HL-LHC project

(including introduction to Hi-Lumi Design Study)

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CERN

sLHC-PP Public events @ CERN 8 March 2011

Content

- Scope of HL-LHC
- Main technologies
  - sLHC as key step toward high luminosity
- HiLumi LHC, an FP7 Design Study
  - A global collaboration

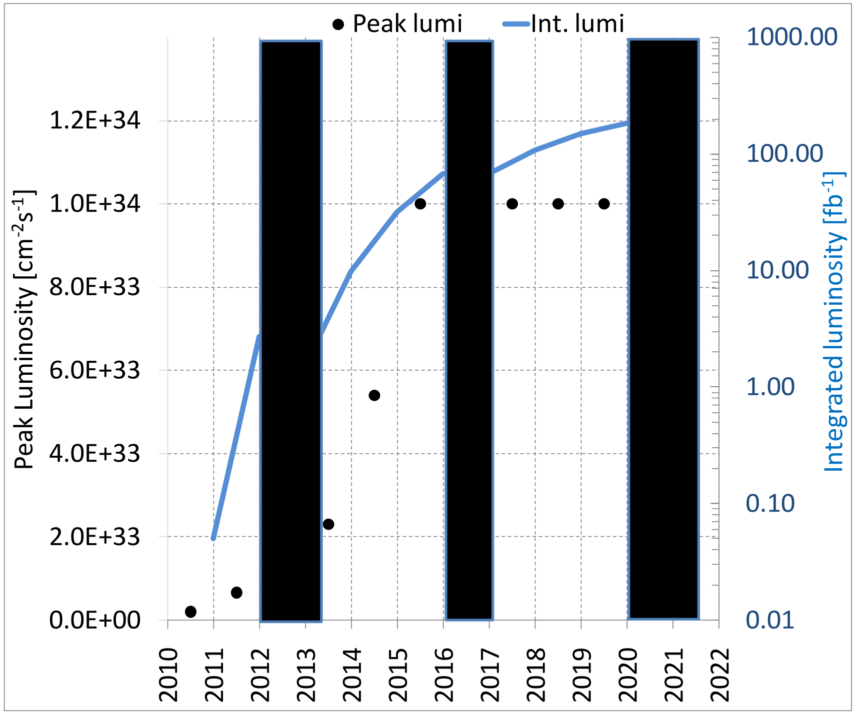
How the lumi might evolve in LHC

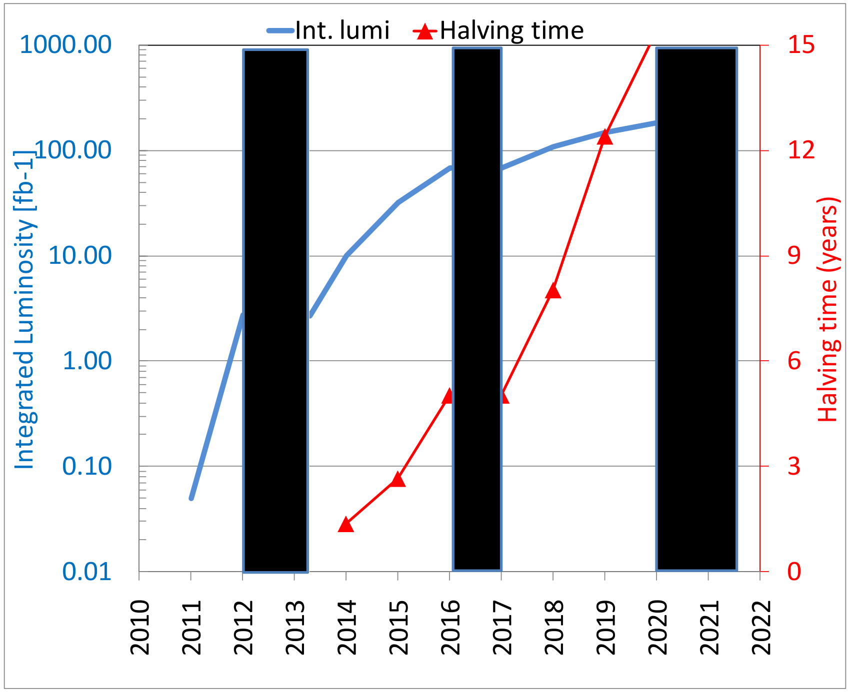
Prudent assumptions, **of September 2010**:

Better than expected LHC behaviour **is not yet** integrated.

It is assumed to saturate at design luminosity of 1.e34. Today we **may assume** 1.7-2 e34 !

The new shutdown plan (approved 31 January 2011) not yet integrated (shutdown in 2013)

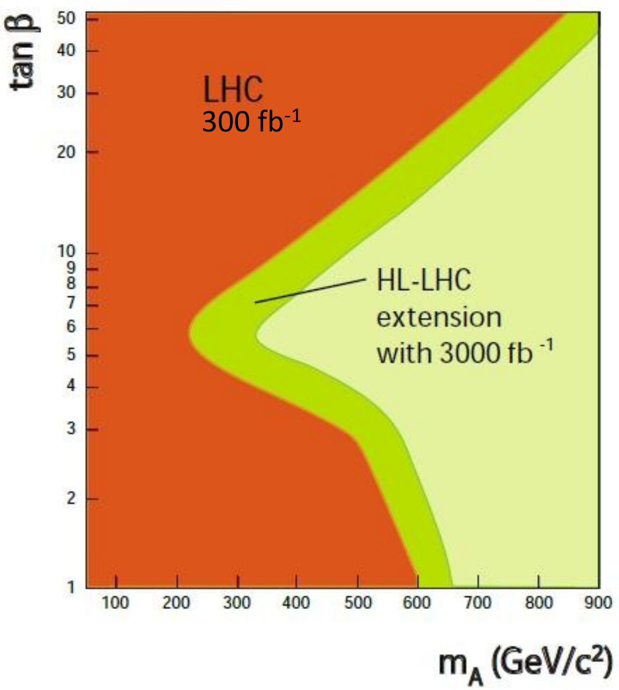


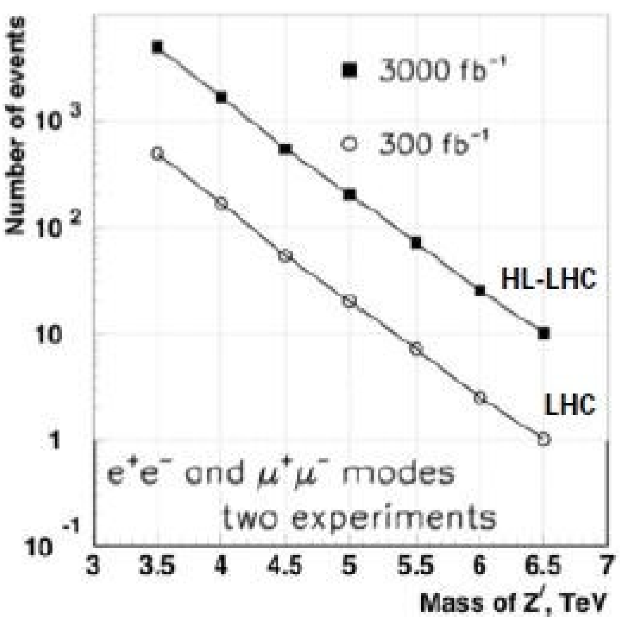


Better performance may push the integrated lumi to 300 fb^{-1} before 2020.

(some of the) Phyics motivation

In particular, operation at higher luminosity as foreseen by **HL-LHC has three main purposes**:
•**Perform more accurate measurements** on the new particles discovered in the LHC.
•**Observe rare processes**, whether predicted by the Standard Model (SM) or by the new physics scenarios unveiled by the LHC, which have rates below the sensitivity of the current phase.
•Extend the **exploration of the energy frontier, therefore extending the discovery reach**, by probing the very rare events where most of the proton momentum is concentrated in a single quark or gluon.



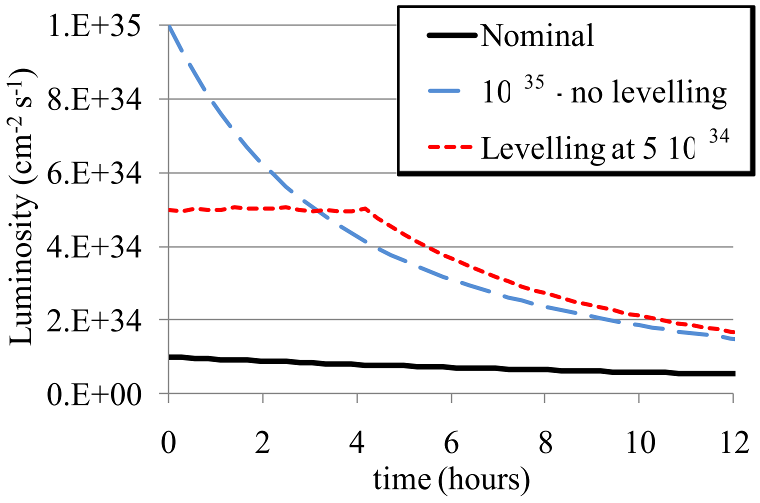


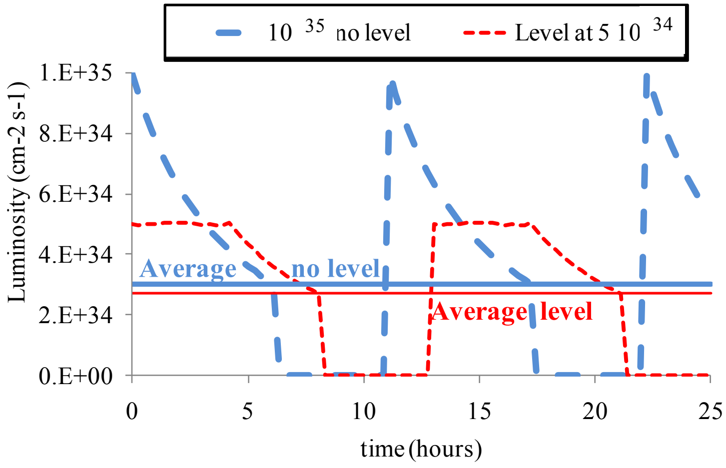
The goal

The main objective of HL-LHC is to implement a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

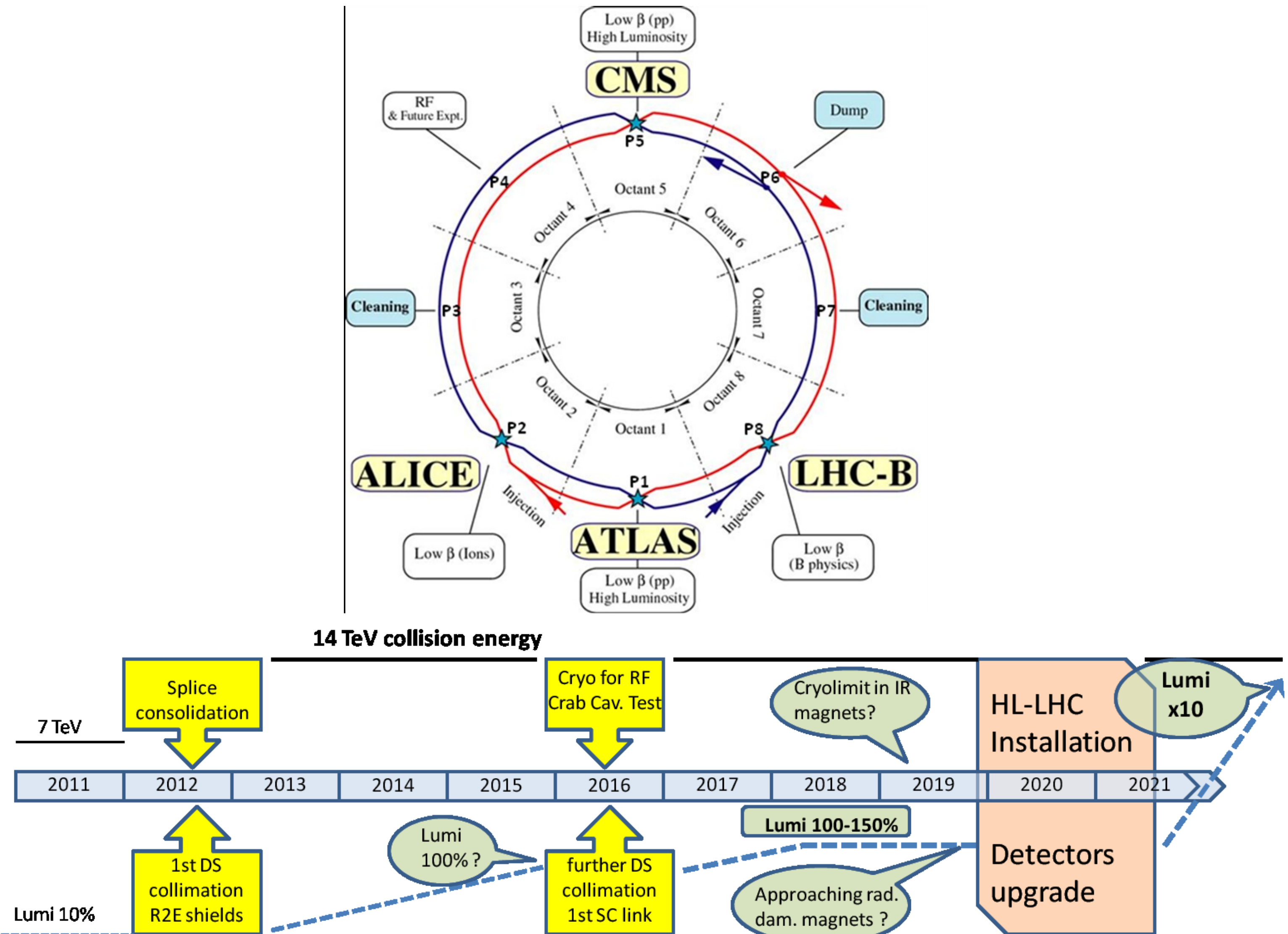
•A peak luminosity of **5×10^{34} $cm^{-2}s^{-1}$ with levelling**, allowing:

•An integrated luminosity of **250 fb^{-1}** per year, enabling the goal of **3000 fb^{-1}** twelve years after the upgrade. This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.





The path toward high lumi

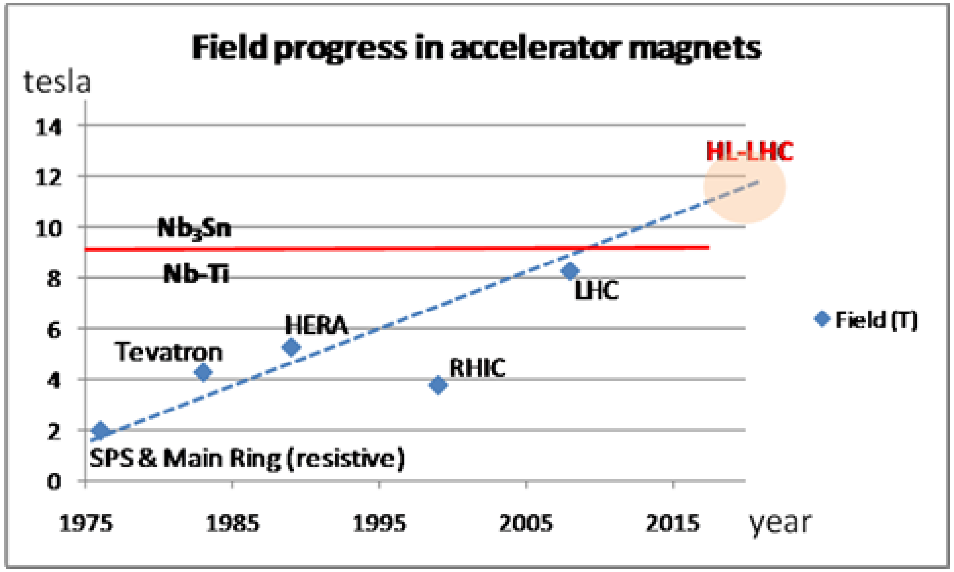


What is new from last year

- Phase 1 upgrade (of which sLHC has been an important pillar) have evidenced the difficulty to go to β^* sensibly smaller than LHC.
- Necessity to go beyond a change of the IR (inner triplet quads+ D1)
- Necessity of levelling and of means to beat the geometric reduction factor

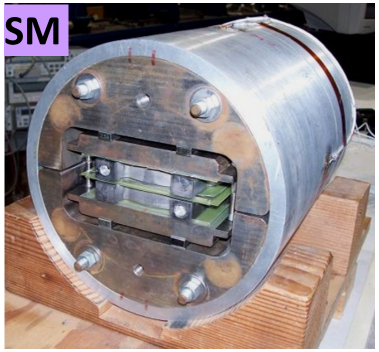
Squeezing the beam
High Field SC Magnets

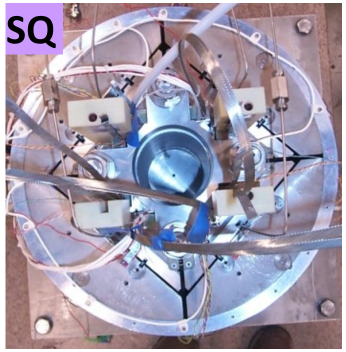
- 13 T, 150 mm aperture Quads for the inner triplet
  - LHC: 8 T, 70 mm.
  - sLHC-PP: 8.5 T 120 mm
- More focus strength, β* as low as 15 cm (55 cm in LHC)
- Dipole separators capable of 6-8 T with 150-180 mm aperture (LHC: 1.8 T, 70 mm)

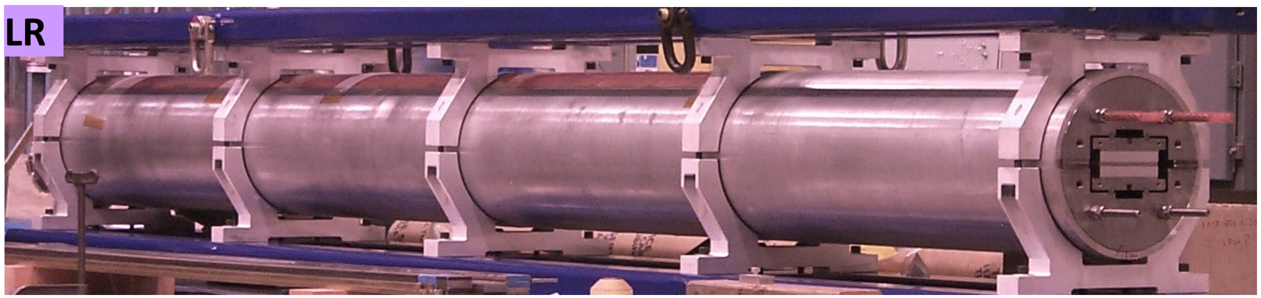


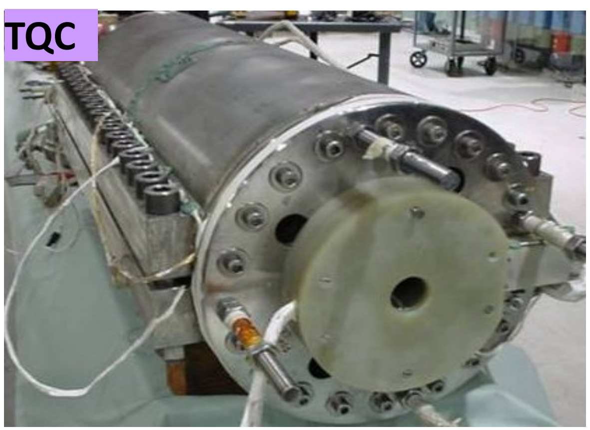
LARP

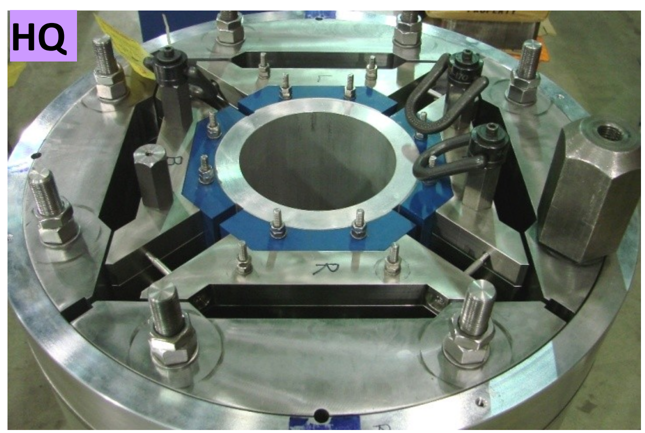
LARP Magnets



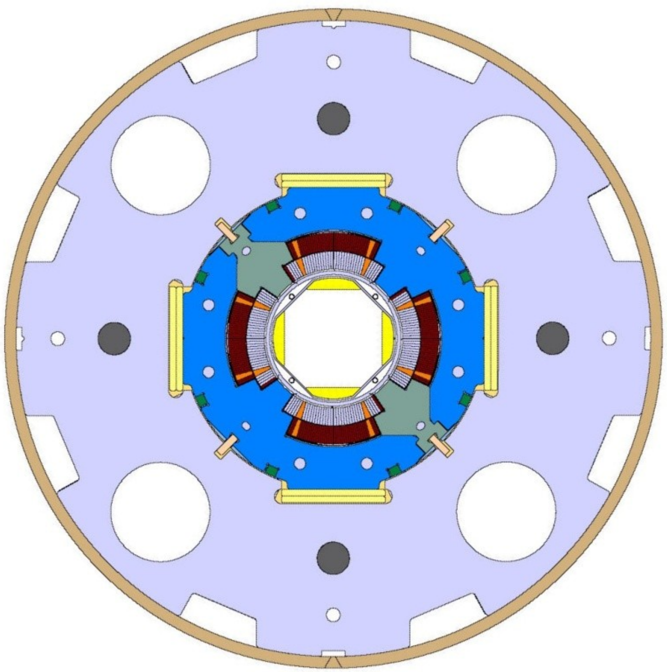


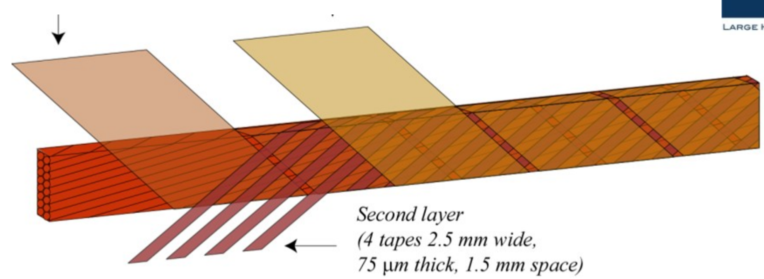


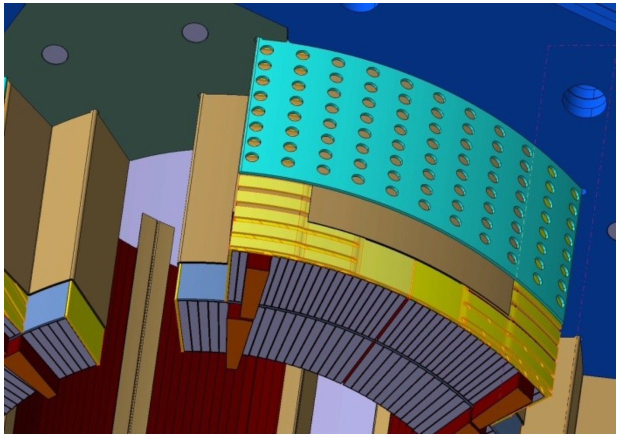




Direct benefit from sLHC program: improved Nb-Ti technolgy

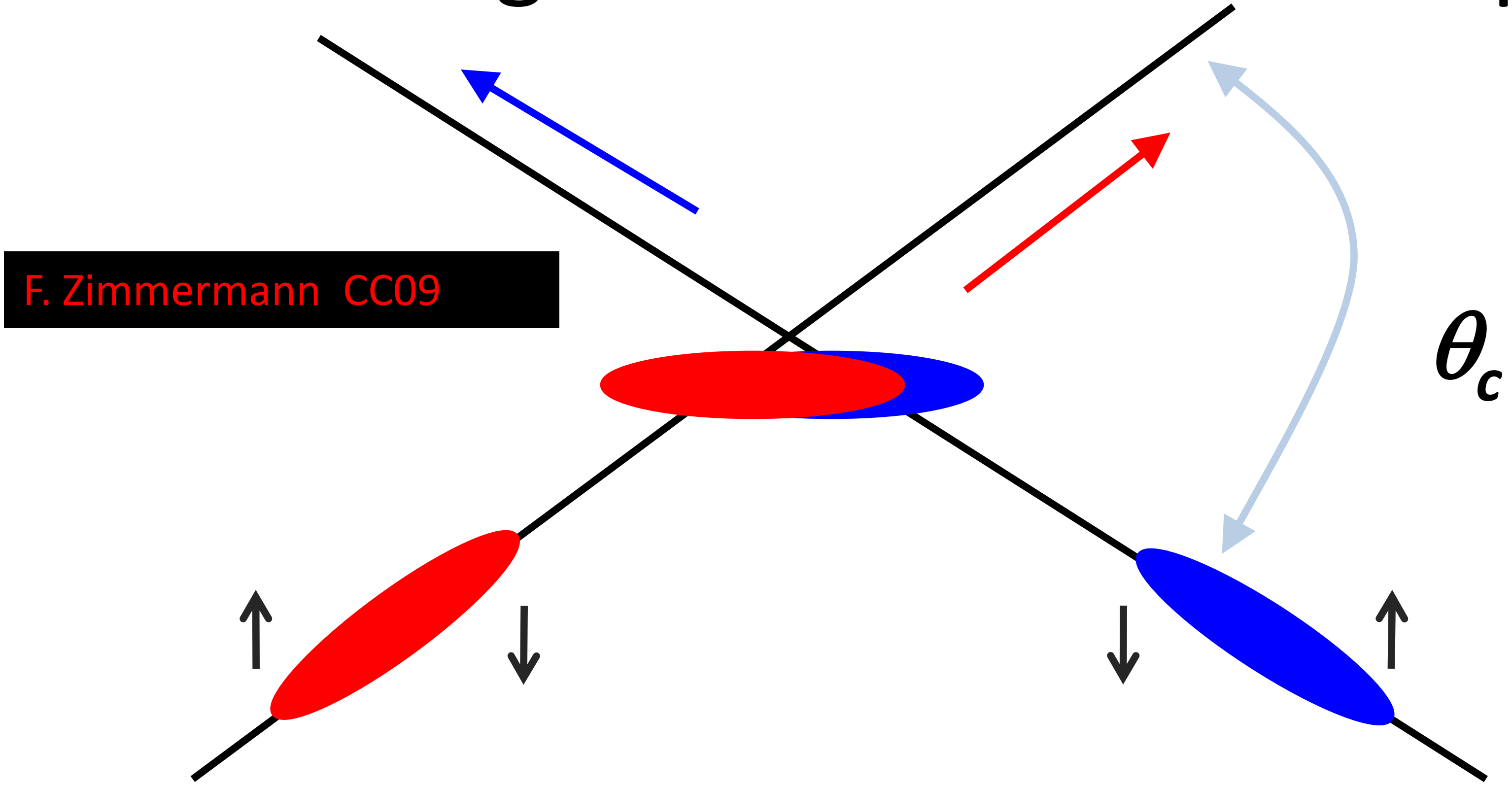






Favorite scheme of HL-LHC requires new Nb-Ti more pushed wrt to present LHC for the matching sections: larger aperture (85-90 mm, wrt LHC 56/70 mm)
Higher heat deposition will demand use of the new insulation scheme

crab crossing restores bunch overlap

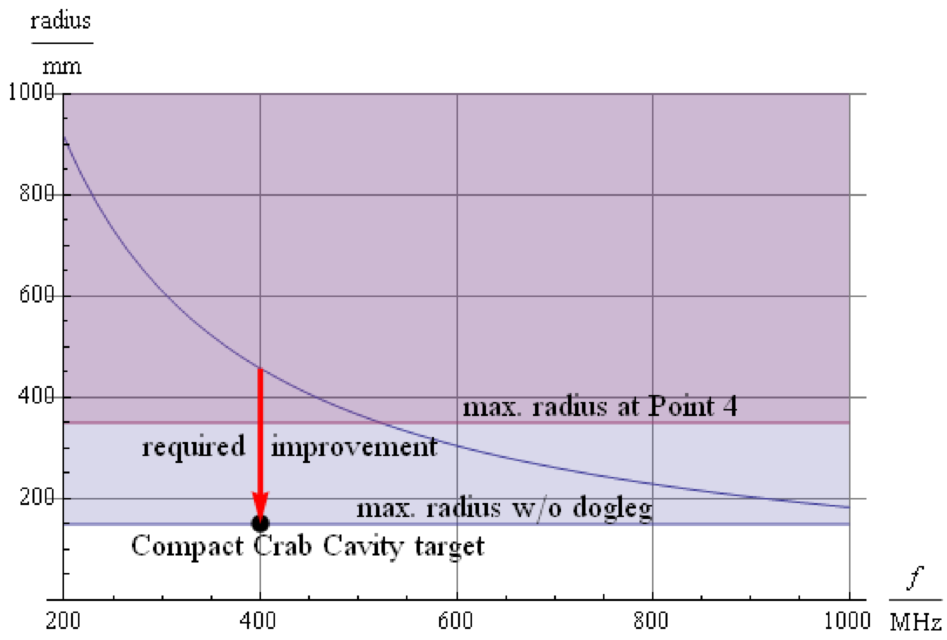


- **RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" for luminosity and tune shift**
- **bunch centroids still cross at an angle (easy separation)**
- **1st proposed in 1988, in operation at KEKB since 2007**

$\longrightarrow$ ***world record luminosity!***

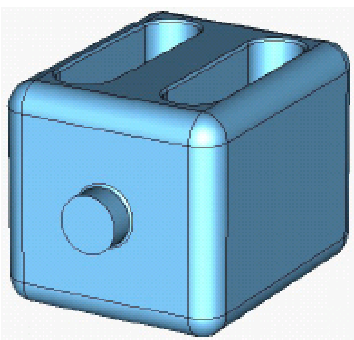
Improve beam overlap
SC RF Crab cavities

- Crab cavities to rotate the beam and colliding with good overlap
- Providing « easy » way for levelling
- Necessary to fully profit of the low β*
- Very demanding phase control (better than 0.001°) and protection
- Very compact design
- 40-80 MV (16 MV in LHC)

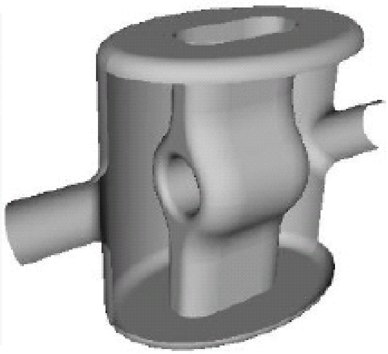


Compact 400 MHz (see 4th LHC CC workshop)

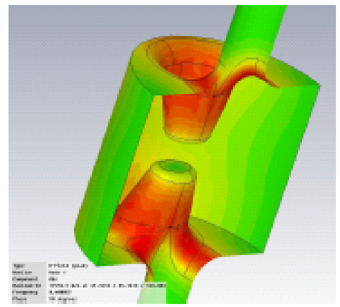
HWDR, JLAB,OD



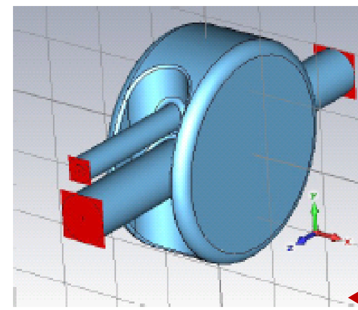
HWSR, SLAC-LARP



DR, UK, TechX



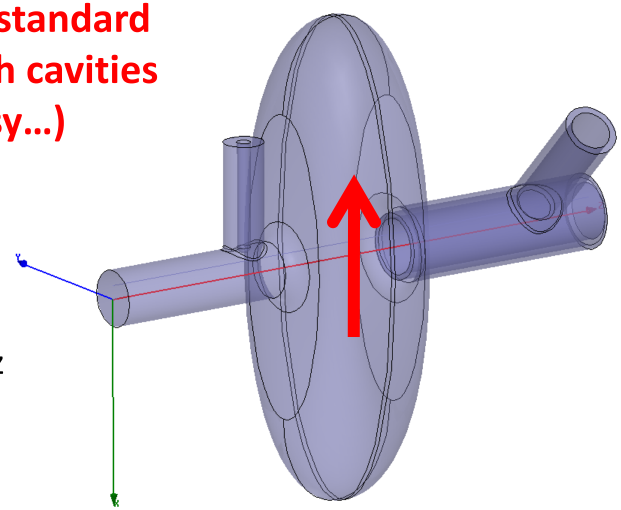
Kota, KEK

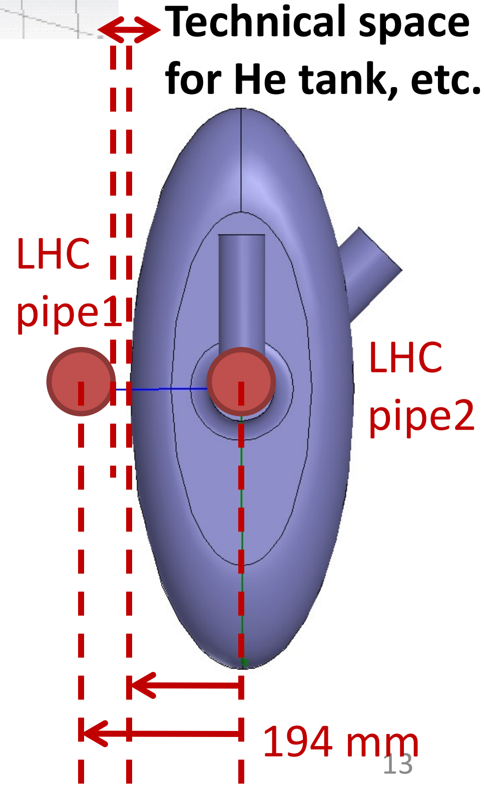


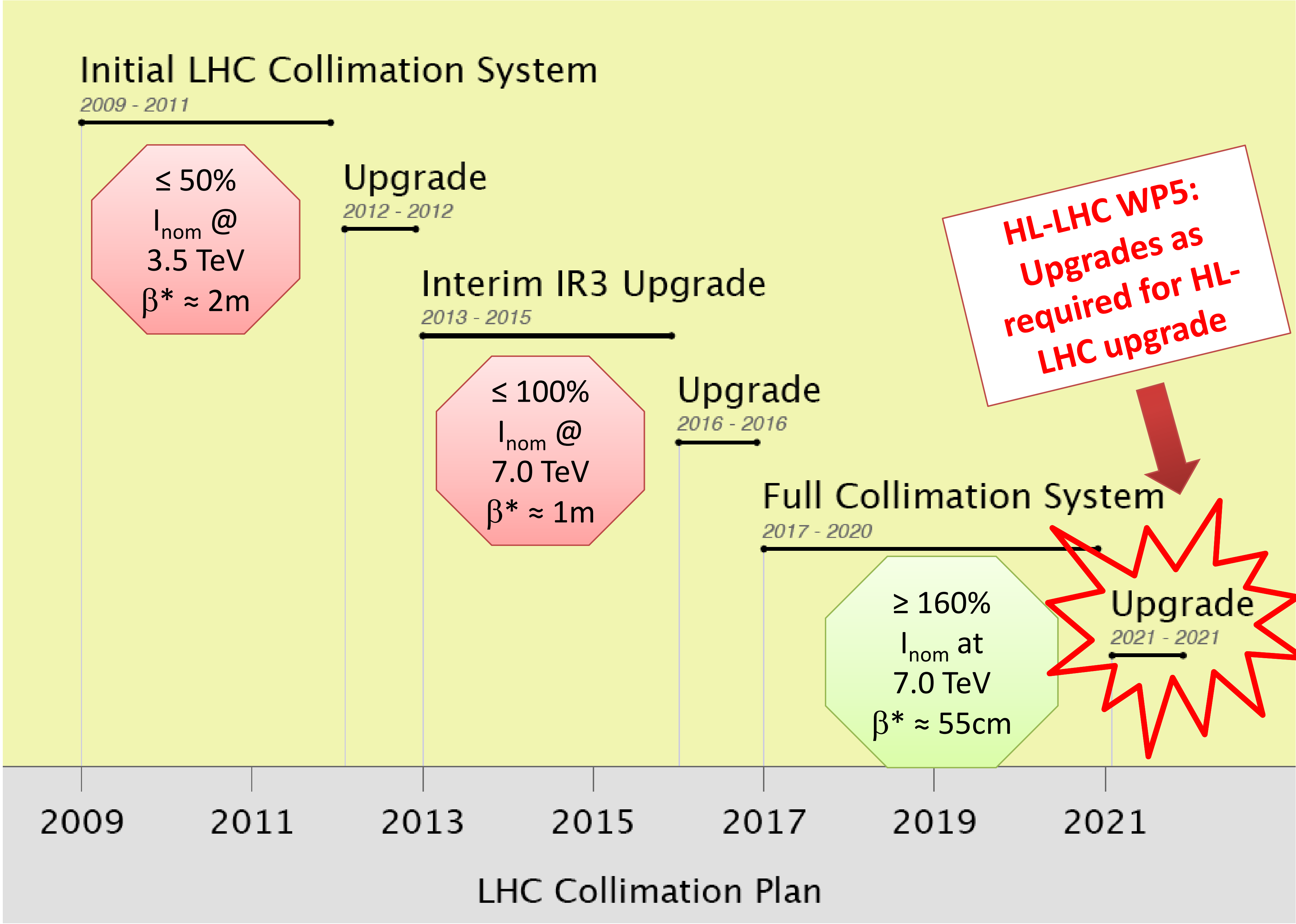
Compact cavities aiming at small footprint & 400 MHz, ~5 MV/cavity

All these 400 MHz can fit into the standard 194 mm LHC beam separation with cavities in a common cryostat (but not easy…)

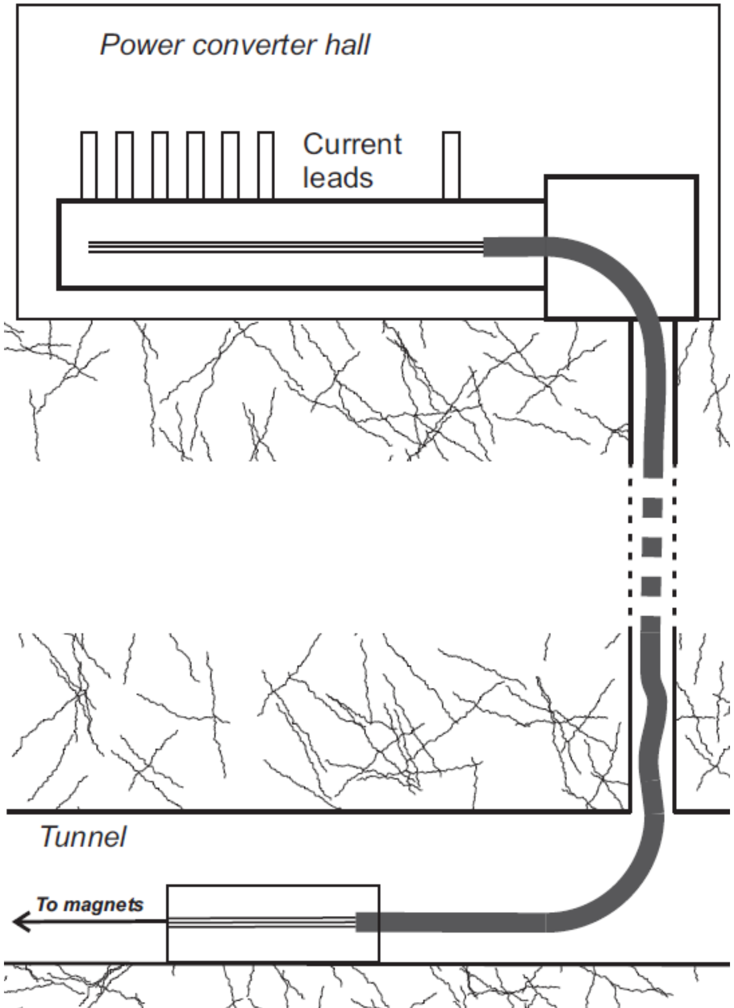
New idea for a very compact elliptical 800 MHz

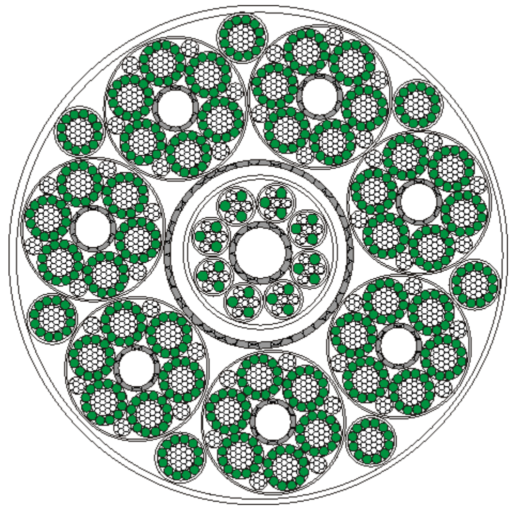


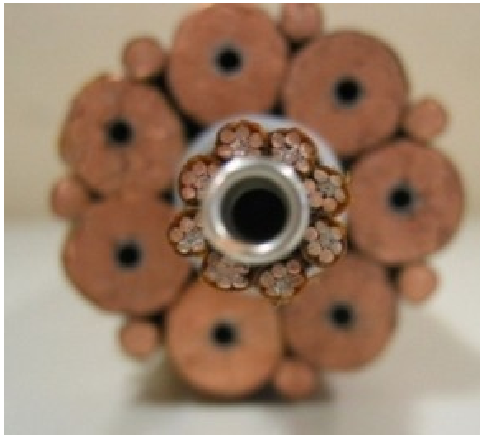



Initial LHC Collimation System
2009 - 2011
≤ 50%
I nom @
3.5 TeV
β* ≈ 2m
Upgrade
2012 - 2012
Interim IR3 Upgrade
2013 - 2015
≤ 100%
I nom @
7.0 TeV
β* ≈ 1m
Upgrade
2016 - 2016
HL-LHC WP5: Upgrades as required for HL-LHC upgrade
Full Collimation System
2017 - 2020
≥ 160%
I nom at
7.0 TeV
β* ≈ 55cm
Upgrade
2021 - 2021
2009
2011
2013
2015
2017
2019
2021
LHC Collimation Plan

Removal of Electrical Power Converter (200kA-5 kV SC cable, 100 m height)







Φ = 62 mm

MgB2
(or other HTS)

7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables – Itot~120 kA @ 30 K

Also DFs with current leads removed to surface

Definitive solution to R2E problem

Make room for shielding unmovable electronics

Make much easier maintnance and application ALARA

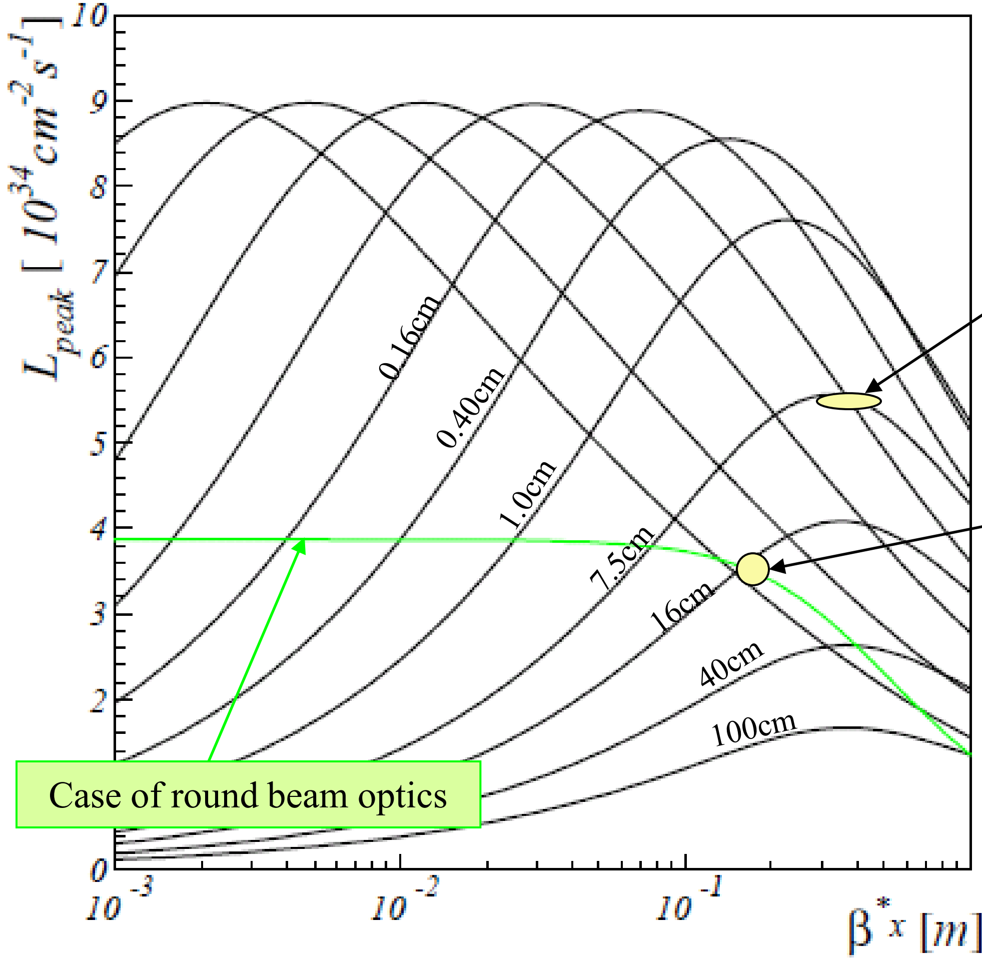
Technical reasons for the upgrade (or at least for important improve)

- The zone of the triplets will wear out
  - Radiation damage limit
  - Hardware and shielding that has not been really optimized for very high radiation
    - Better and increased shieldin of the tripelt and other elements
    - Better design (absorbers, TAS) also for background
    - Removing power supply, longer lines, necessity of a re-layout
  - Necessity to increase to heat removal capacity
    - Restoring cooling capacity in IR5 Left and decoupel RF from Magnets 2016-17
    - Locally (inside triplet) and transport away
    - Cooling capacity
    - Cooling sectorization (compelte decoupling of IR form arc

example HL-LHC parameters, β*=15 cm

parameter	symbol	nom.	nom.*	HL crab	HL sb + lrc	HL 50+lrc
protons per bunch	N_b [10^{11}]	1.15	1.7	1.78	2.16	3.77
bunch spacing	Δt [ns]	25	50	25	25	50
beam current	I [A]	0.58	0.43	0.91	1.09	0.95
longitudinal profile		Gauss	Gauss	Gauss	Gauss	Gauss
rms bunch length	σ_z [cm]	7.55	7.55	7.55	5.0	7.55
beta* at IP1&5	β* [m]	0.55	0.55	0.15	0.15	0.15
full crossing angle	θ_c [μrad]	285	285	(508-622)	508	508
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0.65	0.65	0.0	1.42	2.14
tune shift	ΔQ_{tot}	0.009	0.0136	0.011	0.008	0.010
potential pk luminosity	L [10^{34} cm^{-2}s^{-1}]	1	1.1	10.6	9.0	10.1
events per #ing		19	40	95	95	189
effective lifetime	τ_{eff} [h]	44.9	30	13.9	16.8	14.7
run or level time	$t_{run,level}$ [h]	15.2	12.2	4.35	4.29	4.34
e-c heat SEY=1.2	P [W/m]	0.2	0.1	0.4	0.6	0.3
SR+IC heat 4.6-20 K	P_{SR+IC} [W/m]	0.32	0.30	0.62	1.30	1.08
IBS ε rise time (*z, x*)	$\tau_{IBS,z/x}$ [h]	59, 102	40, 69	38, 66	8, 33	18, 31
annual luminosity	L_{int}[fb^{-1}]	57	58	300	300	300

Luminosity vs. β* in the Xing plane (with hour-glass effect) for different values of β* in the other plane: nominal emittance and bunch length, ultimate intensity, <u>no crab-cavity</u>



<u>Example of flat optics</u>:

β^* =30 cm in the crossing-plane

$\beta^* = \sigma_z$ =7.5 cm in the other plane

$\Theta_c = 10\sigma$ in the plane of biggest β^*

→ Peak lumi ~5.6 $10^{34}cm^{-2}s^{-1}$

<u>"Equivalent" round optics</u>:

β^* =15 cm in both planes

$\Theta_c = 10\sigma$

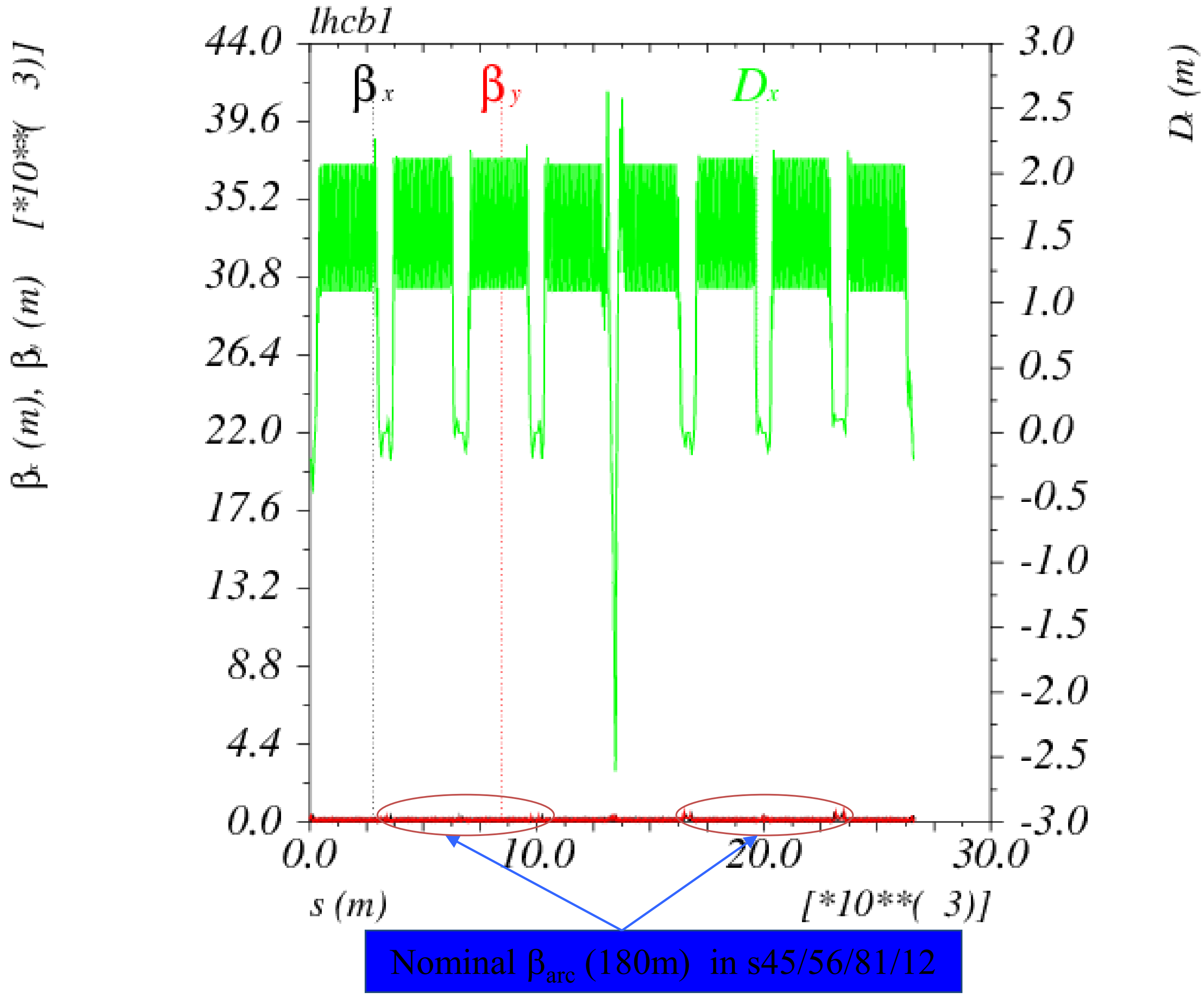
→ Peak lumi ~3.5 $10^{34}cm^{-2}s^{-1}$

S. Fartoukh, sLHC-PR0049 & LMC 21/07/2010

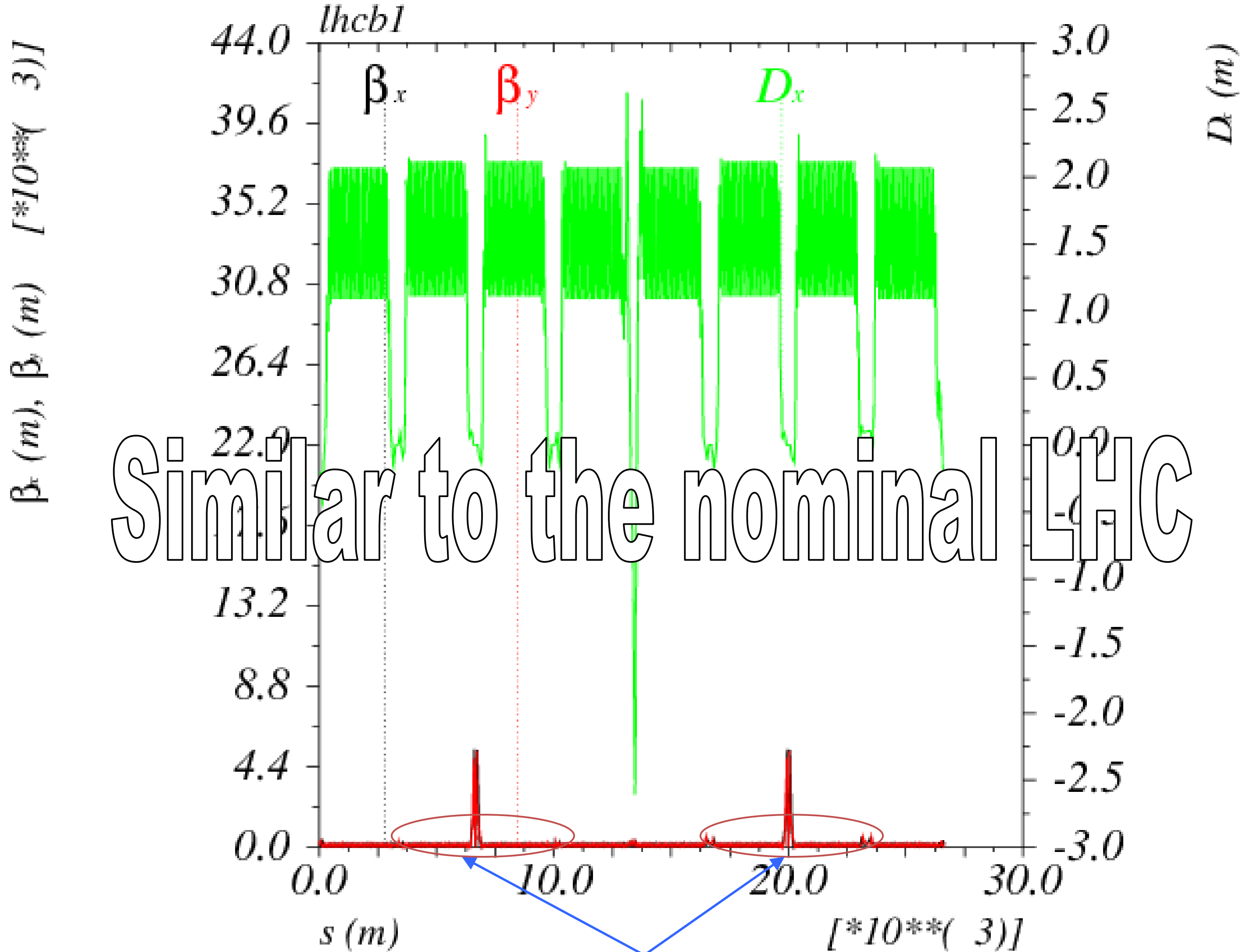
R. D. Maria, S. Fartoukh, sLHC-PR0050 & LMC 21/07/2010

1. The "virtual" performance of the two optics is equivalent with crab-cavity (~8-9E34),
2. In all cases the two options requires to push β* well beyond the Phase I limit of 30 cm. …Nb3Sn can only improve the situation by ~25%, not more!

Injection optics: $\beta^* = 14$ m in IR1 and IR5



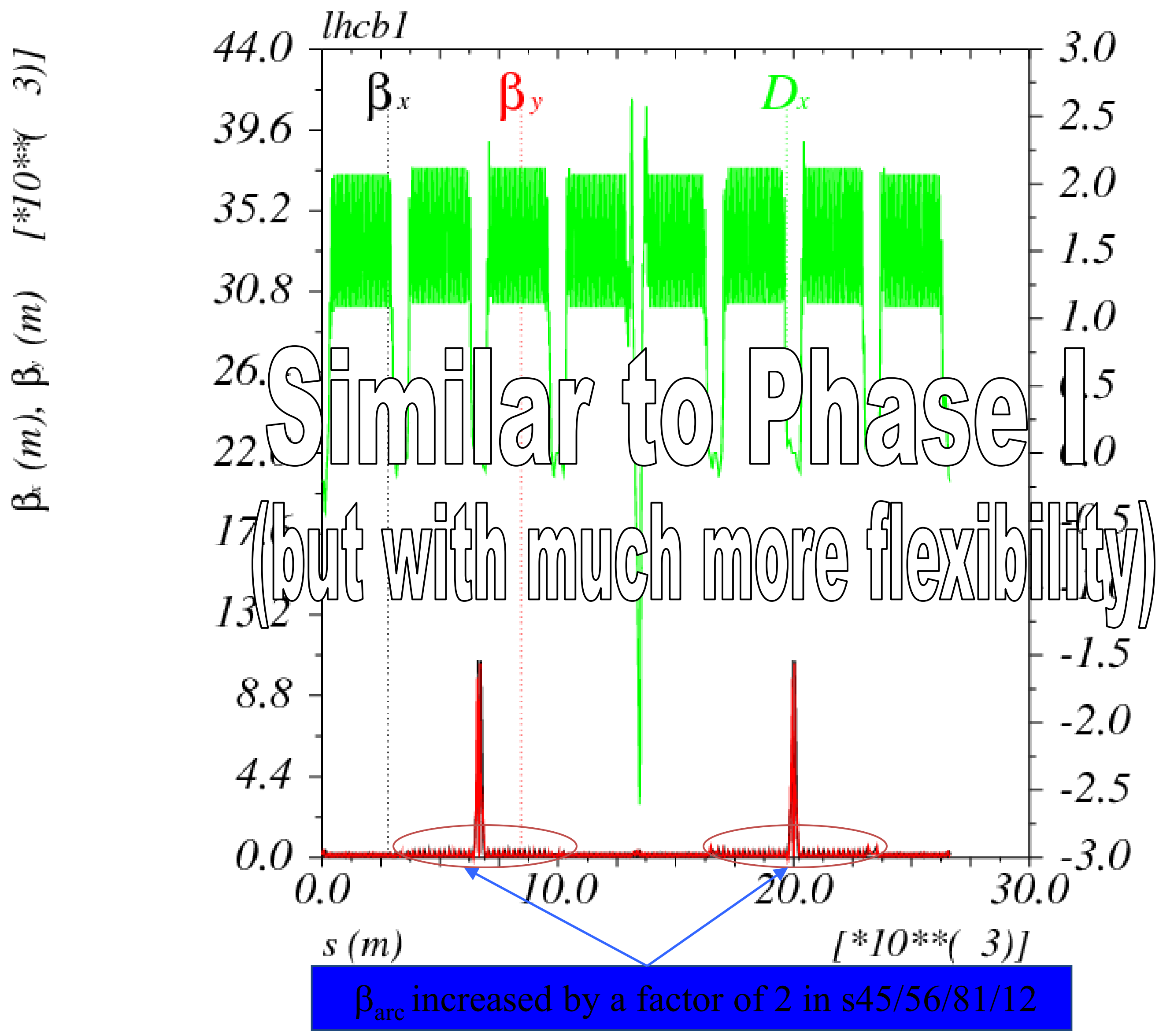
Pre-squeezed optics: $\beta^* = 60$ cm in IR1 and IR5: "1111"



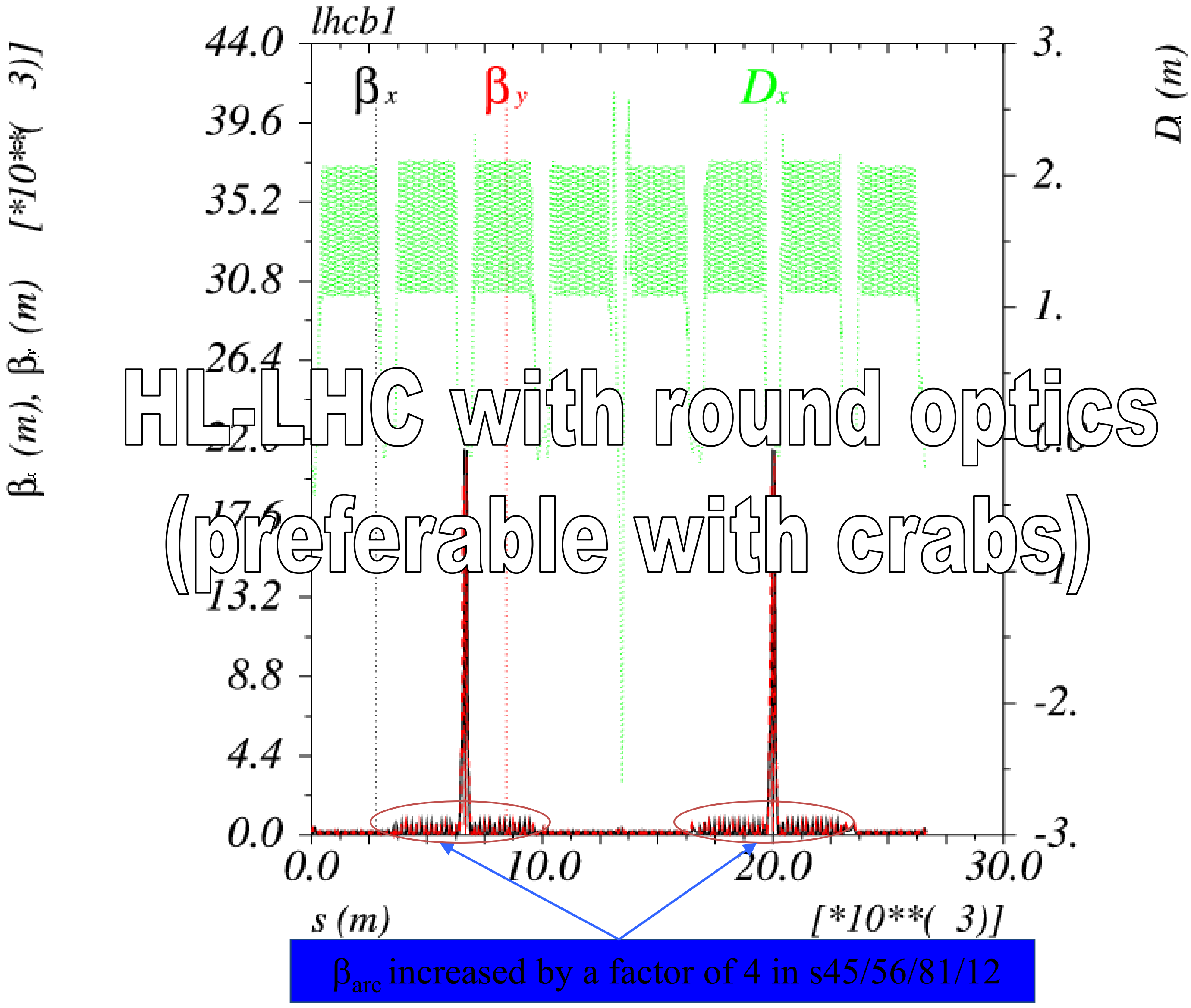
Similar to the nominal LHC

Nominal β_{arc} (180m) in s45/56/81/12

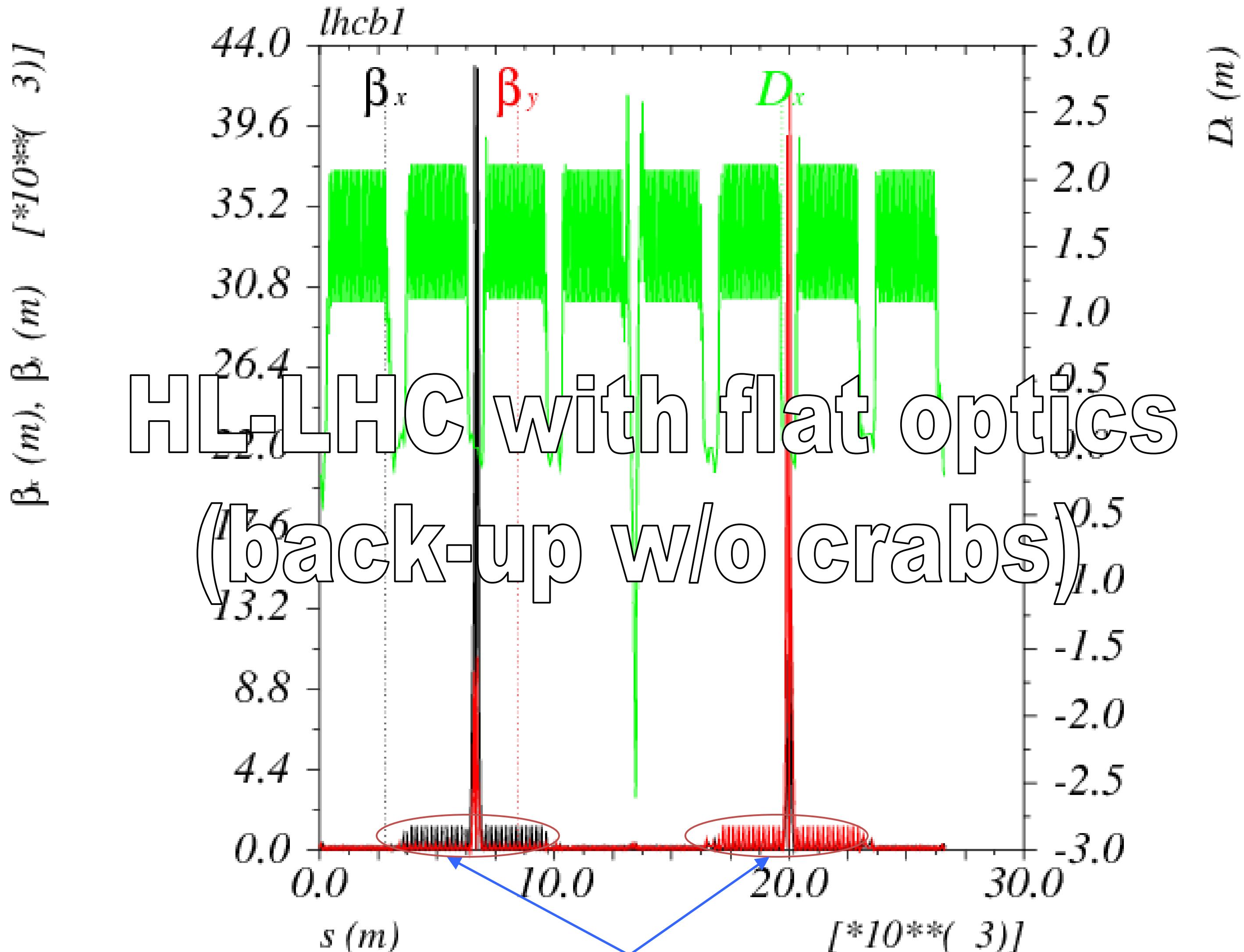
Intermediate squeezed optics: β^* = 30 cm in IR1 and IR5: "2222"



Squeezed optics (round): β^* = 15 cm in IR1 and IR5: "4444"



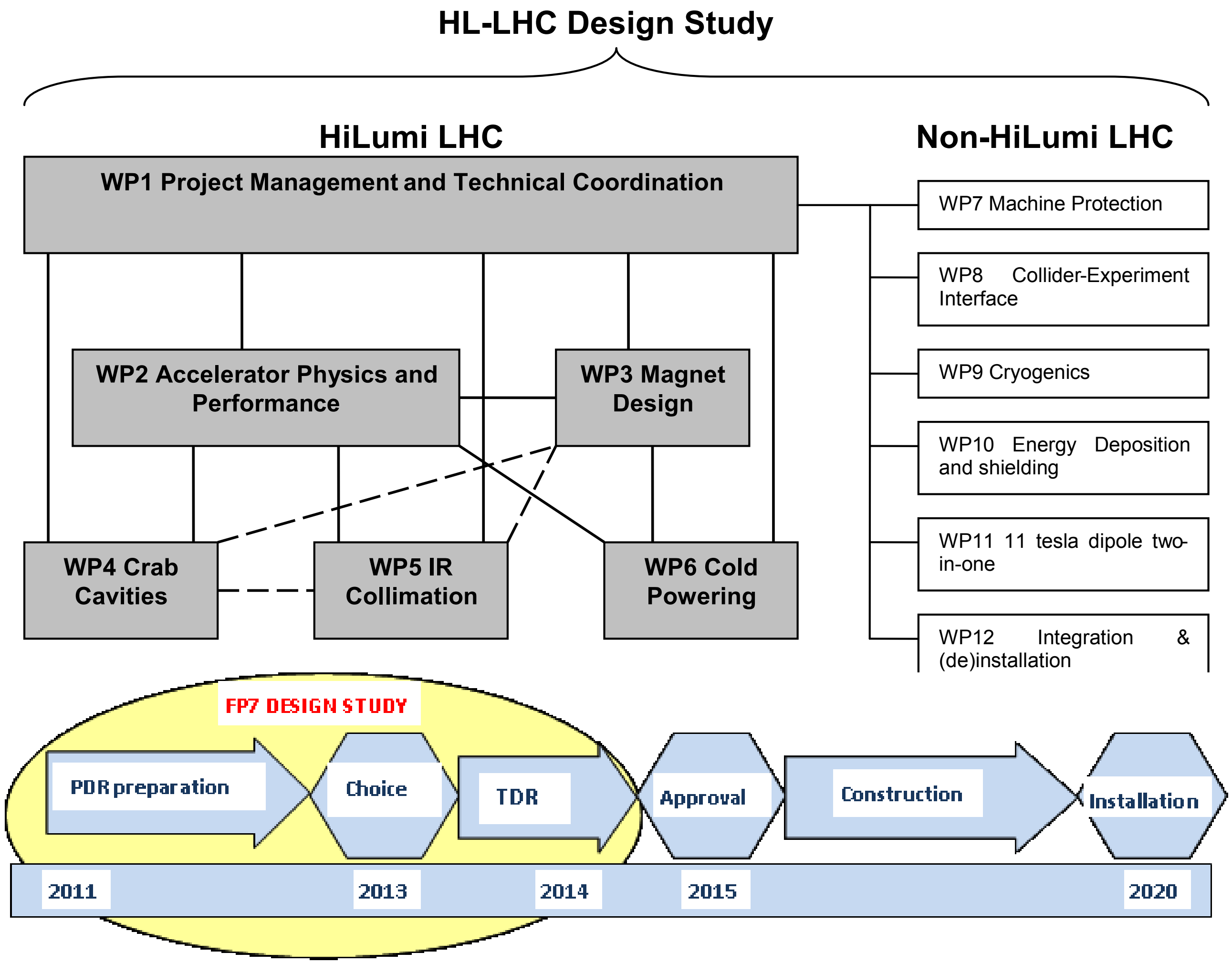
Squeezed optics (flat): $\beta^*_{x/y}$ = 7.5/30 cm alternated in IR1 and IR5: “8228”



HL-LHC with flat optics (back-up w/o crabs)

β_{arc} increased by a factor of 2 or 8 in s45/56/81/12 depending on the β^* aspect ratio in IP1 and IP5

Structure of the project HL-LHC and the HiLumi FP7 Design Study

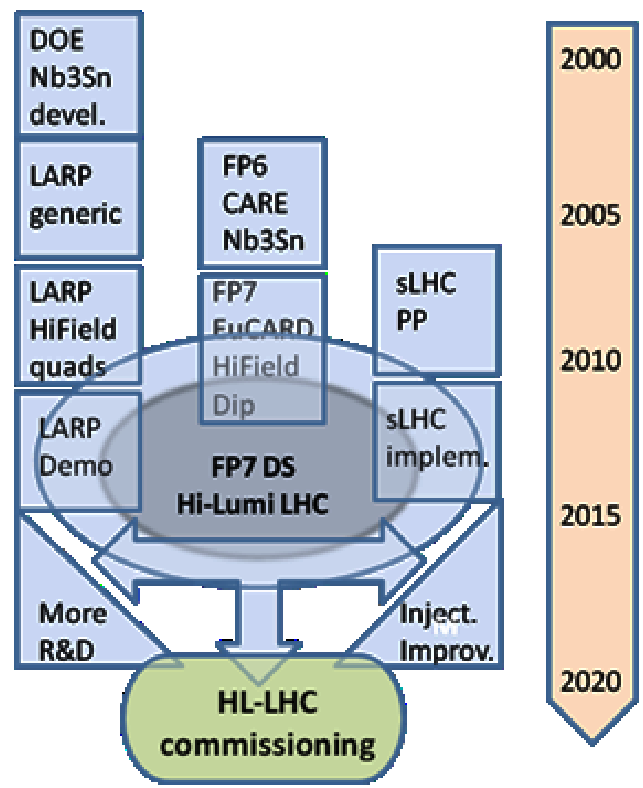


Large participation application 25 Nov 2010

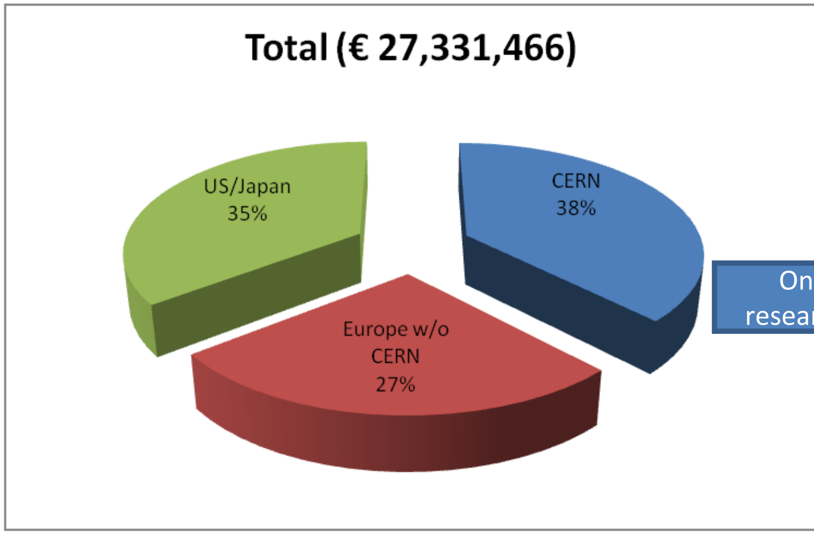
Participant no.	Participant organisation name	Short name	Country
1 (Coordinator)	European Organization for Nuclear Research	CERN	IEIO[1]
2	Commissariat à l'Énergie Atomique et aux énergies alternatives	CEA	France
3	Centre National de la Recherche Scientifique	CNRS	France
4	Stiftung Deutsches Elektronen-Synchrotron	DESY	Germany
5	Istituto Nazionale di Fisica Nucleare	INFN	Italy
6	Budker Institute of Nuclear Physics	BINP	Russia
7	Consejo Superior de Investigaciones Cientificas	CSIC	Spain
8	École Polytechnique Fédérale de Lausanne	EPFL	Switzerland
9	Royal Holloway, University of London	RHUL	UK
10	University of Southampton	SOTON	UK
11	Science & Technology Facilities Council	STFC	UK
12	University of Lancaster	ULANC	UK
13	University of Liverpool	UNILIV	UK
14	University of Manchester	UNIMAN	UK
15	High Energy Accelerator Research Organization	KEK	Japan
16	Brookhaven National Laboratory	BNL	USA
17	Fermi National Accelerator Laboratory (Fermilab)	FNAL	USA
18	Lawrence Berkeley National Laboratory	LBNL	USA
19	Old Dominion University	ODU	USA
20	SLAC National Accelerator Laboratory	SLAC	USA

HiLumi is the focal point of 20 years of converging International collaboration

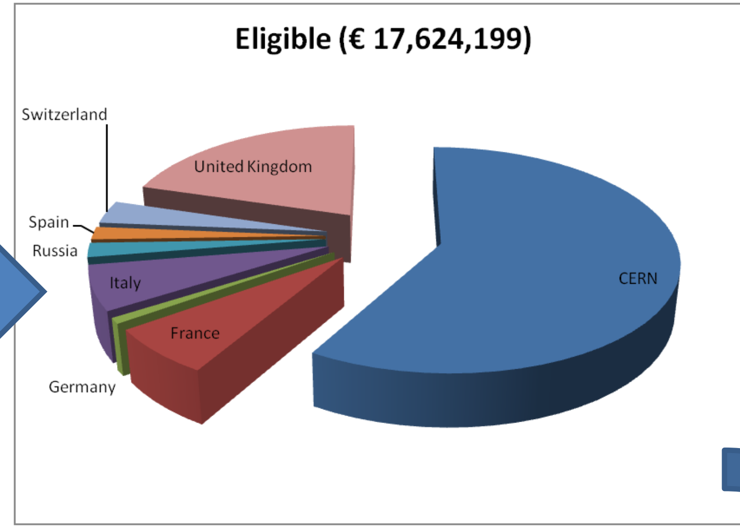
- The collaboration wiht US on LHC upgrafe started during the cosntruction of LHC
- EU programs have been instruemntal in federatin all EU efforts
- With Hi-Lumi the coordination makes a step further: from coordinated R&D to a common project
- CERN is not anymore the unique owner, rather is the motor and cathalizer of a wider effort.
- Manged like a large detector collaboration (with CERN in special position as operator of LHC)



Budget FP7 HiLumi

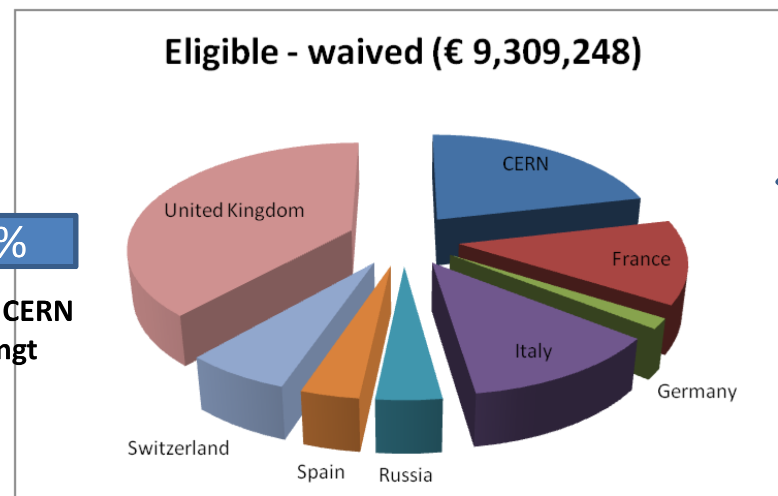


Only EU research area



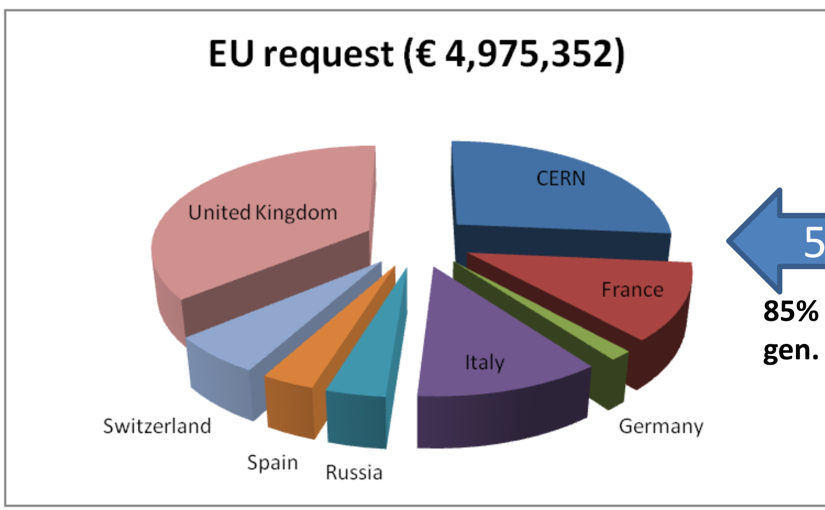
CERN waives all technical works: LHC is core program. Only kept the CERN cost for managem.

Waiving effect

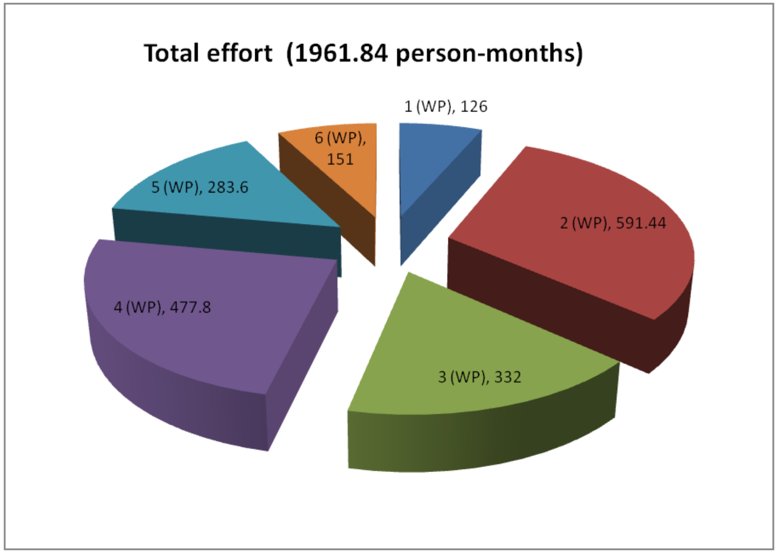


50%

85% of CERN gen. mngt



Budget cont.



Personnel for HiLumi by WP

1. Manag and Tech. Coord. (6%)
2. Acc. Physics and beam
3. Magnets for IR
4. Crab Cavities
5. Collimators
6. Sc links

Estimated cost for the the whole HL-LHC over 10 years in M€

	Design in FP7 HiLumi	Extra effort for Design	R&D and proto	Industrialization & Construction	TOT	Industry
W1-WP6	27	10	50	200	287	160
WP7-12	0	15	30	100	145	80
Other	0	5	10	50	65	40
TOT	27	30	90	350	497	280

Conclusion

- HL-LHC project is starting, forming a large international collaboration
- HL-LHC has a flexible plan: however the development of the main hardware is –almost – traced
- **HL-LHC builts on the strength and expertise of sLHC**
  - For the injectors (that will deliver the needed beam)
  - For the beam studies (fundamental understanding the limitation of Phase 1)
  - For the pushed Nb-Ti technologies for magnets:
    - Essential for Matching Section magnets
    - Important back-up solution for the low-β magnets
  - For the radiation studies, safety aspect and management tools.