EuPRAXIA & SPARC_LAB

Massimo.Ferrario@lnf.infn.it
On behalf of the EuPRAXIA@SPARC_LAB team

LNF Scientific Committee – May 9, 2019

EuPRAXIA SciCom Recommendations

- The operation and personnel aspects of the EuPRAXIA@SPARC_LAB proposal should be further developed. These are key aspects for the operation of the facility

- For the longer term, consider operation with two separate electron injectors for beam driver and beam witness. This is necessary for demonstrating the HEP application of a multi-staged, high energy plasma-based accelerator where driver and witness beams have independent features. It also allows much more flexibility. The required space should be reserved in the EuPRAXIA@SPARC_LAB layout from the start.

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- Since the outlook for the plasma-based FEL of the EuPRAXIA@SPARC_LAB project largely relies on start-to-end simulation results, it is recommended that (in particular) plasma simulation results be benchmarked with different simulation codes and, whenever possible, against experimental results.

Project Office – (LNF Steering Board)

LNF Director - LNF Administration – Resp. Divisioni (R,A,T)
Edilizia – Impianti –Sicurezze – Radio Prot. - Project Leader & Technical Team

- A Project Office has been established aiming to bring together in a "control room" some of the key figures of the project and to be the indispensable managerial-organizational complement to the activities of the EuPRAXIA @ SPARC_LAB Collaboration, which remains responsible for the technical-scientific choices of the project, as well as its construction, installation, installation and achievement of scientific goals.

- The mandate of the PO will include:

- deliver the Organisational Breakdown Structure (OBS) of the EuPRAXIA@SPARC_LAB project

- carry out all the steps necessary for the construction of the building intended to house EuPRAXIA @ SPARC_LAB, monitor the project and its execution, the installation of technical services and the performance of all tender and administrative procedures, including the timing and financial resources;

- carry out all the necessary steps for the preparation of the Technical Design Report for each subsystem of the EuPRAXIA @ SPARC_LAB machine, monitor the project, also in relation to the necessary R&D developments. Subsequently, coordinate their construction, installation and implementation, with particular regard to the timing and aspects relating to human and financial resources.

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EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

Retreat in the Alps,
February 27, 2019,
Hotel am Badersee, Grainau

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Implementation: 5 Pillars

Horizon 2020

The **proposed EuPRAXIA implementation model** relies on various pillars:

1. The **common goal** of the EuPRAXIA consortium, as described above.
2. Several groups or **clusters of institutes** that address particular and well-defined challenges in the EuPRAXIA project. **International partners** are included through bilateral or EU programs, within the rules of funding agencies.
3. **Four EuPRAXIA support facilities in France, Portugal, UK and Czech Republic.** The support facilities provide the scientific and technical capabilities required for solving critical R&D challenges in due time. These facilities will profit heavily from already existing infrastructures and expertise.
4. **Two EuPRAXIA construction sites in Italy and Germany** where the consortium will build the final plasma accelerators and user lines, realizing complementary technologies and applications.
5. An **overarching and lean EuPRAXIA project management structure**. It coordinates the overall technical design and prototyping, it oversees construction work, and it links to **industrial partners** through work packages at the collaborating institutes (funding passes through existing institutes and administrative structures).

Implementation: Clusters

The EuPRAXIA consortium proposes the following clusters of institutes for addressing the critical challenges in our project:

1. **Cluster theory and simulation**: Performance predictions, specification of hardware, evaluation of measured hardware performance, development of new concepts and mitigation measures. Institutes: ...
2. **Cluster laser technology**: R&D on laser drivers, prototyping, tests, construction of final hardware. Institutes: ...
3. **Cluster plasma accelerator:** R&D on plasma sources, targets and plasma injectors, prototyping, tests, construction of final hardware. Institutes: ...
4. **Cluster RF and accelerator technology:** R&D on RF injectors, RF drivers, transfer lines, prototyping, tests, construction of final hardware. Institutes: ...
5. **Cluster application development**: R&D on applications and required components (undulators, collimation, experimental areas), prototyping, tests, construction of final hardware. Institutes: ...
6. **Cluster diagnostics**: **:** R&D on diagnostics, prototyping, tests, construction of final hardware. Institutes: ...
7. **Cluster xxx**: ...

Implementation: 4 Support Facilities

Horizon 2020

The following four EuPRAXIA support facilities are being proposed :

1. A **EuPRAXIA laser and prototyping facility on the Plateau de Saclay, close to Paris in France**. A EuPRAXIA prototype laser will be installed by French EuPRAXIA institutes together with laser industry to generate and accelerate electron beams to 1 GeV. High quality feedback systems will be developed, acting on the parameters of the laser and the plasma structure developed in the French institutes. The Saclay prototype will be optimized to achieve the required stability goals for EuPRAXIA. In continuation of the COXINEL project in France, FEL quality beams will be demonstrated by generating FEL light. Both the plasma accelerator technology and the FEL process will then be optimized for EuPRAXIA.
2. A **EuPRAXIA theory and simulation facility at the Instituto Superior Técnico in Lisbon, Portugal**. The center will coordinate EuPRAXIA work on theory and simulations that will be performed at the various partner institutes. Common standards and comparability of results will be ensured. An increase of simulation capabilities through smarter algorithms and access to super computers will be essential to establish a full operational model of EuPRAXIA performance including imperfections, feedback systems and user needs.

Implementation: 4 Support Facilities

3. A **EuPRAXIA application beamline facility in the UK**. The Central Laser Facility CLF (Rutherford Appleton Laboratory), the CLARA facility at Daresbury (Cockcroft Institute), the SCAPA facility in Glasgow (University of Strathclyde) and the Queen's University Belfast combine unique expertise in plasma accelerators, in X-ray based medical imaging, in industrial applications and in schemes for positron production. The UK-based EuPRAXIA consortium will design and prototype a EuPRAXIA application beamline.
4. A **EuPRAXIA incubator at ELI-Beamlines at Prague, Czech Republic for user aspects and for transfer of plasma accelerator technology into ELI**. The EuPRAXIA incubator at ELI will provide input and guidance on key components for high repetition rate laser-driven FELs from the laser community to EuPRAXIA. In addition, it will provide ELI with a direct open innovation access to the accelerator technology developed inside the EuPRAXIA project, such that it can provide this to its users.

The concepts, the technical designs, technical drawings of prototype devices and results achieved at the facilities listed above and at the construction sites (see below) will be made available in the form of open innovation to the whole consortium. The facilities described above will serve as continued development and testing areas during EuPRAXIA operation, developing necessary improvements for various components or preparing facility upgrades.

Implementation: 2 Construction Sites

In parallel to and after the technical design and prototyping work, we foresee that **the consortium will construct the joint EuPRAXIA plasma accelerator and user facilities**. Considering constraints and interests in the collaborating institutes and countries, the conceptual design has converged on two construction sites at existing laboratories with complementary technology and user areas:

1. The **EuPRAXIA facility for the laser-driven plasma accelerator is constructed in Hamburg, Germany**. The host laboratory is DESY and laser pulses will be provided from industrial lasers, as developed for the EuPRAXIA needs. The Hamburg site of EuPRAXIA will build on the investments in laser-driven plasma acceleration that have been put forward by the German and Hamburg governments and the Helmholtz association since 2012, for example as part of the ATHENA project. This proposal also reflects on the German interest in the most compact accelerator solution for future FELs, complementing the existing big science FELs at DESY and in Germany. User applications for EuPRAXIA@ATHENA will focus on a compact 1-5 GeV free-electron laser, plasma-based medical imaging, a compact positron source for applications and test beams.

Implementation: 2 Construction Sites

Horizon 2020

2. The **EuPRAXIA for the beam-driven plasma accelerator is constructed in Frascati, Italy**. The host lab is LNF/INFN and the electron driver will rely on the most compact RF technology available, namely X band structures from CERN. The Frascati site of EuPRAXIA will build on the investments in beam-driven plasma acceleration at SPARC_LAB. This proposal also reflects on the Italian interest in an FEL user facility that combines a 1 GeV RF-based FEL option with a plasma-based advanced FEL setup at possibly higher energy. EuPRAXIA@SPARC_LAB would be the first FEL on the Frascati site. The dual approach will ensure that a new FEL user community at Frascati can be served with maximum availability and flux. User applications for EuPRAXIA@SPARC_LAB will focus on a 1 GeV free-electron laser with an upgrade to 2-5 GeV, a Thomson photon source, high energy positron beams and test beams.

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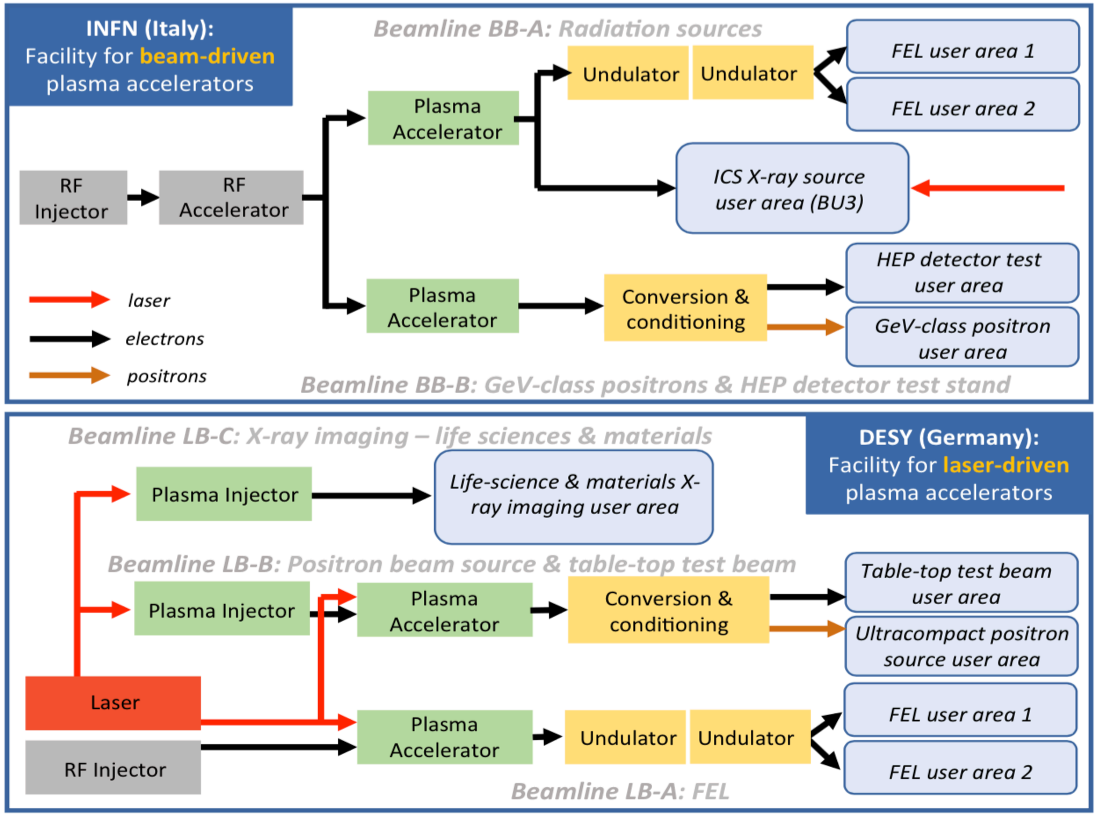
Phased Implementation of Construction Sites

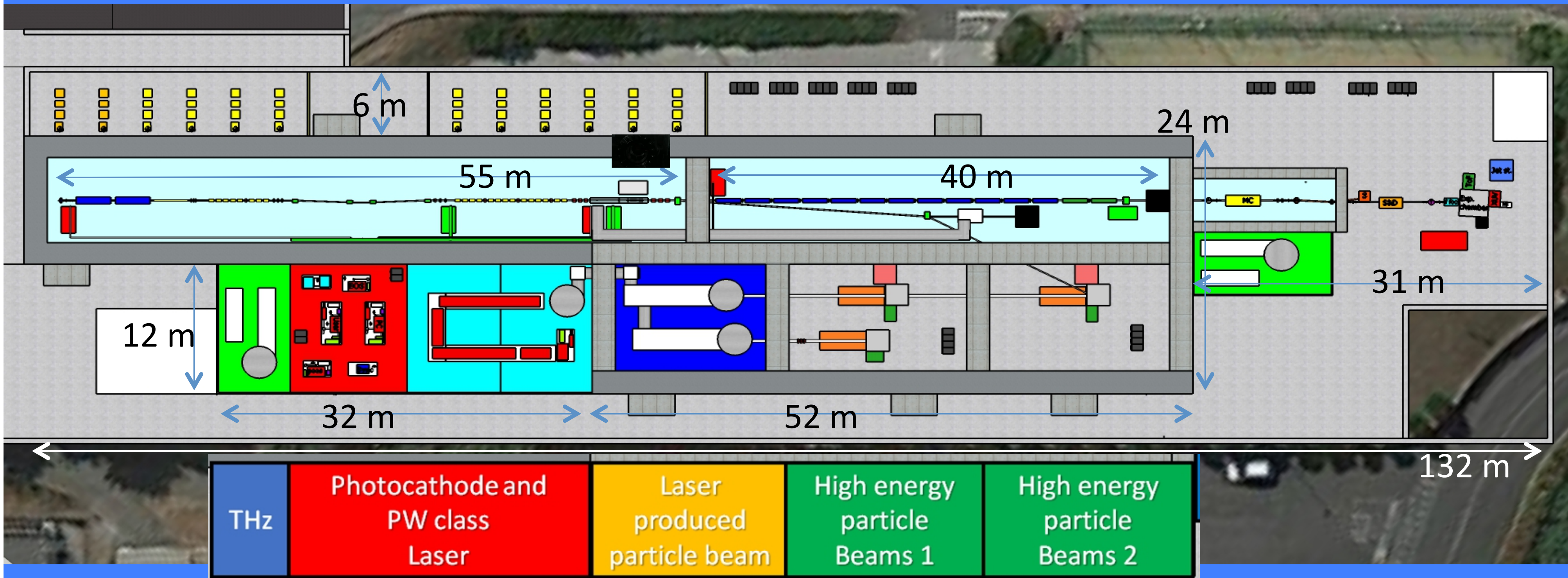
Horizon 2020

Phase 0

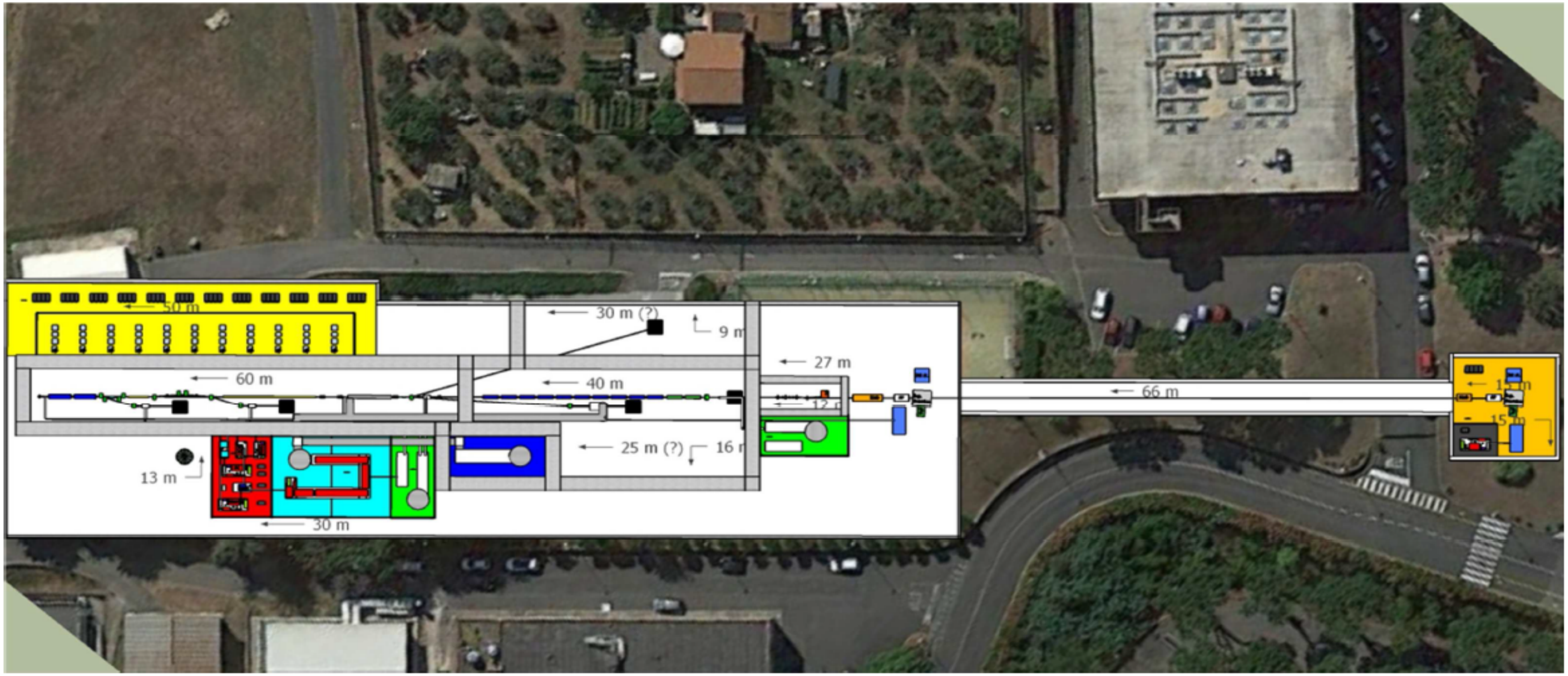
	DESY	INFN
Phase 1	✓ FEL beamline to 1 GeV + user area 1 ✓ Ultracompact positron source beamline + positron user area	✓ FEL beamline to 1 GeV + user area 1 ✓ GeV-class positrons beamline + positron user area
Phase 2	✓ X-ray imaging beamline + user area ✓ Table-top test beams user area ✓ FEL user area 2 ✓ FEL to 5 GeV	✓ ICS source beamline + user area ✓ HEP detector tests user area ✓ FEL user area 2 ✓ FEL to 5 GeV
Phase 3	✓ High-field physics beamline / user area ✓ Other future developments	✓ Medical imaging beamline / user area ✓ Other future developments

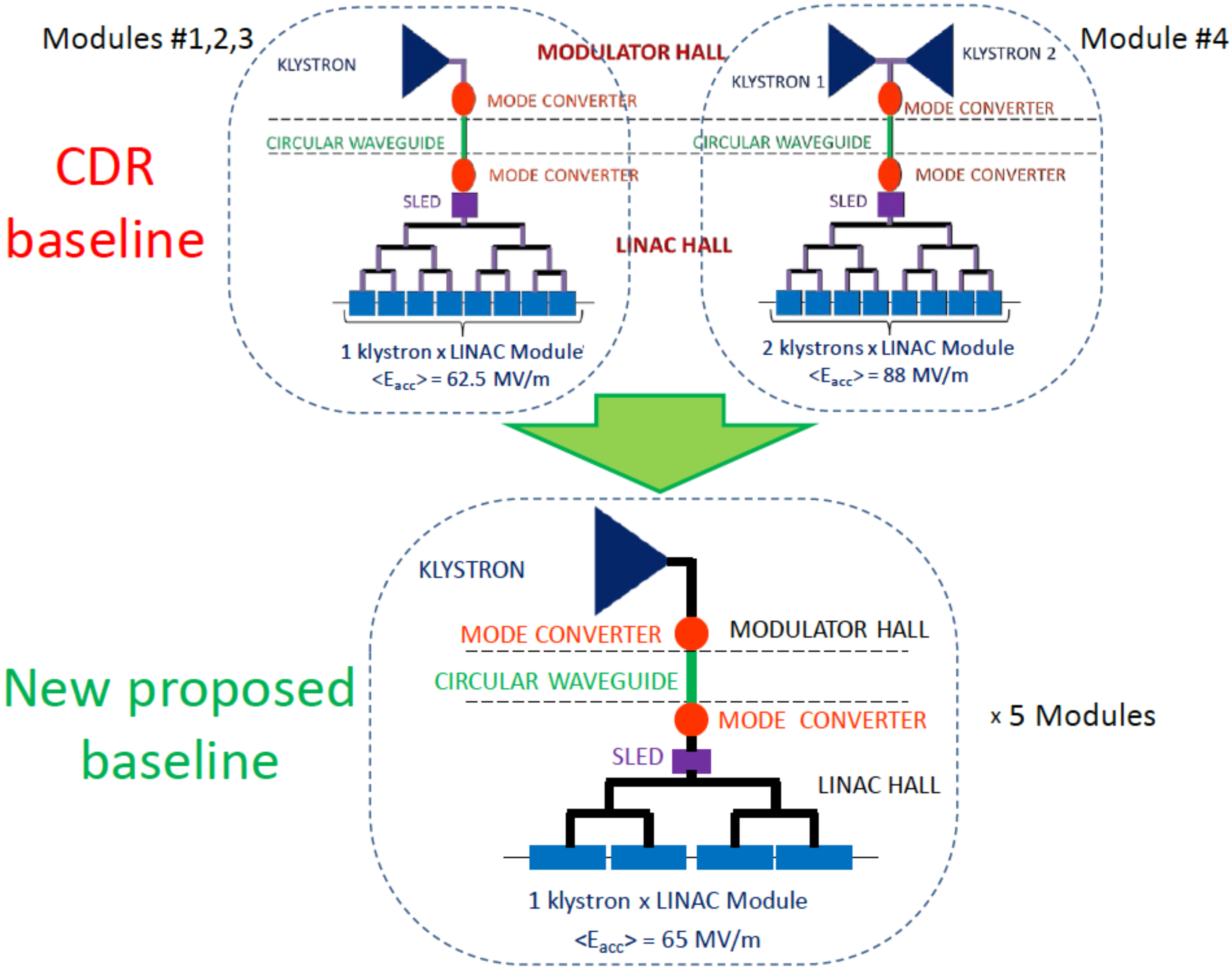


- A more detailed Machine Layout is in progress and it will allow a more precise definition of the available room for the "European beam lines"



Possible building extension




Modules #1,2,3
Module #4
CDR baseline
KLYSTRON
MODULATOR HALL
MODE CONVERTER
CIRCULAR WAVEGUIDE
MODE CONVERTER
SLED
LINAC HALL
1 klystron x LINAC Module
$\langle E_{acc} \rangle$ = 62.5 MV/m
KLYSTRON 1
KLYSTRON 2
MODE CONVERTER
CIRCULAR WAVEGUIDE
MODE CONVERTER
SLED
2 klystrons x LINAC Module
$\langle E_{acc} \rangle$ = 88 MV/m
New proposed baseline
KLYSTRON
MODE CONVERTER
MODULATOR HALL
CIRCULAR WAVEGUIDE
MODE CONVERTER
SLED
LINAC HALL
1 klystron x LINAC Module
$\langle E_{acc} \rangle$ = 65 MV/m
x 5 Modules

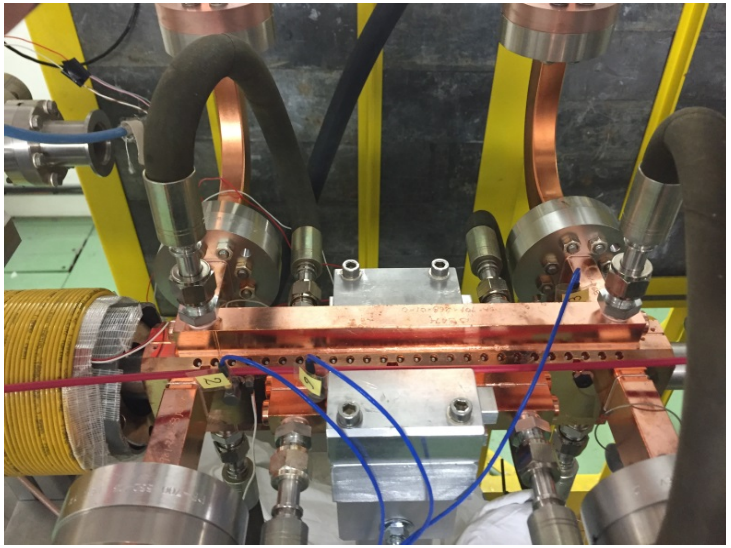
Compact

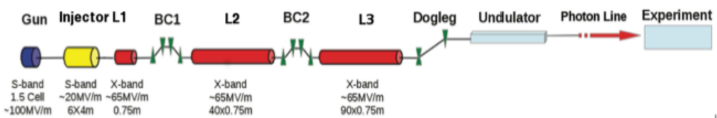
EU Design Study Approved

3 years – 3 MEuro

Coordinator: G. D'Auria (Elettra)

Focus on X-band technology





The key objective of the CompactLight Design Study is to demonstrate, through a conceptual design, the feasibility of an innovative, compact and cost effective FEL facility suited for user demands identified in the science case.

REMINDER: CompactLight Preliminary Specification

	Soft x-ray	Hard x-ray
Photon energy [keV] (min-max)	0.25 - 2	2 - 25
Wavelength [nm] (max-min)	5 - 0.6	0.6 - 0.05
Repetition rate [Hz]	**1000**	**100**
Maximum pulse energy [mJ]	Not specified	1 (at 25 keV, less at other energies?)
Number of photons	Not specified	2.5×10^{11} at 25 keV
Pulse duration [fs]	0.1 – 50	
Polarisation	Variable, selectable	Not specified
Two-colour pulses: time separation [fs]	-20 -> +40	
Two-colour pulses: photon energy variation (max. of E2/E1)	2 (270-530eV), 1.2 for the rest of the range	1.1

The table separates the FEL output requirements into the two regimes of operation (soft/hard x-ray) to show which parameters are required in combination.

3rd scenario: high rep rate – reduced peak power klystrons

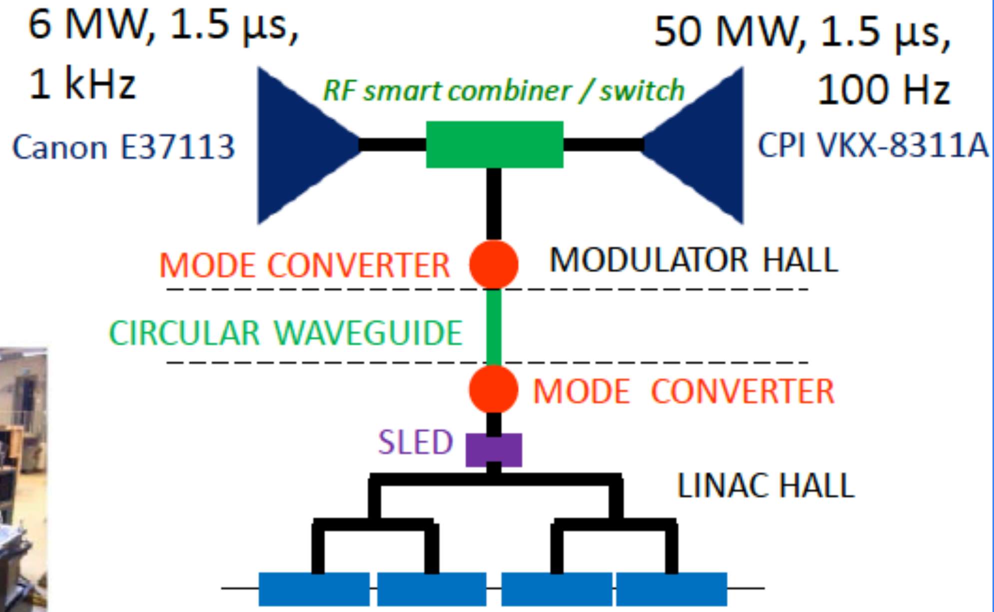
rep rate increase based on dedicated tubes, in substitution of or in addition to high peak power ones

Canon E37113 klystrons

Scandinova solid state modulators

Parameters	Specifications	units
	E37113	
RF Frequency	11.9942	GHz
Peak RF power	6	MW
RF pulse length	5	µs
Pulse repetition rate	400	Hz
Klystron voltage	150	kV
Micro perveance	1.5	

6 MW, 1.5 µs, 1 kHz operation probably possible



2 klystrons x LINAC Module

$\langle E_{acc} \rangle$ = 65 MV/m @ 100 Hz

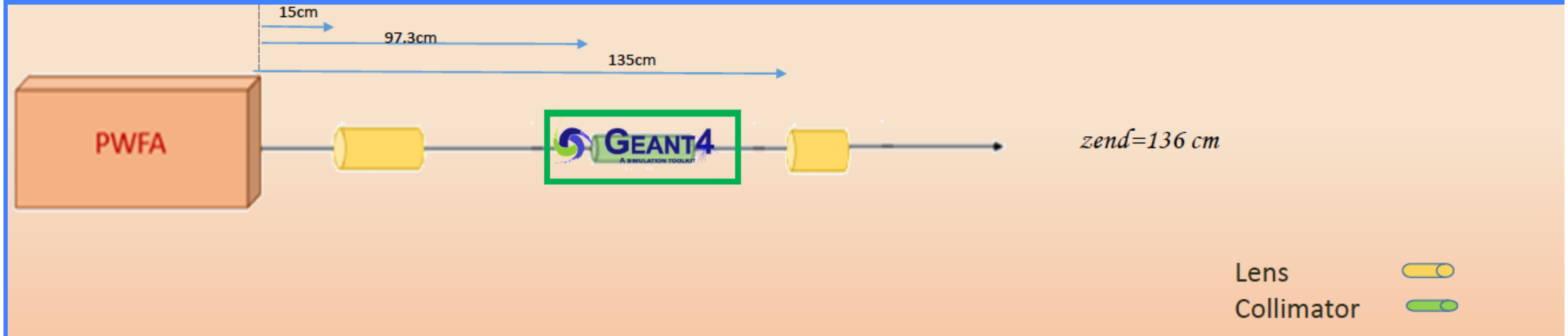
$\langle E_{acc} \rangle$ = 23 MV/m @ 1 kHz

- 1 kHz rep rate capability, with linac energy up to ≈ 410 MeV (35% of the max value);
- Switching or combining 2 sources would preserve high gradient at low rep rate;
- If source combination is possible, gradients > 30 MV/m available at rep rates ≤ 250 Hz;
- CPI will probably announce a new tube capable of delivering 10 MW, 1.5 µs, 1 kHz (≈ 30 % gradient increase wrt E37113)

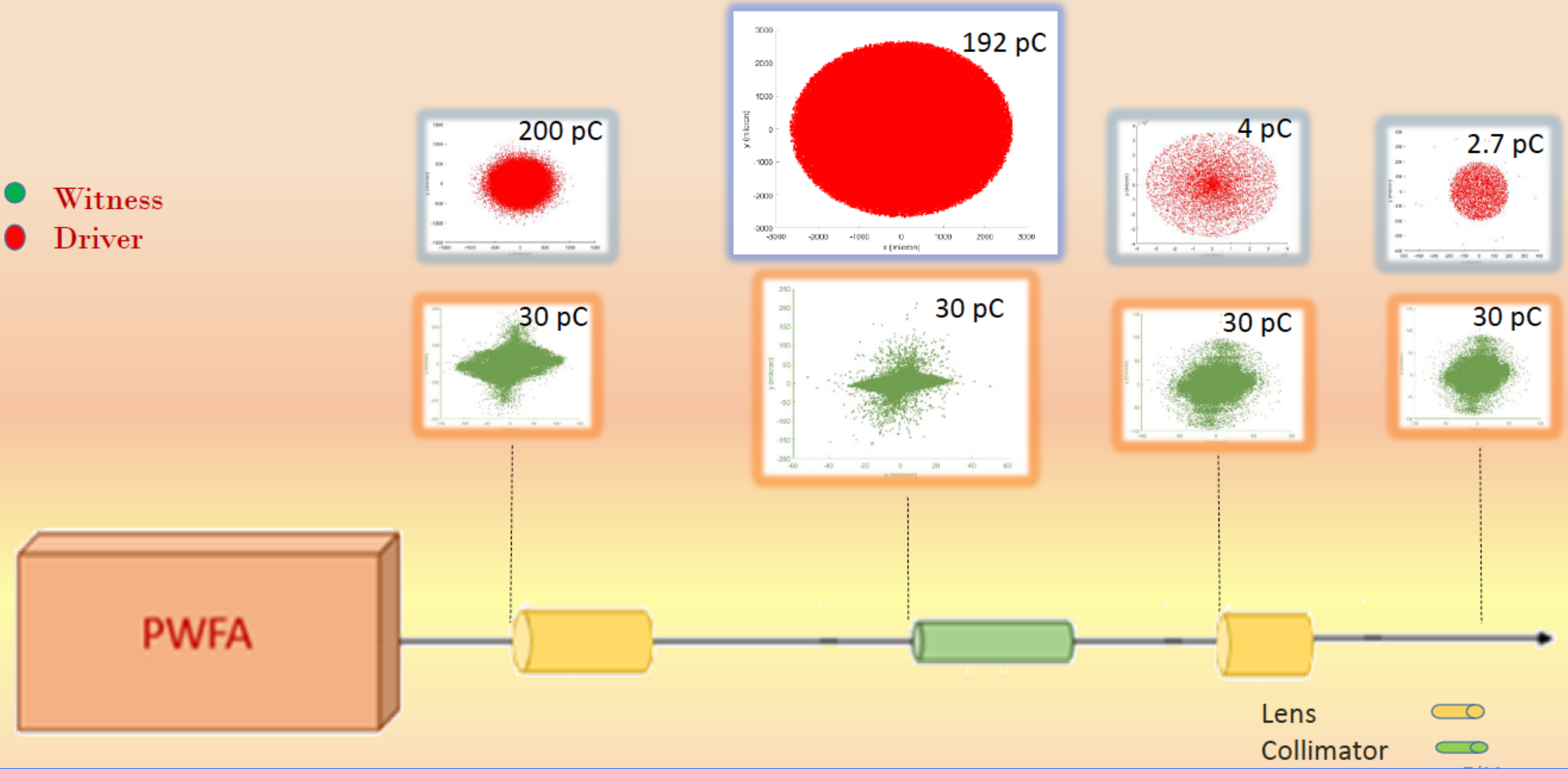
Compact and tunable active-plasma lens-based system for witness extraction and driver removal

Pasqualina Iovine
INFN-NA
DIPARTIMENTO DI FISICA-UNINA

Under the supervision of Dr Riccardo Pompili
Collaboration with Dr Alessio Del Dotto



Spot evolution



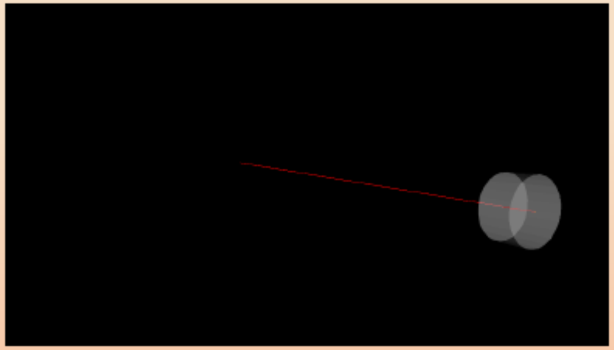
Z start=0 cm

	Charge (pC)	Emittance (μm)	σ_x (μm)	*Energy (MeV)*
Witness	30	0.6	1	1000
Driver	200	5.0	7	460

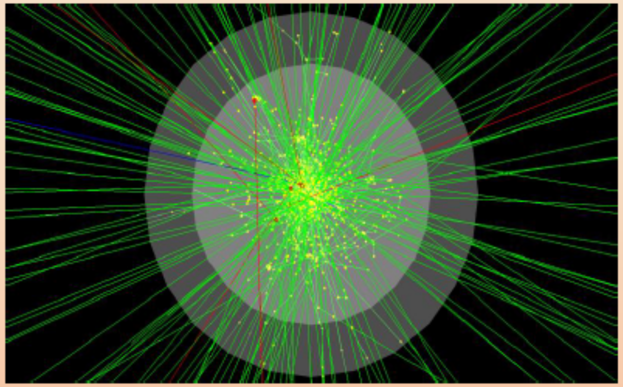
Lens/coll parameters

	l (cm)	d(cm)	I(kA)	r (μm)
lens1	2	15	1	500
coll	3	97,3	-	200
lens2	1	135	0,583	500

Geant4 simulation



Wtness electrons in collimator



Interaction of driver electrons with collimator.

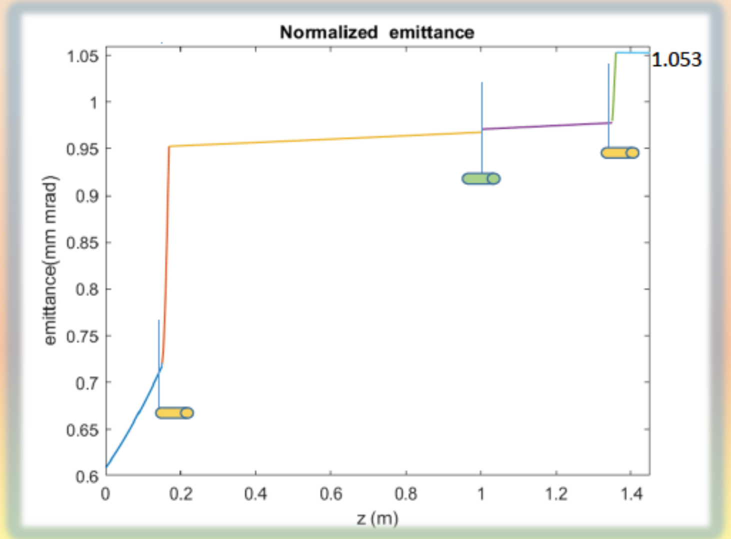
Negative charges ->red
Positive charges -> blue
Neutral charges -> green

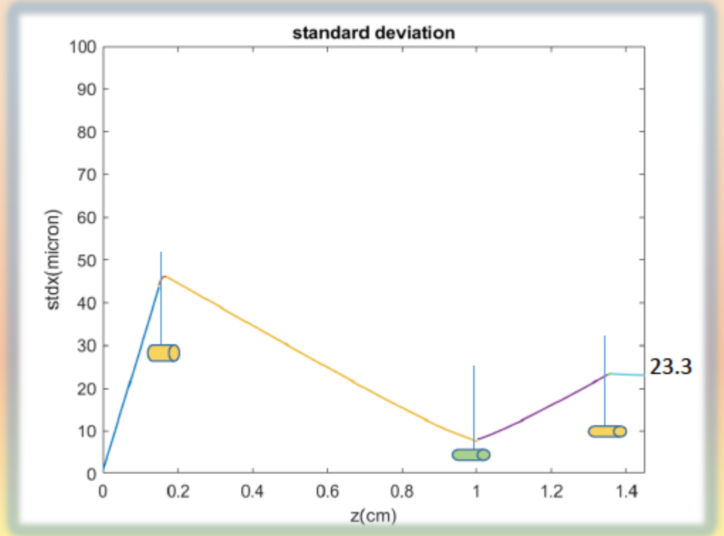
Main electromagnetic processes included:
- Ionization energy loss
- Production of gamma rays
- Bremsstrahlung
- Multiple scattering
- Photoelectric Effect, Compton scattering, Pair production

➡ The rest of the simulations made only with primary electrons

Thanks to Dr.Alessio Del Dotto

Witness parameters along transport line





Lens

Collimator

zstart=0 cm

	Charge (pC)	Emittance (μm)	σ_x (μm)	*Energy (MeV)*	*energy spread (MeV)*
Witness	30	0.6	1	1000	5
Driver	200	5.0	7	460	70

zend=136 cm
(exit 2° lens)

Charge (pC)	Emittance (μm)	σ_x (μm)
30	1.05	23
2.7	6.86	138

condensed matter

MDPI

Article

The Potential of EuPRAXIA@SPARC_LAB for Radiation Based Techniques

Antonella Balerna [1], Samanta Bartocci [2], Giovanni Batignani [3], Alessandro Cianchi [4,5], Enrica Chiadroni [1], Marcello Coreno [1,6], Antonio Cricenti [6], Sultan Dabagov [1,7,8], Andrea Di Cicco [9], Massimo Faiferri [2], Carino Ferrante [3,10], Massimo Ferrario [1], Giuseppe Fumero [3,11], Luca Giannessi [12,13], Roberto Gunnella [9], Juan José Leani [14], Stefano Lupi [3,15], Salvatore Macis [4,5], Rosa Manca [2], Augusto Marcelli [1,6], Claudio Masciovecchio [12], Marco Minicucci [9], Silvia Morante [4,5], Enrico Perfetto [4,16], Massimo Petrarca [3,15], Fabrizio Pusceddu [2], Javad Rezvani [1], José Ignacio Robledo [14], Giancarlo Rossi [4,5,17], Héctor Jorge Sánchez [14,18], Tullio Scopigno [3,10], Gianluca Stefanucci [4,5], Francesco Stellato [4,5,*], Angela Trapananti [9] and Fabio Villa [1]

EuPRAXIA Users Workshop
Roma, June 17-18

5 GeV plasma based case

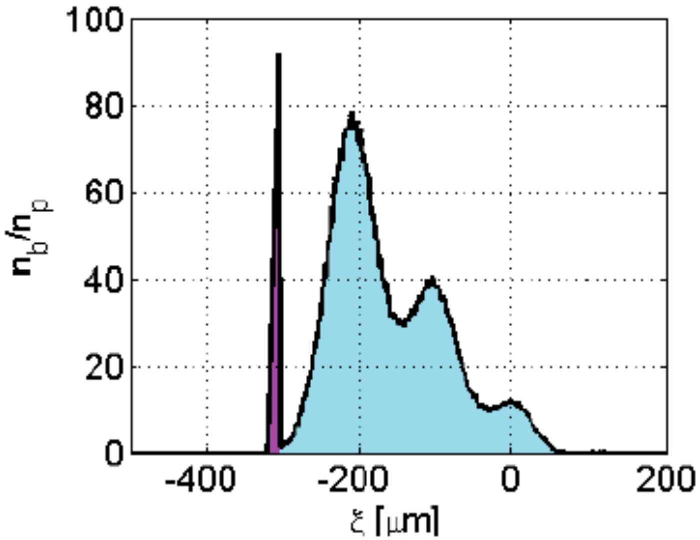
Train of N drivers $R_T \approx 2N$

$$\gamma = 2348$$
$$\varepsilon_{n(x,y)} = 1\text{mm mrad}$$
$$\sigma_z = 33\mu\text{m}$$
$$\sigma_{x,y} = 1\mu\text{m}$$
$$Q_{tot} = 40 + 140 + 270\text{pC}$$

Plasma density

$$n_p = 2.5 \cdot 10^{16}\text{cm}^{-3}$$

Train of drivers allows to reach transformer ratio >2



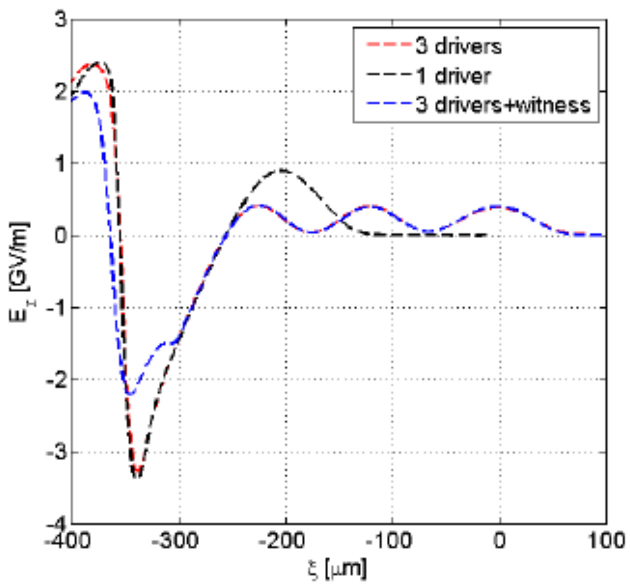
Witness

Triangular shape

3 kA peak current

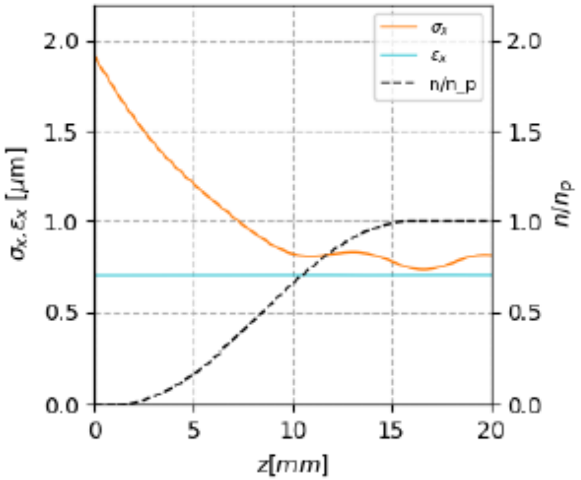
$$\gamma = 2348$$
$$\varepsilon_{n(x,y)} = 0.7\text{mm mrad}$$
$$\sigma_z = 16\mu\text{m (3.8 rms)}$$
$$\sigma_{x,y} = 0.8\mu\text{m}$$
$$Q = 30\text{pC}$$

Witness triangular shape allows fine beam loading compensation of energy spread



Witness Evolution (1.6 m)

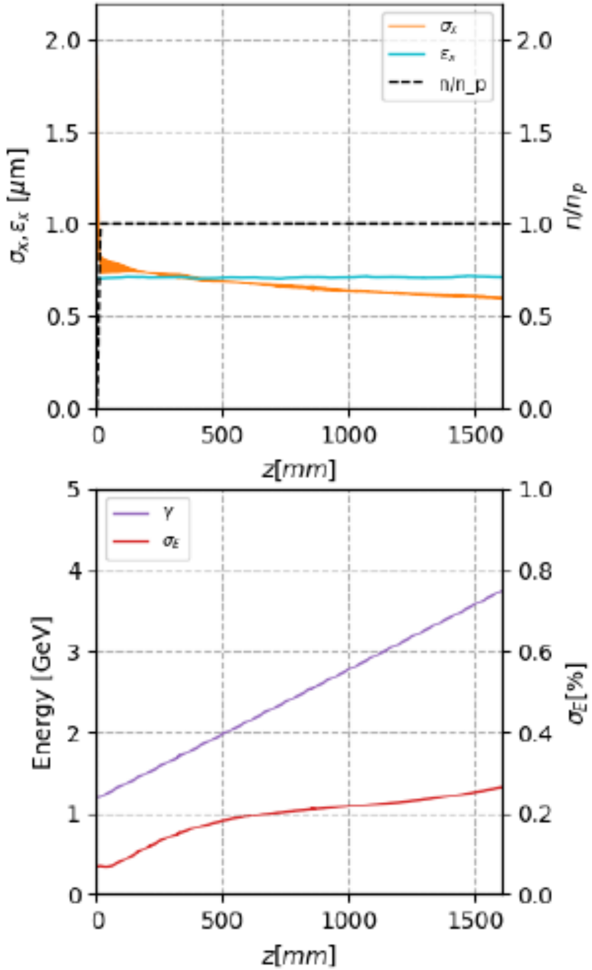
Injection detail



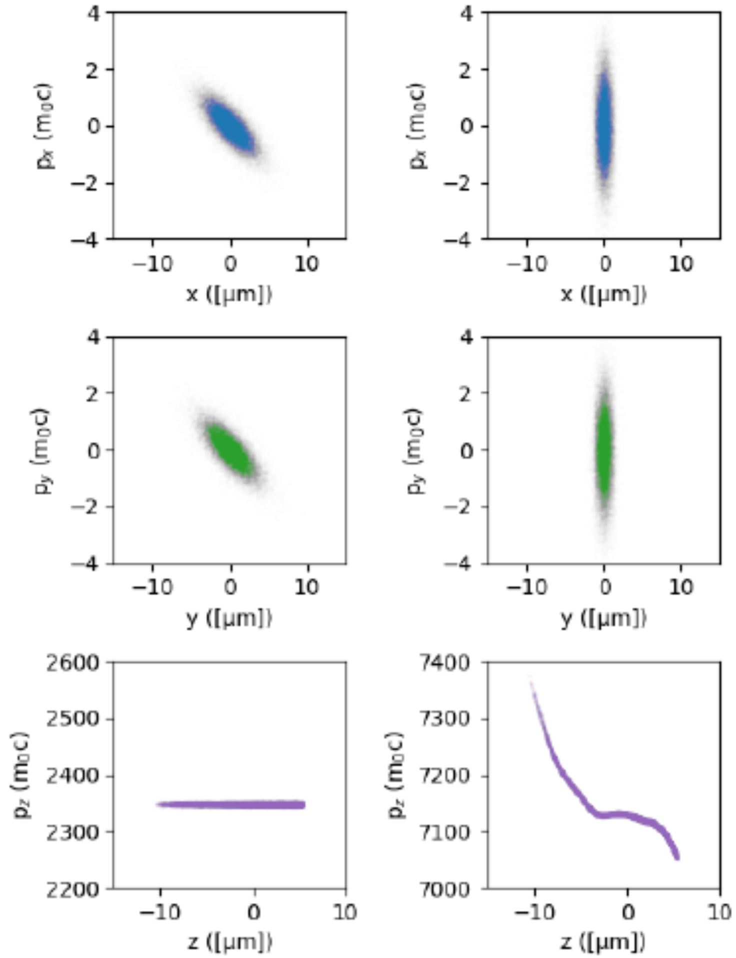
$$E_z = 1.65 GV/m$$

$$R_T = 3.65$$

Witness evolution



Phase space



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IST/UCLA INFN OSIRIS Agreement signed

This agreement is entered to between Luis O. Silva and Massimo Ferrario on Date May 1rst, 2019

The 1D, 2D and 3D particle-in-cell code OSIRIS is distributed for *collaborative* projects with the partners of the OSIRIS Consortium. The OSIRIS Consortium is currently composed of the University of California Los Angeles (UCLA), and the Instituto Superior Tecnico (IST). This Consortium is currently funded in the US by the Department of Energy and the National Science Foundation, and in Portugal is funded by the European Union and by the Fundação para a Ciência e a Tecnologia.

Currently, the OSIRIS software infrastructure is maintained on a server at IST. By giving the Istituto Nazionale di Fisica Nucleare (INFN), Frascati, Italy, access and permission to use the IST server, it is understood that the scientific work and the development of the OSIRIS resources should be developed in close collaboration between the INFN and the OSIRIS Consortium. Professors L.O. Silva at IST and W.B. Mori at UCLA should be aware of research and results based on the use of OSIRIS.

The OSIRIS Consortium is willing to provide access to the OSIRIS 4.0 infrastructure[1] available at/on the IST server that includes

- OSIRIS 4.0 source code
- OSIRIS 4.0 binaries (for a limited number of platforms)
- Existing online documentation
- Visualization infrastructure (vizXD)
- Version control server for OSIRIS and vizXD
- OSIRIS 4.0 mailing list

Under the following rules:

1. The official designation of the OSIRIS infrastructure hosted on the IST server is OSIRIS 4.0, and it should be mentioned as such in all publications and public documents, until further notice.
2. The OSIRIS 4.0 infrastructure, as a whole or its individual components, cannot be used, distributed, copied, provided or accessed without the written agreement of the OSIRIS Consortium.
3. The resources of the OSIRIS 4.0 infrastructure can only be used, and accessed by registered collaborators.
4. Registered members will access the online resources through a personal username and password, issued by IST, associated with a single IP address, and with a single email, with two levels of access: developer and user.
5. Any concerns or issues with algorithms within OSIRIS 4.0 must be communicated to the OSIRIS Consortium immediately and kept within the Consortium until they are resolved.
6. The contact person/responsible for OSIRIS 4.0 at INFN is Massimo Ferrario.
7. The registered members of the OSIRIS 4.0 infrastructure at the INFN (all of which agree to abide this agreement now and in the future) are:

a. Alessio Del Dotto (Post Doc)

b. Stefano Romeo (Post Doc)

c. Chiara Badiali (Graduate Student)

8. Other members of the INFN, working under the guidance of the registered users mentioned before (6.), can use and access OSIRIS 4.0 only after the approval of a formal request for registration, submitted to the Consortium by Massimo Ferrario.
9. Scientific work using OSIRIS 4.0 should acknowledge the OSIRIS Consortium, according to the information posted on the IST OSIRIS web site. As of **[????]**, the guidelines are:

a. In papers:

i. Acknowledgement section of the paper must include the following text:

> The authors would like to acknowledge the OSIRIS Consortium, consisting of UCLA and IST (Lisbon, Portugal) for the use of OSIRIS, for providing access to the OSIRIS 4.0 framework.

ii. Reference to the OSIRIS 4.0 papers should be:

R. A. Fonseca et al., LECTURE NOTES IN COMPUTER SCIENCE 2331: 342-351 (2002); R. A. Fonseca et al., Plasma Physics and Controlled Fusion 50, 124034 (2008); R. A. Fonseca et al., Plasma Physics and Controlled Fusion 55, 124011 (2013);

b. In talks:

i. Talk must include the official OSIRIS 4.0 slide or the official OSIRIS 4.0 logo (including the IST and UCLA logos), available at the IST OSIRIS web site.

ii. Speaker should mention explicitly the Consortium as the distributor of the OSIRIS version being used.

c. In conference and workshop presentations:

i. Poster must include the official OSIRIS 4.0 slide or the official OSIRIS 4.0 logo (including the IST and UCLA logos), available at the IST OSIRIS web site.

d. In grant proposals/applications:

i. For grant proposals/applications that include the use and development of OSIRIS, IST should be contacted.

10. An agreement with IST on co-authorship of scientific/technical work should be made on every project/paper, as soon as the project is initiated. This will avoid possible conflicts with ongoing projects in the OSIRIS Consortium.
11. A copy of all scientific papers using OSIRIS 4.0 should be sent to IST when submitted for publication.
12. Technical work regarding the development of the OSIRIS infrastructure must be submitted to the IST version control server.
13. The IST OSIRIS 4.0 infrastructure cannot be used and/or accessed for commercial use.
14. This MoU is valid for one year and it is automatically renewed until further notice from IST or INFN.

EuPRAXIA SciCom Recommendations

- ✓ The operation and personnel aspects of the EuPRAXIA@SPARC_LAB proposal should be further developed. These are key aspects for the operation of the facility

- For the longer term, consider operation with two separate electron injectors for beam driver and beam witness. This is necessary for demonstrating the HEP application of a multi-staged, high energy plasma-based accelerator where driver and witness beams have independent features. It also allows much more flexibility. The required space should be reserved in the EuPRAXIA@SPARC_LAB layout from the start.

- ✓ The European aspects of EuPRAXIA@SPARC_LAB should be developed, including a clear view on moving from a national facility to a European facility. The possibility to define the facility from the start as a trans-national access facility, for example in the context of the ARIES European framework, should be considered.

- ✓ The major strategic building blocks of the EuPRAXIA@SPARC_LAB project should be defined more clearly, including for example an INFN component (a 1GeV, x-band based FEL) and a broader, more ambitious component (e.g. a 5GeV, plasma-based FEL requiring broad European support and funding).

- ✓ Since the outlook for the plasma-based FEL of the EuPRAXIA@SPARC_LAB project largely relies on start-to-end simulation results, it is recommended that (in particular) plasma simulation results be benchmarked with different simulation codes and, whenever possible, against experimental results.

Two injectors option

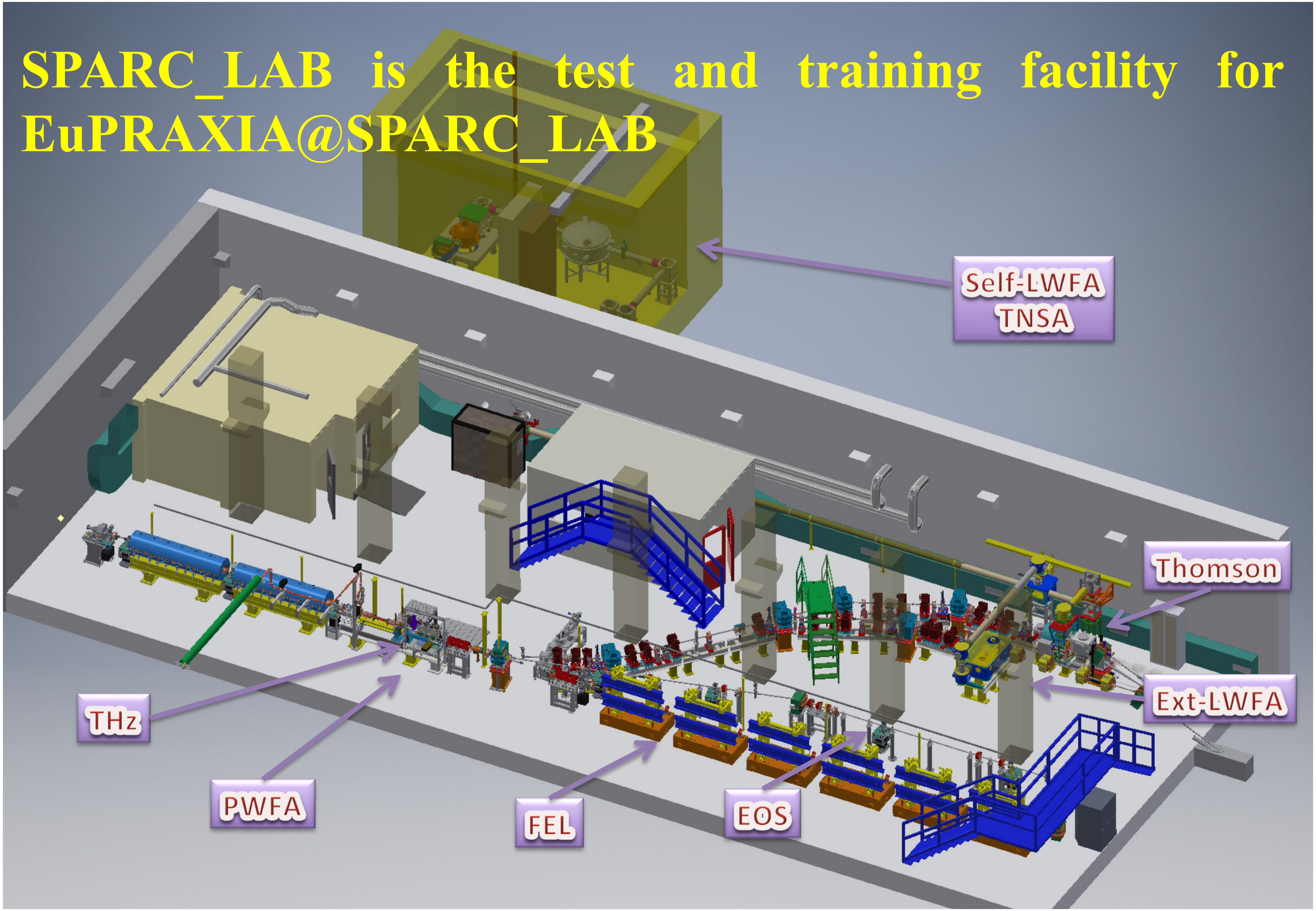
under investigation

CDR Review Committee Meeting June. 20-21

- D. Angal-Kalinin (STFC)
- P. Muggli (MPI) – Chair
- M. Pedrozzi (PSI)
- L. Scibile (CERN)
- S. Schreiber (DESY)

http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

SPARC_LAB is the test and training facility for EuPRAXIA@SPARC_LAB



SPARC_LAB SciCom Recommendations

- The priorities of beam-driven versus laser-driven plasma acceleration experiments at SPARC_LAB should be reviewed with consideration of available resources, impact of R&D and theEuPRAXIA@SPARC_LAB goals.

- The SPARC_LAB team should develop a list of science topics and measurements required to support the EuPRAXIA@SPARC_LAB proposal and to demonstrate critical feasibility issues.

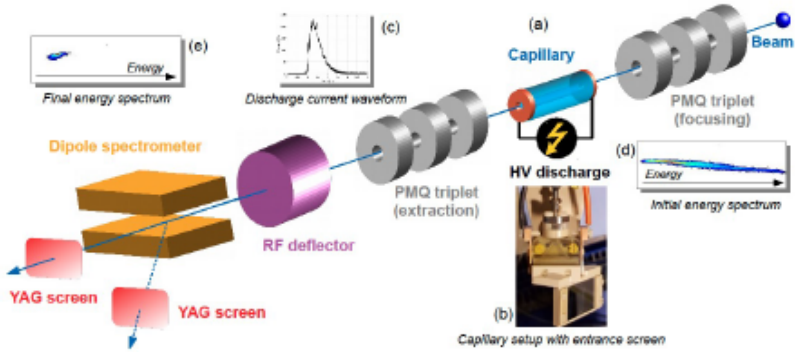
- A beam-driven SPARC_LAB plasma accelerator setup should be operated over an extended period, for example one week, to demonstrate and test the required reliability and stability for EuPRAXIA@SPARC_LAB.

- Experimental results with plasma lens-based beam focusing and beam transport should be compared with focusing and transport by permanent magnet quadrupoles (PMQs).

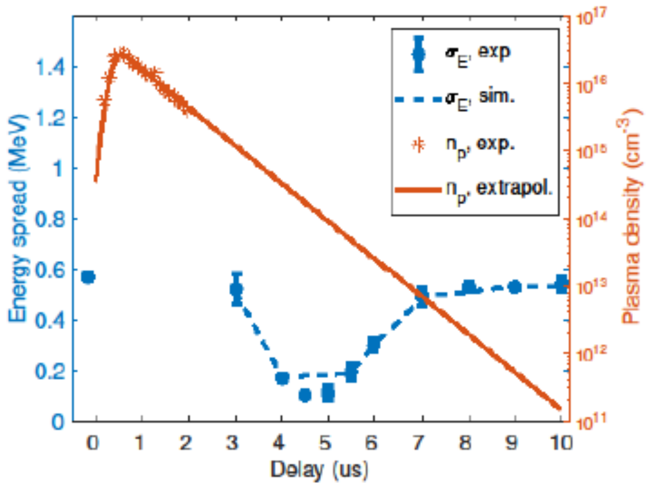
- The laboratory management is encouraged to continue promoting SPARC_LAB and its activities as a critical lab activity in preparation for the EuPRAXIA@SPARC_LAB project.

Plasma Dechirper

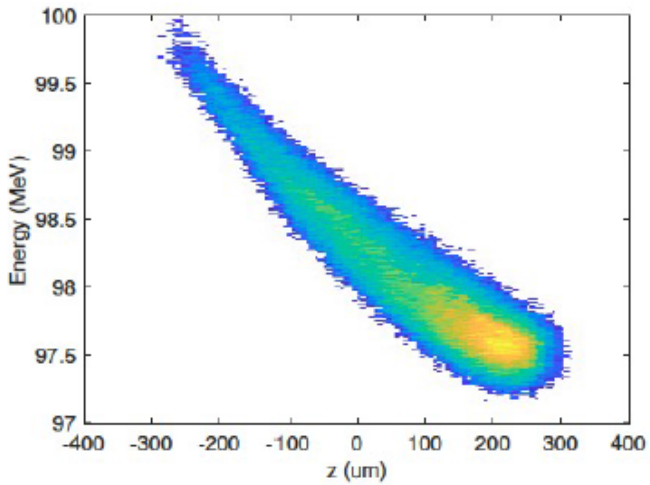
- Beam-driven plasma wakefields can be used to tune/reduce the beam energy-chirp
  - The tail of the beam is decelerated with respect to the head
- Several knobs allow to adjust the energy-time correlation
  - Plasma density, bunch charge/density, bunch length, capillary length
- It allows to remove such correlation and reduce the overall energy spread to its uncorrelated term



Energy spread (plasma density)

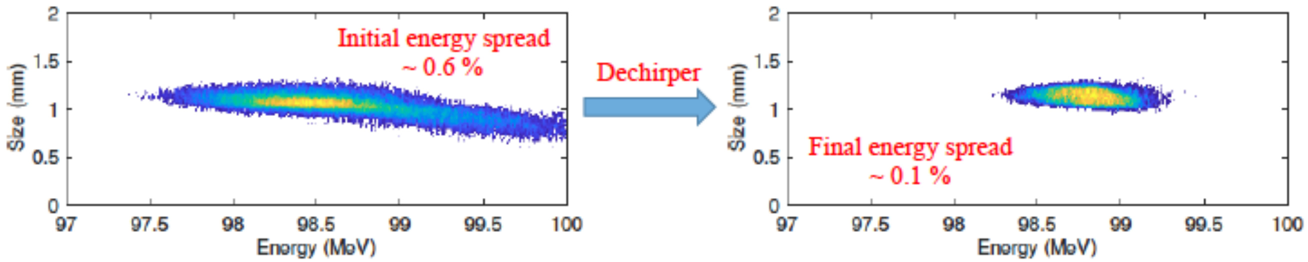


Beam LPS at the injection



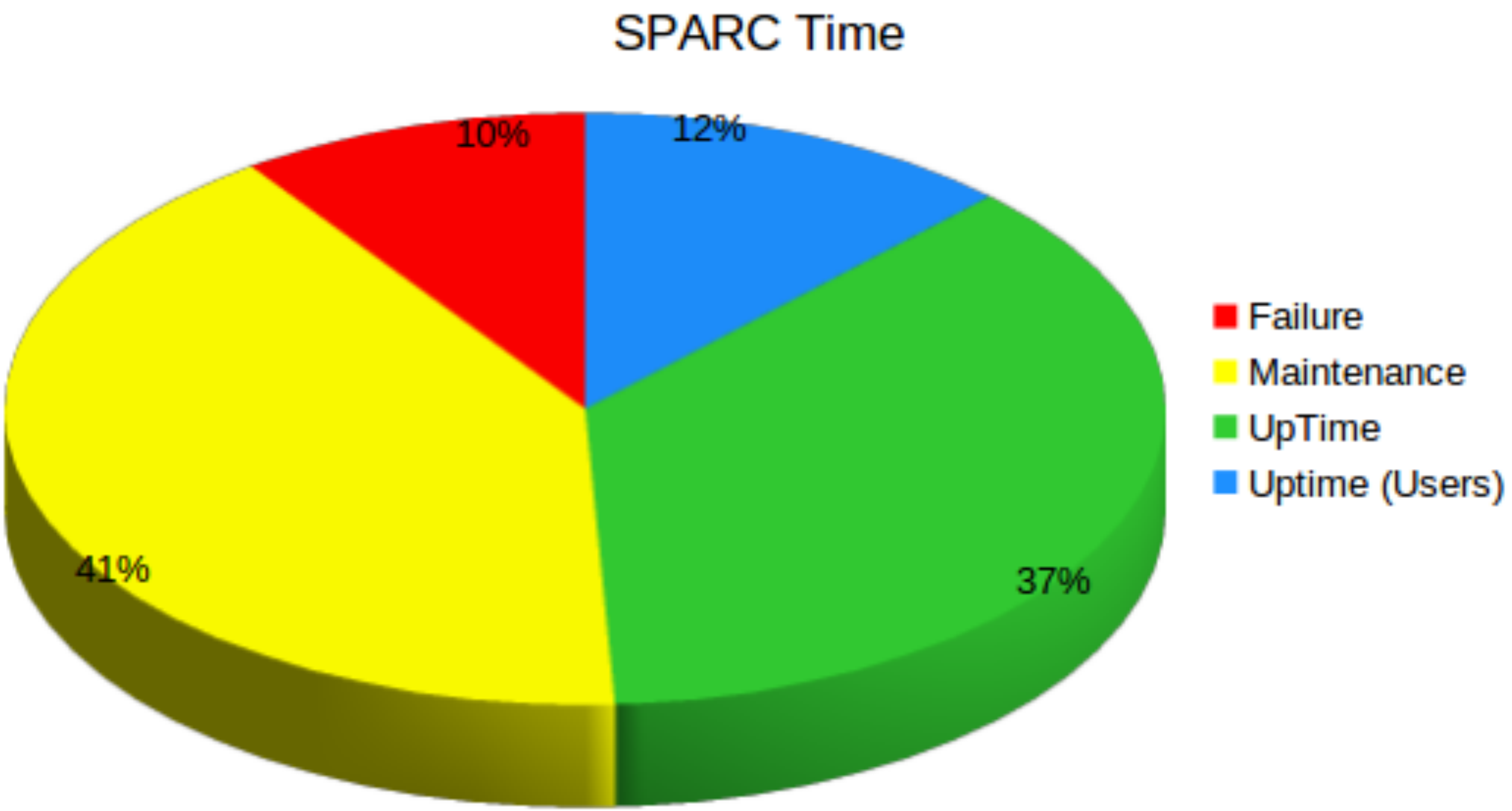
Beam parameters

- ✓ $E = 100\ MeV$
- ✓ $Q = 200\ pC$
- ✓ $\sigma_{x,y} \approx 20(32)\ \mu m$
- ✓ $\sigma_z = 75\ \mu m\ (250\ fs)$
- ✓ $\varepsilon_{x,y} \approx 1.1(1.4)\ \mu m$

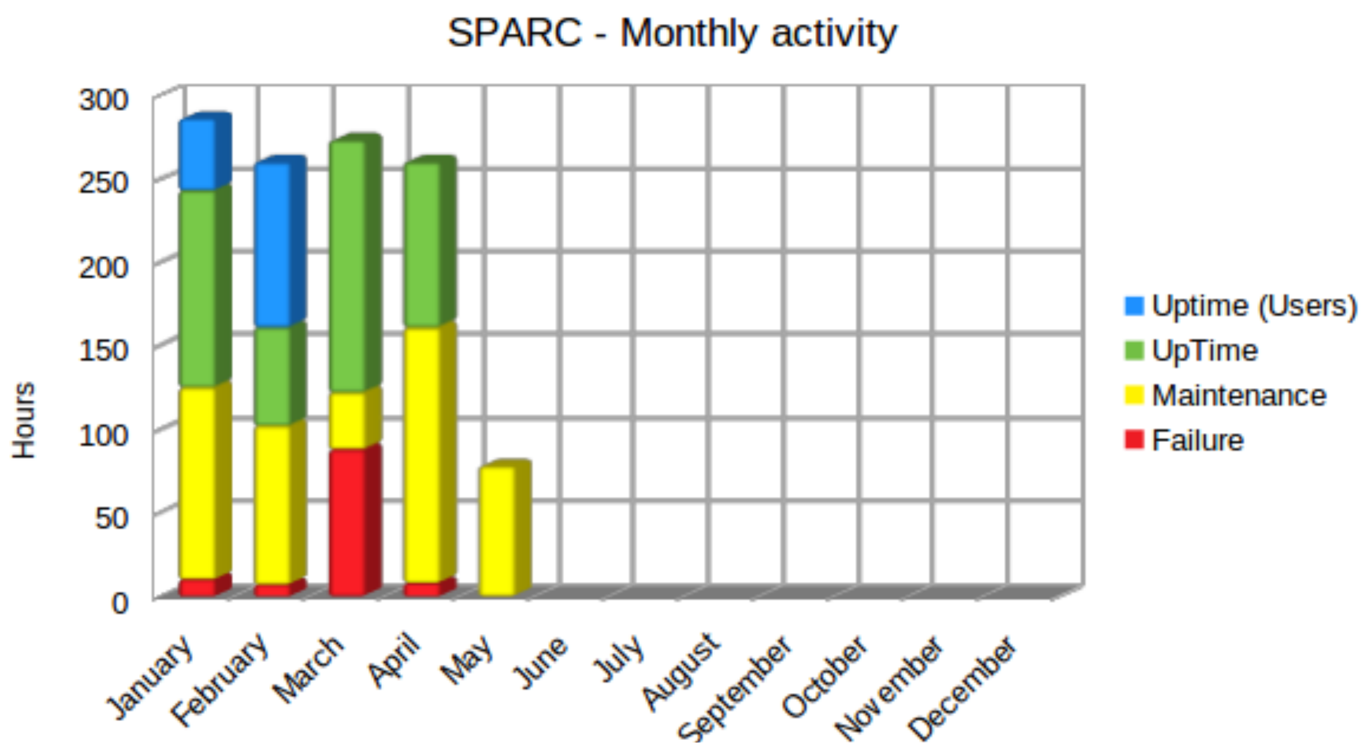


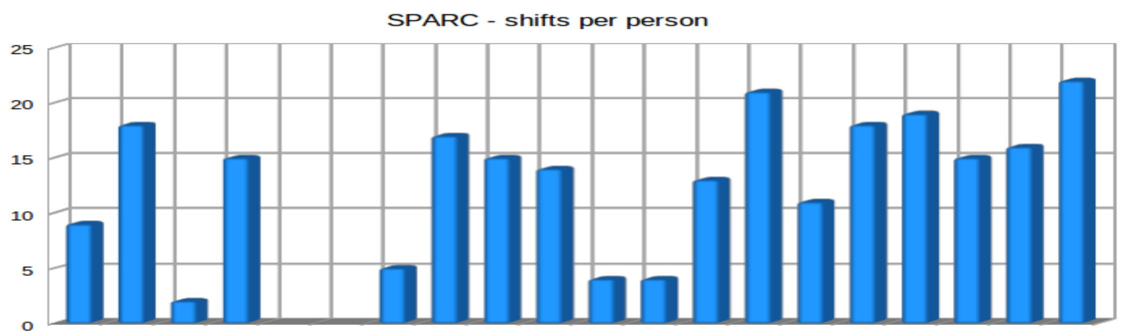
Shpakov V., et al. Physical Review Letters* 122 *(2019), 114801

SPARC 2019 Uptime



2019 activity detail





Summary of December activities

SPARC operations have begun in December after fixing the failure of the K2 ceramic window

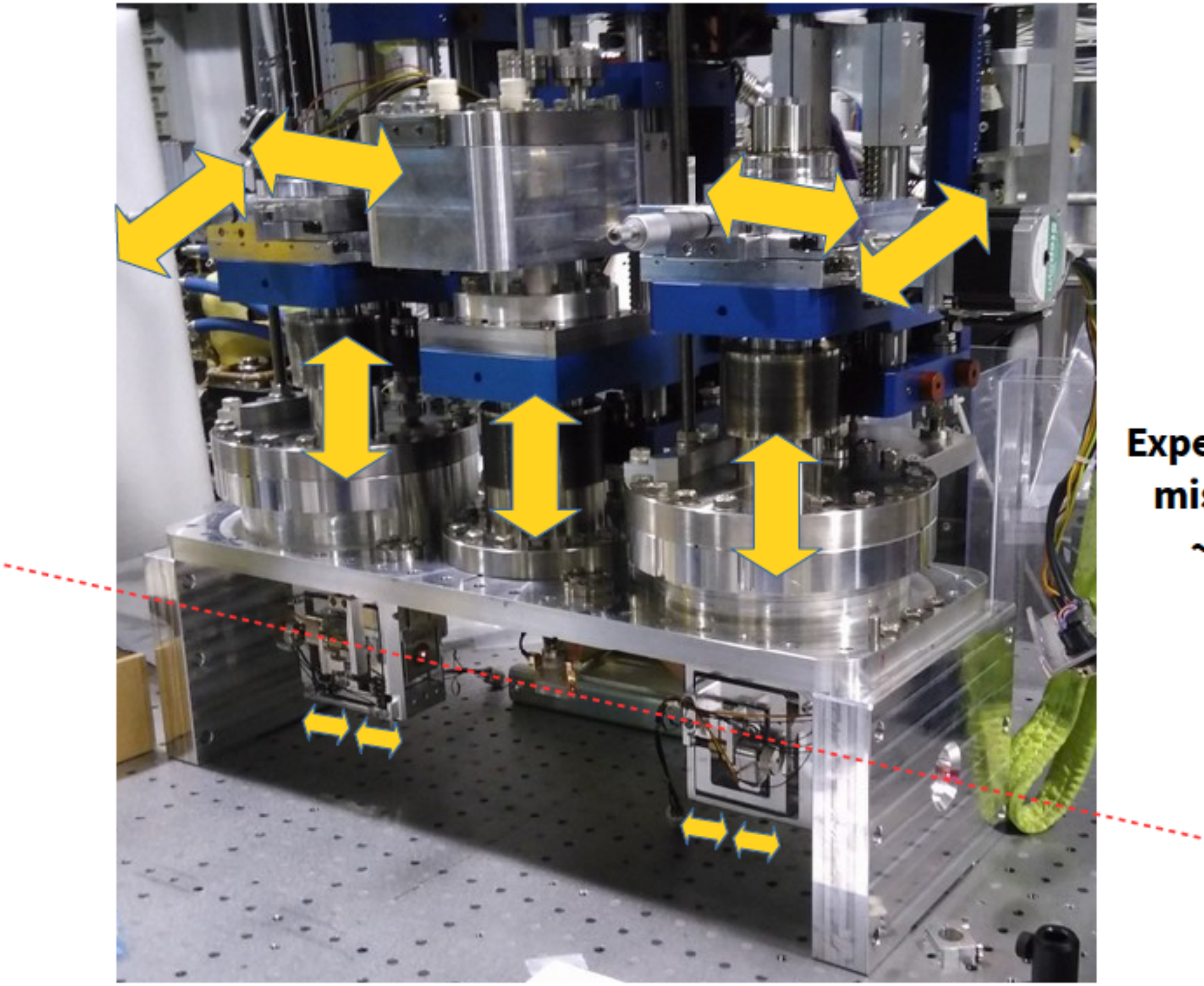
Several tasks have been accomplished in few days of activities

- Beam-based alignment of PMQs in the COMB chamber. Preservation of emittance downstream the focusing system. Tests done with single-bunch (on-crest)
- Definition of the COMB working point (200 pC driver + 20 pC witness). Characterization of the compressed configuration with different bunch spacings.
- PMQ focusing of the compressed COMB beam (to be optimized)
- COMB beam-plasma interaction. First tests of acceleration (to be optimized)

Uptime still non optimal due to vacuum interlocks on K2 line

- Operation at 50 MW (~100 MeV beam energy) was really unstable during data taking
- Need to condition the W2BPHS01 phase-shifter (many interlocks came from it)

Magnetic alignment of PMQs



Expected average misalignment: ~15-20 um

PMQ beam-based alignment results

Alignment of PMQs was performed with single PMQ triplets and both

We moved the triplets in X/Y directions looking at the offset of the beam centroid

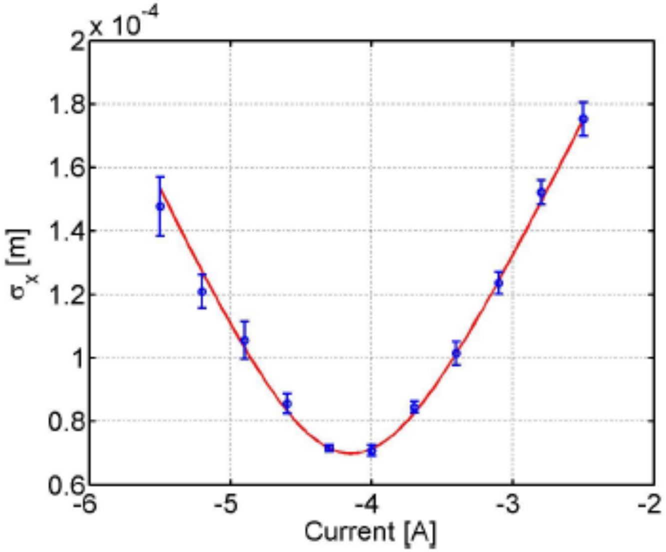
Finer adjustment looking to the emittance

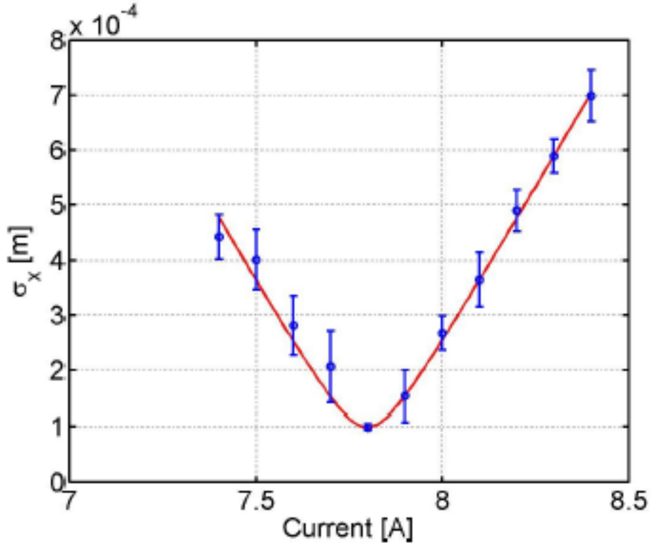
Emittance with no PMQ: 1.2(0.6) um in X(Y)

Emittance with 1st PMQ triplet: 1.2(0.7) um in X(Y)

Emittance with 2nd PMQ triplet: 1.2(0.6) um in X(Y)

Emittance with both triplets: 1.2(0.7) um in X(Y)





COMB beam (compression)

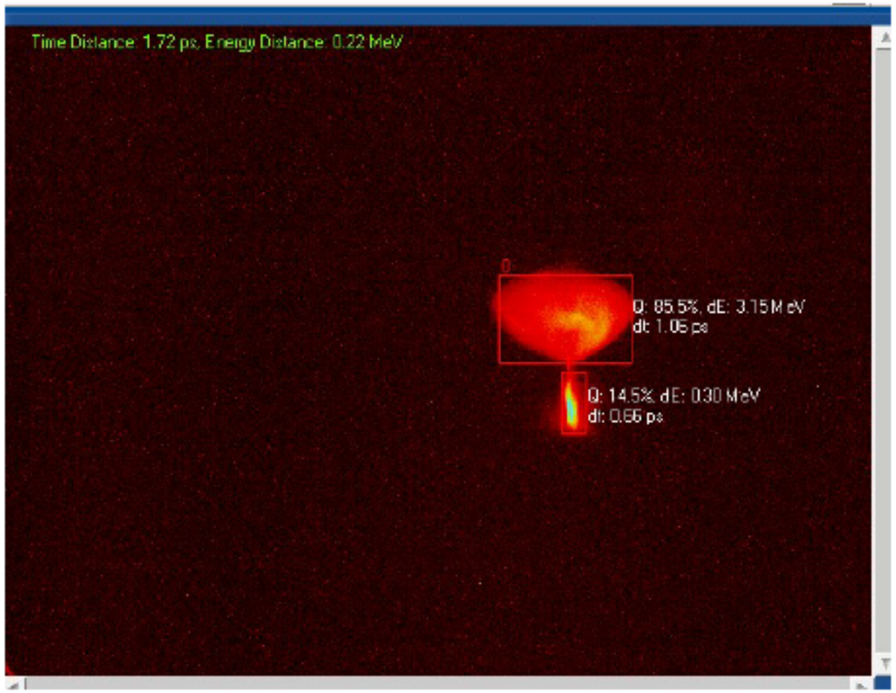
The compressed COMB beam was setup to try the first beam-plasma interactions

Few days of operation with many RF interlocks did not allow to fully characterize the beam and define a good working point. We need to improve

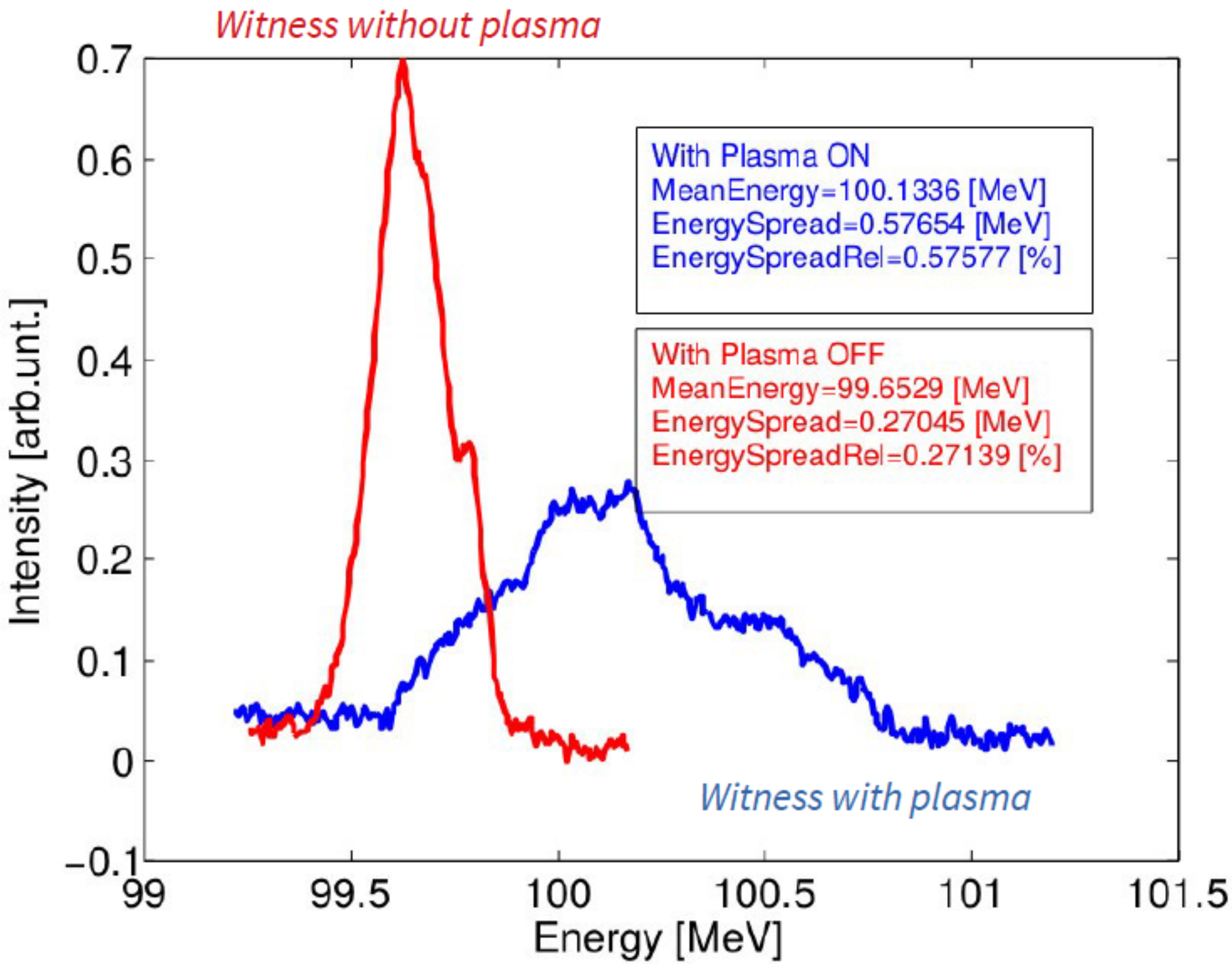
- Trajectory
- Emittance
- Energy spread
- Bunch spacing
- PMQ focusing

First tests showed a clear signature of deceleration (for one and two bunches)

Small (unstable) acceleration reached



Beam-plasma interaction tests



Summary of January-February activities

SPARC beam time dedicated to user experiments. Machine stability was good after conditioning

Smith-Purcell radiation-based diagnostics (Calipso+ collaboration)

- Tested and validated a new electronic
- Observed a signal that was dependant on the grating position, angle and pitch
- Unfortunately, it seems that this signal was not coherent

THz-based diagnostics for single-shot measurements (ELI beamline)

- Beam parameters at SPARC can be manipulated to produce CTR spectrum with high enough intensity within the wavelength range of interest
- Several issues with experimental setup (alignment, detector, DAQ)

One-shot emittance experiment (LNF-ToV)

- Lot of data acquired, analysis to be completed
- Clear signals from multi-shot measurements
- Performances of the ICCD must be improved/understood to have larger SNR on single-shot signals

SPARC LAB

Calipso+ experiment

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

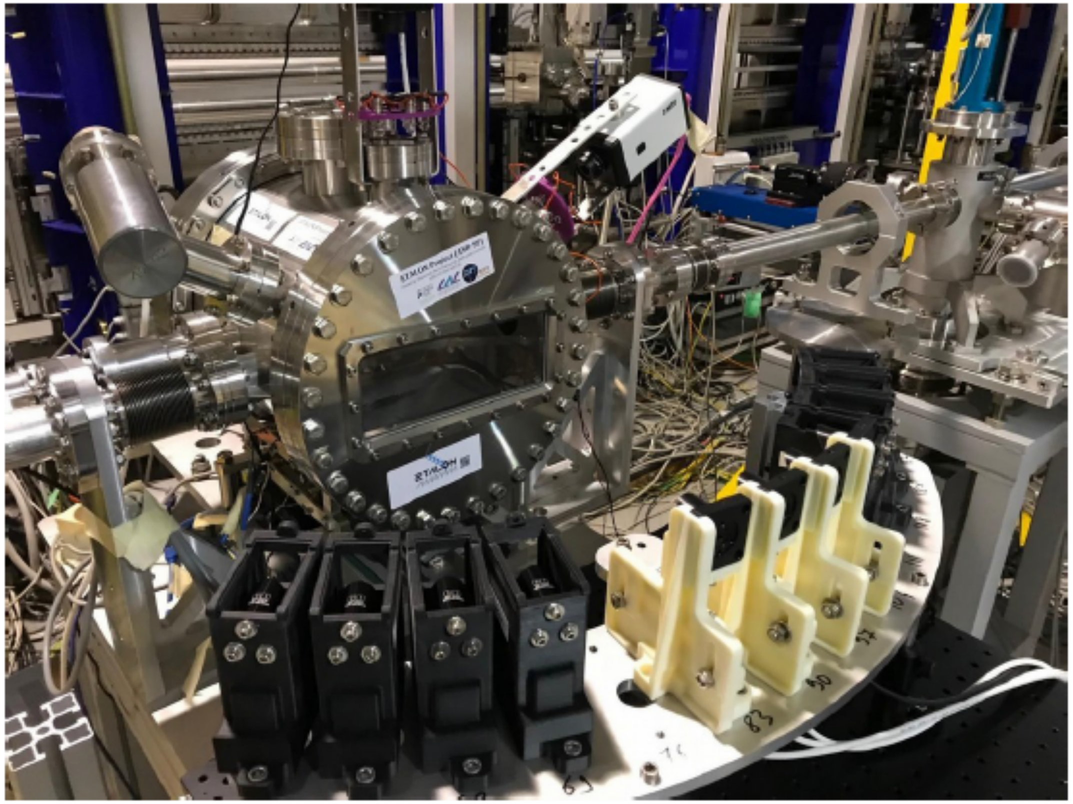
Charge: 300-400 pC

Duration: 200-500 fs (rms)

Energy: 100 MeV

Beam transported at the end of the dogleg line

Beam request: Large charge , short duration



The whole week was dedicated to Calypso experiments with Smith-Purcell radiation. The ultimate goal of these experiments is to measure the bunch length by measuring the radiation intensity, generated by grating, at different angles. The setup is located at the DogLeg line. Aside from necessity to transport the beam to DGL the beam needed to be compressed

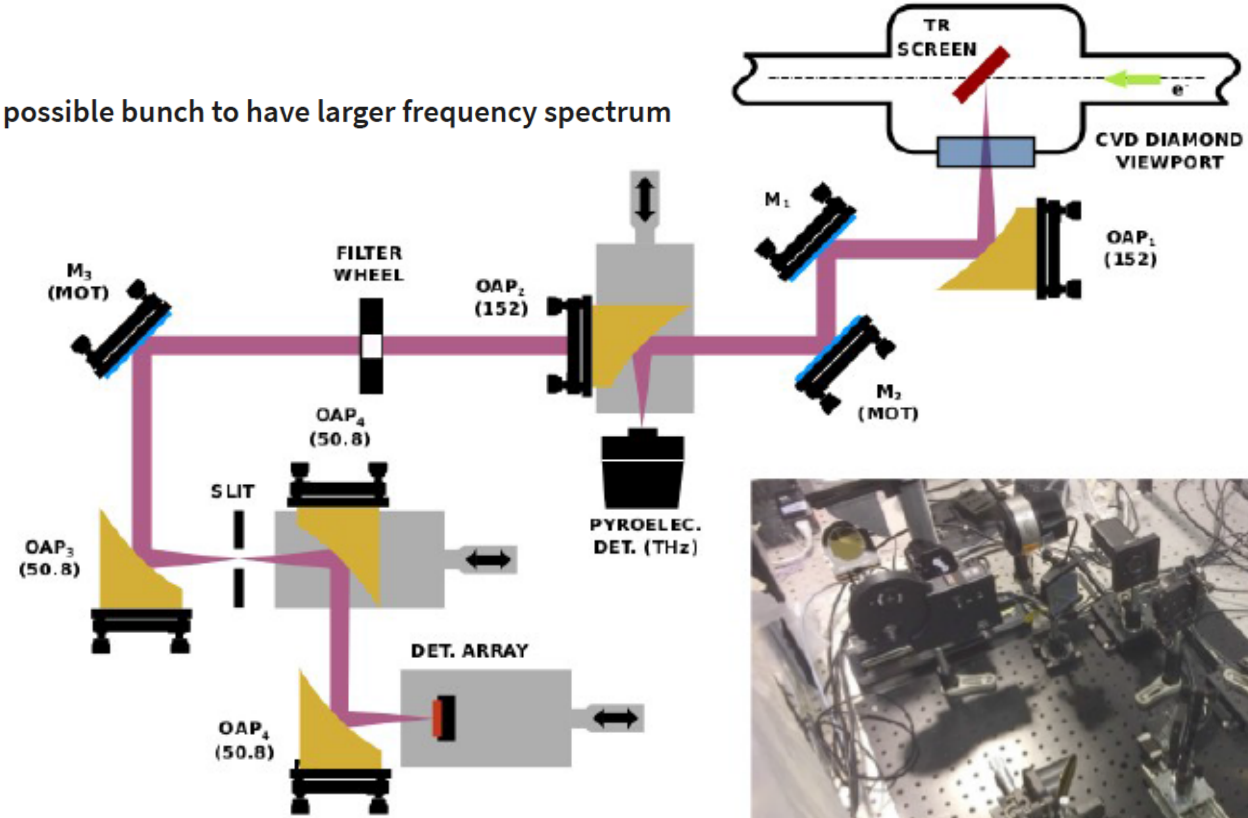
ELI beamline experiment

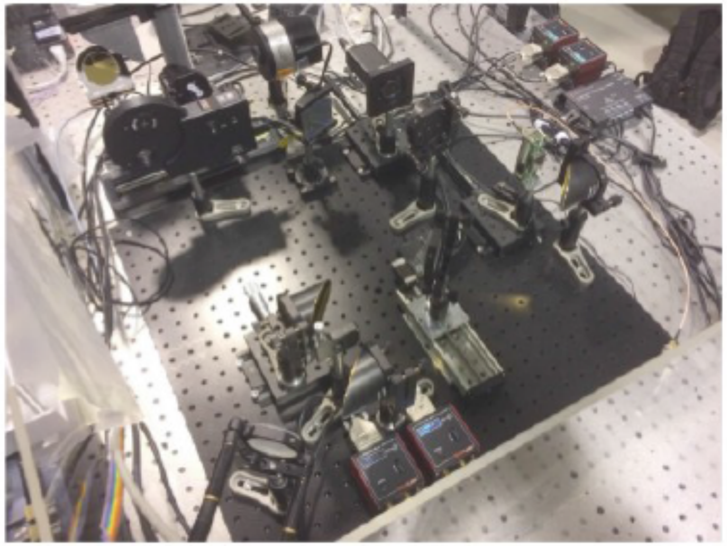
Charge: 20 pC

Duration: 20 fs (rms)

Energy: 100 MeV

Beam request: shortest possible bunch to have larger frequency spectrum





Summary of March-April-May activities

March: SPARC beam time dedicated to the preparation of the COMB experiment. Dual bunch operation (driver+witness)

- Beam dynamics of 1 driver (200 pC) + witness (20-50 pC)
- Tests of plasma deceleration/acceleration
- Failure of the EVOLUTION laser pump. Replaced with the one from ENEA SEEDING laser

April: operations on the photo-cathode laser to shorten the witness pulse

- Removal of Cube Polarizing Beam Splitter. Substituted with plates
- Optimization of the UV generation. Now 100 fs fwhm UV pulses on cathode. Witness duration less than 50fs (rms)
- Tests with IR laser on cathode. Very low charge observed. Laser too long? To be investigated

May: maintenance

- Amplitude visit, removal of the ENEA Gas harmonics chamber. Control on fluids

Final beam parameters

Driver

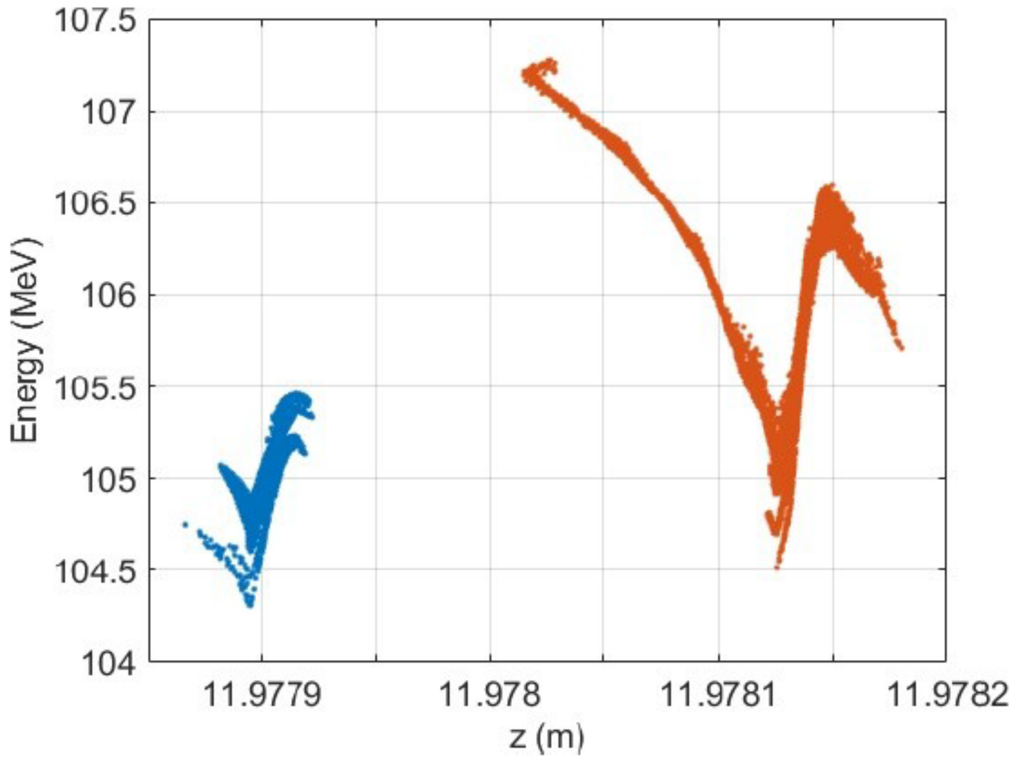
- Duration: 100 fs (rms)
- Energy spread: 0.55 MeV
- Emittance: 3.3 um, Twiss (α/β): -0.2/1.5

Witness

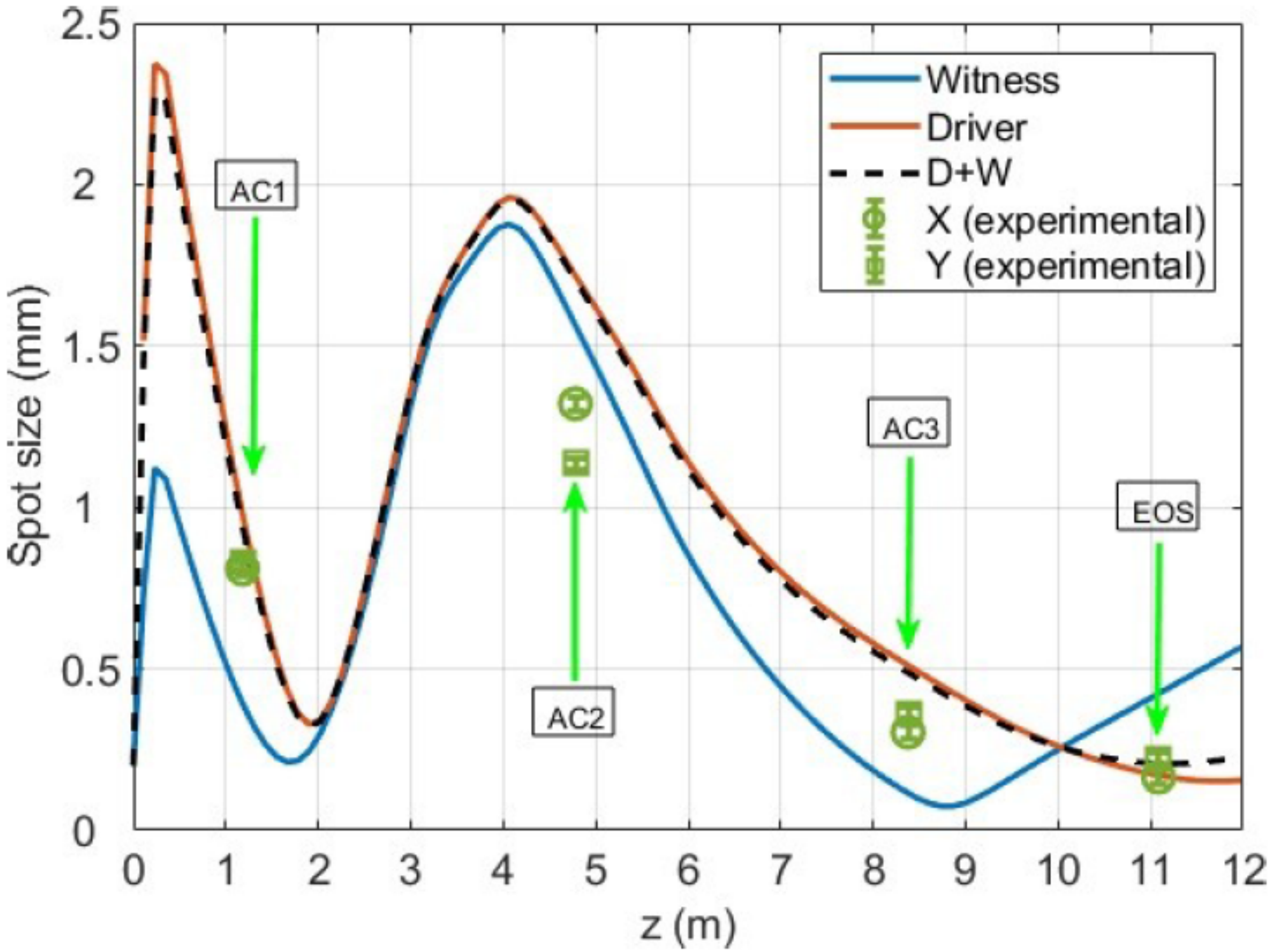
- Duration: 25 fs (rms)
- Energy spread: 0.19 MeV
- Emittance: 2.6 um, Twiss (α/β): -7.1/25

D+W (entire beam)

- Distance → 730 fs (220 um)
- Energy spread: 0.6 MeV
- Emittance → 4.7 um, Twiss (α/β): -0.5/2.3

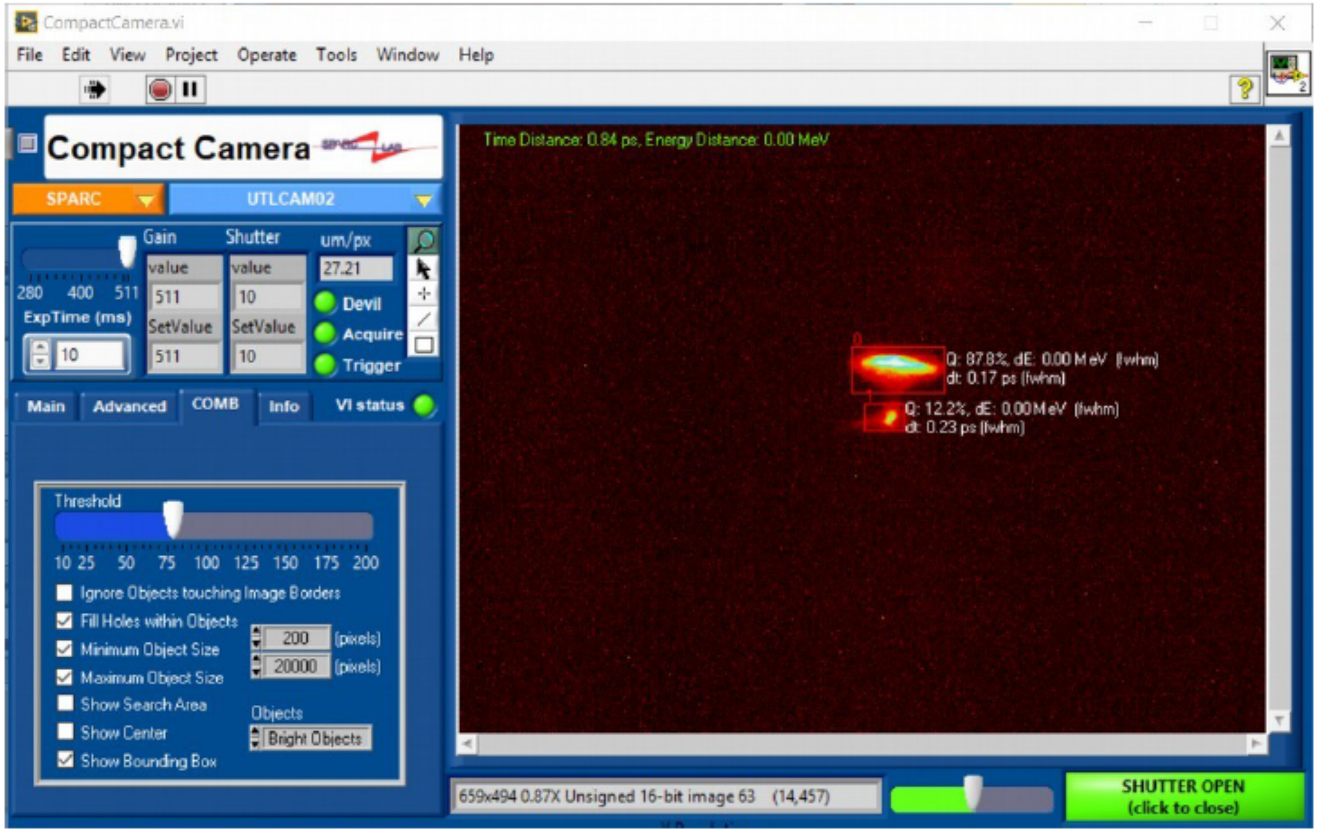


Comparison with experimental data



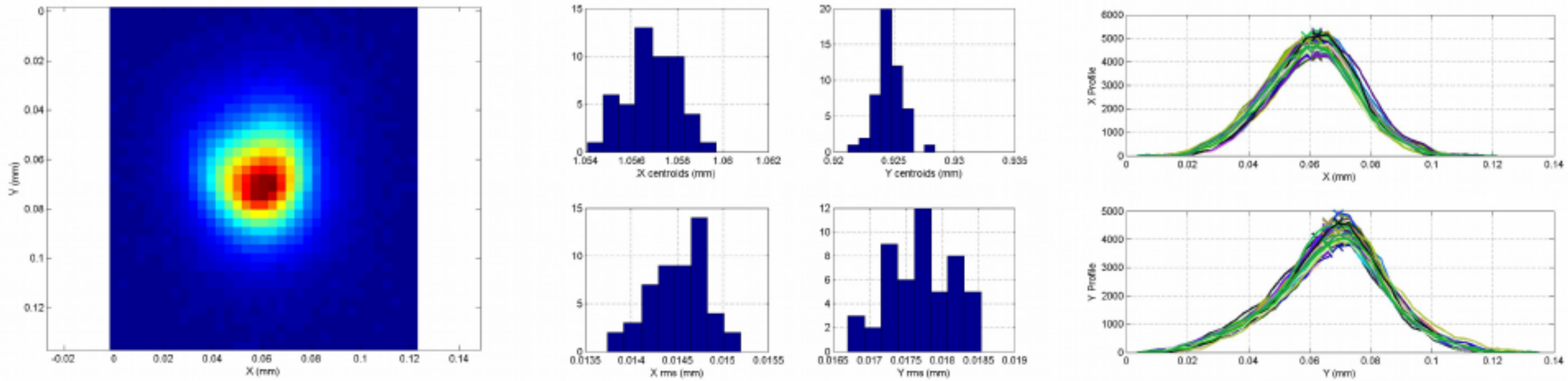
After characterizing the on-crest we moved to the compression working point

-89° compression phase

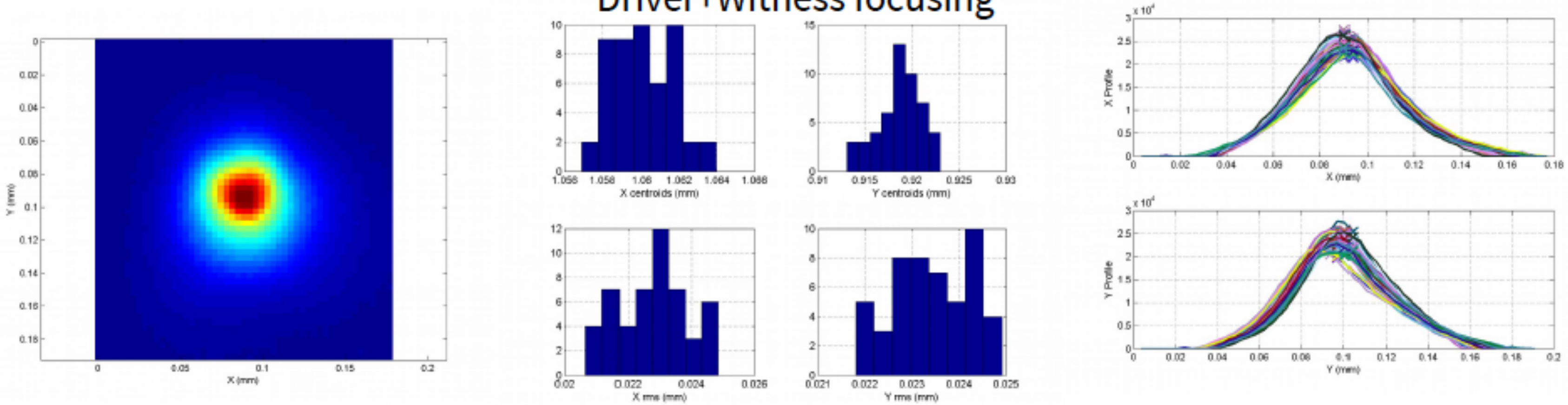


PMQ focusing

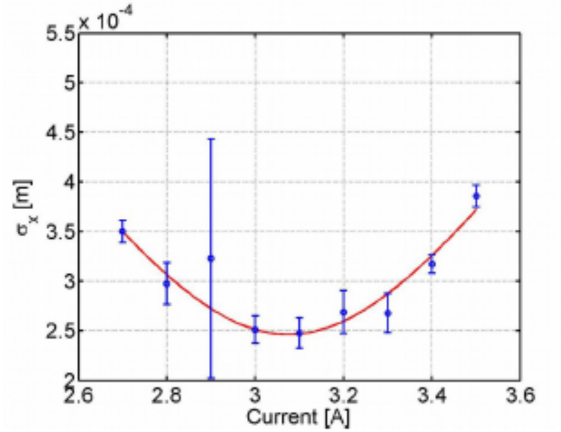
Witness focusing



Driver+Witness focusing



Measured emittances with RFD turned on → useful to evaluate single bunch Twiss parameters

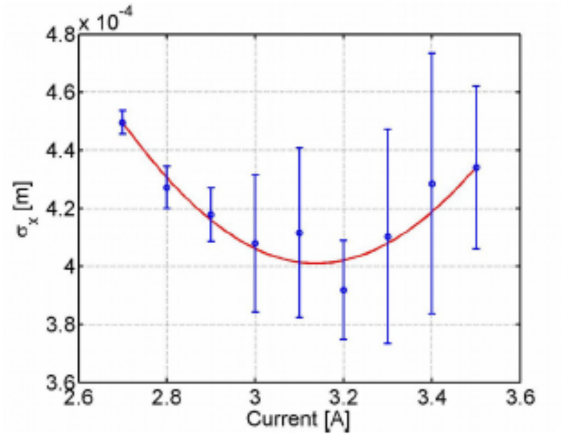


Witness

emitnx=1.81487 mm mrad

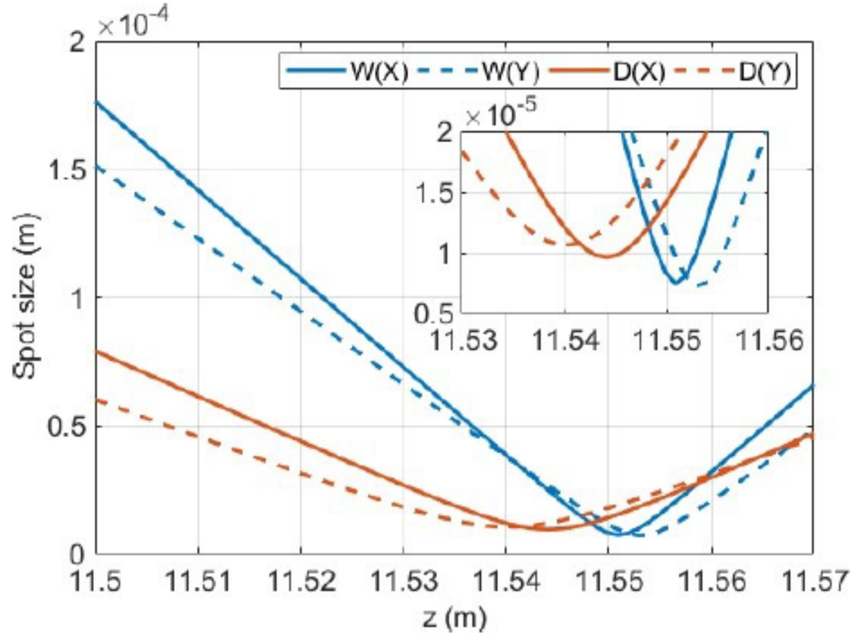
Driver

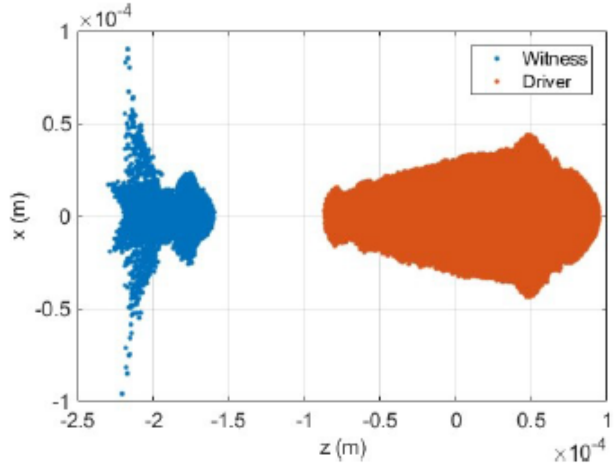
emitnx=2.06902 mm mrad



Final Focusing simulations

- Due to the different energies and envelopes → Driver and Witness are focused in different positions (about 5-6 mm in z)
- Considering the positions with round spots we have
  - Driver → 12 um (rms)
  - Witness → 8 um (rms)
- There is a growth of the witness emittance after focusing.
  - From 2.6 um to 4.6 um (rms)





- **Plasma acceleration experiment has started at the end of February and will continue till July 2019**
  - Optimization of the working point (beam dynamics, no plasma) from 25th February to 23rd March
  - First tests of beam-plasma interaction from 25th March to 19th April
- **Technical stop is planned from 23rd April to 10th May**
  - Maintenance/installations in the SPARC bunker
  - New Amplitude visit
- **Optimization of beam-plasma interaction from 13th May to 5th July**
- **Several measurements on active plasma lens and wakefield will be performed till the closure of Labs in August**

Laser parameter & tunability

Last configuration (220 pC, 2 bunch Comb):

Temporal length: <200fs FWHM, separation: 4 ps

Transverse dimension: 800 um diameter

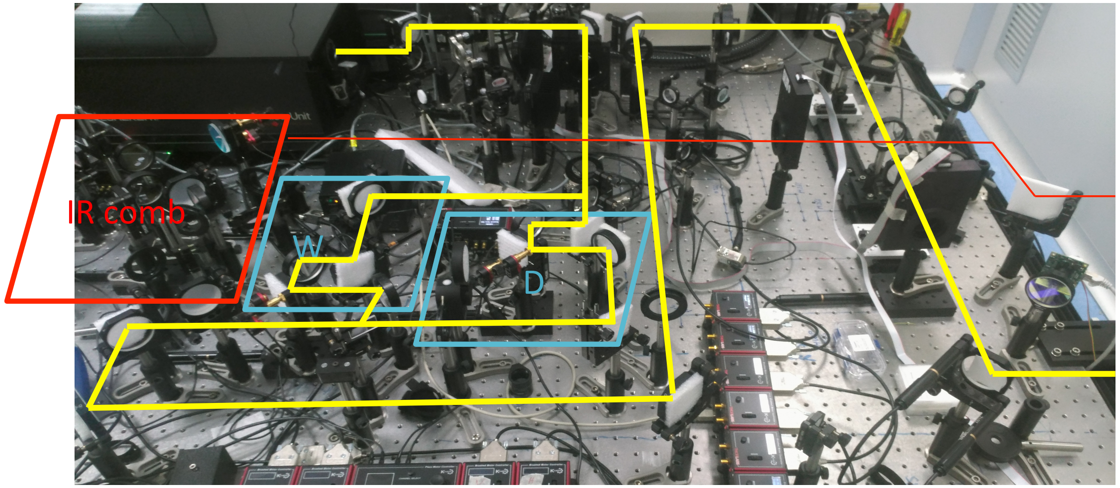
Energy: 100 uJ @264 nm, 2% rms stability

Duration tuning: 0.2-4 ps FWHM

Separation tuning: ±50 ps resolution 10 fs

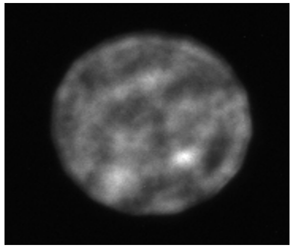
Transverse tuning: 250-1000 um diameter

Energy available: up to 300 uJ



Split & delay system

UV on virtual cathode



Laser operations and configurations

11/18	Amplitude installation of 2nd CFR pump laser to reach nominal IR energy, single bunch configuration
12/18	Comb test with 2 pulses via birefringent crystal
01/19	Single bunch for Calipso+ users
02/19	Amplitude test for flat top pump configuration, installation of comb system with split & delay lines
03/19	Substitution of Evolution pump laser
04/19	Fine tuning of shortest temporal duration, IR comb test on cathode
05/19	Amplitude modification of laser pumps, split & delay with different dimensions and duration

New laser parameters

Bunch charges

- Witness → 20 pC
- Driver → 200 pC

Time distance @ cathode

- **5 ps** (witness before driver), tunable with delay line

Laser durations

- Witness → **100 fs (rms)**
- Driver → **200 fs (rms) → must be longer than the witness!!!**

Laser spot sizes

- Witness → **0.7 mm (fwhm)**
- Driver → **1 mm (fwhm) → must be larger than the witness!!!**

Compression Working Point

RF power

- Line 1 → 30 MW, Line 2 → 55 MW, Line 3 → 29 MW

RF Gun phase

- GUN → **40**°+2° from phase zero

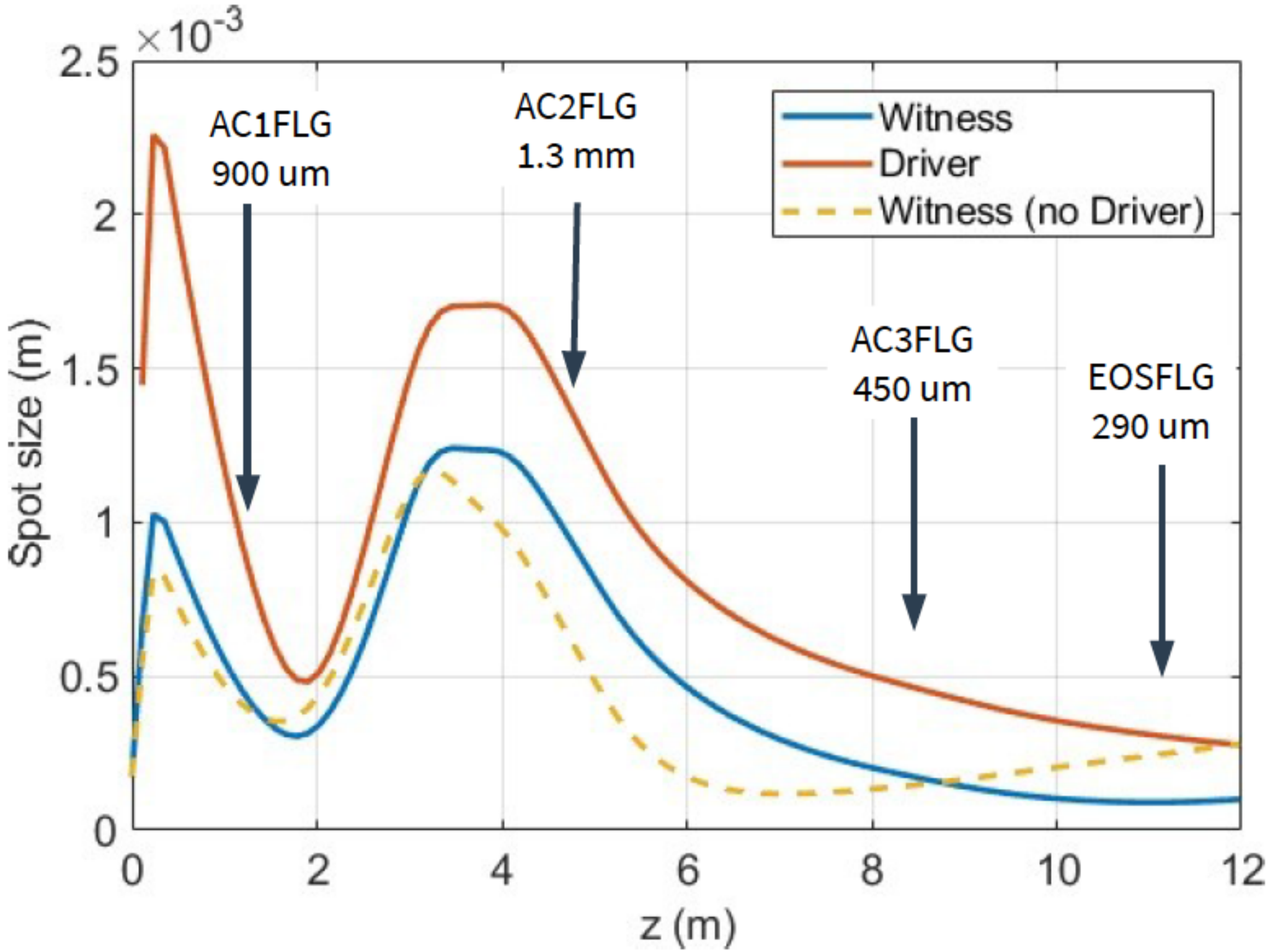
RF phases (with respect to the on-crest ones)

- S1 → -91°
- S2 → -30°
- C3 → -30°

Magnets → **now only the last two triplets on S1 are used. AC2SOL turned off**

- GUNSOL → 200 A
- AC1SOL → 0 A, 0 A, 0 A, **80 A, 95 A**
- AC2SOL → **OFF**

Envelope (compression)



Driver

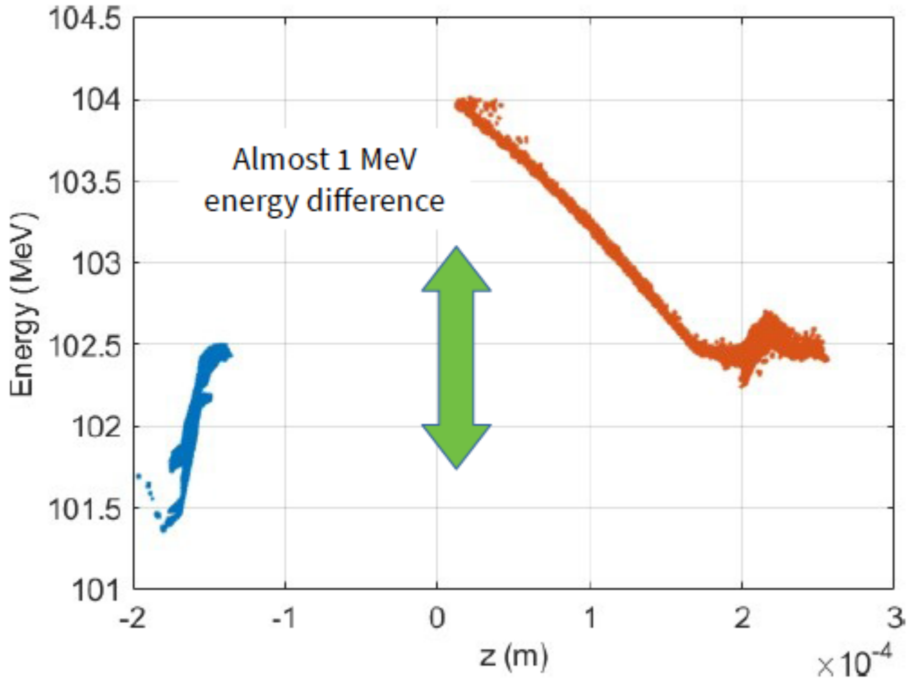
- Duration: 174 fs (rms)
- Energy spread: 0.4 MeV
- Emittance: 2.8 um

Witness (without Driver it is more over-compressed)

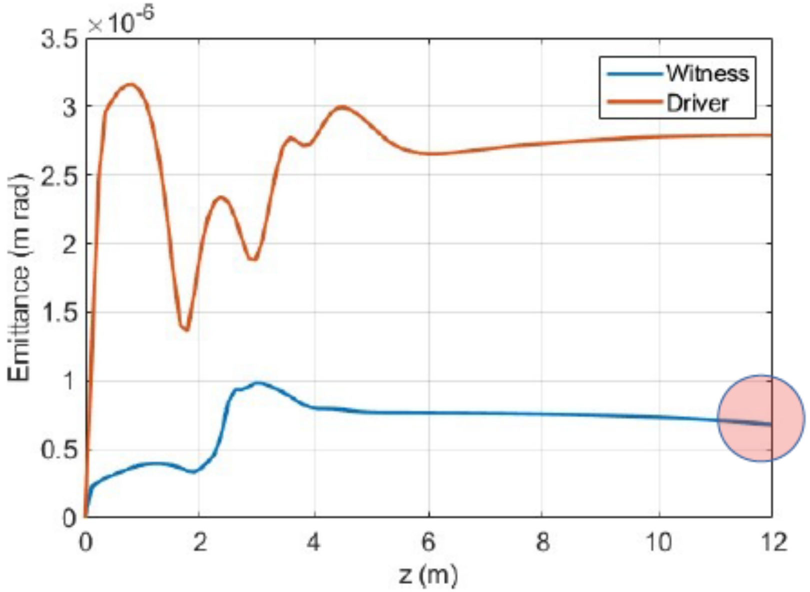
- Duration: 20 fs (rms) → 30 fs without Driver
- Spread: 0.2 MeV → 0.5 MeV without Driver
- Emittance: 0.7 um → 0.4 um without Driver

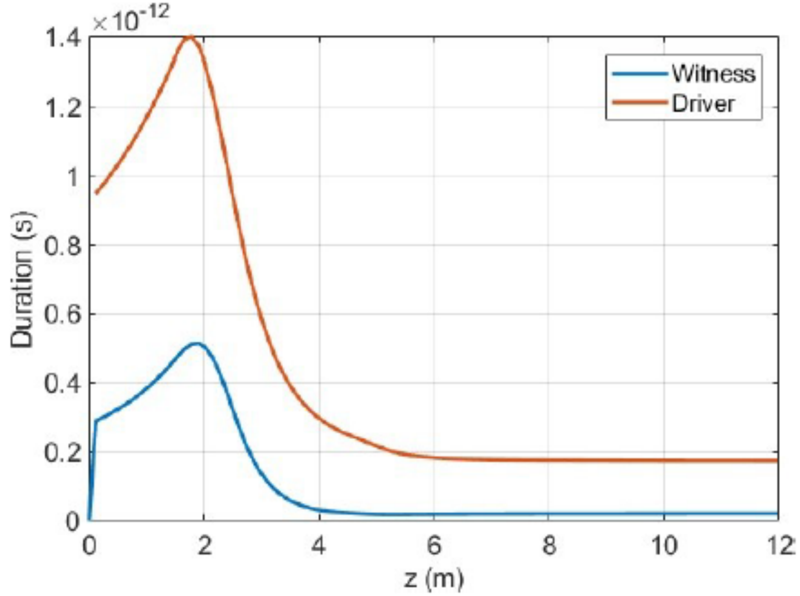
D+W (entire beam)

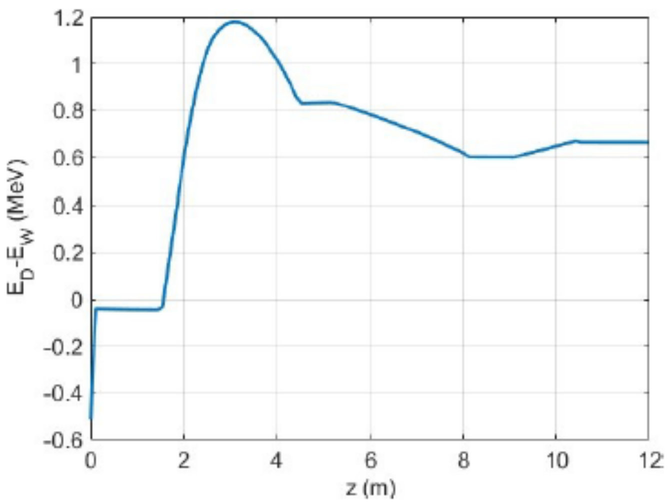
- Distance → 1.1 ps (330 um), Duration → 360 fs
- Energy spread: 0.44 MeV
- Emittance → 2.8 um

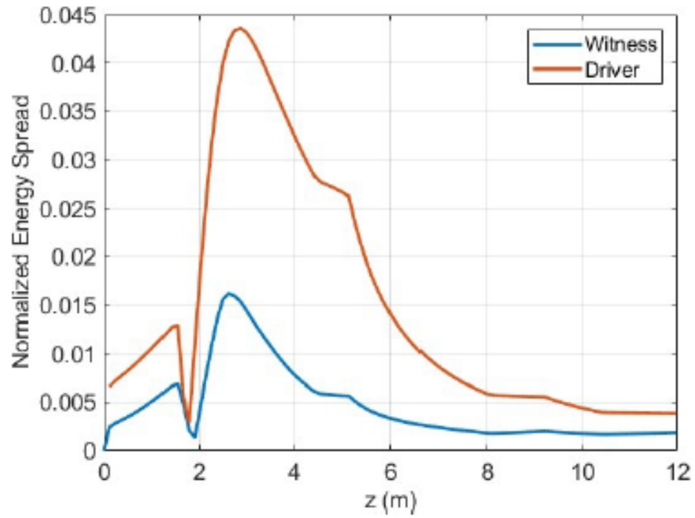


VB plots


×10^-6
Emittance (m rad)
z (m)
Witness
Driver


×10^-12
Duration (s)
z (m)
Witness
Driver


E_D-E_W (MeV)
z (m)


Normalized Energy Spread
z (m)
Witness
Driver

Possible benefits of the new configuration

- A shorter witness is obtained (it was 25 fs, now 20 fs)
    - By tuning the compression phase, also 16 fs are possible in principle
- Witness emittance in VB now is <1um (it was 2-3 um before)
- The W-D distance has been increased to test plasma acceleration at lower plasma densities
    - → Relaxed parameters both for transverse and longitudinal planes
    - Larger distances better for diagnostics (emittance with RFD)
- The Witness is in over-compression. The Driver now is in under-compression
    - The driver energy-chirp can be removed during the witness acceleration (→ dechirper)
    - Should be easier to distinguish the witness from the driver on the spectrometer

Final Focus

The small difference in energy between the bunches would produce waists in different positions along z

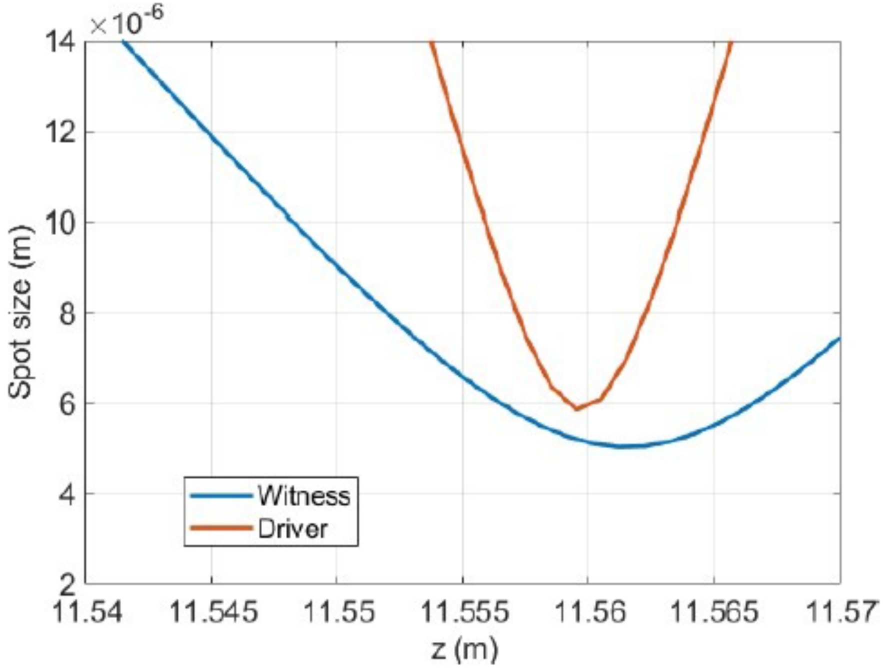
- This is avoided by making the D-W envelopes slightly different

Witness waist → 5 um (rms)

- Twiss-beta function: 7 mm

Driver waist → 6 um (rms)

- Twiss-beta function: 4 mm

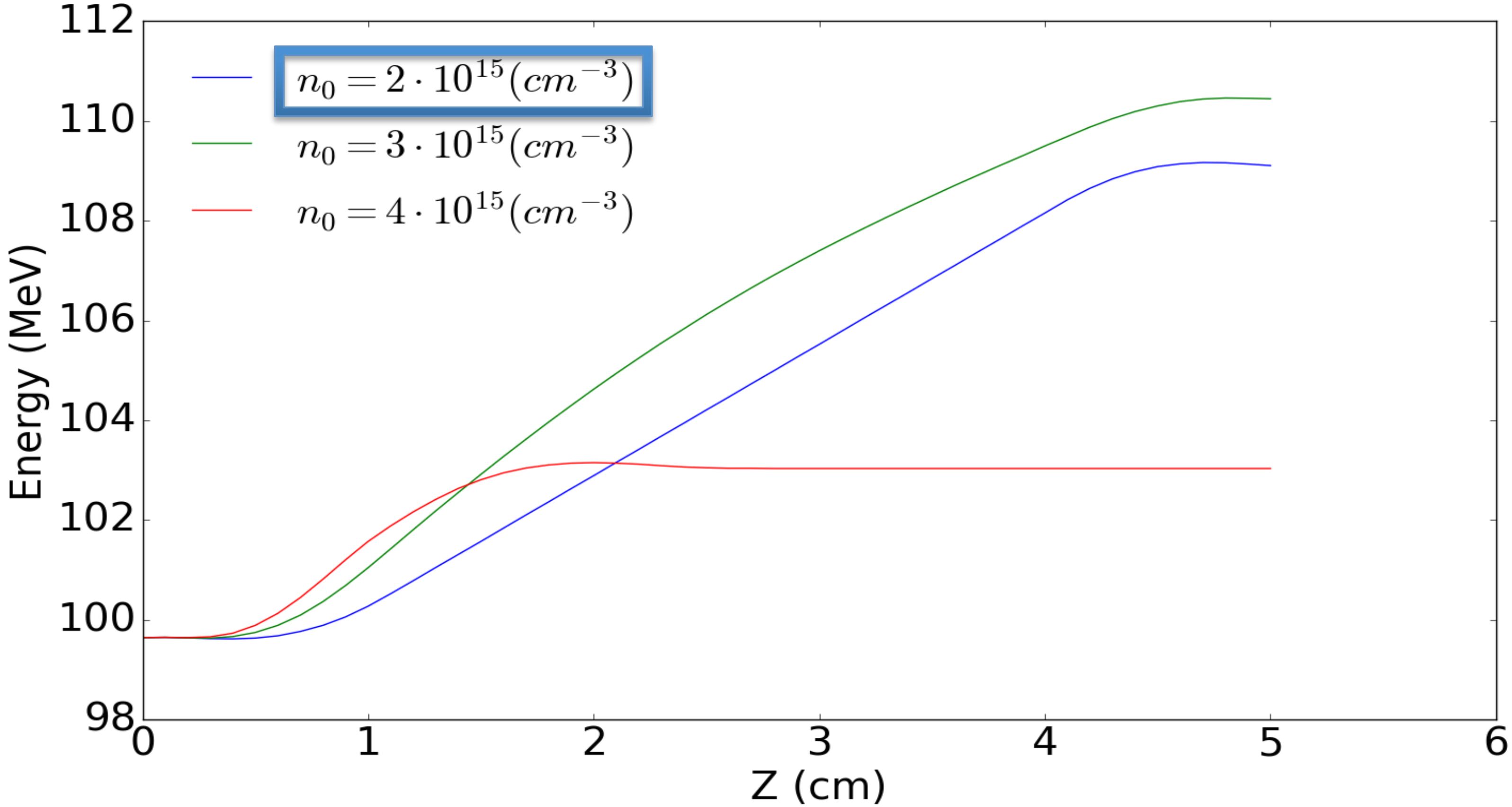


Input parameters for PWFA simulations

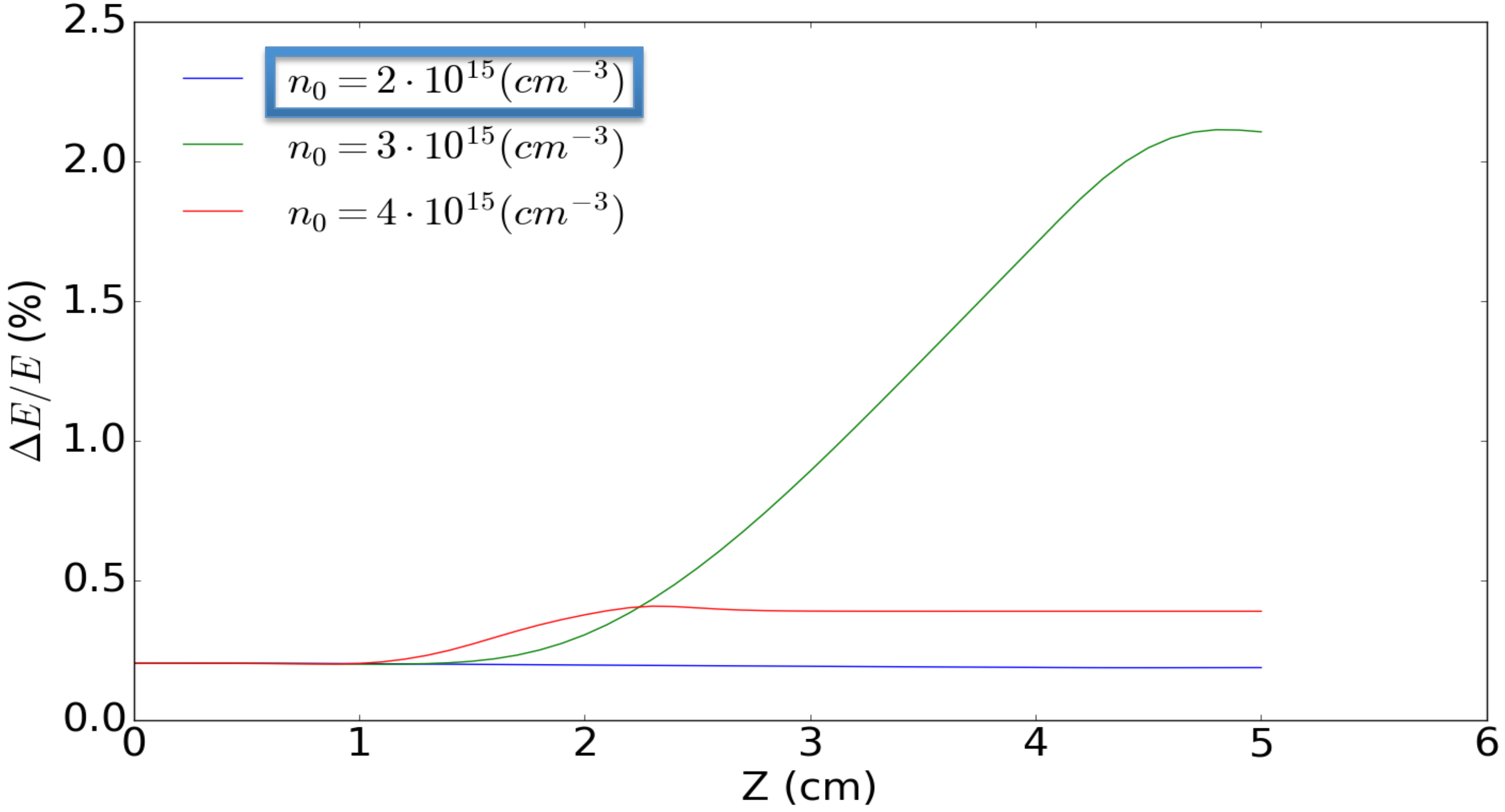
- Driver
- Charge 200 pC
- Spot size 26 um, length 52 um
- emittance 2.8 mm mrad
- alpha=4.4126, beta=0.0565 m

- Witness
- Charge 20 pC
- Spot size 10 um, length 6 um
- emittance 0.7 mm mrad
- alpha=1.8497, beta=0.0342
- Distance 1.1 ps
- Energy 100 MeV , Energy spread 0.4 %

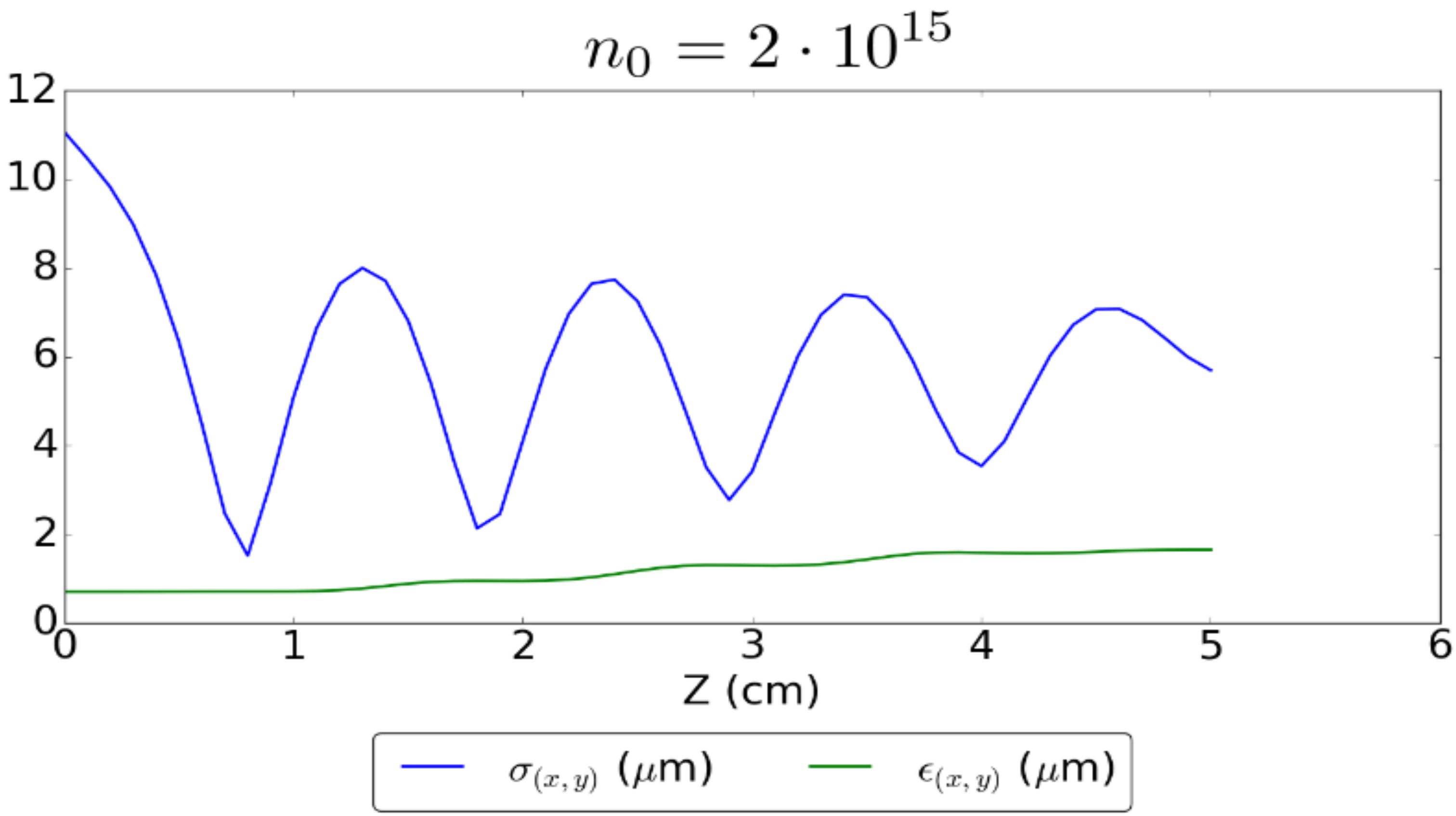
Energy at different plasma densities



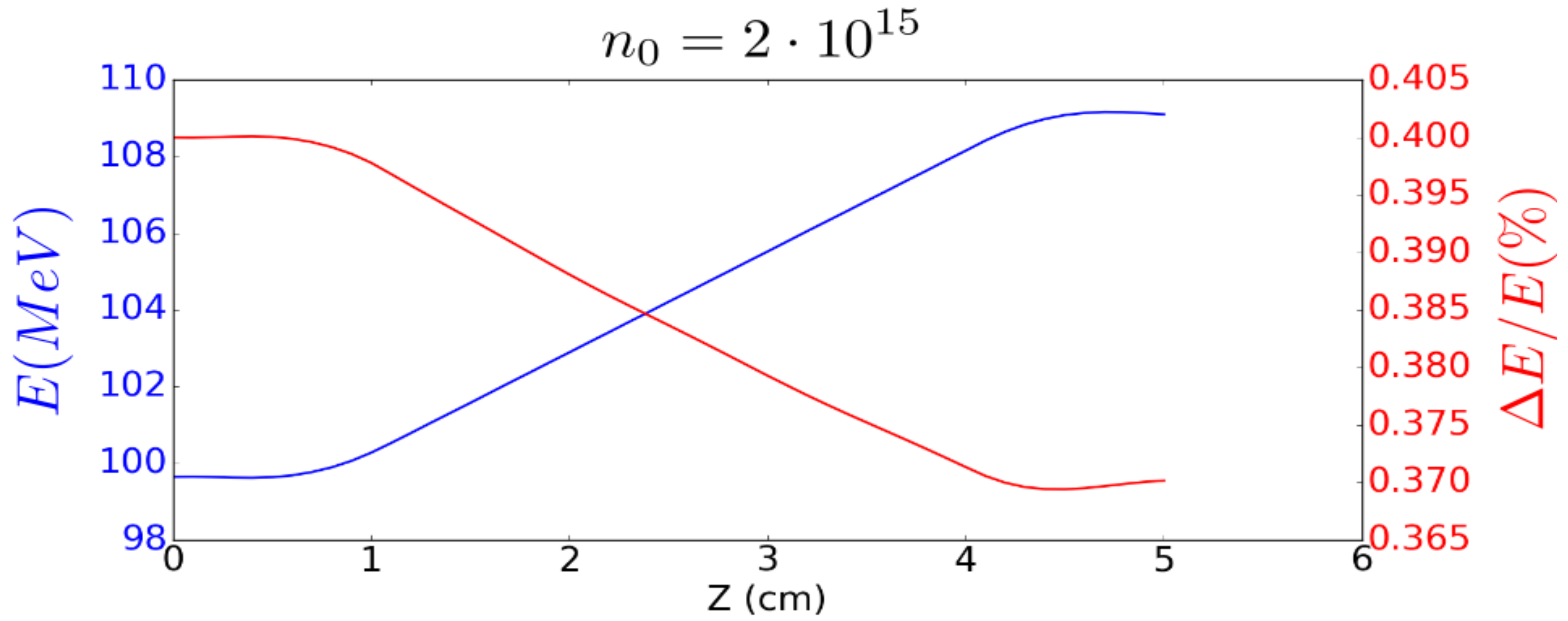
ΔE at different plasma densities



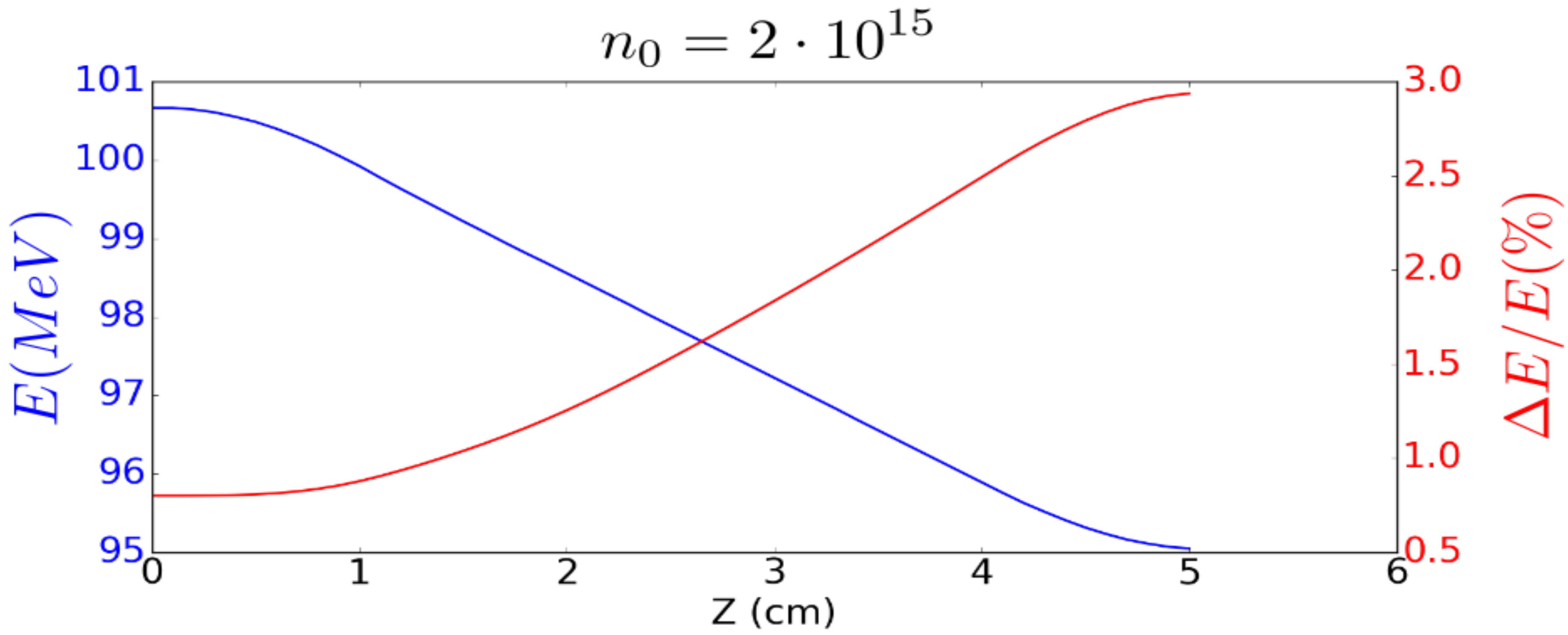
Spot and emittance



Witness energy gain

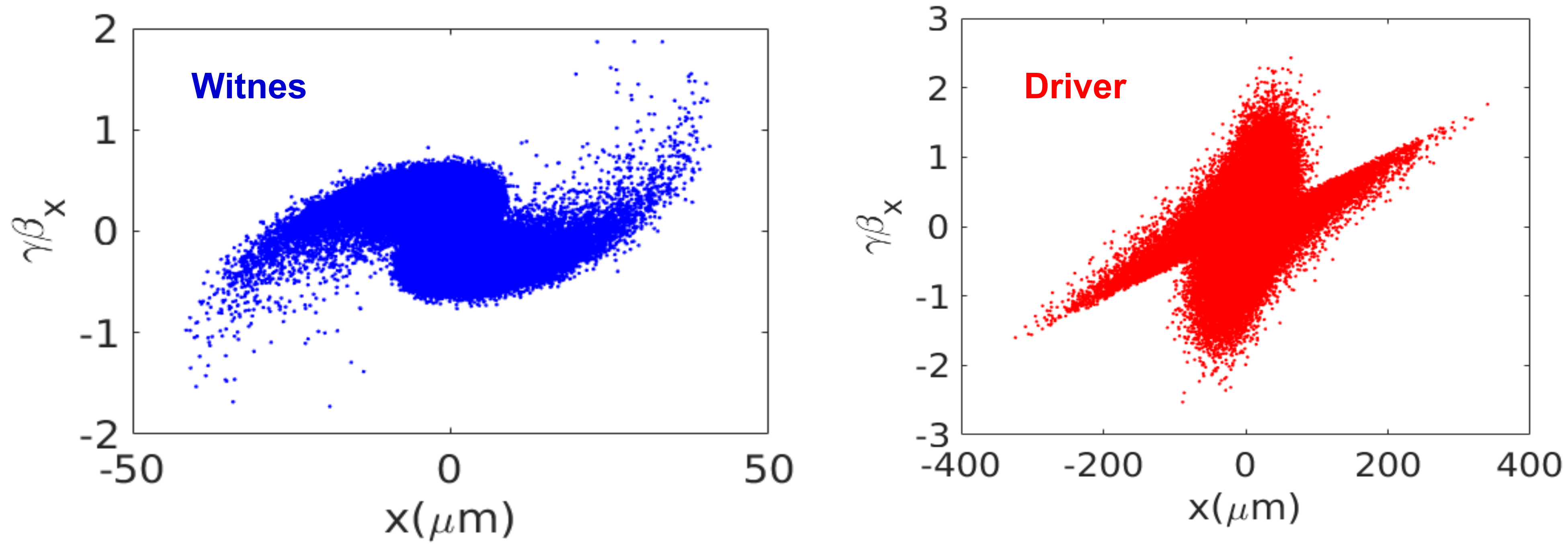


Driver energy loss

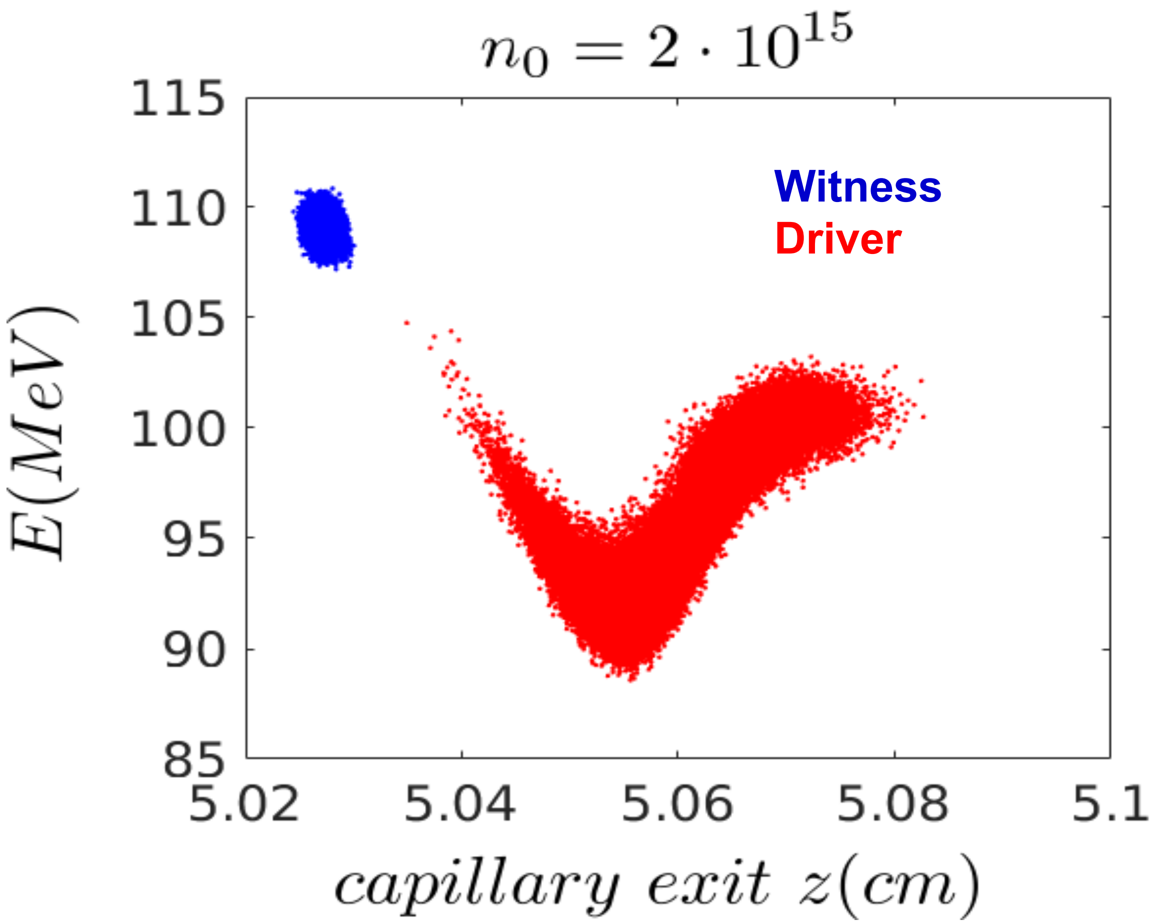


Transverse phase space

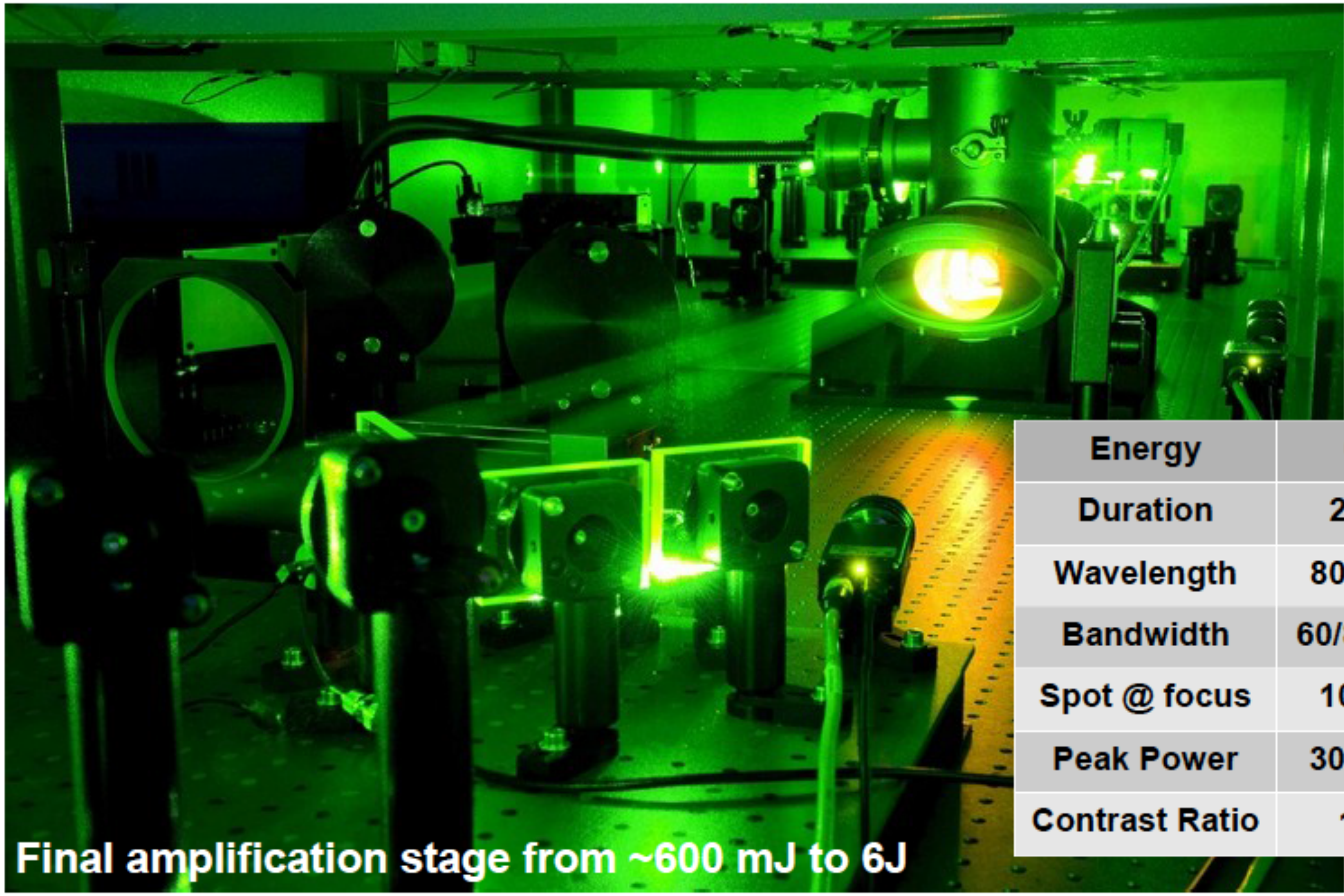
$$n_0 = 2 \cdot 10^{15}$$



Longitudinal phase space



FLAME activity



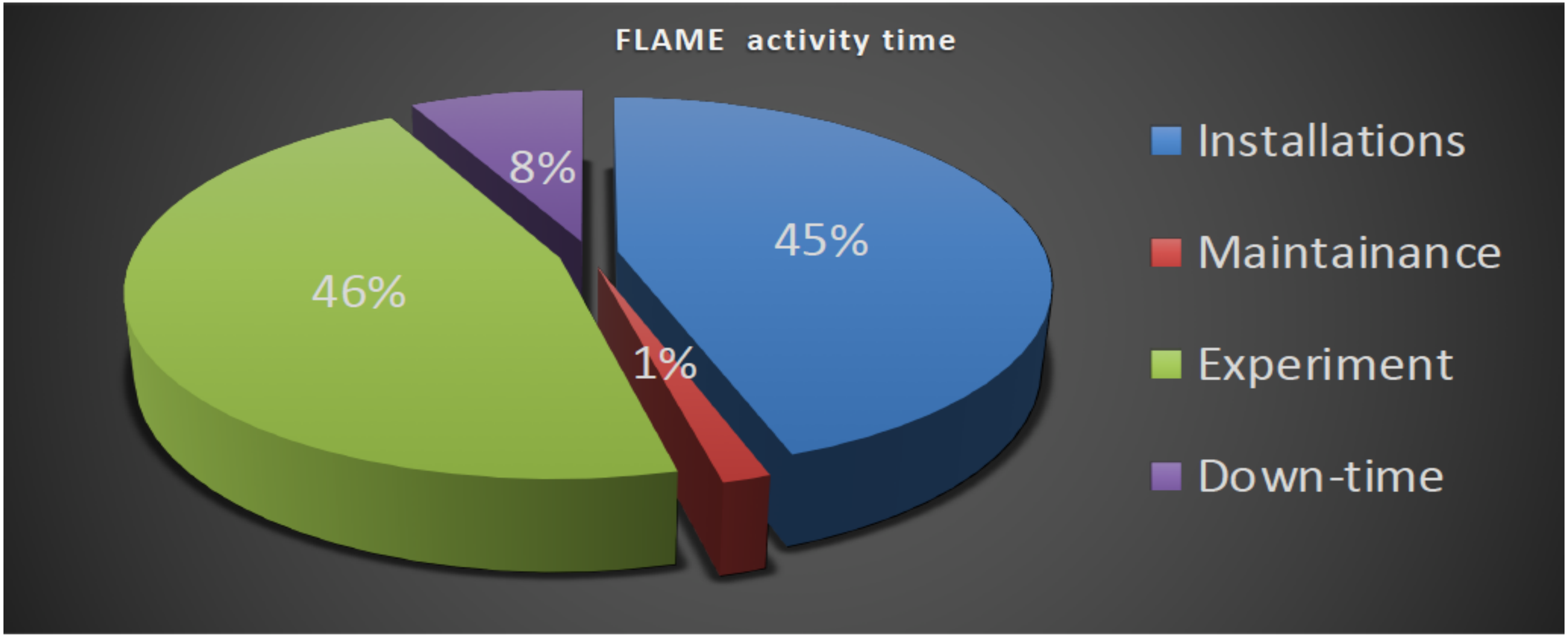
Final amplification stage from ~600 mJ to 6J

Energy	6 J
Duration	23 fs
Wavelength	800 nm
Bandwidth	60/80 nm
Spot @ focus	10 μm
Peak Power	300 TW
Contrast Ratio	10^{10}

FLAME laser parameters

- Routinely delivering >100TW on target:
  - Energy: 3 J
  - Temporal duration: 25 fs FWHM
  - Focal spot size: 16 um FWHM

FLAME up-time



FLAME experimental activities

1. Plasma generation and characterization in gas-filled capillaries through HV discharge for laser guiding;
2. Proton accelerated via TNSA mechanism:
   a) Energy spectrum measurements by diamond-based TOF detector;
   b) Characterization of electron emitted from laser-solid target interactions through EOS diagnostic.

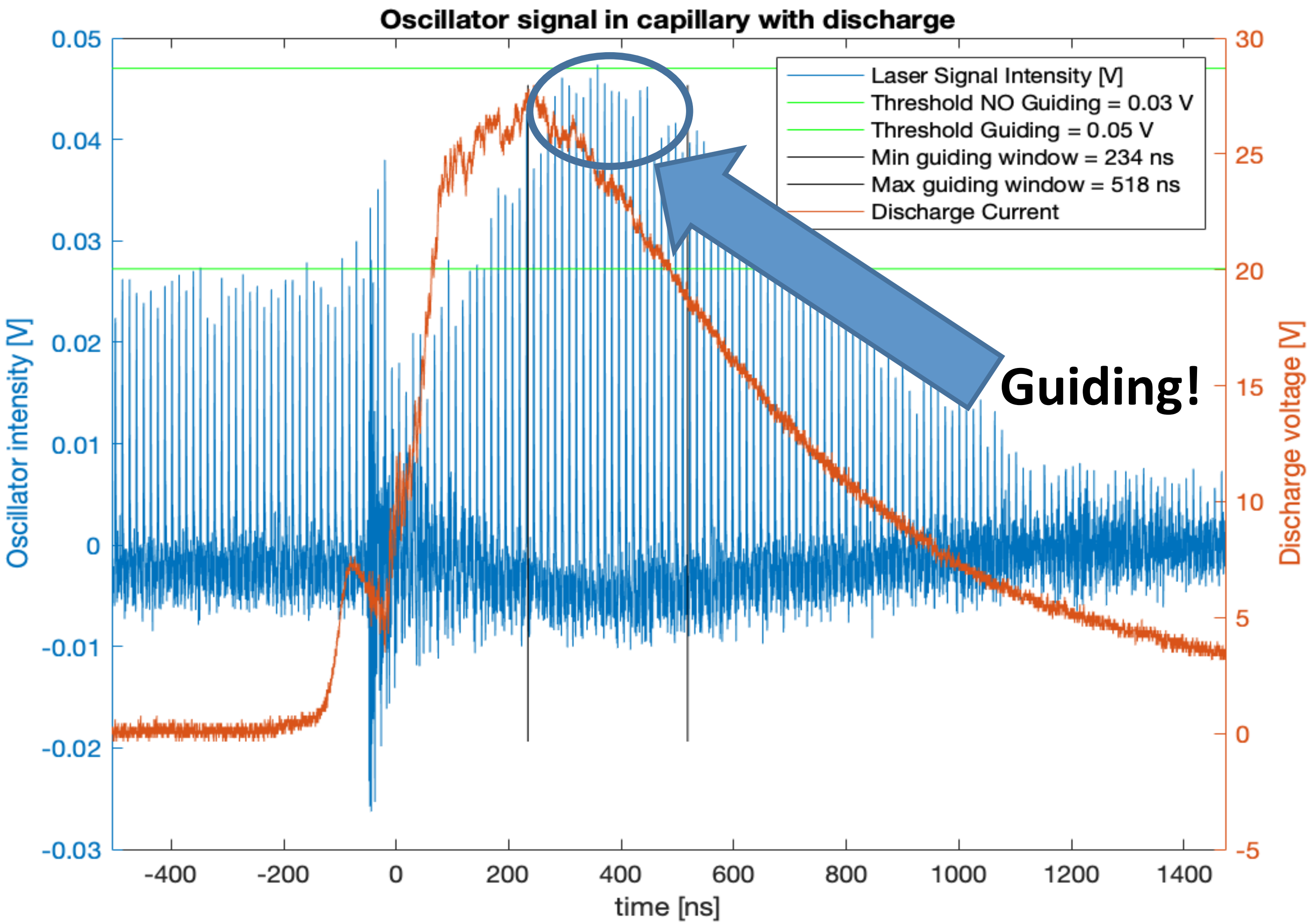
Plasma laser guiding

$$n_e(r) \cong n_0 + \frac{\Delta n}{r_m} r^2 \quad \Rightarrow \quad \boxed{\frac{d^2R}{dz^2} = \frac{1}{Z_M^2 R^3}\left(1 - \frac{\Delta n}{\Delta n_c} R^4\right)} \quad \Rightarrow$$

Laser envelope oscillation: guiding!

- Plasma parabolic channel from discharge in gas-filled capillary characterization:
  - Guiding temporal window measurement
  - Transverse density profile measurements
  - Plasma waveguide test through optical modes detection

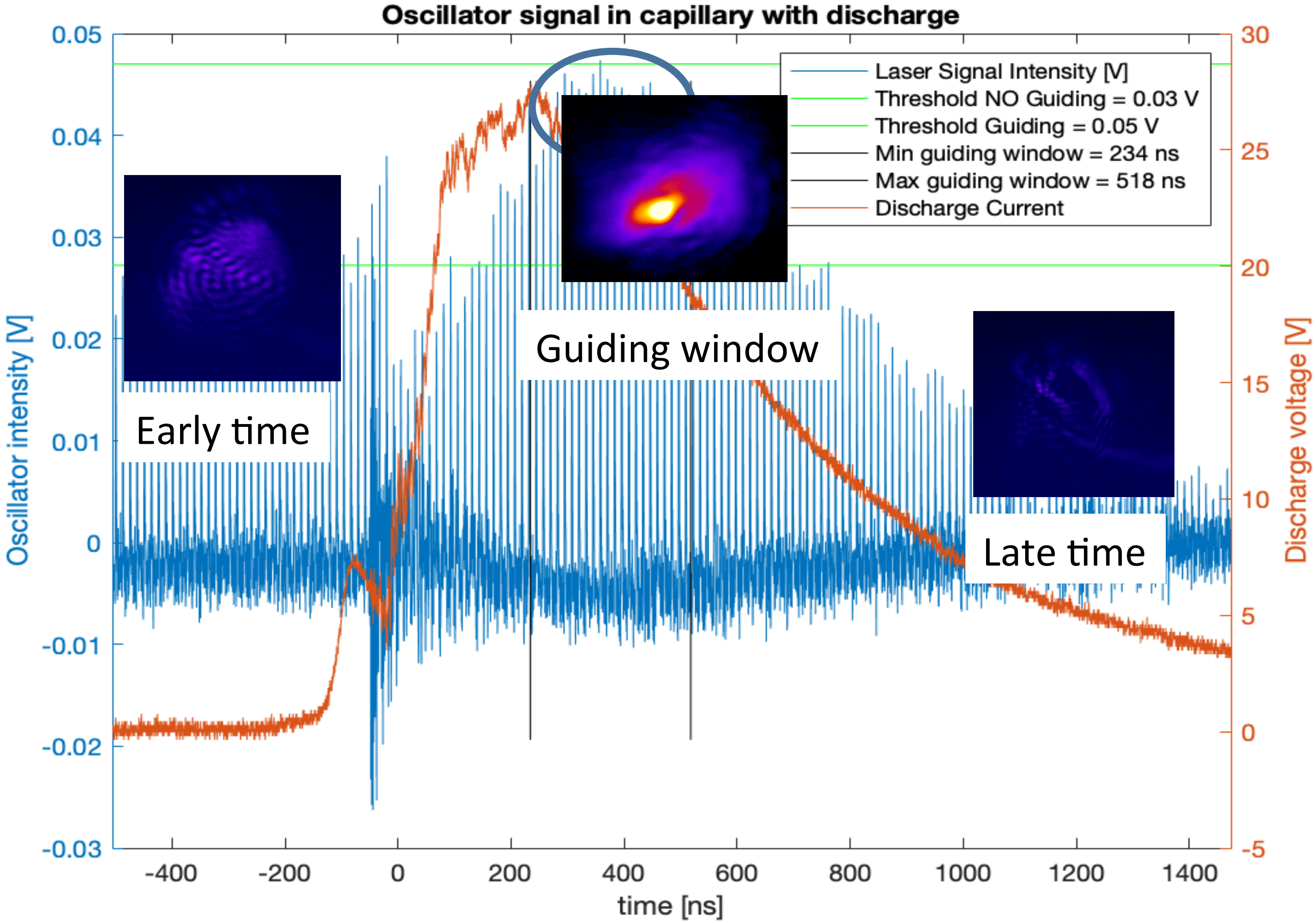
Guiding temporal window



FLAME oscillator has been sent into the plasma to easily find the temporal window for guiding thanks to the high rep.rate (79.667 MHz)

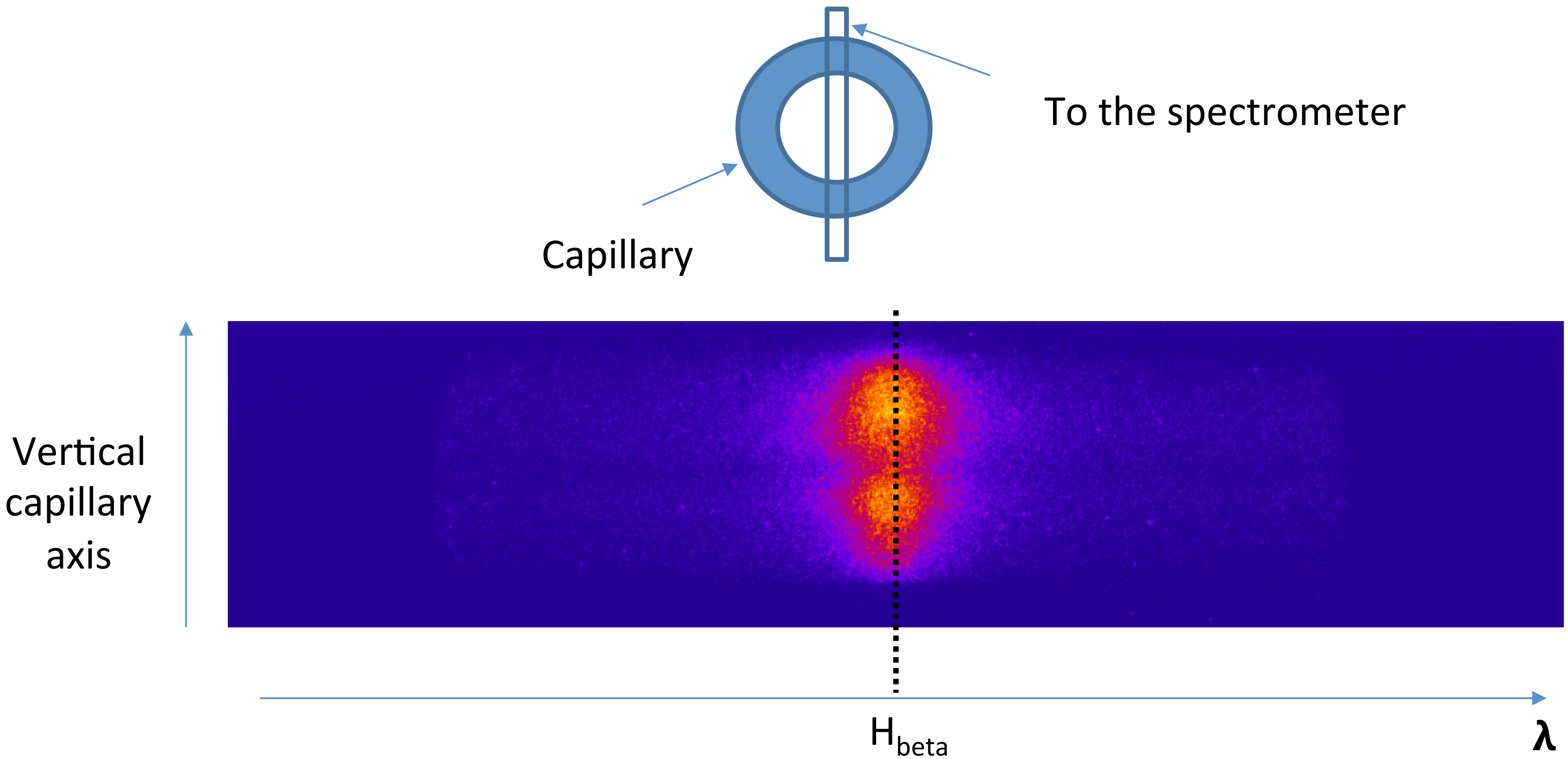
Transmission efficiency:
- **no plasma 40%**
- **with guiding 70%**

Laser mode output



- Low intensity (<10^{12} W/cm^2) single pulse laser has been detected at capillary exit with relay imaging system.
- A temporal scan has been performed to investigate laser output mode by delaying discharge.

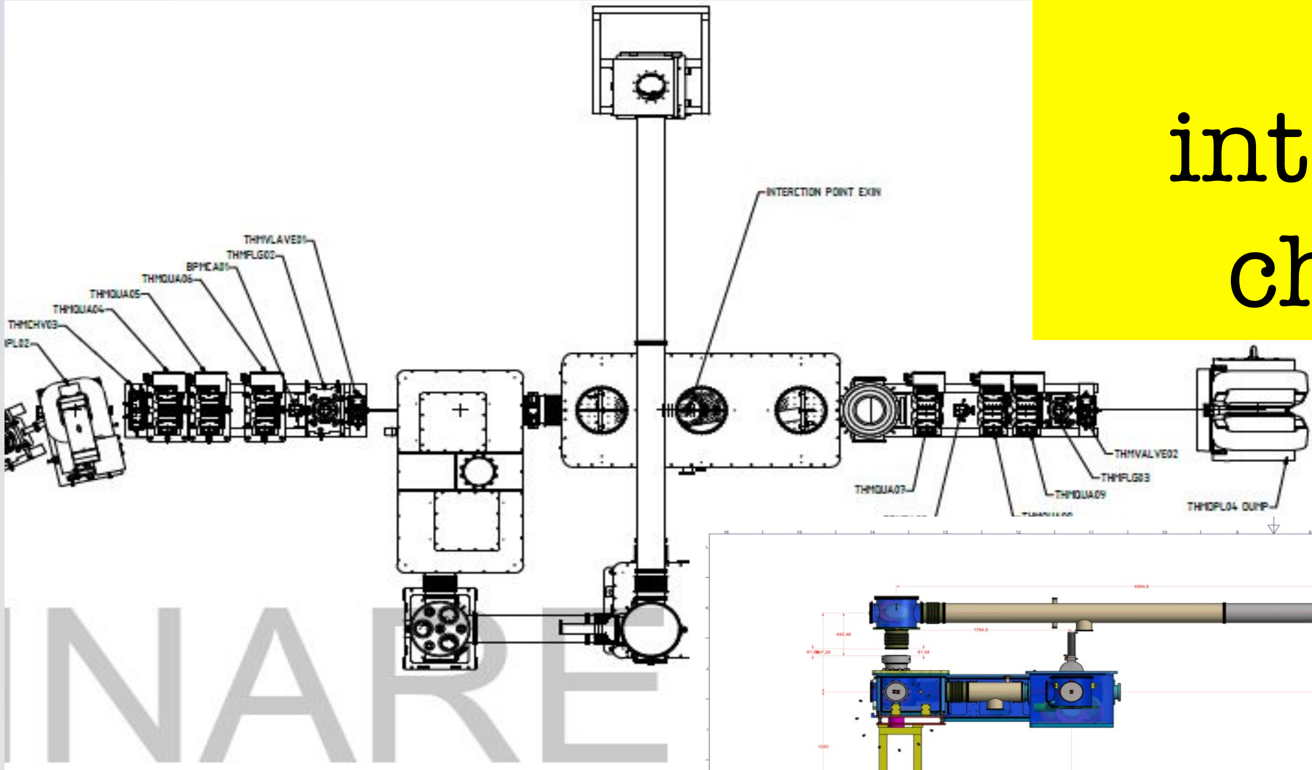
Transverse density profile measurement

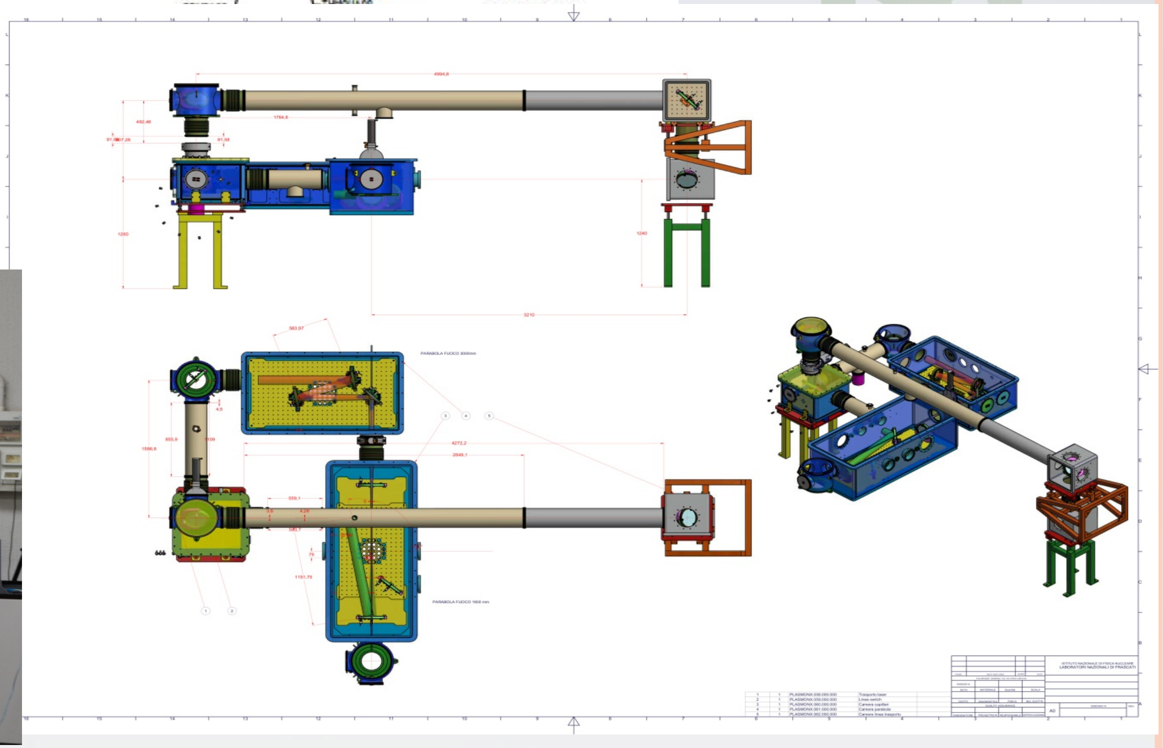


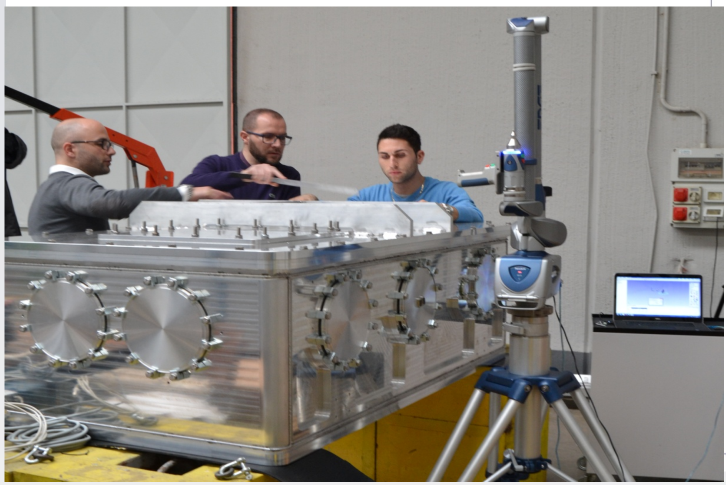
$$n_e = 8.02\ 10^{12}\ (\Delta\lambda/\alpha)^{3/2}\ \mathrm{cm}^{-3}$$

Each horizontal line gives the electron density at a certain vertical position:
Line profile reconstruction

EXIN interaction chamber







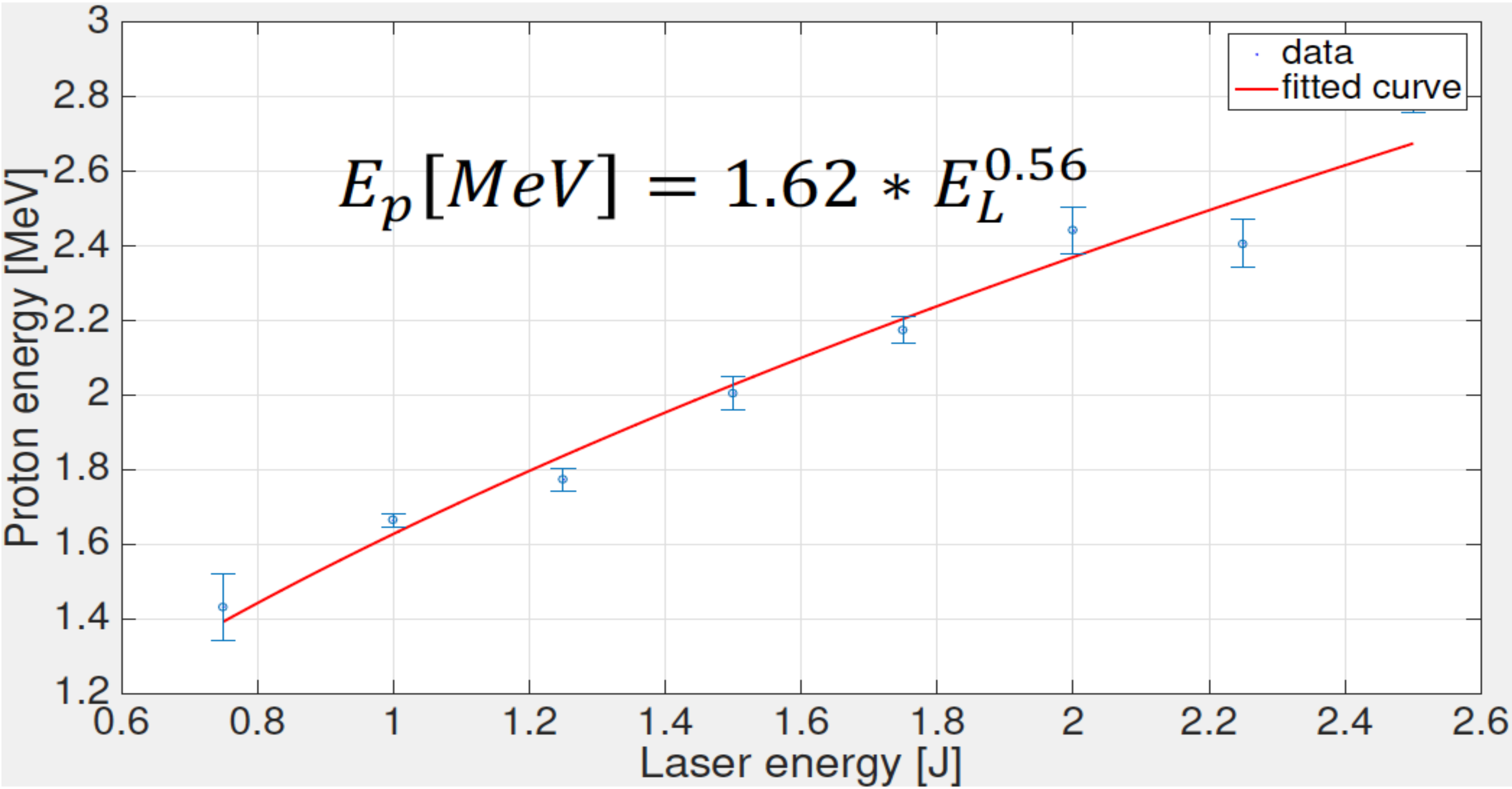
- To complete (by June 2019)
  - The realization of the interaction and injection chambers
  - The e-beam dump line design
  - The design of the final line for laser transfer line up to the injection chamber
  - the sizing vacuum system for operations with H2
- Defined:
  plasma, e-beam and laser diagnostics
  the transfer line for e-beam from linac to interaction chamber
  the FLAME laser transfer line
- Completed:
  existing e-beam transport line (thomson- plasmonx)
  All the magnets elements of the e-beam line and relative power supplies
  the discharge system
  the FLAME laser transfer line up to the first parabola chamber

  Installation of the interaction chamber: from January 2020

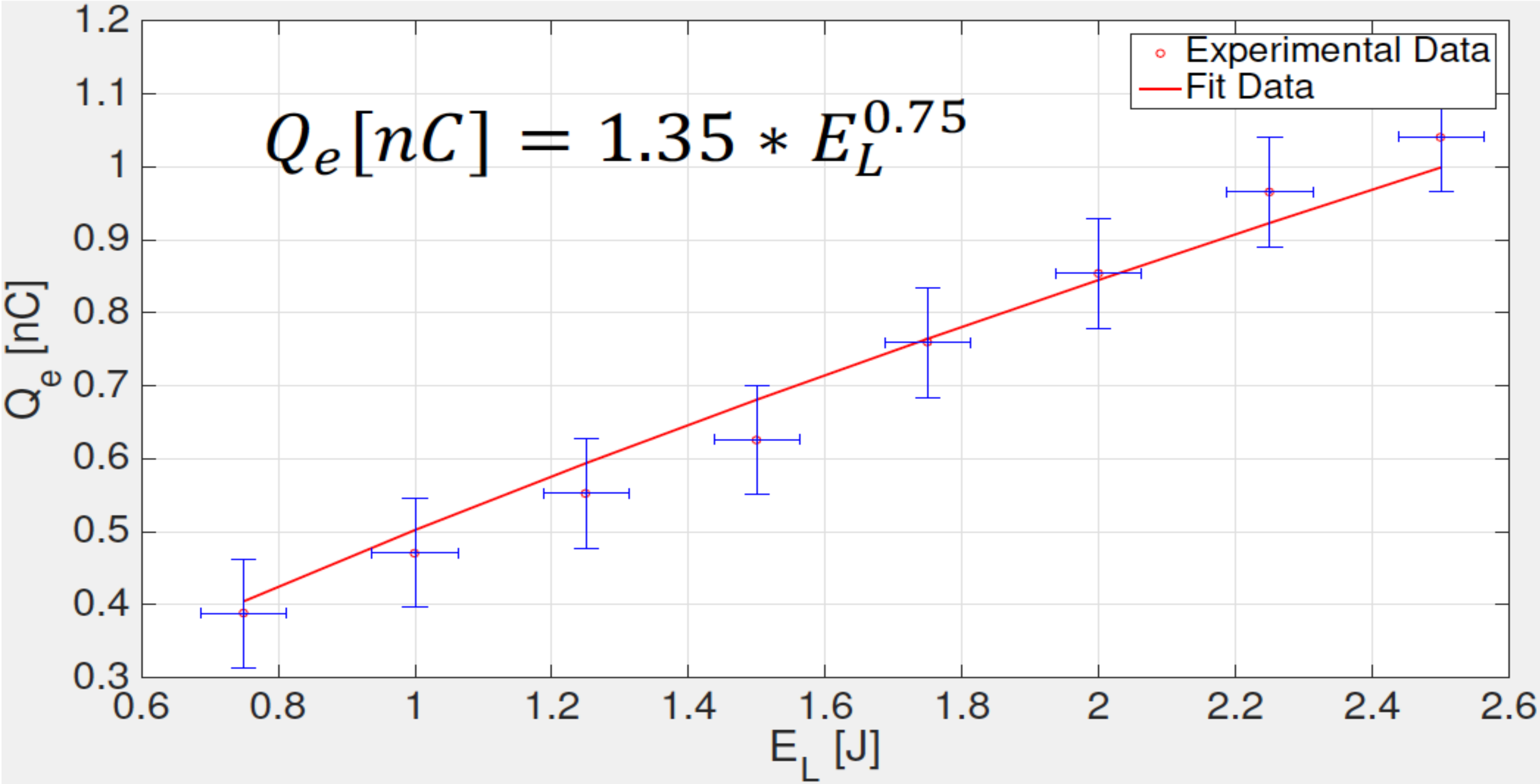
TNSA studies

- Parametric studies using aluminium foils as target varying:
  - Target thickness,
  - Laser energy,
  - Laser spot size,
  - Laser temporal length
- Both protons and electrons detected for each shot to study their property correlations.

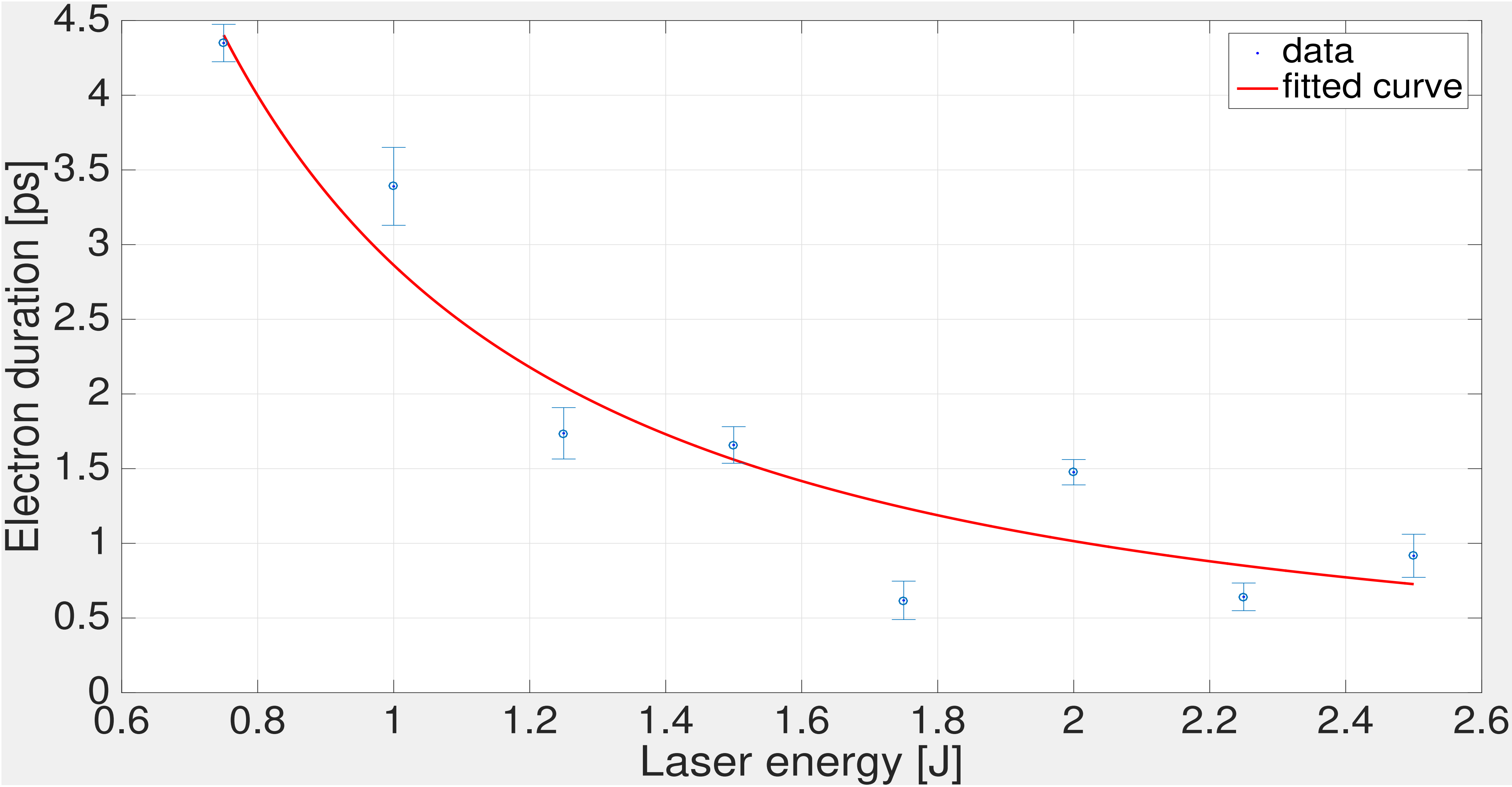
Proton energy scaling



Fast-electron charge scaling



Fast-electron temporal duration scaling



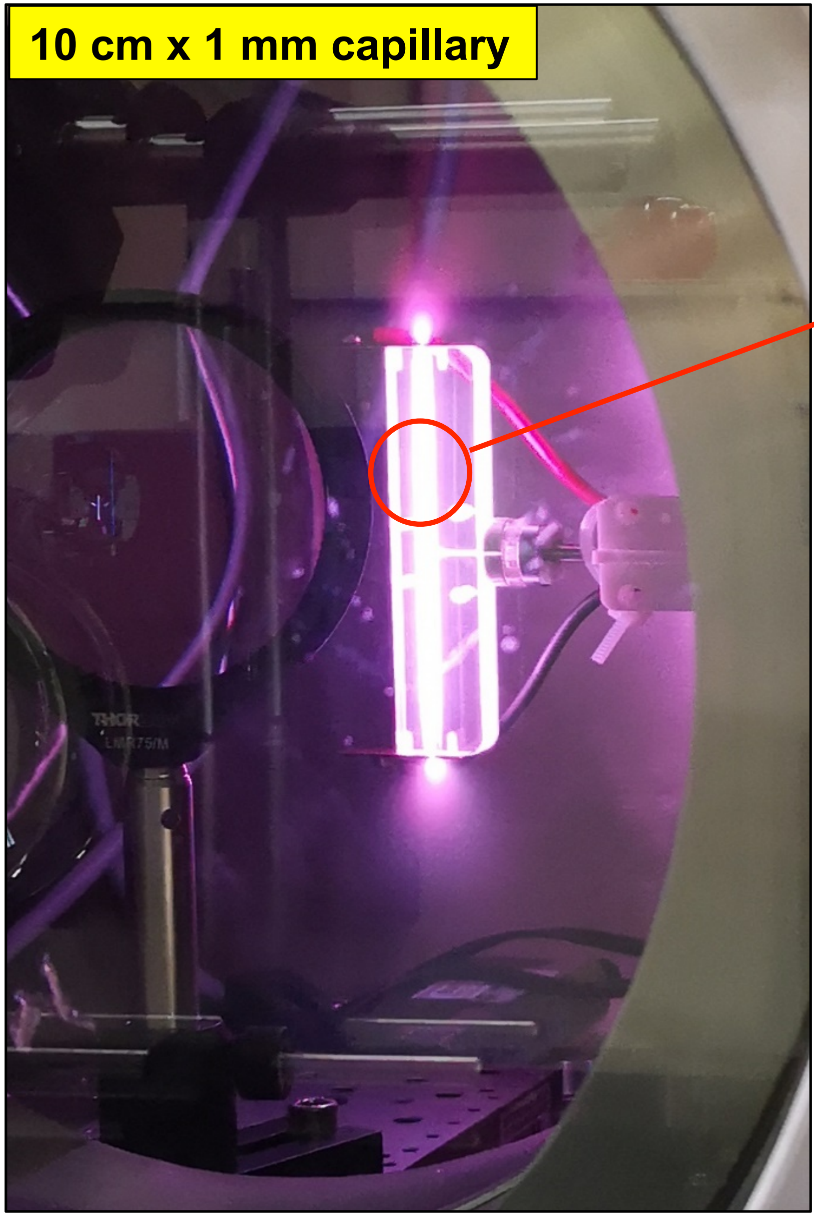
SPARC_LAB activities related to the EuPRAXIA R&D

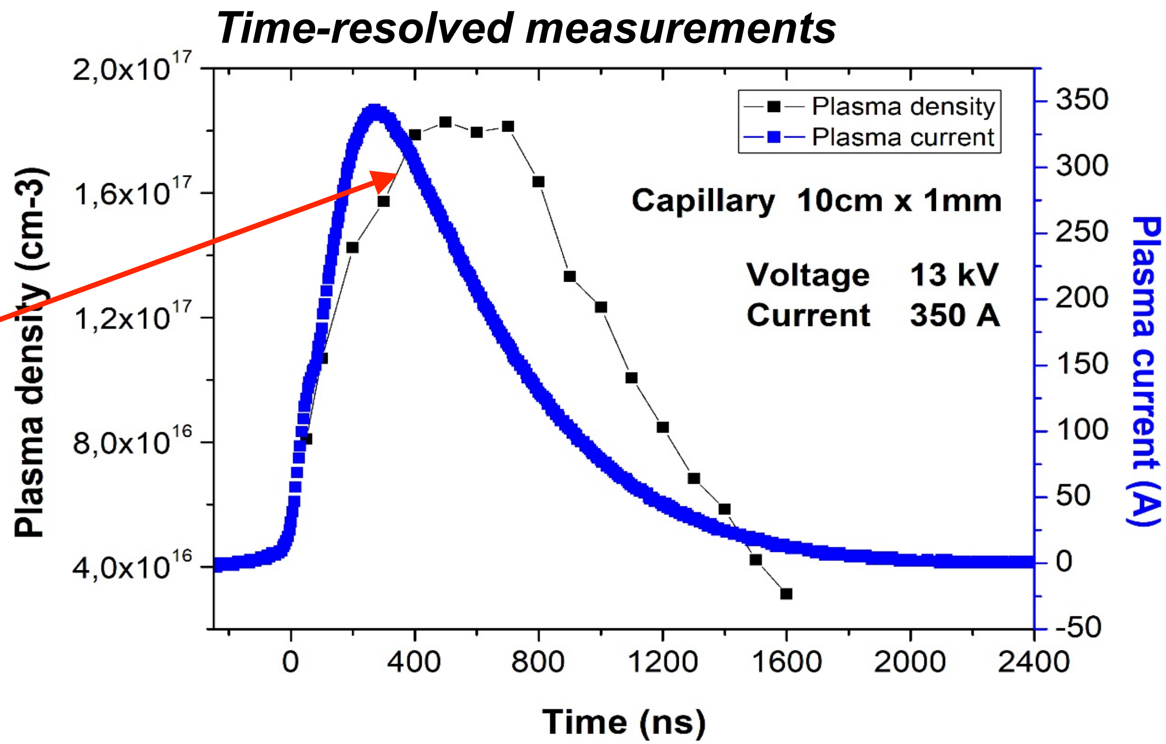
- Laser Comb technique
- S/C RF gun design and fabrication
- X-band test facility
- Velocity Bunching
- fs Synchronization
- Single shot diagnostics

- **Capillary characterization**
- Laser guiding
- Active Plasma Lens
- Plasma Dechirper
- PWFA acceleration experiments
- High transformer ratio studies

- LWFA with external injection
- Plasma driven FEL test

Characterization of longer plasma capillaries



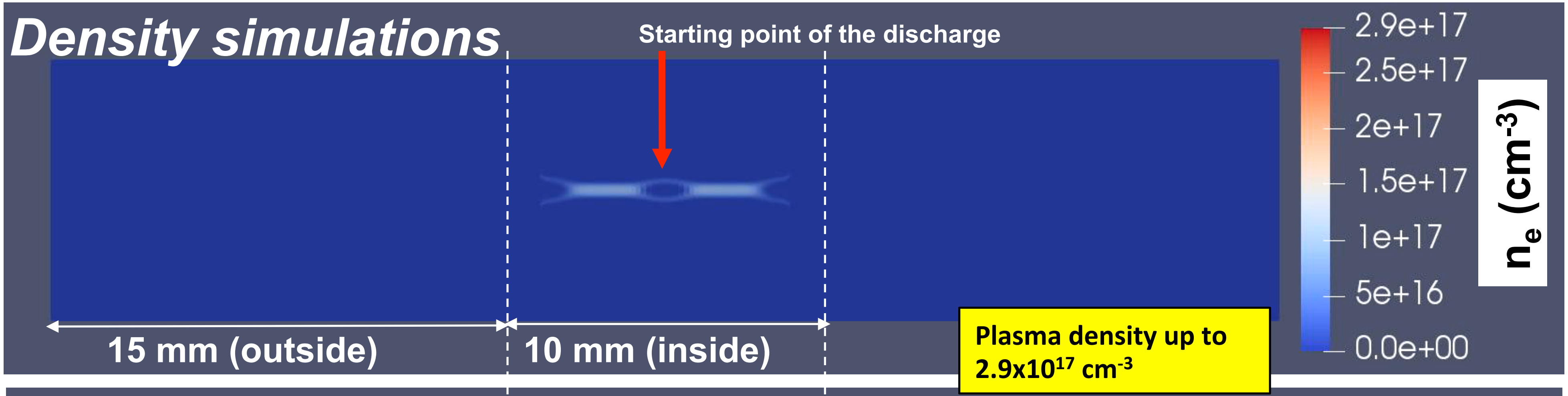


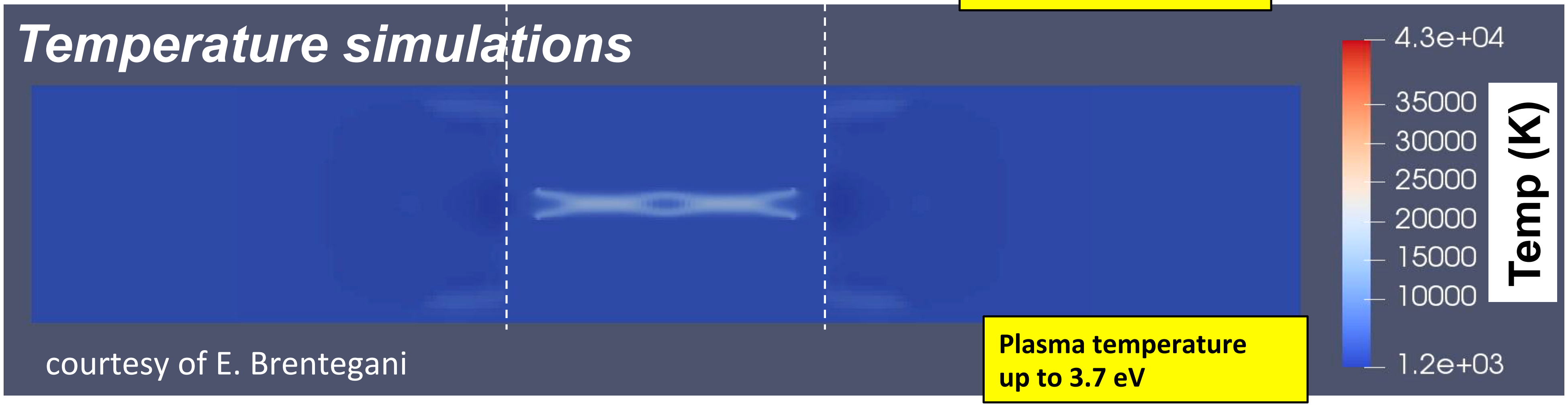
- Minimum voltage to obtain plasma discharge for 10 cm capillaries is around 11kV with 290 A (for 3 cm capillaries this values is around 6-7 kV with 170 A)

- The plasma density values reach around $2x10^{17}$ cm^{-3}

Plasma behaviour simulations

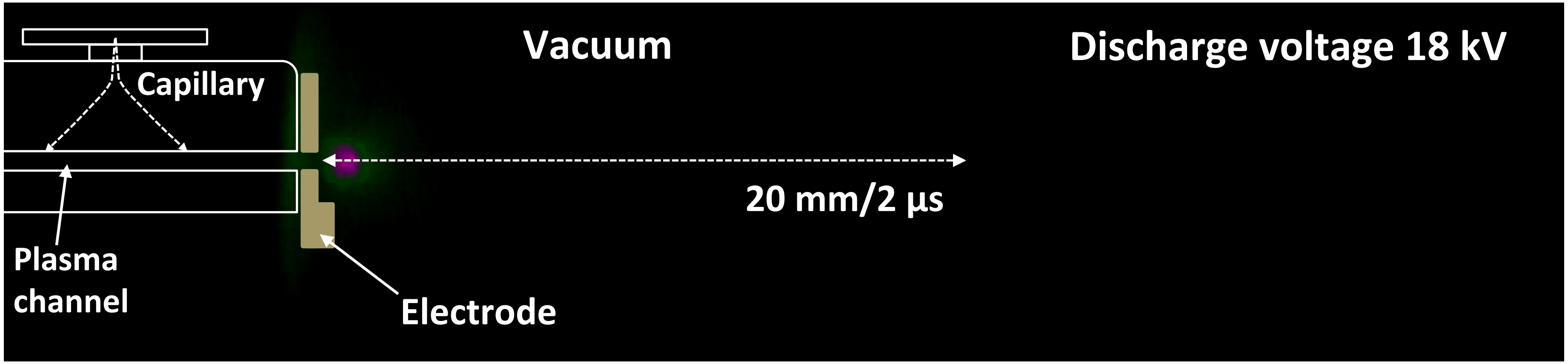
Results from computational model for two-dimensional axially symmetric capillary discharges: **1cm x 1 mm capillary at 18 kV and 240 A of the plasma current**

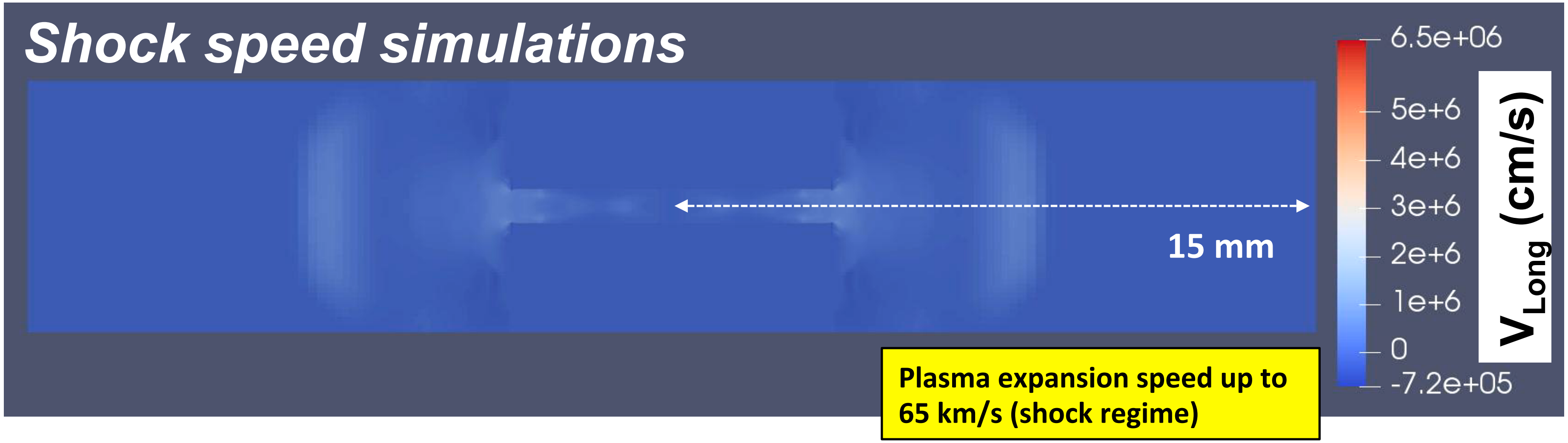




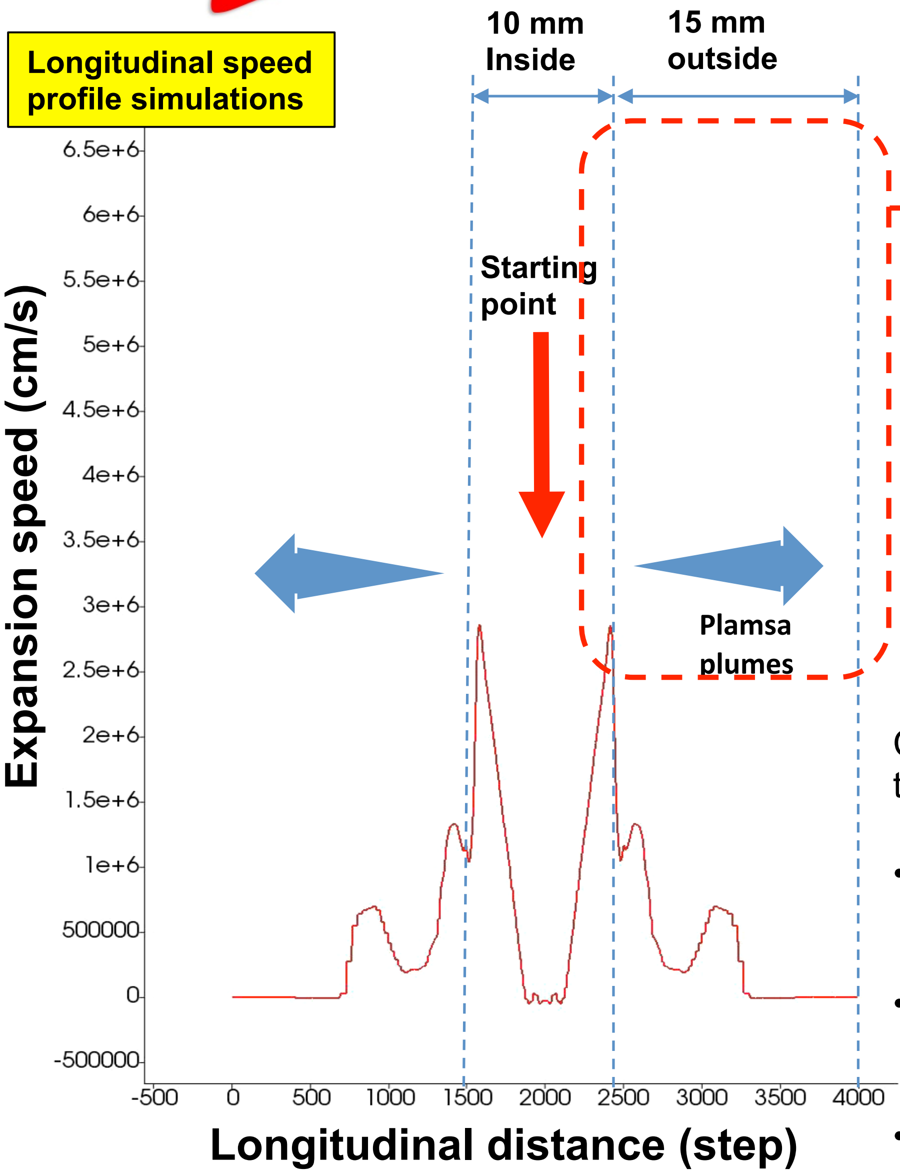
Plasma behaviour simulations

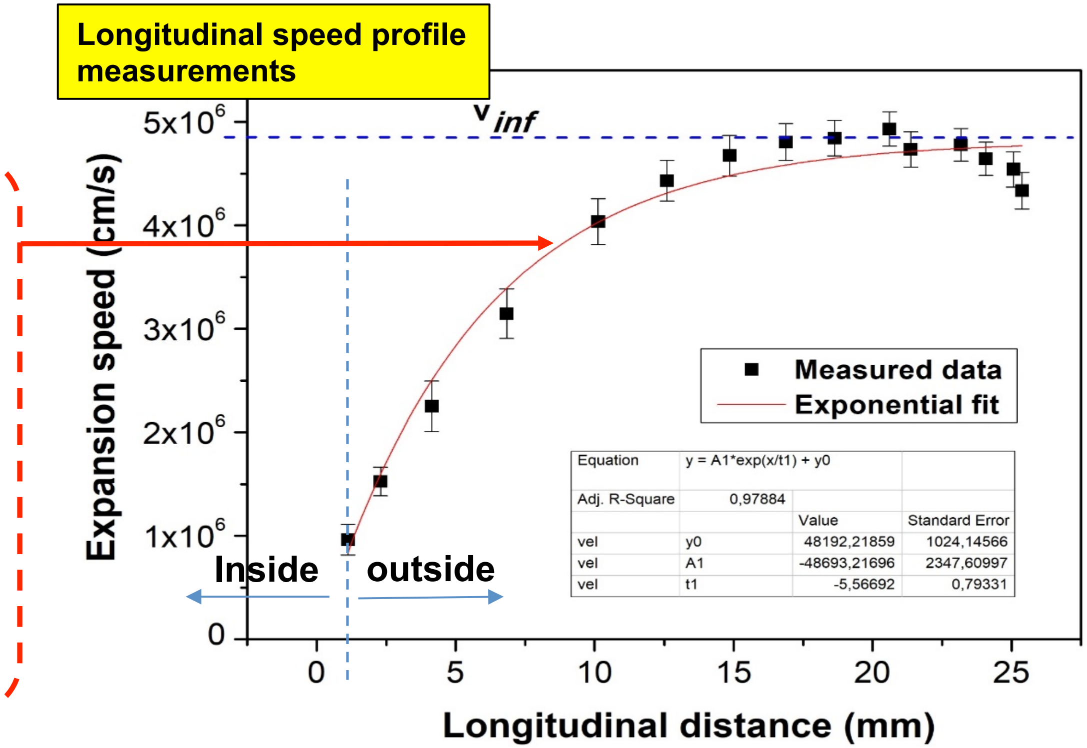
A validation of the computational model can be done by using our measurements about the shock regime formation at the ends of the capillary





Plasma behaviour simulations

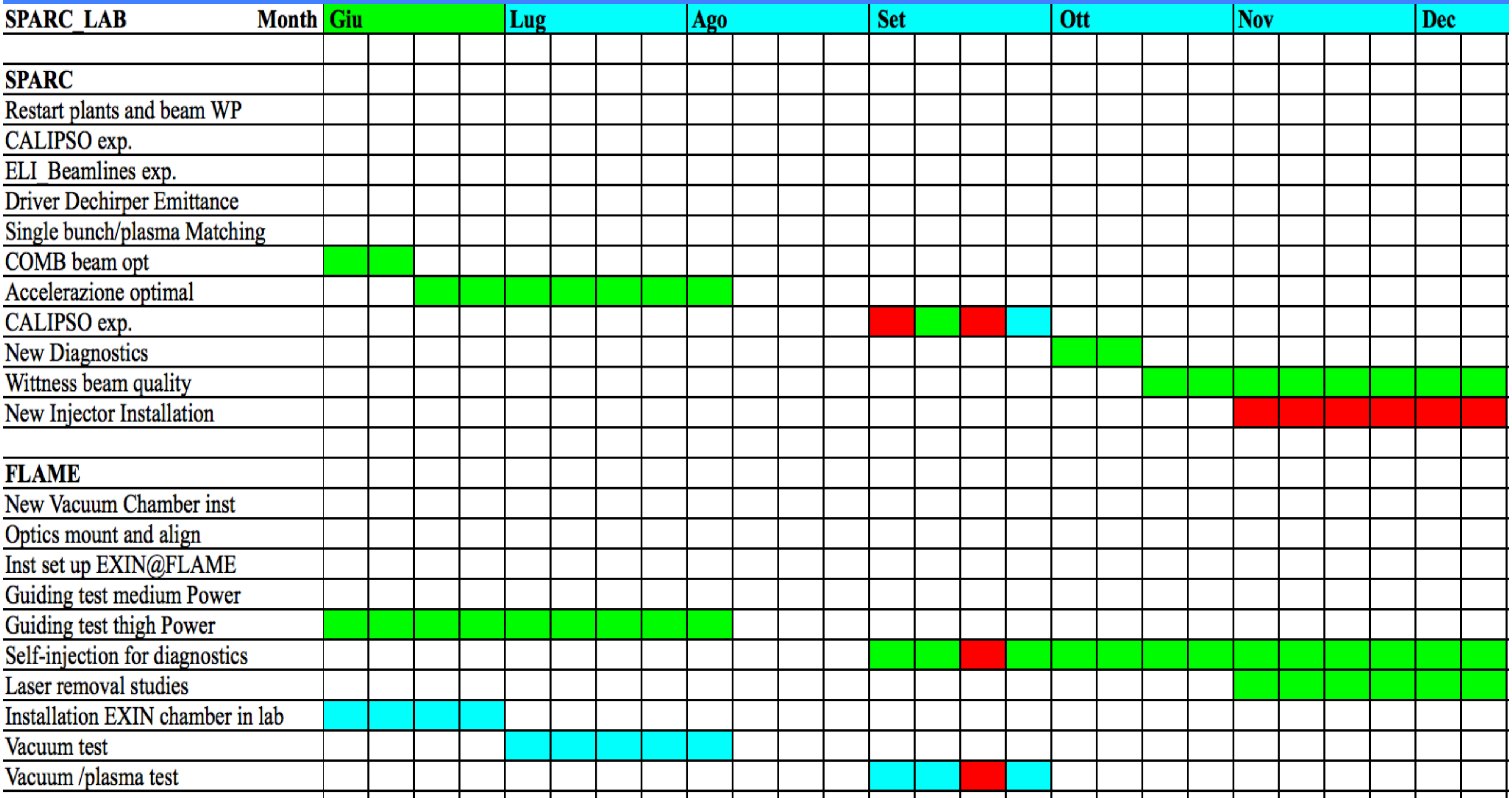




Comparison between simulations and measurements to validate the computational model:

- good agreement though the measured maximum velocity is lower than the simulated one (~20%)
- the inlets in the 2D-model are not included but there is only a starting point of the discharge
- the plume expansion outside the capillary fit very well with the real behaviour, in agreement with the shock wave formation (exponential growth of the speed)

SPARC_LAB Work Plan until end of 2019



Unione europea

REGIONE LAZIO

AVVISO PUBBLICO

POTENZIAMENTO DELLE INFRASTRUTTURE DELLA RICERCA PNIR PER ELEVARE IL TASSO DI INNOVAZIONE DEL TESSUTO PRODUTTIVO REGIONALE

SABINA

SOURCE of ADVANCED BEAM IMAGING for NOVEL APPLICATIONS

FELs OF EUROPE

INFN LNF

Istituto Nazionale di Fisica Nucleare


4th EAAC 15-22 September, 2019
Isola d'Elba
TALKS
BREAKFAST
COFFEE
MEALS
DISCUSSIONS
WAVE-BREAKING
https://agenda.infn.it/event/17304/