CERN

Ar-Nb ion energy distribution and thin film properties in HiPIMS with a positive voltage pulse

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[2] CERN, TE/VSC-VSM
[3] CERN, BE/RF-LRF
[4] CERN, EN/MME

Outline

- Framework
- R&D simulations
- R&D experiments
- Next steps
- Conclusions

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The CRAB cavity: what for?

HL-LHC upgrade (**by 2025**) aim at increasing luminosity by a factor of 5.
16 CRAB cavities will be mounted around the two main experiments (CMS-ATLAS).

Why CRAB?

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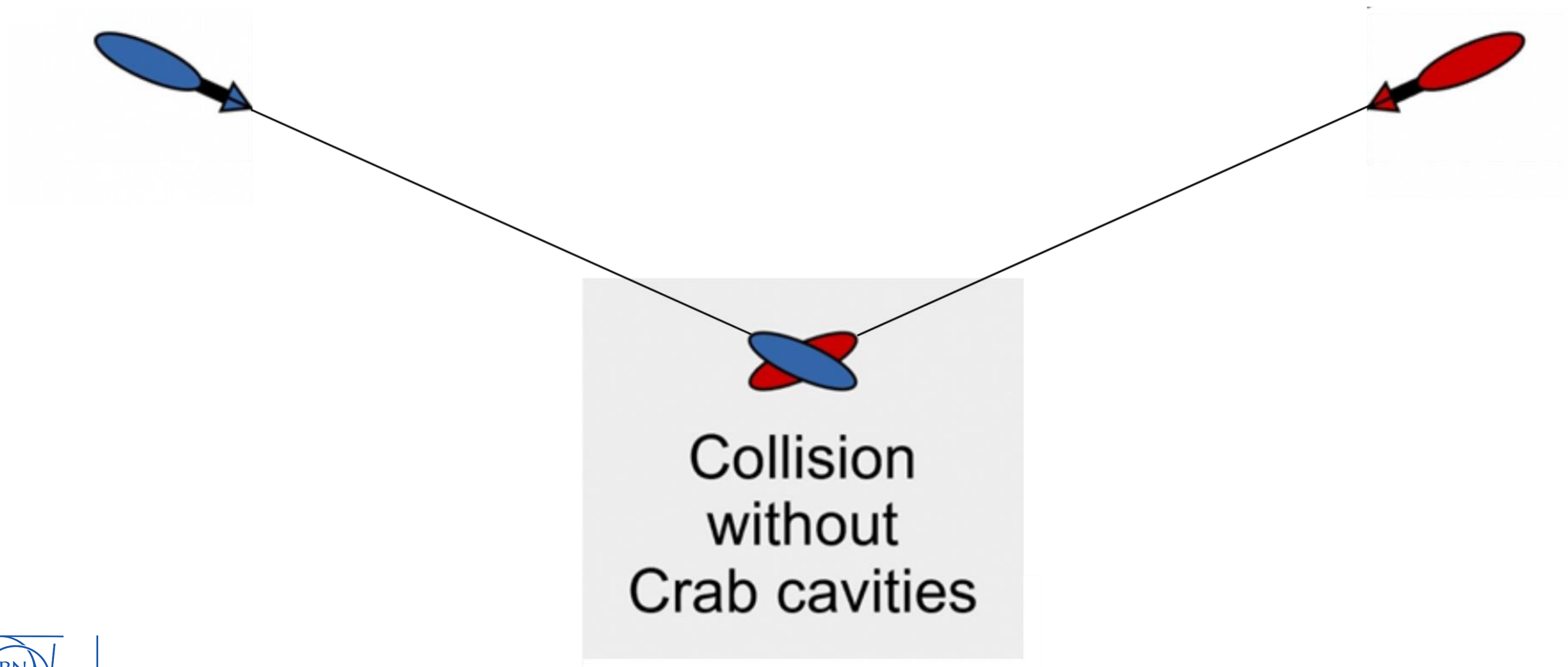

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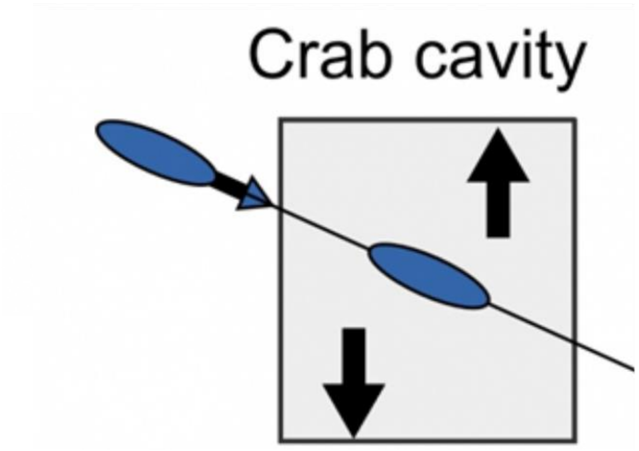

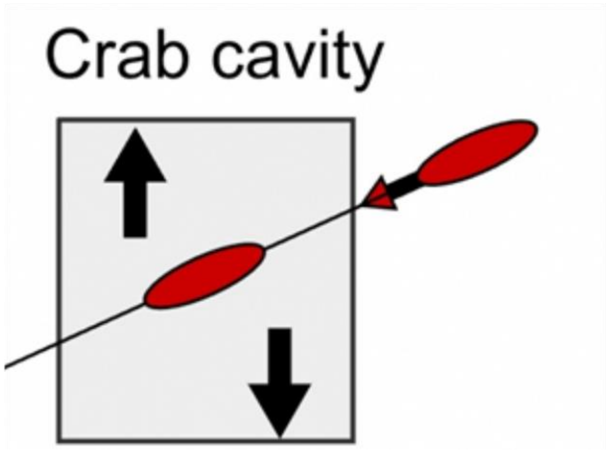

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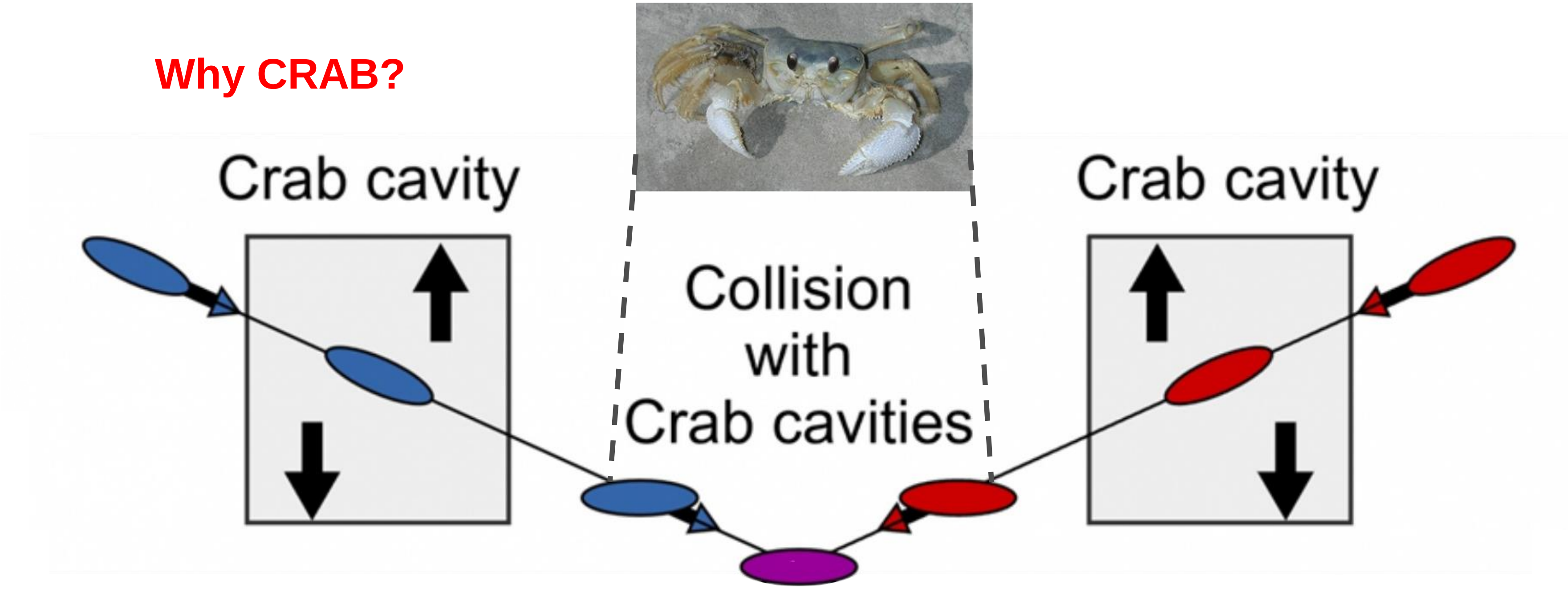

The CRAB cavity R&D

1st **bulk Nb** CRAB cavity for **HL-LHC completed** and **under test** in SPS

0.66 m

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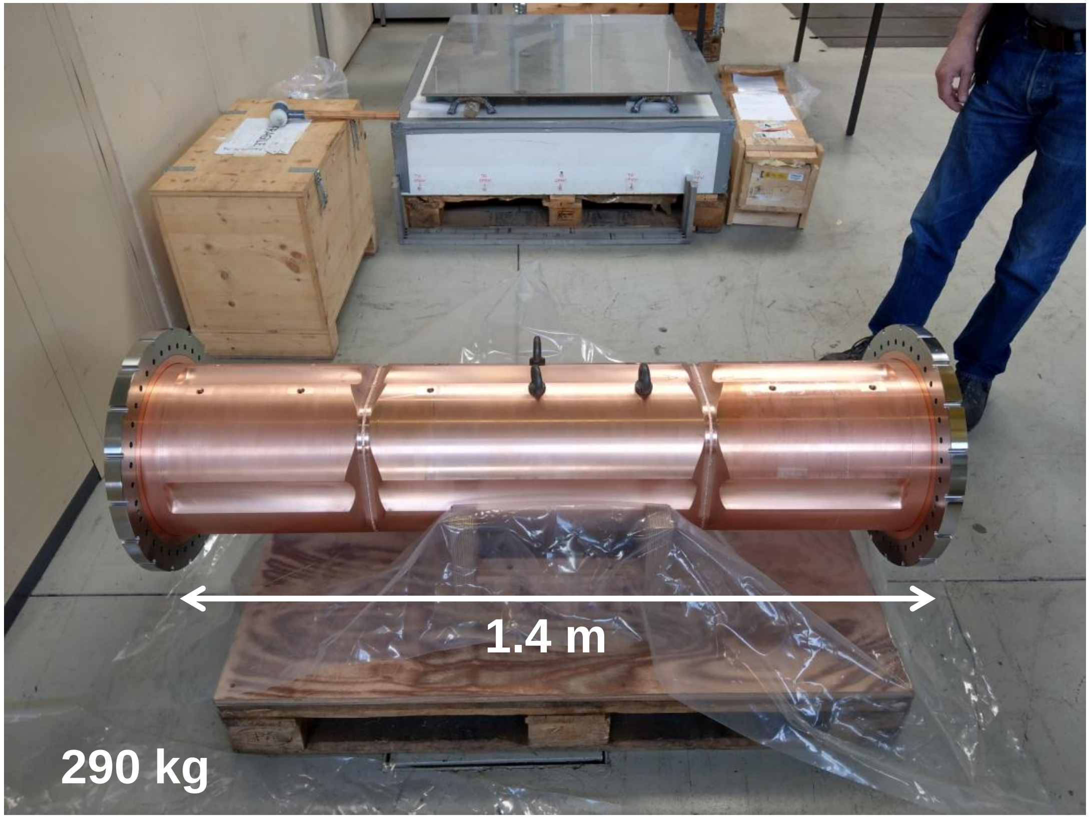
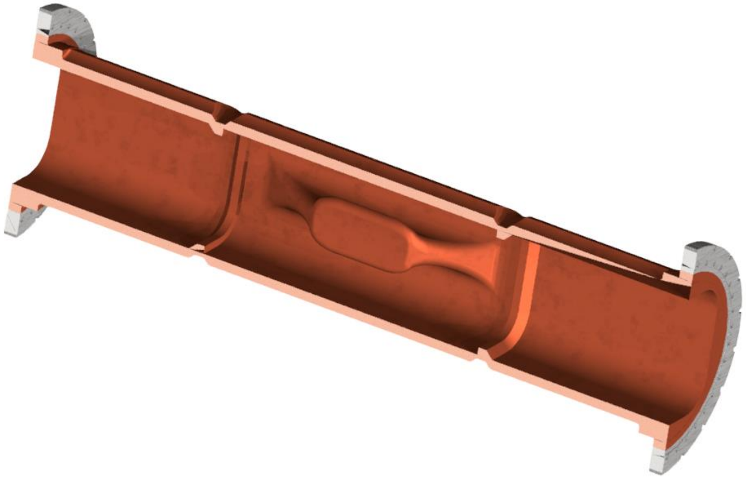
R&D in the **FCC** framework for alternative **Nb/Cu** WOW CRAB cavities

1st **Cu WOW** CRAB cavity prototype **to be Nb coated**



The CRAB Cu cavity

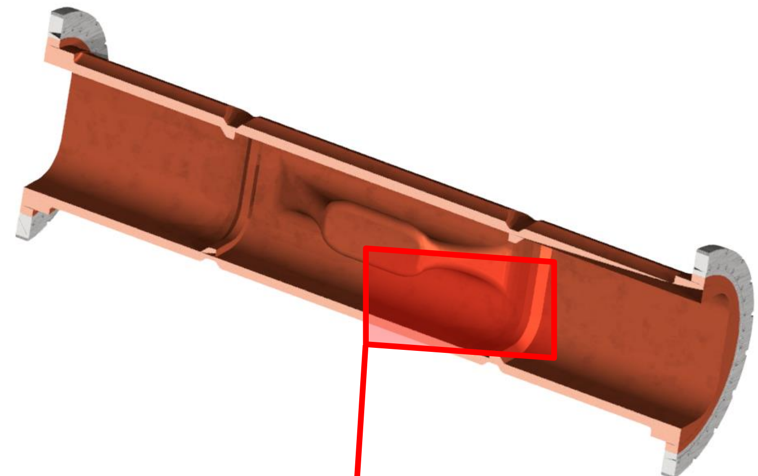


CHALLENGES:

1. Superconducting cavities require high purity and defect-free coatings

2. Complex shape: avoid shadowing / uniform growth

The CRAB Cu cavity



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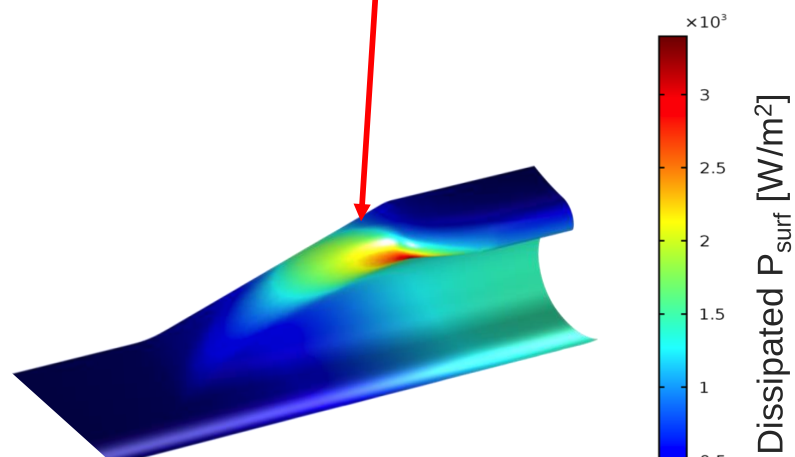
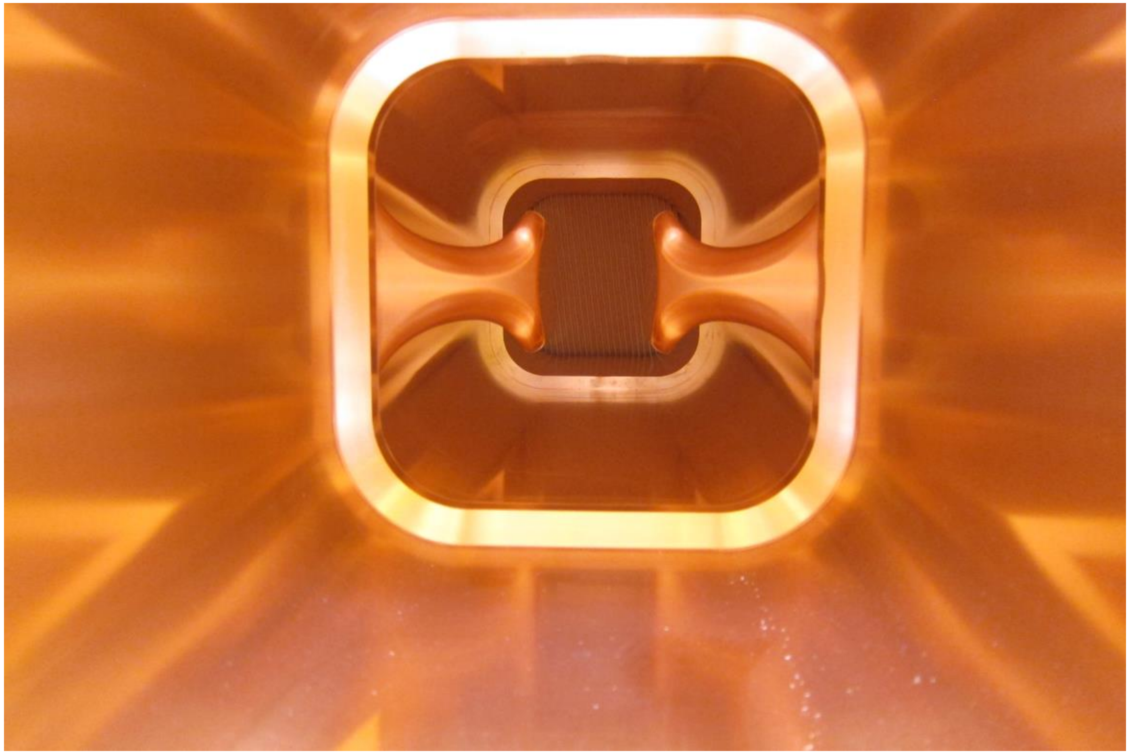


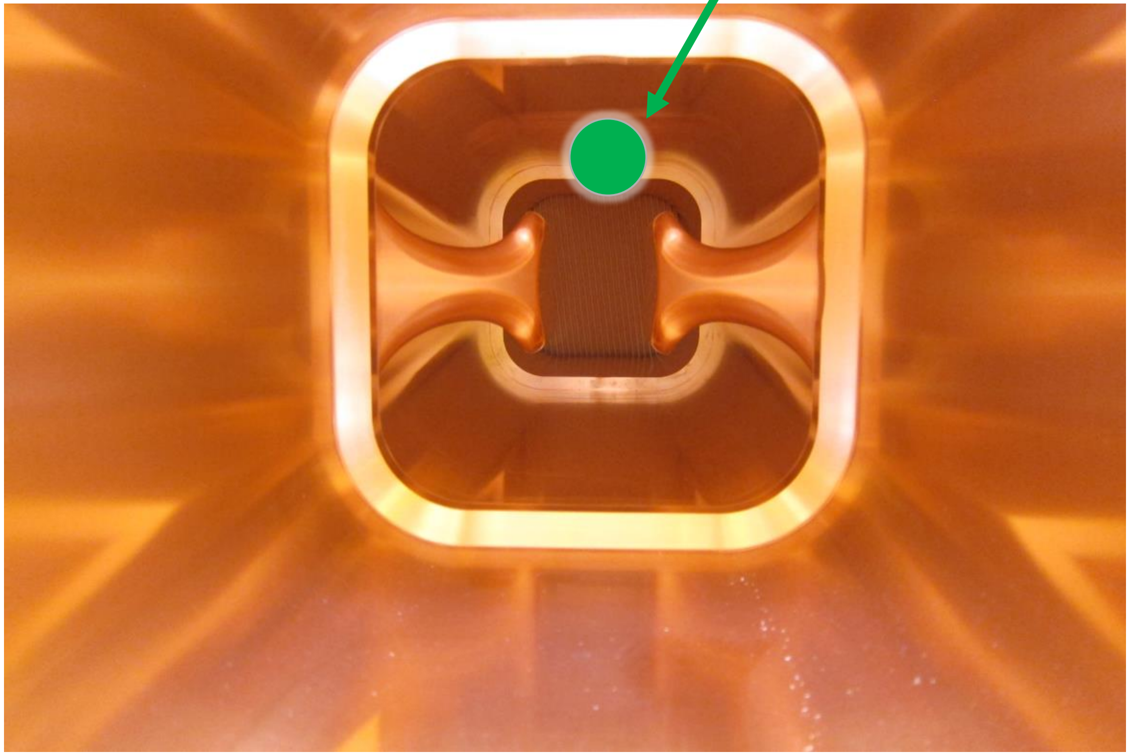
Total power loss ~ 60W
@ $Q_0 = 4\text{x}10^8$ / 3 MV deflection

CRAB cavity coating challenge



CRAB cavity coating challenge

Cylindrical sputtering source



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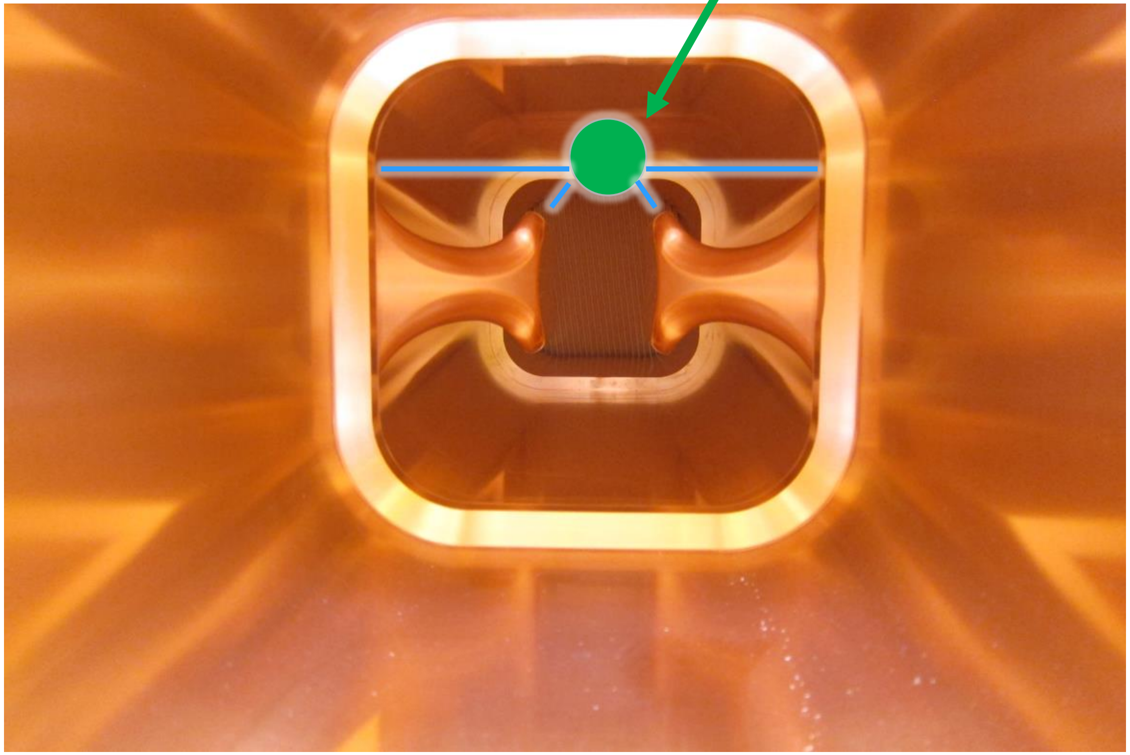
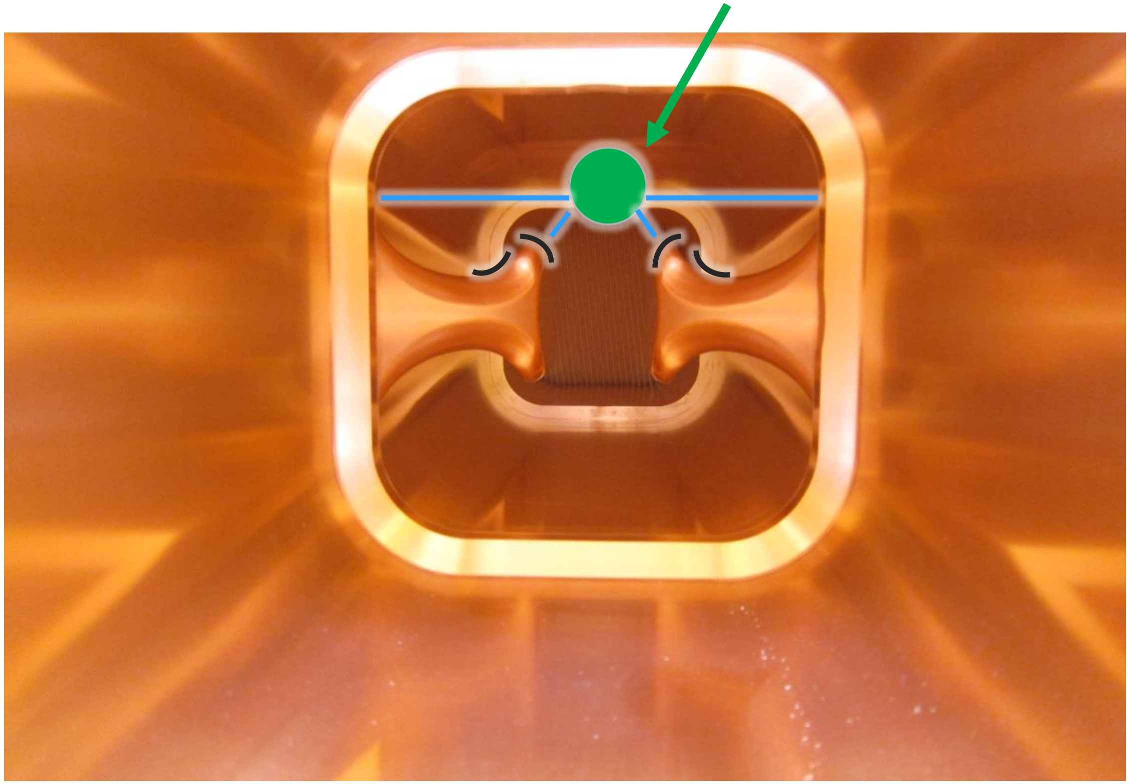


Coating surfaces at different:

- distances (50 – 150 mm)

CRAB cavity coating challenge



Coating surfaces at different:

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- incident angles (0 – 90 °)

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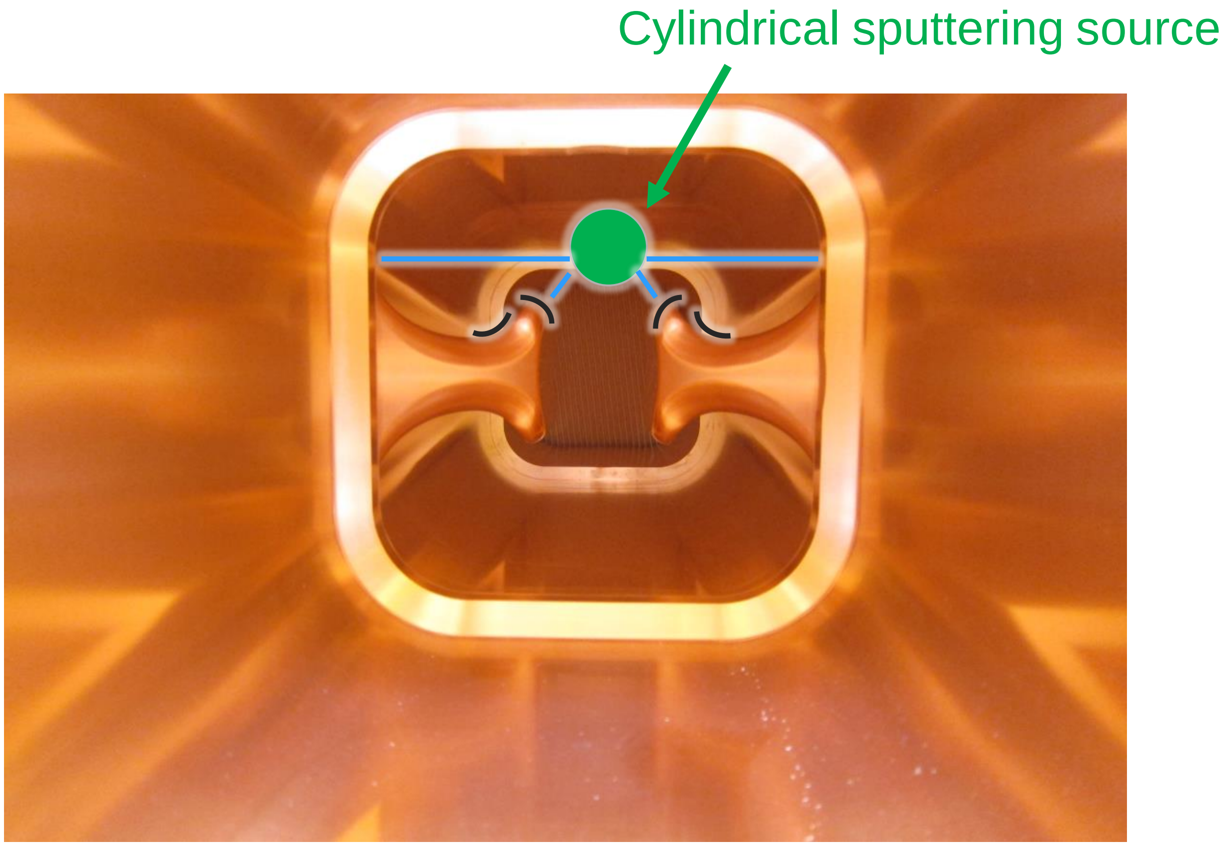

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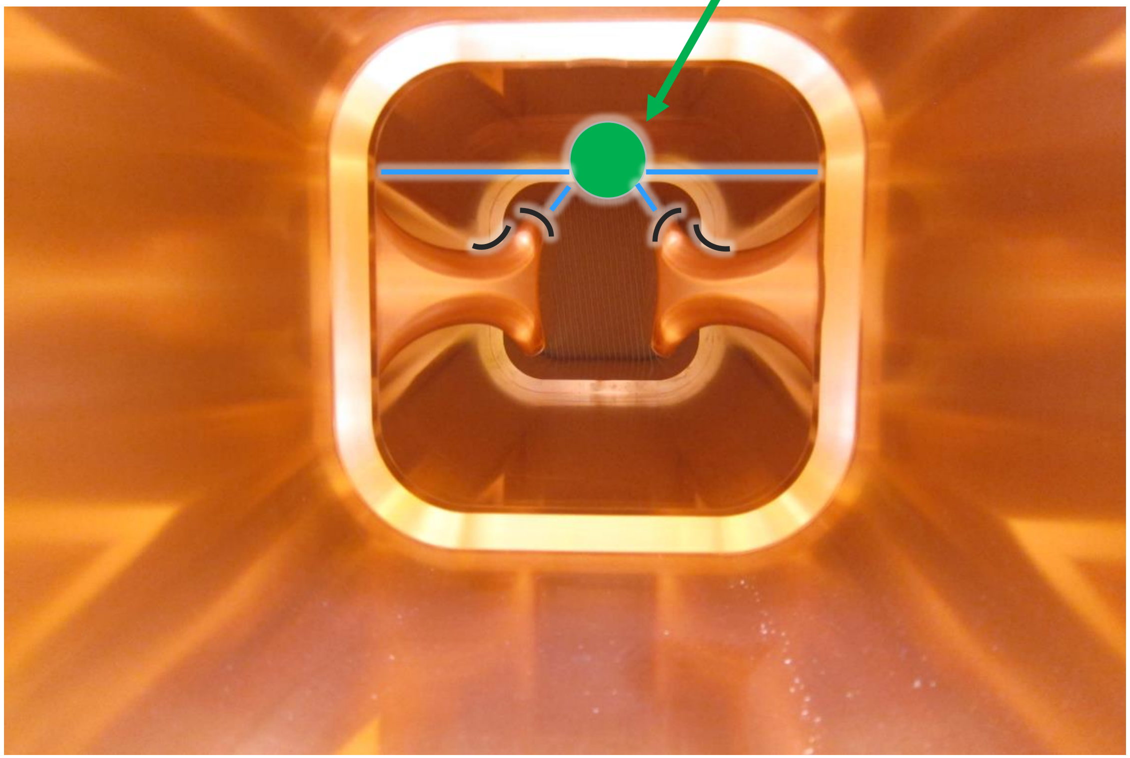

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From R&D to scale-1 cavity

1. Basic tests in a R&D experimental setup:

- Basic plasma physics in HiPIMS
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- Parallel implementation of plasma diagnostics
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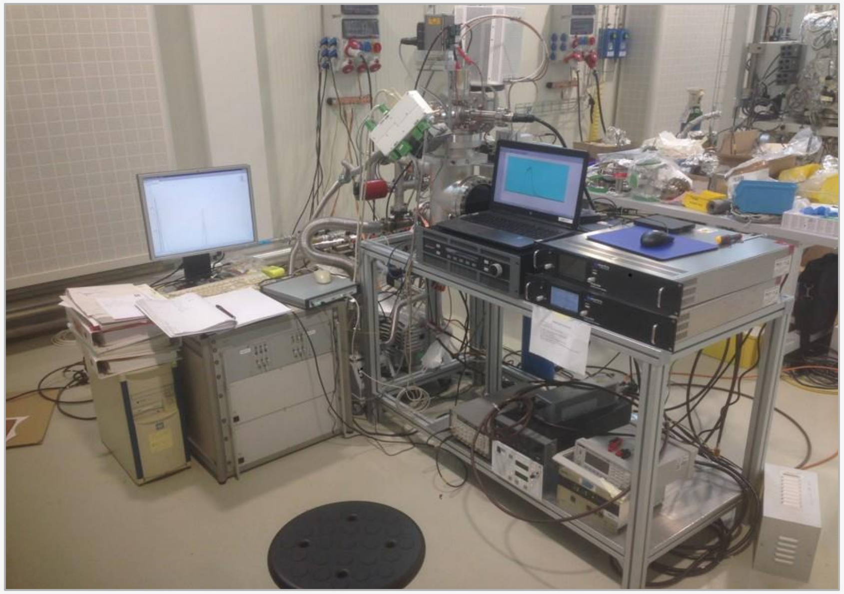
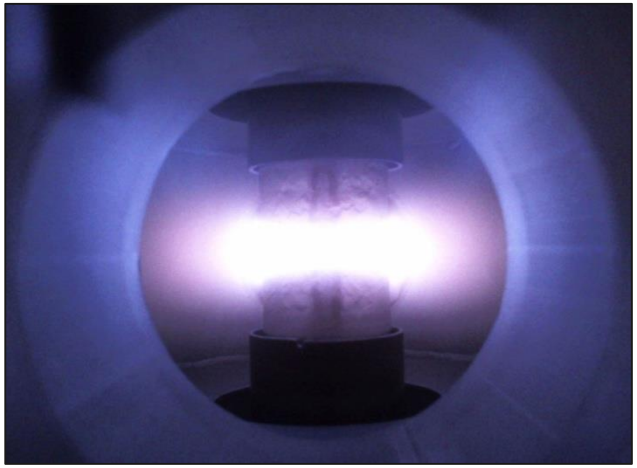


Plasma simulation of 60 mm long cylindrical cathode

Experiment
P = 5.10^{-3} mbar / Ar / 1kW / DCMS

60 mm cathode



Side view of the cylndrical cathode (permanent magnet inside)

Plasma simulation of 60 mm long cylindrical cathode

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Plasma simulation
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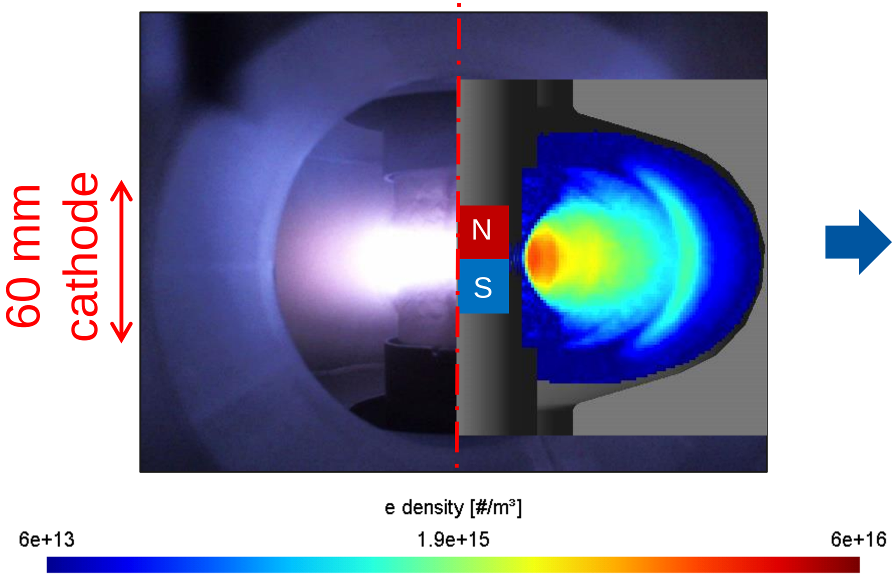
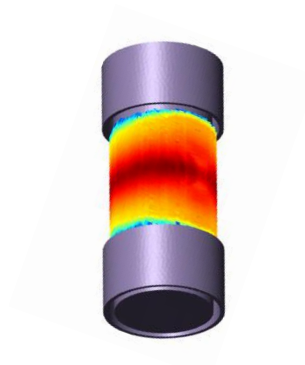
Output: Nb sputtering profile





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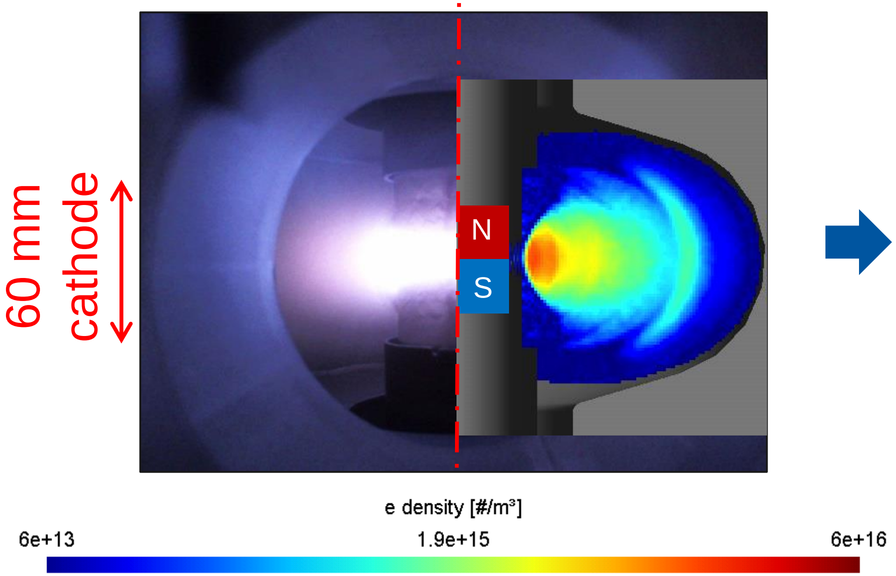

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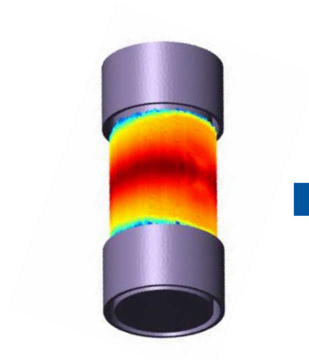
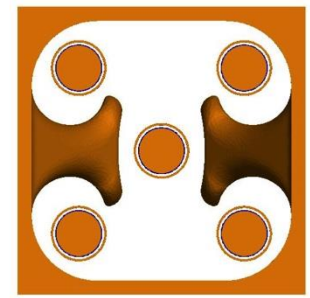
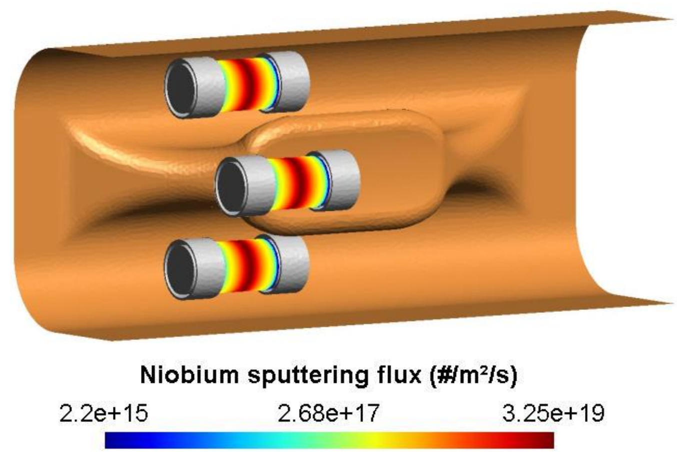
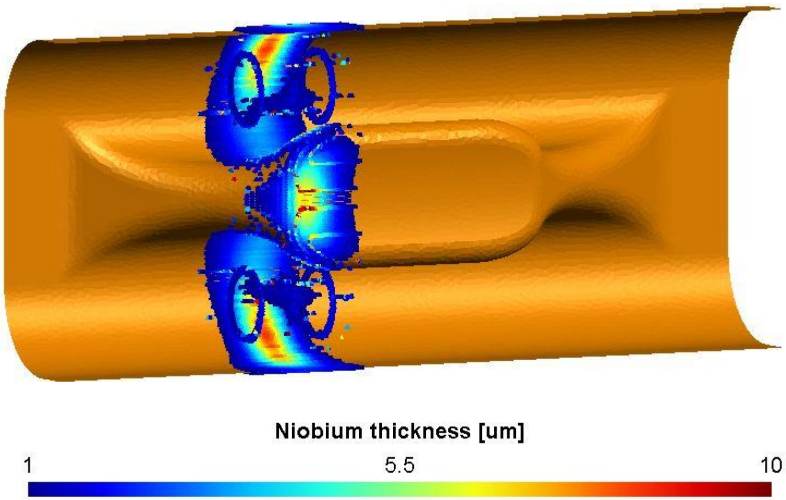


x5 cathodes in WOW





Transport simulation and thickness profile



→ Nb thickness profile, scaled to an equivalent 15’ coating at 1kW/cathode

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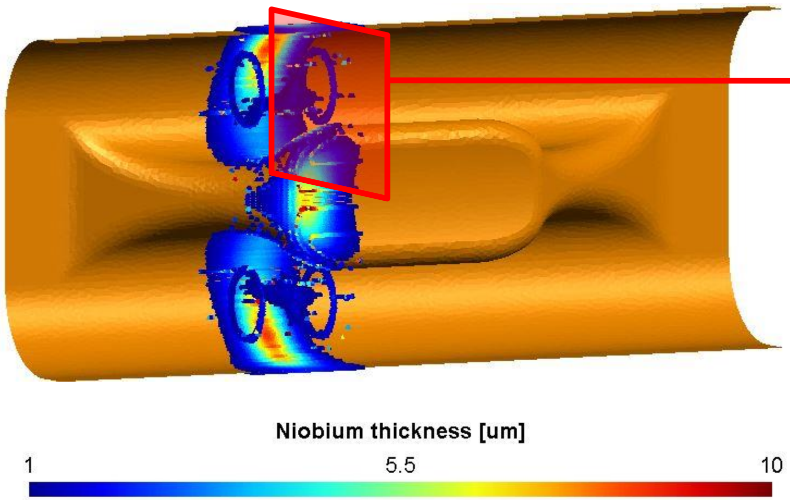

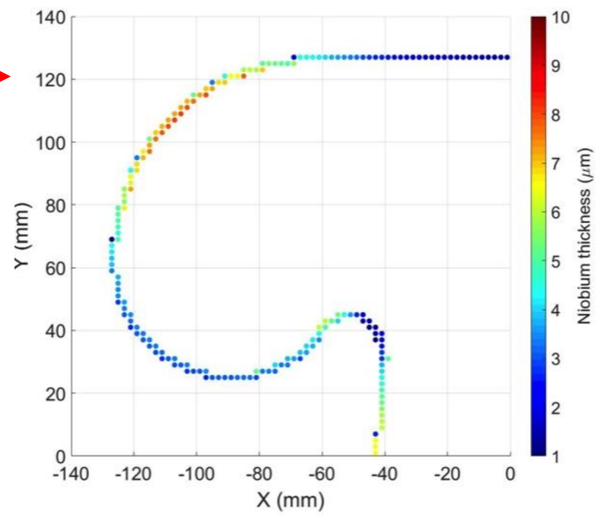

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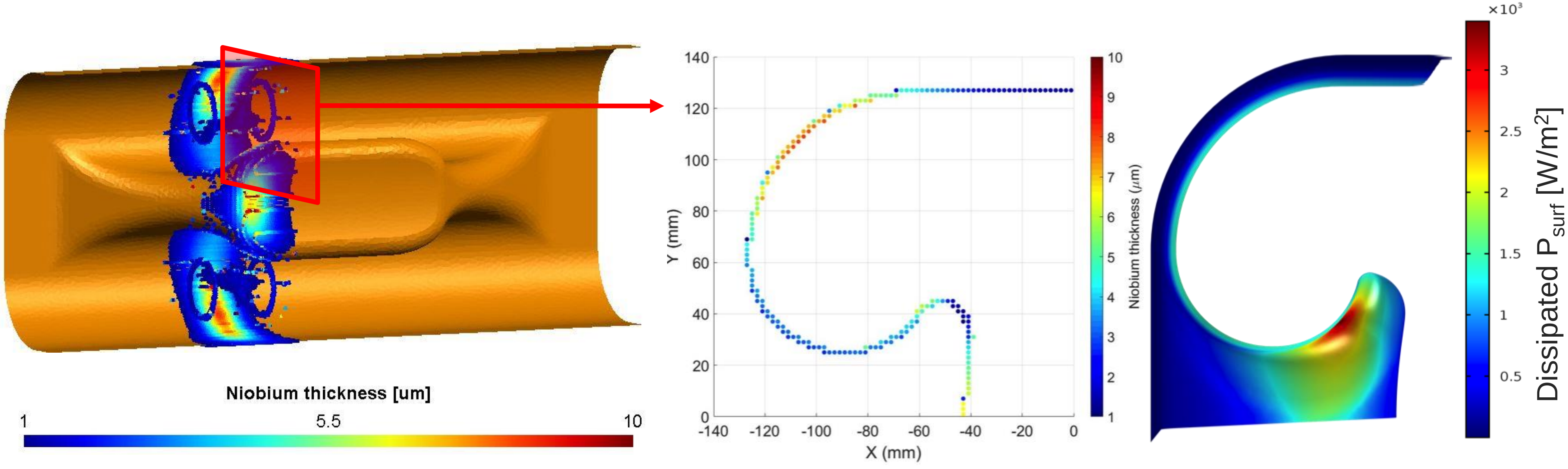

→ Nb thickness profile, scaled to an equivalent 15' coating at 1kW/cathode

→ Uniformity copes with peak power density position → layer morphology?

Could HiPIMS ?

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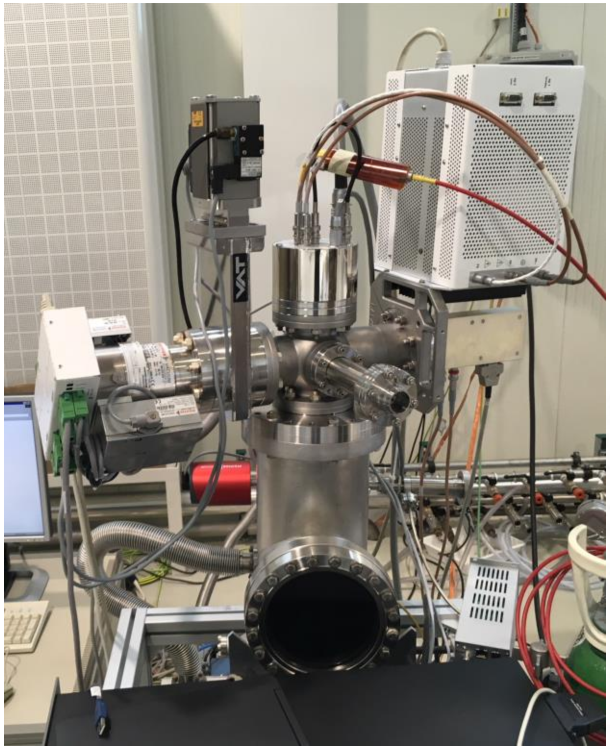
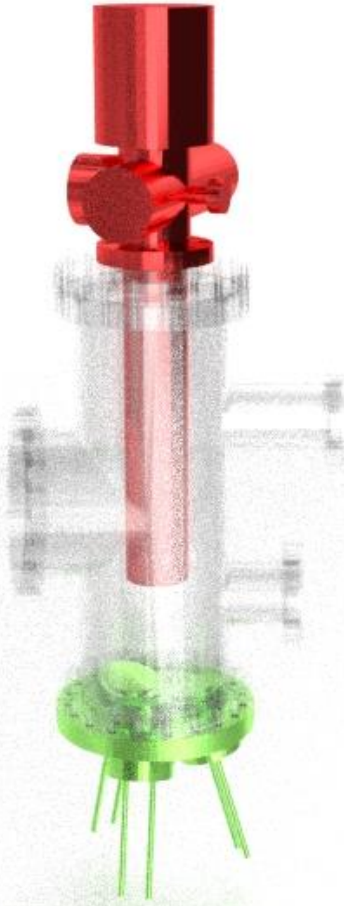
R&D experimental setup

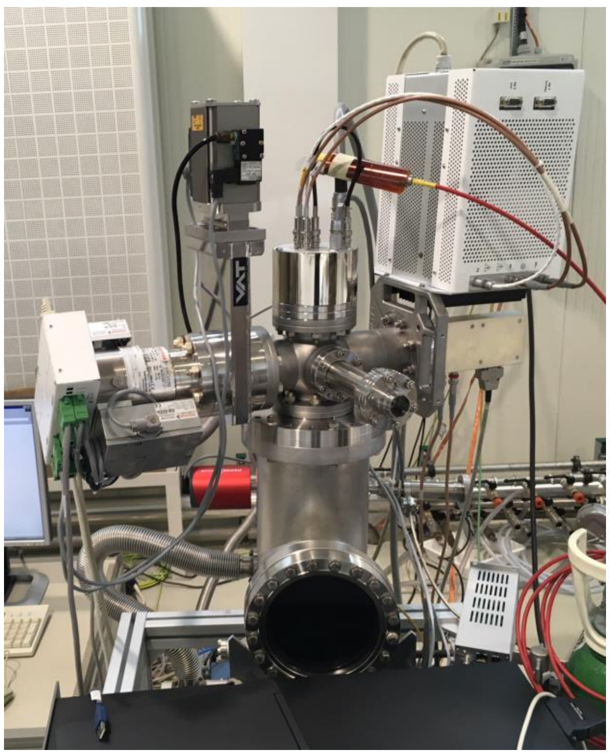
- 43 cm high DN150 vacuum chamber

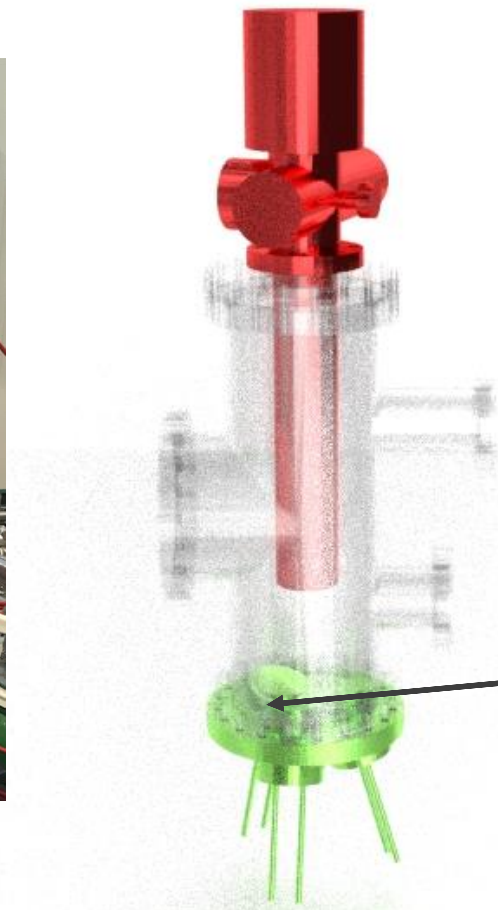


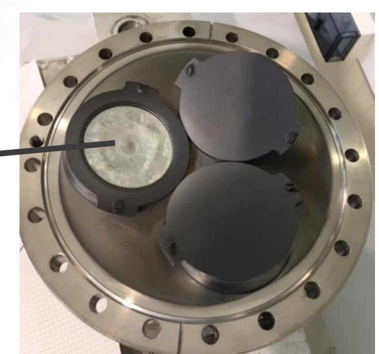


R&D experimental setup

- 43 cm high DN150 vacuum chamber
- 2'' magnetron source, 15° tilted



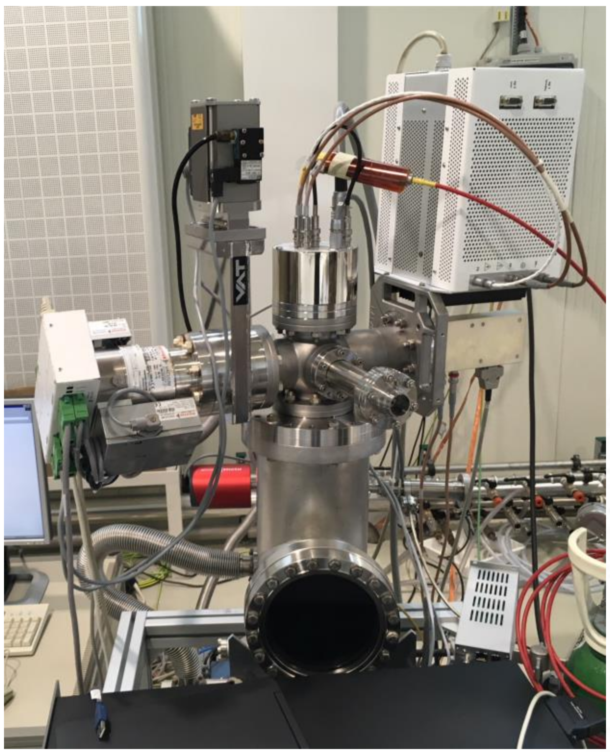


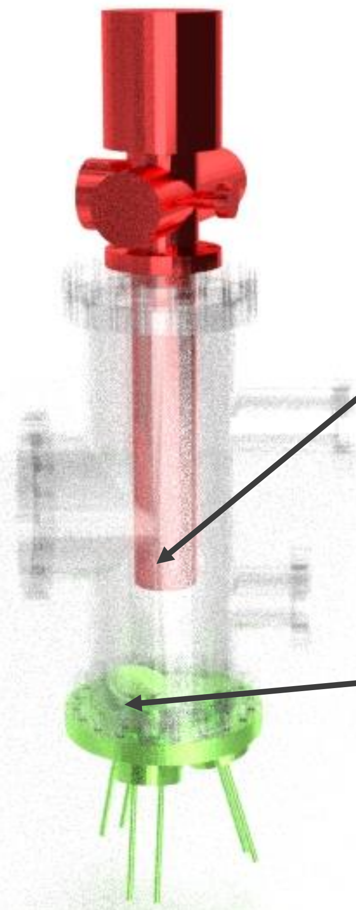


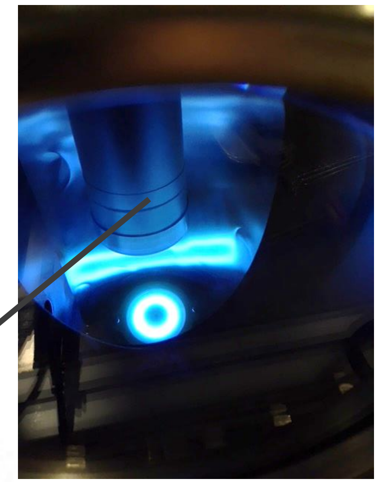
R&D experimental setup

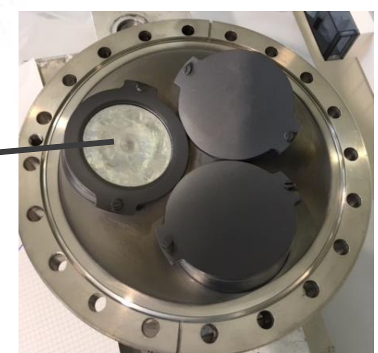
- 43 cm high DN150 vacuum chamber
- 2'' magnetron source, 15° tilted
- Mass and energy analyser (MEA):

  time integrated + time resolved measurements of ion fluxes



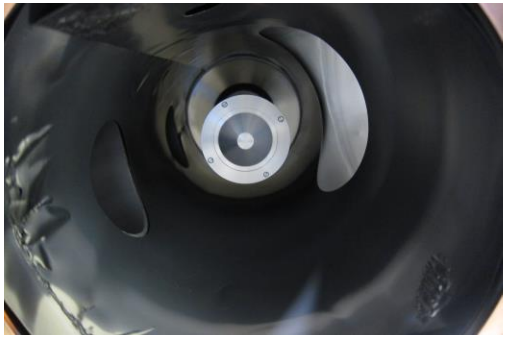






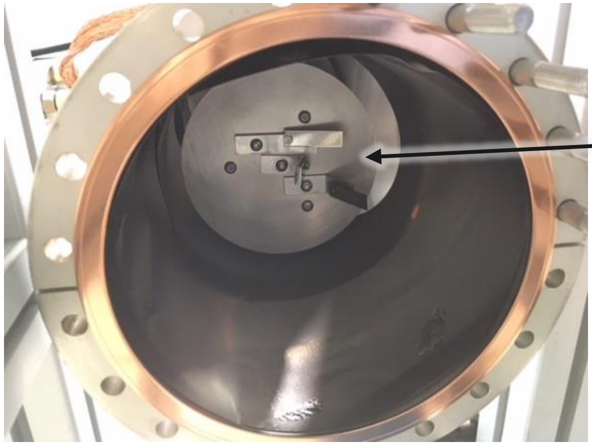
Samples and holder

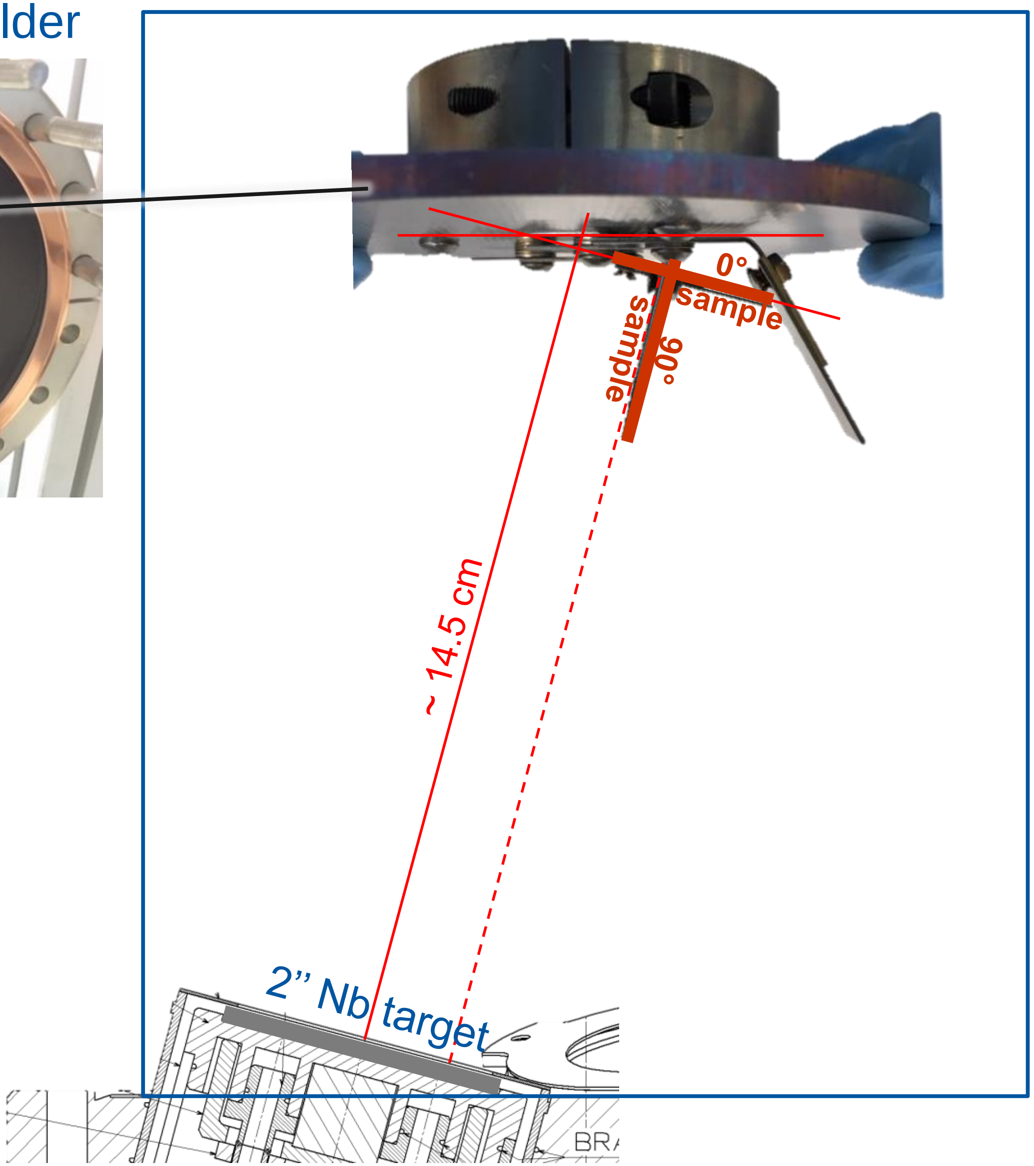
View from bottom of the MEA entrance orifice



Samples and holder

View from bottom with sample holder





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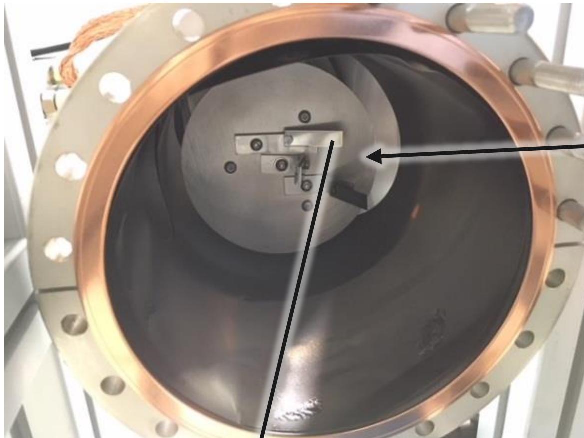
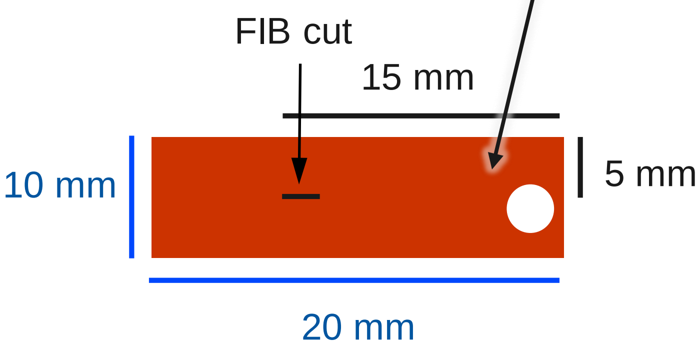
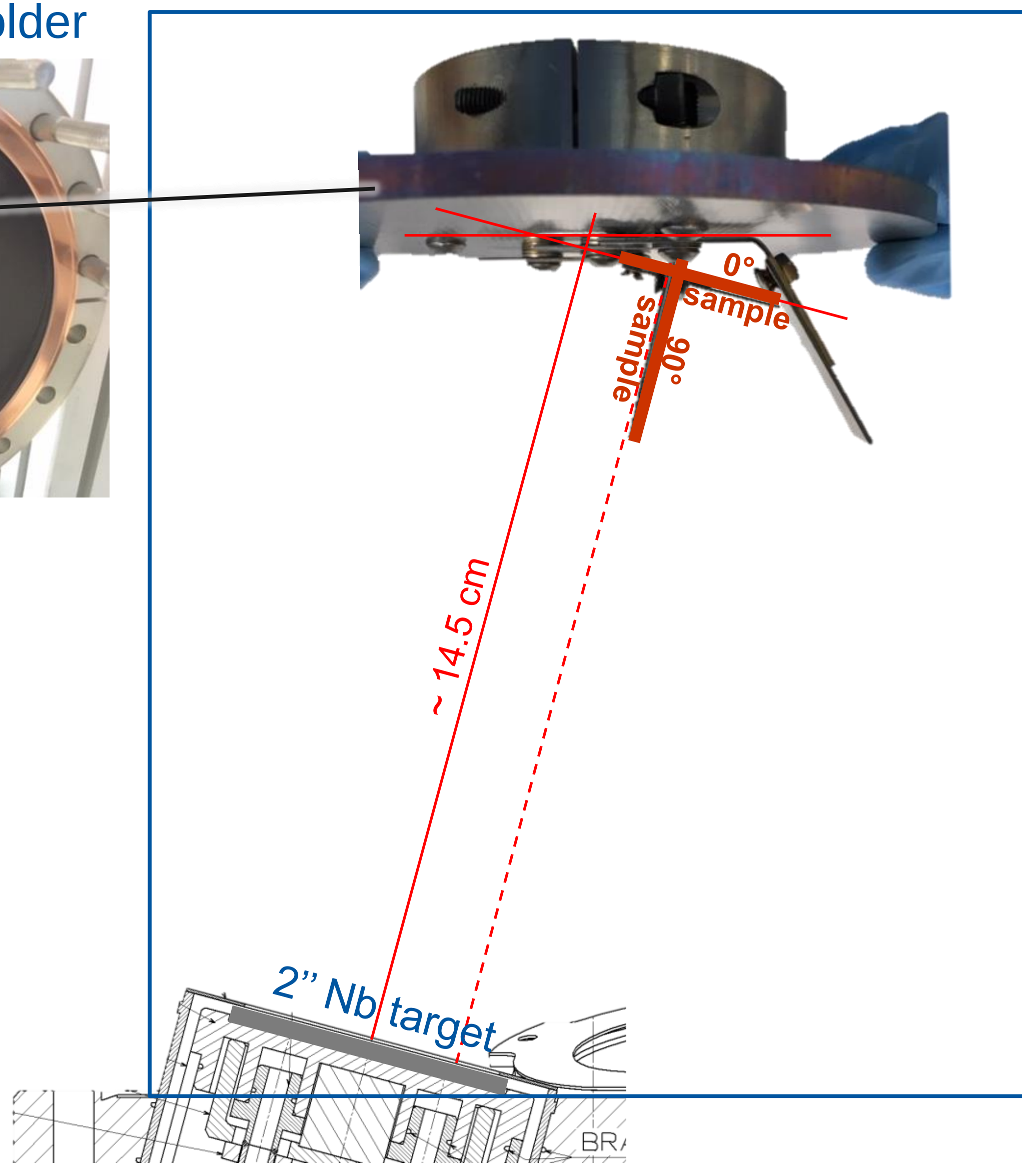
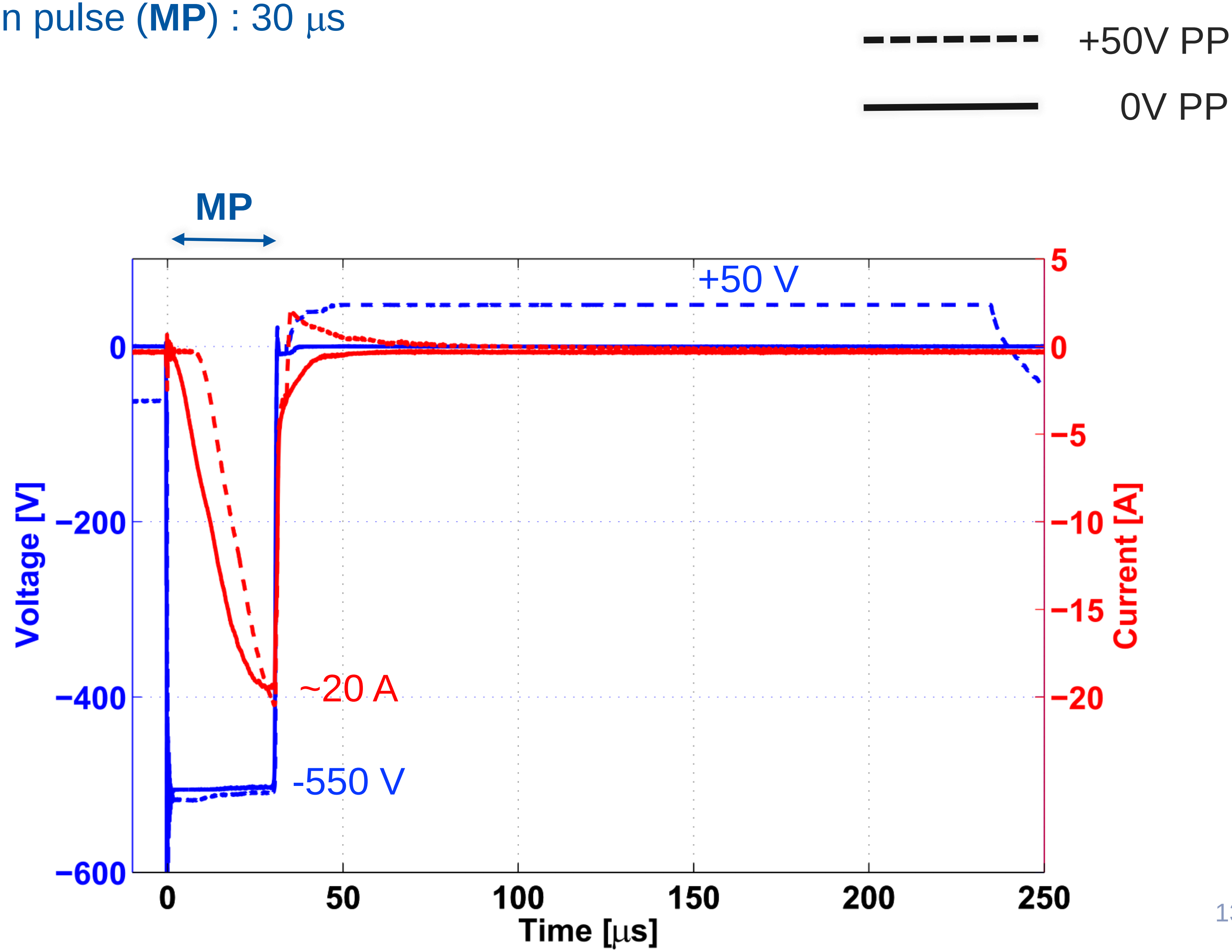






HiPIMS configurations

- Duty cycle : 1 kHz
- Main pulse (**MP**) : 30 μs



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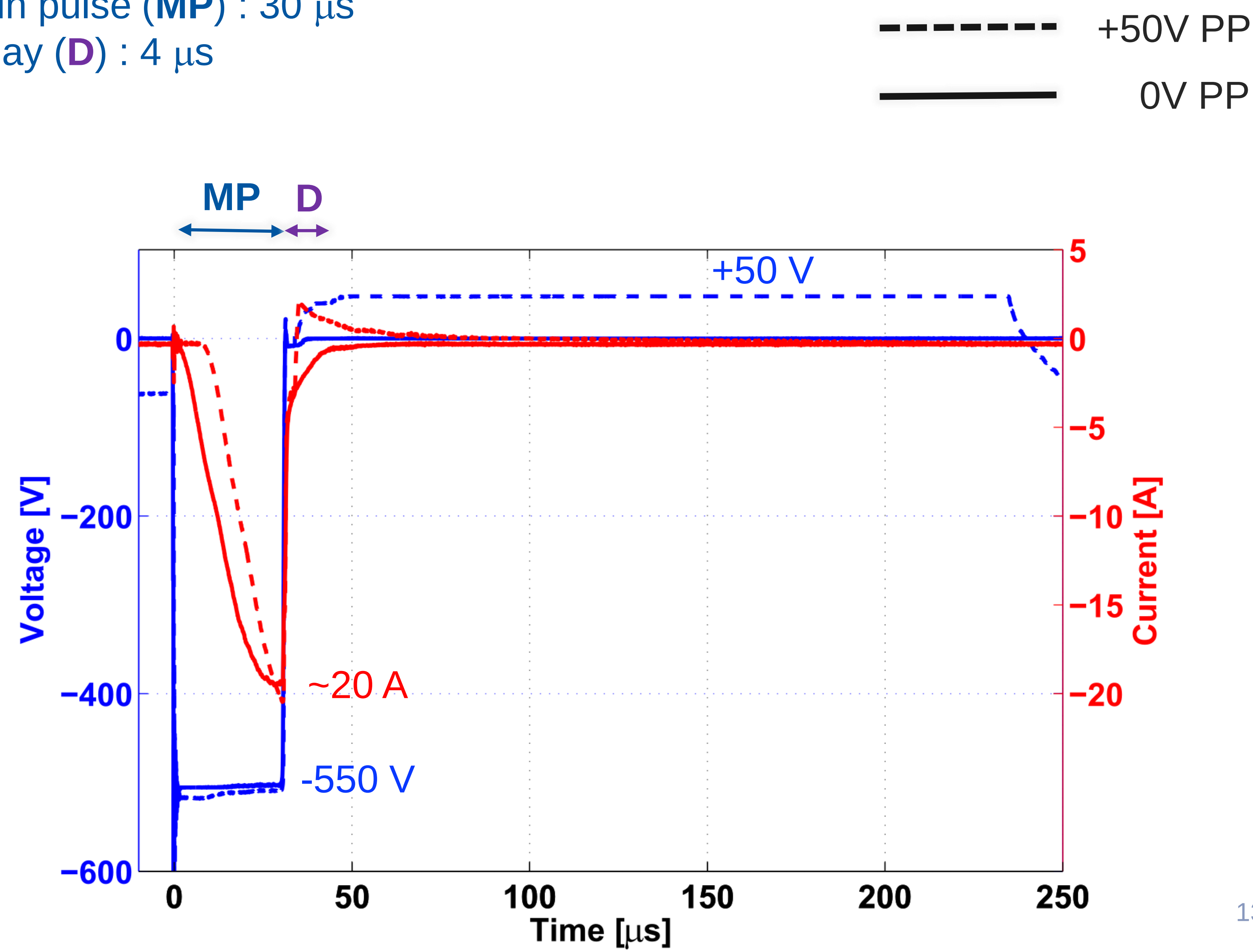
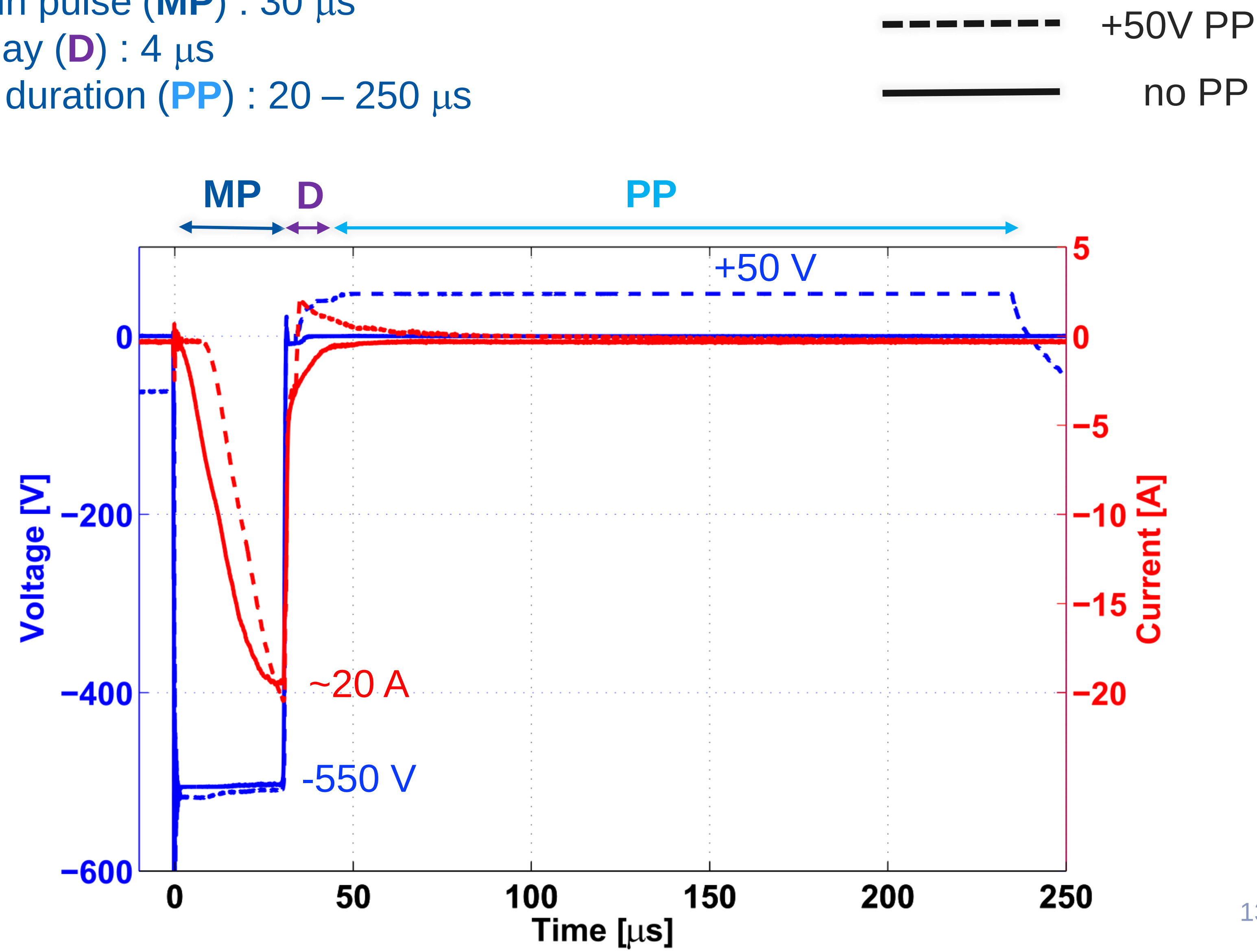
HiPIMS configurations

- Duty cycle : 1 kHz
- Main pulse (**MP**) : 30 μs
- Delay (**D**) : 4 μs



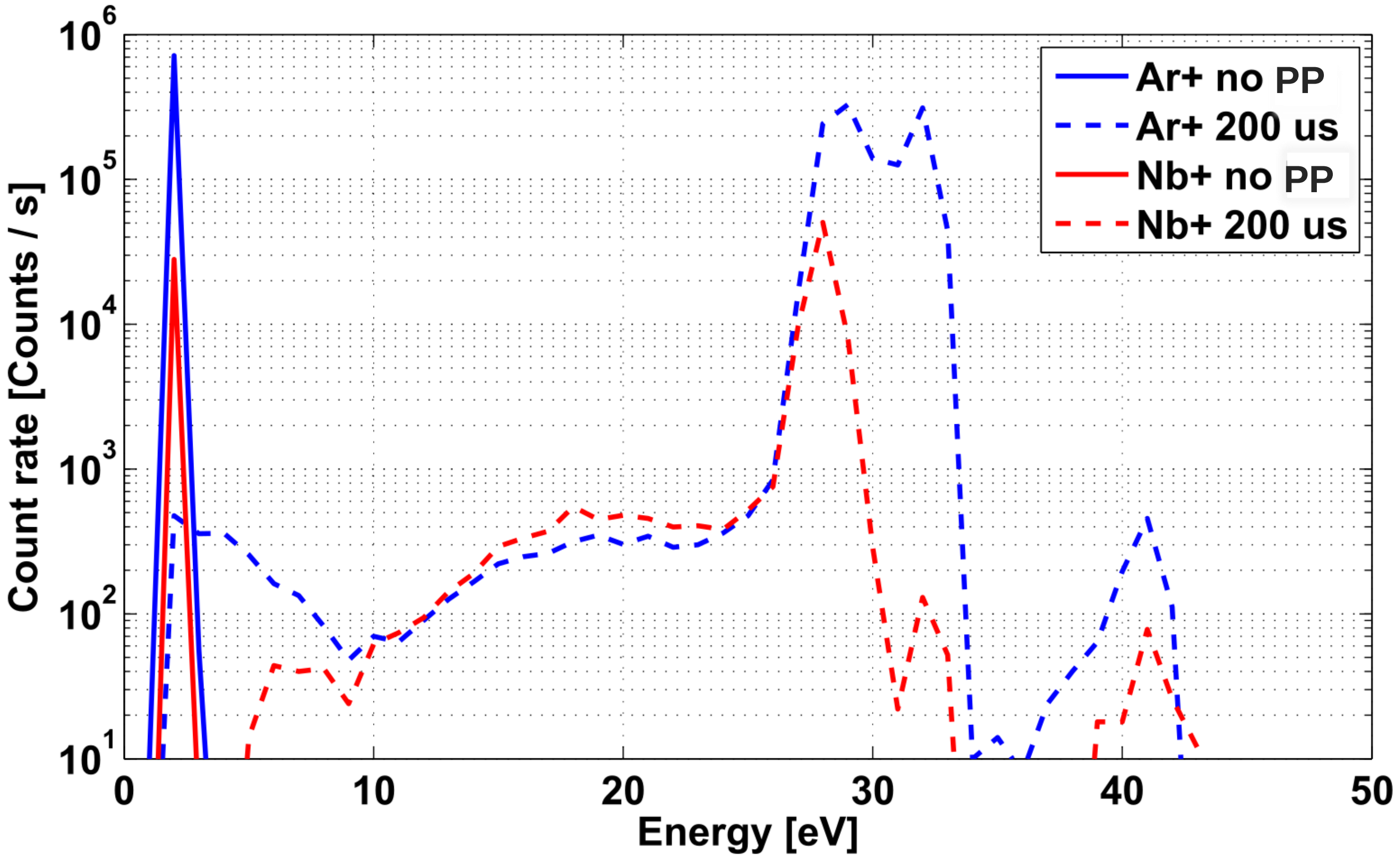
HiPIMS configurations

- Duty cycle : 1 kHz
- Main pulse (**MP**) : 30 μs
- Delay (**D**) : 4 μs
- PP duration (**PP**) : 20 – 250 μs



Time-integrated IEDF

By using the MEA



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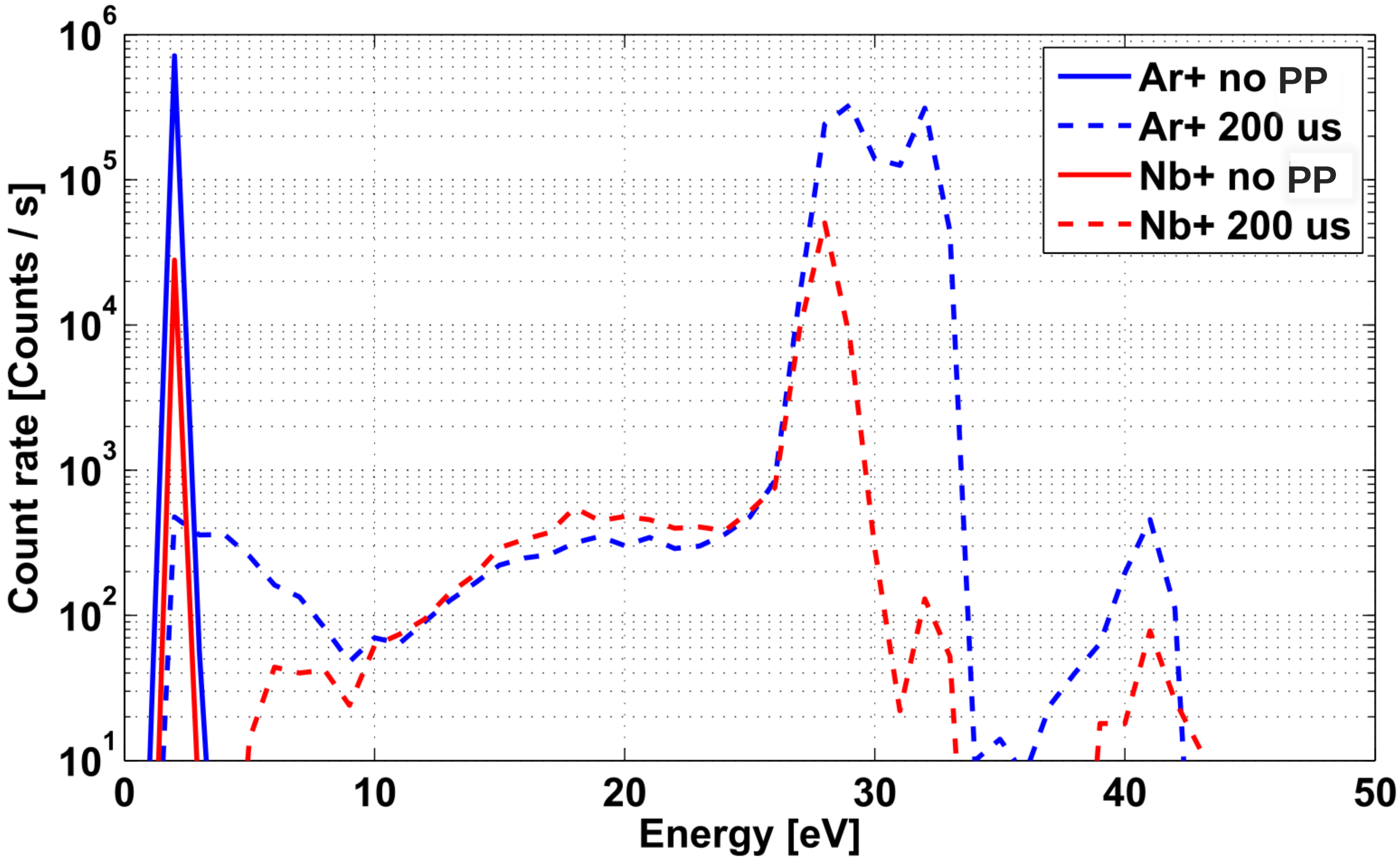


Evidence of a dominant high energy ion population!

FIB on DCMS coatings

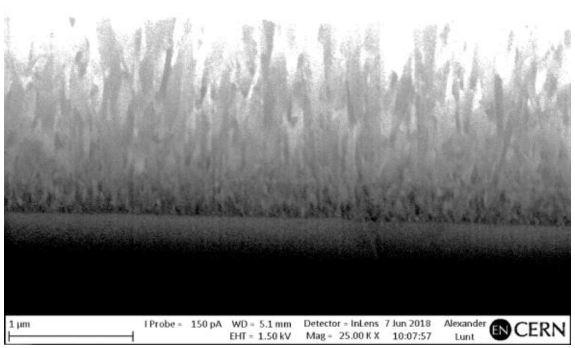
Experimental parameters:

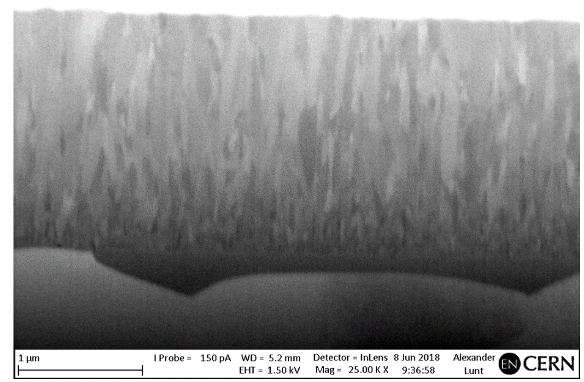
- Argon pressure : $8x10^{-3}$ mbar
- Niobium target
- Power : 250 W (1.5 hours)

DCMS with grounded substrate

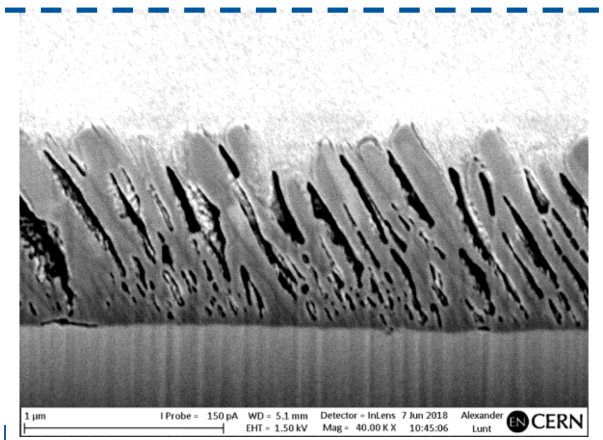
DCMS with -50V bias on substrate

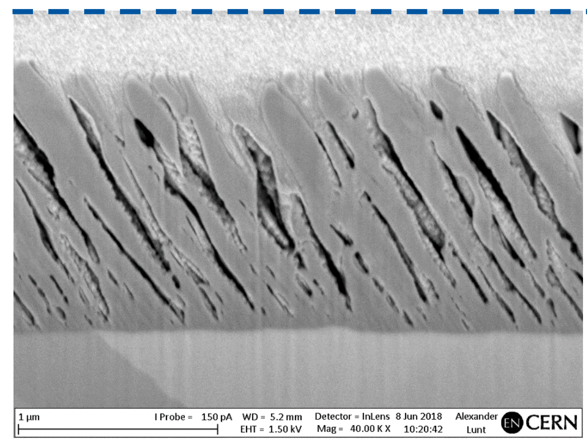
0°





90°

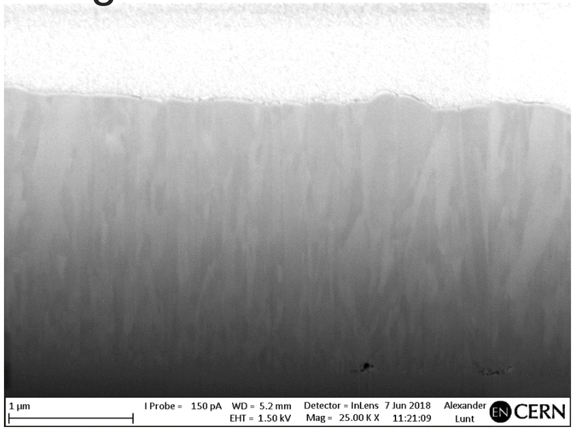




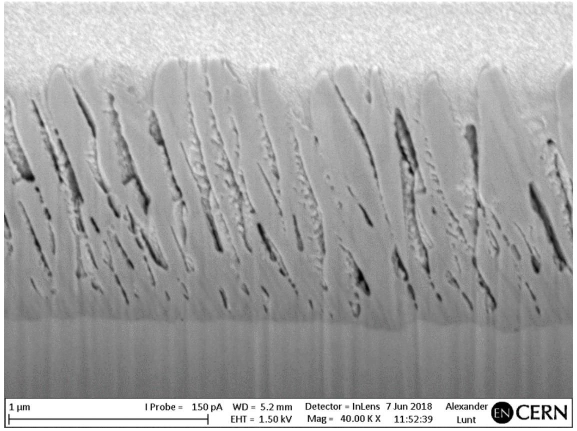
FIB on HiPIMS coatings

a) HiPIMS, no PP, grounded substrate

0°



90°

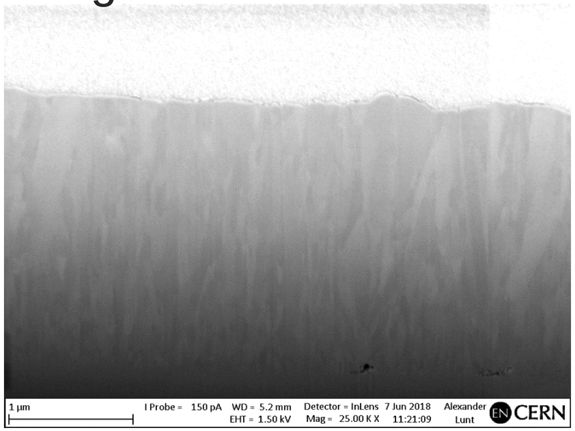


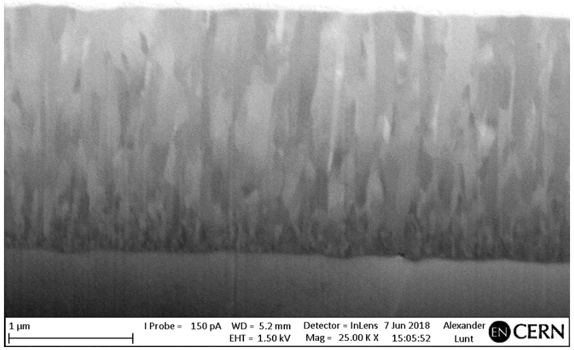
FIB on HiPIMS coatings

a) HiPIMS, no PP, grounded substrate

b) HiPIMS, no PP, -50 V bias on substrate

0°





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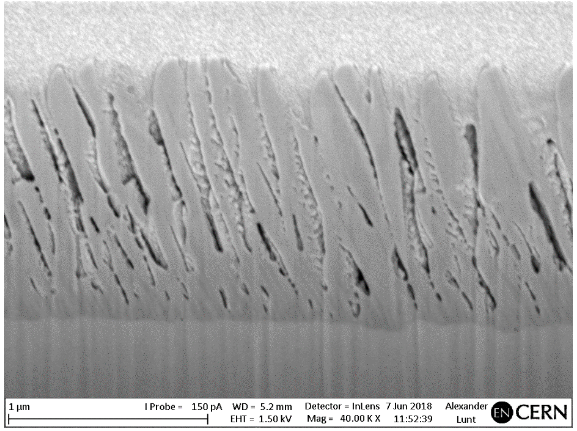
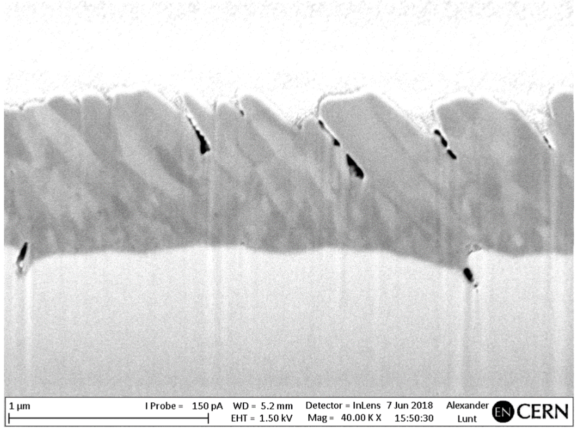




FIB on HiPIMS coatings

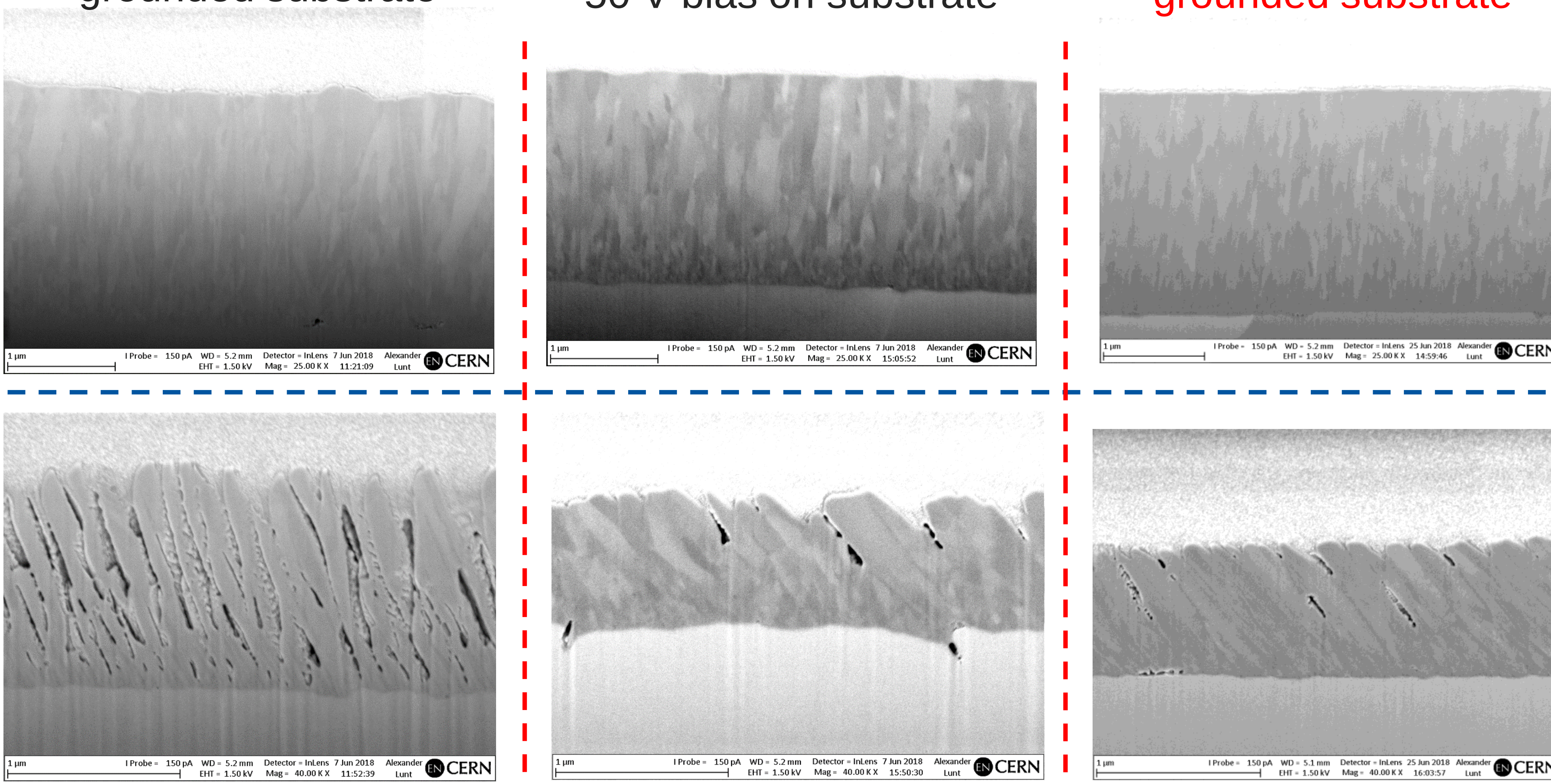
a) HiPIMS, no PP, grounded substrate

b) HiPIMS, no PP, -50 V bias on substrate

c) HiPIMS, +50 V PP, grounded substrate

0°

90°



<u>Biased-like effect with a positive pulse!</u>

90° sample gets densified with 200 μs positive pulse at +50V

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- Parallel implementation of plasma diagnostics
- New sputtering source development

3. Coating of the first scale-1 cavity prototype

From R&D to scale-1 cavity

1. Basic tests in a R&D experimental setup:

- Basic plasma physics in HiPIMS
- Optimization of HiPIMS parameters

2. Coating of samples reproducing cavity shape

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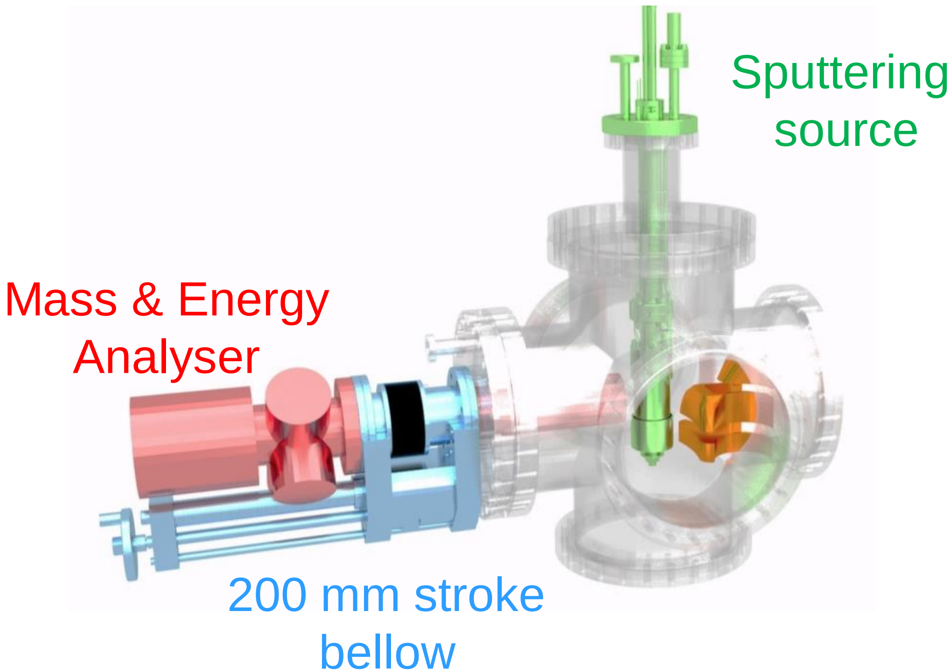
3. Coating of the first scale-1 cavity prototype

Validation of coating setup with **mockup** samples



→ Time- and spatially-resolved (substrate-cathode distance) IEDF measurements
→ Deposition on samples reproducing the CRAB cavity shape
→ Assess layer uniformity and SC properties with different coating configurations

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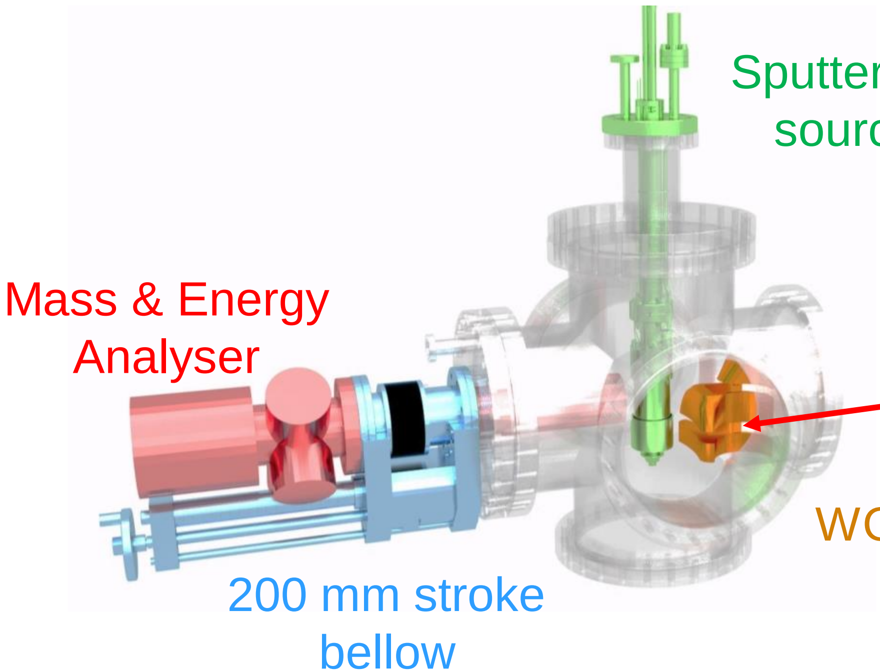

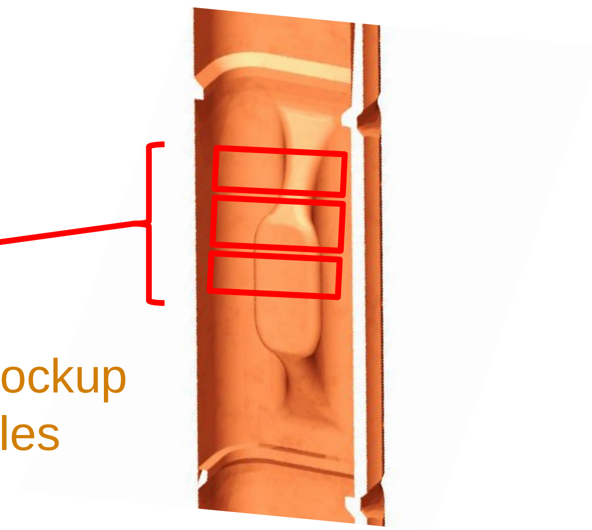

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Conclusions

- First indication of coating uniformity with simulations in DCMS

- Measured mass-, energy-resolved ion fluxes (Ar^+, Nb^+)
  <u>Evidence of a dominant high energy ion population with positive pulse</u>

Conclusions

- First indication of coating uniformity with simulations in DCMS

- Measured mass-, energy-resolved ion fluxes (Ar^+, Nb^+)
  Evidence of a dominant high energy ion population with positive pulse

- Performed sample coatings in different HiPIMS configurations:
  FIB analysis indicates a biased-like effect with a positive pulse!
  90° sample gets densified with 200 μs, +50V positive pulse

Backup Slides

Process	Sample	XRF [μm]	FIB [μm]	Dr [nm/min]
DCMS (1.5 h / 250W)	0°	1.5	1.6	17.8
	90°	0.5	1	11.1
DCMS and -50V bias on samples (1.5h / 250W)	0°	1.9	1.93	21.4
	90°	0.6	1.3	5.4
HiPIMS 30 μs pulse (4h / 250W)	0°	2.1	2.1	8.8
	90°	0.7	1.3	5.4
HiPIMS 30 μs pulse and -50 V bias on samples (4h / 250W)	0°	2	2	8.3
	90°	0.7	0.8	3.3
HiPIMS 38 μs pulse and +50V / 200 μs reverse kick (4h / 250W)	0°	2	2.2	9.2
	90°	0.67	0.8	3.3

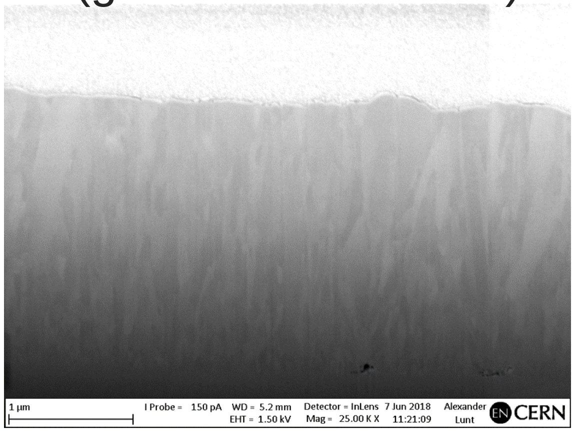
FIB on HiPIMS coatings

a) HiPIMS (grounded substrate)

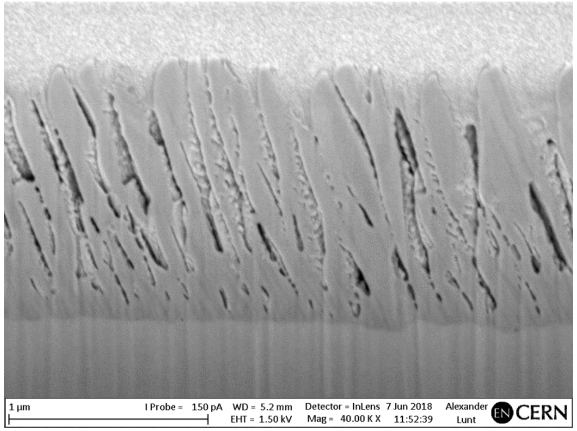
b) HiPIMS with -50 V bias on substrate

c) HiPIMS with +100 V positive pulse (grounded substrate)

0°



90°



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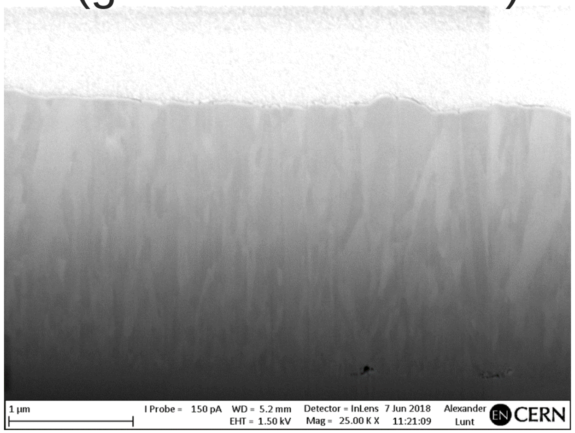

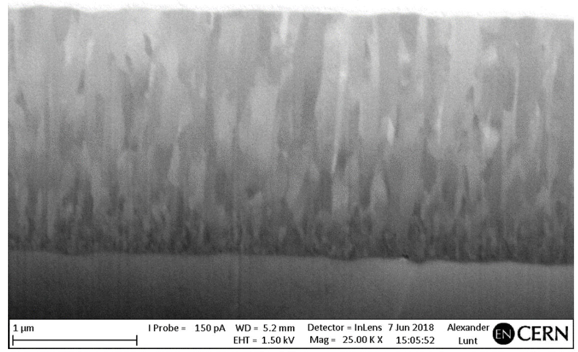

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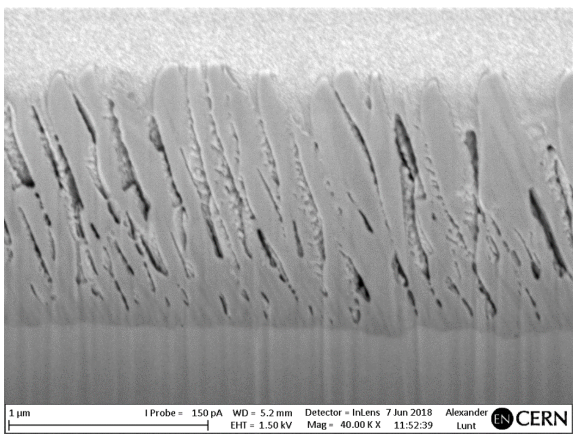

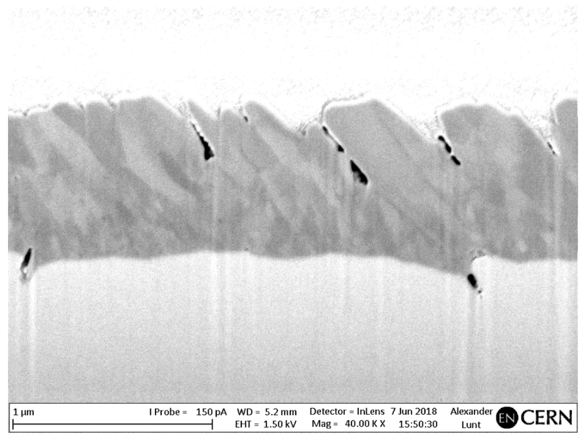

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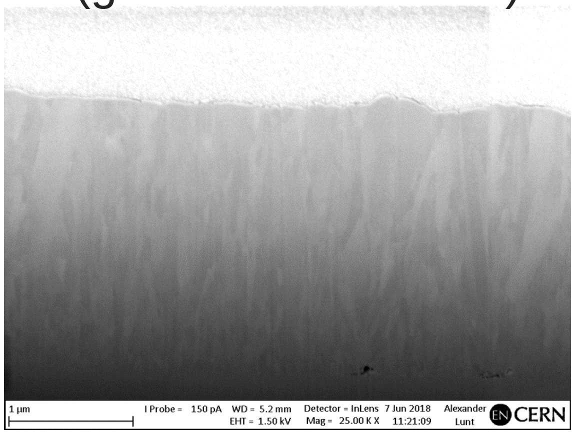
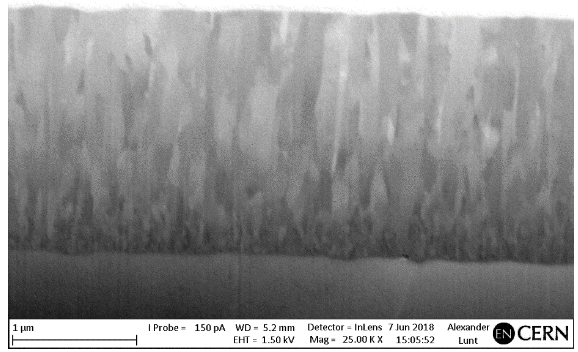
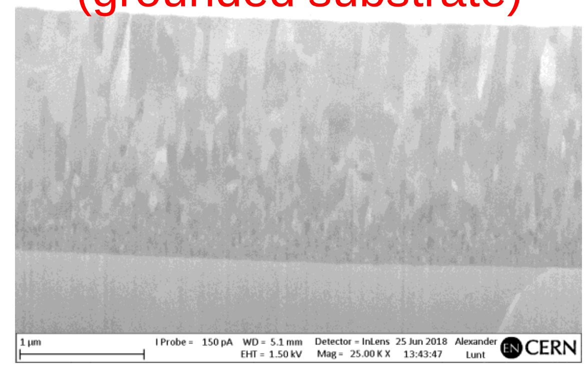
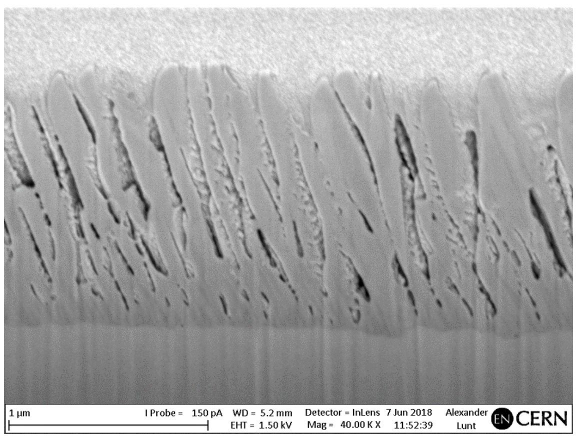
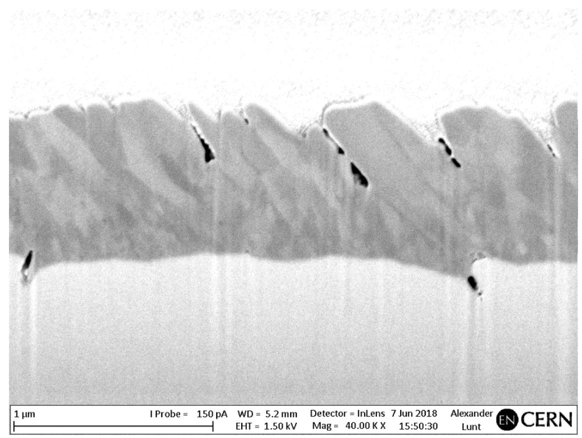


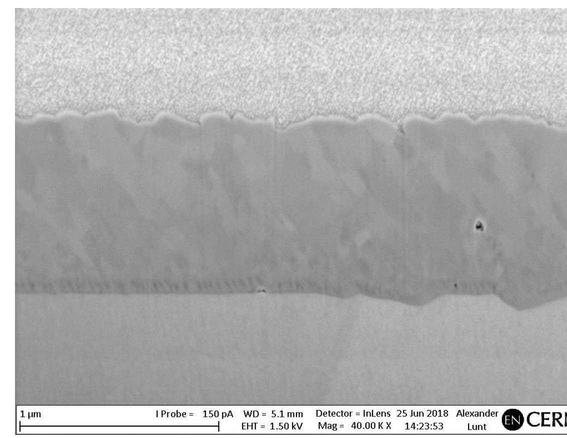




90°



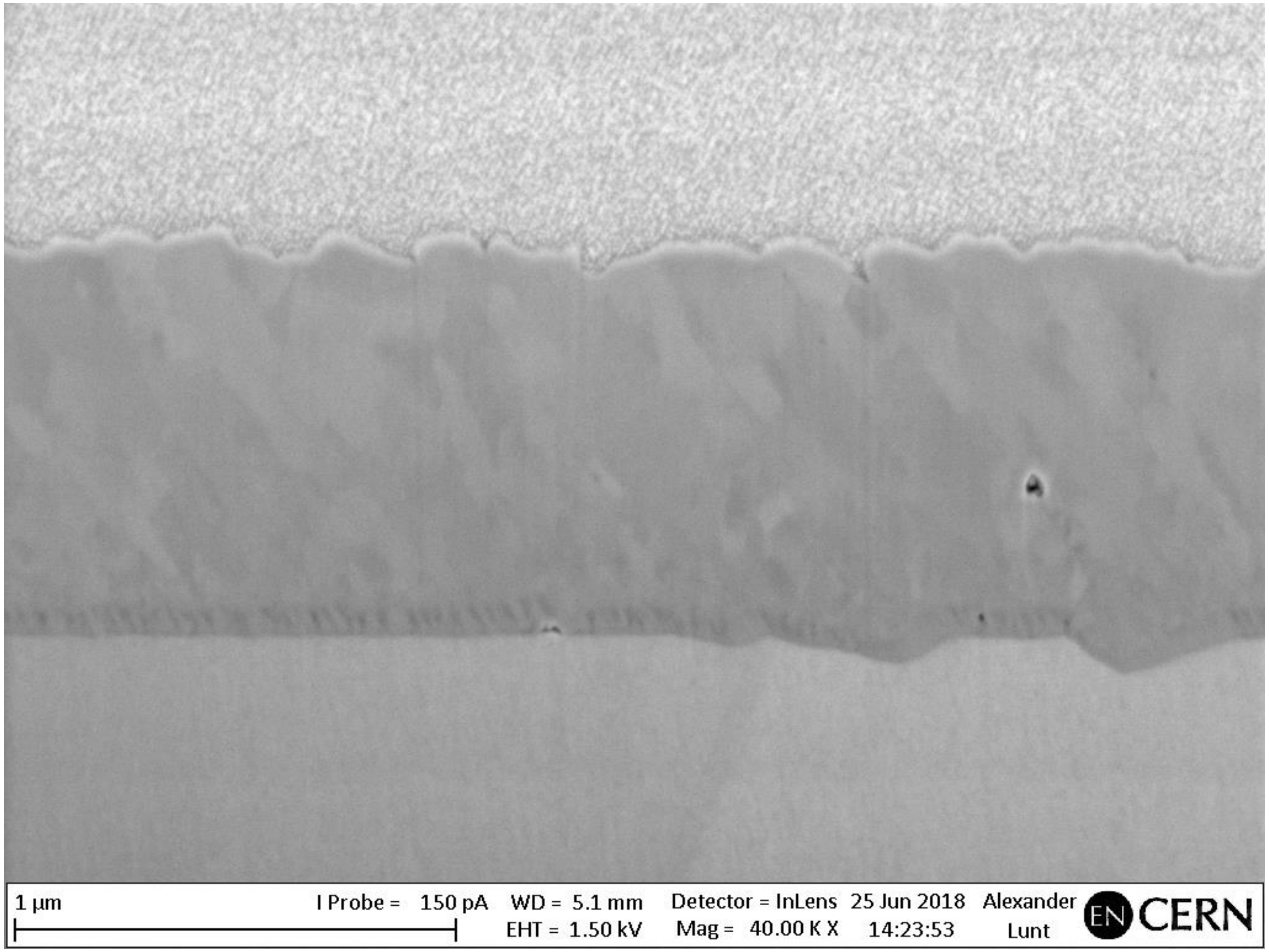




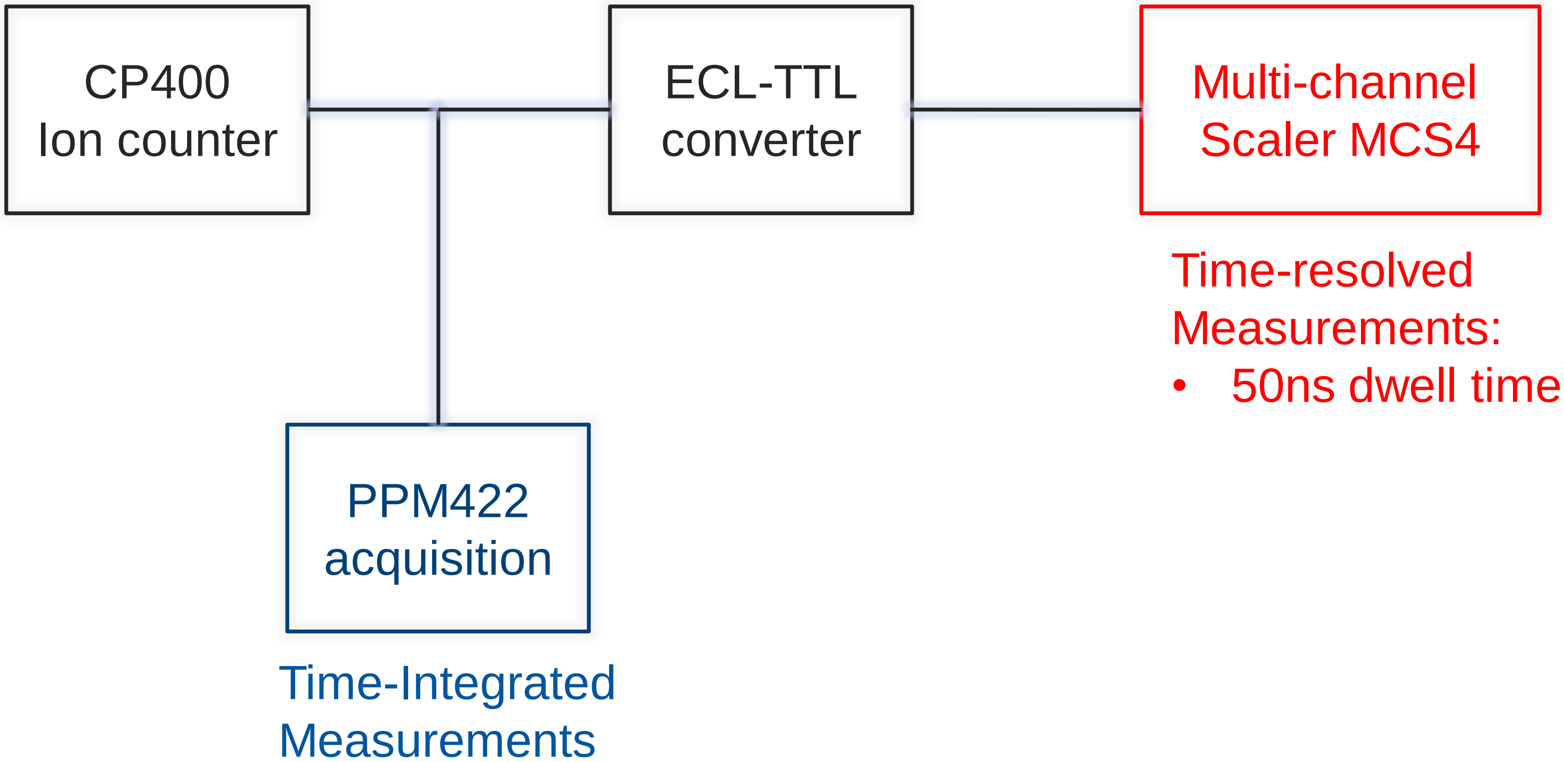
<u>Biased-like effect with a positive pulse!</u>

90° sample gets densified with 200 μs, +100V positive pulse

30us MP – 4us D – 200us RK 100V



How to measure time-resolved ion fluxes



Time-resolved Ar^+ fluxes