SPARC_LAB recent results and activities

November 26, 2020

R. Pompili (LNF-INFN)
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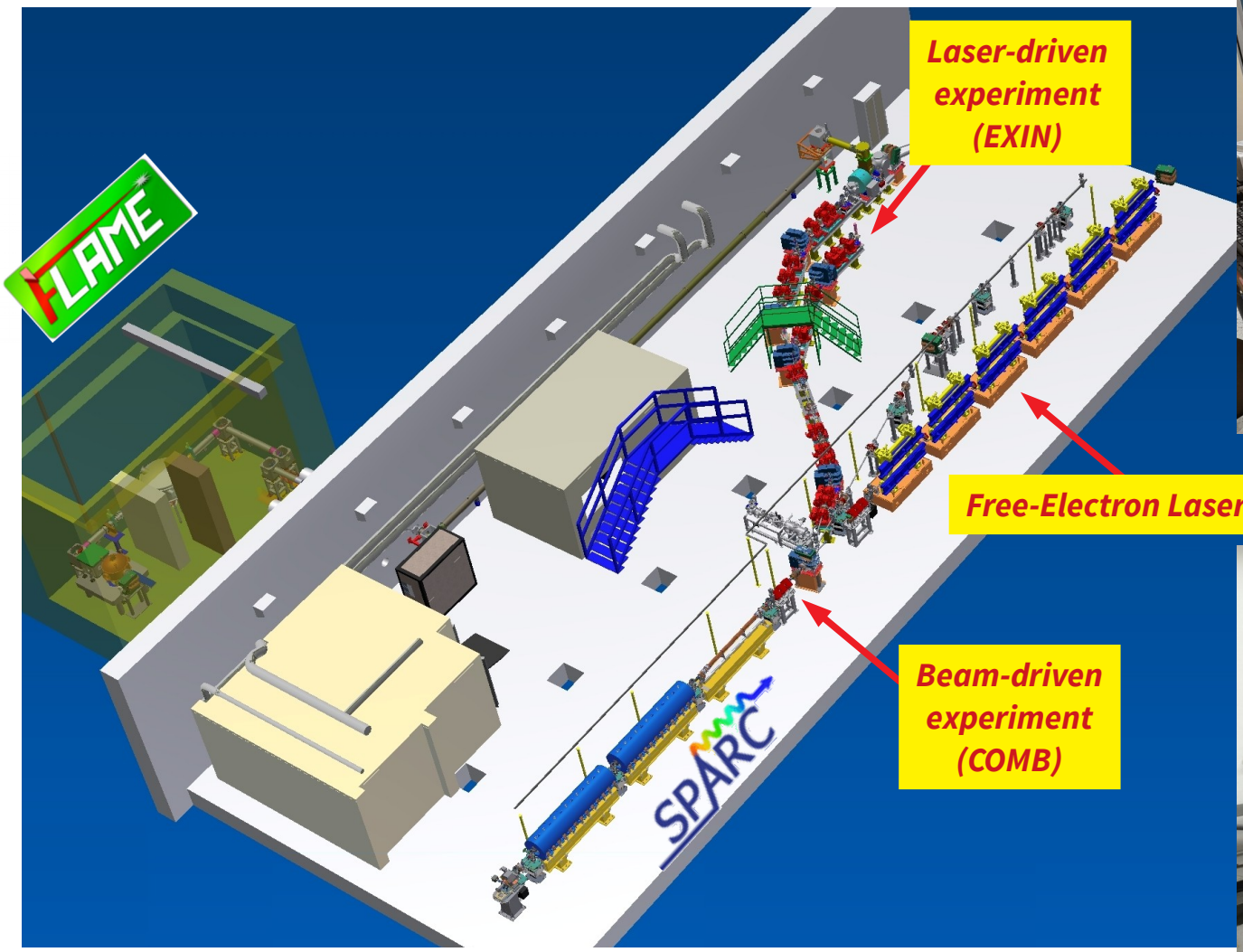
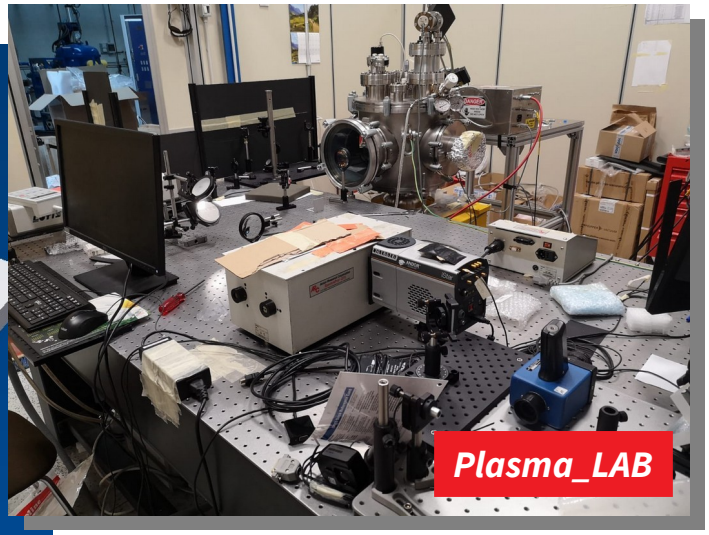
On behalf of the SPARC_LAB collaboration

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

SPARC_LAB facility





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

Planning for 2021

Task Name	Duration	Start	Finish
SPARC restart	**10 days**	**Mon 04/01/21**	**Fri 15/01/21**
Laser setup	5 days	Mon 04/01/21	Fri 08/01/21
Beam commissioning	5 days	Mon 11/01/21	Fri 15/01/21
User experiments	**175 days?**	**Mon 18/01/21**	**Fri 17/09/21**
ELI beamline	**10 days?**	**Mon 18/01/21**	**Fri 29/01/21**
Calipso+	**10 days?**	**Mon 01/02/21**	**Fri 12/02/21**
Diamond EOS	**10 days**	**Mon 15/02/21**	**Fri 26/02/21**
One-shot emittance	**10 days?**	**Mon 06/09/21**	**Fri 17/09/21**
Plasma Lens experiment	**10 days**	**Mon 15/02/21**	**Fri 26/02/21**
FEL experiment (SEED?)	**30 days**	**Mon 10/05/21**	**Fri 18/06/21**
COMB (2d+1w) experiment	**95 days**	**Mon 21/06/21**	**Fri 29/10/21**
Installations	**25 days?**	**Mon 01/03/21**	**Fri 02/04/21**
Replacement of last ondulator	25 days	Mon 01/03/21	Fri 02/04/21
COMB laser setup (2D+W)	25 days?	Mon 01/03/21	Fri 02/04/21
SABINA (downtime required)	**240 days?**	**Mon 01/03/21**	**Fri 28/01/22**
New RF gun	**45 days**	**Mon 01/03/21**	**Fri 30/04/21**
Network & Cabling	15 days?	Mon 02/08/21	Fri 20/08/21
Electrical plant	15 days?	Mon 02/08/21	Fri 20/08/21
Compressed air	10 days?	Mon 01/11/21	Fri 12/11/21
Water demineralization	20 days?	Mon 01/11/21	Fri 26/11/21
Dry-cooler	10 days?	Mon 01/11/21	Fri 12/11/21
UTA	10 days?	Mon 01/11/21	Fri 12/11/21
Hydraulic distribution	35 days?	Mon 01/11/21	Fri 17/12/21
Data storage	20 days?	Mon 01/11/21	Fri 26/11/21
C-band modulator	19 days?	Mon 29/11/21	Thu 23/12/21
LLRF	20 days?	Mon 01/11/21	Fri 26/11/21
BOC	5 days?	Mon 02/08/21	Fri 06/08/21
Solenoids accelerating sections	45 days?	Mon 29/11/21	Fri 28/01/22
EXIN (downtime required)	**20 days?**	**Mon 01/03/21**	**Fri 26/03/21**
Interaction chamber	20 days?	Mon 01/03/21	Fri 26/03/21

Preparation of the machine

Completion of user experiments

FEL run (phase 2)

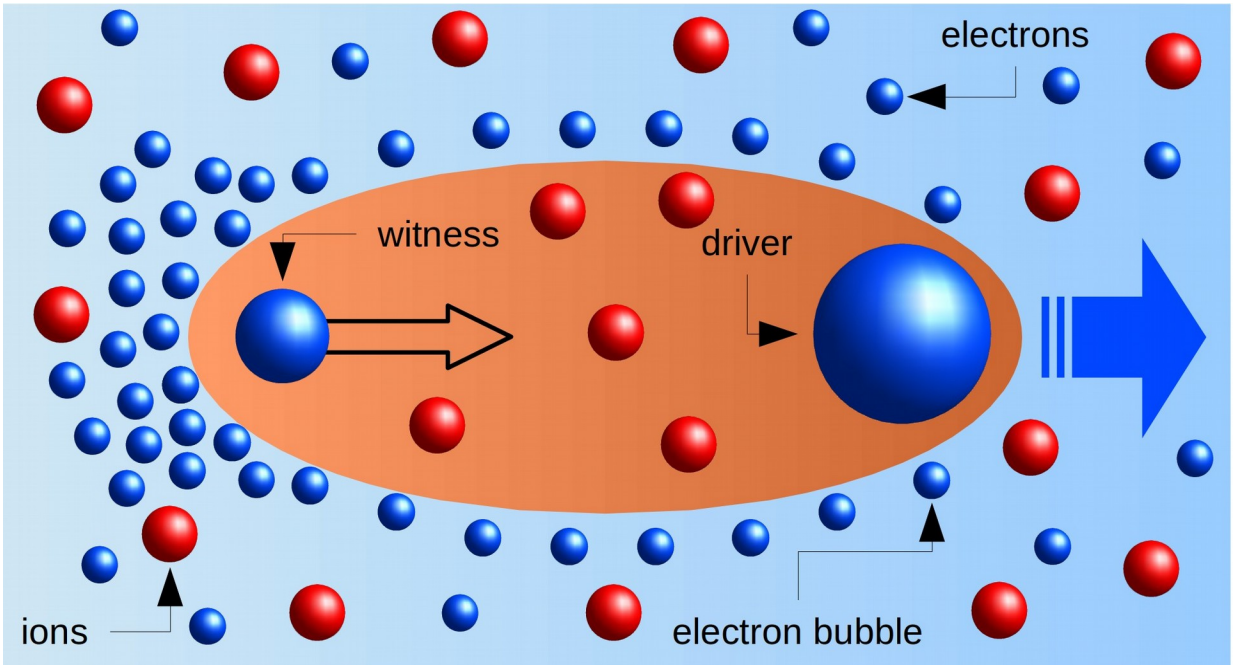
Plasma acceleration (phase 2)

Two main shutdown
March-April 2021
November 2021-tbd

SABINA operations (requiring access to the SPARC bunker)

EXIN installations

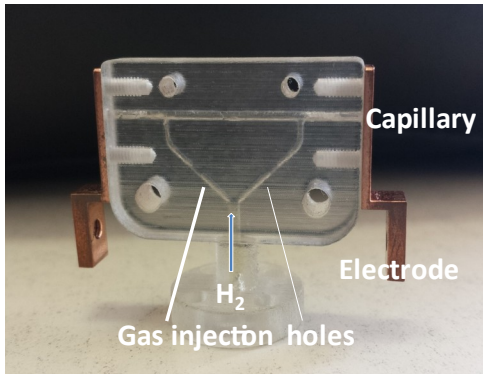
Plasma acceleration



The **driver** can be a
- *Particle bunch (PWFA)*
- *Laser pulse (LWFA)*

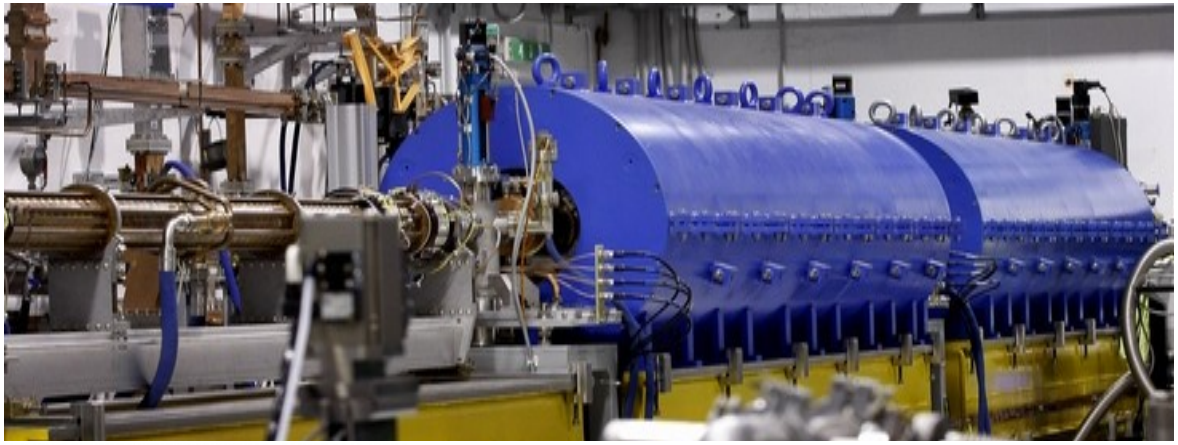
The **witness** can be
- *Self-injected*
- *Externally injected*

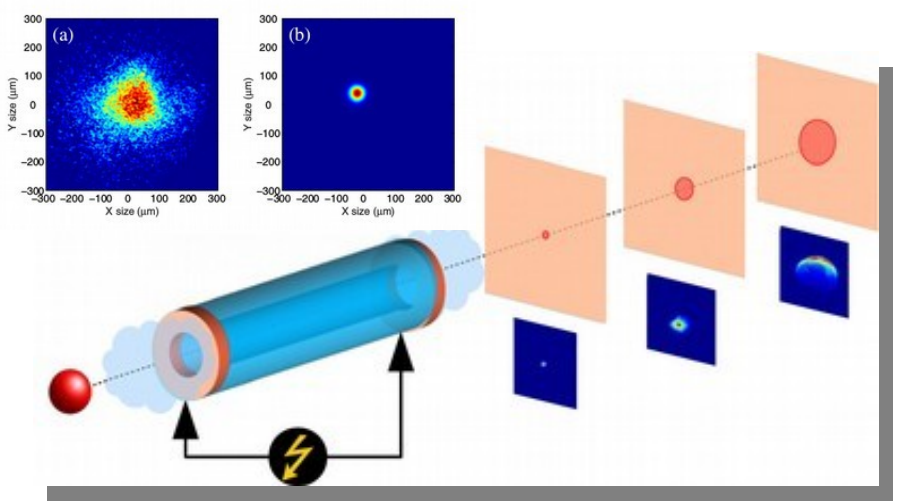
$$E_0 = \frac{m_e c\,\omega_p}{e} \simeq 96\sqrt{n_0(cm^{-3})} \rightarrow E_0 \approx 10\frac{GV}{m} @\, n_0 = 10^{16}\, cm^{-3}$$



Experience with plasma @ SPARC

Activities with the high-brightness SPARC photo-injector

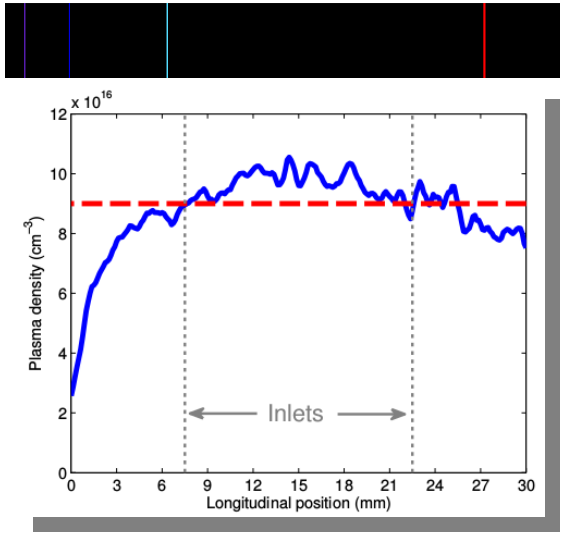




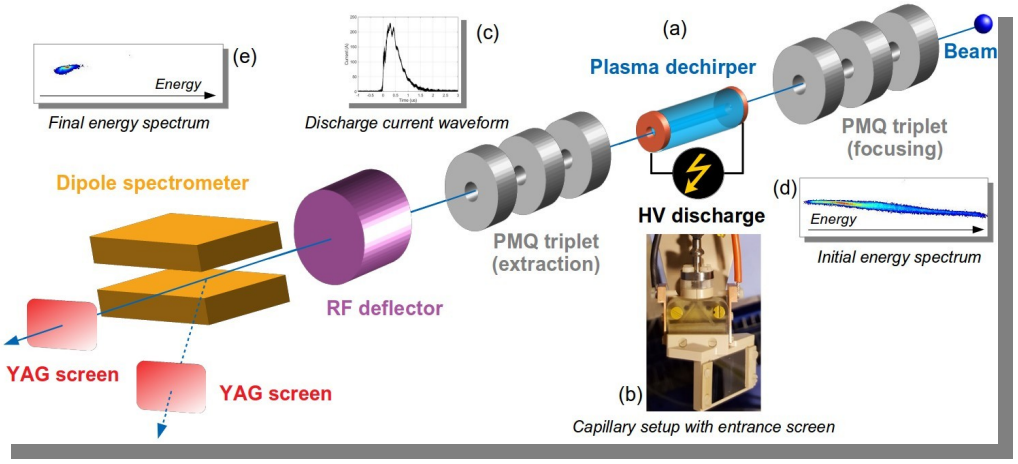
Focusing and emittance preservation with active-plasma lenses

Pompili, R., et al., Physical review letters 121.17 (2018): 174801.
Pompili, R., et al., Applied Physics Letters 110.10 (2017): 104101.

Plasma characterization



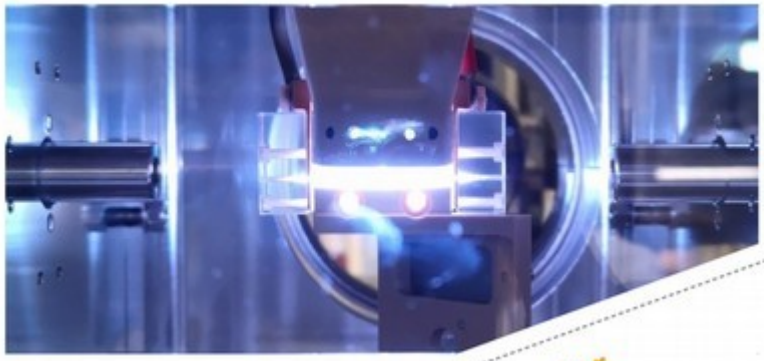
Biagioni, A., et al., Journal of Instrumentation 11.08 (2016): C08003.

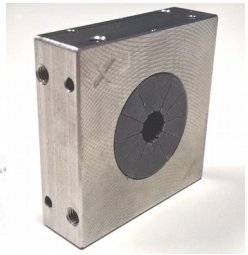


Plasma-dechirper

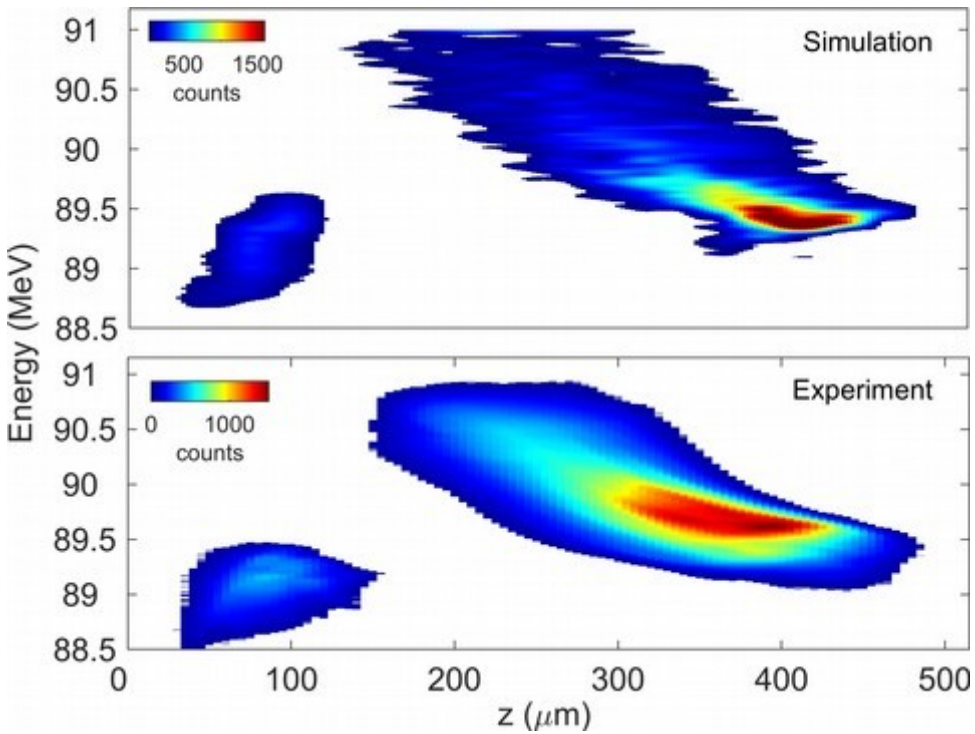
V. Shpakov et al. Phys. Rev. Lett. 122, 114801 (2019)

Plasma acceleration experiment





Beam configuration



Two-bunches configuration produced directly at the cathode with laser-comb technique

200 pC driver (charge increased up to 350 pC) followed by witness bunch (20 pC)

Ultra-short durations (200 fs + 30 fs)

Separation approximately equal to ¾ of the plasma wavelength (~1 ps)

Plasma acceleration results (1)

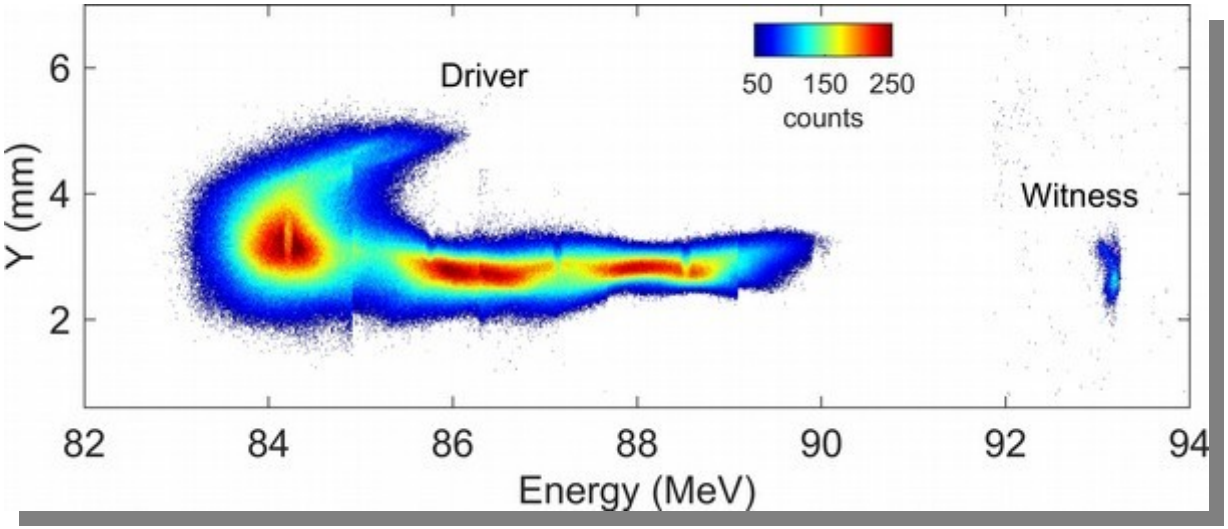
Achieved 4 MeV acceleration in 3 cm plasma with 200 pC driver

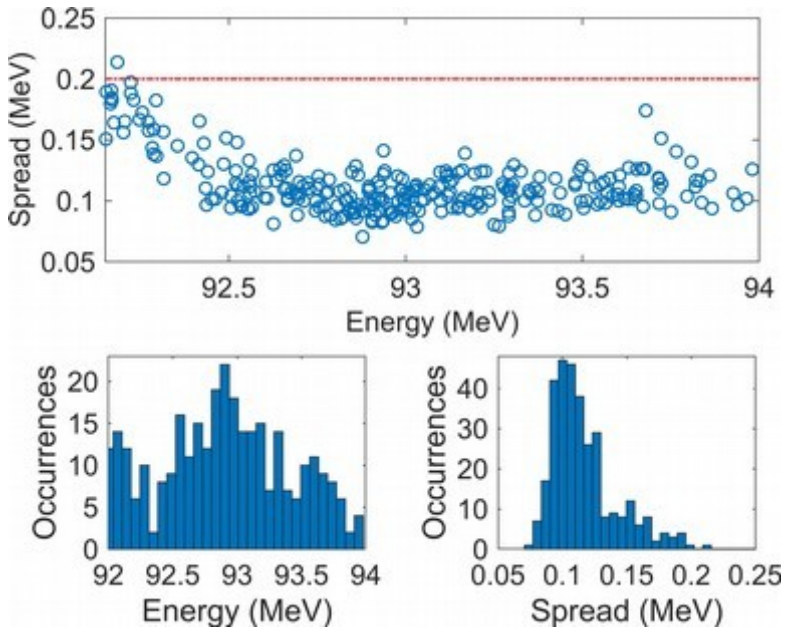
- *~133 MV/m accelerating gradient*
- *$2x10^{15}$ cm^{-3} plasma density*

First ever demonstration of energy spread compensation during acceleration

- *Energy spread reduced from 0.2% to 0.12%*
- *99.5% energy stability*

So far is the highest beam quality ever reached in a plasma-based accelerator





R. Pompili et al, "Energy spread minimization in a beam-driven plasma wakefield accelerator", accepted for publication by Nature Physics

Plasma acceleration results (2)

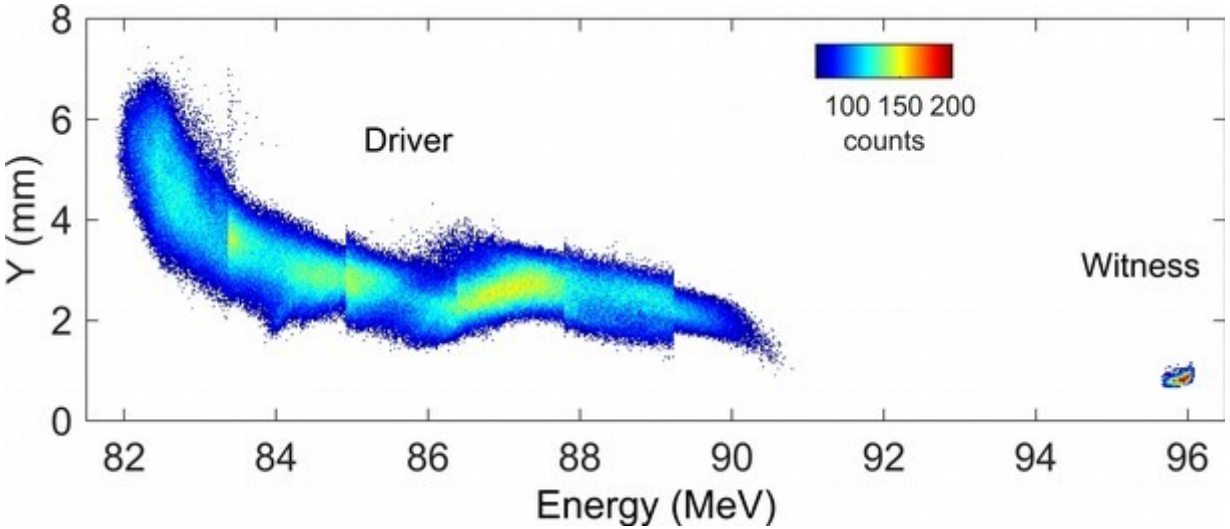
Achieved 7 MeV acceleration in 3 cm plasma with 350 pC driver

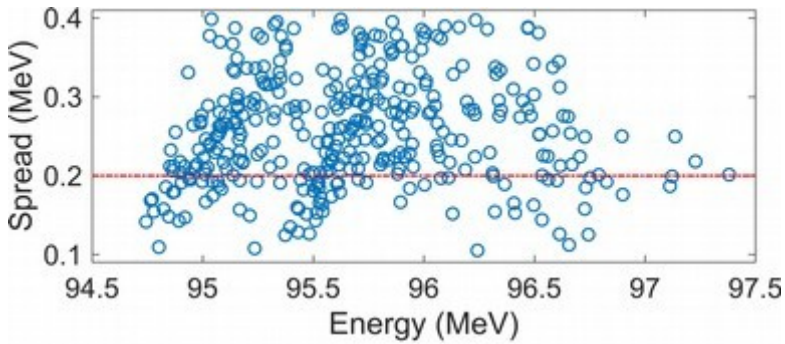
- *~233 MV/m accelerating gradient*
- *$2x10^{15}$ cm^{-3} plasma density*

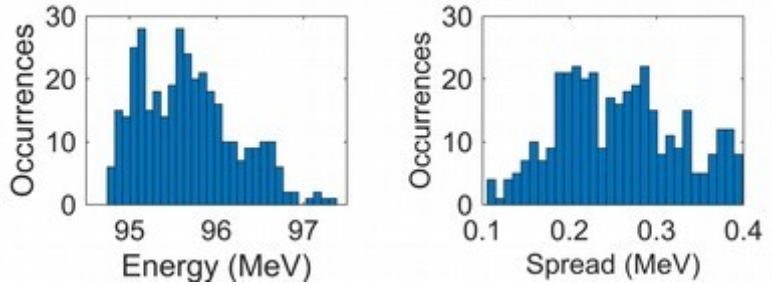
Energy spread of the accelerated beam slightly increased

- *Energy spread from 0.2% to 0.26%*
- *99.4% energy stability*

Still order of magnitudes lower spread with respect to previous experiments



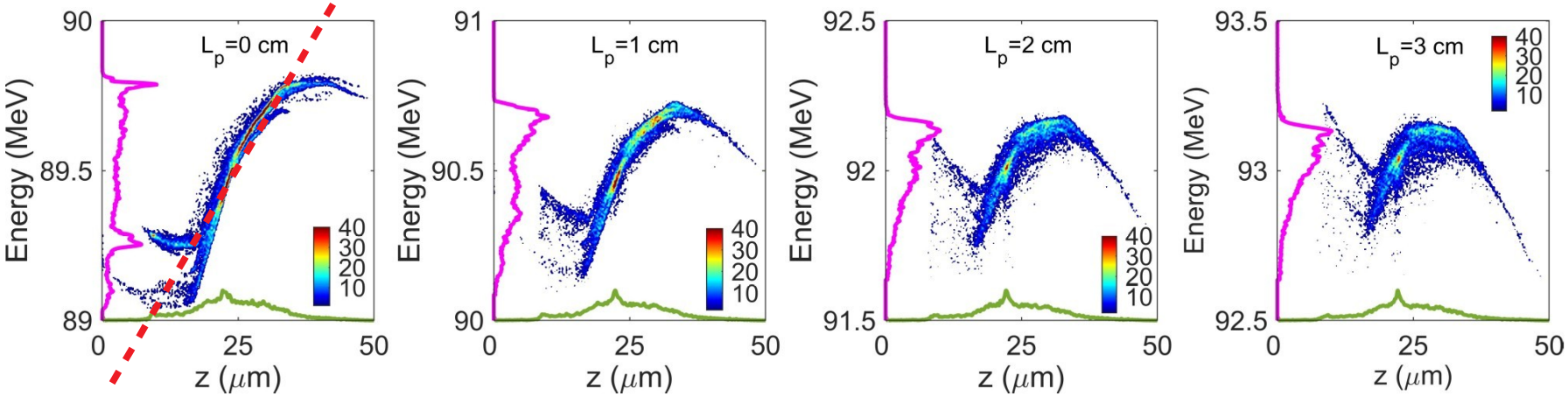


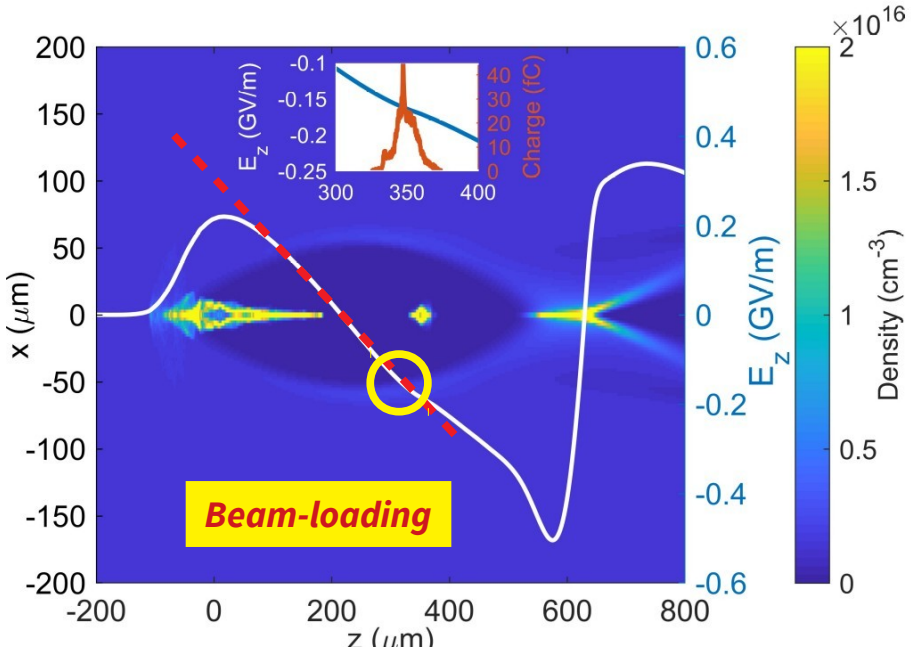


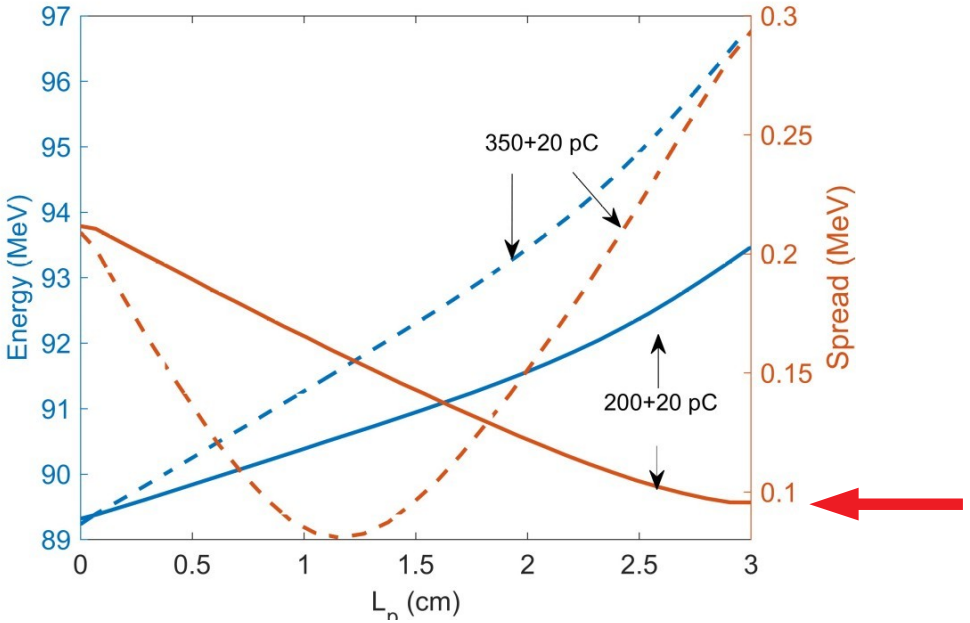
R. Pompili et al, "Energy spread minimization in a beam-driven plasma wakefield accelerator", accepted for publication by Nature Physics

Assisted beam-loading technique

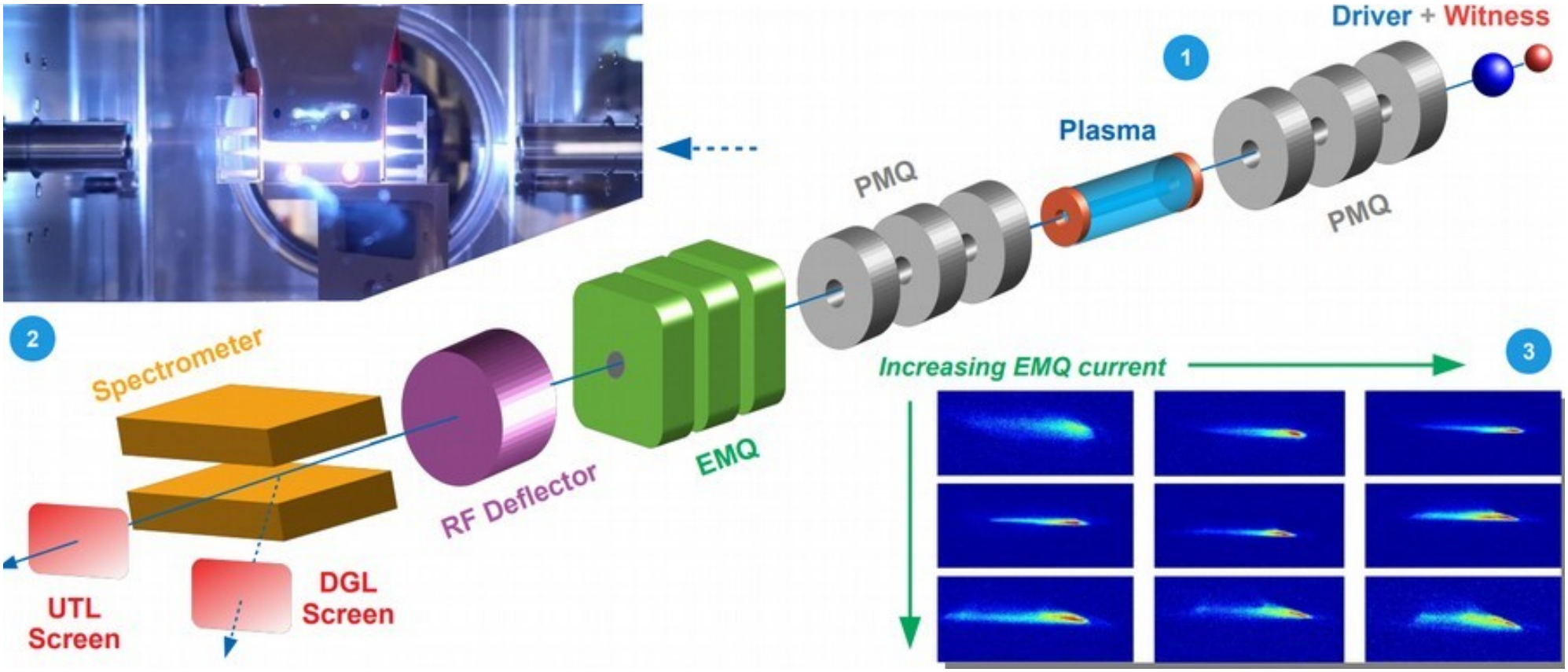
Pre-chirp to compensate wakefield slope







Accelerated witness characterization (1)



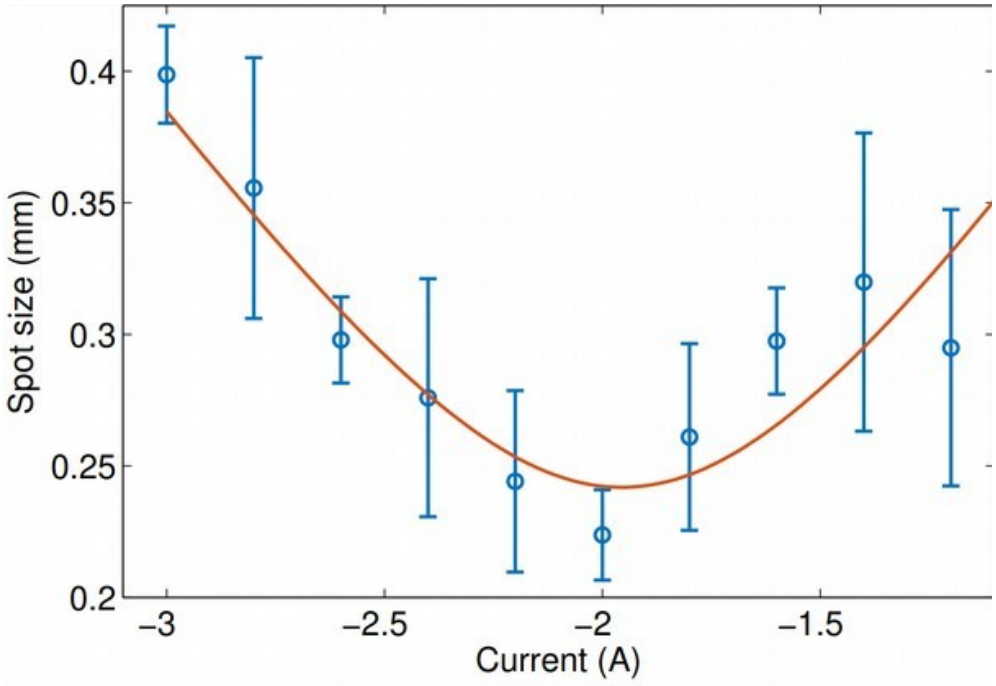
Quadrupole-scan for emittance evaluation (on the vertical plane)

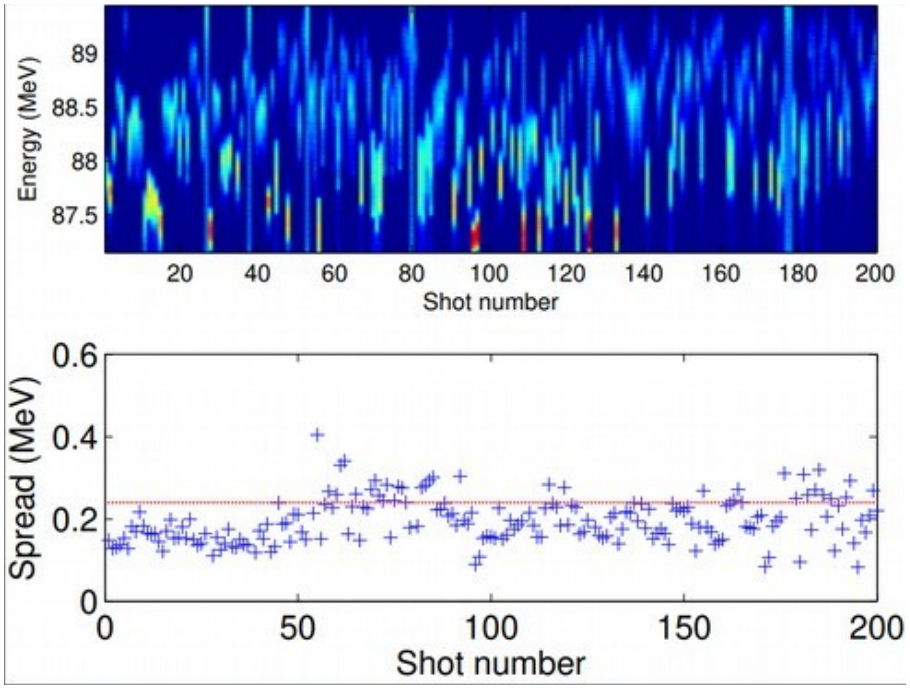
Accelerated witness characterization (2)

In July 2020 we completed the characterization of the plasma accelerated witness bunch

Measurement of its normalized emittance through quadrupole scan technique

We found emittance increase from 2.7 um to 3.7 um (rms) during acceleration





V. Shpakov, paper submitted

Dynamics of beam-plasma interactions

Two works are currently in preparation trying to interpret the dynamics of the interaction between the electron beam and the plasma

Both works "probe" the plasma wakefields by means of a 200 pC long beam (~1.5 ps, rms)

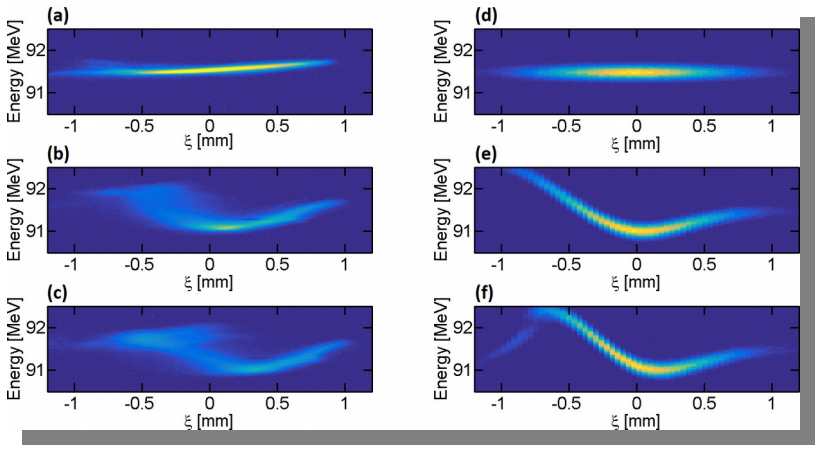
Longitudinal phase-space

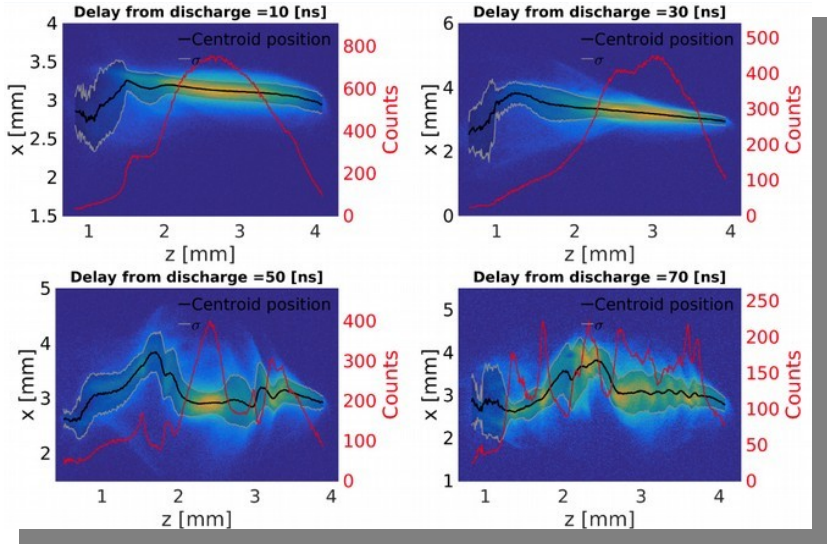
Analysis of energy modulations to retrieve the wakefield excited in the plasma

Transverse phase-space

Analysis of transverse modulations where it is observed the transition from hose instability to self-modulation instability

S. Romeo, in preparation





A. Del Dotto, in preparation

Ongoing FEL activity (SL_COMB2FEL)

The experimental beam parameters measured in the PWFA experiment have been used as input for a preliminary evaluation of FEL performances

GENESIS 1.3 time-dependent simulations

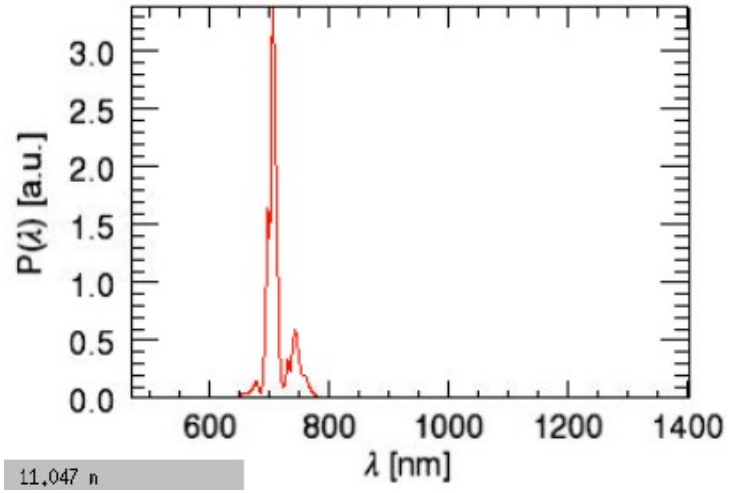
measurable growth of the FEL gain achieved

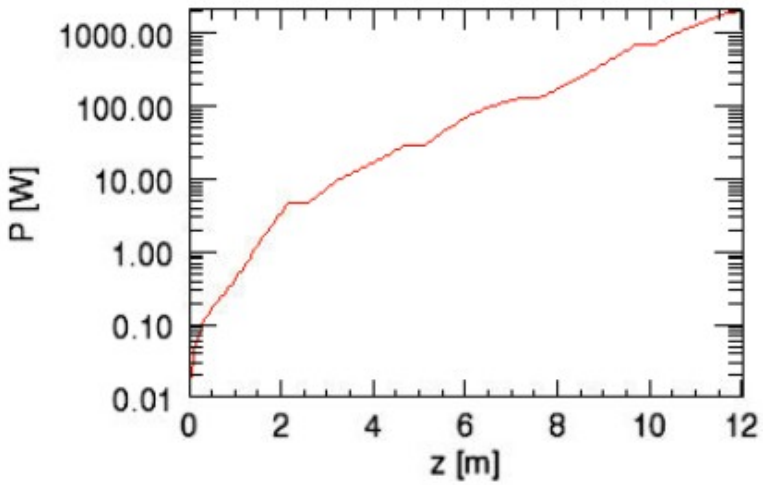
E. Chiadroni (LNF)
F. Nguyen (ENEA)

Witness beam parameters	
γ	174
ΔE/E (%)	0.28*
$\varepsilon_{nx,y}$(mm mrad)	3.5**
Q (pC)	20
I_{peak} (A)	214

Undulator parameters	
λ_u (cm)	2.8
K_{rms}	0.72
FODO β function (m)	1.6
λ_r (nm)	700

*It is the rms energy spread
**projected emittance





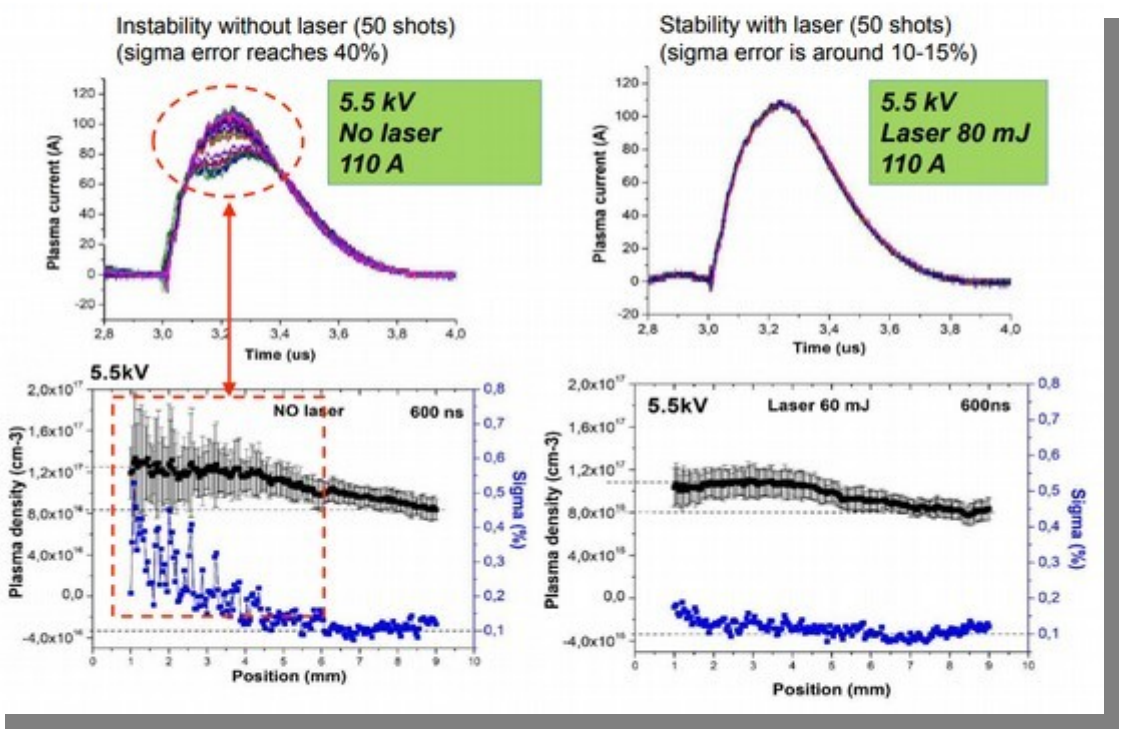
Plasma discharge stabilization

Setup for plasma stabilization in Plasma_LAB has been replicated in the SPARC bunker

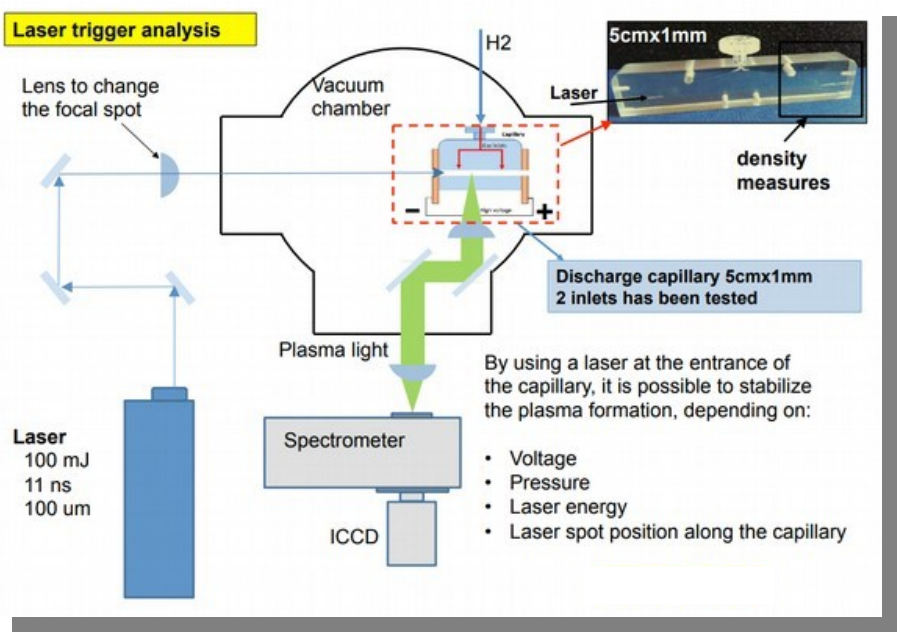
Measurements done in July 2020

We discovered that the LINAC dark current provides the same stabilization of the external laser

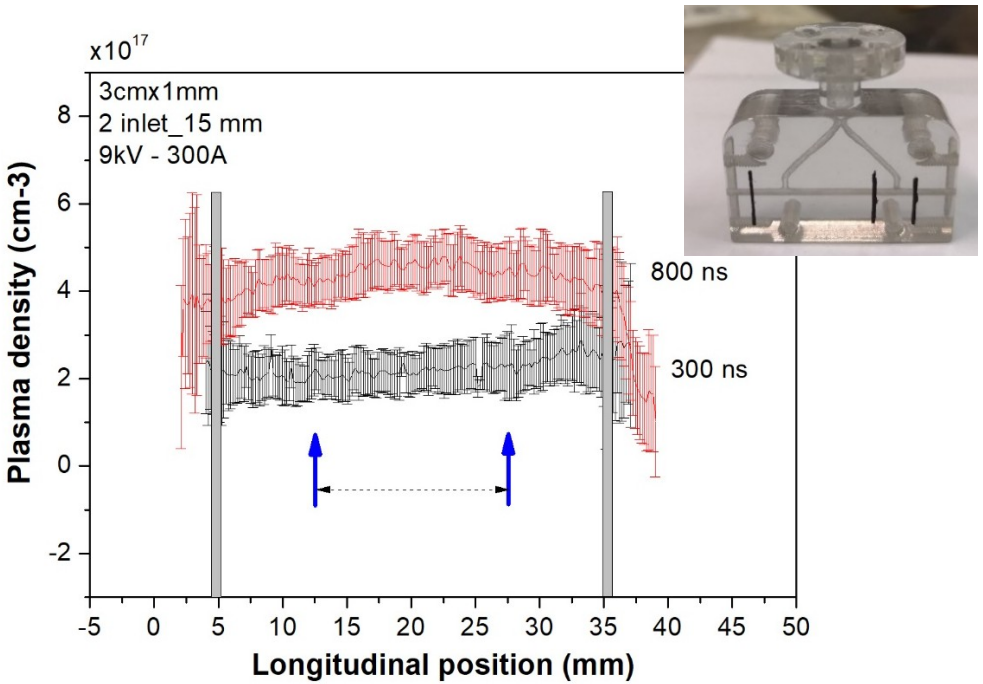
Analysis of experimental results (laser vs dark current) ongoing

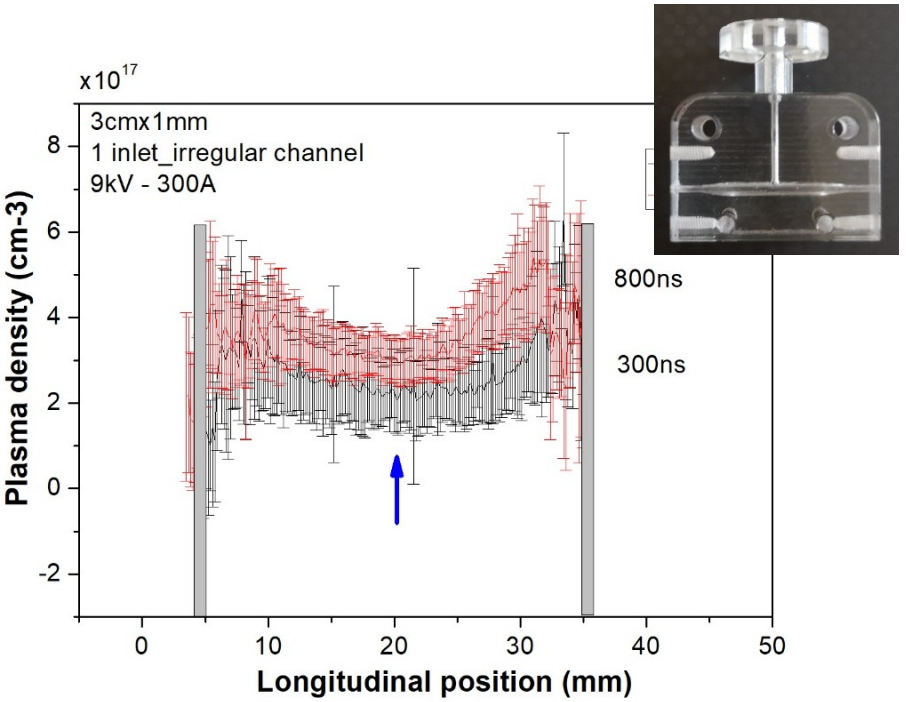


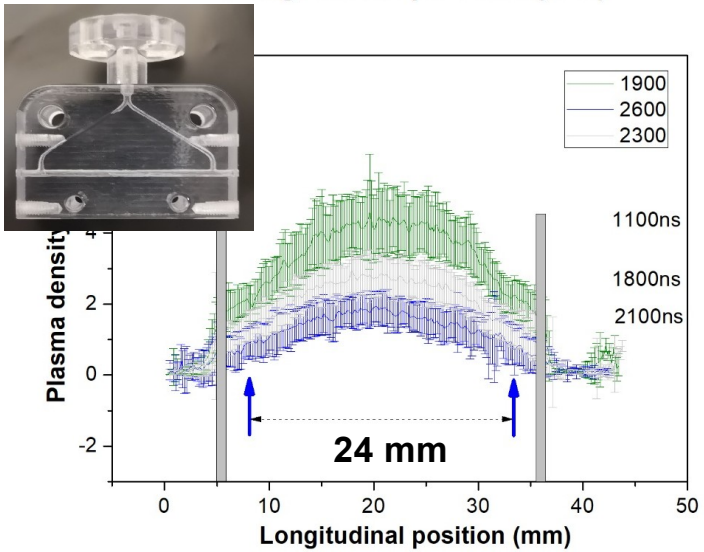
M. Galletti, in preparation

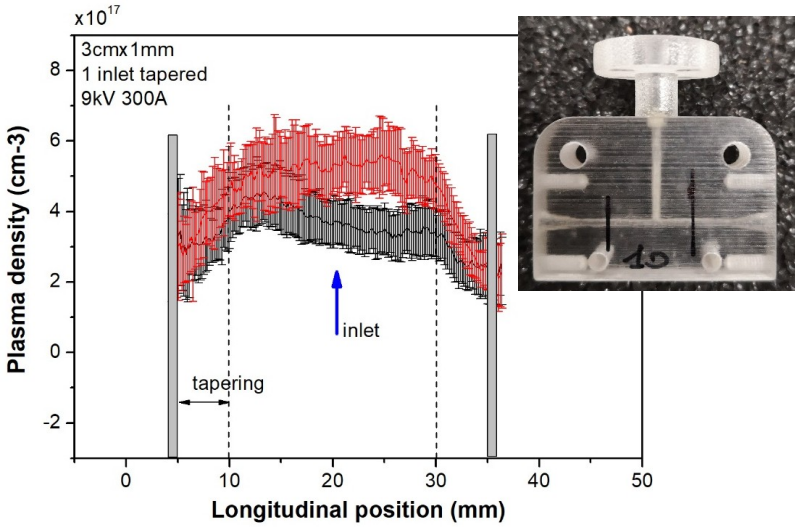


A. Biagioni, in preparation


x10^17
3cmx1mm
2 inlet_15 mm
9kV - 300A
800 ns
300 ns
Plasma density (cm-3)
Longitudinal position (mm)

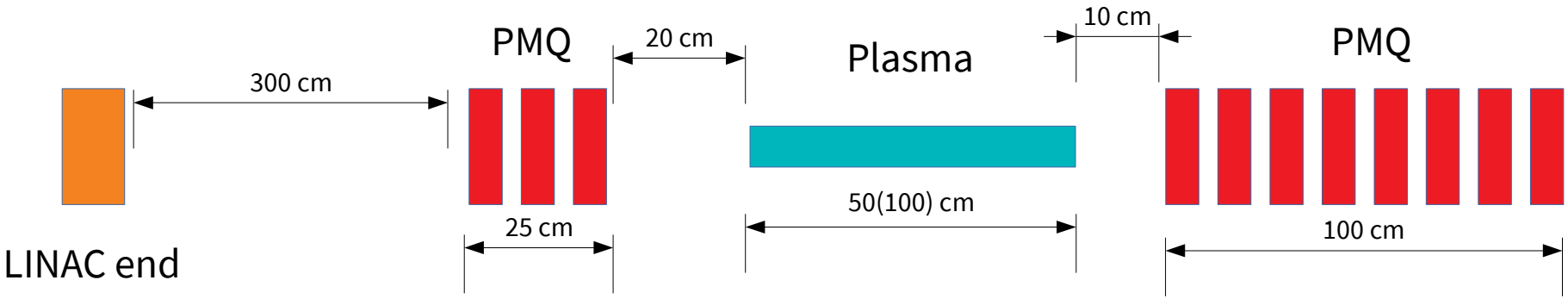

x10^17
3cmx1mm
1 inlet_irregular channel
9kV - 300A
800ns
300ns
Plasma density (cm-3)
Longitudinal position (mm)


1900
2600
2300
1100ns
1800ns
2100ns
24 mm
Plasma density
Longitudinal position (mm)


x10^17
3cmx1mm
1 inlet tapered
9kV 300A
inlet
tapering
Plasma density (cm-3)
Longitudinal position (mm)

A. Biagioni

Open issues for EuPRAXIA@SPARC_LAB



For EuPRAXIA@SPARC_LAB the plasma length is 50 cm (extendable up to 1 m)

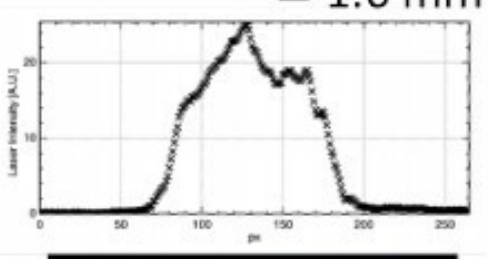
- *Vacuum constraints to avoid gas reaching the X-band structures*
- *Imposes limits on the gas flow repetition rate*
- *Impedances needed along the beamline*

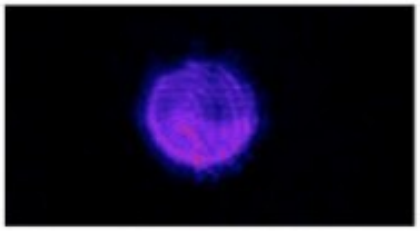
Some space needed for matching optics

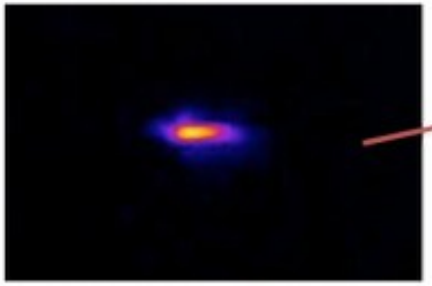
- *Beam focusing/extraction*
- *Energy-depleted driver removal*

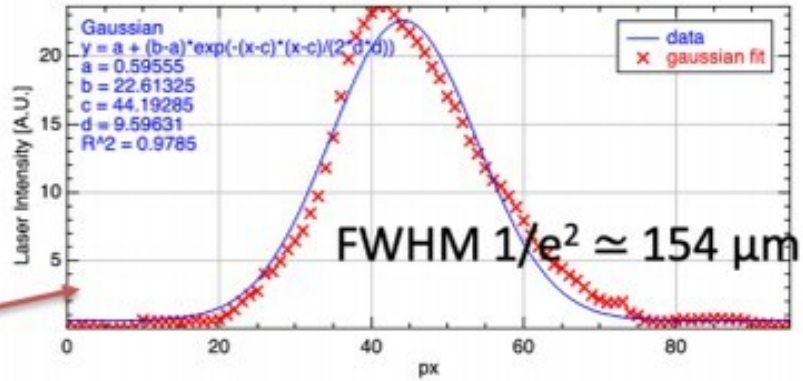
FLAME laser guiding

≃ 1.6 mm



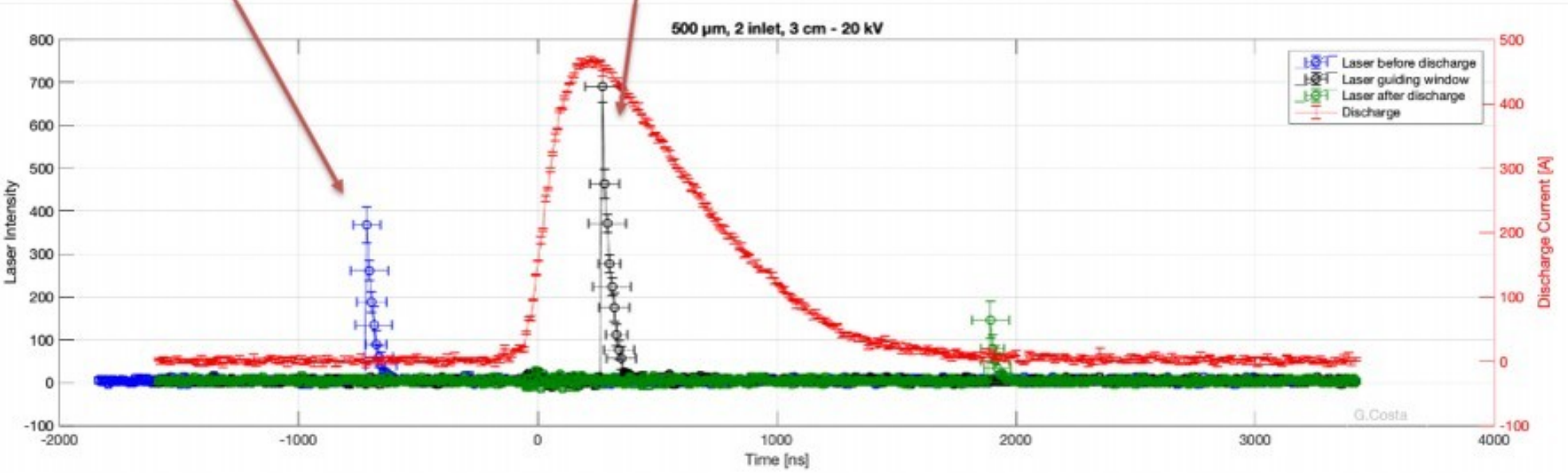




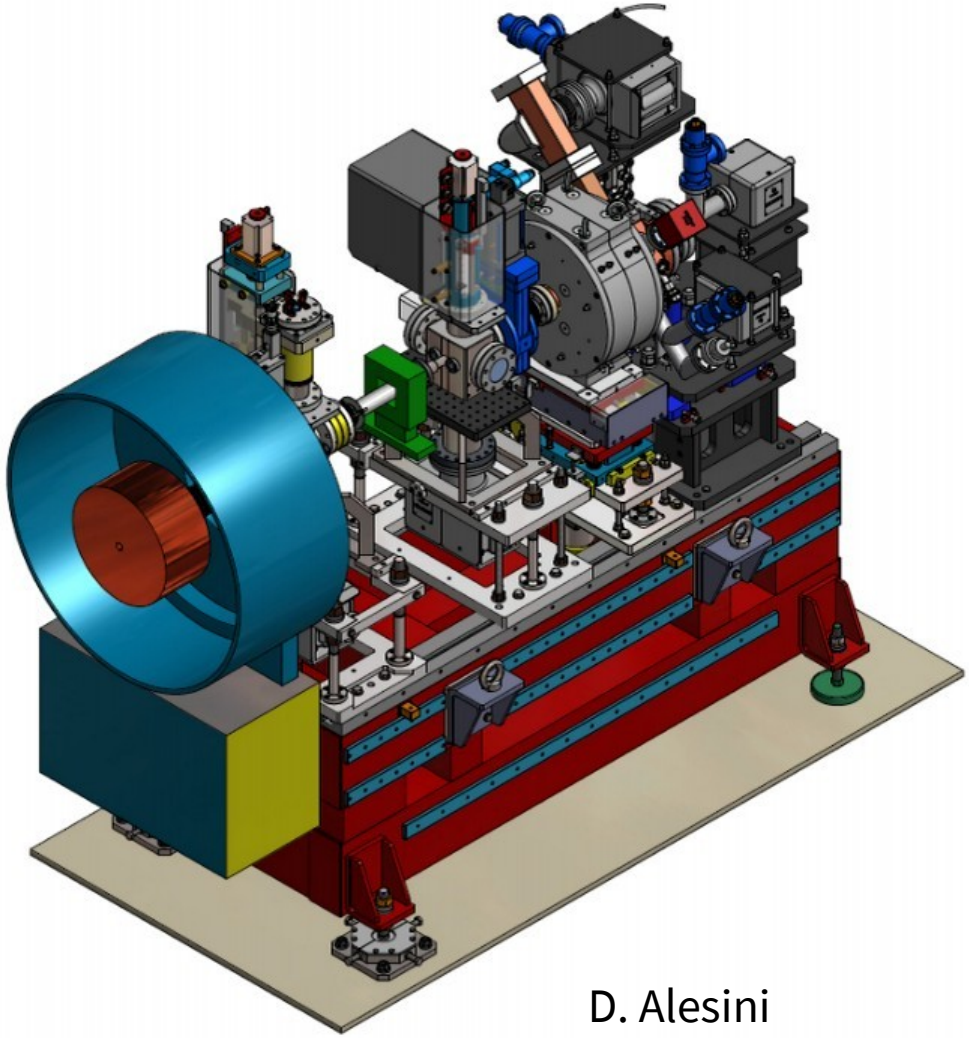


focus FWHM $1/e^2 \simeq 120$ µm and $\Delta t \simeq 50$ fs

$n_e = ((4.7 \times 10^3 \times r_{capillary}^{1/2})/ r_{laser})^{-4} \simeq 2.5 \times 10^{18}$ cm^{-3}

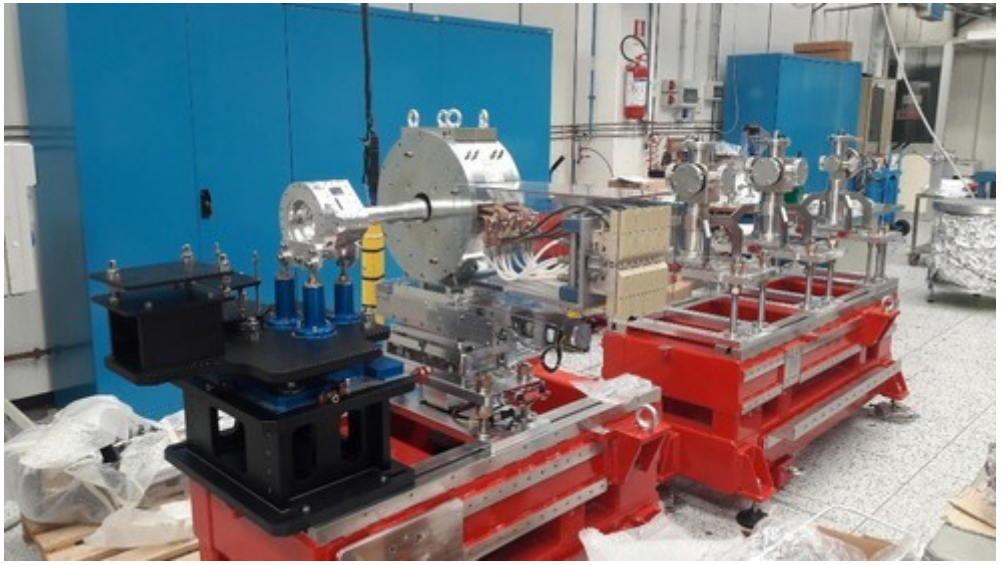


New RF gun (SABINA)



D. Alesini

- All components have been delivered
- Assembly in progress
- RF gun under construction (delivered expected January 2021)
- Expected date for final injector assembly: March 2021



Thanks!

November 26, 2020

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On behalf of the SPARC_LAB collaboration