SPARC_LAB
recent results and activities

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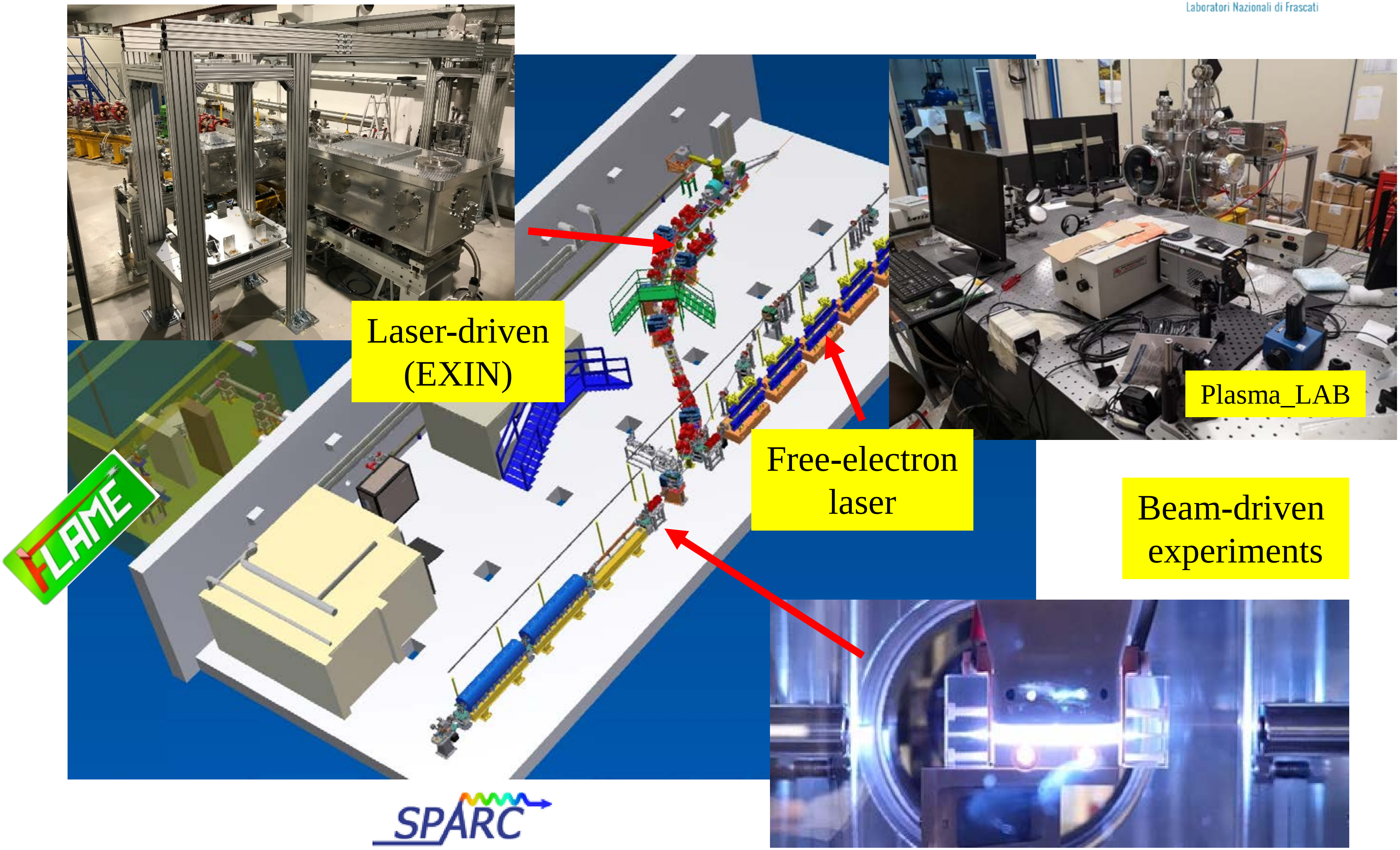
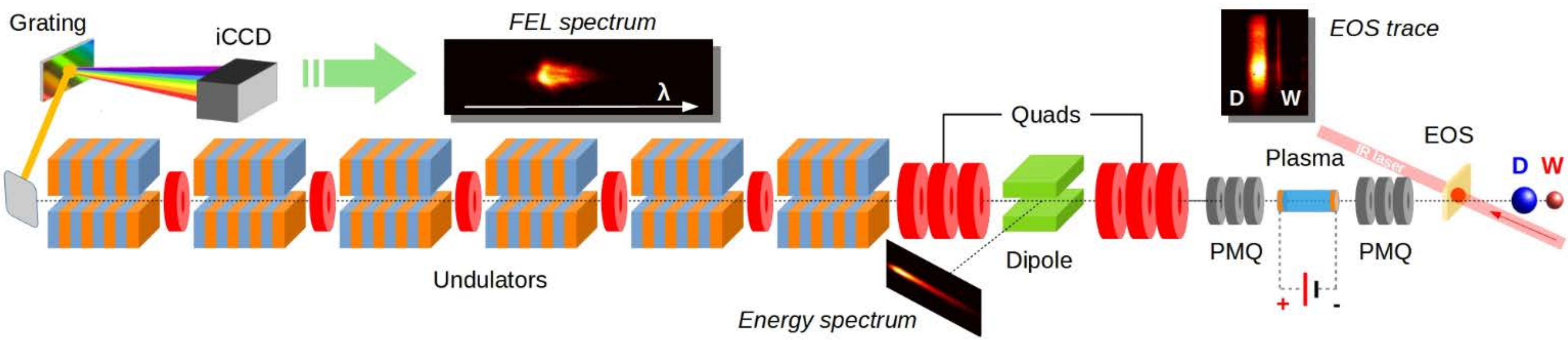
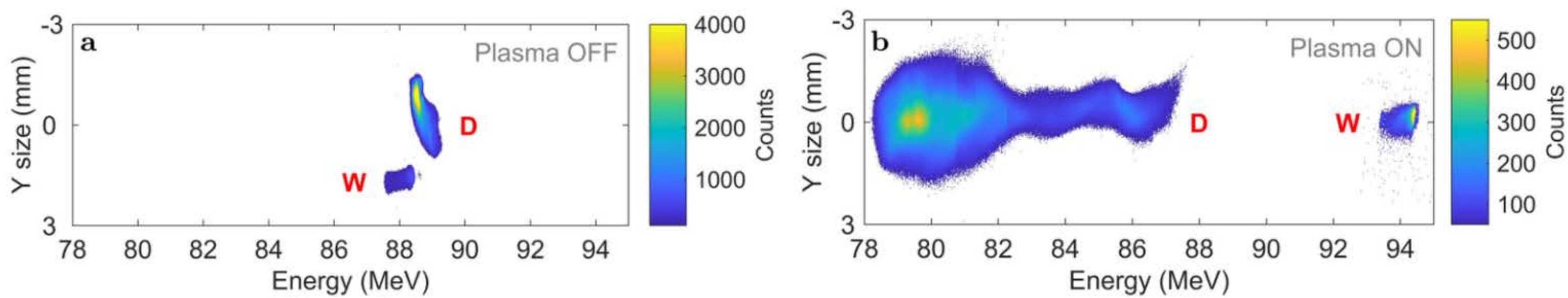
on behalf of SPARC_LAB collaboration

SPARC_LAB facility





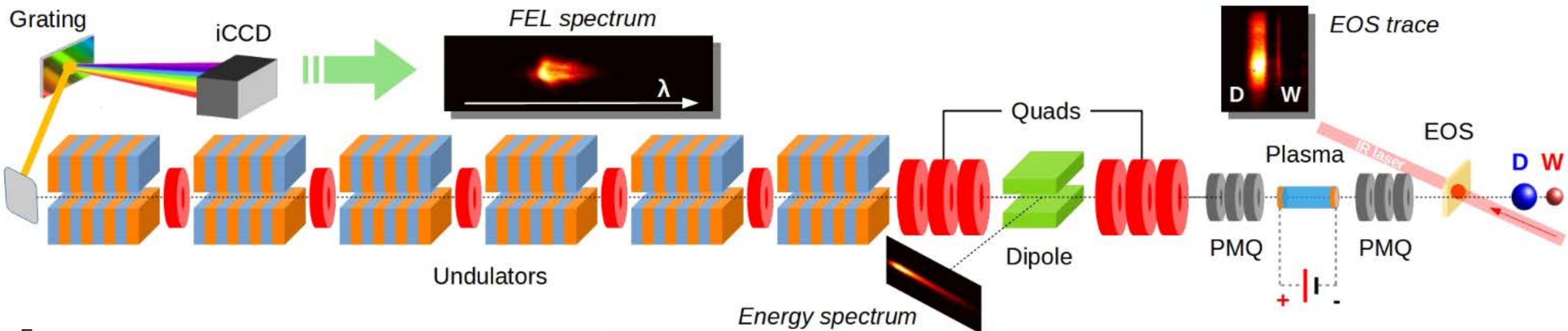


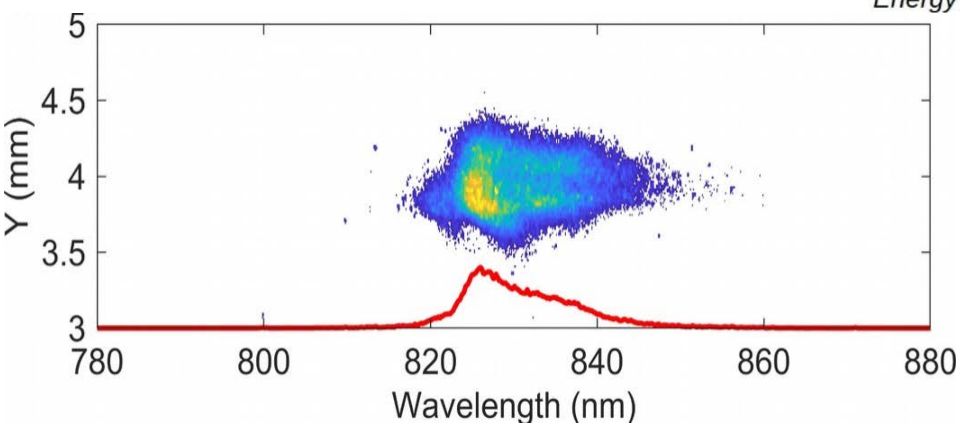
Plasma density set to 1.6x10^{15} cm^{-3}
Train configuration:

- 200 pC driver + 20 pC witness
- Separation between bunches ~1 ps
- Driver duration ~230 fs, witness ~30 fs

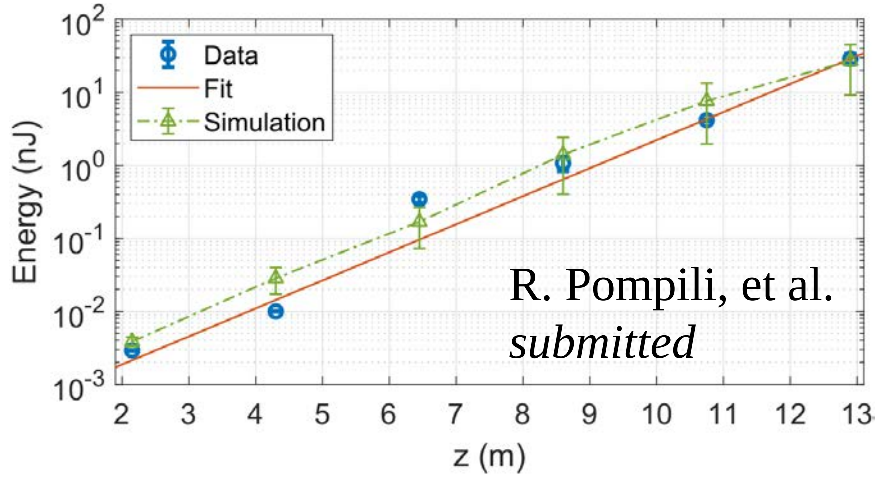
Witness after the plasma:

- Energy: 94 MeV (~200 MV/m gradient)
- Energy spread 0.3 MeV
- Emittance: 2.7(X) um, 1.3(Y) um





Exponential gain of PWFA FEL



SASE FEL radiation:

- peak at 830 nm;
- 6 undulators, ~ 15 m;
- data taken with 6 (Si) photo-diodes, after each undulator.

First LWFA FEL

Wentao Wang, et al .,Nature 595.7868 (2021): 516-520.

Recommendation from previous SC

- *The SC recommends continuing the present SPARC_LAB run to consolidate the data set and possibly try for higher plasma acceleration, before the facility is shut down for installation of the new RF gun.*

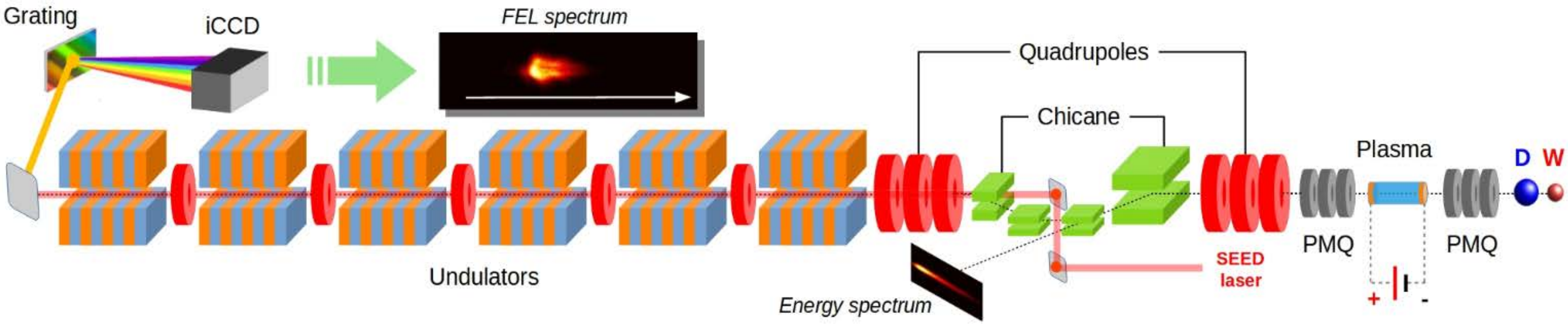
- *The increase of the energy gain in the plasma acceleration and further improvements of stability are recommended as the main guiding principles for further upgrades of SPARC_LAB.*

- *The new capability for characterizing timing jitter should trigger a vigorous R&D towards reducing this jitter in the RF, laser and synchronization. This is also of key importance for the future success of EuPRAXIA.*

- *The SC recommends continuing the present SPARC_LAB run to consolidate the data set and possibly try for higher plasma acceleration, before the facility is shut down for installation of the new RF gun.*

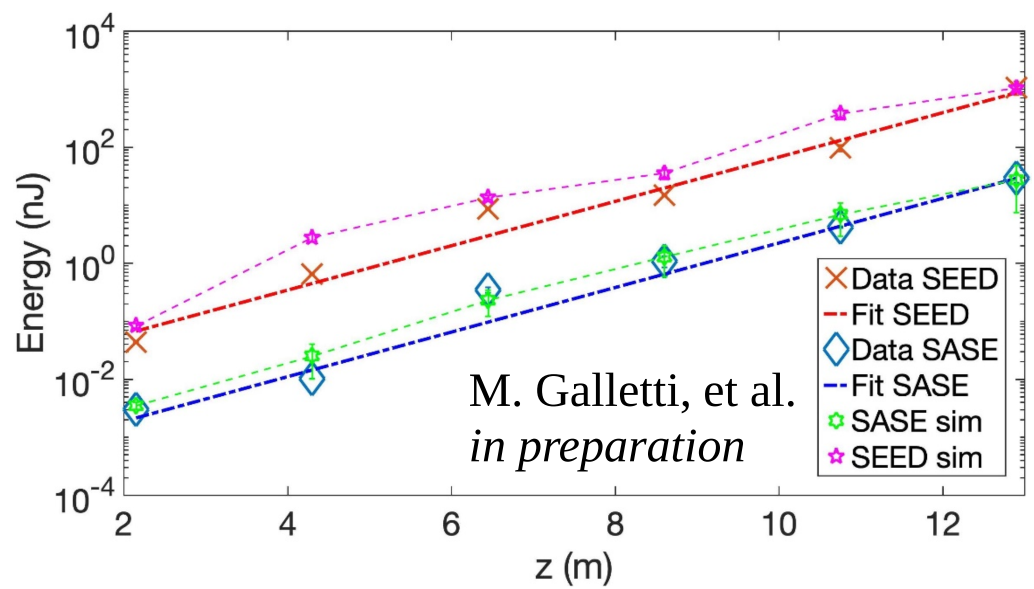
Reply

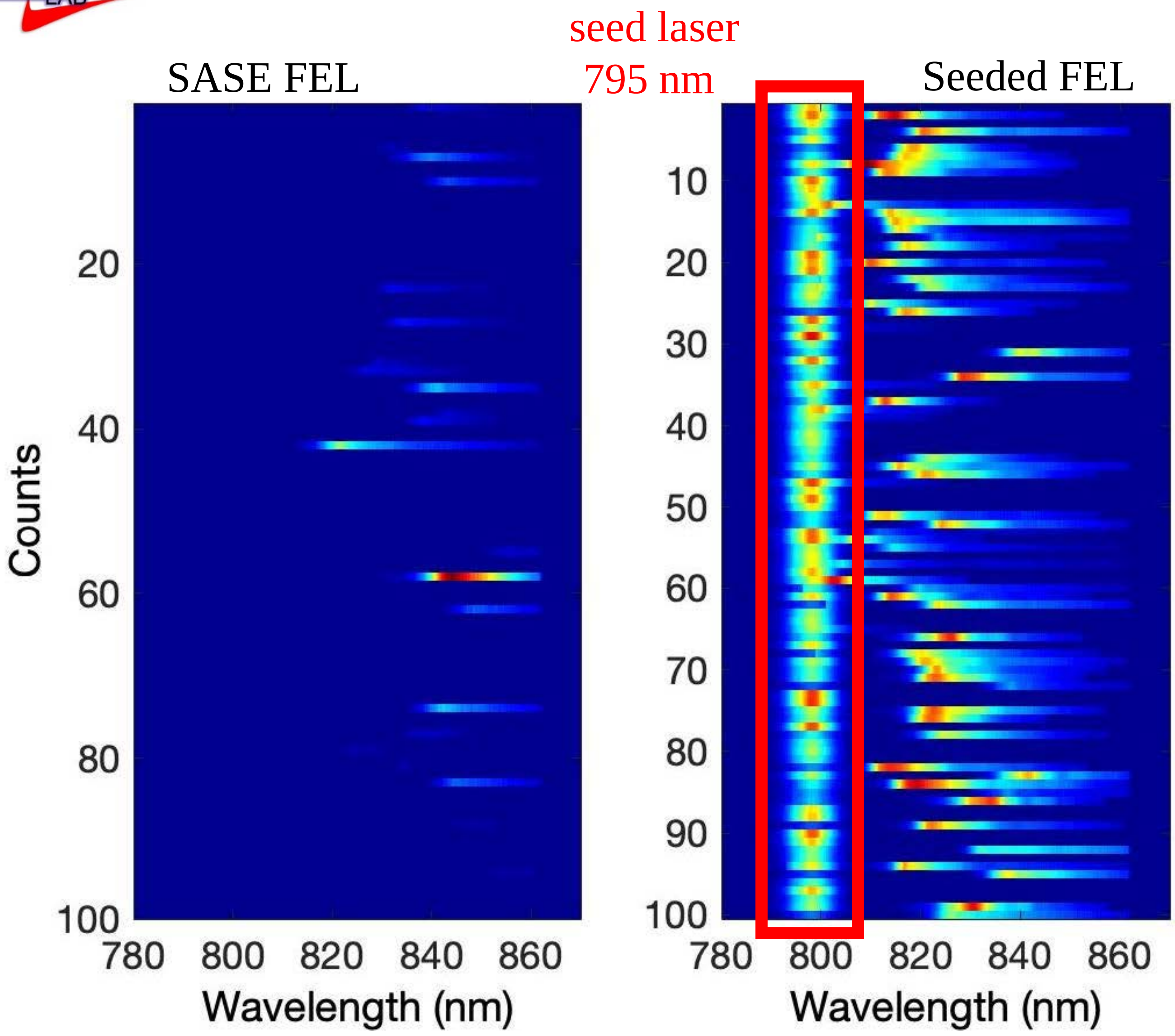
- To complete the set of FEL data the seeding laser was introduced into a system. Part of the EOS laser was used as a seed. Use of the seeding laser allowed to increase the overall energy FEL yield by two orders of magnitude, from ~30 nJ up to ~1 μJ. On top of that the seeding laser significantly improved the stability of radiation.
- the higher energy gain would require a better focusing of the beam. It was not possible to provide a better focusing of the beam before machine shutdown. However, the new injection system is already under construction and will be installed in next few month.



Seeded FEL radiation:

- part of the EOS laser was used as a seed;
- seed laser 795 nm, FEL peak still at 827 nm;
- pulse energy increase from ~30 nJ up to ~ 1 μJ;
- increased stability of radiation.




seed laser
795 nm
SASE FEL
Seeded FEL
Counts
20
40
60
80
100
10
30
50
70
90
780
800
820
840
860
Wavelength (nm)

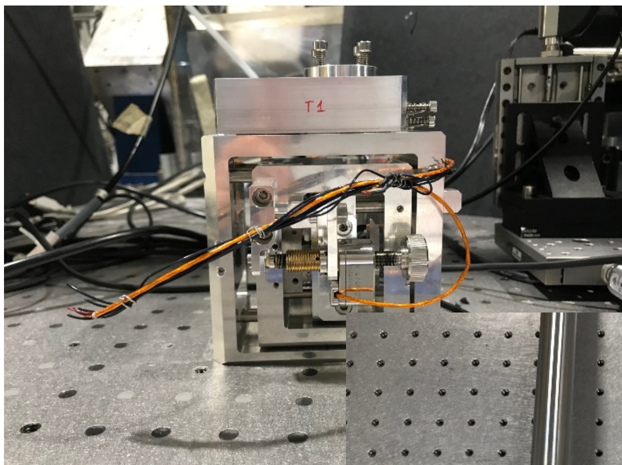
- *The increase of the energy gain in the plasma acceleration and further improvements of stability are recommended as the main guiding principles for further upgrades of SPARC_LAB.*

Reply

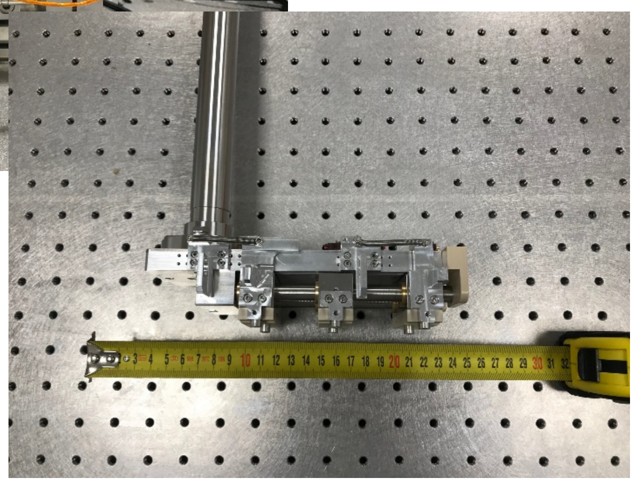
- in its core the only way to increase the acceleration gradient is to increase the plasma density. With higher plasma density comes a necessity for a higher driver density and necessity for a better focusing of the driver at the injection. The new focusing system was already designed and assembled. The installation will take place before the next plasma run.
- to lay down a path for the beam stabilization a series of measurements was taken to identify the core of the problem. It was demonstrated that in case of the compressed beam the absolute majority of arrival time jitter comes from a timing jitter of the 2nd Klystron, the Klystron which feeds the 1st accelerating section used in velocity bunching mode.

Increase of the energy gain in the plasma

- *The increase of the energy gain in the plasma acceleration and further improvements of stability are recommended as the main guiding principles for further upgrades of SPARC_LAB.*



Old focusing setup

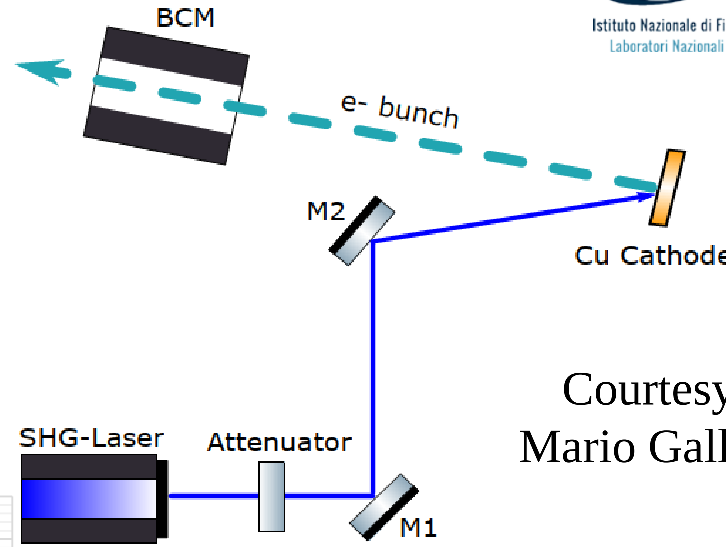


New focusing setup

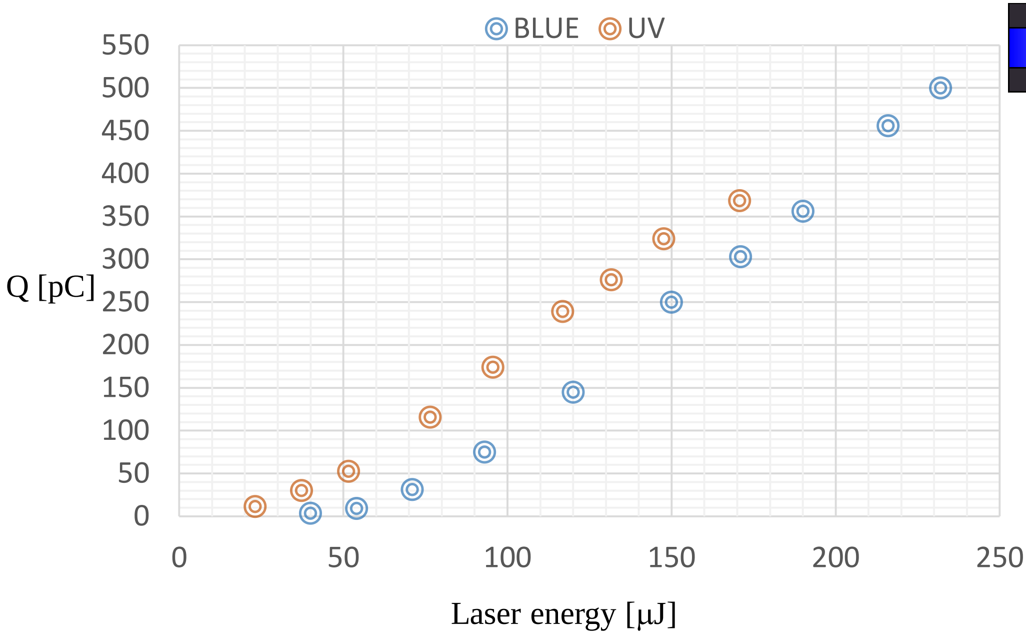
New injection system:

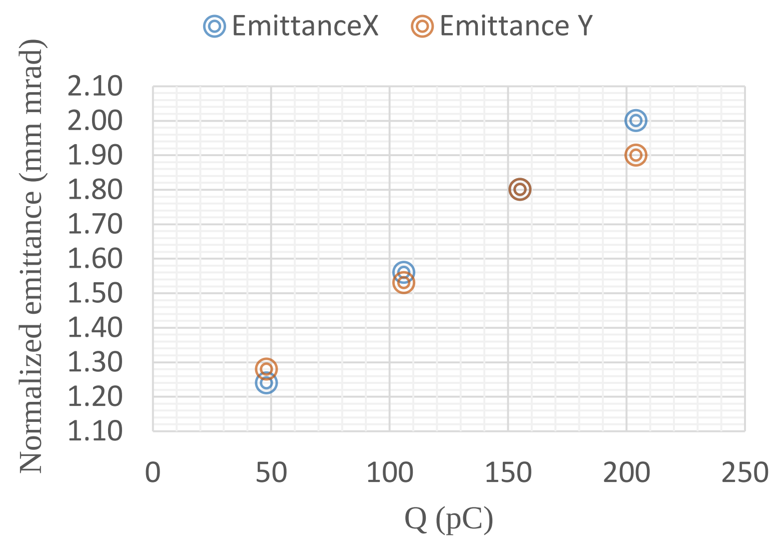
- the assembly will finished at January 2022;
- the installation is foreseen in March, in parallel with C-band modulator installation
- 3 times shorter focal length
- larger energy spread acceptance ~ 70-100 MeV.

- Simplification of the current laser setup (namely transport, diagnostics).
- Increasing energy, transverse homogeneity and temporal stability of the laser.



Courtesy:
Mario Galletti





R. Pompili, et al. "Time-resolved study of nonlinear photoemission in radio frequency photoinjectors", Opt.Lett. 46, 2844-2847 (2021)

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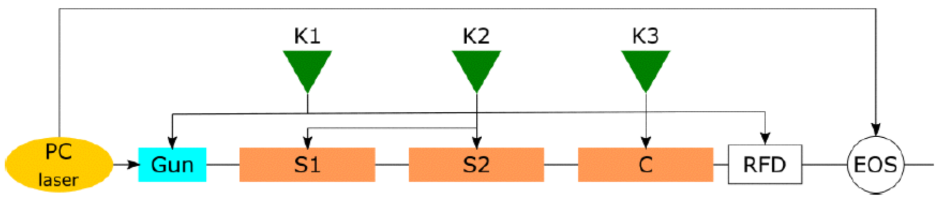


There are 4 subsystems to contribute into ATJ:

- photo-cathode laser (feeds both photo-cathode and EOS)
- 1st Klystron (K1, S-band), feeds the Gun and RFD
- 2nd Klystron (K2, S-band), feeds first two accelerating sections
- 3rd Klystron (K3, C-band) feeds the last accelerating sections

It was established that:

- for the full ON-crest working point (maximum energy, no compression), K1 and photo-cathode laser are the primary source of the beam arrival jitter.
- however, for the velocity bunching mode (compression) the dominating source of the beam jitter is the second klystron, K2.

Courtesy: Giacomo Giannetti, Marco Bellaveglia, Luca Piersanti

- *The new capability for characterizing timing jitter should trigger a vigorous R&D towards reducing this jitter in the RF, laser and synchronization. This is also of key importance for the future success of EuPRAXIA.*

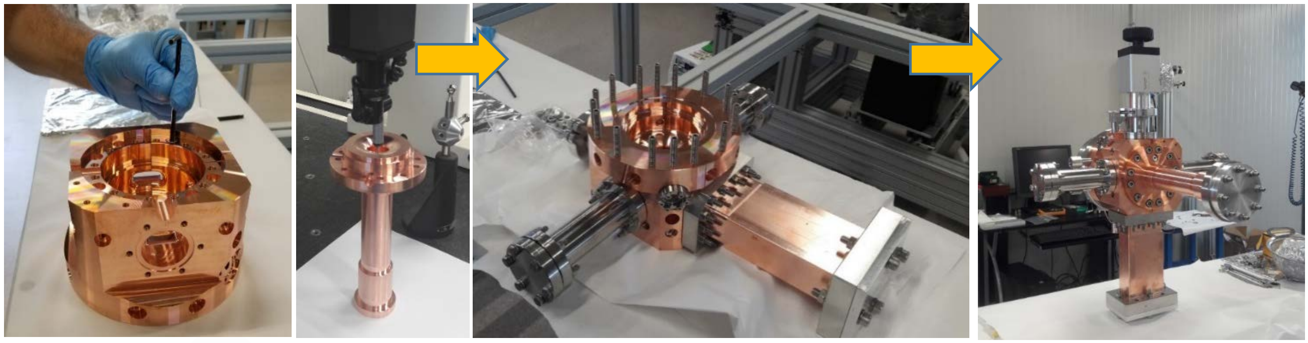
Reply

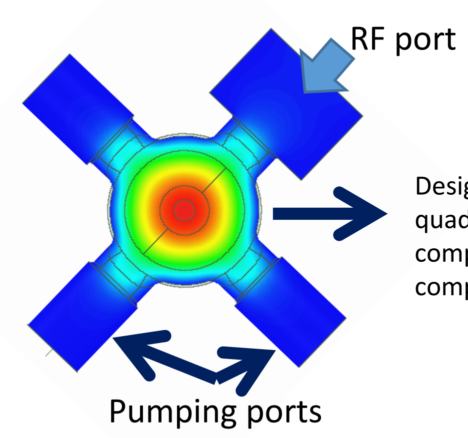
- There was created and validated a model of the jitter sources and their contribution to beam ATJ. The model helped to identify the phase jitter of the Klystron 2 as the main source of the ATJ in RF compression regime.
- Thus we are investigating a possibility to reduce the jitter from the klystron by using the Solid State modulator.
- At the moment a conventional modulator equipped with fast phase loop (intra-pulse correction) reaches stability ~40 fs (RMS phase jitter).
- The state-of-art solid state modulator capable to provide a similar stability. To determine a precise value of the phase jitter, for the solid state modulator + fast klystron loop system, further studies are necessary.

With respect to the “old” injector the new one:

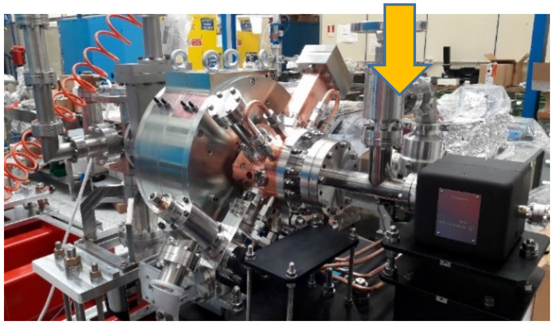
1) Integrate an RF gun fabricated with the **new brazing free technology**;
2) Integrate a **new solenoid** with a **remote control of the transverse position at the <+/-10 μm level;**
3) allows **on axis laser injection system** with the last mirror in air and not into the beam pipe;
4) Has been designed with the possibility of a **future integration of an X/C band cavity linearizer;**
5) Has a **variable skew quadrupole** after the gun for the compensation of residual quadrupole components
6) Has an electromagnetic design with a **full compensation of the quadrupole components**
7) Has an **improvement of the effective pumping speed** with two added pumping ports
8) **No cathode tuning is necessary**

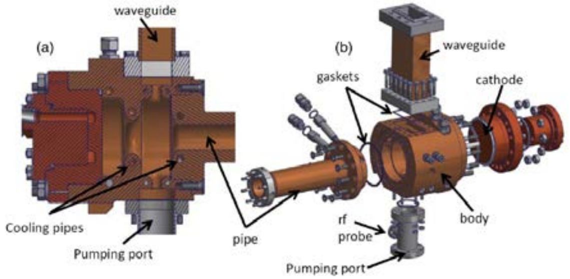
9) **Overcoupling (β=2)**





Design with full quadrupole field component compensation

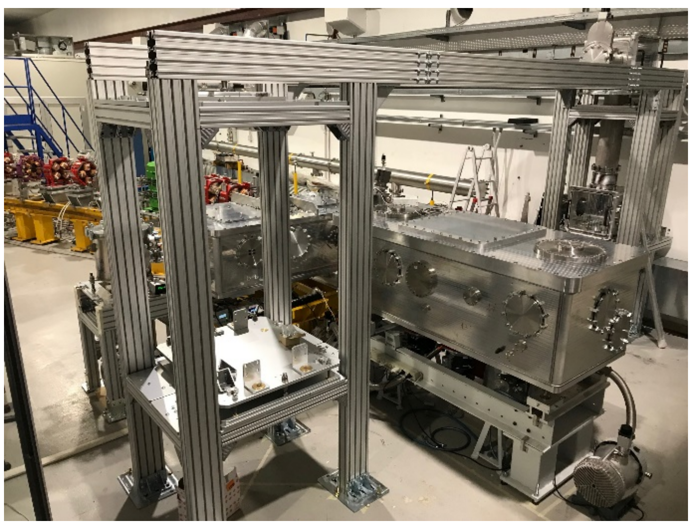




Installations

New gun

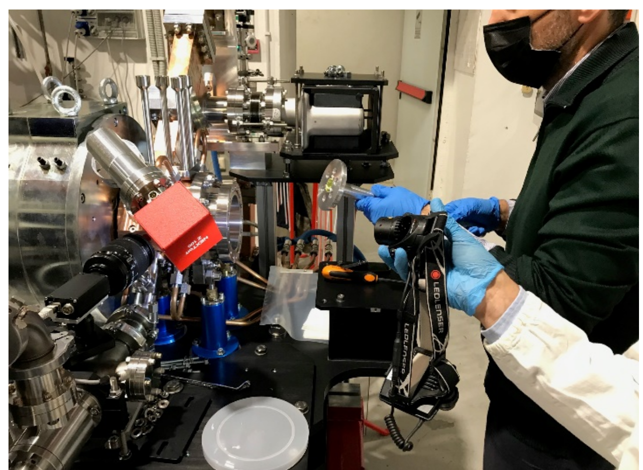
EXIN

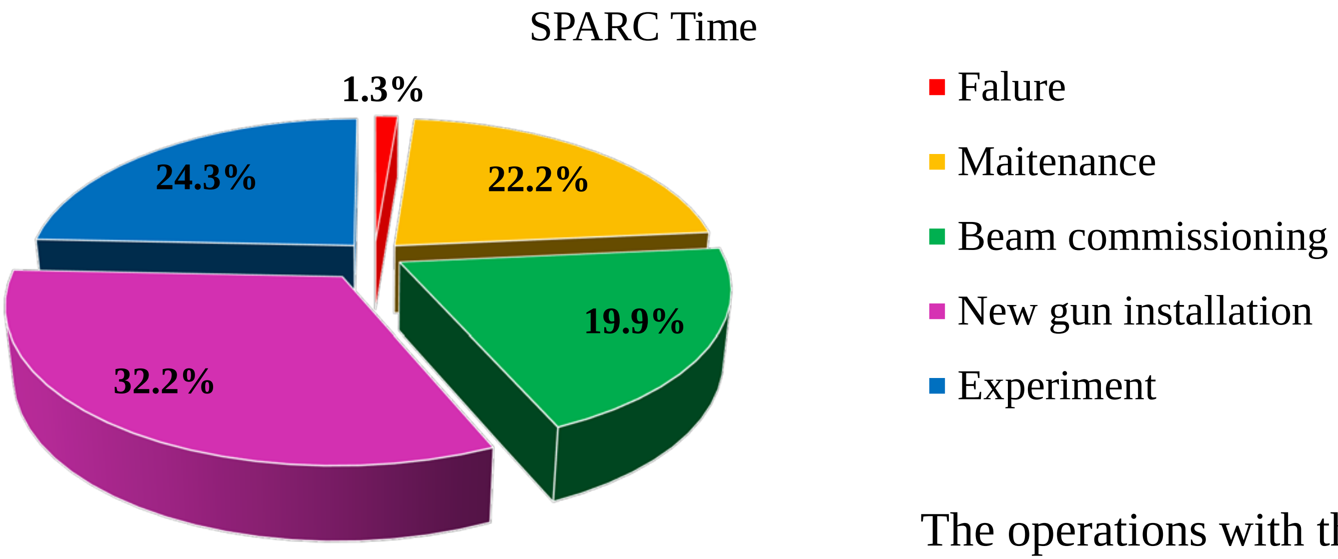


- the new gun is in place
- the conditioning is underway
- the nominal power should be reached by mid-November, the commissioning will last up until the end of the 2021

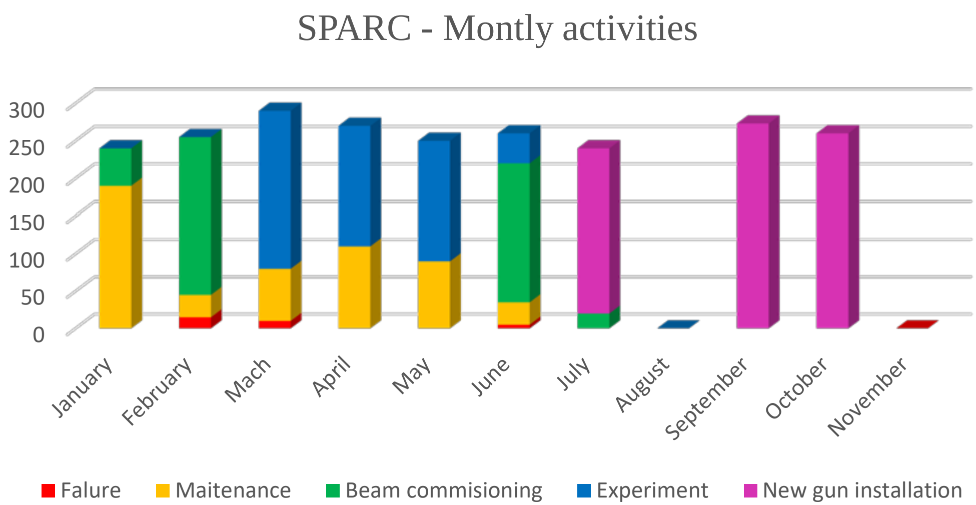
Expected advantages from the new gun

New fabrication process, optimized RF design	New optics system	Overcoupling β=2
Higher stability, lower discharge rate	Improved beam emittance	102 → 120 MeV/m





The operations with the old gun were stopped at 2nd July

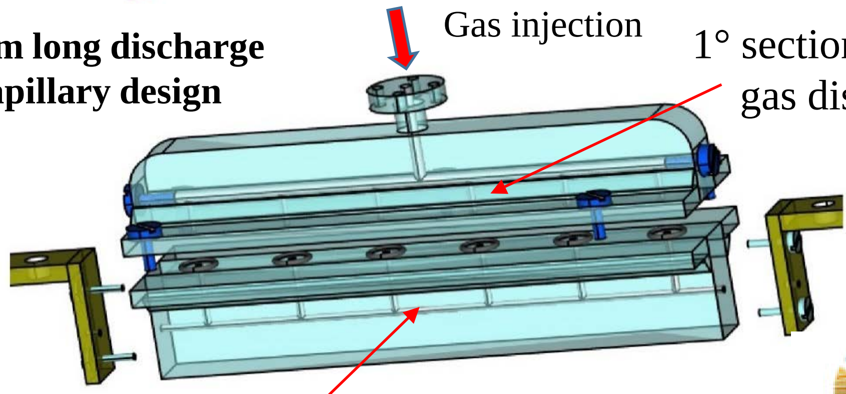


New electron gun was transported to the bunker in the middle of July to conduct tests with high power RF and consecutive installation

40-cm long discharge capillary design

Gas injection

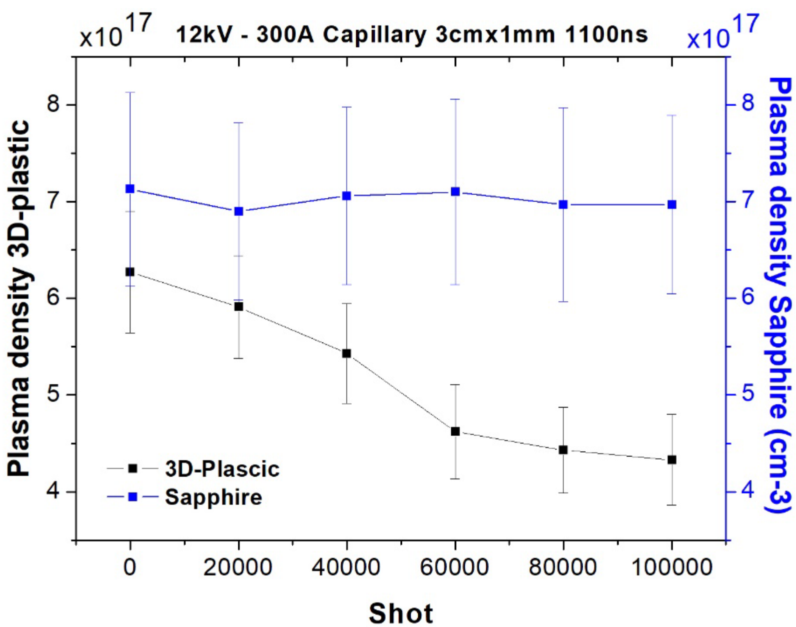
1° section for neutral gas distribution

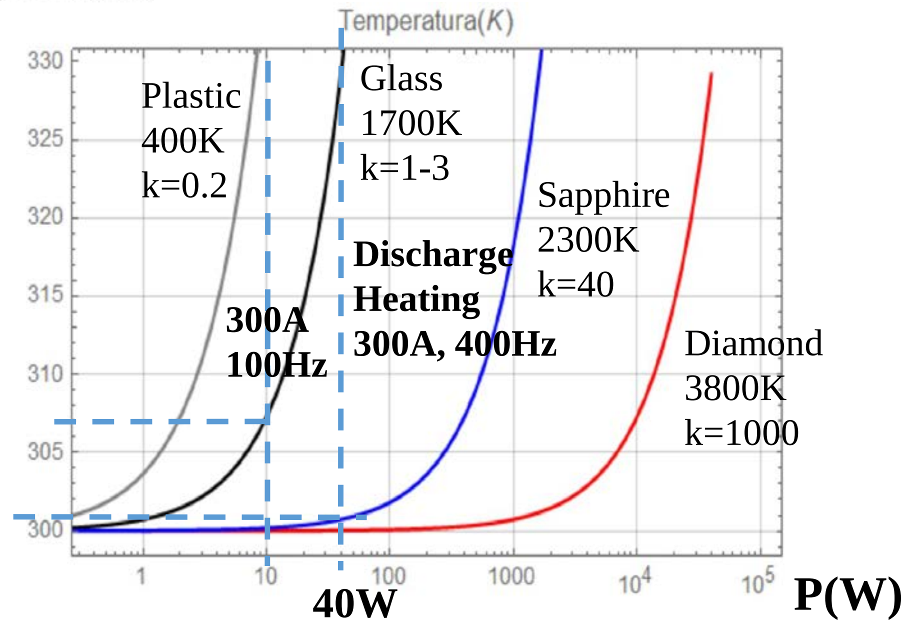


2° section for plasma formaiton channel

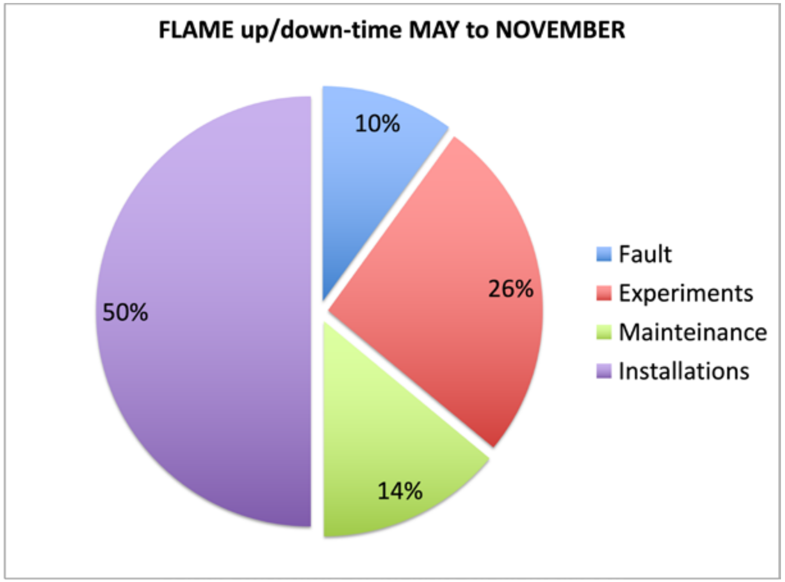
Core activities/ study:

- increase the discharge frequency
- longevity of the capillary
- increase of the capillary length
- production possibilities



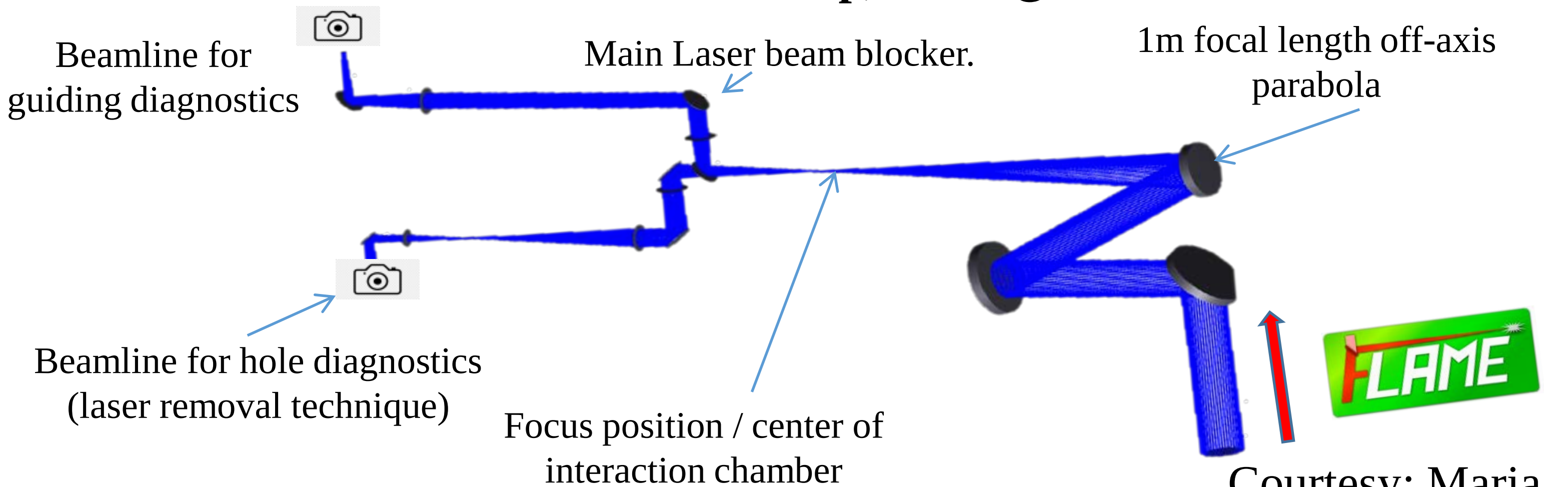


Courtesy: Angelo Biagioni



- EXIN project: installation of the new optical line to test a laser guiding and laser removal technique
- !CHAOS control system installation
- installation of the new control system from Amplitude
- increase maintenance time because of the aging of the system

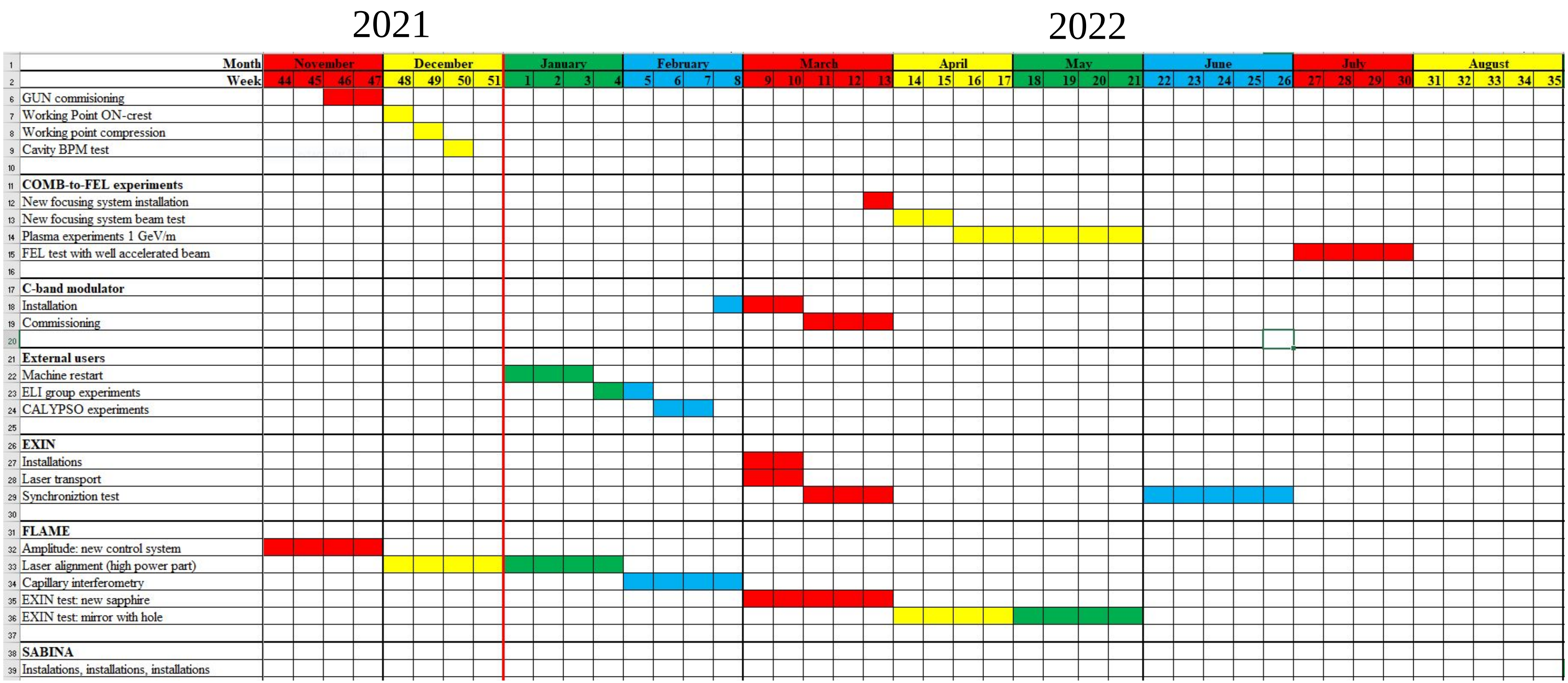
New set-up, EXIN@FLAME



Courtesy: Maria Pia Anania

1. September – November 2021. New gun installation. All installations were done at the end of October, the RF power was sent into the gun at 25 October. In parallel were done installations for the EXIN experiments.
2. November – December 2021. Gun conditioning and characterization. We should have a fully operational machine before the Christmas 2021.
3. January – February 2022: external users. Both experiments are new methods for longitudinal beam diagnostics, base on Smith-Purcell and Transition radiation.
4. March 2022: new C-band modulator installations. The total installation time, including conditioning/commissioning - one month.
5. April – July 2022. The plasma season. The main goal is to reach acceleration gradient 1 GeV/m and higher. The FEL run is planned, under condition that will reach necessary beam quality. EXIN synchronization test.
6. September – December 2022. Major SPARC overhaul, SABINA project installations. New section solenoids, THz undulators (DGL line), excavation to make room for SABINA users, water and air systems at SPARC, number of smaller works/improvements/updates.

SPARC_LAB chart 2021-2022



Thank You!