# The nonlinear APL in action

## Demonstration of the nonlinear APL with plasma-accelerated bunches

A joint project between LMU and University of Oslo (UiO)

F. Peña | SPARTA Seminar |11.06.2026

# Motivation

- Staging of Plasma Accelerators for Realizing Timely Applications [1]
  - We want to demonstrate a staging concept and provide a pre-CDR for an application

- Demonstration of staging at different stages
  - At CLEAR (CERN): we characterize the plasma lens
  - At CALA (LMU): we demonstrate the plasma lens can handle plasma-accelerated bunches as designed
  - At CLARA (UK): we demonstrate the interstage optics work as designed

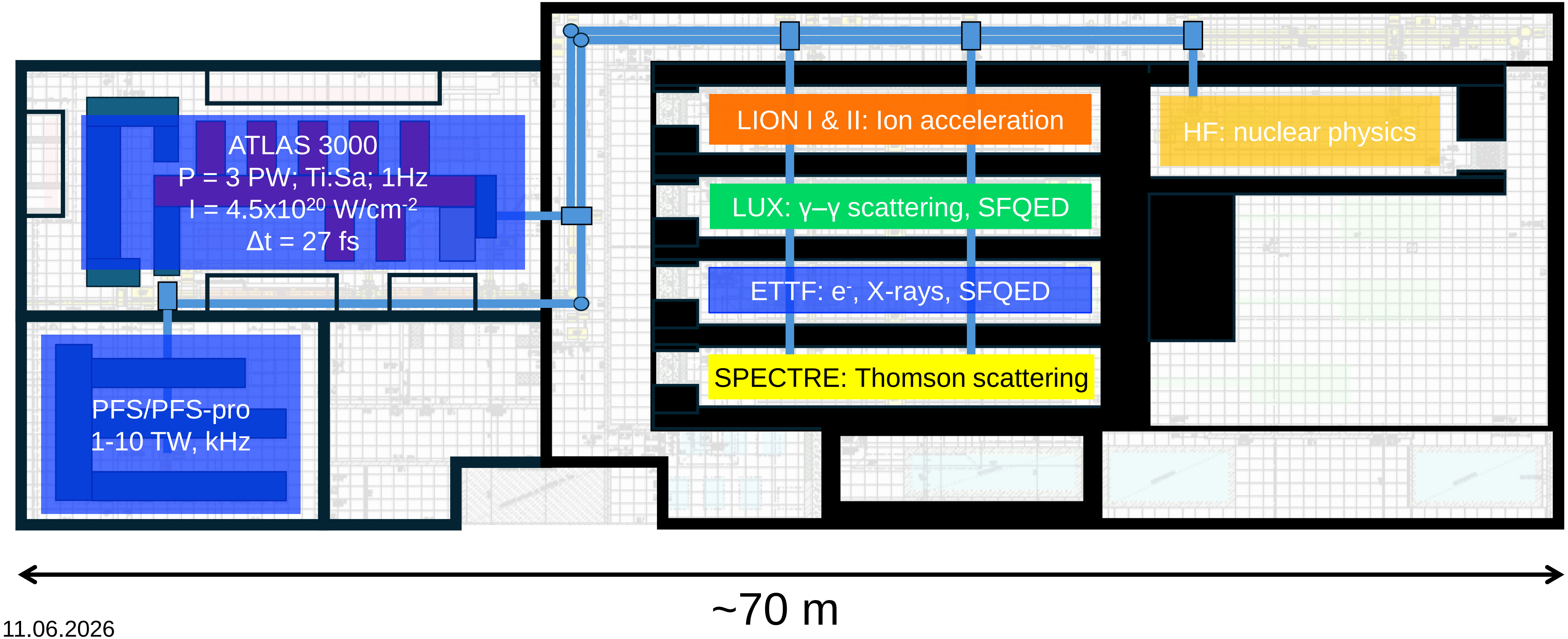
- I’m tasked with the experiments at CALA

[1] http://mn.uio.no/fysikk/english/research/projects/staging-of-plasma-accelerators-for-timely-applications/

# Centre for Advanced Laser Applications

## CALA – In Munich

- CALA is a laser facility shared by five groups with different research goals
  - All use the same high-intensity laser (except for focusing optics)



# Plasma wakefield acceleration at CALA

**AG-Karsch group**

- In my group, we focus on electron acceleration (laser **and** beam driven), and experiments/applications with these: X-ray production and imaging, Breit-Wheeler process, few-cycle probing, etc.

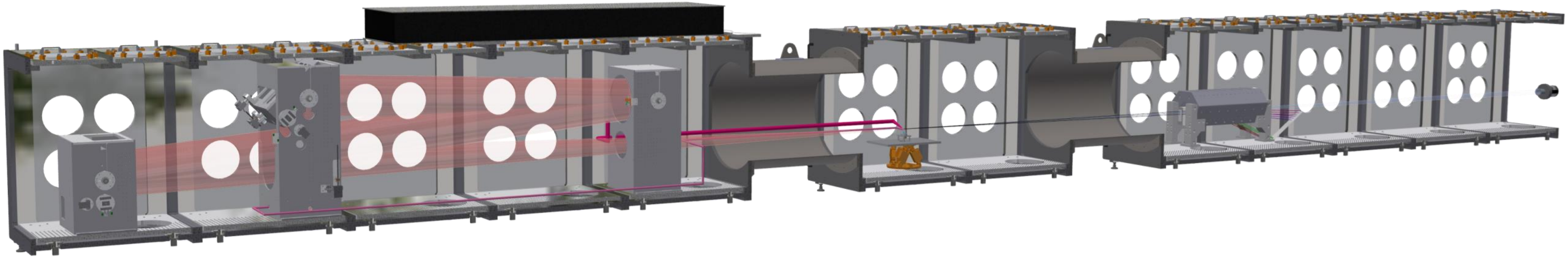
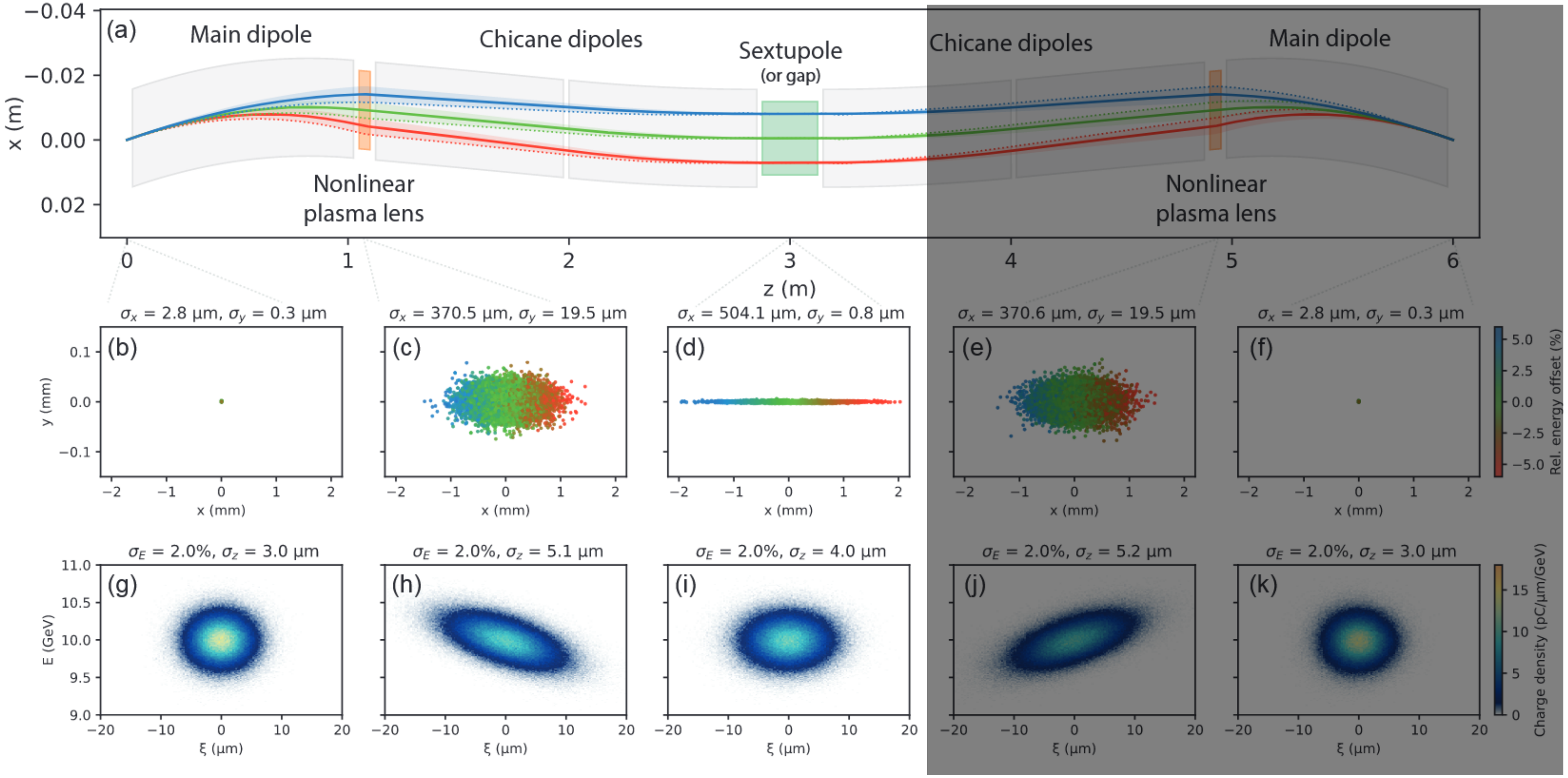


Figure: Lindstrøm et al., submitted

# The demonstration at CALA

**Main goal**

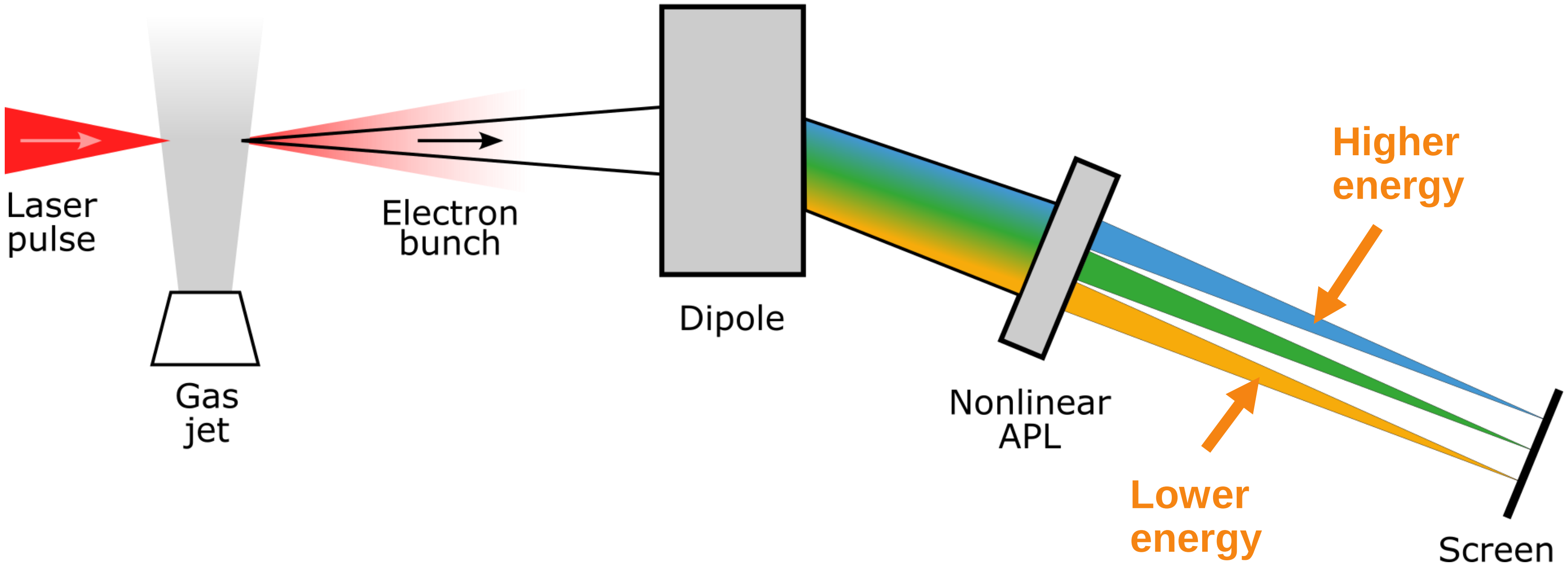
- Use the plasma lens in a **simple setup** such that
  - it's useful as an application
  - it demonstrates it's suitability for the staging optics



# An achromatically-imaging spectrometer

**A new diagnostic for high energy resolution across all energies**

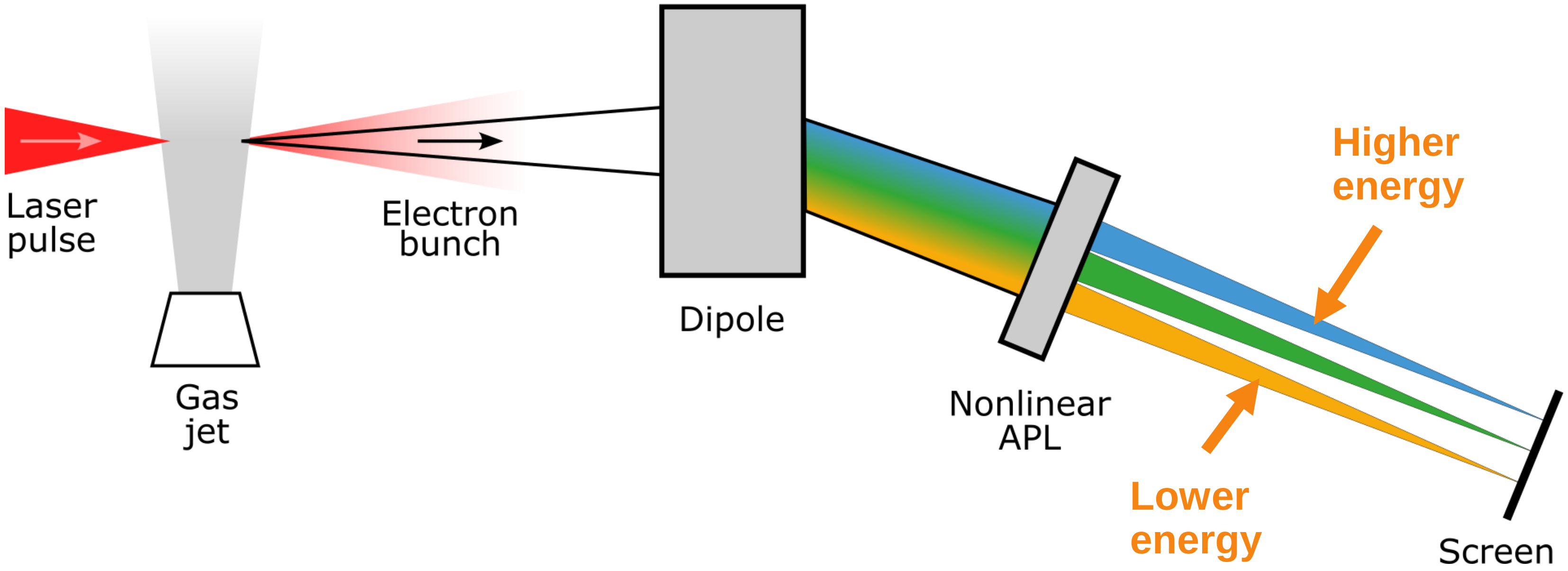
- The dipole sorts the particles vertically by their energy
- We use a focusing element that focuses with different strengths at different vertical positions
  - An active plasma lens with an adjusted B-field can do the trick
- All particles are imaged irrespectively of their energy → "achromatically"



# Implementation at CALA

## Identifying the pieces of the puzzle

- The plasma accelerator is already there, but the rest is missing:
  - Dipole magnet there is too bulky and heavy
  - No active plasma lens
  - No gas system at 3-30 mbar absolute
  - No discharge system for the plasma lens



# Symbiosis

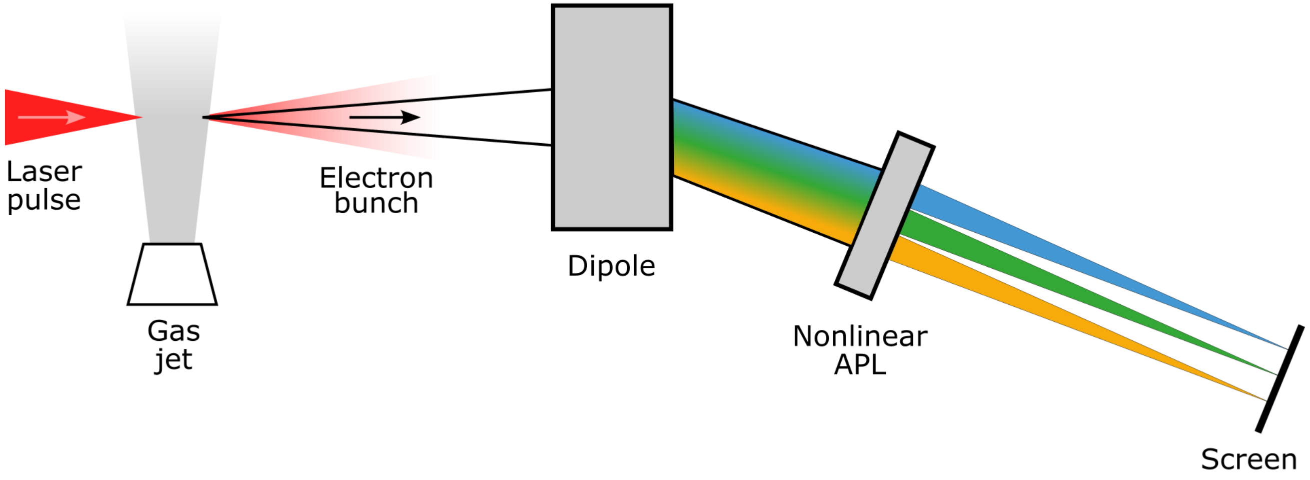
**Both projects profit**

- Good for CALA
  - The current electron spectrometer doesn't image the electrons
    - The spectrum is blurred out due to the particles' angles, i.e., divergence
    - Energy resolution is ~8%
    - With the new setup the simulations show a resolution down to 0.5% [1]
  - The lens can be used to measure the emittance of the bunches
    - Strong interest for the flagship project "LWFA–PWFA Hybrid acceleration"
- Good for SPARTA
  - Infrastructure of CALA:
    - Laser pulse
    - Well established electron acceleration
    - Large vacuum chamber and working laboratory
  - A more challenging test that increases credibility

[1] Peña *et al.*, IPAC 2025 Proceedings

# Roadmap at CALA

1. Install a plasma lens in the chamber
   - Challenges: Gas load for vacuum system; gas delivery system; discharge electronics; safety; etc.
2. Emittance measurement (linear APL)
   - With existing dipole and a new high-resolution screen–camera setup
   - Good test for gas/discharge/lens/diagnostic systems; “pays the bill” for CALA
3. Achromatic spectrometer
   - With the nonlinear APL and a compact dipole
   - Can also measure the emittance (object plane scan), validating previous step and lens nonlinearity



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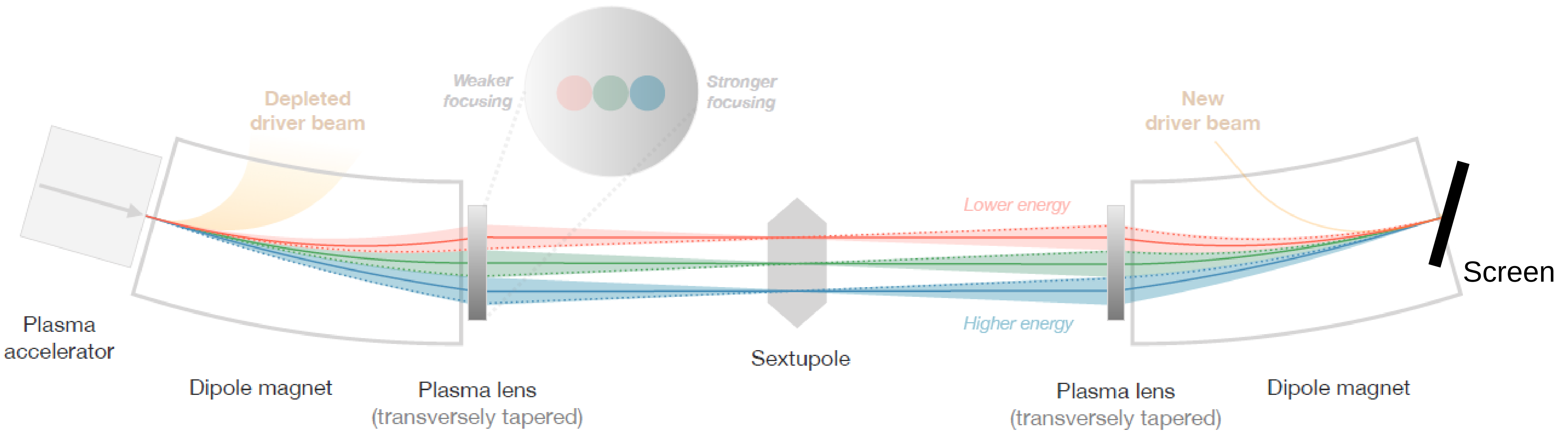


4. (aspirational) Full staging optics
   - Double and mirror the setup: add another small dipole and nonlinear APL
   - Only one nozzle, measurements on a screen

Figure: C. A. Lindstrøm

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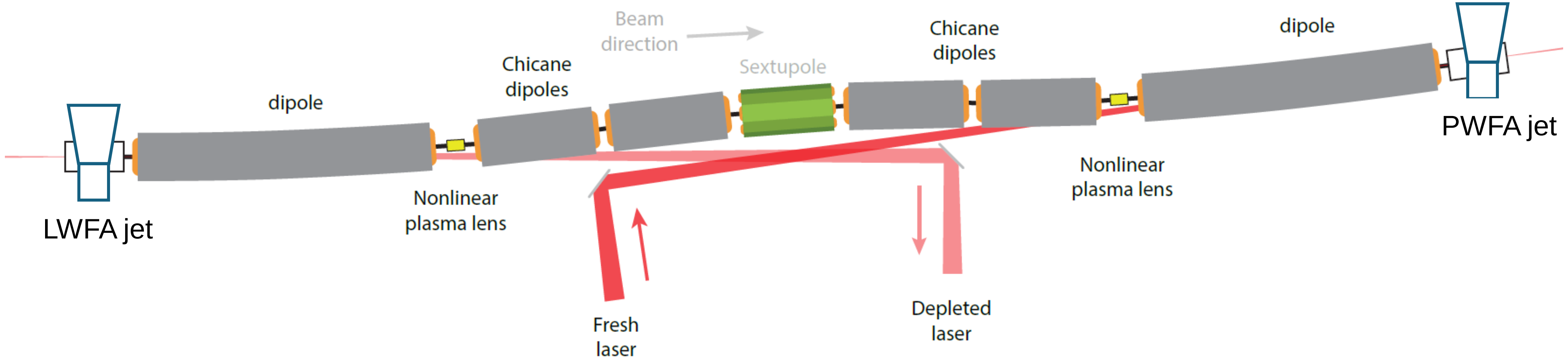


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   - Double and mirror the setup: add another small dipole and nonlinear APL
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5. (very aspirational) Hybrid acceleration
   - Adding a PWFA nozzle, and smaller chicane dipoles
   - Setup allows to optimize the driver bunch length and beam size → high efficiency

Figure: C. A. Lindstrøm

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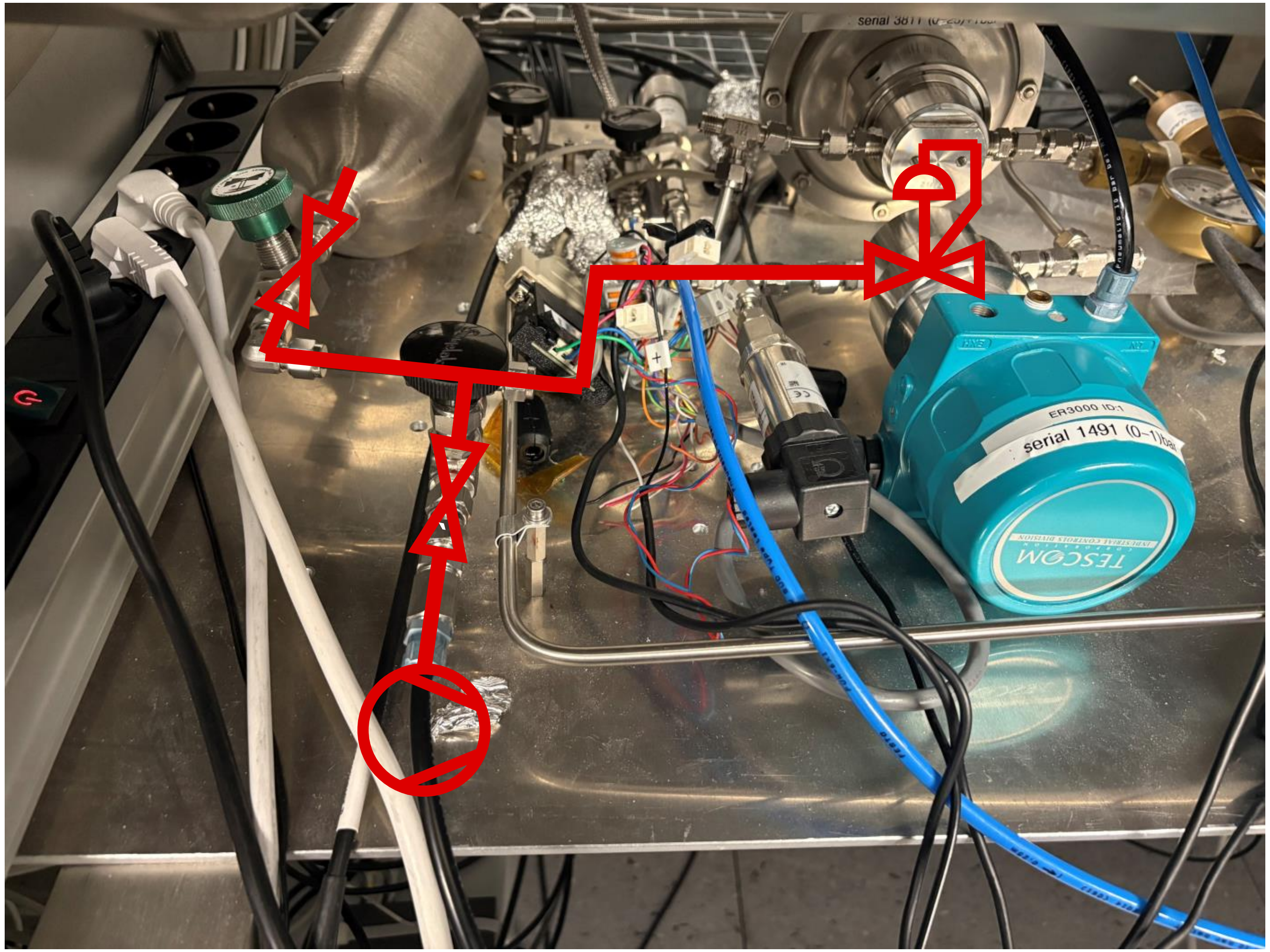
# Progress so far

## Gas system

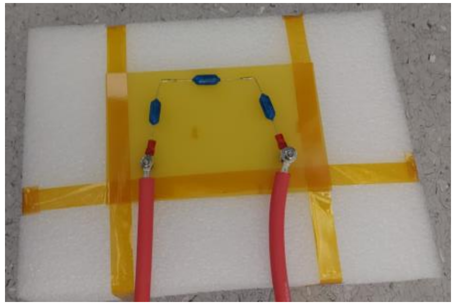
- Can the vacuum system handle the extra gas load introduced by the plasma lens?
  - YES, tested simultaneously with LWFA and PWFA stage
- How do we deliver 3–30 mbar absolute to the plasma lens?
- Pressure down to 2 mbar
- Leakage of ~1 mbar/s in the pipe; negligible compared to 1l buffer volume
- Pressure adjustable remotely



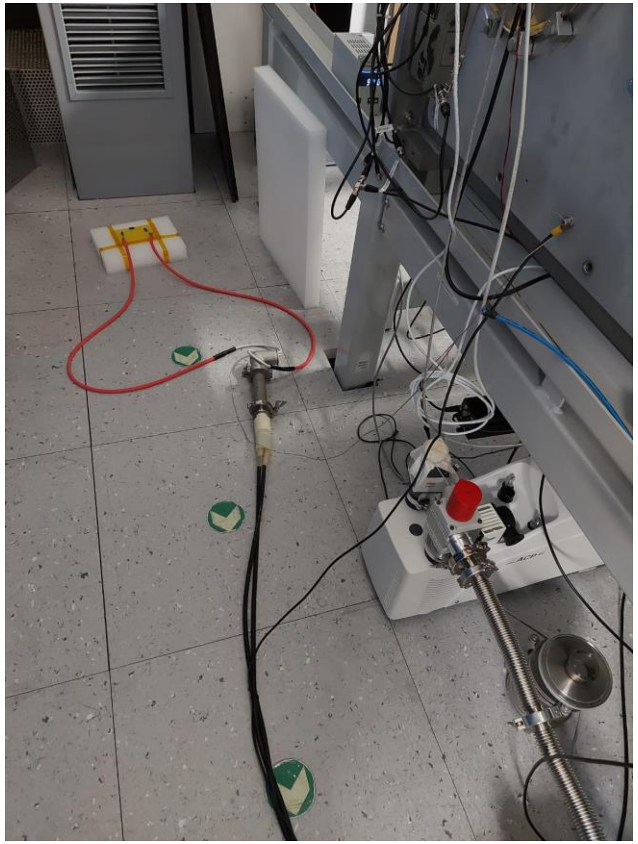

Adapted/improved the gas delivery system

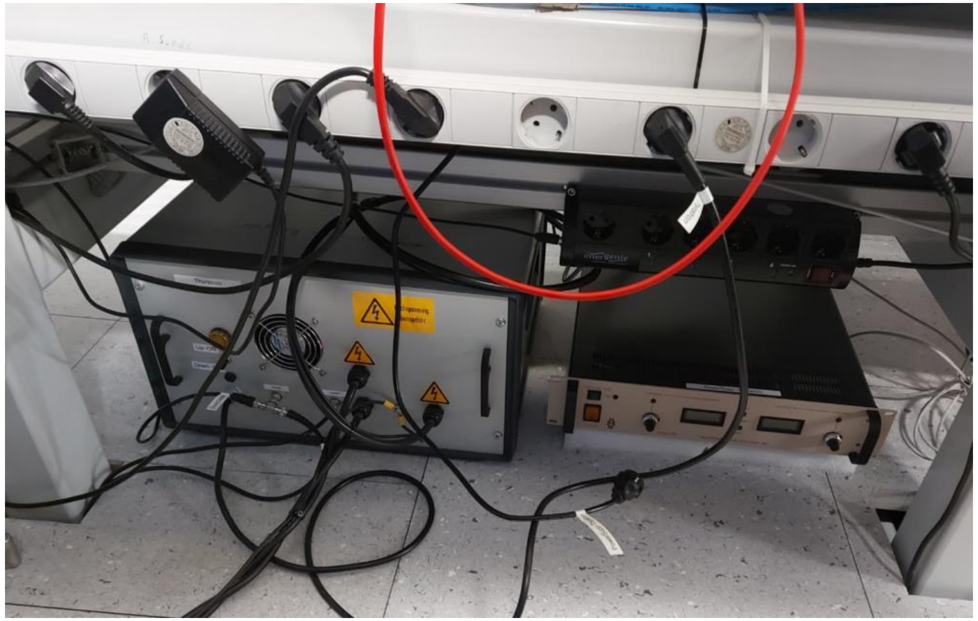
# Progress so far

## Discharge system



- How do we provide the discharge for the APL?
    - Marx Banks as at CLEAR?
    - Revive an old Thyratron (30 kV) of pre-CALA times?



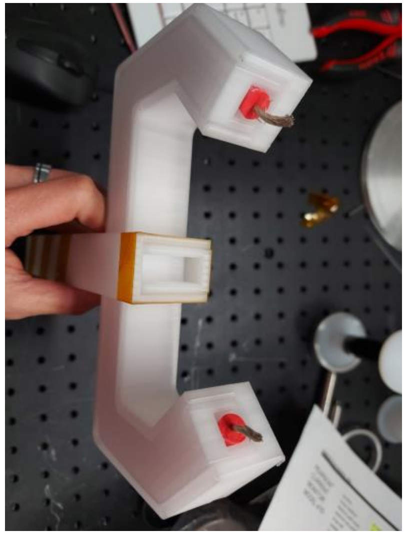


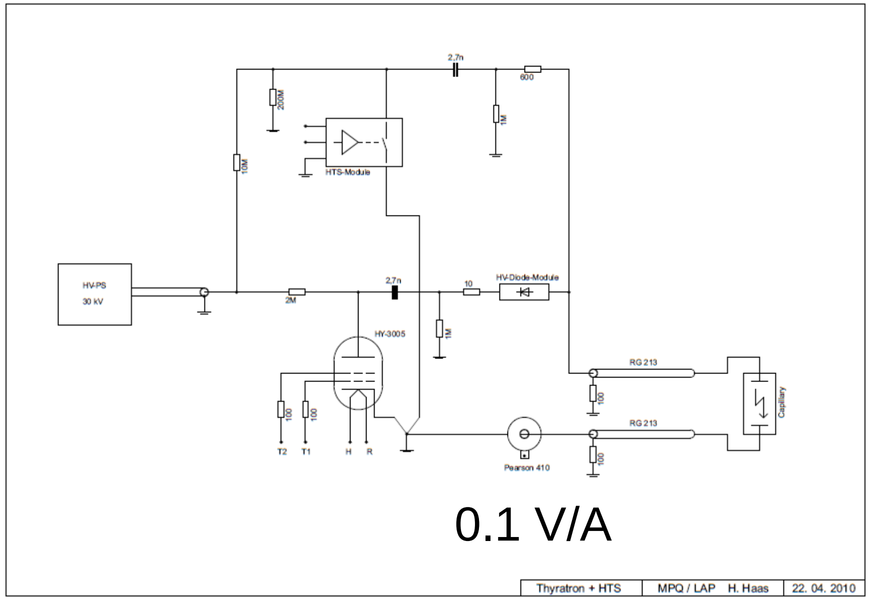
Thyratron is
- repaired (thanks to Harald Haas of MPQ)
- conditioned with a dummy load
- safe operation was possible

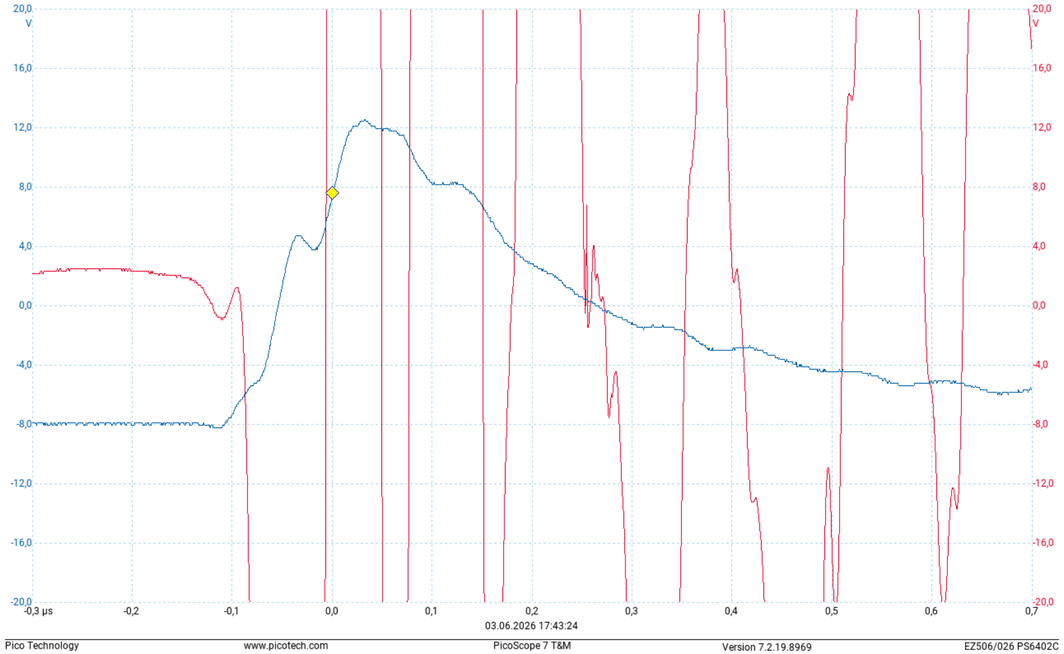
# Progress so far

## Discharge system; Conditioning

- I have conditioned/tested the Thyratron with a dummy load (in air)
- A digital oscilloscope is now installed to record the current during experiments



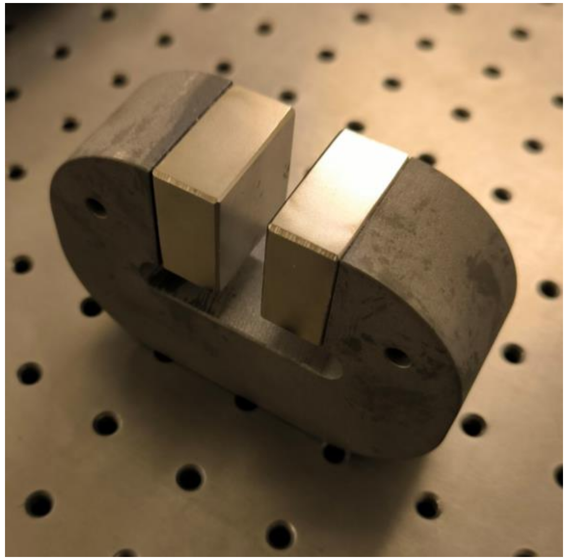


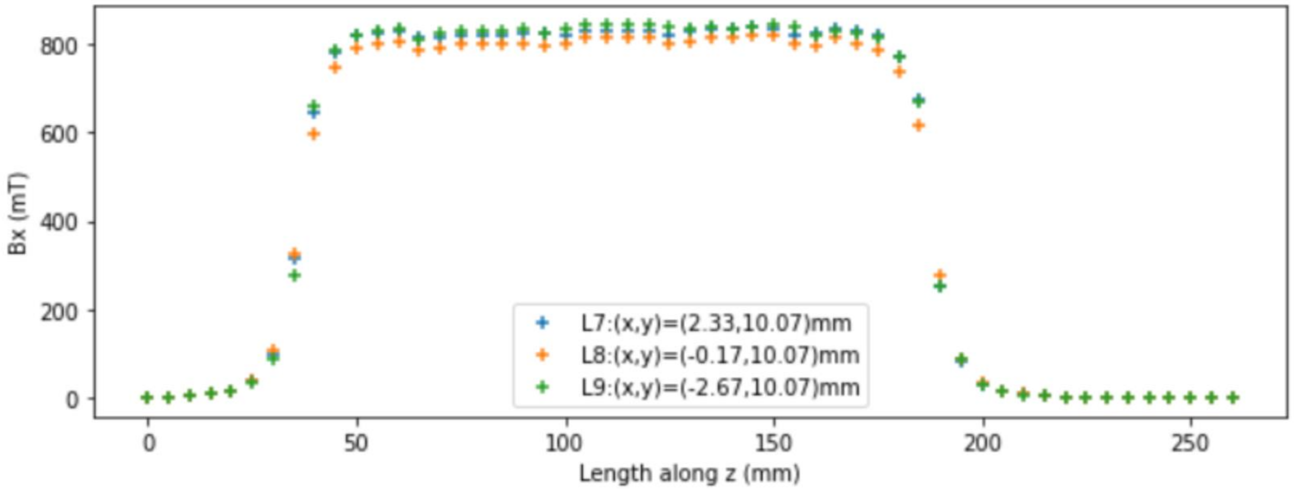




# Progress so far

**Compact magnet**

- Pierre, Jonas from ILab and me have designed and constructed a new magnet dipole
- Goals:
    - Modular design
    - Easy modifiable since it’s our design and we have control
    - To be used in other future experiments, e.g., CLARA or future SPARTA machine
    - Ideally cheap 1000-1500 NOK per module (5 modules)
    - Pierre hast characterized the magnetic field





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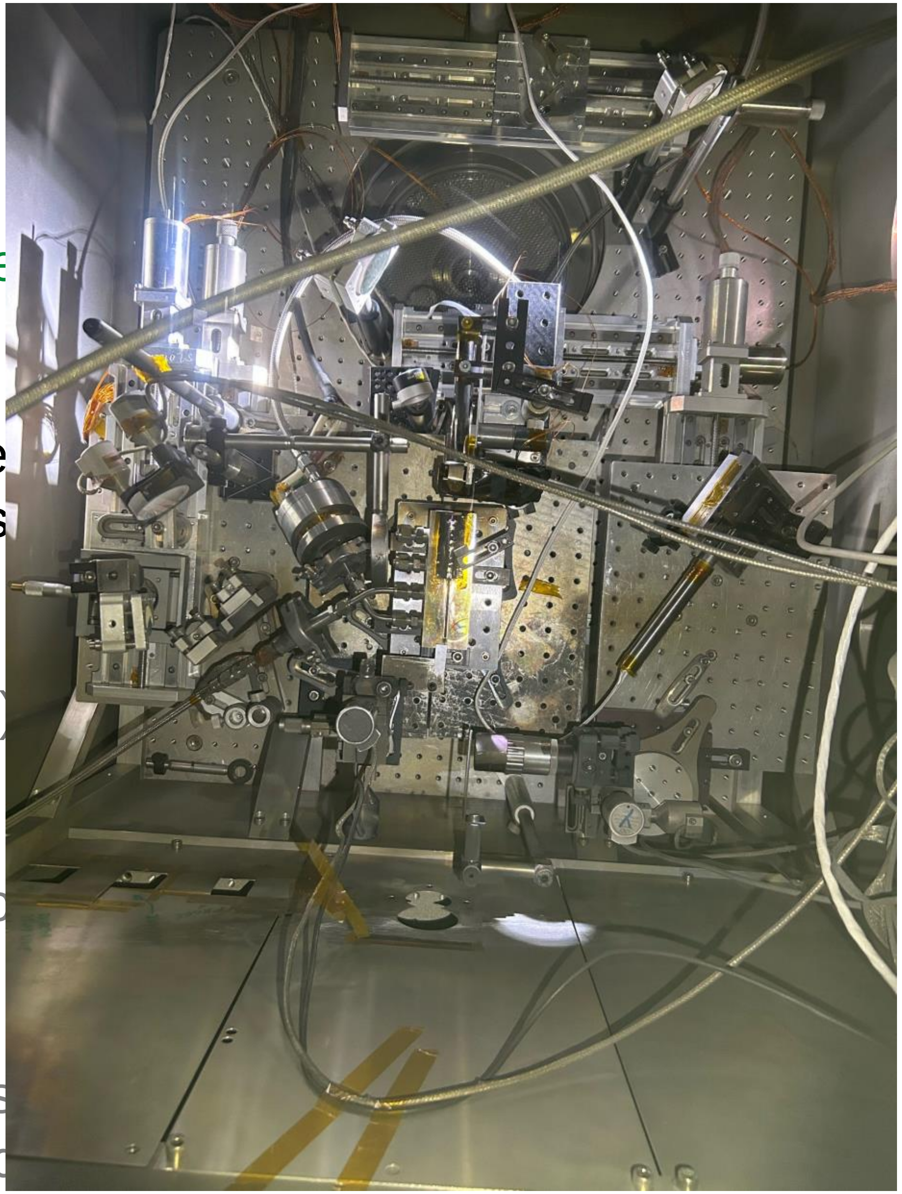
Next step: test all systems simultaneously, i.e., the discharge with the plasma lens in vacuum



# Some thoughts/open questions

- The current magnet design is not a sector dipole
  - This will lead to edge focusing and complicate analysis
  - For the next iteration it should be changed to a sector dipole

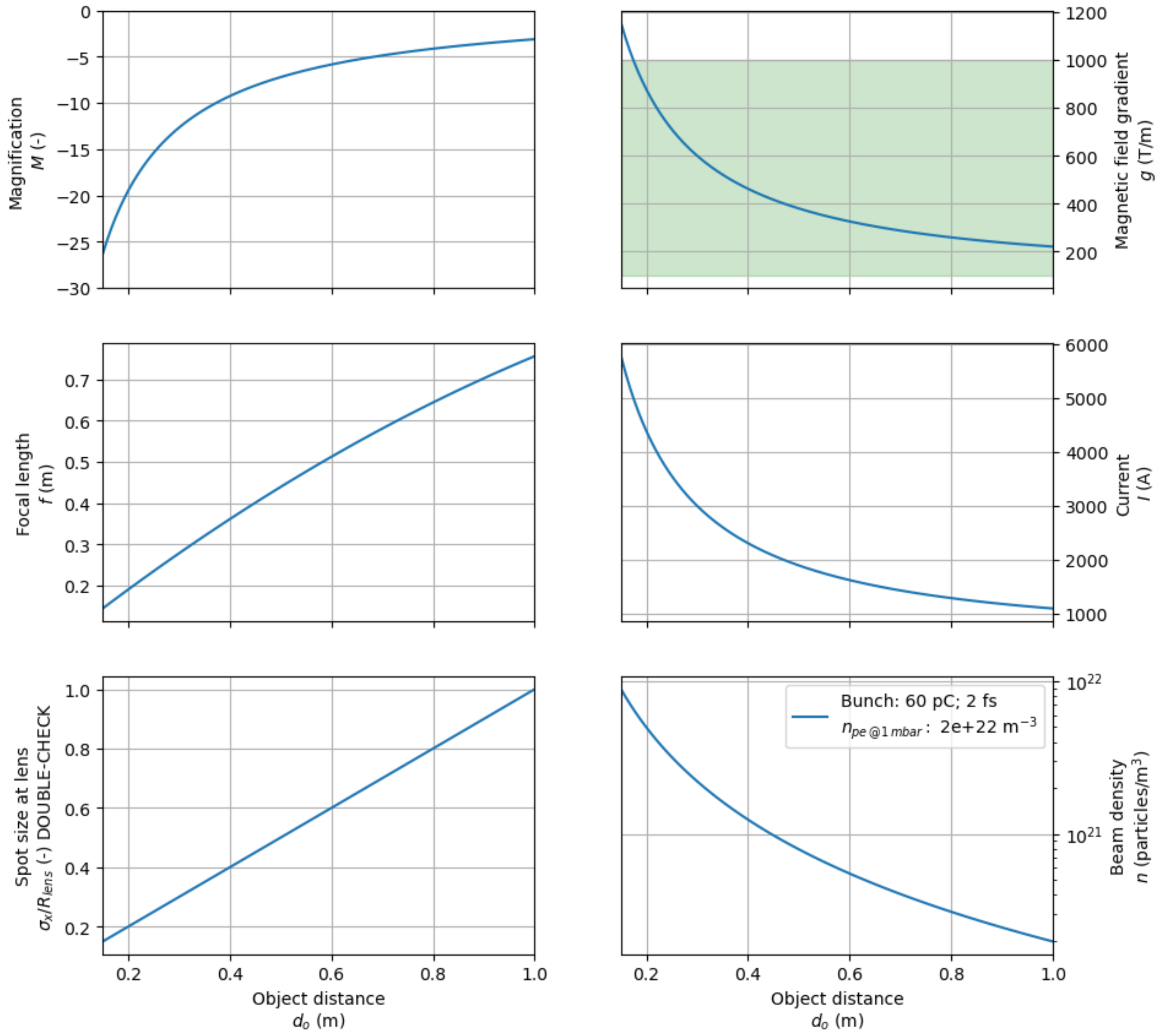
- Do we have a fallback if the current of the plasma lens is too low?

# Thank you

# Backup slides

# Imaging parameters of the lens

- L_tot = 4.1  # [m]
- L_lens = 0.02  # [m]
- Energy = 1E9  # [eV]
- divergence = 1E-3  # [rad]
- R_lens = 1E-3  # [m]
- d_o = np.linspace(0.15, 1, 100)
- pressure = 1E-3  # [bar]



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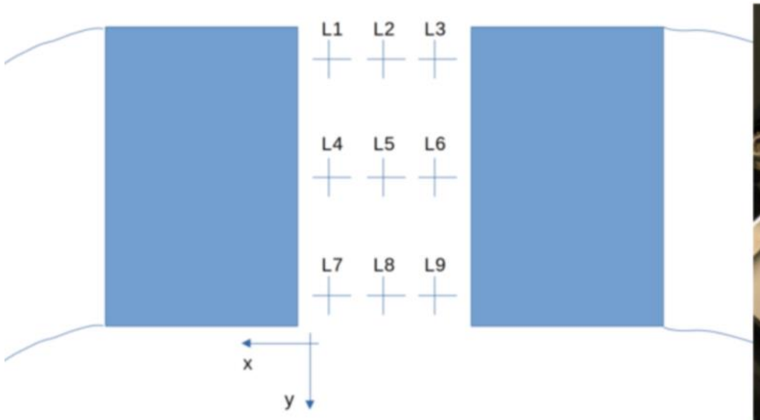
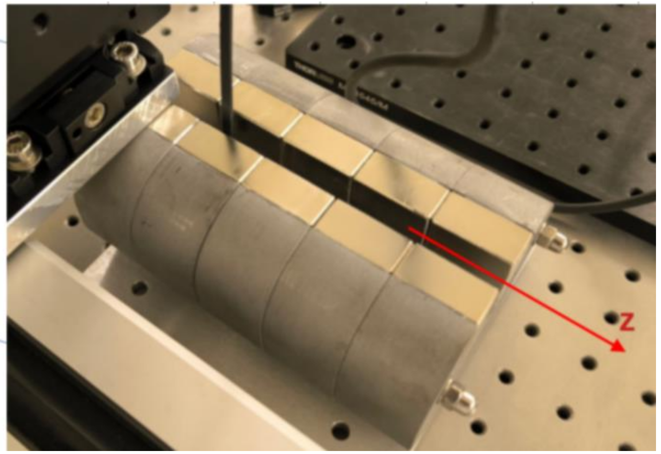
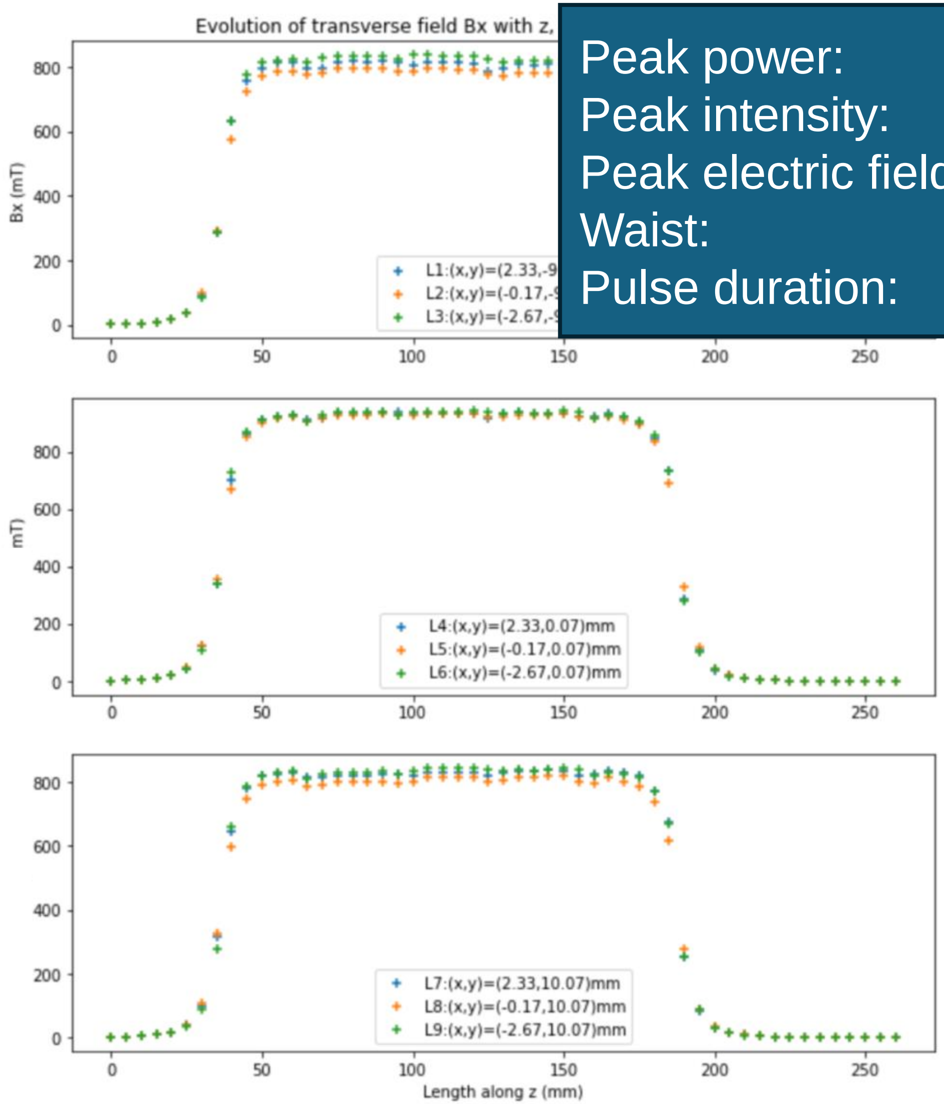
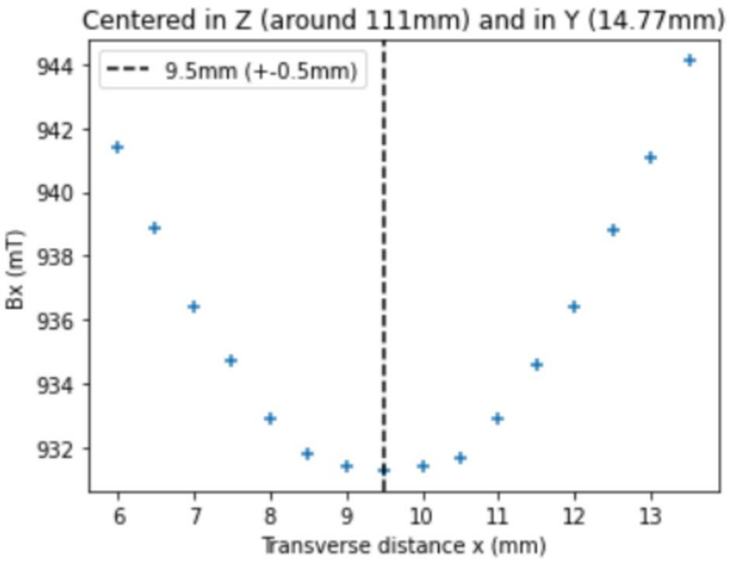
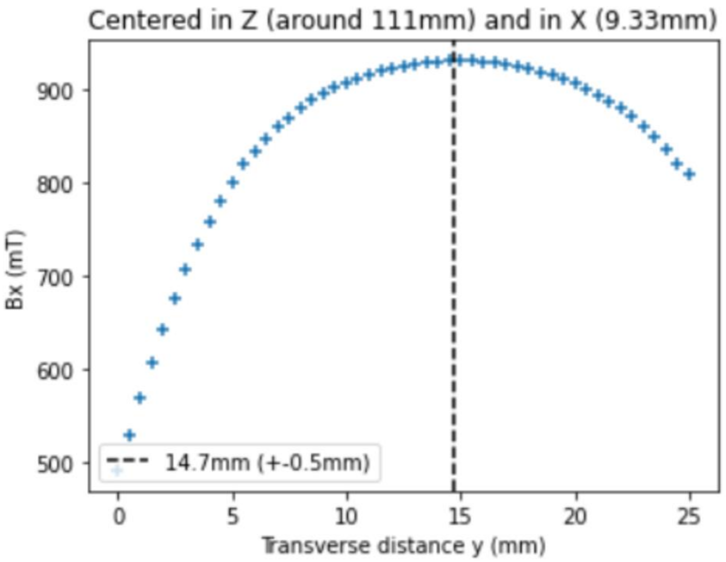



Peak power: 3
Peak intensity: 4.
Peak electric field: 5
Waist: 20
Pulse duration: 27



# Laser parameters

- aa

| | |
|---|---|
| Peak power: | 3 PW |
| Peak intensity: | 4.5 $10^{20}$ W/cm$^{-2}$ |
| Peak electric field: | 58 TV/m |
| Waist: | 20 um |
| Pulse duration: | 27 fs |