High Luminosity LHC

Program, technologies and opportunities

Isabel Bejar Alonso HL-LHC Technical coordinator

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Goal of High Luminosity LHC (HL-LHC)

The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

Prepare machine for operation beyond 2025 and up to **2035**

Devise beam parameters and operation scenarios for:

enabling a total integrated luminosity of **3000 fb^{-1}**

implying an integrated luminosity of **250 fb^{-1} to 300 fb^{-1} / year**,

design oper. for <μ> **140** (➔ peak luminosity of **5 10^{34} cm^{-2} s^{-1}**)

design equipment for 'ultimate' performance of **7.5 10^{34} cm^{-2} s^{-1}**

> Ten times the luminosity reach of first 10 years of LHC operation!!

HL-LHC Baseline Parameters

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

Parameter	Nominal LHC (design report)	HL-LHC 25ns (standard)	HL-LHC 25 ns (BCMS)	HL-LHC 50ns
Beam energy in collision [TeV]	7	**7**	7	7
N_b	1.15E+11	**2.2E+11**	2.2E11	3.5E+11
n_b	2808	**2748**[1]	2604	1404
Number of collisions at IP1 and IP5	2808	**2736**	2592	1404
N_{tot}	3.2E+14	**6.0E+14**	5.7E+14	4.9E+14
beam current [A]	0.58	**1.09**	1.03	0.89
x-ing angle [μrad]	285	**590**	590	590
beam separation [σ]	9.4	**12.5**	12.5	11.4
β^* [m]	0.55	**0.15**	0.15	0.15
ε_n [μm]	3.75	**2.50**	2.50	3
ε_L [eVs]	2.50	**2.50**	2.50	2.50
r.m.s. energy spread	1.13E-04	**1.13E-04**	1.13E-04	1.13E-04
r.m.s. bunch length [m]	7.55E-02	**7.55E-02**	7.55E-02	7.55E-02
IBS horizontal [h]	80 -> 106	**18.5**	18.5	17.2
IBS longitudinal [h]	61 -> 60	**20.4**	20.4	16.1
Piwinski angle	0.65	**3.14**	3.14	2.87
Geometric loss factor R0 without crab-cavi	0.836	**0.305**	0.305	0.331
Geometric loss factor R1 with crab-cavity	(0.981)	**0.829**	**0.829**	**0.838**
beam-beam / IP without Crab Cavity	3.1E-03	**3.3E-03**	3.3E-03	4.7E-03
beam-beam / IP with Crab cavity	3.8E-03	**1.1E-02**	1.1E-02	1.4E-02
Peak Luminosity without crab-cavity [$cm^{-2}\, s^{-1}$]	1.00E+34	**7.18E+34**	6.80E+34	8.44E+34
Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2}\, s^{-1}$]	(1.18E+34)	**19.54E+34**	18.52E+34	21.38E+34
Events / crossing without levelling w/o crab-cavity	27	**198**	198	454
Levelled Luminosity [$cm^{-2}\, s^{-1}$]		**5.00E+34**	5.00E34	2.50E+34
Events / crossing (with levelling and crab-cavities for HL		**138**	146	135
Peak line densit		**1.25**	1.31	1.20
Levelling time [h		**8.3**	7.6	18.0

LIU required

Impedance, efficiency etc.

ATS required

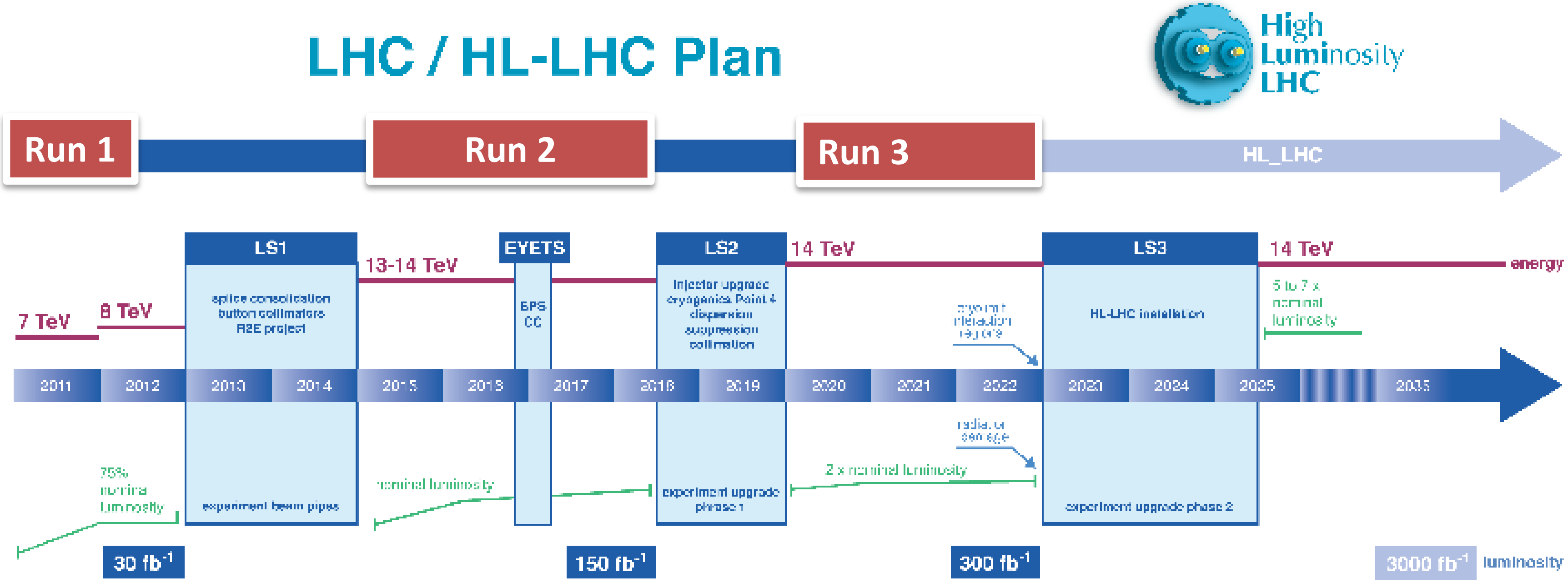
Crab Cavity required

Leveling required

Efficiency requires long fill times (ca. 10h)!

Collision values

HL-LHC Plan



As much work as compatible with LIU, maintenance, consolidatina and Experiments upgrade

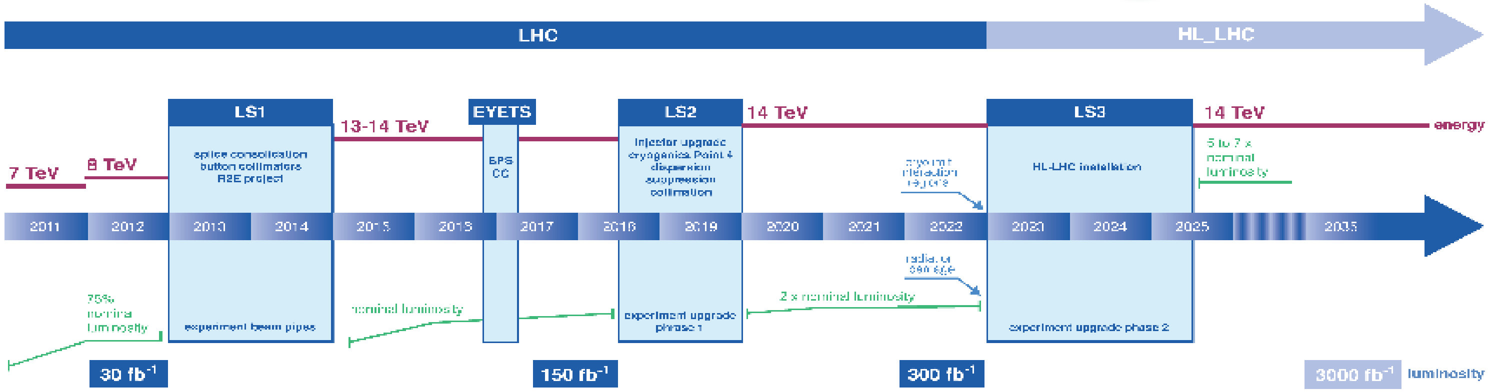
Work programme

HL- LHC Project will need (2014 – 2023)

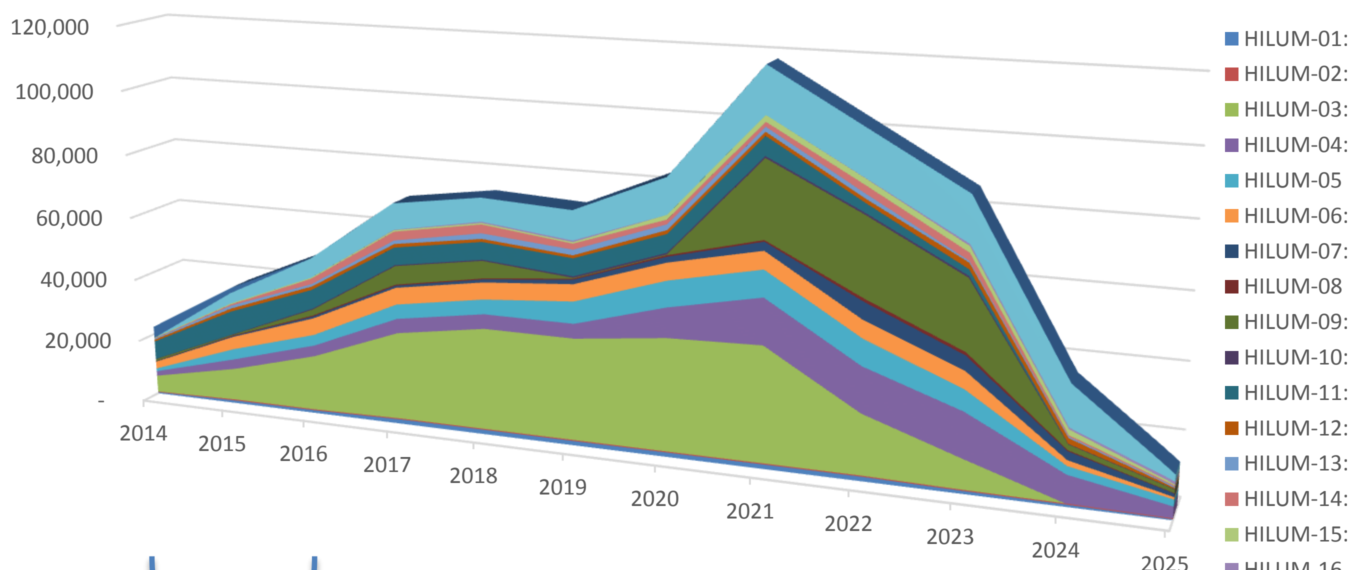
- Magnets
- RF Cavities
- Collimators
- Cold Powering (HTS superconducting links, power converters)
- Machine Protection & Magnet QPS
- Collider-Experiment Interface
- Cryogenics
- Energy Deposition & Absorber
- 11-T Magnet
- Vacuum
- Beam Diagnostics
- Radiation resistant solid state switches for kicker magnets
- Integration and (de-)installation
- Hardware commissioning
- Infrastructure, Logistic and Civil Engineering

HL-LHC

LHC / HL-LHC Plan

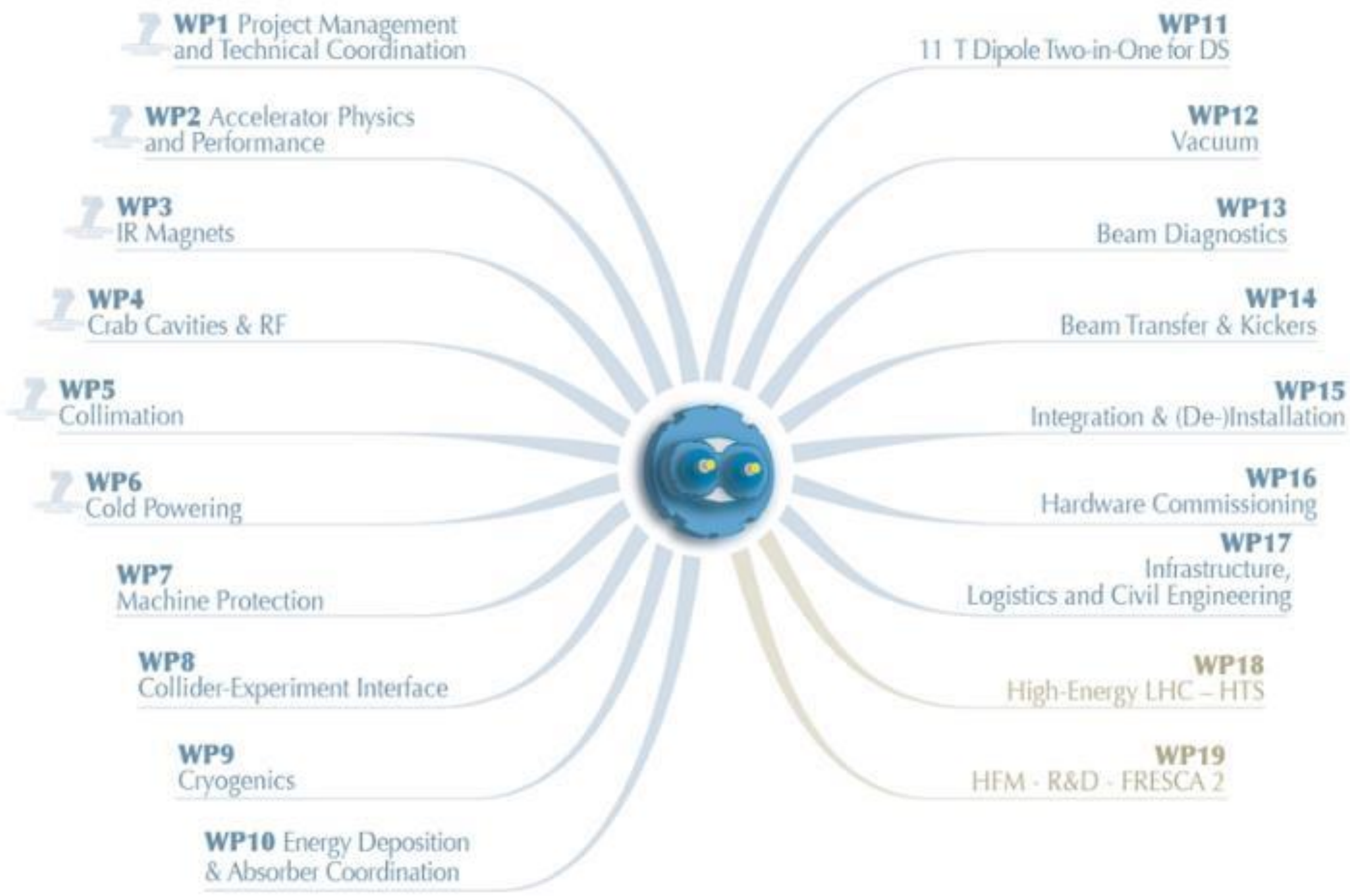


Budget allocation by WP



R&D and prototyping

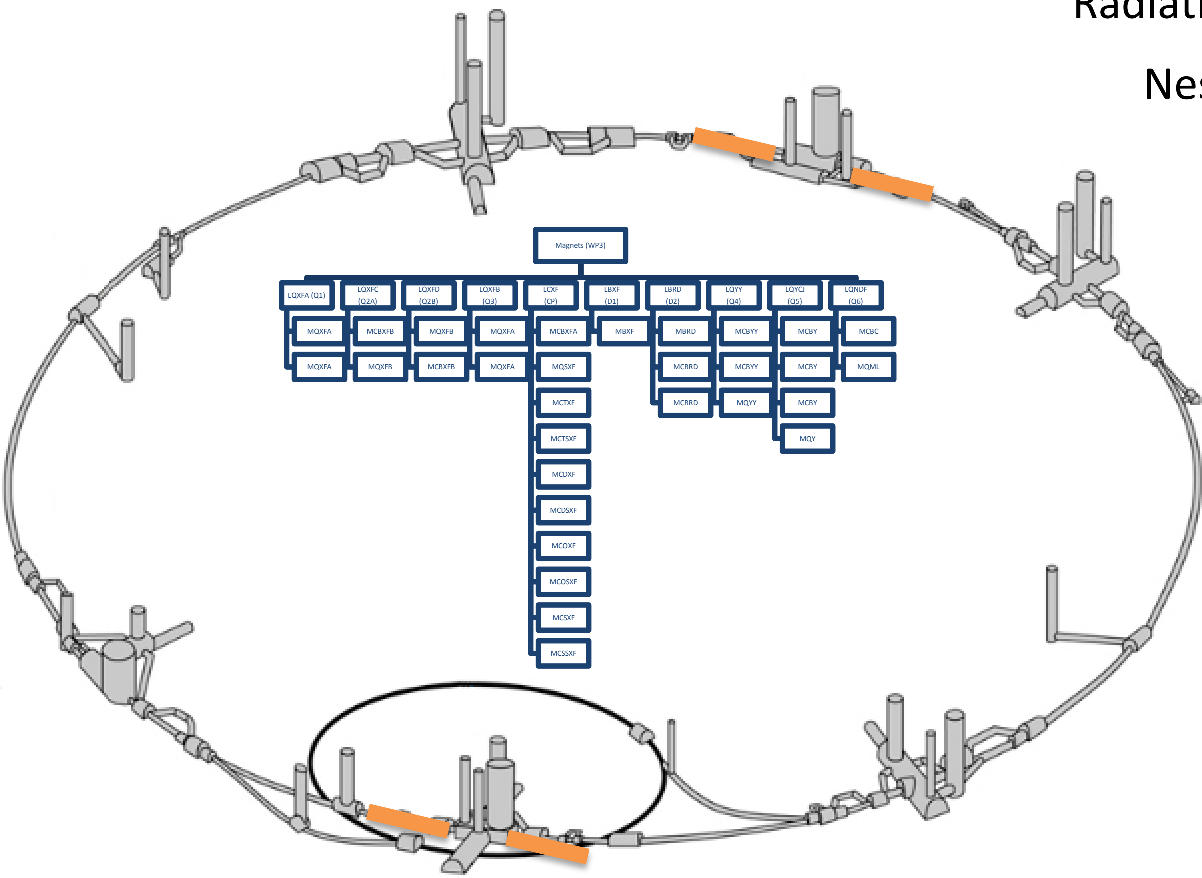
HL-LHC Work Packages



Performance improvement, increase availability ,radiation damage mitigation, ALARA ….

High Luminosity LHC Participants today

WP3 – IR Magnets - Why



Radiation damage regime of

Nested corrector magnets 300 fb^{-1}

IT quadrupoles 700 fb^{-1}

Replacement coupled with:
- Increase quadrupole aperture
- Redesign of quadrupoles, corrector package, D1 and D2
- New electrical feedbox to remove senstive equipment from the tunnel and reduce the amount of human interventions near the triplet

More tan 20 different types of magnets

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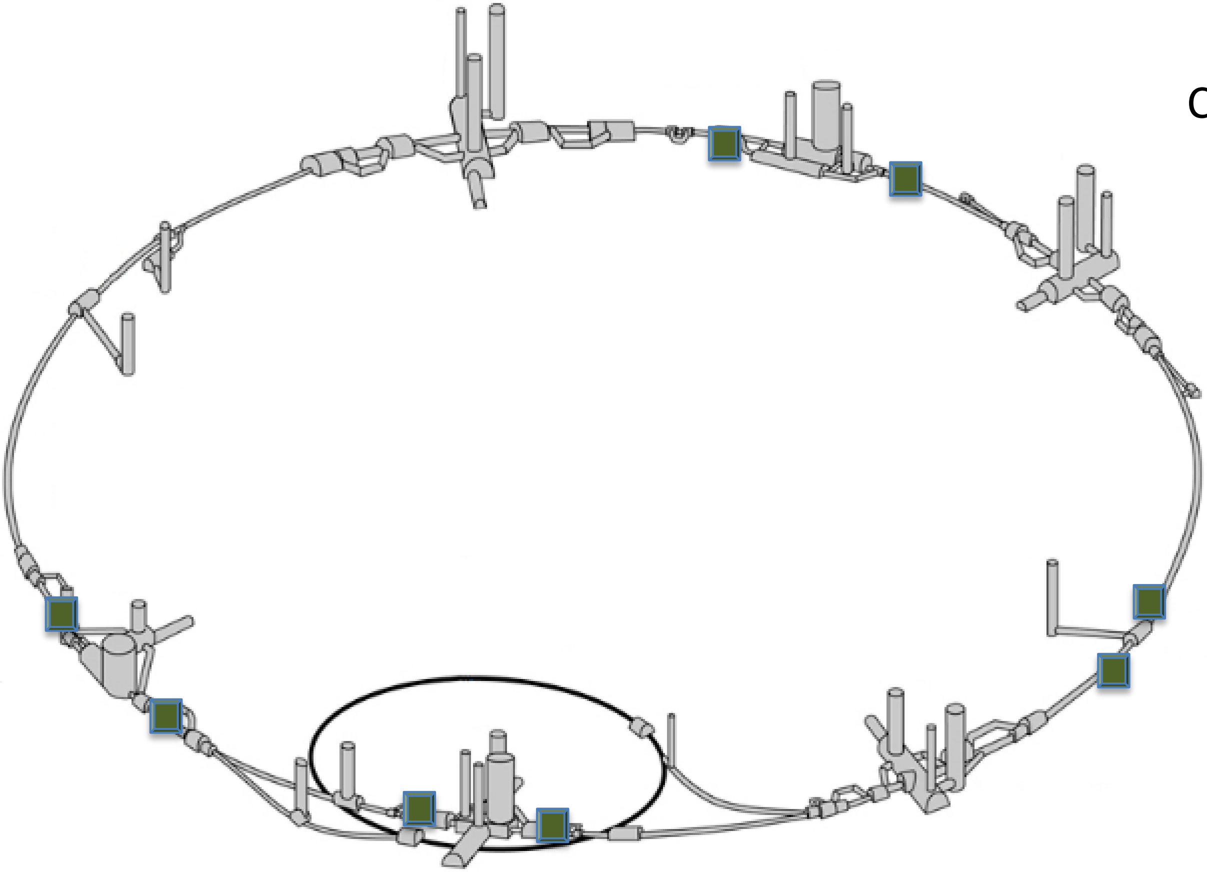
WP11 – 11 Magnets DS - Why

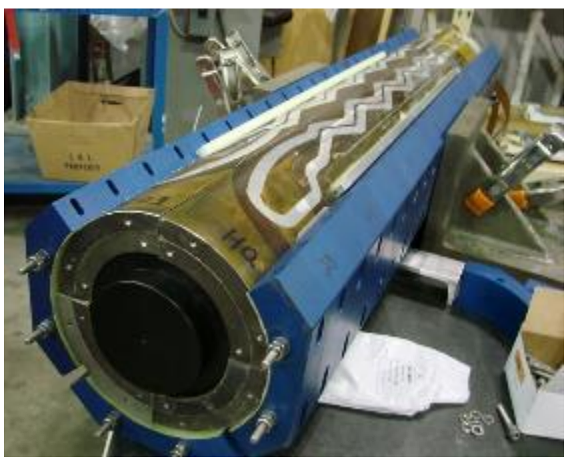


Create space for the installation of collimators in the dispersion suppressors

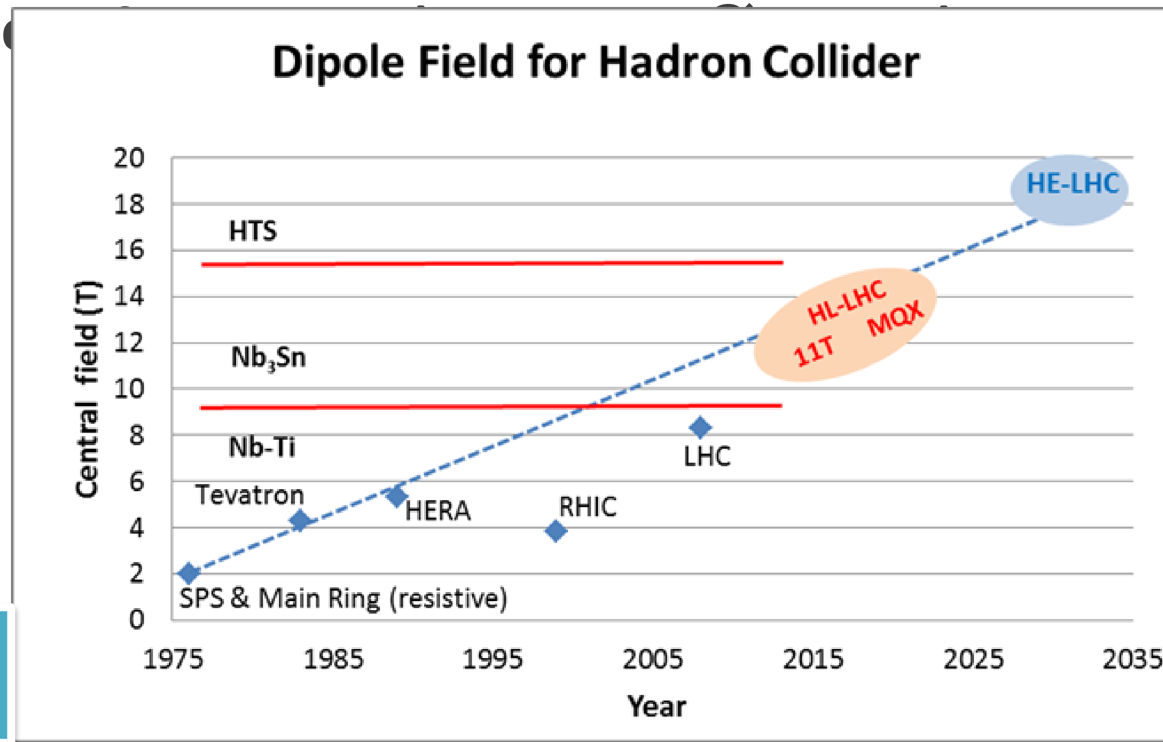
Critical for reaching maximum ion luminosity

Magnet technology **jump**

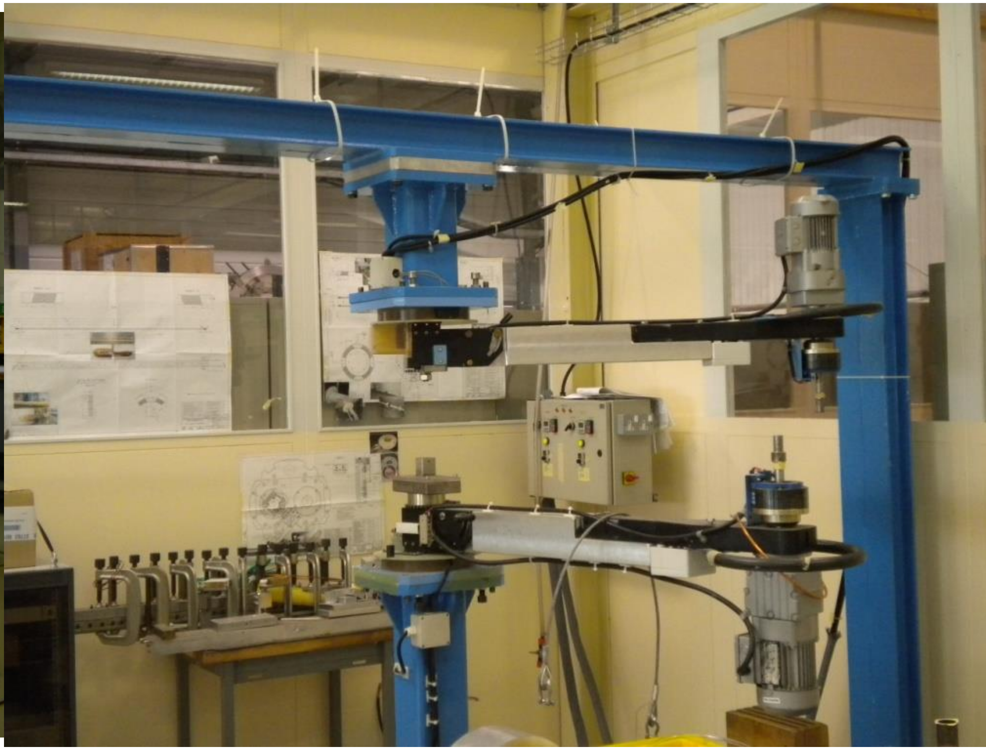
- **LHC is already very pushed**
- **Passing from 8 T to 11 T in 2018 in LHC dipoles (cryocollimators)**
- **Passing to 12-13 T in IR Triplet: ∅140 mm!!**
- **But even more ambiti**



12 T magnet developed in the USA by LARP



Technology for new magnets: precision machines, with movements, automatized,



3 Rotating winding machine for coil up to 3 meters of length

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Coil Curing

Sc coil with specially machiend insulators (5-axis machine)
Accuracy of the winding: 20 μm!

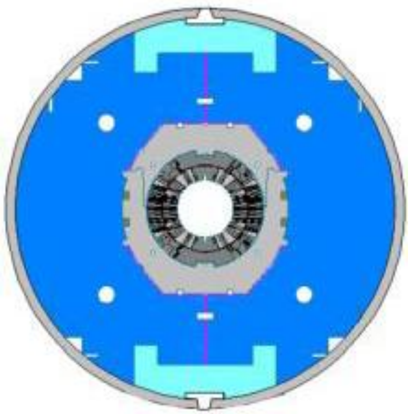
2 curing presses : tooling precise at 20 μm and 200 °C.

Magnet Assembly

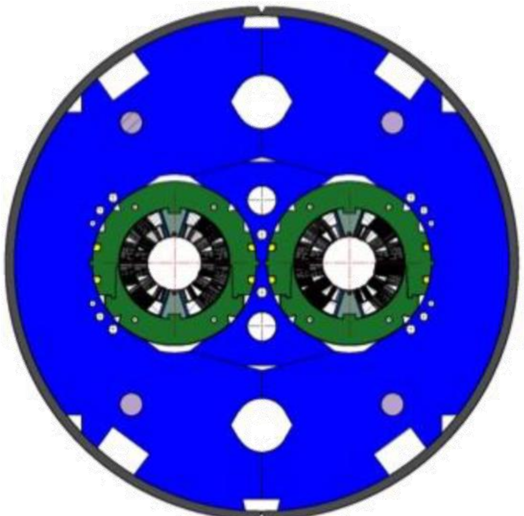
2 collaring presses. Precision mechanics under large forces with high pressure precisom hydraulics, precision sensor, automatization

New technology Nb_3Sn 11T Dipole: soon under construction also at CERN

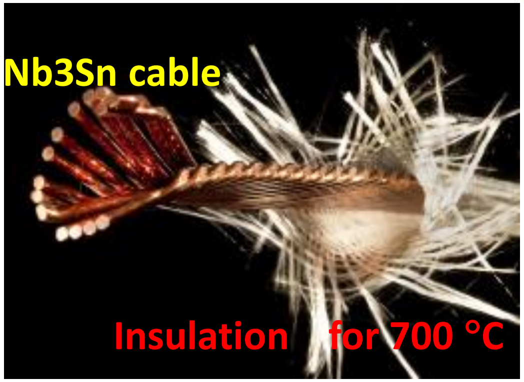
Single aperture model



Twin aperture model



Fermilab



Automatized precision tooling with advanced sensoring

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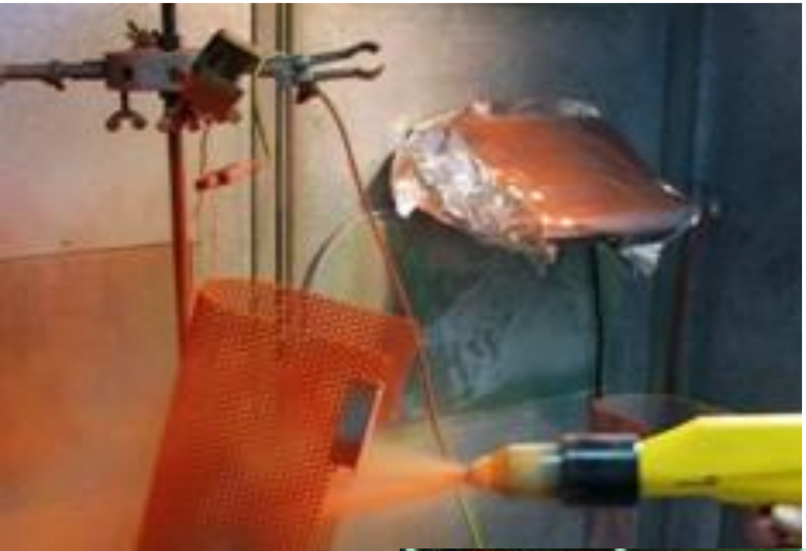
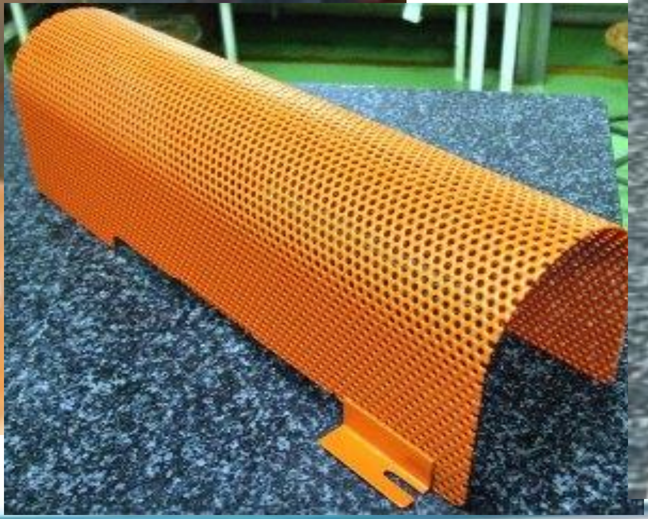
Polymers laboratories activity for which we may have industrial partnership

Electrostatic paint



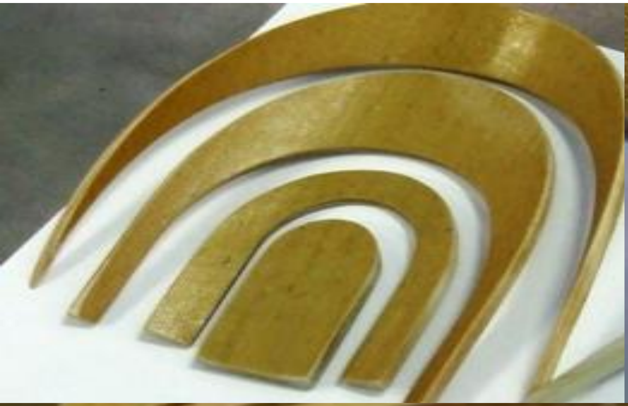


The epoxy paint have an insulation and radiation protection of 30KV for 0.5mm thickness

Polymers laboratories activity

3D printer

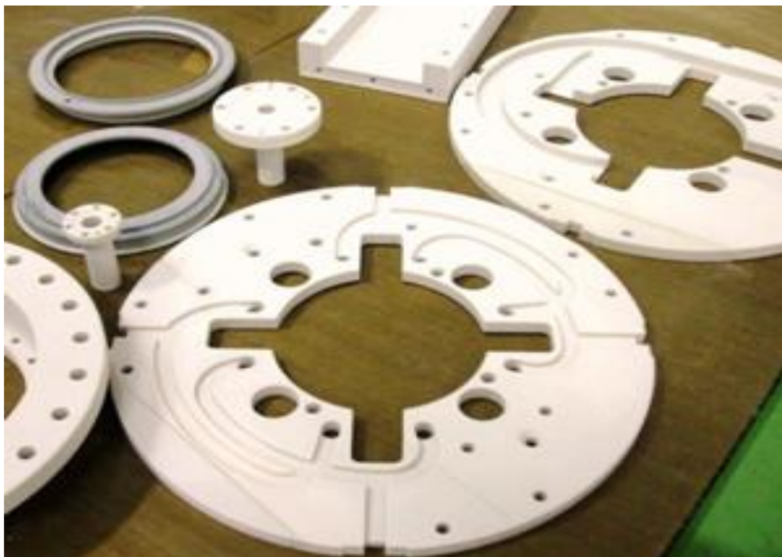
Head pacer for new prototype made with the 3D printer are impregnated with the cyanate ester resin and reinforced with glass fiber to obtain the desired mechanicals properties due to the thin wall thickness



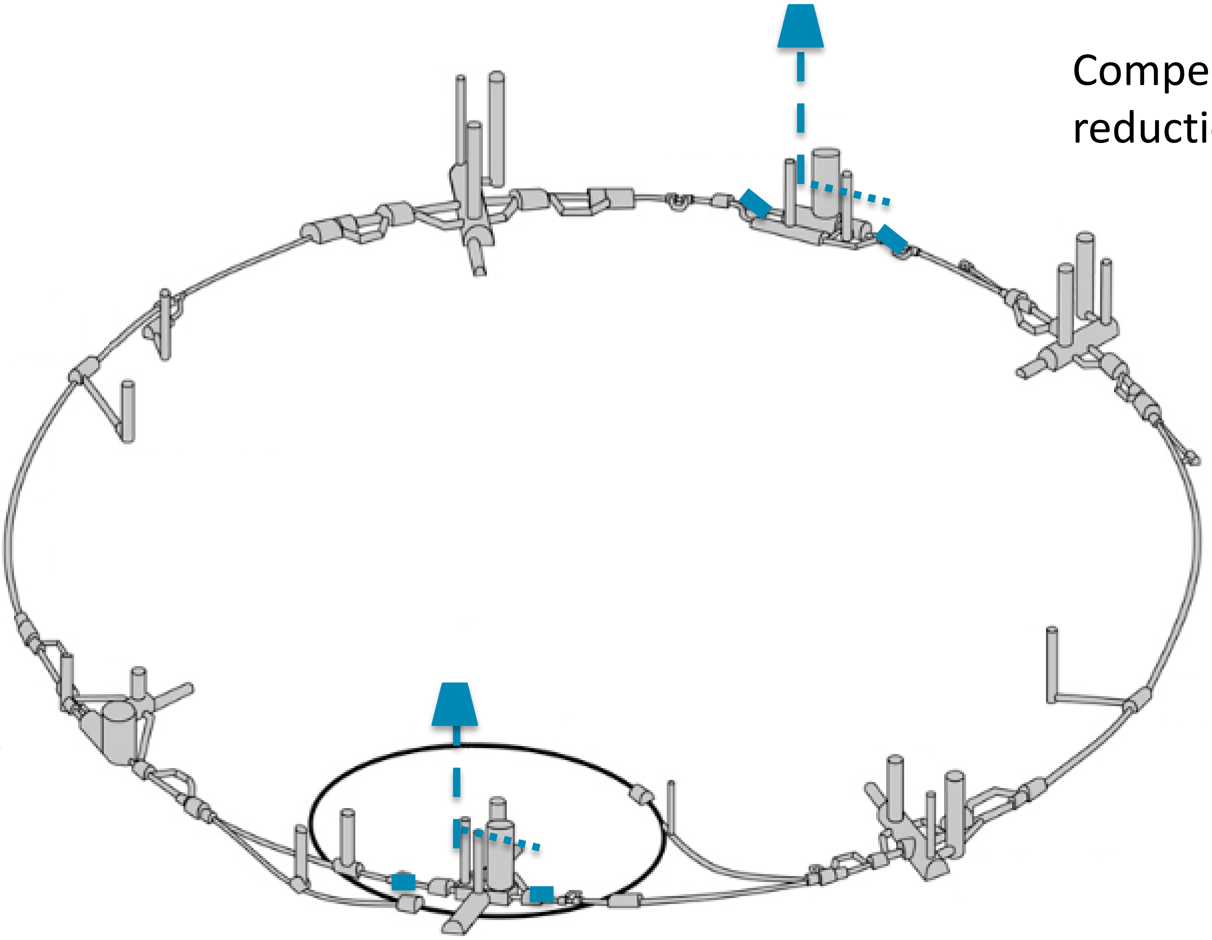
Needed for cryogenic devices in special insulation materials (accuracy 0.1 mm)

Several different pieces made on the 3 D printer and impregnated were used to check the design.

3D printer



WP4 – Crab cavities & RF - Why



Compensate for the geometric reduction factor

Option

Possibility of using them to rotate the beam in the crossing plane and to deflect in the ortogonal plane (crab kissing scheme)

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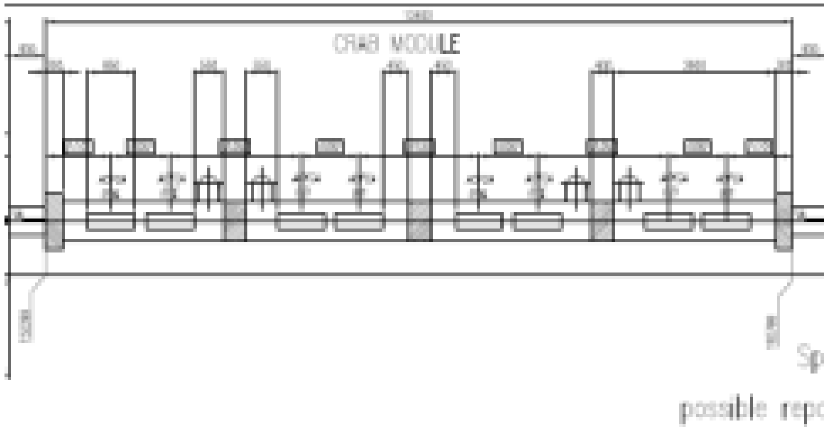
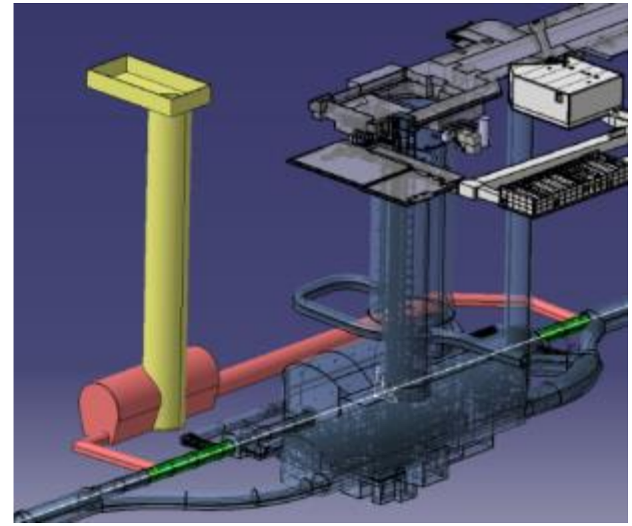
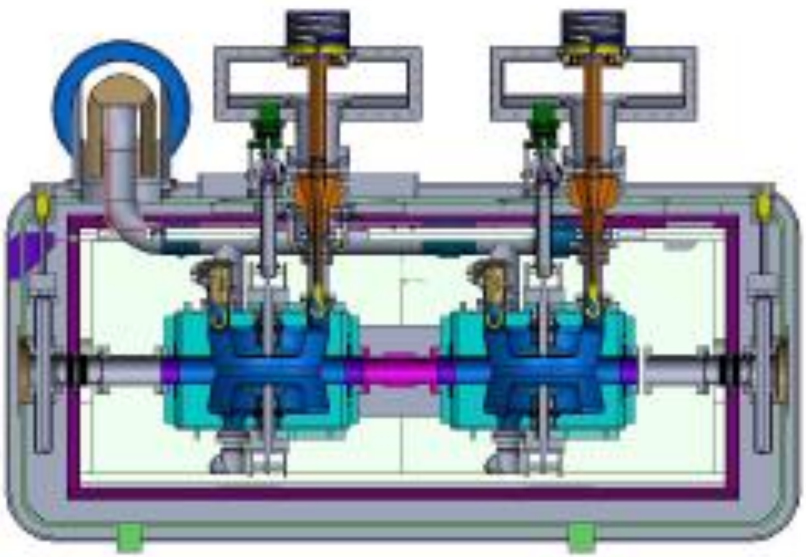
IR1-IR5 Between D2 and Q4 and Surface

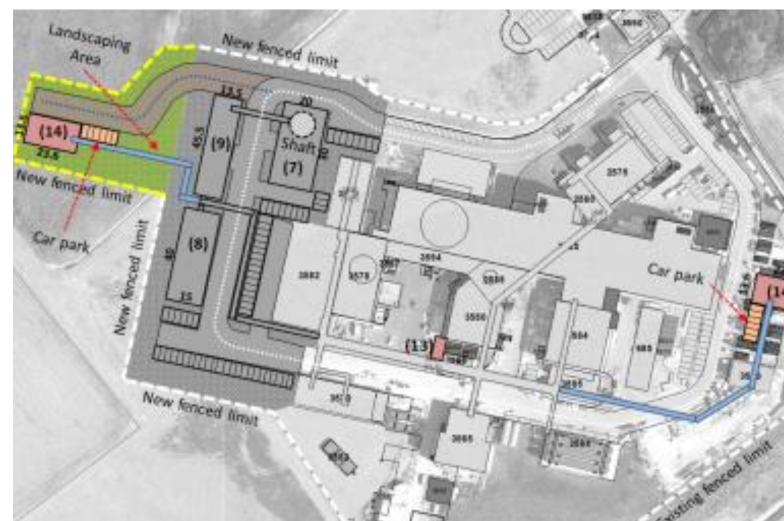
ATLAS
CMS



C4.R5







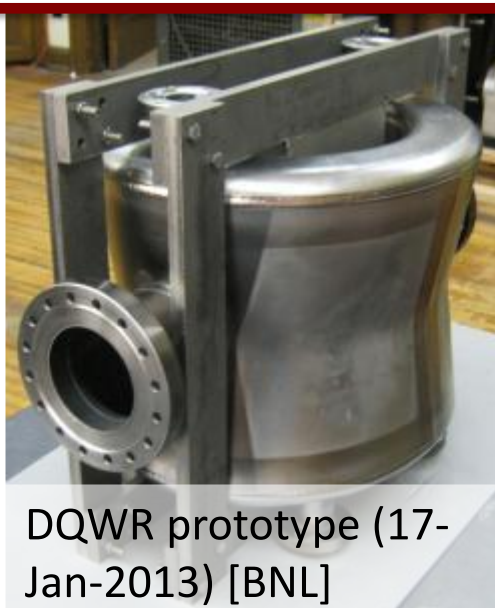
Courtesy of R. Calaga, O. Capatina & P. Fessia

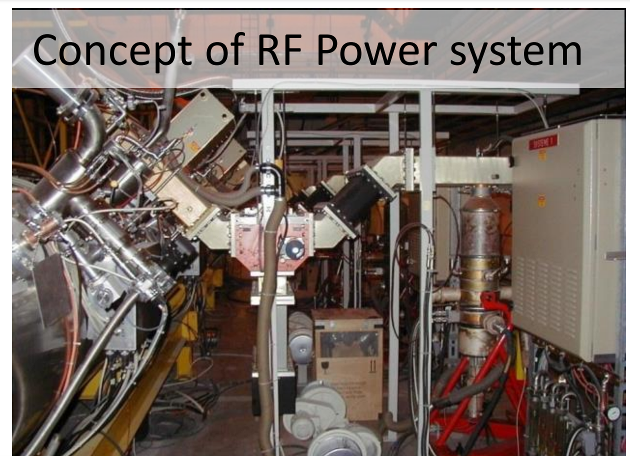
Development of Crab Cavity prototypes


RF-Dipole Nb prototype [ODU-SLAC]


4-rod in SM18 for RF measurements [Lancaster UK]


4-rod prepared for rinsing @ CERN


DQWR prototype (17-Jan-2013) [BNL]


Concept of RF Power system

Technology for SC RF cavities

Electron-beam welding of body and end plates

End plates stamped out of sheet metal

Cu to Nb

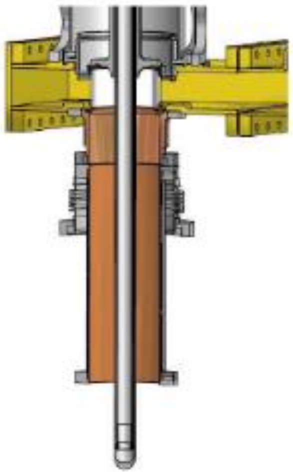
Beam pipe and other ports pulled out (ball rolling)
Welding of brazed beam pipes onto end-plates

Brazed stainless steel
conflat flanges

Electronics and Power supplies

RF Power

Courtesy E. Montesinos

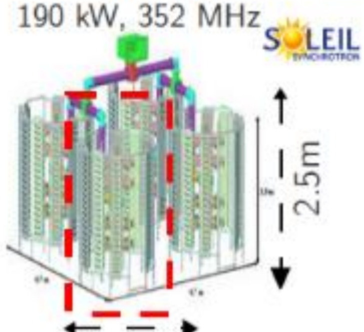


- 50 kW/cavity, moderate power
  - Simplified (modified) LHC coupler
  - Redesign of the vacuum-air ceramic (?)
- RF Power
  - Three choices (Tetrodes, IOTs, SSA)
  - Not a big challenge, but opportunity to use new tec

Tetrode (SPS)
400 MHz, ~50kW

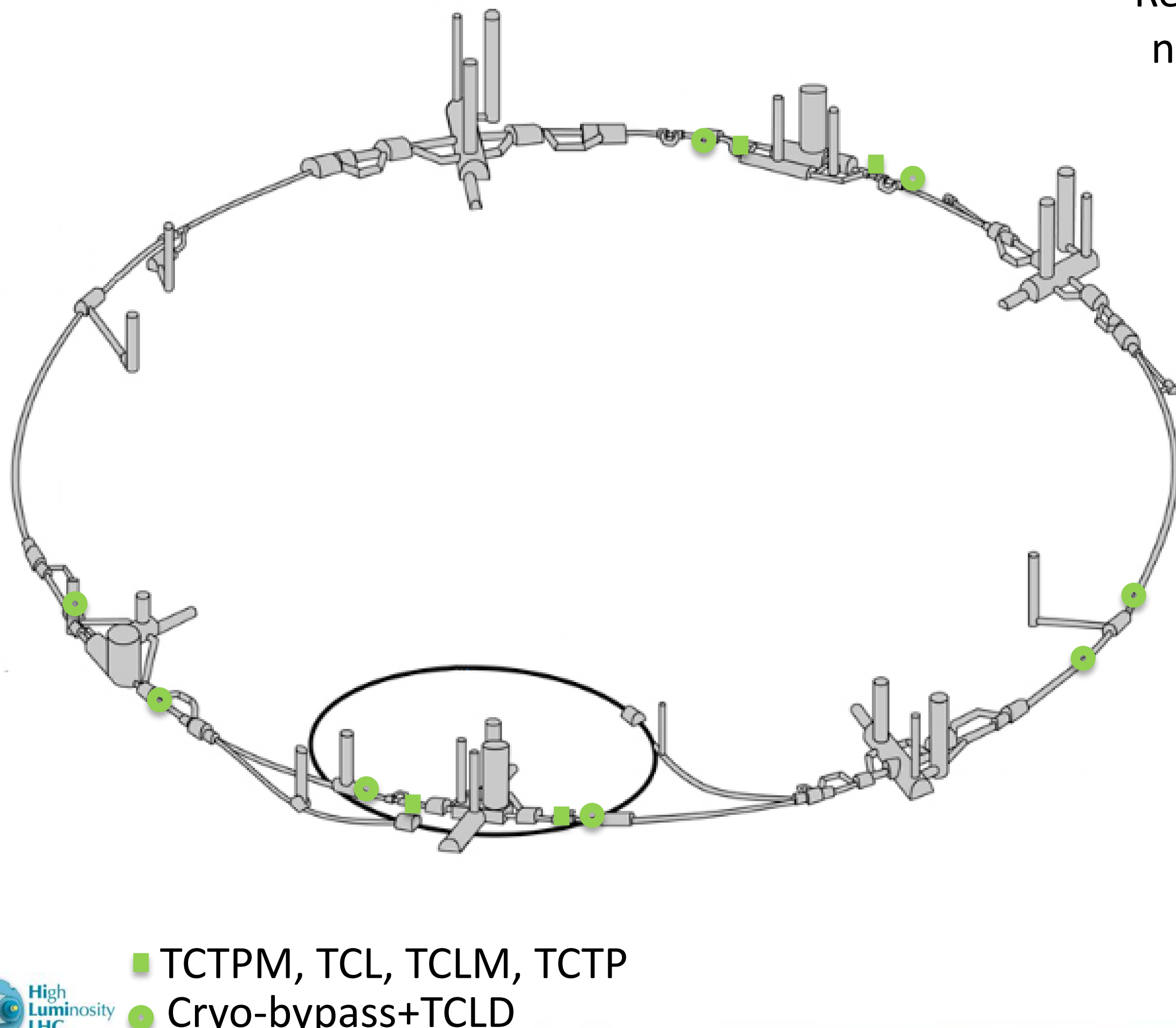
IOTs (TV Transmitter)
Light Sources

Solid State Amplifiers
190 kW, 352 MHz



Single tower < 3m

WP5 – Collimation- Why



Reduction of impedance may be needed if beam instabilities are triggered at intensity close to nominal

Protection of the new triplet

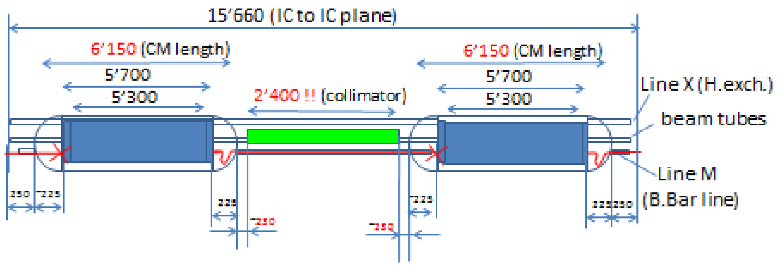
Collimation in dispersion suppressors

Replacement in other regions must be assessed during Run 2

High Luminosity LHC

Collimation

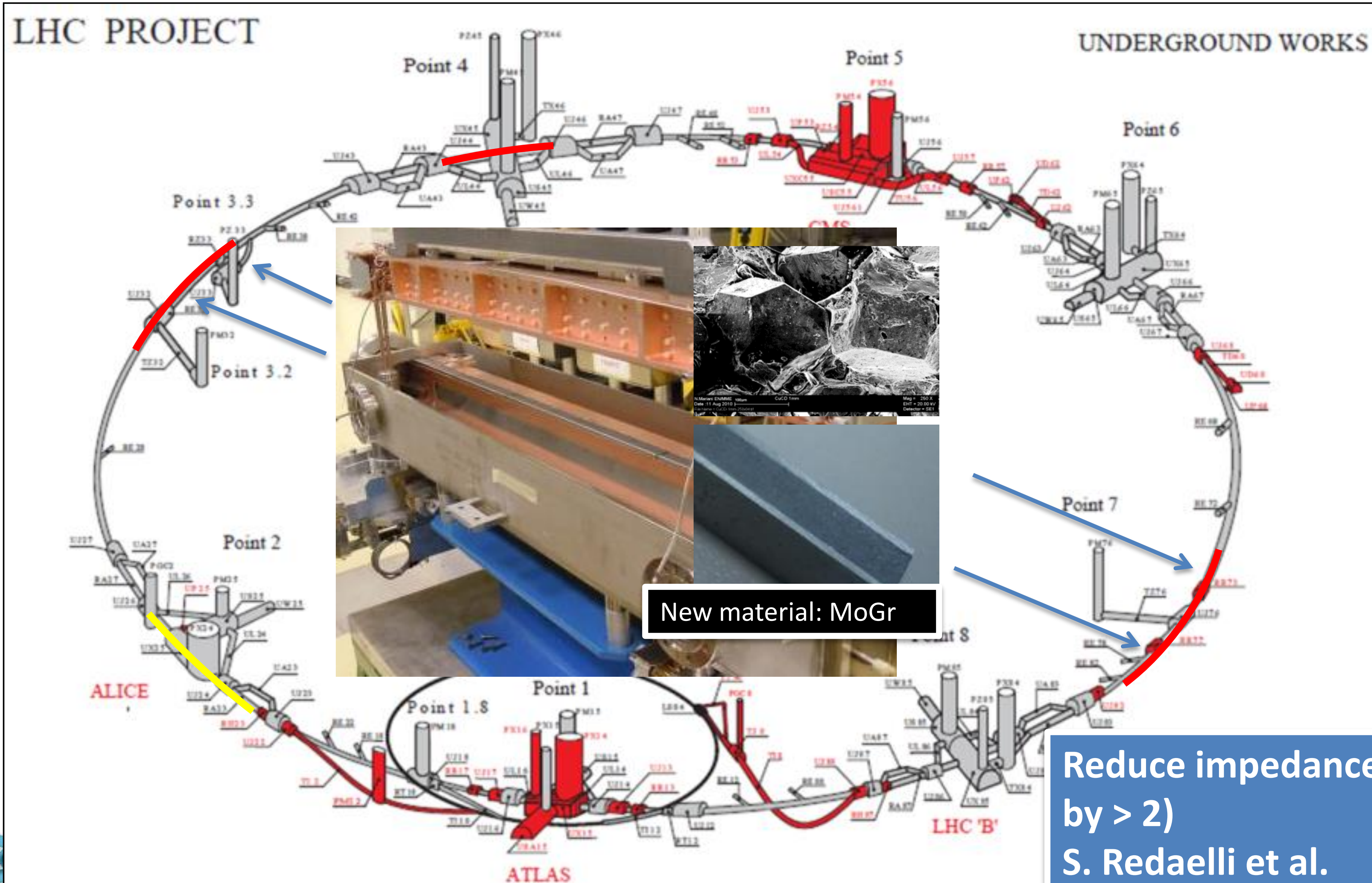
Longitudinal layout (Option 3)



Collimator space reduced by 600 mm (w.r.t option 2)

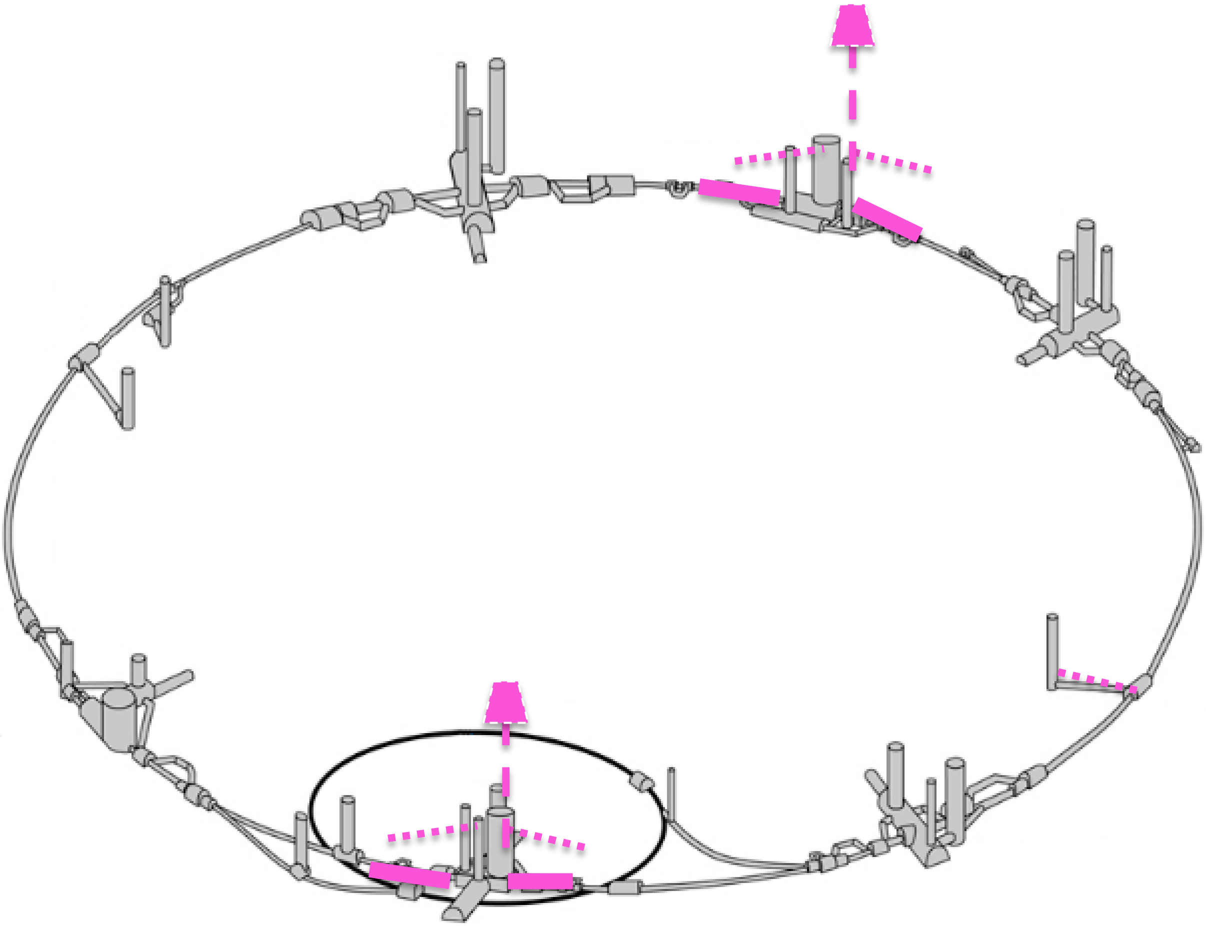
First cold catcher tested FAIR 2011

Low impedence collimators(LS2 & LS3)



Reduce impedance by > 2)
S. Redaelli et al.

WP6 – Cold powering - Why



Move power converters and DFBs to radiation free zones to reduce/eliminate dose to personnel and to equipment

Under study need to remove powering of the arc magnets in IR1-IR5

Possibility of moving power converters in P1 and P5 to parallel tunnel radiation free

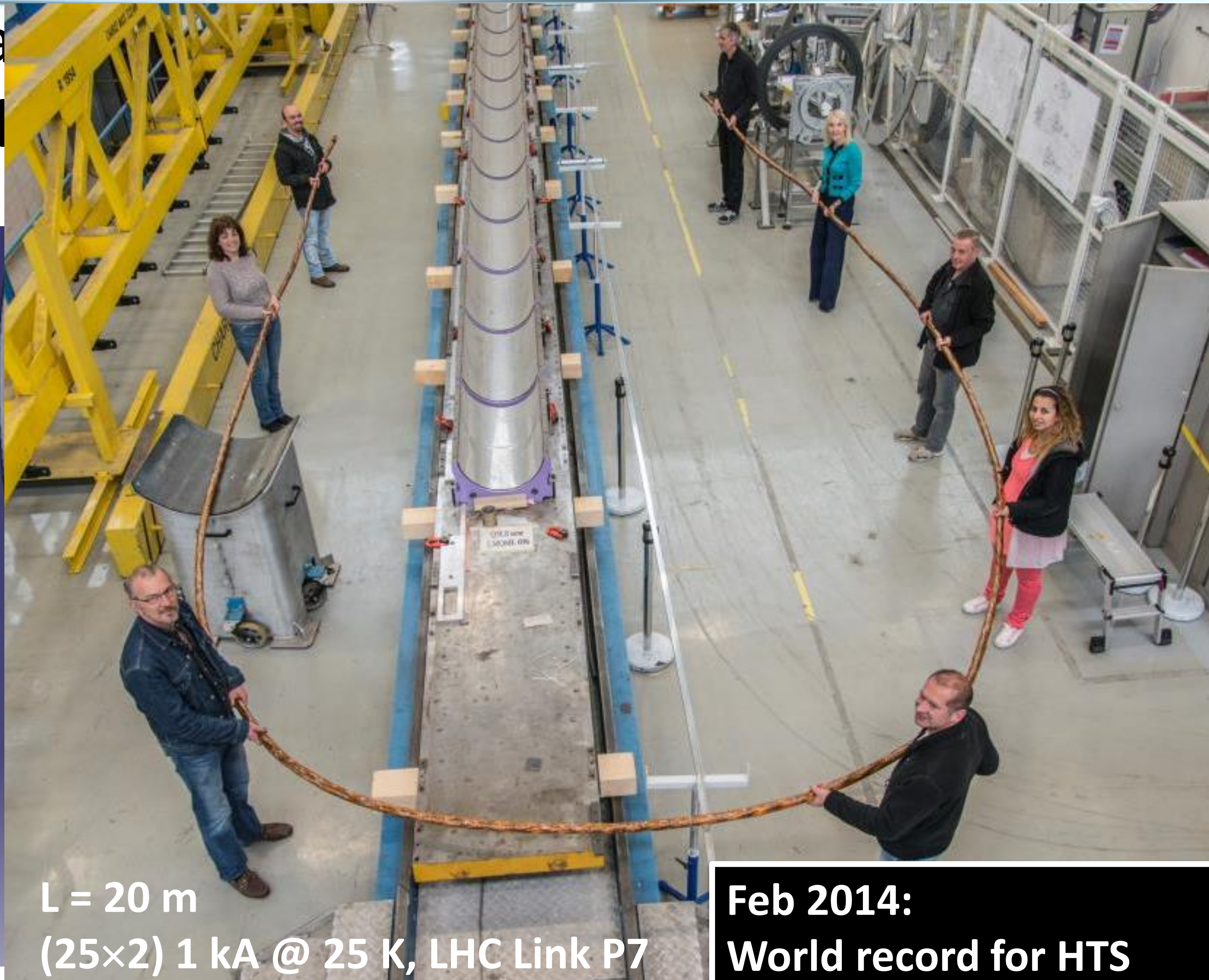
Flexible cryostats and many croygenic equipment, controls, valves, etc…

Supraleitendes LTS-Kabel für die Fusionsforschung in Japan (NIFS)
Superconducting LTS cable for Fusion Science in Japan (NIFS)

Photo courtesy of Southwire

Ava

SC I



L = 20 m

(25×2) 1 kA @ 25 K, LHC Link P7

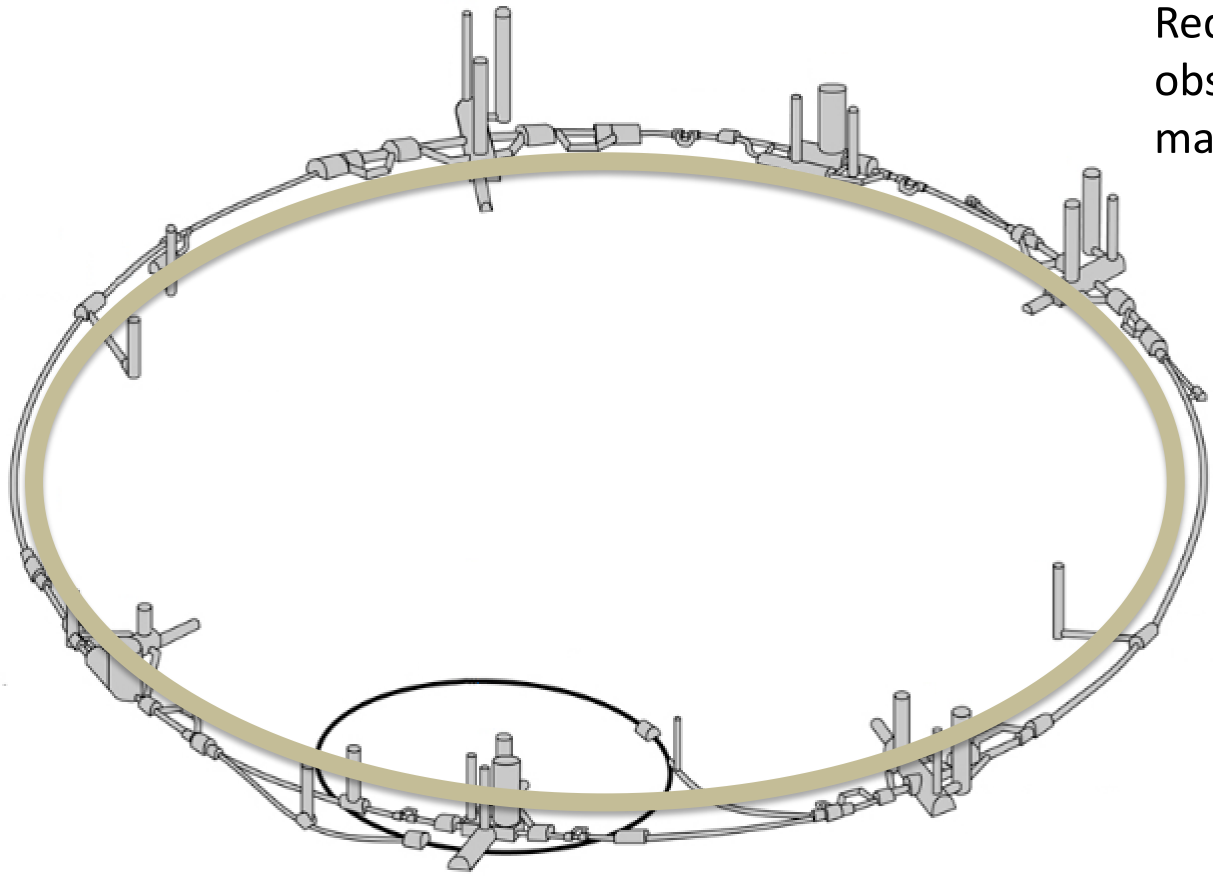
S3

3

S

Feb 2014:
World record for HTS

WP7 – Machine protection- Why



Redundancy, flexibility, … of obsolescent QPS and other machine protection systems

Adapt to fast events such as crab cavities failures or UFOs

Protection of new components

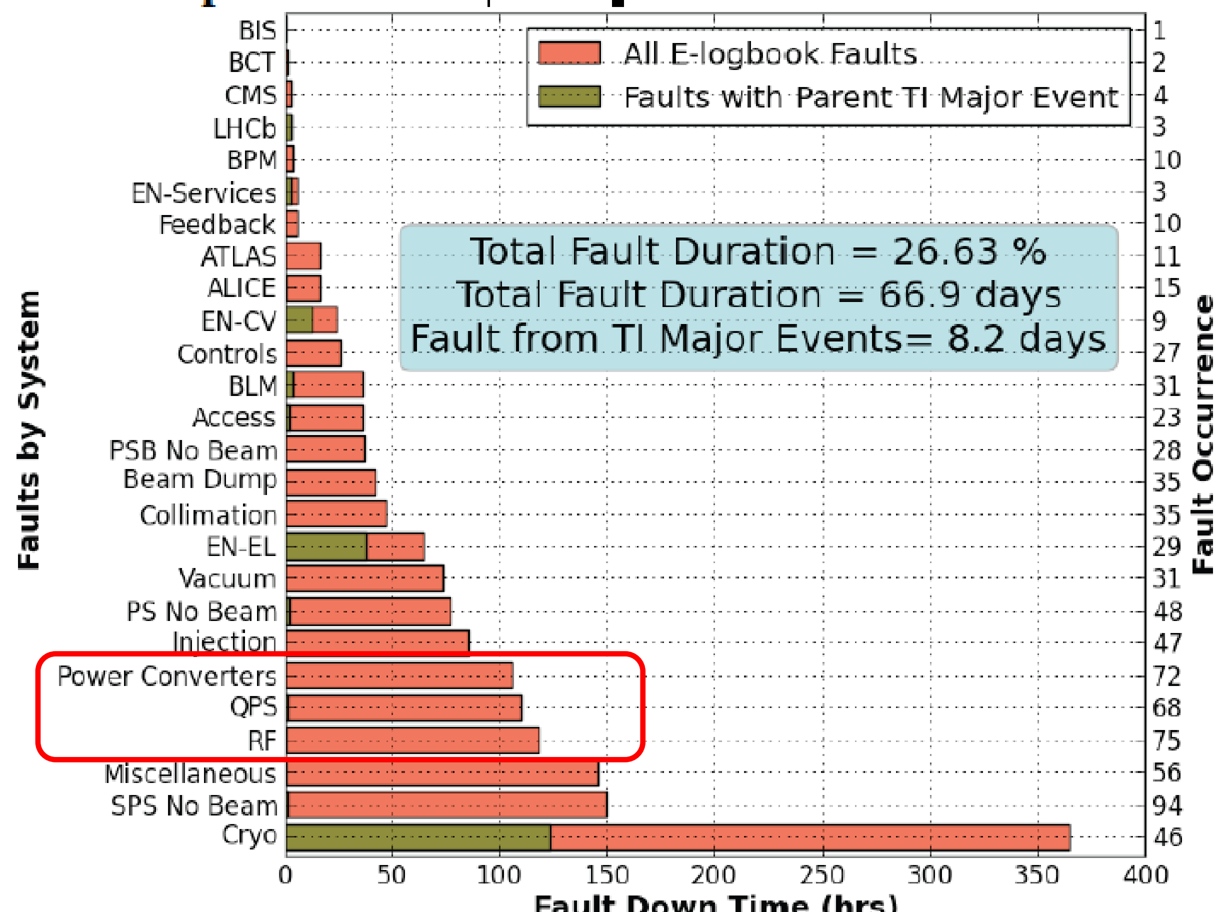
Partly required also without upgrade

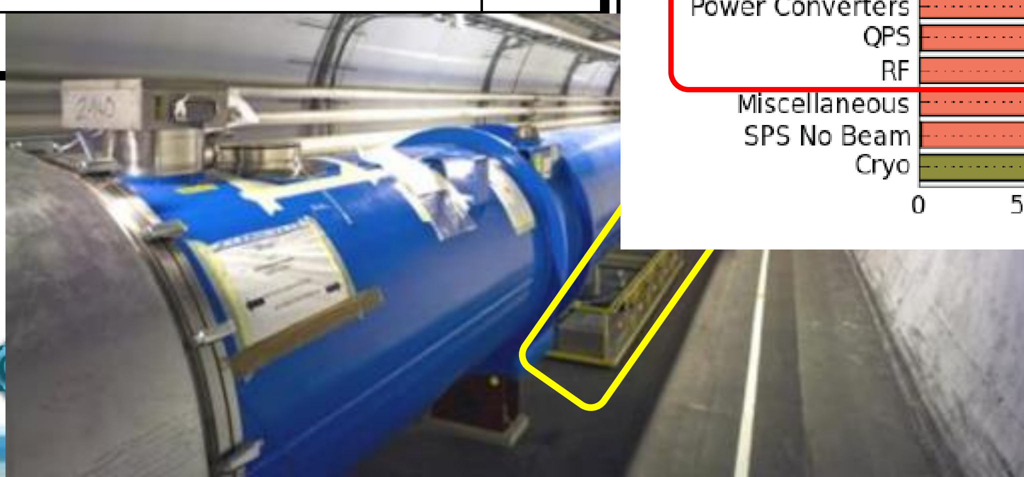
High Luminosity LHC

HL-LHC Challenge: Machine Efficiency

Dump Cause	#
Beam: Losses	58
Quench Protection	56
Power Converter	35
Electrical Supply	26
RF + Damper	23
Feedback	19
BLM	18
Vacuum	17
Beam: Losses (UFO)	15
Cryogenics	14
Collimation	12

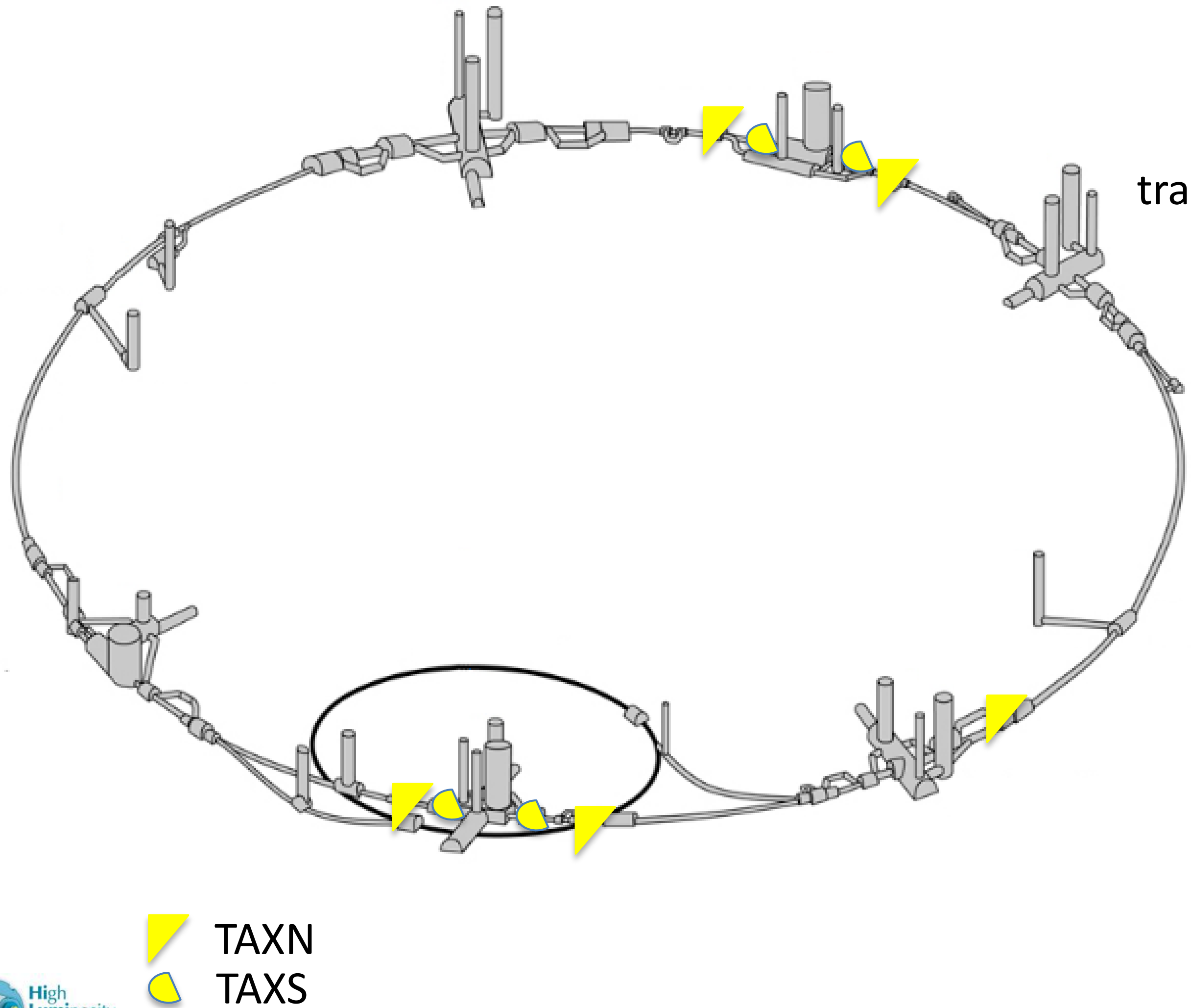
Dump Cause	#





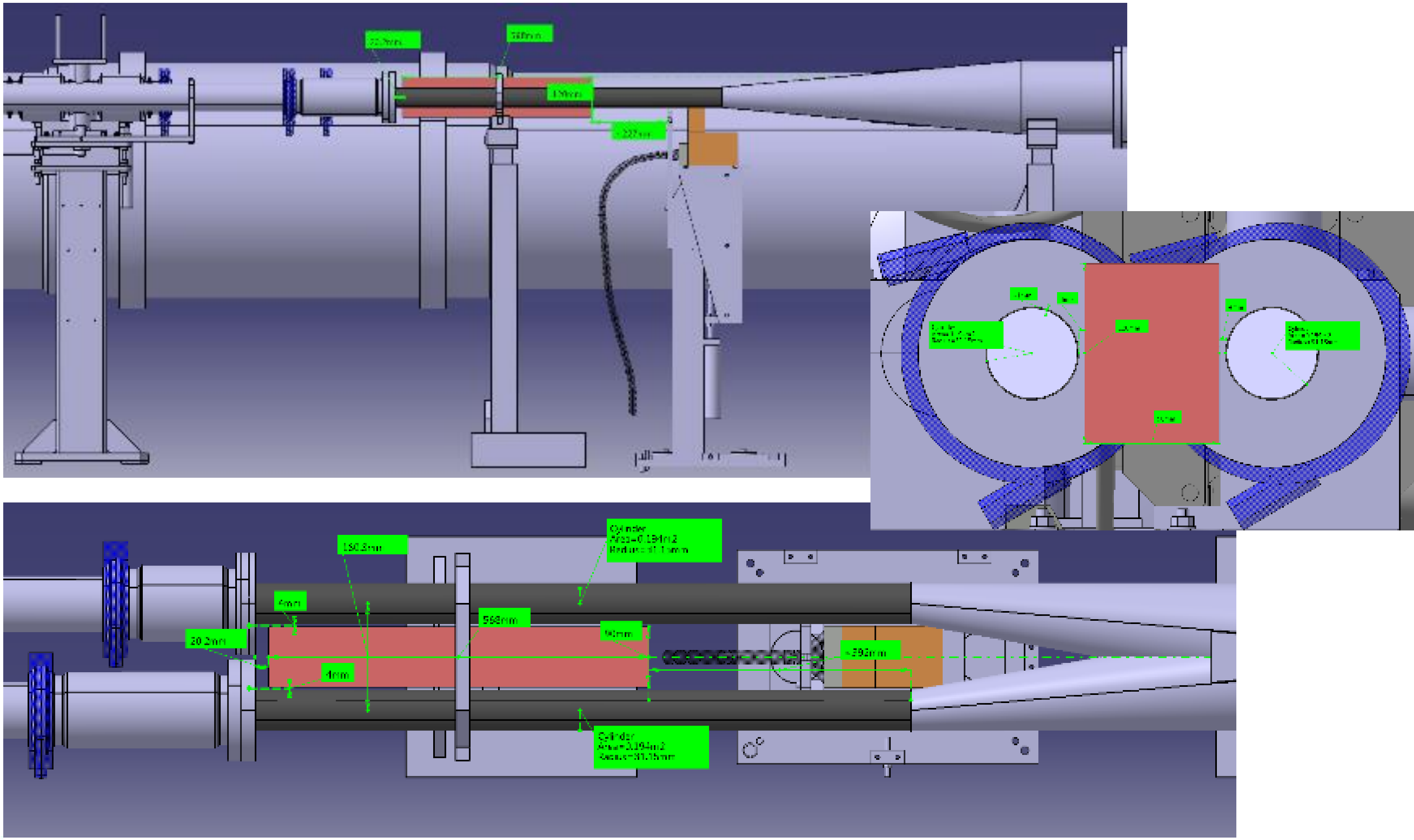
Consolidation of infrastructure !
But also new paradigme: remove as much as possible from the tunnel

WP8 – Collider experiment interface - Why

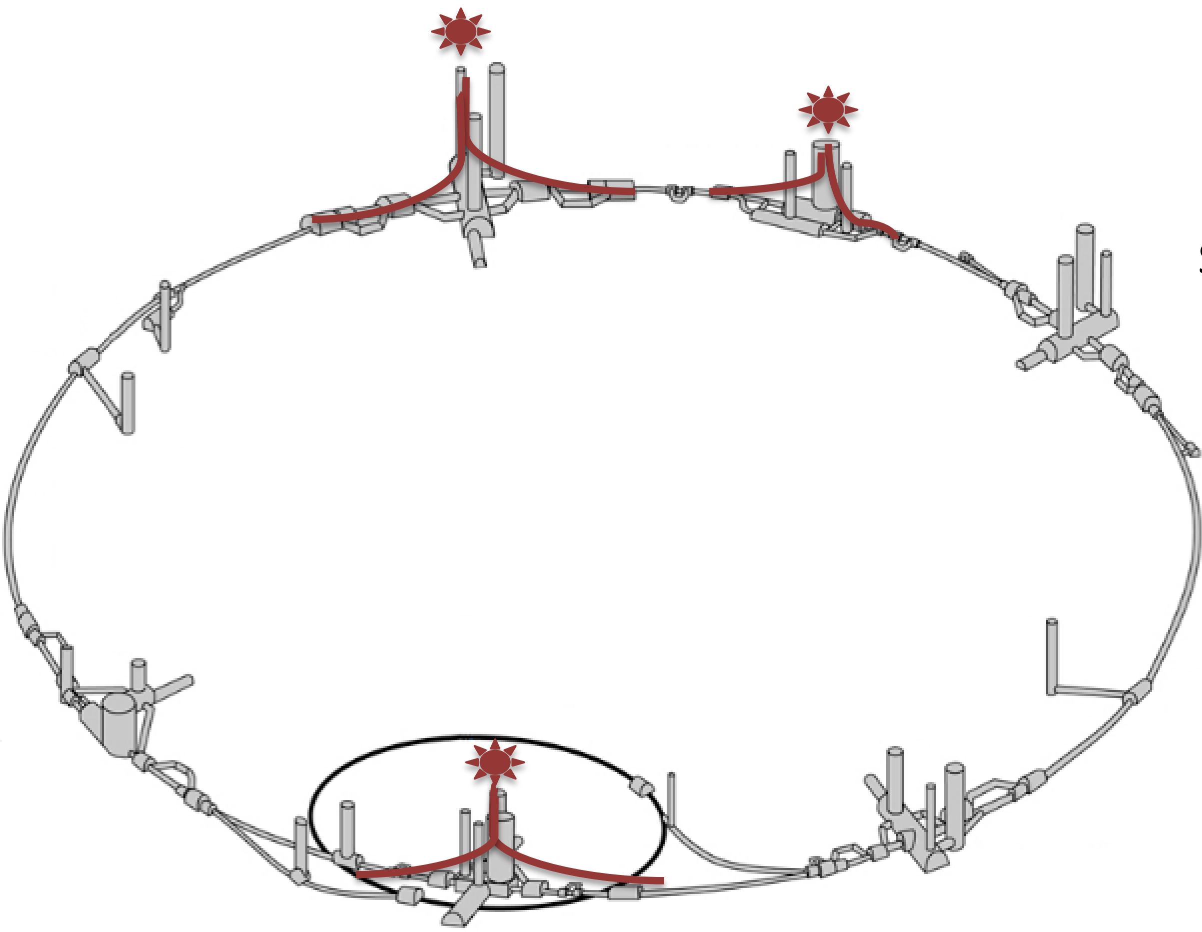


Reduce the maximum instantaneous power density transmitted from the interaction debris in the downstream elements

Absorbers



WP 9 – Cryogenics - Why



Increase flexibility and availability

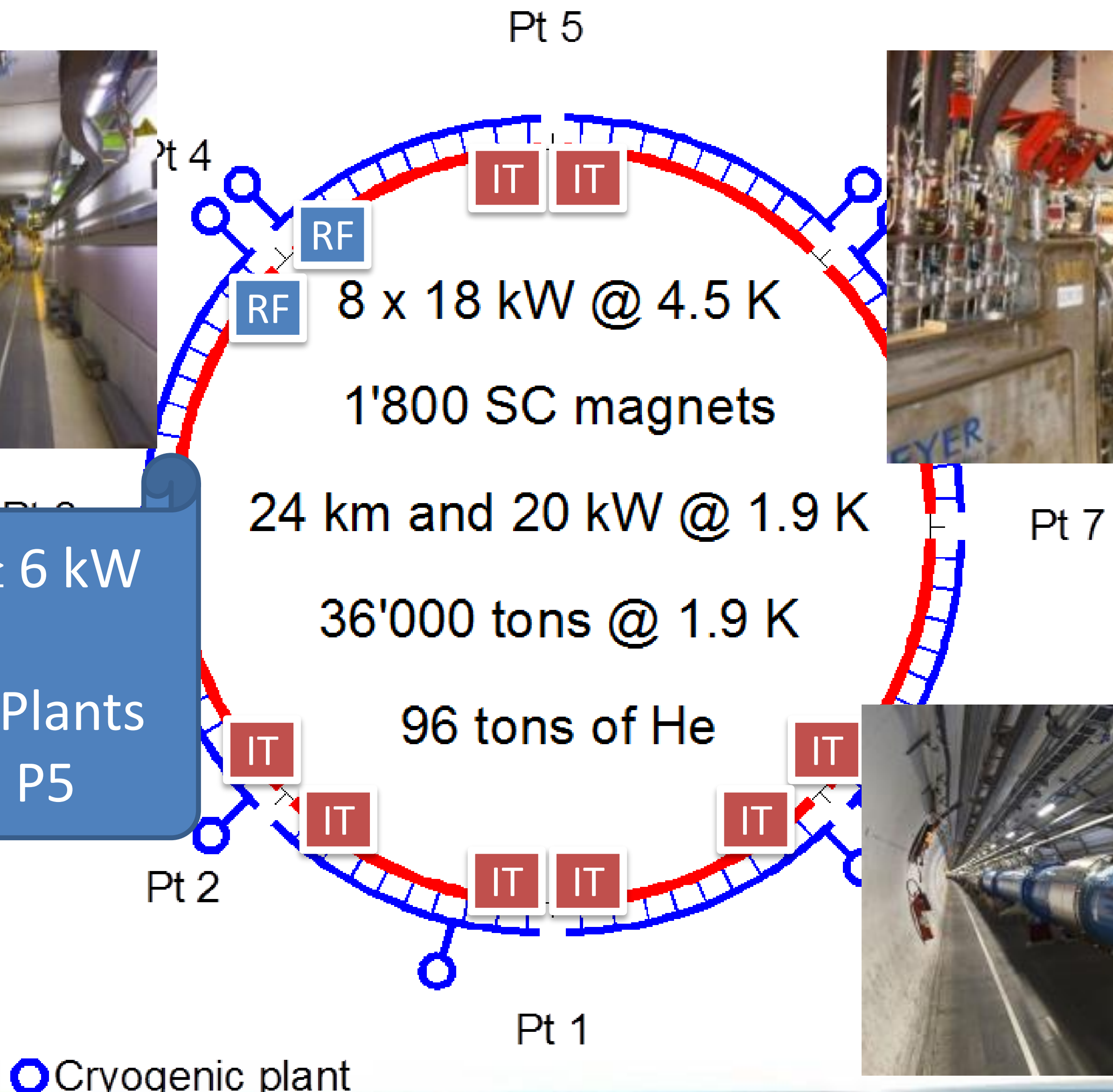
Separation cryogenics RF and magnets in P4

Separation cryogenics from Q1 to Q6 from the arcs and consequently feeding new components

Under study create redundancy with experiments cryogenics

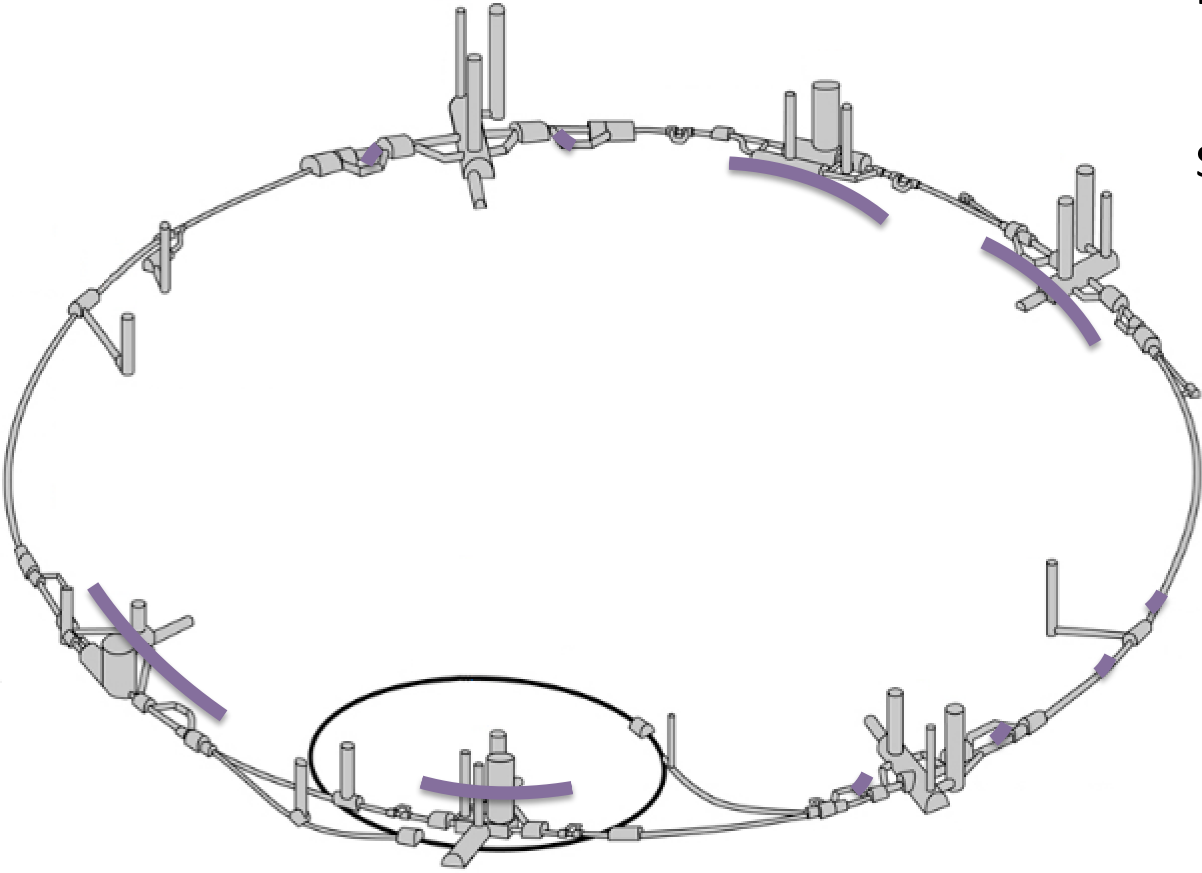
High Luminosity LHC

Cryogenics P4- P1 –P5



New Plant ≥ 6 kW
in P4
New 18 kW Plants
in P1 and P5

WP 12 – Vacuum - Why

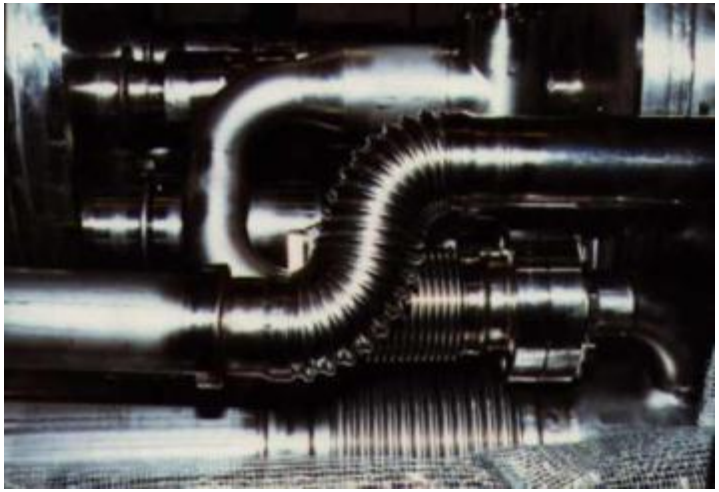


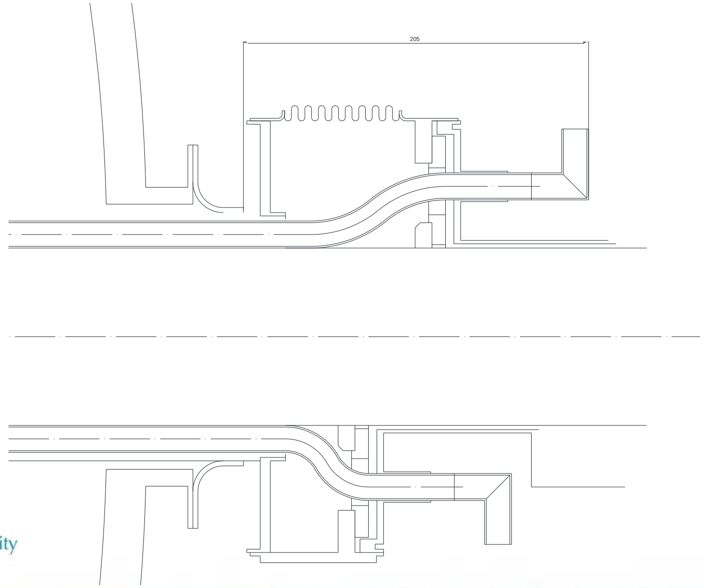
Non shielded beam screens to screen cold bore from beam induced heating

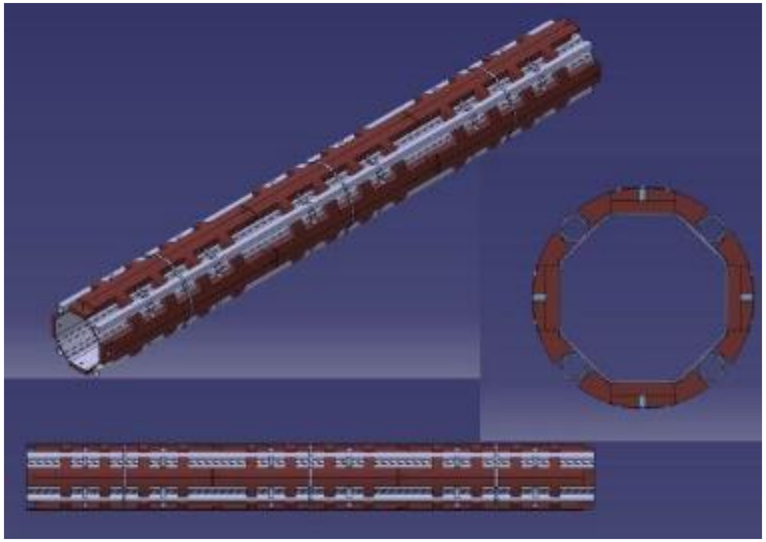
Shielded beam screens to also protect from physics debris

Vacuum for all new elements

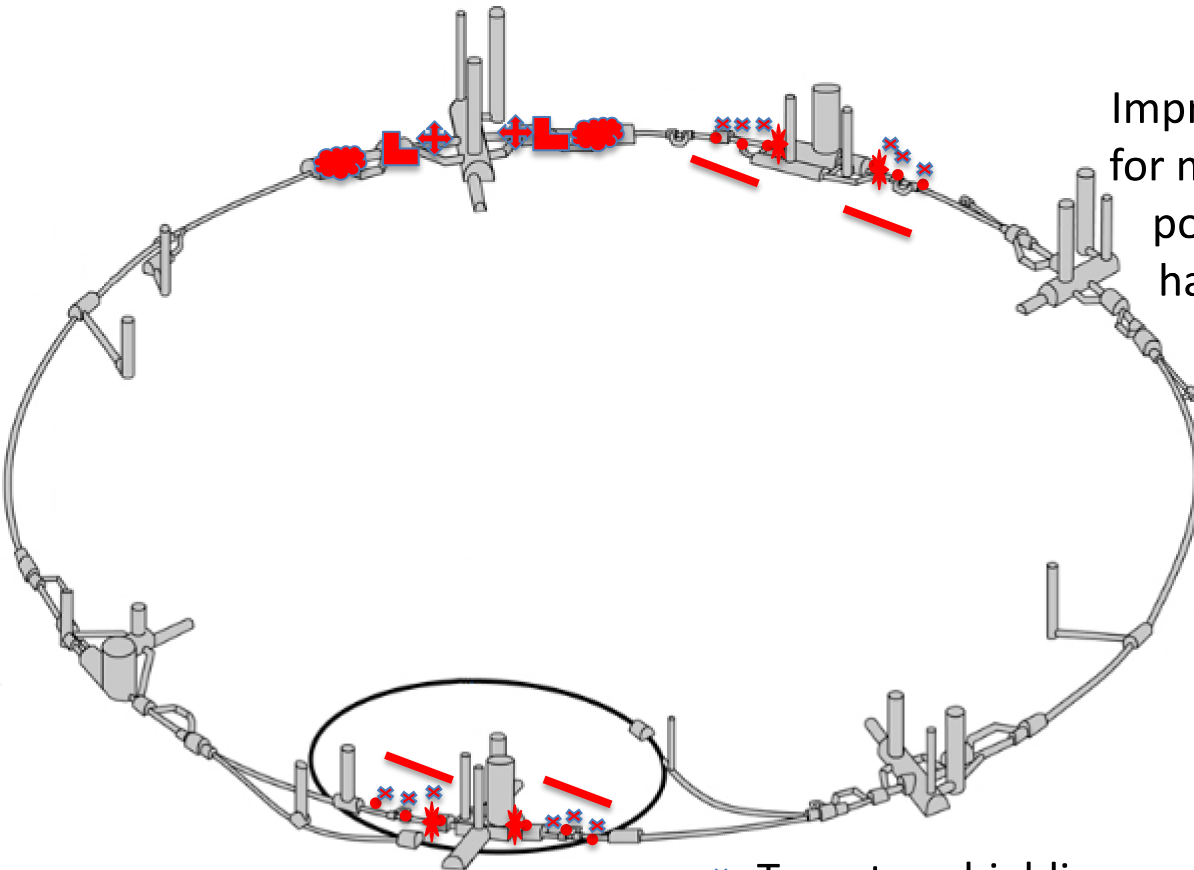
Vacuum







WP 13 – Beam instrumentation- Why

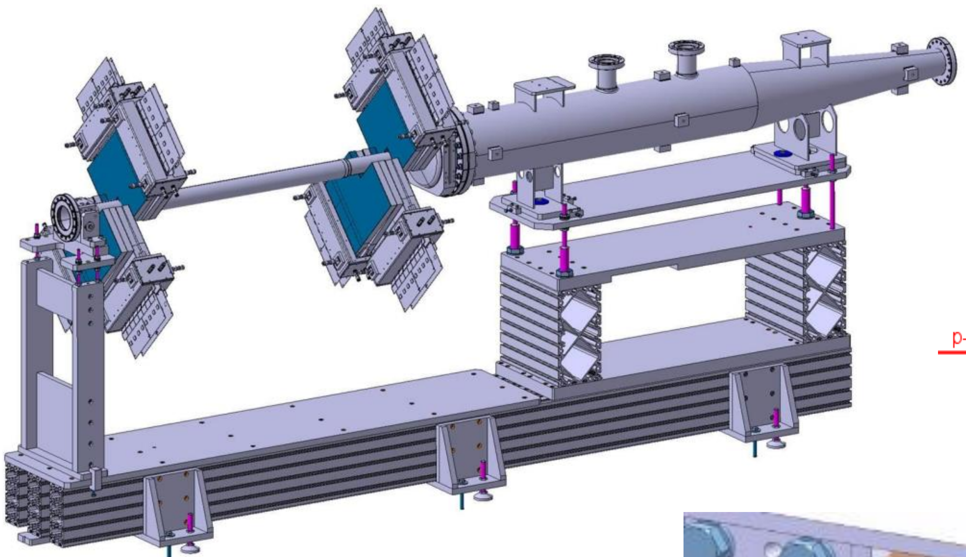


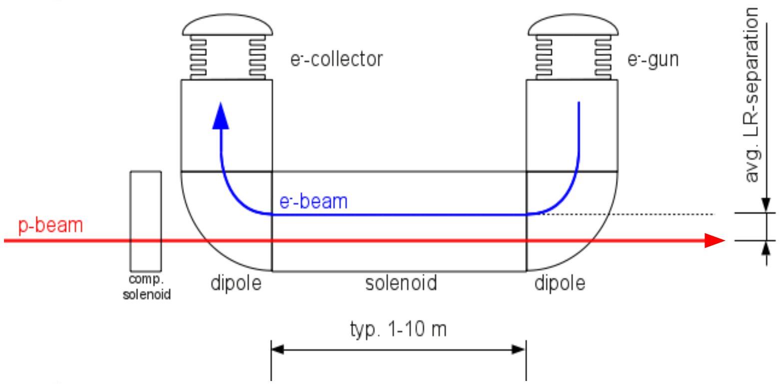
Improved beam instrumentation for more accurate beam size and position measurements, beam halo and intra-bunch position, beam size evolution, …

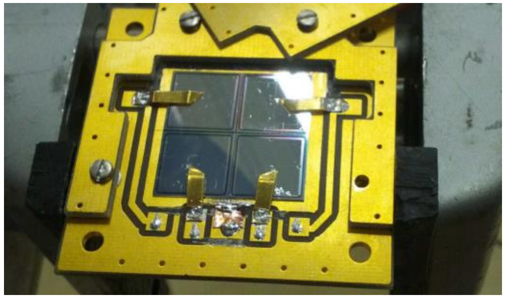
Beam monitoring for new elements such as the crab cavities

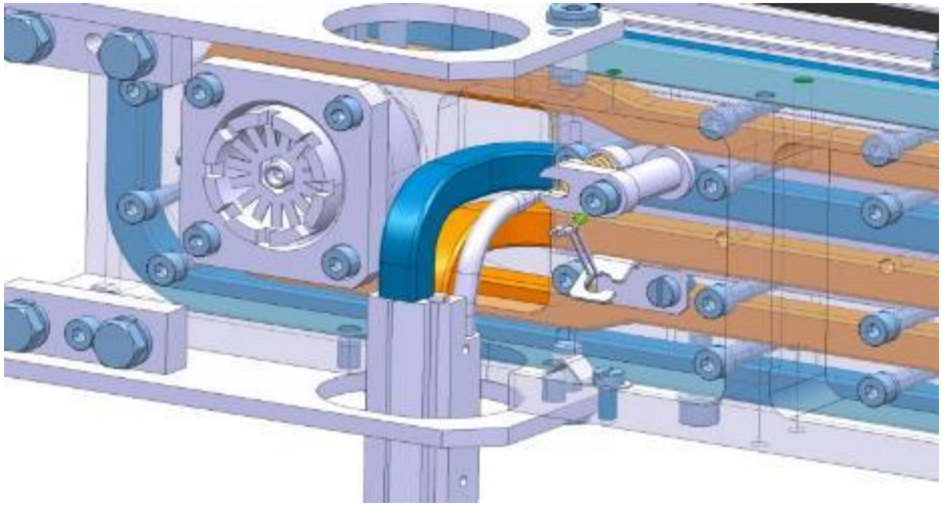
- Fast wire scanners
- Cryogenic BPMs
- Warm stripline BPMs
- Tungsten shielding cryo stripline BPMs
- Light extraction system
- BGV
- Cryogenic Beam Loss Monitors

Beam instrumentation



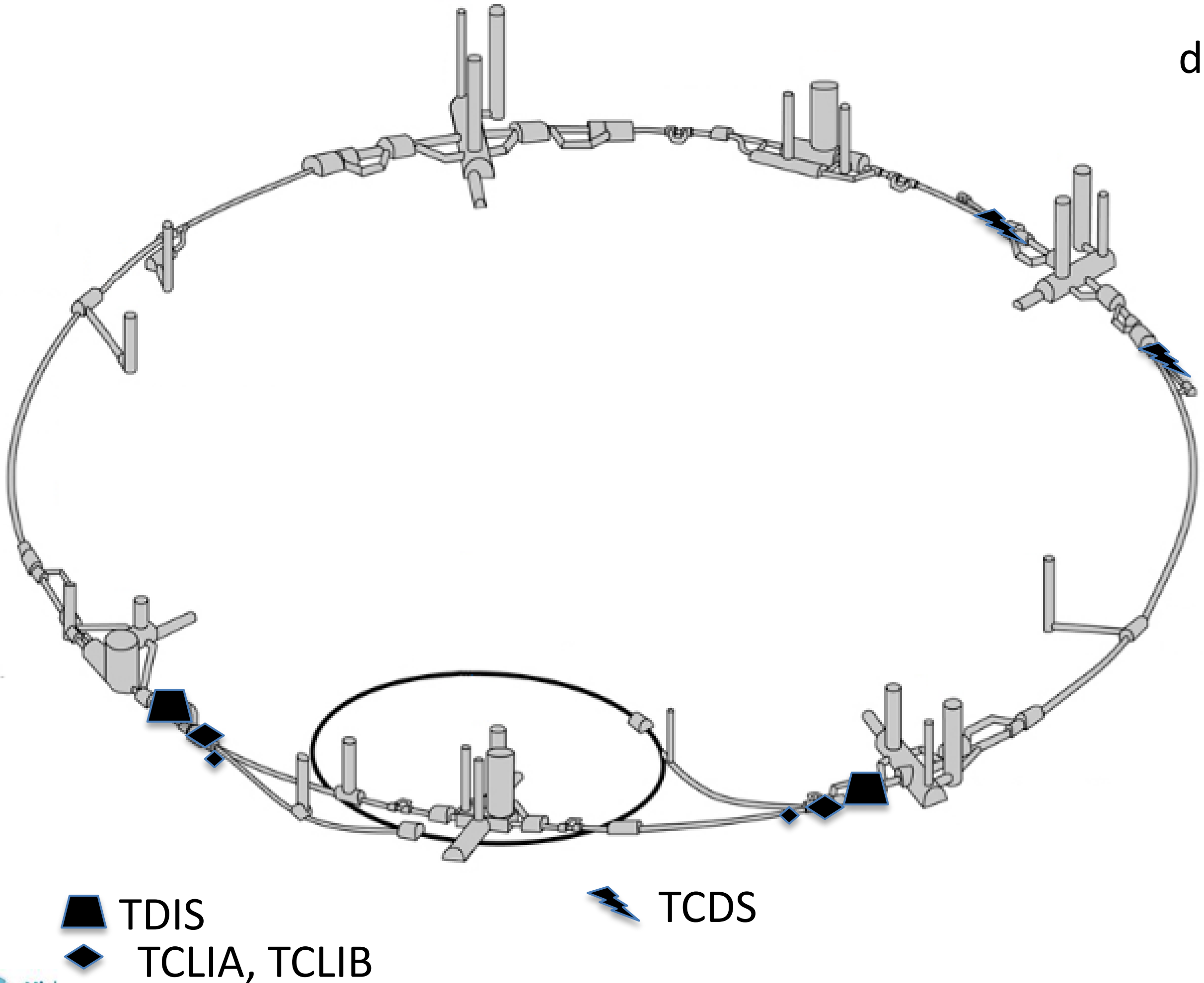




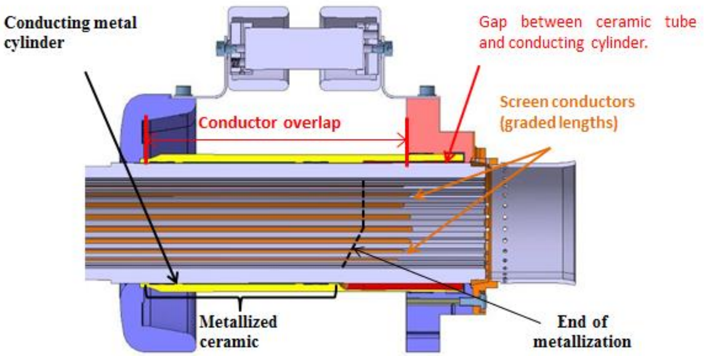


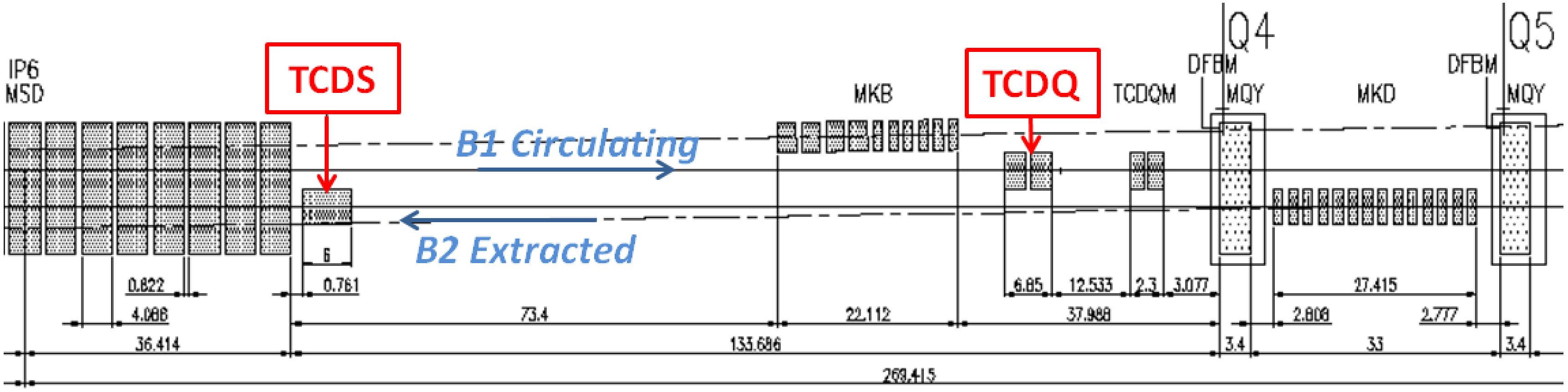
WP 14 – Beam transfer & kickers - Why

Protect from increased energy deposition in case of impact and of increased radiation background

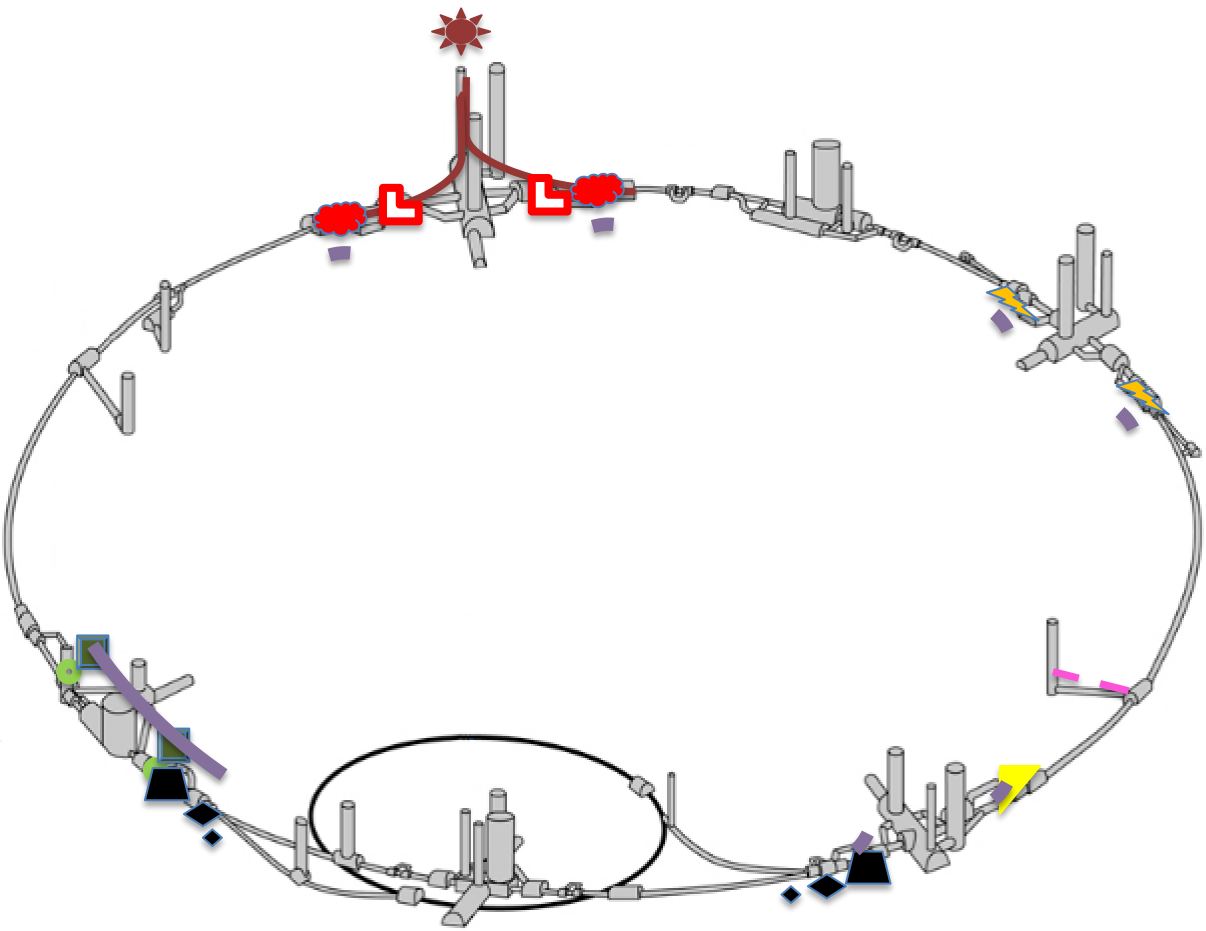


Beam transfer & kickers





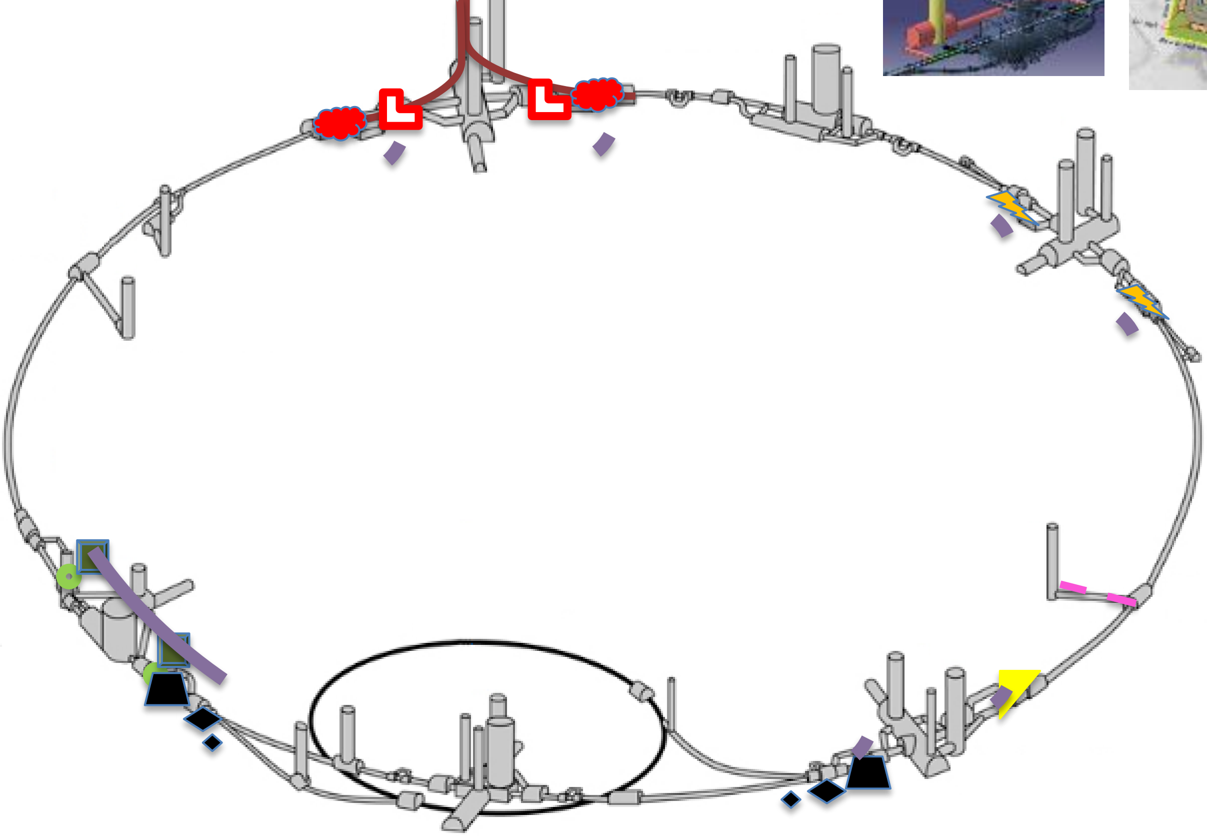
Working on the different scenarios LS2



Present installation baseline for LS2 still depending of the evaluation of several options

TAXN | Fast wire scanners | TDIS | 11T Dipole | Vacuum
Cryo-bypass+TCLD | BGV | TCLIA, TCLIB | New Q5

Working on the different scenarios LS2



Including early civil Works and

feedback from Run 2

High Luminosity LHC

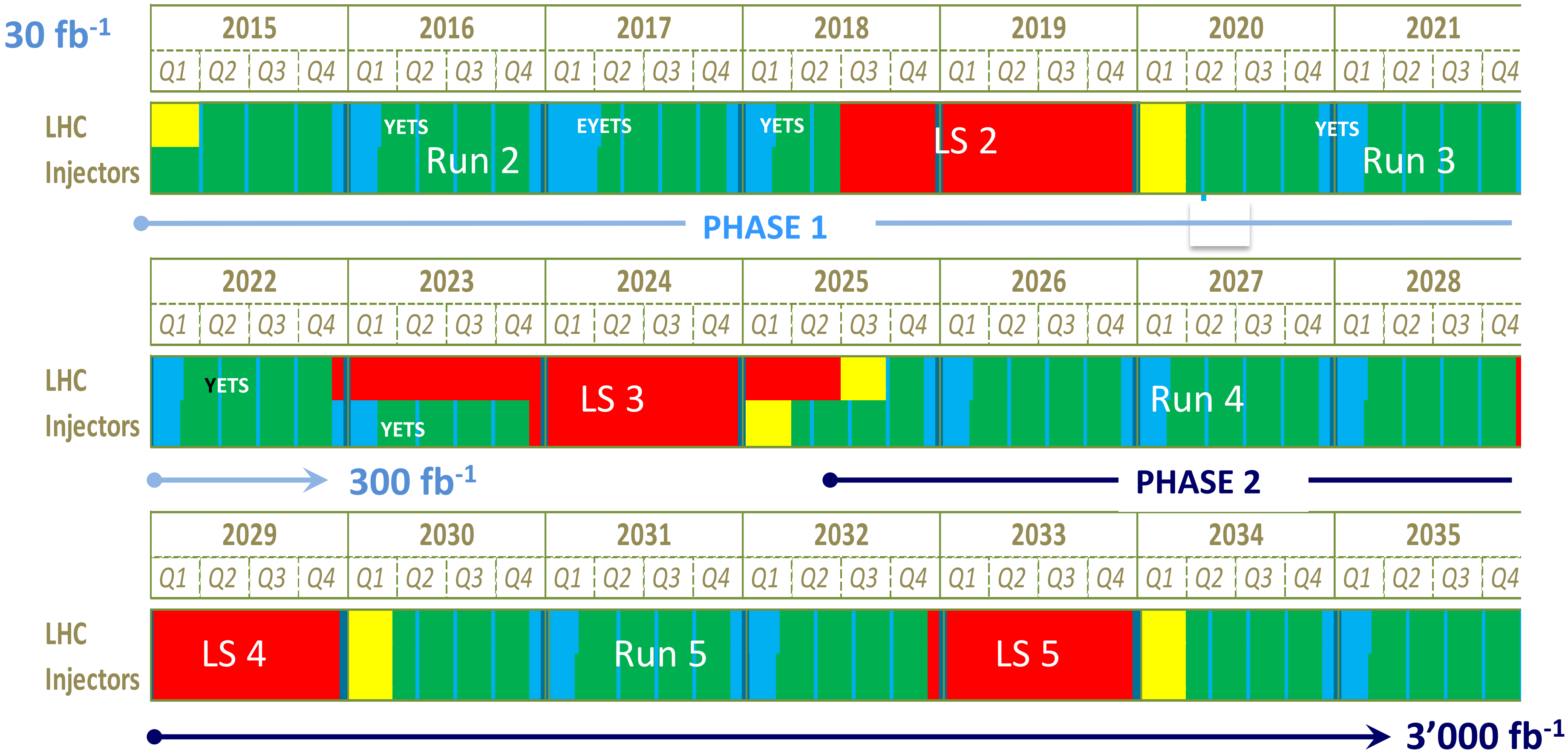
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

LHC roadmap: schedule beyond LS1

LS2	starting in 2018 (July)	=>	18 months + 3 months BC
LS3	LHC: starting in 2023	=>	30 months + 3 months BC
	Injectors: in 2024	=>	13 months + 3 months BC

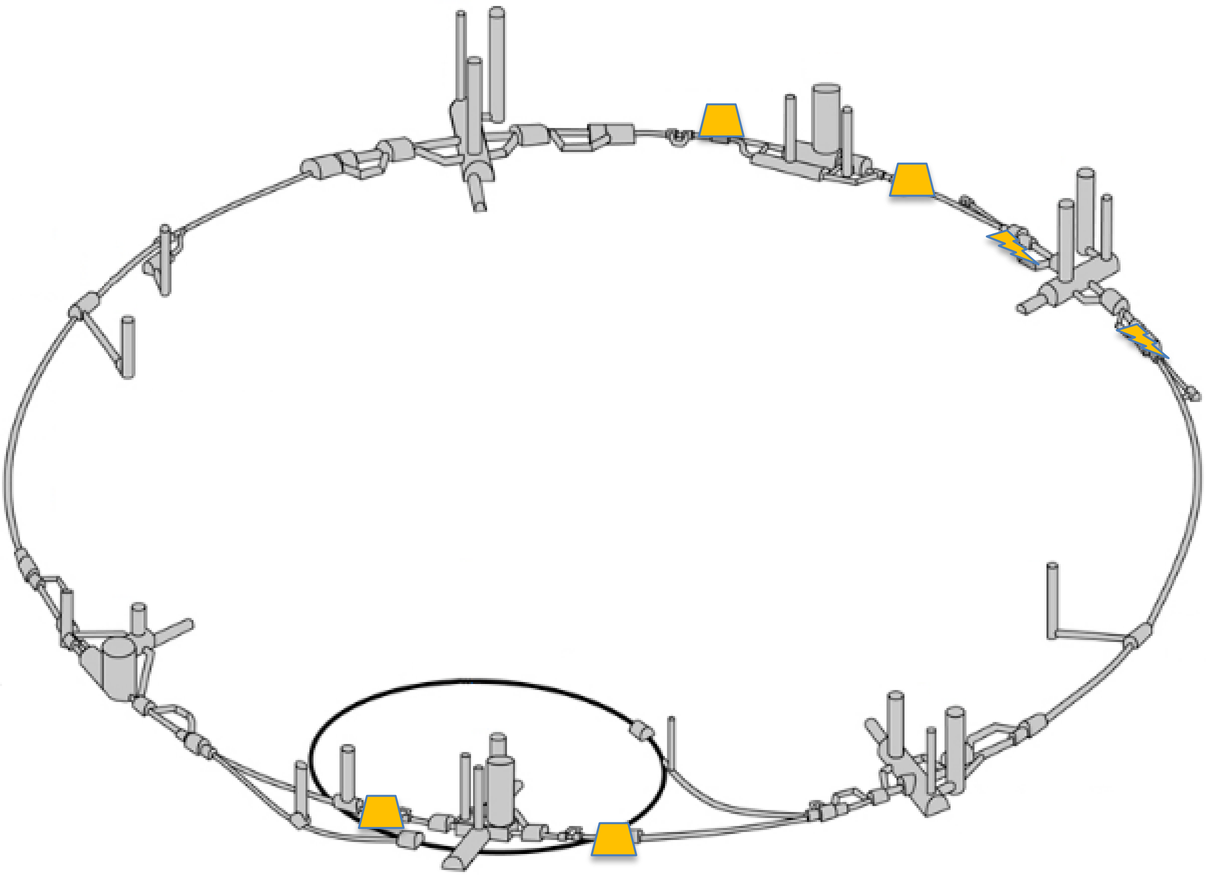
(Extended) Year End Technical Stop: (E)YETS

- Physics
- Shutdown
- Beam commissioning
- Technical stop



High Luminosity LHC

Other components - Why



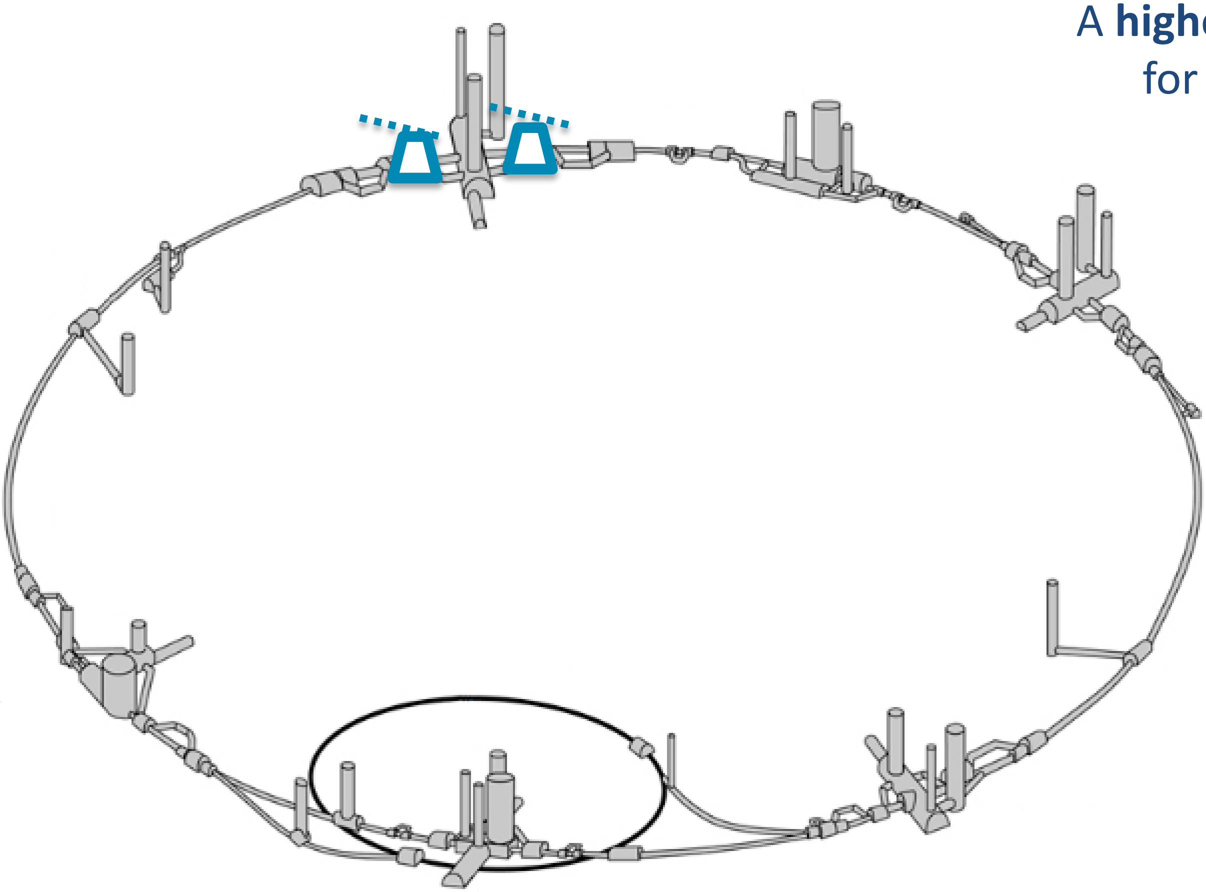
Sextupole Q10

New Q5

Requested by ATS optics

Options

WP4 – Crab cavities and RF - **Options**



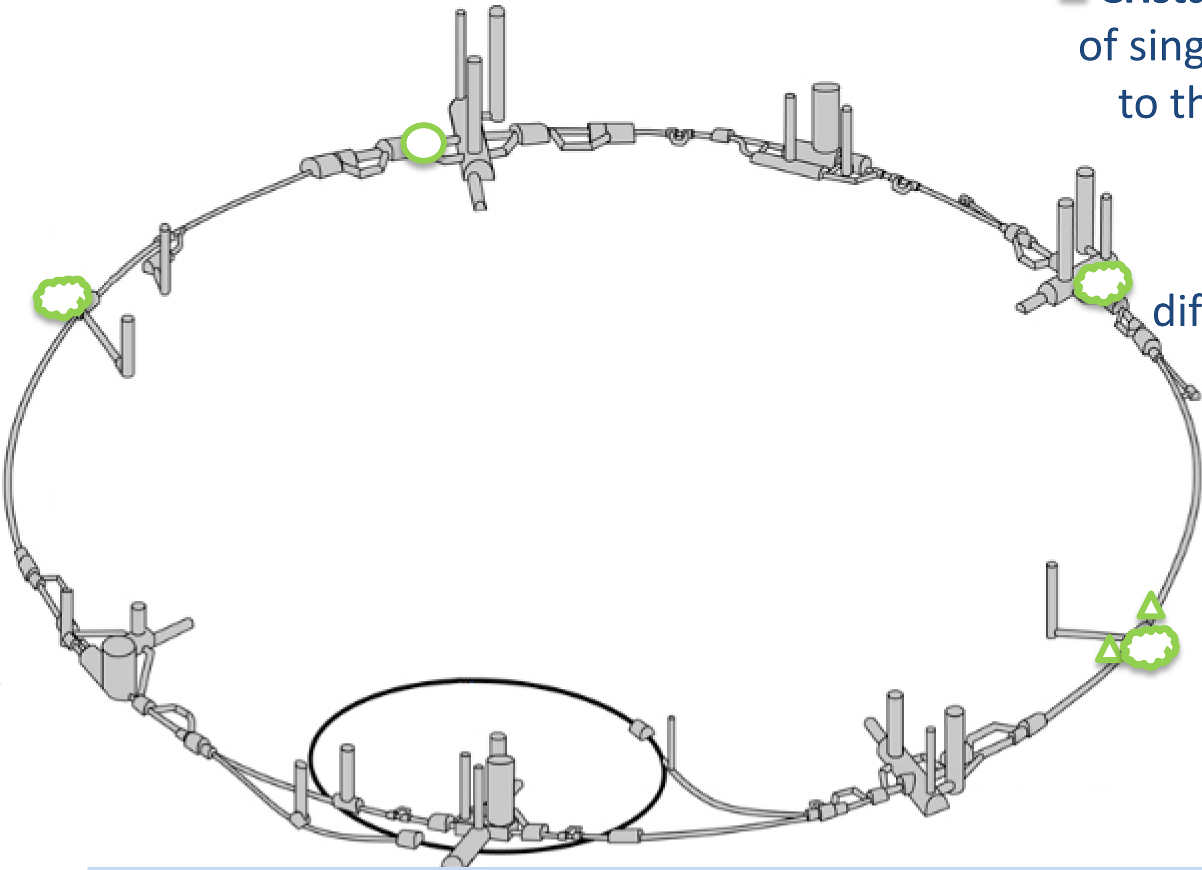
A **higher harmonic (800 MHz)** either for changing the bunch profile or the synchrotron frequency distribution to improve beam stability

A **sub-harmonic (200 MHz)** system can either replace the existing main RF system or work with the 400 MHz RF system which in this case will act as the 2nd harmonic to increase bunch stability

When:
To reduce the beam induced heating, effect of intra-beam scattering, improve longitudinal beam stability and in some scenarios to increase or level luminosity

High Luminosity LHC

WP5 – Collimation - **Options**



△ **Cristal collimation**: reduced impact of single diffractive losses compared to the present primary collimators

○ **Hollow e-lens**: control the diffusion speed of the main beam halo

Collimation upgrade: can be part of the consolidation or HL-LHC depending on the machine behaviour

When:

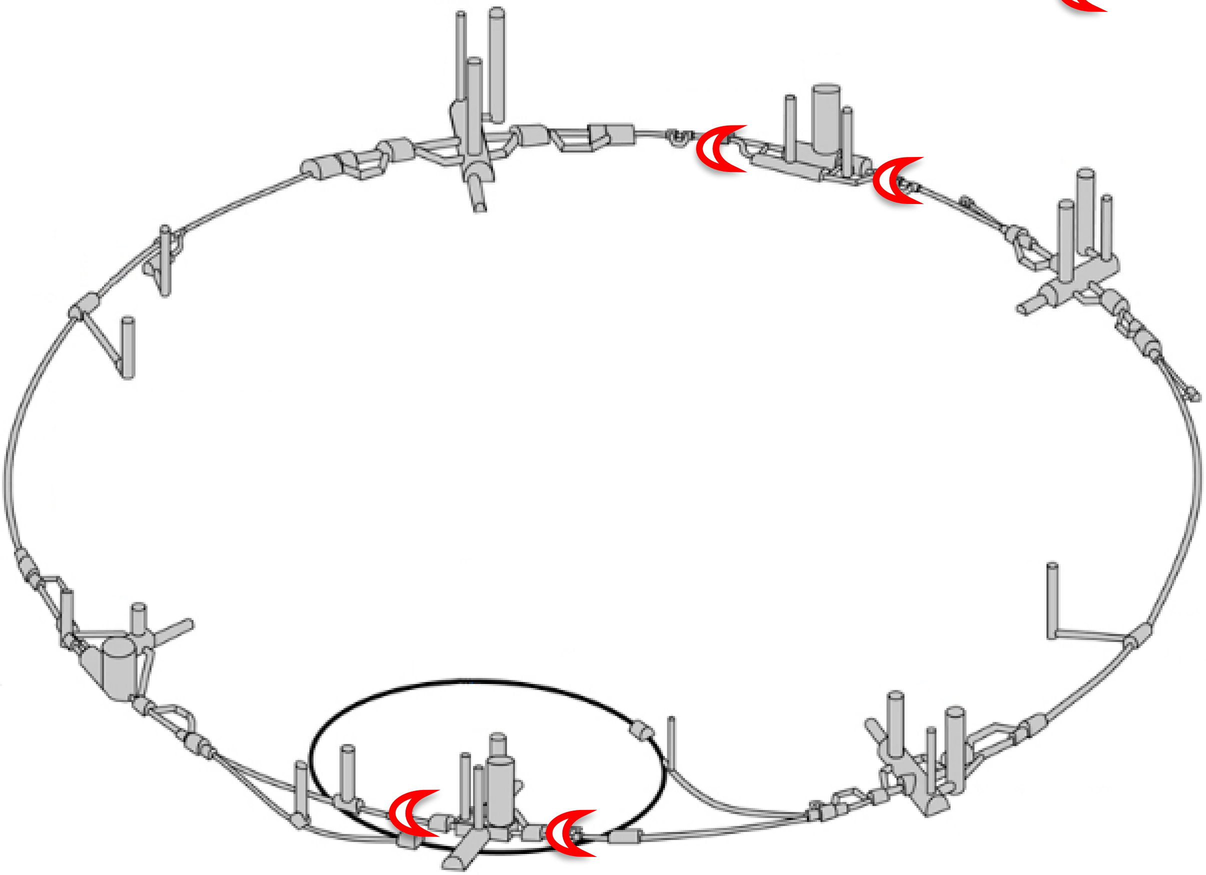
△ If required to reduce further impedance by reducing the number of secondary collimators. If required to improve the betatron cleaning of ion beams

○ Fast failure scenarios of the crab cavities

High Luminosity LHC

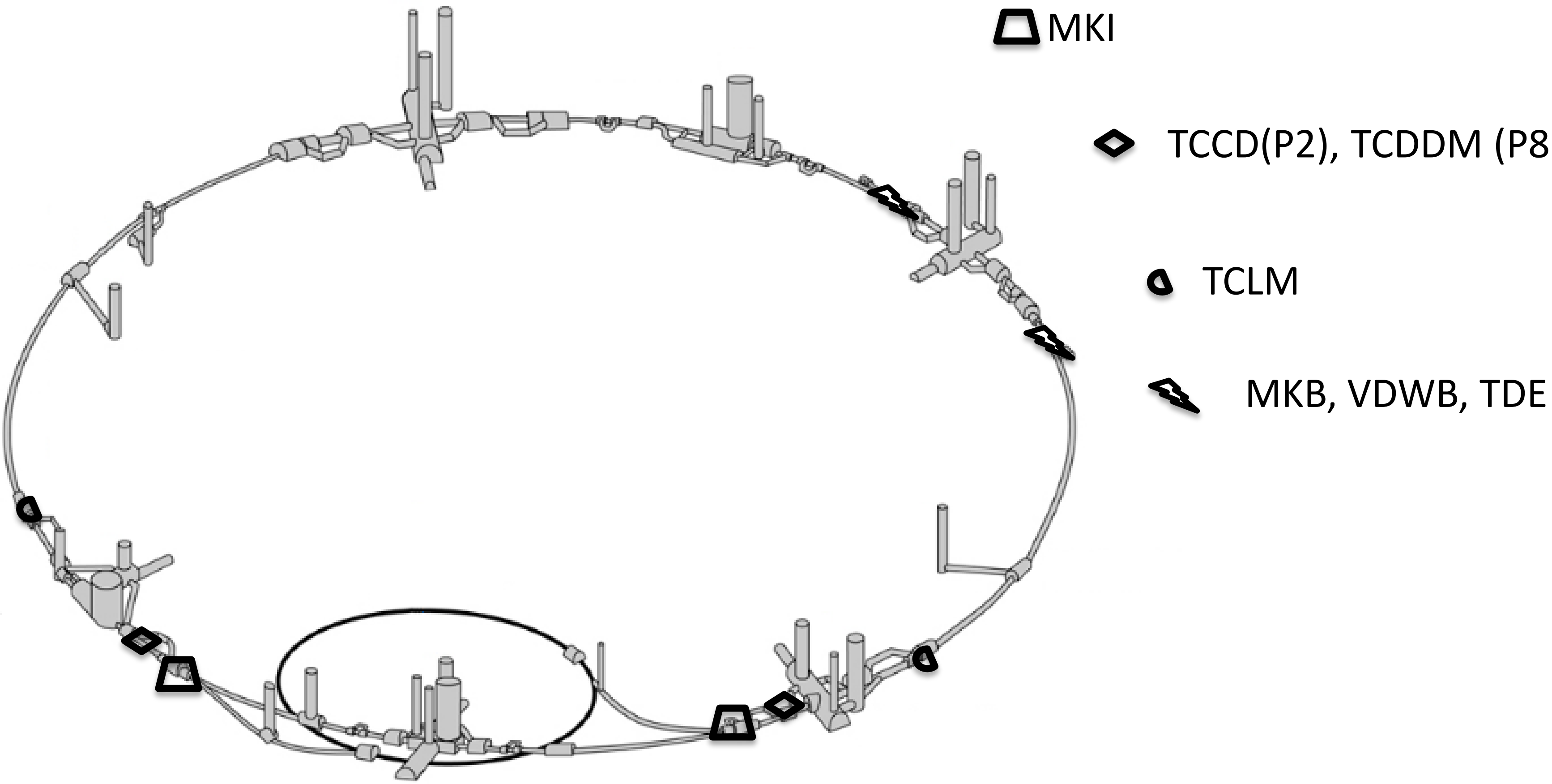
WP 13 – Beam instrumentation- **Options**

- **BBLR:** corrects non-linear effects of long range interactions



When:
- if missing Crab cavities

WP 14 – Beam transfer & kickers - **Options**



When: In case present system is not compatible with HL-LHC beam