The LHC Upgrades in Luminosity and Energy: Options and Plan

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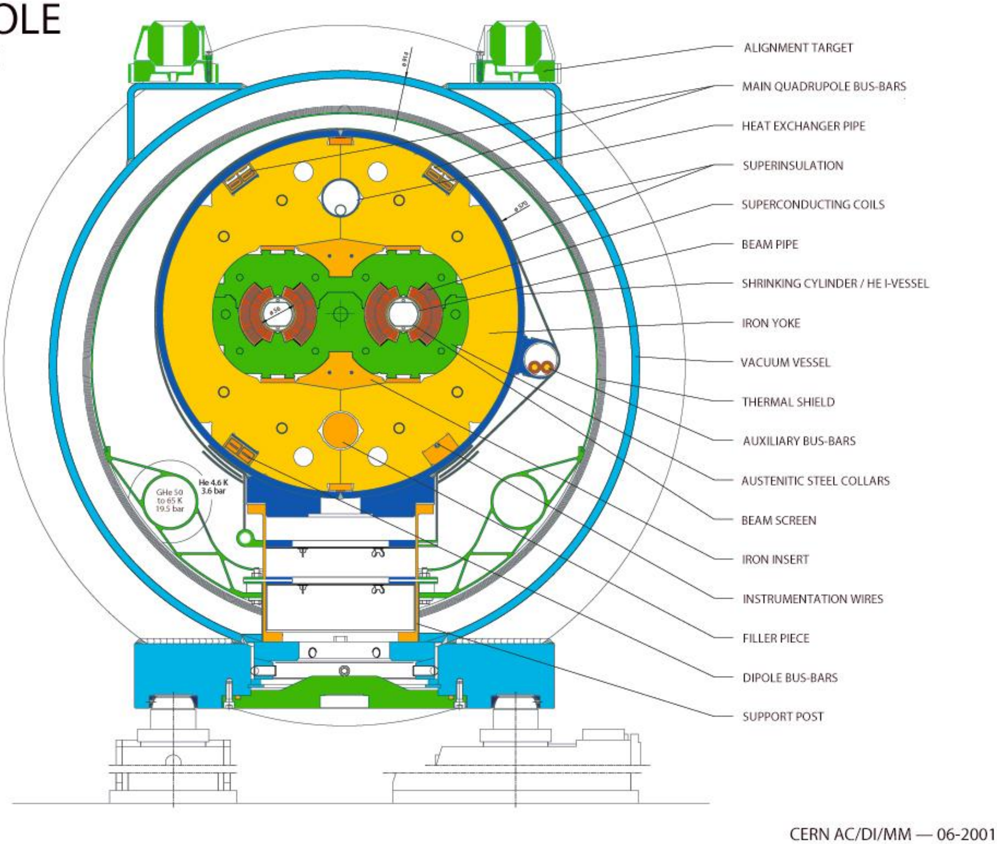
Highlights

- LHC today : performance
- Luminosity : which goal, parameters and hardware changes
- High Luminosity LHC
  - Magnets
  - SC Crab Cavities
  - SC Links
- LHC: a long history, a longer future?
- High Energy: towards a farther energy frontier

LHC: the numbers

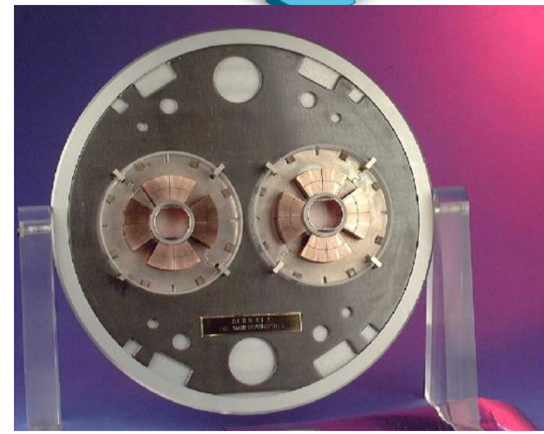
- 27 km, p-p at 7+7 TeV
  3.5+3.5 start, **4+4 in 2012**
- 1232 x 15 m Twin Dipoles
- Operational field 8.3 T @11.85 kA (9 T design)
- HEII cooling, 1.9 K with 3 km circuits (130 tonnes He inventory).
- Field homogeneity **of 10^{-4} at 1 cm** from the coils, bending strength uniformity better then 10^{-3}. Field quality control (geometric and SC effects) at 10^{-5}.

LHC DIPOLE
CROSS SECTION



LHC: the numbers (cont.)

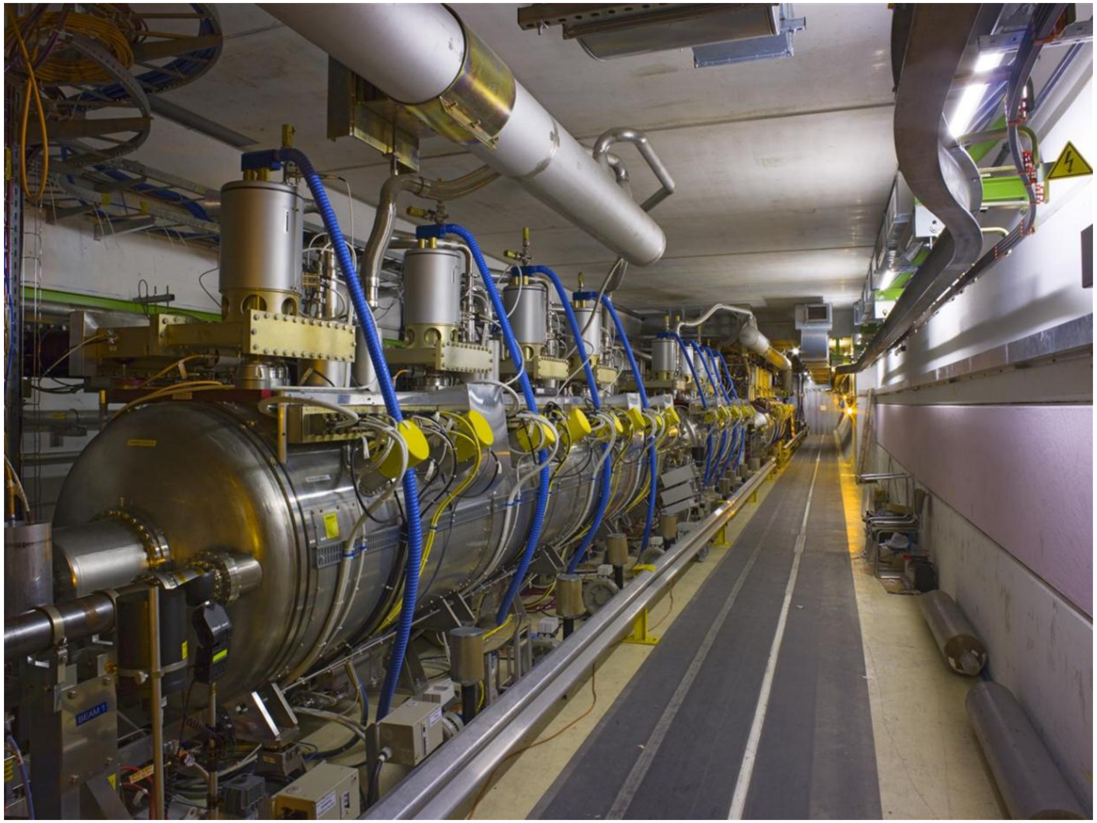
- 392 Main Quads Two-In-One rated for a peak field of 7 T.
- About 100 other Two-in-One MQs
- 32 MQX (low-β) single bore for luminosity (design $L=1\cdot10^{34}\ cm^{-2}s^{-1}$), 70 mm apertures, about 8 T peak field, high quality
- A «zoo» of 7600 «small» Sc magnets (correctors and higher order magnets, till dodecapoles: so far only 6th and 8-th pole used)
- Total: 9 MJ stored energy (at nominal)
- Large detector magnets
  - ATLAS toroid – 25 m long 1.2 MJ
  - CMS solenois – 12 m long 2.5 MJ



LHC: the numbers (cont.)

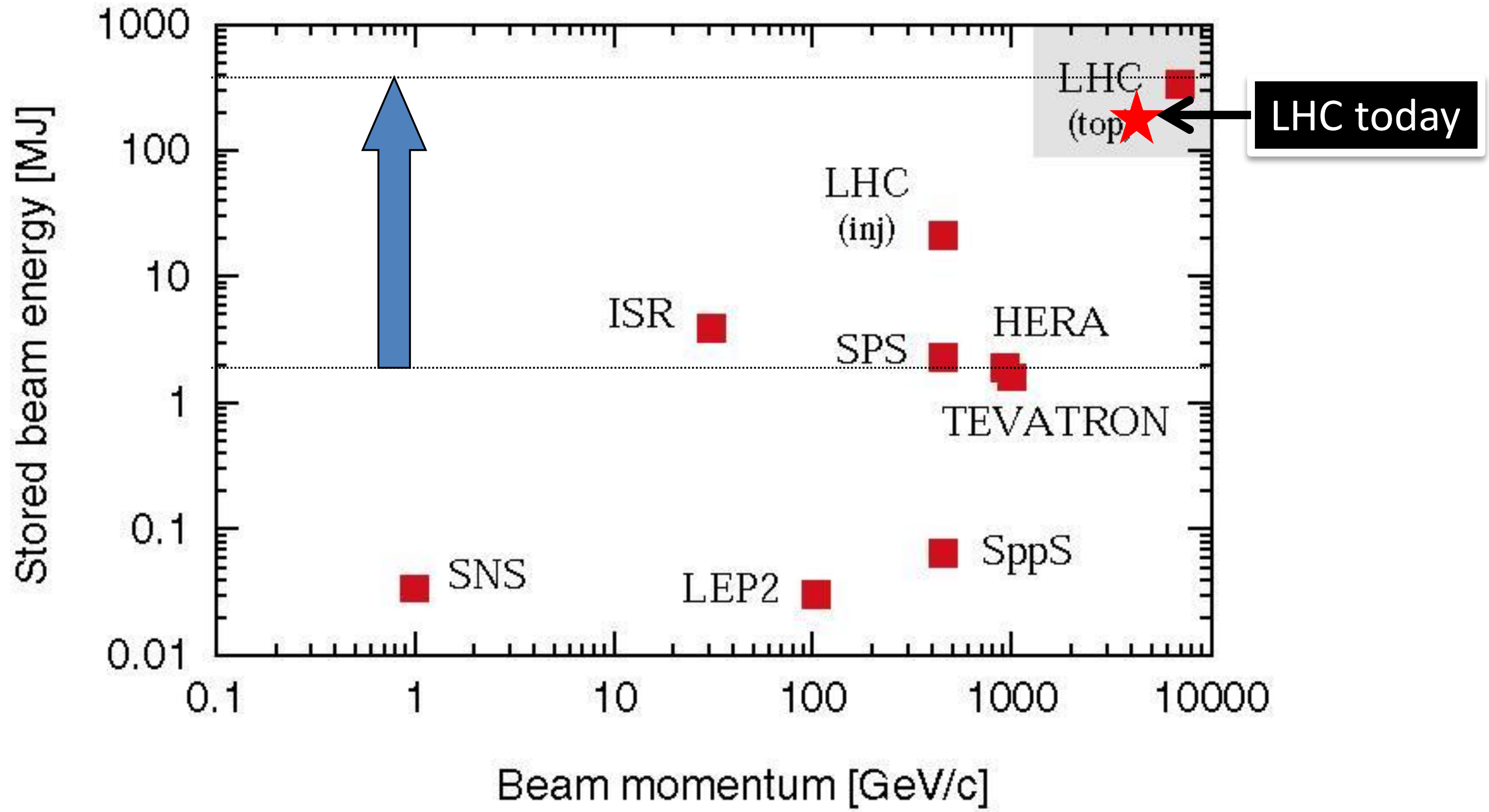
400 MHz Standing wave RF

- 4 single cell cavities in cryomodule, 2 crym per beam. Total 16 cavities.
- Sputtered niobium design (as LEP)
- Gradient 5.5 MV/m nominal (8 MV/m available)
- Nominal 2MV, up to 3 MV at 8 MV/m
- Center frequency mechanically tunable in a range of 100kHz by a stepper motor
- Located in P4 (es LEP experiment) share cryo with the magnets



The power of LHC beams

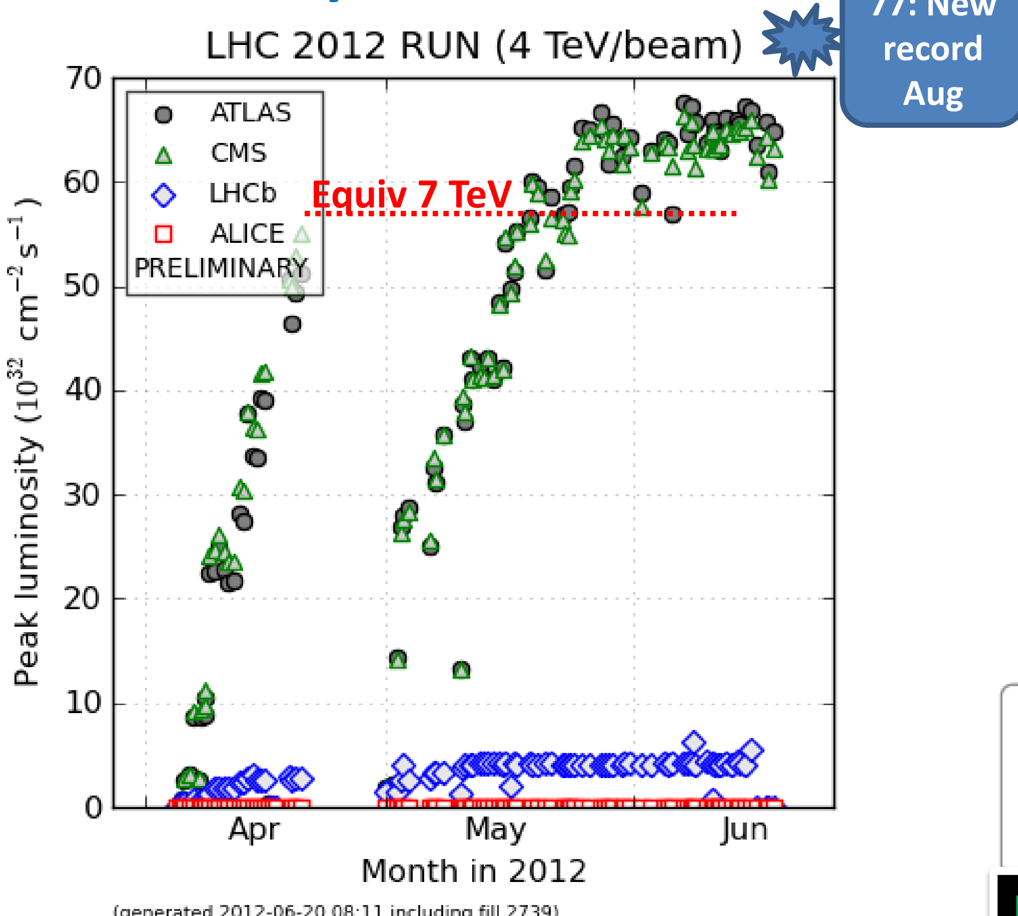
Nominal LHC design: 3×10^{14} protons accelerated to 7 TeV/c circulating at 11 kHz in a SC ring

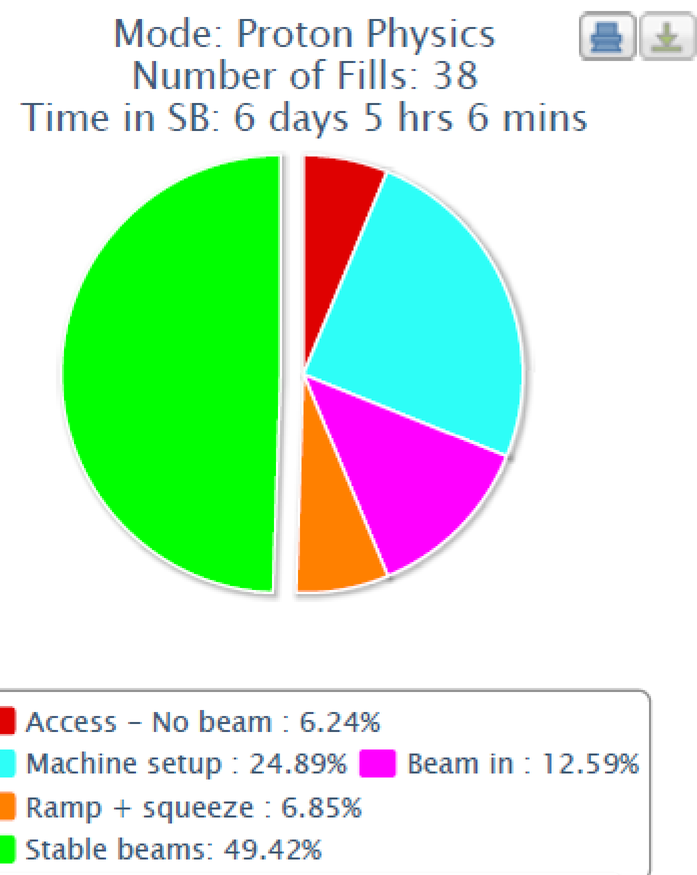


At less than 1% of nominal intensity LHC enters new territory. Collimators must survive expected beam loss…

Performance

Luminosity: ∝ rate of collisions

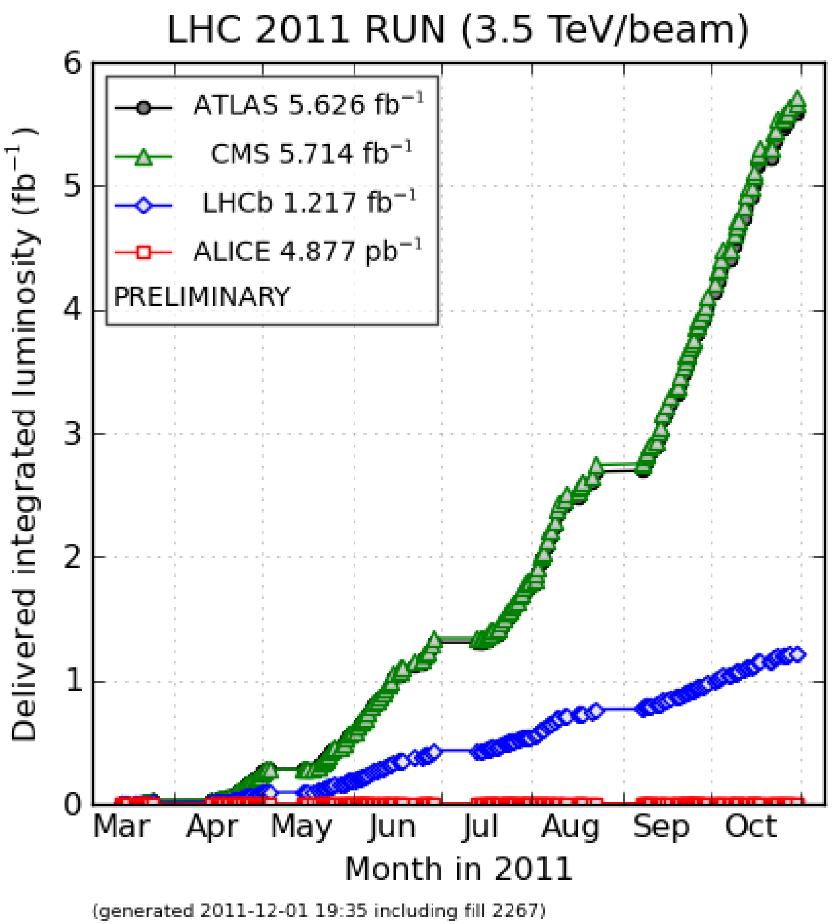


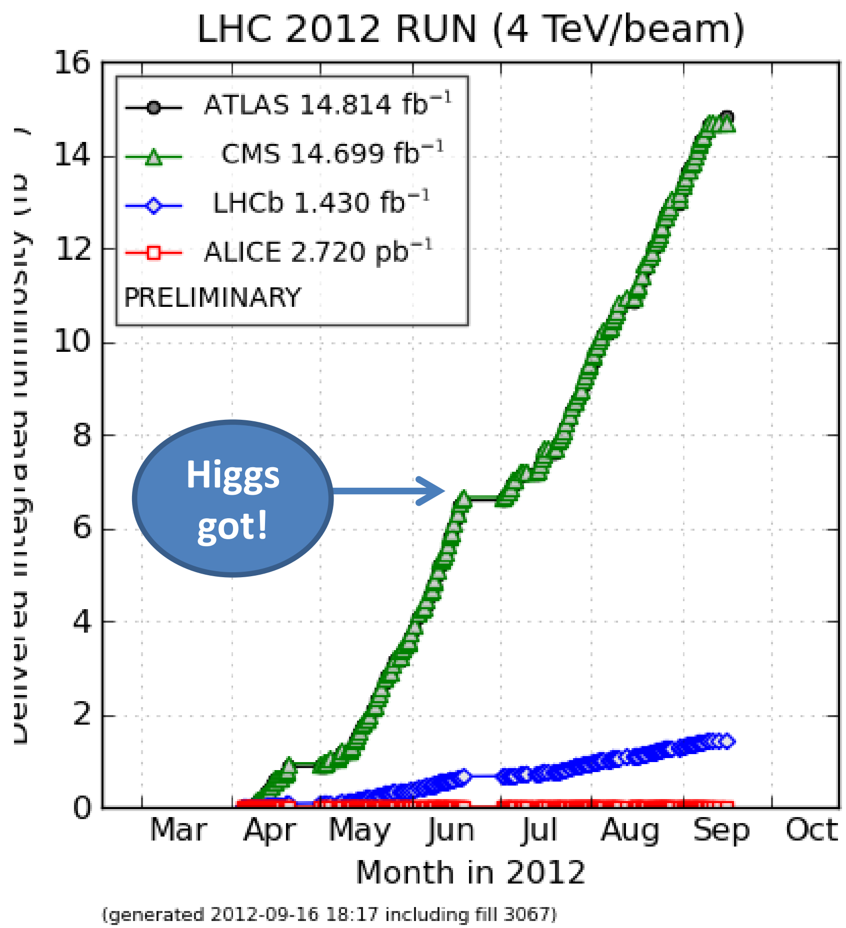


Best period 3 weeks in June !!

Performance (cont.)

Integrated lumi: ∝ # of collisions

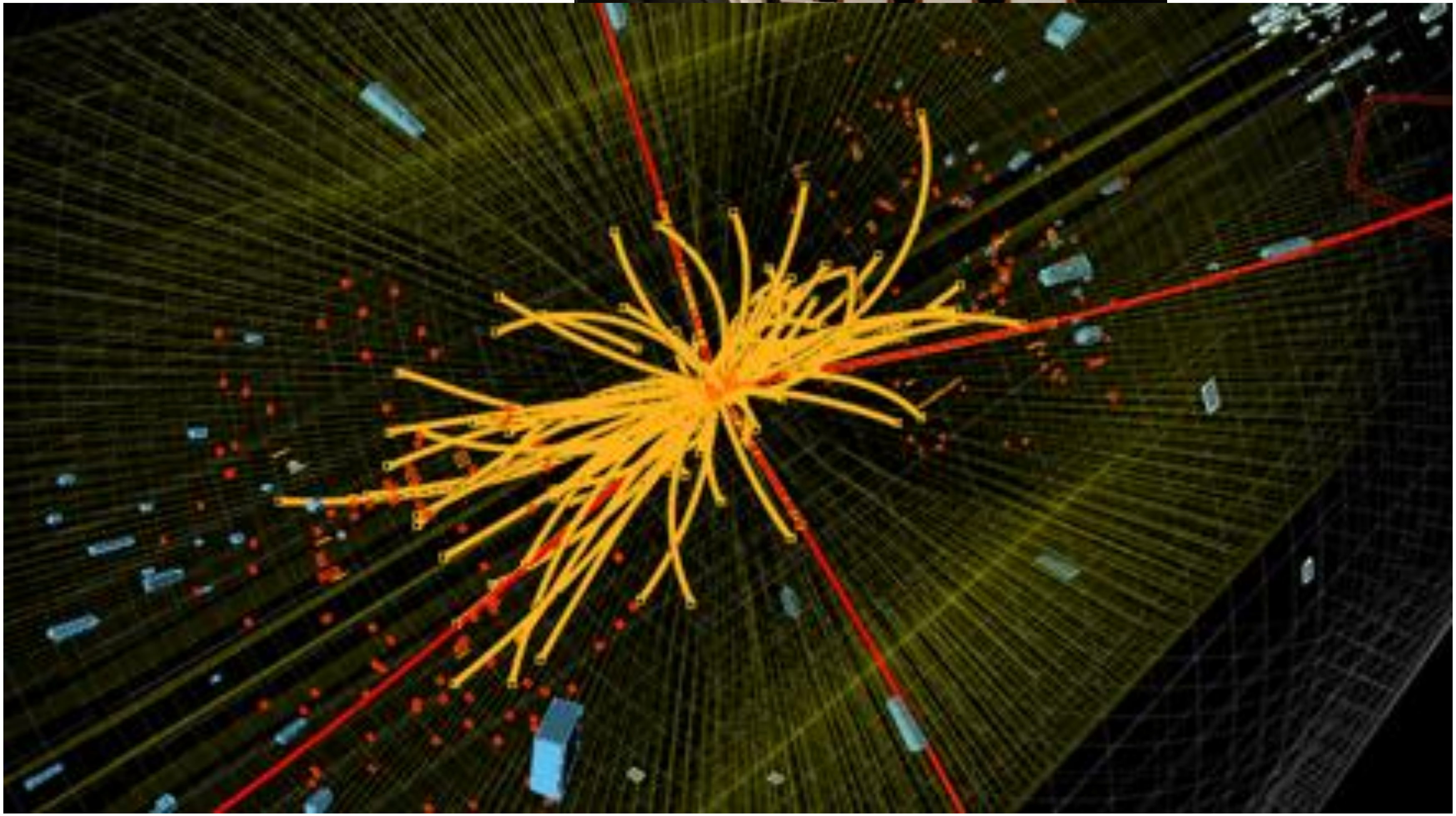




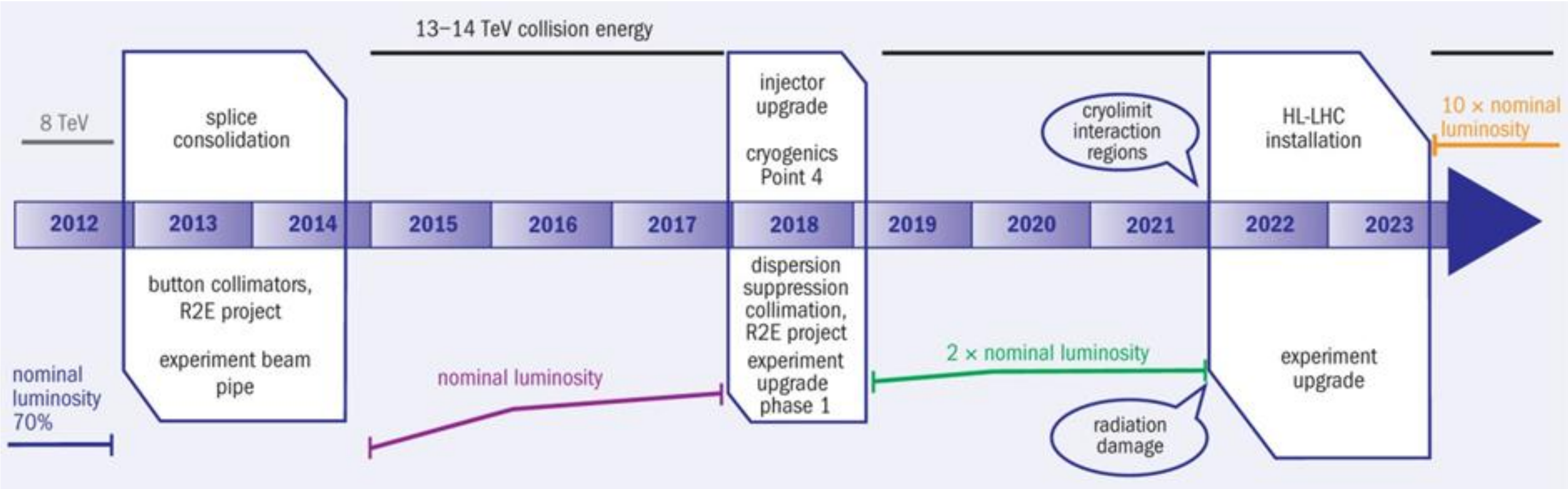
Promised minimum 2011 : 1 fb^{-1}

Promised 2012 (after extension) : 25 fb^{-1}

Higgs found

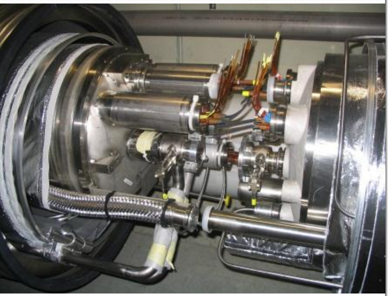


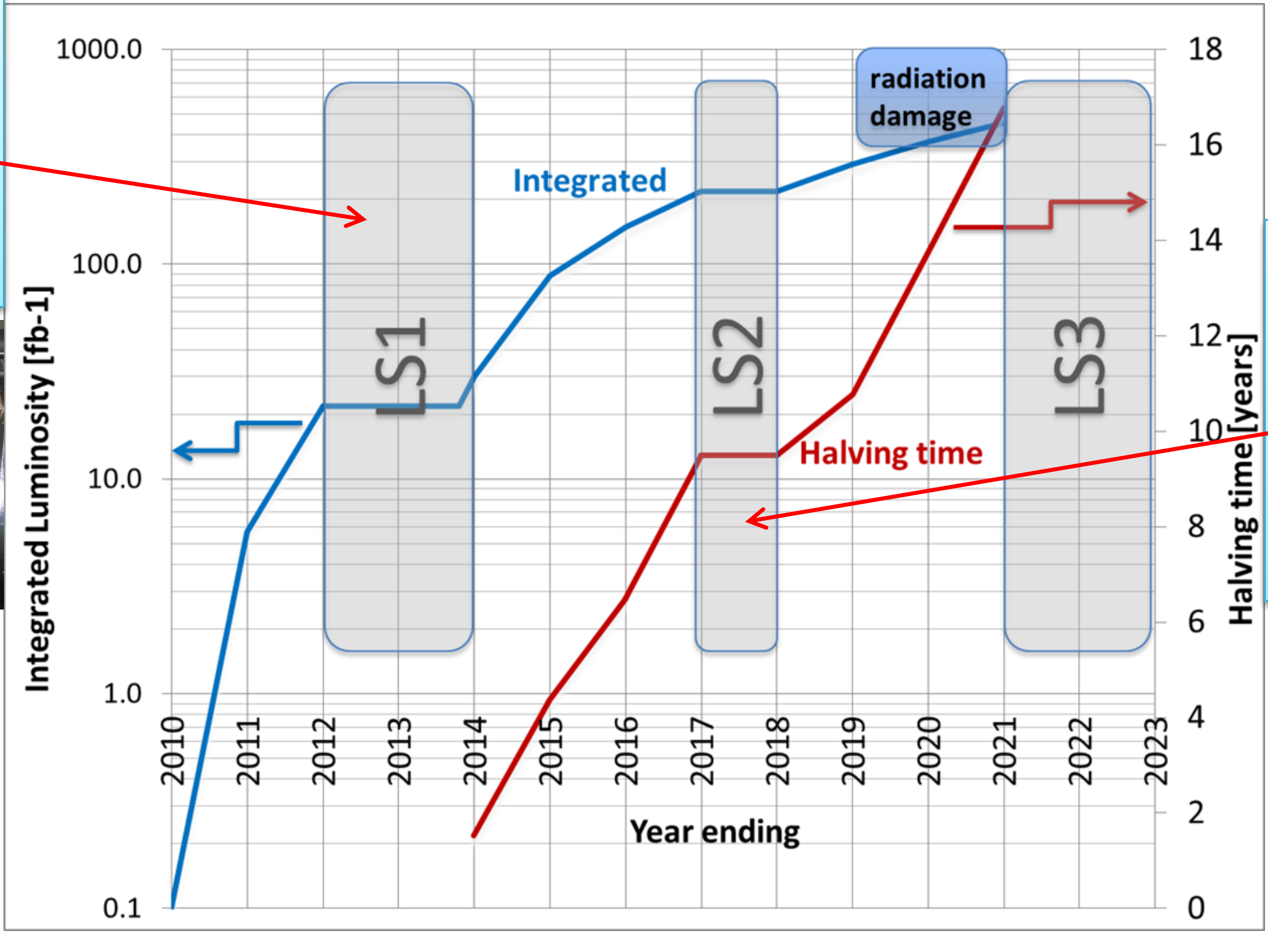
From here: where to go? The CERN 10 y plan



Next ten year plan for LHC

Shut down to fix interconnects and overcome energy limitation (LHC incident of Sept 2008)





Shut down to overcome beam intensity limitation (Injectors, collimation)

Luminosity: main ingredients

High Luminosity LHC

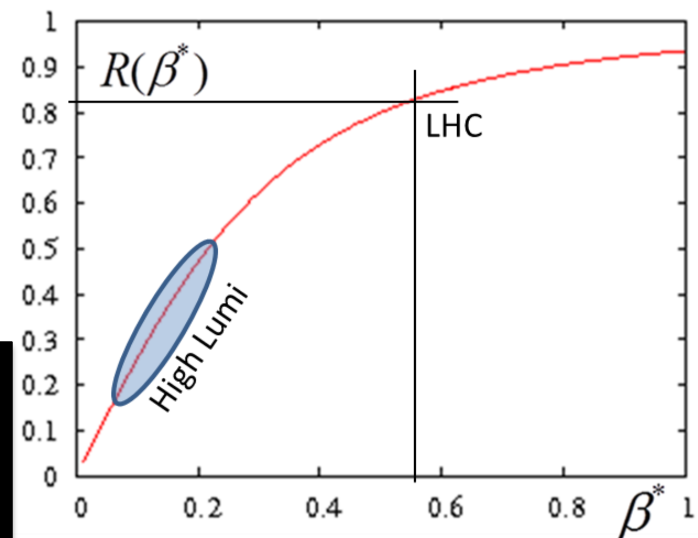
$$L = \gamma \frac{f_{rev}\, n_b\, N_b^{\,2}}{4\pi \varepsilon_n \beta^*} R$$

Beam current

energy

Beam size

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



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

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

Unit of lumi through the talk
LHC has been designed for L_0
All systems have singularly designed tentatively for ultimate $2L_0$ (to be verified…)

High Luminosity LHC project

- To push the performance above the ultimate, **to 5 10^{34} or more**
  - If pile up allows it. Today we have 30-35, experiments design upgrade for 140 evt/crossing average with a max of 200/crossing)
  - If energy deposition by collision debris in the nearest SC magnets (low.β triplet quads) allows it
- **Use of lumi levelling** to maximize integrated luminosity for a given max lumi.
- **Final goal is : 3000 fb^{-1} by 10-12 years**

Target parameters for HL-LHC run

Efficiency is defined as the ratio between the annual luminosity target of 250 fb^{-1} over the potential luminosity that can be reached with an ideal cycle run time with no stop for 150 days: $t_{run}=t_{lev}+t_{dec}+t_{turn}$. The turnaround time after a beam dump is taken as 5 hours, t_{decay} is 3 h while t_{lev} depends on the total beam current

Parameter	Nom. 25 ns	Target 25 ns	Target 50 ns	LIU 25 ns	LIU 50 ns
N_b [10^{11}]	1.15	2.0	**3.3**	1.7	2.5
n_b	2808	2808	1404	2808	1404
I [A]	0.56	1.02	0.84	0.86	0.64
θc [μrad]	300	475	445	480	430
β* [m]	0.55	**0.15**	**0.15**	**0.15**	**0.15**
ε_n [μm]	3.75	**2.5**	**2.0**	**2.5**	**2.0**
ε_s [eV s]	2.5	2.5	2.5	2.5	2.5
IBS h [h]	111	25	**17**	25	**10**
IBS l[h]	65	21	**16**	21	**13**
Piwinski	0.68	2.5	2.5	2.56	2.56
F red.fact.	0.81	0.37	0.37	0.37	0.36
b-b/IP[10^{-3}]	3.1	3.9	**5**	3	**5.6**
L_{peak}	1	7.4	8.4	5.3	**7.2**
Crabbing	no	**yes**	**yes**	**yes**	**yes**
$L_{peak\ virtual}$	1	20	22.7	14.3	19.5
Pileup $L_{lev}=5L_0$	19	95	190	95	190
Eff.† 150 days	=	0.62	0.61	0.66	0.67

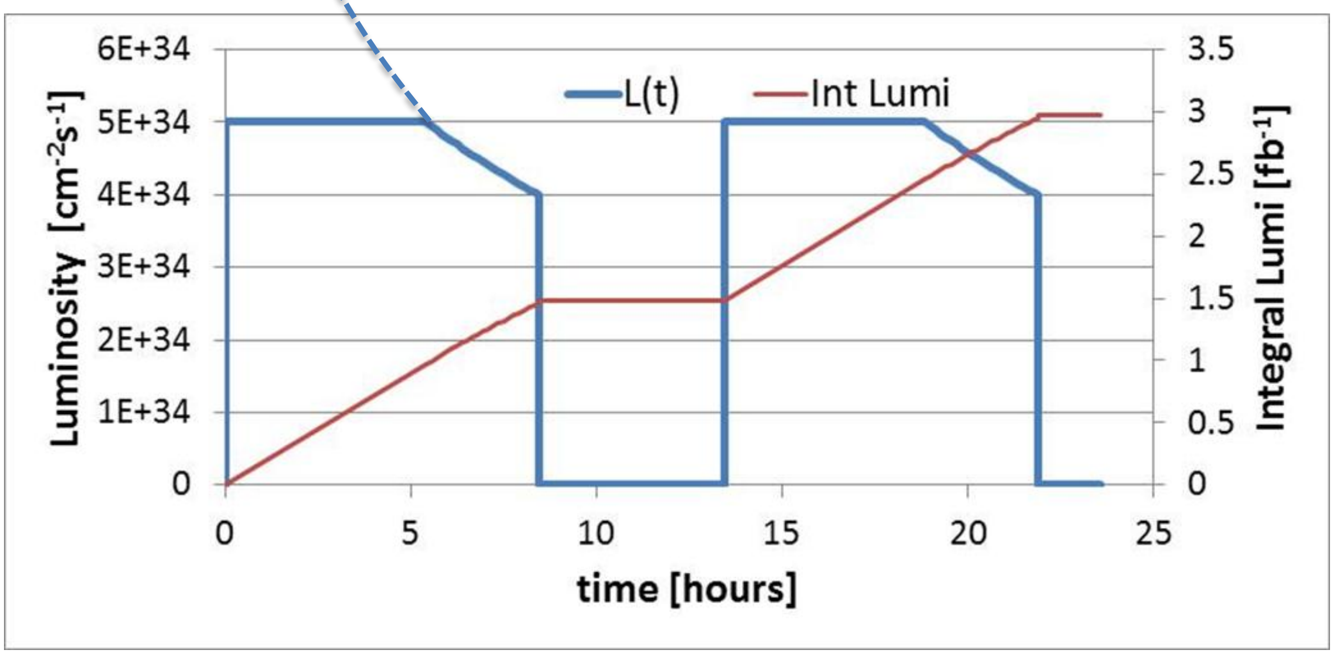
baseline

Cycle in the HL-LHC run

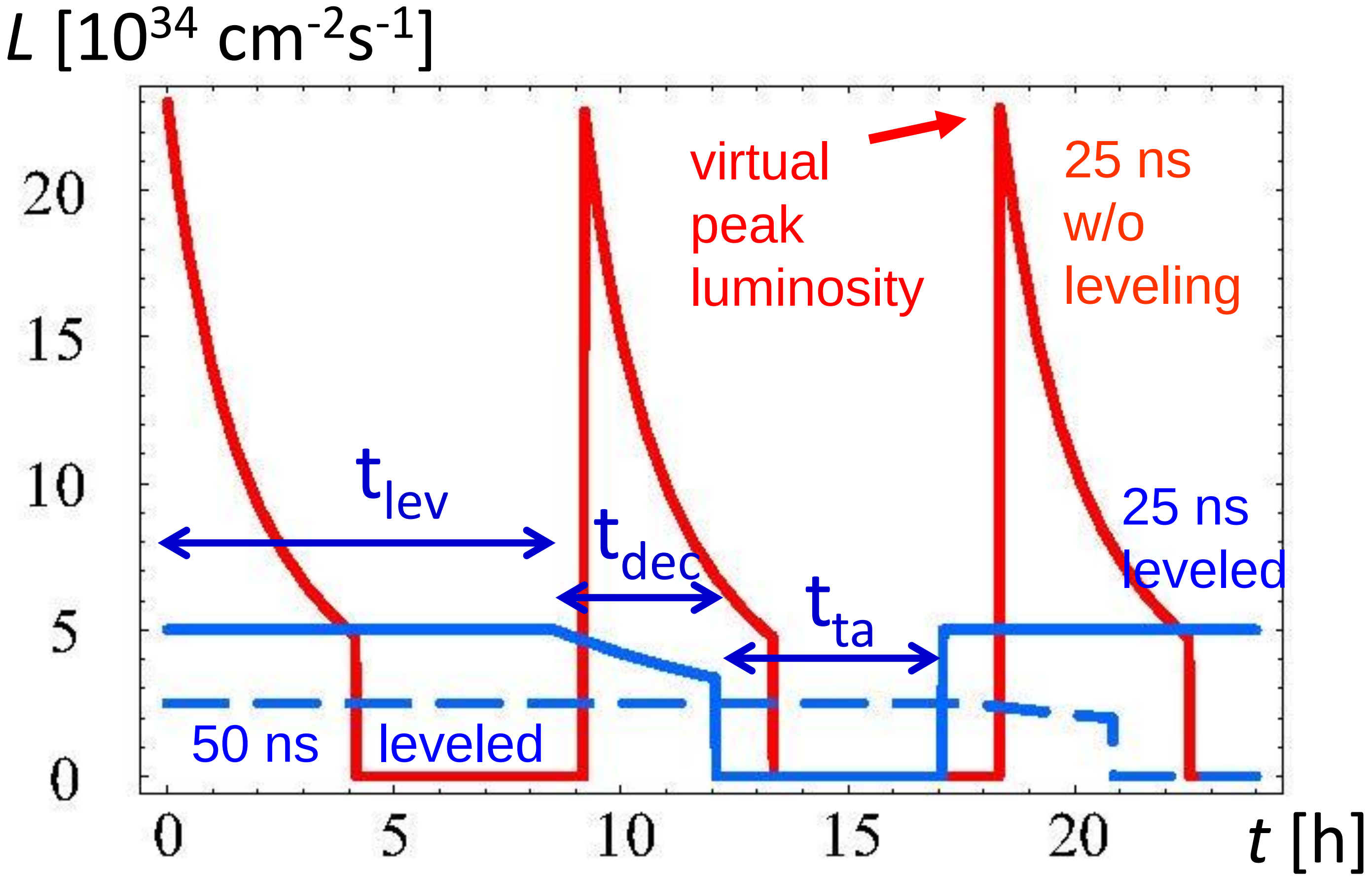
20E+34

pile up
heat deposition in IR and DS
other?

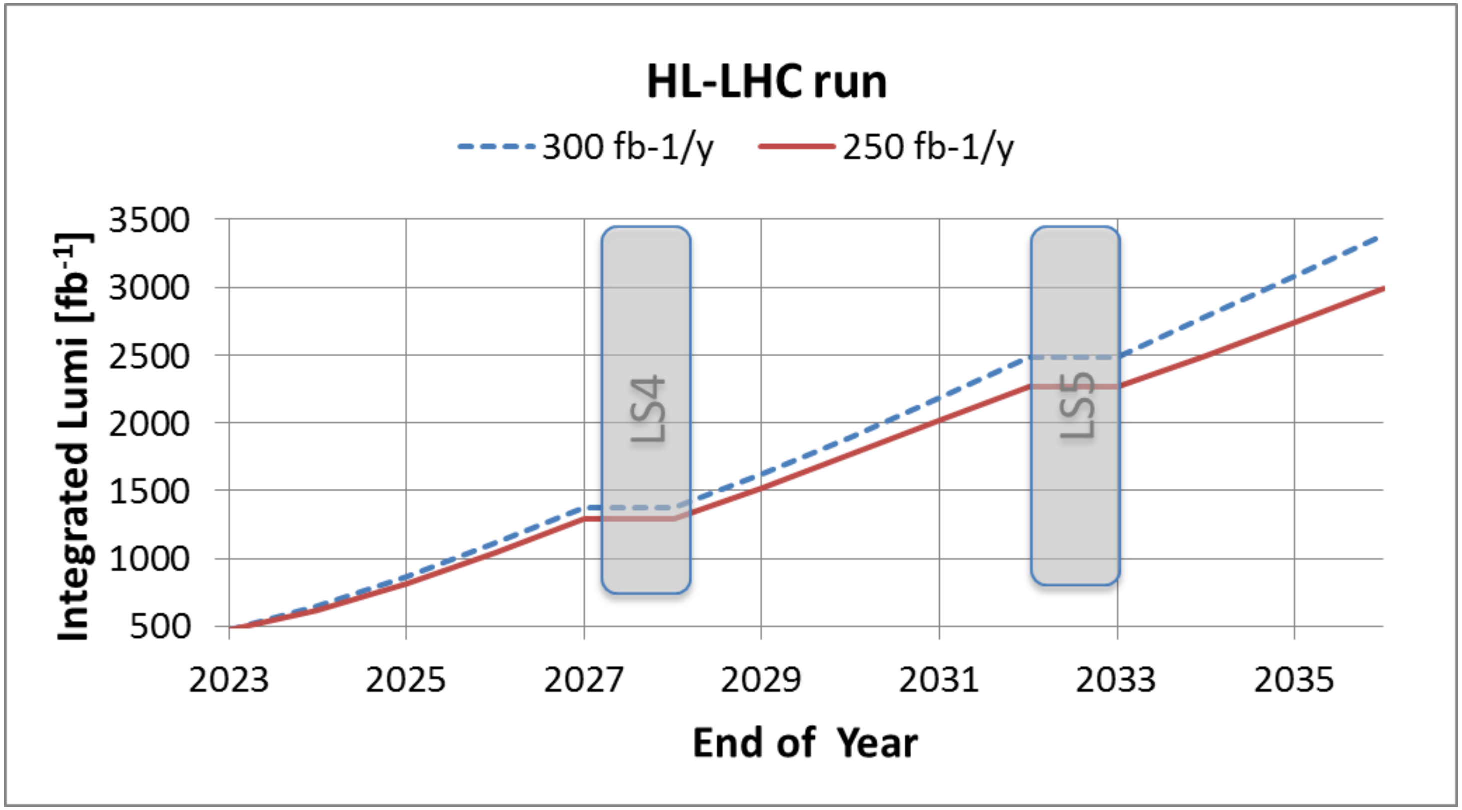
Levelling



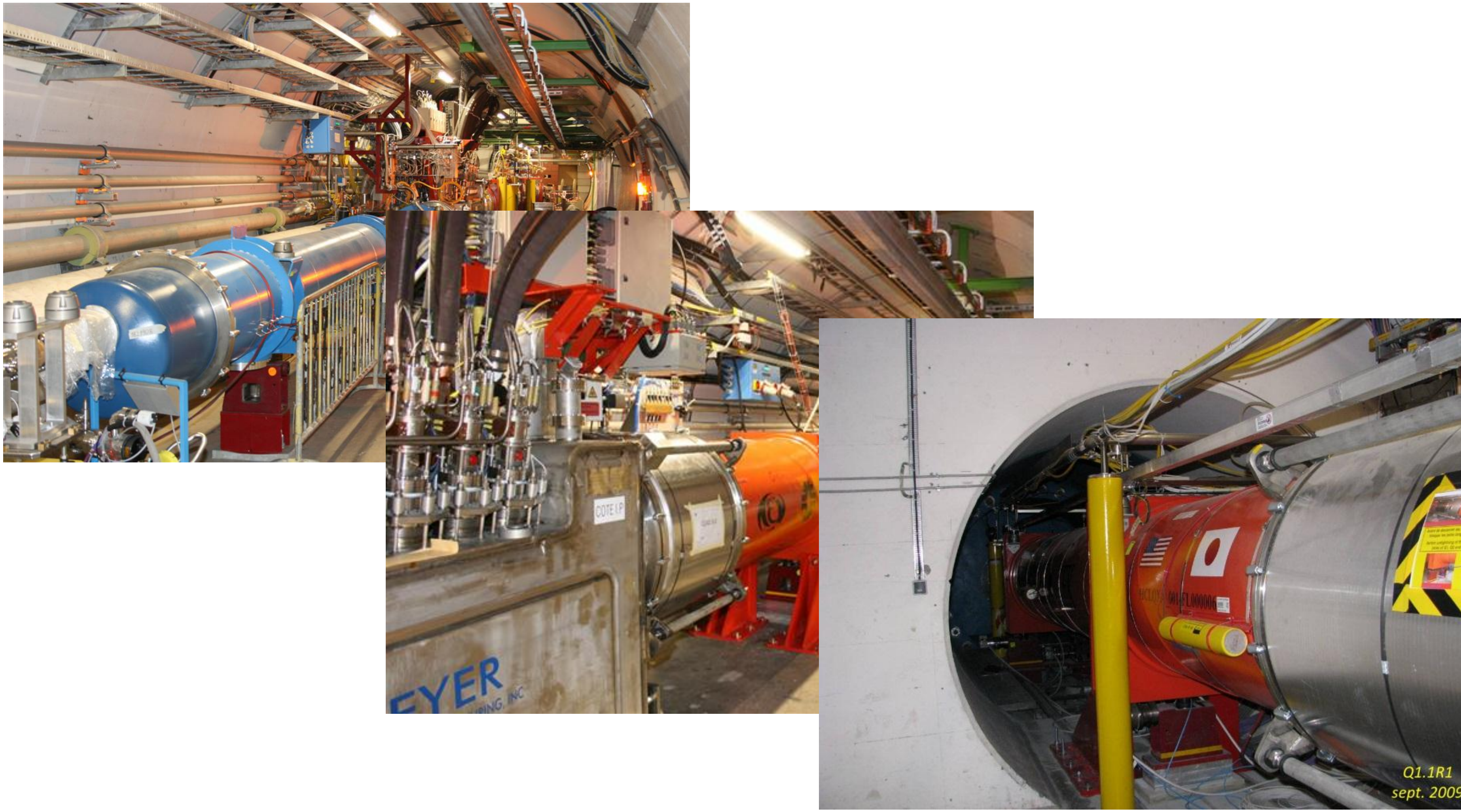
Pushing virtual lumi up to make longer run



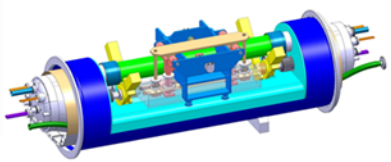
The goal
3000 fb^{-1} in 10-12 years

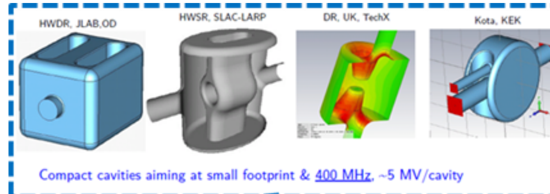


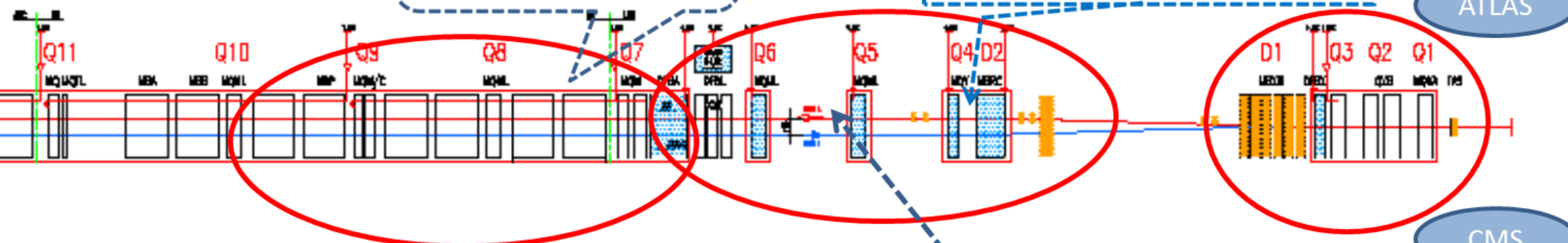
Here the magnets for the low β in present LHC



Changing 300x2 m both ATLAS & CMS (+LHC-b & Alice …)



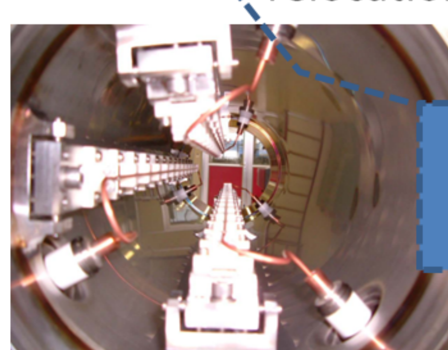




1. Deep change in the IRs and interface to detectors; relocation of Power Supply

2. Deep change also matching section: Magnets, collimators and CC

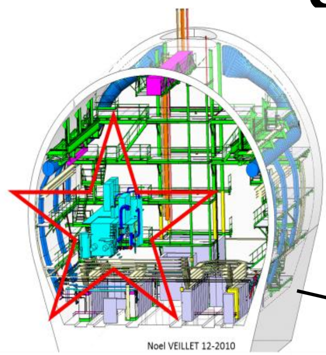
3. For collimation we need to change also this part, DS in the continuous cryostat



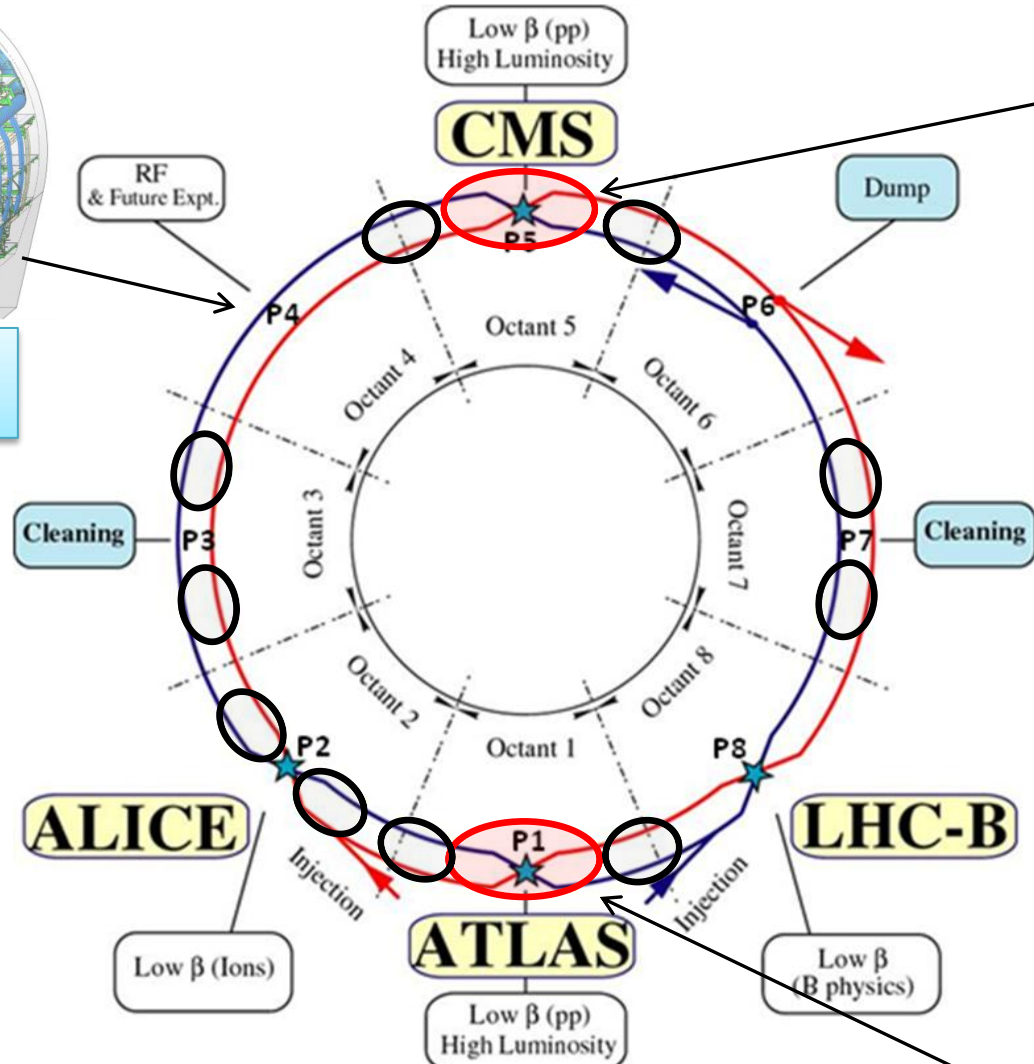
4. LR BB compensation wires

1.2 km of LHC !!

HL-LHC installation all around the ring…

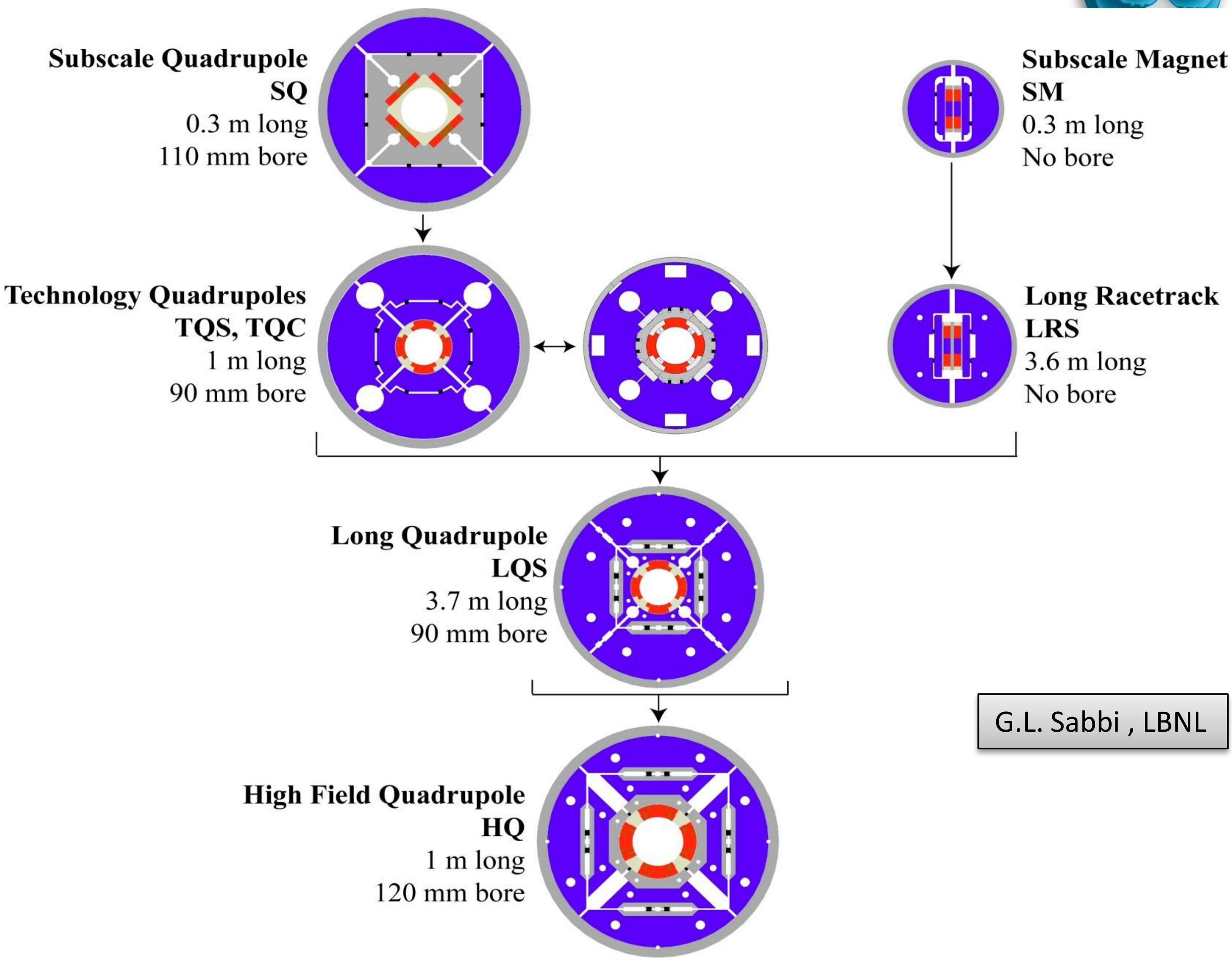


6.5 kW@4.5K cryoplant



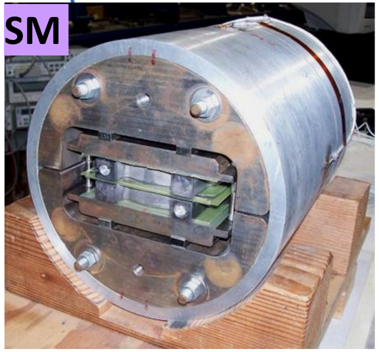
2 x 18 kW @4.5K cryoplants for IRs

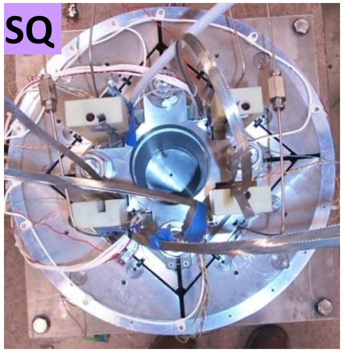
US LARP: Magnet Develop. Chart

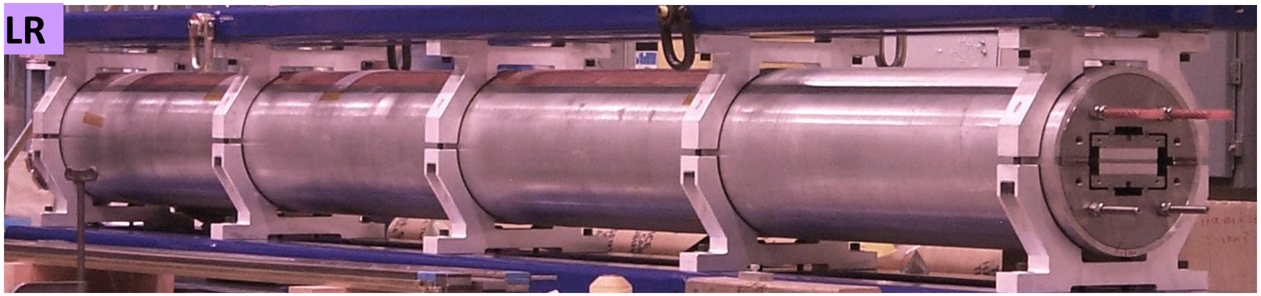


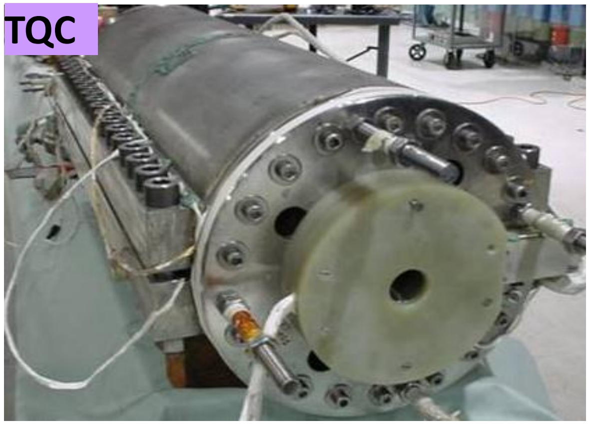
G.L. Sabbi , LBNL

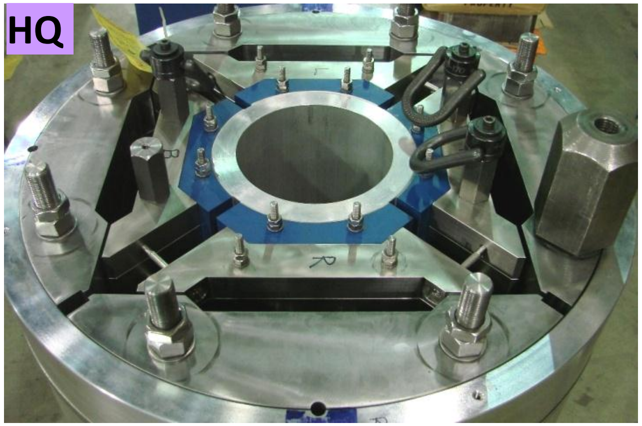
LARP (US LHC program) Magnets



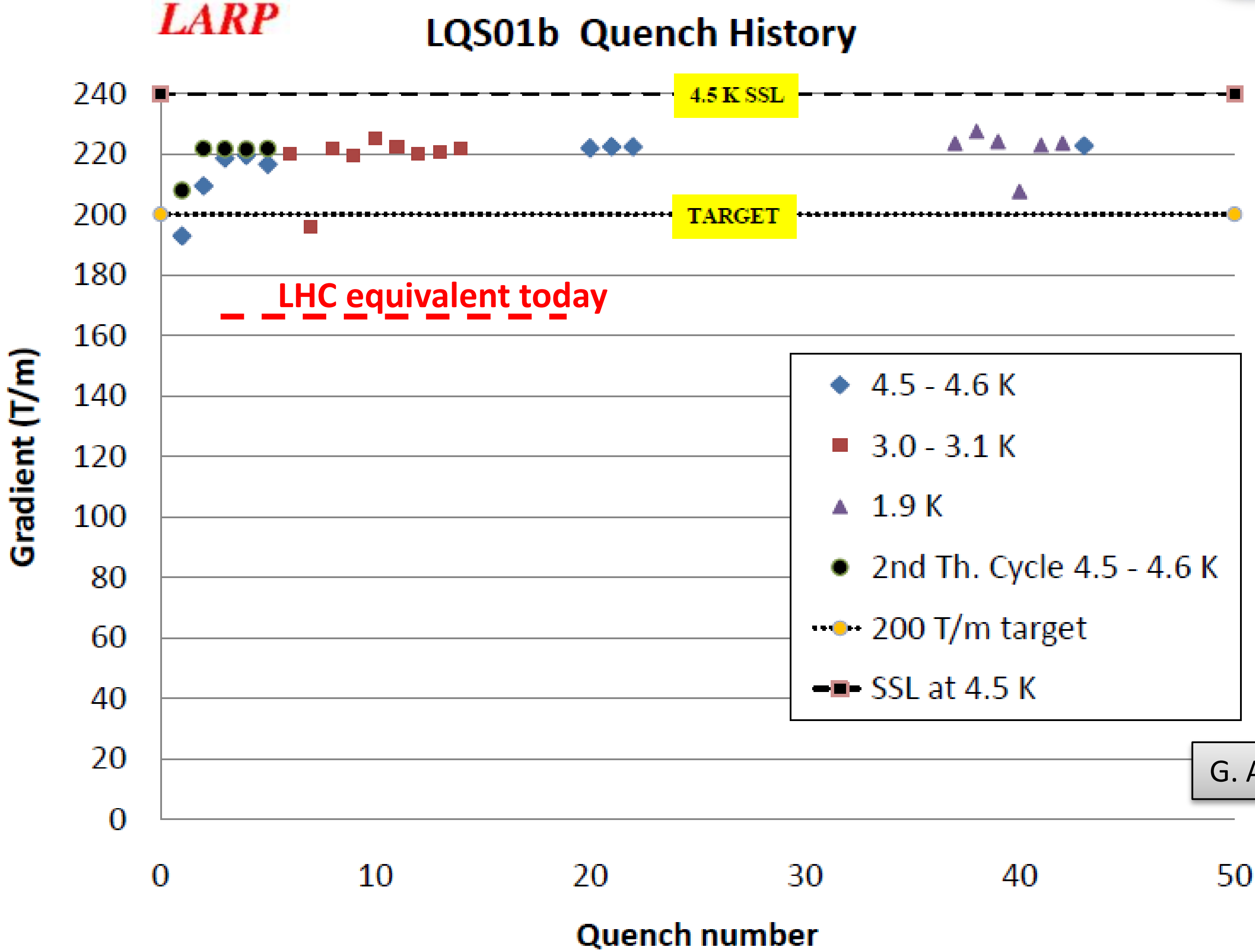






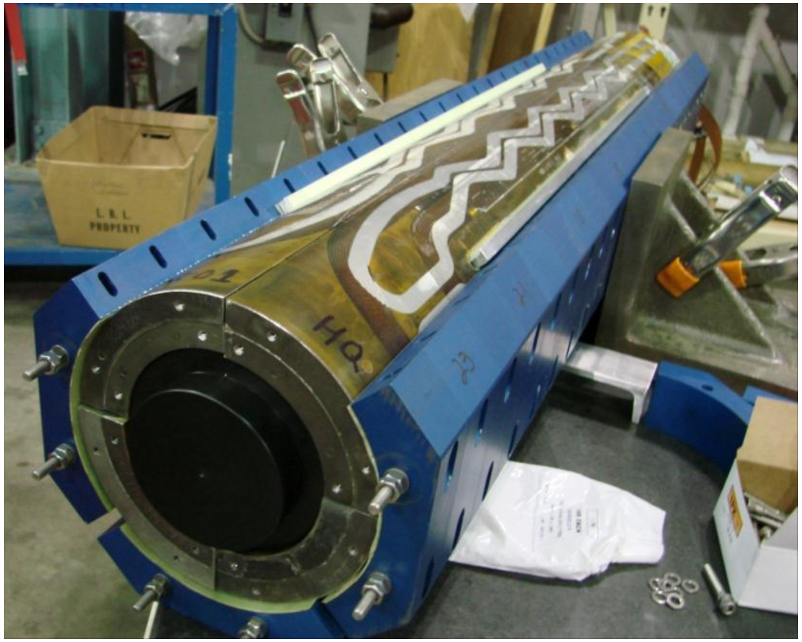


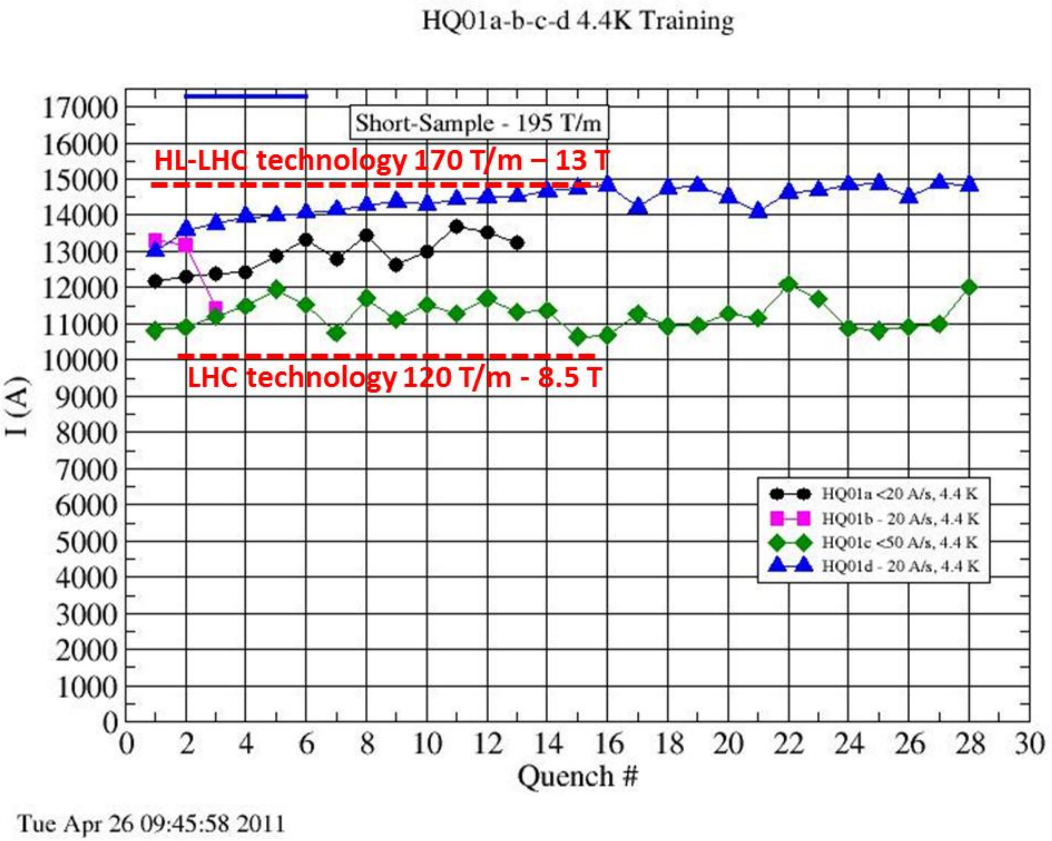
Results LARP LQ (90 mm vs 70 mm LHC)

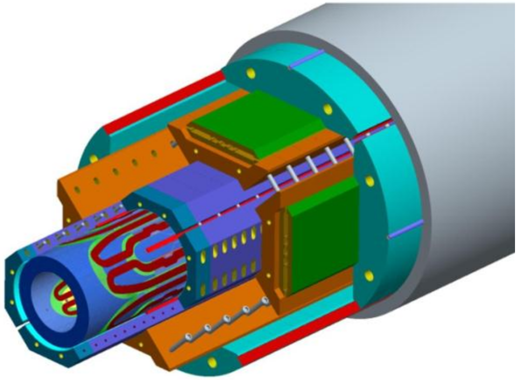


G. Ambrosio, FNAL

LARP HQ (120 mm- 13 T)

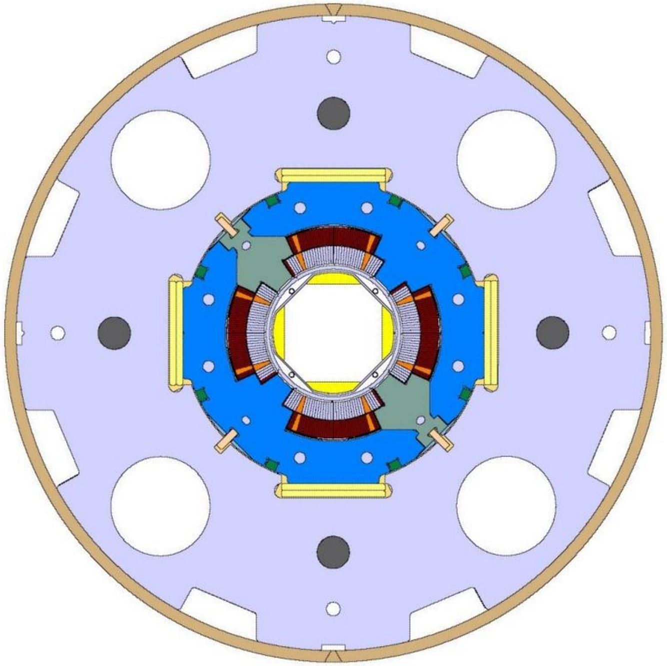


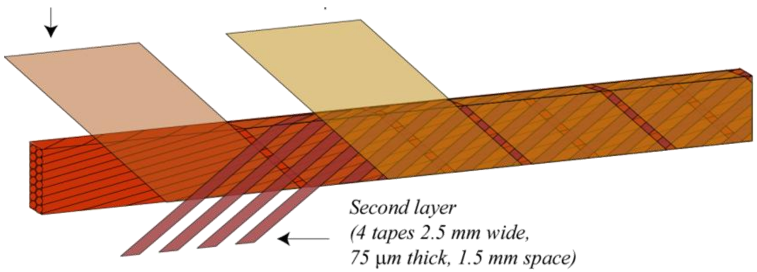


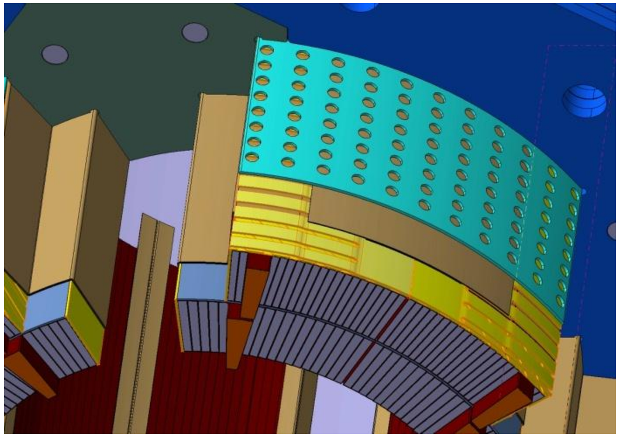


S. Caspi , LBNL

Improved Nb-Ti technology Low-β quads and MS magnets

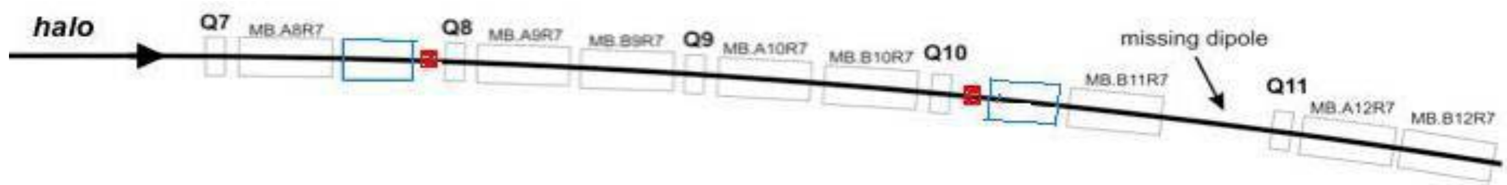


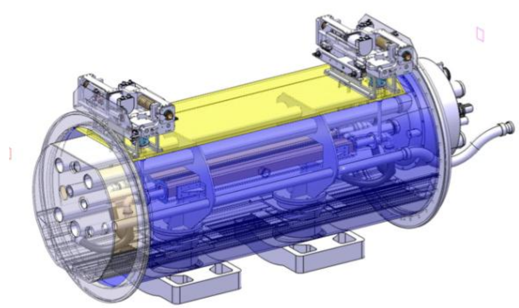


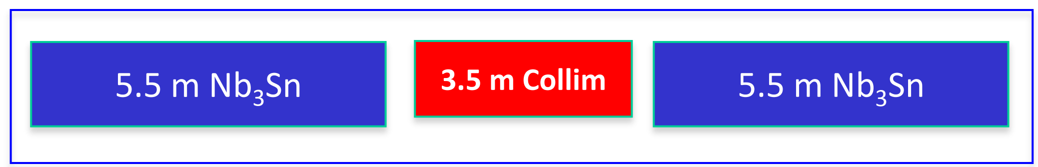


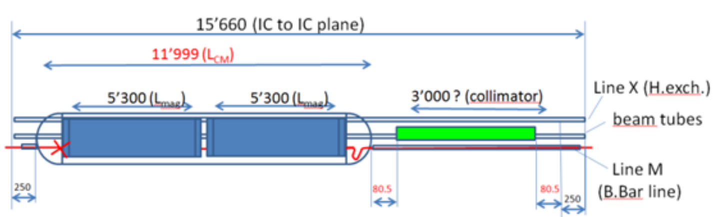
new insulation scheme, more porous in the coils and in the structure
Higher heat removal (matching the gap to NbSn ?)

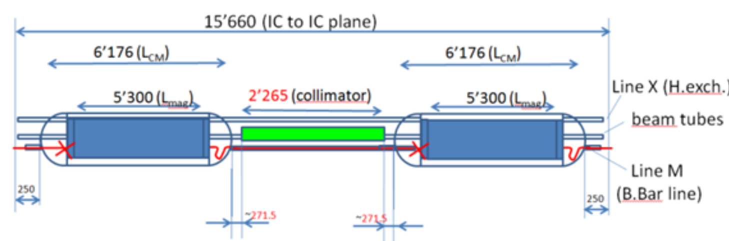
Avoid off-momentum protons on SC dipoles (diffractive)



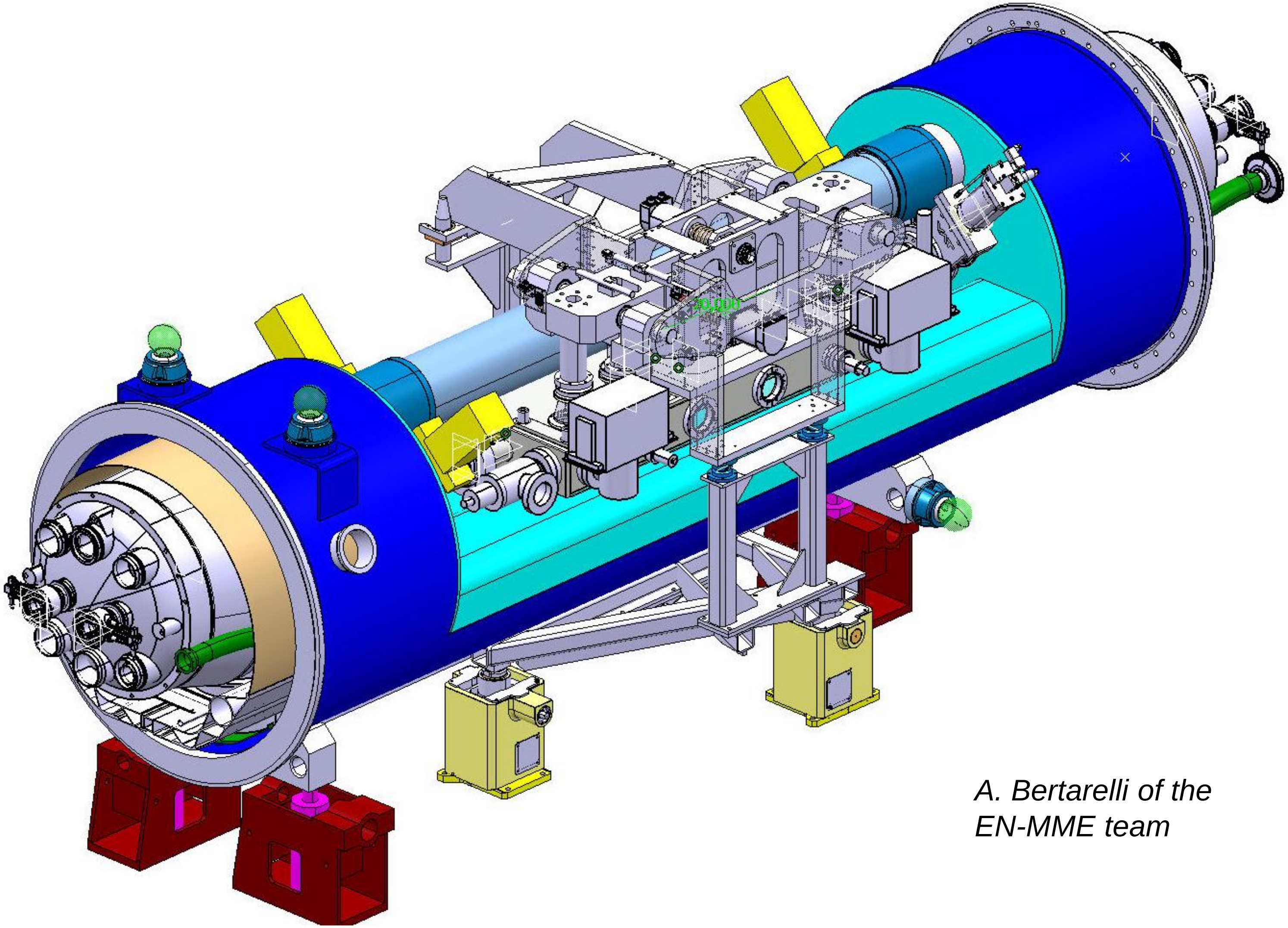






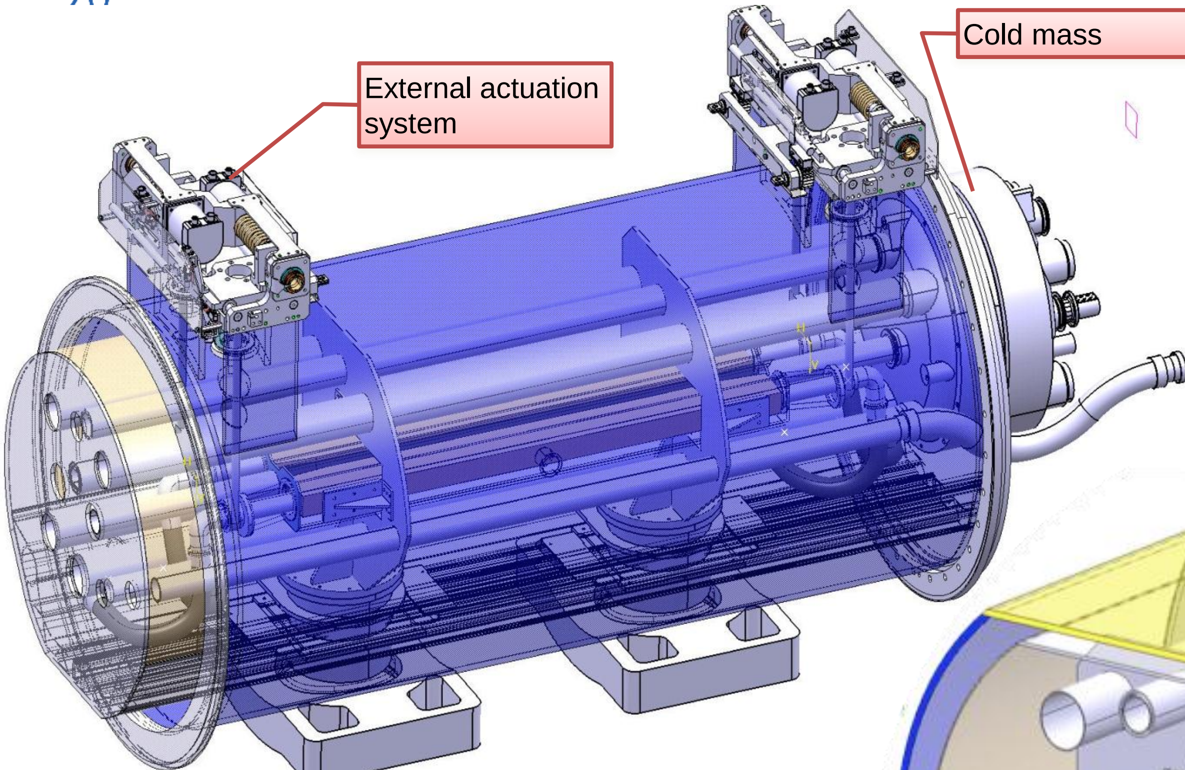


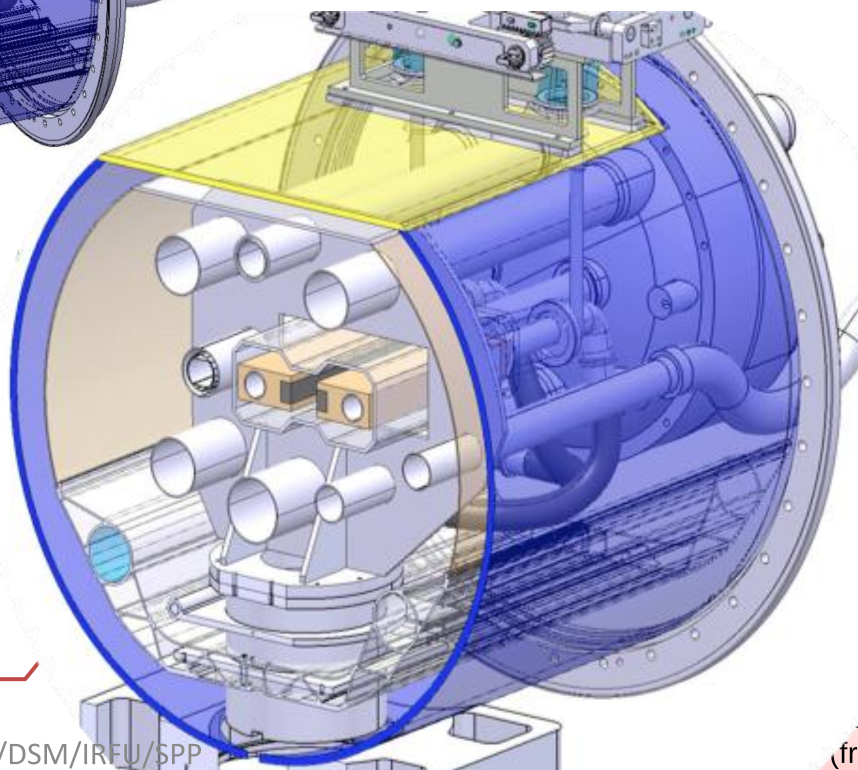
Warm collimators in the cold region



A. Bertarelli of the EN-MME team

Cold collimator design

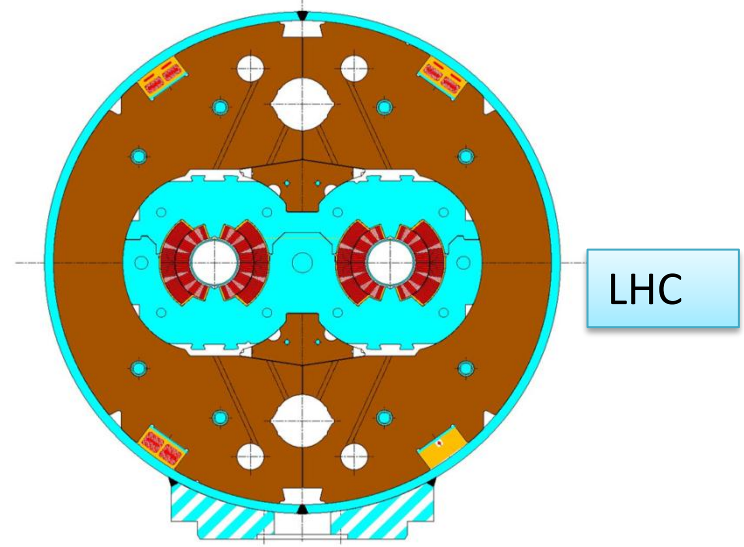


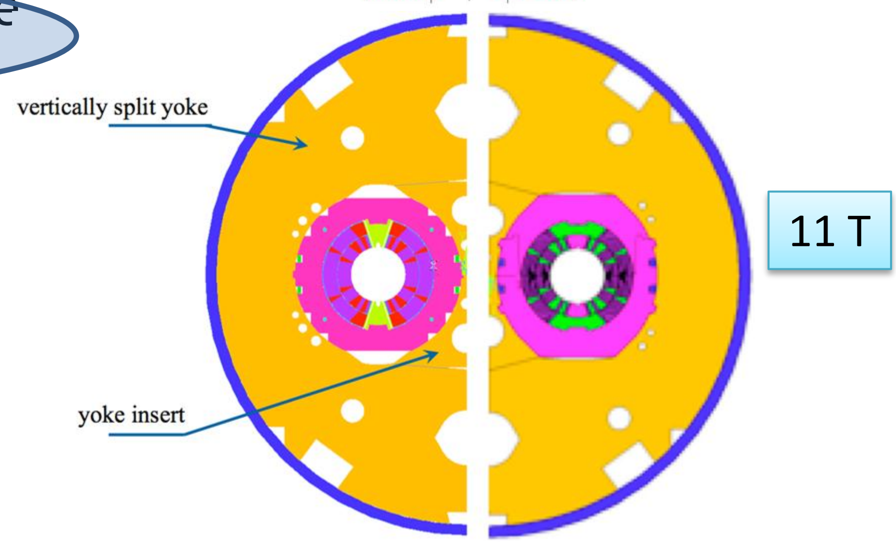


D. Duarte Ramos
Ch. Mucher

11 T-11 m dipole CERN-FNAL collaborations

- Series to LHC dipoles: BL/I =120Tm/11.85kA
  - Cable, strand constrained
  - Nested power supply ±300 A
- Field quality
  - Fe saturation 6.5→0.5
  - Pers. Current (40 μm fil. Size): 44 →20→10? Enough (few magnet)
- Forces, energy 70% higher in same envelope
- Demo (single, 2 m) by 2012; Proto by 2013-14
- 1 unit = 2x5.5m⇒straight
- First NbSn in operation?



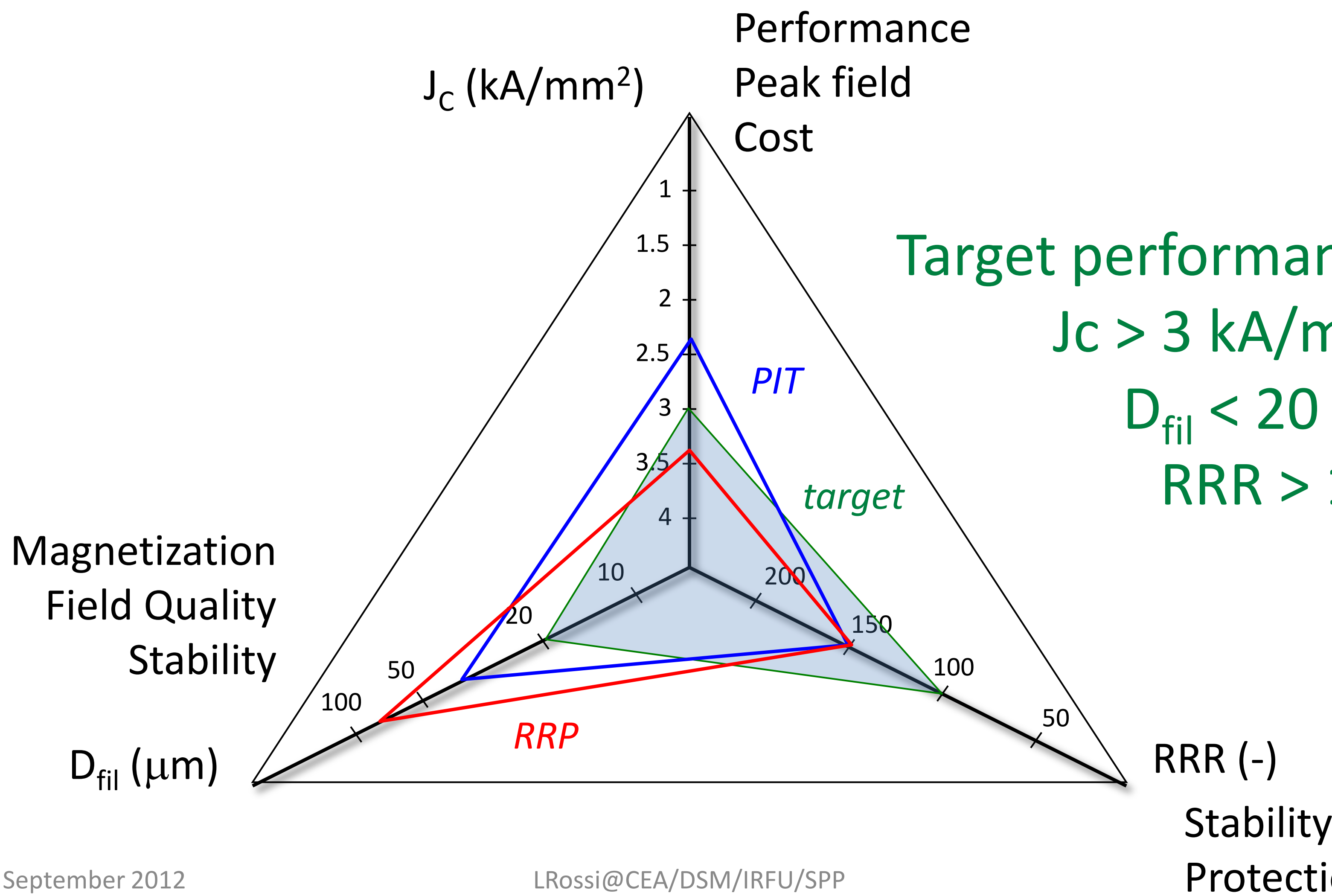


11 T
Demo 2 m single bore

Project launched September 2010
Fermilab/CERN collaboration
Collared coil Dec 2011

Cold mass finished in May 2012
Test: very good to 10.4 T
Limited by a single spot
Next model by beginning of 2013

Performance targets for Nb_3Sn



Target performance:

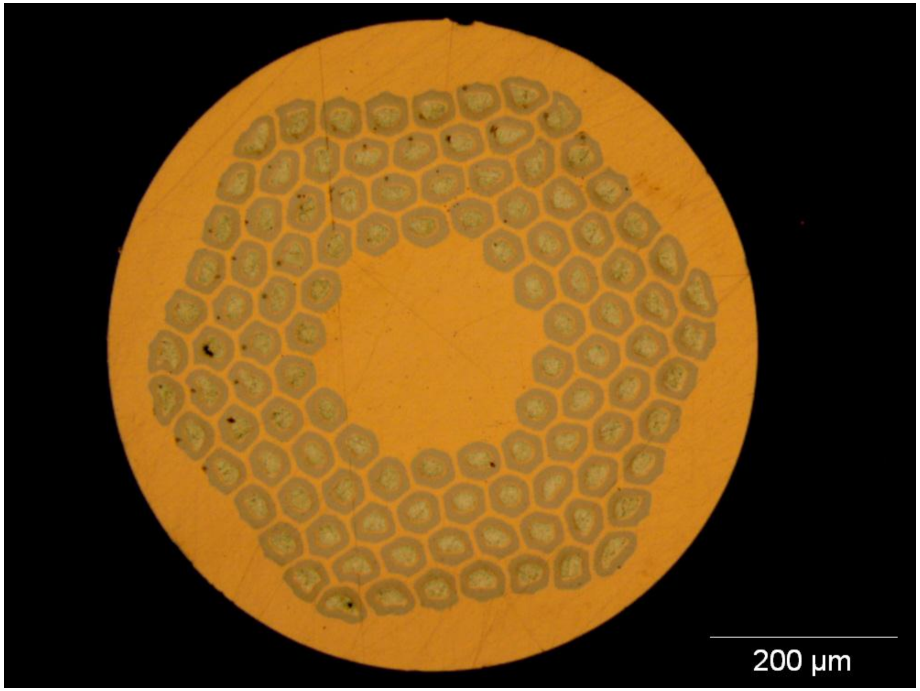
$Jc > 3$ kA/mm²

$D_{fil} < 20$ μm

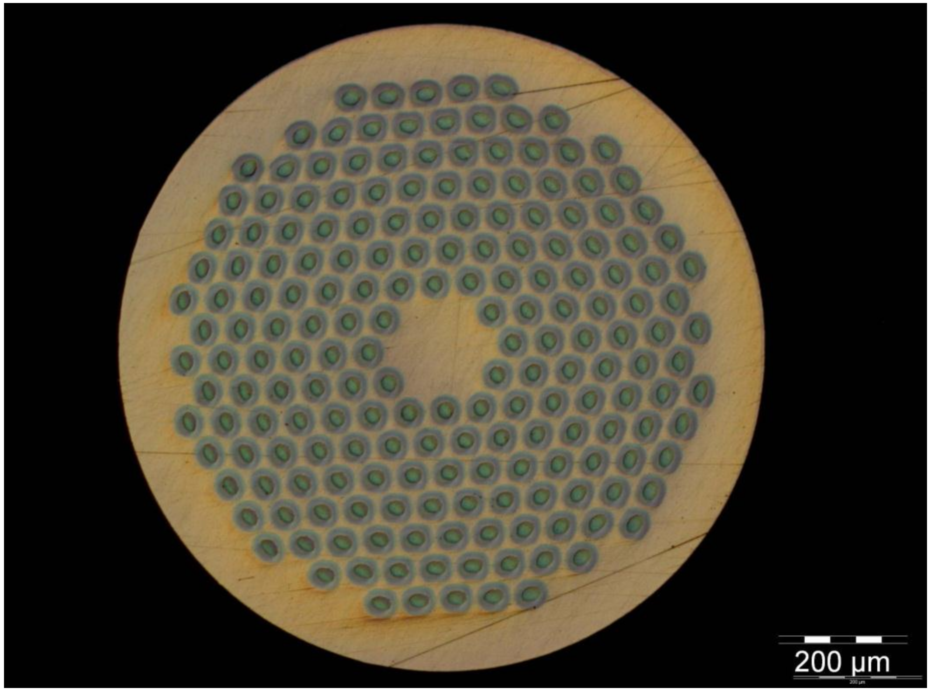
RRR > 100

Procured strands

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



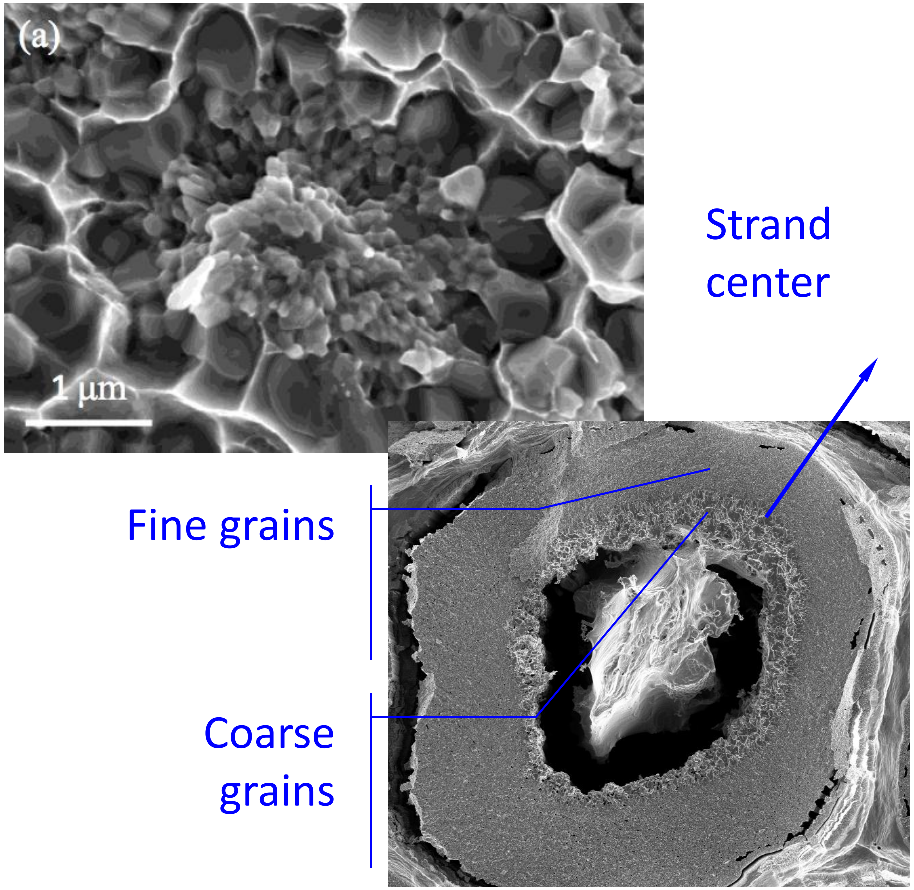
1 mm, 192 tubes PIT from **Bruker EAS**

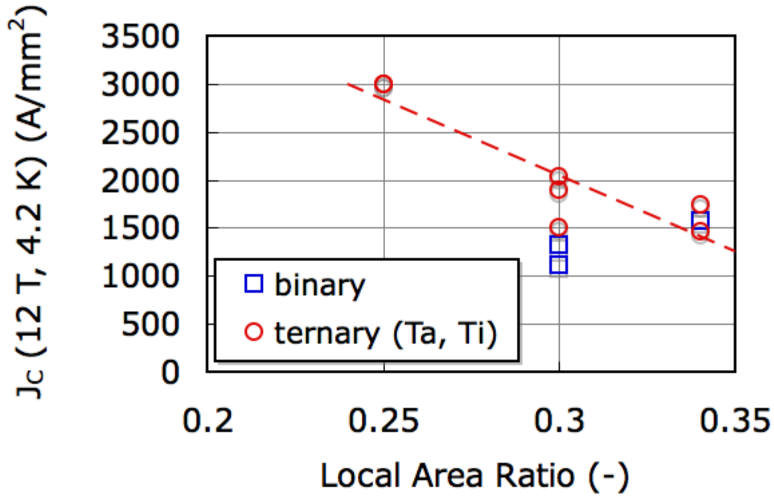


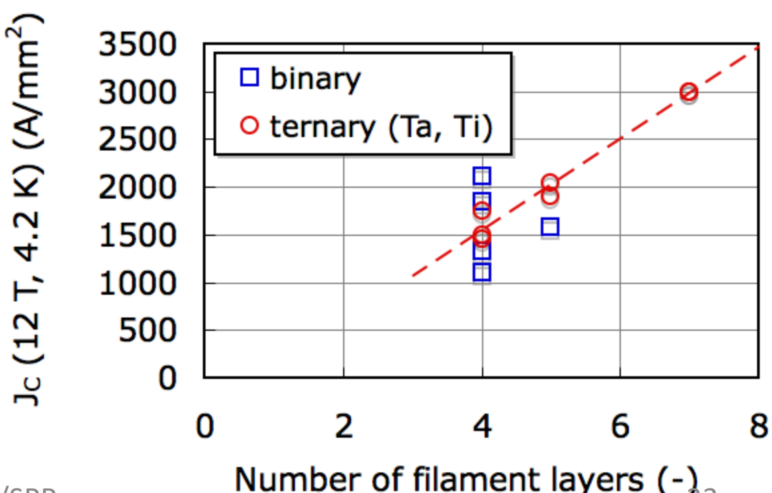
Work is on-going on **a new strand architecture (169 stack)** to reduce the filament diameter to 52 μm at 1 mm strand diameter, and 35 μm at 0.7 mm strand diameter

R&D started for an alternative architecture with filaments of **30 μm at 0.7 mm** strand diameter

Material R&D *(basic science)*

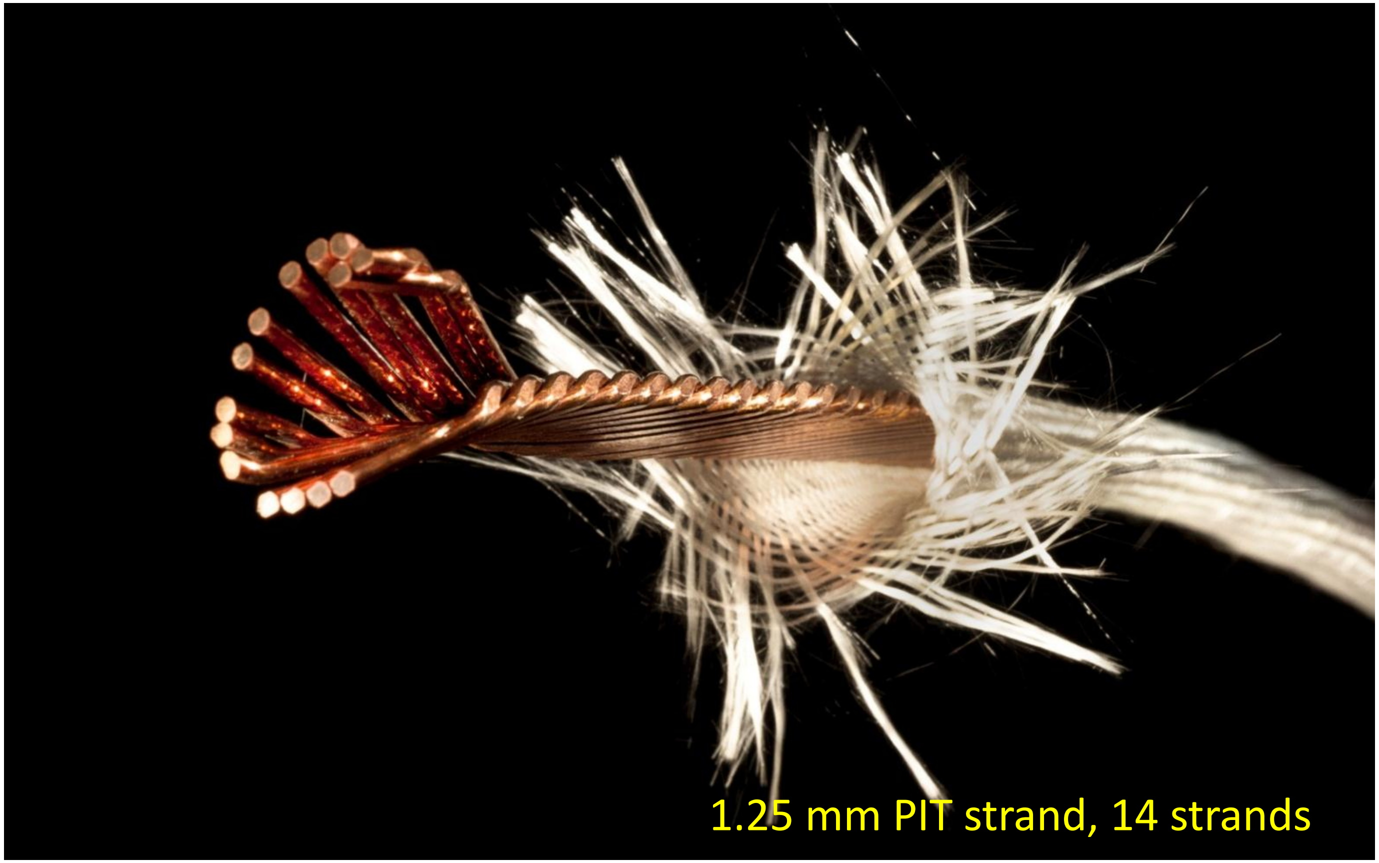






By courtesy of I. Pong and L. Oberli

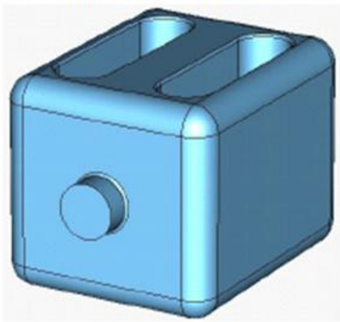
The *successful* SMC-3 cable



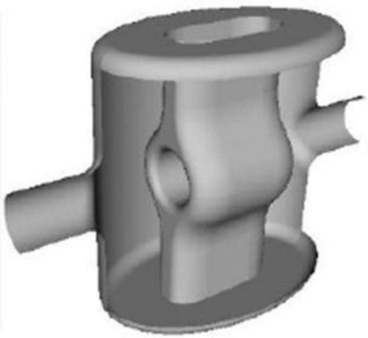
Conductor: done? Not at all: instability and FQ issues will continue to play a major role
Strand, cabling and cable behavior need to be modelized more deeply.

Crab Cavity, for p-beam rotation **at fs level!**

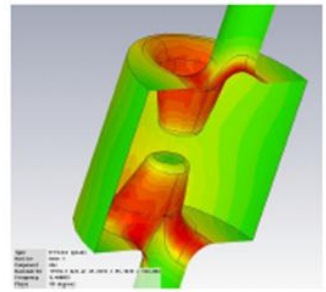
HWDR, JLAB,OD



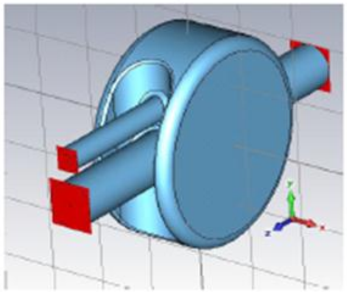
HWSR, SLAC-LARP



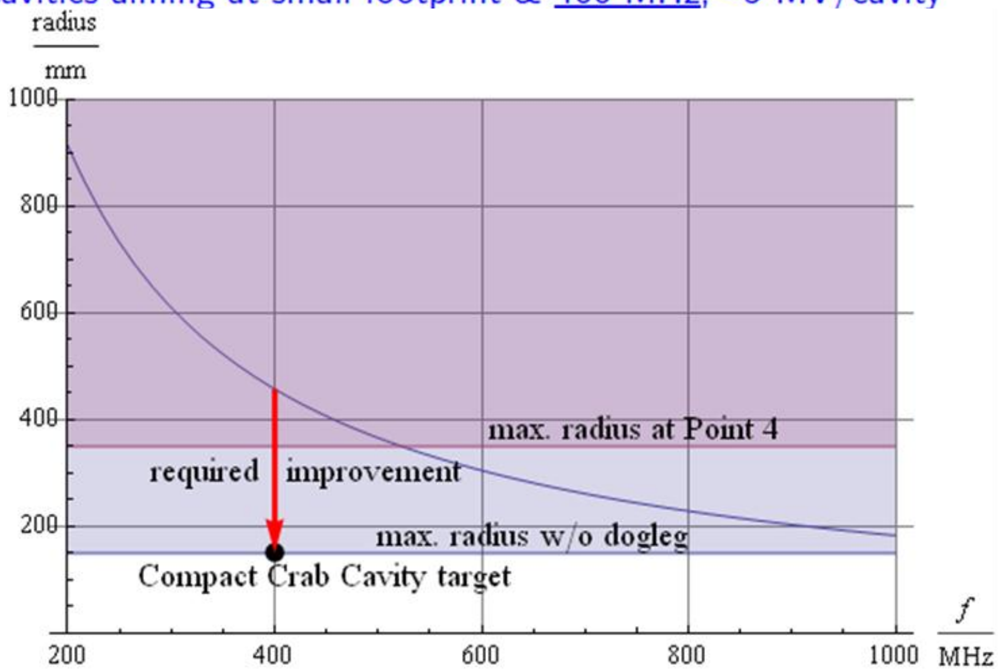
DR, UK, TechX



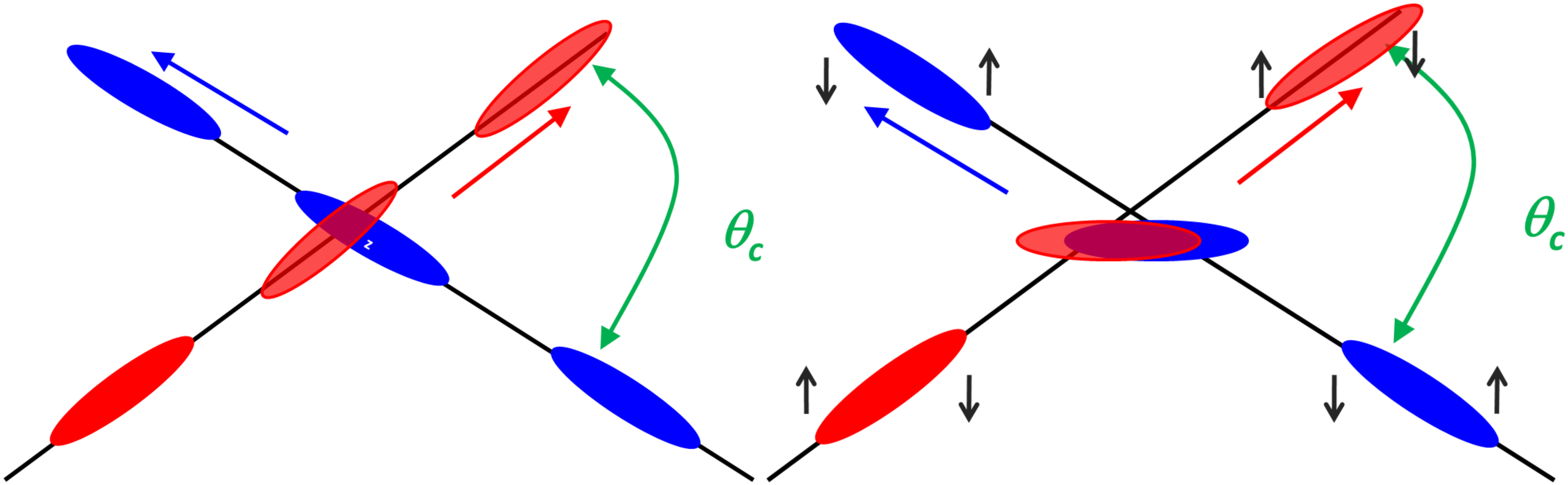
Kota, KEK



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



Effect of the crab cavity



- **RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" and then luminosity is maximized**
- ***Crab cavity maximzes the lumi and can be used also for lumimosity levelling: if the lumi is too high, initially you don't use it, so lumi is reduced by the geometrical factor. Then they are slowly turned on to compensate the proton burning***

Crab Cavity:

- Effort going on at SLAC-ODO and in BNL, USA
- Effort going on in Daresbury (Cockcroft Institute and STCF) with CERN.

Progress in SC Crab Cavities

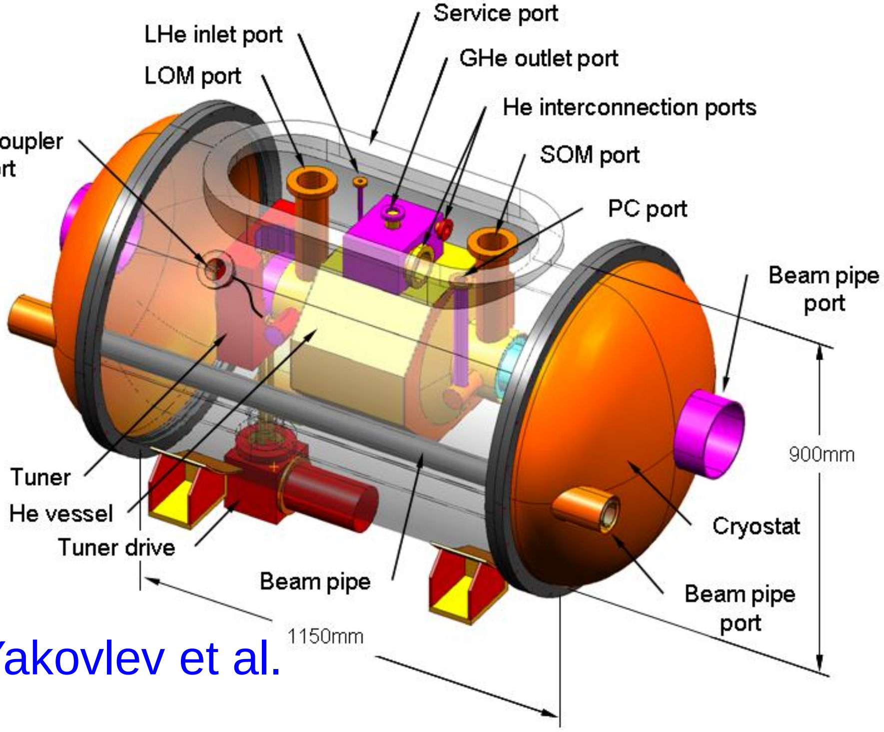
UK - Cockcroft

Finished cavity at Niowave

Jan 2012 → May 2012

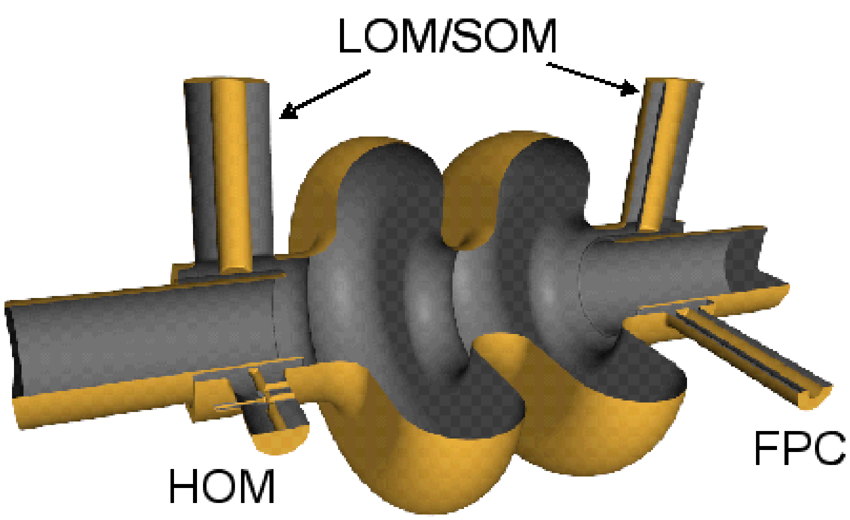
USA (ODU)

Crab cavity ; cryomodule and cavity



Y. Yakovlev et al.

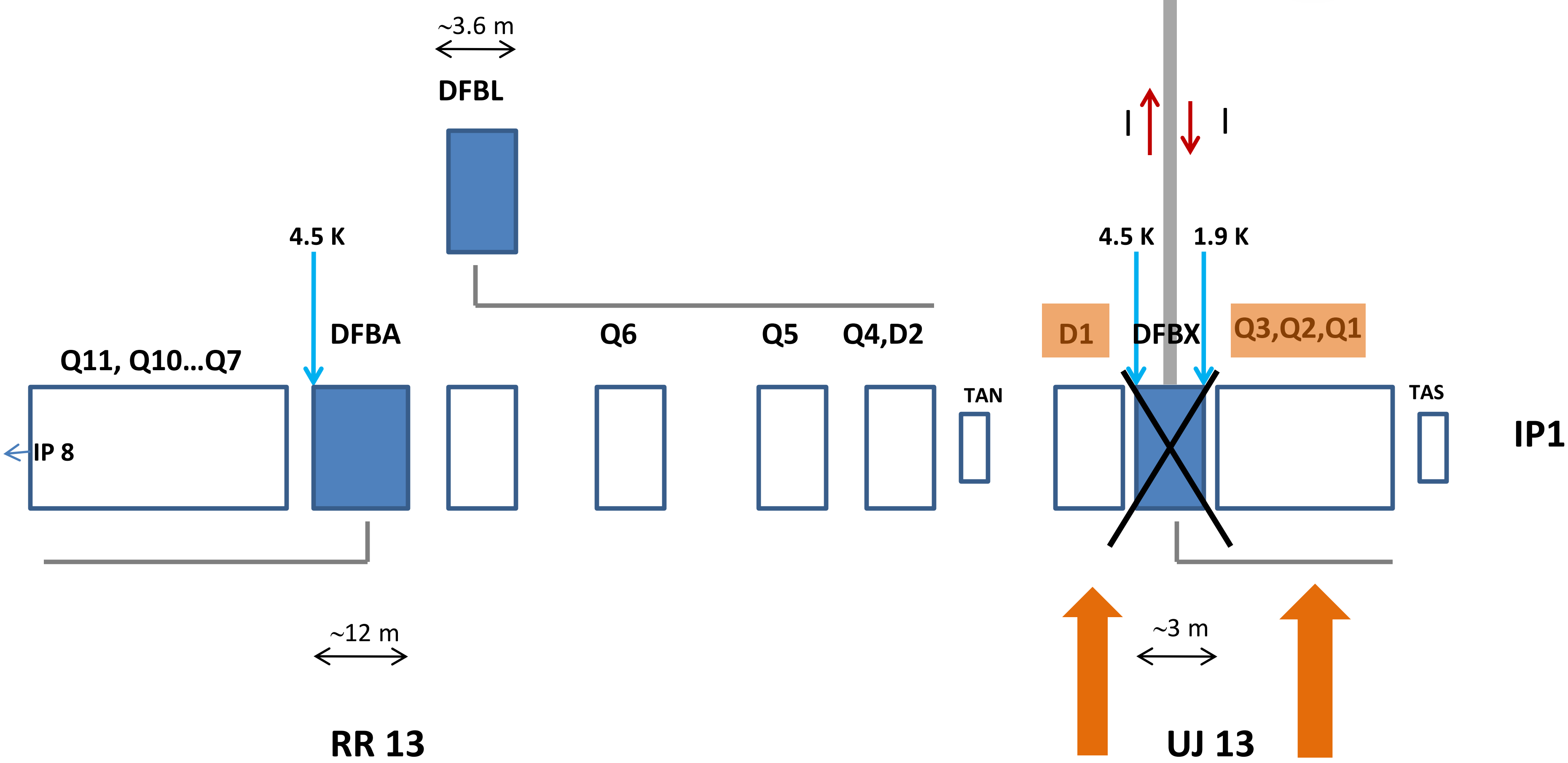
L. Xiao et al.



~250 mm outer radius

SC Links

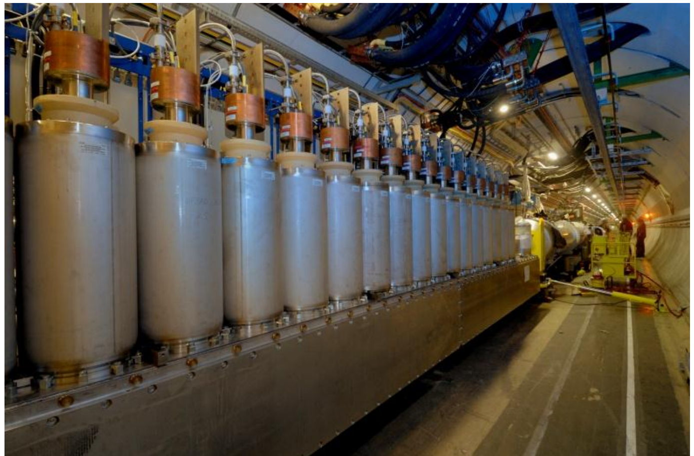
Layout at Point 1



A. Ballarino, 18 Nov. 2011

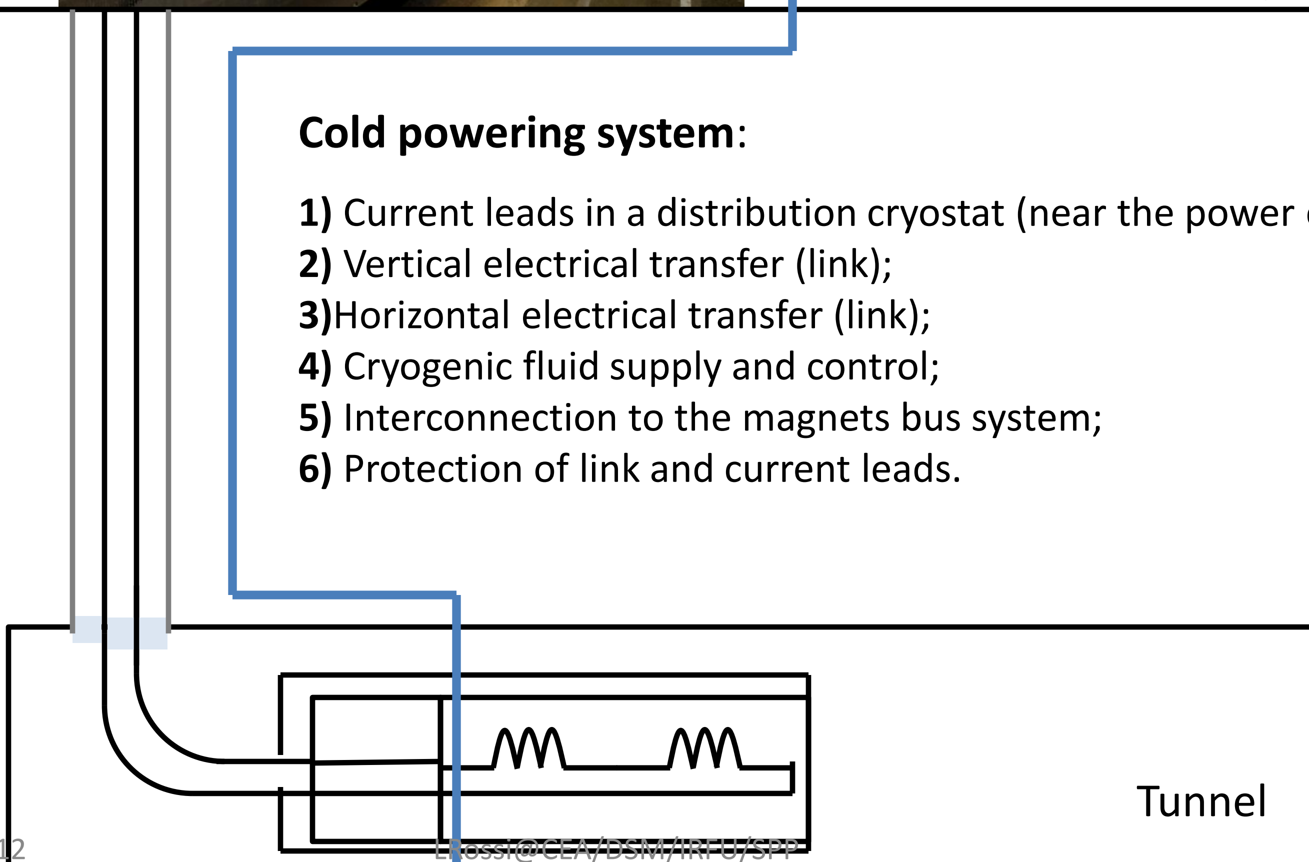
Room temperature

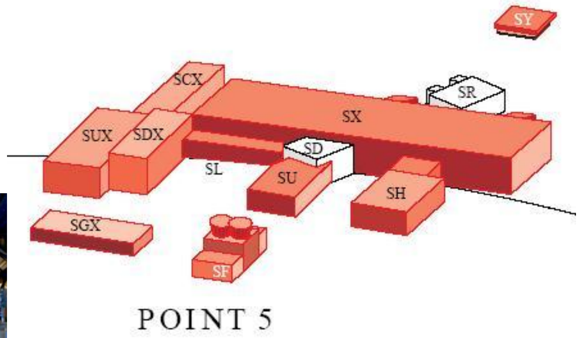
Cryogenic environment
(4.5 K LHe in the DFBs)

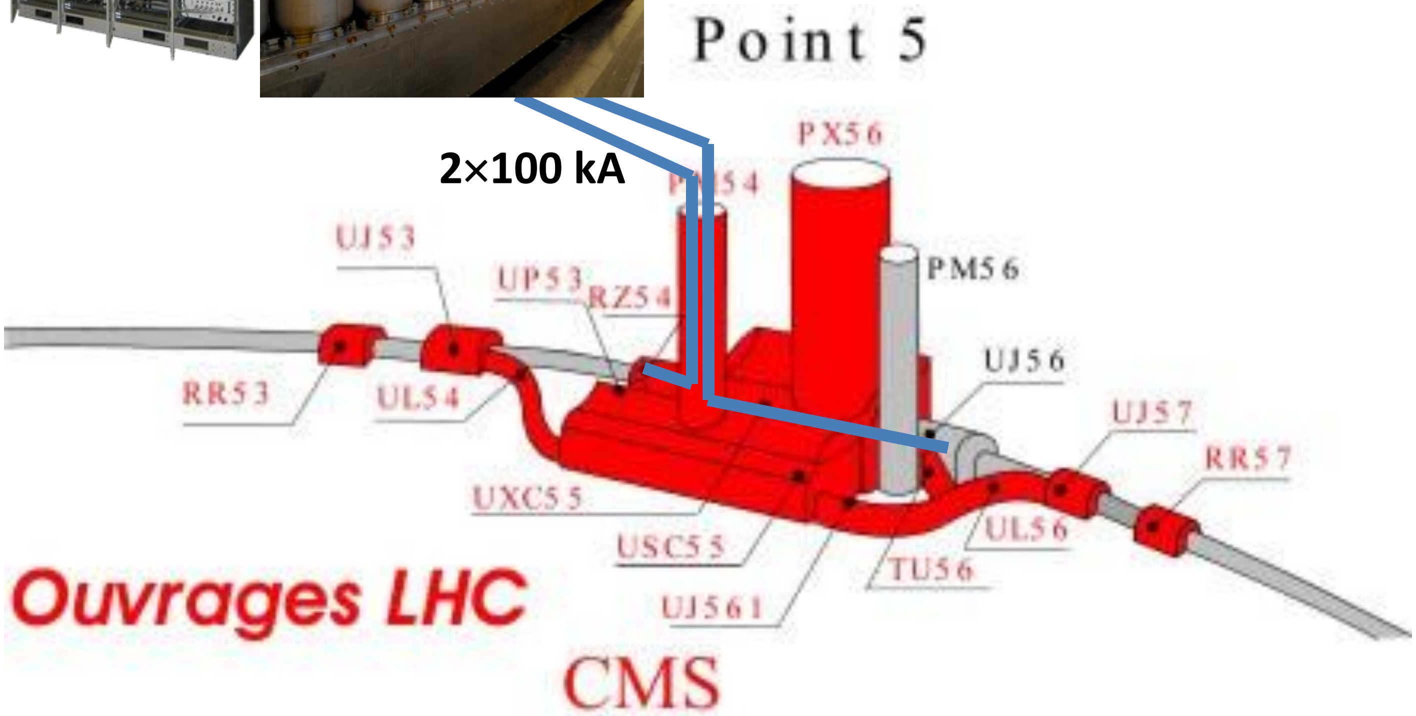


Cold powering system:

1) Current leads in a distribution cryostat (near the power converters);
2) Vertical electrical transfer (link);
3)Horizontal electrical transfer (link);
4) Cryogenic fluid supply and control;
5) Interconnection to the magnets bus system;
6) Protection of link and current leads.



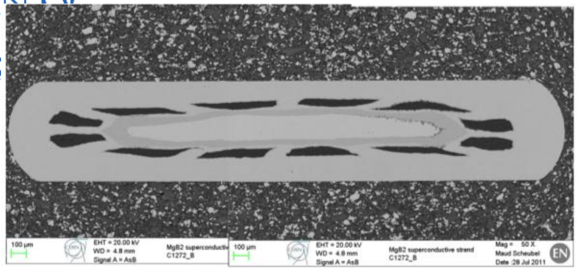




A. Ballarino, 18 Nov. 2011

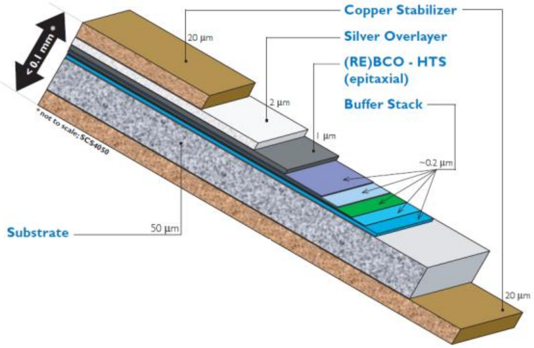
Conductors in Superconducting Links

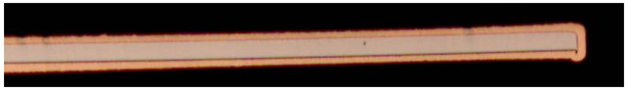
MgB_2



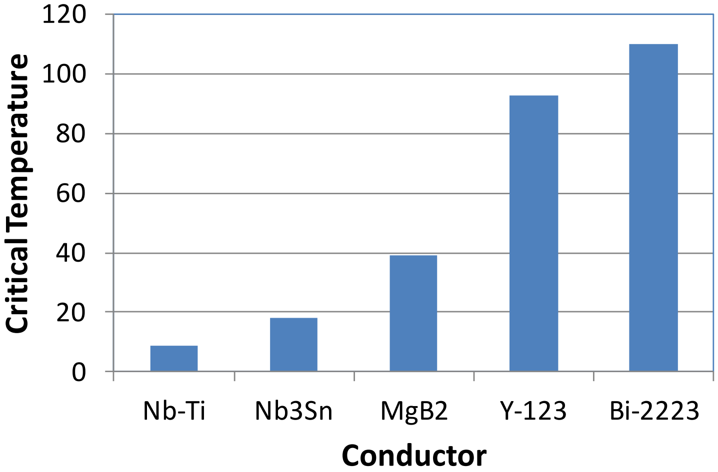
MgB_2 Tape : 3.64×0.65 mm^2
MgB_2 : 12 %
Cu : 15 %

YBCO

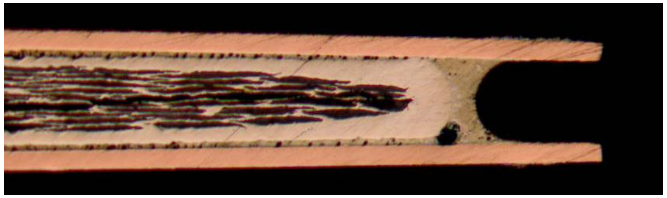




YBCO Tape : 4 ×0.1 mm^2
YBCO: 1-3 µm
Cu : 2×20 µm



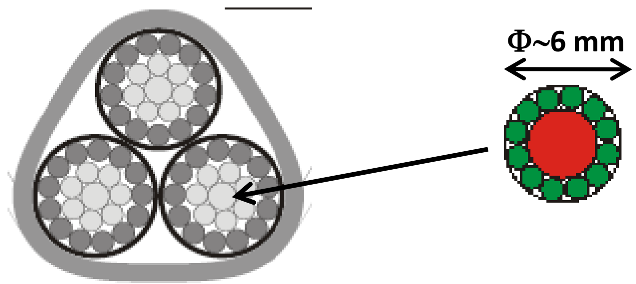
Bi-2223



Bi-2223 Tape : 4.5 ×0.4 mm^2
BSCCO: 23 %
Cu : 2×50 µm

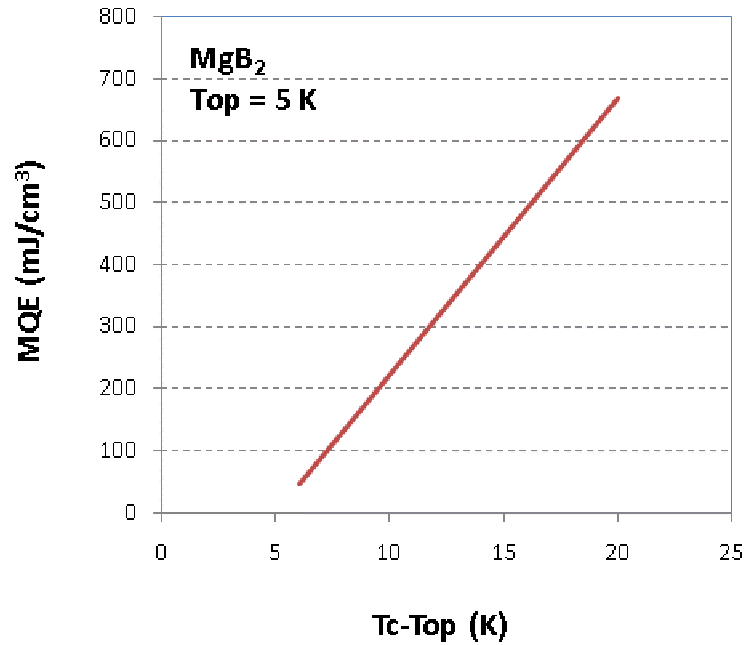
Minimum quench energy of superconductors

Nb-Ti cables
used in LHC
6 kA at 6 K



MgB_2 cable
6 kA at 20 K
(> 12 kA at 4.5 K)

Nb-Ti, Top = 5 K
Tc= 6 K → MQE = **2.63 mJ/cm³**
Tc = 7 K → MQE = **5.26 mJ/cm³**



Tc = critical temperature
Top = operating temperature
MQE= Minimum Quench Energy

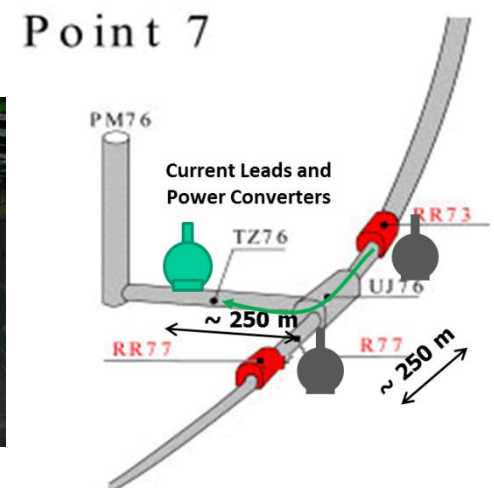
A. Ballarino, 18 Nov. 2011

PLAN

First installation SC link 2017?

Nexan Cryoflex® line
(20 m long cryostat of link)
procured and
installed in the CERN
SM-18 laboratory
20 kA – 4 to 80 K test

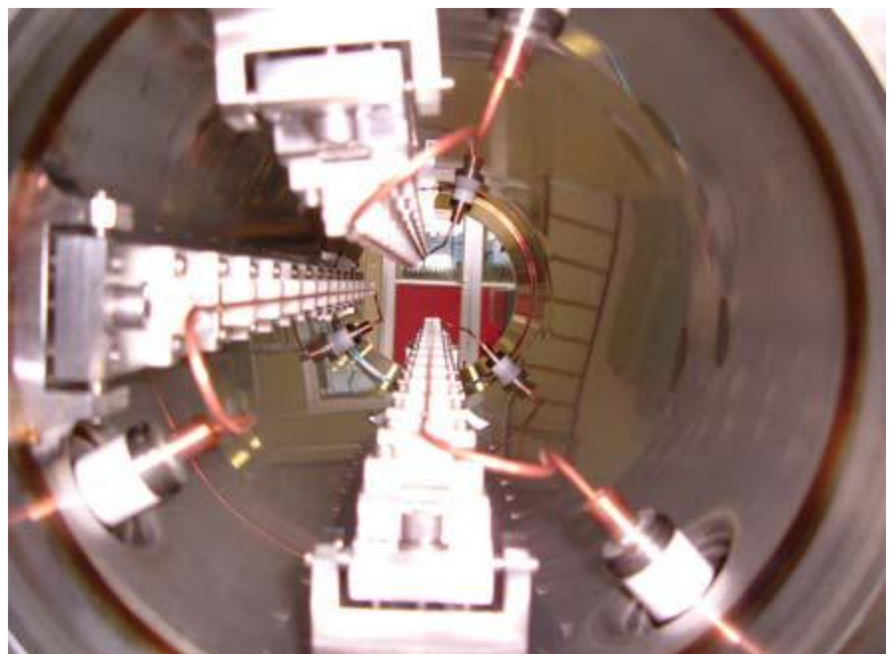
- Horizontal SC link in P7: RR with many 600 A EPCs in RR just downstream betatron cleaning



Beam Diagnostic & Instrumentation

- BPM capable to withstand more intense beam
- Cryo BLM
- Long range beam wire for LRBB compensation

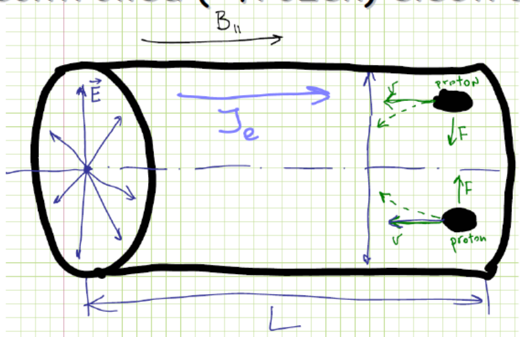
Experiments in SPS and RHIC demonstrated ability to affect the beam (destroy it) but not yet to cure it
(we can only do i LHC)
It is a collimator like device: 10 σ or less form beam



E-lens? From FNAL?

What Is Electron Lens?

- it is very stable and very well controlled (~frozen) electron cloud



~10^{12} e-

Can control current, diameter, length, position timing, velocity, shape, angle, direction

Electron Lenses for LHC - Vladimir Shiltsev

What is it good for?

- **IT CAN KILL**
  - blow up emittances in controlled fashion
  - drive particles out – randomly or via resonance drive
  - remove unwanted particles, bunches, e.g.:
    - only in between bunches
    - just 1 out of 3000
    - only satellites
    - only those with a>5 x Sigma , etc, etc

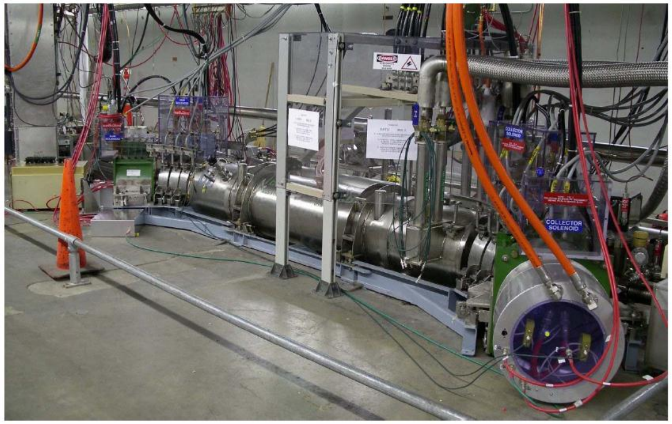
Electron Lenses for LHC - Vladimir Shiltsev

What is it good for?

- **IT CAN HEAL**
  - reduce emittance blowup caused by other processes:
    - space-charge forces
    - beam-beam forces, etc
  - reduce beam loss rates by moving particles away from dangerous resonances
  - selective resonant extraction
  - introduce incoherent tune spread to stabilize beams

Electron Lenses for LHC - Vladimir Shiltsev

TEL-2 in the Tunnel (July 2006)

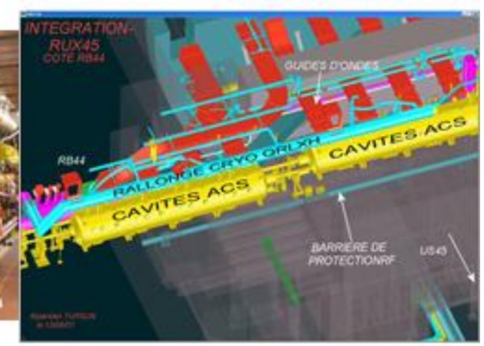


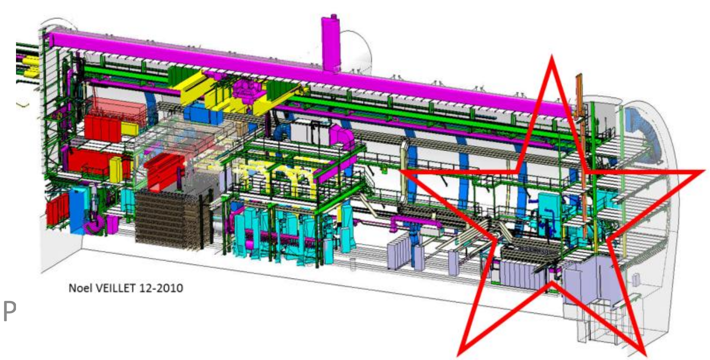
Electron Lenses for LHC - Vladimir Shiltsev

LS2 - 2018

- Cryogenics P4 $\Rightarrow$ separation between SC Magnets and RF Cavities cooling circuit
- 5-6 kW plant
- crab cavity test P4
- Anticipated 2017:
  - Sc link in P7
  - Test crab cavities in SPS

Potential interconnection options for "redundancy" with QRL





LS2 - 2018

- DS Cryo-collimation with 11 T in 1 IP: priority NOT yet decided: IP1,IP5 or IP2 ?
  Review of collimation needs in Spring 2013
- Vertical SC links in RRs of P1, P5 (stand-alone)
- Improve triplet cooling
- Some Beam diagnostics
- Some Collimators
- INJECTORS!

LS3

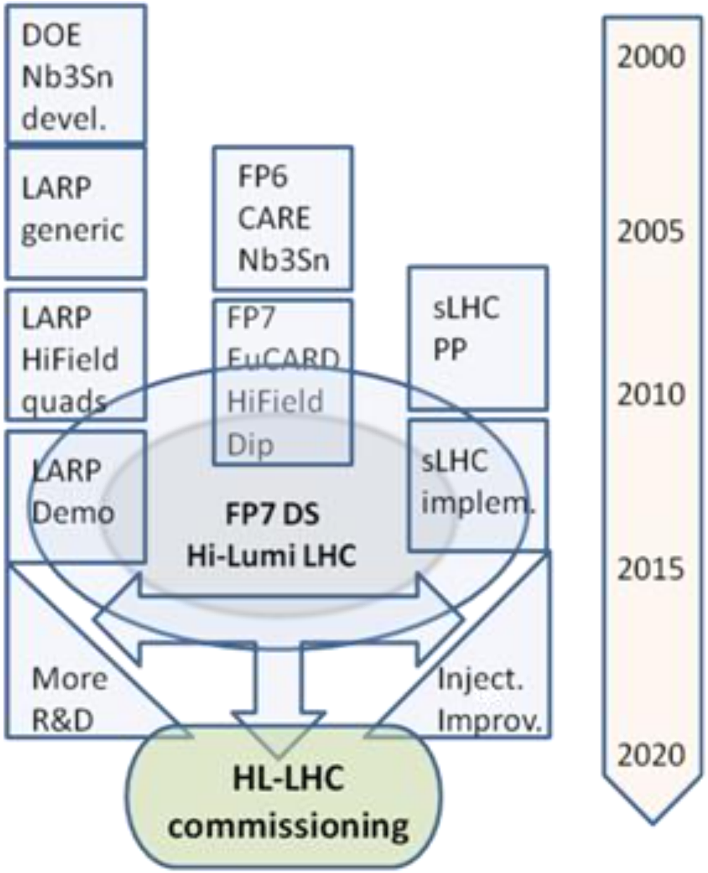
- **Triplets + D1-D2** (disinstallation)
- TAS + Exp-interfaces
- New cryo in IP1-IP5 with **separation Arc-IR**
- New MS magnets (Q4-Q5) and correctors
- CC cavities with its local cryo
- Vertical links for all new magnets IP1-IP5
- New collimators
- Diagnostics & wigglers

FP7 HiLumi Design Study application 25 Nov 2010

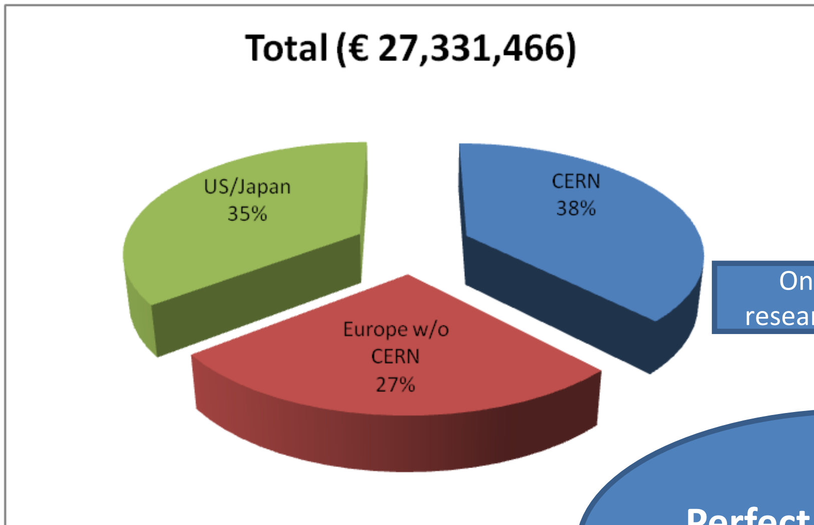
Participant no.	Participant organisation name	Short name	Country
1 (Coord-inator)	European Organization for Nuclear Research	CERN	IEIO[1]
2	Commissariat à l'Énergie Atomique et aux énergies alternatives	CEA	France
3	Centre National de la Recherche Scientifique	CNRS	France
4	Stiftung Deutsches Elektronen-Synchrotron	DESY	Germany
5	Istituto Nazionale di Fisica Nucleare	INFN	Italy
6	Budker Institute of Nuclear Physics	BINP	Russia
7	Consejo Superior de Investigaciones Cientificas	CSIC	Spain
8	École Polytechnique Fédérale de Lausanne	EPFL	Switzerland
9	Royal Holloway, University of London	RHUL	UK
10	University of Southampton	SOTON	UK
11	Science & Technology Facilities Council	STFC	UK
12	University of Lancaster	ULANC	UK
13	University of Liverpool	UNILIV	UK
14	University of Manchester	UNIMAN	UK
15	High Energy Accelerator Research Organization	KEK	Japan
16	Brookhaven National Laboratory	BNL	USA
17	Fermi National Accelerator Laboratory (Fermilab)	FNAL	USA
18	Lawrence Berkeley National Laboratory	LBNL	USA
19	Old Dominion University	ODU	USA
20	SLAC National Accelerator Laboratory	SLAC	USA

HiLumi is the focal point of 20 years of converging International collaboration

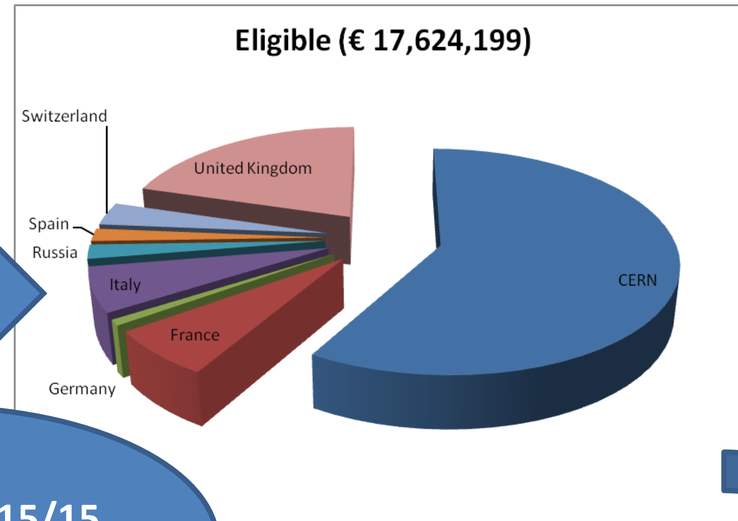
- The collaboration wiht US on LHC upgrade started during the construction of LHC
- EU programs have been instrumental in federating all EU efforts
- With Hi-Lumi the coordination makes a step further: from coordinated R&D to a common project
- CERN is not anymore the unique owner, rather is the motor and cathalizer of a wider effort.
- Managed like a large detector collaboration (with CERN in special position as operator of LHC)



Budget FP7 HiLumi



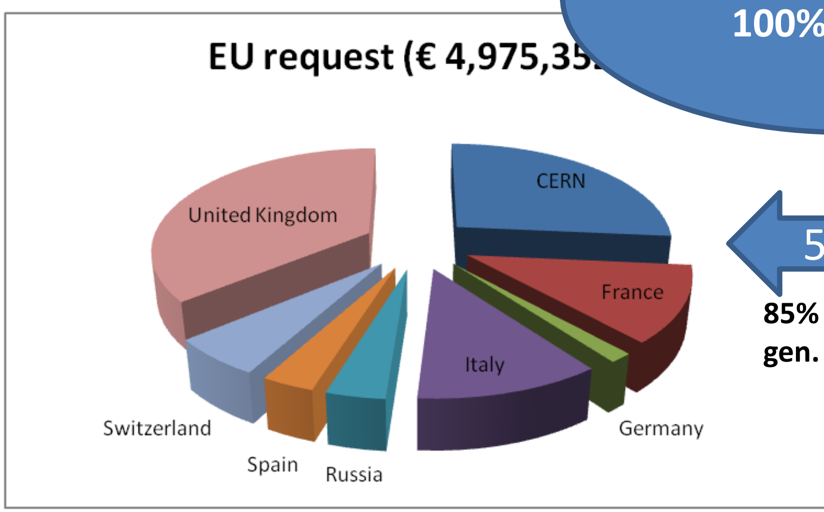
Only EU research area



CERN waives all technical works: LHC is core program. Only kept the CERN cost for managem.

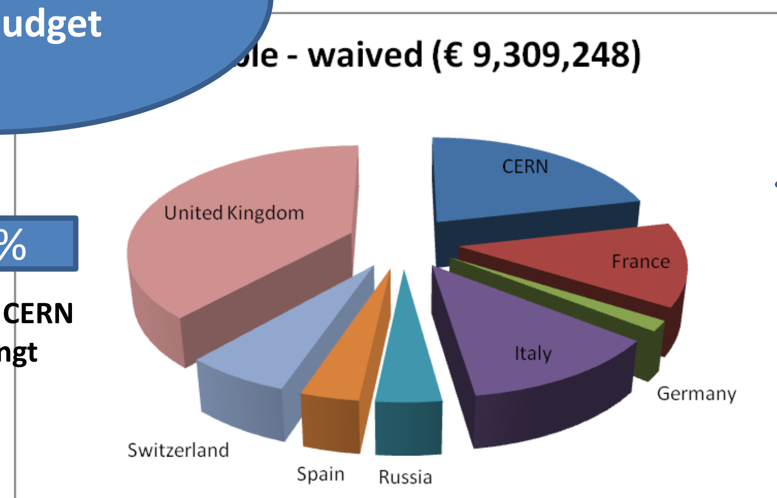
Perfect score 15/15, 100% budget

Waiving effect

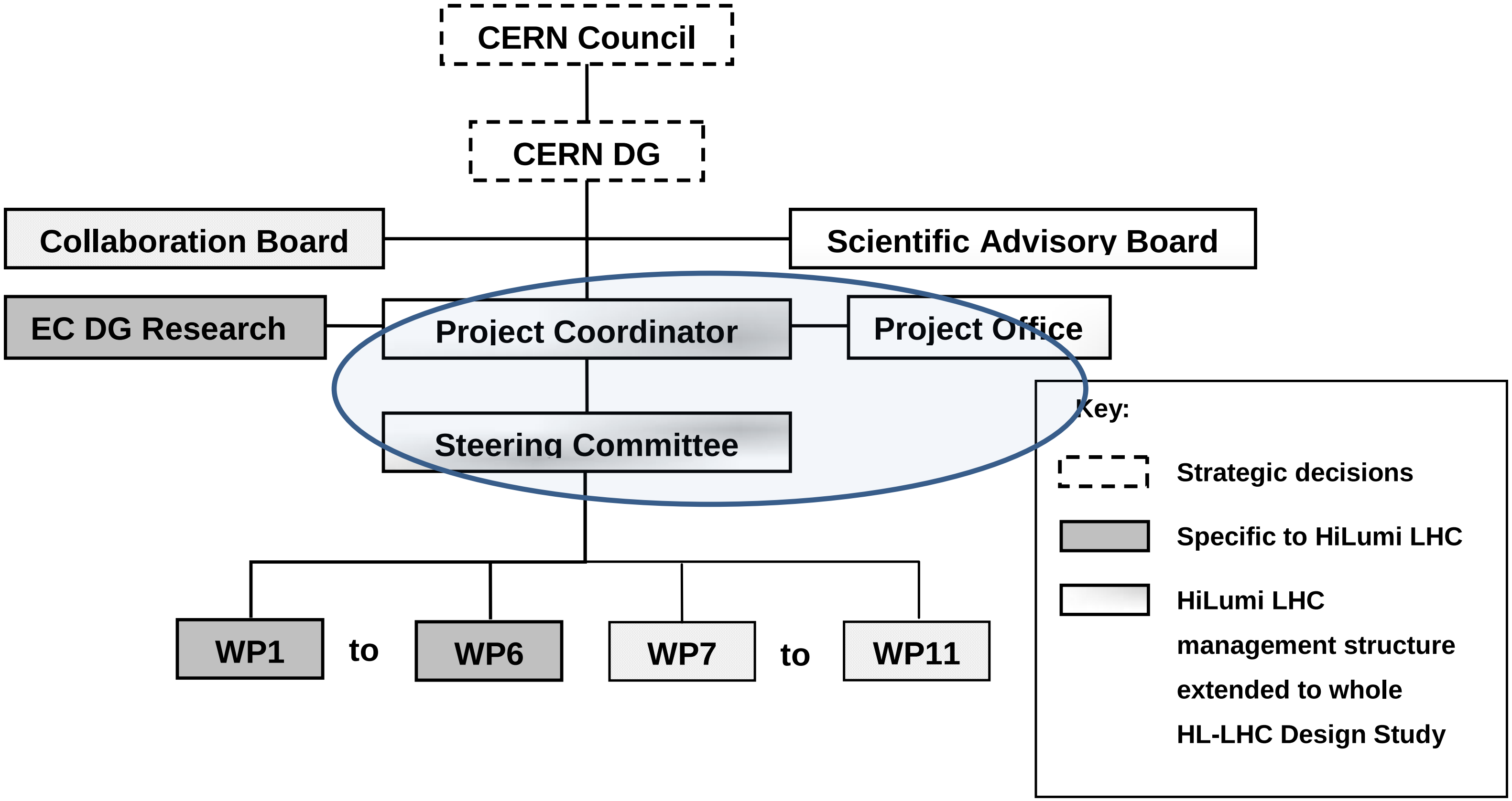


50%

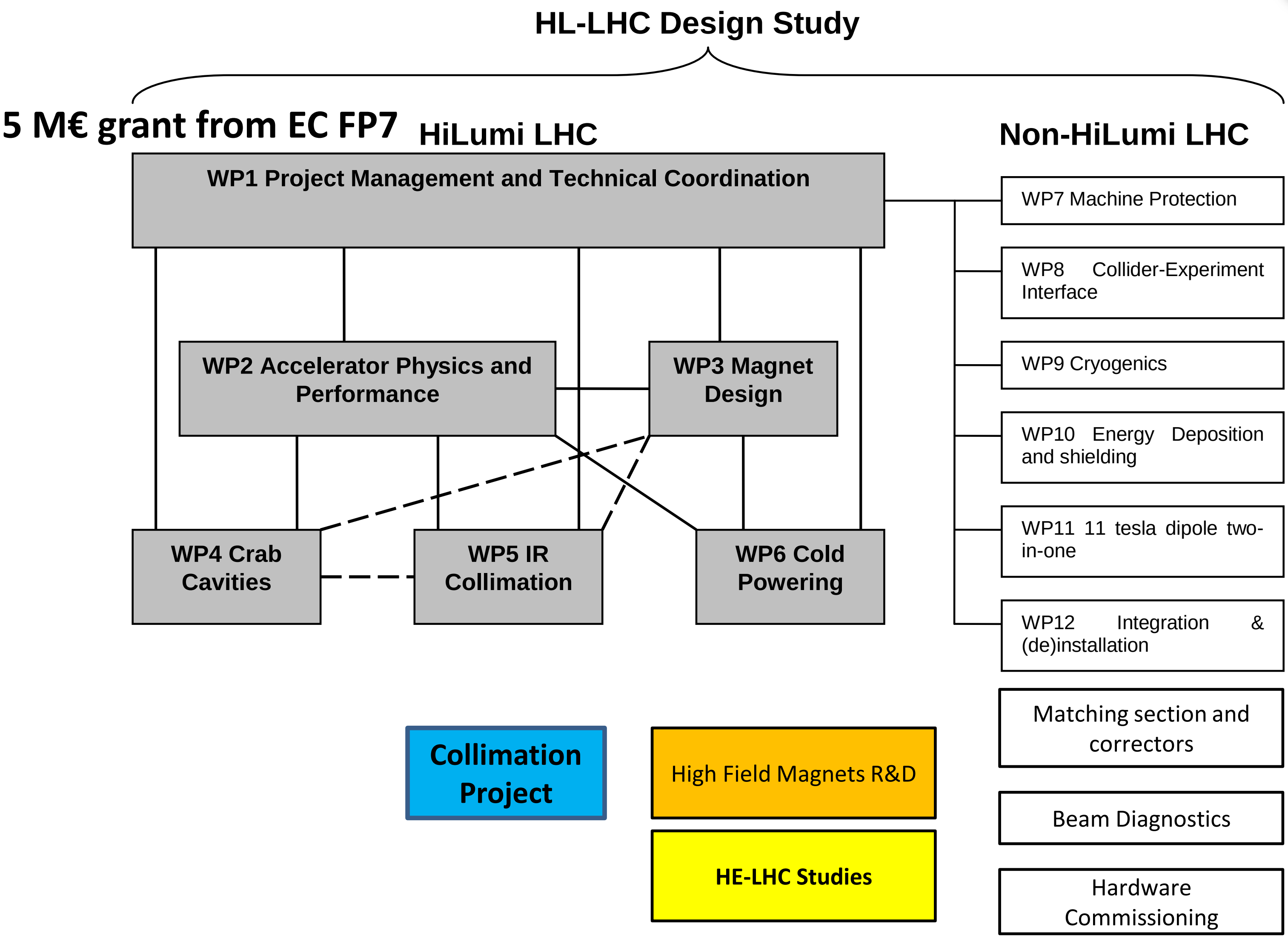
85% of CERN gen. mngt



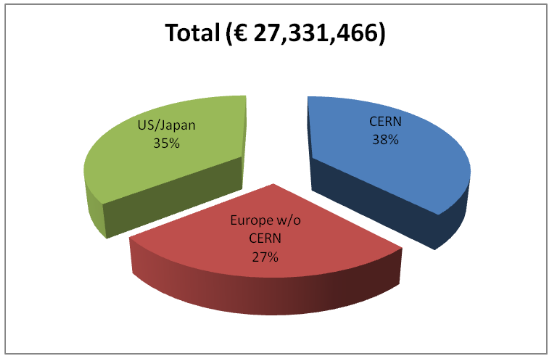
HL-LHC management

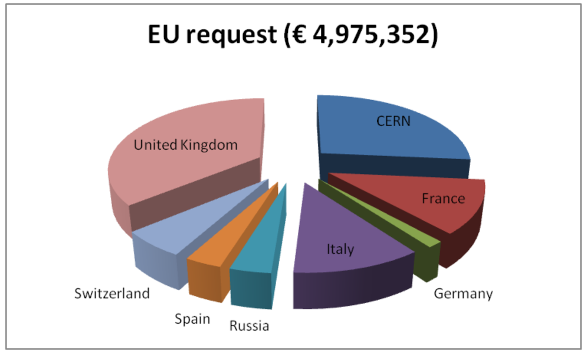


HL-LHC composition



Budget of HiLumi DS and HL-LHC





HiLumi covers 6 WPs

1. Manag and Tech. Coord. (6%)
2. Acc. Physics and beam
3. Magnets for IR
4. Crab Cavities
5. Collimators
6. Sc links

Table 2. Summary of the cost of HL-LHC with split between Performance Improving-Consolidation and Full performance i.e. all HL-LHC)

	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

Lumi reach in the two cases

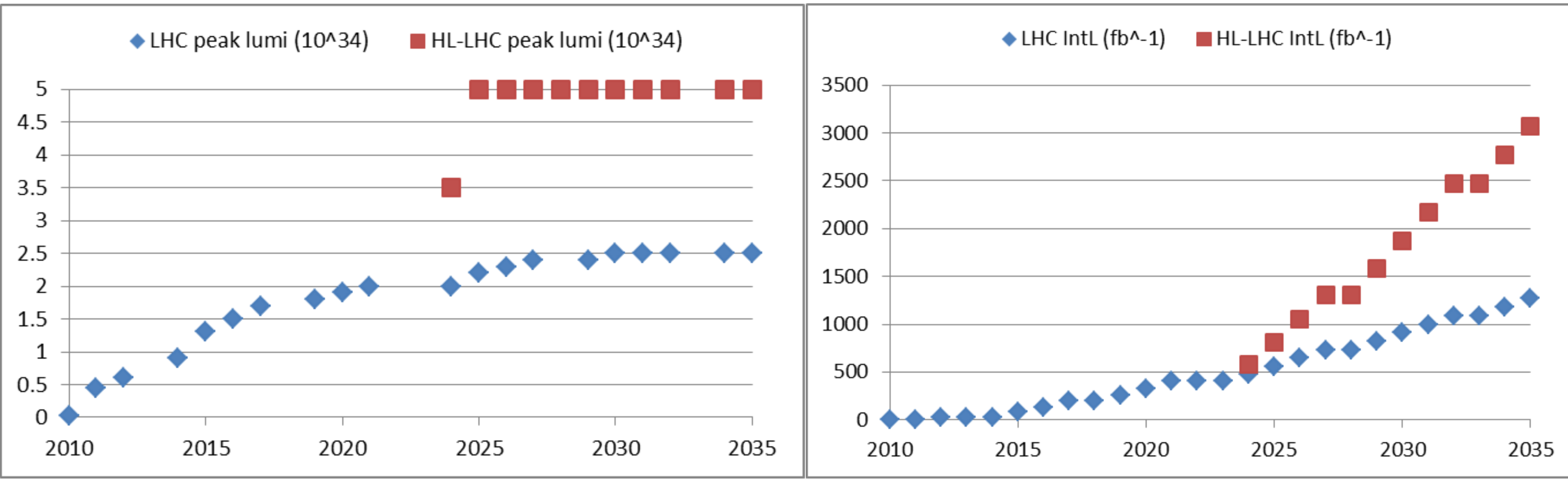


Figure 1.10. Left graph: peak luminosity for LHC with improving consolidation (diamonds) and with HL-LHC full performance (square markers). Right graph: the same for the integrated luminosity.

And after?
Can we run LHC forever?

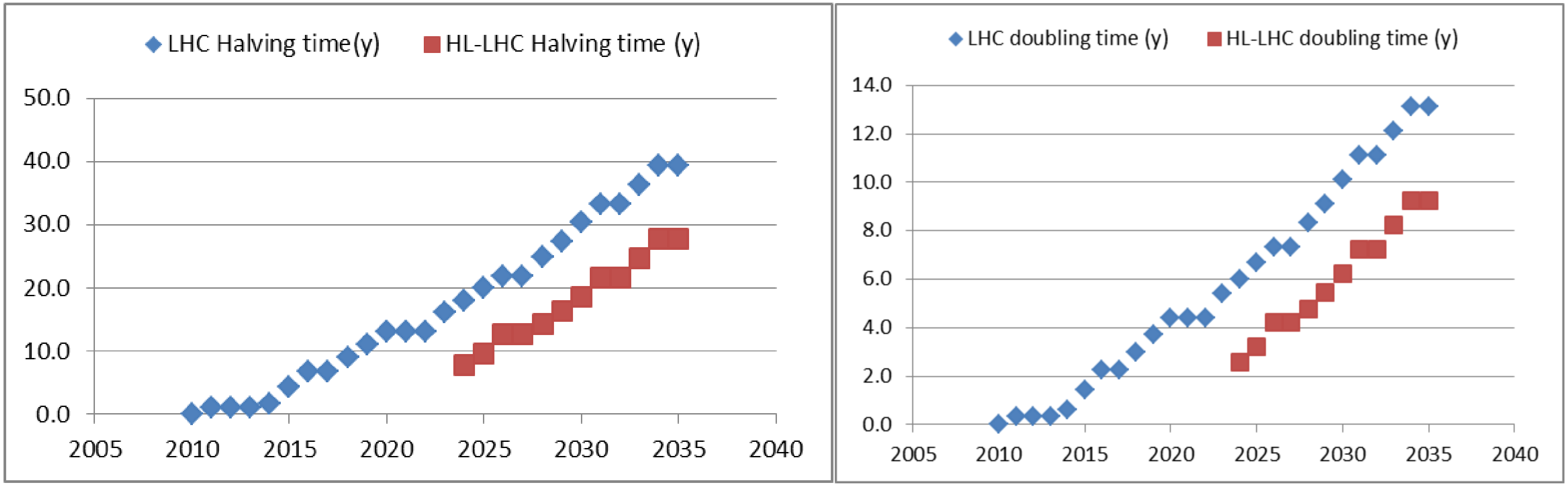
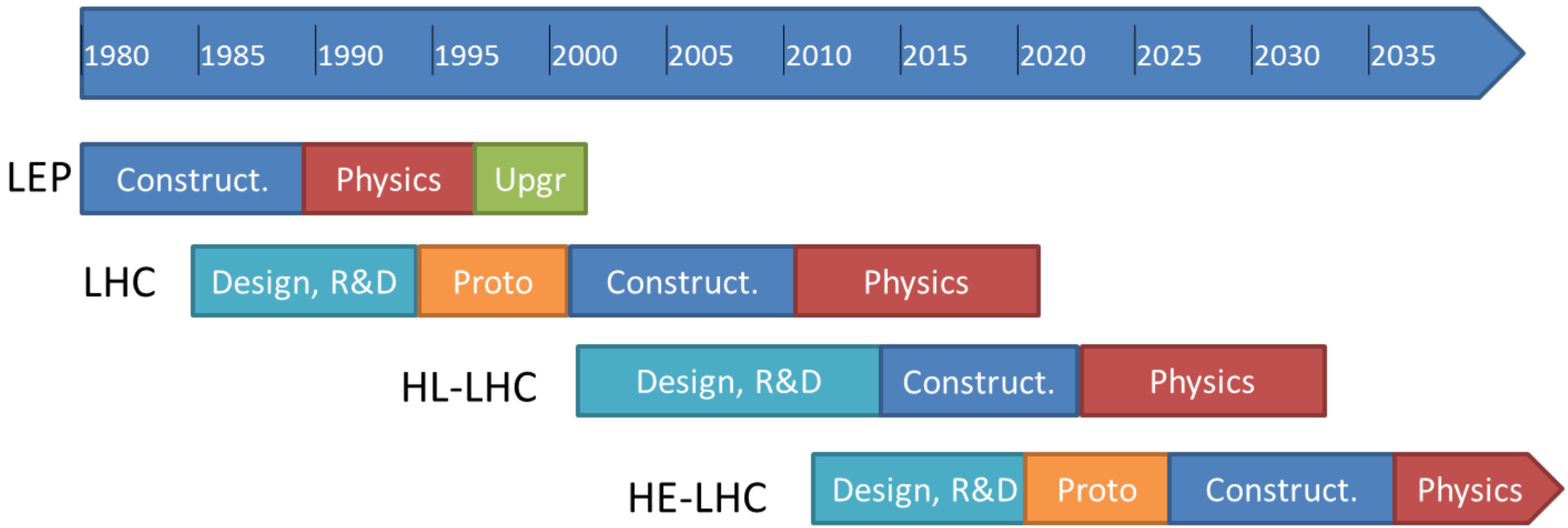


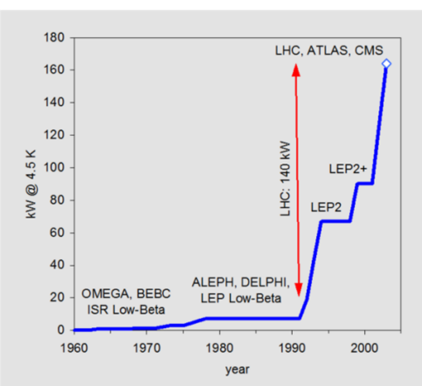
Figure 1.11 Halving time and doubling time for the LHC with improving consolidation and for HL-LHC with full performance.

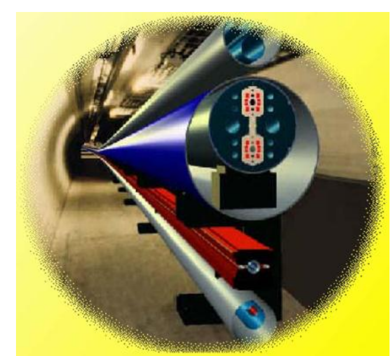
NO: history demonstrates that at certain point, to get resources for new projects, previous accelerators are closed (despite last minute claims of new discovery…)

High Energy LHC may be the answer

The super-exploitation of the CERN complex: Injectors, LEP/LHC tunnel, infrastructures







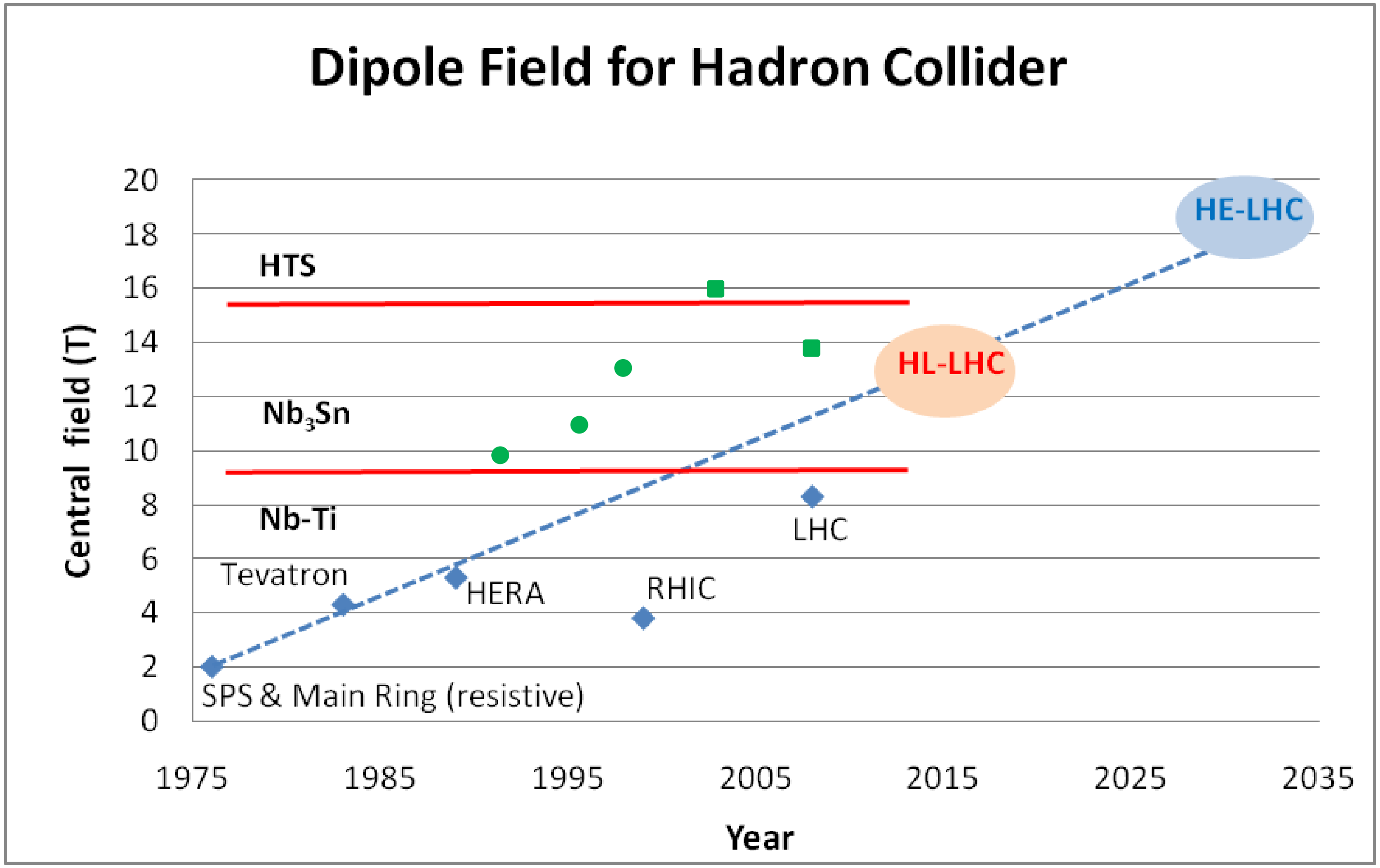
Possible list of parameters

	nominal LHC	HE-LHC	
beam energy [TeV]	7	16.5	
dipole field [T]	8.33	20	
dipole coil aperture [mm]	56	40	
beam half aperture [cm]	2.2 (x), 1.8 (y)	1.3	
injection energy [TeV]	0.45	>1.0	
#bunches	2808	1404	
bunch population [10^{11}]	1.15	1.29	1.30
initial transverse normalized emittance [μm]	3.75	3.75 (x), 1.84 (y)	2.59 (x & y)
initial longitudinal emittance [eVs]	2.5	4.0	
number of IPs contributing to tune shift	3	2	
initial total beam-beam tune shift	0.01	0.01 (x & y)	
maximum total beam-beam tune shift	0.01	0.01	
beam circulating current [A]	0.584	0.328	
RF voltage [MV]	16	32	
rms bunch length [cm]	7.55	6.5	
rms momentum spread [10^{-4}]	1.13	0.9	
IP beta function [m]	0.55	1 (x), 0.43 (y)	0.6 (x & y)
initial rms IP spot size [μm]	16.7	14.6 (x), 6.3 (y)	9.4 (x & y)
full crossing angle [μrad]	285 (9.5 $\sigma_{x,y}$)	175 (12 σ_{x0})	188.1 (12 $\sigma_{x,y0}$)
Piwinski angle	0.65	0.39	0.65
geometric luminosity loss from crossing	0.84	0.93	0.84

List parameters - cont.

stored beam energy [MJ]	362	478.5	480.7
SR power per ring [kW]	3.6	65.7	66.0
arc SR heat load dW/ds [W/m/aperture]	0.17	2.8	2.8
energy loss per turn [keV]	6.7	201.3	
critical photon energy [eV]	44	575	
photon flux [10^{17}/m/s]	1.0	1.3	
longitudinal SR emittance damping time [h]	12.9	0.98	
horizontal SR emittance damping time [h]	25.8	1.97	
initial longitudinal IBS emittance rise time [h]	61	64	~68
initial horizontal IBS emittance rise time [h]	80	~80	~60
initial vertical IBS emittance rise time [h]	~400	~400	~300
events per crossing	19	76	
initial luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0	
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0	
beam lifetime due to *p* consumption [h]	46	12.6	
optimum run time t_r [h]	15.2	10.4	
integrated luminosity after t_r [fb^{-1}]	0.41	0.50	0.51
opt. av. int. luminosity per day [fb^{-1}]	0.47	0.78	0.79

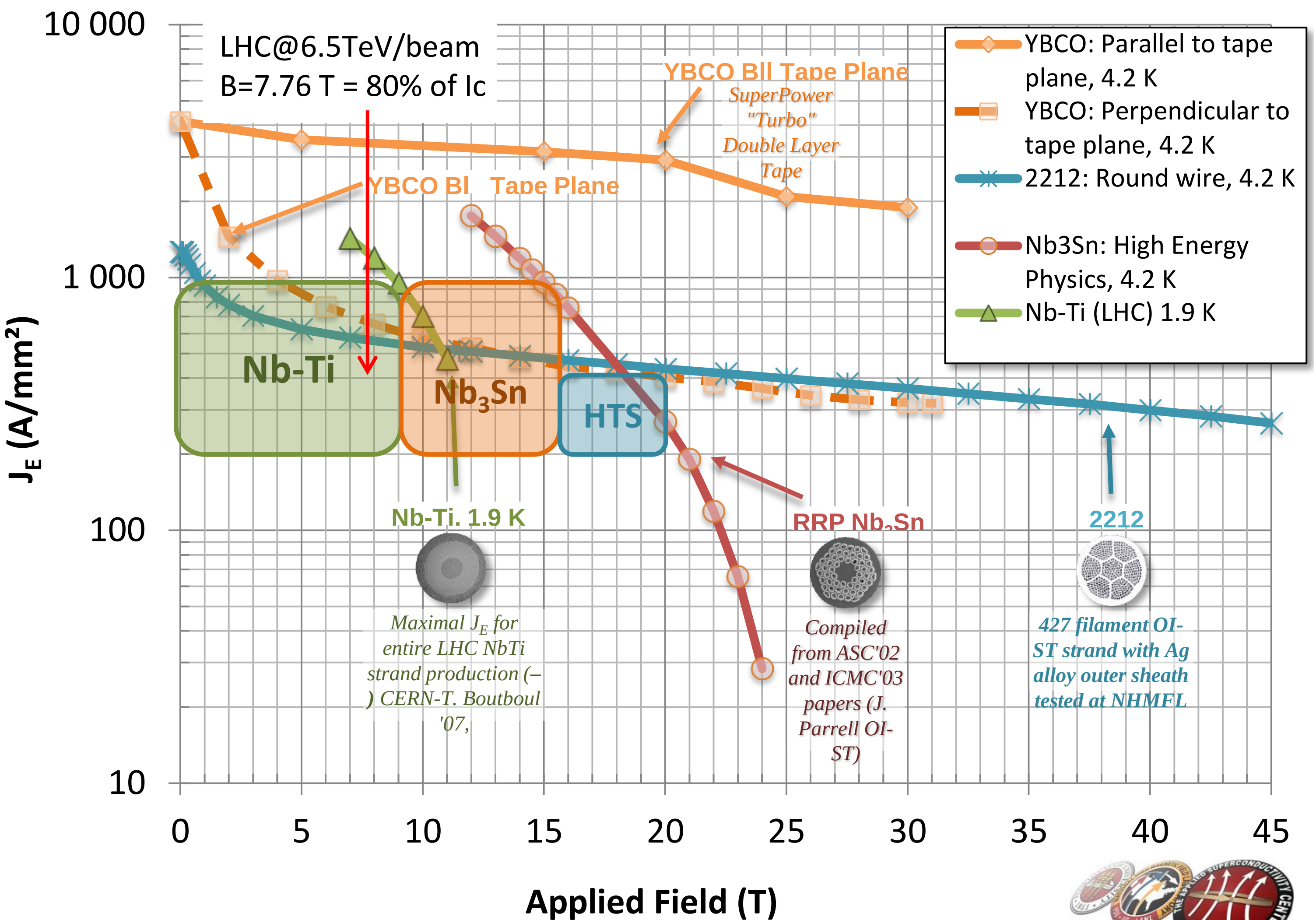
Main dipoles: is it possible ?



Looking at performance offered by practical SC, considering tunnel size and basic engineering (forces, stresses, energy) **the practical limits is around 20 T.** Such a challenge is similar to a 40 T solenoid (μ-C)

◆ **Nb-Ti operating dipoles;** ● **Nb3Sn cosϑ test dipoles** ■ **Nb3Sn block test dipoles**

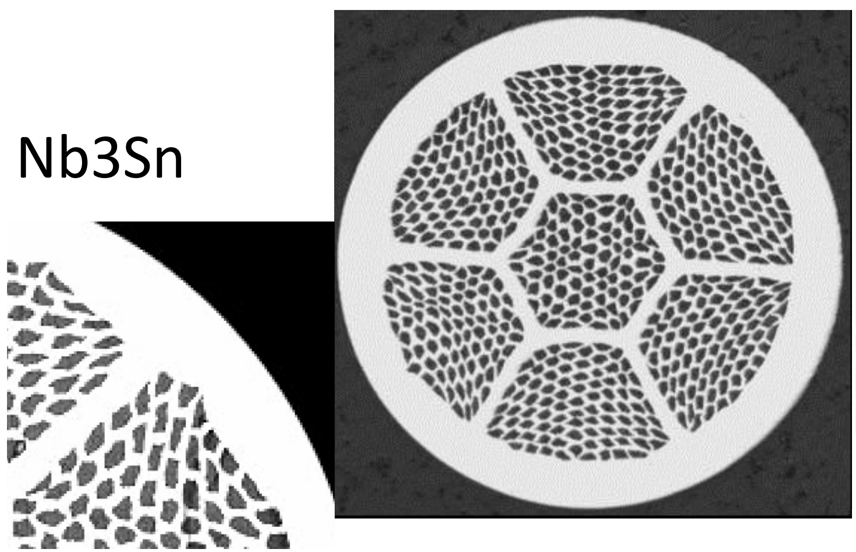
The Superconductor « space »

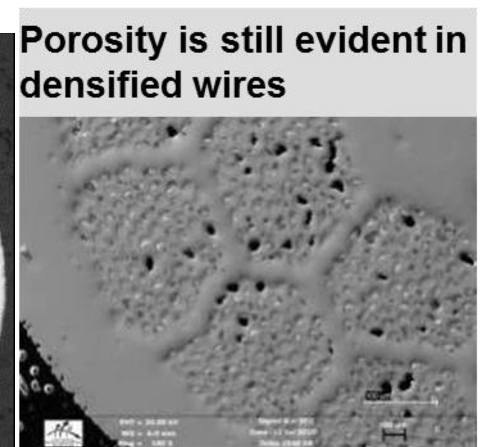


The « new » materials: HTS Bi-2212

- Round wire, isotropous and **suitable to cabling**!
- HEP only users (good < 20K and for compact cable)
- Big issue: very low strain resistance, brittle
- Production ~ 0,
- cost ~ 2-5 times Nb3Sn (Ag stabilized)

- DOE program 2009-11 in USA let to a factor 2 gain. We need another 50% and more uniformity, eliminating porosity and leakage

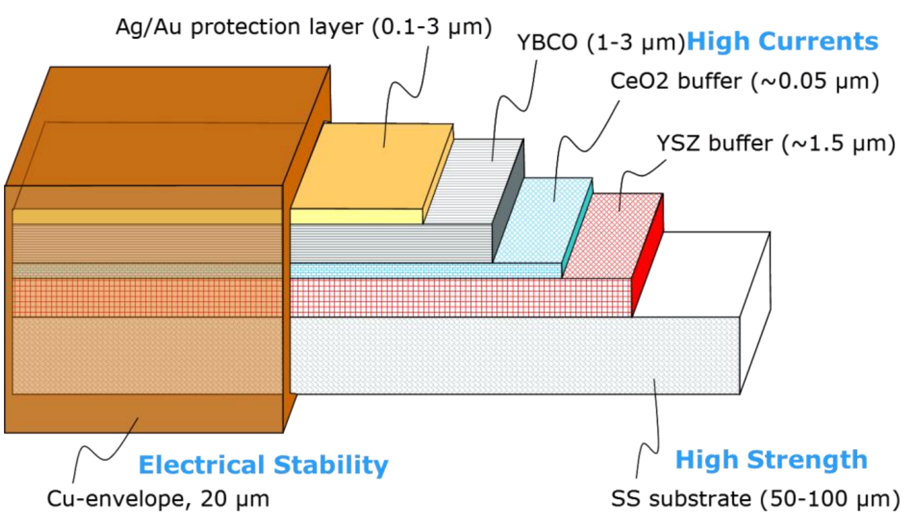


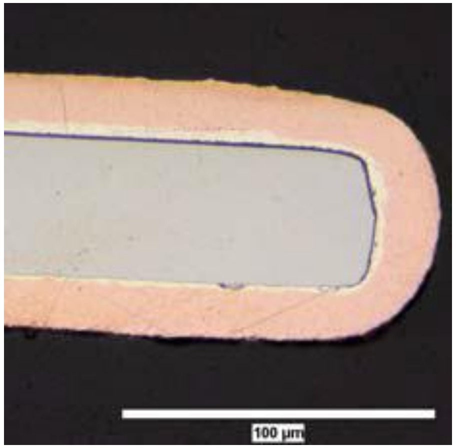


J. Jiang et al 2011

The « new » materials: HTS YBCO

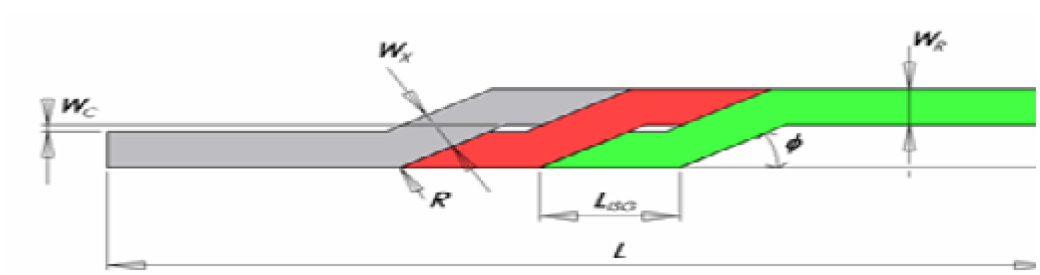
- Tape of 0.1-0.2 mm x 4-10 mm : difficult for compact (>85%) cables
- Current is EXCELENT but serious issue is the anisotropy;
- >90% of world effort on HTS are on YBCO! Great synergy with all community
- Cost : today is 10 times Nb_3Sn, target is same price: components not expensive, process difficult to be industrialize at low cost
- FP7 Eucard is developing EU Ybco

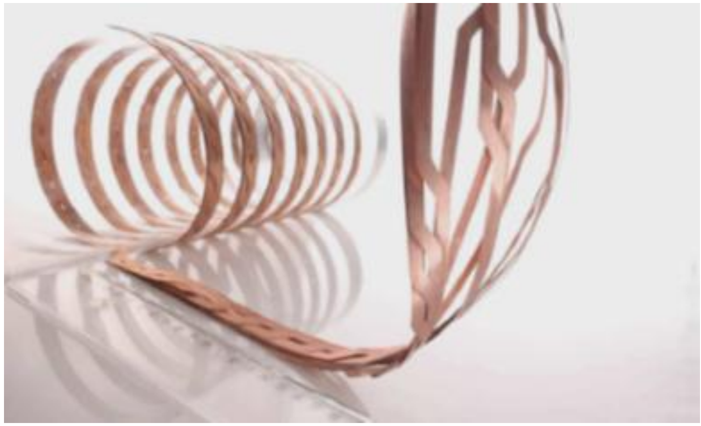


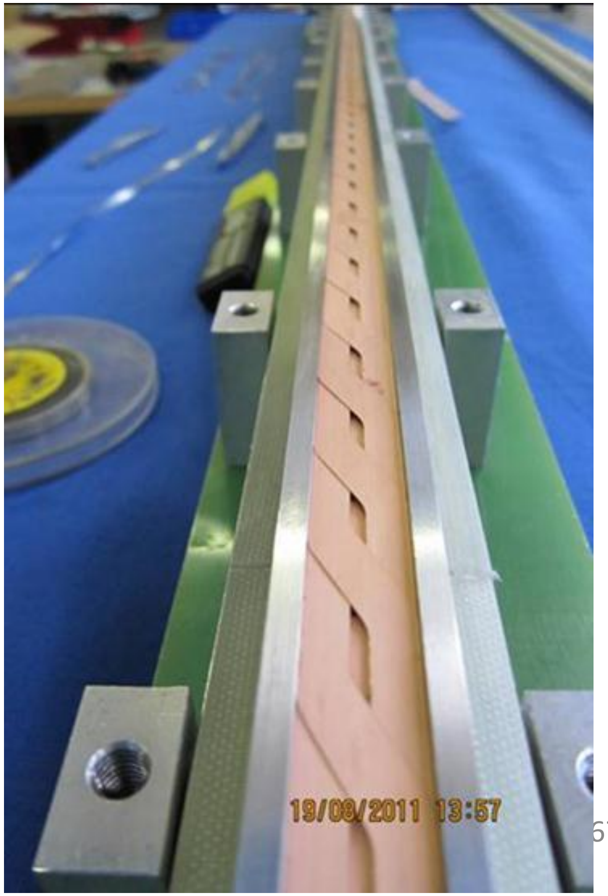


New (old) approach to cabling suitable for tapes

- An old type of cabling (Roebel) suitable for tapes has been recently rivisited (Karlsruhe, New Research Industry NZ)
- Here a first 2 m long test cable done at CERN

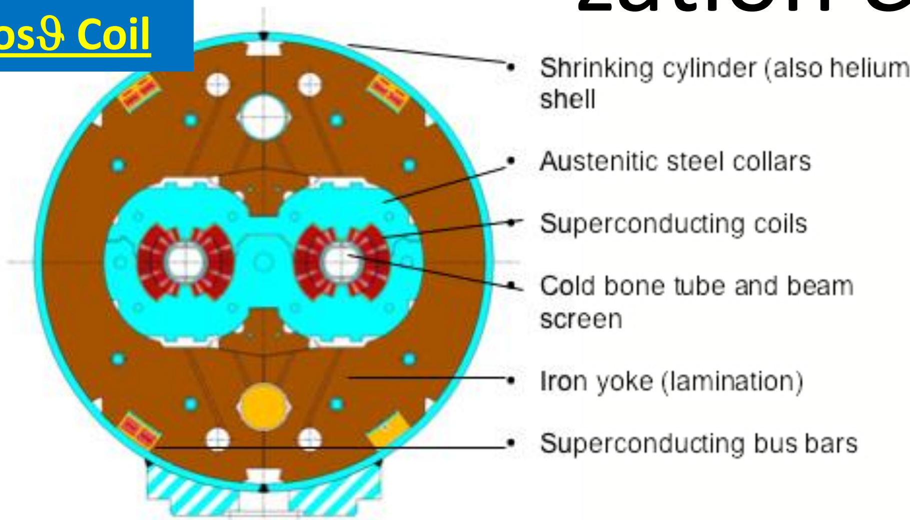




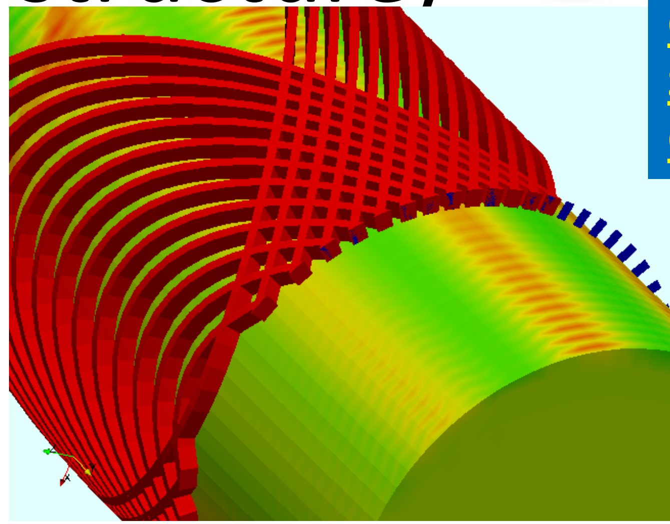


Magnet shapes (field optimization & structure)

Cosϑ Coil

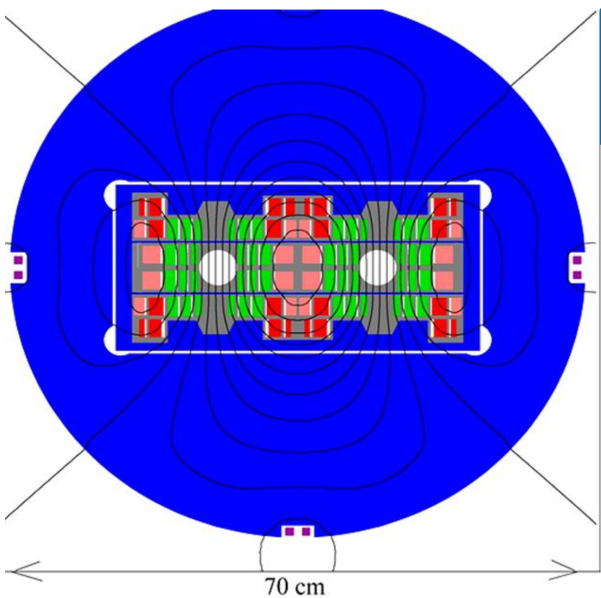


Canted Solenoid Coil



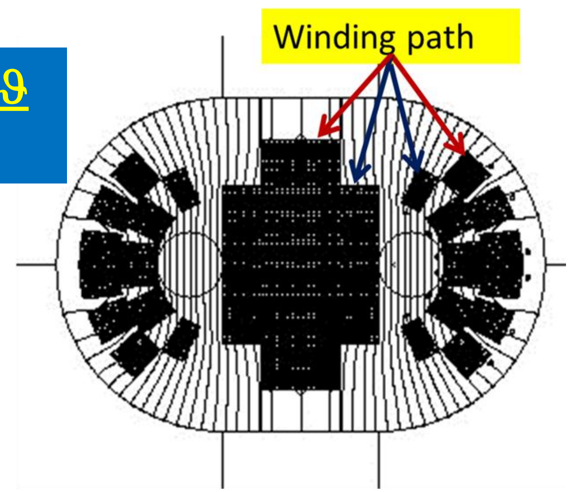
S. Caspi

Block Coil



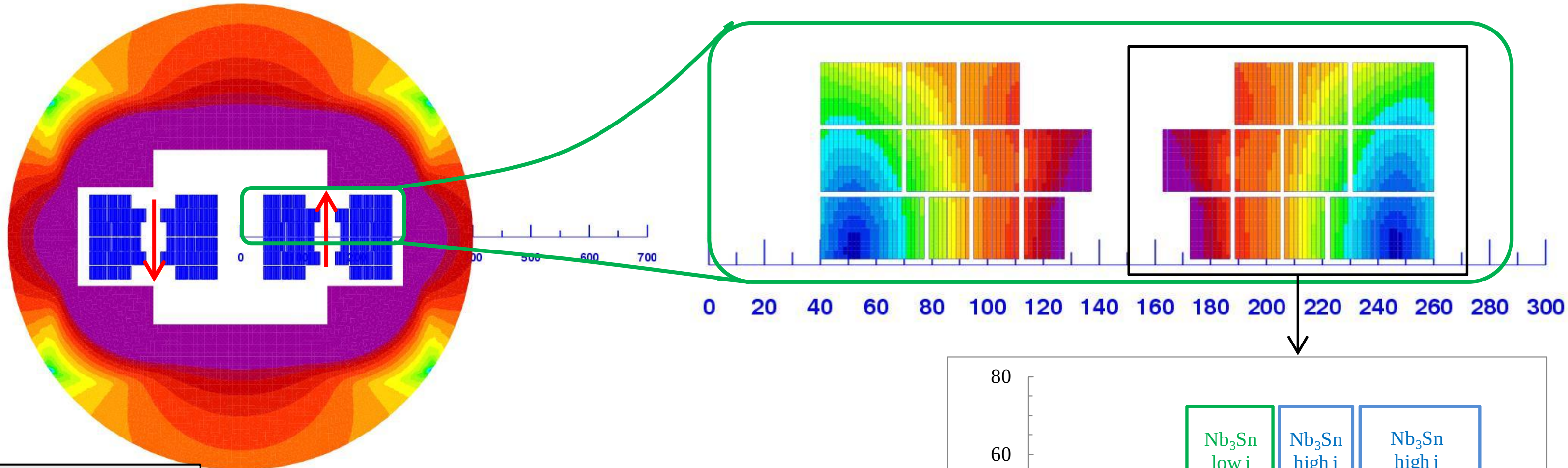
P. McIntyre

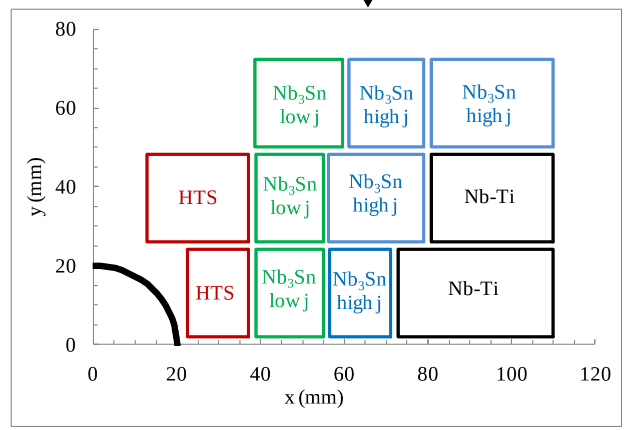
Hybrid Cosϑ Block Coil



- Beam bore diameter – 40 mm
- Winding bore diameter – 87 mm

First consistent cross section,
2010 WG and Malta (fits our tunnel)





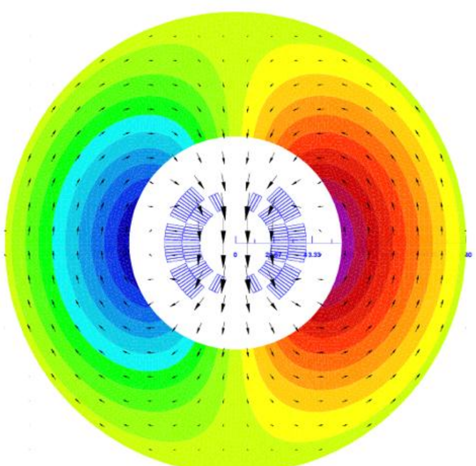
L. Rossi and E. Todesco

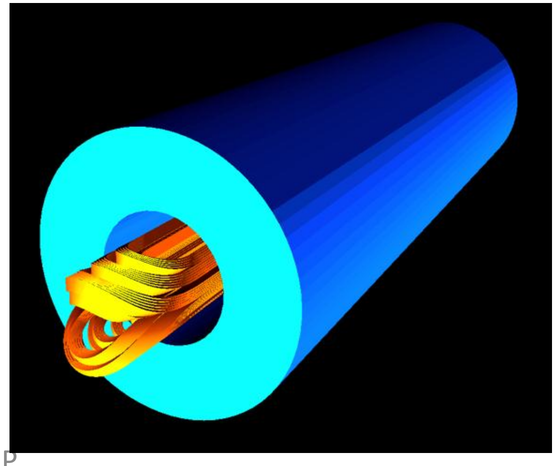
Material	N. turns	Coil fraction	Peak field	$J_{overall}$ (A/mm^2)
Nb-Ti	41	27%	8	380
Nb3Sn (high Jc)	55	37%	13	380
Nb3Sn (Low Jc)	30	20%	15	190
HTS	24	16%	20.5	380

Magnet design: 40 mm bore (depends on injection energy: > 1 Tev)
Very challenging but feasable: 300 mm inter-beam; **anticoils to reduce flux**
Approximately 2.5 times more SC than LHC: 3000 tonnes!
Multiple powering in the same magnet for FQ (and more sectioning for energy)
Certainly only a first attempt: cosϑ and other shapes will be also investigated

The EU program
The chance for HTS

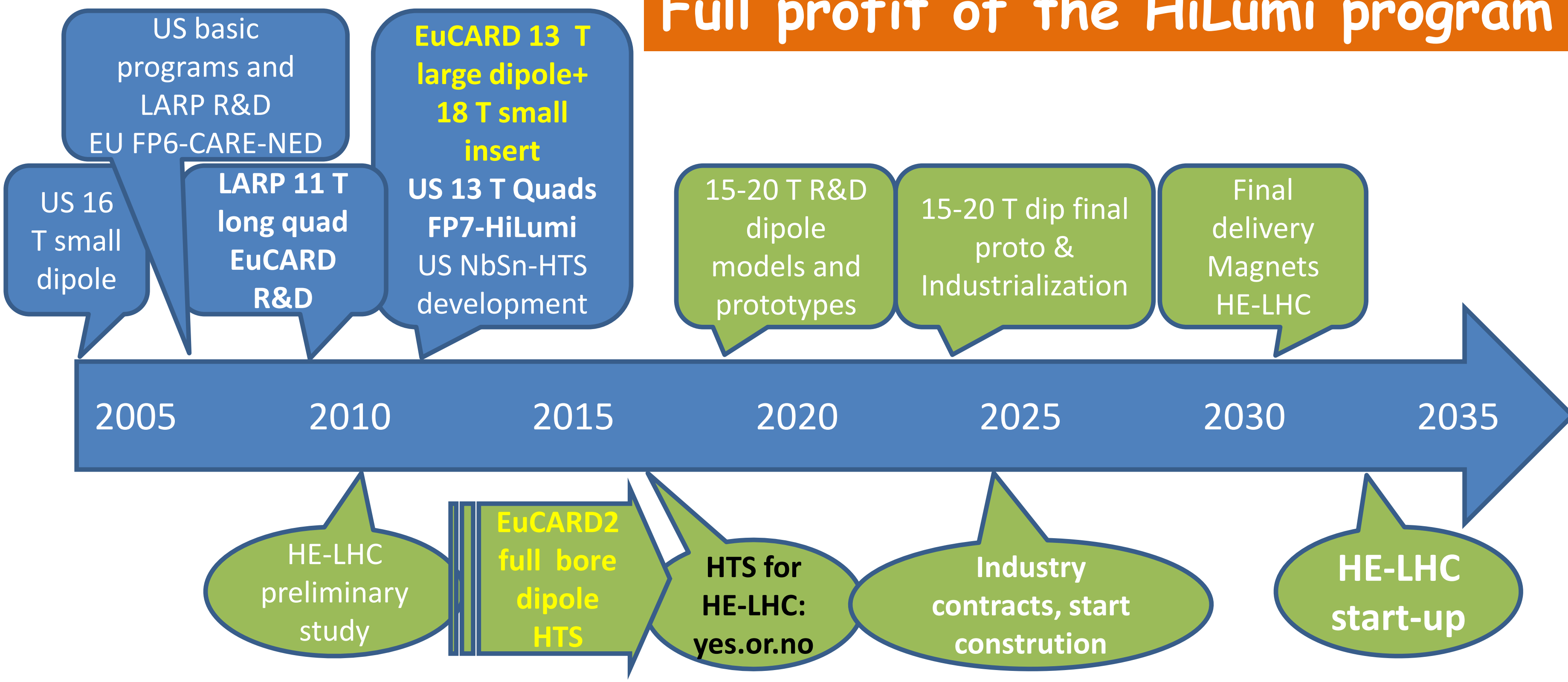
- Last FP7 call in Nov2011: EuCARD2 (2013-16)
- Approved; under negotiation for signature
- WP-10Future Magnets
  - Assessment of YBCO and Bi-2212 for HE-LHC
  - **Development of 10 kA class HTS compact cable**
  - **Prototype of a 5 T real accelerator quality magnet**
  - Test the coil in a 13-15 T background field to proof 18-20 T principle with 10 kA HTS conductor.





What is the possibile for HE-LHC?

Full profit of the HiLumi program



Other important issues (among many …)

- **Synchrotron radiation**
- 15 to 30 times!
- The best is to use a window given by vacuum stability at around 50-60 K (gain a factor 15 in cryopower removal!)
- First study on beam impedance seems positive but to be verified carefully
- Use of HTS coating on beam screen?

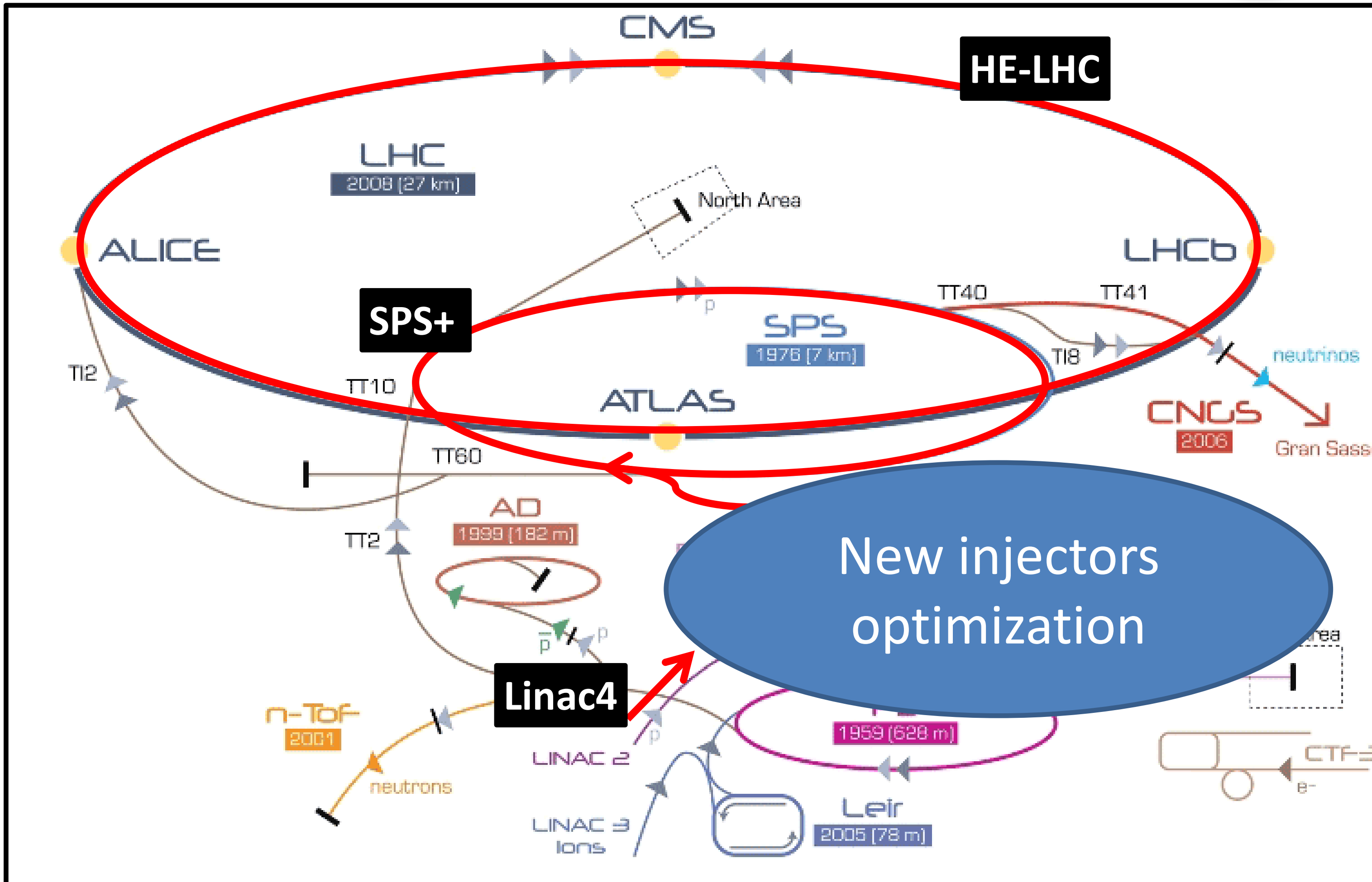
- **Beam in & out**
- Both injection and beam dump region are constraints.
- Ideally one would need twice stronger kickers
- Beam dumps seems feasable by increasing rise time from 3 to 5μs
- Injection would strongly benefit form stronger kickers otherwise a new lay-out is needed (different with or wihtout experiments)

Injector chain

- Various reason to renew
- Age! PS 80 years old by 2039
- SPS will have seen an amount of radiation well beyond its design
- **Chance to redesign the chain in synergy with other programs**
  - **Low energy physics**
  - **Neutrino**

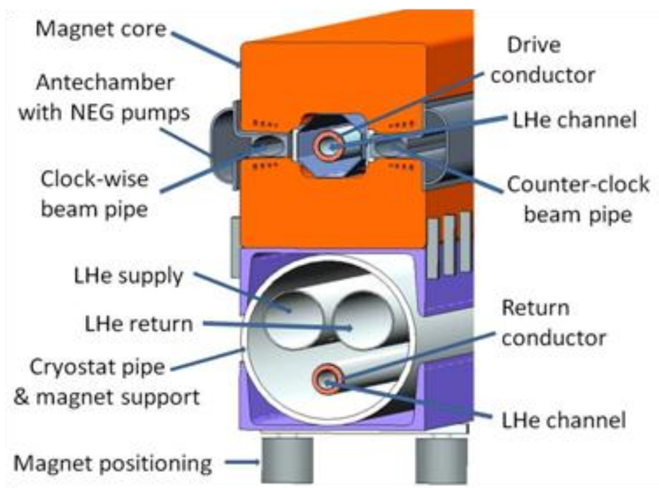
- SPS+ (1-1.2 TeV) R&D is progressing thanks to FAIR SIS300 design.
- Discorap INFN magnet, 4.5 T pulsed at 1-2 T/s, test in July : success

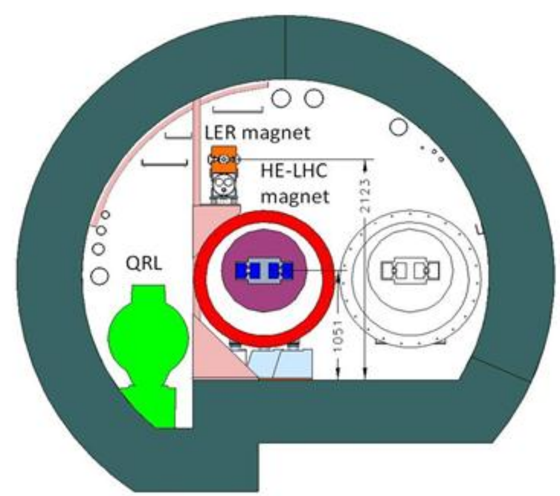
Between Linac4 and SPS+



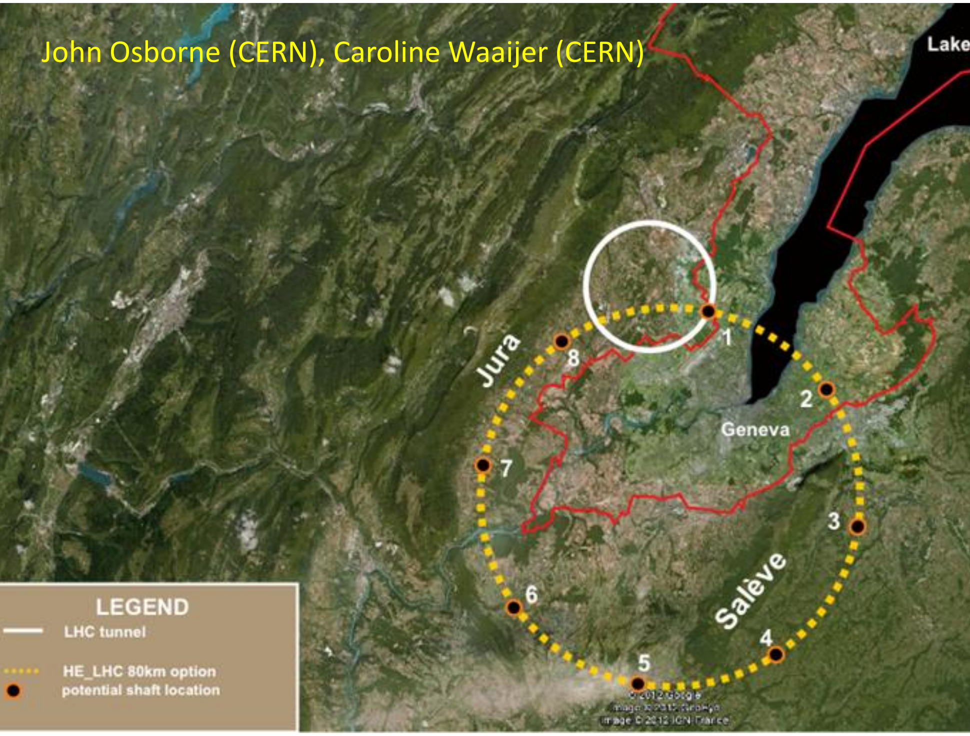
Alternate scenarios for Injectors

- Avoid touching the SPS (and its transfer lines: 6 km!)
- Install a Low Energy Ring in the LHC tunnel using superferric Pipetron magnets (W. Foster). Possible with adequate logistic and change in the experiment (workshop 2006 FP6-CARE-HHH network, revisited for LHeC ring-ring option).
- Work done in collaboration with Fermilab (H. Piekartz)





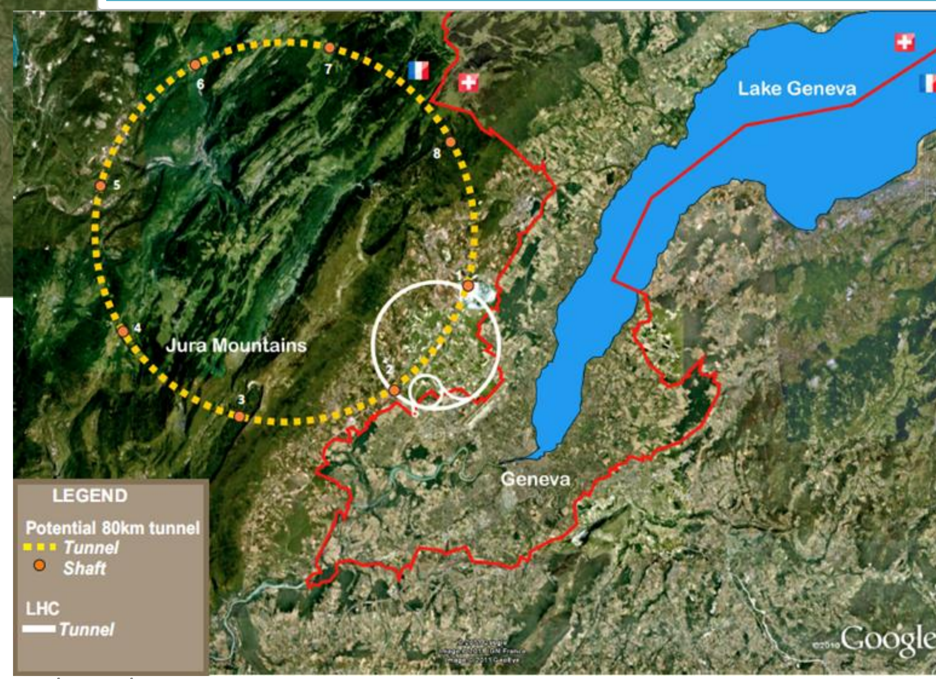
The big leap forward: a 80 km tunnel for a VLHC



Option 1 (preferred)

For a LEP300?, then for HE-LHC Optimitation could be at 16 T field level: collision **energy 80 TeV c.o.m.** Much better new infrastructure. However many costs go linearly, or more, with length. Magnet stored energy, beam energy also a concern

Whatever solution, a vigorous Magnet R&D will enable to go beyond LHC energy



Option 2