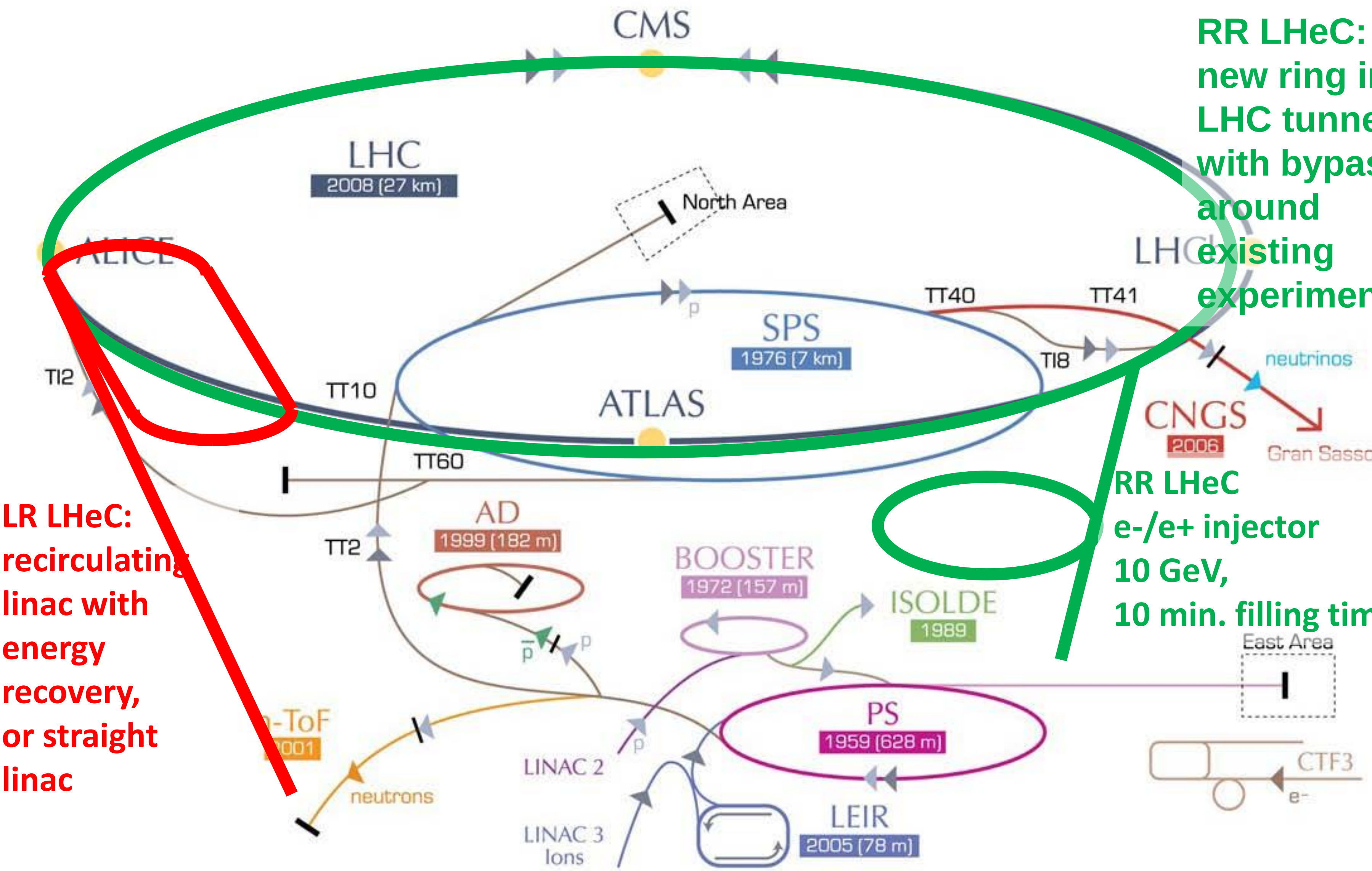
LHeC

- Design Considerations
- Two options: -Ring-Ring collider

  -Linac-Ri[illegible]der with Energy Recovery
- IR Layout
- Plann[illegible]imeline
- Next steps

On behalf of the LHeC Collaboration!

LHeC options: RR and LR

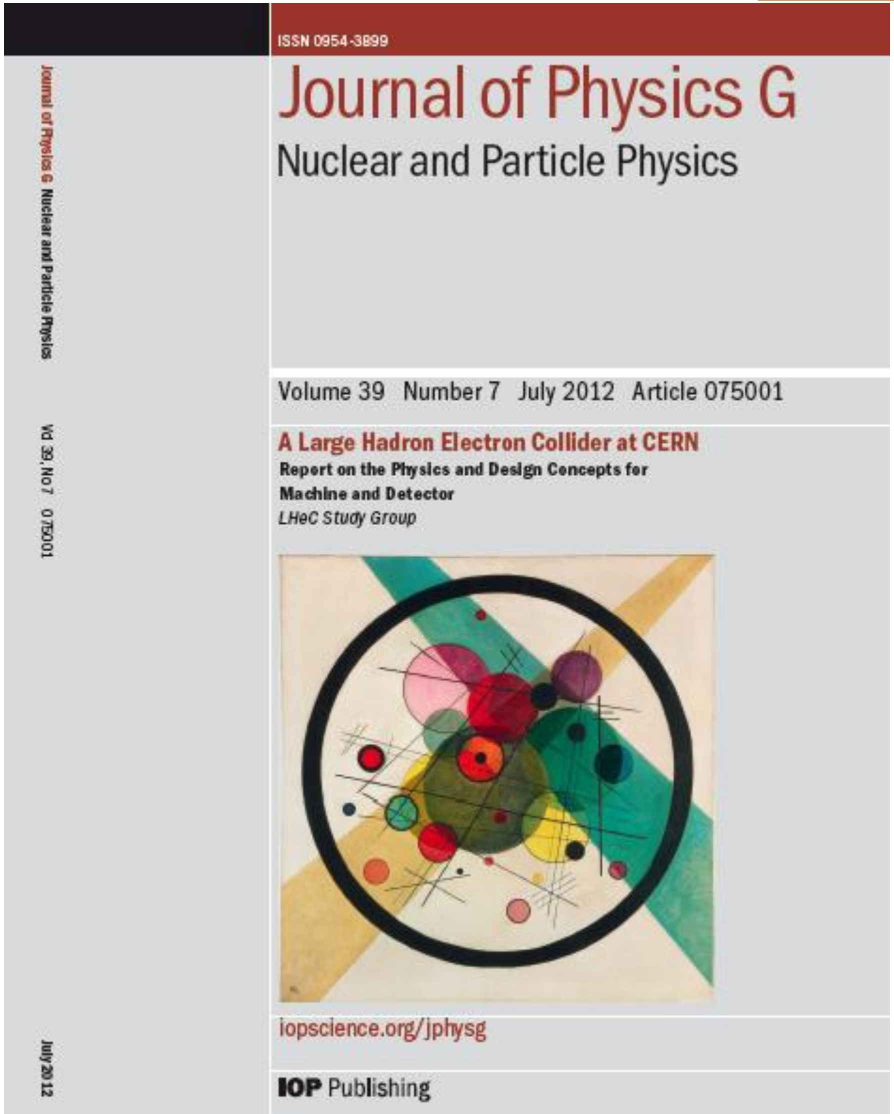


RR LHeC: new ring in LHC tunnel, with bypasses around existing experiments

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

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

LHeC CDR



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 or injector to TLEPP or others 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

Current 10 Year Plan for LHC Operation

R-R Installation is very challenging within current schedule!

LS1 and LS2 are too soon to be used for LHeC activities inside LHC tunnel!

Leaves essentially only one long shutdown for LHeC installation!

➔

Chavannes 2012 decision to focus future activities on ERL option which allows Construction and installation Independent of LHC schedule!

Inje

of

for

Inje

CERN Mandate 2012: 5 main points

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

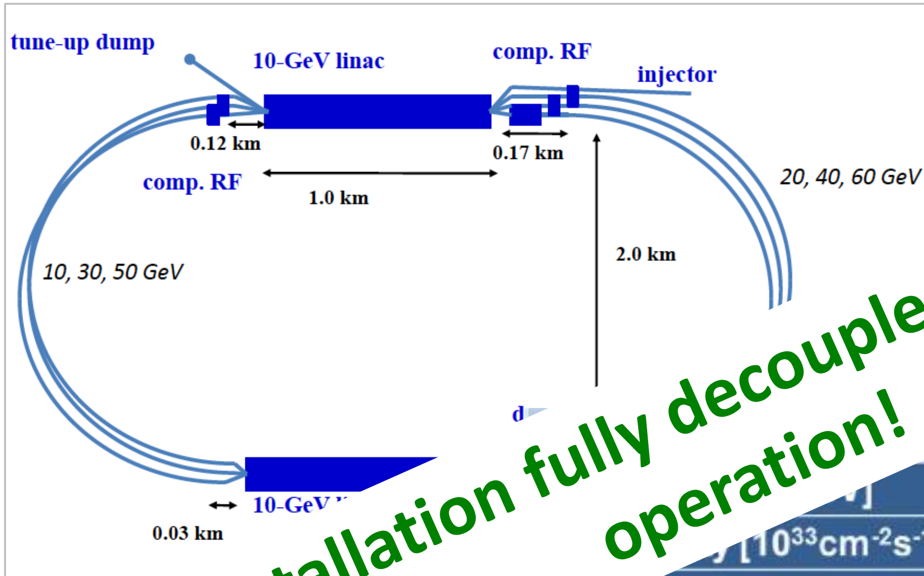
- Superconducting RF system for CW operation in an Energy Recovery Linac (high Q_0 for efficient energy recovery) S
- Superconducting magnet development of the insertion regions of the LHeC with three beams. The studies require the design and construction of short magnet models
- Studies related to the experimental 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

LHeC: Baseline Linac-Ring Option

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



Two 1 km long SC lin… CW operation

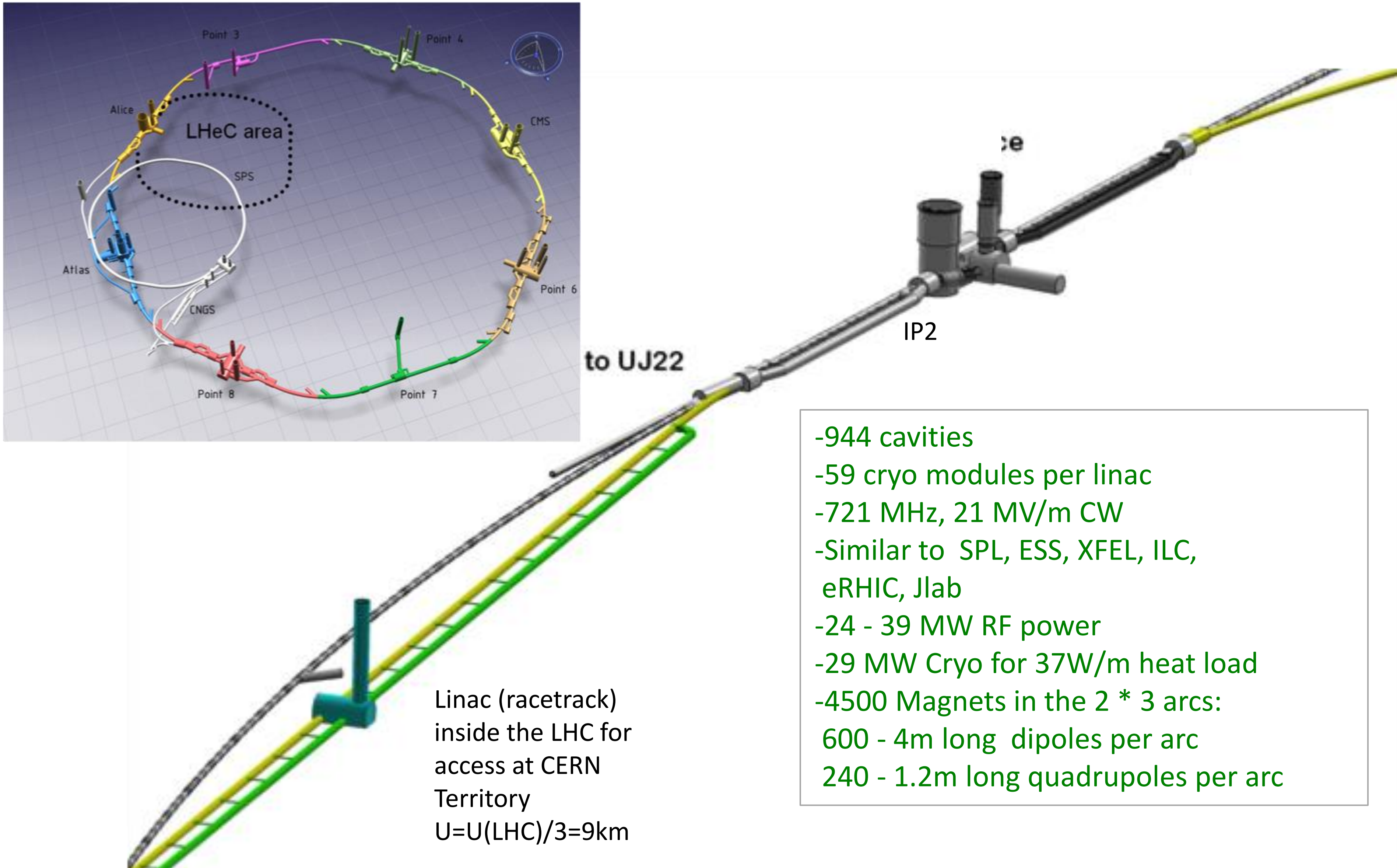
requires Cryogenic

Installation fully decoupled from LHC operation!

	PROTONS	ELECTRONS
…]	7000	60
… [$10^{33}cm^{-2}s^{-1}$]	1	1
…malized emittance $\gamma\varepsilon_{x,y}$ [µm]	3.75	50
Beta Function $\beta^*_{x,y}$ [m]	0.10	0.12
rms Beam size $\sigma^*_{x,y}$ [µm]	7	7
rms Divergence $\sigma'_{x,y}$ [µrad]	70	58
Beam Current [mA]	(860) 430	6.6
Bunch Spacing [ns]	25 (50)	25 (50)
Bunch Population	$1.7*10^{11}$	$(1*10^9)\ 2*10^9$

- Relative … retu…
  - → ca. 9 k… undergrou…
  - → total of 19 km ben…
  - → same magnet desig…

LINAC – Ring: connection to the LHC



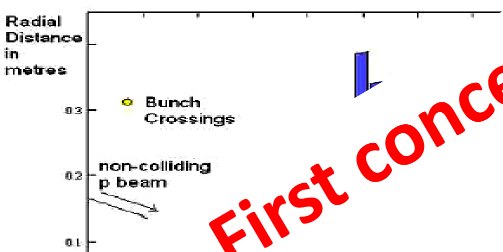
Linac (racetrack)
inside the LHC for
access at CERN
Territory
U=U(LHC)/3=9km

- -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: Accommod... ...eams

Small crossing angle of about 1mrad to avoid first...
(Dipole in detector? Crab cavities? Design fo...
Synchrotron radiation –direct and bac...

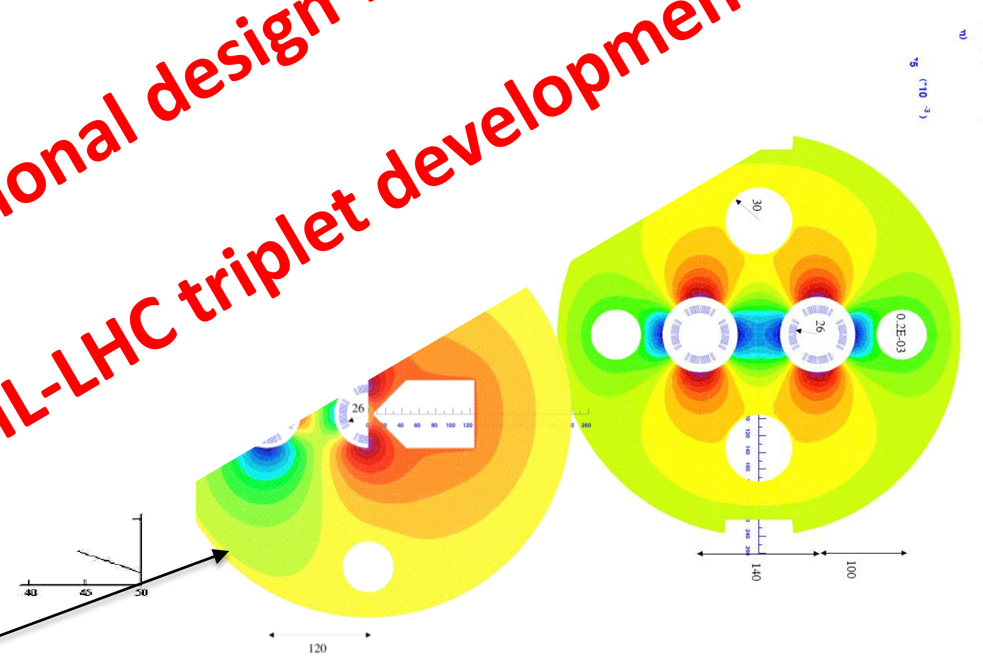
Focus of current activity



First conceptual SC magnet designs exist

But: Still requires additional design work and R&D!

Synergies with HL-LHC triplet development!



1st ... ...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

LHeC Options: Executive Summary

LHeC

Ring-Ring option:

-We know we

•Details remain to be addressed

W

•Decision to focus R&D work on LR technologies over coming 4 years

➔Main Conclusion so far:
LHeC can be realized in parallel with HL-LHC!

current, high energy SC ERL

Challenge 2: Positron source

Post CDR Studies and Decisions:

Post CDR Studies: RF Frequency

LHeC

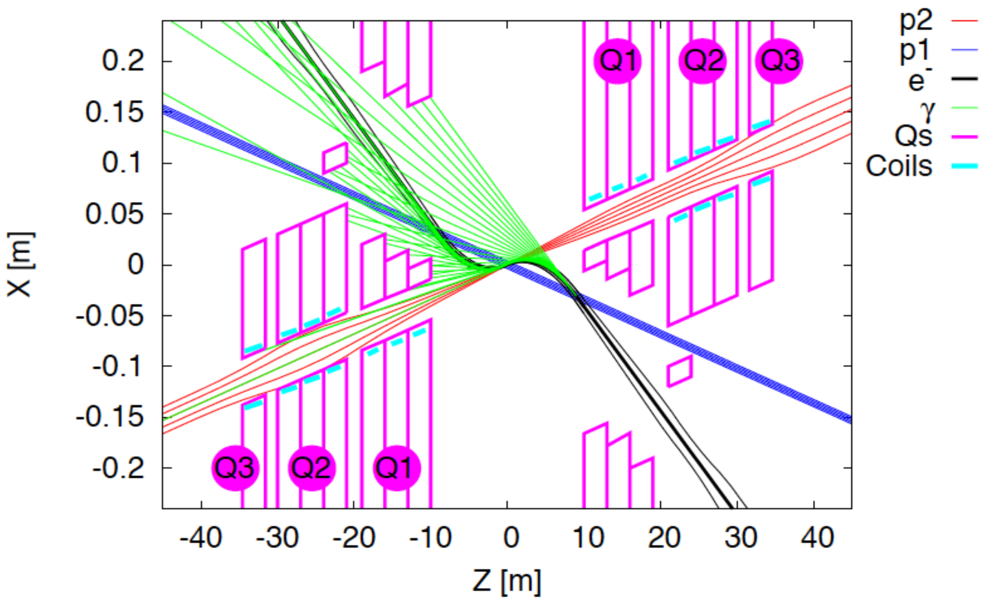
LHeC CDR based on 721 MHz cavity design

But RF Frequency has been re-optimized after publication of the CDR!

→ 801.58 MHz chosen in the end for better Synergy with other projects (e.g. HL-LHC, and FCC ee and hh) and international collaboration options (e.g. MESA)

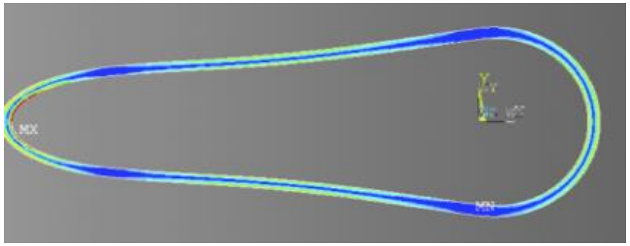
But having the harmonic number be a multiple of the ERL symmetry is not a strong requirement → asymmetric bunch patterns

Next Steps: Interaction Region Design

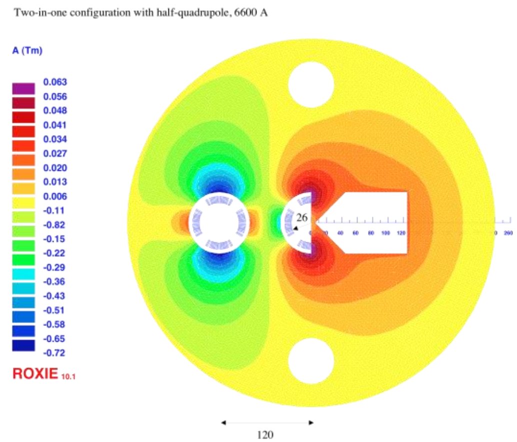


Beam pipe: in CDR 6m, Be, ANSYS calculations

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



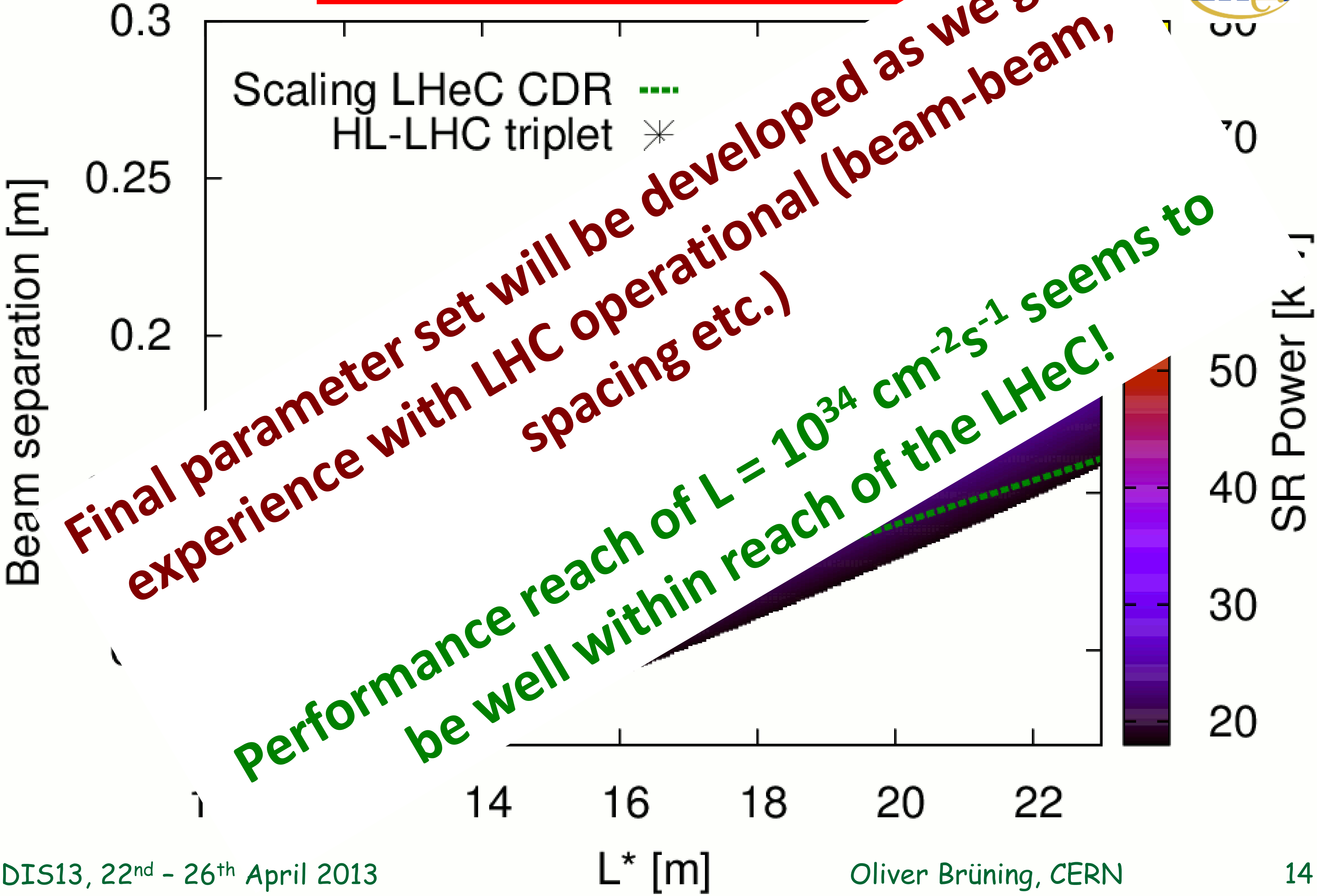
Have optics compatible with LHC ATS optics and β*=0.1m
Head-on collisions mandatory →
High synchrotron radiation load, dipole in detector



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: Post CDR Plans

LHeC

- Develop an ERL test facility @ CERN:

  -Beam Dynamics for ERL operation ➔ develop expertise at CERN

  -Synergy with other research plans: SC RF and TLEP

- Mandate an International Advisory Committee:

  -Mandate and formation by CERN directorate (Chair:H. Schopper)

  -First Meeting at January 2013 Workshop

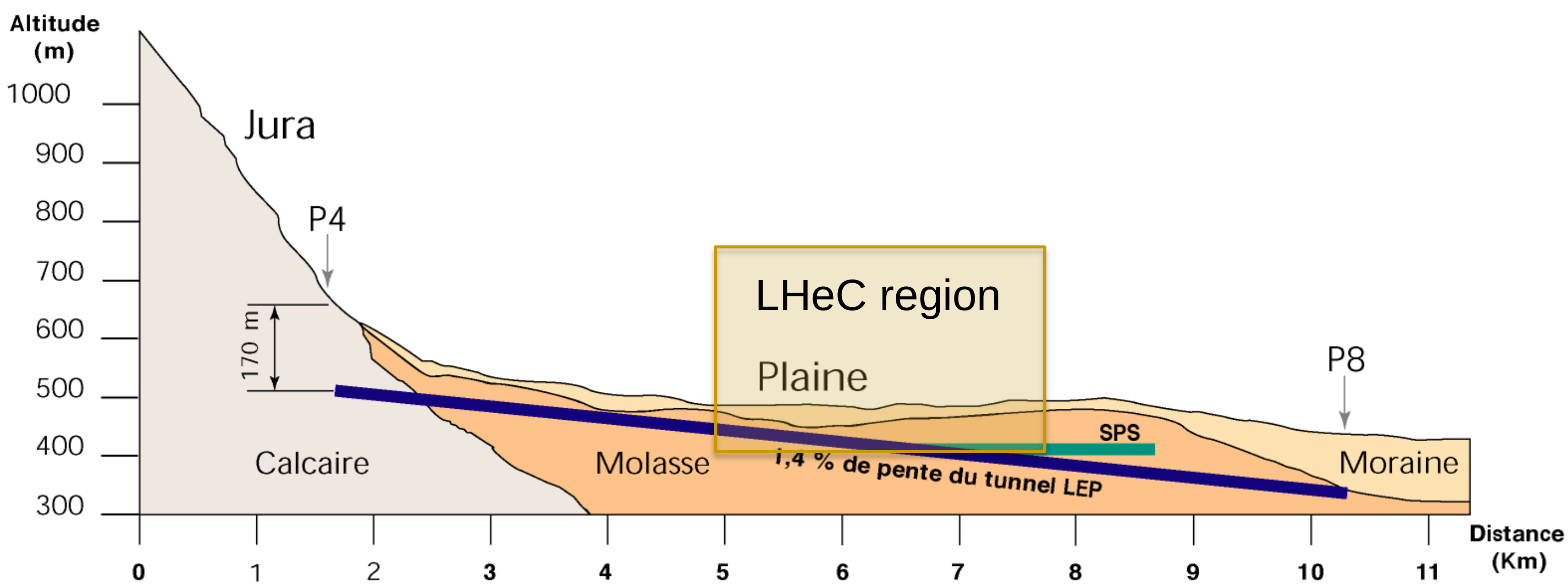
LHeC Workshop January 2013

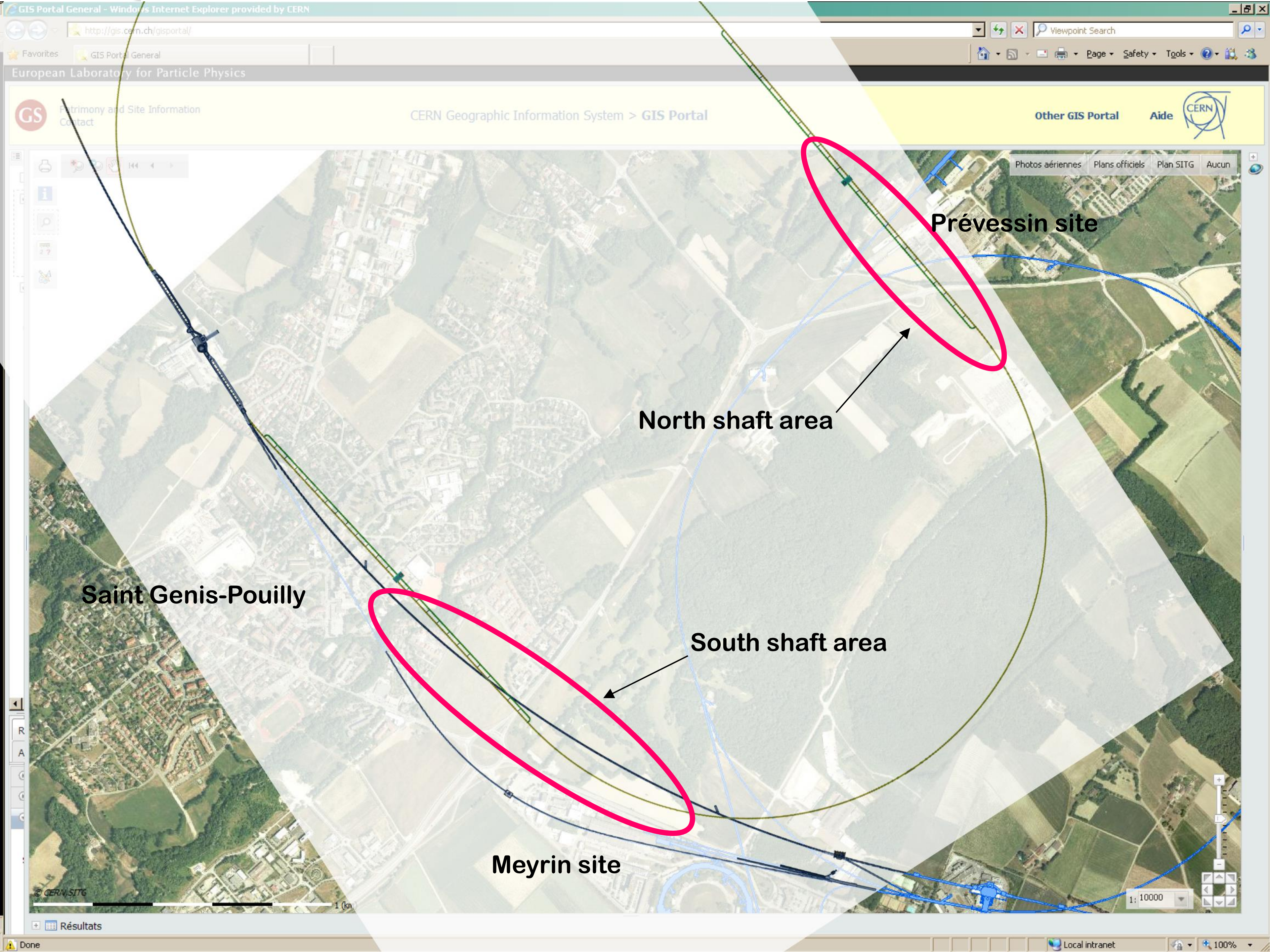
- We have a first estimate for civil engineering [John Osborne]:
  -Layout, cost estimate and construction planning (4y)

Site Features *geology*

- Geology:
  - Molasse – Moraine
    - Profile LHeC region (showing also location of LHC and SPS)

John Osborne

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North shaft area
Saint Genis-Pouilly
South shaft area
Meyrin site
© CERN, SITG
1 km
1: 10000
Résultats
Done
Local intranet
100%

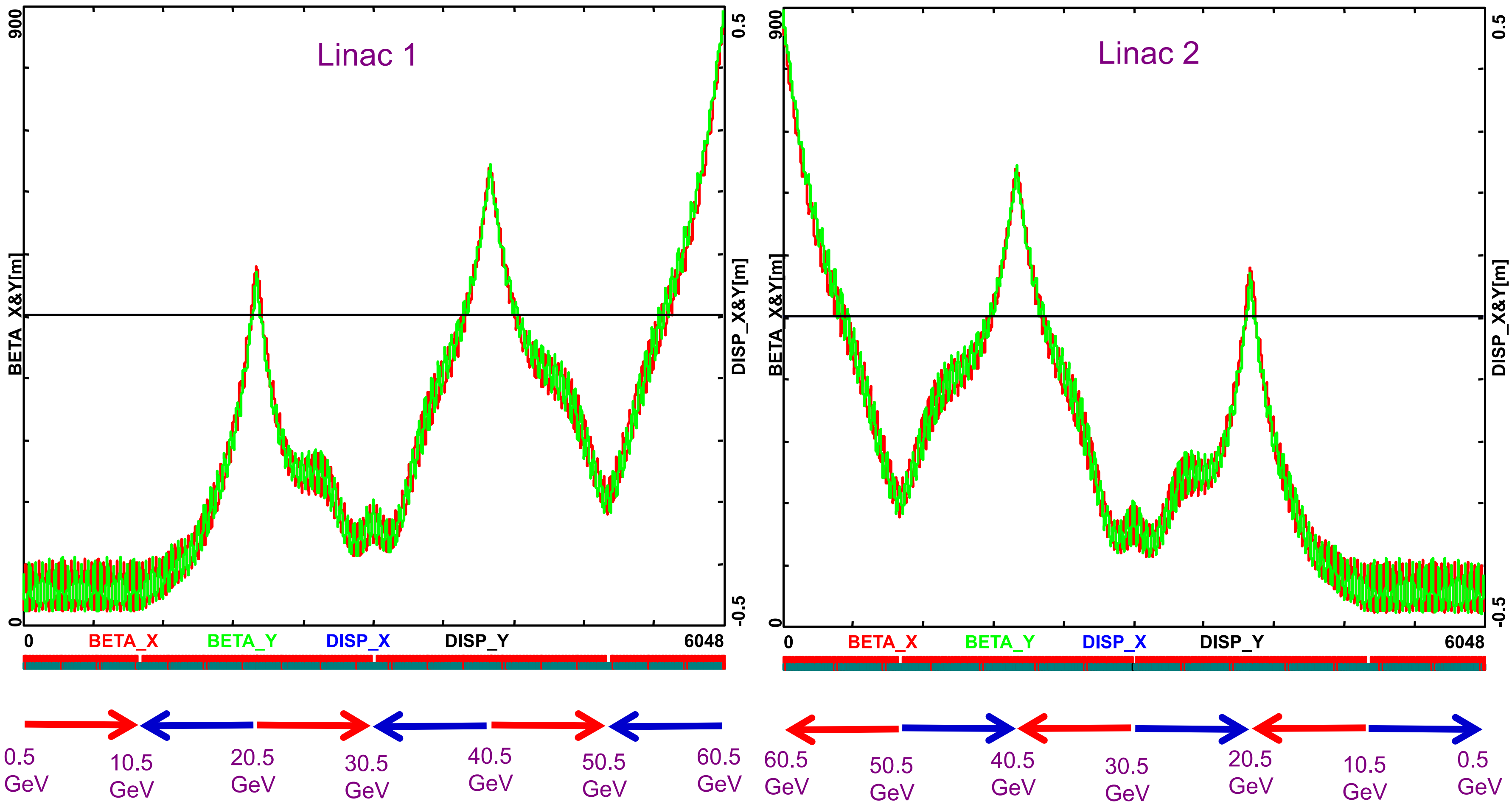
LHeC Workshop January 2013

- We have a good optics baseline for ERL:

Linac 1 and 2 – Multi-pass ER Optics

Alex Bogacz

Acceleration/Deceleration

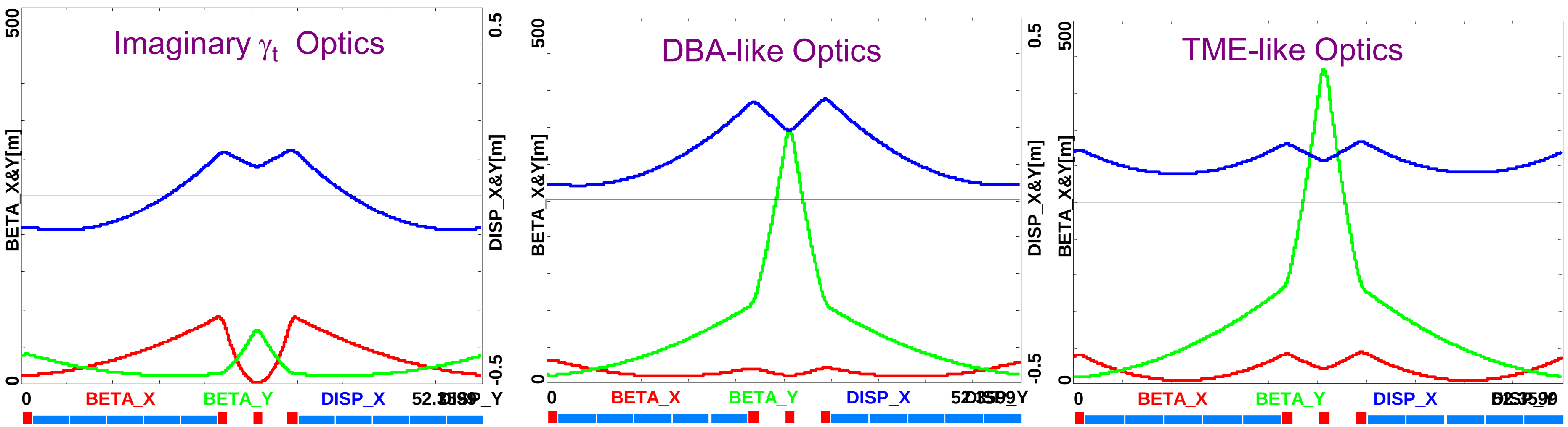


Arc Optics – Emittance preserving FMC cell

$$\Delta\varepsilon^N = \frac{55\, r_0}{48\sqrt{3}} \frac{\hbar c}{mc^2} \gamma^6 \langle H \rangle \frac{\theta}{\rho^2} \qquad H = \gamma D^2 + 2\alpha D D' + \beta D'^2$$

Alex Bogacz

Arc 1 , Arc2 — Arc 3, Arc 4 — Arc5, Arc 6



$\langle H \rangle = 8.8 \times 10^{-3}\ m$ — $\langle H \rangle = 2.2 \times 10^{-3}\ m$ — $\langle H \rangle = 1.2 \times 10^{-3}\ m$

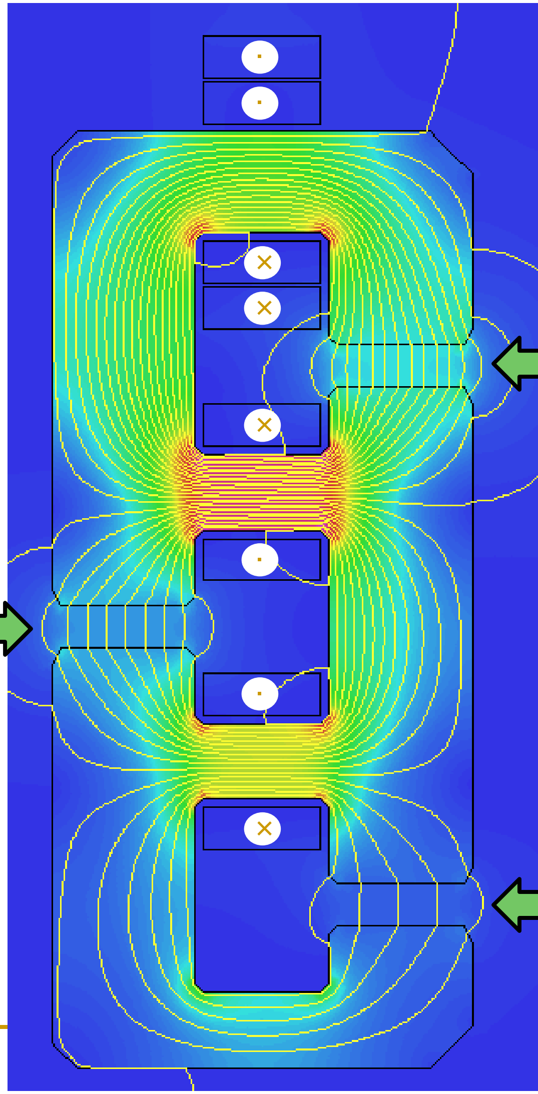
factor of 18 smaller than FODO

FMC = Flexible Momentum Compaction

total emittance increase in Arc 5: $\Delta\varepsilon_x^N = 4.268\ \mu\text{m rad}$

Dipoles in post-CdR

Attilio Milanese

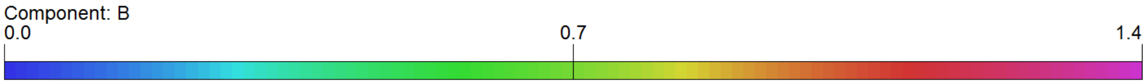


<u>Alternative coil arrangement</u>

- keep the idea of recycling Ampere-turns
- stack the apertures vertically but offset them also transversally
- same vertical gap, 25 mm
- simple coils / bus-bars, same powering circuit
- as before, trim coils can be added for two of the apertures, to give some tuning

Dipoles in post-CdR

Attilio Milanese

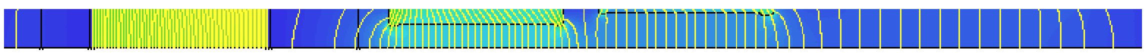


Side-by-side

Interesting area for Prototype Development!

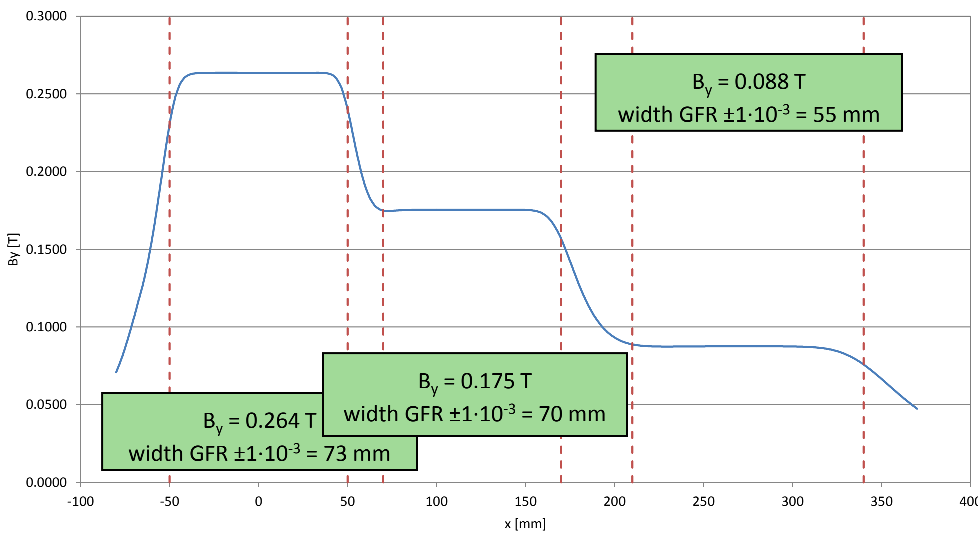
en

)



(1/2 of the dipole shown)

field across the three apertures



keep a flat enough field distribution

- the Ampere-turns are fully recycled for the three energies
- trim coils can be added for two of the apertures, to give some tuning

LHeC Workshop January 2013

LHeC

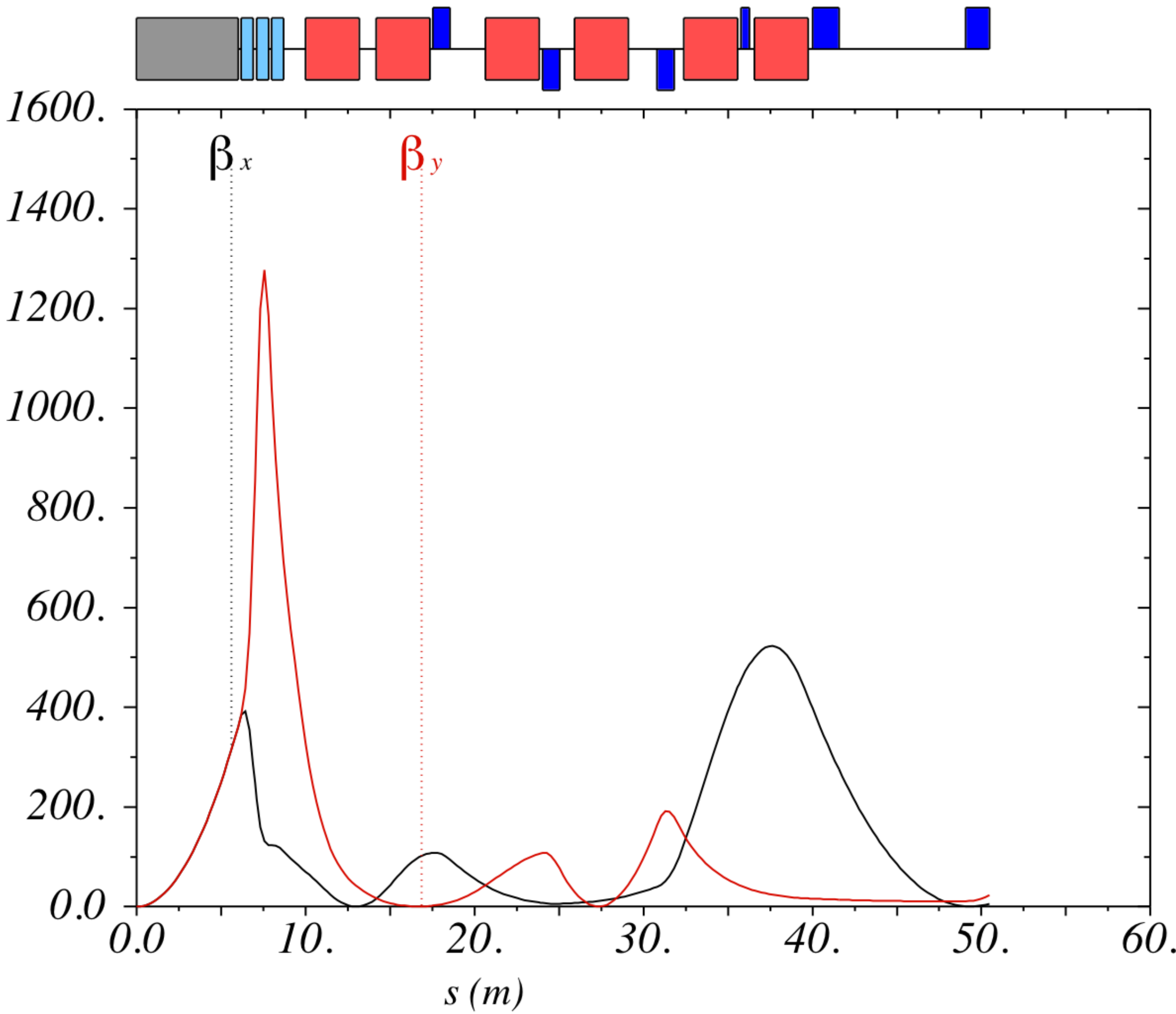
- We have a first p-optics integration into HL-LHC [Rogelio Thomas, Luke Thompson, Emilia Cruz]

- Ongoing optimization for Interaction Region:
  - -Performance need in light of Higgs & FCC integration
  - -optimization of L* (SRP, magnet design, luminosity)
    - ➔ ATS optics and Q' correction
    - ➔ synchrotron radiation issues for LHeC

Electron IR Optics – Half-Quadrupole

Luke Thompson

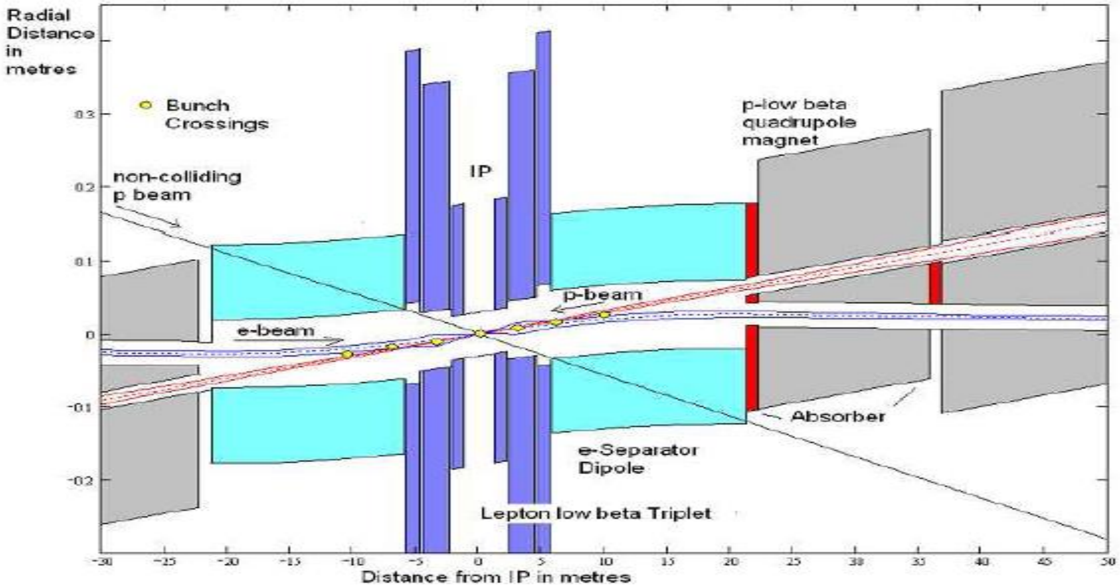
Proton L*=10m



- Electron final triplet (offset)
- Electron matching
- Proton final triplet
- Electron dipoles

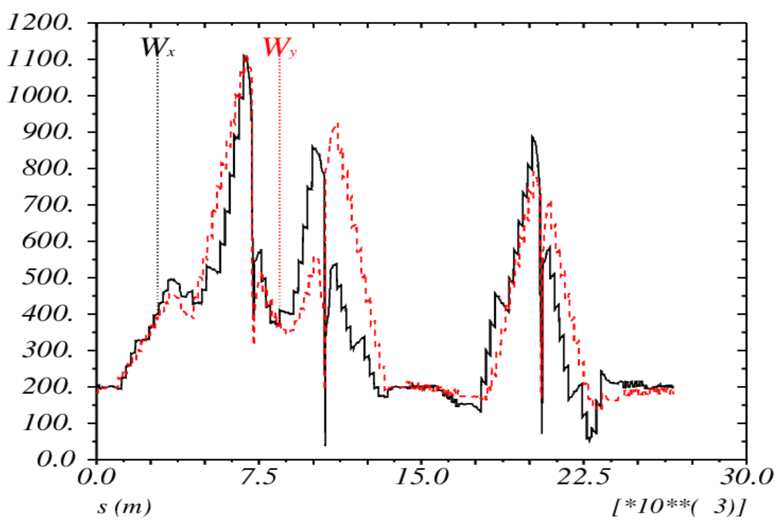
Proton IR Optics – Half-Quadrupole

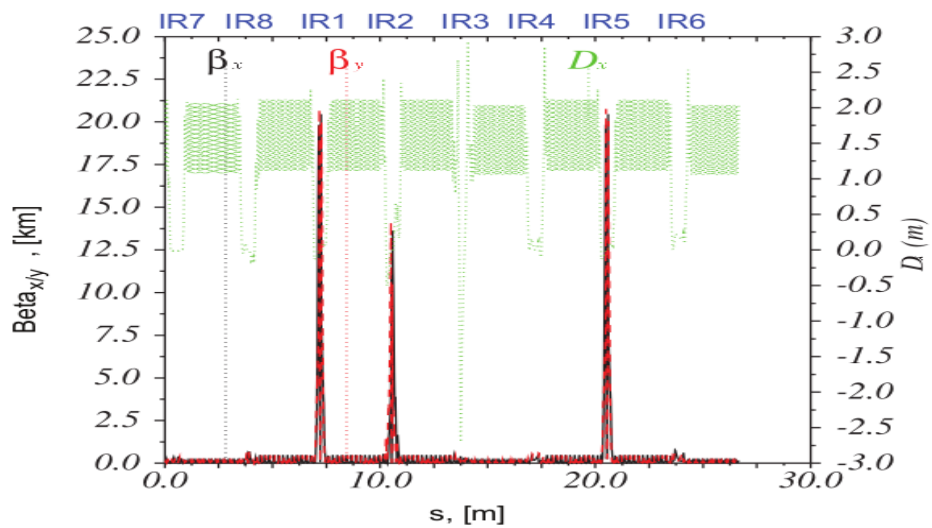
Emilia Cruz



β^*=10cm in IP2

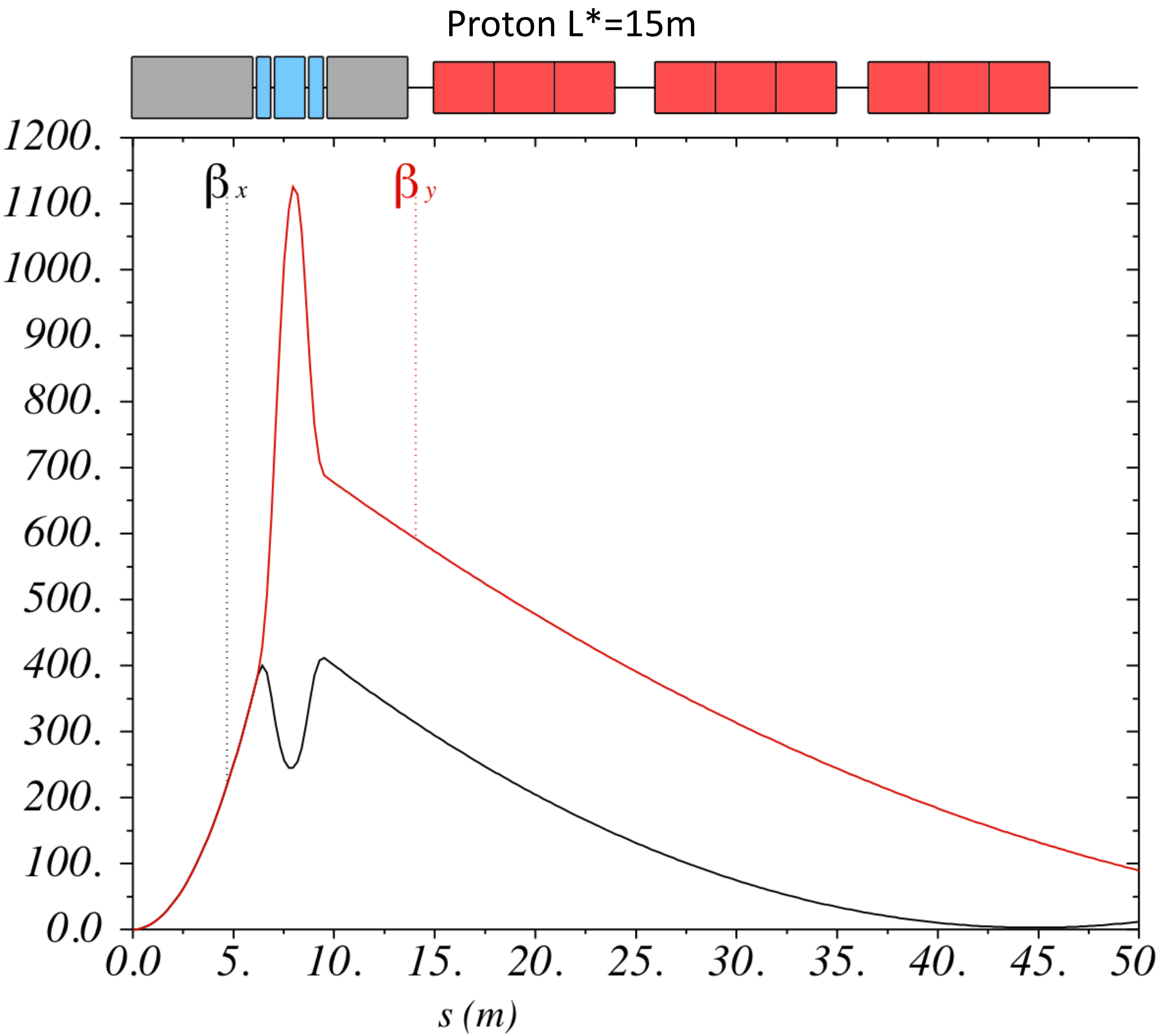
β^*=15cm in IP1 & IP5





Electron IR Optics – No Half-Quadrupole

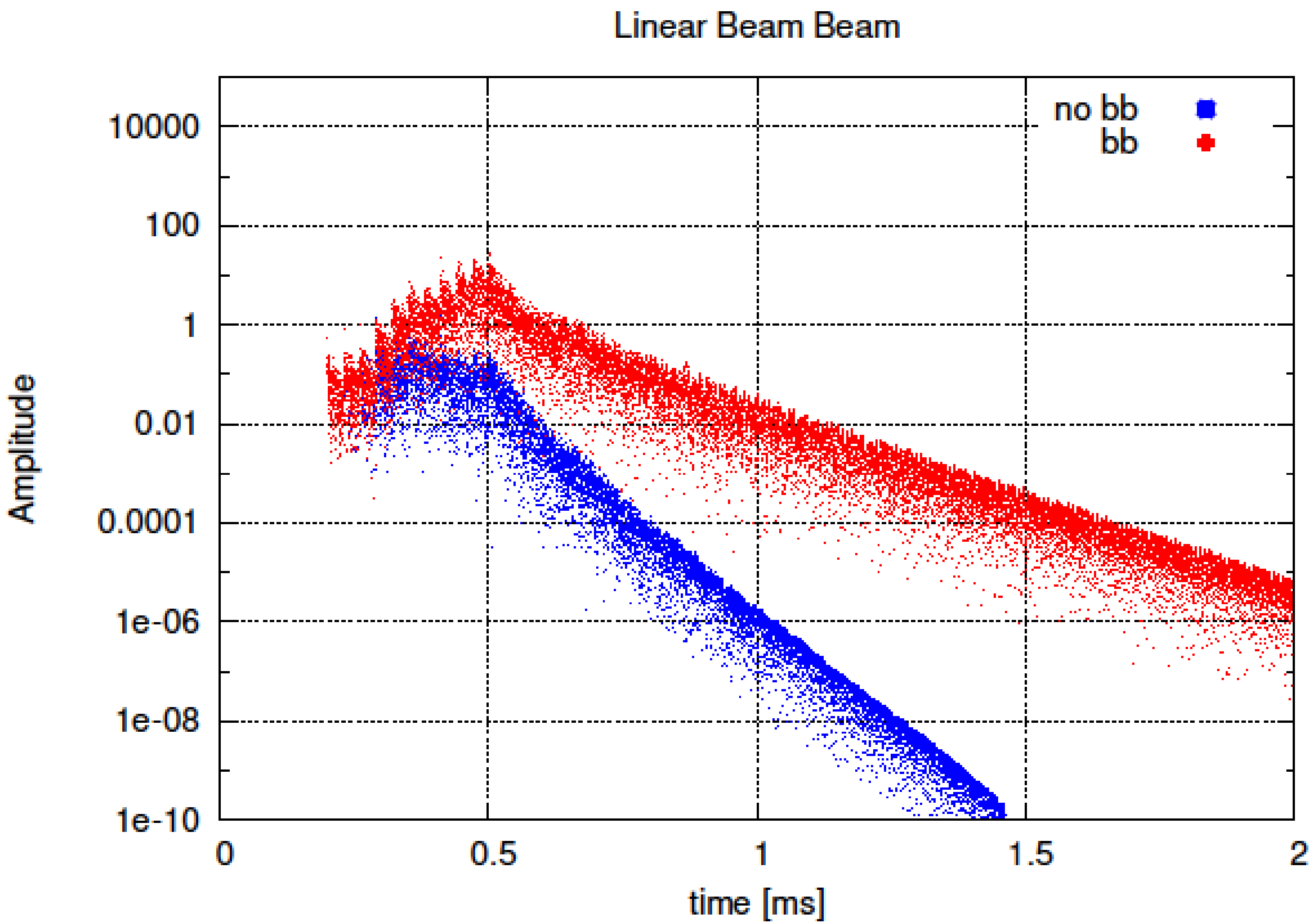
Luke Thompson



- Electron final triplet (offset)
- Proton final triplet
- Electron dipoles

Linear Beam-Beam effect

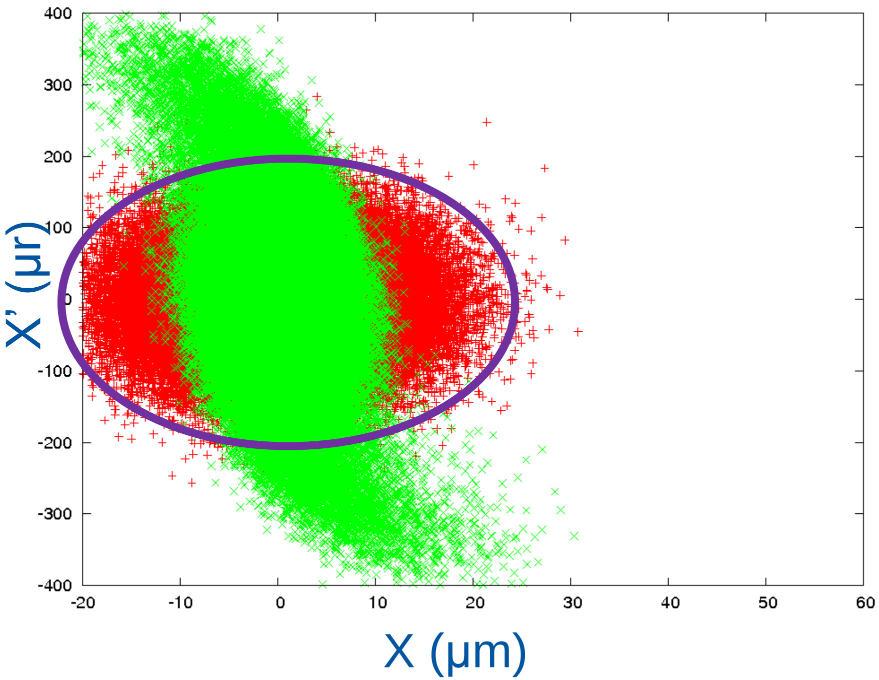
Dario Pellegrini



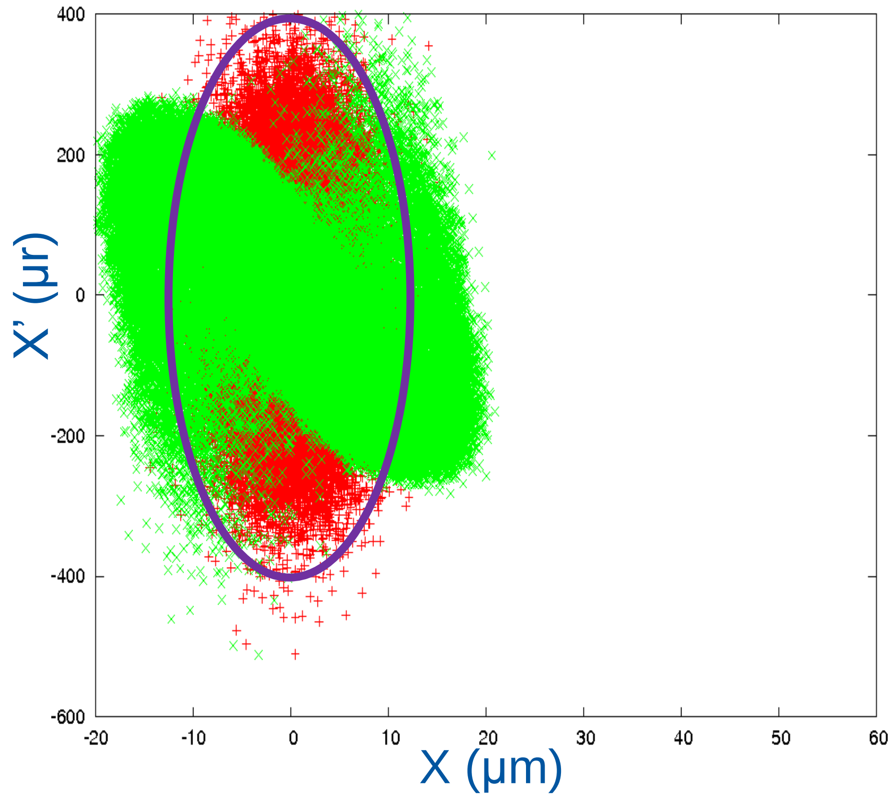
Spent Electron Beam

Edward Nissen

Nominal Parameters



High Luminosity



Red particles show the beam without beam-beam effects, green particles show the electron beam with beam-beam effects. Each frame is a single interaction at an increasing offset.

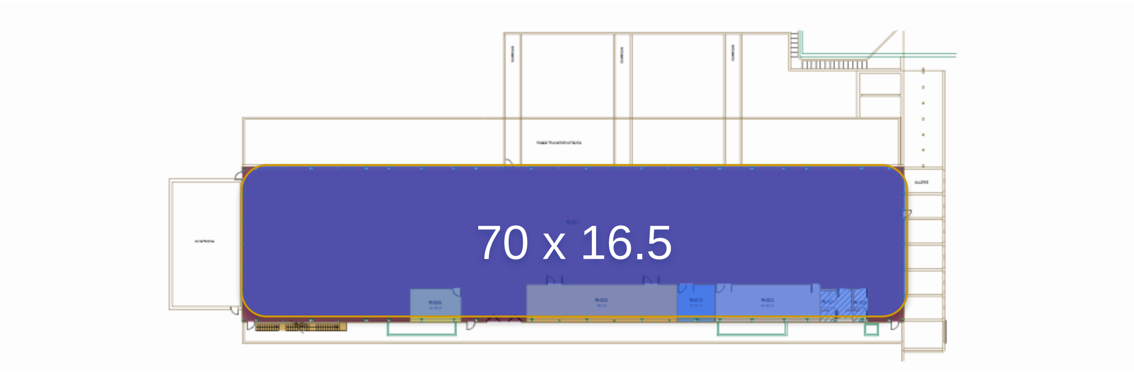
LHeC Workshop January 2013

LHeC

- Beam Dynamic Studies:
  - -Beam stability of the electron beam in the ERL (wake fields, HOM and beam-beam, beam disruption and losses?)
  - -Impact of the beam-beam on proton beam (beam-beam with high luminosity parameters, noise!)

- Studies in Preparation of an ERL Test Facility @ CERN
  - -site choice
  - -auxiliary applications (magnet test facility, physics etc)
  - -RF preparations

Building 2275. Point 2



LEP power converters and klystrons spares. Current use under investigation.

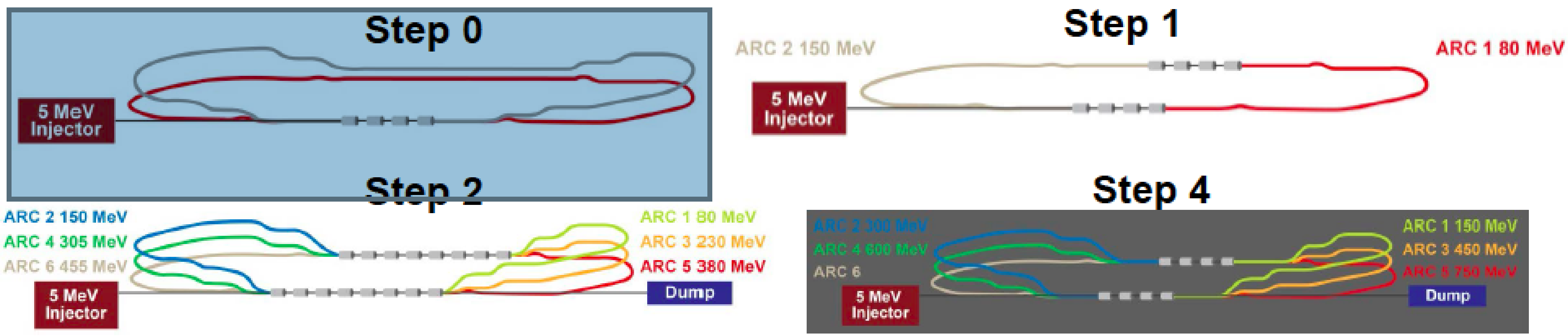
Power converters already in place.
Geographically perfect as injector for LHeC ERL

Slightly narrower than required
Can it be extended?

Nuria Catalan

Planning for each stage

Alessandra Valloni



ARC	Step 0	Step 1	Step 2	Step 3
ARC 1	80 MeV	80 MeV	80 MeV	150 MeV
ARC 2	155 MeV	155 MeV	155 MeV	305 MeV
ARC 3			230 MeV	455 MeV
ARC 4			305 MeV	605 MeV
ARC 5			380 MeV	755 MeV
ARC 6			455 MeV	905 MeV

Controlled quench tests of SC magnets

Alessandra Valloni

Potentially many more auxilliary applications for an ERL test facility:

-FCC magnet test facility

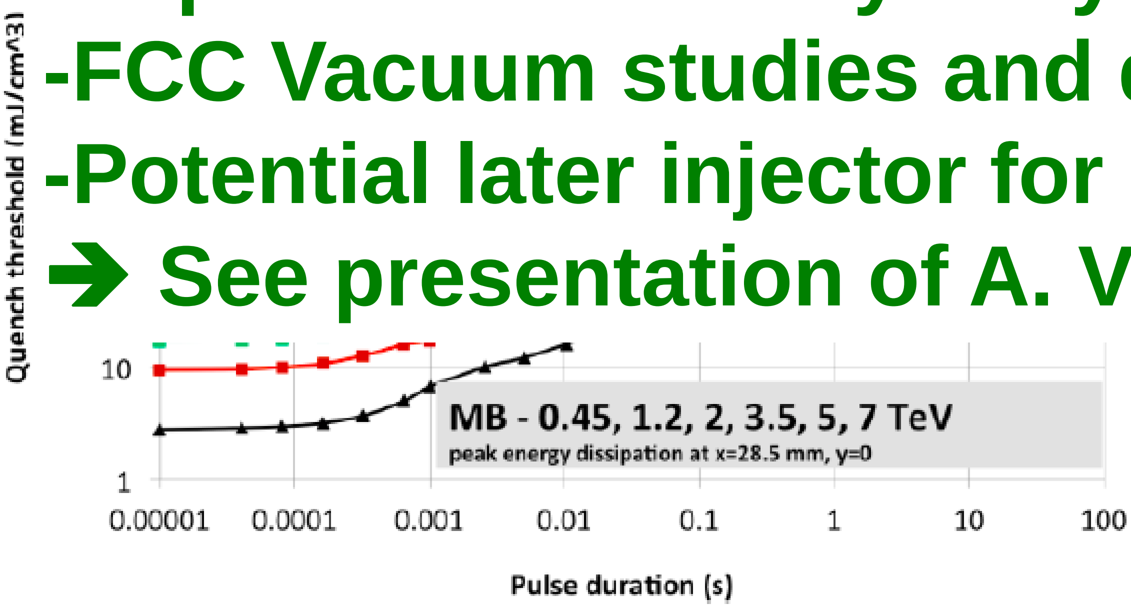
-FCC SC RF test facility

-Experimental facility in synergy to MESA

-FCC Vacuum studies and developments

-Potential later injector for FCC ee

➔ See presentation of A. Valloni later



dipole as expected from QP3 simulations for different pulse durations

Courtesy A. Verweij

LHeC Workshop January 2013

LHeC

Upcoming Tasks and Opens Issues:

-SC RF design with HOM damper and cryostat

-ERL TF design with options / phases and specific site proposal (SC magnets & physics) → leading to CDR

-'Finalize' high L LHeC (Higgs) option / parameters (dump [13MW], beam-beam, SRL in detector, injector)

-Full integration into HL-LHC (and FCC?) (L^*, injection optics, layout, transfer lines, dump etc)

-Beam dynamic studies (ERL full cycle with disruption; proton beam with beam-beam and 'noise')

LHeC Workshop January 2013

LHeC

- Collaborations and International Activities:

  -MESA @ University Mainz

  ➔ SC RF cavity and cryostat prototypes
  ➔ includes collaboration with JLab

  -JLab ERL ('LHeC like', injector, halo, op. experience)

  -BNL SC RF activities & ERL
  (HOM, eRHIC, applications, frequency choice, cost and complexity)

  -Cornell ERL (frequency choice, high Q_0, errors, HOM)

  -ALICE ERL and UK (operational experience)

LHeC organisation

LHeC

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)
Jos Engelen (CERN)
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Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigdor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

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Max Klein - chair (Liverpool)
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Emmanuelle Perez (CERN)
Wesley Smith (Wisconsin)
Bernd Surrow (MIT)
Katsuo Tokushuku (KEK)
Urs Wiedemann (CERN)
Frank Zimmermann (CERN)

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Max Klein (Liverpool)
Interaction Region and Fwd/Bwd
Bernhard Holzer (DESY),
Uwe Schneekloth (DESY),
Pierre van Mechelen (Antwerpen)
Detector Design
Peter Kostka (DESY),
Rainer Wallny (U Zurich),
Alessandro Polini (Bologna)
New Physics at Large Scales
George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)
Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwenlan (Oxford)
Physics at High Parton Densities
Nestor Armesto (Santiago),
Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (MSU)

Review Panel with experts on physics, detector, accelerator, specific systems

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

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T. Gehrmann (Zurich)
C. Glasman (Madrid)
R. Godbole (Tata)
B. Goddard (CERN)
T. Greenshaw (Liverpool)
A. Guffanti (Freiburg)
V. Guzey (Jefferson)
C. Gwenlan (Oxford)
T. Han (Harvard)
Y. Hao (BNL)
F. Haug (CERN)
W. Herr (CERN)
B. Holzer (CERN)
M. Ishitsuka (Tokyo I.Tech.)
M. Jacquet (Orsay, LAL)
B. Jeanneret (CERN)
J.M. Jimenez (CERN)
H. Jung (DESY)
J. Jowett (CERN)
H. Karadeniz (Ankara)
D. Kayran (BNL)
F. Kosac (Uludag)
A. Kilic (Uludag}
K. Kimura (Tokyo I.Tech.)
M. Klein (Liverpool)
U. Klein (Liverpool)
T. Kluge (Hamburg)
G. Kramer (Hamburg)
M. Korostelev (Cockcroft)
A. Kosmicki (CERN)
P. Kostka (DESY)
H. Kowalski (DESY)
D. Kuchler (CERN)
M. Kuze (Tokyo I. Tech.)
T. Lappi (Jyvaskyla)
P. Laycock (Liverpool)
E. Levichev (BINP)
S. Levonian (DESY)
V.N. Litvinenko (BNL)
A.Lombardi (CERN)
C. Marquet (CERN)
B. Mellado (Harvard)
K-H. Mess (CERN)
S. Moch (DESY)
I.I. Morozov (BINP)
Y. Muttoni (CERN)
S. Myers (CERN)
S. Nandi (Montreal)
P.R. Newman (Birmingham)
T. Omori (KEK)
J. Osborne (CERN)
Y. Papaphilippou (CERN)
E. Paoloni (Pisa)
C. Pascaud (LAL Orsay)
H. Paukkunen (St. de Compostela)
E. Perez (CERN)
T. Pieloni (CERN)
E. Pilicer (Uludag)
A. Polini (Bologna)
V. Ptitsyn (BNL)
Y. Pupkov (BINP)
V. Radescu (Heidelberg U)
S. Raychaudhuri (Tata)
L. Rinolfi (CERN)
R. Rohini (Tata India)
J. Rojo (Milano)
S. Russenschuck (CERN)
C. A. Salgado (St. de Compostela)
K. Sampai (Tokyo I. Tech)
E. Sauvan (Lyon)
M. Sahin (Ankara)
U. Schneekloth (DESY)
A.N. Skrinsky (Novosibirsk)
T. Schoerner Sadenius (DESY)
D. Schulte (CERN)
N. Soumitra (Torino)
H. Spiesberger (Mainz)
A.M. Stasto (Penn State)
M. Strikman (Penn State)
M. Sullivan (SLAC)
B. Surrow (MIT)
S. Sultansoy (Ankara)
Y.P. Sun (SLAC)
W. Smith (Madison)
I. Tapan (Uludag)
P. Taels (Antwerpen)
E. Tassi (Calabria)
H. Ten Kate (CERN)
J. Terron (Madrid)
H. Thiesen (CERN)
L. Thompson (Cockcroft)
K. Tokushuku (KEK)
R. Tomas Garcia (CERN)
D. Tommasini (CERN)
D. Trbojevic (BNL)
N. Tsoupas (BNL)
J. Tuckmantel (CERN)
S. Turkoz (Ankara)
K. Tywoniuk (Lund)
G. Unel (CERN)
J. Urakawa (KEK)
P. Van Mechelen (Antwerpen)
A. Variola (SACLAY)
R. Veness (CERN)
A. Vivoli (CERN)
P. Vobly (BINP)
R. Wallny (ETHZ)
G. Watt (CERN)
G. Weiglein (Hamburg)
C. Weiss (JLab)
U.A. Wiedemann (CERN)
U. Wienands (SLAC)
F. Willeke (BNL)
V. Yakimenko (BNL)
A.F. Zarnecki (Warsaw)
F. Zimmermann (CERN)
F. Zomer (Orsay LAL)

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 fundar ... o 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!

Unanimously supported by rECFA and ECFA plenary in November 2007

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

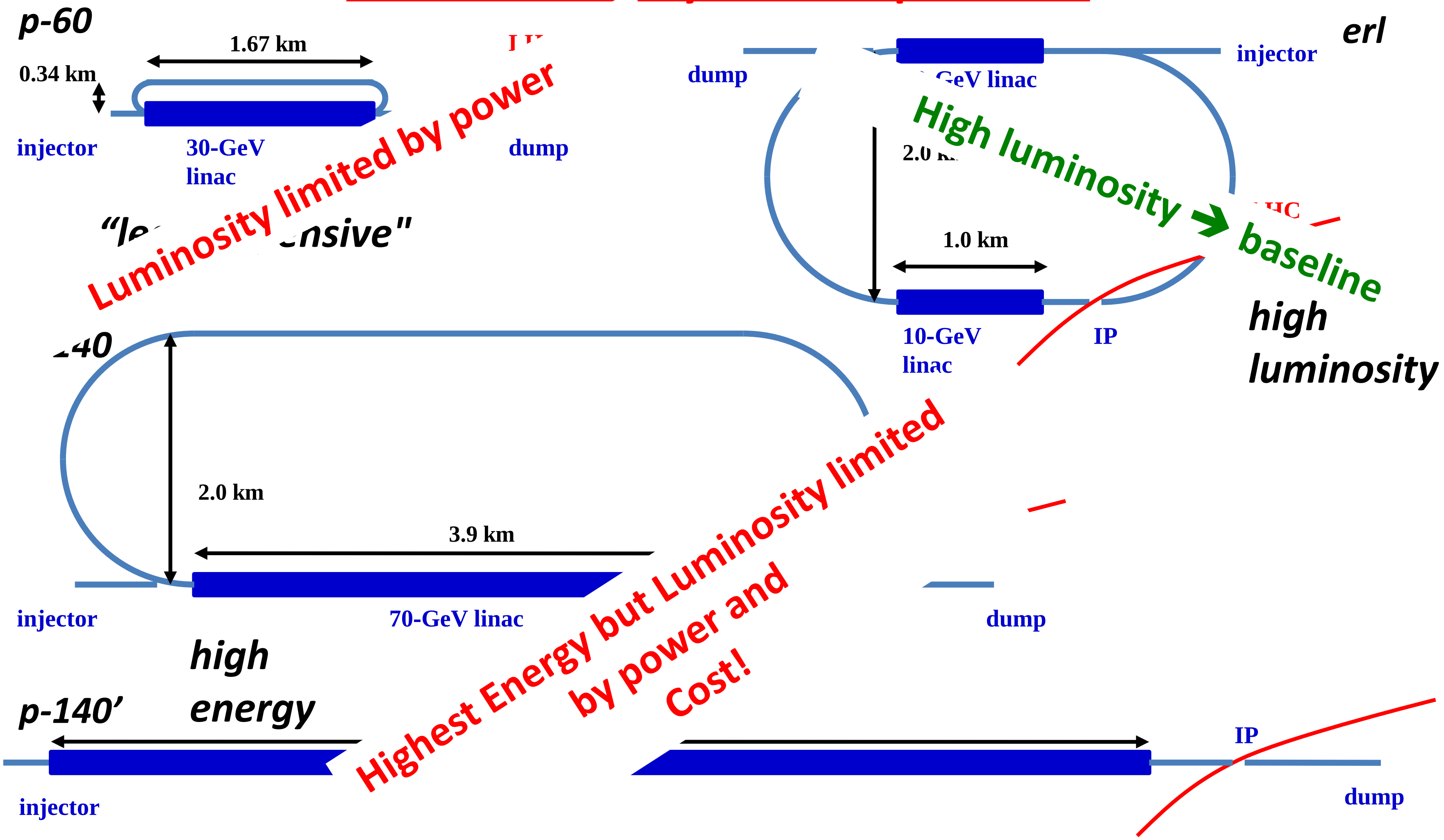
LHeC

		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

LHeC: Linac-Ring Option Considered

Various Layout Options



LHeC: Post CDR Plans

LHeC

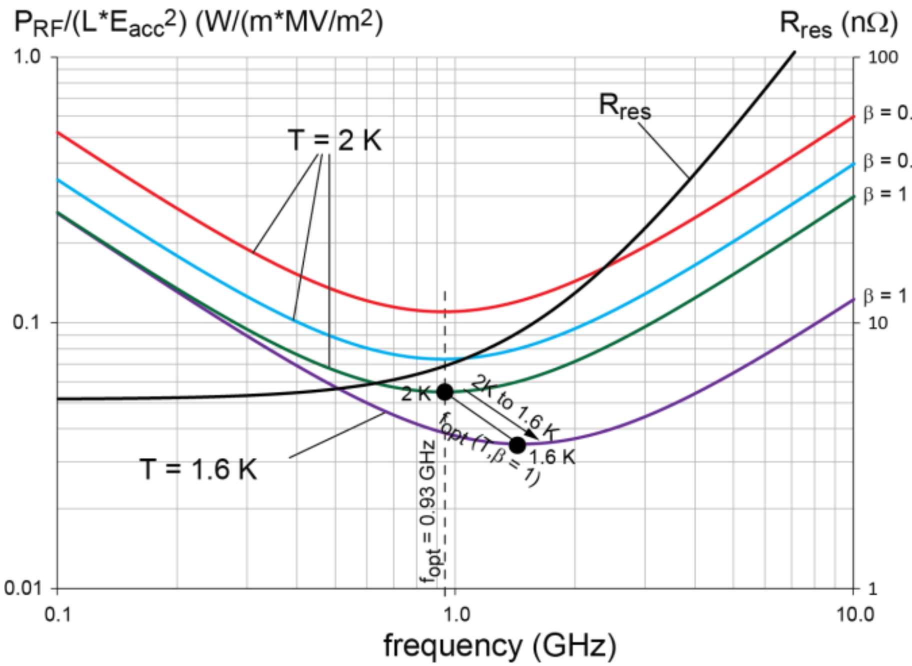
- Launch SC RF and ERL R&D and Establish collaborations:
  - -SC RF R&D has direct impact on cryo power consumption
    - -Synergy with HL-LHC and TLEP!
  - -ERL is a hot topic with many applications
    - -Synergy with national research plans: e.g. MESA

- 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

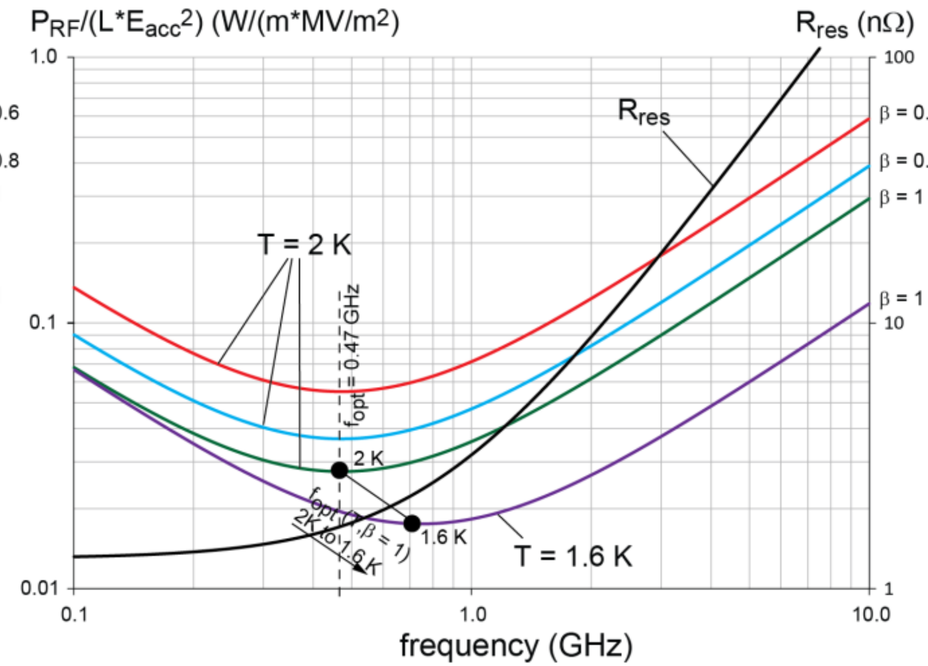
Optimum RF Frequency: Power Considerations

Results from F. Marhauser

Erk Jensen at Daresbury meeting 12 March 2013



Small-grain (normal) Nb:
Optimum frequency at 2K between 700 MHz and 1050 MHz
Lower T shift optimum f upwards



Large-grain Nb:
Optimum frequency at 2K between 300 MHz and 800 MHz
Lower T shift optimum f upwards