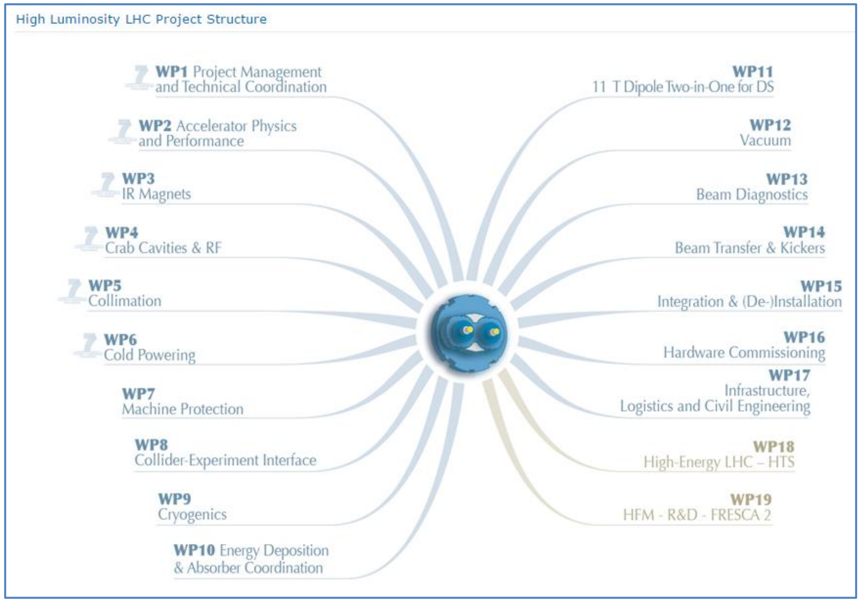
The High Luminosity LHC (HL-LHC) Project at CERN: The Challenge Ahead

High Luminosity LHC



R. Kersevan

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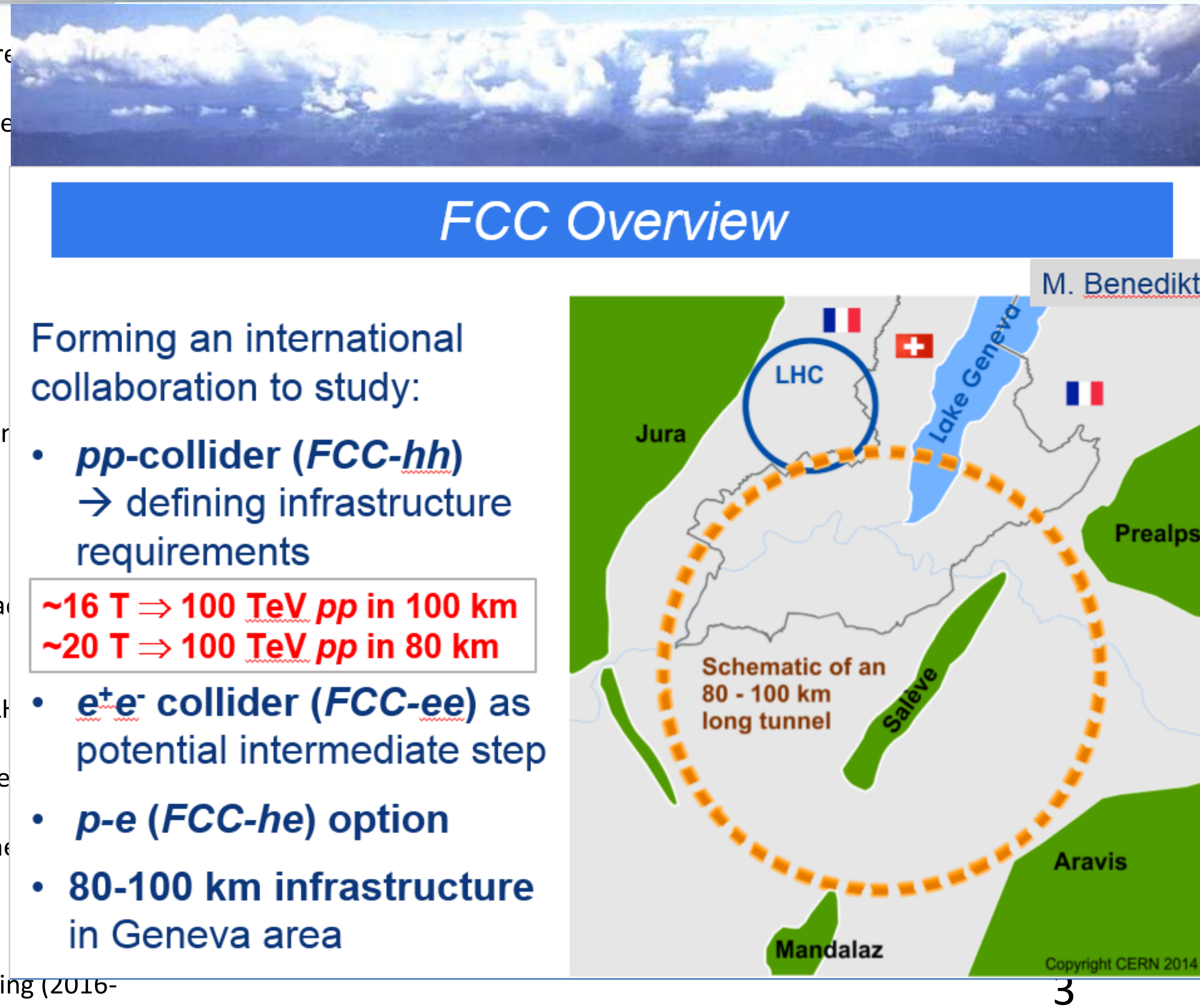
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

What is CERN?

Mostly known for LHC (“the Higgs Boson”), but there
more…

- Chain of accelerators, all connected together (e
  CTF-3, CLIC)
- Beam energies:
  - LINAC-2 → 50 MeV
  - Booster → 1.4 GeV
  - PS → 25 GeV
  - SPS → 450 GeV
  - LHC → 7000 GeV
- Other accelerators:
  - AD: Antiproton Decelerator, antiprotor
    studies
  - N-TOF: Neutron Time-Of-Flight
  - LEIR: Low-Energy Ion Ring
  - LINAC-3: ion injector to LEIR
  - ISOLDE: Isotope Separation On Line, ra
    beams
  - CTF-3: CLIC Test Facility
- Main Experiments (LHC): ATLAS, CMS, ALICE, LH
- Other experiments:
  - Control room of AMS-2 (docked to Inte
    Space Station)
  - NA-62, and other fixed-target experime
- New Projects:
  - LINAC-4 (160 MeV)
  - HIE-ISOLDE (High-energy upgrade)
  - ELENA: Extra-Low Energy Antiproton ring (2016-
    2017)
  - AWAKE: Plasma wake acceleration (2016)
  - **Hi-Lumi LHC (HL-LHC) (2023)**
- Studies: Future Circular Colliders, FCC-hh, FCC-ee, FCC-he
  (80~100 km rings)



TE-VSC

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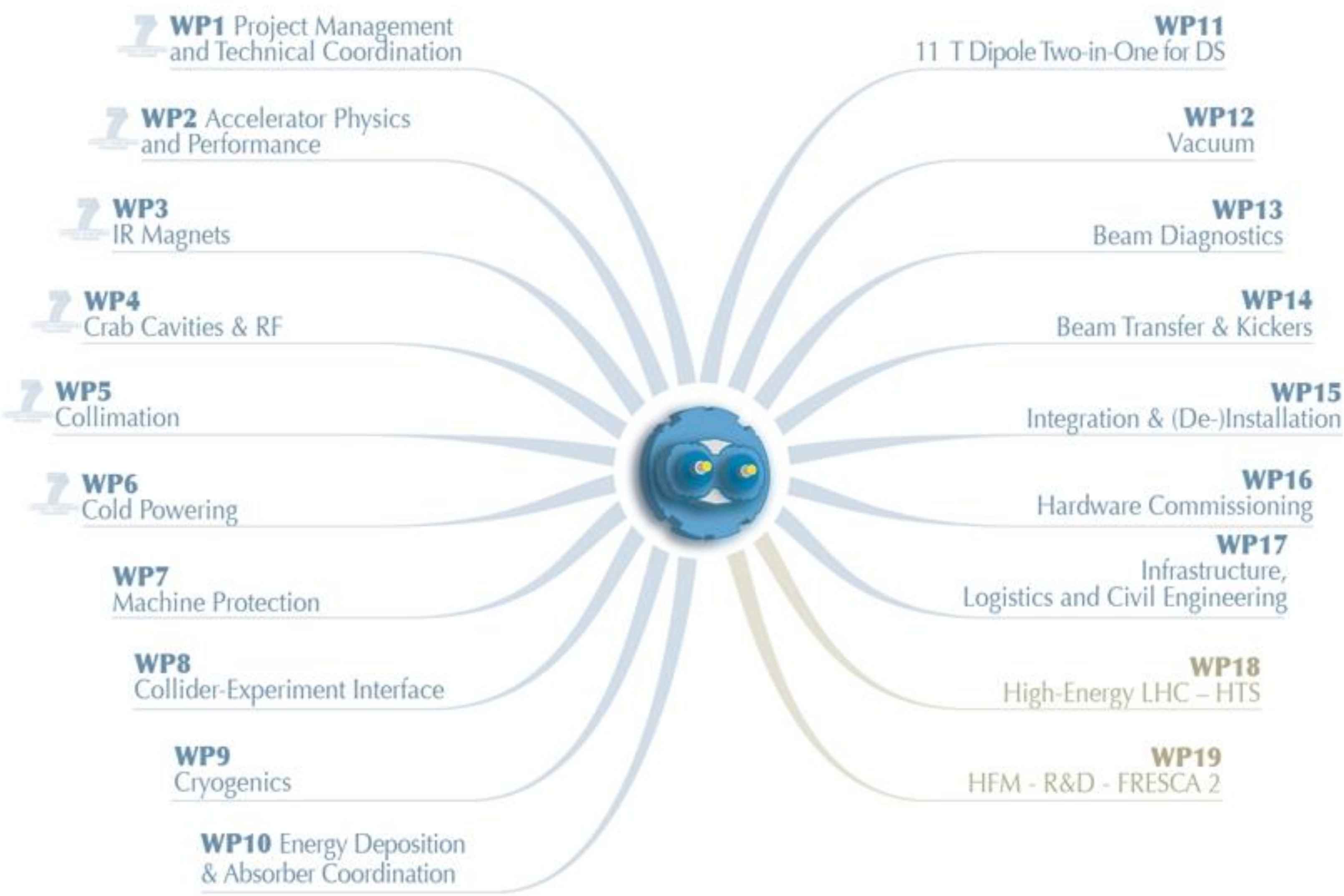
High Luminosity LHC Project Structure



Nov 2013: Daresbury Kick-off Meeting of the HL-LHC collaboration

From: LRossi-HL status@4th Annual Meeting@KEK

HL-LHC Baseline Parameters WP2 charge – PLC webpage

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

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**	[illegible]	3
ε_L [eVs]	2.50	[illegible]	[illegible]	2.50
r.m.s. bunch length [m]	7.5[illegible]	[illegible]	[illegible]02	7.55E-02
Piwinski angle	[illegible]	[illegible]	3.14	2.87
Geometric loss factor R0 without crab	[illegible]	**0.305**	0.305	0.331
Geometric loss factor R1 with cr[illegible]	[illegible](0.981)	**0.829**	**0.829**	**0.838**
beam-beam / IP without [illegible]	3.1E-03	**3.3E-03**	3.3E-03	4.7E-03
beam-beam / IP with Cra[illegible]	3.8E-03	**1.1E-02**	1.1E-02	1.4E-02
Peak Luminosity without [illegible]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 [$cm^{-2} s^{-1}$]	[illegible]	**5.00E+34**	5.00E34	2.50E+34
Events / crossing (with levelling and crab-cavities f[illegible]	[illegible]	**138**	146	135
Peak line d[illegible]	[illegible]	**1.25**	1.31	1.20
Levelling ti[illegible]	[illegible]	**8.3**	7.6	18.0

LIU required

Impedance, efficiency etc.

New IT Quads & ATS

C[illegible]

This makes 250 fb^{-1}/y a solid goal

Levelling required

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

Collision values

Climbing to the top...

HL-LHC *(3000 fb^{-1})* *(>2025)*

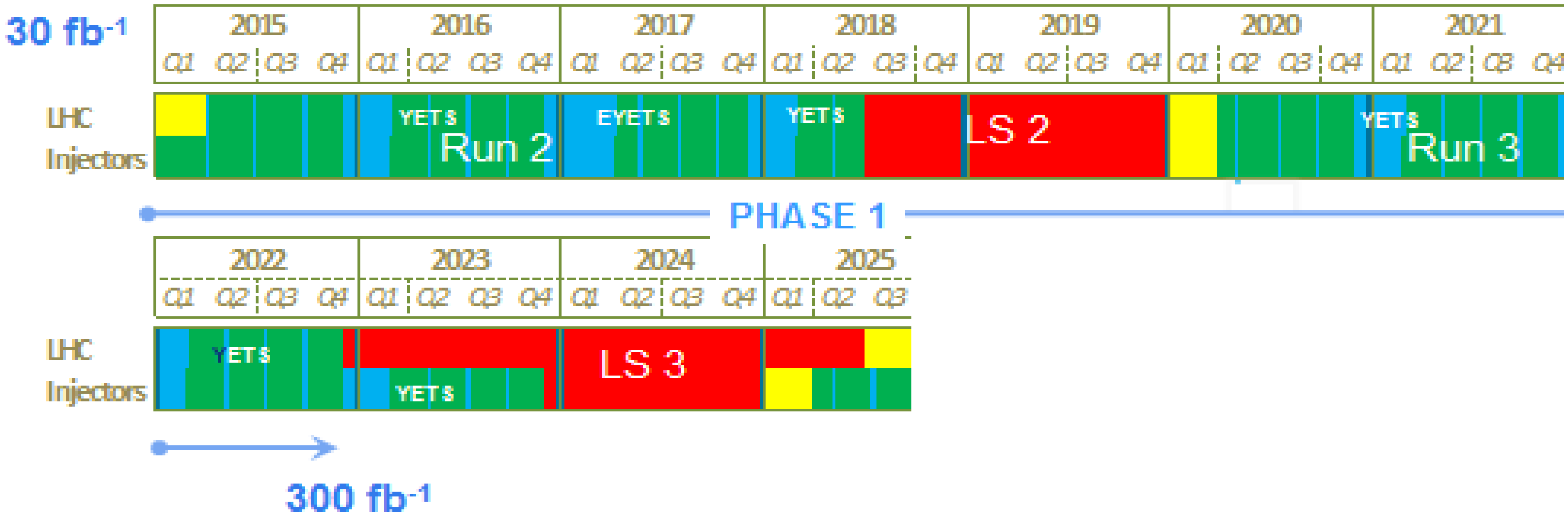
1 inverse femtobarn
$10^{-15} \times 10^{-28}$ m^2 = 10^{-43} m^2:
«a 150 m-long beach of fine sand extending 100 m into the land and with a depth of 1 m contains roughly the same number of sand grains as that number of collisions»

Worldwide LHC Computing Grid:
The data stream from the detectors provides approximately 300 GByte/s of data, which after filtering for "interesting events", results in a "raw data" stream of about 300 MByte/s, or **5400 Tbytes** of data for a 5000 hour/y run

LHC 13-14 TeV *(300 fb^{-1})* *(2015-2023)*

LHC 7-8 TeV *(30 fb^{-1})* *(2008-2012)*

LHC goal for 2015 and for Run 2 and 3



Integrated luminosity goal:

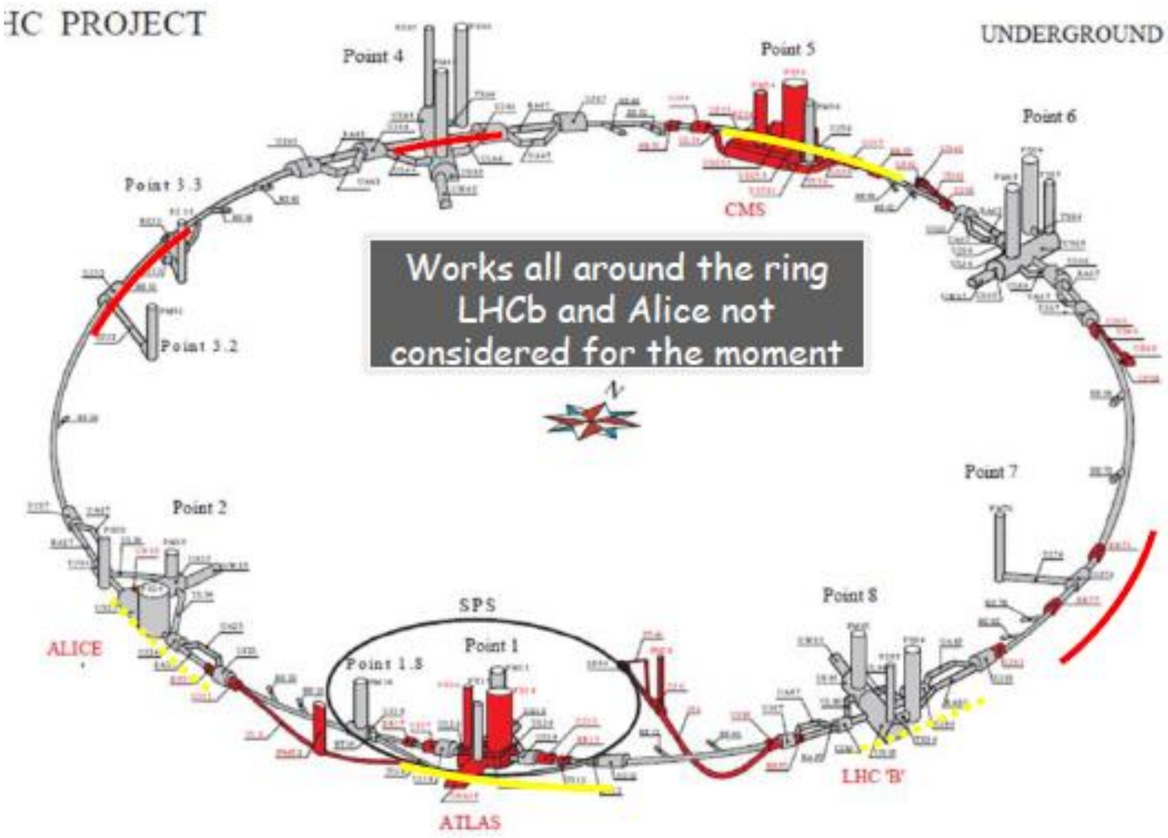
2015 : 10 fb^{-1}

Run2: ~100-120 fb^{-1}
(better estimation by end of 2015)

300 fb^{-1} before LS3

Adapted from F. Bordry - 4th Annual Meeting@KEK

The HL-LHC Project



- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- VACUUM ←
- …

Major intervention on more than 1.2 km of the LHC

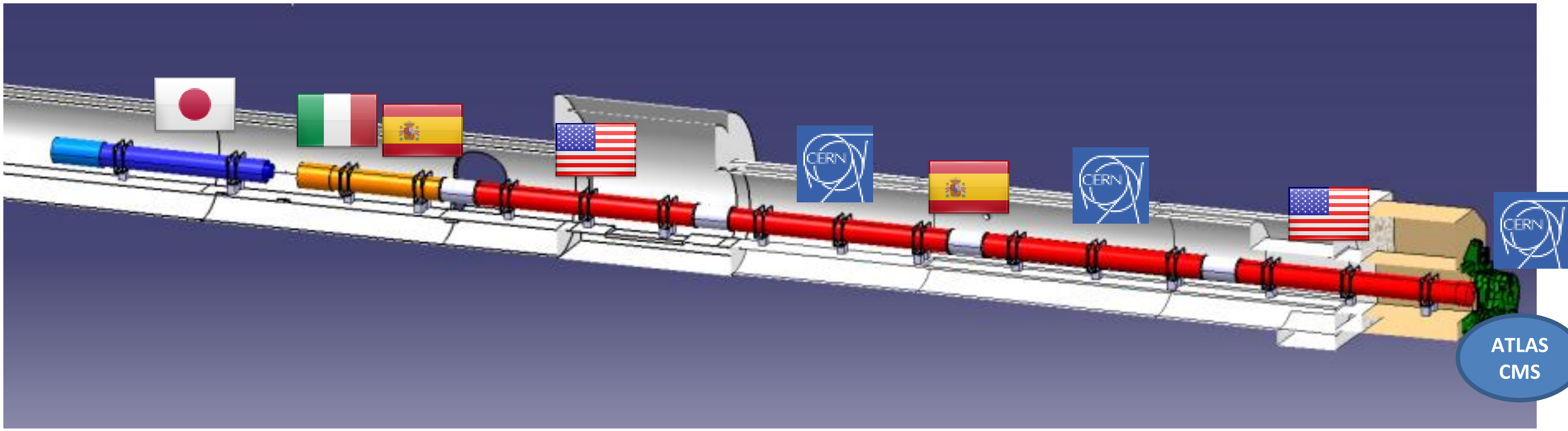
Project leader: Lucio Rossi; Deputy: Oliver Brüning

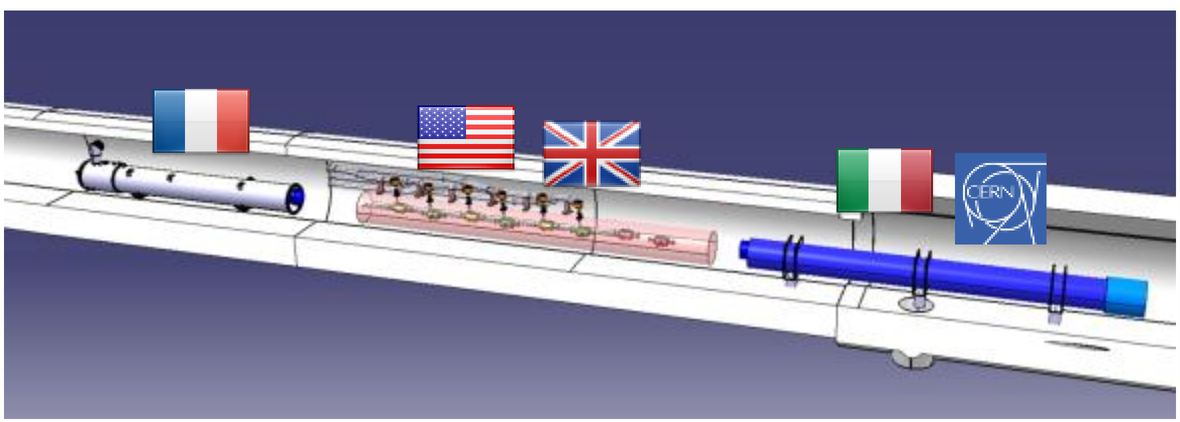
High Luminosity LHC

Adapted from F. Bordry - 4th Annual Meeting@KEK

High Luminosity LHC Participants

In-kind contribution and Collaboration for HW design and prototypes





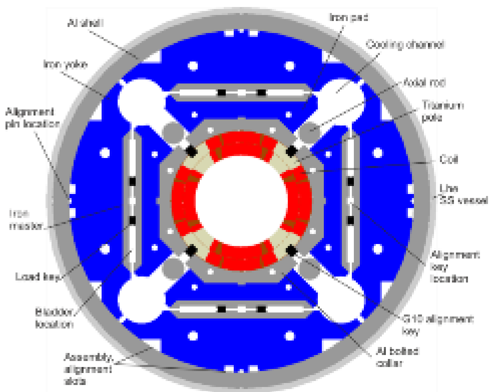
Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

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

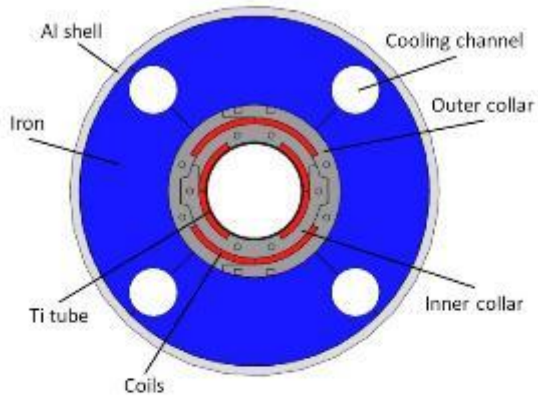
CC : R&D and Design **UK**

WP3 the magnet zoo in the IR

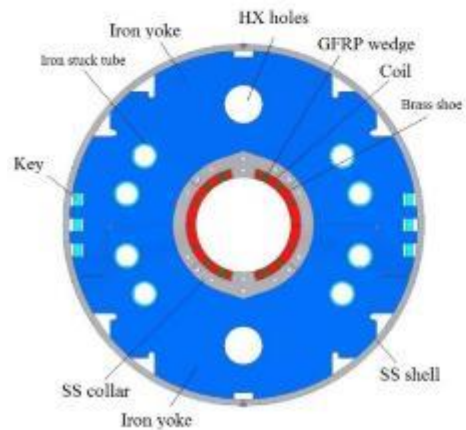
Ezio Todesco



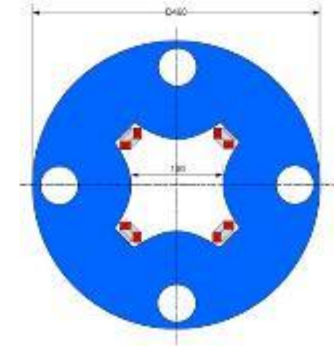
Triplet QXF (LARP and CERN)



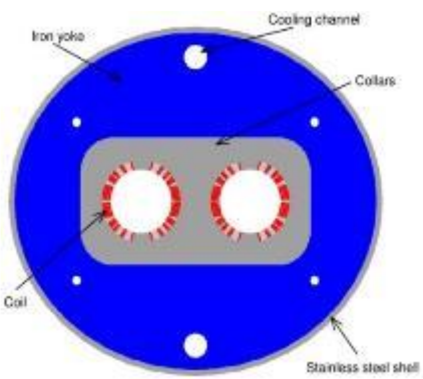
Orbit corrector (CIEMAT)



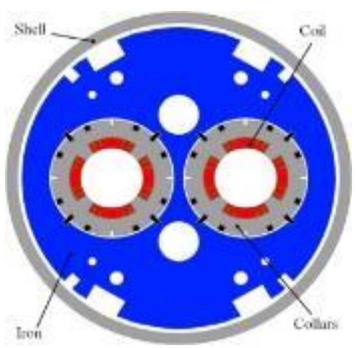
Separation dipole D1 (KEK)



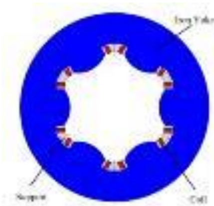
Skew corrector (INFN)



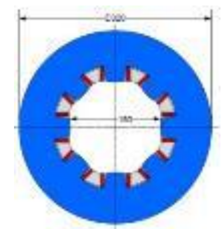
Recombination dipole D2
(INFN design)



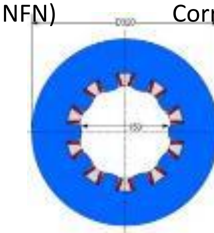
Q4 (CEA)



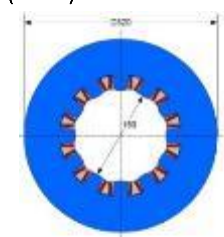
Corrector sextupole (INFN)



Corrector octupole (INFN)



Corrector decapole (INFN)

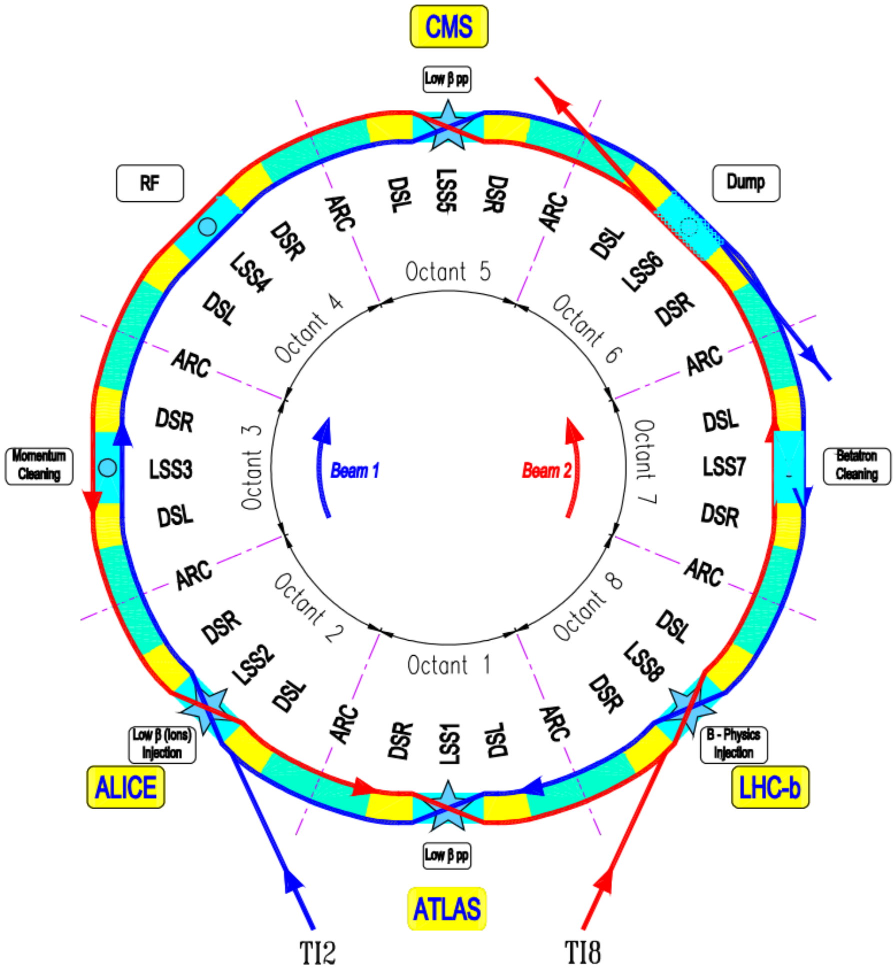


Corrector dodecapole (INFN)

High Luminosity LHC

Cross-sections to scale

LHC layout



LHC: 8 Arcs, 8 Insertions.

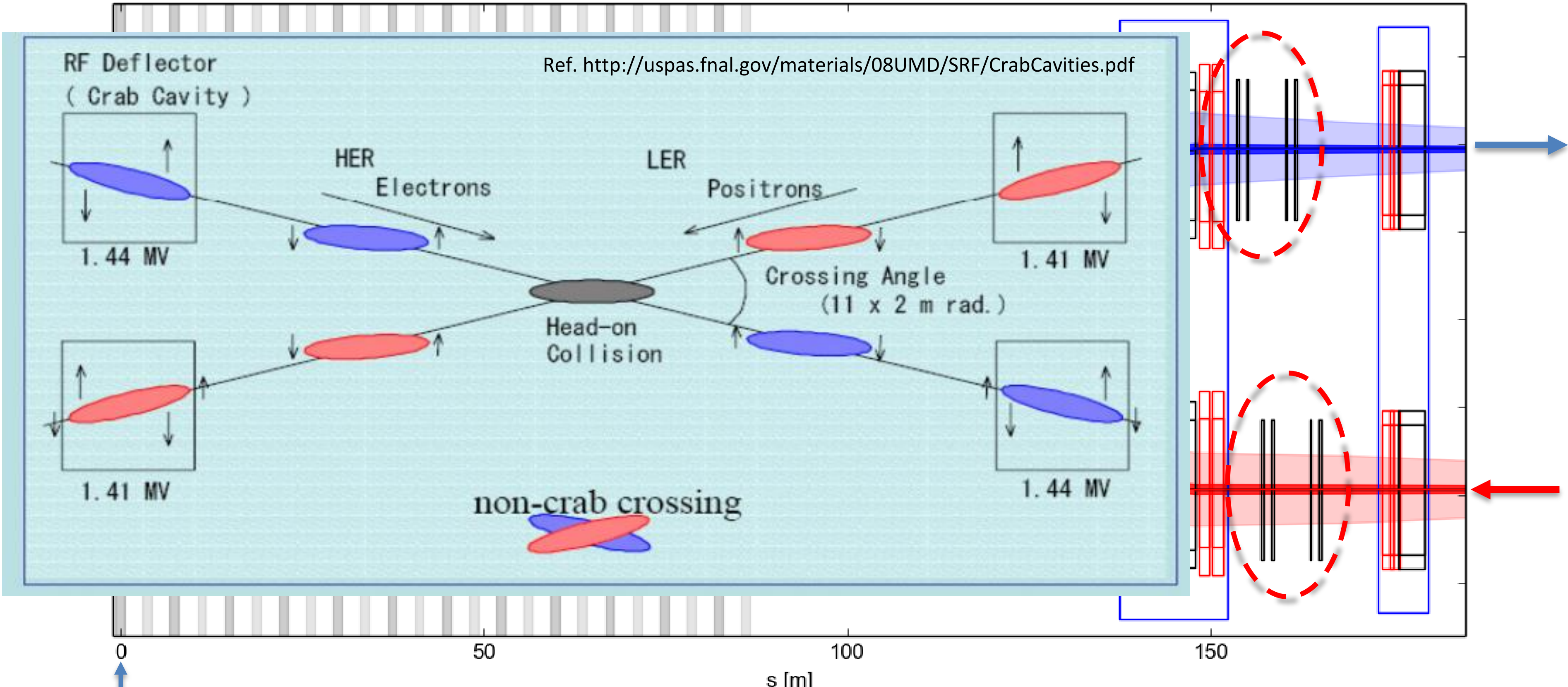
Insertion Region (IR): contains individual powered quadrupoles for optics changes.
It comprises:

- Dispersion suppressor (DS): Q7-Q13 left/right
- Long Straight Section (LSS): Q1-Q7 left/right
  - Triplet in the LSS: Q1-Q3
  - Separation dipoles in LSS: D1-D2, D3-D4

IR6: has no Q7, Q6, Q3, Q2, Q1
IR4: has no Q4, Q3, Q2, Q1
IR3, IR7: special layout

One arc has:
1 MB family, 2 MQ family,
4 MQT (2 per beam): trim tune,
8 MS (4 per beam): control chromaticity,
4 MCS (2 per beam): correct coupling,
4 MSS (2 per beam): chromatic coupling,
4 M0 (2 per beam): Landau damping,
MCS, MCO, MCD: MB field quality correction.

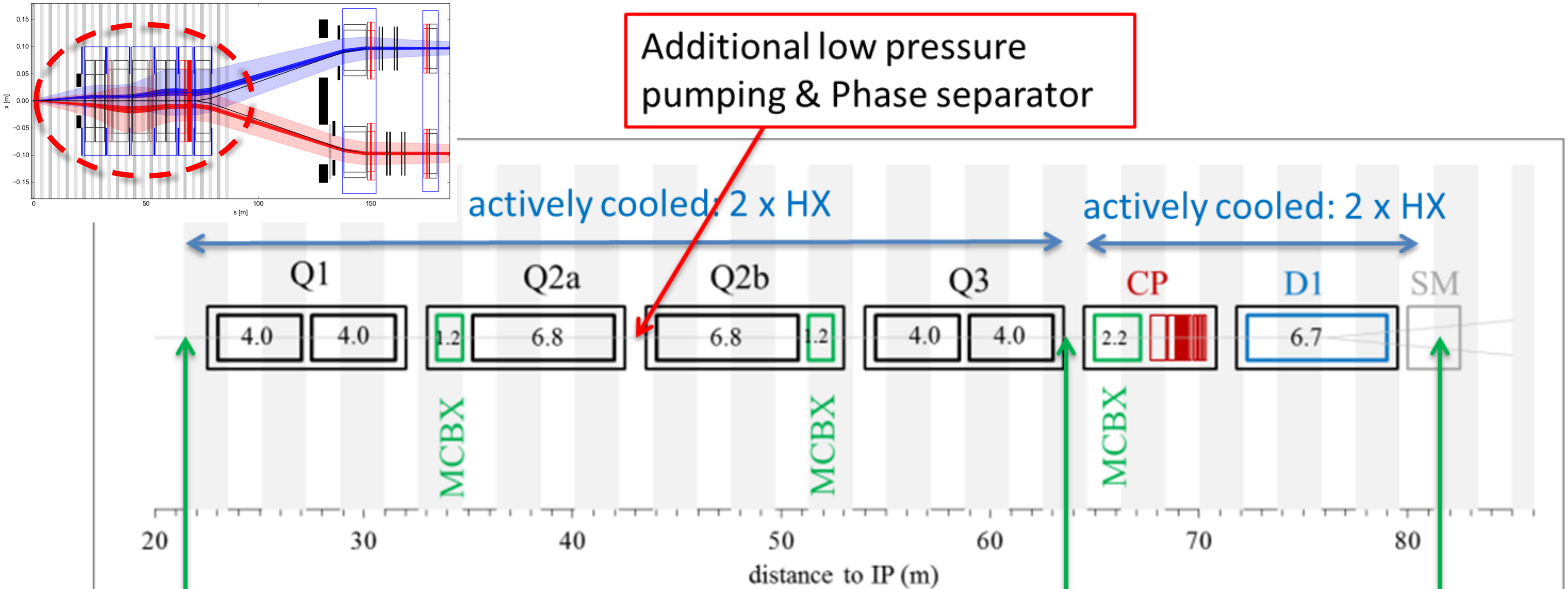
It’s all about orbits…



Right side of IR1/IR5

Interaction Point

Cryogenics: Local Layout (schematic)

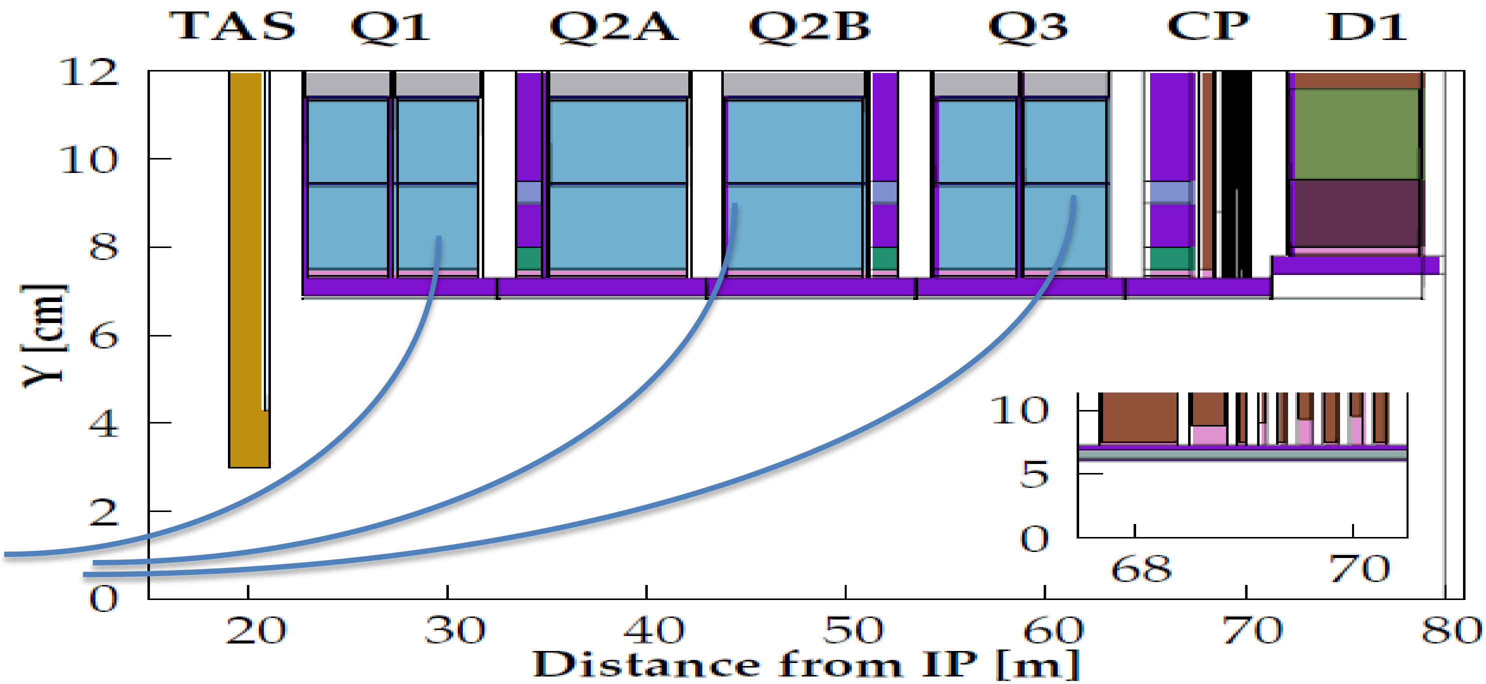


- Phase-separator &
- Piping entries/exits

- Phase-separator &
- Piping entries/exits
- QRL-jumper

- SM &
- QRL-jumper
- Phase-separator
- Piping entries/exits

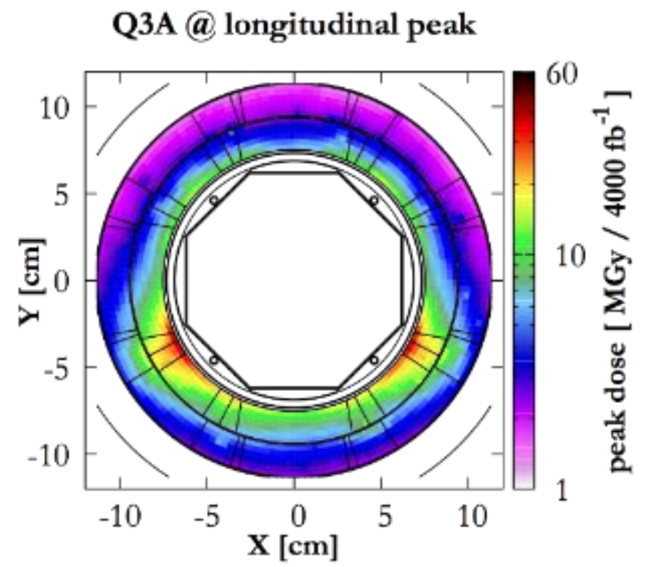
schematic placement of external interfaces (QRL-jumpers) over the magnet chain needed for the cryogenic services

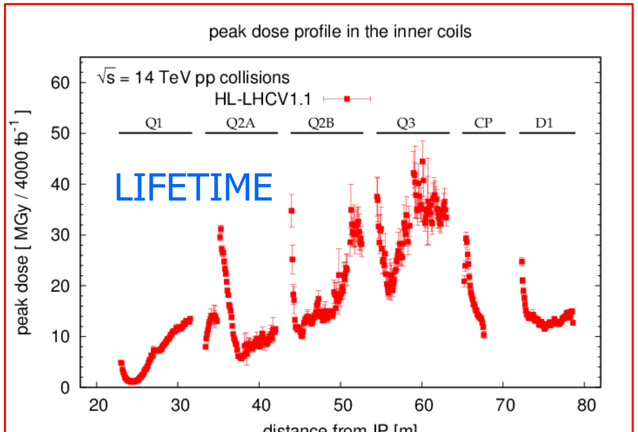


The **collision debris** generated by the high-luminosity interactions is lost mainly in two planes perpendicular to each other, across the quadrupolar focusing-defocusing fields of the triplet magnets, as the beam exits the IP. A **large power deposition** incompatible with the cryogenic system takes place. Also, **the SC coils can get radiation-damaged**.

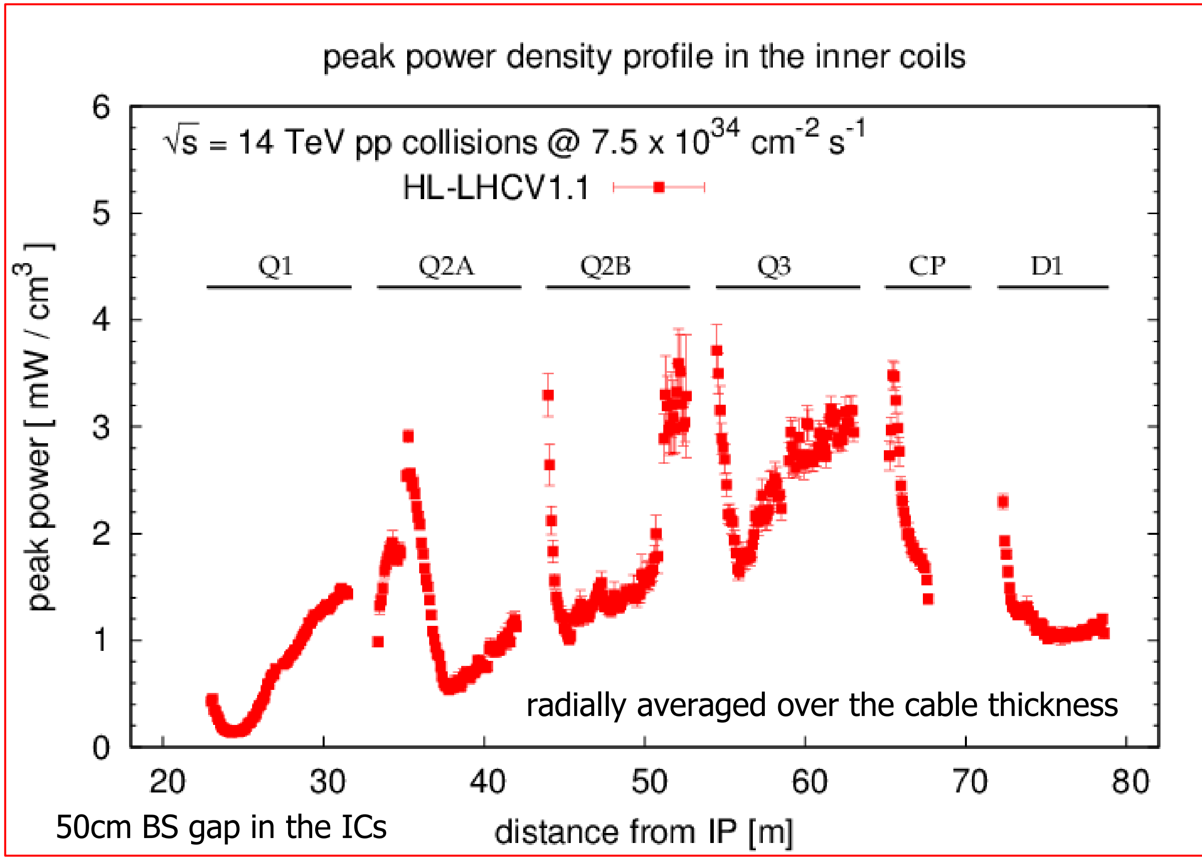
Solution? Add high-Z material shielding INSIDE the vacuum system

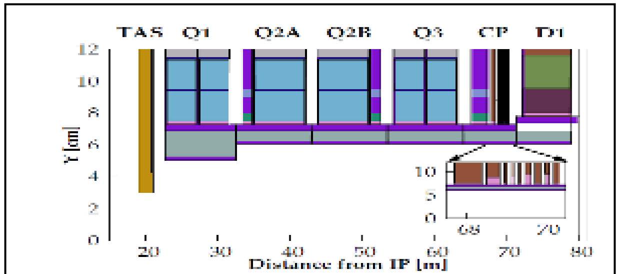
2D VIEW [I]



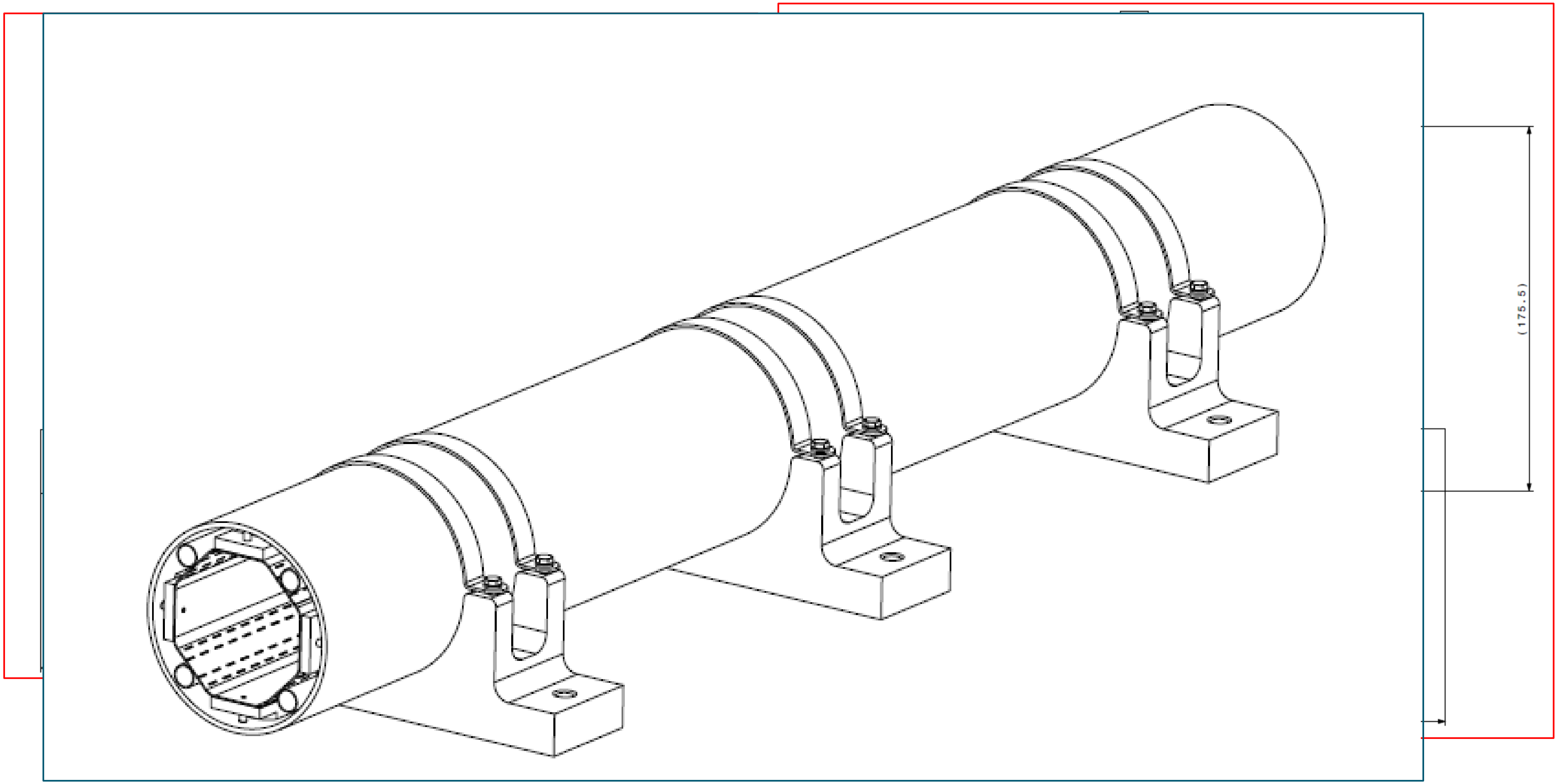


MARGIN TO QUENCH





Tungsten-shielded Beam Screen



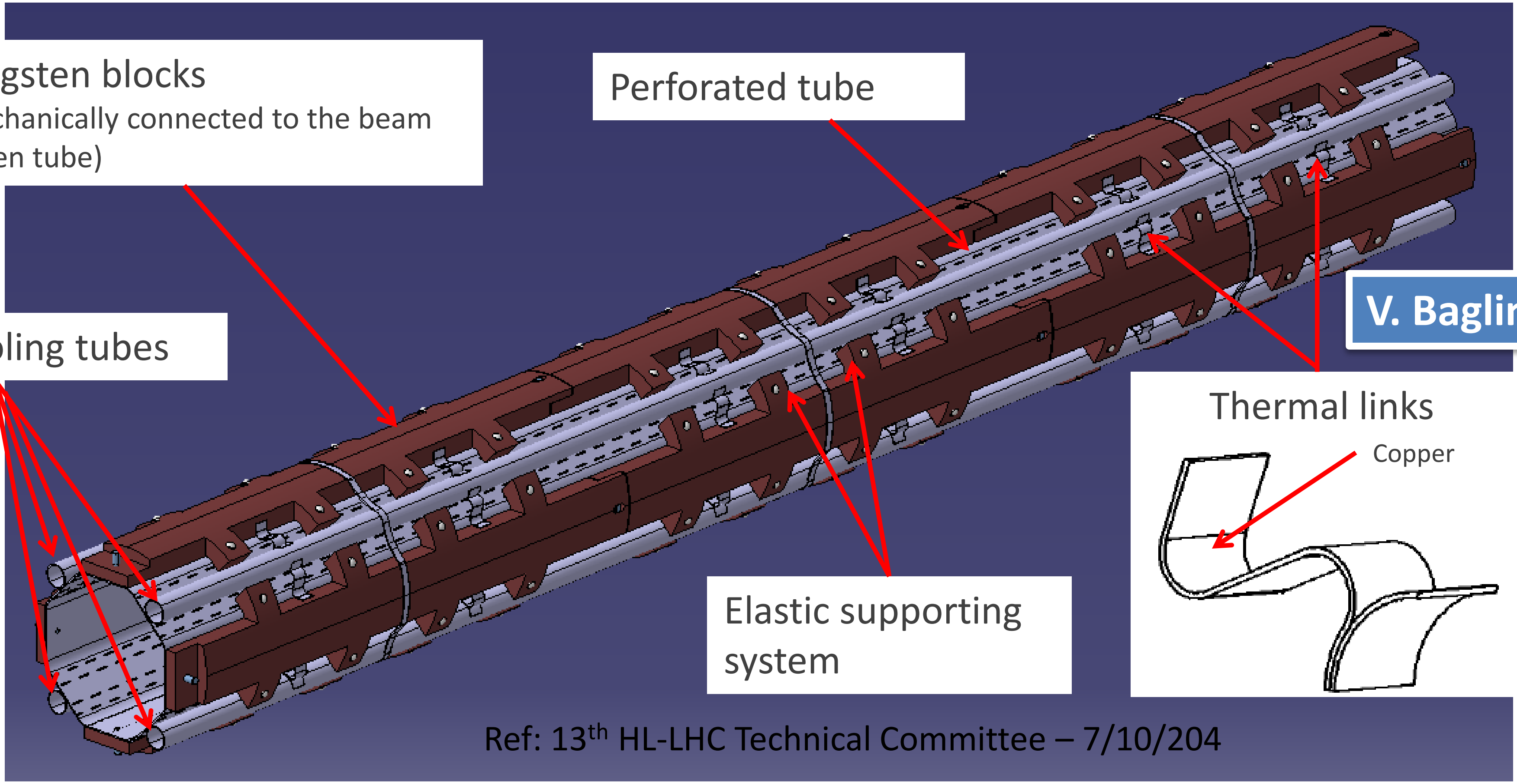
Material: Inermet 180 (95% W, 5% Ni/Cu); density 18 kg/dm^3

(PLANSEE Tungsten Alloys - 446, avenue des Digues BP301, 74807 Saint Pierre en Faucigny, France)

Courtesy C. Garion, TE-VSC

Design of the Shielded HL-LHC Beam Screen

Assembly of the Q1 beam screen



- Design studies
- Mechanical analysis : impact of quench, heat transfer, supporting system
- Tests with tungsten prototypes
- Q2-Q3 2015: short (1 m long) prototype

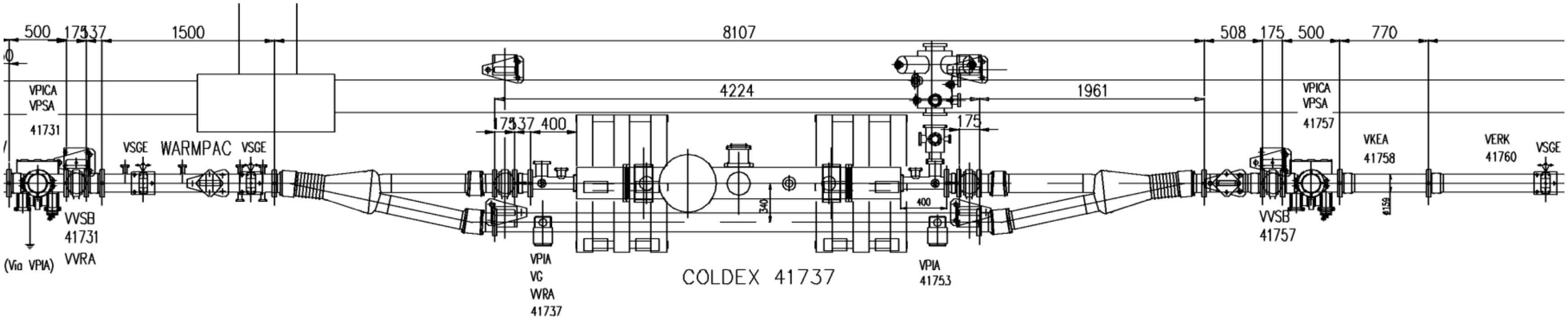
High Luminosity LHC

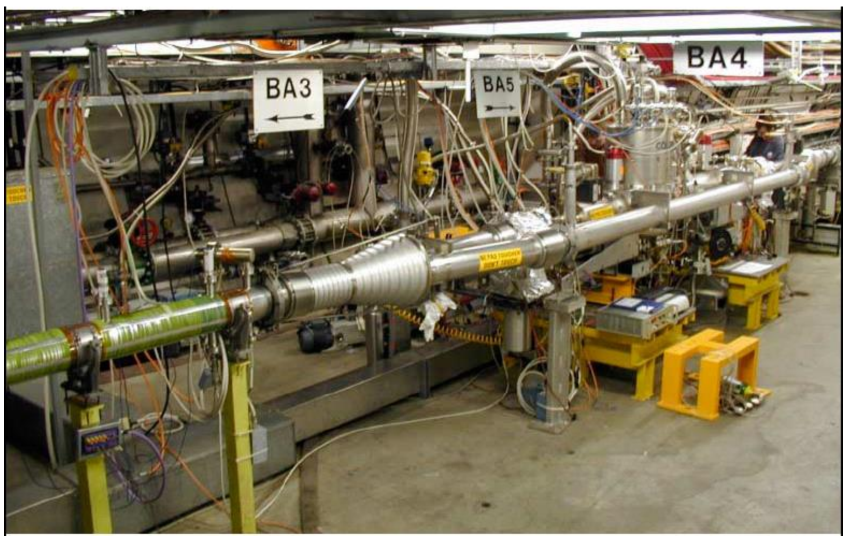
Electron-cloud: a potential killer for HL-LHC

- The e-cloud effect is well known in positively-charged accelerator since long time
- It has already impacted the operation of LHC, limiting the performance due to an abnormally high power load on the cryogenic system, and pressure bursts
- For RUN 1 of the LHC, the solution has been either going to 50 ns bunch spacing, or wrapping solenoids around the areas where e-c was the highest
- During LS1, many room temperature chambers have been coated with NEG, which is known to have a low secondary electron yield (SEY)
- For the cold sections (arcs, triplets, stand-alone) there is no possibility to activate the NEG (minimum temperature is ~180 C), and therefore amorphous-carbon (a-C) has been tested, with success.
- For HL-LHC there is still time (not much, though!) to try a-C on the beam screen, and test it. For this the COLDEX experiment has been brought back to life.
- COLDEX had been used already when LEP was in operation in order to validate the concept of LHC (e.g. V. Baglin's thesis)
- COLDEX is now installed in the SPS, with an a-C BS. A first test (two weeks ago) has confirmed a very low e-c signal as compared to the neighboring un-coated chambers…. very promising!
- We are also testing the a-C coating on room temperature chambers using synchrotron radiation at the Photon Factory (KEK Laboratory, Japan) (M. Ady, PhD student EPFL/CERN). In the future such tests with SR will be performed on cryogenic surfaces.

What is COLDEX ?

COLD (Bore) **EX**(periment) – installed at CERN-SPS (BA4)
Mimics the LHC cold bore and beam screen section, for electron cloud studies





- Mitigate the electron cloud build-up with amorphous carbon coating
- Operate in the BS in the 40 to 60 K temperature range
- Reduce background to experiments

- Refurbishment of COLDEX : strong support and commitment of many CERN groups: TE-CRG, BE-OP, BE-ABP, TE-EPC, EN-ICE

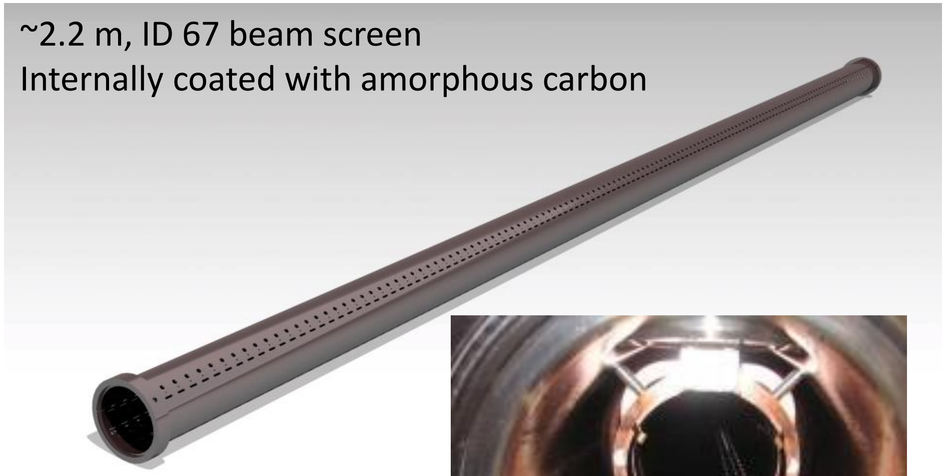
COLDEX Scientific Objectives

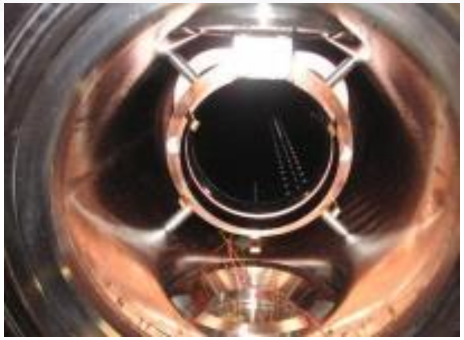
- Accumulate beam time with:
  - a-C coating on Cu (HL-LHC inner triplets & matching section)
- Studies with LHC type beams of:
  - Pressure increase
  - Gas composition
  - Heat load
  - Electron flux
- Study multipacting triggering vs:
  - BS temperature
  - Beam structure and bunch intensity
- Study the impact of BS temperature:
  - 5-20 K for HL-LHC matching section
  - 40-60 K for HL-LHC inner triplets
- Studies of operational impact of:
  - Gas pre-condensation, H_2, CH_4, H_2O, CO and CO_2: simulates long term operation and impact of quenches
  - Temperature oscillations / excursion

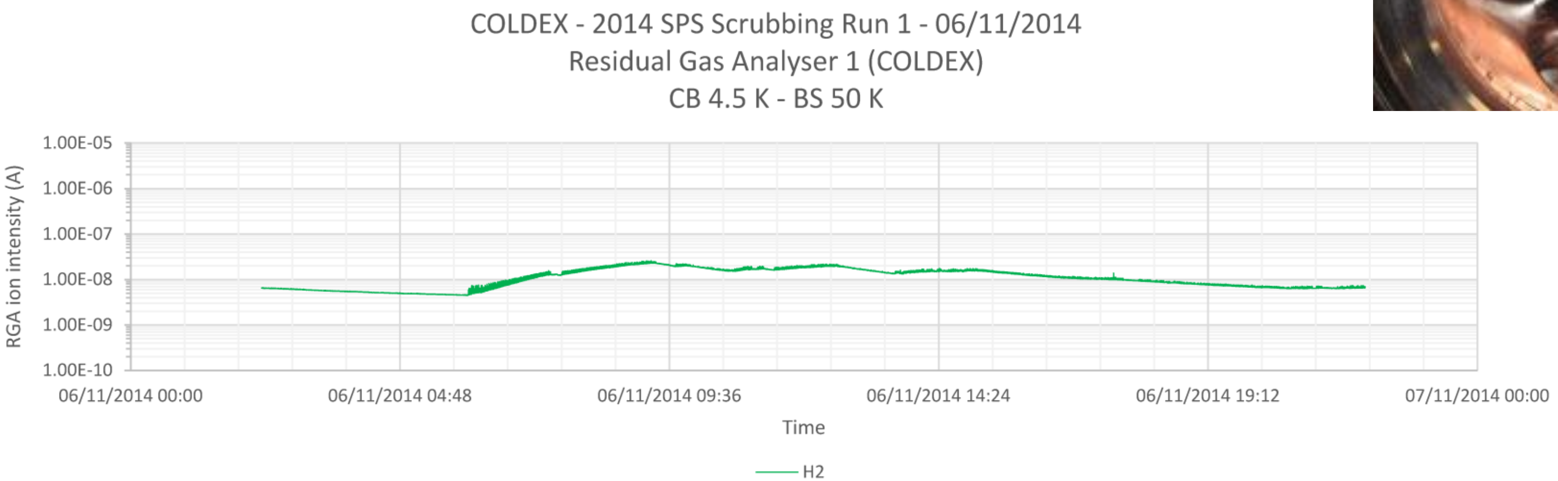
Preliminary results

- a-C beam screen held at 50 K, 5 k then 10 K while cold bore ~ 4K

- LHC type beams circulating in SPS (3-9/11/2014):
  - Heat load < 1 W/m
  - Pressure rise < 5 10^{-9} mbar
  - Main gas is H_2



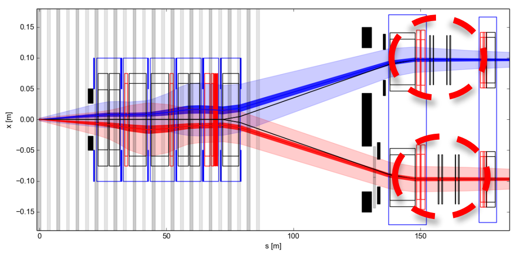


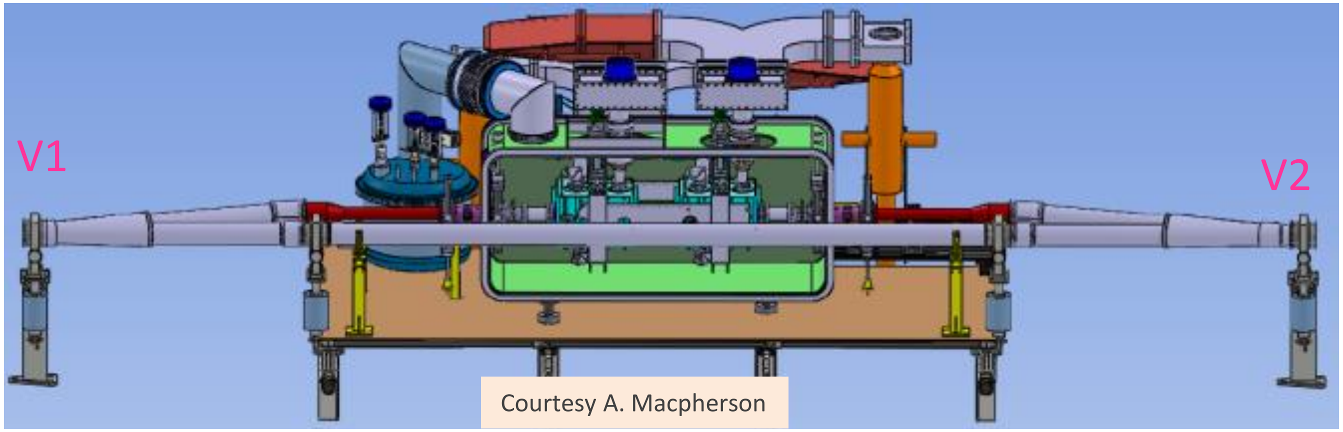


R. Salemme, IEFC, 14/11/2014

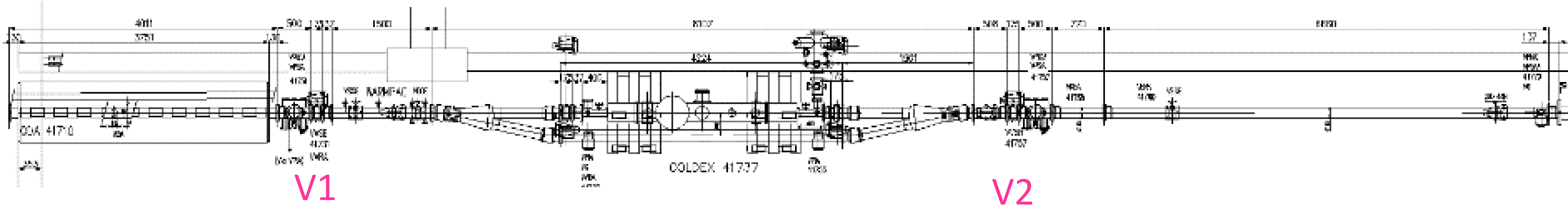
Crab-Cavity tests in the SPS: Layout

- Operating pressure ~ 10^{-10} mbar with beams: a detailed computational analysis is needed
- Similarly to LHC, NEG coated vacuum chambers between V1 and V2 (except CC module !)
  - Differential pumping system between V1/V2 and module
  - If needed, a-C coating or solenoids could be implemented elsewhere





Courtesy A. Macpherson



- A new layout must be defined by June 2015 to complete the design of the “Y” chamber and start the procurement of components

High Luminosity LHC

Summary:

- The HL-LHC project is fully underway
- Many new concepts have been validated, others have been modified, as the scope of the project has slightly changed (in concert with experiments)
- Vacuum-wise the most important area of work is the Inner Triplets around IP1/IP5 (ATLAS/CMS)
- The challenging concept of a beam-screen with integrated tungsten shielding has been proposed
- Fabrication of a short-scale prototype is underway
- The COLDEX experiment has been installed in the SPS
- Synchrotron radiation desorption studies are underway at the Photon Factory/KEK
- The vacuum layout for the crab-cavity test is being studied
- Other important tests with relevant vacuum input are the **11 T dipoles with the integrated new collimators** (necessary to protect the new Inner Triplets/Crab Cavities) are scheduled (not discussed here for lack of time)

High
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