarised electron source**
  - **Positron source**
  - **Interaction region**
  - **SCRF**
  - **Optics and beam dynamics**
  - **Magnets**
  - **Instrumentation**
- CI is participating in HL-LHC and have worked earlier on ring-ring option, both synergetic with Linac-Ring option.

Present Status:

•New resources required to embark on this challenging project.

•Programmatic review underway in STFC.

•Following outcome of European Strategy, clear mandate from CERN with commitment to LHeC project is crucial.

•MOU between STFC and CERN

- Iteration on drafts – STFC and CERN legals
- MoU specific to LHeC at present *but could be modified to include Generic Accelerator Science and Technology R&D if necessary*.

Our participation is driven by the synergies with ALICE and collaboration which would maintain and develop generically applicable skills which support energy recovery machines.