On behalf of Experimental Vacuum Project Team
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Upgrade of the experimental vacuum chambers during the LS2

Content of the seminar

Introduction

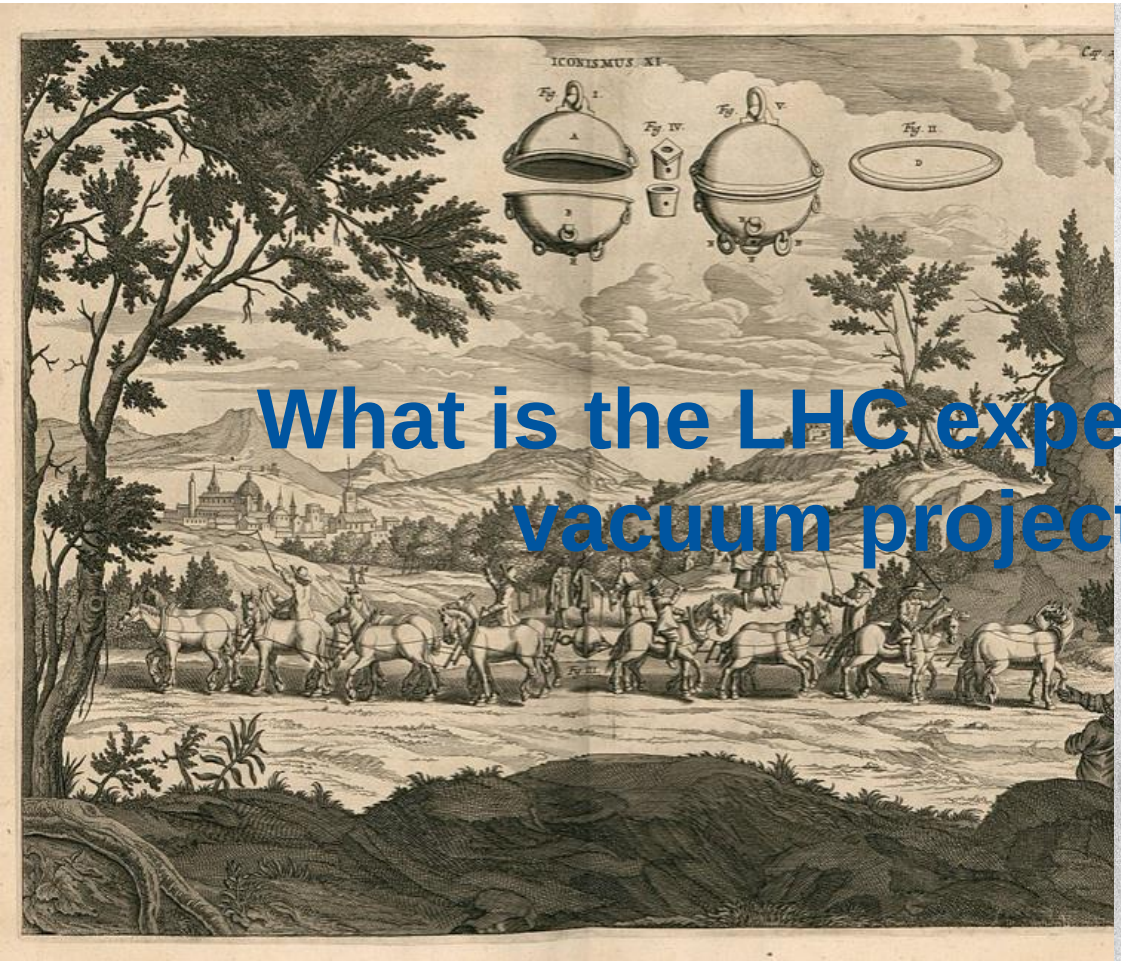
Experimental vacuum systems

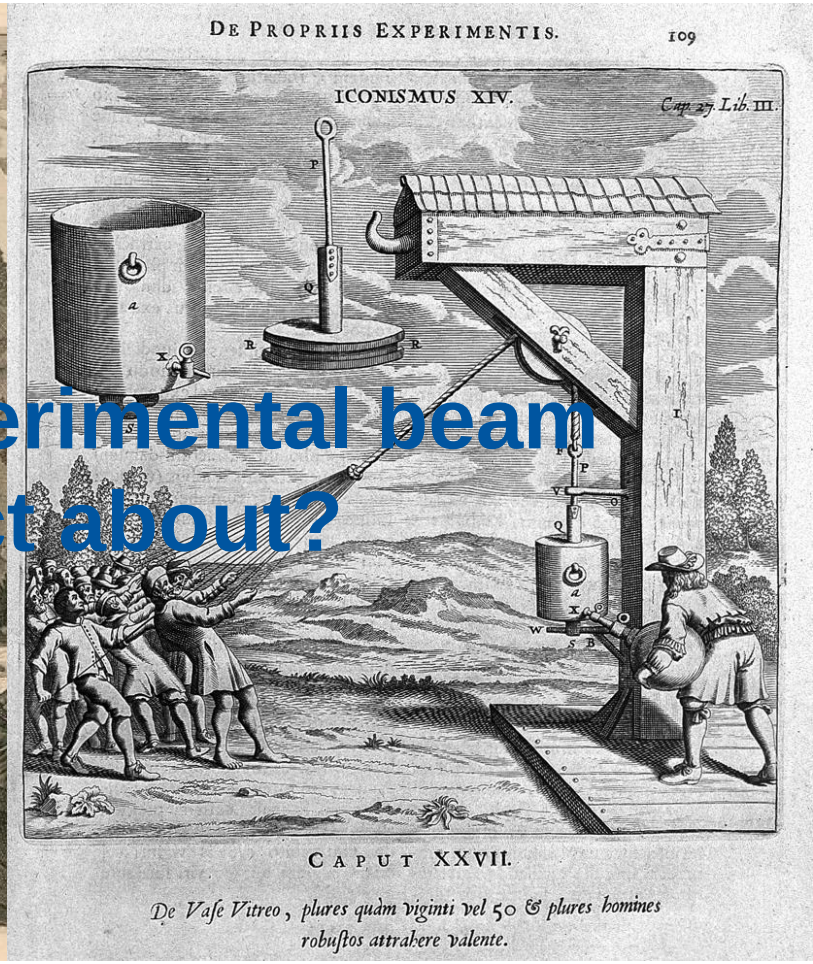
Questions & Answers

Upgrade during the Long Shutdown

Your Questions & Answers

Introduction

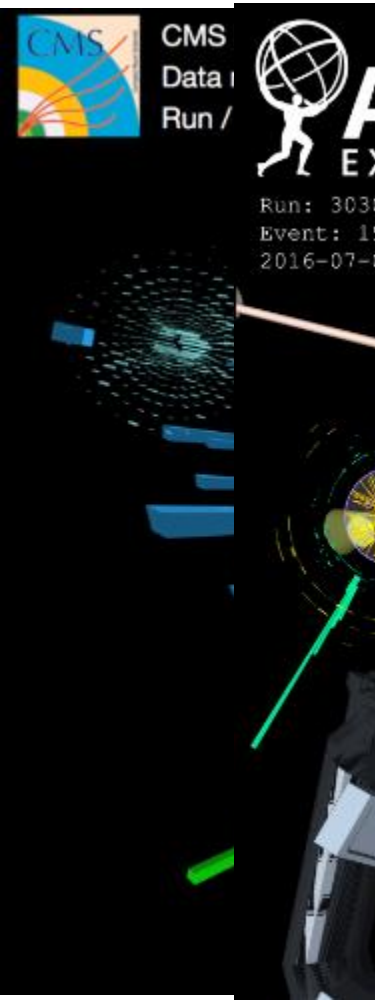


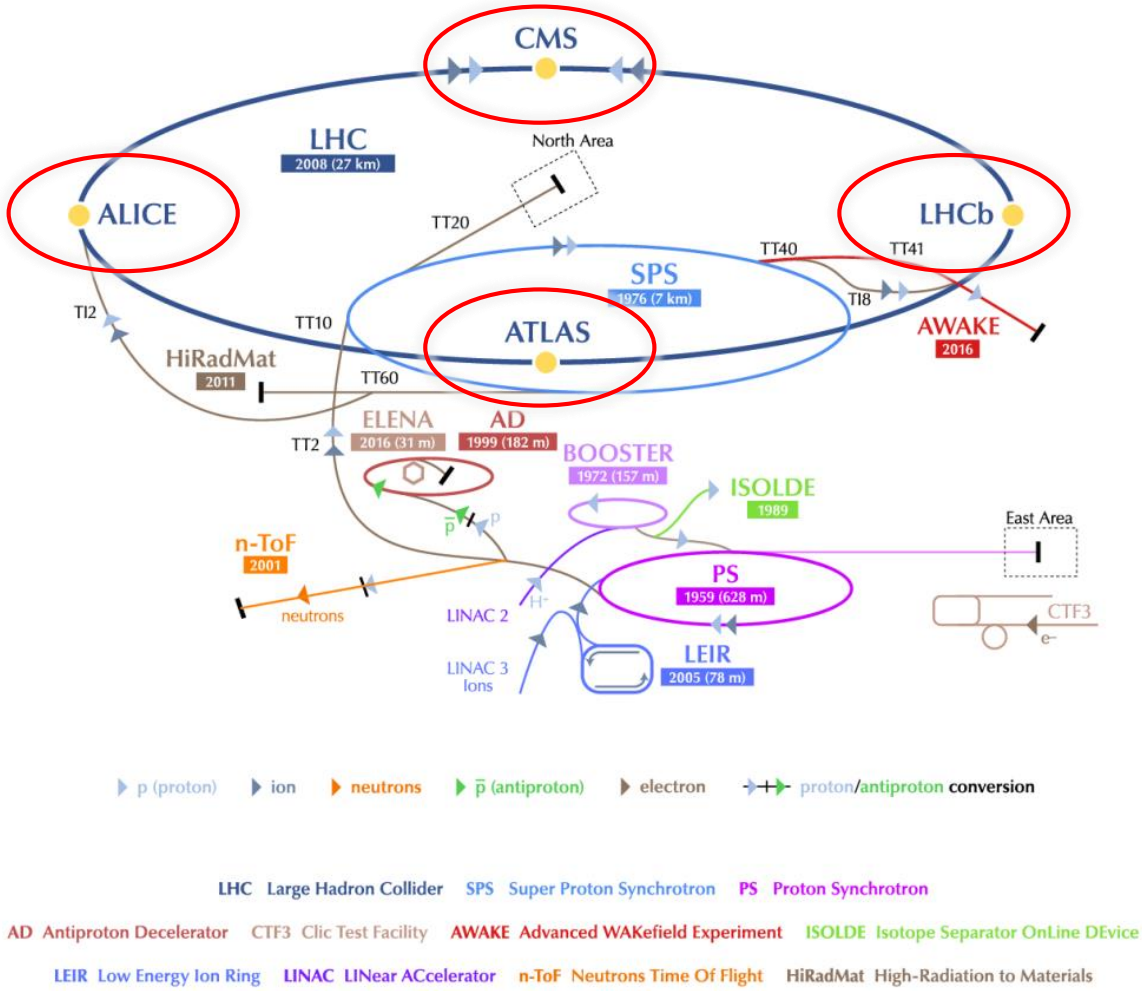


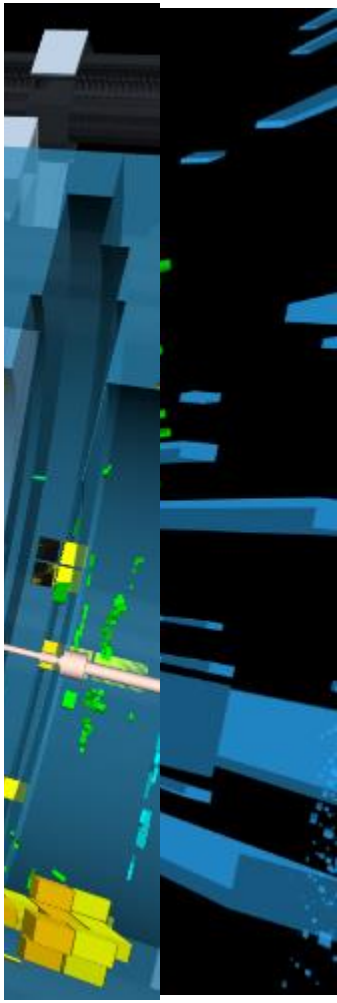
What is the LHC experimental beam vacuum project about?

Source: Wikipedia & Wikimedia

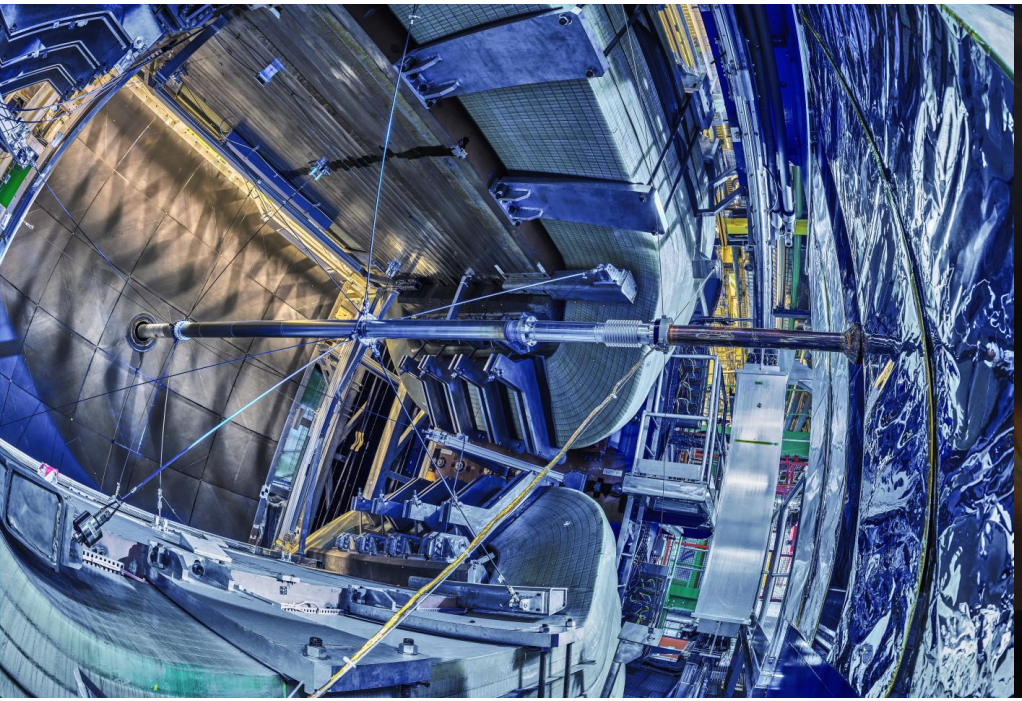
Introduction



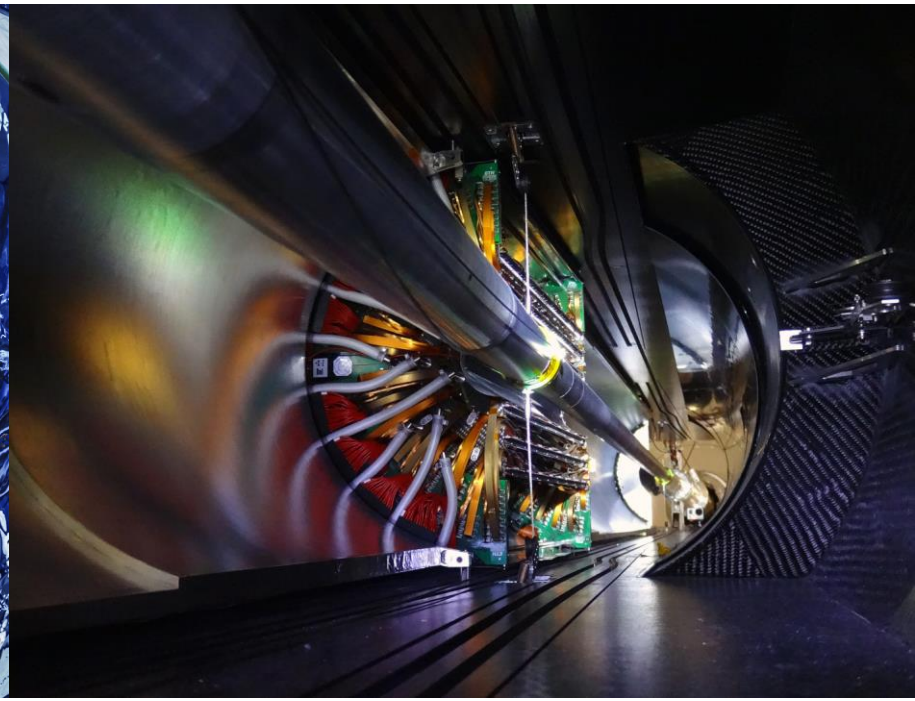




Introduction



LHCb vacuum chambers UX85 1-2-3



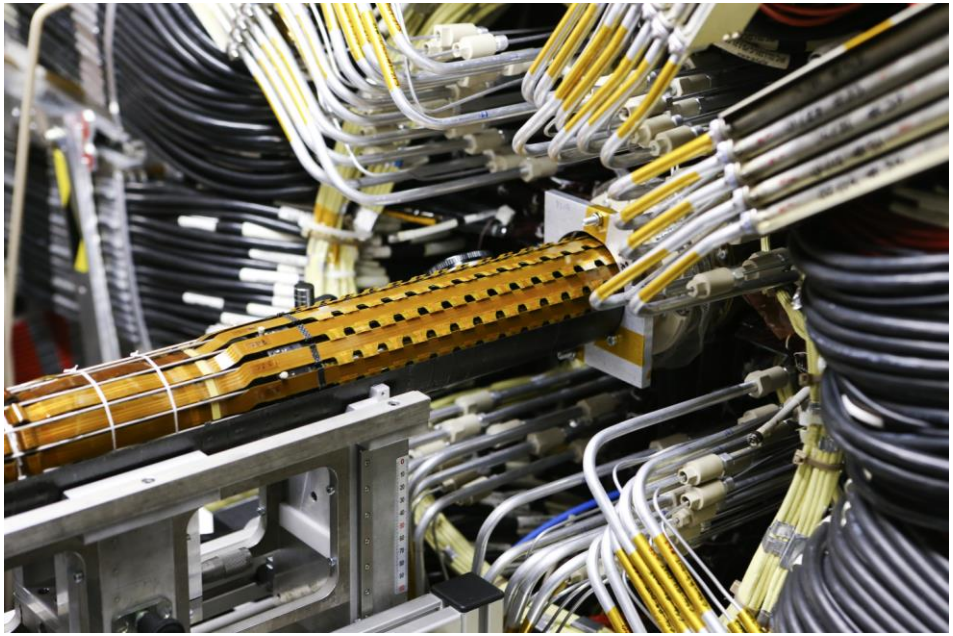
CMS central chamber with b-Pixel

Design – Production – Operations – Maintenance

of the LHC beam vacuum sectors consisting of customized vacuum chambers made of aluminum and beryllium

Main challenges

- Experiment = Collaboration = Many voices involved
- Number of contradictory parameters and requirements
- Strong space constraints within the experimental caverns



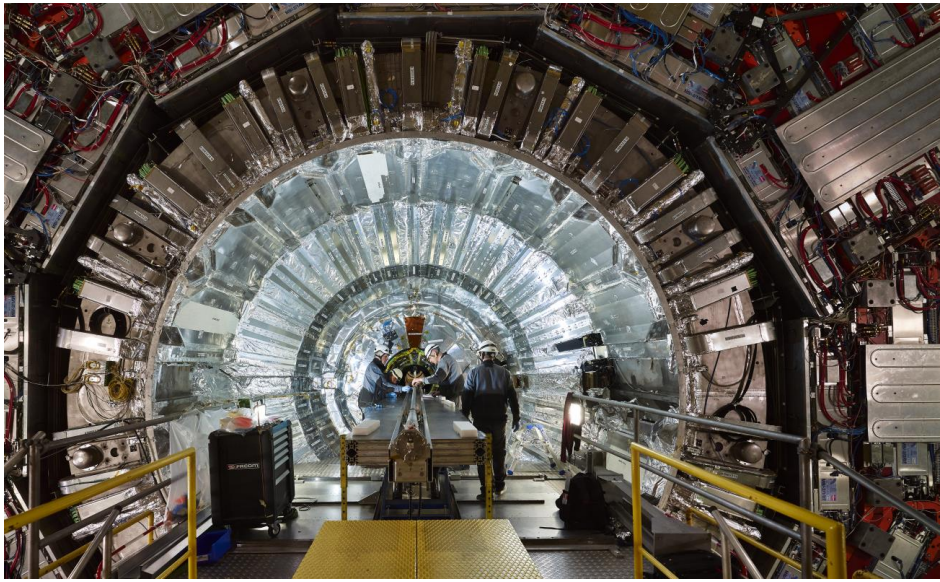
ATLAS central chamber with insertable beta layer

- Reduced diameter
- Optimized shape
- Optimized wall-thickness
- Optimized supporting points
- Less vacuum equipment

- Vacuum performance
- Structural stability
- Manufacturing feasibility
- Commissioning (NEG)
- Maintainability (ALARA)

Main challenges

VSC team working in ATLAS forward region



VSC team working in the CMS tracker area

- Specific environmental conditions

  temperature, magnetic fields, RP sources, work at height

- Limited access conditions

  no interventions during Technical Stop, limited by the YETS – system vented with Ne

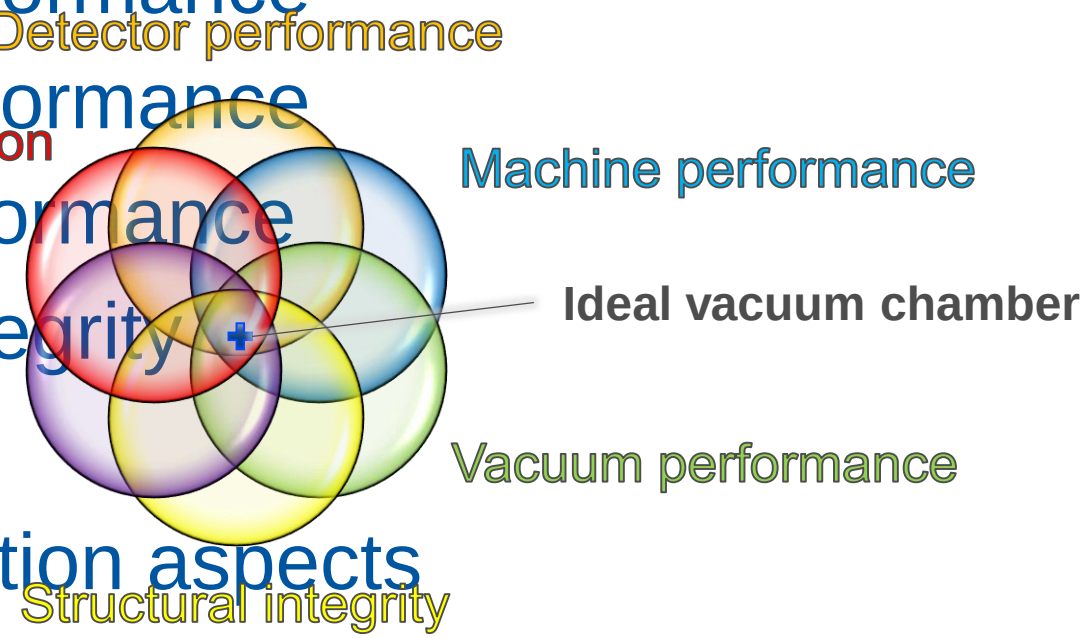
- Exchange of a chamber is possible only during the Long Shutdown

  or with non-negligible impact on the operations or YETS schedule

Design approach

Experimental vacuum chambers must meet various design criteria related to:

- Detector performance
- Machine performance
- Vacuum performance
- Structural integrity
- Integration
- Radio-protection aspects

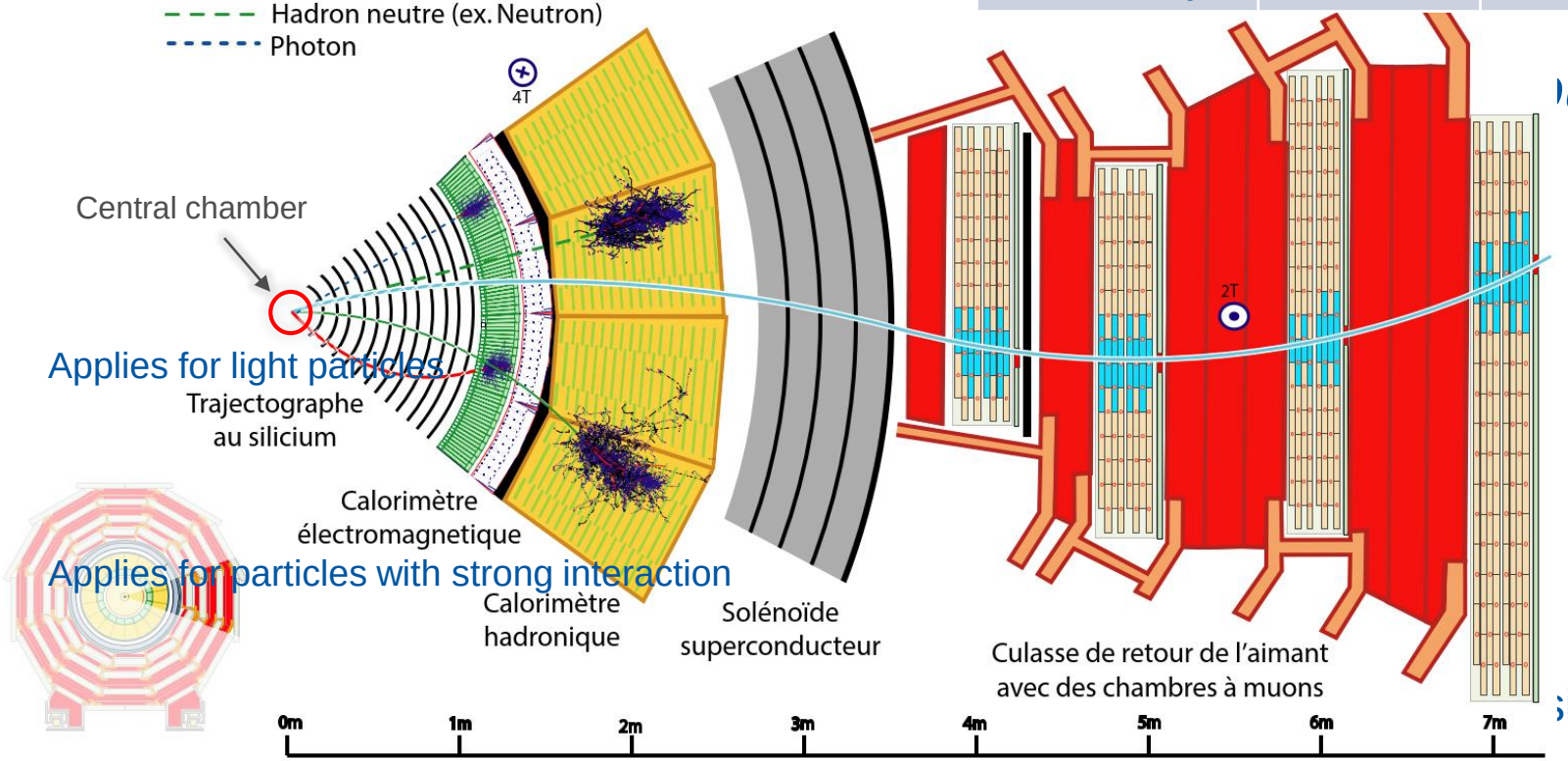


What is the advantage of beryllium and aluminum alloys?

Detector performance

	X_O [mm]	λ_T [mm]
Beryllium	353	418
Aluminum based alloys	≈ 89	≈ 287
Ferrous based alloys	≈ 18	≈ 130

- Légende: Muon, Électron, Hadron chargé (ex. Pion), Hadron neutre (ex. Neutron), Photon

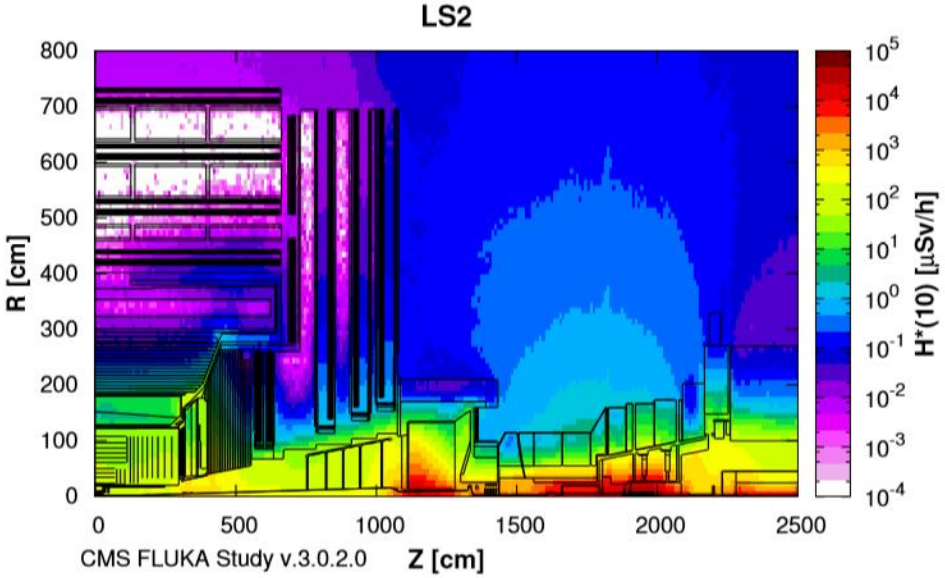


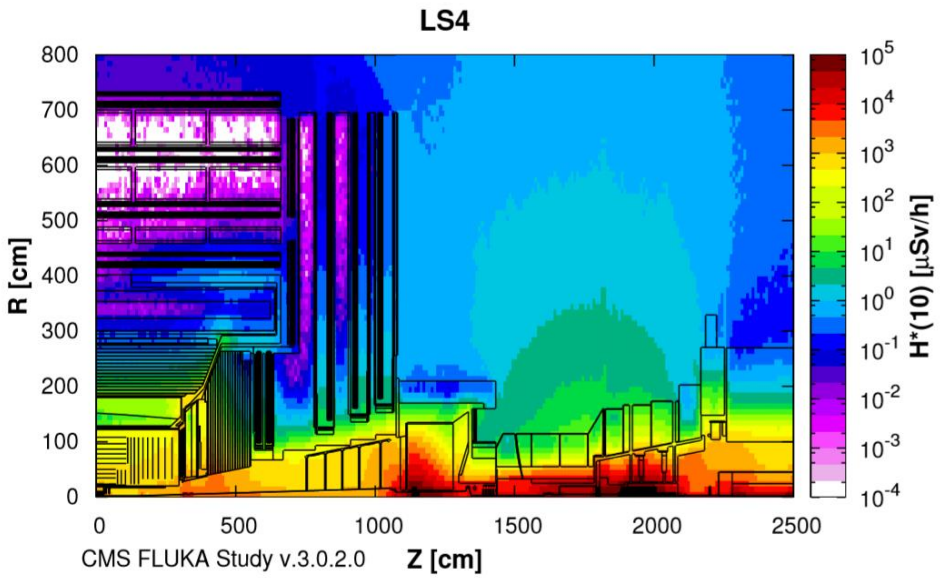
- ut
- ❑ Applies for light particles
- ❑ Applies for particles with strong interaction
- w sity
- of the material

Radiation environment

ALARA principle (As Low As Reasonably Achievable)

- Environment – vacuum chambers; detector structures
- Way of working – best practice; tooling (or not);

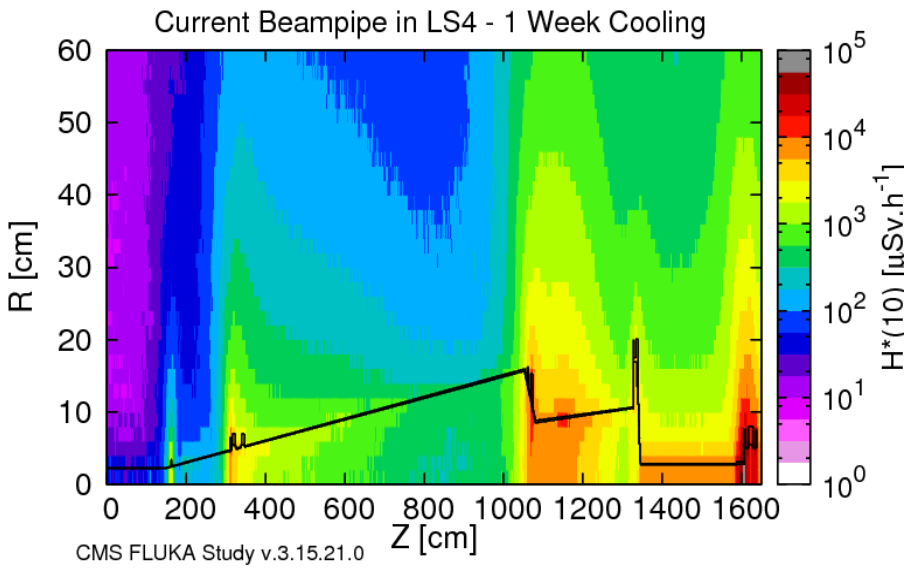


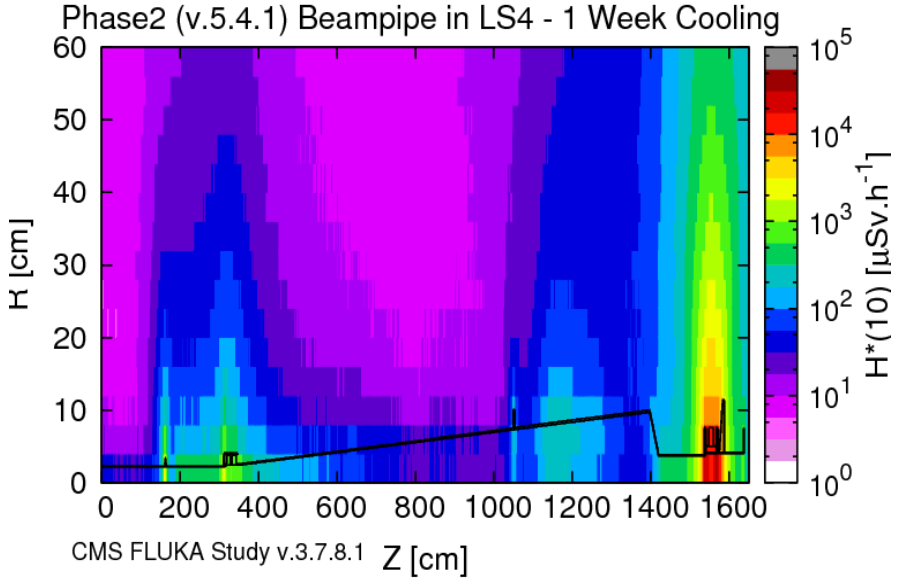


Efficiency by preserving safety and quality of work

Radiation environment

- Equipment made of aluminum reduces dose obtained by personnel by factor ≈ 5.





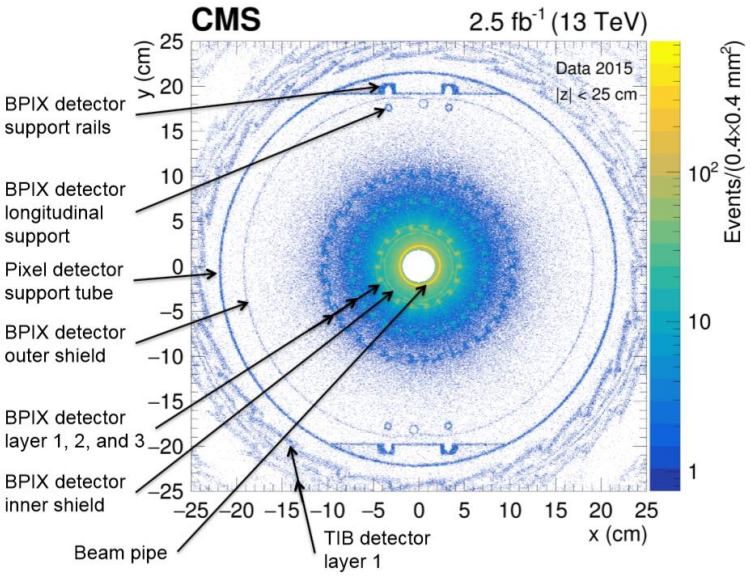
- Stainless steel equipment is still unavoidable.

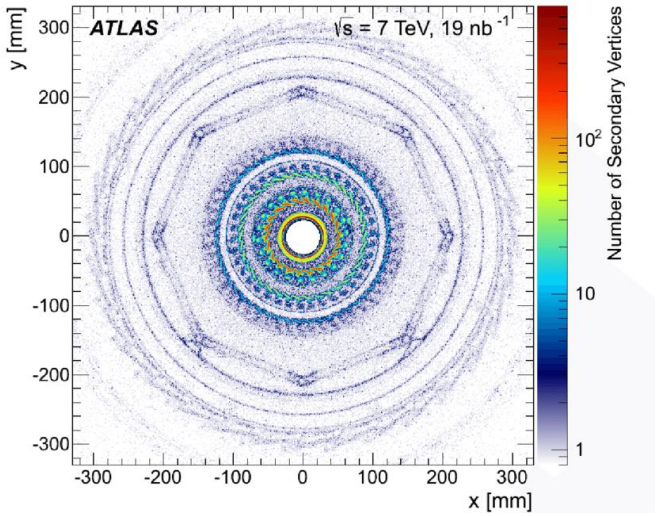
  Bimetallic flanges, edge-welded bellows, ion pumps, gauges etc…

How the size & shape of the chambers are defined?

Physics performance

- Background from secondary particles
  - Vacuum chamber = first equipment seen by particles





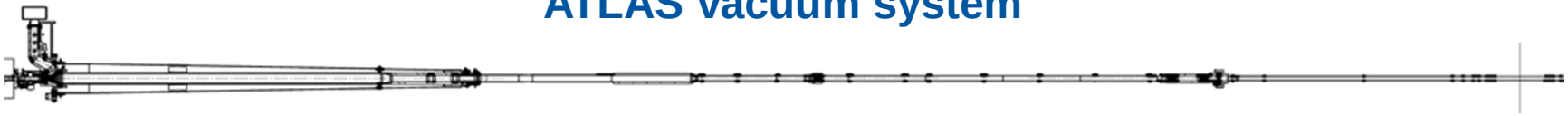
Inelastic interaction between primary particle and wall of the chamber produces “secondary” (low momentum) particle.

Physics performance

- Cylindrical or conical chamber?

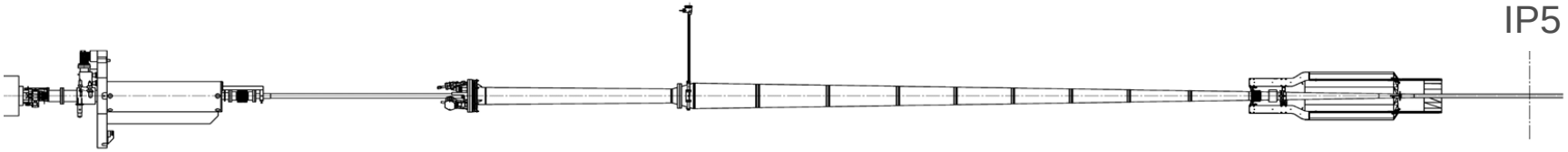
ATLAS vacuum system

IP1



CMS vacuum system

IP5

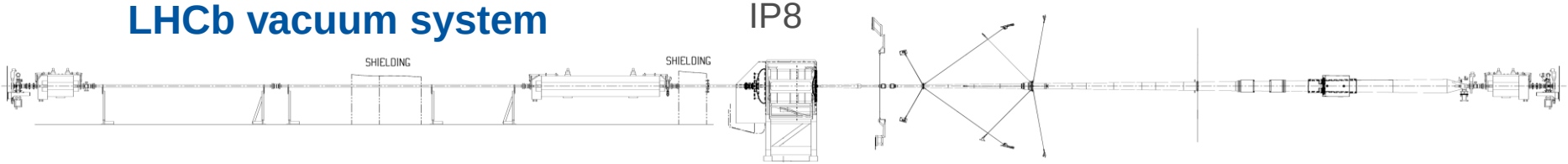


ALICE vacuum system

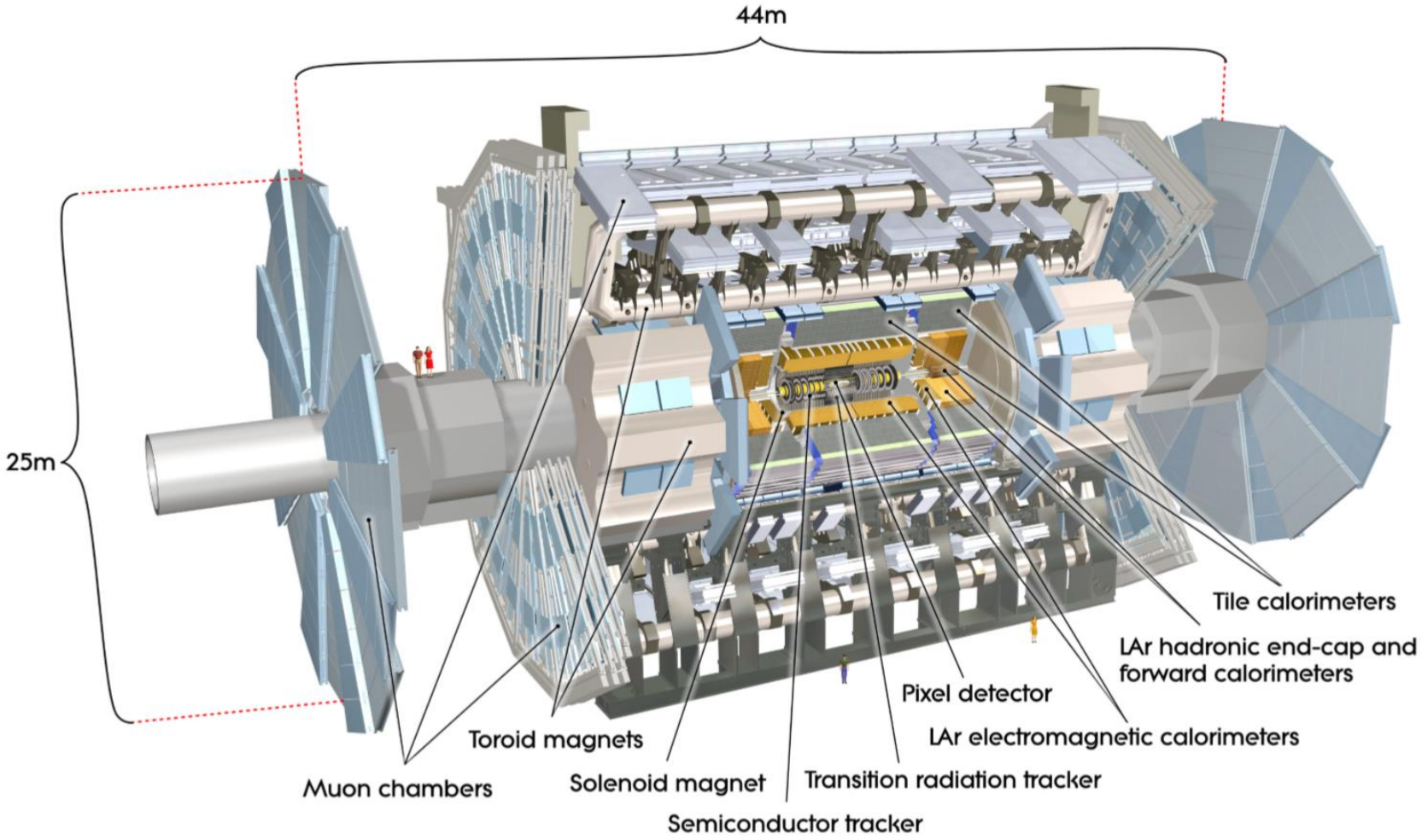
IP2

LHCb vacuum system

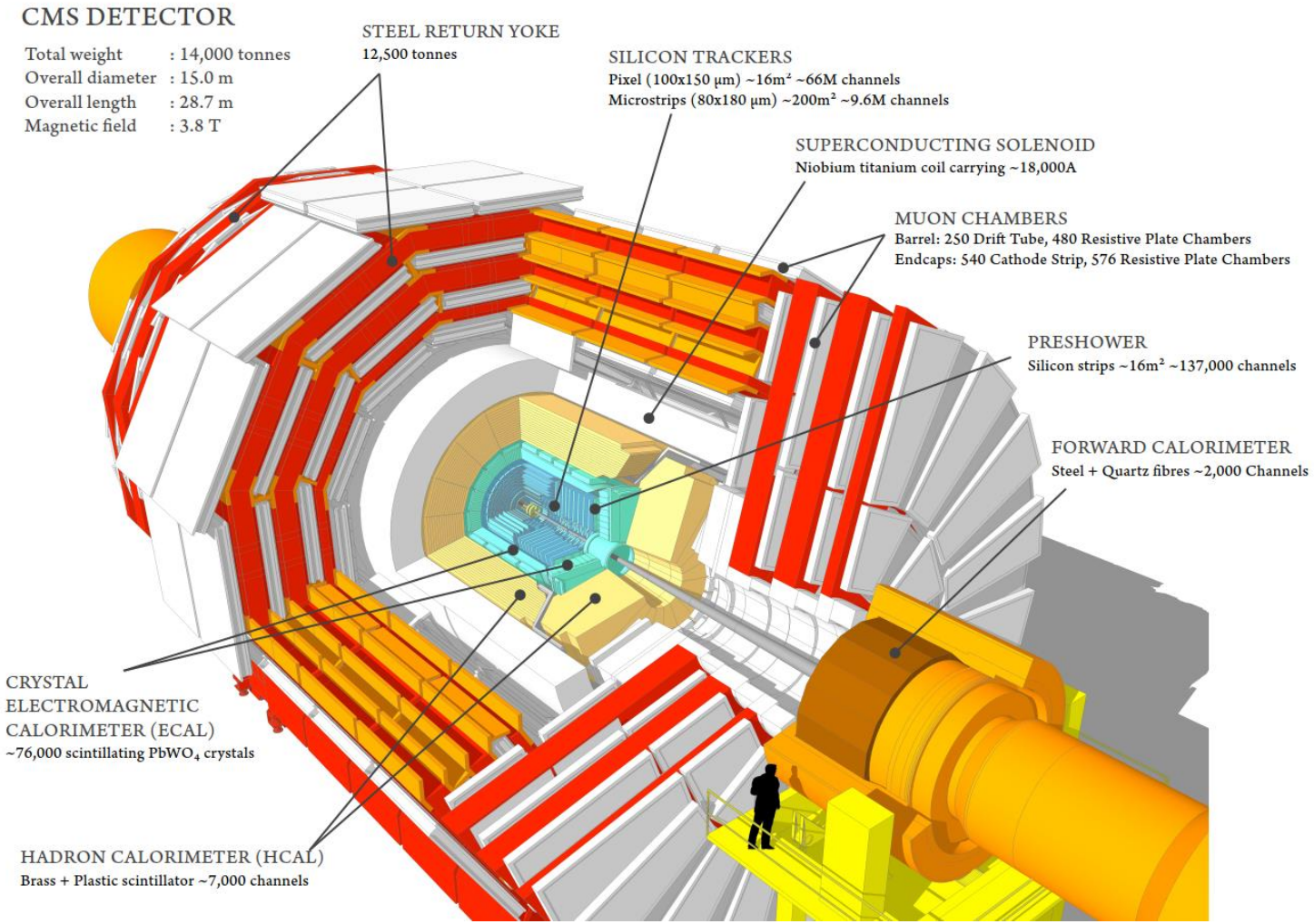
IP8



Physics performance



Physics performance



Another geometrical limitations?

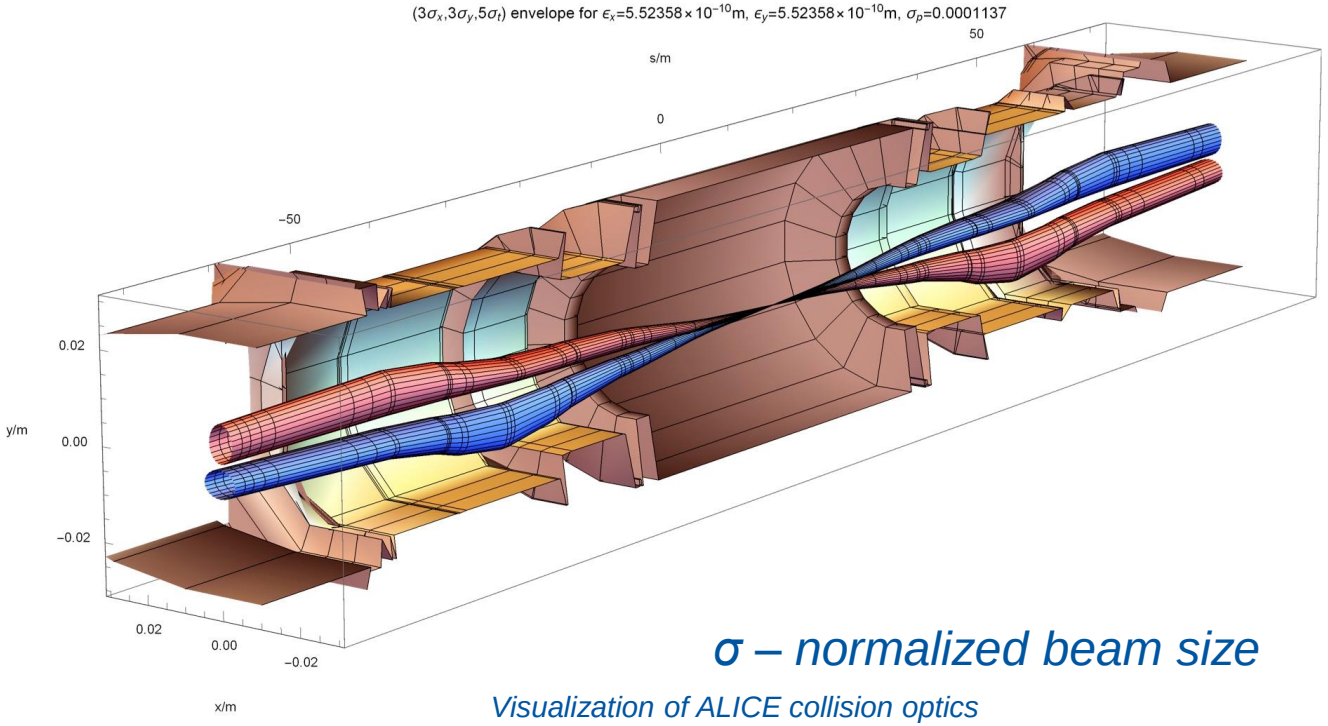
Yes please ☺

- Mechanical aperture
- Impedance requirements
- Structural integrity - buckling
- Structural integrity – deformation and stresses
- Vacuum (conductance, molecular gas density, critical beam current)
- Integration and detector space reservations
- Manufacturing feasibility

….

Machine performance

- Mechanical aperture
  - Aperture target for the LHC experiments $n_1 = 7\sigma$



σ – normalized beam size

Visualization of ALICE collision optics

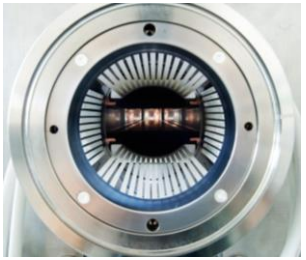
Layout for aperture analysis
Segments of equal cross-section

Aperture analysis
Injection & Collision
Optics settings
Separation

Machine performance

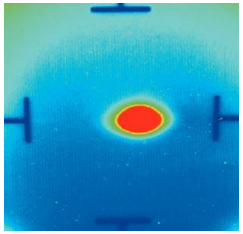
- Impedance
  - Interaction of the beam with environment of the vacuum chambers (EM RF field).

Sources of impedance
Geometrical : aperture transitions, restrictions and cavity like shapes
Material: Different resistivity; presence of coatings



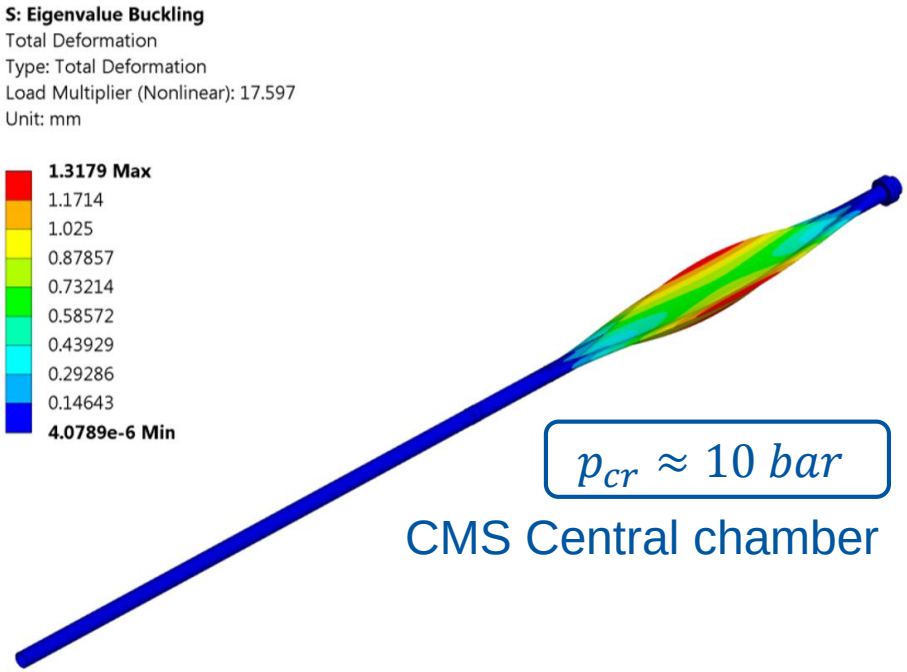
Effect on the vacuum chambers
Power loss → beam induced heating → degradation of mechanical and vacuum performance of the chambers

“Collective effects” related with impedance
Effect of beam emittance → beam losses → beam life time



Structural integrity

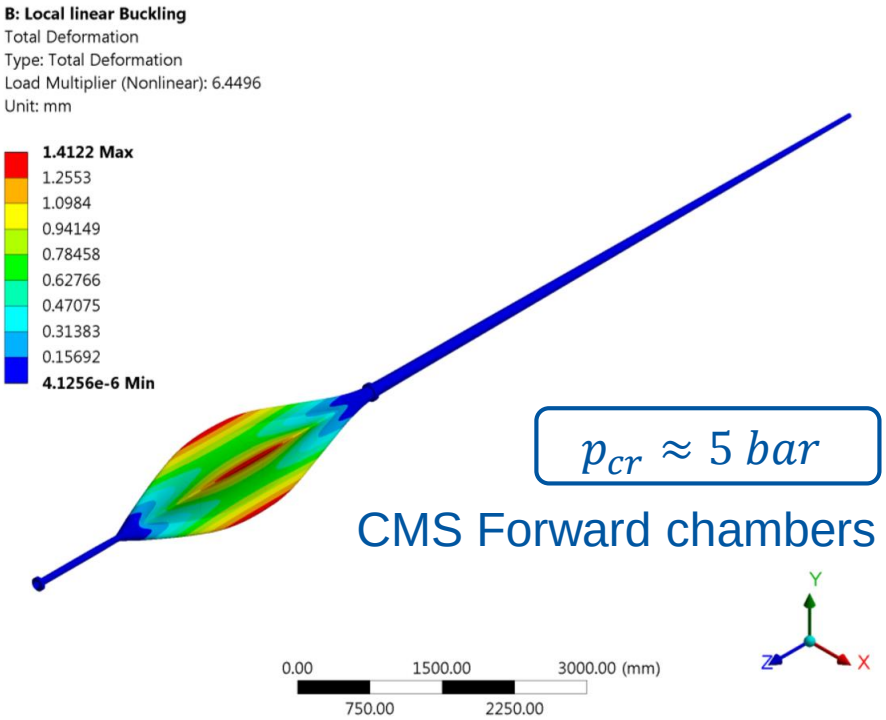
- Buckling due to external pressure
  - Vacuum chambers should withstand $p_{cr} \geq 3\ bar$



$p_{cr} \approx 10\ bar$

CMS Central chamber

CMS central chambers – buckling analysis



$p_{cr} \approx 5\ bar$

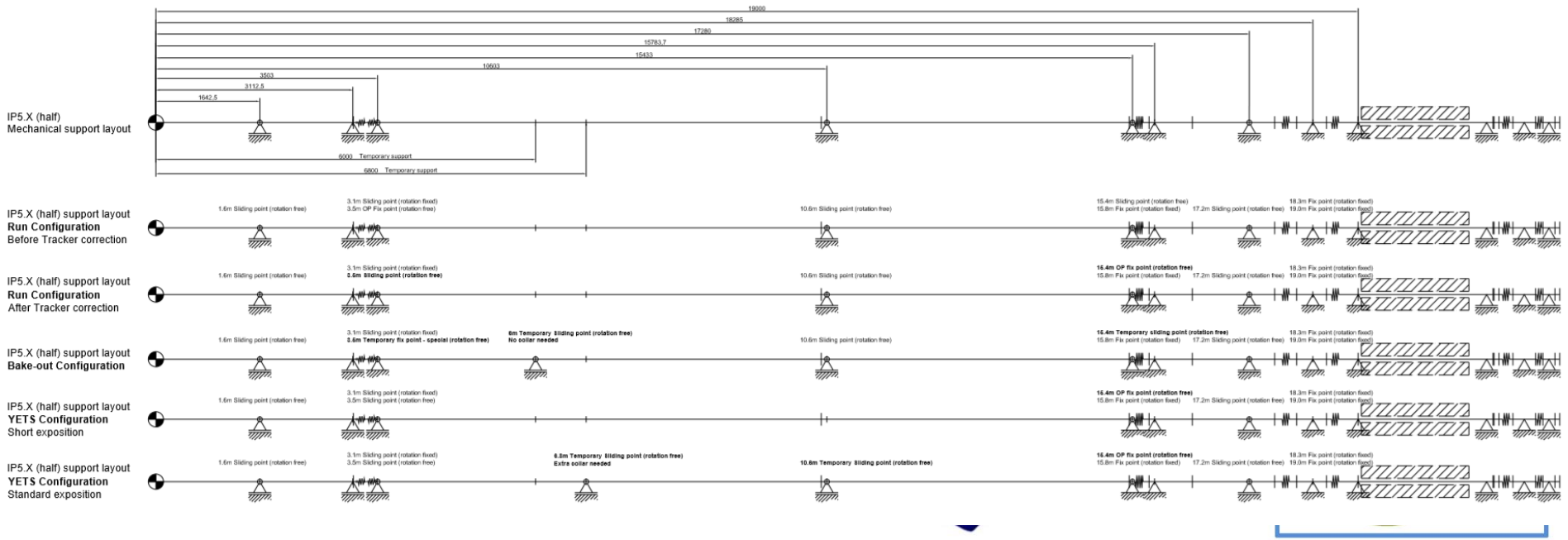
CMS Forward chambers

CMS forward chambers – buckling analysis

Structural integrity

- Deformation & stress analysis
  - Operations – Maintenance – Bake-out regime

Assessment for all applicable use-cases (OP, Maintenance, Bake-out)

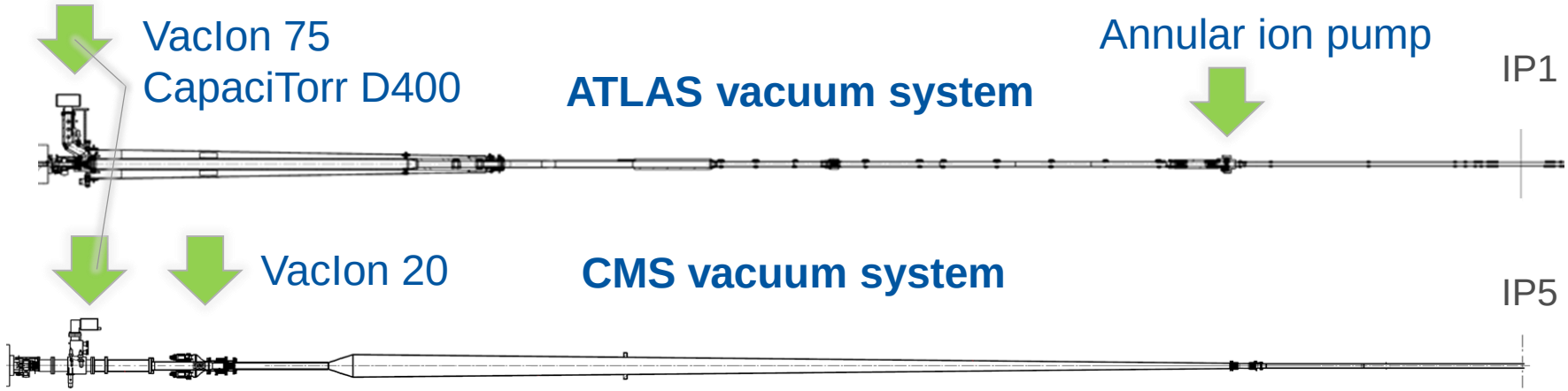


What are the specifications and limitations of the vacuum system?

Vacuum performance

Experimental vacuum relies on distributed pumping speed of the NEG Ion pumps ≈ 16 – 18m far from IP to pump CH_4

- Space reserved for the ion pumps and instrumentation follows design of the detector
- System operates in presence of strong magnetic fields



Vacuum performance

1D phyVASCO

- Critical current analysis
  - Assessment of beam induced dynamic effects
    - Ion induced desorption & e^- and photon stimulated outgassing
    - Function of pumping speed and NEG saturation

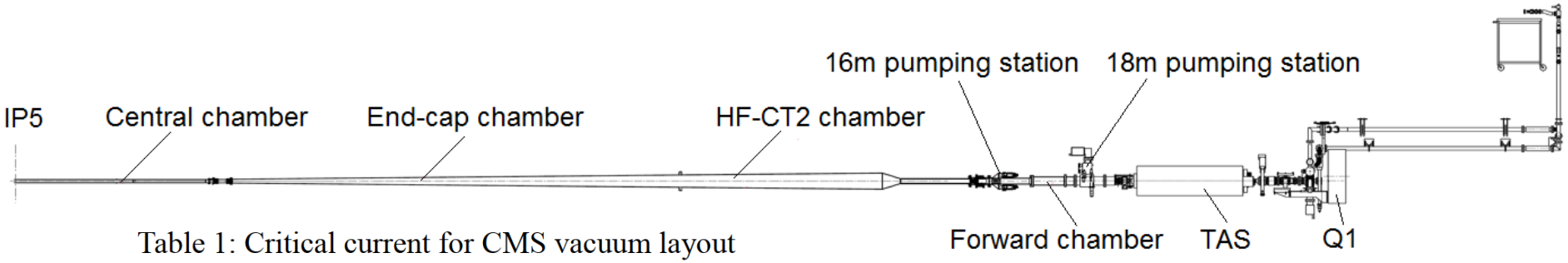


Table 1: Critical current for CMS vacuum layout

Ion pumps (16 m)	NEG saturation [%]	Critical current [A]	Dominant gas
ON	0	75	CH_4
ON	99	30	H_2
OFF	100	5	CO

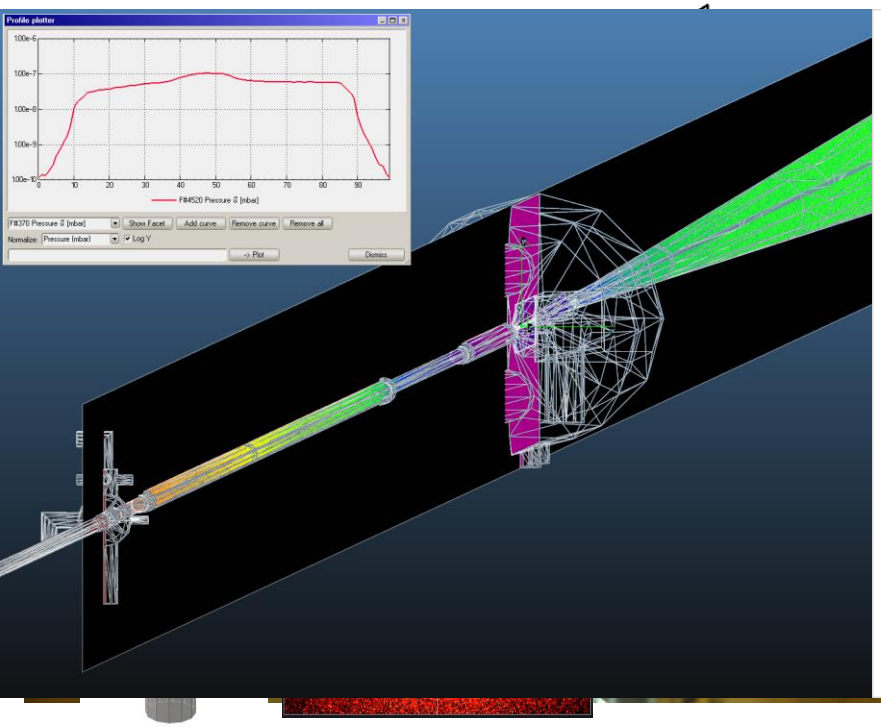
Critical current I_C
LHC: $I_C/2 > 2 \cdot 0.85$ A
HL-HLC: $I_C/2 > 2 \cdot 1.12$ A

Vacuum performance

3D
MolFlow+

- Pressure profile simulations
  - Simulations of static pressure profiles and gas injections

LHCb Pressure profile during SMOG injection



OK a lot of things to keep in mind…

But still, it is a tube and two flanges no? ☺

So what do we need in order to produce such a kind of chamber? (as conform as possible)

Raw material

- **Beryllium S-200-F (98.5% pure Be)**
  - Powder metallurgy
  - Processed by vacuum or hot isostatic pressing
- **Aluminum EN-AW-2219**
  - Copper based aluminum alloy
  - Mechanical properties at elevated temperatures
  - Main segments of the chambers & flanges
- **Aluminum EN-AW-5083**
  - Magnesium based aluminum alloy
  - Mechanical properties at elevated temperatures
  - Corrosion resistance and weldability
  - Cold-worked sheets 0.3 mm for aluminum bellows

Raw material

- **Aluminum EN-AW-2219**
  - Challenging microstructural requirements – grain size

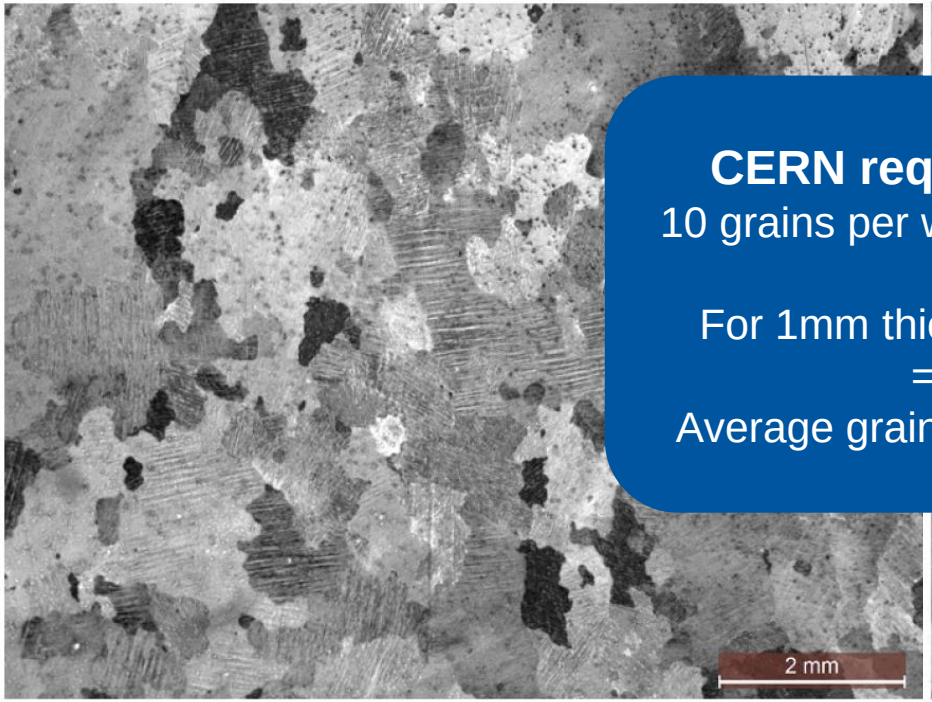


Image 1 specimen A04: Transversal section

CERN requirement
10 grains per wall-thickness

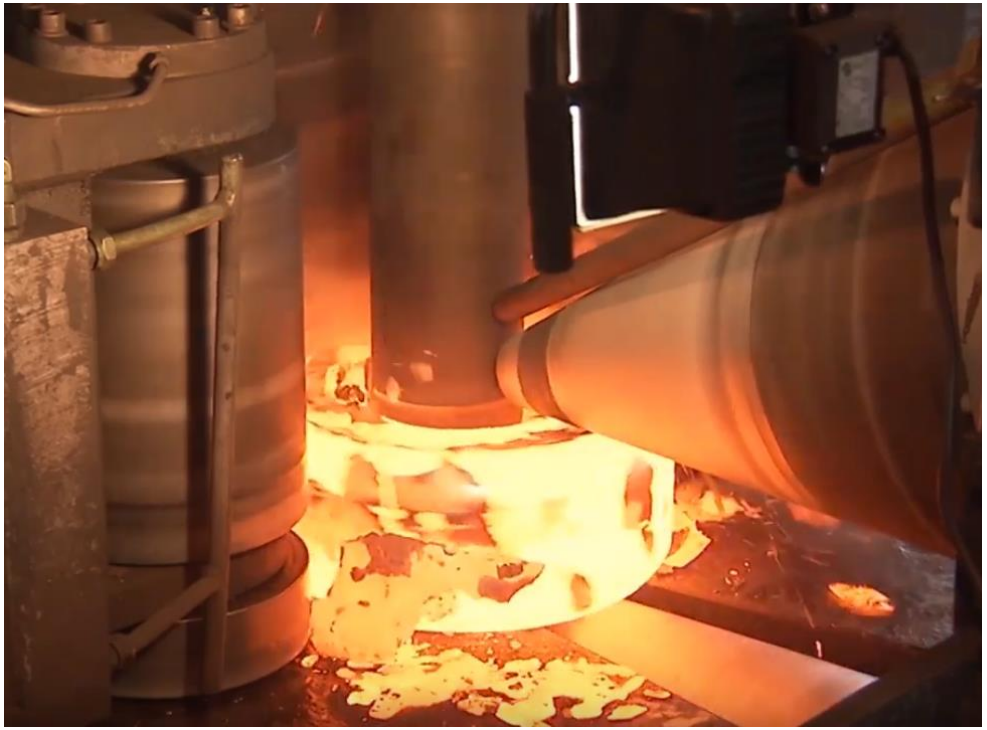
For 1mm thick chamber
=
Average grain size 100µm

Image 1 specimen A04: Transversal section

Raw material

Post forging process includes
Heat treatment
Stretching
Artificial aging

- **Aluminum EN-AW-2219**
  - Combination of ring rolling and free forging



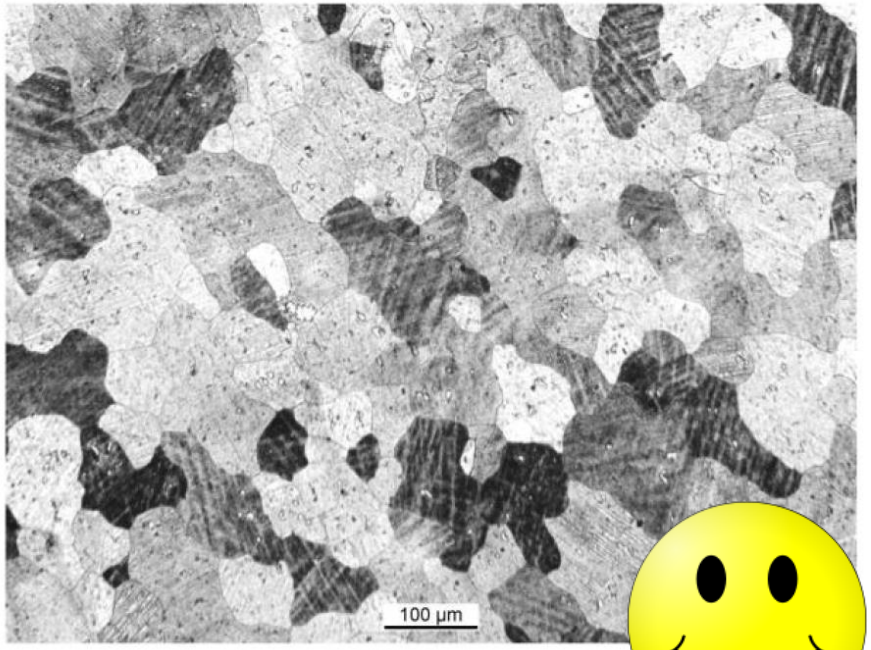


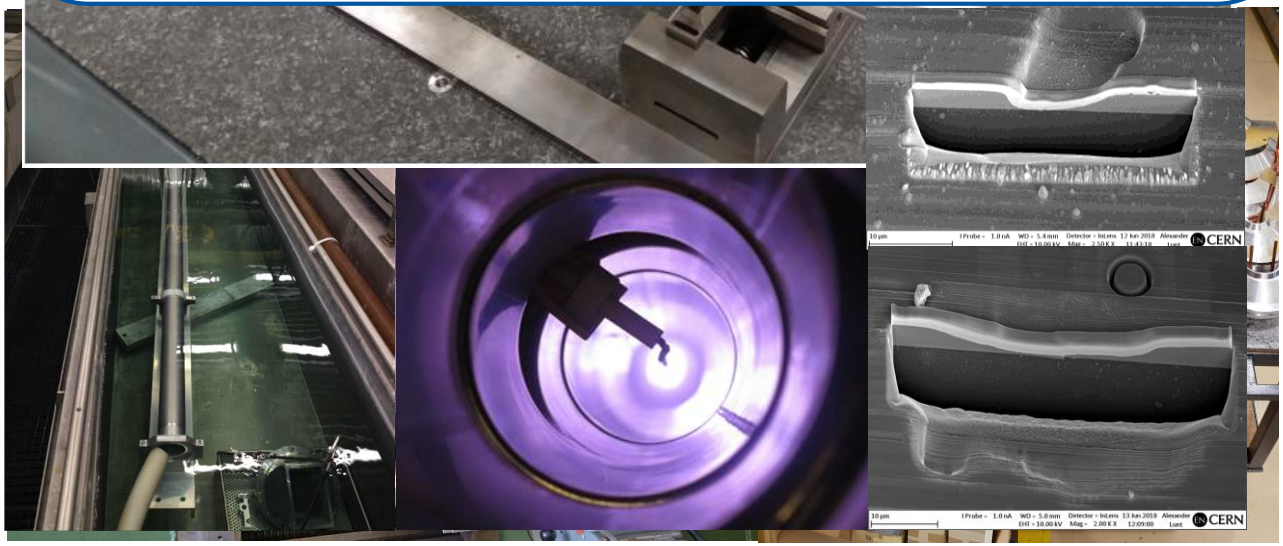
Fig. 2: microsection B366/4

Production process - qualification

Surface treatments

NEG coating is the baseline for experimental chambers

- Surface chemical treatments
  - Cleaning to remove contamination
  - Etching to improve NEG adhesion
- NEG coating
  - Aluminum chambers cleaned and coated
  - Central chambers – no pre / post treatment possible



Machining qualification

Welding qualification

Surface treatments qualification

Production and post-production process

Production process

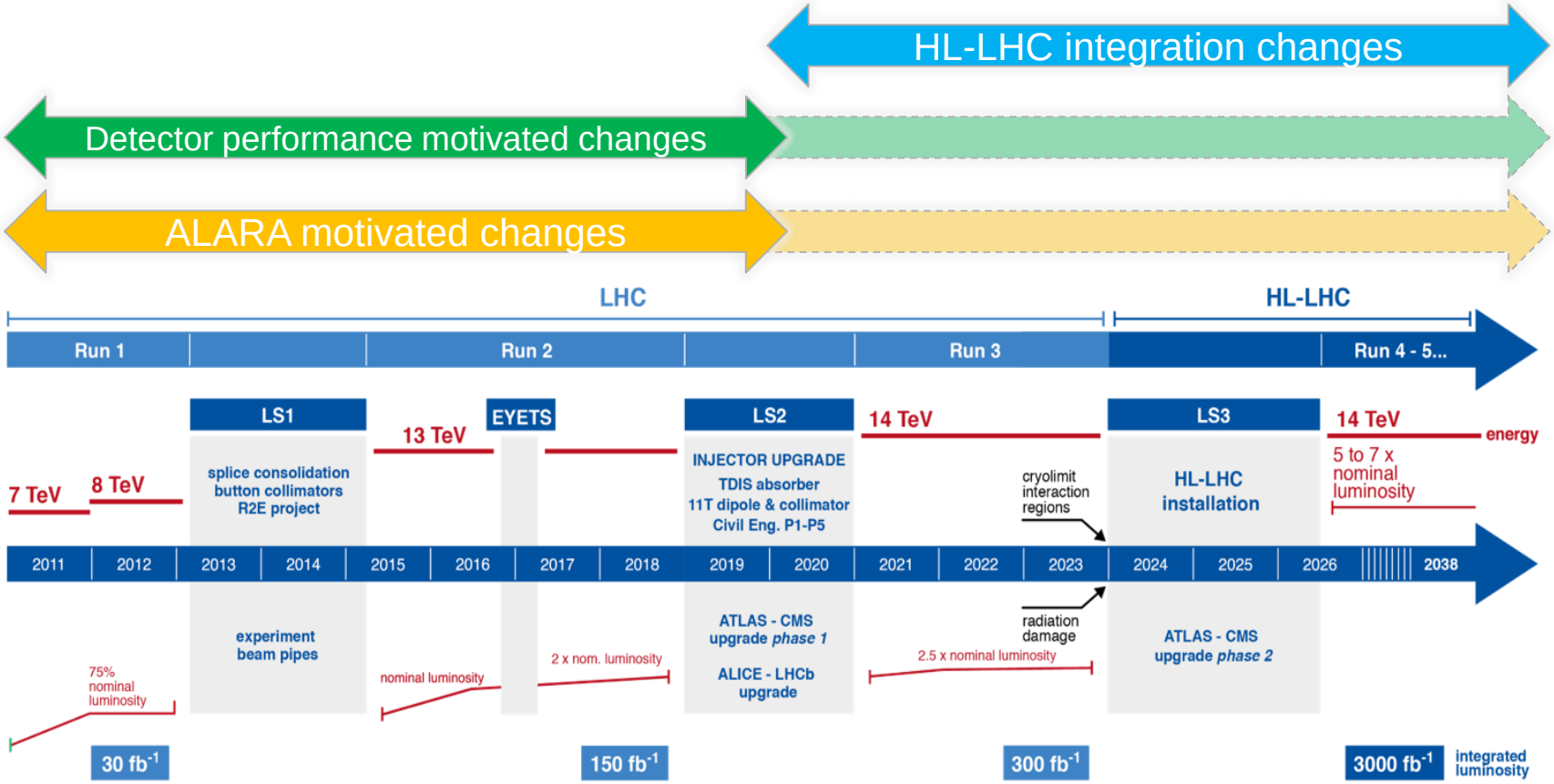
1. Rough machining
2. Heat treatment (semi-finished product)
3. Fine machining
4. Metrology
5. Surface treatment (cleaning, etching)
6. Welding
7. Intermediate leak detection
8. Final metrology
9. Cleaning (if applicable)

Post-production process

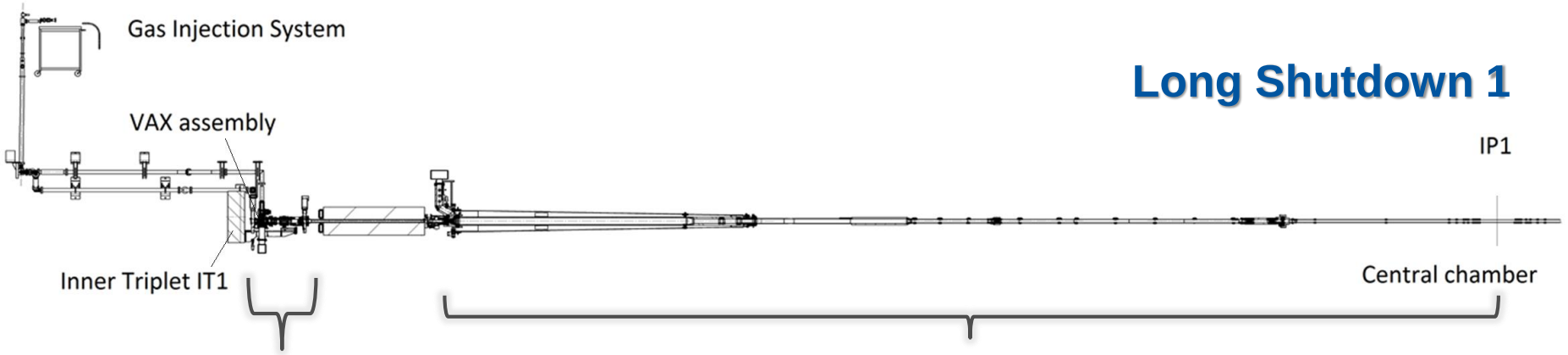
1. Leak testing
2. Installation of bake-out
3. Vacuum acceptance test
4. Post bake-out metrology (bow effect)
5. NEG coating
6. NEG acceptance test
7. Installation of permanent heaters
8. Integration test

Long Shutdown 2

Experimental & HL-LHC



ATLAS experiment



Long Shutdown 1

New A1L/R1.X layout

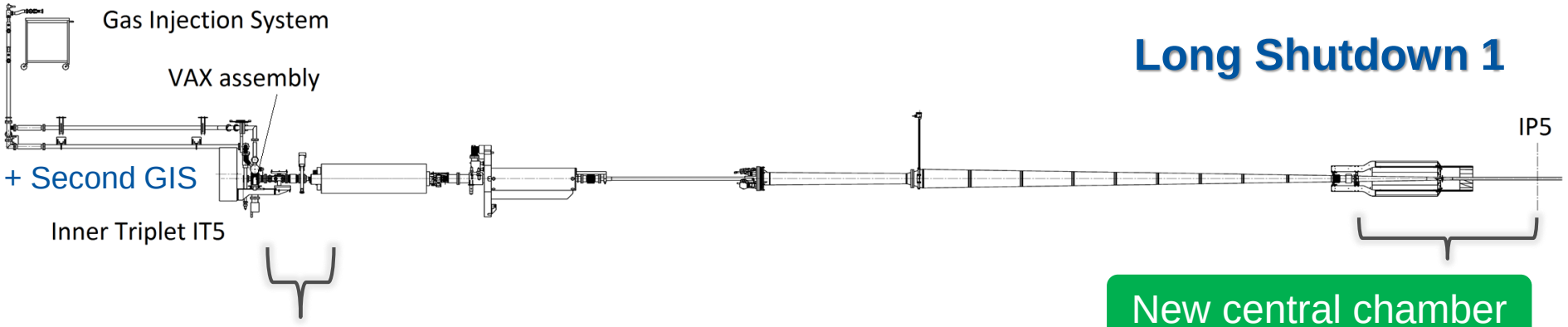
Aluminum chambers up to TAS

New central chamber

Long Shutdown 2

Modification of VT supports
due to shielding changes

CMS experiment

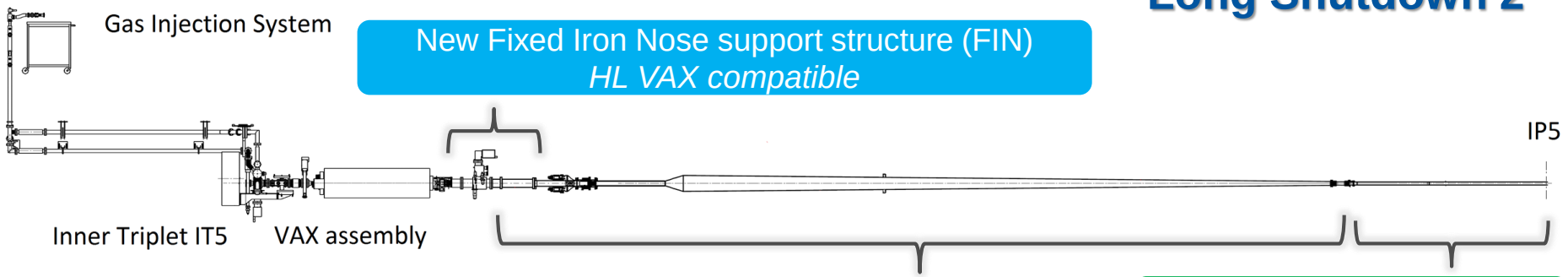


Long Shutdown 1

New A1L/R5.X layout

New central chamber

Long Shutdown 2



New Fixed Iron Nose support structure (FIN)
HL VAX compatible

Aluminum chambers up to ±18m

New central chamber

ALICE experiment

Long Shutdown 1

New BA vacuum gauge

Long Shutdown 2

New central chamber VC2C

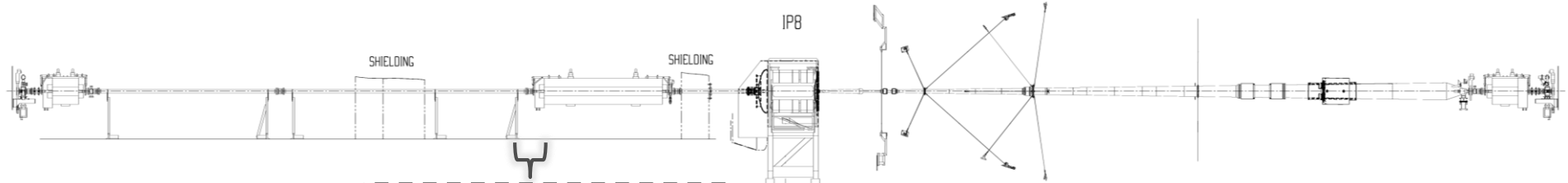
New A1L2.X (RB24) layout
Accommodating different length of VC2C
Request for reduction of high Z material upstream of IP2

New sector valve
With relocated VGRB

LHCb experiment

Long Shutdown 1

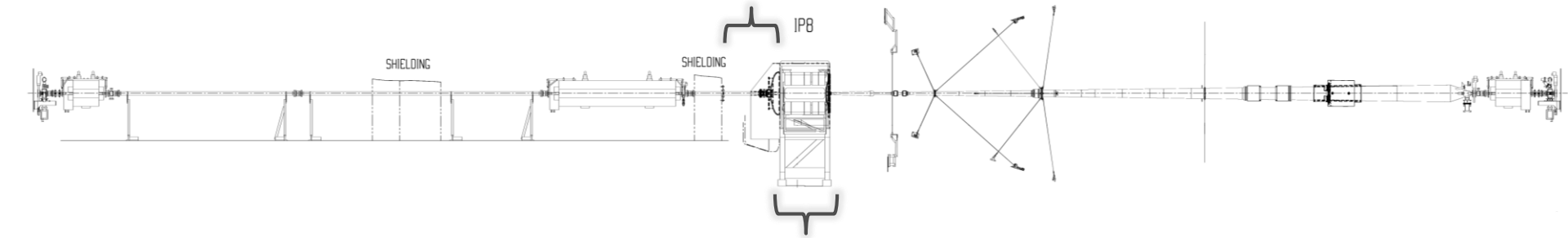
EYETS 2017



Calibrated BA gauge

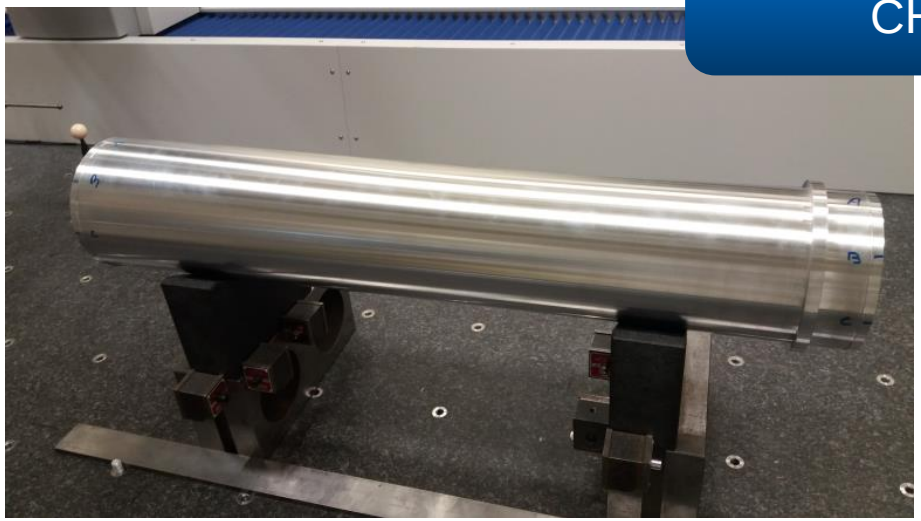
Long Shutdown 2

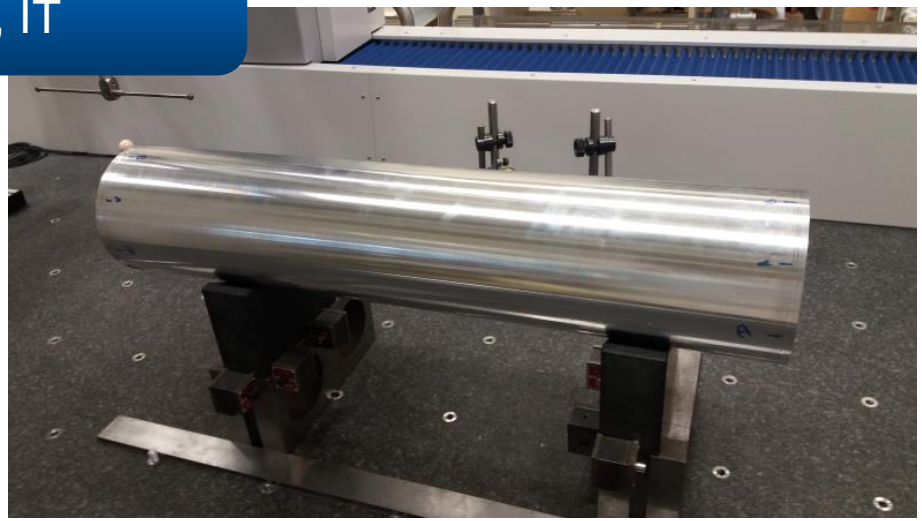
Additional sectorization upstream of VELO
Including rearrangement of VELO vac equipment

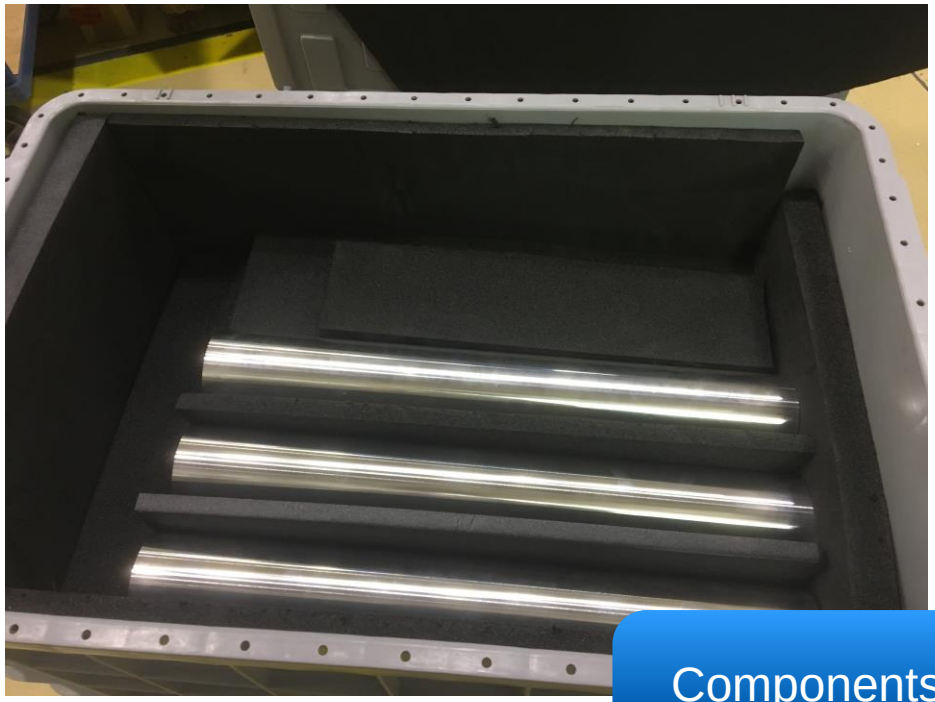


VELO Mk2 Upgrade; Control system; SMOG2

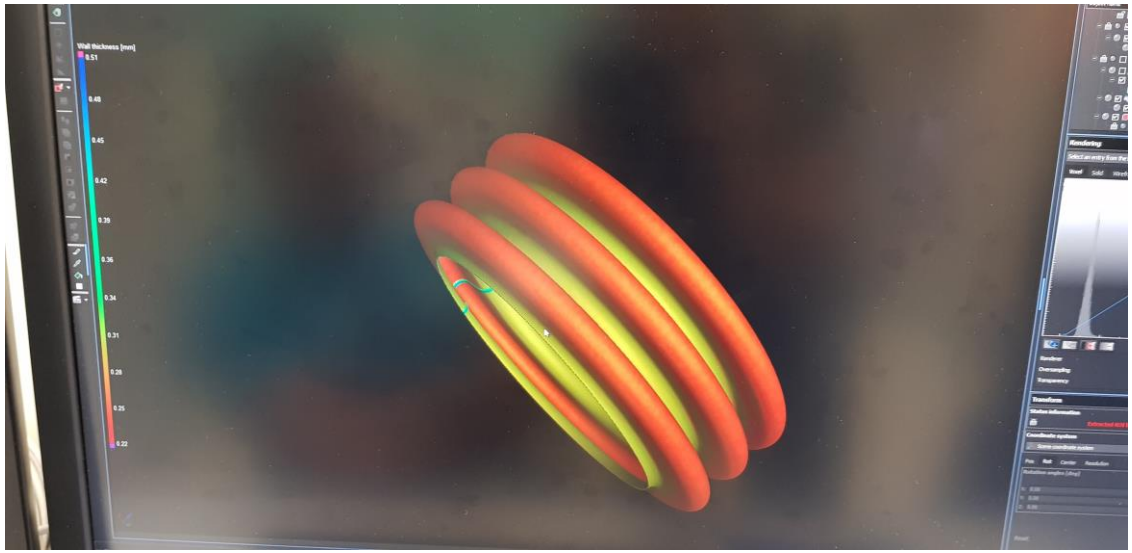
External production
CH, IT

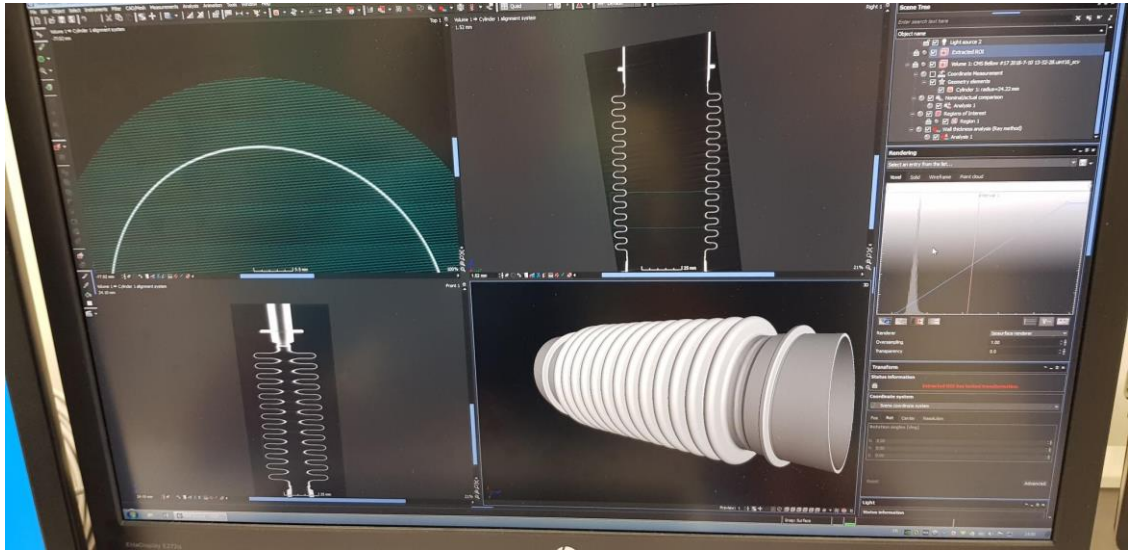


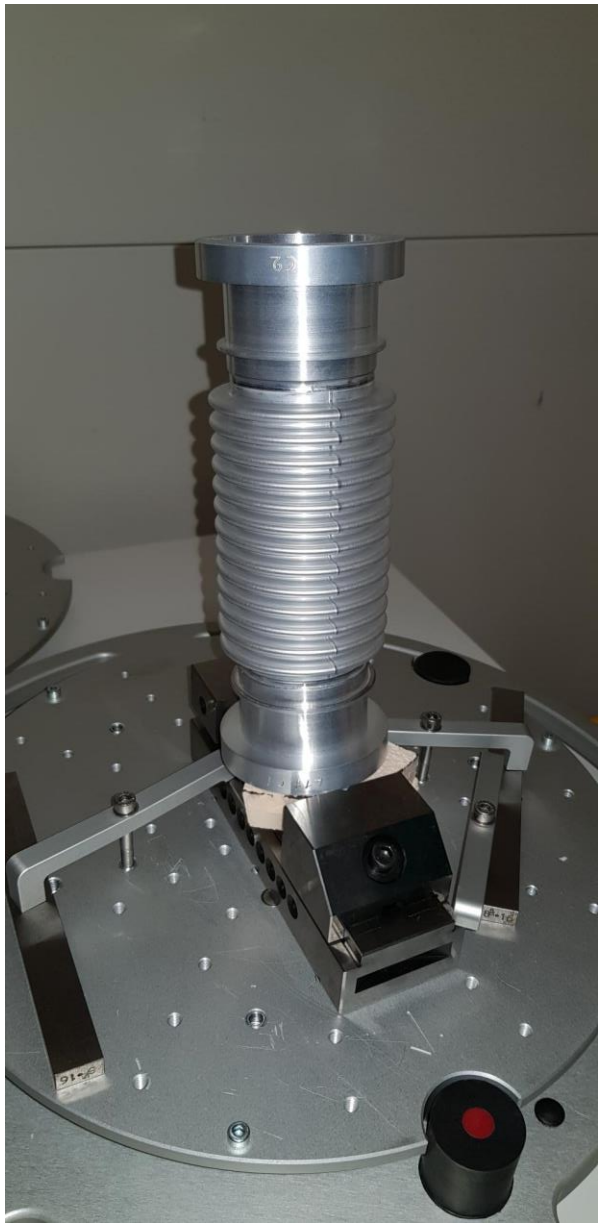




Components ready for final assembly at CERN







Internal production of aluminium bellows for CMS

1st beryllium chamber of LS2 in b.113

Thank you for your attention

Big thanks to basically everybody here around!

Giuseppe, Jerome, Patrick, Didier, Nicolas R., Chiara, Piotr, Nicolas Z., Julien, Eric P., Eric N., Gregory, Cesar and BVO team

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Cedric, Hendrik, Herve, Jaime and DLM team

Paolo, Paul, Vincent and Germana

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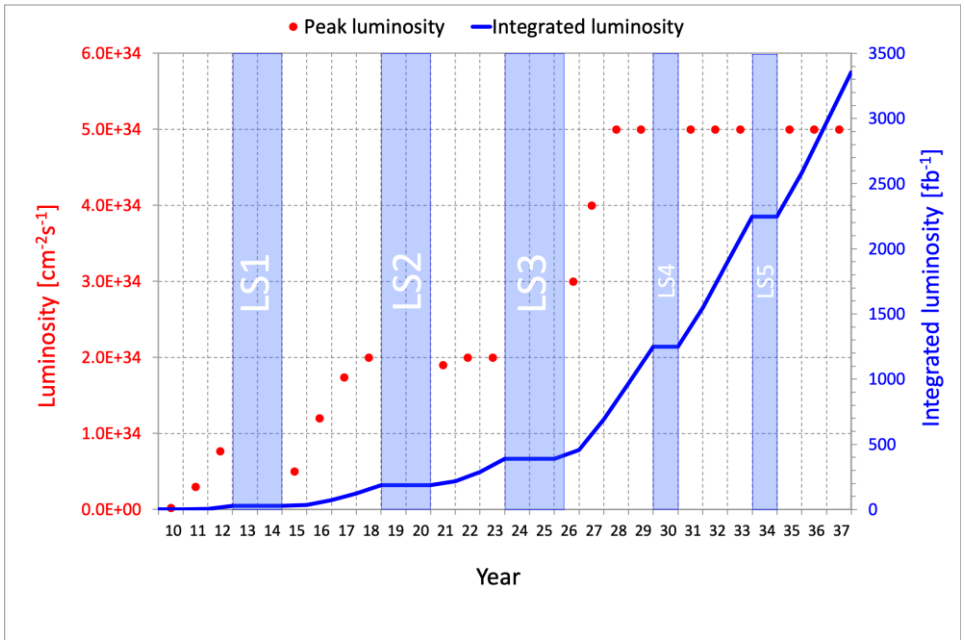
Spare slides

Radiation environment

- **Personnel dose** and foreseen evolution

Experiment	IP	Peak levelled luminosity [cm^{-2} s^{-1}]	
		HL-LHC	LHC
ATLAS	1	5×10^{34}	2×10^{34}
CMS	5	5×10^{34}	2×10^{34}
ALICE	2	1×10^{31}	1×10^{31}
LHCb	8	2×10^{33}	4×10^{32}



LS 1

LS 2 ≈ 2.5 × LS1

Collective 1.7 mSv

LS 3 ≈ 4 × LS1

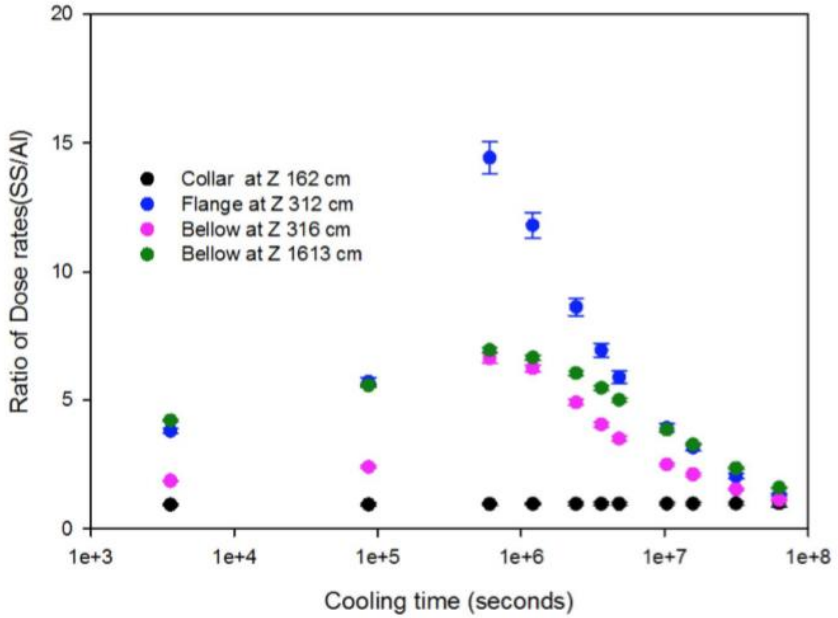
Collective 2.7 mSv

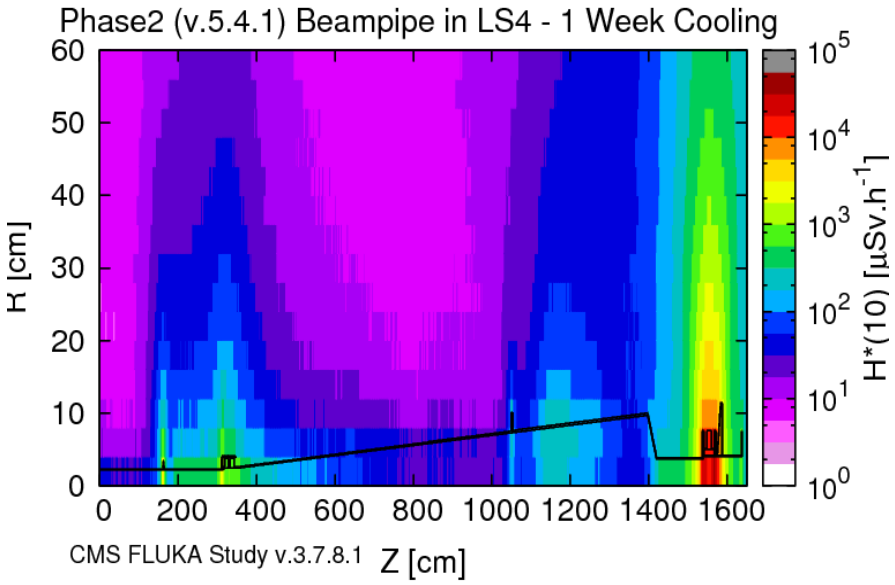
LS 4 ≈ 20 × LS1

Collective 13.6 mSv

Radiation environment

- Equipment made of aluminum reduces dose obtained by personnel (by factor of 5).

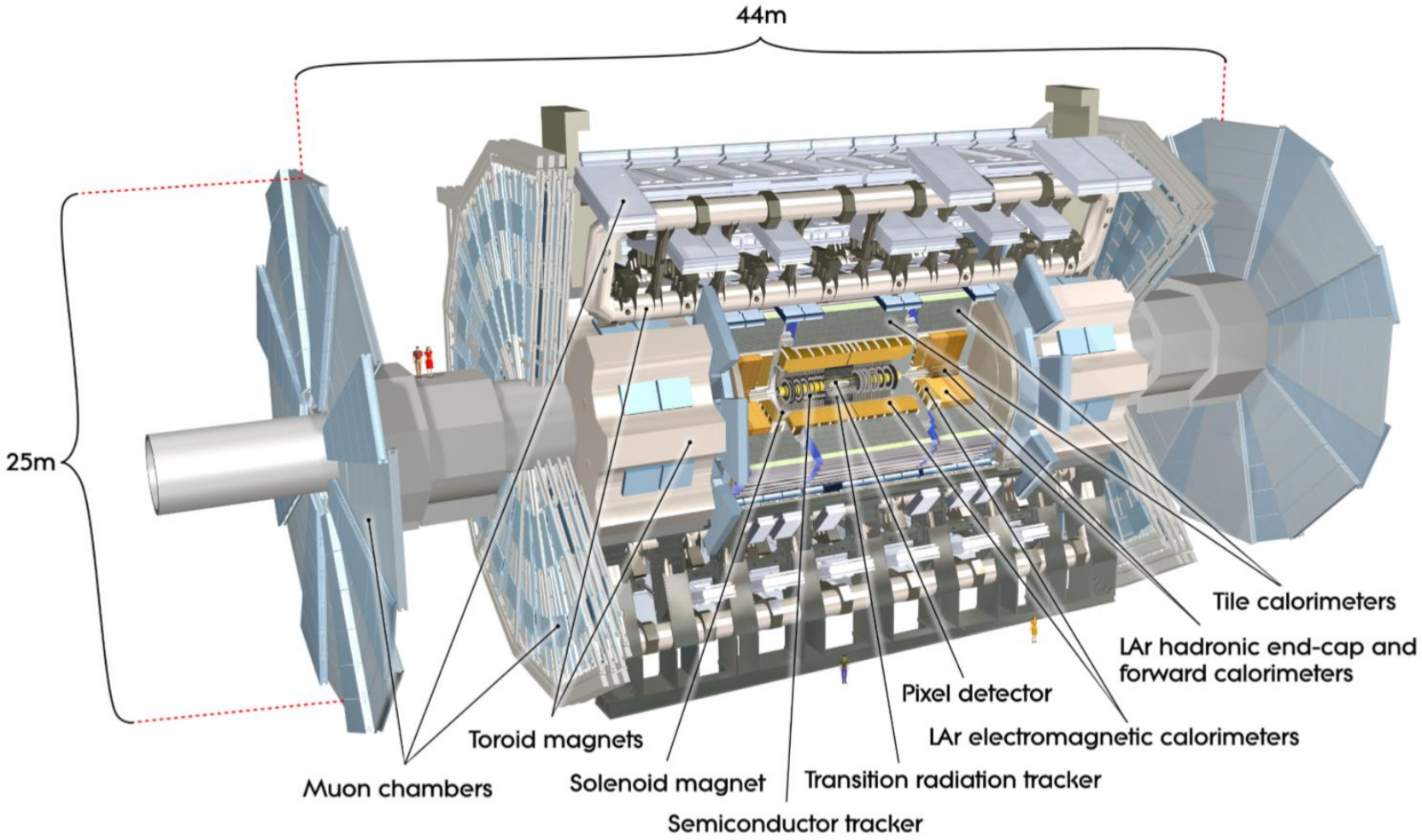




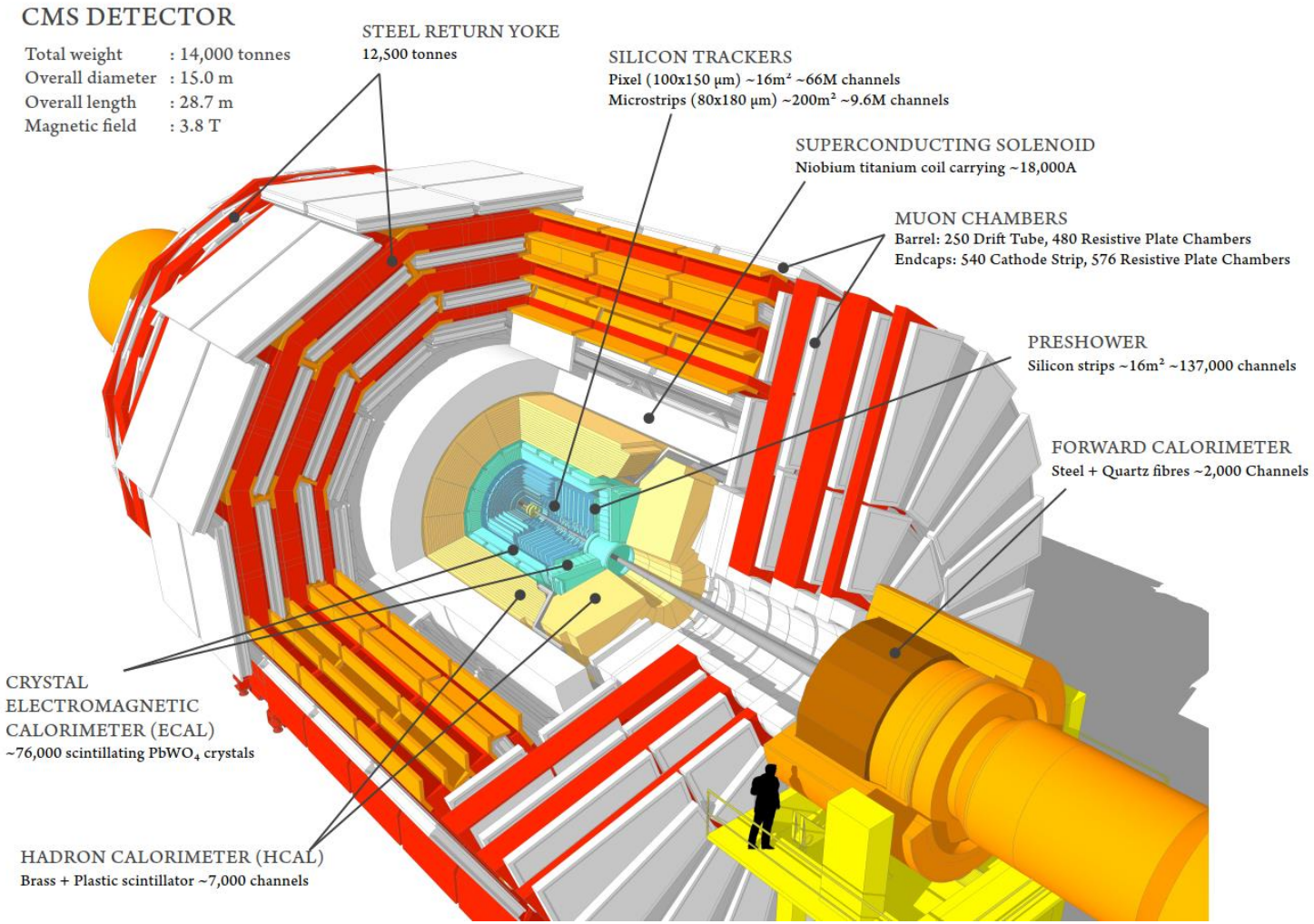
- Stainless steel equipment is still unavoidable.

  Bimetallic flanges, edge-welded bellows, ion pumps, gauges etc…

Physics performance

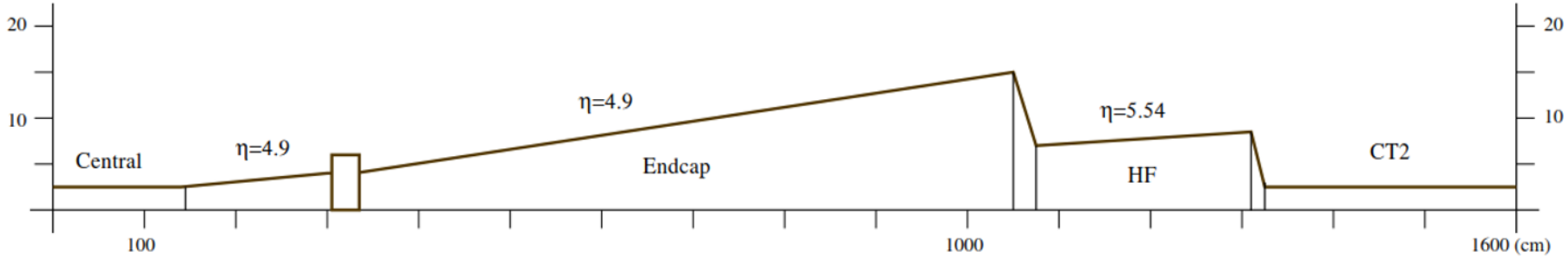


Physics performance



Physics performance

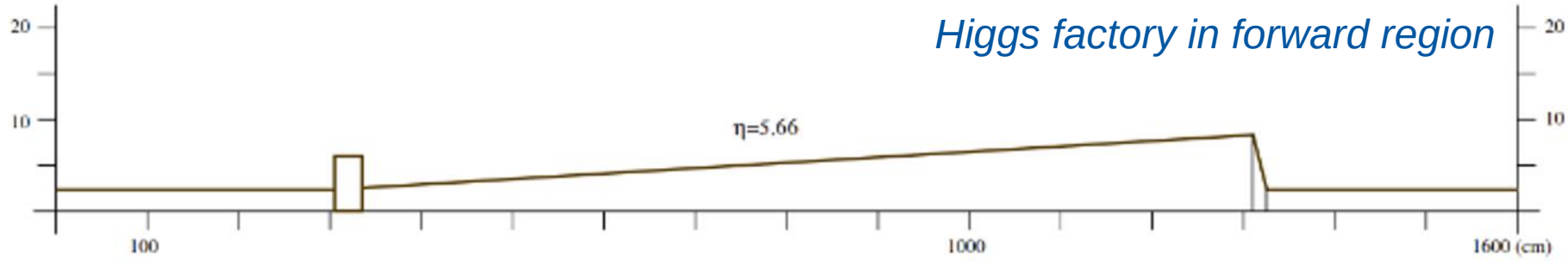
- Pseudorapidity and acceptance angles
  - Design of the detector (tracker, calorimeters, B-field)



CMS chambers Run 1, 2

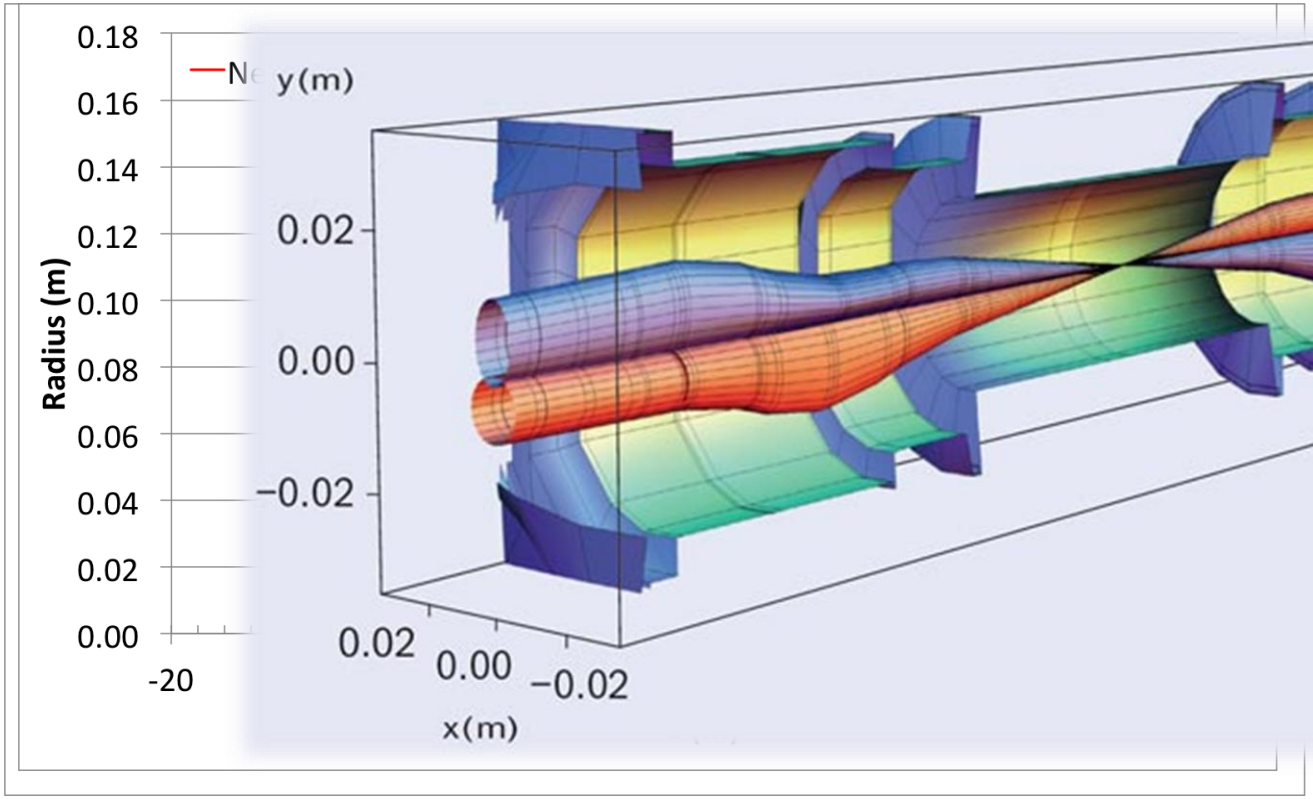
CMS chambers Run 3, 4

Higgs factory in forward region



Machine performance

- Mechanical aperture
  - Aperture target for the LHC experiments $n_1 = 7\sigma$



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