Thanks to all Contributors

Challenges for Vacuum Technology of Future Accelerators

Dr. José Miguel Jimenez
CERN Technology Department Head

Main topics

HEP Plans & CERN’s road map

Vacuum operational challenges

Vacuum design challenges

Closing remarks

HEP Plans & CERN’s road map

GLOBAL PARTICLE PHYSICS STRATEGY

ICFA (International Committee for Future Accelerators)

Japan: Future HEP Projects

– „… Japan should take the leadership role in an early realisation of an e+e- linear collider.“

Update of European Strategy for by CERN Council (May 2013)

- LHC, incl. HL-LHC
- accelerator R&D
- strong support for ILC
- long-baseline neutrino
- importance of theory

European Strategy for Particle Physics

USA: Snowmass conclusions and recommendations to P5 in line with worldwide strategy statements

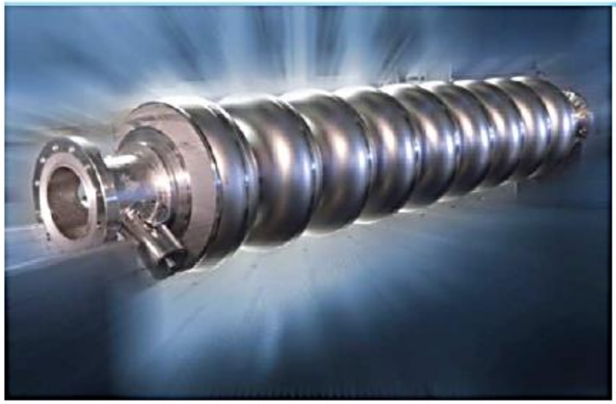
- Different flavours in different regions of the world
- But looks like an emerging global, coherent strategy in particle physics
- Next update of European strategy 2020; US to follow 2-3 years after.

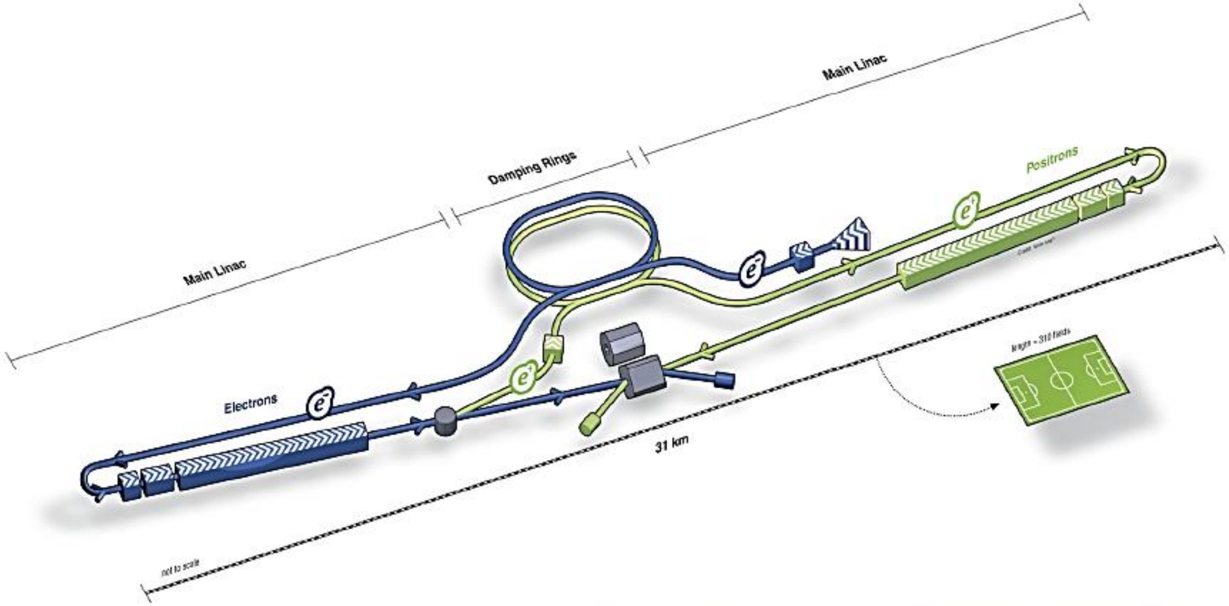
ICFA View: A Global Strategy

- Encourage strategic studies and planning of international facilities in different regions of the world
  - ILC in Japan
  - CEPC/SPPC in China
  - CLIC/FCC in Europe
  - LBNF in US

- Encourage global coordination in planning of future energy frontier colliders
  - ILC and CLIC groups working together
    - Linear Collider Board (and Linear Collider Collaboration) under ICFA
  - CEPC/SPPC and FCC

The International Linear Collider





ILC Scheme | © www.form-one.de

- e^+e^- collider
- Superconducting RF Technology
- Initial Design: $\sqrt{s}$ = 250 - 500 GeV
- Upgradeable to 1 TeV
- Luminosity > 10^{34} cm^{-2} s^{-1}

Collider efforts in China

CEPC:

- Circular electron positron collider
- 50 - 100 km ring
- 90 - 250 GeV
- Z and Higgs factory

SPPC:

- Super pp Collider
- In the same ring as CEPC

Yifang Wang

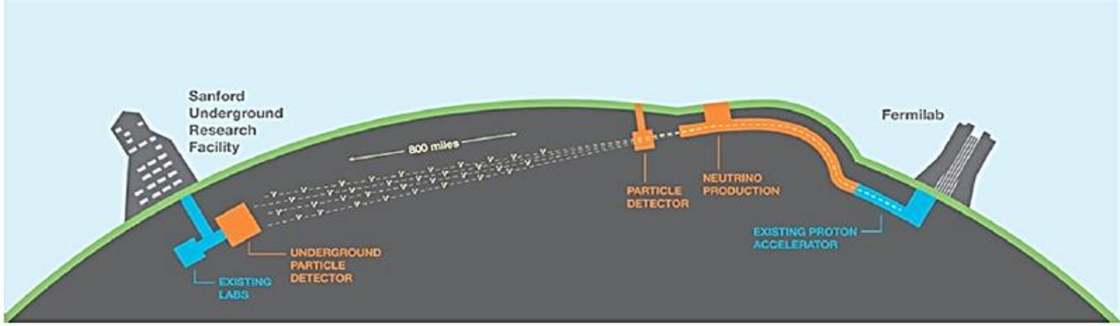
CEPC Design –Higgs Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	2*120 GeV
Luminosity (peak)	>2*10^34/cm^2s
No. of IPs	2

CEPC Design – Z-pole Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	2*45.5 GeV
Integrated luminosity (peak)	>10^34/cm^2s
No. of IPs	2
Polarization	to be considered in the second round of design

LBNF status:

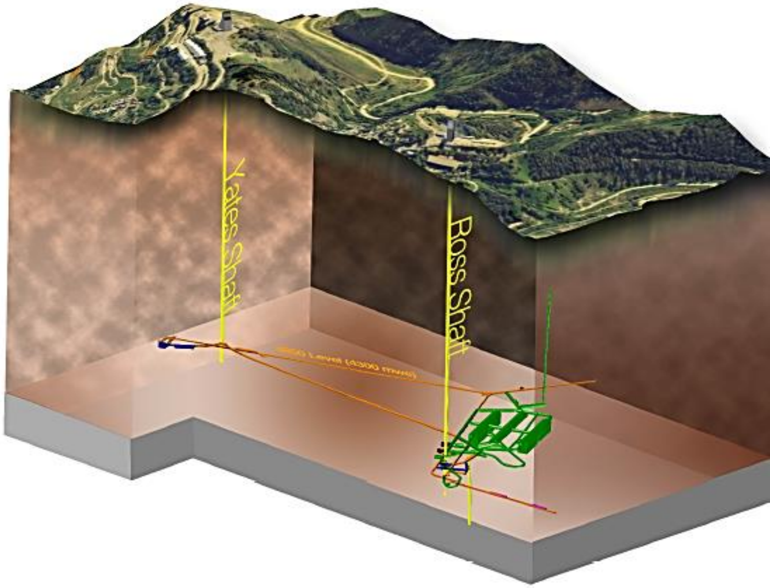


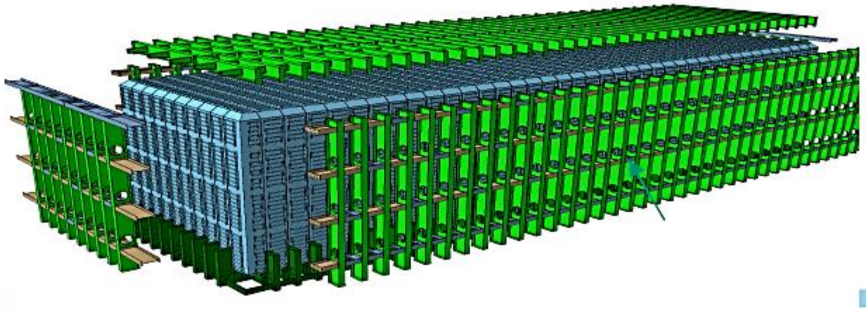
2017 Funding Status:

- Appropriation for LBNF/DUNE-US approved by U.S. Congress 5 May 2017

Construction Start Authority

- With DOE CD-3a approval, Congressional authority to start construction, and FY17 appropriation, LBNF project is ready to begin Far Site construction
- Groundbreaking ceremony in South Dakota planned for July





HEP Plans & CERN's road map

European Strategy – High Energy Frontiers…

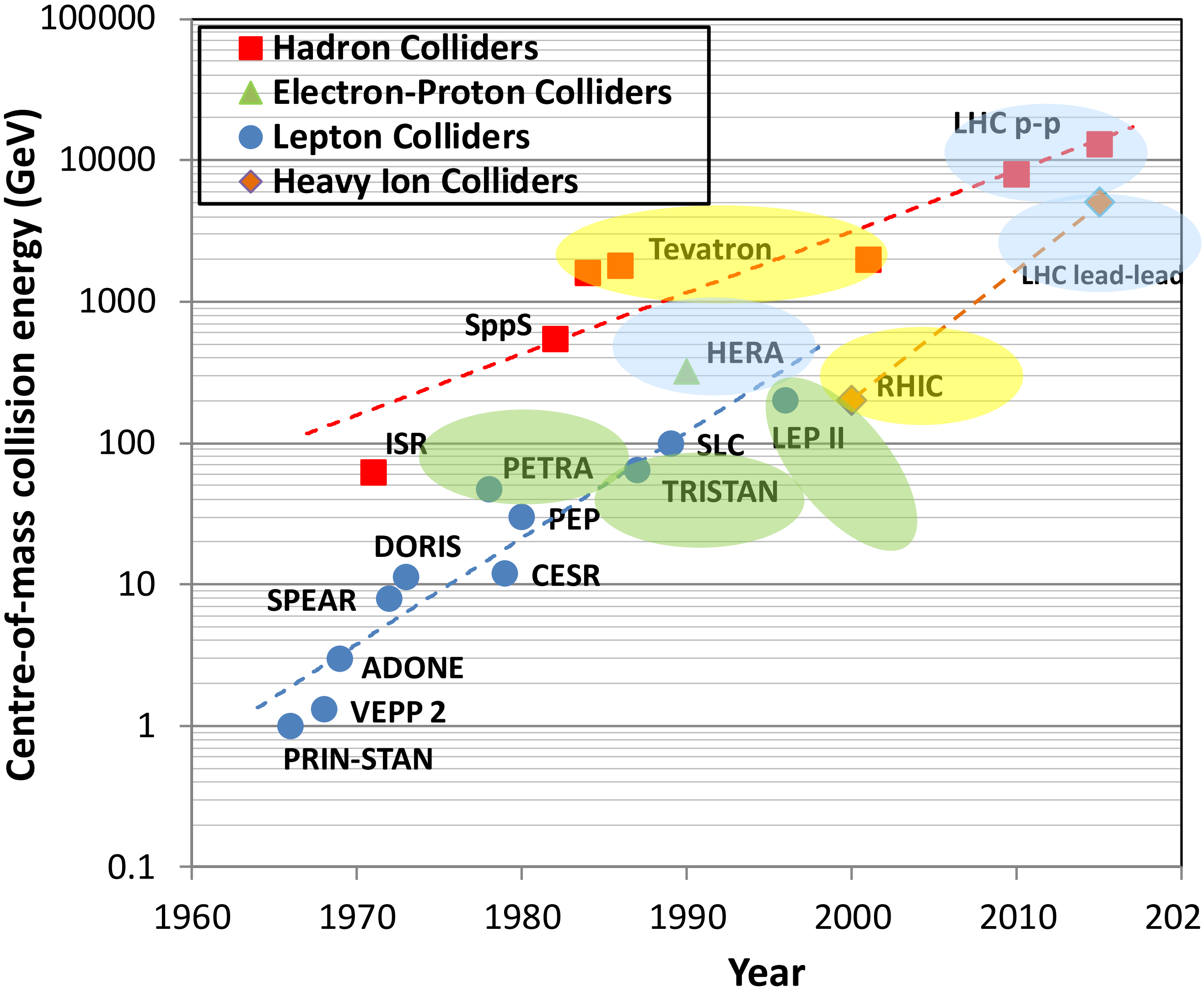
- Using **electrical fields (RF cavities)** to accelerate and **magnetic fields (accelerator magnets)** to guide and collide **charged particle beams** (electrons, protons & anti-particles)

- **Aim at higher energy accelerators for 2 reasons**:
  - **Production of new heavier particles (according to Einstein):** **E** = **m**c^2 ≤ 2E beam (collider)
  - **Resolving smaller distances (according to de Broglie):** **Wavelength** λ = hc/**E** **for LHC** ~ $2 \cdot 10^{-18}$ cm

Higher energy → **Increased potential for discoveries**

HEP Plans & CERN's road map

Colliders & Superconductivity



🟩 Colliders with superconducting RF system

🟨 Colliders with superconducting arc magnet system

🟦 Colliders with superconducting magnet & RF

HEP Plans & CERN’s road map

Medium term plan guiding principle

- **Driven by Science** and aiming at implementation of European Strategy for Particle Physics.
- Takes into account **technical feasibility and financial affordability**.
- Ensure **adequate resources for maintenance and consolidation** of scientific and general infrastructure, and for **compliance with Safety** requirements.
- Next 10 years dominated by construction of **High Luminosity LHC project** (HL-LHC) ~950 MCHF.

HEP Plans & CERN's road map

Three main scientific pillars

- **Full exploitation of the LHC**:
  - successful Run 2, LS2, and Run 3 start-up.
  - Upgrade of LHC Injectors; on-track construction of HL-LHC.
- **Scientific diversity programme** serving a broad community:
  - ongoing experiments and facilities at Booster, PS, SPS and their upgrades.
  - participation in accelerator-based neutrino through CERN Neutrino Platform.
- **Preparation of CERN's future**:
  - vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness.
  - design studies for future accelerators: CLIC, FCC (includes HE-LHC).
  - future opportunities of diversity programme: "Physics Beyond Colliders".

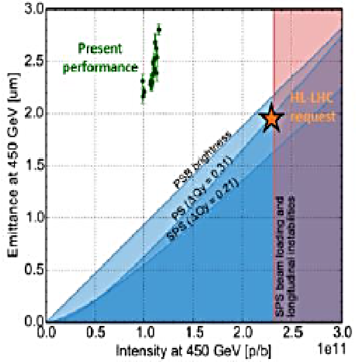
Important milestone: update of the European Strategy for Particle Physics (ESPP) in 2019-2020.

HL-LHC and LHC injector upgrades

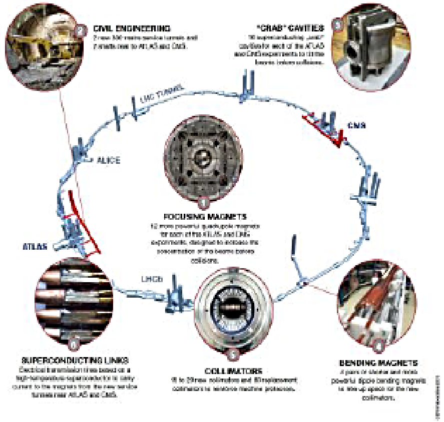
LIU & HL-LHC project

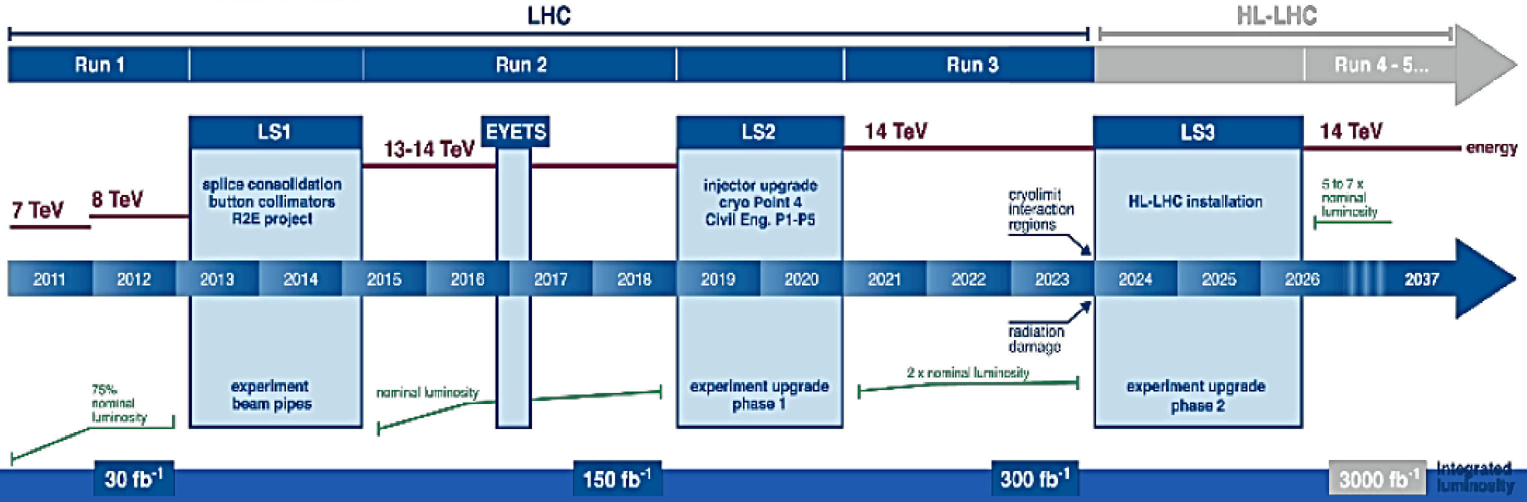
formal approval by CERN Council (June 2016)

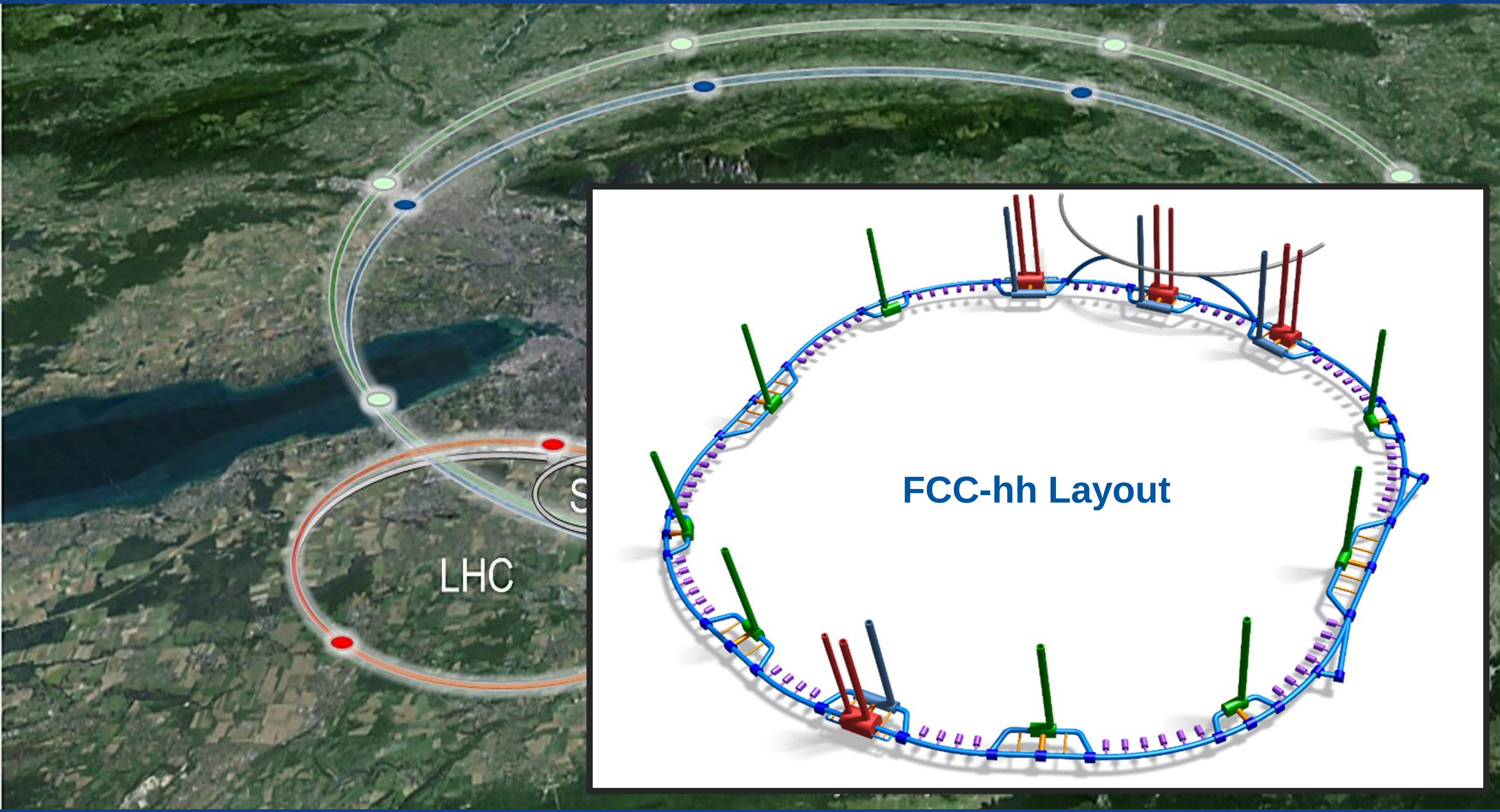
LIU performance reach for protons with SPS impedance reduction



	$\mathcal{N}$ (x 10^{11} p/b)	ε (μm)
LIU Baseline	2.3	2.2
HL-LHC	2.3	2.1



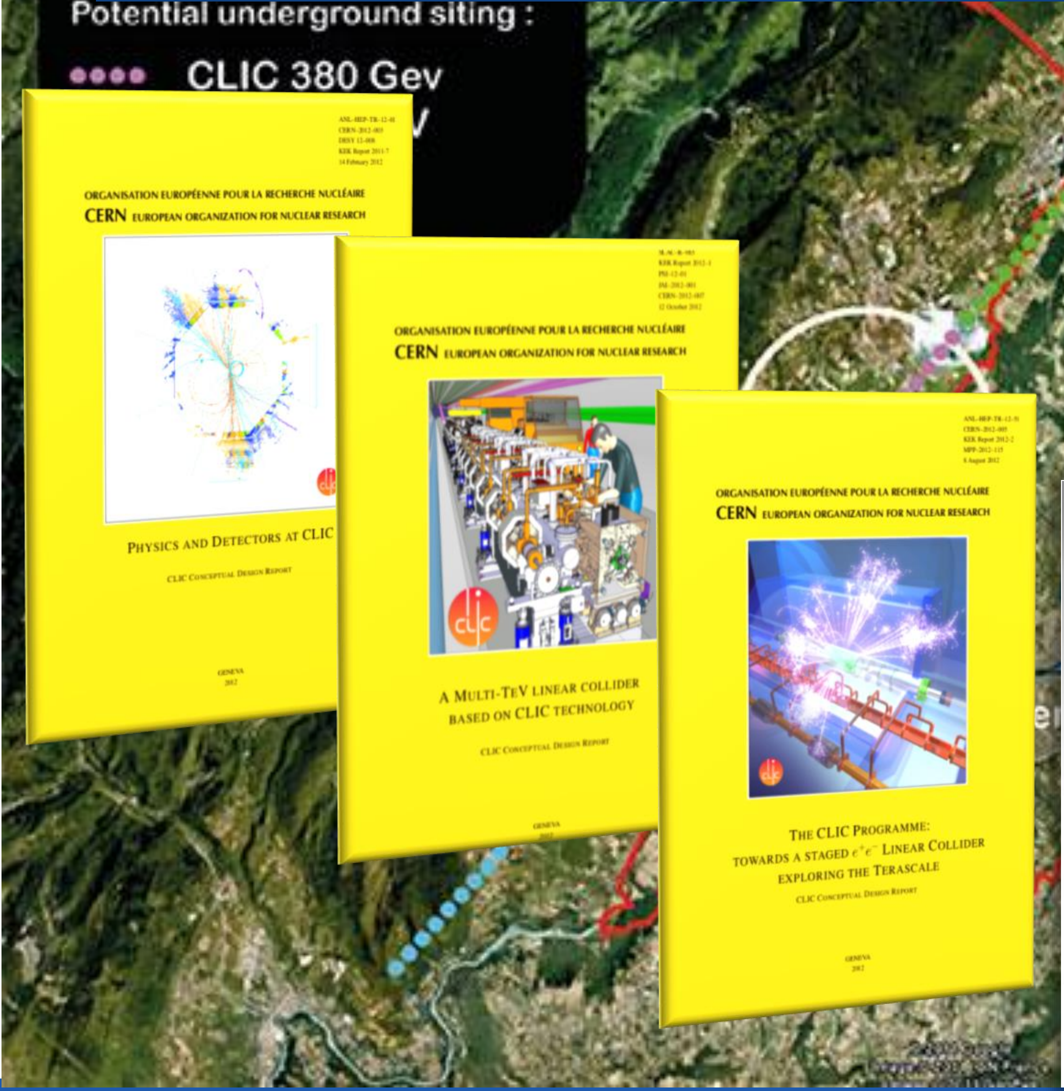




LHC	**HE-LHC baseline**	**FCC-hh baseline**	**FCC-hh**
27 km, 8.33 T	**27 km, 16 T**	**100 km, 16 T**	80 km, **20 T**
14 TeV (c.o.m.)	26 TeV (c.o.m.)	100 TeV (c.o.m.)	100 TeV (c.o.m.)
1300 tons NbTi	**2500 tons Nb_3Sn**	**10000 tons Nb_3Sn**	**2000 tons HTS** **8000 tons LTS**

A vibrant R&D on breakthrough technologies!

Vectors of technology! the Compact Linear Collider (CLIC)



ANL-HEP-TR-12-01
CERN-2012-003
DESY 12-008
KEK Report 2011-7
14 February 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PHYSICS AND DETECTORS AT CLIC

CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012

SLAC-R-985
KEK Report 2012-1
PSI-12-01
JAI-2012-001
CERN-2012-007
12 October 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

A MULTI-TEV LINEAR COLLIDER BASED ON CLIC TECHNOLOGY

CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012

ANL-HEP-TR-12-51
CERN-2012-005
KEK Report 2012-2
MPP-2012-115
6 August 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
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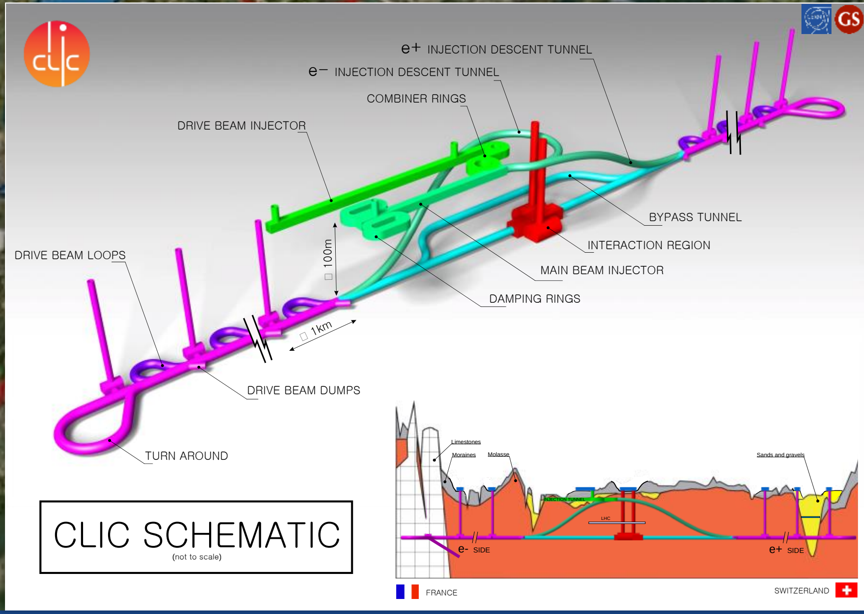
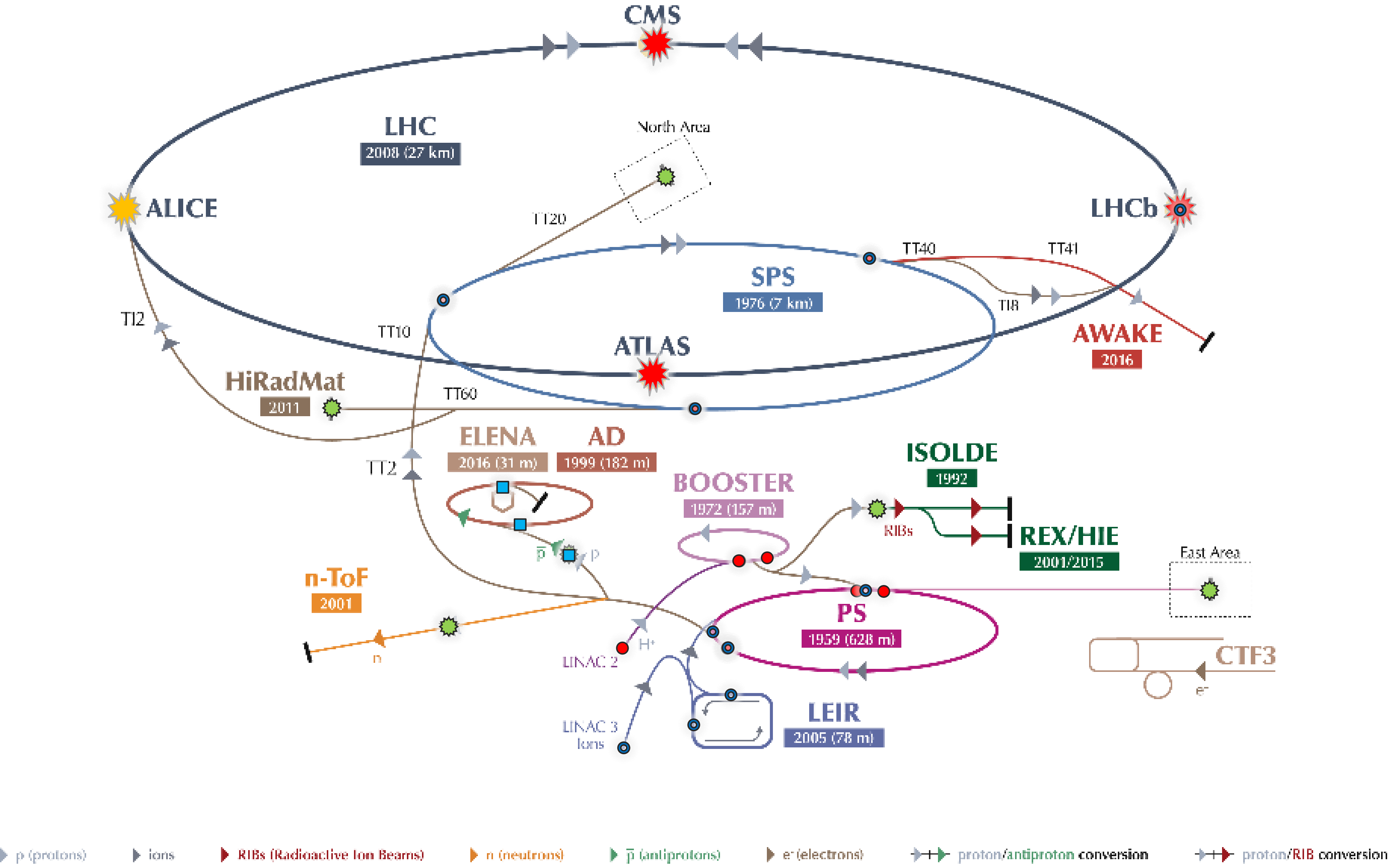
THE CLIC PROGRAMME: TOWARDS A STAGED e^+e^- LINEAR COLLIDER EXPLORING THE TERASCALE

CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012



CLIC SCHEMATIC
(not to scale)



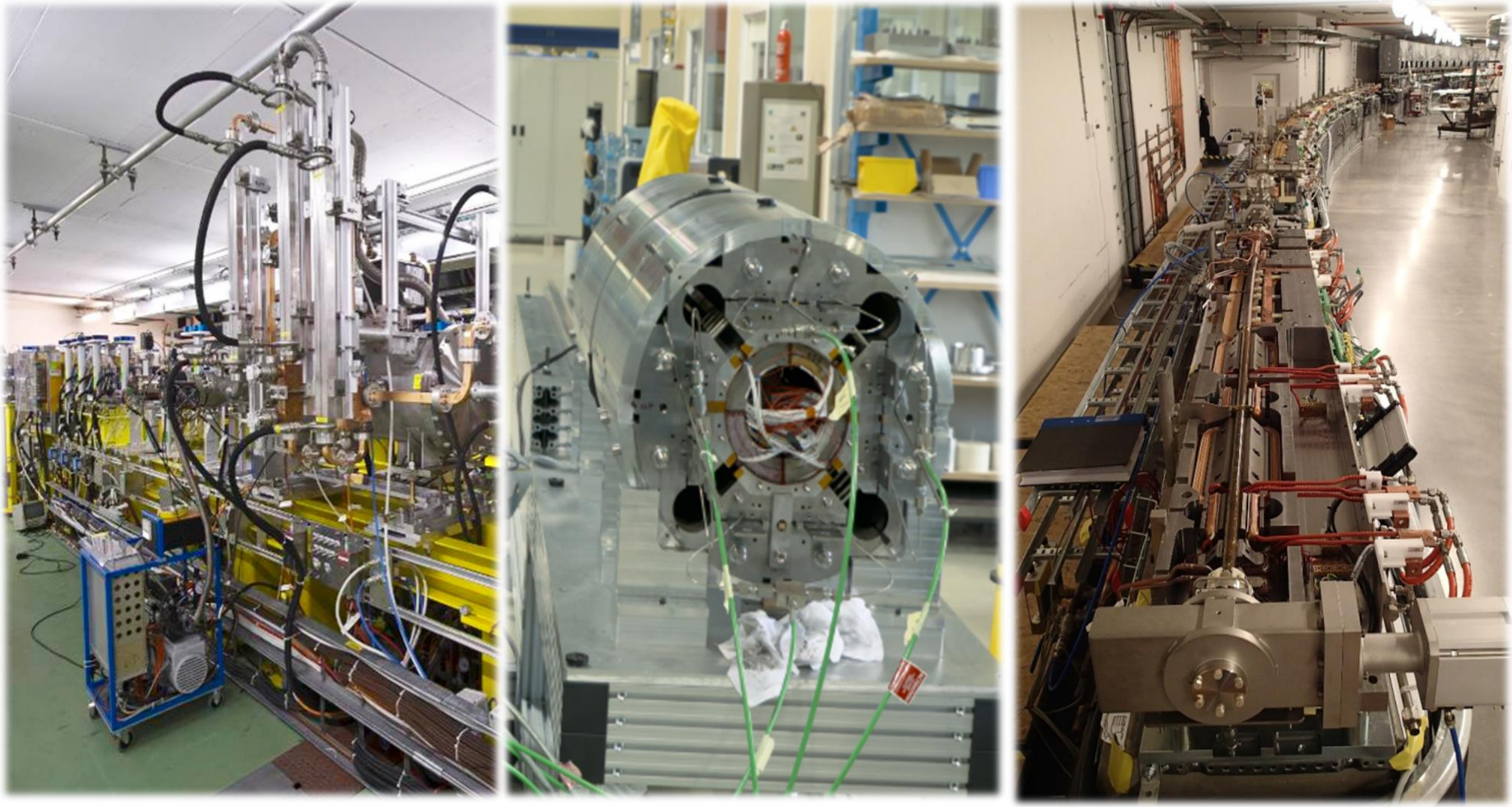
LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron AD Antiproton Decelerator CTF3 Clic Test Facility

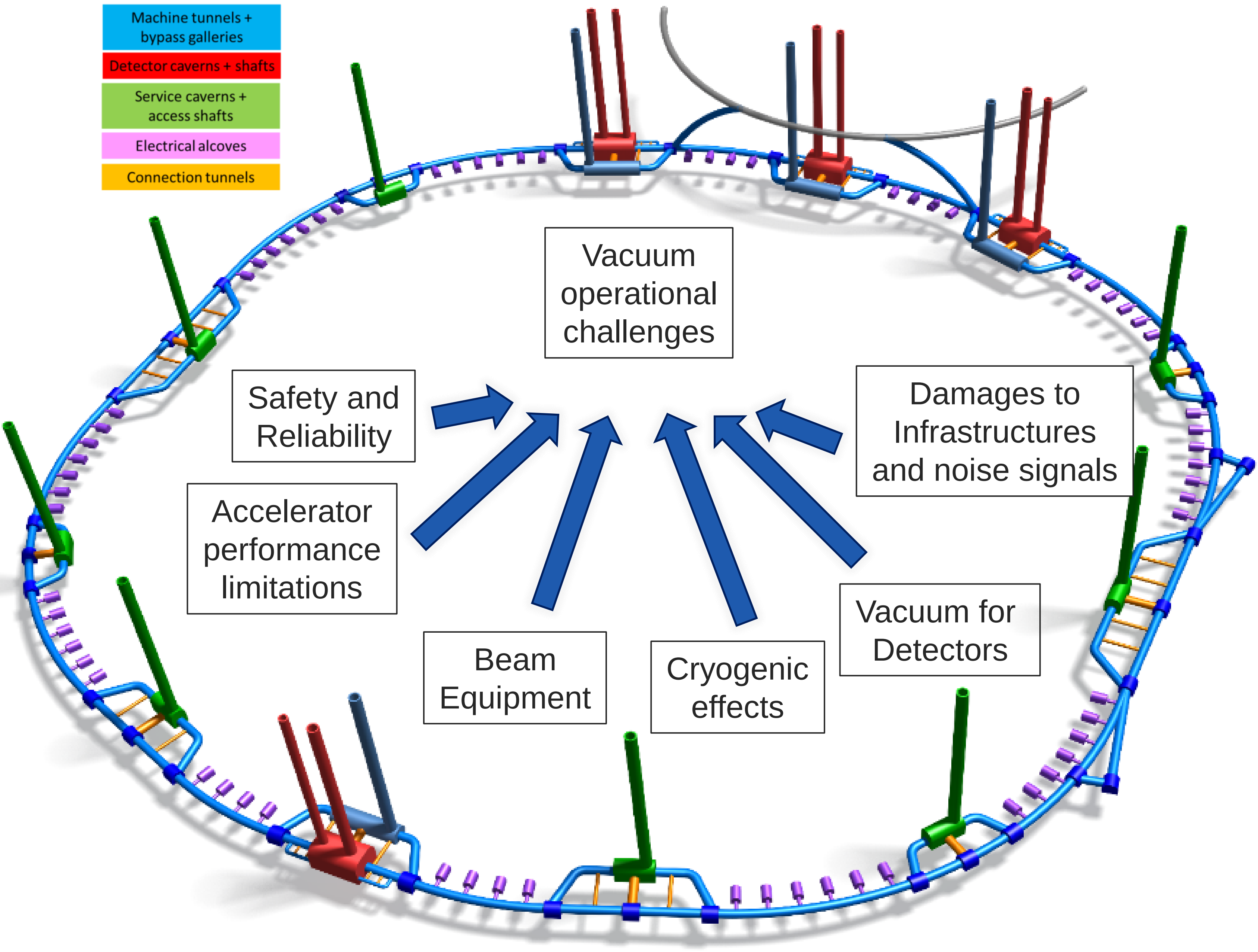
AWAKE Advanced WAKefield Experiment ISOLDE Isotope Separator OnLine REX/HIE Radioactive EXperiment/High Intensity and Energy ISOLDE

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

Vacuum challenges

High Gradient, High Field and High Intensities





Vacuum operational challenges

Safety and Reliability

Accelerator performance limitations

Beam Equipment

Cryogenic effects

Vacuum for Detectors

Damages to Infrastructures and noise signals

Vacuum operational challenges

Safety and Reliability

Minimise the beam losses resulting from beam-gas interactions, to increase:

- Safety
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  - Ai
- Reliabi
  beam p
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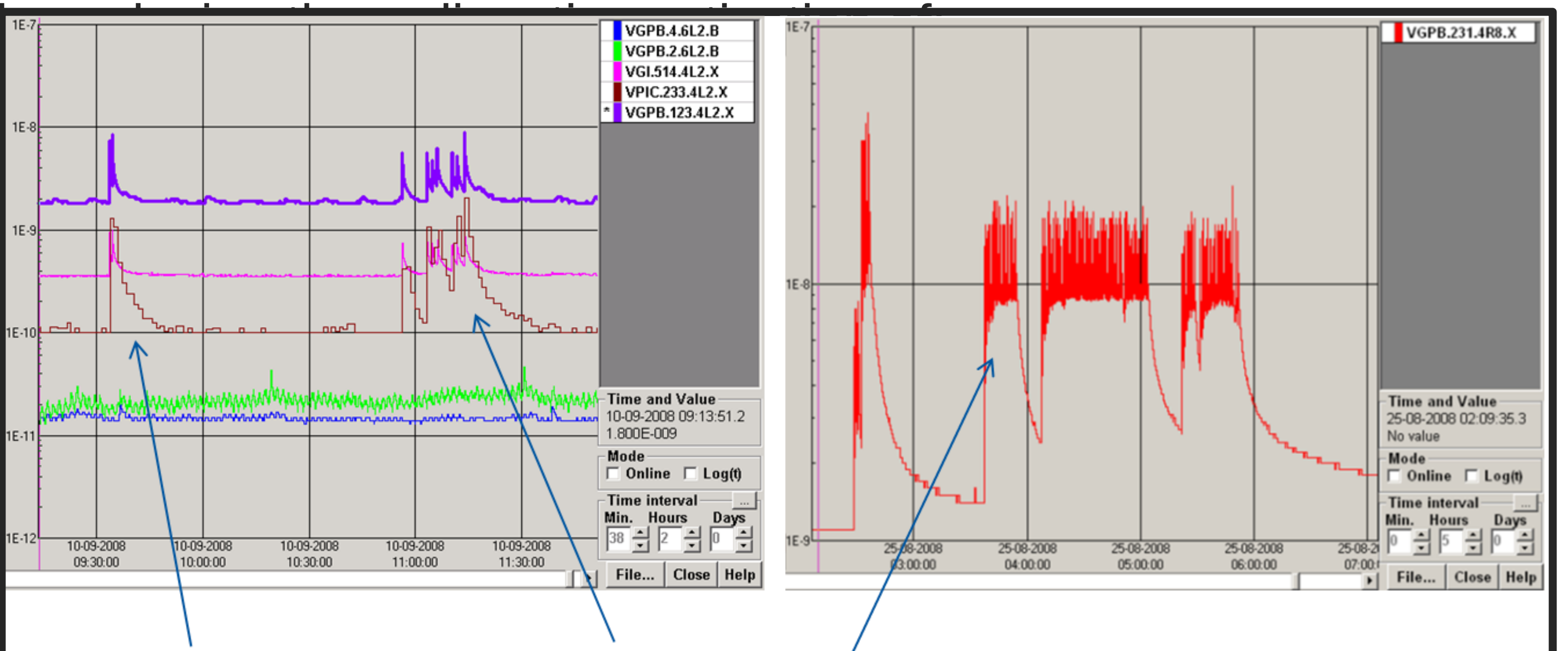
  - Ser



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Single shot

Multiple shots

Pressure rise induced by the beam impact on the injection collimator
1 bunch (pilot) @ 450 GeV, 2.10^9 protons!

Vacuum operational challenges

Accelerator performance limitations

- Vacuum is required in particle accelerators to minimize beam-gas interactions, thus:
  - Ensuring an acceptable beam lifetime;
  - Minimizing the heat load to the 1.9K cold mass due to the scattered beam particles for cryogenic beam vacuum systems.

- Machine performance limitations
  - Reduction of beam lifetime (nuclear scattering);
  - Reduction of machine luminosity (multiple coulomb scattering);
  - Intensity limitation by pressure instabilities (ionization);
  - Electron (ionization) induced instabilities (beam blow up);
  - Magnet quench i.e. transition from the superconducting to the normal state.
    - Heavy gases are the most dangerous

Vacuum operational challenges

Beam equipment vs vacuum compatibility

- Design to be ALARA compatible
  - Simplicity and easily maintainable
  - Shielding, appropriate routing of cables
  - Redundancy, duplication
  - Radiation tolerant or resistant
  - Integration optimisation

- Beam pipes (RT)
- Magnets
  - RT
  - SC
- RF systems
  - RT cavities
  - SC cavities
  - Feedback
  - Pick-ups
- Injection & Extraction septa
- Collimators & Beam absorbers
- Beam dump
- Beam instrumentation
- RF feedback & Pick-ups

- Material
  - Metallic / Non-metallic
  - Density / Porosity
  - Radiation resistant
  - HT firing
  - …
- Surface processing
  - Surface cleaning (chemistry)
  - Surface finishing (electrpolishing)
  - Coating – Electroplating / Plasma
  - …
- Outgassing / Cryosorption
  - Bake-out compatibility / Gas thermal recycling
- Engineering interfaces
  - Water/Coolant circuit
  - Cryogenic circuit
  - Beam/Thermal screens
  - Interconections and Feedthroughs
  - Soft transitions (HOM)
  - Bellows (multiplies)
  - RF fingers
  - Photon absorbers
  - Movable arms, jaws, bellows
  - Vacuum Windows
  - …
- …

Vacuum operational challenges

Beam equipment vs vacuum compatibility

- Design to be ALARA compatible
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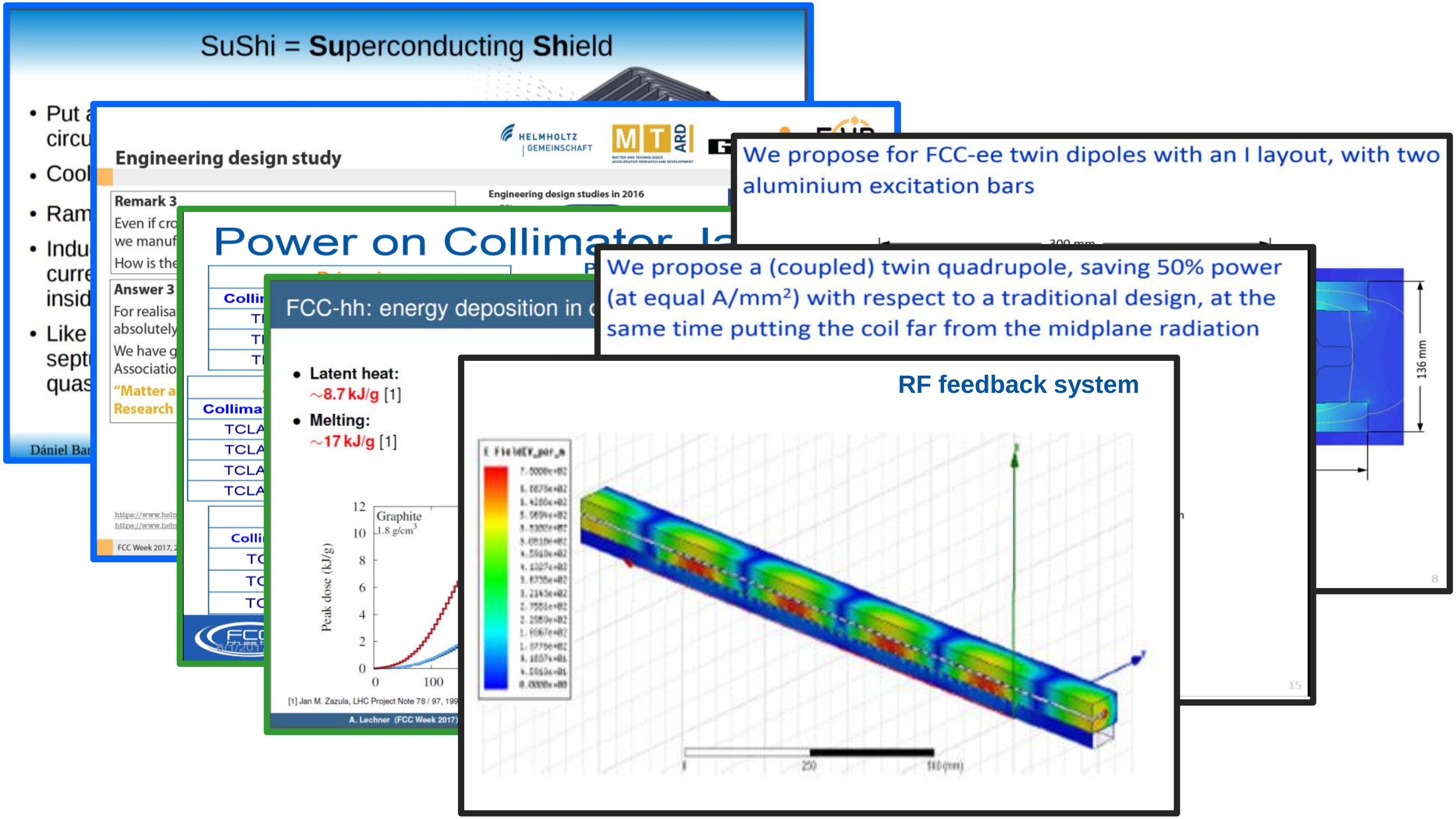
Beam pipes (RT)
Magnets
    RT
    SC
RF systems
    RT cavities
    SC cavities
    Feedback
    Pick-ups
Injection & Extraction septa
Collimators & Beam absorbers
Beam dump
Beam instrumentation
RF feedback & Pick-ups

Beam-induced effects
    Ion instability
        Ion stimulated desorption
    Electron Cloud
        Electron stimulated desorption
        Induced heat load (cryogenic systems)
    Synchrotron radiation
        Photo-electrons generation
        Photon stimulated desorption
        Induced heat load
    High Order Modes (HOM)
        Material
        Section changes / gaps
    Impedance
    …
Processes
    Local gas injection
…

Vacuum operational challenges

Beam equipment vs vacuum compatibility



SuShi = **Su**perconducting **Sh**ield

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- Cool
- Ram
- Indu
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- Like
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Dániel Bar

Engineering design study

Remark 3

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Answer 3

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Research**

https://www.helm
https://www.helm

FCC Week 2017, 2

HELMHOLTZ | GEMEINSCHAFT

MT ARD
MATTER AND TECHNOLOGIES
ACCELERATOR RESEARCH AND DEVELOPMENT

Engineering design studies in 2016

Power on Collimator Ja

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FCC-hh: energy deposition in c

- **Latent heat:**
~**8.7 kJ/g** [1]
- **Melting:**
~**17 kJ/g** [1]

[1] Jan M. Zazula, LHC Project Note 78 / 97, 199

A. Lechner (FCC Week 2017)

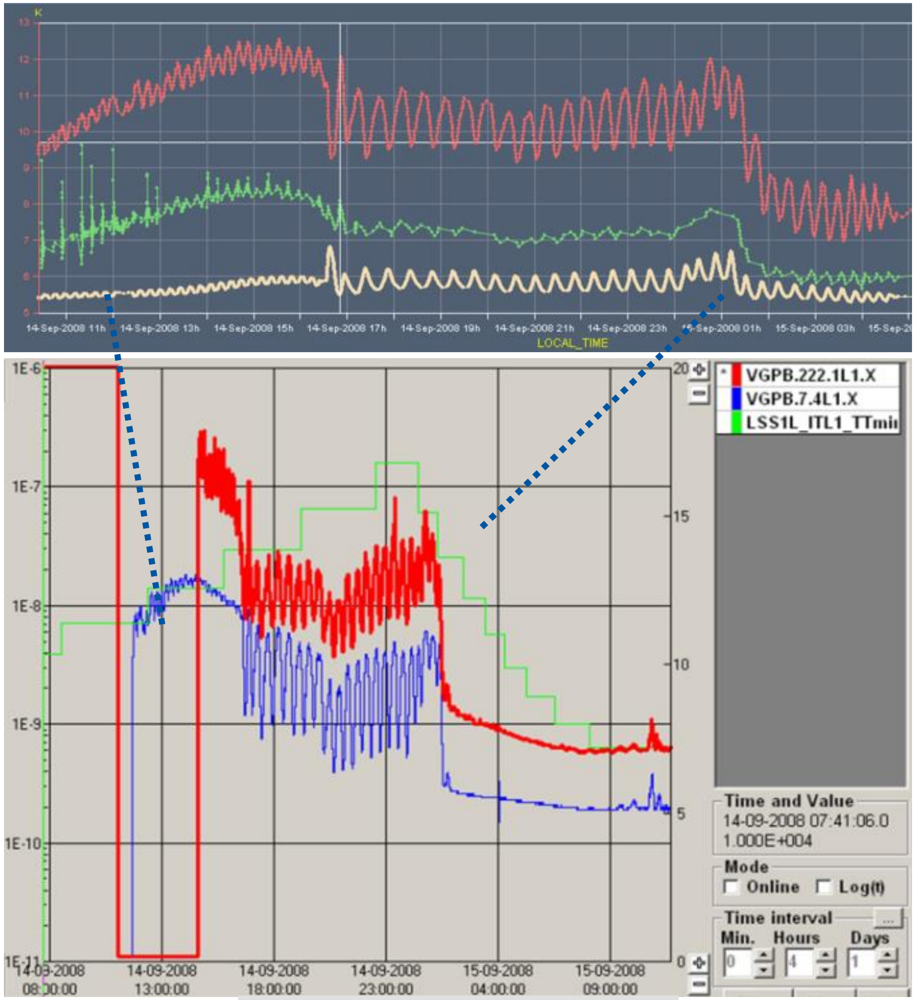
We propose for FCC-ee twin dipoles with an I layout, with two aluminium excitation bars

We propose a (coupled) twin quadrupole, saving 50% power (at equal A/mm²) with respect to a traditional design, at the same time putting the coil far from the midplane radiation

RF feedback system

Vacuum operational challenges

Cryogenic effects: hydrogen oscillation on LHC beam screen/cold bore



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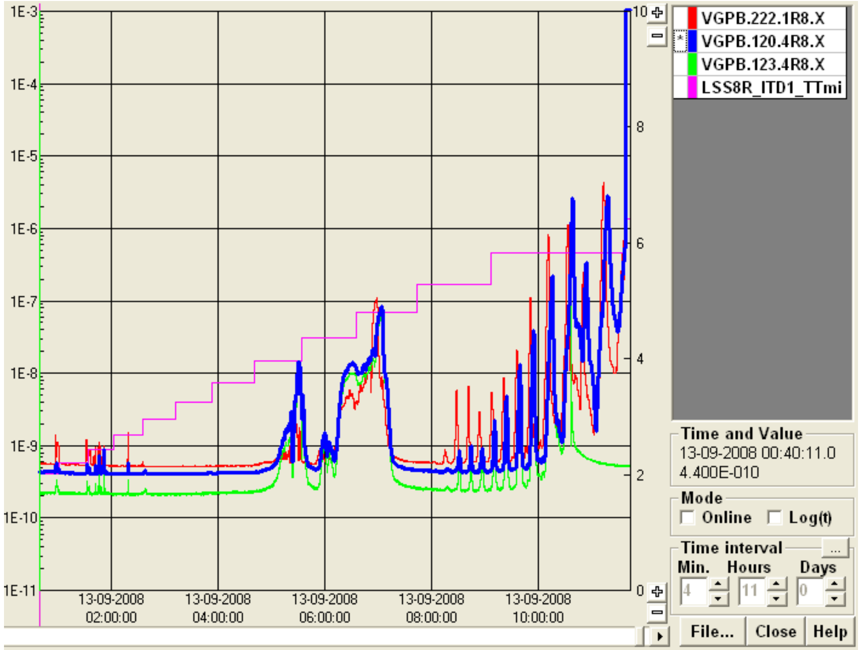
Beam screen case

Cold bore case



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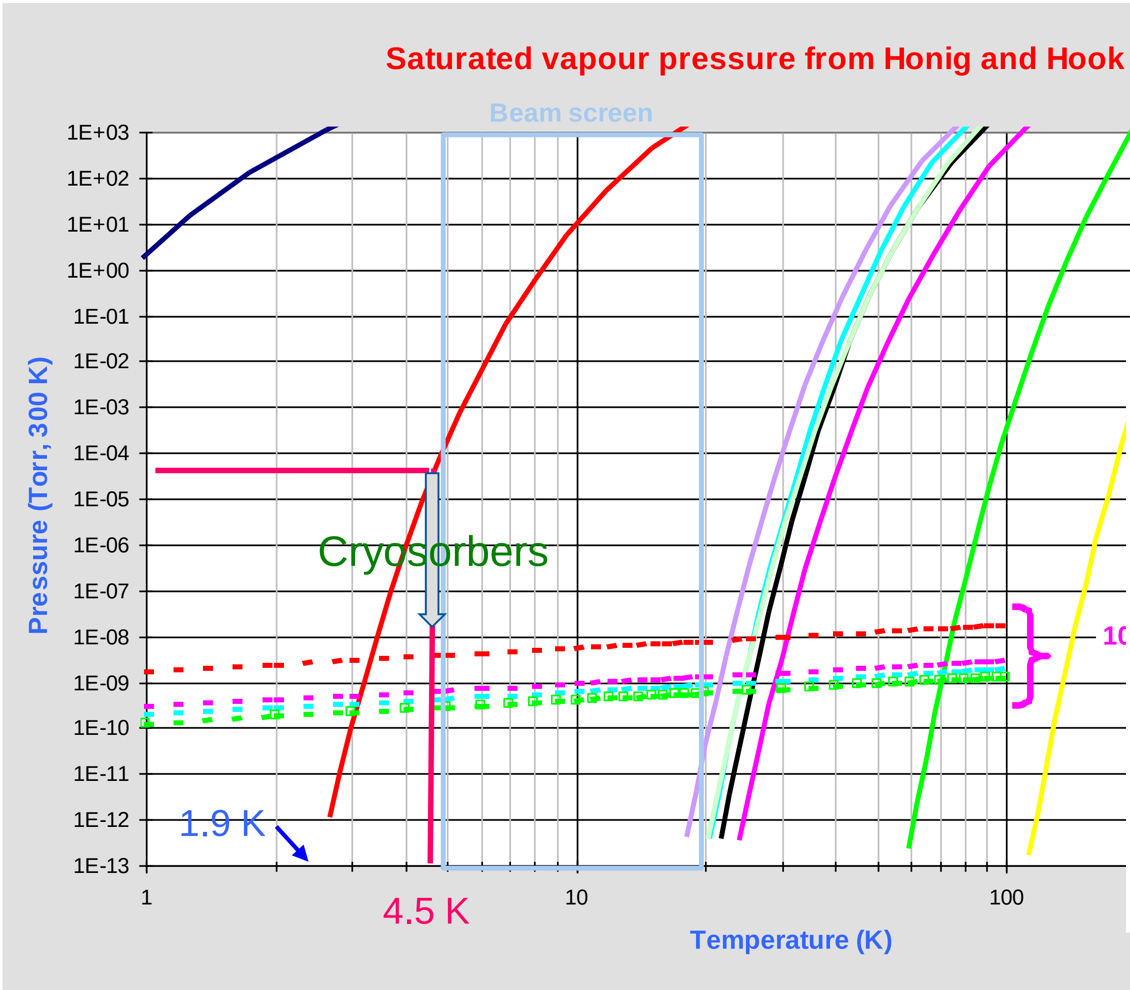
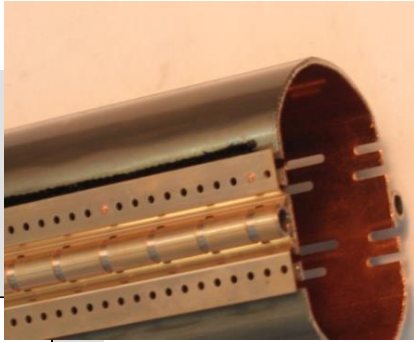
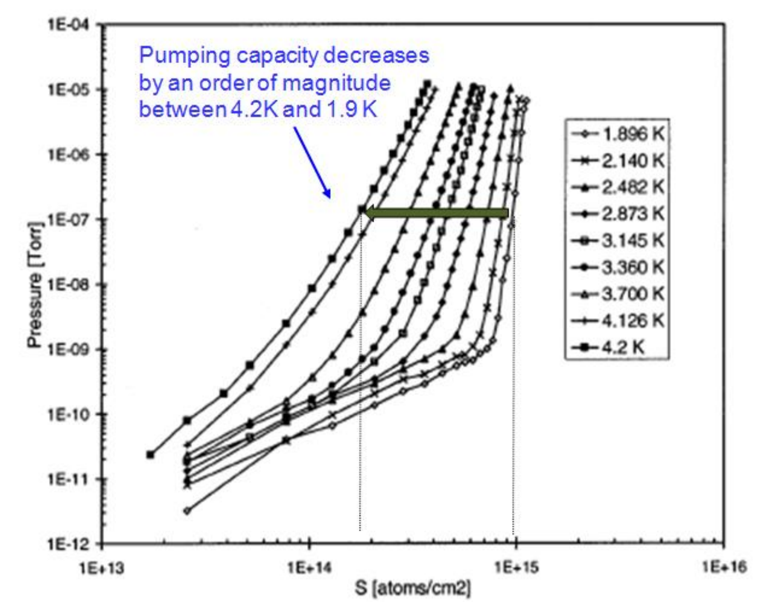
Temperature instabilities around 3 K lead to hydrogen oscillations in both beam screen and cold bore

Vacuum operational challenges

Cryogenic effects: LHC Arc Beam Vacuum (Cryobeam Vacuum)







He adsorption isotherms on stainless steel

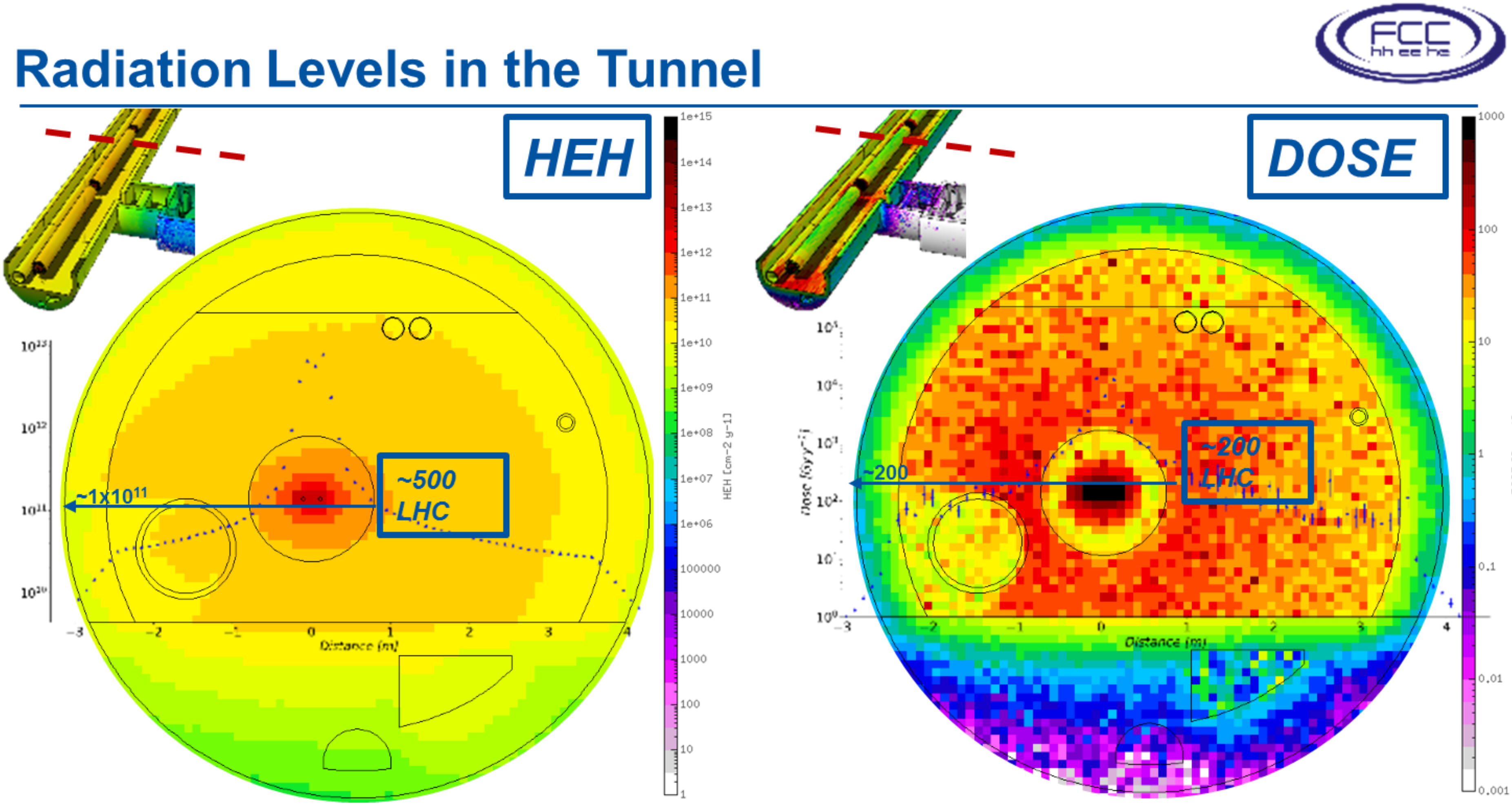
Vacuum operational challenges

Vacuum for Detectors

- Reduce beam-gas interaction responsible for Background to the experiments
  - Non-captured particles which interact with the detectors
  - Nuclear cascade generated by the lost particles upstream the detectors
- Integration: Vacuum installation follows detector closure
  - “Bad surprises” are not acceptable
  - Temporary supports and protections required at each stage of the installation
- Reliability
  - Leak detection and bake-out testing compulsory at each step of the installation
  - Vacuum pipes get encapsulated in the detector
- Availability
  - Detector installation imposes the “speed” and sequence of the installation
- Performances
  - Vacuum (<1015 H2.m-3), HOM, impedance and alignment requirements
  - Must be fulfilled
- Engineering
  - Beryllium and aluminium material used since “transparent” to the particles escaping from the collision point
  - Innovative bake-out solutions to fit with the limited space available between vacuum pipes and the detector

Vacuum operational challenges

Damage to Infrastructures & Noise Signals



Radiation Levels in the Tunnel

HEH

~500 LHC

~1x10^11

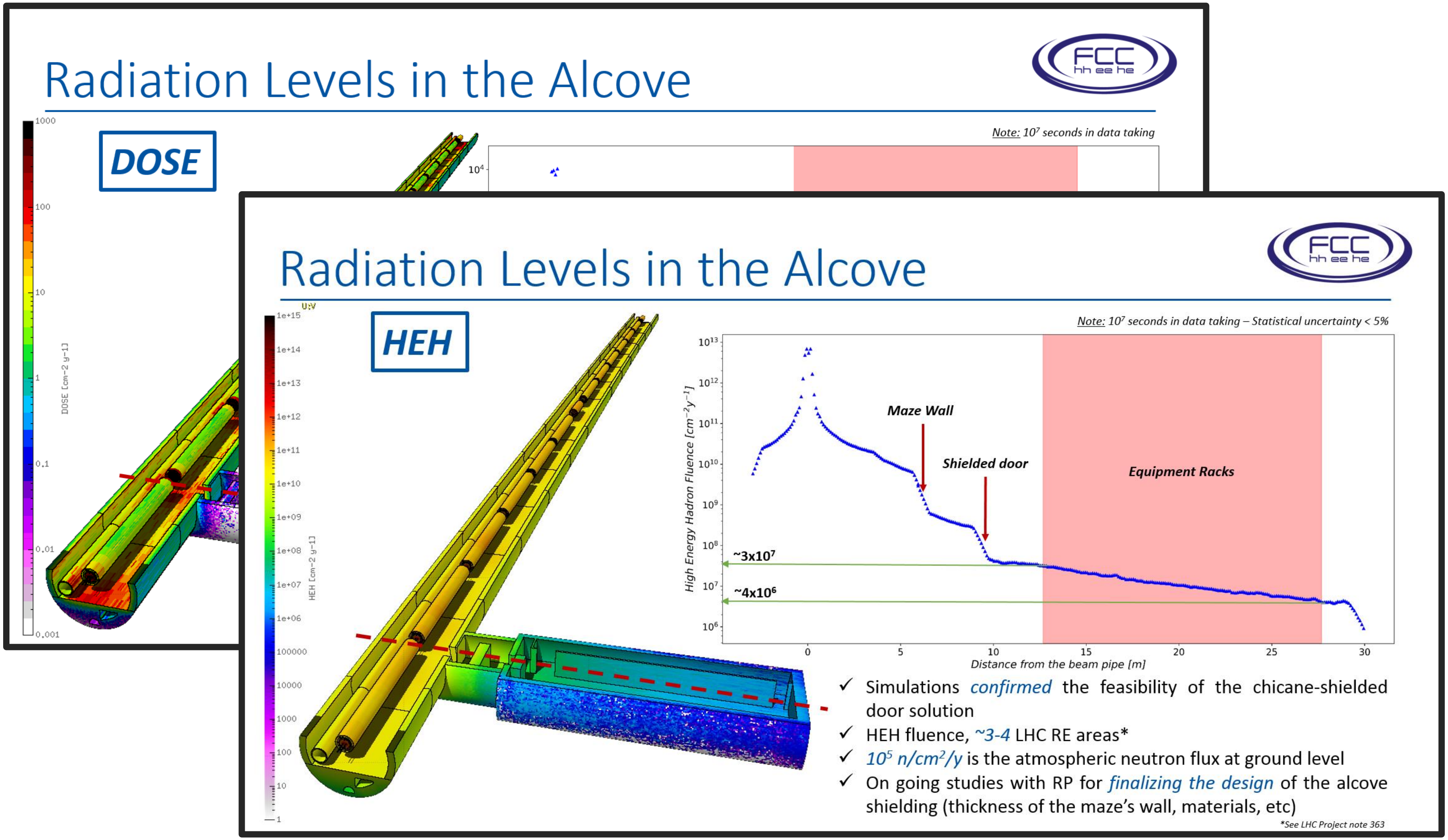
DOSE

~200 LHC

~200

Vacuum operational challenges

Damage to Infrastructures & Noise Signals



Radiation Levels in the Alcove

DOSE

Note: 10^7 seconds in data taking

Radiation Levels in the Alcove

HEH

Note: 10^7 seconds in data taking – Statistical uncertainty < 5%

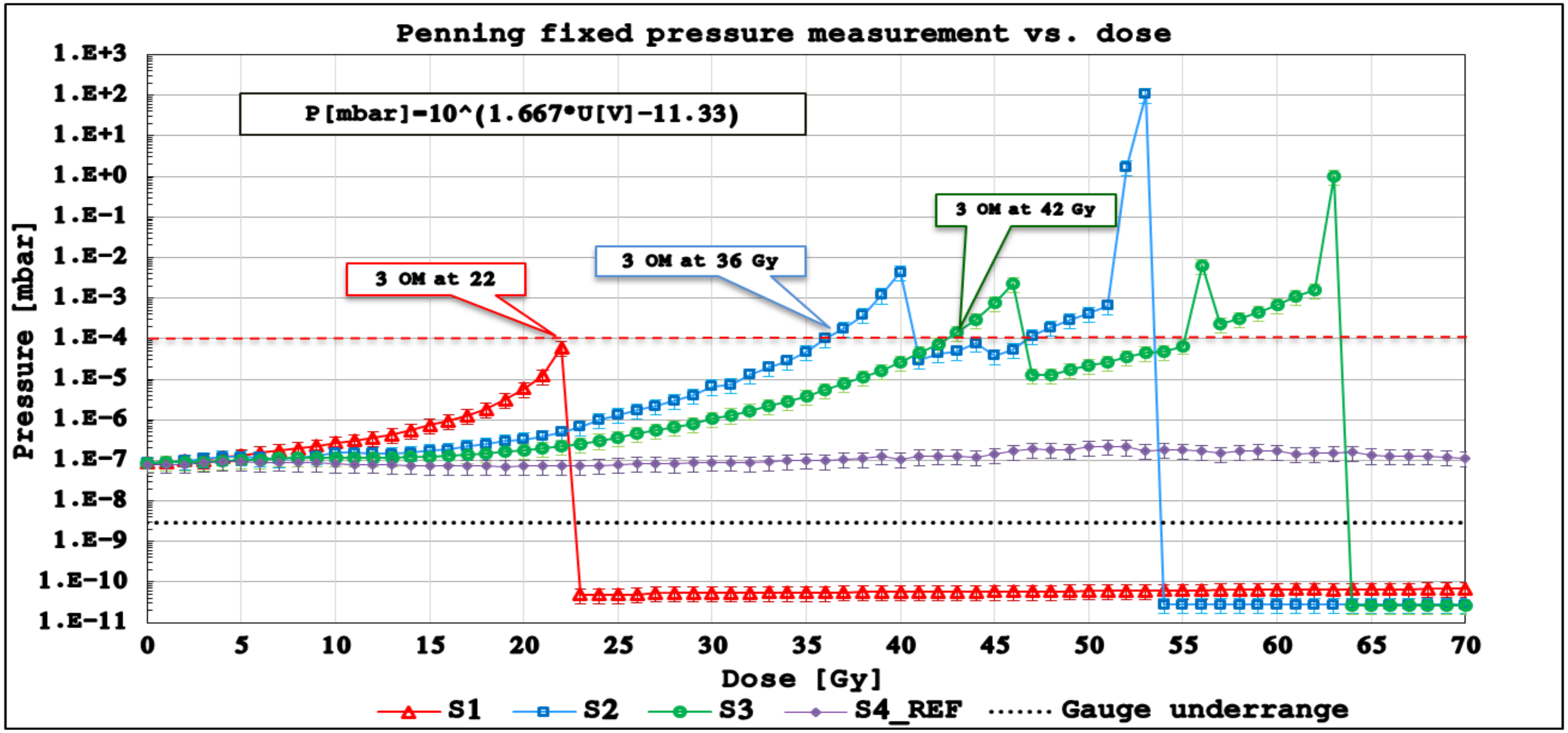
- ✓ Simulations *confirmed* the feasibility of the chicane-shielded door solution
- ✓ HEH fluence, *~3-4* LHC RE areas*
- ✓ *10^5 n/cm^2/y* is the atmospheric neutron flux at ground level
- ✓ On going studies with RP for *finalizing the design* of the alcove shielding (thickness of the maze's wall, materials, etc)

**See LHC Project note 363*

Vacuum operational challenges

Damage to Infrastructures & Noise Signals

Penning electronics irradiation - test results



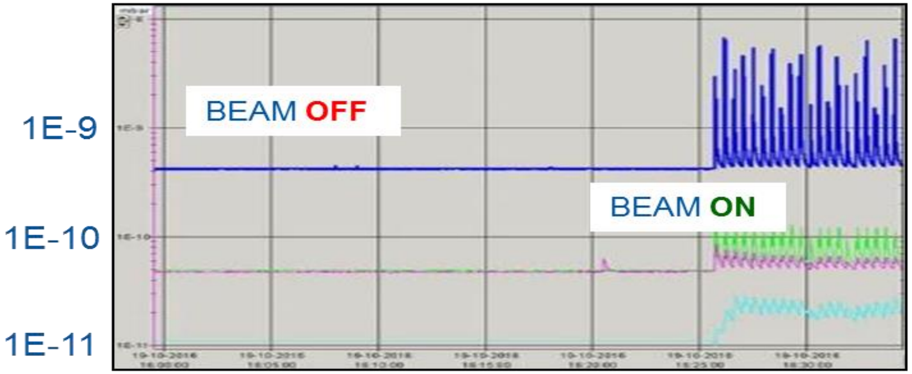
- Strong radiation induced effects already at **15 Gy**
- Pressure readout **4 orders of magnitude higher** than the reference signal

Vacuum operational challenges

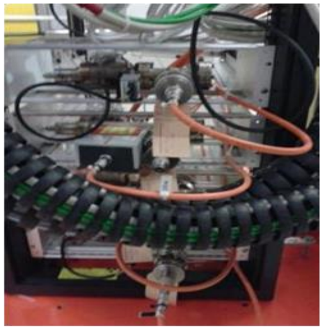
Damage to Infrastructures & Noise Signals

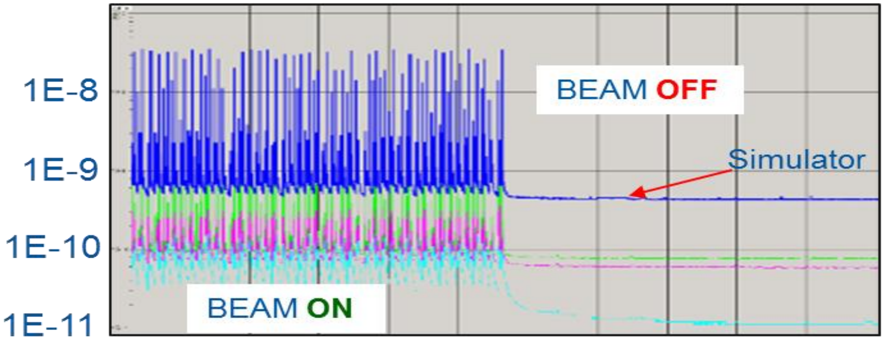
Penning gauge and its HV cable

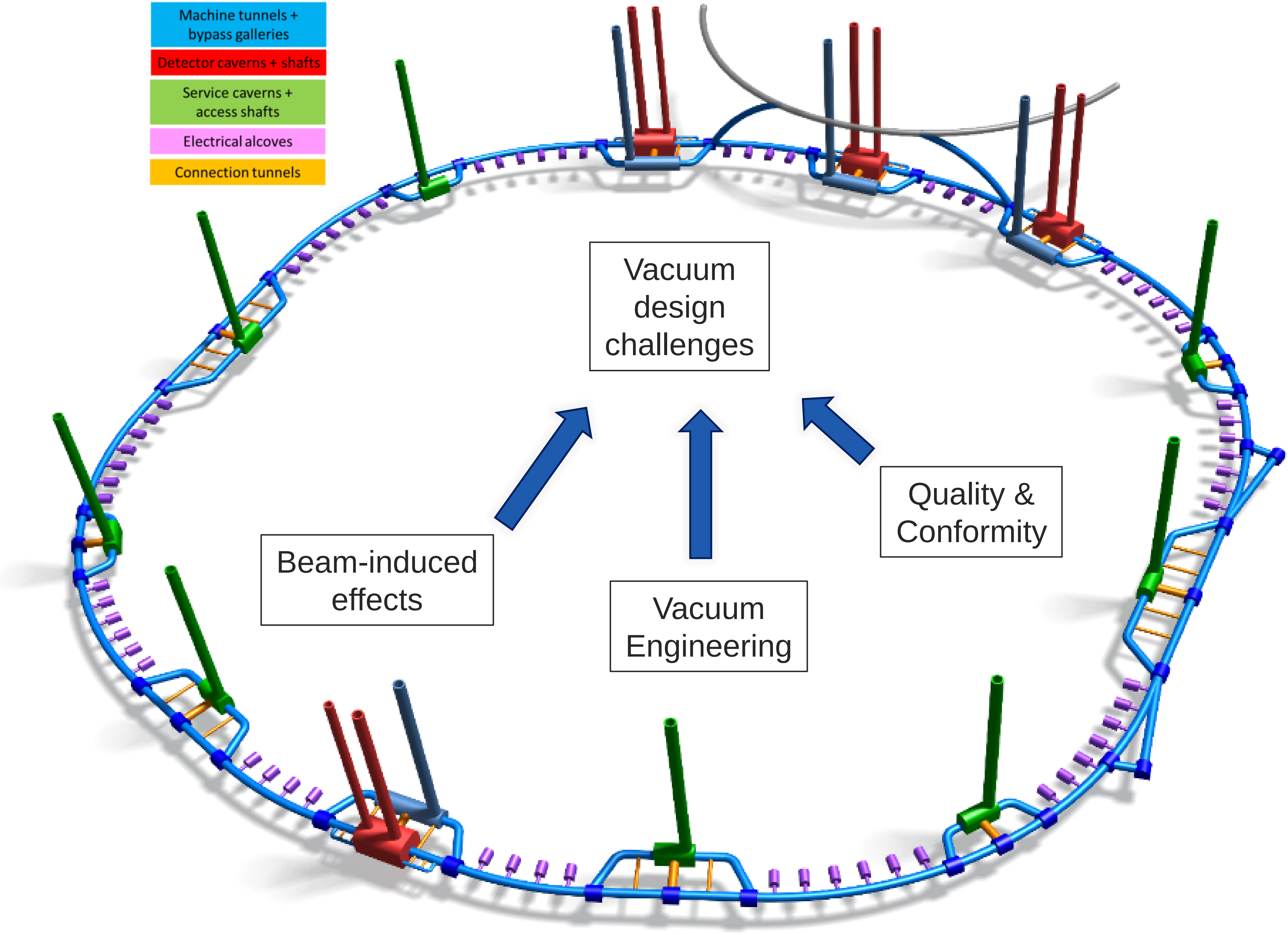
- 3 runs of 1 week each (fluence of $3\text{x}10^{12}$ cm^{-2} ; TID of ~ 1kGy)
- 4 small pre-pumped vacuum chambers (range of 10^{-11} - 10^{-10} mbar)
- **Run[1]**: monitoring of 4 Pennings



- **Run[2,3]**: monitoring of 3 Pennings + 1 simulator (11 TΩ resistor $6\text{x}10^{-10}$ mbar)







Vacuum design challenges

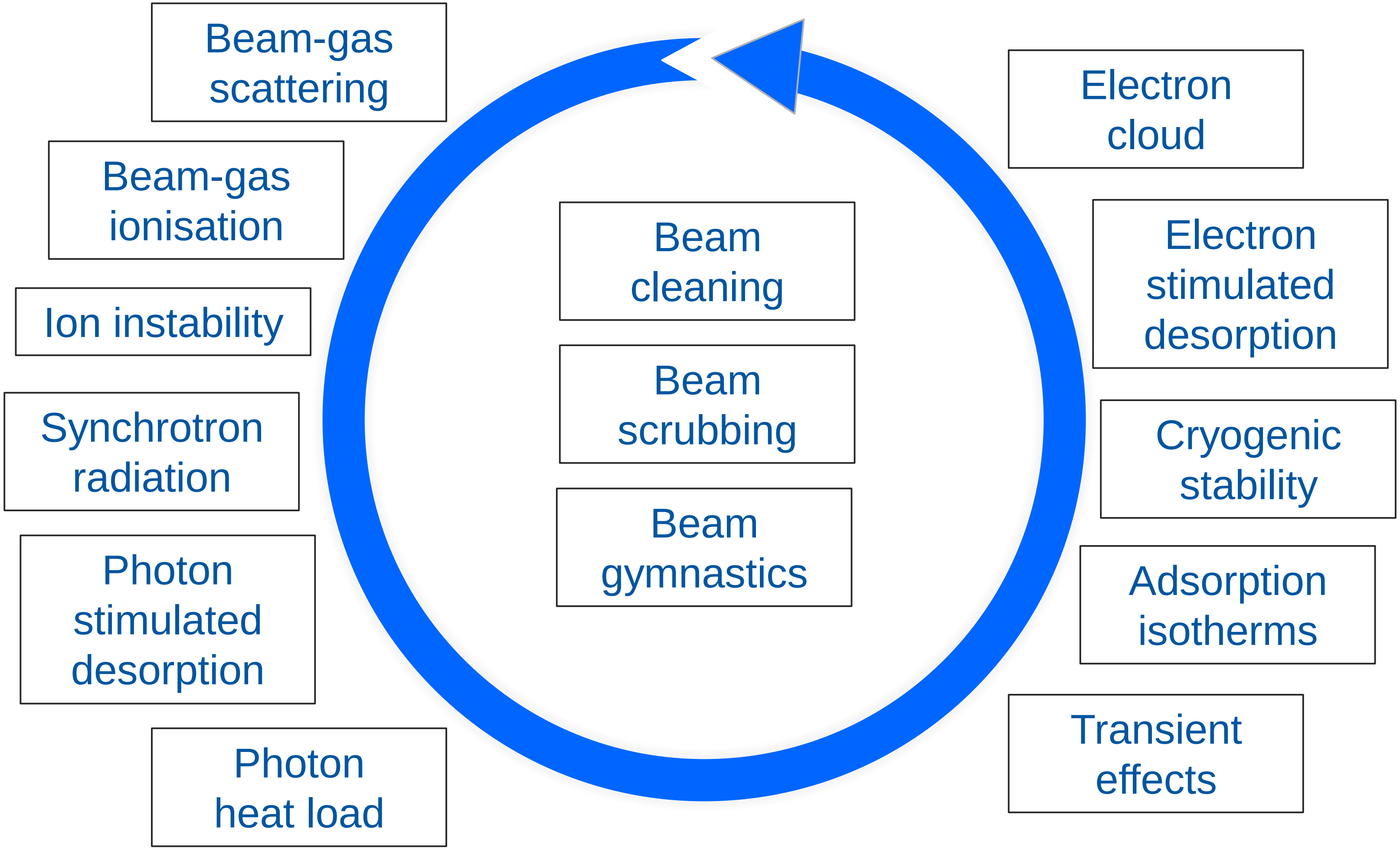
Beam-induced effects

Vacuum Engineering

Quality & Conformity

Vacuum design challenges

Beam-induced effects



Beam-gas scattering

Beam-gas ionisation

Ion instability

Synchrotron radiation

Photon stimulated desorption

Photon heat load

Beam cleaning

Beam scrubbing

Beam gymnastics

Electron cloud

Electron stimulated desorption

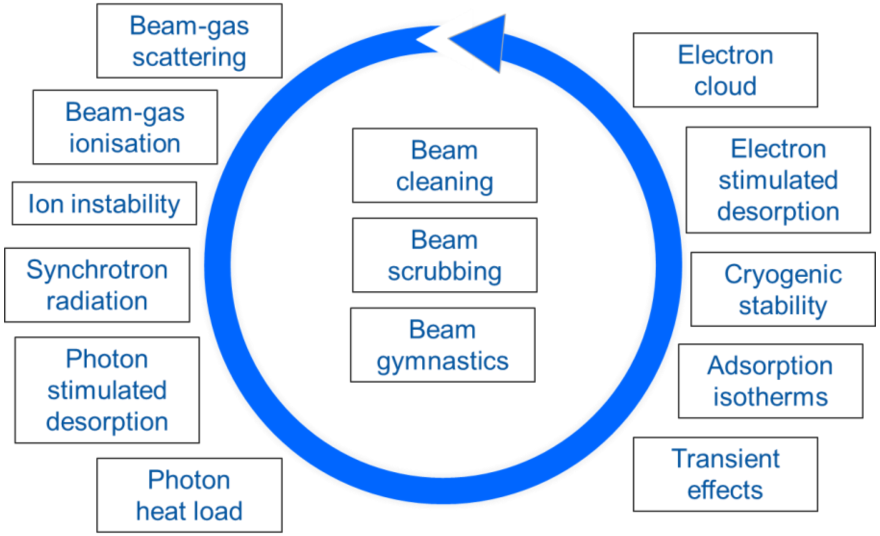
Cryogenic stability

Adsorption isotherms

Transient effects

Vacuum design challenges

Beam-induced effects



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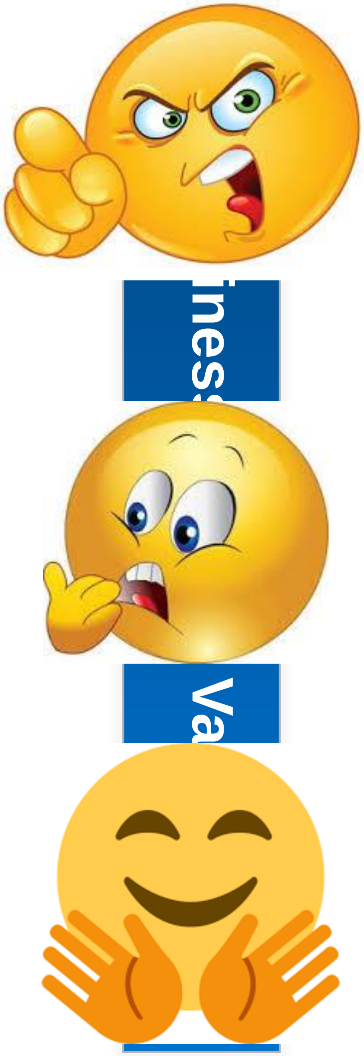
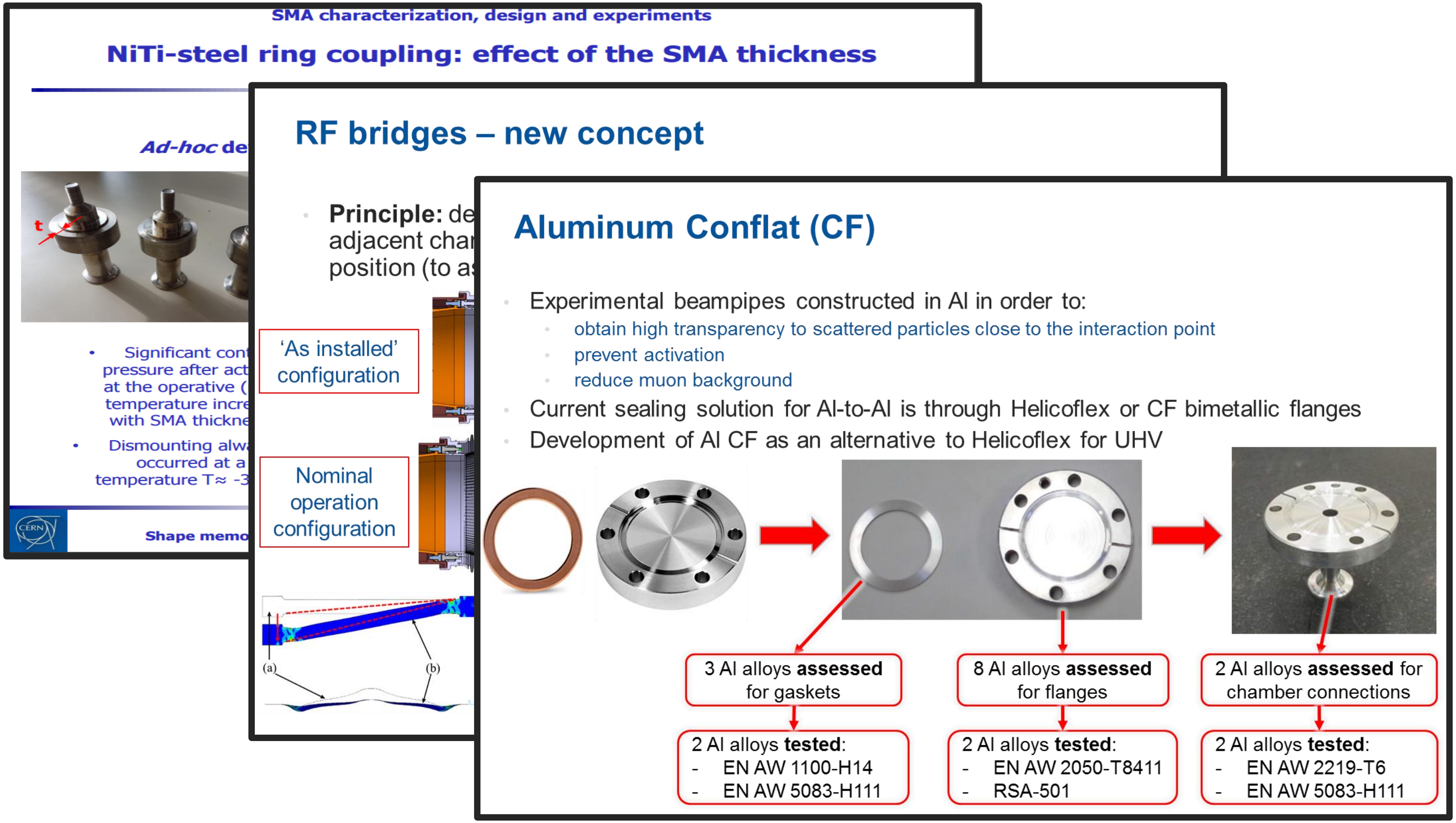
Adsorption isotherms

Transient effects



Vacuum design challenges - Engineering

Breaking technics for Vacuum applications - Connections



SMA characterization, design and experiments

NiTi-steel ring coupling: effect of the SMA thickness

Ad-hoc de

- Significant cont
pressure after act
at the operative (
temperature incre
with SMA thickne
- Dismounting alw
occurred at a
temperature T≈ -3

Shape memo

RF bridges – new concept

- **Principle:** de
adjacent char
position (to as

'As installed' configuration

Nominal operation configuration

Aluminum Conflat (CF)

- Experimental beampipes constructed in Al in order to:
  - obtain high transparency to scattered particles close to the interaction point
  - prevent activation
  - reduce muon background
- Current sealing solution for Al-to-Al is through Helicoflex or CF bimetallic flanges
- Development of Al CF as an alternative to Helicoflex for UHV

3 Al alloys **assessed** for gaskets

2 Al alloys **tested**:
- EN AW 1100-H14
- EN AW 5083-H111

8 Al alloys **assessed** for flanges

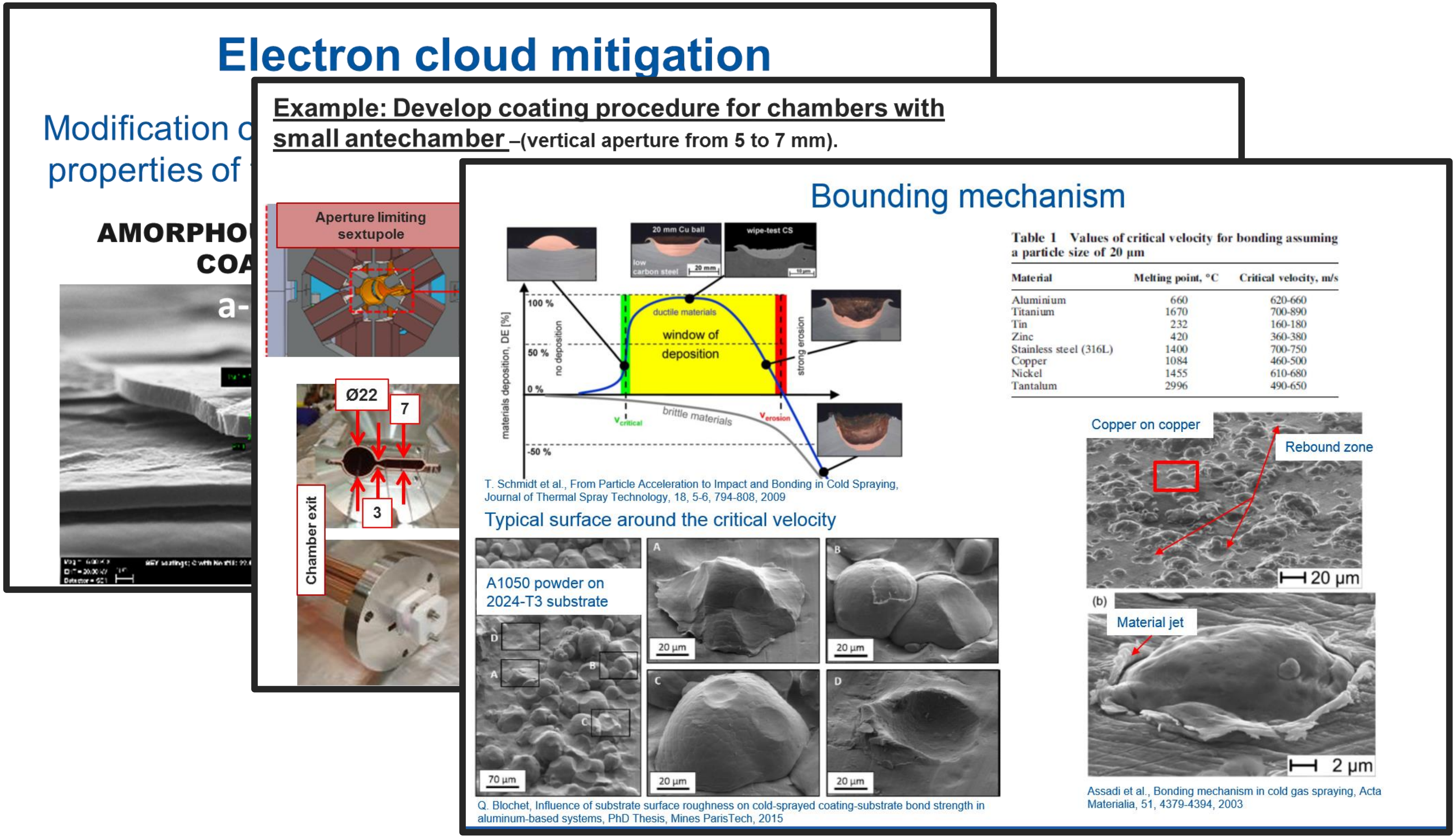
2 Al alloys **tested**:
- EN AW 2050-T8411
- RSA-501

2 Al alloys **assessed** for chamber connections

2 Al alloys **tested**:
- EN AW 2219-T6
- EN AW 5083-H111

Vacuum design challenges - Engineering

Breaking technics for Vacuum applications – Surface treatments



Electron cloud mitigation

Modification o
properties of

AMORPHO
COA

a-

Example: Develop coating procedure for chambers with small antechamber –(vertical aperture from 5 to 7 mm).

Bounding mechanism

T. Schmidt et al., From Particle Acceleration to Impact and Bonding in Cold Spraying, Journal of Thermal Spray Technology, 18, 5-6, 794-808, 2009

Typical surface around the critical velocity

Q. Blochet, Influence of substrate surface roughness on cold-sprayed coating-substrate bond strength in aluminum-based systems, PhD Thesis, Mines ParisTech, 2015

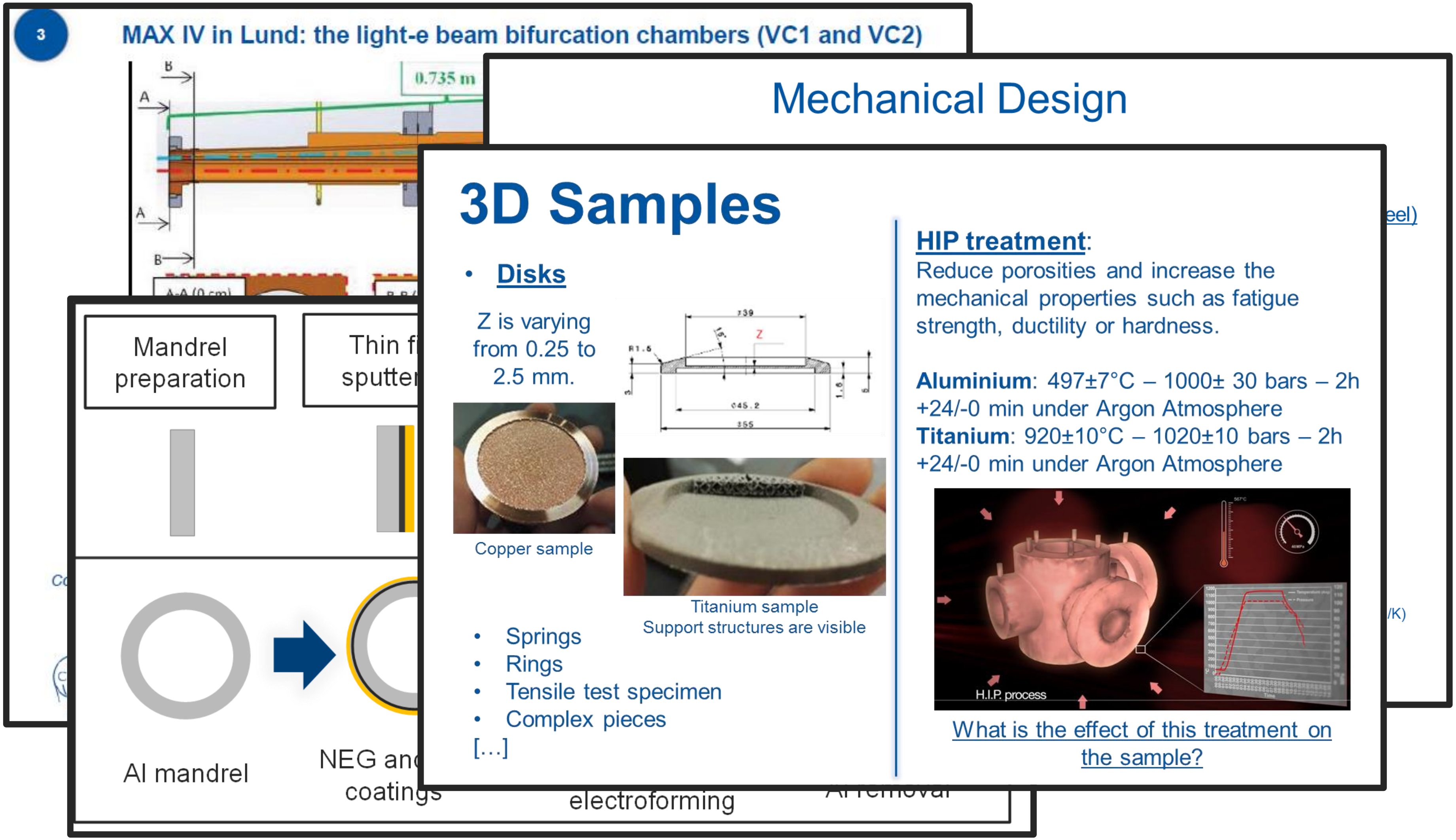
Table 1 Values of critical velocity for bonding assuming a particle size of 20 µm

Material	Melting point, °C	Critical velocity, m/s
Aluminium	660	620-660
Titanium	1670	700-890
Tin	232	160-180
Zinc	420	360-380
Stainless steel (316L)	1400	700-750
Copper	1084	460-500
Nickel	1455	610-680
Tantalum	2996	490-650

Assadi et al., Bonding mechanism in cold gas spraying, Acta Materialia, 51, 4379-4394, 2003

Vacuum design challenges - Engineering

Breaking technics for Vacuum applications – Beampipes



3 MAX IV in Lund: the light-e beam bifurcation chambers (VC1 and VC2)

Mechanical Design

Mandrel preparation

Thin f… sputter…

Al mandrel

NEG an… coatings

electroforming

Al removal

3D Samples

- **Disks**

Z is varying from 0.25 to 2.5 mm.

Copper sample

Titanium sample
Support structures are visible

- Springs
- Rings
- Tensile test specimen
- Complex pieces

[…]

HIP treatment:
Reduce porosities and increase the mechanical properties such as fatigue strength, ductility or hardness.

Aluminium: 497±7°C – 1000± 30 bars – 2h +24/-0 min under Argon Atmosphere
Titanium: 920±10°C – 1020±10 bars – 2h +24/-0 min under Argon Atmosphere

What is the effect of this treatment on the sample?

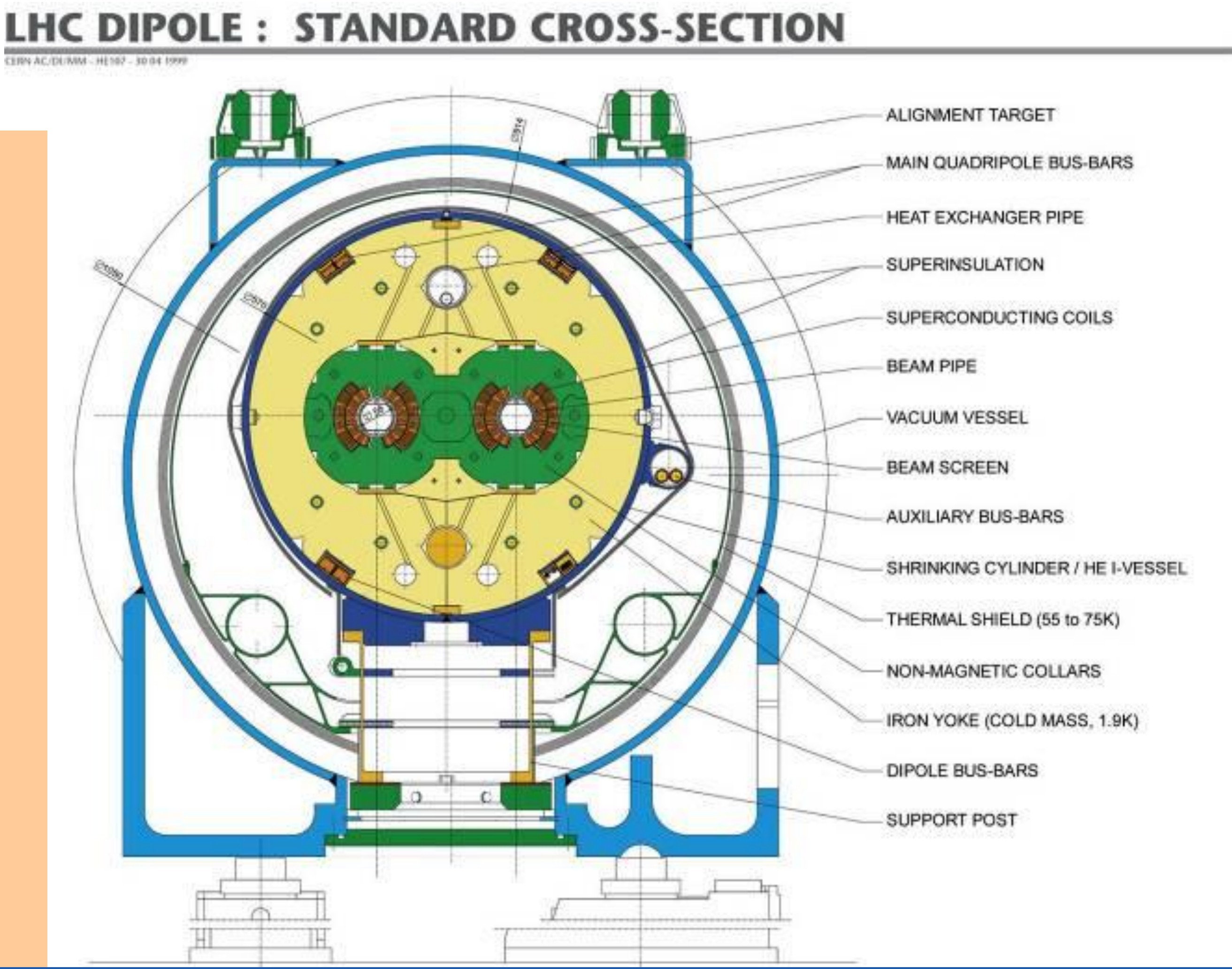
Vacuum design challenges - Quality & Conformity

Illustration with LHC Cryodipoles & Cryoline

Insulation vacuum is a high vacuum between:

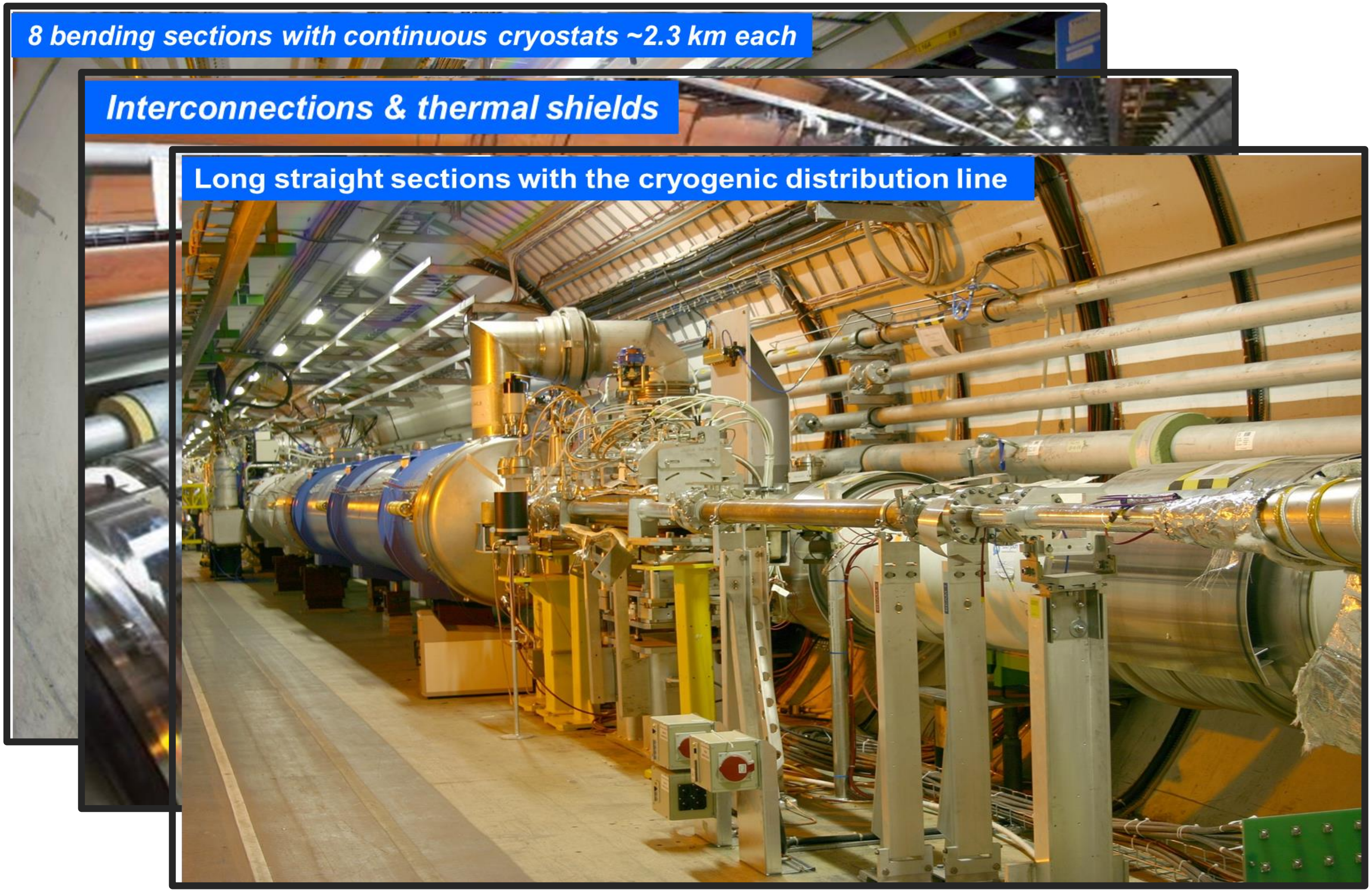
- Cryomagnet and its cryostat
- Inner cold cryogenic lines and the outer envelope of the liquid helium transfer lines

Both are wrapped with super insulation layers



Vacuum design challenges - Quality & Conformity

Illustration with LHC Cryodipoles & Cryoline



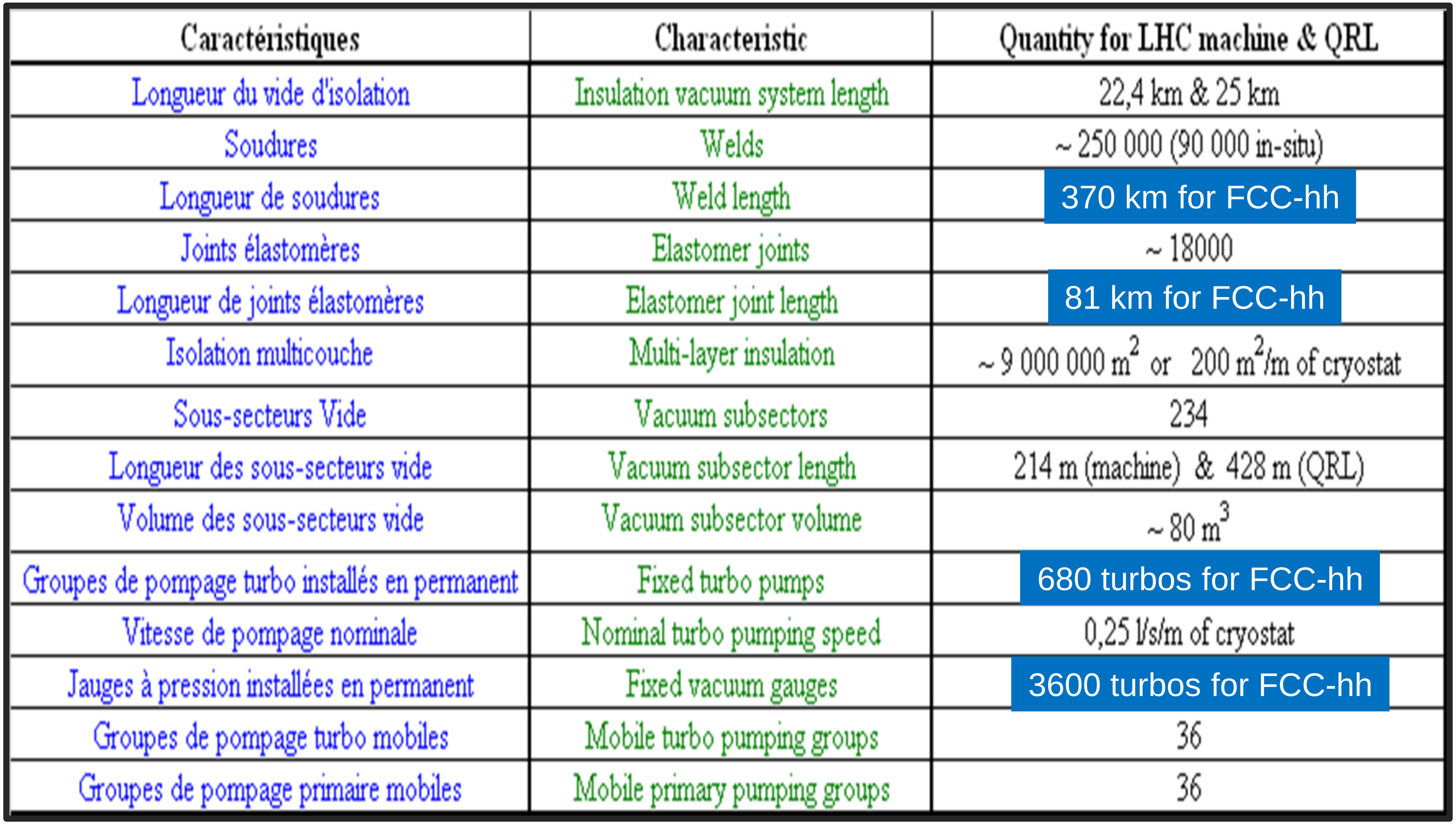
8 bending sections with continuous cryostats ~2.3 km each

Interconnections & thermal shields

Long straight sections with the cryogenic distribution line

Vacuum design challenges - Quality & Conformity

Illustration with LHC Cryodipoles & Cryoline



Caractéristiques	Characteristic	Quantity for LHC machine & QRL
Longueur du vide d'isolation	Insulation vacuum system length	22,4 km & 25 km
Soudures	Welds	~ 250 000 (90 000 in-situ)
Longueur de soudures	Weld length	370 km for FCC-hh
Joints élastomères	Elastomer joints	~ 18000
Longueur de joints élastomères	Elastomer joint length	81 km for FCC-hh
Isolation multicouche	Multi-layer insulation	~ 9 000 000 m^2 or 200 m^2/m of cryostat
Sous-secteurs Vide	Vacuum subsectors	234
Longueur des sous-secteurs vide	Vacuum subsector length	214 m (machine) & 428 m (QRL)
Volume des sous-secteurs vide	Vacuum subsector volume	~ 80 m^3
Groupes de pompage turbo installés en permanent	Fixed turbo pumps	680 turbos for FCC-hh
Vitesse de pompage nominale	Nominal turbo pumping speed	0,25 l/s/m of cryostat
Jauges à pression installées en permanent	Fixed vacuum gauges	3600 turbos for FCC-hh
Groupes de pompage turbo mobiles	Mobile turbo pumping groups	36
Groupes de pompage primaire mobiles	Mobile primary pumping groups	36

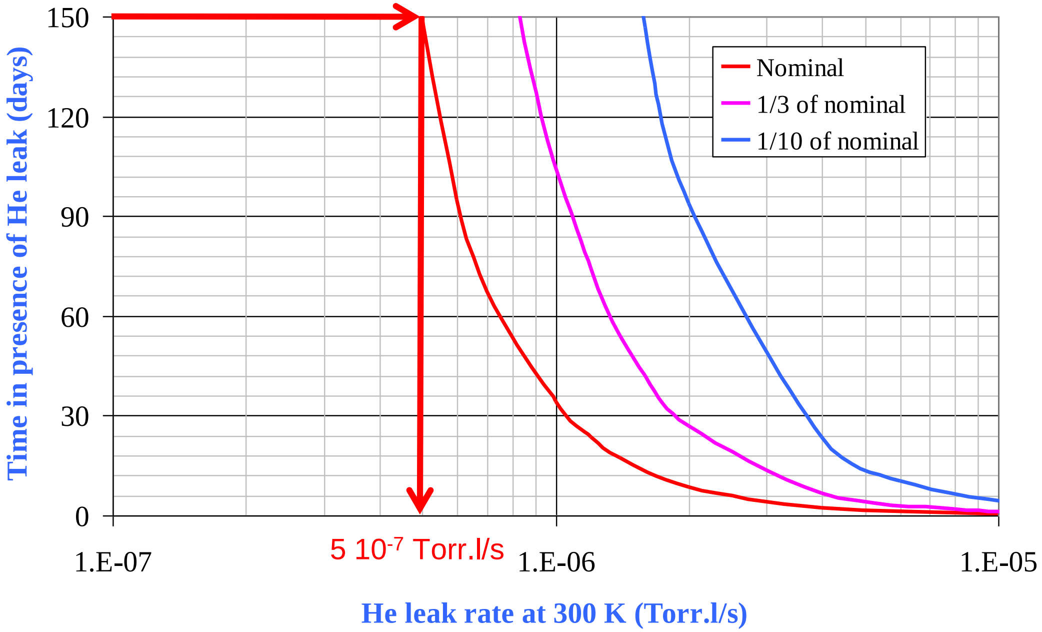
Vacuum design challenges -Quality & Conformity

Illustration with LHC Cryodipoles & Cryoline

1 year of operation ~ 150 days

Helium leak rate above 5 10^{-7} Torr.l/s shall be detected to avoid the risk of a quench !

Time to provoke a quench



- Lower leak rate :
  - Require a pumping of the beam tube on the yearly basis (cold bore >~4K)
- Larger leak rate will provoke a magnet quench within :
  - 30 to 100 days beam operation for He leak rate of 10^{-6} Torr.l/s
  - A day of beam operation for He leak rate of 10^{-5} Torr.l/s

Well after hours of LAB, simulations, engineering...

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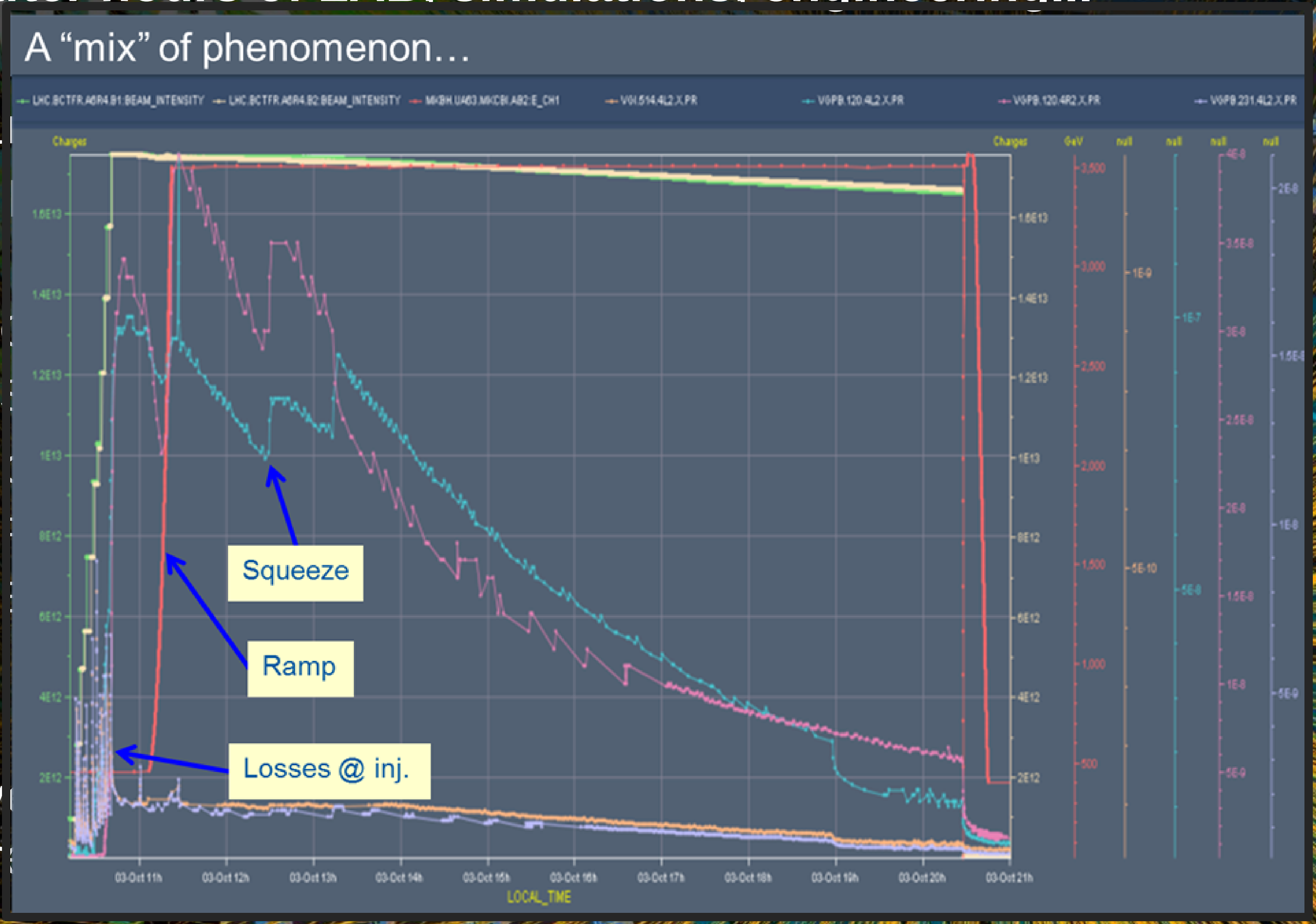
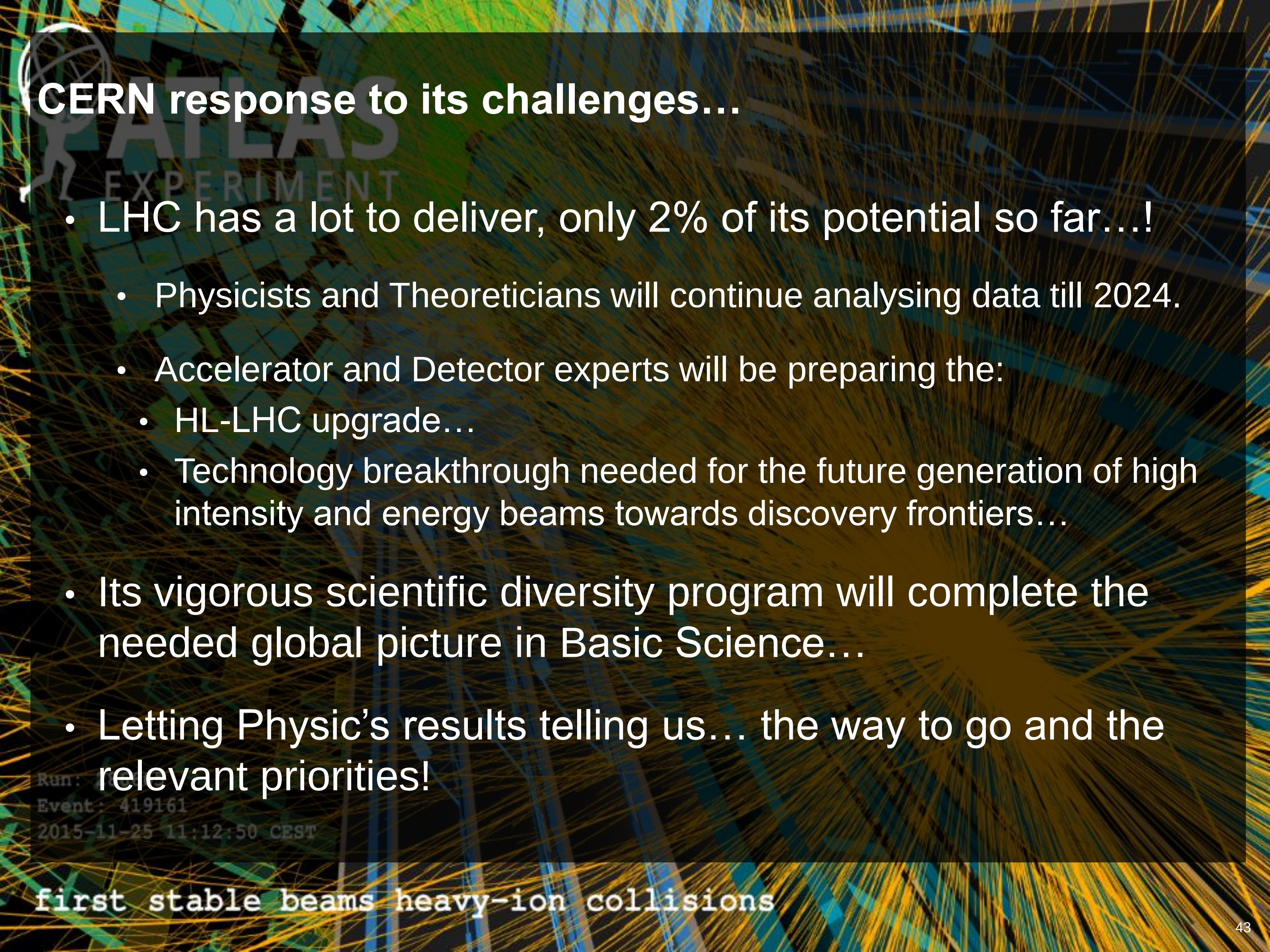


A “mix” of phenomenon…

Run:
Event: 419
2015

first stable beams heavy-ion collisions

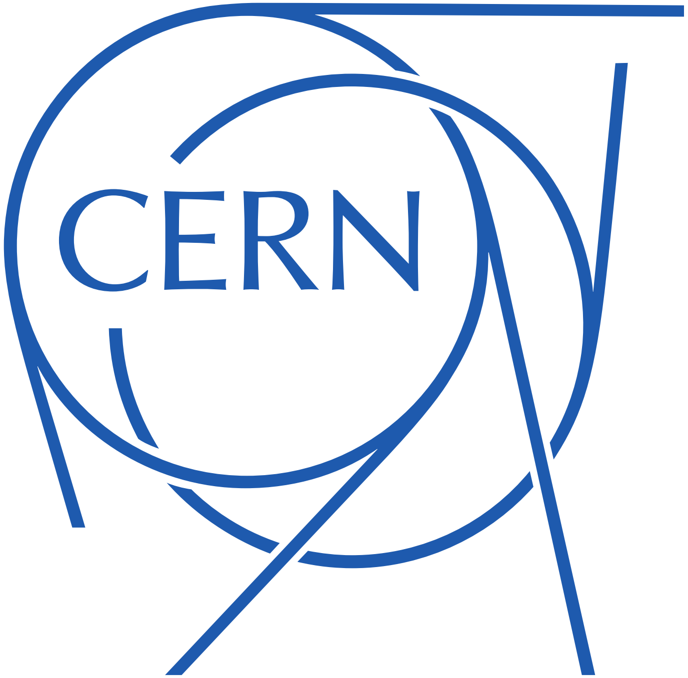
CERN response to its challenges…



- LHC has a lot to deliver, only 2% of its potential so far…!
  - Physicists and Theoreticians will continue analysing data till 2024.
  - Accelerator and Detector experts will be preparing the:
    - HL-LHC upgrade…
    - Technology breakthrough needed for the future generation of high intensity and energy beams towards discovery frontiers…
- Its vigorous scientific diversity program will complete the needed global picture in Basic Science…
- Letting Physic’s results telling us… the way to go and the relevant priorities!

Thanks for your attention

Accelerating Science and Innovation


CERN

Reserves