

L'amélioration en luminosité du LHC : le projet HL-LHC



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CERN

High Lumi LHC Coordinator



**High
Luminosity
LHC**

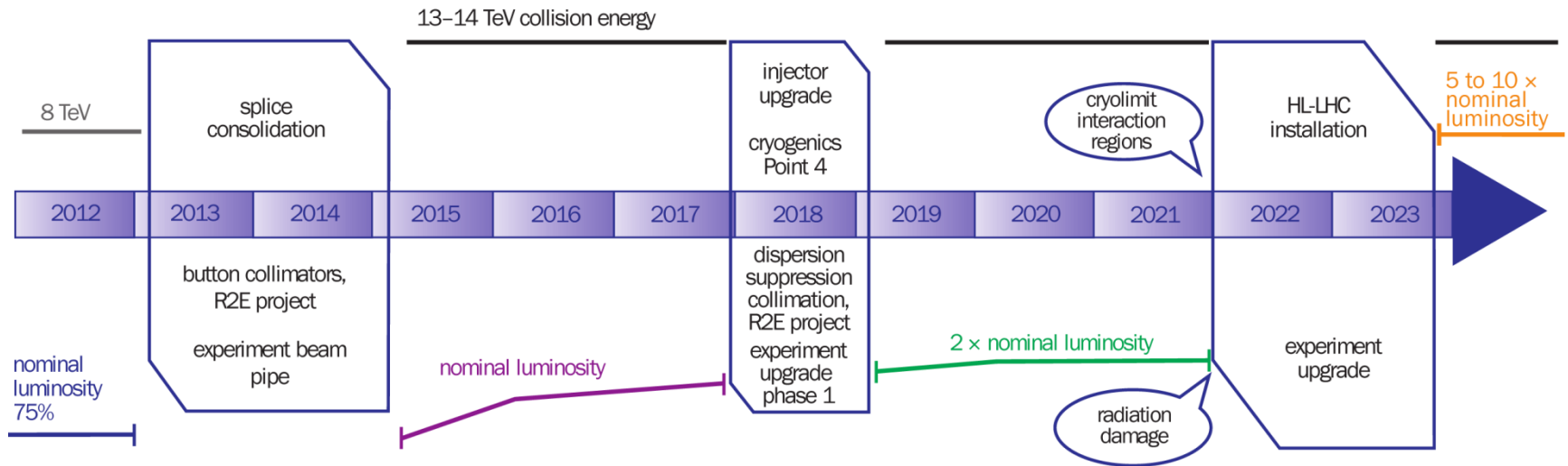
AFF Commission Cryogénie et Supraconductivité.
Les Journées Thématiques au CERN:
LHC, premiers résultats et perspectives.
June 6th-7th, 2013



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



10 y plan of LHC



Luminosity $L \equiv N_{\text{events}}/\text{cross section}$; $N_{\text{events}} = L * \sigma$

Luminosity will continue to increase in LHC thanks to better understanding of the operations and thanks to interventions during LS

Around 2021 we expect to meet few limitations:

- Radiation damage and general wear in the machine and detector
- Limitation of the increase in luminosity, which is necessary for physics

Lumi: main ingredients

$$L = \underbrace{\gamma}_{\text{energy}} \cdot \underbrace{\frac{f_{\text{rev}} n_b N_b^2}{4\pi \epsilon_n \beta^*}}_{\text{Beam current} \cdot \text{Beam size}} \cdot R$$

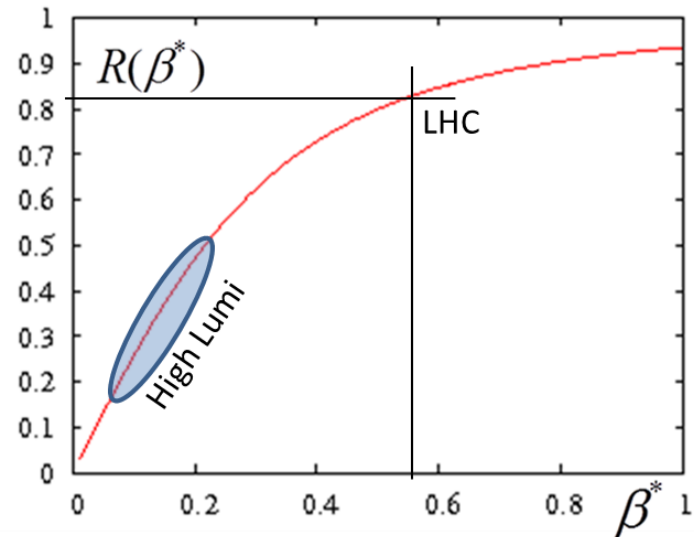
Small $\beta^* \rightarrow$ big θ_c

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

Beam current and emittance:
involve Inj chain and whole ring
 β^* involve «only» 2 IRs, 600 m.

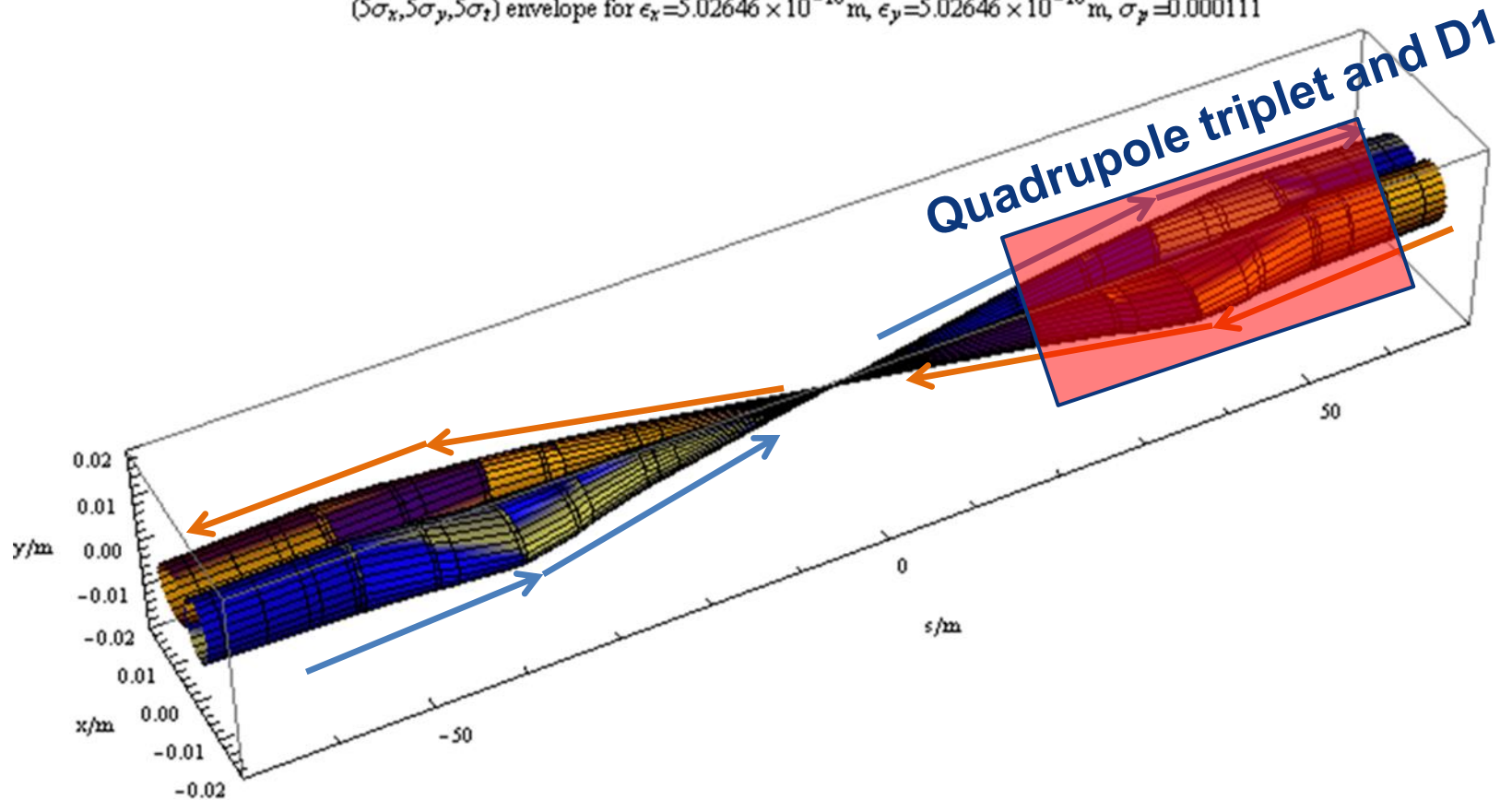
$$L_0 = 1 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$$

Unit of lumi through the talk



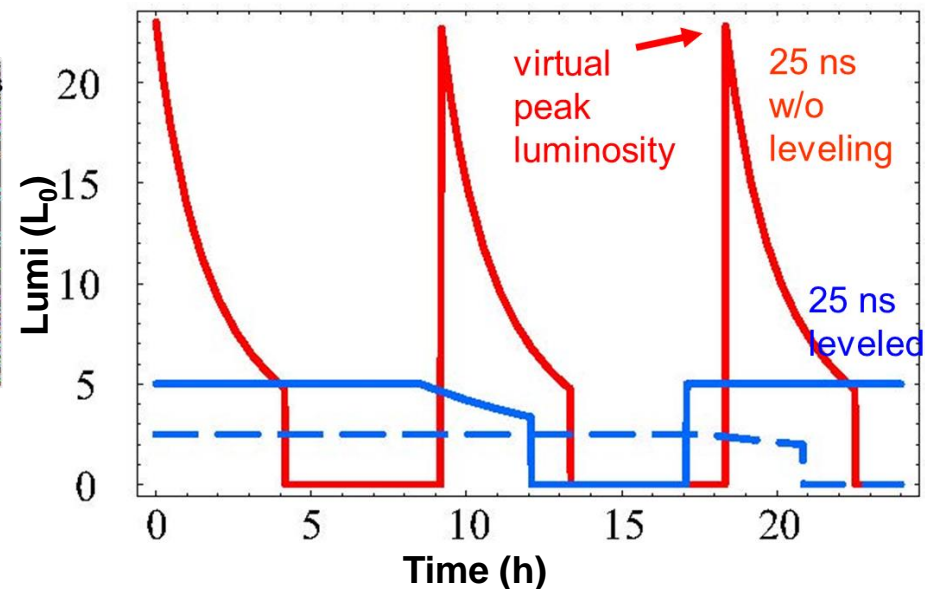
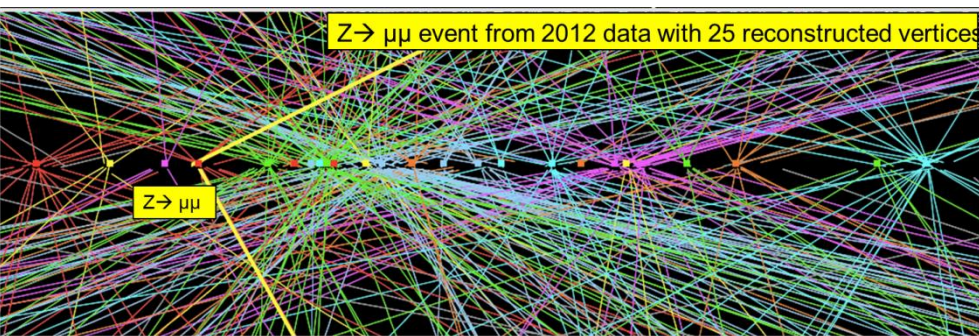
How to do small β^*

$(5\sigma_x, 5\sigma_y, 5\sigma_z)$ envelope for $\epsilon_x = 5.02646 \times 10^{-10}$ m, $\epsilon_y = 5.02646 \times 10^{-10}$ m, $\sigma_z = 0.000111$

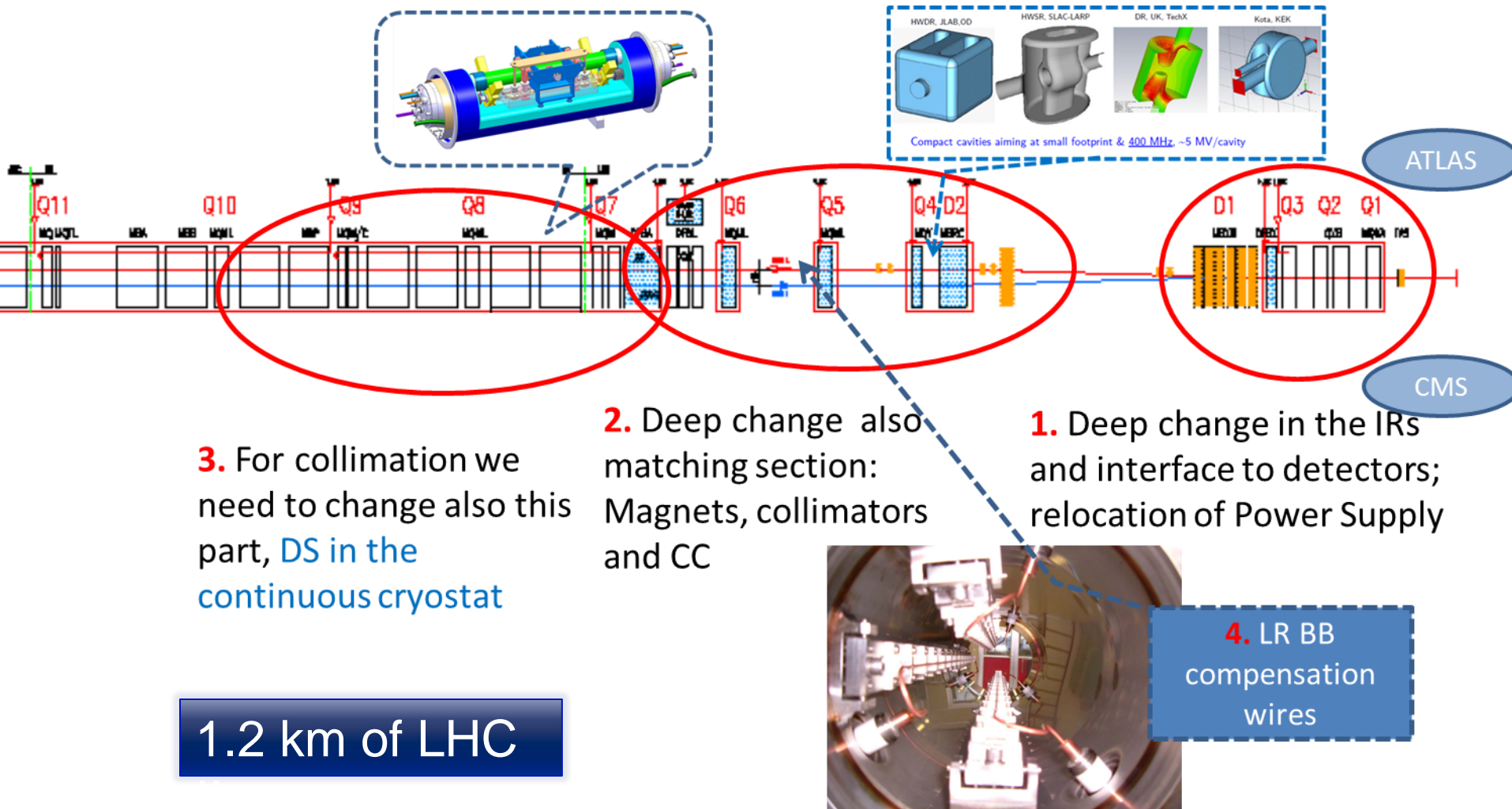


Goals of the HL-LHC established in autumn 2010

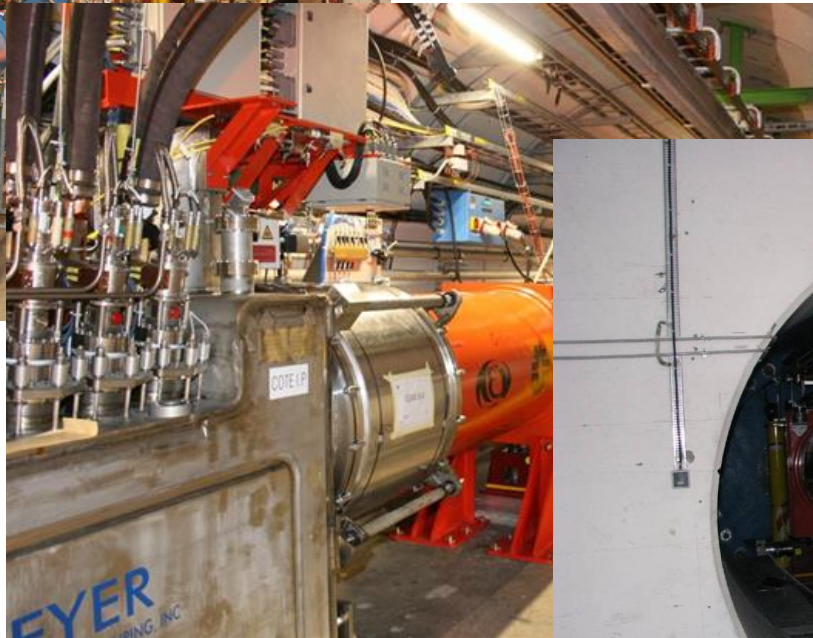
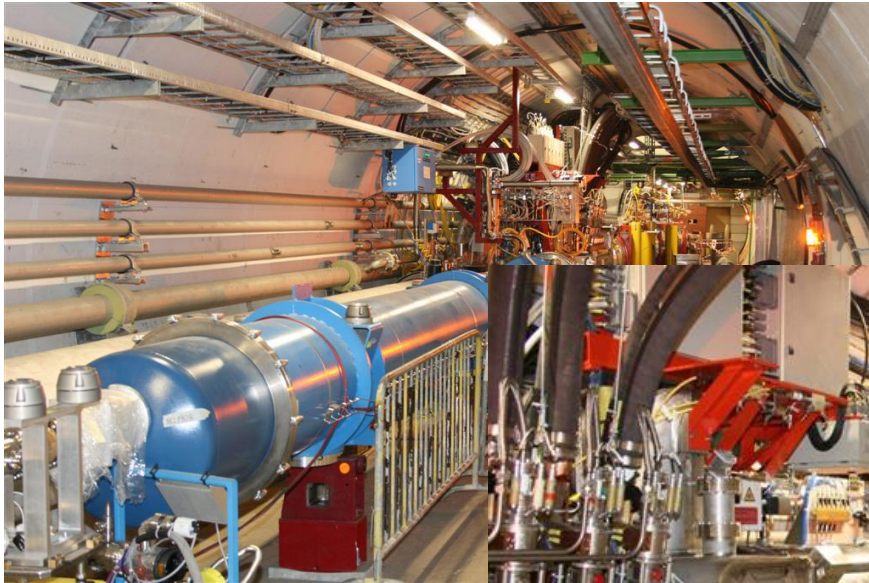
- Working at levelled luminosity:
- $L_{\text{const}} = 5 L_0 (5 \cdot 10^{34})$ limit pileup and heat depo
- Produce $\sim 250 \text{ fb}^{-1}/\text{year} \Rightarrow 3000 \text{ fb}^{-1}$ by 2035
 - Before LHC; $\sim 10\text{-}15 \text{ fb}^{-1}$
 - LHC 2012: $\sim 25 \text{ fb}^{-1}$ with extended year
 - LHC design : $300 (700) \text{ fb}^{-1}$



The LHC region(s) to change



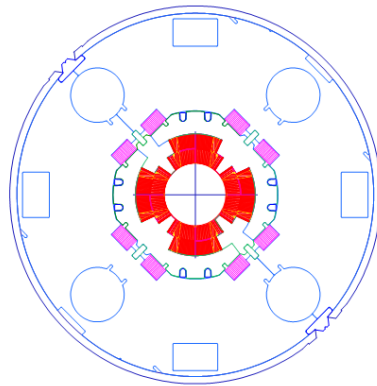
Here the region of low- β^*



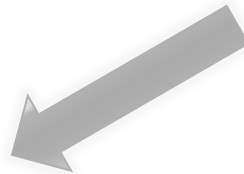
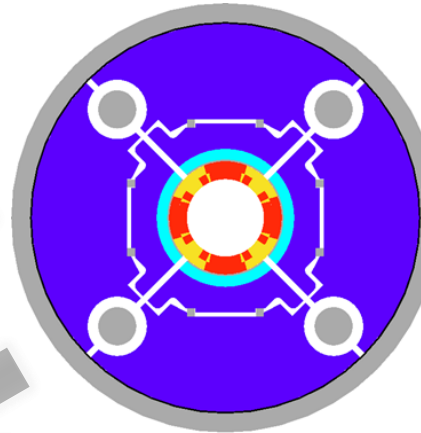
Q1.1R1
sept. 2009

LHC low- β quads: steps from present LHC toward HL-LHC

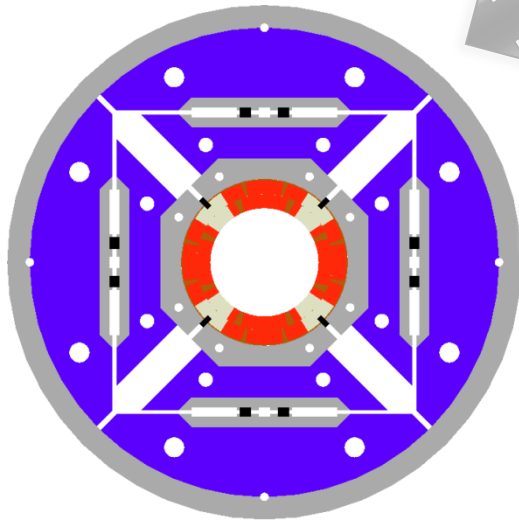
LHC (USA & JP, 5-6 m)
 $\varnothing 70$ mm, $B_{\text{peak}} \sim 8$ T
1992-2005



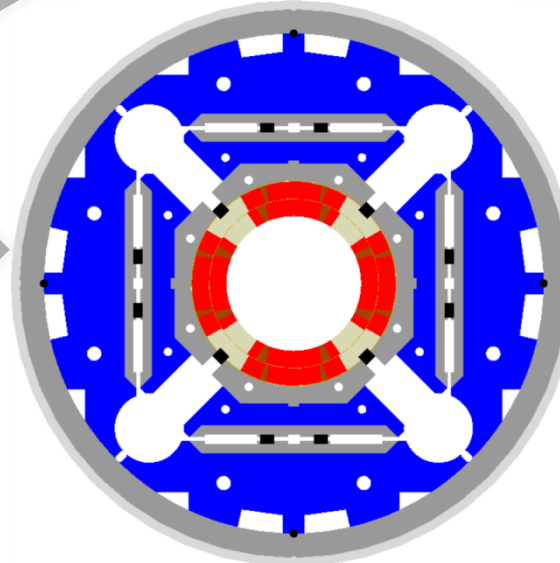
LARP TQS & LQ (4m)
 $\varnothing 90$ mm, $B_{\text{peak}} \sim 11$ T
2004-2010



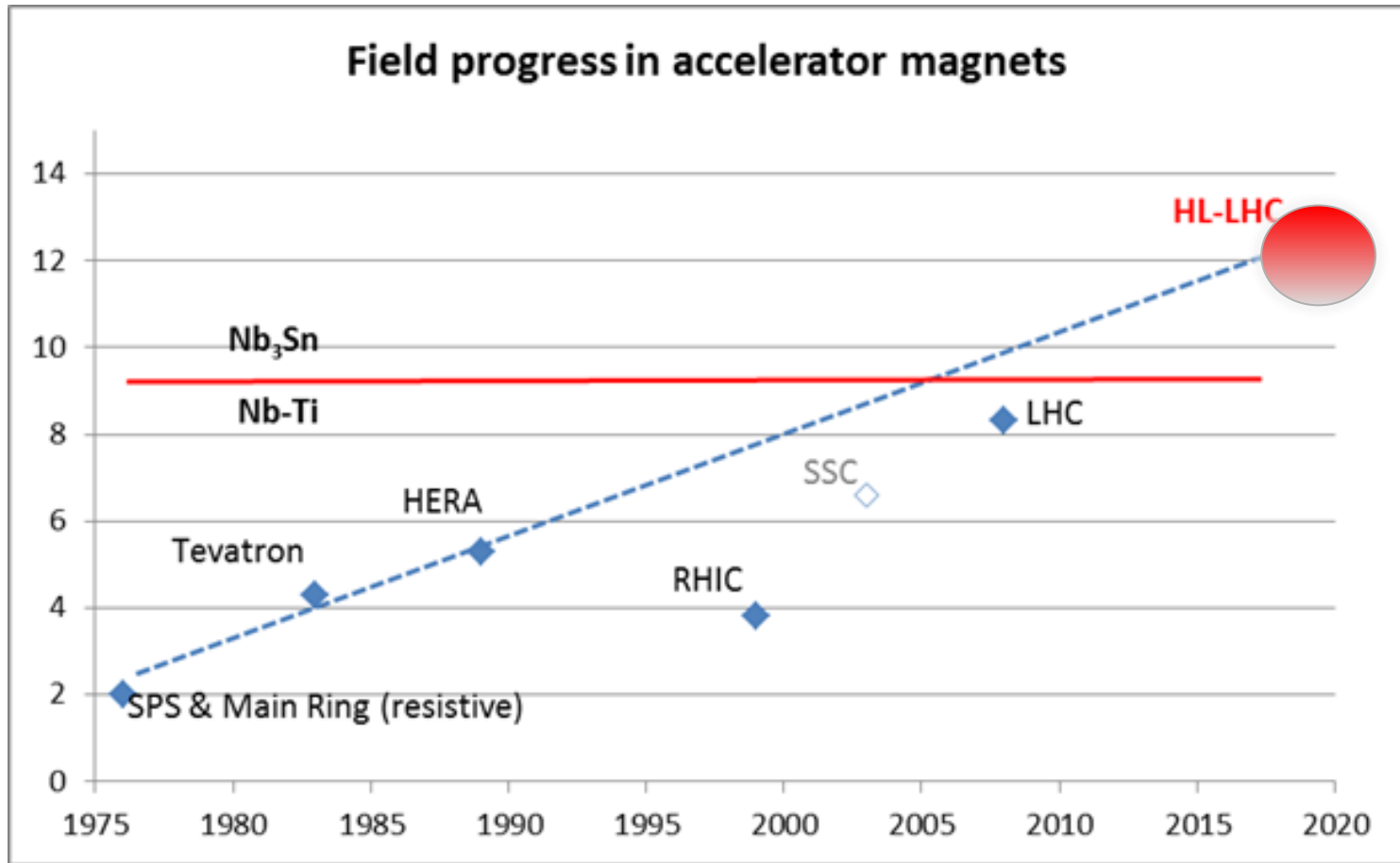
LARP HQ
 $\varnothing 120$ mm,
 $B_{\text{peak}} \sim 12.5$ T
2008-2014



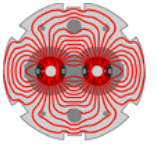
LARP & CERN
MQXF
 $\varnothing 70$ mm,
 $B_{\text{peak}} \sim 8$ T
2013-2020



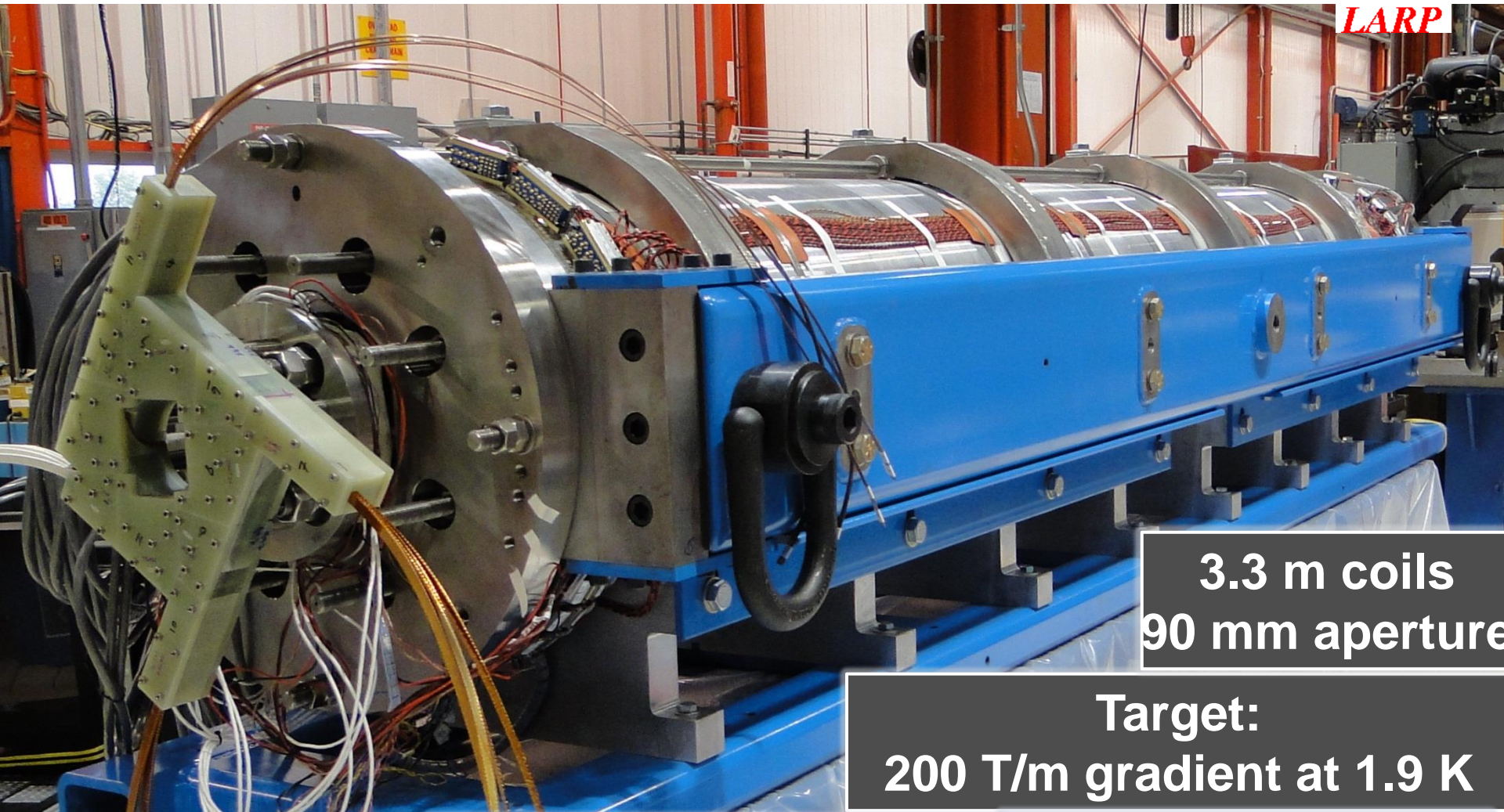
SC Magnets: evolution with projects



LSQ of LARP



LARP



**3.3 m coils
90 mm aperture**

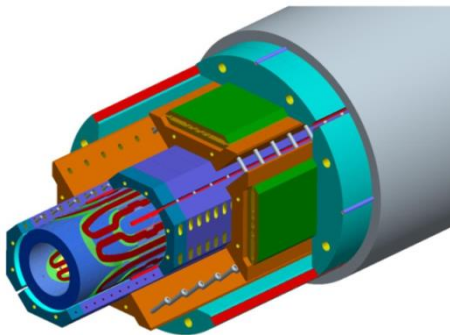
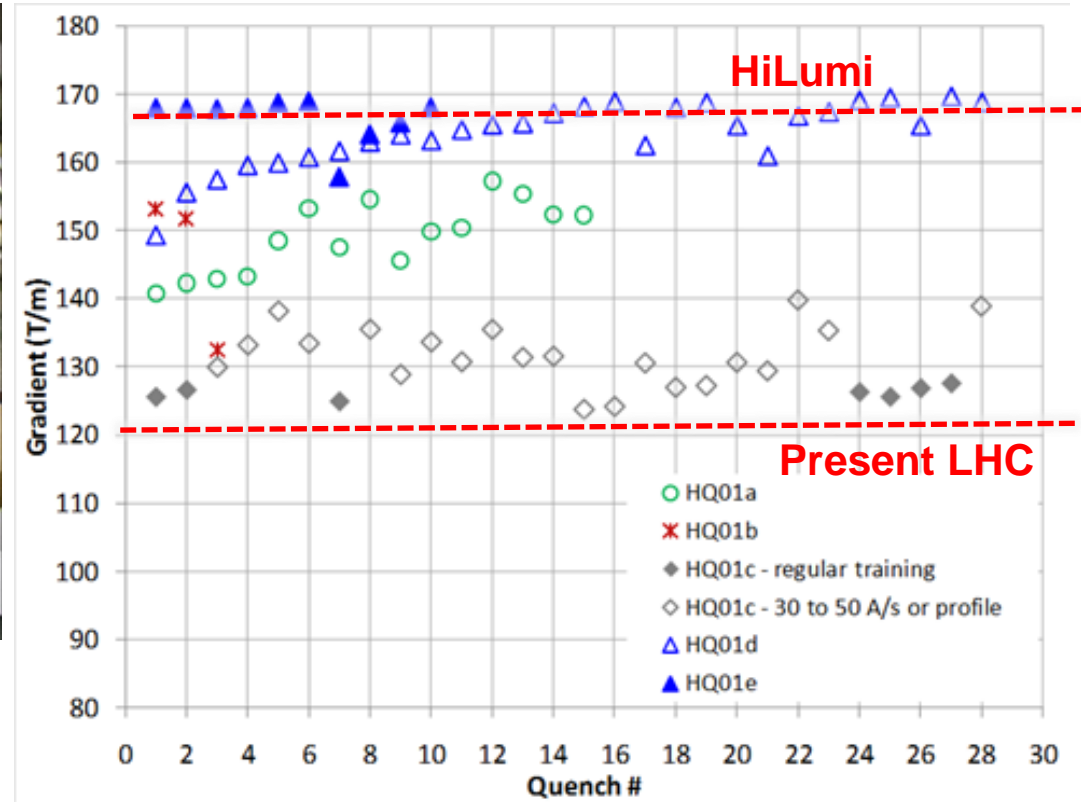
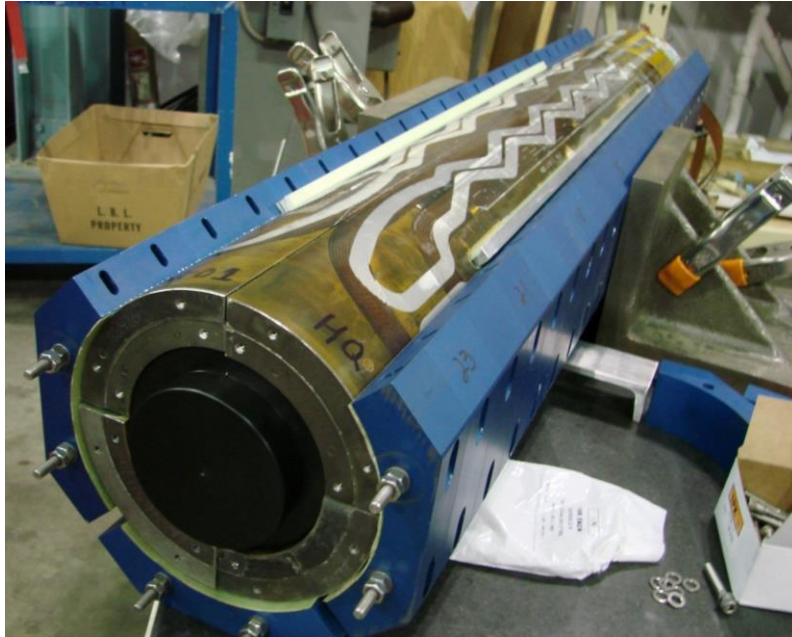
**Target:
200 T/m gradient at 1.9 K**

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

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

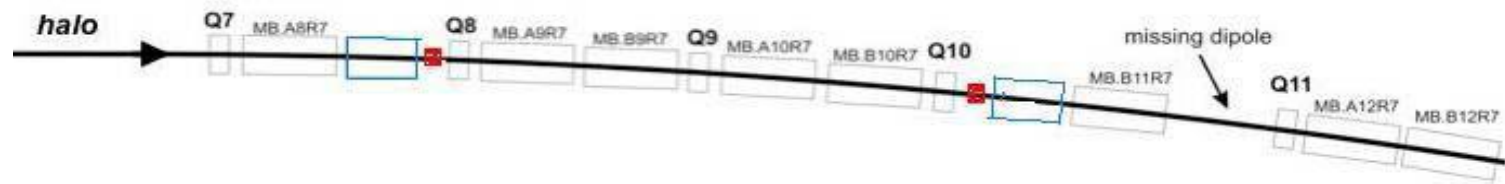


HQ – 1 m long - $\varnothing 120$ mm



S. Caspi , H. Felice, G. Sabbi, LBNL

New collimation in the DS for off-momentum particles: **11 T dipole!**



5.5 m Nb₃Sn

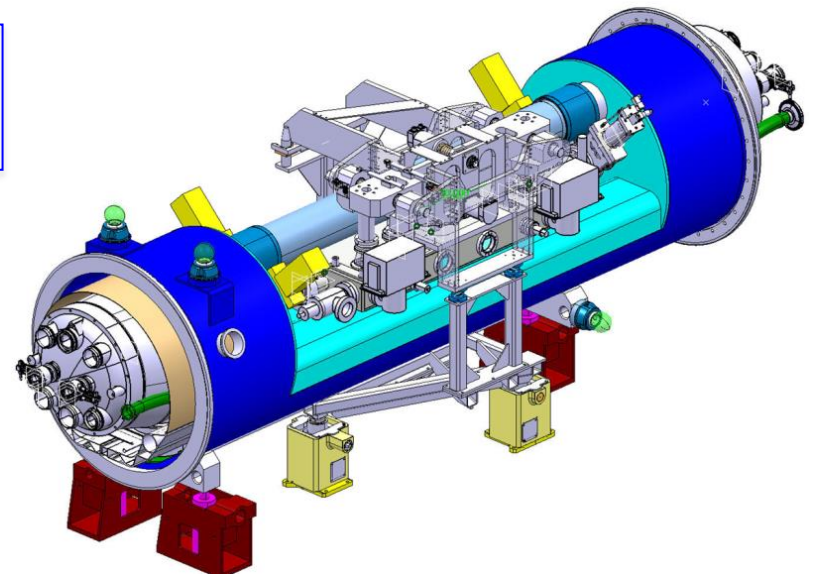
3.5 m
Collim

5.5 m Nb₃Sn

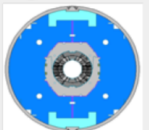
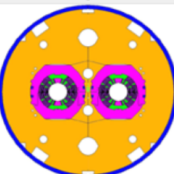
5.5 m Nb₃Sn

3.5 m
Collim.

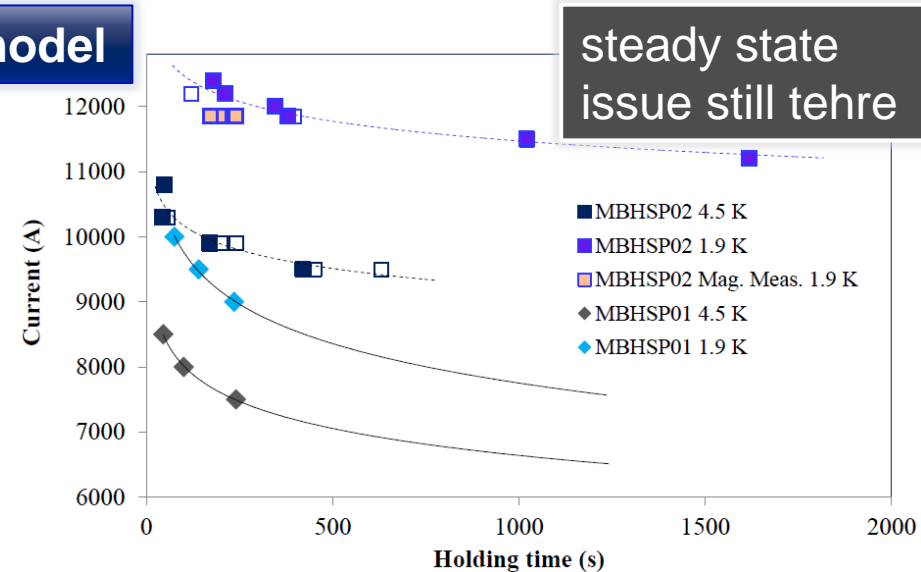
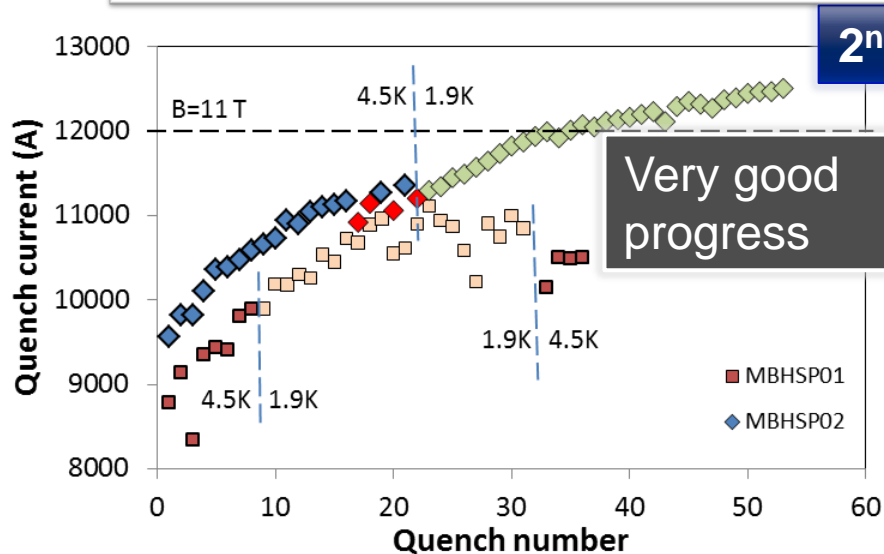
5.5 m Nb₃Sn



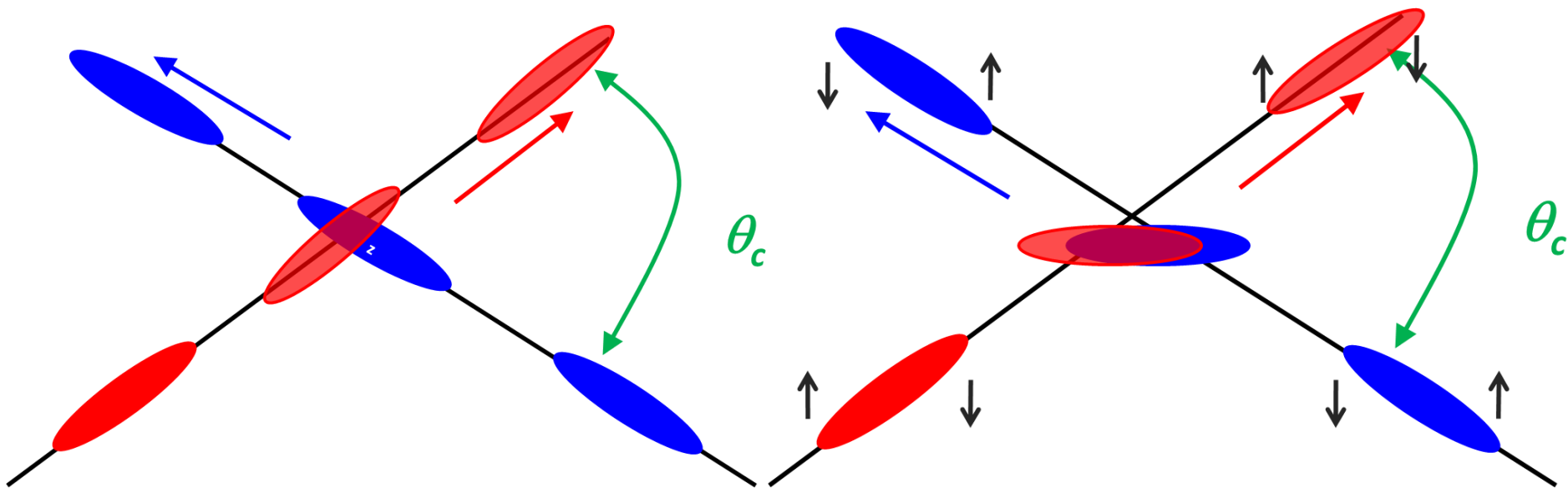
11 T results and issue Fermilab

Parameter	Single-aperture	Twin-aperture
		
Aperture	60 mm	
Yoke outer diameter	400 mm	550 mm
Nominal bore field @11.85 kA	10.88 T	11.23 T
Short-sample bore field at 1.9 K	13.4 T	13.9 T
Margin B_{nom}/B_{max} at 1.9 K	0.81	0.83
Stored energy at 11.85 kA	424 kJ/m	969 kJ/m
F_x per quadrant at 11.85 kA	2.89 MN/m	3.16 MN/m
F_y per quadrant at 11.85 kA	-1.58 MN/m	-1.59 MN/m

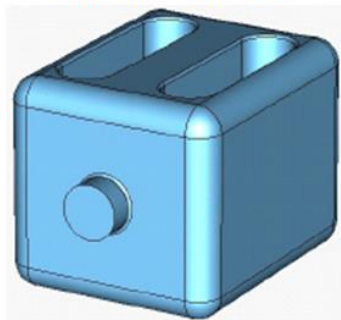
Jc(12T, 4.2K)=2750 A/mm², cable Ic degradation 10%.



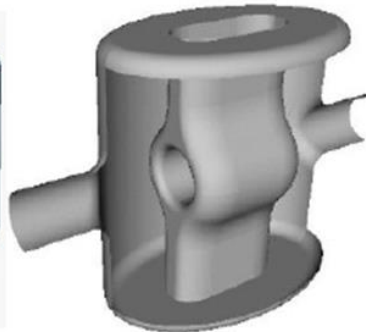
Beating the geometric reduction factor: Crab Cavity



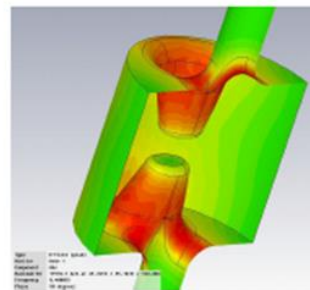
HWDR, JLAB, OD



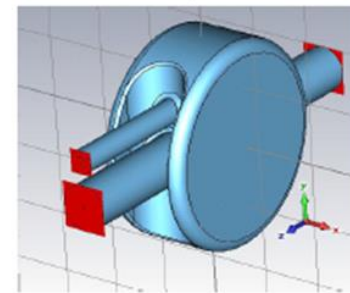
HWSR, SLAC-LARP



DR, UK, TechX

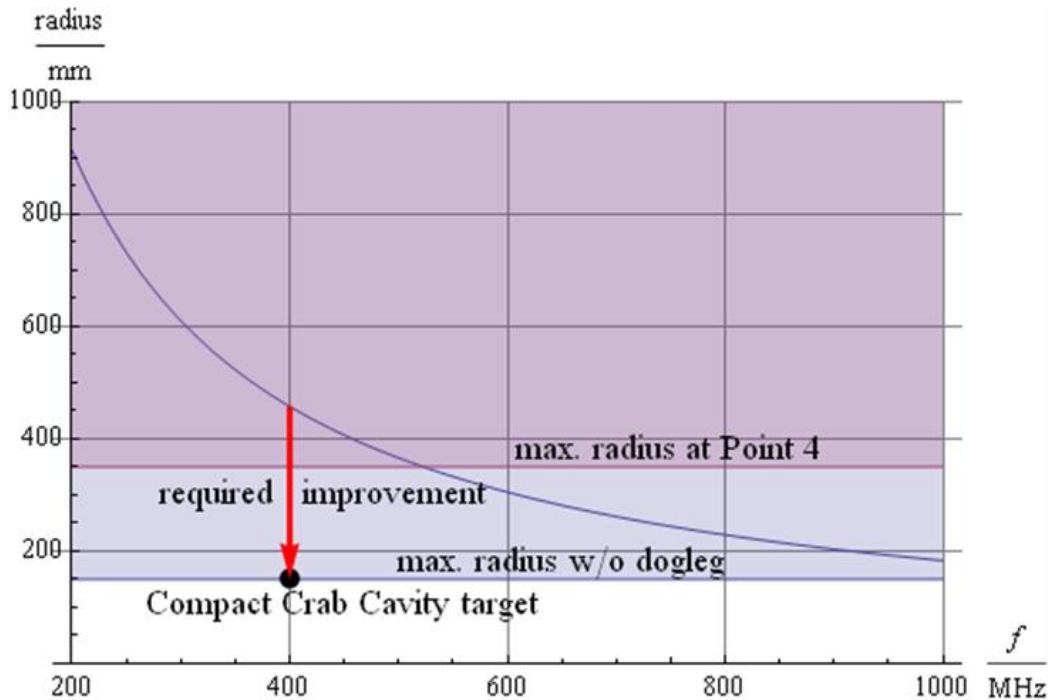


Kota, KEK



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

Really compact to fit into LHC



Lancaster cavity

Present design of CCs

4-rod in SM18 for RF measurements



Cockcroft Institute
& Lancaster Univ.

ODU (Old Dominion Univ.)
and JLAB (USA)
RF-Dipole Nb prototype



DQWR prototype (17-Jan-2013)

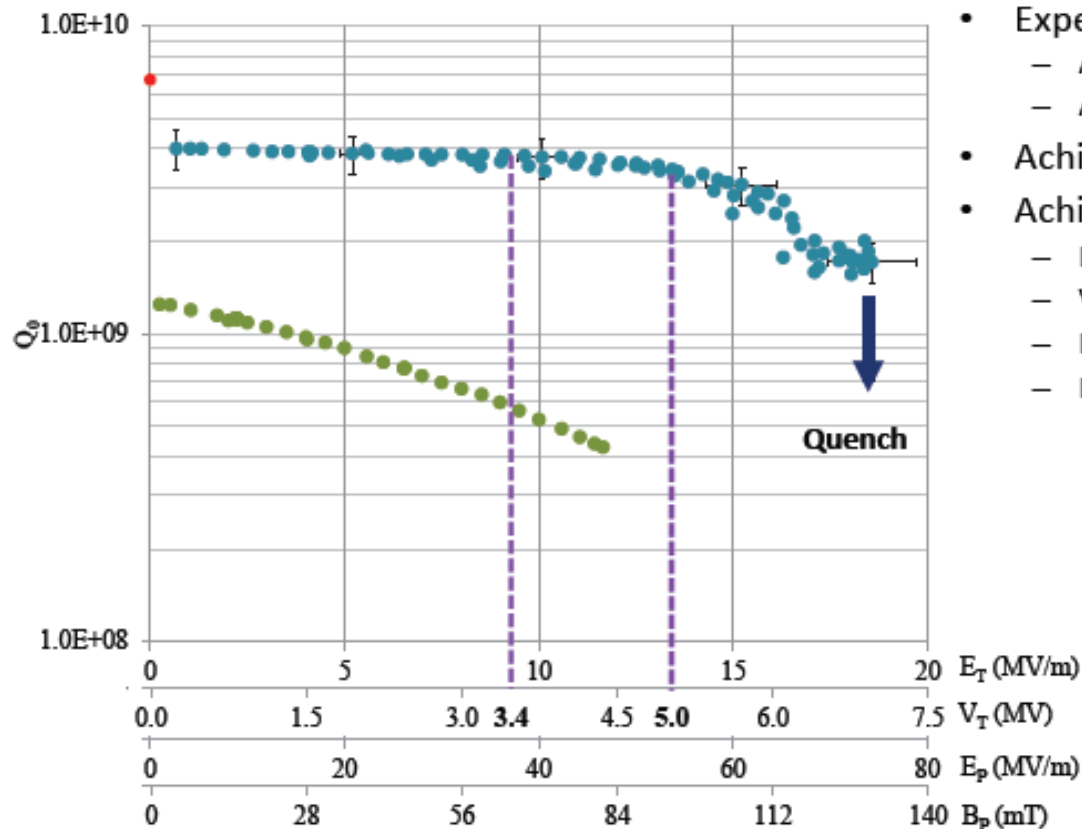
BNL



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



PoP RF Dipole 4.2 K and 2 K Test Results



- Expected $Q_0 = 6.7 \times 10^9$
 - At $R_s = 22 \text{ n}\Omega$
 - And $R_{\text{res}} = 20 \text{ n}\Omega$
- Achieved $Q_0 = 4.0 \times 10^9$
- Achieved fields
 - $E_T = 18.6 \text{ MV/m}$
 - $V_T = 7.0 \text{ MV}$
 - $E_p = 75 \text{ MV/m}$
 - $B_p = 131 \text{ mT}$

Courtesy
A. Ratti, LBNL



Thinking to cryomodule and test in SPS (2015-16)

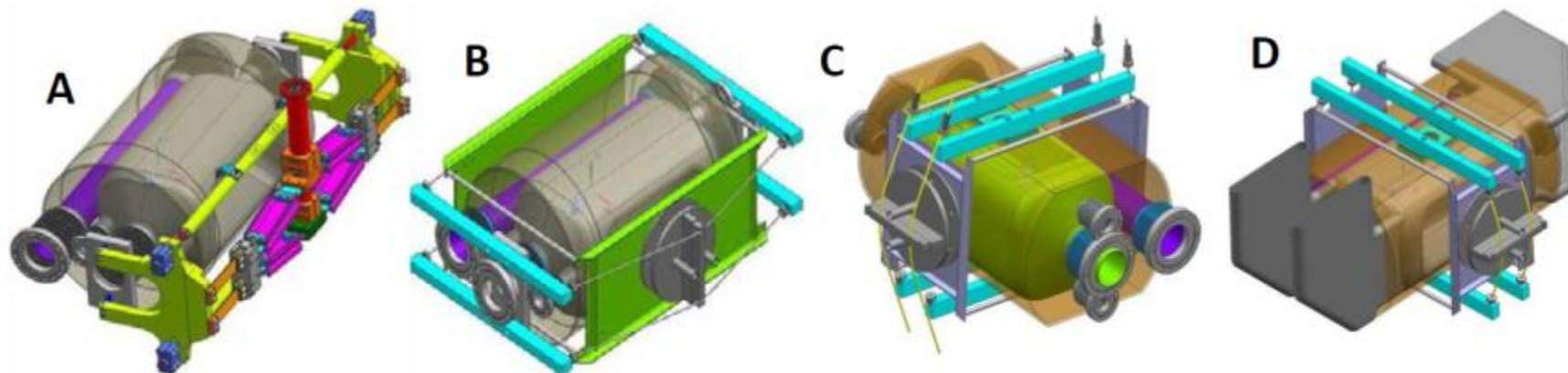
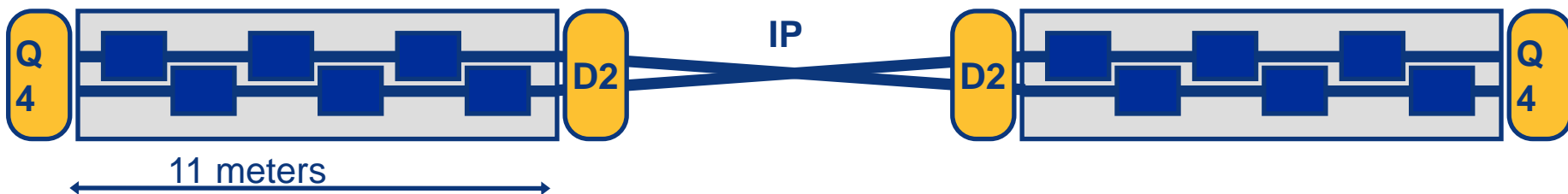
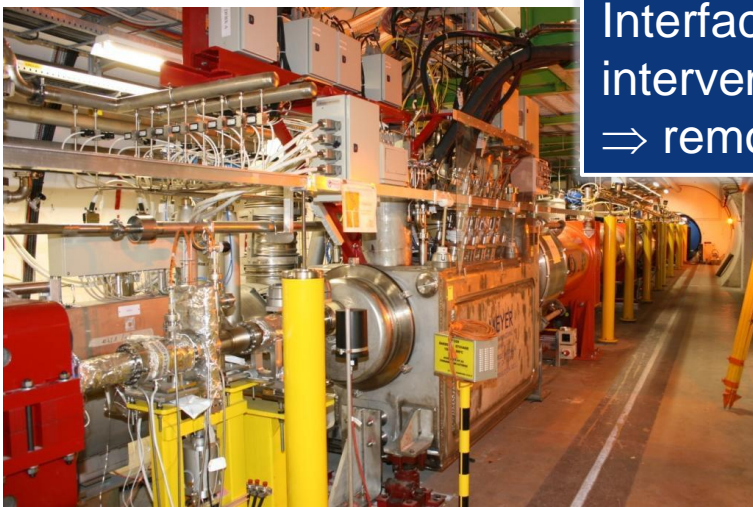
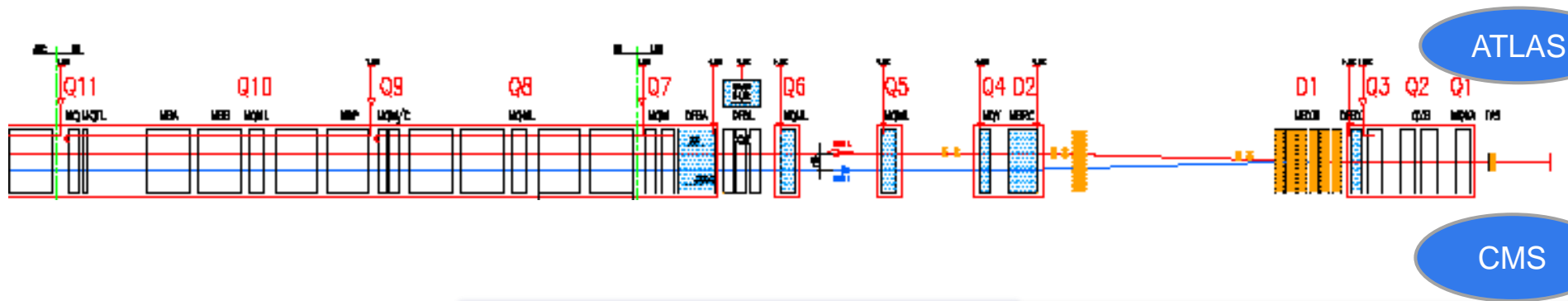


Figure 1: LHC crab cavity cryostat concept – A) JLab design, B) ANL design (helium pressure actuates bellows), C) ANL design (tuner deforms cavity outer surfaces), D) Waveguide



Reducing radiation risk at 3000 fb^{-1} and increase availability: SC links

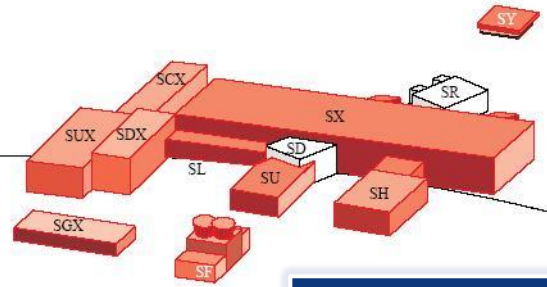


Interface warm-cold requires intervention for maintenance
⇒ remove on surface

1. New Magnets in the IRs and interface to detectors; relocation of Power Supplies via use of **SC links**

Power convertes are very vulnerable to radiation (SEU)



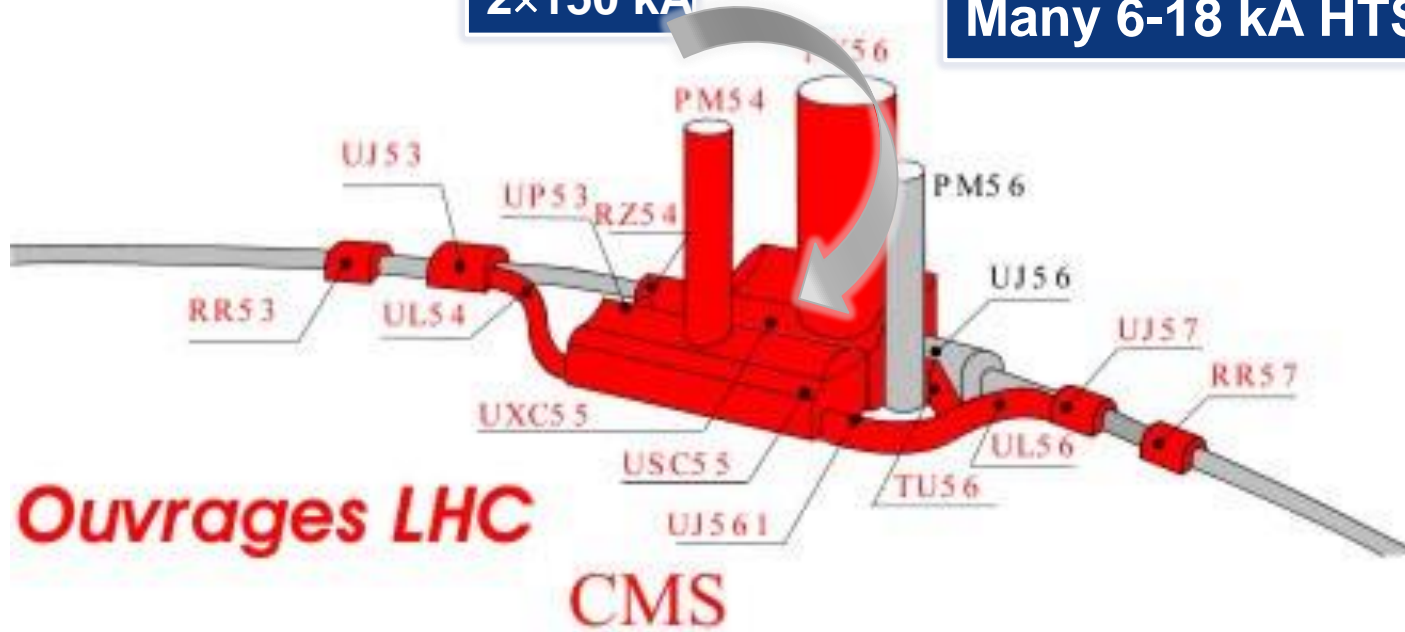


POINT 5

1 pair 700 m 50 kA – 2016-17
 4 pairs 300 m 150 kA – 2018
 4 pairs 300 m 150 kA – 2021
 Many 6-18 kA HTS Cur.Leads

2×150 kA

Point 5



Ouvrages LHC

CMS

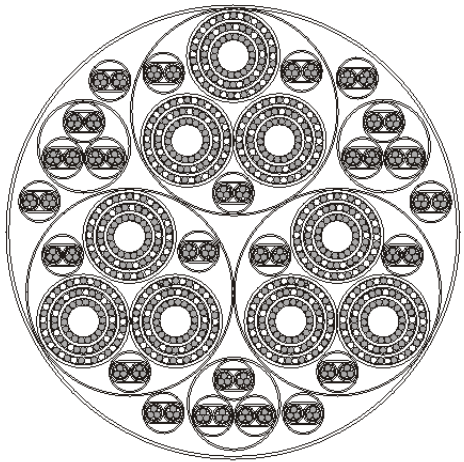
MgB₂ baseline

Cable structure using MgB₂ wires

27 cables 6000 A

48 cables 600 A

$I_{\text{tot}} = 190 \text{ kA}$ ($\sim 2 \times 95 \text{ kA}$)

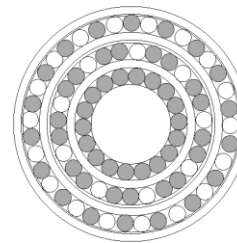


$\Phi = 75$

$\sim 7 \text{ kg/m}$

$\sim 900 \text{ m}_{\text{HTS}}/\text{m}_{\text{cable}}$

$3 \times 6 \text{ kA}$

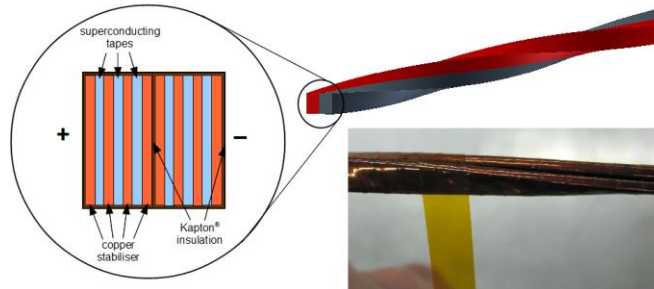
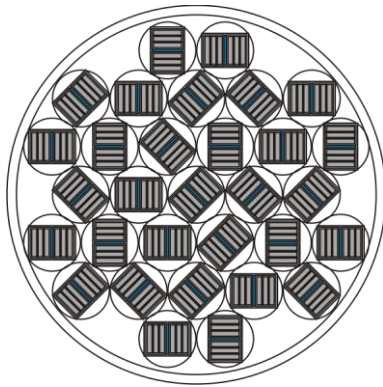


Courtesy A. Ballarino,
CERN

HTS possible for “smaller cable”: $24 \times 2 \times 600 \text{ A}$ ($2 \times 15 \text{ kA}$) @ 25 K MgB_2 @ 65 K (YBCO and Bi-2223)

$\sim 2 \text{ kg/m}$

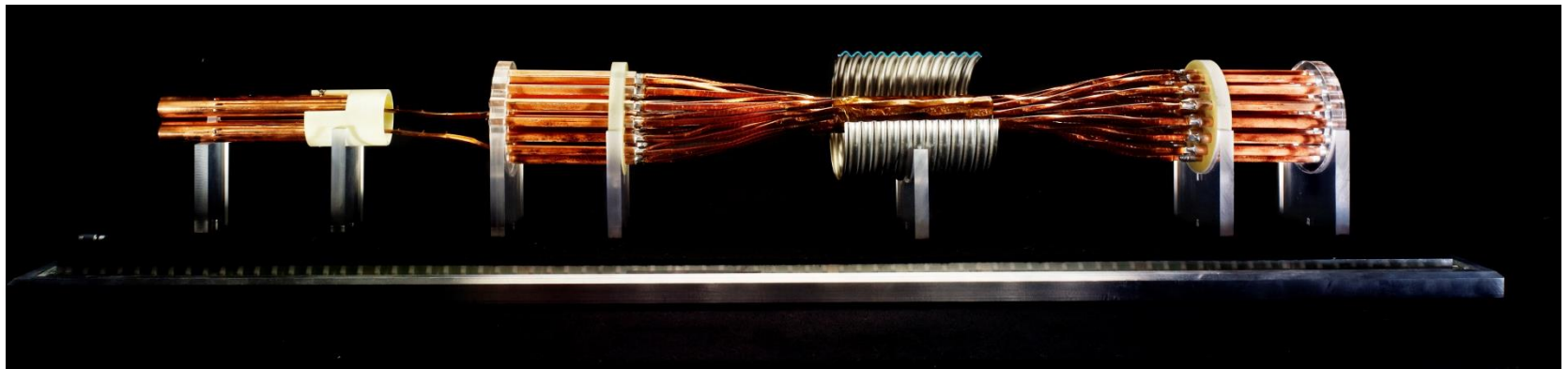
$\sim 200 \text{ m}_{\text{HTS}}/\text{m}_{\text{cable}}$



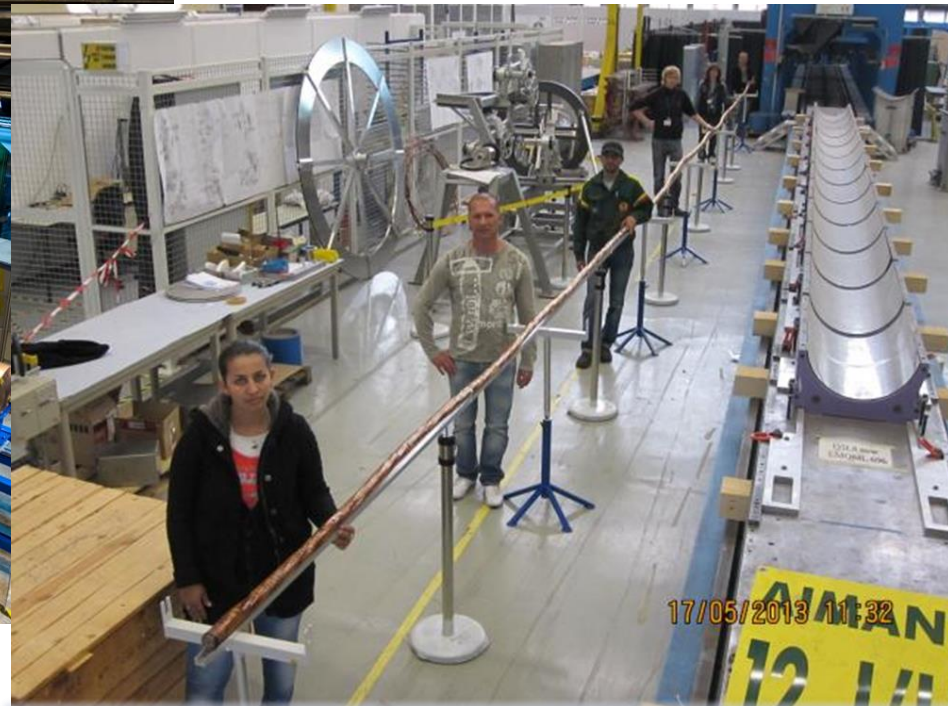
Novel cable concept
using tapes (MgB_2 ,
YBCO or YBCO)



A. Ballarino, CERN

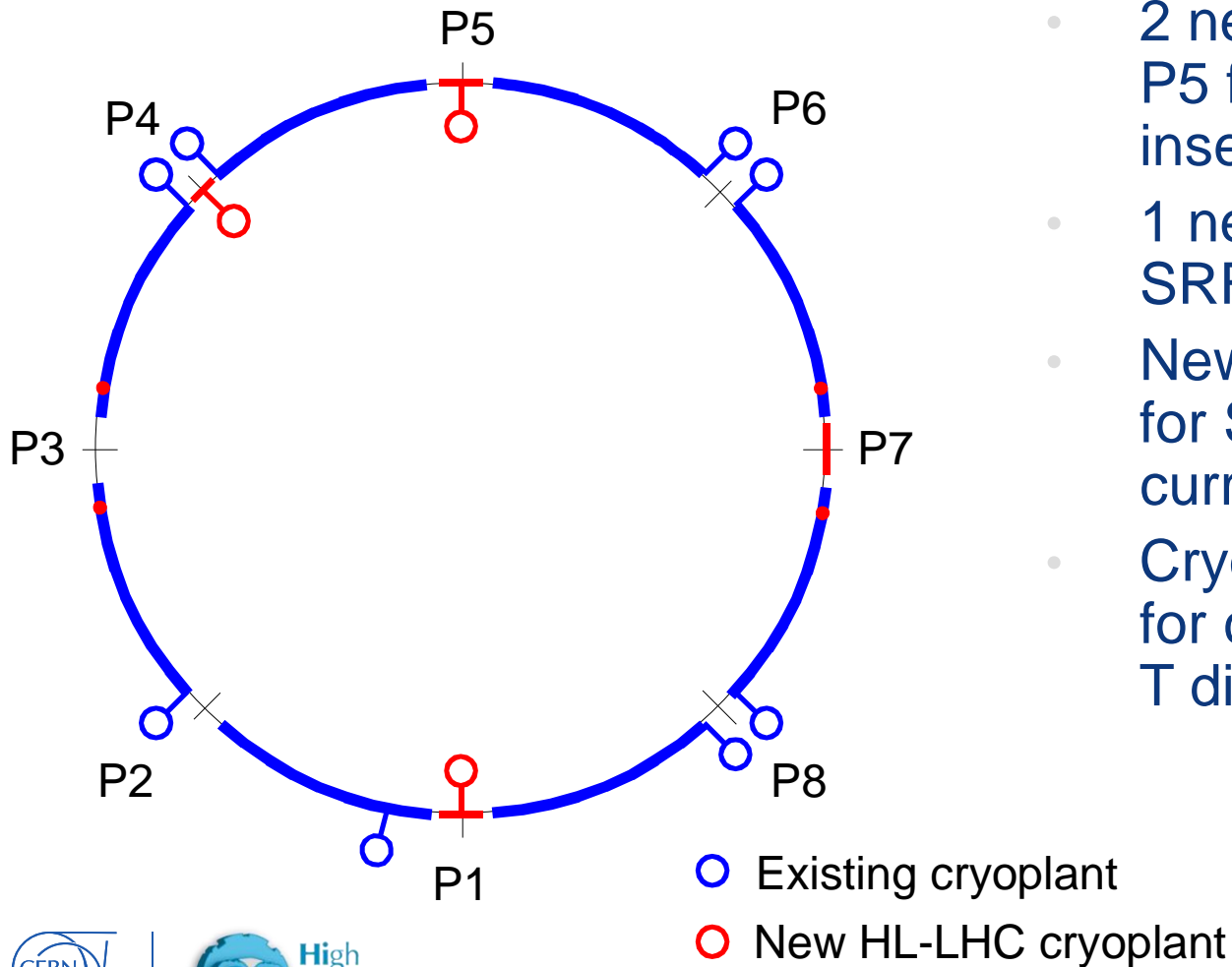


A unique tool: the CERN test station: 20 kA, variable temper.



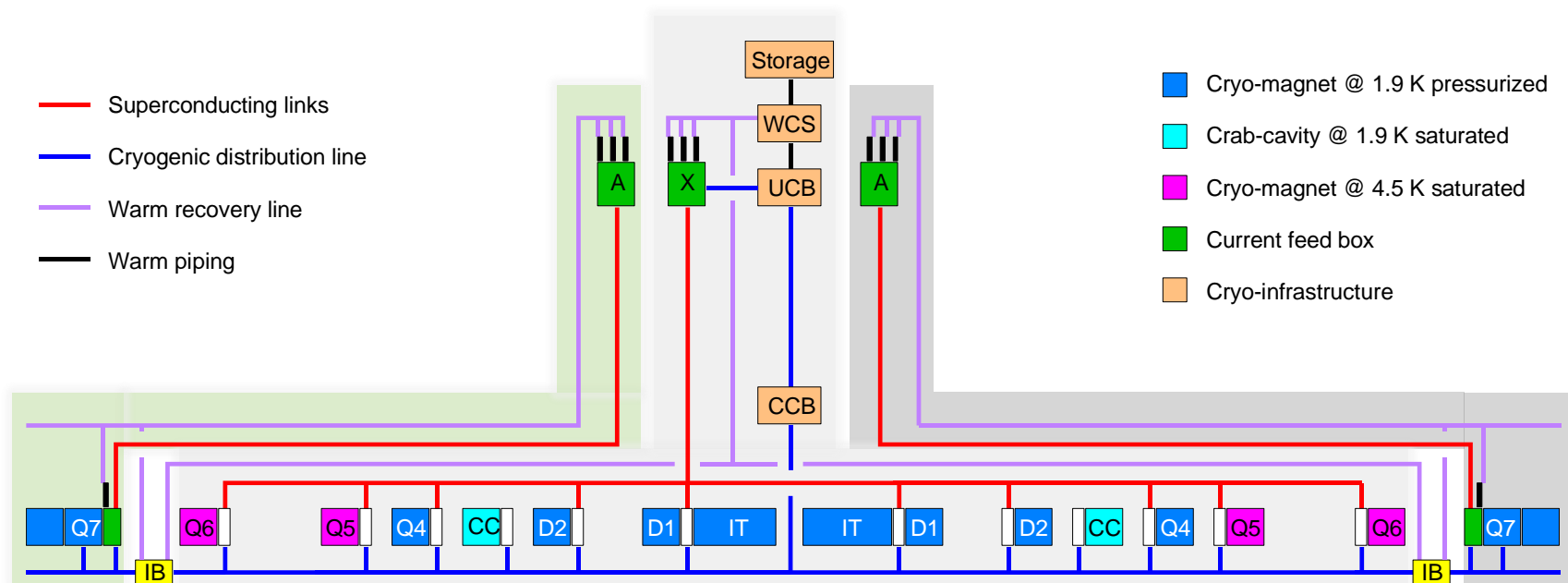
Completion of 20 m long prototype superconducting link for P7 (50□600 A @ 25 K, MgB2)

Overall new cryo HL-LHC layout



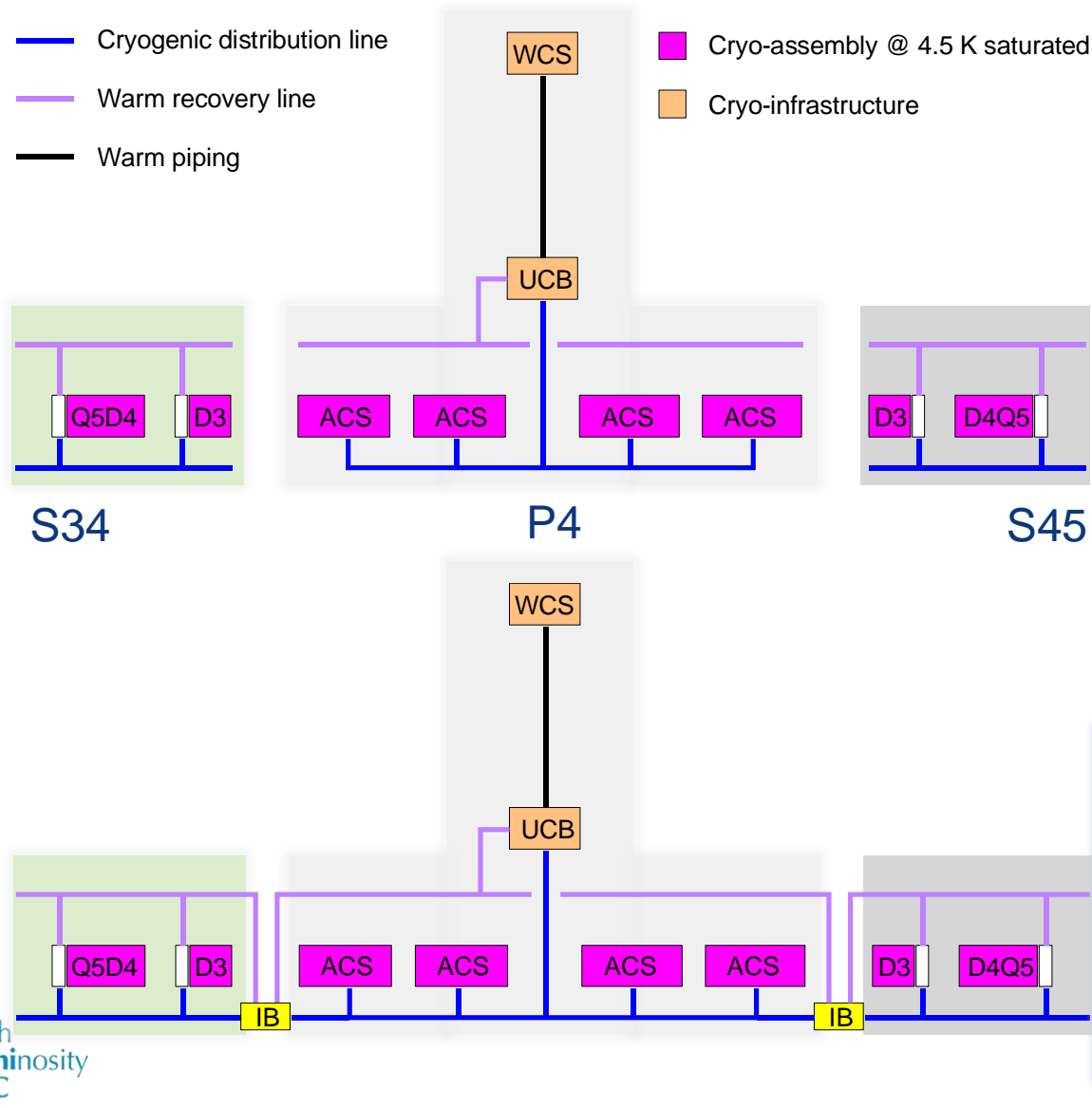
- HL-LHC cryo-upgrade:
 - 2 new cryoplants at P1 and P5 for high luminosity insertions
 - 1 new cryoplant at P4 for SRF cryomodules
 - New cooling circuits at P7 for SC links and deported current feed boxes
 - Cryogenic design support for cryo-collimators and 11 T dipoles at P3 and P7

Low- β^* and MS region (LSS) cryo

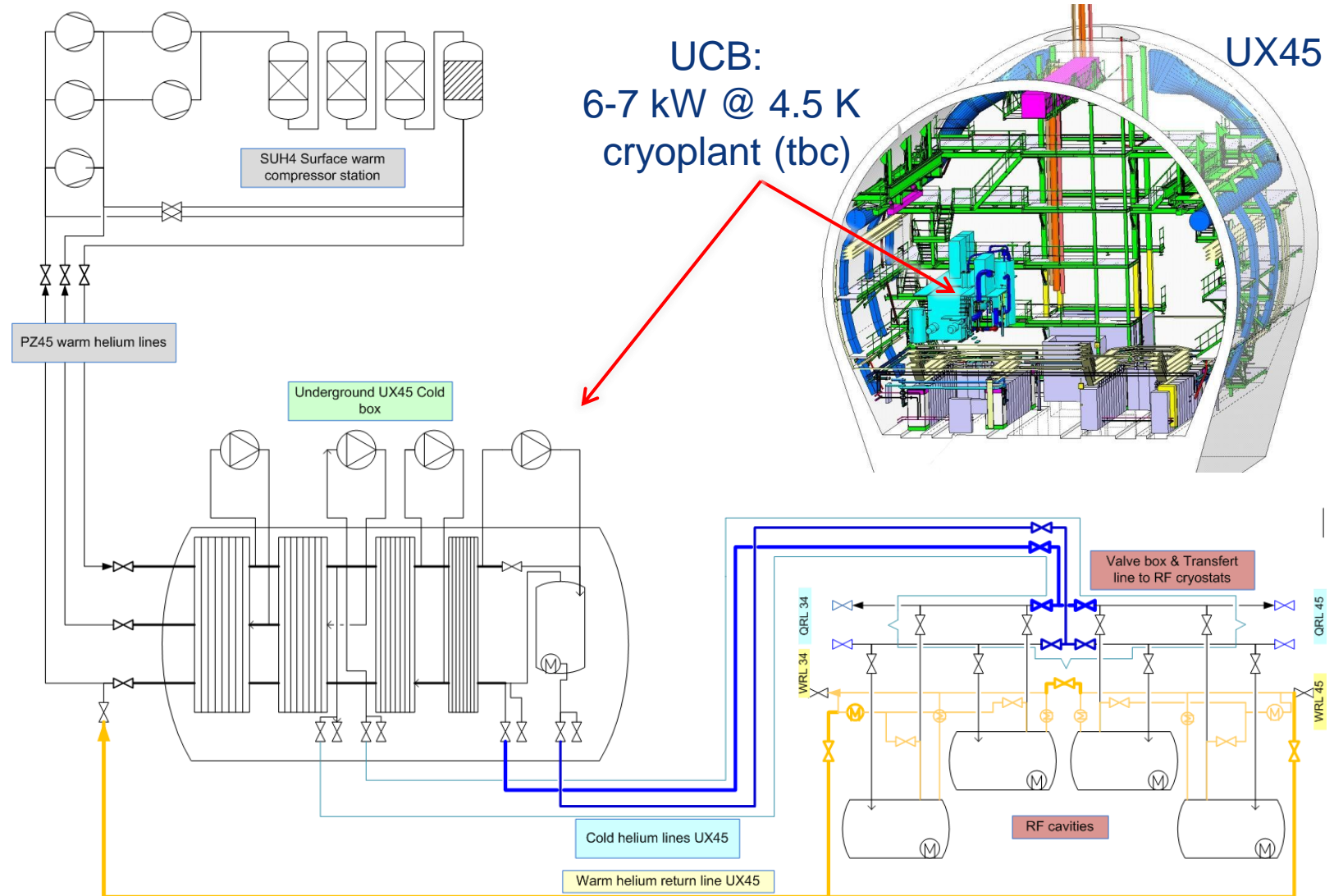


2 new plants for : 18 kW (4.2 K equiv.) delivering 1.8 K to:
2x (4xMQX,D1,D2,CC, Q4,Q5,Q6)
Providing redundancy with the arc
Liberating more cryopower for e-clouds and other effects

P4 Layout: new cryogenics for SRF module



P4 cryogenic process & flow diagram



EU strategy update document: approved 30 May 2013 by Council

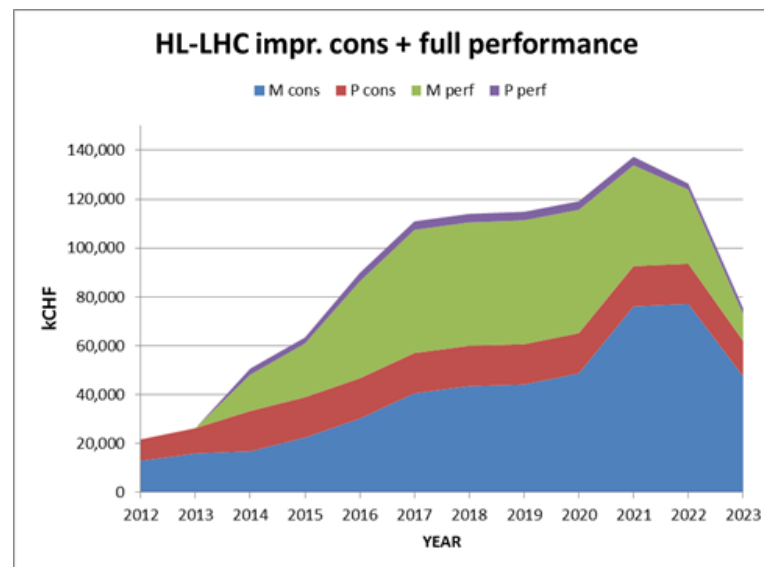
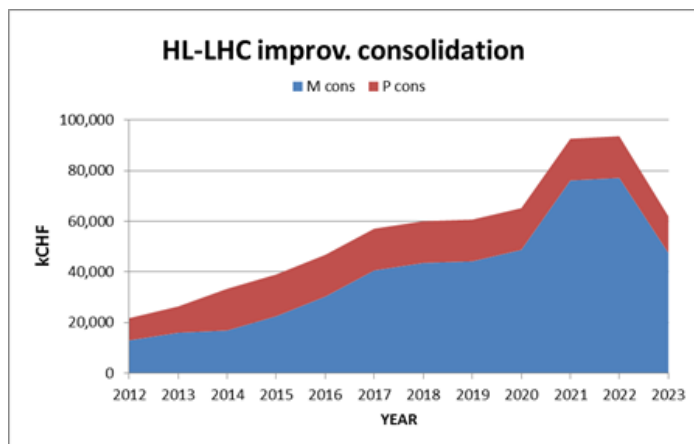
High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *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.

Required Budget

Performance Improving Consolidation (PIC): Equipment for which upgrade is a plus but change is a must



	Improving Consolidation	Full performance	Total HL-LHC
Mat. (MCHF)	476	360	836
Pers. (MCHF)	182	31	213
Pers. (FTE-y)	910	160	1070
TOT (MCHF)	658	391	1,049