SPARC_LAB – EuPRAXIA@SL status

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On behalf of the SPARC_LAB – EuPRAXIA collaboration

LNF Scientific Committee Meeting, November 14, 2017

SPARC_LAB Recent Results

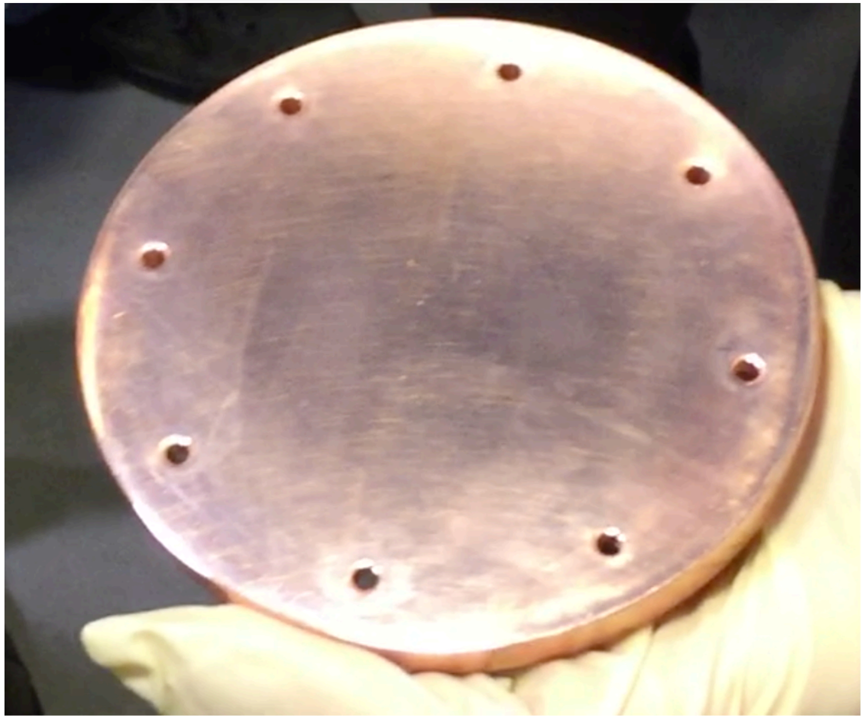
- New cathode cleaning technique
- C-band commissioning
- Plasma Lens studies
  - A. Marocchino et al., Experimental characterization of the effects induced by passive plasma lens on high brightness electron bunches, Appl. Phys. Lett. 111, 184101 (2017)
- Capillary R&D
- Diagnostics with Betatron Radiation
  - Curcio, A., et al. "Trace-space reconstruction of low-emittance electron beams through betatron radiation in laser-plasma accelerators." *Physical Review Accelerators and Beams* 20.1 (2017): 012801.

The Machining

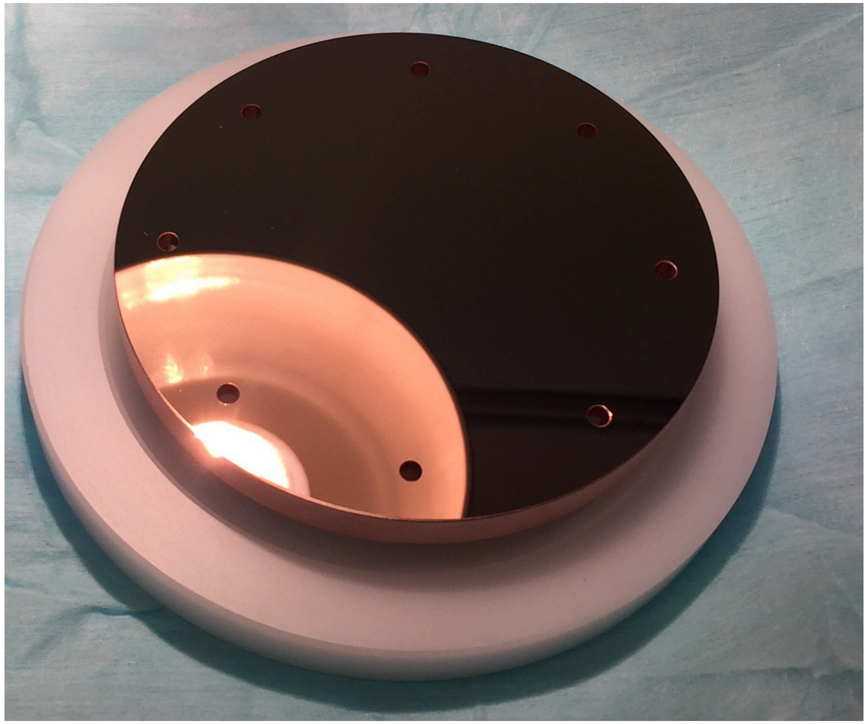
➤ The photocathode surface has been machined by means of diamond milling and blown with nitrogen. The machining has been done without the use of any oil or cooling fluid (dry machining).

BEFORE MACHINING

Our cathode time life was about 6 years

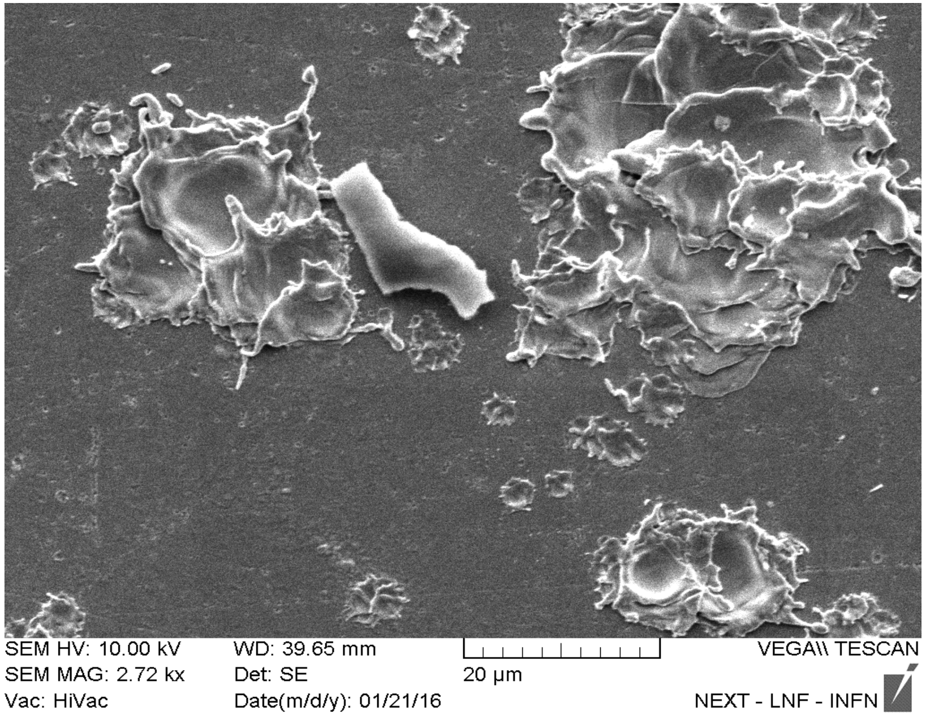


AFTER MACHINING

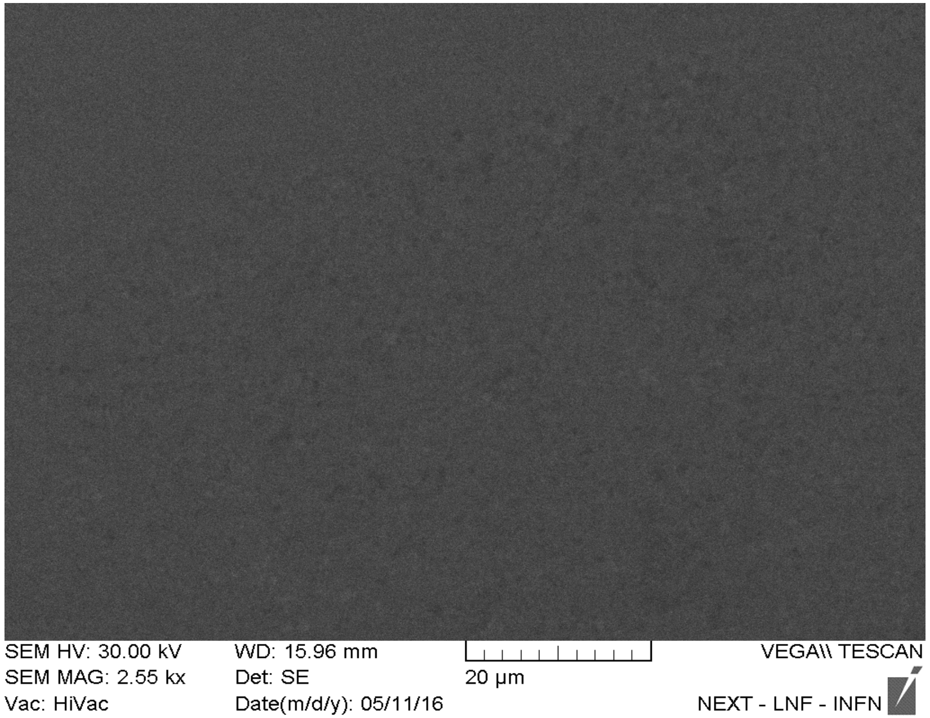


The Machining

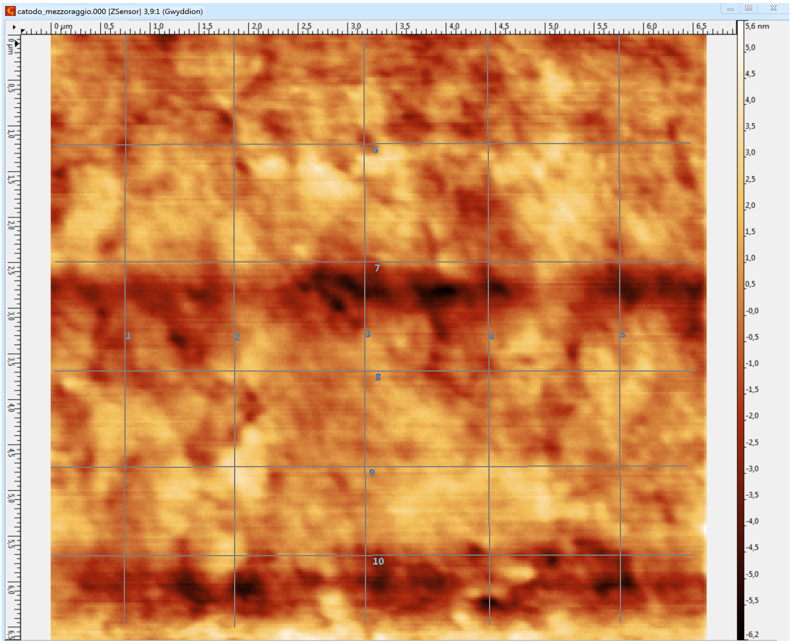
BEFORE MACHINING



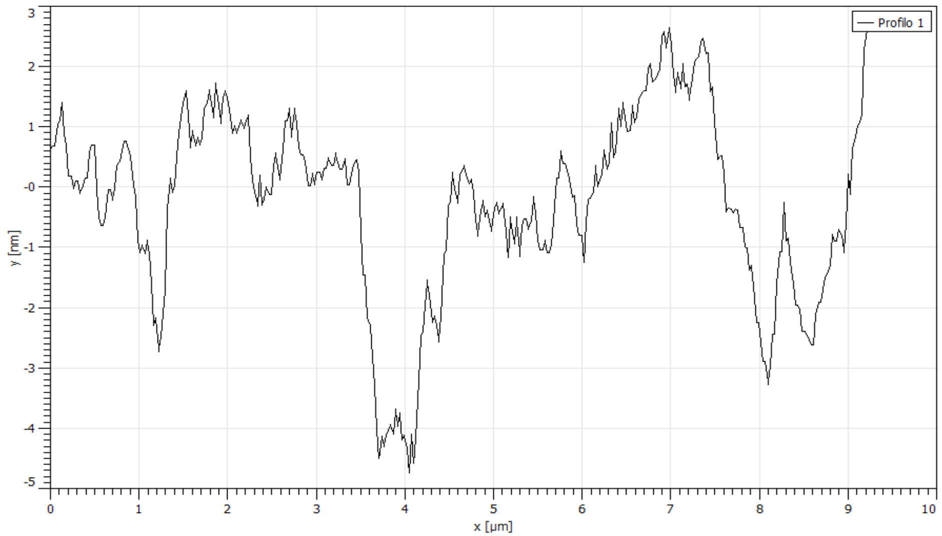
AFTER MACHINING

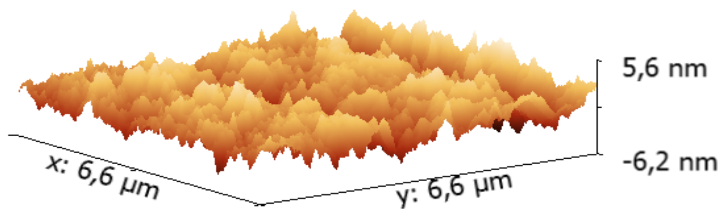


Atomic Force Mic. analysis after n-machining



Profile of image





Statistical parameters:

Min_value:	-6,16 nm
Max_value:	5,60 nm
Ra (Sa):	1,18 nm
Rms (Sq):	1,501nm

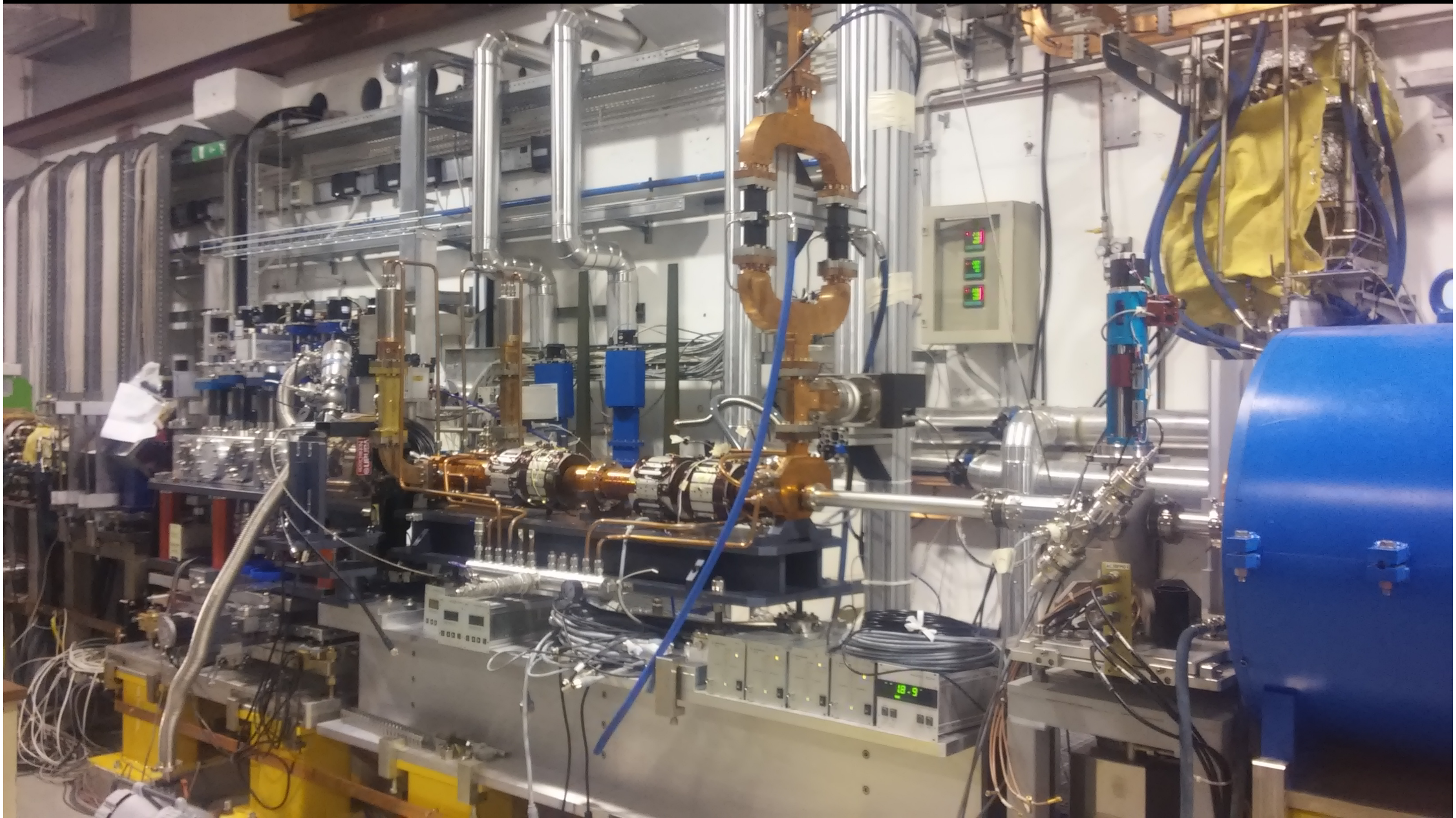
J. Scifo

Intrinsic Emittance measurements before and after n-machining

Parameters:
- Epeak= 84MV/m
- Working RF phase=30°
- Longitudinal length laser beam=5ps - FWHM (Gaussian profile)
- Bunch charge≅ 6pC

	Before n-machining		***After n-machining***	
E_acc (MV/m)	**ε_x(mmmrad)**	**ε_y(mmmrad)**	**ε_x(mmmrad)**	**ε_y(mmmrad)**
84	0.24±0.04	0.28±0.04	0.13±0.017	0.15±0.02

C-Band accelerating structure and PWFA chamber



Results of C-Band high power test and energy gain measurement

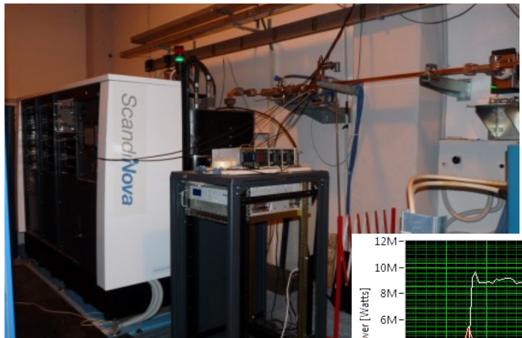
The high power test of the C-band has been performed in two windows between May 2017 and July 2017.

- Initially the klystron output was connected to a dummy load in order to test the system after the work performed on the ScandiNova modulator. With this set-up 8 MW of RF power have been reached at the klystron output with 150 us RF pulse length.

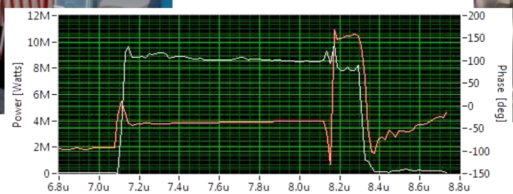
- In the second run the klystron was connected through the SLED to the accelerating structure. With the pulse compressor detuned and the power produced by the klystron directly feeding the structure: **15 MW of RF power have been reached with 200 ns pulse length** and **8 MW with 1.2 us**.

- Then the SLED has been tuned in order to run the klystron and the modulator at low power exploiting the power gain factor of the pulse compressor: **9 MW of RF power** at the klystron output have been reached with **1.2 us pulse length**, giving **26 MW peak power at the input of the accelerating structure**.

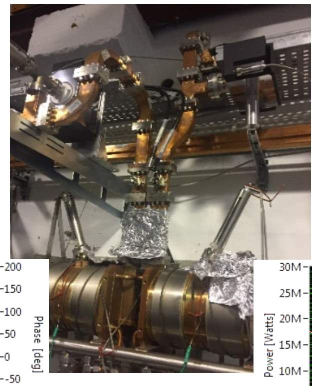
1) Pulsed Solid State Modulator and Klystron



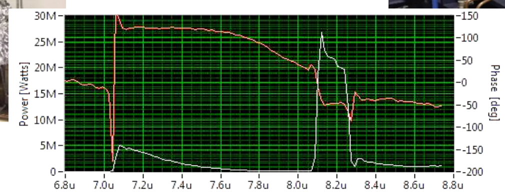
9 MW
1.2 us



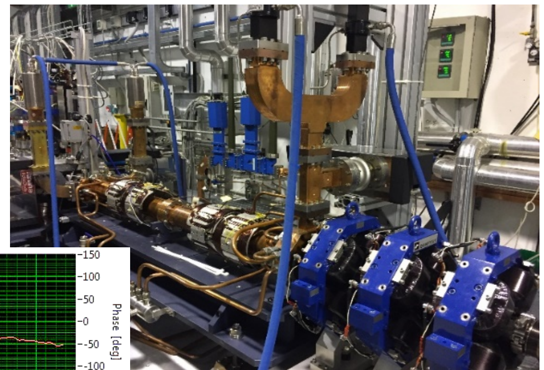
2) SLED pulse compressor



26 MW
200 ns



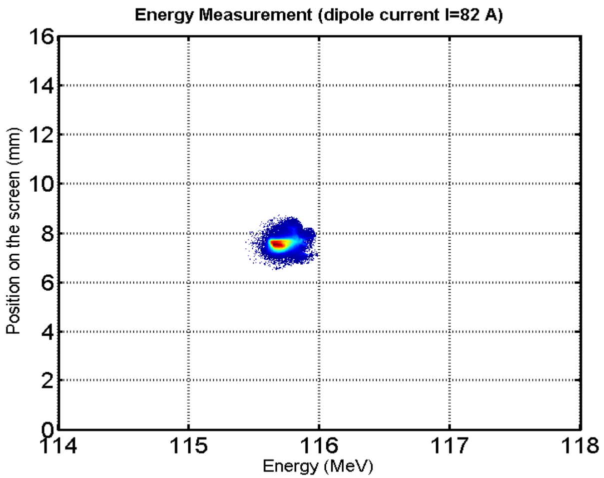
3) C-band accelerating structure



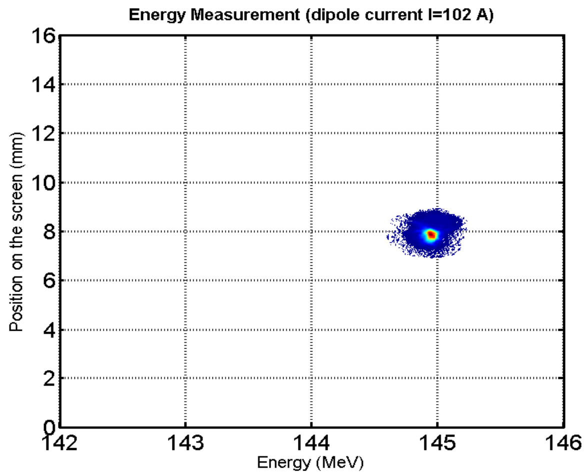
Results of C-Band high power test and energy gain measurement

With this last Set-Up an electron **energy gain of about 30 MeV** has been measured.

C-band RF off



C-band RF on



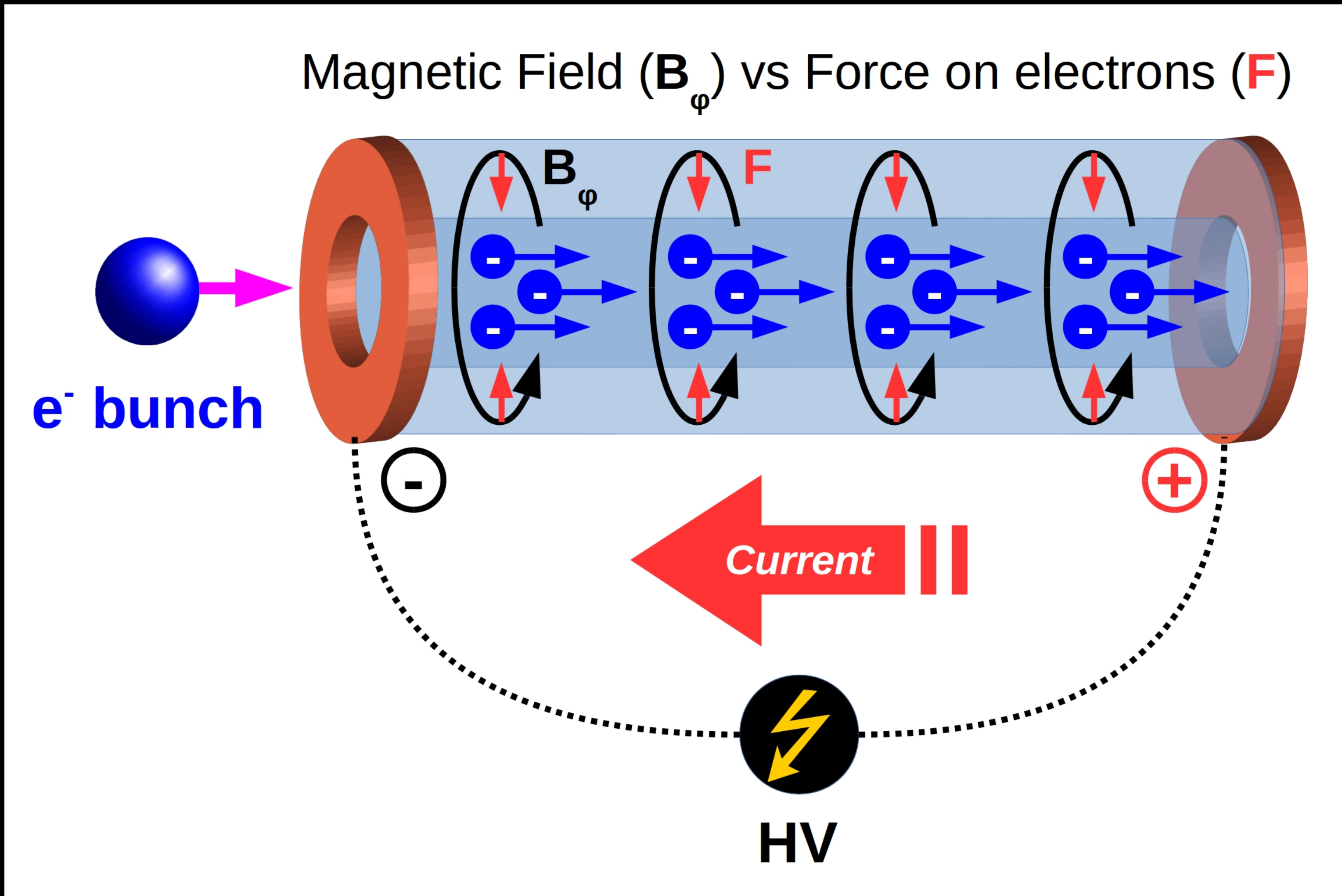
Future development:

- Further tests are foreseen in November/December 2017.
- To increase further the power and to reach the final nominal gradient in the C-band structure (50 MeV energy gain) a ScandiNova intervention has been requested to fix a couple of troubles we still have on the modulator.

Acknowledgements:

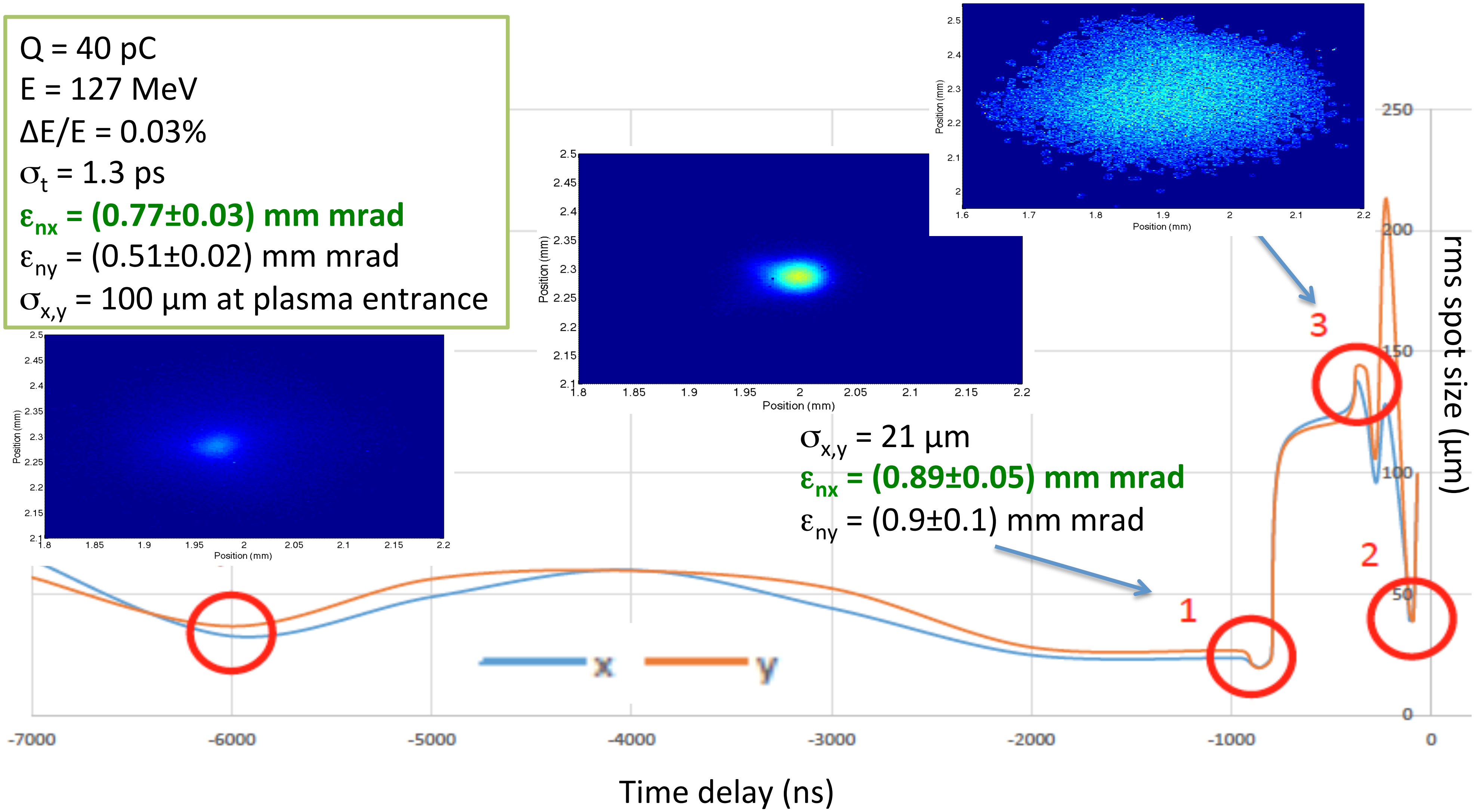
D. Alesini, M. Bellaveglia, B. Buonomo, F. Cardelli, R. Ceccarelli, P. Chimenti, R. Clementi, A. Gallo, C. Di Giulio, R. Di Raddo, L. Foggetta, L. Piersanti, L. A. Rossi, S. Strabioli on behalf of the Linac, RF and Vacuum groups.

Active Plasma Lens



Active Plasma Lens Experiment:
3 cm long, 0.5 mm radius, sapphire capillary

Q = 40 pC
E = 127 MeV
$\Delta E/E = 0.03\%$
$\sigma_t = 1.3$ ps
$\varepsilon_{nx} = (0.77\pm0.03)$ mm mrad
$\varepsilon_{ny} = (0.51\pm0.02)$ mm mrad
$\sigma_{x,y} = 100$ µm at plasma entrance



Passive Plasma Lens Experiment

Over-dense regime

The plasma is produced by a H_2-filled discharge capillary

Passive lens effect also due to the plasma jets at both edges of the capillary

Study of the effect on emittance

Beam parameters

$E = 127$ MeV

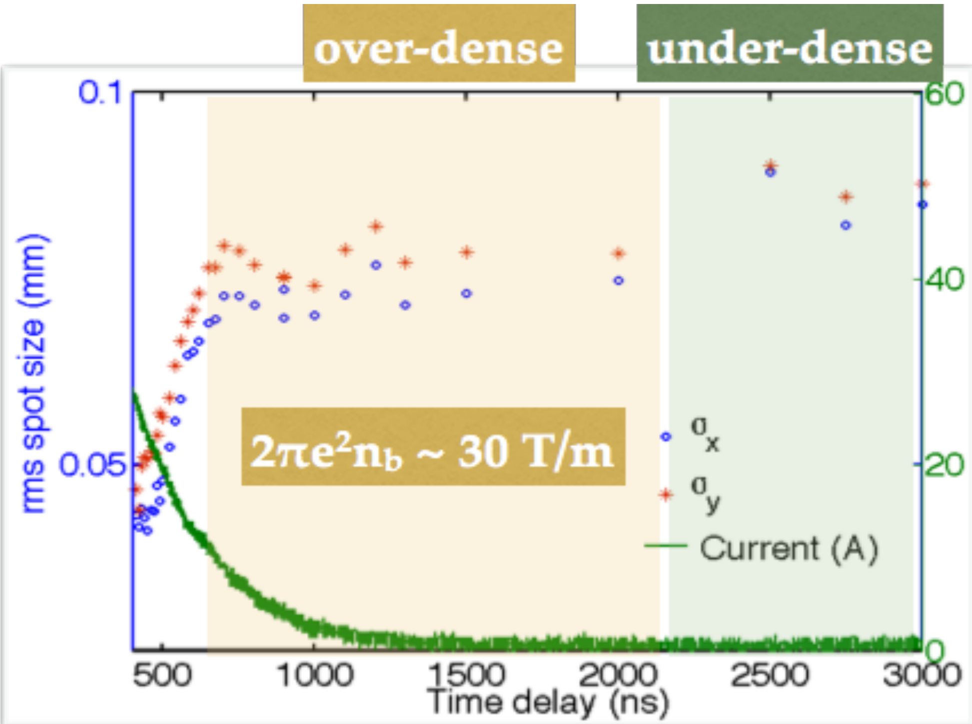
$\Delta E/E \sim 0.2\%$

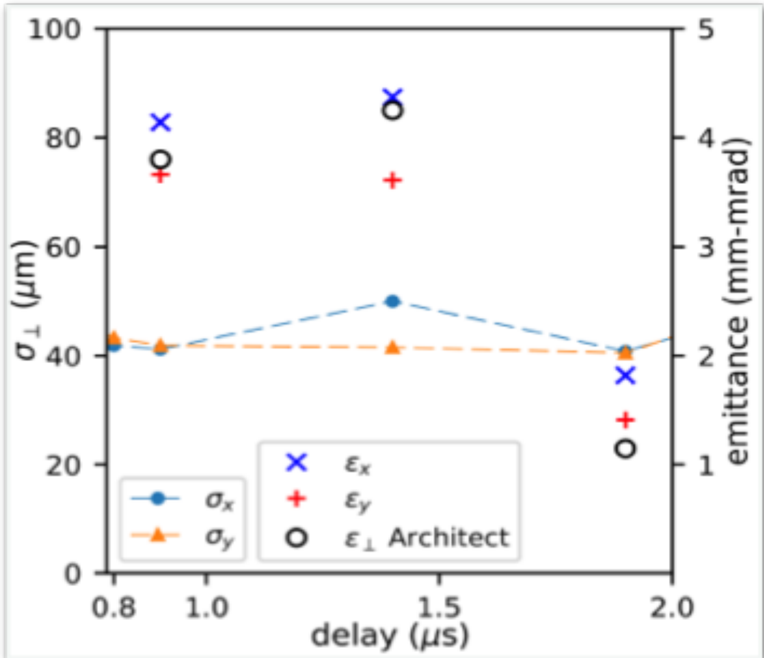
$Q \sim 50$ pC

$\sigma_t \sim 1$ ps

$n_b \sim 6\ 10^{12}$ cm^{-3}

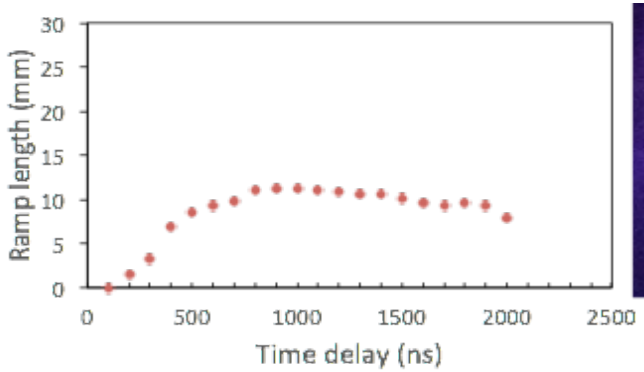
$n_p \sim 1.2\ 10^{15}$ cm^{-3}

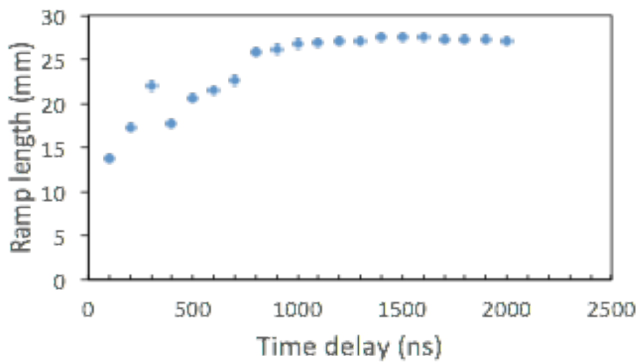




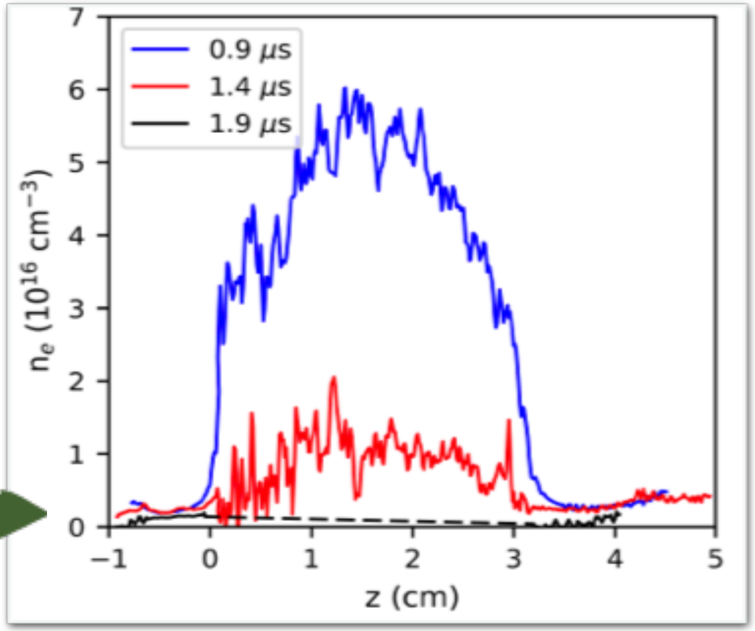
A. Marocchino et al., Appl. Phys. Lett. **111**, 184101 (2017)

Characterization of plasma jets





~ 3 10^{15} cm^{-3}

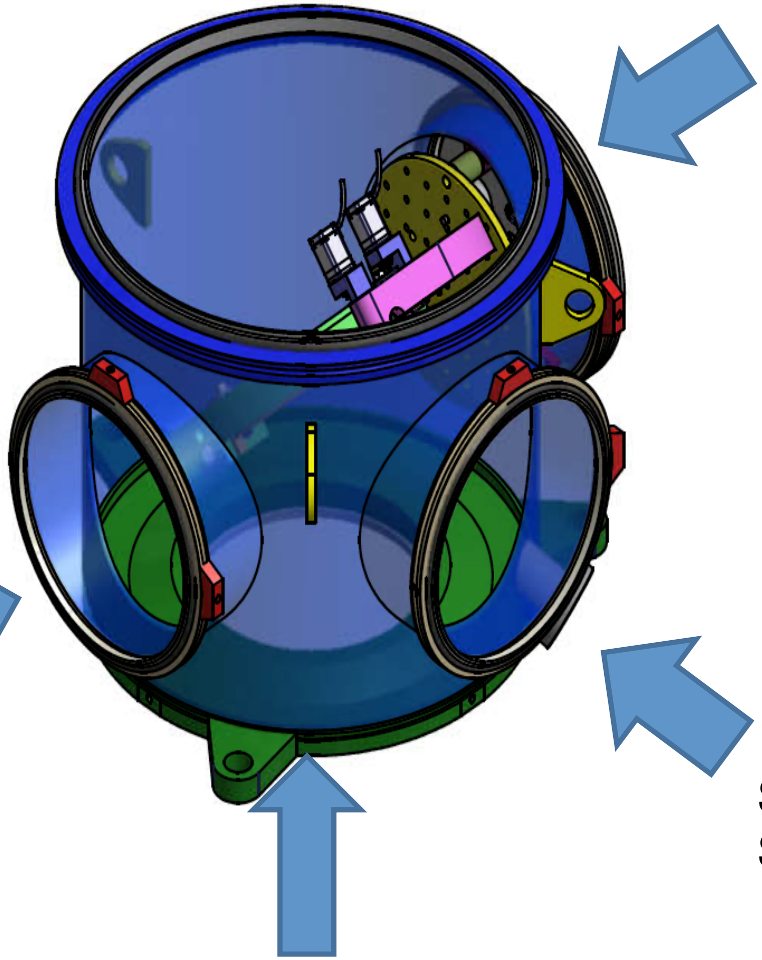


Courtesy of
F. Filippi and A. Biagioni

A. Marocchino et al., Appl. Phys. Lett. **111**, 184101 (2017)

New experimental chamber in the Plasma_Lab

We mounted a new experimental chamber for further plasma studies, in particular plasma target for acceleration experiments.

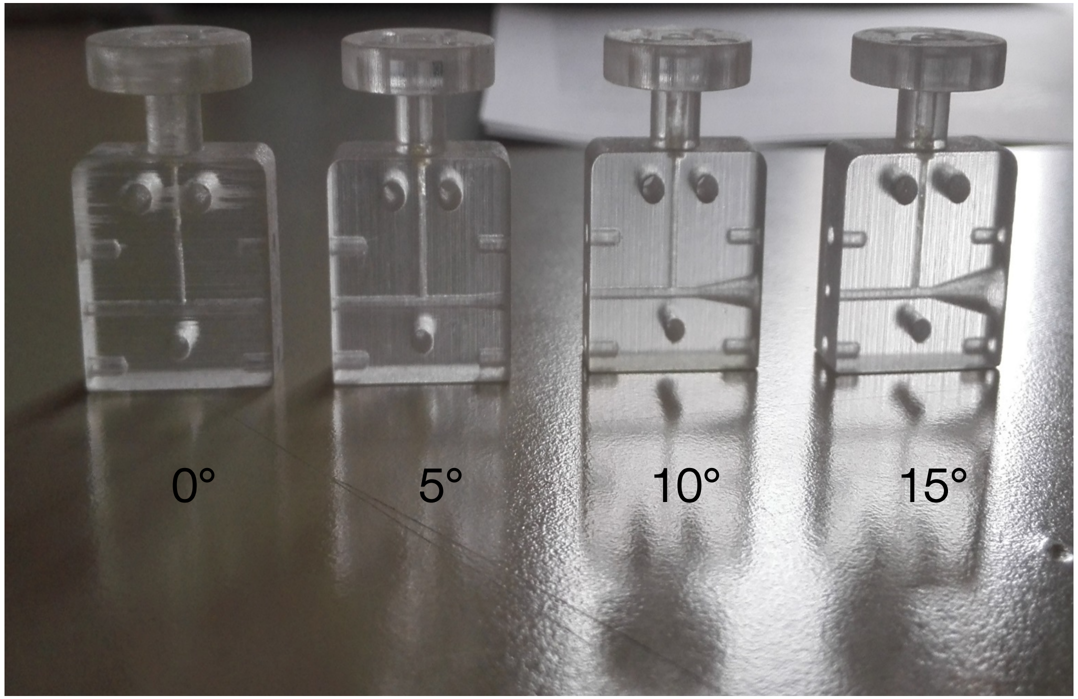


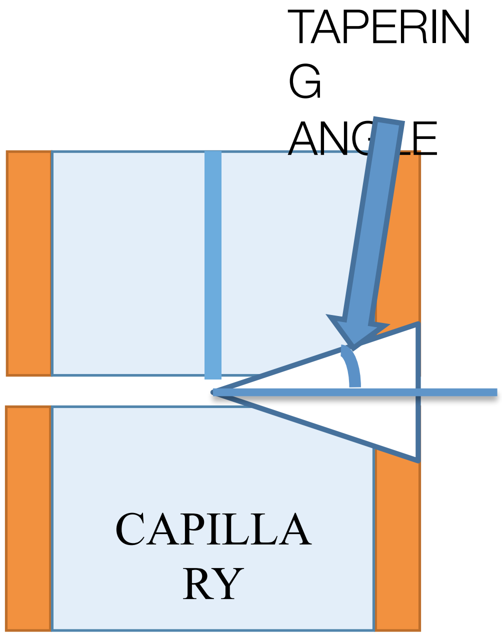
Courtesy of R. Sorchetti

Tapered capillaries

Local control of the plasma density is required to match the laser/electron beam into the plasma. Tapering the capillary diameter is the easiest way to change locally the density.

TAPERING OF:





Next experimental campaign in Plasma Lab.

3. Simulations: preliminary results of 2D simulations

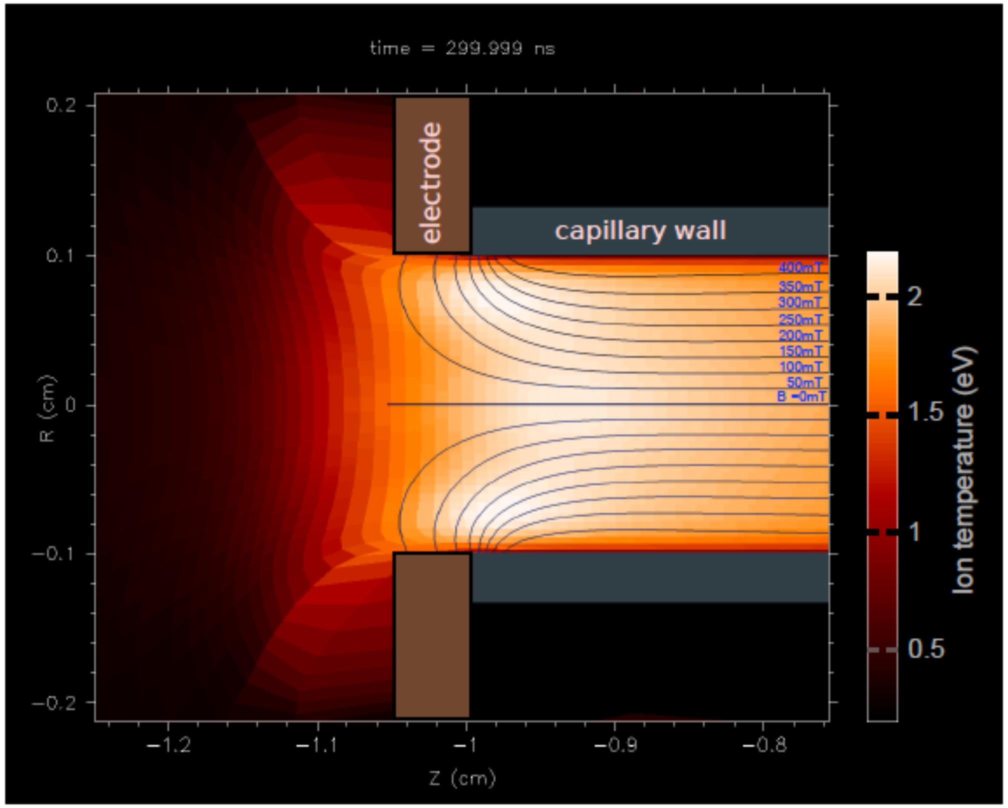
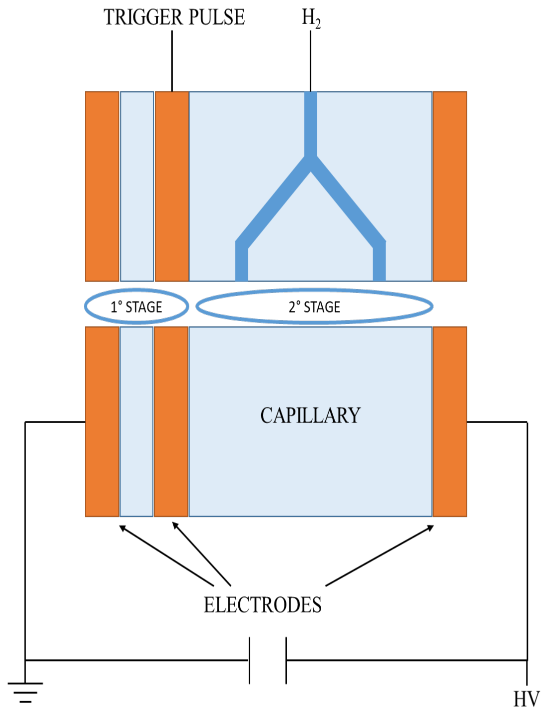


Figure: Particular of the plasma temperature (colored map) and azimuthal magnetic field (contour lines) in proximity of the left electrode at 300ns from the start of the discharge.

- It is possible to compute the magnetic field as post-processing
- Maps of other relevant quantities can be obtained
- The temperature reached by the plasma seems to be in qualitative agreement with what expected

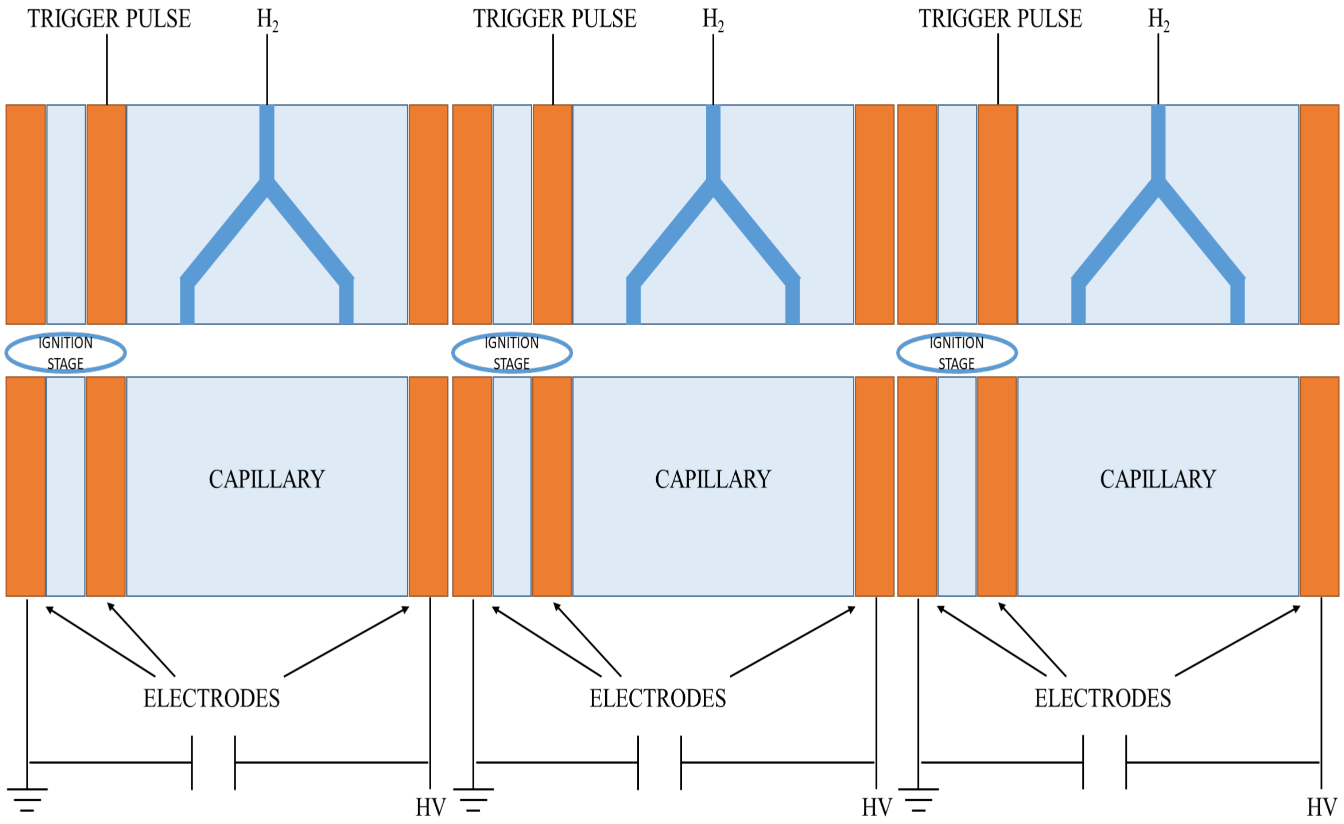
Plasma source

We pre-ionize the capillary with a preformed plasma prior the main discharge. The initial plasma is formed in a short primary capillary by a high voltage pulse discharge. Part of this plasma and free electrons expanding into a long capillary that is connected to a high voltage capacitor. Since the discharge process follows the Paschen law, the breakdown threshold of the long capillary is lowered and the discharge can develop.
This strategy allow to ionize long capillaries with reasonable applied voltage in controlled and homogeneous way.



Plasma source

This scheme can be reproduced for tens-of-centimetre capillaries. This single unit can be integrated simply by adding more units obtaining up to tens of centimetre capillaries homogenously ionized and controlled independently one to each other, leading to the desired length of plasma (almost 30 cm) with the proper density (10^{17} cm^{-3}) required for this project.



Conclusions

- We are going to investigate the possibility to implement up to tens of centimeters long capillaries for future plasma based accelerators.

- We have studied the possibility to use hydrogen-filled double capillaries to reduce the breakdown threshold and ensures long plasma channel. This solution will allow for multi-staging increasing the length of the plasma channel.

- Further studies are ongoing also for LWFA Laser guiding.

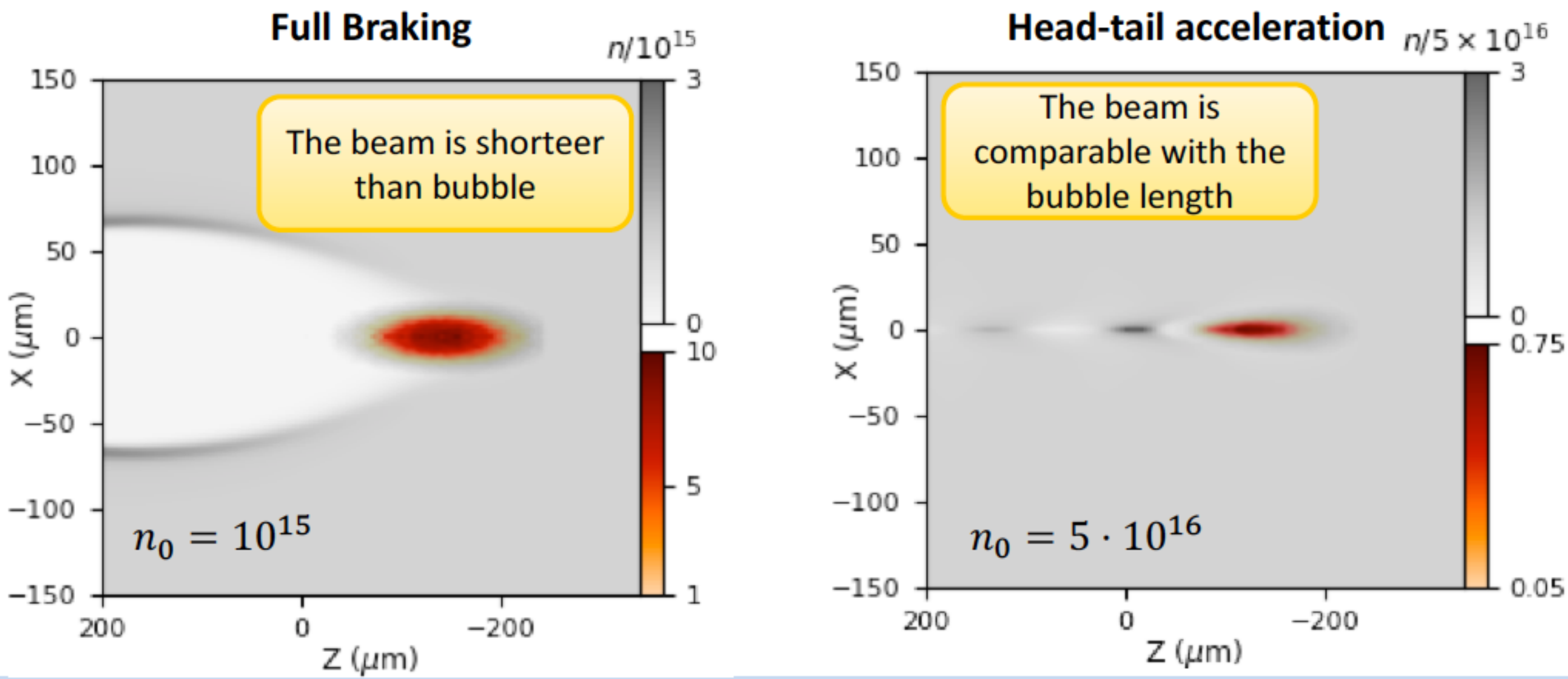
Plasma HEAD-TAIL acceleration experiment

1: bunch generate a bubble PWFA basic concept
2: the tail of the bubble feels its own wake

3.1: the bunch is shorter than the bubble **FULL BRAKING**

3.2 the bunch is comparable with the bubble length **HEAD-TAIL Acceleration**

Q=200pC



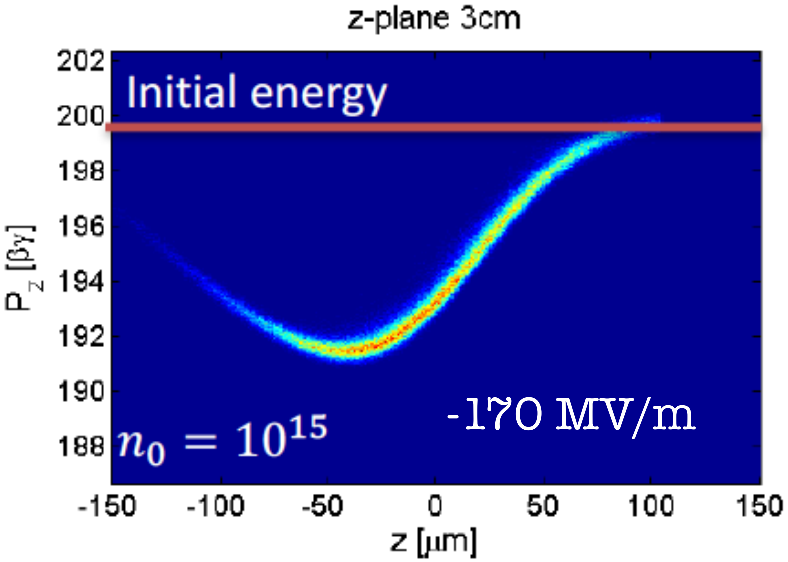
Plasma HEAD-TAIL acceleration experiment

Bunch parameters at plasma entrance

$$\sigma_z = 50\mu m$$
$$\sigma_r = 10\mu m$$
$$\varepsilon_{x,y} = 3\mu m$$
$$\sigma_E = 0.1\%$$

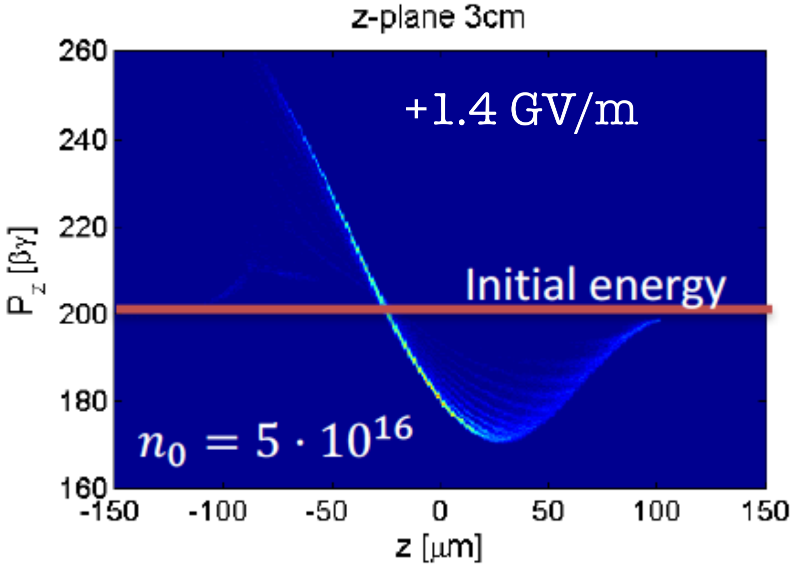
Full Braking

$$n_0 = 10^{15}$$

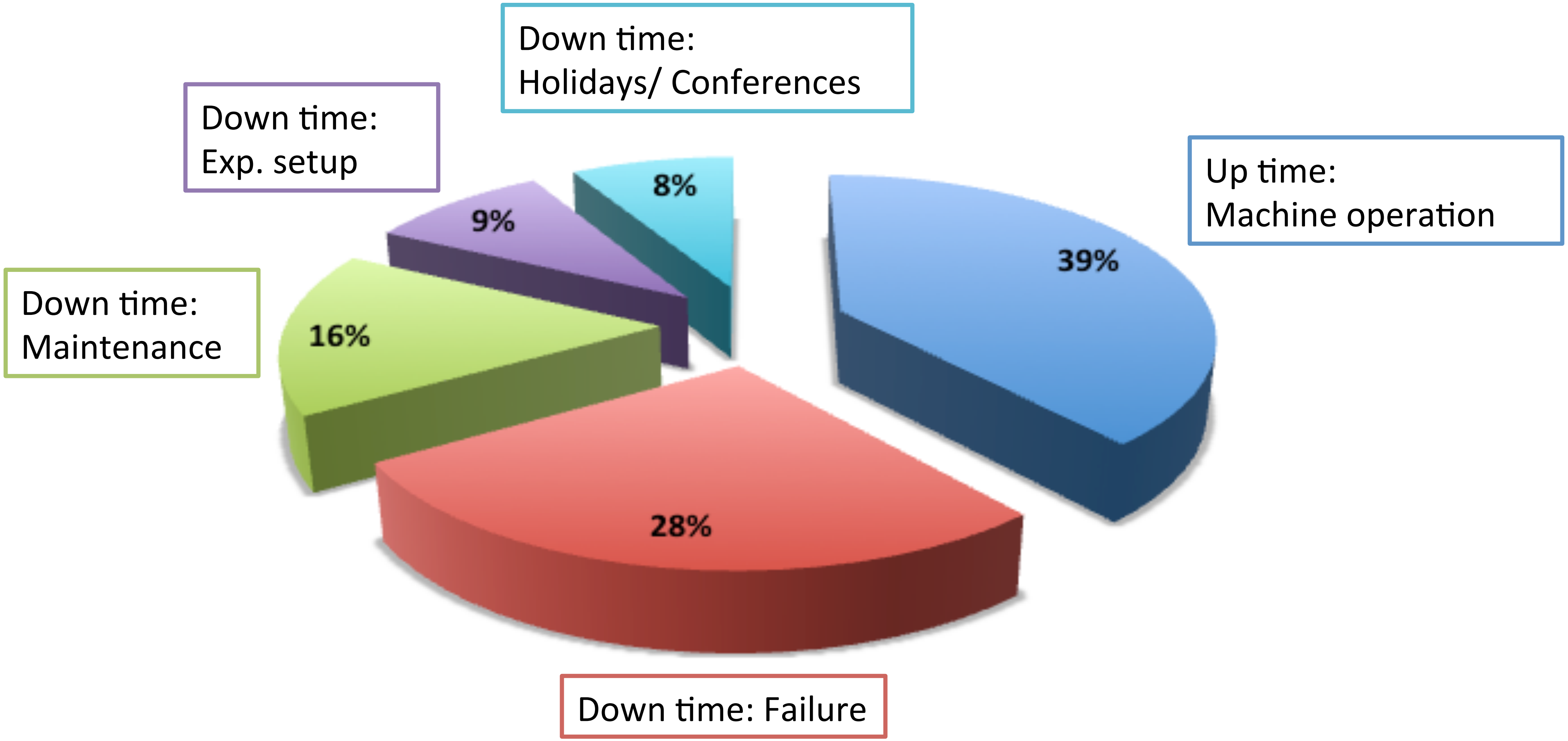


Head-tail acceleration

$$n_0 = 5 \cdot 10^{16}$$

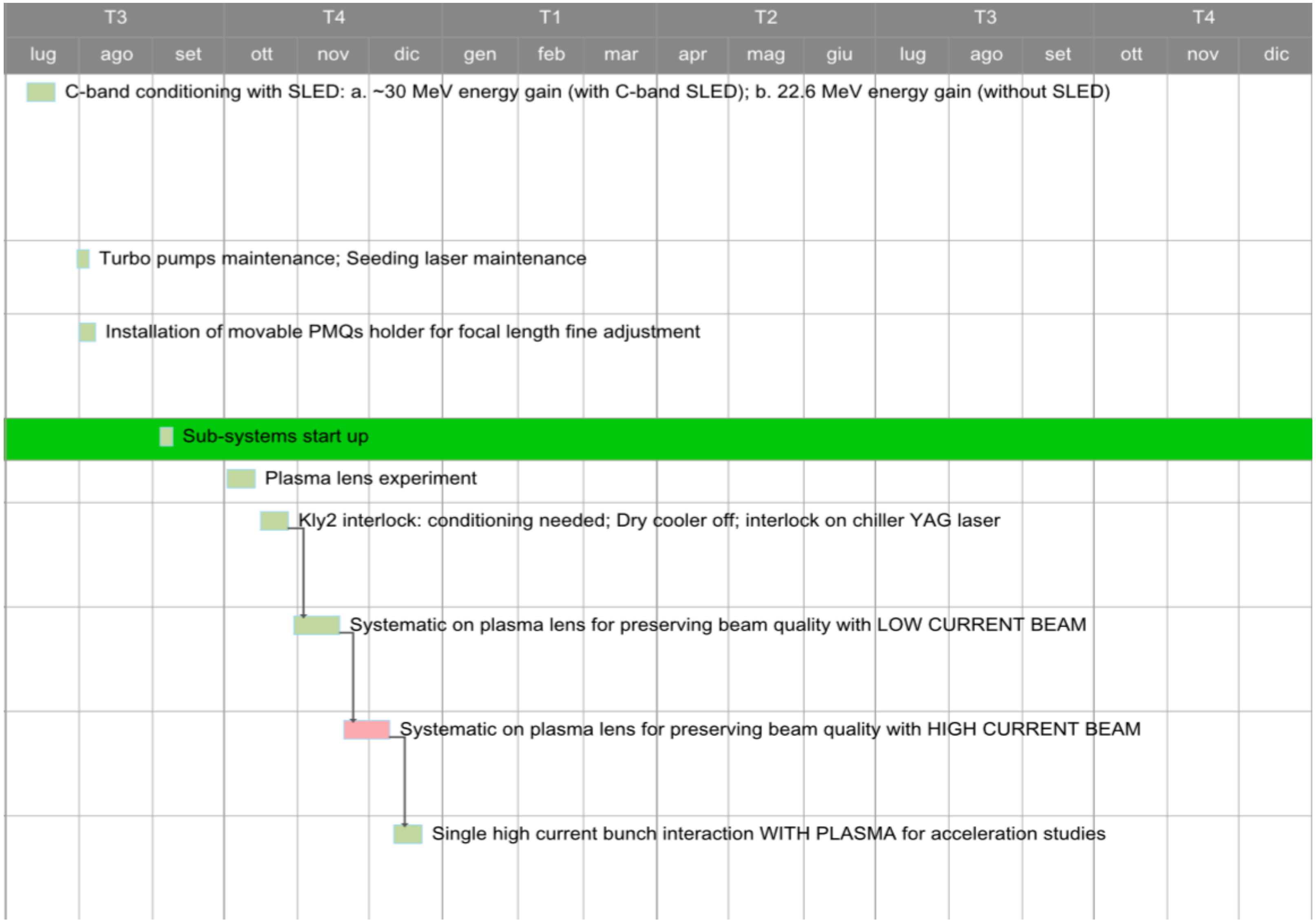


Up and Down Time 2017



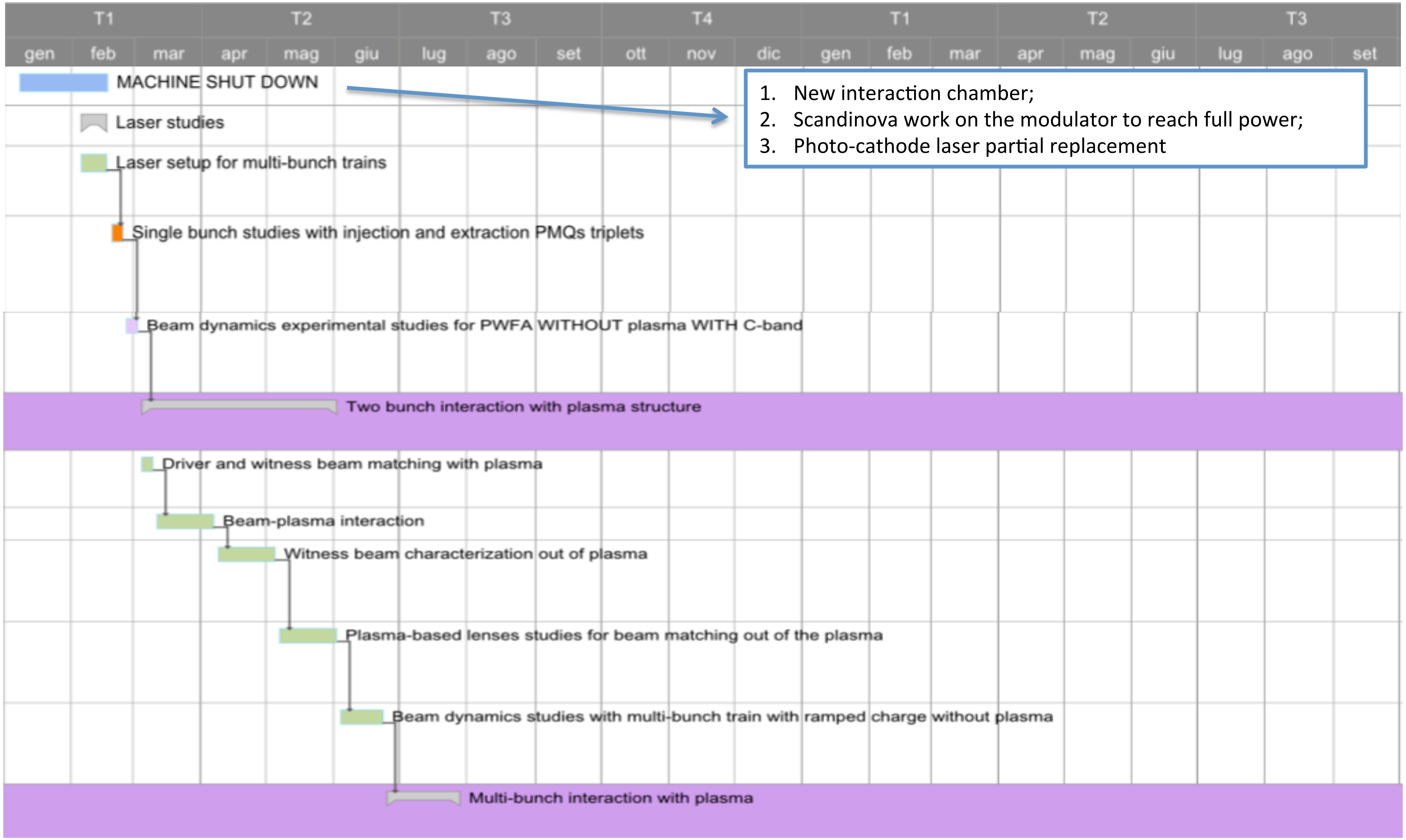
Percentage of the working days in 2017 up to Oct. 31st

Activity in the 2nd half of 2017

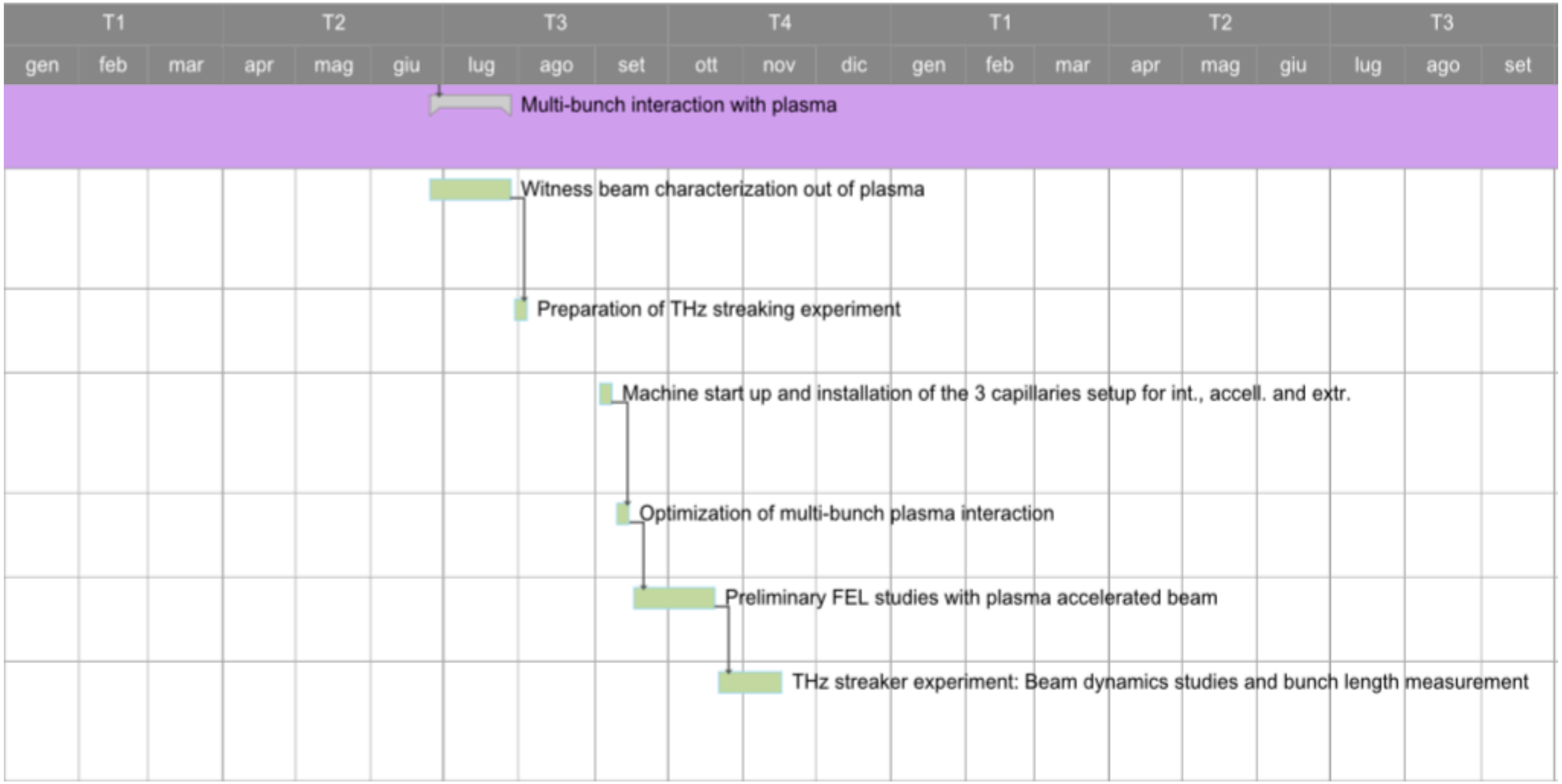


New Vacuum Chamber to be installed in January

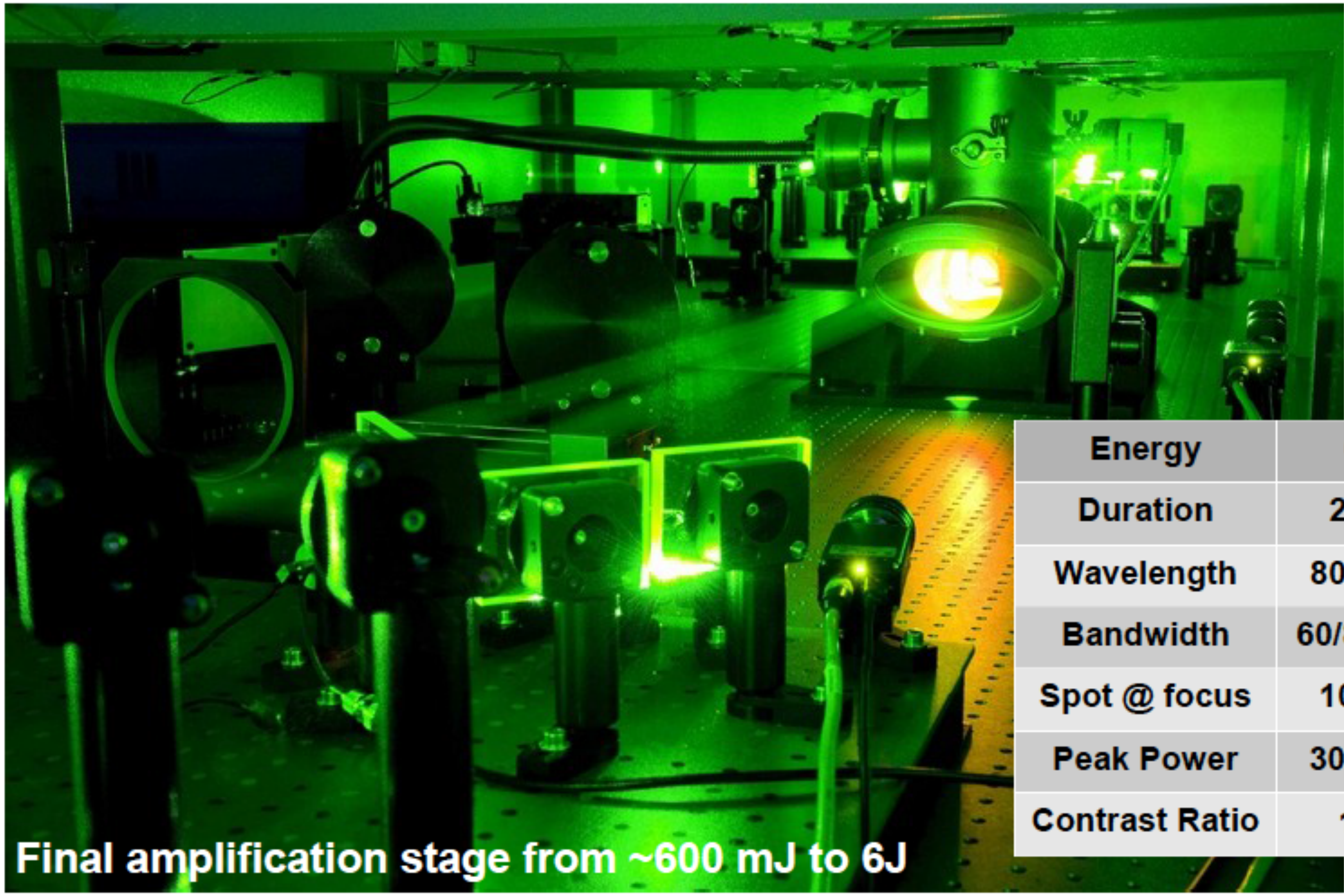
Planning 1st half of 2018



Planning 2nd half of 2018



Ti:Sa FLAME laser

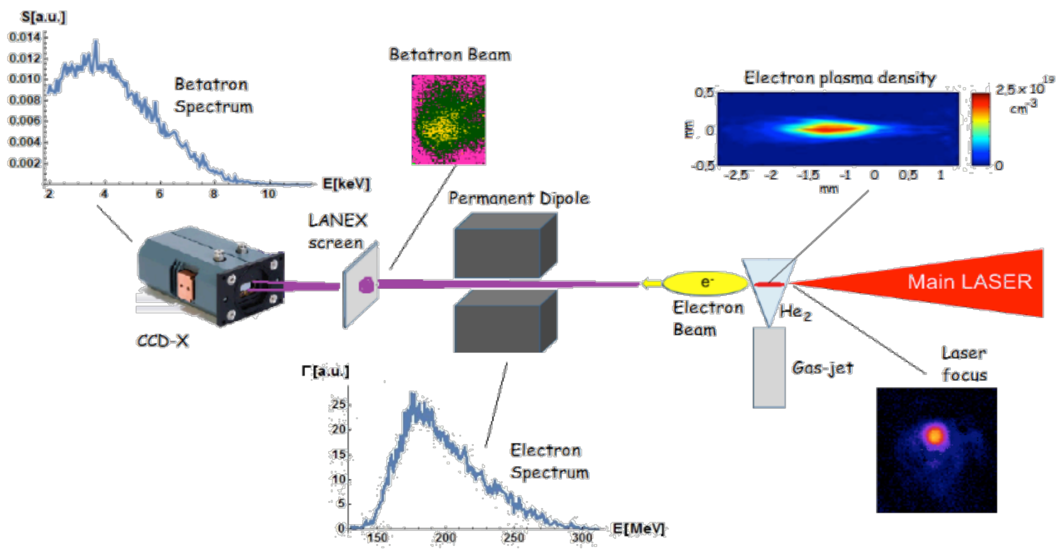


Energy	6 J
Duration	23 fs
Wavelength	800 nm
Bandwidth	60/80 nm
Spot @ focus	10 µm
Peak Power	300 TW
Contrast Ratio	10^{10}

Emittance measurement using Betatron Radiation

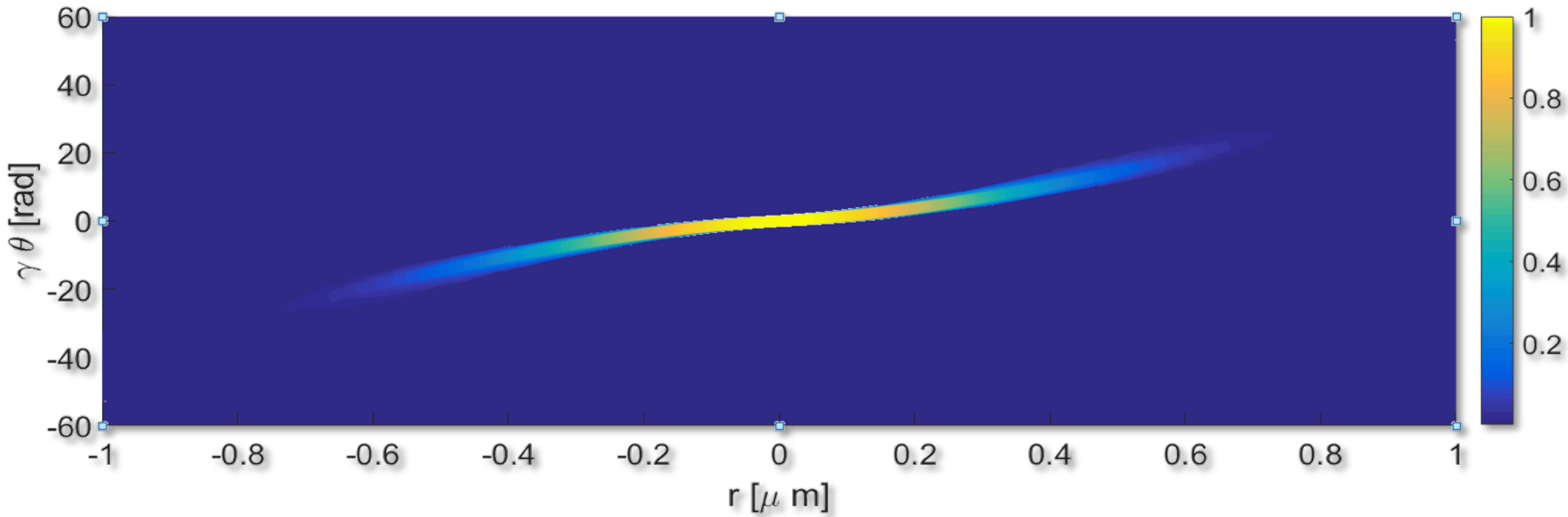
- First measurement of the emittance including the correlation term
- The <u>beam profile</u> is retrieved not simply the average dimensions
- An expression is given for the correlation function between the betatron oscillation amplitude and the divergence of the single accelerated electrons, i.e. the angle with respect the acceleration axis, in order to obtain the distribution of the electron divergences.

1 J
30 fs (FWHM)
10 μm diameter focus,
a0 ~ 4.4
$n_e=(8\pm1)10^{18}$ cm^{-3}



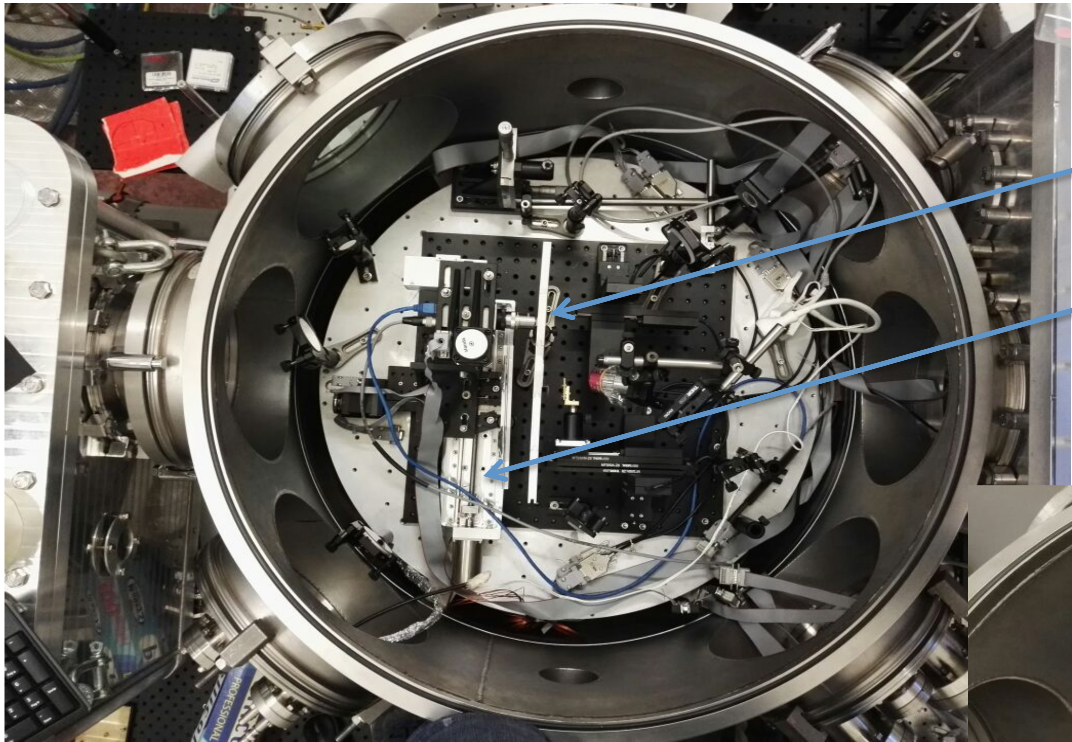
Curcio, A., et al. "Trace-space reconstruction of low-emittance electron beams through betatron radiation in laser-plasma accelerators." *Physical Review Accelerators and Beams* 20.1 (2017): 012801.

Transverse Phase space reconstruction



- Normalized rms emittance (correlated): 0.6 mm mrad
- Normalized rms emittance (non correlated, upper limit): 1.6 mm mrad

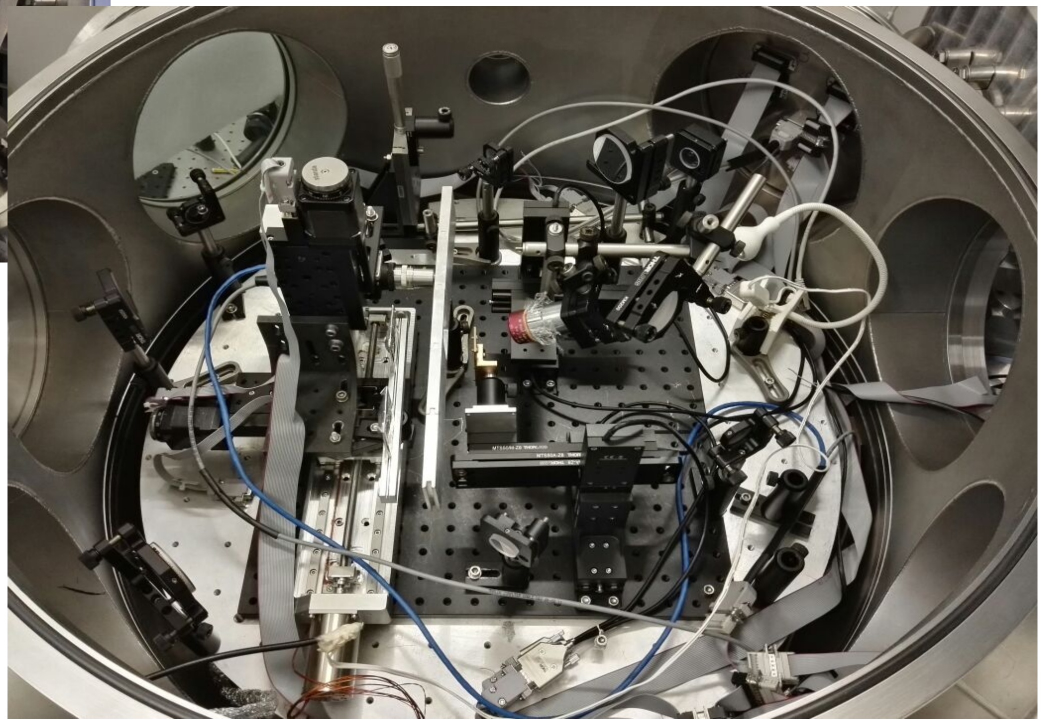
FLAME status: EOS experiment



More diagnostic added:

CR39 films to measure proton energy and charge.

Electron spectrometer to measure electron energy.



Main diagnostic is still EOS crystal.

The goal is to understand the scaling laws that governing particle acceleration from solid targets and the correlation between target shape and proton yield

FLAME status

In the last few months we have seen no signal from EOS experiments and this has been addressed to contrast ratio. At the beginning the contrast was low due to a damage on the booster crystal and even after replacing the crystal, contrast was worse than Amplitude specifications. What they claim is the ageing of the “Key components” (Pockel cells).

We have placed a new order to Amplitude for the Mazzler crystal which also include a regenerative cavity upgrade which should also improve contrast ratio (pre-pulses are now of the order of 10^{-6} and we expect to be able to bring them at the level of 10^{-8} as Amplitude specifications!).

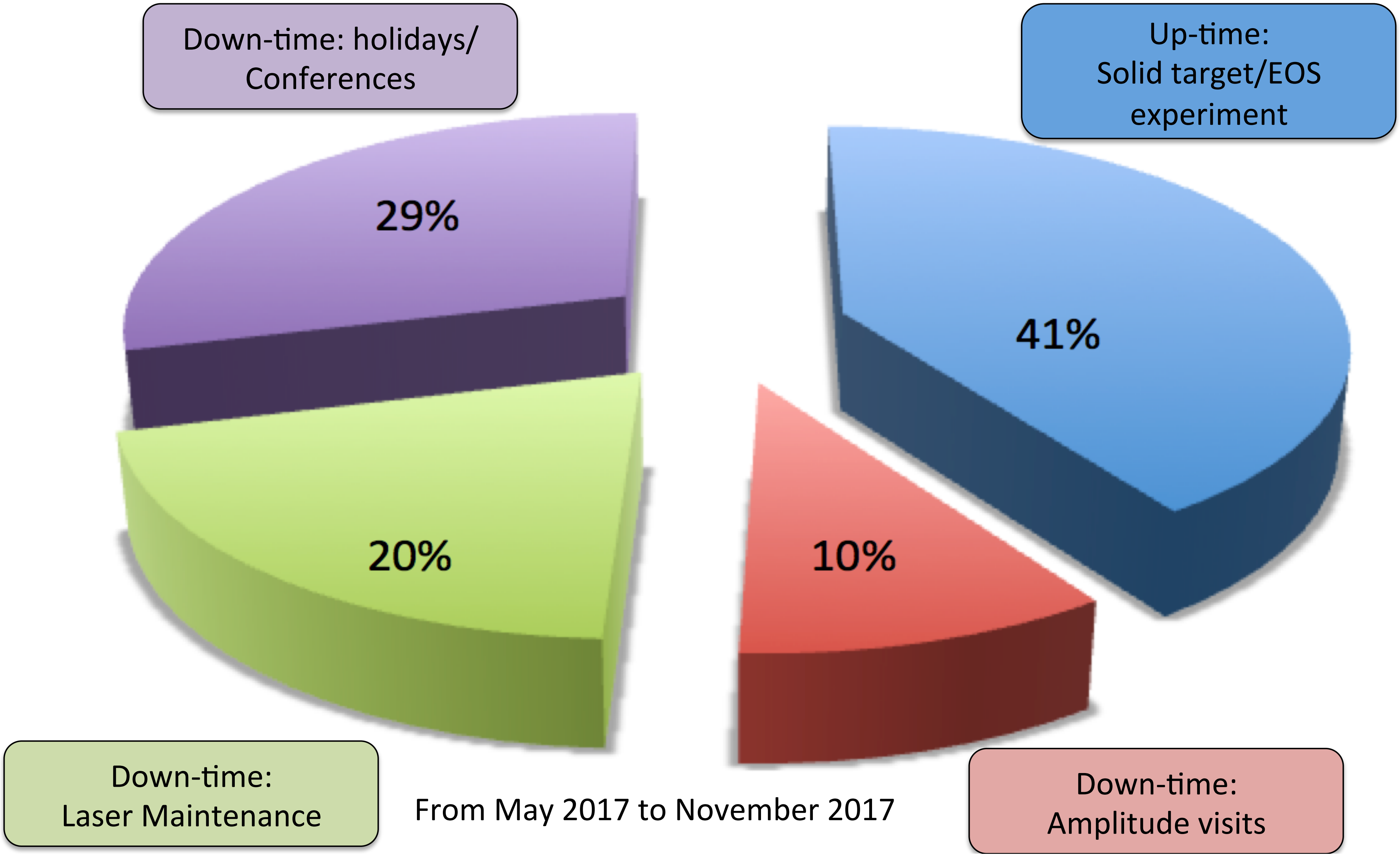
FLAME status

After fire accident (Oct. 2016) FLAME has been recovered and now is in operation.

We are still waiting for the end of the upgrade of the last amplifier, which took much longer than expected (Amplitude problems with 2nd harmonic crystals). This is expected to end by December.

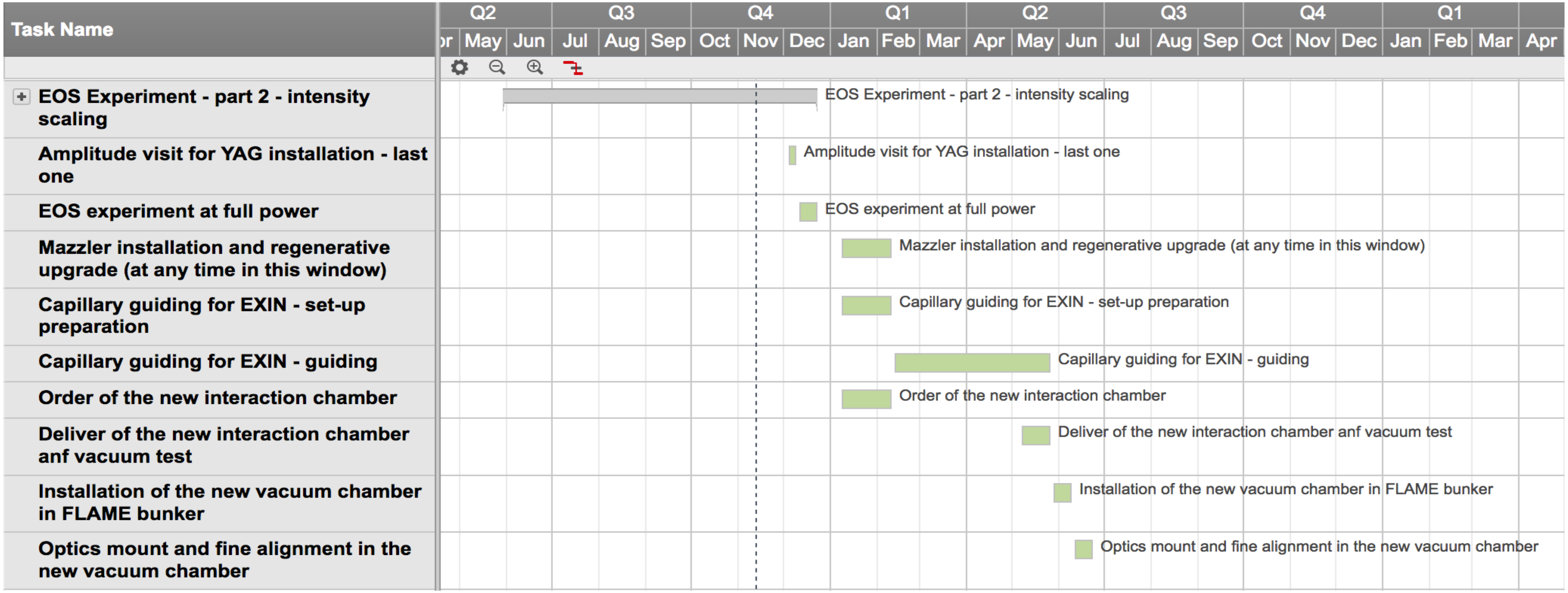
We are still running experiments with EOS to finalize the intensity scaling and 5 YAGs missing is an issue. At the moment, the maximum energy on target is a bit more than 1J (1.8 J before compression).

FLAME up-down time



From May 2017 to November 2017

Gantt Chart for FLAME operations



FLAME status: what next

EOS experiment - phase 2.

The aim of this experimental campaign is to add more diagnostic to the previous experimental campaign. Diagnostic included in this experimental campaign are electron charge and energy.

Moreover, a more comprehensive study of the potential barrier will be carried out.

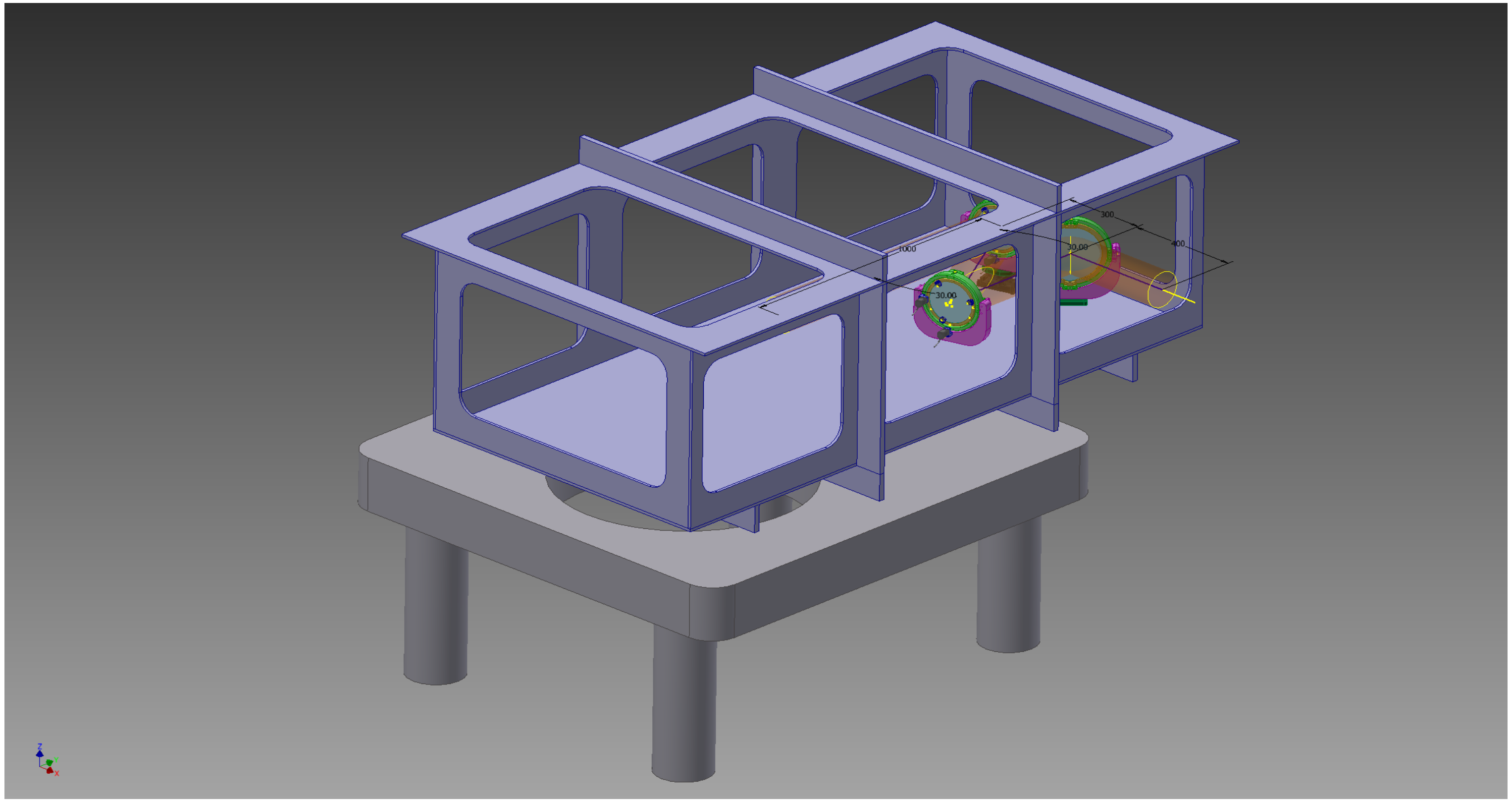
Capillary guiding for EXIN

The goal of the experiment is to guide high power laser in a capillary in order to prepare the wakefield for the external injected electrons.
During the experimental campaign overseen in FLAME, we aim to understand which is the best capillary choise (between monomode capillaries and preformed plasma capillaries) and to grow knowledge on the capillary alignment as well as the diagnostic of laser not only for the interaction but also for the post-interaction.

FLAME status: what next

The new interaction chamber has been designed: it guarantees the maximum flexibility and space for diagnostic.

The order for the new interaction chamber will be placed soon (in January) and the chamber will be delivered in INFN in March (and we will test it) and will be installed in the bunker hopefully before summer.



FLAME publications - 2017

1. Fabrizio Bisesto, Maria Pia Anania, Mordechai Botton, Enrica Chiadroni, Alessandro Cianchi, Alessandro Curcio, Massimo Ferrario, Mario Galletti, Riccardo Pompili, Elad Schleifer, Arie Zigler; Novel Single-Shot Diagnostics for Electrons from Laser-Plasma Interaction at SPARC_LAB. **Quantum Beam Science** 10/2017; 1(3)., DOI: 10.3390/qubs1030013

2. A Curcio, M Anania, F. Bisesto, E Chiadroni, A Cianchi, M Ferrario, F Filippi, D Giulietti, A Marocchino, M Petrarca, V Shpakov, A Zigler: Trace-space reconstruction of low-emittance electron beams through betatron radiation in laser-plasma accelerators. **Physical Review Special Topics - Accelerators and Beams** 01/2017; 20(1)., DOI:10.1103/PhysRevAccelBeams.20.012801

3. A Curcio, M Anania, F Bisesto, E Chiadroni, A Cianchi, M Ferrario, F Filippi, D Giulietti, A Marocchino, F Mira, M Petrarca, V Shpakov, A Zigler; Single-shot non-intercepting profile monitor of plasma-accelerated electron beams with nanometric resolution. **Applied Physics Letters** 09/2017; 111(13)., DOI: 10.1063/1.4998932

4. FG Bisesto, Maria Pia Anania, A Cianchi, E Chiadroni, Alessandro Curcio, Massimo Ferrario, Riccardo Pompili, Arie Zigler; Innovative single-shot diagnostics for electrons from laser wakefield acceleration at FLAME. **Journal of Physics: Conference Series** 07/2017; 874(1); DOI: 10.1088/1742-6596/874/1/012035

FLAME publications - 2017

5. FG Bisesto, MP Anania, E Chiadroni, A Cianchi, G Costa, A Curcio, M Ferrario, M Galletti, R Pompili, E Schleifer, A Zigler; Innovative single-shot diagnostics for electrons accelerated through laser-plasma interaction at FLAME. Proc. SPIE 10240, **Laser Acceleration of Electrons, Protons, and Ions** IV, 102400K; 07/2017 ; DOI: 10.1117/12.2265691

6. A Curcio, M Anania, F Bisesto, E Chiadroni, A Cianchi, M Ferrario, F Filippi, D Giulietti, A Marocchino, F Mira, M Petrarca, V Shpakov, A Zigler; First measurements of betatron radiation at FLAME laser facility. **Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms** 03/2017; 402; DOI: 10.1016/j.nimb.2017.03.106

7. Riccardo Pompili, Maria Pia Anania, Marco Bellaveglia, Fabrizio Bisesto, Enrica Chiadroni, Alessandro Cianchi, Alessandro Curcio, Domenico Di Giovenale, Giampiero Di Pirro, Massimo Ferrario, Arie Zigler; Electro-Optical Methods for Multipurpose Diagnostics. 5th Int. Beam Instrumentation Conf.**(IBIC'16)**, Barcelona, Spain, Sept. 13-18, 2016. JACOW, Geneva, Switzerland, 2017

EuPRAXIA and SPARC_LAB

Massimo.Ferrario@lnf.infn.it

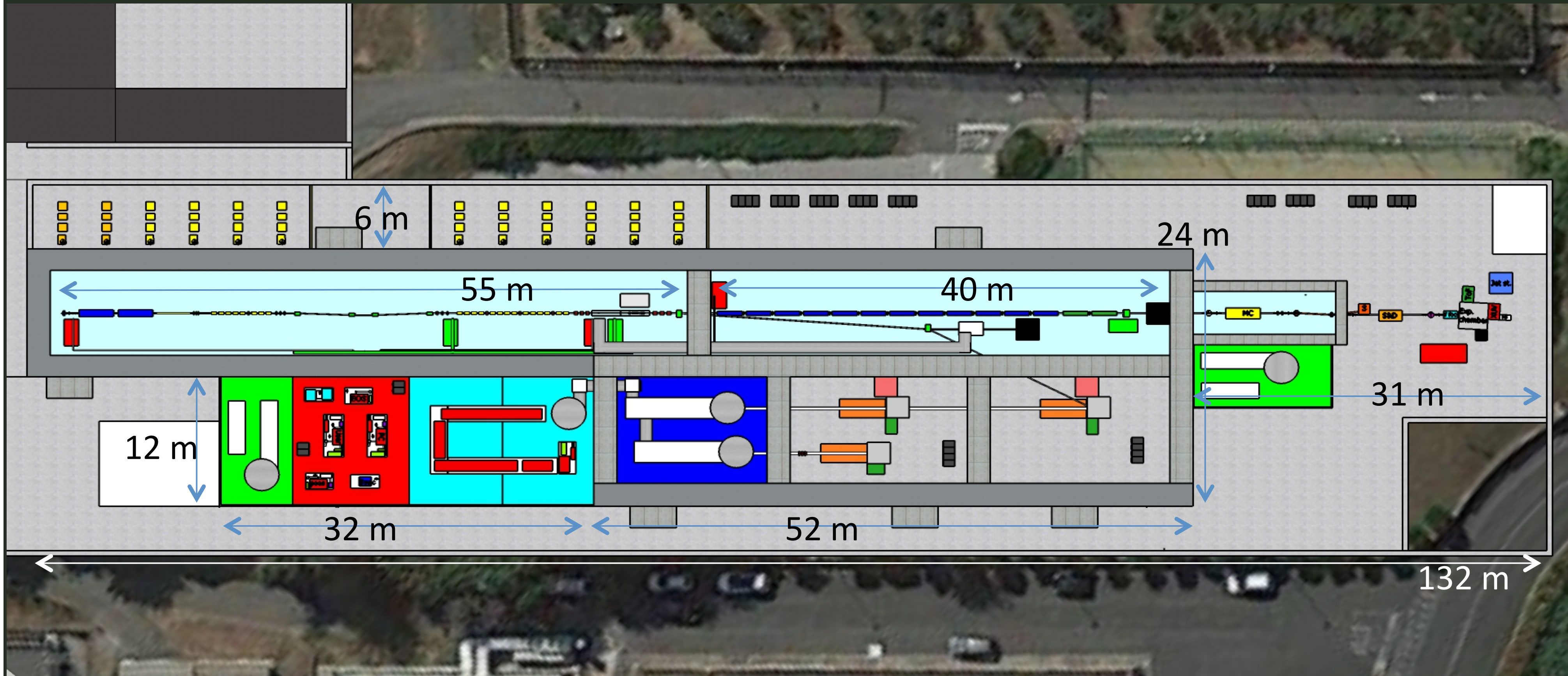
LNF SciCom –14 November 2017

- D. Alesini, M. P. Anania, R. Bedogni, M. Bellaveglia, A. Biagioni, F. Bisesto, E. Brentegani, B. Buonomo, P.L. Campana, G. Campogiani, S. Cantarella, F. Cardelli, M. Castellano, E. Chiadroni, R. Cimino, R. Clementi, M. Croia, A. Curcio, G. Costa, S. Dabagov, M. Diomede, A. Drago, D. Di Giovenale, G. Di Pirro, A. Esposito, M. Ferrario, F. Filippi, O. Frasciello, A. Gallo, A. Ghigo, A. Giribono, S. Guiducci, S. Incremona, F. Iungo, V. Lollo, A. Marcelli, A. Marocchino, V. Martinelli, A. Michelotti, C. Milardi, L. Pellegrino, L. Piersanti, S. Pioli, R. Pompili, R. Ricci, S. Romeo, U. Rotundo, L. Sabbatini, O. Sans Plannell, J. Scifo, B. Spataro, A. Stecchi, A. Stella, V. Shpakov, C. Vaccarezza, A. Vannozzi, A. Variola, F. Villa, M. Zobov.
- **INFN - Laboratori Nazionali di Frascati**
- A. Bacci, F. Broggi, C. Curatolo, I. Debrot, A. R. Rossi, L. Serafini. **INFN - Sezione di Milano**
- D. Cirrincione, A.Vacchi. **INFN - Sezione di Trieste**
- G. A. P. Cirrone, G. Cuttone, V. Scudieri. **INFN - Laboratori Nazionali del Sud**
- M. Artioli, M.Carpanese, F.Ciocci, D.Dattoli, S.Licciardi, F.Nguyen, S. Pagnutti, A.Petralia, E. Sabia. **ENEA – Frascati and Bologna**
- L. Gizzi, L. Labate. **CNR - INO, Pisa**
- R. Corsini, A. Grudiev, N. Catalan Lasheras, A. Latina, D. Schulte, W. Wuensch. **CERN, Geneva**
- C. Andreani, A. Cianchi, G. Festa,V. Minicozzi, S. Morante, R. Senesi, F. Stellato. **Universita' degli Studi di Roma Tor Vergata and Sezione INFN**
- V. Petrillo, M. Rossetti. **Universita' degli Studi di Milano and Sezione INFN**
- G. Castorina, L. Ficcadenti, S. Lupi, M. Marongiu, F. Mira, A. Mostacci. **Universita' degli Studi di Roma Sapienza and Sezione INFN**
- S. Bartocci, C. Cannaos, M. Faiferri, R. Manca, M. Marini, C. Mastino, D. Polese, F. Pusceddu, E. Turco. **Università degli Studi di Sassari, Dip. di Architettura, Design e Urbanistica ad Alghero**
- M. Coreno, G. D'Auria, S. Di Mitri, L. Giannessi, C. Masciovecchio. **ELETTRA Sincrotrone Trieste**
- A. Ricci. **RICMASS, Rome International Center for Materials Science Superstripes**
- A. Zigler. **Hebrew University of Jerusalem** J. B. Rosenzweig. **University of California Los Aangeles**

CDR.0 delivery expected by end of the year

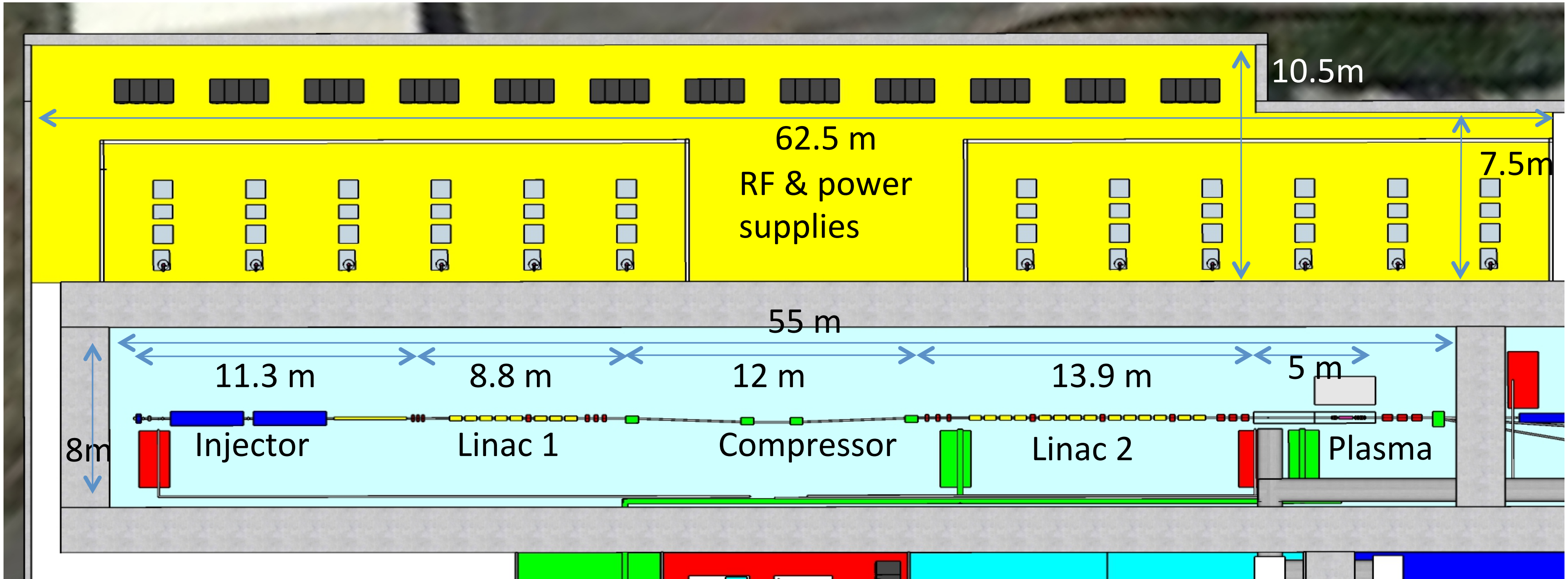
WG 0 – Project Management	
0.1 Executive summary	(M. Ferrario)
WG 1 – Electron beam design and optimization	
1.1 Advanced High Brightness Photo-injector	(E. Chiadroni)
1.2 HB Linac technology,	(A. Gallo)
1.3 Linac design and parameters	(C. Vaccarezza)
WG 2 – Laser design and optimization	
2.1 FLAME upgrade	(M. P. Anania)
2.2 Advanced Laser systems	(L. Gizzi)
WG 3 – Plasma Accelerator	
3.1 PWFA beam line	(A. Marocchino)
3.2 LWFA beam line	(A. R. Rossi)
3.3 Plasma and Beam Diagnostics	(A. Cianchi)
WG 4 – FEL pilot applications	
4.1 Conventional and Plasma driven FEL	(V. Petrillo)
4.2 Advanced FEL schemes	(G. Dattoli)
4.3 Photon beam lines	(F. Villa)
4.4 FEL user applications	(F. Stellato)
WG 5 – Radiation sources and user beam lines	
5.1 Advanced (dielectric) THz source	(S. Lupi)
5.2 Compton source	(C. Vaccarezza)
5.3 Secondary Particle Sources	(LNS)?
5.4 Laser-driven neutron source	(Cianchi)
5.4 User beam lines	(P. Valente)
WG 6 – Low Energy Particle Physics	
6.1 Advanced positron sources	(A. Variola)
6.2 Fundamental physics experiments , LabAstro	(C. Gatti)
6.3 Plasma driven photon collider	(L. Serafini)
WG 7 – Infrastructure	
7.1 Civil Engineering and conventional plants	(U. Rotundo)
7.2 Control system	(G. Di Pirro)
7.3 Radiation Safety	(A. Esposito)
7.4 Machine layout	

- Candidate LNF to host EuPRAXIA (1-5 GeV)
- FEL user facility (1 GeV – 3nm)
- Advanced Accelerator Test facility (LC) + CERN



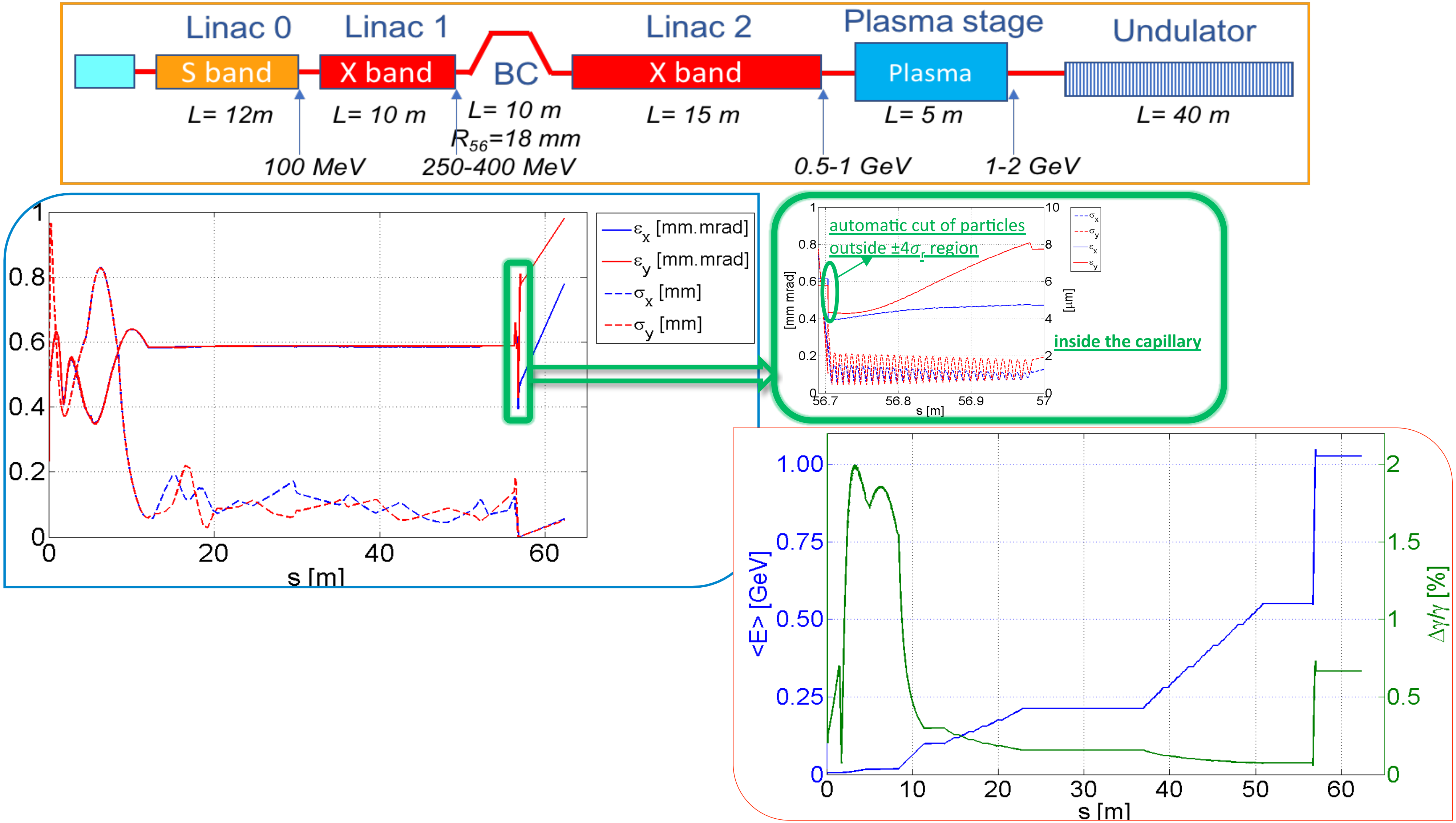
- 500 MeV by RF Linac + 500 MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only
- Final goal compact 5 GeV accelerator

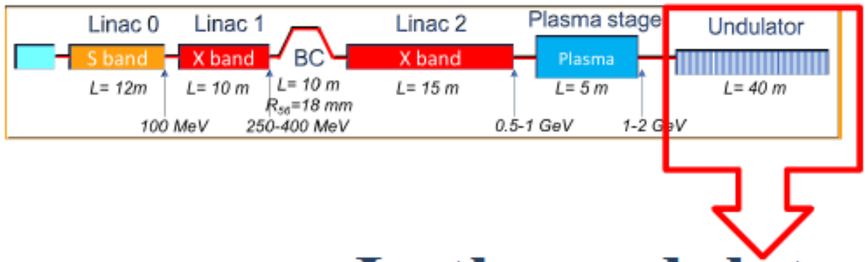
Accelerator (X-band EU frequency – 100 Hz?)



- Injector:
  - Gun+solenoid
  - 3x 3m s-band sectons
- Linac 1:
  - 8x 0.5m x-band sections
  - Matching Quads
- Compressor:
  - 2.19° deflection
- Linac 2:
  - 14x 0.5m x-band sections
  - Matching Quads
- Plasma:
  - PMQ matching
  - 0.6 m capillary

30 pC beam Start To End Simulations



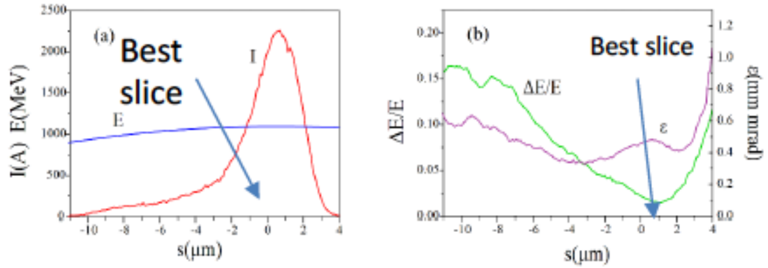


In the undulator

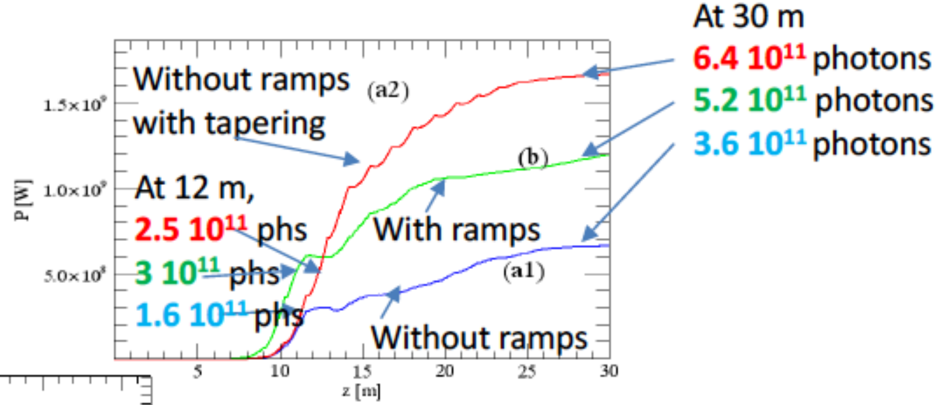
FEL Genesis simulation with laser driven plasma accelerated electron beams

Radiation: λ=2.7 nm
E_{phot}=0.45 keV

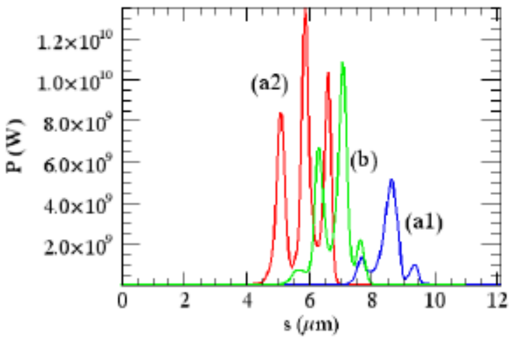
Undulator λ_u=1.5 cm,
a_w=0.8



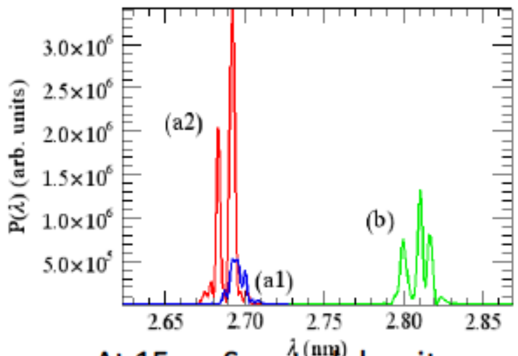
Characteristics of the electron beam, case a1



Growth of the radiation along the undulator



At 15 m, Power density
Quasi-single structure



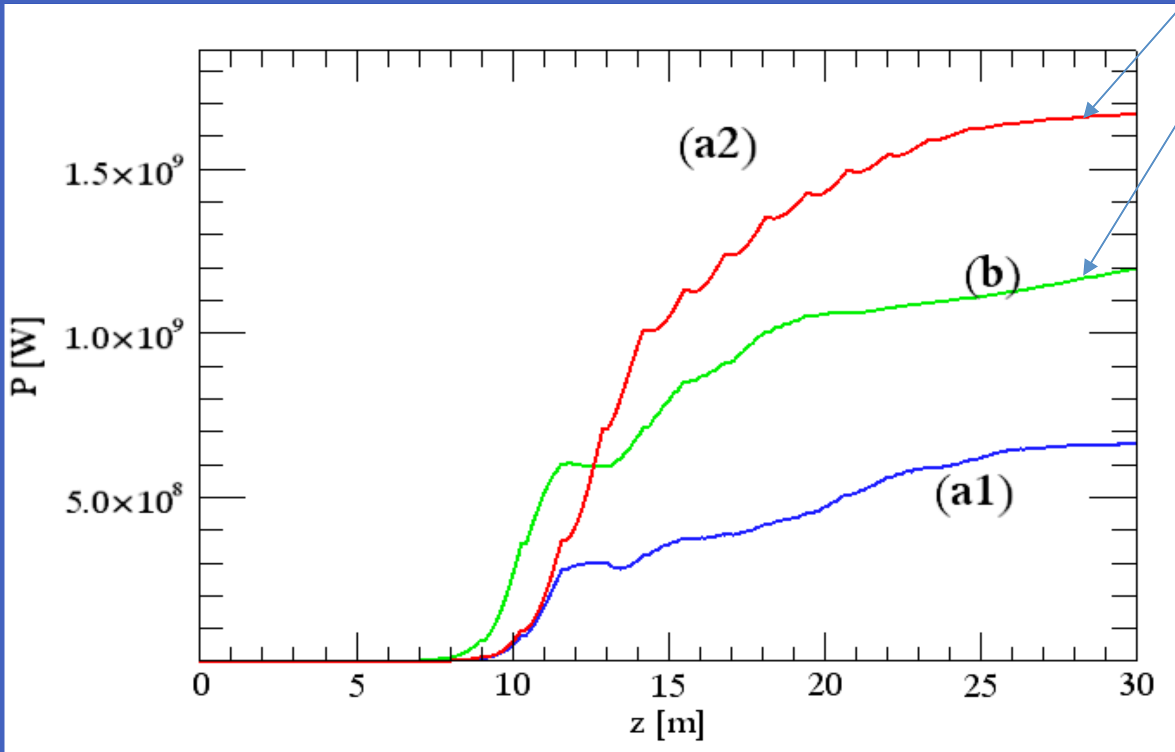
At 15 m, Spectral density
Quasi-single spike structure

	(a)
Q(pC)	30
ε_x (mmmrad)	0.45
ε_y (mmmrad)	0.49
ΔE/E (10^{-4})	1.54
I_{peak}(A)	2258
z_1(m)	12
E(z_1) (μJ)	12
N_{phot}(z_1) (10^{11})	1.62
z_2(m)	30
E(z_2) (μJ)	27.
N_{phot}(z_1)(10^{11})	3.63
Bandwidth(%)	0.15
Divergence(μrad)	50
Rad. Size (μm)	155

Courtesy of V. Petrillo

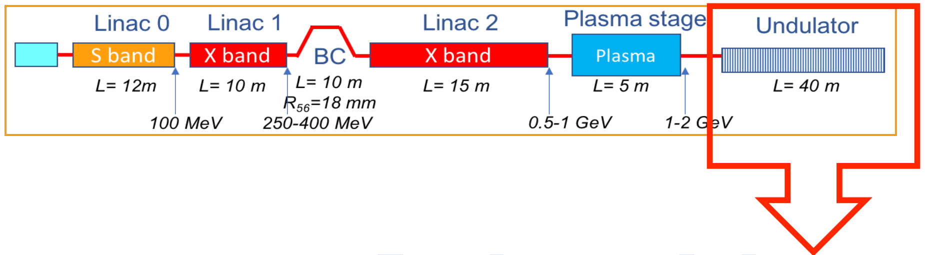
FEL driven by LWFA

At 30 m
6.4 10^{11} photons
5.2 10^{11} photons
3.6 10^{11} photons



Growth of the radiation along the undulator

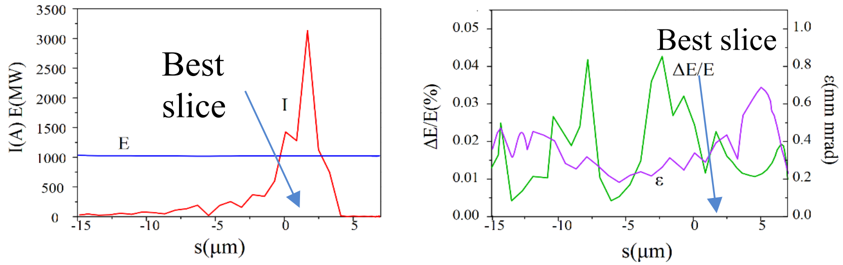
FEL Genesis simulation with **particle driven plasma accelerated electron beams**



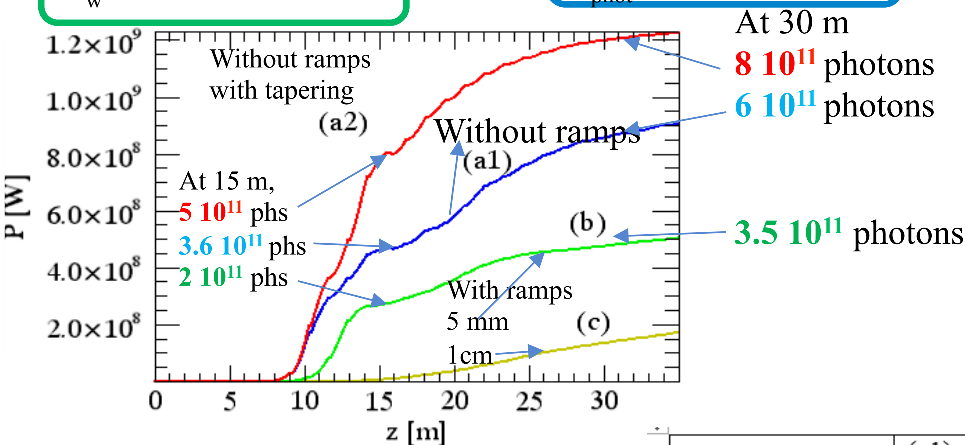
In the undulator

Undulator λ_u=1.5 cm, a_w=0.7

Radiation: λ=2.78 nm E_{phot}=0.44 keV

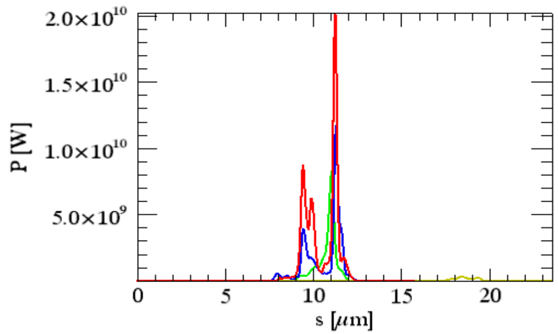


Characteristics of the electron beam

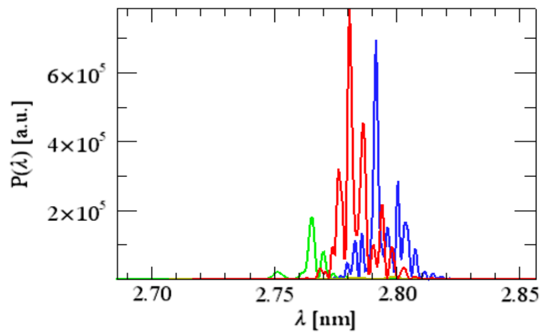


Growth of the radiation along the undulator

	(a1)
Q(pC)	30
ε_x (mmmrad)	0.39
ε_y (mmmrad)	0.309
ΔE/E (10^{-4})	2.49
I_{peak}(A)	3131
z_1(m)	15
E(z_1) (μJ)	25.8
$N_{phot}(z_1)$ (10^{11})	3.61
z_2(m)	30
E(z_2) (μJ)	43.9
$N_{phot}(z_1)$(10^{11})	6.1
Bandwidth(%)	0.15
Divergence(μrad)	40
Rad. Size (μm)	195

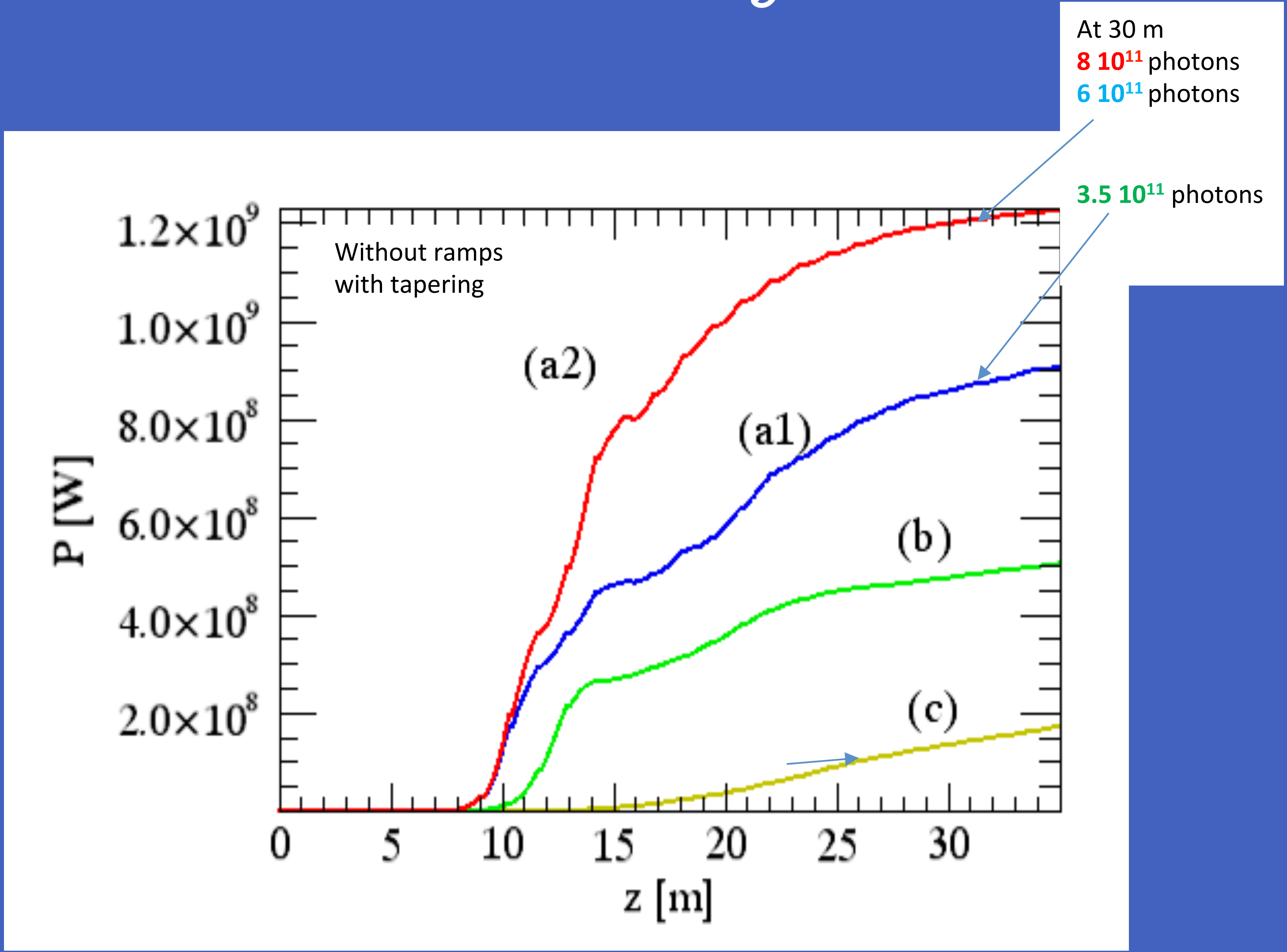


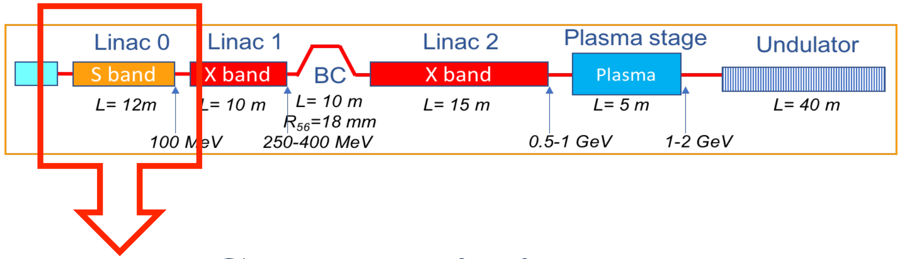
At 15 m, Power density
Quasi-single structure



At 15 m, Spectral density
Quasi-single spike structure

FEL driven by PWFA

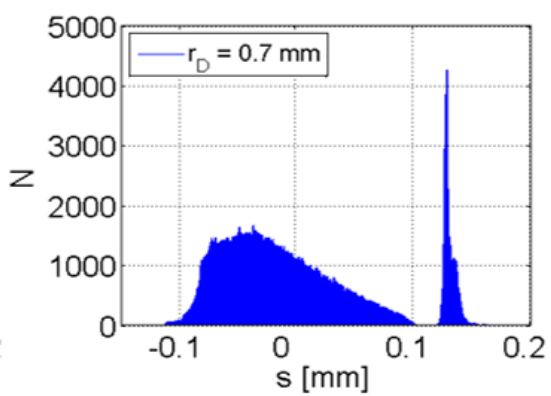




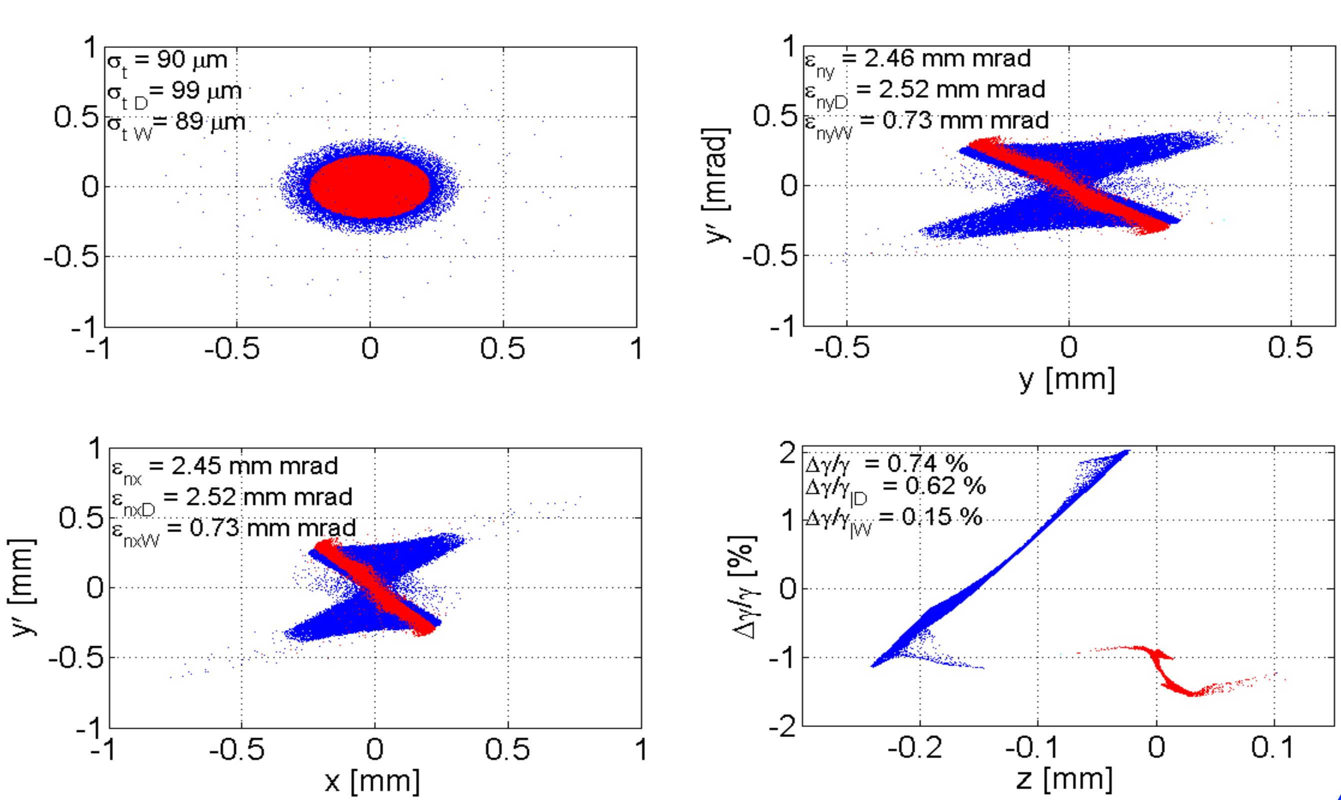
In the S-band injector:

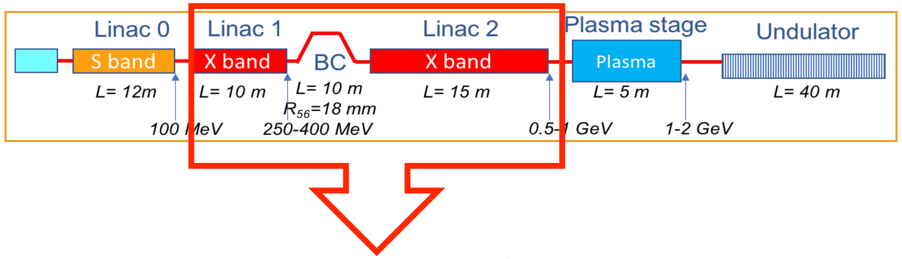
Tstep simulation for the driver +witness (30pC-2kA) up to the X-band linac entrance

Trailing bunch @Photoinj.Exit	
E [MeV]	98.85
$\varepsilon_{x,y}$ [mm mrad]	0.73
$\sigma_{z\text{-FWHM}}$ [μm]	~ 3.0
$\sigma_{z\text{-rms}}$ [μm]	6.0
ΔE/E [%]	0.15
$\sigma_{x\text{-rms}}$ [μm]	89
$I_{peak\ [FWHM]}$ [kA]	3



@photoinjector exit





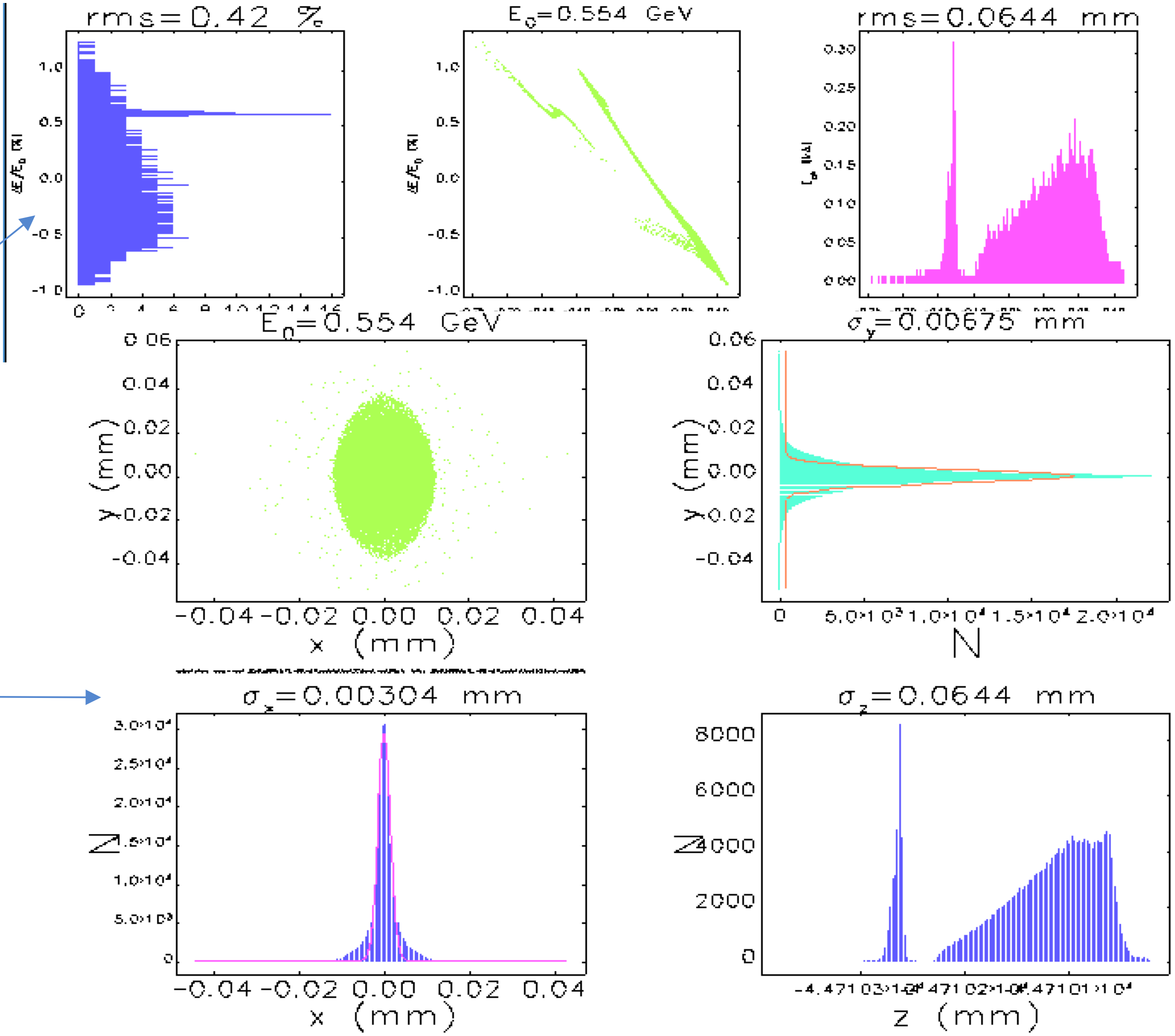
Elegant simulation for the driver + witness (30pC-2kA) up to the capillary entrance

In the X-band Linac:

Accelerated DRIVER+WITNESS
obtained at the the cathode
with Tstep code

Long phase space

Transv phase space



FEL driven by PLASMA

	Units	1 GeV PWFA with Undulator Tapering	1 GeV LWFA with Undulator Tapering
Bunch charge	pC	29	26.5
Bunch length rms	fs	11.5	8.4
Peak current	kA	2.6	3.15
Rep. rate	Hz	10	10
Rms Energy Spread	%	0.73	0.81
Slice Energy Spread	%	0.022	0.015
Average Rms norm. emittance	μm	0.6	0.47
Slice norm. emittance	μm	0.39-0.309	0.47
Slice Length	μm	1.39	1.34
Radiation wavelength	nm	2.79	2.7
ρ	$x\ 10^{-3}$	2	2
Undulator period	cm	1.5	1.5
K		0.987	1.13
Undulator length	m	30	30
Saturation power	GW	0.850-1.2	1.3
Energy	μJ	63	63.5
Photons/pulse		$8.8\ x\ 10^{11}$	$8.6\ x\ 10^{11}$
Bandwidth	%	0.35	0.42
Divergence	μrad	49	56
Rad. size	μm	210	160
Brilliance per shot	$(s\ mm^2\ mrad^2 bw\ (‰))^{-1}$	$0.83\ x\ 10^{27}$	$1.22\ x10^{27}$

FEL simulation with linac accelerated electron beams, high flux case

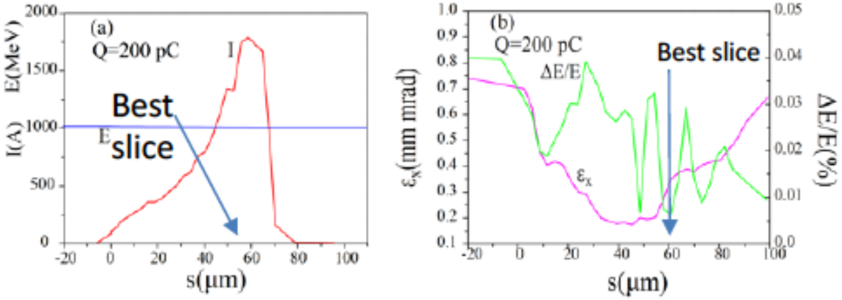
Case with 200 pC

Undulator λ_u=1.5 cm, a_w=0.7

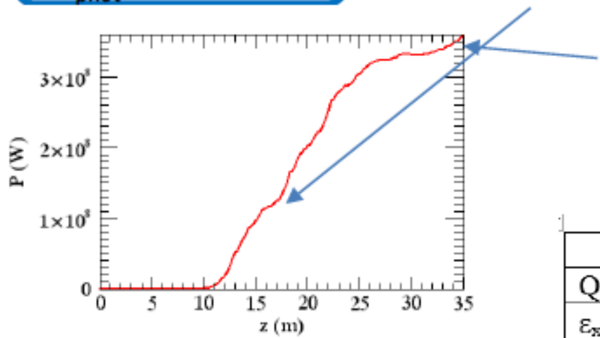
Radiation: λ=2.87 nm E_{phot}=0.43 keV

First saturation at 15 m with **9.1 10^{11}** photons

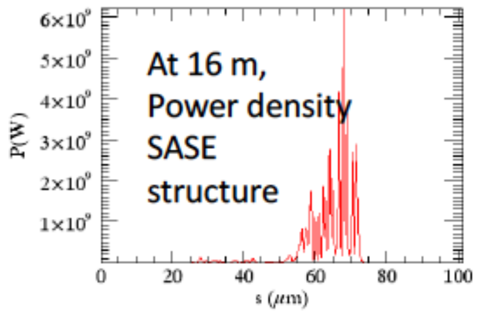
At 35 m, **2.7 10^{12}** photons

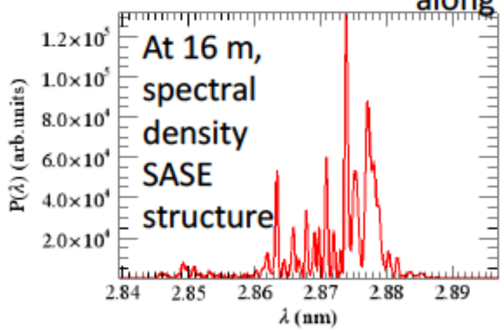


Characteristics of the electron beam



Growth of the radiation along the undulator





	(b)
Q(pC)	200
ε_x (mmmrad)	4.05
ε_y (mmmrad)	3.75
ΔE/E (10^{-4})	1.8
I_{peak}(A)	1788
z_1(m)	16
E(z_1) (μJ)	64
N_{phot}(z_1) (10^{11})	9.1
z_2(m)	35
E(z_2) (μJ)	192
N_{phot}(z_1)(10^{11})	27.5
Bandwidth(%)	0.16
Divergence(μrad)	27
Rad. Size (μm)	220

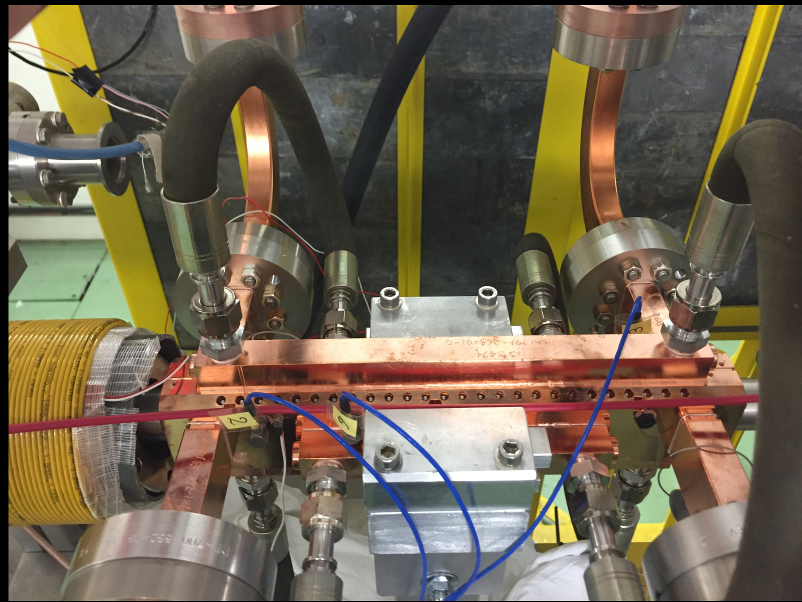
Courtesy of V. Petrillo

FEL driven by X-band only

	Units	1 GeV with X-band linac only 100 pC	1 GeV with X-band linac only 200 pC
Bunch charge	pC	100	200
Bunch length rms	fs	38.2	55.6
Peak current	kA	2.	1.788
Rep. rate	Hz	10	10
Rms Energy Spread	%	0.1	0.05
Slice Energy Spread	%	0.018	0.02
Average Rms norm. emittance	μm	0.5	0.5
Slice norm. emittance	μm	0.35-0.24	0.4-0.37
Slice Length	μm	1.25	1.66
Radiation wavelength	nm	2.4 (0.52 keV)	2.87(0.42 keV)
ρ	$x\ 10^{-3}$	1.9(1.7)	1.55(1.38)
Undulator period	cm	1.5	1.5
K		0.987	0.987
Saturation length	m	15-25	16-30
Saturation power	GW	0.361-0.510	0.120-0.330
Energy	μJ	48-70	64-177
Photons/pulse		$5.9\text{-}8.4\ x\ 10^{11}$	$9.3\text{-}25.5\ x\ 10^{11}$
Bandwidth	%	0.13-2.8	0.24-0.46
Divergence	μrad	17.5-16	28-27
Rad. size	μm	65-75	120-200
Brilliance per shot	$(s\ mm^2\ mrad^2 bw\ (‰))^{-1}$	$Fx3.8\text{-}2.2\ 10^{28}$	$Fx2.5\text{-}1.4\ 11^{27}$

Technological Aspects

X-band Linac



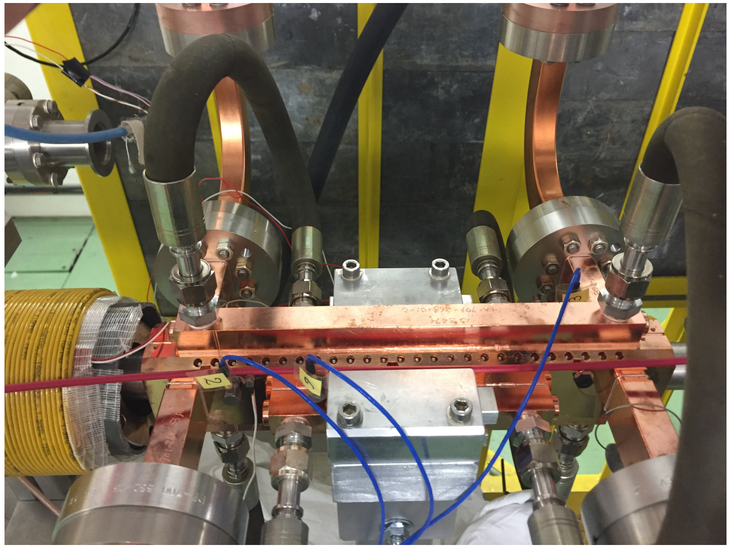
Compact

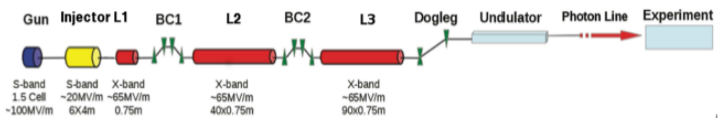
New EU Design Study Approved

3 years – 3 MEuro

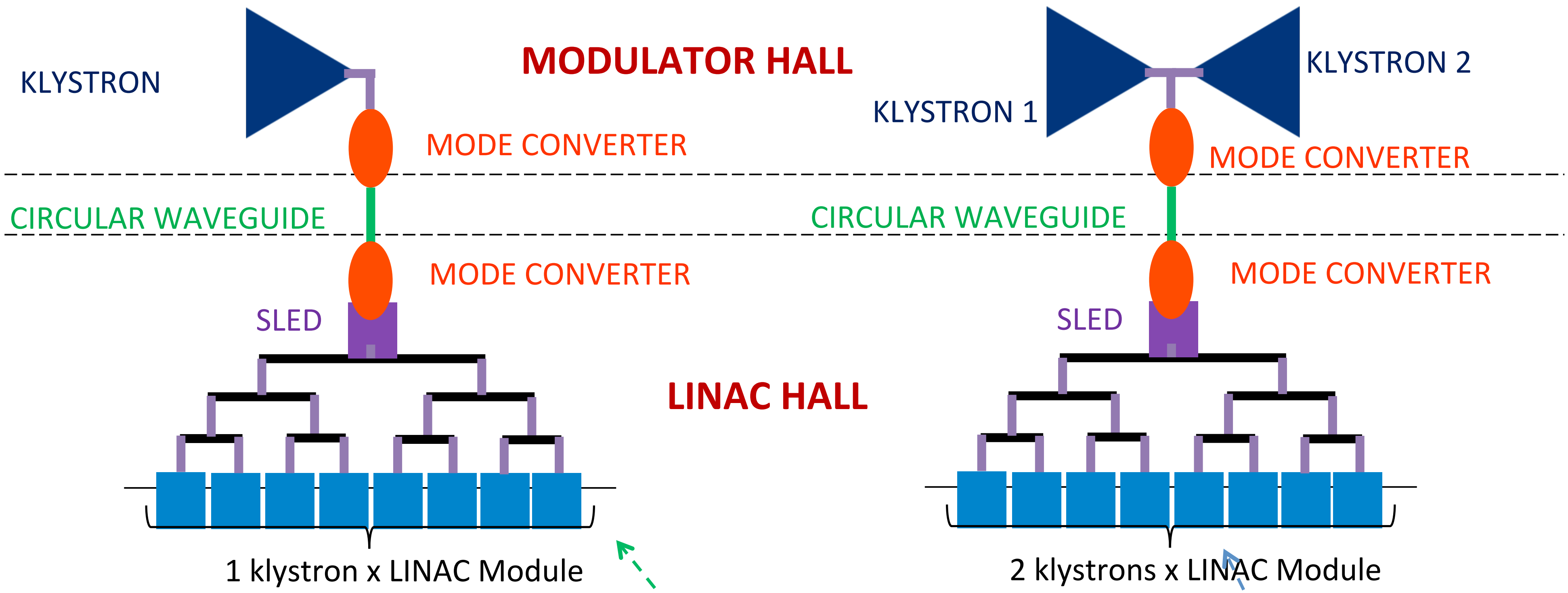
(➔212 kEuro INFN)

Coordinator: G. D'Auria (Elettra)





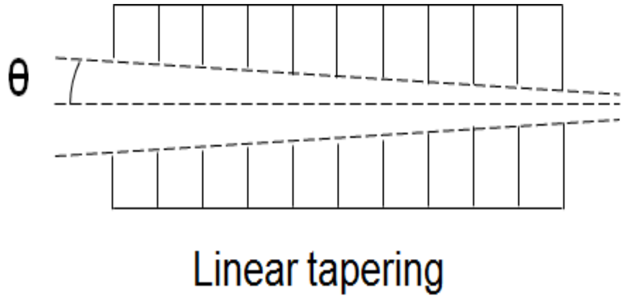
The key objective of the CompactLight Design Study is to demonstrate, through a conceptual design, the feasibility of an innovative, compact and cost effective FEL facility suited for user demands identified in the science case.

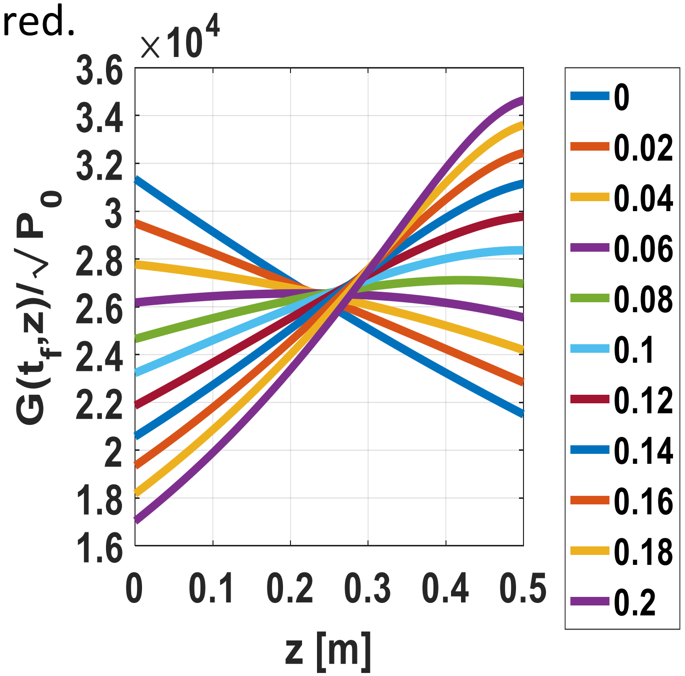


X-Band LINAC parameters			
total active length L_t	16 m		
Number of sections N_s	32 (4 modules x 8 sections)		
available RF power	50 MW (@klystron output coupler) 40 MW (@ section input couplers)		
	Injection in the plasma	Injection in the undulator	Ultimate
linac energy gain ΔW_{linac}	480 MeV	910 MeV	1280 MeV
average acc gradient $<E_{acc}>$	30 MV/m	57 MV/m	80 MV/m
total required RF power P_{RF}	44 MW	158 MW	310 MW

EuPRAXIA@SPARC_LAB X-band linac optimization

The accelerating structures have been optimized **tapering the irises apertures and maximizing the effective shunt impedance** that takes into account also the RF pulse compression from the SLED. Different structure lengths have been also considered.





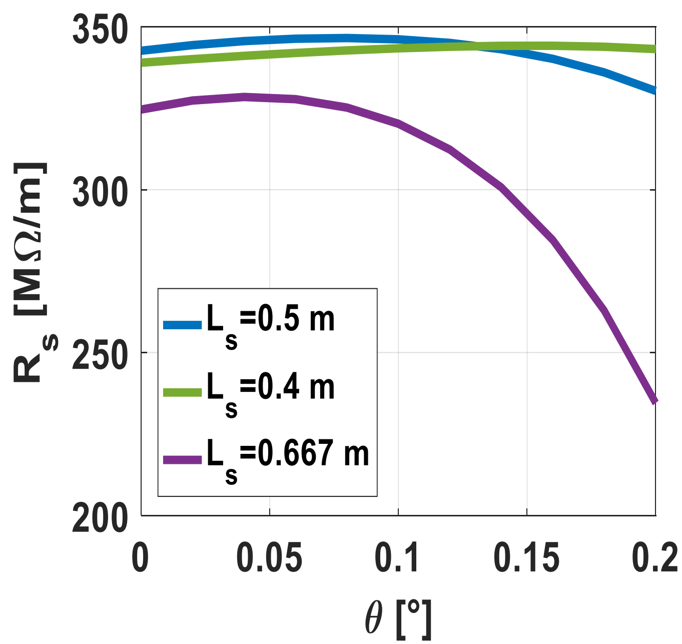
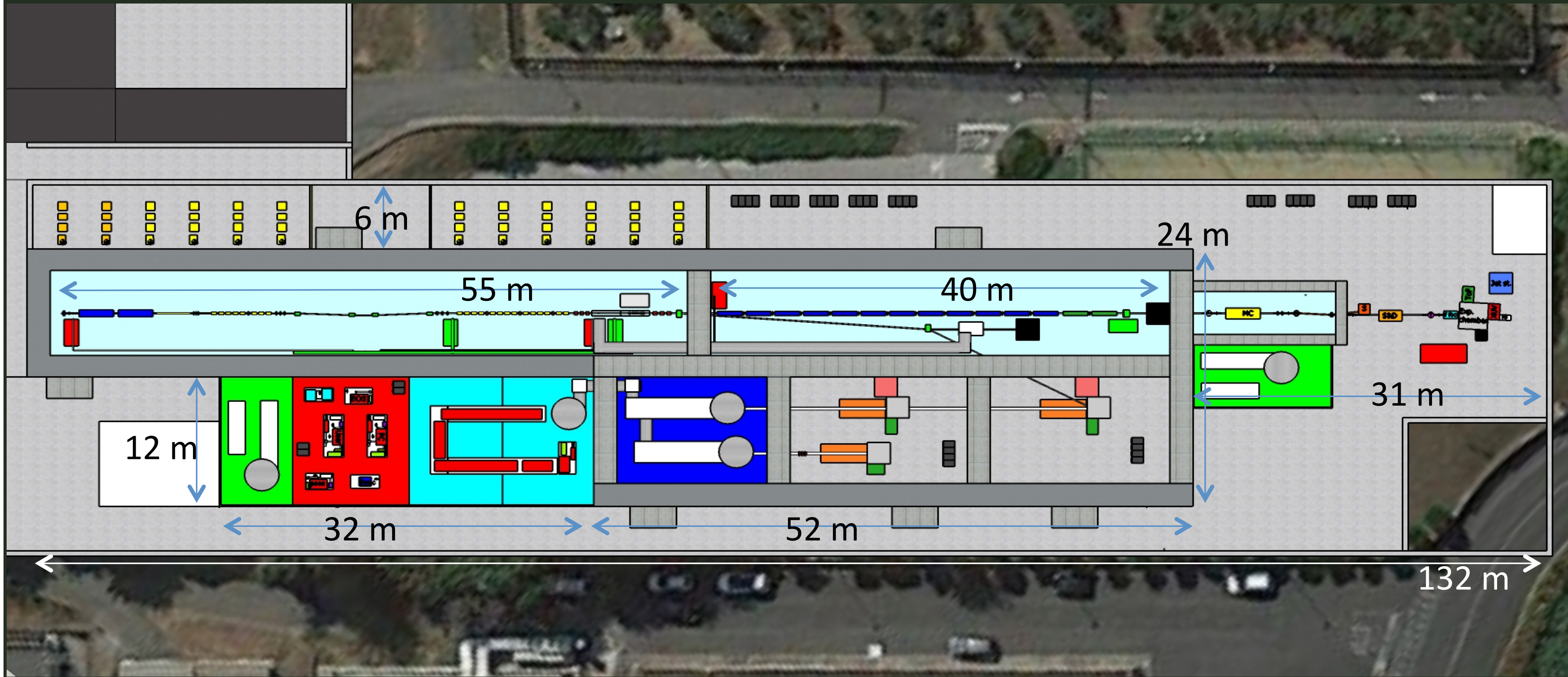


Figure: normalized gradient profile along the structure (0.5 m)

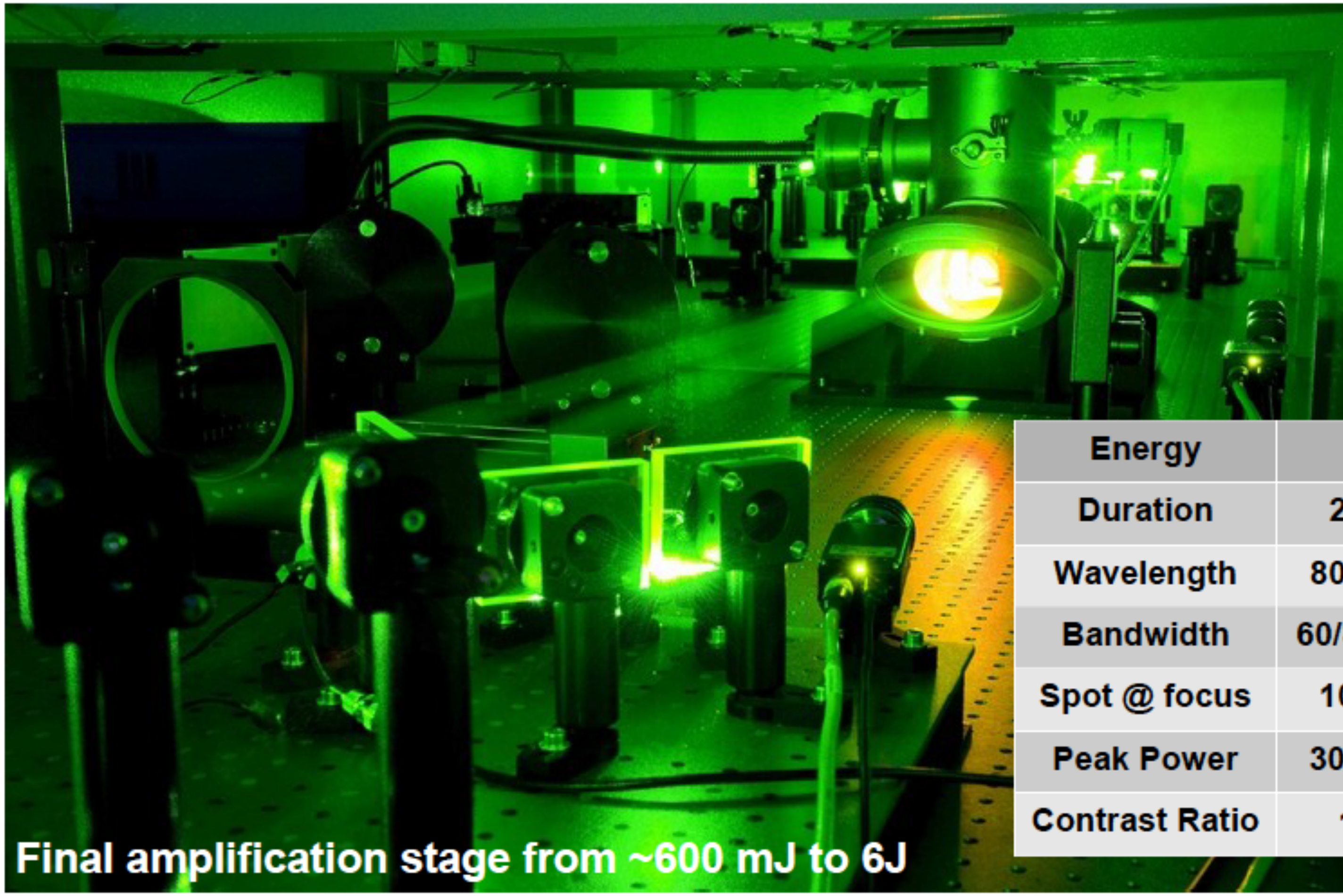
Figure: Effective shunt impedance per unit leng

The **best compromise** in term of structure efficiency and final layout configuration has been found with **accelerating cavities of 0.5 m**.

- The High Power Laser system



Ti:Sa FLAME laser



Final amplification stage from ~600 mJ to 6J

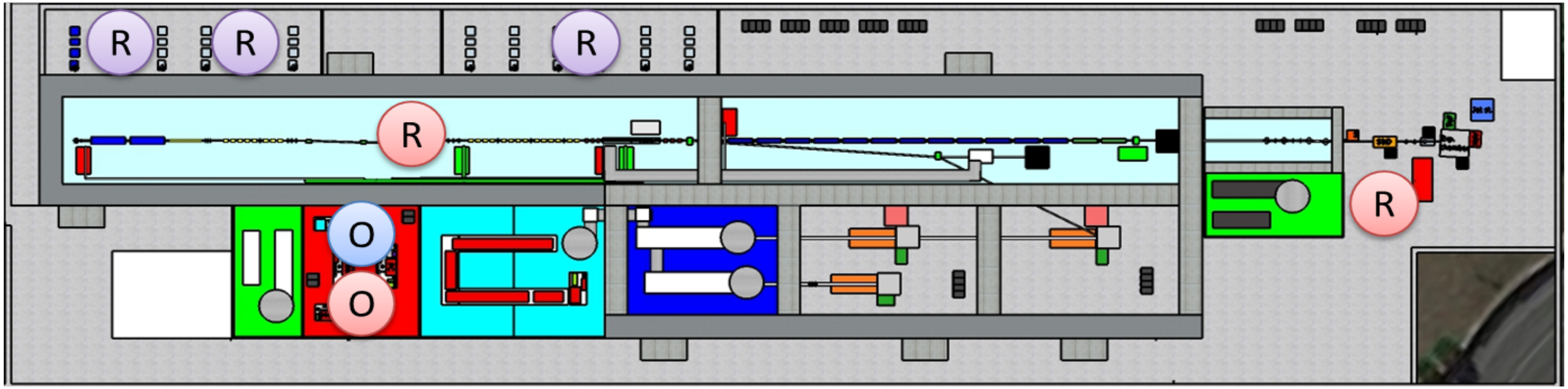
Energy	6 J
Duration	23 fs
Wavelength	800 nm
Bandwidth	60/80 nm
Spot @ focus	10 μm
Peak Power	300 TW
Contrast Ratio	10^{10}

Parameters of the 500 TW laser

Parameters	FLAME today	FLAME upgrated
Wavelength [nm]	800	800
Bandwidth [nm]	60-80	60-80
Repetition rate [Hz]	10	1-5
Max energy before compression [J]	7	20
Max energy on target [J]	4	13
Min pulse length [fs]	25	25
Max power [TW]	250	500
Contrast ratio	10^{10}	10^{10}

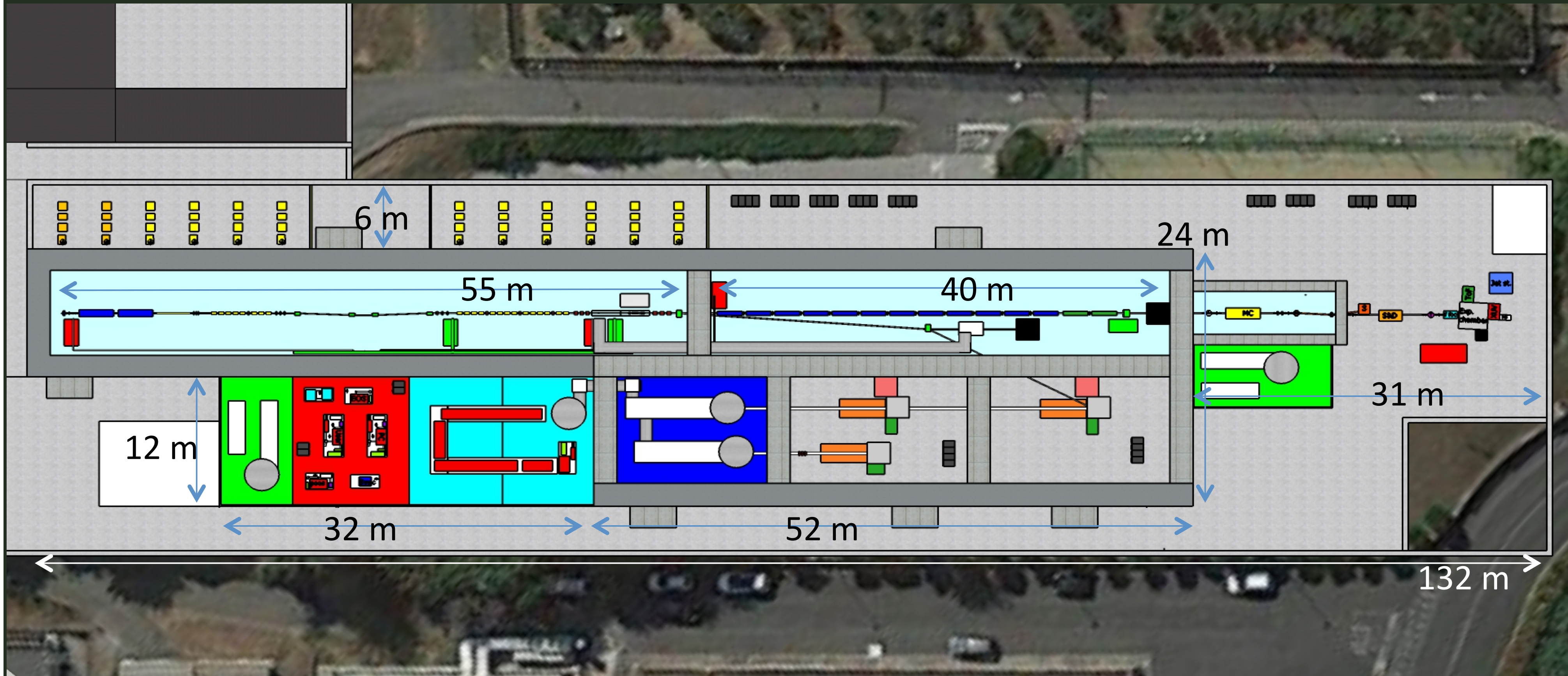
Comparison between the parameters of the actual FLAME system and the upgraded FLAME system.

Eupraxia@SPARC_LAB synchronization system



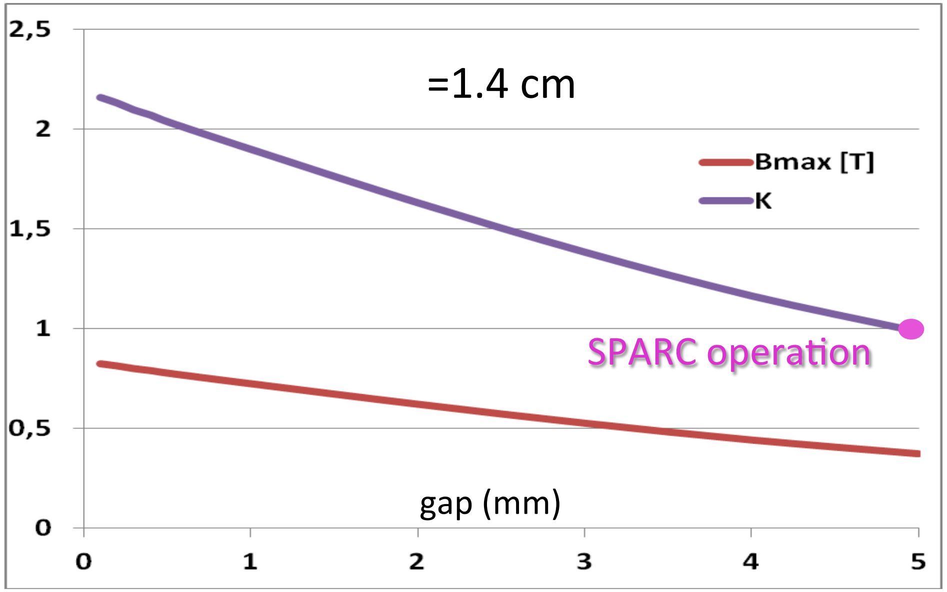
Synchronization system: A fine temporal alignment among all the relevant sub-system oscillators that guarantees temporal coherence of their outputs (**precision ~10fs**)
Tasks: triggers to sub systems (RF pulses, laser amplifiers, BPM, injection/extraction kickers), event tagging
Layout: 1 Electrical and 1 Optical Master Oscillator, 3 RF extractors, 2 optical link ends (diagnostics and users)

- The FEL Undulators



- 500 MeV by RF Linac + 500 MeV by Plasma
- 1 GeV by RF Linac only (EuSPARC)

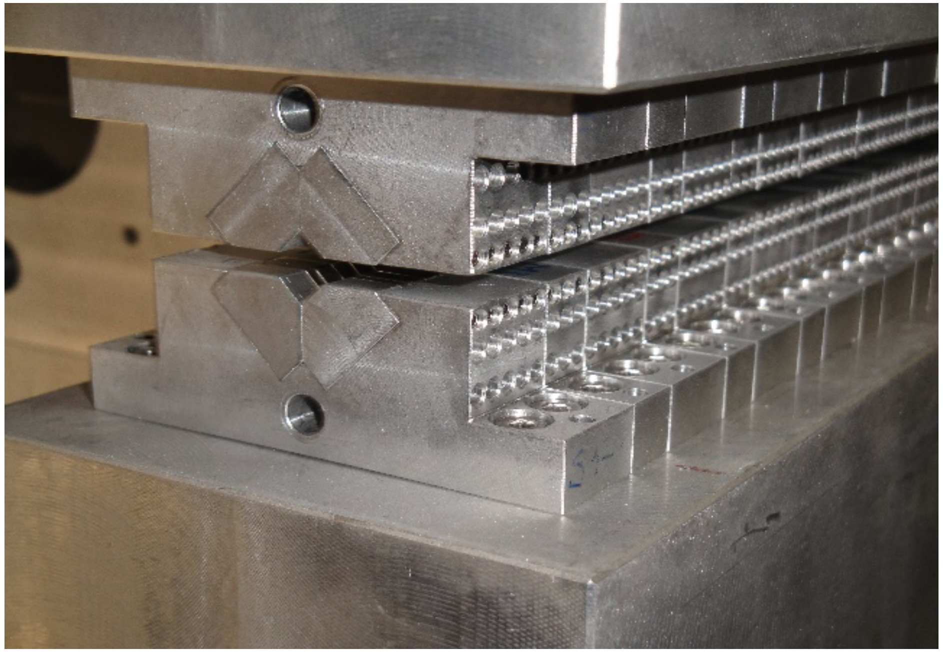
KYMA Δ undulator:
designed by ENEA Frascati,
constructed by Kyma Trieste,
tested on beam at SPARC_LAB



- DELTA like undulator

  λ_u = 1.4 cm, gap g = 5mm, Br = 1.22T.

Undulator tested in two stage SASE-FEL:
630nm to 315 nm



ENEA INFN

L'iniziativa EuPRAXIA@SPARC_LAB è valutata, quindi, di grande rilevanza scientifica per Elettra, che la considera sinergica con le proprie attività di ricerca.

Con la presente lettera Elettra intende esprimere, perciò, il proprio interesse a collaborare con INFN alla preparazione del TDR di EuPRAXIA@SPARC_LAB, con particolare attenzione allo sviluppo del linac in banda X, alla concezione di ondulatori compatti, allo studio degli schemi FEL più adatti allo scopo e alla progettazione delle relative linee di luce. Allo scopo di favorire la collaborazione con INFN in questi campi, Elettra potrà rendersi disponibile ad ospitare giovani ricercatori per brevi periodi di training.

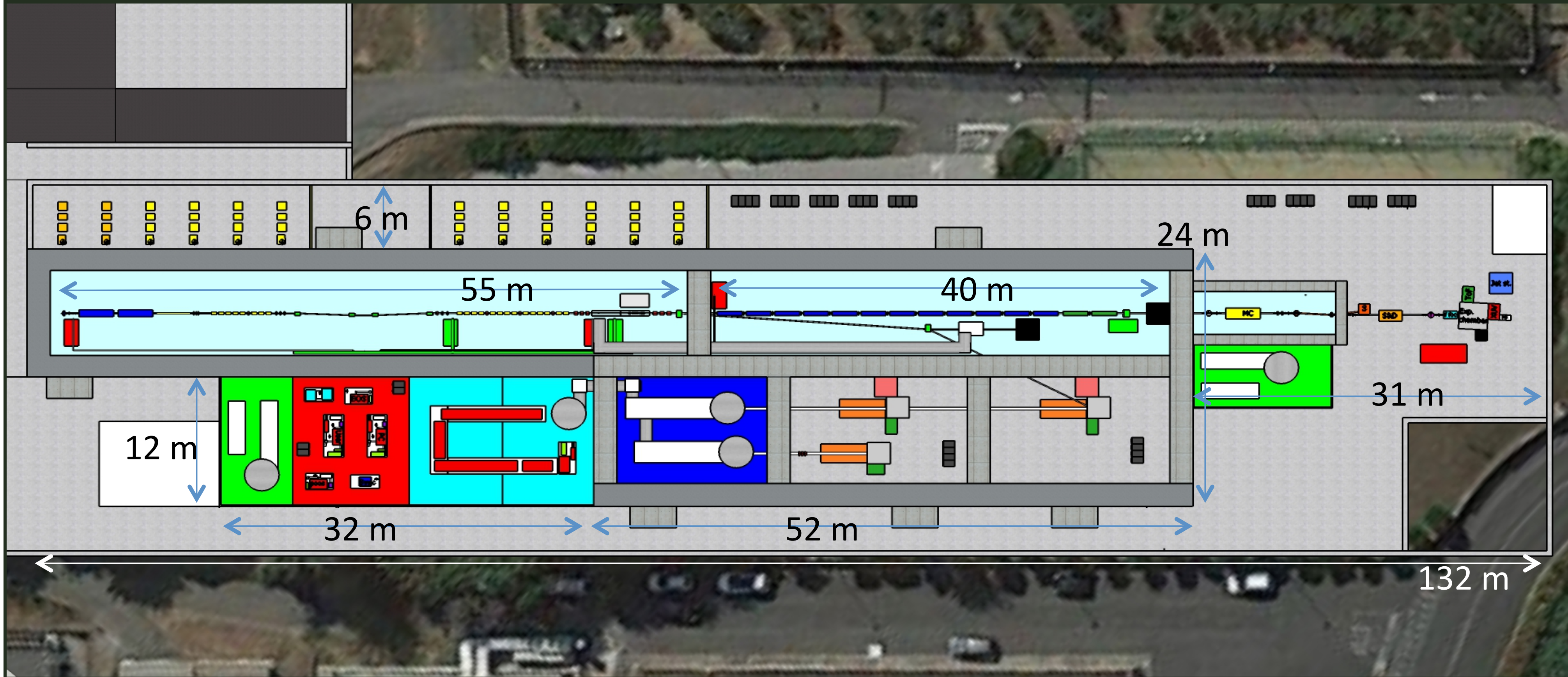
Cordiali saluti

Elettra Sincrotrone Trieste

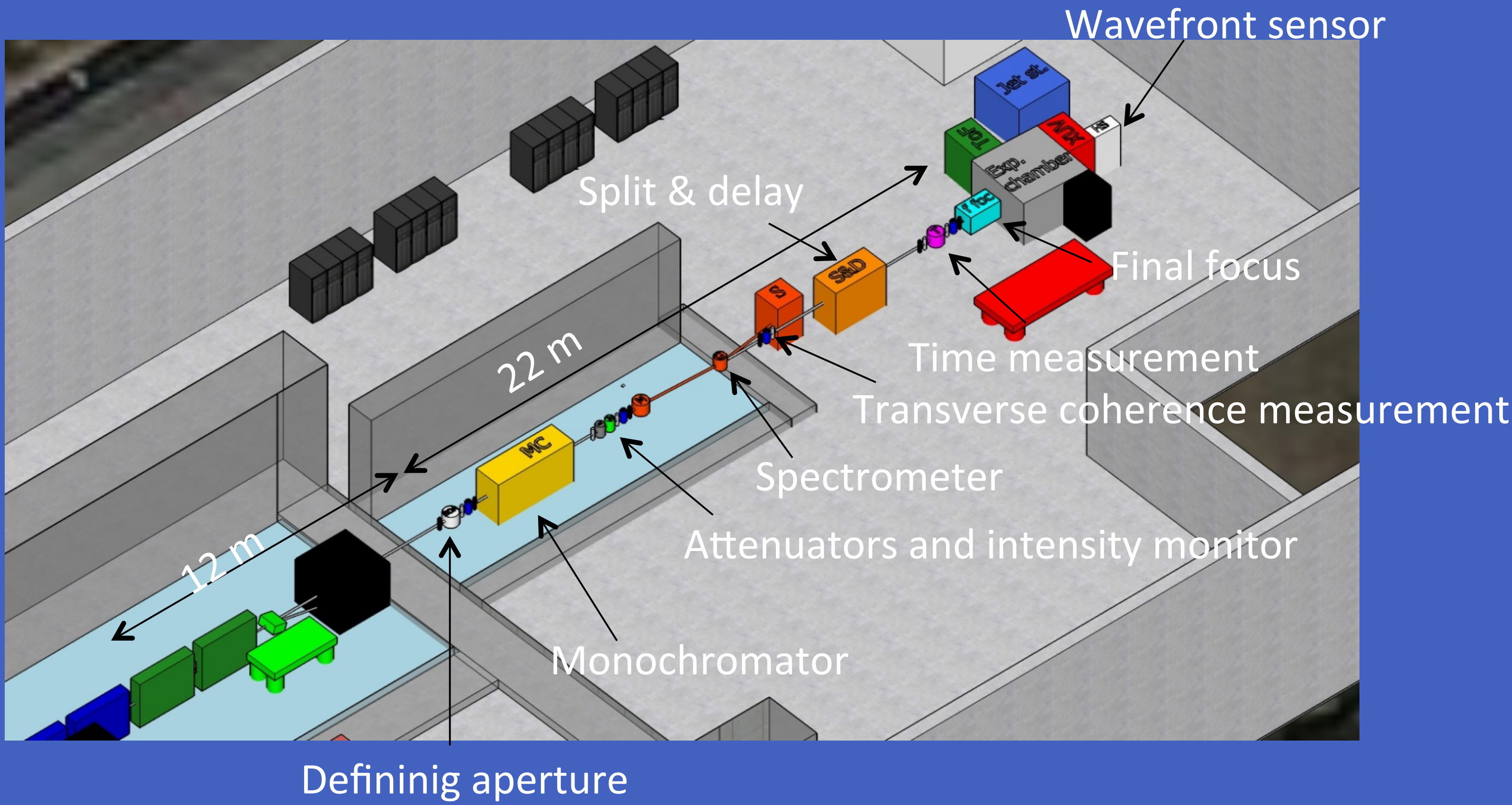
Il Presidente e Amministratore Delegato

Prof. Alfonso Franciosi

- The User Beam Line



Photon beam line

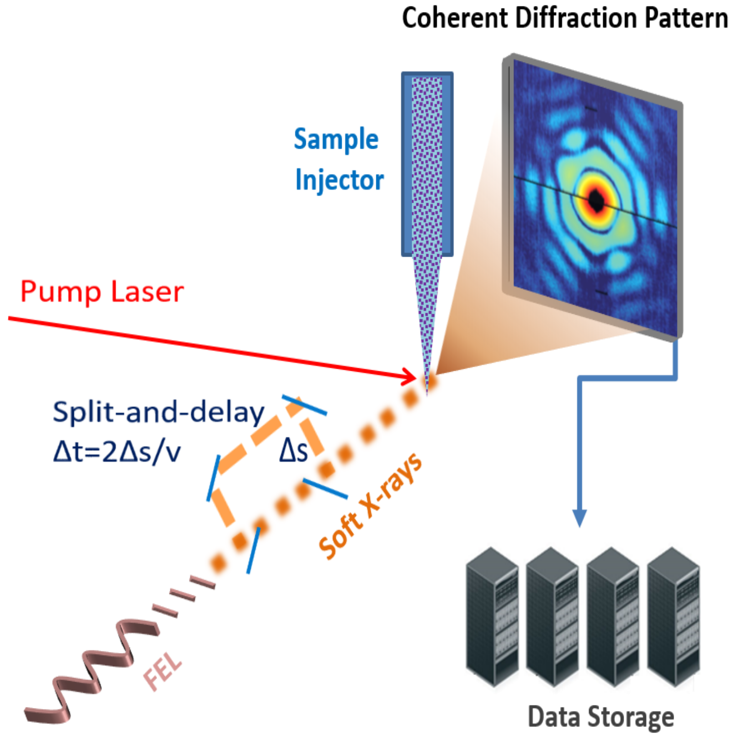


Coherent Imaging @ EuSPARC/EuPRAXA

2 key issues: brilliance and coherence of the FEL radiation

1 experimental station performing coherent imaging experiments

Many applications, ranging from biological systems to condensed matter physics

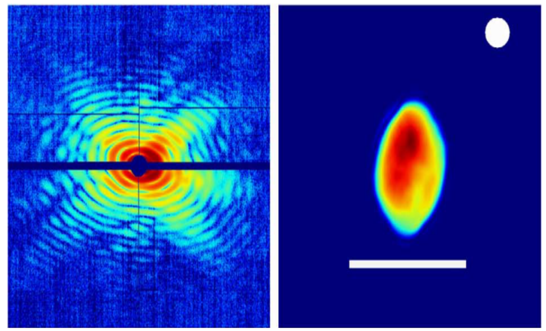


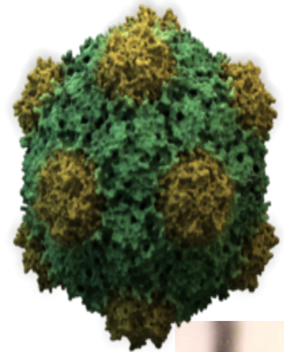
Water Window Coherent Imaging of biological systems

Energy region between oxygen and carbon K-edge

2D and 3D images of biological samples will be obtained

viruses, cells, organelles, protein fibrils…





Condensed-matter

High Temperature superconductors

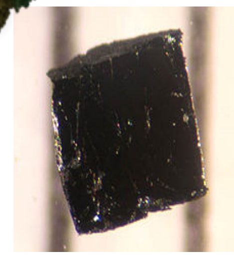
Metal-insulating transitions

Colossal magnetoresistance phenomena

Ferroelectrics & multiferroics materials

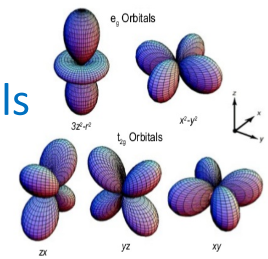
Skyrmions, spintronics

Nanoparticles and plasma



Colossal Magnetoresistance

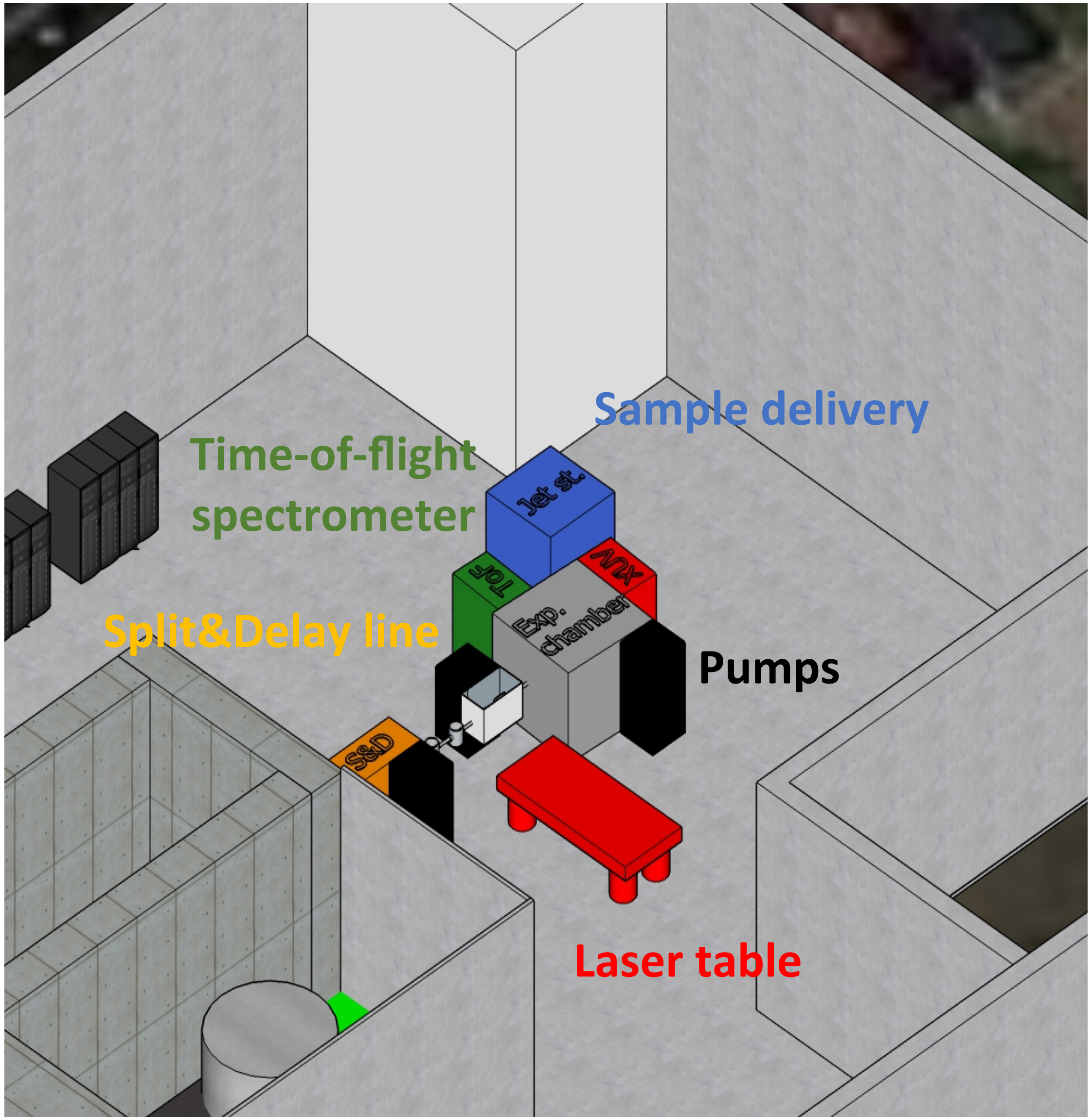
3d Orbital Types



The Experimental Endstation

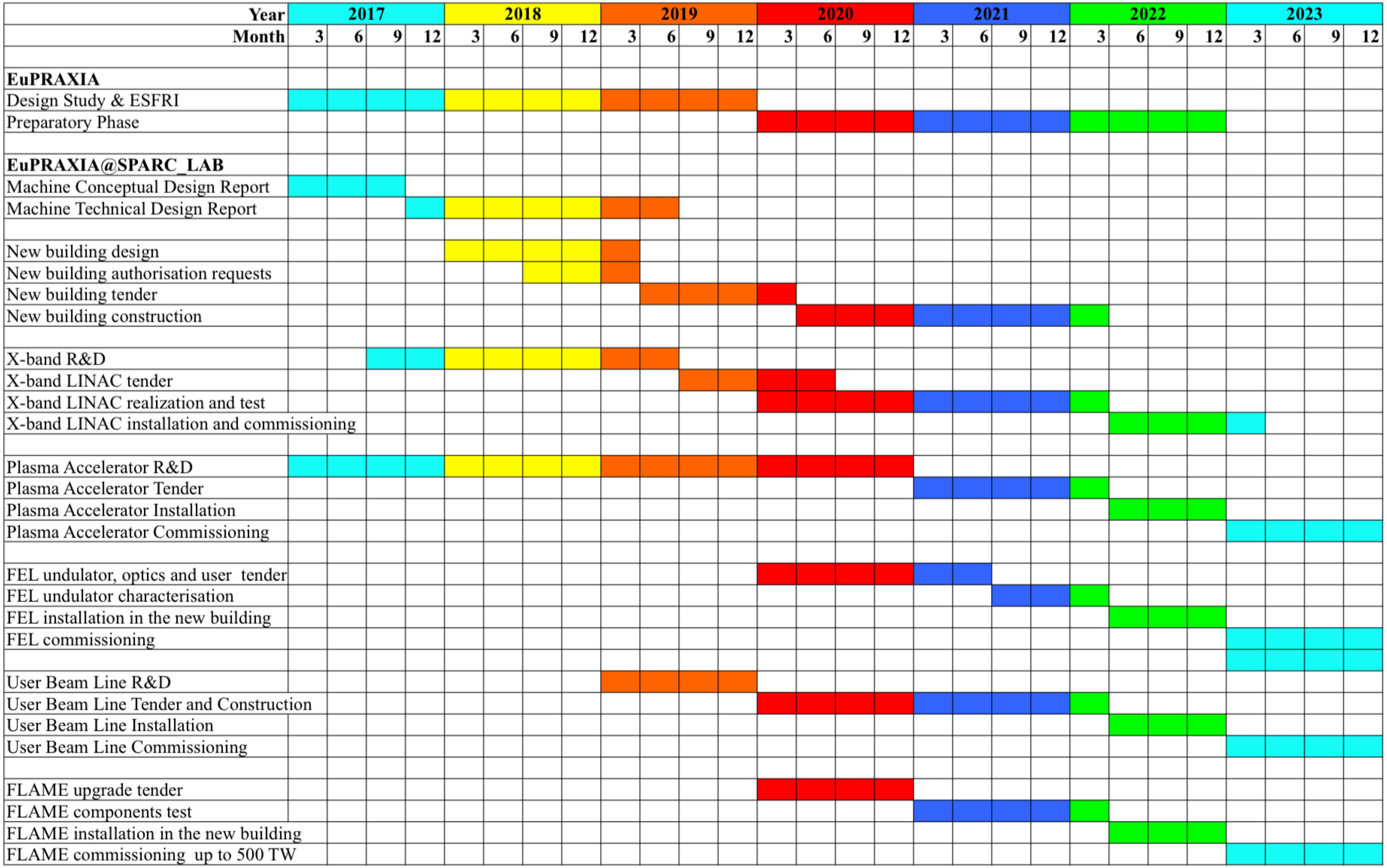
Parameters	Expected values
Radiation wavelength	2-4 nm (310-620 eV)
Photons per pulse*	$1\text{-}7 \times 10^{11}$
Pulse length (FWHM)	10-50 fs
Repetition rate	10-100 Hz
Bandwidth (FWHM)	1 eV

A versatile, state-of-the art, fully equipped experimental station (and a transport line) will be necessary to exploit the brilliant, ultra-short and coherent FEL pulses



EuPRAXIA@SPARC_LAB

EuPRAXIA@SPARC_LAB timeline



EuPRAXIA@SPARC_LAB

- X-band RF technology implementation,➔ CompactLight
- Science with short wavelength Free Electron Laser (FEL)
- Physics with high power lasers and secondary particle source
- R&D on compact radiation sources for medical applications
- Detector development and test for X-ray FEL and HEP
- Science with THz radiation sources
- Nuclear photonics with γ-rays Compton sources
- R&D on polarized positron sources
- Quantum aspects of beam physics, Quantum-FEL development
-
- R&D in accelerator physics and industrial spin – off