*LNF Scientific Committee*
*Frascati*

# *SPARC_LAB activity report*

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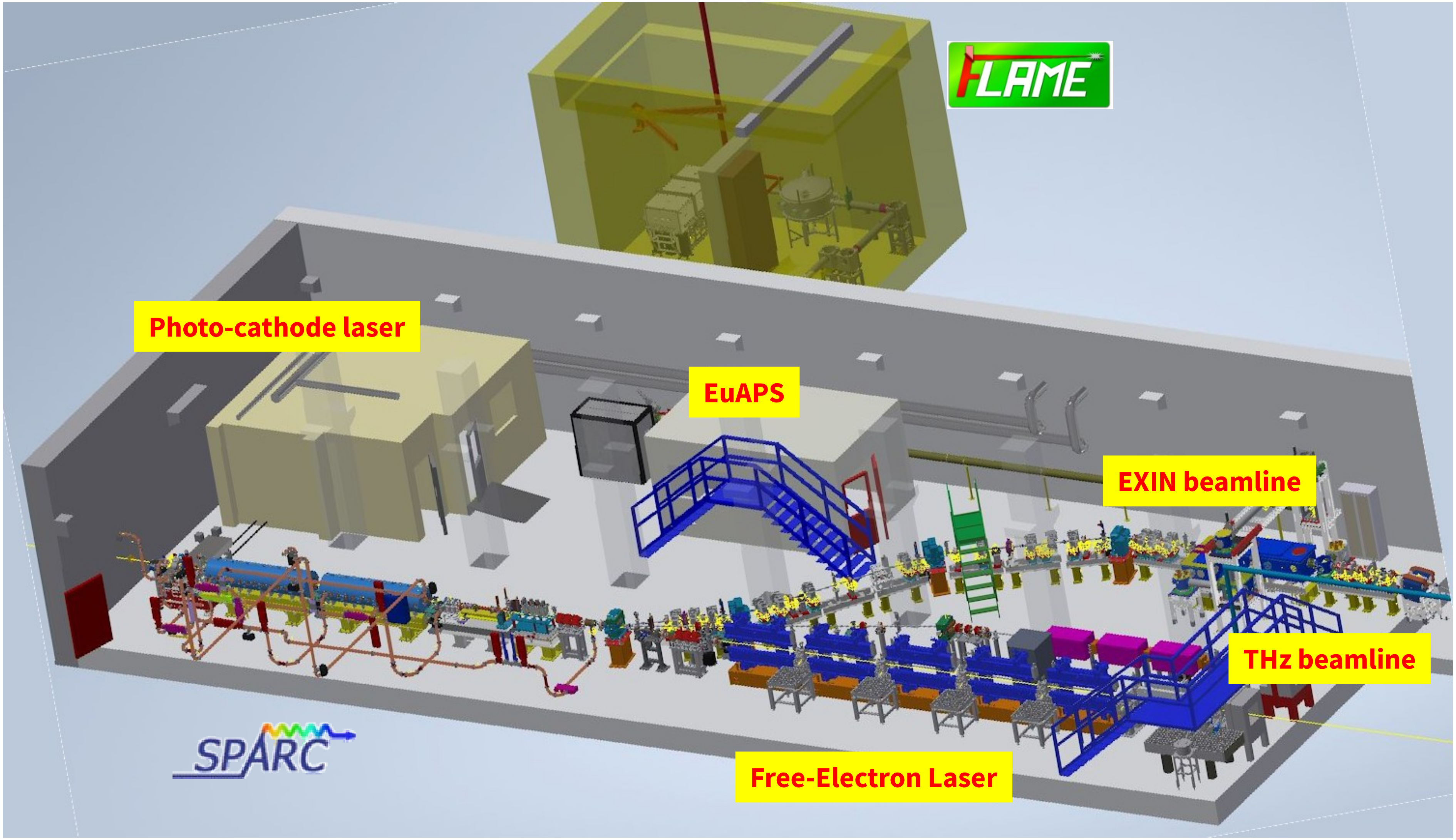
*On behalf of the SPARC_LAB collaboration*

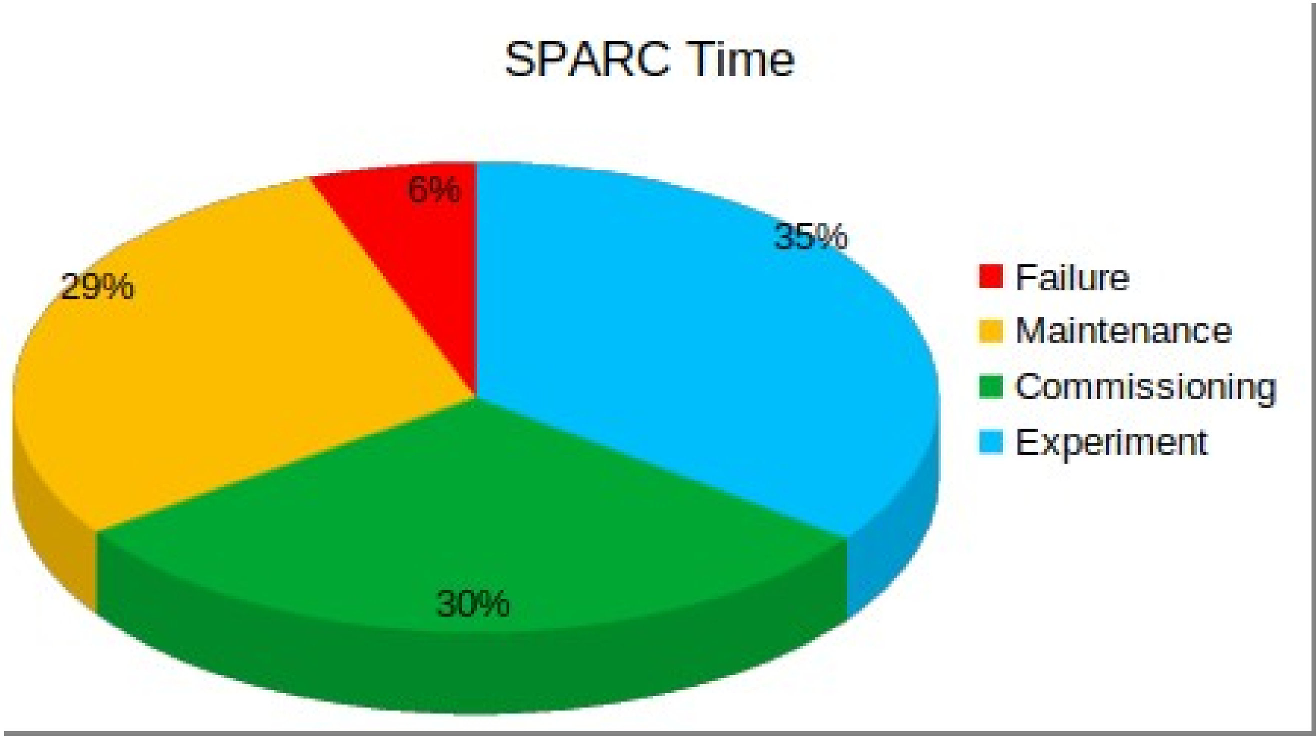
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

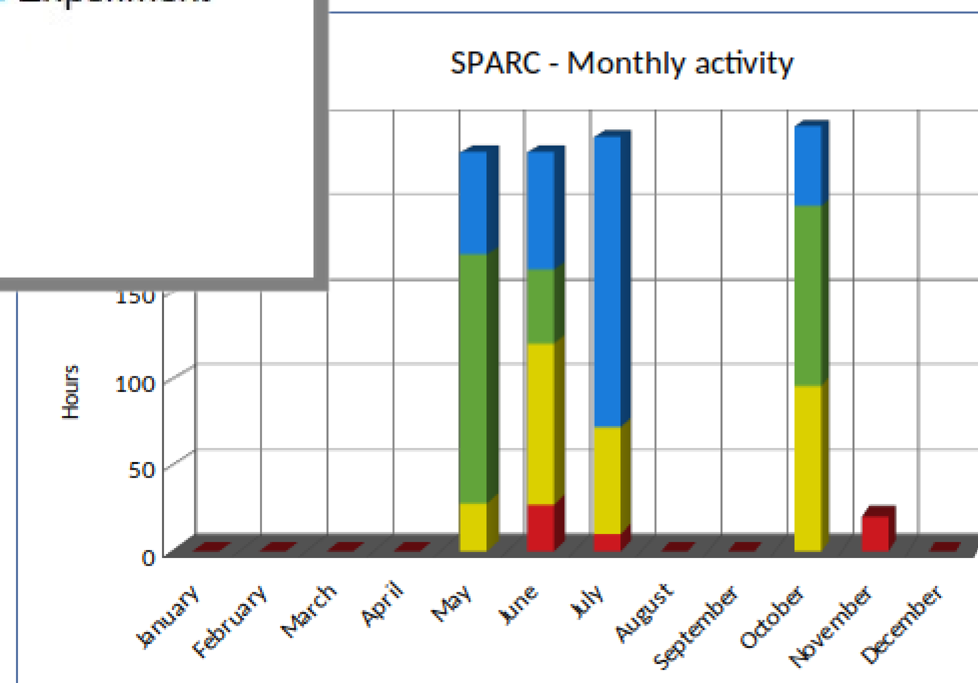



Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.

# SPARC up time (2023)





# Recommendations from previous SC

- *Implement the plans on solid state modulators as soon as possible, so that EuPRAXIA@SPARCLAB can still profit from the SPARC_LAB experience.*
- *Keep an eye on priority for activities which support the strategic goals of EuPRAXIA@SPARCLAB*
- *Follow both paths for focusing into the plasma, i.e. plasma lens and permanent magnet quadrupoles to assure that at least one is successful.*

  - *The purchase process of two solid-state modulators has begun few weeks ago. We know it'll take approximately a year for its completion. For the final installation a detailed plan must be foreseen since it'll strongly impact the SPARC activities*

# Recommendations from previous SC

- *Implement the plans on solid state modulators as soon as possible, so that EuPRAXIA@SPARCLAB can still profit from the SPARC_LAB experience.*
- *Keep an eye on priority for activities which support the strategic goals of EuPRAXIA@SPARCLAB*
- *Follow both paths for focusing into the plasma, i.e. plasma lens and permanent magnet quadrupoles to assure that at least one is successful.*

  - *The first step was to understand the availability for experiments we'll have next year due to the SABINA and EuAPS installations. A temporal window between May and November has been found that will allow us to plan the SPARC activities in the direction of EuPRAXIA*

# Recommendations from previous SC

- *Implement the plans on solid state modulators as soon as possible, so that EuPRAXIA@SPARCLAB can still profit from the SPARC_LAB experience.*
- *Keep an eye on priority for activities which support the strategic goals of EuPRAXIA@SPARCLAB*
- *Follow both paths for focusing into the plasma, i.e. plasma lens and permanent magnet quadrupoles to assure that at least one is successful.*
  - *The last experimental runs were exactly focused on this topic. We started to test the use of two active-plasma lenses in place of the two PMQ triplets and we got some preliminary results. These are shown in the next slides*

# *All-in-one capillary results*

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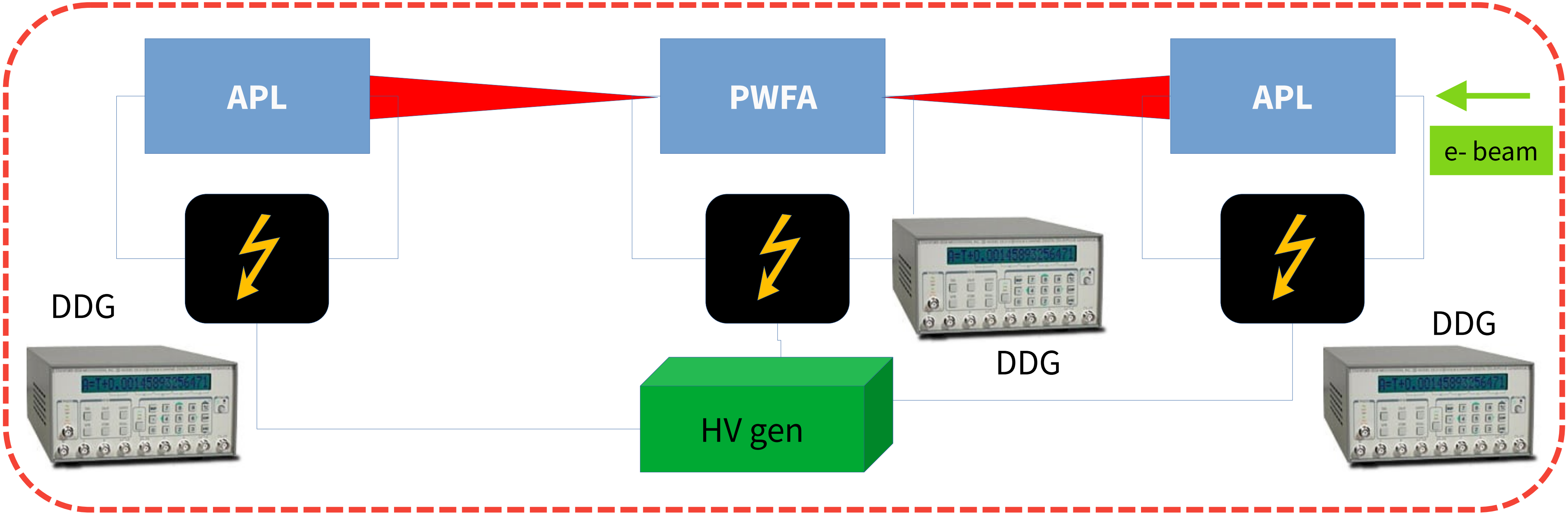
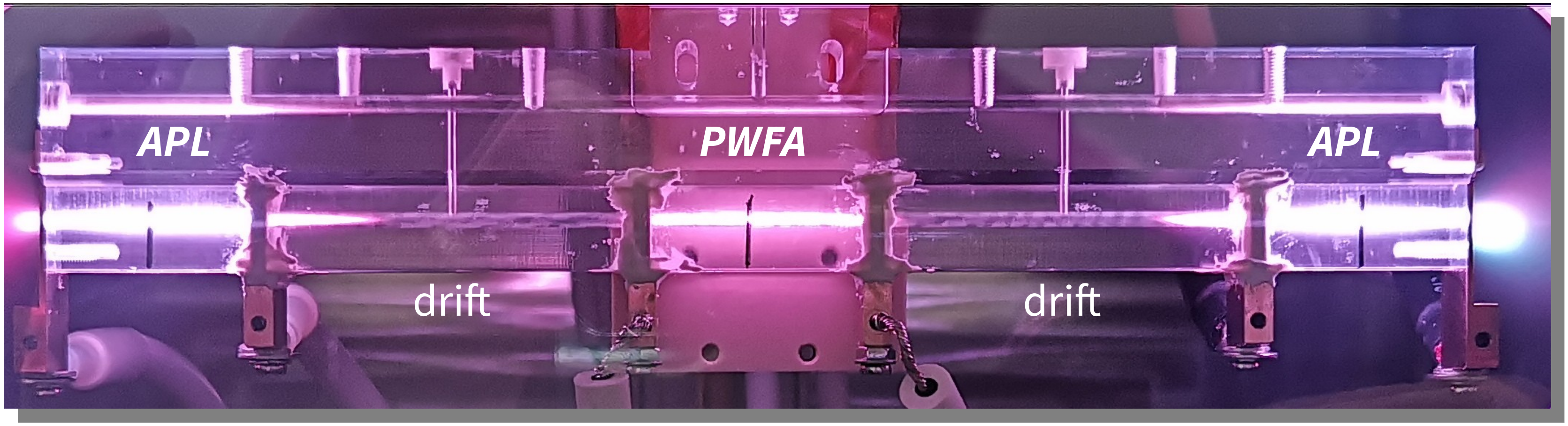
SPARC LAB

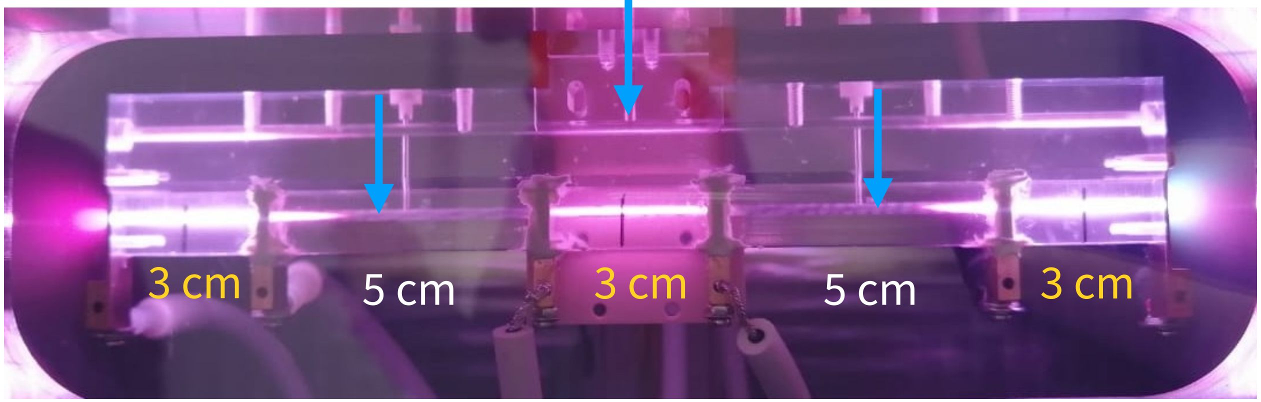
# Basic idea of the "all-in-one" capillary



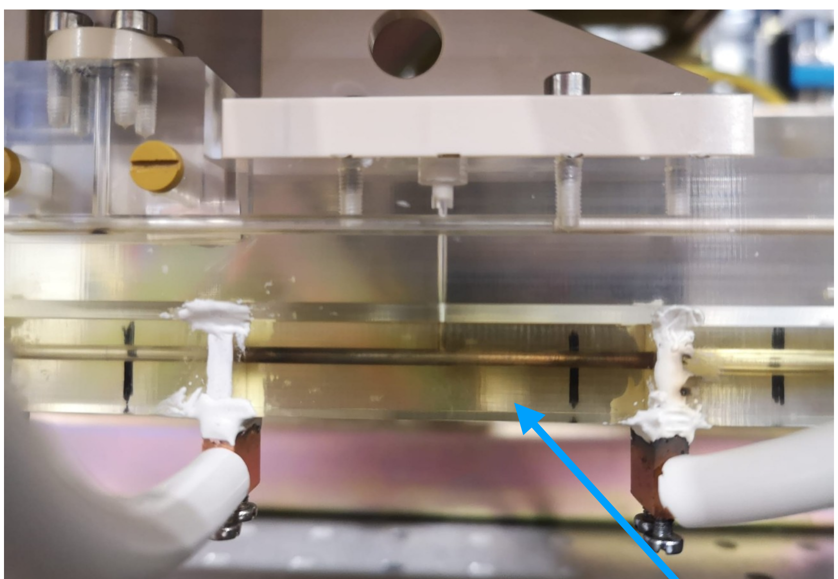



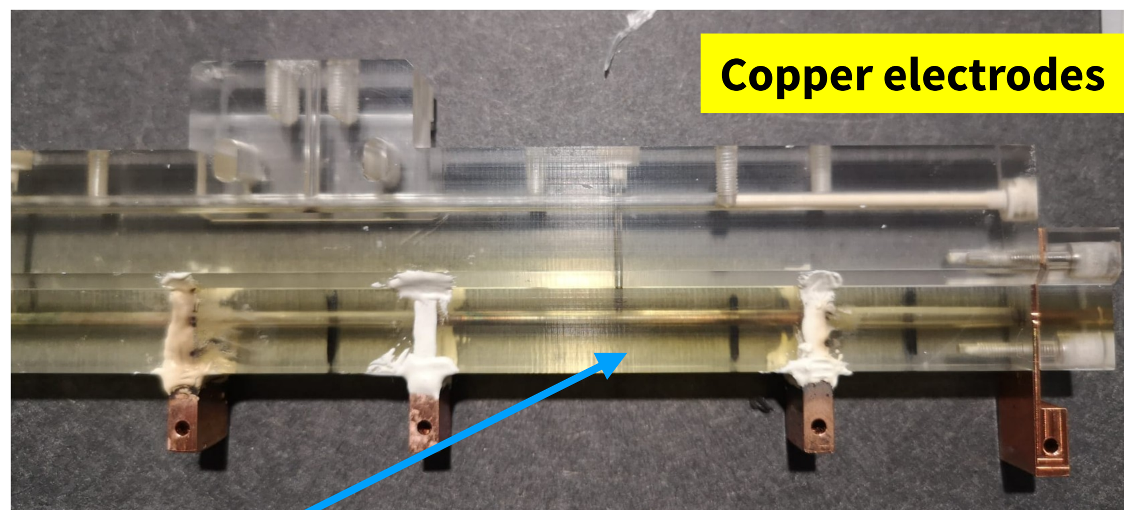
# *First offline tests (2 inlets prototype)*

$H_2$ or $N_2$



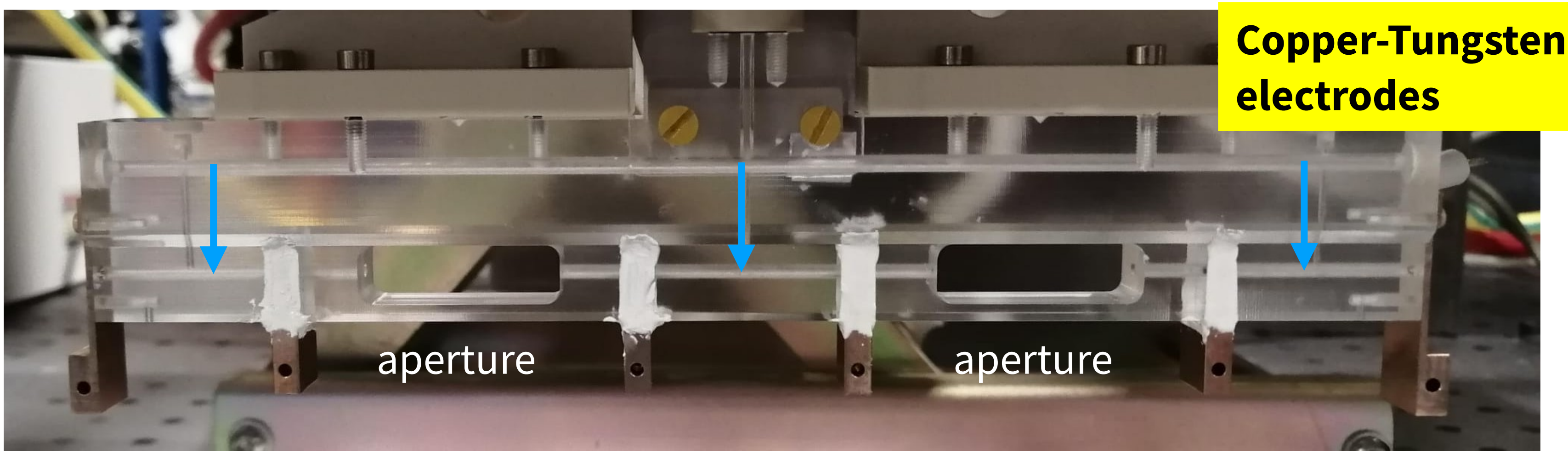

Offline tests
@ PLASMA_LAB

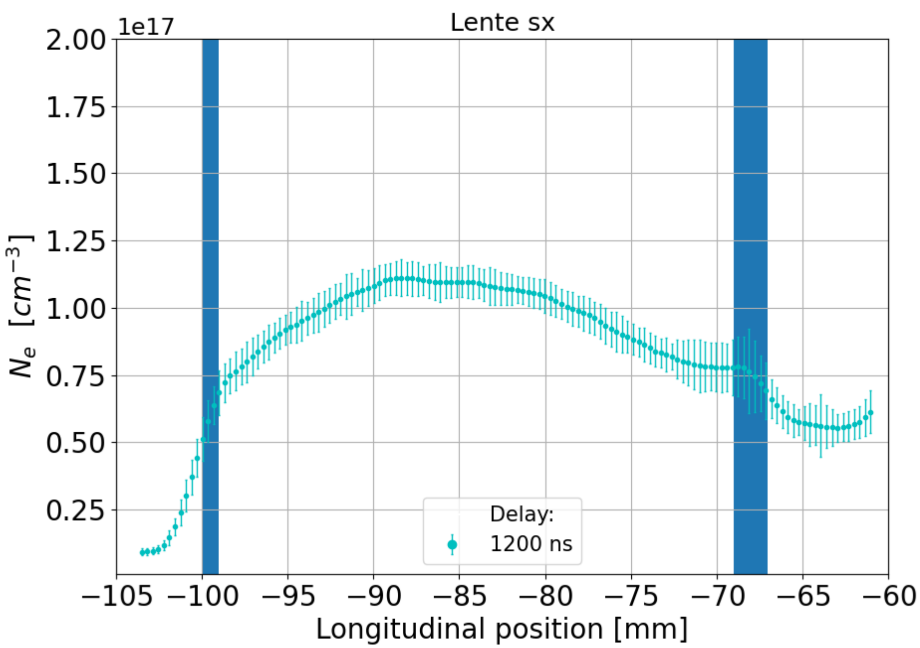


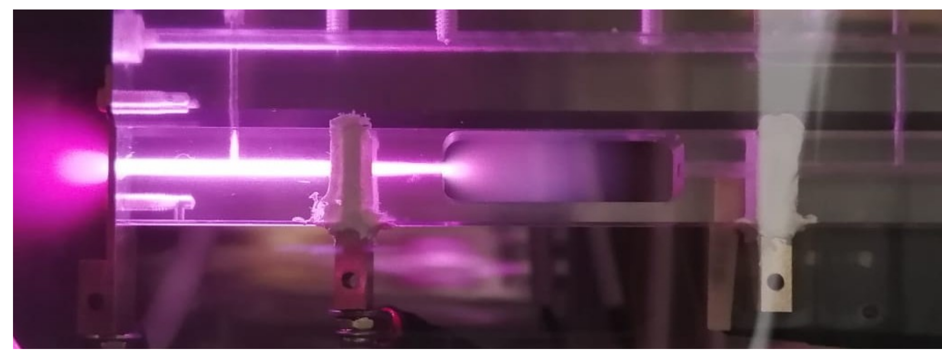


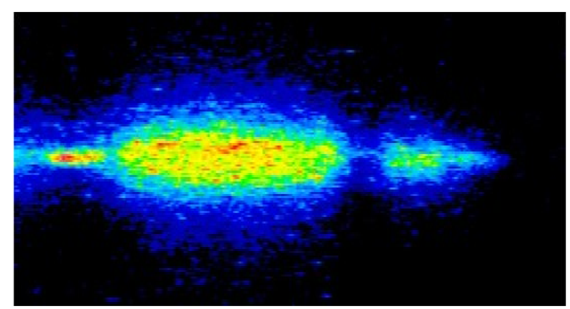

Spattered copper

# New prototype (3 inlets)



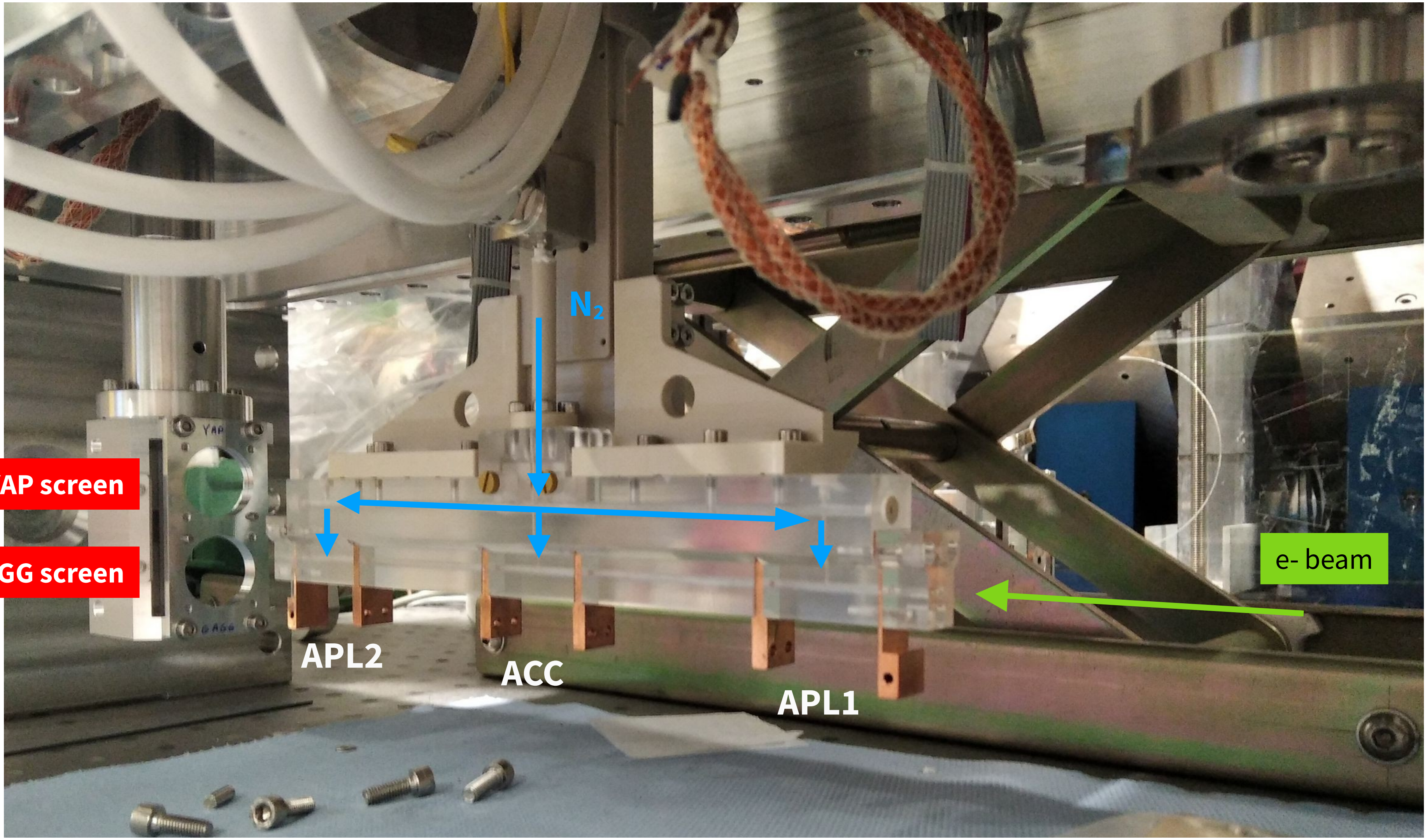



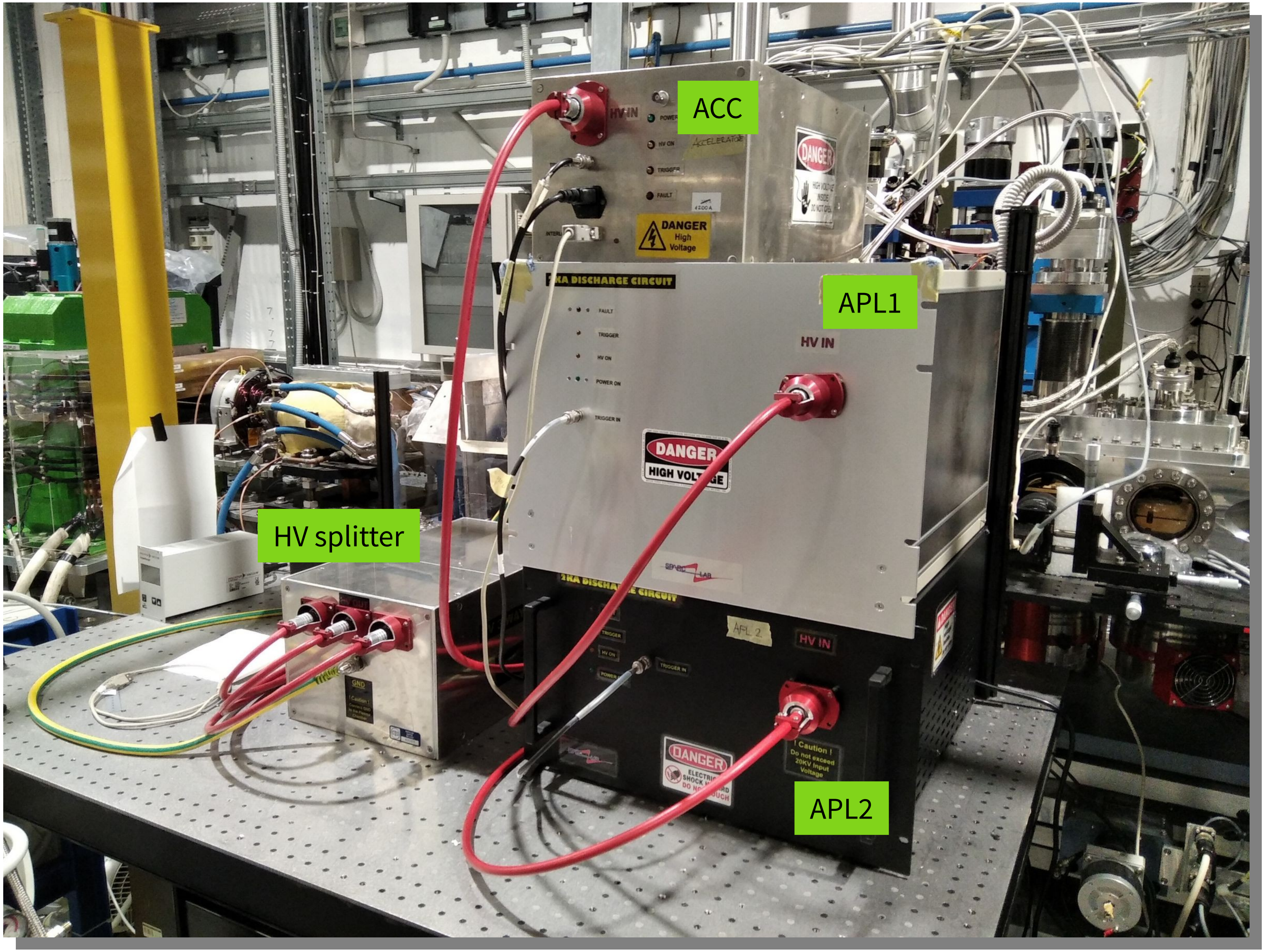


Stark-broadening Measurement with Hydrogen

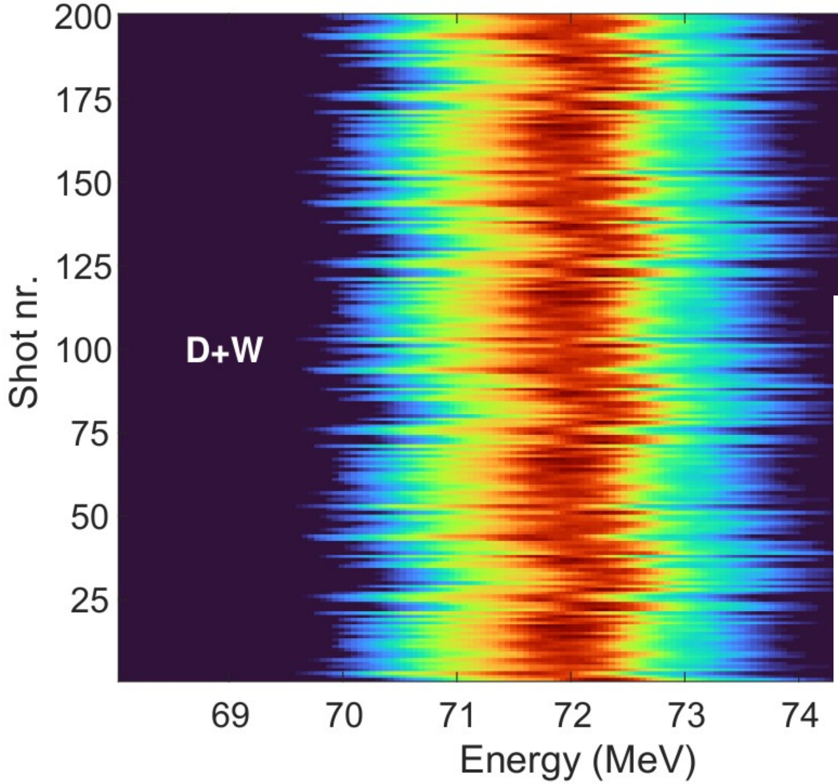
# Installation in the vacuum chamber



# HV setup

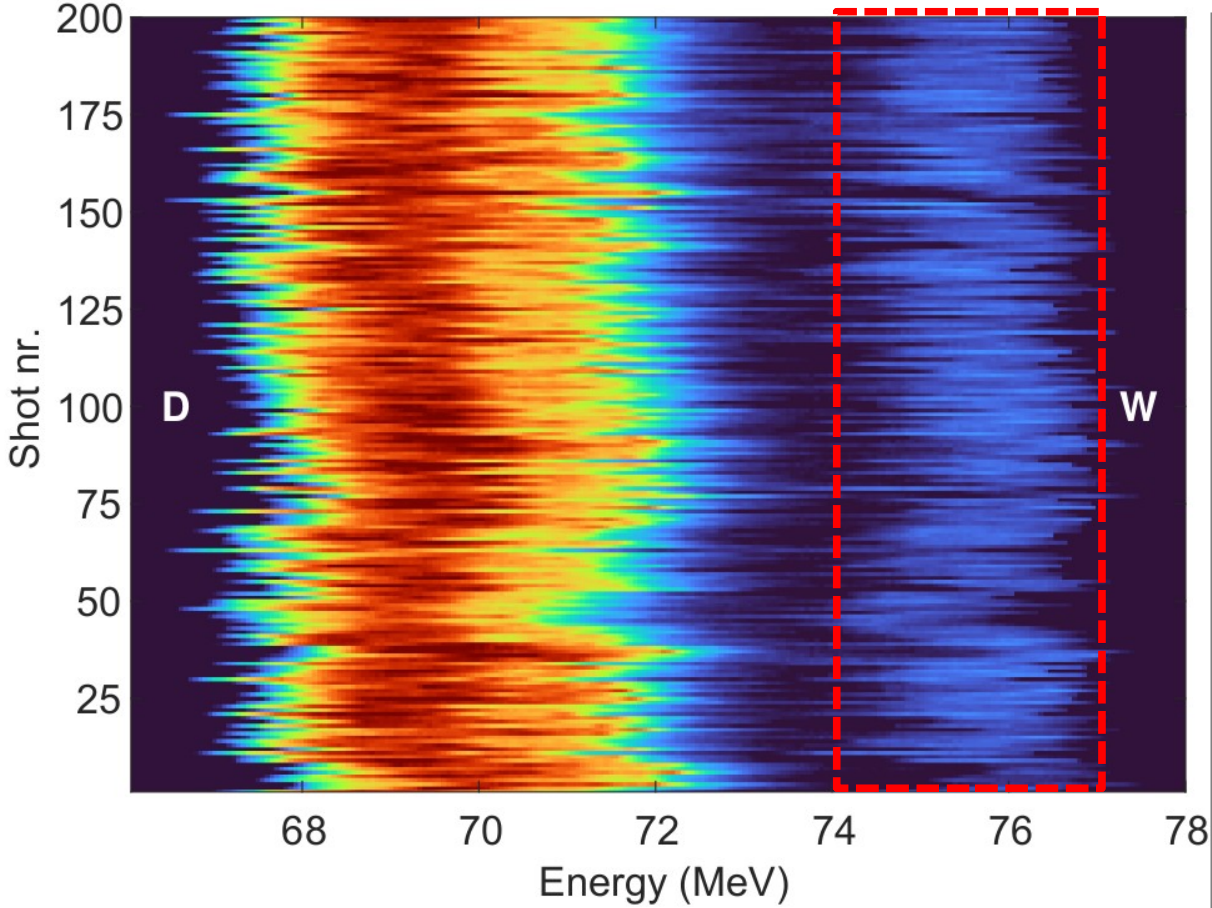

ACC
APL1
HV splitter
APL2
DANGER
High Voltage
HV IN
DANGER
HIGH VOLTAGE

# First accelerated witness



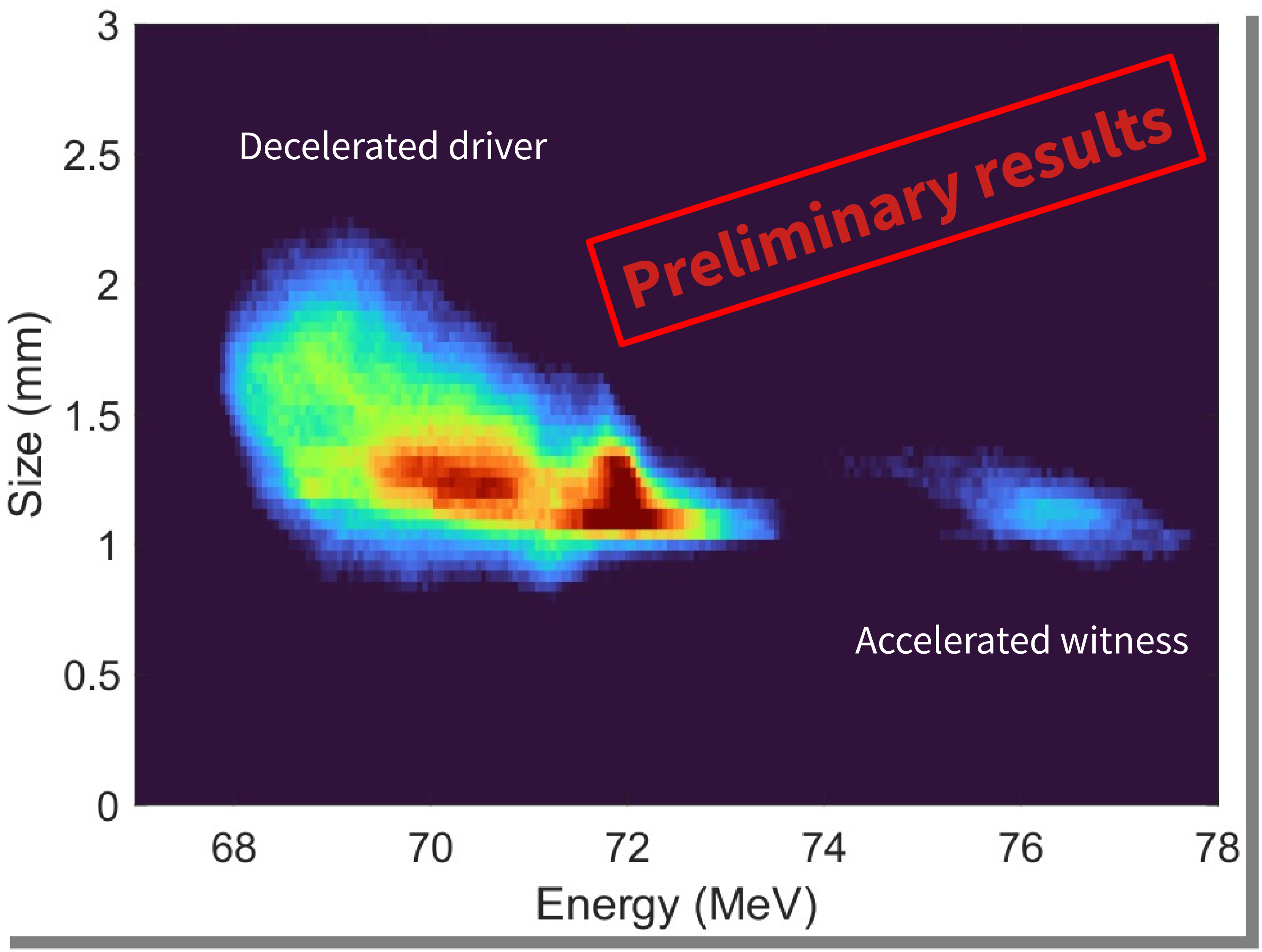

Lenses ON, Accelerator **OFF**

Lenses ON, Accelerator **ON**




Preliminary results

# Single-shot spectrum



# *Active-plasma bending results*

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Active Plasma Bending (APB) is an extension of the Active-Plasma Lens (APL) mechanism

- *The Lorentz force due to the current-induced magnetic field pushes the particles toward the capillary axis*
- *The same applies in a curved capillary: particles stay close to the bent path*
- *Plasma can sustain large currents (> 70 kA have been proved). As an example, **25 kA** currents produce **~6 T** magnetic fields*

Idea is to provide an alternative to classic bending magnets

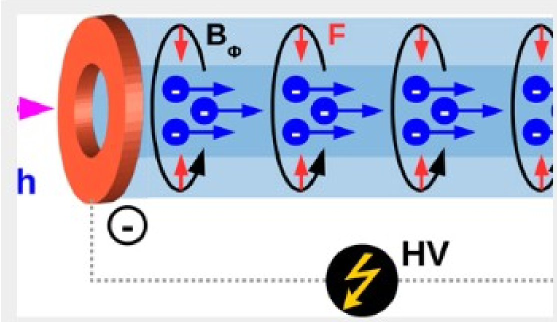
- *Compactness. Large deflection angles, no need of cryogenic systems*
- *Tunability. The bending is tuned by adjusting the discharge-current*
- *Cheap solution (capillary+discharge pulser)*
- ***Tunable dispersion (dispersion-free also possible) by changing the discharge current***

AIP AIP Advances

JAN 25 2018 Editor's picks

**Guiding of charged particle beams in curved capillary-discharge waveguides**

Pompili et al.




Pompili, R., et al. "Guiding of charged particle beams in curved capillary-discharge waveguides." AIP Advances 8.1 (2018): 015326.

# Working principle

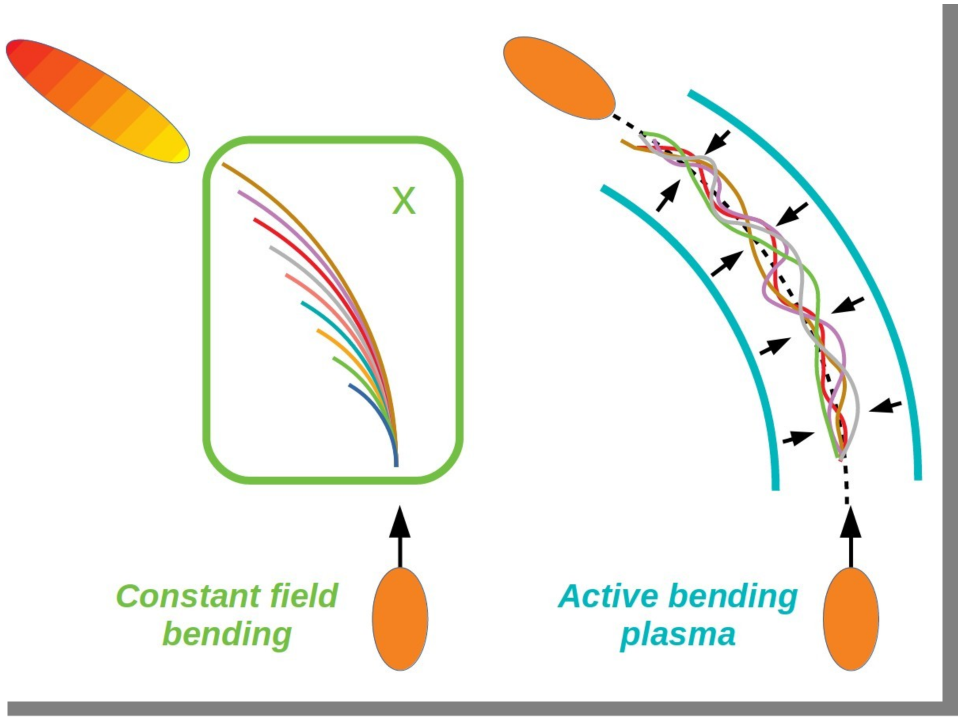


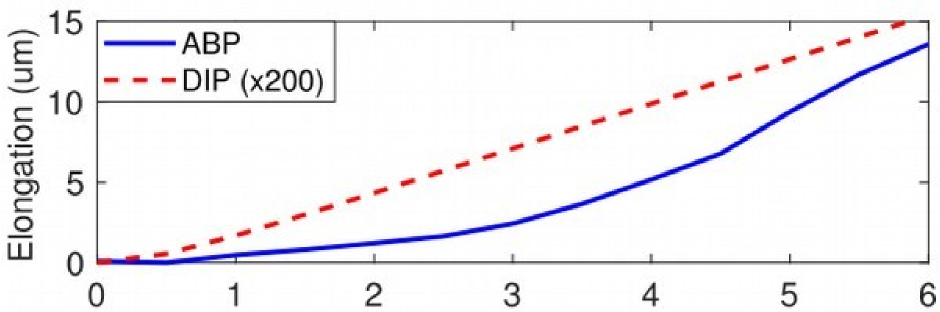
Particle motion in the APB is different with respect to a classic bending magnet

- *Its magnetic field is radially increasing (not constant like in a planar bend)*
- *Large energy particles → large offset with respect to the capillary axis → stronger deflection*

Bunch elongation/dispersion can be made negligible even with large energy spreads

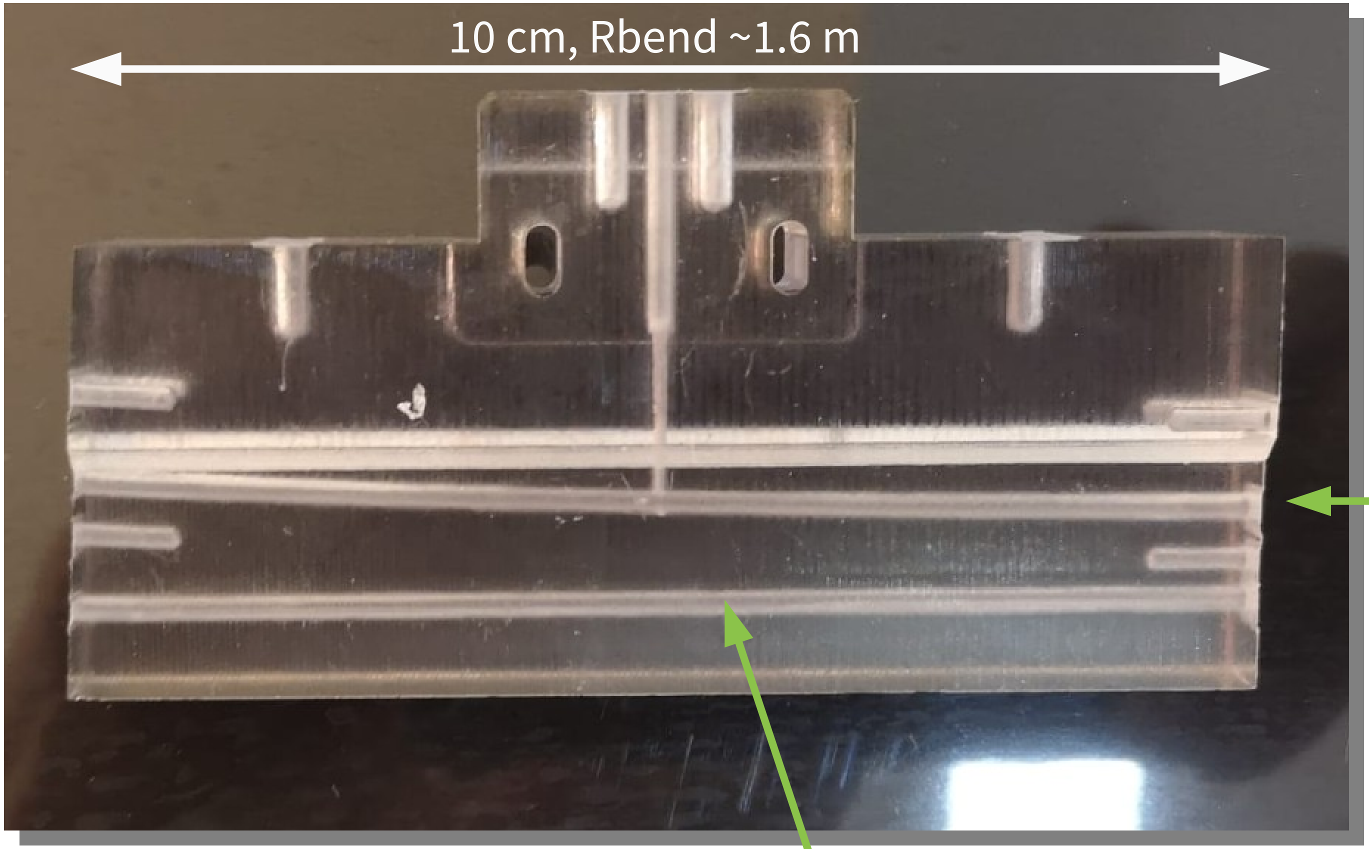
- *The ABP does not require any manipulation on the beam LPS as in the case of standard bending magnets!*
  - *No dispersion-matching optics (quads, sextupoles)!*
- *Simple and affordable solution in view of compact machines.*



# SPARC prototype (3D printed)

Vertical bending
3 mm offset
2mm hole



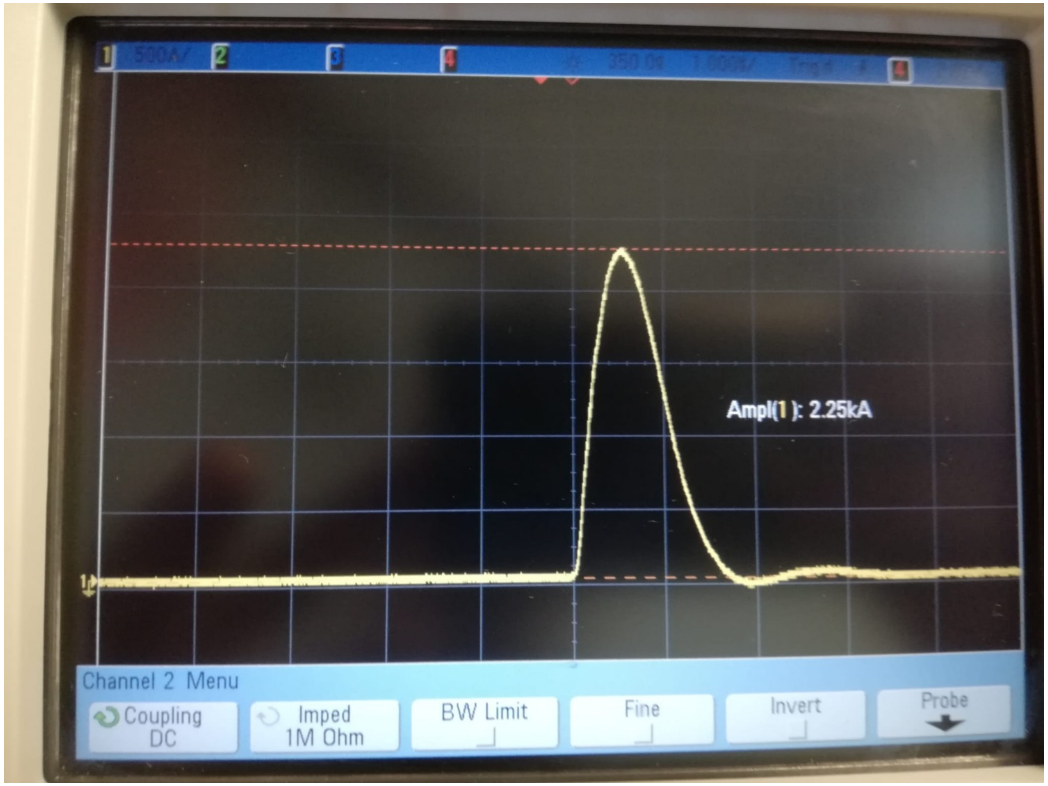

beam

Hole for laser alignment

# Discharge pulser



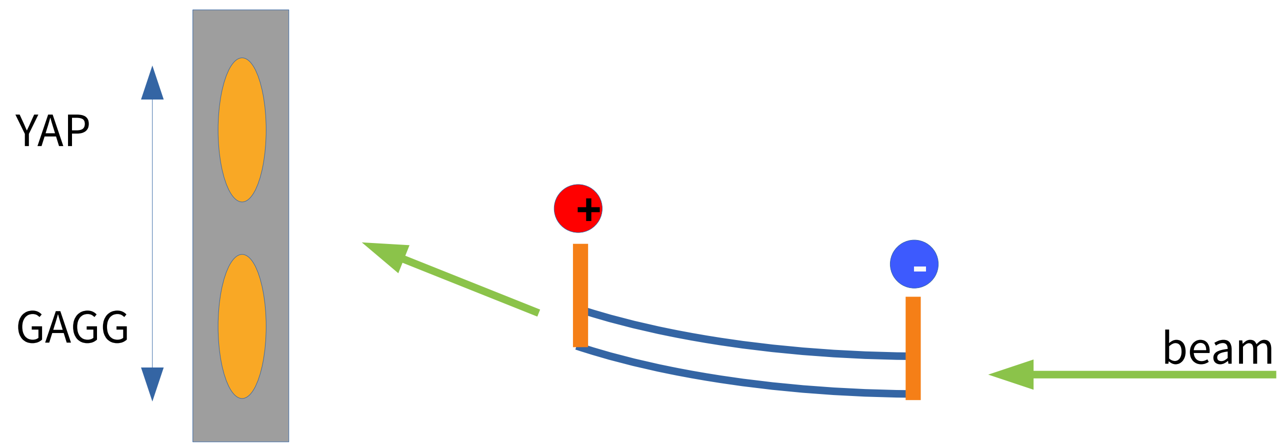

HV pulser (thanks to D. Pellegrini, T. De Nardis)




First results @ 2.25 kA

# Experiment @SPARC






We have used a 50 pC test beam on-crest (~1 ps)

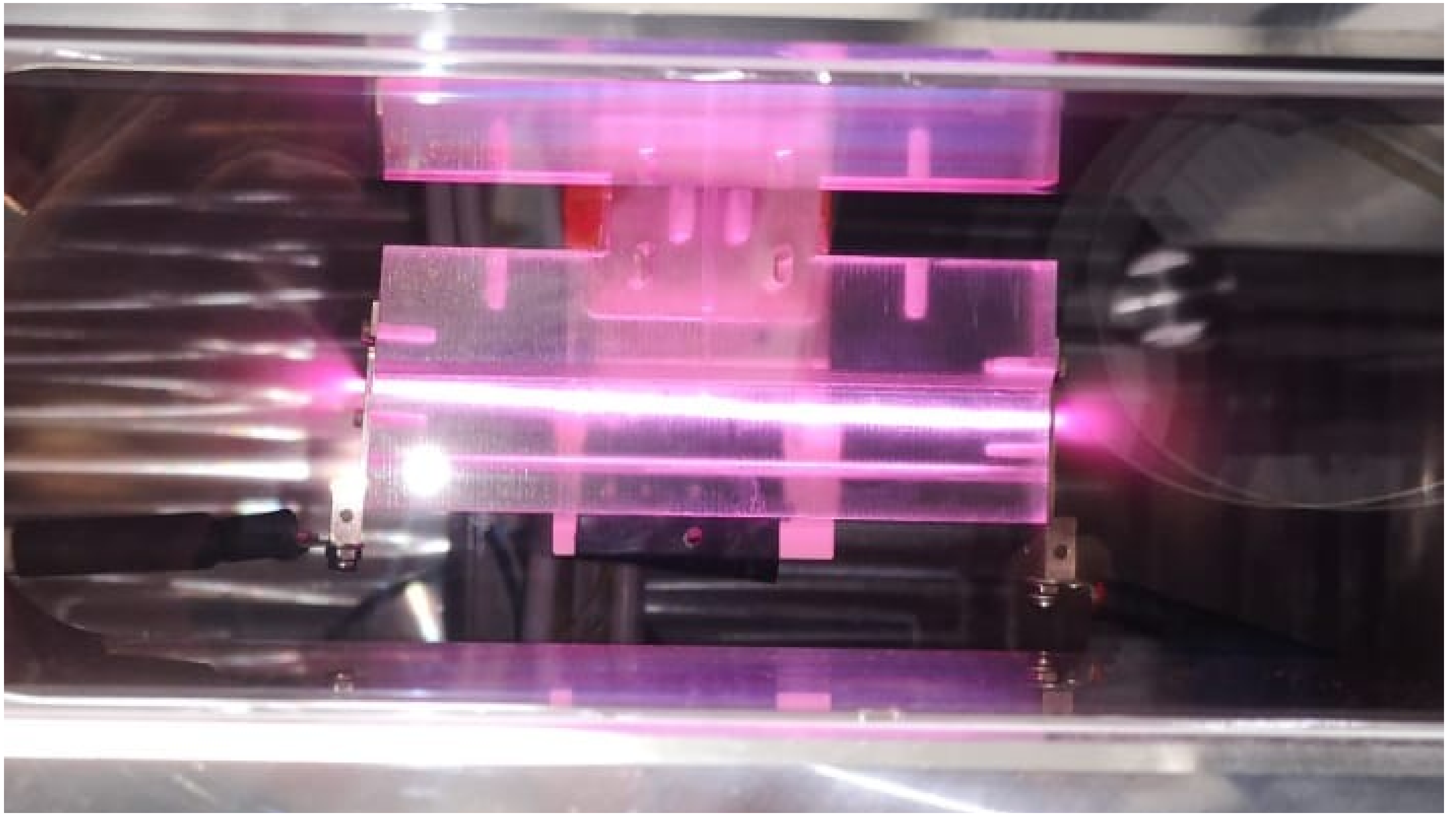
The energy of the beam is set to 60 MeV

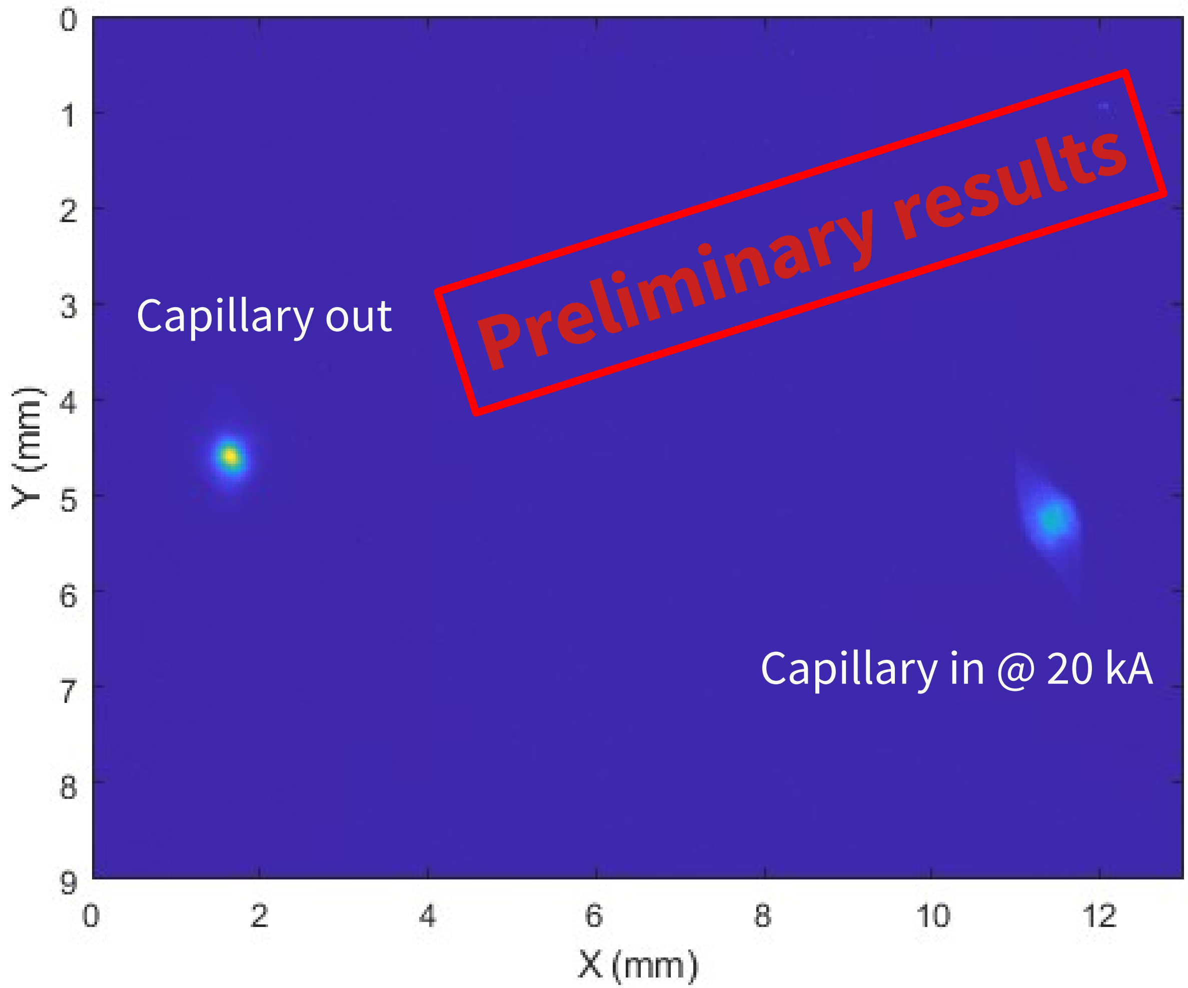
*1.6 m bending radius, ~4° deflection angle in 10 cm capillary*

The beam is imaged on the YAG/GAGG screen located ~10 cm downstream the capillary exit

**Put an energy-chirp on the beam to evaluate the beam dispersion @ screen**

# Offline tests @ PLASMA_LAB




Capillary out
Preliminary results
Capillary in @ 20 kA
Y (mm)
X (mm)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12

# *FLAME*

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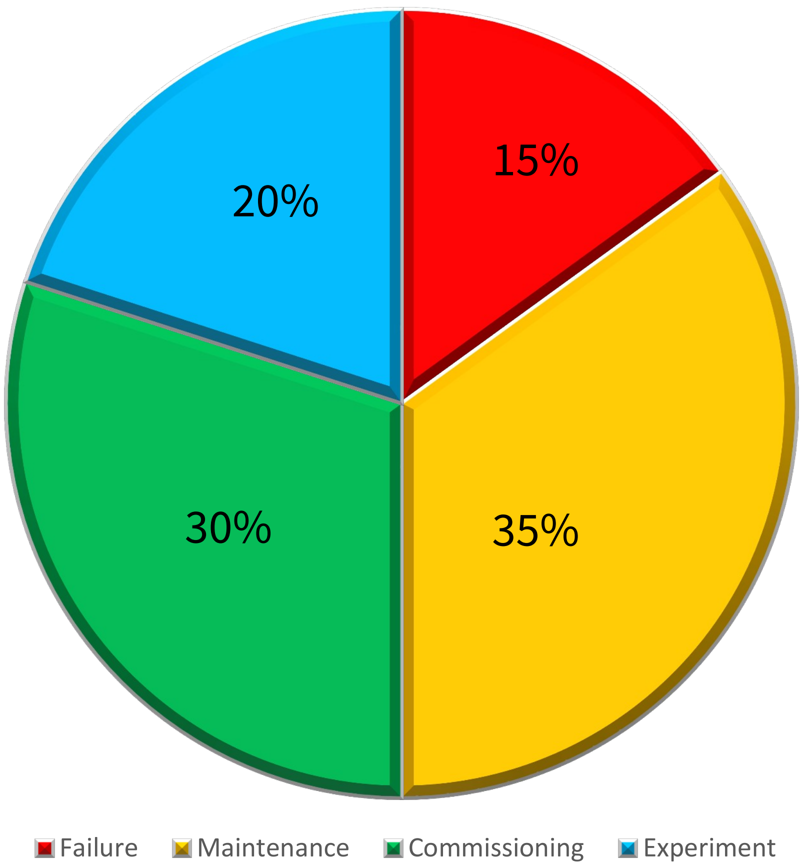
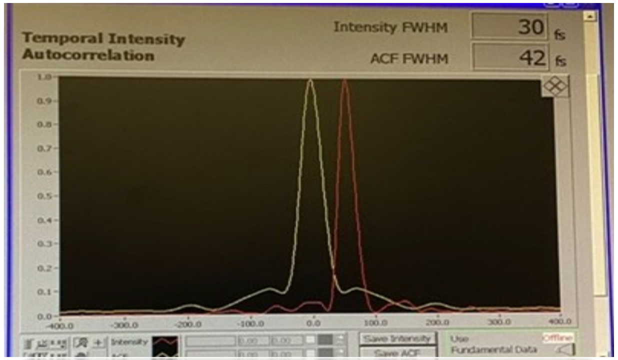
Laboratori Nazionali di Frascati
SPARC LAB

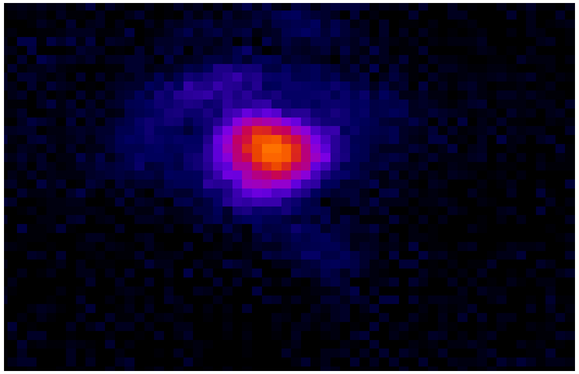
# FLAME uptime in 2023



# Laser parameters

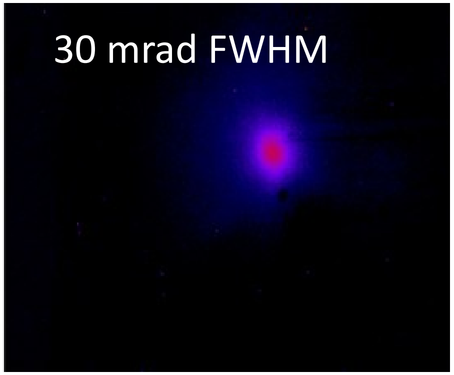
1. Laser energy @compressor output ≈ **6,38 J * 0.5 (transport efficiency)**
2. Laser energy in the focal spot ≈ **70%**
3. Laser duration ≈ **30 fs**
4. Laser transverse profile ≈ 9x9 pixel -> **18x18 um2**

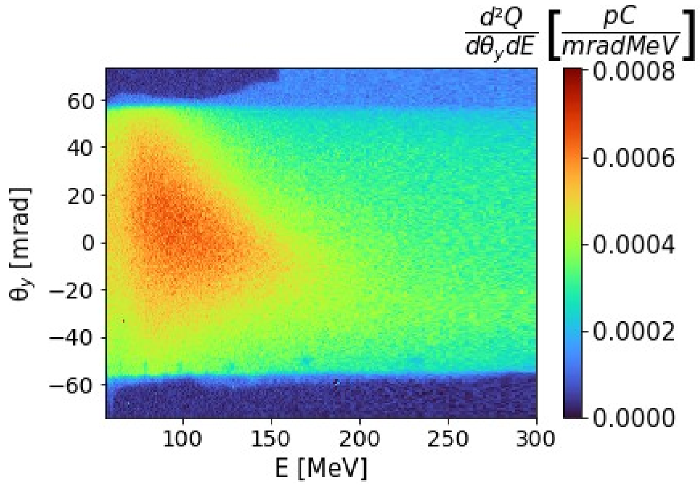



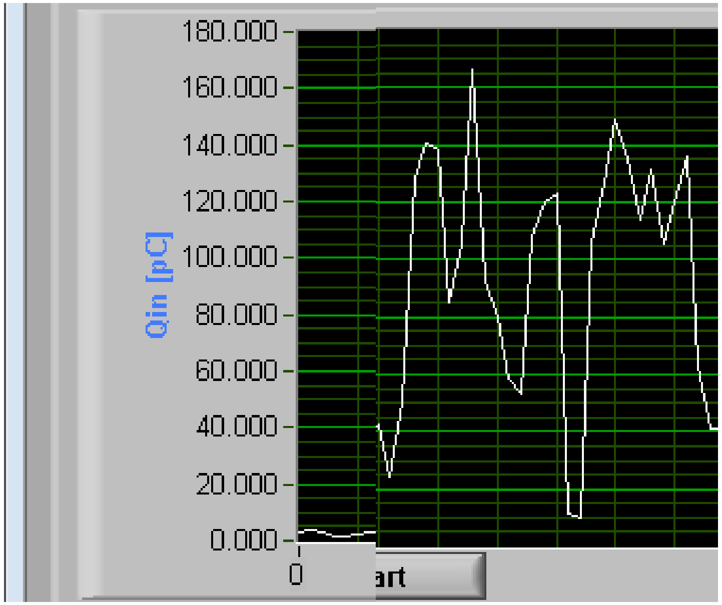



## Accelerated e-beam parameters

1. e-beam divergence ≈ **30 mrad** and pointing stability ≈ **3 mrad**
2. e-beam charge @1.2m downstream the interaction point ≈ **150 pC**
3. e-beam maximum energy ≈ **250 MeV**

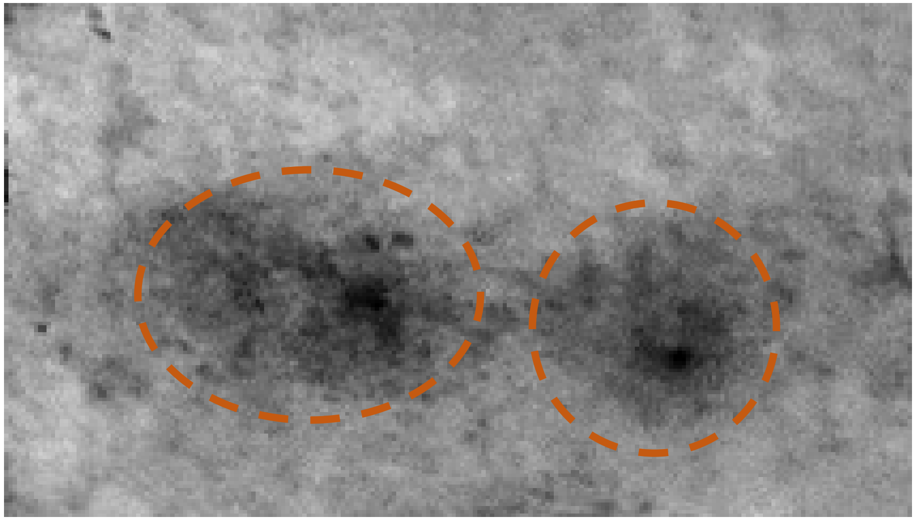


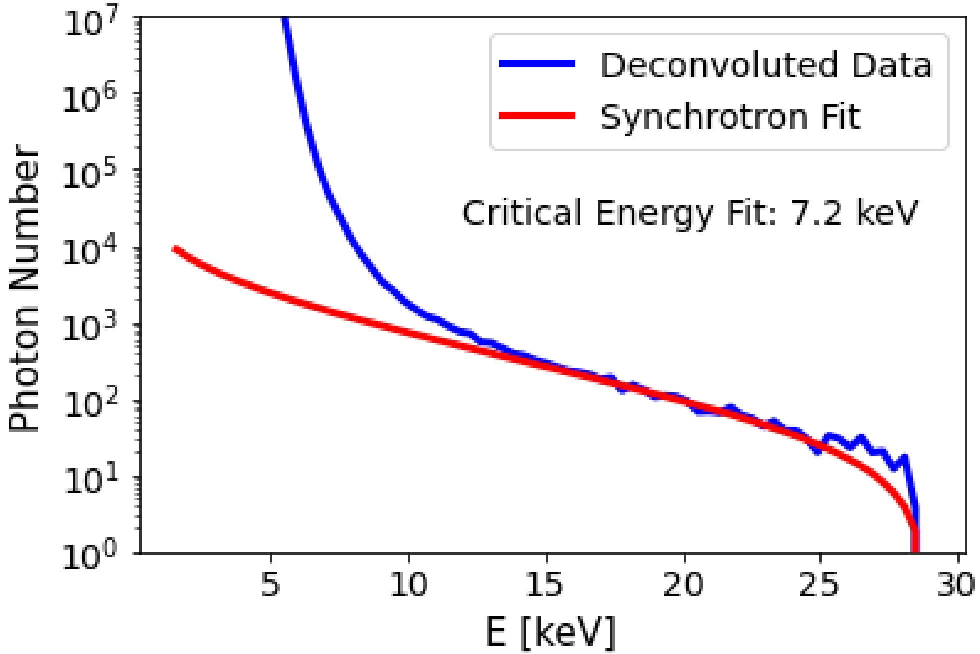



## Betatron X-ray beam – preliminary results

1. X-ray beam profile – multi-shot acquisition
2. X-ray spectrum





# EuAPS

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SPARC LAB

# Parameters list



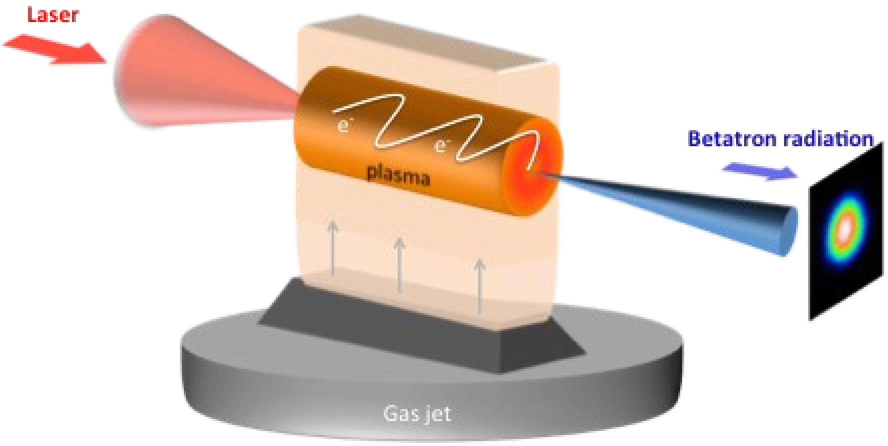
**Work plan:** The betatron X rays source will be developed at FLAME (200 TW, 35 fs) bunker optimizing

- *Laser parameters*
- *Plasma source devices*
- *Electron diagnostics*
- *X rays spectrum and photon flux*

At the beginning of 2024 it will be moved in the SPARC bunker, with the installation of a new compressor and a refurbishing of the old one.

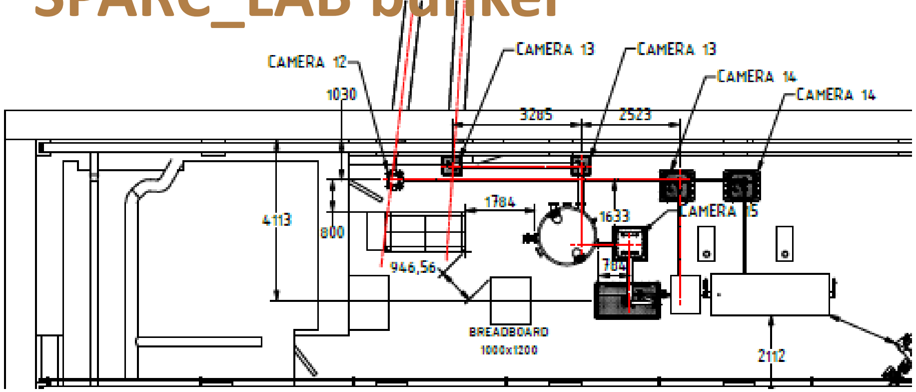
The main goal is to make a replica of the source developed at FLAME

The advanced photon diagnostics and the user end station will be tested and installed during/after the commissioning of the source

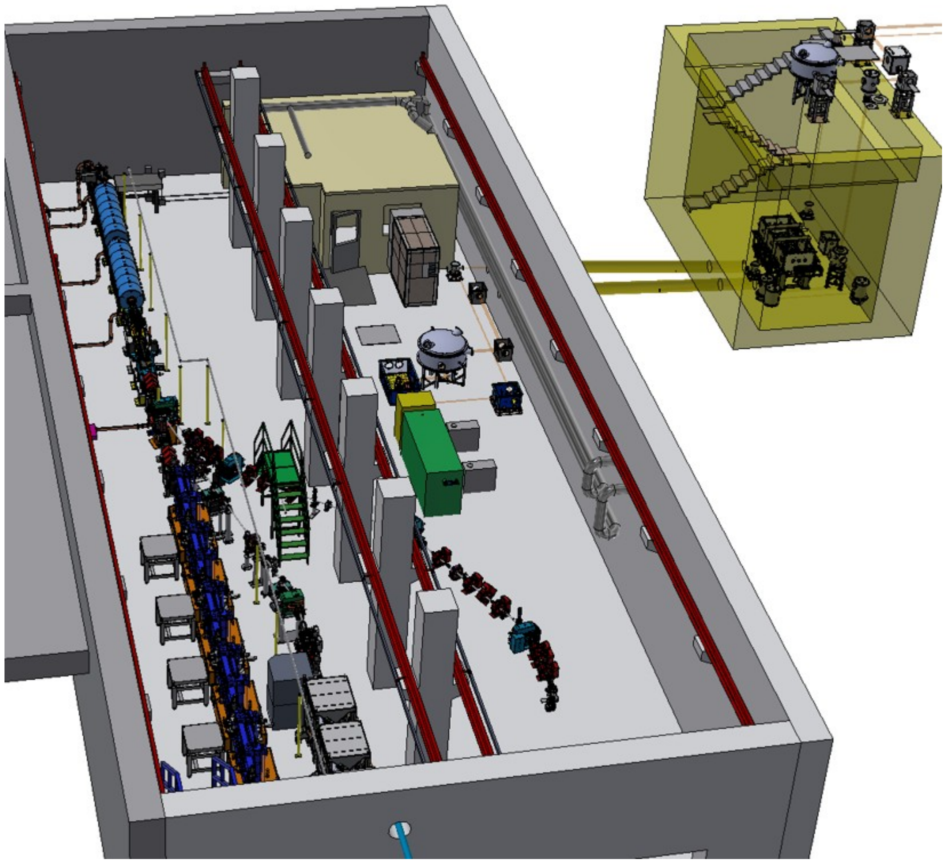



| Parameter | Value | unit |
|---|---|---|
| Electron beam Energy | 100-800 | MeV |
| Plasma Density | $10^{17}$-$10^{19}$ | $cm^{-3}$ |
| Photon Critical Energy | 1 -10 tunable | keV |
| Number of Photons/pulse | $10^{6}$-$10^{9}$ | |
| Repetition rate | 1-10 | Hz |
| Beam divergence | 3-20 | mrad |

## SPARC_LAB bunker




- Layout in the SPARC bunker and connection with FLAME building



S. Lauciani

# Layout of the interaction point

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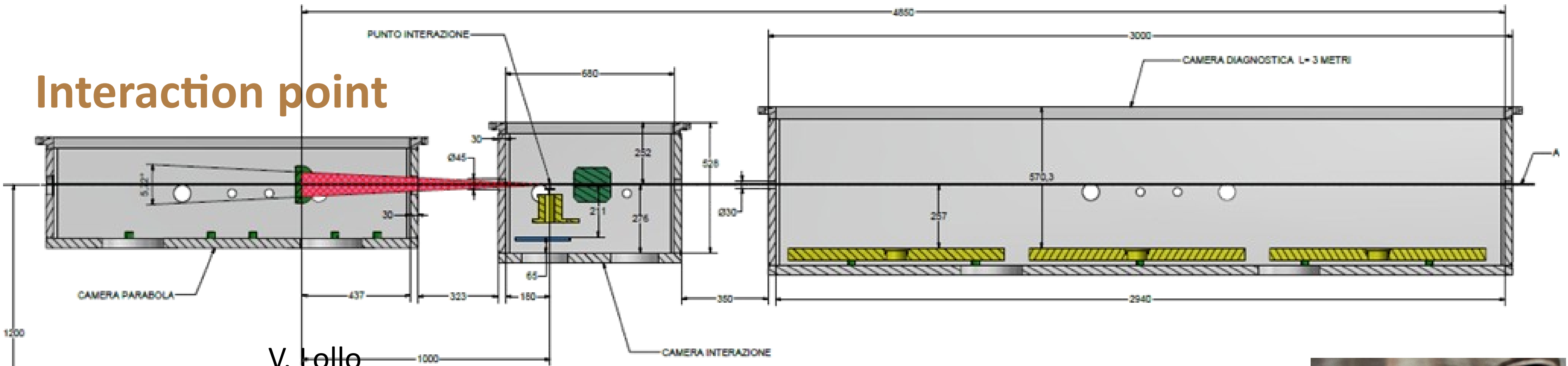
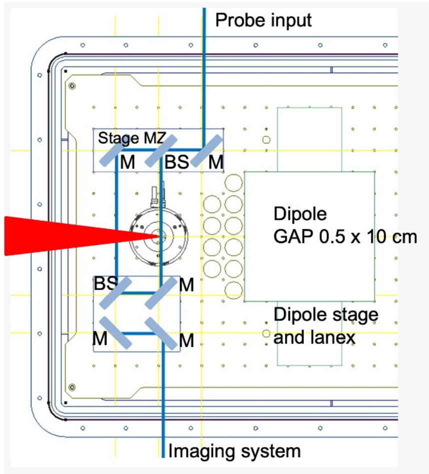
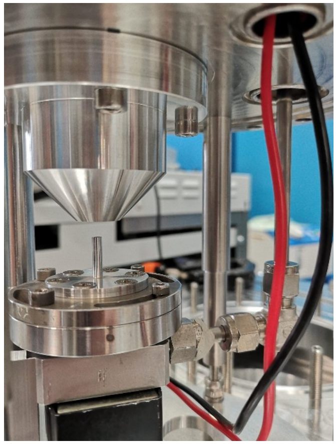
Interaction point




V. Lollo

- Main issue is the pumping of 20-30 bar with repetition rate at least 1 Hz
- The focusing parabola has to be at least at $10^{-4}$ mbar



# *Thanks!*

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*On behalf of the SPARC_LAB collaboration*

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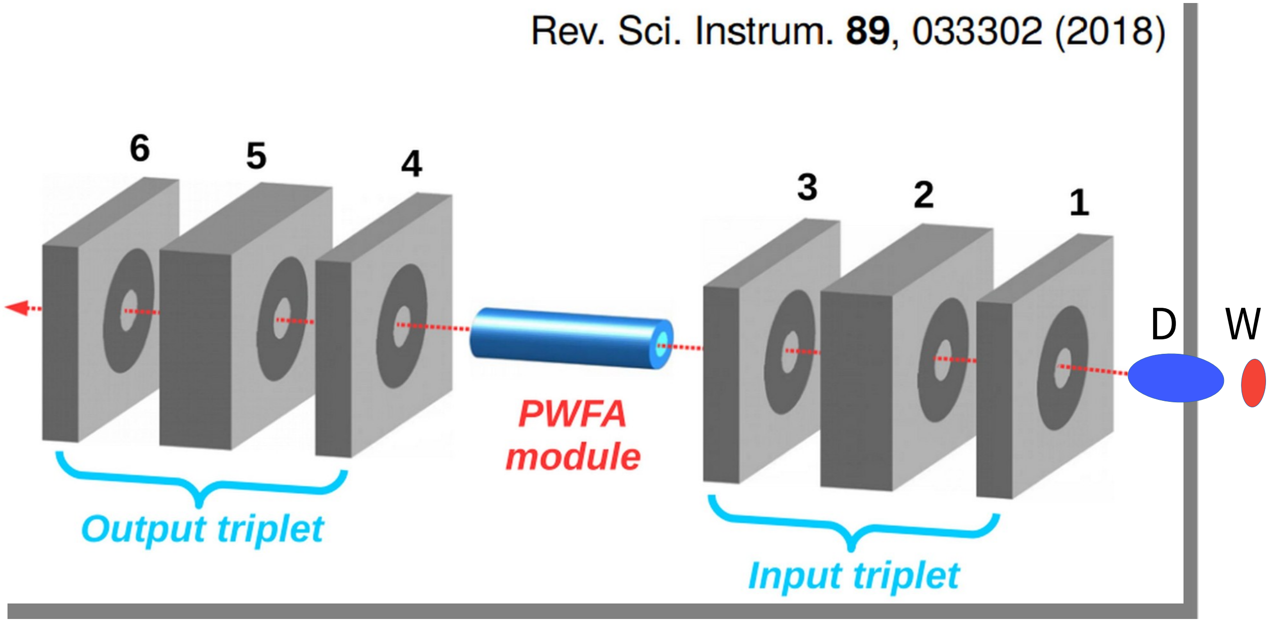
Laboratori Nazionali di Frascati

# Acceleration and matching in a plasma






In a **PWFA** the beam must be transversely focused at the plasma entrance

*Driver beam charge density (together with plasma density) sets the accelerating gradient*

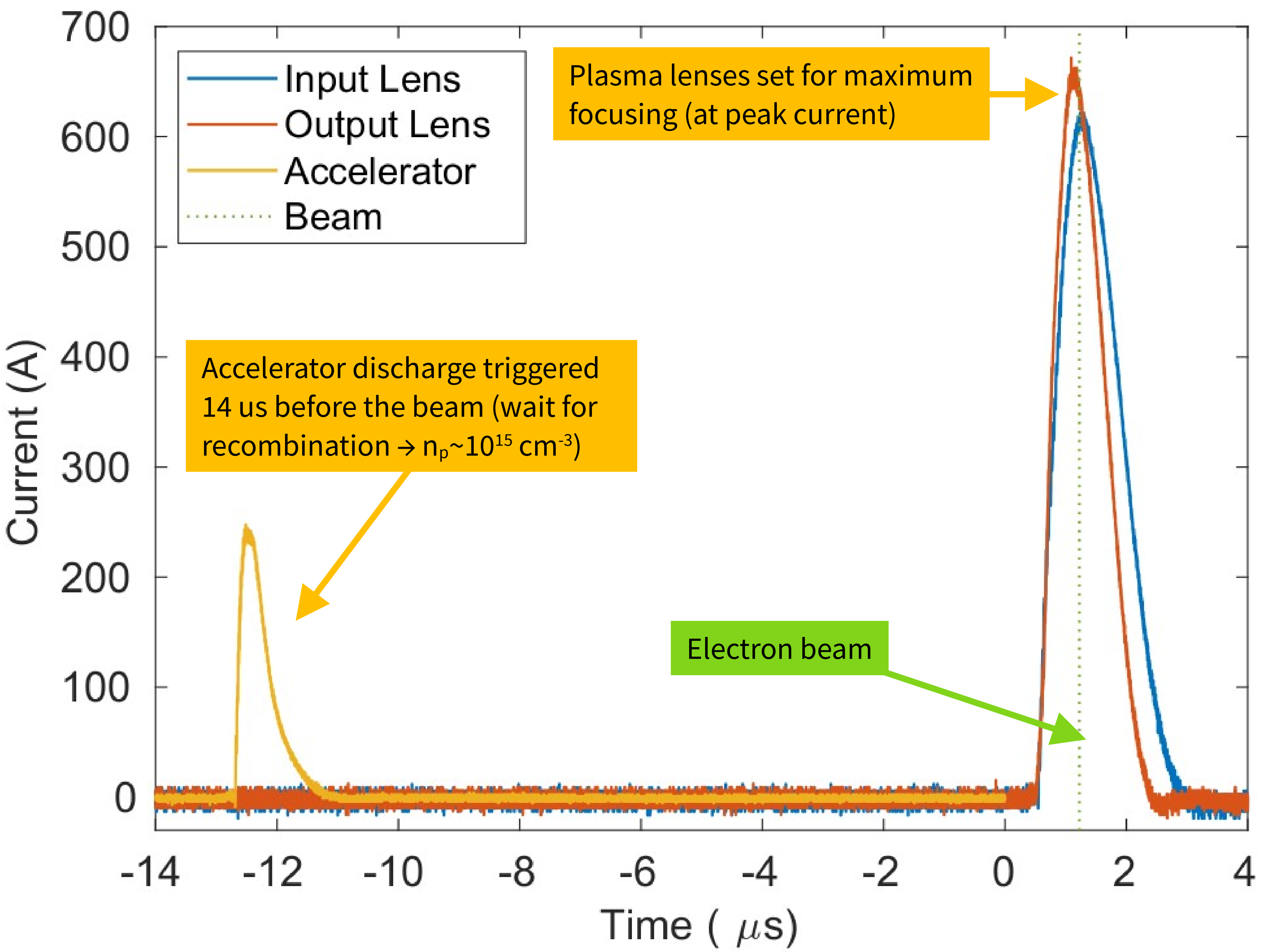
*Witness beam must be transversely matched to avoid emittance spoiling*

$$\beta_{eq} = \sqrt{\frac{\gamma}{2\pi r_e n_p}}$$

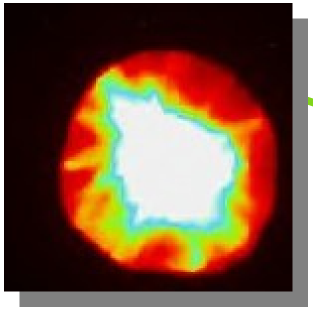
Barov, N., et al., Physical Review E 49.5 (1994): 4407.

The PWFA needs focusing optics upstream (matching) and downstream (capture)

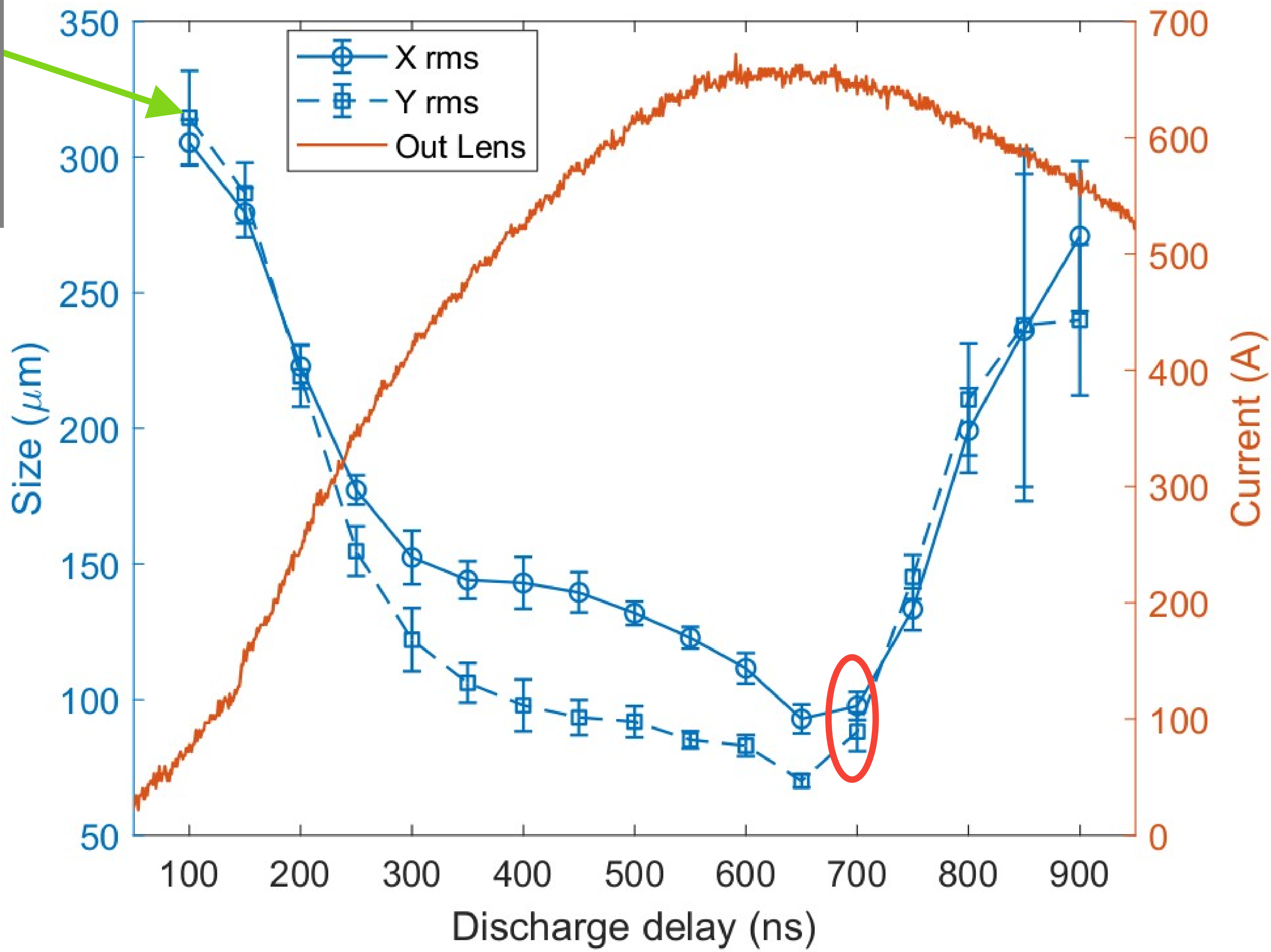
# Discharges timing setup



Scan obtained using only the APL2 (APL1 and ACC turned OFF)

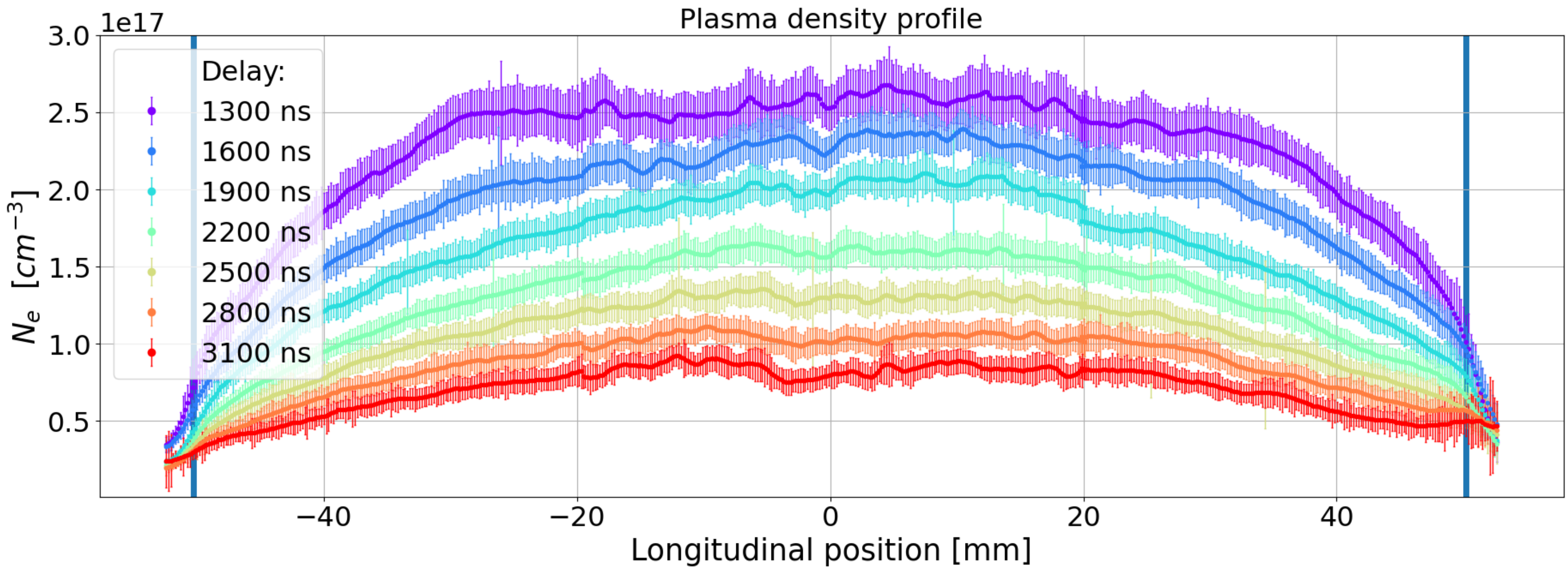


2 mm



# Plasma density measurements

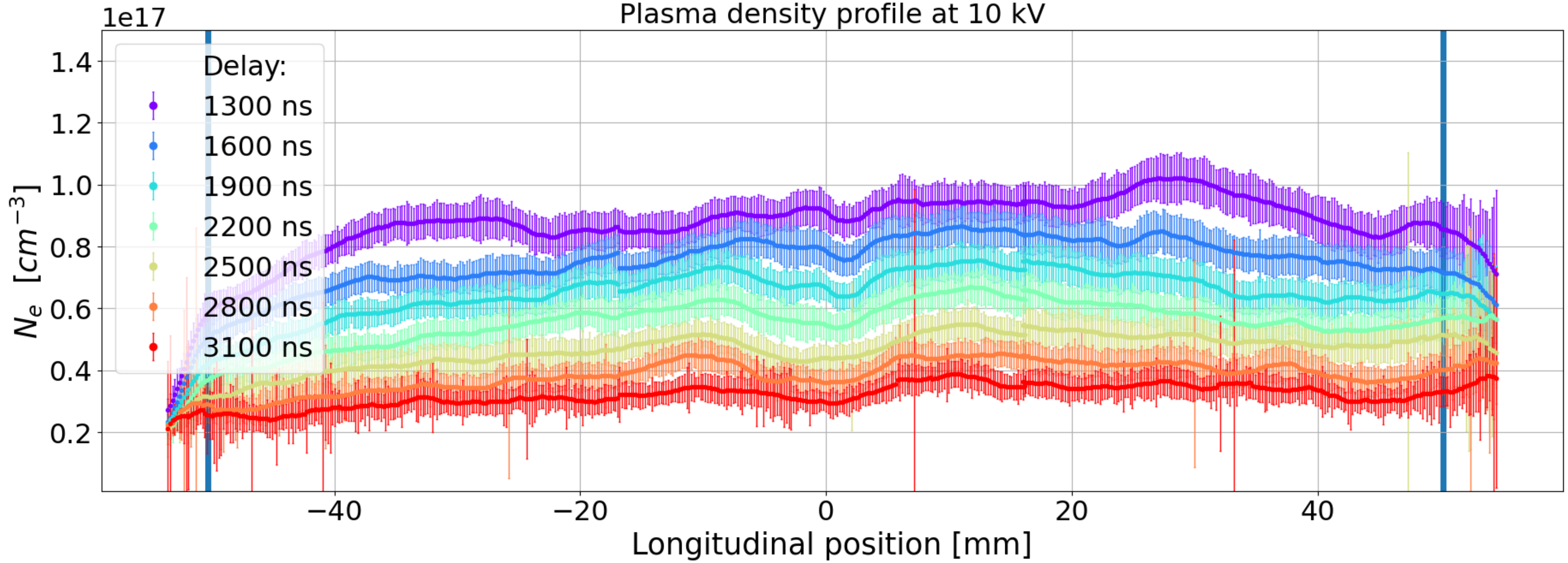
Before test 10 kV – 730 A, 1 bar



## *Plasma density measurements*

After test

10 kV – 730 A, 1 bar




Degradation of the capillary (ablation) gave lower densities