CERN summary of Chamonix 2012 – 15 February 2012

S09 -LHC related projects and studies – Part(II)

(long term future: resuming next 50 years in 15 minutes!)

Lucio Rossi

&

Riccardo De Maria

Beam Current Limit for HL-LHC

Ralph Assman

$$L = \frac{6.24 \cdot 10^{18} (\mathrm{As})^{-1} \cdot i_{beam} \cdot N_p}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot R(\varphi, \beta^*, \varepsilon_n, \sigma_s)$$

LHC: Total beam current

Bunch Intensity

HL-LHC: LHC Machine

$$L \approx \frac{6.24 \cdot 10^{18} (\mathrm{As})^{-1} \cdot i_{beam} \cdot N_p}{4\pi \cdot \beta^* \cdot \varepsilon_n}$$

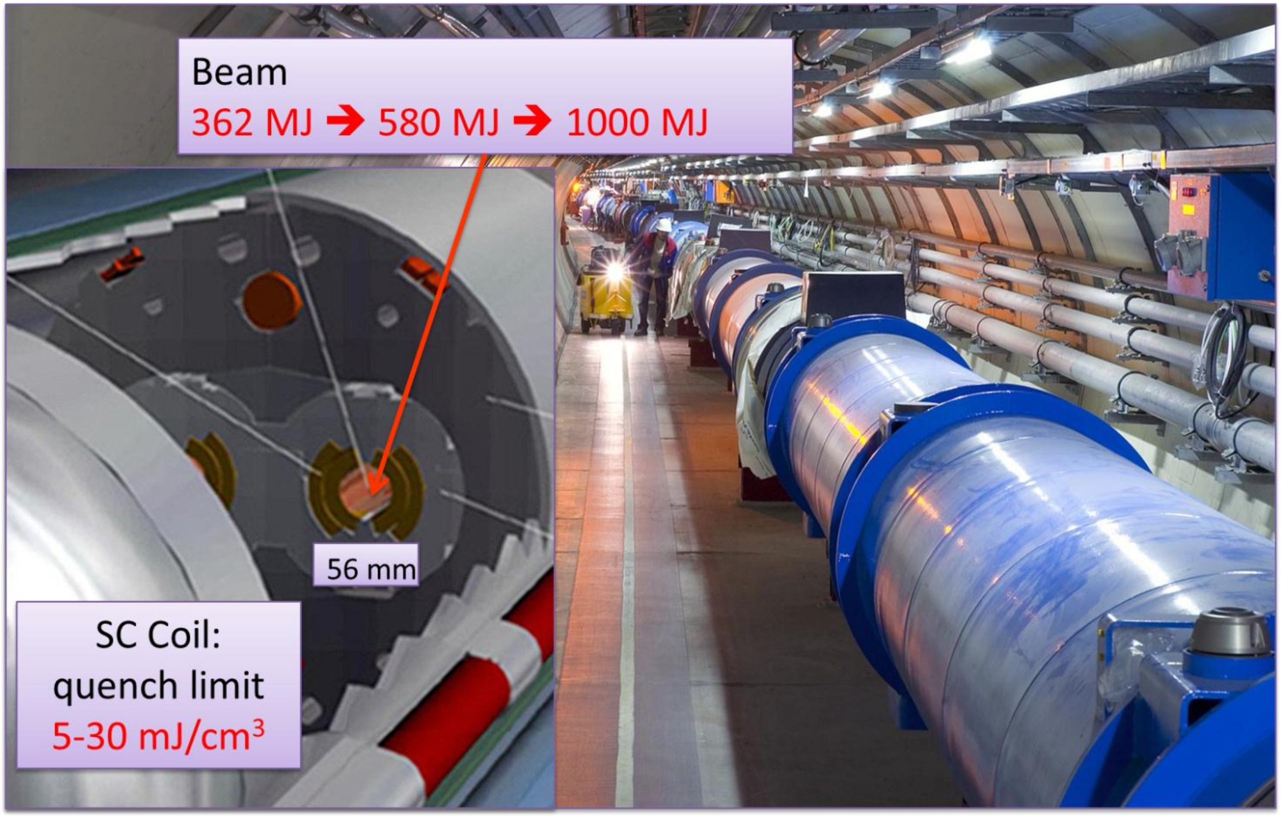
LIU: INJECTORS

LHC: beta*
(optics, collimation, MP)

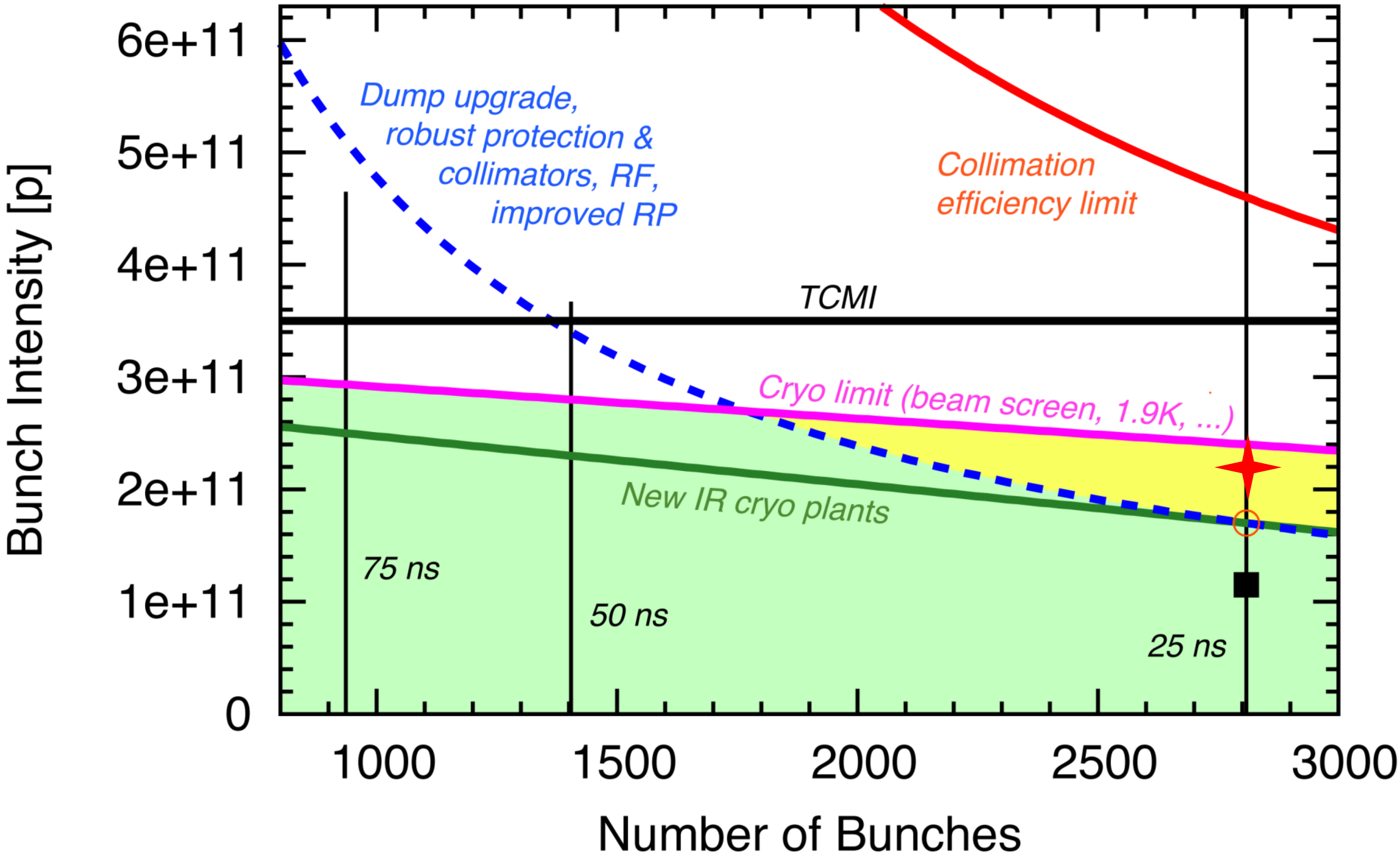
Normalized Emittance

Going Through Systems…

- Injection and Protection
- RF
- Vacuum
- e-cloud
- Cryo
- Magnets
- Collimation
- R2E
- RP



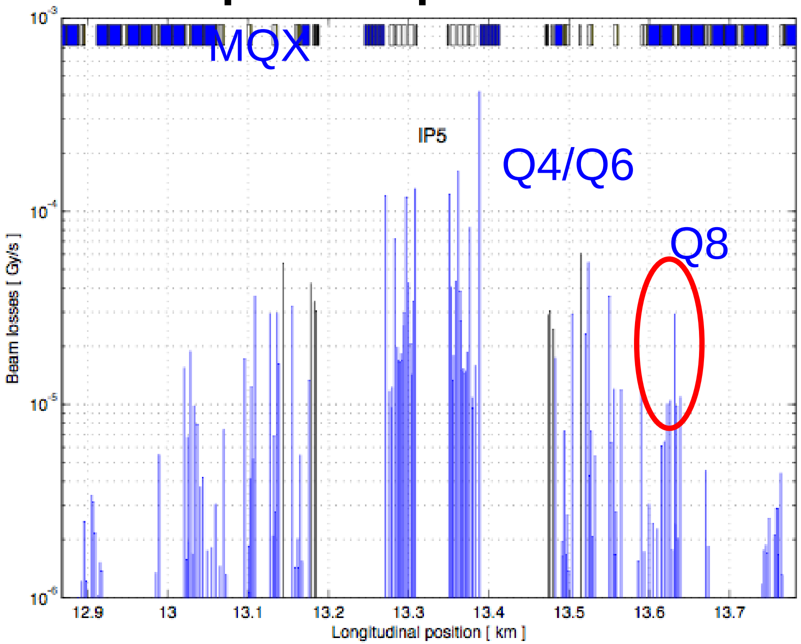
Summary Beam Current Limitation



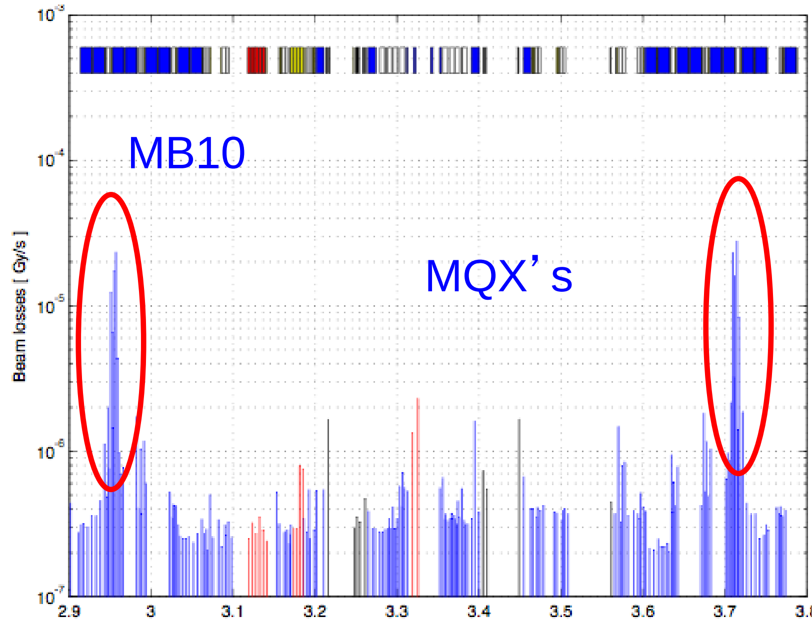
Do we really need an upgrade of the collimation system for HL-LHC?

Stefano Redaelli

IP5: proton operation



IP2: Ion operation



- **Continuous** losses in the dispersion suppressors of experimental regions during physics production
- Different loss locations for proton and ion beams in different IRs
- Local radiation caused by losses affected already the LHC operation!
- Can be cured satisfactorily only by local collimators in the DS

Conclusions

- ☑ The LHC machine and its **collimation system** work **well** (up to 110 MJ)
  - *- Full validation of all major collimator HW/SW design choices!*
  - *- Indication that IR3/7 cleaning is ok for ultimate LHC intensity*
  - *- Need continuous studies in 2012 to extrapolate at larger E and smaller β^**
  - *- Final verification only in 2015!*
- ☑ The LHC collimators will not last forever!
  - *- Pursuing R&D program on new materials to improve impedance and robustness*
  - *- Inputs expected at the end of 2012 after beam tests at HiRadMat*
  - *- Can profit of existing space reservation to add new collimators when/if needed*
- ☑ The LHC collimation cannot protect the **cold magnets** in the **DS's**.
  - *- Focus of present studies is moved to **experimental regions***
  - *- **Quench**: no obvious limitation for proton beams but ions might be closer to limit*
  - *- **Magnet lifetime** to be assessed carefully by magnet guys (implications on collimation system!)*
- ☑ **LS1**: collimators with **integrated BPMs** in experiment and dump regions
- ☑ We want to be ready with **a design of DS collimation** in IR1/2/5 for **LS2**
  - *- **11 T dipole** development is critical.*
- ☑ **New collimation** in the experimental regions to be worked out for **LS3**
  - *- We see no show stoppers for HL-LHC challenges*

New Magnets for the IR

How ~~far~~ close are we from the HL-LHC Target?

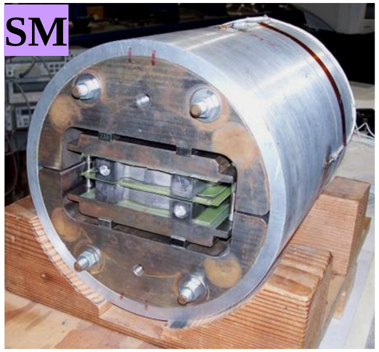
GianLuca Sabbi

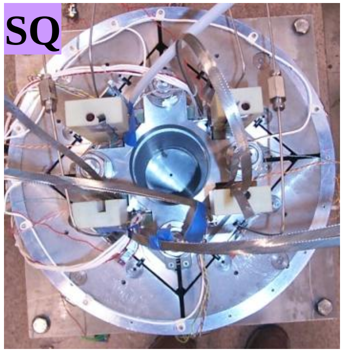
for the US LHC Accelerator Research Program

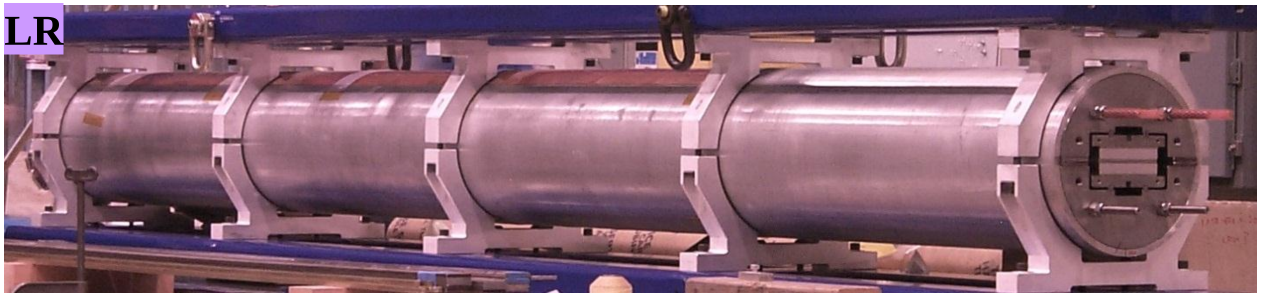
LHC Performance Workshop – Chamonix 2012

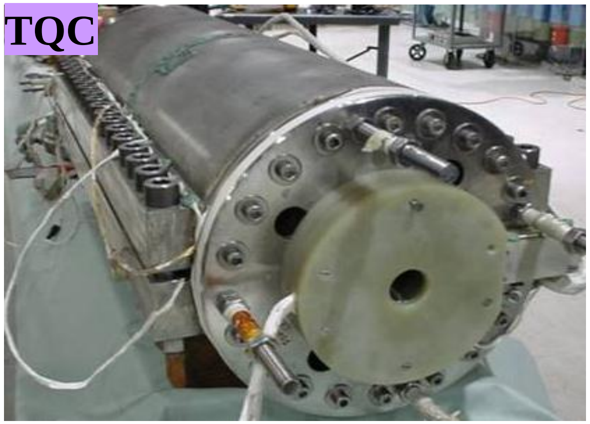
LARP

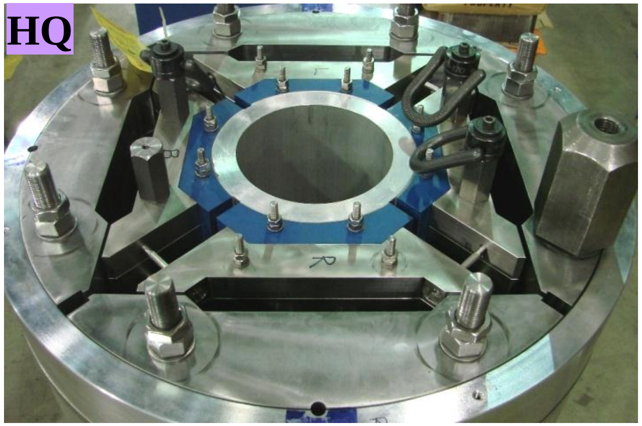
LARP Magnets











Program Achievements - Timeline (2/2)

Dec. 2009 LQS01a reaches 200 T/m at both 4.5K and 1.9K

- *LARP meets its "defining" milestone*

Feb. 2010 TQS03d shows no degradation after 1000 cycles (*)

- *Comparable to operational lifetime in HL-LHC*

July 2010 LQS01b achieves 220 T/m with RRP 54/61

- *Same TQS02 level at 4.5K, but no degradation at 1.9K*

Apr. 2011 HQ01d achieves 170 T/m in 120 mm aperture at 4.5 K

Nb-Ti 120-130 T/m

- *At HL-LHC operational level with good field quality*

Oct. 2011 HQM02 achieves ~90% of SSL at both 4.6 K and 2.2 K

Close to 200 T/m

- *Reduced compaction results in best HQ coil to date*

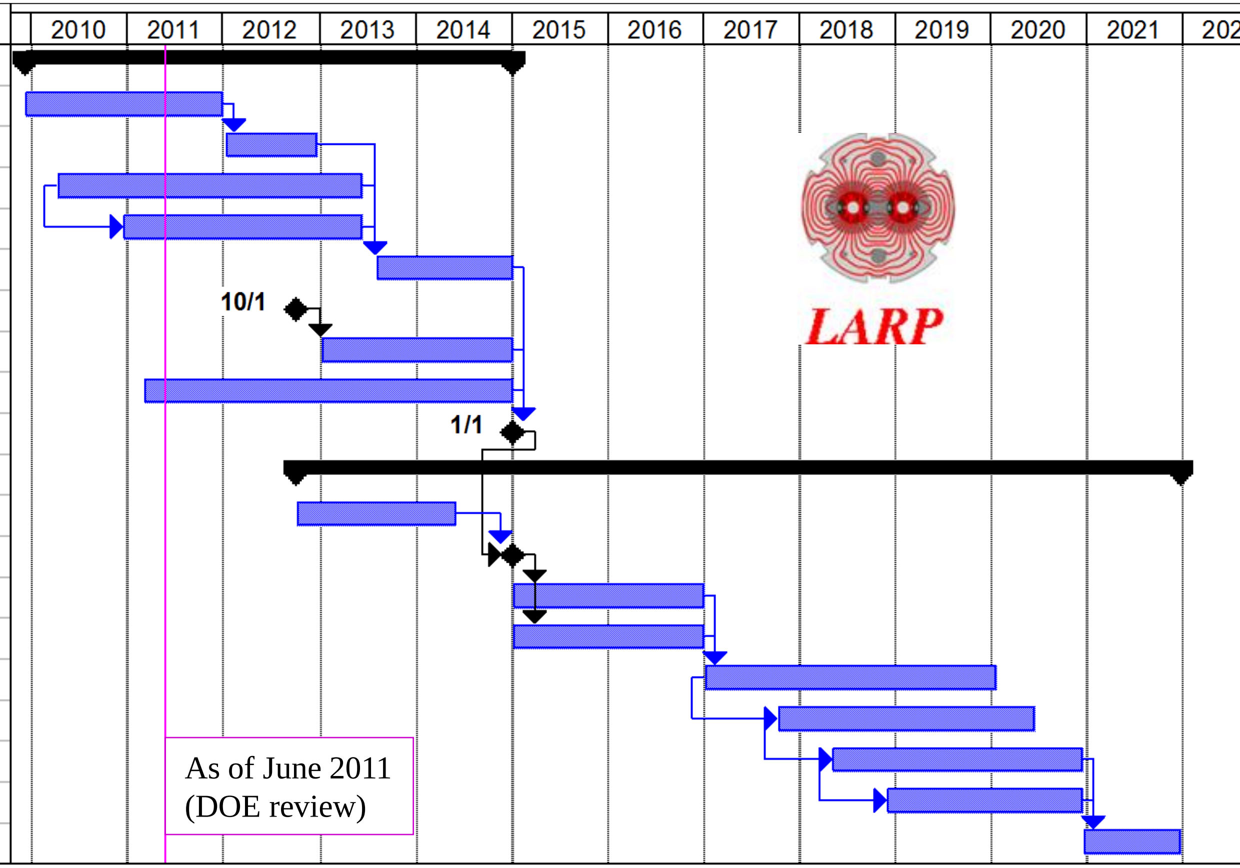
(*) Test performed at CERN

Accelerator Quality in LARP Models

Design Features	LR	SQ	TQS/LQS	TQC	HQ	LHQ (Goals)
Geometric field quality					√	√
Structure alignment		√	√	√	√	√
Coil alignment		√			√	√
Saturation effects				√	√	√
Persistent/eddy currents						√
End optimization			√		√	√
Cooling channels				√		√
Helium containment				√		√
Radiation hardness						√

R&D and Construction Schedule

ID	Task Name
1	**R&D & Design (US+CERN)**
2	LQS01/2 tests (RRP 54/61)
3	LQS03 tests (RRP 108/127)
4	HQ/HQM tests
5	LHQ design and fabrication
6	LHQ tests
7	IR Quad Aperture selection
8	IR Quad short model
9	HL-LHC Design Study
10	IR specification finalized
11	**IR Construction Project (US+CERN)**
12	Prototype infrastructure & tooling
13	Construction project start
14	IR Quad Prototype
15	Production infrastructure & tooling
16	Coil and structure fabrication
17	Magnet assembly
18	Cryostat assembly & test
19	String Tests
20	Installation



Significant contributions from CERN will be required to implement this plan, in particular if the larger aperture and/or the full length coil option is selected

Crab Cavities

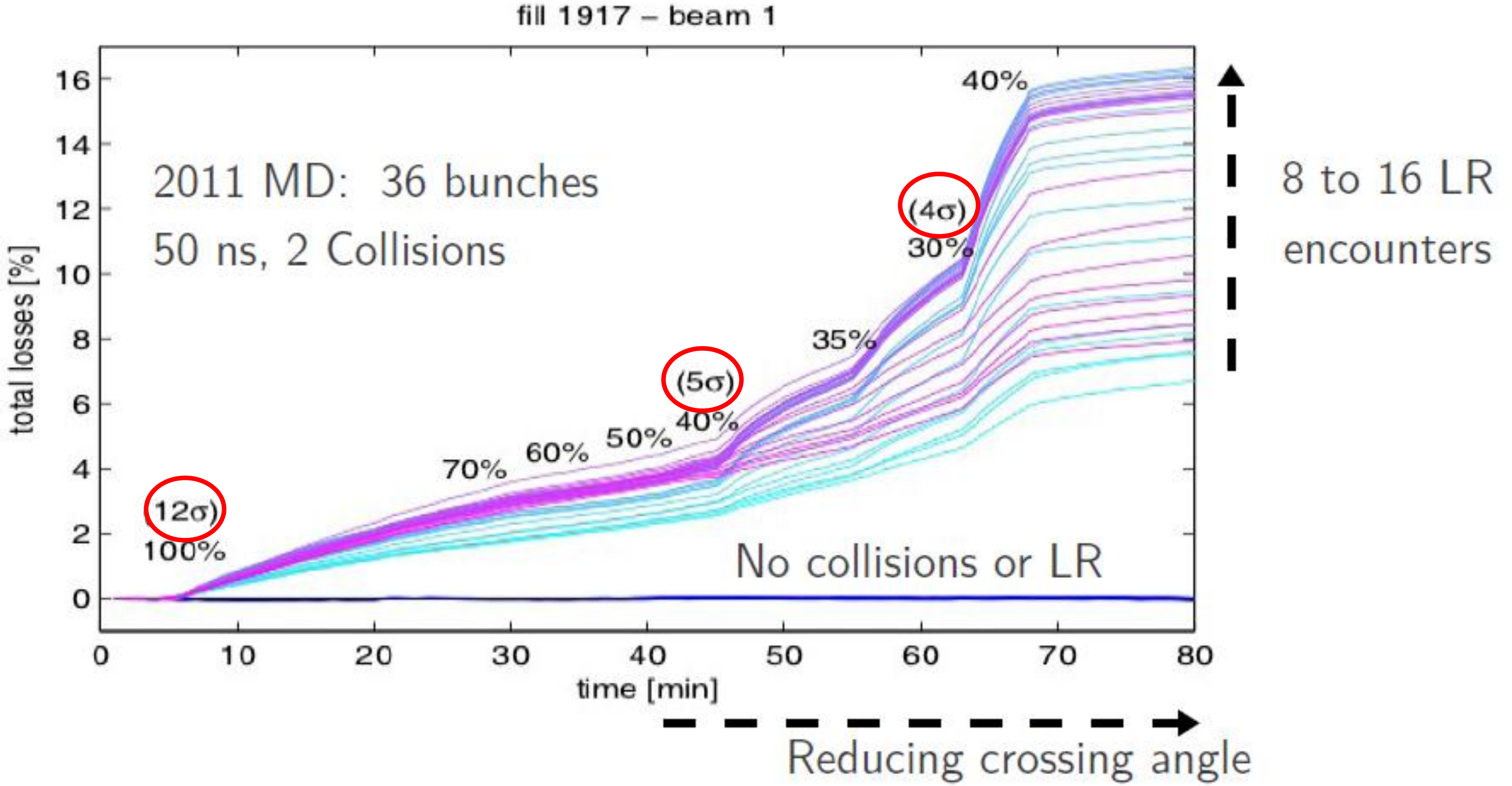
"FROM VIRTUAL REALITY TO REAL REALITY"

R. Calaga, BE-RF, LHC-PW, Chamonix 2012

On behalf of the LHC-CC collaboration

The Real " Problem"

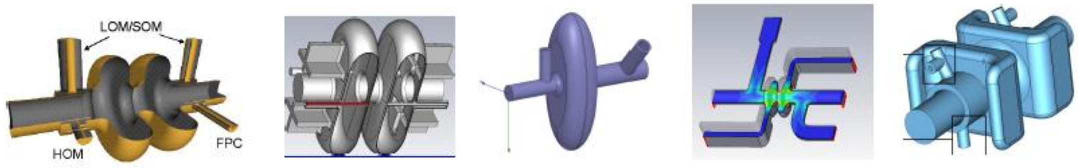
Beam-Beam Team
CERN-ATS-2011-217

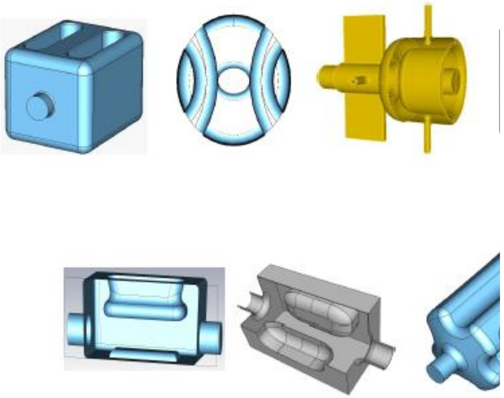


Nominal → 4 IRs, 120(+) parasitic encounters

Sufficiently large crossing angle inevitable (8-12σ sep)

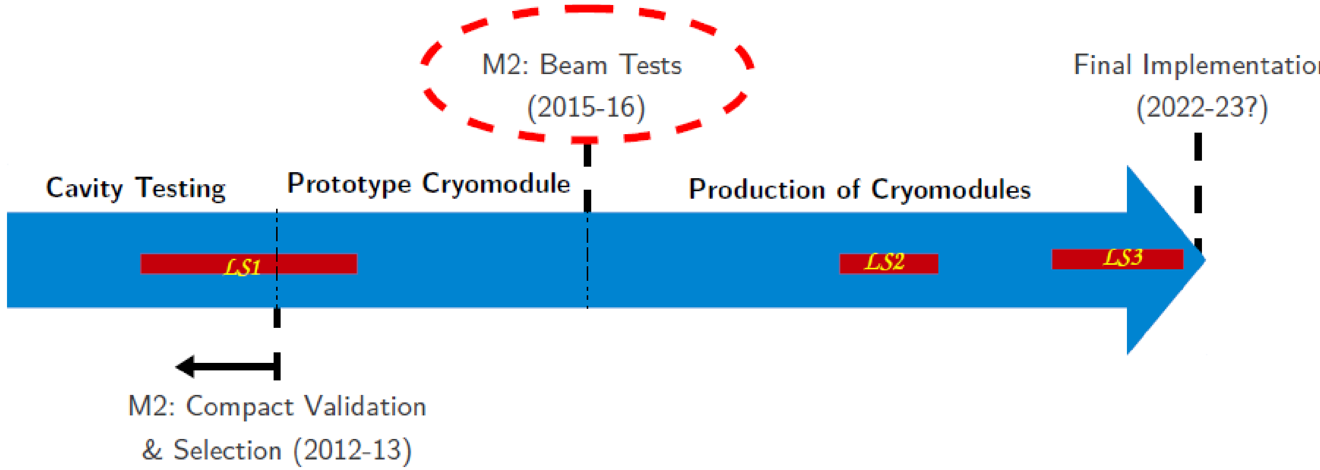
Pillboxes → TEM Cavities



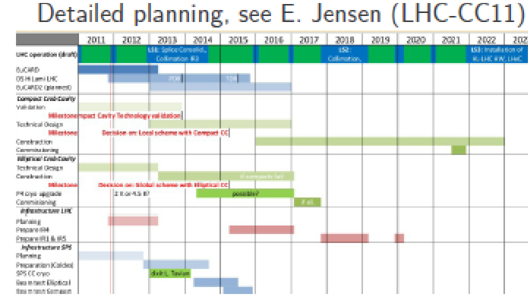


~4yr of design evolution

Planning Overview

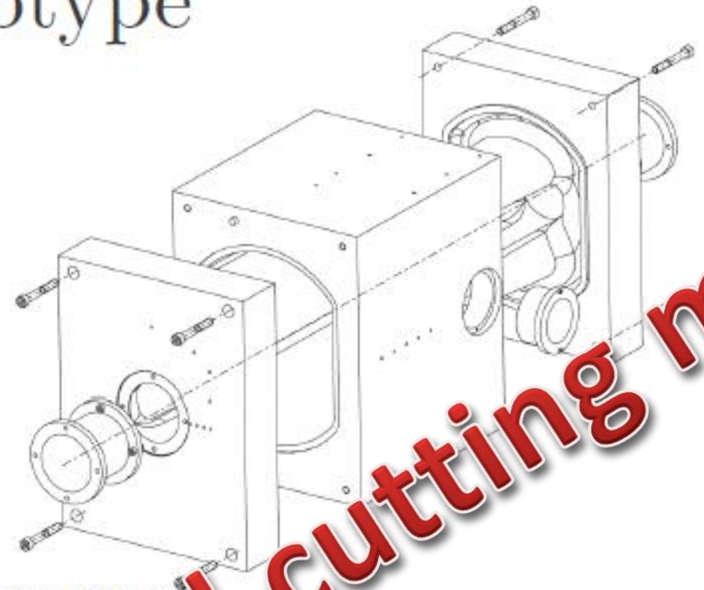


Detailed planning, see E. Jensen (LHC-CC11)



4R Al-Prototype

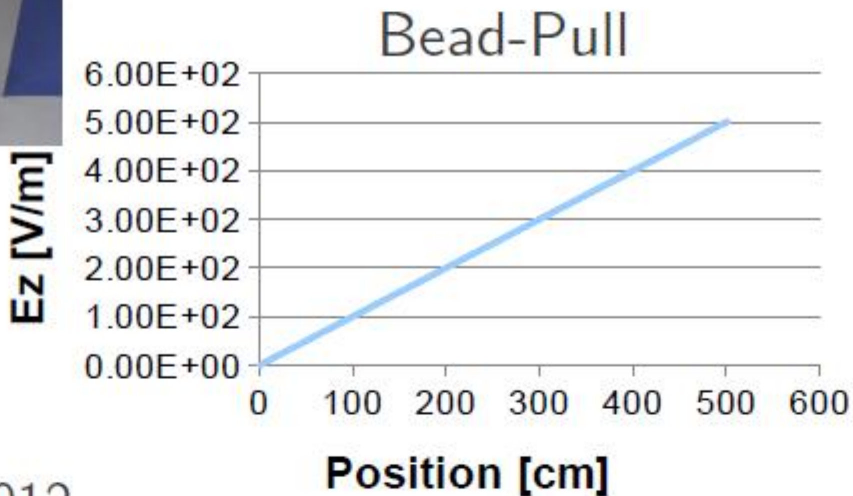
Courtesy G. Burt, B. Hall



Nb Cavity from solid Ingot

Al-prototype for field measurement

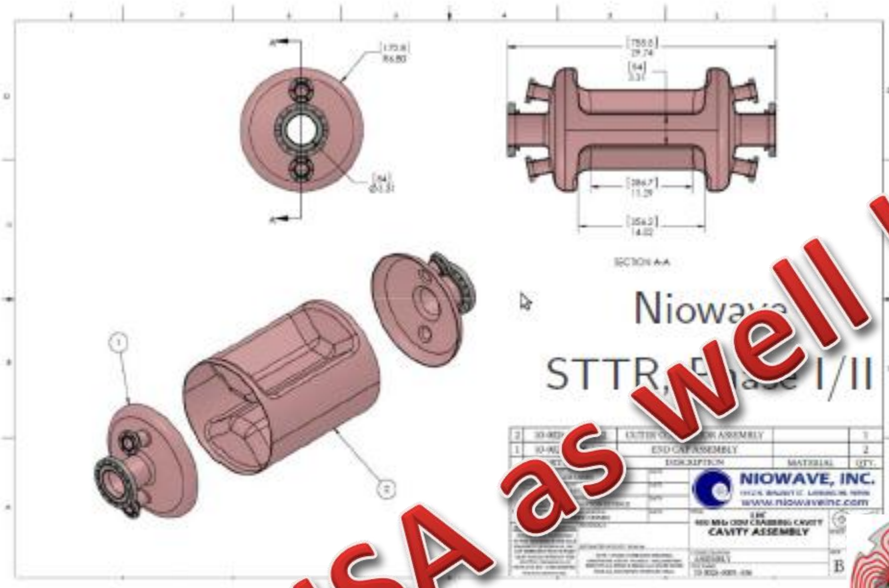
They started cutting metals!

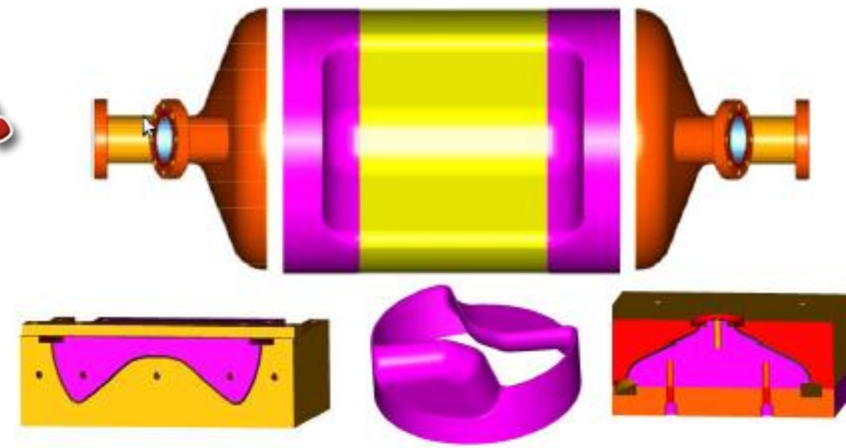


Niobium cavity to be delivered in March 2012

Double Ridge Fabrication

Courtesy:J. Delayan, Niowave





In USA as well !!!

LARP

Nov 2011 ⟶ Jan 2012

Testing April 2012

LHeC and HE-LHC: accelerator layout and challenges

project layouts; main accelerator-physics & technology challenges; required LHC modifications; global schedules with decision points

Frank Zimmermann

Chamonix LHC Performance Workshop 2012

Many thanks to:

Jose Abelleira, Ralph Assmann, Nathan Bernard, Alex Bogacz, Chiara Bracco, Oliver Brüning, Helmut Burkhardt, Swapan Chattopadhyay, Ed Ciapala, John Dainton, Octavio Dominguez, Anders Eide, Miriam Fitterer, Brennan Goddard, Friedrich Haug, Bernhard Holzer, Miguel Jimenez, John Jowett, Max Klein, Peter Kostka, Vladimir Litvinenko, Peter McIntyre, Karl Hubert Mess, Steve Myers, Alessandro Polini, Louis Rinolfi, Lucio Rossi, Stephan Russenschuck, GianLuca Sabbi, Daniel Schulte, Mike Sullivan, Laurent Tavian, Ezio Todesco, Rogelio Tomas, Davide Tommasini, Joachim Tückmantel,…

Key references:

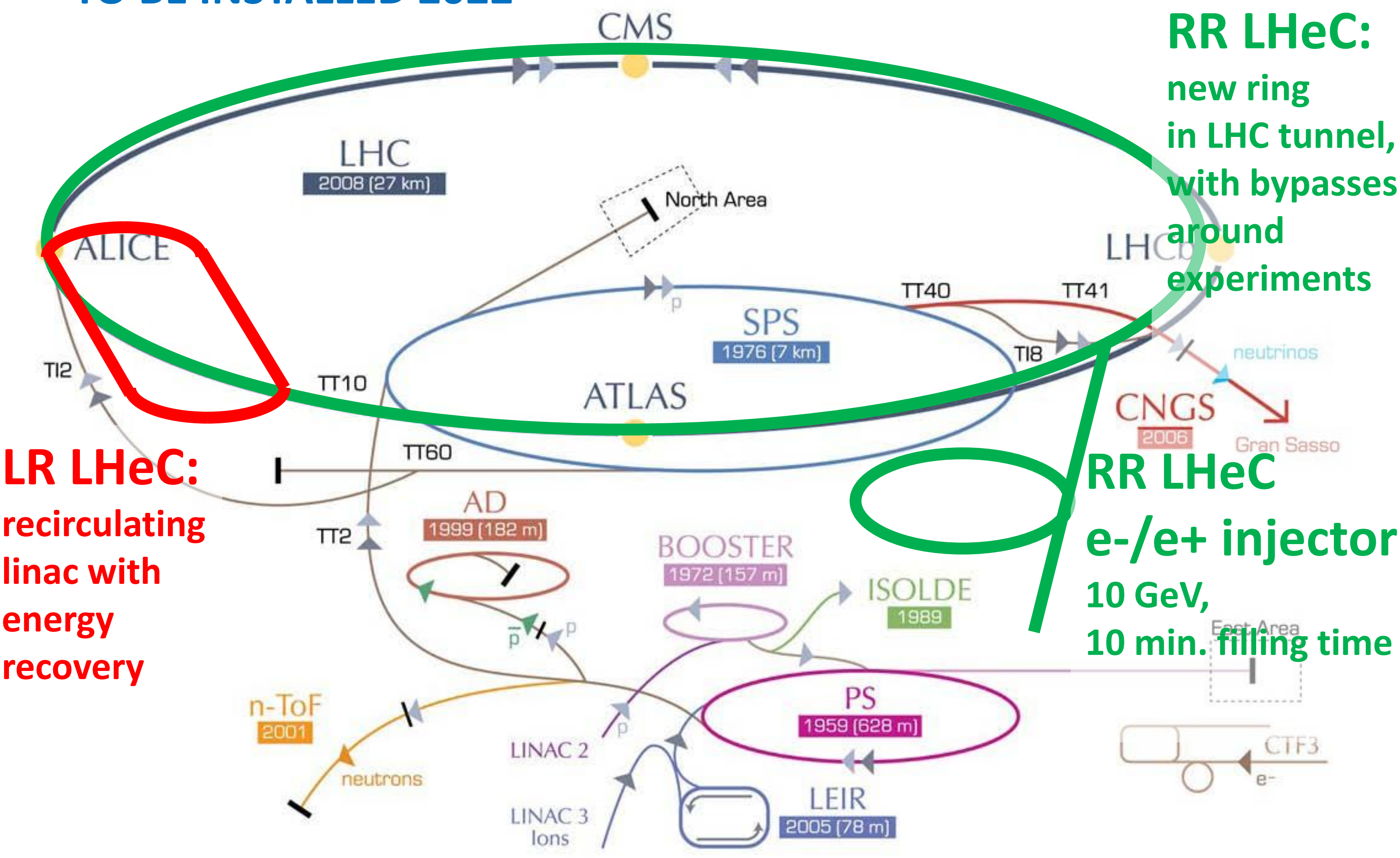
O. Brüning, LHeC Accelerator, ECFA Meeting at CERN, 25.11.2011

E. Todesco, High Energy LHC, 2nd EuCARD Meeting, Paris, 11.05.2011

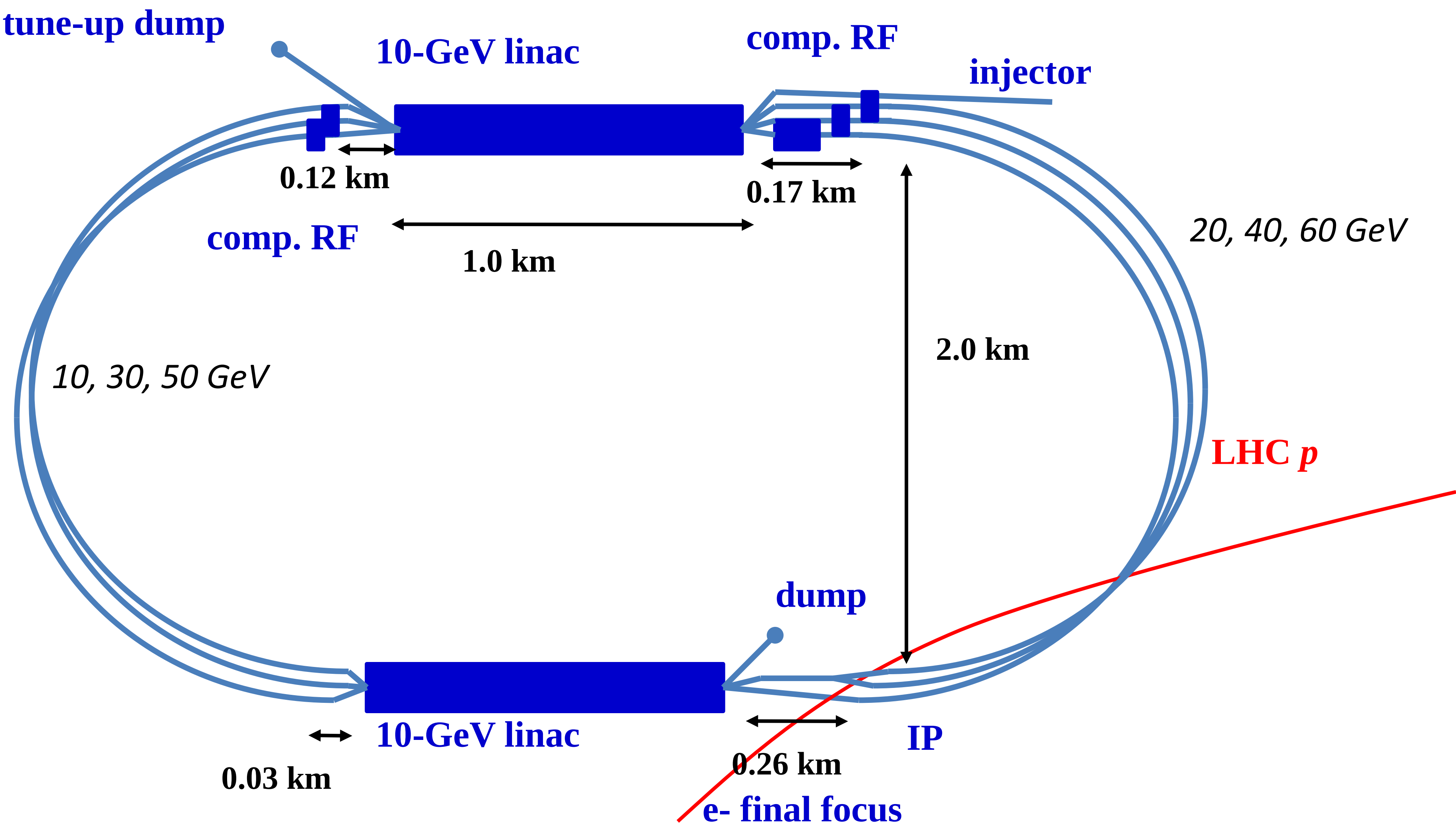
Large Hadron electron Collider

draft LHeC CDR completed (~600 pages);
TDR by 2014

TO BE INSTALLED 2022

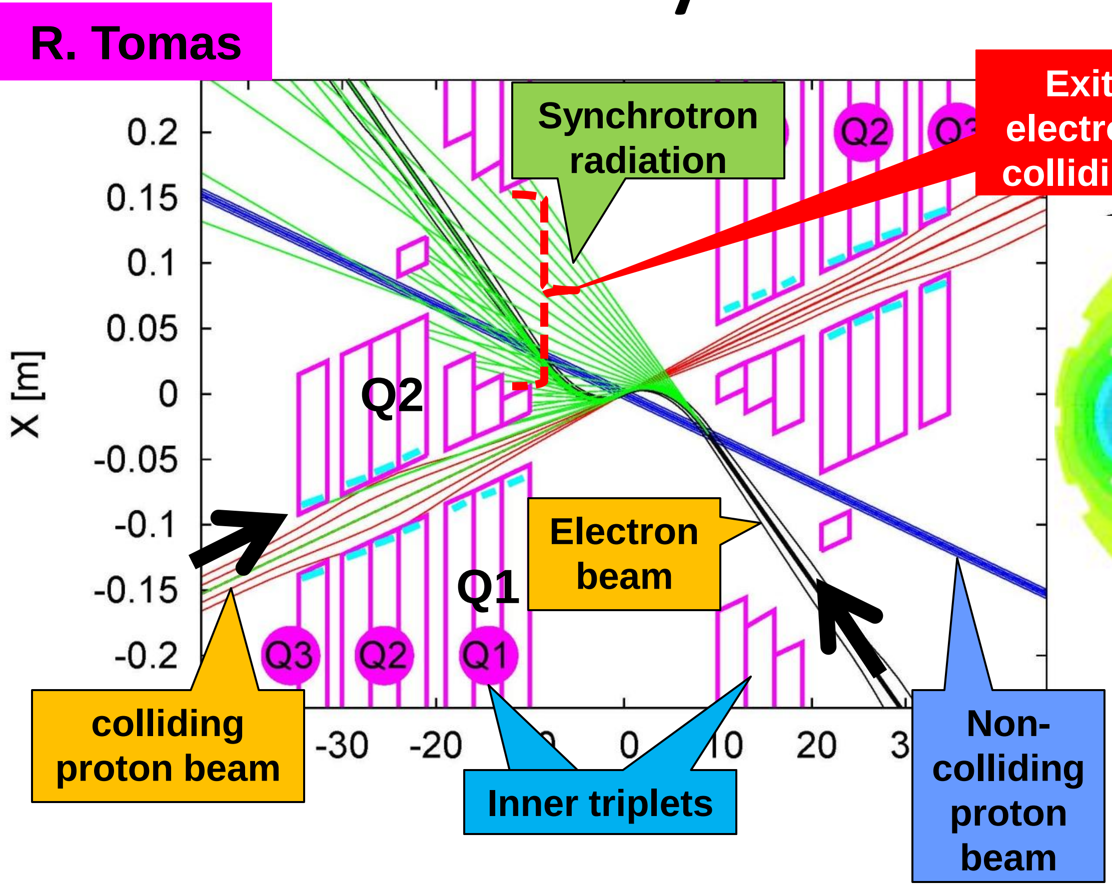


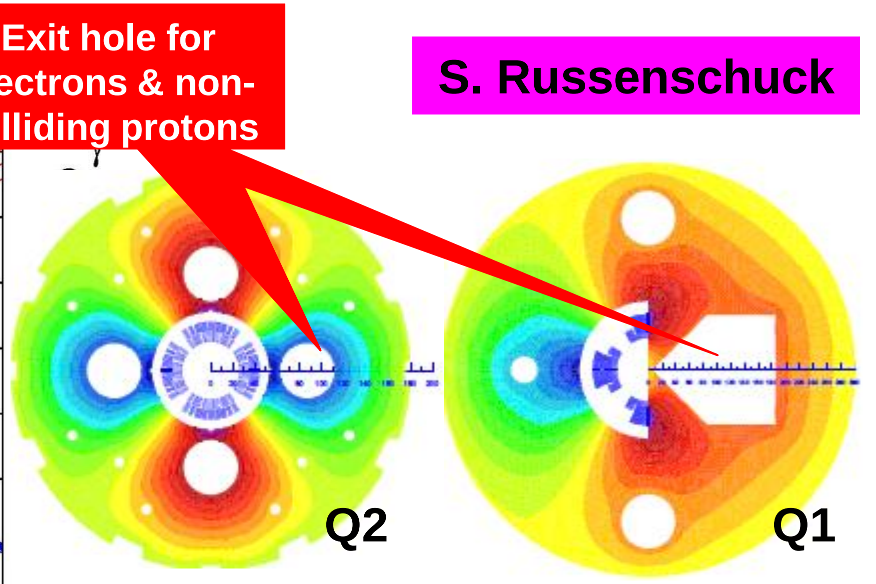
ERL configuration



total circumference ~ 8.9 km

LR LHeC IR layout & SC IR quadrupoles





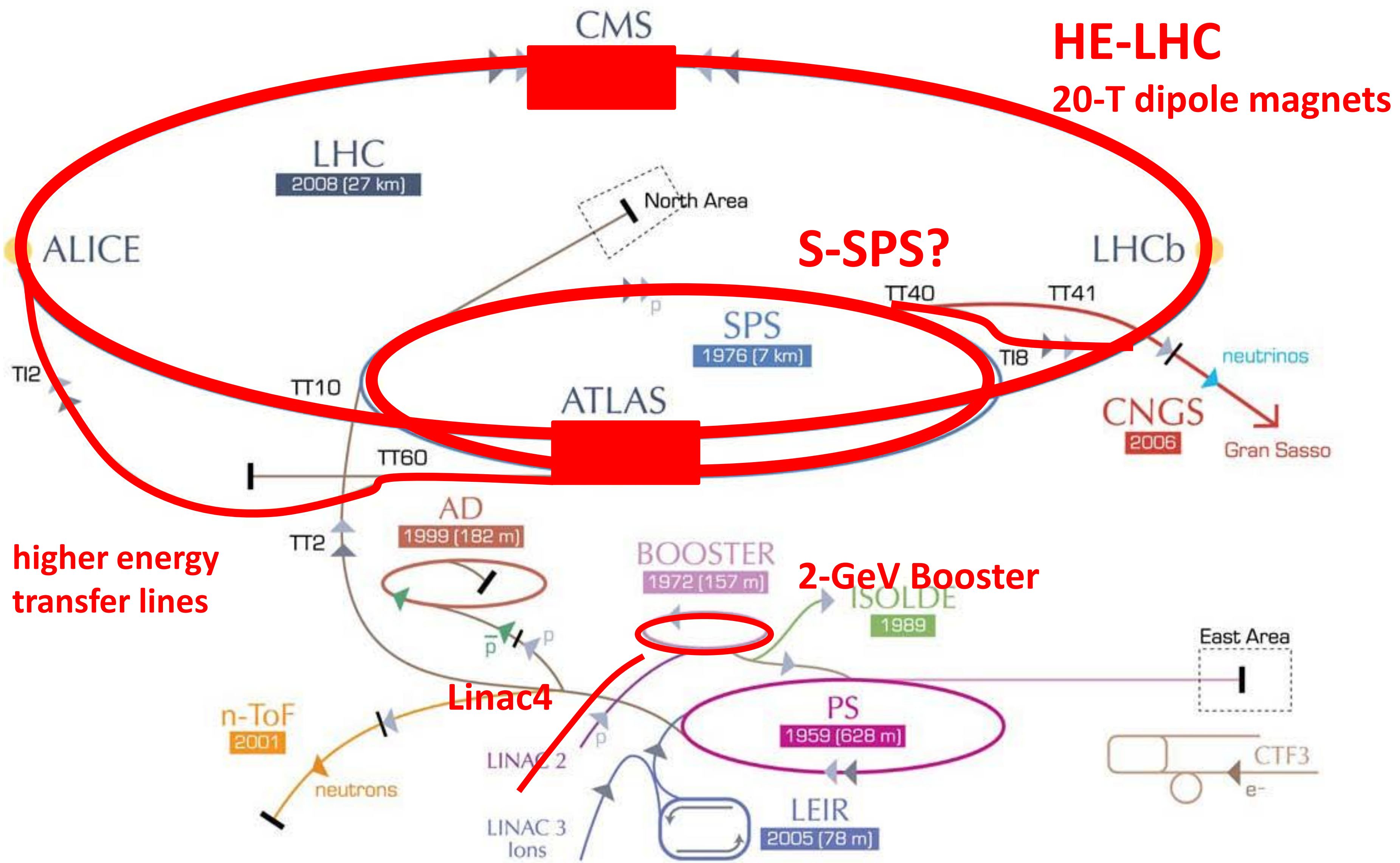
Nb3Sn (HFM46): 5700 A, 175 T/m, 4.7 T at 82% on LL (4 layers), 4.2 K	Nb3Sn (HFM46): 8600 A, 311 T/m, at 83% LL, 4.2 K
46 mm (half) ap., 63 mm beam sep.	23 mm ap.. 87 mm beam sep.
0.5 T, 25 T/m	0.09 T, 9 T/m

High-gradient SC IR quadrupoles based on Nb3Sn for colliding proton beam with common low-field **exit hole for electron beam and non-colliding proton beam**

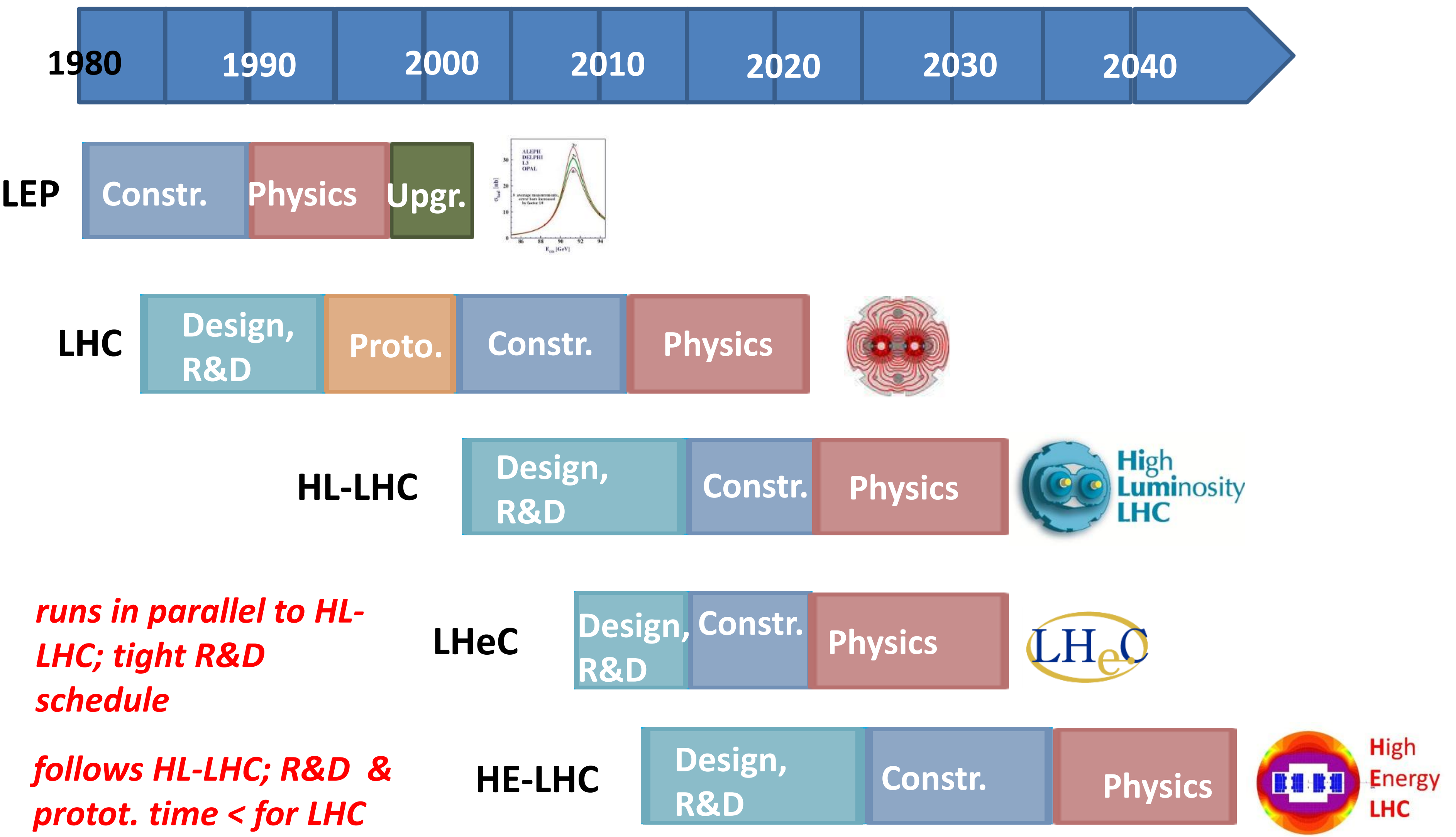
detector integrated dipole: 0.3 T over +/- 9 m

LHeC

High Energy LHC



time line of CERN HEP projects



Source: L. Rossi. LMC 2011 (modified)

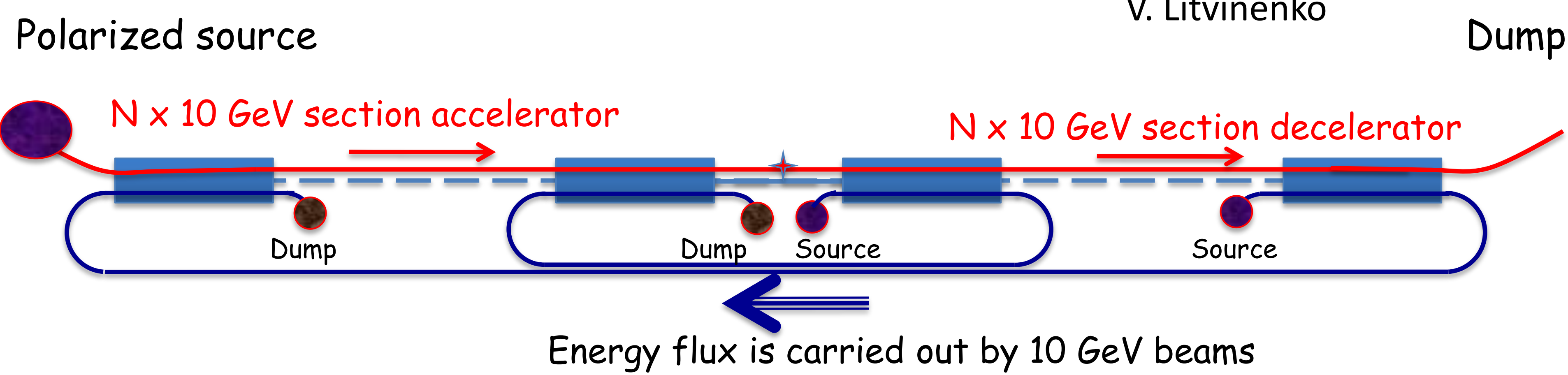
beyond 2040

further great upgrades on the horizon:

- HL-HE-LHC (10^{35} $cm^{-2}s^{-1}$ at 33 TeV c.m.)
- HE-LHeC (150 GeV e^- x 16.5 TeV p^+)

high energy ERL using "CLIC" technology

V. Litvinenko



thank you for your attention!

Accelerator Magnet R&D in the Perspective of a LHeC and a HE-LHC

Synergy or Competition ?

Circles in a circle
V. Kandinsky, 1923
Philadelphia Museum of Art

Presented by L. Bottura

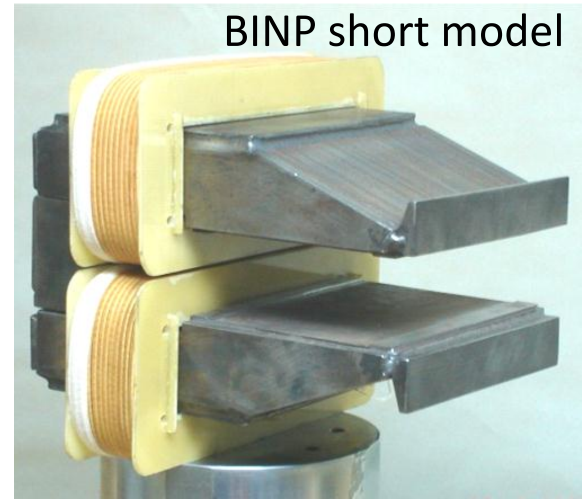
LHC Performance Workshop
Chamonix 2012
10 February, 2012

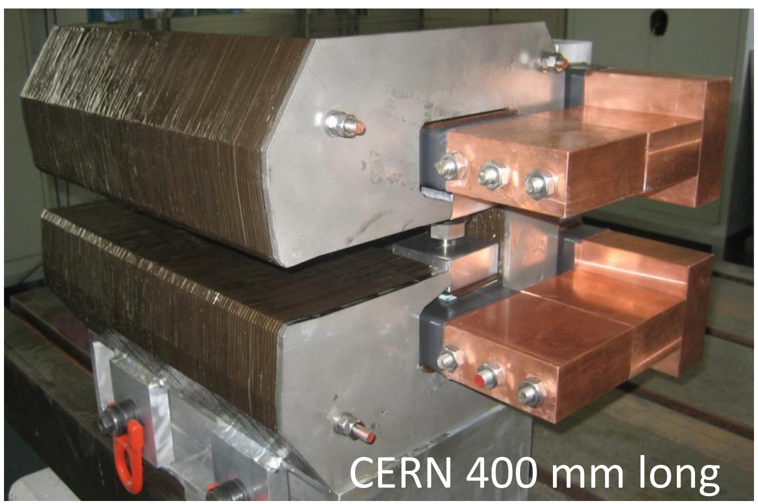
Low field dipoles for LHeC

Compact and lightweight to fit in the existing tunnel, yet mechanically stable

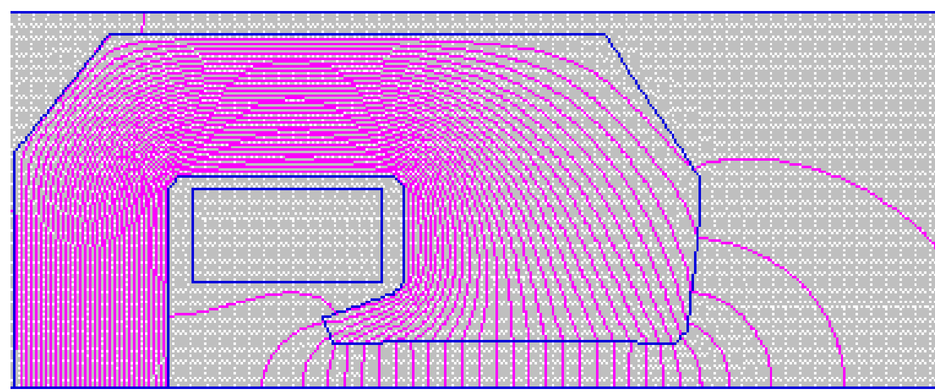
Field homogeneity in the whole range of operation ?

Field reproducibility at injection ?

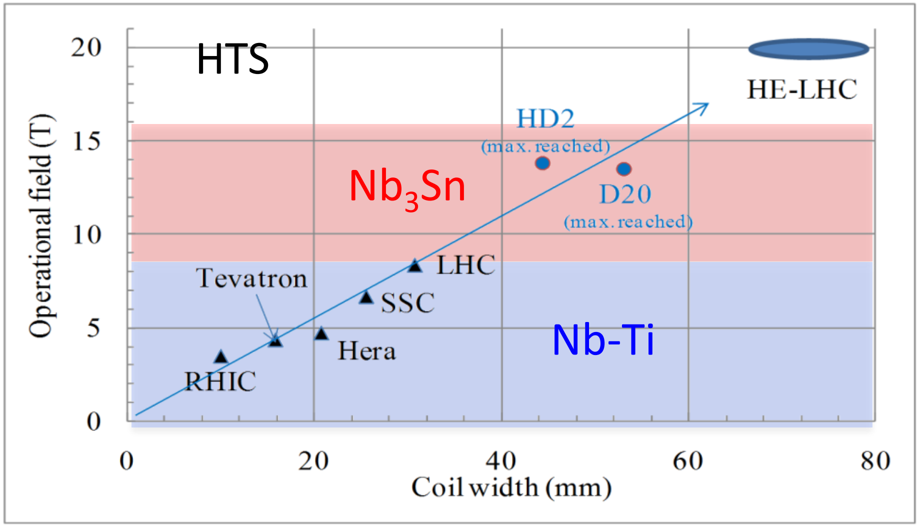


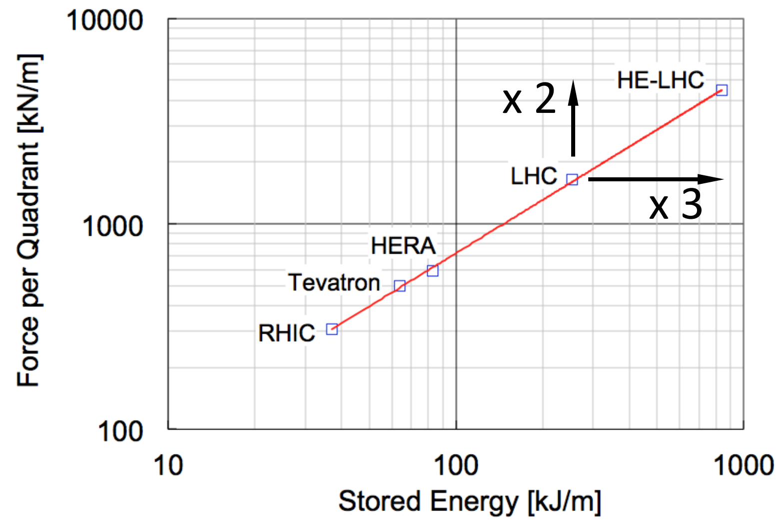


CERN design study

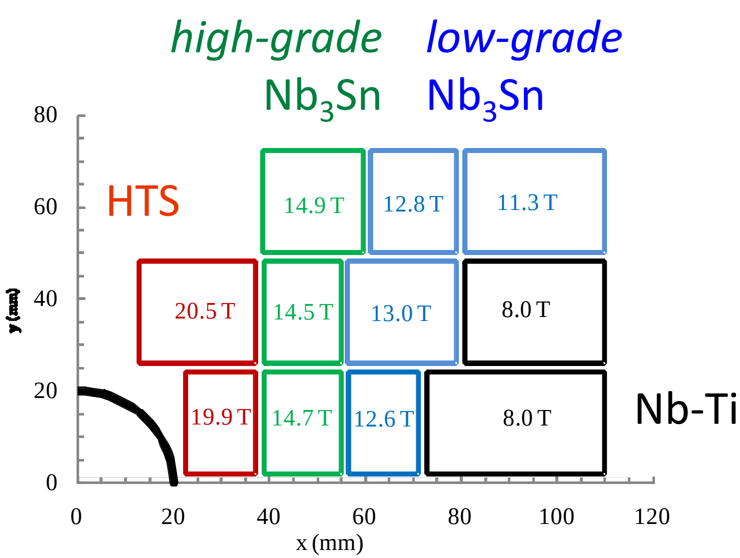


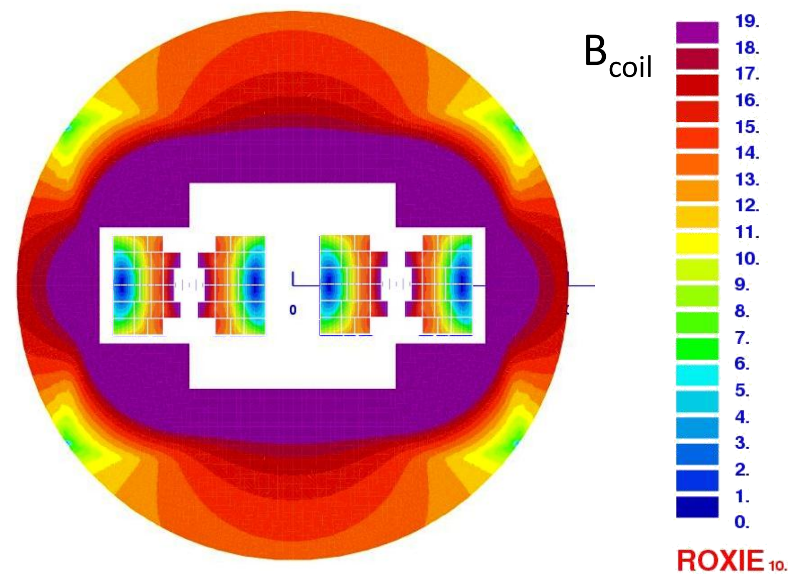
A *really high field* dipole





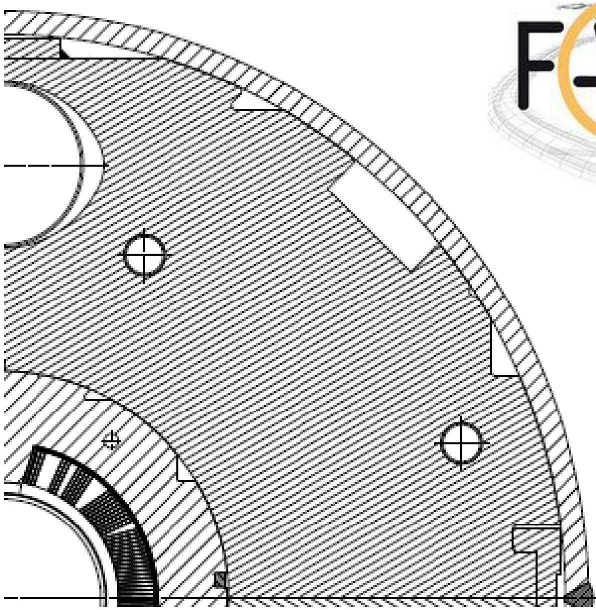
HTS/Nb_3Sn/Nb-Ti nested coil magnet



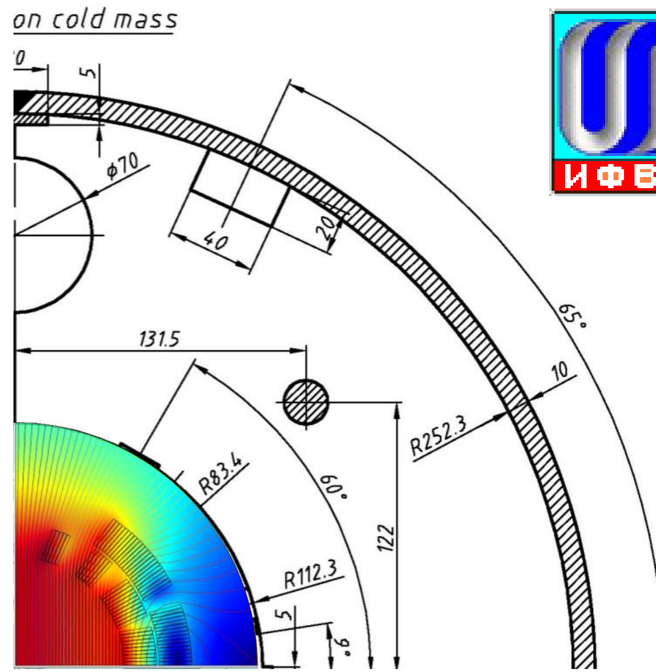


By courtesy of E. Todesco

Low-loss pulsed magnets



4.5 T, Nb-Ti single layer design



6 T, Nb-Ti double layer design

Quench performance and operating margin (recall that the booster was a major stumble for SSC)

AC loss in the SC coil: 10 W/m over 7 km of magnets are 70 kW of required cryogenic power, or 20 MW socket power

By courtesy of P. Fabbricatore (INFN)

Summary table

			LHeC RR dipole prototype	CRISP and fast cycled SC magnets	MQXC R&D	EuCARD FReSCa-II	DS 11 T MB program	US-LARP IR quadrupole program	EuCARD HTS insert	EuCARD2 HTS model	activated SC magnets handling for	Comments
LHeC	Low field resistive magnets	field quality and reproducibility	**X**									demonstrated
		operating cost		x								tests planned in 2012
		integration in the LHC tunnel									x	study launched in 2012 (LS1)
	IR magnets	large aperture			**X**			**X**				results in 2012…2014
		large gradient						**X**				
		heat removal		x	**X**							results in 2012
	co-activities and tunnel works										x	integration study and models (BINP); schedule revision
HE-LHC	Very high field magnets	15 T dipole outsert				**X**						deliverable Q1 2014
		5 T dipole insert							**X**	**X**		EuCARD2 proposal
		high gradient quadrupoles						**X**				US-LARP technology demonstration by 2014
		magnet protection				**X**	**X**	**X**				
		heat loads and removal			x	**X**						dedicated model tests
		field quality					**X**	**X**		**X**		
	Pulsed SC magnets	quench performance and margin		**X**								
		low-loss cables		**X**								
	Transfer lines											options reviewed at HE-LHC workshop in Malta, 2010
	Material availability and cost					**X**	**X**	**X**	x	x		
	Installation in 2030										**X**	study launched in 2012 (LS1)

SC Cavities R&D for LHeC and HE-LHC

Erk Jensen, BE-RF

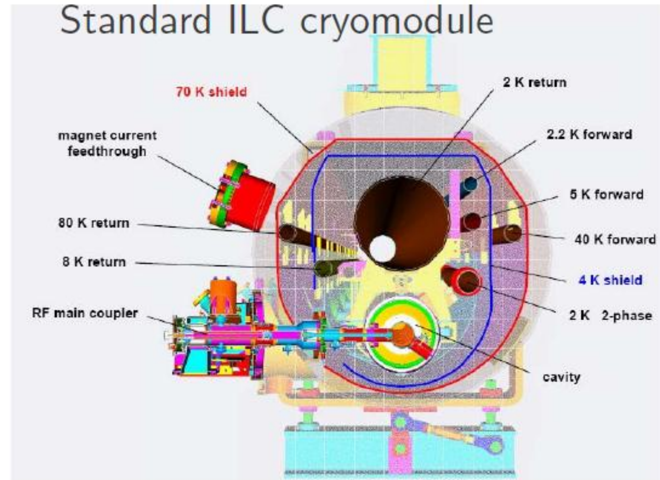
Many thanks to O. Brunner, E. Ciapala, R. Calaga, S. Calatroni, T. Junginger, D. Schulte, E. Shaposhnikova, J. Tückmantel, W. Venturini, W. Weingarten

and all those I forgot to mention

Potential Options for Energy RECOVERY Linac

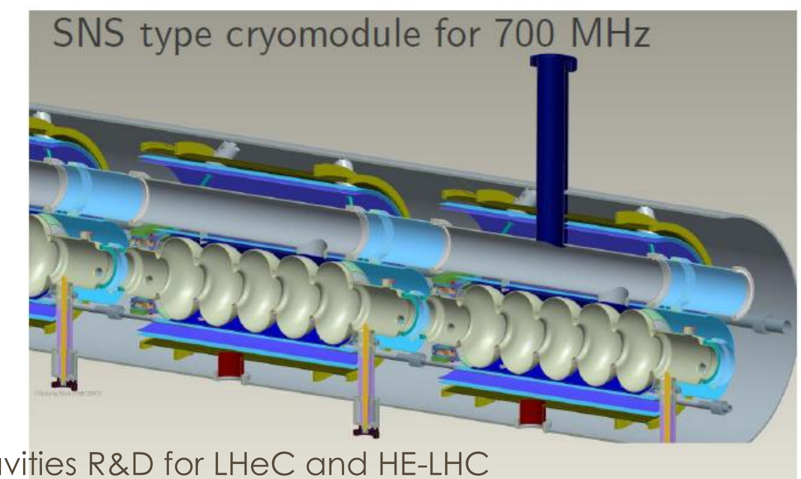
1.3 GHz

ILC Collaboration



704 MHz

ESS, eRHIC, SPL



Power consumption estimates (rough)

	Units	721.4 MHz	1322.6 MHz
Main linacs (no beam loading)			
R/Q	[Ω]	500	1036
Q_0 @ 2 K		2.4×10^{10}	1×10^{10}
V/cavity	[MV]	20.8	20.8
P_{RF}/cavity	[kW]	43.4	20.9
n_{cav}		960	960
total RF power	[MW]	41.7	20.1
P_{AC}	[MW]	**59.6**	**36.5**
Synchrotron radiation compensation			
total RF power	[MW]	12.4	
P_{AC}	[MW]	**20.7**	
Heat load (assuming Q_0 @ 2 K, conversion factor 600)			
P_{AC}/cav	[kW]	21.25	24.2
$P_{cryo,\ AC}$	[MW]	**20.4**	**23.2**
HOM's	[MW]	**0.75**	**2.34**
Static, coupler, interconnects	[MW]	**3**	**3**
0.3 GeV injector			
P_{AC}	[MW]	**5**	
Total P_{AC}	**[MW]**	**109.5*)**	**90.74**

Assuming $Q_{ext} = 10^7$

Can this be recovered?

η = 60% assumed

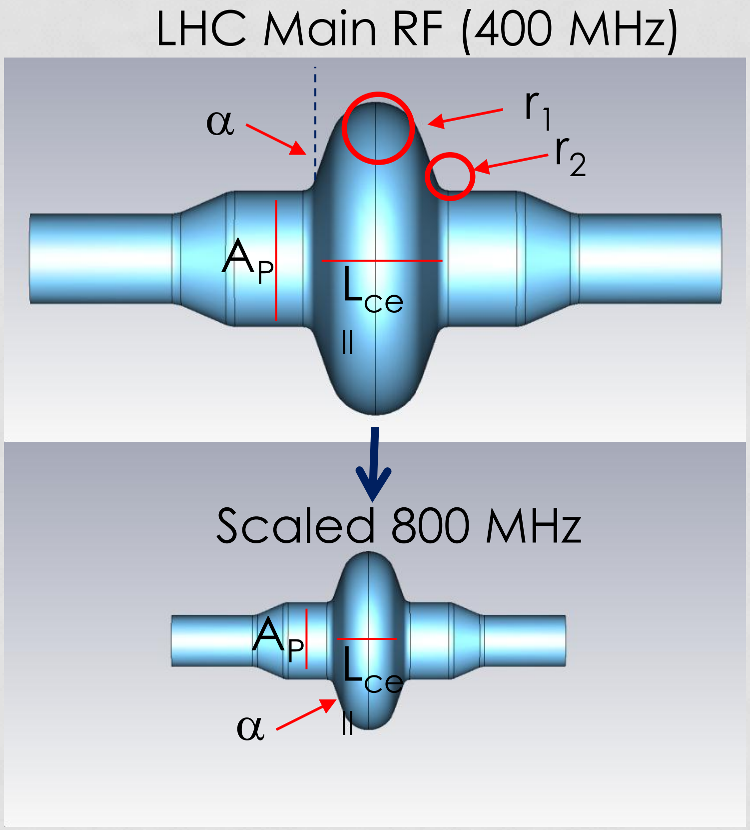
preliminary – needs x-check!

*) **78.6** with adapted Q_{ext}

800 MHz LHC (or HE-LHC) Landau Cavity

f	400 MHz	800 MHz
L_{CELL}	320	~160
A_p	300	150
α	11^0	$< 11^0$
R_1	104	52
R_2	25	12.5

f	[MHz]	400	800
V	[MV]	2.0	2.0
R/Q	[Ω]	44	45.5
E_{pk}	[MV/m]	11.8	29.2
B_{pk}	[mT]	27.3	56.4



L. Ficcadenti, J. Tückmantel, R. Calaga

Conclusions

- No show stopper for HL-LHC goal from beam current/collimation…
- The main tehcnologies, HFM and SC RF are well «en route»: but ten years is a short time (when in // with LS1, LS2… many other interesting projects)
- LHC tunnel and machine is the cross-road linking the past LEP-1 to the future till 2050 with HL, HE, LHeC, LEP-III and all possible combinations!