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Exploitation of LHC and Future Circular Colliders

Frédérick Bordry

Basics of Accelerator Science and Technology at CERN – Chavannes 8th November 2013

Outline

- **LHC recall and 1st Run**
- **LS1 status**

- **Run 2 (from LS1 to LS2)** ⇒ ***13-14 TeV***
- **LS2 and Run 3** ⇒ **300 fb^{-1}**

- **High Luminosity LHC project** ⇒ **3'000 fb^{-1}**

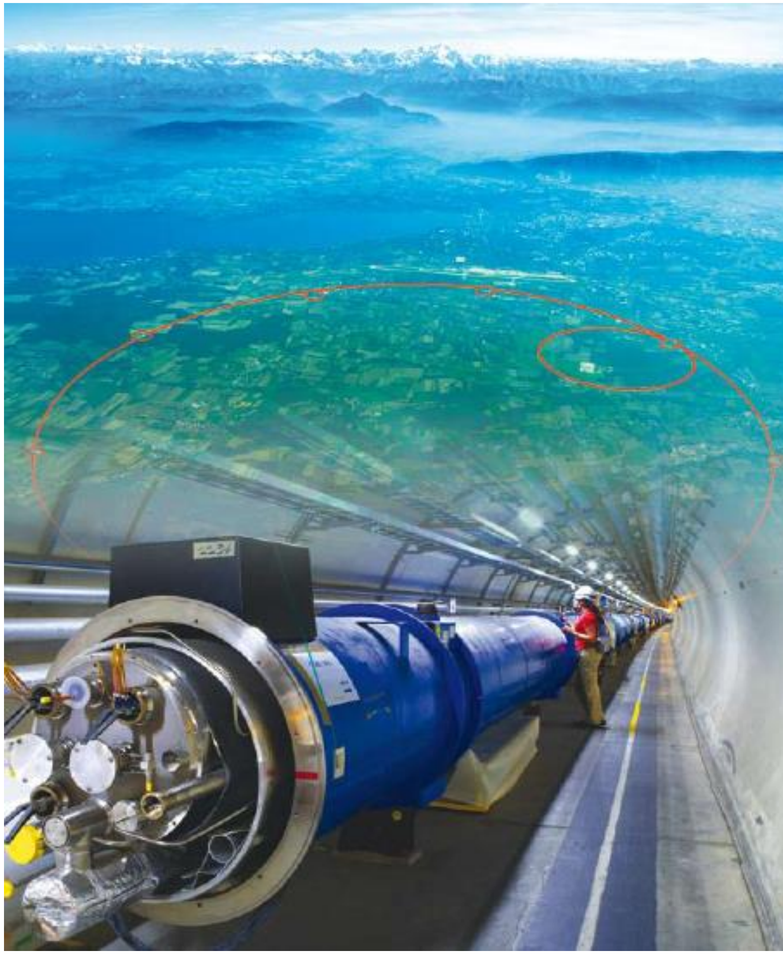
- **Future Circular Colliders** ⇒ ***100 TeV***

- **Conclusion**

LHC (Large Hadron Collider)

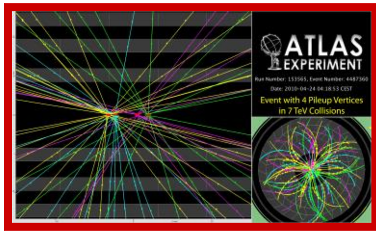
14 TeV proton-proton accelerator-collider built in the LEP tunnel

Lead-Lead (Lead-proton) collisions

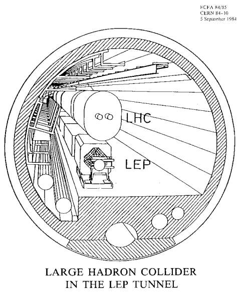


1983 : First studies for the LHC project
1988 : First magnet model (feasibility)
1994 : Approval of the LHC by the CERN Council
1996-1999: Series production industrialisation
1998 : Declaration of Public Utility & Start of civil engineering
1998-2000: Placement of the main production contracts
2004 : Start of the LHC installation
2005-2007: Magnets Installation in the tunnel
2006-2008: Hardware commissioning
2008-2009: Beam commissioning and repair
2009-2030: Physics exploitation

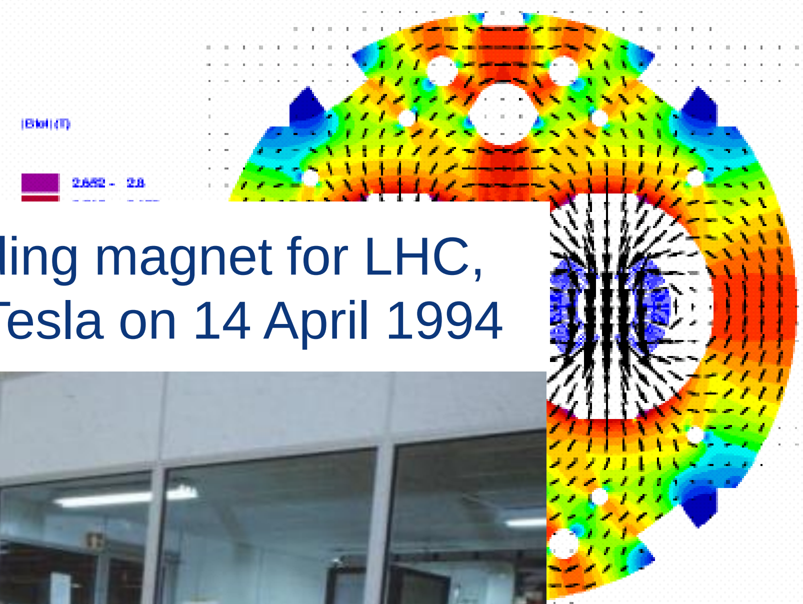
LHC, the construction timeline: Nb-Ti magnet maturation



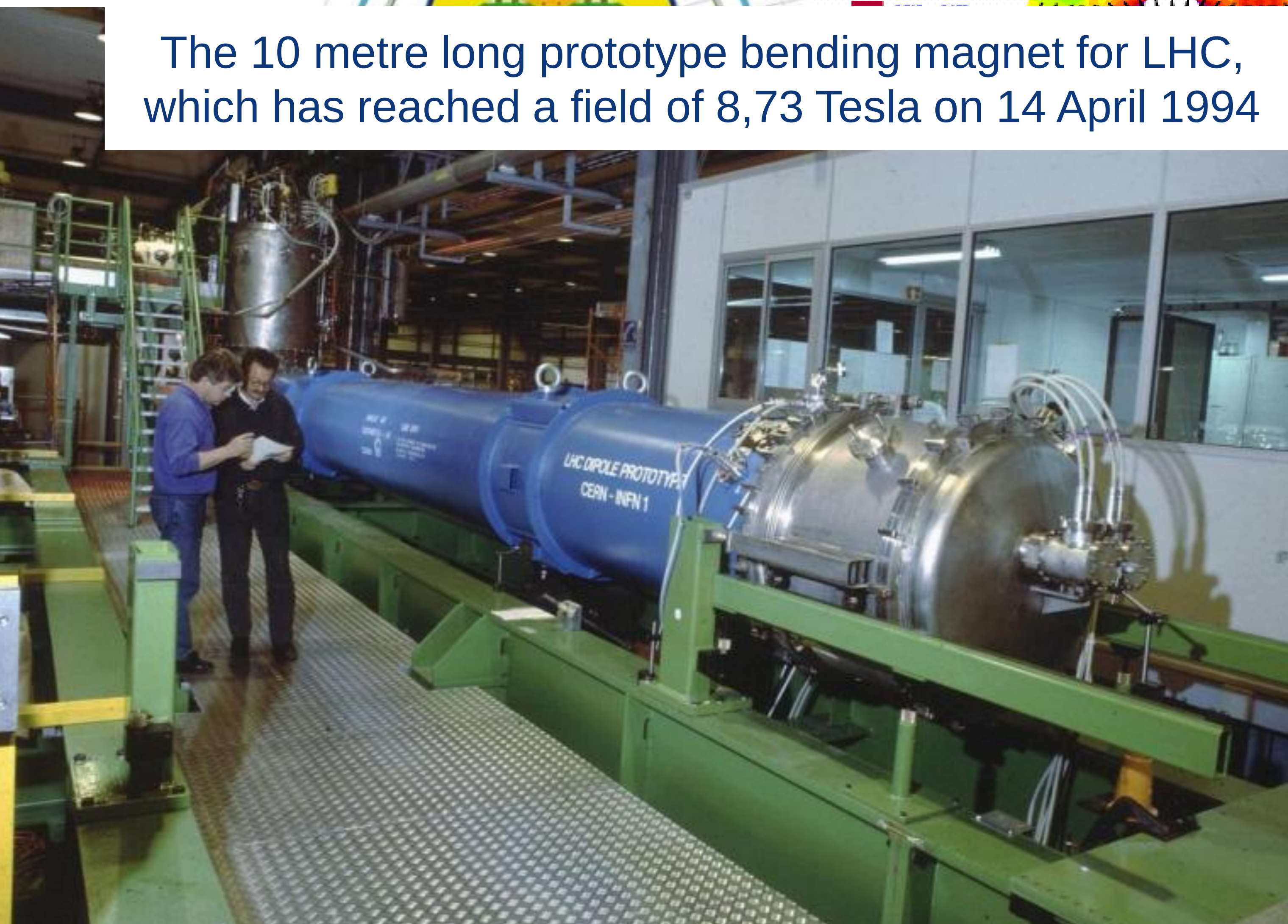
- 1985 – LHC study
- 1987 – 9 T - 1 m single bore
- 1990 – 10 T-1m Nb3Sn dipole; Decision for Nb-Ti
- 1994 – 9 T -10 m long protoype
- 2000 – 9 T-15 m final protoype; Industry contracts Nb-Ti
- 2006 – Last LHC dipole
- 2010 – LHC start-up

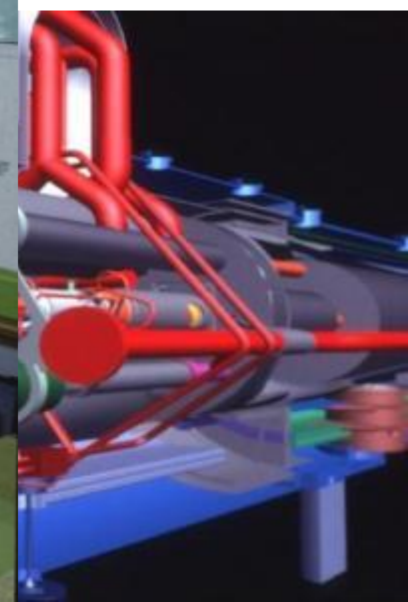


Prototype and industrialisation



The 10 metre long prototype bending magnet for LHC, which has reached a field of 8,73 Tesla on 14 April 1994

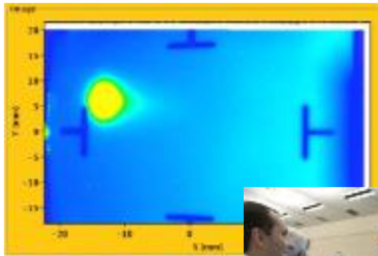


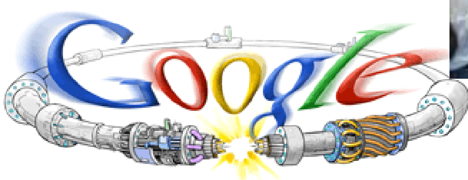


LHC Timeline

3.5 TeV

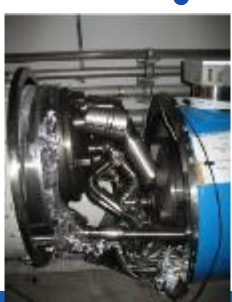
August 2008
First injection test





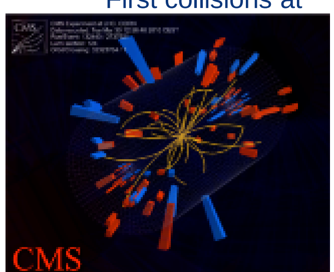
September 10, 2008
First beams around

September 19, 2008
Disaster
Accidental release of 600 MJ stored in one sector of LHC dipole magnets



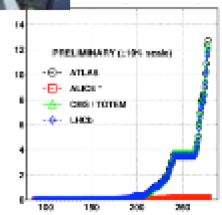
November 29, 2009
Beam back

March 30, 2010
First collisions at



April 2010
Squeeze to 3.5 m

October 14 2010
1e32
248 bunches



November 2010
Ions

June 28 2011
1380 bunches

1380

1380 bunches

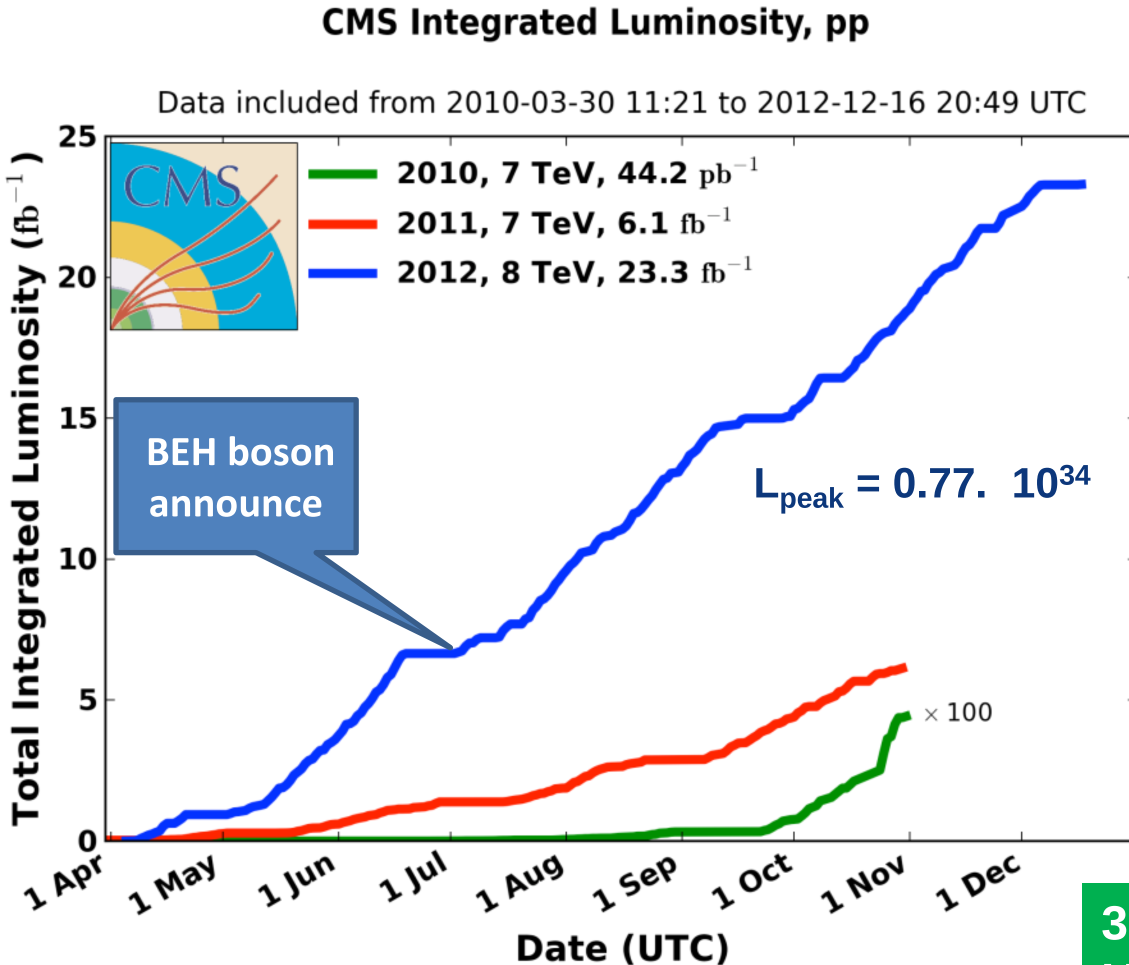
6 June, 2012
6.8e33

18 June, 2012
6.6 fb^{-1}
to ATLAS & CMS

4 July, 2012
Higgs discovery

2008 | 2009 | 2010 | 2011 | 2012

2010-2012: LHC integrated luminosity



2010: **0.04 fb^{-1}**
7 TeV CoM
Commissioning

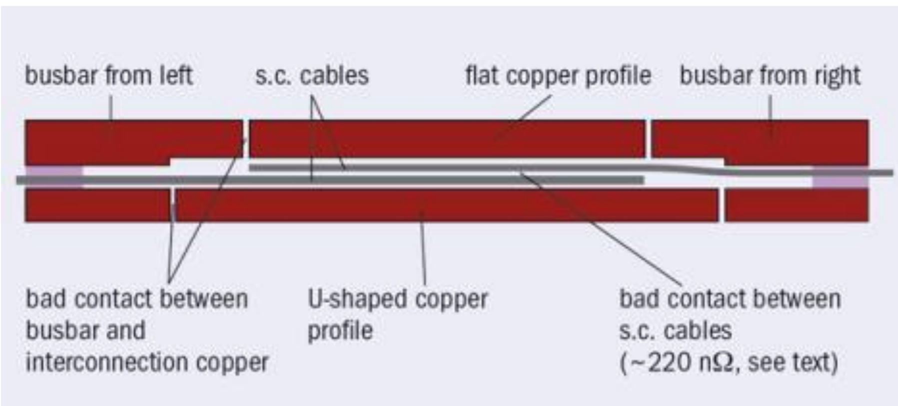
2011: **6.1 fb^{-1}**
7 TeV CoM
… exploring limits

2012: **23.3 fb^{-1}**
8 TeV CoM
… production

3.5 TeV and 4 TeV in 2012
Up to 1380 bunches
with1.5 10^{11} protons

Long Shutdown 1

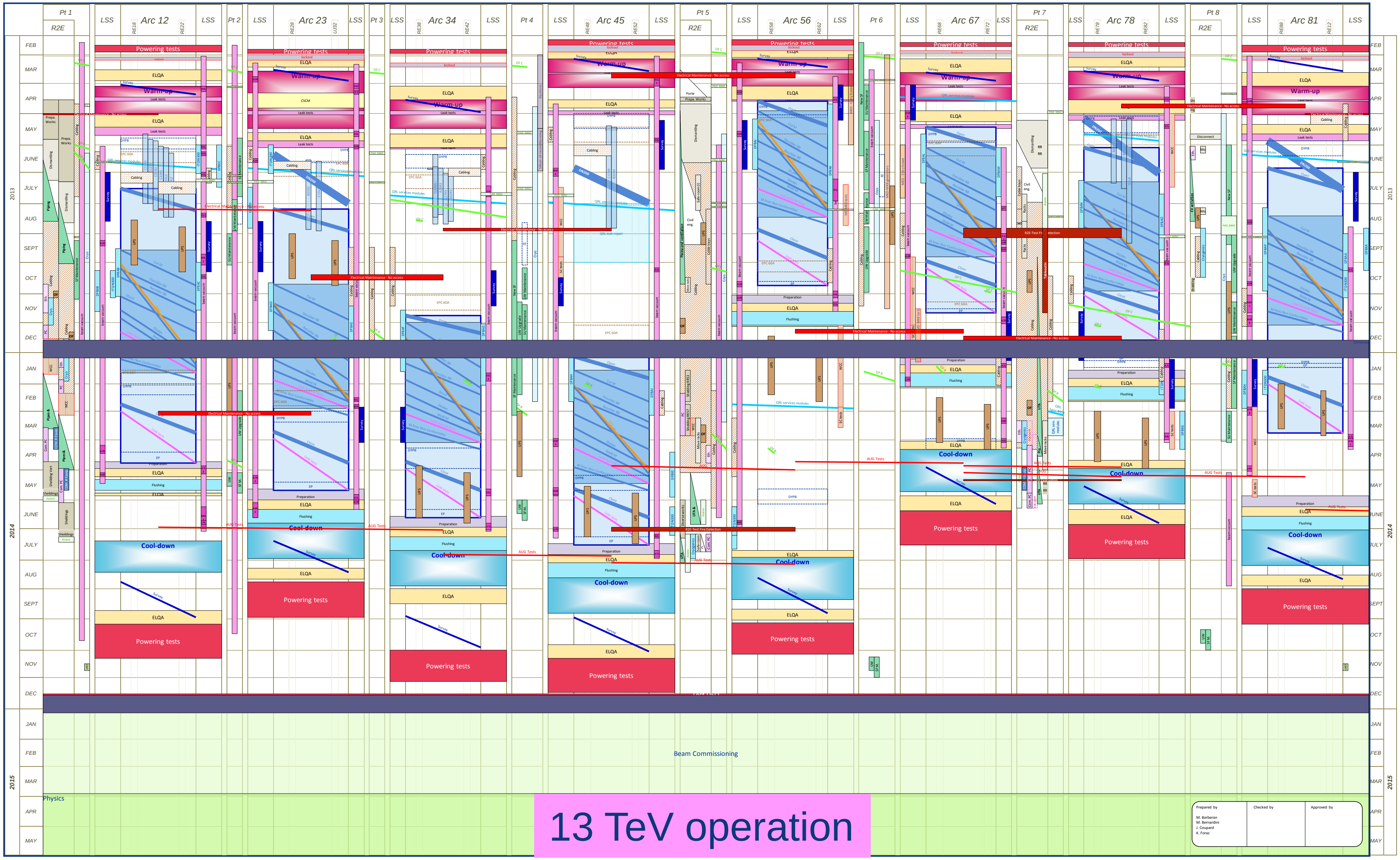
LS1 starts as the shutdown to repair the magnet interconnects to allow nominal current in the dipole and lattice quadrupole circuits of the LHC.



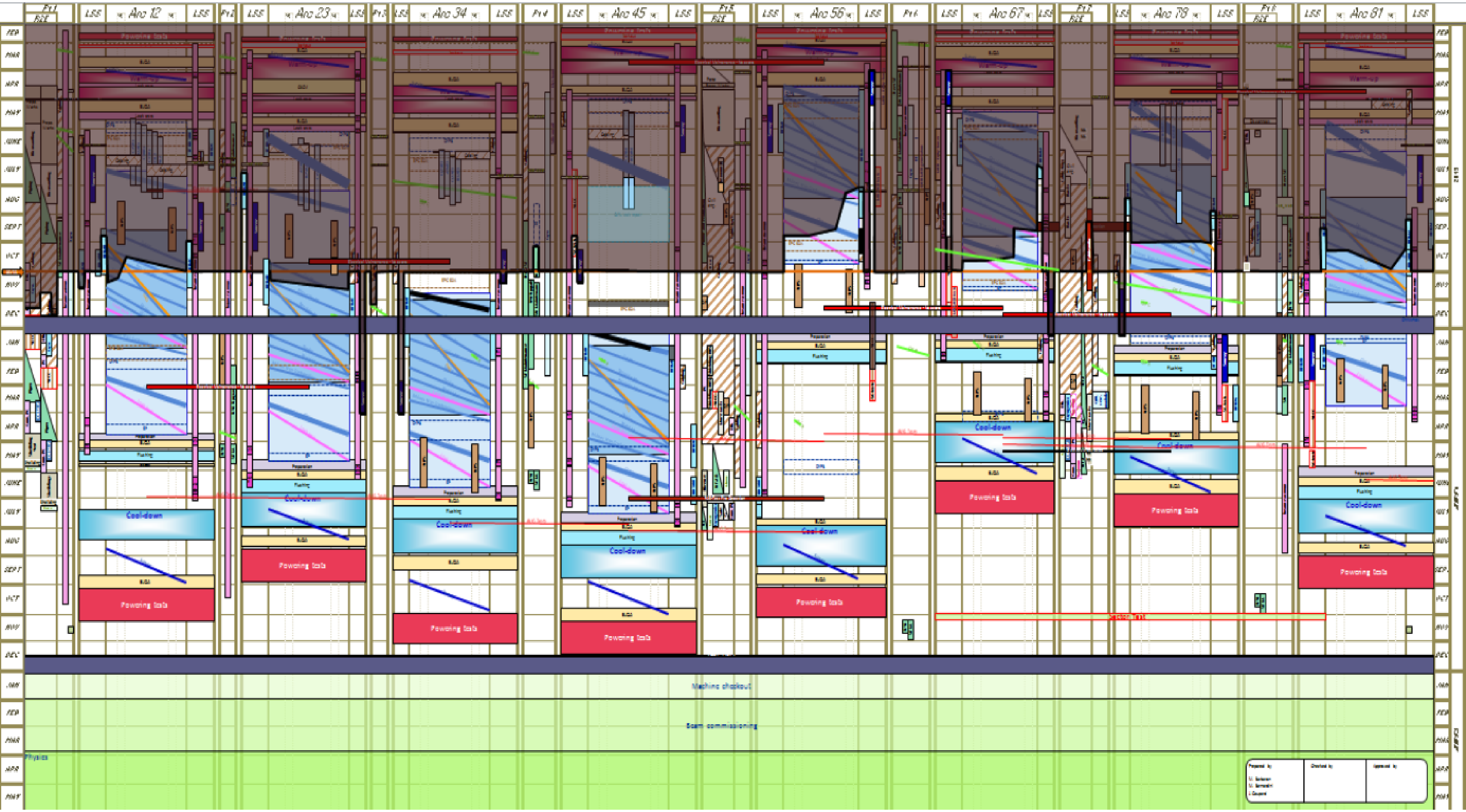
or shutdown which, in repairs, maintenance, nd cabling across the x and the associated experimental facilities.

All this in the shadow interconnects.

LS1: LHC schedule



So far, LS1 is on schedule
for beams in January 2015 for LHC



http://cern.ch/ls1dashboard

The main 2013-14 LHC consolidations

1695 Openings and final reclosures of the interconnections

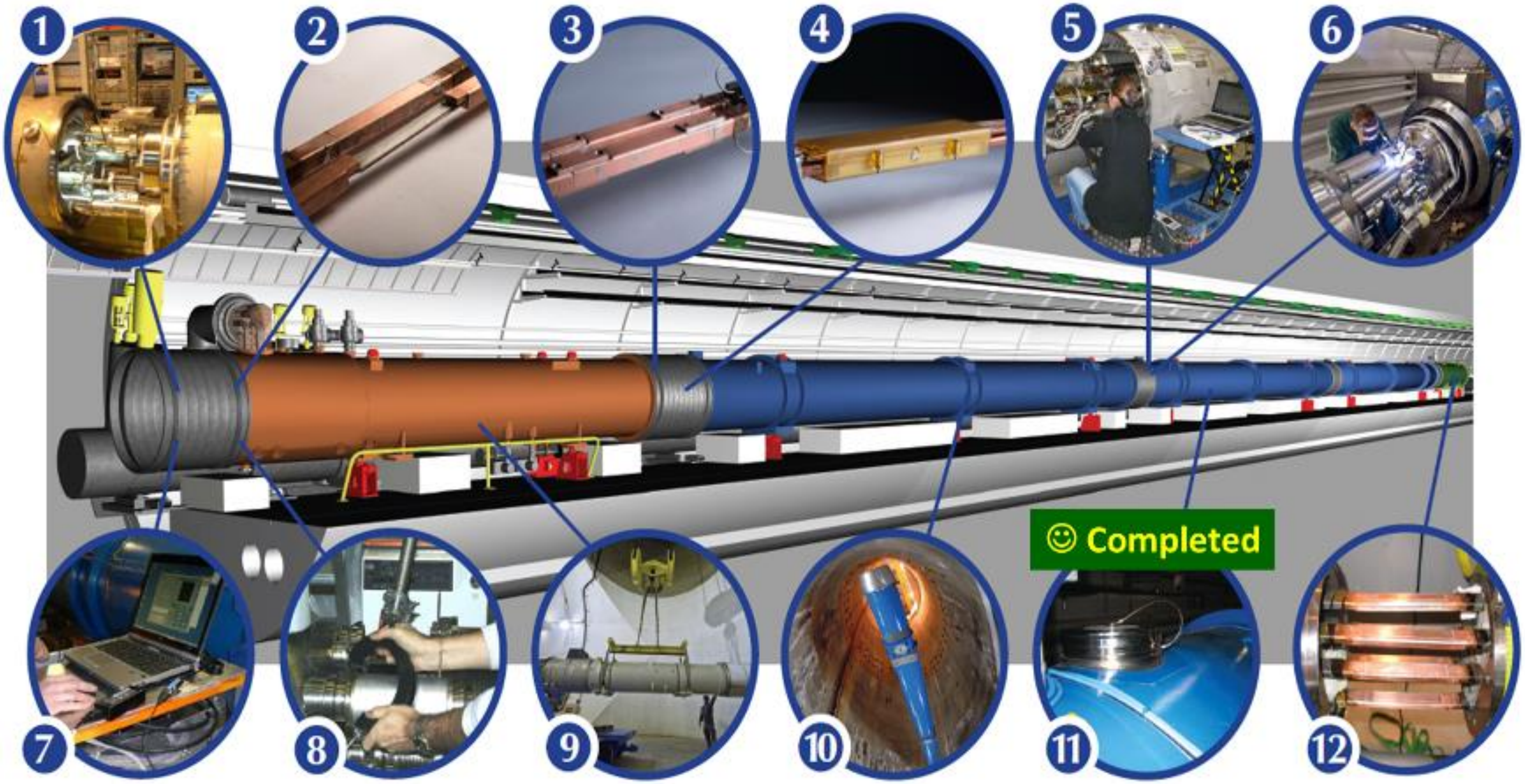
Complete reconstruction of 3000 of these splices

Consolidation of the 10170 13kA splices, installing 27 000 shunts

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

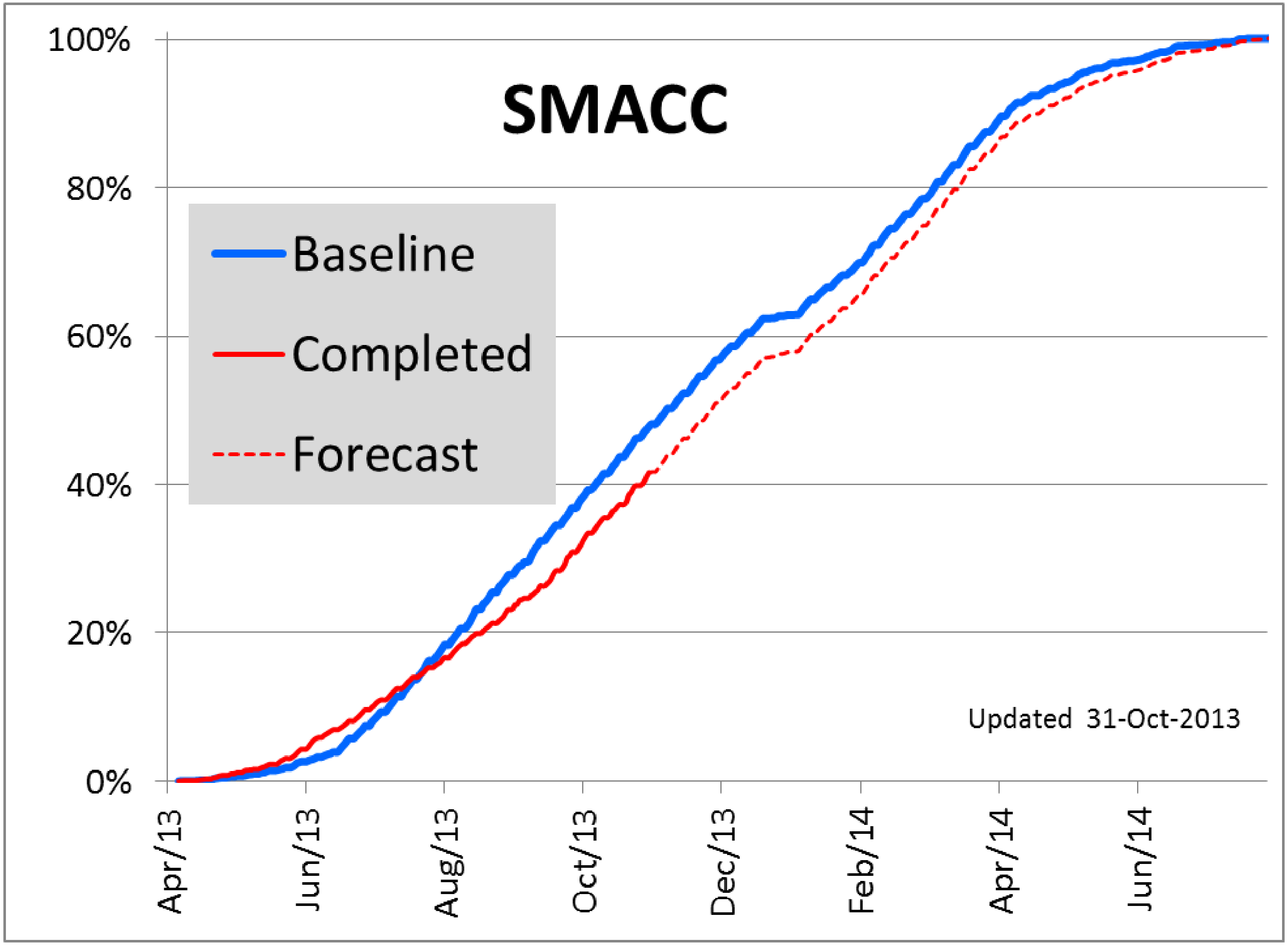
3 quadrupole magnets to be replaced

15 dipole magnets to be replaced

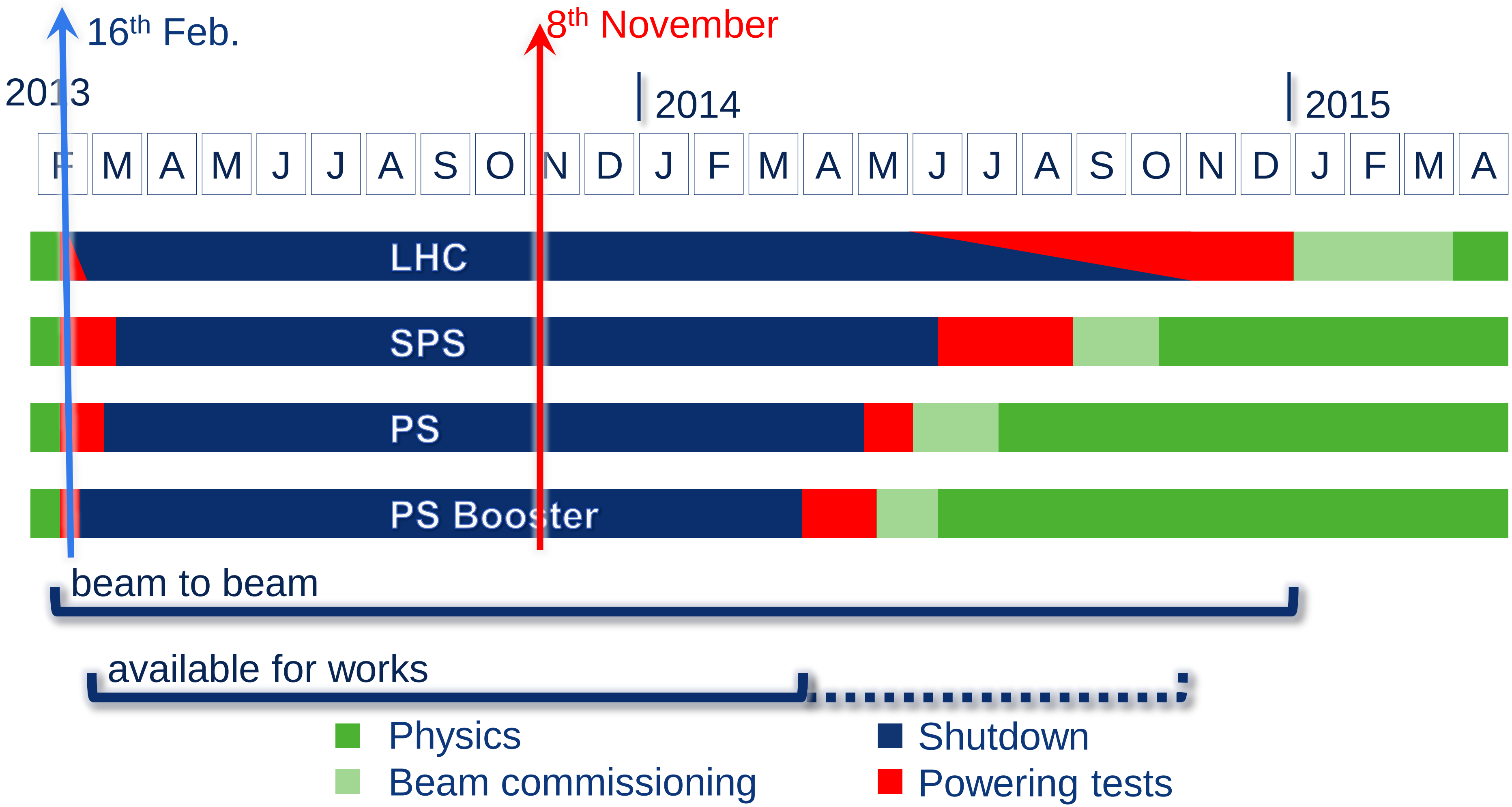
Installation of 612 pressure relief devices to bring the total to 1344

Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes

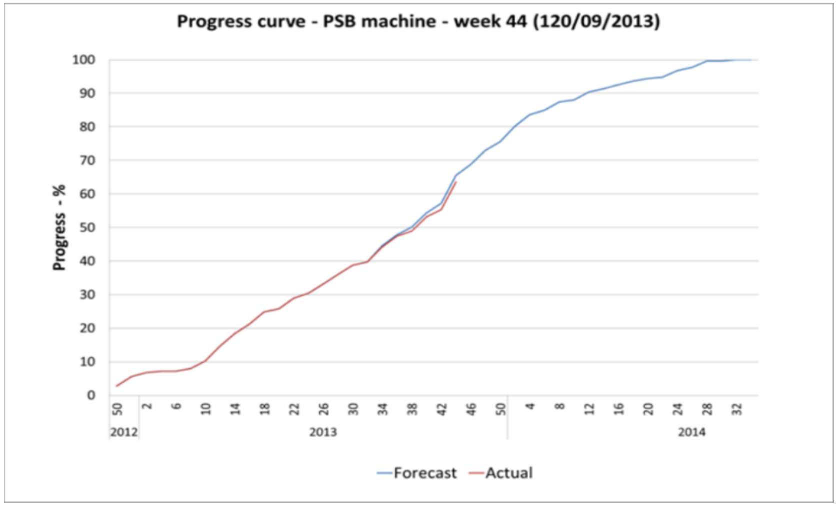
SMACC Dashboards

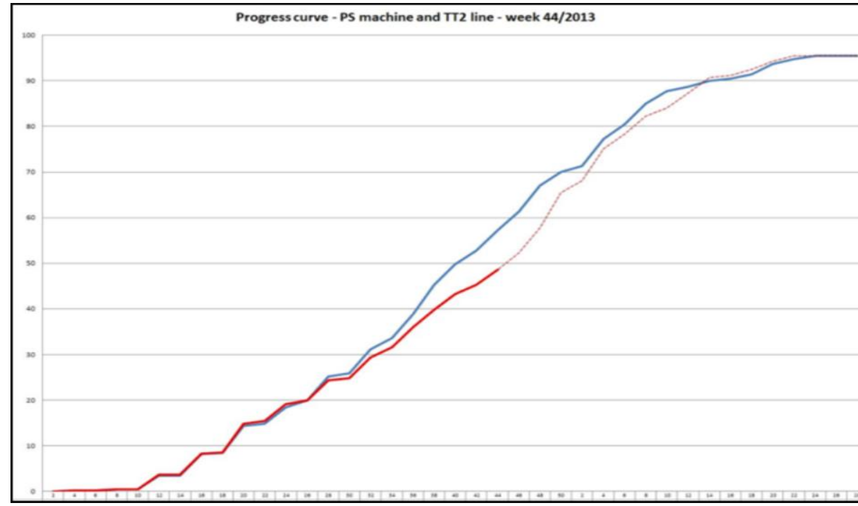


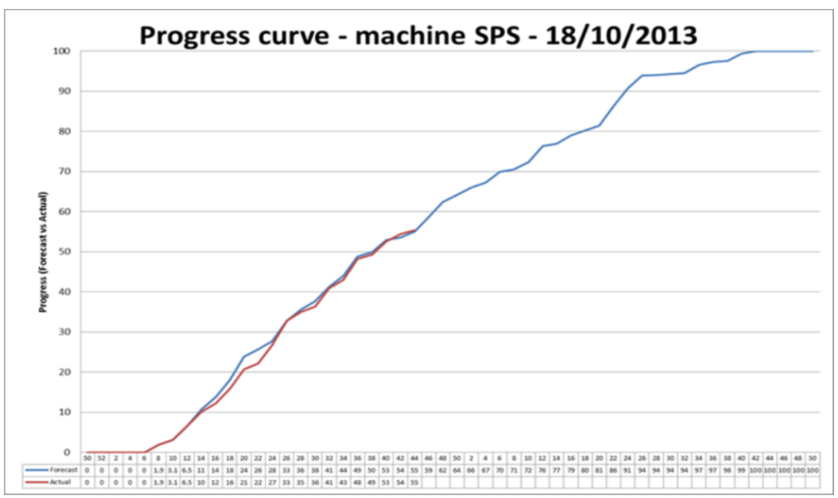
LS 1 from 16th Feb. 2013 to Dec. 2014

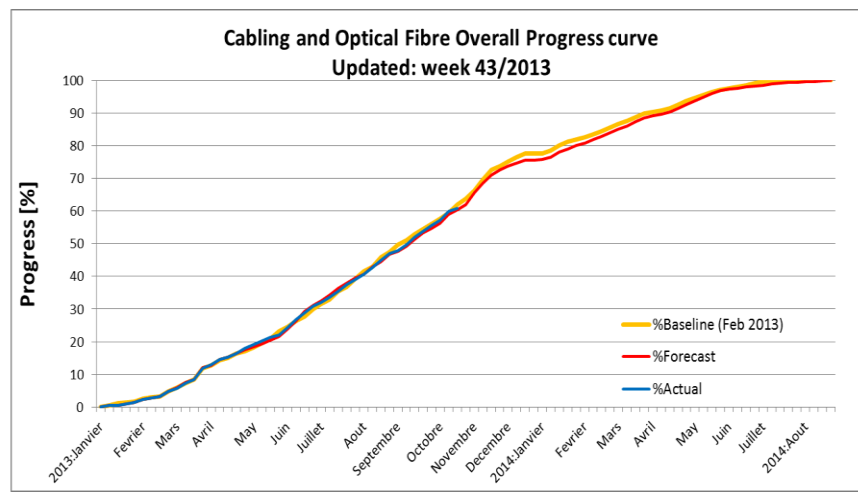


LS1: LHC Injectors status and cable status

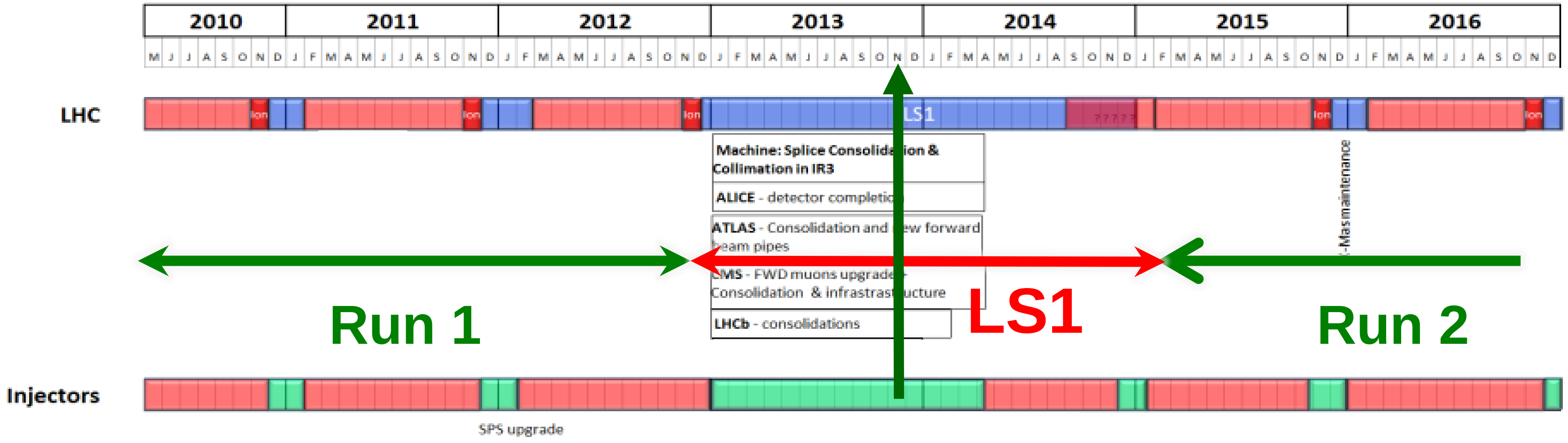


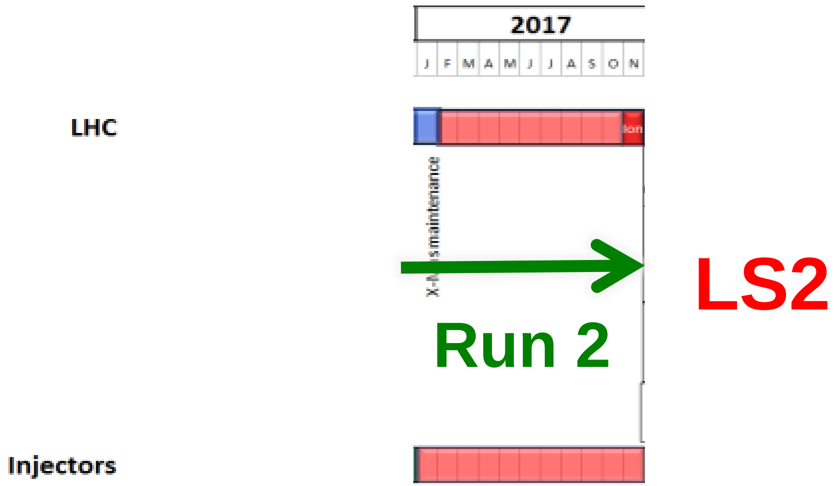






Run2: 3 years Operation Run after LS1





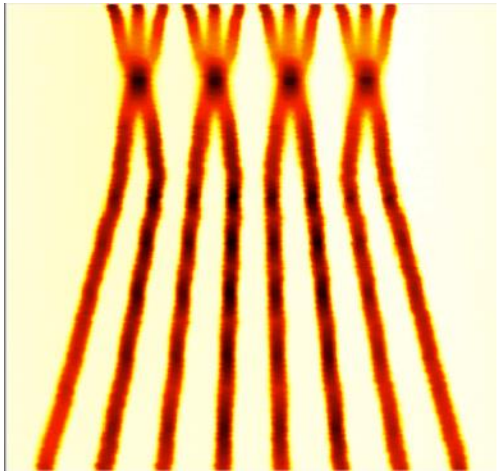
Run 2:
Start with 6.5 TeV and later decision towards 7 TeV according to magnet training

Expectations after Long Shutdown 1 (2015)

- Collisions at least at **13 TeV** c.m.
- **25 ns** bunch spacing

  Using new injector beam production scheme (BCMS), resulting in brighter beams.

Batch Compression and Merging and splitting (BCMS)



Courtesy of the LIU-PS project team

- **β^* ≤ 0.5m** (was 0.6 m in 2012)
- Other conditions:
  - Similar turn around time
  - Similar machine availability
- Expected maximum luminosity: **1.6 x 10^{34} cm^{-2} s^{-1}** ± 20%
  - Limited by inner triplet heat load limit, due to collisions debris

	Number of bunches	Intensity per bunch	Transverse emittance	Peak luminosity	Pile up	Int. yearly luminosity
25 ns BCMS	2508	1.15 × 10^{11}	1.9 µm	1.6×10^{34} cm^{-2}s^{-1}	~43	~42 fb^{-1}

Potential performance

	Number of bunches	Ib LHC [1e11]	Collimat or scenario	Emit LHC (SPS) [um]	Peak Lumi [cm-^{2}s^{-1}]	~Pile-up	Int. Lumi [fb^{-1}]
25 ns	2760	1.15	S1	3.5 (2.8)	9.2e33	21	24
25 ns low emit	***2508***	***1.15***	***S4***	***1.9 (1.4)***	***1.6e34***	***43***	***42***
50 ns	1380	1.6	S1	2.3 (1.7)	1.7e34 levelling 0.9e34	76 levelling 40	~45*
50 ns low emit	1260	1.6	S4	1.6 (1.2)	2.2e34	108	…

- **6.5 TeV**
- **1.1 ns bunch length**
- **150 days proton physics, HF = 0.2**

All numbers approximate

* different operational model – caveat - unproven

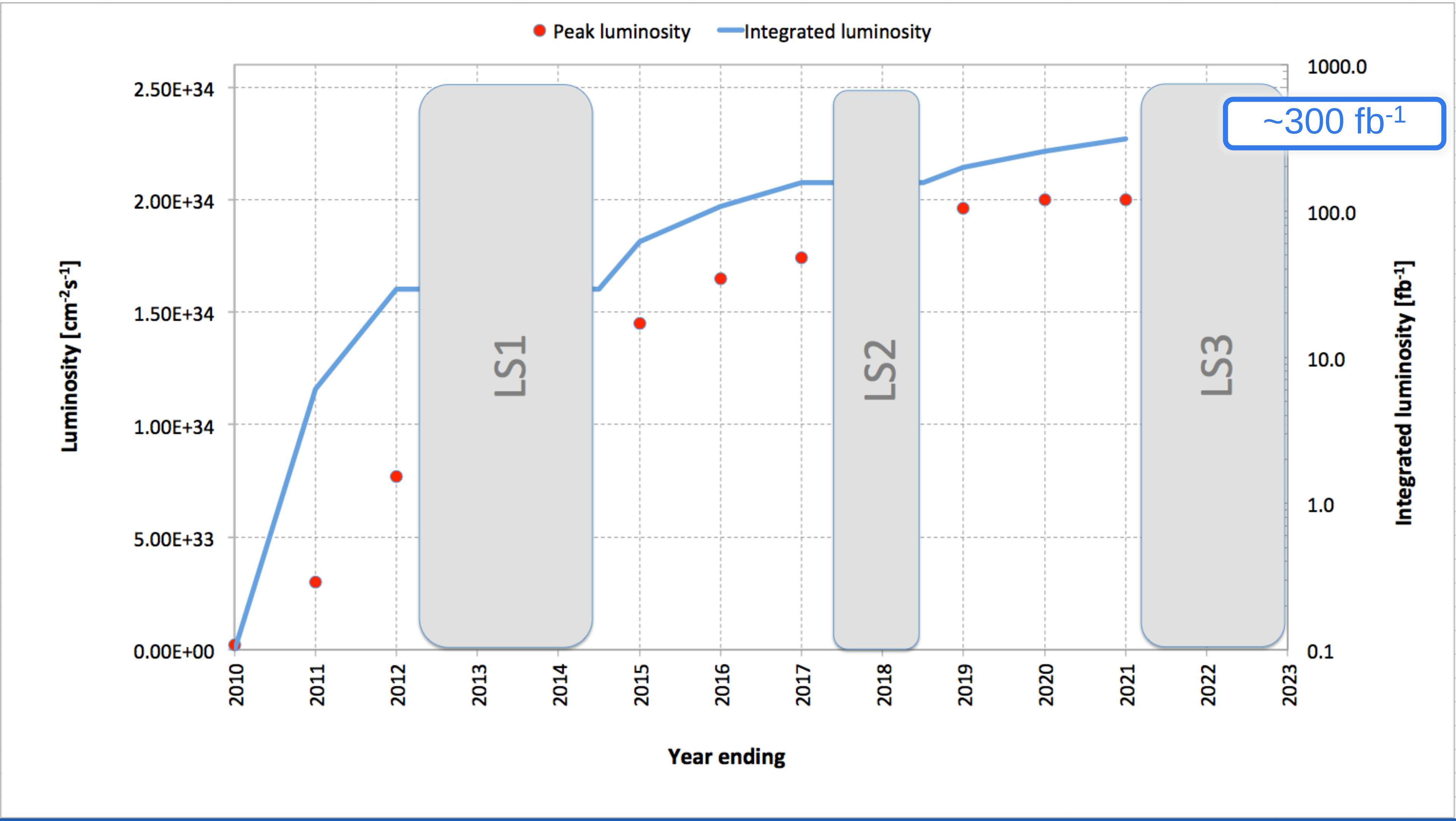
Courtesy Mike Lamont

“Baseline”

	J	F	M	A	M	J	J	A	S	O	N	D
2011		1	2	3	4	5	6	7	8	9	IONS	
2012			1	2	3	4	5	6	7	8	9	
2013	IONS	IONS	**LS1 - SPLICE CONSOLIDATION**									
2014												
2015	CHECK-OUT	RECOM	RECOM	RAMP-UP	2	3	4	5	6	7	IONS	
2016		RAMP-UP	1	2	3	4	5	6	7	8	IONS	
2017		RAMP-UP	1	2	3	4	5	6	7	8	IONS	
2018	**LS2 (LIU UPGRADE: LINAC4, BOOSTER, PS, SPS...)**											
2019	RECOM	RECOM	RAMP-UP	1	2	3	4	5	6	7	IONS	
2020		RAMP-UP	1	2	3	4	5	6	7	8	IONS	
2021		RAMP-UP	1	2	3	4	5	6	7	8	IONS	
2022	**HL-LHC UPGRADE**											

- Technical stop or shutdown
- Proton physics
- Ion Physics
- Recommissioning
- Intensity ramp-up

“Baseline” luminosity



Review of LHC & Injector Upgrade Plans Workshop (RLIUP)

29-31 October 2013
Centre de Convention, Archamps
Europe/Zurich timezone

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- Timetable
- Timetable and Session Information - pdf
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- Shuttle Timetable
- Lunch Menu

Support

Acc-Tec-Director.Offi...

*** **Invitation Only*****

The workshop will focus on:

Review of the parameters of the LIU and HL-LHC projects following the experience and changes in the beam parameters experienced in the past two years

Produce a staged plan(beam parameters, technical work, all machines) of how we proceed from the performance at the end of 2012 to the required performance for the HL-LHC. In order to do this we need to know at what level of integrated luminosity will necessitate replacement of the inner detectors and the insertions. Also to see the importance of 3000fb-1 and what level of minimum integrated luminosity would be tolerated.

- Chairman : Steve Myers
- Co-Chairman : Frédérick Bordry
- Deputy Chairman : Mike Lamont
- Scientific Secretary: Frank Zimmermann
- Deputy Scientific Secretary: Brennan Goddard
- Technical Support Pierre Charrue

Editor of proceedings: Frank Zimmermann and Brennan Goddard

DRAFT timetable and session information

Deadline for registration:** Friday 27 September 2013

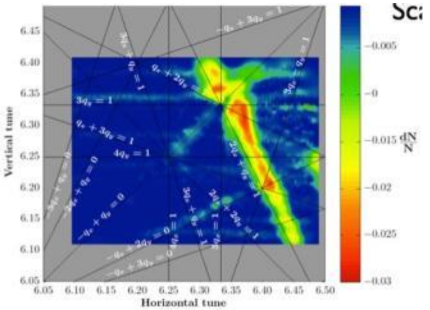
LS2 : (2018), LHC Injector Upgrades (LIU)

LINAC4 – PS Booster:

- H^- injection and increase of PSB injection energy from 50 MeV to 160 MeV, to increase PSB space charge threshold
- New RF cavity system, new main power converters
- Increase of extraction energy from 1.4 GeV to 2 GeV

PS:

- Increase of injection energy from 1.4 GeV to 2 GeV to increase PS space charge threshold
- Transverse resonance compensation
- New RF Longitudinal feedback system
- New RF beam manipulation scheme to increase beam brightness

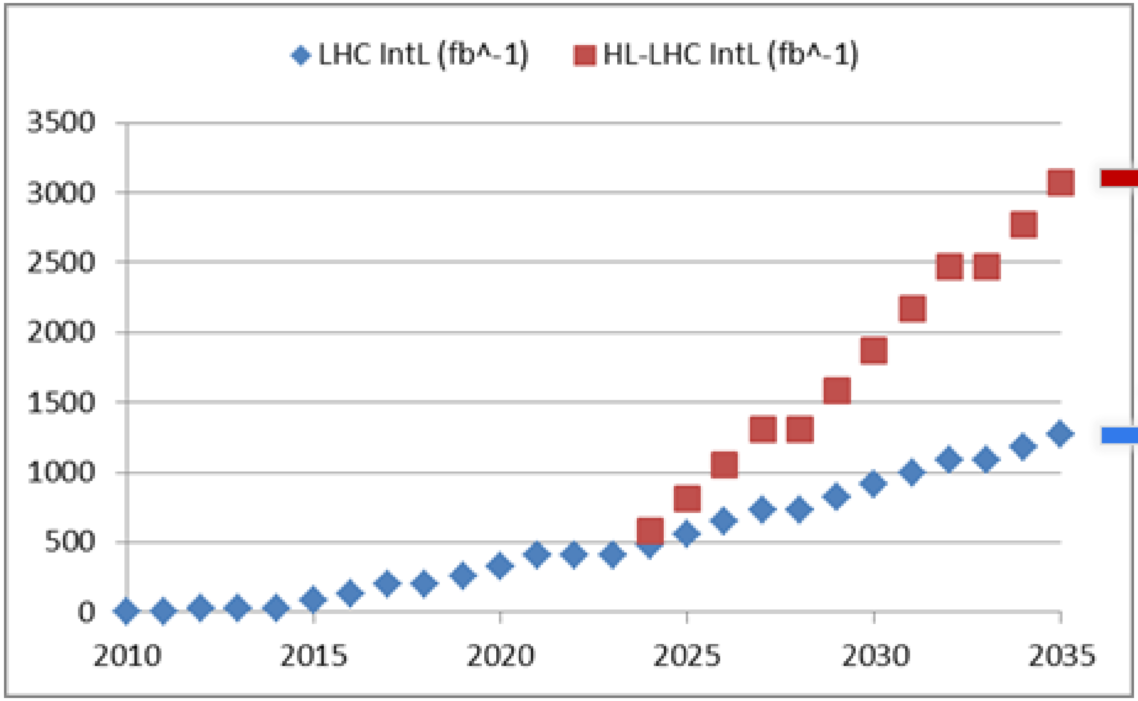


SPS

- Electron Cloud mitigation – strong feedback system, or coating of the vacuum system
- Impedance reduction, improved feedbacks
- Large-scale modification to the main RF system

These are only the main modifications and this list is far from exhaustive
Project leadership: R. Garoby and M. Meddahi

Why High-Luminosity LHC ? (LS3)



By implementing HL-LHC

Almost a factor 3

By continuous performance improvement and consolidation

Around 300 fb^{-1} the present Inner Triplet magnets reach the end of their useful life (due to radiation damage) and must be replaced.

Goal of HL-LHC project:

- 250 – 300 fb^{-1} per year
- **3000 fb^{-1} in about 10 years**

The European Strategy for Particle Physics
Update 2013

c) *Europe's top priority should be the* ***exploitation of the full potential of the LHC****, including the high-luminosity upgrade of the machine and detectors with a view to collecting* ***ten times more data than in the initial design, by around 2030****. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

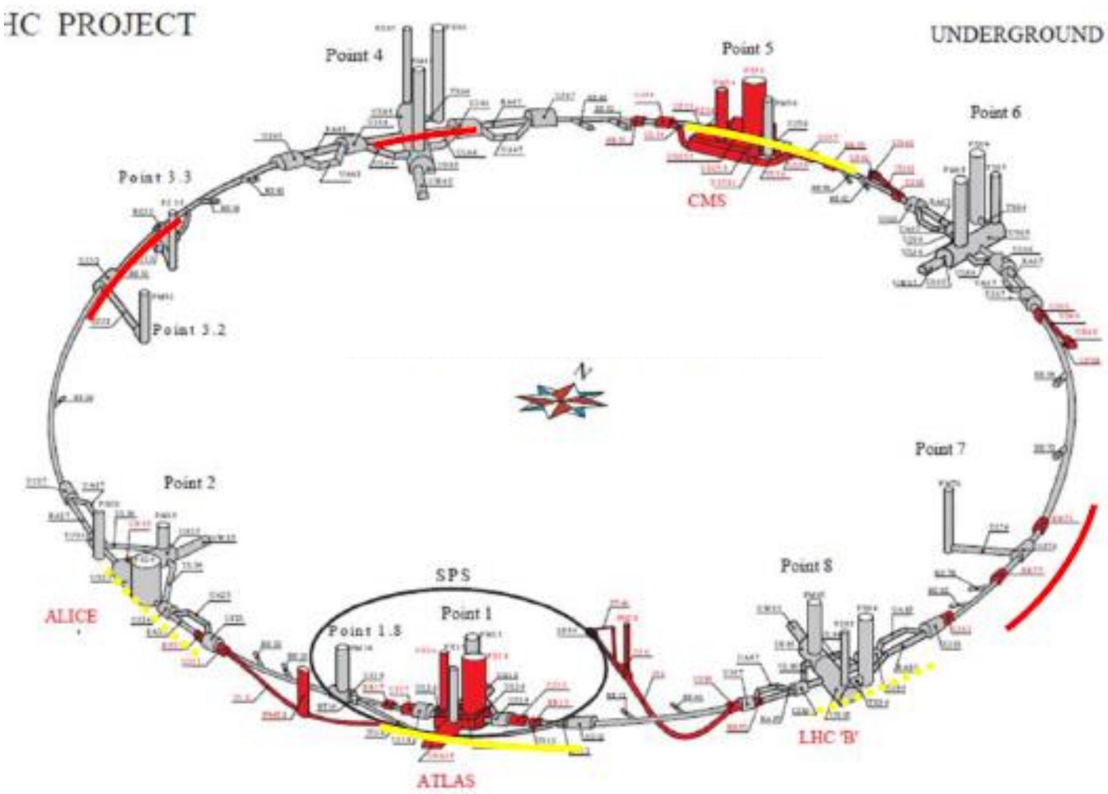
HL-LHC from a study to a PROJECT

300 fb^{-1} → 3000 fb^{-1}

including LHC injectors upgrade **LIU**

(Linac 4, Booster 2GeV, PS and SPS upgrade)

The HL-LHC Project



- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- …

Major intervention on more than 1.2 km of the LHC

Project leadership: L. Rossi and O. Brüning

Squeezing the beams: High Field SC Magnets

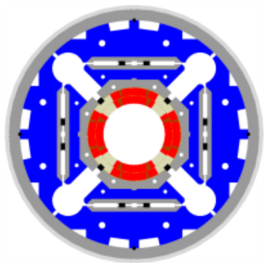
Quads for the inner triplet

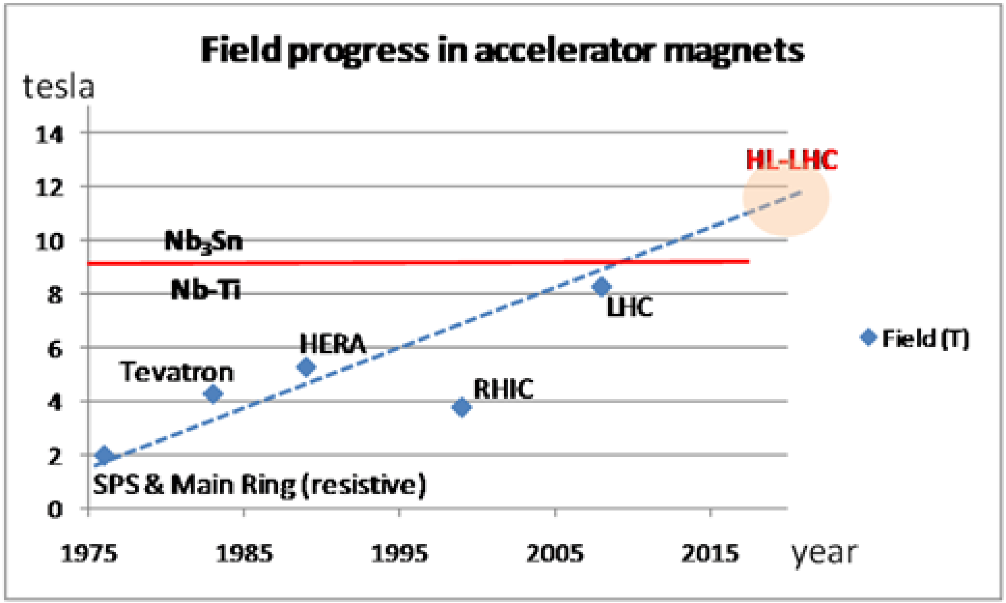
Decision 2012 for low-β quads

Aperture ∅ 150 mm – 140 T/m

(B_{peak} ≈12.3 T)

(LHC: 8 T, 70 mm)





More focus strength,

β* as low as 15 cm (55 cm in LHC)

thanks to ATS** (Achromatic Telescopic Squeeze) **optics

In some scheme even β down to 7.5 cm are considered*

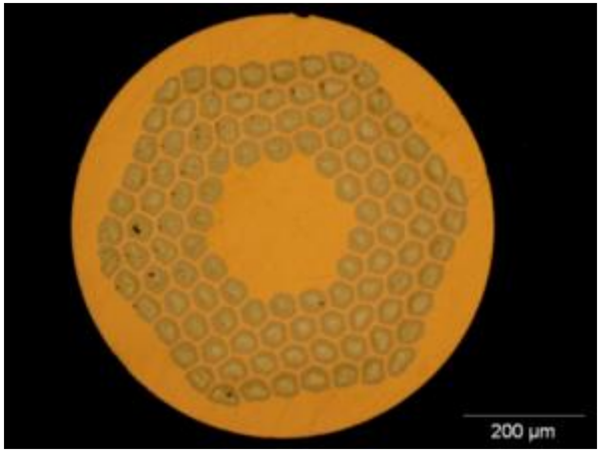
- Dipoles for beam recombination/separation capable of 6-8 T with 150-180 mm aperture (LHC: 1.8 T, 70 mm)
- Dipoles 11 T for LS2 (see later)

The « new » material : Nb_3Sn

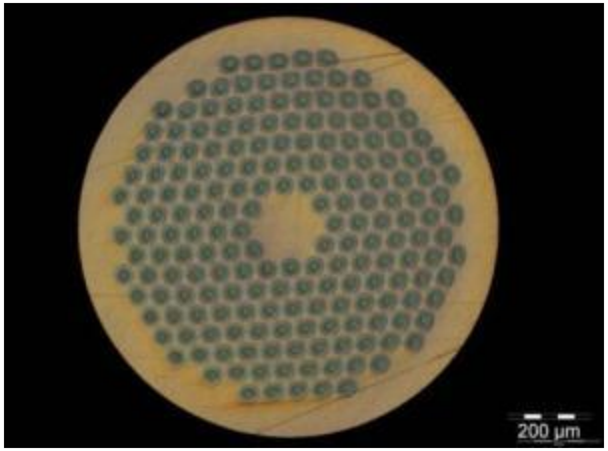
- Recent 23.4 T (1 GHz) NMR Magnet for spectroscopy in Nb_3Sn (and Nb-Ti).
- 15-20 tons/year for NMR and HF solenoids. Experimental MRI is taking off
- ITER: 500 tons in 2010-2015!

  It is comparable to LHC *(1200 tons of Nb-Ti but HL-LHC will require only 20 tons of Nb_3Sn)*

- HEP ITD (Internal Tin Diffusion):
  - High Jc., 3xJc ITER
  - Large filament (50 µm), large coupling current...
  - Cost is 5 times LHC Nb-Ti

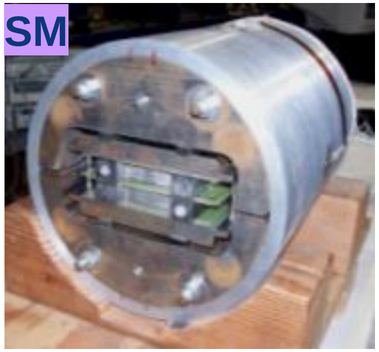


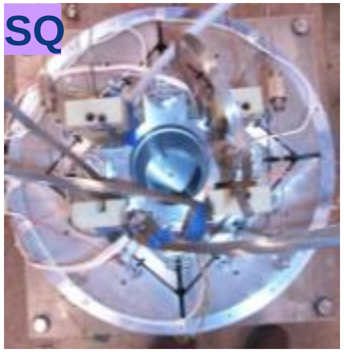
0.7 mm, 108/127 stack RRP from **Oxford OST**

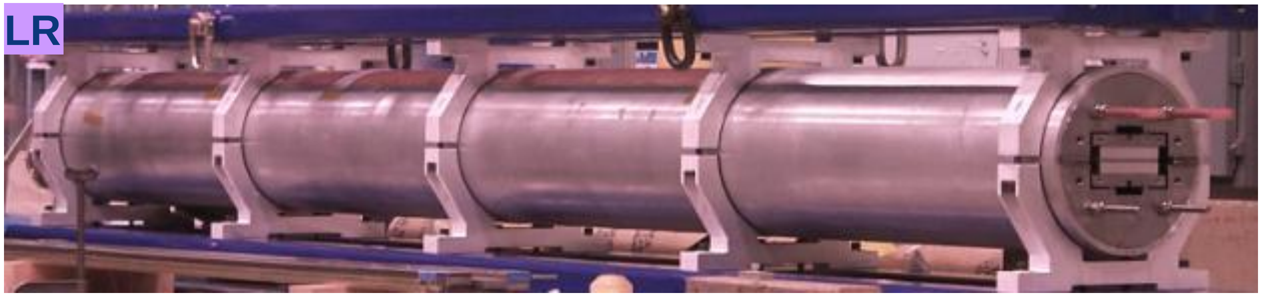


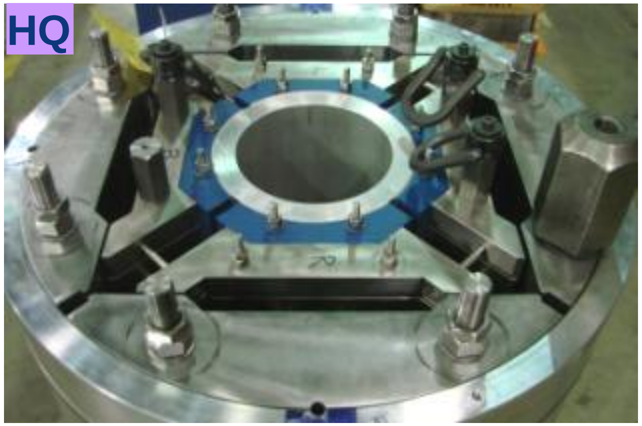
1 mm, 192 tubes PIT from **Bruker EAS**

LARP (US LHC program) Magnets





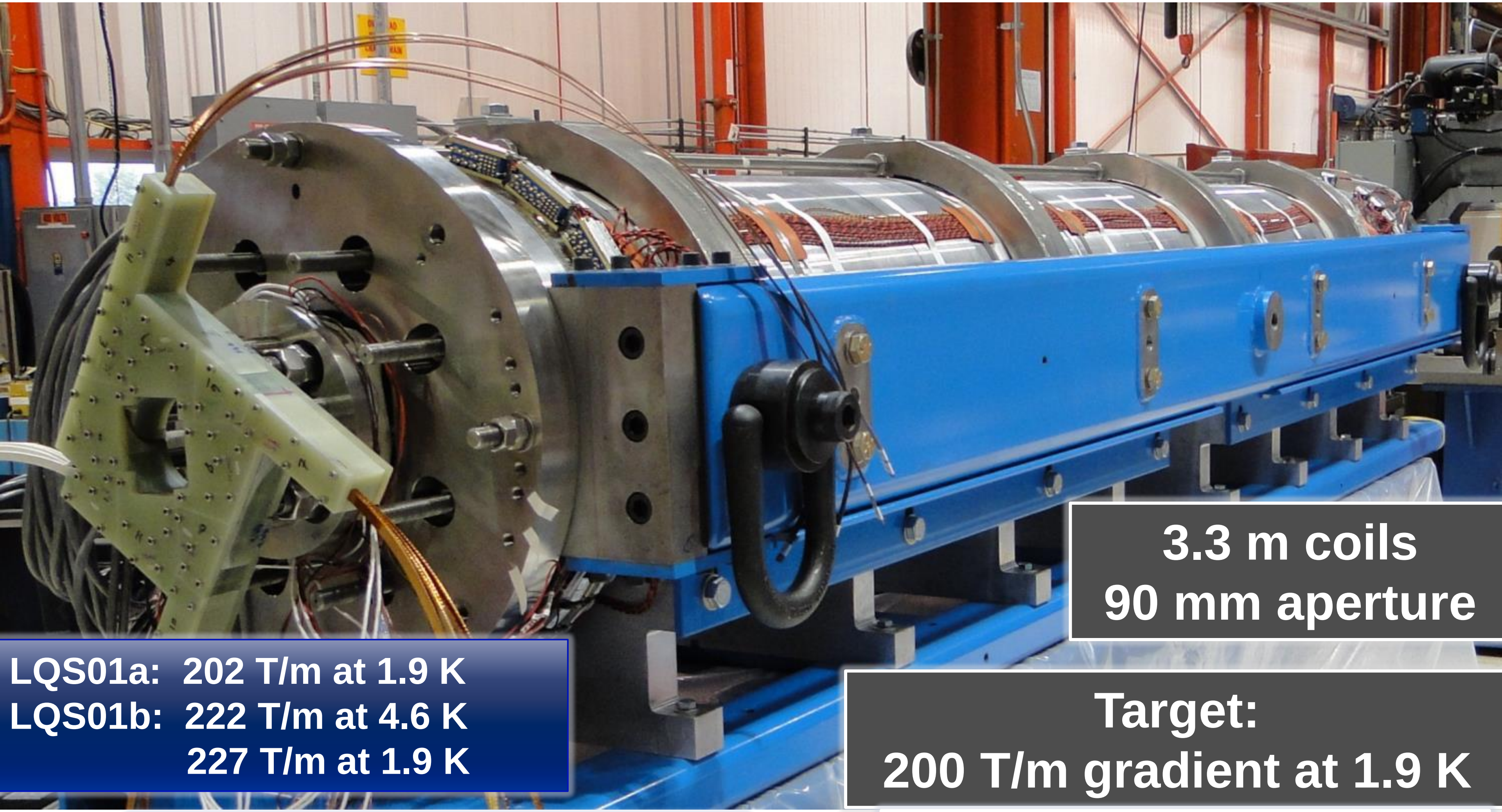




LQS of LARP

Courtesy: G. Ambrosio FNAL and G. Sabbi , LBNL

LARP



3.3 m coils
90 mm aperture

LQS01a: 202 T/m at 1.9 K
LQS01b: 222 T/m at 4.6 K
227 T/m at 1.9 K

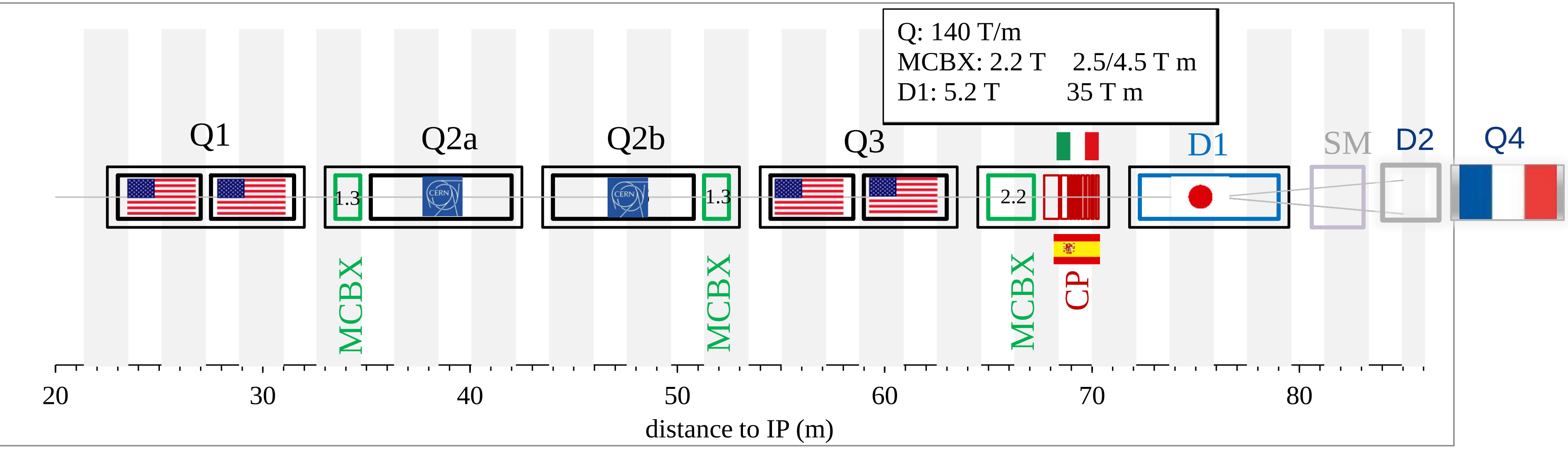
Target:
200 T/m gradient at 1.9 K

LQS02: 198 T/m at 4.6 K 150 A/s
208 T/m at 1.9 K 150 A/s
limited by one coil

LQS03: 208 T/m at 4.6 K
210 T/m at 1.9 K
1^{st} quench: 86% s.s. limit

Setting up International collaboration

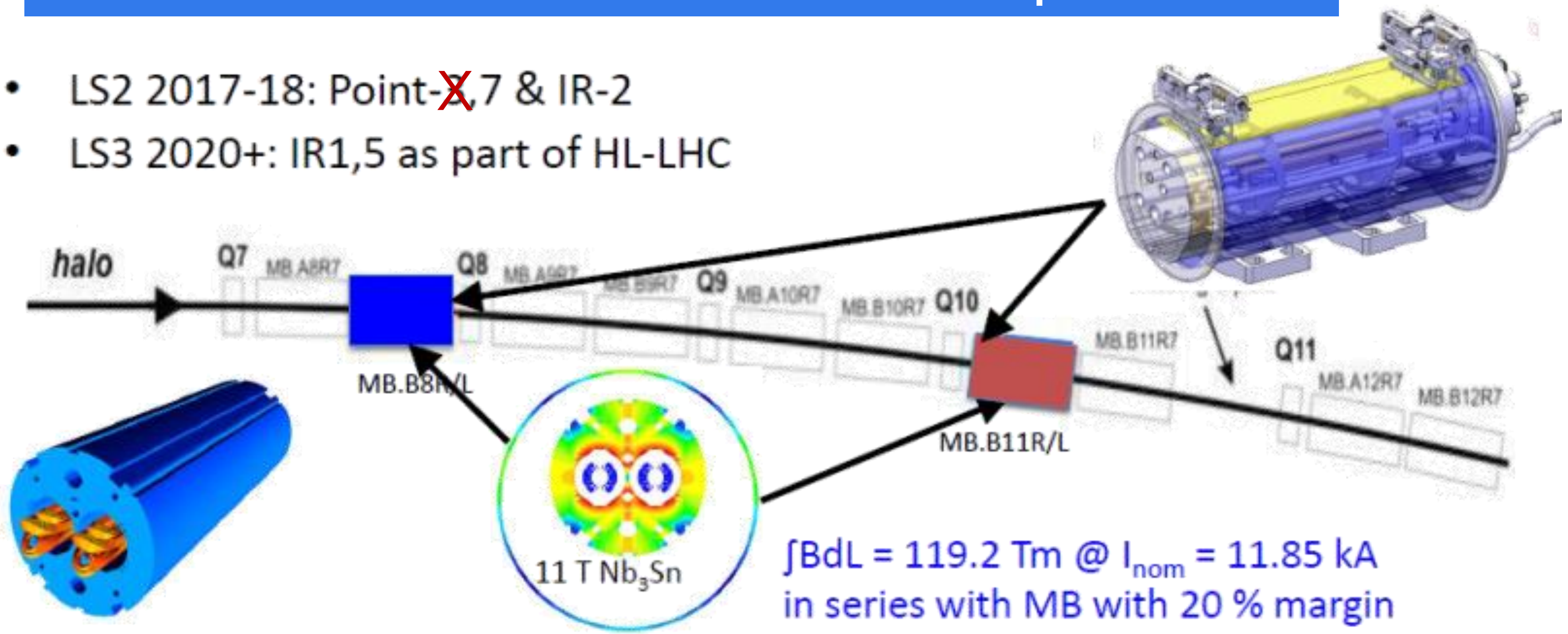
with national laboratories but also involving industrial firms



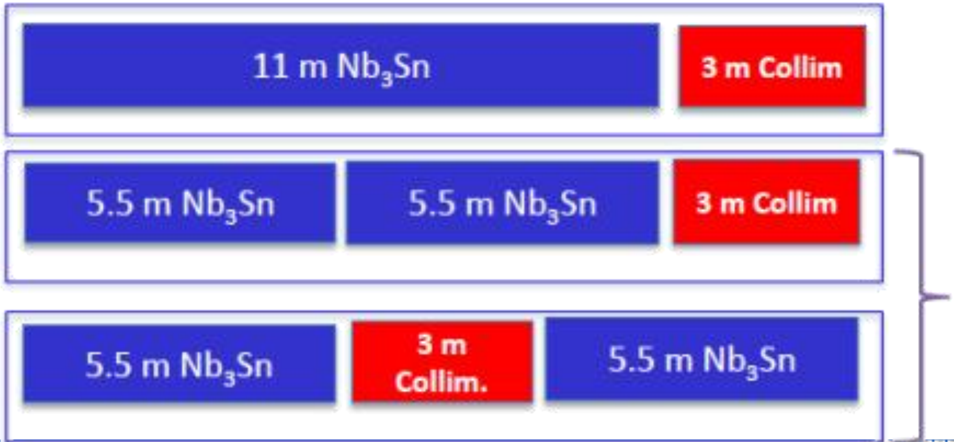
Baseline layout of HL-LHC IR region

LS2 : collimators and 11T Dipole

- LS2 2017-18: Point-~~3~~,7 & IR-2
- LS3 2020+: IR1,5 as part of HL-LHC



∫BdL = 119.2 Tm @ I_{nom} = 11.85 kA
in series with MB with 20 % margin

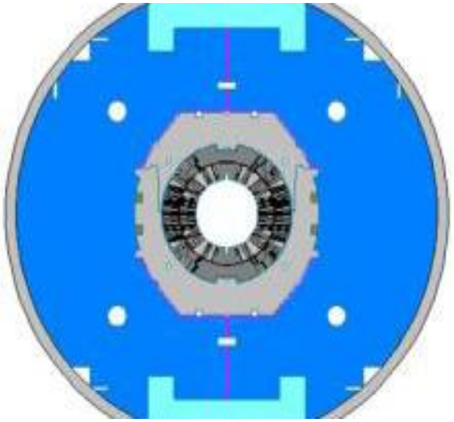


LS2: 12 coldmass + 2 spares = 14 CM
LS3: 8 coldmass + 2 spares = 10 CM
Total 24 CM

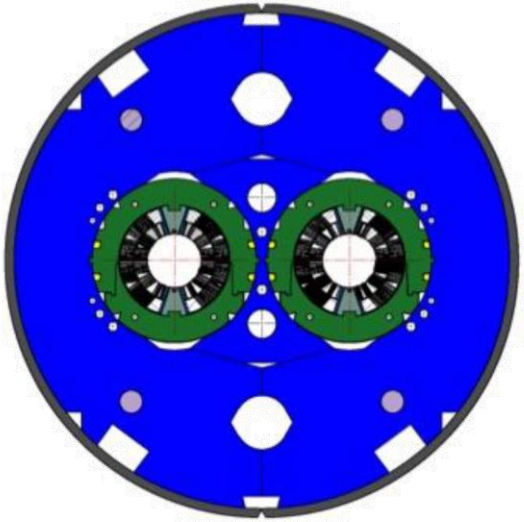
LS2: 24 coldmass + 4 spares = 28 CM
LS3: 16 coldmass + 4 spares = 20 CM
Total 48 CM

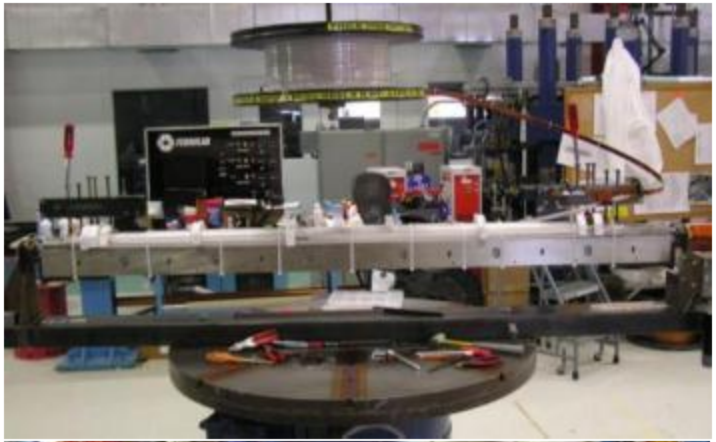
Nb_3Sn 11T Dipole R&D

Single aperture model



Twin aperture model



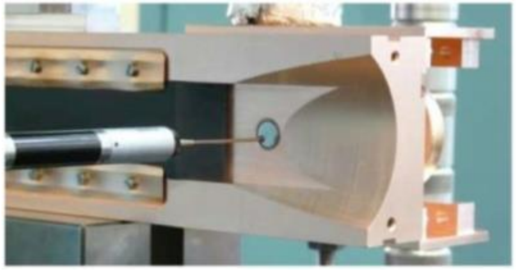


Fermilab

IR Collimation Upgrade

Update of present collimation system during LS1:

- Replace existing collimators
- Reduce setup time (gain of factor ~100)
- Improved monitoring



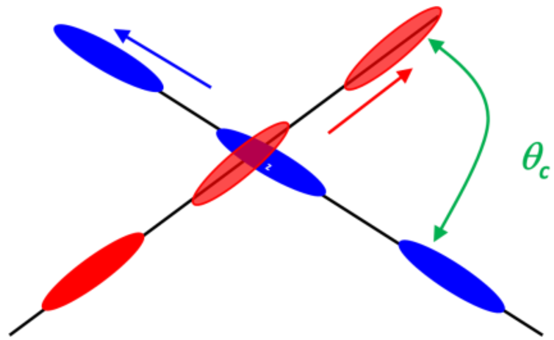
For HL-LHC add dispersion suppressor collimation

- Eliminate off-momentum particles in a region with high dispersion
- Technology of choice for the DS collimators is warm with by-pass cryostat
- **low impedance collimators: coating with Molybdenum**
- Design completed with 4.5 m integration length.
- Prototyping on-going

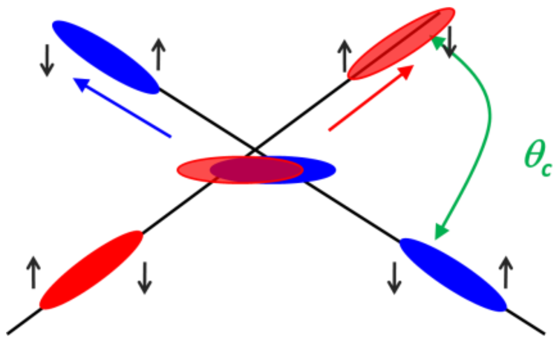
Crab Cavities, Increase “Head on”

Aim: reduce the effect of the crossing angle

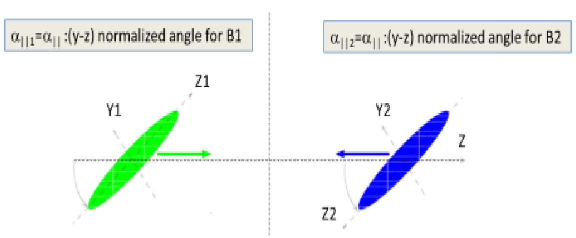
Without crabbing



Without crabbing



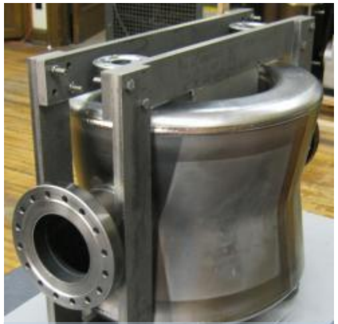
New crossing strategy under study to soften the pile-up density:
some new schemas have interesting potential as “crab-kissing”, to be discussed with all experiments
(“Pile-up at HL-LHC and possible mitigation” Stephane Fartoukh)



- 3 proto types available
- Cavity tests are on-going
- Test with beam in SPS foreseen in 2015-2016
- Beam test in LHC foreseen in 2017

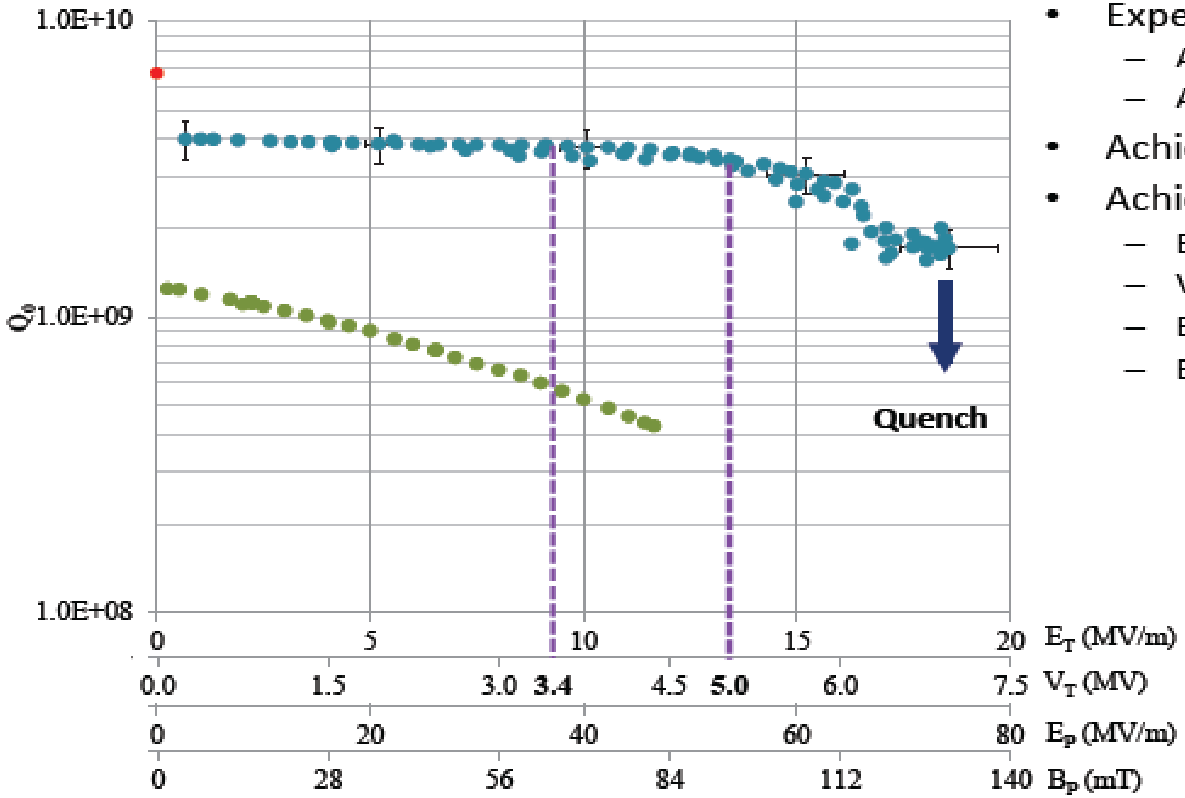

RF-Dipole Nb prototype


4-rod in SM18 for RF measurements

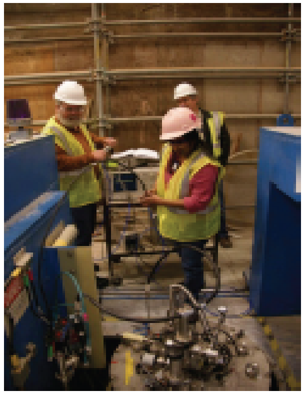

DQWR prototype
17-Jan-2013

First test of RF dipole (April 2013) (ODU-SLAC at J-LAB)

PoP RF Dipole 4.2 K and 2 K Test Results



- Expected $Q_0 = 6.7\times10^9$
  - At $R_S = 22\ n\Omega$
  - And $R_{res} = 20\ n\Omega$
- Achieved $Q_0 = 4.0\times10^9$
- Achieved fields
  - $E_T = 18.6$ MV/m
  - $V_T = 7.0$ MV
  - $E_P = 75$ MV/m
  - $B_P = 131$ mT



Courtesy A. Ratti, LBL

Thinking to cryomodule…

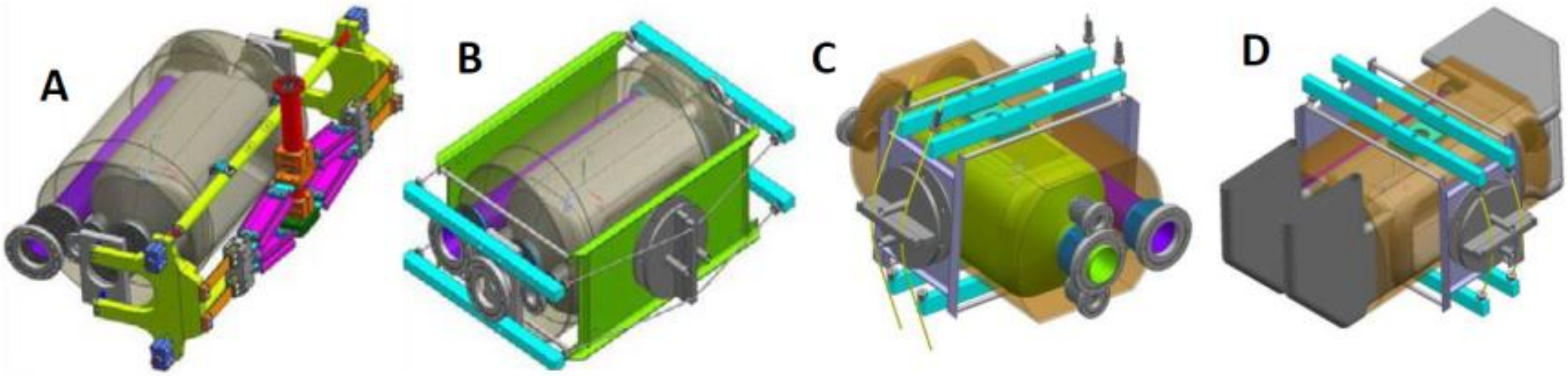
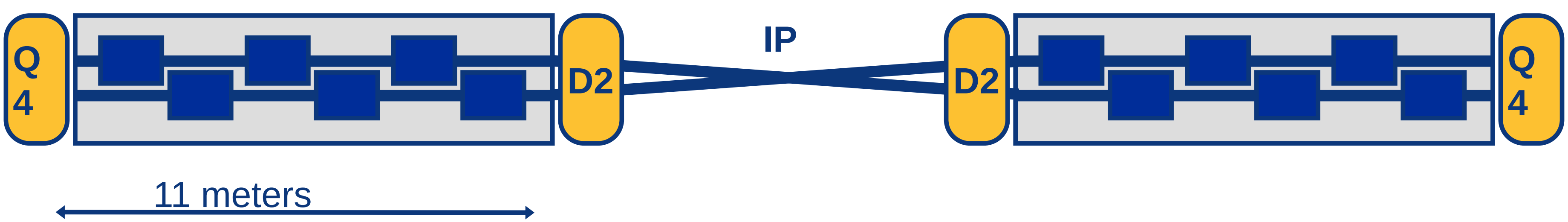
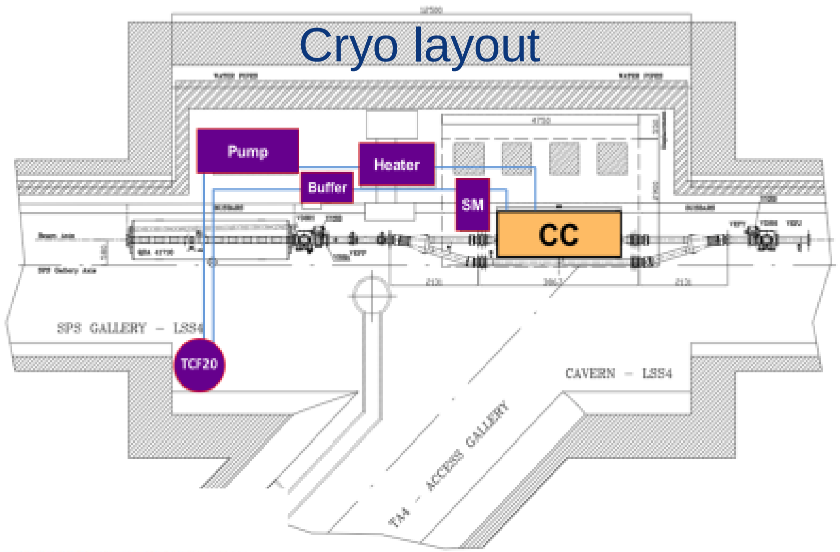


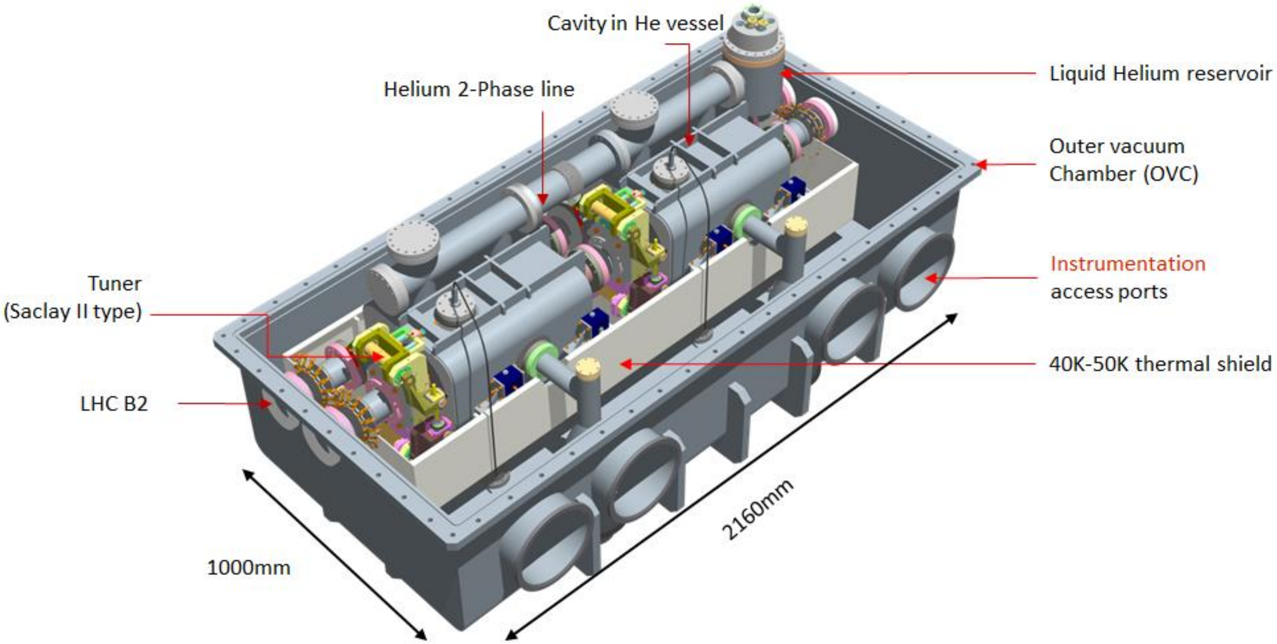
Figure 1: LHC crab cavity cryostat concept – A) JLab design, B) ANL design (helium pressure actuates bellows), C) ANL design (tuner deforms cavity outer surfaces), D) Waveguide



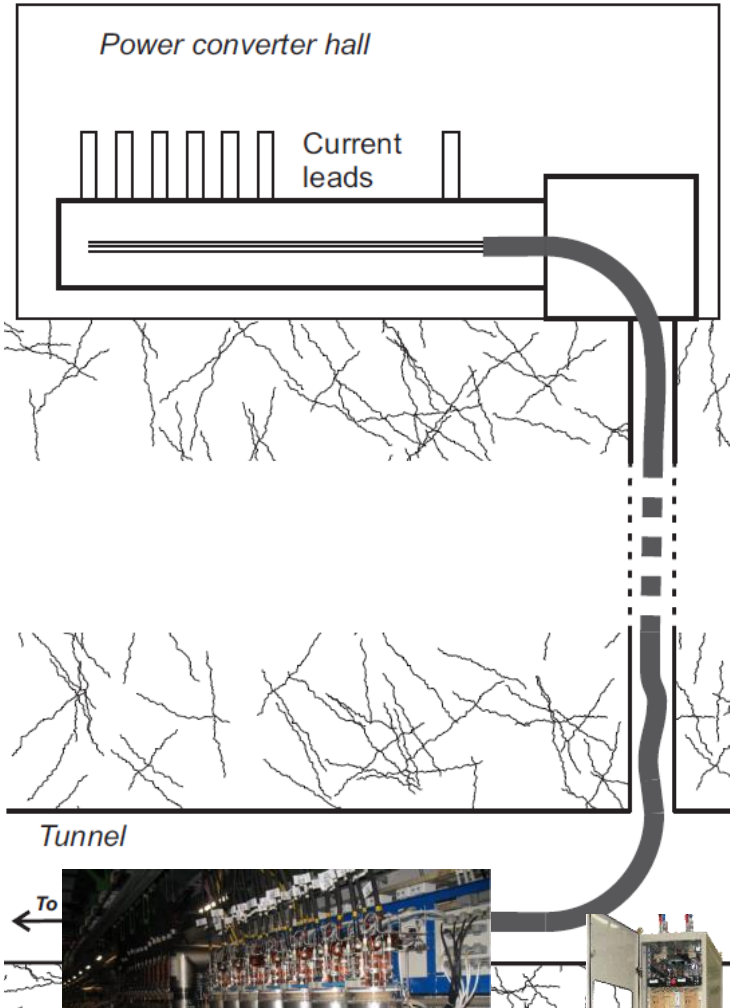
Courtesy Lucio Rossi

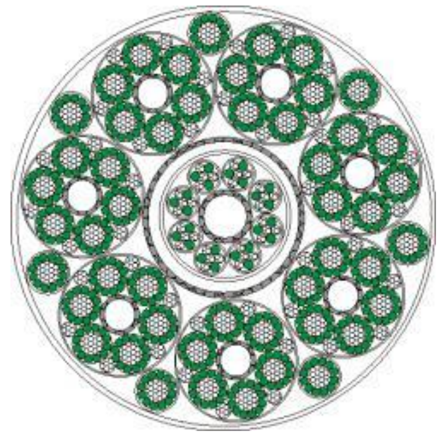
…and to test with beam in the CERN SPS (2016-2017)



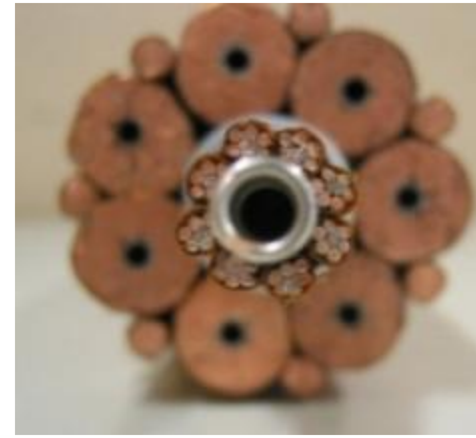


R2E: Removal of Power Converter (200kA-5 kV SC cable, 100 m height)





Φ = 62 mm

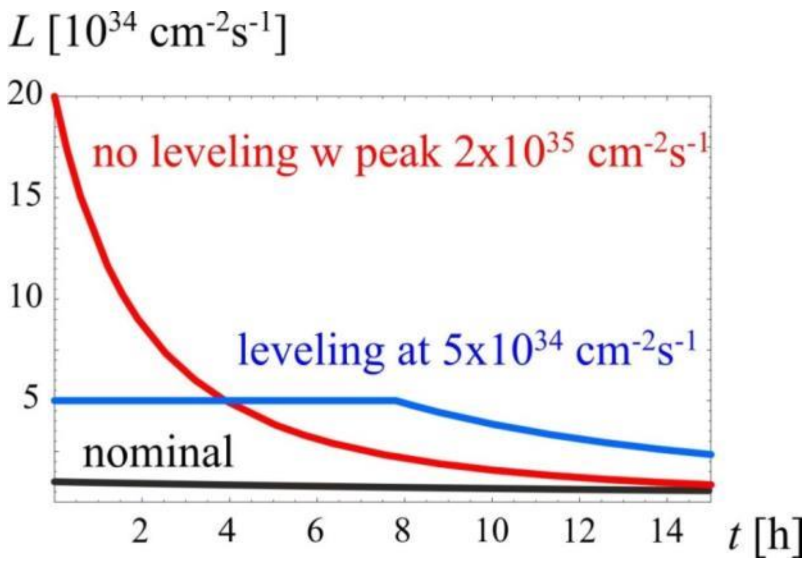


MgB_2
(or other HTS)

7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables – Itot~120 kA @ 30 K

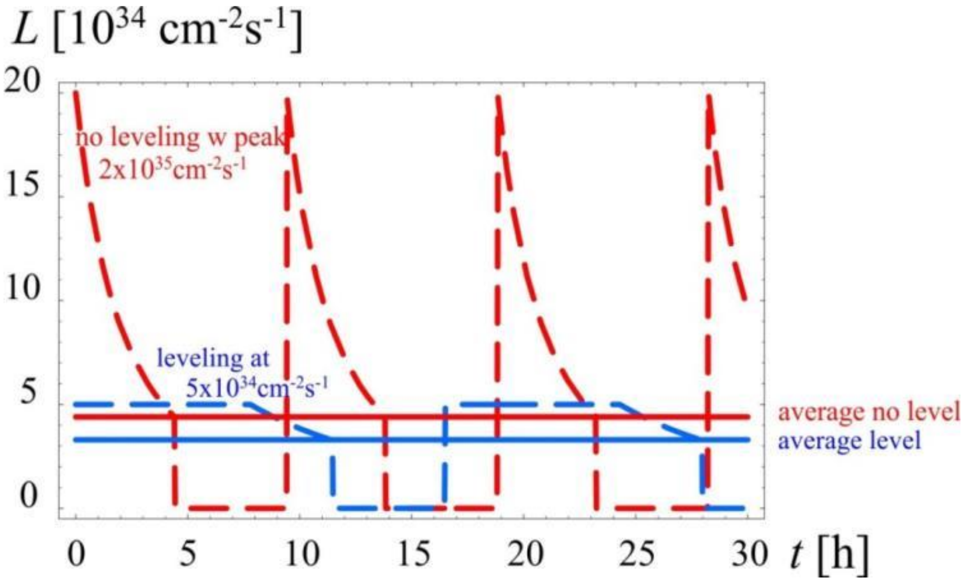
Also DFBs (current lead boxes) removed to surface
Final solution to R2E problem – in some points
Make room for shielding un-movable electronics
Make the maintenance and application of ALARA principle much easier and effective

Luminosity Levelling, a key to success



- High peak luminosity
- Minimize pile-up in experiments and provide "constant" luminosity

- Obtain about 3 - 4 fb^{-1}/day (40% stable beams)
- About 250 to 300 fb^{-1}/year



Baseline parameters of HL for reaching 250 -300 fb^{-1}/year

25 ns is the option

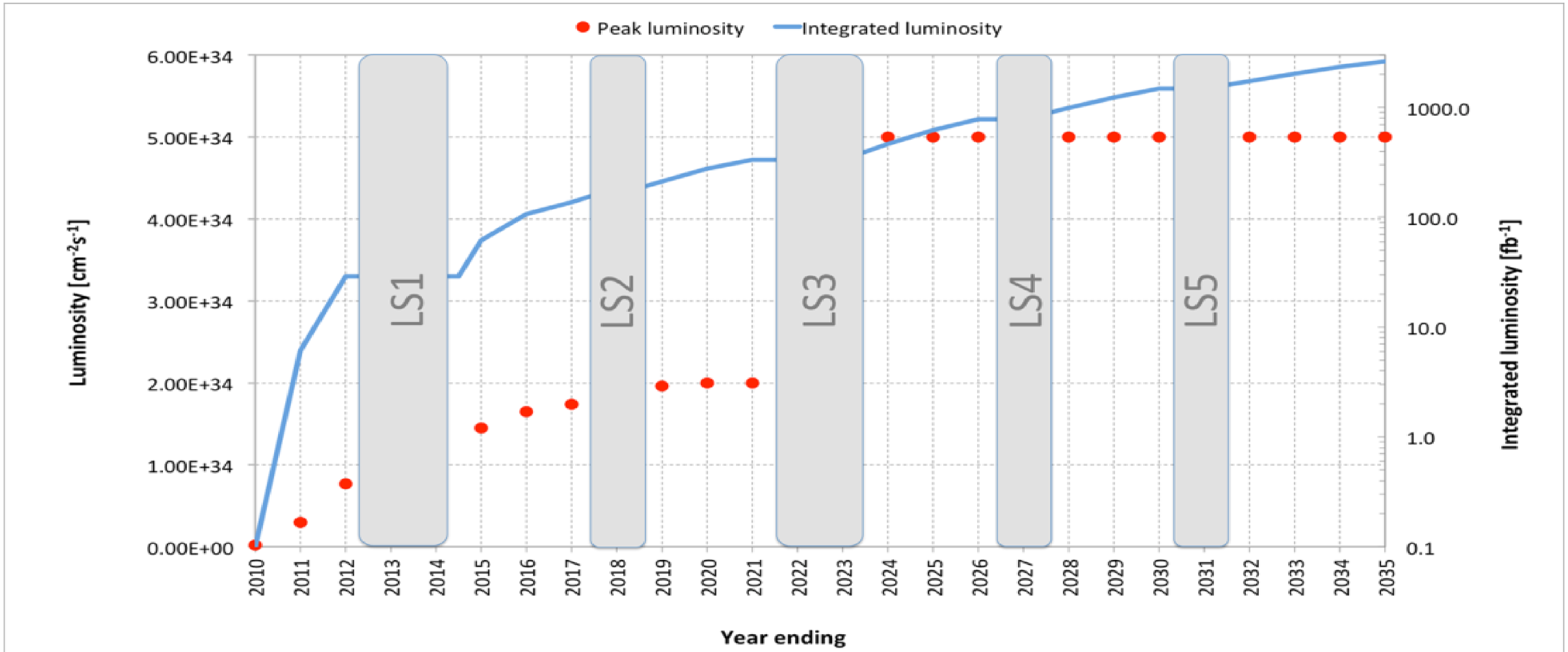
However:
50 ns should be kept as alive and possible because we DO NOT have enough experience on the actual limit *(e-clouds, I_{beam})*

Continuous global optimisation with LIU

	25 ns	50 ns
# Bunches	2808	1404
p/bunch [10^{11}]	**2.0 (1.01 A)**	**3.3 (0.83 A)**
ε_L [eV.s]	2.5	2.5
σ_z [cm]	7.5	7.5
$\sigma_{\delta p/p}$ [10^{-3}]	0.1	0.1
$\gamma\varepsilon_{x,y}$ [μm]	**2.5**	**3.0**
β^* [cm] (baseline)	15	15
X-angle [μrad]	**590 (12.5 σ)**	**590 (11.4 σ)**
Loss factor	0.30	0.33
Peak lumi [10^{34}]	6.0	7.4
Virtual lumi [10^{34}]	20.0	22.7
$T_{leveling}$ [h] @ 5E34	**7.8**	**6.8**
#Pile up @5E34	123	247

Courtesy Oliver Brüning

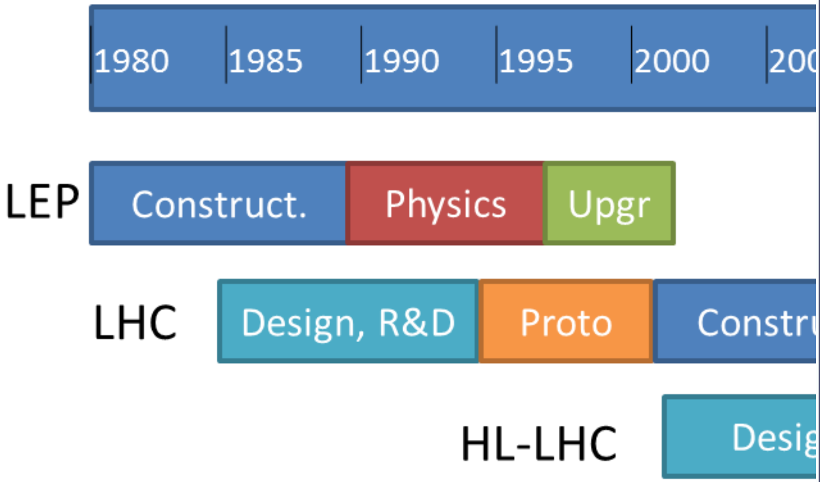
The plan of HL-LHC (baseline)



Levelling at 5 10^{34} cm^{-2} s^{-1}: 140 events/crossing in average, at 25 ns; several scenarios under study to limit to 1.0 → 1.3 event/mm

Total integrated luminosity of 3000 fb^{-1} for p-p by 2035, with LSs taken into account and 1 month for ion physics per year.

"…exploitation of the full pote
high-luminosity upgrade of th
=> High Lumi



Kick-off meeting: 11th Nov. 2013
(Daresbury)

http://cern.ch/hilumilhc

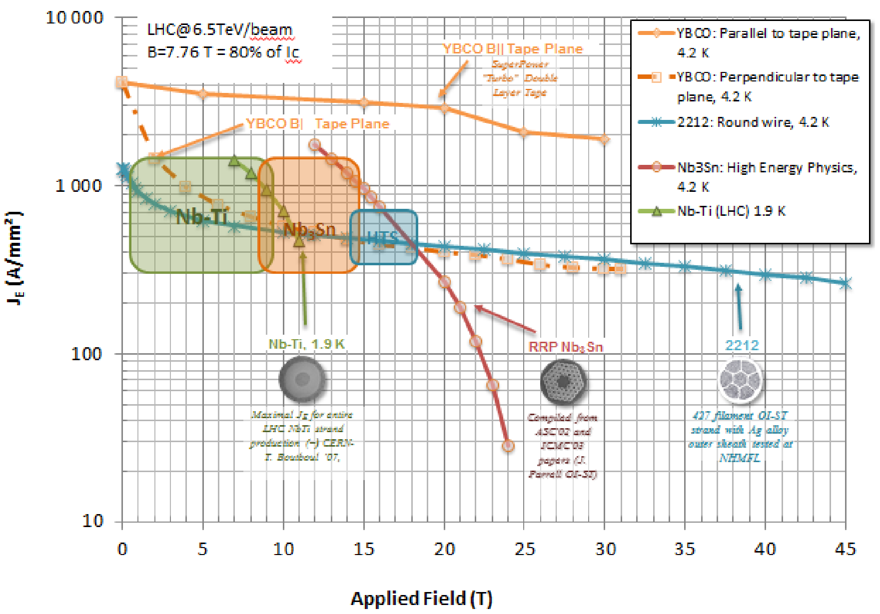
Next Milestones: High Luminosity LHC

Jun. 2014:	PDR (Preliminary Design Report) and re-baseline (costing, time) of the project
Sep. 2015:	First short model QXF (inner triplet)
Nov. 2015:	TDR and end of FP7 Design Study
Sep. 2016:	First full size MQXF (long triplet Quad)
2016-17:	Test Crab Cavities in SPS
	Start Construction
LS2 (2018):	Installation in LS2 of Cryogenics P4, SC horizontal link P7, 11 T dipole and DS collimators in P2, first Molybdenum collimators
LS3 (2022-23) :	installation of all HL-LHC hardware synchronized with long detector shutdown

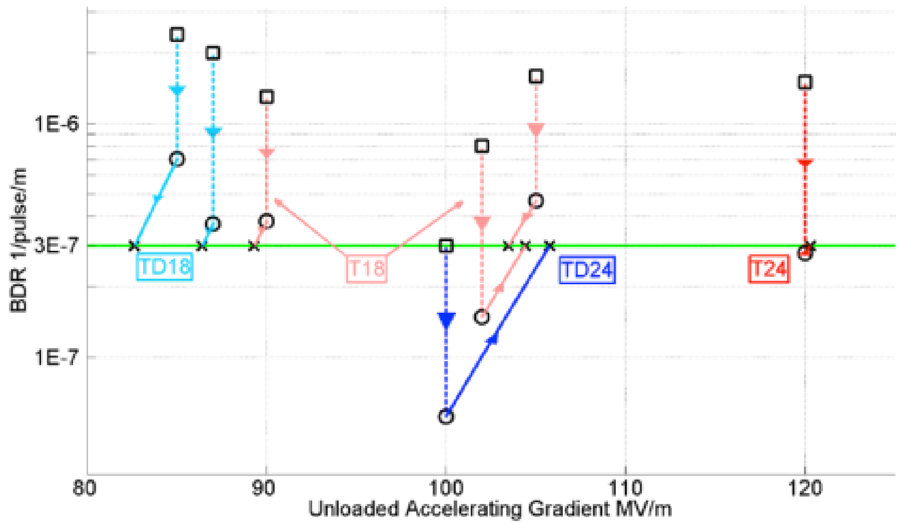
“to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update”

d) *CERN should undertake design studies for accelerator projects in a global context,* *with emphasis on **proton-proton and electron-positron high-energy frontier machines**. These design studies should be coupled to a vigorous accelerator **R&D programme**, including **high-field magnets and high-gradient accelerating structures**, **in collaboration with national institutes, laboratories and universities worldwide.***

HFM



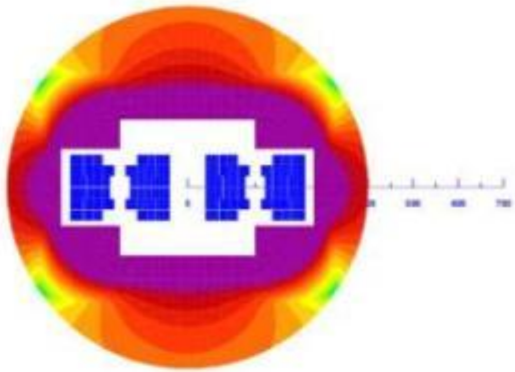
HGA

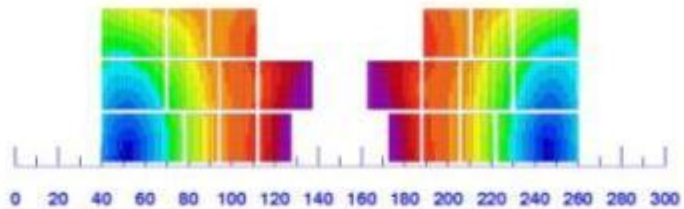


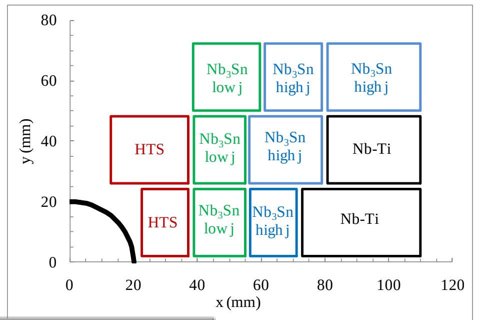
And also R&D on Proton-Driven Plasma Wakefield Acceleration (AWAKE Expt at CERN)

Malta Workshop: **HE-LHC @ 33 TeV c.o.m.**

14-16 October 2010







Material	N. turns	Coil fraction	Peak field	$J_{overall}$ (A/mm^2)
Nb-Ti	41	27%	8	380
Nb3Sn (high Jc)	55	37%	13	380
Nb3Sn (Low Jc)	30	20%	15	190
HTS	24	16%	20.5	380

Magnet design (20 T): very challenging but not impossible.

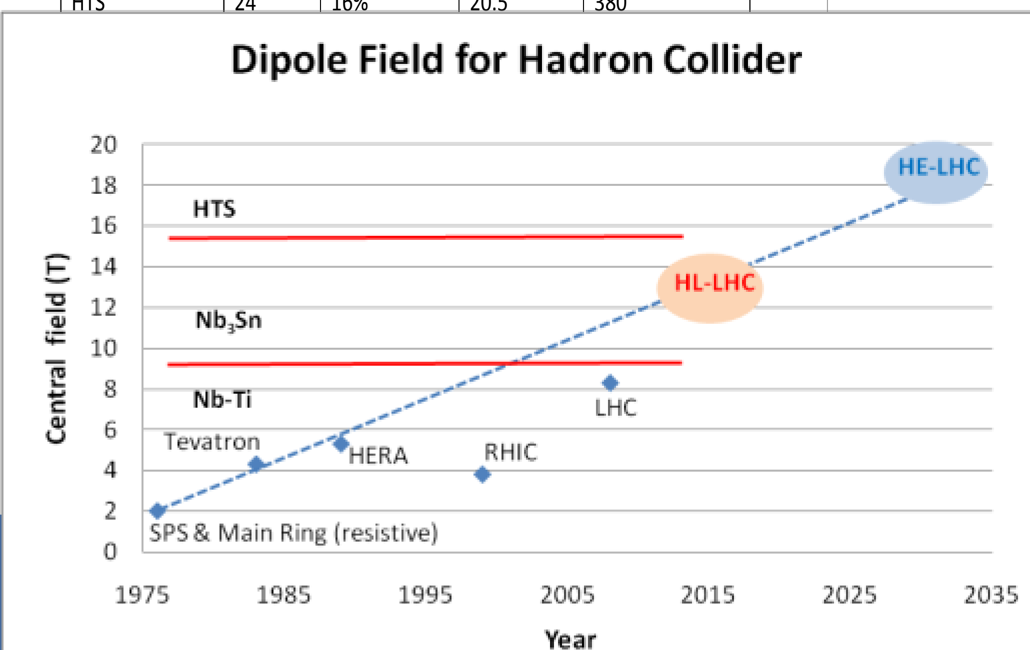
300 mm inter-beam

Multiple powering in the same magnet (and more sectioning for energy)

Work for 4 years to assess HTS for 2X20T to open the way to 16.5 T/beam .

Otherwise limit field to 15.5 T for 2x13 TeV

Higher INJ energy is desirable (2xSPS)



ng the beam screen at 60 K.

ks to dumping time.

IC. Reaching $2x10^{34}$ appears reasonable.

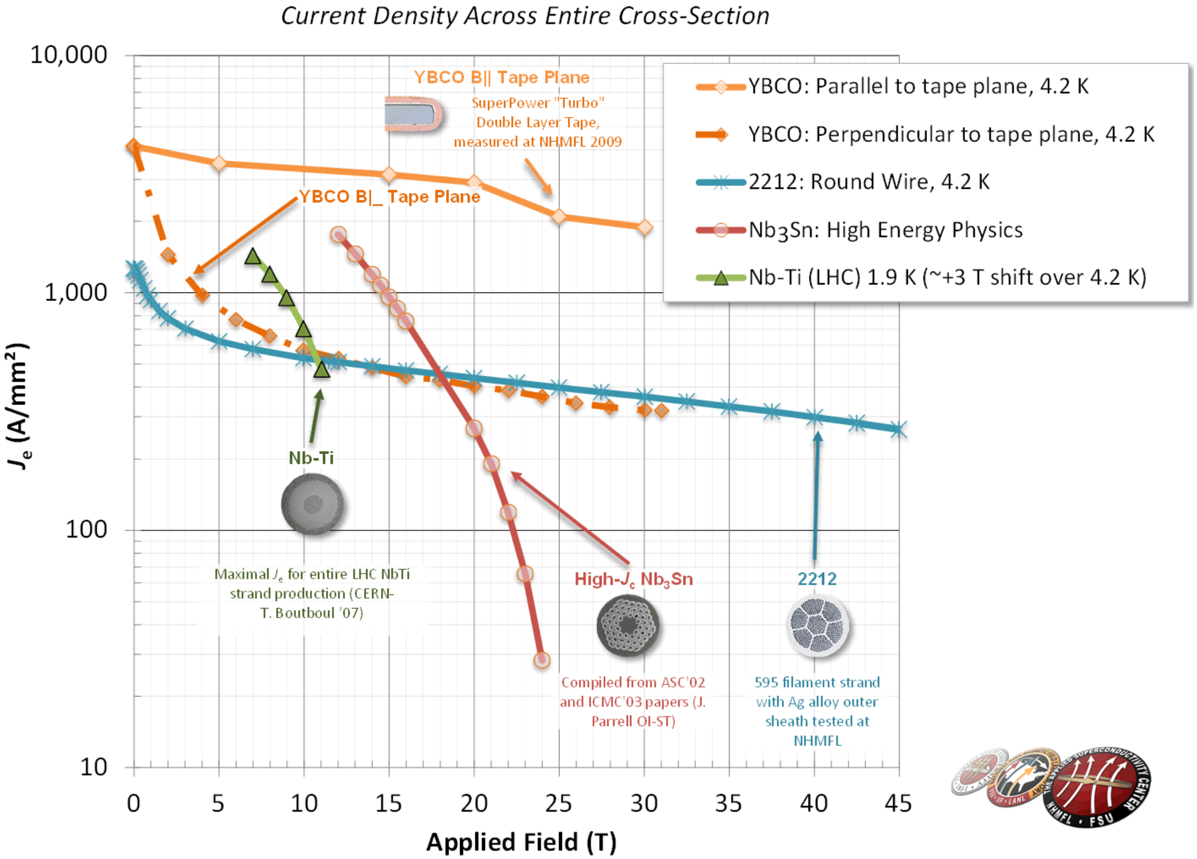
s beam handling for INJ & beam dump:

nake twice more room for LHC kickers.

HE-LHC main parameters

parameter	LHC	HL-LHC	HE-LHC
c.m. energy [TeV]	14		33
circumference C [km]	26.7		26.7
dipole field [T]	8.33		20
dipole coil aperture [mm]	56		40
beam half aperture [cm]	~2		1.3
injection energy [TeV]	0.45		>1.0
no. of bunches	2808		2808
bunch population N_b [10^{11}]	1.15	2.2	0.94
init. tr. norm. emittance [μm]	3.75	2.5	1.38
init. longit. emittance [eVs]	2.5		3.8
no. IPs contributing to ΔQ	3	2	2
max. total b-b tune shift ΔQ	0.01	0.015	0.01
beam current [A]	0.584	1.12	0.478
rms bunch length [cm]	7.55		7.55
IP beta function [m]	0.55	0.15	0.35
rms IP spot size [μm]	16.7	7.1 (min.)	5.2

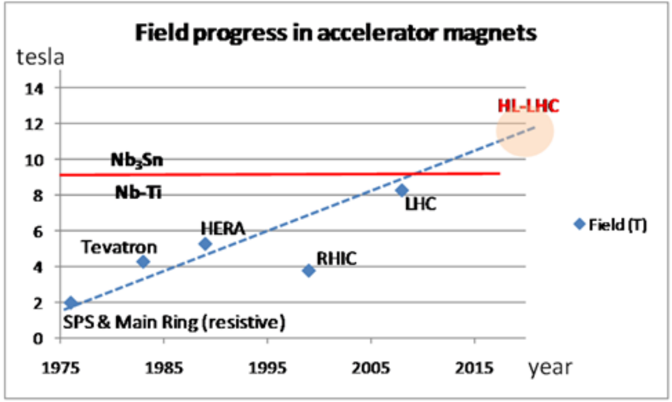
Superconductors: from materials to applications



Superconductors as seen by the eye of an engineer

The grand challenge of today is to develop the technology of **high-field superconductors** **(field quality,…)**

LTS (NbTi ; Nb_3Sn)



NbTi mature but limited to 9T

Is Nb_3Sn mature ? Yes, and no

performance of Nb_3Sn wires has seen a great boost in the past decade (factor 3 in J_C w/r to ITER)

However, Nb_3Sn magnets were never built nor operated in accelerators. Manufacturing, quench, training, protection, strain tolerance, field quality are the focus today to make this new technology a reality

Solid and aggressive R&D in HFM (High Field Magnet) for accelerators must be intensified

From Luca Bottura

HTS

Can HTS displace LTS ? Not today

Much needs to be done to bring this technology to a point where it can be sold as “mature”

Materials have potential that can be exploited

- OPHT for BSCCO-2212
- Thicker layer for YBCO tapes
- The Holy Grail of a round YBCO wire

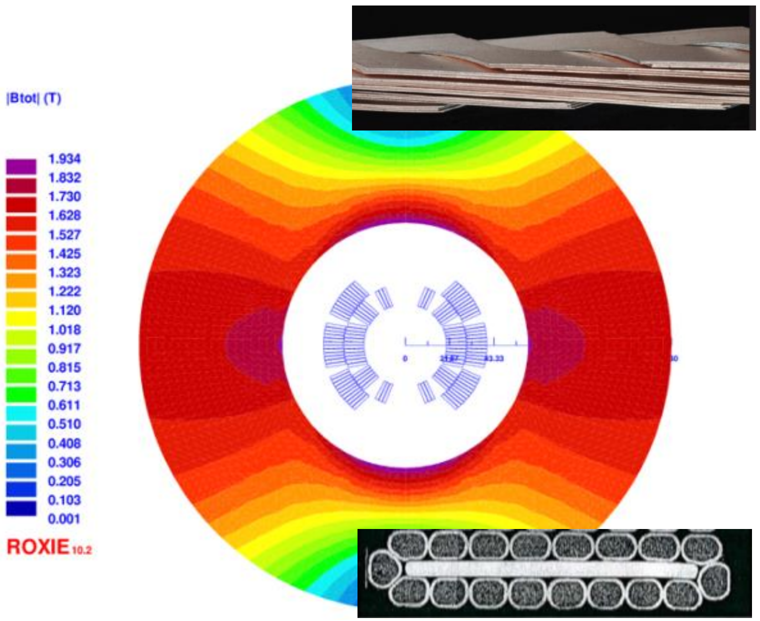
Production quantities, homogeneity and cost need to evolve

Step-up application demands, from self-field (SC-link is an ideal test-bed) to high-field accelerator magnets (feasibility)

From Luca

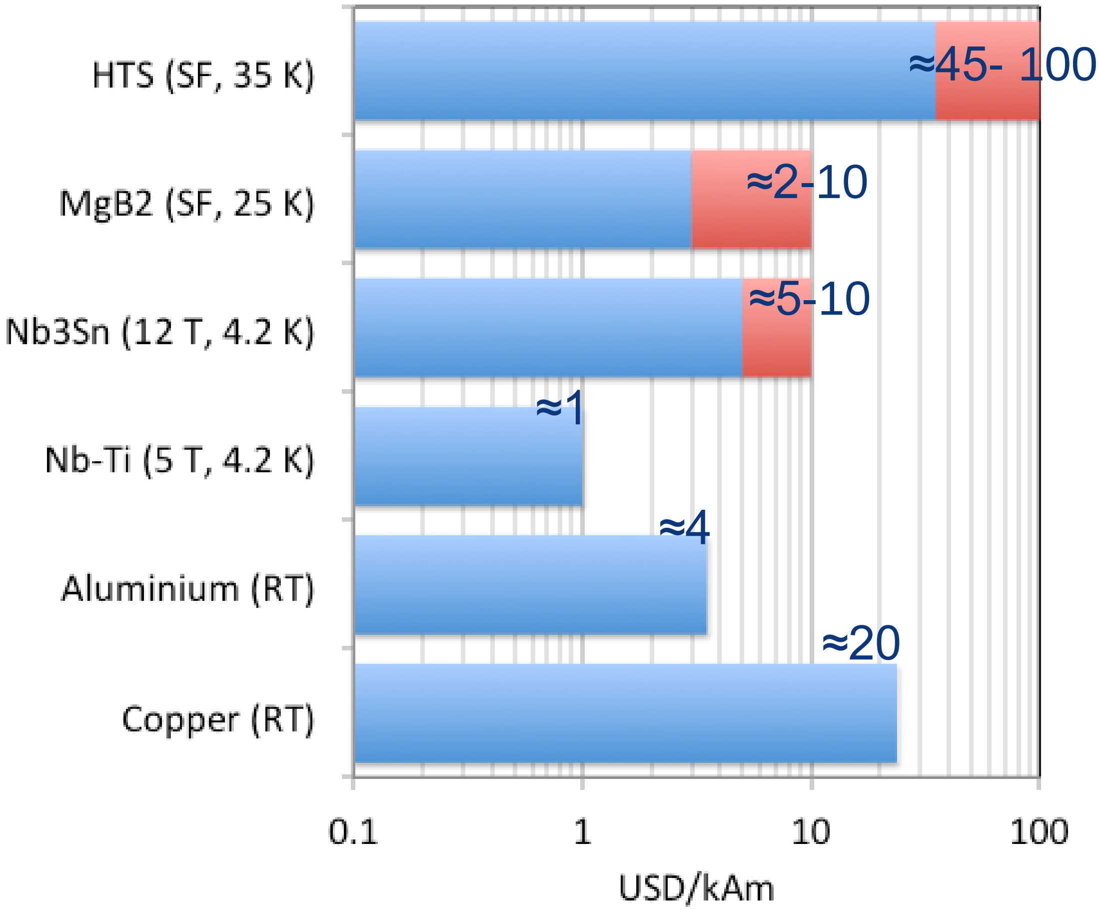
Program Eucard2 on HTS

EuCARD2: Develop 10 kA class HTS accelerator cable using Bi-2212 and YBCO. Test stability, magnetization, and strain tolerance



WP10: a 5 T, 40 mm bore HTS dipole

From materials to applications



Superconductors as seen by the eye of a manager

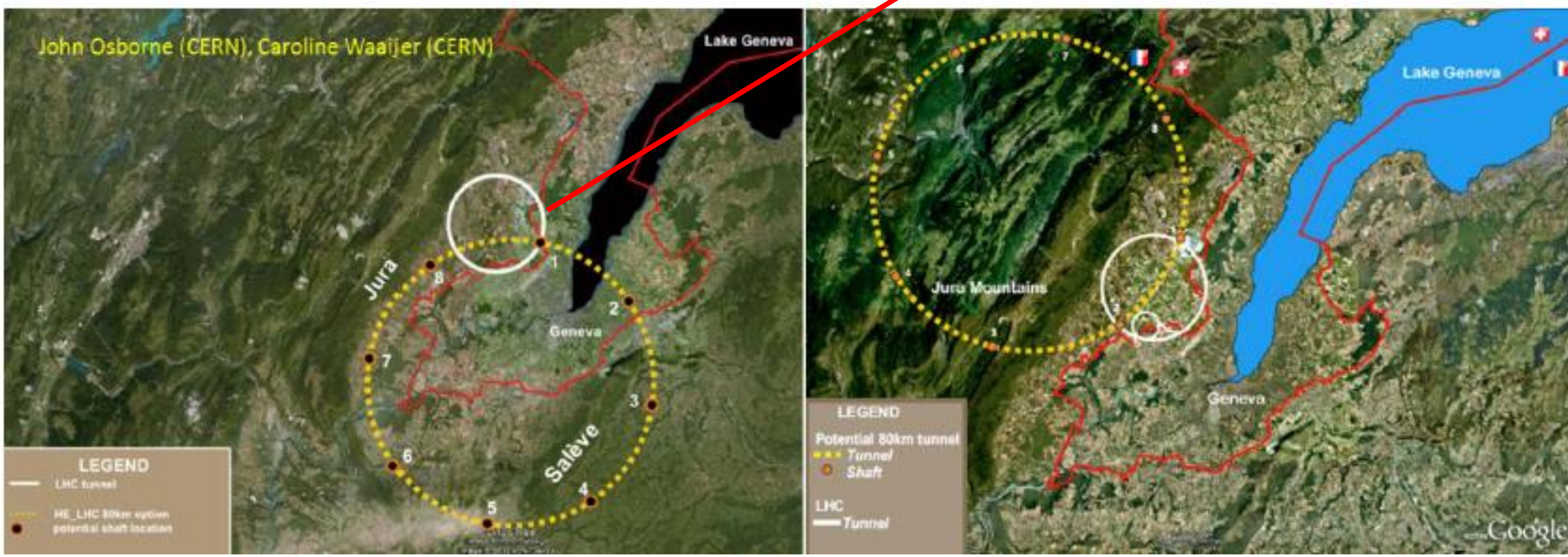
The grand challenge of today is availability of **long lengths of reasonably priced commercial materials**

"Very High Energy LHC"

First studies on a new 80 km tunnel in the Geneva area

- **42 TeV with 8.3 T using present LHC dipoles**
- **80 TeV with 16 T based on Nb_3Sn dipoles**
- **100 TeV with 20 T based on HTS dipoles**

HE-LHC :33 TeV with 20T magnets

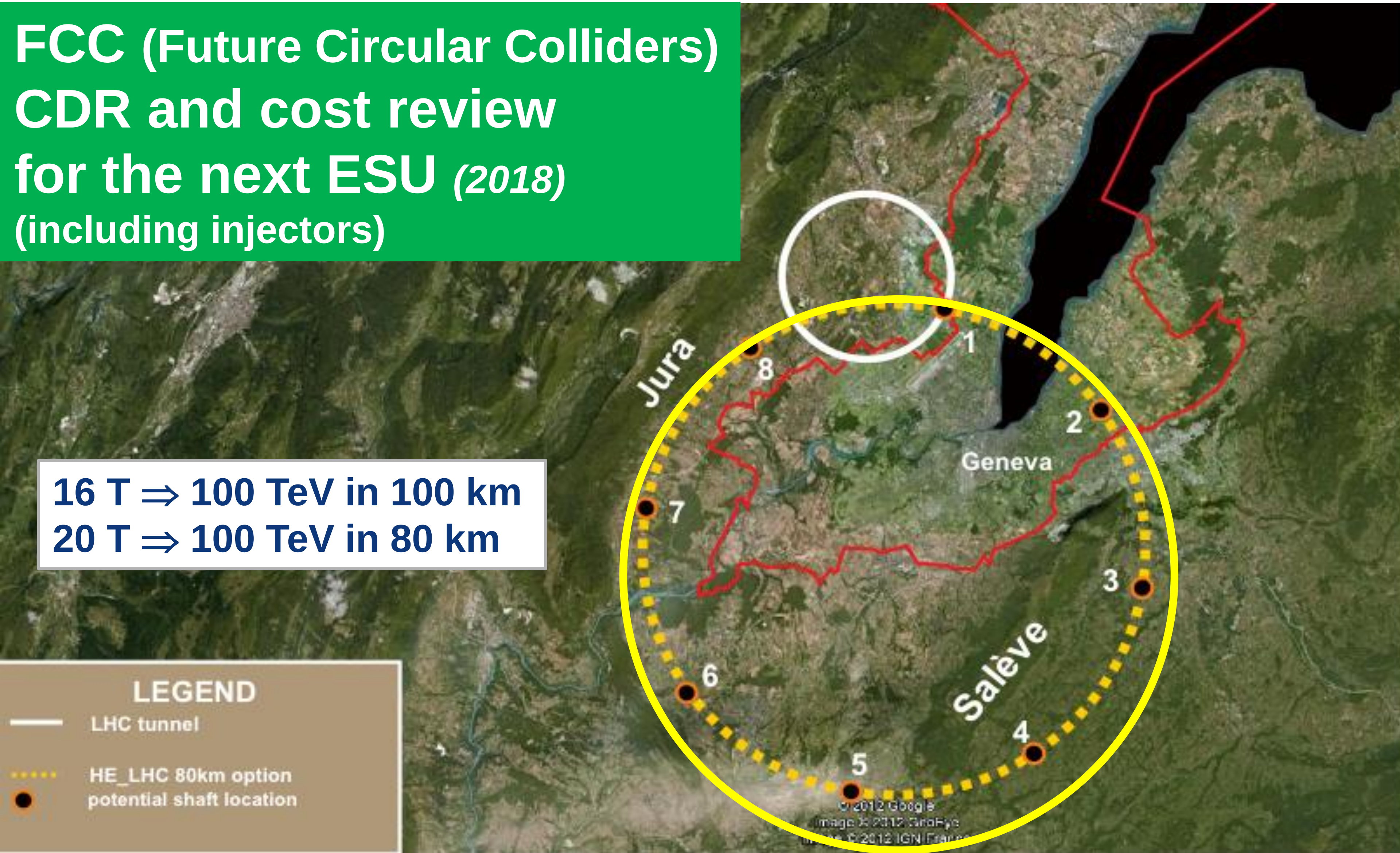


80-100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements

with possibility of e+-e- (TLEP) and p-e (VLHeC)

FCC (Future Circular Colliders) CDR and cost review for the next ESU *(2018)*
(including injectors)

16 T ⇒ 100 TeV in 100 km
20 T ⇒ 100 TeV in 80 km



FCC Study Scope and Structure

Future Circular Colliders - Conceptual Design Study for next European Strategy Update (2018)

Infrastructure

tunnels, surface buildings, transport (access roads), civil engineering, cooling ventilation, electricity, cryogenics, communication & IT, fabrication and installation processes, maintenance, environmental impact and monitoring,

Hadron injectors

Beam optics and dynamics
Functional specs
Performance specs
Critical technical systems
Operation concept

Hadron collider

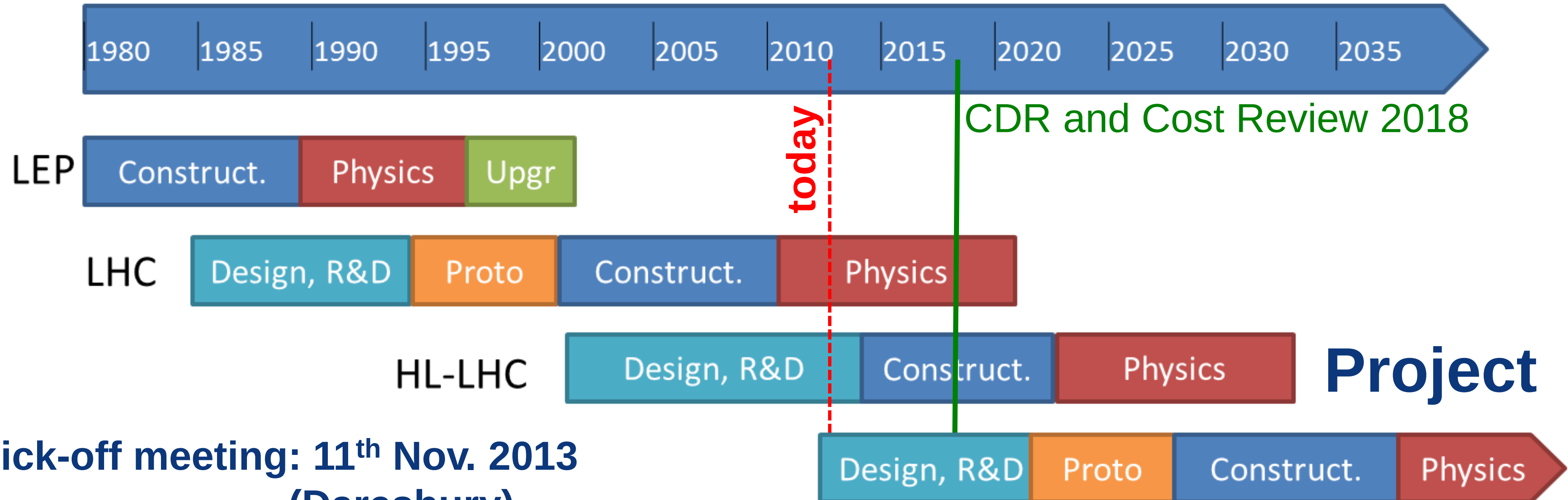
Optics and beam dynamics
Functional specifications
Performance specs
Critical technical systems
Related R+D programs
HE-LHC comparison
Operation concept
Detector concept
Physics requirements

e+ e- collider

Optics and beam dynamics
Functional specifications
Performance specs
Critical technical systems
Related R+D programs
Injector (Booster)
Operation concept
Detector concept
Physics requirements

e- p option: Physics, Integration, additional requirements

"CERN should undertake design studies for accelerator projects in a global context, with emphasis on ***proton-proton*** *and electron- positron* ***high-energy frontier machines****."*



Kick-off meeting: 11th Nov. 2013 (Daresbury)

FCC Study : p-p towards 100 TeV

Kick-off meeting: 12th-14th Feb. 2014

FCC: Future Circular Colliders

Conclusion: "Exploitation of the full potential of the LHC"

- LS1 [2013-2014] : 1st beams in 2015
- Run 2 : 13 TeV – 25 ns – up to 1.7 10^{34} $cm^{-2}.s^{-1}$, 40-45 fb^{-1} per year
- LS2 (higher intensity - LIU) [2018 or 2019]
- Run 3 (up to ~2.0 10^{34} $cm^{-2}.s^{-1}$)

300 fb^{-1} before LS3

- HL-LHC : R&D => now an approved project with a kick-off meeting on 11th Nov. 2013

A lot of technical and operation challenges :
- Nb3Sn magnets (accelerator field quality) (HFM roadmap)
- Collimators
- Superconducting links
- Crab cavities
- Increased availability (machine protection,…)
- …

Accelerator-experiment interface are central:
- Bunch spacing, pile-up density, crossing schemas, background, forward detectors, collimation,…

3000 fb^{-1} before 2035

Conclusion cont'd : FCC

- **CERN is undertaking an international study for the design of future circular colliders (FCC) in the 100 km range:**

CDR and cost review for the next ESU (target 2018)

- **Main emphasis is on a hadron collider with a c.m. energy of ~100 TeV at the energy frontier, determining the infrastructure.**

- **The common study will also contain an e^+e^- collider, as potential intermediate step, and look at an e-p option.**

- ***Preparation of FCC Design Study kick-off meeting:***

12-14th February 2014 in Geneva area

  - ***Establishing international collaborations***
  - ***Set-up study groups and study committees***
  - ***International Advisory Committee (IAC)***

Thanks for your attention

CERN

www.cern.ch

Main parameters for FHC *(VHE-LHC)*

- **energy = 100 TeV c.m.**
- **dipole field = 16 T (baseline)**

  [20 T option] (design limit)
- **circumference ~100 km**
- **#IPs = 2**
- total beam-beam tune shift = 0.01
- bunch spacing = 25 ns [10 …5 ns option]
- **peak luminosity = $5x10^{34}$ $cm^{-2}s^{-1}$**
- β^* = 1.1 m *[2 m conservative option]* linked to total beam current (~0.5-1 A)

From M. Benedikt and F. Zimmermann

Main parameters for FEC *(TLEP)*

- **energy =** 91-Z, 160-W, **240-H,** 350-t **GeV c.m.** (energy upgrade 500-ZHH/ttH)
- **circumference ~100 km**
- **total SR power ≤ 100 MW** (design limit)
- **#IPs = 2 or 4**
- beam-beam tune shift / IP scaled from LEP
- **peak luminosity / IP = 5×10^{34} $cm^{-2}s^{-1}$ at Higgs**
- top-up injection
- $\beta_y^* = 1$ mm ~ σ_z

From M. Benedikt and F. Zimmermann

Main parameters FHEC *(VELHC-TLEP)*

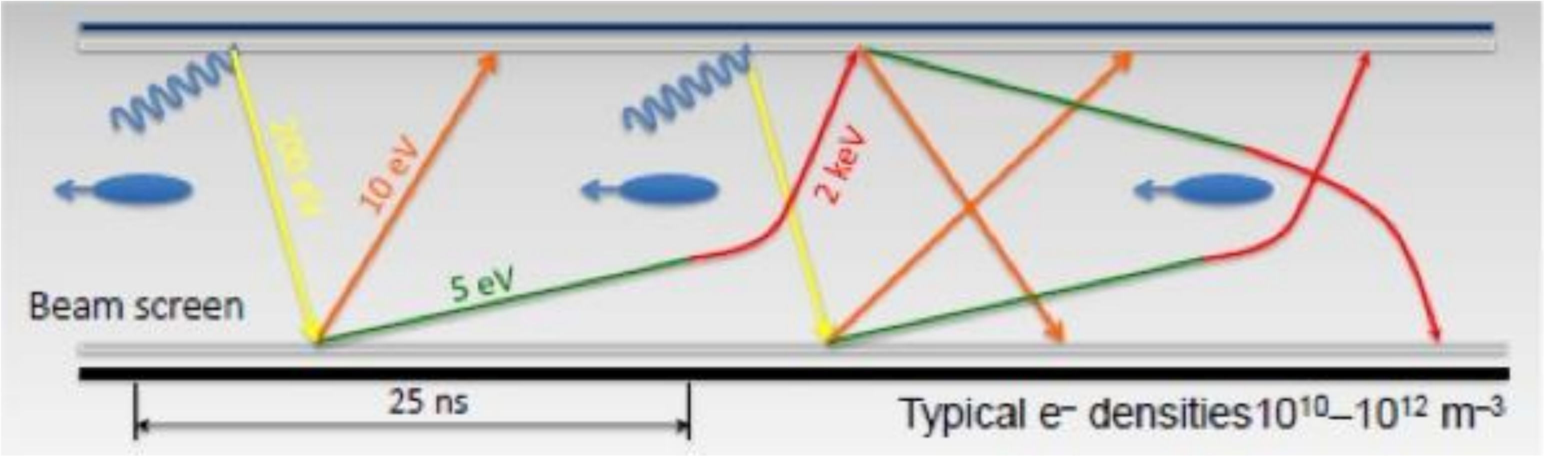
- ***e*- energy = 60, 120, 250 GeV**
- ***p* energy = 50 TeV**
- spot size determined by p
- e^- current from FLC (SR power ≤ 50 MW)
- **#IPs = 1 or 2**

From M. Benedikt and F. Zimmermann

Some Limitations:

Electron cloud

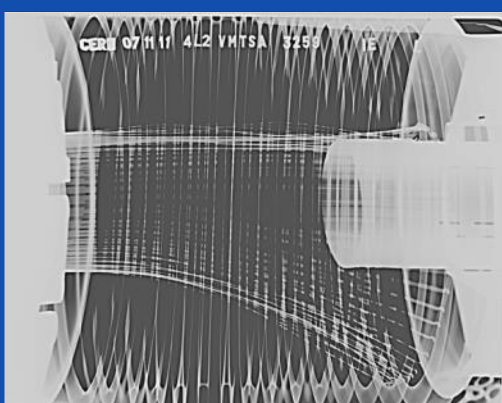
- Reason for running with 50 ns
- Scrubbing to suppress electron cloud build up by reducing the secondary electron yield (SEY)
- Remains still worrisome in the arcs for 25 ns bunch spacing



Some Limitations: cont'd

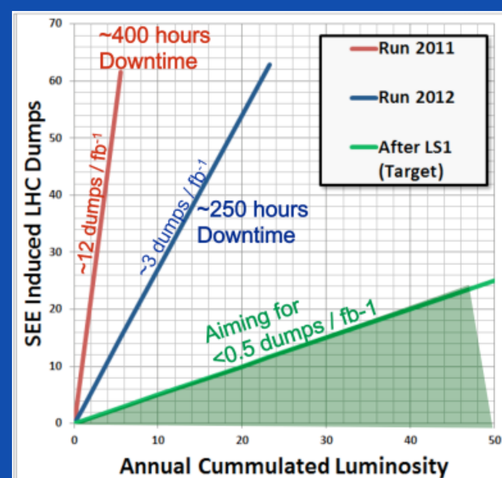
Beam induced heating

- Local non-conformities (design, installation)
  - Injection protection devices
  - Sync. Light mirrors
  - Vacuum assemblies



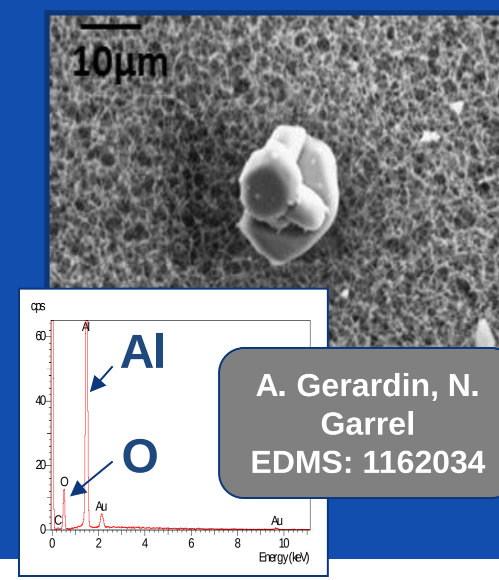
Radiation to electronics

- Concerted program of mitigation measures (shielding, relocation…)
- Premature dump rate down from 12/fb^{-1} in 2011 to 3/fb^{-1} in 2012



UFOs

- 20 dumps in 2012
- Timescale 50-200 μs
- Conditioning observed
- Worry about 6.5 TeV



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