HL-LHC Re-Baseline and Status

V. Baglin on behalf of WP12

HL-LHC VSC Seminar, CERN, 9th December 2016

OUTLINE

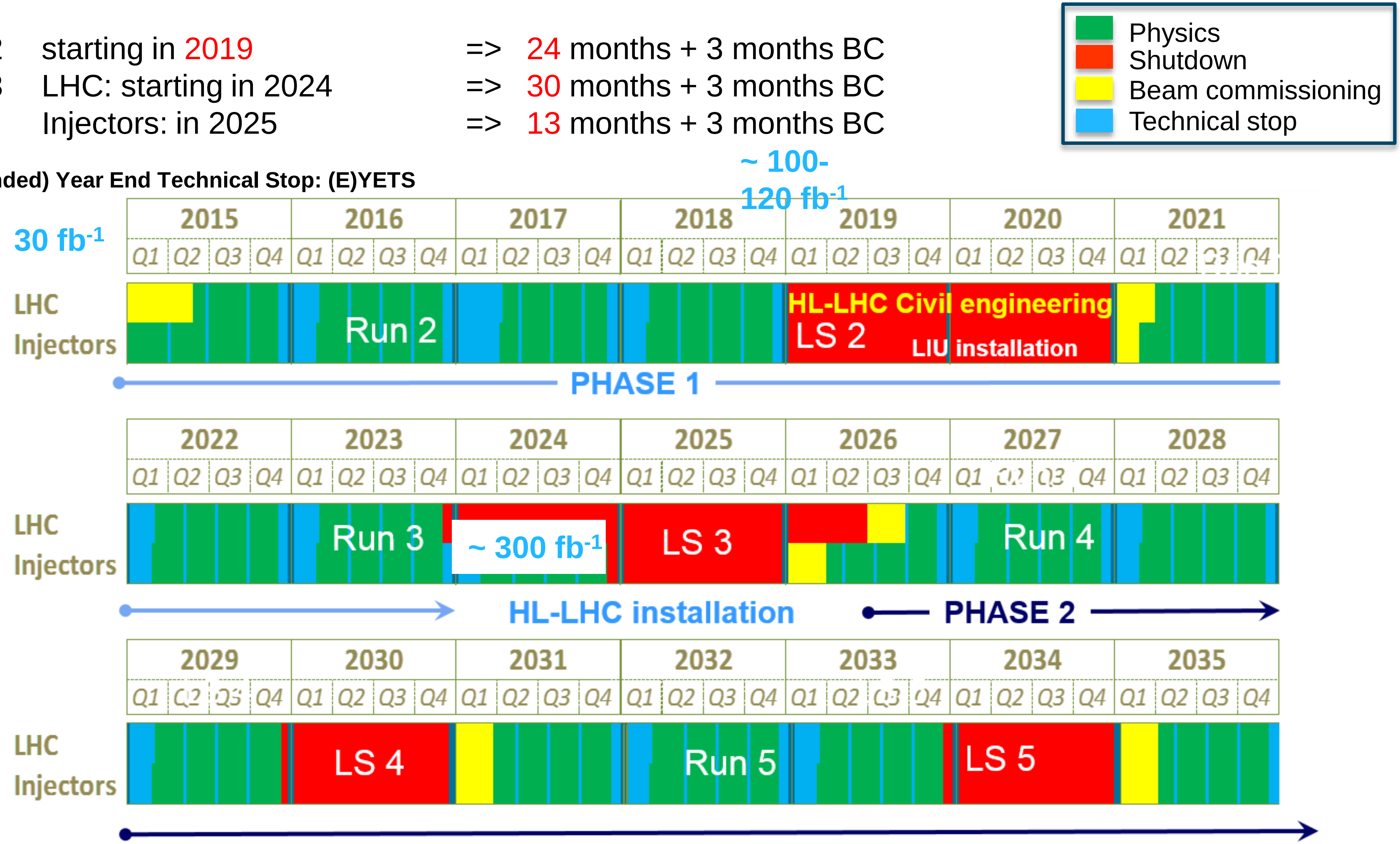
1. Introduction
2. HL-LHC beam screens
3. HL-LHC Layout
4. LS2
5. LS3 & Studies
6. Summary

1. Introduction

LHC roadmap: according to MTP 2016-2020

LS2	starting in 2019	=>	24 months + 3 months BC
LS3	LHC: starting in 2024	=>	30 months + 3 months BC
	Injectors: in 2025	=>	13 months + 3 months BC

(Extended) Year End Technical Stop: (E)YETS

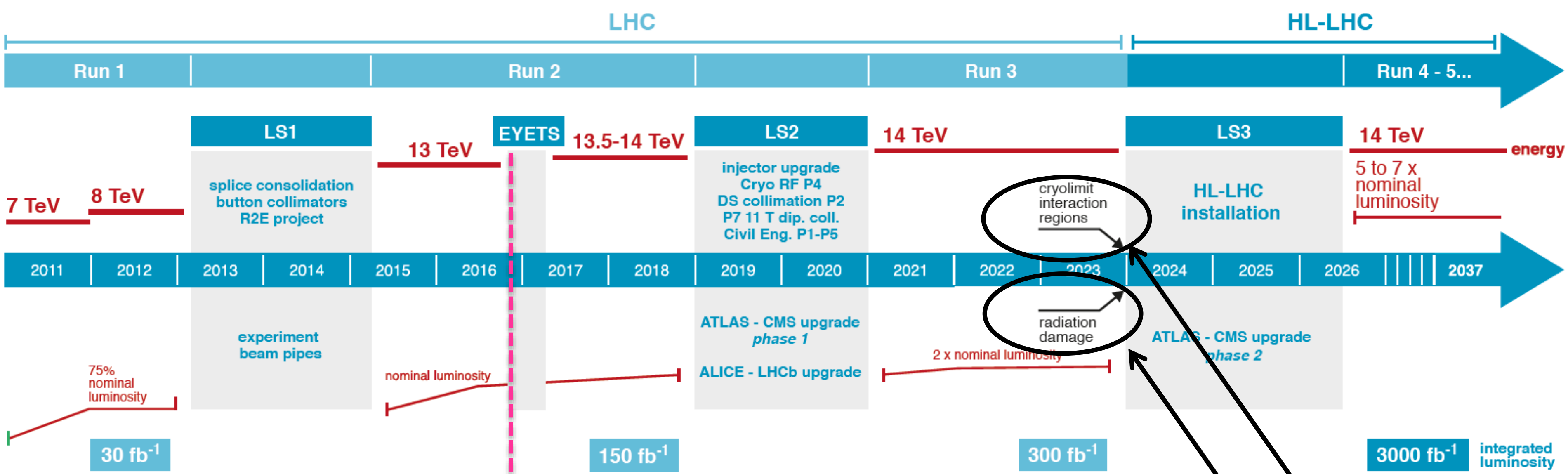


Goal of 3'000 fb^{-1} by mid 2030ies

F. Bordry

LHC / HL-LHC PLAN

LHC / HL-LHC Plan



L. Rossi

Today

Remember:
2 technical limits !

Technical limits to lumi increase
(Machine & Experiments)

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

From FP7 HiLumi LHC Design Study application

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 L_{peak} = **5×10^{34} cm^{-2}s^{-1} with levelling**, allowing:

An integrated luminosity of **250 fb^{-1} per year**, enabling the goal of **L_{int} = 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.

Ultimate performance established 2015-2016: with same hardware and same beam parameters: use of **engineering margins**:
$L_{peak\ ult}$ ≅ 7.5 10^{34} cm^{-2}s^{-1} and **Ultimate Integrated $L_{int\ ult}$ ~ 4000 fb^{-1}**
LHC should not be the limit, would Physics require more…

HL-LHC Baseline Parameters

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

Back-up scenario

Tech. Coord. Committee, V6.1

Parameter	LHC	HL-LHC	8b+4e
Beam energy [TeV]		7	
Bunch spacing [ns]		25	
Bunch population [10^{11}]	1.15	2.2	2.2
Number of bunches	2808	2748	1968
Beam current [A]	0.58	1.09	0.82
Crossing angle [μrad]	285	510	480
Beam separation [σ]	9.4	12.5	12.5
Betatron function at interaction point β* [m]	0.55	0.2	0.2
Normalised emittance ε_n [μm]	3.75	2.5	2.2
ε_L [eVs]	2.5	2.5	2.5
rms bunch length [m]	0.075	0.081	0.081
Peak Luminosity without crab cavities [10^{34} cm^{-2}s^{-1}]	1	6.5	5.8
Virtual luminosity with crab cavities without levelling [10^{34} cm^{-2}s^{-1}]	(1.18)	12.6	11.5
Levelled luminosity with crab cavities [10^{34} cm^{-2}s^{-1}]	-	5	3.8
Events per crossing	27	132	140
Integrated luminosity [fb^{-1}/year]	45	**260**	190

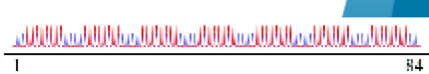
Efficiency requires long fill times (6-10 h)

LIU

New IT Quads & ATS

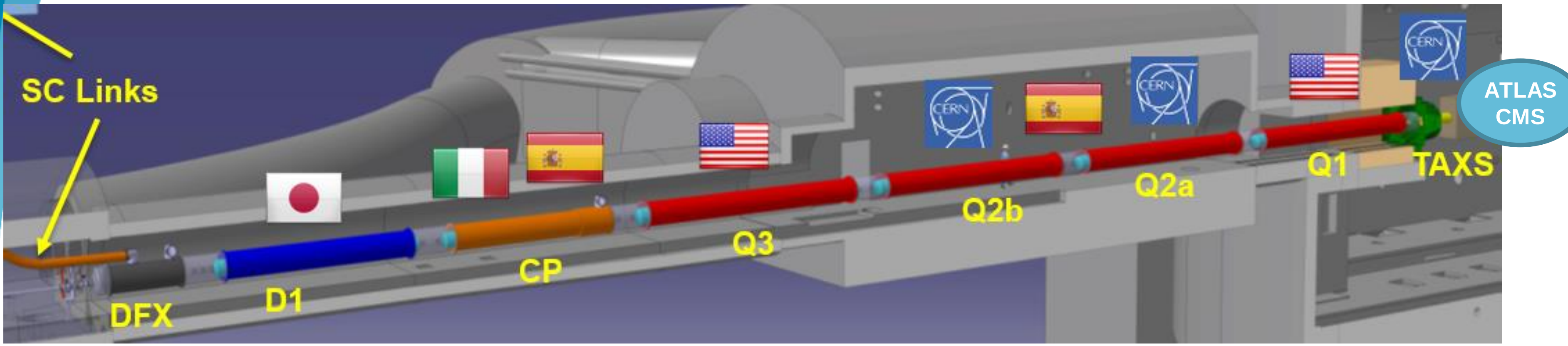
Crab Cavity with levelling

VSC to review performance compatibility with HL-LHC to **identify consolidation** and build **new systems compatible with HL-LHC**



NEW focussing quadrupole and merging dipole

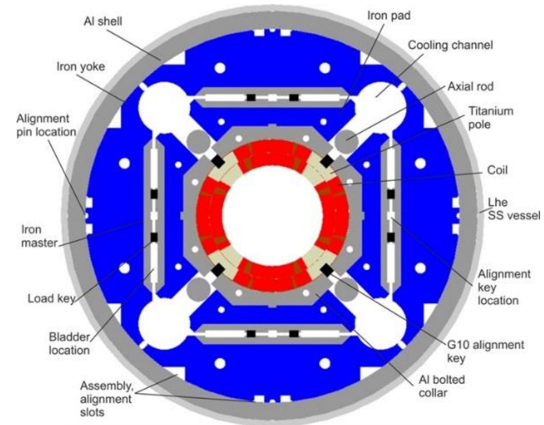
- Decrease beta (*i.e* beam size) at collision point (beta*) from 55 cm to 15 cm



- All superconducting magnets at 1.9 K with a beam screen at 5-20 K or 40-60 K

- Q1, Q2, Q3, CP (corrector package)
    - Nb_3Sn (new technology)
    - 150 mm ID, gradient = 130 T/m, peak field 11.5 T
- D1, D2
    - NbTi (classical technology)
    - 150 mm, 5.6 T

E. Todesco



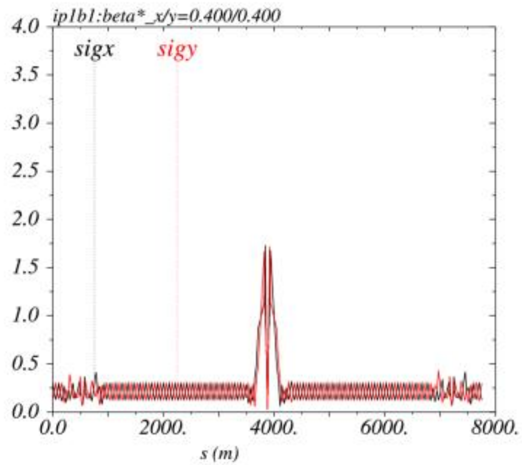
- Present IT+D1 **to be completely removed** (radiation to personnel !!)

Achromatic Telescopic Squeezing (ATS)

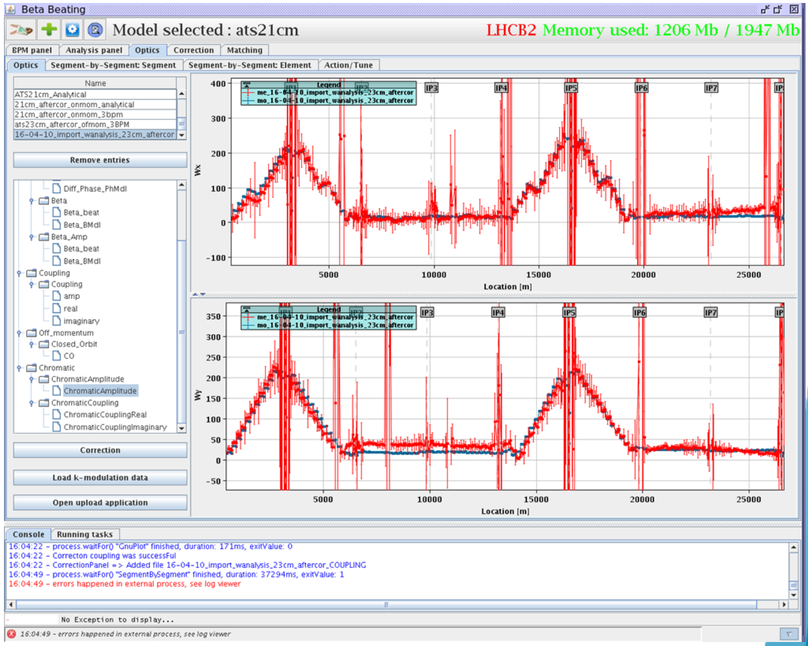
- New optic scheme
- Use of the available aperture to blow-up the β function in the arcs in order to reduce further β* at the collision point

- Recent MD studies have shown that β* =12 cm could be reached with probe beams

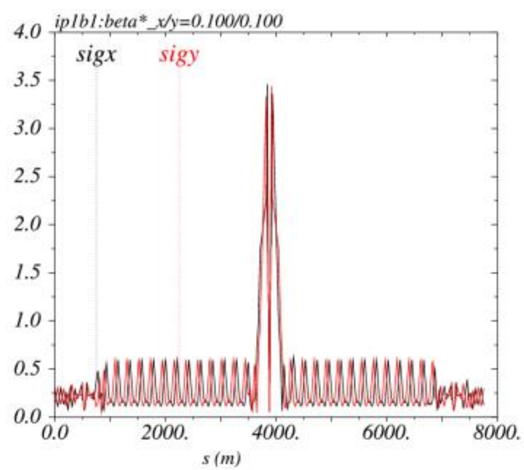
LHC: 40 cm



Chromaticities are under controlled all around the ring



HL-LHC: 10 cm



S. Fartoukh

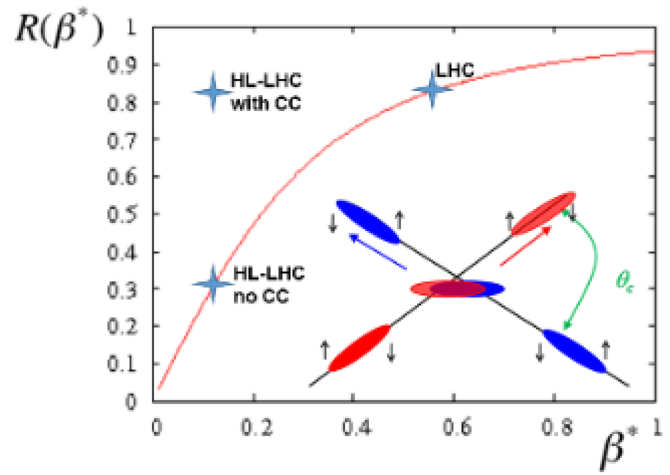
Crab cavities - luminosity

- Increase instantaneous luminosity by a factor 3 by "crabbing" the bunches
- Requires luminosity levelling to minimise number of event per crossing

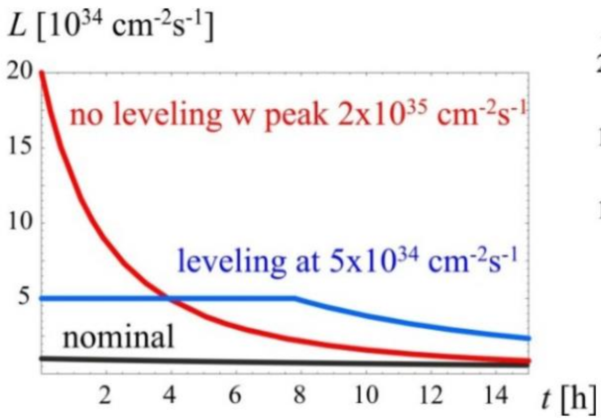
R. Calaga

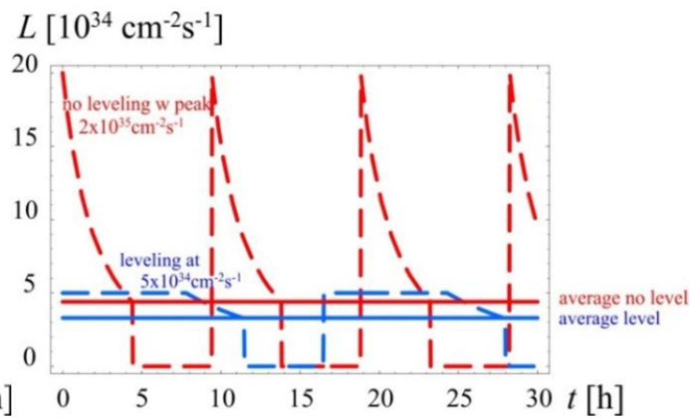
$$L = \gamma \frac{f_{rev}\, n_b\, {N_b}^2}{4\pi \varepsilon_n \beta^*} R$$

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

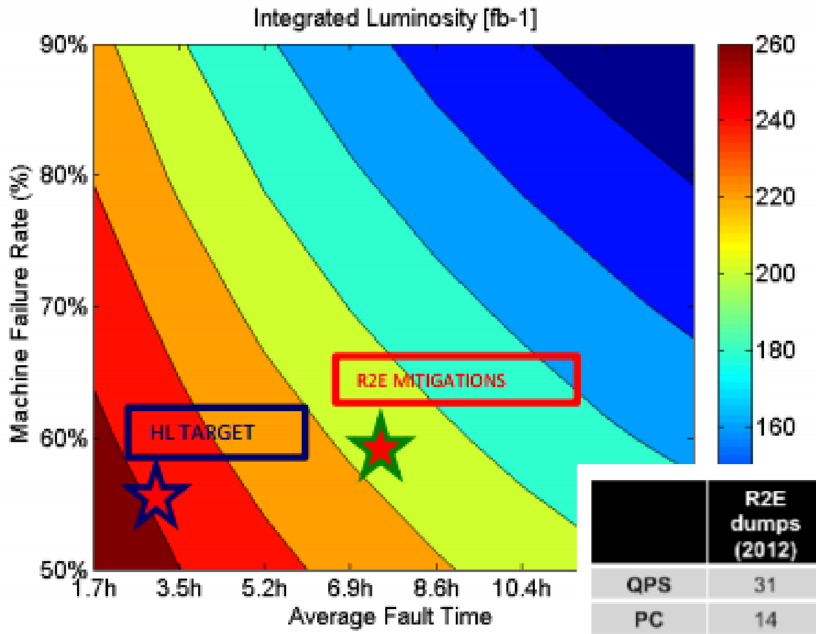


- Crab cavities maximise luminosity and can be used for luminosity levelling:
  - when luminosity is too high, CC are almost off and are slowly turned on to compensate proton burning ➔ allow to optimise integrated luminosity

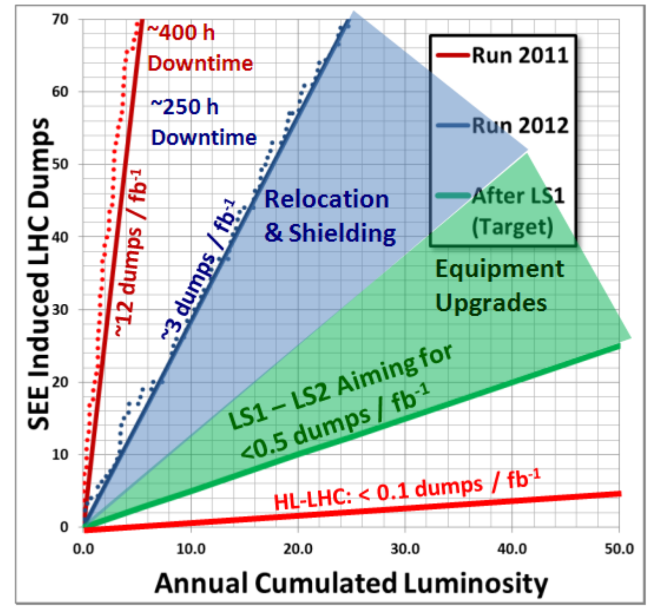




Availability and Downtime



	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



D. Wolmann

M. Brugger

Upgrade of interlocking system (integration to avoid spurious dump)
Reduction of (generous) of interlock levels
R2E
Robust and reliable equipments
Identification of “fast” repair scenario
Etc.

VSC performances:
Still on track for HL-LHC !

Year	Issue count	Average downtime	Beam dump
2015	6	2.5 h	1
2016	2	0.7 h	0

High Luminosity Work Packages after FP7 DS:

HL-LHC PROJECT MANAGEMENT

Project Leader: Lucio Rossi, CERN
Deputy Project Leader: Oliver Brüning, CERN
Project Office Manager: Laurent Tavian, CERN
Configuration, QA, Resource Manager: Isabel Bejar Alonso, CERN
Integration: Paolo Fessia, CERN
Collaborations (in-kind): Beniamino Di Girolamo, CERN
Budget Officer: Benoit Delille, CERN
Safety Officer: Thomas Otto, CERN
Communication: Isabel Bejar Alonso, CERN
Secretariat: Cécile Noels, CERN

WP2 Accelerator Physics
Gianluigi Arduini
Rogelio Tomas Garcia

WP3 IR Magnets
Ezio Todesco
Paolo Ferracin

WP4 Crab Cavities & RF
Rama Calaga
Ofelia Capatina

WP5 Collimation
Stefano Redaelli
Roderik Bruce

WP6A Cold Powering
Amalia Ballarino
Vittorio Parma

WP6B Warm Powering
Jean-Paul Burnet
Michele Martino

WP7 Machine Protection
Daniel Wollman
Reiner Denz

WP8 Collider-Experiment Interface
Helmut Burkhardt – F. Sanchez Galan
Sébastien Evrard

WP9 Cryogenics
Serge Claudet
Rob Van Weelderen

WP10 Energy Deposition & R2E
Markus Brugger – Francesco Cerutti

WP11 11 T Dipole
Frédéric Savary
Hervé Prin

WP12 Vacuum
Vincent Baglin
Roberto Kersevan

WP13 Beam Instrumentation
Rhodri Jones
Adriana Rossi

WP14 Beam Transfer
Chiara Bracco
Brennan Goddard

WP15 Integration & (De-)Installation
Paolo Fessia
Hélène Mainaud Durand (Survey)

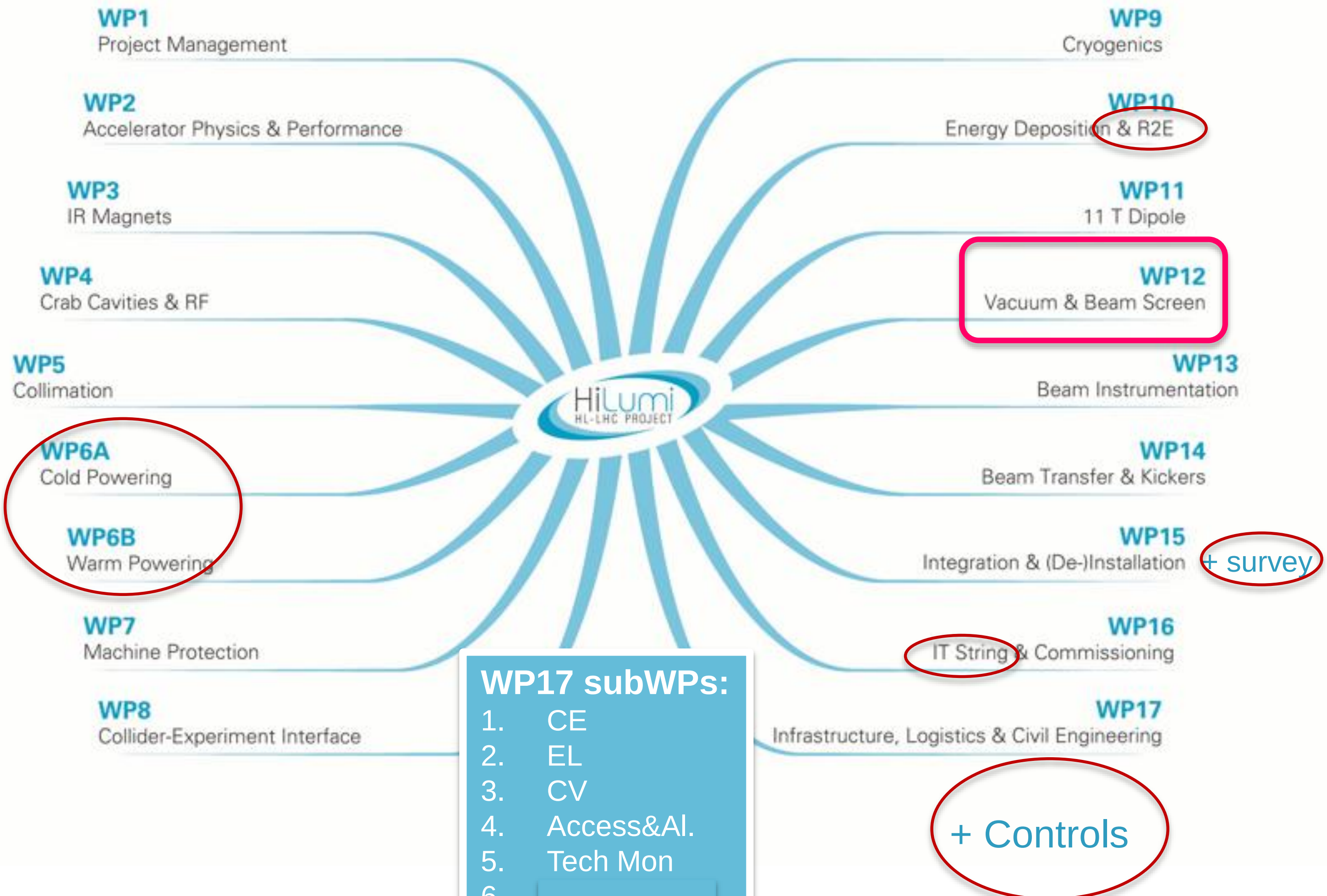
WP16 IT String & Commissioning
Marta Bajko – Mirko Pojer

WP17 Infrastructure & Logistics
Laurent Tavian
Beniamino Di Girolamo

HiLumi HL-LHC PROJECT
CERN

Organisation

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



WP17 subWPs:

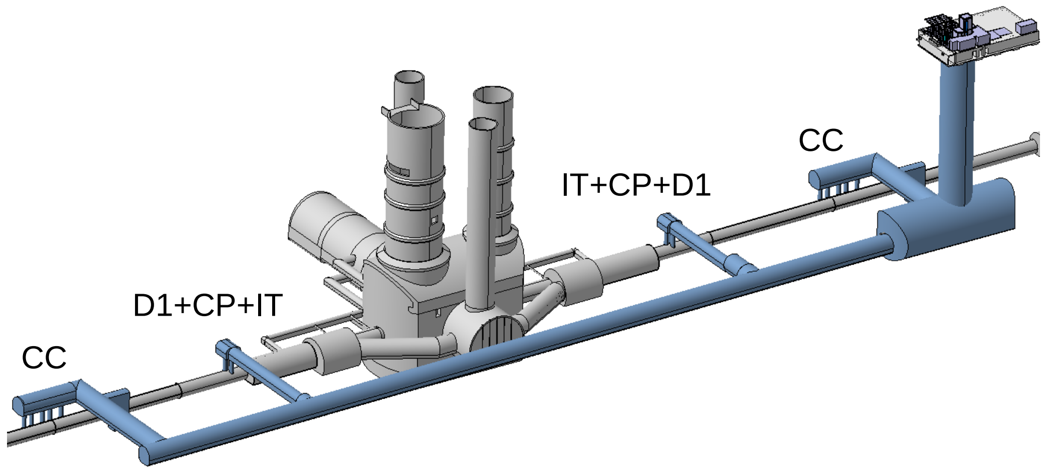
1. CE
2. EL
3. CV
4. Access&Al.
5. Tech Mon
6.
7. Transport
8. (SM18 Upr)
9. Log&Storage
10. Op. Safety

Main HL-LHC events in 2016

- Joint LARP CM26/Hi-Lumi meeting, May 2016
  - https://indico.fnal.gov/conferenceTimeTable.py?confId=11049#20160518.detailed
- 2nd HiLumi Industry Day, October 2016
  - https://indico.cern.ch/event/557233/timetable/#20161031.detailed
- Joint LIU / HL-LHC meeting, October 2015
  - https://indico.cern.ch/event/437662/
- Cost and Schedule Review, October 2016
- 6th HL-LHC collaboration meeting, November 2016
  - https://indico.cern.ch/event/549979/timetable/#all.detailed
- TDR-v0, Del-D1.10: http://hilumilhc.web.cern.ch/science/deliverables
- Reviews and regular meetings such as Technical Coordination Committee and with WPs

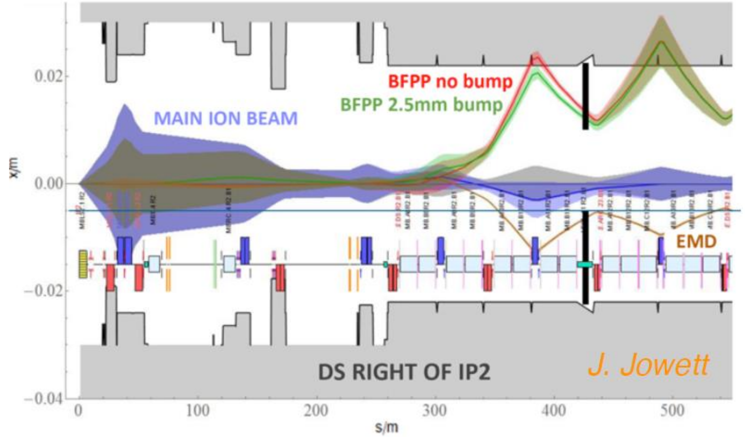
Decisions before June 2016 - Rebaselining

- Underground double decker to allow access during HL-LHC operation



P. Fessia

- Reduction of SC link length, reduction of Q4 operating current, one circuit for triplet powering (WP6 A/B)
- Increase length of triplet due to gradient reduction from 140 to 130 T/m
- Use of a magnetic bump in P2 for ion collisions avoiding 11 T magnets in the DS



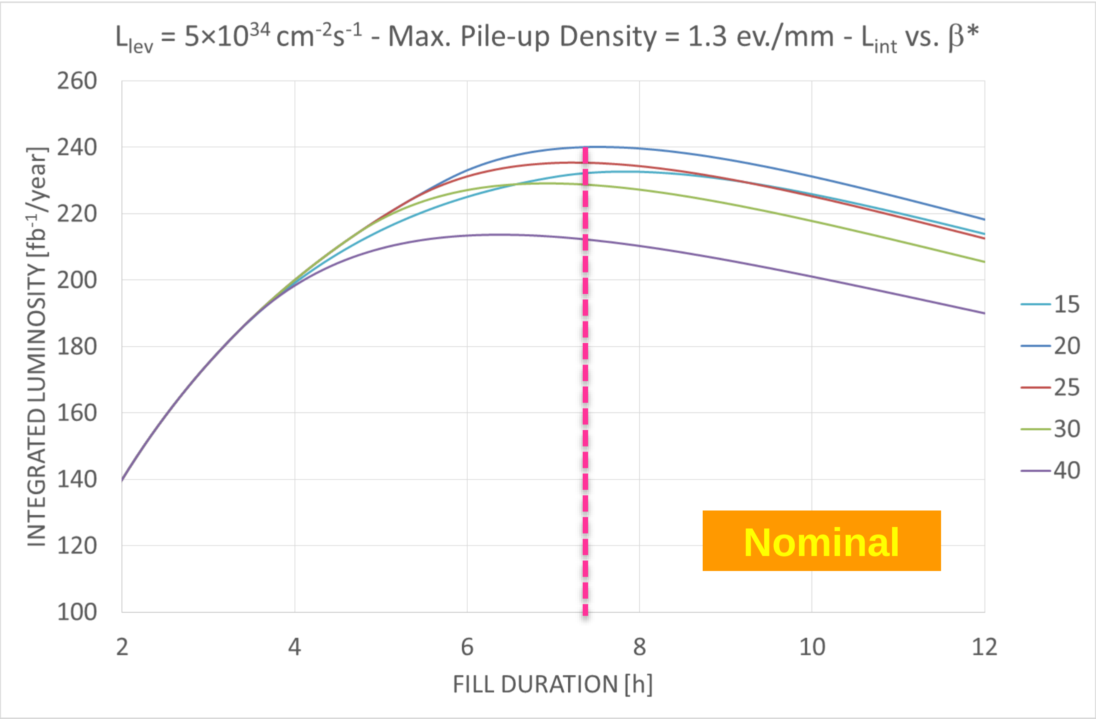
J. Jowett

June 2016 - Rebaselining

- Objective: includes ~ 120MCHF extra cost for civil engineering (caverns, buildings) at without increase on HiLumi project CtC ➔ impact on all WP

- WP4: reduction from 4 to 2 cryomodules per IP side (the reduction is reversible)
  - Optimum at Beta* = 20 cm with larger pile-up densities (> 1.3 Event/mm)

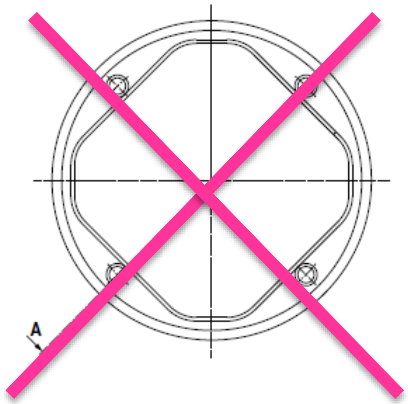
160 days of physics
50% performance efficiency



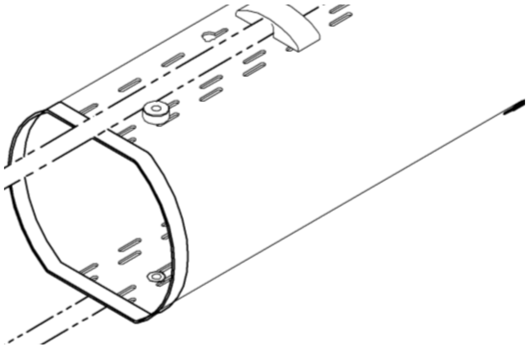
WP2

June 2016 - Rebaselining

- WP3: replace MQYY, as new HL-LHC Q4, with LHC Type MQY at 1.9 K (instead of 4.5K in LHC)
  - If needed, the 90 mm aperture MQYY could be installed after HL-LHC construction (i.e. LS4 ?)
  - CB aperture reduced to ID 63 with race track shape beam screen (instead of octagonal)
  - ➔ Impact on flat beams performances (beta* limited to 40/15 cm)



Q4: octagonal shape,
CB ID: 79.8



Q4: racetrack shape,
CB ID: 63

June 2016 - Rebaselining

- WP3: optimisation of the QPS system
  - Minimum configuration, maintaining all systems, with redundancy
- WP5: optimisation of the collimation system
  - TCLD collimators in P7 reduced from 4 to 2 (impact on WP11)
  - Reduction of spares
- WP8: new TANB in LSS8
- WP9: new cryobox layout
- WP11: optimisation of the 11 T magnet system
  - 11 T magnets in P7 reduced from 4+1 to 2+1
  - 11 T magnets in P2 replaced by 2+1 connection cryostat
- WP12: optimisation of vacuum layout, internalisation of resources
- Other WP: minor impact

The impact of the re-baselining over the whole project is still in evaluation

A Word from the Project Leader

Dear colleagues,

Further to the **2nd Cost & Schedule Review (Oct. 2016)**, it is my pleasure to send you the final report prepared by the CMAC members chaired by Norbert Holtkamp.

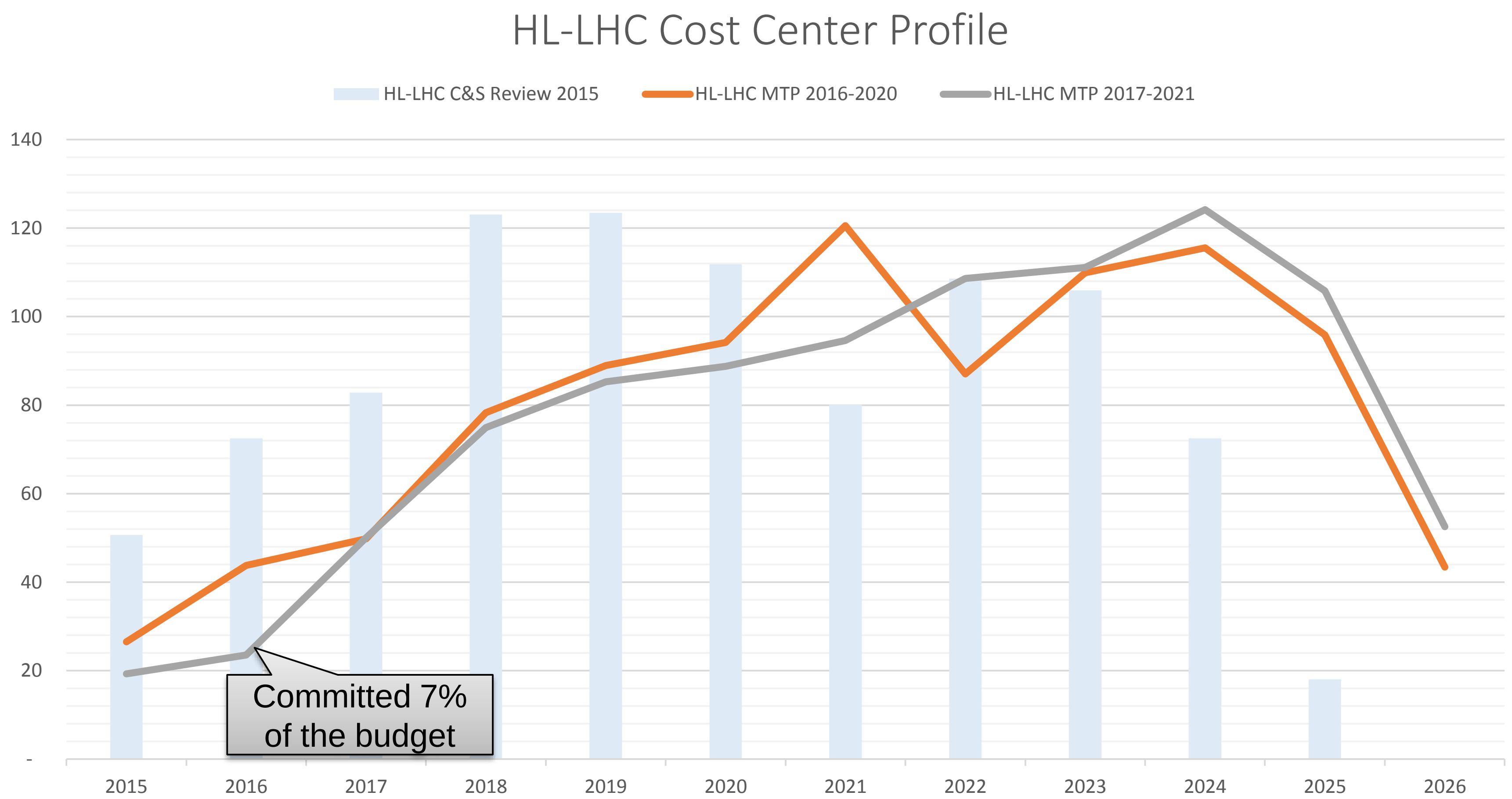
I believe the outcome of the review for the project was really excellent. We will work hard to study and implement, as far as we can, the recommendations. I am glad to underline that the reviewers warmly congratulated the HiLumi teams for taking the recommendations of the 1st C&SR very seriously. We need to continue along the same line.

I take this opportunity to thank you all for the review preparation, the outstanding efforts and for the quality of the work. Please transmit our wholeheartedly thanks to all the collaborators with less exposure who also contributed to this successful achievement.

Best regards,
Prof. Lucio Rossi

High Luminosity LHC Project Leader
CERN – Accelerator & Technology Sector

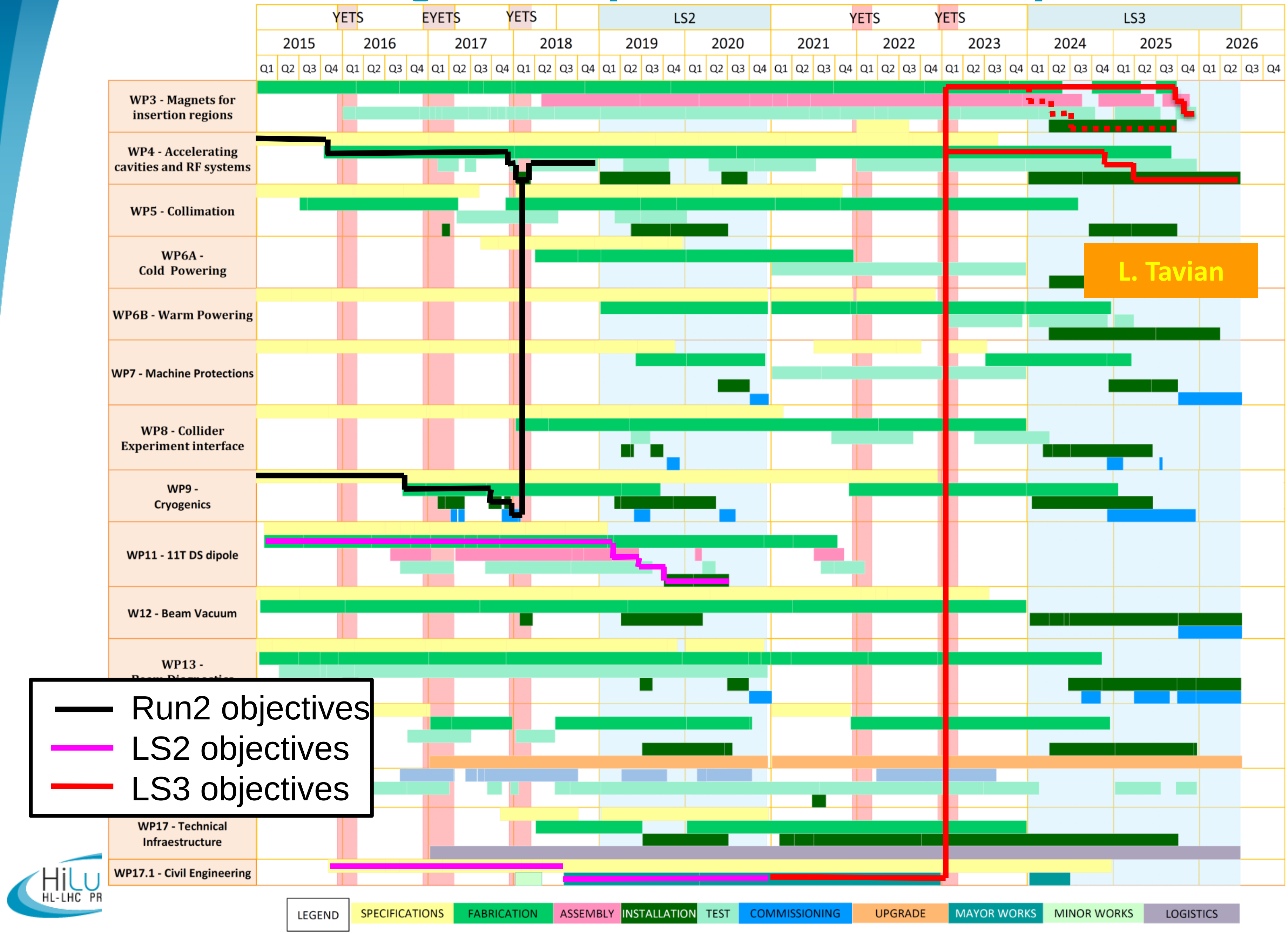
HL-LHC Budget (CtC) : 950 MCHF (2015 CHF)



Σ_{WP}: 17+3+9+4+6A+5 = 75%

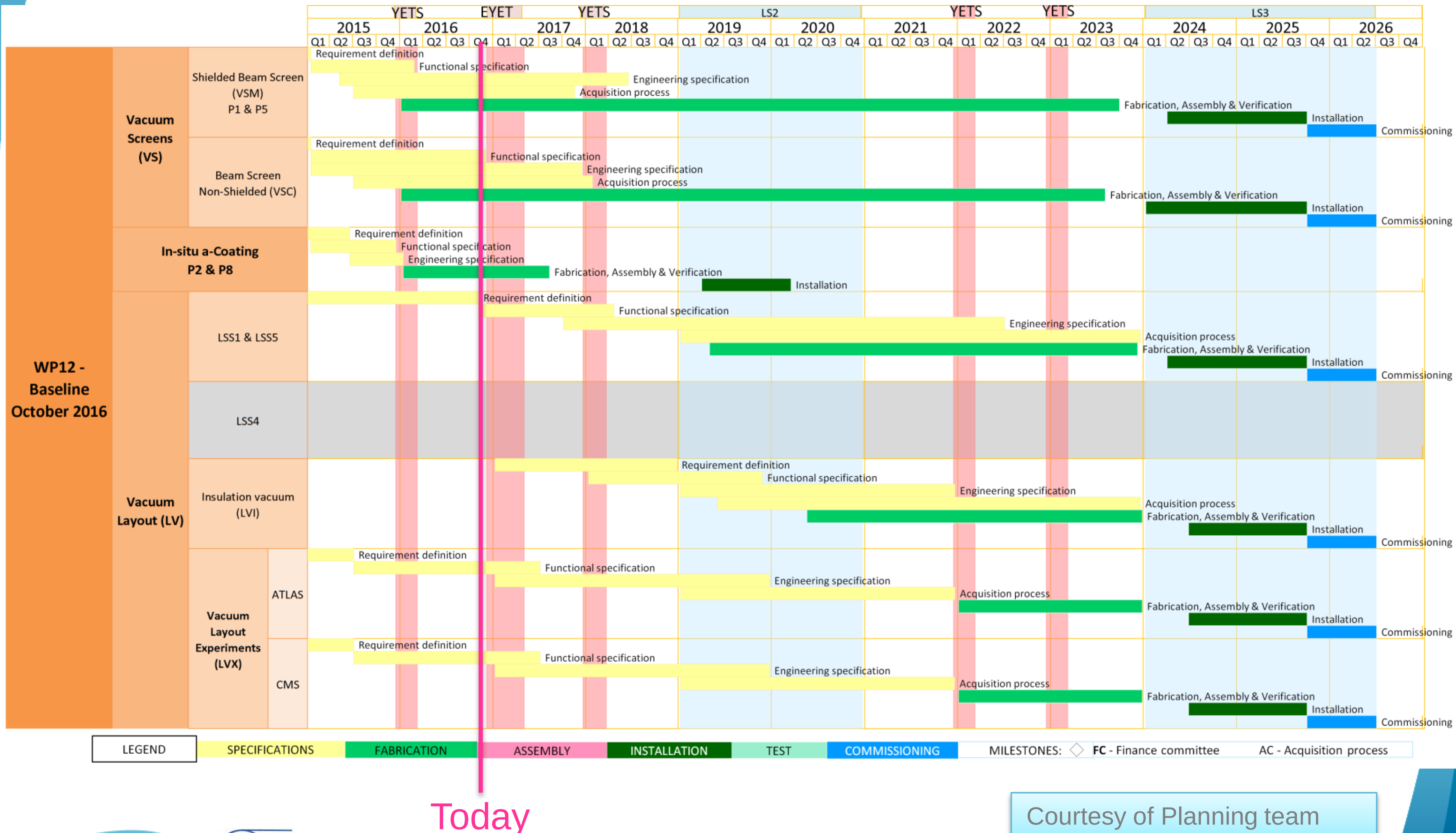
Main drivers: civil engineering, magnets, cryo, RF, cold powering, collimation

Detailed general plan with critical path



WP12: Schedule

- Step 1: Vacuum Screens & in-situ coating
- Step 2: Layout completion



Courtesy of Planning team

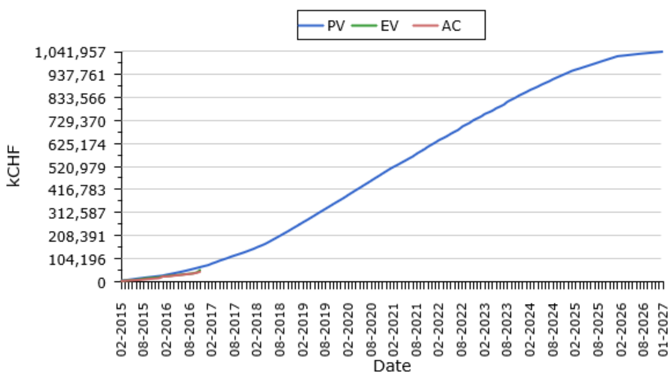
WP12 Cost to Completion

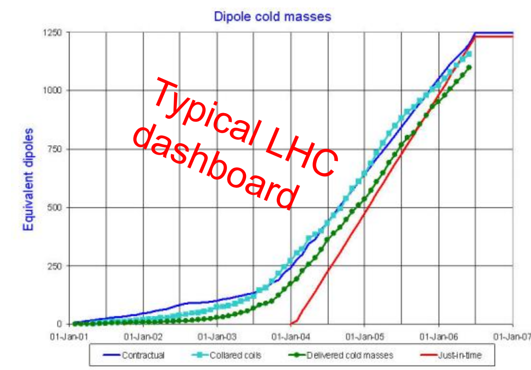
- Covers 2015 till 2026 – Updated following last C&S review
- Includes studies, design, prototyping, procurement, assembly, testing and installation for:
  - Shielded beam screens
  - Non-shielded beam screens
  - *In-situ* treatment of IT2 & 8
  - Room temperature vacuum system in LSS1, 5
  - RT vacuum system in exp. areas 1 & 5 (without exp. beam pipes)
  - Insulation vacuum

HLLHC 11: HL-LHC High Luminosity LHC Project WP 11 - 11 T Dipole Magnets
HLLHC 12: HL-LHC High Luminosity LHC Project WP 12 - Vacuum
- **HLLHC 12.1:** WP 12 - Vacuum - VS - Vacuum screens
  - **HLLHC 12.1.1:** WP 12 - Vacuum - VSM - Shielded Beam Screen
  - **HLLHC 12.1.2:** WP 12 - Vacuum - VSC - Beam Screen non-shielded
- **HLLHC 12.2:** WP 12 - Vacuum - LV - Vacuum layout
  - **HLLHC 12.2.1:** WP 12 - Vacuum - LV - LSS1
  - **HLLHC 12.2.2:** WP 12 - Vacuum - LV - LSS5
  - **HLLHC 12.2.3:** WP 12 - Vacuum - LV - LSS4
  - **HLLHC 12.2.4:** WP 12 - Vacuum - LV - Insulation Vaccuum (LVI)
  - **HLLHC 12.2.5:** WP 12 - Vacuum - LV - Vacuum Layout Experiment (LVX)

HLLHC 13: HL-LHC High Luminosity LHC Project WP 13 - Beam diagnostics & instrumentation
HLLHC 14: HL-LHC High Luminosity LHC Project WP 14 - Beam transfer & kickers

- EVM needs to be filled:
  - Definition of work unit
  - Follow-up of:
    - PV
    - EV
    - AC

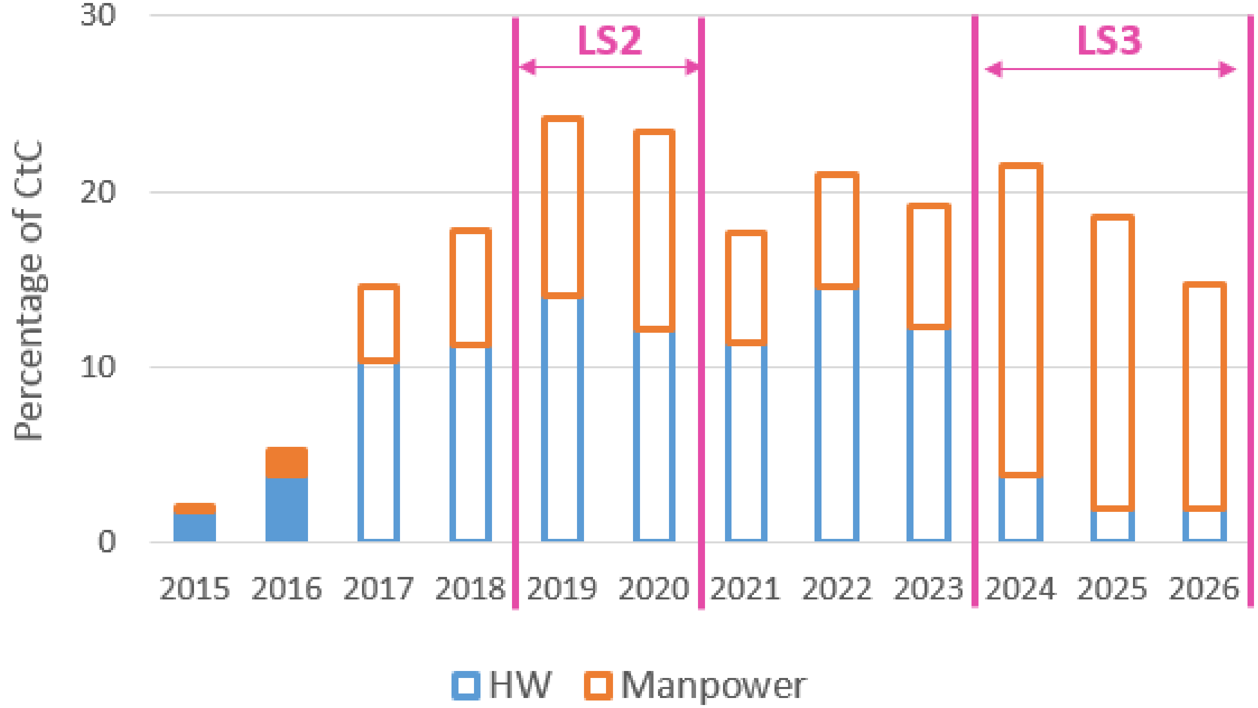




- Next C&S review: ~ Feb-March 2018

WP12 Cost to Completion: Status

- We are at the beginning !
- The inputs are all integrated/updated in APT (activity planning tool)
- Spending are followed with CET (thanks Germana & Laura)
- Already a good start …. still 95 % to go !



We shall continue our effort to engage money for HW and Manpower

HL-LHC Budget Codes

- Follows the PBS
- For WP12 scope only (yellow band):
  - HL-LHC money
  - CONS money
- For other WP scope (green band)

PBS	Type	Budget Co	Unit	Description
5	HL-LHC	53707	TE-VSC	HL-LHC WP05 Collimator production - TCLD
5	HL-LHC	53708	TE-VSC	HL-LHC WP05 Collimator production - TCLD
14	HL-LHC	63226	TE-VSC	HL-LHC WP14-Vacuum for absorbers(TDIS/TCDD/TCDS)-Spares&Cons
12.2.2	HL-LHC	91701	TE-VSC	HL-LHC WP12-Vacuum for LSS
12.2.5	HL-LHC	91702	TE-VSC	HL-LHC WP 12-Vacuum Layout Experiment
14	HL-LHC	91703	TE-VSC	HL-LHC WP14-Vacuum for absorbers
12.1.1	HL-LHC	91704	TE-VSC	HL-LHC WP12-Vacuum Screens
14	HL-LHC	91705	TE-VSC	HL-LHC WP14 Vacuum for kickers
12.2.1	HL-LHC	91706	TE-VSC	HL-LHC WP12-On-Situ Coating IT2 & IT8
14	HL-LHC	91707	TE-VSC	HL-LHC WP14 Vacuum for absorbers/kickers (Personnel)
14	HL-LHC	91708	TE-VSC	HL-LHC WP14-Vacuum for absorbers(TCDD)
14	HL-LHC	91709	TE-VSC	HL-LHC WP14-Vacuum for absorbers(TCDS)
12.2.4	HL-LHC	91710	TE-VSC	HL-LHC WP12-Insulation Vacuum
12	HL-LHC	91711	TE-VSC	HL-LHC WP12-Vacuum (Personnel)
12.1.2	HL-LHC	91712	TE-VSC	HL-LHC WP12-Beam Screen Non-Shielded
12.2.3	HL-LHC	91713	TE-VSC	HL-LHC WP12-Vacuum for LSS4
14	HL-LHC	91715	TE-VSC	HL-LHC WP14-Vacuum for absorbers(TCDS)-CONS
5	HL-LHC	99150	TE-VSC	HL-LHC WP05 Collimation - Vacuum
5	HL-LHC	99151	TE-VSC	HL-LHC WP05 Collimation (Personnel)
5	HL-LHC	99152	TE-VSC	HL-LHC WP05 Collimation - Remote Handling

Please use:

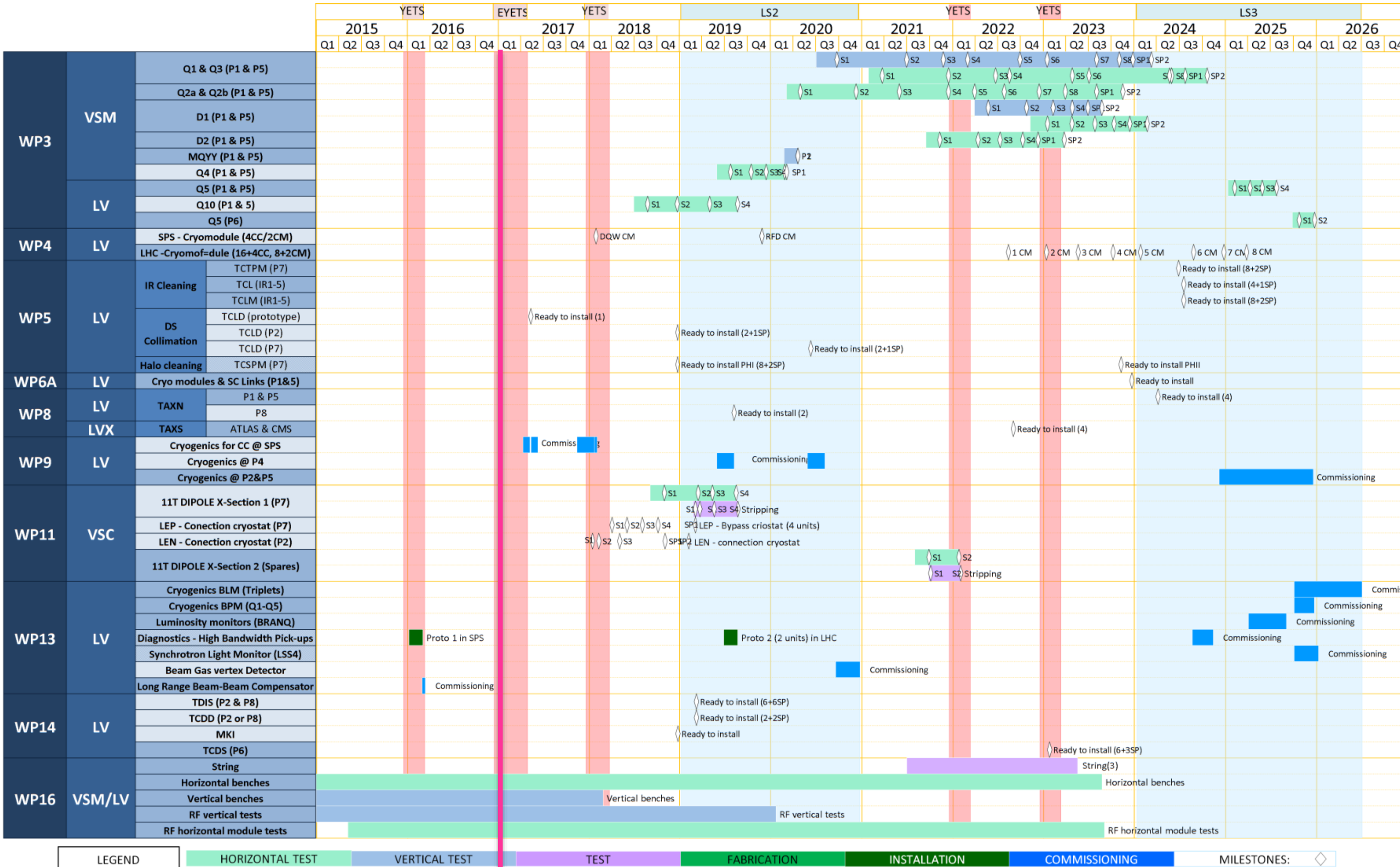
91701 VSC Prj: HL-LHC WP12-Vacuum for LSS for HL-LHC activities related to the room temperature beam vacuum system.
91702 VSC Prj: HL-LHC WP 12-Vacuum Layout Experiment for HL-LHC activities related to the LHC experiments (i.e. between Q1 and Q1), machine side.
91704 VSC Prj: HL-LHC WP12-Vacuum Screens for HL-LHC activities related to the cryogenic beam vacuum system.
91710 VSC Prj: HL-LHC WP 12-Insulation Vacuum for HL-LHC activities related to the insulation vacuum system.
91711 HL-LHC WP 12-Vacuum (Personnel) for HL-LHC personnel (P and M4P).

In case of doubts, please do not hesitate to contact me,

Please respect the appropriate use of BC !

Schedule – WP12 Contribution to other WP

- Identification of major milestones (beam screens etc.)

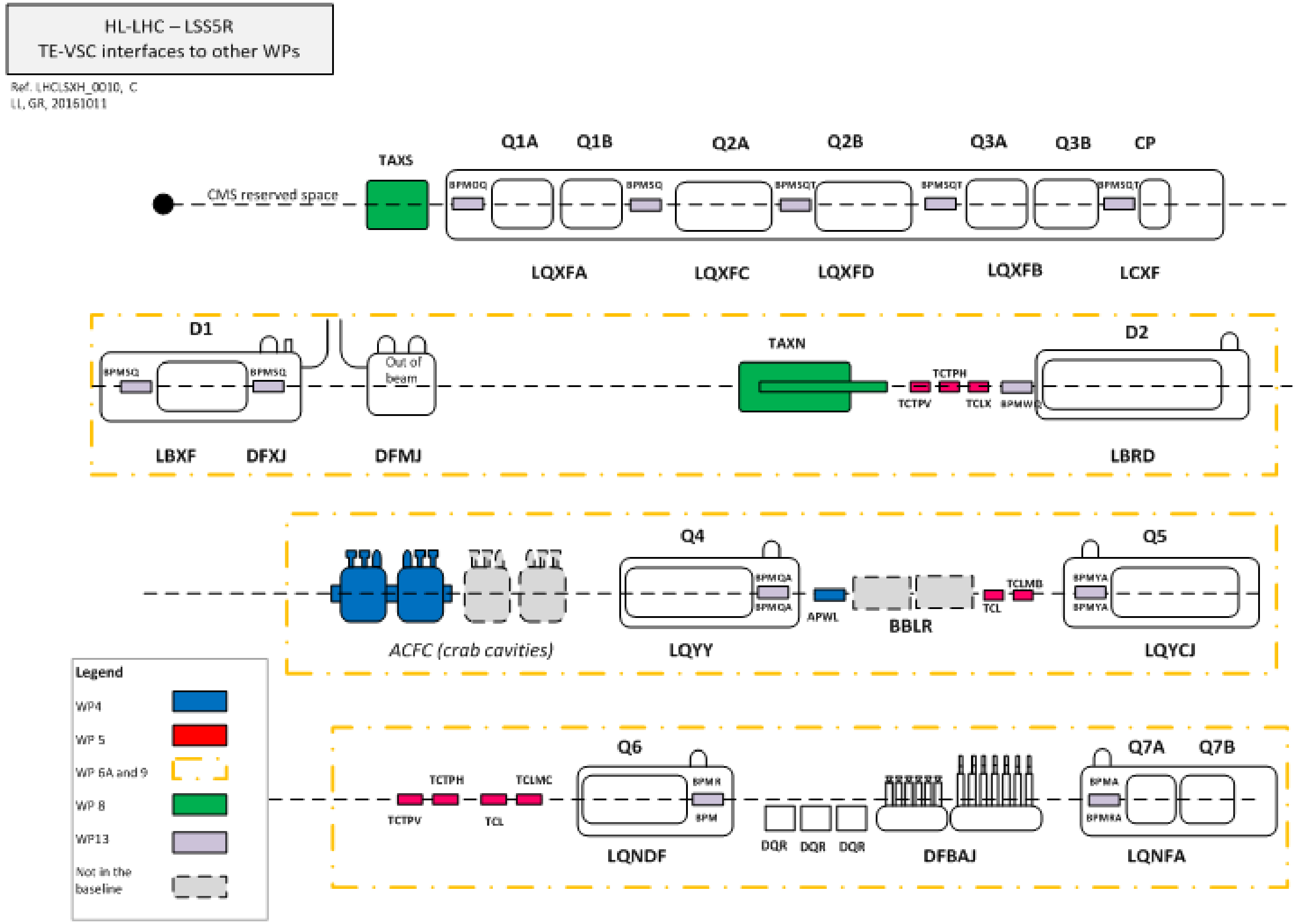


Today

Courtesy of Planning team

Interfaces Contribution Synoptic

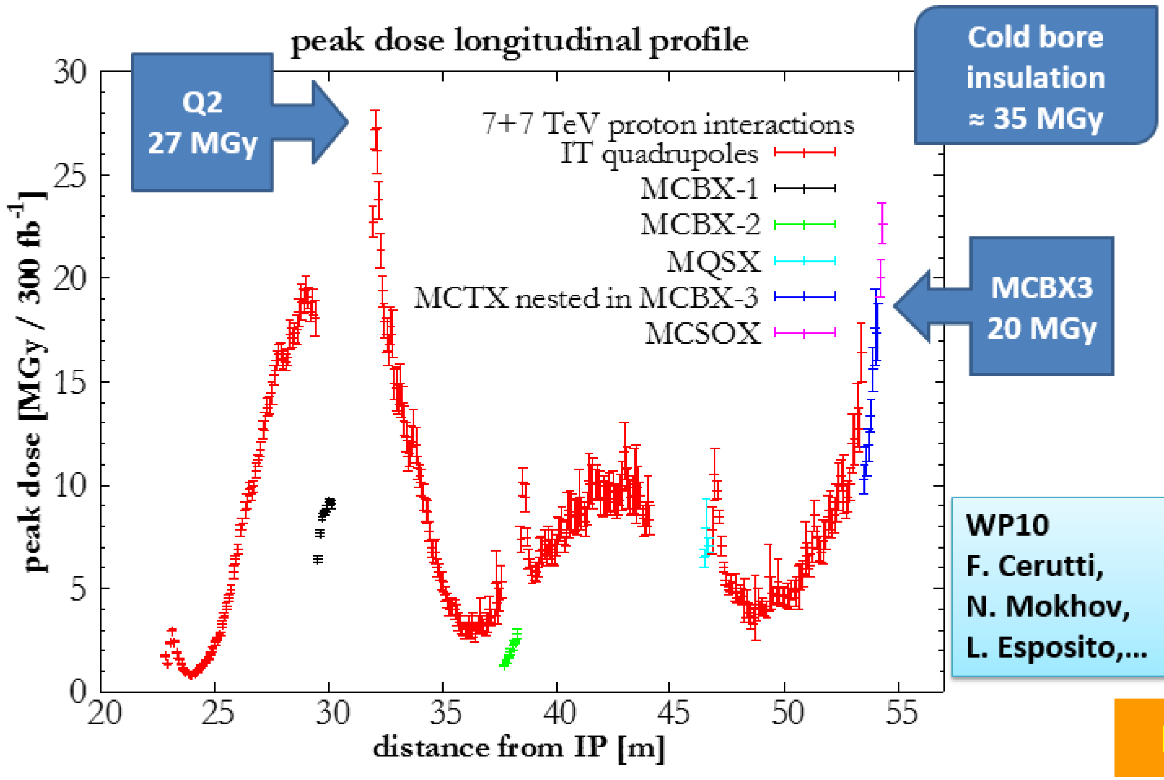
- All WP12 contribution CtC are defined: budget codes created or to be created
- Planning or realisation needs to be consolidated



2. HL-LHC Beam Screen

2.1 Design Studies

The 1st technical trigger of the upgrade: Radiation damage in low-beta triplet region



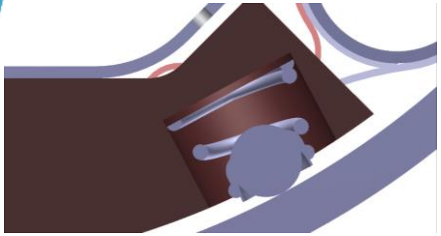
WP10
F. Cerutti,
N. Mokhov,
L. Esposito,…

L. Rossi

The Shielded Beam Screens (BS) are key devices of the HL-LHC project

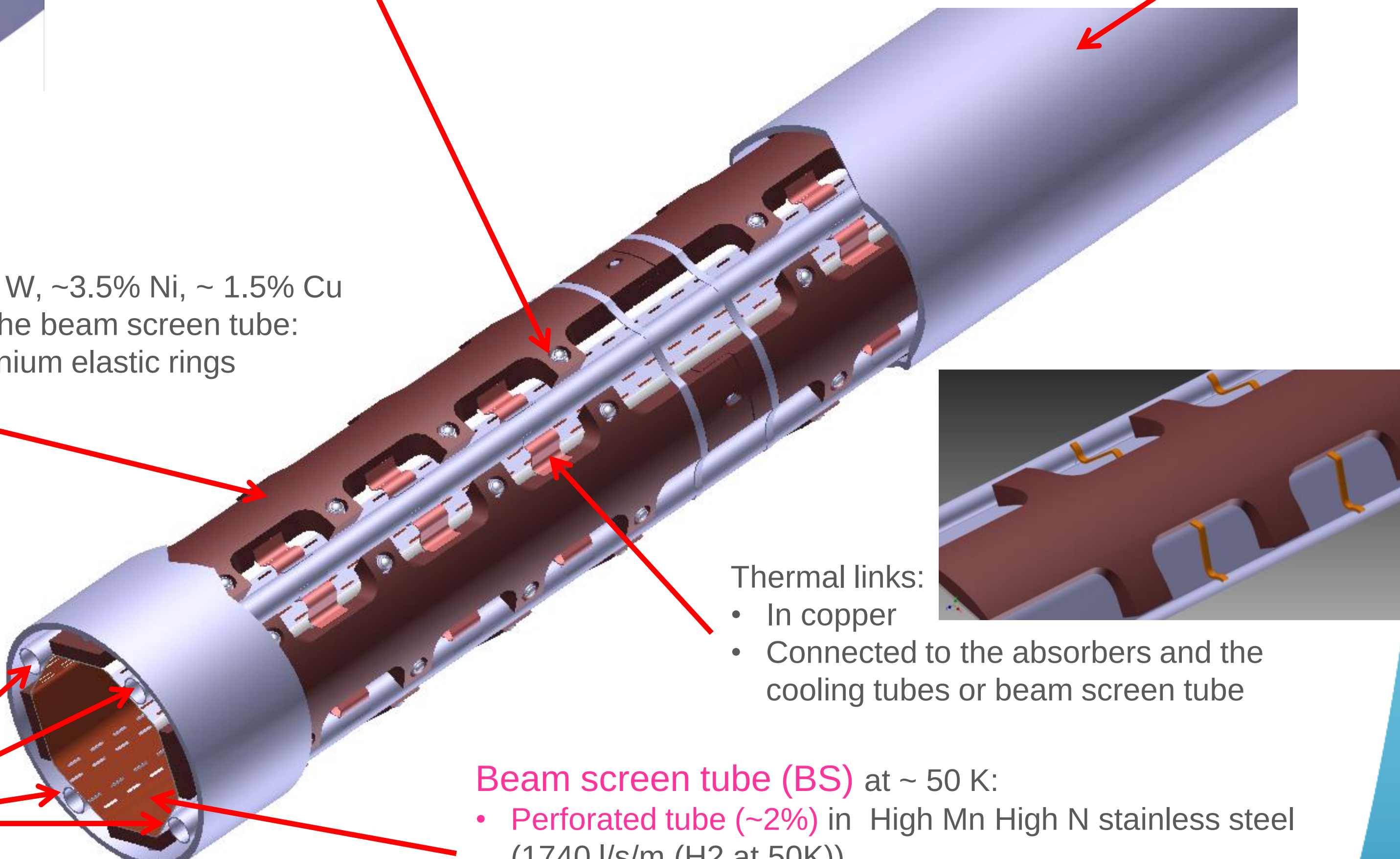
Shielded Beam Screen Concept

Assembly of the beam screen



Elastic supporting system:
Low heat leak to the cold bore tube at 1.9K
Ceramic ball with titanium spring

Cold bore (CB) at 1.9 K:
4 mm thick tube in 316LN



Tungsten alloy blocks:

- Chemical composition: 95% W, ~3.5% Ni, ~ 1.5% Cu
- mechanically connected to the beam screen tube: positioned with pins and titanium elastic rings
- Heat load: 15-25 W/m

Thermal links:

- In copper
- Connected to the absorbers and the cooling tubes or beam screen tube

C. Garion

Beam screen tube (BS) at ~ 50 K:

- Perforated tube (~2%) in High Mn High N stainless steel (1740 l/s/m (H_2 at 50K))
- Internal copper layer (80 μm) for impedance
- a-C coating (as a baseline) for e- cloud mitigation

Cooling tubes:

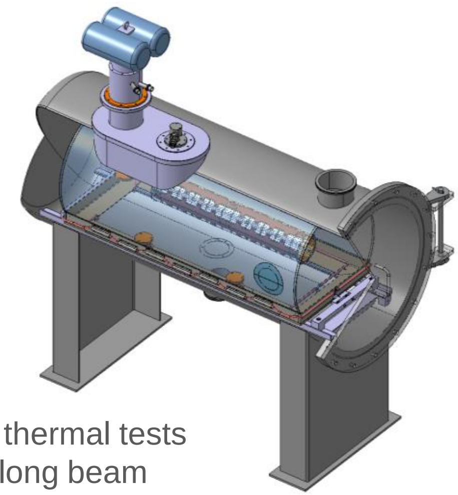
- Outer Diameter: 10 or 16 mm
- Laser welded on the beam screen tube

Progress & next Milestones

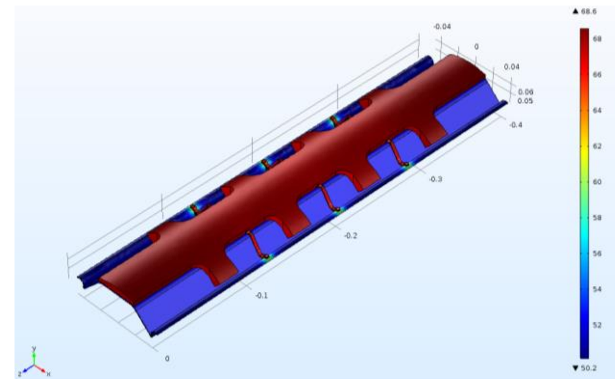
- Thermal and quench models of the beam screen/ cold bore assembly are developed
  ➔ Under validation against experimental investigations (mid 2017)

- Thermal tests (in collaboration with WP 9):
  - Thermal link evaluation
  - Global evaluation

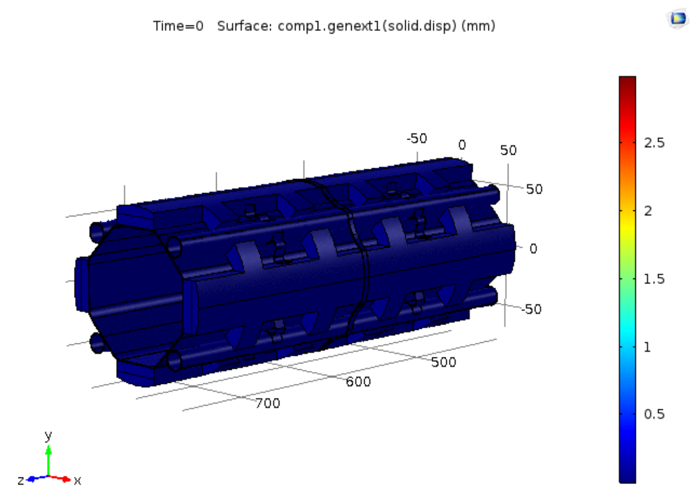
C. Garion



Set-up for the thermal tests of a 80 cm long beam screen / cold bore system



M. Moronne

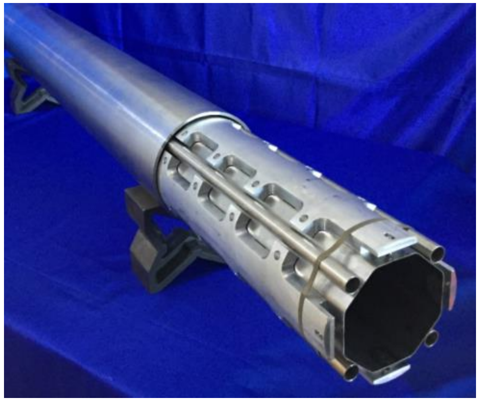


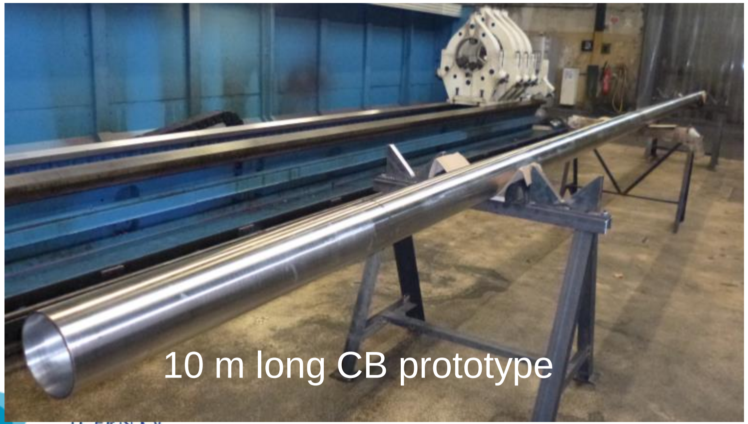
- Quench tests (in collaboration with WP 3):
  - 2m long beam screen prototype is being prepared for quench tests in MQXF model in spring 2017

Progress & next Milestones

- Beam screen and cold bore mechanical design completed
  - ➔ CB prototypes produced, tolerances to be fixed by end 2016
  - ➔ Beam screen prototypes to be produced, tolerances to be frozen by end 2017
- Beam Screen Finishing Facility ready by mid 2107
- BS:
  - Stainless steel for BS &Cooling tube ➔ ordered, delivery Q3 2017
  - Co-lamination ➔ contract to be placed, delivery Q4 2017
  - Beam screen punching, forming, welding:
    - ➔ proto Q3 2017, first tube 2018
- CB:
  - Raw material delivery end 2017
  - Production starts 2018

C. Garion





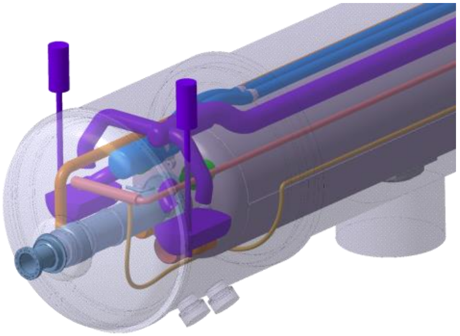
10 m long CB prototype

A. Vidal

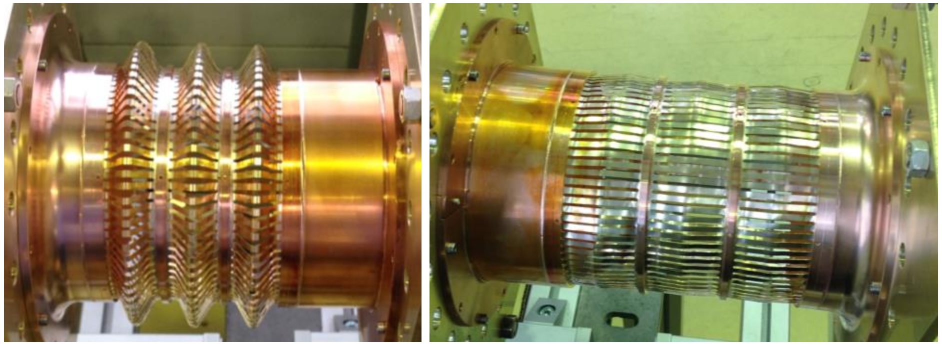
Reception test of the gantry crane

Cold warm transition and interconnect design

- Interconnection baseline with deformable RF bridge

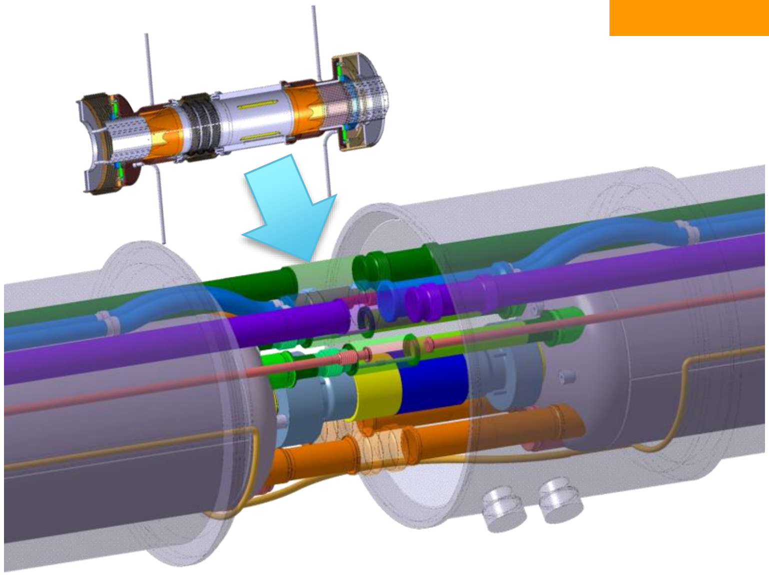


Q1 cold/warm transition



Deformable RF fingers considered as baseline

M. Sitko, J. Perez Espinos
WP3

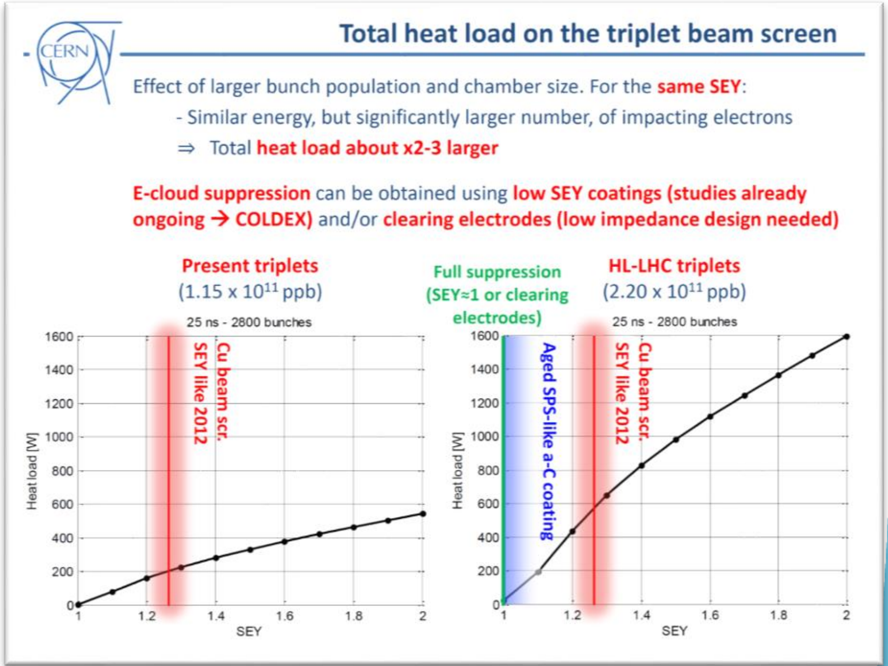


Mock-up under construction

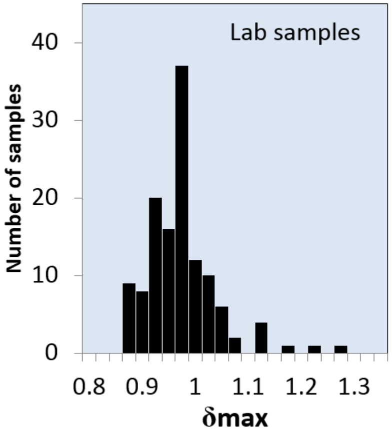
2.2 a-C Coating Performances Studies

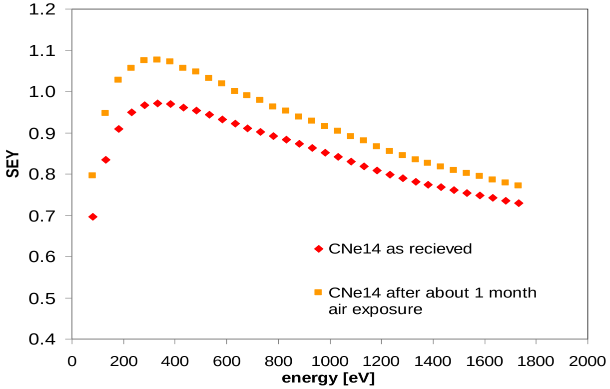
The 2nd technical trigger of the upgrade: Cryogenic heat load

- Too large heat load (>600 W) originating from electron cloud are predicted for HL-LHC IT beam screens.
- It will be associated with larger (than LHC) background to the experiments.
- a-C coating is proposed to mitigate electron multipacting reducing electron cloud to acceptable values.
- Performances at cryogenic temperature of a-C shall be compatible with HL-LHC parameters



G. Rumolo, G. Iadarola





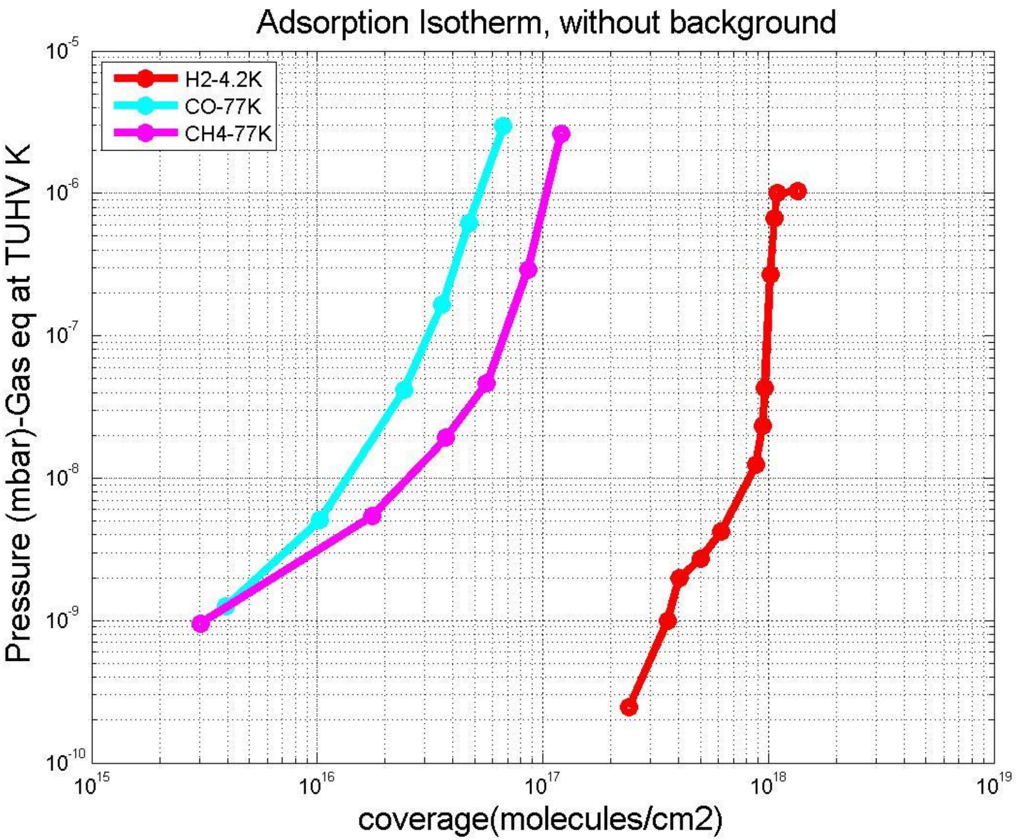
The a-C coating is a key technology for the HL-LHC project

M. Taborelli

Adsorption Isotherms at 4.2 and 77 K

- ~ 500 nm thick coating
- H_2, CO and CH_4
- At 4.2 K, the capacity is much more than one monolayer (10^{15} H_2/cm^2)
- The capacity decrease with increasing temperature

- The coating is porous
- Capacity ~ 100 x Cu



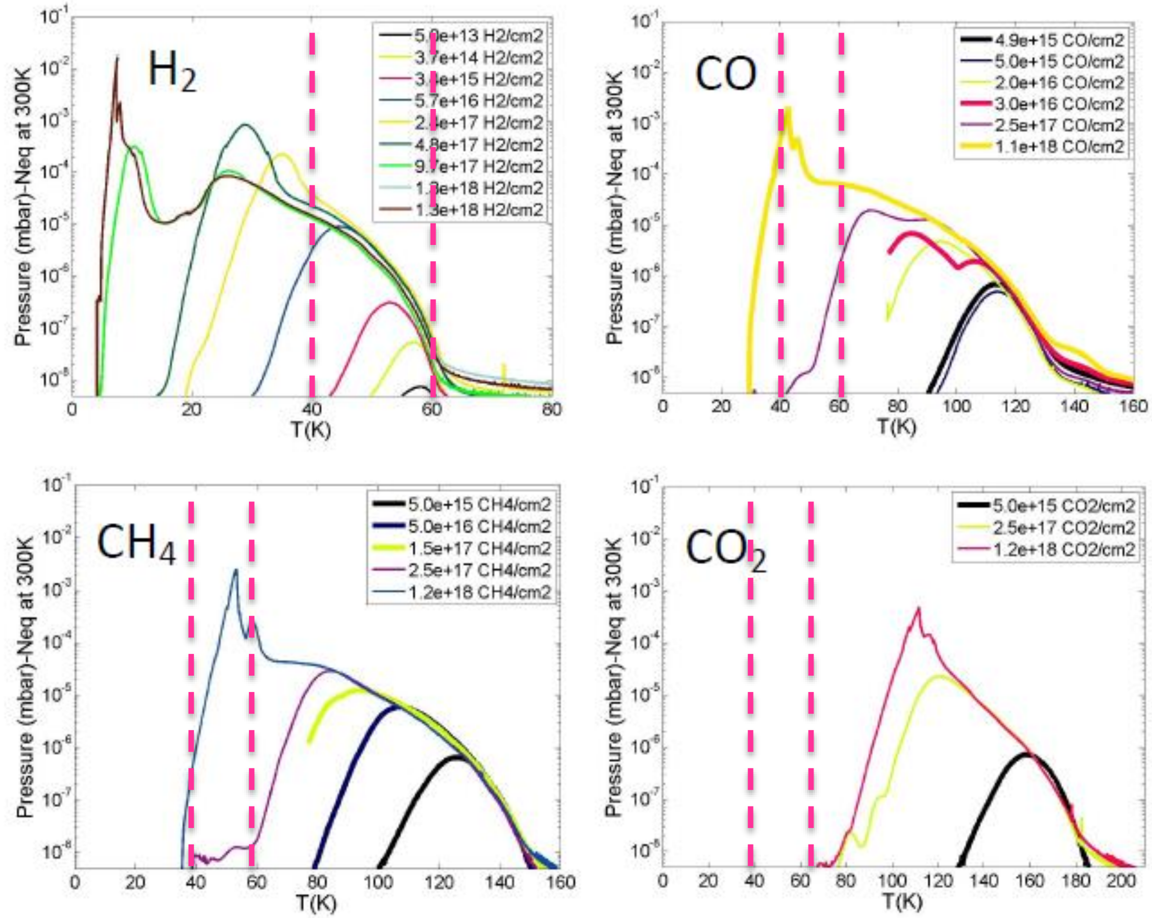
A-L. Lamure

- Next steps:
  Pumping speed & adsorption isotherms and isosteres in the 20-100 K range, set-up available by spring 2017

a-C Coating Thermal Desorption Spectroscopy

- The larger the coverage, the lower the desorption temperature.
- Binding energies are in the range 100-500 meV and decrease with surface coverage

A-L. Lamure

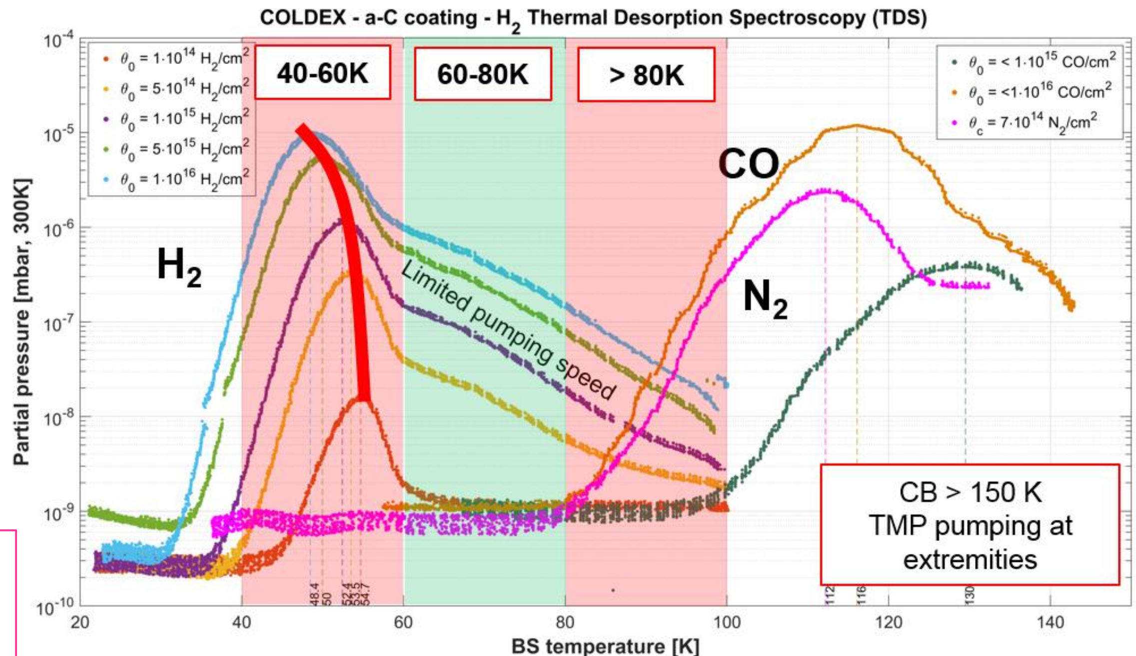


	H2	CH4	CO	CO2
Peak in 40-60 K	Any coverage	For coverage > 10^{17} CH_4/cm^2	For coverage > 2 10^{16} CO/cm^2	For coverage > 10^{18} CO_2/cm^2

Potential modification of the proposed BS operating temperature

a-C Coating Studies with COLDEX

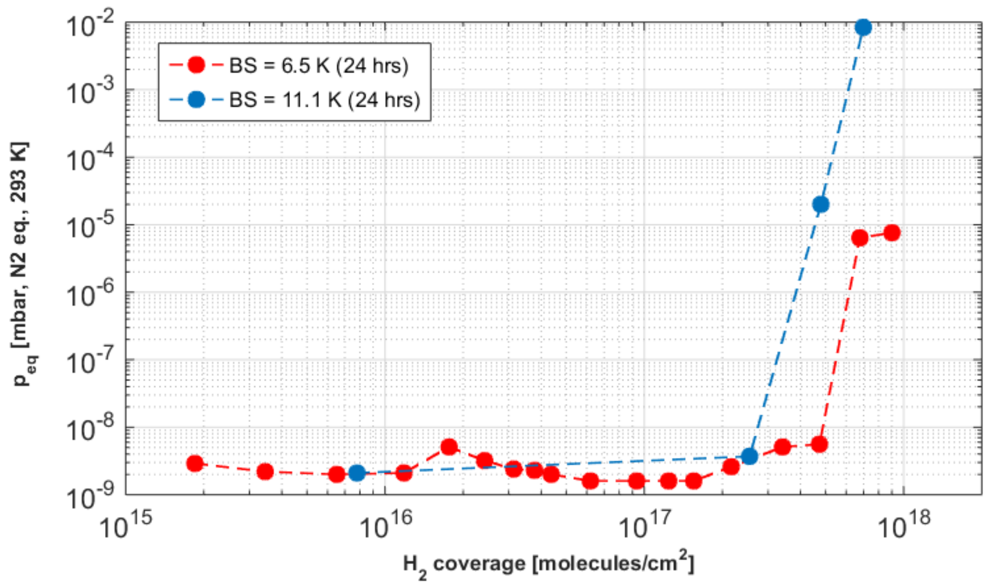
- H_2 is desorbed in the range 40-60 K
- N_2 and CO are desorbed above 80 K
- The activation energy (temperature) for desorption (release) is dependent on the coverage



A possible new operating temperature window for the beam screen could be ~ 60-80 K

- The cryosorption capacity for H_2 is ≥ $2\cdot10^{17}$ H_2/cm^2 below 10 K
- It is intermediate between metallic surfaces and common cryosorbers

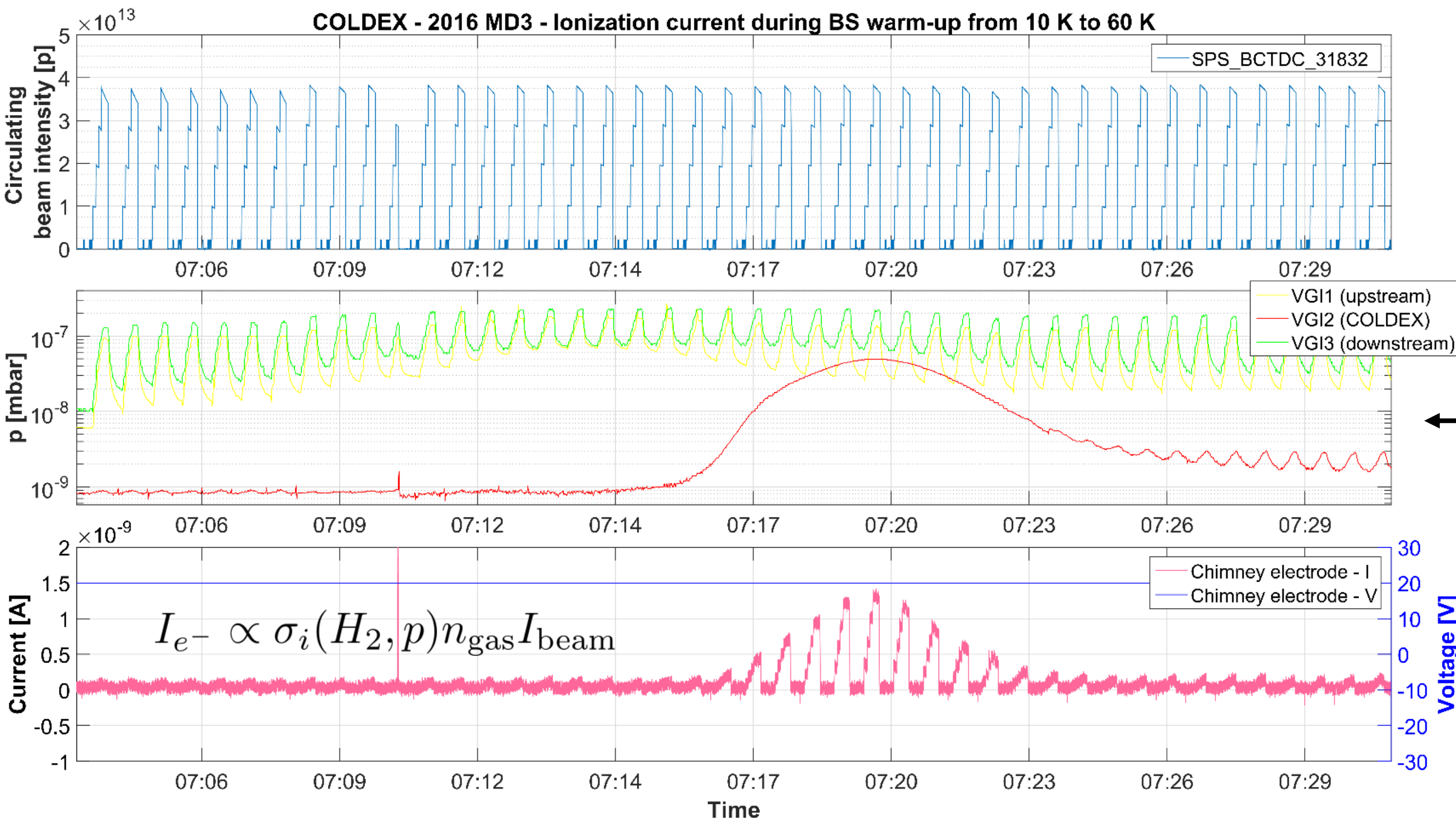
R. Salemme



Observation of Beam-Gas Ionisation with COLDEX

- COLDEX's electrode is sensitive enough to measure beam gas ionisation!
- Sensitivity ~ 0.1 nA i.e. ~$4\cdot10^6$ $e^-/(mm^2\ s)$

$$I_{e^-} \propto \sigma_i(H_2, p) n_{\rm gas} I_{\rm beam}$$



Beam circulating intensity

P at extremities

a-C, pressure bump

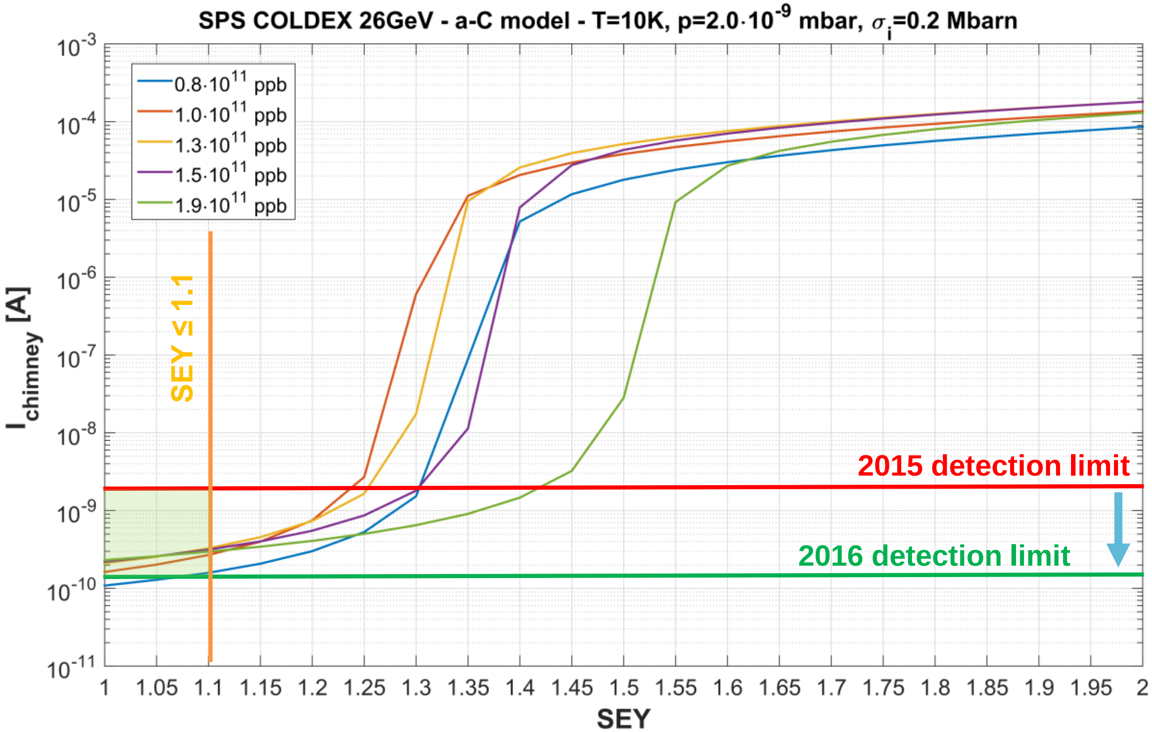
Electron/ion current

R. Salemme, PhD Thesis

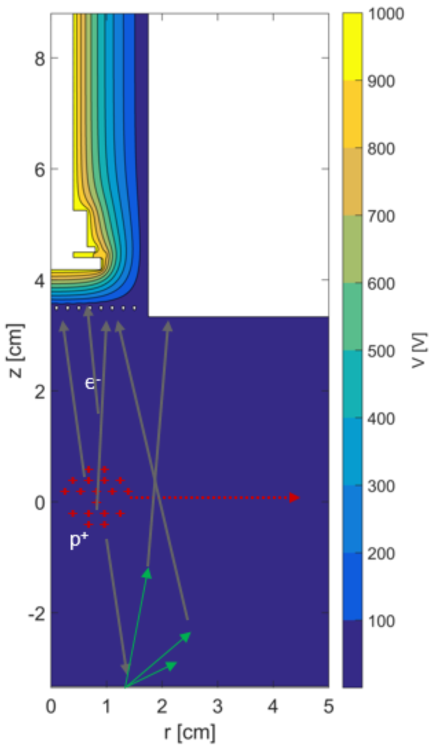
a-C Coating Performances Studies with COLDEX

- No dynamic pressure larger than 10^{-9} mbar due to ESD is observed for:
  - bare surface
  - surface coverages of:
    - ~3 10^{16} H_2/cm^2 , ~2 10^{16} CO/cm^2, ~3 10^{16} CO_2/cm^2
- Measured dynamic heat load are within:
  - 0.2 +/- 0.1 W/m for all studied cases
- No multipacting electron activity is measured above 0.1 nA

$\delta_{max} < 1.1$



Electron pick-up inserted through RT chimney Shielded by a grid Circular, D = 18 mm



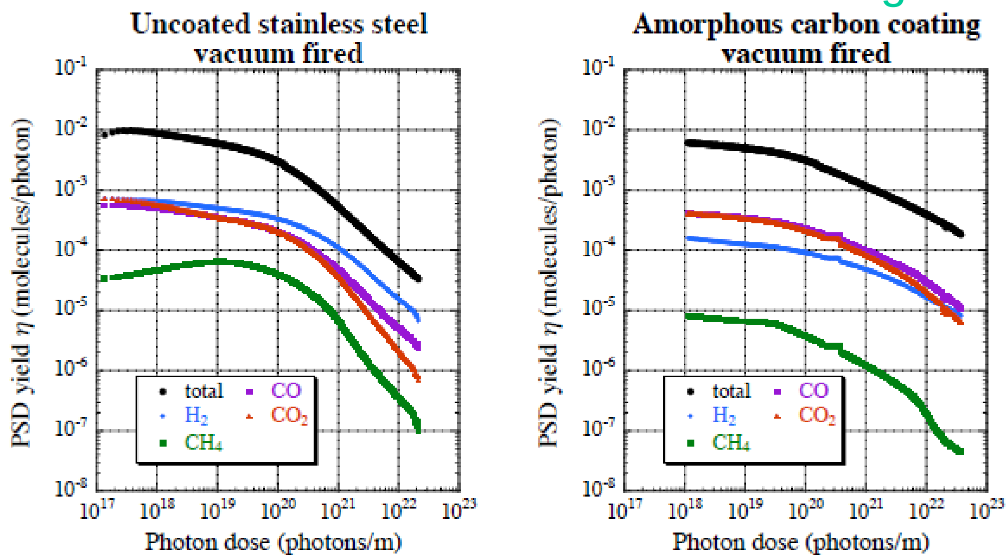
R. Salemme, PhD Thesis

a-C coating and Synchrotron Radiation

- KEK Collaboration:
  - 4 KeV critical energy (x100 LHC)
  - Desorption yields of a-C coating larger than stainless steel
  - Conditioning with beam

M. Ady

In-situ bakeout at 120 deg

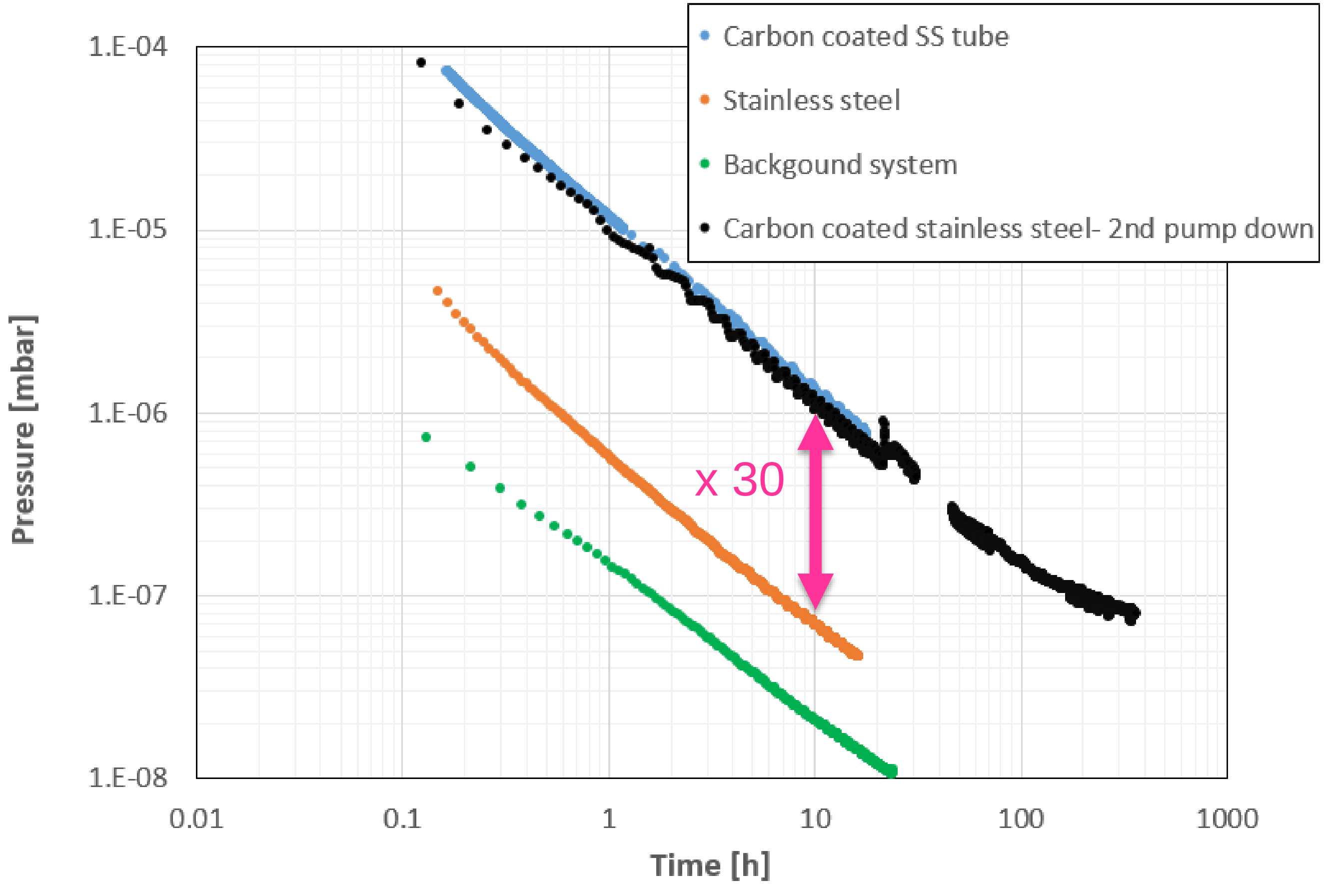


- BINP Collaboration:
  - Set-up under construction
  - Unbaked sample at room and cryogenic temperature
  - ~ 50 eV critical energy
  - Results expected by ~ mid-end 2017

V. Baglin,
A. Krasnov (BINP)

a-C Coating and Thermal Outgassing

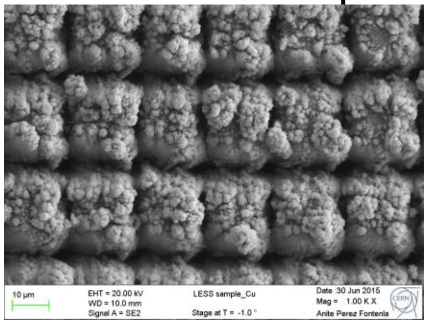
- Unbaked a-C coated stainless steel tube, 450-500 nm thick:
  - Mass spectrum is water dominated
  - ~ x 30 unbaked stainless steel
  - 2nd pump down very similar to 1st one
- After 10h pumping:
  - Stainless steel = 2 10^{-10} mbar.l/s/cm^2
  - a-C coating = 6 10^{-9} mbar.l/s/cm^2



I. Wevers

Laser Engineered Surface Structures: LESS

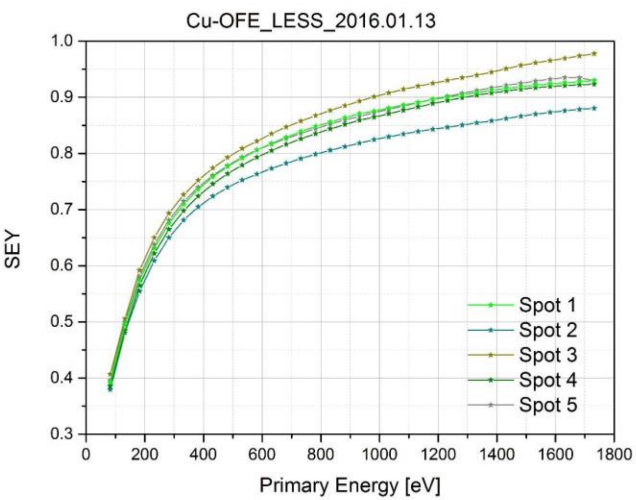
- A studied alternative to a-C coating. Principle: laser treatment of a tube at atmospheric pressure
- Collaboration with university of Dundee and ASTEC
- Challenges: validate vacuum performances before LS2:
  - Outgassing thermal and stimulated
  - Produce a tube and realise implementation on the field



A. Abdolvand *et al.*,
Dundee University' s samples

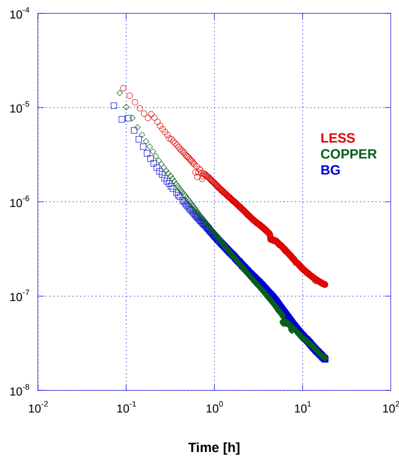
- Test liners validated in SPS BA5 and to be installed in COLDEX

$\delta_{max} < 1$!



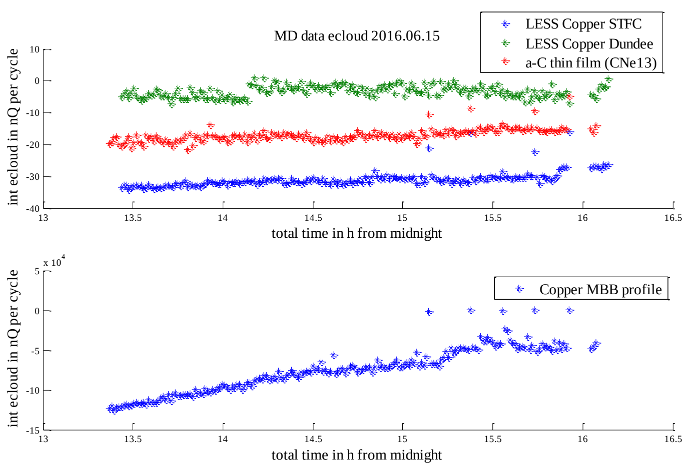
E. Garcia-Tabares Valdivieso

Large H_2O outgassing



I. Wevers

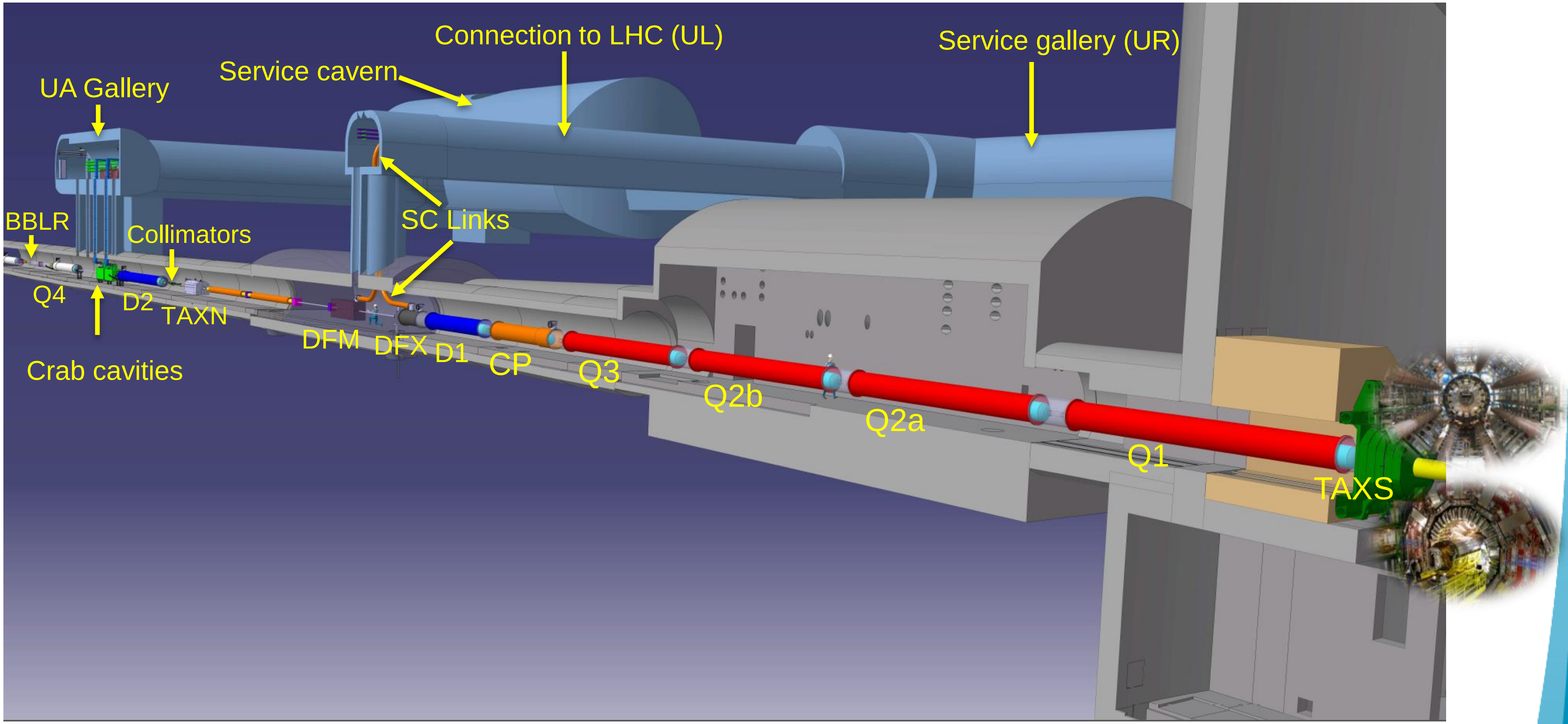
Electron cloud suppression by 4 order of magnitude as compared to Cu



H. Neupert

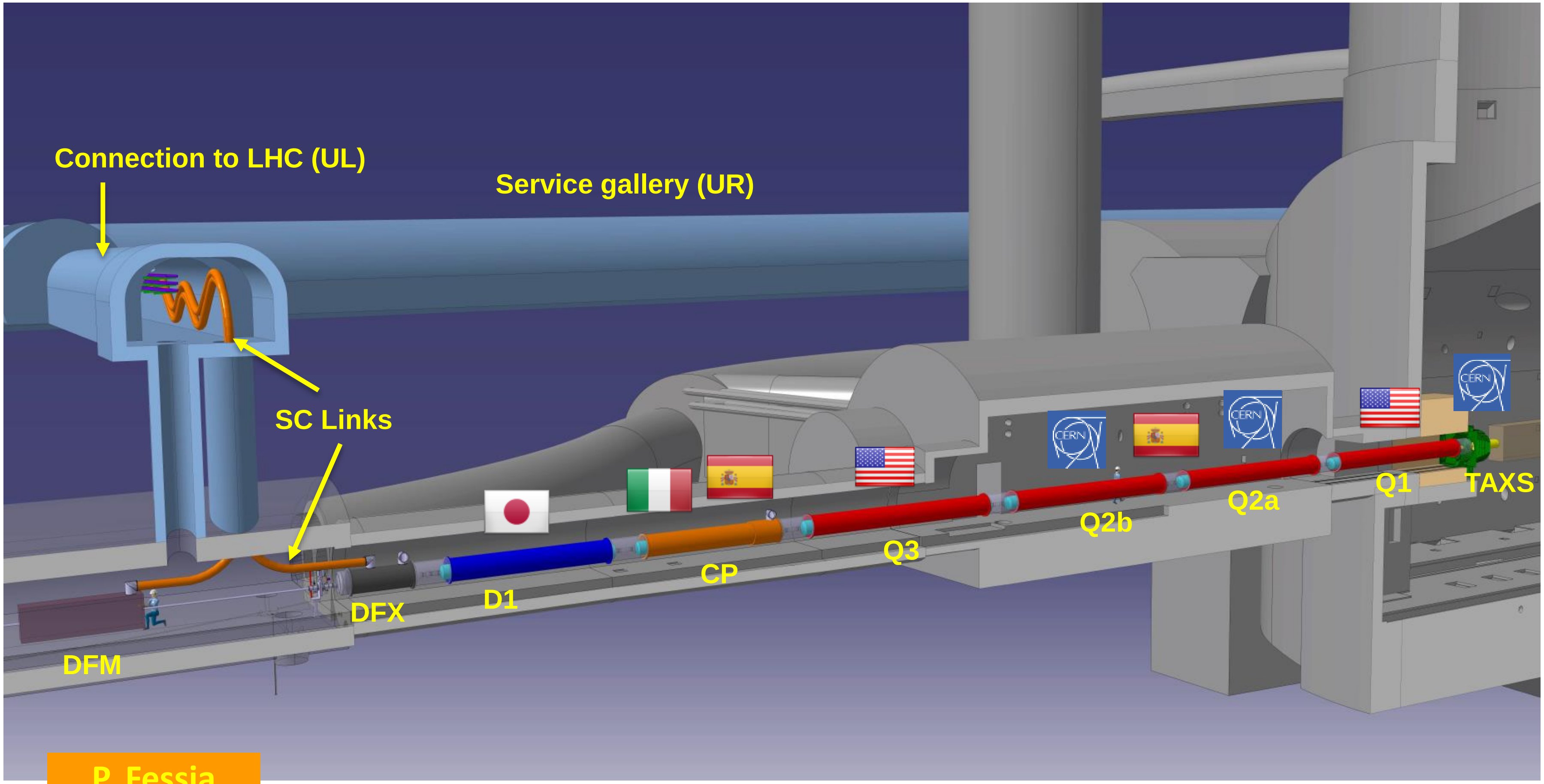
3. HL-LHC Layout

The Insertion Region (till Q4)



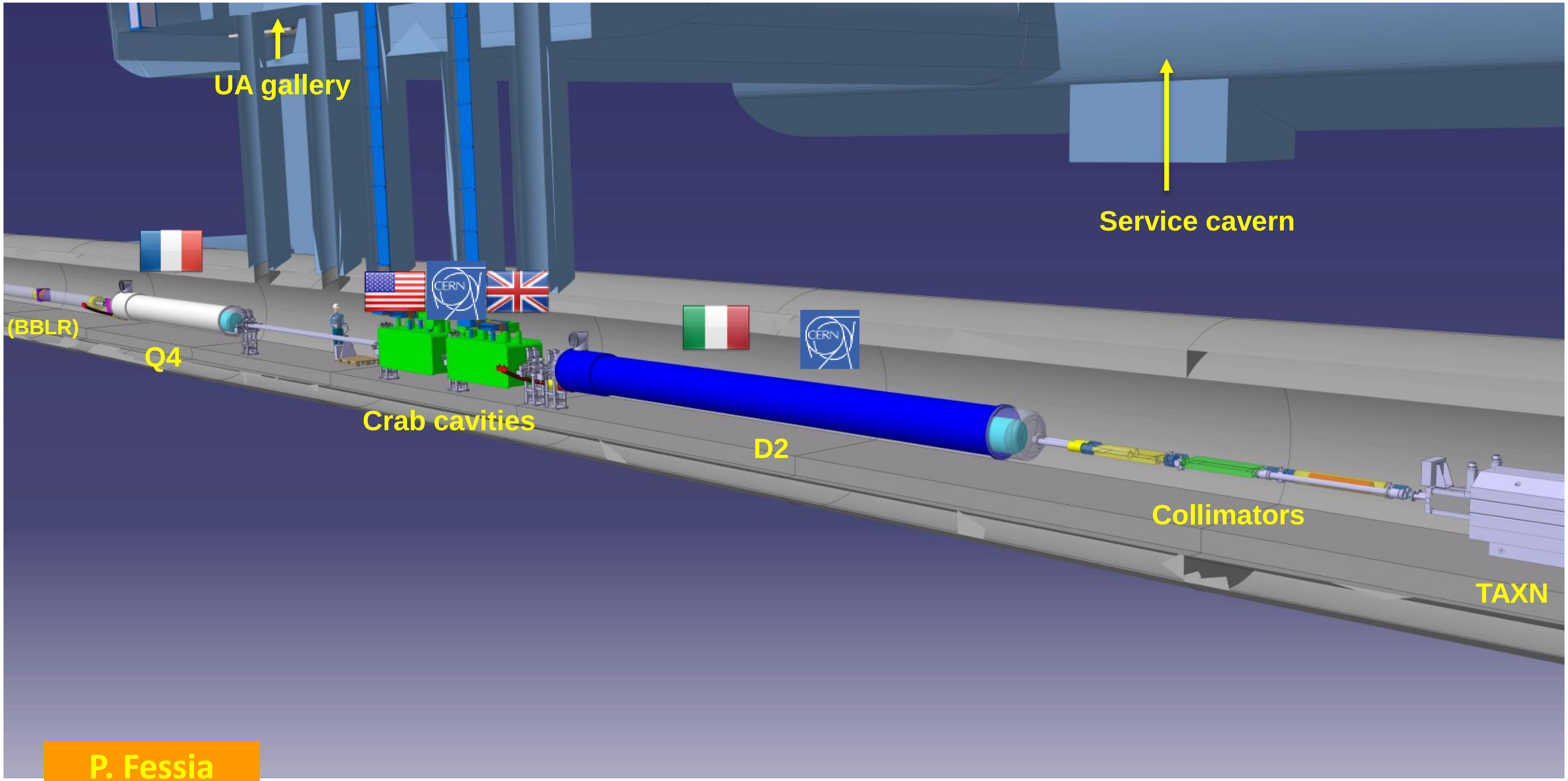
P. Fessia
WP15

The Inner Triplet region with in-kinds



P. Fessia
WP15

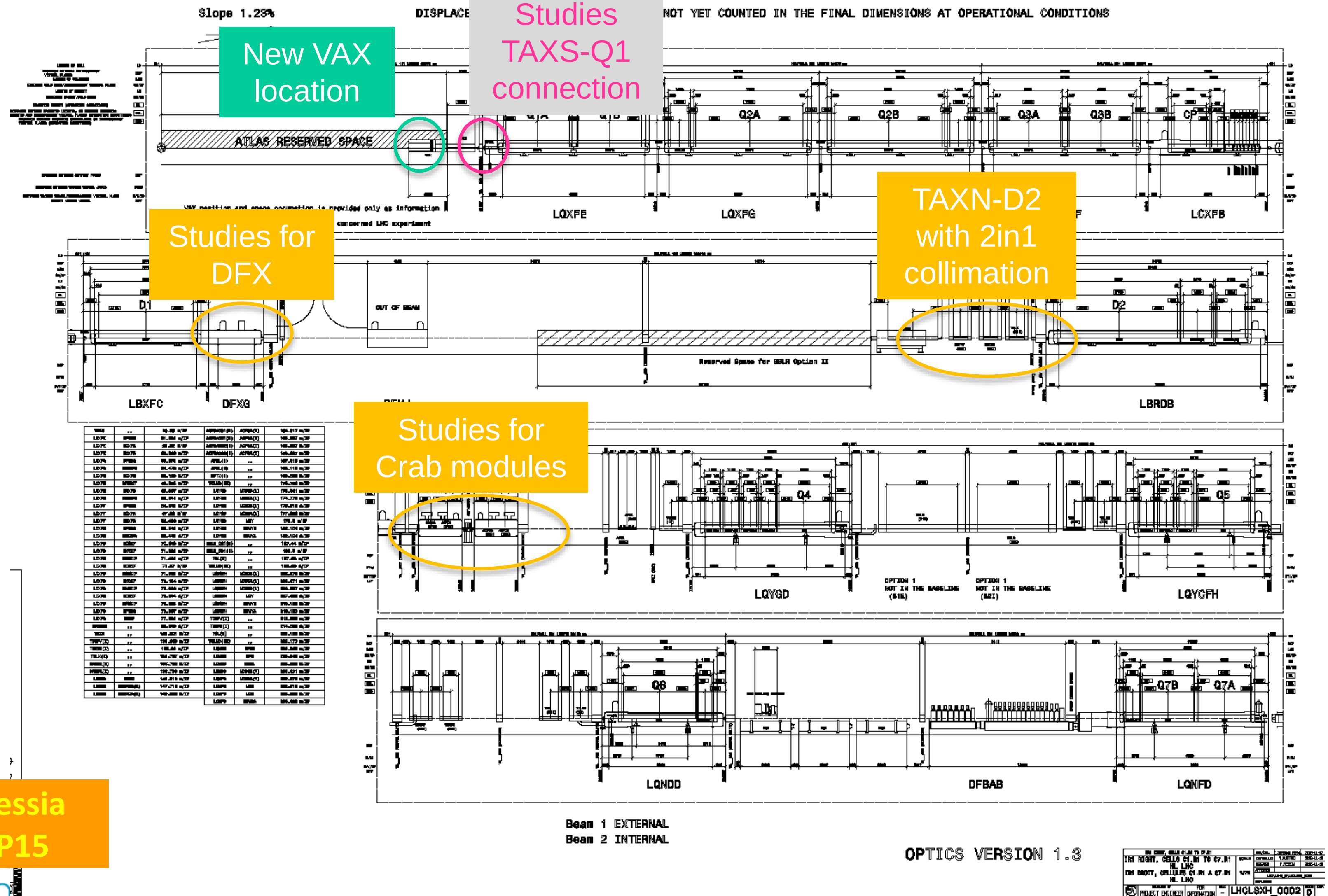
The MS region with in-kinds



P. Fessia
WP15

Layouts

- LHCLSXGH0003 and LHCLSXGH007 for insertions 1 and 5
- LSS1 and 5, right and left are available !
  - LHCLSXH_0001 ; LHCLSXH_0002 ; LHCLSXH_0009 ; LHCLSXH_0010



P. Fessia
WP15

Vacuum Chambers Apertures

- Input beam aperture table from WP2
- New vacuum chambers and vacuum modules to be designed / produced for D1-Q4 region
- Additional inner diameters standards: 91 and 248.1 mm

	HL-LHC beam aperture [mm]	Vacuum chamber aperture [mm]
D1	0 - 130	
D1 - TAXN	130 - 233	VCT - 212.7 - VCT - 248.1
TAXN	85	VCTY
TAXN - D2	85	91
D2	87	
D2 - Q4	85	91
Q4	72.41	
Q4 - Q5	72.41	80
Q5	57.8	
Q5 - Q6	57.8	80
Q6	45.1	
Q6 - Q7	45.1	80

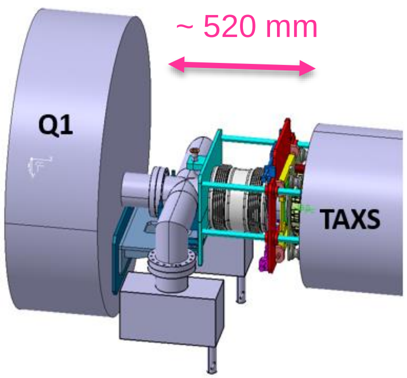
P. Santos Diaz

New VAX area in IR1 and 5

- Move the instrumentation in front of Q1 to the experiment's cavern to reduce radiation to the personnel: robustness, remote handling and tooling are required
- Installation in LS3 during TAS exchange, the impact on the experimental vacuum chamber beam pipe is under study
- TAXS-Experiments & Q1-TAXS areas studies are coordinated by WP8
- Unbaked a-C coated TAXS

Pumping and bellow to decouple room temperature TAS from cryogenic temperature triplet

Sectorisation to decouple experiment's vacuum from machine vacuum

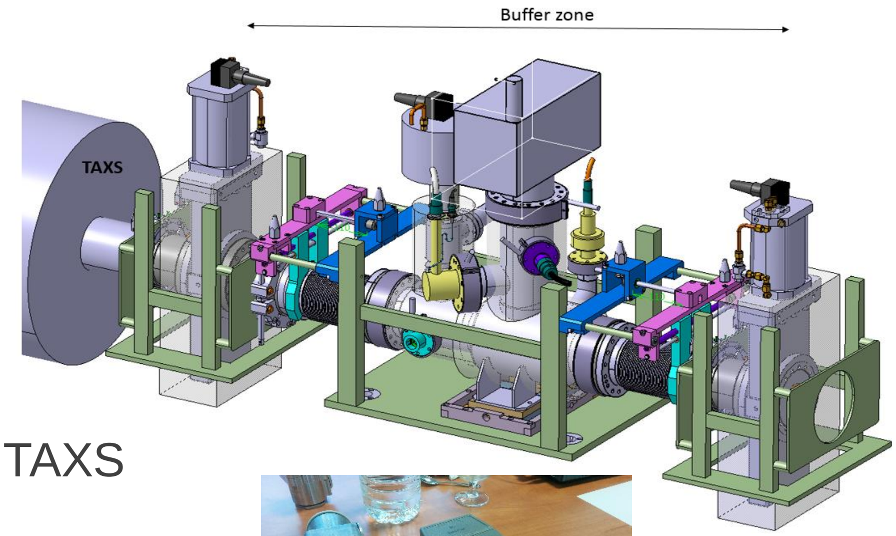


Q1

Courtesy L. Krzempek

TAXS

TAXS

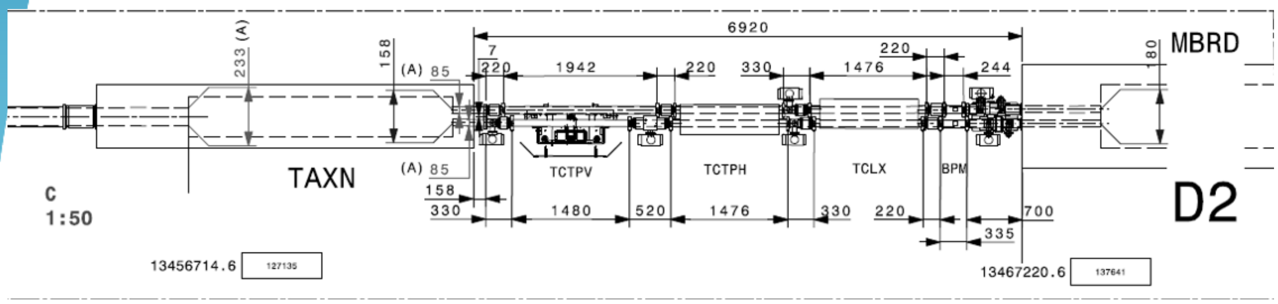


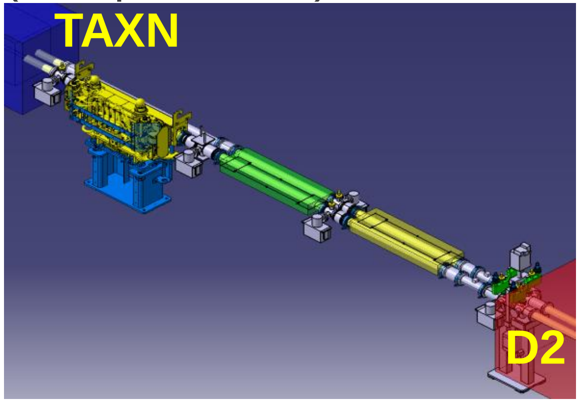
~ 16 m

J. Perez. Espinos, G. Pigny
WP8

TAXN – D2 area

- Tertiary collimation to protect IT from incoming beams
- Longitudinal layout defined but without 5th axis for collimation (except TCTPV)





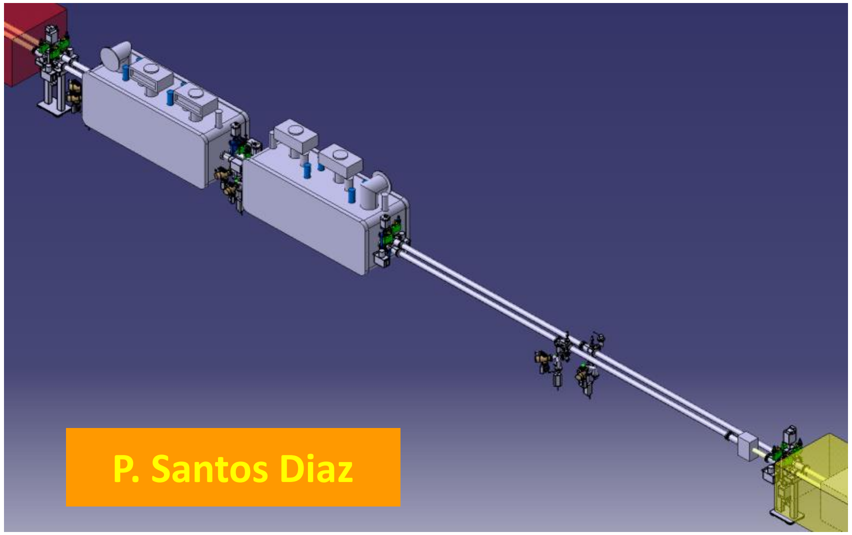
P. Santos Diaz

- New designs:
  - 2 beam in one vessel for TCL and TCTH (responsibility of the collimation project, WP5).
  - New bellows and RF transitions.
  - New chambers, supports etc.

- Base line (in collaboration with survey): minimise radiation to the personnel during intervention
  - Supports of vacuum equipment are aligned by survey during installation.
  - Vacuum components are exchangeable without re-alignment of the supports+ chamber system
  - Smoothing, when needed, during LS

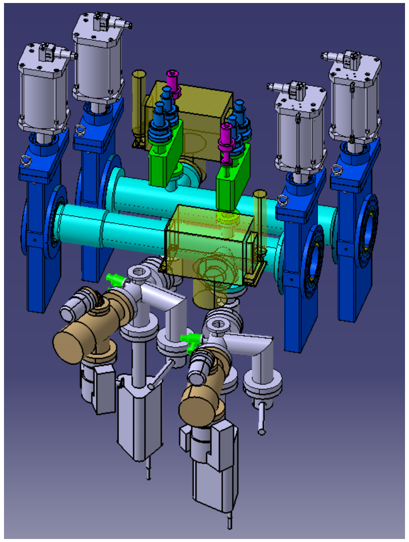
Layout D2-Q4: crab cavities area

D2



Q4

CC



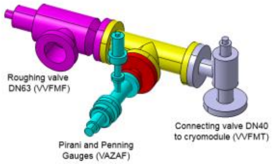
CC

- Room temperature sectors (except CC modules): bakeable and NEG coated
- 2 sectorised CC modules: unbaked, operating at cryogenic temperature (2K)
- 3 types of sector valves assemblies (VAB)

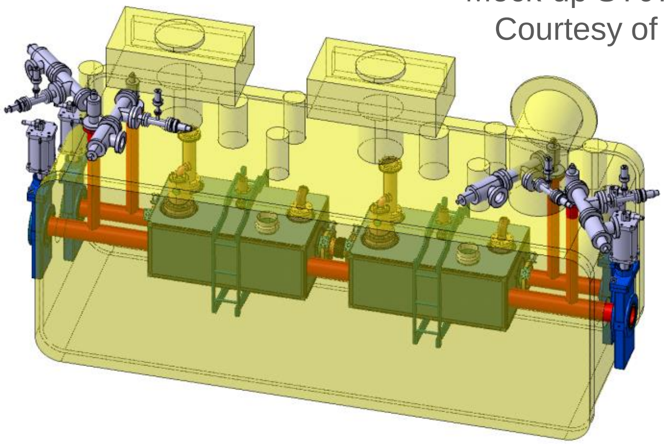
Crab Cavities Cryomodule: Status

- Interlocked valve

- Ports are equipped with vacuum gauges and roughing valves for monitoring and maintenance of the cryomodule



Mock-up ST0782198_01*
Courtesy of T. Capelli



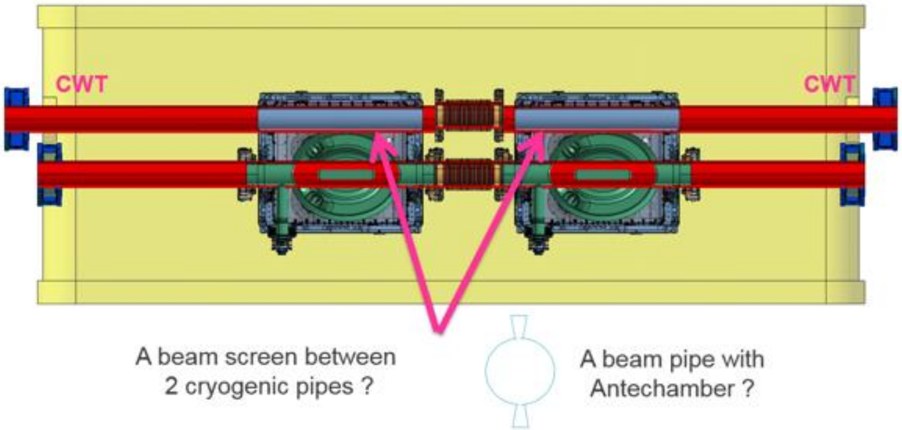
P. Santos Diaz

- The 2nd beam pipe is held at 2 K and has its diameter limited by space

- Needs to be designed with a beam screen type system

- Cold warm transitions (CWT) have to be designed

- Detailed studies are needed to comply with vacuum stability and pressure level (background to experiments)



4. LS2
J-2(365)

HL-LHC activities during LS2 & LS3

- Presented during LS2 days (L. Tavian, G. Bregliozzi)
  - In-situ a-C coating of IT in LSS2 and 8
  - Support to other WP

	Equipment requiring VSC contribution		
WP4	CC sectorisation	EYETS	SPS
	CC bypass	YETS	SPS
WP5	TCLD collimator	LS2	P2, P7
	TCSPM sec. collimator	EYETS&LS2	P7
WP8	TANB	LS2	P8
	Forward shielding modification	LS2	P1, P5
WP11	11 T Dipole	LS2	P7
	Cryo-bypass	LS2	P2, P7
	Connection cryostat	LS2	P2
WP13	High bandwidth BPM	LS2	P4
	Wire in jaw collimator	EYETS	?
	Beam gas vertex detector	LS2	P4
WP14	TDIS	LS2	P2, P8
	D1 mask	LS2	P2, P8
	MKI	YETS&LS2	P2, P8

L. Tavian
LS2 days

- LS2 days: https://indico.cern.ch/event/564604/

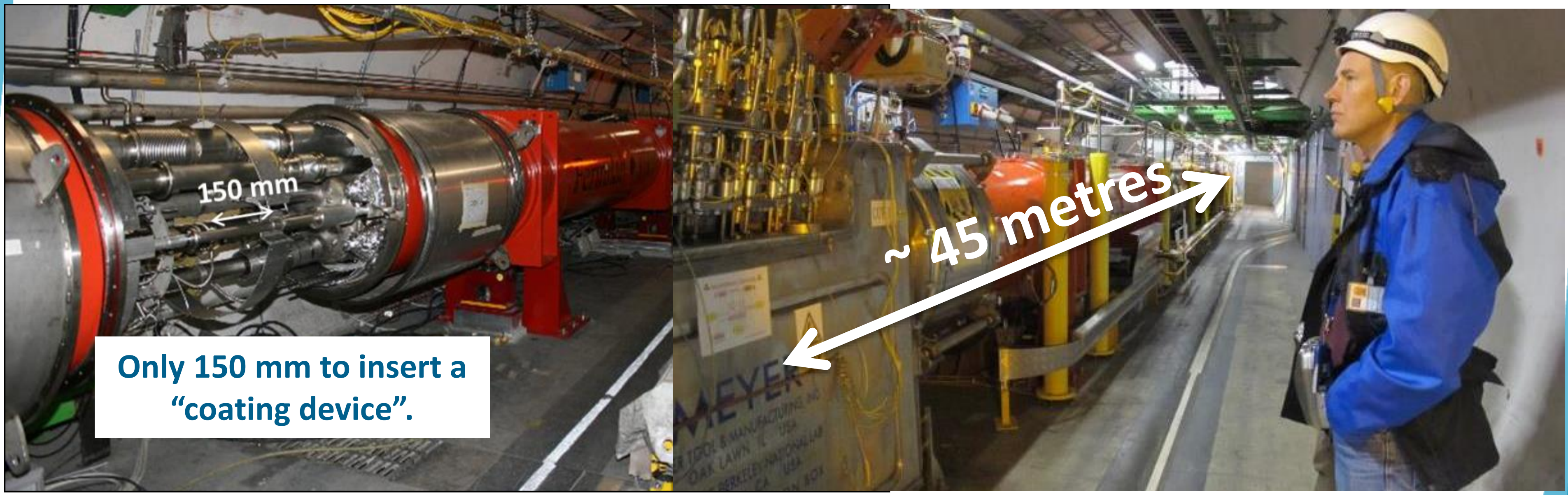
- Detailed activities during LS2 are in PLAN and during LS3 are drafted

	LHC	LS1	HL-LHC		
	Vacuum Sectors	Vacuum Sectors	Vacuum Sectors	LS2: Length (m)	LS3: Length (m)
Cryogenic temperature	92	92	80	210	770
Baked Room temperature	185	146	183	850	2680
Unbaked Room temperature	6	2	6	400	500

* HL-LHC options are excluded

a-C coating: *In-Situ* Implementation

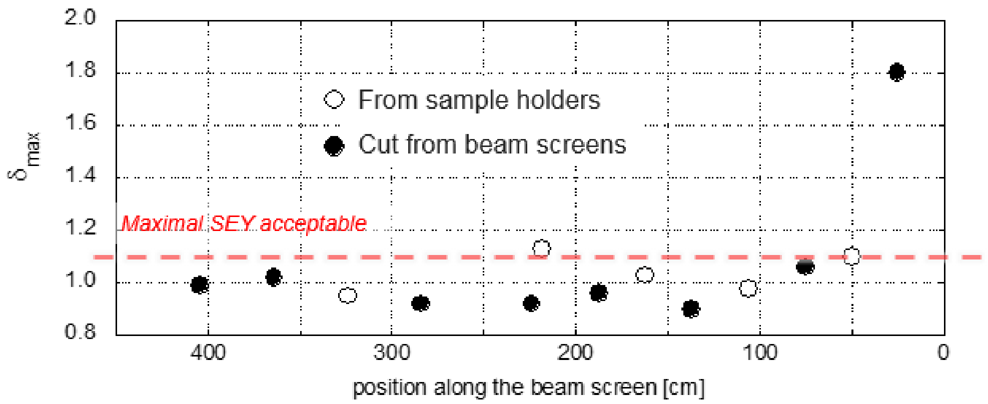
- Length to be *in-situ* coated: ~45 meters per "string" (Q1, Q2, Q3, DFBX & D1) of LSS2 and LSS8

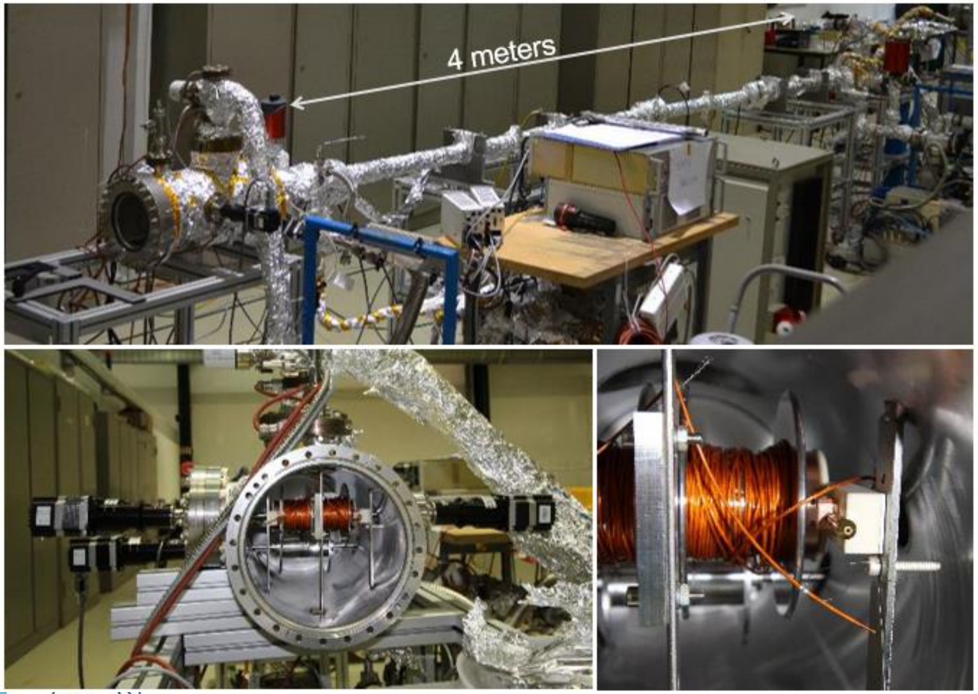


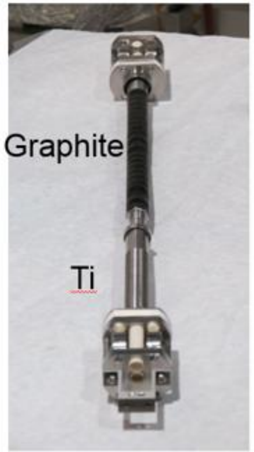
- Development of a "modular sputtering source" that can be inserted in a 150 mm slot and pulled by cables along D1 and the triplets

In-situ a-C Coating Status

- Magnetron sputtering of a graphite cathode using permanent magnets with Ti underlayer + molecular dragging (@ 1W/cm; p_{Ar}= 0.1 mbar).
- δ_{max}< 1.1 along 4 m!







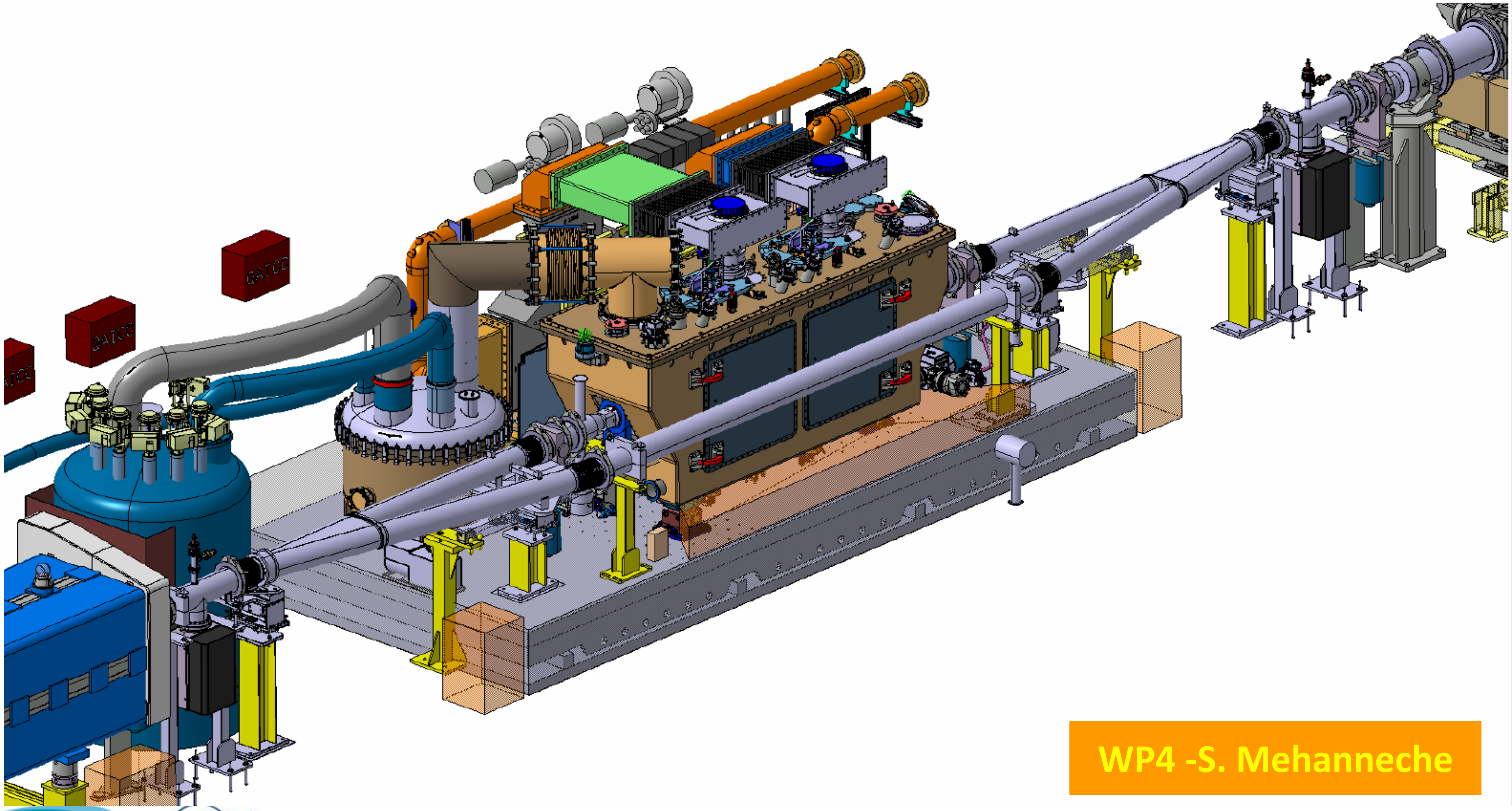
P. Costa Pinto
P. Demolon

Crab Cavities Cryomodule: SPS Test

- A layout is defined with a-C coating as antimultipactor
- Sectorisation implemented during this EYETS!
- Y chamber and bypass assembly designed, to be produce

- Final installation: 2017-18

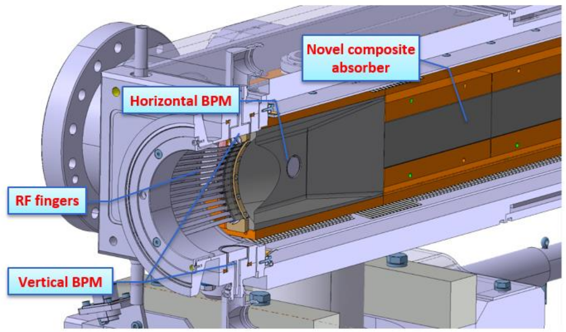
C. Pasquino, J. Hansen, Q. Deliege



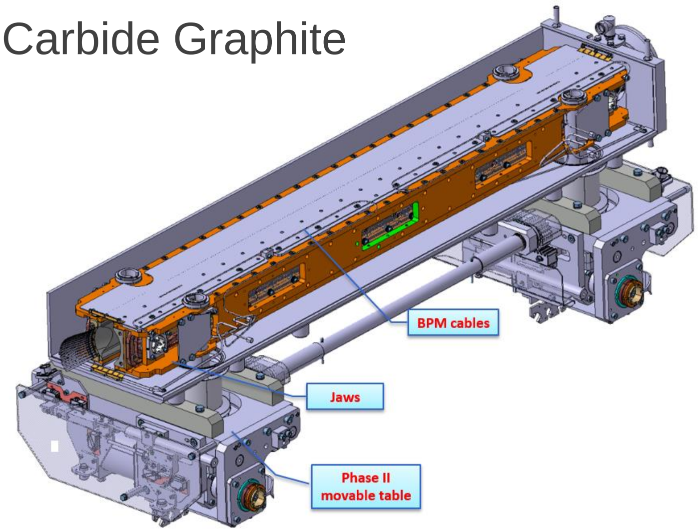
WP4 -S. Mehanneche

TCSPM collimators

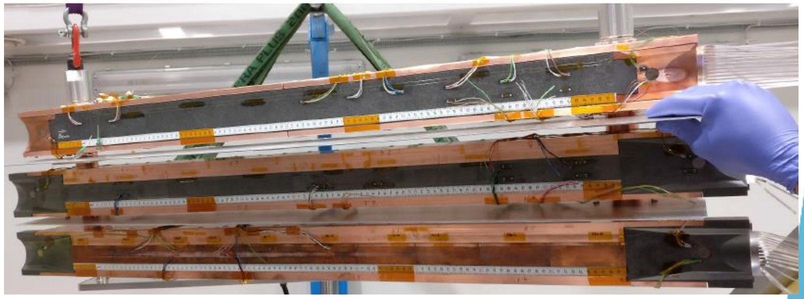
- Low impedance collimators: with coated Molybdenum Carbide Graphite (MoGr) and in jaw beam position monitors
- To be installed in LSS7 and LSS3, partially in LS2



F. Carra



- Evaluation under irradiation, evaluation of impedance and outgassing under way …



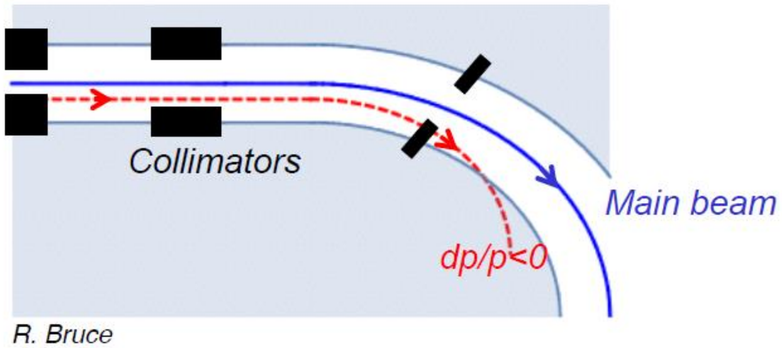
- HiRadMat tests showed that MoGr and CuCD jaws could withstand the respective design failure

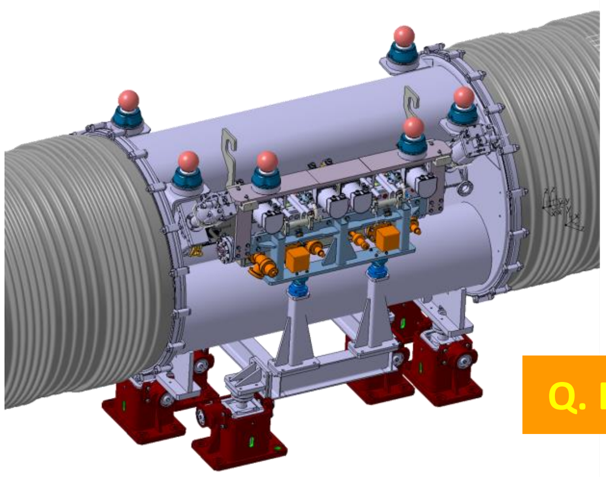
- Three stripes of different coatings, MoGr, Mo, ceramic, for impedance measurements with beams next year !

S. Redaelli – EN/MME

11 T – DS collimator in IP7

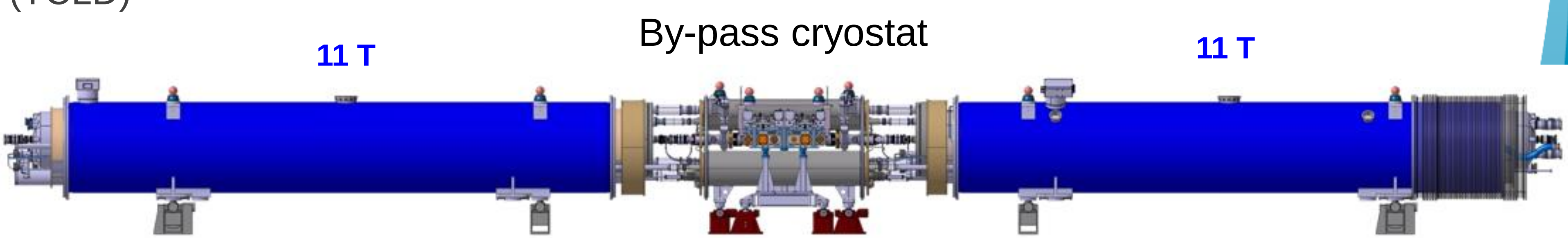
- Arc Dispersion Suppressor areas (Q7 to Q11) serve as "energy spectrometer" : a collimator is needed to reduce background to ALICE with ion operation and to reduce beam loss on the cold masses with proton beams





Q. Deliege

- Using $NbSn_3$ technology, the dipole field can be increased up to 11 T
- A standard LHC dipole can be replaced by two 5.8 m long 11 T magnets and one collimator (TCLD)

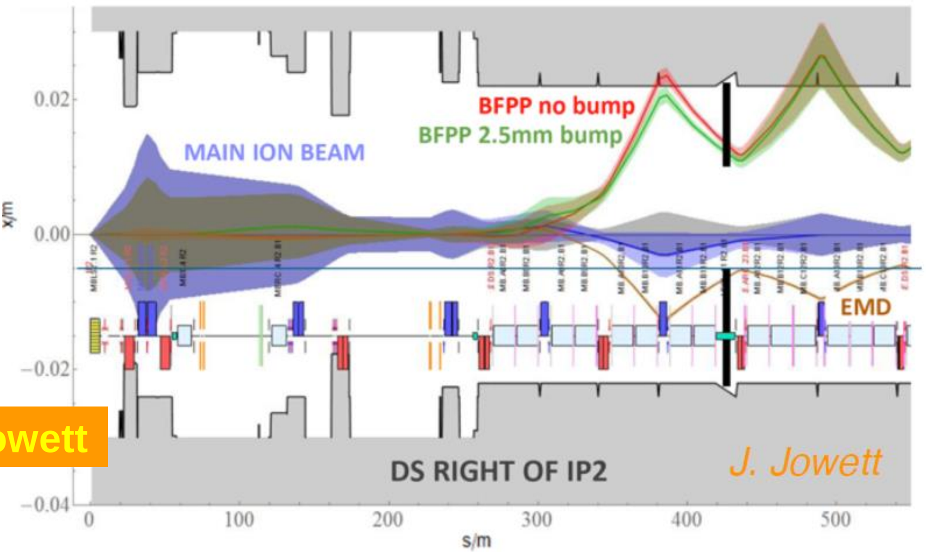


WP5&11 – F. Savary

DS collimator in IP2

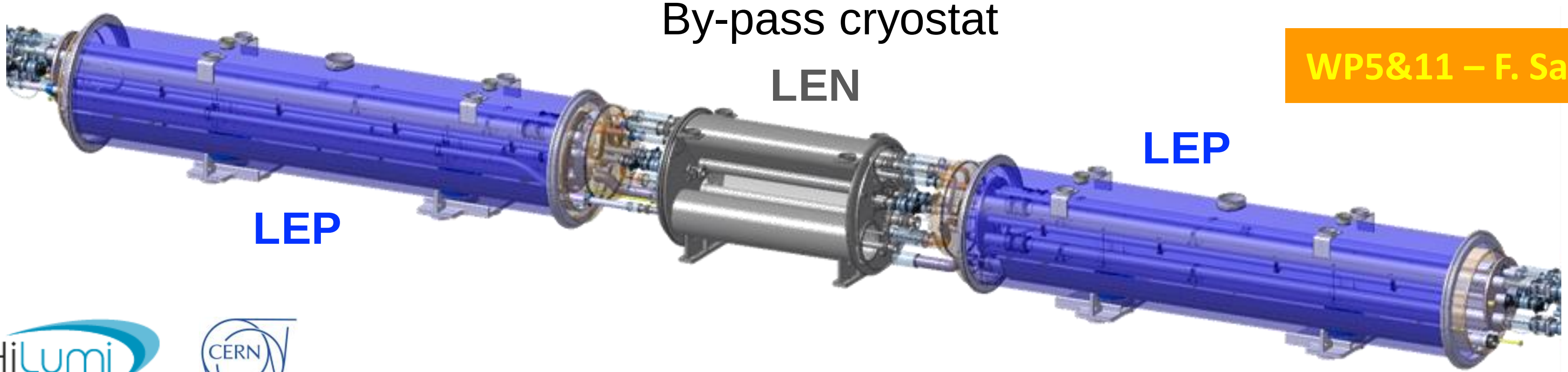
- Arc Dispersion Suppressor areas (Q7 to Q11) serve as “energy spectrometer” : a collimator is needed to reduce background to ALICE with ion operation and to reduce beam loss on the cold masses with proton beams

J. Jowett



- A TCLD by-pass and two connecting cryostats are placed instead of LHC empty cryostat I

By-pass cryostat

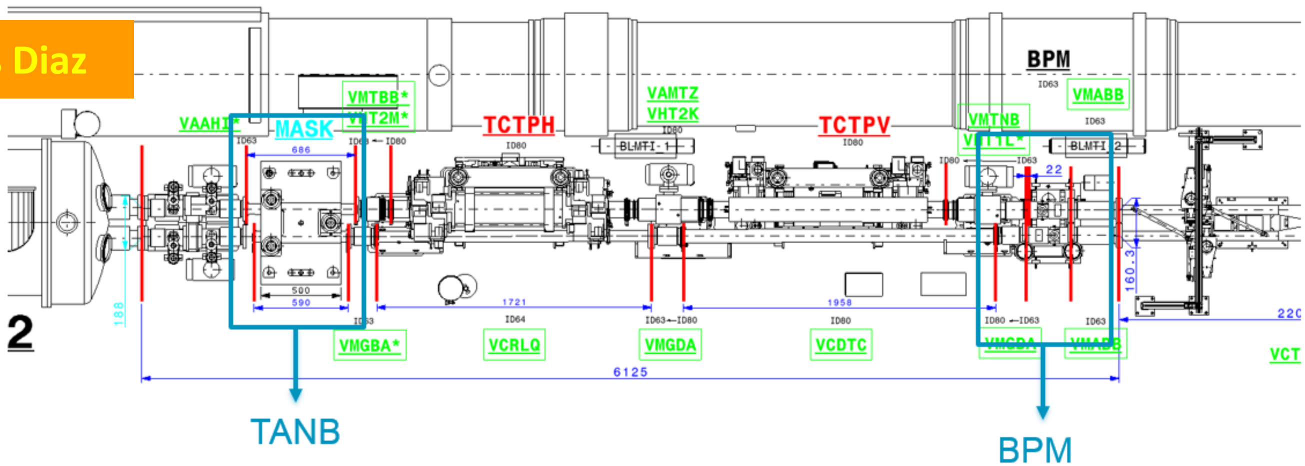


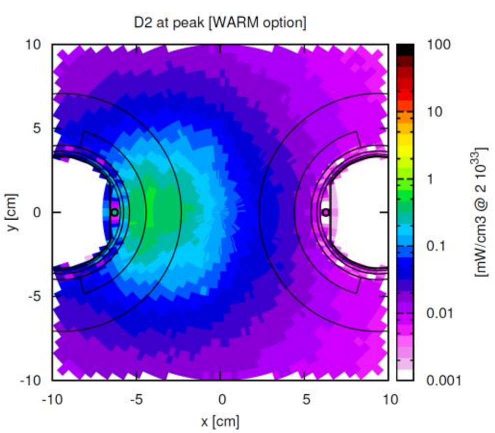
WP5&11 – F. Savary

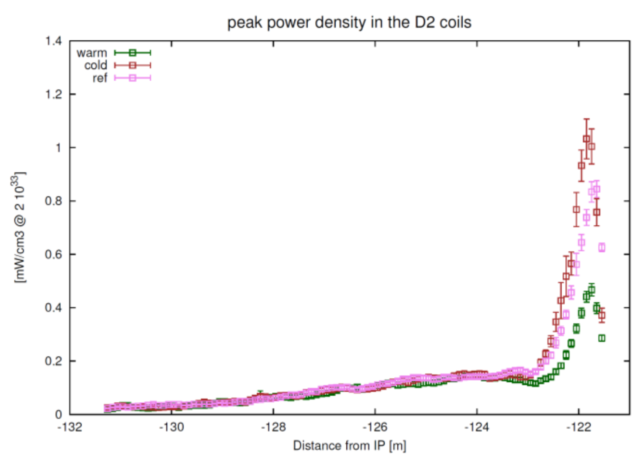
TANB

- Protects the D2 from increased luminosity in LHCb
- Integration proposed to be validated

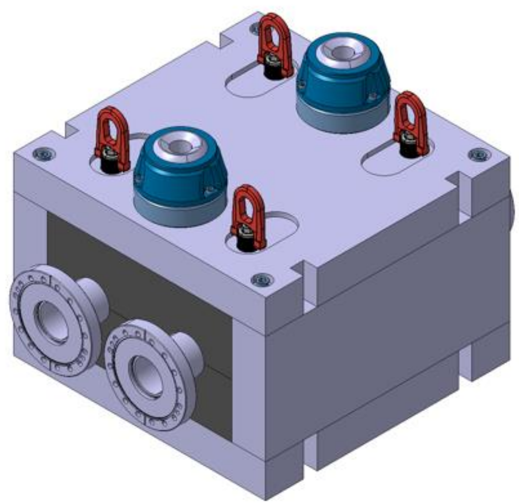
P. Santos Diaz







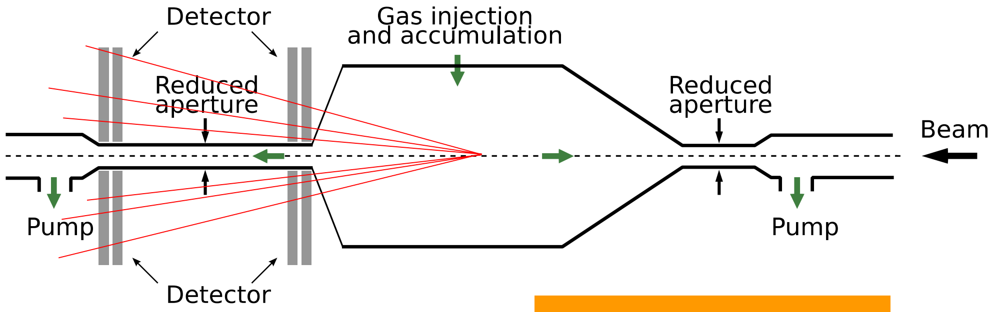
F. Cerutti

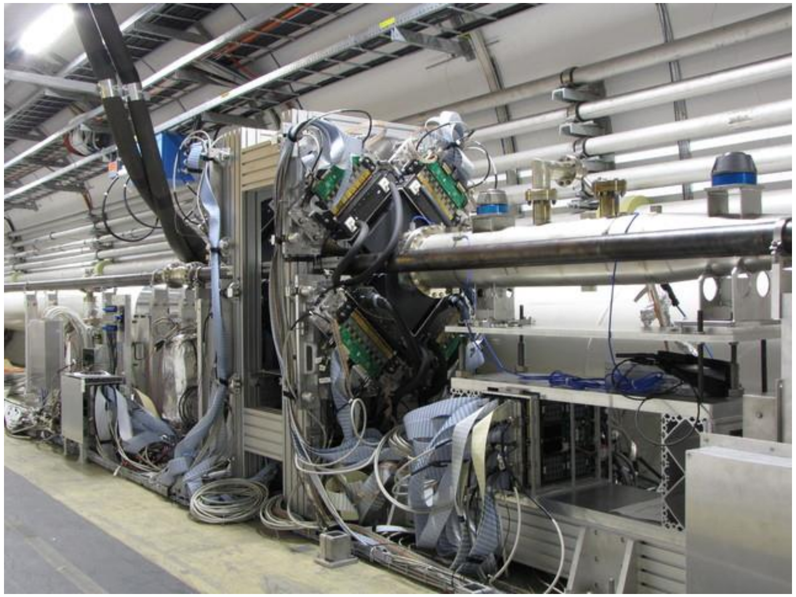


F. Sanchez Galan

Beam Gas Vertex Detector

- Aim
  - Use tracks from beam-gas interactions to reconstruct beam spot in a non-invasive way
  - Provide bunch-by-bunch size with a 5% resolution within 1 minute
    - Demonstrator aims at 5% within 5 minutes
  - Provide average beam size with absolute accuracy of 2% within 1 minute
    - Demonstrator aims at 10% within 5 minutes
- Demonstrator
  - Collaboration with Aachen University, EPFL & LHCb
  - Installed during LS1 on Beam 2
  - Fully commissioned in 2016

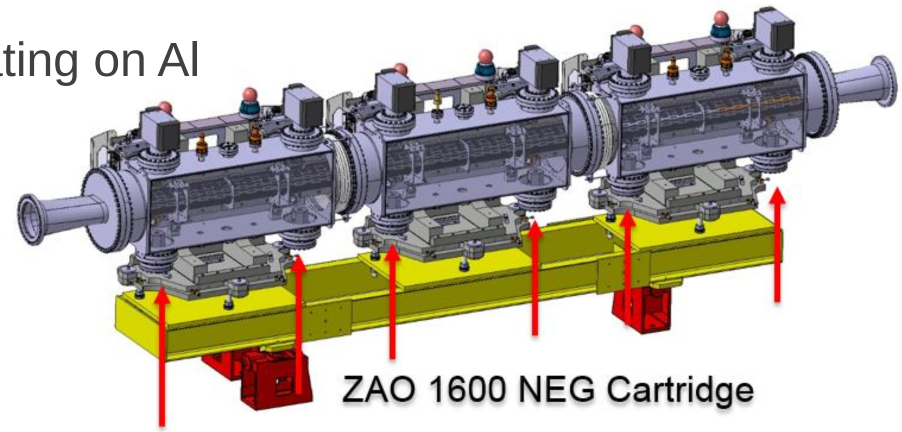




WP13 – R. Jones

TDIS

- TDI is one of the weakest component of LHC: to be replaced by TDIS !
- New improved design taking into account previous issues
- 3 blocks: 2 x SGL graphite + 1 x (Al + Cu)
- Impedance: no coating on graphite – Ti coating on Al



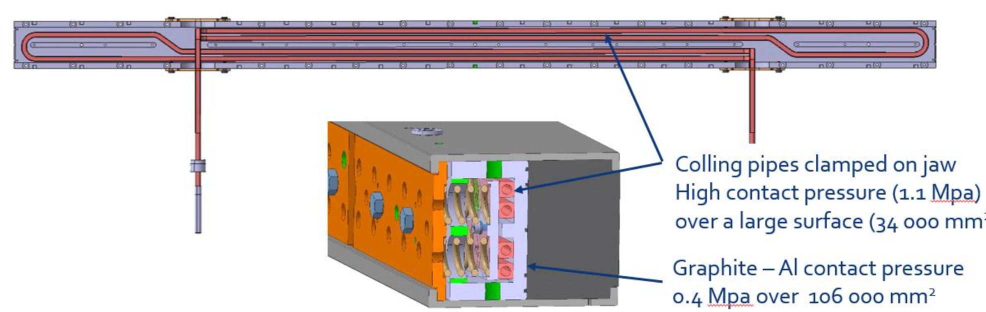
- TDI: ~ 6000 l/s vs TDIS: ~ 13 500 l/s
  ➔2 time more pumping speed
- Material outgassing: 10^{-8} mbar.l/s

Material	Outgassing rate Baked [mbar·l/s cm²]	RGA Baked	Outgassing rate Unbaked [mbar·l/s cm²]	RGA Unbaked	
				< 50 amu	> 50 amu
3d CC Heracles	$\approx 9.0\cdot10^{-12}$ ✓	✓	$\approx 2.3\cdot10^{-8}$ ✗	✗	✓
Graphite Mersen	$\approx 2.5\cdot10^{-12}$ ✓	✓	$\approx 2.3\cdot10^{-9}$ ✓	✓	✓
3d CC Mersen	$\approx 3.5\cdot10^{-11}$ ✗	✓	$\approx 2.9\cdot10^{-8}$ ✗	✓	✓
Graphite SGL	$\approx 5.0\cdot10^{-13}$ ✓	✗	$\approx 6.5\cdot10^{-10}$ ✓	✓	✗

Graphite SGL	Total surface for the first 2 modules $\approx 1.7\cdot10^{4}$ cm²	Expected total outgassing $\approx 1\cdot10^{-8}$ [mbar·l/s]

G. Bregliozzi

- Improved cooling system
- Improved RF fingers design
- no interferometer but LVDT

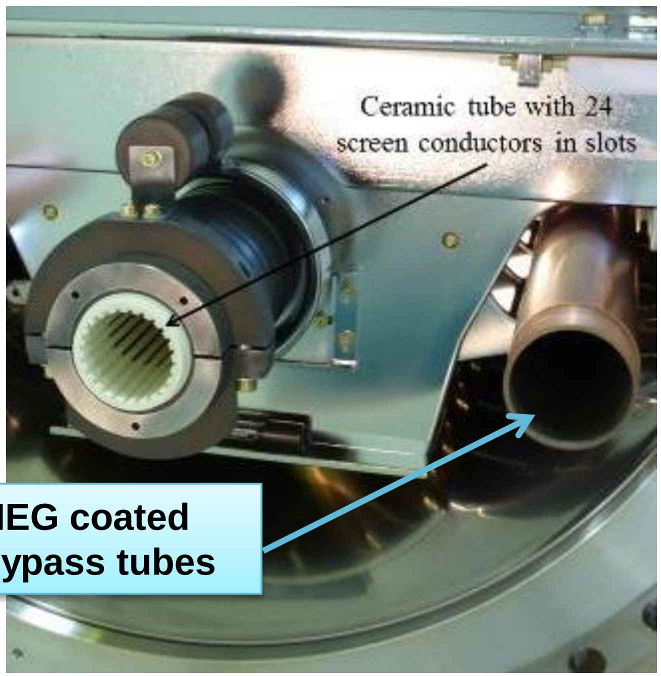


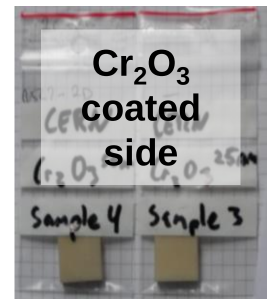
WP14 – A. Perillo-Marcone - L. Gentini

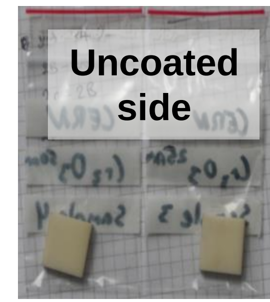
HiLumi HL-LHC PROJECT CERN

Kickers heating, and electron cloud

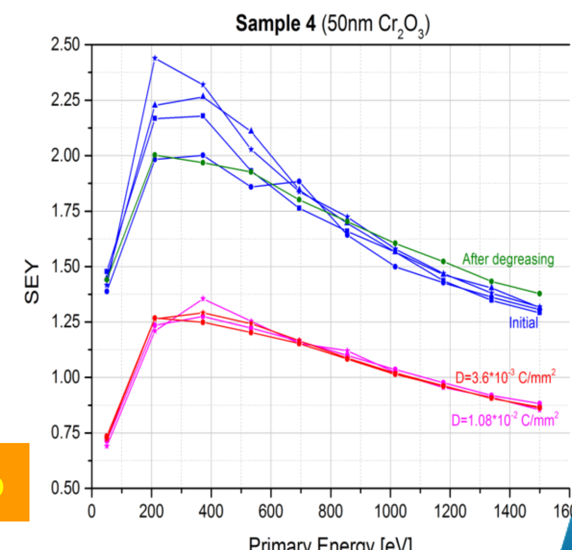
- Ceramic tube can still be an issue with SEY values 6 – 10.
  - ➔ Required SEY ~ 1.4
- Cr_2O_3 coated ceramics by Polyteknik: SEY ≈ 2, conditioned to < 1.4
  - ➔Test in SPS BA5 liner in 2017
- Increase tank thermal emissivity (coating, electrochemistry, Laser)
- Ferrite Curie temperature & outgassing optimization
- Looking for position in machine for passive prototype to be installed in YETS2017-2018







M. Barnes

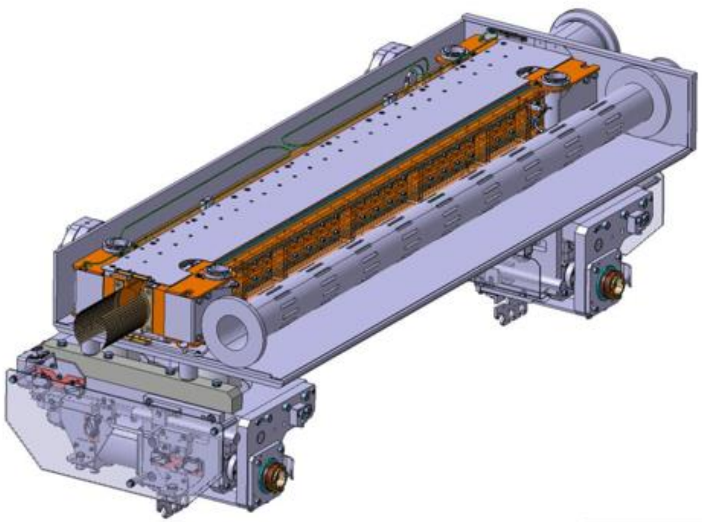


E. Garcia-Tabares Valdivieso

5. LS3 & studies

WP5: Collimation baseline

- Low impedance collimators
- Masks, Primary, secondary, tertiary collimators
- Innovative 2 beam in one TCT & TCLX to solve interferences between TAXN-D2



L. Gentini

Updated production tables

DS cleaning

Low-impedance

IR collimation

Consolidated primary and secondaries

Consolidated IR collimation

New MQW layouts

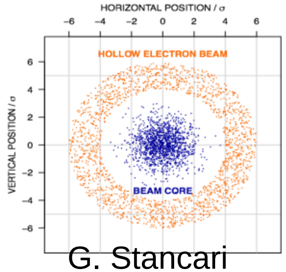
		Mar. 2015		Feb. 2016		Jun. 2016	
Type	**IR**	**LS2**	**LS3**	**LS2**	**LS3**	**LS2**	**LS3**
TCLD	IP2	2		2		2	
	IP7		4	2	2	2	
	IP1						
	IP5						
TCSPM	IP3						
	IP7	8	14	8	14	8	14
TCTPM	IP1		6		6		4
	IP5		6		6		4
TCTPX	IP1		2		2		2
	IP5		2		2		2
TCL	IP1/5		8		8		4
TCLX	IP1/5		4		4		4
TCLM	IP1/5		8		8		**12**
TOTAL - HL		**10**	**54**	**12**	**52**	**12**	**42**
TCPP	IP3	2			2		2
	IP7	6		4	2	4	2
TCSP	IP3		8		8		8
	IP7						
TCTPM	IP1/5	4		4		4	
	IP2		4		4		4
	IP8		4		4		4
TCAP	IP7	2		2		2	
TOTAL - CONS		**14**	**16**	**10**	**20**	**10**	**20**

S. Redaelli, 6th HL-LHC meeting

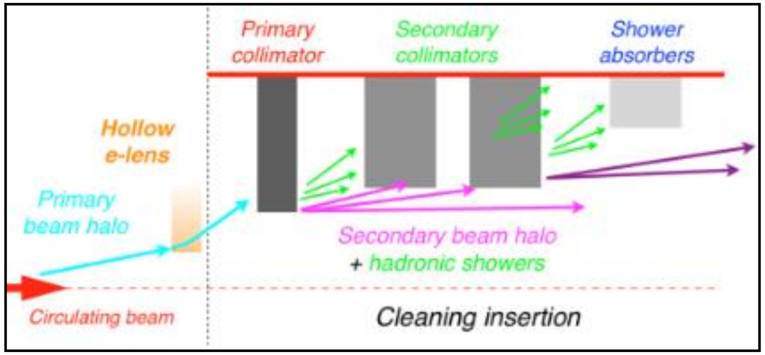
S. Redaelli

WP5 option: hollow e-lens

- Hollow electron beams running coaxially to the proton beam will provide an active control of beam halo population and beam loss rate. Installation 2 lenses in LS3
- Used at Tevatron and RHIC
- Received a positive feedback at a recent review: could be integrated in HiLumi baseline

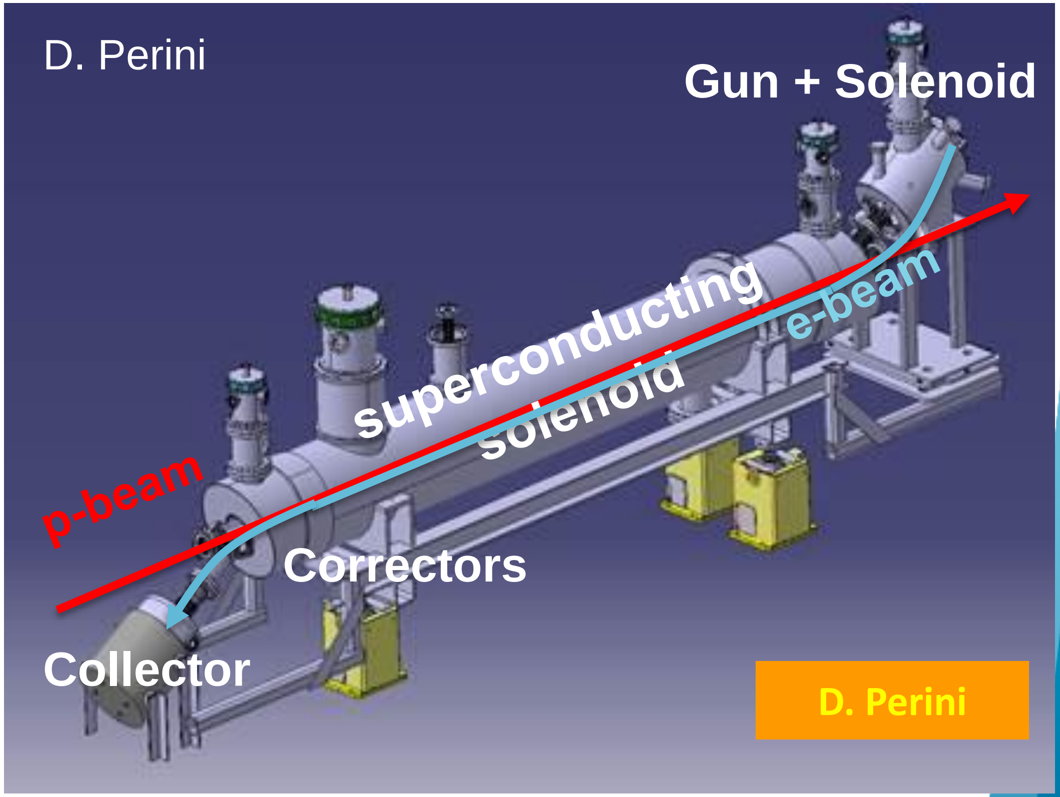


G. Stancari



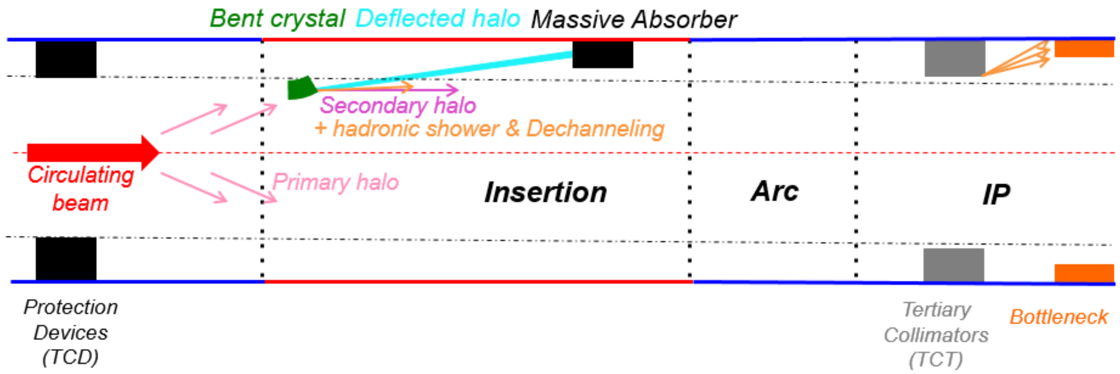
S. Redaelli

- 5T field
- 3 m long
- RT vacuum system, bakeable



WP5 study: cristal collimation

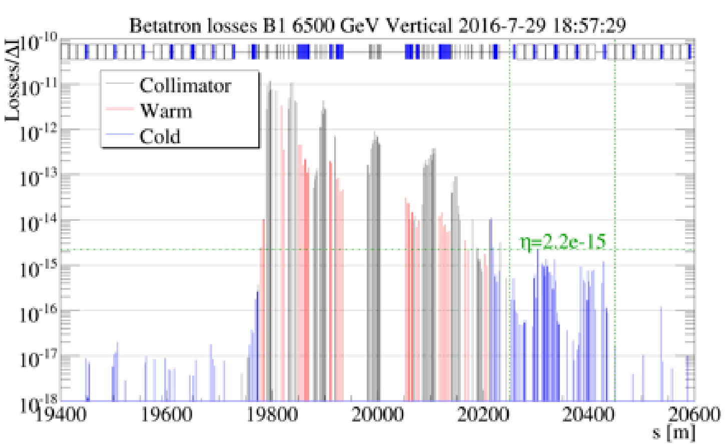
- Objective is to improve ion cleaning
- Allows reduction of the number of collimators and larger gaps:
  ➔ collimation has much less impact on impedance budget



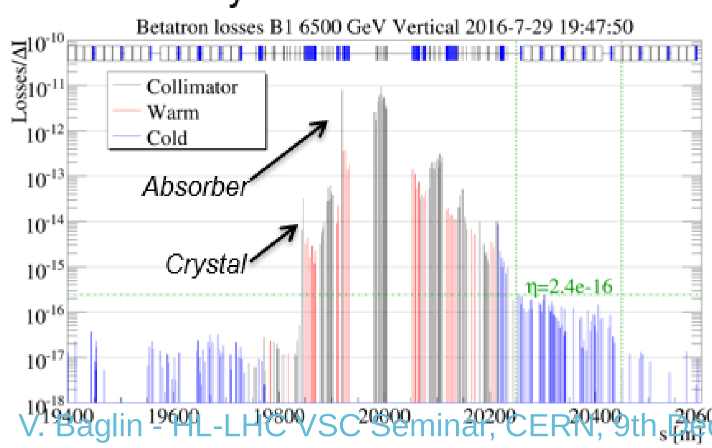
S. Redaelli

- Two crystals are already installed in LSS7 (more to come), equivalent bending radius is 310 T at 7 TeV.
- Channelling observation with protons and ions beams
- A factor ~ 10 better cleaning that actual collimation system is observed with crystals

Standard collimation



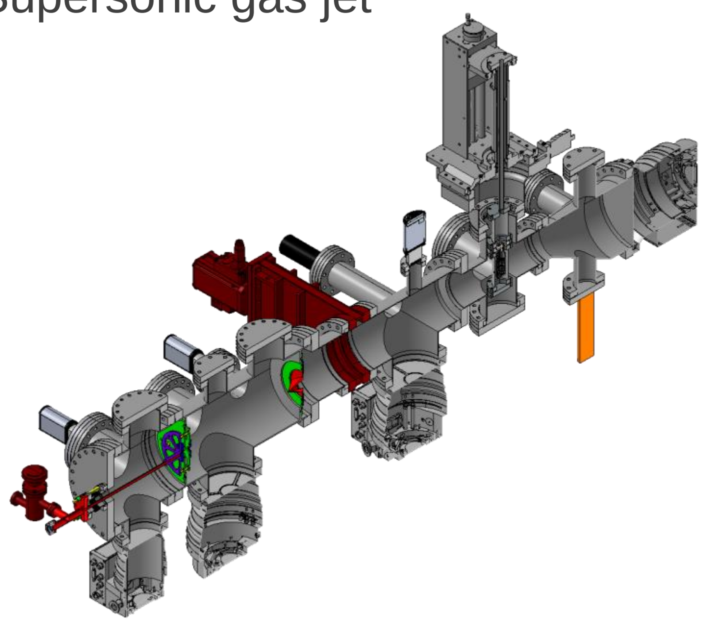
Crystal collimation



D. Mirarchi

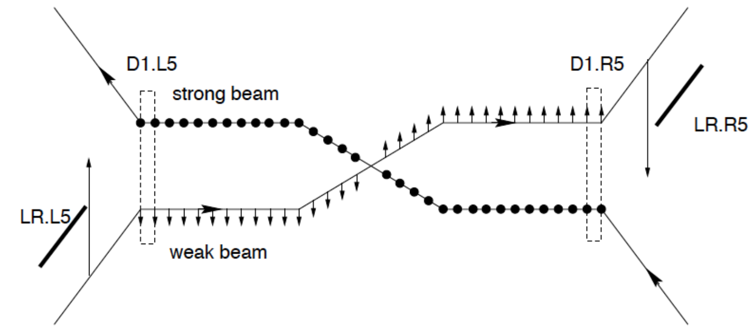
WP13 studies: gas jet monitor & BBLR

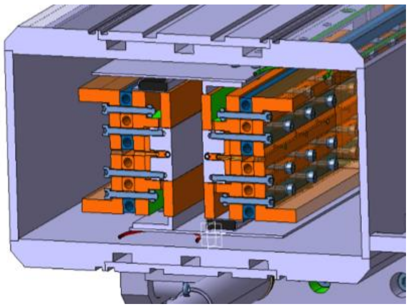
- Aims to provide a non-invasive method of aligning electron beam devices with the proton beam
- Application with hollow electron lens or long-range beam-beam compensator
- First design done
- Supersonic gas jet



R. Jones

- Long range beam beam compensation study
- Wire embedded TCTW
- Installed this EYETS in IR5
- 350 A in the wire





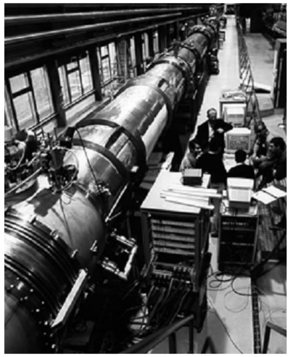
A. Rossi – WP5

WP18: String Test in SM18

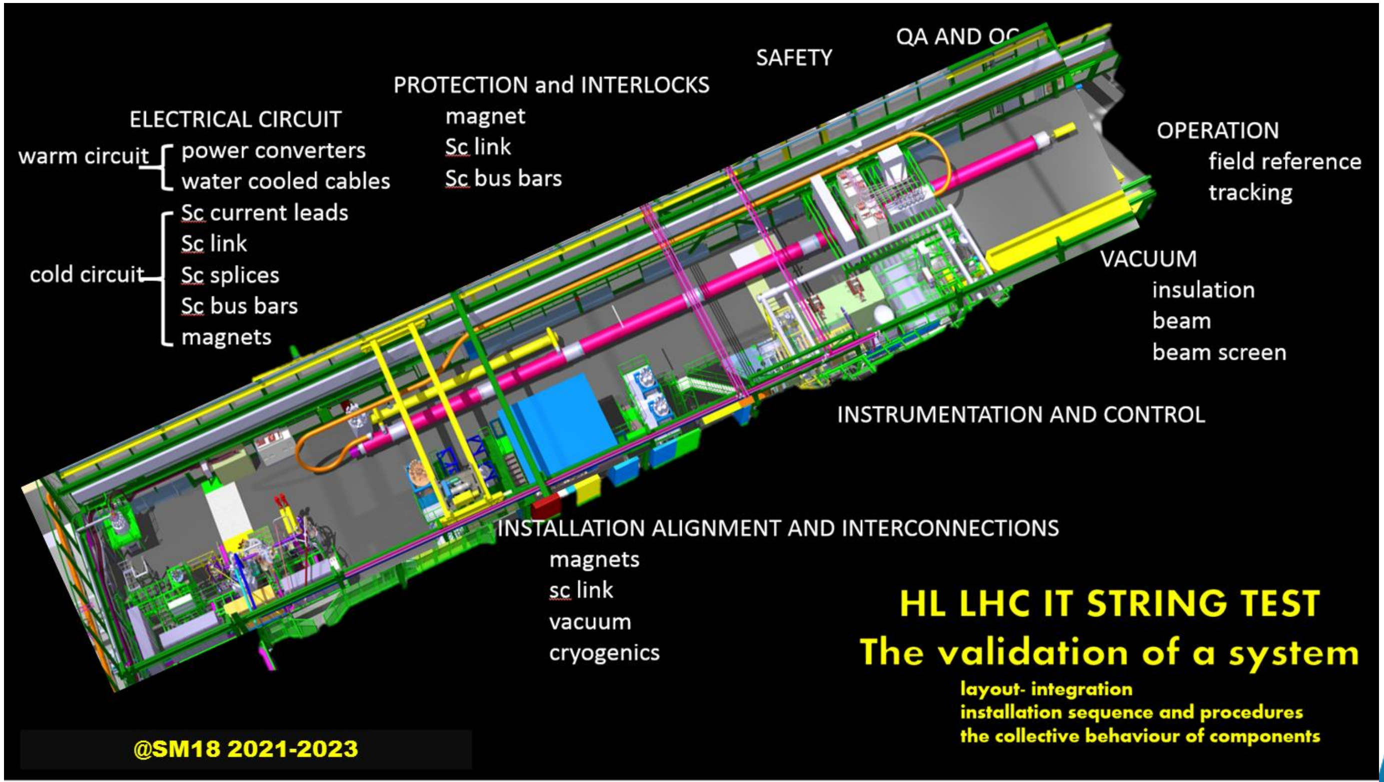
- Validation of: cryogenics, vacuum, quench and protection, powering, accelerator relevant operation etc.

- 2021-2023

1994-1998 STRING-1
ONE **HALF** LHC CELL
3 MB (10 m) + 1 MQ



2000-2004 STRING-2
ONE **FULL** LHC CELL
6 MB (15 M) + 2 MQ + CORRECTORS



M. Bajko

6. Summary

Summary

- The HL-LHC baseline has significantly evolved since 2015

- The design of the HL-LHC vacuum system baseline is progressing very well.
  - Cold bore and beam screen design to be frozen soon, for production in 2018.
  - Interconnects and cold warm transitions to be designed, for production in 2019.
  - Performance evaluation at cryogenic temperature of a-C shall continue, evaluation of LESS shall start.
  - Vacuum layout definition to continue.

- Many activities during LS2 are linked to the HL-LHC project
  - Production of in-situ coating is on good track for implementation during LS2

Acknowledgments

- This presentation reflects the work of many people from the group. Particular credits should go to:

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Thank you for your attention