



HL-LHC Status at CM # 8

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HL-LHC Project Leader

CERN – 15 March 2018



Goal of HL-LHC as fixed in 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 $L_{\text{peak}} = 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ **with levelling**, allowing:

An integrated luminosity of **250 fb⁻¹ per year**, enabling the goal of $L_{\text{int}} = 3000 \text{ fb}^{-1}$ twelve years after the upgrade.

This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

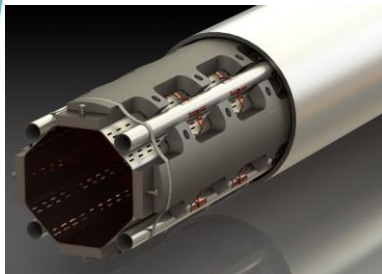
Ultimate performance established 2015-2016: with same hardware and same beam parameters: use of **engineering margins**:

$L_{\text{peak ult}} \cong 7.5 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and **Ultimate Integrated** $L_{\text{int ult}} \sim 4000 \text{ fb}^{-1}$

LHC should not be the limit. would Physics require more...

Project approved by CERN Council in June 2016

Technology landmarks



CIVIL ENGINEERING
2 new caverns and two new 300-metre service galleries, two new large shafts;
10 new technical buildings on surface in P1 and P5 (ATLAS and CMS)



"CRAB" CAVITIES
8 superconducting "crab" cavities for each of the ATLAS and CMS experiments to tilt the beams before collisions.



BENDING MAGNETS
2 pairs of shorter and more powerful dipole bending magnets to free up space for the new collimators.



FOCUSING MAGNETS
12 more powerful quadrupole magnets for each of the ATLAS and CMS experiments, designed to increase the concentration of the beams before collisions.



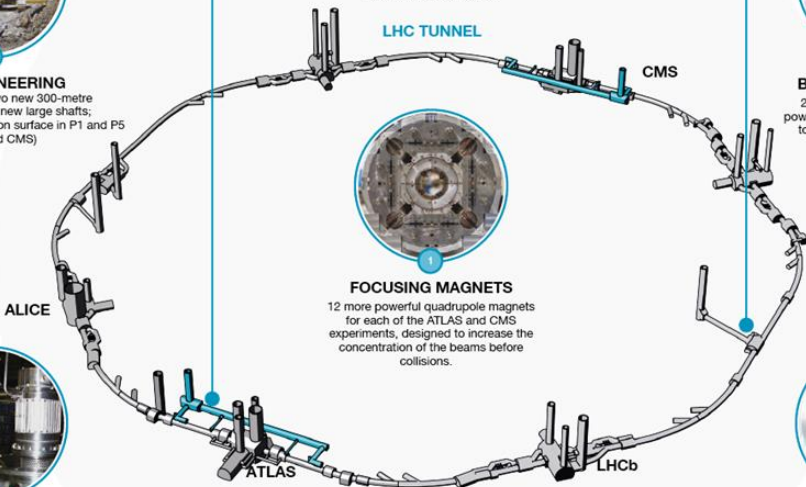
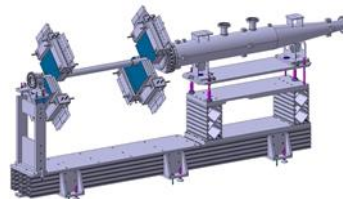
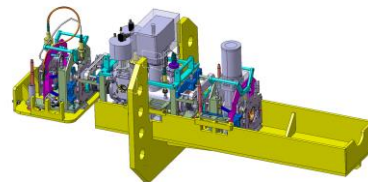
CRYOGENICS
2 new large 1.9 K helium refrigerators for HL-LHC near ATLAS and CMS



SUPERCONDUCTING LINKS
Electrical transmission lines based on a high-temperature superconductor to carry current to the magnets from the new service galleries to the LHC tunnel.



COLLIMATORS
15 to 20 new collimators and 60 replacement collimators to reinforce machine protection.



High Luminosity LHC Project



¹ In kind contributions

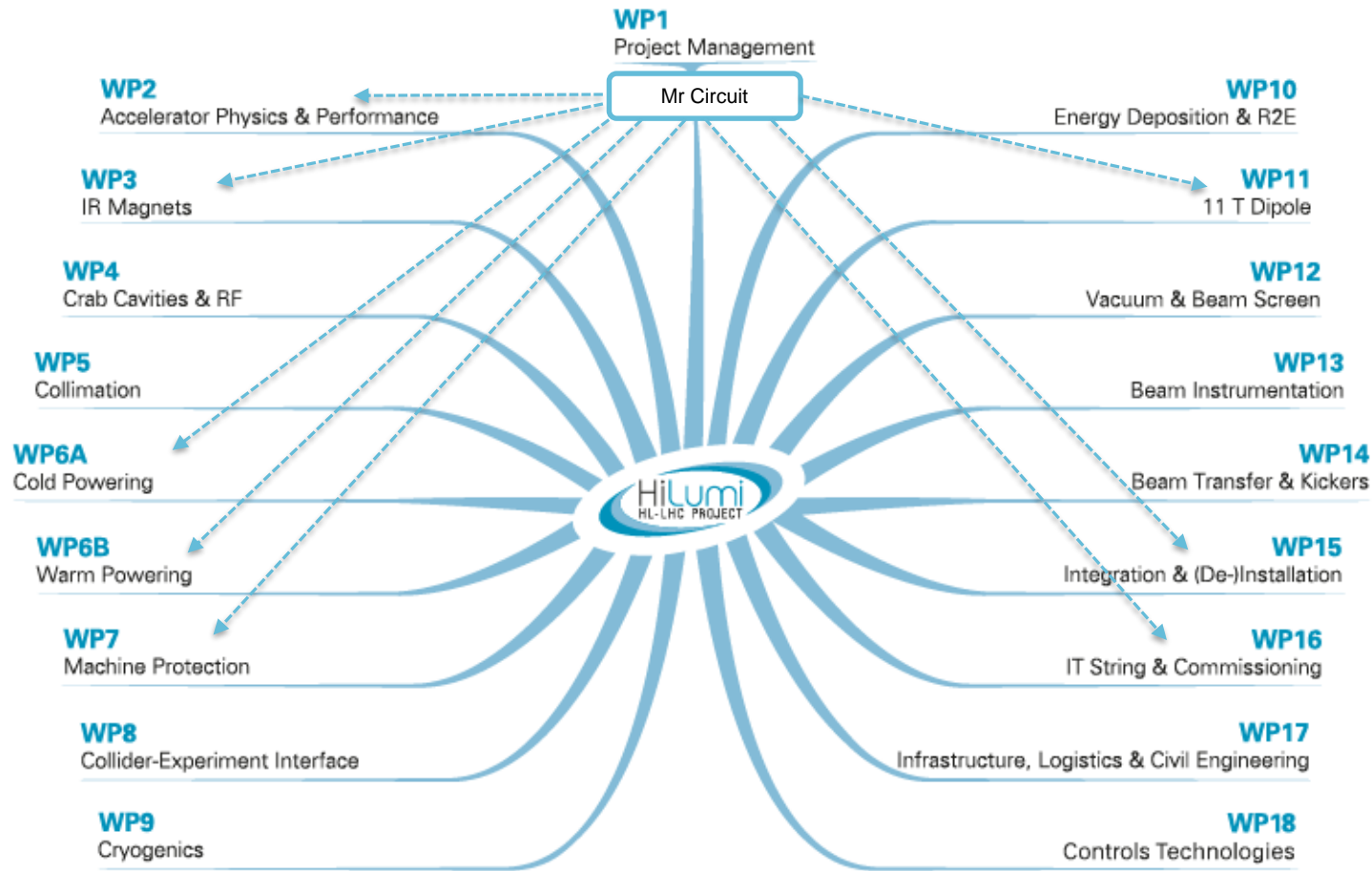
² INFN Directorate

³ INFN Milano LASA

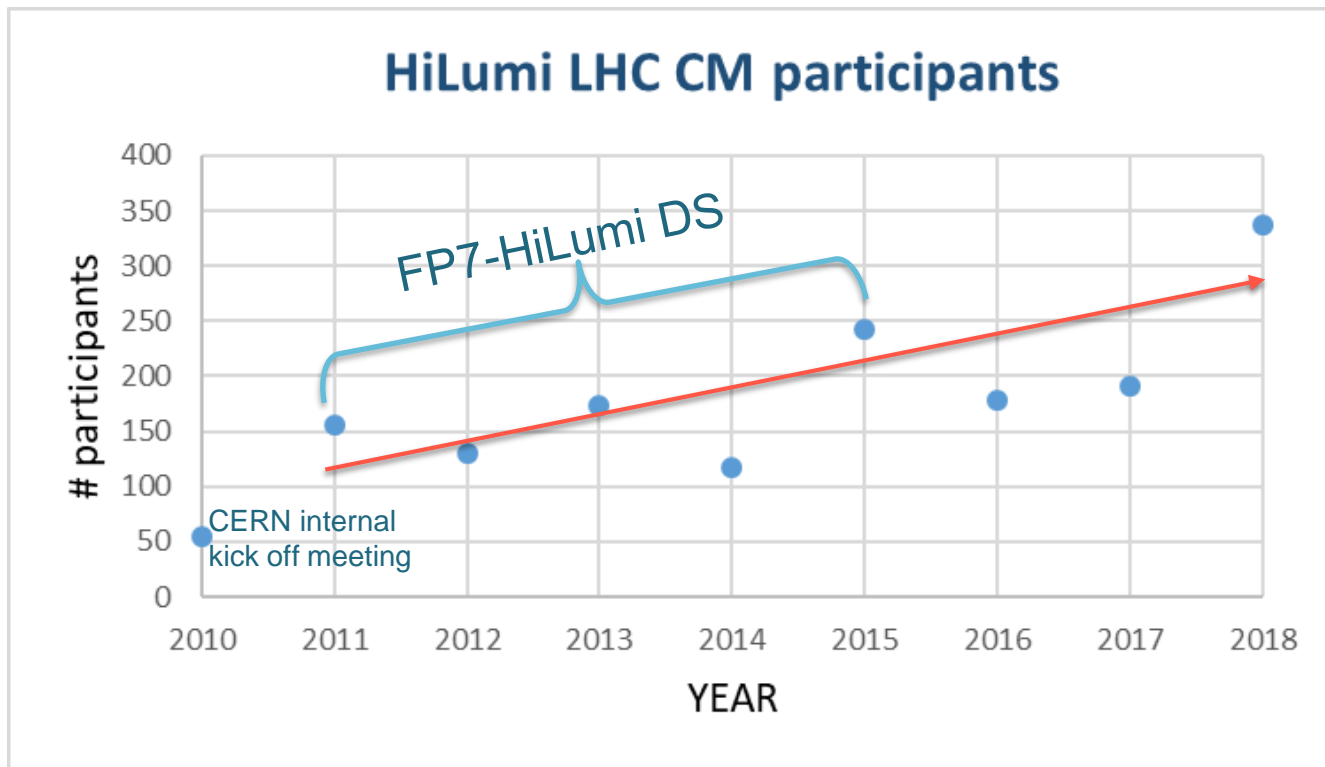
⁴ INFN Genova

See Hilumi web page

<http://hilumilhc.web.cern.ch/>



Participants HiLumi Collaboration Meetings



Project management full steam ahead

Technical Coordination Committee

- Installed in 2016 (replacing TC and PLC of HiLumi DS)
- Chaired by O. Bruning
 - M. Zerlauth, Y. Papaphilippou, A. Apollonio
- **In total 59 meetings (20/y)**
- **267 presentations**
- A few critical decisions 2018
 - Optics configuration change, new perf. Table
 - ATLAS shielding, CMS beam pipe support
 - Circuit layout and local 120 A CL
 - Cold Diodes (subj.to final confirmation)
 - FQ of IT quads \leftrightarrow HOC magnet length
 - Loss of reversibility (no second set CC)
- Average attendance: >35 people

PSM Project Steering Committee

- Started in 2017
- Scope: review of each WP by HLPO with GL & Dep. Head concerned, of: budget, MS & DLV, procurement and plan
- With template
- **So far 67 PSMs (~1/week)**
 - Max 5 times WP3-6A-8-11-15
 - Min 1 for WP18 (recent set up)

Production Readiness Reviews & Manufacturing Reviews (Quality)

- **PRR** – for each equipment (~20) is assessed:
 - Scope of work: is there a clear definition and clear interfaces?
 - Procedures, construction specifications, executive drawings: are all in approved status, verified by due authority, and well documented?
 - Is Quality Assurance correctly in place: procedures, documentation, check/holding points, etc.?
 - Components, Assembly tools, Availability, qualifications
 - Production planning robustness.
- **MR** – to ensure the quality is kept during production:
 - Adequateness and validity of certifications
 - Correct implementation and application of QP and MIP
 - Site organization (manufacturing, storage of components, finished product)
 - Implementation of document managing system
 - Actual training for documentation and of personnel
- Review panel with few permanent members and a few appointed *ad hoc* :
- Chair PRR: D. Perini (EN/MME); **Reviewed**: TDIS, TANB, 11 T dipole coils and cold mass
- Chair MRR: I. Bejar Alonso (HLPO); to start in **January '19** (TDIS, DQW-CC, Collimators...)
- **When the case, organized with Collaborating Institutes for in-kind**



BINP+...
Absorbers
CC ampli.
e-lens?...

TRIUMF
CC
cryostat

IHEP
CCT
corrector

CERN-
KEK R&D

KEK D1
design and
constru
ction

DOE
Nb3Sn
R&D

LARP
generic

LARP
HiField
quads

LARP
Demo

FP6
CARE
Nb3Sn

FP7
EuCARD
HiField
Dip

**FP7 DS
Hi-Lumi LHC**

FP7
sLHC PP
(INJ)

sLHC INJ
implem.

Project DS started

today

**HL-LHC
Construction**

Injector
upgrade

**HL-LHC
install.& comm.**

2000

2005

2010

2015

2024

Non binding MoU
for HL-LHC

The time for
“booking” in-kind
contributions is
shrinking!
Certain items
require a long
qualification
process for
companies and
also for Labs

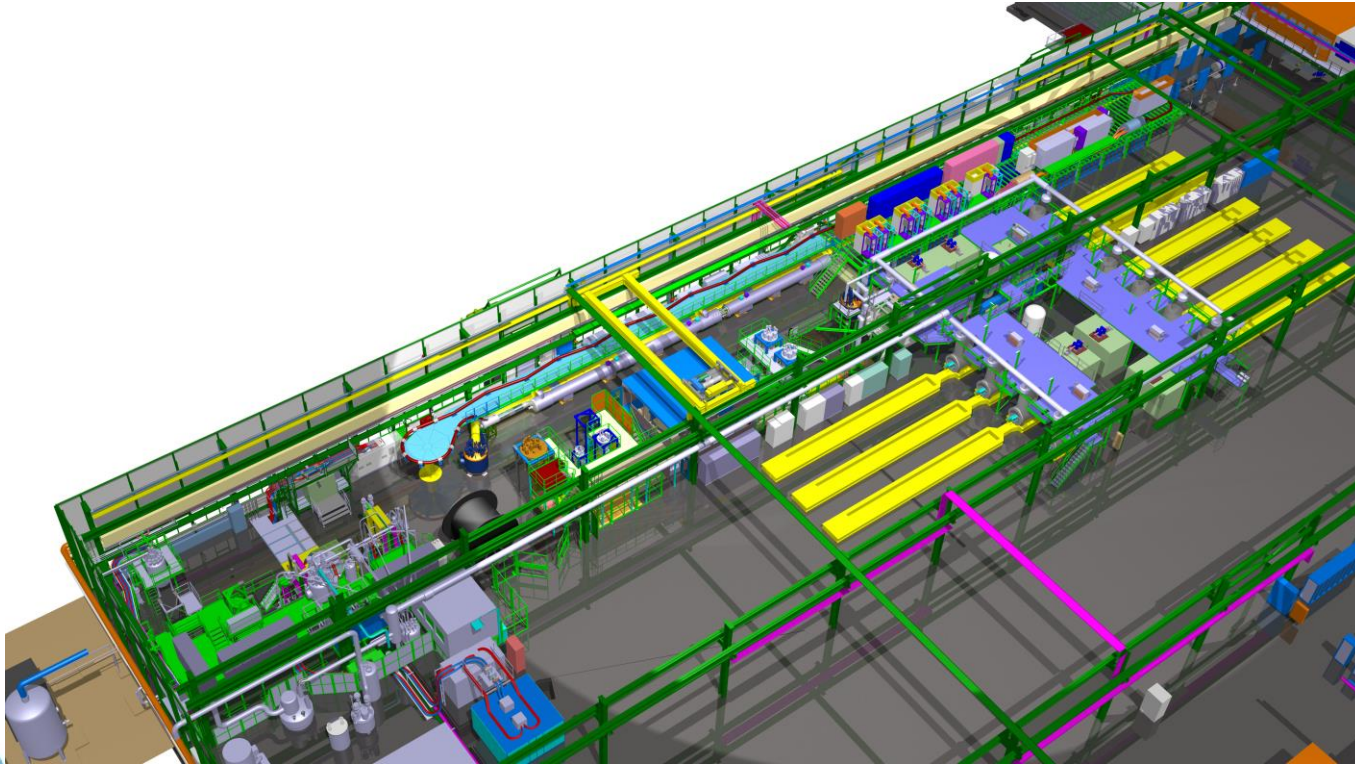


Recent signed collaborations and in-kinds



The HL-LHC IT STRING in the crowded SM18

The String gives the clock to many WPs!



Recent internal review of the IT string

HL LHC IT STRING is foreseen to *study the collective behaviour* of the IT zone

- ☐ The main components are: Q1-D1 with complete cold and warm powering
- ☐ The test stand will be integrated into SM18
- ☐ Infrastructure upgrade is well advanced
- ☐ **P5L** will be reproduced without slope
- ☐ **180 quenches/or power aborts** are planned
- ☐ **400 W** heat extraction possibility exist

Talk of Marta Bajko THU morning

ID CARD of the TEST STAND: HL-LHC IT STRING

TEST Facility LOCATION: SM18 (b. 2173)

TEST DATE: 2021-2022

OPERATIONAL TEMPERATURE: 1.9 K

OPERATIONAL CURRENT: Ultimate (108% $I_{\text{nominal}} = 18 \text{ kA}$)

MAGNETS: Q1, Q2a, Q2b, Q3, CP, D1

COLD POWERING: SC link, HTS leads DFH and DFX,

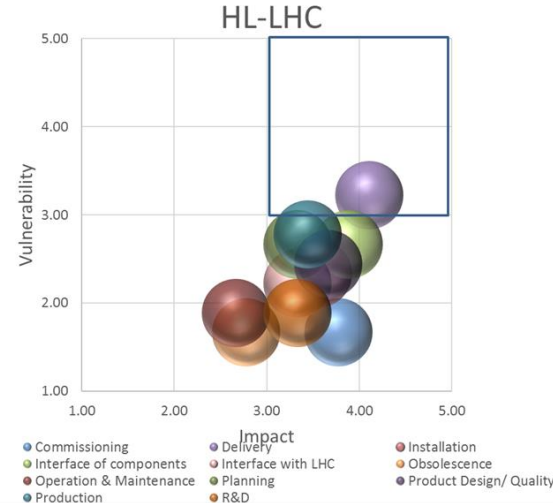
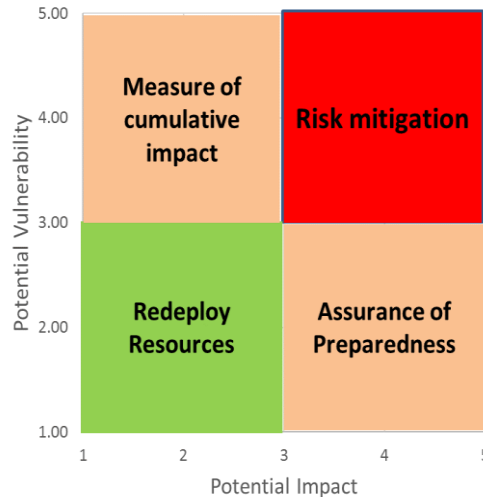
WARM POWERING: 1 x PC for 18 kA + 3 Trim for Q1-Q3 + 6 x 2 kA + 1 x 12 kA + 9x 0.1 kA + WCC

PROTECTION: CLIQ and QH ; EE where is baseline

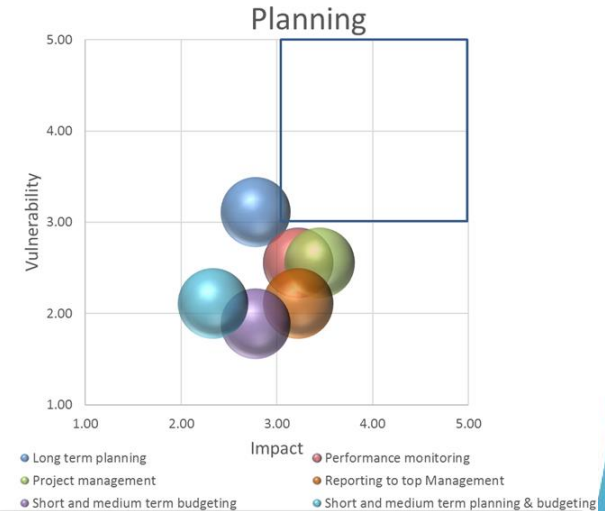
Risk register:new feature from 2017

Are we too optimists?

See presentation by I. Bejar Alonso on Thursday



Risks related to Delivery on mission



Risks related to Strategy & Planning

Main changes affecting Baseline since 2015!

From C&S Review 2015 to C&S Review 2016

- **New WP** : WP18 - Control Technologies
 - Confirmation of dedicated resources to WP16 – Hardware Commissioning, including “**String test**”
- Main baseline changes:
- WP3: **keep** 70 mm aperture Q4 magnets (**MQY**) in the HL LHC (MQYY);
 - WP3: decision to adopt **laminated structure** in the HL LHC
 - WP4: reduction by **half of the** cost
 - WP5: **reduction of** cost
 - **collimator**
 - **Rebaselining of August 2016 to recover 120 MCHF**
(re-evaluation of C.E. – extra cost and extra-scope - and T.I.)
~80 MCHF on WP1-16 by re-scoping ~ 40 MCHF on C.E.-T.I.
Full performance all recovered (but less margin!)
 - **‘double-decker’ solution** for
 - **cryostats** around LHC-P7 (2 sets of dipoles) and connection cryostats in
 - **cryostats**;
 - **inside the Budget At Completion of a new cost estimate (increased!)**, as provided during an
 - **C&S review of this WP in May 2016.**
- AND
- CERN Accelerator **Master Schedule change**: Long Shutdown 2 delayed by 6 month and extended by 6 month. Long Shutdown 3 delayed by one year while maintaining its duration.

Main changes affecting Baseline since 2015!

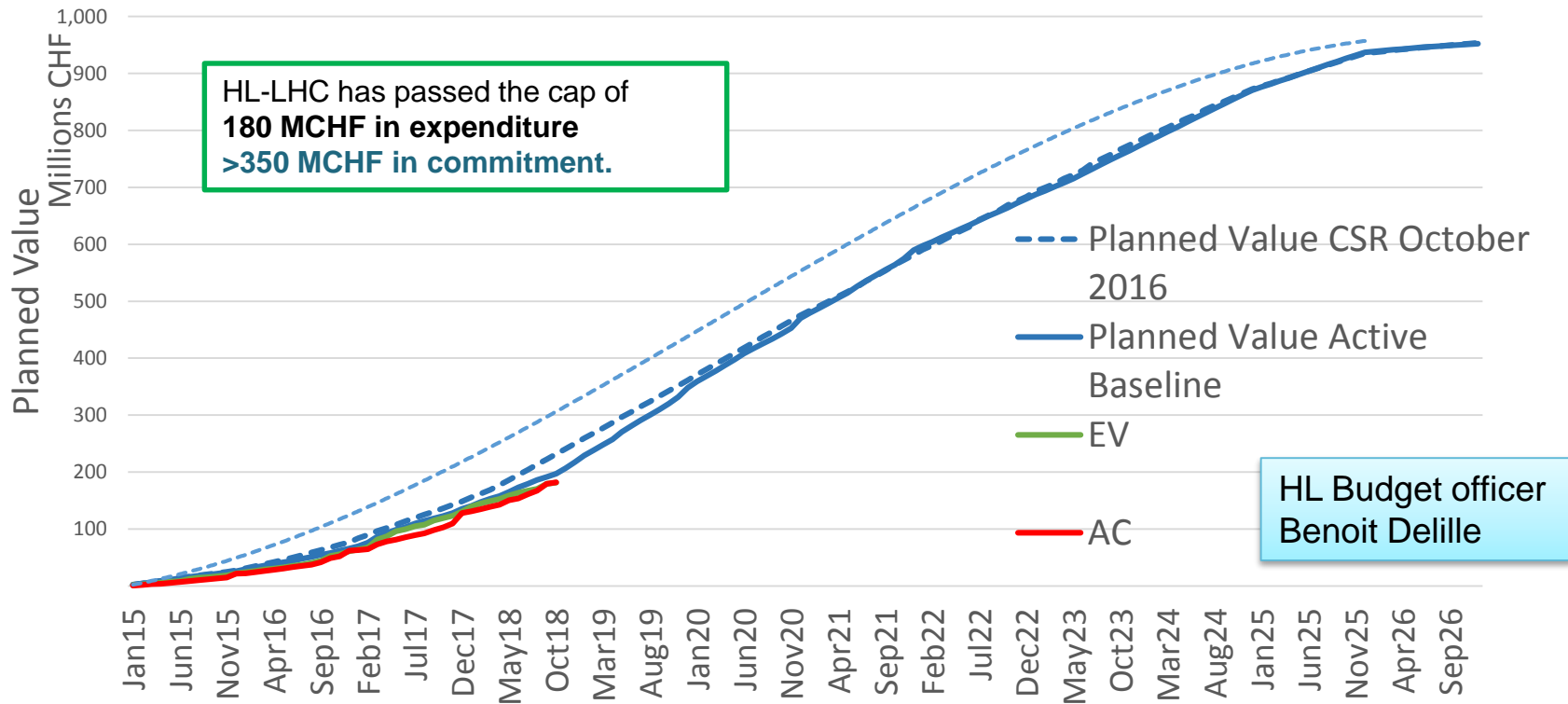
From C&S Review 2016 to C&S Review 2018

Main baseline changes:

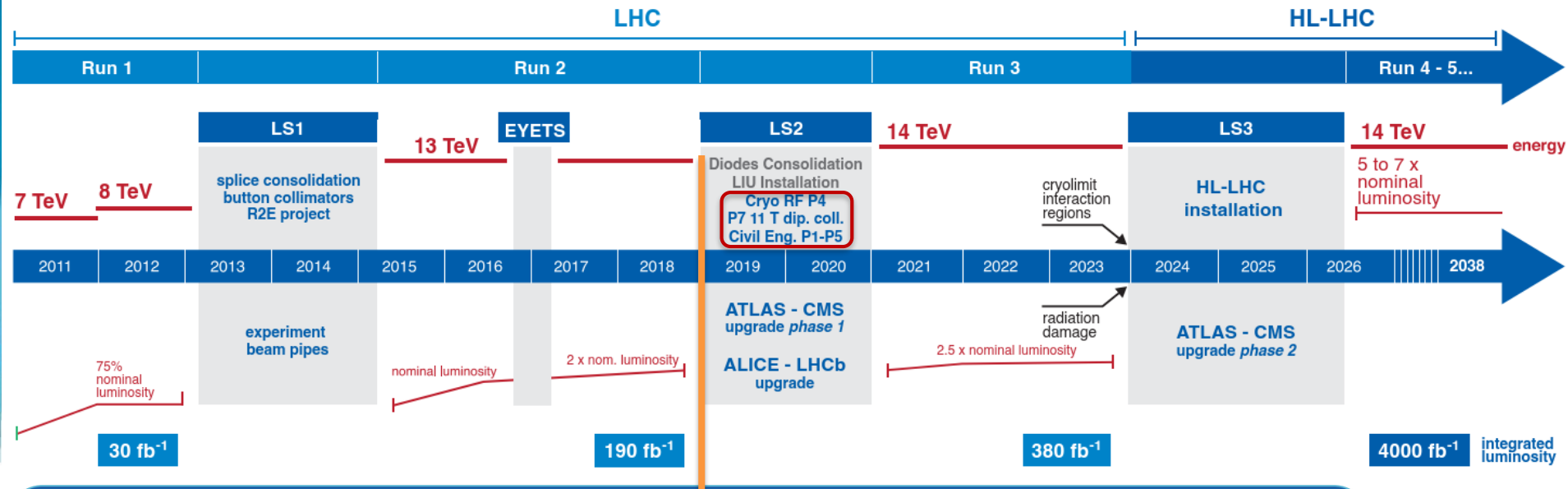
- WP3: Additional proto for orbit correctors, **no PIT R&D**, reduced scope for Warm Magnets
- WP5: Contribution to **low impedance material in primary** collimators
- WP6A: Link **design change** (R&D needs), additional copper stabilizer
- WP6B: New R2E 120A converters and adding **redundancy**
- WP7: **R&D on cold diodes**
- WP9: New refrigerator at LHC P4 replaced by **upgrade of existing refrigerator** + purchase of mobile refrigerator for RF (**Big saving! WP9**)
- WP11: **No PIT R&D**, **No PIT prototype**, No tooling in industry
- WP12: New Tungsten supporting system (impact of CLIQ), **coating of Q5&Q6 during LS2**, alignment capabilities of +/- 2.5mm
- WP13: Implementation of final design on BGV proto, **no cryo BLMs**
- WP14: **new design for MKI** beam screens
- WP17: **Cancellation of activities** for CE, CV, EL **for LHC-P4** (see WP9)

EVM & Planned value evolution since 2015

950 MCHF (Material)



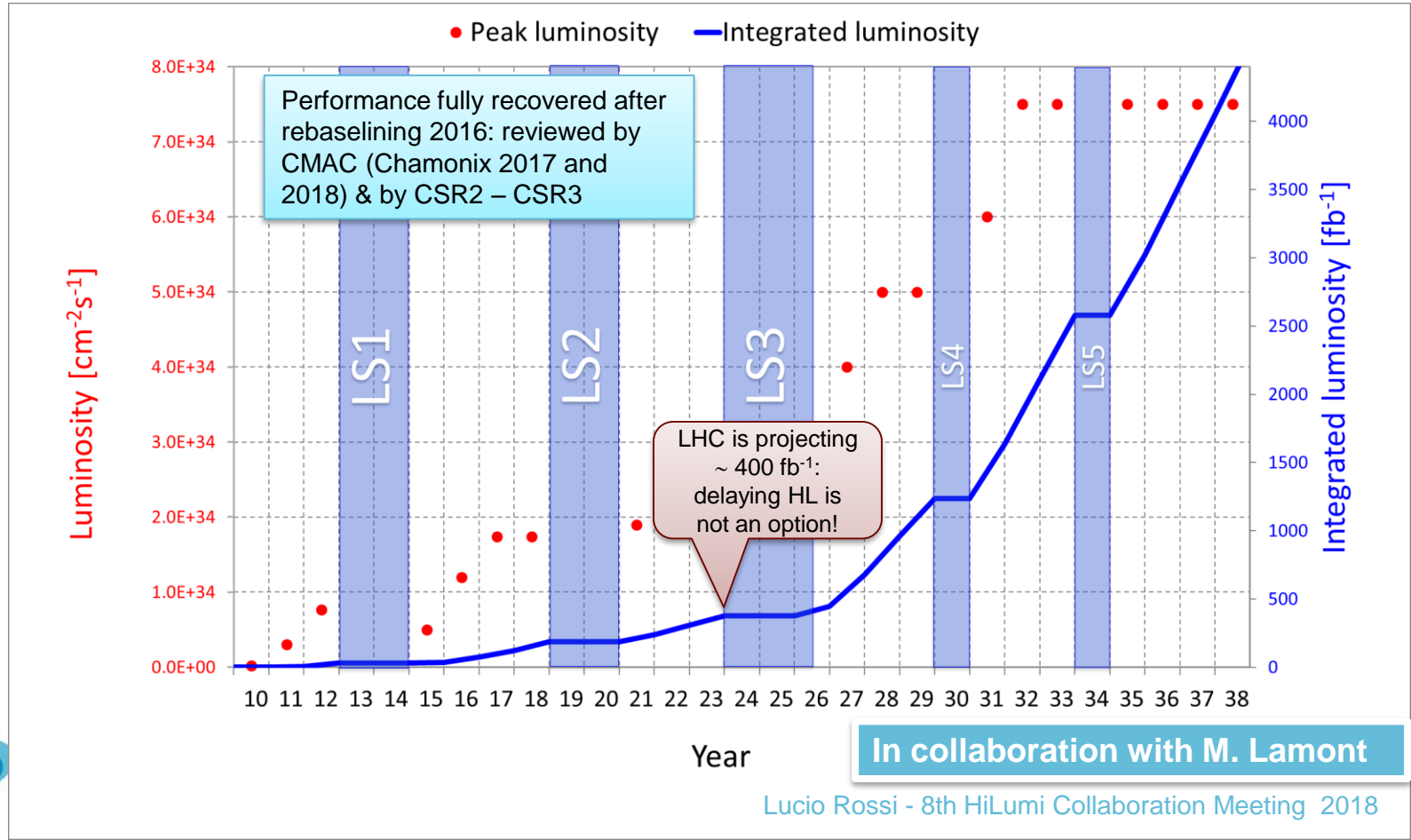
LHC / HL-LHC Plan



HL-LHC established in summer 2010 in view of FP7-Hilumi LHC DS
 Installation of equipment will start in 2024 and HWC in 2026; today Oct. 2018 we are
HALF WAY through the project duration!

DWARE

ULTIMATE HL-LHC performance



Updated table of parameters

| Parameters | Nominal LHC (Design report) | LHC 2018 max values | HL-LHC (standard) | HL-LHC 8b+4e ¹² | HL-LHC (Ultimate) |
|---|--------------------------------|------------------------|----------------------|-------------------------------|----------------------|
| Beam energy in collision [TeV] | 7 | 6.5 | 7 | 7 | 7 |
| N _b | 1.15E+11 | 1.15E+11 | 2.2E+11 | 2.2E+11 | 2.2E+11 |
| n _b | 2808 | 2556 | 2760 | 1972 | 2760 |
| Number of collisions in IP1 and IP5 ¹ | 2808 | 2544 | 2748 | 1967 | 2748 |
| N _{tot} | 3.2E+14 | 2.9E+14 | 6.1E+14 | 4.3E+14 | 6.1E+14 |
| beam current [A] | 0.58 | 0.52 | 1.1 | 0.79 | 1.1 |
| x-ing angle [μrad] | 285 | 320 ==> 260 | 500 | 470 ¹⁰ | 500 |
| beam separation [σ] ¹¹ | 9.4 | 10.3 ==> 6.8 | 10.5 | 10.5 ¹⁰ | 10.5 |
| β* [m] | 0.55 | 0.30 ==> 0.25 | 0.15 | 0.15 | 0.15 |
| ε _n [μm] | 3.75 | 2 ==> 2.5 | 2.50 | 2.20 | 2.50 |
| r.m.s. bunch length [m] | 7.55E-02 | 8.25E-02 | 7.61E-02 | 7.61E-02 | 7.61E-02 |
| Total loss factor R0 without crab-cavity | | | 0.342 | 0.342 | 0.342 |
| Total loss factor R1 with crab-cavity | | | 0.716 | 0.749 | 0.716 |
| Virtual photon flux | | | 1.70E+35 | 1.44E+35 | 1.70E+35 |
| Number of protons per bunch | 1.00E+34 | 2.00E+34 | 5.0E+34 ⁵ | 3.82E+34 | 7.5E+34 ⁵ |
| Number of crab-cavities for HL-LHC ⁸ | 27 | 55 | 131 | 140 | 197 |
| Proton density of events [event/mm] (max over stable beams) | 0.21 | 0.38 | 1.3 | 1.3 | 1.9 |
| Leveling time [h] (assuming no emittance growth) ^{8, 13} | - | | 7.2 | 7.2 | 3.5 |

Flat optics very promising!!
 HiLumi Plan B that may be «upgraded» to main
 See talk of S. Fartoukh Thu morning

Avancement from 7th Collaboration Meeting of Madrid

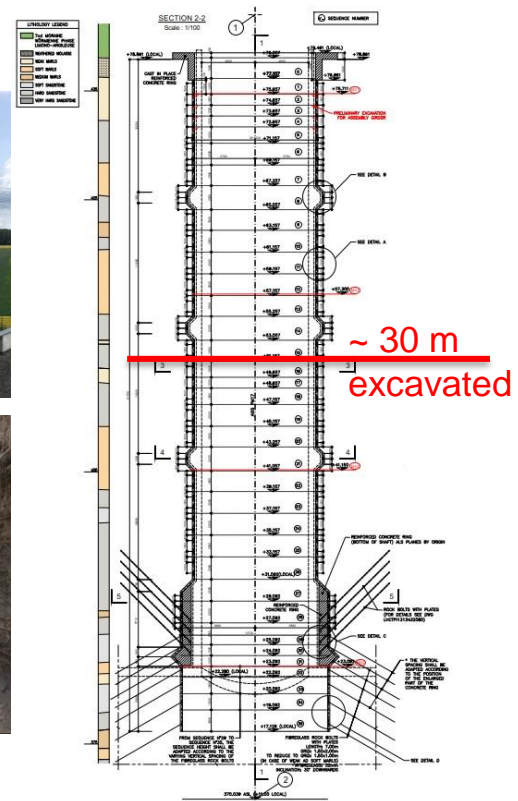
- CC into SPS with new cryogenic infrastructure and first proton crabbing! Mission accomplished!
- USA: good quench performance of 1st Nb₃Sn IT QUAD Proto; Second proto, full length 4.2 m IT quad under test; Coils for series started.
- CERN 7.2 m IT near completion; starting coils for series!
- 1st proto 5.5 m 11 T dipole tested, **under revamping (one coil not good)!**
- 2 exceptional good short magnets in Nb₃Sn (11 T and QXF)
- Low impedance collimator proto tested in LHC!

Avancement from previous CM – 2

Two large C.E. contracts signed - groundbreaking 15 June 2018!!!

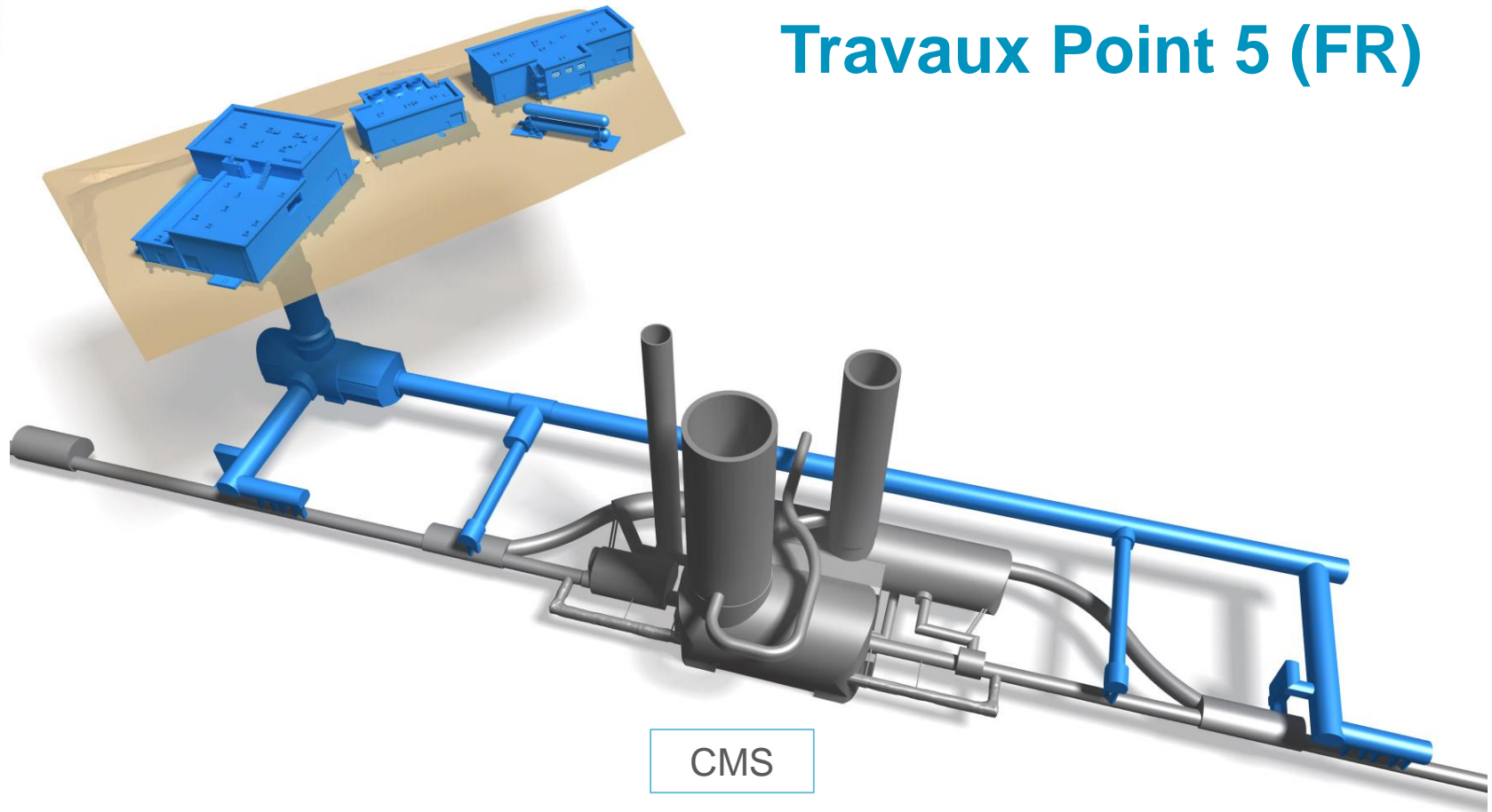


WP17.1: Civil-engineering work at Point 1



See specific presentation by P. Mattelaer on Wednesday
Technical visit on Friday

Travaux Point 5 (FR)

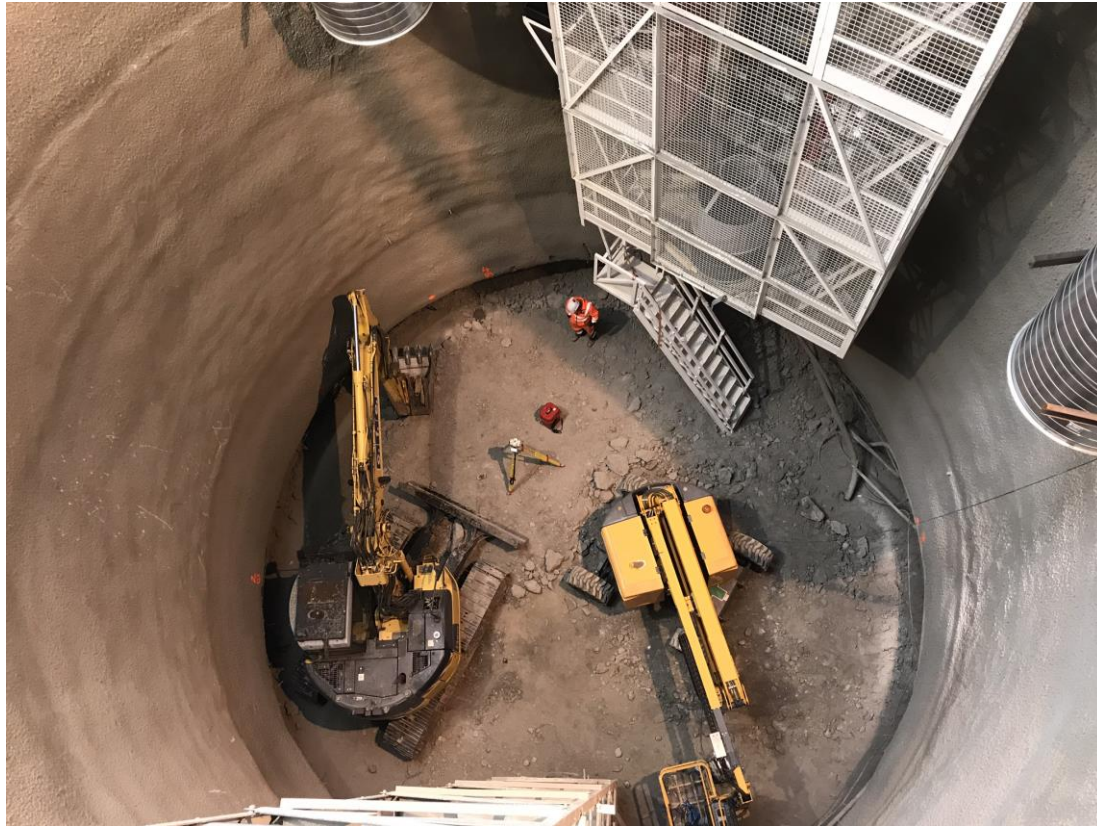


CMS

Travaux Point 5



Chantier Point 5 : almost 25 m excavated

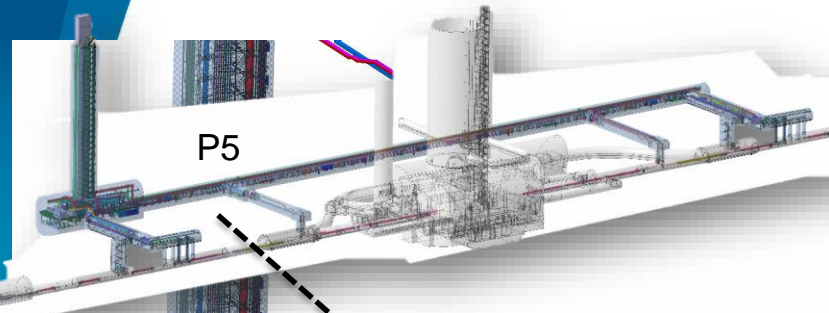


Avancement from previous CM – 3

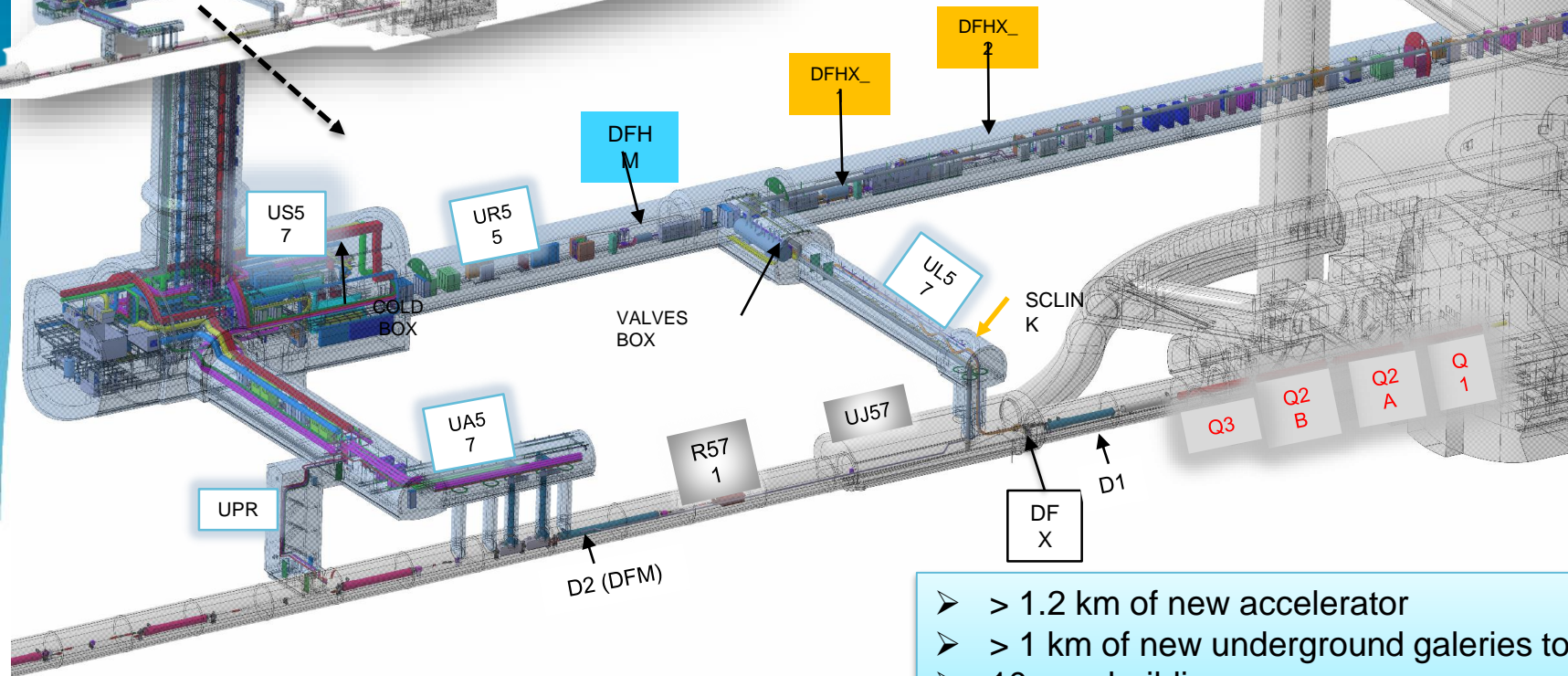
- First important contracts for HiTech equipment construction issued!
 - **All Nb₃Sn conductor placed: at budget cost (RRP)**
 - Industrial service for 11 T collared coils : high overcost
 - **CC DQW, (dressed cavities) supply (pre and series):** moderate undercost
 - Low impedance collimators (first batch for LS2): moderate undercost
- Launching last purchase of MgB2 and all cabling for SC links!
- **Simple 2-wall cryostat validated (only 1.5 W/m losses!)**
- Last call for in-kinds! And securing it. All final opportunity for options

Avancement from previous CM – 4

- Final optimization approved, or almost:
 - Magnet powering & circuits
 - Integration
 - ***Optimization of MS (full remote alignment; simplification of correctors; shorter cryogenics...) Task force P. Fessia & S. Claudet, looks very positive!! See talk by P. Fessia on TUE. (and by H. Mainaud Durand on THU on remote alignment)***
 - Decision on many options (see talk by **O. Bruning** on Tuesday).
- De-installation and installation: List of tasks and costs and interfaces completed in bottom up approach
- **First «detailed» technical evaluation of de-installation (M. Modena)**
- **Readiness of installation with margin assessed (P. Fessia)**

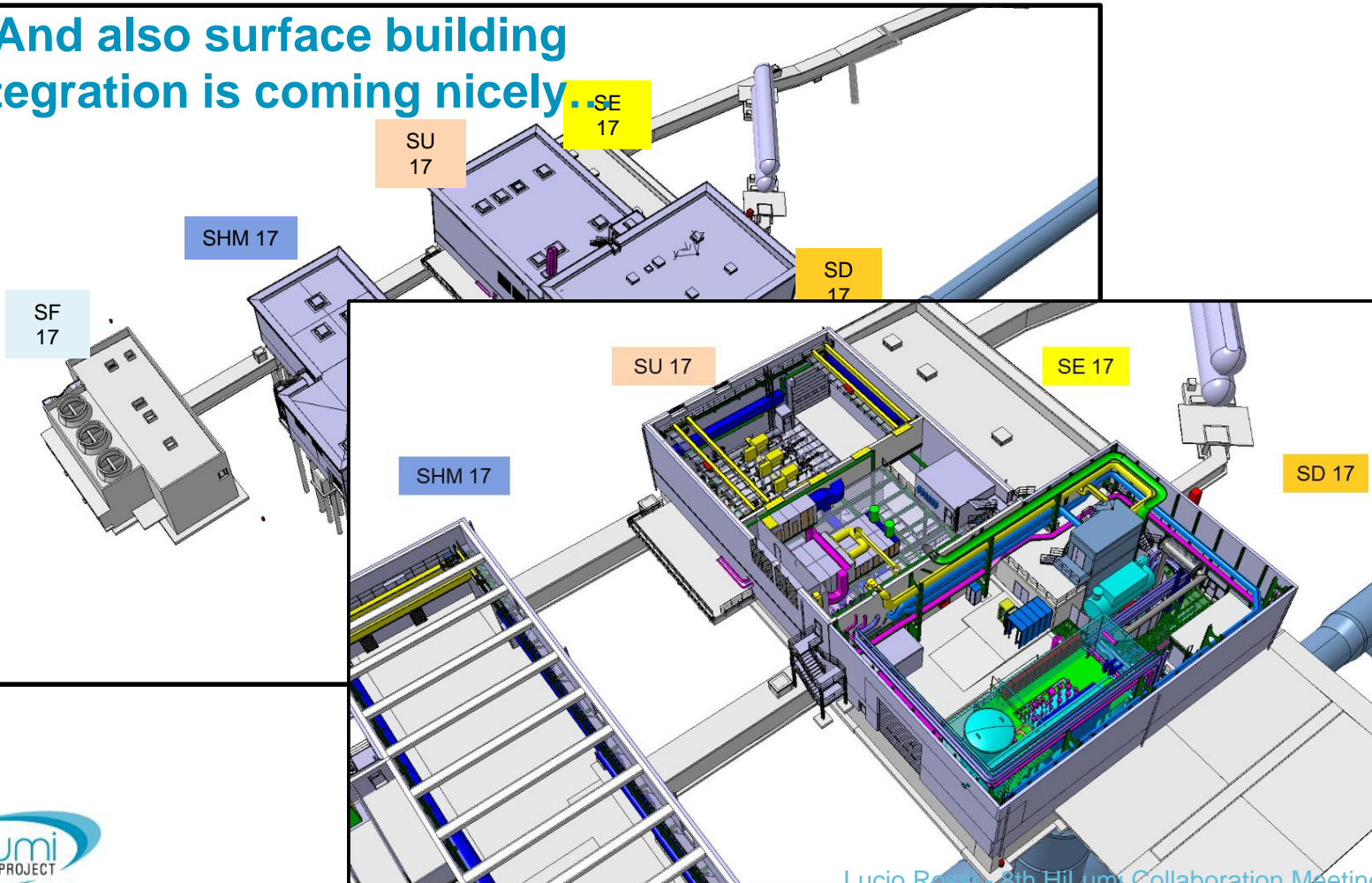


Integration: the puzzle that is – almost – solved!

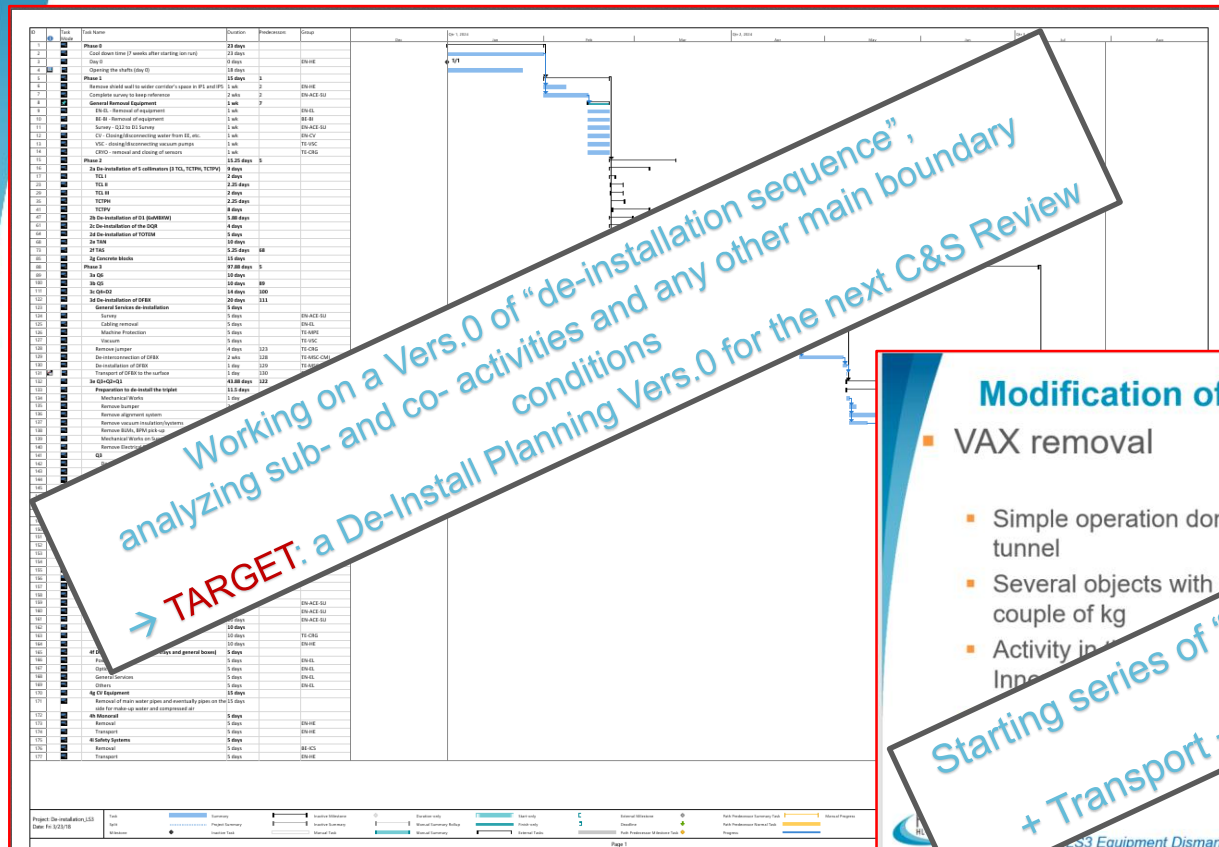


- > 1.2 km of new accelerator
- > 1 km of new underground galleries to fill!
- 10 new buildings

And also surface building
integration is coming nicely



LS3 DE-INSTALLATION studies started !



Modification of the TAS and VAX @ ATL

- VAX removal
 - Simple operation done via the tunnel
 - Several objects with a couple of kg
 - Activity in the tunnel

Starting series of “ad-hoc” meetings with main WPs

+ Transport + RP + Planning teams etc.

Which step ?

V1.4 Optics and Layout

Major changes with respect to previous baseline:

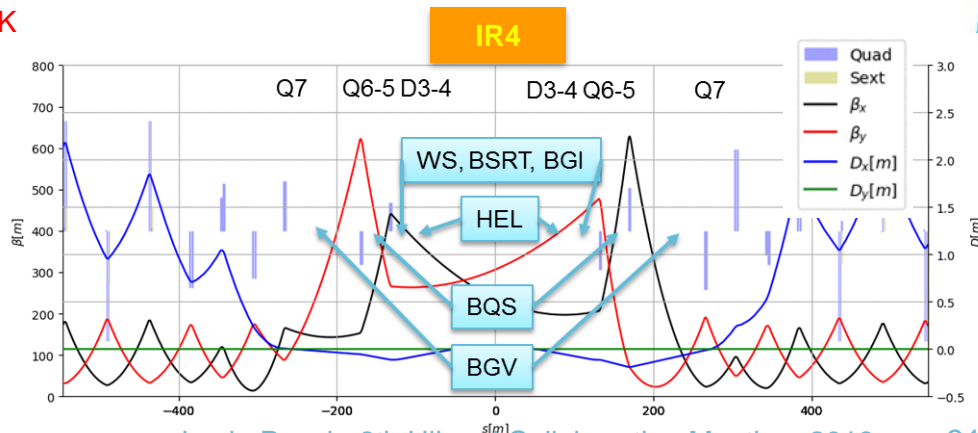
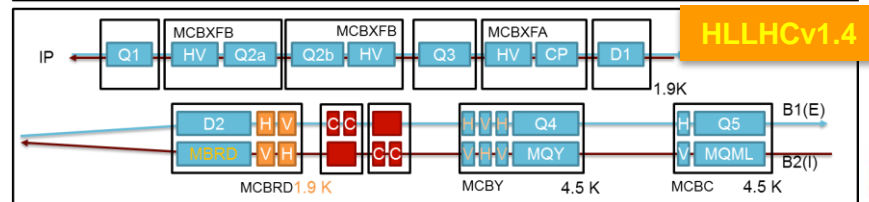
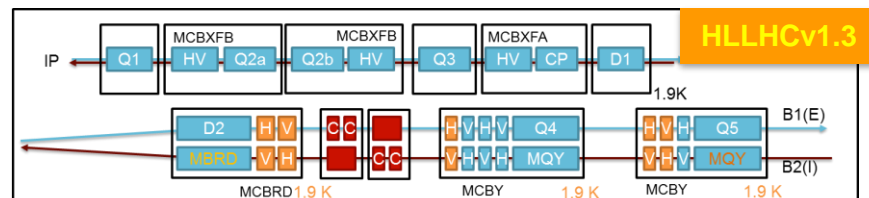
- Q4: reusing **existing cold mass (MQY+3MCBY) @ 4.5 K**
- Q5: reusing **existing cold mass (MQML+1MCBC) @ 4.5 K**
- Possible thanks to the deployment of a fully remote alignment system to be used with safe beam.**
- Apertures compatible with Round Optics with $\beta^*=15$ cm and Flat optics $\beta^*=7.5/18-30$ cm

Optics

- Improved Point 4 optics for Beam Instrumentation and e-lens.
- Further reduction of Q5.R6 required strength **to avoid 1.9 K upgrade at 7.5 TeV**

Possible optimization

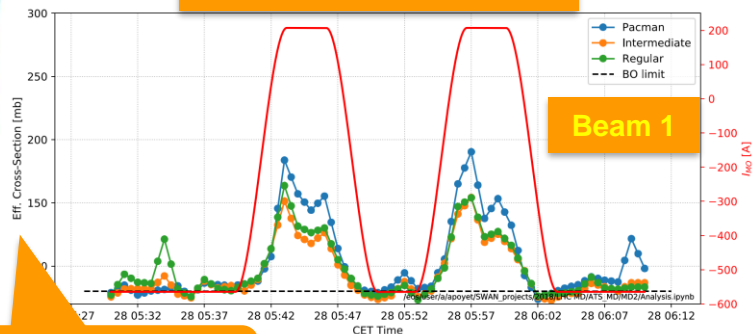
- Crab angle increase for 7 TeV operations if Q7 can reach ultimate current
- TAXN aperture could be reduced by few mm \rightarrow useful to reduce radiation to the matching section elements



BBLR compensation

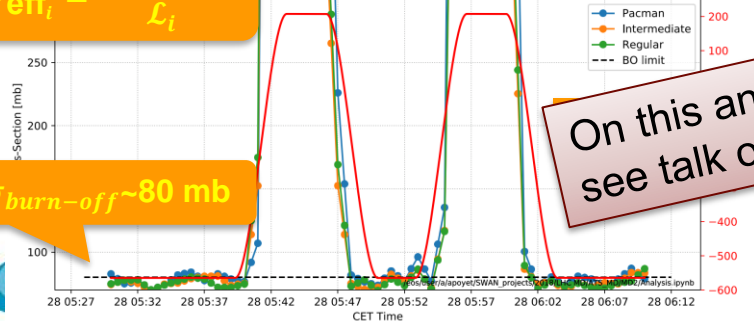
- Successful demonstration of the compensation of the Beam-Beam Long Range effects (for flat and round beams) in machine studies both with **octupoles** and **wires** in IR1 and IR5
- Important tools to further **enhance performance** (virtual luminosity, pile-up density, lifetime)

Octupoles



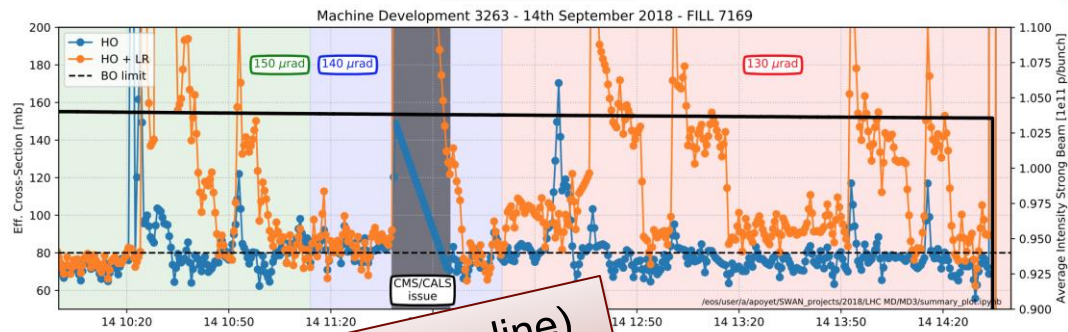
$$\sigma_{eff_i} \stackrel{\text{def}}{=} \frac{|dN_i/dt|}{\mathcal{L}_i}$$

Machine Development 2148 - 28th July 2018 - BEAM 2 - BCMS
 $\theta_c/2 = 100 \mu\text{rad}$ - $N_{B1} = 0.93 \cdot 10^{11} p$

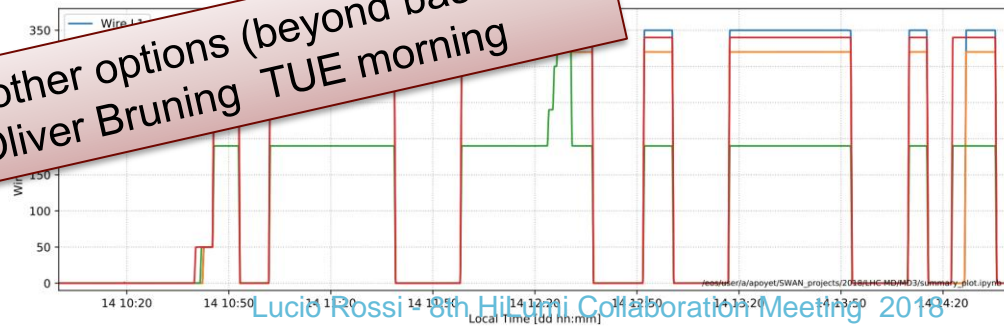


$\sigma_{burn-off} \sim 80 \text{ mb}$

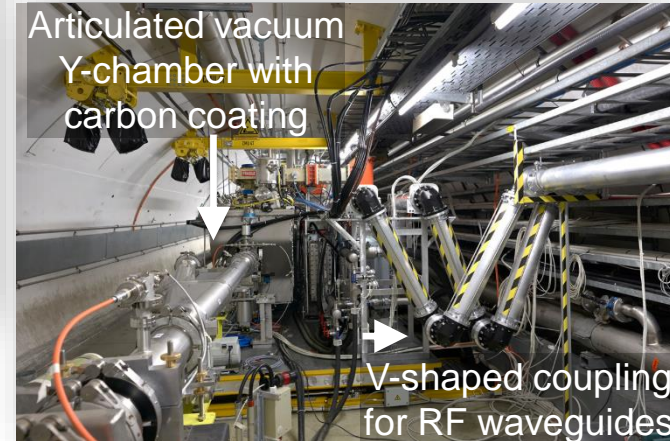
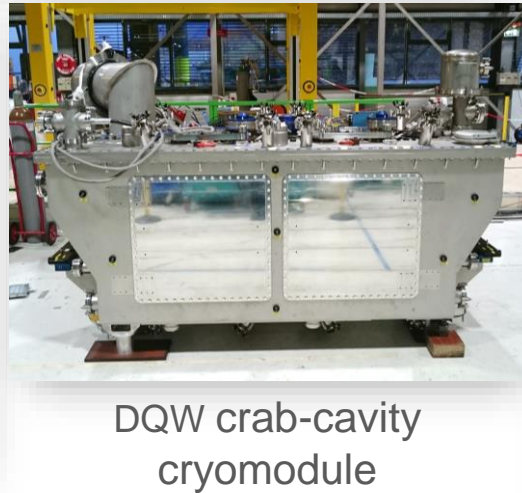
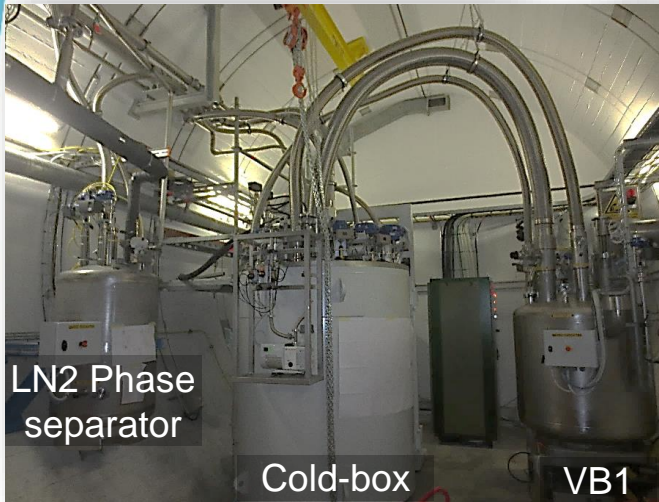
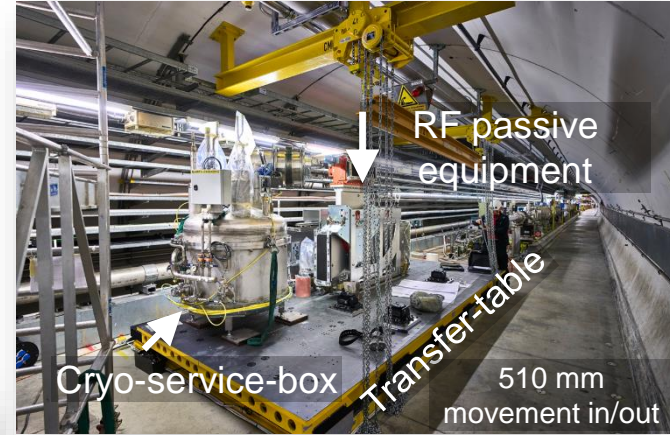
Wires



On this and other options (beyond baseline)
 see talk of Oliver Brüning TUE morning

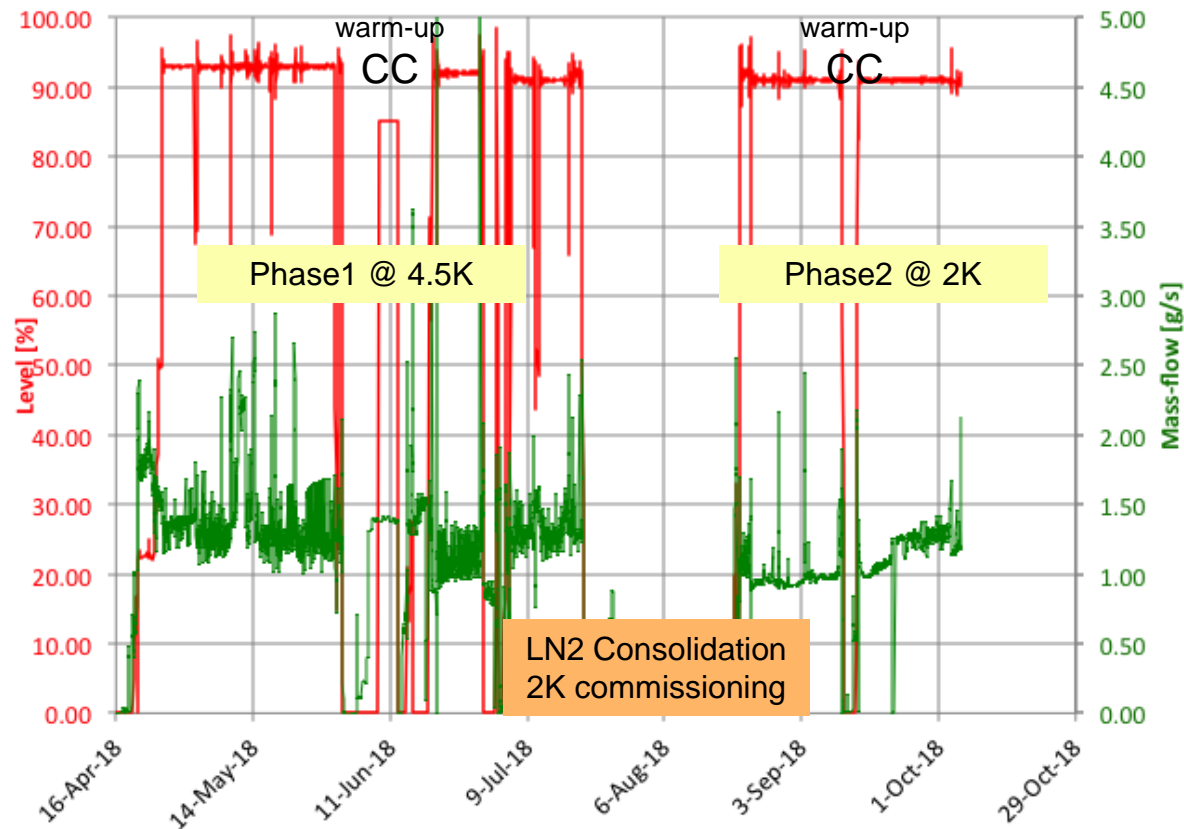


HL-LHC SPS Test stand for crab-cavities



SPS-BA6, CC operation in 2018

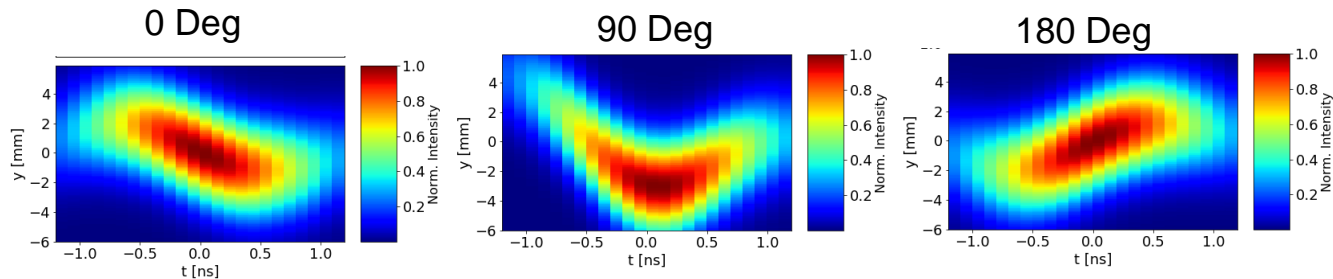
Cryogenic operation facts for 1st year after completion of this new facility



SPS-DQW MDs with Beam

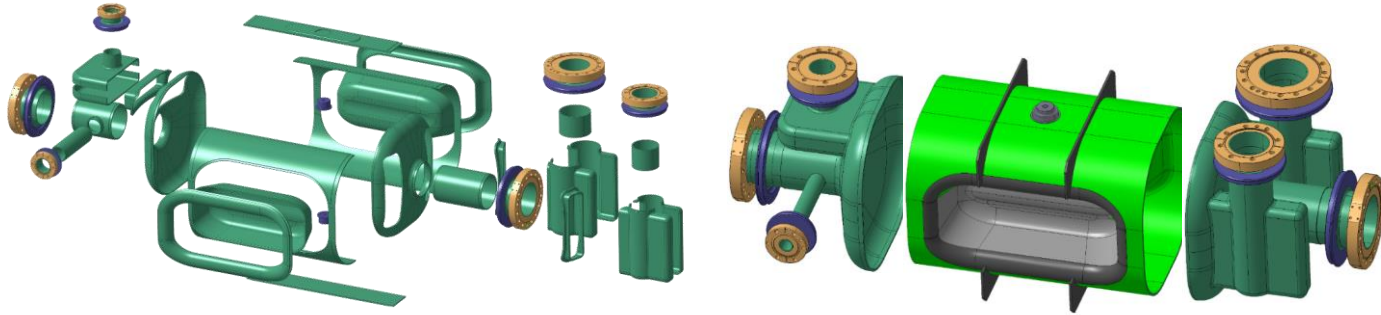


First injection – 12:55, May 23
 2×10^{11} protons / bunch, 26 GeV

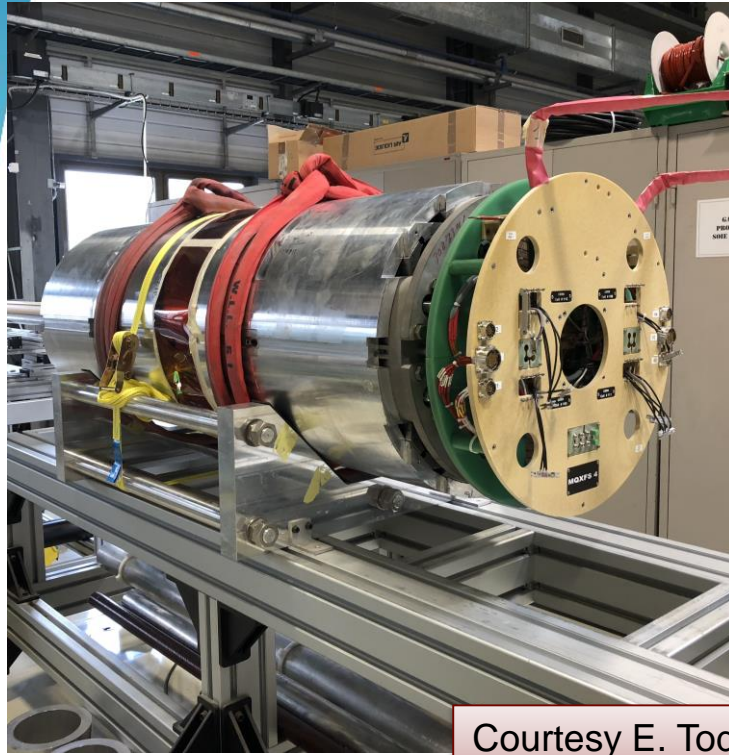


RF phase scan w.r.t the beam phase with cavity 1

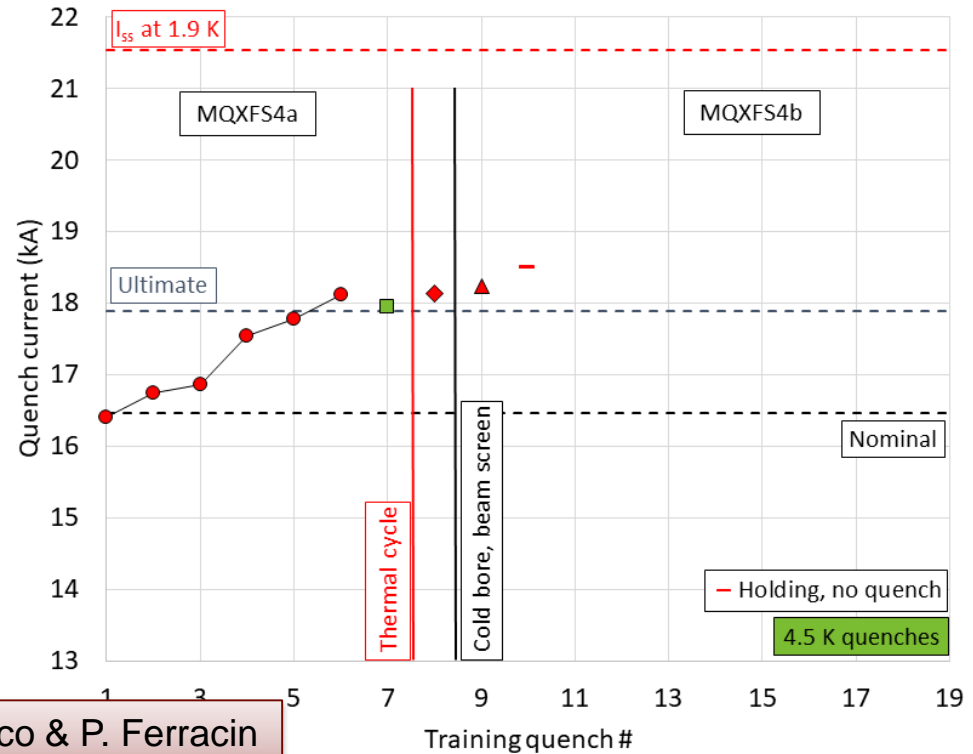
CERN-RFD Fabrication Ongoing



IT Quad model MQXFS4 – final RRP Nb₃Sn



Courtesy E. Todesco & P. Ferracin

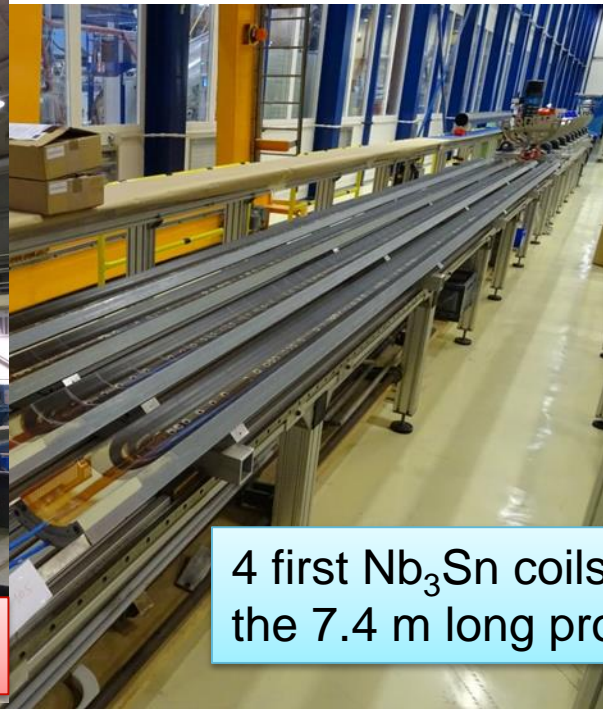


Progress of long IT Quad at CERN

Assembly with 4 practice coils



USA: talk by S. Rolli today
and G. Apollinari tomorrow

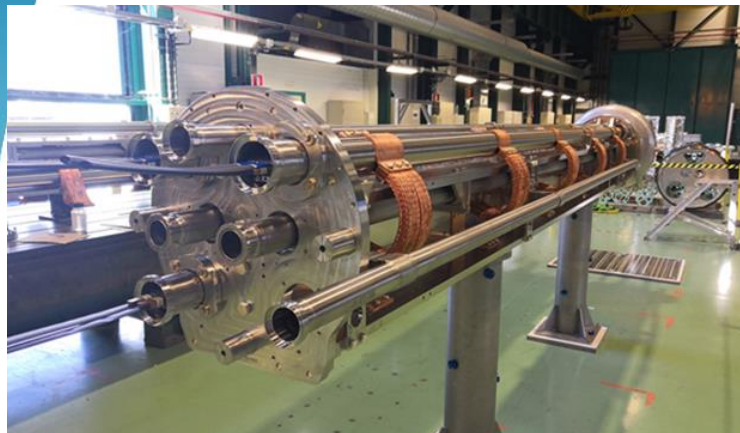


4 first Nb₃Sn coils for
the 7.4 m long proto

Cold Power: effort for 60 m DEMO1 validation by end of the year

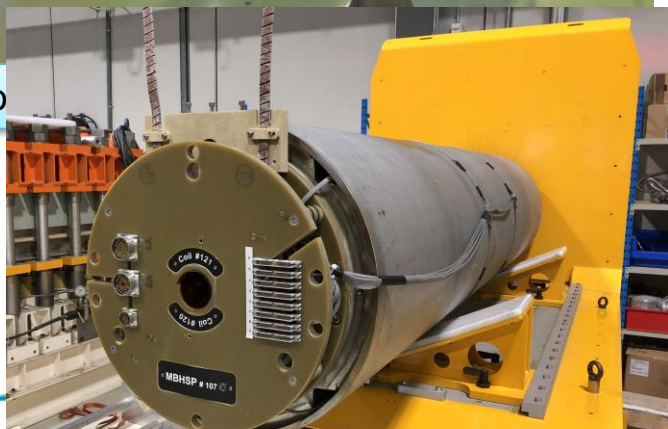


11 T dipole (and new connection cryostat)

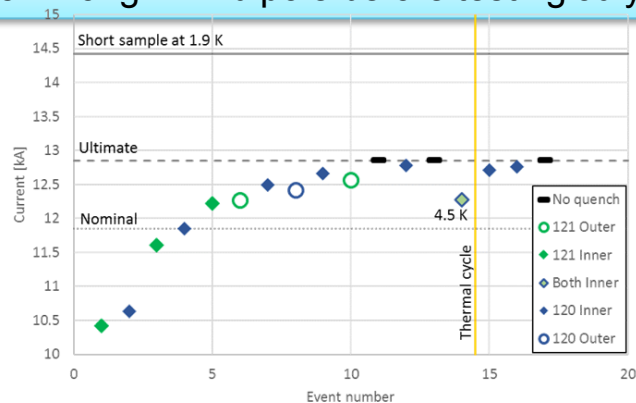


1st 5.5 m long 11 T dipole before testing July '18

First co



Model SP107 (new layout – taskforce)

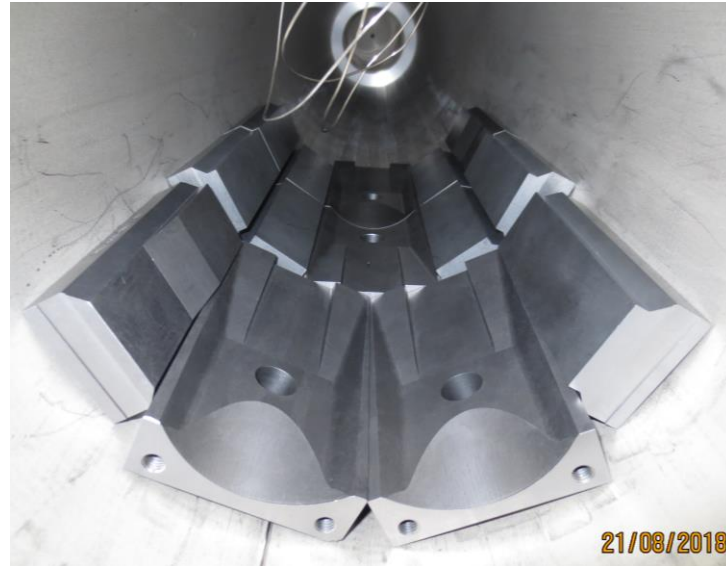


WP5: first HL-LHC hardware in the LHC

First TCLD jaw prototype at the company (courtesy of EN/STI)



Samples of MoGr (Molybdenum-Graphite) from producer (courtesy of EN/MME)



Dedicated talk by S. Gilardoni

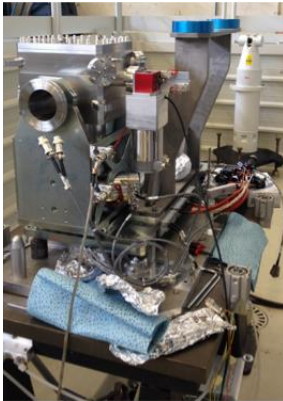
WP5: Update on crystal collimation

Scope: further improvement of ion cleaning after 2016 re-baselining.

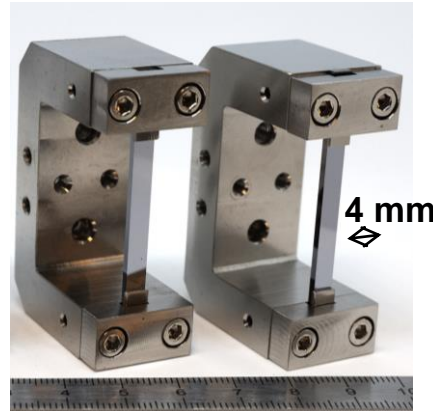
Studying if, for ions, this can be an “adiabatic” upgrade of the IR7 system.

2017: improved by up to x60 collimation cleaning of Xe beams!

Courtesy EN/SMM



Courtesy UA9/PNPI

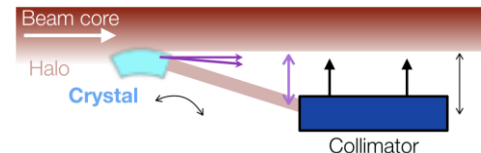


**4 mm = 50 μ rad,
or 10 x 15m long LHC dipoles
or 300 T at 7 TeV**

Two goniometers installed on B1 in LS2; two more on B2 in 2017, upgraded in 2018.

4 operational crystals for collimation.

HL-LHC Crystal Collimation Day



*All details: special workshop
organised this Friday!*

<https://indico.cern.ch/event/752062>



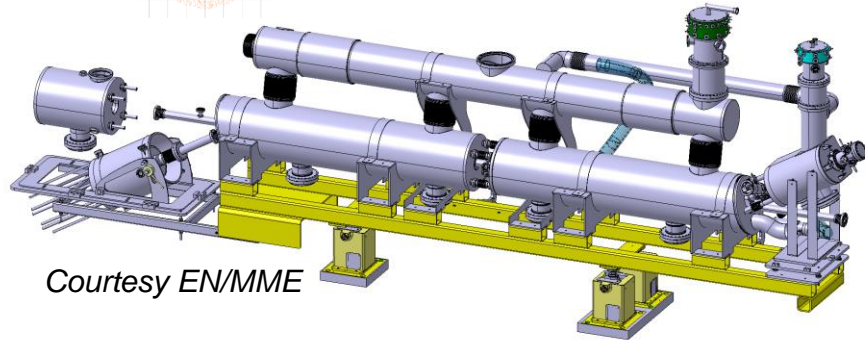
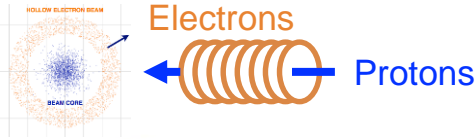
19 October 2018
CERN
Europe/Zurich timezone

Overview
Timetable
Contribution List
My Conference
My Contributions

The HL-LHC project is considering crystal collimation as an option to improve the ion collimation cleaning efficiency. While the definitive assessment of needs and feasibility of such a system can be carried out only in 2019, the HL-LHC Project envisages to have a preliminary review of the state-of-the-art and possible solutions for HL-LHC considering the results of an in-depth study during Run3. For this purpose, a crystal collimation day is organised as a satellite meeting to the 8th Annual Meeting. Although this is not a formal review, an advisory panel is foreseen, composed by

Lucio Rossi 8th HiLumi Collaboration Meeting 2018

WP5: pushing even further accelerator technology

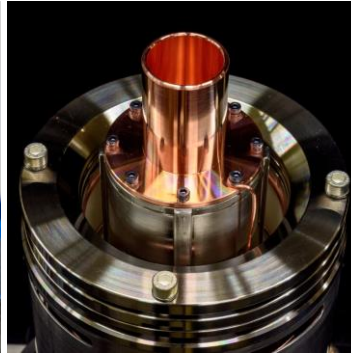


Courtesy EN/MME

It would allow controlling **actively** the halo, through a hollow electron beam (overlapped over three meters to the proton/ion beams) that selectively excites halo particles.



Cathode



Electron gun

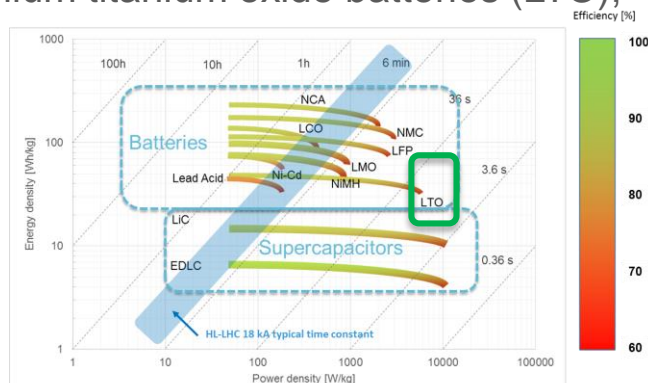
Design nearly complete.
Surpassed target e-beam current of 5A, now final cathode design (smaller) under test at FNAL.

Ready to built it it if integrated into the baseline.

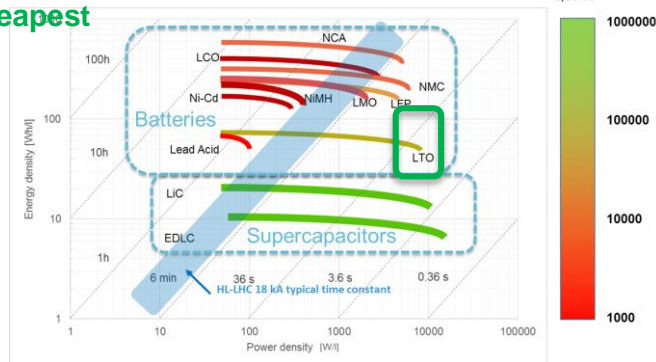
WP6B: R&D in Power & Precision

Selection of Technology for Energy Storage for the 18kA

Lithium titanium oxide batteries (LTO),

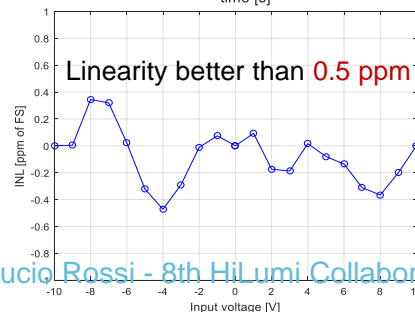
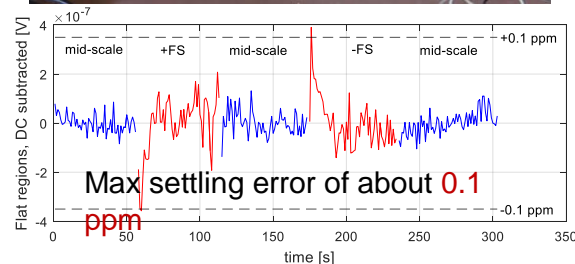


LTO: the most suitable but also the safest and cheapest



ADC development for Class 0

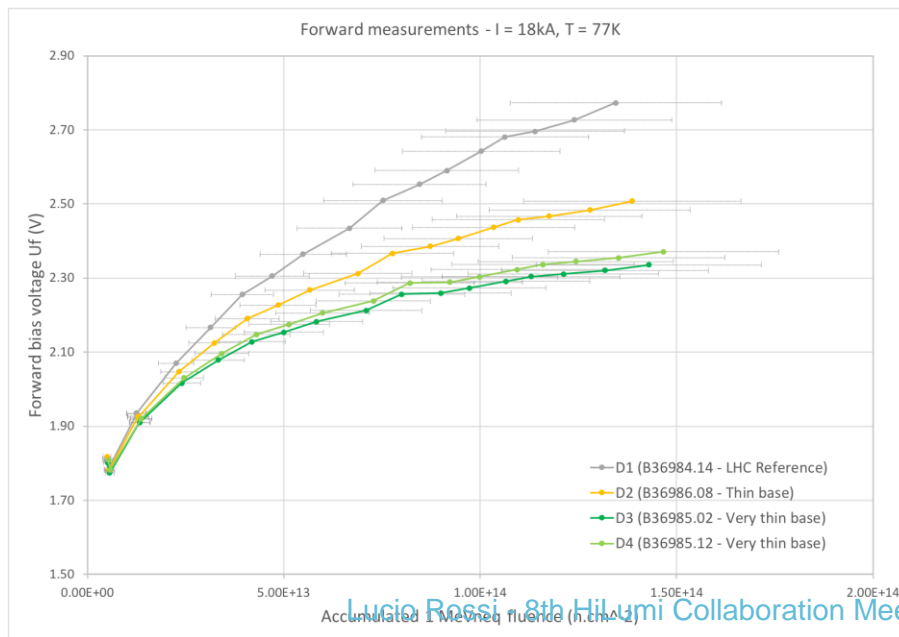
New HPM7177 (based on commercial ADC): first prototype of signal conditioning and ADC tested. Noise up to 0.1 Hz better than **0.05 ppm rms**: well within HL-LHC specs 😊



Irradiation test of triplet cold by-pass diodes



- Cold diode irradiation cryostat installed in CHARM on 10.04.2018
- Two stacks of four diodes (77K, 4K), weekly measurement of forward characteristic up to 18 kA, turn on voltage, reverse blocking voltage and capacitance.
- Measurements to be continued until November (end of protons in injectors), expected to reach total ~ 10 kGy and $\sim 2e14$ 1MeVneq/cm²
- Annealing tests will be performed after the end of the irradiation period



WP12: *in-situ* a-C coating system ready for LS2

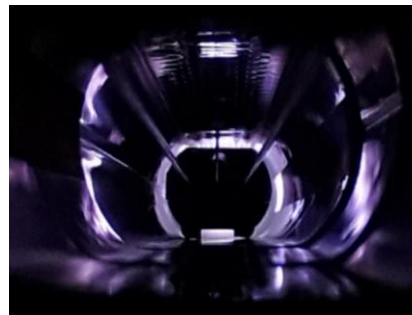
- Fabrication of the coating system for the production in the tunnel during LS2.
- First coating in a real magnet with a beam screen already exposed to the LHC beam (SSS#243, removed from the LHC in LS1 and stored in air since then) with:
 - No impact on cold bore kapton insulation
 - No impact on button BPM response
 - Good adhesion
 - Maximal Secondary Electron Yield along the 6 meters: $\langle \delta_{\max} \rangle = 1.01 \pm 0.04$
- **TE-VSC is ready for the coating campaign in LS2** (Q5 + Q6 in IR2R and IR8L)



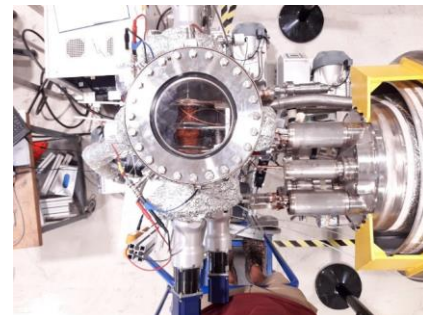
Modular sputtering source



SSS#243 during coating

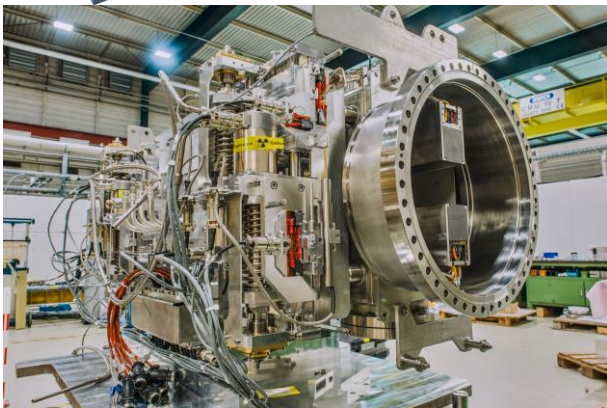
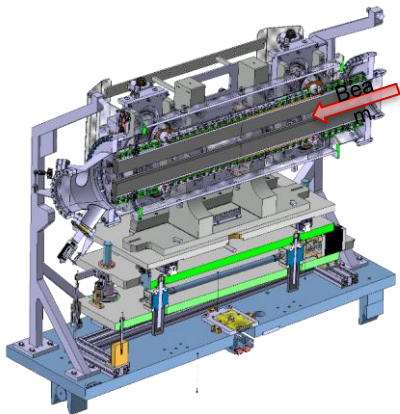


a-C deposition in SSS#243



Spools for the electrical and mechanical cables

WP14: first TDIS module tested in HiRadMat



- Full TDIS module tested under high intensity beam impact
- **Test completed successfully on 24th August 2018**
- Jaws tested for high impact parameters.
- Intensities/position producing equivalent thermal loads as HL beams
 - Impacts with **1.2E11 p/b x 288b** → total intensity per pulse = **3.5E13 p**
- Two different material options tested for the back-stiffener:
 - TZM (baseline)
 - Aluminium (back-up)
- Cooling circuit performed well → room temperature reached after ~10 min
- Post Irradiation Examinations to be performed soon...

Master plan with critical path

— LS2
— LS3



Thanks to the WPLs, GLs,
HLPO, and all those who
provided inputs and materials



The HiLumi LHC boat is sailing, with favorable wind, so far...