Update on the development of scalable plasma sources at CERN

Alban Sublet for the plasma source R&D teams

Scalable plasma source R&D

- Demonstrate uniformity, scalability and reproducibility within spec.: ne = $7x10^{14}$ cm^{-3}/0.25% uniformity

→ Focus on plasma diagnostics

→ Get inputs from institutes for hardware design/optimization

→ Build scalable modules at CERN for both sources:

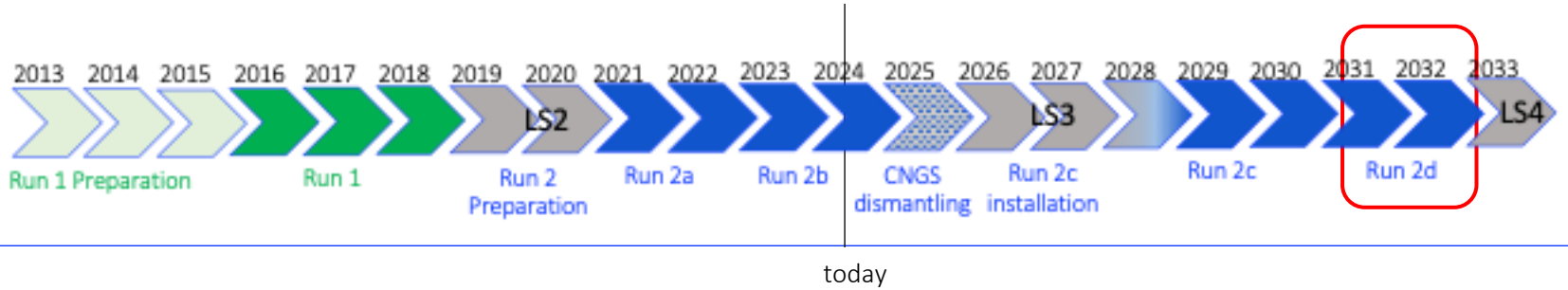
10 m in 4 segments for the Discharge Plasma Source (DPS) / 2.5 m for the Helicon Plasma Source (HPS)

- Milestones:

→ 1st milestone achieved = 10 m DPS test with protons in the AWAKE tunnel "DPS May 2023 Run"

→ End 2025 = Internal review whether scalable technology can already be used for Run 2c

→ Scalable Plasma Source review (around 2027): decision for Run 2d scalable source, procurement and design



HPS 1.0 m – hardware upgrades since end 2023

RF: new RF-leads shielding with common RF return path, new lower RF-screen, digital indicators for matchboxes

- All 3 RF-generators back and working
- less cross-talk between antennas, easy matching,
- minimum reflected power (~ 30W at 10kW setpoint),
- de-phasing btw antenna to compensate different RF-cable lengths,
- supported by RF-lines simulations (SimSmith),

→ Much lower noise

→ **stable operation at 3x 10kW without arcing**

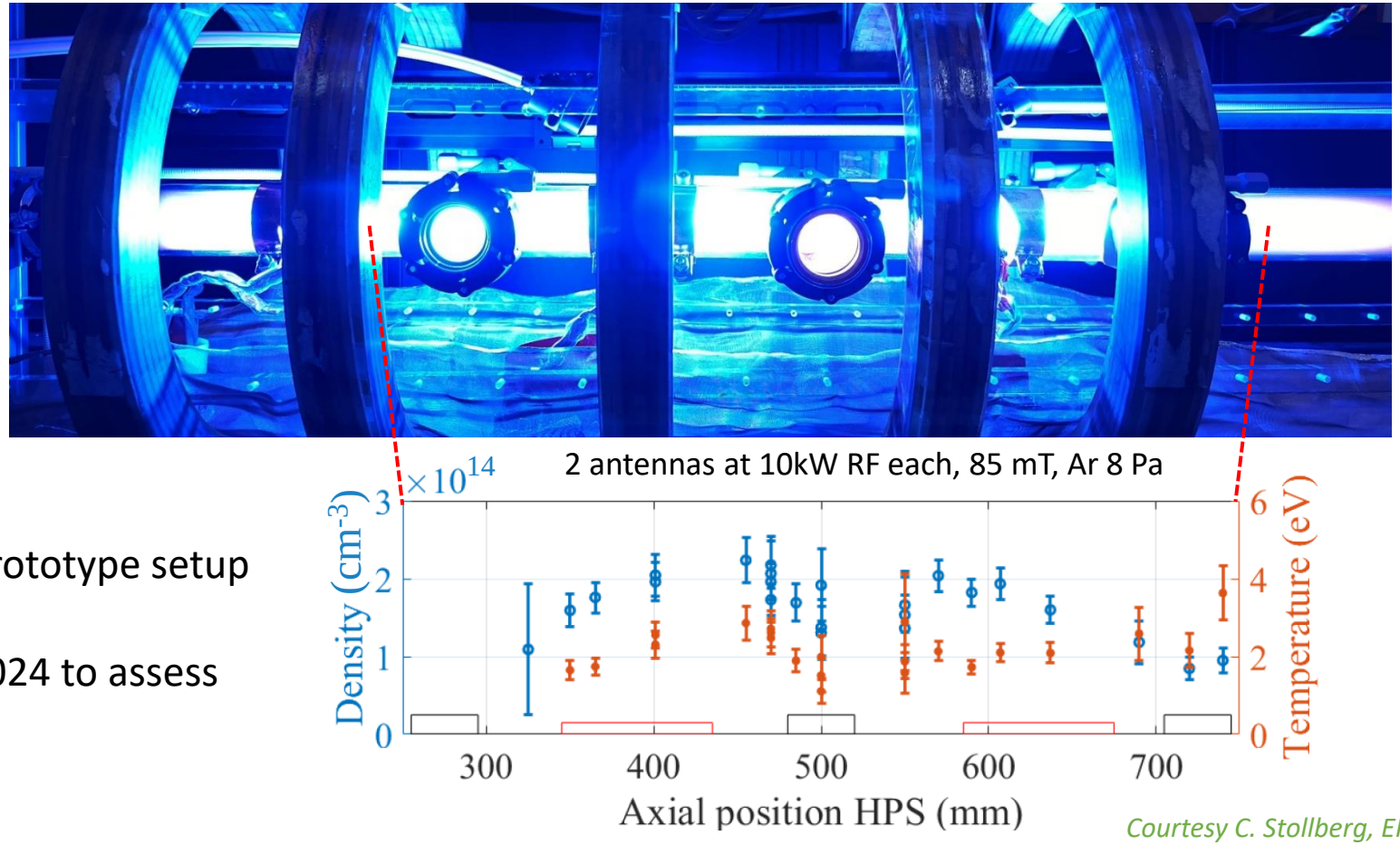
- DC: new cooling hoses for field coils
  - Larger diameter, safer connections and operation
  - lower coil temperature (by 30°C…) at 450 A (110 mT)

  → Working on smoother cooling regulation and DC source stability

- Refurbished feet for the optical table
- New 1 m borosilicate straight tube received

HPS 1.0 m – Dec. 2023 uniformity

→ Preliminary density profile with **Thomson Scattering (TS)**:



Courtesy C. Stollberg, EPFL-SPC

→ TS diagnostic qualification on HPS prototype setup

→ Will be applied to **DPS** in summer 2024 to assess longitudinal uniformity

→ 2025: apply diagnostics on longer sources

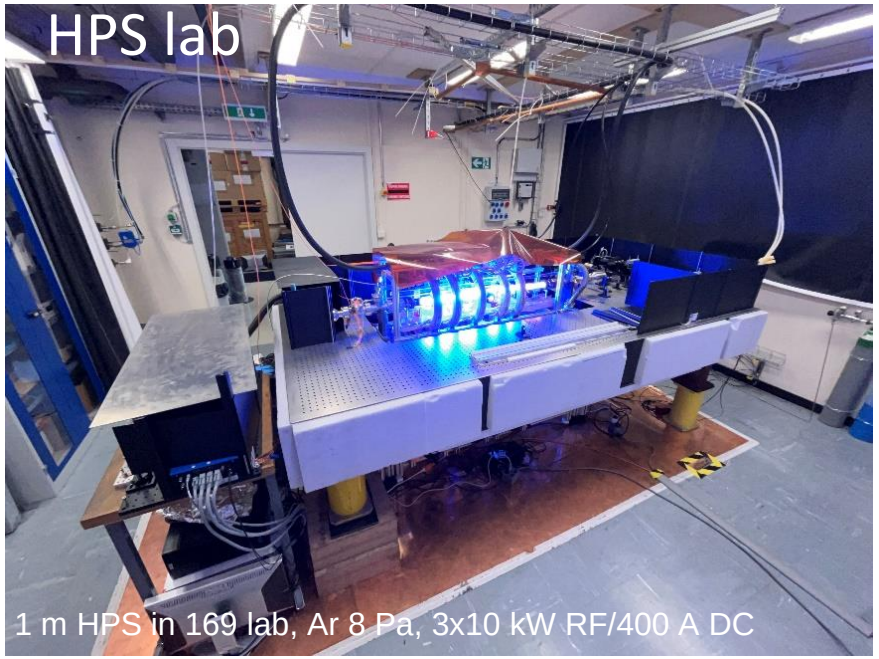
HPS 2024 program

- Jan-Feb. 2024, CERN: TS with upgraded setup at nominal plasma parameters (8Pa Ar, 10 kW/antenna, 110 mT)
- April, CERN: Langmuir probe for radial scan to assess plasma expansion in viewports at CERN
- May, CERN: benchmarking of CO2 interferometer (IPP-Greifswald) and TS (EPFL-SPC) at CERN
- May-June, Wisconsin: microwave cut-off on MAP system → uniformity and antenna spacing
- June, CERN: LIF after re-qualification on MAP?

- Second half 2024 at CERN:

TS/interferometry with different antennas and spacing

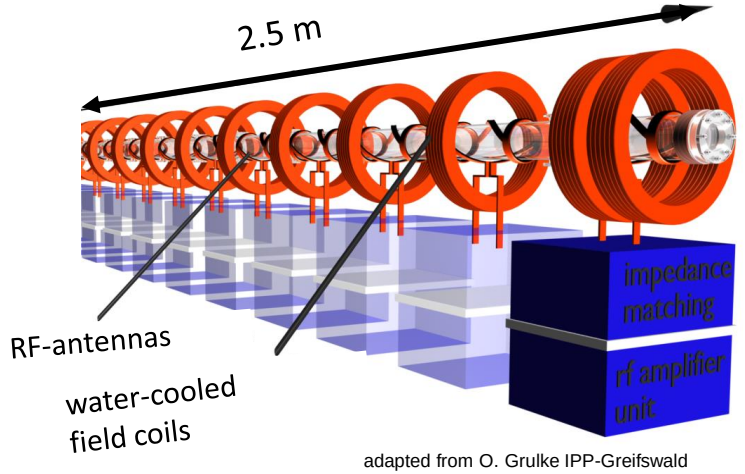
- In parallel at CERN, design of the 2.5 m HPS



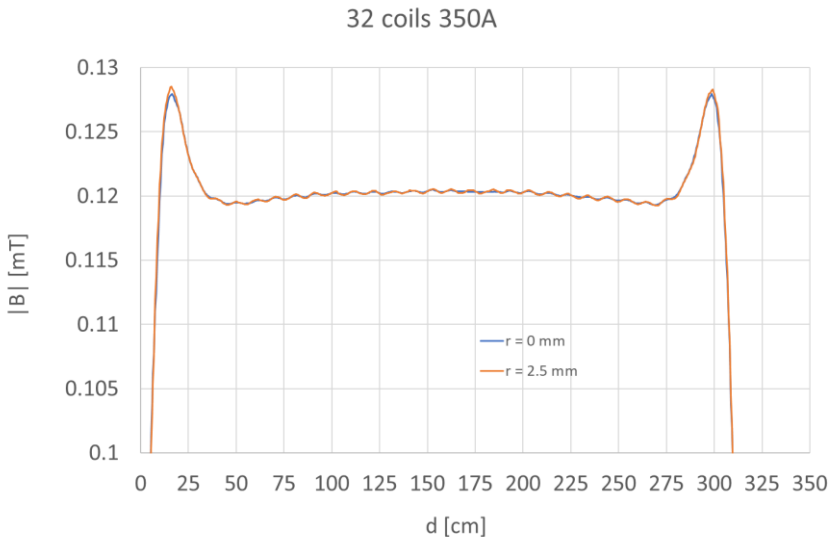
HPS 2.5 m – specifications

- Lab space/facilities available (room next to the HPS 1.0 m source)
- Extend laser room for plasma diagnostics
- RF: new RF-generators + matchboxes 13.56 MHz (10x 10kW?)
  - → **Missing** optimal antenna spacing! Need inputs (exp./sim.) to decide # generators/power
  - → Potential suppliers identified, mostly from semiconductor industry
  - → For high stability and reproducibility with ready to use control and monitoring
- DC: new field coils design under study
  - B-field = 120 mT on axis
  - uniformity = 0.25% over 2.5 m (same as density requirements) within 5 mm diameter
  - coil inner diameter = 20-25 cm
  - gap between coils ≥ 50 mm, for diagnostics access

→ Build begin/mid 2025



adapted from O. Grulke IPP-Greifswald



DPS – lab activities since end 2023

- Extended interferometry measurements for manuscript preparation on 2023 DPS run/lab interferometry
- Breakdown/Paschen curves studies on the single 10 m plasma setup: **example in Ar**

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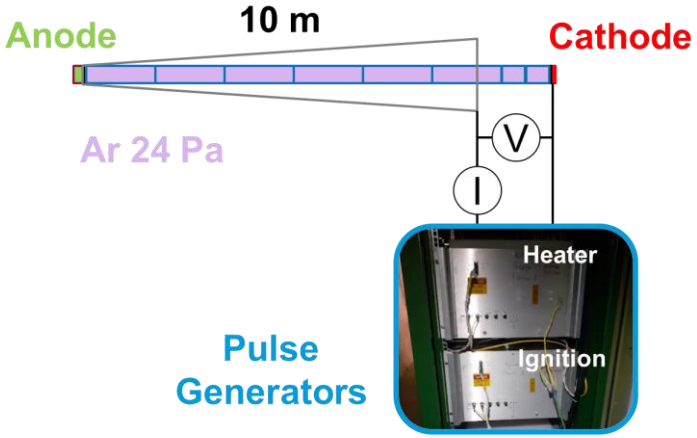

Preliminary, courtesy Carolina Amoedo

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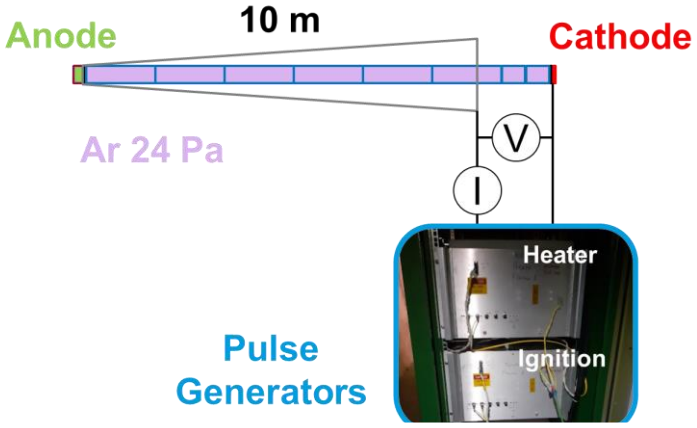
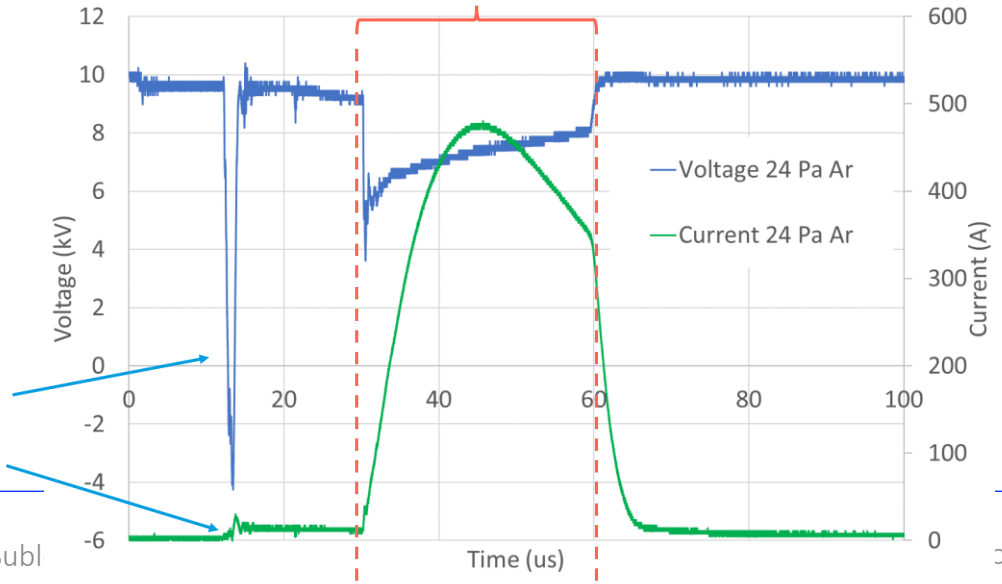


Heater pulse 5 kV, 500 A

Ignition of the plasma
Voltage breakdown -13 kV



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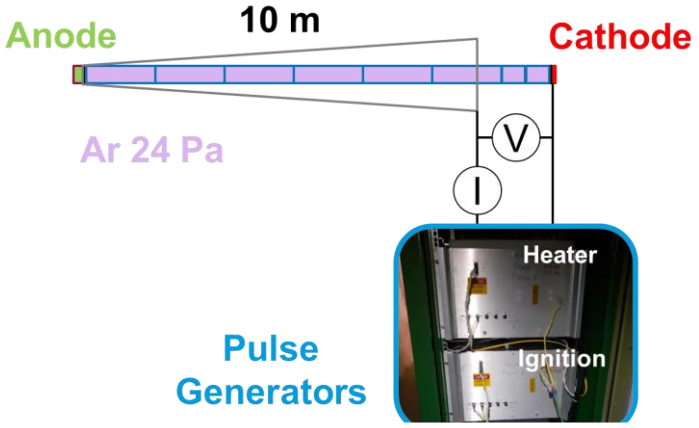

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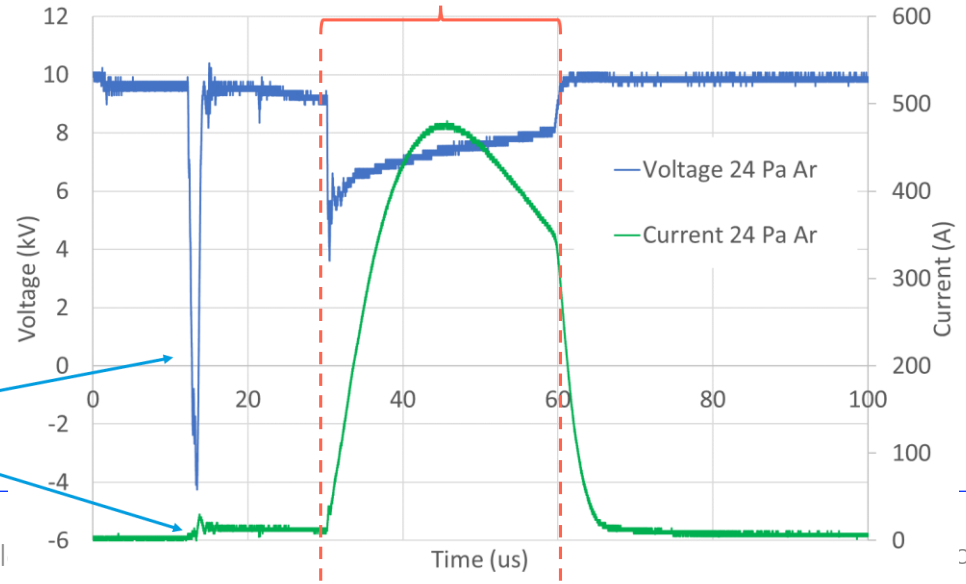

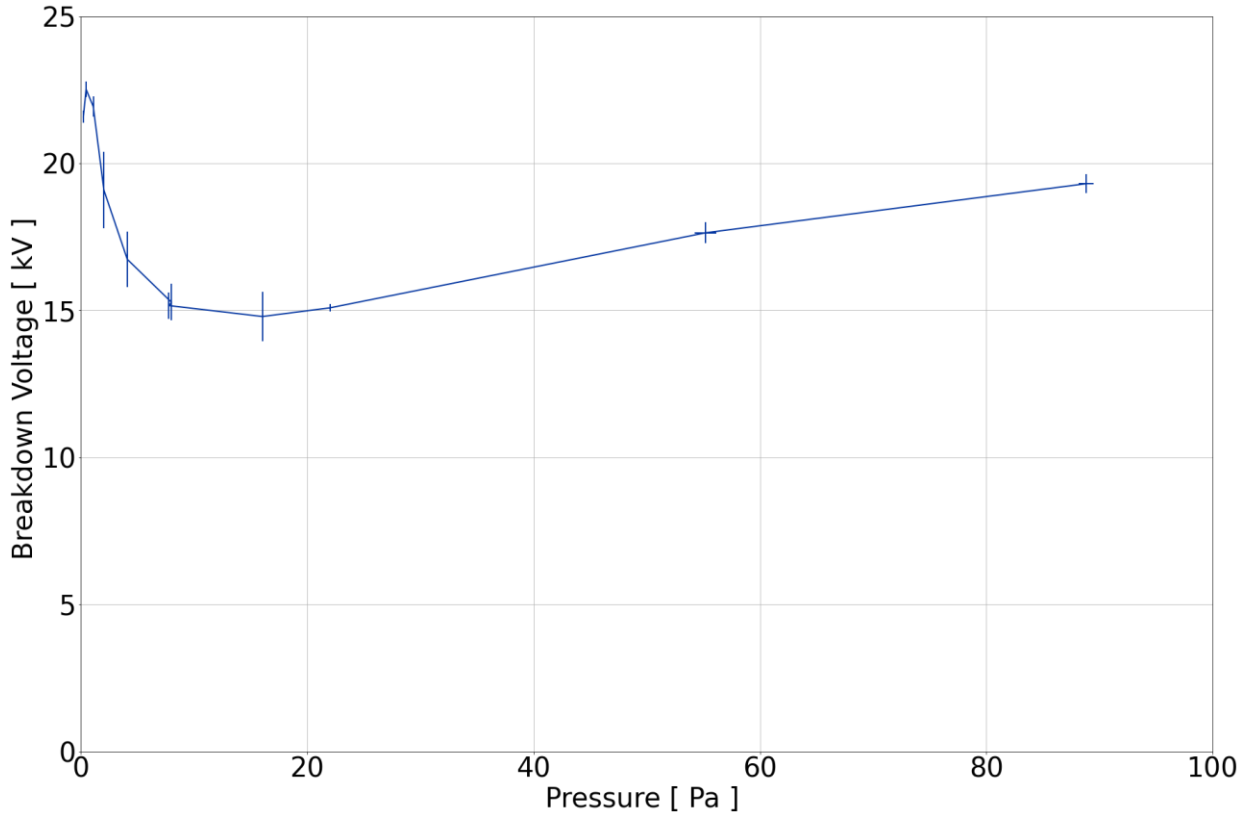

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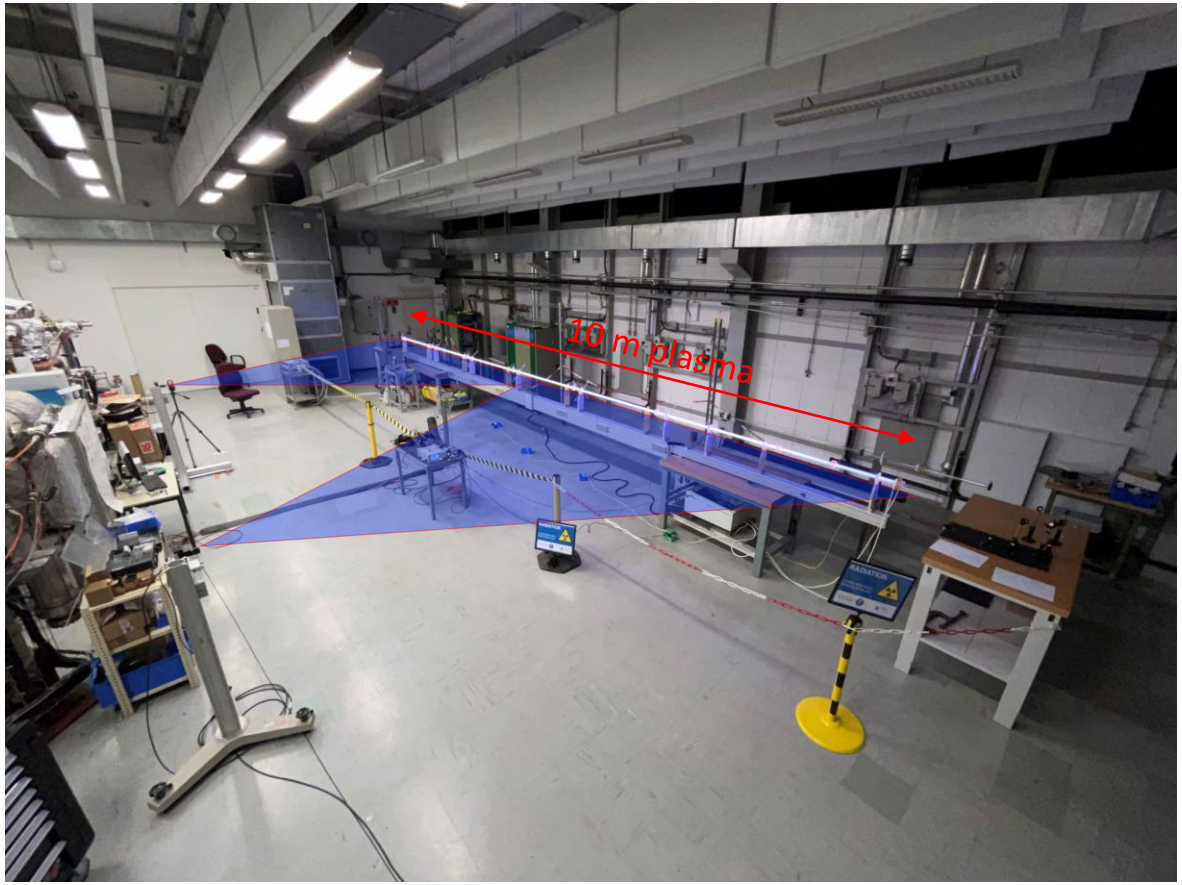
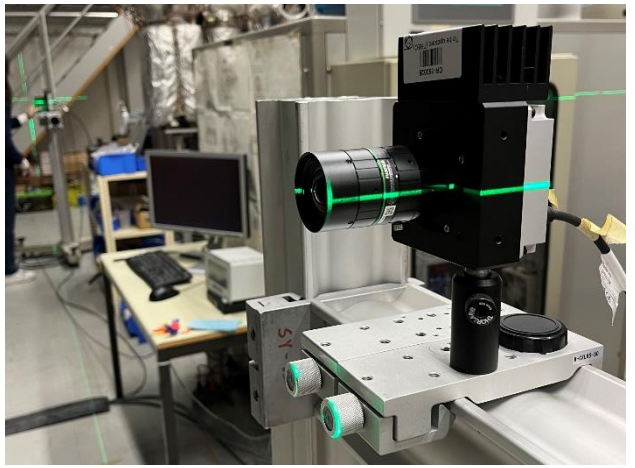
DPS – lab activities since end 2023

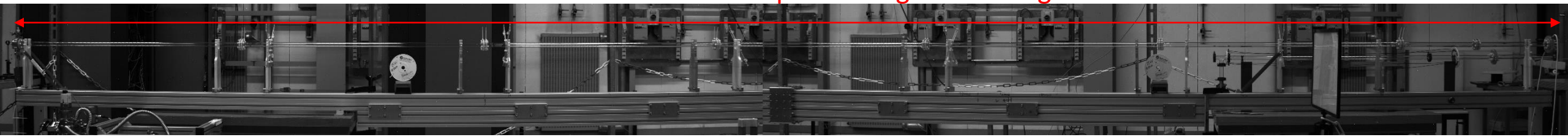
- Setup of microsecond cameras for time and space resolved plasma light recording





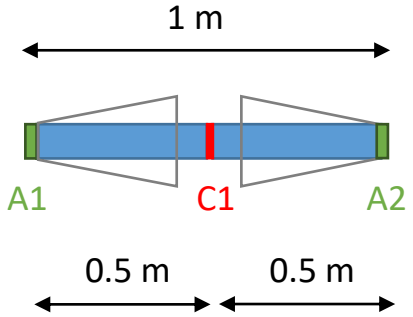
- 2x Basler Boost microsecond camera (same as for DPS run)
- Timing: triggering, incremental delay, etc. done
- Fine alignment and lens corrections pending
- Analysis of plasma light as a tool for uniformity assessment
- Look at possible “calibration” with Thomson Scattering

~ 10000 x 30 px discharge tube image



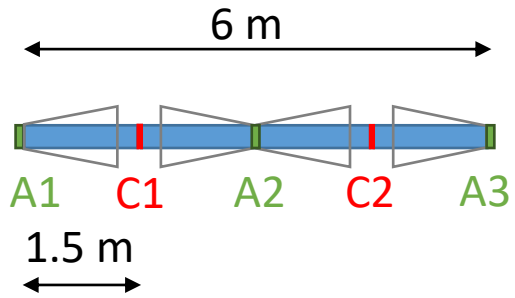
DPS 2024 program at CERN

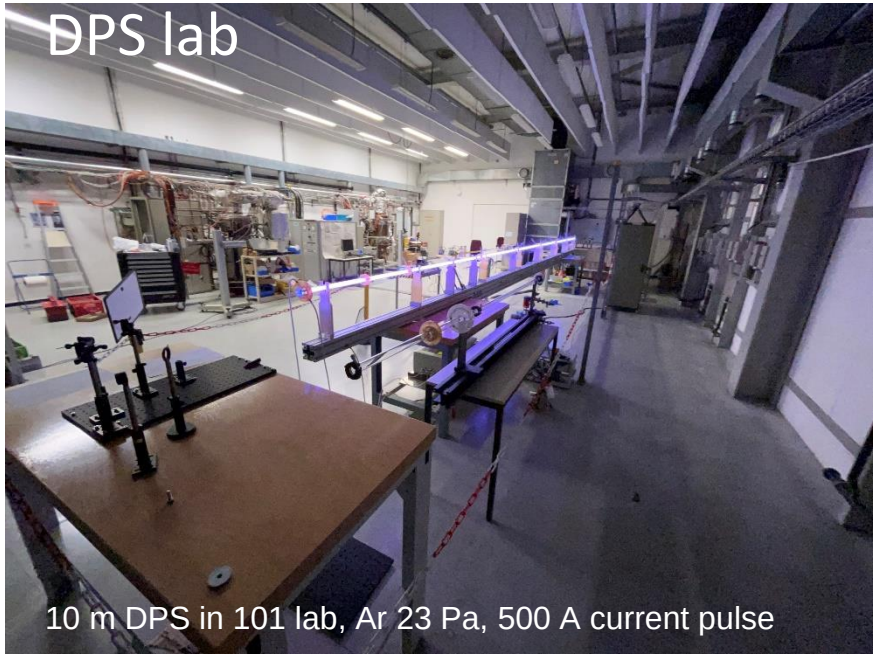
- February 2024: setup of microsecond cameras for time and space resolved plasma light recording
- Spring: measurement of plasma light with single and double plasma (10 m or 2x 5 m) and around electrodes area
- Summer/fall: Thomson Scattering on 1 m long double plasma DPS:



- Winter: quadruple plasma (1.5 m + 1.5 m + 1.5 m + 1.5 m)

with 2 pulse generators to test common anode/cathode schemes:

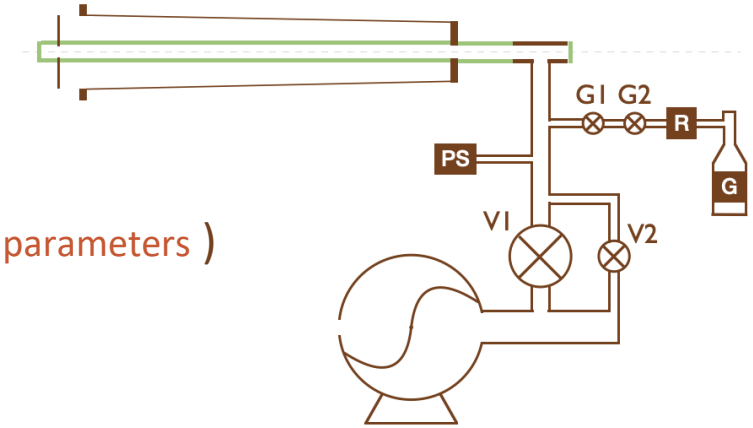




DPS IST test tube - best stability runs (in progress)

… DPS operating with total renew of gas between shots for reproducibility studies

… gas injection is the major source of density variability



… longitudinal Temp. gradient in steady state (~ 1 ºC preliminary, depends on injection parameters)

(steady state… > 15 gas changes + discharge)

… this was expected … confirms the need for planned tube & gas system temperature forcing

(even if AWAKE DPS planned to operate with smaller gas renewal)

… electrical circuit progress

… improved transformer isolation >> efficiency improved from ~ 50 % to ~ 70 %

… improved CBM winding geometry and parameters >> 100% reliability in symmetric double pin cathode currents

DPS IST test tube - planned activity

… no funds for CERN related projects presently

… thermal stabilised demo tube (prop. last CB) postponed

… relevant research for a Run 2C tube to be carried in 2024 with existing tube /equipment

- … R&D of tube and gas system for a discharge in a leaky tube (HQ beam injection)
- … improvement of axial integrated time resolved interferometry
- … technical preparation for small series construction of DPS electrical circuitry

… IST DPS tube characterisation almost complete - paper in progress

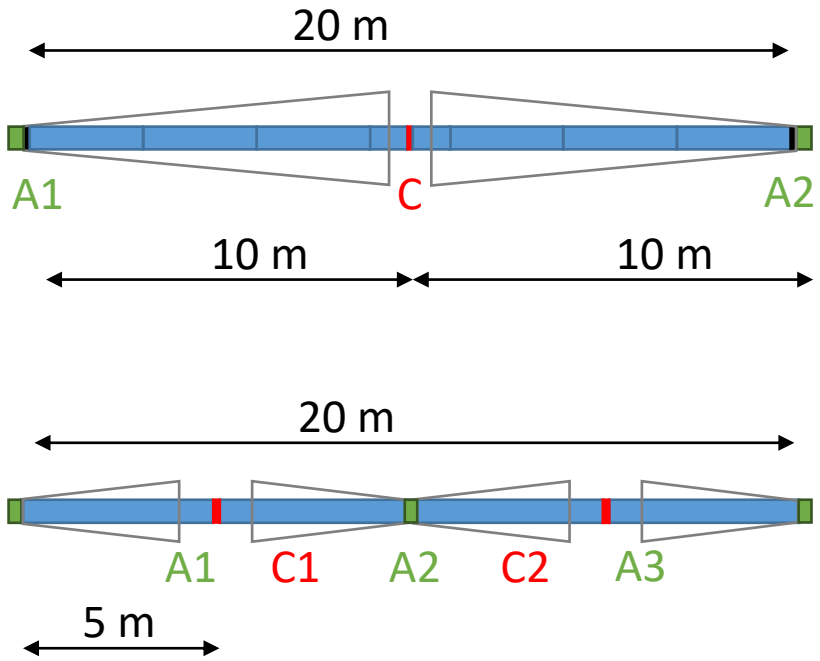
Scalability and reproducibility (> 2026)

DPS: scalability driven by tunability and arrangement of the source

Double plasma (10 m + 10 m) with common cathode

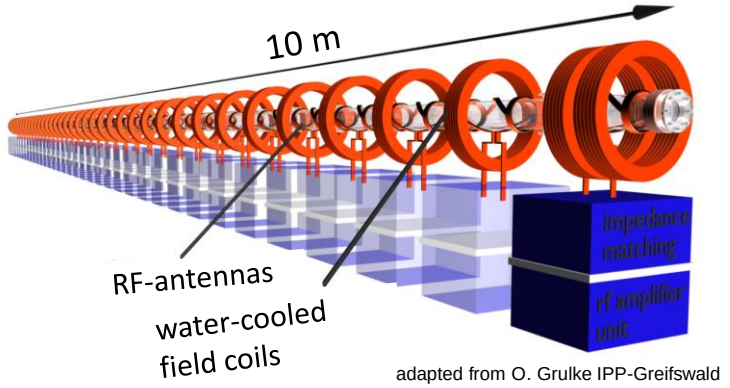
Quadruple plasma (5 m + 5 m + 5 m + 5 m): A/C/A/C/A scheme

→ New generation of high precision pulse generator (outsourced)



HPS: scalability by adding antenna/coils/generators

10 m source (4x 2.5 m unit module) with 40 antennas/RF generators



adapted from O. Grulke IPP-Greifswald

+ Address technical aspects for tunnel integration/operation: control and regulation of tube temperature/pressure/gas/interfaces...

Summary

- Focus on plasma uniformity characterisation for both sources (1 m scale) by the end of 2024
- And scalability with design studies of 2.5 m HPS and 4-segments DPS plasma
- Hardware consolidation/developments to support stability and reproducibility of the sources
- Thomson scattering setup qualified for axial profile measurements
- Several diagnostic campaigns scheduled for both sources this year

→ Plasma diagnostic forum on 19th March (organized by EPFL-SPC)