Findings on Linac4 RFQ Vane Damage and Proposed Mitigation Strategies

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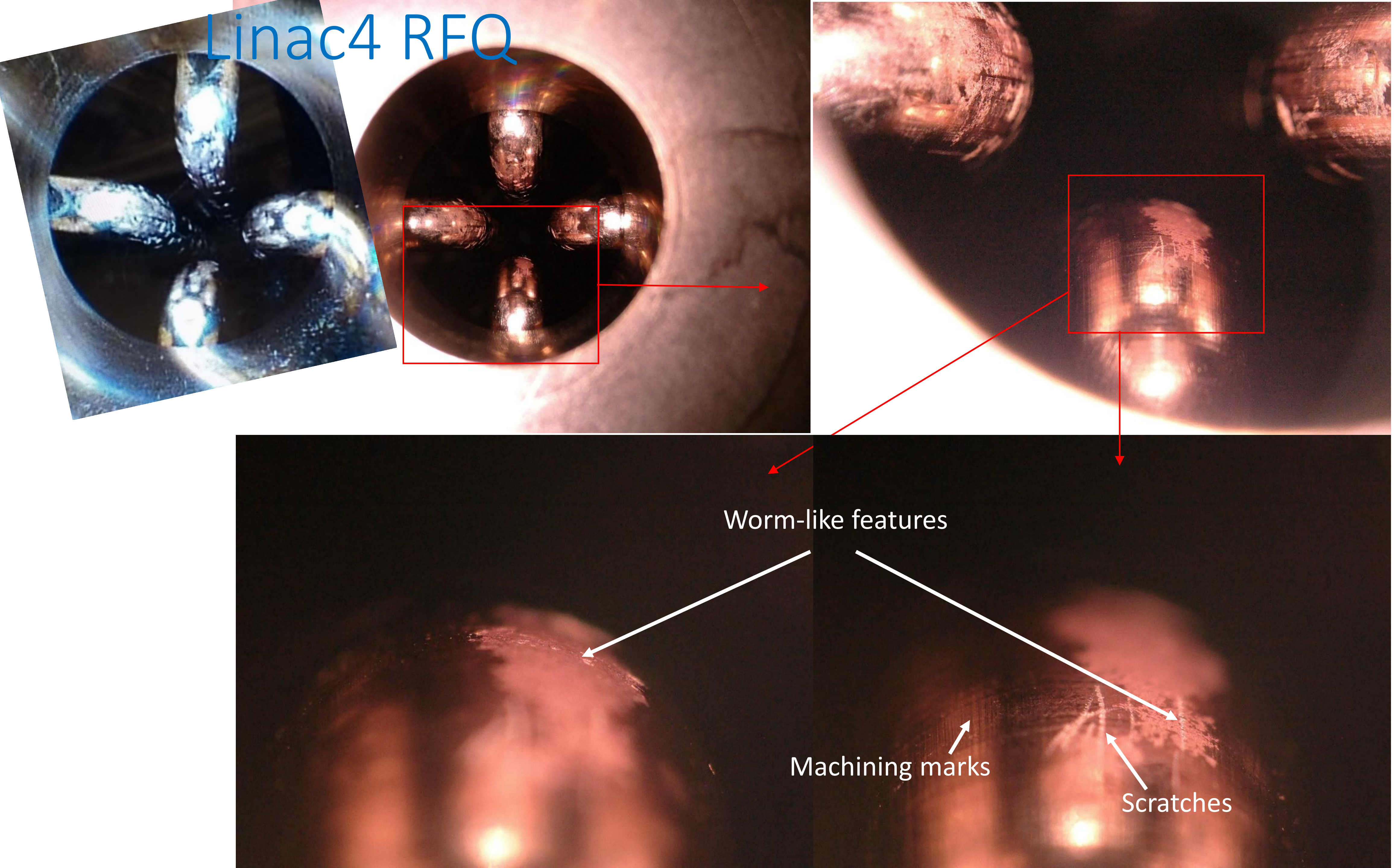
Visual investigation of the RFQ

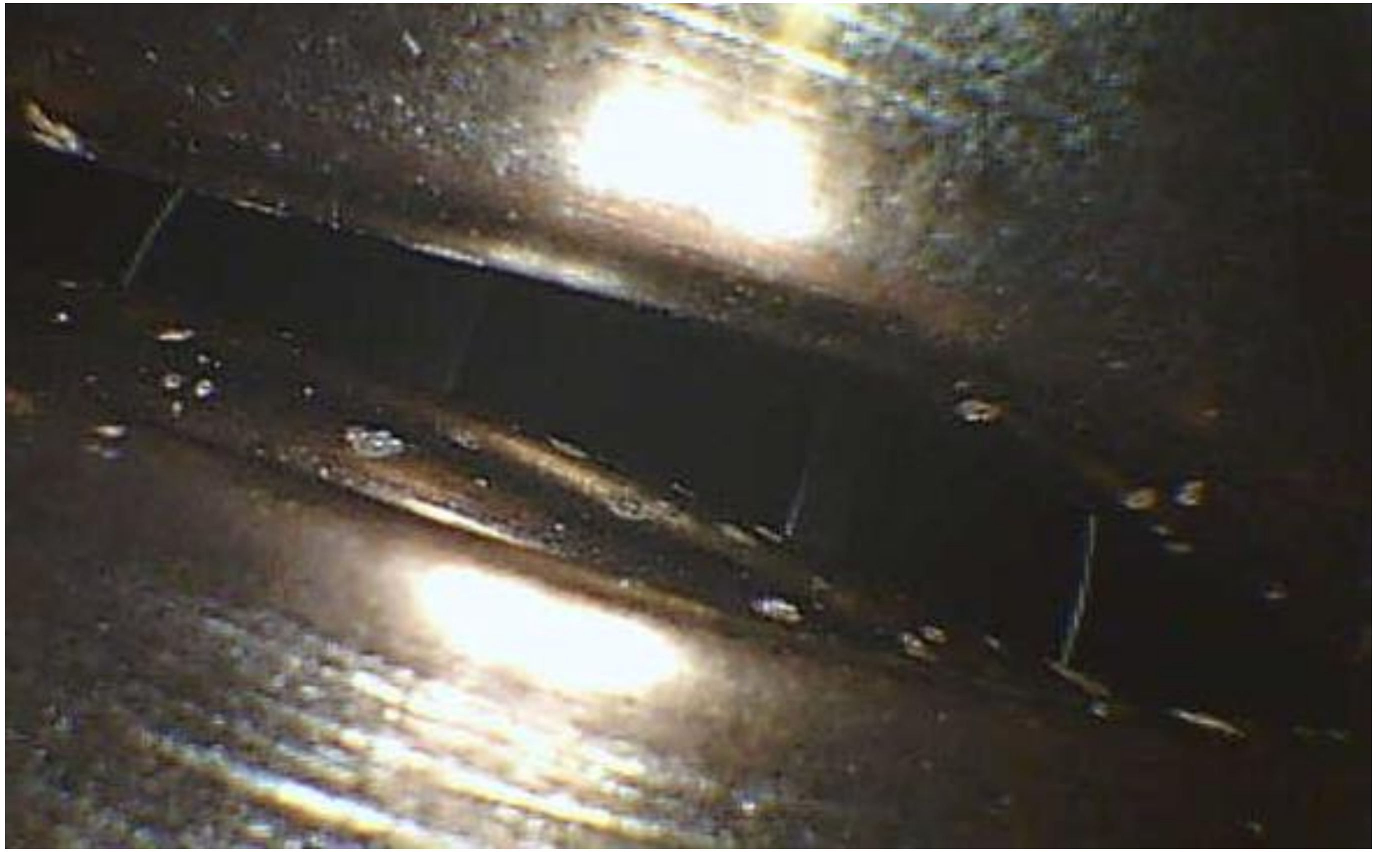
- Initial endoscopic images taken in January 2020.
- High resolution images taken in February 2020.
- (No similar images from before 2020, a few lower resolution photographs after beam tests show unblemished surfaces)

Linac4 RFQ



Breakdown Craters Along Vanes

- RF breakdown craters observed along the electrodes.



View between vanes – image from N. Thaus, R. Wegner

Visual investigation of the RFQ

- Endoscopic images can be miss-leading. High resolution photographs are more reliable.
- With the resolution of the optical means used to inspect the front part of the Linac4 RFQ it was confirmed the presence of breakdown craters. Observation of “worm-like-features” that modify locally the topography of the copper. No presence of *macroscopic* blistering* or sign of peel-off were noticed.
- The “worm-like-features” are also observed on the Linac2 RFQ (and CLIC structures).
- No significant degradation of the Linac4 RFQ in beam and RF performance had been detected so far.
- (More info at IEFC 262)

* No blistering was observed with this resolution.

Observation of Blistering

- However, low energy protons have been shown to cause blistering in copper.
- We do not know how blisters are linked to the macroscopic features seen.
- The blisters could be observed at the test stand by bombarding copper for ~24 hrs (approximately 1×10^{19} H-). ~10^{21} ions to be produced by Linac4 per year.
- See next slides.

H^- and p beam impact onto copper – blistering

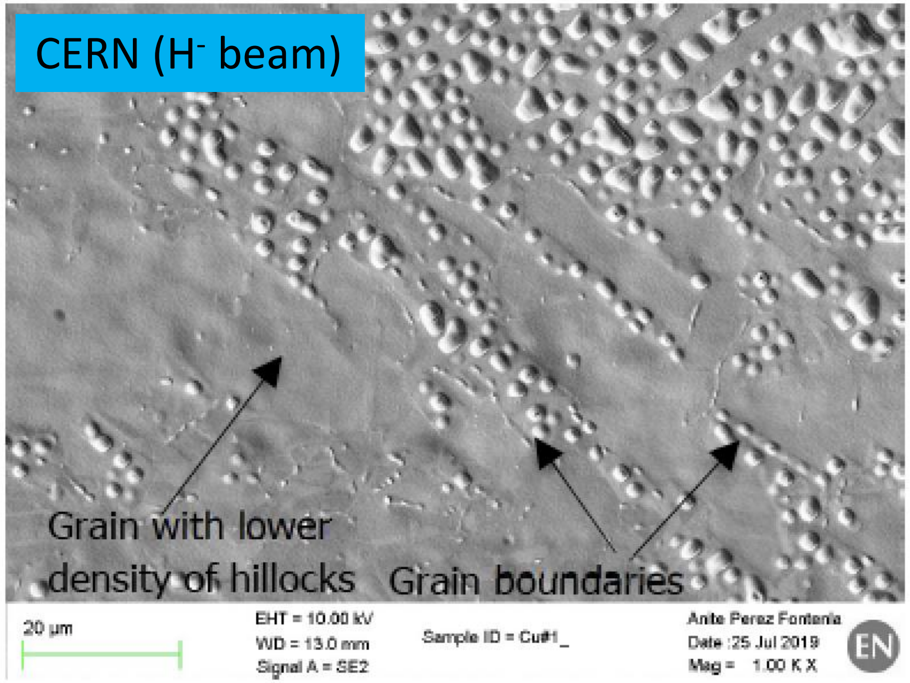


Fig. 4. SEM image (Cu #1) of the observed **hillocks** around the square hole (aperture 10.4 x 10.4 mm^2) of the first RFQ mask.

E = 45 KeV, I ≈ 30 mA, fluence: area dependent

Hillocks have a **preferential location** on the **grain boundaries** and their presence is more numerous in some grains (maybe related to crystallographic orientation)

A.T. Pérez Fontana, S. Sgobba, **CERN report 07.08.2019**
Microscope inspection on masks from Linac 4 test stand

E. Mahner, CERN, 23.01.2020, EDMS 2318561

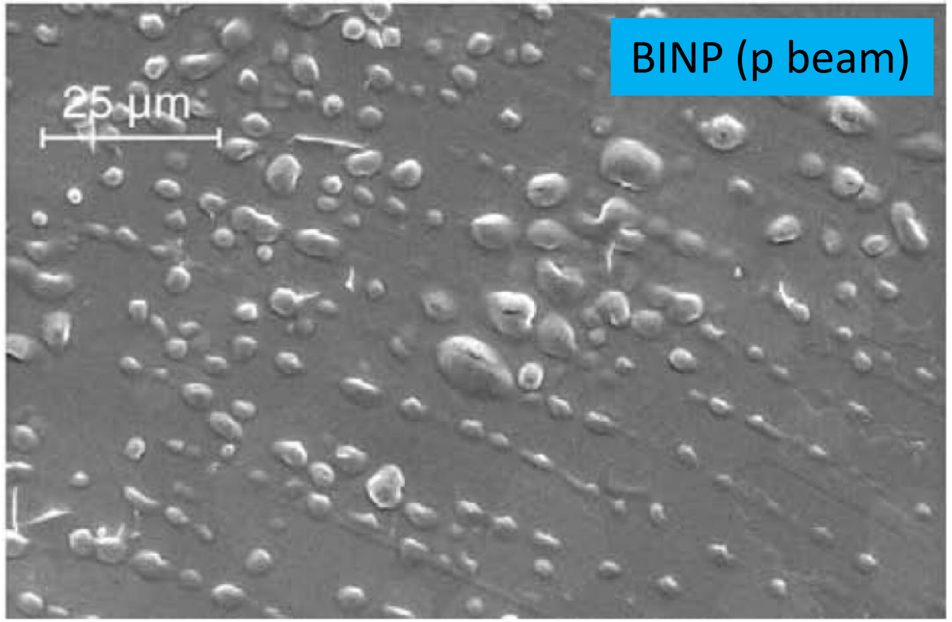
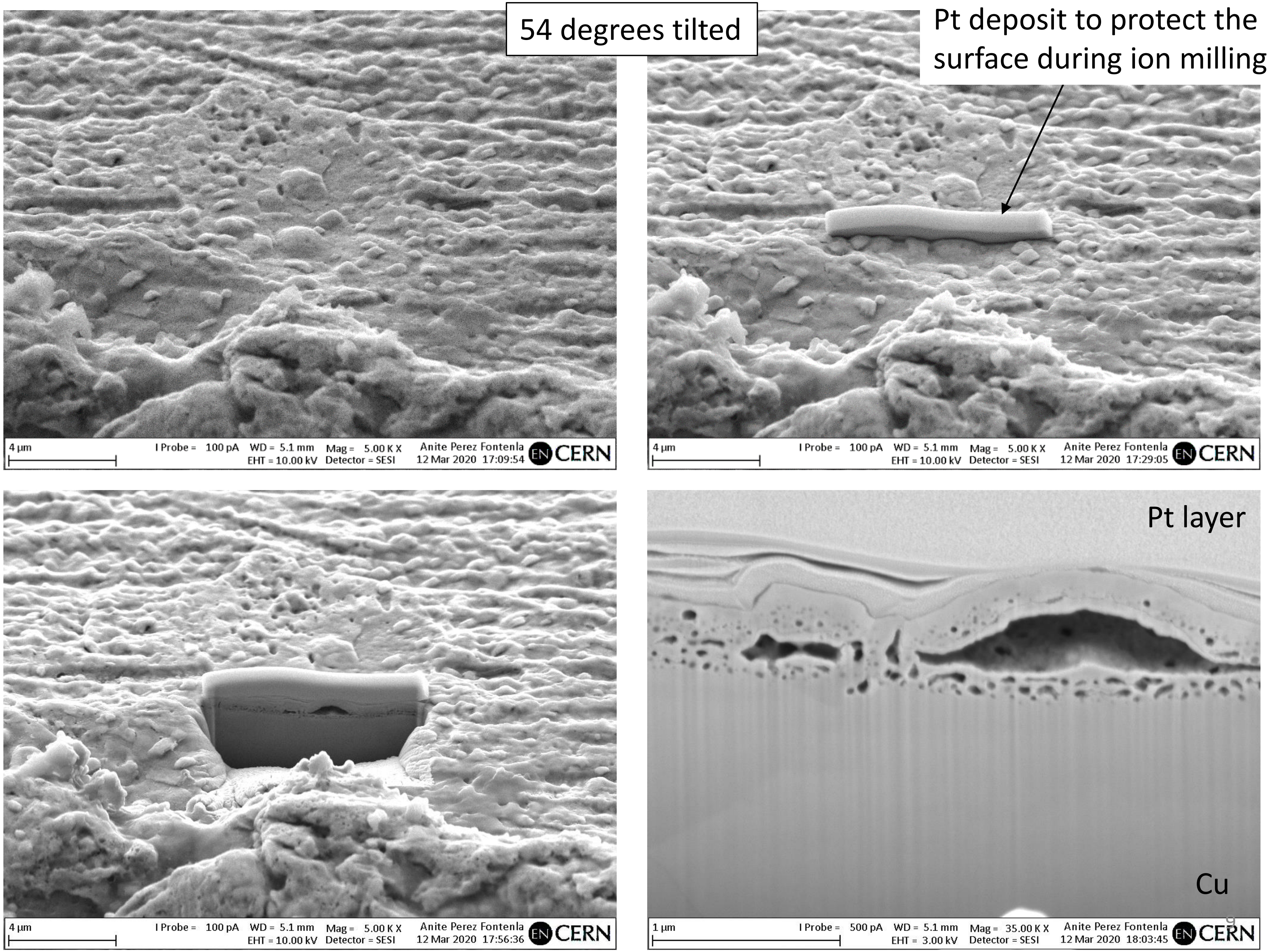


Fig. 5. SEM image of irradiated copper target, **blisters** at the track of diamond cut.

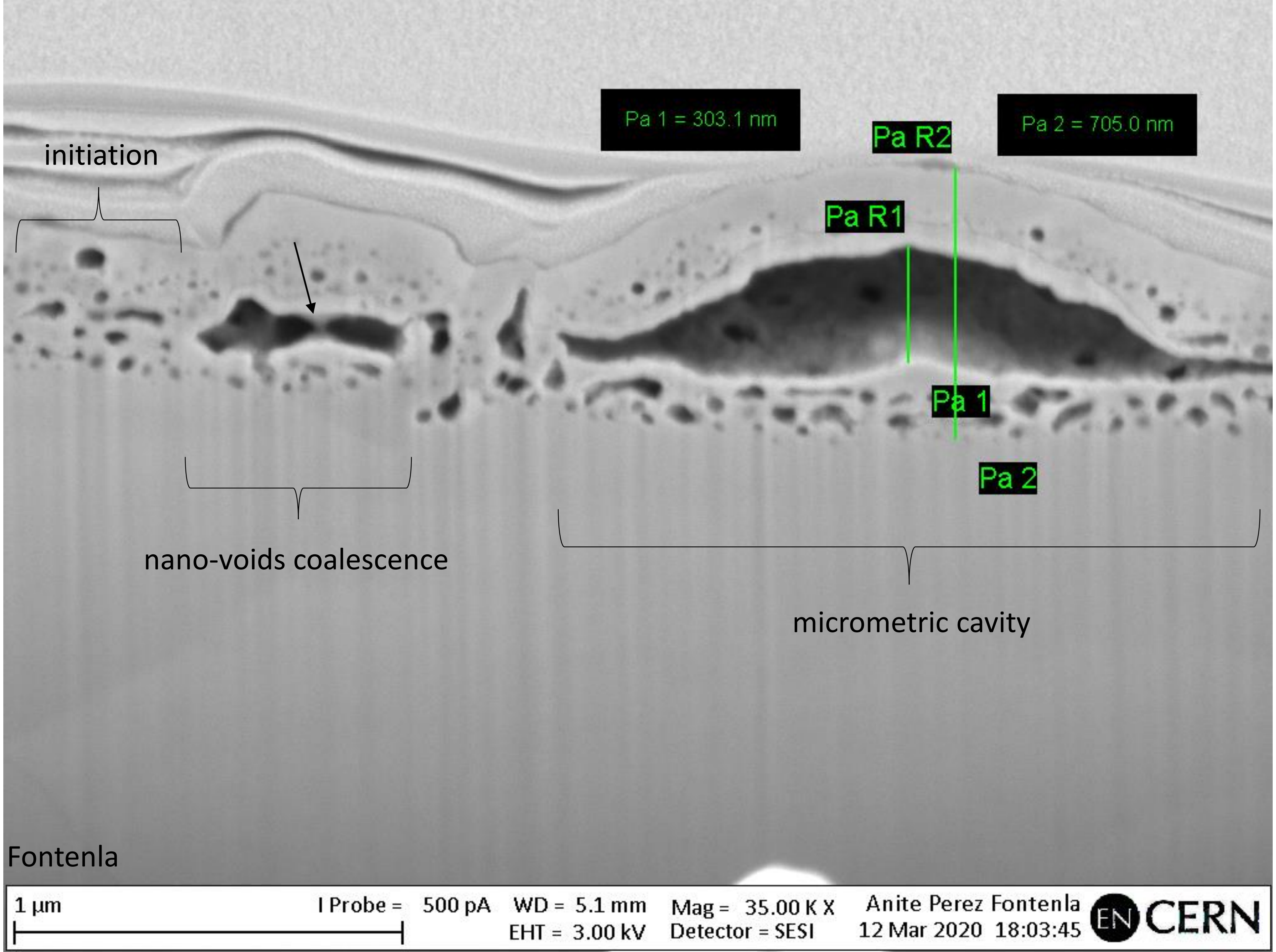
E = 190 KeV, I ≈ 1-2 mA, fluence: 11.4 x 10^{22} m^{-2}

V.T. Australian et al, **Journal of Nuclear Materials 396 (2010) 43-48**
Blistering of the selected materials irradiated by intense 200 KeV proton beam

Ion Beam milling of the surface of copper bombarded with H- ions at 45keV.



A.-T. Perez Fontenla



A.-T. Perez Fontenla

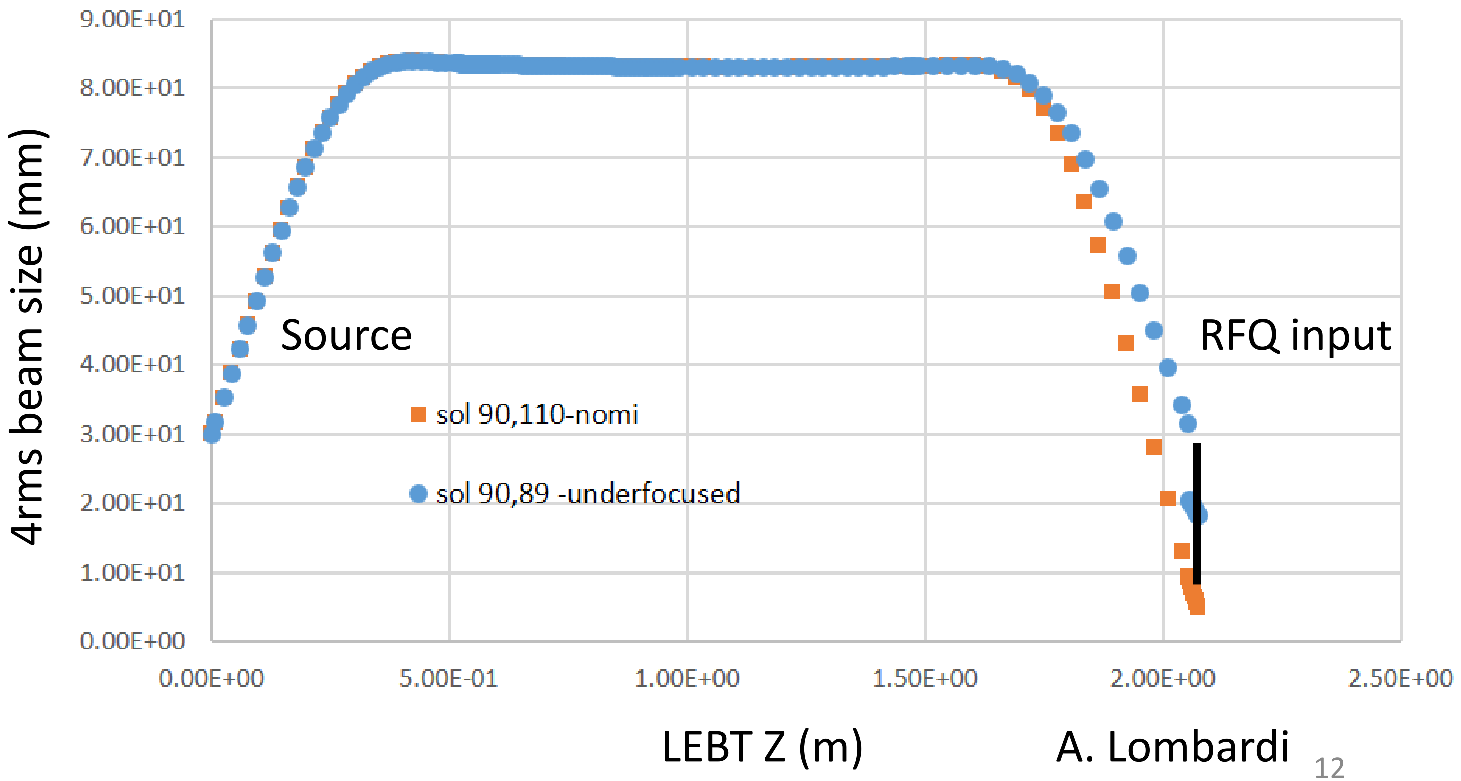
Strategy to Manage the RFQ

- Given the criticality of the RFQ to CERN, and the reports from other institutes, it is clearly justified to produce a spare.
- Spare production is a long process (it is expected to be validated mid-2022).
- Protect the present RFQ, while maintaining today's operation:
  - 25mA out of the RFQ.
  - Manage the breakdowns to reduce the cratering.
  - Keep losses low.

Collimate?

- Option explored to collimate with a mask in front of the RFQ.

- When placed close to the RFQ, it can help collimate under-focused beam, however the existing input aperture of the RFQ already helps in this respect.
- The collimator has little effect on miss-steered beam



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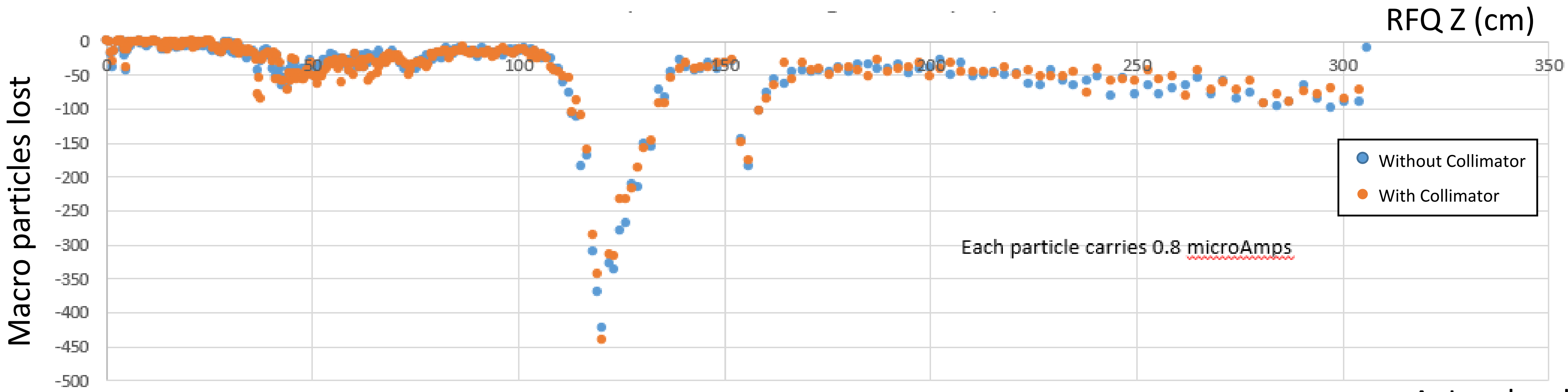
- In the nominal optics case, the mask has very little useful effect on the losses in the RFQ.
- Decided to be more effective to control the LEBT settings.



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Proposal for Implementation of Beam & RF Interlock Protections

- RF breakdown detection (reduction of cratering):
  - RF inhibited when a breakdown is detected (forward power stopped).
  - Next pulse normally enabled.
  - Unless: A cluster of breakdowns is detected => inhibit beam and ramp up field level.
  - See Rolf and Bartosz's presentations.
- LEBT Settings Management (reduction of un-necessary losses):
  - Monitor acquisition of important LEBT elements.
  - Stop the beam using SIS+BIS when equipment not at correct values.
  - See Richard and Tibor's presentations.

Summary

- Observations of the RFQ show we need a spare, and we should protect the present RFQ to maintain its performance.
- This is proposed to be done with additional interlocking on RF breakdowns and upstream optics settings.