LHeC

On behalf of the LHeC Collaboration!

➔ LHeC-Note-2011-001 GEN

- Introduction & motivation
- Two options: -Ring-R ...
  ...th Energy Recovery
- IR La...
- ...
- Plan... ...g and timeline

CDR Authorlist 29.6.11

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LHeC: Motivation

- Exploring the interaction of matter in three channels:

  -hadronic interaction: pp or pp-bar collisions (e.g. SppS, Tev)
  -leptonic interactions: ep collisions (e.g. SLC, LEP)
  -hadronic-leptonic interactions (e.g. HERA)

  In the past the exploration of all three channels have provided vital insight for the construction of the Standard Model

- e-p collisions for the TeV Scale:
  -TeV CM collision energies using the LHC require lepton beam energies between 60 GeV and 140 GeV
  -Efficient exploitation requires a luminosity of: $L \approx 10^{33}\ cm^{-2}\ s^{-1}$

LHeC Proposal endorsed by ECFA (30.11.2007)

As an add-on to the LHC, the LHeC delivers in excess of 1 TeV to the electron-quark cms system. It accesses high parton densities 'beyond' what is expected to be the unitarity limit. Its physics is thus fundamental and deserves to be further worked out, also with respect to the findings at the LHC and the final results of the Tevatron and of HERA.

First considerations of a ring-ring and a linac-ring accelerator layout lead to an unprecedented combination of energy and luminosity in lepton-hadron physics, exploiting the latest developments in accelerator and detector technology.

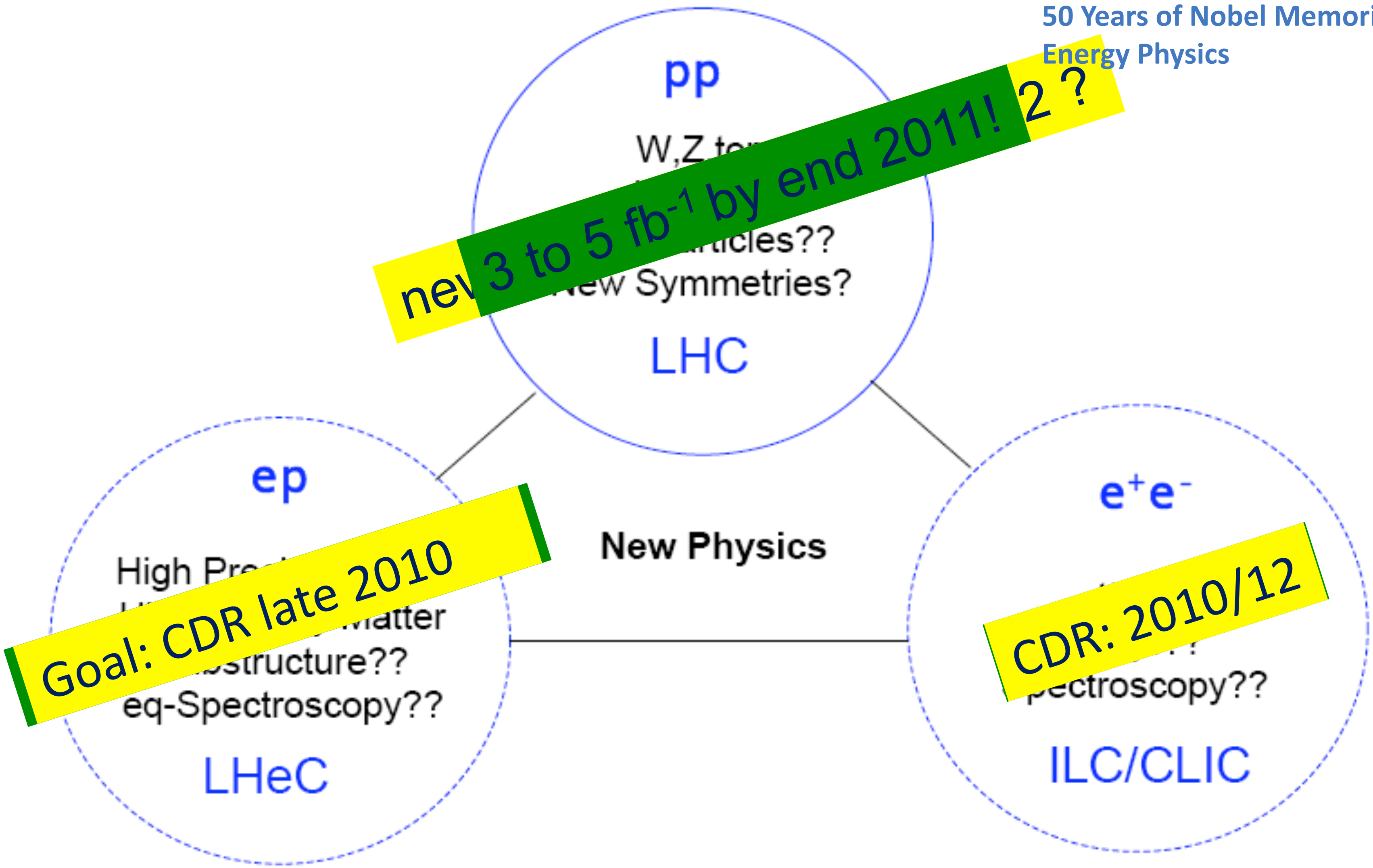
It is thus proposed to hold two workshops (2008 and 2009), under the auspices of ECFA and CERN, with the goal of having a Conceptual Design Report on the accelerator, the experiment and the physics. A Technical Design report will then follow if appropriate.

Unanimously supported by rECFA and ECFA plenary in November 2007

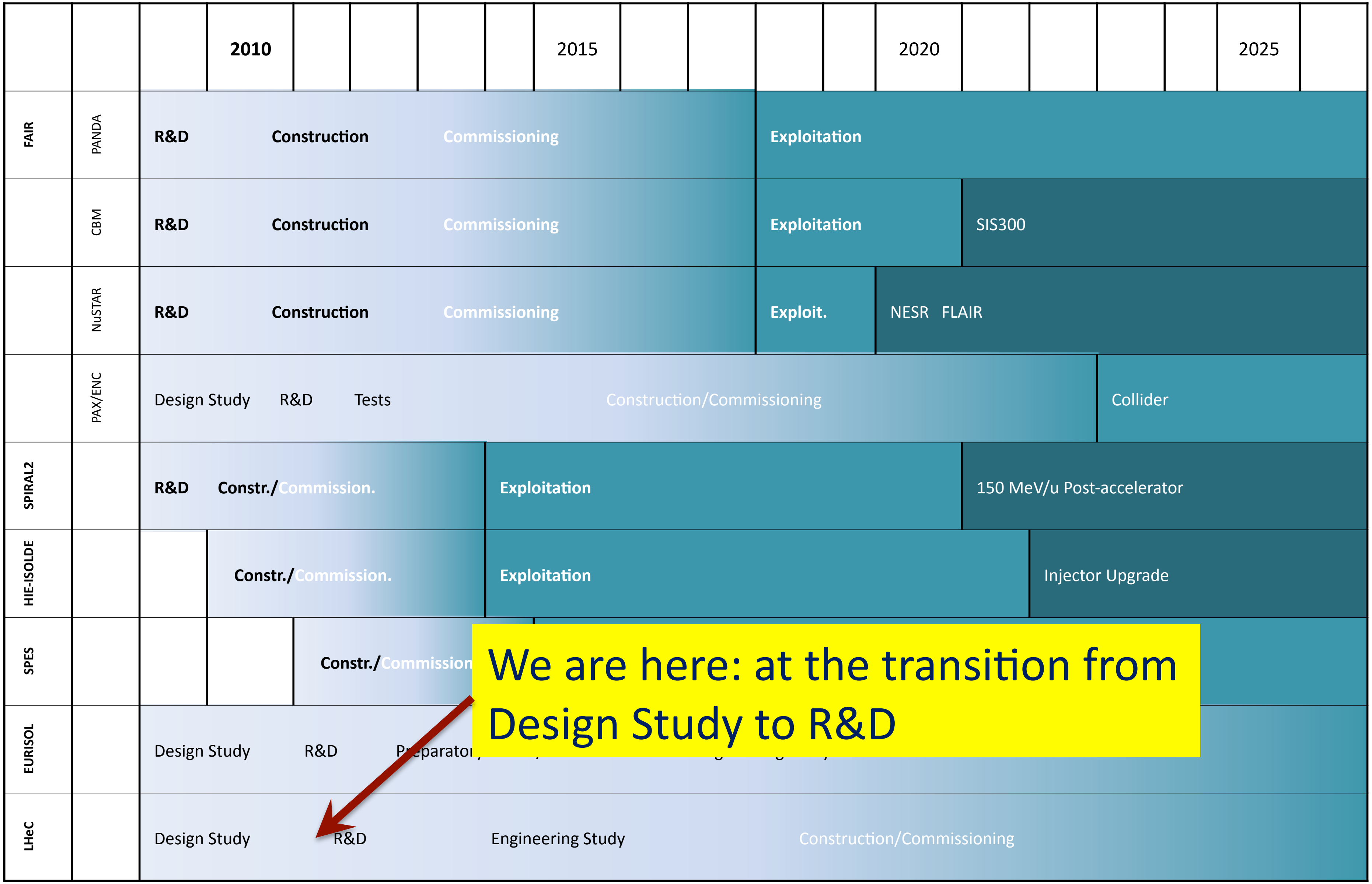
The TeV Scale [2008-2033..]

Rolf Heuer: 3/4. 12. 09 at CERN: From the Proton Synchroton to the Large Hadron Collider

50 Years of Nobel Memories in High-Energy Physics



NuPECC – Roadmap 5/2010: New Large-Scale Facilities



G. Rosner, NuPECC Chair, Madrid 5/10 – published in December 2010

Design Considerations

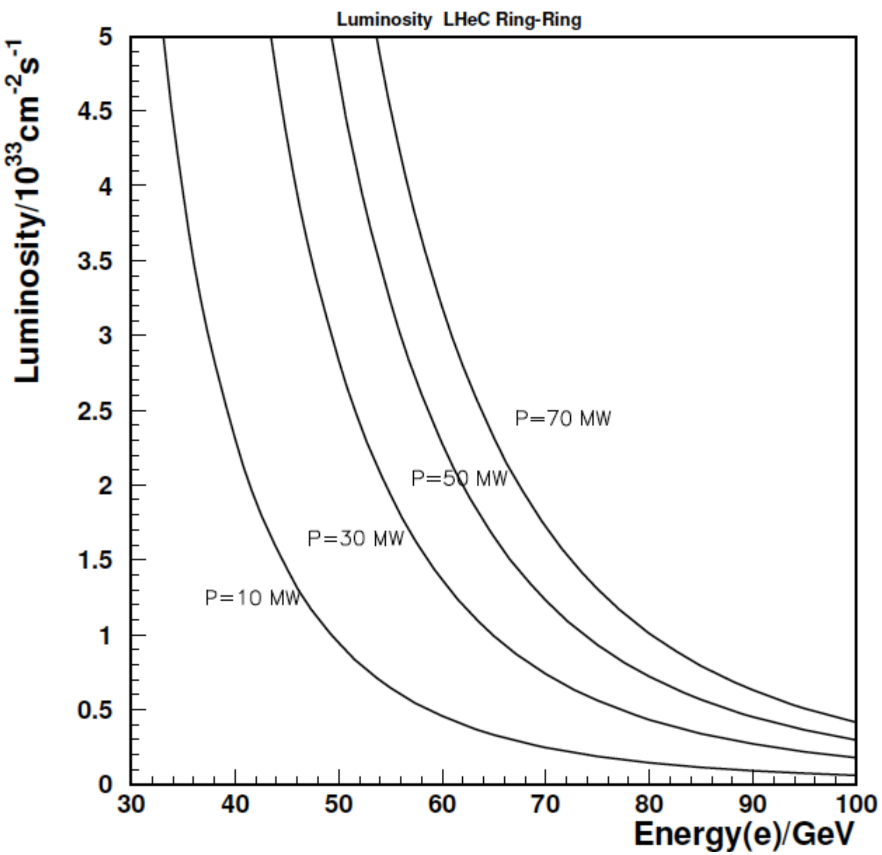
LHC hadron beams: E_p=7 TeV; CM collision energy: $E^2_{CM} = 4\ E_e{}^*\ E_{p,A}$ ➔ 50 to 150GeV

Integrated e±p : O(100) fb^{-1} ≈ 100 * L(HERA) → synchronous ep and pp operation

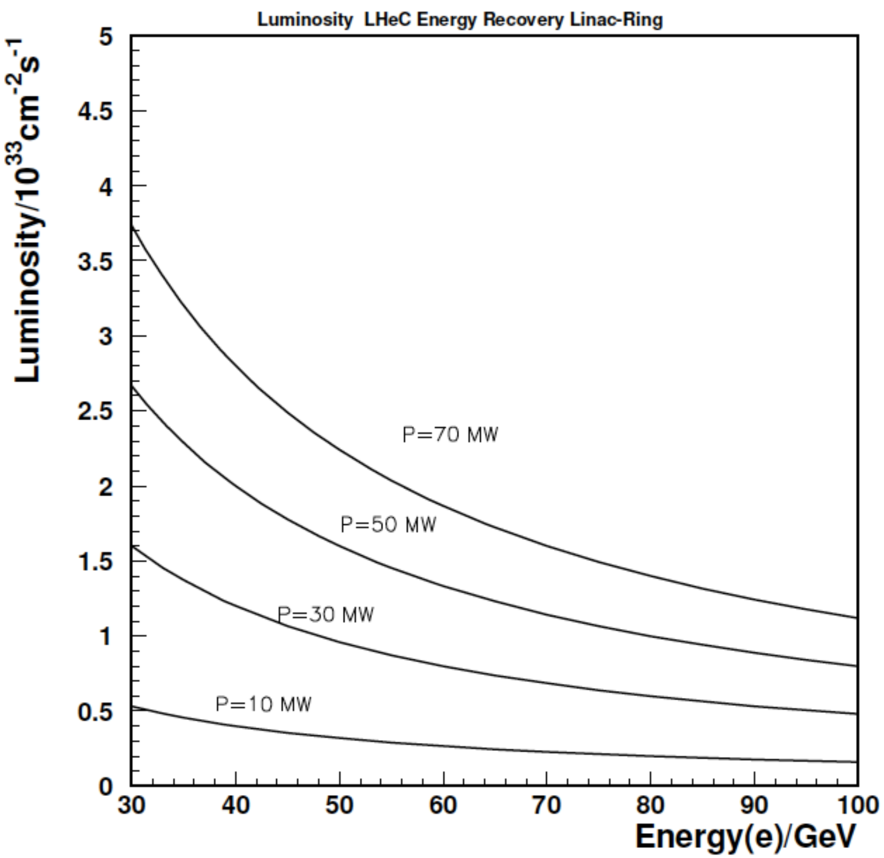
Luminosity O (10^{33}) $cm^{-2}s^{-1}$ with 100 MW power consumption ➔ Beam Power < 70 MW

Start of LHeC operation together with HL-LHC in 2023 (installation in LS3 in 2022)

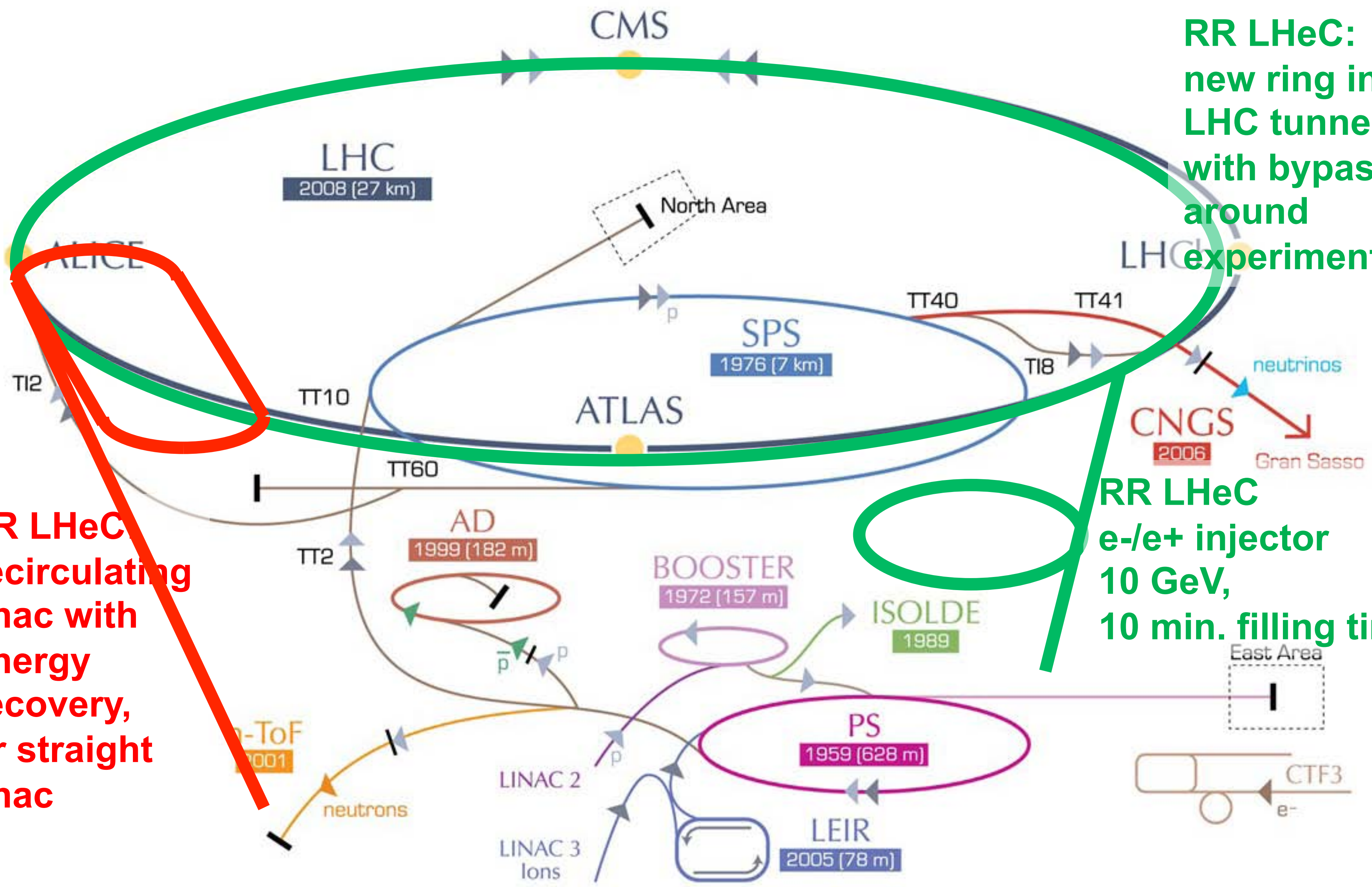
e Ring in the LHC tunnel (Ring-Ring - RR)



Superconducting ERL (Linac-Ring -LR)



LHeC options: RR and LR

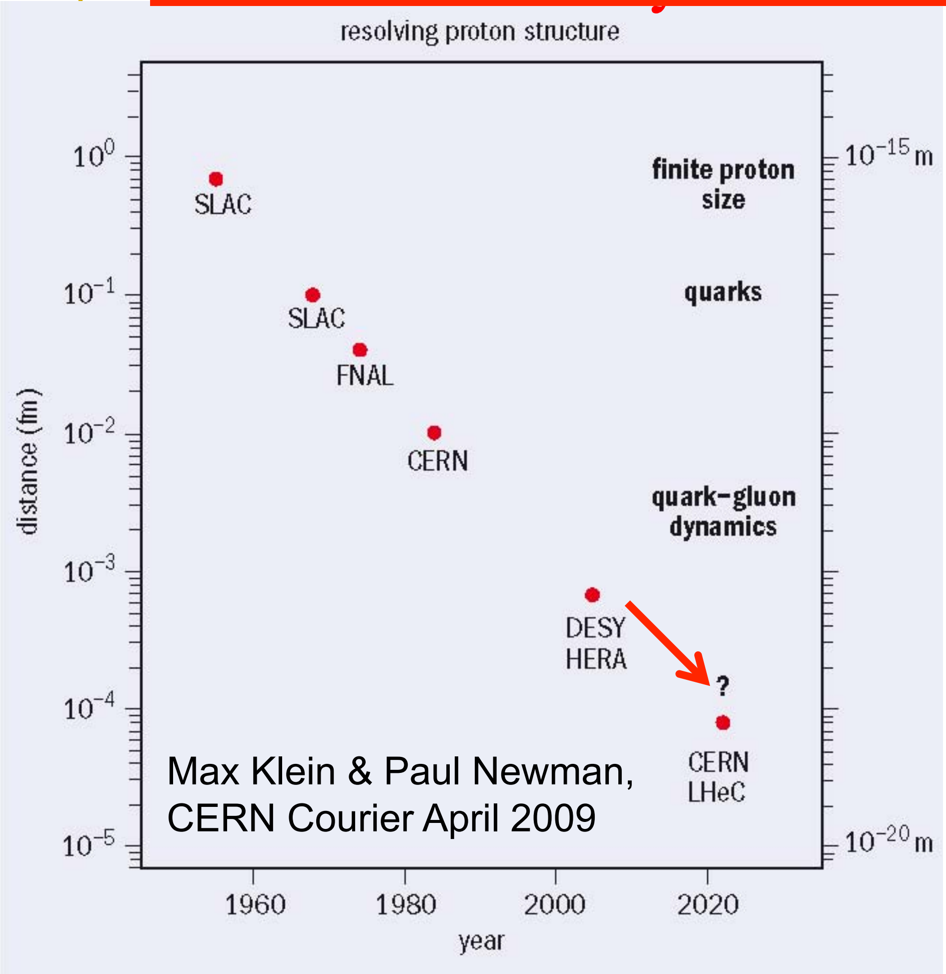


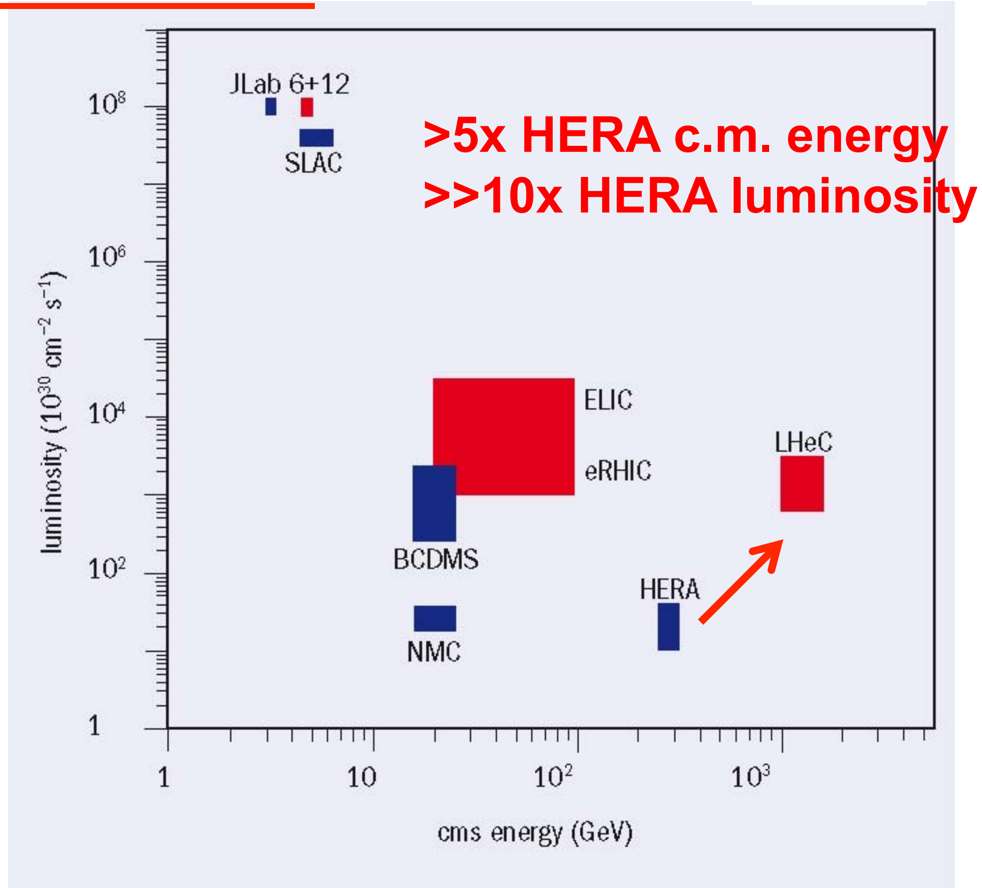
RR LHeC: new ring in LHC tunnel, with bypasses around experiments

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

LR LHeC: recirculating linac with energy recovery, or straight linac

LHeC - Physics motivation





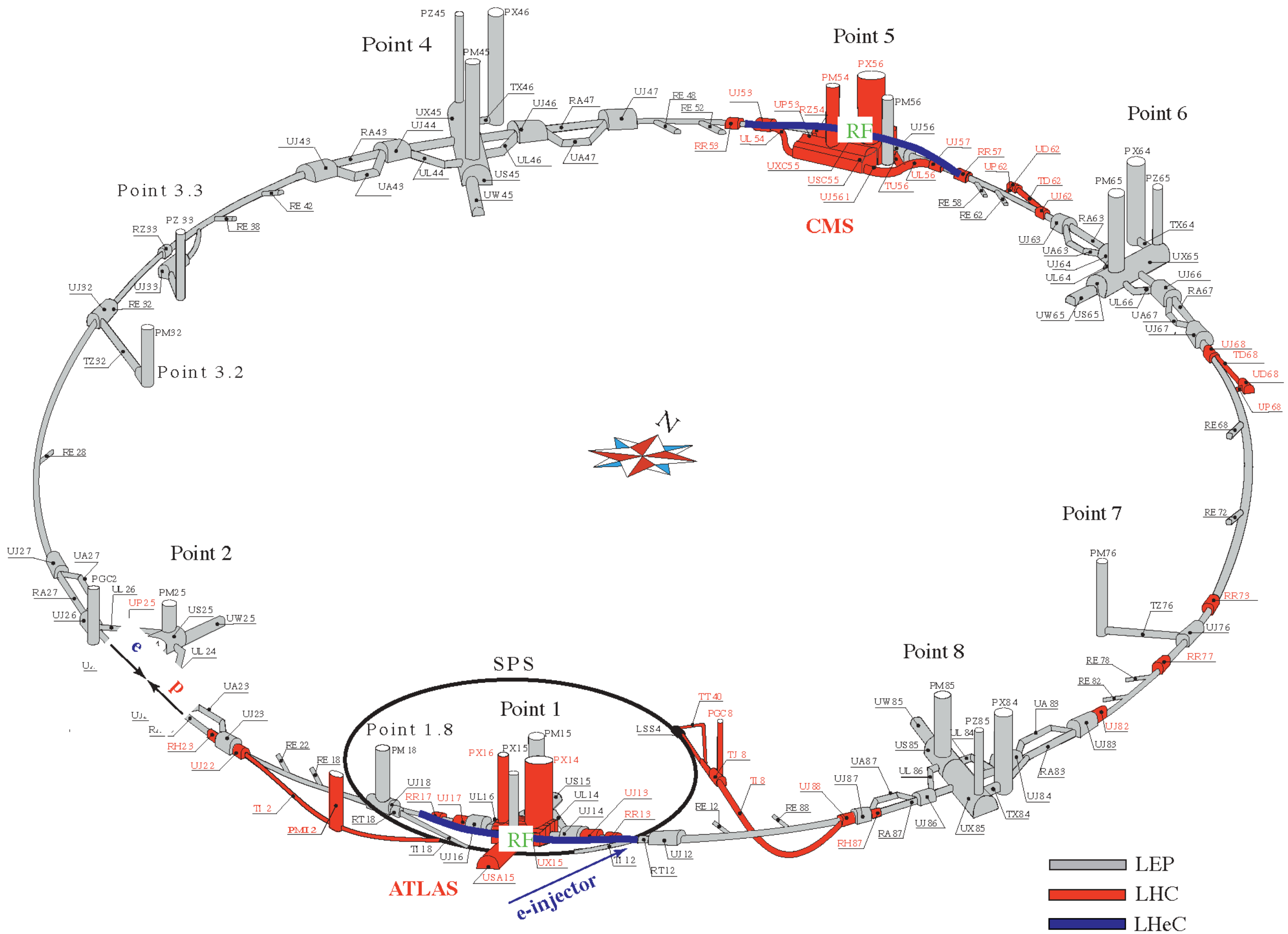
Max Klein & Paul Newman, CERN Courier April 2009

distance scales resolved in lepton-hadron scattering experiments since 1950s, and some of the new physics revealed

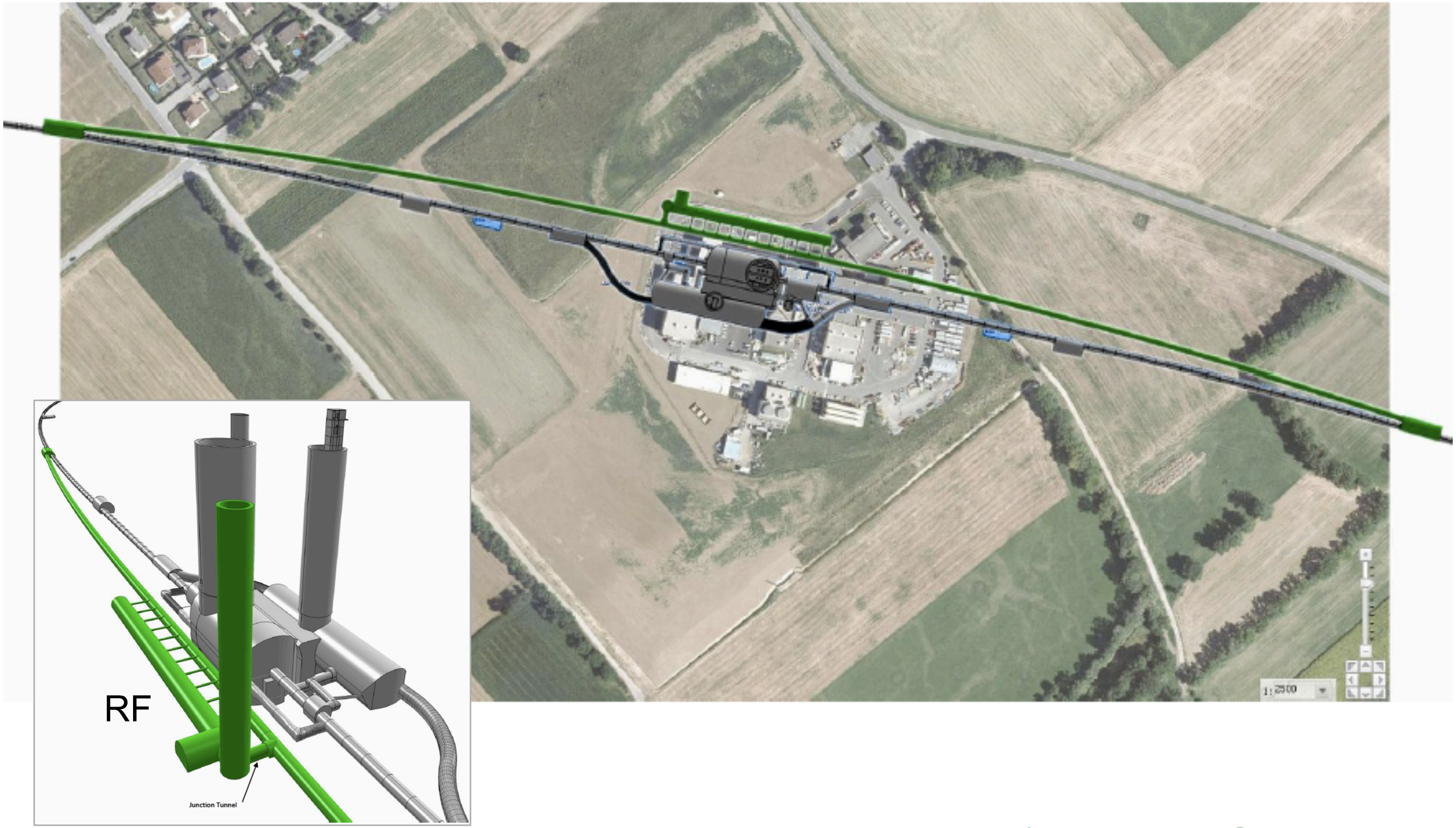
energies and luminosities of existing and proposed future lepton-proton scattering facilities

LHeC: Ring-Ring Option

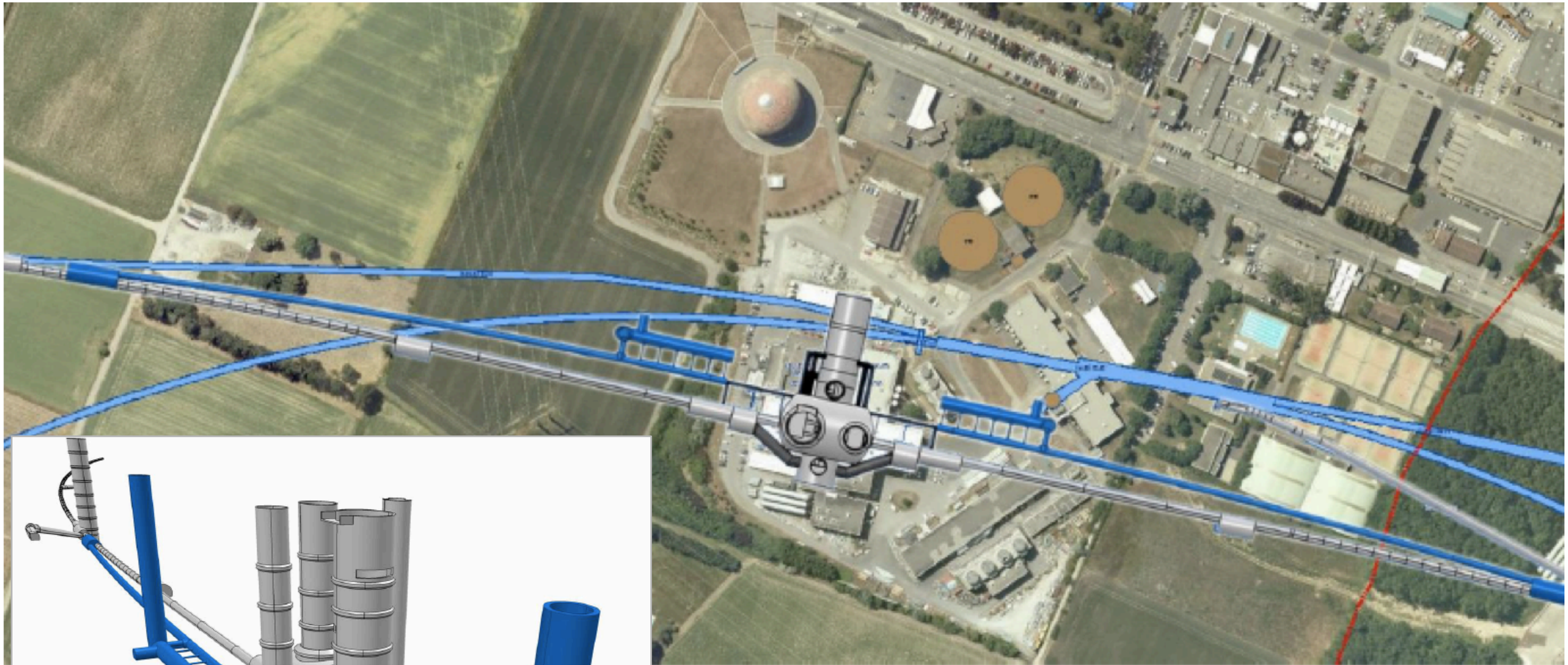
Challenge 1: Bypassing the main LHC detectors

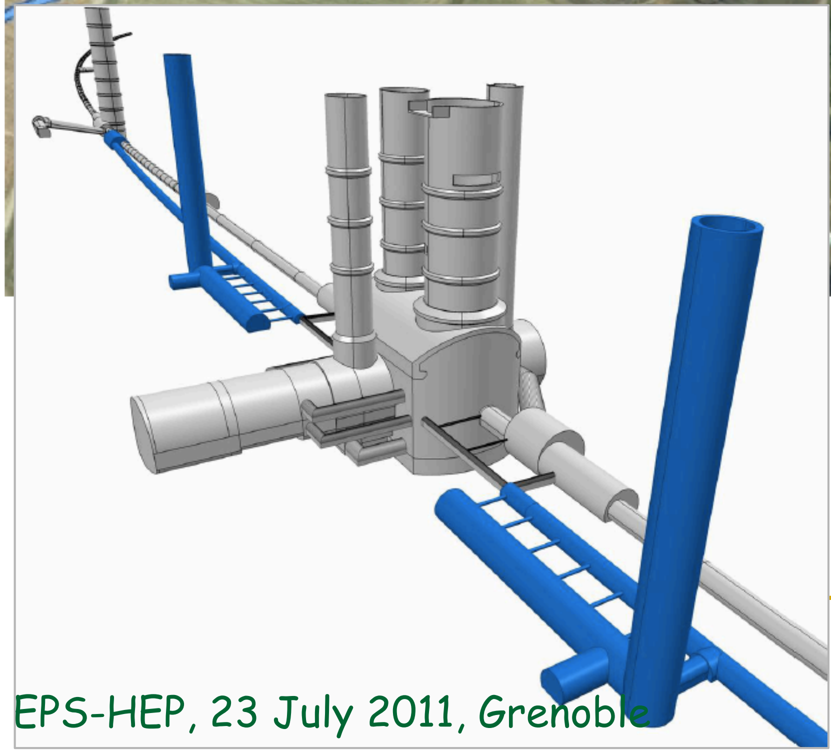


Bypassing CMS: 20m distance to Cavern



Bypassing ATLAS: 100m wo survey gallery

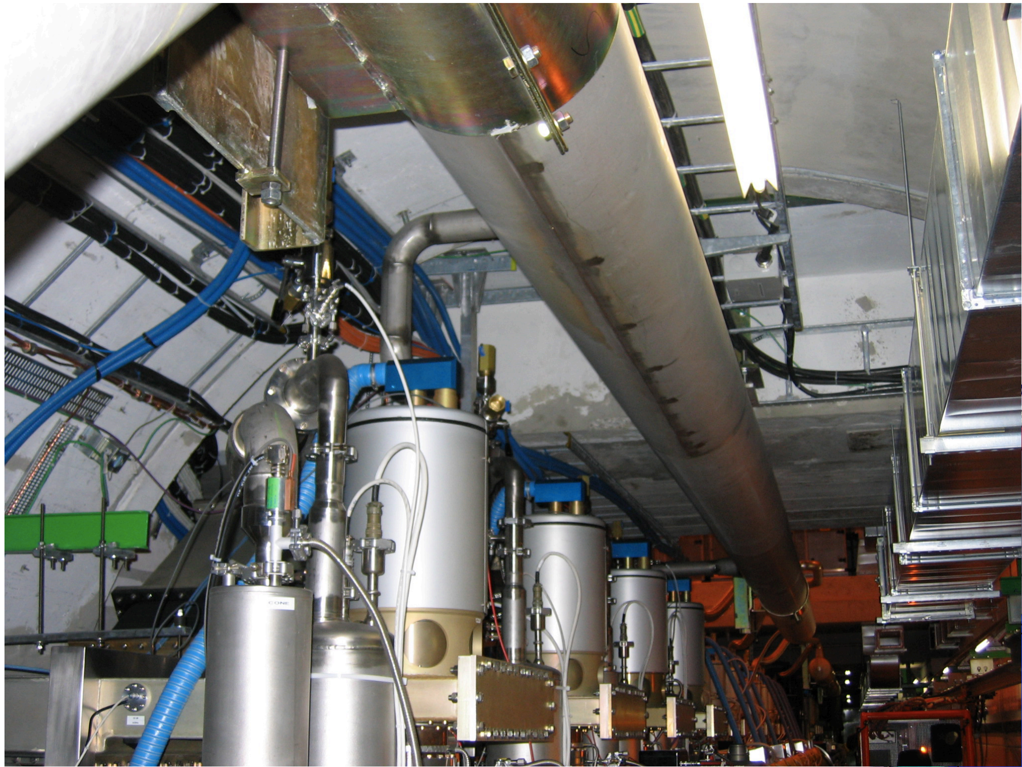




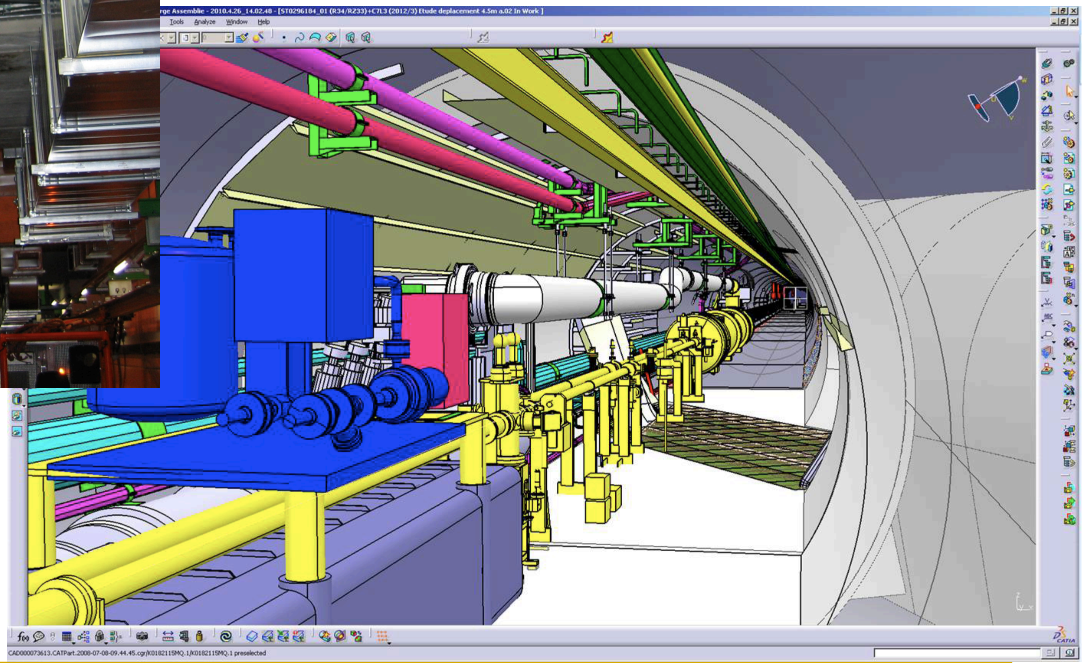
For the CDR the bypass concepts were decided to be confined to ATLAS and CMS

LHeC: Ring-Ring Option

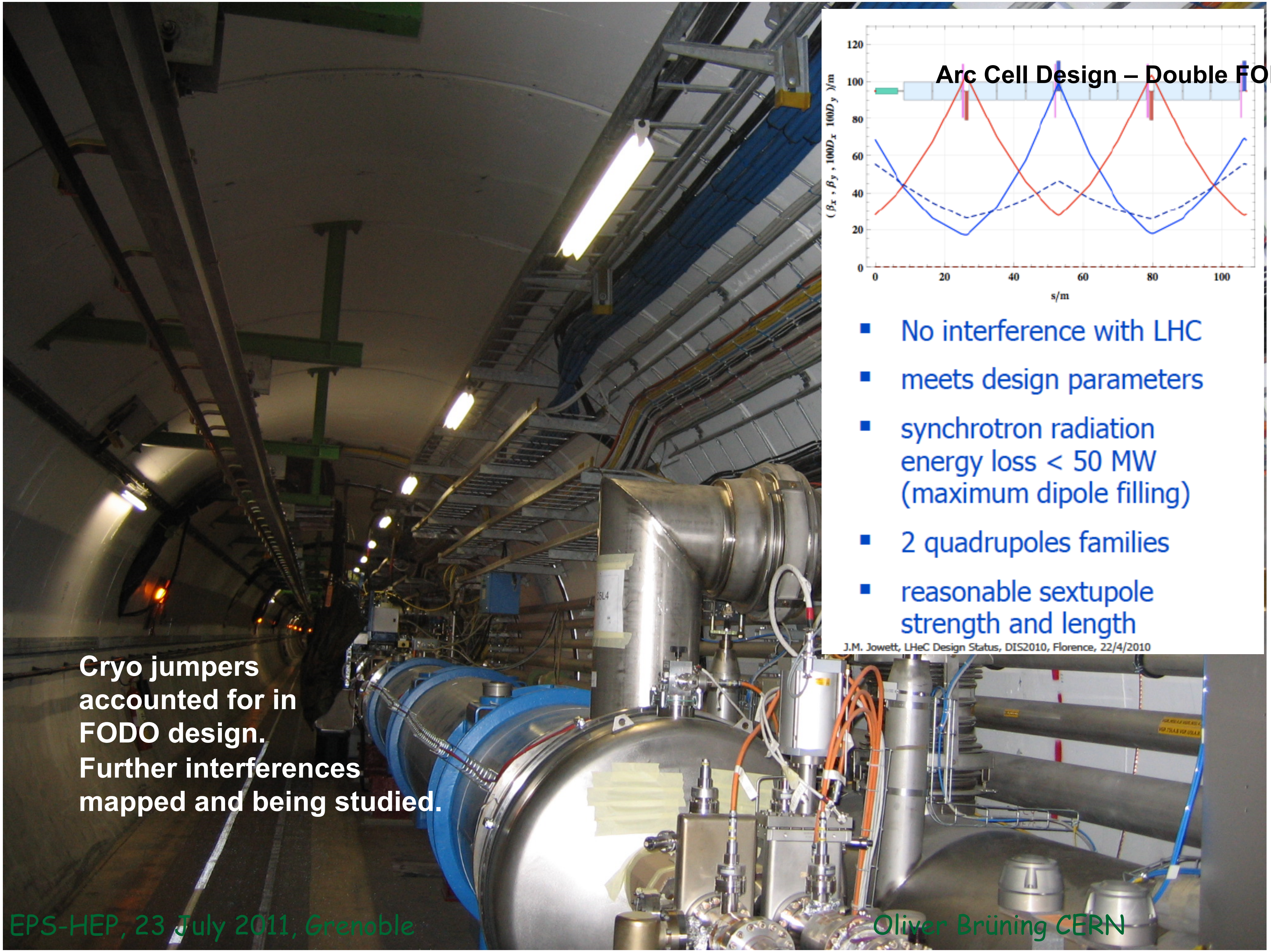
Challenge 2: Integration in the LHC tunnel



RF Installation in IR4



Cryo link in IR3



- No interference with LHC
- meets design parameters
- synchrotron radiation energy loss < 50 MW (maximum dipole filling)
- 2 quadrupoles families
- reasonable sextupole strength and length

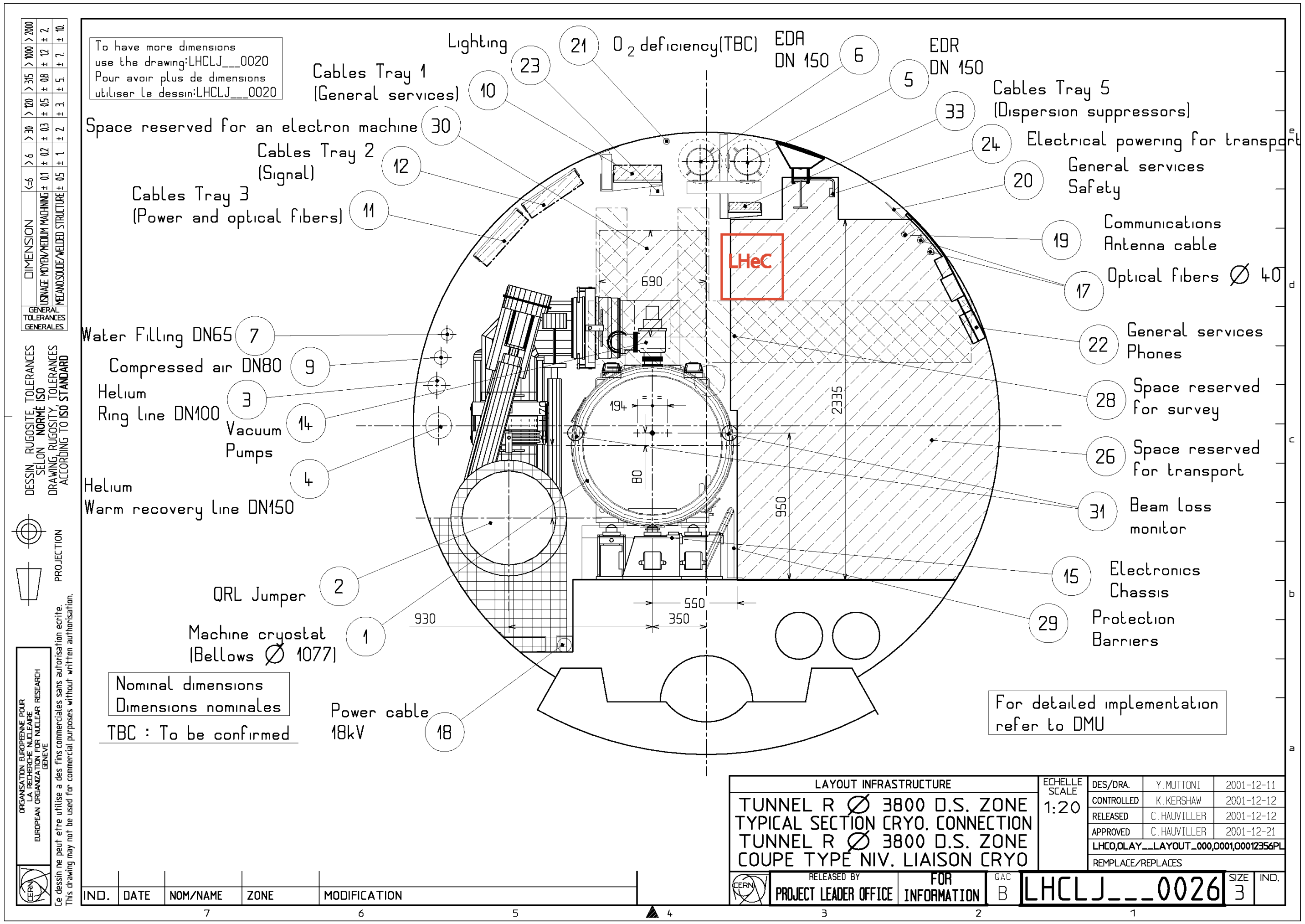
J.M. Jowett, LHeC Design Status, DIS2010, Florence, 22/4/2010

Cryo jumpers accounted for in FODO design. Further interferences mapped and being studied.

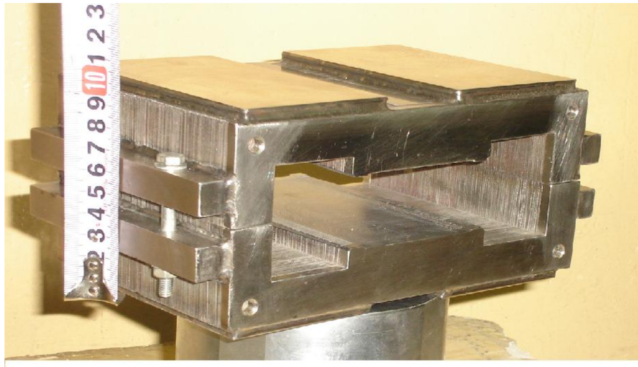
LHeC: Ring-Ring Option

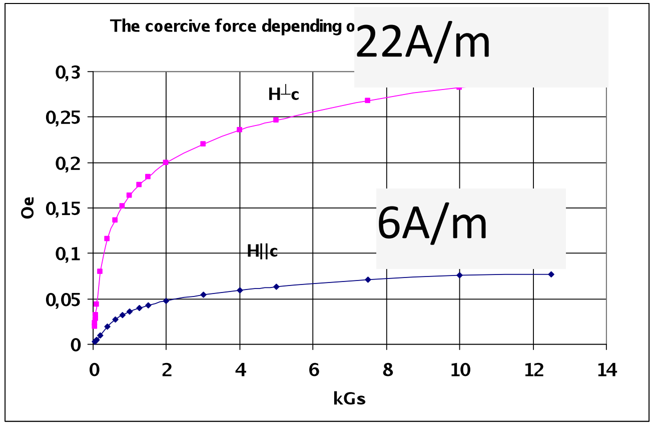
Challenge 3: Installation with LHC circumference:

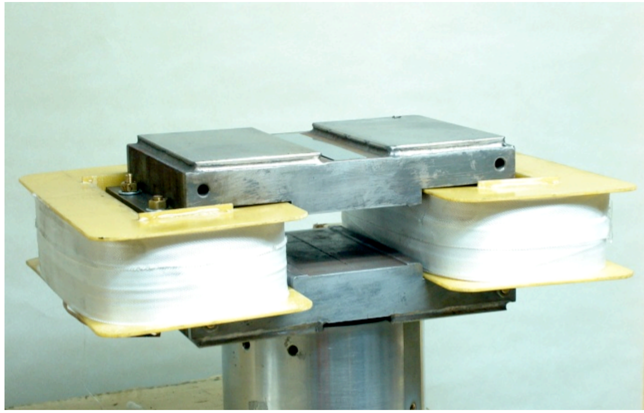
requires: support structure with efficient montage and compact magnets

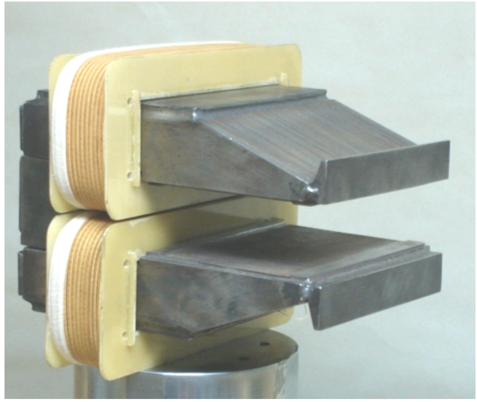


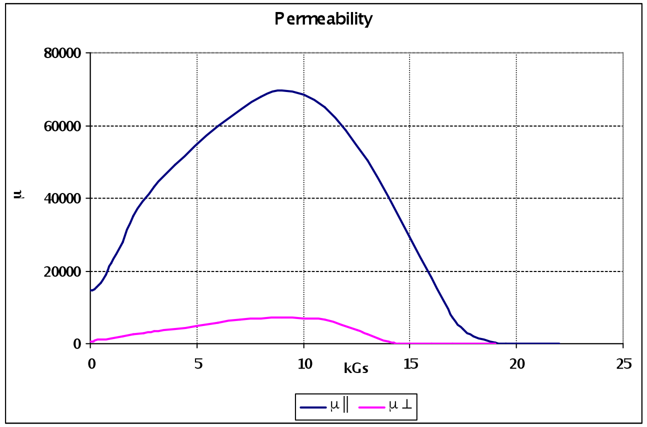
Dipole Prototype- BINP (Novosibirsk)

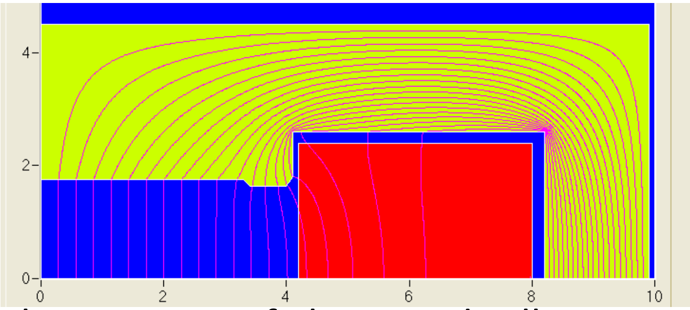




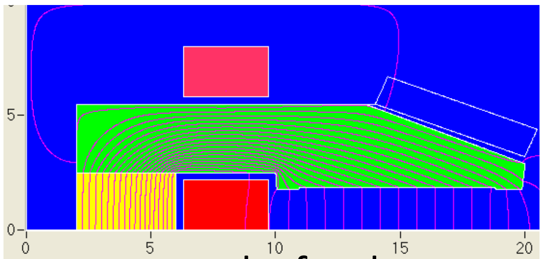








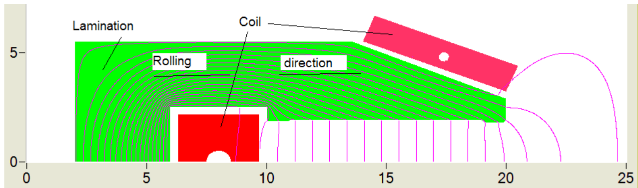
laminations of alternated rolling



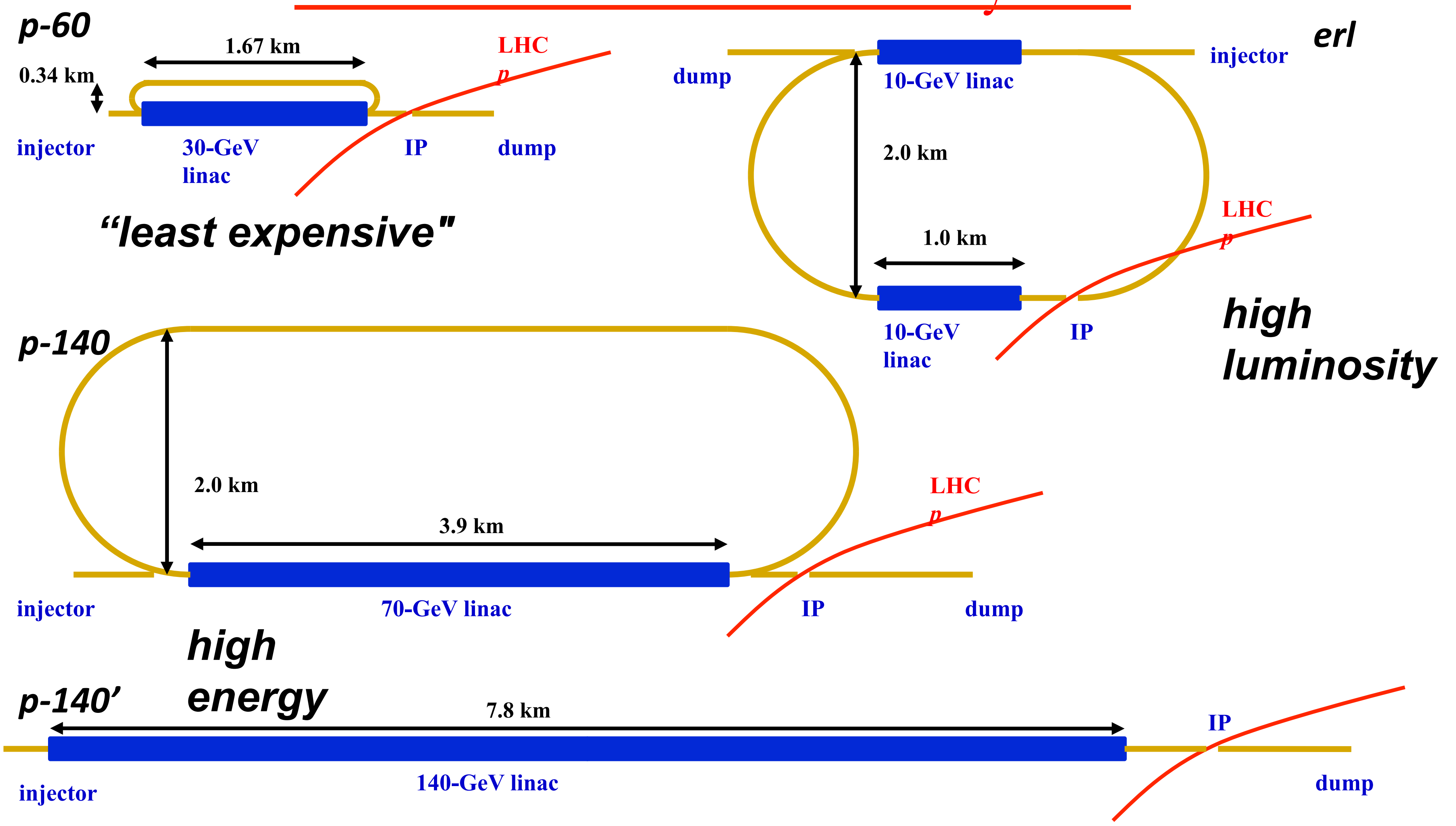
same results for the two alternatives

3408 grain oriented steel
0.35 mm thick laminations

Reproducibility of injection field is below 0.1 Gauss!



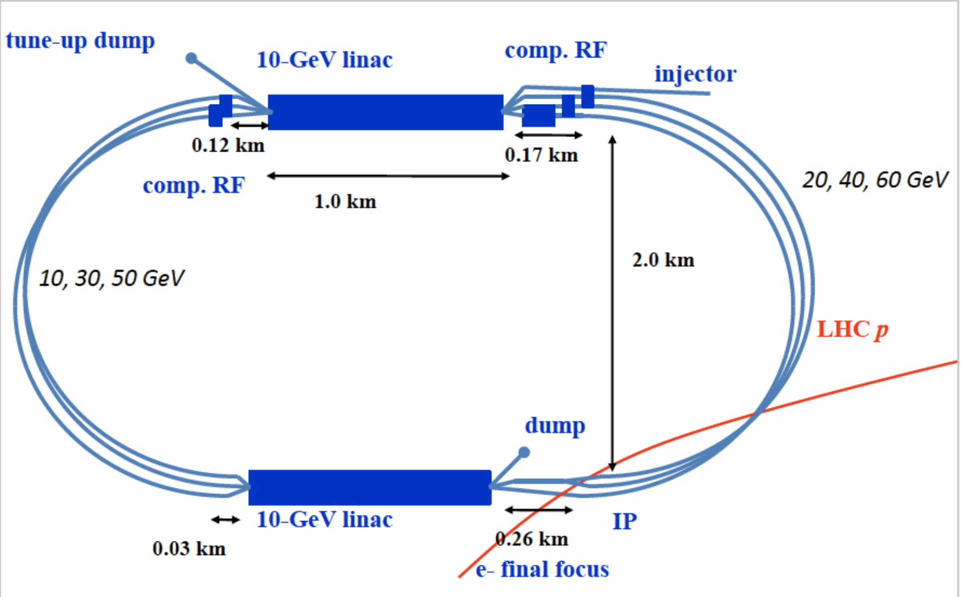
LHeC: Linac-Ring Option → Considered Various Layout



LHeC: Baseline Linac-Ring Option

LHeC

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



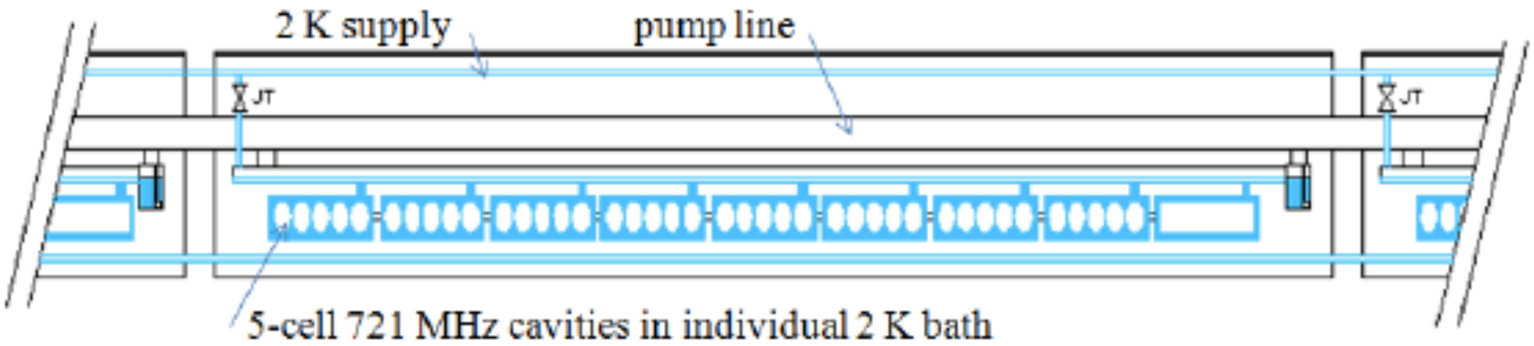
Two 1 km long SC linacs in CW operation ($Q \approx 10^{10}$)

➔ 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

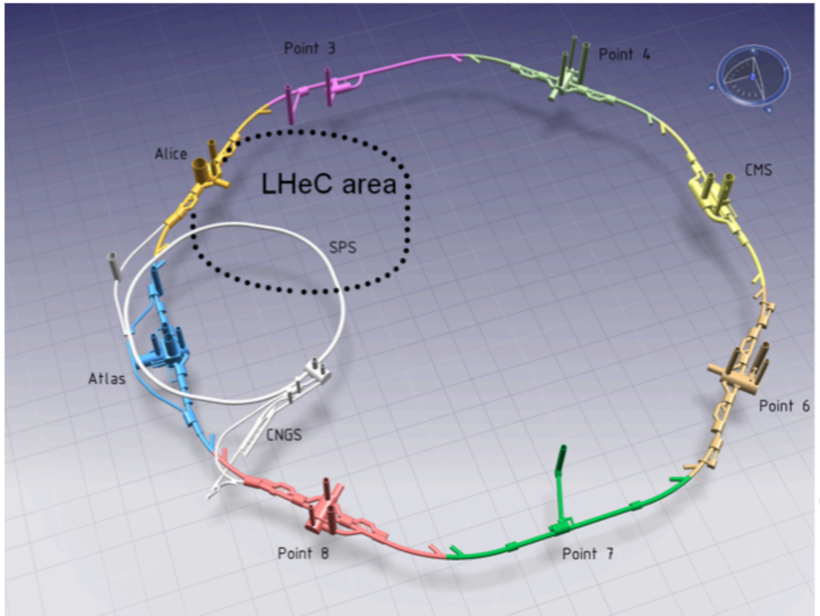
CDR draft

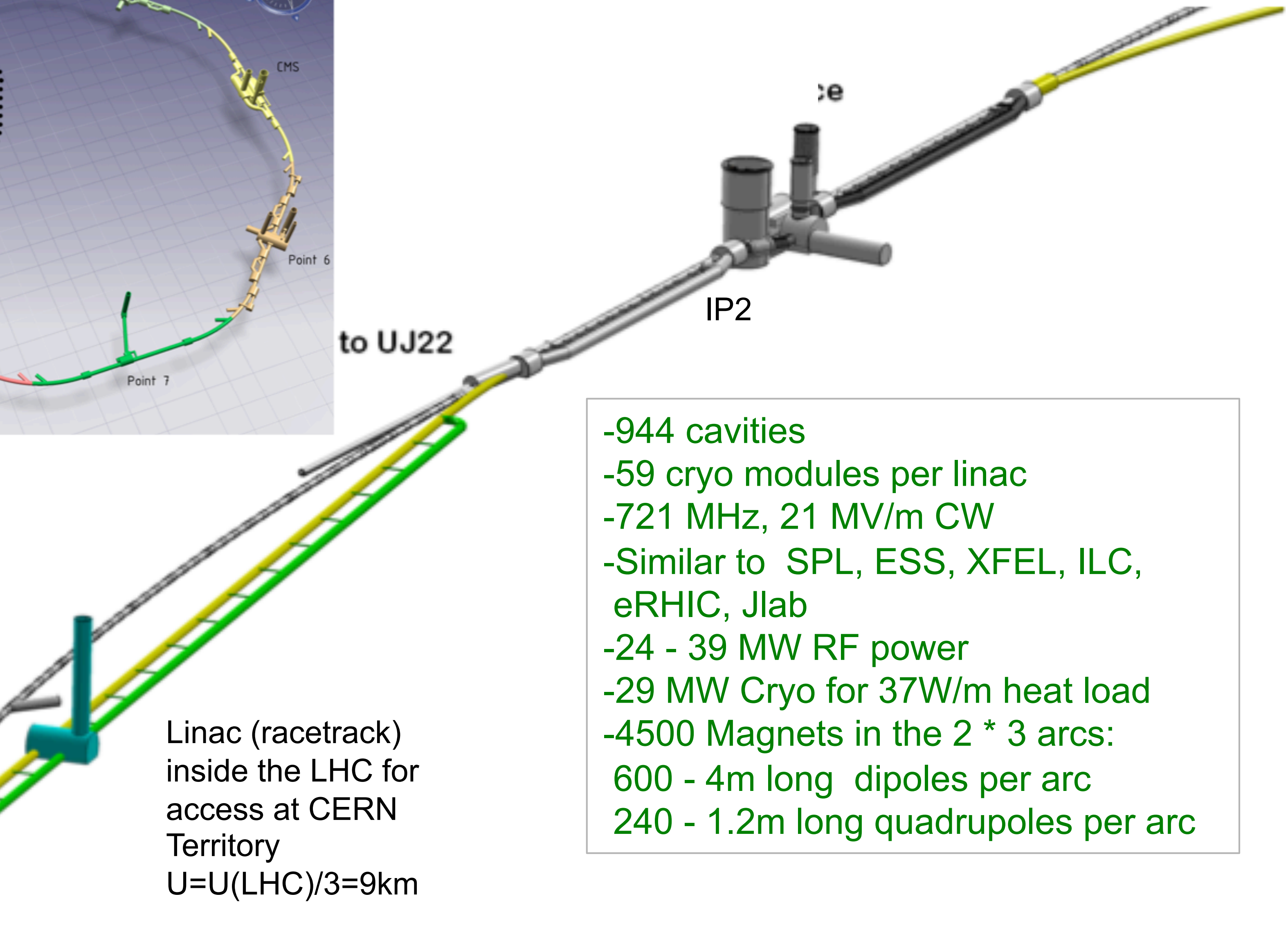
Parameter	Value
Two linacs	length 1 km
5-cell cavities	length 1.04 m
Number	944
Cavities/ cryomodule	8
Number cryomodules	118
Length cryomodule	14 m
Voltage per cavity	21.2 MV
R/Q	285Ω
Cavity Q0	$2.5 \cdot 10^{10}$
Operation	CW
Bath cooling	2 K
Cooling power/cav.	32 W @2 K
Total cooling power (2 linacs)	30 kW @2 K



systems will consist of a complex task. Further cavities and cryomodules will require a limited R&D program. From this we expect improved quality factors with respect to today's state of the art. The cryogenics of the L-R version consists of a formidable engineering challenge, however, it is feasible and, CERN disposes of the respective know-how.

LINAC – Ring: connection to the LHC





Linac (racetrack) inside the LHC for access at CERN Territory
U=U(LHC)/3=9km

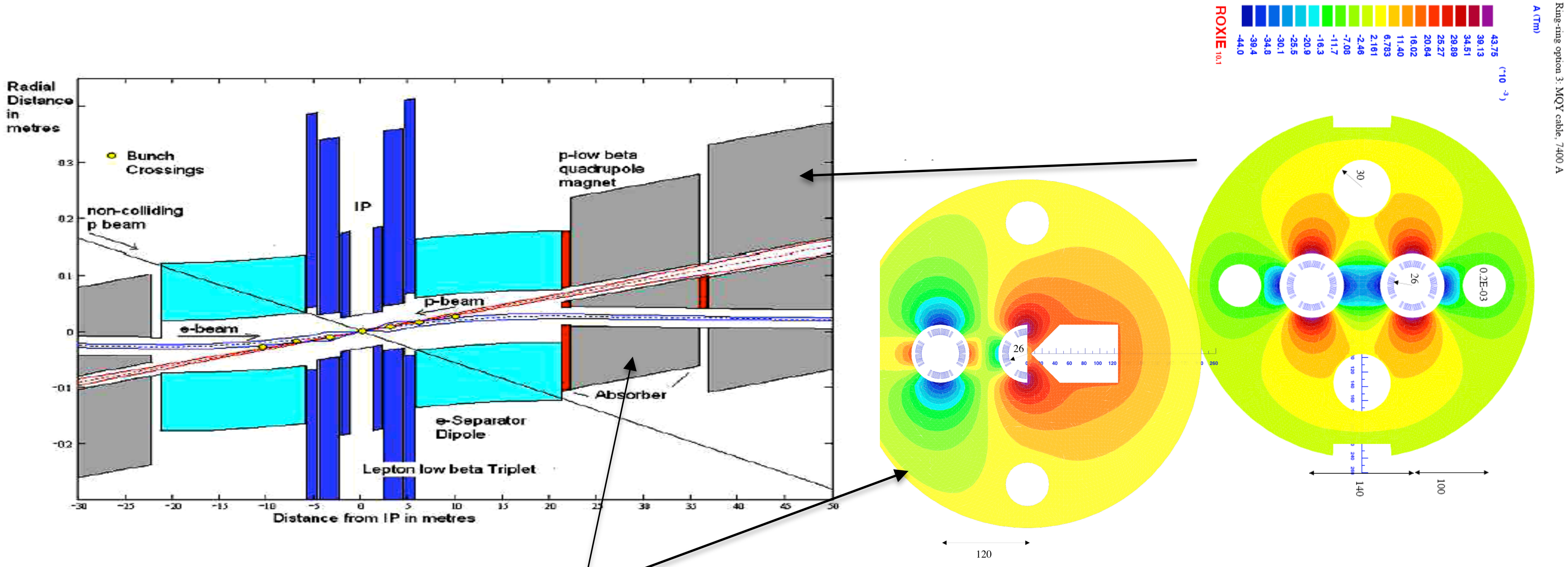
- -944 cavities
- -59 cryo modules per linac
- -721 MHz, 21 MV/m CW
- -Similar to SPL, ESS, XFEL, ILC, eRHIC, Jlab
- -24 - 39 MW RF power
- -29 MW Cryo for 37W/m heat load
- -4500 Magnets in the 2 * 3 arcs:
  600 - 4m long dipoles per arc
  240 - 1.2m long quadrupoles per arc

Interaction Region: Accommodating 3 Beams

LHeC

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

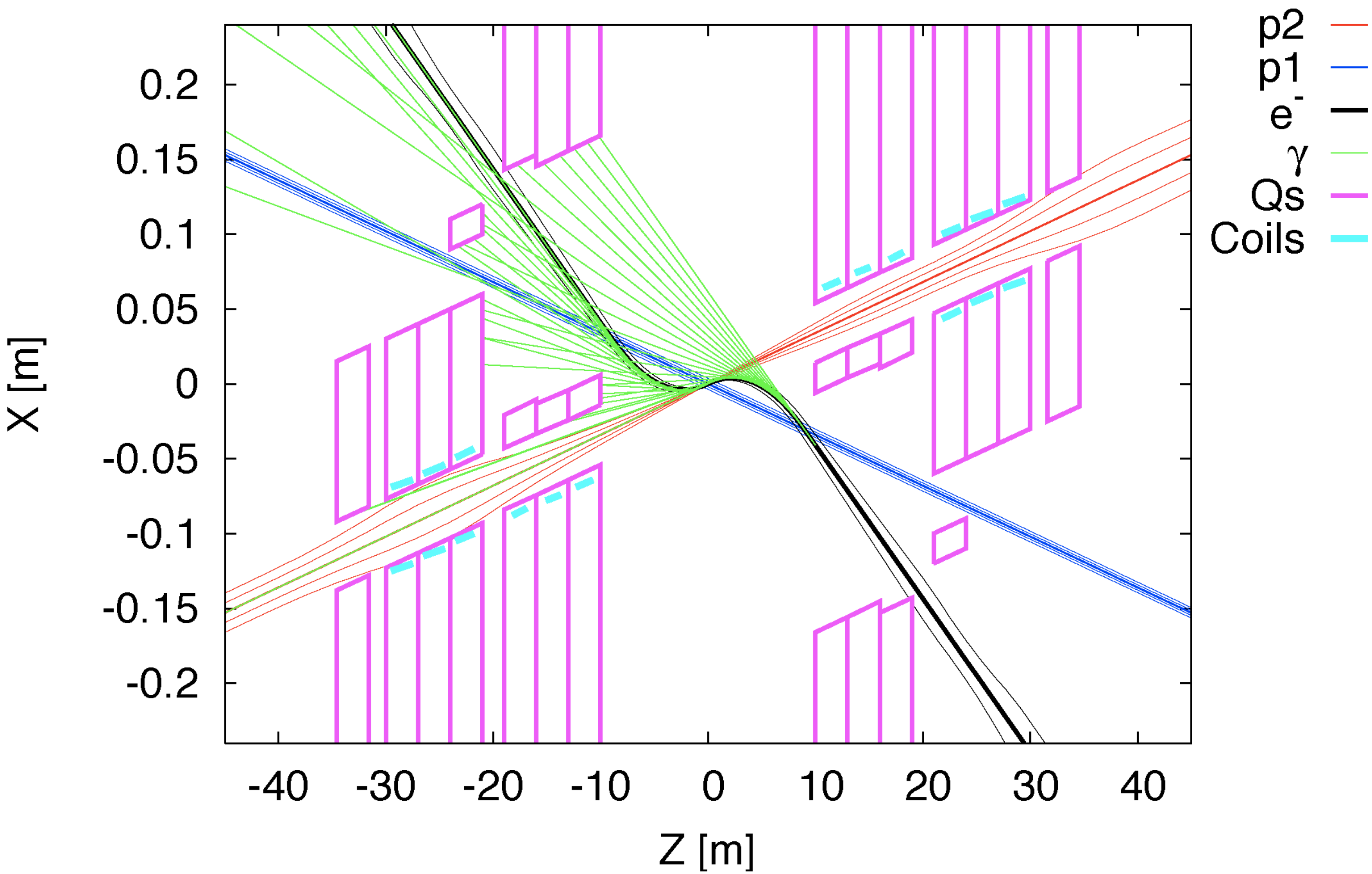


1st sc half quad (focus and deflect)
separation 5cm, g=127T/m, MQY cables, 4600 A

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

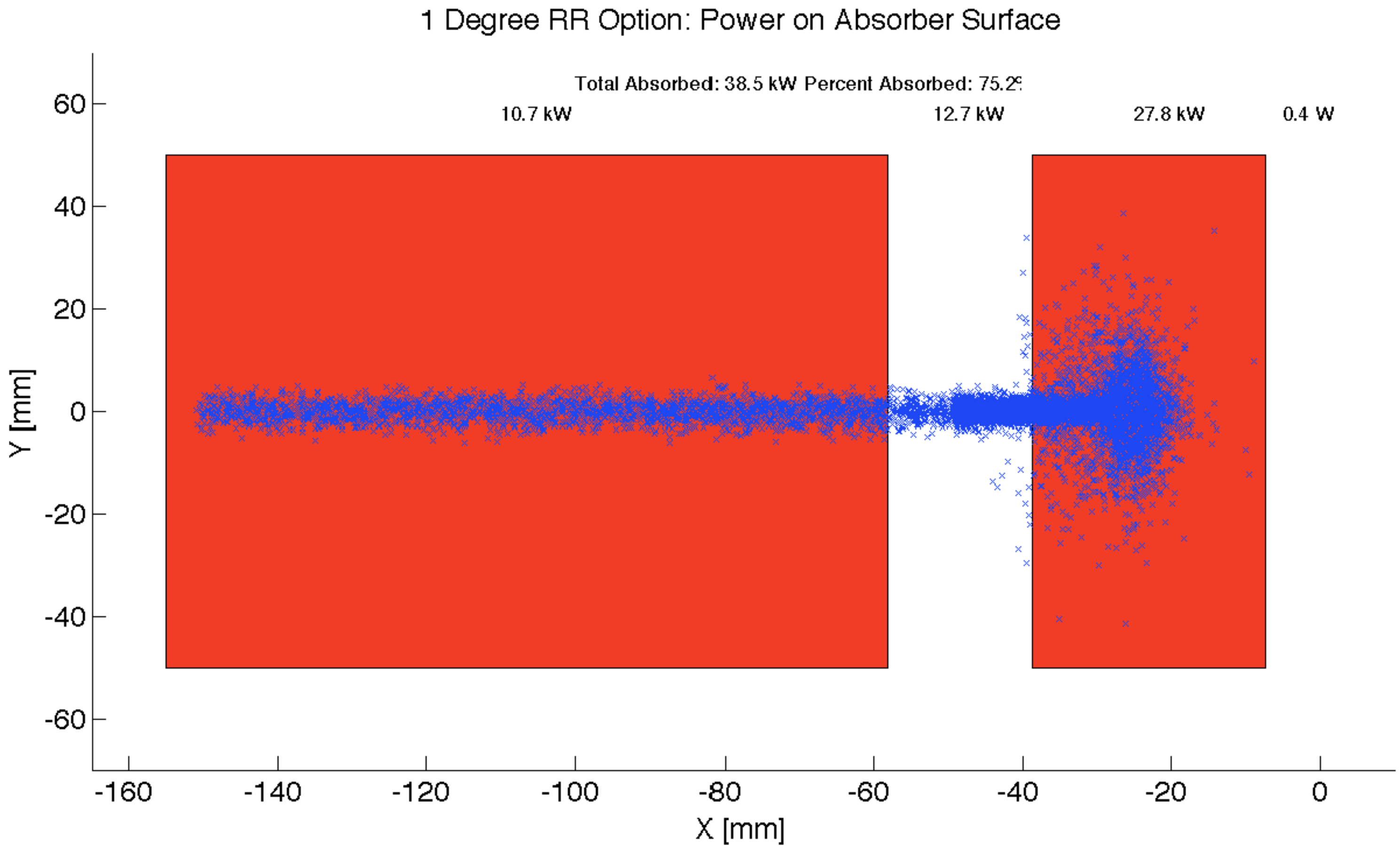
Interaction Region: Synchrotron Radiation

Radiation Fan: Example Linac-Ring



Interaction Region: Synchrotron Radiation

Significant power: > 20 kW. Example Ring-Ring



Design Parameters

electron beam	RR	LR	LR*
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	17	10	
polarization [%]	40	90	
bunch population [10^9]	26		
e- bunch length [mm]	1		
bunch interval [ns]			
transv. emit. $\gamma\varepsilon_{x,y}$ [m			
rms IP beam si			
e- IP beta			
full			
ge			
repe			
beam			5
ER effici			N/A
average cu		6.6	5.4
tot. wall plu	00	100	100

R	LR
	1.7
	3.75
	7
	1

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

servative

also for deuterons w) and lead (exists)

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

RR= Ring – Ring
LR =Linac –Ring

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

pulsed, but high energy ERL not impossible

Disclaimer:

- Very short summary of CDR with ca. 500 pages:

  -Many topics could not be covered here:

  Physics

  Detector

  Accelerator:

  Sources
  Damping rings and injector complex
  Injection and injector complex
  Collective effects and Beam-Beam
  Cryogenic system
  Polarization
  Beam Dump
  Vacuum
  Power generation and distribution, etc…..

→ LHeC-Note-2011-001 GEN

LHeC Options: Executive Su…

LHeC

- Ring-Ring option:

  -We know we can do it: ➔ LEP …

  -Challenge 1: integration … with LHC hardware

  -Challeng… LHC schedule

- …

  … LHC operation and shutdown planning

  -I… …ment with potential exploitation beyond LHeC

  -Cha… …new technology: high current SC ERL

CDR will be reviewed by Expert Panel

The goal is to identify the best option for the LHeC by the end of the year

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

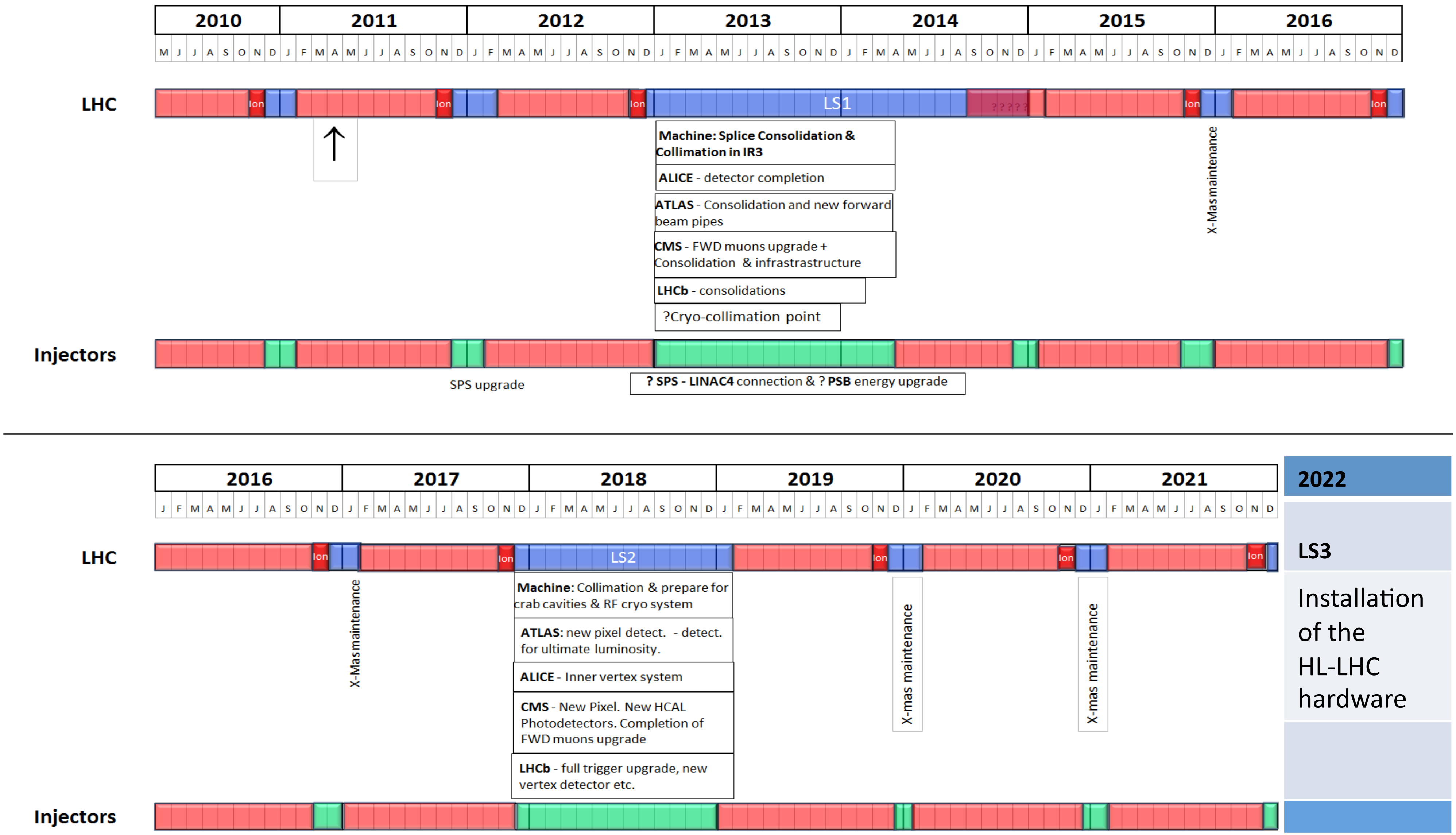
- LHeC operation:

  -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

New rough draft 10 year plan

Not yet approved!



LHeC Planning and Timeline

LHeC

CERN Medium Term Plan:

-Only 2 long shutdowns planned before 2022

-Only 10 years for the LHeC from CDR to project start (other smaller projects like ESS and PSI XFEL plan for 8 to 9 years [TDR to project start] and the EU XFEL plans for 5 years from construction to operation start)

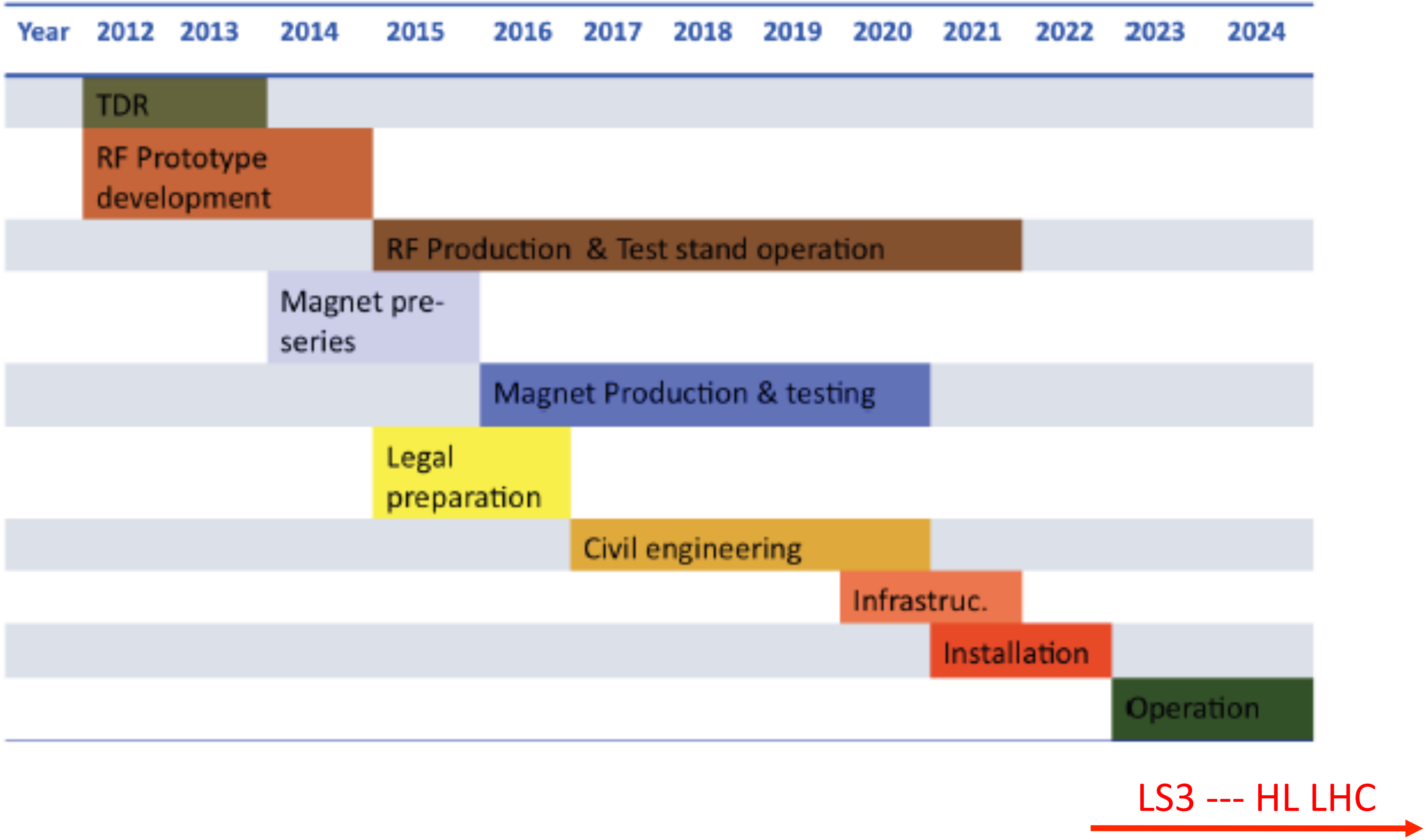
LHeC planning:

-Need to start R&D work as soon as possible

-Need to develop detailed TDR after feedback from review panel

➔ concentrate future effort on only one option

LHeC Tentative Time Schedule



We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)

LHeC Planning and Timeline

R&D activities:

-Superconducting RF with high Q-value

-Normal conducting compact magnet design

-Superconducting IR magnet design

-Test facility for Energy recovery operations and – or compact injector complex

-High intensity polarized positron sources

LHeC - Participating Institutes: A very rich collaboration

LHeC

CERN

SLAC
NATIONAL ACCELERATOR LABORATORY

NTNU
Norwegian University of Science and Technology

CLIC

The Cockcroft Institute
of Accelerator Science and Technology

Jefferson Lab
Thomas Jefferson National Accelerator Facility

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TOBB ETU

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Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

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LAL
Physique des accélérateurs

ECFA

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

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LHeC organisation

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Reserve Transparencies

7.12.4 10 GeV injector

For the acceleration to 10 GeV we propose a re-circulating LINAC, designed as a downscaled, low energy version of the 25 GeV ELFE at CERN design [?] using modern ILC-type RF-technology.

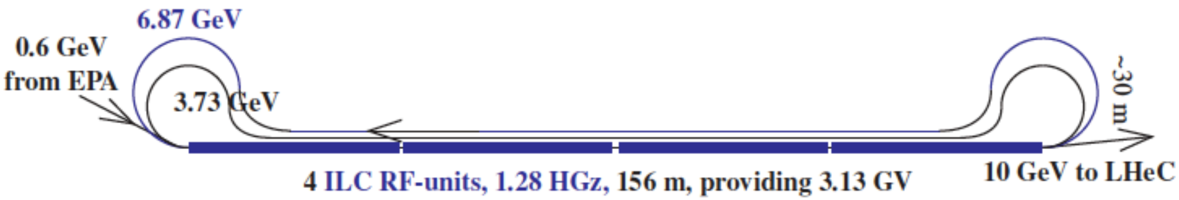


Figure 7.62: Recirculator using 4 ILC modules.

Magnets

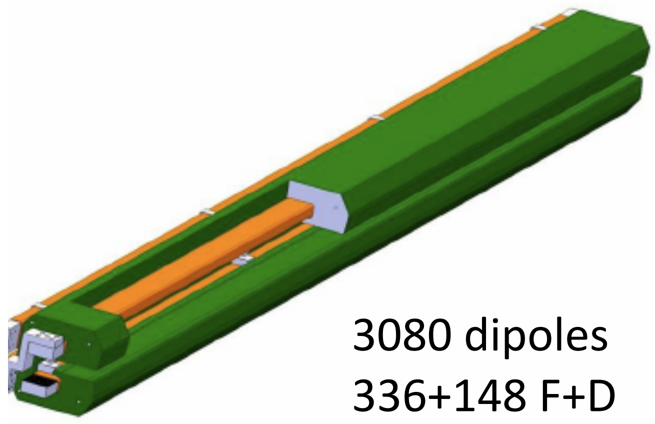
Injector to Ring – similar to Linac design [R+**D**]

Parameter	Value	Units
Beam Energy	10-60	GeV
Magnetic Length	5.35	Meters
Magnetic Field	0.0127-0.0763	Tesla
Number of magnets	3080	
Vertical aperture	40	mm
Pole width	150	mm
Number of turns	2	
Current @ 0.763 T	1300	Ampere
Conductor material	copper	
Magnet inductance	0.15	milli-Henry
Magnet resistance	0.16	milli-Ohm
Power @ 60 GeV	270	Watt
Total power consumption @ 60 GeV	0.8	MW
Cooling	air or water	depends on tunnel ventilation

Table 9.4: Main parameters of bending magnets for the RR Option.

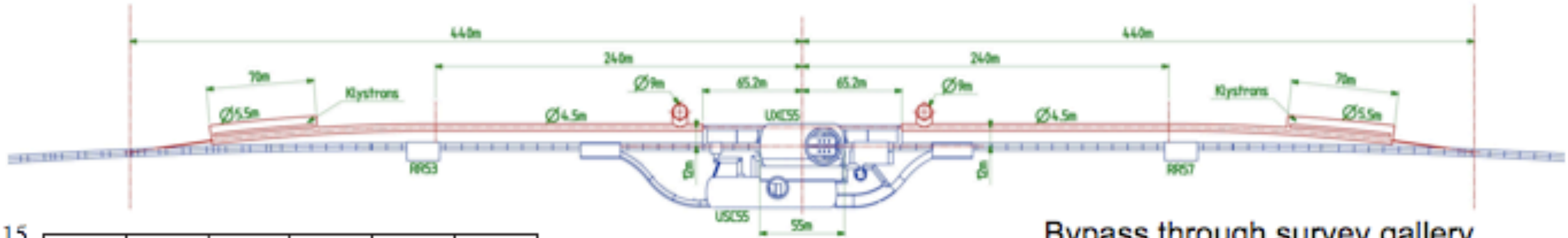
Novosibirsk dipole prototype measured field reproducible to the required 2 10^{-4}

CERN prototype under test

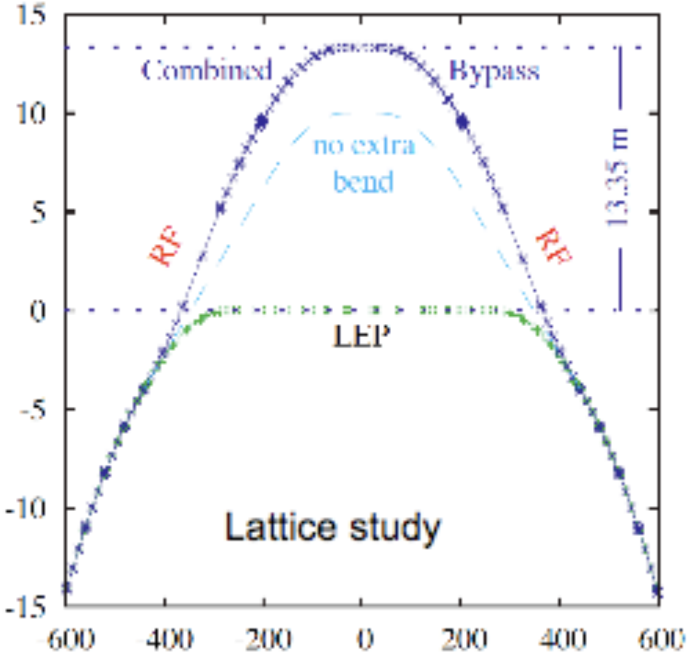


3080 dipoles

336+148 F+D

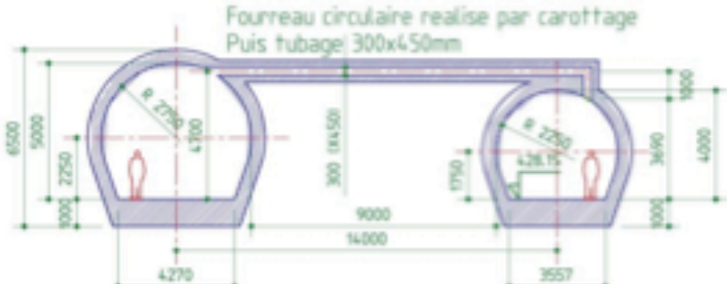


Bypass through survey gallery
13m distance, 2 shafts

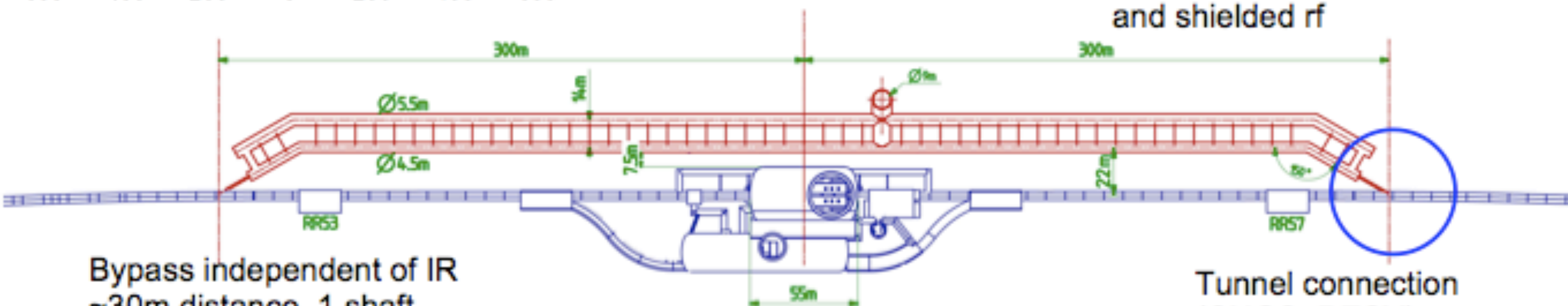


Bypass

point 5



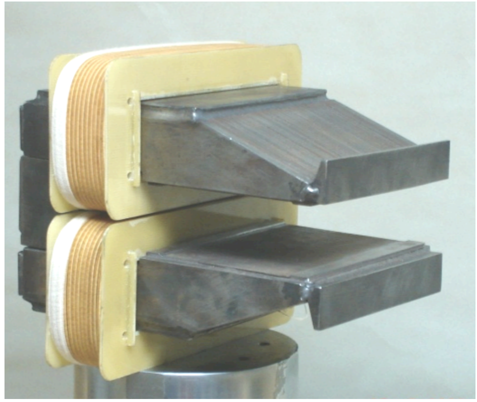
2 tunnels for ring
and shielded rf



Bypass independent of IR
~30m distance, 1 shaft

Tunnel connection
(CNGS, DESY)

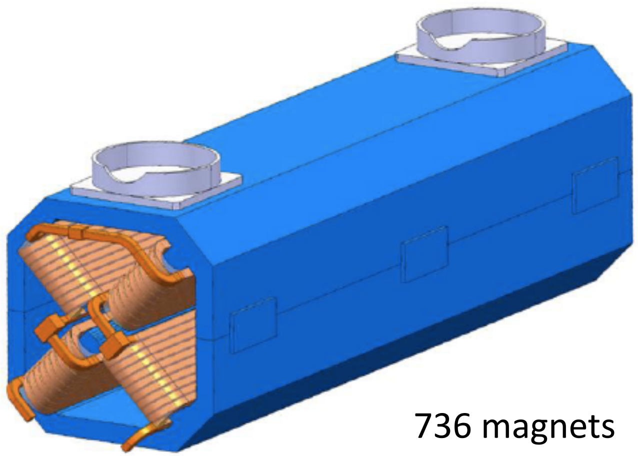
Ring: Dipole + Quadrupole Magnets



BINP & CERN prototypes

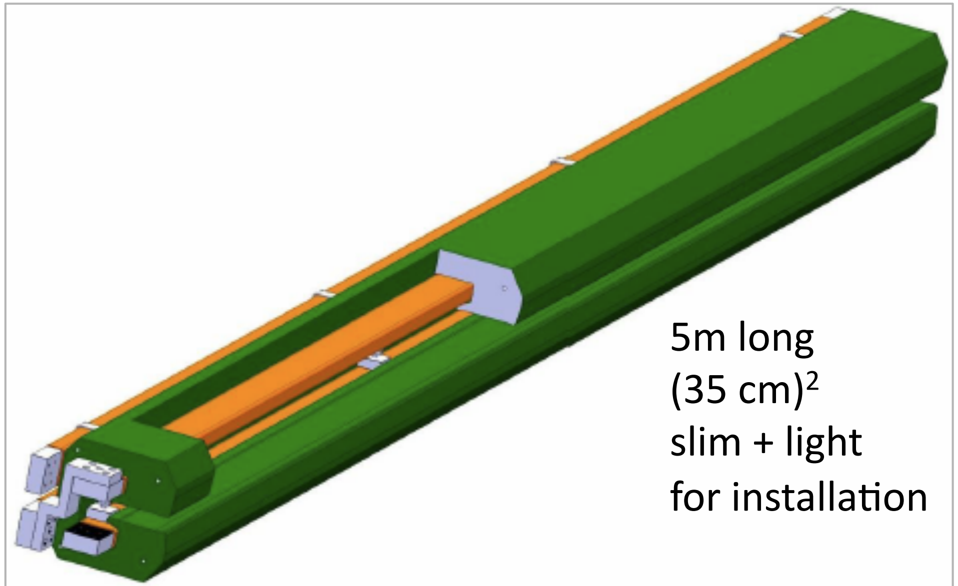
Parameter	Value	Units
Beam Energy	10-60	GeV
Magnetic Length	5.35	Meters
Magnetic Field	0.127-0.763	Tesla
Number of magnets	3080	
Vertical aperture	40	mm
Pole width	150	mm
Number of turns	2	
Current @ 0.763 T	1300	Ampere
Conductor material	copper	
Magnet inductance	0.15	milli-Henry
Magnet resistance	0.16	milli-Ohm
Power @ 60 GeV	270	Watt
Total power consumption @ 60 GeV	0.8	MW
Cooling	air or water	depends on tunnel ventilation

Table 3.2: Main parameters of bending magnets for the RR Option.



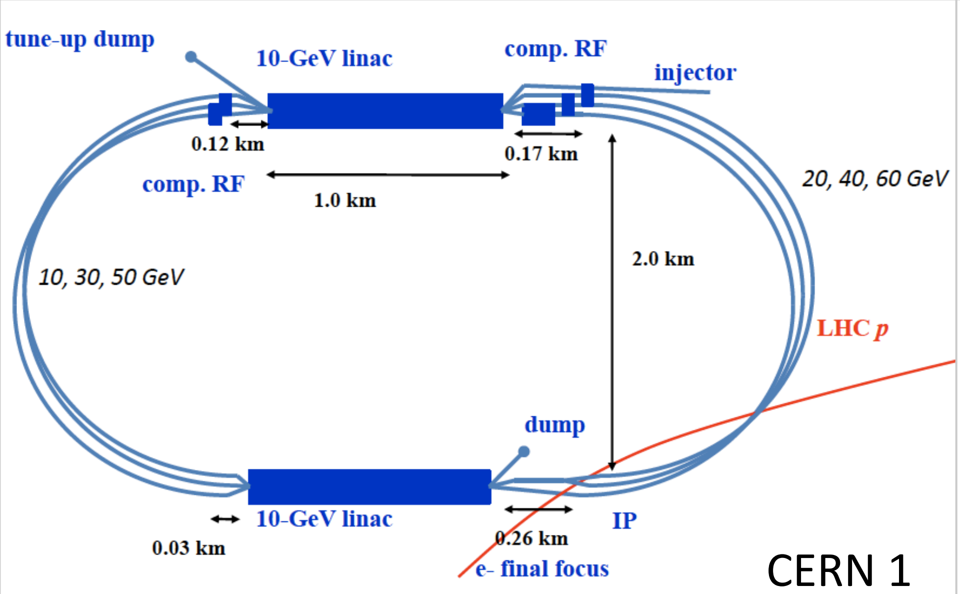
736 magnets
1.2 m long

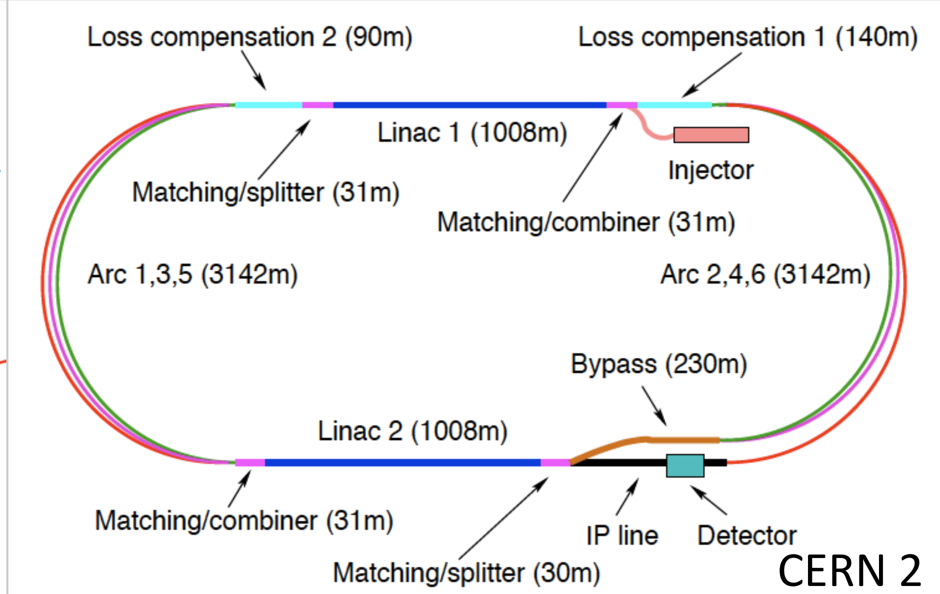
Arc quadrupole magnets for the RR Option

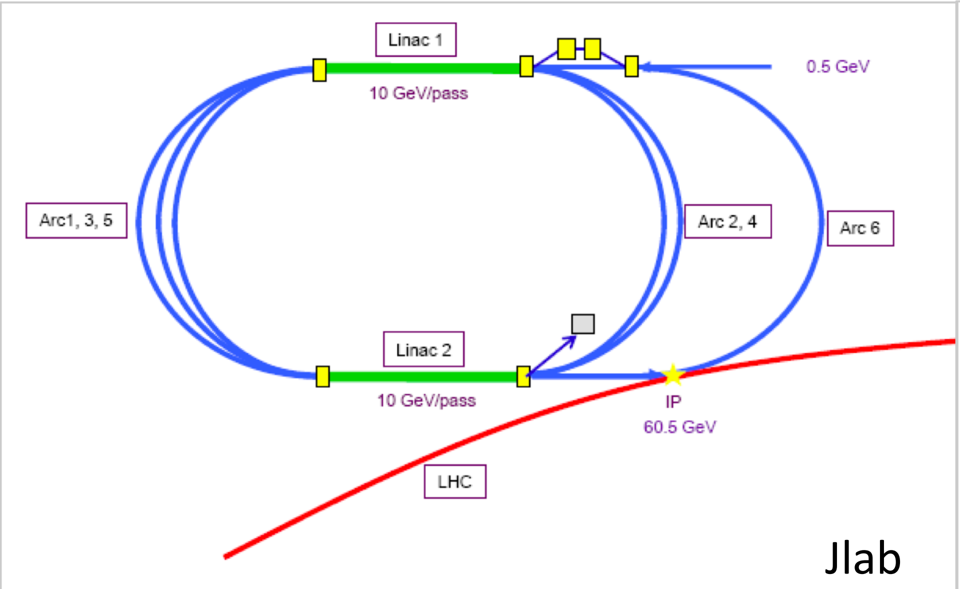


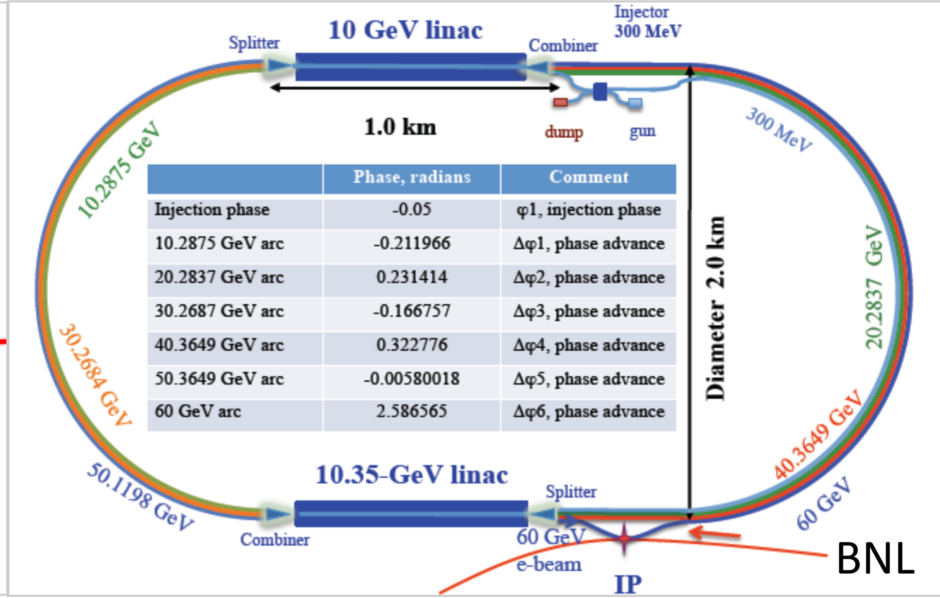
5m long
(35 cm)^2
slim + light
for installation

60 GeV Energy Recovery Linac







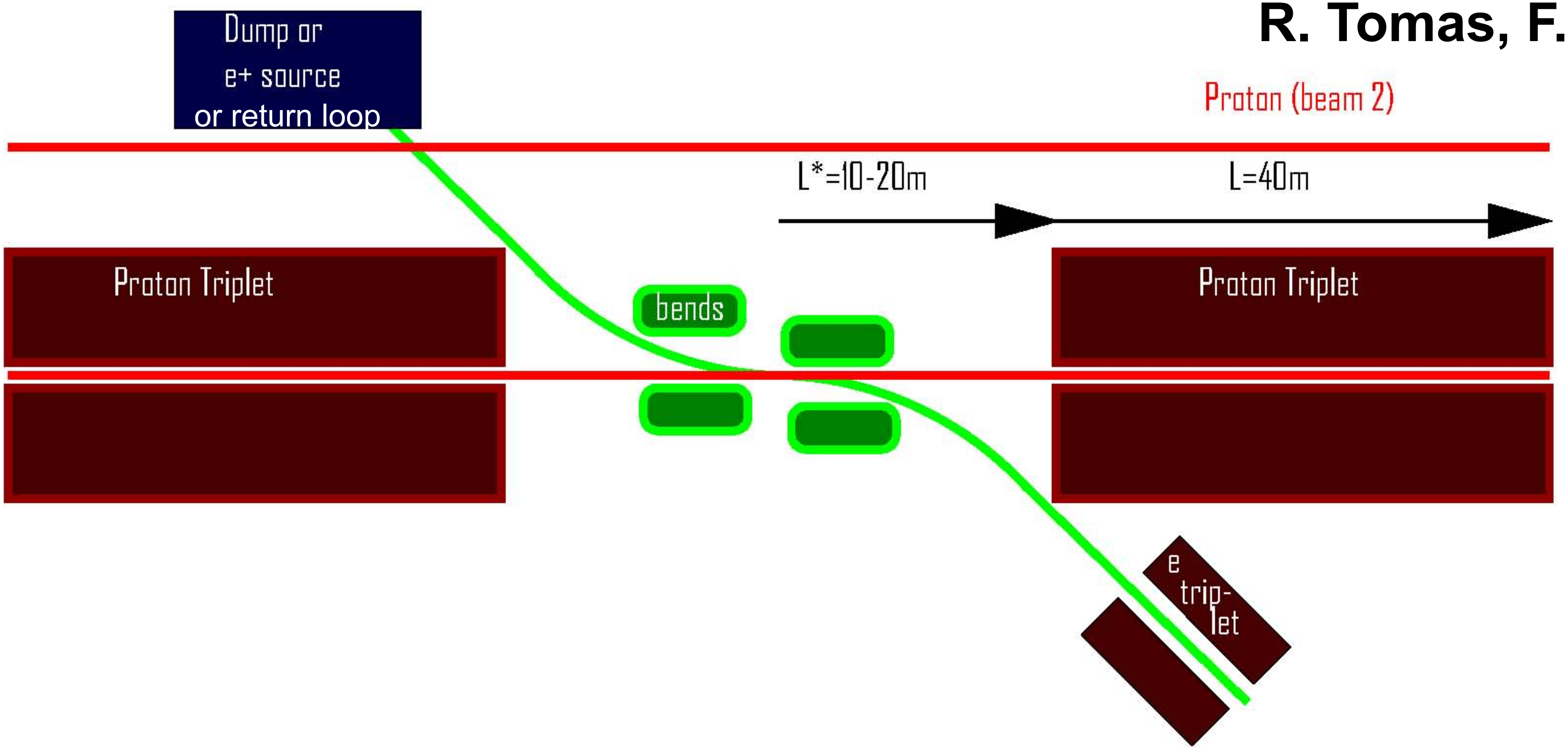


	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc	2.586565	Δφ6, phase advance

Two 10 GeV energy recovery Linacs, 3 returns, 720 MHz cavities

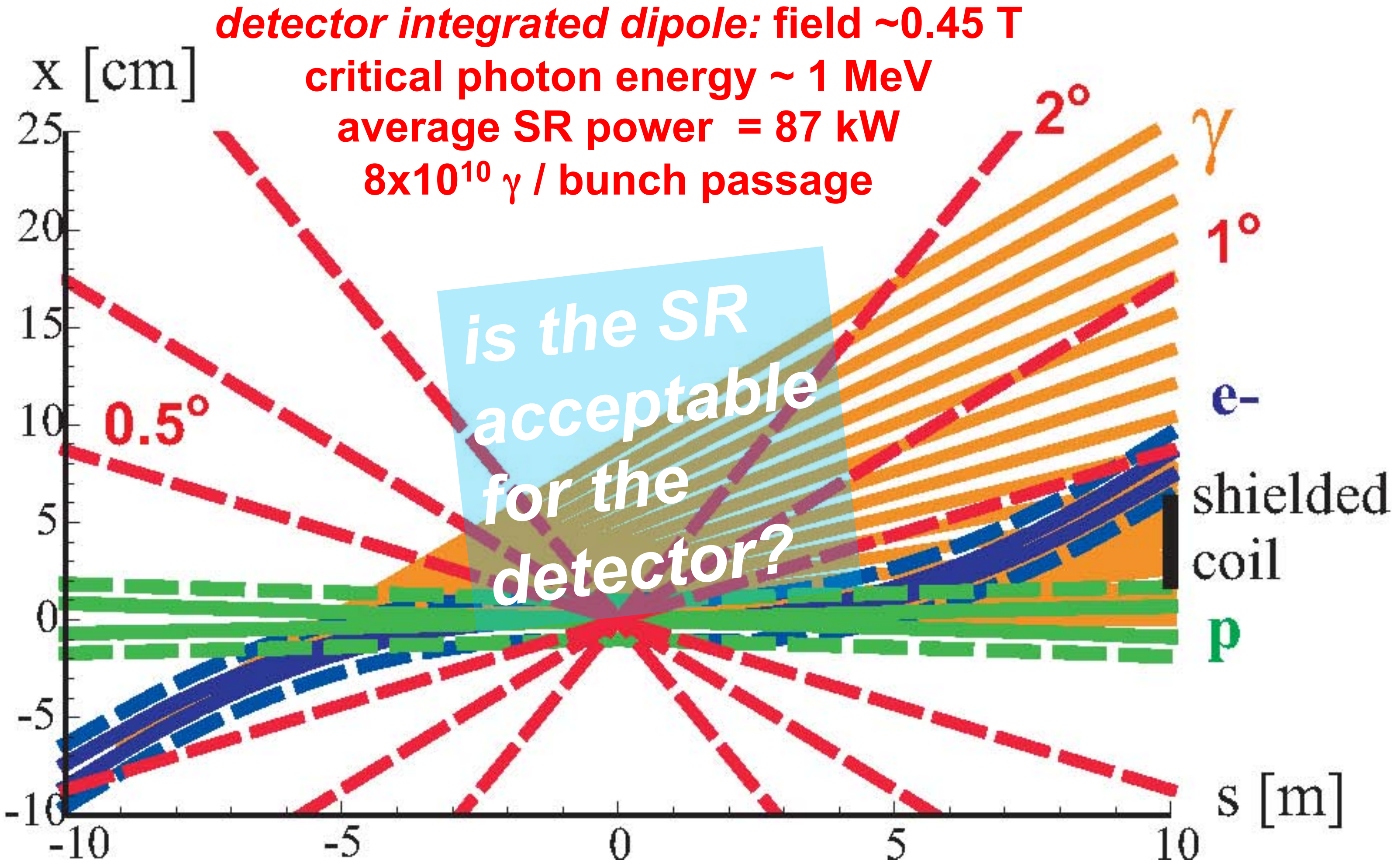
interaction region (2008)

R. Tomas, F.Z.



small e- emittance → relaxed β_e^* → $L_e^* > L_p^*$, can&must profit from $\downarrow\beta_p^*$; single pass & low e-divergence → parasitic collisions of little concern; → head-on e-p collision realized by long dipoles

IR layout w. head-on collision



beam envelopes of 10σ (electrons) [solid blue] or 11σ (protons) [solid green], the same envelopes with an additional constant margin of 10 mm [dashed], the synchrotron-radiation fan [orange], and the approximate location of the magnet coil between incoming protons and outgoing electron beam [black]

CDR draft

LINAC 60 GeV ERL

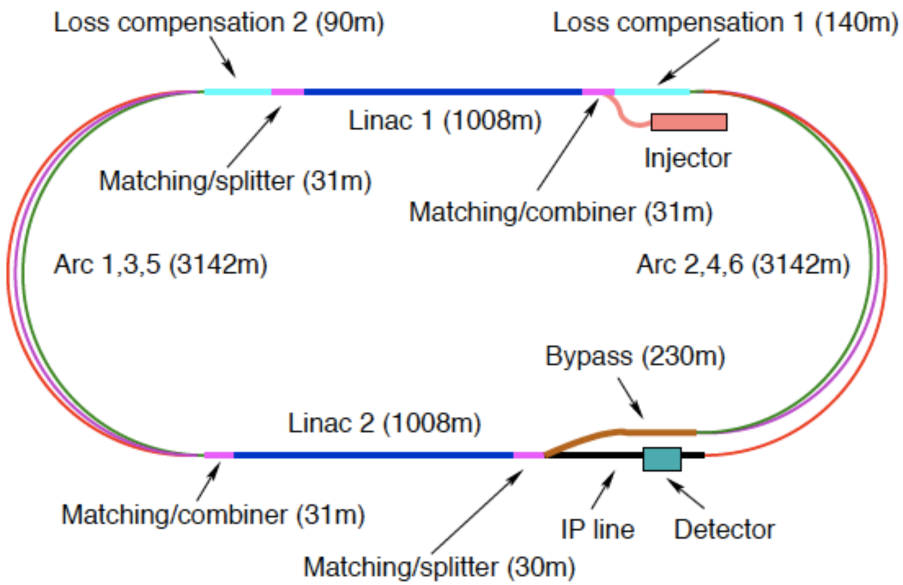
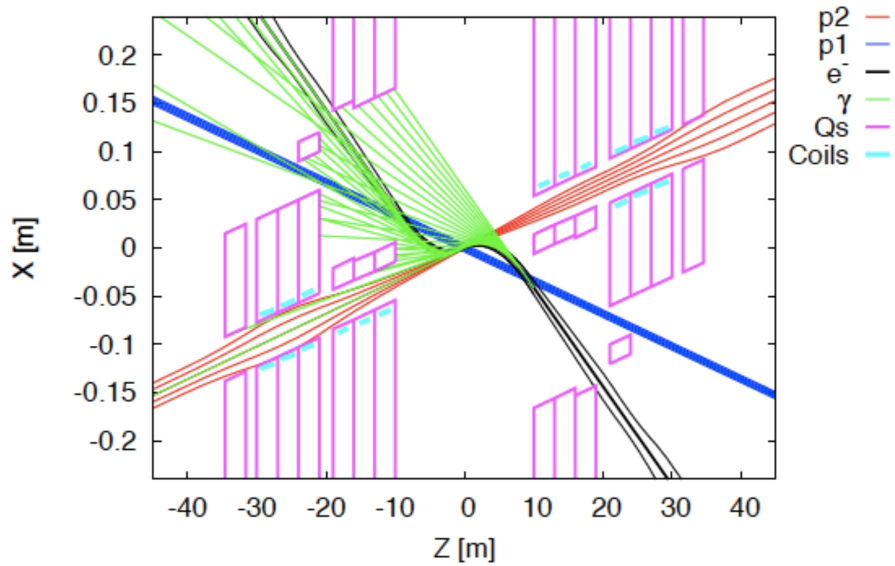


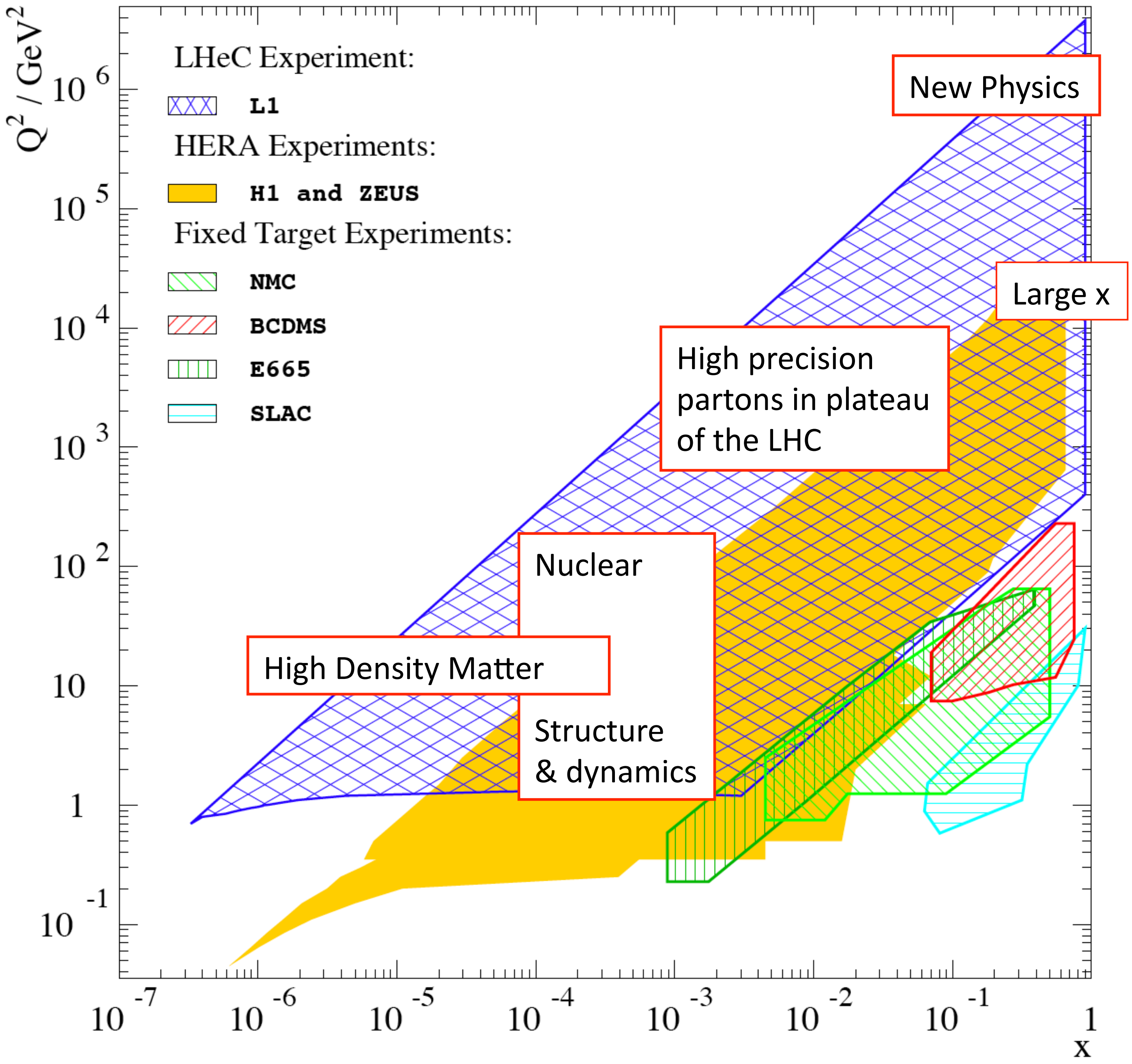
Figure 8.29: The schematic layout of the recirculating linear accelerator complex.

Table 8.2: IP beam parameters

	protons	electrons
beam energy [GeV]	7000	60
Lorentz factor γ	7460	117400
normalizwed emittance $\gamma\epsilon_{x,y}$ [μm]	3.75	50
geometric emittance $\epsilon_{x,y}$ [nm]	0.,40	0.43
a IP beta function $\beta^*_{x,y}$ [m]	0.10	0.12
rms IP beam size $\sigma^*_{x,y}$ [μm]	7	7
initial rms IP beam divergence $\sigma^*_{x',y'}$ [μrad]	70	58
beam current [mA]	$\geq$430	6.4
bunch spacing [ns]	25 or 50	(25 or) 50
bunch population [ns]	1.7×10^{11}	(1 or) 2×10^{9}



required for high luminosity, the linac must be based on superconducting (SC) radiofrequency (RF) technology. The development and industrial production of its components can exploit synergies with numerous other advancing SC-RF projects around the world, such as the DESY XFEL, eRHIC, ESS, ILC, CEBAF upgrade, CESR-ERL, JLAMP, and the CERN HP-SPL.



Q^2 = 4momentum transfer^2

x = Bjorken x: fraction of p's momentum

Physics

eQ states
GUT ($\delta\alpha_s$=0.1%)
Excited fermions
Hot/cold spots
Single top
Higgs
PDFs
Multi-Jets
DVCS
Unintegrated partons
Saturation
Vector Mesons
IP - graviton
Odderons
NC couplings
$\sin^2\Theta$
Beauty
Charm
Partons in nuclei
Shadowing
....

Detector:

Integrated dipole field?

The Next Decades

Rolf Heuer: 3/4. 12. 09 at CERN:
From the Proton Synchroton to the Large Hadron Collider

50 Years of Nobel Memories in High-Energy Physics

Initial Phase of LHC will tell the way to go

Possible ways beyond LHC

hadron - hadron collider (sLHC / DLHC)

lepton - lepton collider (ILC / CLIC)

lepton - hadron collider (LHeC)