2nd Townhall Meeting High Gradient Accelerator Plasma/Laser
Friday, 21st May 2021

High beam quality R&D at SPARC_LAB

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on behalf of the collaboration

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Motivation

- PWFA experiments at SPARC_LAB to demonstrate the preservation of high quality electron beams to drive a plasma-driven FEL
    - **Energy spread compensation**
    - Proper transport and matching from plasma to the undulator
    - **Jitter minimization**
        - **Plasma discharge stabilization**
            - **Plasma density jitter**
        - **Arrival Time Jitter**
    - Driver Removal
    - R&D on diagnostics
- **Path towards EuPRAXIA@SPARC_LAB test user facility**
    - **Miniaturization** of ancillary components to move towards a **compact facility**
        - accelerating modules, diagnostics, measurement stations, beam position monitors, ..

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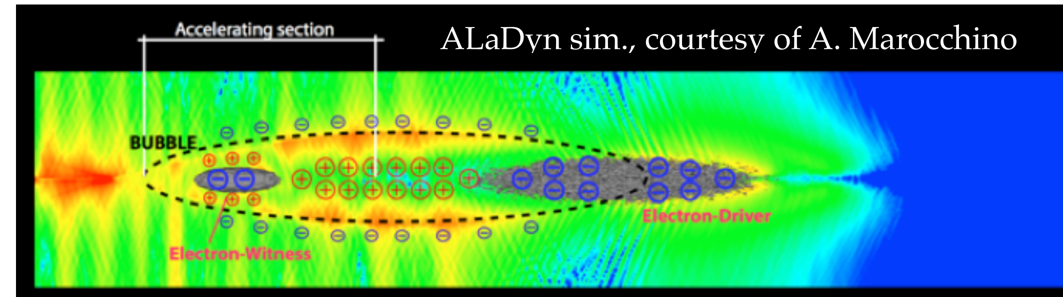
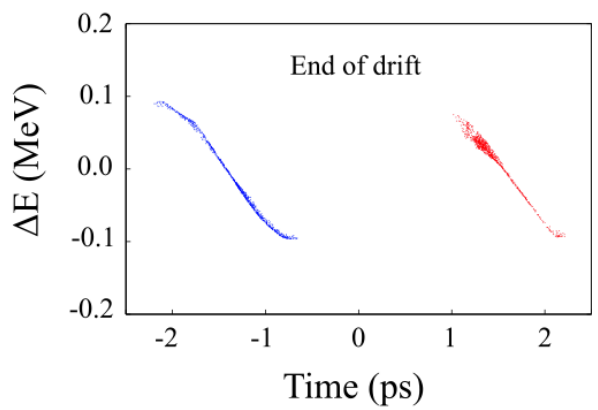
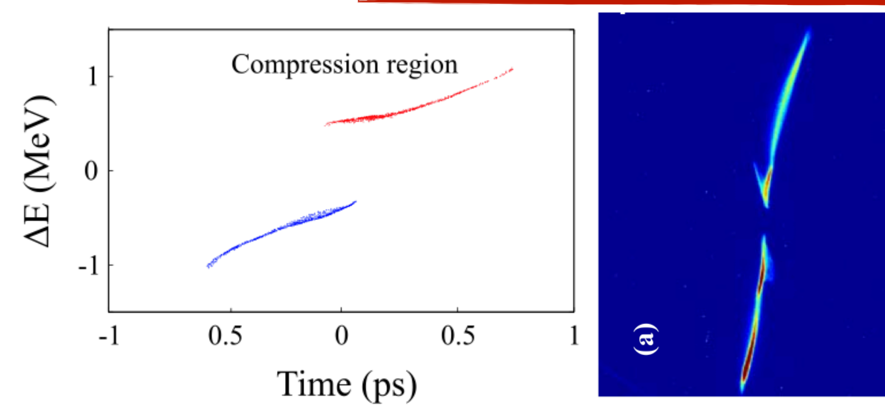
PWFA at SPARC_LAB

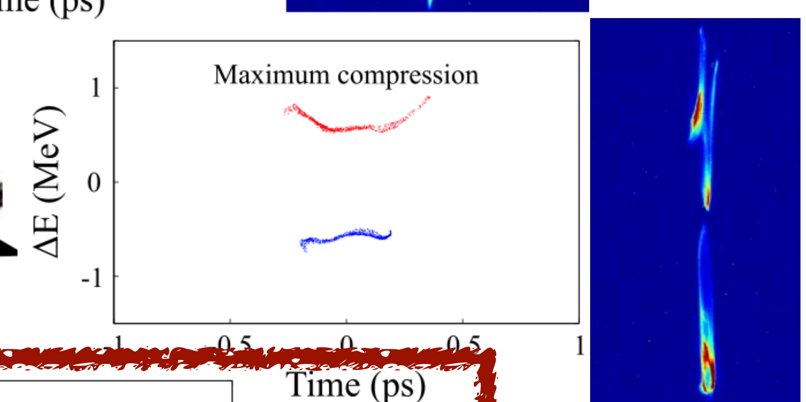
- **High quality** $\varepsilon_n \ll 1mm\ mrad, I_{peak} \sim kA, \frac{\Delta\gamma}{\gamma} \ll 1\%$
  - External injection of high brightness electron beams

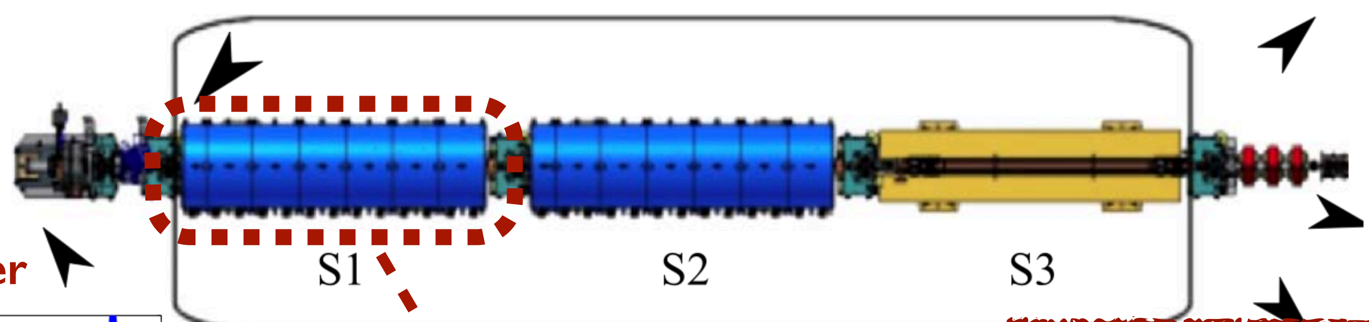


$\lambda_p \approx 330\mu m\ @\ n_p = 10^{16} cm^{-3}$

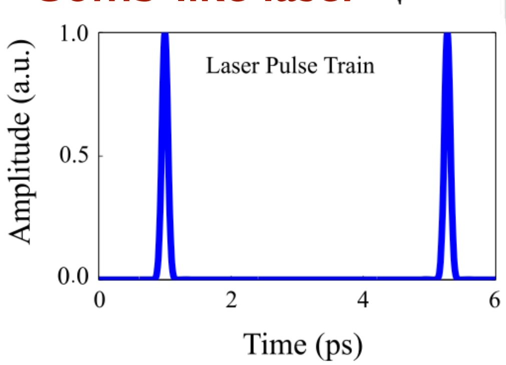




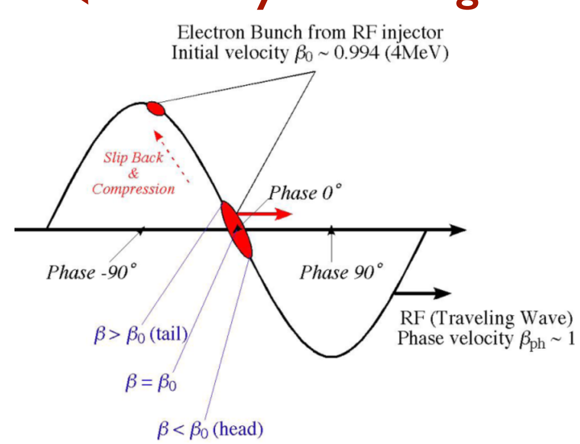


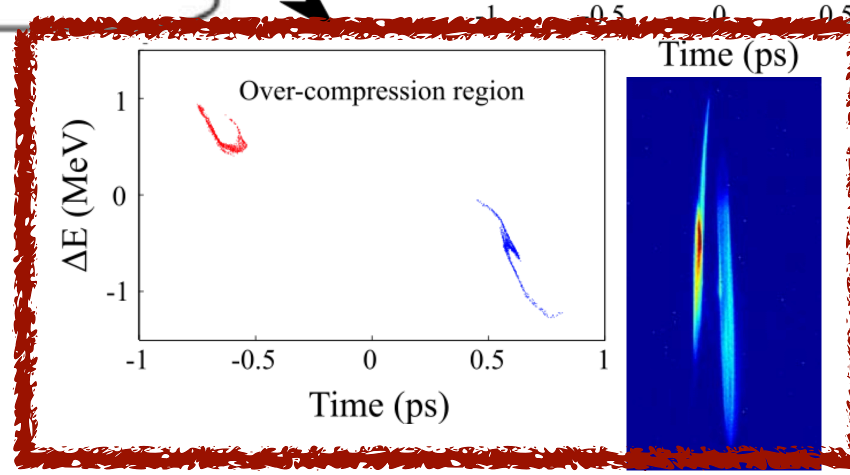


Comb-like laser



Velocity bunching





- **P. O. Shea et al.**, Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- **M. Ferrario et al.**, Int. J. of Mod. Phys. B, 2006

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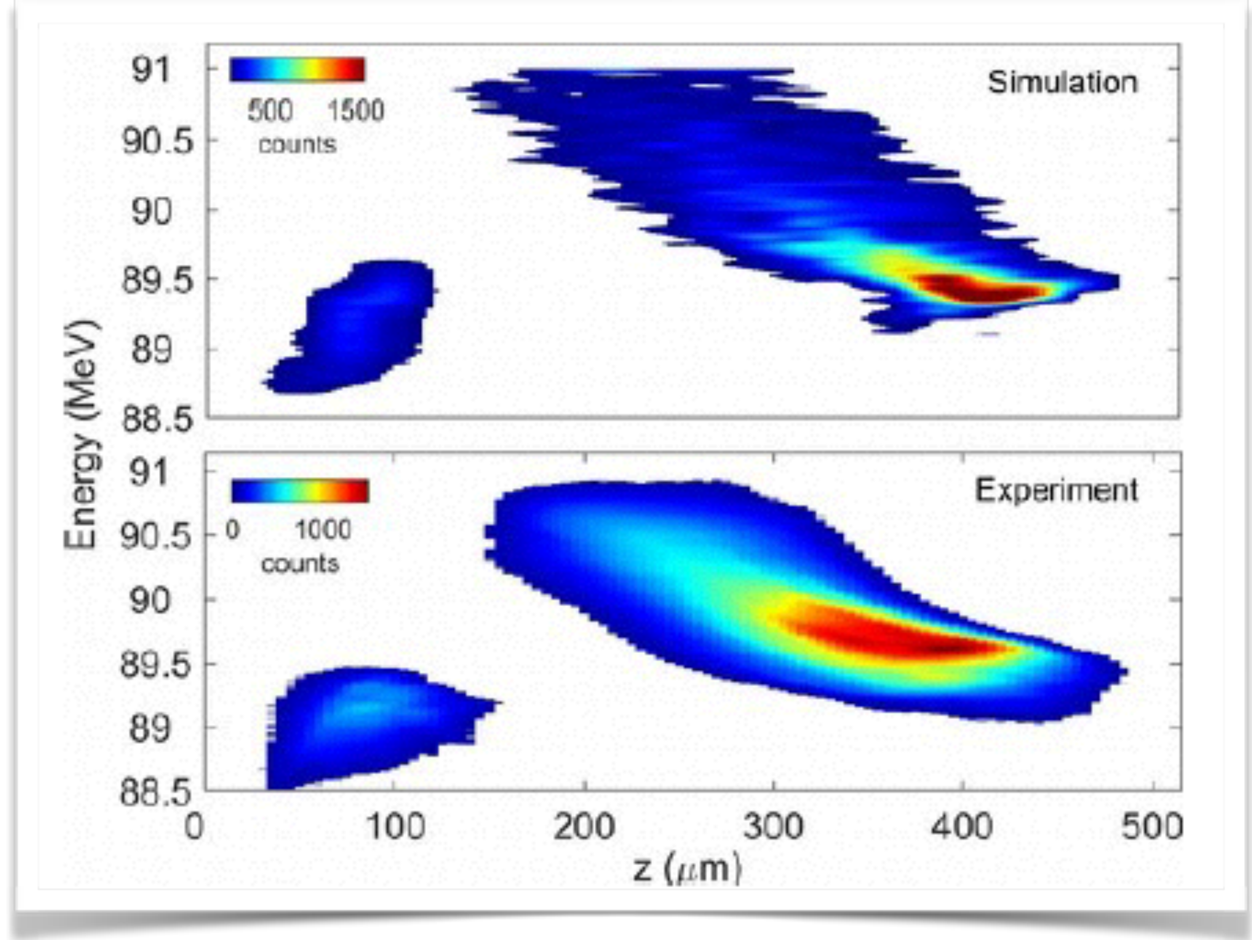
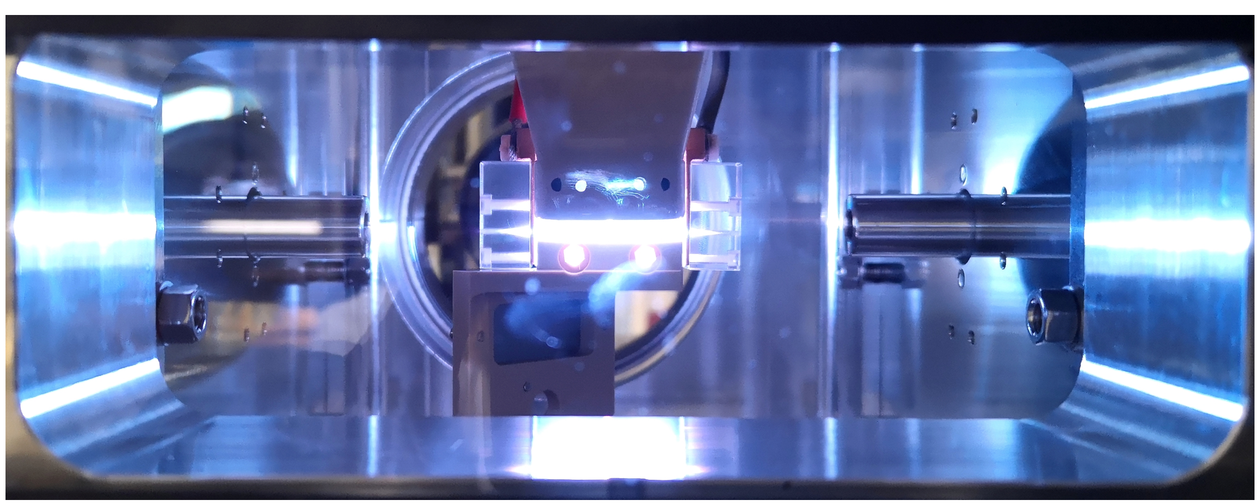
Two-beams configuration

- Two-bunches configuration produced directly at the cathode with laser-comb technique
  - 200 pC driver followed by witness bunch (20 pC)
- Ultra-short durations (200 fs + 30 fs)
- Separation approximately equal to 3/4 of the plasma wavelength (~1 ps)





- 3 cm long 3D-printed plastic capillary, 1 mm diameter aperture
- plasma is produced by ionizing hydrogen gas, injected through two inlets, by means of a high-voltage discharge (12 kV, 300 A) at 1 Hz repetition rate

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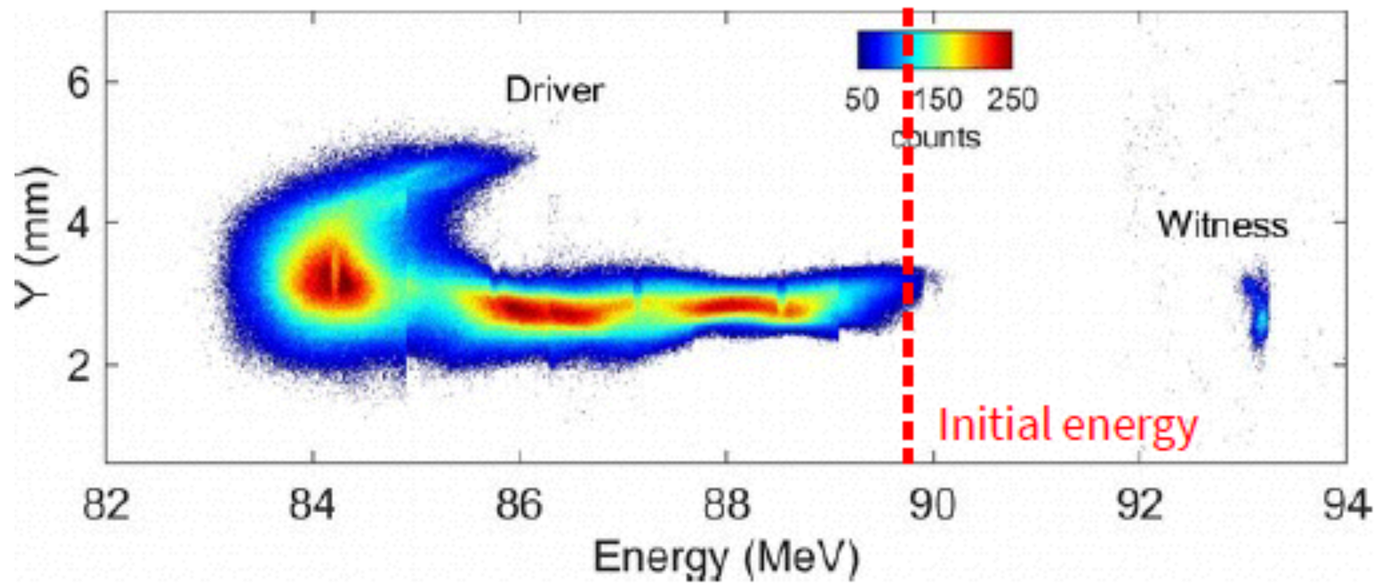
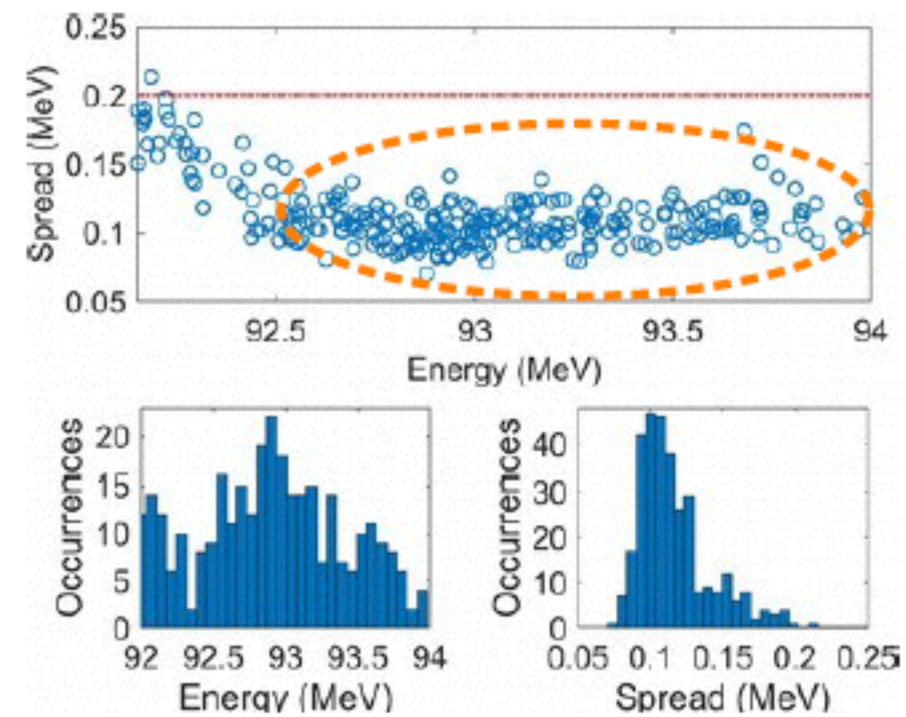
Energy Spread Minimization

- 4 MeV acceleration in 3 cm plasma with 200 pC driver
  - ~133 MV/m accelerating gradient
  - $2\text{x}10^{15}$ cm^{-3} plasma density
- First ever demonstration of energy spread reduction
  - Spread from 0.2% to 0.12%





Energy jitter of the witness energy is 0.5 MeV

nature physics
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https://doi.org/10.1038/s41567-020-01116-9
Check for updates

Energy spread minimization in a beam-driven plasma wakefield accelerator

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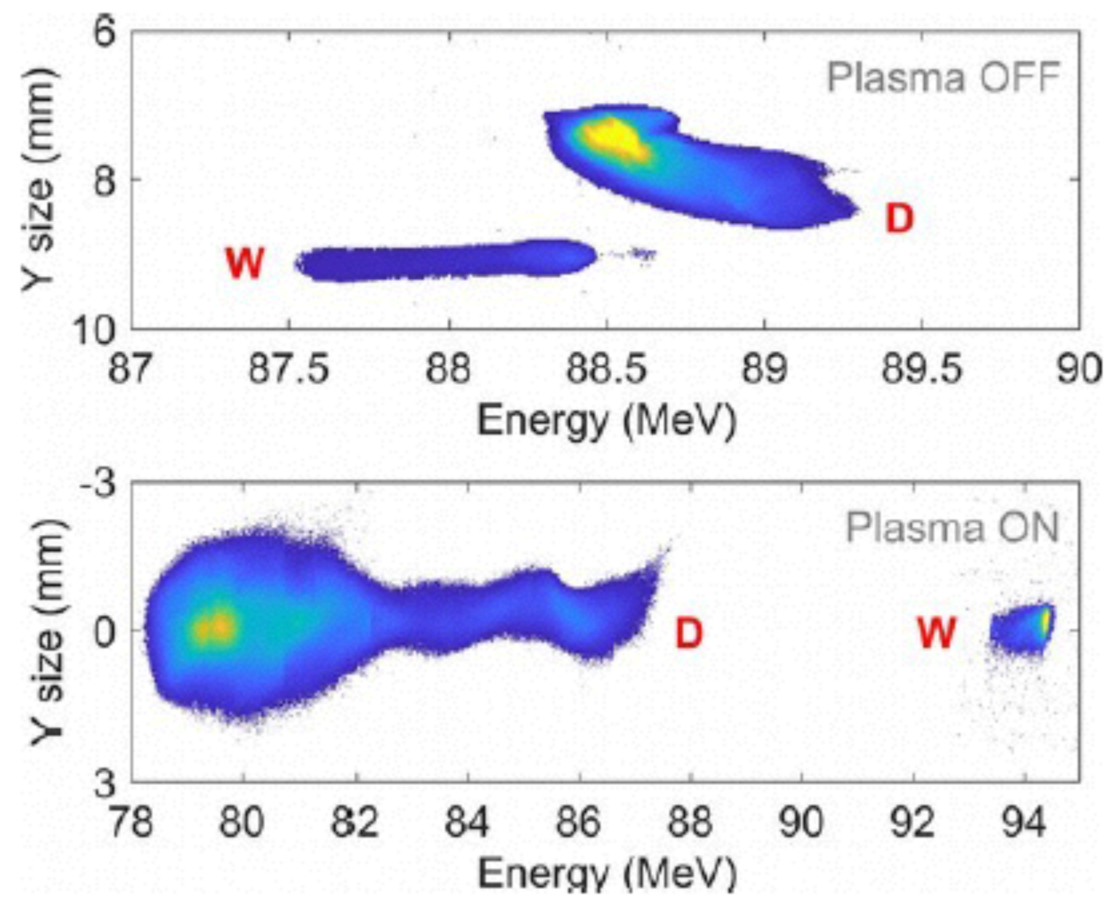
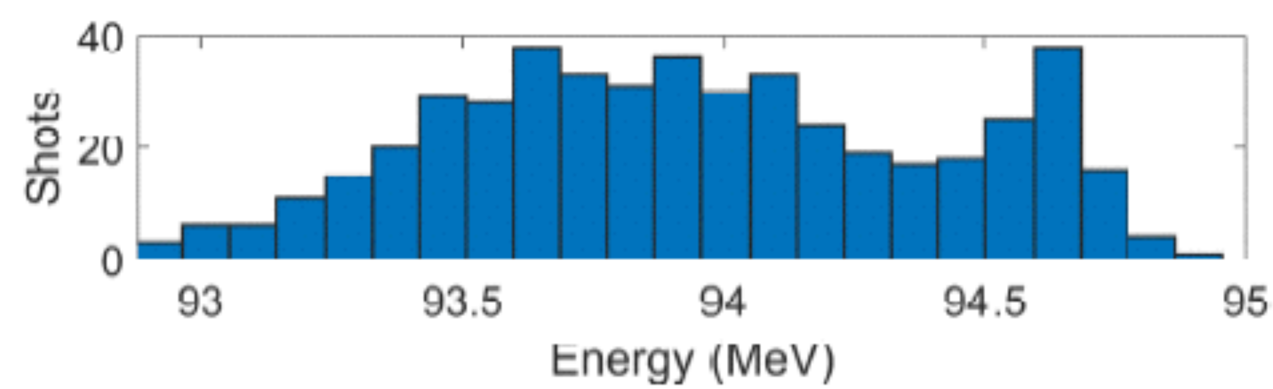
Energy Spread Minimization

- Plasma density set to 2×10^{15} cm^{-3}
- Witness gains 6 MeV over 3 cm plasma
  - Driver decelerated up to 10 MeV
- Witness emittance in the 1-2 um range
- Energy spread is preserved (0.2-0.3 MeV)
- Energy jitter reduced to 0.3 MeV





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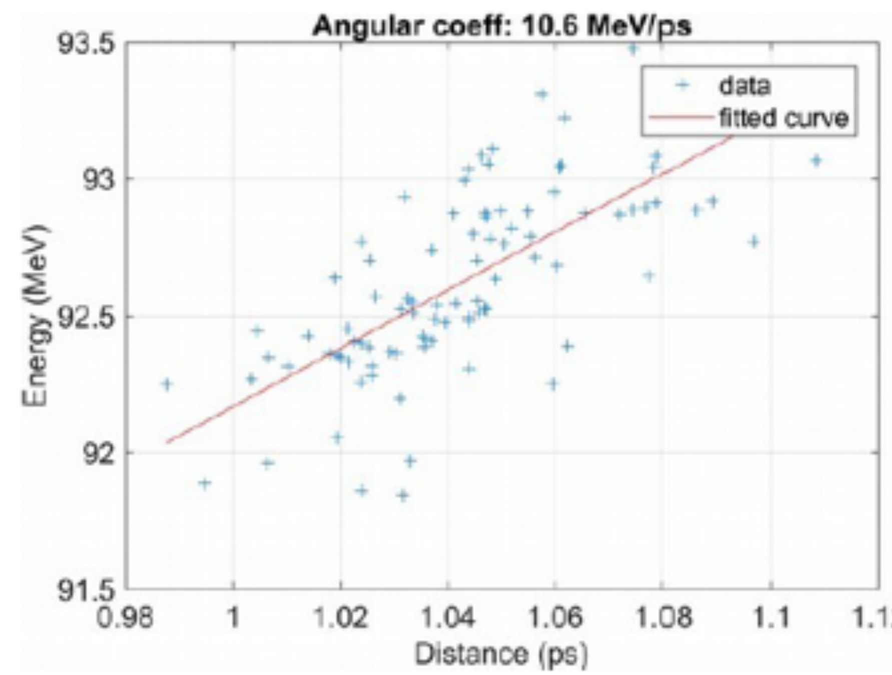
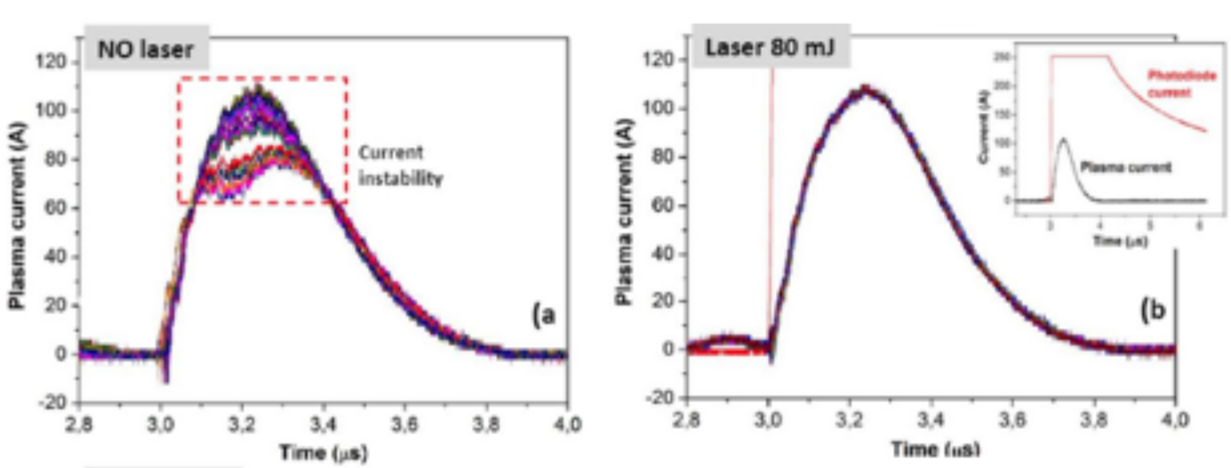
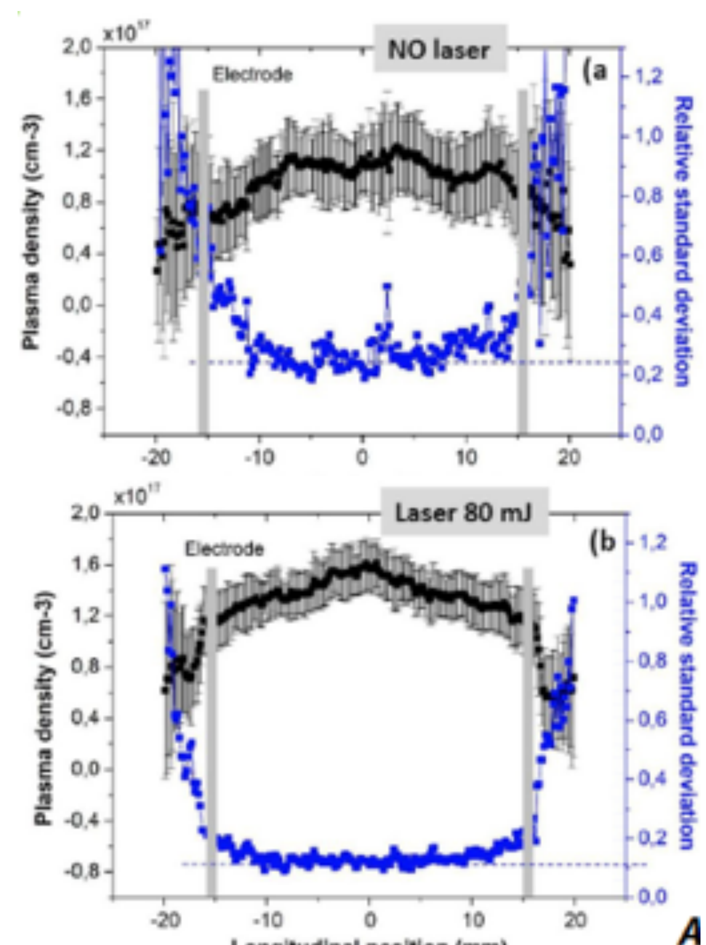
Jitter Studies

- The use of the non-intercepting and non-destructive **EOS diagnostics** allowed to monitor the plasma accelerated witness as a function of the RF timing-jitter (wrt to the laser)
  - Currently the D-W distance jitter is ~20 fs
  - We found clear correlation between D-W distance jitter (due to RF jitters) and the witness energy



- **Plasma stabilization with external laser**
  - Plasma density instability reduced from 25% to 11% @ 5 kV
  - Instability of ~5% when operating at >8 kV (from Stark meas)





Courtesy of A. Biagioni and R. Pompili

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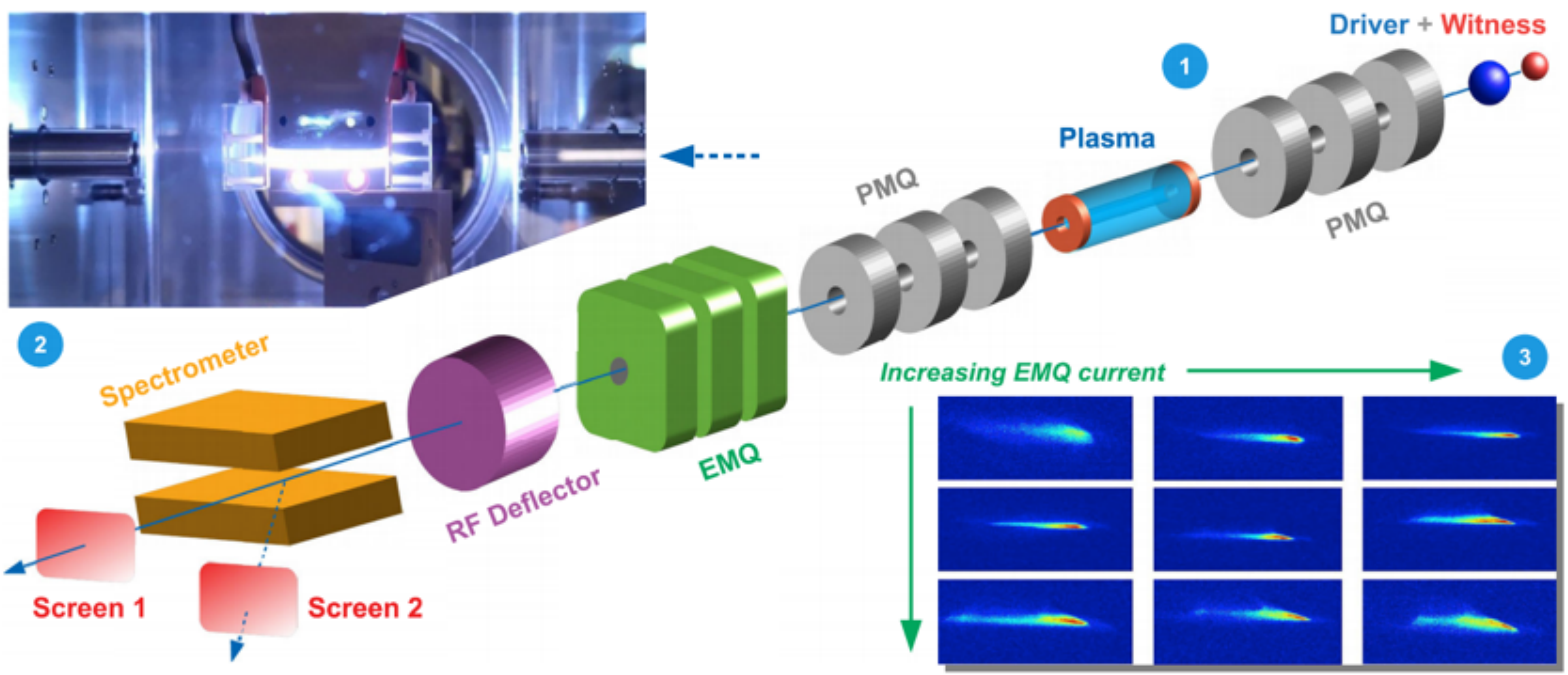
Emittance Characterization

- Multi-shot quadrupole scan technique to measure the plasma-accelerated witness normalized emittance
    - We found emittance increase from 2.7 um to 3.7 um (rms) during acceleration

V. SHPAKOV *et al.* PHYS. REV. ACCEL. BEAMS **24**, 051301 (2021)



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Conclusions

- R&D at **SPARC_LAB shows promising results concerning stability and beam quality** needed to pilot a FEL
    - **PWFA-driven FEL experimental studies ongoing**
- The **SPARC_LAB** Test Facility is the **test bench of the EuPRAXIA@SPARC_LAB plasma-based user facility** to fix those critical issues affecting stability and reproducibility, for instance
    - jitters (e.g. charge, plasma density, RF, …)
    - fine tuning of injector working points (e.g. laser comb technique for double or multi-bunch generation)
        - laser pulse shaping
    - control system testing
    - plants upgrade

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Q&A: Part I

1. Where do you see HEP applications of advanced accelerators in 30 years?

2. **What intermediate physics applications/steps do you see until a HEP linear collider?**
   - Beam quality improvement
   - Stability improvement
   - Reproducibility
   - Staging
   - Rep rate increase
   - "Background" minimization at the IP => driver removal

3. **What is the synergy with related fields?**
   - Jitter minimization (e.g. arrival time jitter, pointing stability, energy jitter, …)
   - Development of methods and techniques for single shot measurements
   - Technological aspect for minimization of ancillary components

4. **What is the role of your work here?**
   - R&D to improve beam quality, stability and reproducibility
   - R&D on advanced diagnostics
   - R&D on driver removal methods
   - Test bench for the operation of a plasma-based test facility

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Q&A: Part II

1) What are the important milestones for the next 10 years to get there from today?

- Beam quality improvement (energy spread and emittance, in particular, as required by specific applications)
- Stability improvement
- Reproducibility
- Staging
- Rep rate increase
- “Background” minimization at the IP => driver removal

Stable operation of plasma-based accelerators

2) What additional support is needed to achieve these?

- Technological

3) What should be proposed as deliverables until 2026? Please list in order of priority.

- Stable operation of plasma-based accelerators
- Demonstration of PWFA-driven FEL

4) Is the R&D work for each of those deliverables already funded and, if not, what additional resources / support would be needed?

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Q&A: Part III

1) What key R&D needs can be achieved in existing R&D facilities?
- Demonstration of proof-of-principle experiments
- Development, operation and improvement of ancillary components
- Set up and characterization of beam configurations scalable at different energies
- Training of personnel and students, which will operate future machines

2) What is the role of the already planned future facilities in Europe and world-wide?
- Test of different schemes of acceleration to define the most suitable for each user application, fix critical issues which might prevent from routinely operation
- Consolidate the community
- Train user community

3) What can be done with the existing and planned funding base?

4) Is a completely new facility needed?
- YES

5) Are additional structures needed beyond existing networks and projects, e.g. a design study for a collider or an advanced accelerator stage?
- YES

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