Beam-Induced Surface Modification of the LHC Beam Screens: the Reason for the High Heat Load in Some LHC Arcs?

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Electron cloud in the LHC

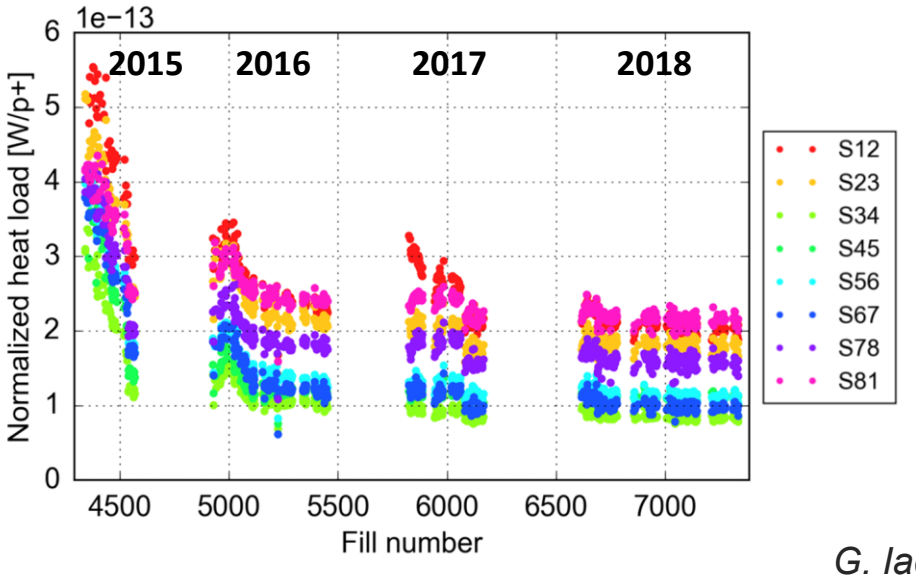
See G. Iadarola's presentation

The **electron cloud** developing in the beam pipes of the LHC is a **source of heat load** onto the **cryogenics system** of its superconducting magnets in its arcs. Since the beginning of the LHC Run 2 (2015), this heat load exhibits **puzzling features**:

- **Wide spread** along the ring, in spite of an identical design of the 8 arcs
- Spread persisting during **conditioning**

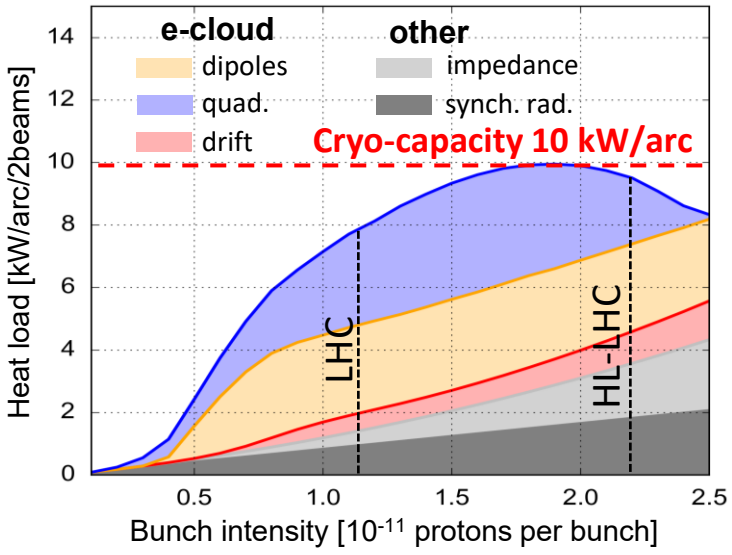
High heat load arcs are close to the **cryogenic capacity limit**

→ **critical issue** for High-Luminosity LHC (higher beam intensity)



G. Iadarola

Simulations for high heat load arcs



Aim and strategy

During the **Long Shutdown 2** (2019-2020), extraction of beam screens from a **low** and a **high heat load** LHC dipole and investigation of any **surface state difference** which could explain the **heat load spread**.

→ Analysis in **azimuth** of copper face of beam screen slices cut **from magnetic field** and **field-free** regions (Surface chemistry, Secondary Electron Yield, conditioning behaviour)

→ Comparison with expectations from **conditioning** and **deconditioning laboratory studies**

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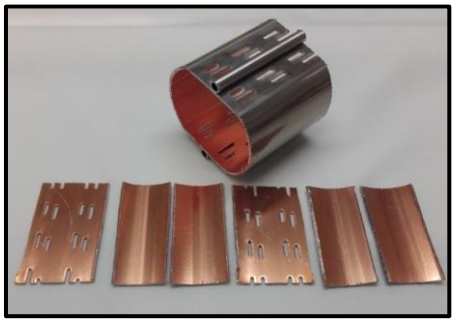
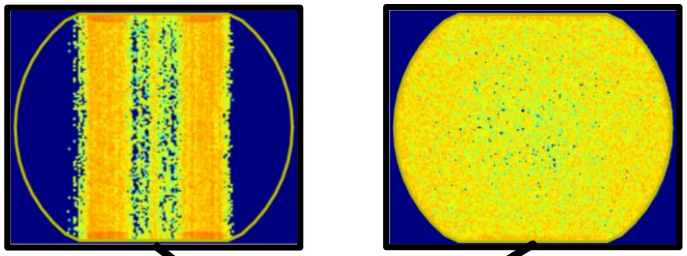
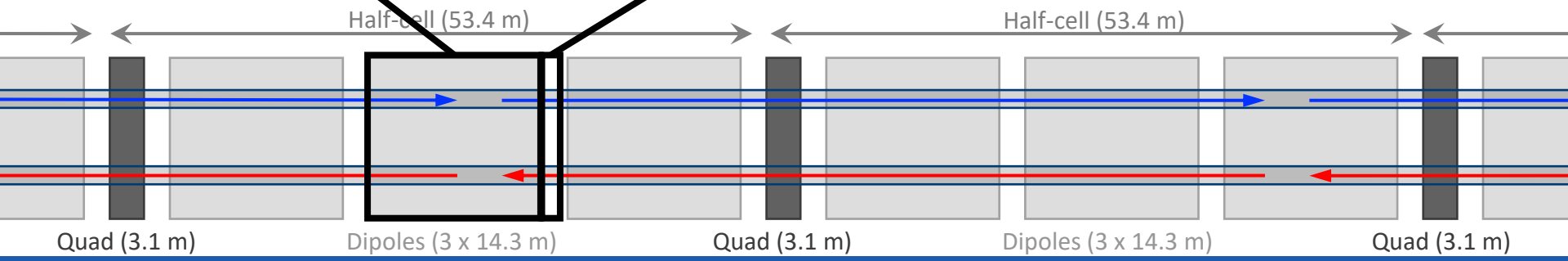
Dipole extraction from the tunnel
35 tons, 16 m long



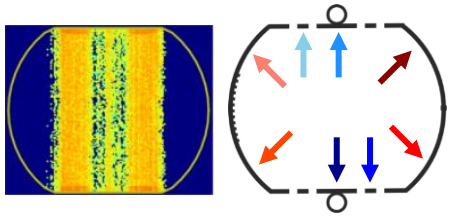
Beam screen samples

simulated e-cloud distribution
G. Iadarola

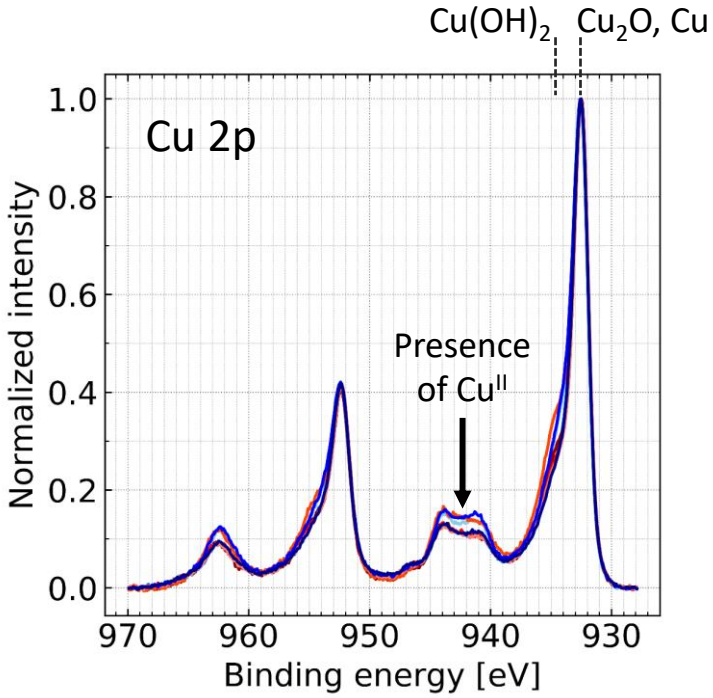


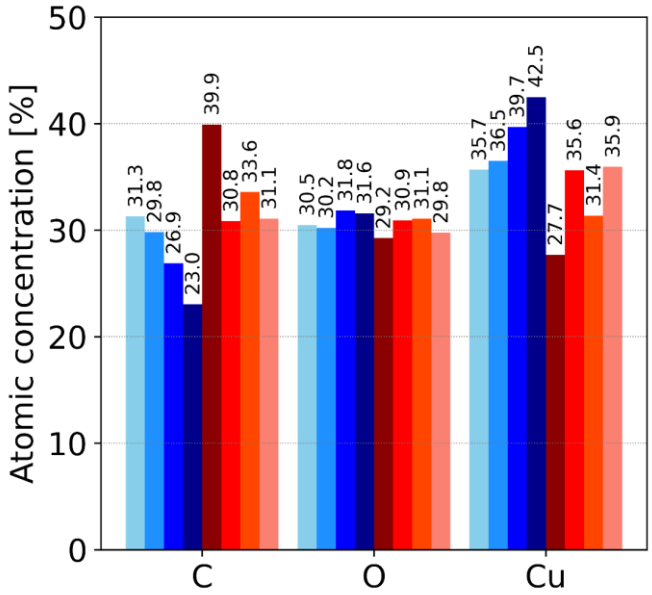


Beam screens from low heat load dipole



In field



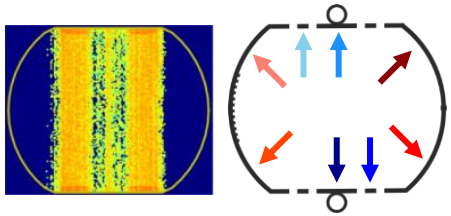


Surface chemical analysis by X-Ray Photoelectron Spectroscopy

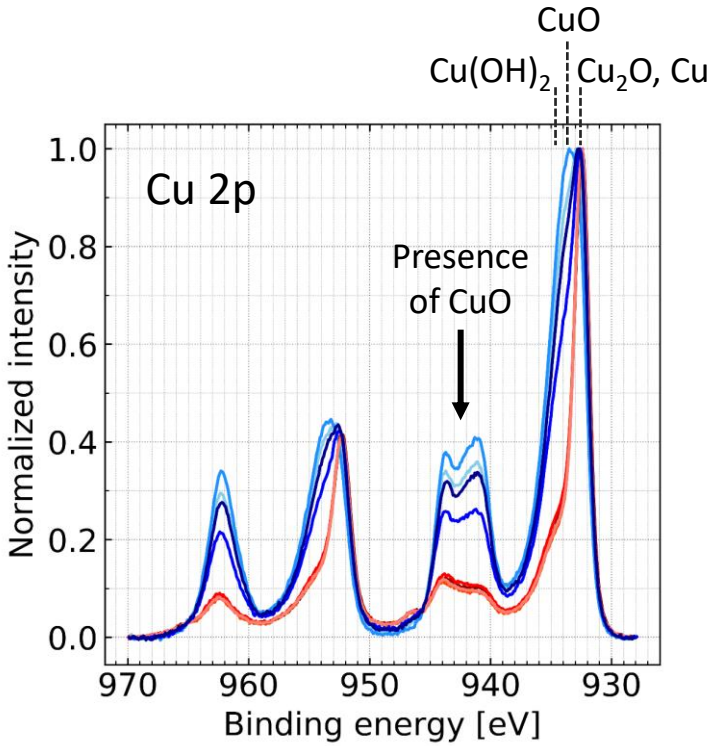
- Main copper oxidation product is **Cu_2O (native oxide)** and low coverage by copper hydroxide $Cu(OH)_2$
- Usual atomic composition
- Homogeneous in azimuth

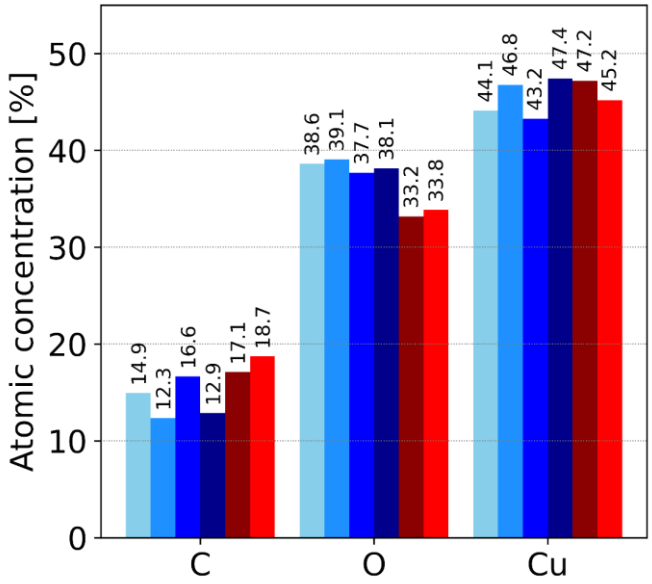
Beam screen surface of low heat load dipole compatible with expectations from laboratory studies on copper conditioning / deconditioning

Beam screens from high heat load dipole



In field

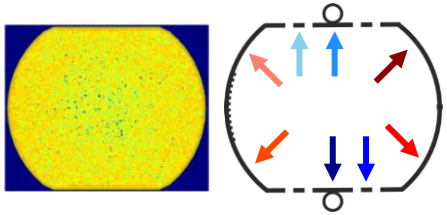




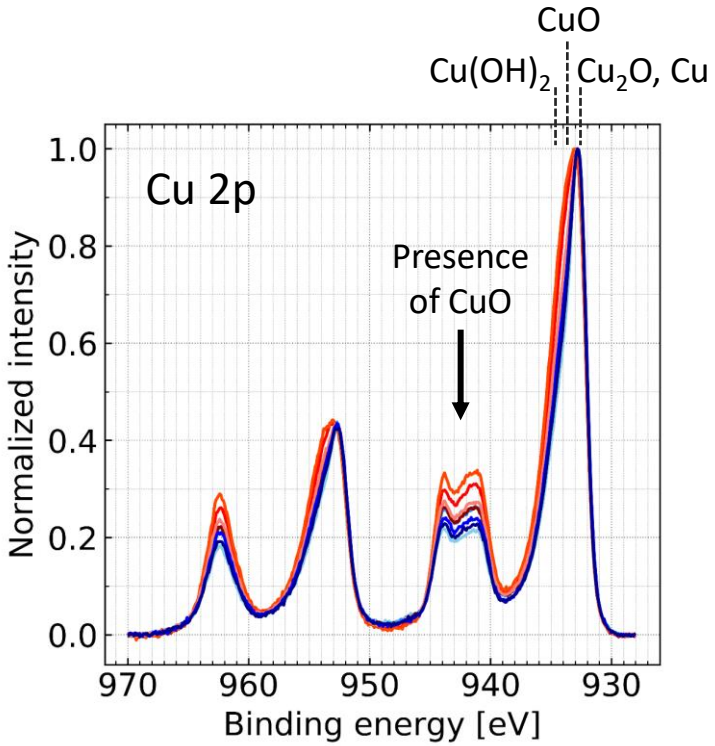
Surface chemical analysis by X-Ray Photoelectron Spectroscopy

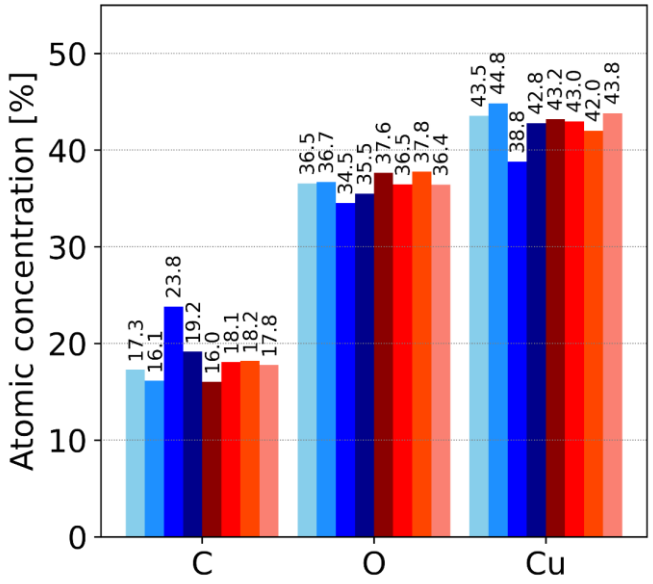
- On most irradiated sides: presence of **CuO (non-native oxide)**, in large amount
- On least irradiated sides: native **Cu_2O** oxide
- Extremely **low surface carbon content** (unachievable by initial beam screen cleaning) at all azimuths

Beam screens from high heat load dipole



Field-free

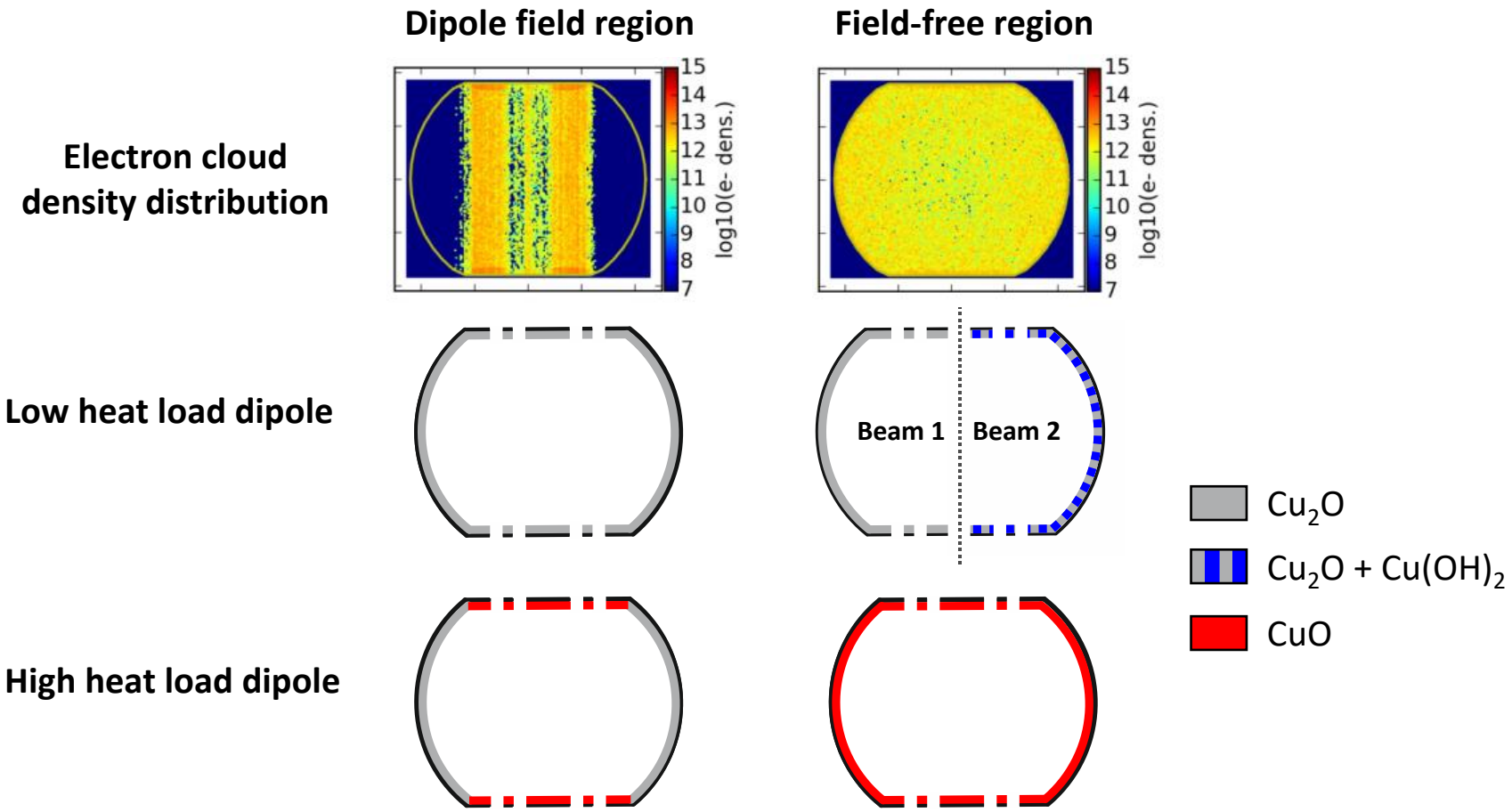




Surface chemical analysis by X-Ray Photoelectron Spectroscopy

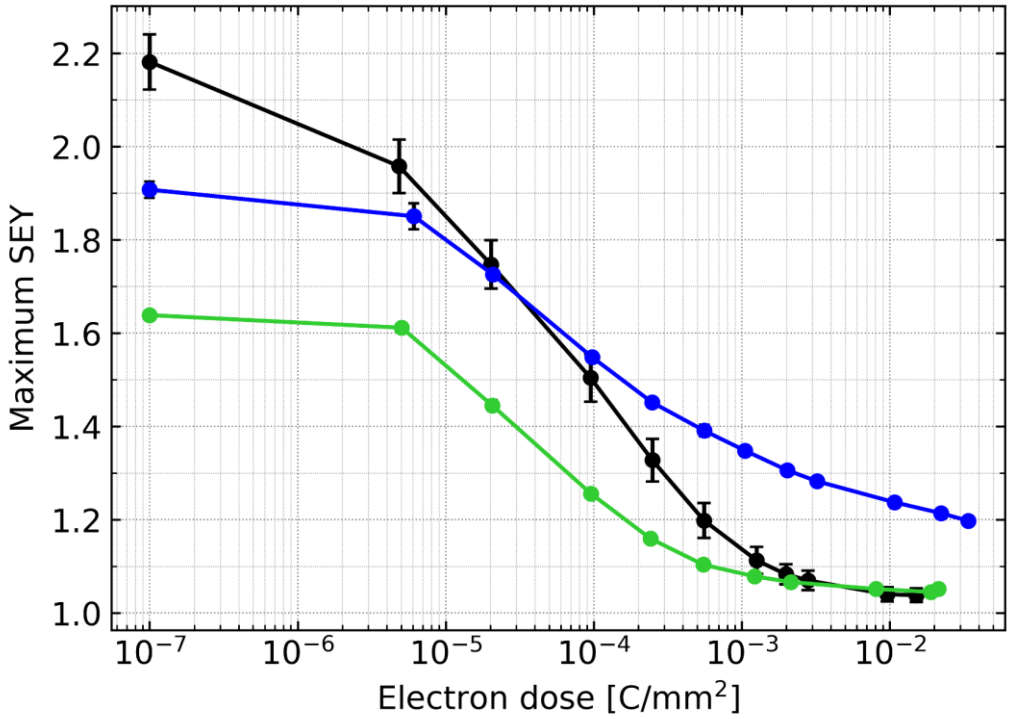
- Presence of **CuO (non-native oxide)** at all azimuths
- Extremely **low surface carbon content** (unachievable by initial beam screen cleaning) at all azimuths

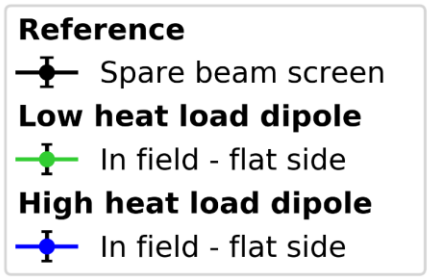
Beam screen surface chemistry - summary

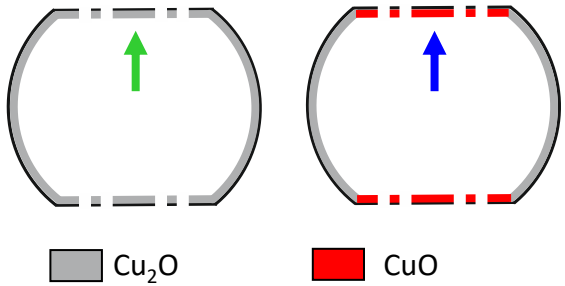


Beam operation is an essential element in the formation of CuO and decrease of carbon amount

High versus low heat load – conditioning @ RT







- **Nominal** conditioning for the **low heat load** beam screens
- **Slower** conditioning for the **high heat load beam screen** in the presence of **CuO**

Summary, conclusions and perspectives

- This study allowed to identify **surface chemical differences** between components of the LHC which could be **related to their different performances.**

Difference of **surface chemistry** → Difference of **SEY** and **conditioning** → Difference of **e^- cloud activity** → Difference of **heat load**

- Mechanisms of CuO build-up will be investigated by **electron irradiation experiments at 10K in a combined XPS and SEY measurement setup** (on going commissioning)

- These results open the door to the development of **curative solutions against the presence of CuO** to overcome the critical heat load limitation.