Electron cloud: potential mitigation strategies and plans for interventions during LS3

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https://indico.cern.ch/event/1293138/timetable/#20230926

Outline

1. Electron cloud in the LHC
    - Run 1 and Run 2
    - Surface analysis of LHC-extracted beam screens during LS2
    - Run 3 and beyond
    - HL-LHC heat load forecast

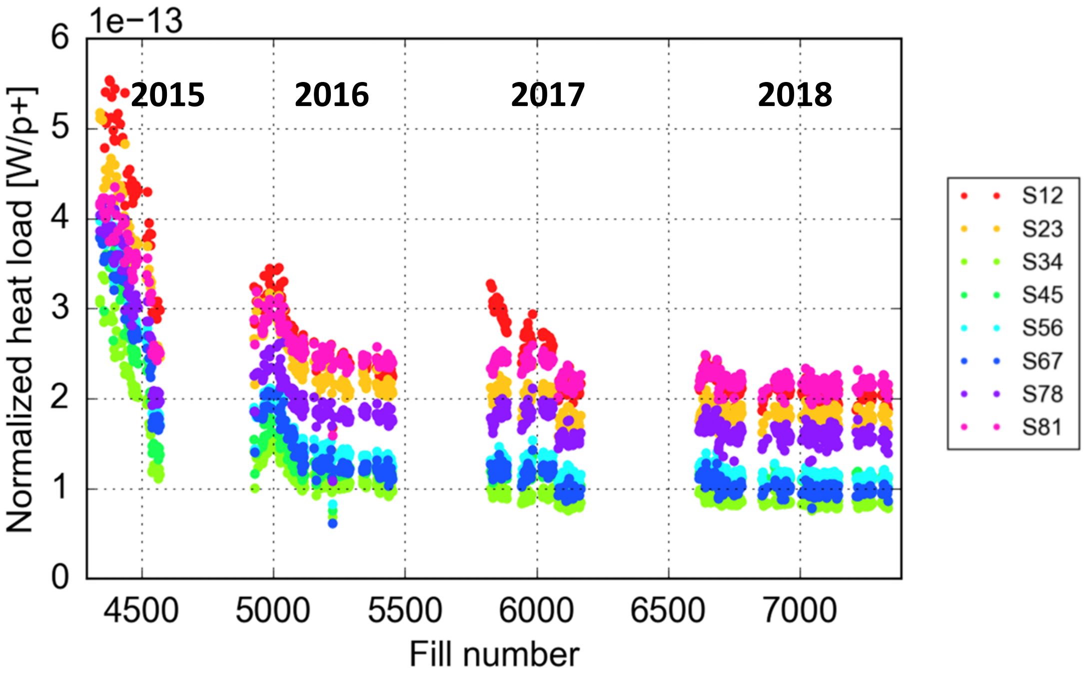
2. Proposed mitigation project
    - Phase 1 – Process selection and optimization
    - Phase 2 – Mock-up demonstration / Personnel training
    - Phase 3 – Implementation

3. Summary

1. Electron cloud in the LHC

Electron cloud in the LHC – Run 1 and Run 2

- **After LS1**, we observed a **wide beam-induced heat load spread** between low and high heat load arcs and between consecutive cells within an arc
- Heat loads are in **good agreement with electron cloud effects** assuming a **deterioration of the Secondary Electron Yield** (SEY, multiplication factor of the electrons in the beam pipe) of some beam screens



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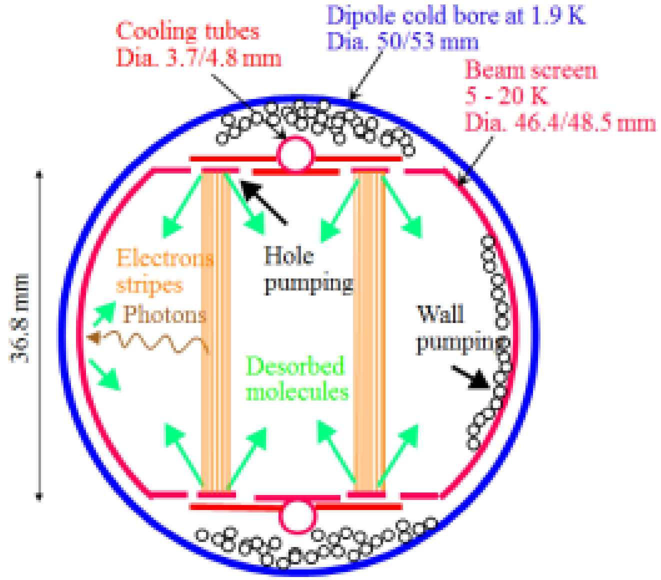
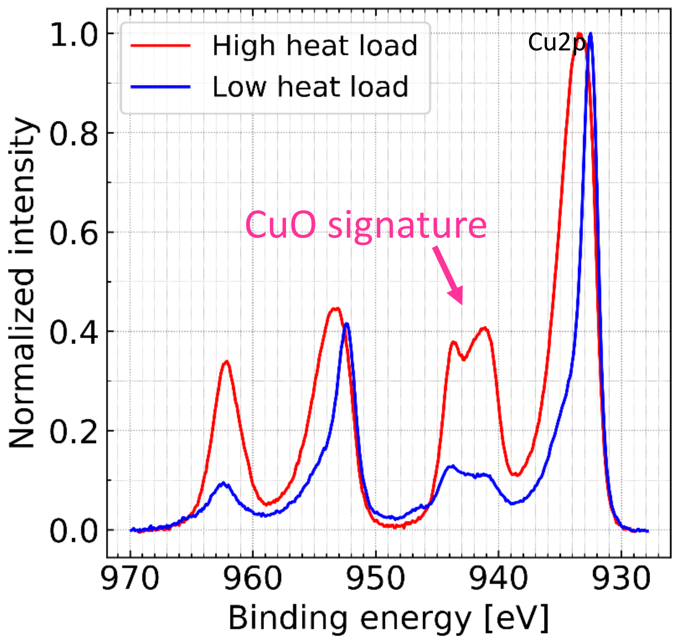
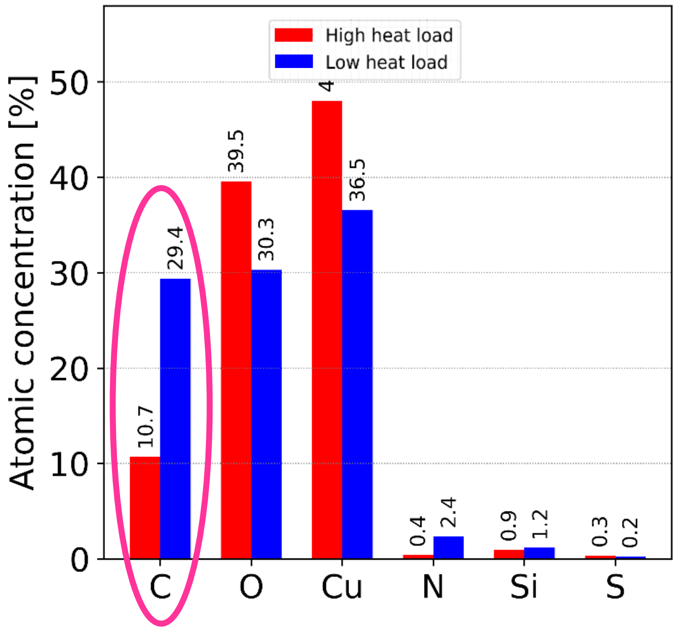
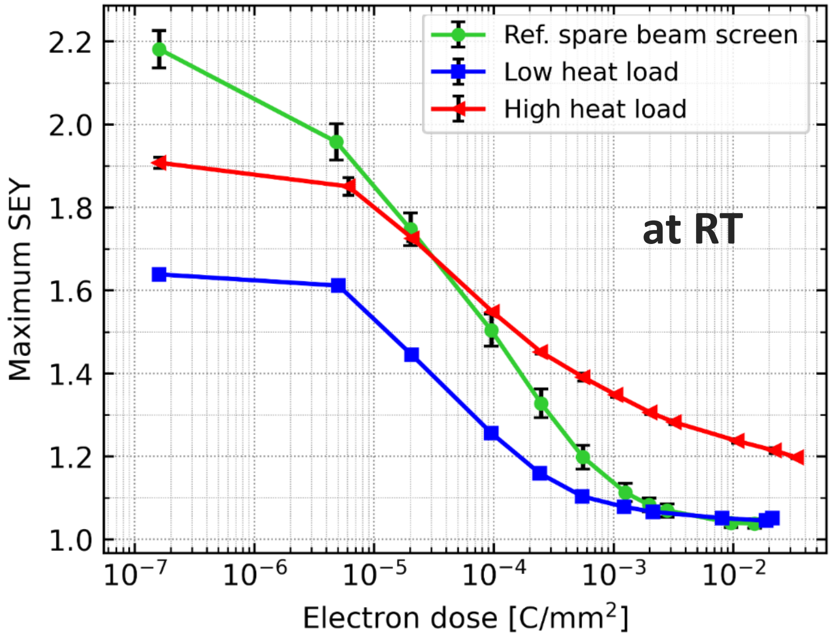


Surface analysis of LHC-extracted beam screen during LS2

- **Surface analysis** at RT of **low and high heat load beam screens** extracted from the LHC during LS2 suggest **CuO** (Cu II oxide or cupric oxide) **and low carbon amount as responsible for high heat loads**





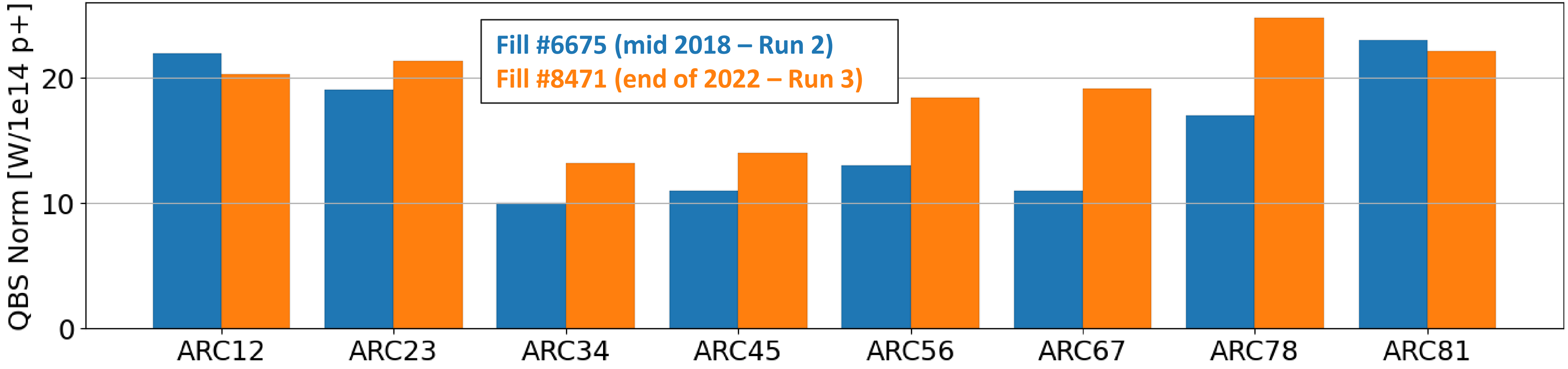


Run 3 and beyond

- Although additional precautions were implemented for LS2 (dry air venting, limited air exposure time…), further heat load degradation are observed during Run 3.
- Since we currently do not control the process of the **surface ageing** in the different sectors, **further degradation cannot be excluded** for Run 4 and beyond.

  → keep investigating this aspect with laboratory experiments

  → **need for mitigation solutions** e.g. hybrid beams for LHC



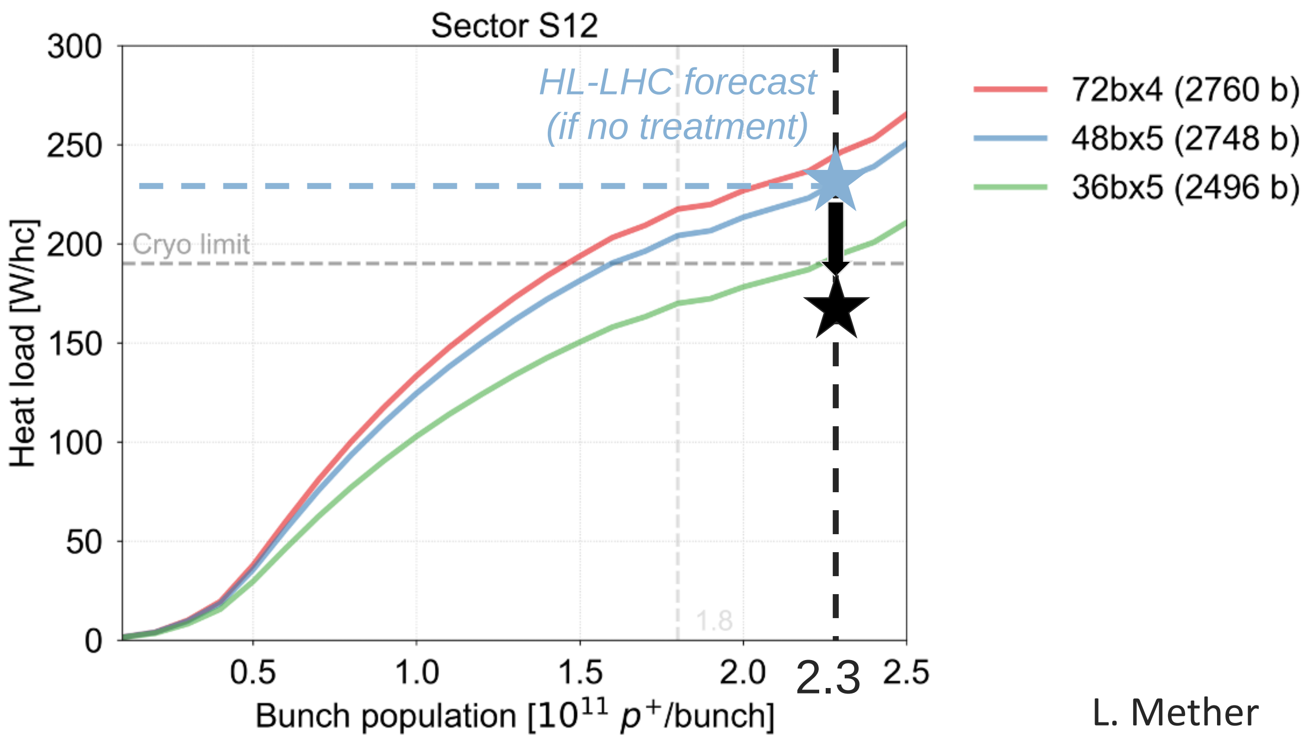
B. Bradu

HL-LHC heat load forecast

Example of Sector 12:

- Heat load simulation for high intensity beams based on recent heat load measurements
- Heat load estimate **overcomes the cryogenic capacity**

  → a beam screen **treatment** is required to bring **heat loads 10% below cooling capacity**



L. Mether

2. Proposed mitigation:
Beam Screen Treatment Project

BST Project overview

Objective

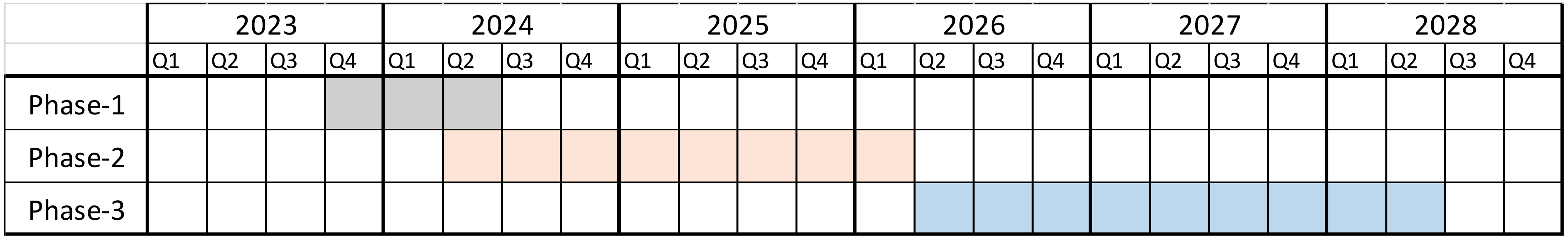
- **Remove CuO** and/or **increase surface carbon concentration** on selected beam screens
- Beam screen **surface passivation** (robustness against re-oxidation)

Strategy

- Limit the number of magnet interconnection opening
  → treatment of full half-cells (3 dipoles + 1 quadrupole, 53 m) in a single step
- Treatment campaign during LS3

Project phasing

- **Phase 1** – Process selection / optimization (2 technological choices) (up to Q2-2024)
- **Phase 2** – Mock-up demonstration / Personnel training (Q2-2024 → Q1-2026)
- **Phase 3** – Implementation in the machine (Q2-2026 → Q2-2028) – LS3

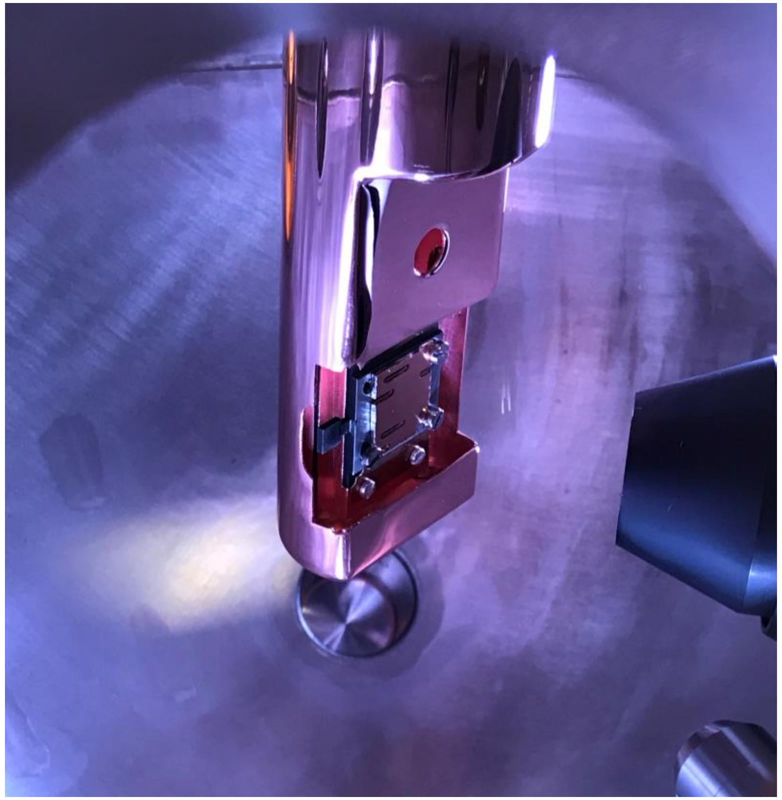


Phase 1: Process selection / optimization

Quality assessment

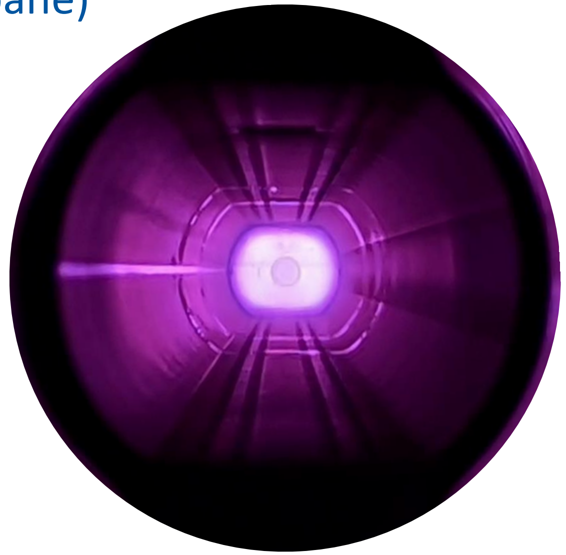
- **S**econdary **E**lectron **Y**ield: « as produced » and after electron conditioning at 15 K
- **P**hoto-**E**lectron **Y**ield quantification on samples
- Ageing (multiple 15K conditioning + thermal & air exposure cycles)

  → robustness against re-oxidation
- Adhesion
- **E**lectron **S**timulated **D**esorption



Option 1: Plasma-assisted CuO reduction and carbon recovery (PE-CVD)

+ Efficient CuO reduction and carbon deposition obtained in 10^{-1} mbar of C_3H_8 (propane)
+ Several cm/min → ≈ 1 day/53m/beam line
+ No significant warm-up (≤ 50 W)
- ”as-produced” SEY is high (≈ 1.5 - 2) due to presence of hydrogen in C_xH_y gas



To be further investigated:

→ Optimize gas type, pressure, time…

PE-CVD : Plasma Enhanced Chemical Vapor Deposition

Option 2: Very thin amorphous carbon coating by sputtering (PVD)

+ CERN has expertise (SPS campaign, HL-LHC: in-situ a-C coating of IT2&8 + new IP1&5 beam screens)

+ Compatibility with LHC beam pipe environment already assessed (Q5L8 a-C coated during LS2)

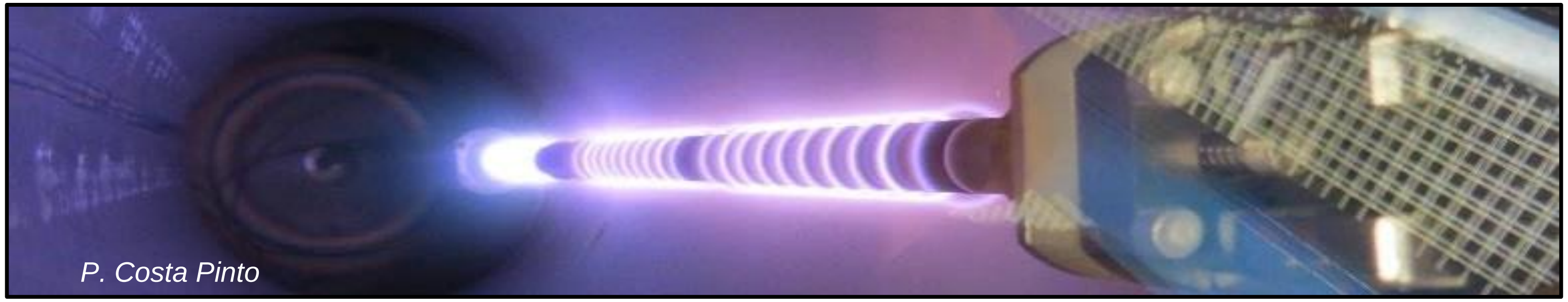
+ Lower “as-produced” SEY achieved than with PE-CVD

- “as-produced” SEY is still high (≈ 1.3) due to the absence of H_2 pumping during the process (performed without Ti sputtering) and due to lower coating thickness as compared to HL-LHC base line (<10 nm vs 50-100 nm)

- ≈ 4 days/53m/beam line

To be further investigated:

→ Evaluate effect of degraded vacuum quality during coating onto SEY

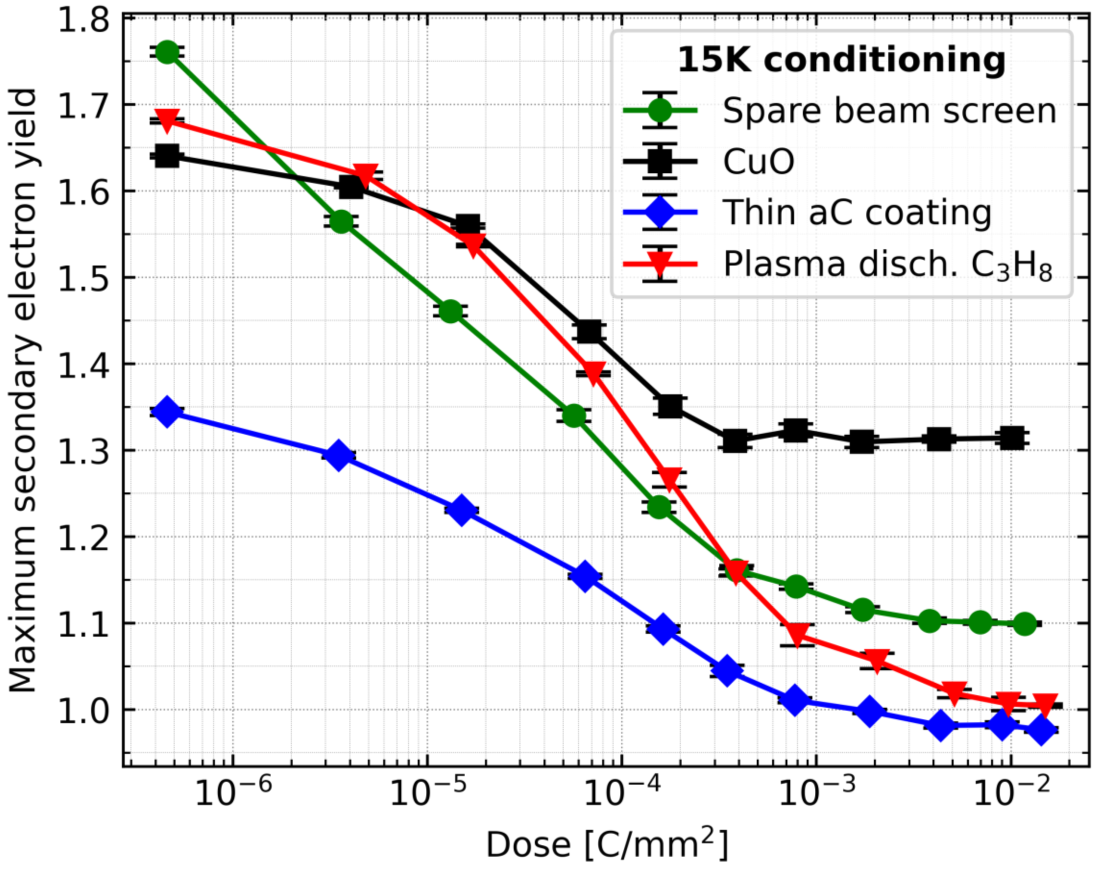


PVD : Physical Vapor Deposition

Assessment of conditioning at 15 K

- Validated behaviour during conditioning at 15 K for both techniques

- Ageing study on going



➔ Decision on technological choice by mid-2024

Phase 2: Mock-up demonstration / Personnel training

Mock-up demonstration and personnel training

- Demonstrate on a **1:1 scale** the **treatment process** over a full 53m long half-cell
- Mock-up = cold bore + beam screen + plug-in modules (PIMs) + beam position monitors (BPMs) with **arc curvature**
- **PIMs and BPM passage** by the coating train
- **Vacuum interface** qualification
- **Process fine tuning**
- **Personnel training** in view of in-situ deployment

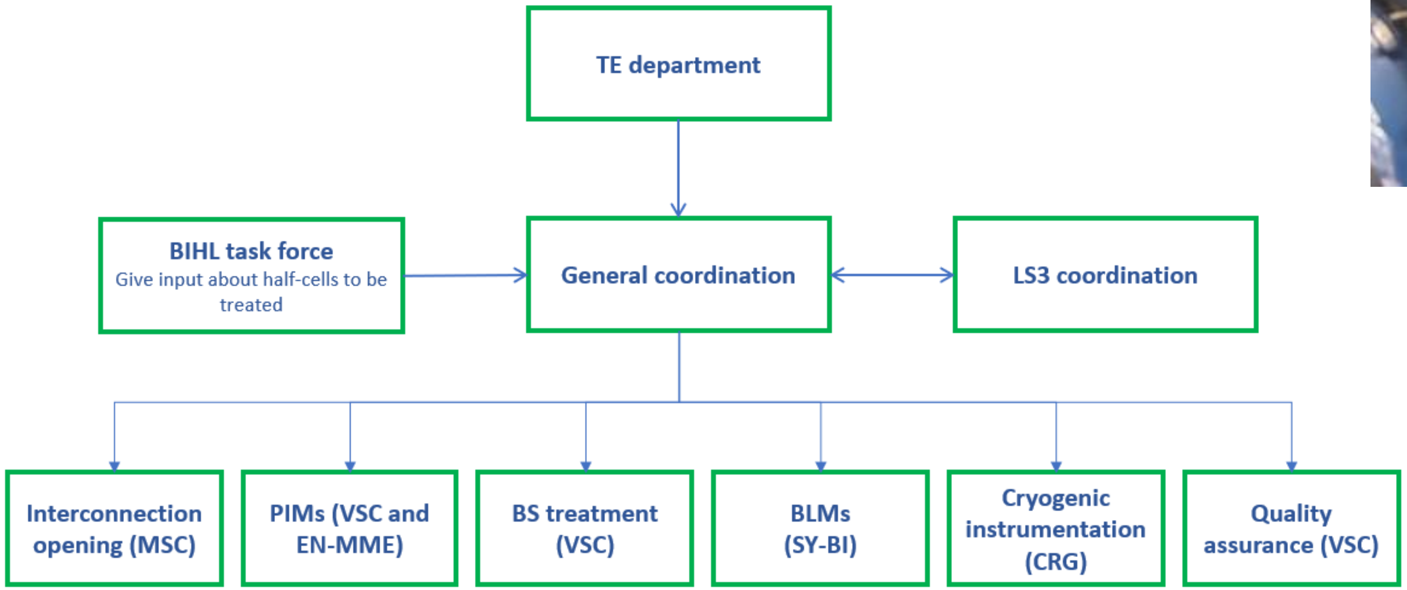
- Ongoing discussion to identify location

HL-LHC in-situ a-C coating test bench

Phase 3 – Implementation in the machine during LS3

Activities and structure identification

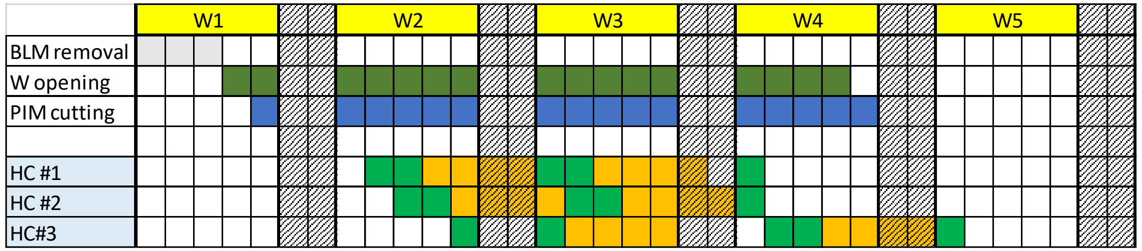
- Interconnections opening / closure (TE-MSC)
- PIMs cutting / re-installation (EN-MME) (component availability ensured by TE-VSC)
- Beam screen treatment + QA (witness sample) (TE-VSC)
- Post treatment QA (cf. LS2 procedures) (TE-VSC)
- Temperature sensors inspection (TE-CRG)
- Beam Loss Monitor removal / re-installation (SY-BI)



Preliminary working sequence

- Assuming effective treatment time ~ **4 days / hc / beamline** (process dependant)
- **2 days** for coating system assembly + **1 day** for disassembly per beam line
- **3 coating setups** used in parallel managed by **2 teams**
- Available time for in-situ treatment: **400 working days**

  → estimate: **100 full half-cells (i.e. 2x5.3 km of beam pipes)**
- Arc sequence determined by LS3 coordination (including synergies with other consolidation activities)



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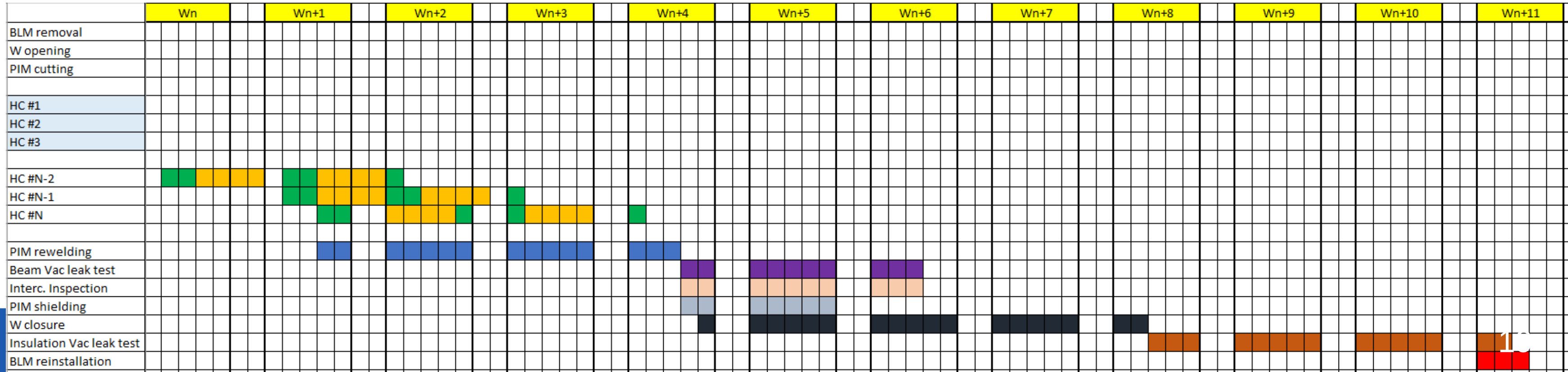

3. Summary

Summary

- Beam-induced heat loads are of **critical importance** for HL-LHC operation
- **Surface-induced effects** are identified as root cause
- **Mitigation project** submitted to CERN ATS management: BST Project
    - Phase 1: process selection + optimization
        - Cryo-conditioning of as-processed films validated
        - Ageing study ongoing
    - Phase 2: mock-up demonstration and personnel training
        - Location in discussion
    - Phase 3: Implementation
        - Ongoing definition
- Ongoing identification of selected half-cells by the CERN Beam-Induced Heat Loads Task Force

Thank you for your attention!