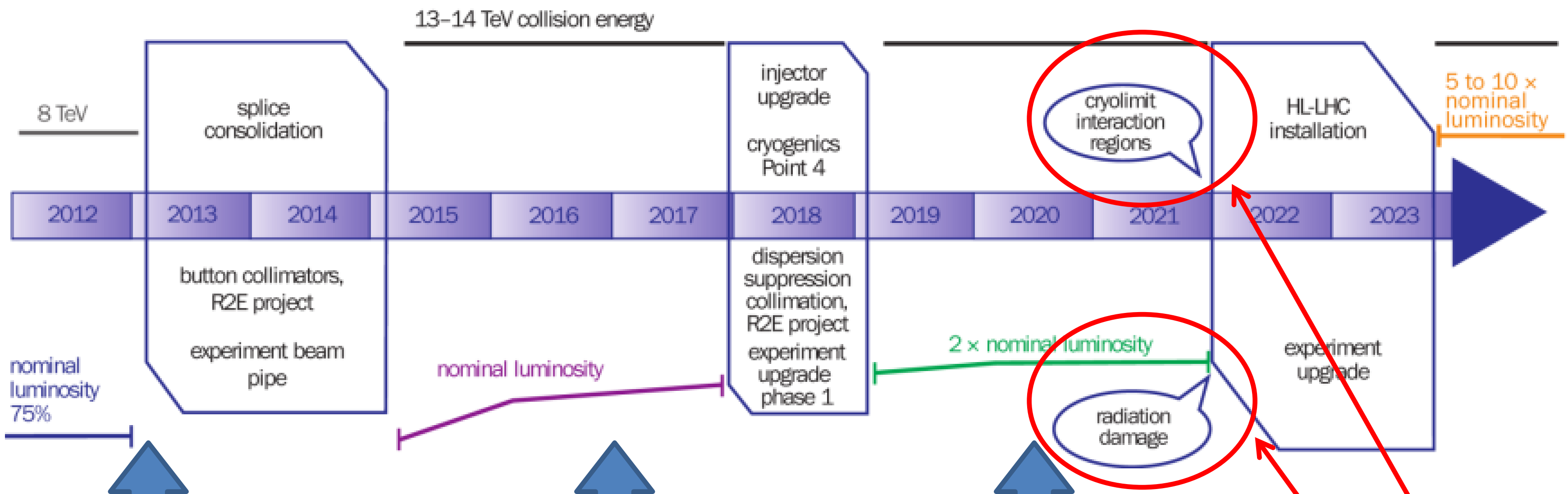
The HL-LHC project

Lucio Rossi - CERN
For the HL-LHC project team

HL-LHC kick-off meeting – Daresbury 11 November 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)



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

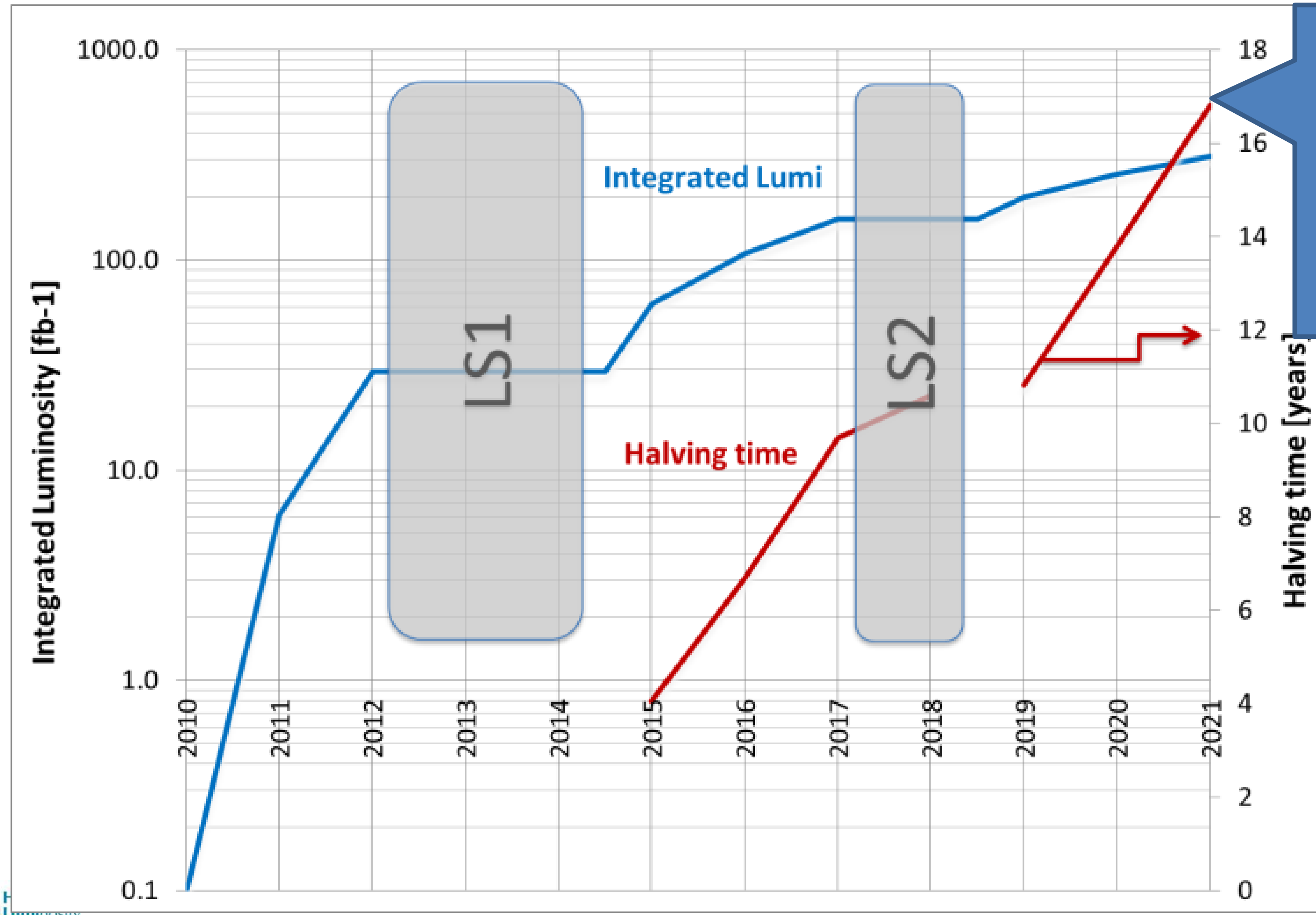
$1.5\ 10^{34}\ cm^{-2}s^{-1}$
25 ns bunch
pile up ~40

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

Technical limits (experiments, too) like :

High Luminosity LHC

Mantain and increase physics reach



Necessity of a jump in luminosity (useful luminosty ⇒ data quality)

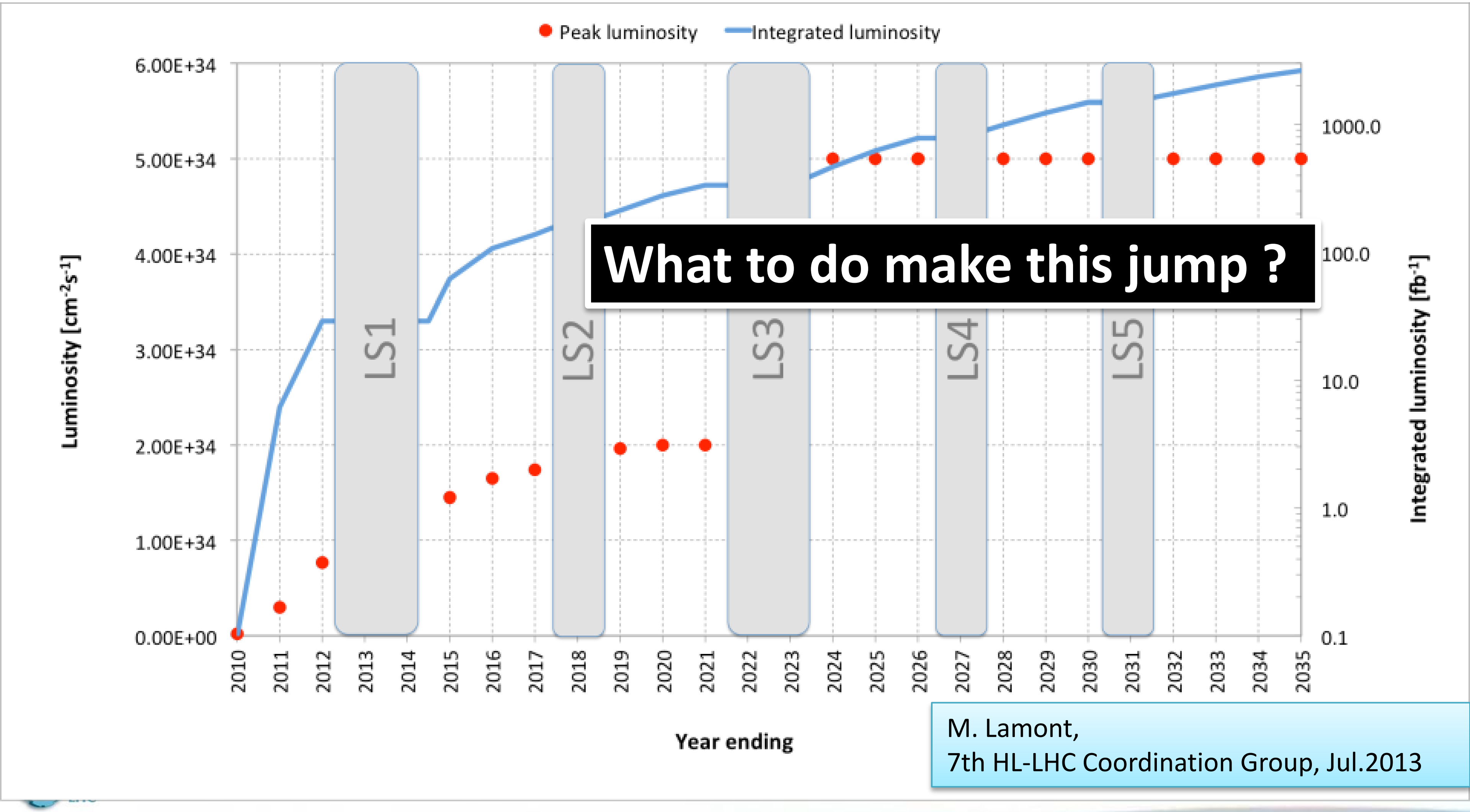
Goal of High Luminosity LHC (HL-LHC) as fixed in November 2010

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:

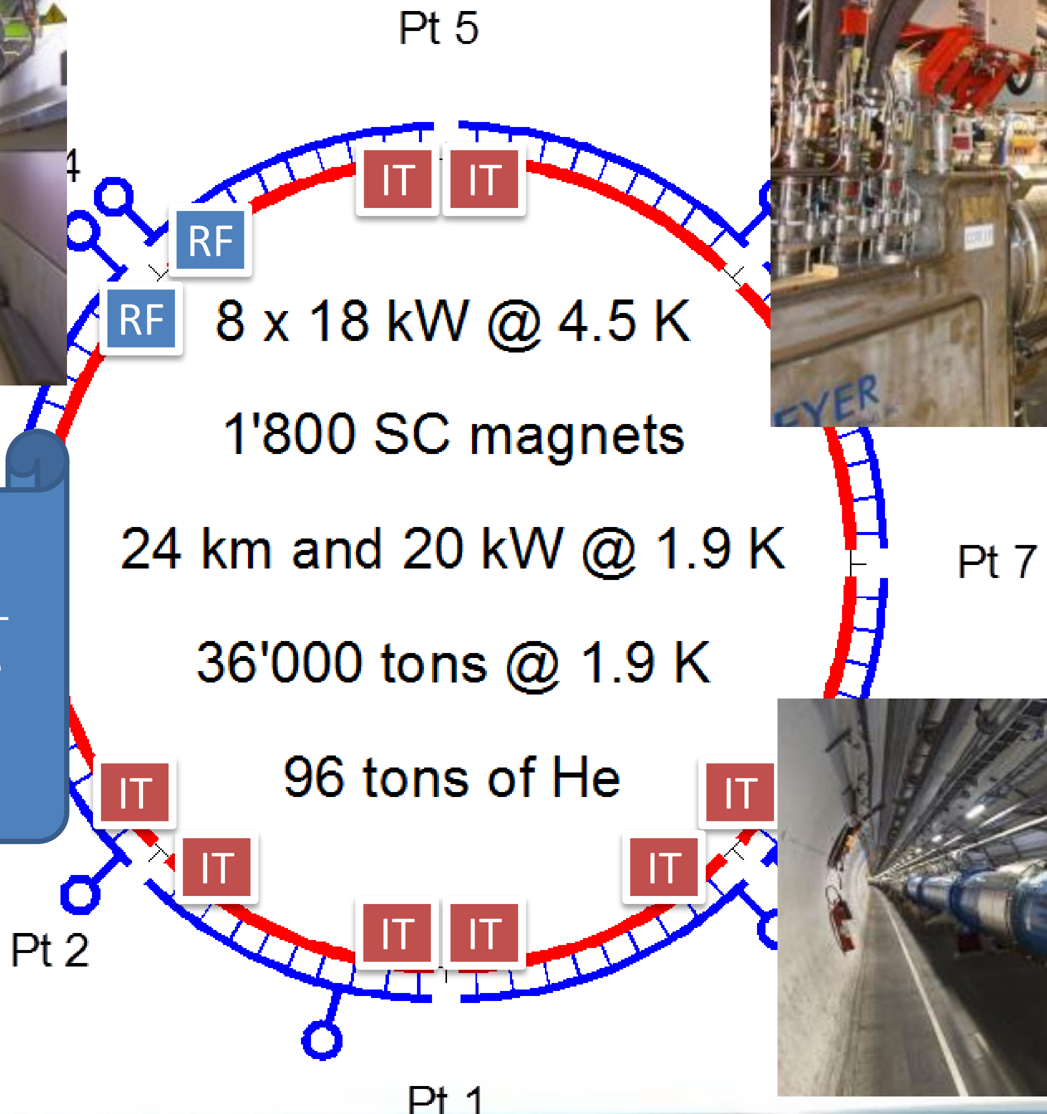
An integrated luminosity of **250 fb^{-1} per year**, enabling the goal of **3000 fb^{-1}** twelve years after the upgrade.
This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

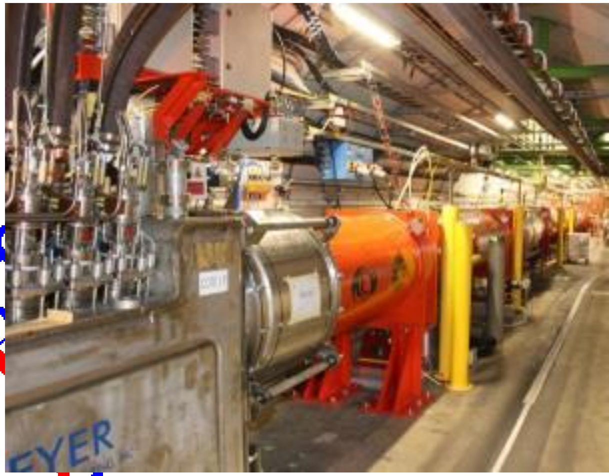
This goal would be reached in 2036



M. Lamont,
7th HL-LHC Coordination Group, Jul.2013

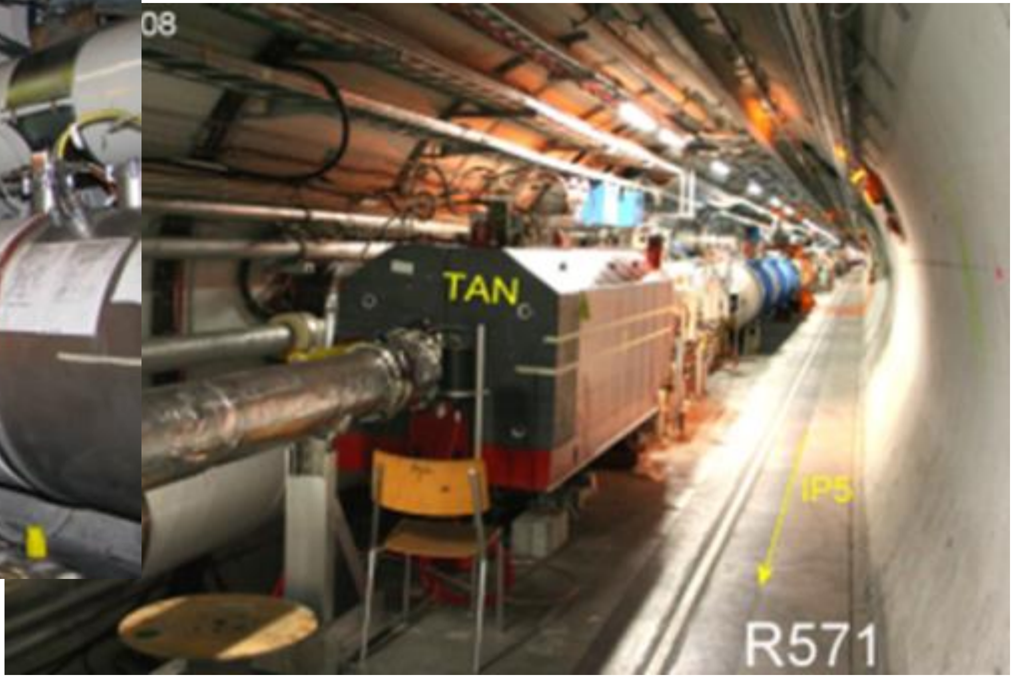
Technical bottlenecks
Cryogenics P4





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)

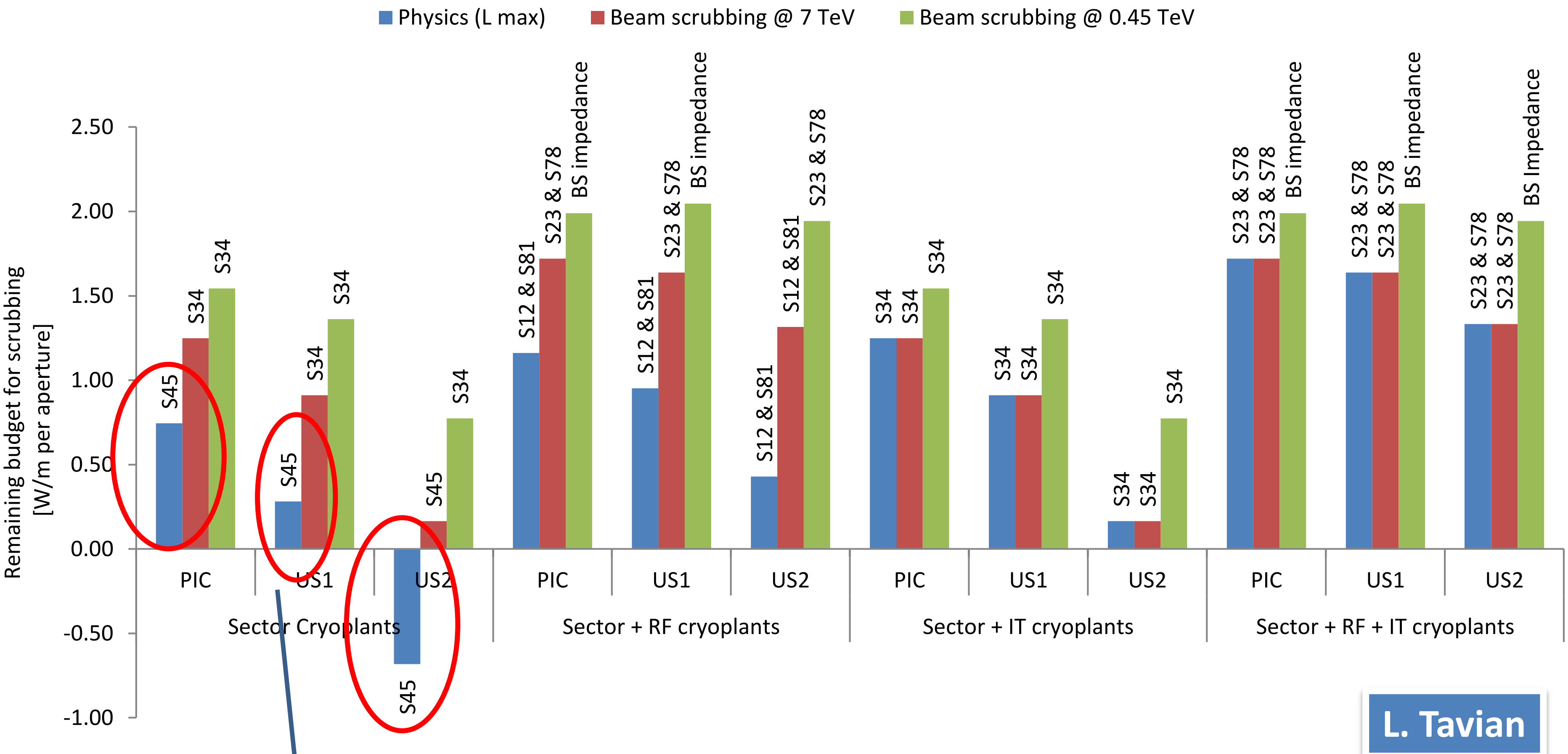
Triplet and MS connection to main arc



The cryoline is continous between the Continuous cryostat (Regular lattice Arc and DS Arc) and the MS-IT zones. This connections have consequences:

- Makes a limitation in cryopower since the IT zone will increase the power deposited with the lumi increase
- A stop in the MS or IT zone would entail a thermal cycle on the entire Sector

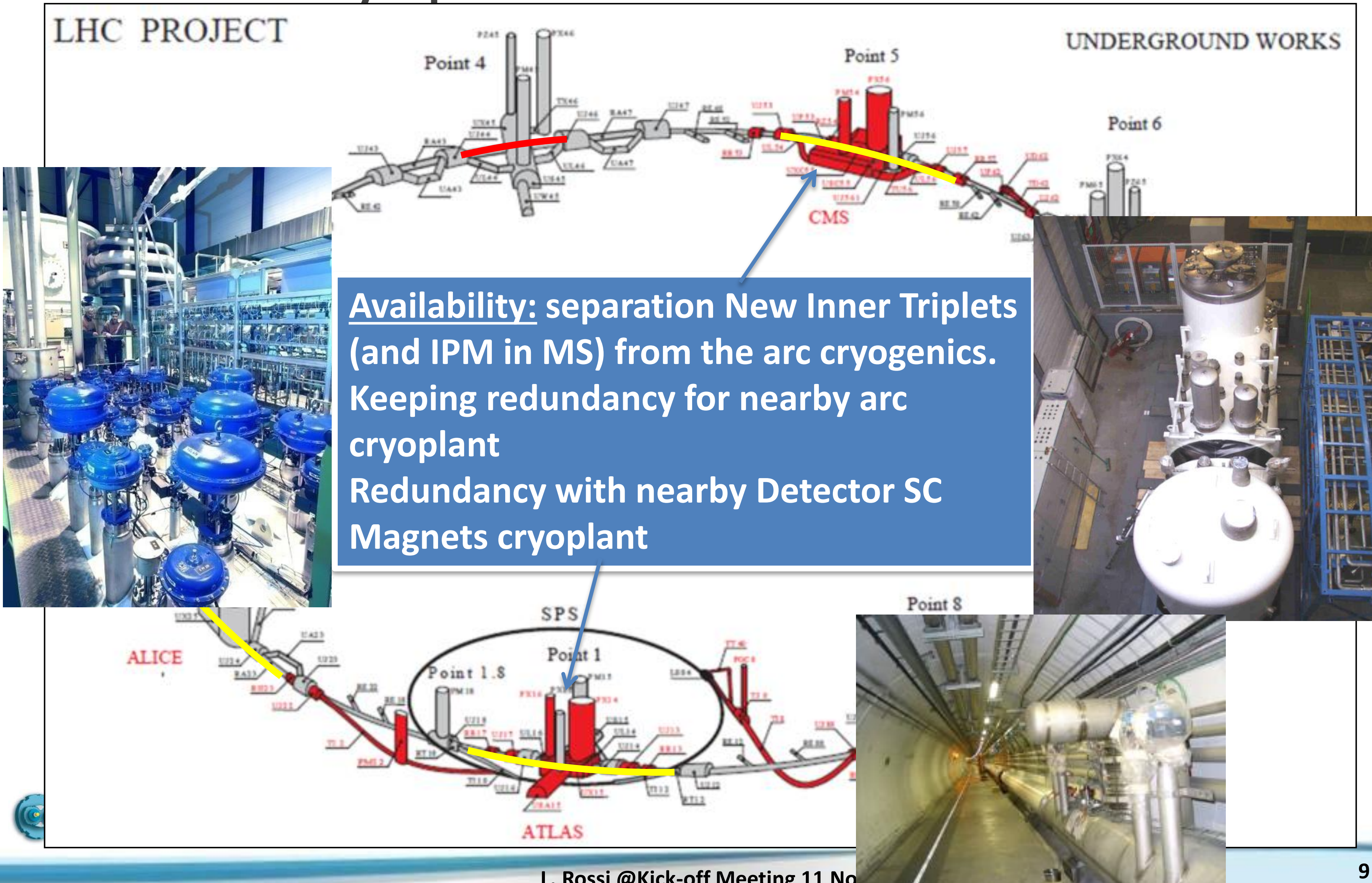
Cryogenic load: sector 4



All existing margins already «used» at around 2 10^{34} (like cryostat consumption 30% less than design)

High Luminosity LHC

IT cryoplants and new LSS QRL

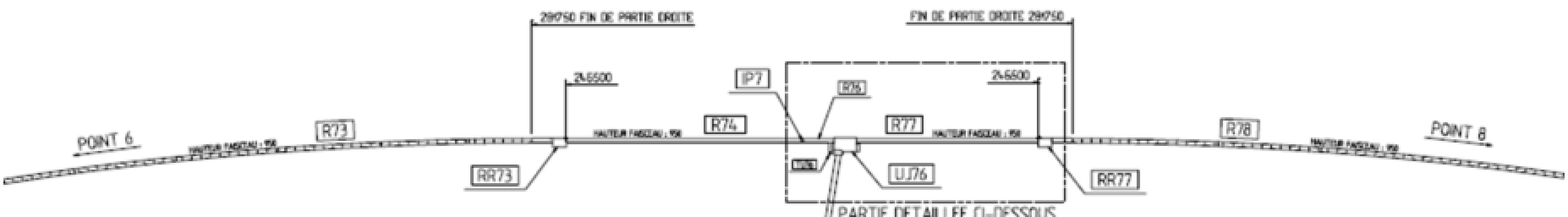


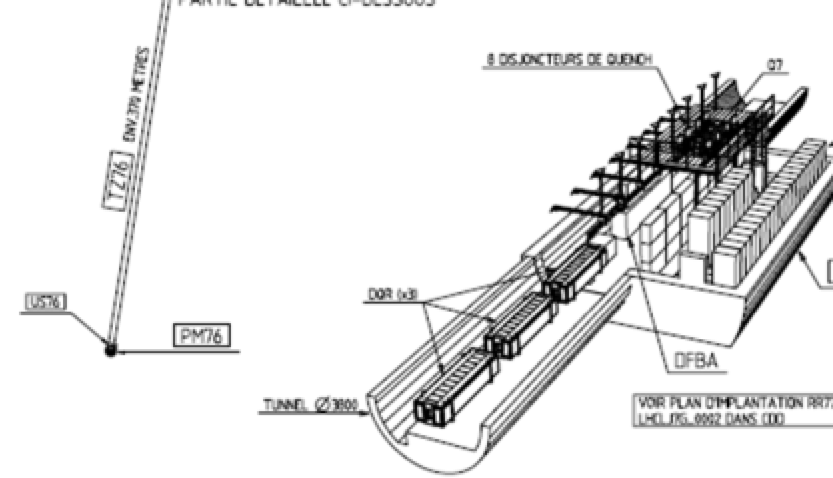
<u>Availability:</u> **separation New Inner Triplets (and IPM in MS) from the arc cryogenics.**

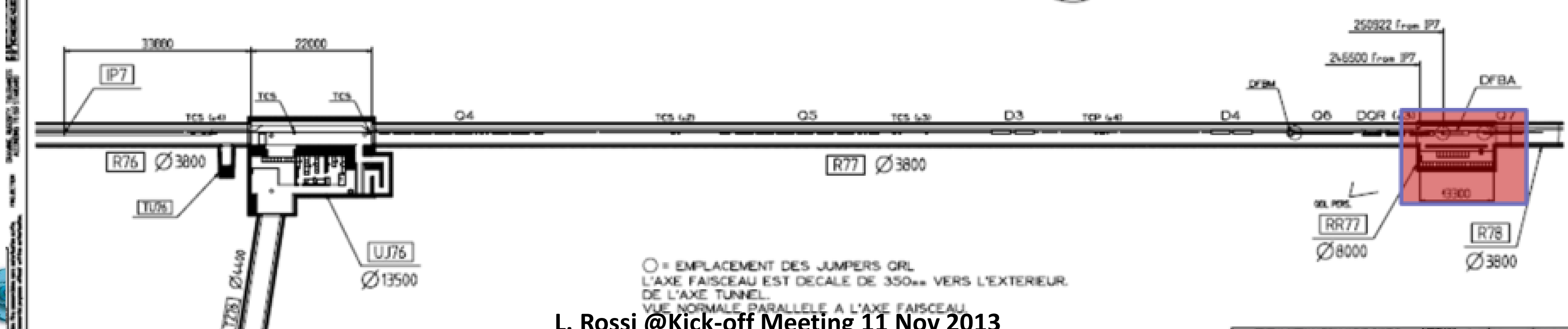
Keeping redundancy for nearby arc cryoplant

Redundancy with nearby Detector SC Magnets cryoplant

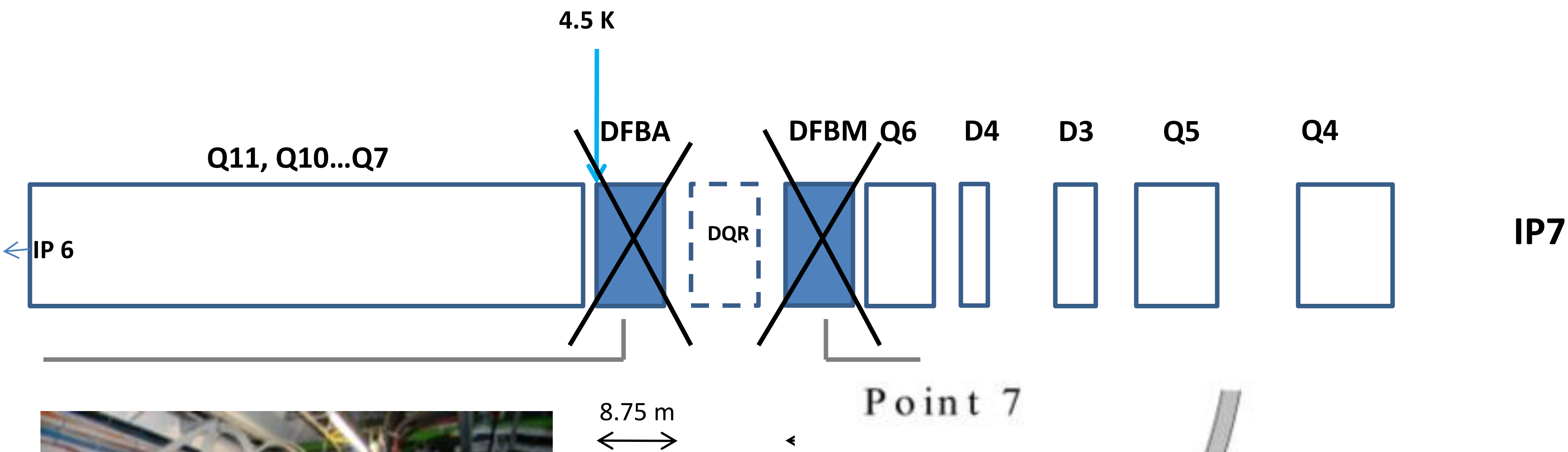
P7 : EPC and DFB near collimators



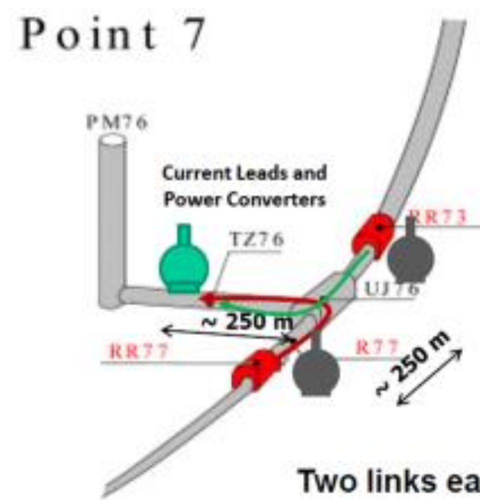




Displacing EPC and DFB in the adjacent TDZ tunnel (~ 500 m away) via SC links

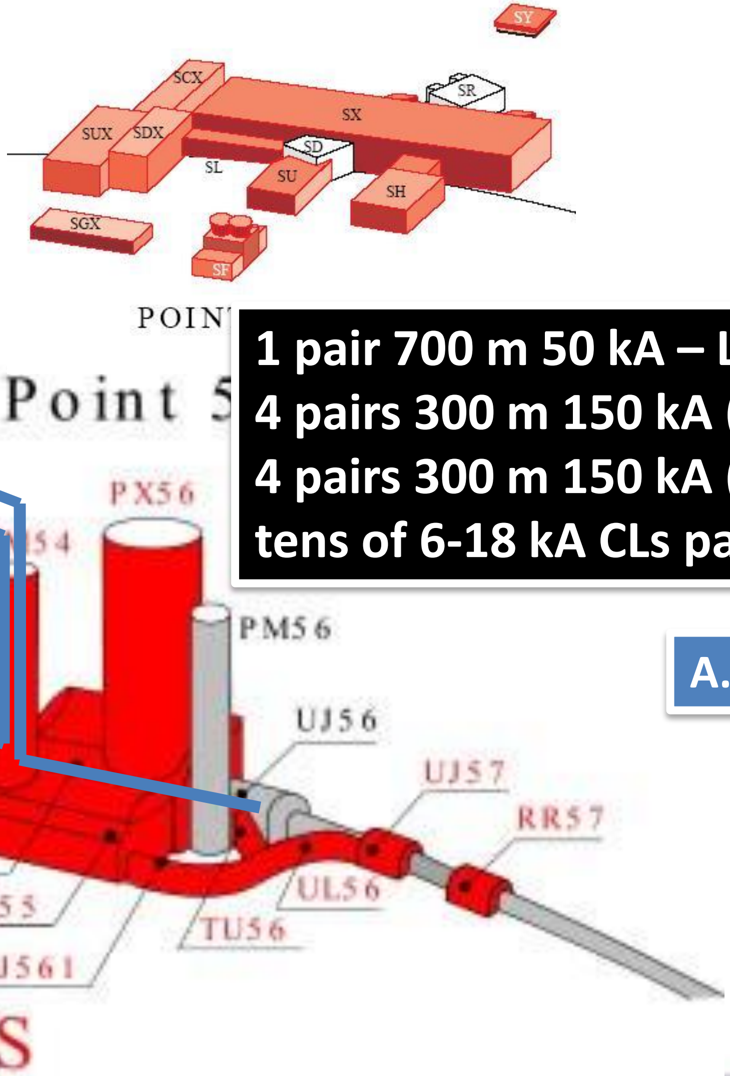


RR 73



Two links each about 500 m long
48 cables rated at 600 A per link

Availability: SC links ⇒removal of EPCs, DFBs from tunnel to surface



2×150 kA

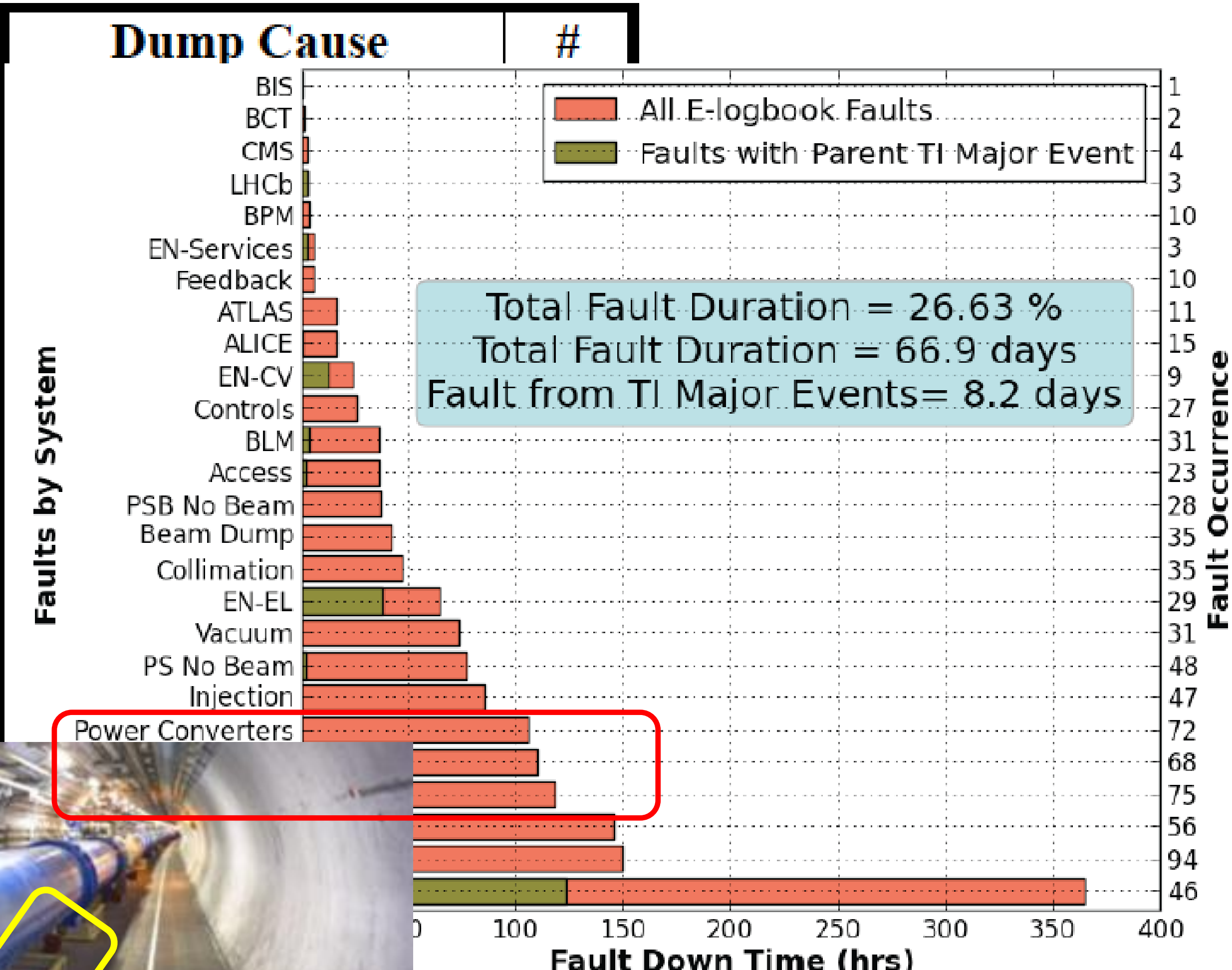
1 pair 700 m 50 kA – LS2
4 pairs 300 m 150 kA (MS)– LS3
4 pairs 300 m 150 kA (IR) – LS3
tens of 6-18 kA CLs pairs in HTS

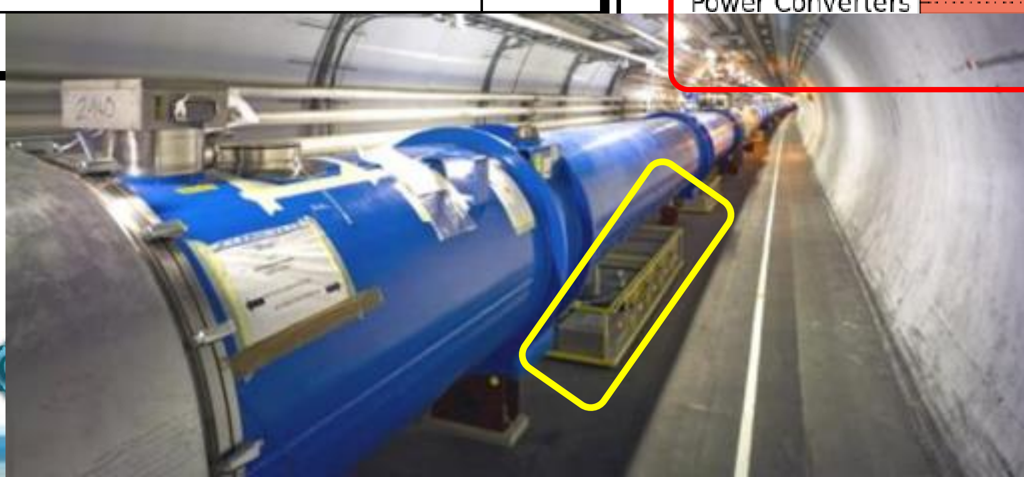
A. Ballarino


L = 20 m
(25×2) 1 kA @ 25 K, LHC Link P7

QPS boxes and intervention time

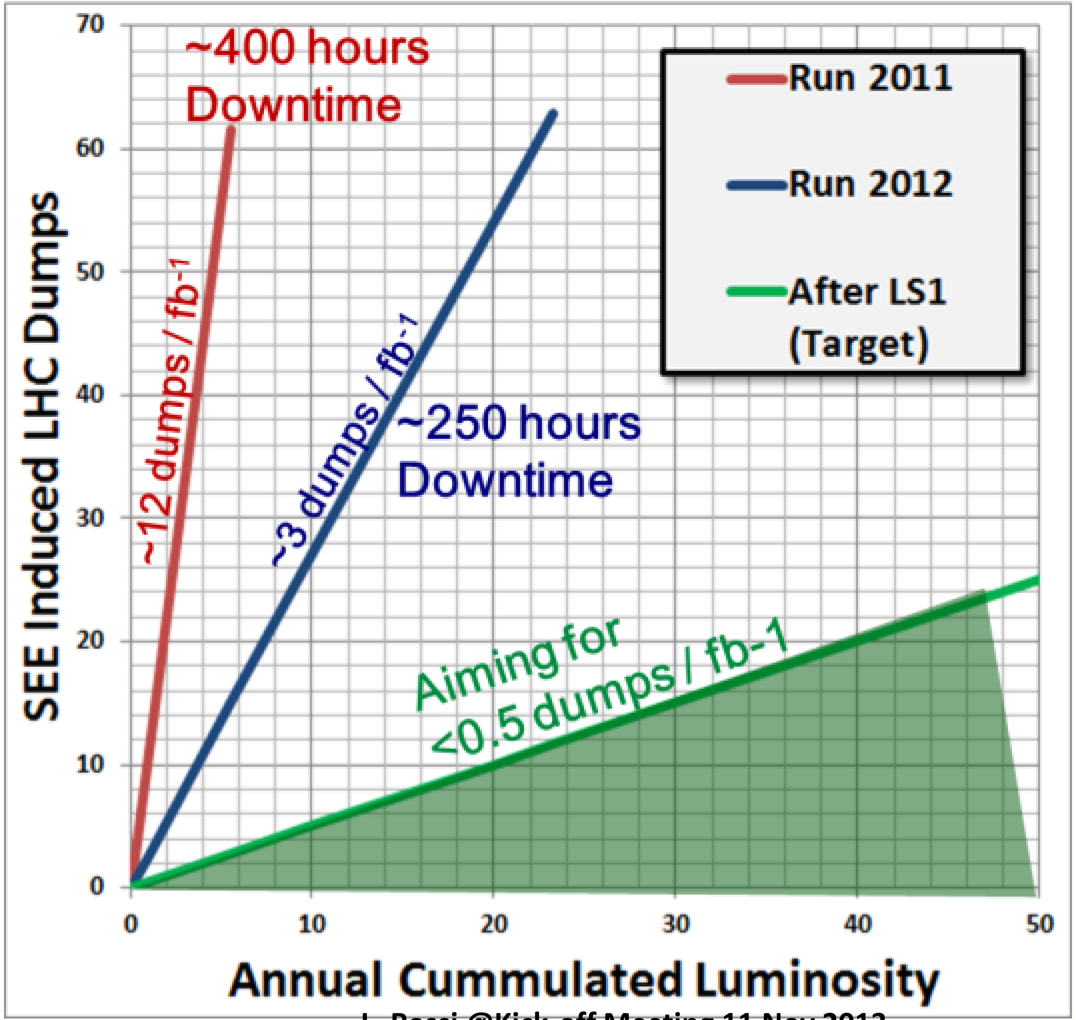
Dump Cause	#
Beam: Losses	58
Quench Protection	56
Power Converter	35
Electrical Supply	26
RF + Damper	23
Feedback	19
BLM	18
Vacuum	17
Beam: Losses (UFO)	15
Cryogenics	14
Collimation	12





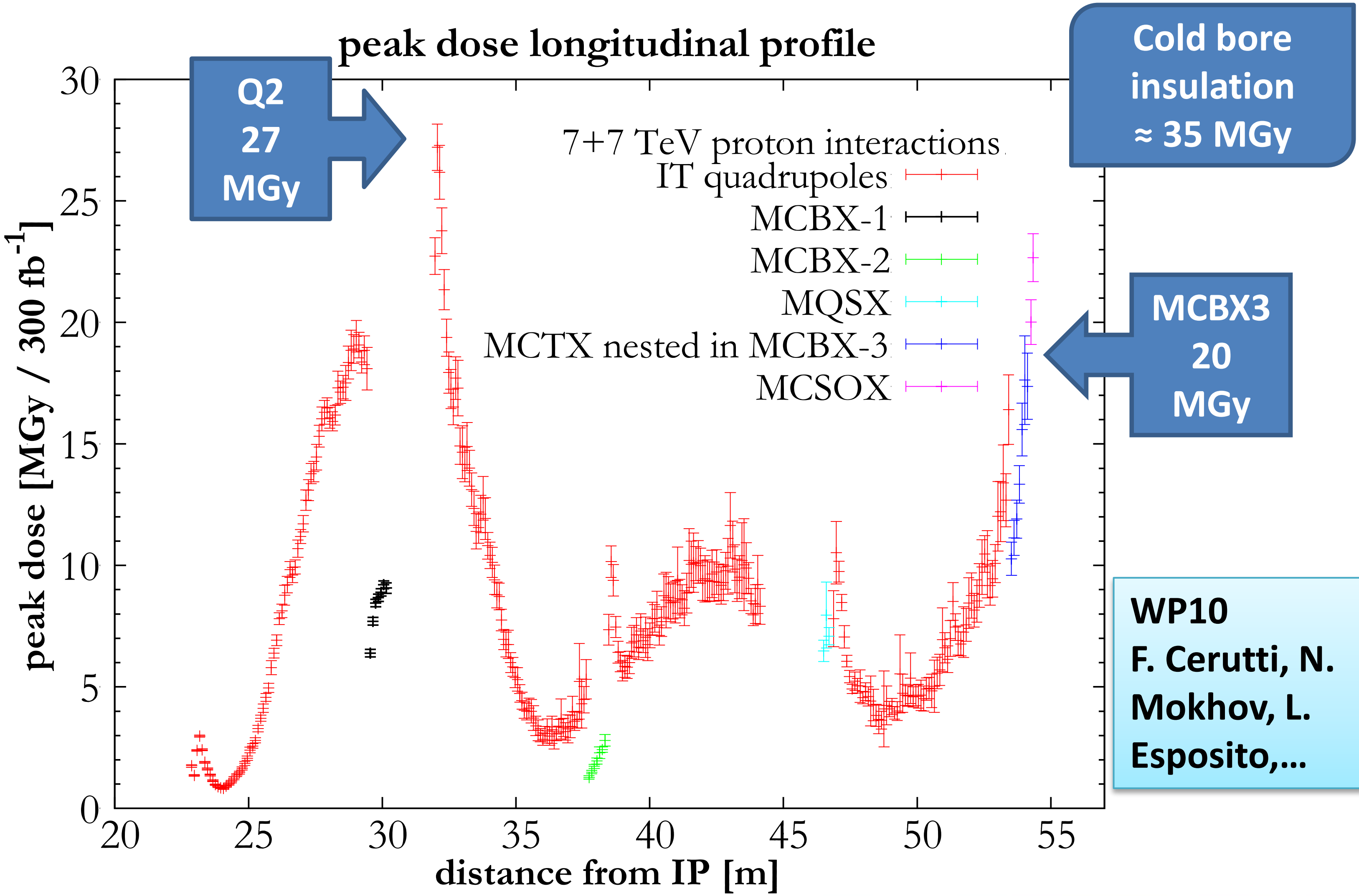
Consolidation of infrastructure !
But also new paradigma: remove from tunnel of QPS (as much as possible)

R2E improvement. Need further for 1-3 fb^{-1}/day!



M. Brugger

The big technical bottleneck: Radiation damage to triplet



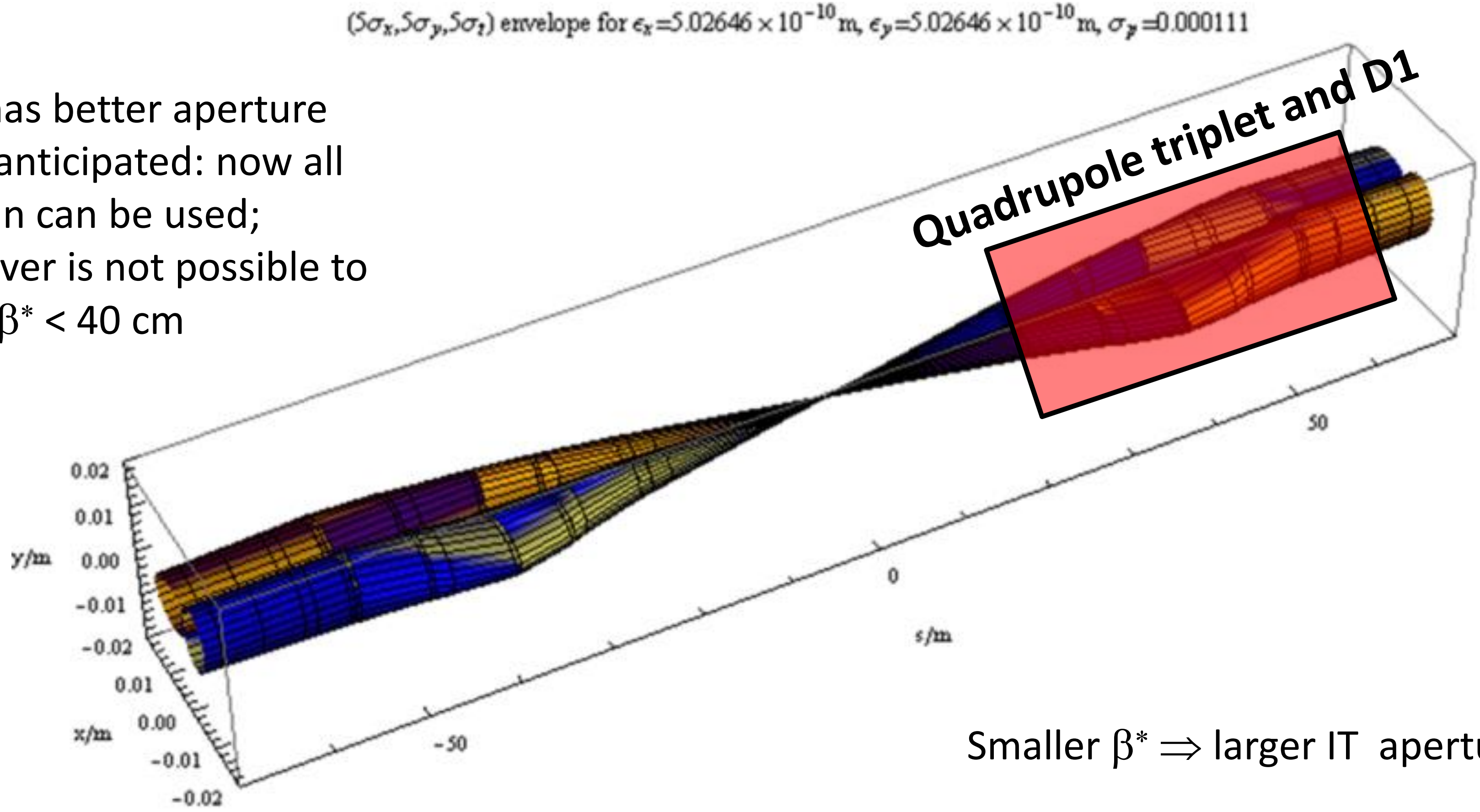
WP10
F. Cerutti, N. Mokhov, L. Esposito,…

High Luminosity LHC

L. Rossi @Kick-off Meeting 11 Nov 2013

The most straight forward action: reducing beam size with a «local» action

LHC has better aperture than anticipated: now all margin can be used; however is not possible to have $\beta^* < 40$ cm



Smaller $\beta^* \Rightarrow$ larger IT aperture

Parameters (PLC web page)

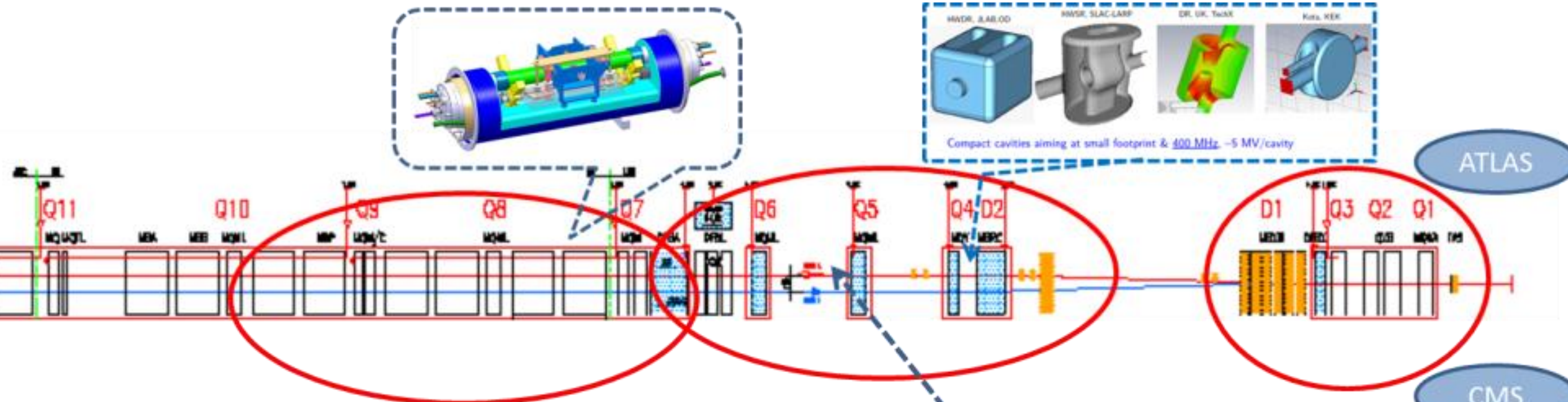
https://espace.cern.ch/HiLumi/PLC/default.aspx

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

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

High Luminosity LHC

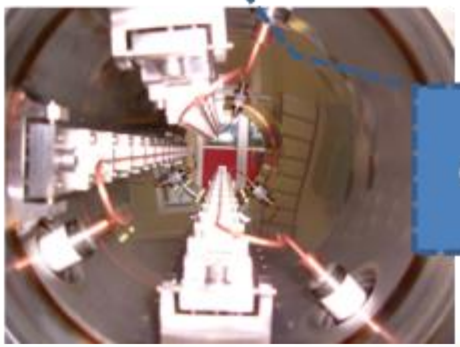
The critical zone around IP1 and IP5



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



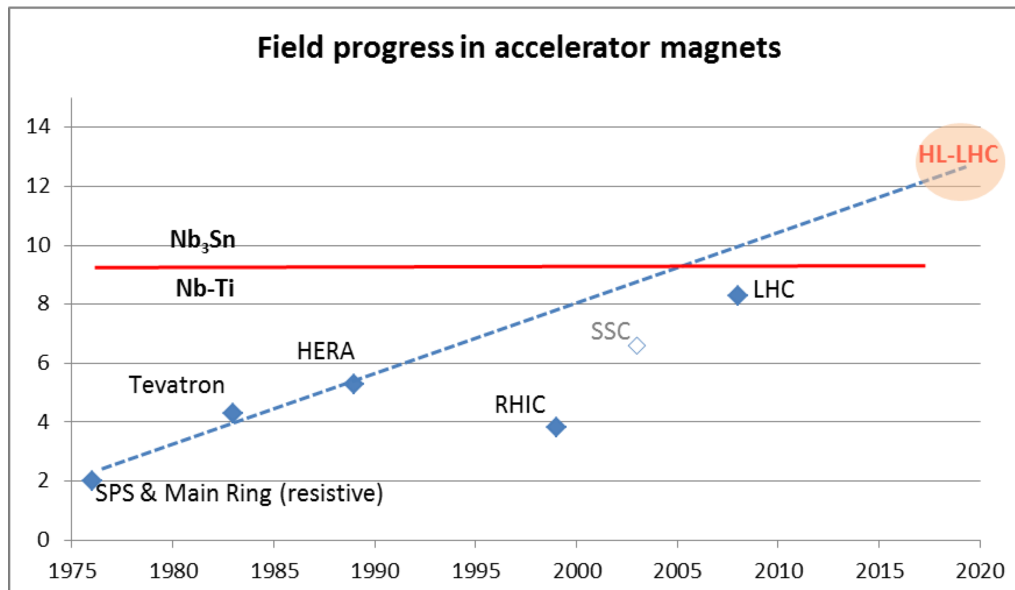
4. LR BB compensation wires

1.2 km of LHC !!

High Luminosity LHC

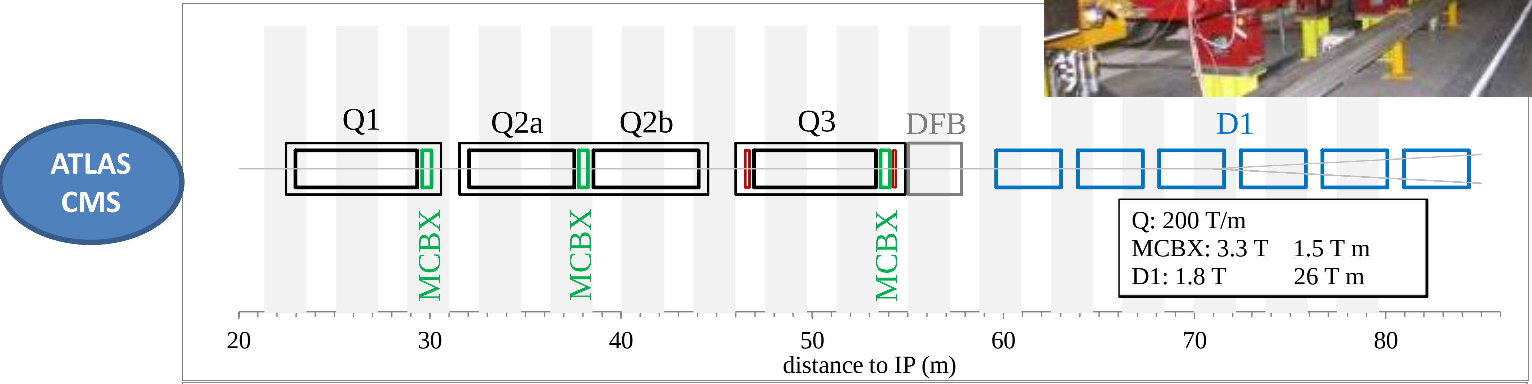
Magnet the progress

- LHC dipoles features 8.3 T in 56 mm (designed for 9.3 peak field)
- LHC IT Quads features 205 T/m in 70 mm with 8 T peak field
- HL-LHC
  - 11 T dipole (designed for 12.3 T peak field, 60 mm)
  - New IT Quads features 140 T/m in 150 mm > 12 T operational field, designed for 13.5 T).



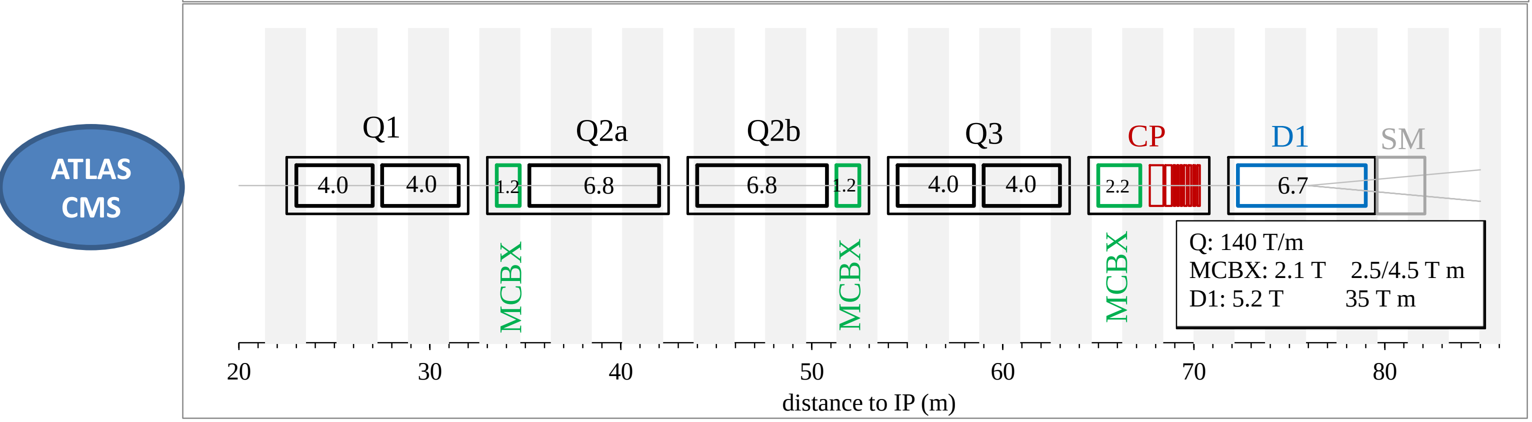
New Interaction Region lay out

Longer Quads; Shorter D1 (thanks to SC)



LHC

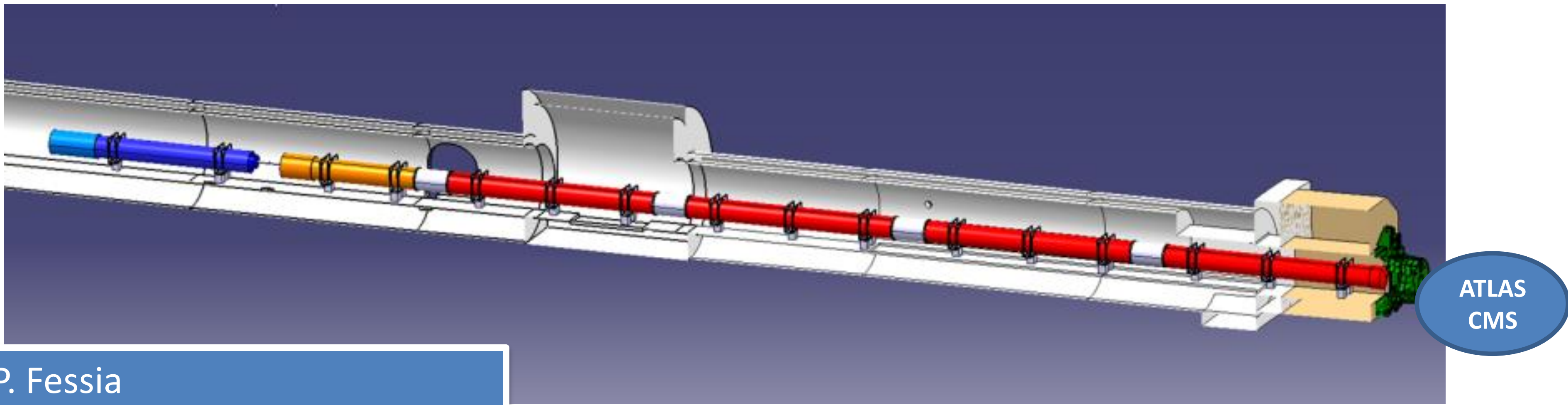
E. Todesco



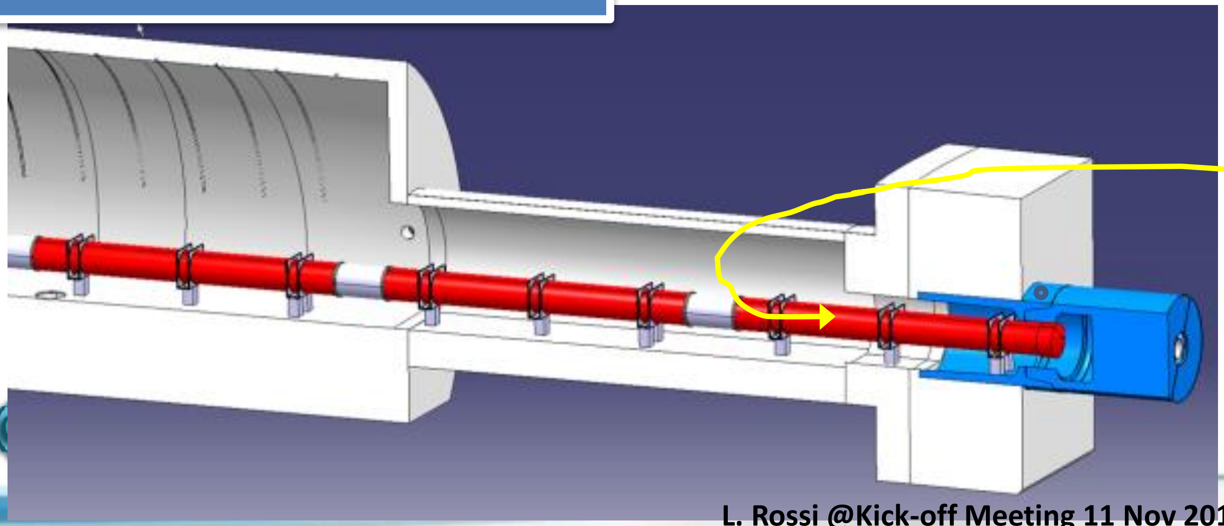
HL LHC

Thick boxes are magnetic lengths -- Thin boxes are cryostats

Integration view of IT zone

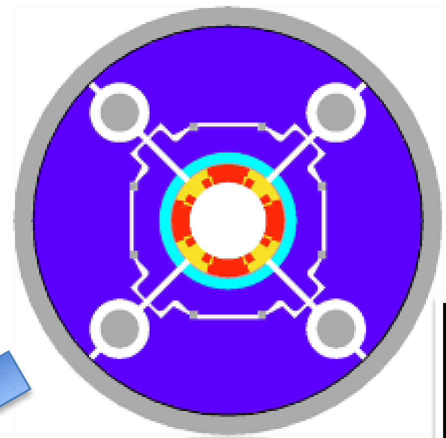


P. Fessia
JP Corso and EN-MEF int. team



LHC low-β quads: steps in magnet technology from LHC toward HL-LHC

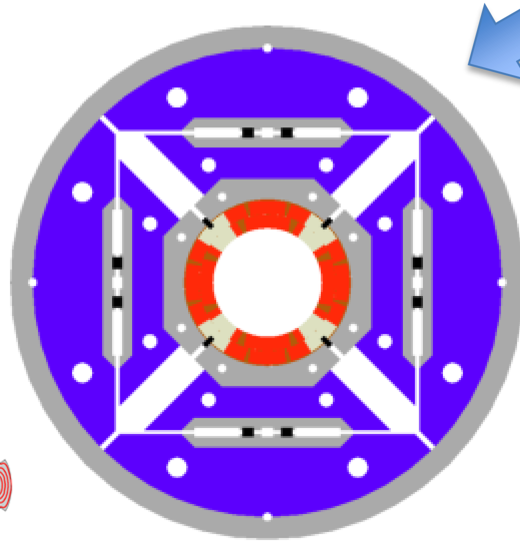
LHC (USA & JP, 5-6 m)
∅70 mm, B_{peak}~ 8 T
1992-2005

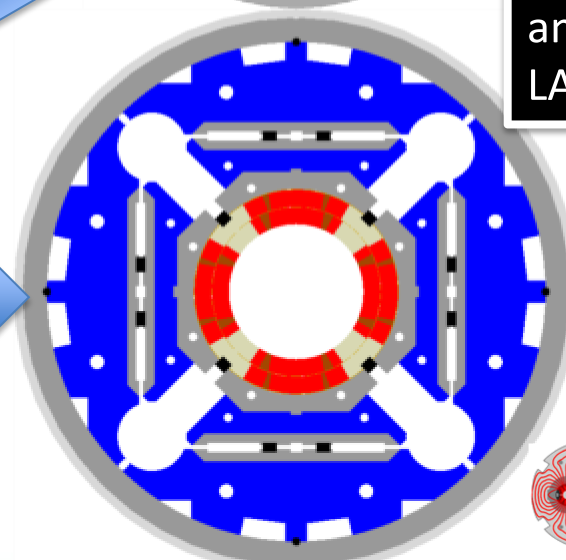


LARP TQS & LQ (4m)
∅90 mm, B_{peak}~ 11 T
2004-2010

New structure based on bladders and keys (LBNL, LARP)

LARP HQ
∅120 mm,
B_{peak}~ 12 T
2008-2014





LARP & CERN
MQXF
∅150 mm,
B_{peak}~ 12.1 T
2013-2020

Progress in MQXF (IT quads)

- First short coils for practice winding fabricated with plastic part completed
- Cu cable by CERN
- Both layer wound and cured
- Nb3Sn cable by LARP
- External review of spacer design in 10/13
- 2 additional short coils planned in Nov/Dec, 2013
- End spacers version v3
- Fabrication of metal end-spacers for first coil early 2014

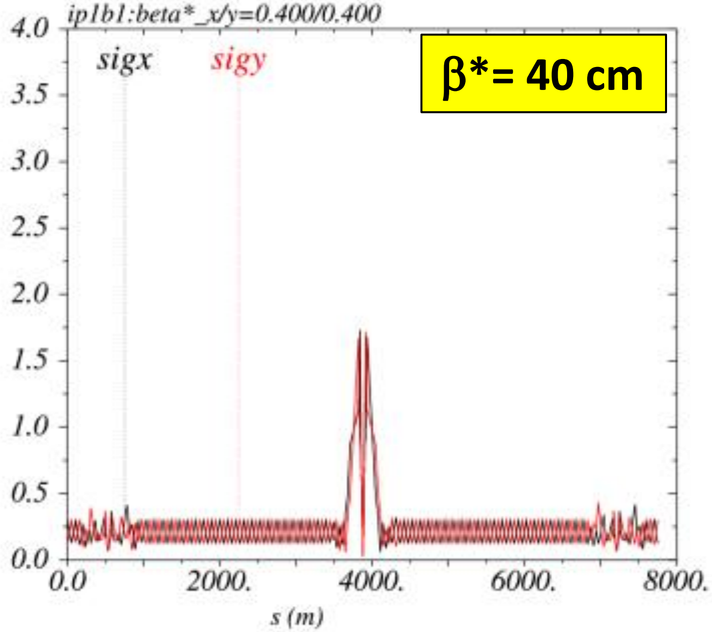
G. Ambrosio – LARP & P. Ferracin - CERN

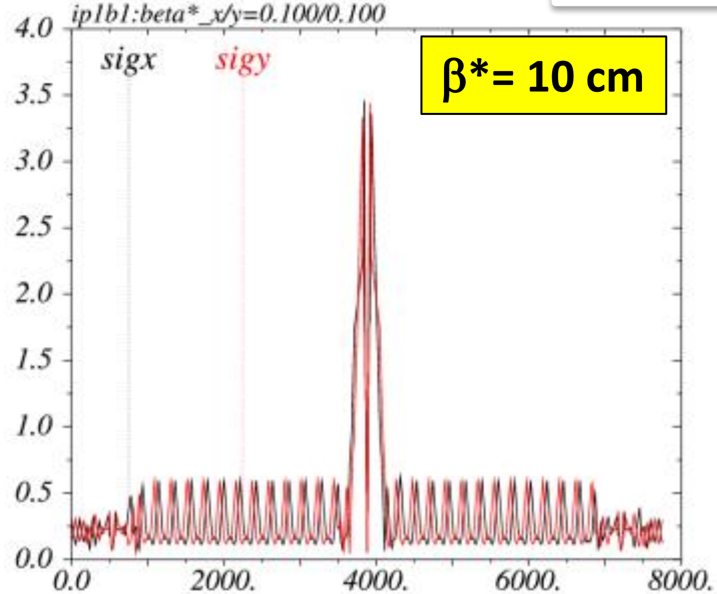
The **Achromatic Telescopic Squeezing** (ATS) scheme

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)



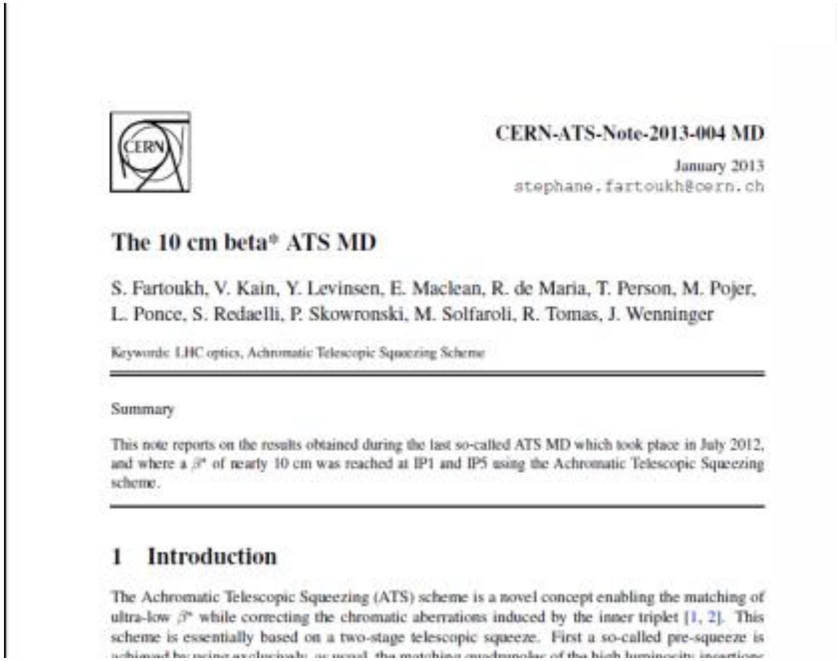


The new IR is sort of 8 km long !

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

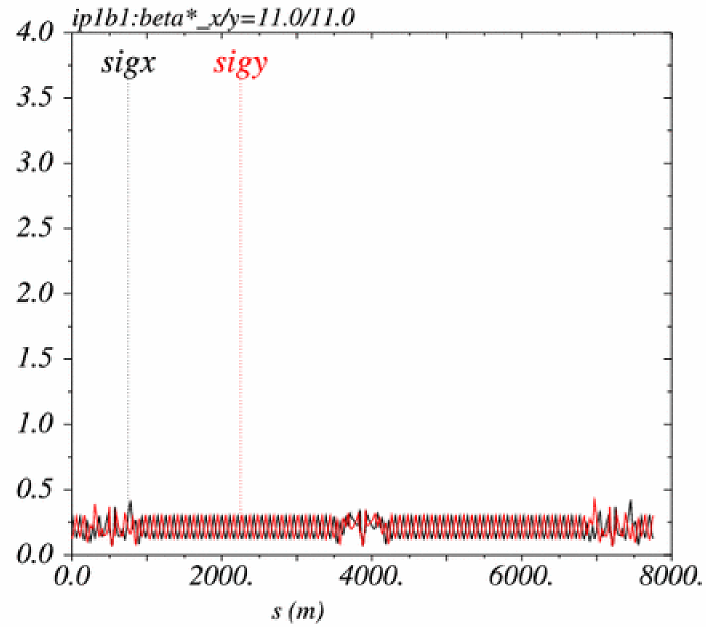
Keywords: LHC optics, Achromatic Telescopic Squeezing Scheme

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.

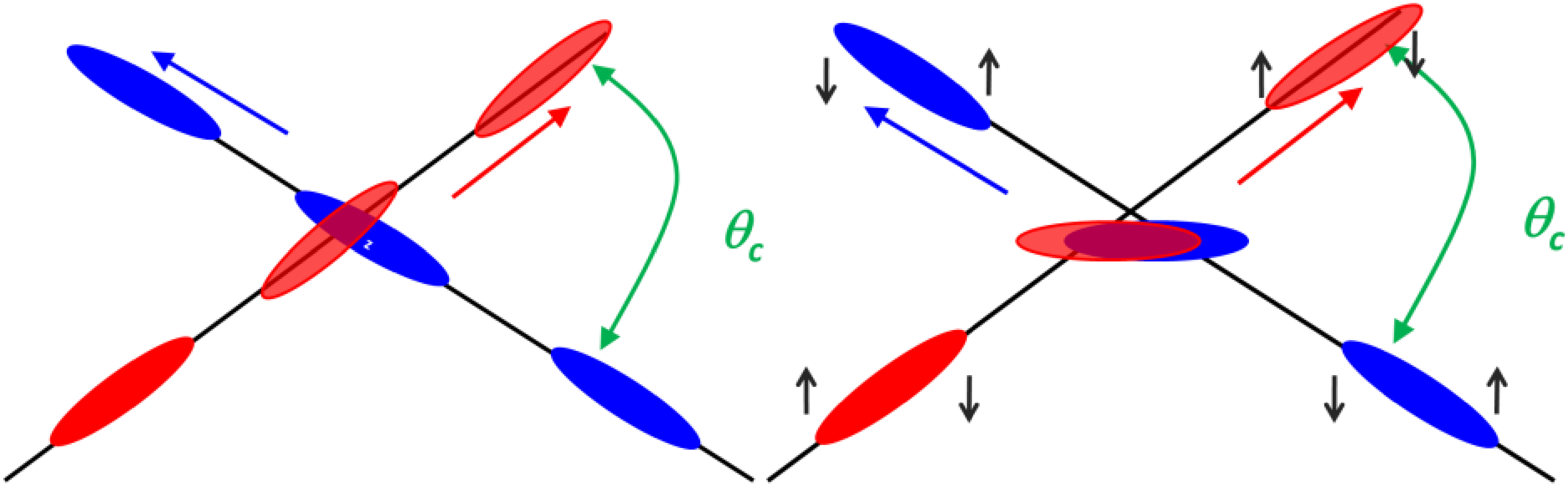
1 Introduction

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

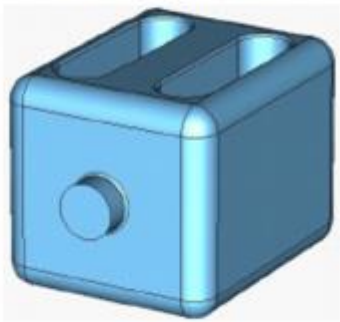
Effect of the crab cavities



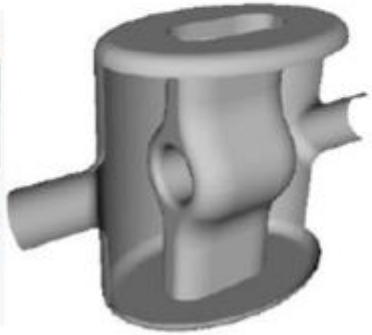
- **RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" and then luminosity is maximized**
- ***Crab cavity maximizes the lumi and can be used also for luminosity levelling: if the lumi is too high, initially you don't use it, so lumi is reduced by the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

Crab Cavity, for p-beam rotation **at 10 fs level!**

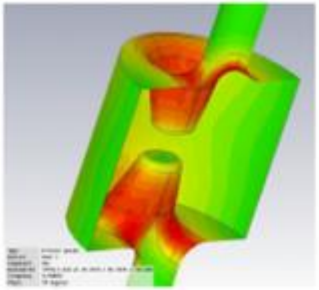
HWDR, JLAB,OD



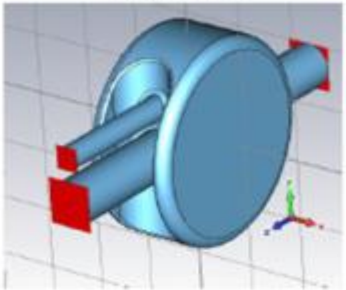
HWSR, SLAC-LARP



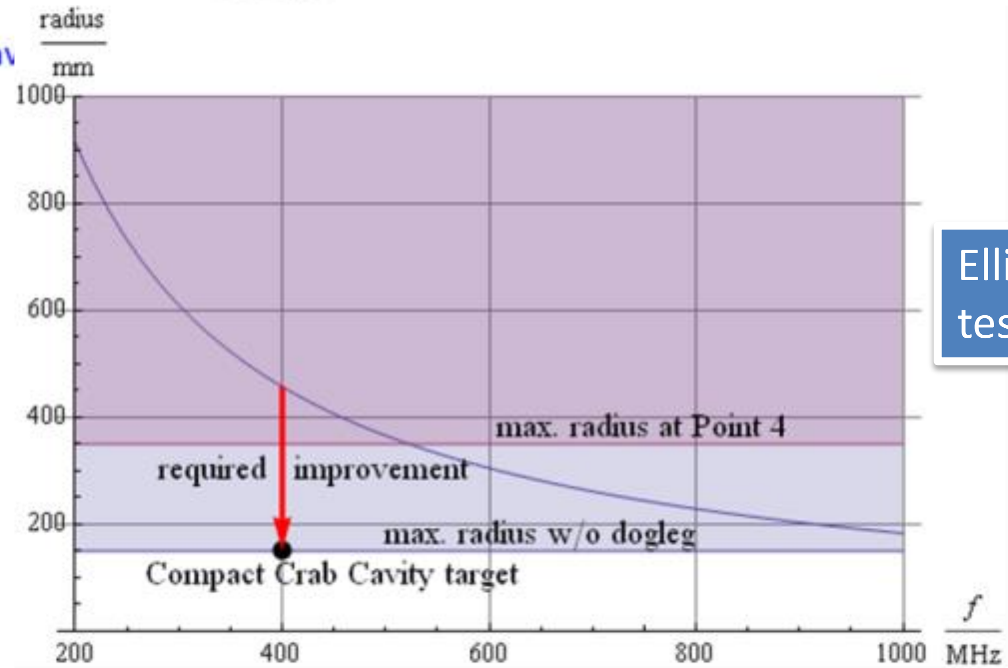
DR, UK, TechX



Kota, KEK



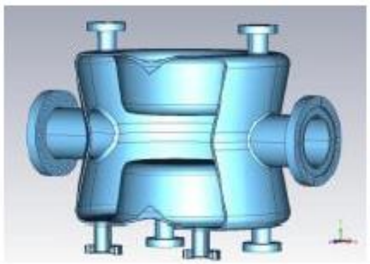
Compact cav

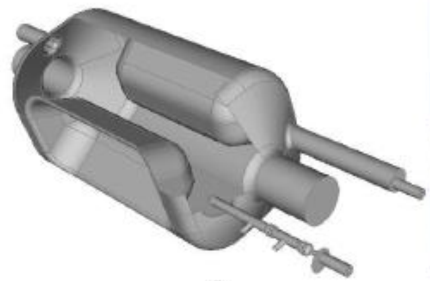


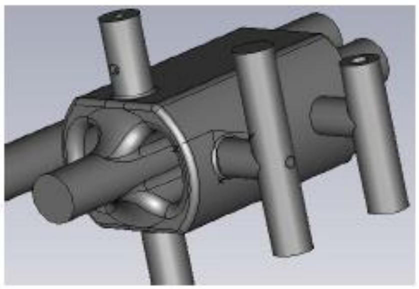
Elliptical type CC has been tested first in KEK 2008

Situation: from drawings to reality…

All Prototypes in Bulk Niobium (2011-12)







LARP-BNL

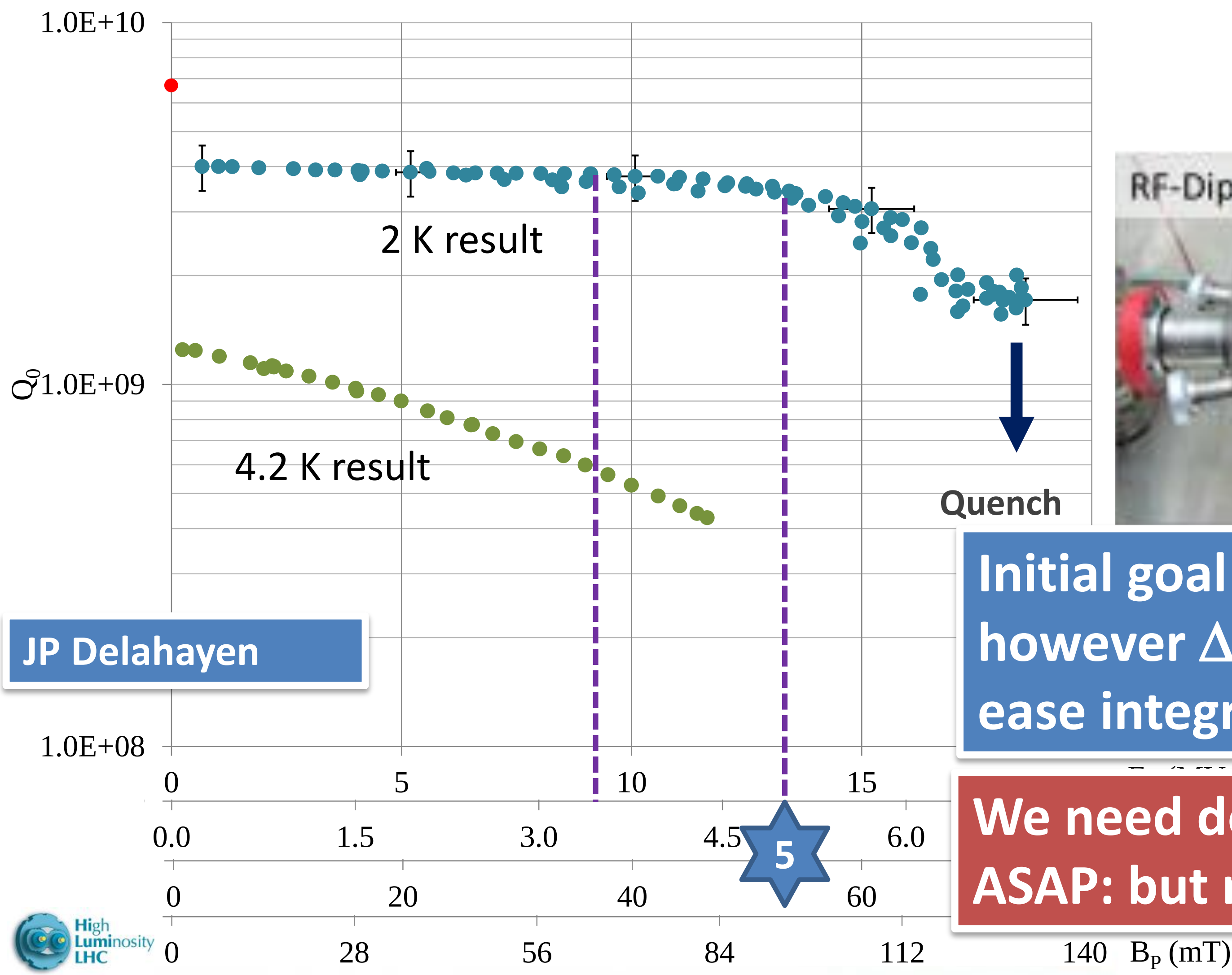
LARP-ODU-JLAB

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

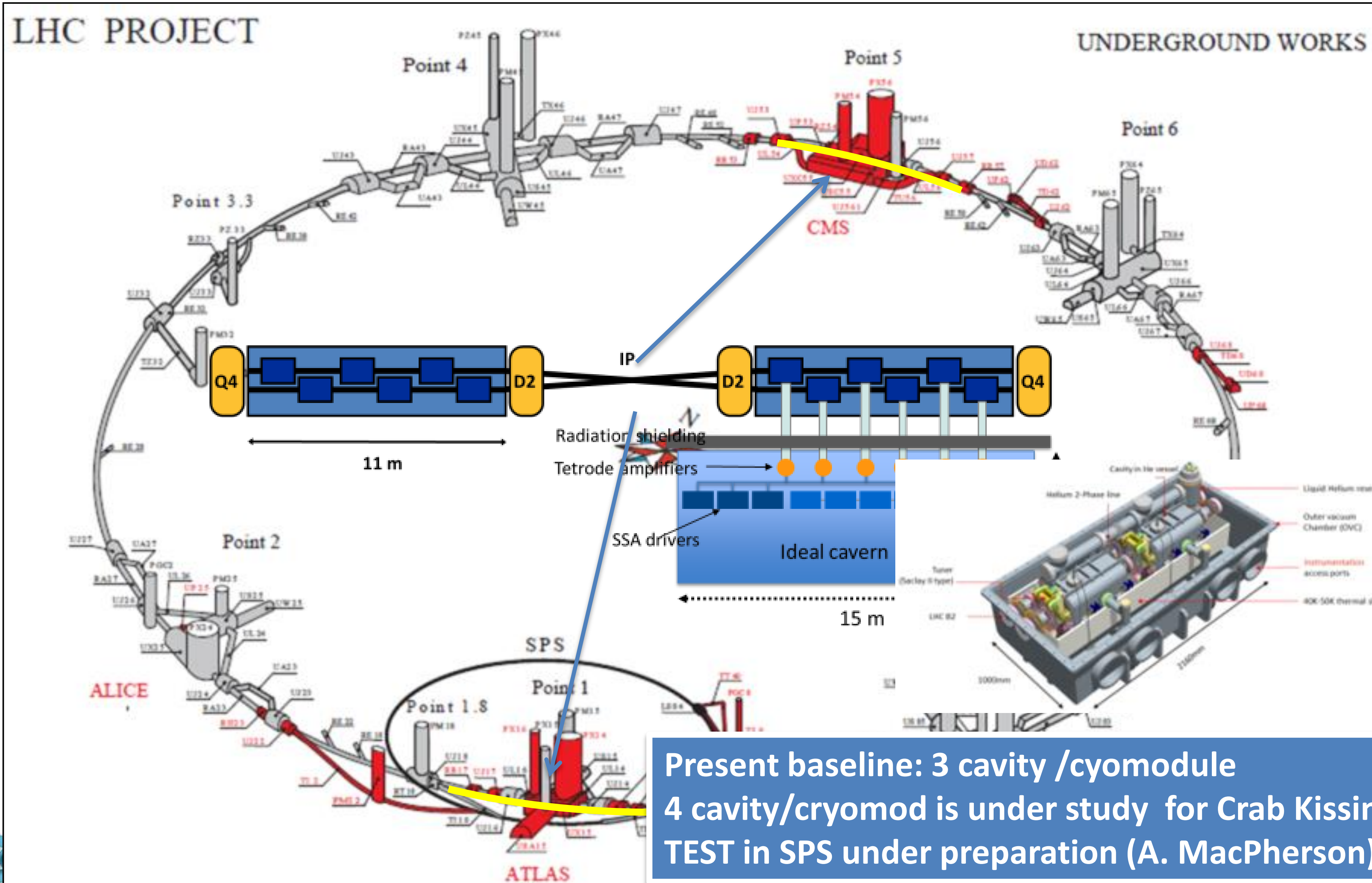


JP Delahayen

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

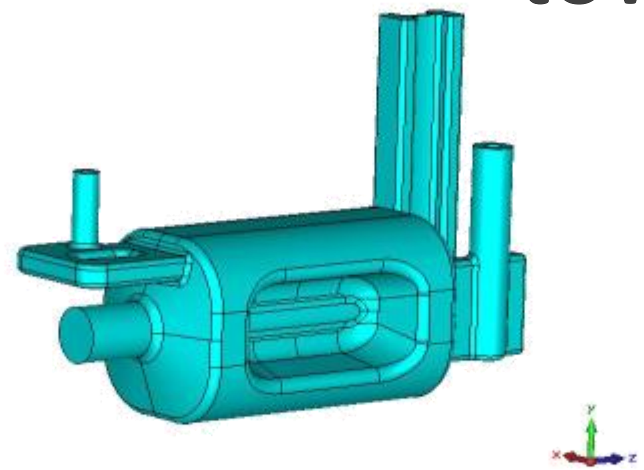
We need downselection, and ASAP: but not too early!

Crab Cavities for fast beam rotation



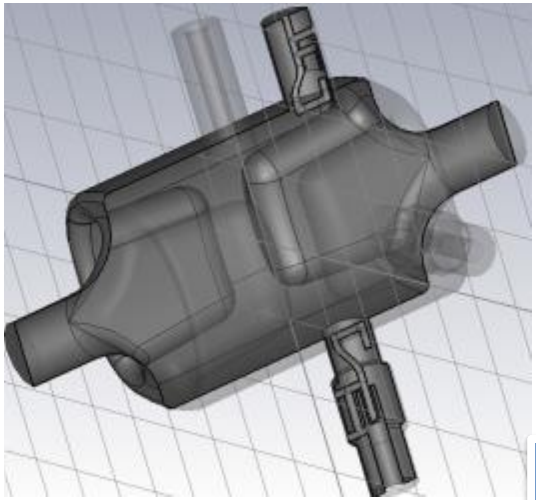
Present baseline: 3 cavity /cyomodule
4 cavity/cryomod is under study for Crab Kissing
TEST in SPS under preparation (A. MacPherson)

Latest cavity designs toward accelerator

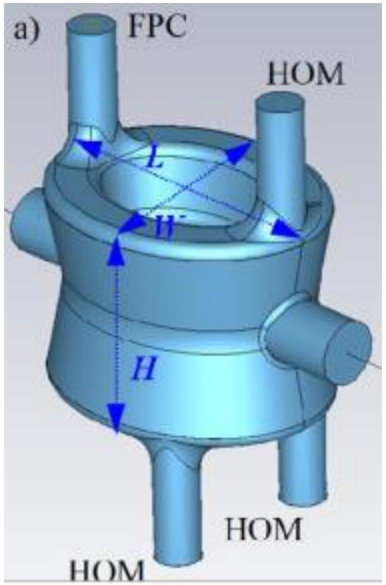


RF Dipole: Waveguide or waveguide-coax couplers

Coupler concepts



4-rod: Coaxial couplers with different antenna types

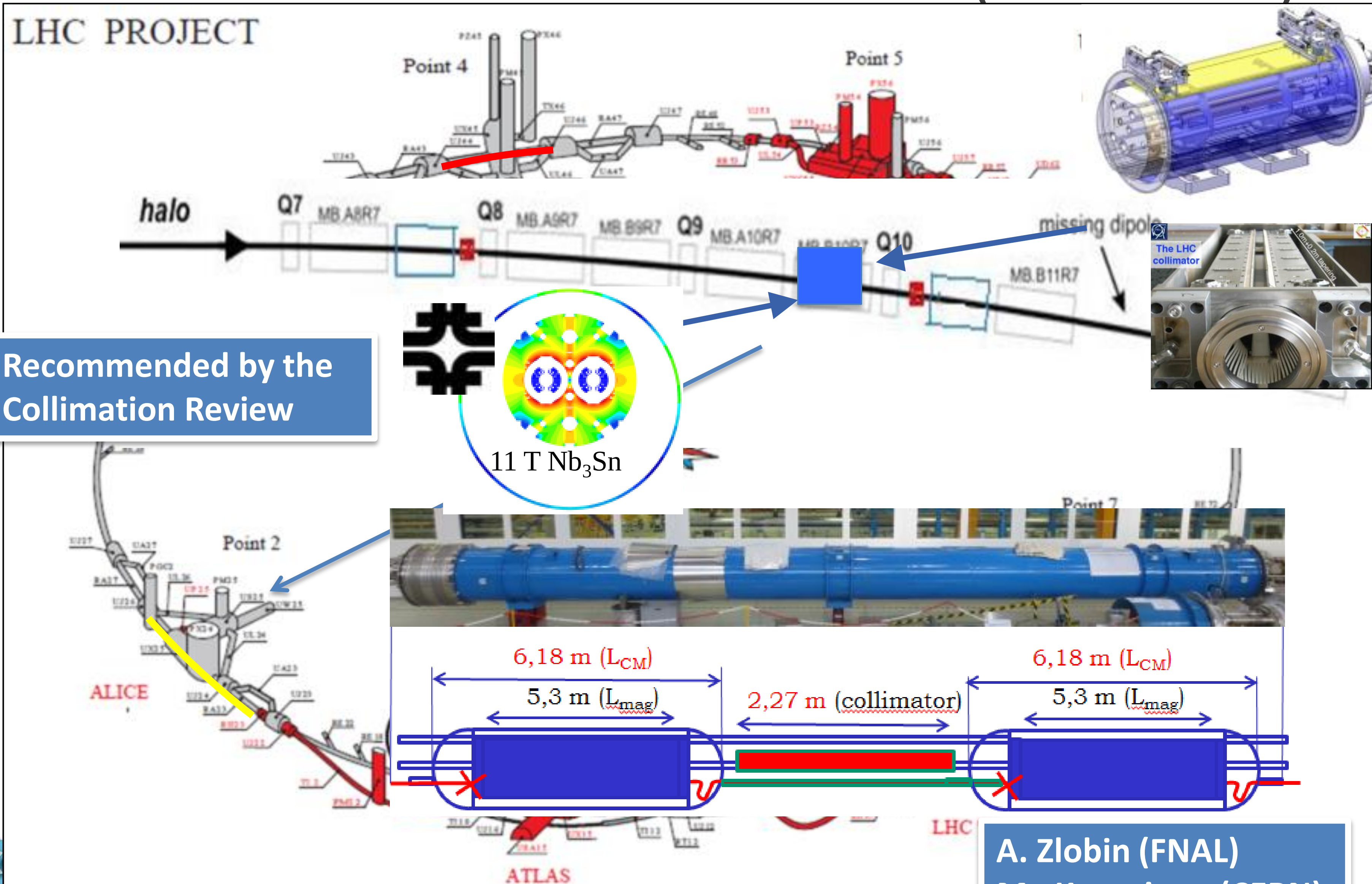


Double ¼-wave: Coaxial couplers with hook-type antenna

E. Jensen (CERN)
G. Burt (U.Lancaster, CI
R. Calaga (CERN, former LARP)
A. Ratti (LBNL, LARP)

High Luminosity LHC

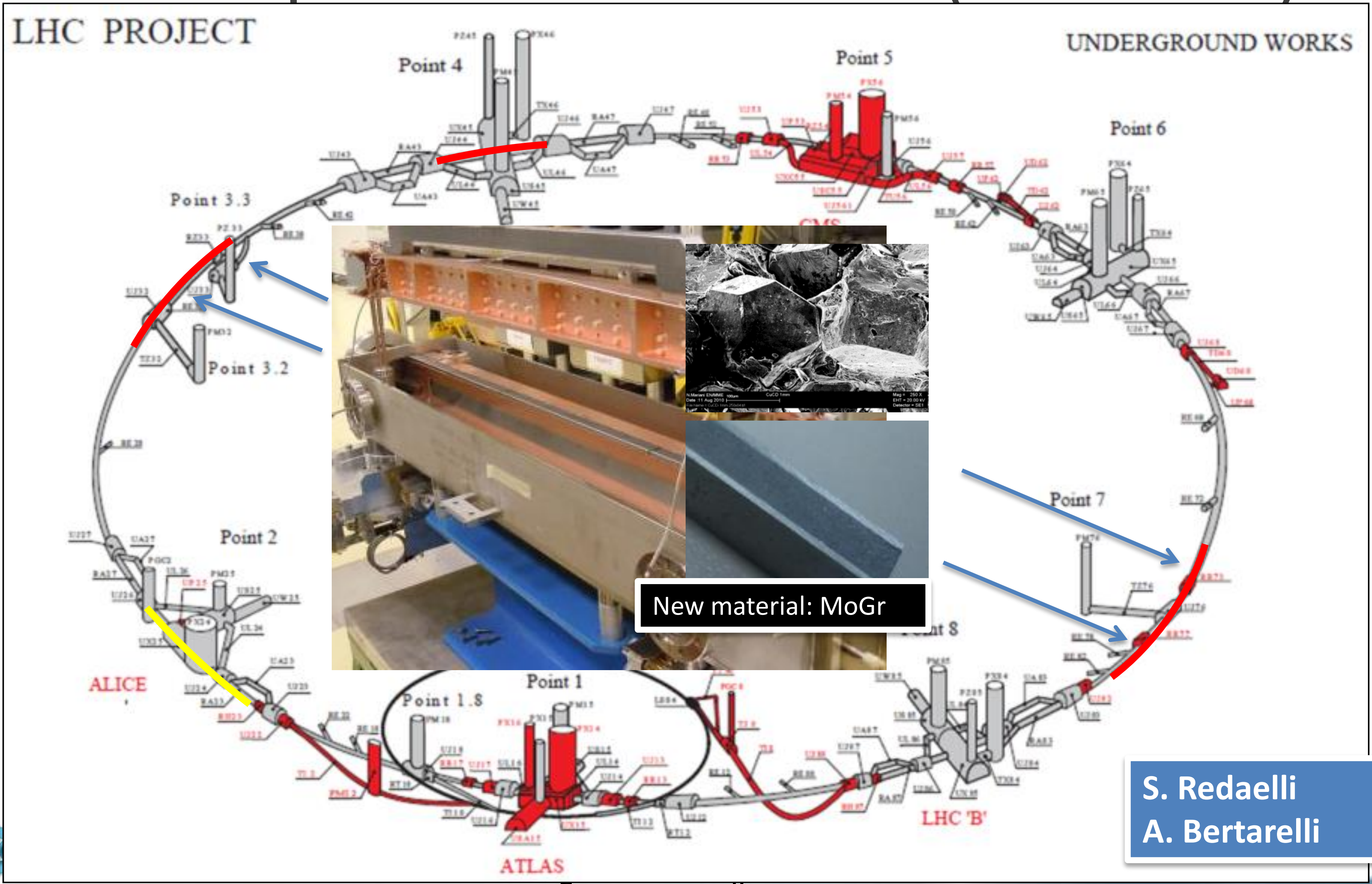
P2 - DS collimators ions – 11 T (LS2 -2018)



Recommended by the Collimation Review

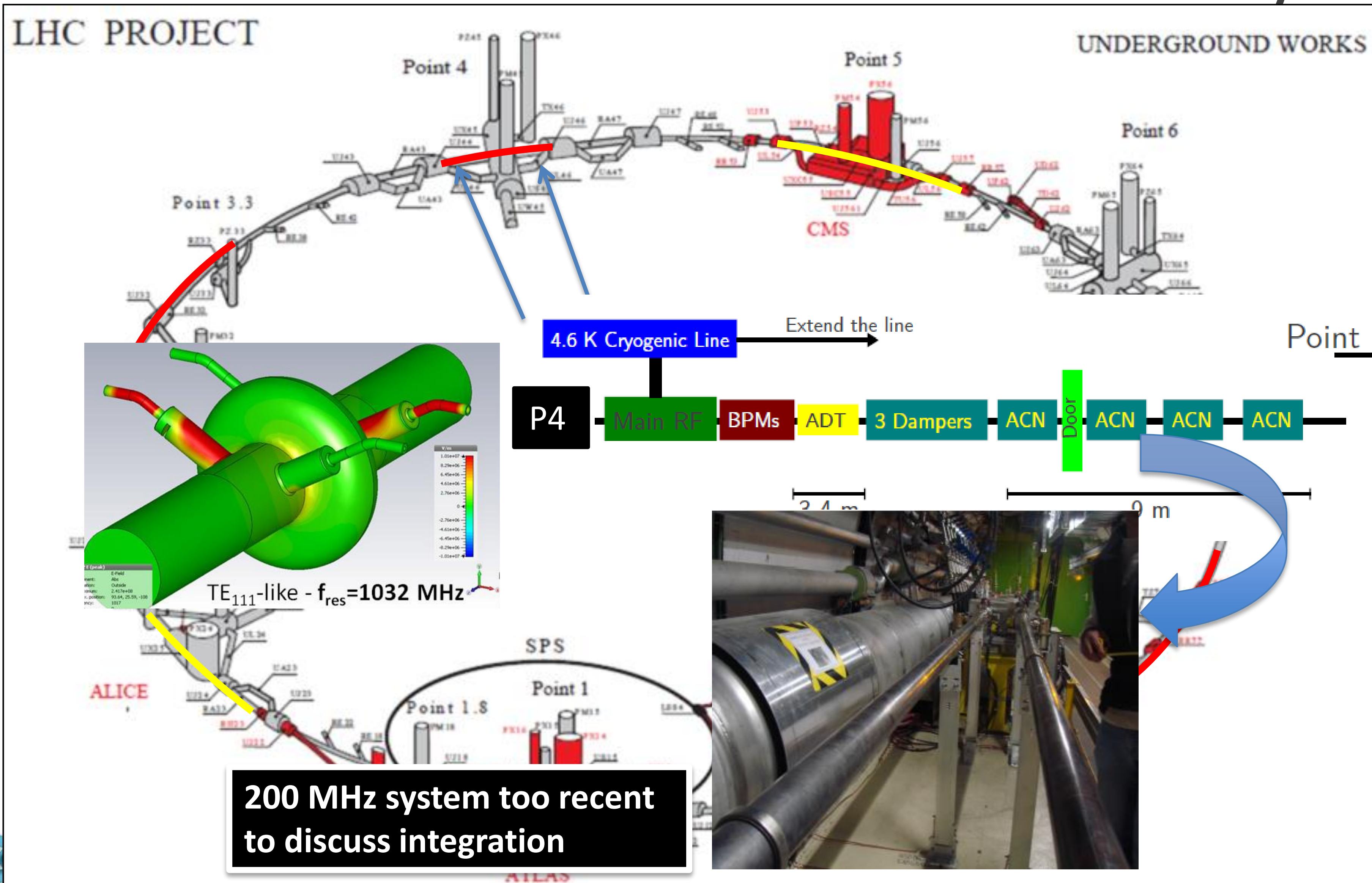
A. Zlobin (FNAL)
M . Karppinen (CERN)

Low impedence collimators(LS2 & LS3)

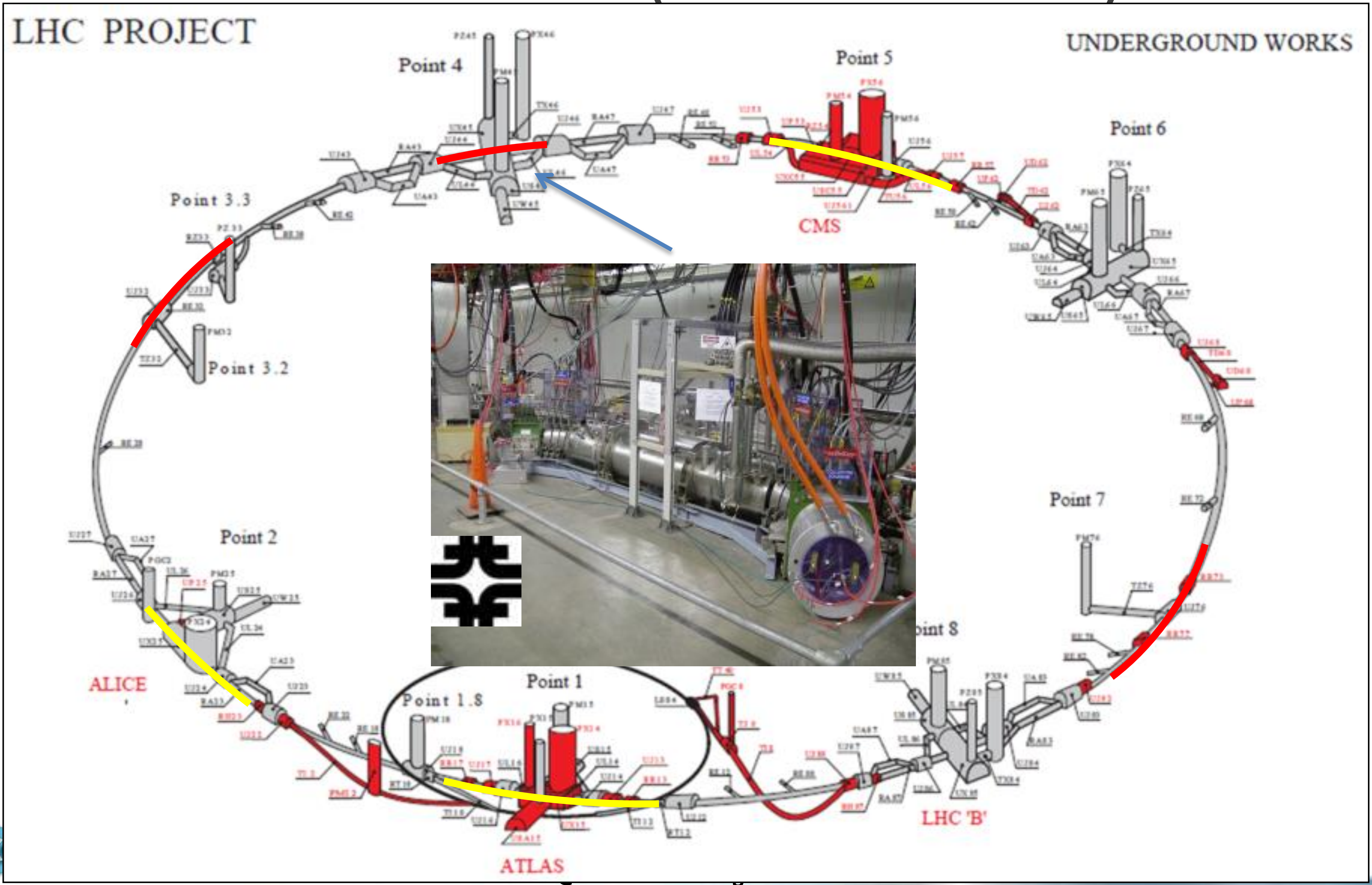


S. Redaelli
A. Bertarelli

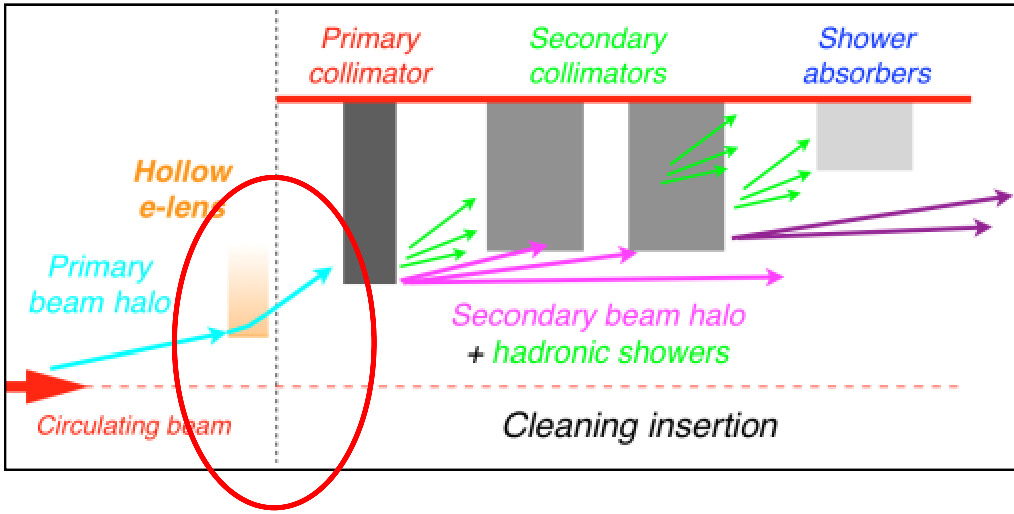
SCRF 800 MHz harmonic: under study

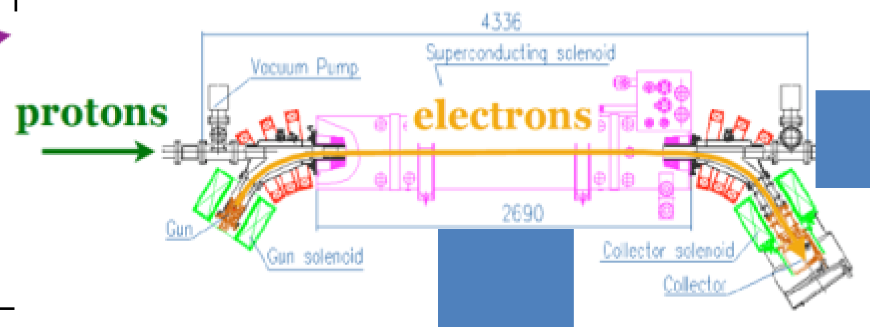


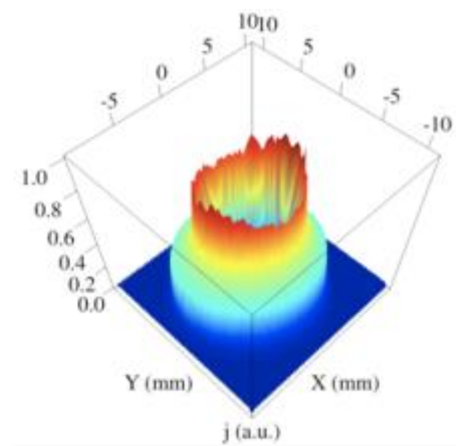
Halo control (hollow e-lens)



Controlling diffusion rate: hollow e-lens







Promises of hollow e-lens:
1. Control the halo dynamics without affecting the beam core;
2. Control the time-profile of beam losses (avoid loss spikes);
3. Control the steady halo population (crucial in case of CC fast failures).

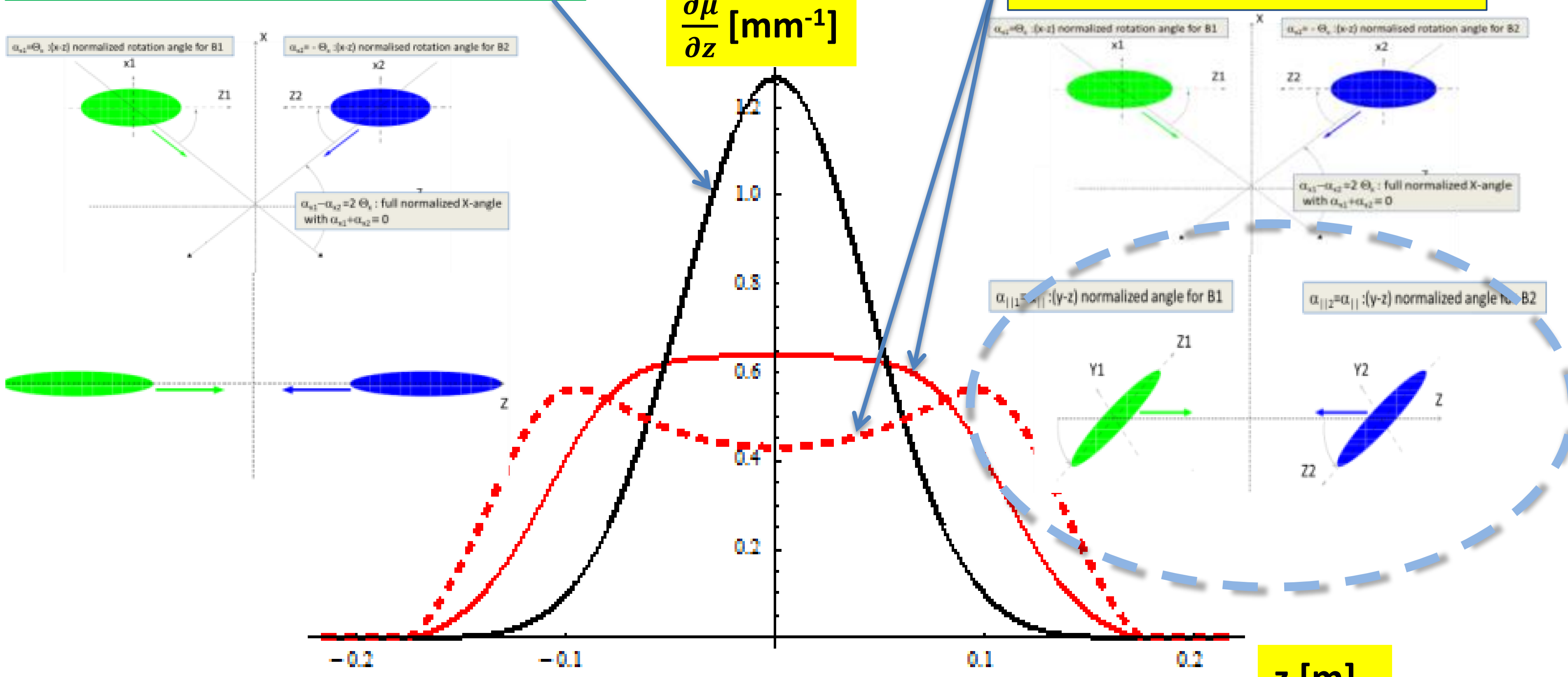
Remarks:
- very convincing experimental experience in other machines!
- full potential can be exploited if appropriate halo monitoring is available.

S. Redaelli
Developed by Fermilab

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.*)

High Luminosity LHC

High Luminosity LHC Project

High Luminosity LHC Project

WP Coordinator
Co-coordinator

PROJECT COORDINATION OFFICE

Project Coordinator: Lucio Rossi, CERN
Deputy Project Coordinator: Oliver Brüning, CERN
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

FP7 HiLumi LHC Design Study

WP1 Project Management
Lucio Rossi, CERN
Oliver Brüning, CERN

WP2 Accelerator Physics
Gianluigi Arduini, CERN
Andy Wolski, UNILIV

WP3 Magnets
Ezio Todesco, CERN
GianLuca Sabbi, LBNL

WP4 CC and RF
Erk Jensen, CERN
Graeme Burt, ULANC

WP5 Collimation
Stefano Redaelli, CERN
Robert Appleby, UNIMAN

WP6 Cold Powering
Amalia Ballarino, CERN
Francesco Broggi, INFN

WP7 Machine Protection
Daniel Wollmann, CERN
Jorg Wenninger, CERN

WP8 LHC-Exp. Interface
H. Burkhardt, I. Efthymiopoulos, CERN,
A. Ball (CMS), B. Di Girolamo, (ATLAS)

WP9 Cryogenics
Laurent Tavian, CERN
Rob Van Weelderen, CERN

WP10 Energy depo.
Francesco Cerutti, CERN
Nikolai Mokhov, FNAL

WP11 11T Dipole
Mikko Karppinen, CERN
Alexander Zlobin, FNAL

WP12 Vacuum
Roberto Kersevan, CERN
Mark-Antony Gallilee, CERN

WP13 Beam Diagnostics
Rhodri Jones, CERN
Hermann Schmickler, CERN

WP14 Beam Transfer
Jan Uythoven, CERN
Brennan Goddard, CERN

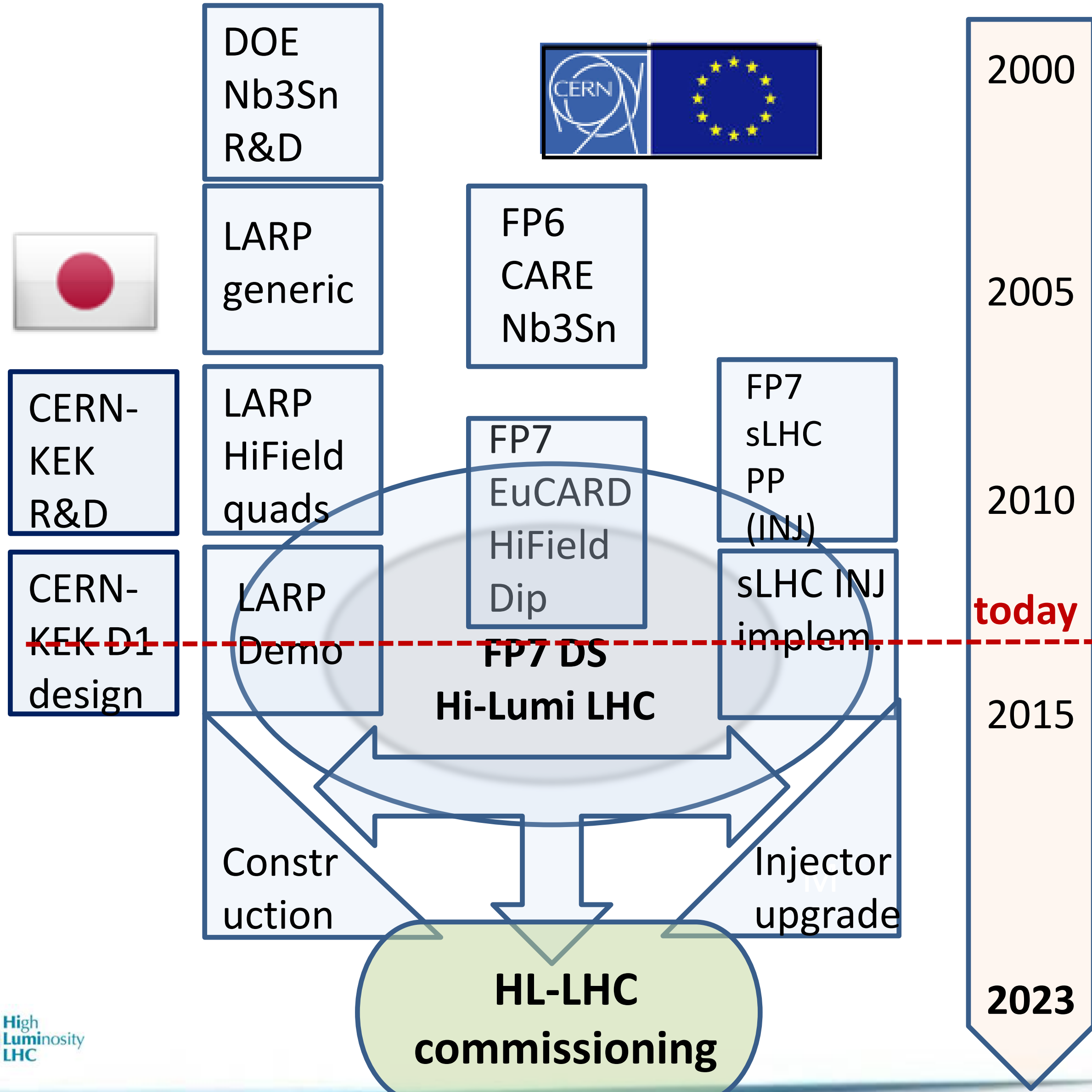
WP15 Integration
Sylvain Weisz, CERN
Paolo Fessia, CERN

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 converging International Collaboration

High Luminosity LHC Participants

cea

CERN

CSIC
Consejo Superior de Investigaciones Científicas

DESY

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

INFN
Istituto Nazionale di Fisica Nucleare

KEK
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

LANCASTER UNIVERSITY

UNIVERSITY OF LIVERPOOL

MANCHESTER 1824

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Science & Technology Facilities Council

UNIVERSITY OF Southampton

BERKELEY LAB

BROOKHAVEN NATIONAL LABORATORY

Fermilab

OLD DOMINION UNIVERSITY

SLAC NATIONAL ACCELERATOR LABORATORY

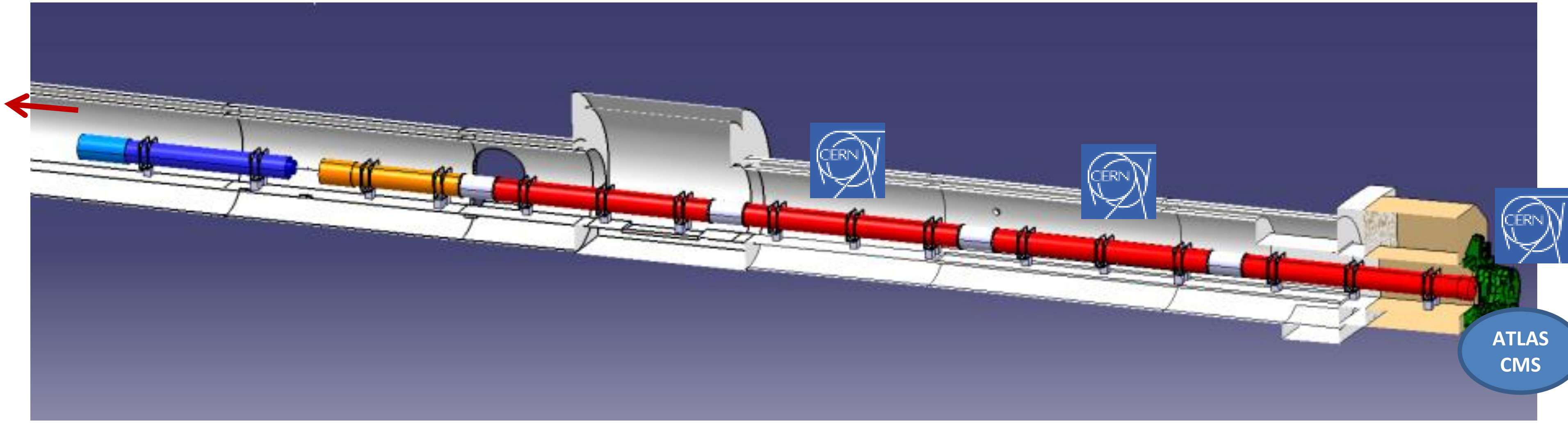
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

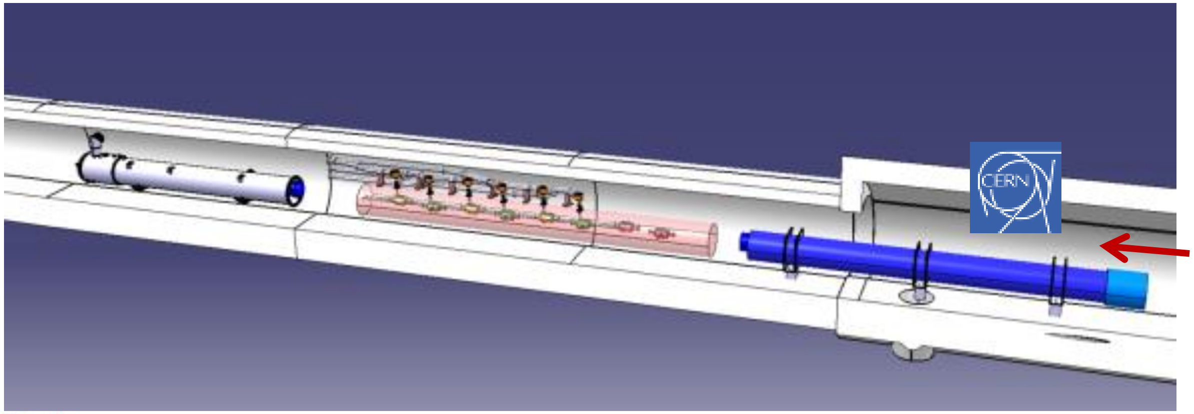
High Luminosity LHC

High Luminosity LHC

High Luminosity LHC Participants

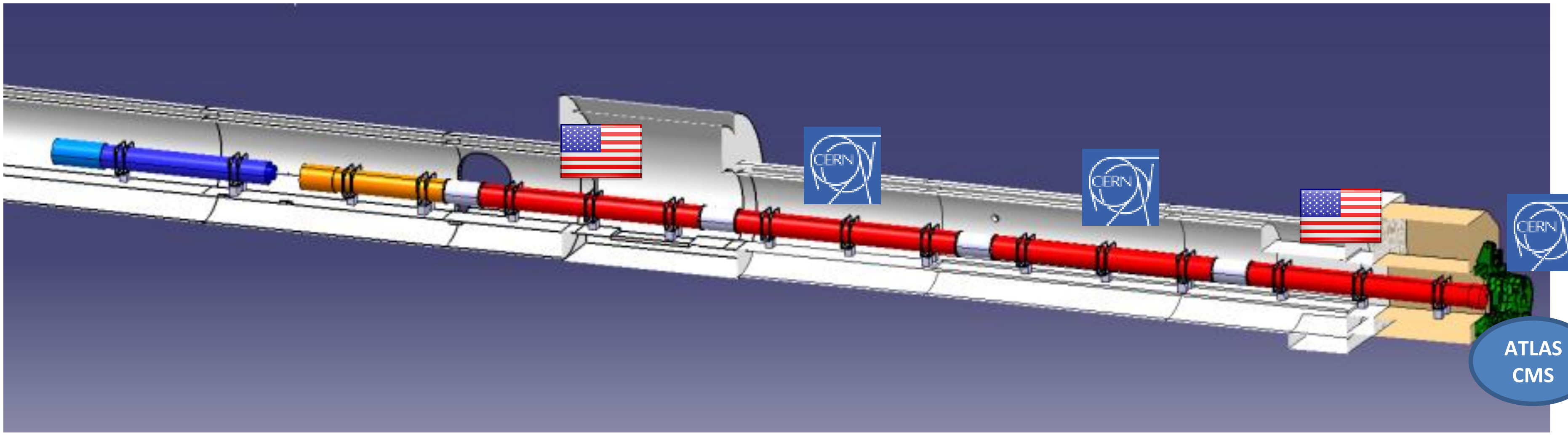
In-kind contribution and Collaboration for HW design and prototypes

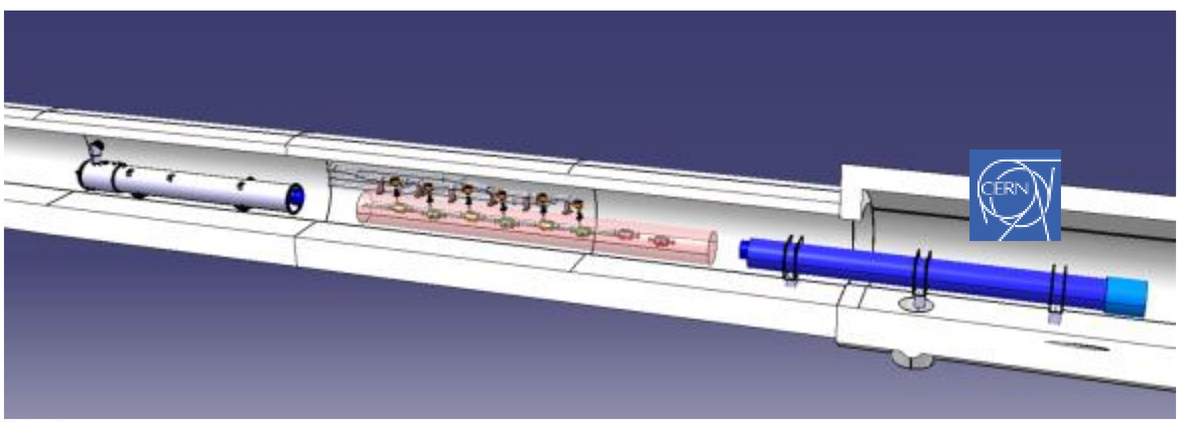




High Luminosity LHC

In-kind contribution and Collaboration for HW design and prototypes

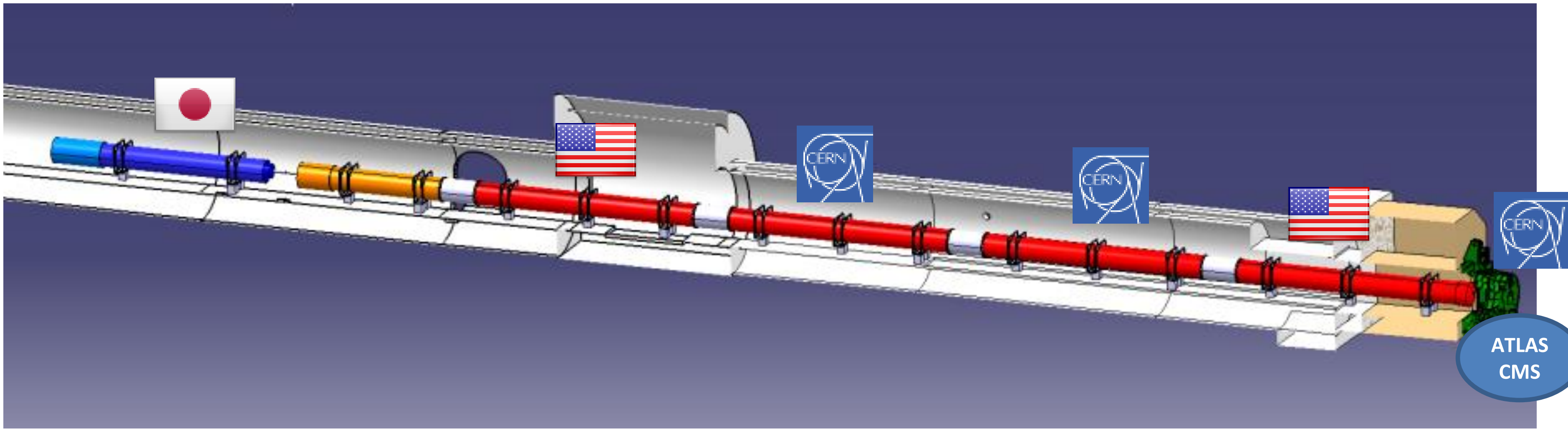


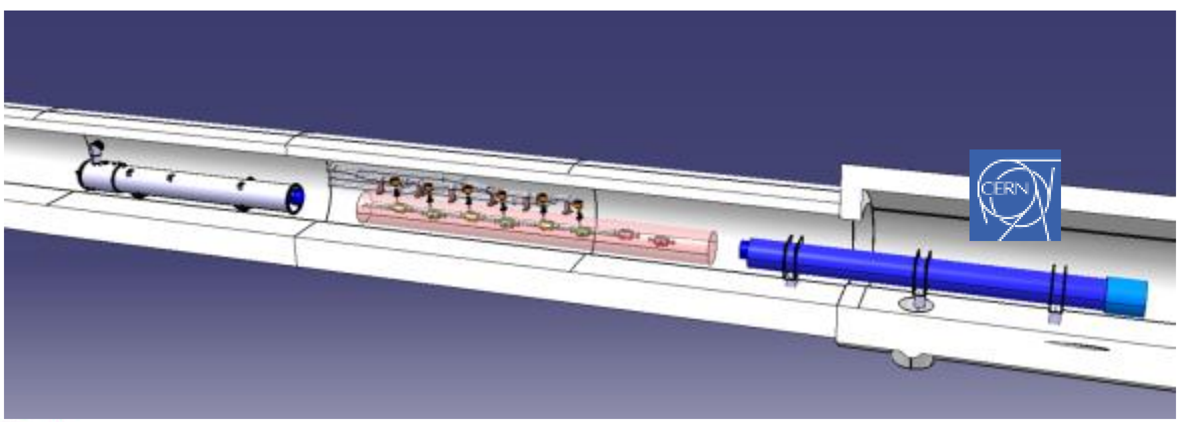


Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**

High Luminosity LHC

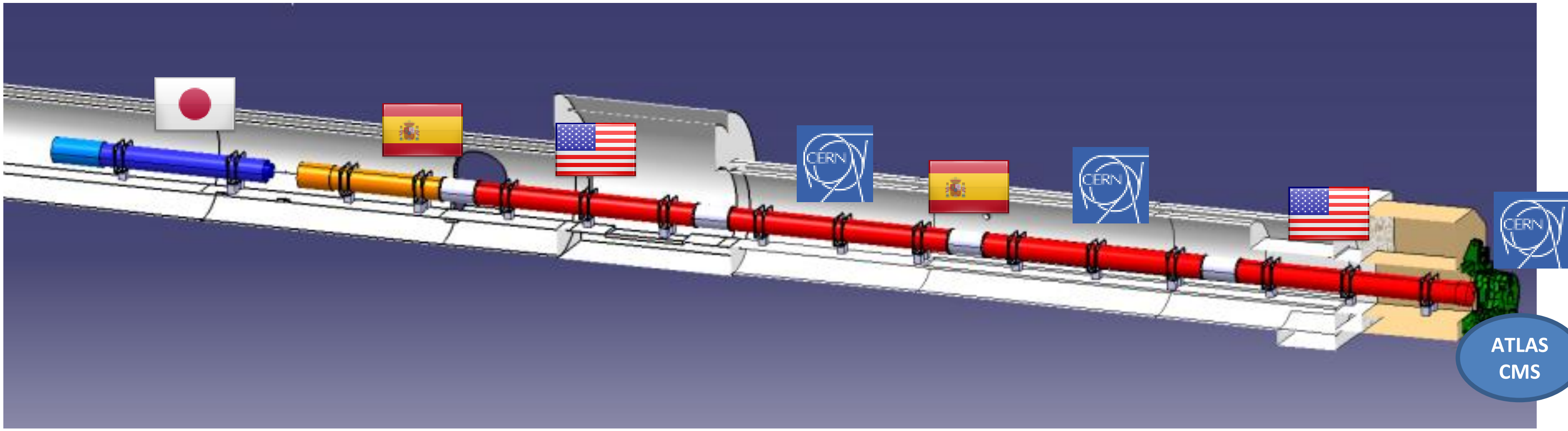
In-kind contribution and Collaboration for HW design and prototypes

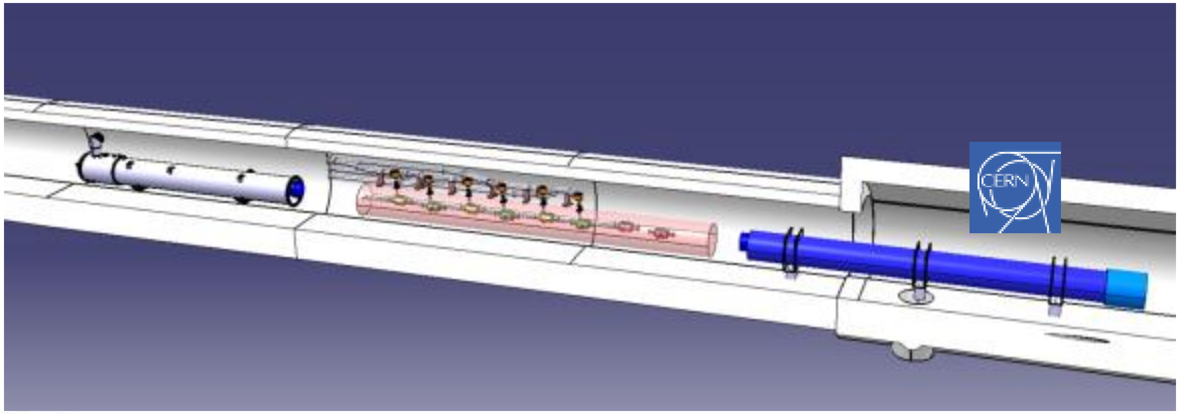




Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**

In-kind contribution and Collaboration for HW design and prototypes

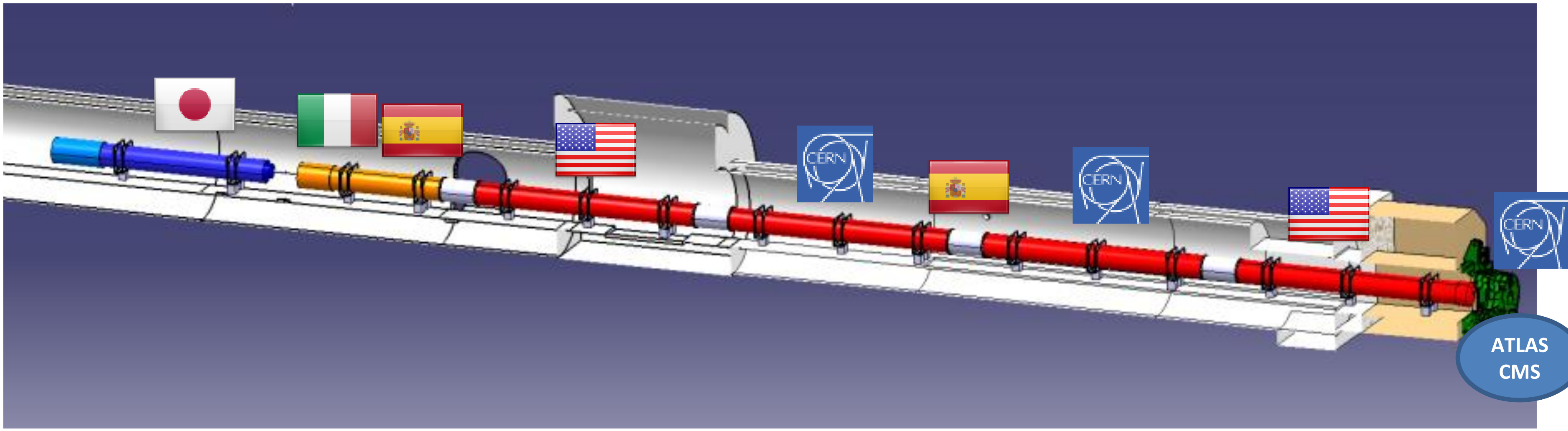


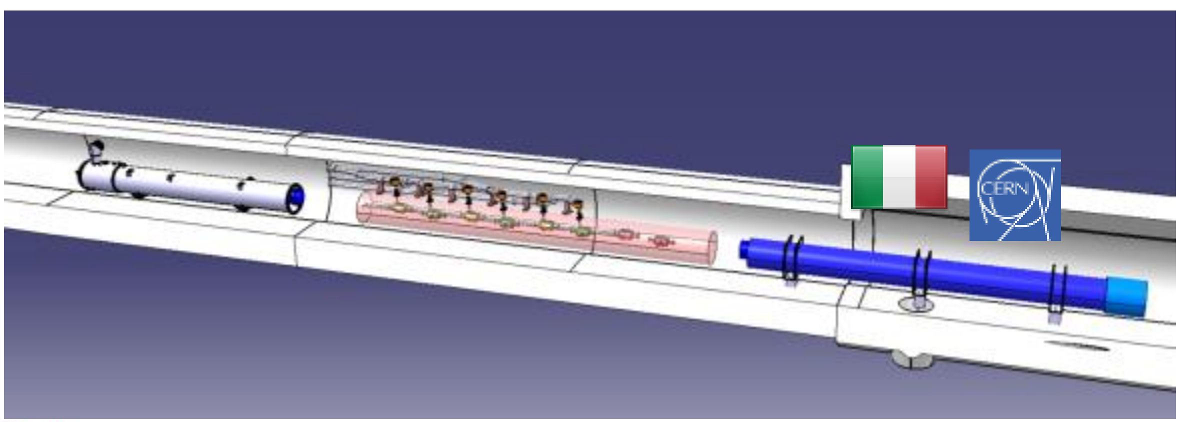


Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**

High Luminosity LHC

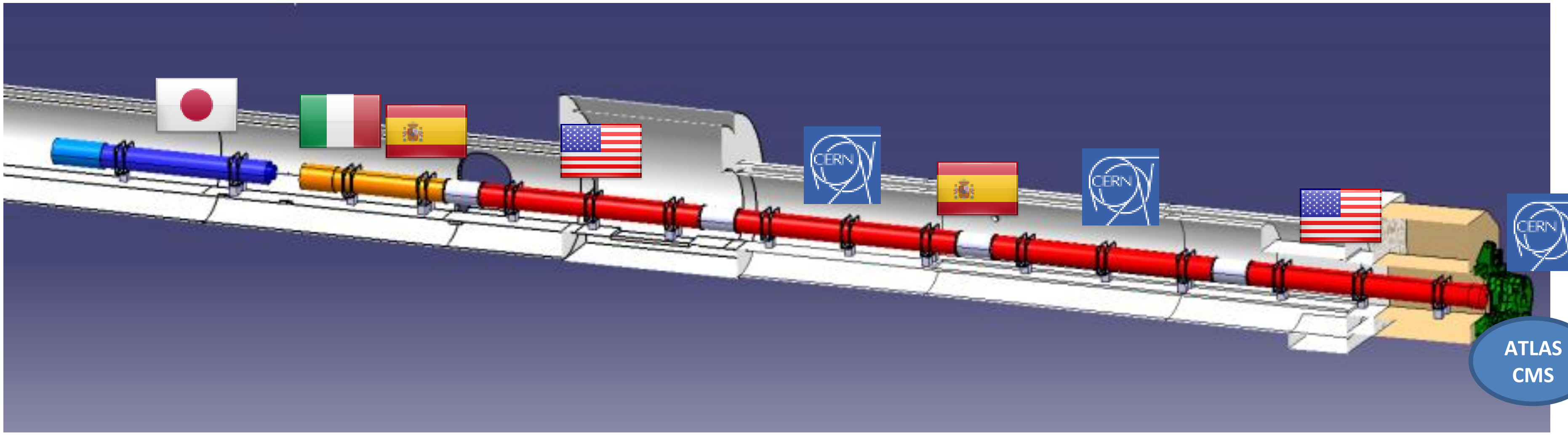
In-kind contribution and Collaboration for HW design and prototypes

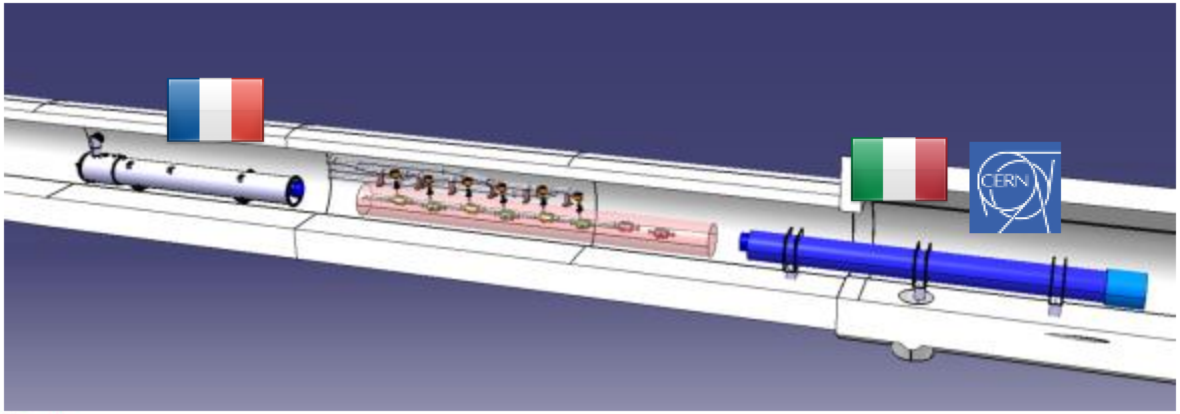




Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**

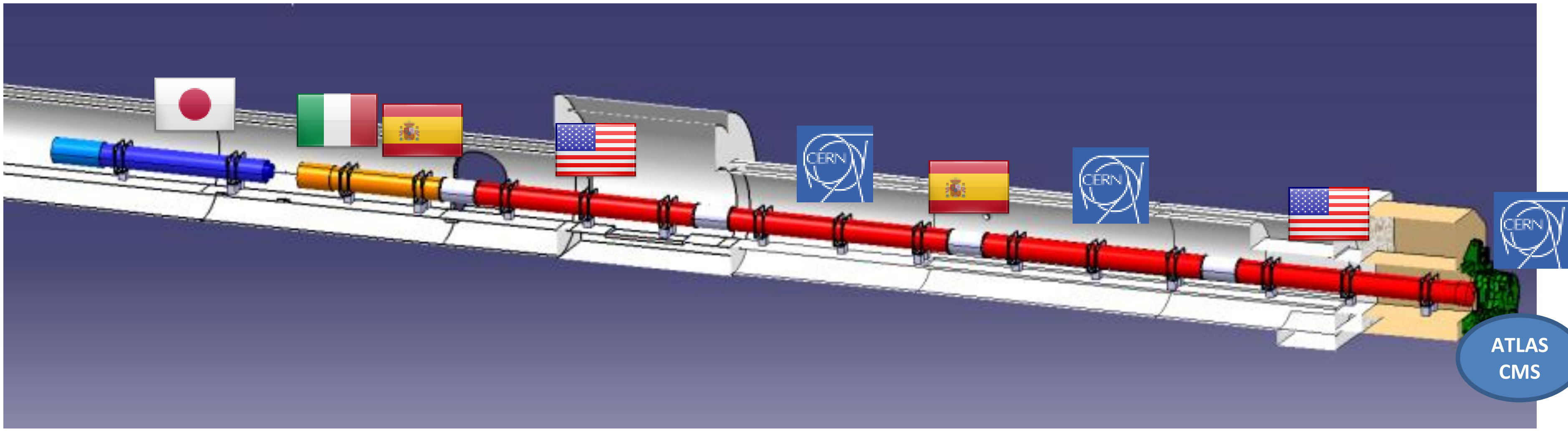
In-kind contribution and Collaboration for HW design and prototypes

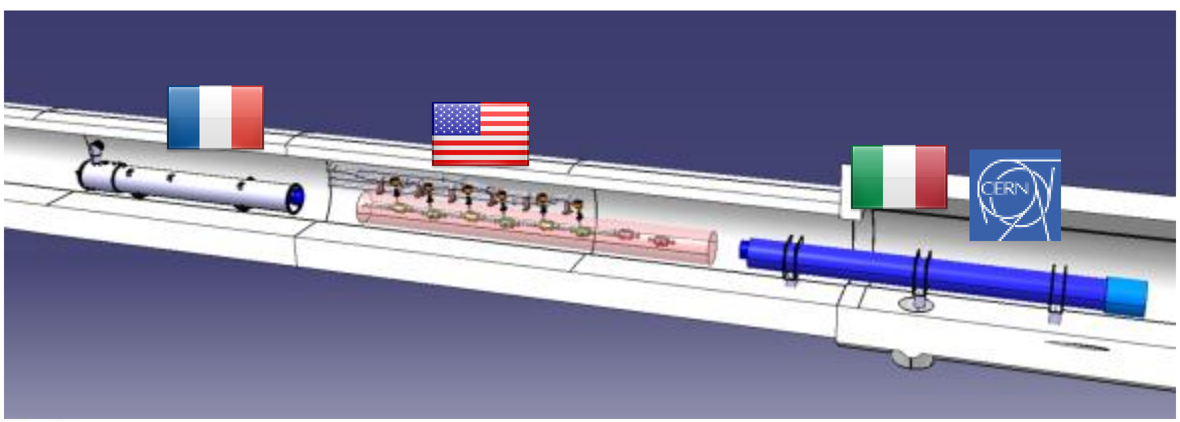




Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

In-kind contribution and Collaboration for HW design and prototypes

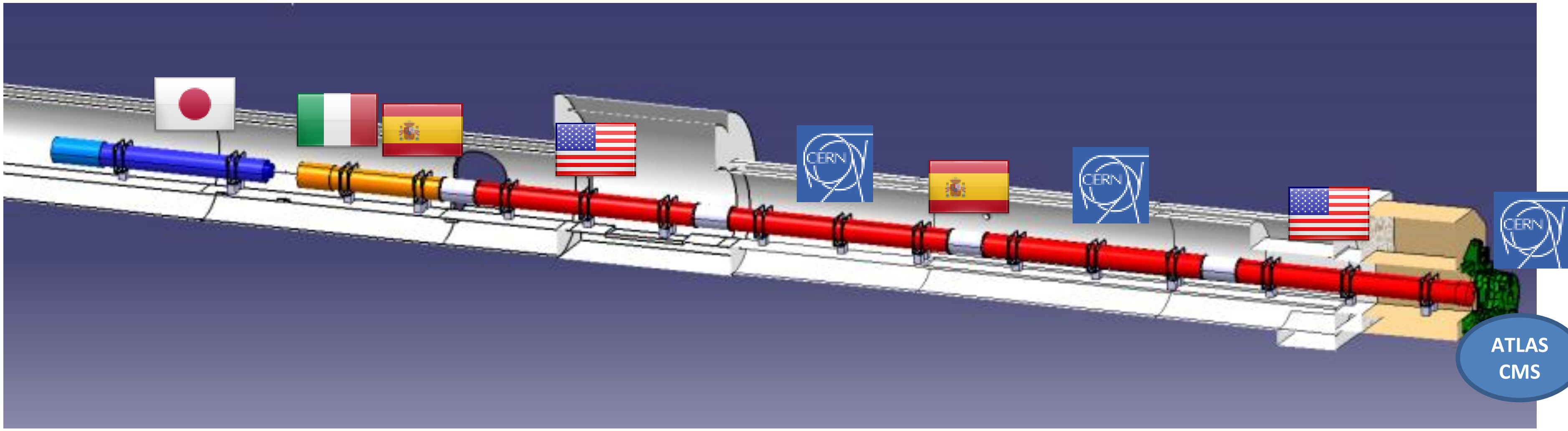


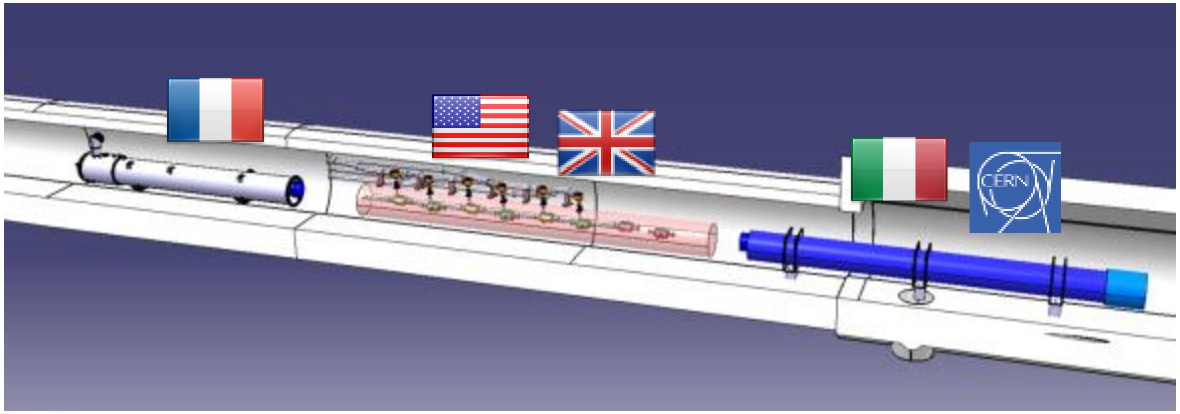


CC : R&D, Design and in-kind **USA**

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**

In-kind contribution and Collaboration for HW design and prototypes



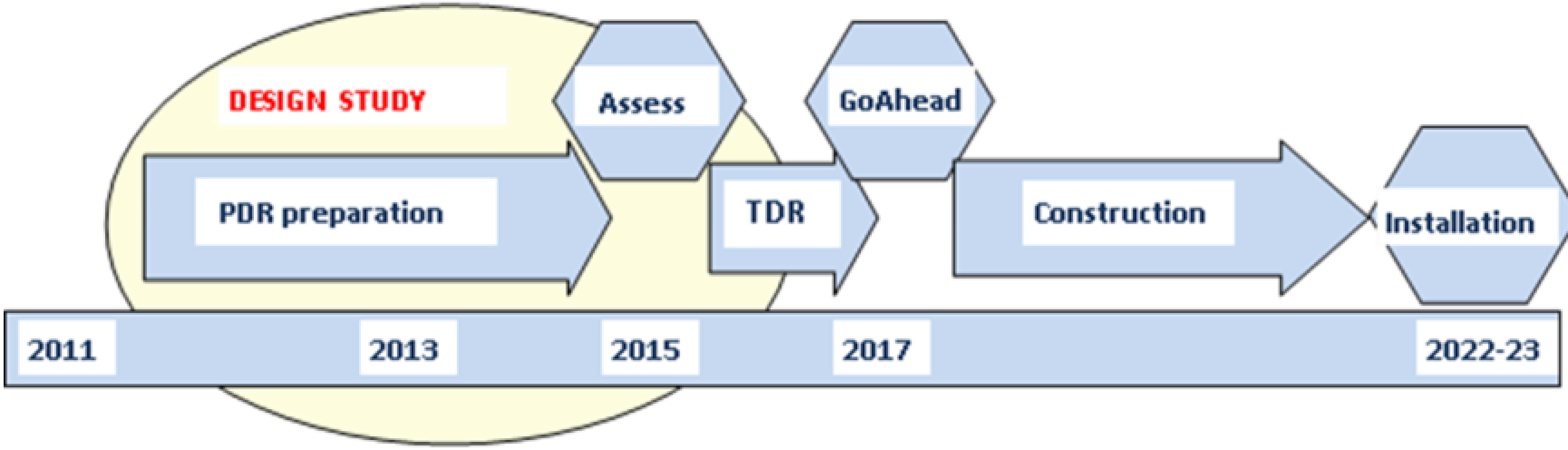


Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

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)