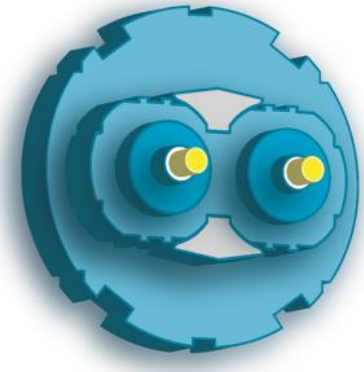
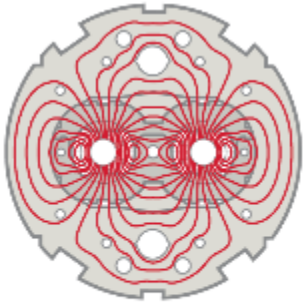


High Luminosity LHC

HL-LHC Status



LARP

Lucio Rossi – CERN
for the HL-LHC project team

talk to 4th HiLumi/ARP
17-22 Nov2014 Annual Meeting @ KEK

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.

Outline

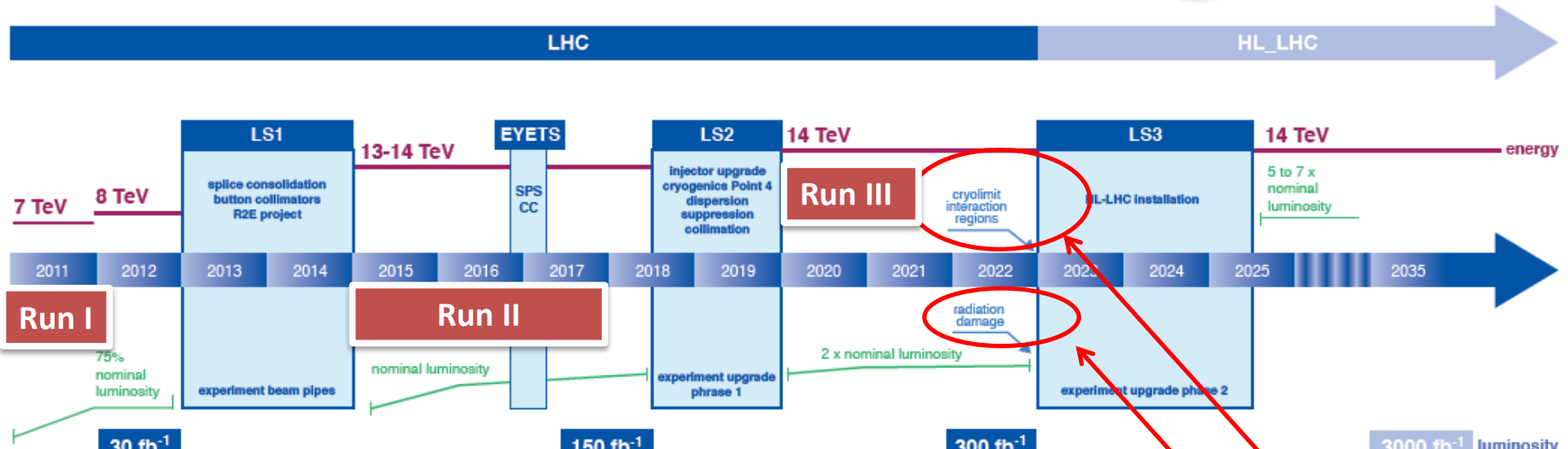
- Progress from last year
  - Baseline and table of parameters
  - Technical Pogress and Reviews (RLIUP, CC, MQXF cables…)
  - Collaborations
  - Hi Lumi Book and PDR (& DB)
  - Status of approval by CERN Council
- Challanges
  - «Stress test» of technical baseline: option roadmap
  - Budget & in-kind contribution
  - Cost & Schedule review
  - Transition from Design Study to Construction Project

1 year ago: Daresbury Kick-off Meeting followed by a 3 days CM in Cockroft Int.

RLIUP (29-31 OCT 2013)

- Fundamental technical milestone for HL-LHC
  - Endorsement of the full upgrade by C-MAC:
    Recommendation (R1): The committee supports the full LHC high luminosity program (HL-LHC), including the full LHC Injector Upgrade (LIU) project and the Upgrade Scenarios 1 and 2, and recommends scheduling LS3 for the installation of all necessary equipment for the HL-LHC as early as possible to maximize the integrated luminosity of the LHC.
  - Clarification of a possible «lost» if the the CC were not available (US1) with about 20-25% less performance.
  - Study or emergence of various options/alternatives:
    - Crab-Kissing scheme
    - E-lens
    - 200 MHz vs 800 MHz
    - flat beams

LHC / HL-LHC Plan



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

50 ⇒ 25 ns

1.7 10^{34} $cm^{-2}s^{-1}$
25 ns bunch
pile up ~45

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

Lumi saturation & Technical bottlenecks:

Plan approved by CERN management upon preparation in HL-LHC Coord Group and RLIUP
See deliverable D1.7 Common LHC time plan

Two important International Reviews

- (May 2013 : Collimation Re
- International Review of the
  5-6 May 2014): Downselect
  SPS TEST!
- International Review of the
  (CERN 5-6 November 2014
  finalize optimization & nee
  Industrialization especially

HL-LHC Baseline Parameters
WP2 charge – PLC webpage

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

Parameter	Nominal LHC (design report)	HL-LHC 25ns (standard)	HL-LHC 25 ns (BCMS)	HL-LHC 50ns
Beam energy in collision [TeV]	7	**7**	7	7
N_b	1.15E+11	**2.2E+11**	2.2E11	3.5E+11
n_b	2808	**2748**[1]	2604	1404
Number of collisions at IP1 and IP5	2808	**2736**	2592	1404
N_{tot}	3.2E+14	**6.0E+14**	5.7E+14	4.9E+14
beam current [A]	0.58	**1.09**	1.03	0.89
x-ing angle [µrad]	285	**590**	590	590
beam separation [σ]	9.4	**12.5**	12.5	11.4
β^* [m]	0.55	**0.15**	0.15	0.15
ε_n [µm]	3.75	**2.50**		3
ε_L [eVs]	2.50			2.50
r.m.s. bunch length [m]				7.55E-02
Piwinski angle			3.14	2.87
Geometric loss factor R0 without crab		**0.305**	0.305	0.331
Geometric loss factor R1 with cr	(0.981)	**0.829**	**0.829**	**0.838**
beam-beam / IP without	3.1E-03	**3.3E-03**	3.3E-03	4.7E-03
beam-beam / IP with Cra	3.8E-03	**1.1E-02**	1.1E-02	1.4E-02
Peak Luminosity without cavity [$cm^{-2}\ s^{-1}$]	1.00E+34	**7.18E+34**	6.80E+34	8.44E+34
Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2}\ s^{-1}$]	(1.18E+34)	**19.54E+34**	18.52E+34	21.38E+34
Events / crossing without levelling w/o crab-cavity	27	**198**	198	454
Levelled Luminosity [$cm^{-2}\ s^{-1}$]		**5.00E+34**	5.00E34	2.50E+34
Events / crossing (with levelling and crab-cavities f		**138**	146	135
Peak line d		**1.25**	1.31	1.20
Levelling ti		**8.3**	7.6	18.0

Collision values

LIU required

Impedance, efficiency etc.

New IT Quads & ATS

Levelling required

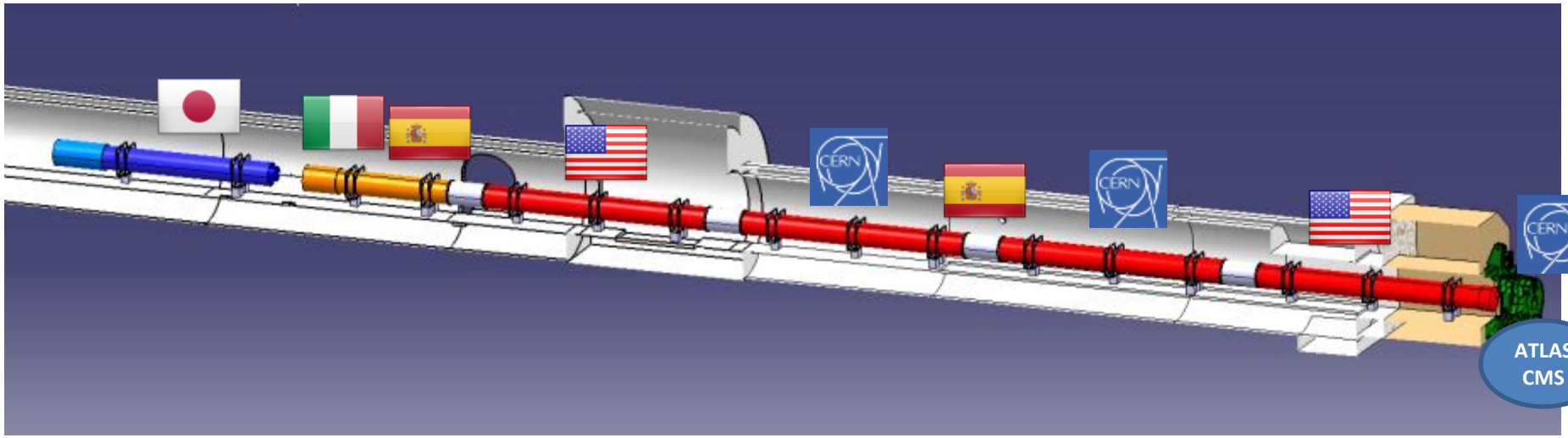
Efficiency requires long fill times (ca. 10h)!

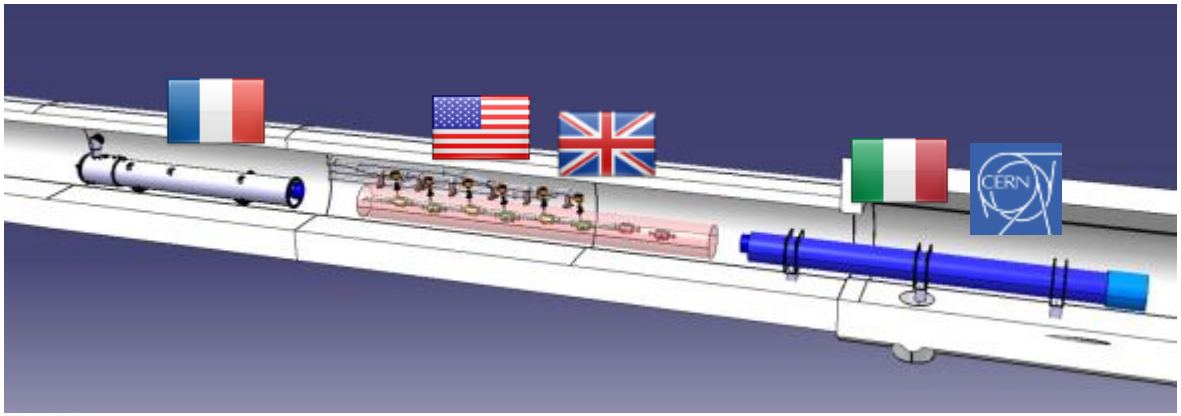
This makes 250 fb^{-1}/y a solid goal

BASELINE (see talks P. Fessia and R. De Maria)

- P1-P5 Interaction Regions : all new from TAXS to D1 included, with **Nb3Sn low-β Quads**, remote powering (SC links) & new Cryoplants; new QRL
- P1 – P5 Matching Sections: all new (including Collimators)
  - Except Q6 (Q5:resuse the previous Q4 at 1.9; Q6 at 1.9K); new QRL.
  - **CC inserted.** (New Ms in Q10 for IP1 and IP5).
- P7 : SC link - IR6 new Q5 for ATS
- P4 : New cryoplant for present RF + spare capacity…
- DS collimators in P2, P7 and P1-P5. Low Z collimators
- Upgrade of TDI and other absorbers.
- **Coated Beam screen for ITR of P2 and P8.**
- Diagnostics.

In-kind contribution and Collaboration for HW design and prototypes





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

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

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**

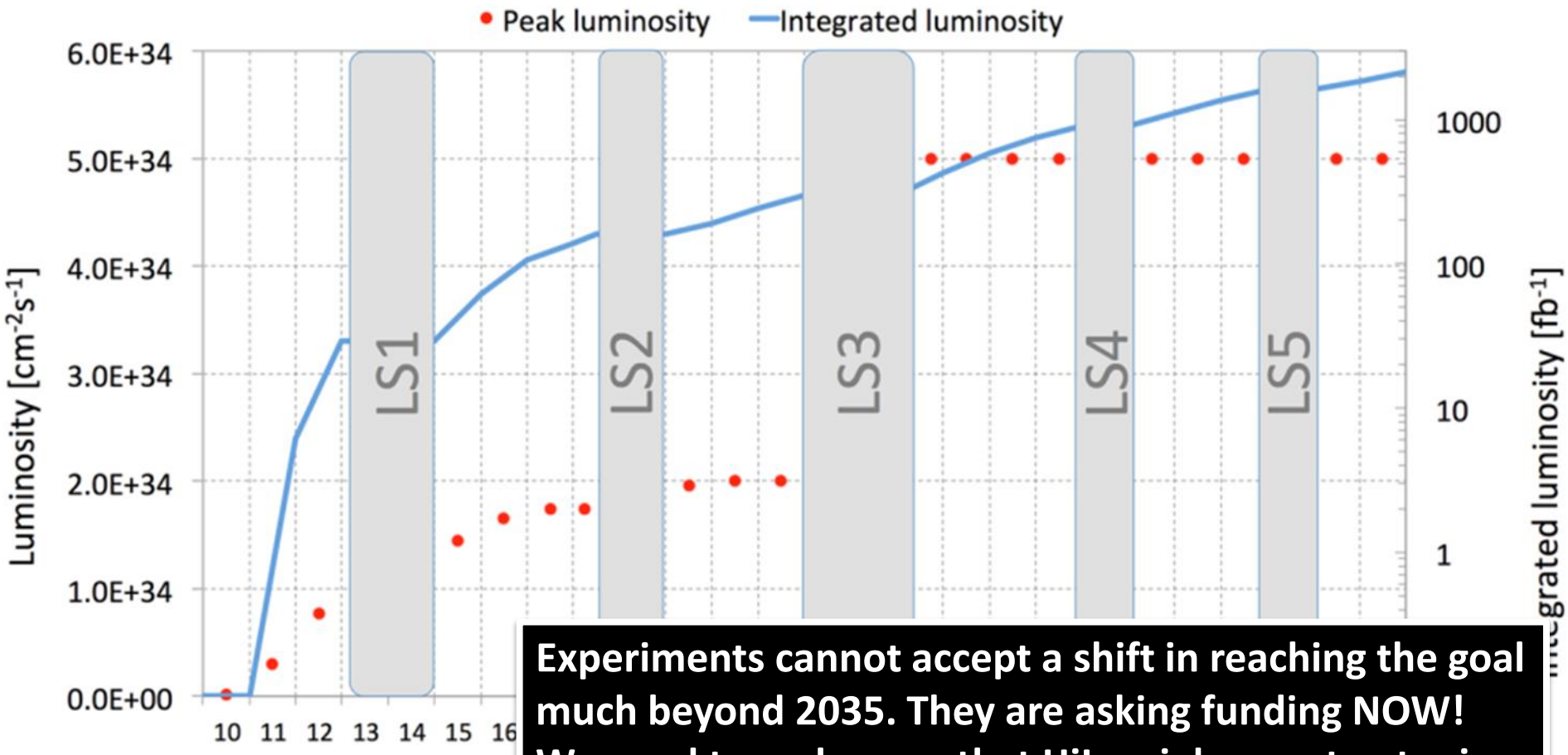
Conclusions

- **The upgrade is robust for 250 (300) fi**
  - Means to maintain or increas ity are under study
- **All hardware is more r 3000 fb^{-1} than it is today for 300 fb**
- **Design S lished by 2015 with the TDR**
- Margins are there and – once e d proved:
  - Possible to decrease pile dens crease to 350 fb^{-1} ($7 \cdot 10^{34}$ of L_{level}) thanks **to crab kiss (CC in II & ⊥ planes) and β* of 10 cm (large aperture IT & ATS)**
  - **Increase data collection to > 4000 fb^{-1}**

Slide form L. Rossi – talk at RLIUP

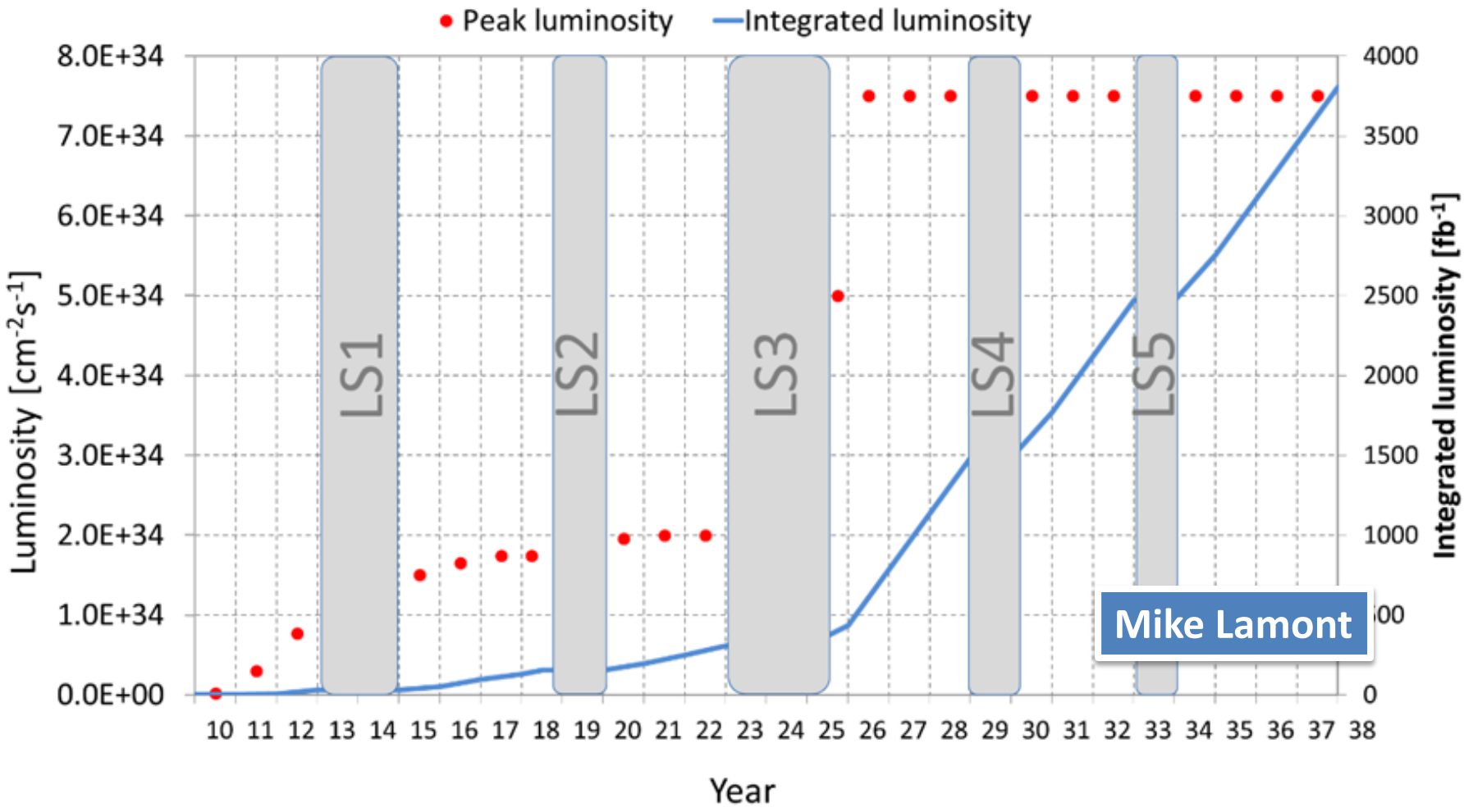
Why?

Lumi with the nominal goal of HL-LHC and new schedule (see D1.7 for history)



Experiments cannot accept a shift in reaching the goal much beyond 2035. They are asking funding NOW! We need to make sure that HiLumi does not enter in competion with other precision projects (ILC)

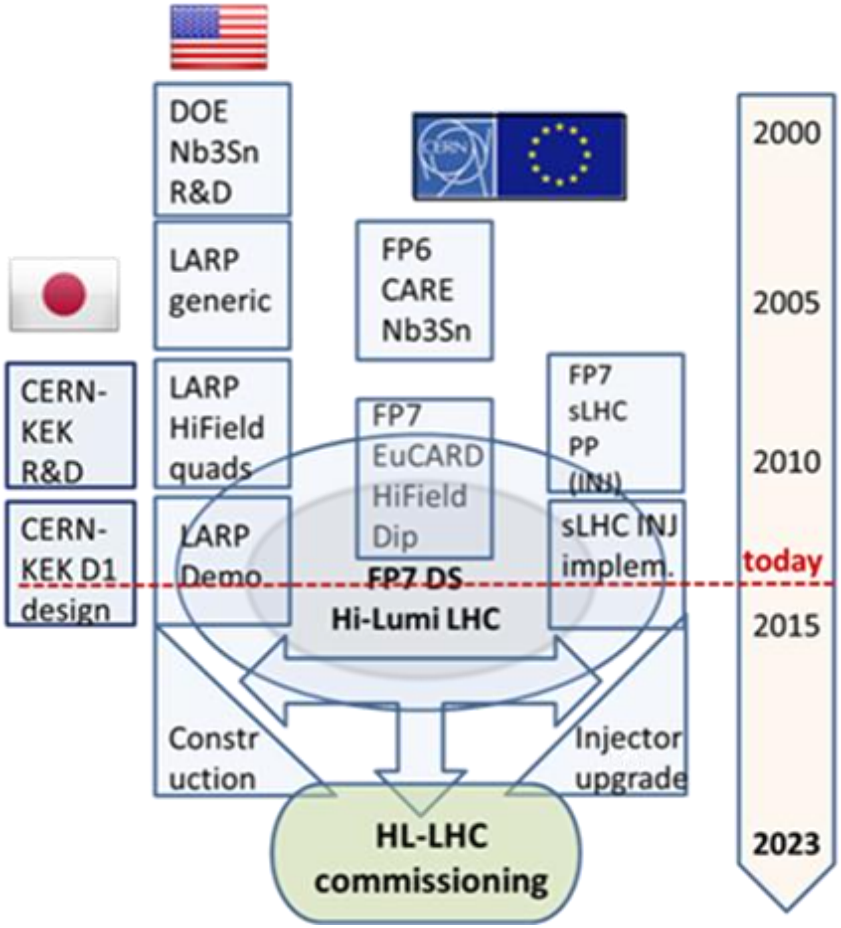
Only with 350 fb^{-1}/y (L_{lev}=7.5 10^{34} and some optimism) the goal is reachable



What to do to reach this realistically?

- Review (use) margins, increase goals
- Reconsider alternatives as OPTIONS (talk R. Tomas)
  - Consider an Harmonic system as additional performance rather than alternative?
  - Launch e-lens ?
  - Asking more to LIU ?
  - Increase efficiency: performance is not enough we need also AVAILABILITY
  - ➢ R2E and Availbility workshop, 14-17 Oct @CERN
- We have to make an effort to be credible in our enhanced (ultimate) goals. Each one is called to take its – reasonable – challenge.

Collaborations



- **In addition to the FP7-HiLumi LHC (CERN contracts):**
- CEA (FR) for Q4 Design & proto (also completion Fresca2 technological demo)
- INFN-Milano (IT): HO Corrector magnets Design and Prototypes
- INFN-Genova (IT): D2 Design
- CIEMAT (ES): IT Orbit corrector magnet (nested) desing and prototype
- UniMan (UK) for collimators
- UniGE (CH), Uni. Bratislava (SK), Twente Univ. (NL) for Nb3Sn
- South Hampton U. (UK) under way for SC links

High Luminosity LHC

The HiLumi LHC Design Study (a sub-system of HL-LHC) is cofunded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404

Short Name	Country	Logo
CERN	Geneva Switzerland	
CEA	Saclay France	
DESY	Hamburg Germany	
INFN	Frascati Italy	
CSIC	Madrid Spain	
EPFL	Lausanne Switzerland	
SOTON	Southampton United Kingdom	
RHUL	London United Kingdom	

Short Name	Country	Logo
STFC*	Daresbury United Kingdom	
ULANC*	Lancaster United Kingdom	
UNILIV*	Liverpool United Kingdom	
UNIMAN*	Manchester United Kingdom	
HUD	Huddersfield United Kingdom	
KEK	Novosibirsk Russia	
BINP	Tsukuba Japan	

Invaluable contribution from USA-LARP (and GARD)

Short Name	Country	Logo	
BNL	Upton, NY USA	BROOKHAVEN NATIONAL LABORATORY	LARP
FNAL	Batavia, IL USA	Fermilab	
LBNL	Berkeley, CA USA		
SLAC	Menlo Park, CA USA	SLAC	
ODU	Norfolk, VA USA	OLD DOMINION UNIVERSITY	

- Accelerator Protocol n. II (attached to the old ICA, expiring in 2017) signed (thanks to Bruce and DOE office of HEP)
- Discussion with DOE for new ICA (Int. Cooperation Agreement) for HL-LHC (including Accelerator & Detectors) started. Hope to be finalized by 2015…

We need more collaborations

- Russia
- China (proposal made but …)
- India (proposal starting: TAXS/T
- Brazil? Mexi
-
- More initiative welcome also from Member States Institutions:
- frame: 50%-50% subdivision of the cost.

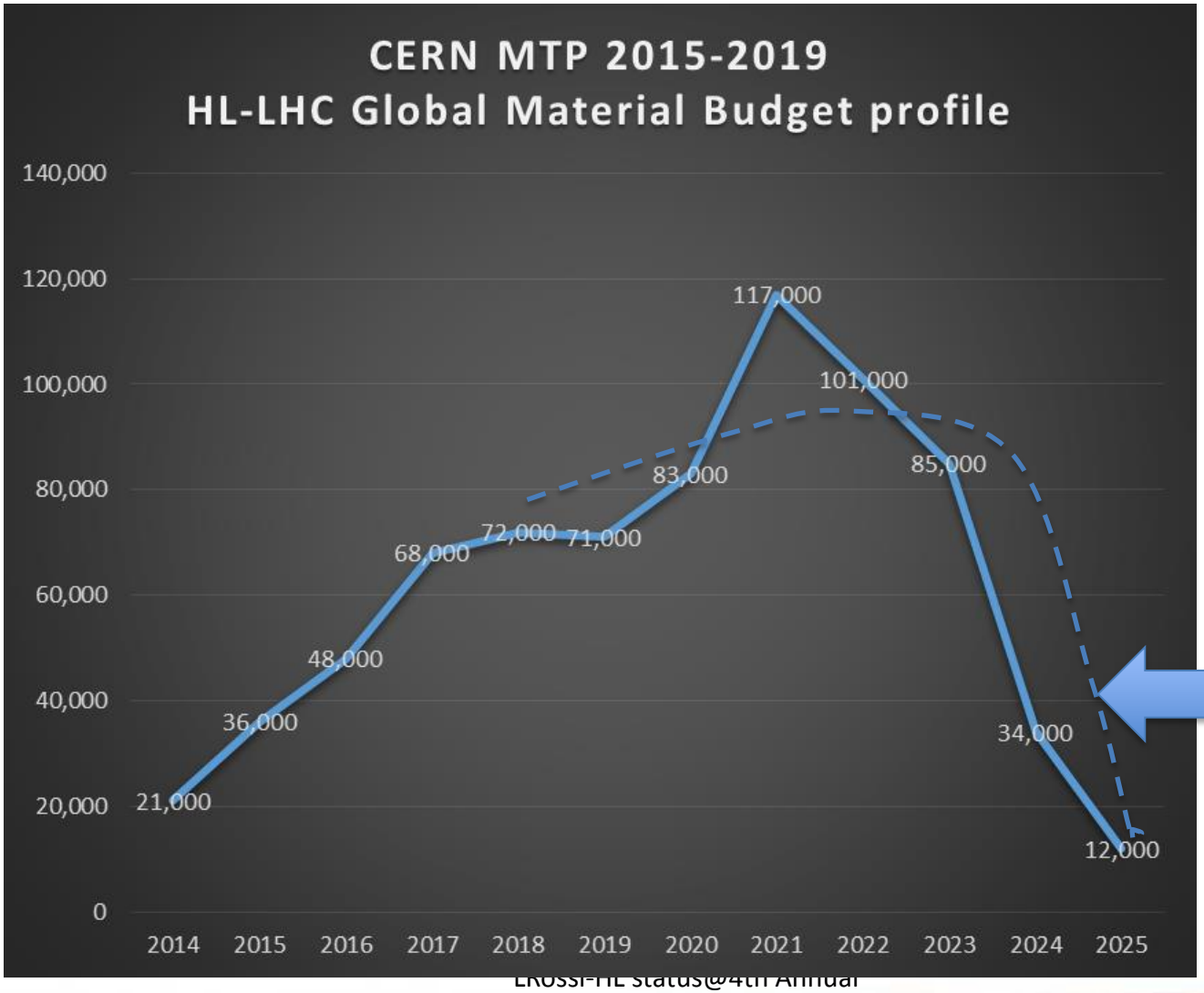
Time to think beyond FP7 Hilumi governance. See talk of O. Bruning for starting the process

Status of approval and Budget

- (May 2013 Brussel : approval by Council as EU)
- (June 2013: first construction money for HL-LHC in the CERN MTP)
- In 2014 HiLumi LHC established as 1st US priority by P5, process under way
- June 2014: approval of MTP 2014-2018 with HL-LHC as main CERN project for the next decade.
- **Council has approved MTP 2015-2019 including Design and initial Construction cost and took note favorably of the total CtC to 2025** (with a cut proposed by CERN management of about 10%).
- We are missing **about 20% (only!)** for the total project wrt to the budgetary evaluation of 2011 (which did not included WP14 and SM18 infrastructure)
- This is a challenge, not a nuisance!

Present CERN Budget profile - total cost

Material only, no overheads (~ 740 MCHF)

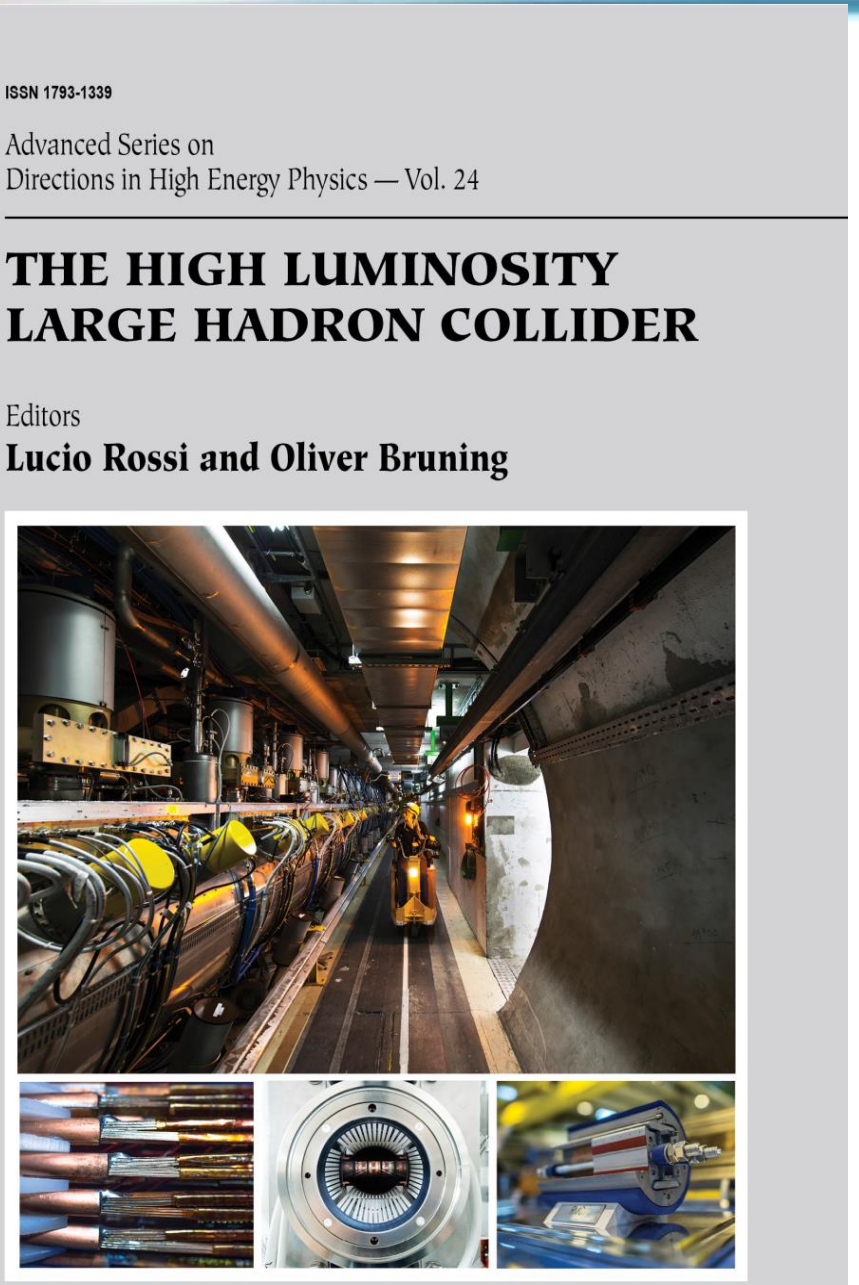


Necessity of a re-baseliene

Benoit De Lille, new Budget Off.

More realistic?

HiLumi Book : a collection of papers in scientific style 20 papers, 300 pages (sorry for the 10 months delay!)



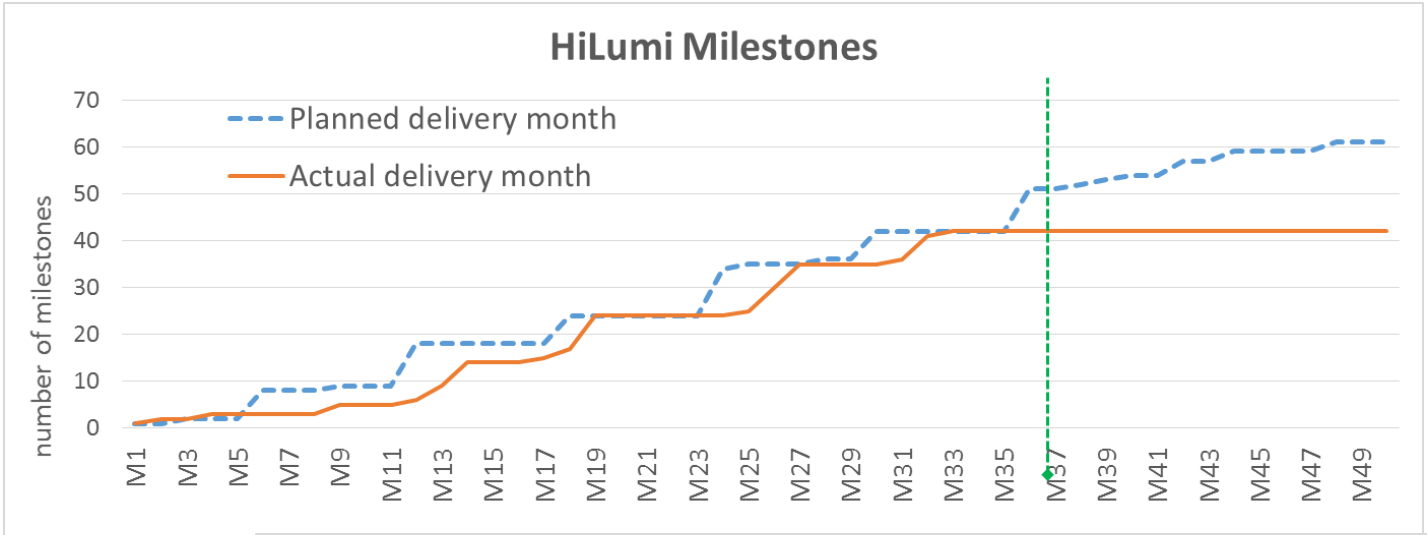
Preliminary Design Report PDR

(see talk I. Bejar)

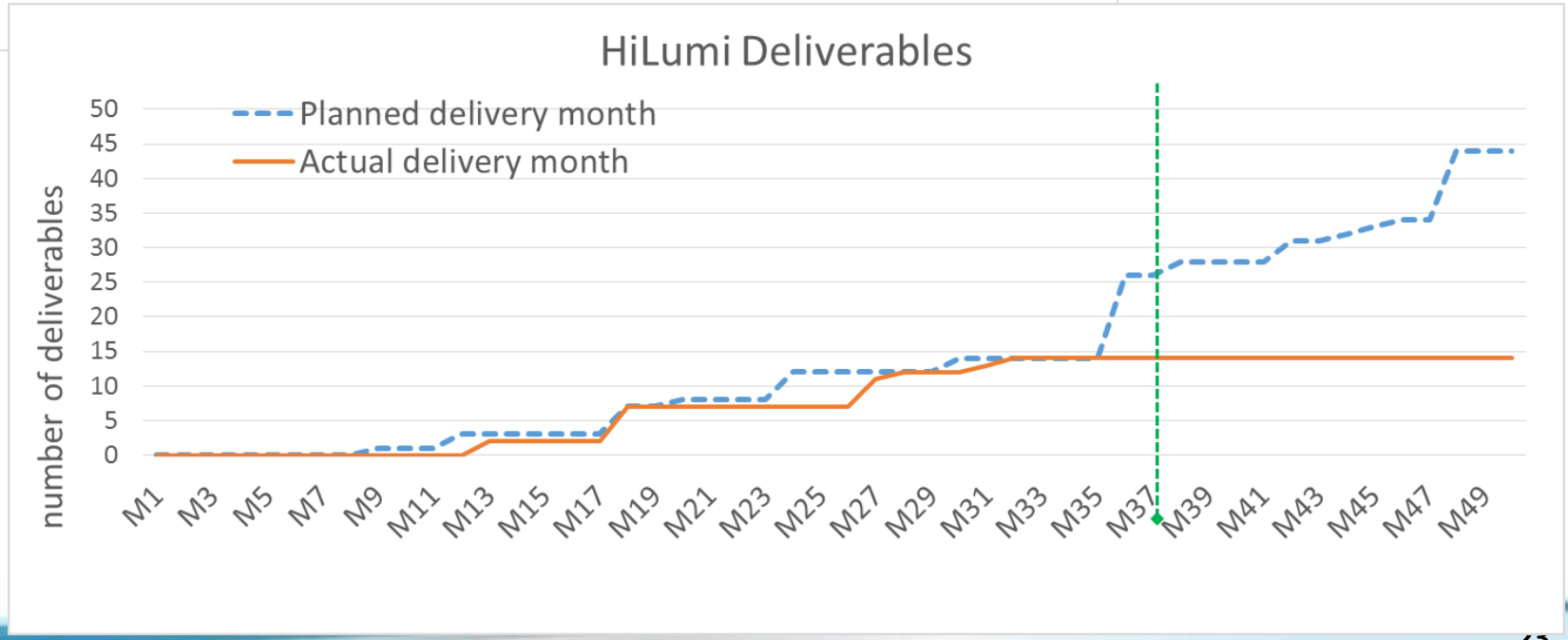
FP7 – HiLumi LHC Design Study

- 2014 novelties (from CM 2013 in Daresbury)
  - Retirement of CNRS (cancel elliptical CC)
  - Membership of Huddersfield U. (UK) Prof. R. Barlow
- All MSs and DLVs met!
- However next year (last one) we risk to have a bottleneck

Deliverable rate in 2015: +250% !!



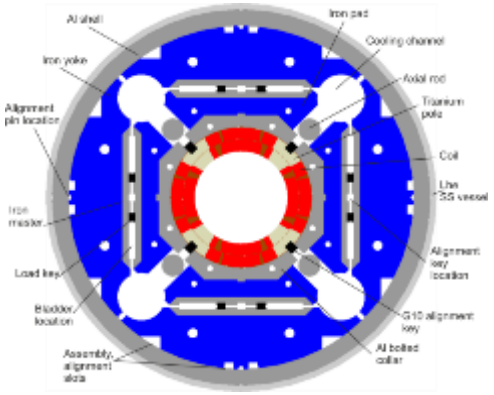
Need to move early at least half of DIvs! Plan by end of the year



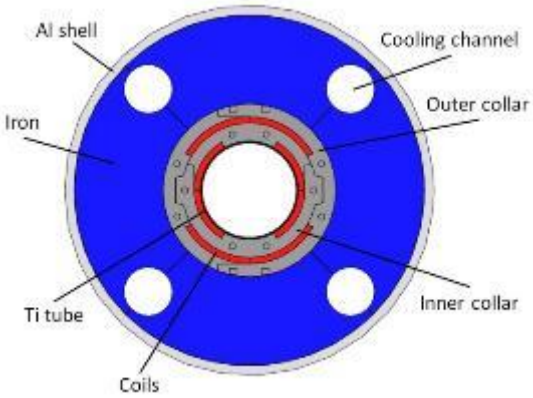
High Luminosity LHC

WP3 the magent zoo in the IR

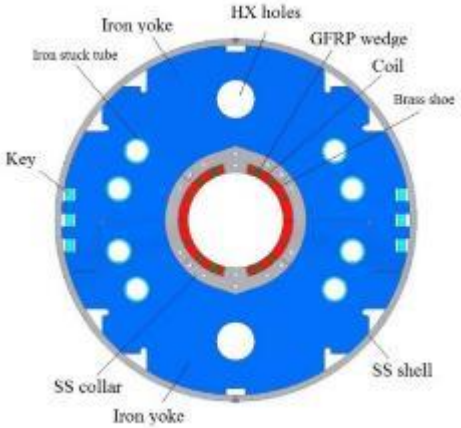
Ezio Todesco



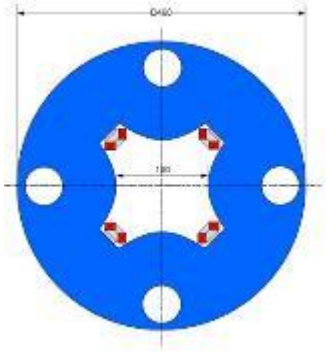
Triplet QXF (LARP and CERN)



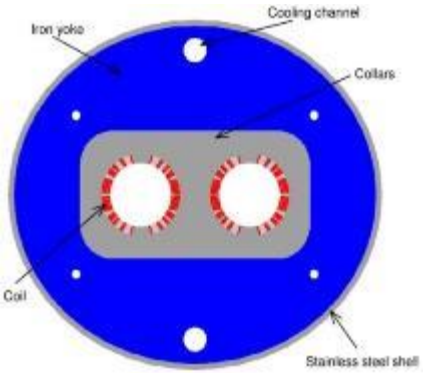
Orbit corrector (CIEMAT)



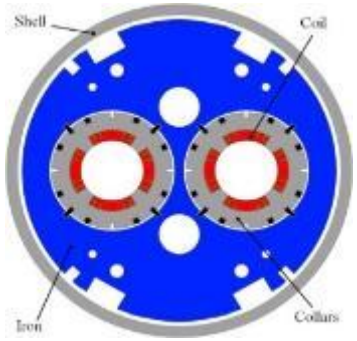
Separation dipole D1 (KEK)



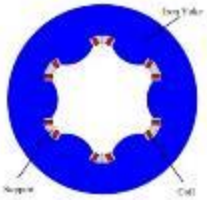
Skew corrector (INFN)



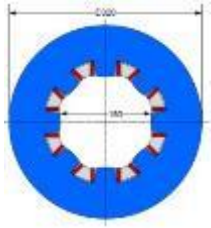
Recombination dipole D2 (INFN design)



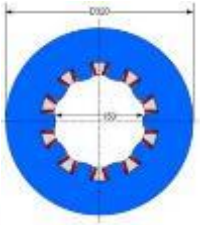
Q4 (CEA)



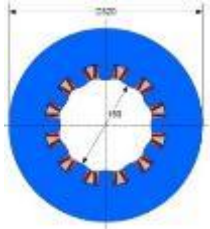
Corrector sextupole (INFN)



Corrector octupole (INFN)



Corrector decapole (INFN)



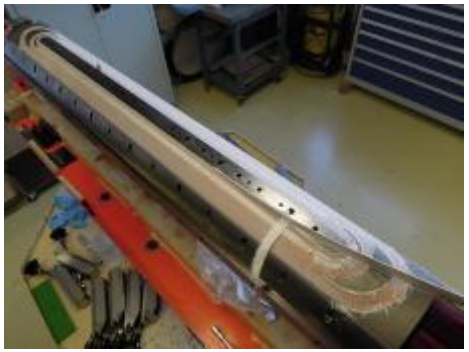
Corrector dodecapole (INFN)

Cross-sections in scale

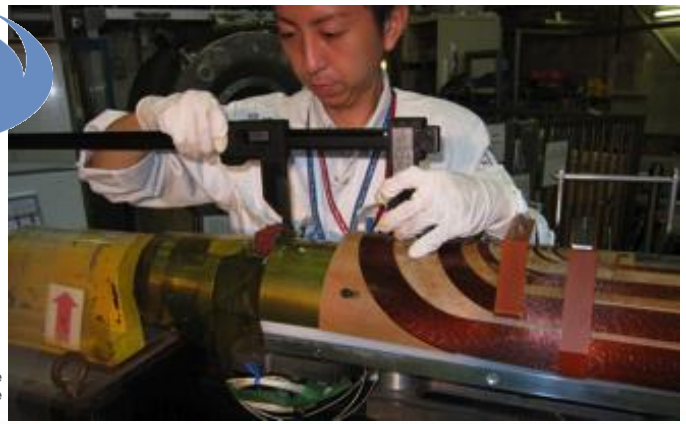
LRos

TRIPLET AND DIPOLES

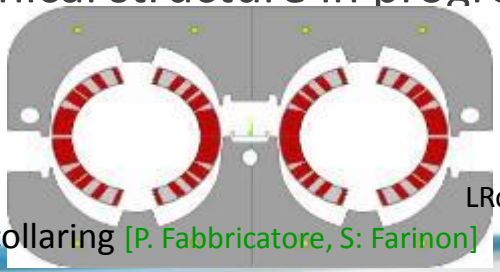
- Triplet
  - First dummy and Nb_3Sn coils manufactured in US and at CERN
  - Cable review done, design in December 2014
  - First quadrupole test in 2015
- Separation dipole D1
  - First Nb-Ti coils being manufactured
  - First test in 2015
- Recombination dipole D2
  - Cross-section defined
  - Mechanical structure in progress



QXF coil wound in US
[G.Ambrosio et al., ASC 2014]

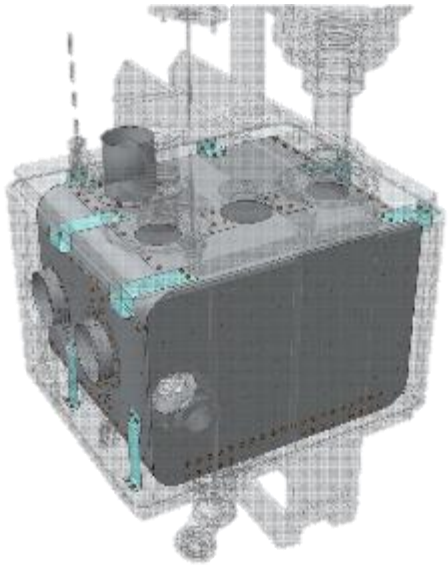


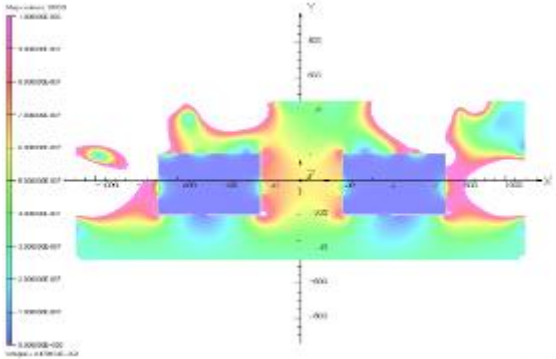
D1 winding at KEK [T. Nakamoto, et al., ASC 2014]

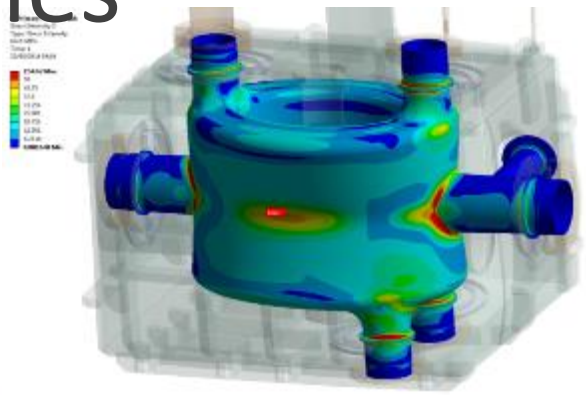


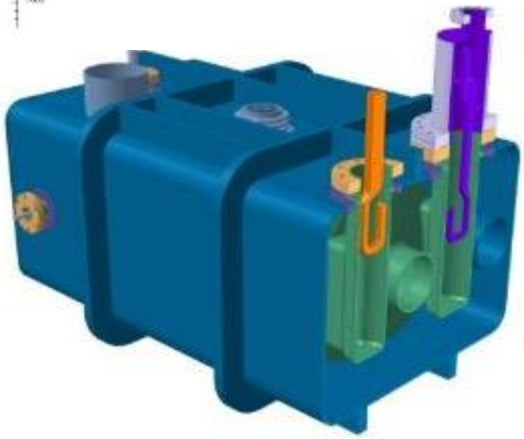
D2 collaring [P. Fabbricatore, S: Farinon]

WP 4 : Dressed Crab Cavities

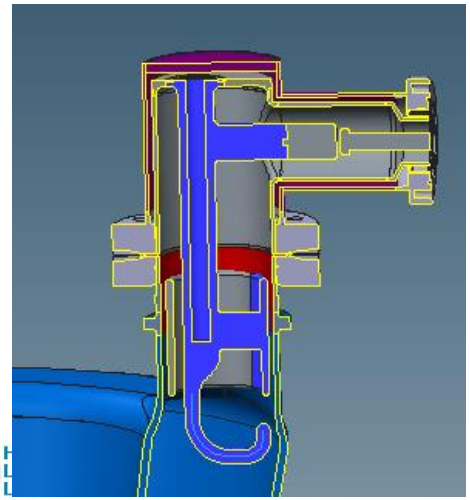


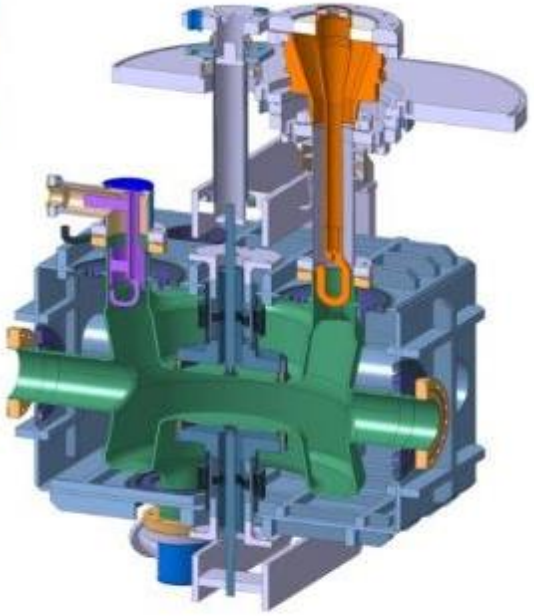






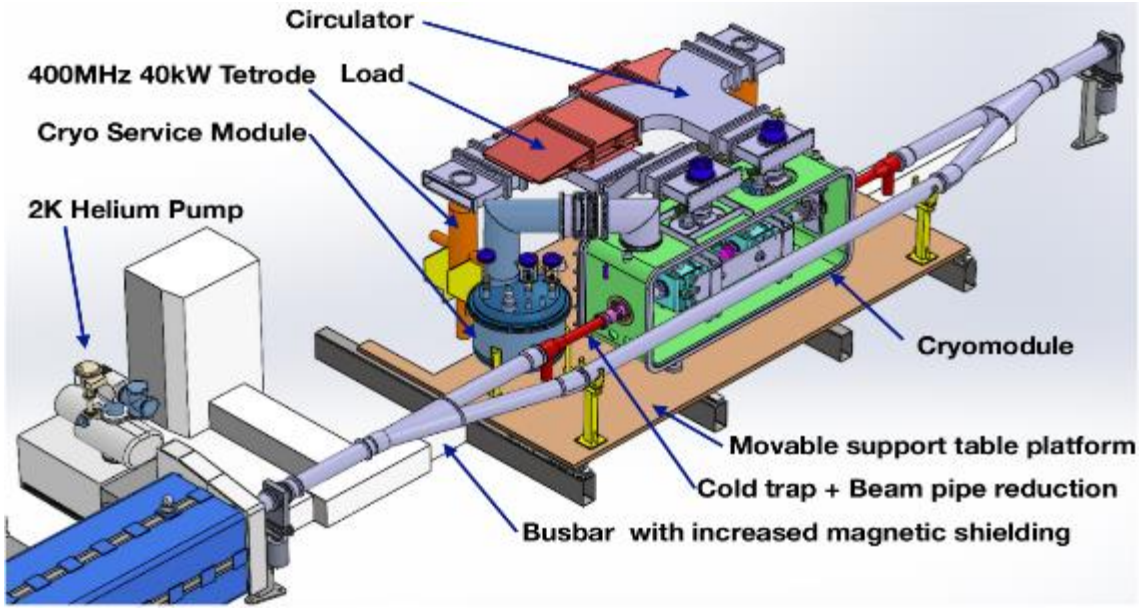
R. Calaga



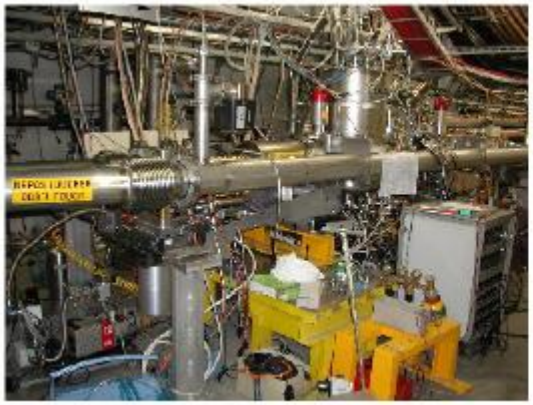


Dressed cavity designs are almost complete.
This includes the cavity, tuner, couplers, magnetic shielding and the LHe vessel.

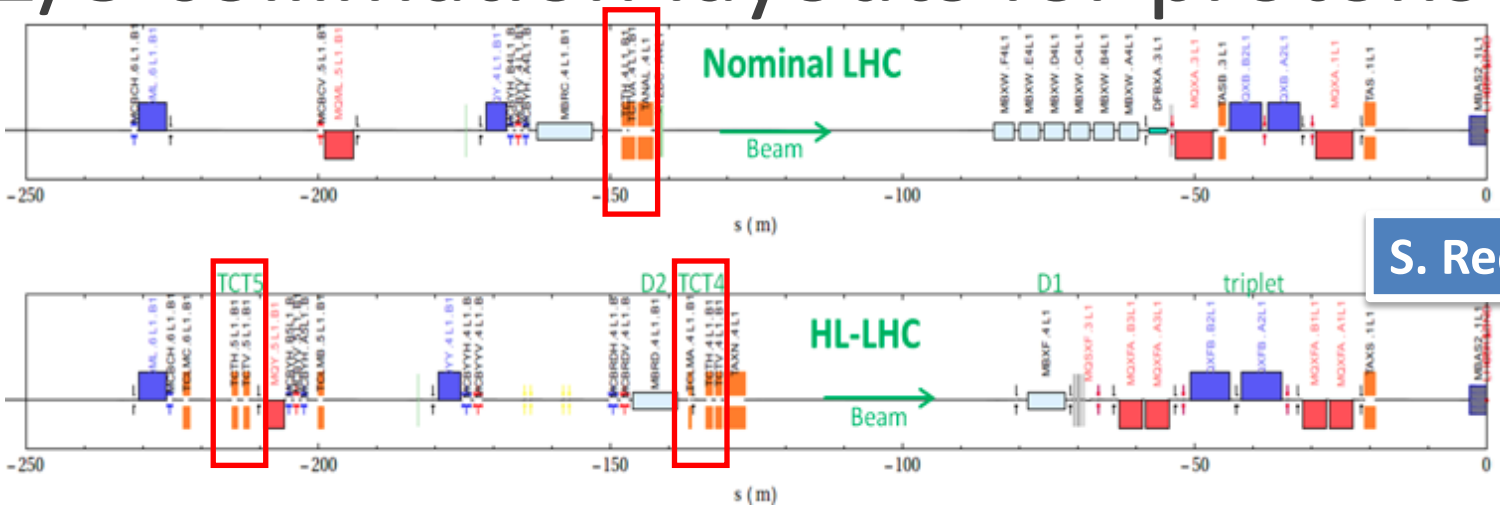
CC SPS tests



On schedule for install the first cryomodule at the end of 2016 and test in in SPS in 2017 and 2018.

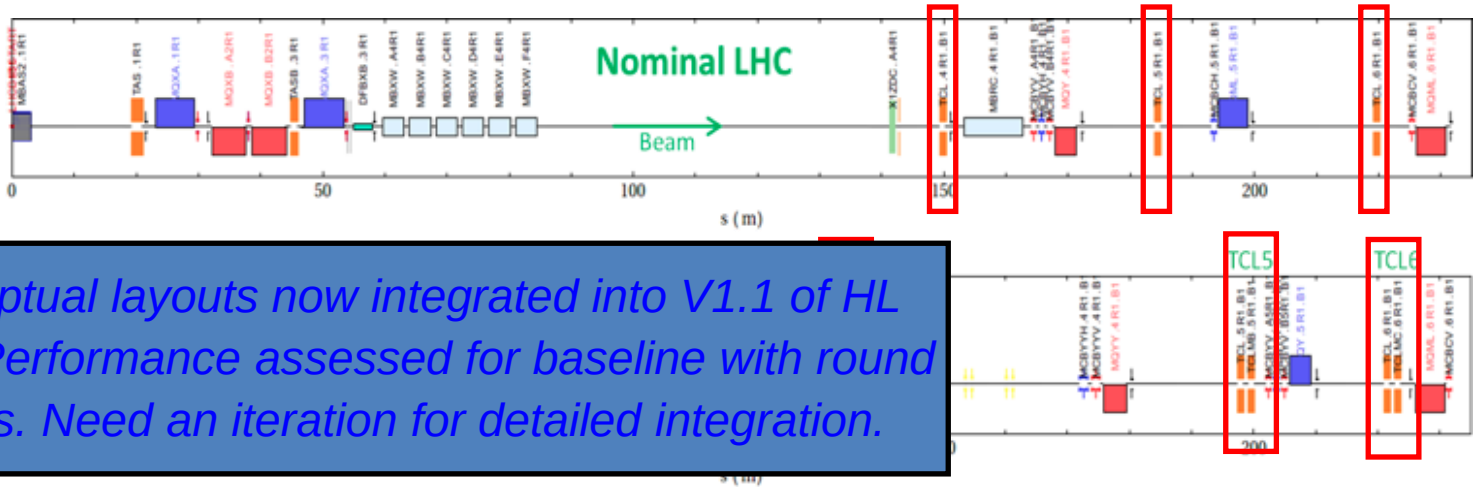


IR1/5 collimation layouts for protons



S. Redaelli

Additional H/V tertiary collimators protect the Q5 aperture from incoming beam losses.



Conceptual layouts now integrated into V1.1 of HL optics. Performance assessed for baseline with round beams. Need an iteration for detailed integration.

Standard TCL layout complemented by fixed mask for outgoing beam cleaning.

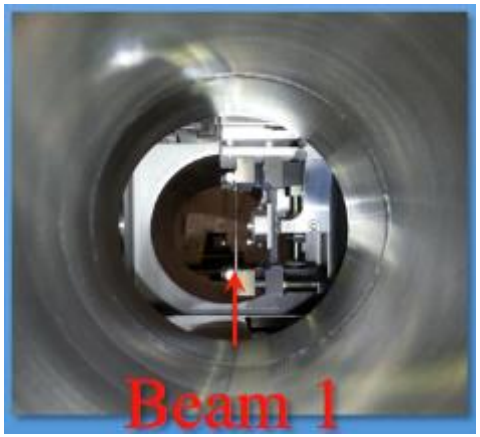
Progress on advance collimation

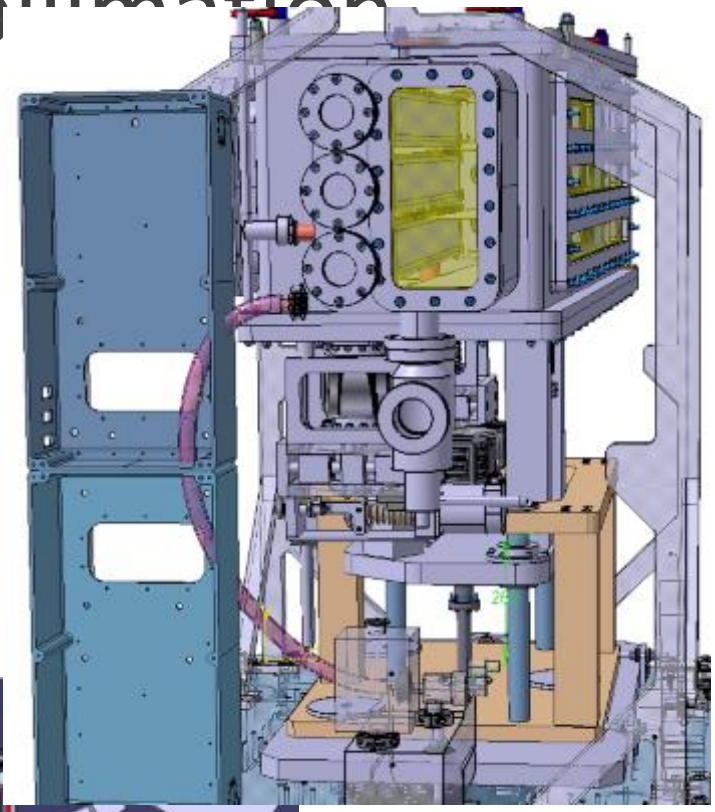
Two crystals installed in the LHC in April 2014 for horizontal and vertical crystal collimation studies with beam!

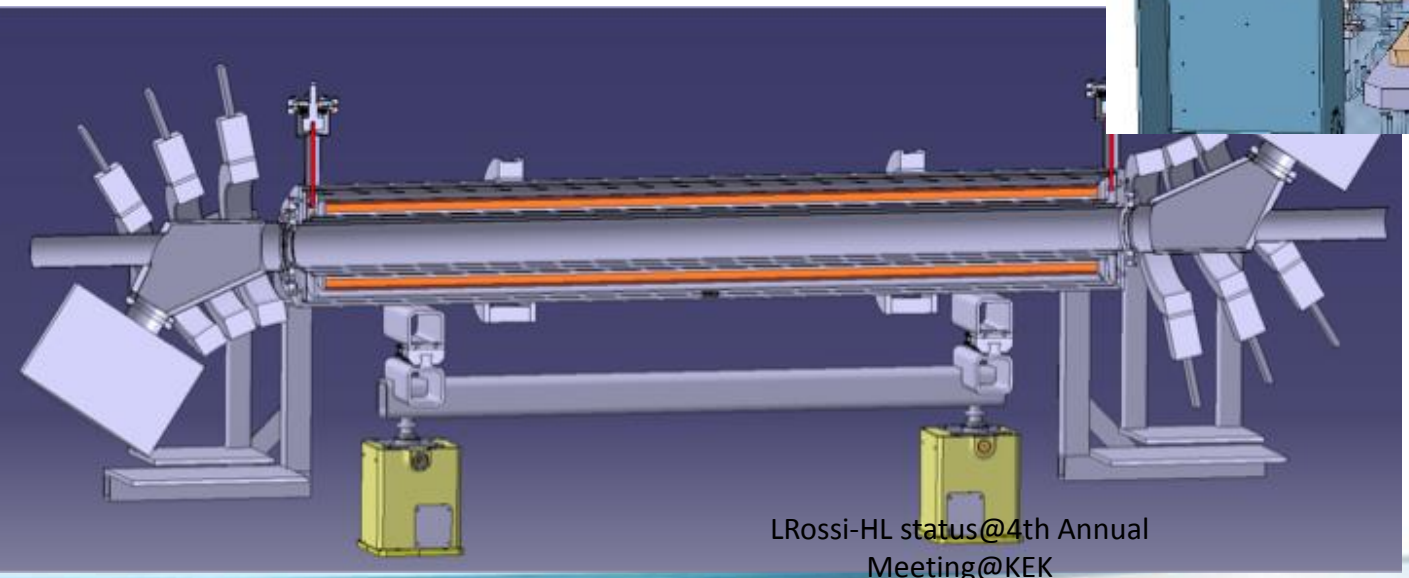
First goals in 2015 (at very low intensity!):

Cleaning as predicted?

Technology suitable for the LHC operation?



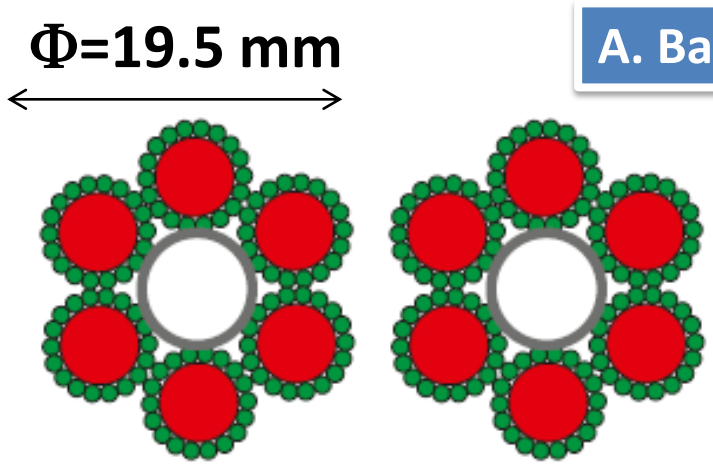




HiRadMat tests for HL secondary collimators: prepare one prototype for 2015! ***A. Bertarelli***

First advanced design study for hollow e-lenses in IR4 ***(D. Perini)***

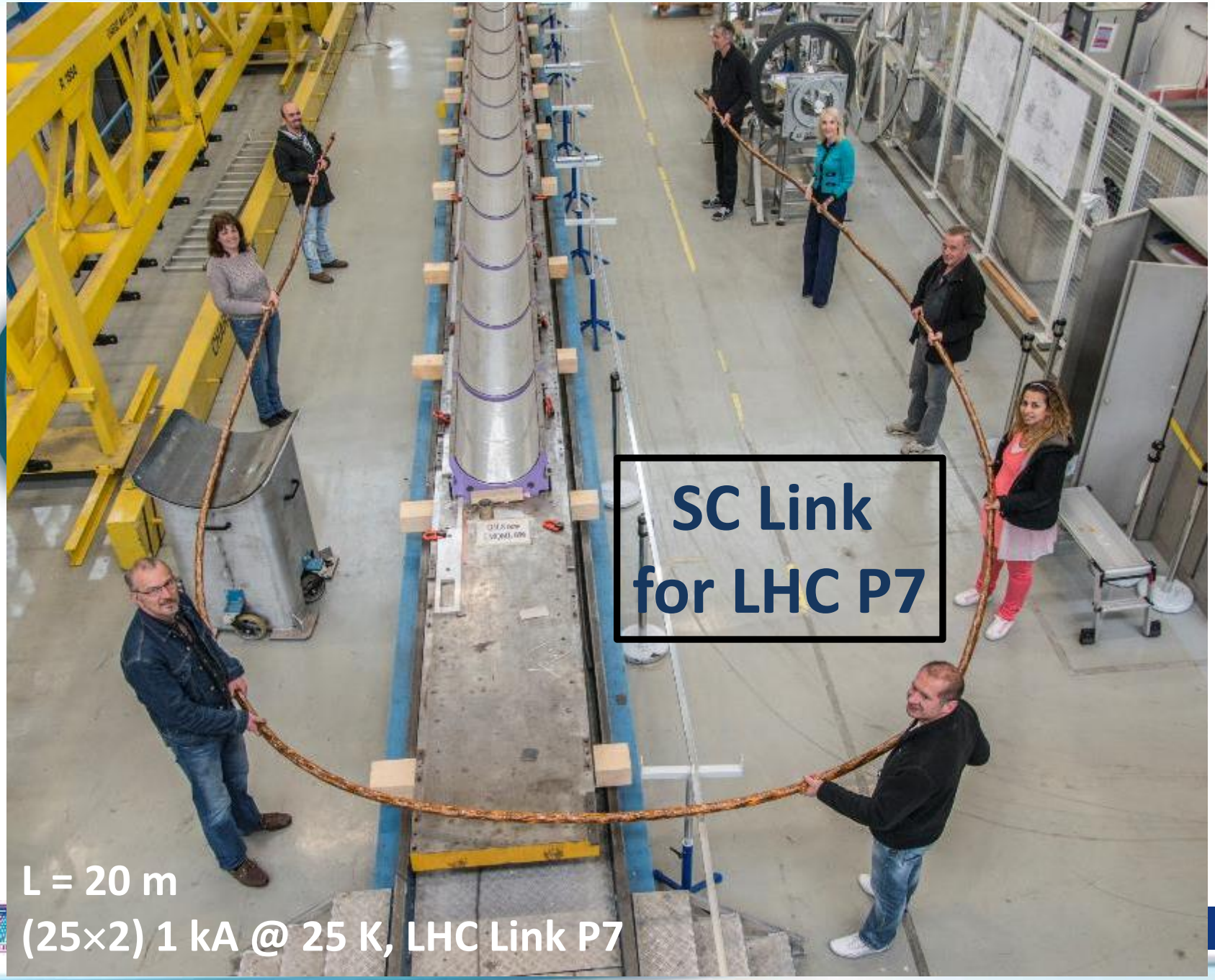
Record in MgB_2 SC Line



A. Ballarino

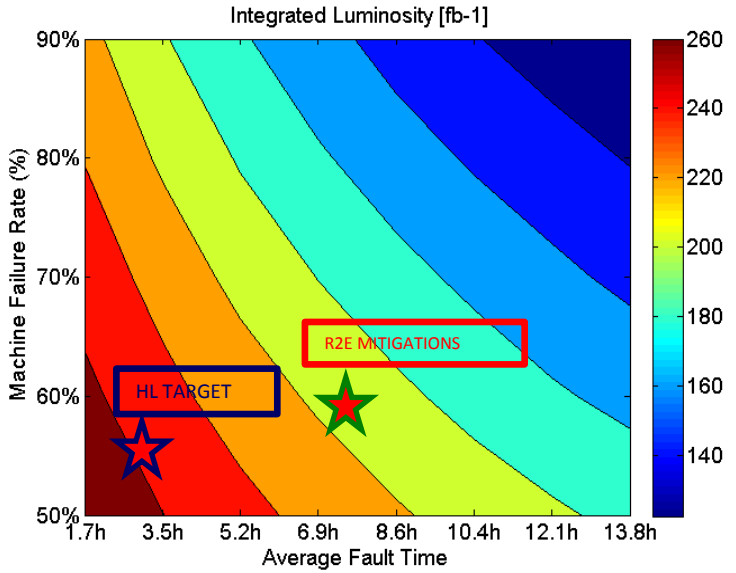
Ltot=2×20 m
I= 20 kA @ 24 K
Bp=1 T
Forced flow of He gas

Demonstration of possibility of transferring high-current in MgB2 cables from round wire


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

Extended availability models for HL-LHC

- **Effect** of (planned) **R2E mitigations** on availability based on 2012 experience.
- Impact of currently **unknown fault** on luminosity production → up to 47fb^{-1}/year could be lost.
- **Un-availability budget** due to radiation induced faults for the "big four" → **to be extended** to more systems and non-radiation induced faults.



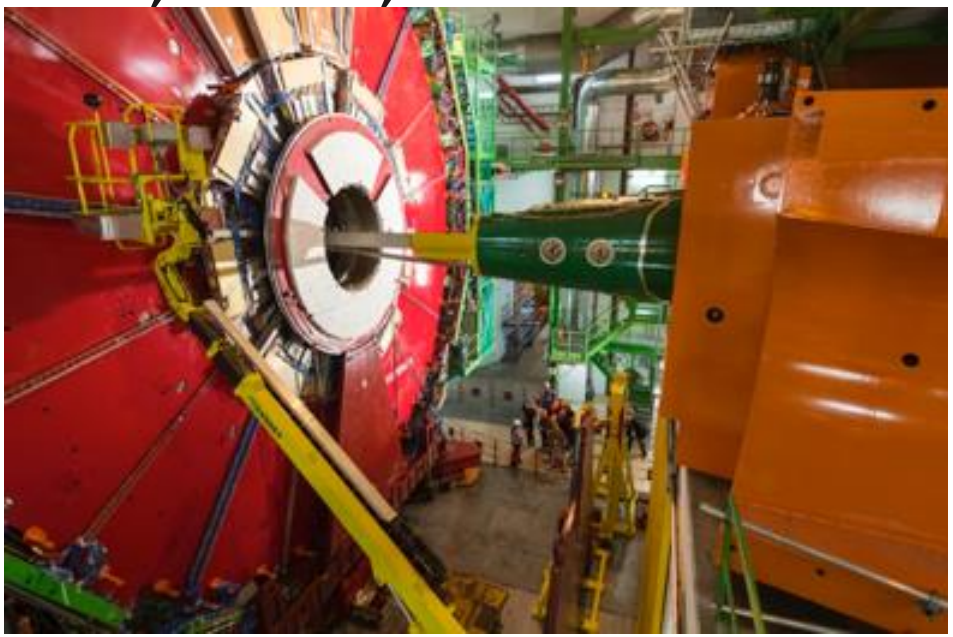
D. Wolmann

	R2E dumps (2012)	R2E downtime (2012)	Target yearly dumps (HL-LHC)	Target R2E downtime (HL-LHC)
QPS	31	~ 80 h	9	32 h
PC	14	~ 60 h	4	14 h
CRYO	4	~ 70 h	1	3.5 h
Vacuum	4	~ 20 h	1	3.5 h
Other	3	~ 30 h	1	3.5 h

Damage studies and beam instrumentation for machine protection.

- Novel method based on closed orbit bump for **verification of protection margins** between dump (IP6) and triplet (IP5) **for ATS optics proposed** → feasibility currently under study.
- **Damage limits of sc. magnets** due to transient beam losses:
  - Study started to identify damage mechanisms and quantify damage limits.
  - Damage experiment in cryogenic environment proposed to HiRadMat scientific board, foreseen for mid/end 2015.
- Detailed study on **damage potential of charged particle beams** at energies from **50MeV to 7TeV** has been performed (see next slide).
- Second **experiment for qualification of diamond particle detectors** with improved readout electronics scheduled for end of November.
- Feasibility study for **monitoring of abort gap population** with beam gas interaction in IP4 was successfully finished → installation in PT4 foreseen → verification with beam during start-up.

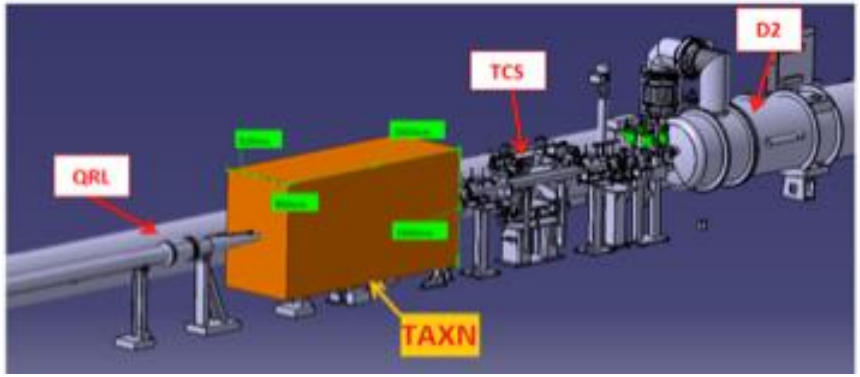
WP8, new TAS, TAN absorbers and Simulations



Larger aperture TASX required for HL-LHC

Design study, planning and coordination with experiments : choice for new TASX, installation in LS3, rather than modular TAS in LS2

H. Burkhardt



Foreseen “minimal” TAXN absorber location in IP8

Functionality described at IPAC’14 TUPRO020

Detailed simulation, in close collaboration with WP2, WP4, WP7, WP10

on detailed aperture modelling

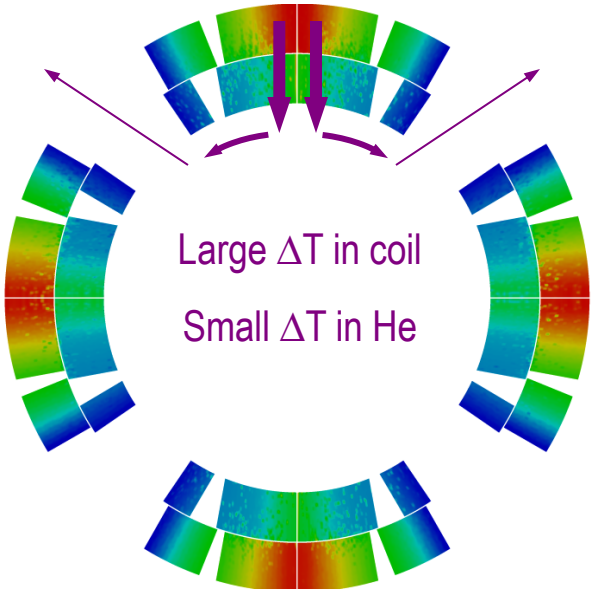
LHC tracking based on SIXTRACK. Extension of SIXTRACK to deal with transients

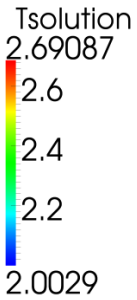
In close collaboration with WP4 crab cavities : detailed modeling of crab cavities transients

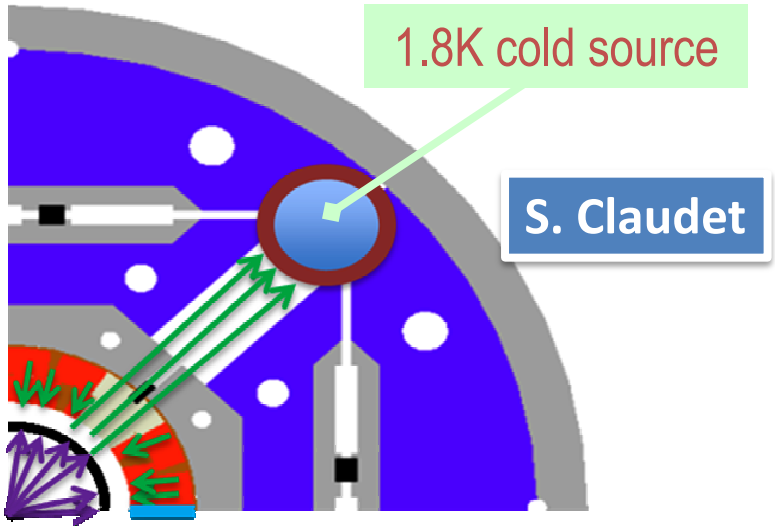
Simulation and minimization of backgrounds and accidental losses in IR region

New inner triplets: Superfluid helium cooling

Model & results for MQXF temperature distribution (5 x 10^{34} $cm^{-1}s^{-1}$)







- Further studies on-going to evaluate robustness of cooling *(ultimate: 7.5 x 10^{34} $cm^{-1}s^{-1}$, Possible additional quench heater, locally higher loads or cooling restrictions issues)*
- Thermal performance and behavior of the new 40K-60K beam screen cooling
- Longitudinal heat extraction at all temperature levels

Extracted from HiLumi-MS42

R. Van Weelderen - G. Bozza

WP10 - DELIVERED [I]

F. Cerutti

- continuous follow up on the **TAS-D1 region**
  - ✓ evaluation of the impact of beam screen design variation ⟹ WP2, WP3, WP9, WP12
  - ✓ dose to beam screen (relevant for carbon coating) ⟹ WP12
  - ✓ dpa and particle fluence in the superconductor and inorganic components ⟹ WP3
  - ✓ HL-LHC radiation levels in the UJ/UL/UP ⟹ R2E WP, WP15
  - ✓ integration of the cryolink in the P1 and P7 FLUKA models ⟹ WP6
  - ✓ evolution of the models of the correctors and of the quad and D1 coils ⟹ WP3
  - ✓ support to the new TAS design (energy deposition maps) ⟹ WP8
  - ✓ FLUKA model made available for Radiation Protection calculations ⟹ WP1

- converging iterations on the **TAN-Q7 region** layout

  (matching section protection by TAN, TCLs, and masks) ⟹ WP2, WP3, WP5, WP8, WP15

- completion of the **HiLumi Book and PDR** chapters

- study of the **D2 protection in P8** (role of a "mini-TAN") ⟹ WP2, WP3, WP8, WP15

DELIVERED [II]

- strategy to monitor the **dose to warm magnets** → WP3 (P. Fessia & Co.), WP5, RP
- study of DS losses for **crystal MD operation** in P7 → WP5

  (expected BLM signals and power density in the magnet coils)
- **load on new collimators** (TCSX, TCTW) for various accident scenarios → WP5
- calculation of the HL-LHC machine induced **background to CMS** → WP5

AHEAD

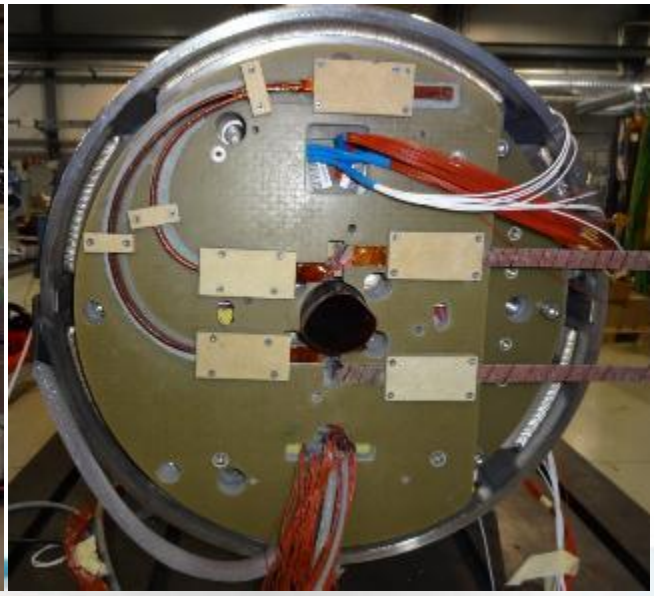
- ion collisions (impact on P2 triplet and P1/P5 DS) ⟹ WP2, WP3, WP5, WP11
- DS proton losses in P1 and P5 ⟹ WP5
- dose to cryostat joints ⟹ WP12
- radiation to the BBLR compensator ⟹ BBLR team
- radiation to electronics calculations ⟹ R2E WP
- analysis of (collimator and cable) sample irradiation tests ⟹ WP3, WP5

RESOURCE SHORTAGE

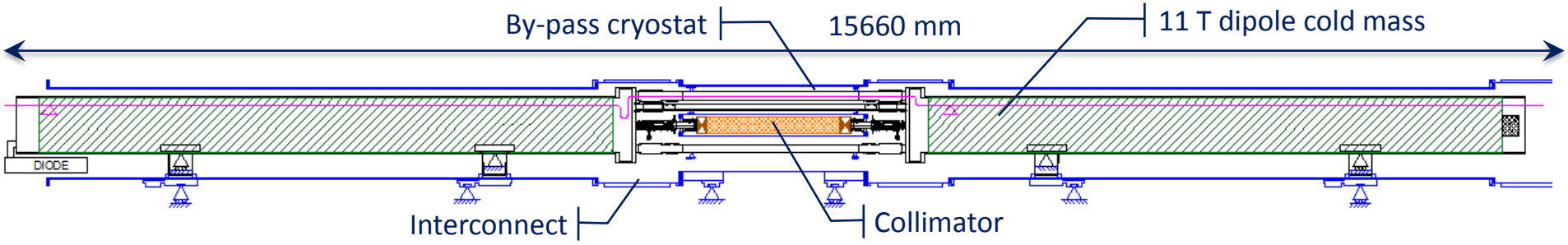
LARP manpower [N. Mokhov and his team] virtually zeroed (factor 10 cut)

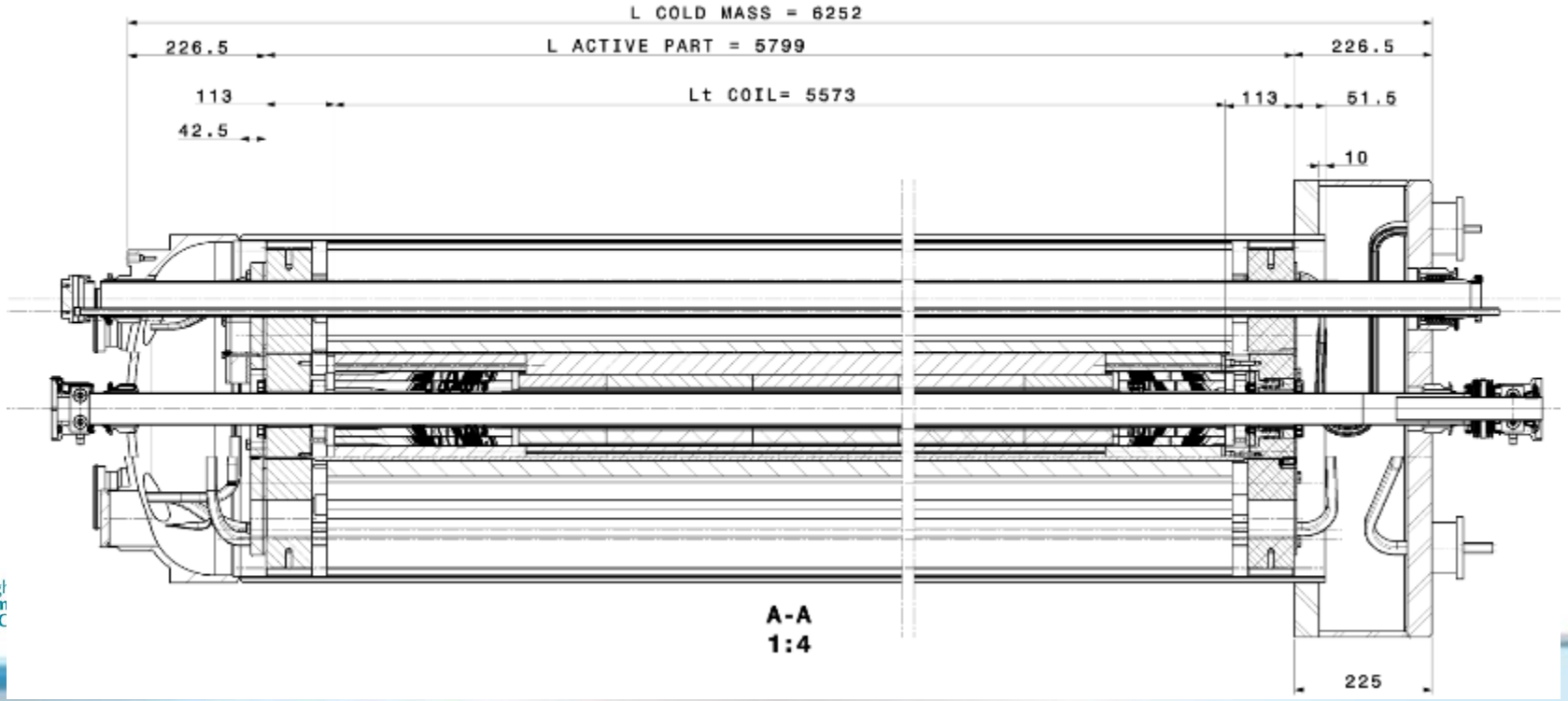
substantial gap in CERN manpower during the first half of 2015 (end of L. Esposito's fellowship)

WP 11 – Models 11 T

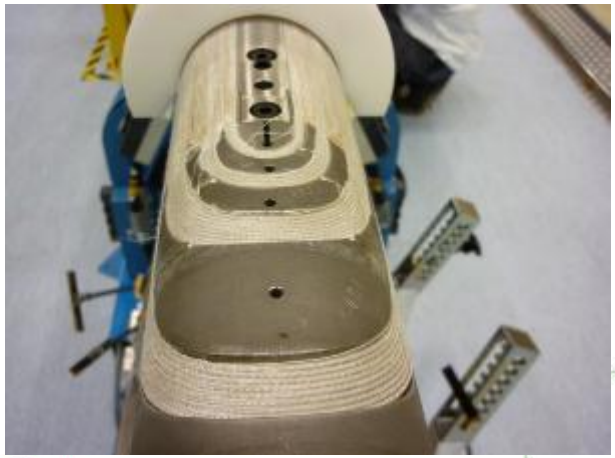


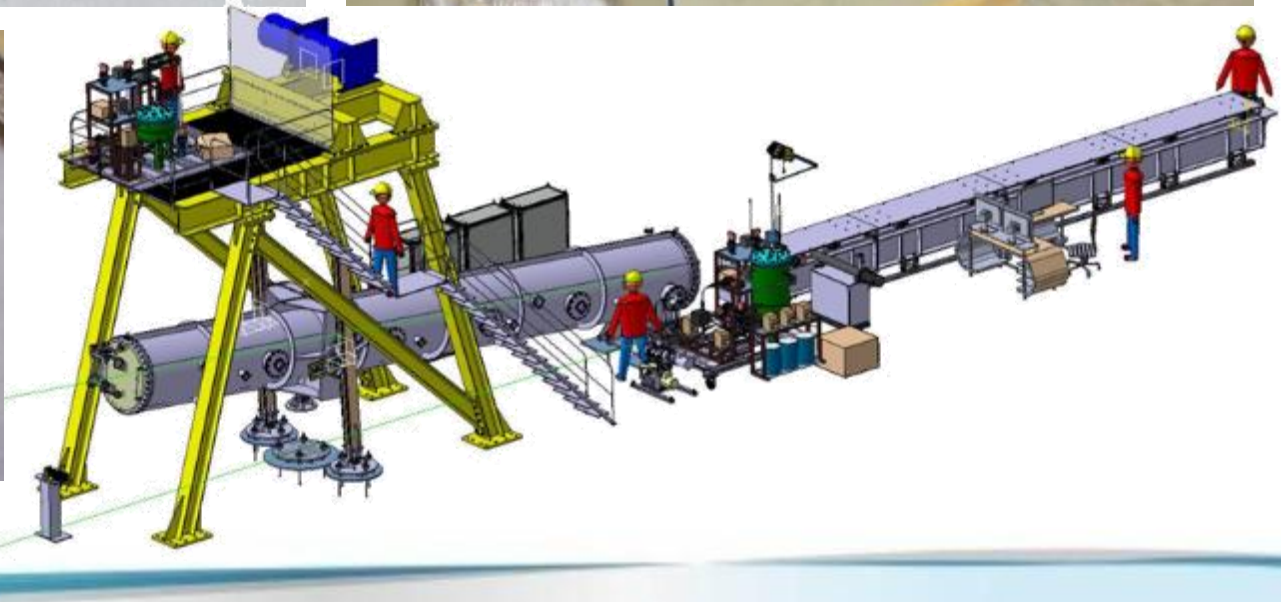
11 T - DS collimator Integration design





Full-length prototype

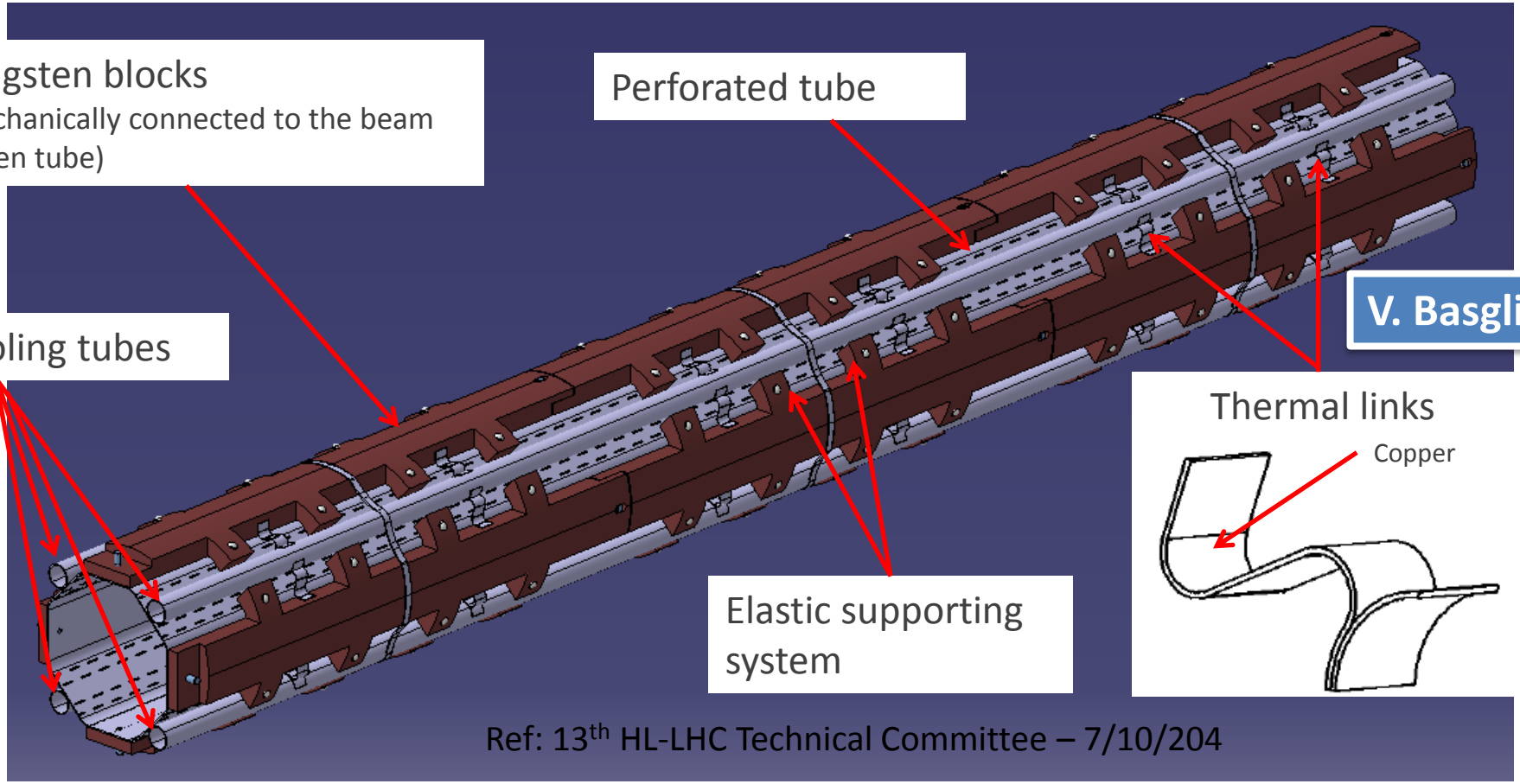




High Luminosity LHC

Design of the Shielded HL-LHC Beam Screen

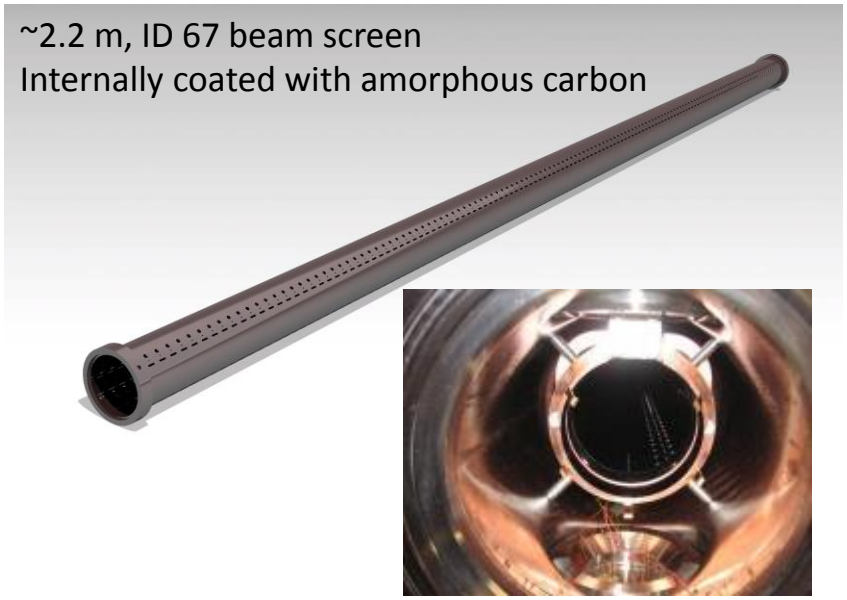
Assembly of the Q1 beam screen

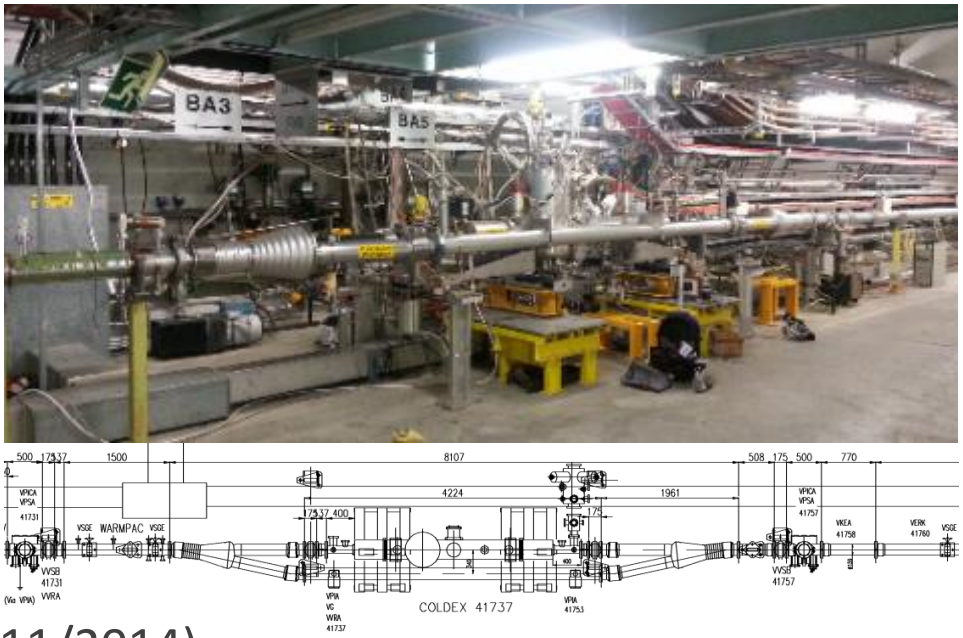


- Design studies
- Mechanical analysis : impact of quench, heat transfer, supporting system
- Tests with tungsten prototypes
- Q2-Q3 2015: short (1 m long) prototype

Performance of a-C coated Beam Screen

- Photon stimulated desorption at RT of a-C coating at KEK Photon Factory (E_c = 4 keV)
- COLDEX equipped with a-C coated beam screen held at 50 K



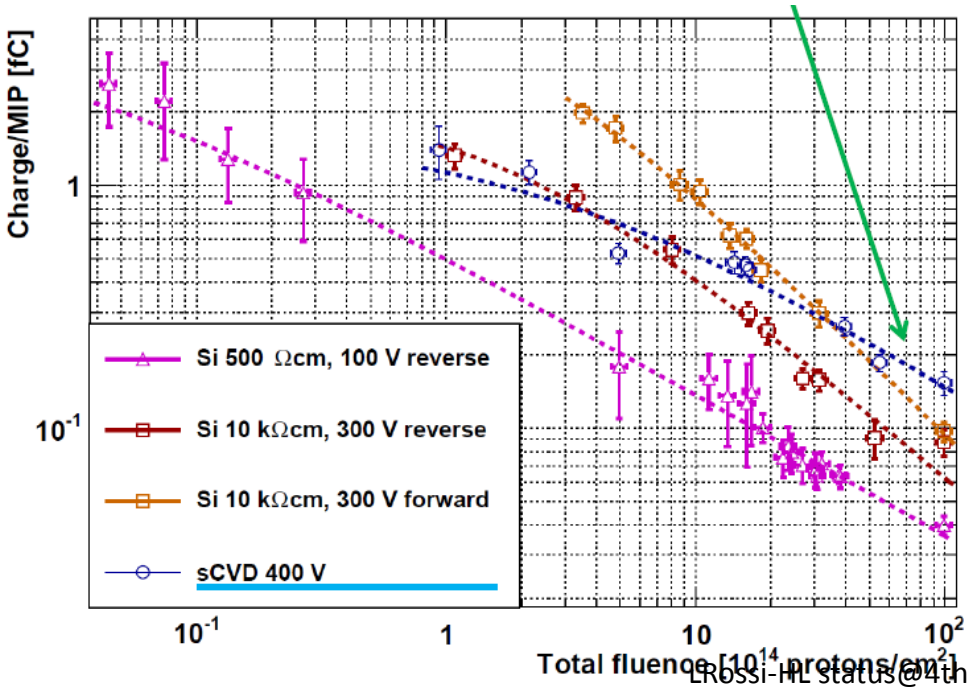


- Tests with LHC type beams in SPS (3-9/11/2014):
  - Heat load < 1 W/m
  - Pressure rise < 10^{-8} mbar (mainly H_2)
- 2015: continue characterisation at cryogenic temperature of a-C coating in the laboratory and with COLDEX

Beam Loss Monitoring

Rhodri Jones

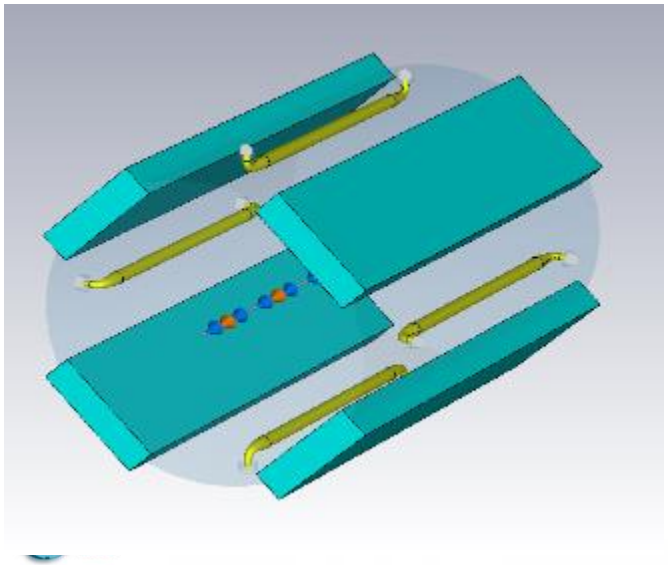
- **Radiation Hard Front-end Electronics**
  - Second prototype being prepared for production
- **Cryogenic BLMs**
  - Silicon and Diamond detectors installed on cold mass of several LHC dipoles for operational tests during Run II
    - Collaboration with Cividec Instrumentation (Austria) and IOFFE Physical Technical Institute (Russia)

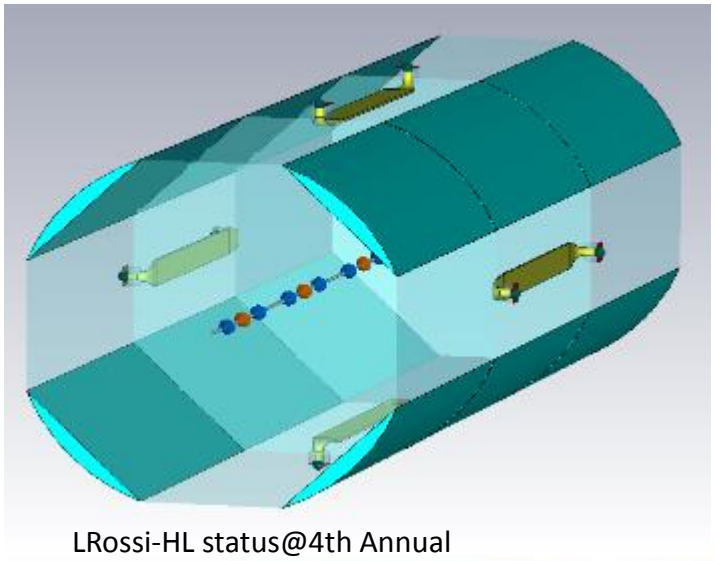


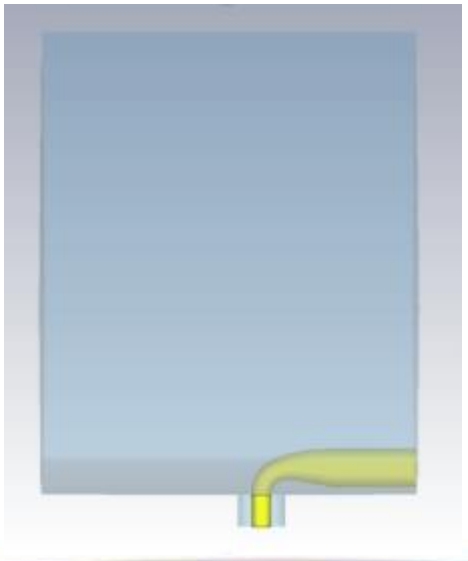
- **Cryogenic Irradiation Tests**
  - Silicon & Diamond detectors irradiated in CERN-PS East Area under cryogenic conditions
    - First time experiments combining low temperature and irradiation on these materials has been performed
  - Above 0.9MGy diamond sensors give the highest signal
  - Operational efficiency of diamond reduced by a factor of 14 for 2MGy irradiation

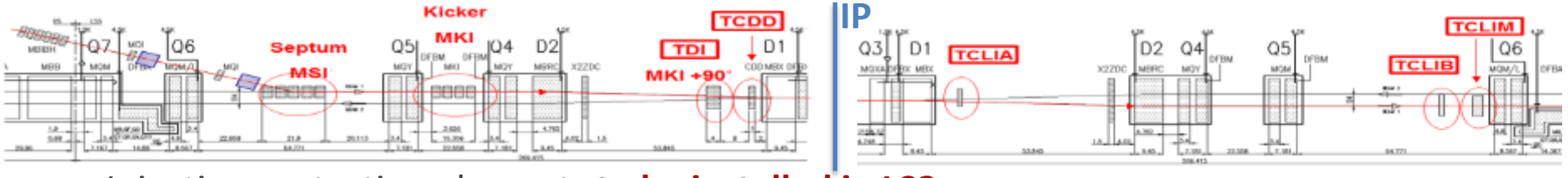
BPMs for the new IR Regions

- **New BPMs Q1 to Q5 – studies starting**
  - New design required for new triplet layout
    - Need to include tungsten shielding
      - Effect of various absorber shapes being simulated
    - Need to improve directivity & minimise transverse impedance
      - Optimisation of stripline to coaxial transition
      - Directivity improved in simulation by nearly 10dB over current design







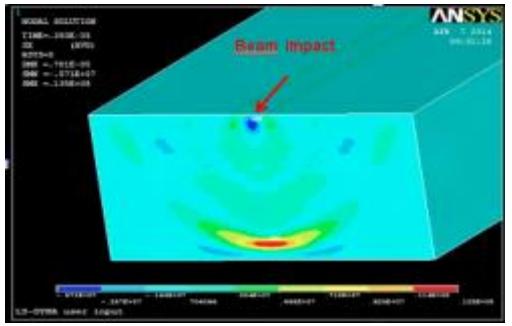


- Injection protection elements **to be installed in LS2**
  - **TDIS** can have about same integrated absorber length as present TDI
    - Preliminary design: two modules with low Z absorber + one module with high Z absorber
  - **TCDD** aperture reduction possibly necessary to protect D1
    - D1 damage limit required, decision end 2014
  - **TCLIA and TCLIB** likely not replaced for protection reasons
    - However TCLIA IP2 larger opening because of ALICE ZDC?

Beam Inj -WP14

- Sur

Beam	Emit. x,y [μm]	N_b [p/bunch]	# bunches	M-C Safety Factor
Standard	2.0	2.3e11	288	1.01
BCMS	1.3	2.0e11	288	0.90
BCMS	1.3	2.0e11	240	1.43



Based on graphite as low Z absorber. New materials under study

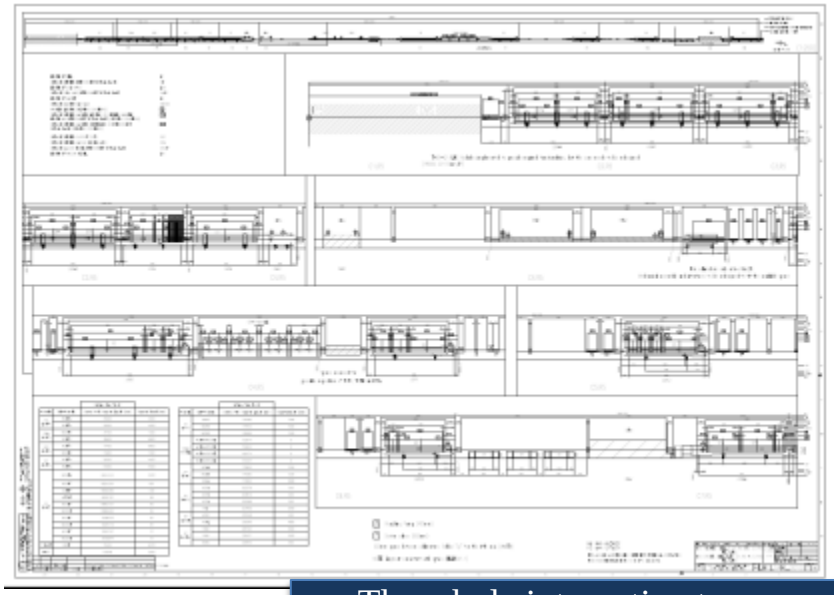
Considering no error from energy deposition calculations

J. Uythoven

- TDI interferometry on the way to be installed during run II
- Contract placed to develop application method for Cr_2O_3 coating of MKI ceramic chamber to reduce SEY. If successful apply on prototype magnet

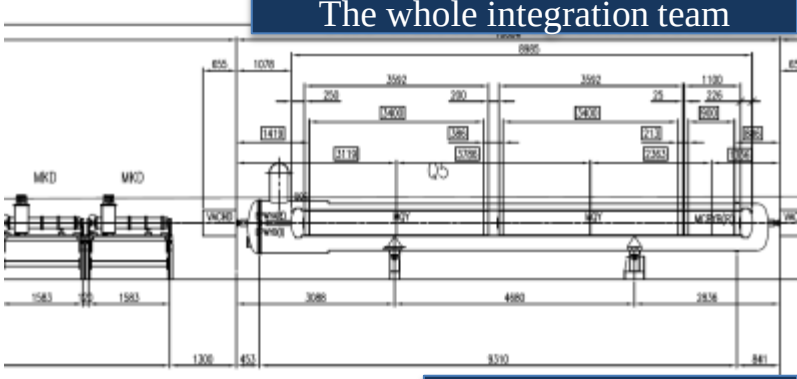
Machine lay-out

- Two full iteration of the lay-out of the IR1/IR5 (deployed in IR5 right) delivered and approved including all equipment on the beam. Went through interactive review process with all WPs. In particular
  - TAS-TAN
  - Magnets with cold masses and cryostats
  - Collimation
  - Radiation Masks
  - Crab cavities
  - Beam instrumentation
  - Vacuum equipment
  - Electrical feed boxes (DFX, DFM) ***space reservation***
  - Beam-beam wire compensator ***space reservation***



The whole integration team

- Analysis of the possible solution for the integration of the Q5 in IR6 started

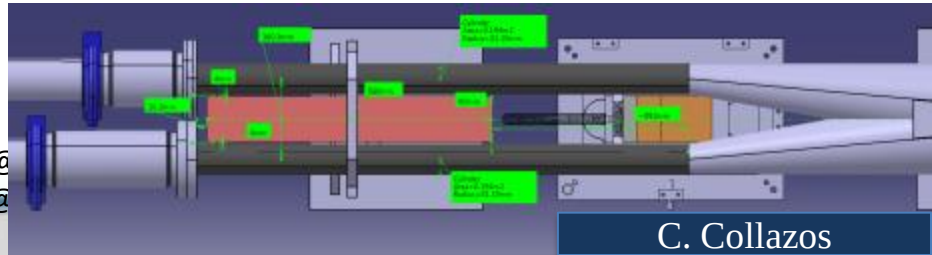


H. Prin

- Cleaning of old reservation in IR4 to free space to HLK-LHC equipment

- Preliminary study for integration constraints

of the mini-TAN at point 8

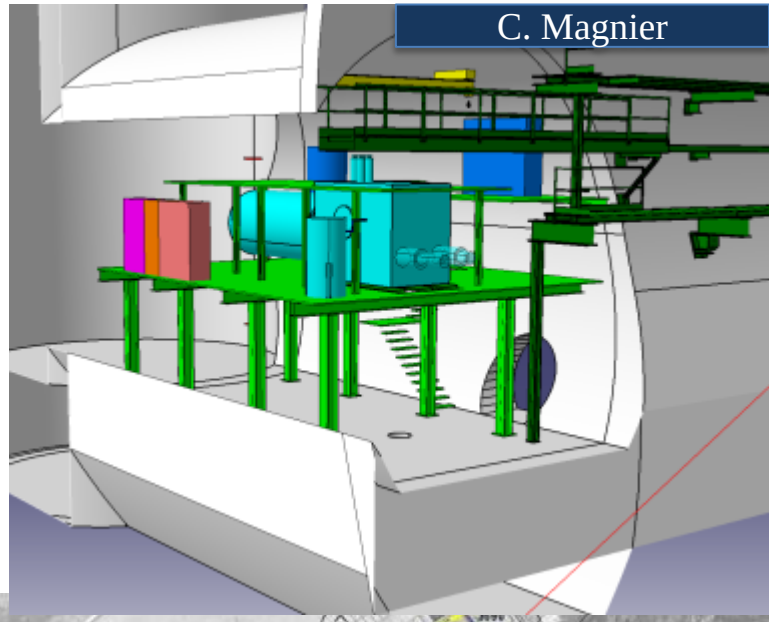


C. Collazos

Large infrastructure studies point 1,5 and 4

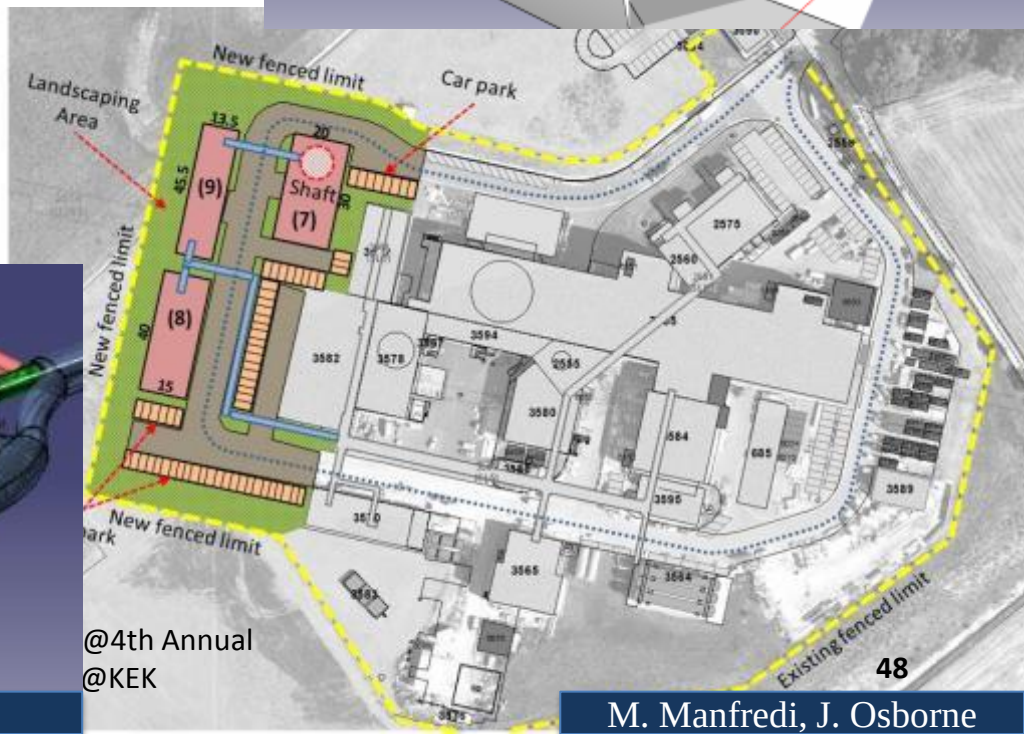
P. Fessia

- New Cryo-plant at point 4 (LS2)

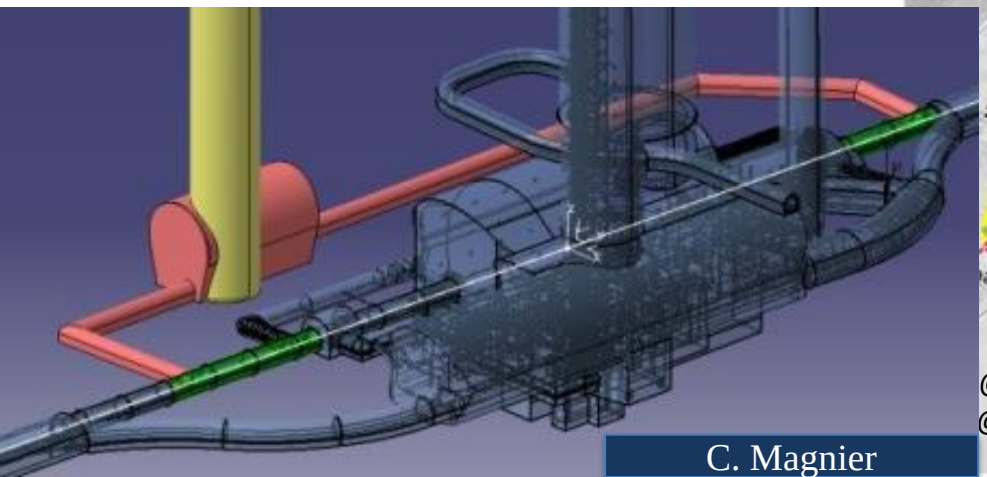


C. Magnier

- Development of concepts for infrastructure installations at point 1 and 5 after having performed a detailed inventory of the space needed by each equipment group:
  - Cryogenics
  - RF
  - Power converters



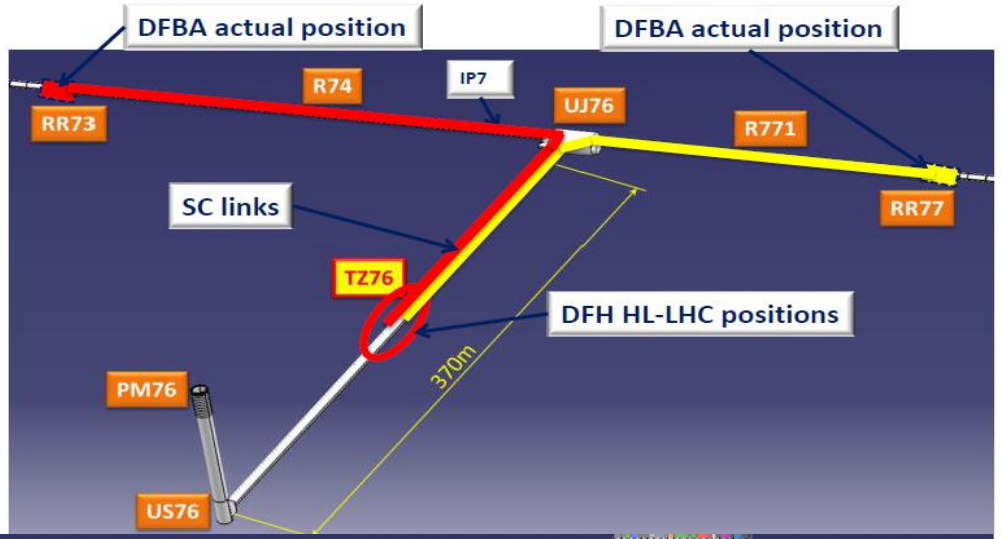
M. Manfredi, J. Osborne

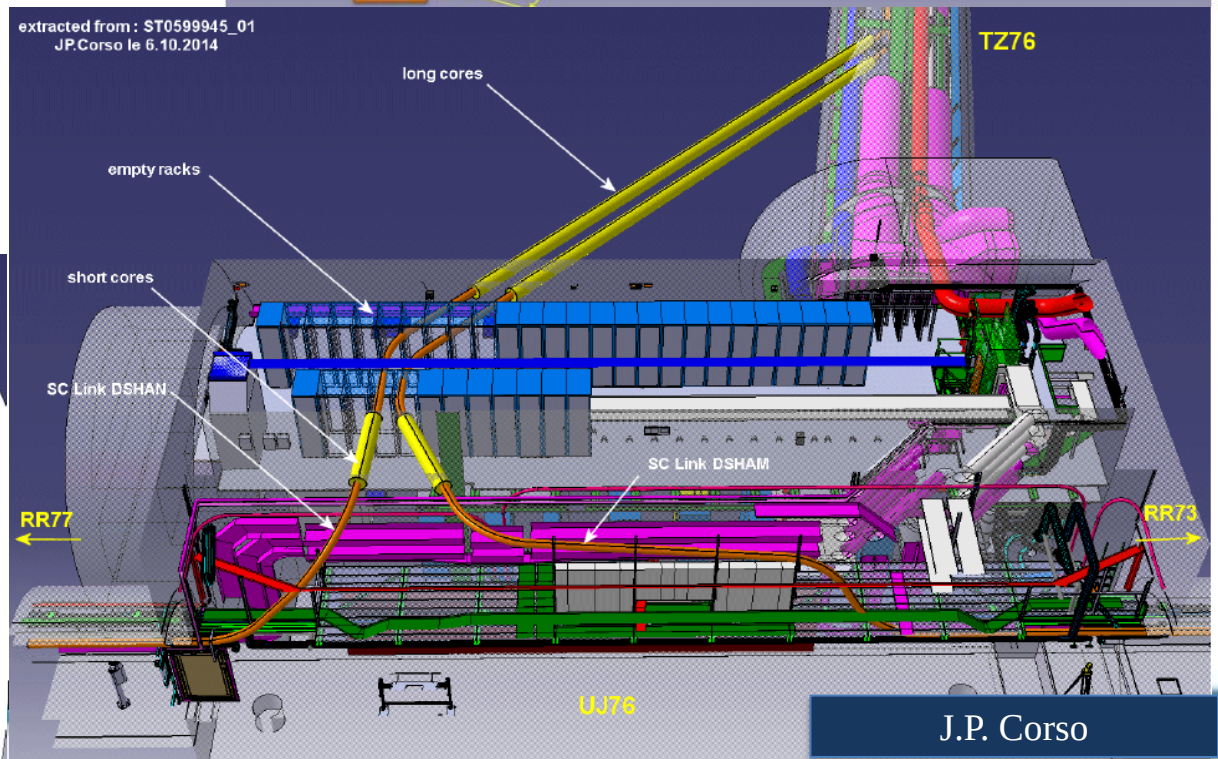


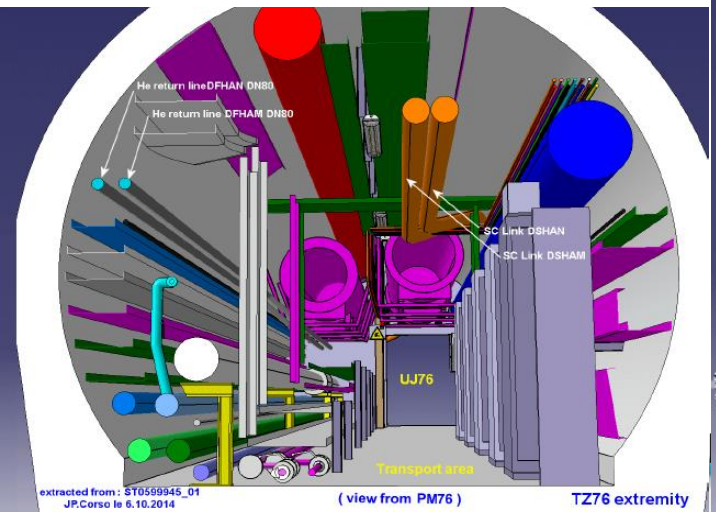
C. Magnier

WP15 SC link (targeting LS2)

Study of the possible integration issues and solution for the installation the SC link in IR7 in LS2







Future reviews

- 8-12 December 2014:
  - 11 T dipole Int. Review
  - MQXF (IT quad) Design Int. Review
- 2015
  - Follow up CC review
  - Follow up MQXF reviews
  - After LHC chain has start operation:
    Review of collimation system for the upgrade TBD?
    Review of the beam Injection & Extraction system ?
    HL & LIU parameters ?
- Clarify relation with Consolidation project

Cost & Schedule Review - Scope

- HL-LHC and LIU projects
- taking into consideration how these are linked to the consolidation project and the operation of the CERN accelerator complex
- **Assess the status of the project development taking into account the technical developments that are still ongoing**
- Assess the project baseline (not technical – RLIUP),i.e.
  - Project Scope
  - Schedule
  - Cost

  And
  - Project Management Methods
  - Risks

Talk B. De Lille and I. Bejar

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