HL-LHC project overview

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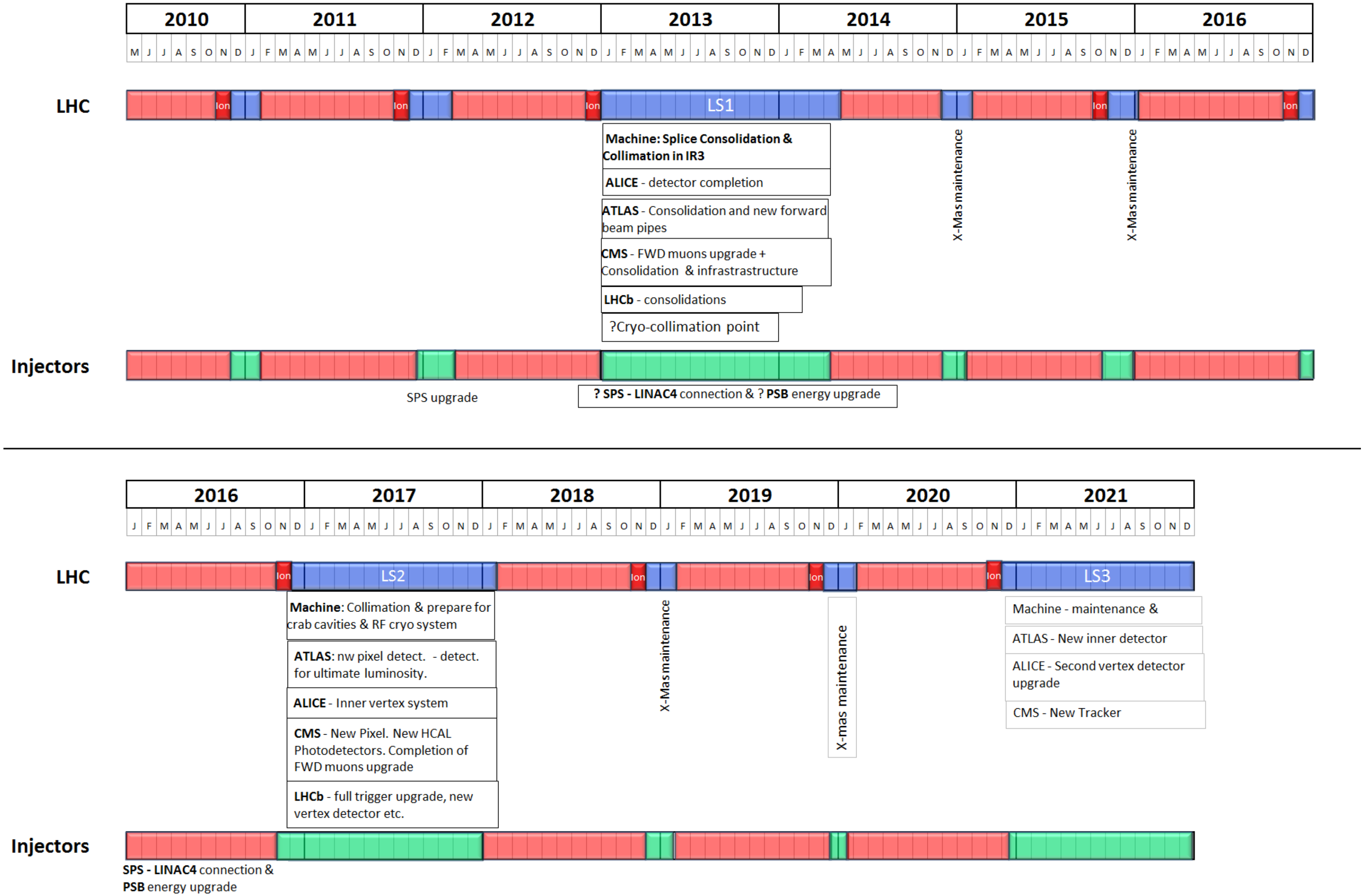
Optics Workhop @ CERN, 22 June 2011

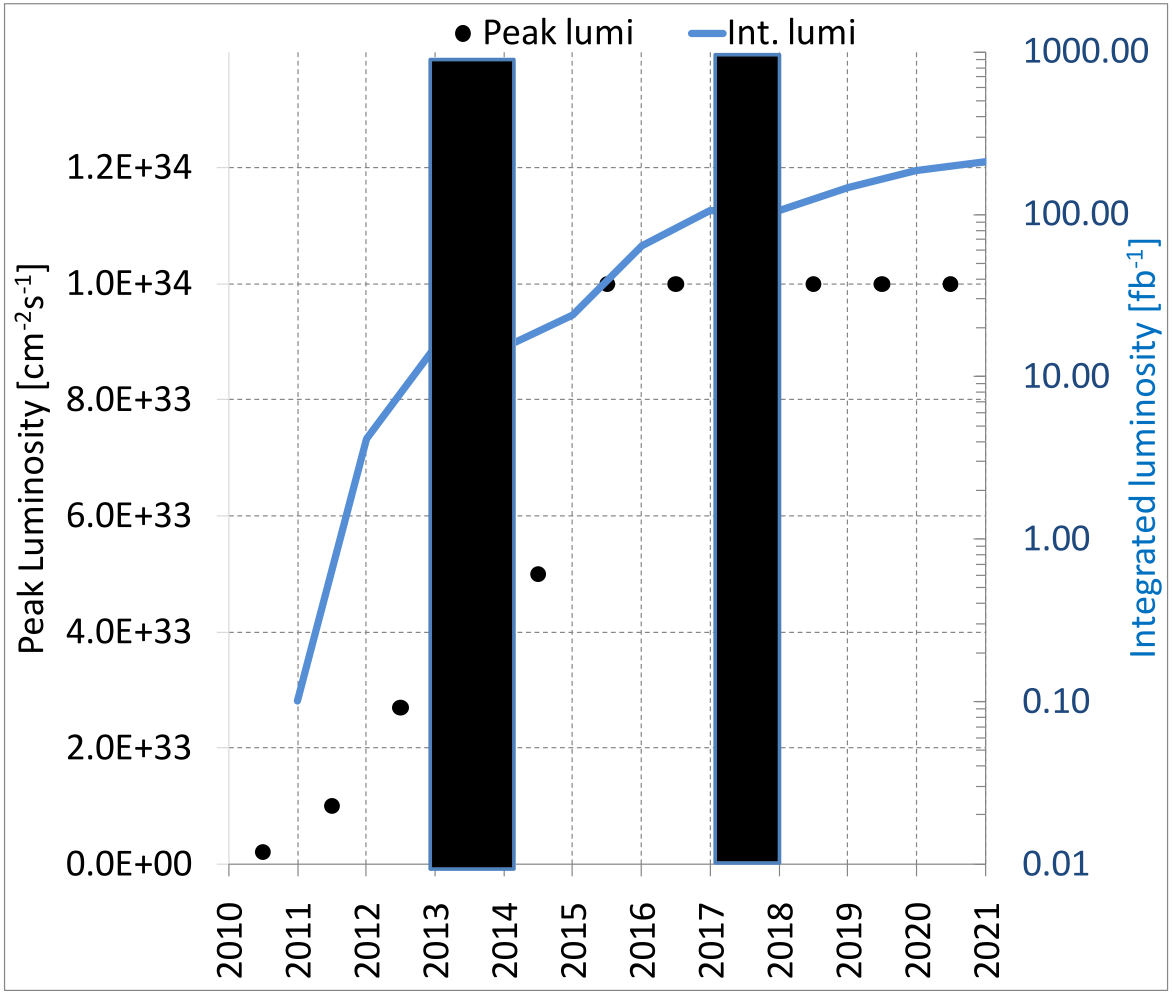
Content

- Scope of HL-LHC
- Main technologies
- HiLumi LHC, an FP7 Design Study
  - A global collaboration

New Rough Draft 10 year plan

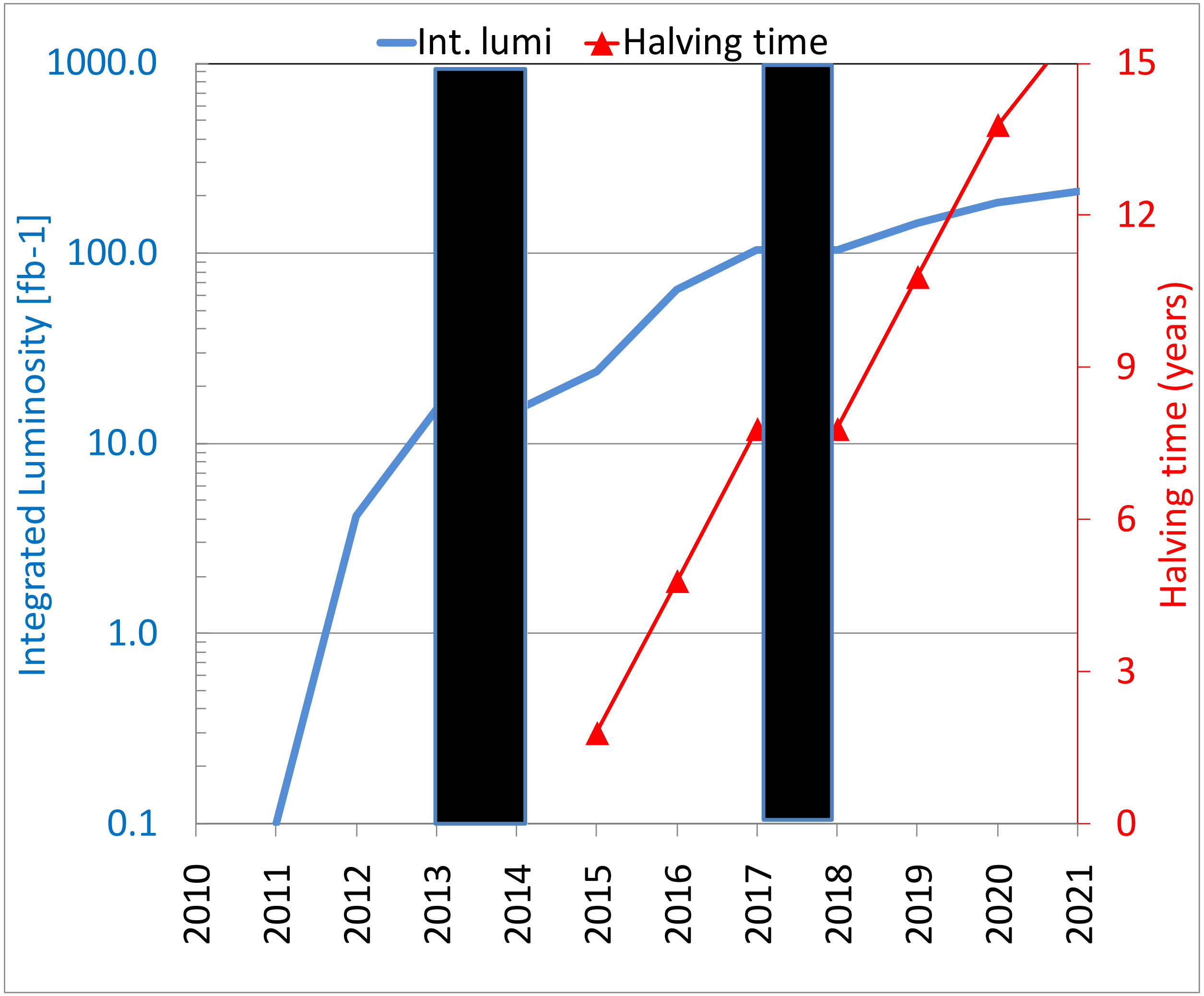


How the luminosity might evolve **optimistic** to 2012, then prudent: nominal



Data from M. Lamont
NOT validated by Mngt

How the luminosity might evolve **optimistic** to 2012, then nominal -cont



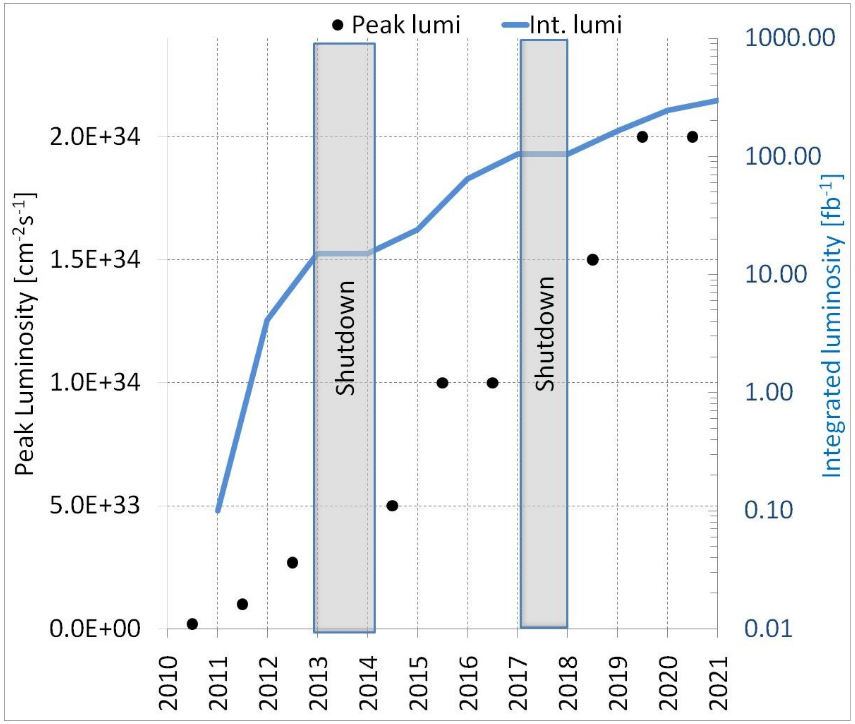
Data from M. Lamont
NOT validated by Mngt

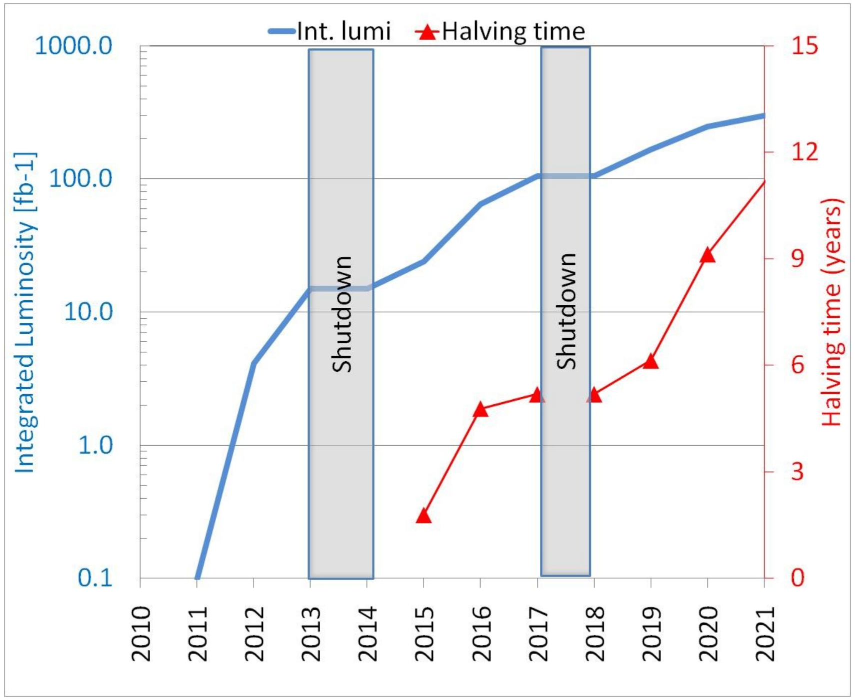
220 inv fb by end of 2020

Lumi evolution: **more otpimistic** (ultimate=2xnominal) is reached

In such case we may reach 320 inv. fb for end of 2020.

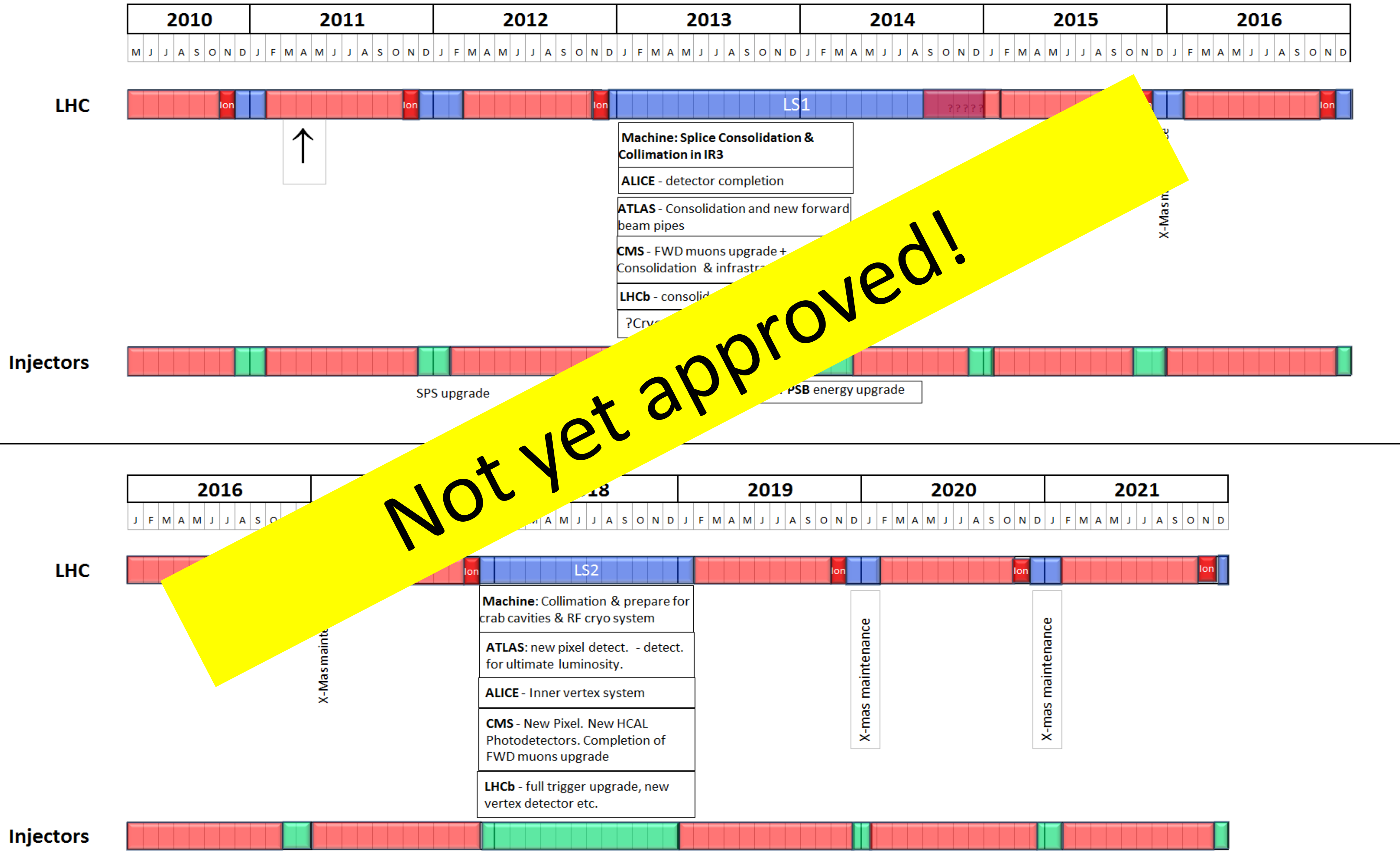
Data from M. Lamont
NOT validatedby Mngt





If LHC performs « nominal »: the upgrade is required by the saturation
If LHC performs better, saturation is 2 years later, but radiation limits may come in earlier

New rough draft 10 year plan

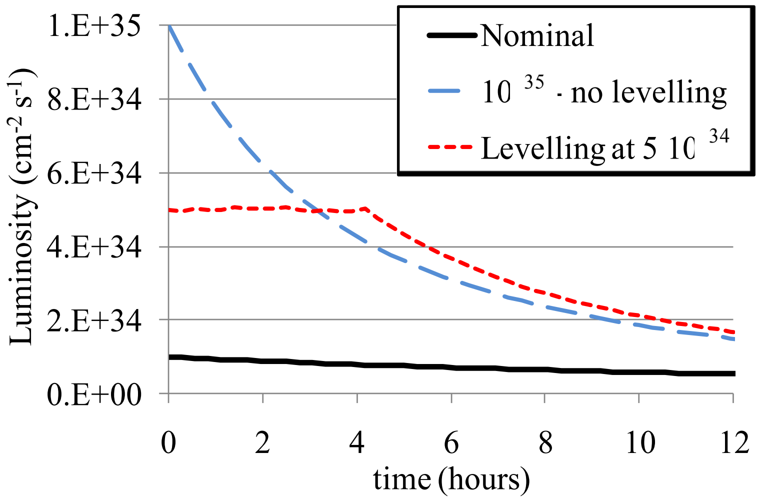


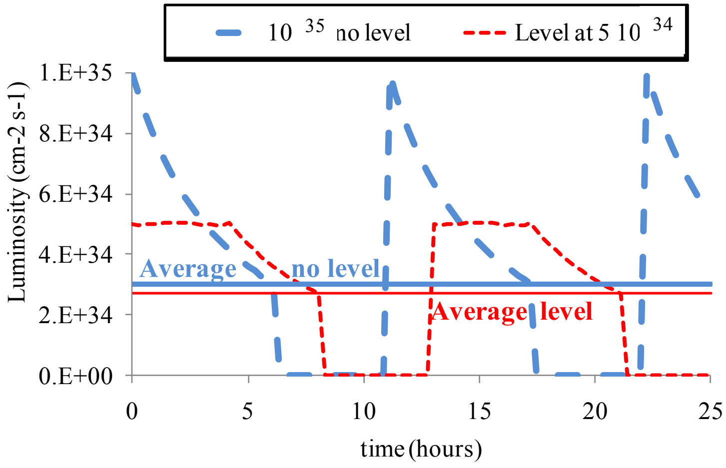
Comment on nominal vs ultimate

- Nominal means: machine as designed
  - In order to assure design operation each system has been designed with some margin at the operation point
- Ultimate means: using all margins in the main hardware (in certain cases needing upgrade of the controls, powering and some modification), the beam current increase 50%, doubling the lumi. However margins in various systems may not be used simultaneously.

The goal of HL-LHC (Installing hardware in 2021-22 in LS3)

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.



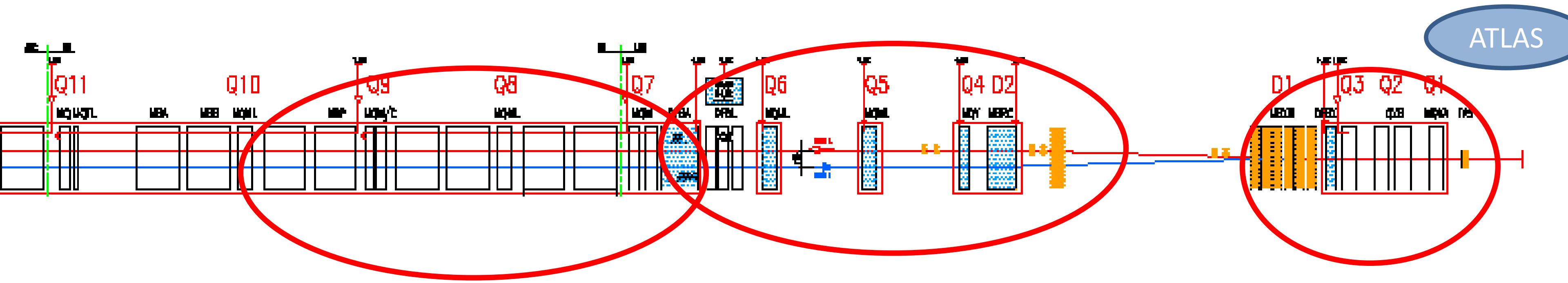


- allow design for lower peak L, less pile up
- less peak heat deposition (a factor 2 may be critical especially in the quad triplet)

Chamonix(s) 2010-2011 emerged with a completely new scenario

- Injectors
  - Lincac4 confirmed as key element for reliability and better beam
  - Suppression of PS2 and SPL (this last as necessary LHC injector)
  - Consideration of a PSBooster upgrade from 1.4 to 2 GeV injection in the PS
  - Preparation for an SPS upgrade
  - Plan for a consolidation for 25 y operation of the present injector chain
- LHC
  - Plan for consolidation and spare for 25 y operation
  - Confirming completion of the collimation system in the LSS
  - Necessity of a collimation system in the DS (cold part) at least in P3 and P7 (P2 for ions?). P3 most urgent (2013-14 shutdown)
  - Phase 1 upgrade (of which sLHC-PP 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 of luminosity, to profit from very low β^* (if limitations of Phase 1 are removed

Here the critical zone

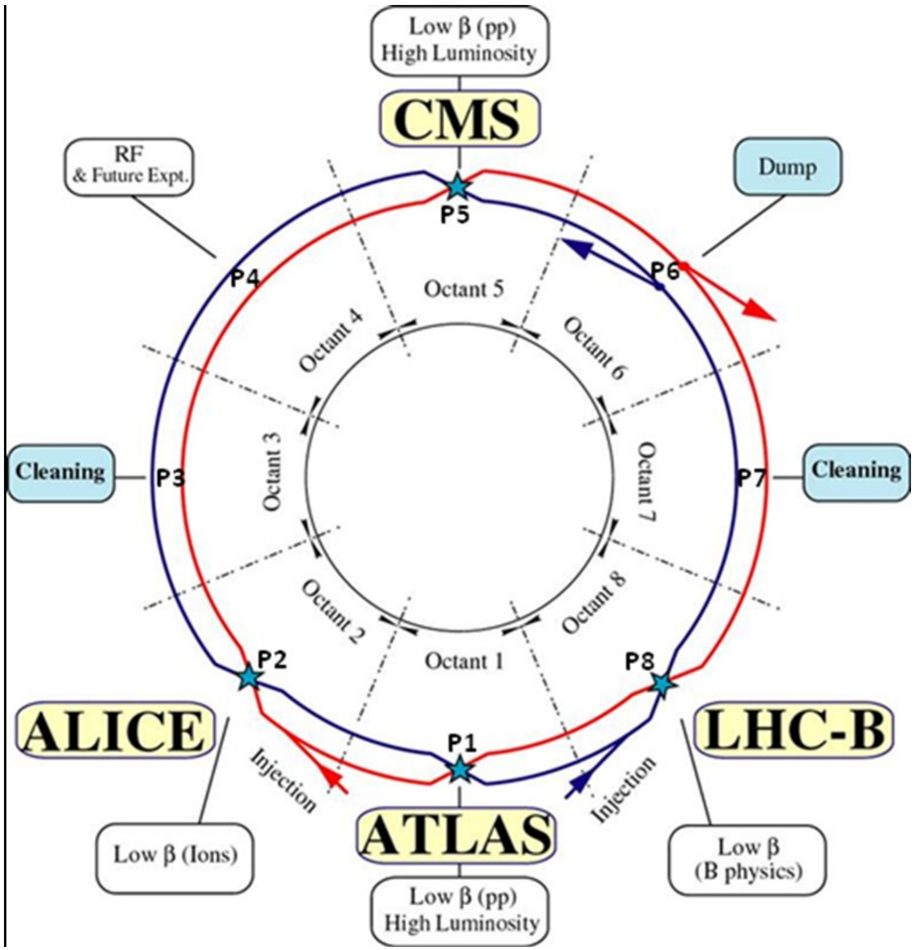


3. For collimation we would like (may be) to change also this part, DS in the continous cryostat

2. We need to touch deeply also the matching section

1. Changing the interaction region is not enough

The path toward high lumi



From Chamonix 2011:

- Integrate also LHCb and Alice in the upgrade picture (so far they were not)
- The shutdown scheme has been shifted of one **year (and now may be 2 y)** : a resource loaded plan under preparation, the length of shutdown(s) is critical
- the assessment of what are the LHC bottlenecks is critical
  - collimation
  - e-clouds
  - Beam tune shift due to collision
  - R2E real limitation
  - Heat deposition and cryogenic limits

The machine is optically better

- The field quality, accuracy and alignement is better than nominal (means that all margins in design are there and even more)
- Emittance si better (caveat : we are still with less bunches than nominal; however the bunch charge is even higher than nominal)
- The tune shift coming from collision is less, or better, the machine seems to tolerate a higher tune shift. However we still have a few encounters, waiting for long range b-b effects

E-cloud and bunch spacing

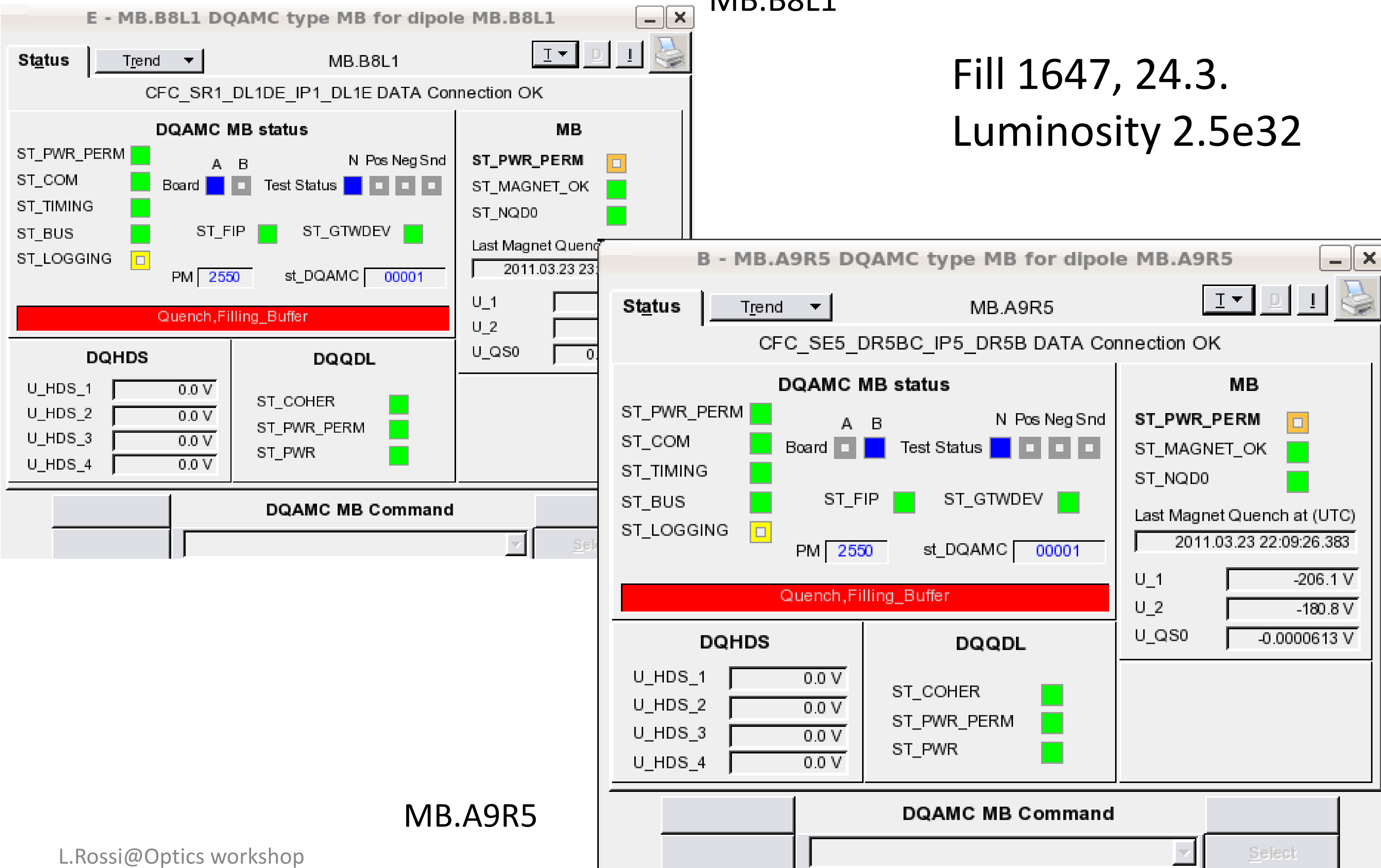
- The e-cloud is basically as expected (however **may be** was triggered ealier by worst surface conditions)
- Scrubbing has been as efficient as expected
- However to cut scrubbing time short (saturation) the best seems to scrub with a bunch spacing smaller than the one used for operation (also: it allow to scrape effecctively at injection energy, big advantage for magnet quench limit))
- 50 ns is less sensitive to e-clouds.
- For 50 ns scraping is done at 25 ns. At 25 ns may be scrub should be attempted at 12.5 ns?
- In LHC we seems to have more margin in cryogenic (good news: it may allow also cryogenic collimator in the DS)
- Limit in the SPS to be assessed…
- However clearly 25 ns will be more difficult than 50 ns for e-cloud, but not imposible**: if 25 ns is (might!) a necessity (?) for $L \geq 10^{34}$**

3.5 TeV: SEU in IR1/5 Disp. Suppressors

MB.B8L1

Fill 1647, 24.3.

Luminosity 2.5e32



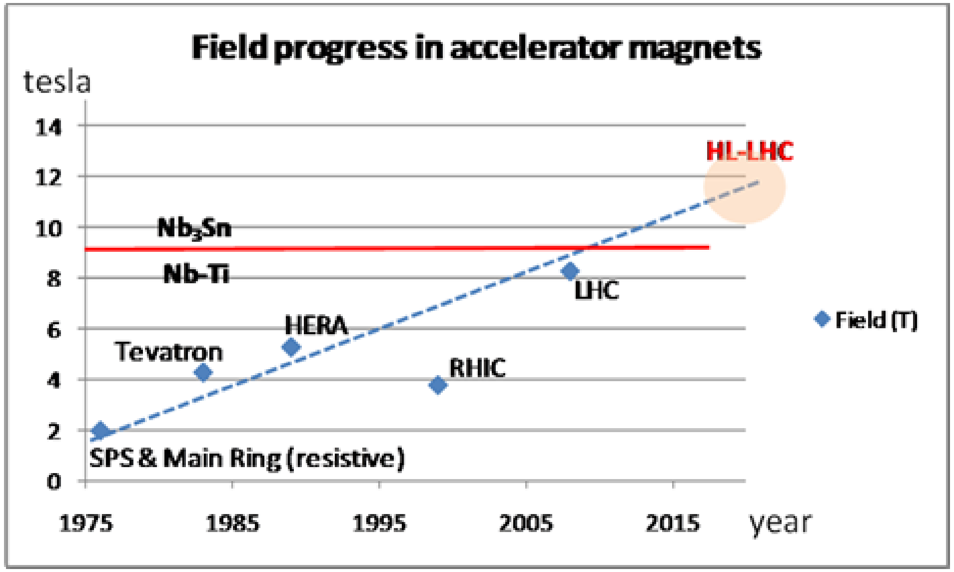
MB.A9R5

Preparation for upgrade

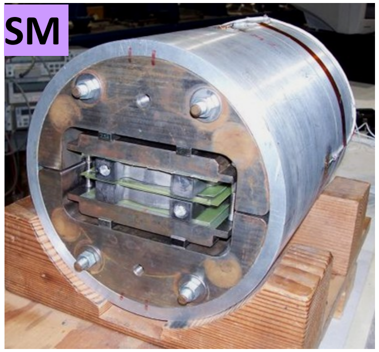
- In any case, how good or less good could be the performance, changing the machine to reach potentially 10^{35} and then levelling at $5\ 10^{34}$ takes a lot of time:
- 10 years work is not a luxury
  - High field magnets
  - Sc crab cavities
  - Extreme collimation in the collision points (and cleaning DS from off-p particle)
  - Sc links to remove problem of R2E to power supply
  - Each item liste above will have a back-up plan in case it will NOT be available in due time.

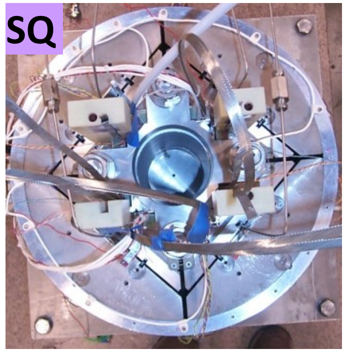
Squeezing the beam High Field SC Magnets

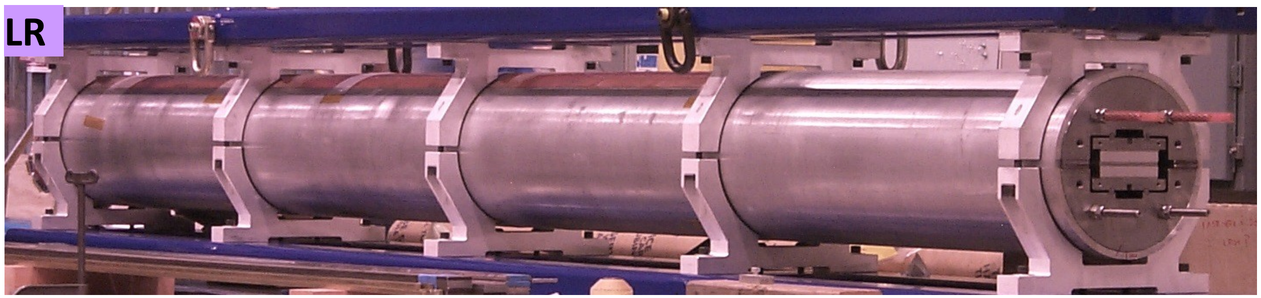
- **13 T, 150 mm** aperture Quads for the inner triplet
  - LHC: 8 T, 70 mm.
  - sLHC-PP: 8.5 T 120 mm
- More focus strength, β* as low as 15 cm (55 cm in LHC). In some scheme even β* down to 7.5 cm are considered
- Dipole separators capable of 6-8 T with 150-180 mm aperture (LHC: 1.8 T, 70 mm)

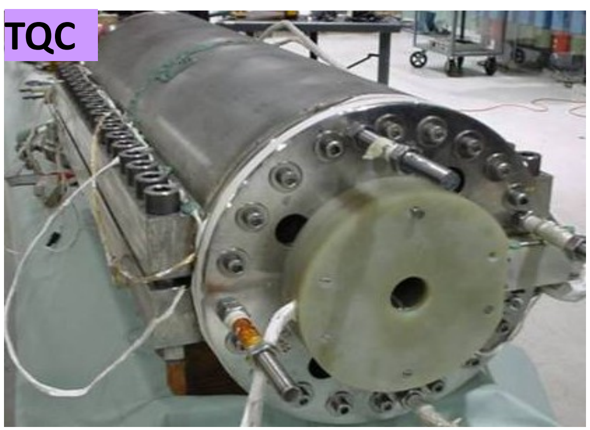


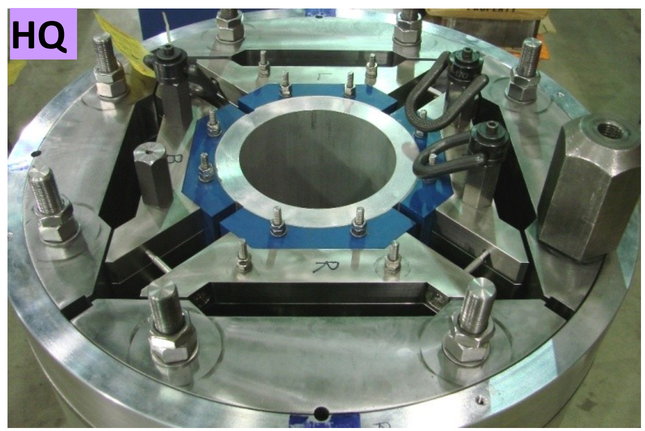
LARP (US LHC program) Magnets



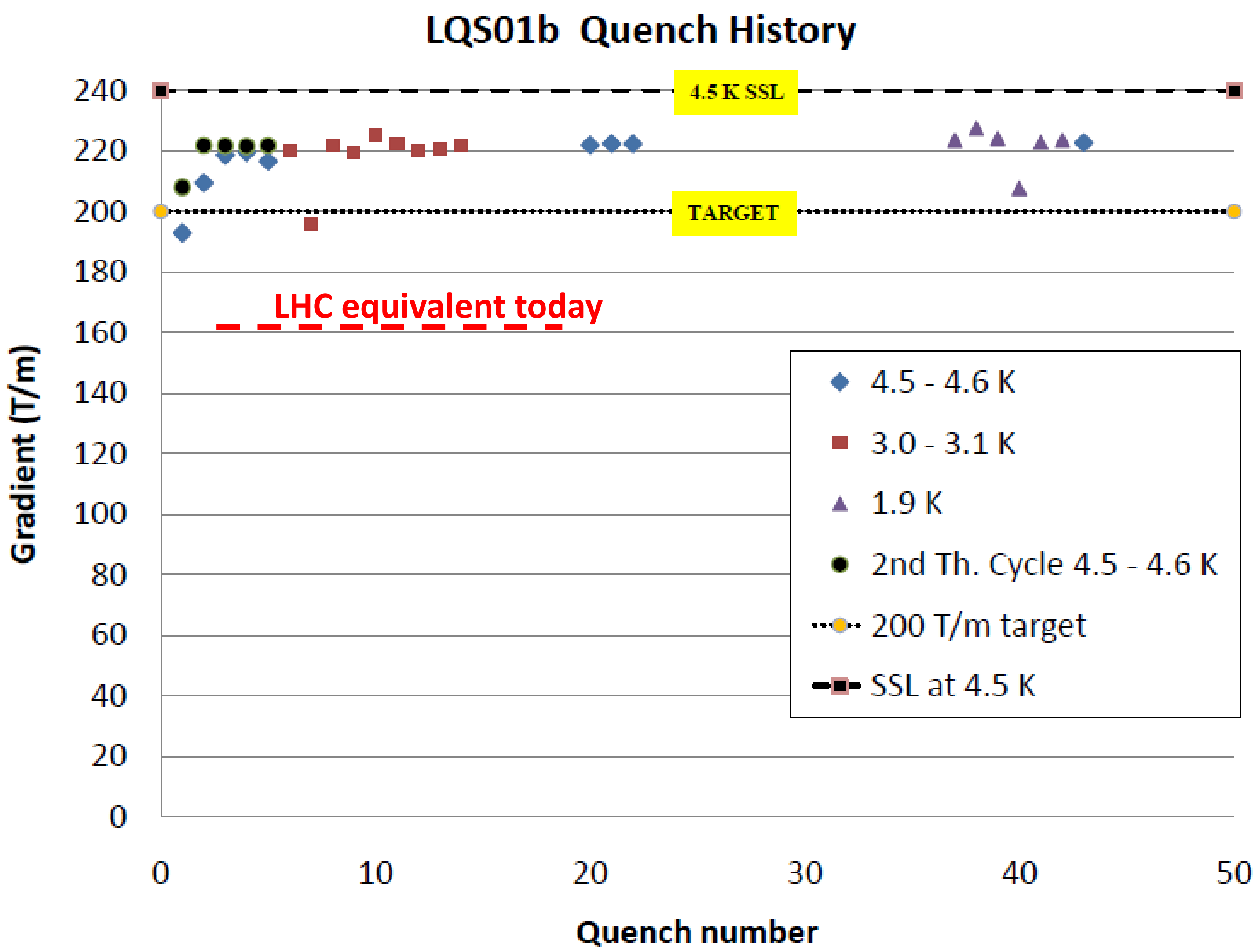




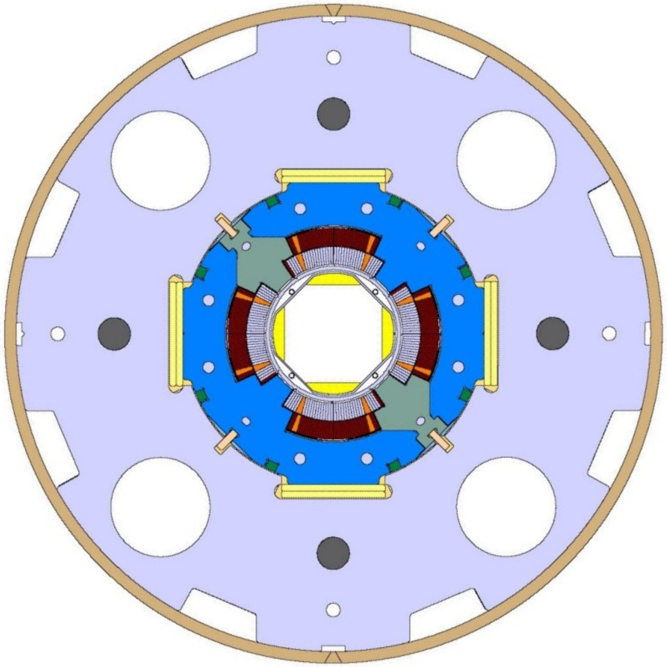


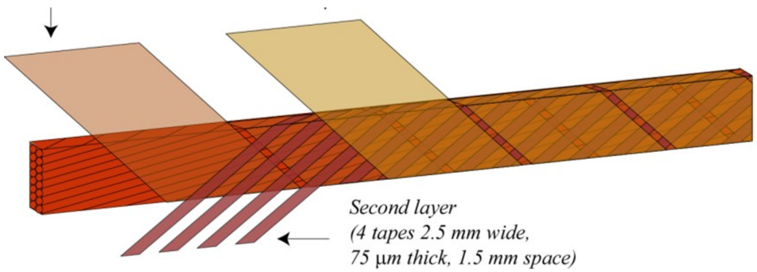


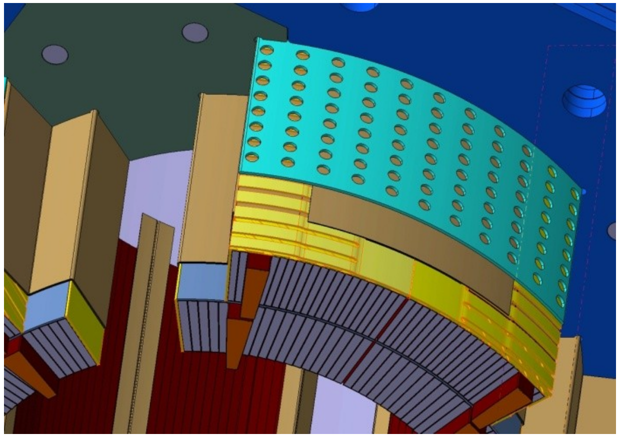
Results LARP LQ (90 mm vs 70 mm LHC)



Benefit from **sLHC (Phase 1 upgrade)** program:improved Nb-Ti technolgy

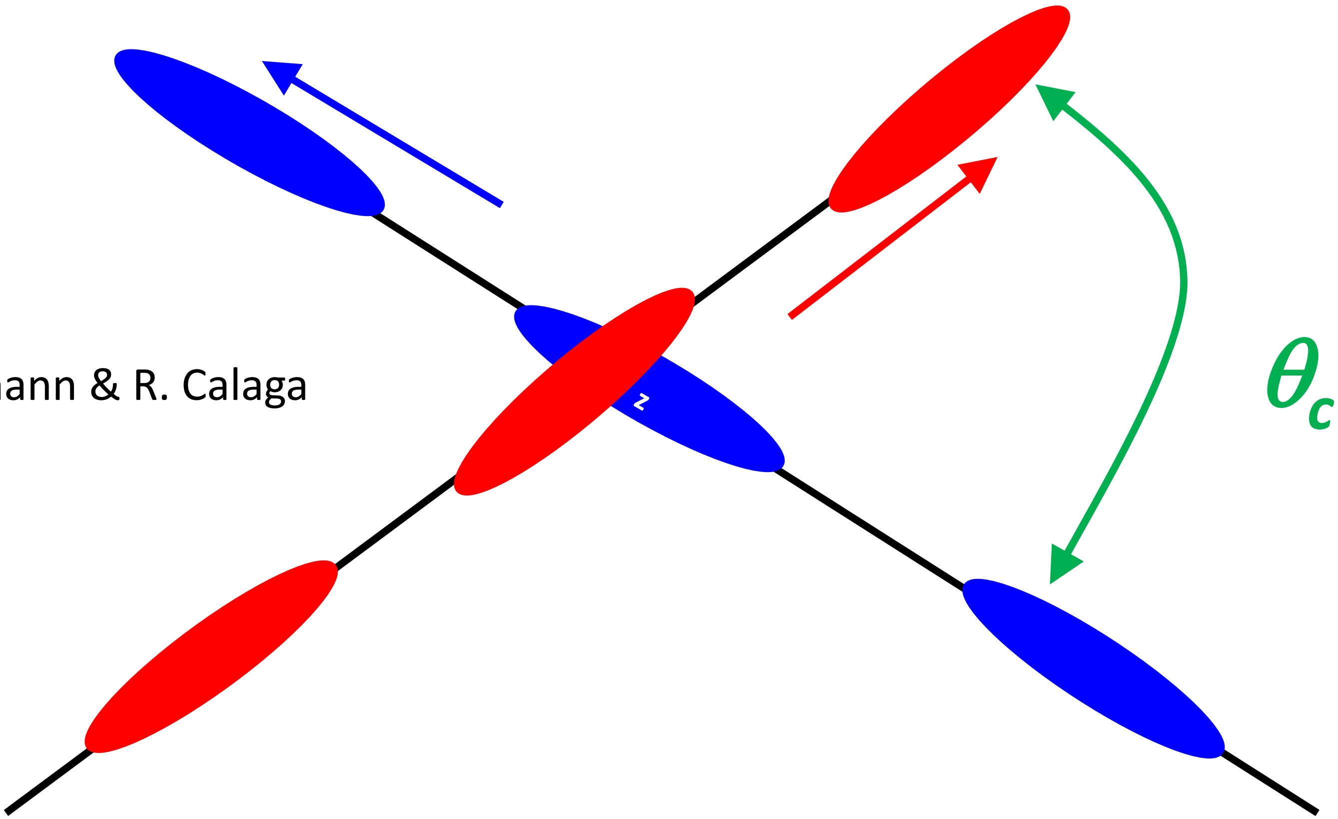






Favorite scheme of HL-LHC requires new Nb-Ti more pushed wrt to present LHC for the matching sections: larger aperture (85-90 mm, vs 56/70 mm of present LHC)
Higher heat deposition will demand use of the new insulation scheme, more porous

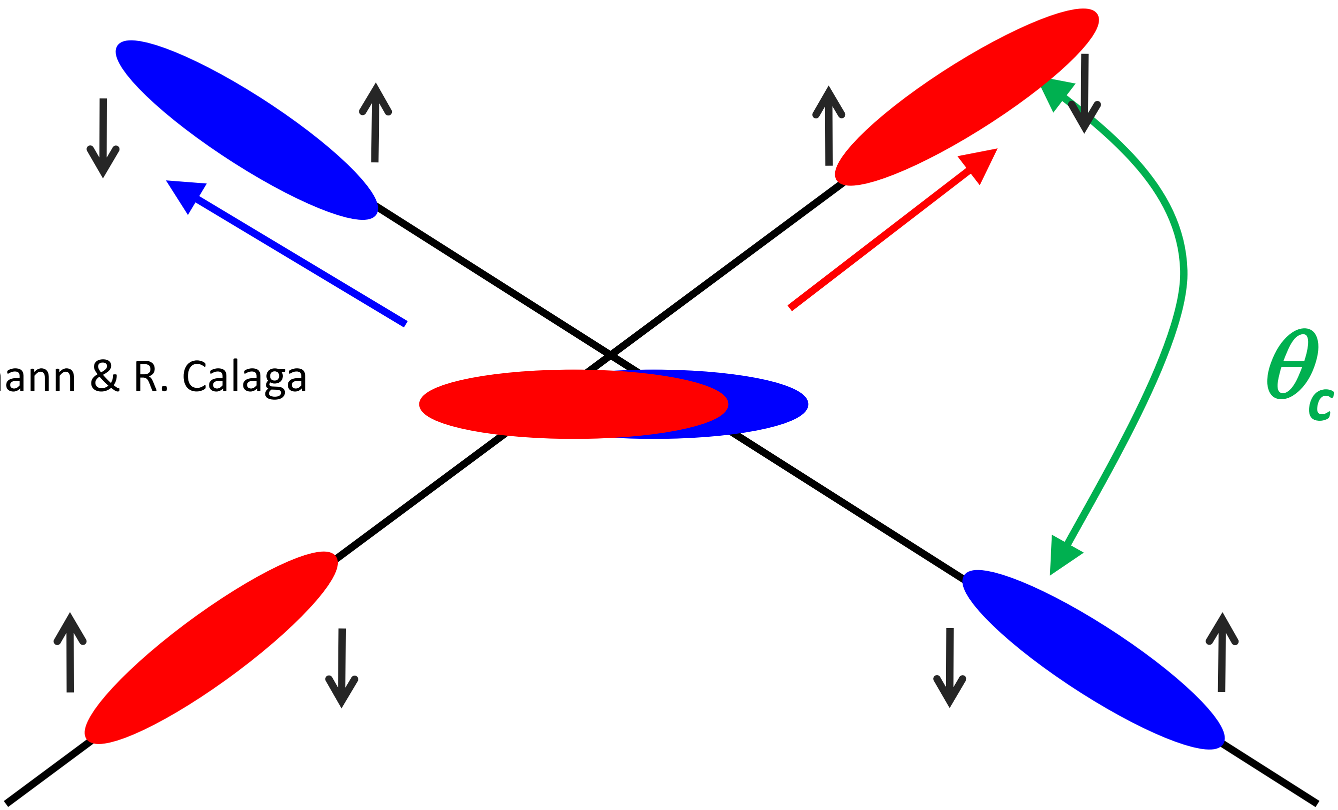
crossing angle reduces the luminosity



F. Zimmermann & R. Calaga

- **luminosity loss comes from imperfect geometric overlap**
- **it becomes significant if $\sigma_z\theta_c/2>\sigma_x^*$ or $\phi_{piw}>1$ with $\phi_{piw}=\sigma_z\theta_c/(2\sigma_x^*)$ the "Piwinski angle"**

crab crossing restores bunch overlap



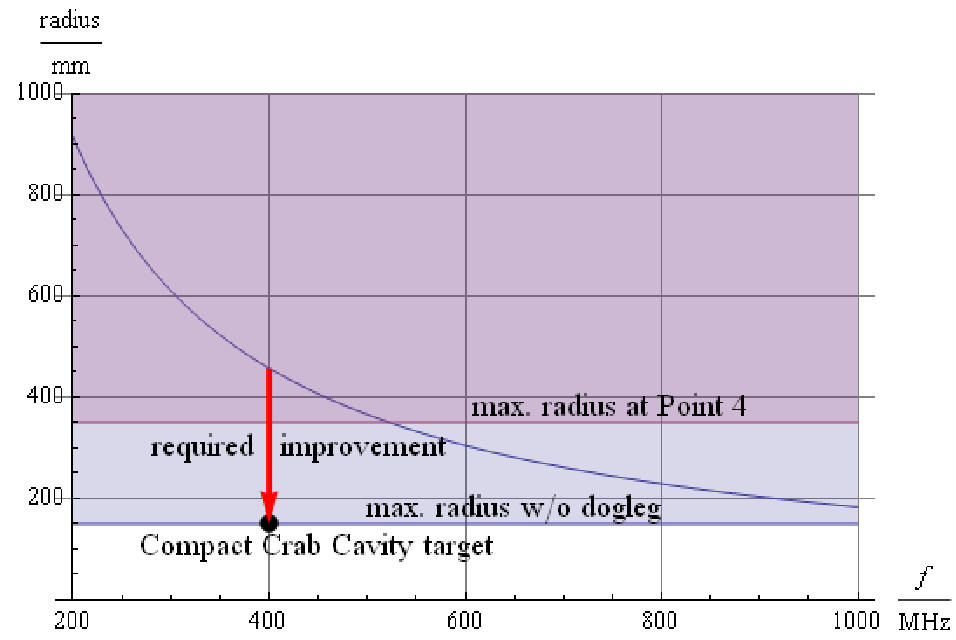
F. Zimmermann & R. Calaga

- **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**

$\rightarrow$ ***world record luminosity!***

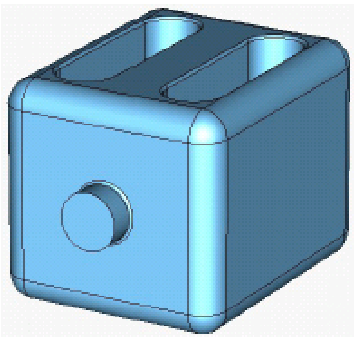
Improve beam overlap SC RF Crab cavities

- 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)

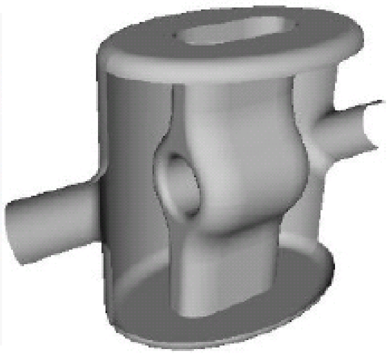


Compact 400 MHz (see 4th LHC CC workshop)

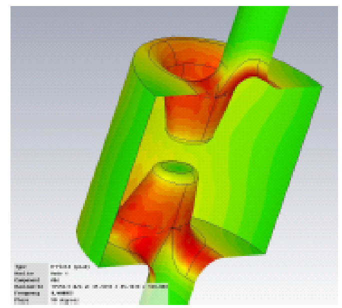
HWDR, JLAB,OD



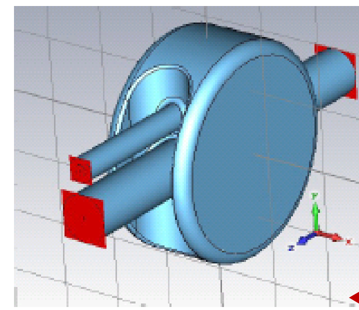
HWSR, SLAC-LARP



DR, UK, TechX

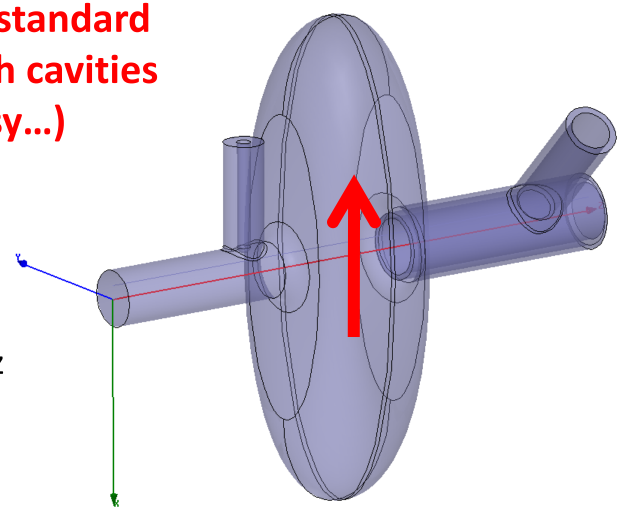


Kota, KEK

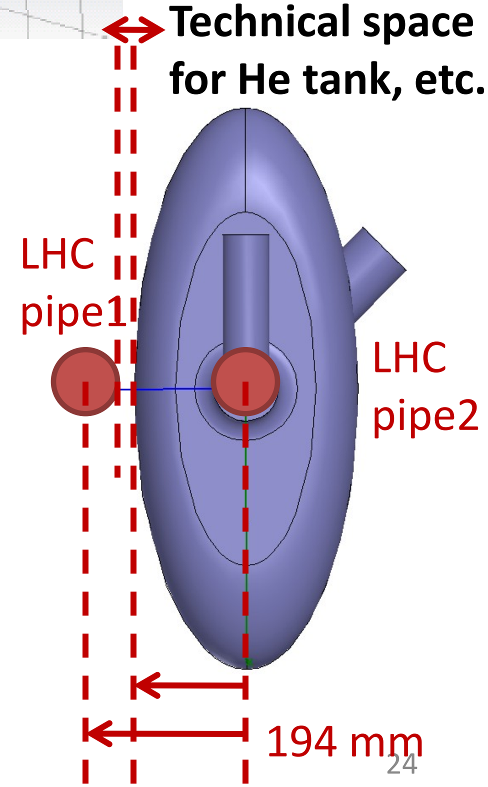


Compact cavities aiming at small footprint & 400 MHz, ~5 MV/cavity

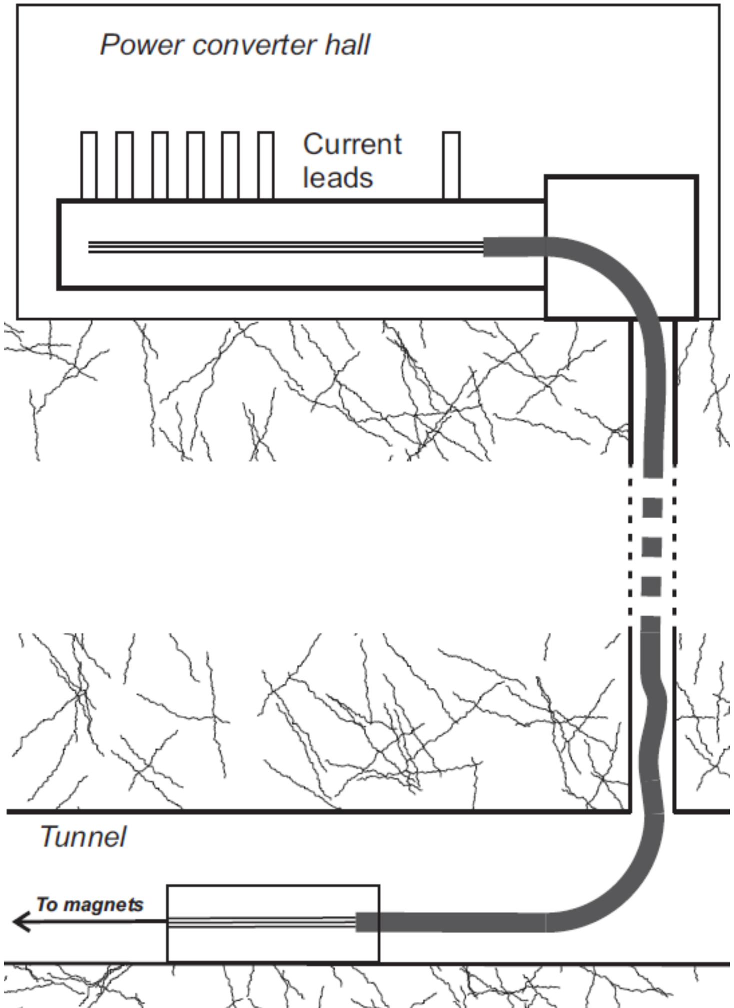
All these 400 MHz can fit into the standard 194 mm LHC beam separation with cavities in a common cryostat (but not easy…)

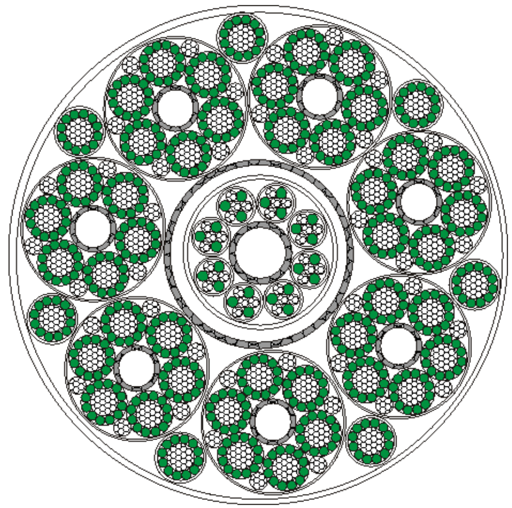


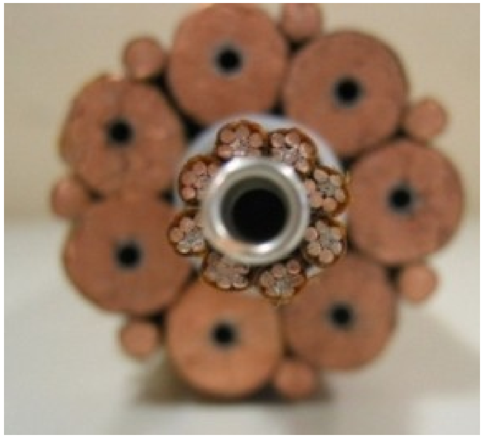
New idea for a very compact elliptical 800 MHz



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 DFBs (current lead boxses) removed to surface
Definitive solution to R2E problem – in some points
Make room for shielding un-movable electronics
Make much easier maintenance and application of ALARA

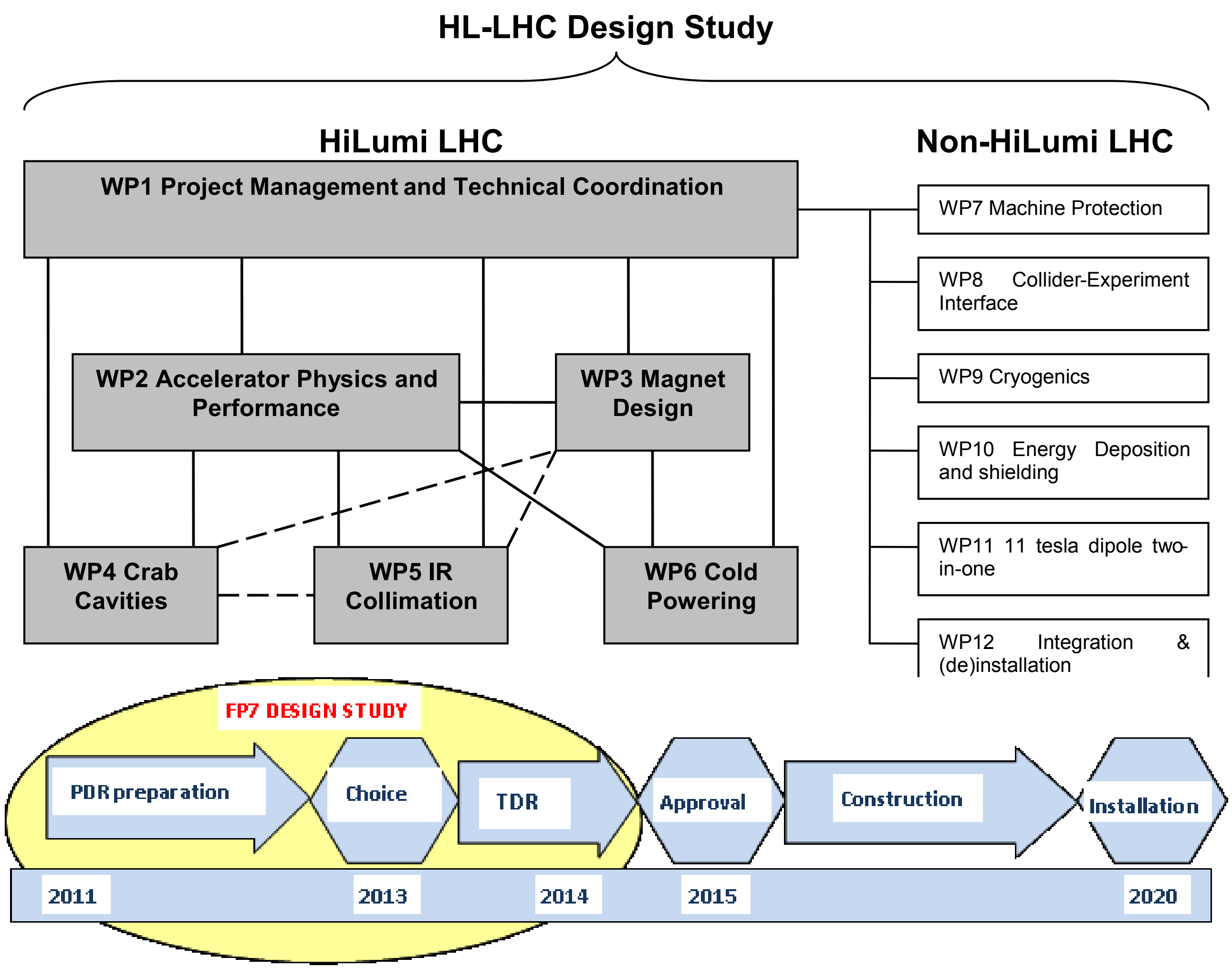
Technical reasons for the upgrade (or at least for important improve)

- The zone of the triplets will wear out
  - Radiation damage limit (300-400 fb^{-1} ? More?)
  - Hardware and shielding that has not been really optimized for very high radiation
    - Better and increased shielding of the triplet 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 decouple RF from Magnets in 2017
    - Local removal (inside triplet) and transport away
    - Cooling capacity
    - Cooling sectorization (complete decoupling of IRs form Arcs: this will allow more budget for e-clouds, 25 ns will may re-favourite)

Very small β* (7 to 15 cm) are at hand: new ATS – see next talk

annual luminosity	L_{int}[fb^{-1}]	**57**	58	**300**	**300**	**300**

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

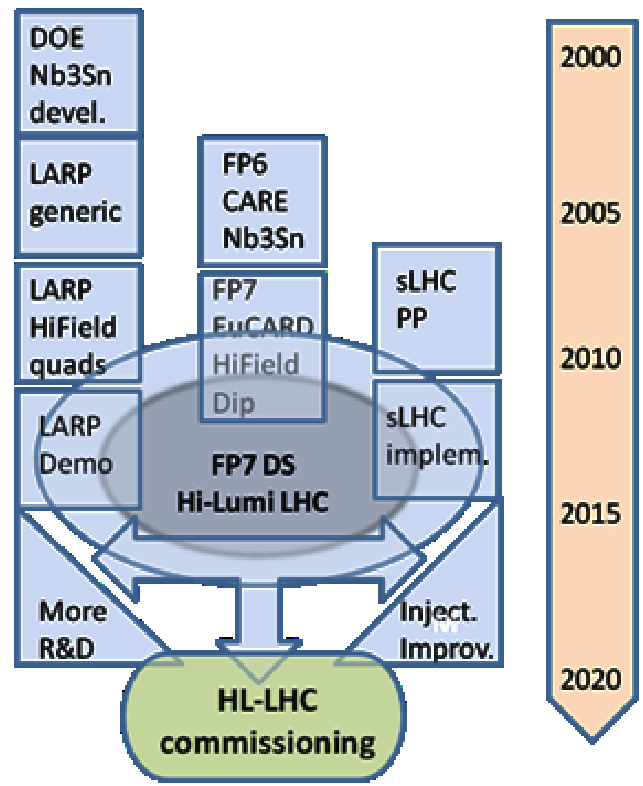


Large participation application 25 Nov 2010

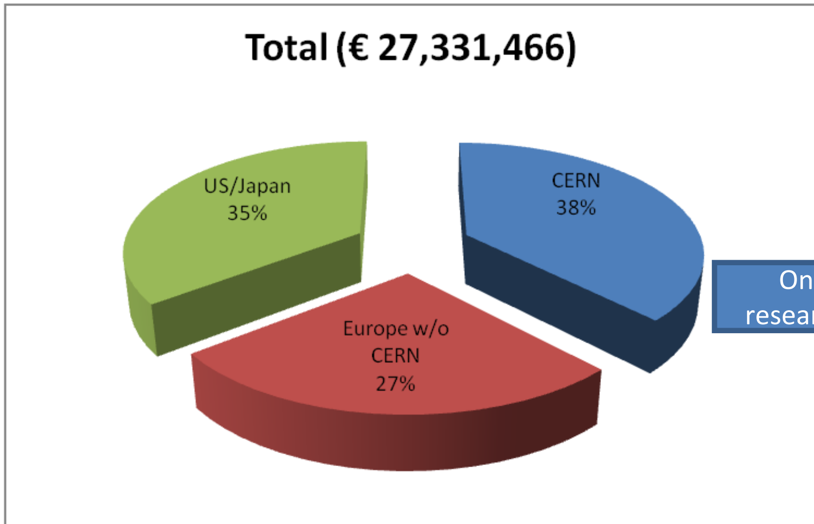
Participant no.	Participant organisation name	Short name	Country
1 (Coord-inator)	European Organization for Nuclear Research	CERN	IEIO[1]
2	Commissariat à l'Énergie Atomique et aux énergies alternatives	CEA	France
3	Centre National de la Recherche Scientifique	CNRS	France
4	Stiftung Deutsches Elektronen-Synchrotron	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

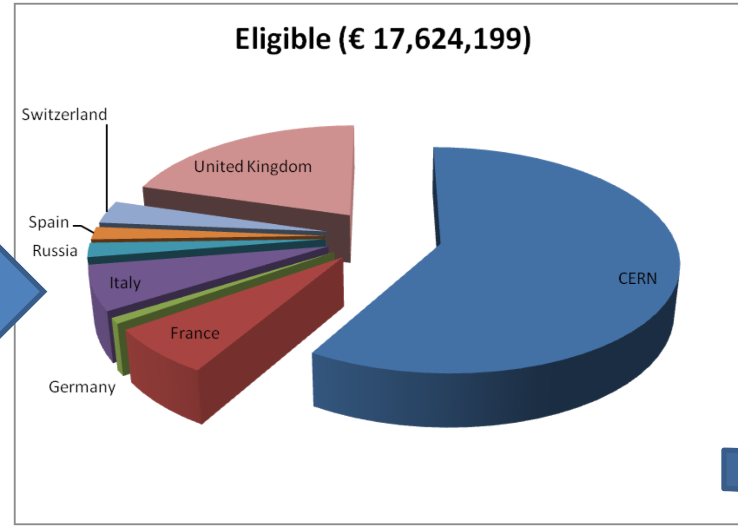
- The collaboration wiht US on LHC upgrade started during the construction of LHC
- EU programs have been instrumental in federating all EU efforts
- With Hi-Lumi the coordination makes a step further: from coordinated R&D to a common project
- CERN is not anymore the unique owner, rather is the motor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



Budget FP7 HiLumi



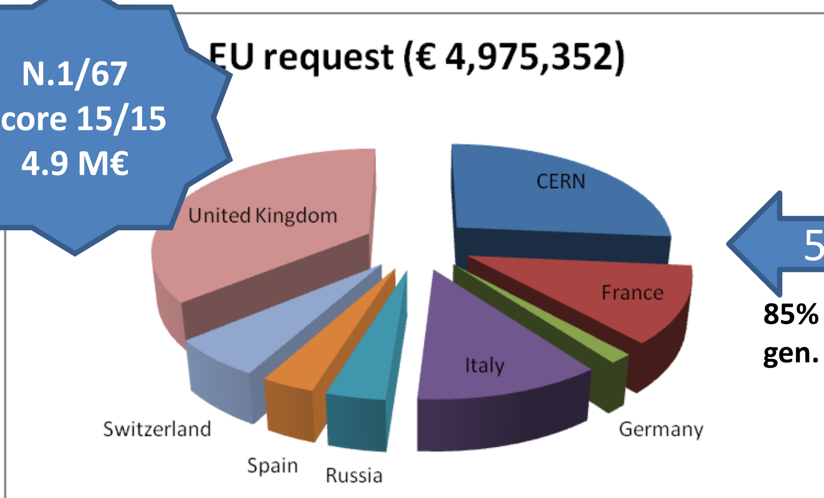
Only EU research area



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

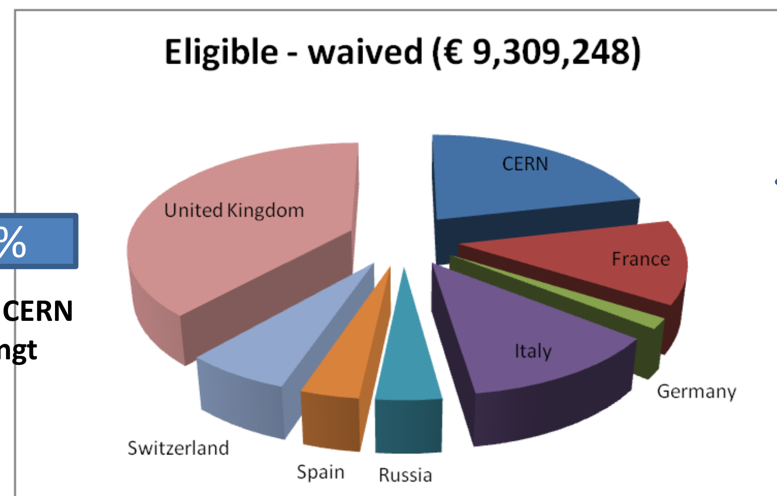
Waiving effect

N.1/67
Score 15/15
4.9 M€

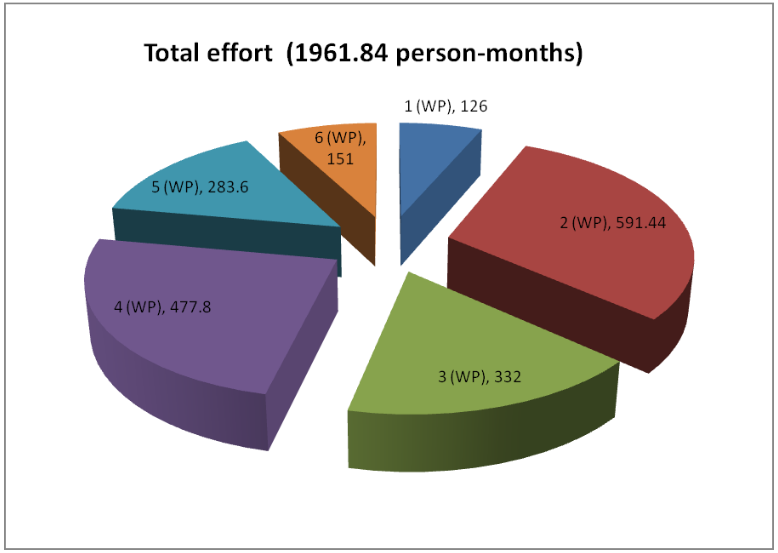


50%

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-1

- 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 « improved » beam)
  - For the beam studies (fundamental understanding the limitation of so called Phase 1 upgrade)
  - 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.

Conclusion - 2

- However while LHC has been the « summa» of 30 y of SC hadron colliders, HL has the scope, in addition to its primary physics goal, to go beyond present technology and pave the way for the future. Given the size and the tim
technologies. For ex
  - SCRF (Crab Cavity)
  - SC link 1 GW rate
  - HF Sc magnets