HL-LHC & Crab Cavities

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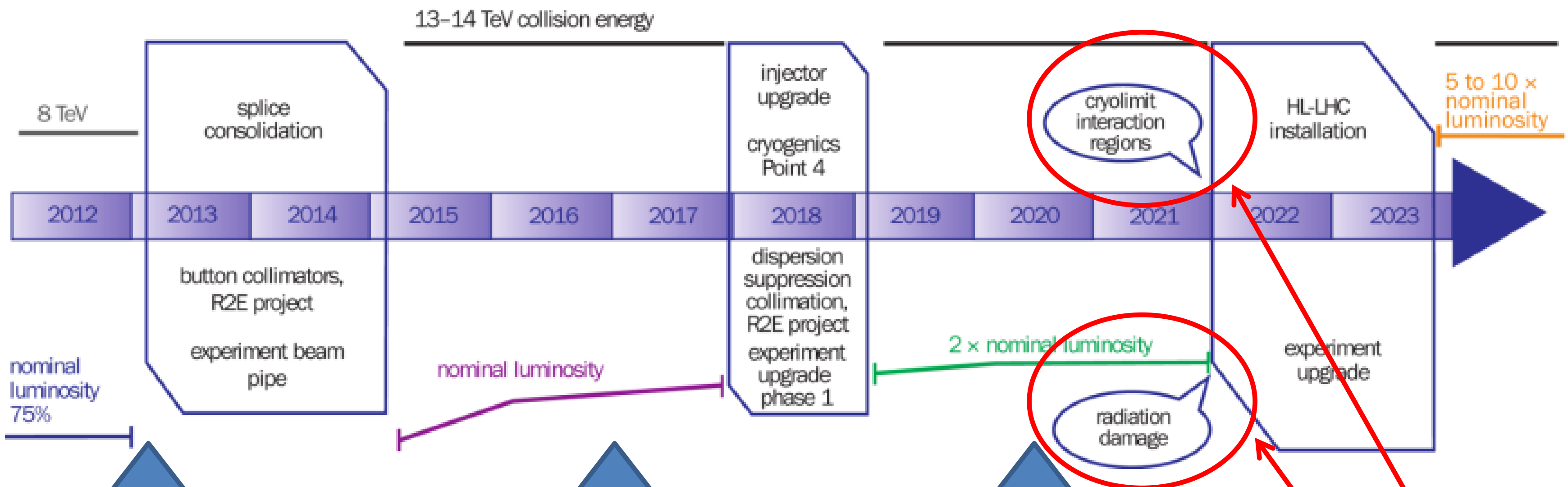
HL-LHC Project Leader

6th Crab Cavity Workshop, CERN, 9 December 2013

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

The CERN 10-year plan
(approved early 2011 – just modified, see later)



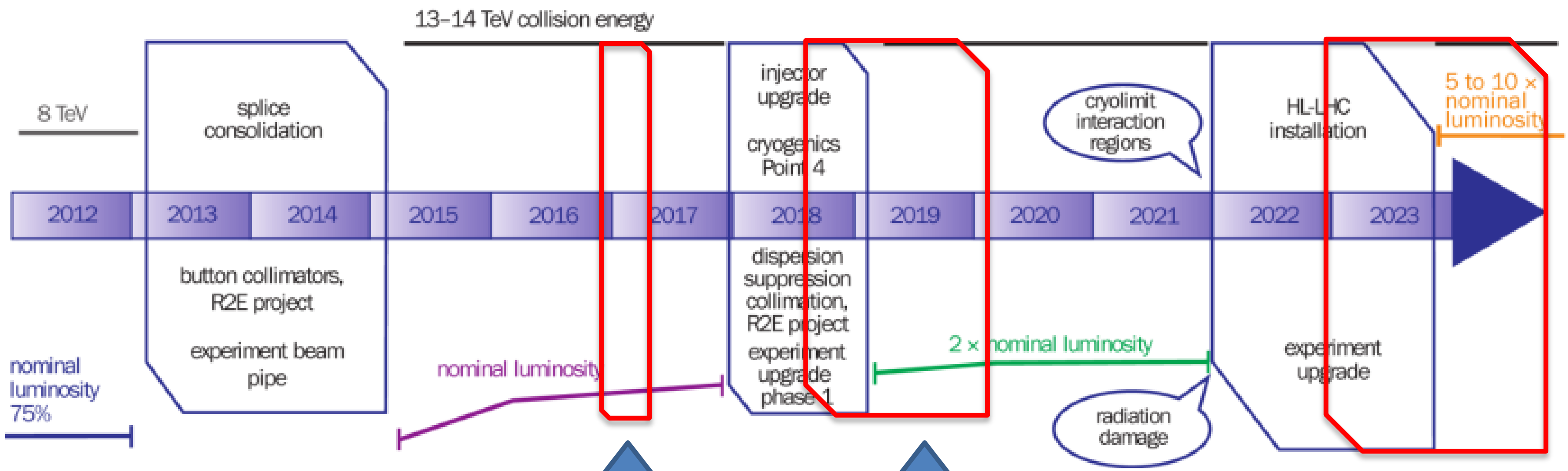
$0.75\ 10^{34}\ cm^{-2}s^{-1}$
50 ns bunch
high pile up ~40

$1.5\ 10^{34}\ cm^{-2}s^{-1}$
25 ns bunch
pile up ~40

$1.7\text{-}2.2\ 10^{34}\ cm^{-2}s^{-1}$
25 ns bunch
pile up ~60

Technical limits (experiments, too) like :

Recent modification to the LHC plan



Big chance to install CC in SPS!

Install New Cryo in IP4, (install CC in IP4 _ NOT beasline) Preparation for CC in LS3

The extra time is just what is needed to to make possible CC in LS3: we should not miss the opportunity

High Luminosity LHC

Goal of High Luminosity LHC (HL-LHC) as fixed in November 2010

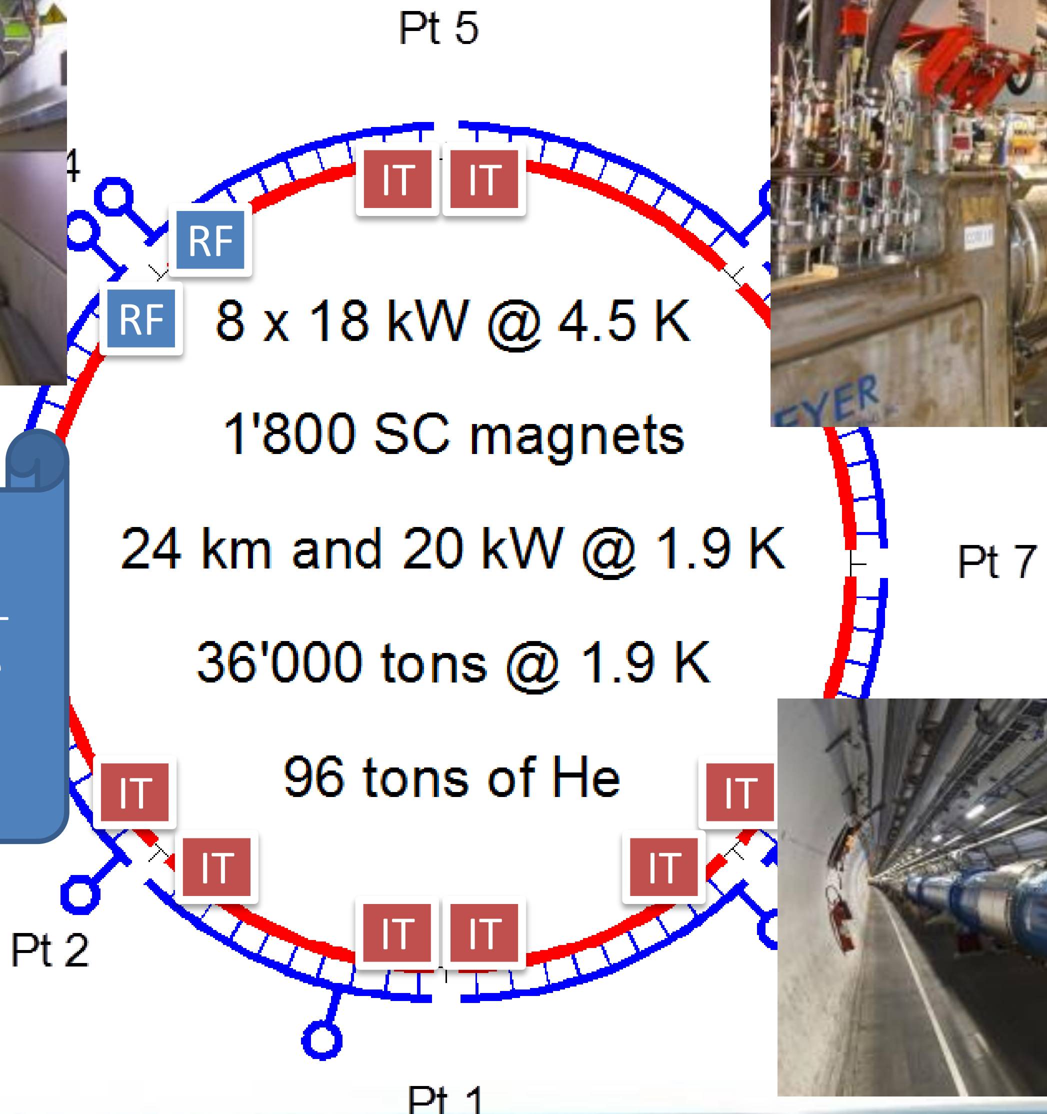
The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

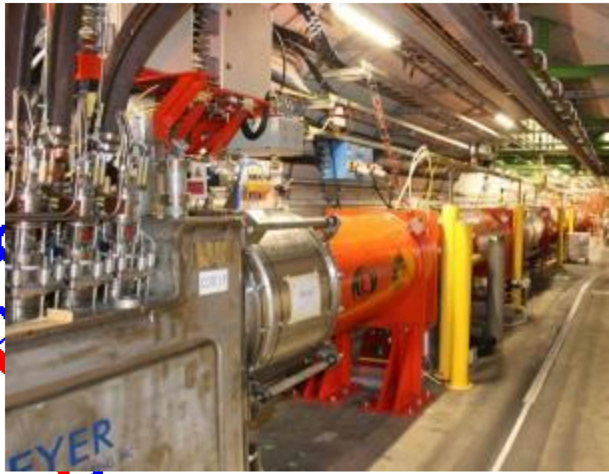
A peak luminosity of **5×10^{34} $cm^{-2}s^{-1}$ with levelling,** allowing:

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.

CC are an essential ingredient to obtain this goal:
First for performance ! CC are critical to increase peak lumi!
Second as method of levelling
Third to improve the data quality by reducing pile up density

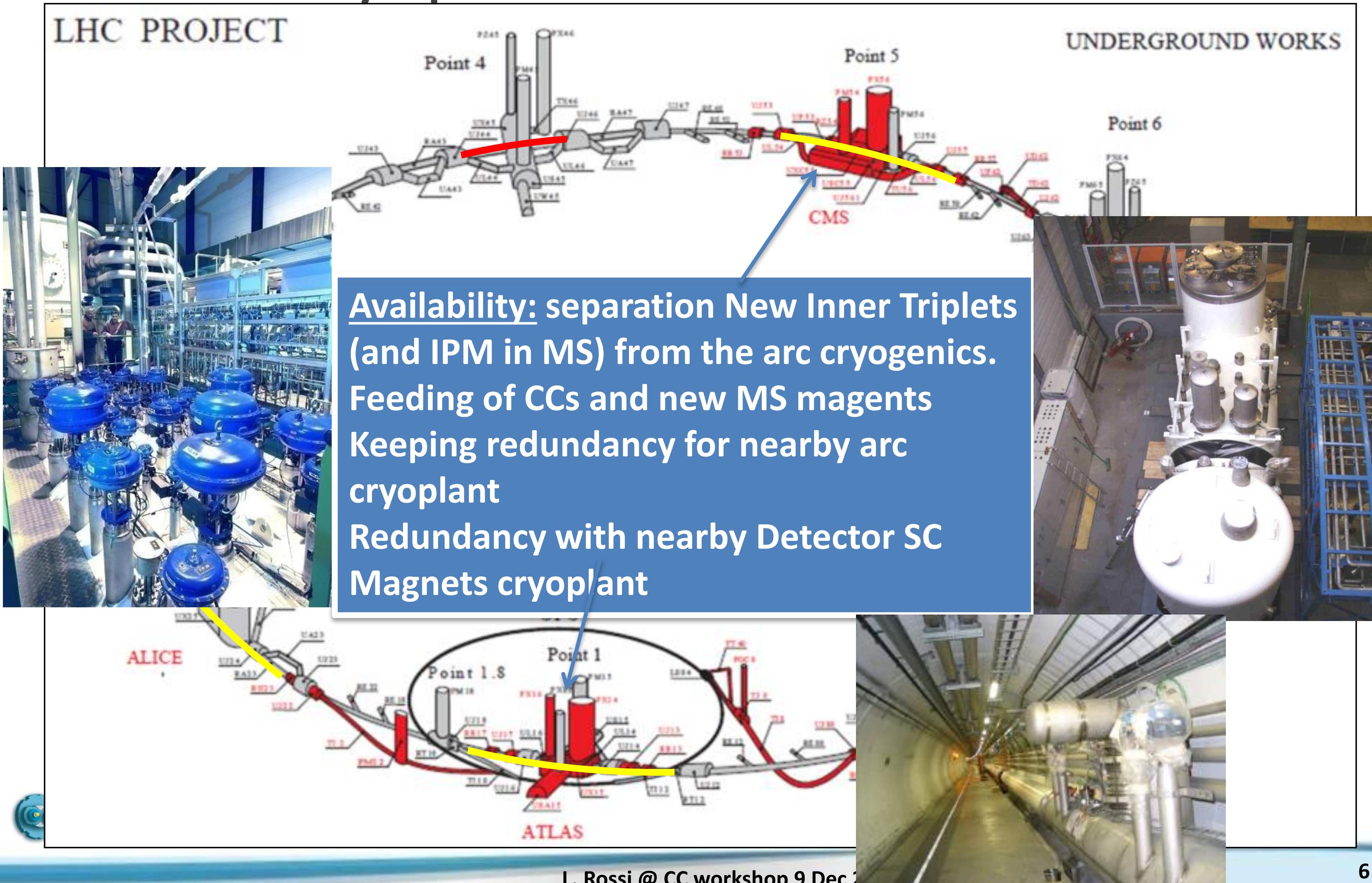
Technical bottlenecks
Cryogenics P4





Never good to couple RF with Magnets !
Reduction of availabe cryo-power and coupling of the RF wiht the Arc (thermal cycle requires > 2 months and many tests)

IT cryoplants and new LSS QRL



Availability: separation New Inner Triplets (and IPM in MS) from the arc cryogenics.
Feeding of CCs and new MS magents
Keeping redundancy for nearby arc cryoplant
Redundancy with nearby Detector SC Magnets cryoplant

Controlling the burning rate: common effort of Magnets and CC

Beam current

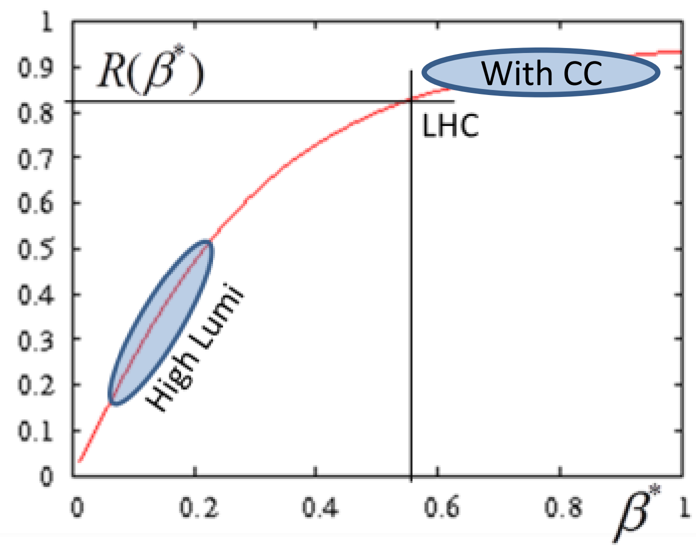
$$L = \gamma \frac{f_{rev}\, n_b\, {N_b}^2}{4\pi \varepsilon_n \beta^*} R$$

energy

Beam size

$$R = \frac{1}{\sqrt{1 + (\frac{\theta_c \sigma_s}{2\varepsilon_n \beta^*}\gamma)^2}}$$

ε_n is already below «nominal»
Further reduction is limted by brightness (we want N_b as large as possible)
So making effective β^* reduction si critical for HL-LHC



High Luminosity LHC

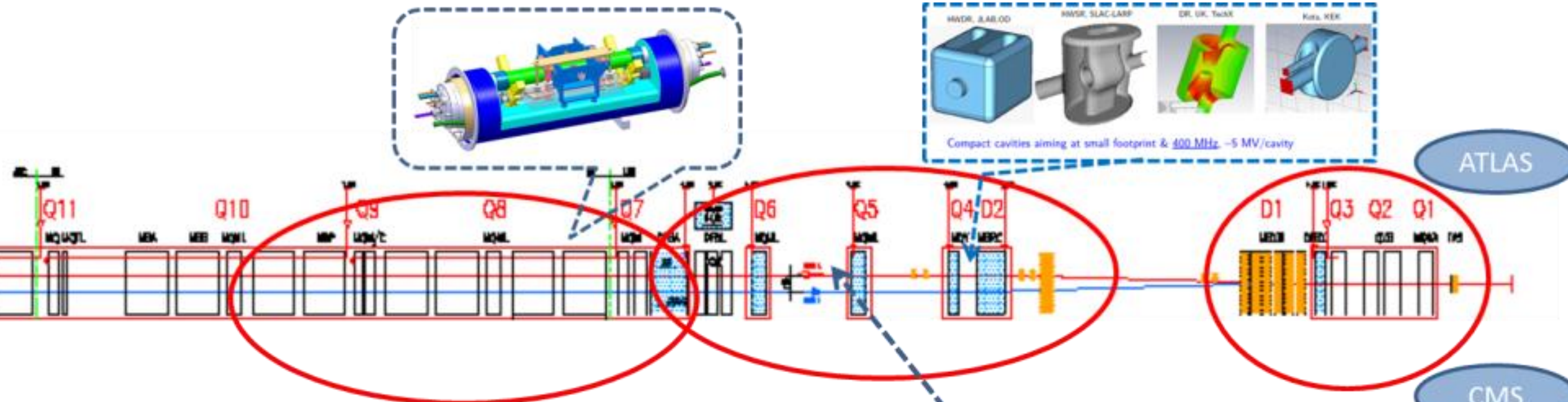
Parameters (PLC web page)

https://espace.cern.ch/HiLumi/PLC/default.aspx

$$L = \gamma \frac{f_{rev}\, n_b\, N_b^{\ 2}}{4\pi\varepsilon_n\beta^*} R$$

Parameter	nominal	25ns	50ns
N_b	1.15E+11	2.2E+11	3.5E+11
n_b	2808	**2808**	1404
N_{tot}	3.2E+14	6.2E+14	4.9E+14
beam current [A]	0.58	**1.11**	0.89
x-ing angle [μrad]	300	590	590
beam separation [σ]	9.9	12.5	11.4
β^* [m]	0.55	**0.15**	0.15
ε_n [μm]	3.75	2.50	3
ε_L [eVs]	2.51	2.51	2.51
energy spread	1.20E-04	1.20E-04	1.20E-04
bunch length [m]	7.50E-02	7.50E-02	7.50E-02
IBS horizontal [h]	80 -> 106	18.5	17.2
IBS longitudinal [h]	61 -> 60	20.4	16.1
Piwinski parameter	0.68	3.12	2.85
Reduction factor 'R1*H1' at full crossing angle (no crabbing)	0.828	0.306	0.333
Reduction factor 'H0' at zero crossing angle (full crabbing)	0.991	**0.905**	0.905
beam-beam / IP without Crab Cavity	3.1E-03	3.3E-03	4.7E-03
beam-beam / IP with Crab cavity	3.8E-03	1.1E-02	1.4E-02
Peak Luminosity without levelling [$cm^{-2}\, s^{-1}$]	1.0E+34	7.4E+34	8.5E+34
Virtual Luminosity: Lpeak*H0/R1/H1 [$cm^{-2}\, s^{-1}$]	1.2E+34	**21.9E+34**	23.1E+34
Events / crossing without levelling	19 -> 28	210	475
Levelled Luminosity [$cm^{-2}\, s^{-1}$]	-	5E+34	2.50E+34
Events / crossing (with leveling for HL-LHC)	*19 -> 28	140	140
Leveling time [h] (assuming no emittance growth)	-	9.0	18.3

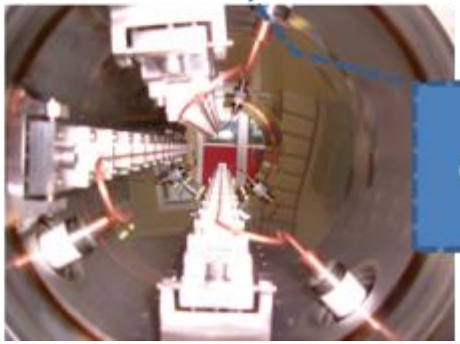
The critical zone around IP1 and IP5



3. For collimation we need to change also this part, DS in the continuous cryostat

2. Deep change also matching section: Magnets, collimators and CC

1. Deep change in the IRs and interface to detectors; relocation of Power Supply



4. LR BB compensation wires

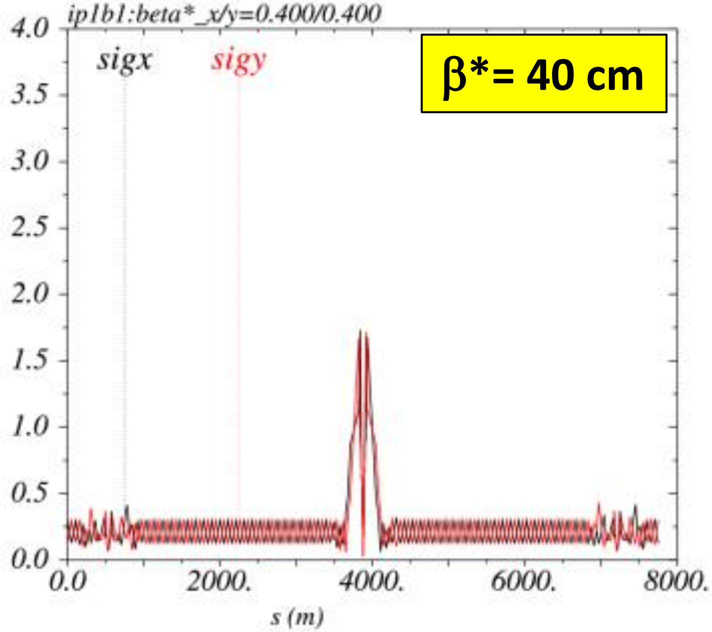
1.2 km of LHC !!

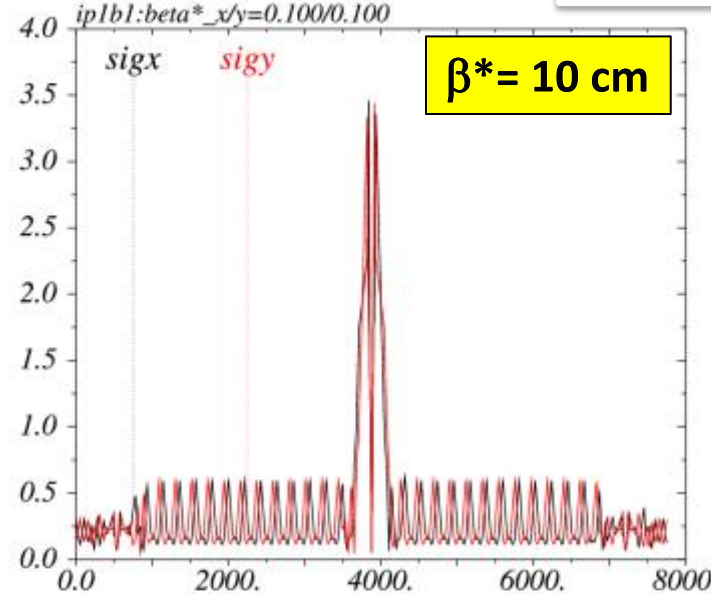
High Luminosity LHC

The ***Achromatic Telescopic Squeezing*** *(ATS) scheme*

Small β* is limited by aperture but not only: optics matching & flexibility (round and flat optics), chromatic effects (not only Q'), spurious dispersion from X-angle,..

A novel optics scheme was developed to reach un-precedent β^* w/o chromatic limit based on a kind of generalized squeeze involving 50% of the ring **(S. Fartoukh)**



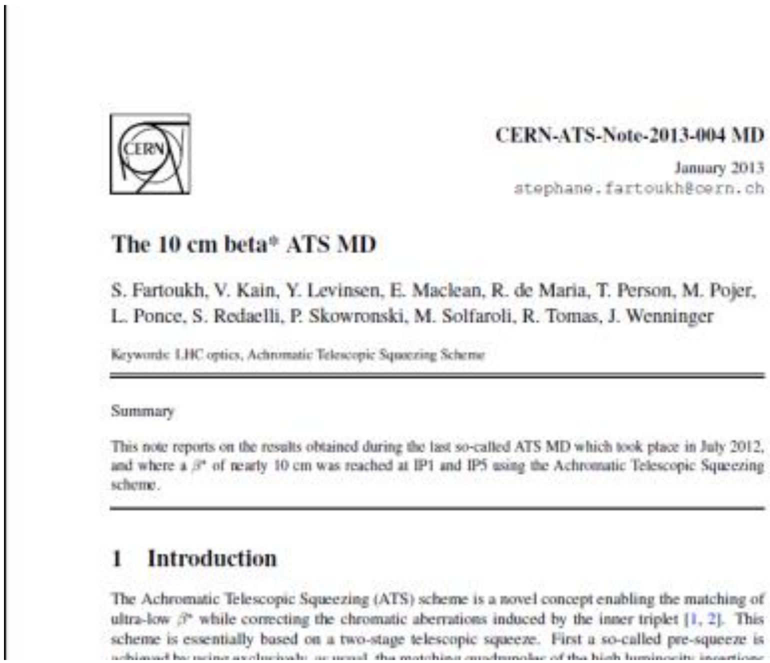


The new IR is sort of 8 km long !

Beam sizes [mm] @ 7 TeV from IR8 to IR2 for typical ATS "pre-squeezed" optics (left) and "telescopic" collision optics (right)

*The **Achromatic Telescopic Squeezing** (ATS) scheme (2/2)*

→ Proof of principle demonstrated in the LHC down to a **β* of 10-15 cm at IP1 and IP5**



CERN-ATS-Note-2013-004 MD
January 2013
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The 10 cm beta* ATS MD

S. Fartoukh, V. Kain, Y. Levinsen, E. Maclean, R. de Maria, T. Person, M. Pojer, L. Ponce, S. Redaelli, P. Skowronski, M. Solfaroli, R. Tomas, J. Wenninger

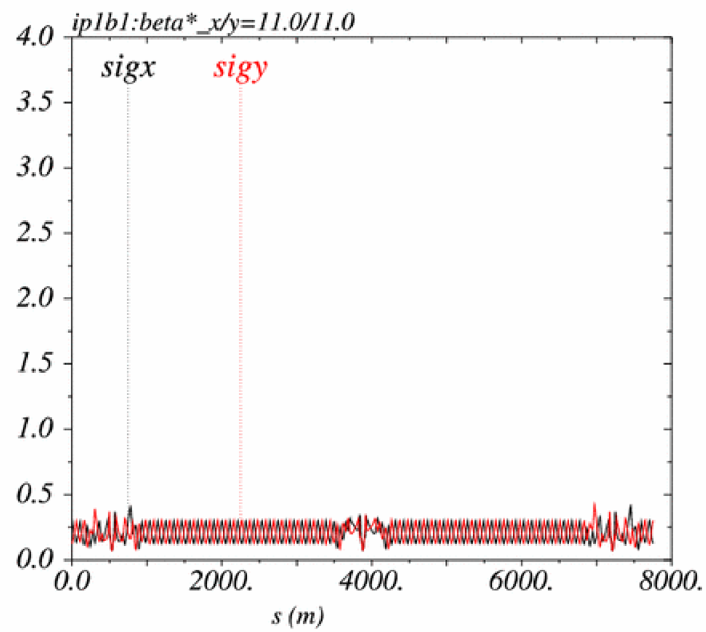
Keywords: LHC optics, Achromatic Telescopic Squeezing Scheme

Summary

This note reports on the results obtained during the last so-called ATS MD which took place in July 2012, and where a β^* of nearly 10 cm was reached at IP1 and IP5 using the Achromatic Telescopic Squeezing scheme.

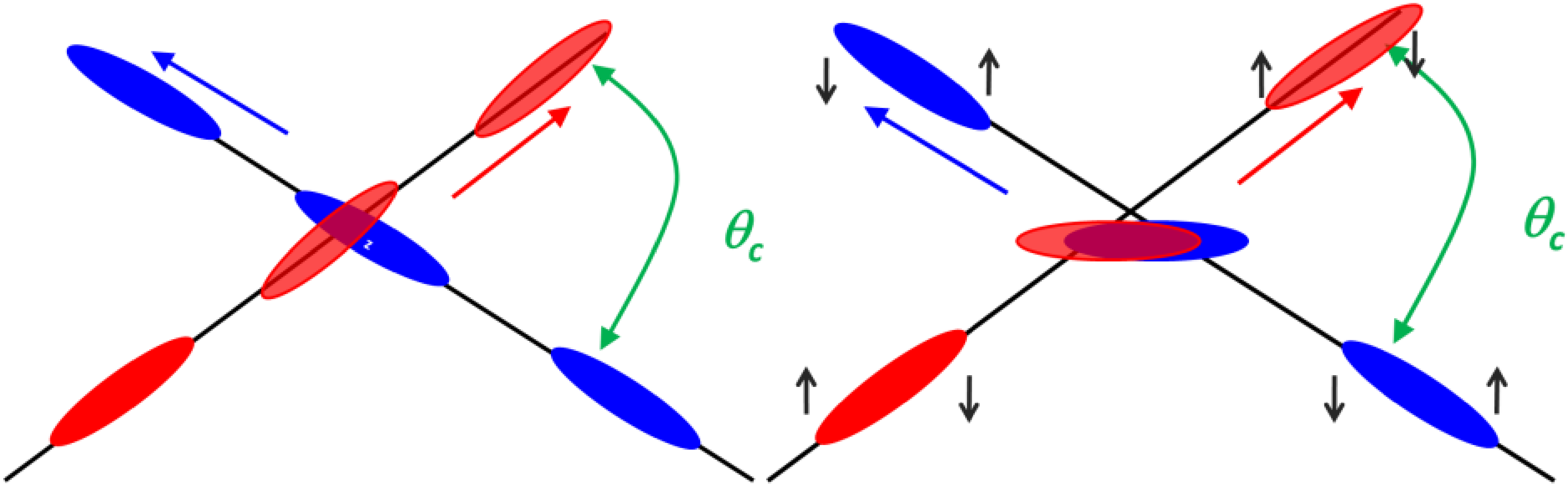
1 Introduction

The Achromatic Telescopic Squeezing (ATS) scheme is a novel concept enabling the matching of ultra-low β^* while correcting the chromatic aberrations induced by the inner triplet [1, 2]. This scheme is essentially based on a two-stage telescopic squeeze. First a so-called pre-squeeze is



S-. Fartoukh

Effect of the crab cavities

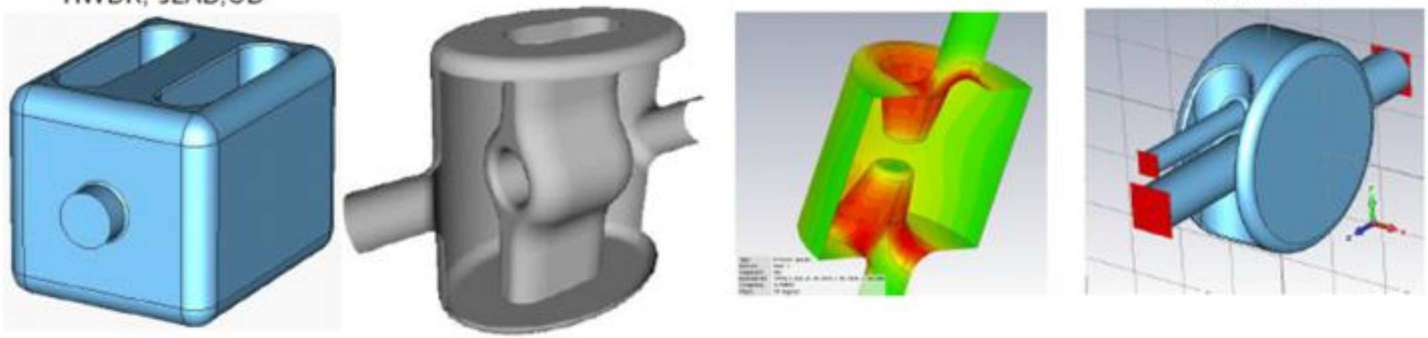


- **RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" and then luminosity is maximized**
- ***Crab cavity maximizes the lumi and can be used also for luminosity levelling: if the lumi is too high, initially you don't use it, so lumi is reduced by the geometrical factor. Then they are slowly turned on to compensate the proton burning***

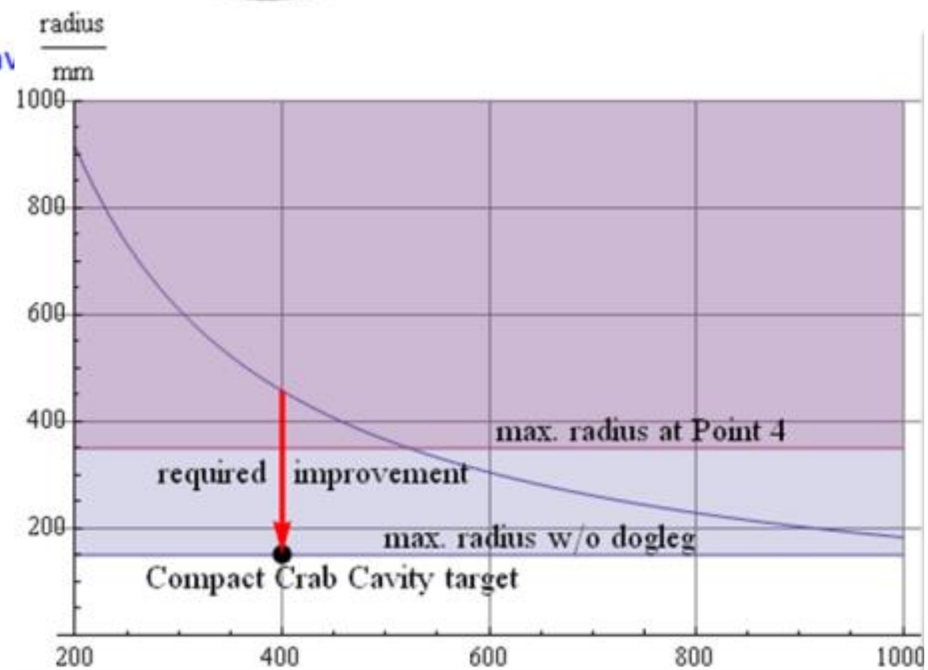
Crab Cavity, for p-beam rotation

at 10-100 fs level!

HWDR, JLAB,OD — HWSR, SLAC-LARP — DR, UK, TechX — Kota, KEK



Compact cav



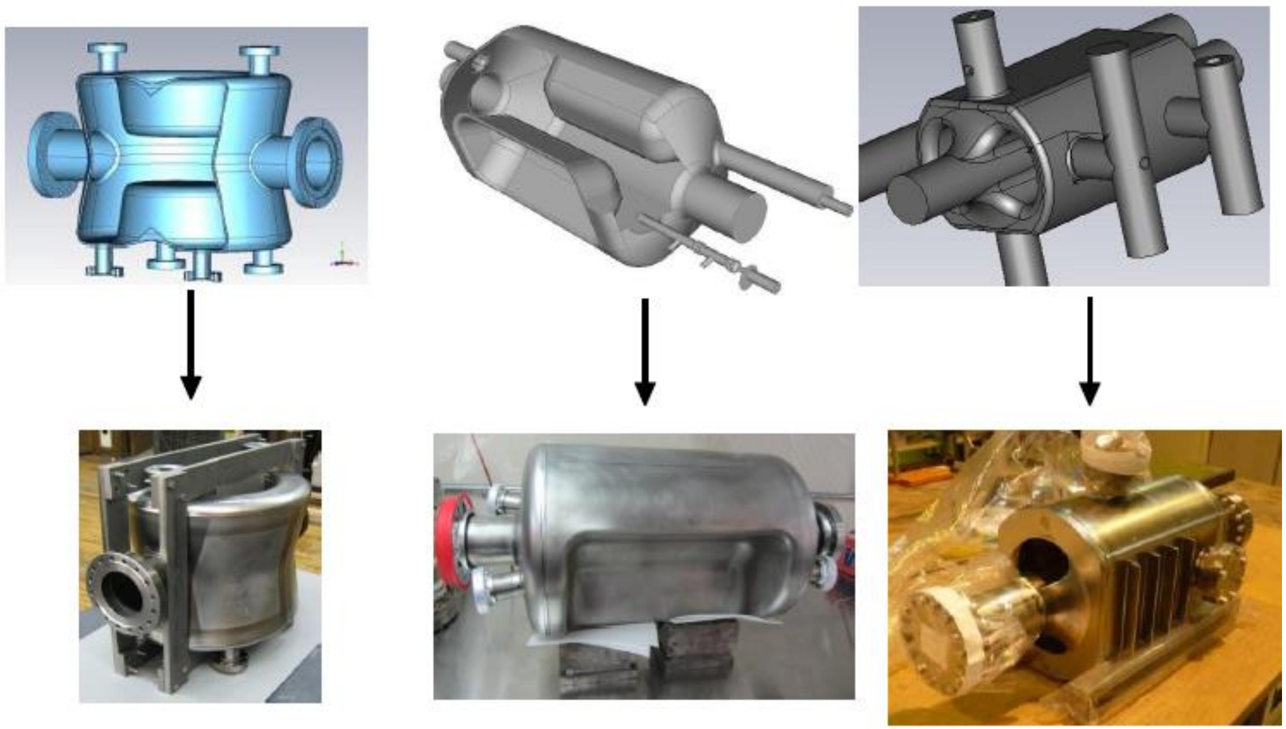
Elliptical type CC has been tested first in KEK 2008

Compact Crab Cavity (CCC) Are really COMPACT!

High Luminosity LHC

Situation: from drawings to reality…

All Prototypes in Bulk Niobium (2011-12)

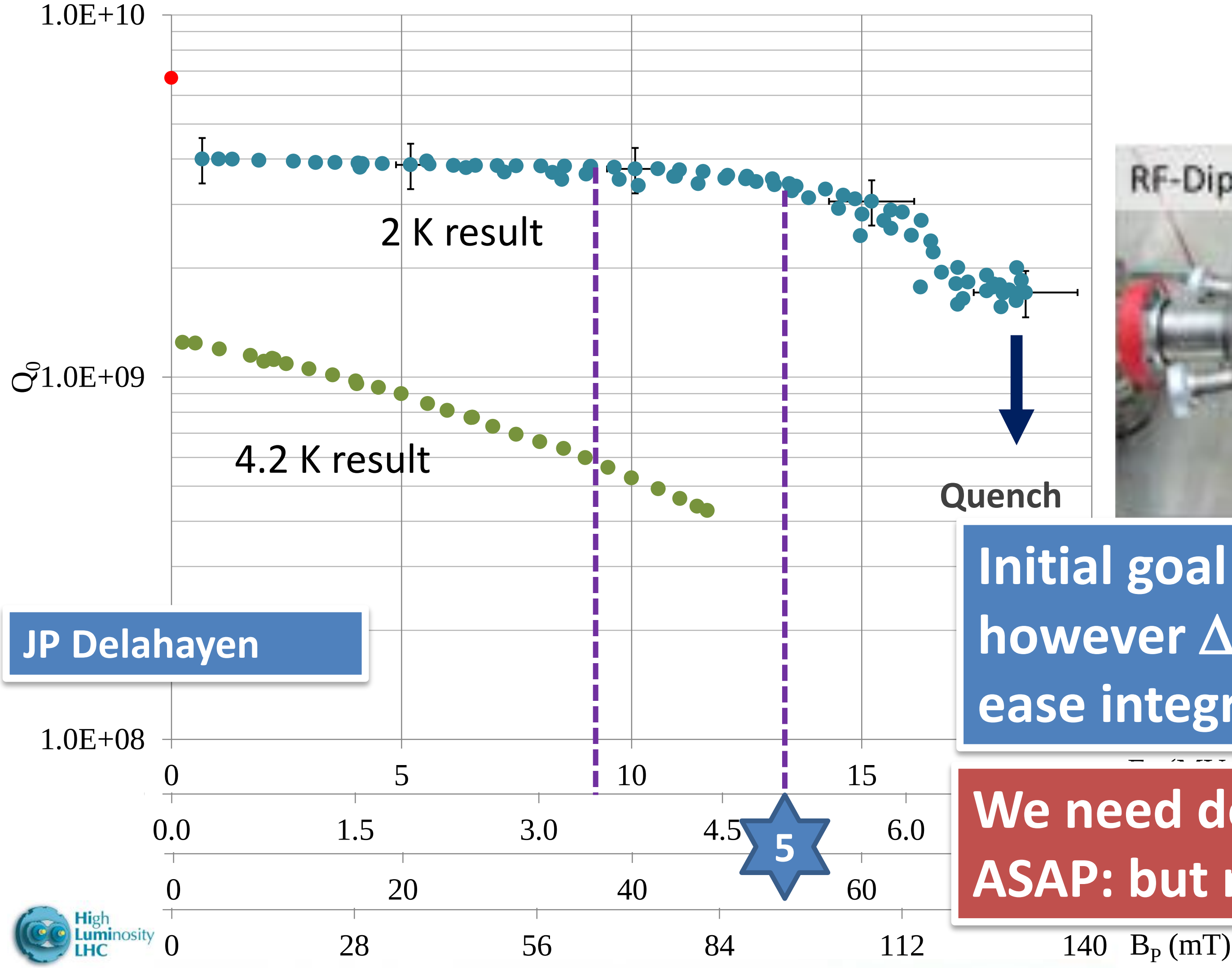


LARP-BNL | LARP-ODU-JLAB | UniLancaster-CI-CERN

And excellent results: RF dipole > 5 MV

¼ w and 4-rods also tested (1.5 MV)

cleaning & vacuum issues: new test under way

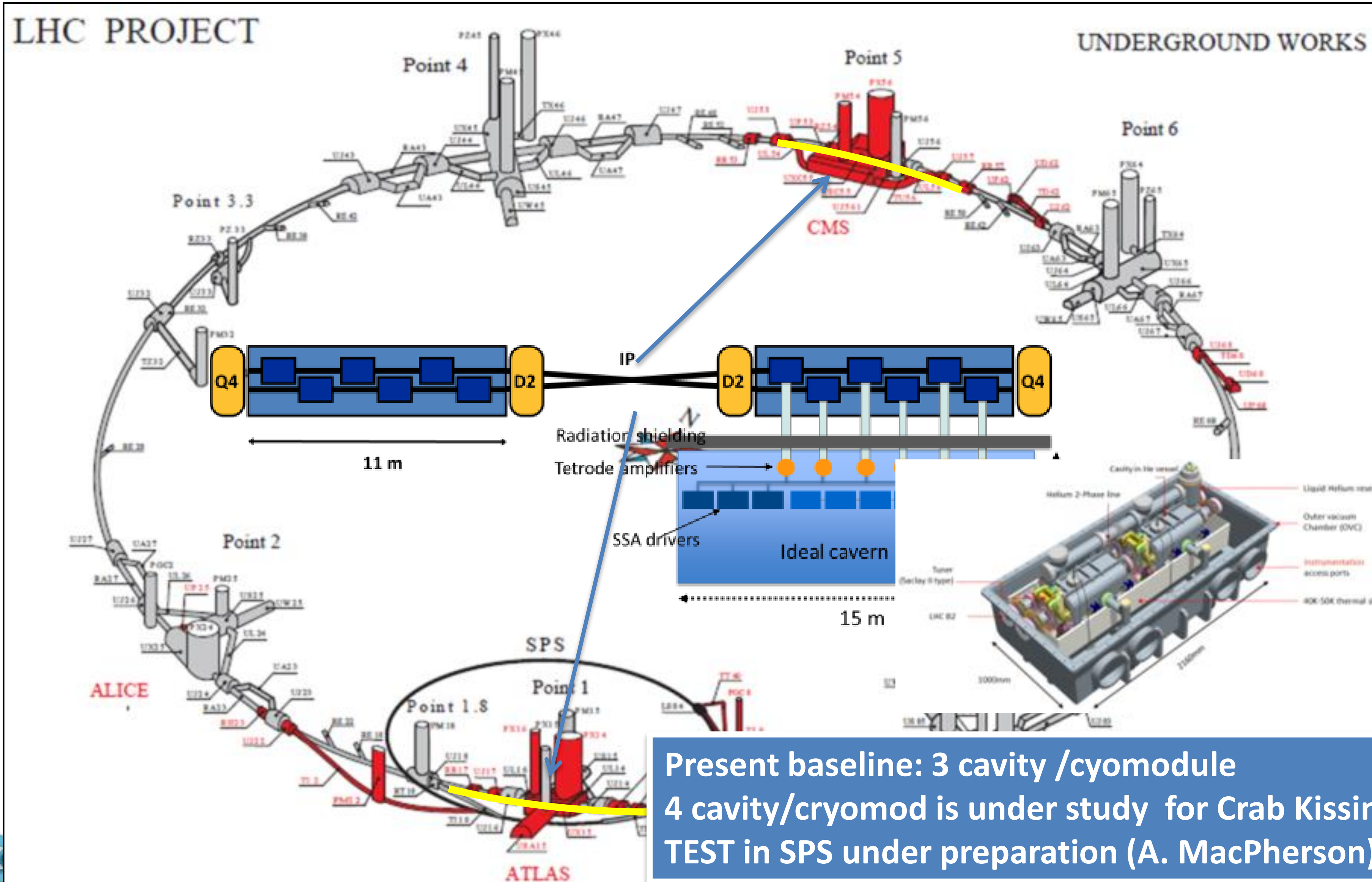


JP Delahayen

Initial goal was 3.5 MV however ΔV > 5-6 MV would ease integration

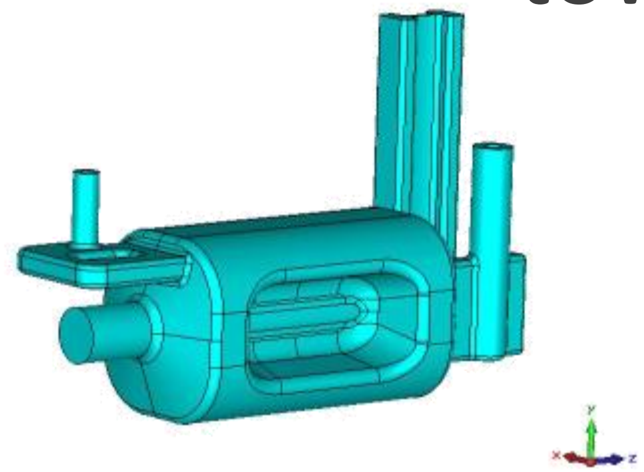
We need downselection, and ASAP: but not too early!

Crab Cavities for fast beam rotation



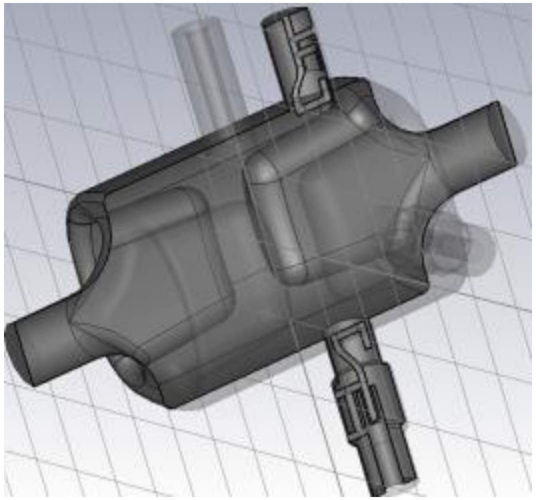
Present baseline: 3 cavity /cyomodule
4 cavity/cryomod is under study for Crab Kissing
TEST in SPS under preparation (A. MacPherson)

Latest cavity designs toward accelerator

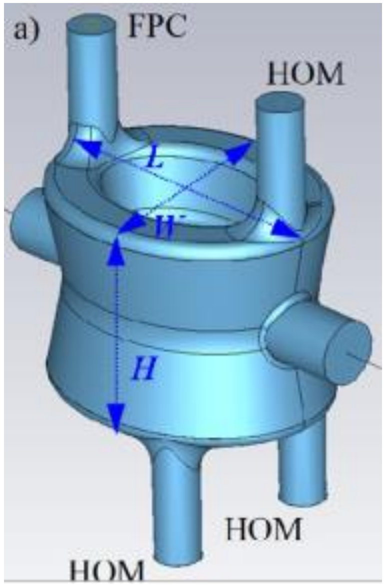


RF Dipole: Waveguide or waveguide-coax couplers

Coupler concepts

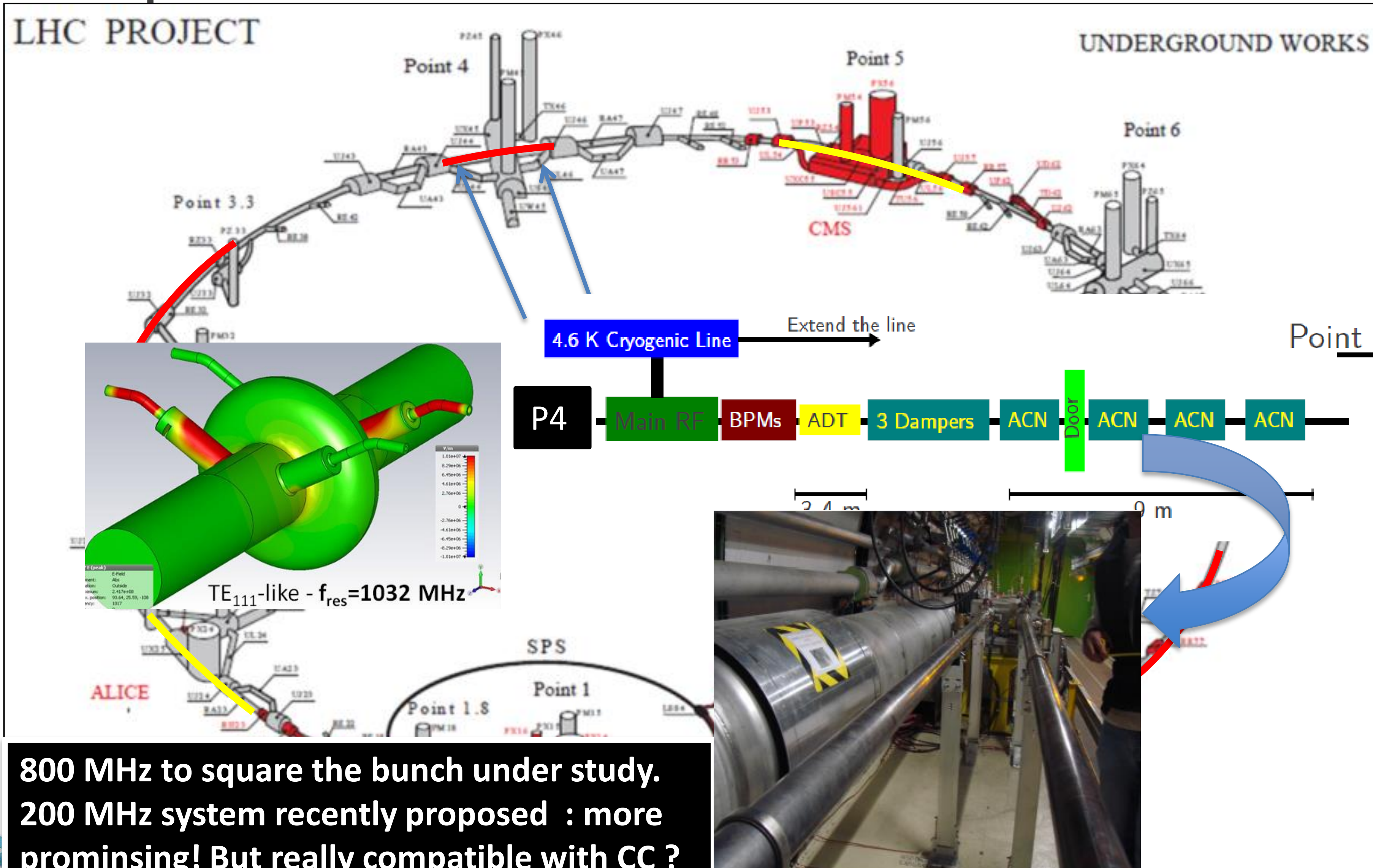


4-rod: Coaxial couplers with different antenna types



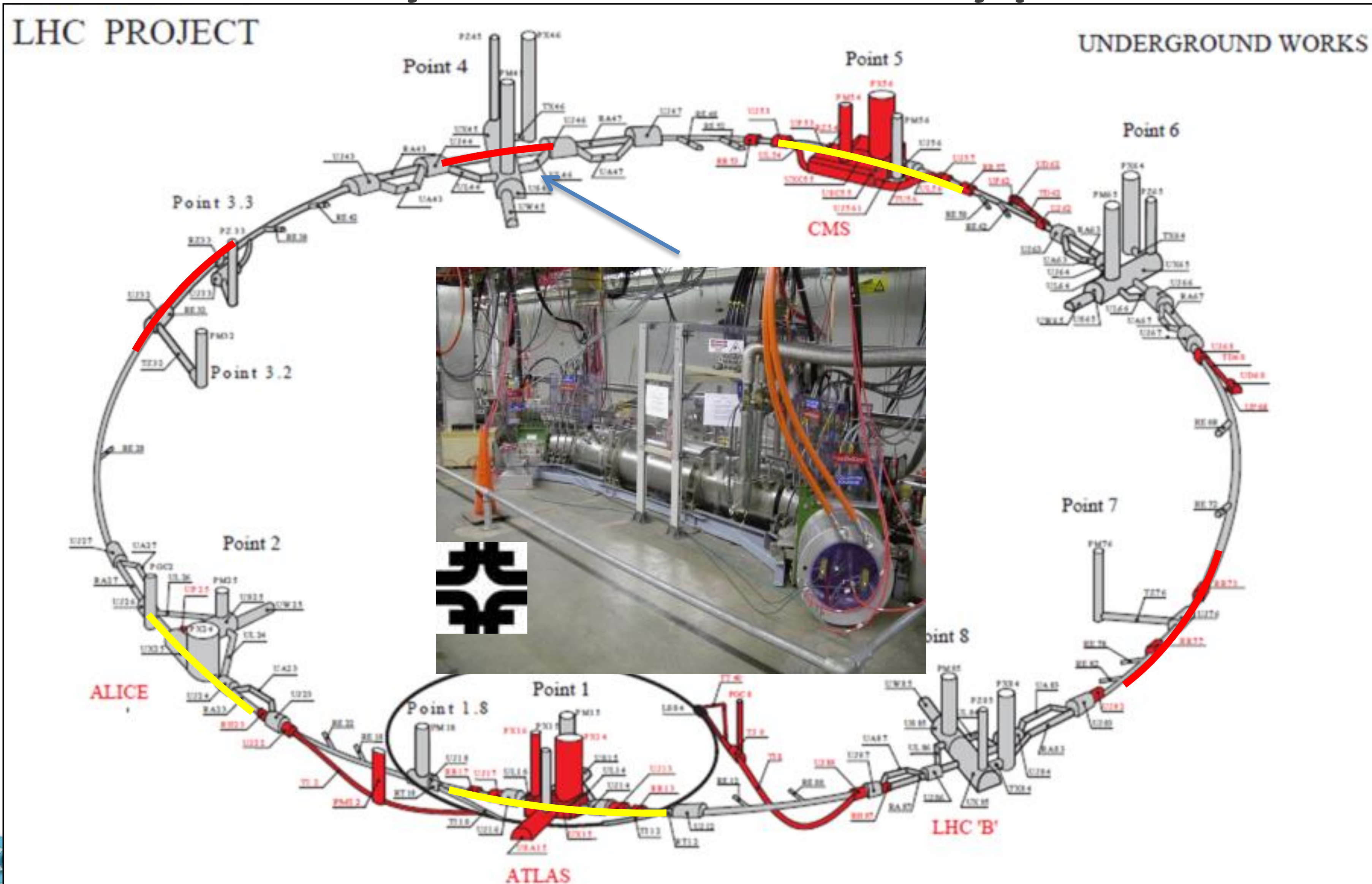
Double ¼-wave: Coaxial couplers with hook-type antenna

New SCRF harmonc system: 800 MHz or 200 MHz ?
Importantant but should not take out attention form CC !!!

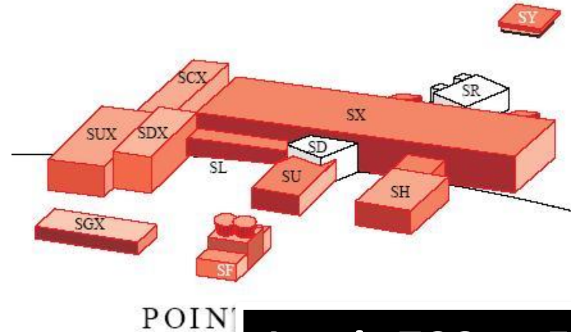


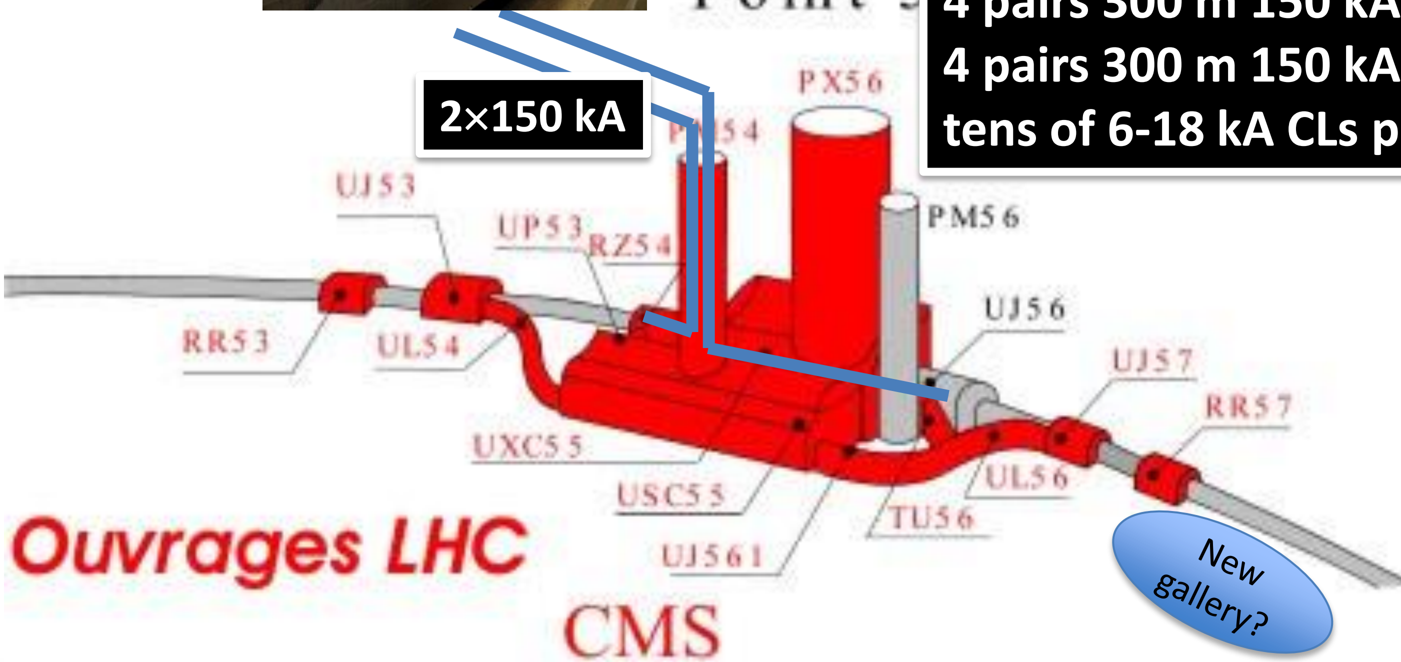
800 MHz to square the bunch under study.
200 MHz system recently proposed : more prominsing! But really compatible with CC ?

Halo control (hollow e-lens)
Is it necessary for CC ? Is it the only protection ?



Study for a new underground hall: really needed? how big?? With new pit???





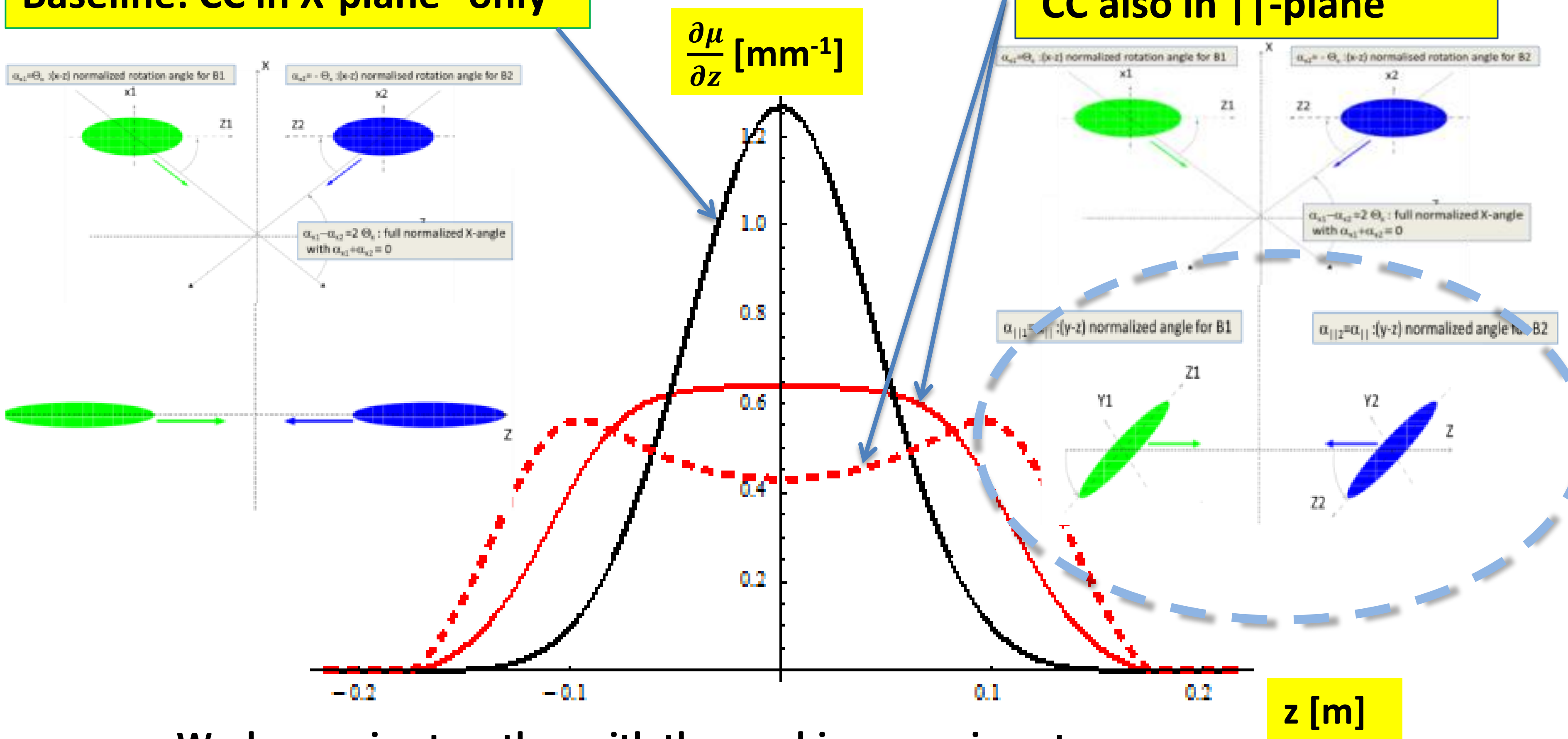
2×150 kA

1 pair 700 m 50 kA – LS2
4 pairs 300 m 150 kA (MS)– LS3
4 pairs 300 m 150 kA (IR) – LS3
tens of 6-18 kA CLs pairs in HTS

The **Crab-kissing** (CK) scheme for **pile-up density** shaping and leveling (S. Fartoukh)

Baseline: CC in X-plane "only"

Crab-kissing & variants: CC also in ||-plane



... Work on-going together with the machine experiments (S. Fartoukh, A. Valishev, A. Ball, B. Di Girolamo, *et al*.)

Consideration on CC and possible choice

CC, like any important hardware has a back up plan.
LRBB compensating wires may partially recovery the loss due to possible absence of CC.

However CC is the most straightforward tool to reach our goal and today the CC are in the baseline (not yet for the LRBB wires).

Especialy in presence of a possible increase of the levelling value (~ 7.5 10 34 ?) the advantage of CC is even accentuated.

If they works, at the end we want to have BOTH CC and LRBB wires!

High Luminosity LHC

High Luminosity LHC Project

PROJECT COORDINATION OFFICE

Project Coordinator: Lucio Rossi, CERN
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Technical Coordinator: Isabel Bejar Alonso, CERN
Project Safety Officer: Thomas Otto, CERN
Budget & Resource Management: Dorothée Duret, CERN
FP7 HiLumi LHC Administrative Manager: Svetlomir Stavrev, CERN
Dissemination & Outreach: Agnes Szeberenyi, CERN
Administrative Support: Cécile Noels & Julia Double, CERN

WP
Coordinator
Co-coordinator

FP7 HiLumi LHC Design Study

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WP2 Accelerator Physics
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Andy Wolski, UNILIV

WP3 Magnets
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WP4 CC and RF
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Graeme Burt, ULA

Substitutte Elliptical with cryomdule

WP5 Collimation
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Robert Appleby, UNIMAN

WP6 Cold Powering
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WP7 Machine Protection
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WP8 LHC-Exp. Interface
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WP9 Cryogenics
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WP10 Energy depo.
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WP11 11T Dipole
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WP12 Vacuum
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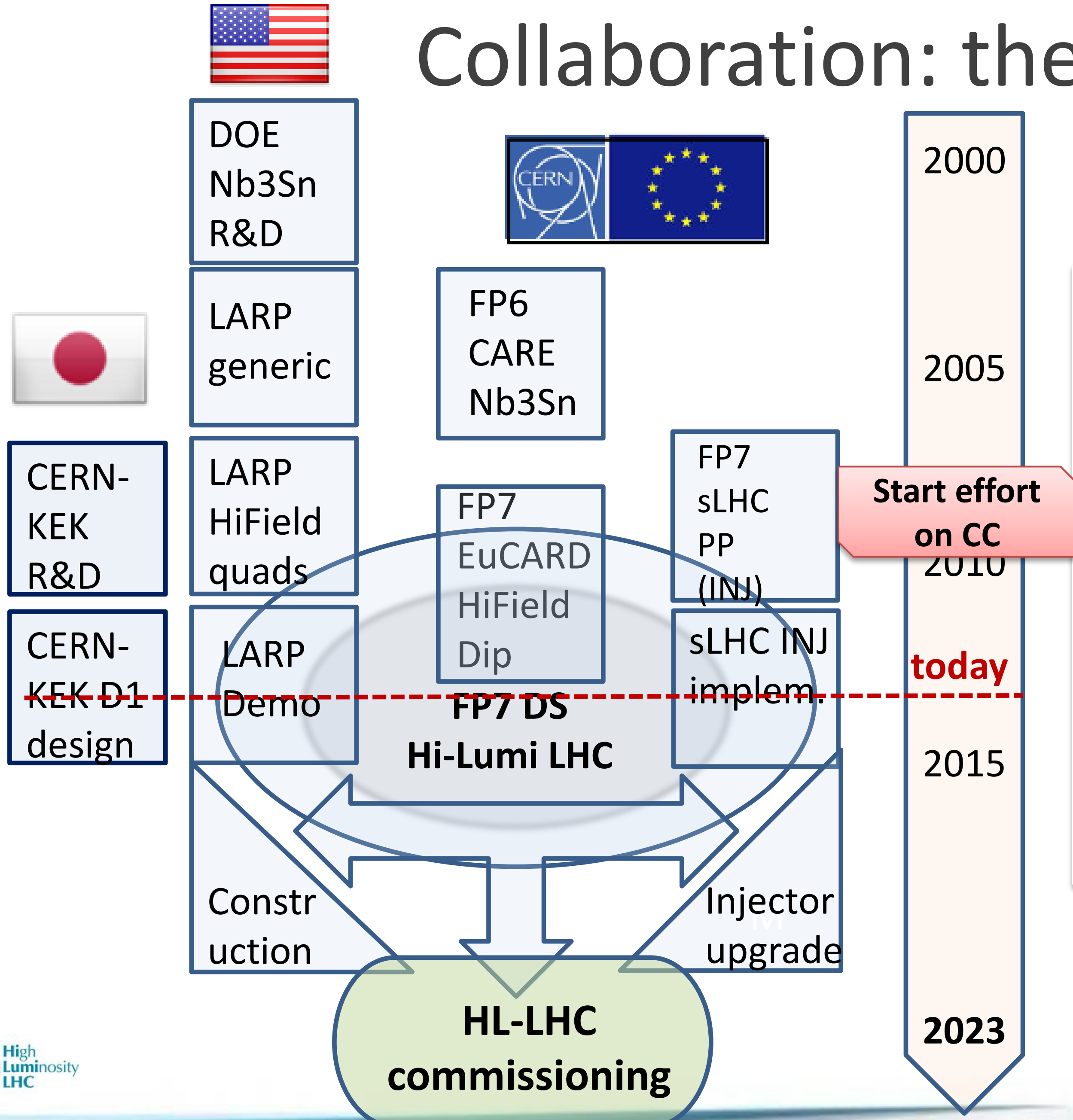
Paolo Fessia, CERN

WP16 Hardware Commissioning
Mirko Pojer, CERN

WP18 High Field Magnets
Gijs de Rijk, CERN
François Kircher, CEA

R&D and Study

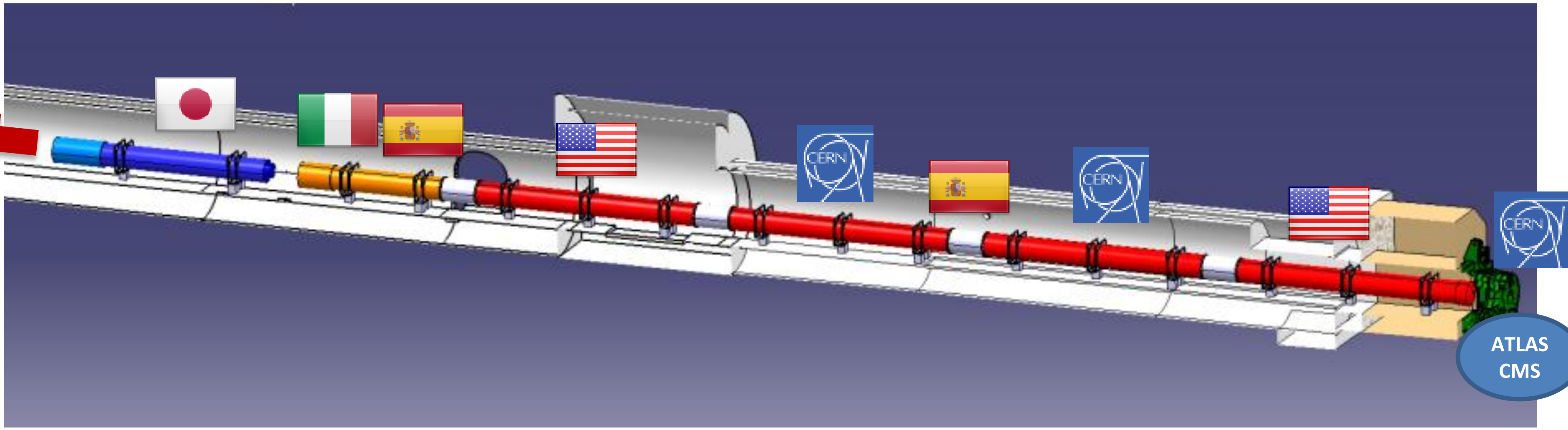
Collaboration: the long way

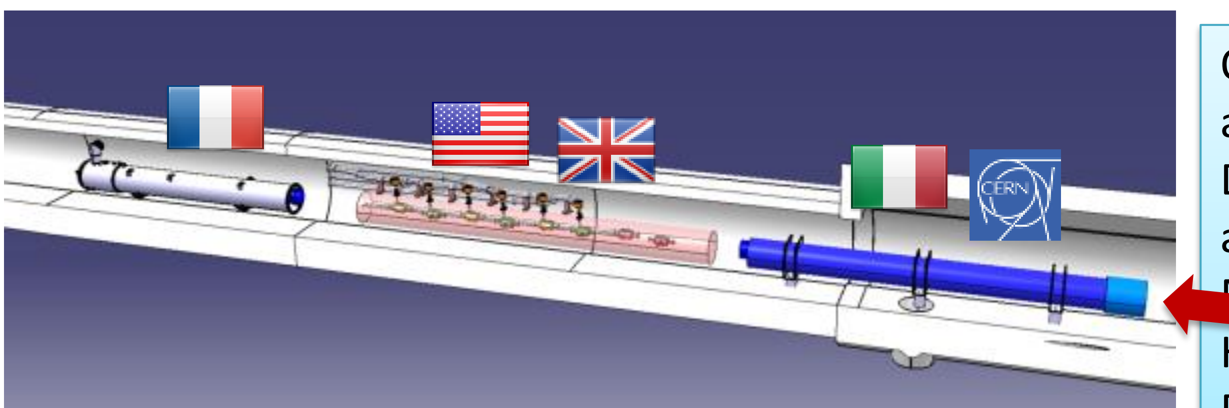


The HL-LHC project formally started in 2010; however it is the focal point of 20 years of <u>converging</u> International Collaboration

High Luminosity LHC Participants

In-kind contribution and Collaboration for HW design and prototypes



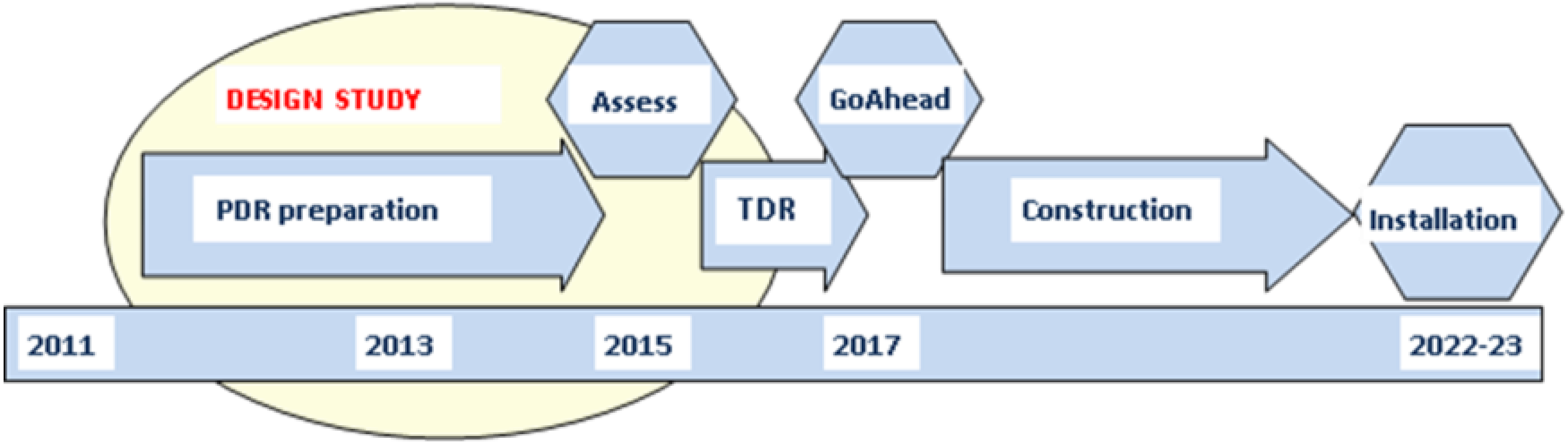


Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

CC : R&D, Design and in-kind **USA**

CC : R&D and Design **UK**

Implementation plan



- All WP active, from diagnostics to Machine Protection;
- Integration started with vigour as well as QA (workshop soon)
- Cryo, SC links, Collimators, Diagnostics, etc. starts in LS2 (2018)
- Proof of main hardware by 2016; Prototypes by 2017
- Start construction 2017/18 from IT, CC, other main hardware
- IT String test (integration) in 2019-20; Main Installation 2022-23
- Though but – based on LHC experience – feasible
- Cost: 810 MCHF (Material, CERN accounting). Now fully funded (wiht in-kind).