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Strategy of Collaboration with Industry for High Luminosity LHC

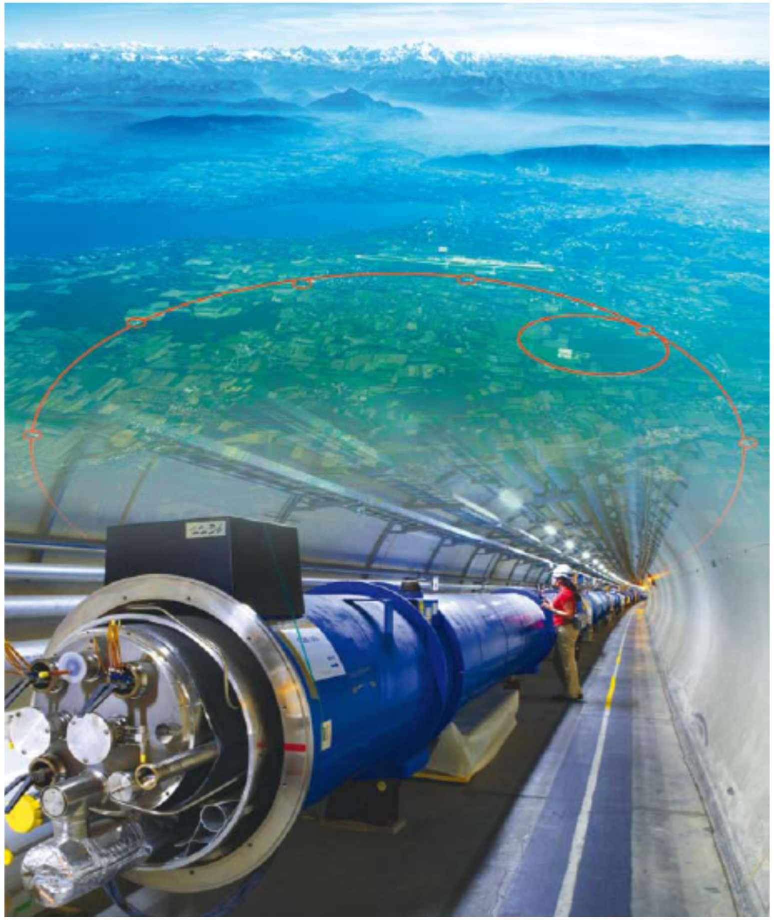
Frédérick Bordry

11th May 2016

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

2010-2035: Physics exploitation
2010 – 2012 : Run 1 ;7 and 8 TeV
2015 – 2018 : Run 2 ; 13 TeV
2021 – 2023 : Run 3
2024 – 2025 : HL-LHC installation

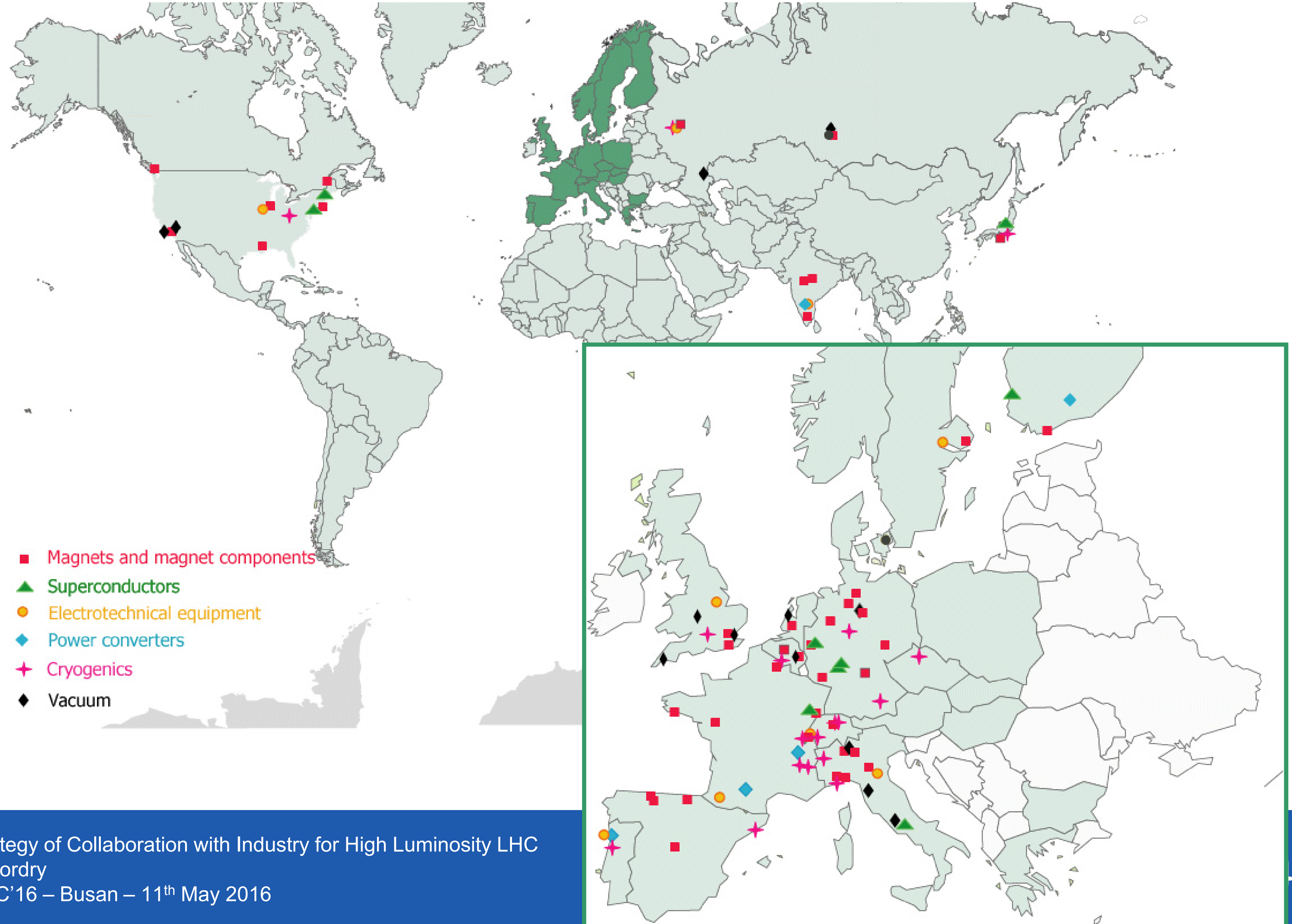
A 27 km circumference collider…

LHC:
technological challenges

The specifications of many systems were over the state of the art.
Long R&D programs with many institutes and industries worldwide.

- **The highest field accelerator magnets: 8.3 T** (1232 dipole magnets of 15 m)
- **The largest superconducting magnet system** (~10'000 magnets)
- **The largest 1.9 K cryogenics installation** (superfluid helium, 150 tons of LHe to cool down 37'000 tons)
- **Ultra-high cryogenic vacuum for the particle beams** (10^{-13} atm, ten times lower than on the Moon)
- **The highest currents controlled with high precision** (up to 13 kA)
- **The highest precision ever demanded from the power converters** (ppm level)
- **A sophisticated and ultra-reliable magnet quench protection system** (Energy stored in the magnet system: ~10 Gjoule, in the beams > 700 MJ)

LHC engineering & technology are also international
100 major high-tech industrial contracts



Industrial procurement
Strategy, constraints, management

- Legal/regulatory framework

- CERN purchasing rules
- Seeking « fair return » among CERN Member States
- Handling special « in-kind» contributions

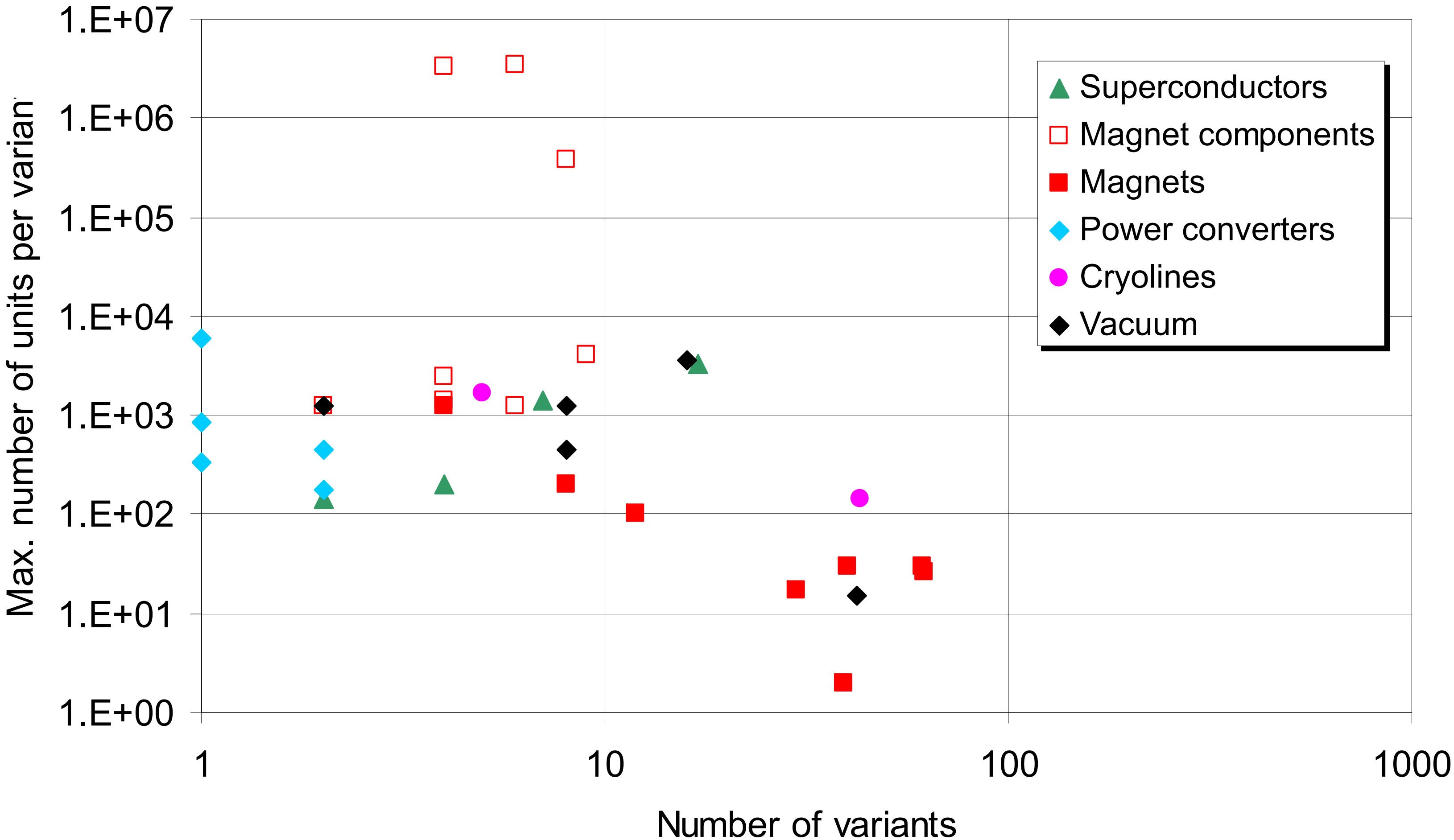
- Call for tenders

- Selecting the right companies
- Building know-how & maintaining interest through prototyping, preseries and series
- Technical specification: functional & interface versus build-to-print; Identify what can be done by the industry and what needs to be done by CERN (costs and risks: breakdown, assembly, performance responsibility, …)

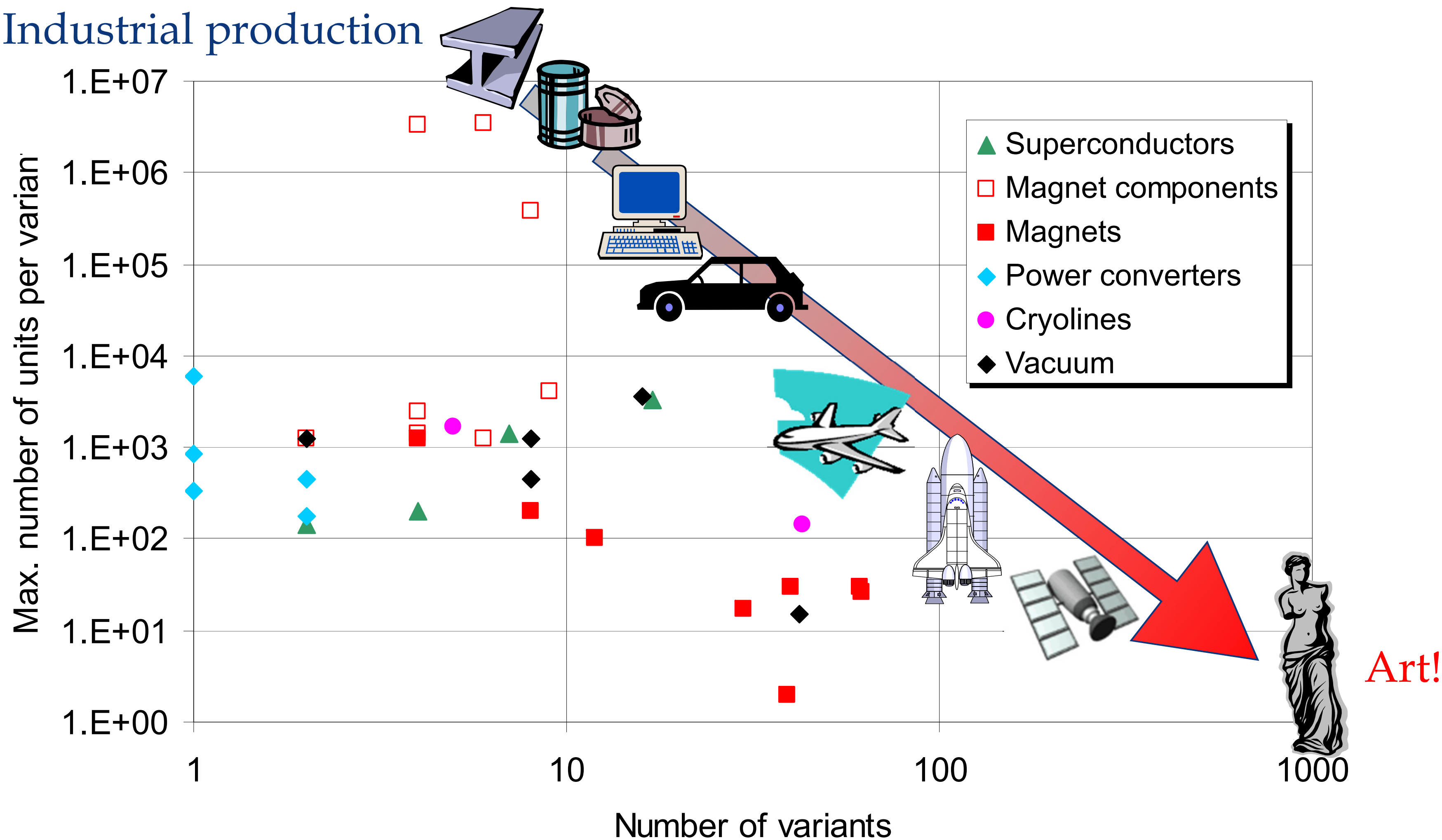
- Industrial Contracts

- Split: security of supply & balanced return versus additional follow-up
  (multiple contracts ; n+1 strategy : prototype and series)
- Intermediate supply & logistics (to ensure the supply of sensitive components)
- JIT (Just In Time) versus production buffer & sorting
- Industrialization, production ramp and de-ramp
- Quality and inspection (a shared QAP is essential)

LHC components & industrial products

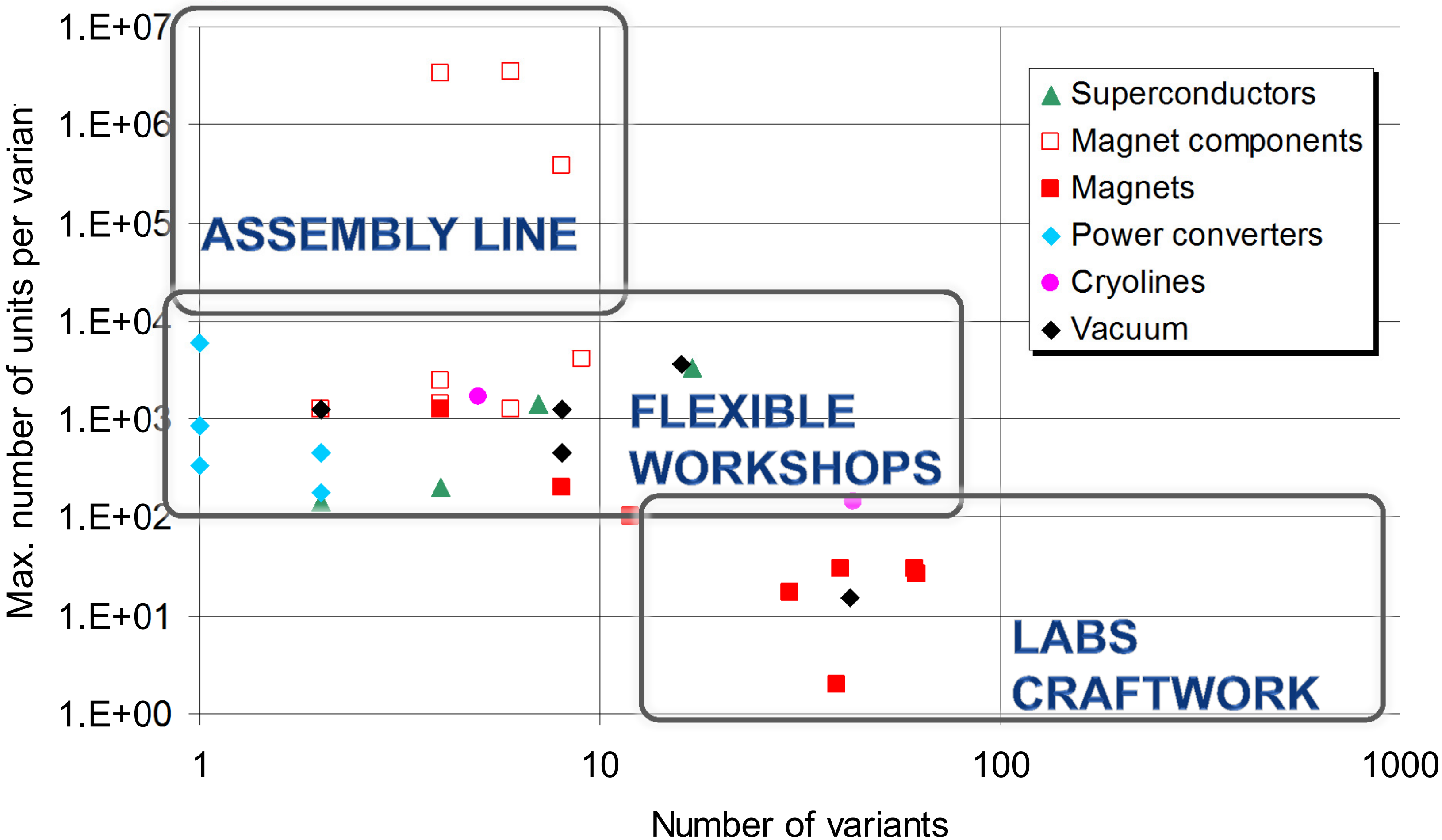


LHC components & industrial products



LHC components & industrial products

Industrial production

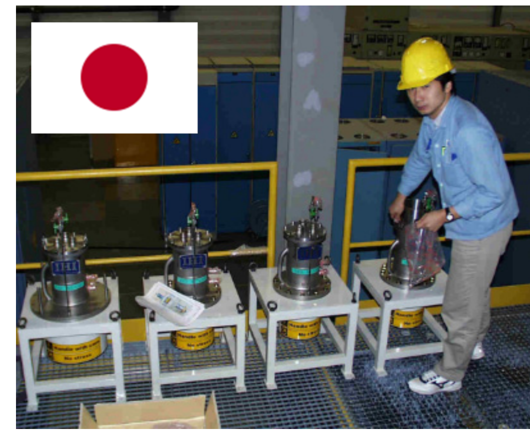


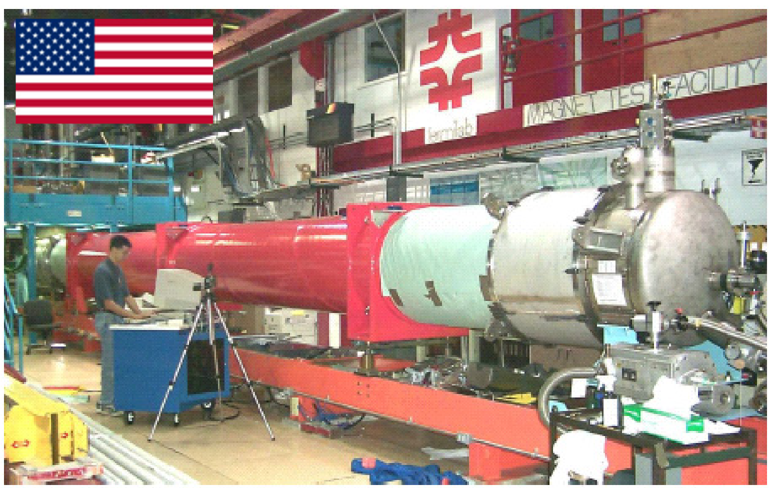
Art!

In-kind contributions:

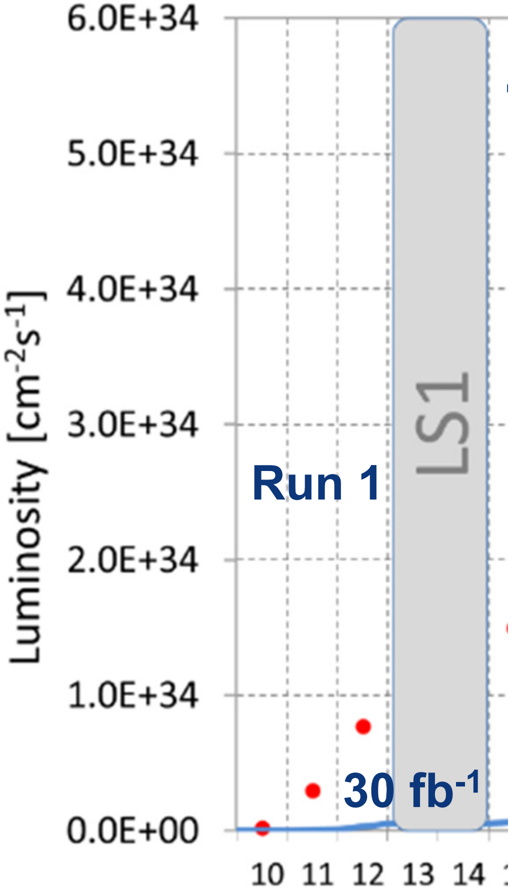
LHC accelerator ~ 15 % (Non-member and host states)

LHC detectors ~ 80 % (Member and non-member states)

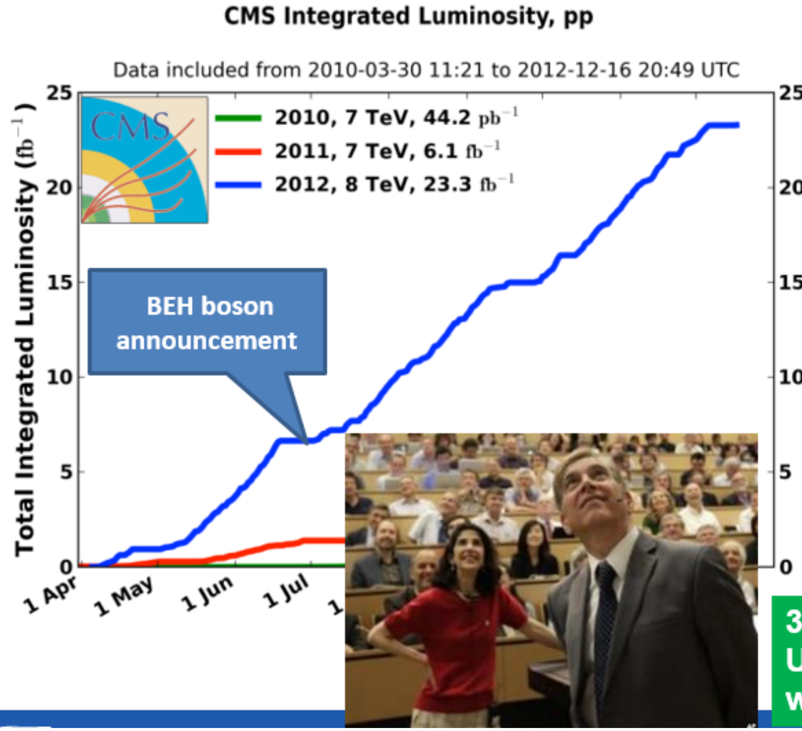




LHC operation



LHC 2010-2012: a rich harvest of collisions



Σ ~30 fb^{-1}
~ 2 10^{15} collisions

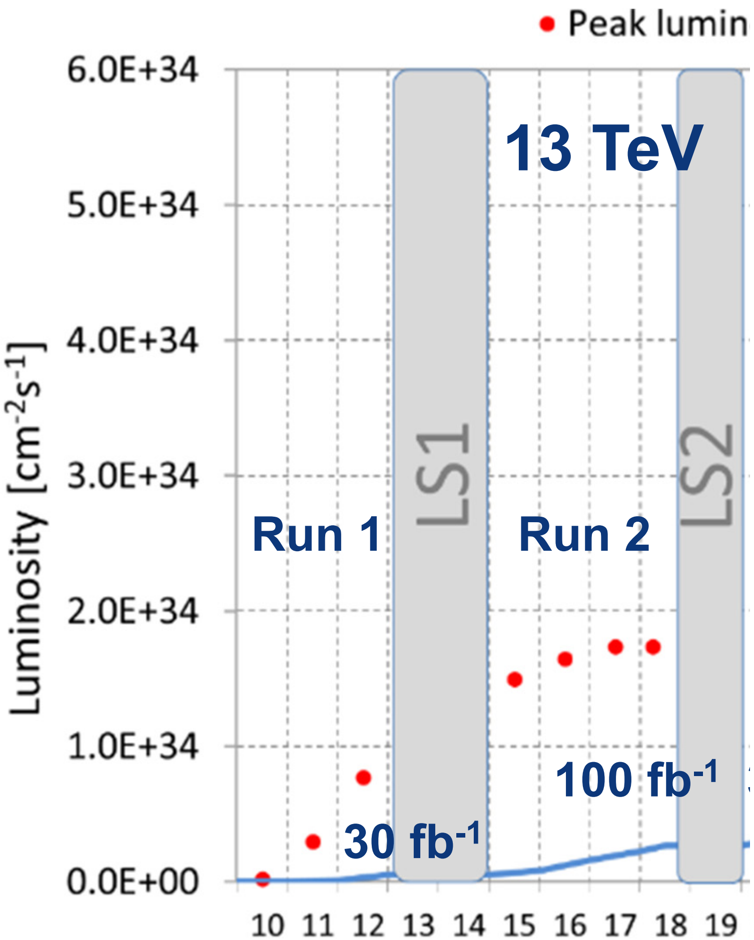
2010: **0.04 fb^{-1}**
7 TeV CoM
Commissioning

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

LHC roadmap: **Goal of 3'000 fb^{-1}** by mid 2030ies



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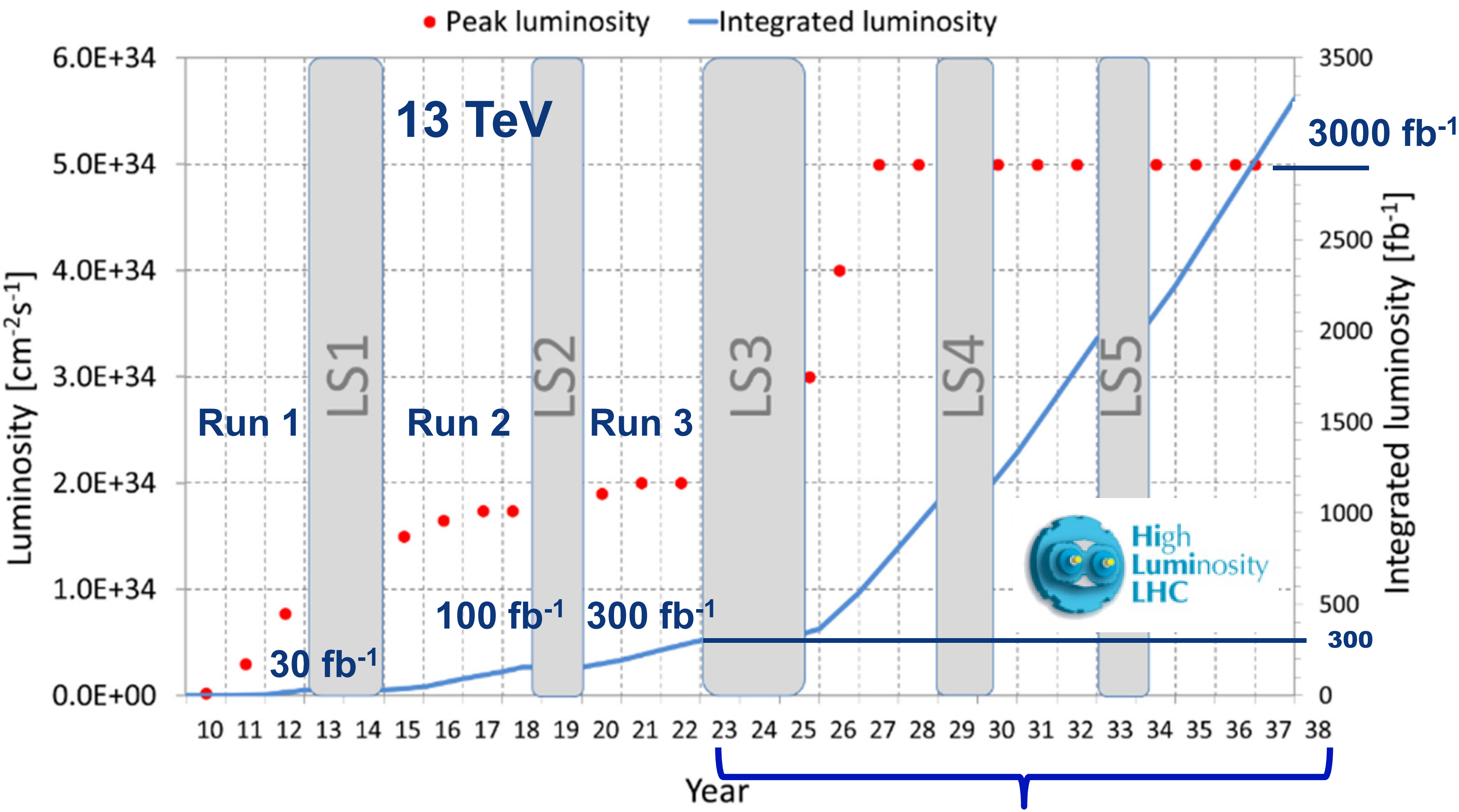
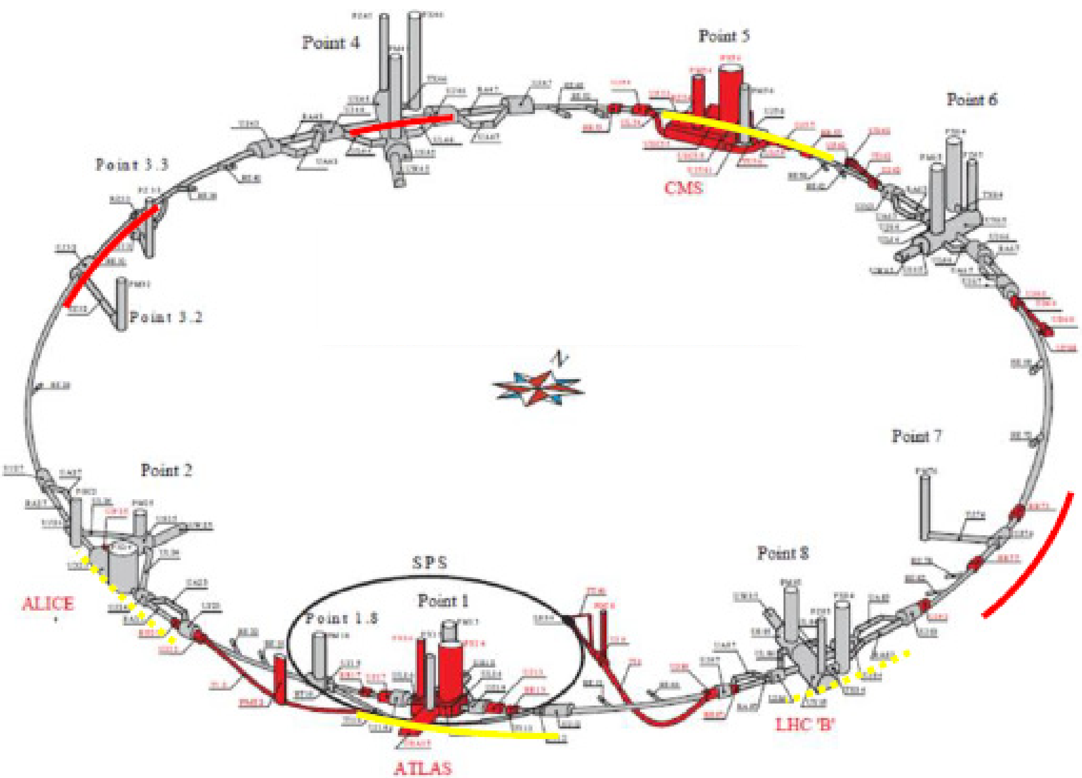


High Luminosity project (HL-LHC)

The HL-LHC Project

HiLumi 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

Squeezing the beams: High Field SC Magnets

Quads for the inner triplet

Decision 2012 for low-β quads

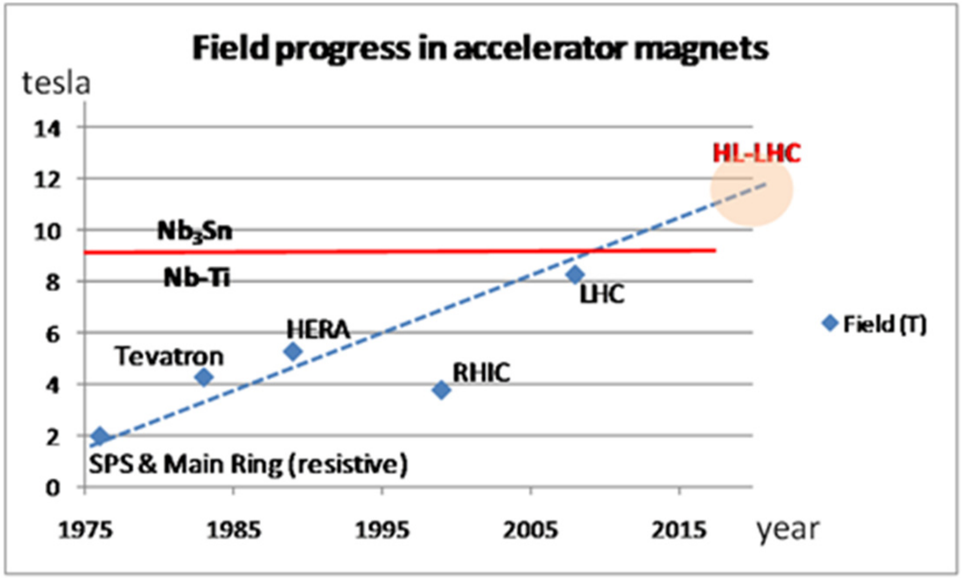
Aperture ∅ 150 mm – 140 T/m

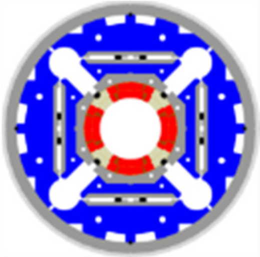
(B_{peak} ≈12.3 T)

operational field, designed for 13.5 T

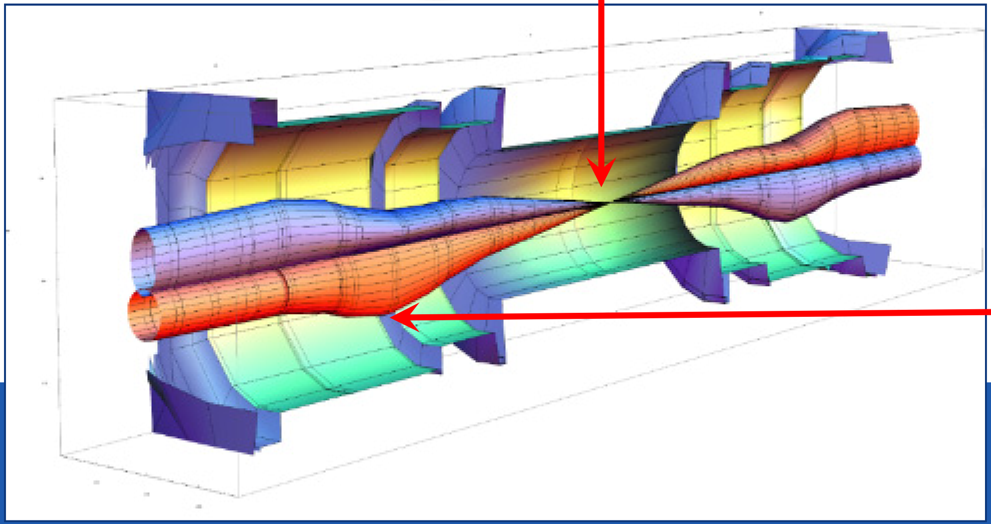
=> Nb_3Sn technology

(LHC: 8 T, 70 mm)





	$\beta_{triplet}$	Sigma triplet	β*	Sigma*
Nominal	~4.5 km	1.5 mm	55 cm	17 um
HL-LHC	~20 km	2.6 mm	15 cm	7 um

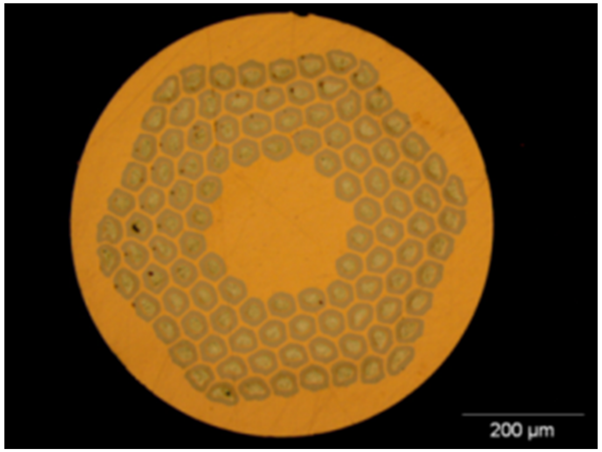


The « new » material : Nb_3Sn

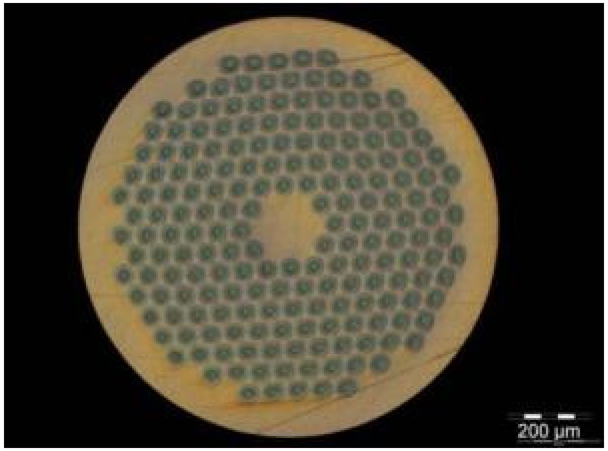
- Recent 23.4 T (1 GHz) NMR Magnet for spectroscopy in Nb_3Sn (and Nb-Ti).
- 15-20 tons/year for NMR and HF solenoids. Experimental MRI is taking off
- **ITER: 500 tons in 2010-2015**

It is comparable to LHC *1200 tons of Nb-Ti*

HL-LHC will require only 20 tons of Nb_3Sn



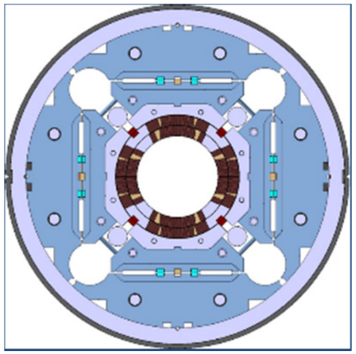
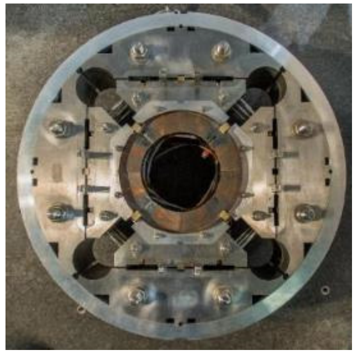
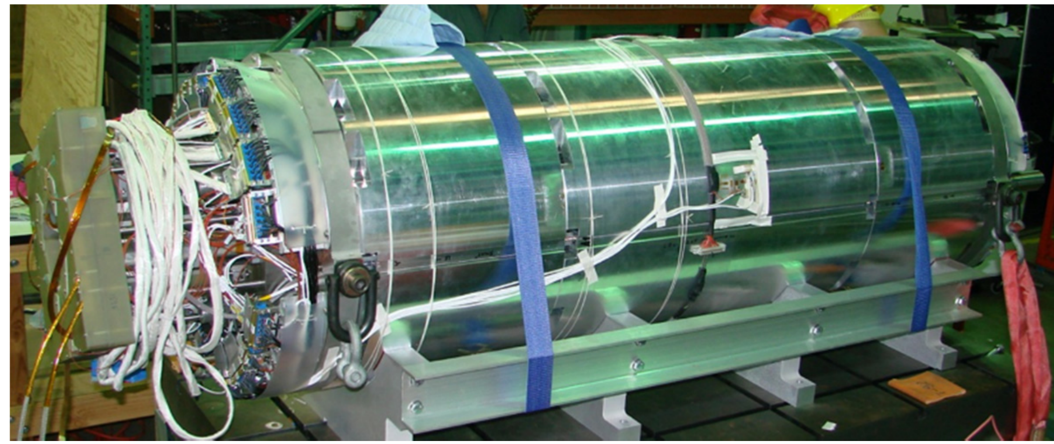
0.7 mm, 108/127 stack RRP from **Oxford OST**



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

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

First short model magnet MQXFS1 (1.5 m)
Inner triplet Quad final cross section (∅ =150 mm)

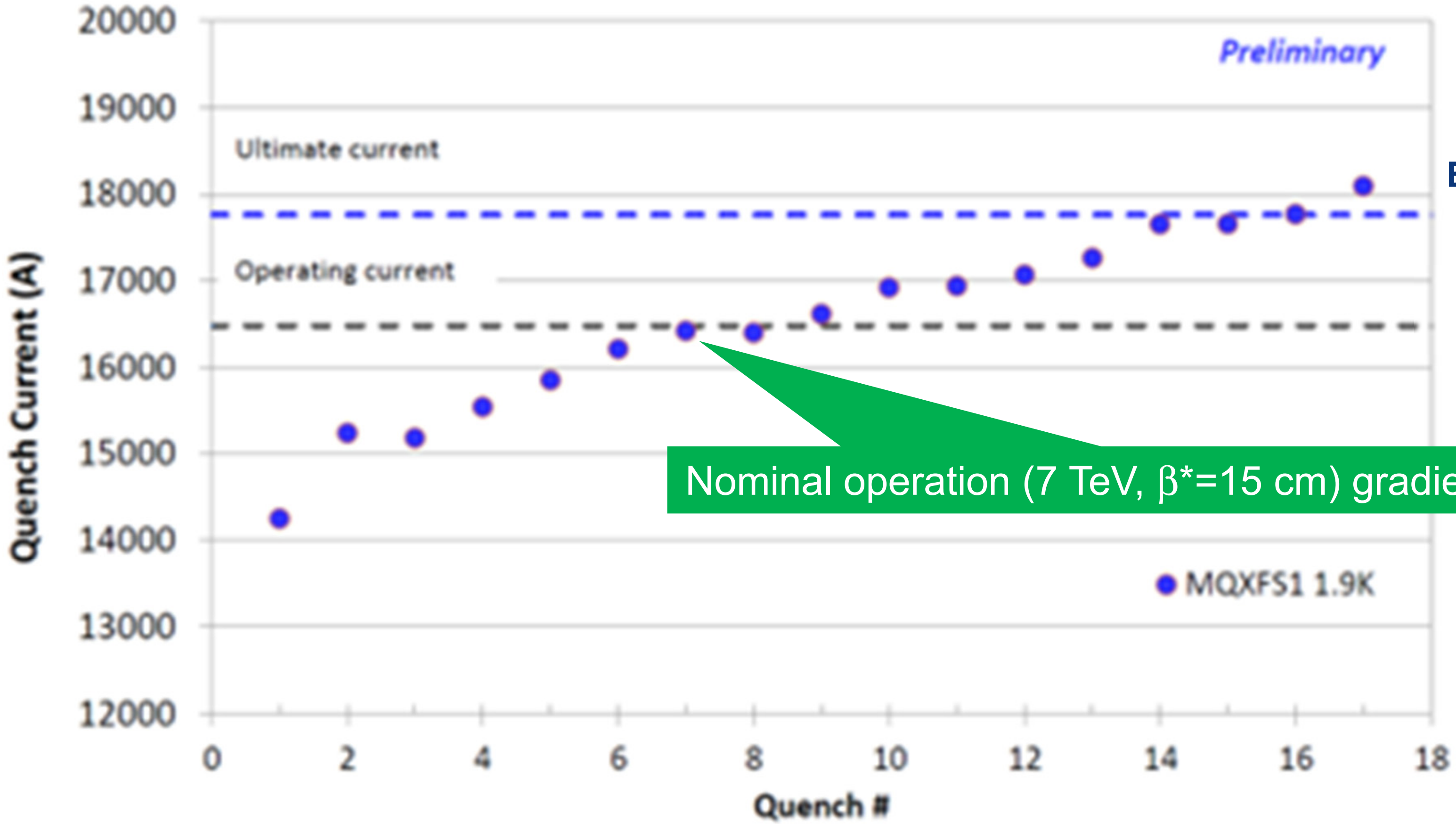




CERN - US LARP collaboration

Design and Nb_3Sn coils by CERN and LARP together (50%-50%)

Full collider characteristics.
Final length will be 3 to 5 times more

First short model magnet MQXFS1 (1.5 m)
Result of the first energization @ FNAL



B_{peak}> 12.5 T

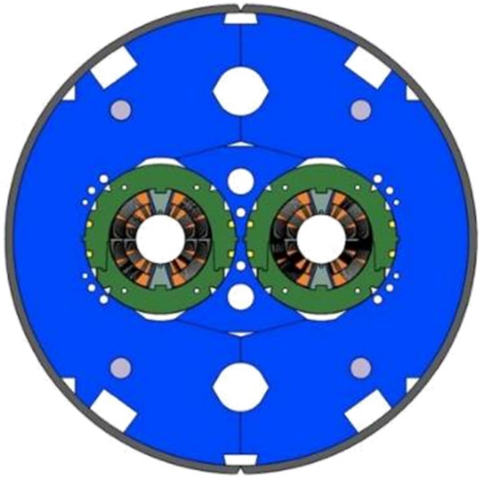
B_{peak} = 11.4 T

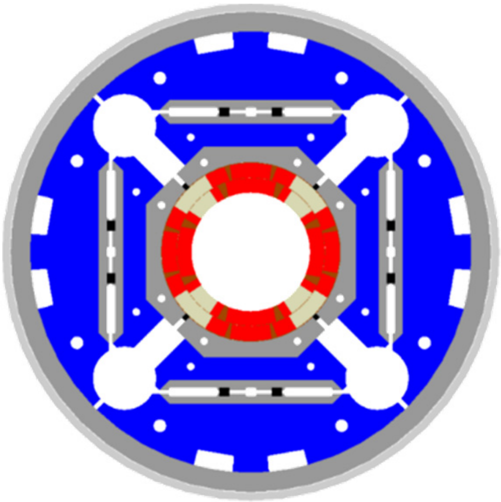
Nominal operation (7 TeV, β*=15 cm) gradient : 133 T/m

Next: thermal cycle and memory test (and more…)

Industrial Service Contracts for Prototyping and Industrialization of Nb_3Sn Magnets for HL-LHC (2013)

- Provision of services for prototyping and industrialization at CERN of **Nb_3Sn magnets** for HL-LHC
- Design and build full scale **prototypes** of the 11T dipole and large aperture quadrupole for the LHC triplets
- Design and build the **tooling** required, develop with CERN the necessary **manufacturing and inspection procedures**





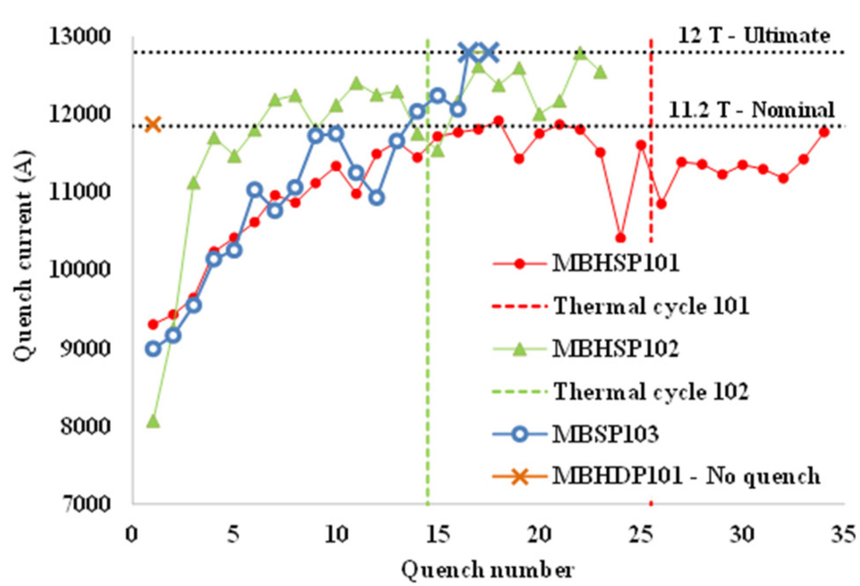
Rationale

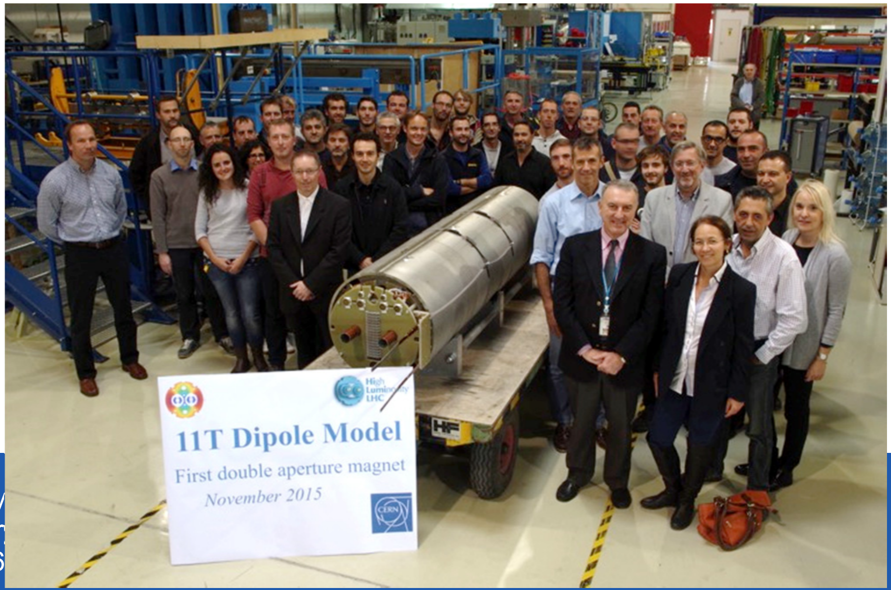
- **High Luminosity Project calls for a novel magnet technology, based on Nb_3Sn, to achieve the required field**
- Declared objectives of the industry service contracts are to:
  - **Share the technology development** with our qualified industrial partners right from the start
  - **Profit from the industrial approach** to the design of the manufacturing process and associated tooling
  - **Prepare industry** to the manufacturing of HiLumi magnets as well as for future projects (e.g. an FCC Future Circular Colliders; 100km collider), anticipating technology transfer

Industrial Service Contracts

- S156/TE (January 2014) – Babcock Noell
- S157/TE (September 2013) – Alstom, now GE
- S158/TE (May 2014) – ASG Superconductors
- S159/TE (November 2013) – Oxford Instruments

11 T Dipole for HL-LHC (Dispersion suppressor collimation)
First assembly in Two-In-One magnet of short coils (1.8 m)
Nb3Sn technology

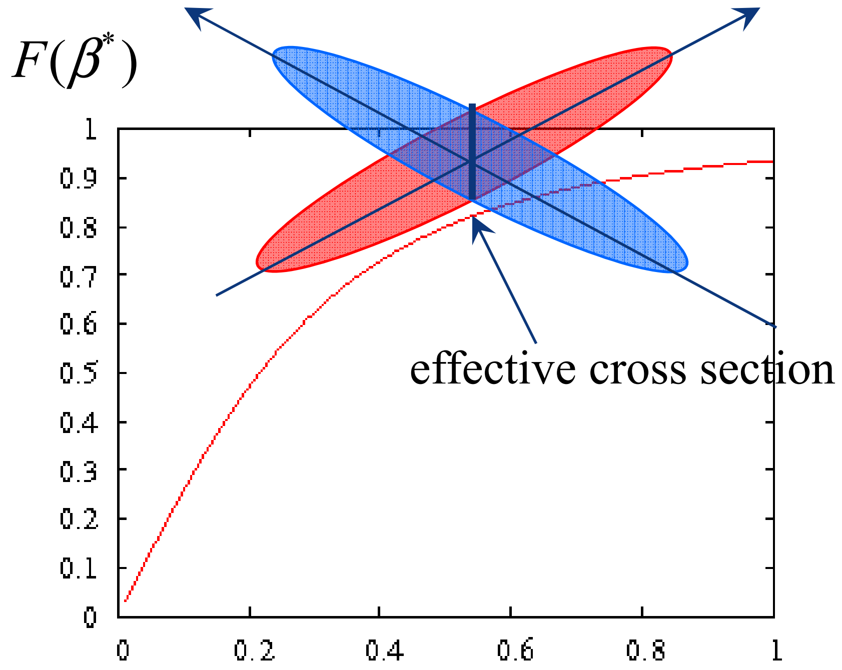




HL-LHC Upgrade Ingredients: Crab Cavities

Geometric Luminosity Reduction Factor:

$$F = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$



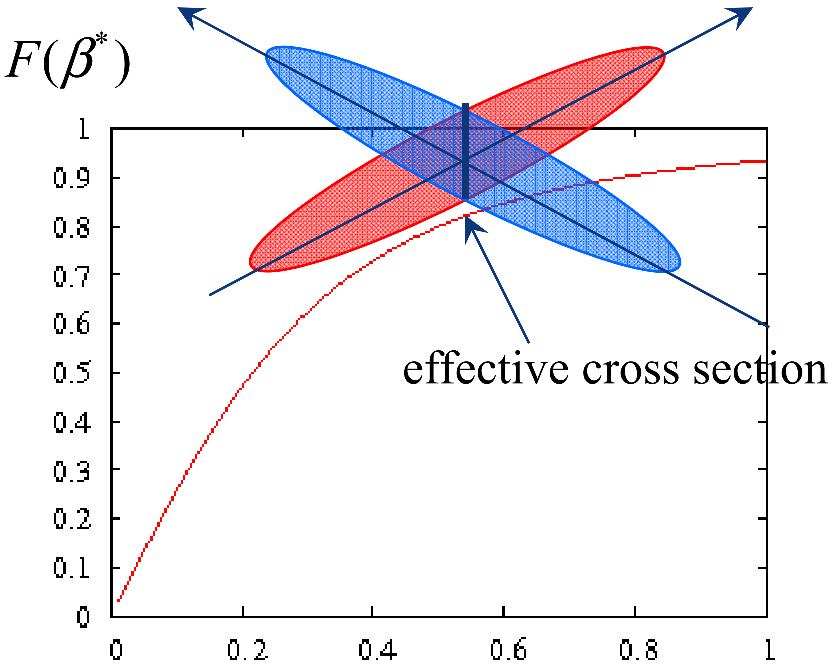
HL-LHC Upgrade Ingredients: Crab Cavities

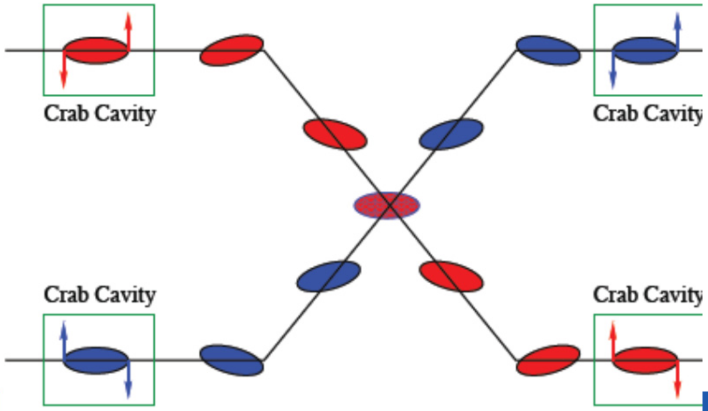
Crab Cavities:

- Reduces the effect of geometrical reduction factor
- Independent for each IP

$$F = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

- Noise from cavities to beam ?
- Challenging space constraints





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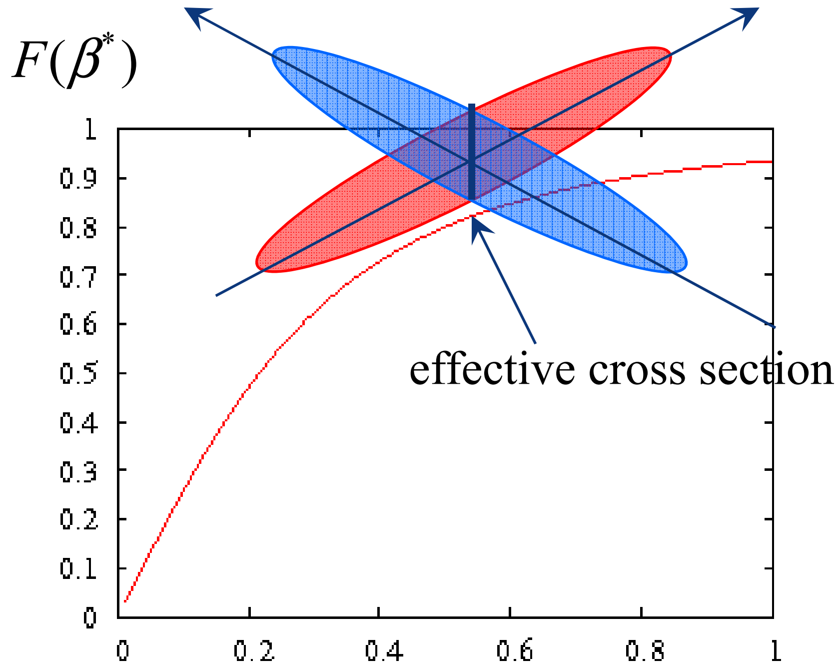
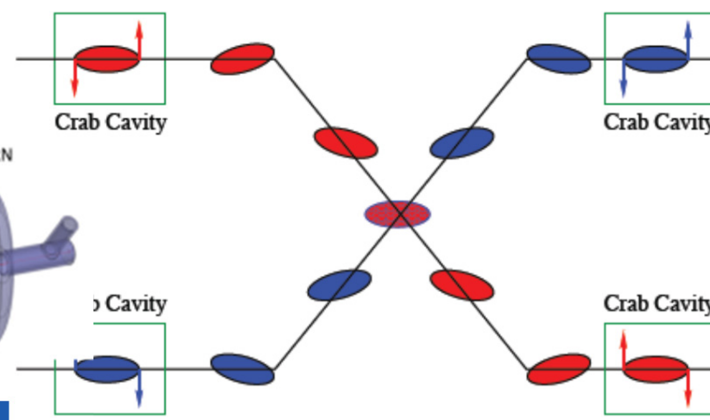
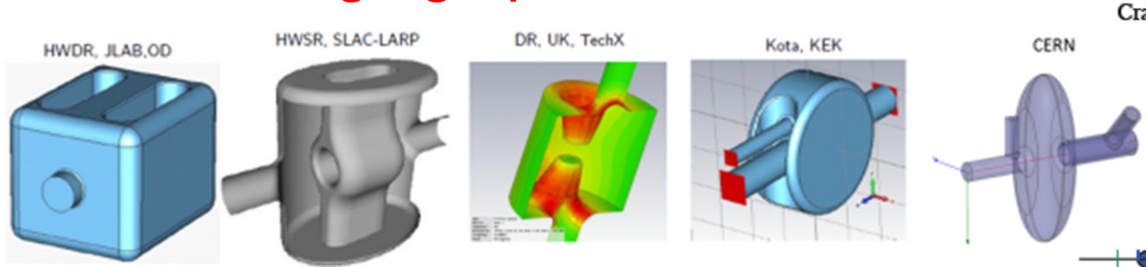


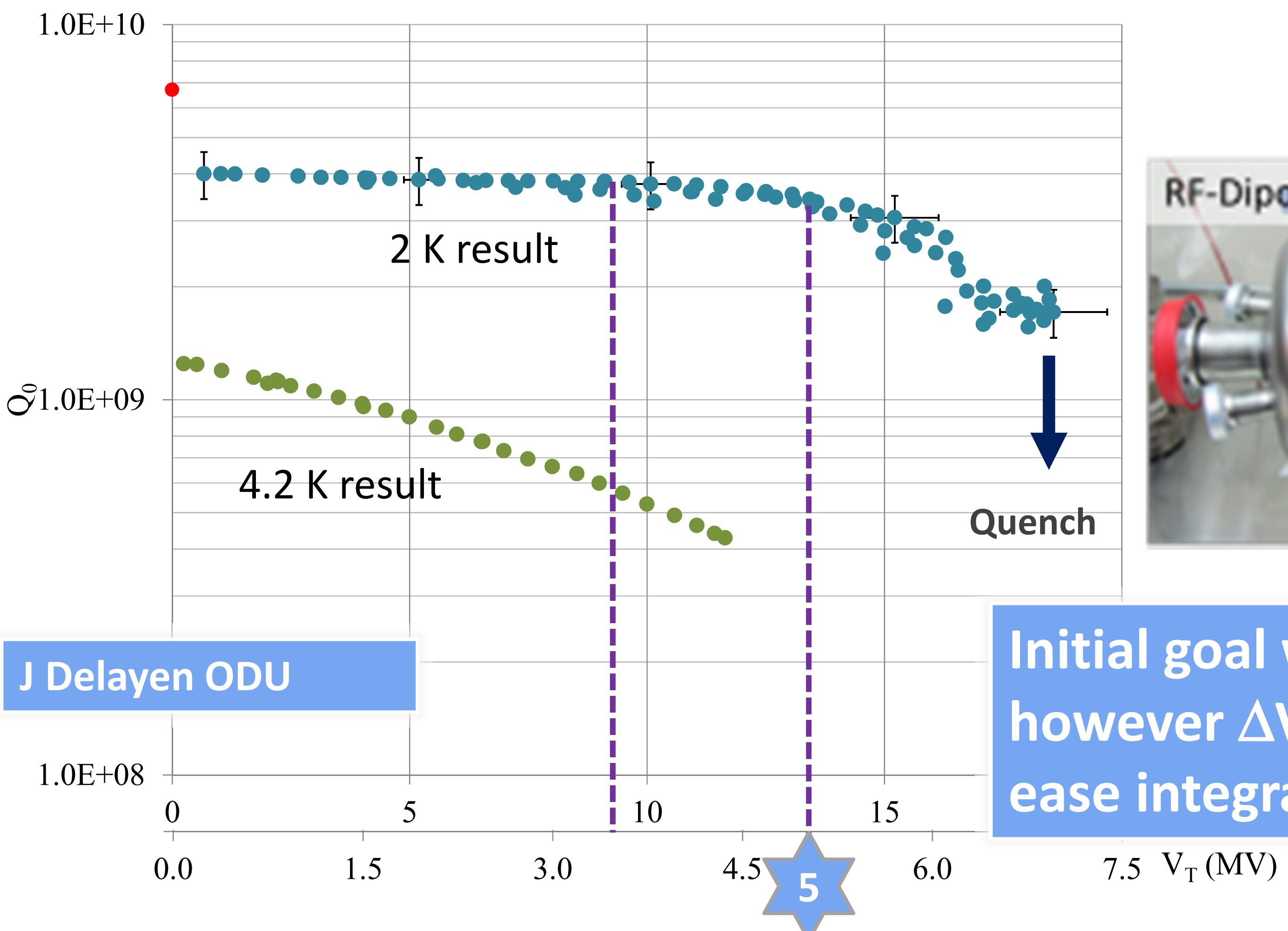




Compact cavities aiming at small footprint & 400 MHz, ~5 MV/cavity

Excellent first results: e.g. RF dipole > 5 MV

¼ w and 4-rods also tested (1.5 MV)

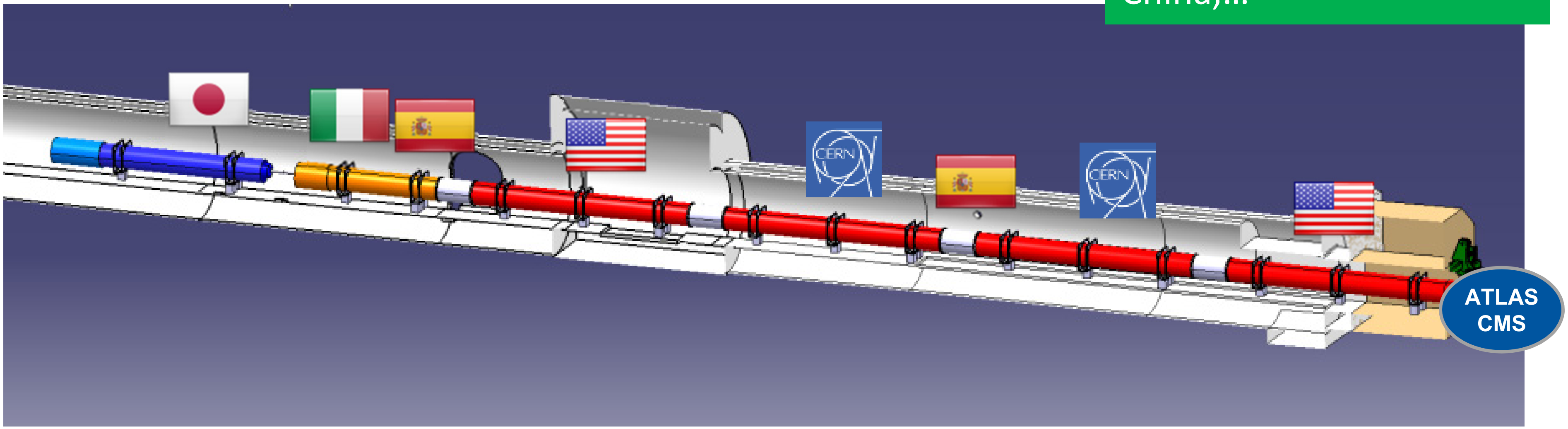


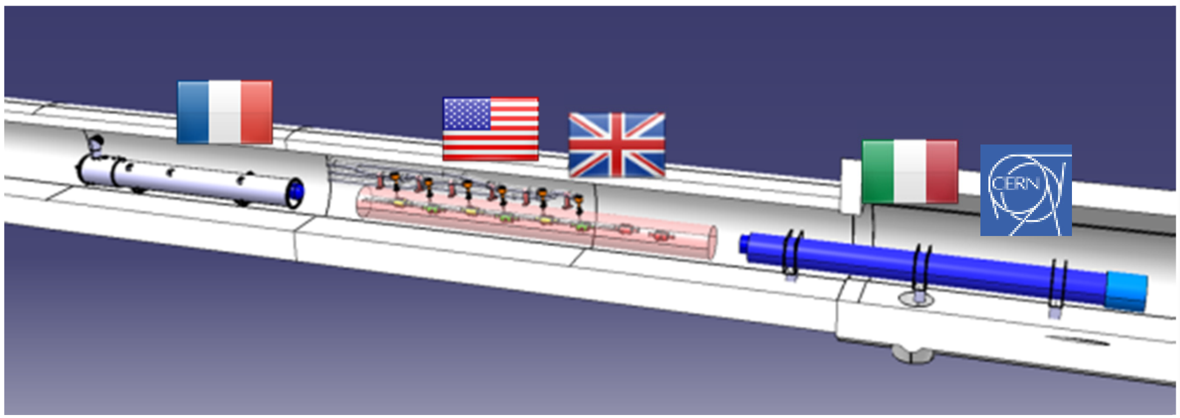
J Delayen ODU

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

In-kind contributions and collaborations for design, prototypes, production and tests

Discussions are ongoing with other countries, e.g Canada, Russia, India, China,…





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

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

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

Managing in-kind contributions

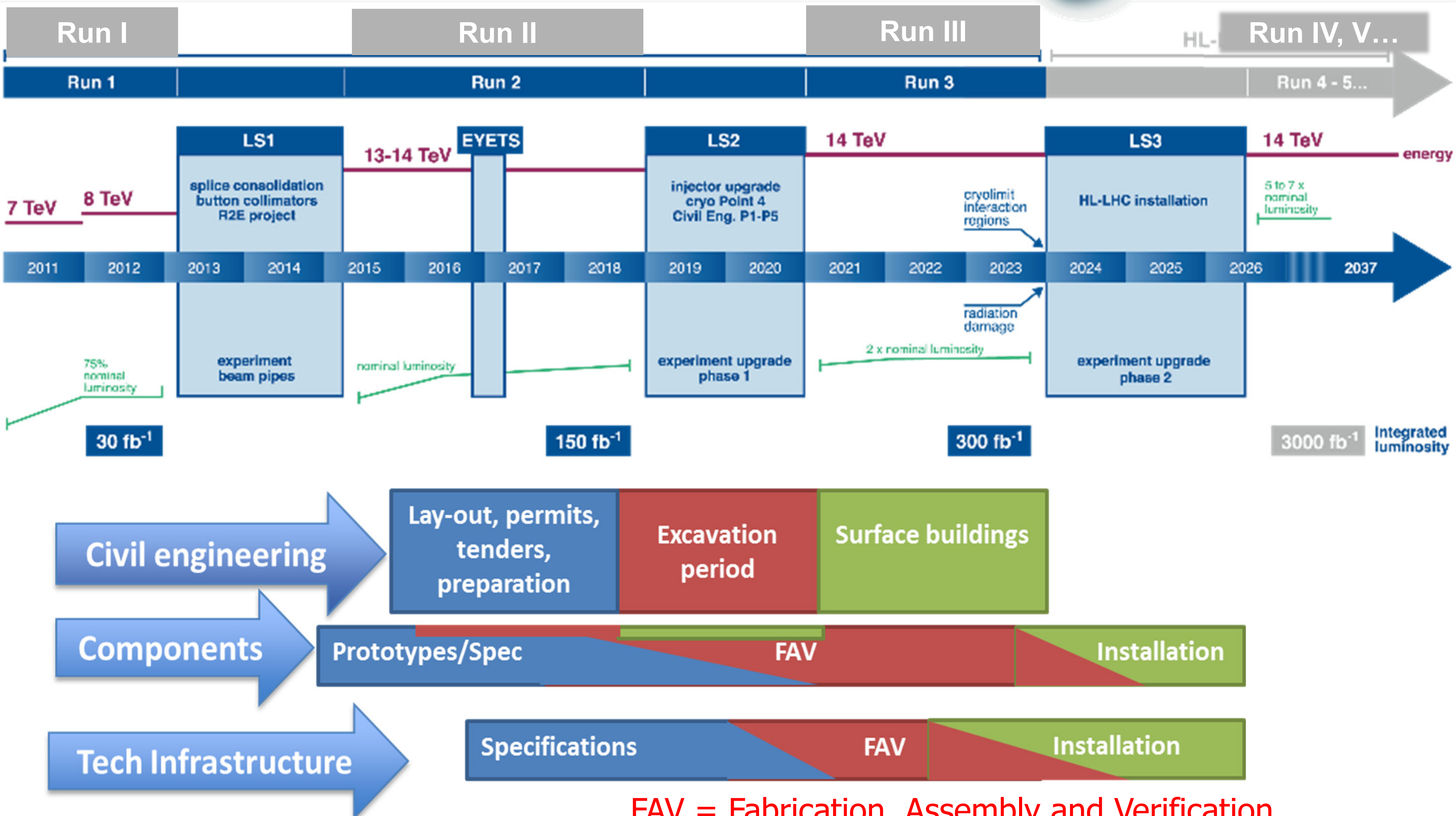
Definition & allocation

- Match project needs, technical competencies, economic and political interests
- Achieve cost effectiveness with respect to world market prices
- Preserve “fair return” to Member States

Execution

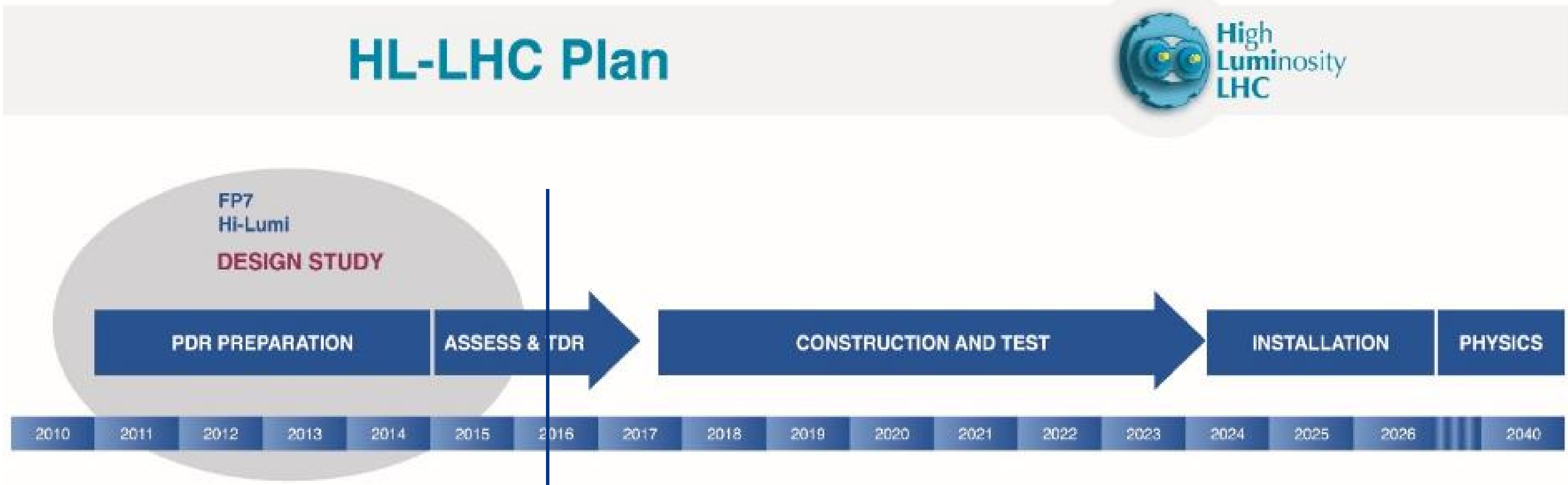
- International procurement and local culture: importance of involving local institutes (not just funding “Funding Agencies”) in follow-up of high-tech supplies
- Project team must maintain sufficient in-house resources to handle emergency situations which **will** occur: non-conformities, QA problems, delays, company insolvencies…

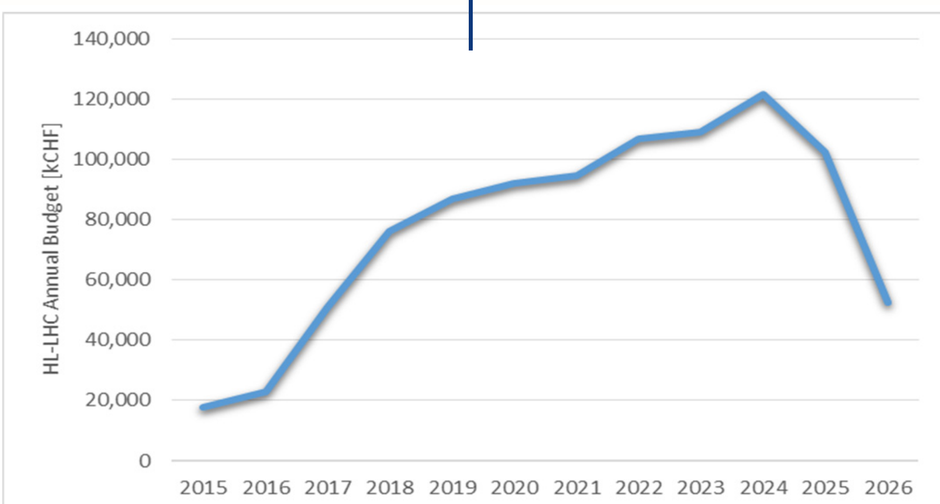
LHC / HL-LHC Plan



FAV = Fabrication, Assembly and Verification

HL-LHC Cost & Schedule





HiLumi HL-LHC PROJECT

HL-LHC and industries

- The High Luminosity project seeks industrial suppliers and collaborations to start the construction phase and make the High Luminosity upgrade.
- CERN aims at fostering R&D collaborations and knowledge exchange also with SMEs, a perfect opportunity to match their capacity with the requirements of HL-LHC
- Next 4 years there will be intensive prototyping and the production of some of the first series of components.

HL-LHC and industries

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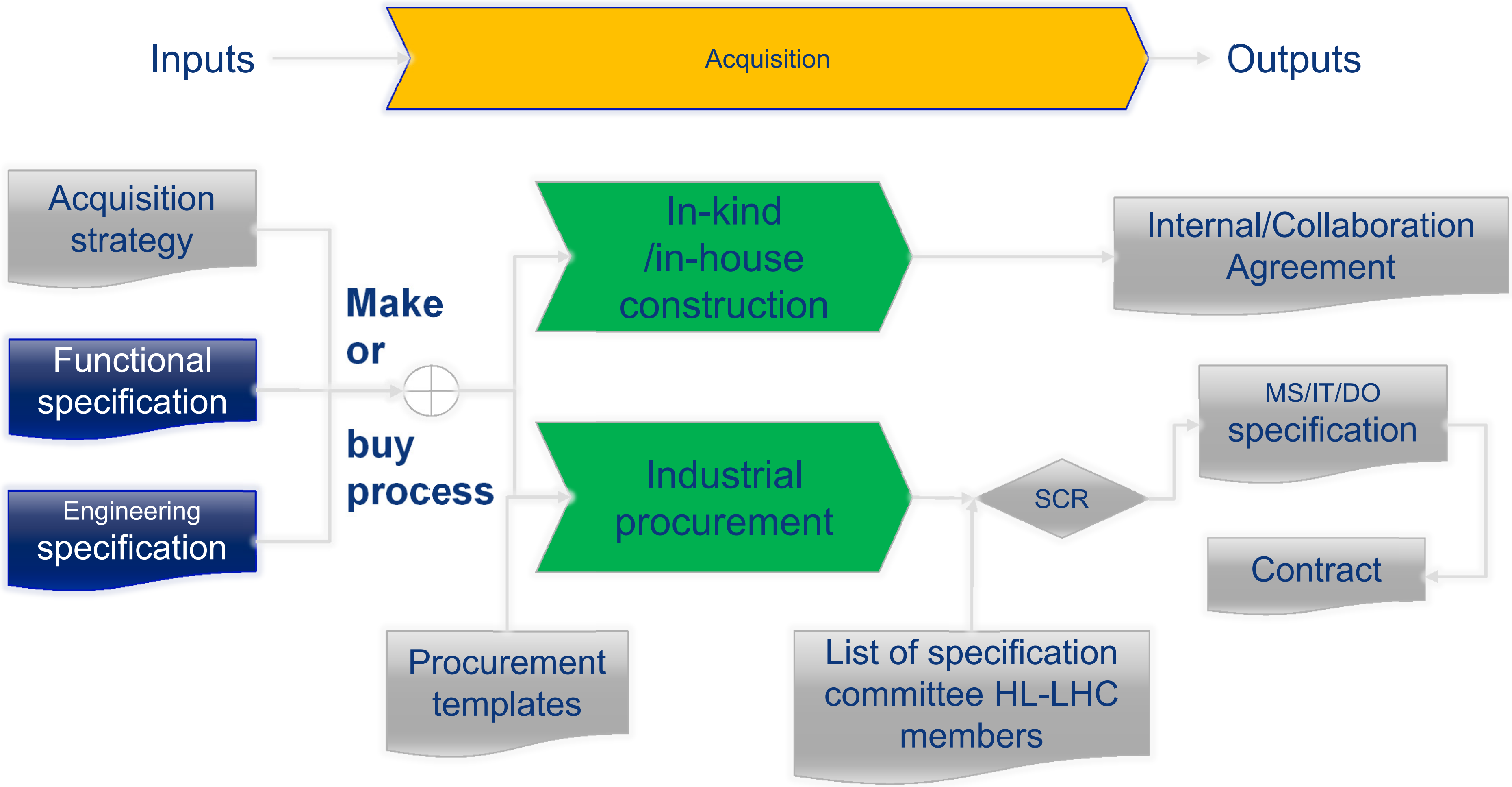
- Next 4 years there will be intensive prototyping and the production of some of the first series of components.
- For CERN: understanding industry capabilities and the know how that could come from industry is the best way to specify equipment that can be built by industry
- For industries: understanding CERN needs are crucial to tender successfully.

Acquisition process



SCR: Specification Committee Review

HL-LHC and industries

Provide timely information of what CERN requires and for when

Clear list of what CERN will need, their main characteristics and when the tendering process will start with easy access to the documents

https://project-hl-lhc-industry.web.cern.ch

HiLumi HL-LHC PROJECT

HL-LHC Industry

Industry Relations and Procurement Website for the HL-LHC project

https://project-hl-lhc-industry.web.cern.ch

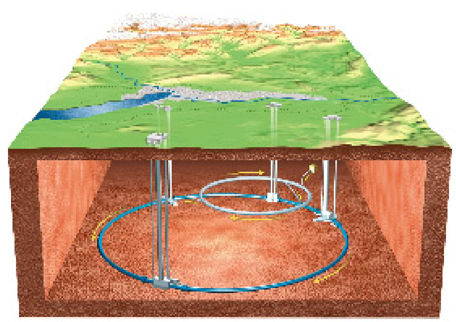
Home | General Info | Procurement Overview | Tendering | Acquisition Timeline | Events | Contact

Building the HL-LHC with the Industry

The HL-LHC Industry Website has been specially designed for all those firms that wish to participate in this ambitious project. We want to share all the relevant information related to the procurement that will be required to accomplish this major upgrade of the LHC.

The industry will have a crucial role and will be heavily involved within the HL-LHC Project since it will be the main source to provide the technologies and equipment that are required to successfully achieve the goals of this upgrade of the LHC.

The HL-LHC will collaborate with many types of industries and businesses to pursue its goals. Knowledge and technology to be developed during the HL-LHC project will make a lasting impact on society.



The Large Hadron Collider (LHC) at CERN at the Franco-Swiss border near Geneva, is the largest scientific instrument ever designed and built for scientific research. It has been exploring the new high-energy frontier since 2010, attracting a global user-community of more than 7,000 scientists spanning more than 60 countries.

After only a little more than one year of operation, on 4th July 2012 the LHC experiments, ATLAS and CMS, could announce the first major discovery: the long-sought Higgs boson, the cornerstone of the Standard Model

ILOS

ILOs Portal

HIGHLIGHTS

7 Abr 2016

QUACO Open Market Consultation

QUACO Open Market Consultation has taken place at CERN on 30 March.

Read more

10 Mar 2016

HL-LHC is now part of the ESFRI Roadmap

The 2016 Roadmap highlights the strong socio-economic impact of research infrastructures as well as their potential to generate innovation through collaboration with industrial partners.

More information on the ESFRI Roadmap 2016

8 Feb 2016

QUACO Open Market Consultation

CERN, as member of the European pre-competitive procurement (PCP) instrument QUACO, is pleased to invite you to the Open Market Consultation (OMC) that will take place on 30^{th}

https://project-hl-lhc-industry.web.cern.ch

HL-LHC Industry

Industry Relations and Procurement Website for the HL-LHC project

HiLumi HL-LHC PROJECT

Search this site | Search

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TENDERING FOR HL-LHC

Calls for tenders for HL-LHC project

Calls for Tenders

Advance information on forthcoming market surveys and calls for tenders expected to exceed 200,000 Swiss francs can be checked on the link below.

Click here to see the current Call for tenders for HL-LHC project

HL-LHC Industry

Industry Relations and Procurement Website for the HL-LHC project

HiLumi HL-LHC PR

Home | General Info

Building t

The HL-LHC Industry W… ambitious project. We w… to accomplish this major…

The industry will have a… main source to provide t… upgrade of the LHC.

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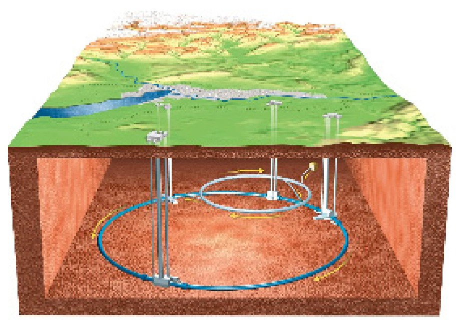

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8 Feb 2016

QUACO Open Market Consultation

CERN, as member of the European pre-competitive procurement (PCP) instrument QUACO, is pleased to invite you to the Open Market Consultation (OMC) that will take place on 30 th

https://project-hl-lhc-industry.web.cern.ch

HL-LHC Industry

Industry Relations and Procurement Website for the HL-LHC project

Home | General Info

Building t

The HL-LHC Industry W
ambitious project. We w
to accomplish this major

The industry will have a
main source to provide t
upgrade of the LHC.

The HL-LHC will collaborate with many types of industrie
technology to be developed during the HL-LHC project will

The Large Hadron Collider (LHC) at CERN at the Franc
instrument ever designed and built for scientific research.
since 2010, attracting a global user-community of more than

After only a little more than one year of operation, on 4th J
could announce the first major discovery: the long-sought

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TENDERING FOR HL-LHC

Calls for tenders for HL-LHC

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WORK PACKAGES & PROCUREMENT INFO

- WP1 - Project Management & Technical Coordination
- WP2 - Acceleratos Physics and Performance
- WP3 - Insertion Regions Magnets
- WP4 - Crab Cavities & RF
- WP5 - Collimation
- WP6A - Cold Powering
- WP6B - Warm Powering
- WP7 - Machine Protection
- WP8 - Collider-Experiment Interface
- WP9 - Cryogenics
- WP10 - Energy Deposition & Absorber Coordination
- WP11 - 11T Dipole
- WP12 - Vacuum
- WP13 - Beam Diagnostics
- WP14 - Beam Transfer & Kickers
- WP15 - Integration & (De-)Installation
- WP16 - Hardware Commissioning
- WP17 - Infrastructure, Logistics and Civil Engineering

WP9 - Cryogenics

WP Leader: Serge Claudet

Main WP Engineers: Daniel Berkowitz, Krzyztof Brodzinski, Laurent Delprat, Gerard Ferlin, Lionel Herblin, Rob Van Weelderen

Technologies: Cryogenics systems for HL-LHC, Electronic, electrical equipment and instrumentation for accelerators

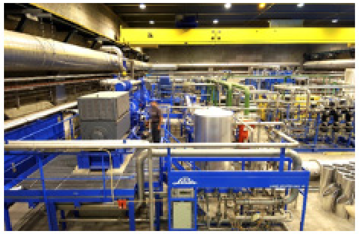
Main materials:

Key external factors: Radiation, 1.9 K

WP9 in a nutshell (Please note that info provided in this document is subject to be changed. Mentioned quantities, materials, parameters, etc. may change along the design and/or manufacturing process of the equipment)

WP9 Main Activities

Next 18 months procurements needs (Access restricted to ILOs)



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Project simplified schedule

The HiLumi life cycle is divided in 4 main phases. The procurement of components is launched between 6 and 18 month before the "Fabrication, Assembly & Verification phase". The time will depend on the cost of the procurement reaching up to 18 month for supplies which value is higher than 750 KCHF.

Requirements Definition	
Development Stage	
Fabrication, Assembly & Verification	
Installation-Commissioning	

WP	PBS Element Description	2016		2017		2018		2019		2020		2021		2022		2023		2024		2025		2026	
		H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
WP3	Q1 and Q3 Magnets*																						
WP3	Q2a and Q2b Magnets*																						
WP3	D1 Separation Dipole*																						
WP3	D2 Recombination Dipole*																						
WP3	Q4 Magnet*																						
WP3	Dipole Corrector Magnet in CP*																						
WP3	Orbit Corrector Magnet for Q2*																						
WP3	Orbit Corrector Magnet for D2 and Q4*																						
WP3	High Orbit Correctors in CP*																						
WP3	Q5 Magnet for IR6*																						
WP3	Q5 Magnet: Option using spares*																						

Conclusions

Cooperation with industry is essential from early stages of the project in order to achieve success within business constraints

- ***Develop and maintain interest in a one-off, technically risky supply***
- ***Series production of innovative items at market prices***
- ***Competition with other products/markets***

The industry will have a crucial role and will be heavily involved within the HL-LHC Project since it will be the main source to provide the technologies and equipment that are required to successfully achieve the goals of this upgrade of the LHC.

https://project-hl-lhc-industry.web.cern.ch

Thanks for your attention

www.cern.ch

"The task of the mind is to produce future"
Paul Valéry