

**High  
Luminosity  
LHC**

# How to implement all the HL-LHC upgrades

Lucio Rossi for the HL-LHC team

**Review of LHC & Injector Upgrade Plans  
(RLIUP Workshop)**  
**Archamps 30 October 2013**



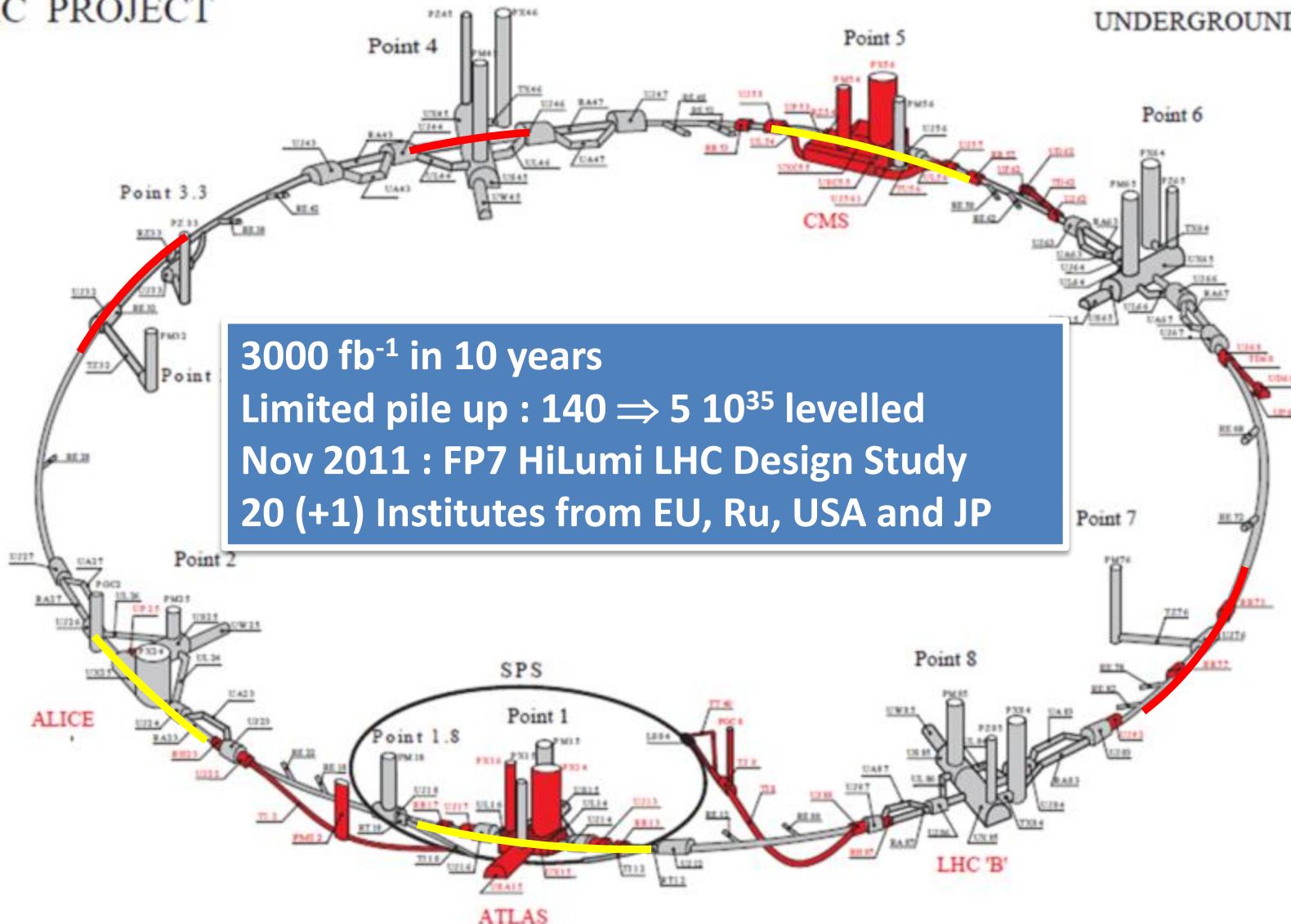
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.



# HL-LHC : work around the ring > 1.2 km

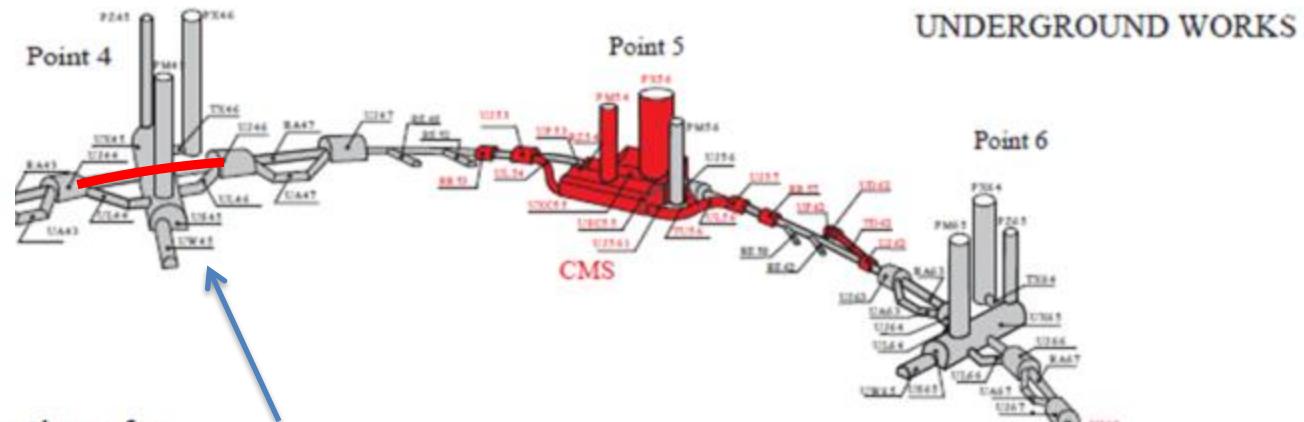
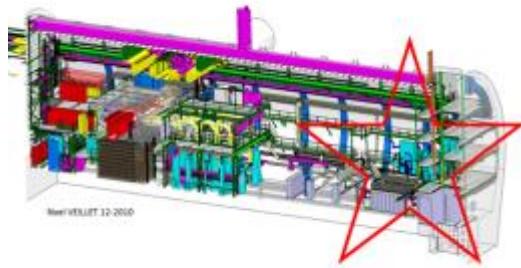
## LHC PROJECT

## UNDERGROUND WORKS



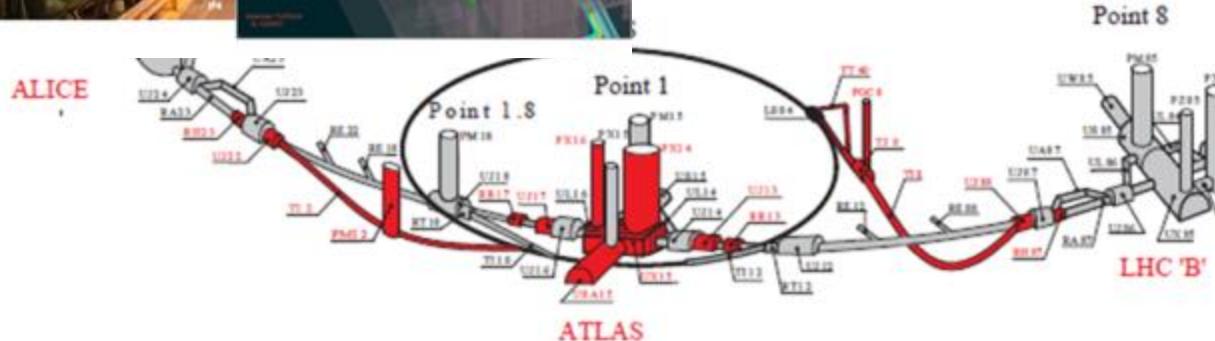
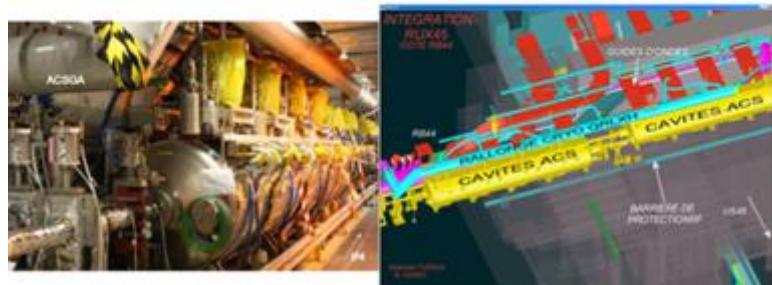
# Point 4 : Cryoplant for RF (LS2 2018)

LHC PROJECT

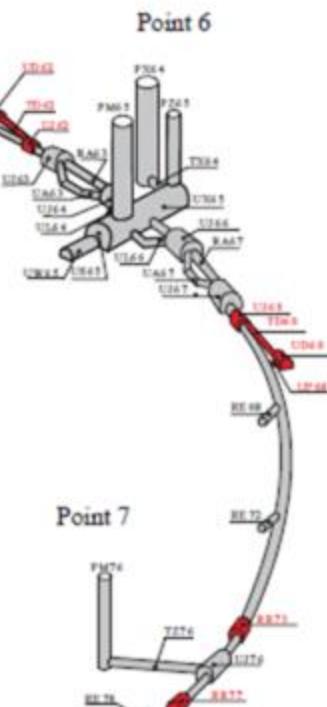


Potential interconnection options for  
“redundancy” with QRL

Main aim is to separate  
SCRF form the arc cooling  
But will have capability  
for a harmonic RF system  
and for e-lens SC solenoid

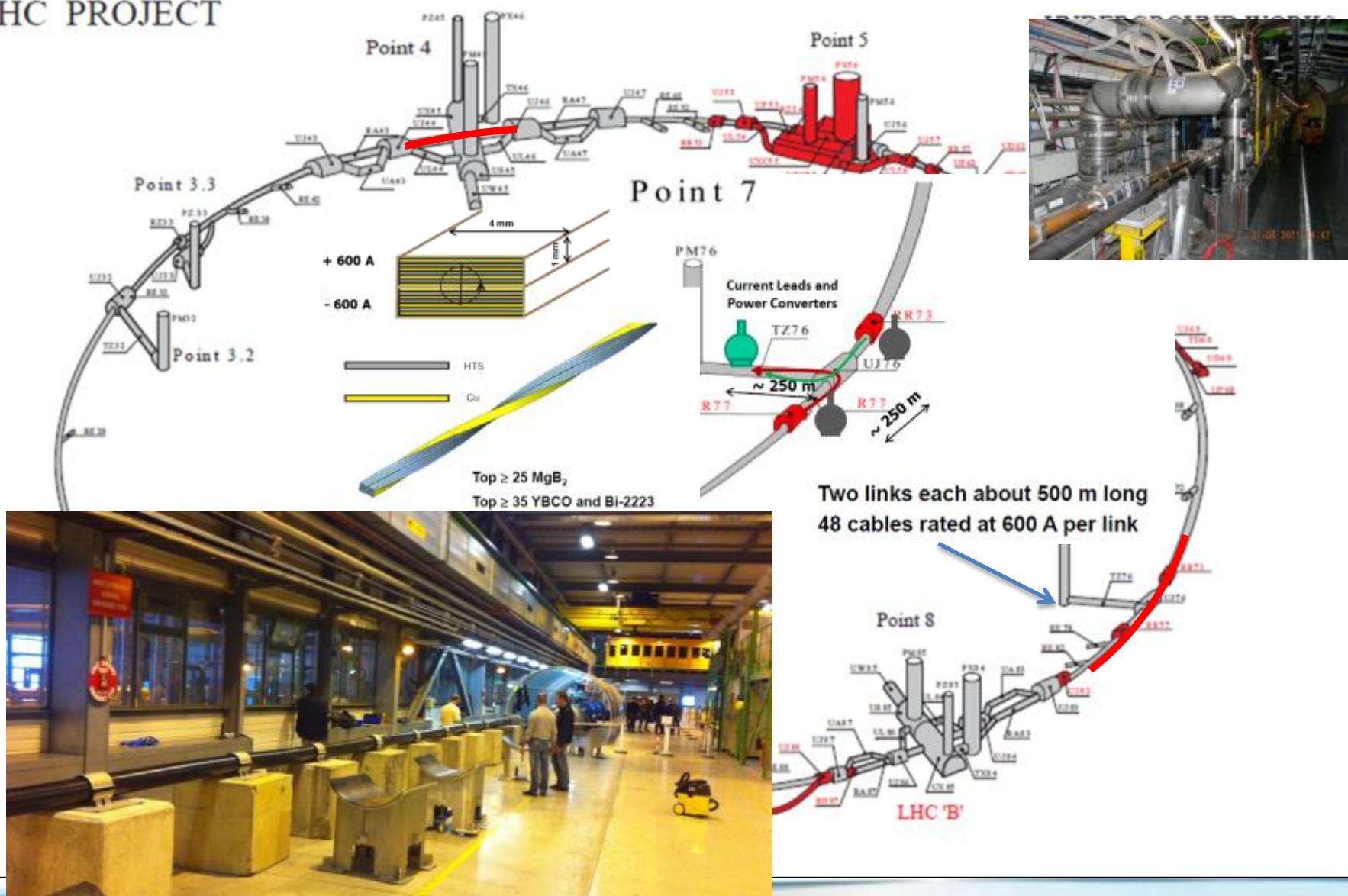


UNDERGROUND WORKS



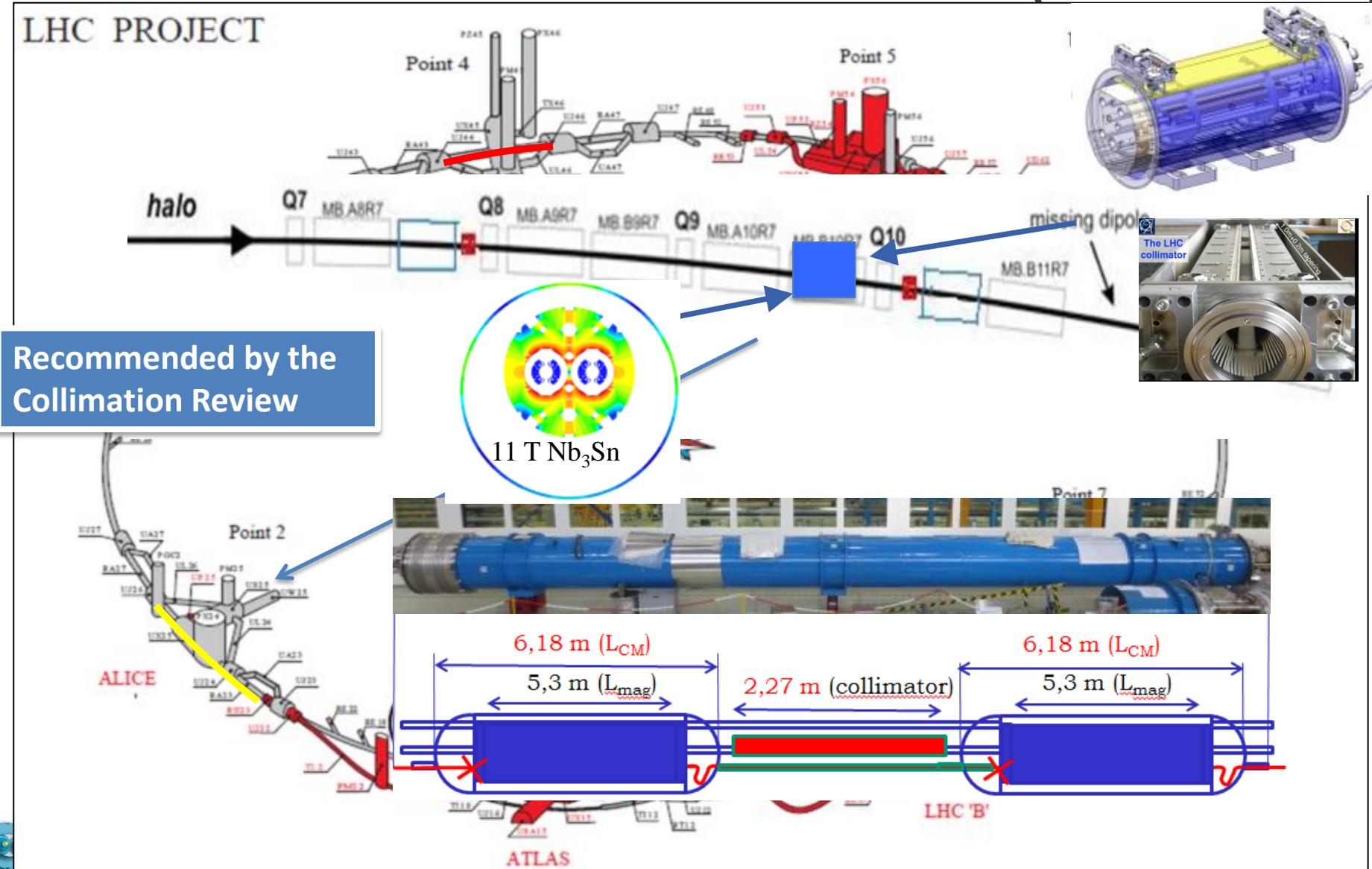
# Point 7: horizontal SC links (LS2 2018)

LHC PROJECT



# P2 - DS collimators ions – 11 T (LS2 -2018)

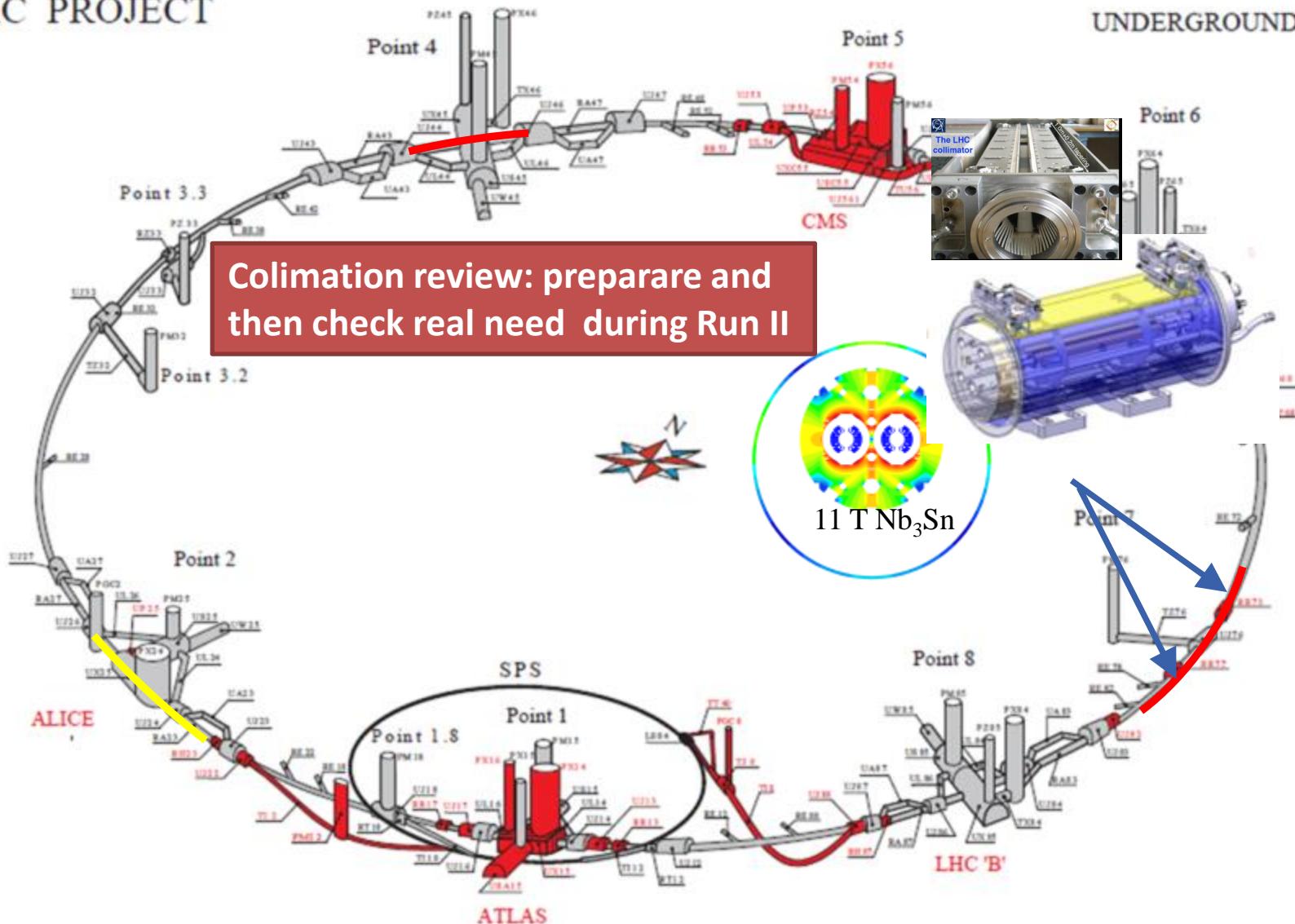
LHC PROJECT



# P7 DS collimation – 11 T (LS2 2018)

LHC PROJECT

UNDERGROUND WORKS

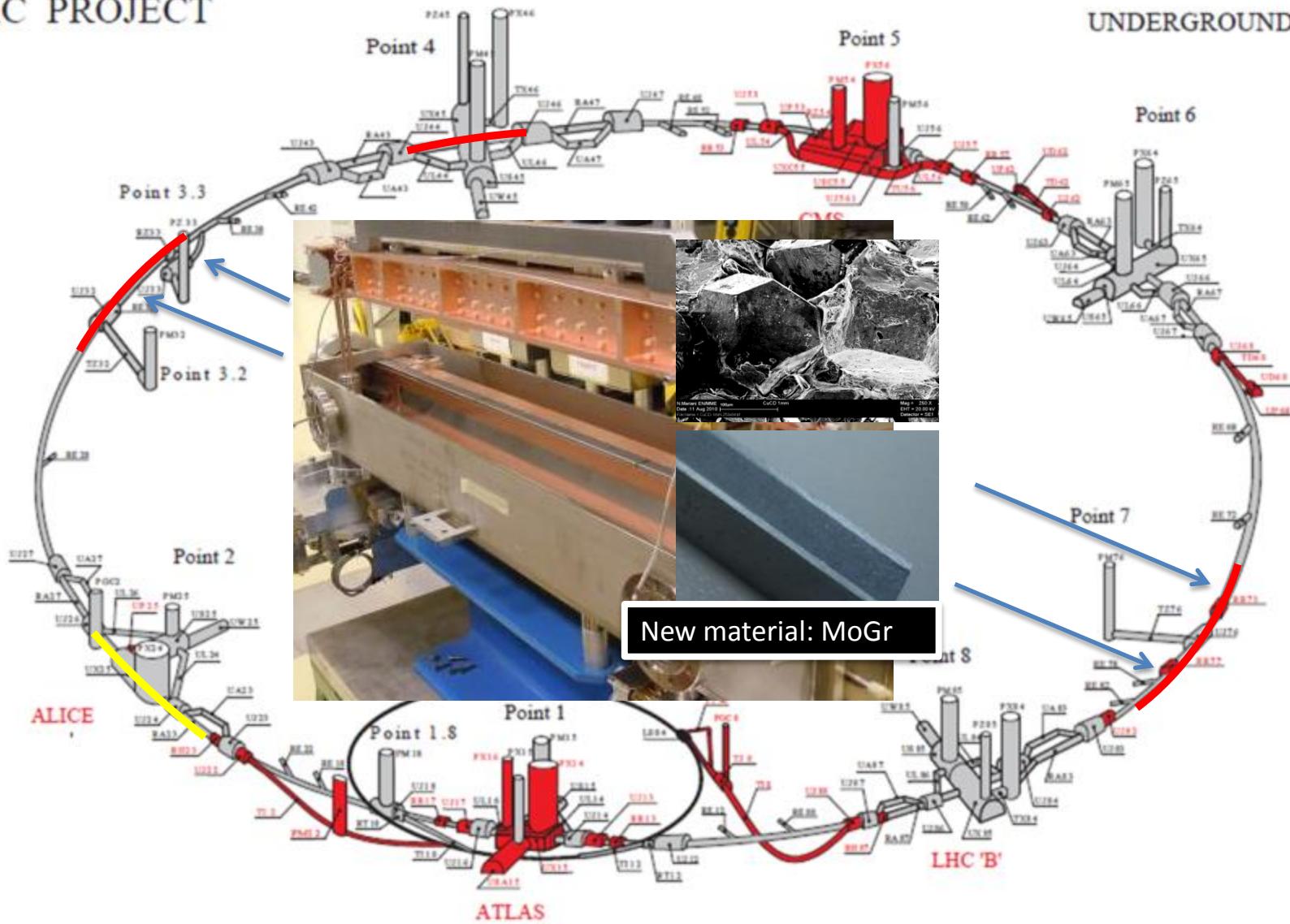


Colimation review: prepare and  
then check real need during Run II

# Low impedance collimators(LS2 & LS3)

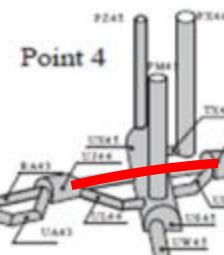
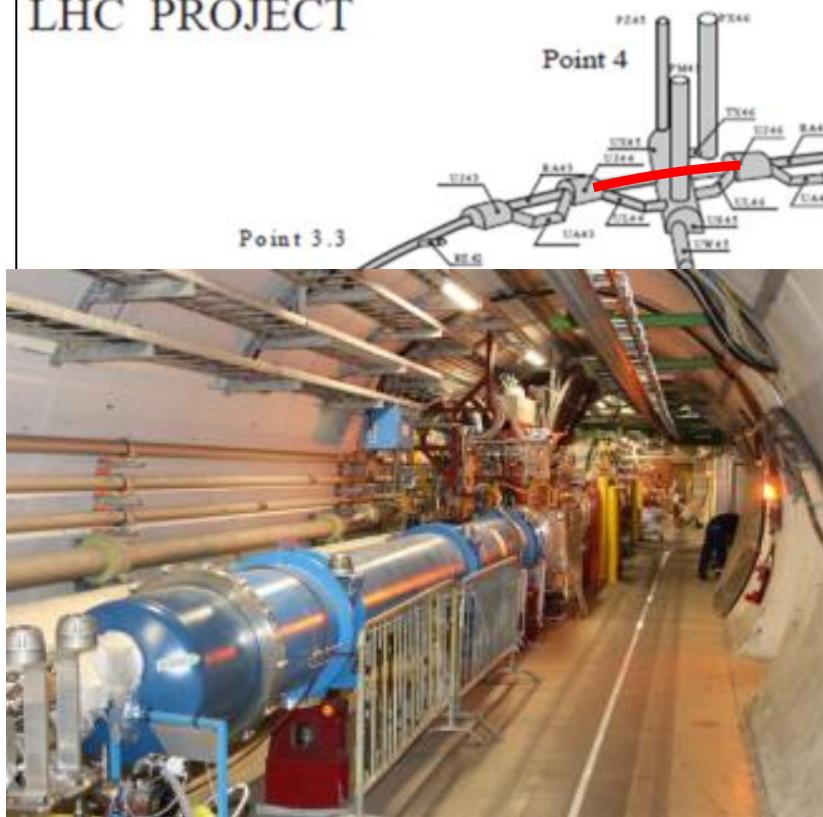
LHC PROJECT

UNDERGROUND WORKS

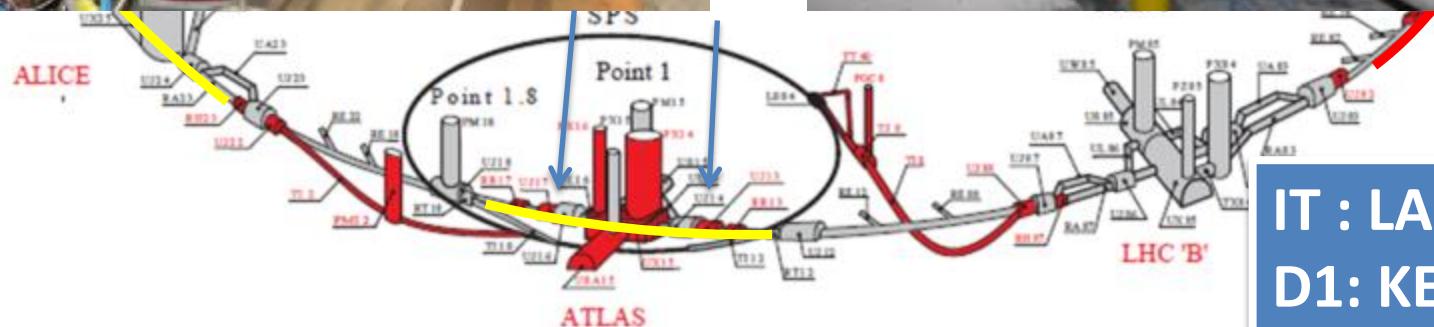
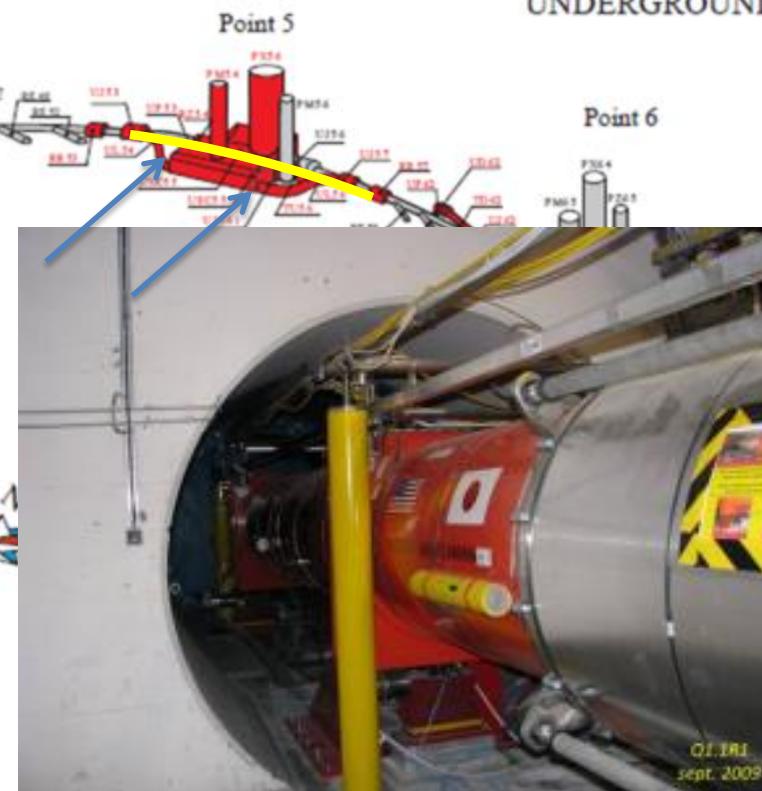


# P1-P5 IR Magnets (IT-D1) Powering, TAS

LHC PROJECT

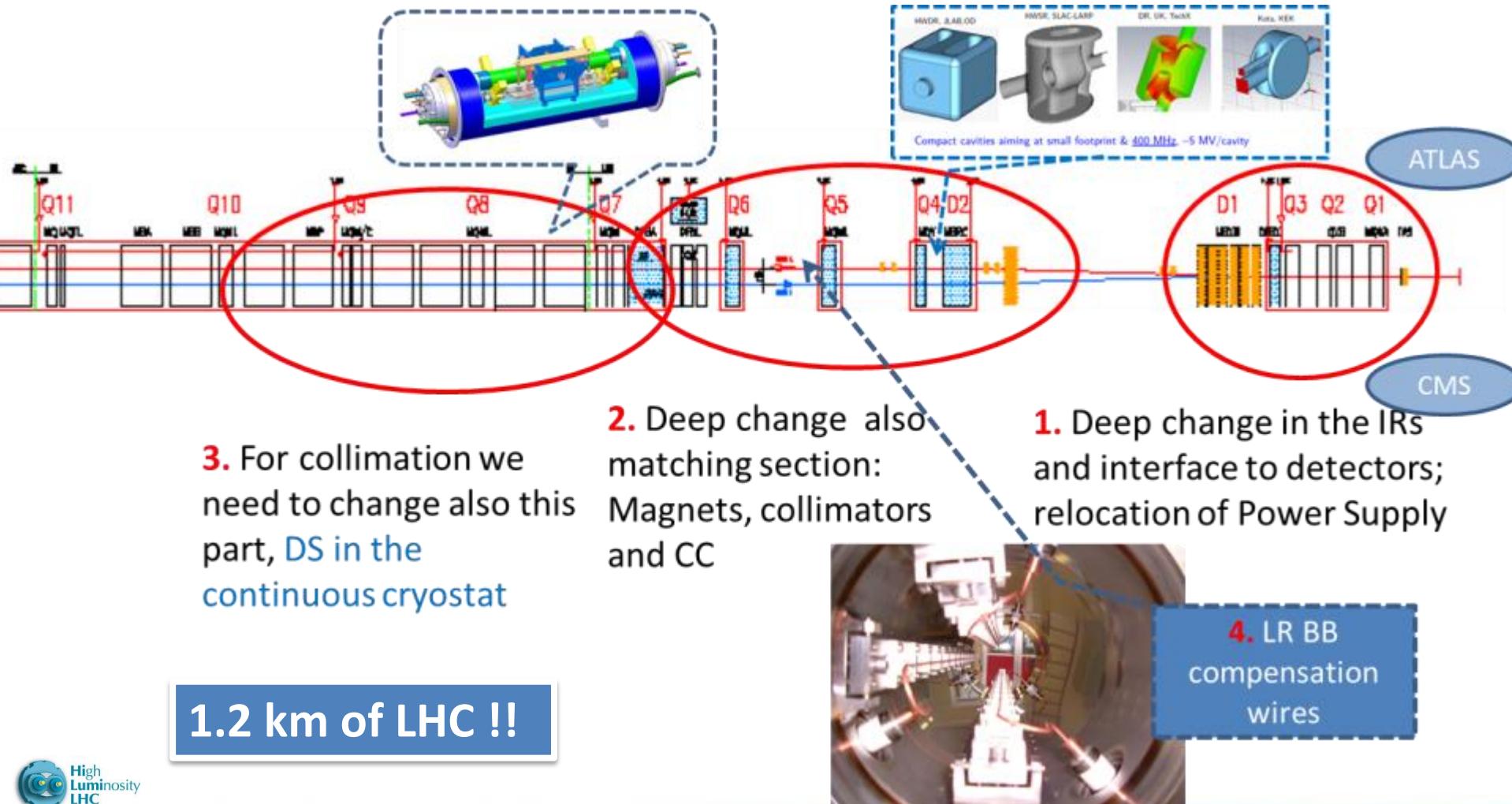


UNDERGROUND WORKS



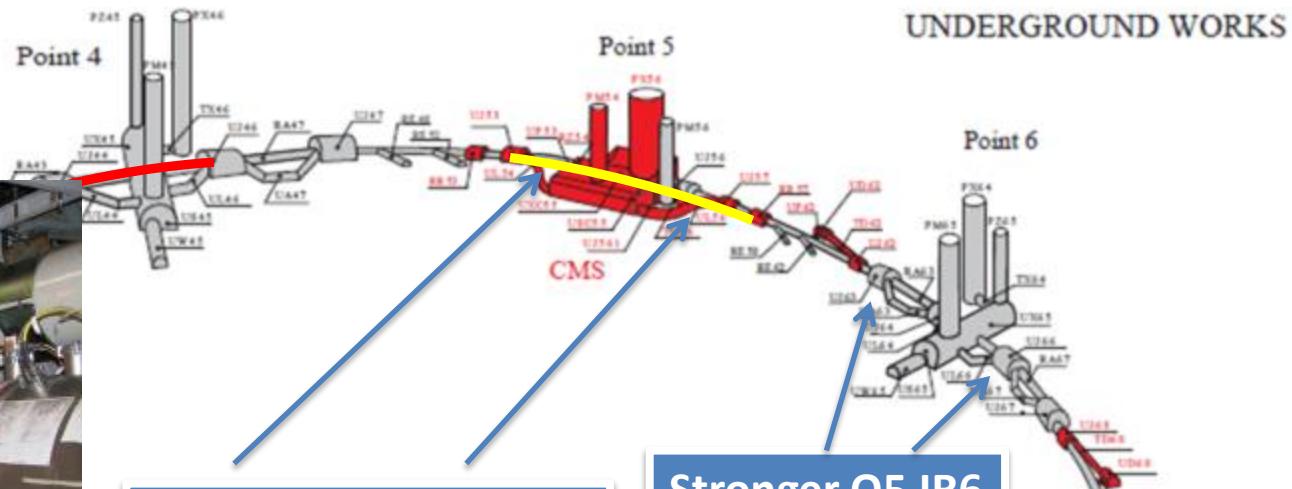
IT : LARP –CERN  
D1: KEK

# The critical zone around IP1 and IP5



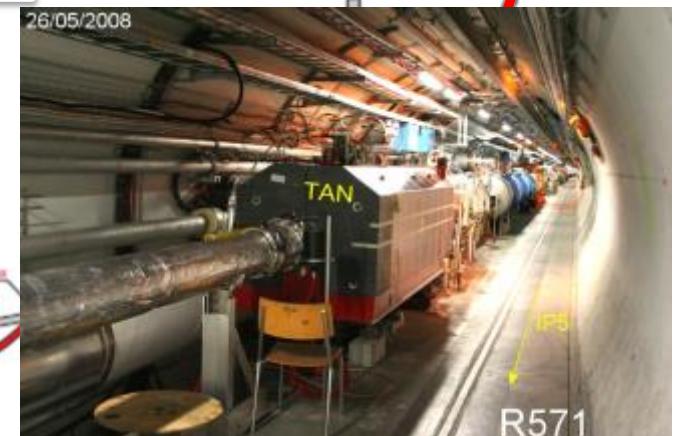
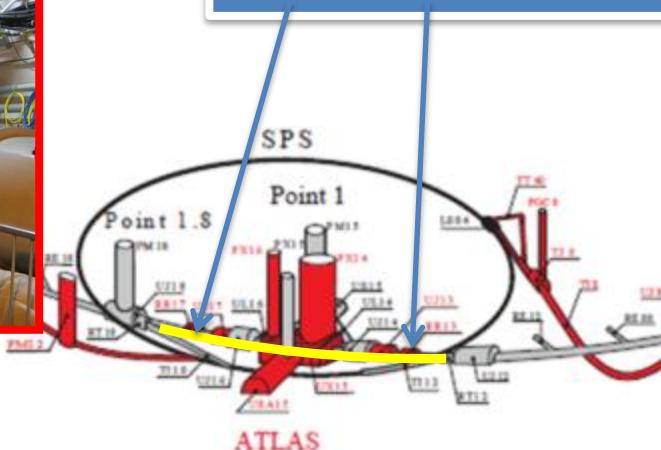
# P1-P5 MS Magnets, Powering, TAN

LHC PROJECT

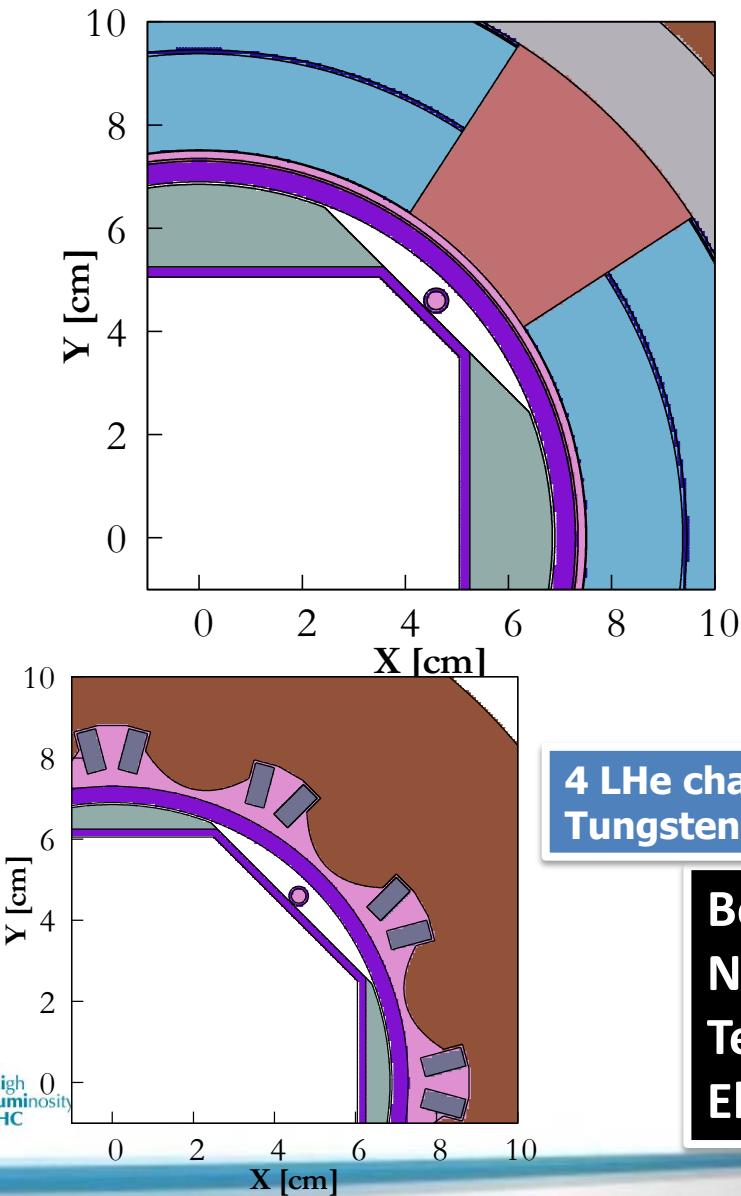


Q4-Q5-Q6  
MS in Q10 in  
Sectors 12,45,56,81

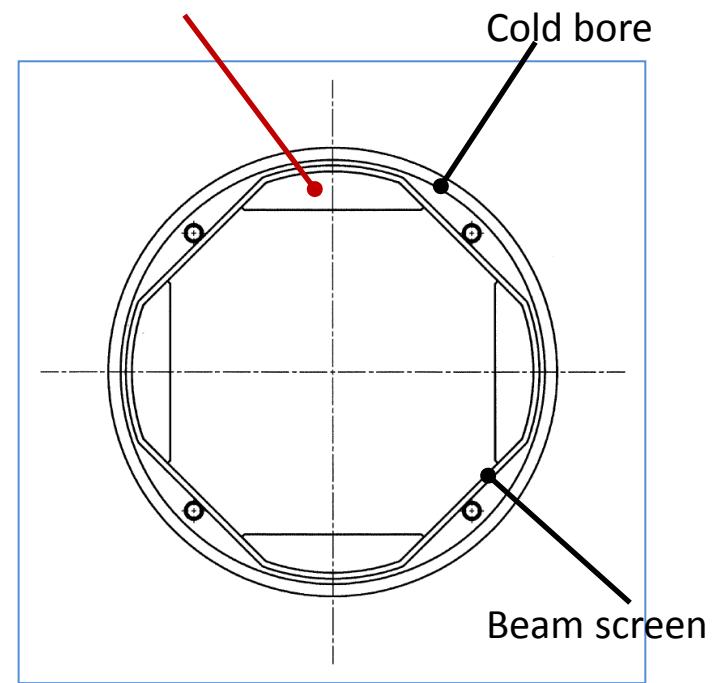
Stronger Q5 IR6  
2 magnets



# IT robustness: beam screen is critical



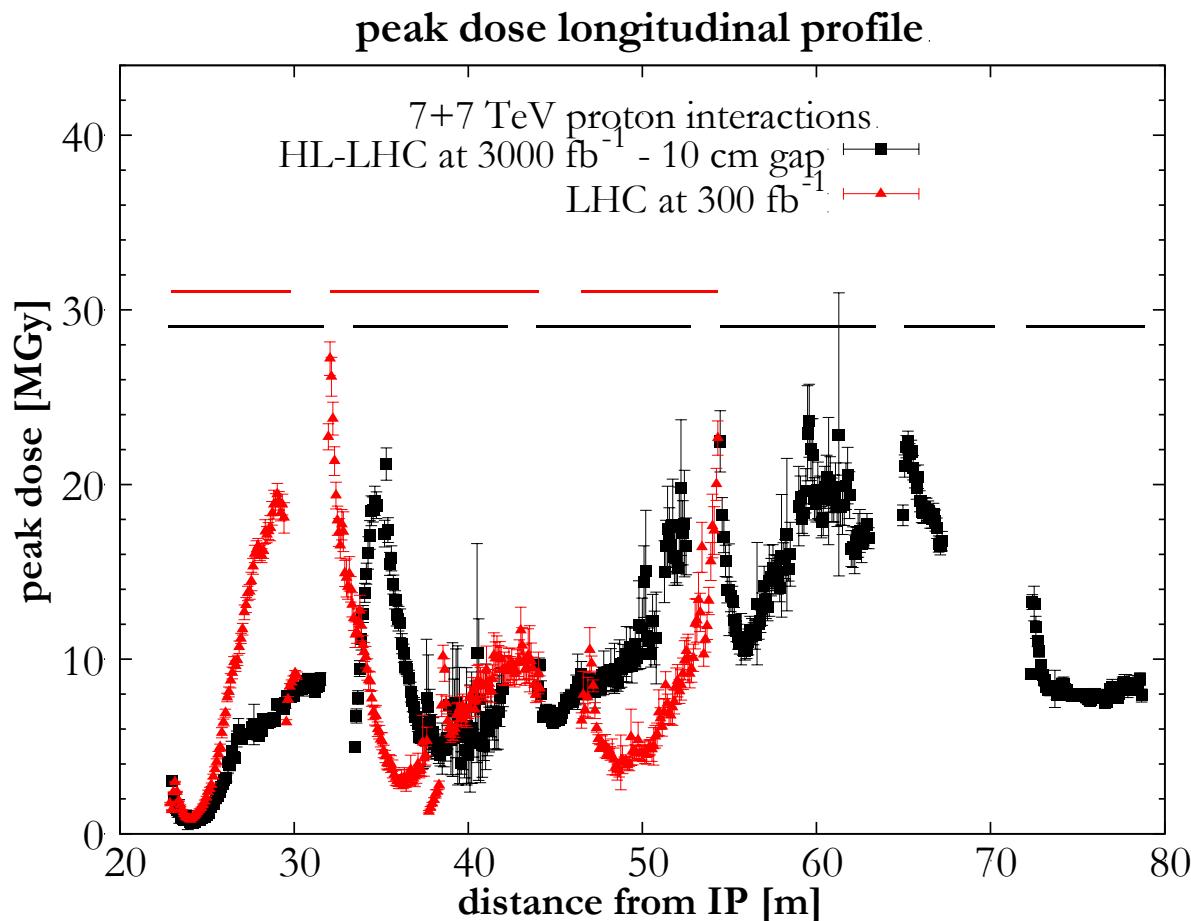
Tungsten inserts



4 LHe channels with inner radius = 1.78 mm  
Tungsten density = 19.3 g/cm<sup>3</sup> (no packing factor)

Beam screen and e-clouds in the triplet  
Nanographite coating for SEY 0.95!  
Test at cold in SPS end of 2014  
Electrodes (tested at LNF in 2012) also studied

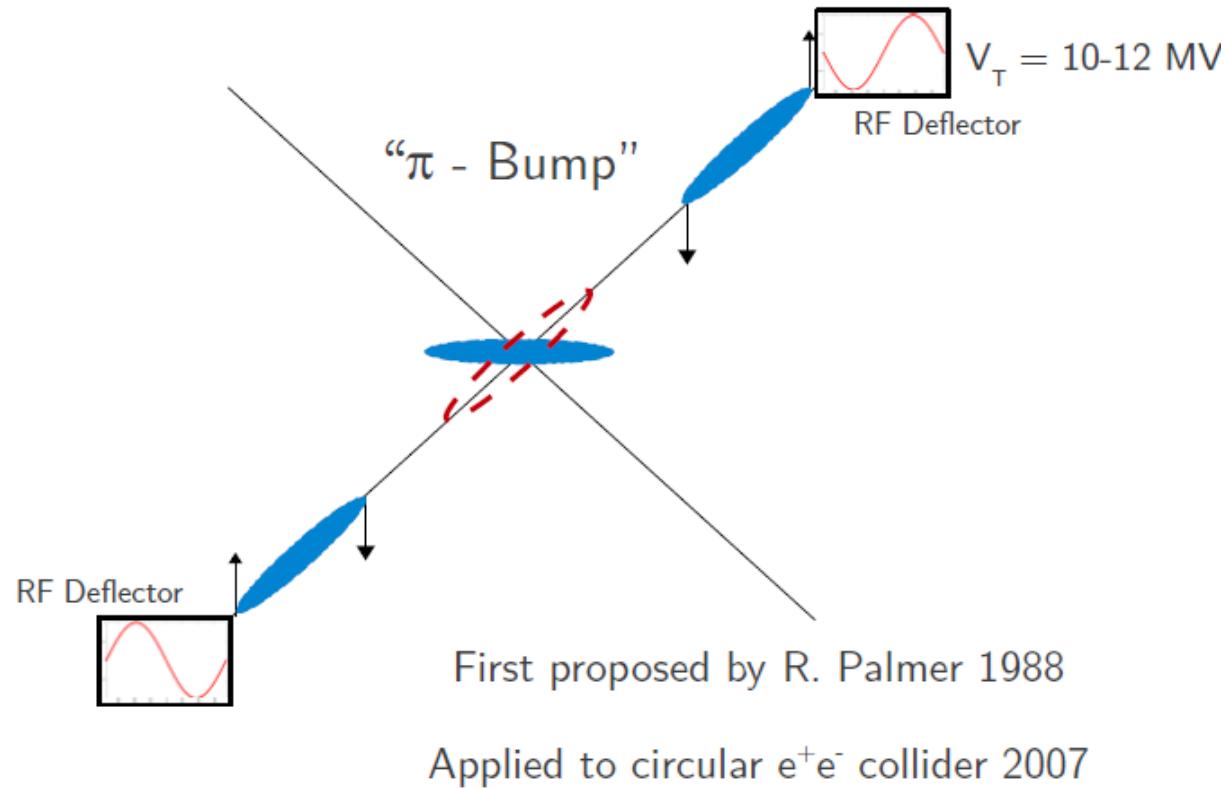
# IT dose on critical components in HL-LHC



However design for rad hard is under way (better insulation, metallic spacers, etc.)

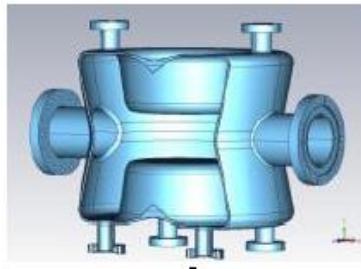
# Crab Cavities

To Maximize Collision Efficiency

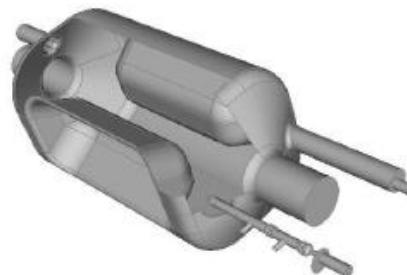


# Situation: from drawings to reality...

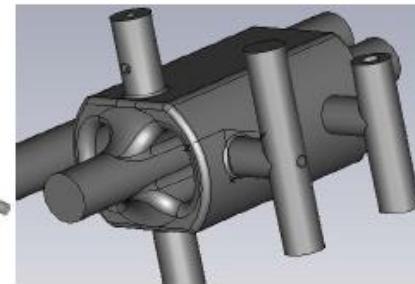
All Prototypes in Bulk Niobium (2011-12)



LARP-BNL



LARP-ODU-JLAB

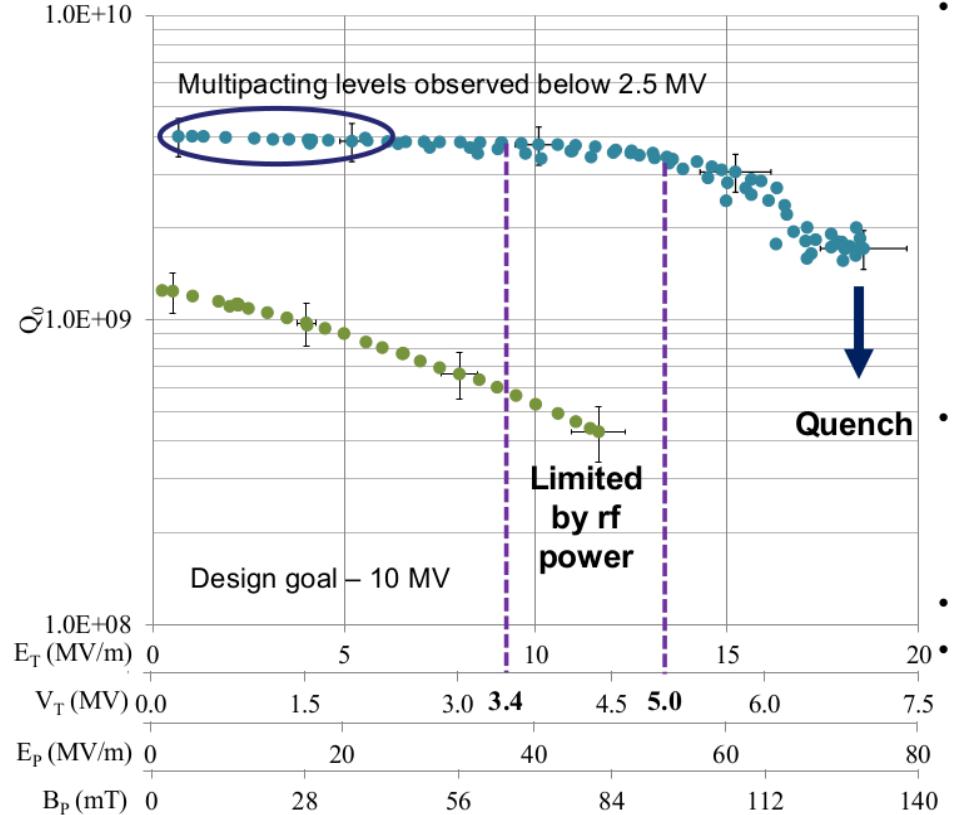


UniLancaster-CI-CERN

# And excellent results: RF dipole > 5 MV

¼ w and 4-rods also tested (1.5 MV)

cleaning & vacuum issues: new test under way)

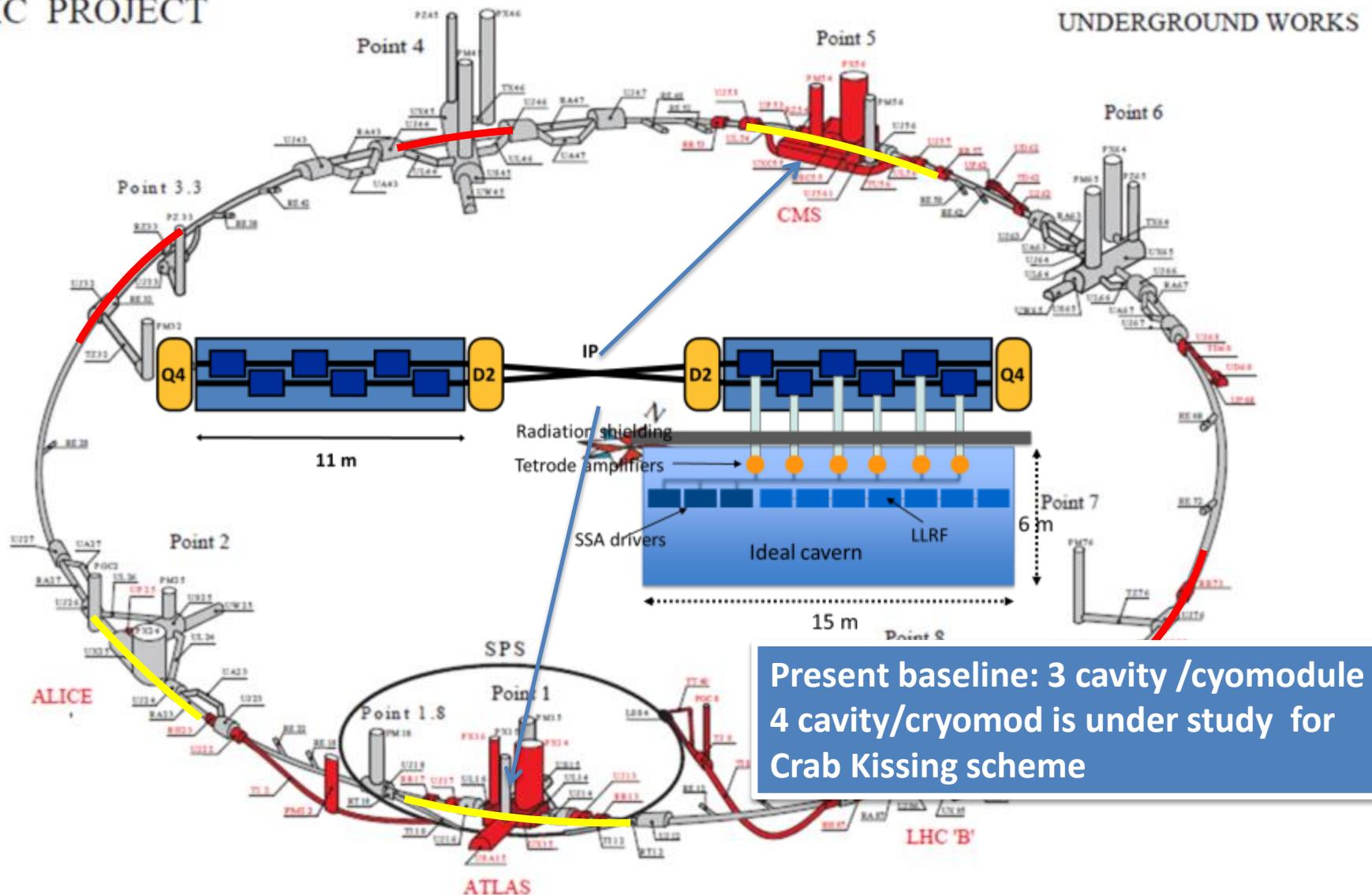


Initial goal was 3.5 MV  
> 5 MV would easy integration

# Crab Cavities for fast beam rotation

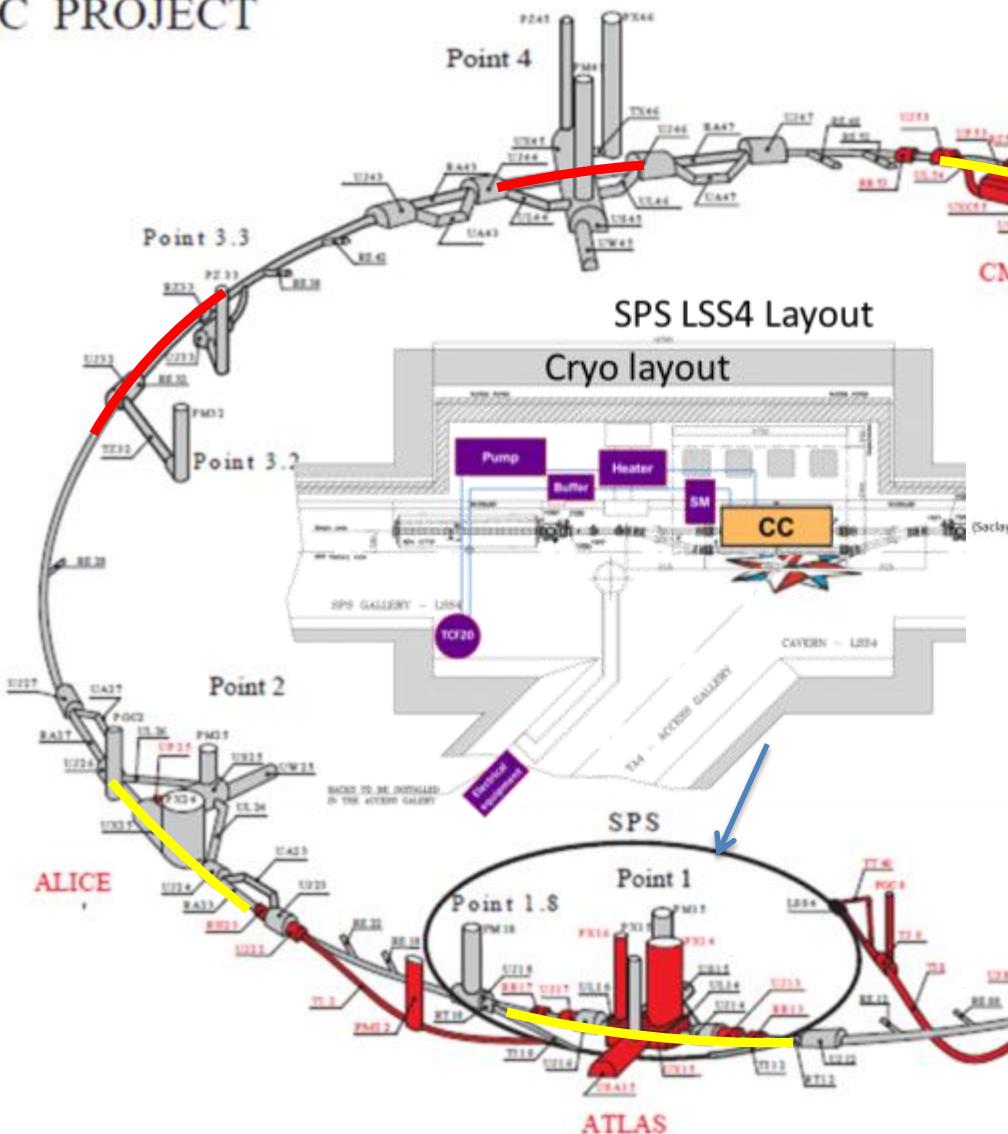
LHC PROJECT

UNDERGROUND WORKS

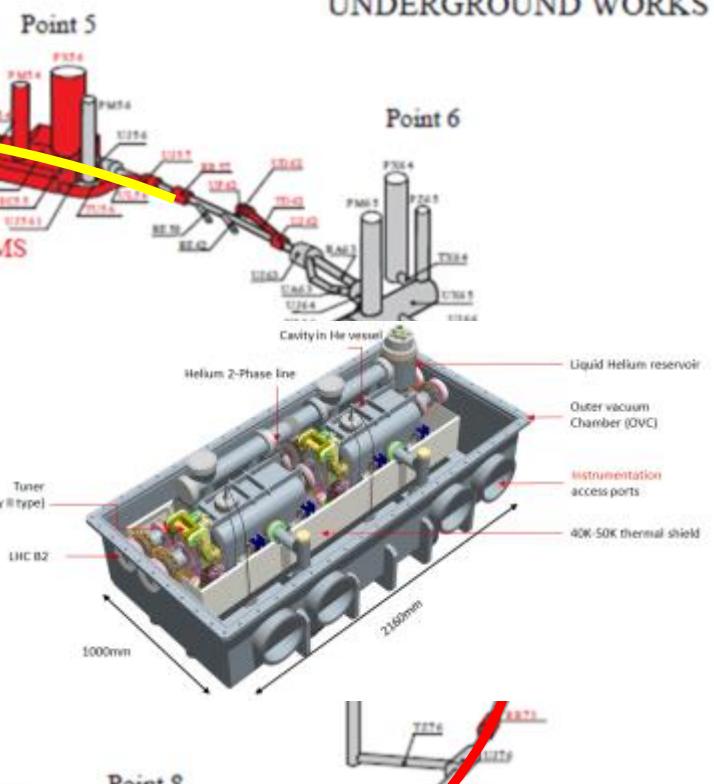


# Crab Cavities roadmap: beam test SPS

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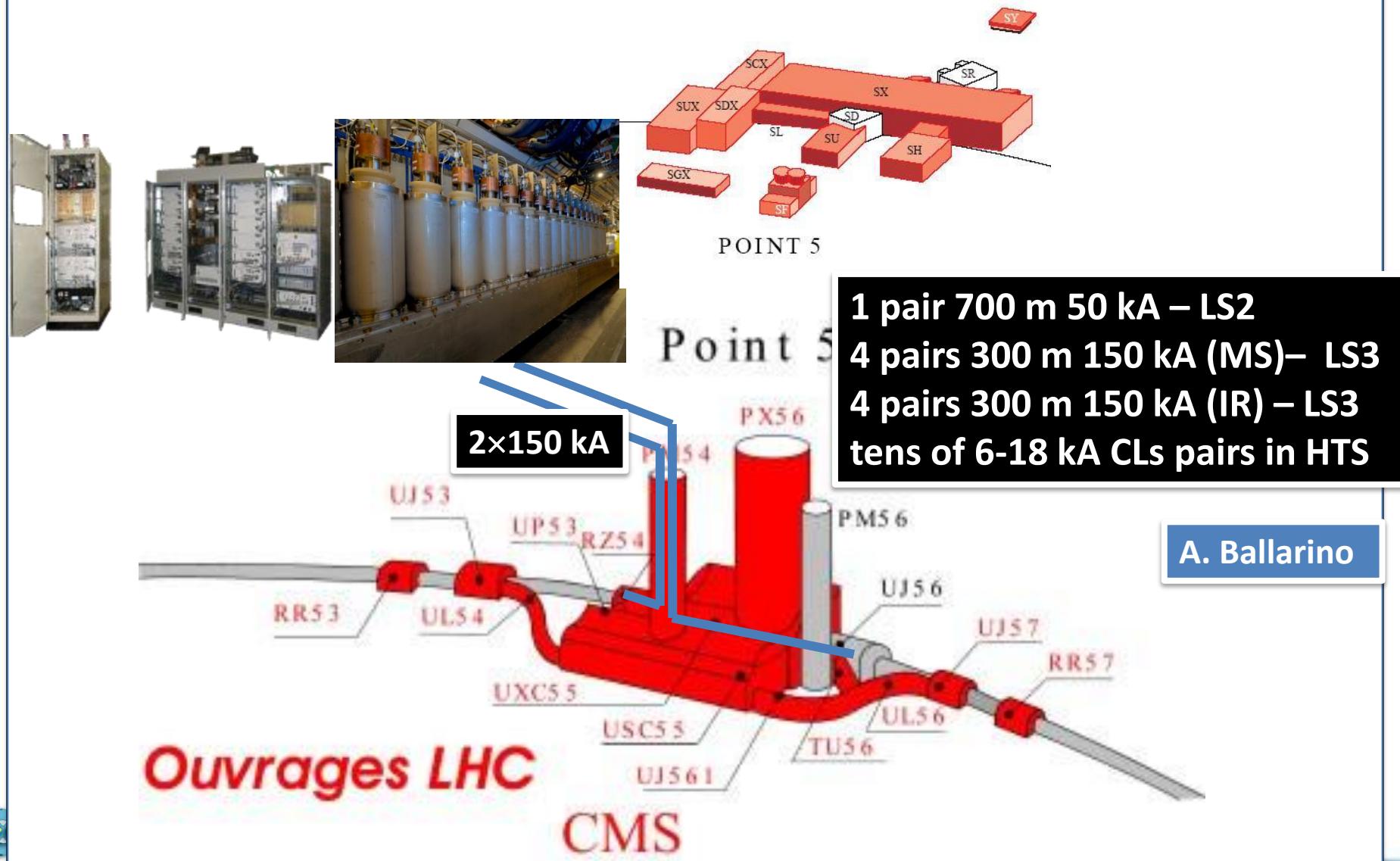


UNDERGROUND WORKS



Test with SPS beam foreseen in  
2016/17; 2 cavity/cryomod.

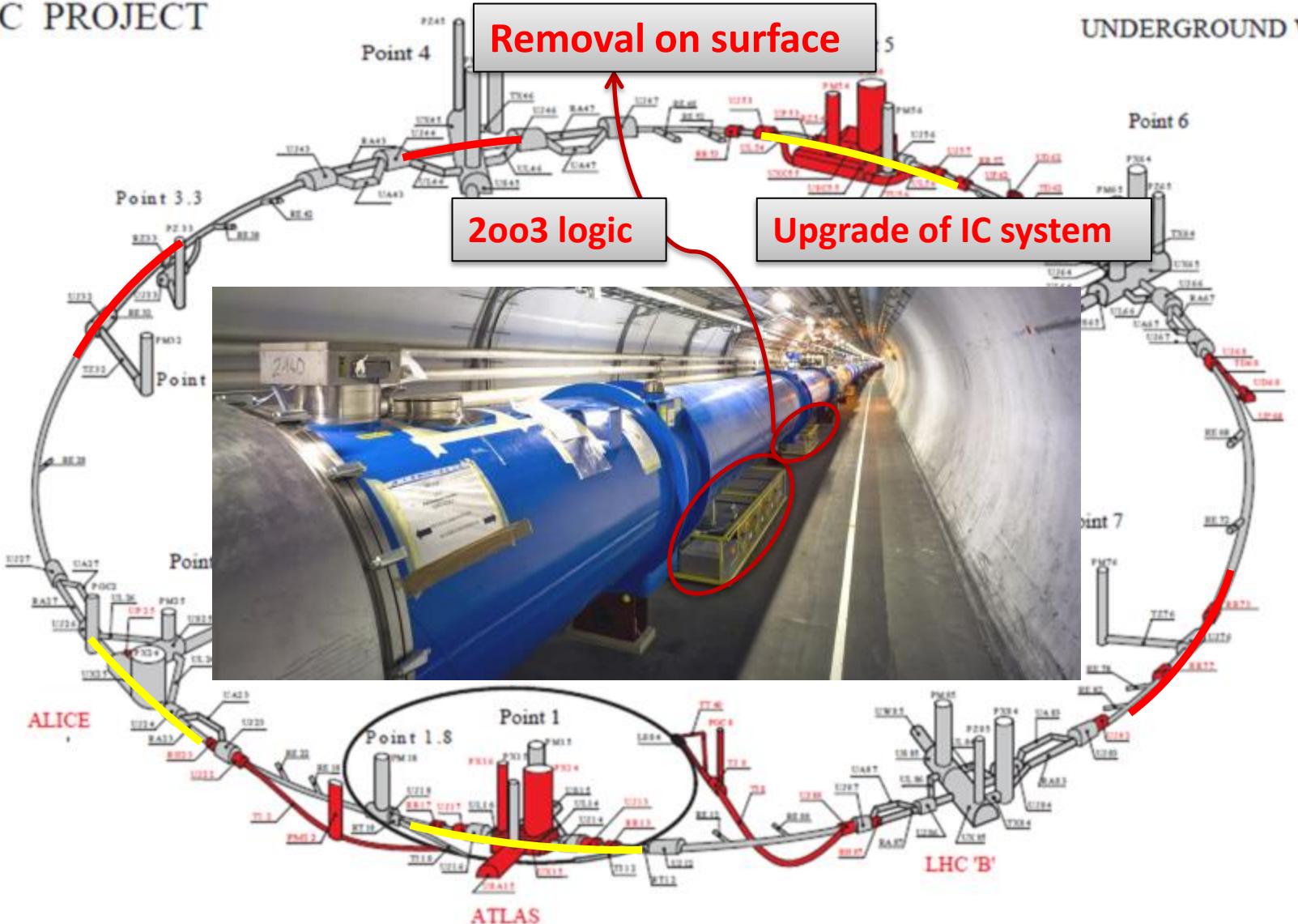
# Availability: SC links $\Rightarrow$ EPCs, DFBs on surface)



# Availability 2: Magnet QPS upgrade

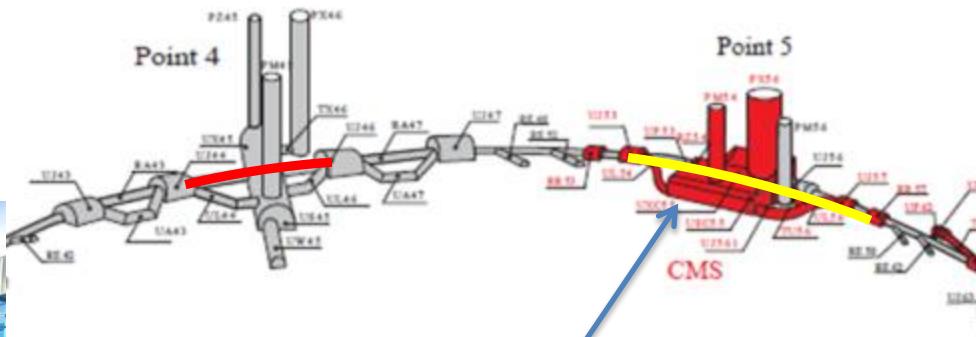
LHC PROJECT

UNDERGROUND WORKS



# IT cryoplants and new LSS QRL

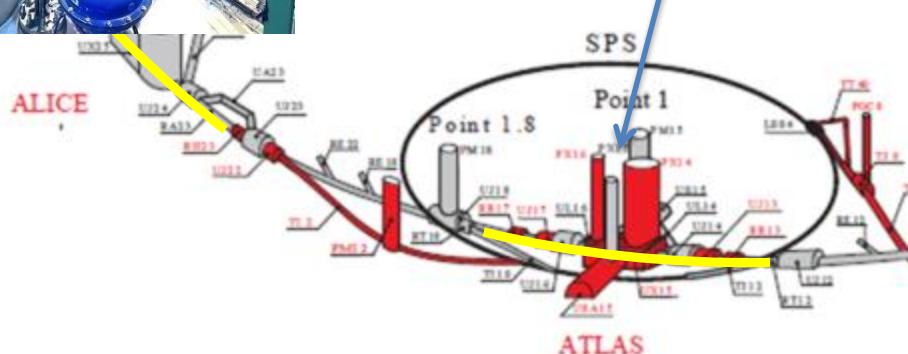
## LHC PROJECT



## UNDERGROUND WORKS

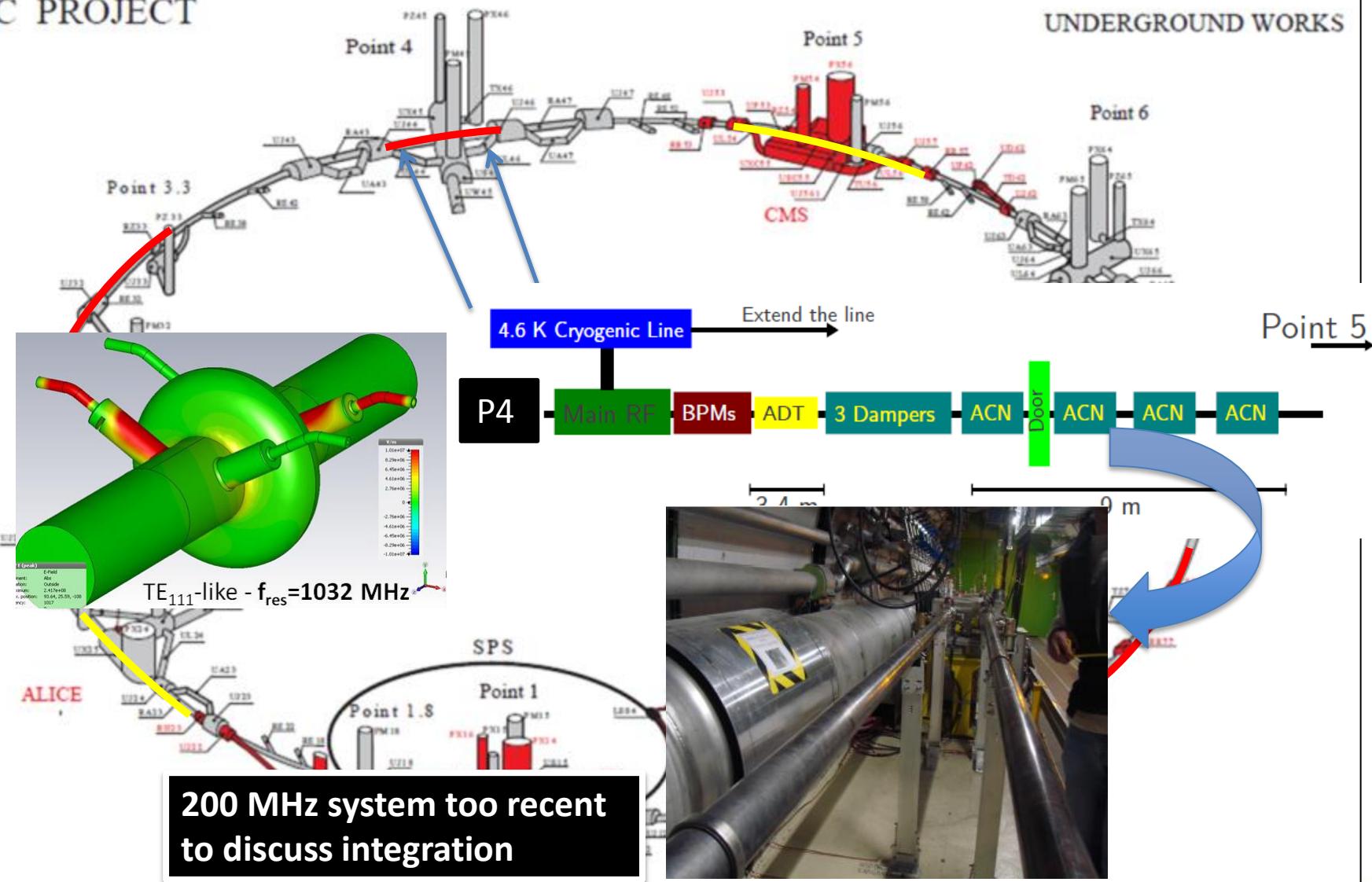


**Availability:** separation New Inner Triplets (and IPM in MS) from the arc cryogenics.  
Keeping redundancy for nearby arc cryoplant  
**Redundancy with nearby Detector SC Magnets cryoplant**



# SCRF 800 MHz harmonic: under study

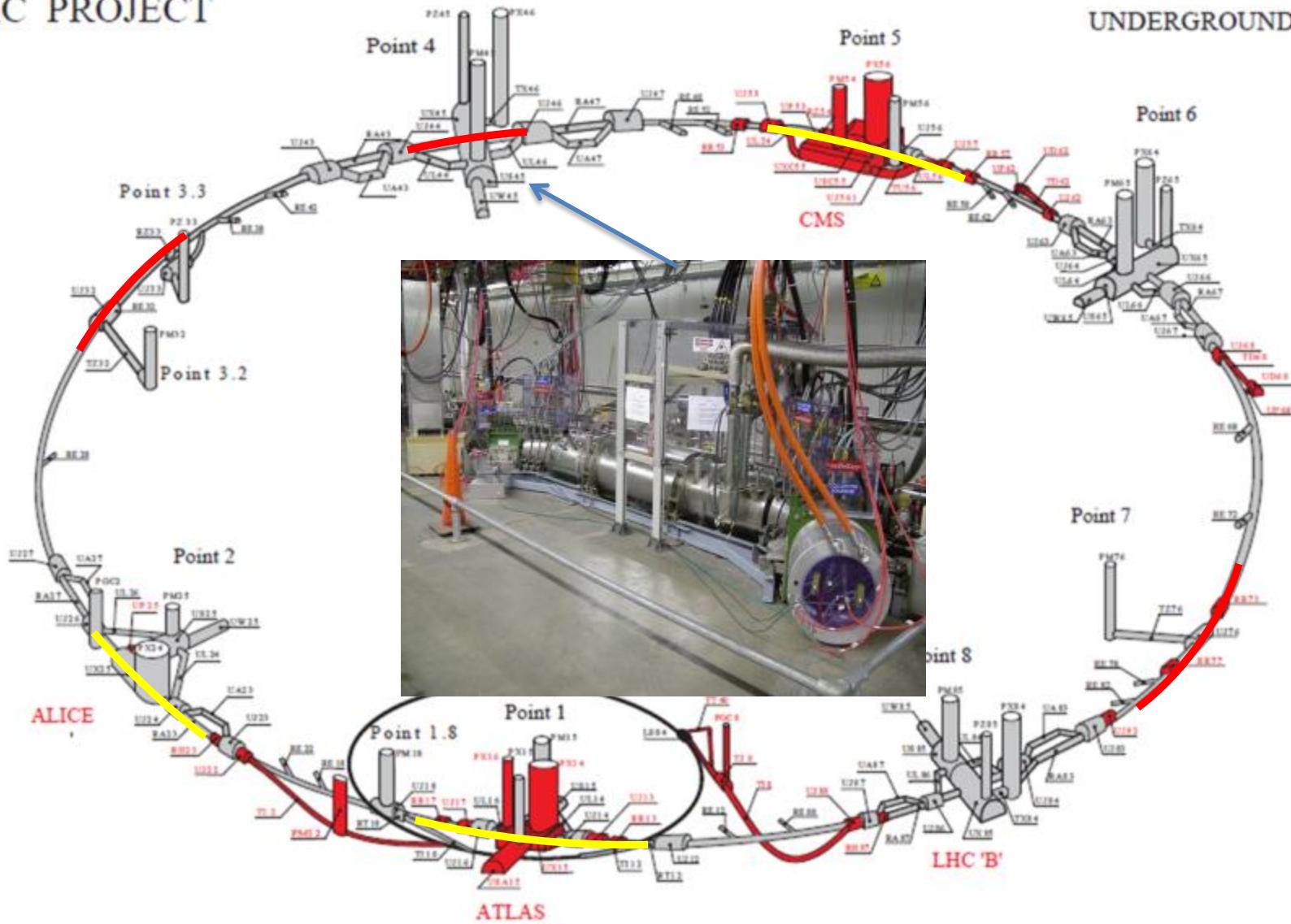
LHC PROJECT



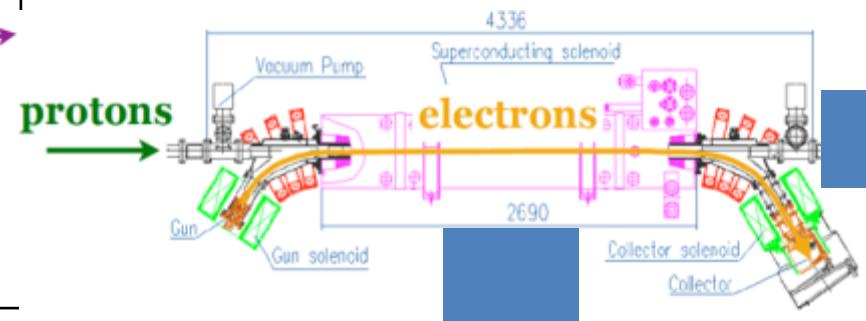
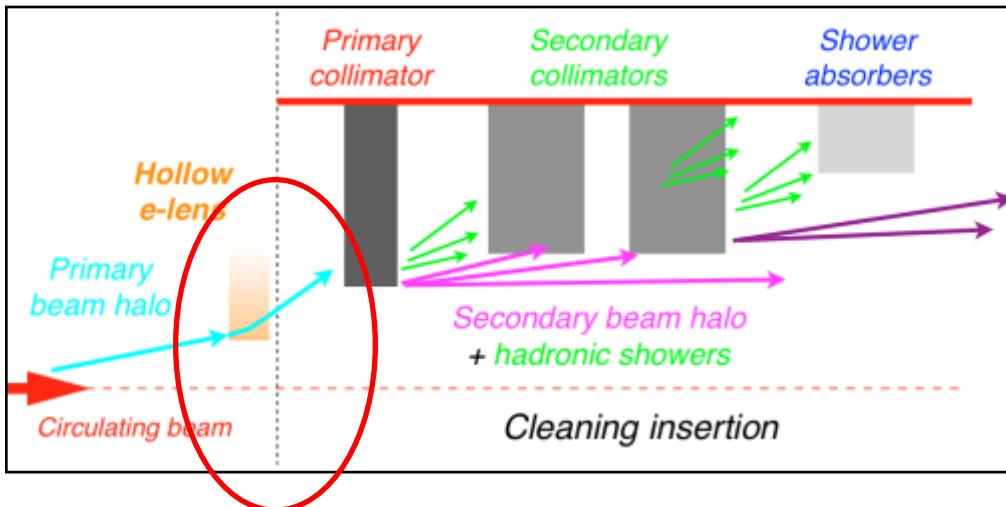
# Halo control (hollow e-lens)

LHC PROJECT

UNDERGROUND WORKS



# Controlling diffusion rate: hollow e-lens

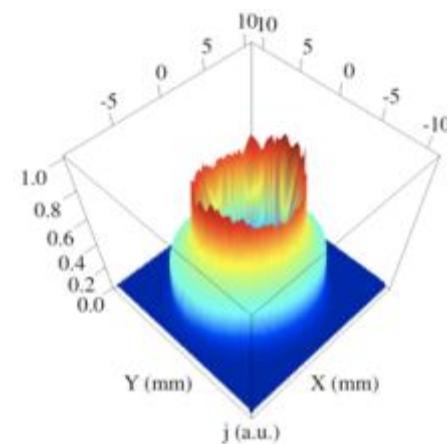


## Promises of hollow e-lens:

1. Control the halo dynamics without affecting the beam core;
2. Control the time-profile of beam losses (avoid loss spikes);
3. Control the steady halo population (crucial in case of CC fast failures).

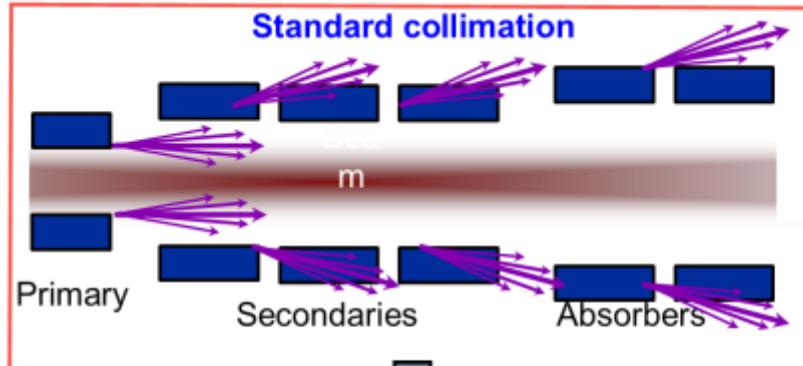
## Remarks:

- very convincing experimental experience in other machines!
- full potential can be exploited if appropriate halo monitoring is available.



S. Redaelli  
Developed by Fermilab

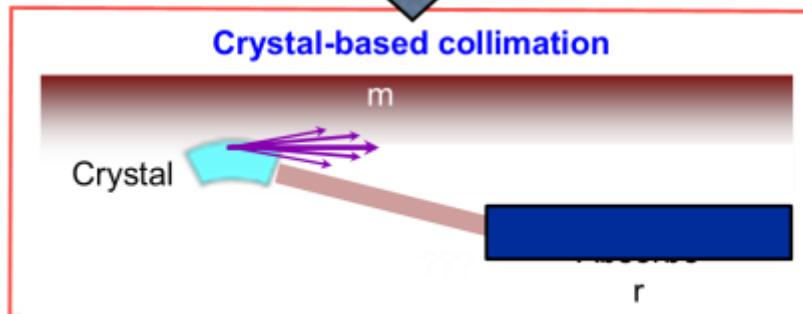
# Option for improved collimation: crystal



Promises of crystal collimation:

1. Improved DS cleaning in channeling;
2. Reduce impedance: less secondary collimators and larger gaps;
3. Much improved cleaning for ion beams.

S. Redaelli

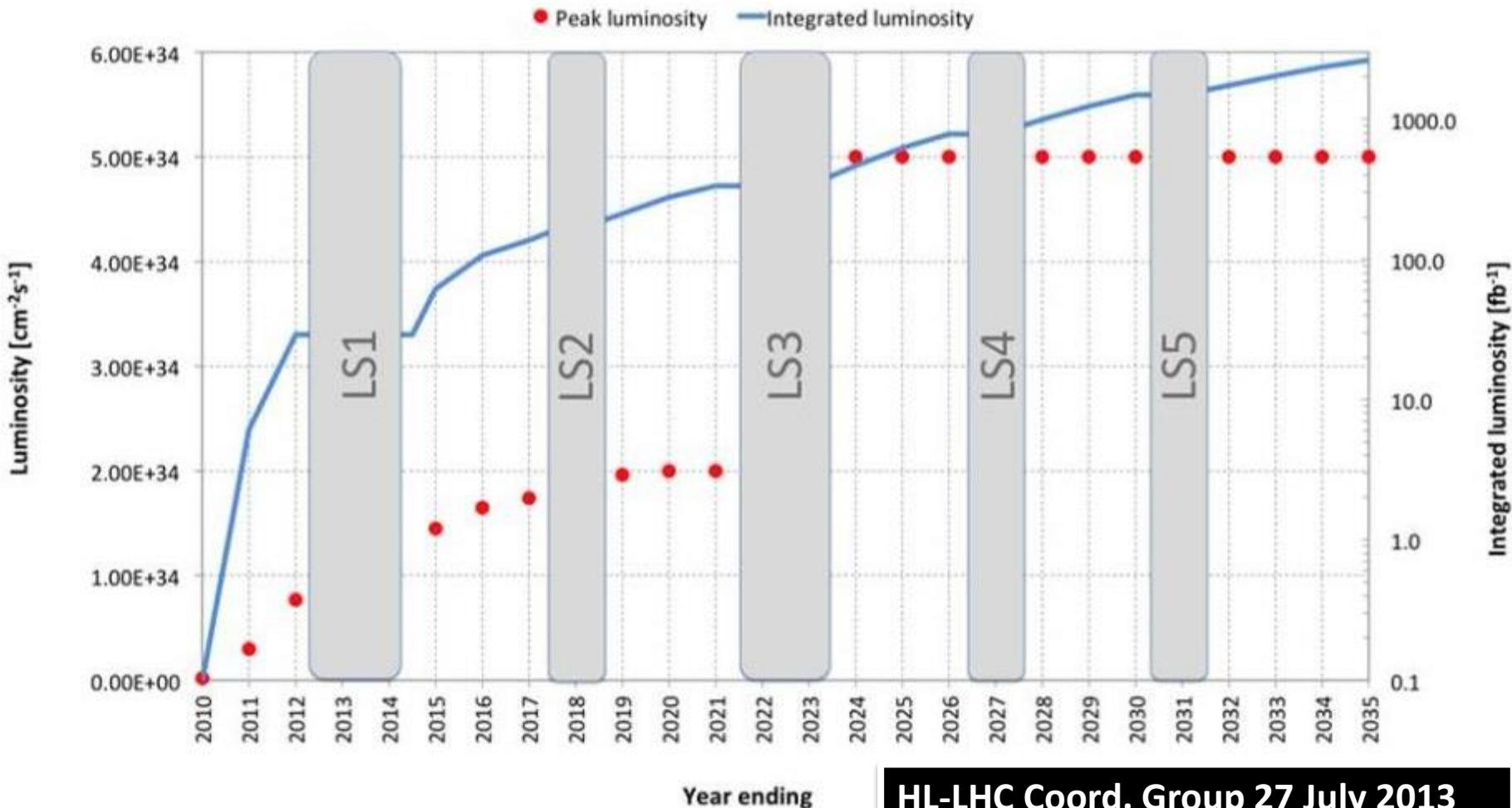


Promising results at the SPS.

Uncertainties on the **extrapolation** to unknown energy territories and **operational challenges** call for solid experimental validation before this technology can be relied upon for future designs.

- Can crystal collimation compete with the present very good cleaning system?
  - Uncertainty for the scaling to higher energy (e.g.: single diffractive losses).
  - Operational challenges for the complex operational cycle (ramp, squeeze, etc...).
  - Some outstanding machine protection concerns must be addressed.
- Can we absorb more than 1 MW in one single block?

# Extended Baseline operation scenario



HL-LHC Coord. Group 27 July 2013  
M. Lamont

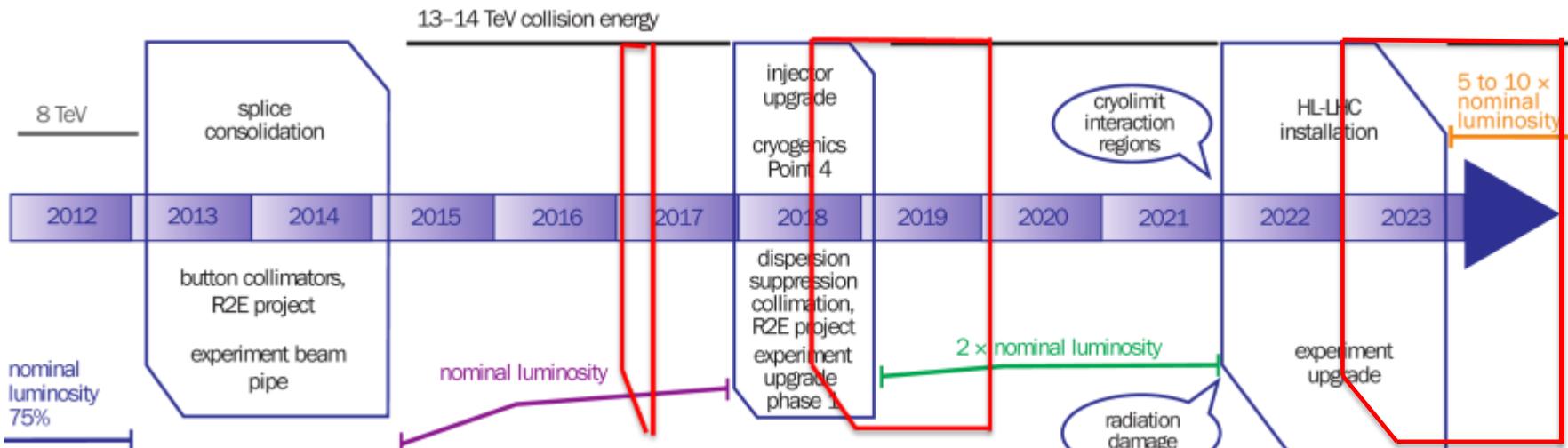
# LHC tunnel will be a hostile environment: robustness, removal to surface (or aside alcove?), remote handling...

| 6 months cooling |       |       |
|------------------|-------|-------|
|                  | x/LS1 | x/LS3 |
| LS2              | 3.4   | 1.3   |
| LS3              | 4.3   | 1.0   |
| LS4              | 20.2  | 4.7   |
| LS5              | 22.0  | 5.1   |
| 2035             | 22.7  | 5.2   |

|            | remaining dose radiation enhancement factor<br>w.r.t. June 2013 (6 months of cooling after RUN I) |
|------------|---|
| LS2 (2019) | 3.4   |
| LS3 (2022) | 4.3   |
| PIC (2035) | 7   |
| US1(2035)  | 15  |
| US2(2035)  | 22.7  |

We need to catch up with Integration Studies and Collider-Experiment Interface  
1 day workshop on remote handling ⇒ start of a WG CERN-wide

# HL-LHC installation fits the present plan



- 11 T (for DS cryolcoll.) by 2017 for P2 (ions) **is difficult**: a shift of six months or more would be welcome
- Demo of CC in 2016-17 (with SPS beam test); 2022 is challenging; one year more would certainly welcome.
- Anticipating infrastructure for LS2: an extended Winter Stop is welcome (but not mandatory)
- Summary:
  - an extended winter stop end of 2016; 6 months shift of LS2 with LS2 = 1.5 y;
  - LS3 covering 2023-24 IS FINE for HL-LHC.
- **Longer «delay» or shift would make reconsider the whole schedule (anticipating IR installation in LS2?, Merging LS2-LS3?)**

# HL-LHC matrix: equipment, time, cost

| LS2 - 1 y (14 months access)     | LS3 - 2 y (26 months access) |     |     |     | Cost (MCHF) | In kind<br>in part |
|----------------------------------|------------------------------|-----|-----|-----|-------------|--------------------|
|                                  | PIC                          |     | US1 | US2 |             |                    |
|                                  | LS2                          | LS3 | LS3 | LS3 |             |                    |
| P4 new cryoplant                 | Y                            |     |     |     | 15          |                    |
| H SC link P7                     | Y                            |     |     |     | 5           |                    |
| IR (IT,D1, TAS)                  | %                            | Y   |     |     | 210         | YES                |
| P1-P5 cryoplant                  | %                            | Y   |     |     | 75          |                    |
| SC link (EPC&DFBX on surface)    | %                            | Y   |     |     | 40          |                    |
| Collimators IR                   |                              | Y   |     |     | 10          |                    |
| Collimators MoGr                 | %                            | Y   |     |     | 15          |                    |
| Collimators for INJ &TCLA Q4/Q5) |                              | Y   |     |     | 5           |                    |
| DS cryocoll.(11T) P2             | Y                            |     |     |     | 20          | 395                |

# HL-LHC matrix: equipment, time, cost

| LS2 - 1 y (14 months access)        | LS3 - 2 y (26 months access) |     |     |     | Cost (MCHF) | In kind<br>in part |
|-------------------------------------|------------------------------|-----|-----|-----|-------------|--------------------|
|                                     | PIC                          |     | US1 | US2 |             |                    |
|                                     | LS2                          | LS3 | LS3 | LS3 |             |                    |
| P4 new cryoplant                    | Y                            |     |     |     | 15          |                    |
| H SC link P7                        | Y                            |     |     |     | 5           |                    |
| IR (IT,D1, TAS)                     | %                            | Y   |     |     | 210         | YES                |
| P1-P5 cryoplant                     | %                            | Y   |     |     | 75          |                    |
| SC link (EPC&DFBX on surface)       | %                            | Y   |     |     | 40          |                    |
| Collimators IR                      |                              | Y   |     |     | 10          |                    |
| Collimators MoGr                    | %                            | Y   |     |     | 15          |                    |
| Collimators for INJ &TCLA Q4/Q5)    |                              | Y   |     |     | 5           |                    |
| DS cryocoll.(11T) P2                | Y                            |     |     |     | 20          | 395                |
| LRBB comp.wires                     |                              | Y   |     |     | 10          |                    |
| DS cryocoll.(11T) P7                |                              | Y   |     |     | 25          |                    |
| DS cryocoll (11 T) P1-P5            |                              | Y   |     |     | 40          |                    |
| SC link (EPC&DFB on surface) for MS |                              | Y   |     |     | 20          | 95                 |

# HL-LHC matrix: equipment, time, cost

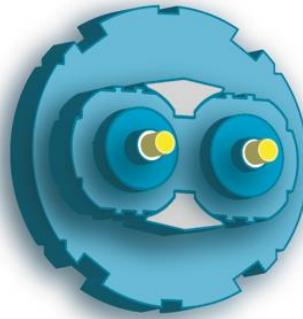
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|-------------------------------------|------------------------------|-----|-----|-----|-------------|--------------------|
|                                     | PIC                          |     | US1 | US2 |             |                    |
|                                     | LS2                          | LS3 | LS3 | LS3 |             |                    |
| P4 new cryoplant                    | Y                            |     |     |     | 15          |                    |
| H SC link P7                        | Y                            |     |     |     | 5           |                    |
| IR (IT,D1, TAS)                     | %                            | Y   |     |     | 210         | YES                |
| P1-P5 cryoplant                     | %                            | Y   |     |     | 75          |                    |
| SC link (EPC&DFBX on surface)       | %                            | Y   |     |     | 40          |                    |
| Collimators IR                      |                              | Y   |     |     | 10          |                    |
| Collimators MoGr                    | %                            | Y   |     |     | 15          |                    |
| Collimators for INJ &TCLA Q4/Q5)    |                              | Y   |     |     | 5           |                    |
| DS cryocoll.(11T) P2                | Y                            |     |     |     | 20          | 395                |
| LRBB comp.wires                     |                              | Y   |     |     | 10          |                    |
| DS cryocoll.(11T) P7                |                              | Y   |     |     | 25          |                    |
| DS cryocoll (11 T) P1-P5            |                              | Y   |     |     | 40          |                    |
| SC link (EPC&DFB on surface) for MS |                              | Y   |     |     | 20          | 95                 |
| MS new layout (P1-P5) and Q5 in P6  |                              |     | Y   |     | 30          | YES                |
| Machine & Magnet QPS (Availability) |                              |     | Y   |     | 25          |                    |
| CC cavity P1-P5                     |                              |     | Y   |     | 95          | YES                |
| SCRF 2nd Harmonic                   |                              |     | Y   |     |             |                    |
| Crystal Coll                        |                              |     | Y ? |     |             | YES ?              |
| Halo control (e-lens)               |                              |     | Y ? |     |             | YES                |
| High Band Feedback System           |                              |     | Y ? |     |             | 150                |

# HL-LHC matrix: equipment, time, cost

| LS2 - 1 y (14 months access)        | LS3 - 2 y (26 months access) |     |     |     | Cost (MCHF) | In kind<br>in part |
|-------------------------------------|------------------------------|-----|-----|-----|-------------|--------------------|
|                                     | PIC                          |     | US1 | US2 |             |                    |
|                                     | LS2                          | LS3 | LS3 | LS3 |             |                    |
| P4 new cryoplant                    | Y                            |     |     |     | 15          |                    |
| H SC link P7                        | Y                            |     |     |     | 5           |                    |
| IR (IT,D1, TAS)                     | %                            | Y   |     |     | 210         | YES                |
| P1-P5 cryoplant                     | %                            | Y   |     |     | 75          |                    |
| SC link (EPC&DFBX on surface)       | %                            | Y   |     |     | 40          |                    |
| Collimators IR                      |                              | Y   |     |     | 10          |                    |
| Collimators MoGr                    | %                            | Y   |     |     | 15          |                    |
| Collimators for INJ &TCLA Q4/Q5)    |                              | Y   |     |     | 5           |                    |
| DS cryocoll.(11T) P2                | Y                            |     |     |     | 20          | 395                |
| LRBB comp.wires                     |                              | Y   |     |     | 10          |                    |
| DS cryocoll.(11T) P7                |                              | Y   |     |     | 25          |                    |
| DS cryocoll (11 T) P1-P5            |                              | Y   |     |     | 40          |                    |
| SC link (EPC&DFB on surface) for MS |                              | Y   |     |     | 20          | 95                 |
| MS new layout (P1-P5) and Q5 in P6  |                              |     | Y   |     | 30          | YES                |
| Machine & Magnet QPS (Availability) |                              |     | Y   |     | 25          |                    |
| CC cavity P1-P5                     |                              |     | Y   |     | 95          | YES                |
| SCRF 2nd Harmonic                   |                              |     | Y   |     |             |                    |
| Crystal Coll                        |                              |     | Y ? |     |             | YES ?              |
| Halo control (e-lens)               |                              |     | Y ? |     |             | YES                |
| High Band Feedback System           |                              |     | Y ? |     |             | 150                |
| Studies                             |                              |     |     |     | 10          |                    |
| Other systems (Studies, Vacuum,     |                              |     |     |     |             |                    |
| Diagnostics, Remote handling        |                              |     |     |     | 30          |                    |
| Infrastructure, Logistics,          |                              |     |     |     |             |                    |
| Integration,Installation HWC        |                              |     |     |     | 130         | 170                |
| <b>Total</b>                        |                              |     |     |     | <b>810</b>  | <b>810</b>         |

# Conclusions

- The upgrade is robust for 250 (300 )  $\text{fb}^{-1}/\text{y}$ 
  - Means to maintain or increase availability are under study
- All hardware is more robust for  $3000 \text{ fb}^{-1}$  than it is today for  $300 \text{ fb}^{-1}$
- Design Study finished by 2015 with the TDR
- Margins are there and – once established and proved:
  - Possible to decrease pile density and/or increase to  $350 \text{ fb}^{-1}$  ( $7 \cdot 10^{34}$  of  $L_{\text{level}}$ ) thanks to crab kiss (CC in II &  $\perp$  planes) and  $\beta^*$  of 10 cm (large aperture IT & ATS)
  - Increase data collection to  $> 4000 \text{ fb}^{-1}$



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.

