60th LNF Scientific Committee
Frascati

SPARC_LAB recent results and activities

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November 16, 2020

On behalf of the SPARC_LAB collaboration

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Outline

SPARC_LAB activities

SPARC photo-injector

- *Demonstration of plasma acceleration (March 2020)*
- *Complete characterization of the accelerated bunch (July 2020)*
- *Transport to the undulators for FEL emission demonstration (ongoing) - SL_COMB2FEL*

FLAME

- *Tests on laser guiding*

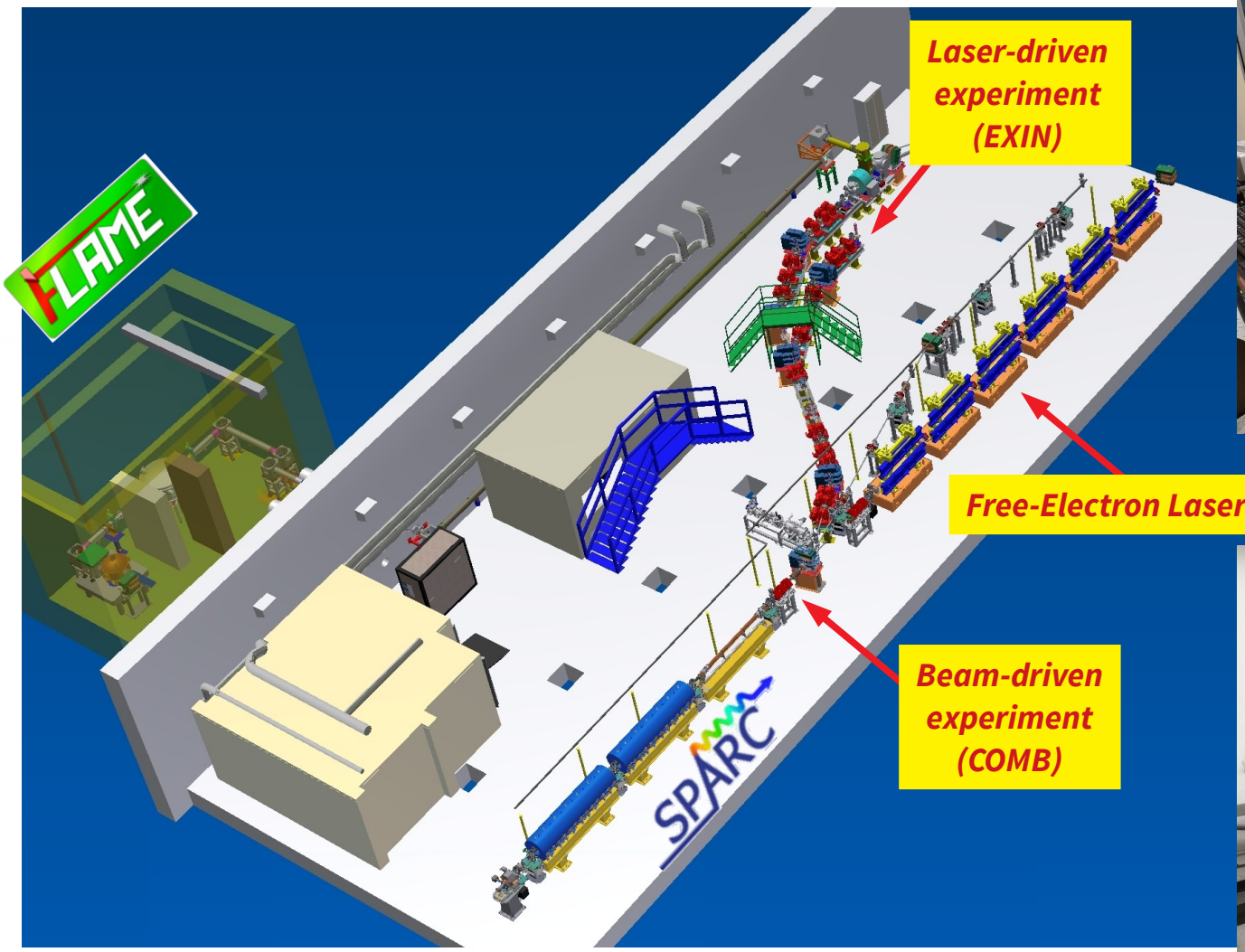
Plasma_LAB

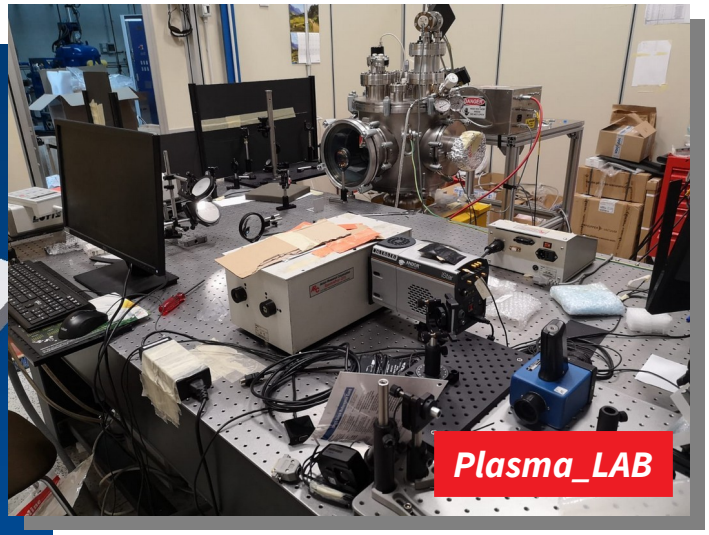
- *Plasma characterization with 3D-printed capillaries having different geometries*

Cathodes LAB

- *Setup of the laboratory with test vacuum chamber*

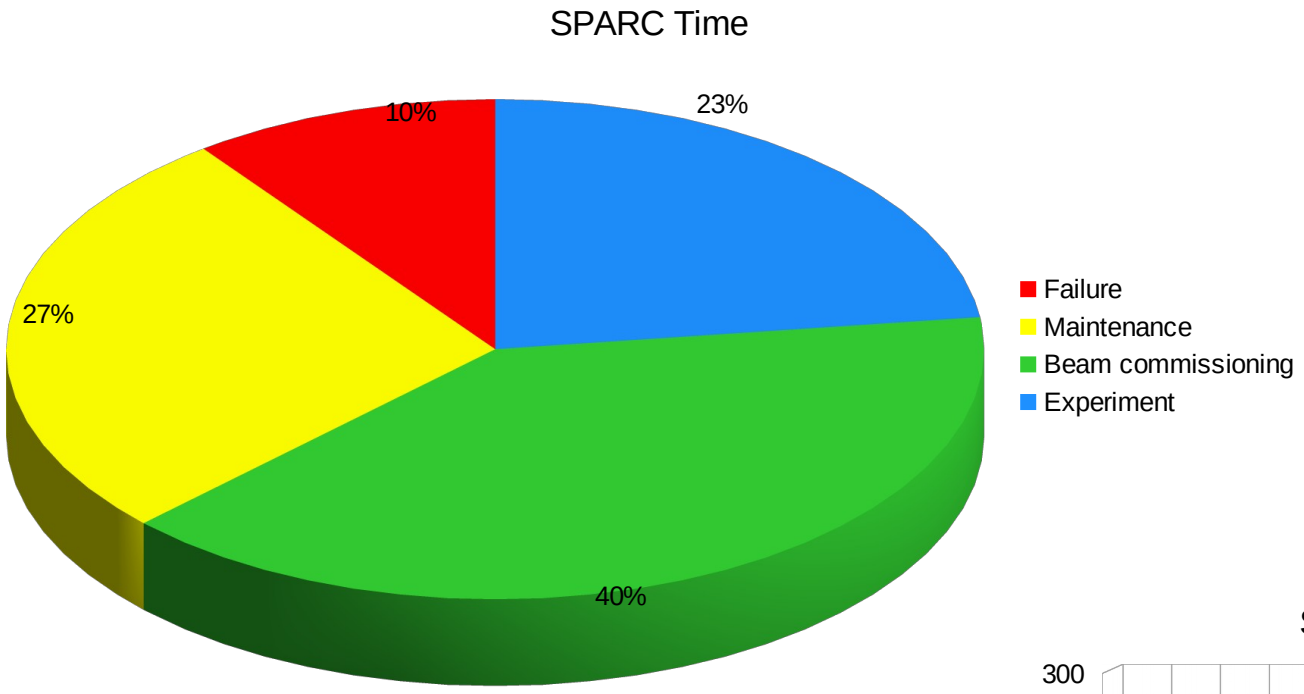
SPARC_LAB facility



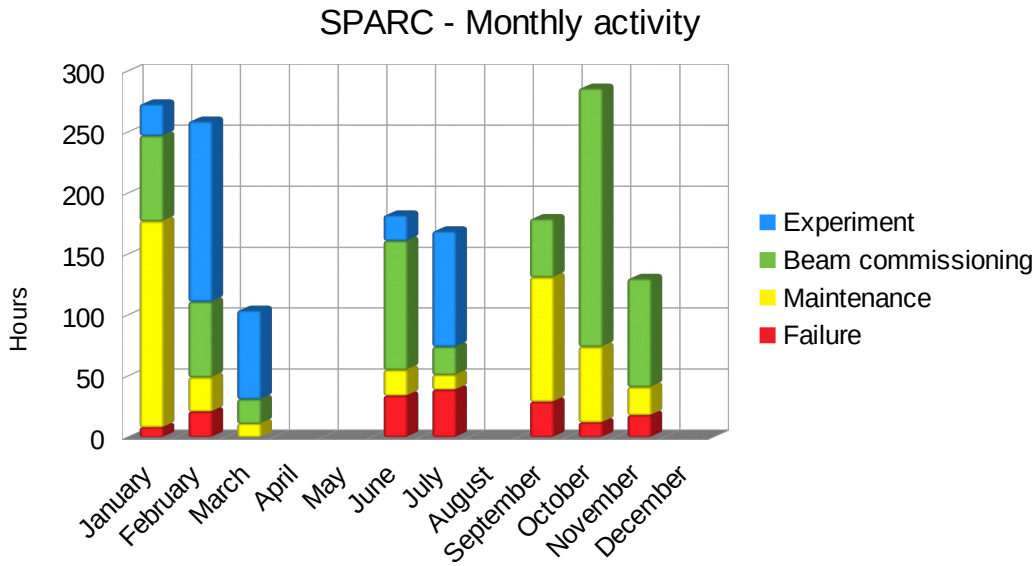


Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.

SPARC up time (2020)



Total Up Time
63%



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)

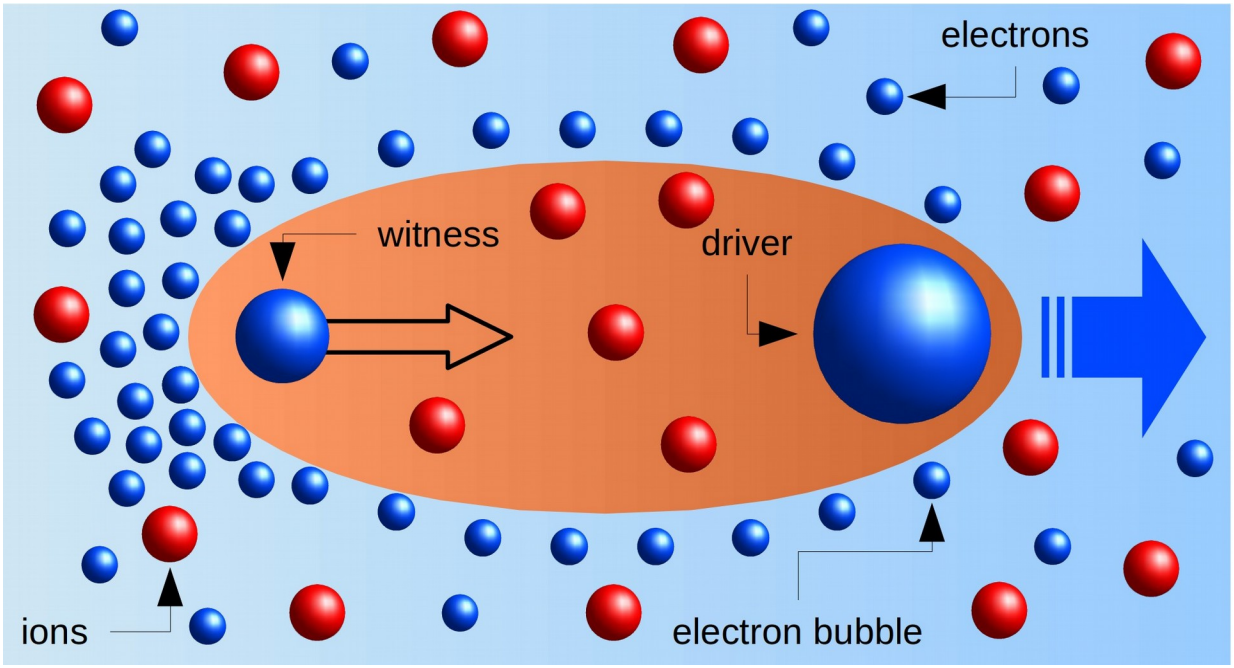
Plasma acceleration (phase 2)

Two main shutdown
March-April 2021
November 2021-tbd

SABINA operations (requiring access to the SPARC bunker)

EXIN installations

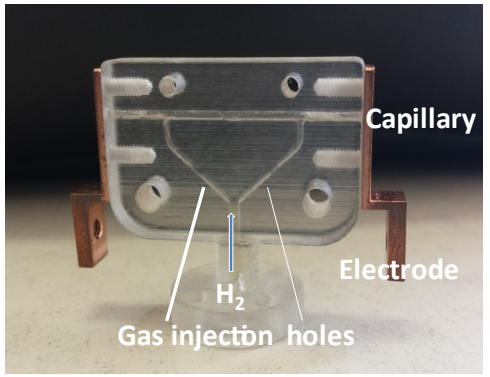
Plasma acceleration



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

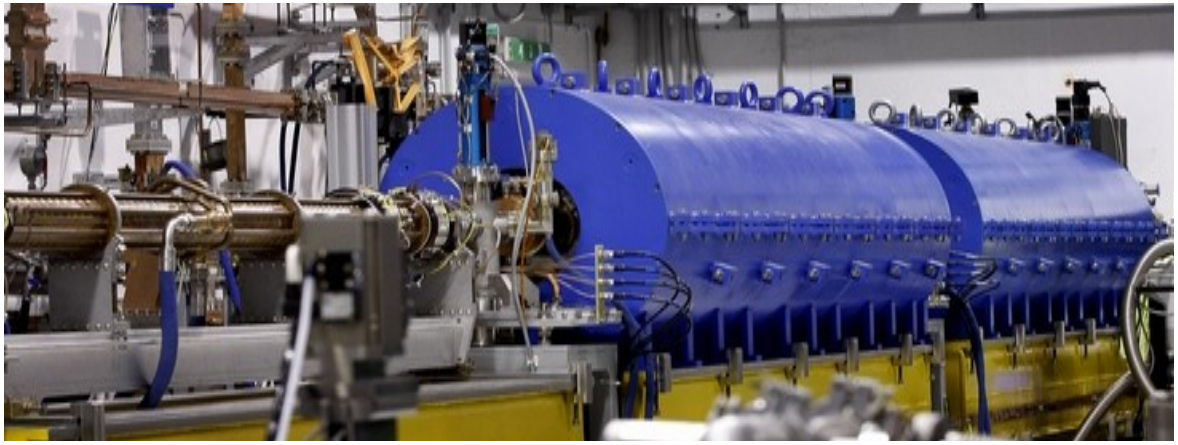
The **witness** can be
- *Self-injected*
- *Externally injected*

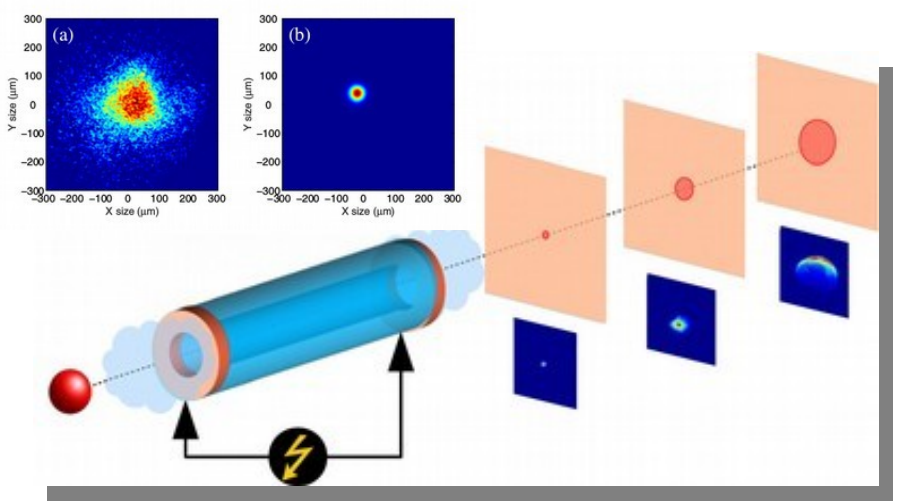
$$E_0 = \frac{m_e c\,\omega_p}{e} \simeq 96\sqrt{n_0(cm^{-3})} \rightarrow E_0 \approx 10\frac{GV}{m} @\, n_0 = 10^{16}\, cm^{-3}$$



Experience with plasma @ SPARC

Activities with the high-brightness SPARC photo-injector

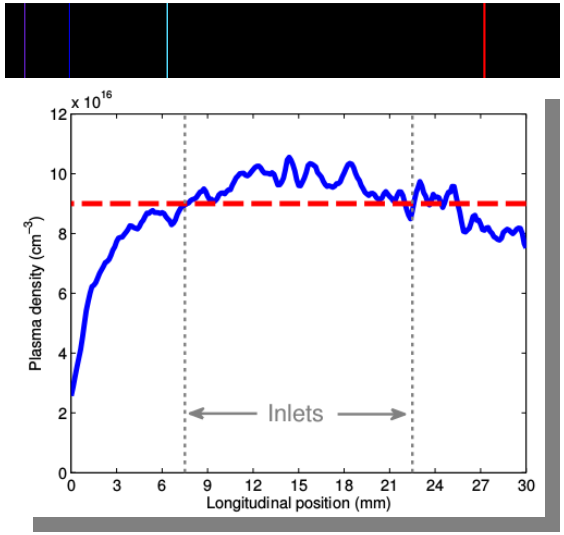




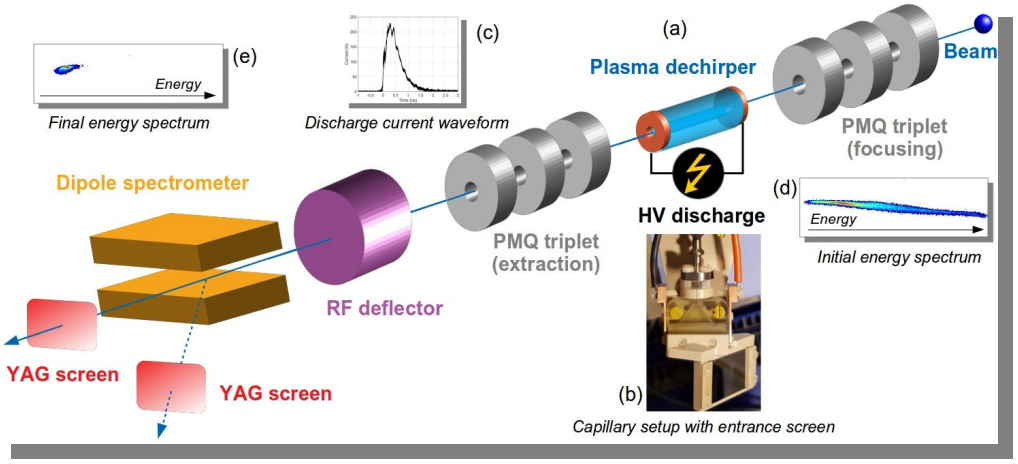
Focusing and emittance preservation with active-plasma lenses

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

Plasma characterization



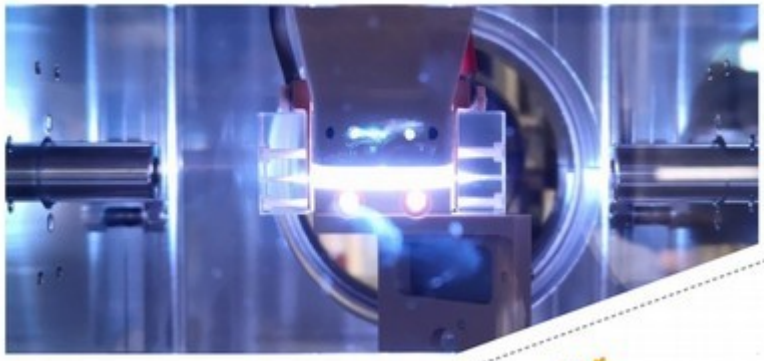
Biagioni, A., et al., Journal of Instrumentation 11.08 (2016): C08003.



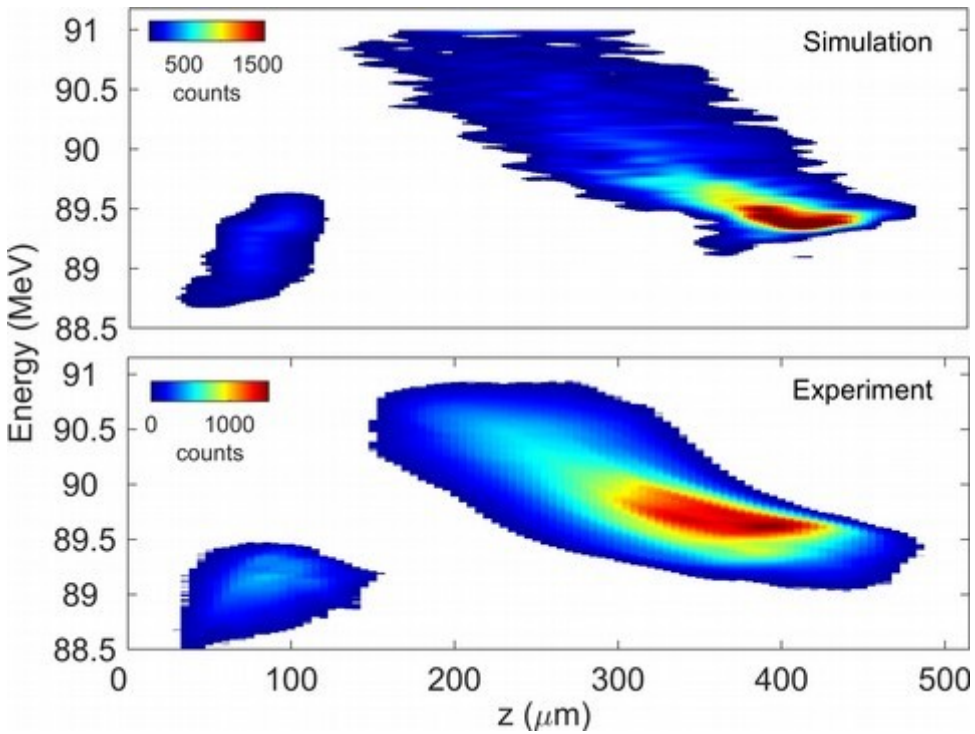
Plasma-dechirper

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)

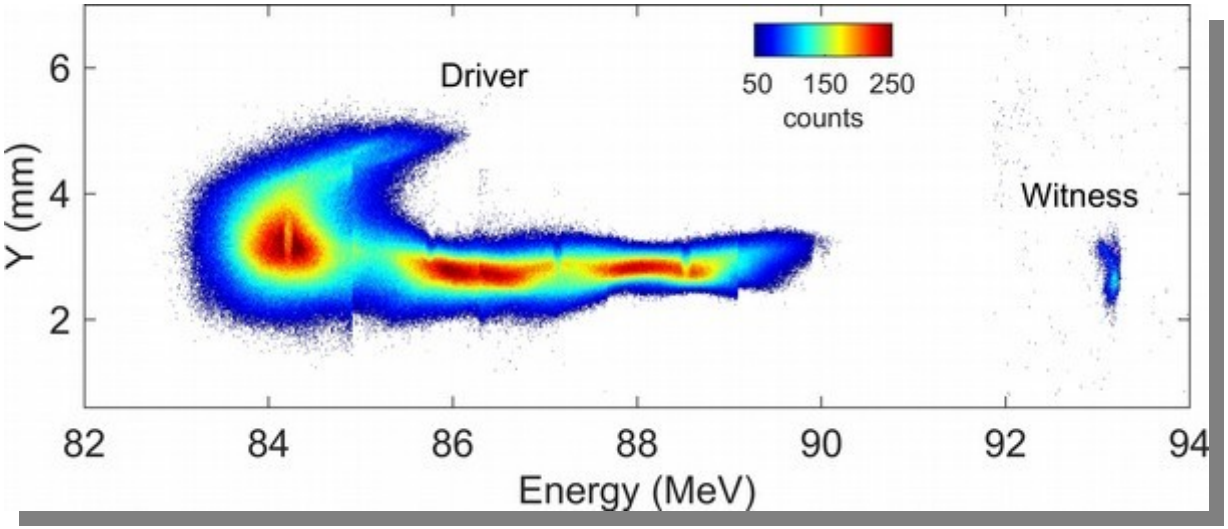
Achieved 4 MeV acceleration in 3 cm plasma with 200 pC driver

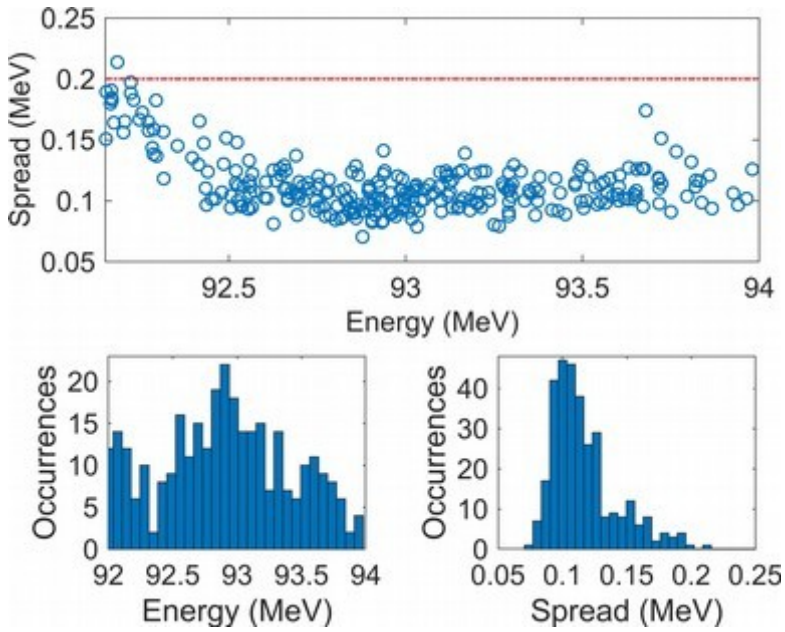
- *~133 MV/m accelerating gradient*
- *2x10^{15} cm^{-3} plasma density*

First ever demonstration of energy spread compensation during acceleration

- *Energy spread reduced from 0.2% to 0.12%*

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)

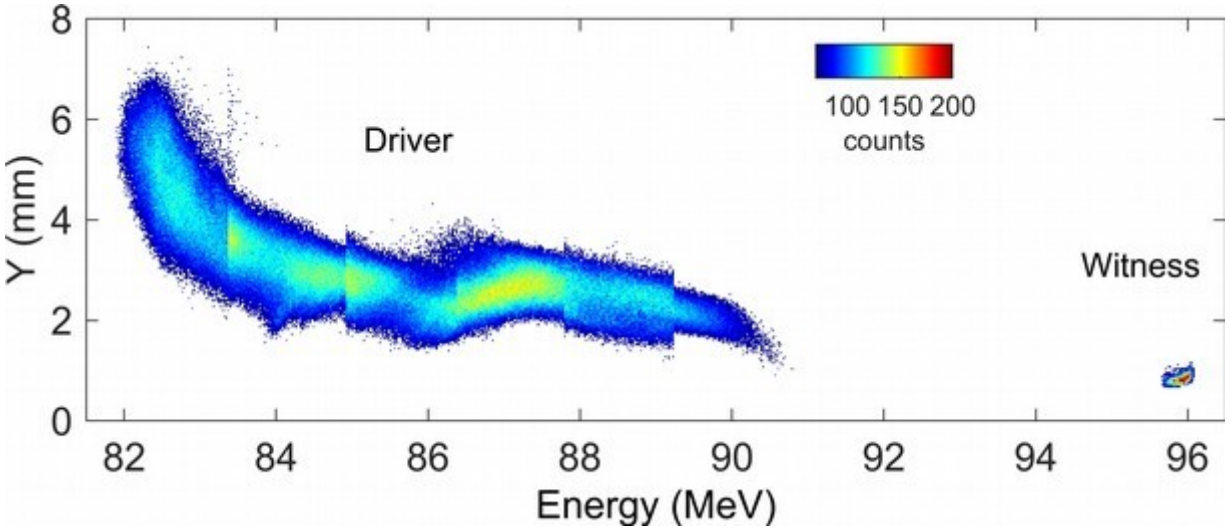
Achieved 7 MeV acceleration in 3 cm plasma with 350 pC driver

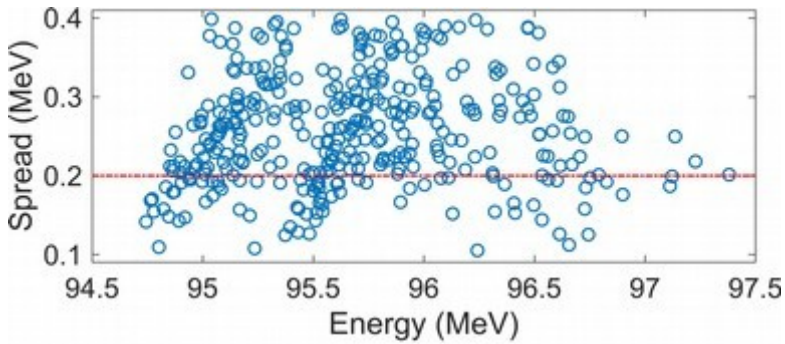
- *~233 MV/m accelerating gradient*
- *2x10^{15} cm^{-3} plasma density*

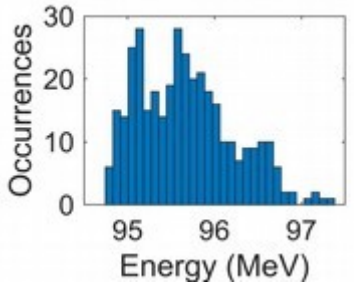
Energy spread of the accelerated beam slightly increased

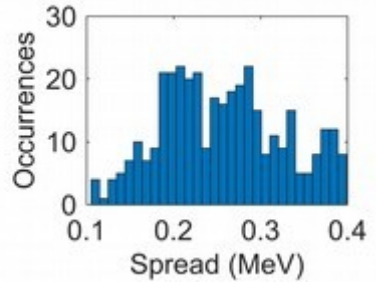
- *Energy spread reduced from 0.2% to 0.26%*

Still order of magnitudes lower spread with respect to previous experiments





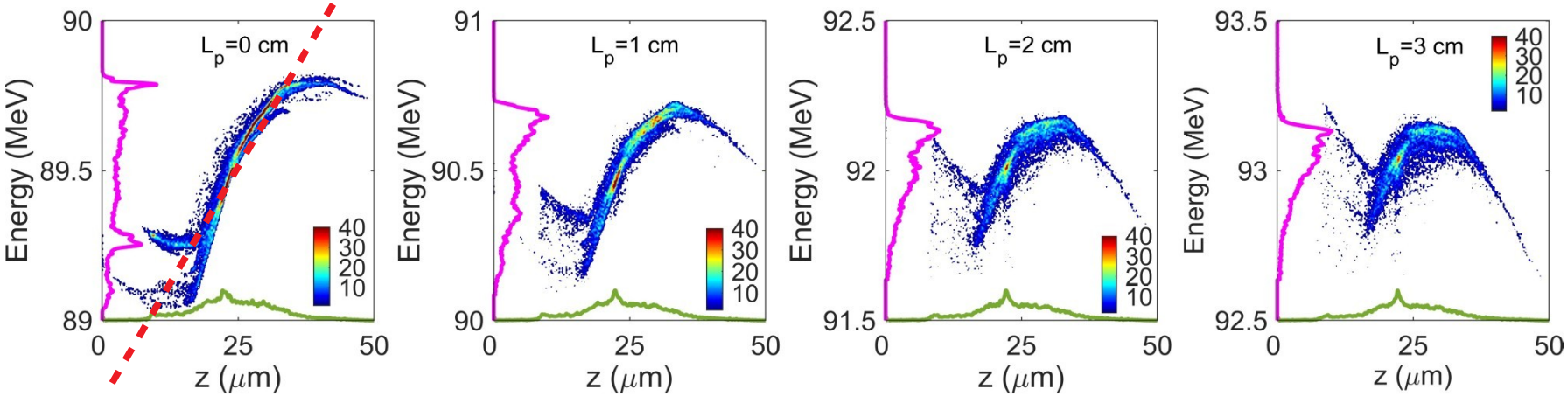


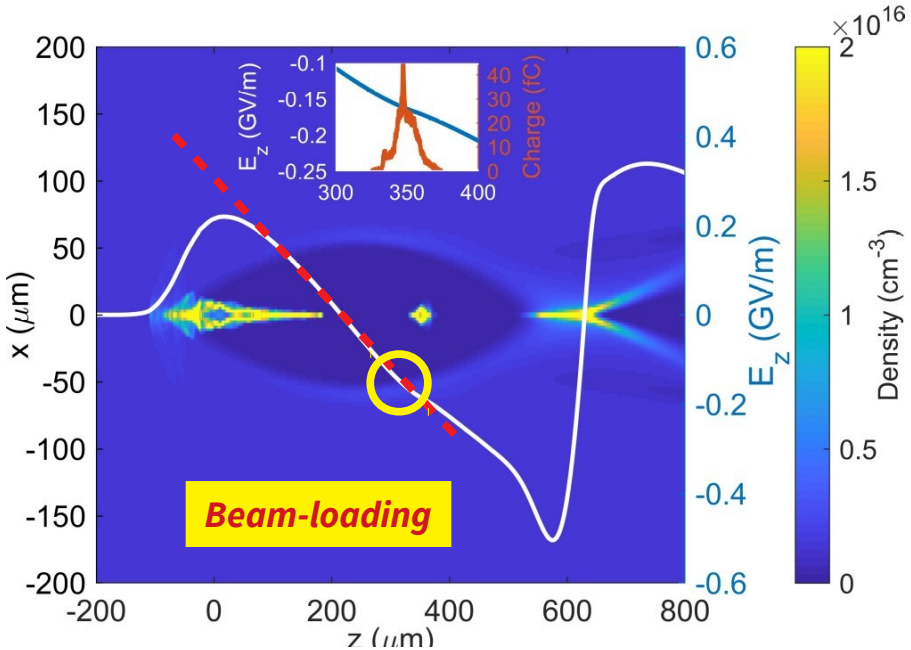


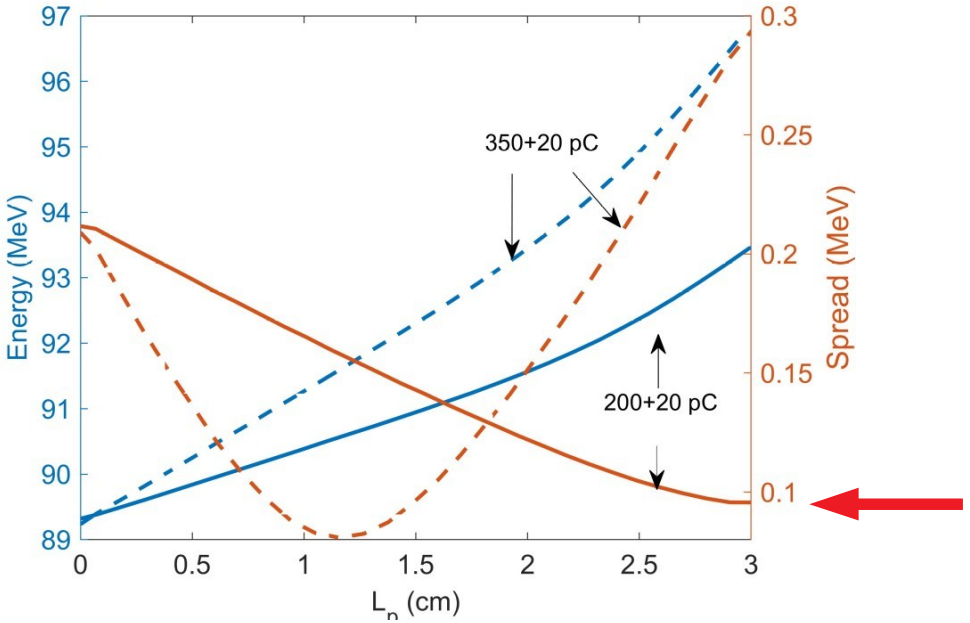
R. Pompili et al, "Energy spread minimization in a beam-driven plasma wakefield accelerator", accepted for publication by Nature Physics

Assisted beam-loading technique

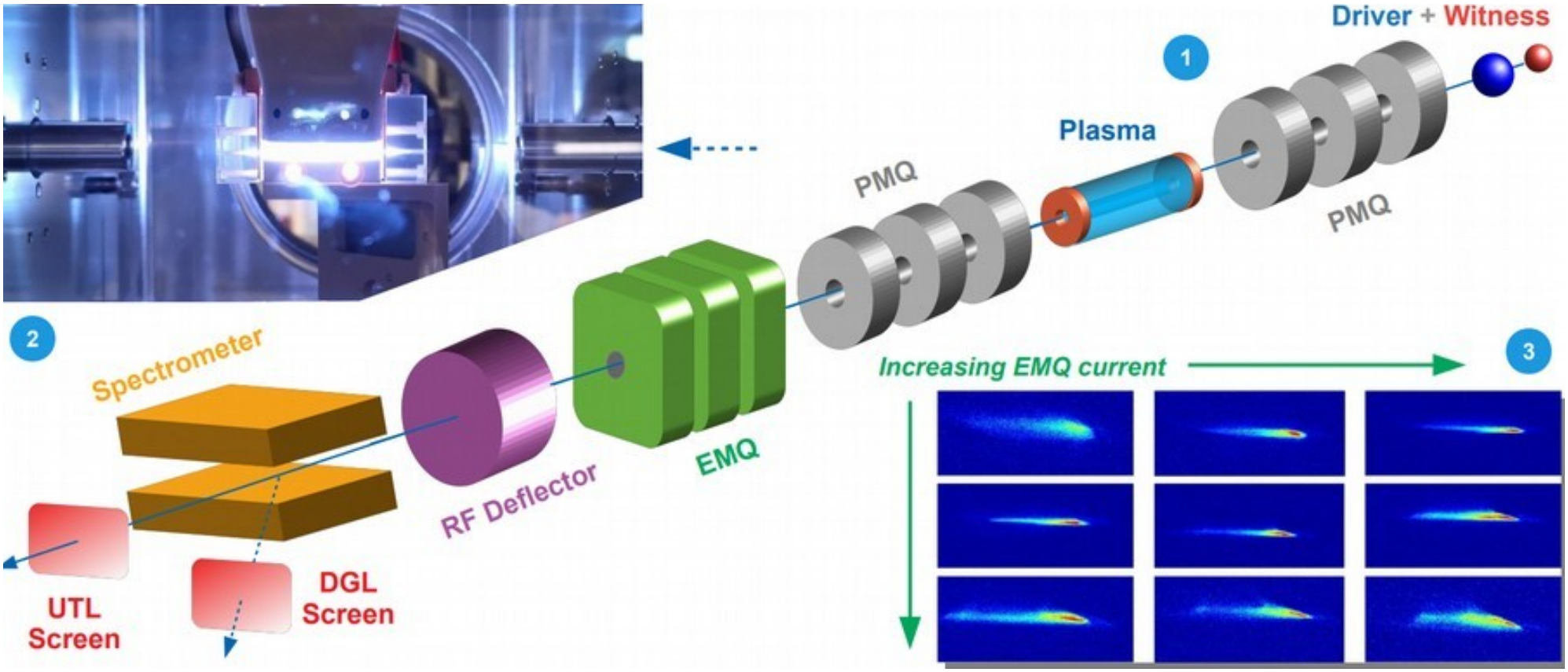
Pre-chirp to compensate wakefield slope







Accelerated witness characterization (1)



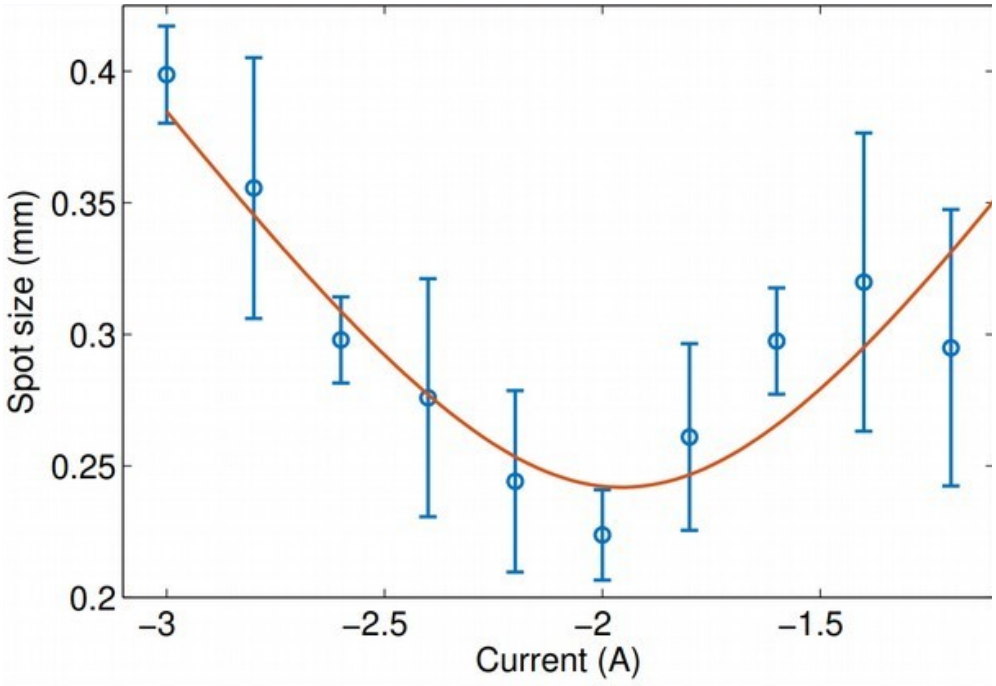
Quadrupole-scan for emittance evaluation (on the vertical plane)

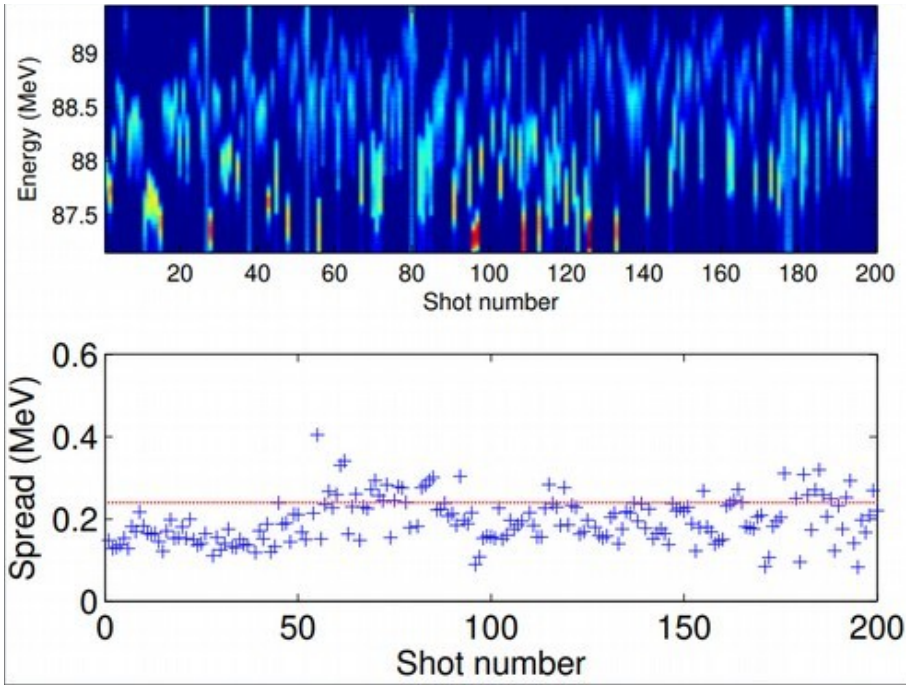
Accelerated witness characterization (2)

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)

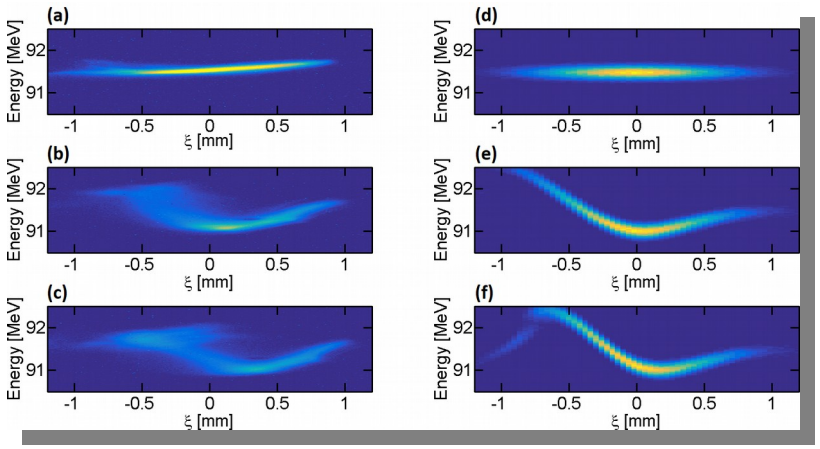
Longitudinal phase-space

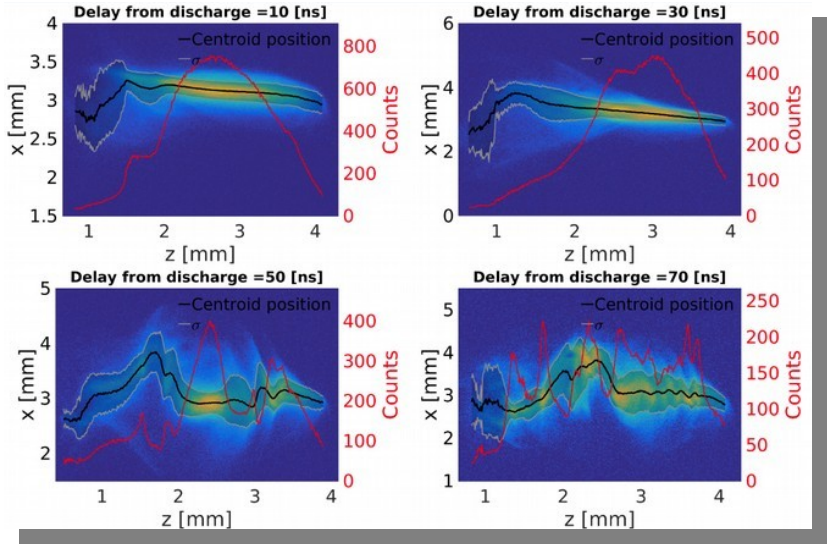
Analysis of energy modulations to retrieve the wakefield excited in the plasma

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

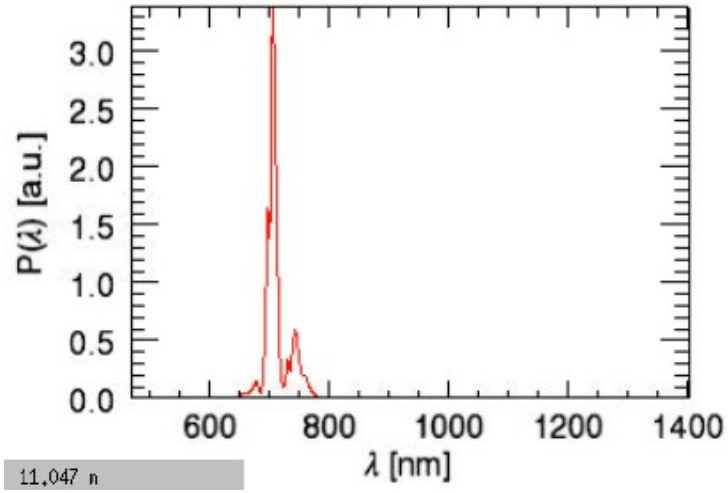
measurable growth of the FEL gain achieved

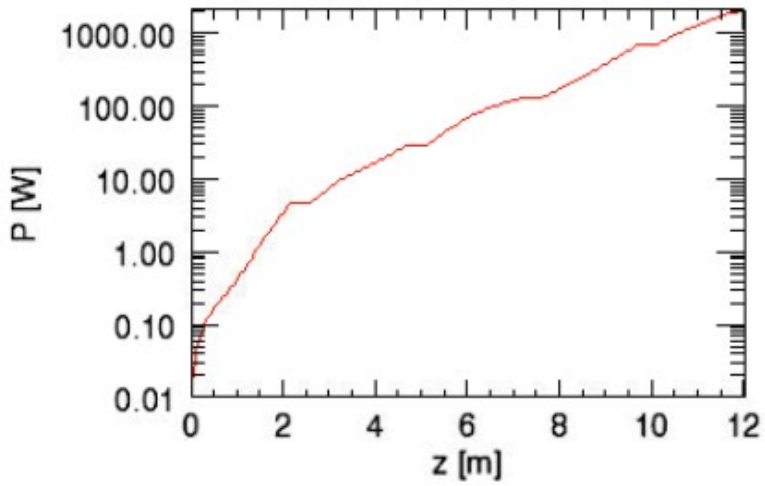
E. Chiadroni (LNF)
F. Nguyen (ENEA)

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





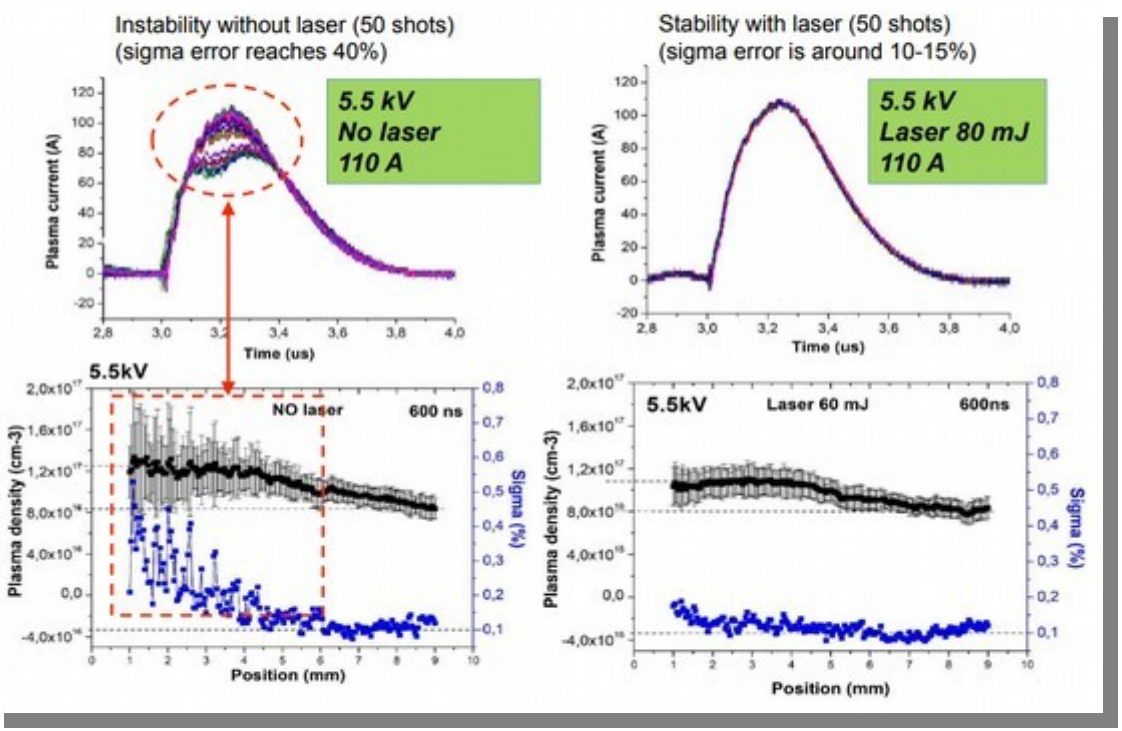
Plasma discharge stabilization

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

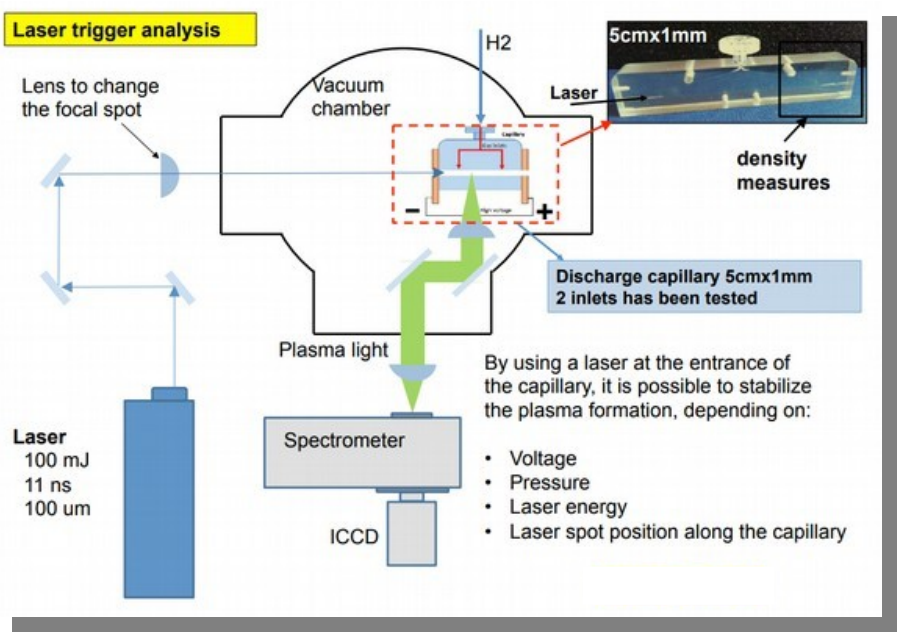
Measurements done in July 2020

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

Analysis of experimental results (laser vs dark current) ongoing

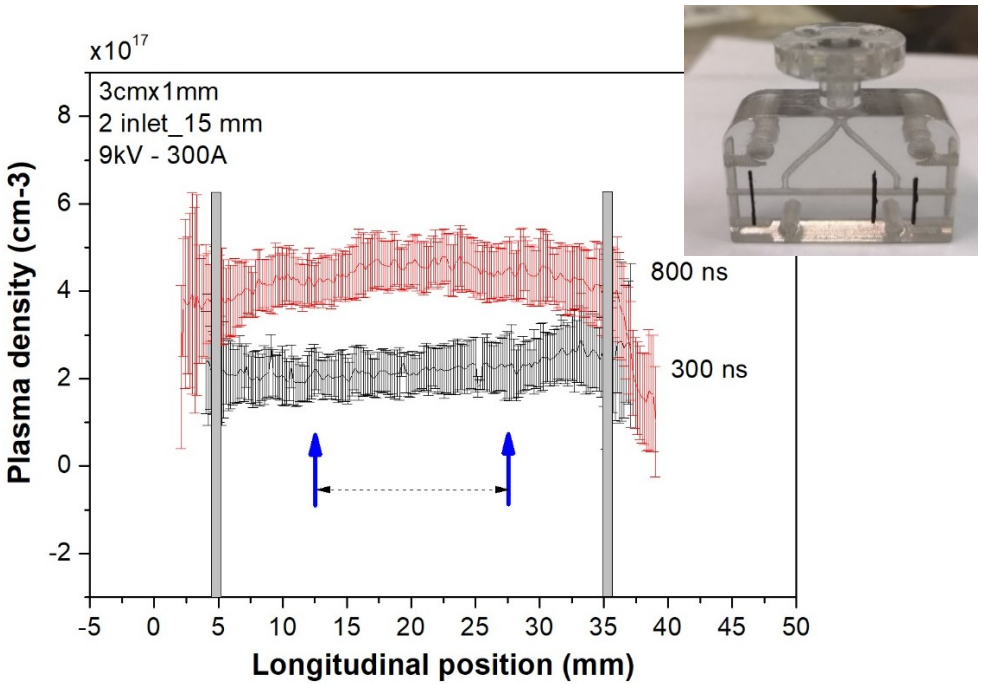


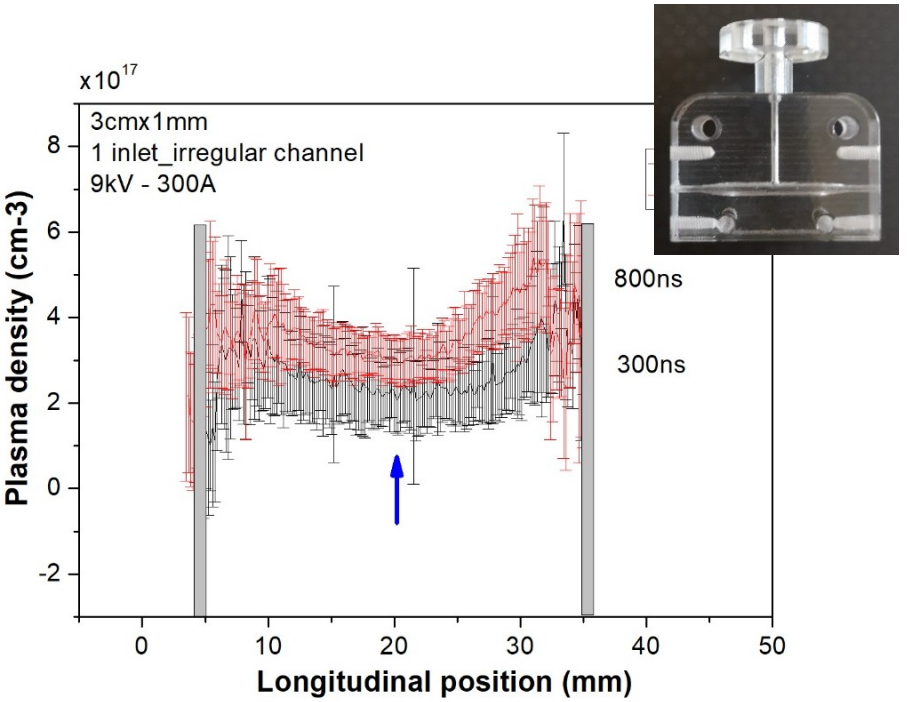
M. Galletti, in preparation

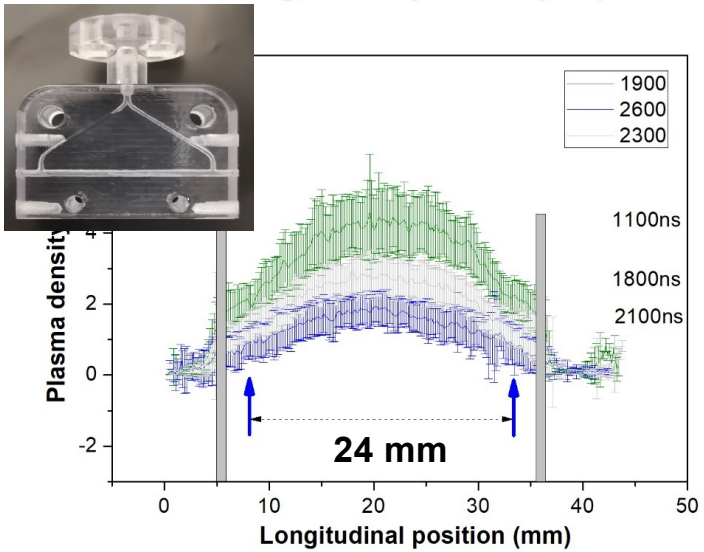


A. Biagioni, in preparation

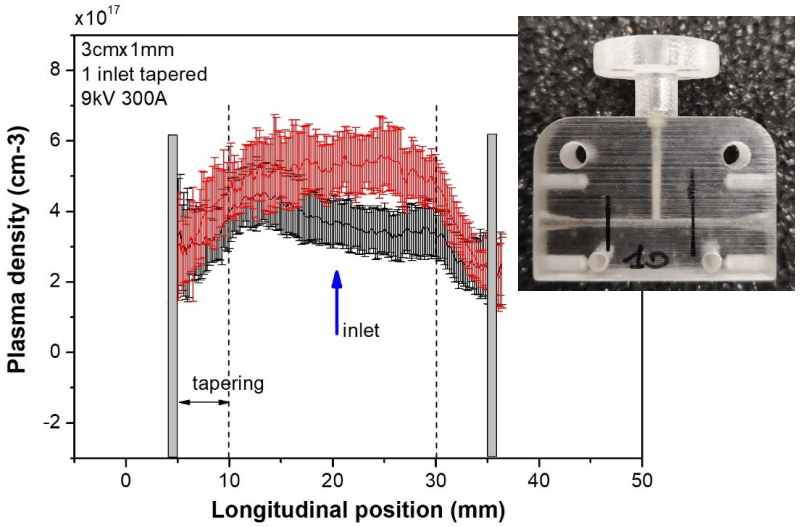
Ongoing activities @ PLASMA_LAB







A. Biagioni



Ongoing activities @ FLAME

The main activities on FLAME have been

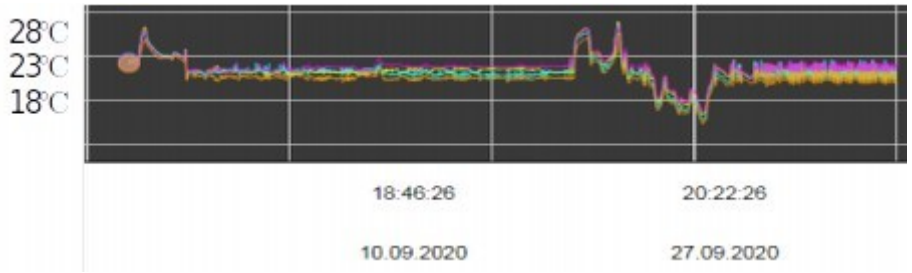
Capillary characterization for laser guiding;

Installation of the new control system;

Design of new generation capillaries;

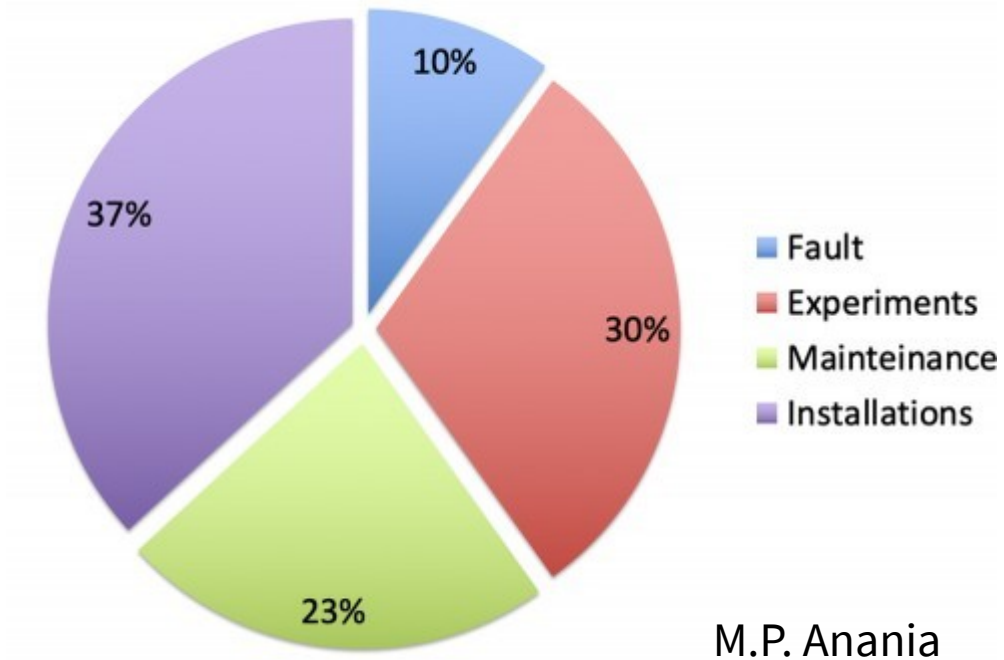
Test of a new gas-jet with rounded parts;

Preparation of the new set-up (EXIN@FLAME);



- Air conditioning issues have been solved only in October, when we have been able to restart the laser with continuity.
- In the mean time, the old set-up in FLAME bunker has been dismounted and installation of the new set-up has started.
- Also a new control system has been installed and soon we hope to start to test it.

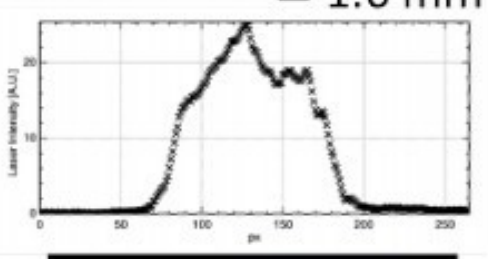
- **Faults are mainly coming from air conditioning system**
- **Experiments have been done only with a small portion of the main laser**
- **Maintenance had a strong impact due to the very long shut down**
- **Installation is still undergoing**

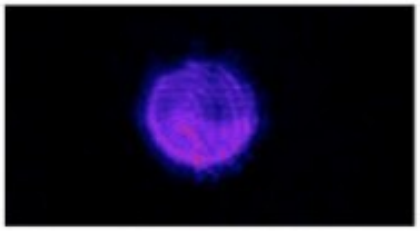


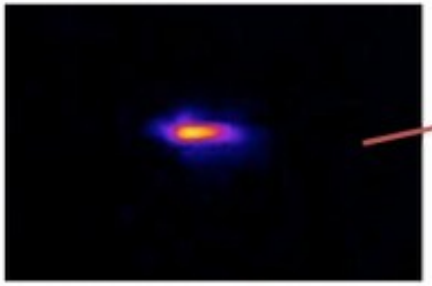
M.P. Anania

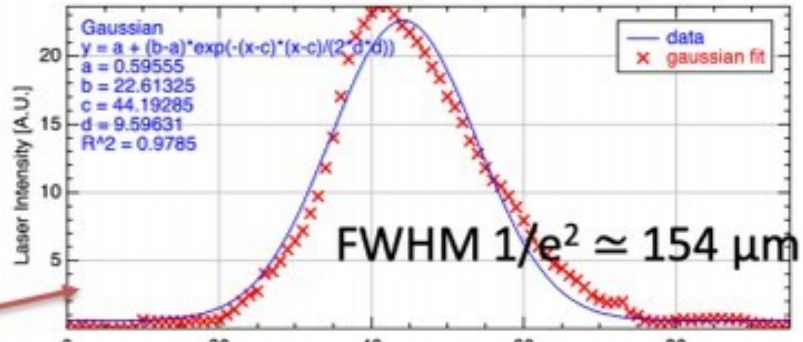
FLAME laser guiding

≃ 1.6 mm



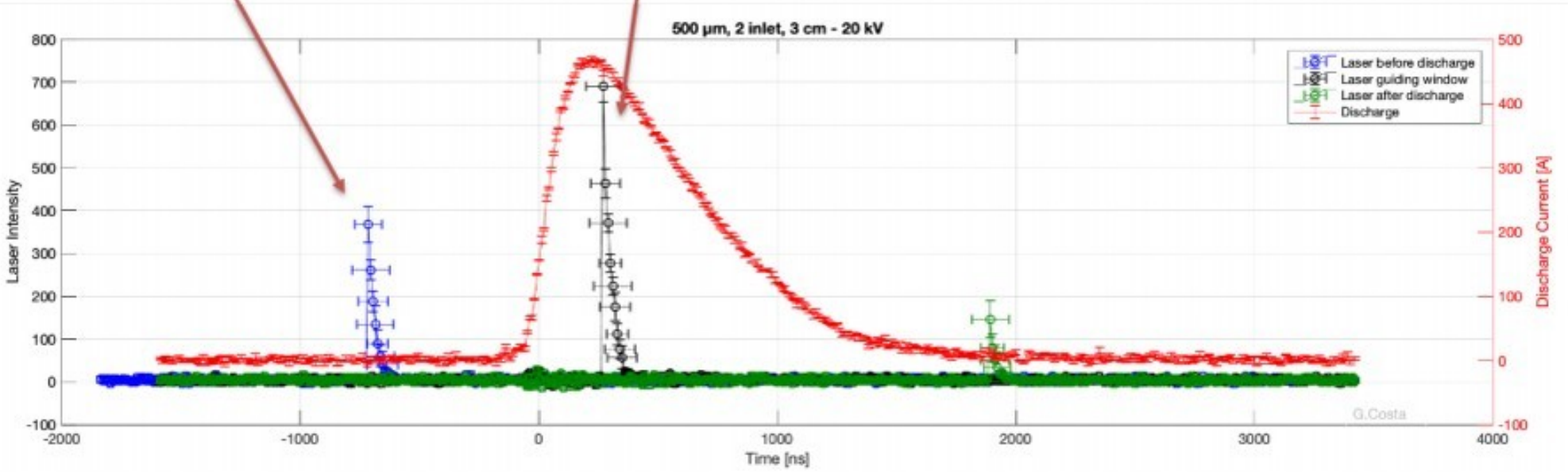


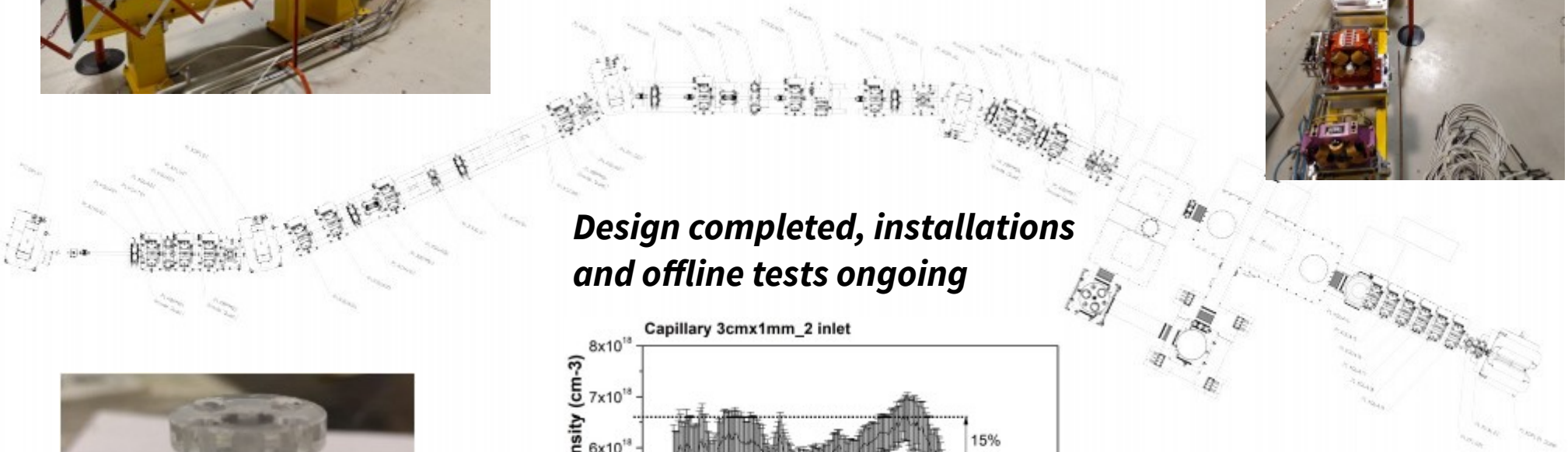




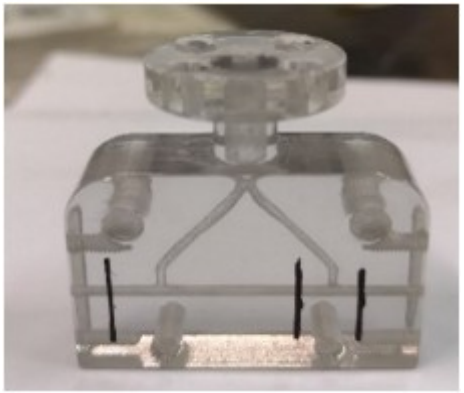
focus FWHM $1/e^2 \simeq 120$ µm and $\Delta t \simeq 50$ fs

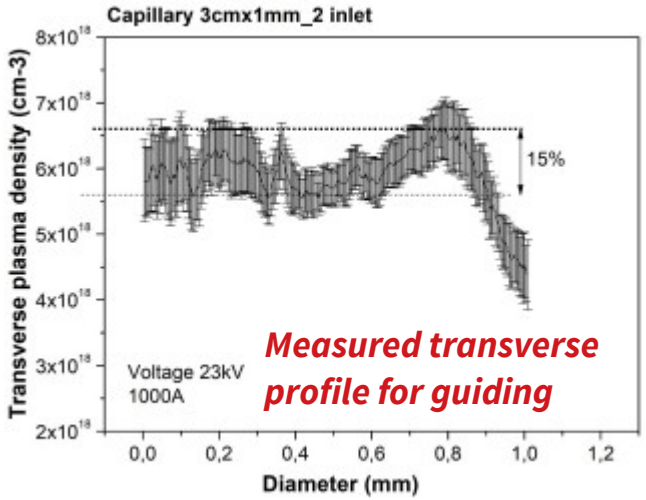
$n_e = ((4.7 \times 10^3 \times r_{capillary}^{1/2})/ r_{laser})^{-4} \simeq 2.5 \times 10^{18}$ cm^{-3}



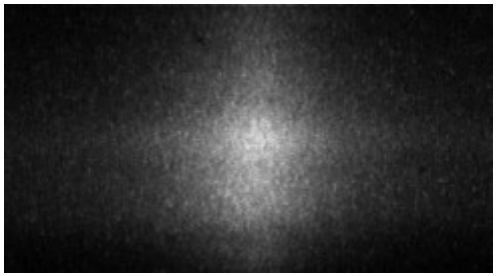


Design completed, installations and offline tests ongoing





Measured transverse profile for guiding



Ongoing activities @ cathodes LAB

R&D activity on electron emission physics

Emission studies of metal photo-cathodes: Quantum Efficiency measurements and emission uniformity

Studies of Laser Beam spatial uniformity

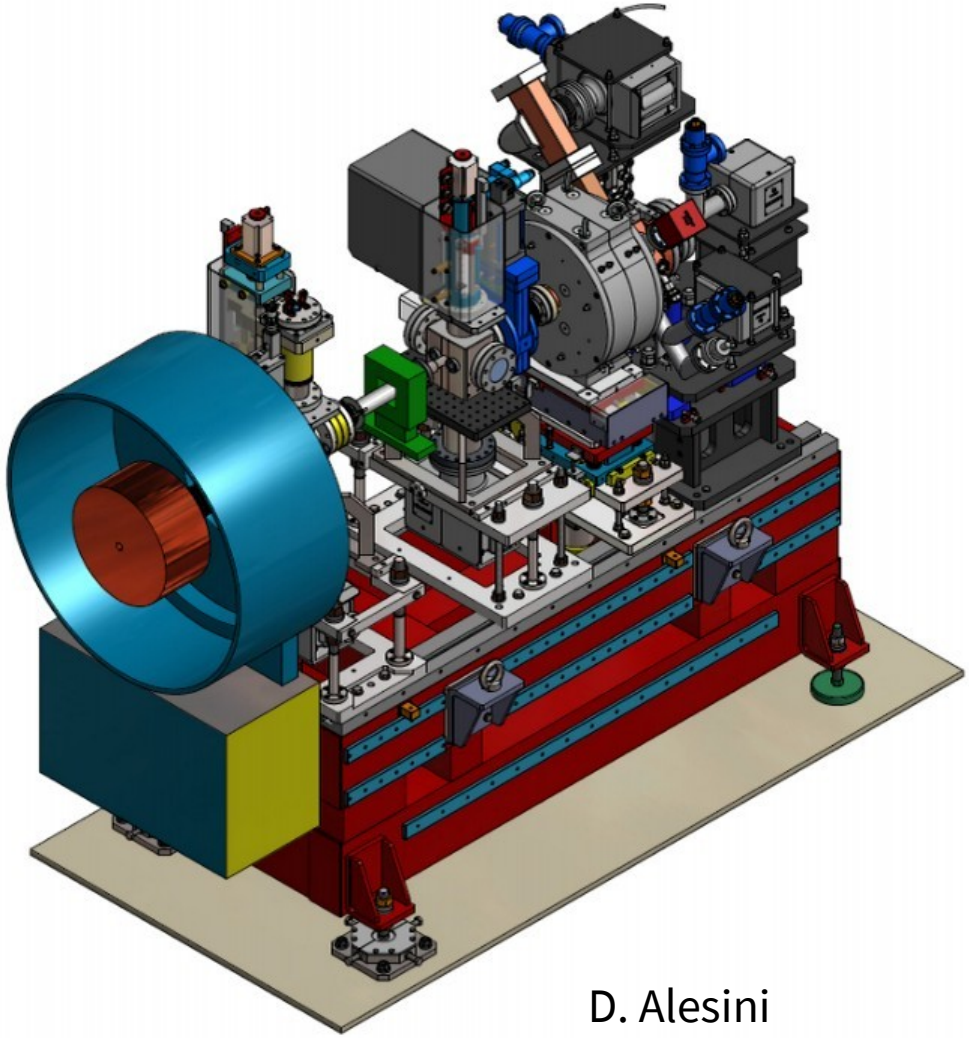
Comparison of deposition techniques: metal thin film cathode studies

Single layer graphene deposition on Cu cathode (SL_COMB2FEL)

Emission and beam dynamics simulations (ASTRA upgrade or new codes)

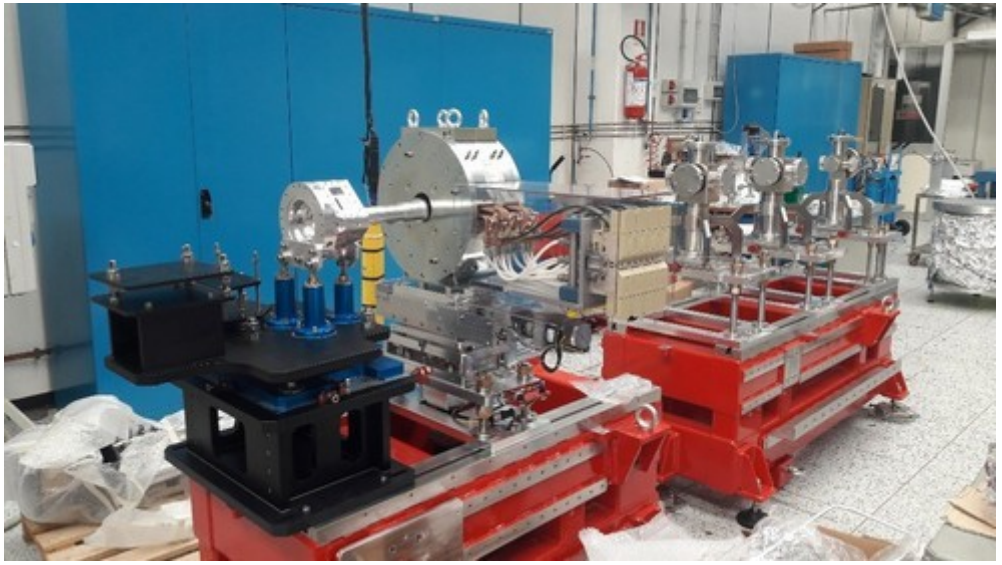
More info:
J. Scifo, D. Di Giovenale, A. Liedl: “Photo-Cathode Testing at Low Accelerating Field Laboratory: a New R&D Activity at INFN-LNF“, ACCDIV-02-2020, 03/07/2020

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



RF synchronization progress

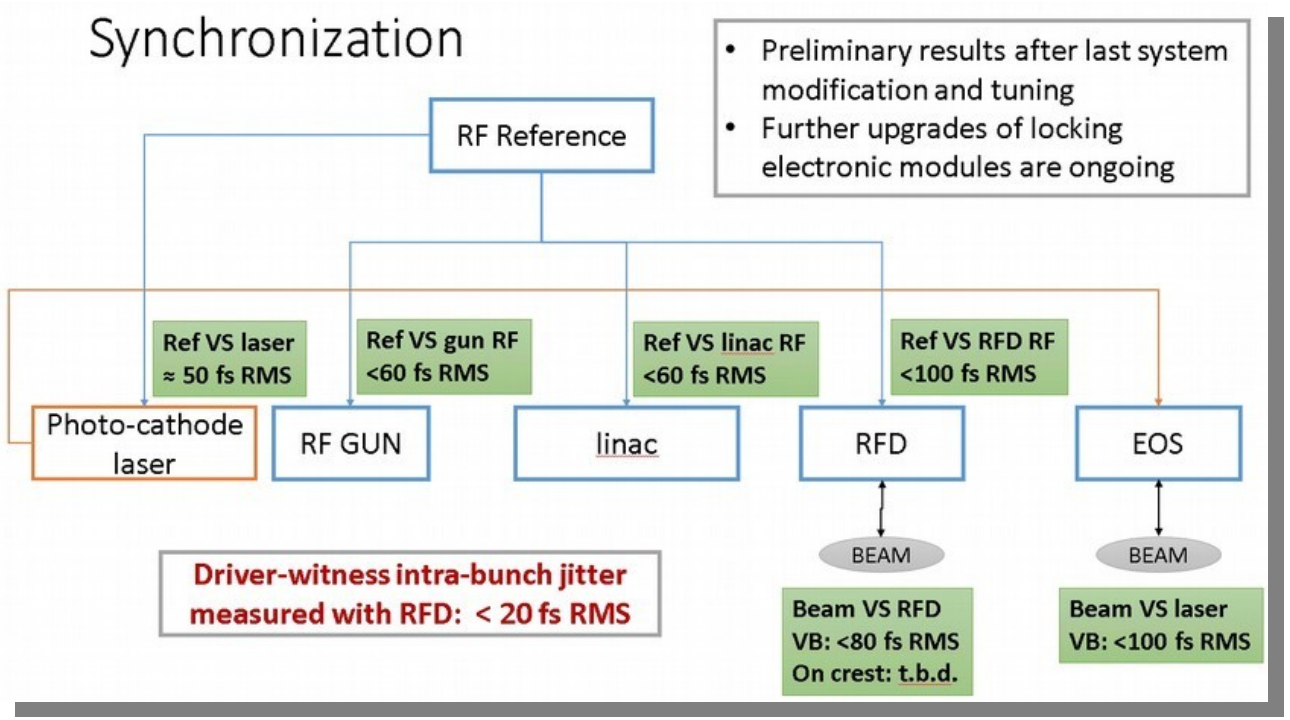
Recently we found rather large timing-jitters affecting the beam performances

*An **Electro-Optical Sampling (EOS)** station has been developed and allowed to estimate ~**300 fs** timing-jitter between the photo-cathode (PC) laser and the compressed beam*

*It translates in ~**70 fs** jitter in the distance between the driver-witness bunches → **MeV jitter with plasma!***

*Issue has been identified in the **photo-diode of the synchronization unit** that has been replaced*

*Last results show ~**80** fs bunch-PC laser jitter, giving ~**19 fs** jitter in the driver-witness distance → **expected lower energy jitter for the plasma accelerated bunch***



Thanks!

November 16, 2020

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On behalf of the SPARC_LAB collaboration

Backup slides

November 16, 2020

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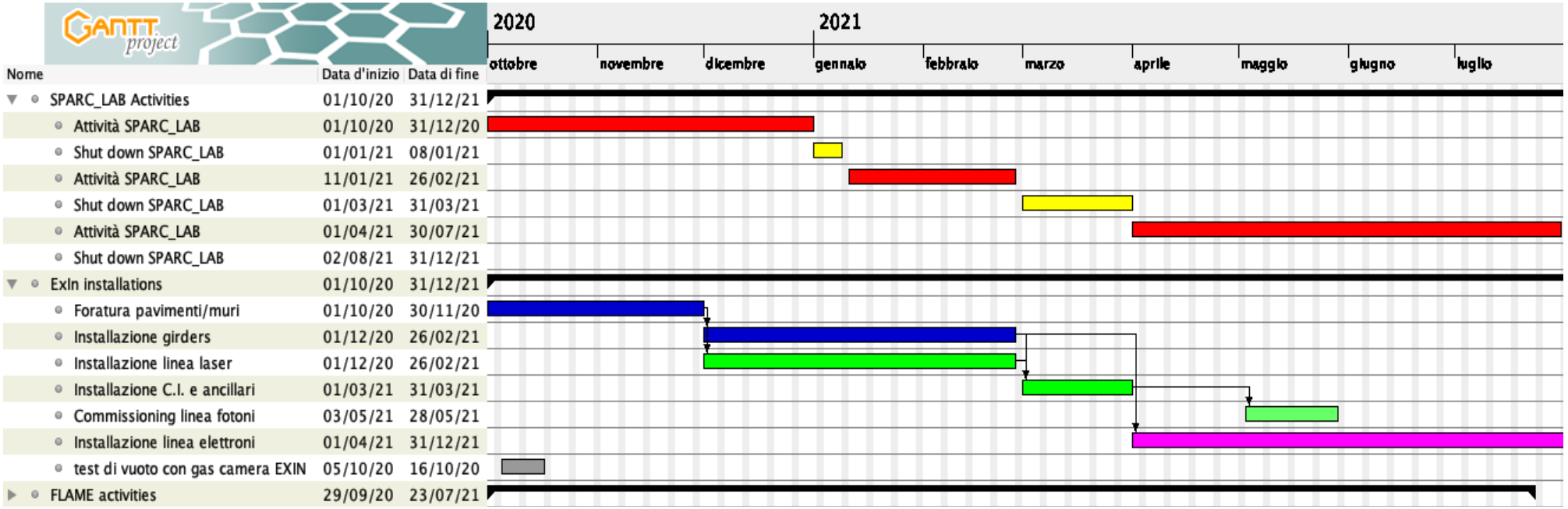
On behalf of the SPARC_LAB collaboration

EXIN timeline



Nome	Data d'inizio	Data di fine
SPARC_LAB Activities	01/10/20	31/12/21
Attività SPARC_LAB	01/10/20	31/12/20
Shut down SPARC_LAB	01/01/21	08/01/21
Attività SPARC_LAB	11/01/21	26/02/21
Shut down SPARC_LAB	01/03/21	31/03/21
Attività SPARC_LAB	01/04/21	30/07/21
Shut down SPARC_LAB	02/08/21	31/12/21
ExIn installations	01/10/20	31/12/21
Foratura pavimenti/muri	01/10/20	30/11/20
Installazione girders	01/12/20	26/02/21
Installazione linea laser	01/12/20	26/02/21
Installazione C.I. e ancillari	01/03/21	31/03/21
Commissioning linea fotoni	03/05/21	28/05/21
Installazione linea elettroni	01/04/21	31/12/21
test di vuoto con gas camera EXIN	05/10/20	16/10/20
FLAME activities	29/09/20	23/07/21