LHeC CDR

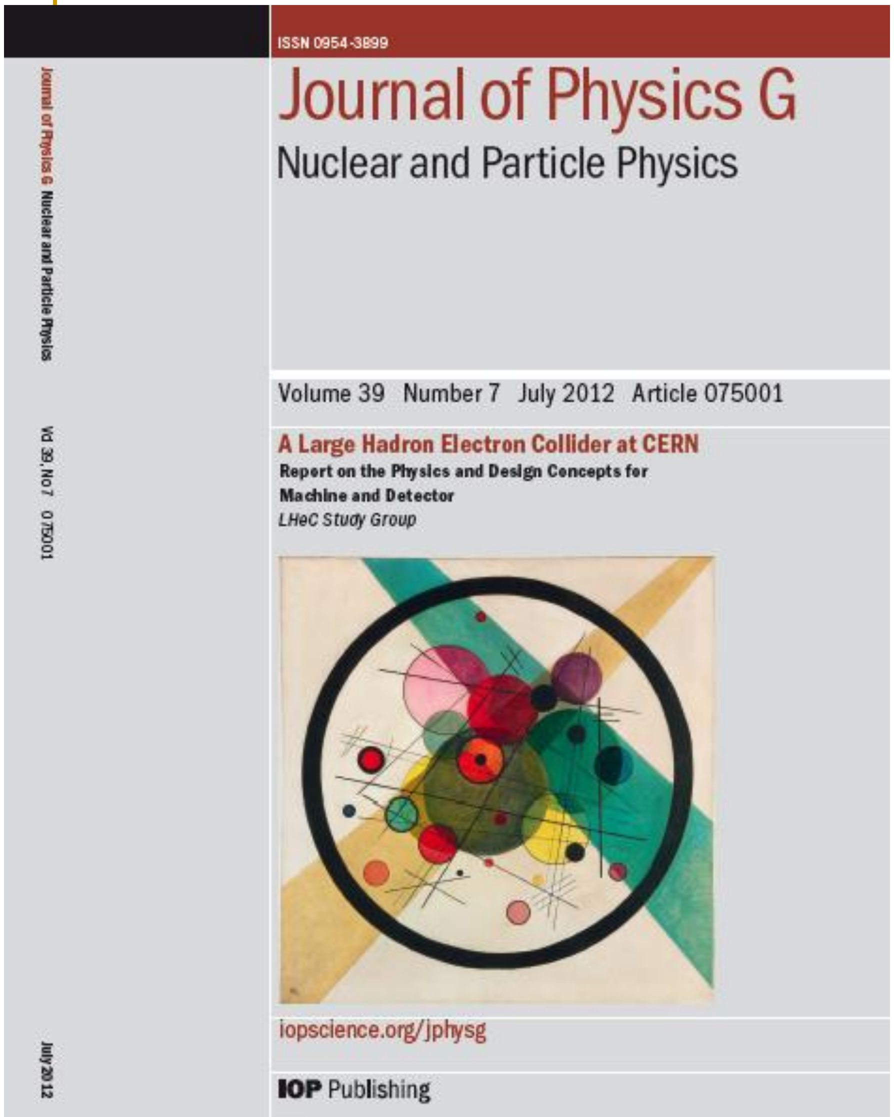
LHeC

- Design Considerations
- Two options: -Ring-R
  ...rgy Recovery
- IR La...
- ...
- Pos... ...steps

On behalf of the LHeC Collaboration!

➔LHeC-Note-2011-003 GEN
(refereed, updated and published)

LHeC CDR: Published Summer 2012



1. Design for synchronous ep and pp operation (including eA) → after LS3 which is about 2025 – no firm schedule exists for HL-LHC, but it may operate until ~2035

2. LHeC is a new collider: the cleanest microscope of the world, a complementary Higgs facility, a unique QCD machine with a striking discovery potential, with possible applications as γγ → H factory and / or injector to TLEPP
   AND an exciting new accelerator project

3. CERN Mandate to develop key technologies for the LHeC for project decision after start of LHC Run II and in time for start parallel to HL LHC phase

LHeC

LHeC Proposal endorsed by ECFA (30.11.2007)

As an add-on to the LHC, the LHeC delivers in excess of 1 Te… quark cms system. It accesses high parton densities 'bey… to be the unitarity limit. Its physics is thus fundam… to be further worked out, also with respect to the fi… the final results of the Tevatron and of HERA.

First considerations of a ring-rin… erator layout lead to an unprecedented combinati… uminosity in lepton-hadron physics, exploiting th… nts in accelerator and detector technology.

It is th… d two workshops (2008 and 2009), under the au… CERN, with the goal of having a Conceptual Design … erator, the experiment and the physics. A Technical Design … follow if appropriate.

Maximum Exploitation of the LHC infrastructure investment!

Organization:

Scientific Advisory Committee

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
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Joel Feltesse (Saclay)
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Alexander Skrinsky (Novosibirsk)
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Steering Committee

Oliver Bruening (CERN)
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Bernd Surrow (MIT)
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Urs Wiedemann (CERN)
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Working Group Conveners

Accelerator Design [RR and LR]
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Interaction Region and Fwd/Bwd
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Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)

Detector Design
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New Physics at Large Scales
George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

Precision QCD and Electroweak
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Paolo Gambino (Torino),
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Claire Gwenlan (Oxford)

Physics at High Parton Densities
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Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (MSU)

Referees of CDR

QCD/electroweak:
Guido Altarelli, Alan Martin, Vladimir Chekelyan

BSM:
Michelangelo Mangano, Gian Giudice, Cristinel Diaconu

eA/low x
Al Mueller, Raju Venugopalan, Michele Arneodo

Detector
Philipp Bloch, Roland Horisberger

Interaction Region Design
Daniel Pitzl, Mike Sullivan

Ring-Ring Design
Kurt Huebner, Sasha Skrinsky, Ferdinand Willeke

Linac-Ring Design
Reinhard Brinkmann, Andy Wolski, Kaoru Yokoya

Energy Recovery
Georg Hoffstatter, Ilan Ben Zvi

Magnets
Neil Marx, Martin Wilson

Installation and Infrastructure
Sylvain Weisz

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

		2010		2015		2020		2025
FAIR	PANDA	**R&D**	**Construction**	**Commissioning**	**Exploitation**			
	CBM	**R&D**	**Construction**	**Commissioning**	**Exploitation**	SIS300		
	NuSTAR	**R&D**	**Construction**	**Commissioning**	**Exploit.**	NESR FLAIR		
	PAX/ENC	Design Study	R&D	Tests	Construction/Commissioning	Collider		
SPIRAL2		**R&D**	**Constr./Commission.**	**Exploitation**	150 MeV/u Post-accelerator			
HIE-ISOLDE			**Constr./Commission.**	**Exploitation**	Injector Upgrade			
SPES			**Constr./Commission.**	**Exploitation**				
EURISOL		Design Study	R&D	Preparatory Phase / Site Decision	Engineering Study	Construction		
LHeC		Design Study	R&D	Engineering Study	Construction/Commissioning			

We are here: at the start of R&D

Design Considerations

LHC hadron beams: E_p=7 TeV; CM collision energy: E^2_{CM} = 4 E_e* E... eV

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

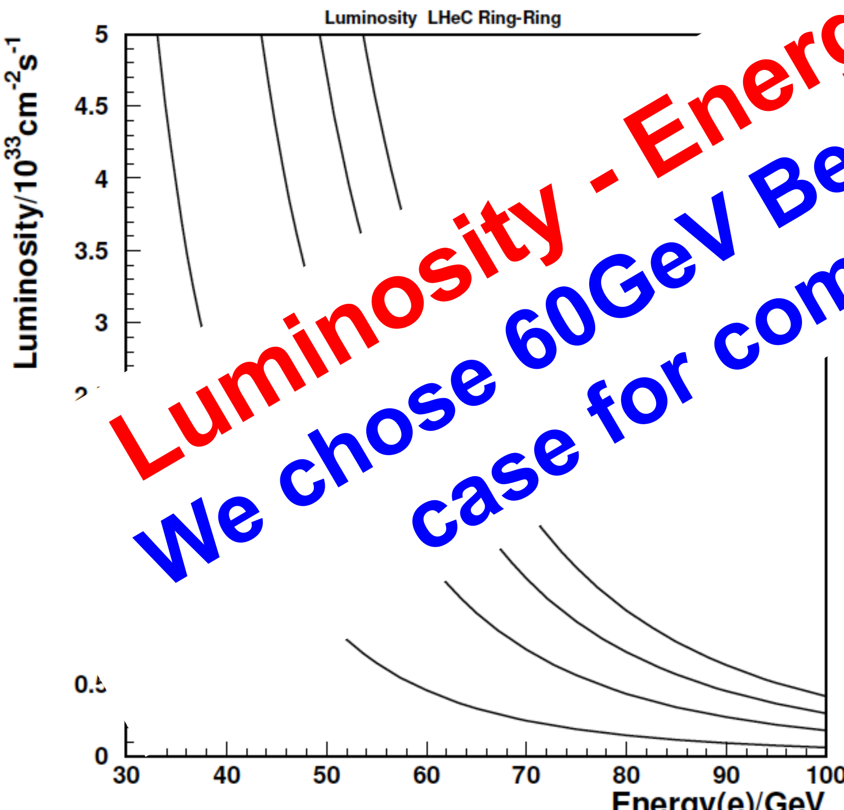
Luminosity O (10^{33}) $cm^{-2}s^{-1}$ with 100 MW power consu... W

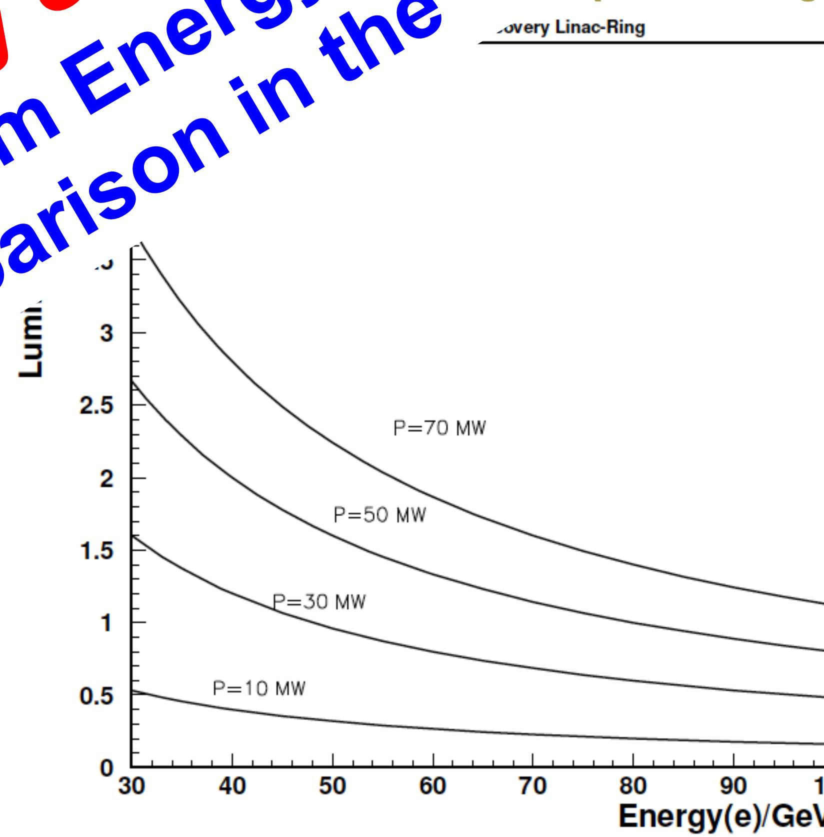
Start of LHeC operation together with HL-LHC i... 22)

e Ring in the LHC tunnel (Ring-Ring - RR) ... **(Linac-Ring -LR)**

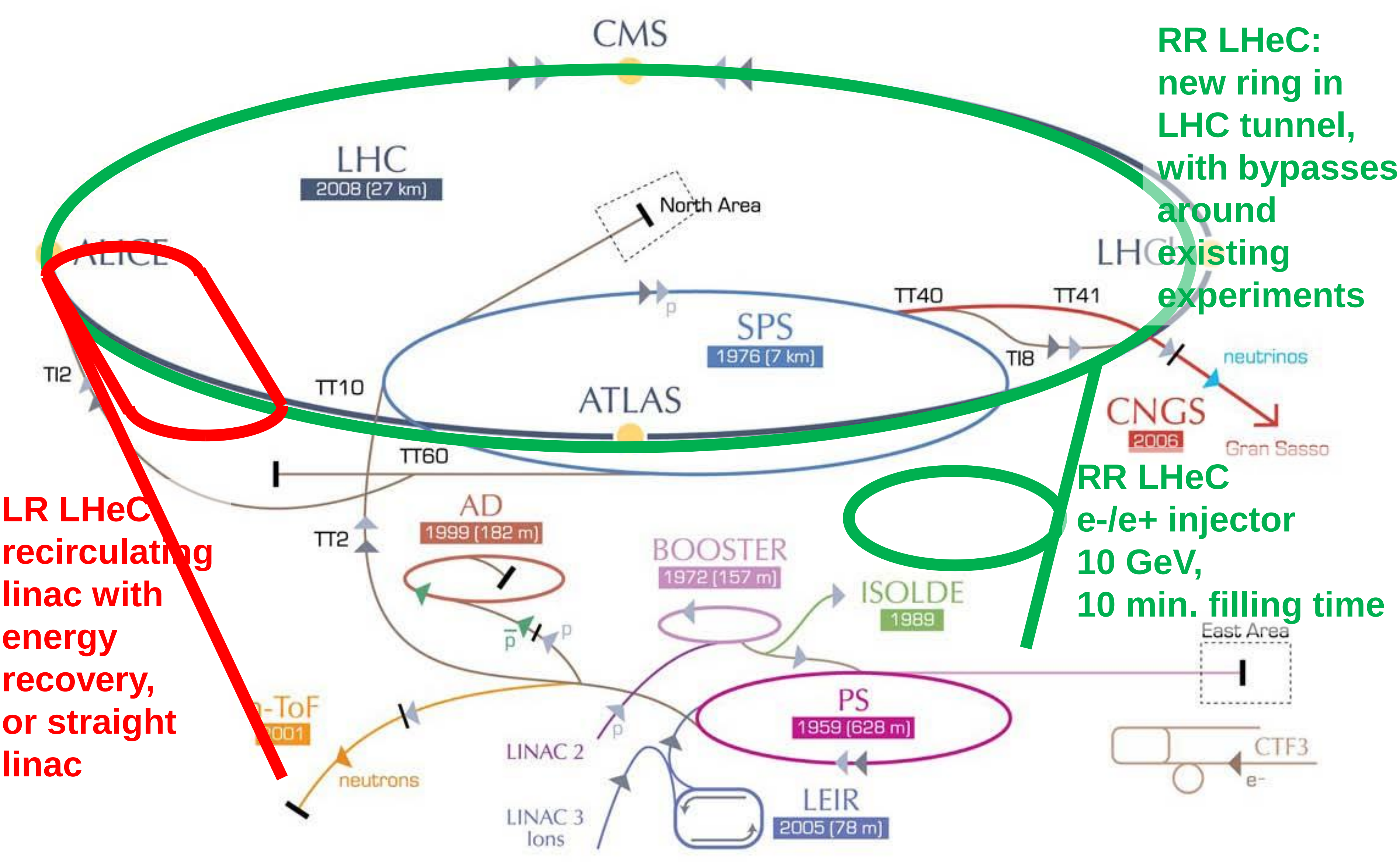
Luminosity - Energy & Power tradeoff

We chose 60GeV Beam Energy as reference case for comparison in the CDR



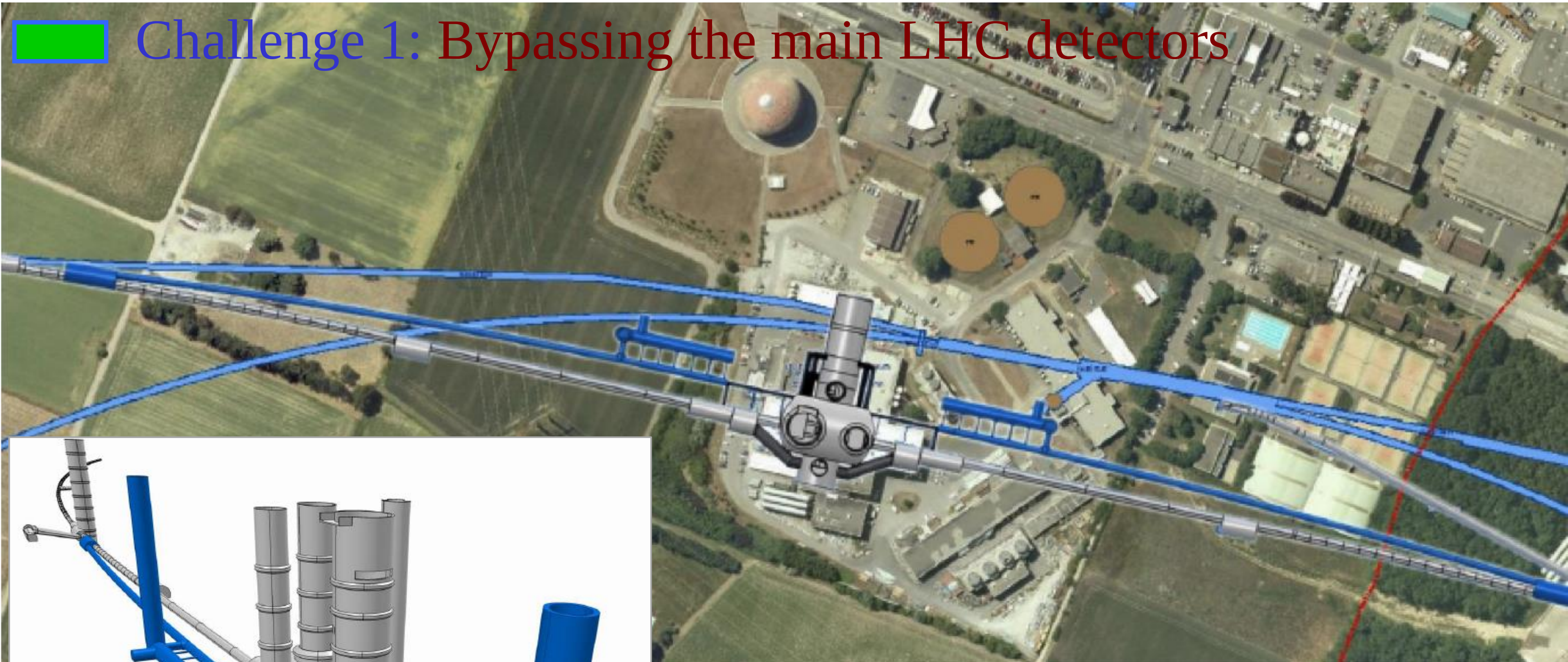


LHeC options: RR and LR



LHeC: Ring-Ring Option

Challenge 1: Bypassing the main LHC detectors



Without using the survey gallery the ATLAS bypass would need to be 100m away from the IP or on the inside of the tunnel!

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

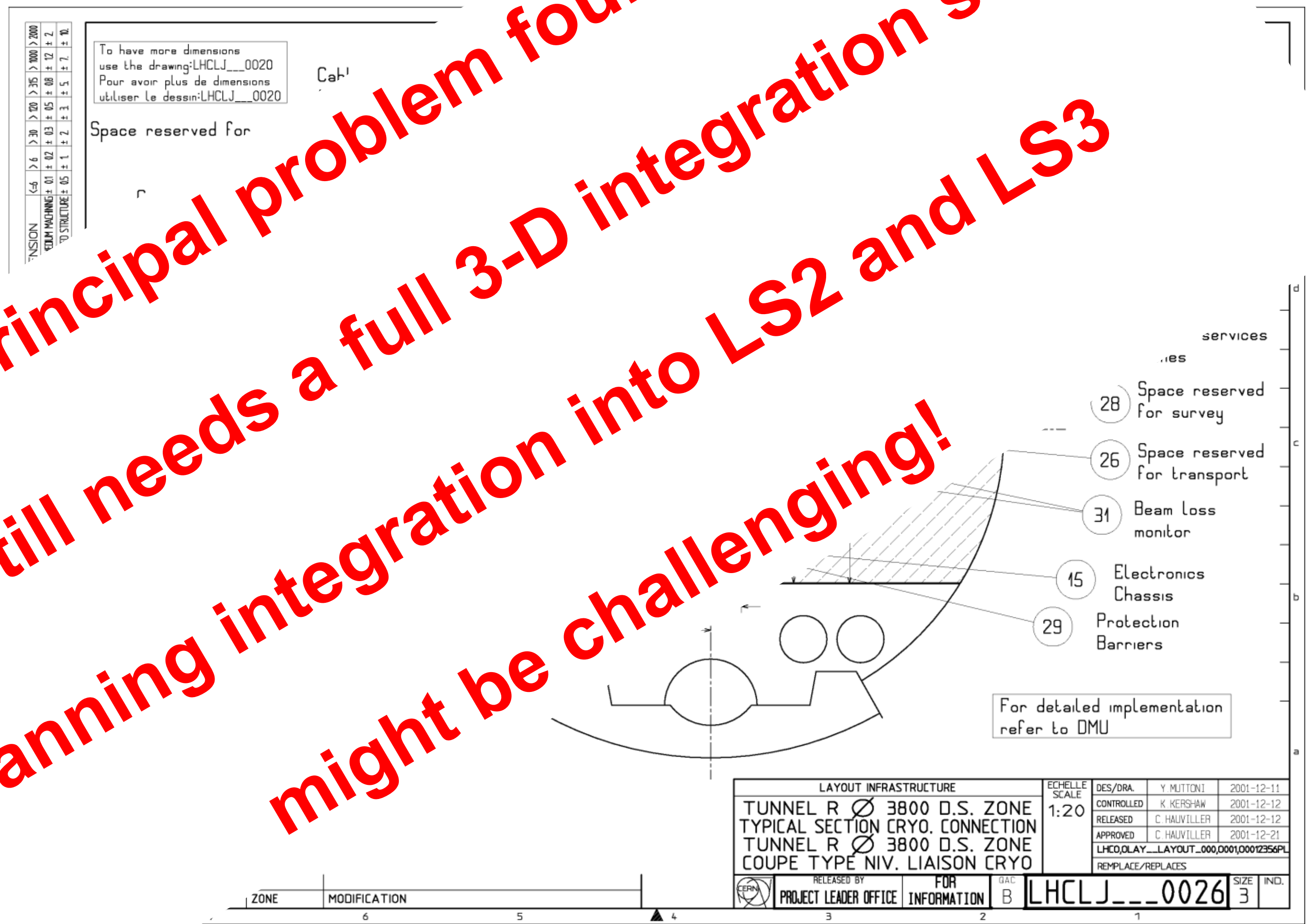
ca. 1.3 km long bypass

ca. 170m long dispersion free area for RF

LHeC: Ring-Ring O

Challenge 3: Installation with L

requires:
support
structure
with
eff



No principal problem found yet.

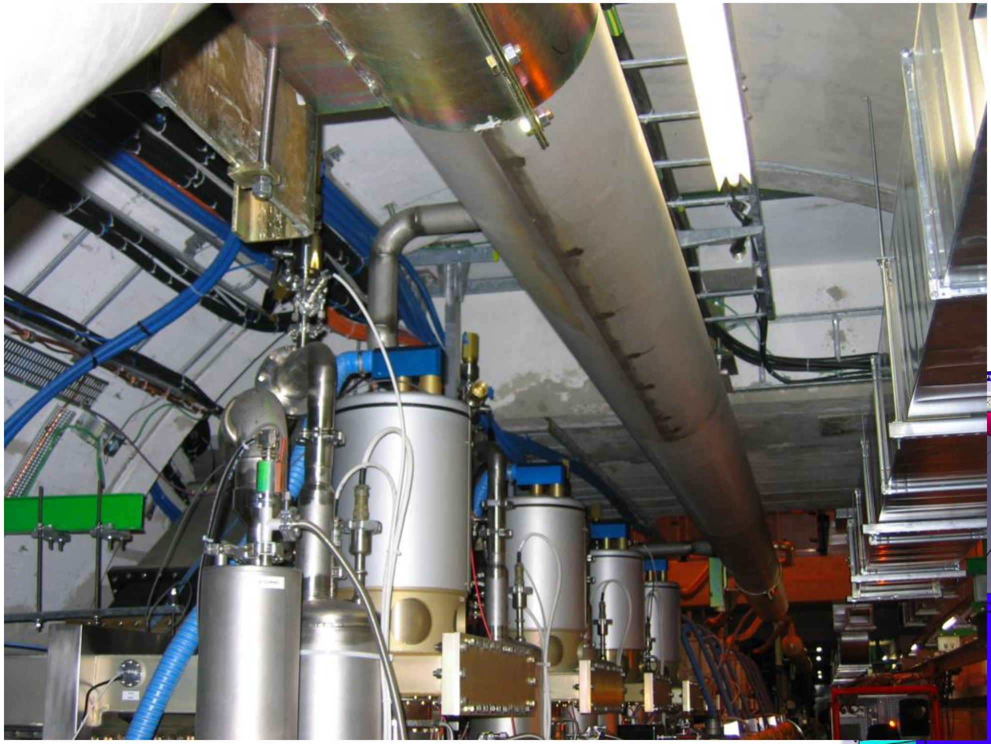
But RR still needs a full 3-D integration study!

Planning integration into LS2 and LS3

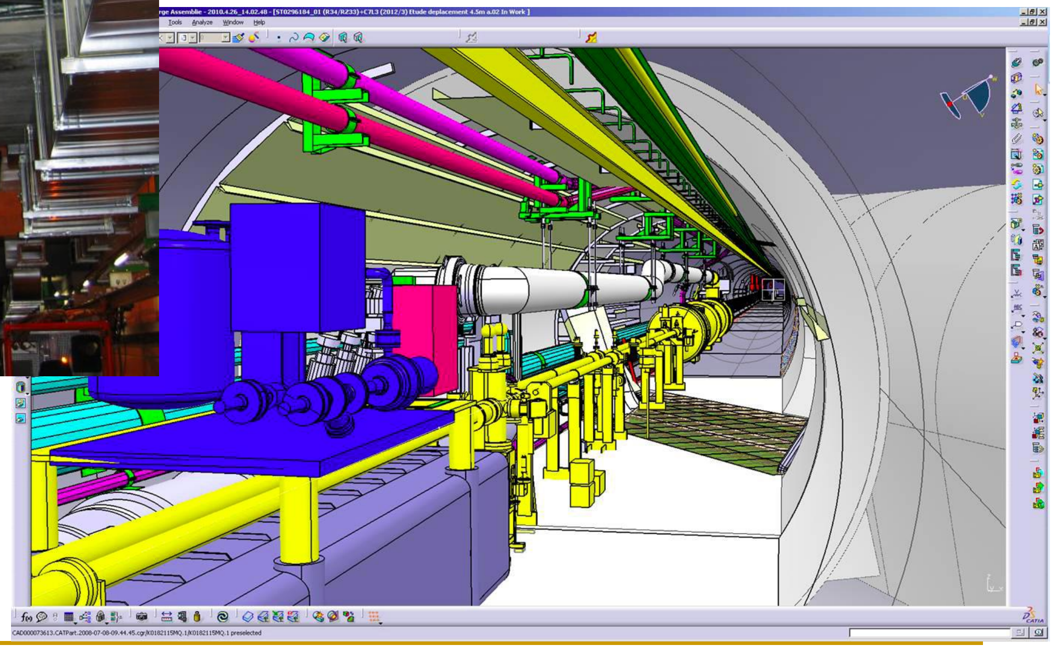
might be challenging!

LHeC: Ring-Ring Option

Challenge 2: Integration in the LHC tunnel



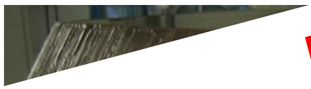
Cryo link in IR3



RF Installation in IR4

LHeC Ring-Ring dipole 400 mm long CE... ovosibirsk

- interleaved ferromagnetic laminations
- air cooled
- two turns only, bolted bars
- 0.4 m models with differ...



Ring-Ring Summary:

No principal problem found yet.

But RR still needs a full 3-D integration study!

Planning integration into LS2 and LS3 might be challenging!

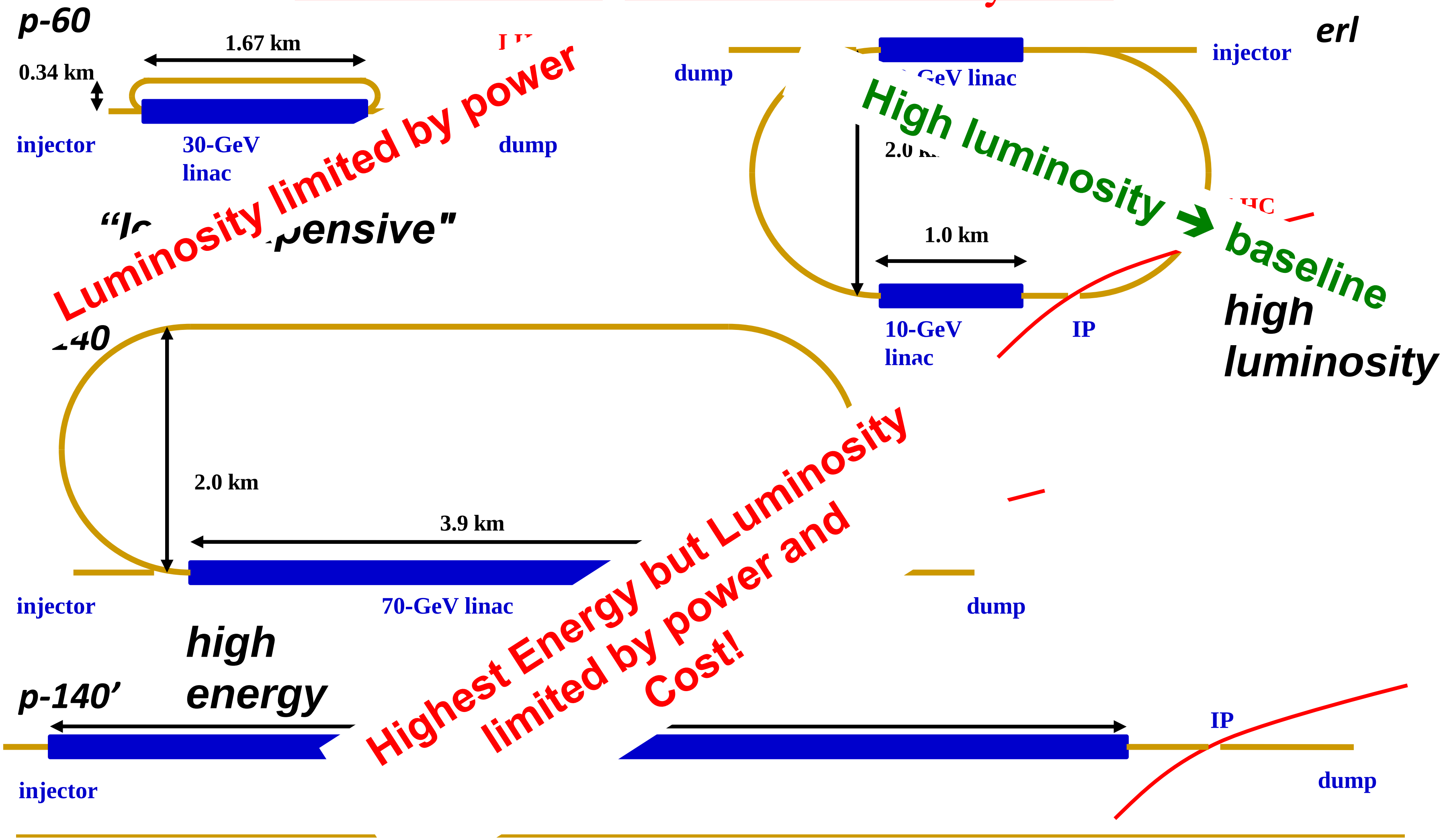
→ Magnet desig...

	150
	2
.../coil	1
...rent [A]	1500
Conductor section [mmxmm]	92x43
Conductor material	aluminum
Magnet Inductance [mH]	0.15
Magnet Resistance [mΩ]	0.2
Power per magnet [W]	450
Cooling	air
Weight [tons]	1.5

$3\cdot10^{-5}$
$5\cdot10^{-5}$
$4\cdot10^{-5}$

M... ...ests of 3 models

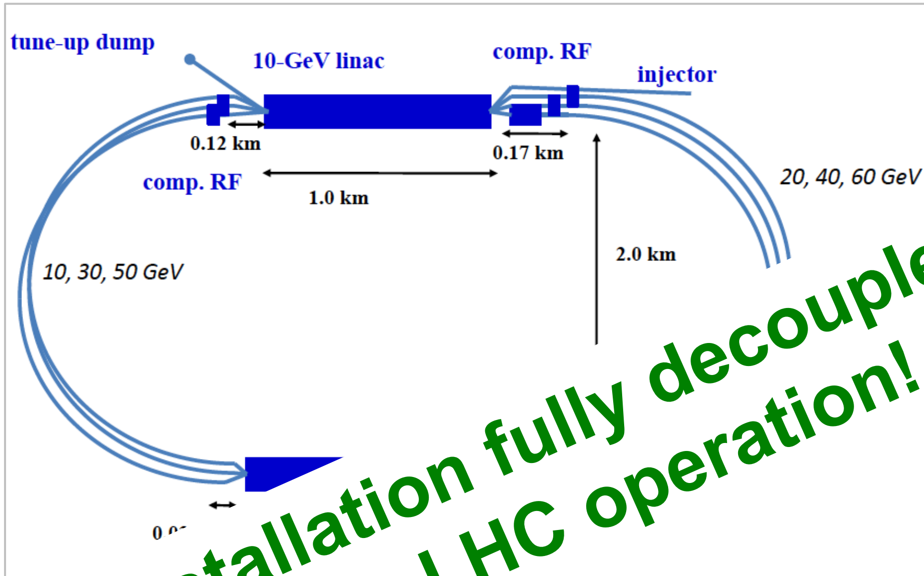
LHeC: Linac-Ring Option ➔ Considered Various Layout



LHeC: Baseline Linac-Ring Option

LHeC

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



Two 1 km long SC

in CW operation

10)

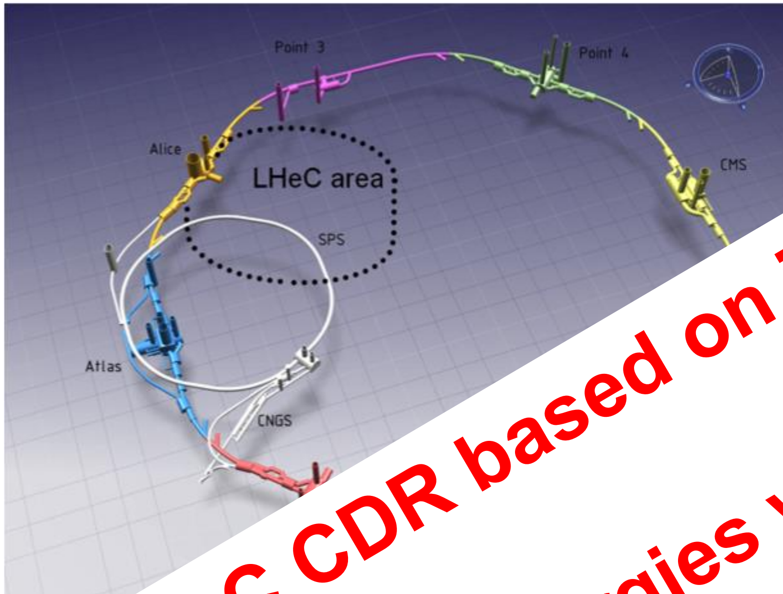
→ requires Cryogenic system comparable to LHC system!

Installation fully decoupled from LHC operation!

Chal… Relatively large return arcs

- → ca. … km underground tunnel installation
- → total of 19 km bending arcs
- → same magnet design as for RR option: > 4500 magnets

LINAC – Ring: connection to th



LHeC CDR based on 721 MHz cavity design

Synergies with ESS and SPL!

(1.3 GHz was also an option)

→ 800 MHz chosen after CDR

→ Synergy with HL-LHC and TLEP!

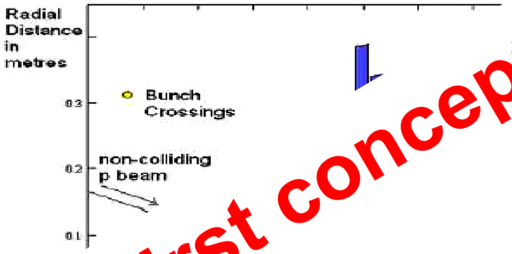
for
CERN
ory
=U(LHC)/3=9km

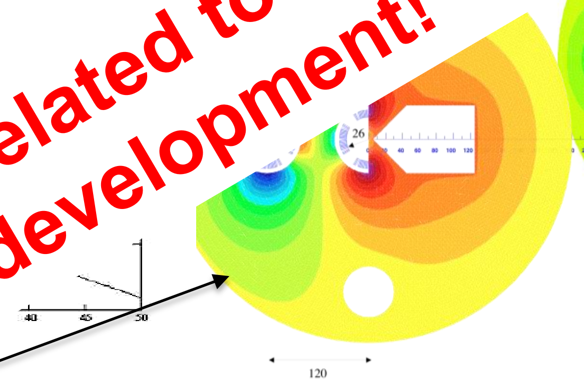
s per linac
1 MV/m CW
to SPL, ESS, XFEL, ILC,
HIC, Jlab
-24 - 39 MW RF power
-29 MW Cryo for 37W/m heat load
-4500 Magnets in the 2 * 3 arcs:
600 - 4m long dipoles per arc
240 - 1.2m long quadrupoles per arc

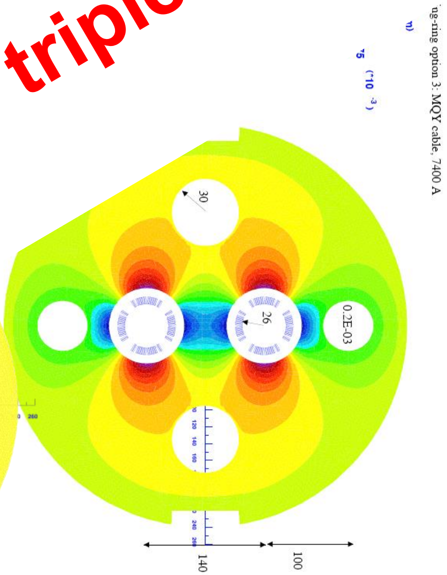
Interaction Region: Accommodatin… …ns

Small crossing angle of about 1mrad to avoi… …77)
(Dipole in detector? Crab cavities? Desi…
Synchrotron radiation –direct and b… …)

Focus of current activity







First conceptual SC magnet designs exist

But requires additional design work and R&D!

Technology related to HL-LHC triplet development!

1st … …d deflect)
sepa… …, MQY cables, 4600 A

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

LHeC CDR:

Total of ca. 500 pages: Detailed coverage of many topics:

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-2011-003 GEN

➔CDR arXiv:1206.2913

LHeC Options: Executiv[e S...]

•Details remain to be addressed

•Decision to focus R&D work on LR technologies over coming 4 years **(keep RR option only as fallback)**

→Main Conclusion so far: LHeC can be realized in parallel with HL-LHC if necessary studies are not delayed!

Post CDR Studies: ERL Beam Dynamics

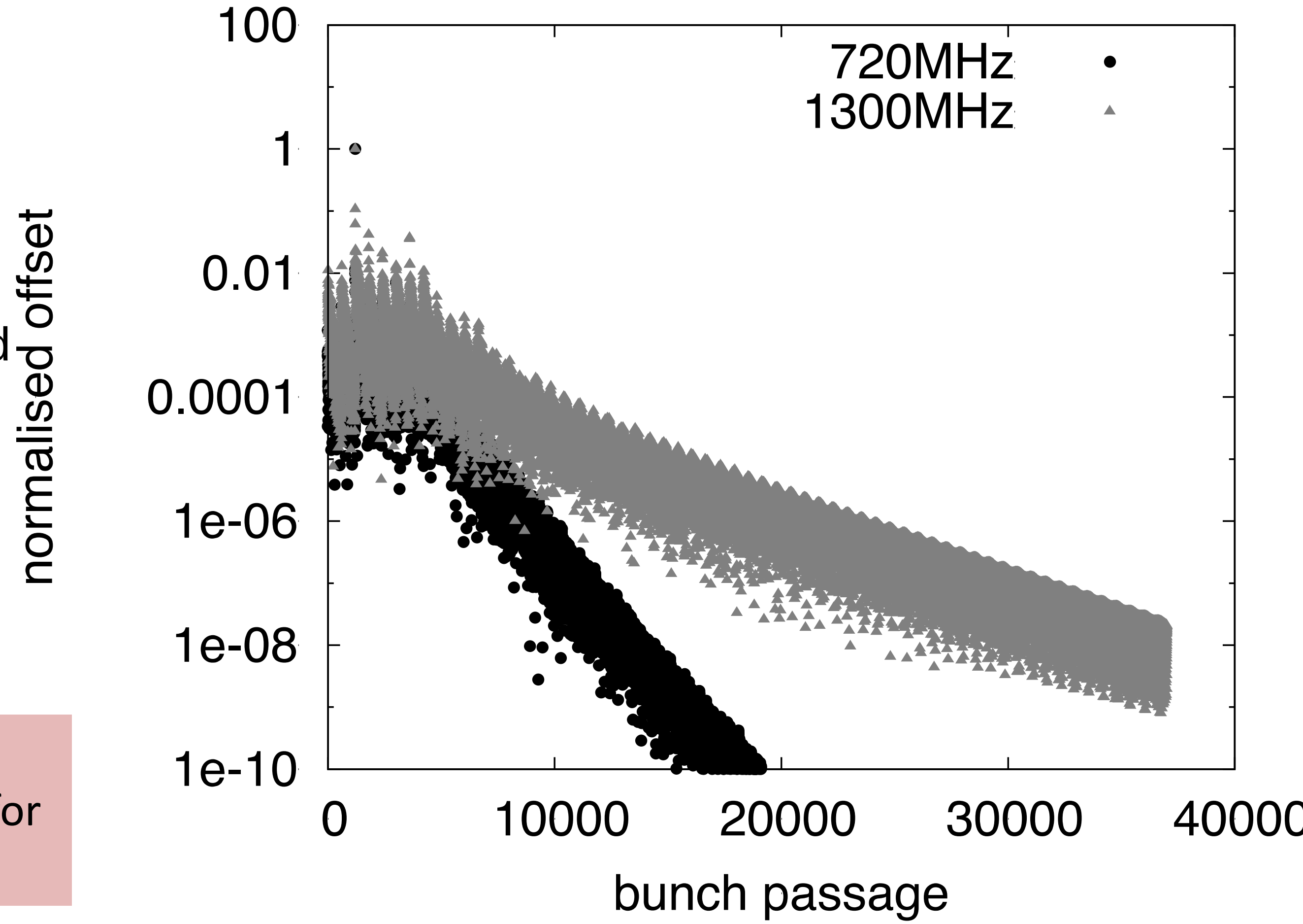
Beam Instabilities:

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

LHeC

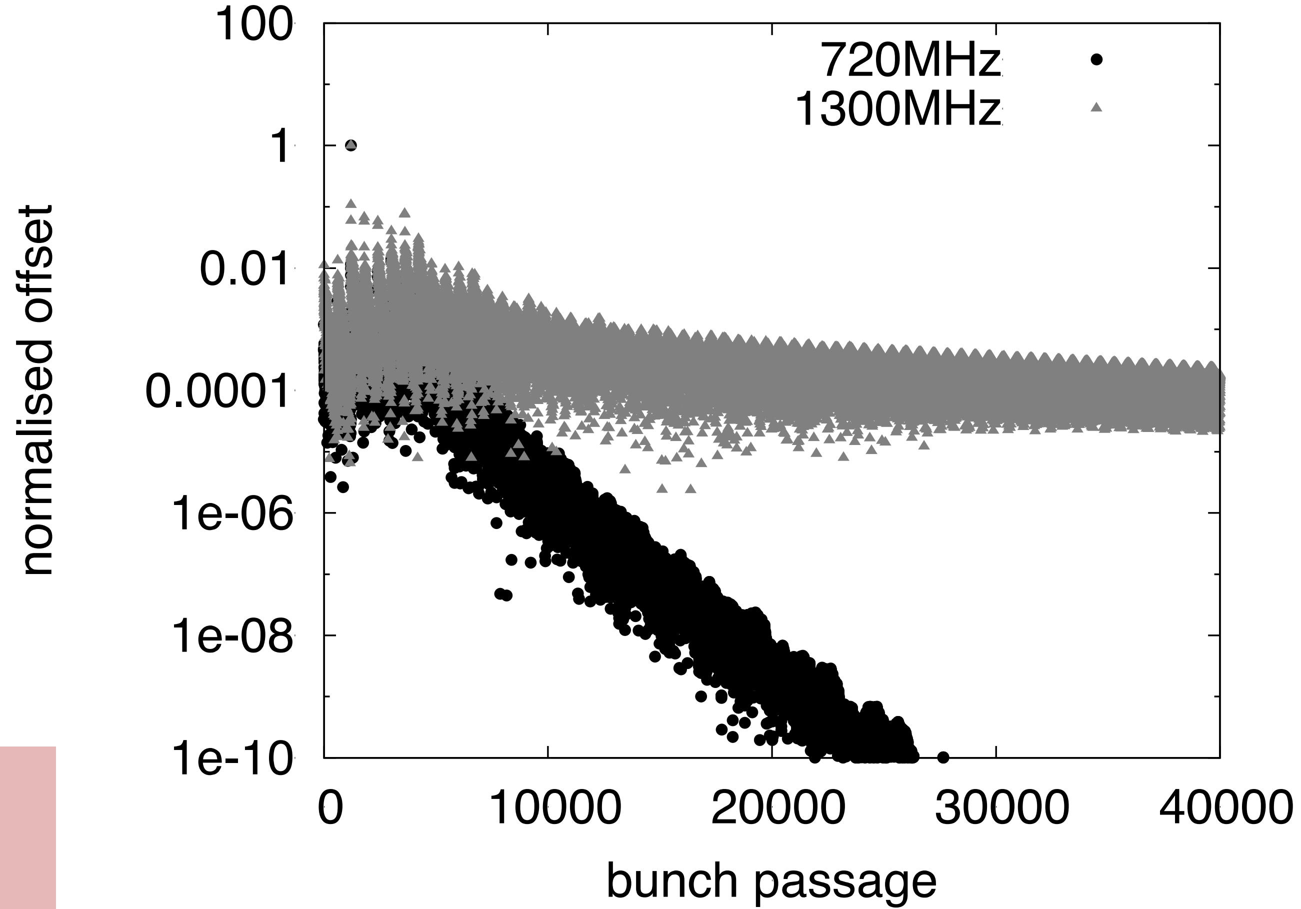
Beam-Beam effects:

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: RF Frequency

LHeC

Review of the SC RF frequency: January 2013 Daresbury

-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 quite different from existing technologies (20MHz)!

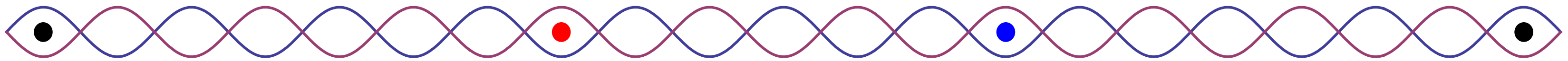
But having the harmonic number be a multiple of the ERL symmetry is not a strong requirement ➔ asymmetric bunch patterns

Optimum RF Frequency: around 800 MHz

Erk Jensen @ March 2013 LHeC Seminar

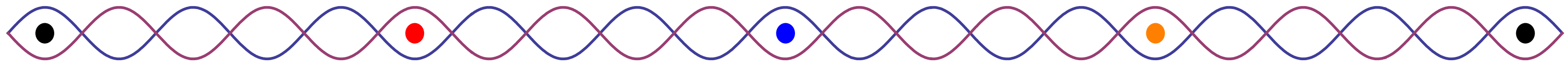
- f_{RF} = 20* 40.079 MHz ➔ 801.58 MHz

➔Buckets with slightly unevenly spaced bunches



1st pass | 2nd pass | 3rd pass | 1st pass

➔One could vary the number of passes through the ERL:



1st pass | 2nd pass | 3rd pass | 4th pass | 1st pass

➔Synergy with HL-LHC: Higher Harmonic RF System and TLEP!

LHeC Planning and Timeline

- 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 Tentative Time Schedule

LHeC

Year	2013	2014	2015	2016	2017	2018	2019	2020	...	2025

RF Proto Type Development

...cture

Installation

Operation

LS3 --- HL LHC

-Only 2 long shutdowns planned before 2022

-Only 10 years for the LHeC from CDR to project start.

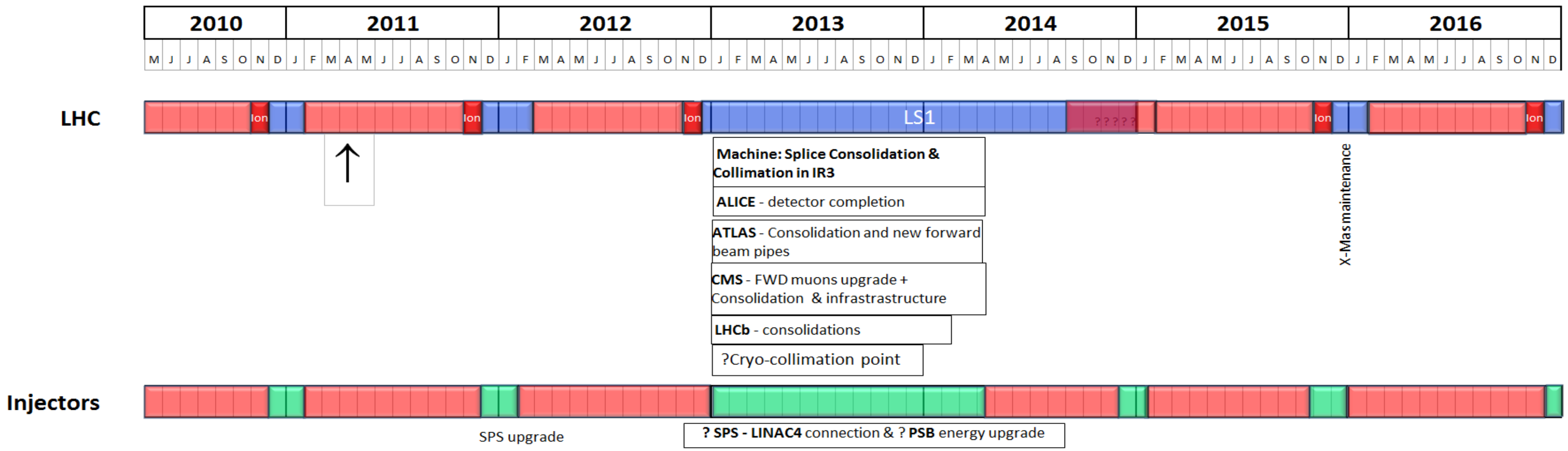
(Other smaller projects like ESS and PSI XFEL plan for 8 to 9 years [TDR to project start] and the EU XFEL plans for 5 years from construction to operation start)

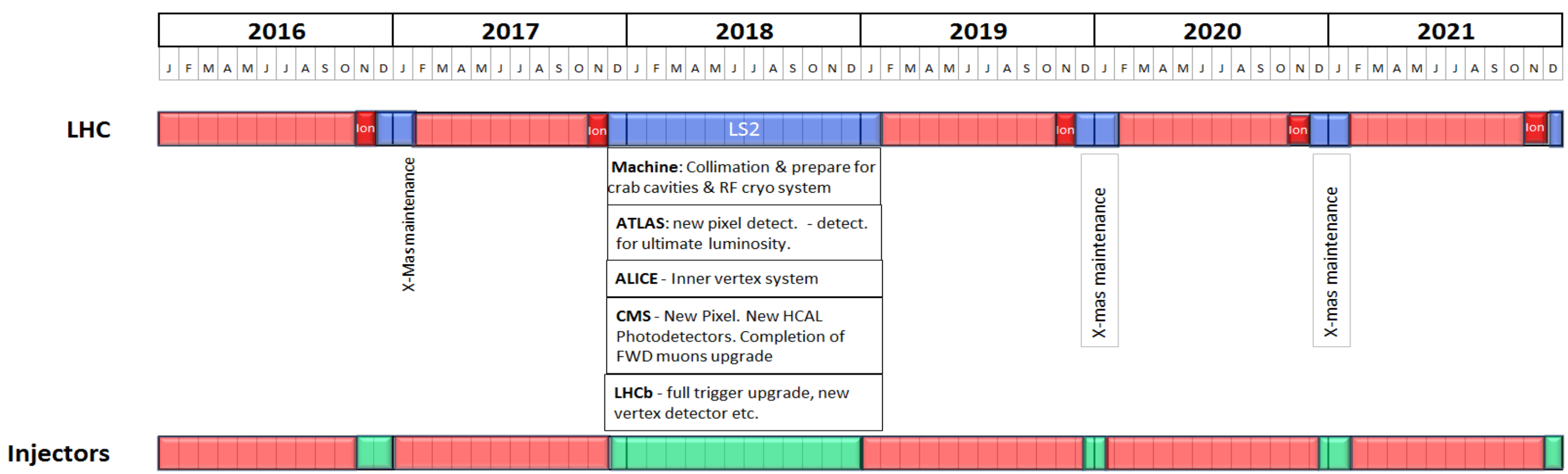
HERA required ca.10 years from proposal to completion

→ SC RF development offers synergies with HL-LHC and TLEP!

We ... for the project time line on the experience of other projects, such as (LEP, L... ...AC4 at CERN and the European XFEL at DESY and the PSI XFEL). In

New rough draft 10 year plan





2022

LS3

Installation of the HL-LHC hardware

Installation of LHeC

Preparation for HE-LHC

LHeC: Post CDR Steps

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

  -SC RF R&D has direct impact …

  … applications

Requires:
small budget & CERN mandate

  Synergy with national research plans: e.g. MESA

- Magnet R&D activities:

  -Normal conducting com…

Requires:
small budget & CERN mandate

  … depends on IR layout and optics

  ➔ Optics & IR magnet design influence experimental vacuum beam pipe

LHeC: Post CDR Steps

- Develop an ERL test facili…

…at CERN

Requires:
significant budget & resources

…arch plans: SC RF and TLEP

Post CDR: CERN Mandate for R&D

The mandate for the technology development **includes studies and prototyping of the following key technical components**:

- Superconducting RF system for CW operation in an Energy Recovery Linac (high Q_0 for efficient energy recovery) S
- Superconducting magnet development of the insertion regions of the LHeC with three beams. The studies require the design and construction of short magnet models
- Studies related to the experimnetal beam pipes with large beam acceptance in a high synchrotron radiation environment
- The design and specification of an ERL test facility for the LHeC.
- The finalization of the ERL design for the LHeC including a finalization of the optics design, beam dynamics studies and identificationof potential performance limitations

The above technological developments require close collaboration between the relevant technical groups at CERN and external collaborators. Given the rather tight personnel resource conditions at CERN **the above studies should exploit where possible synergies with existing CERN studies.**

S.Bertolucci at Chavannes workshop 6/12 based on
CERN directorate's decision to include LHeC in the MTP

Next Steps: RF Prototype and Test Facility LHeC

- Develop 2 RF Cryomodule Prototypes over the nest 3 years

  -LHeC RF frequency choice driven by cryo power & beam stability

  Choice of ERL RF frequency: 801.58 MHz

  ➔ Synergy with HL-LHC HH RF system and TLEP!

- Design an ERL test facility @ CERN:

  -Develop technical expertize at CERN

  -Develop operational expertise at CERN for ERLs

  -Optimize magnet design for ERL return arcs

  ➔ Synergy with TLEP!

Next Steps: Magnet Design and Layout

LHeC

- Optimize LHeC Interaction Region Layout:
  - -L^* variation
  - -SC magnet design for three beams
  - -Synchrotron radiation & Vacuum beam pipe design
- Optimize and Iterate on LHeC ERL layout:
  - -Optimization of linac configuration
  - -Optimization of Civil Engineering layout
  - -Optimization of number of linac passages

Summary LHeC Planning and Tim

LHeC

Questions and required R&D activities for

-Superconducting RF with high Q @ 80

➔ synergies with HL-LHC

-ERL operation in GeV

➔ beam stability ... etc.

-Test facili

➔ ...esbury, Berlin-Pro, MESA

...work and TLEP?

...d positron sources

... with CLIC and ILC and TLEP activities?

The first 3 points fit well into overall strategy for developing SC RF expertise at CERN!

The last two points fit to linear collider and TLEP studies

Concluding Remarks

- LHeC CDR could be developed in 4+ years:

  -Dedicated annual workshops

  -Success based on strong enthusiasm of all collaborators

- LHeC and TLEP have many synergies and common R&D goals:

  -Compact normal conducting magnets

  -SC RF development

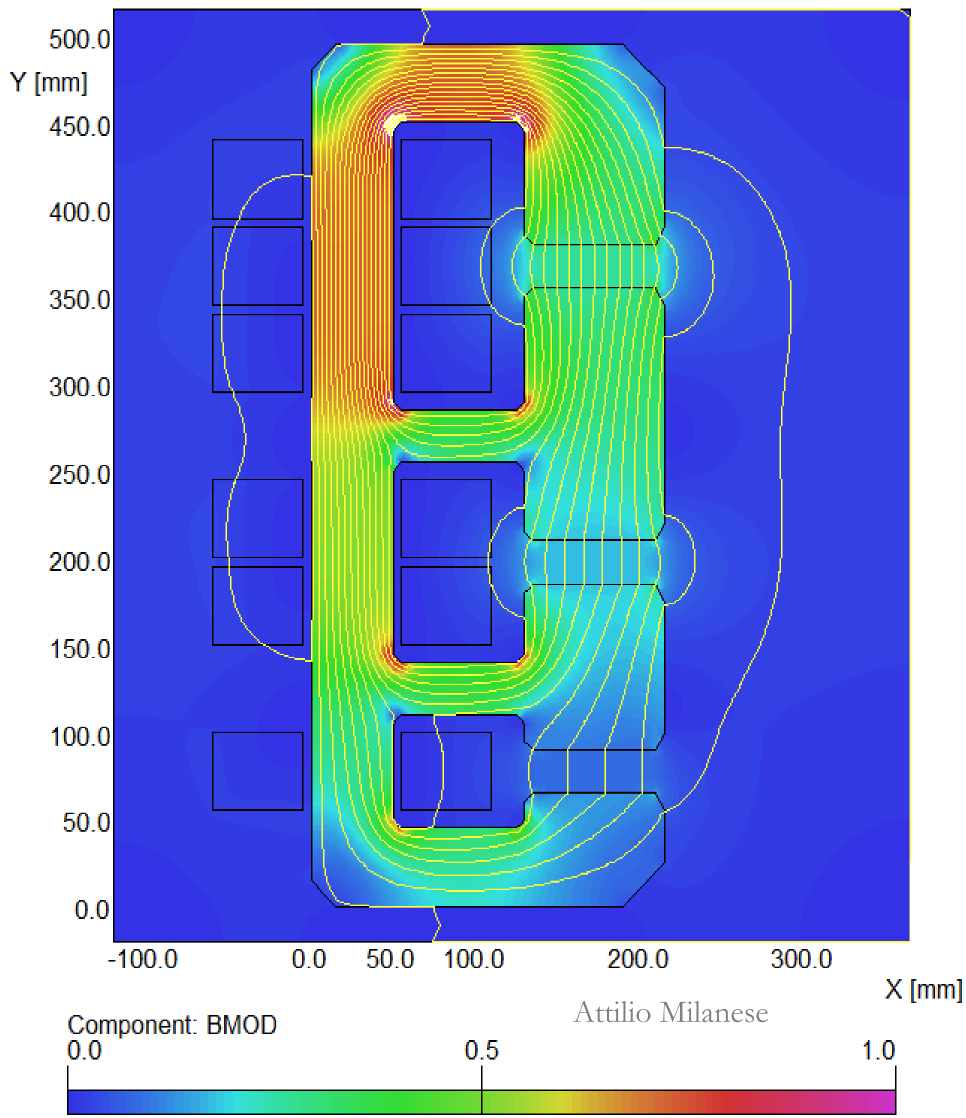
  -Compact lepton injector complex design

  -lepton source development

Depending on the global Planning (TLEP after HL-LHC) one could even recuperate LHeC equipment for TLEP: SC RF & LHeC as injector

Reserve Transparencies

Next Steps: Test Facility and Magnets

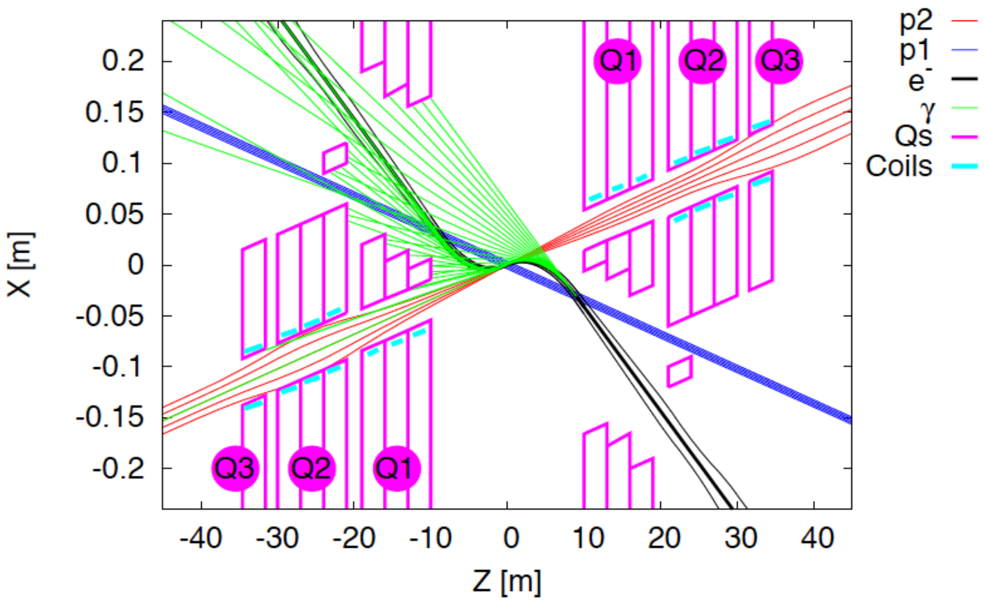


Attilio Milanese

First conceptual cross-section

flux density in the gaps	0.264 T 0.176 T 0.088 T
magnetic length	4.0 m
vertical aperture	25 mm
pole width	85 mm
number of magnets	584
current	1750 A
number of turns per aperture	1 / 2 / 3
current density	0.7 A/mm^2
conductor material	copper
resistance	0.36 mΩ
power	1.1 kW
total power 20 / 40 / 60 GeV	642 kW
cooling	air

Next Steps: Interaction Region Design



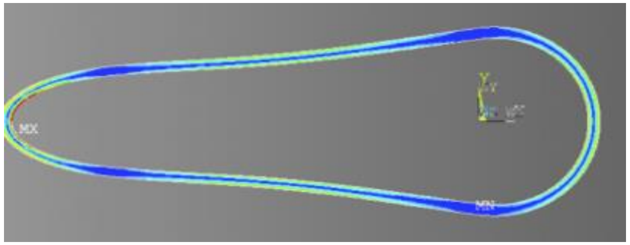
Have optics compatible with LHC ATS optics and β*=0.1m
Head-on collisions mandatory →
High synchrotron radiation load, dipole in detector

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

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

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



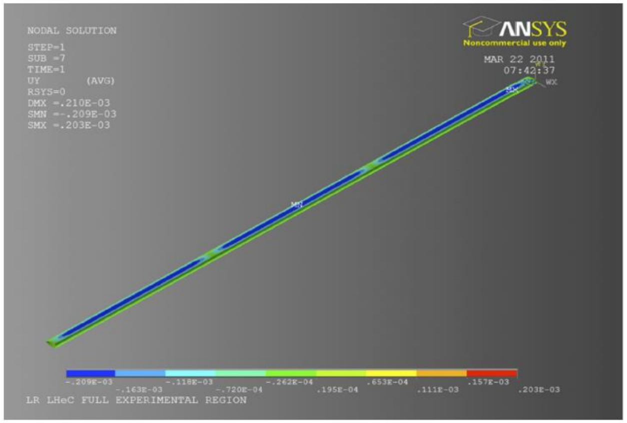
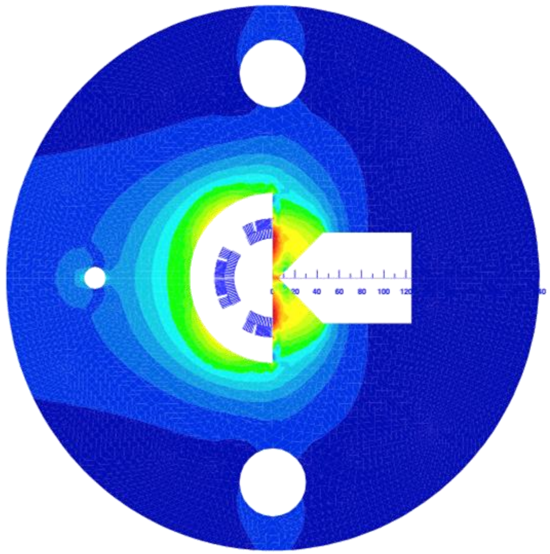
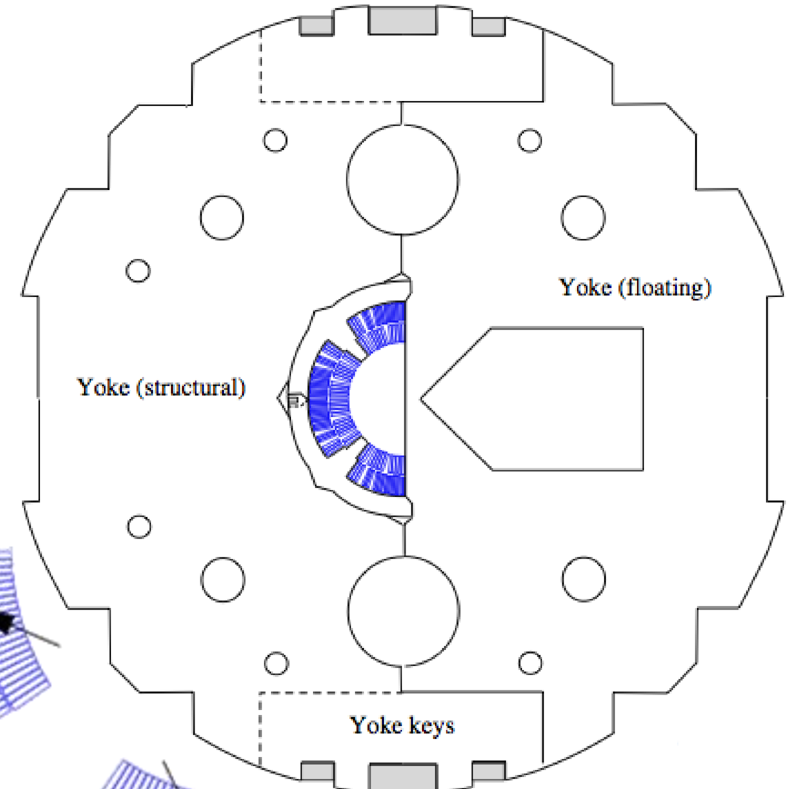


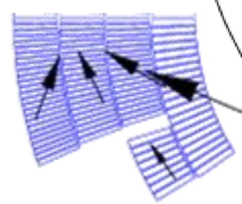
Figure 9.32: 3-D view of the LR geometry showing contours of bending displacement [m].

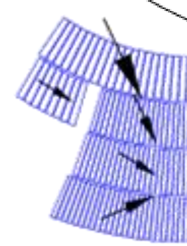
Next Steps: LHeC IR Quadrupole

Luca Bottura @ Chamonix 2012





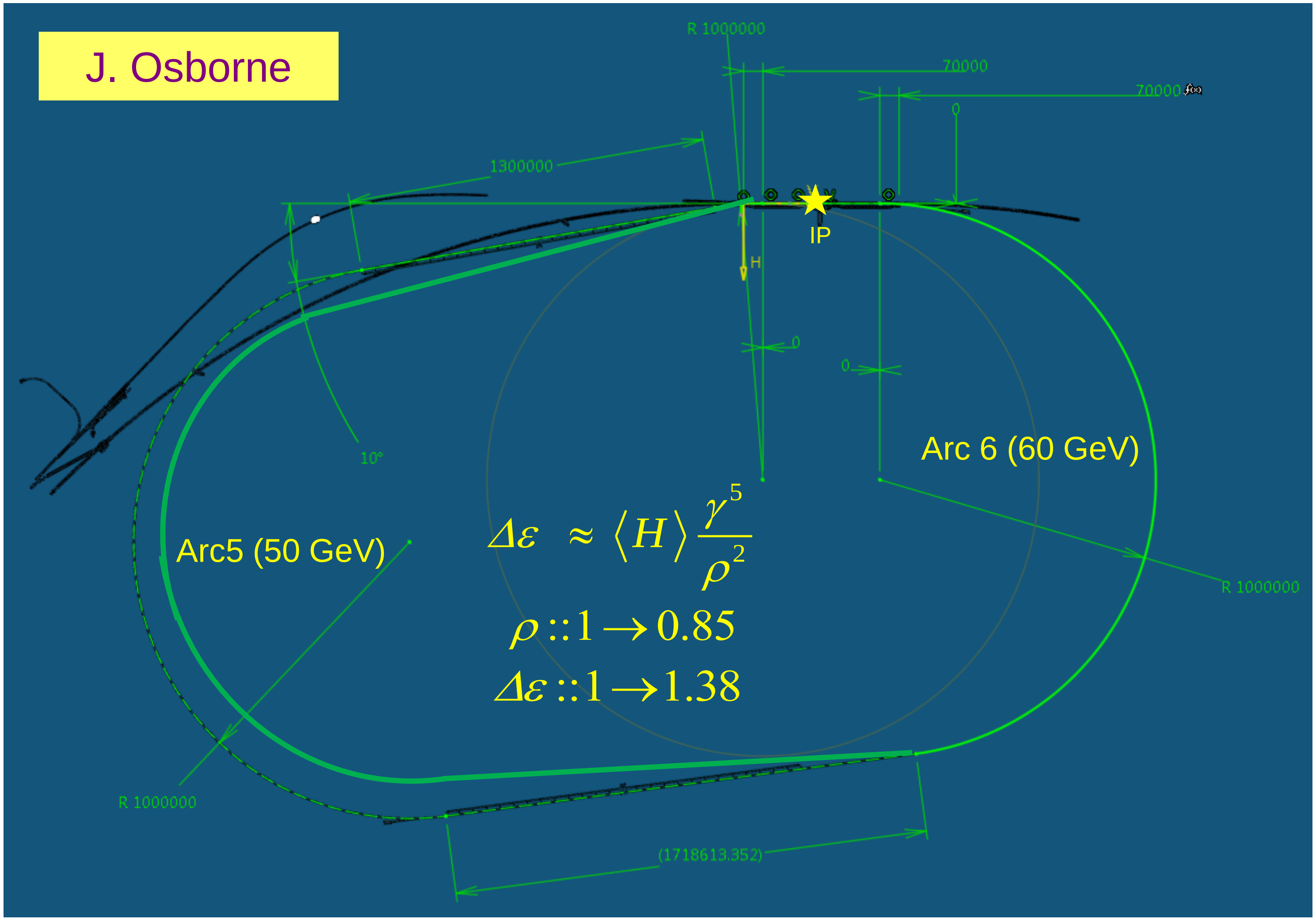




- Half-quad with field-free region, assembled using MQXC coils
  - 2.5 FTE
  - 500 kCHF
  - approx. 2 years till test

Large forces on the magnetic wedge (> 50 tons/m)

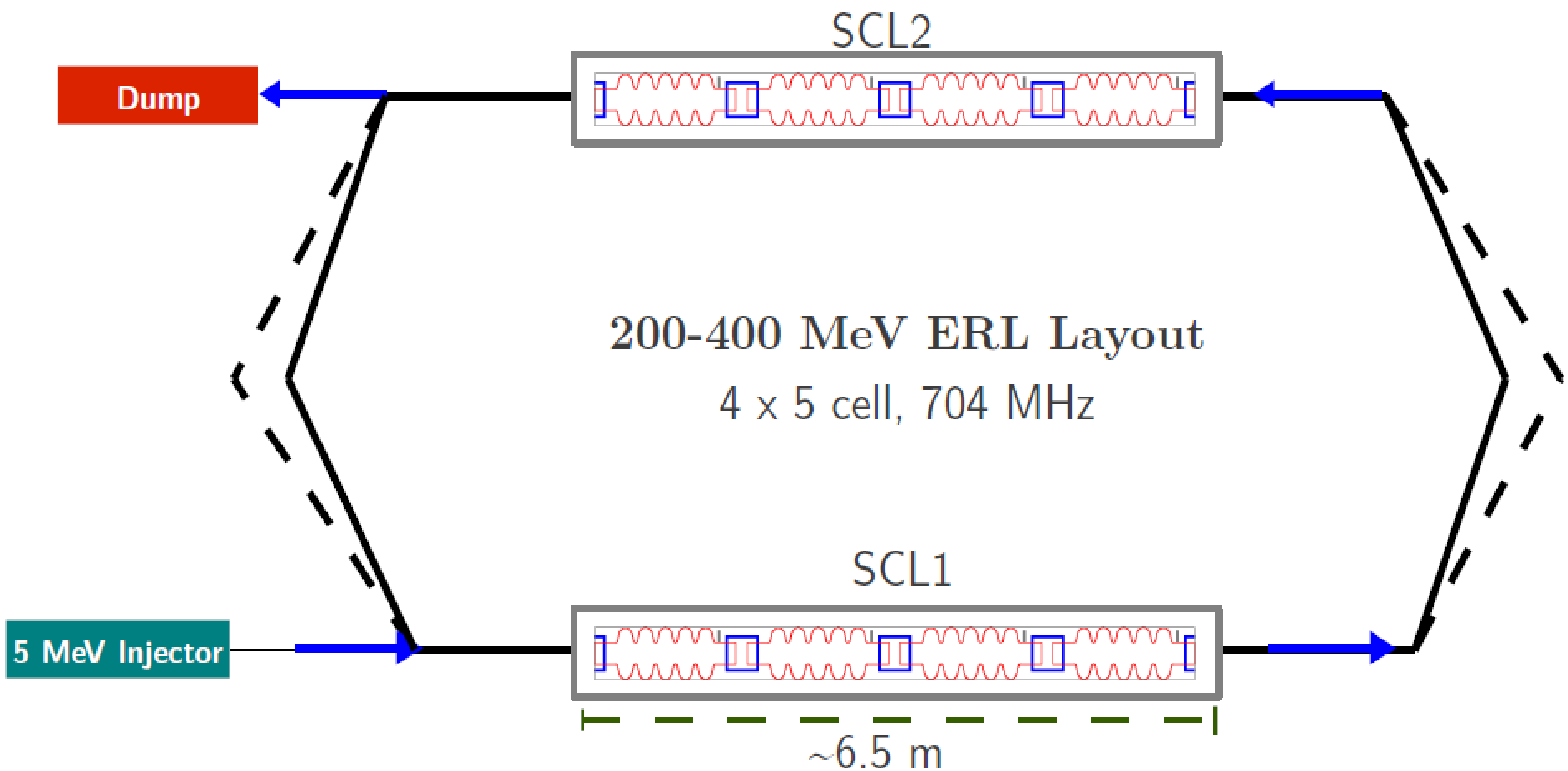
Next Steps: ERL Layout Finalization



John Osborne

ERL Test Facility at CERN

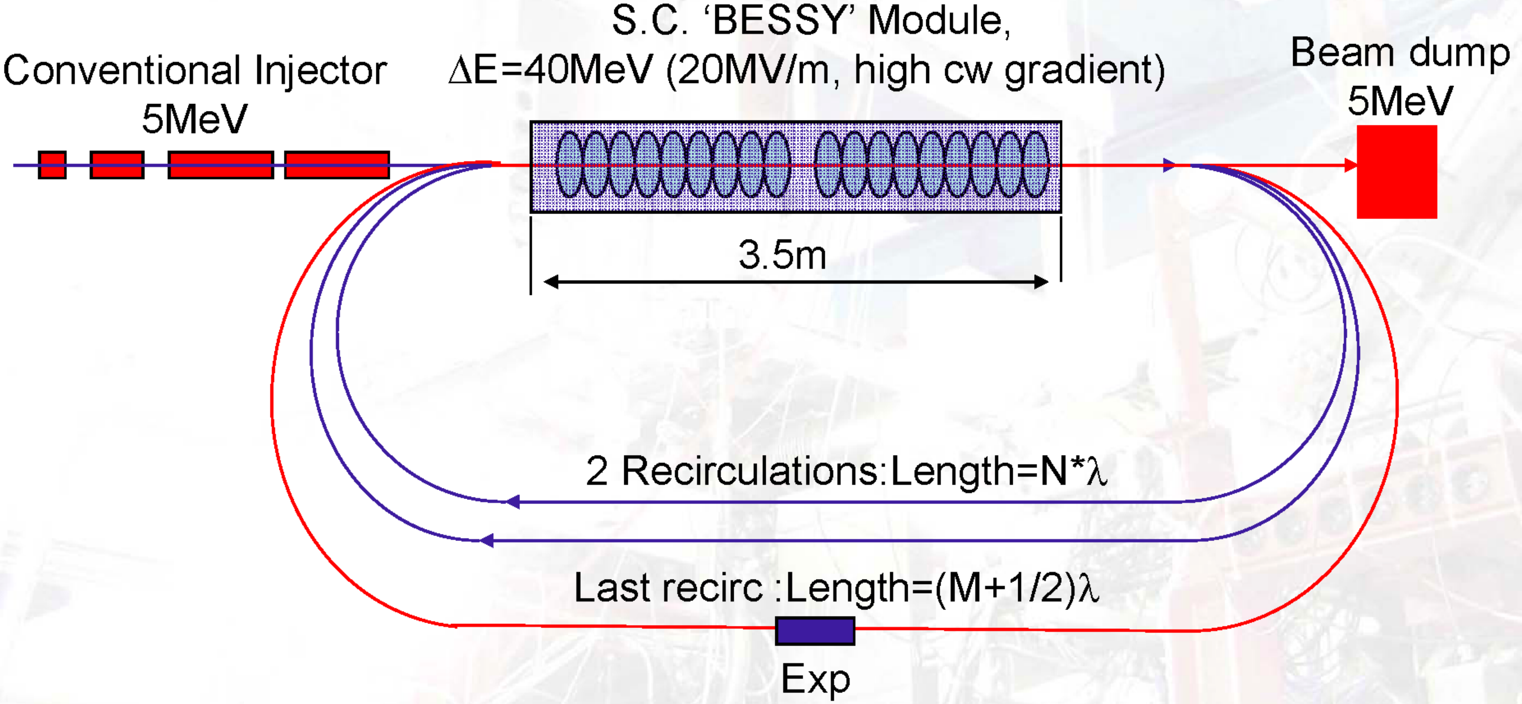
Potential layout:



JOHANNES GUTENBERG UNIVERSITÄT MAINZ

MESA

Mainzer Energieeffiziente Supraleitende Anlage
Mainz Energy recovering Superconducting Accelerator



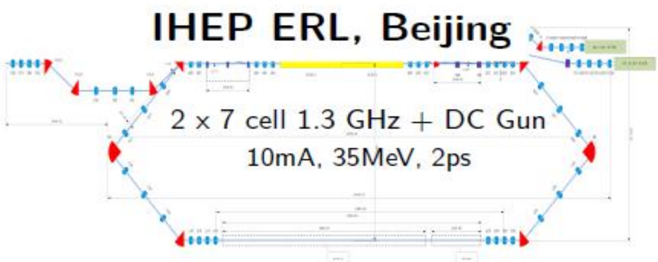
Parameters: (red beam for experiments)
E_{max}= 5-125 MeV; I_{av}=10mA (cw) ; ε_{norm}=10μm, P_{dump}≤50kW, Cost <10M€
Footprint < 20*10m.

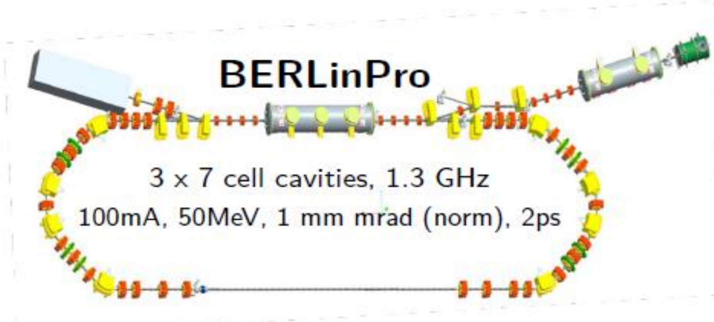
02.04.2009 Kurt Aulenbacher: MESA: A new tool.... 19

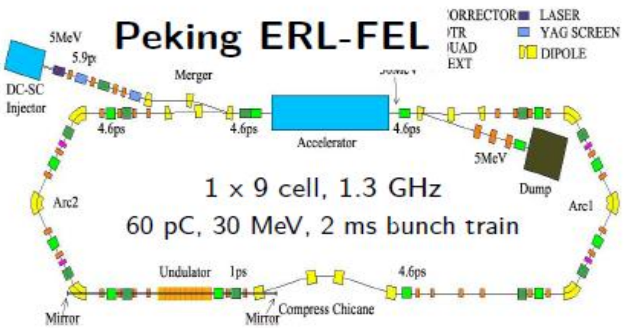
ERL Facilities around the World

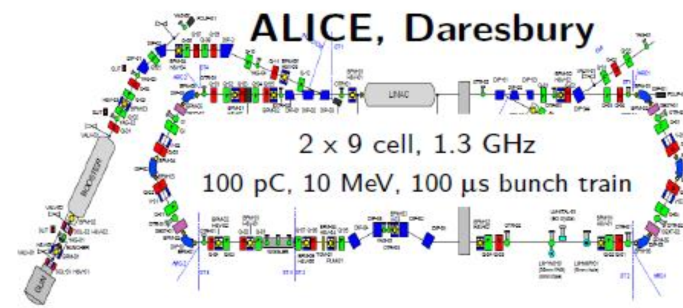
LHeC

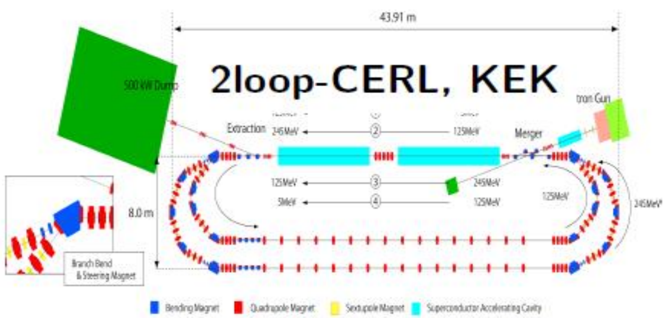
Planned Test Facilities and Installations:





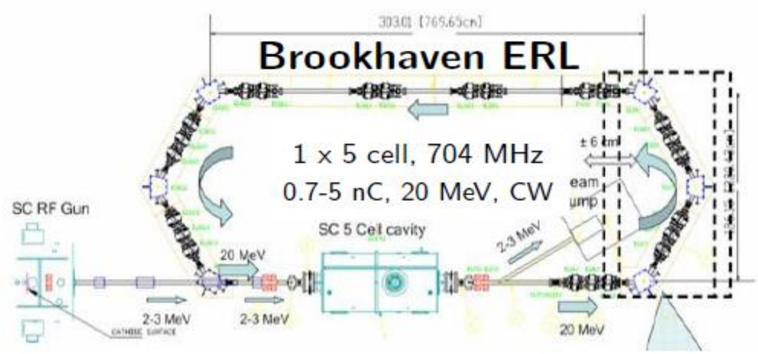






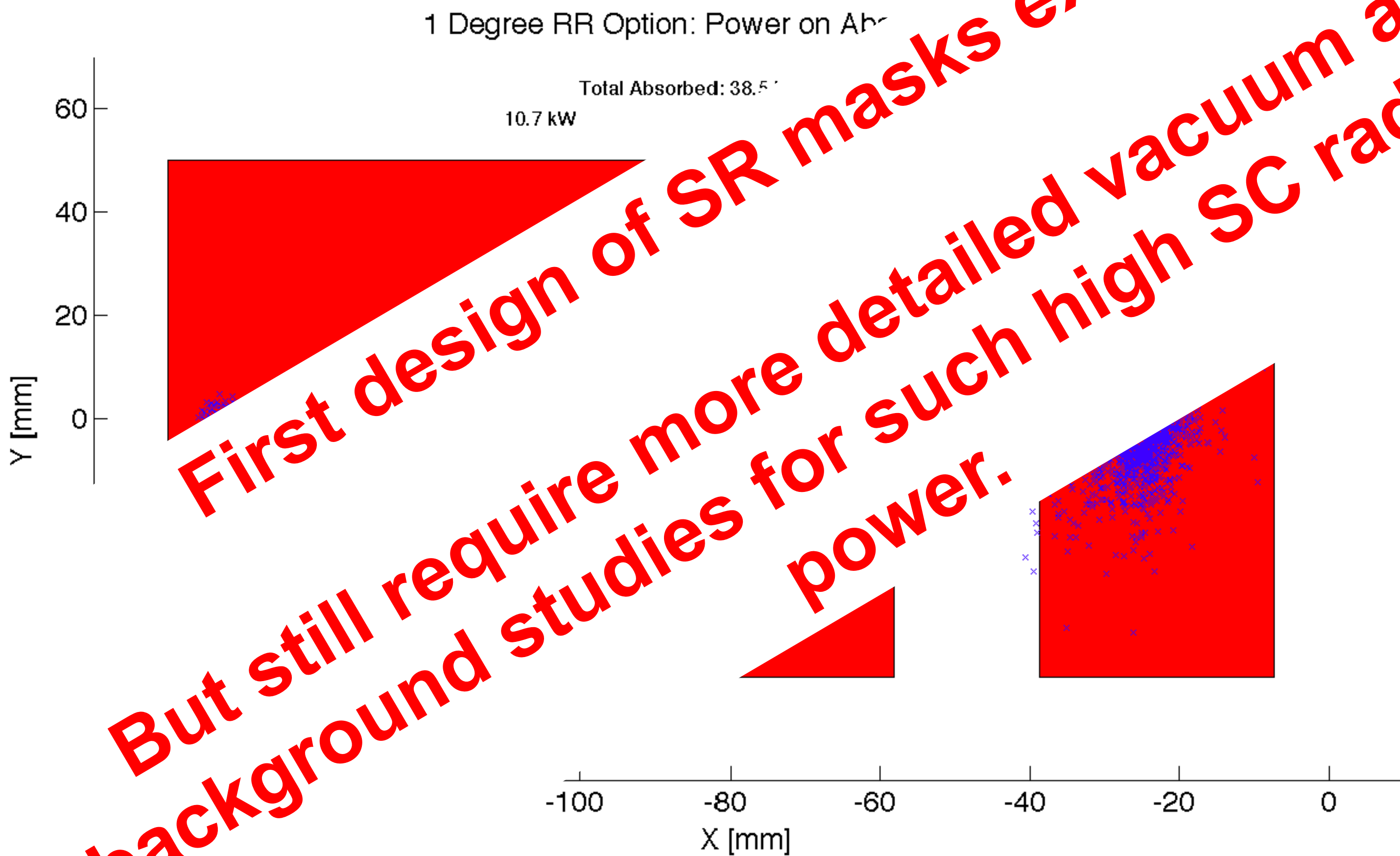
9 cell, 1.3 GHz cavities, 4 modules

77 pC, 245 MeV, 1-3 ps



Interaction Region: Synchrotron R… tion

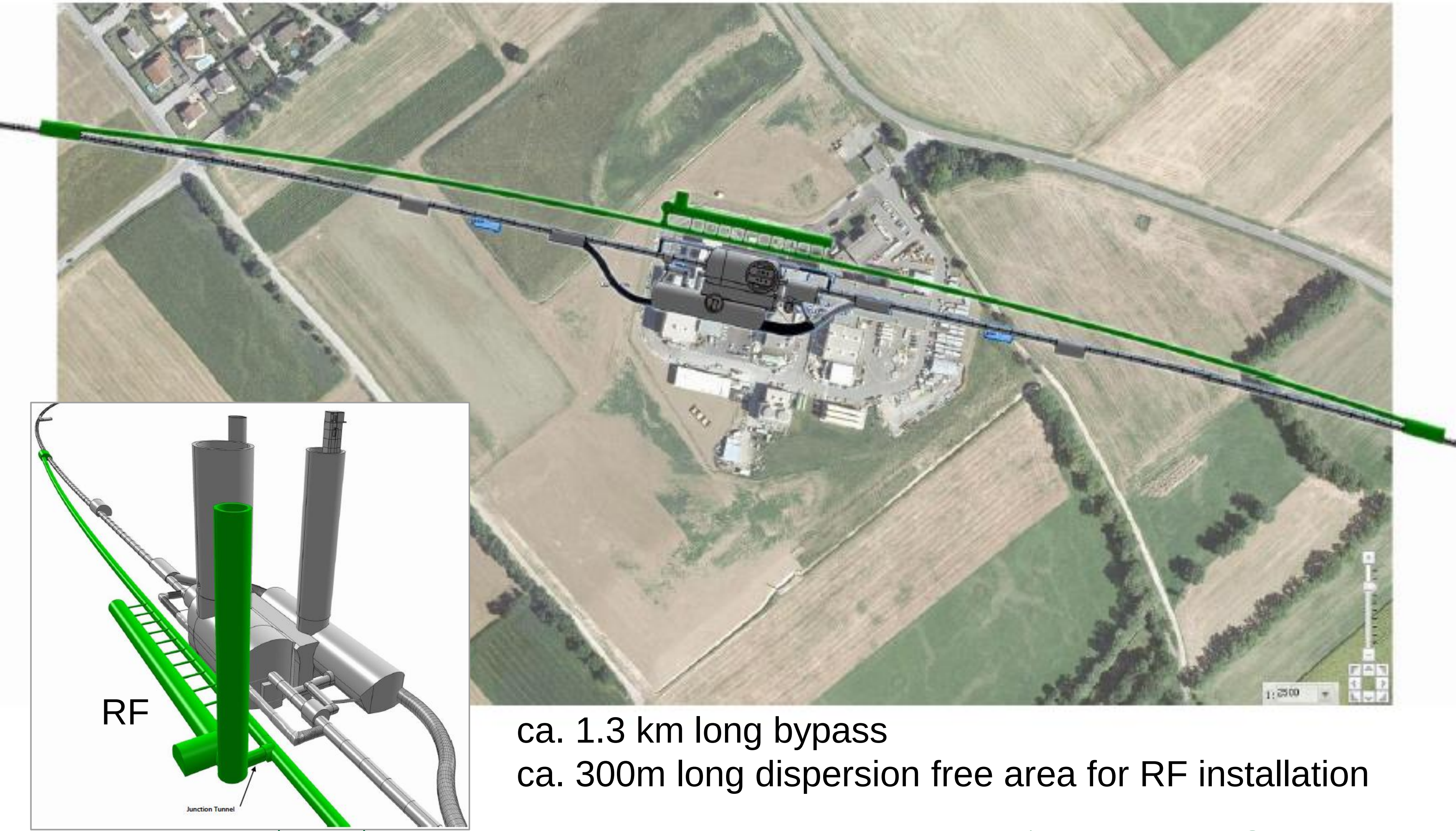
Significant power: > 20 kW. Example Ring-Ring



First design of SR masks exists.

But still require more detailed vacuum and background studies for such high SC radiation power.

Bypassing CMS: 20m distance to Cavern



ca. 1.3 km long bypass
ca. 300m long dispersion free area for RF installation

Design Parameters

electron beam	RR**	LR	LR*
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	0.9	10	[illegible]
polarization [%]	40	90	[illegible]
bunch population [10^9]	20	[illegible]	[illegible]
e- bunch length [mm]	6 [illegible]	[illegible]	[illegible]
bunch interval [ns]	[illegible]	[illegible]	[illegible]
transv. emit. $\gamma\varepsilon_{x,y}$ [m [illegible]	[illegible]	[illegible]	[illegible]
rms IP beam si [illegible]	[illegible]	[illegible]	[illegible]
e- IP beta [illegible]	[illegible]	[illegible]	[illegible]
full [illegible]	[illegible]	[illegible]	[illegible]
geo [illegible]	[illegible]	[illegible]	[illegible]
repeti [illegible]	[illegible]	[illegible]	[illegible]
beam pu [illegible]	[illegible]	[illegible]	5
ER efficien [illegible]	[illegible]	[illegible]	N/A
average cur [illegible]	[illegible]	6.6	5.4
tot. wall plug [illegible]	[illegible]00	100	100

	LR
	1.7
	3.75
	7 [illegible]

[illegible] servative

[illegible] also for deuterons [illegible]w) and lead (exists)

RR= Ring – Ring
LR =Linac –Ring

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

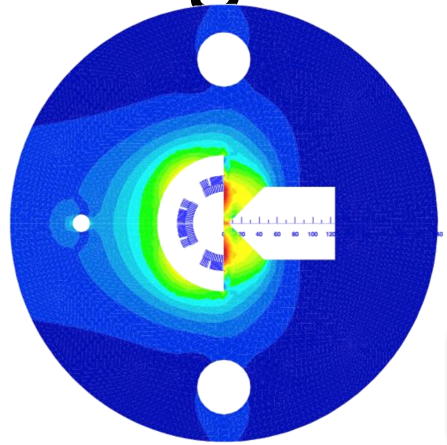
Final parameter set to be developed as we gain experience with LHC operational (beam-beam, spacing etc)

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

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

IR magnets

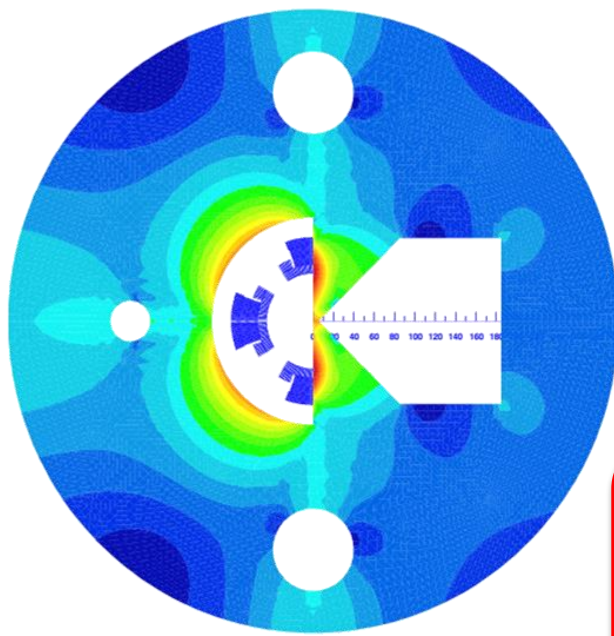
- Ring-ring
  - G=140 T/m
  - A=70 mm
  - **B_{fringe} = 30 mT**
  - **O(15) kW SR power in the proton aperture**

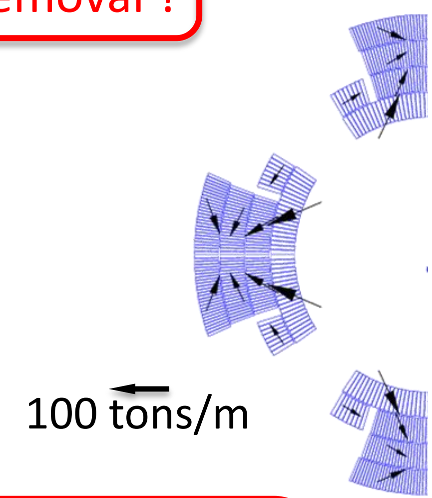


NbTi suitable for this *medium gradient* option

Mechanics ?
Heat removal ?

- Linac-Ring
  - **G=250-300 T/m**
  - **A=90 mm**
  - B_{fringe} = 500 mT
  - **O(2) kW SR power in the proton aperture**





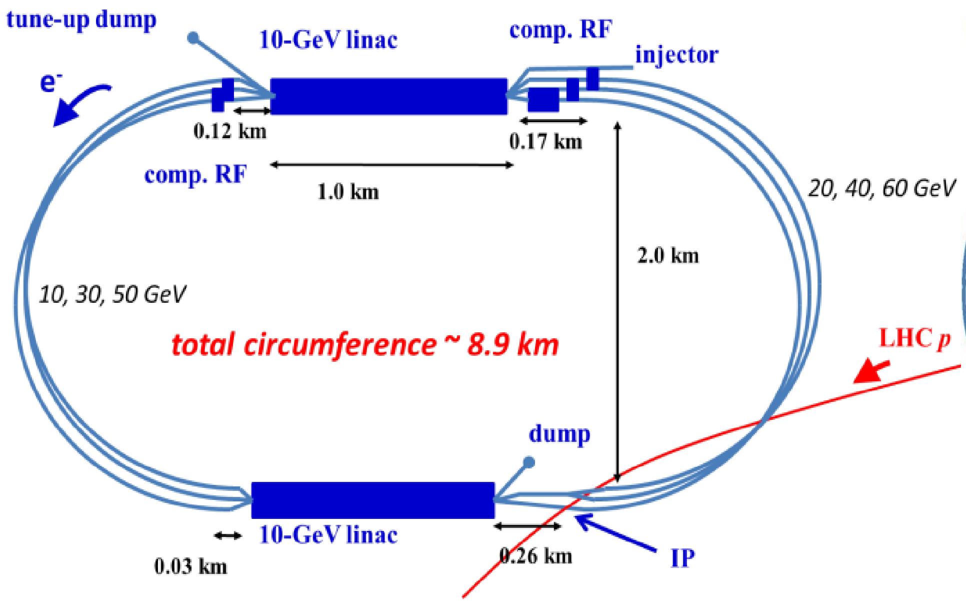
NbTi or Nb3Sn ?
Large aperture ?
Mechanics ?
Heat removal ?

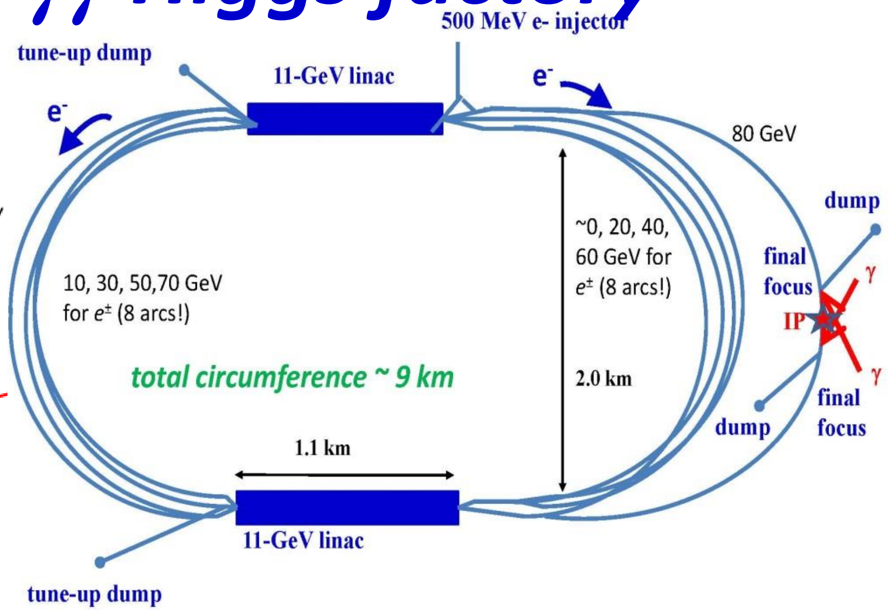
By courtesy of S. Russenschuck

Reconfiguring *LHeC* → *SAPPHiRE*

LHeC-ERL

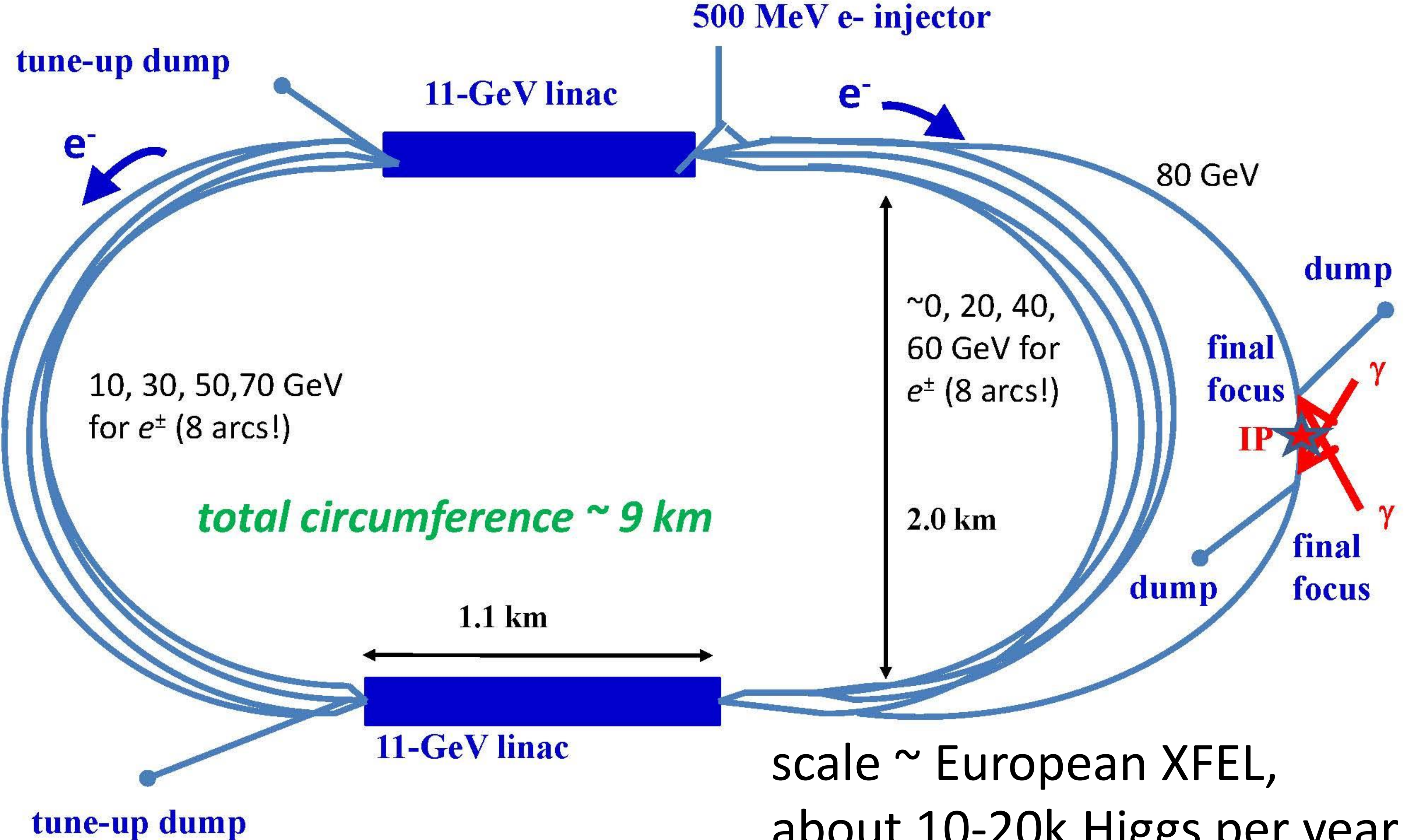
*SAPPHiRE**
γγ Higgs factory





***S**mall **A**ccelerator for **P**hoton-**P**hoton **Hi**ggs production using **R**ecirculating **E**lectrons

SAPPHiRE: a Small $\gamma\gamma$ Higgs Factory



scale ~ European XFEL,
about 10-20k Higgs per year

SAPPHiRE: Small Accelerator for Photon-Photon Higgs production using Recirculating Electrons

SAPPHiRE	symbol	value
total electric power	P	100 MW
beam energy	E	80 GeV
beam polarization	P_e	0.80
bunch population	N_b	10^{10}
repetition rate	f_{rep}	200 kHz
bunch length	σ_z	30 μm
crossing angle	θ_c	≥20 mrad
normalized horizontal/vert. emittance	$\gamma\varepsilon_{x,y}$	5,0.5 μm
horizontal IP beta function	β_x^*	5 mm
vertical IP beta function	β_y^*	0.1 mm
horizontal rms IP spot size	σ_x^*	400 nm
vertical rms IP spot size	σ_y^*	18 nm
horizontal rms CP spot size	σ_x^{CP}	400 nm
vertical rms CP spot size	σ_y^{CP}	440 nm
e^-e^- geometric luminosity	L_{ee}	$2x10^{34}$ $cm^{-2}s^{-1}$

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

ANKARA ÜNİVERSİTESİ

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

ECFA

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

BROOKHAVEN NATIONAL LABORATORY

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