SPARC_LAB – EuSPARC status

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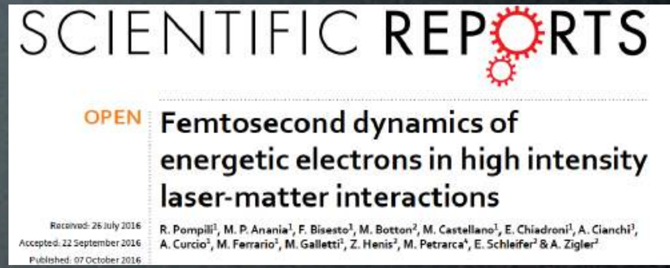
On behalf of the SPARC_LAB – EuSPARC collaboration

LNF Scientific Committee Meeting, November 21, 2016

Highlights

- TNSA: results published by Nature Scientific Reports
- PWFA: active plasma lens results submitted to PRL
- LWFA: self-injected beam accelerated up to > 200 MeV, betatron radiation detected, accelerated charge measured
- EuSPARC design study in progress, layout , linac and FEL studies


SCIENTIFIC REPORTS

OPEN Femtosecond dynamics of energetic electrons in high intensity laser-matter interactions

Received: 26 July 2016
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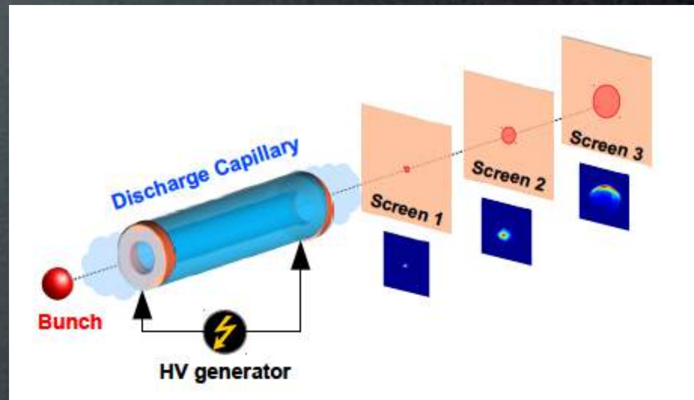
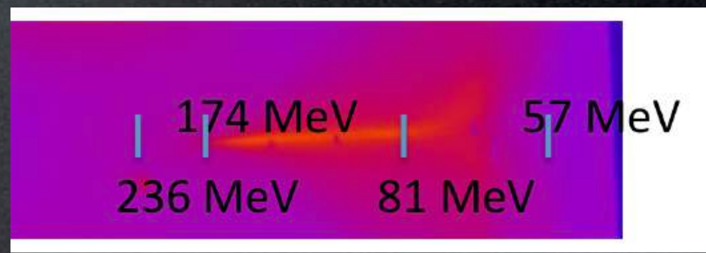
R. Pompili[1], M. P. Anania[1], F. Bisesto[1], M. Botton[2], M. Castellano[1], E. Chiadroni[1], A. Cianchi[3], A. Curcio[1], M. Ferrario[1], M. Galletti[3], Z. Henis[2], M. Petrarca[4], E. Schleifer[2] & A. Zigler[2]



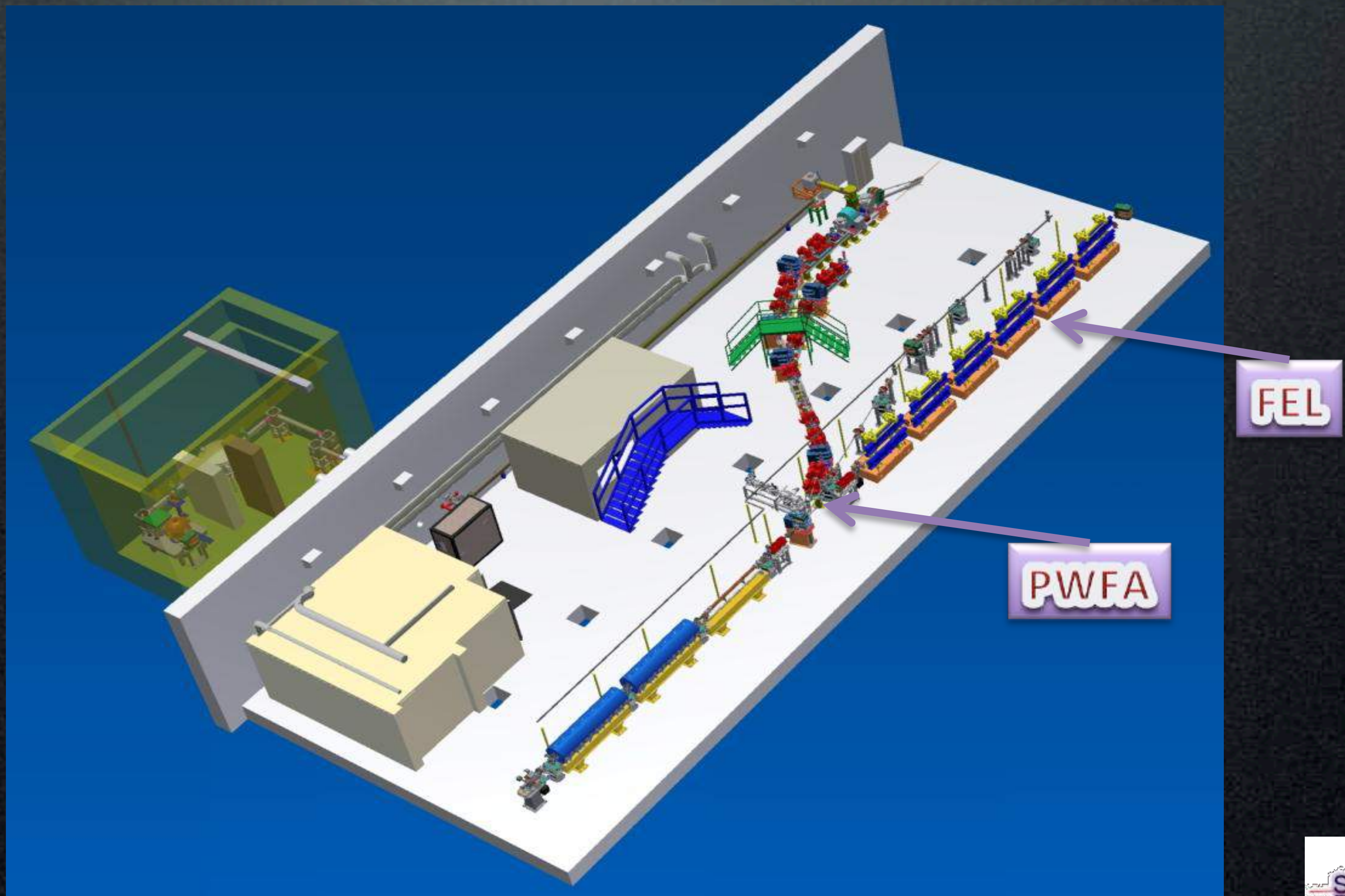


Lowlights

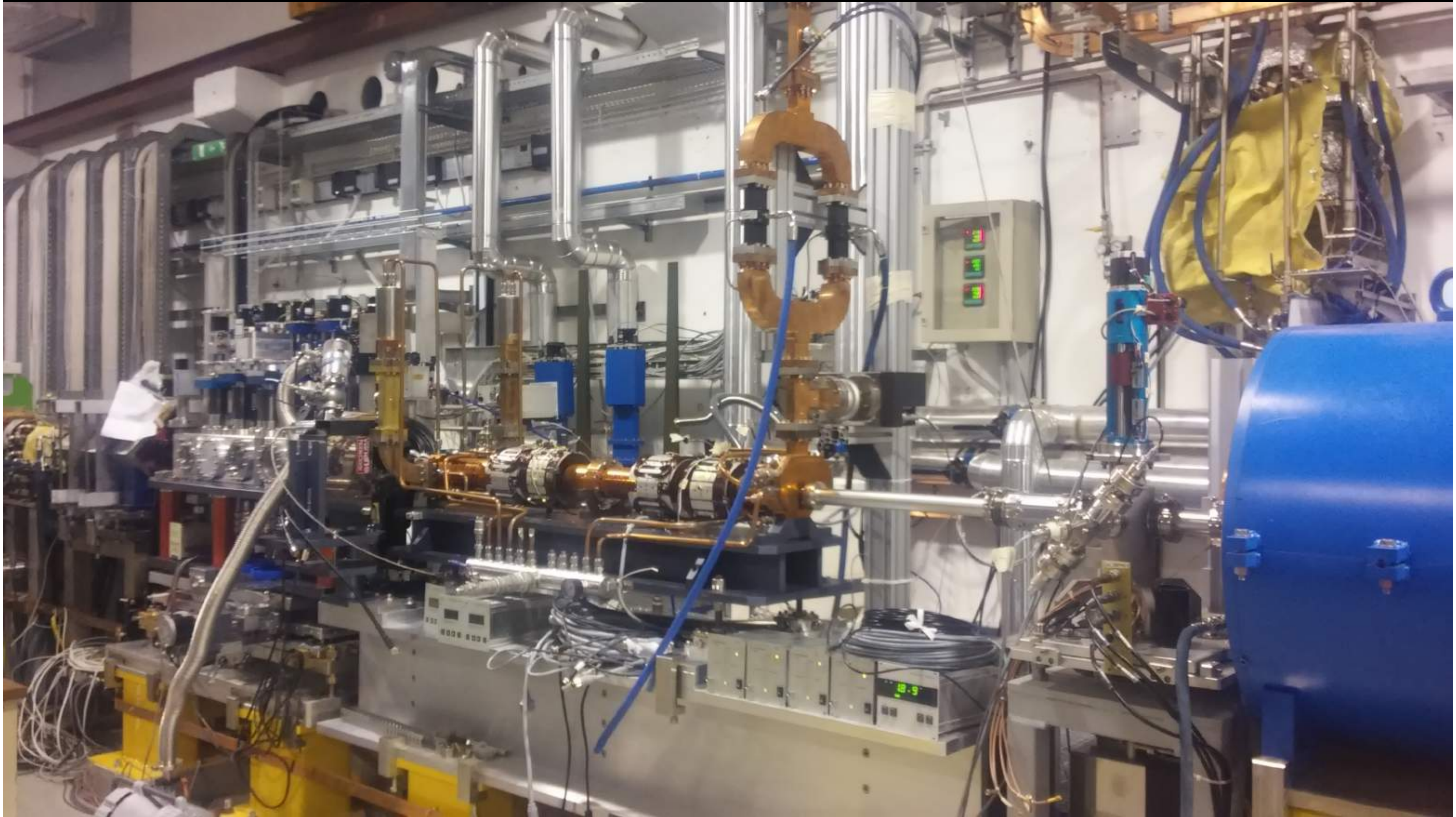
- A fire accident has stopped suddenly FLAME operations: a pump laser completely burned, no interlocks on laser temperature provided by the company.

- Severe discharges on the C-band Modulator/Klystron socket produced a big hole in the inner transparent basement (the one that holds the electrical joint to Klystron)

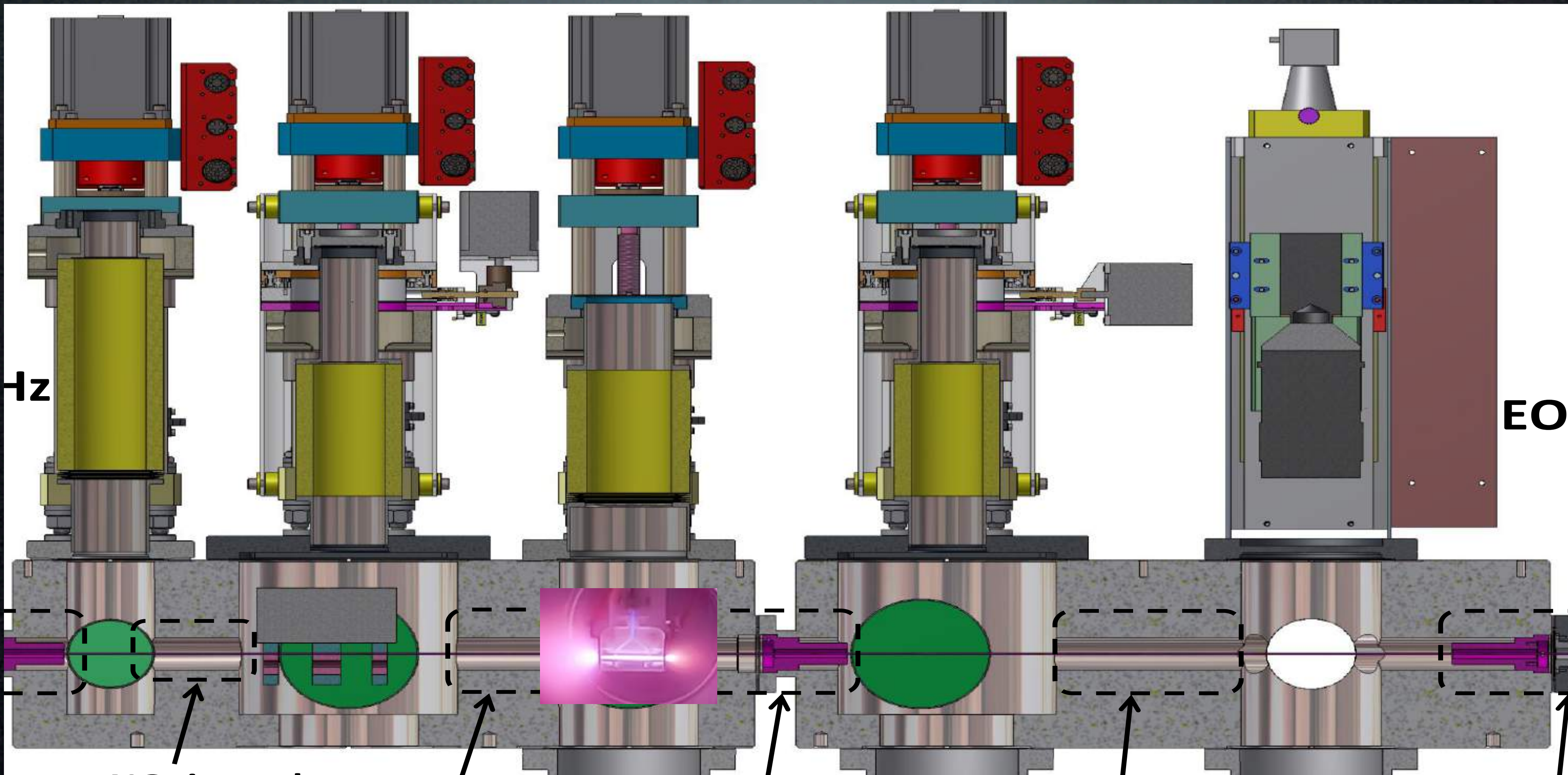
Active Plasma Lens experiments



PWFA experimental layout :



PWFA – plasma target

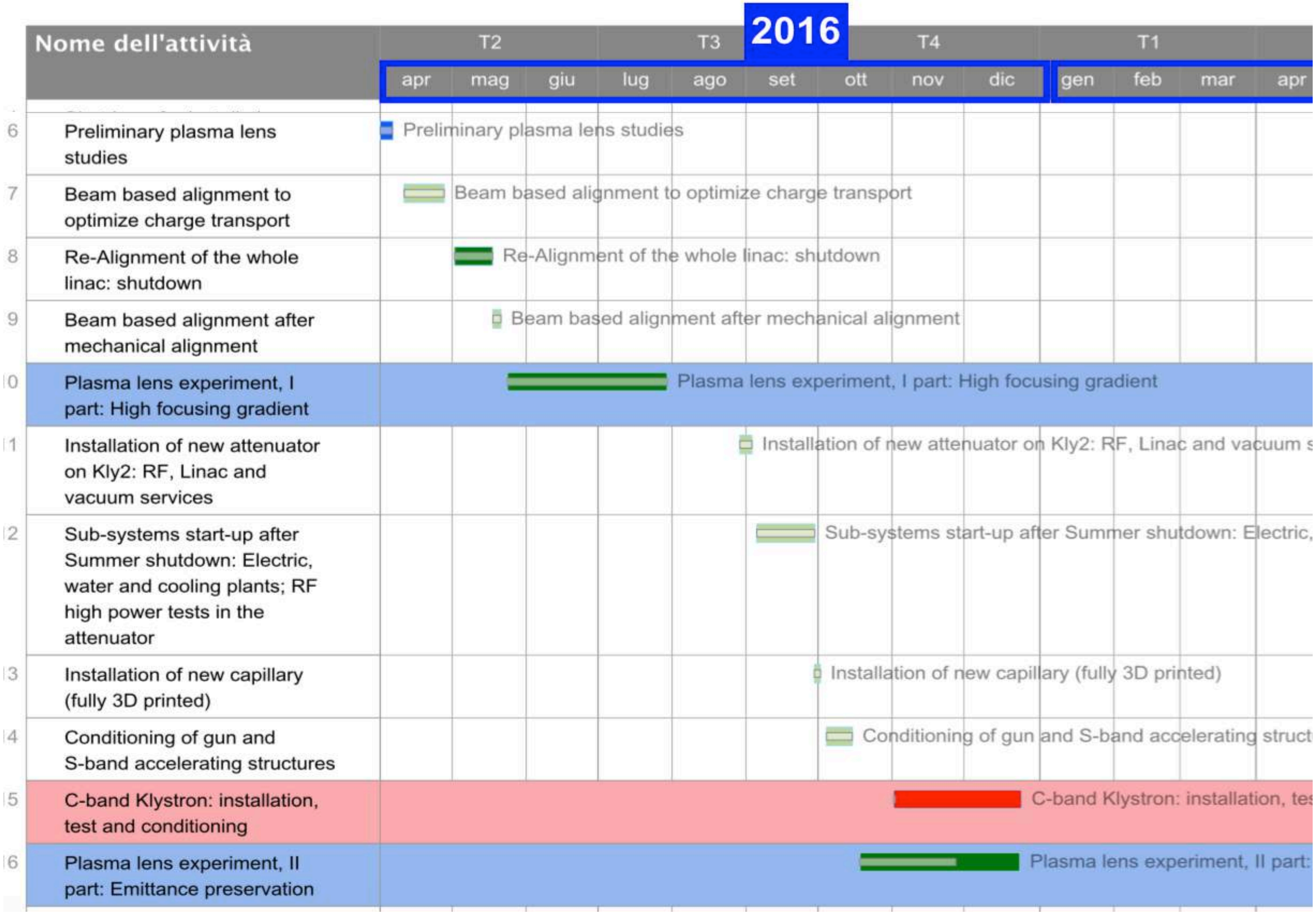


Focusing PMQ

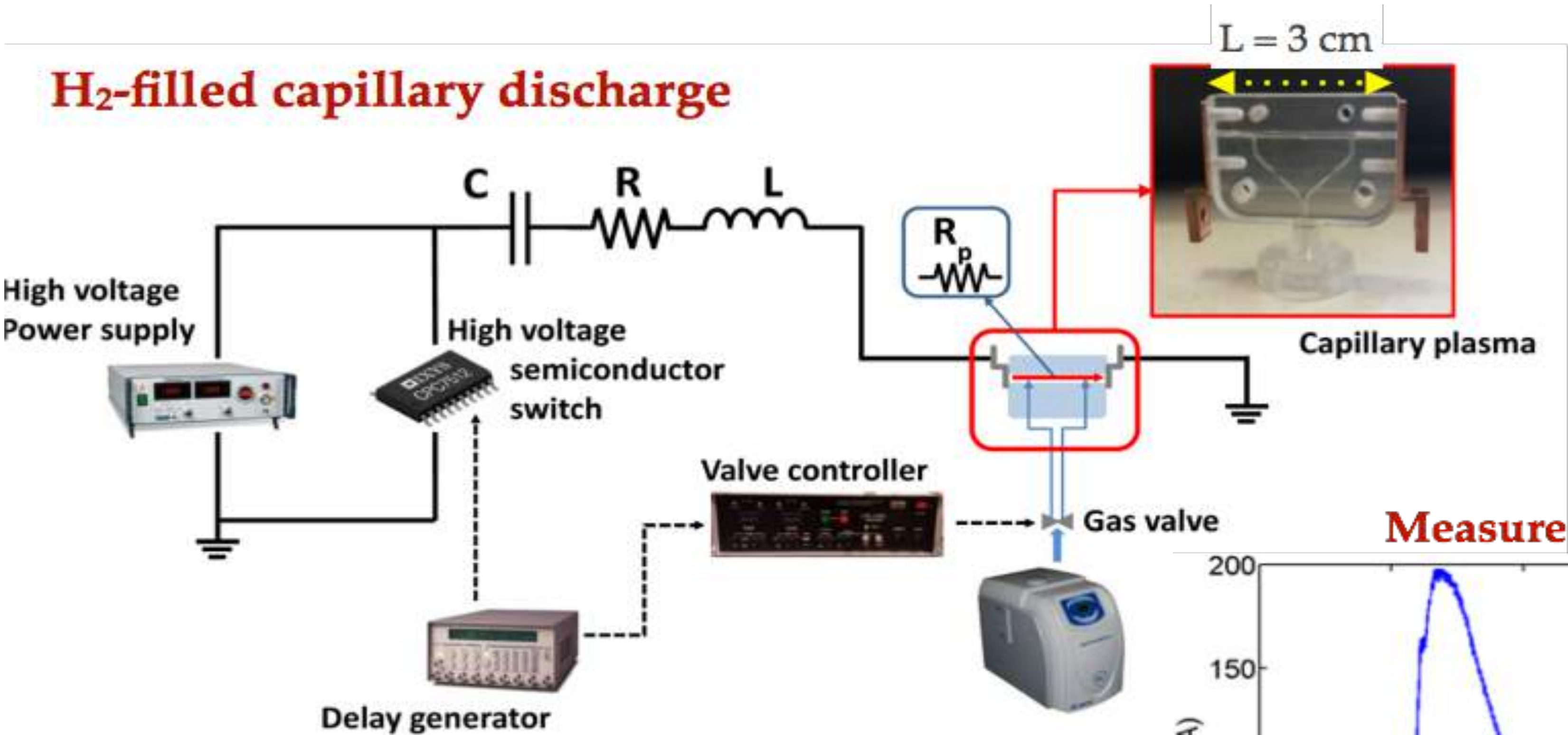
PWFA module

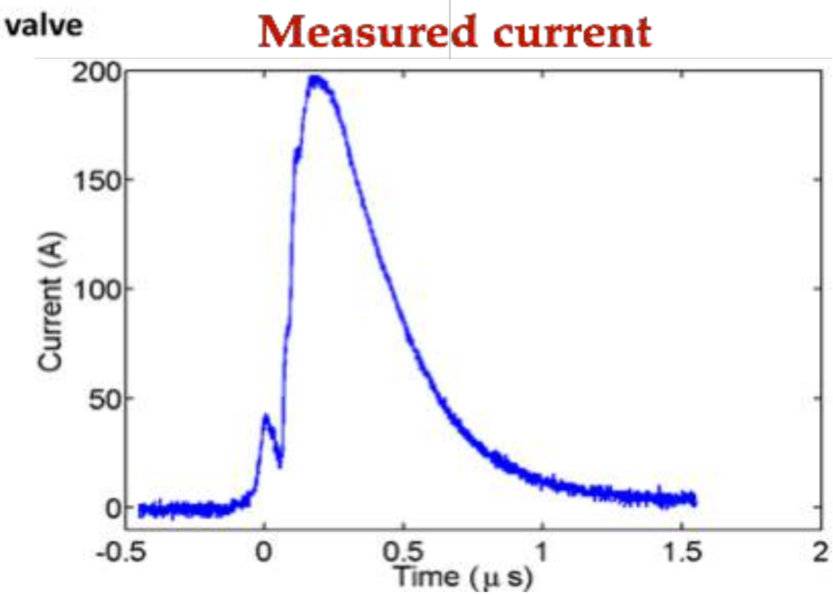
Capture PMQ

April - December 2016



Plasma Source





P_{H2} = 10 mbar
Total discharge duration: 800 ns
Voltage: 20 kV
Peak current: 200 A
Capacitor: 6 nF

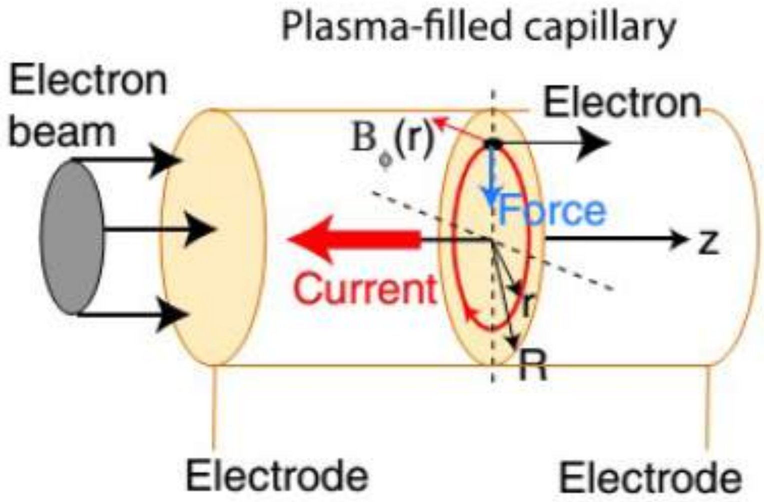
Courtesy of M. P. Anania, A. Biagioni, D. Di Giovenale, F. Filippi, S. Pella

Active plasma lens

- Focusing field produced by electric discharge in a plasma-filled capillary
  - *Focusing field produced, according to Ampere's law, by the discharge current*

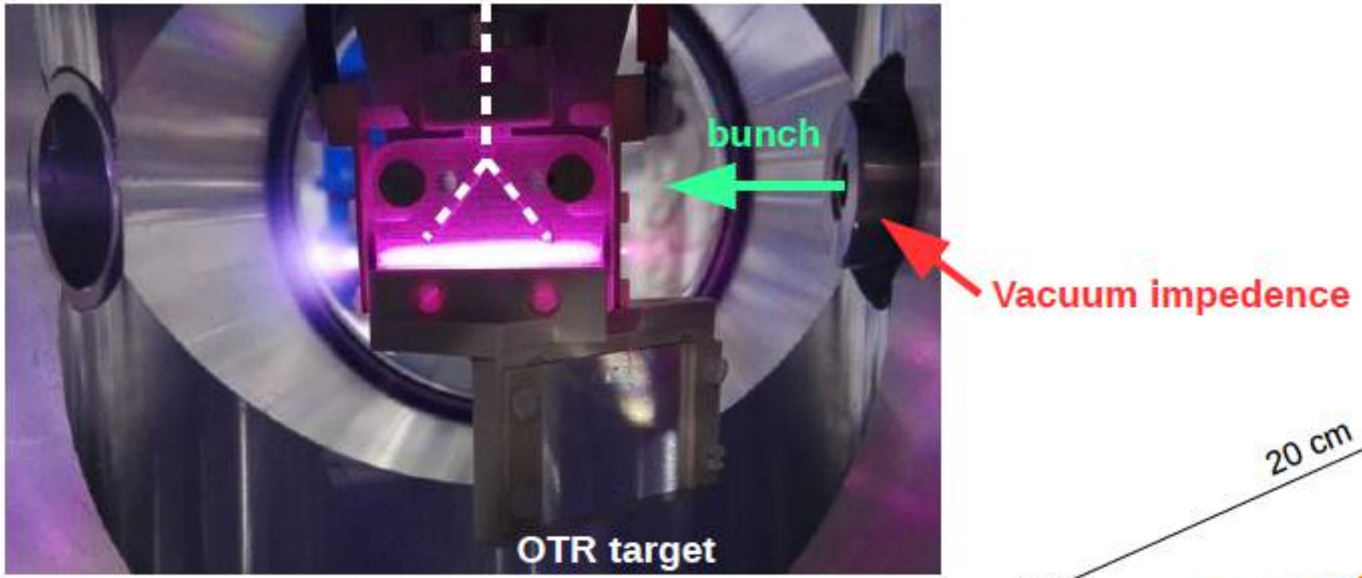
$$B_{\phi}(r)=\frac{1}{2}\int_{0}^{r}\mu_{0}J(r')\,dr'$$

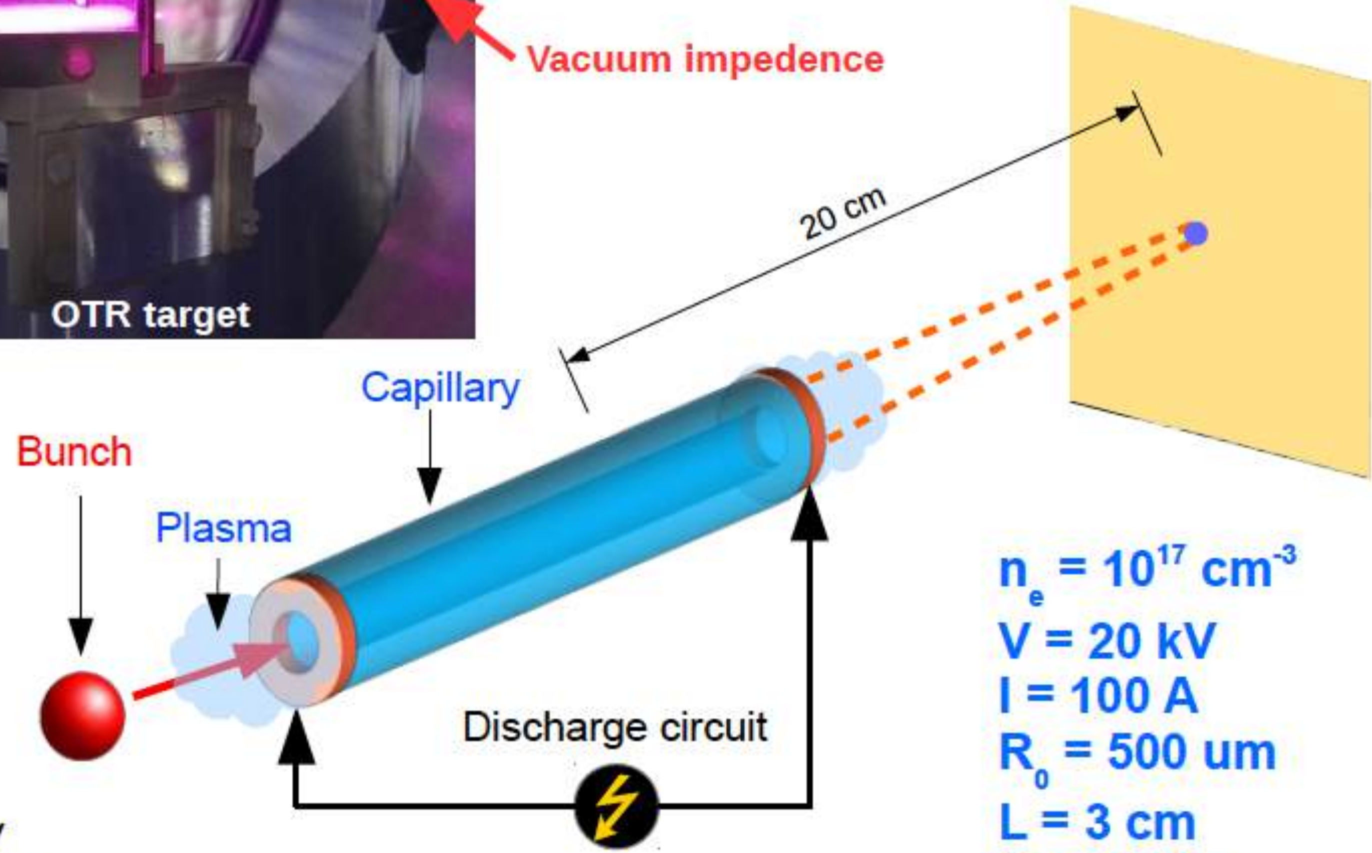
- ✔ Radial focusing
  - *X/Y planes are not dependent as in quads*
- ✔ Weak chromaticity
  - *Focusing force scales linearly with energy*
- ✔ Compactness
  - *Higher integrated field than quad triplets*
- ✔ Independent from beam distribution
  - *Not sensitive to longitudinal/transverse charge profile as in passive plasma lenses*



Van Tilborg, J., et al. "Active plasma lensing for relativistic laser-plasma-accelerated electron beams." Physical review letters 115.18 (2015): 184802.

Experimental layout

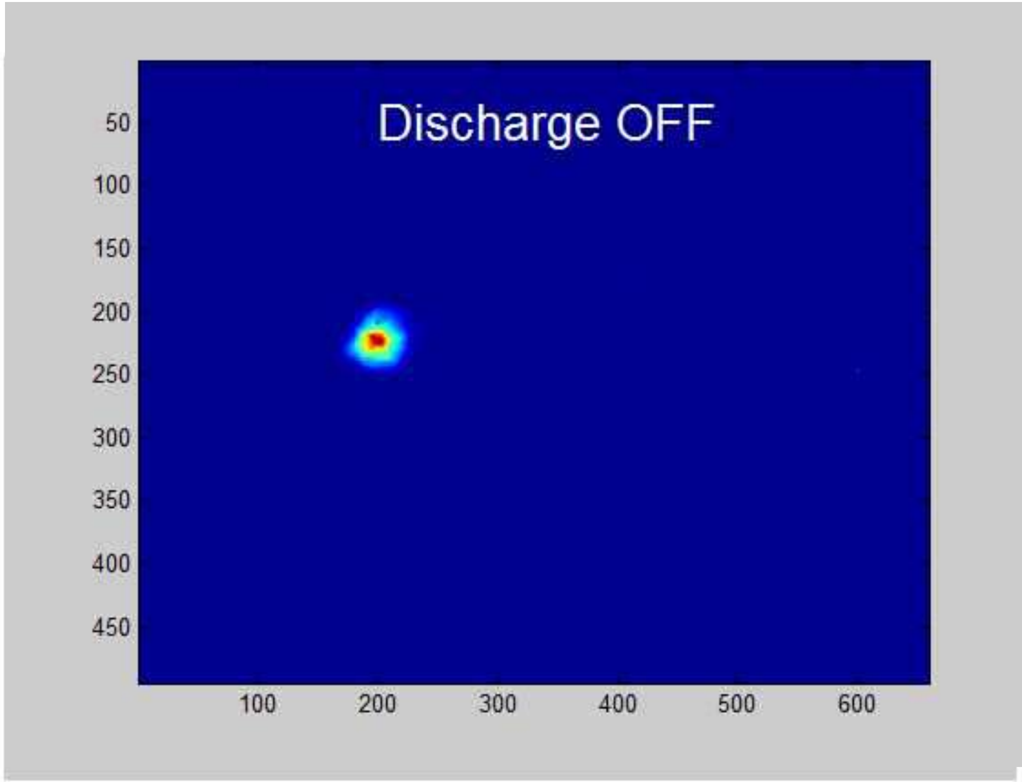


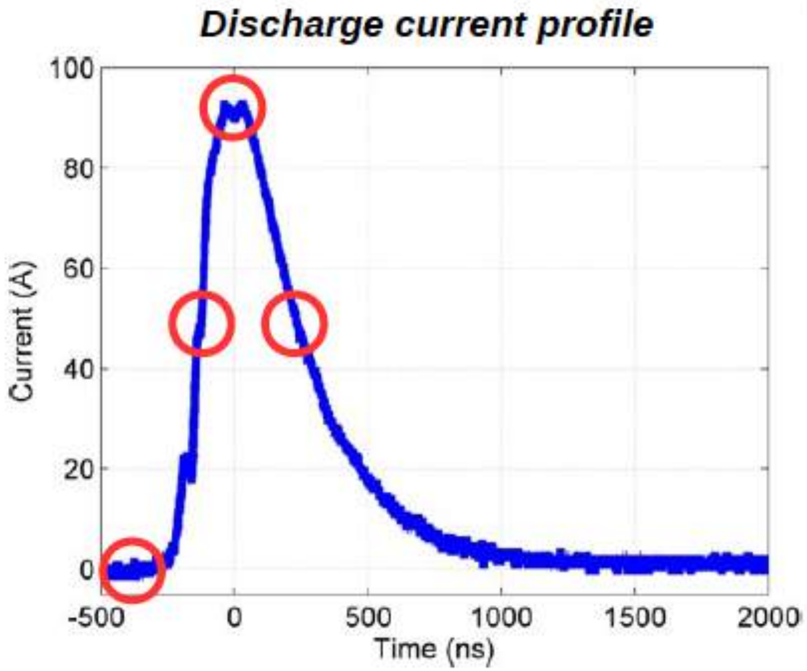


50 pC
1 ps
130 um
120 MeV
1 mm mrad

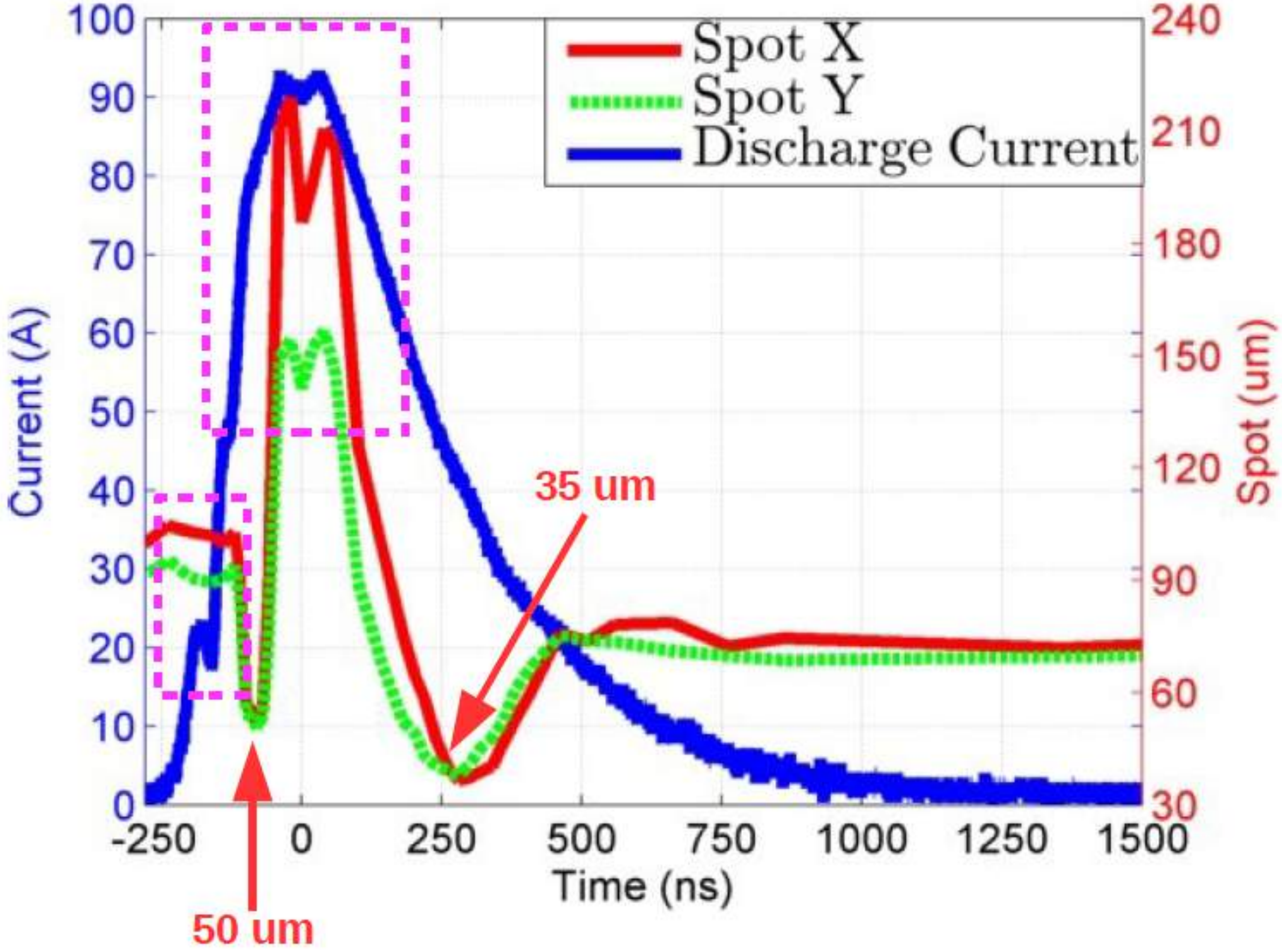
n_e = 10^{17} cm^{-3}
V = 20 kV
I = 100 A
R_0 = 500 um
L = 3 cm
Sapphire

Preliminary results

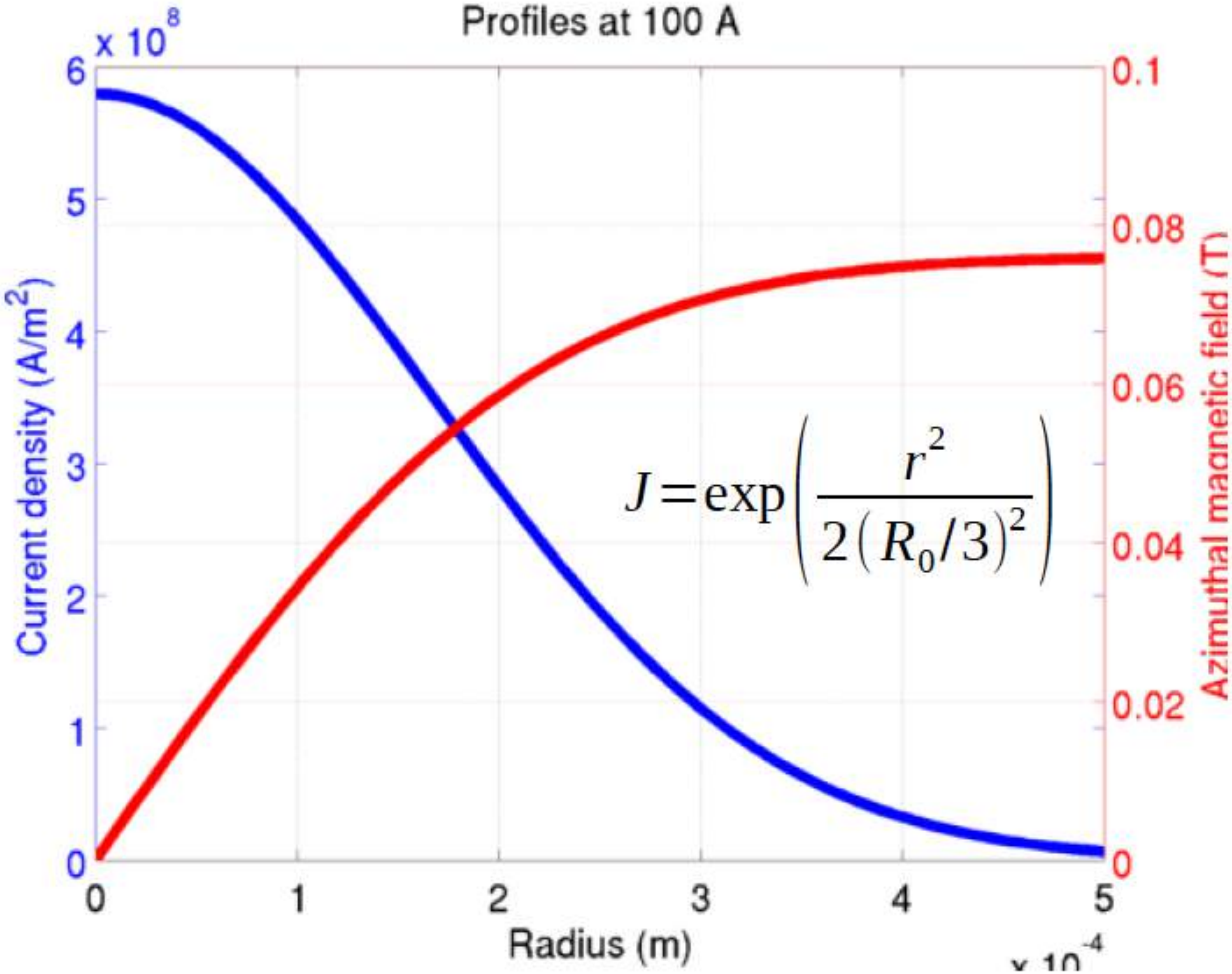




Preliminary results

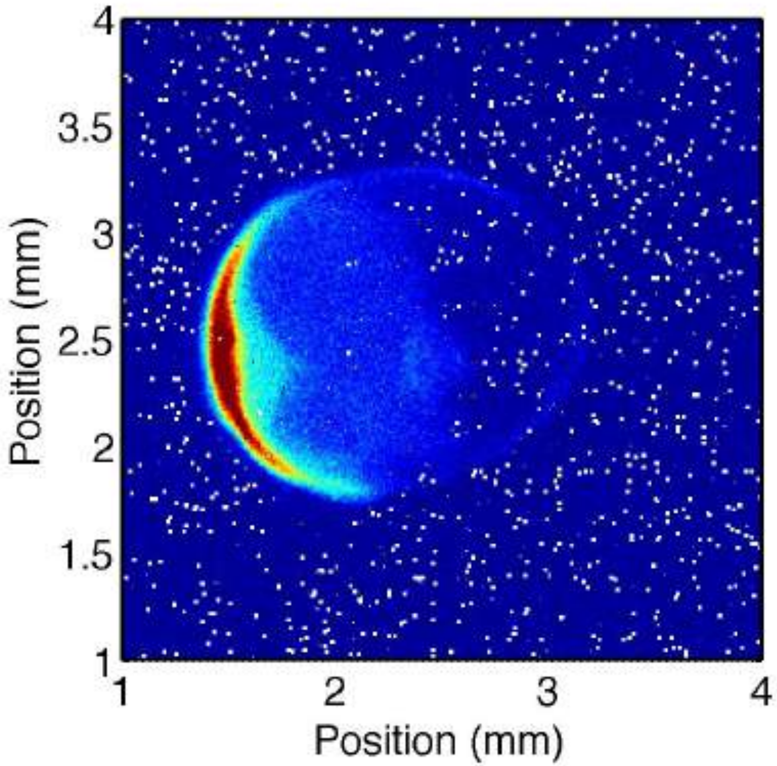


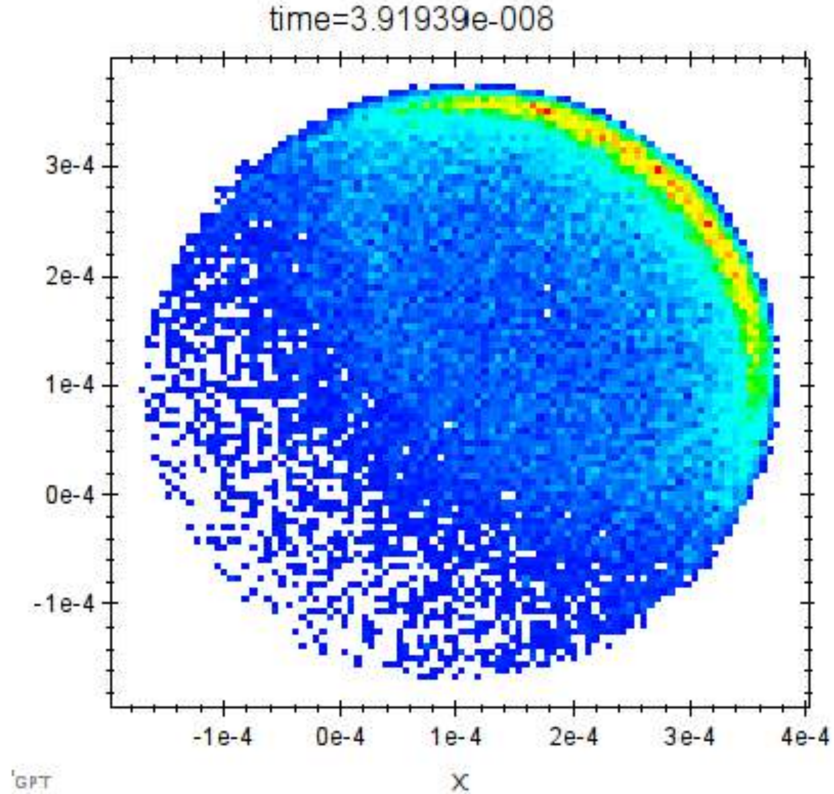
Gaussian current profiles



$$J = \exp\left(\frac{r^2}{2\left(R_0/3\right)^2}\right)$$

Over focusing (max current)

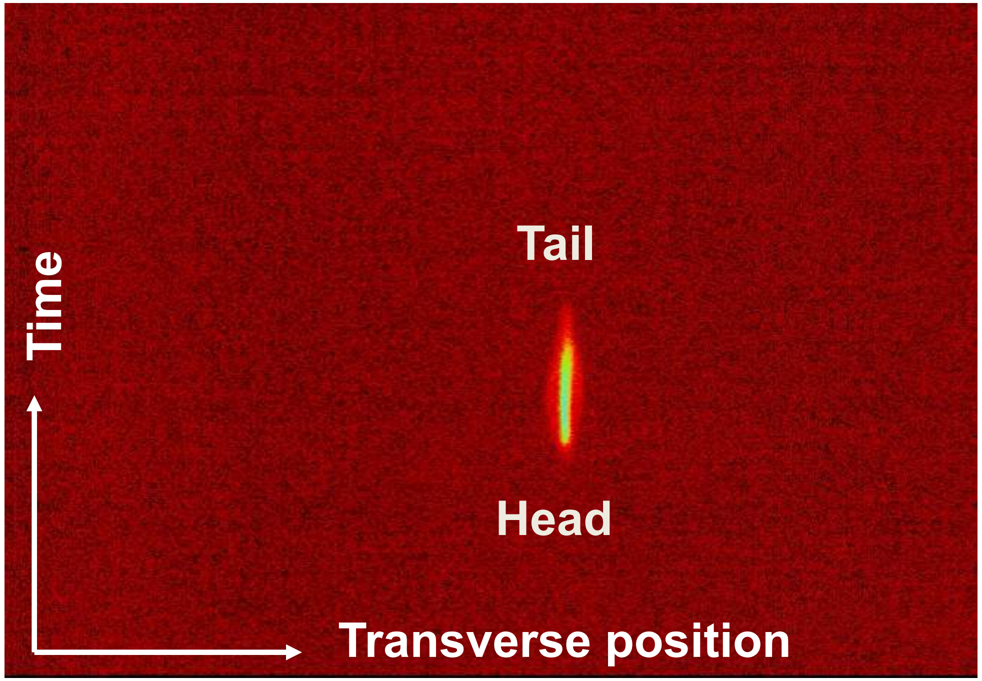




100 um offset

Head-tail instability induced by dielectric wakefield

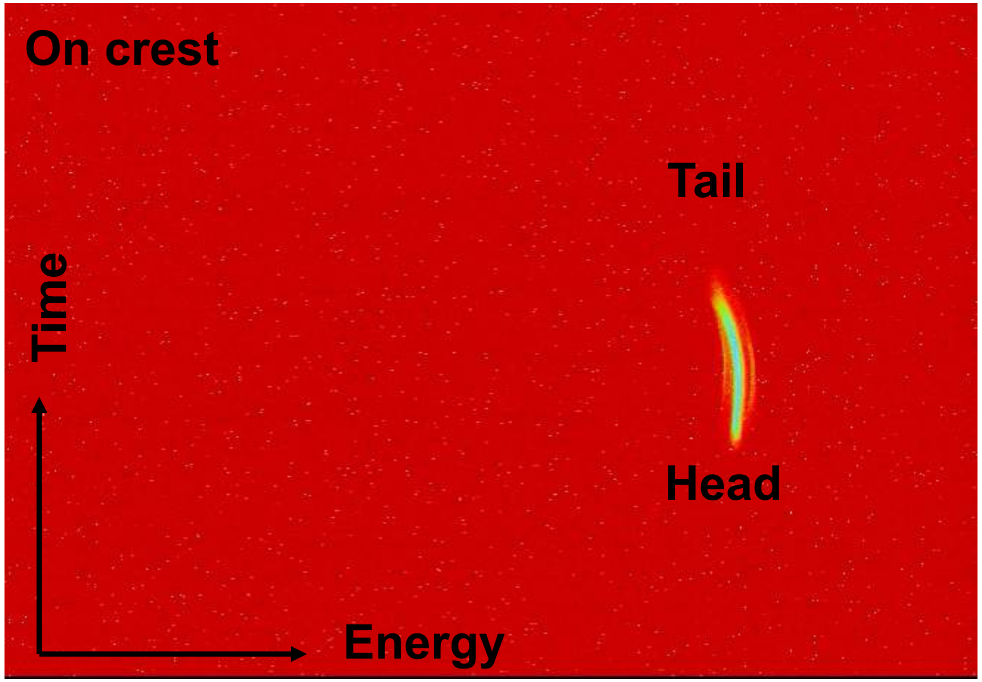
Rf Deflector on



The tail is moving with respect to the head

$$eE_r \cong -\frac{2N_b r_e m_e c^2}{\sqrt{2\pi}\sigma_z a}\exp\left(-\xi^2/2\sigma_z^2\right)$$

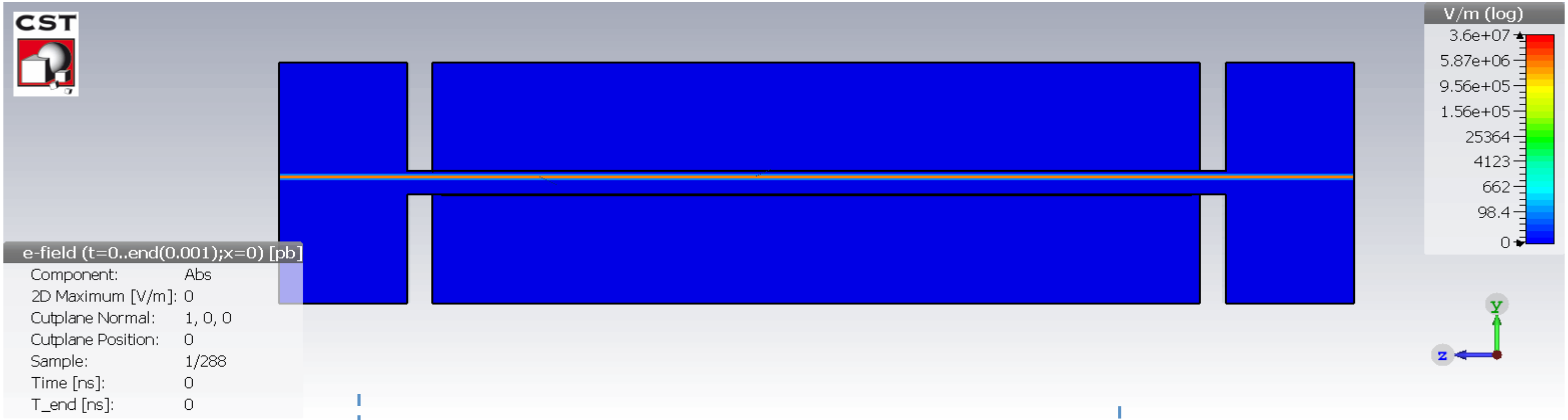
Longitudinal phase space

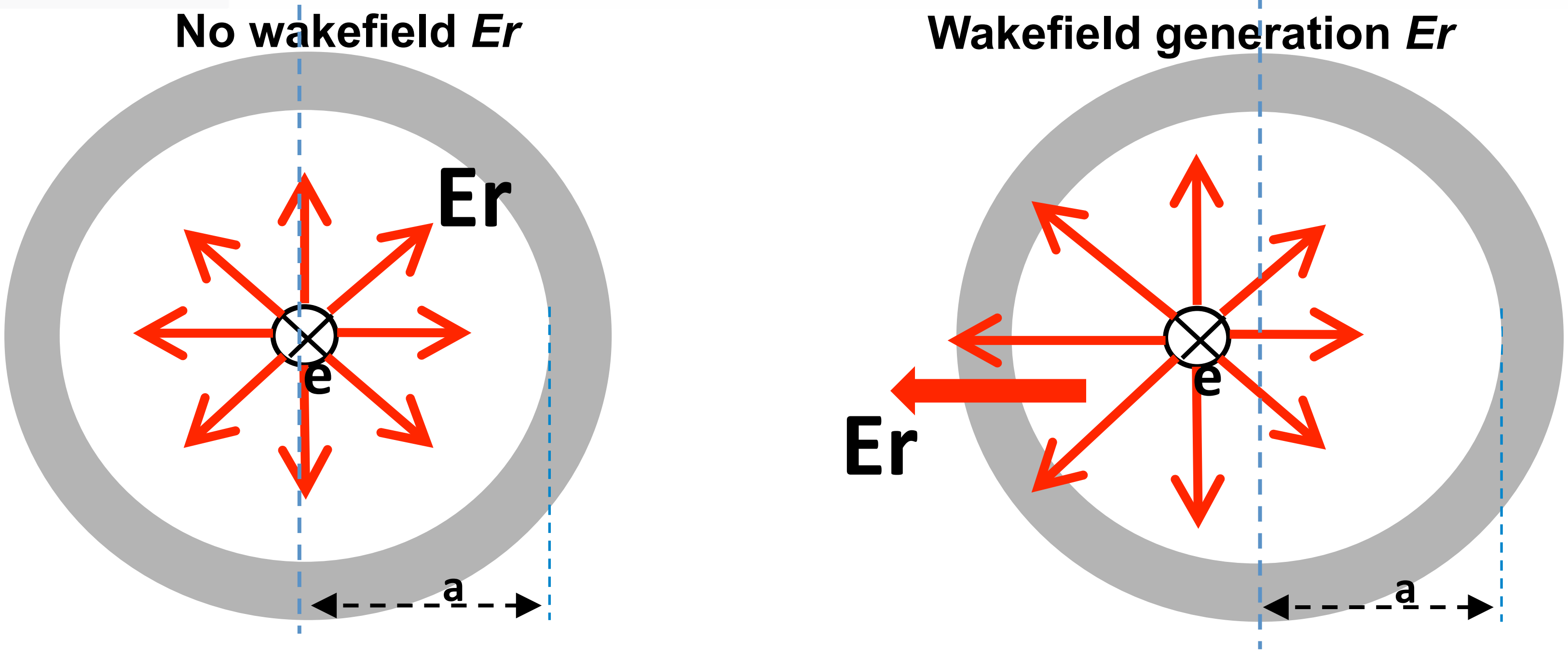


Induced energy spread

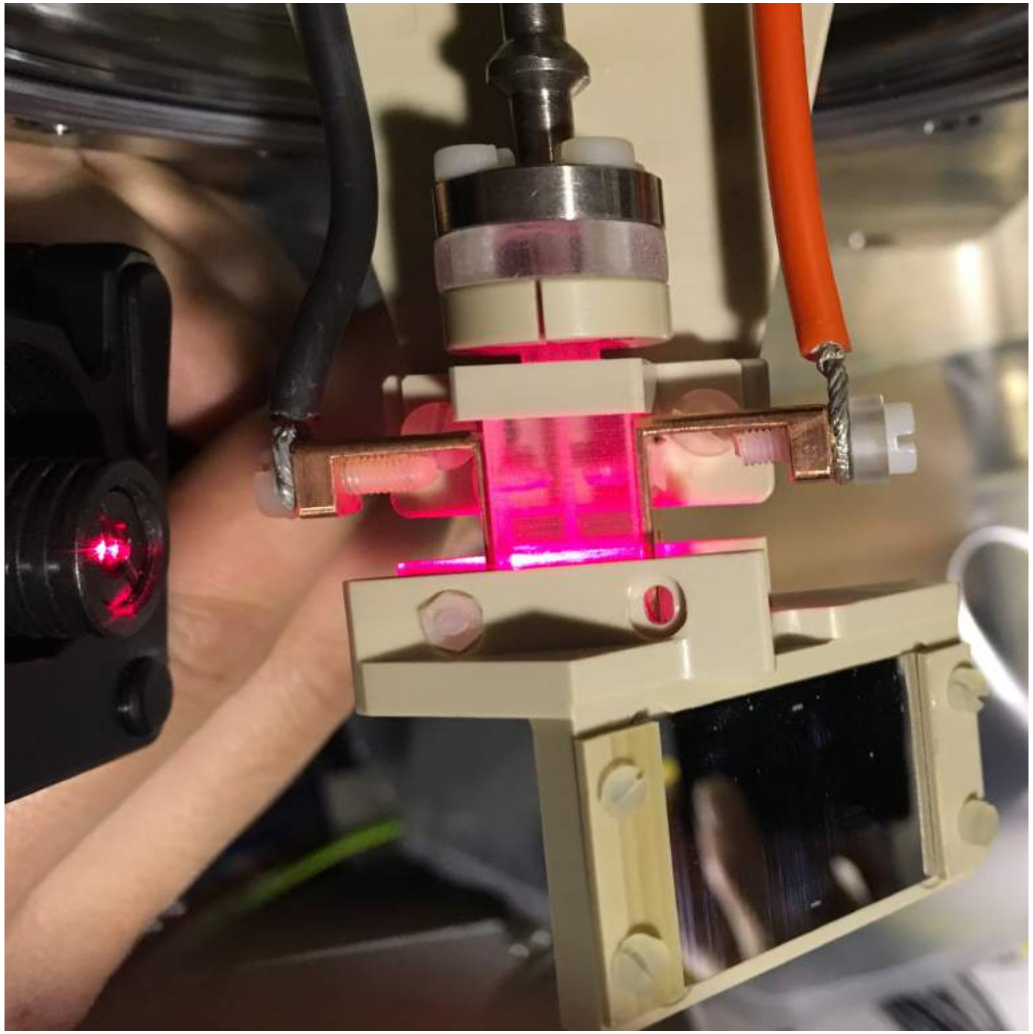
$$E_z / E_r = \tan(\theta_c) = \sqrt{\varepsilon - 1}$$

Dielectric Wakefield

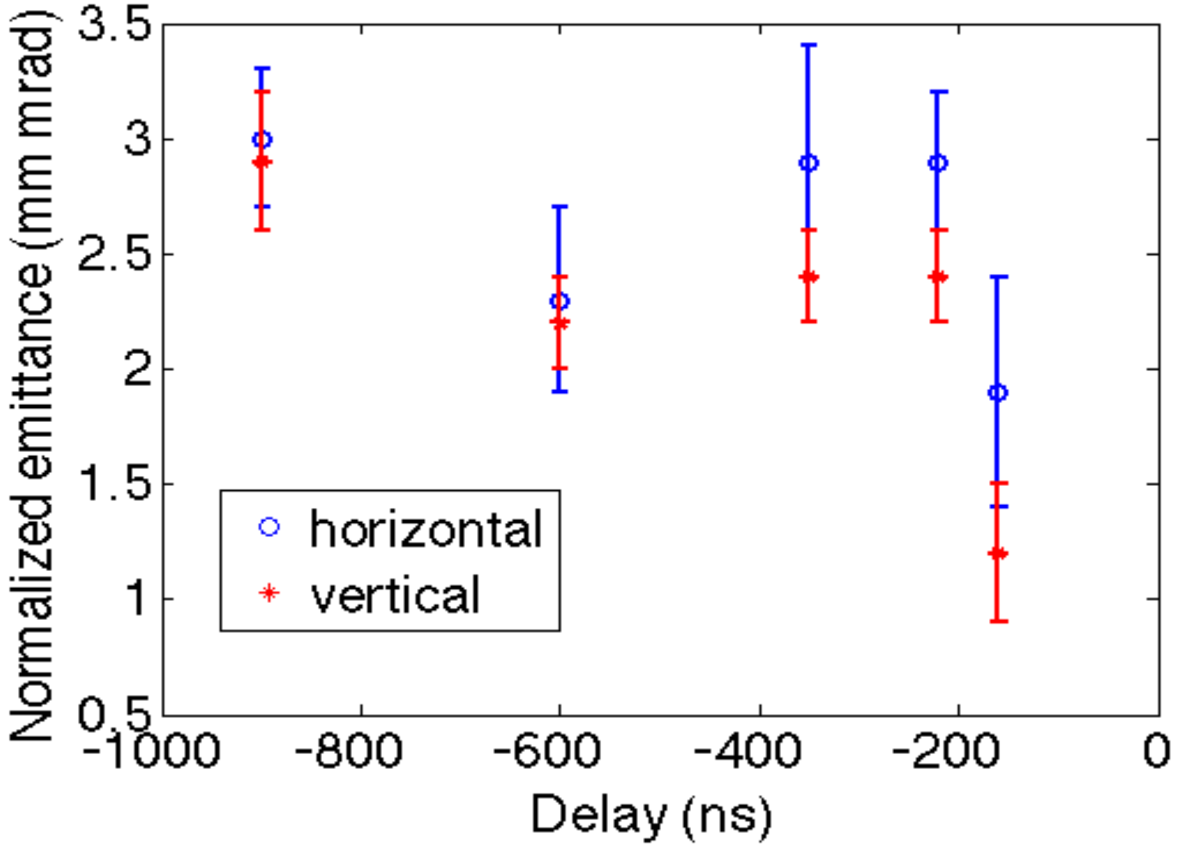




- 1 cm long, 1 mm diameter, fully 3D printed capillary



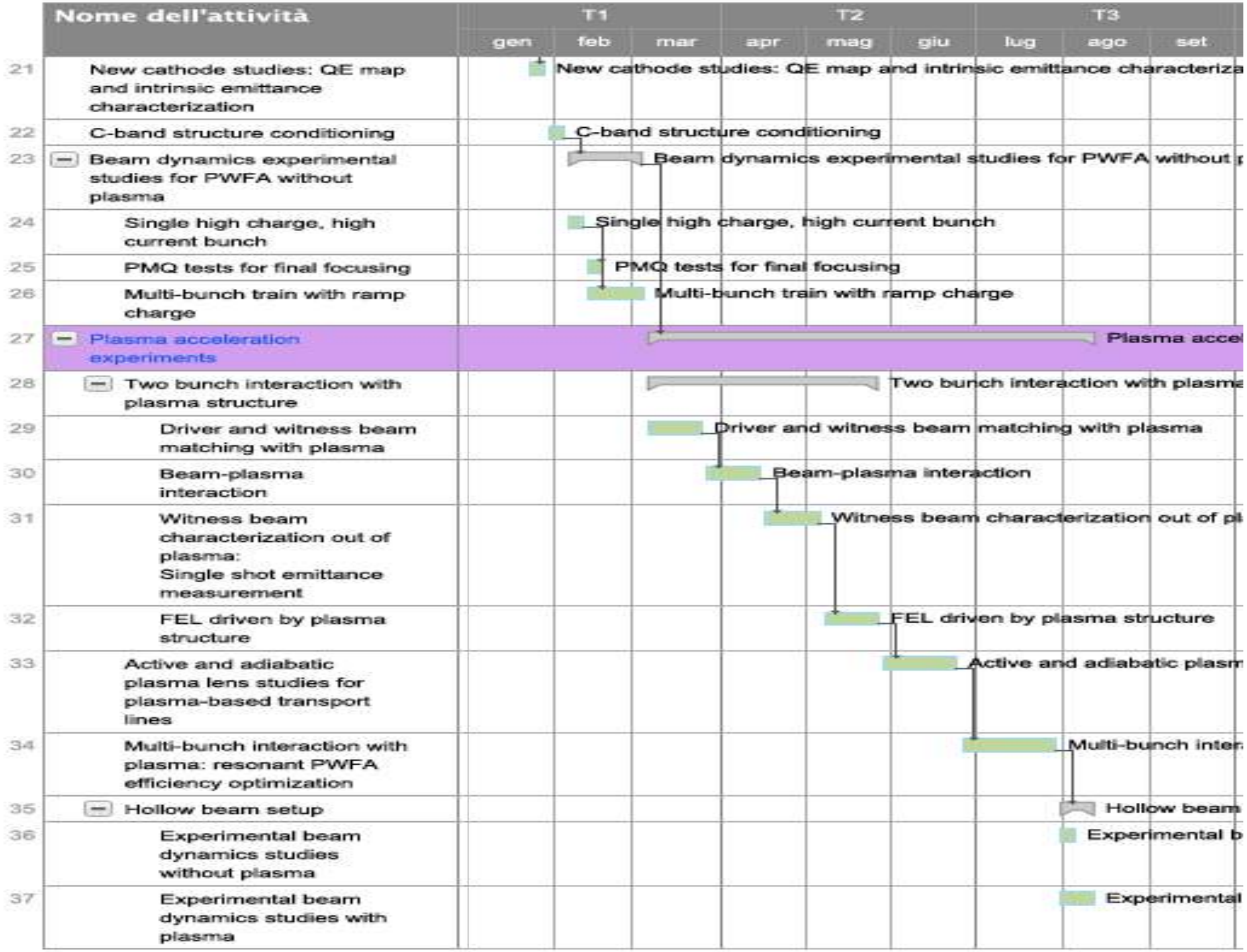
Electron beam parameters
50 pC (at the cathode)
85% transmission through the capillary
126 MeV (0.3‰ energy spread)
1 ps rms bunch length



Milestones achieved so far

- **31-05-2016**
  - Alignment of accelerating sections and solenoid magnets
  - Full transport of the beam charge through the 1 mm capillary diameter
  - Characterization of permanent quadrupole magnets (PMQ) at ENEA (C. Ronsivalle and L. Picardi)
- **31-07-2016**
  - Active plasma lens experiment
    - Preliminary measurement to demonstrate symmetric strong focusing effect
- **30-09-2016**
  - New RF power distribution line to unbalance forward power in S-band structures
  - Installation of EM quadrupole triplet at the end of the 2nd S-band structure to control beam matching at the plasma
- **21-11-2016**
  - Systematic study of active plasma lens with different capillary geometries and materials
    - Better control of emittance

January - August 2016



Program weakness :Discharges on the socket

Very big hole in the inner transparent basement (the one that holds the electrical joint to Klystron), but we cannot understand where from and to the discharge comes.

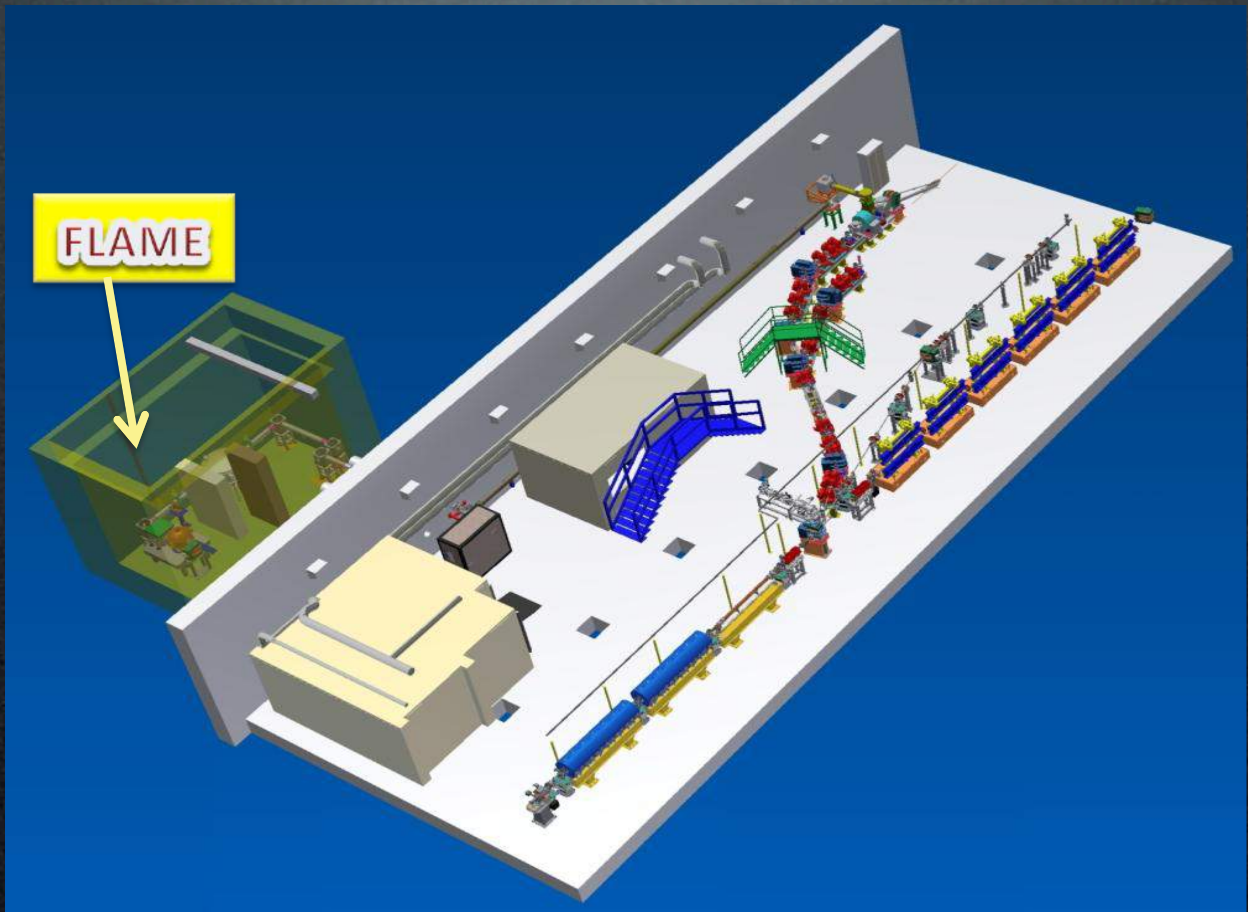
We run at nominal parameters monitoring all signals from the system without particular alarms and interlocks.

Actions

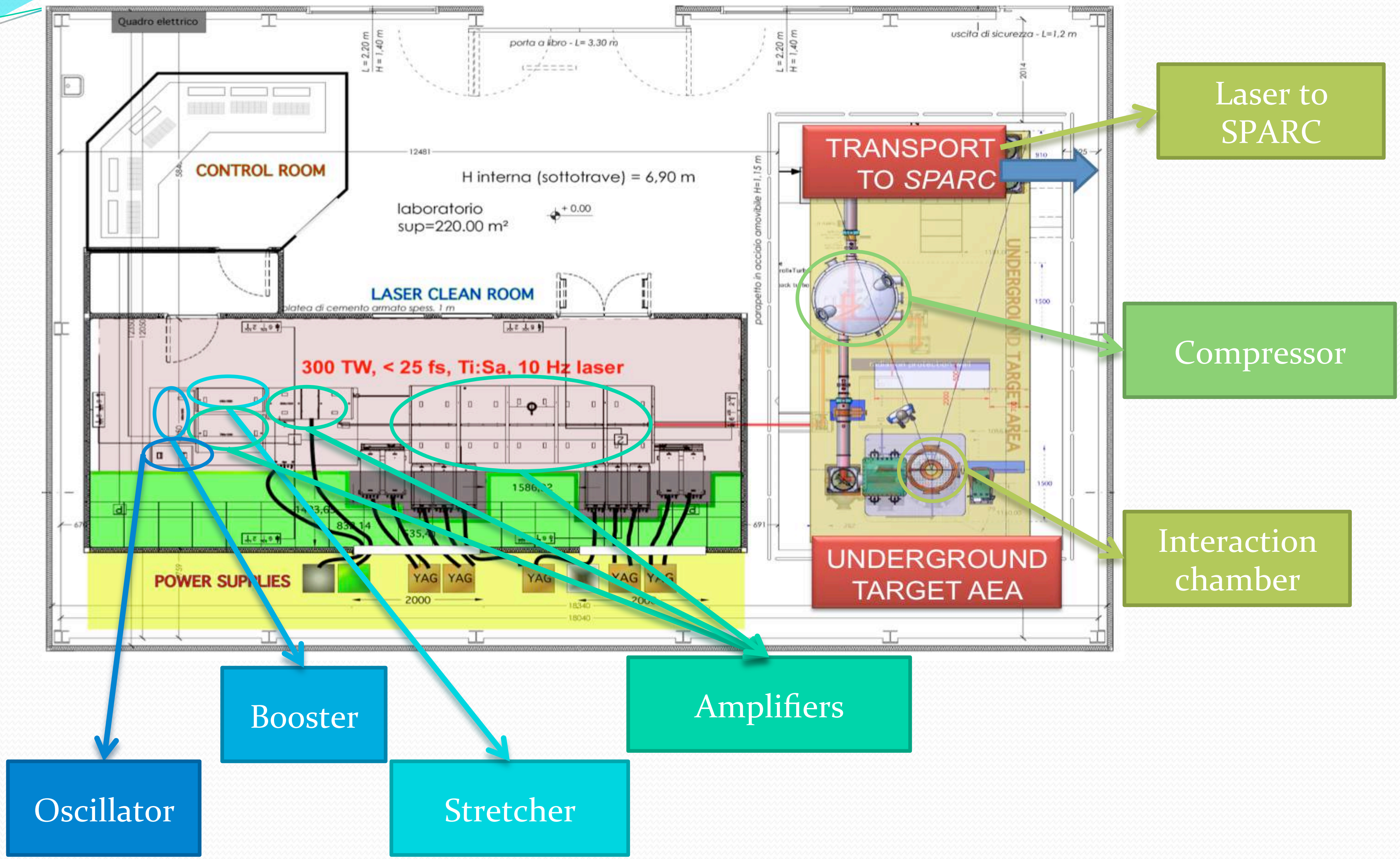
We asked to Scandinova a rapid intervention on the modulator to replace (upgrade) the broken parts and to definitively solve the problem.

This obviously drive to the conclusion that there were critical components in the modulator we bought from Scandinova.

FLAME Laser



FLAME @ SPARC_LAB



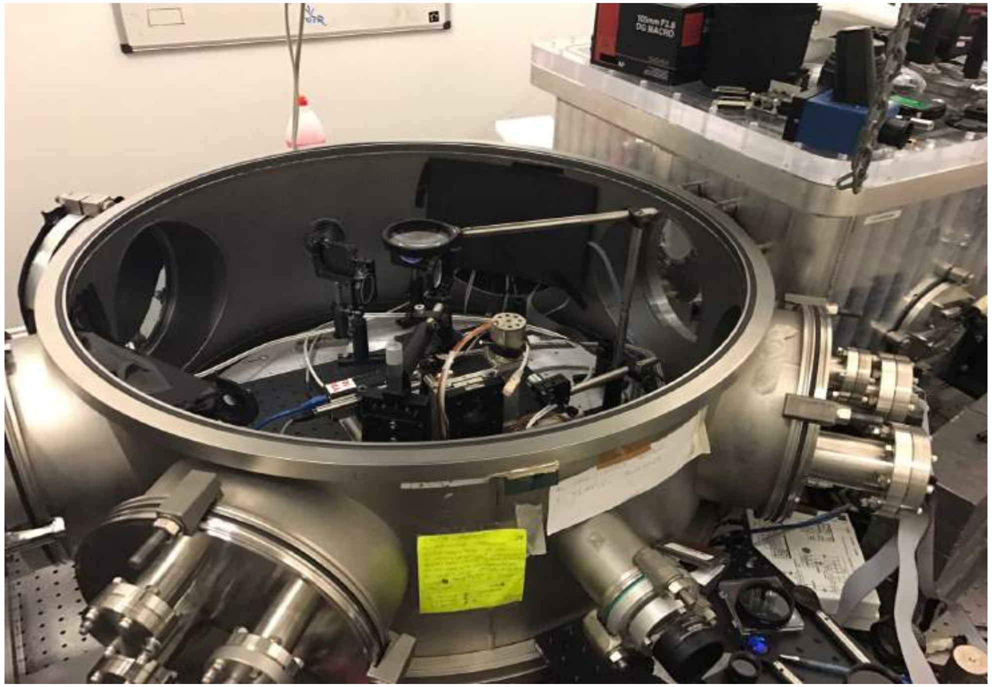
FLAME activities since last SciCom

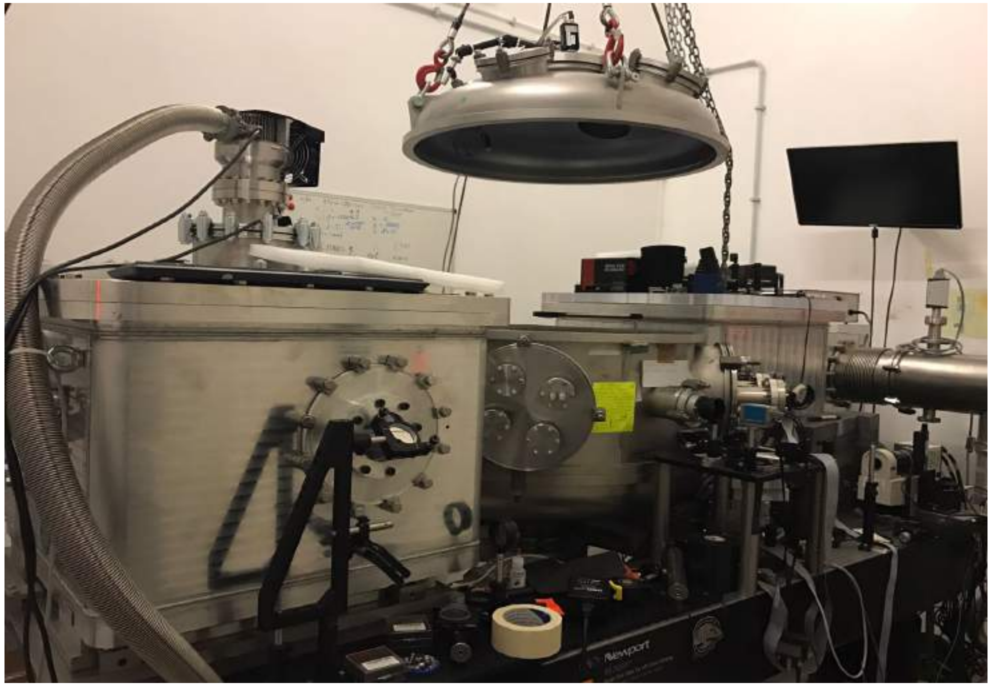
From May to now…

Activity	Start date	End date
LWFA experiments	01/05/2016	03/08/2016
Restart after summer	05/09/2016	03/10/2016
YAG 9 updated, installed and tested	03/10/2016	17/10/2016
Fire accident on YAG 6	17/10/2016	
New FLAME interaction chamber design and ordering	04/07/2016	Order will be placed in March

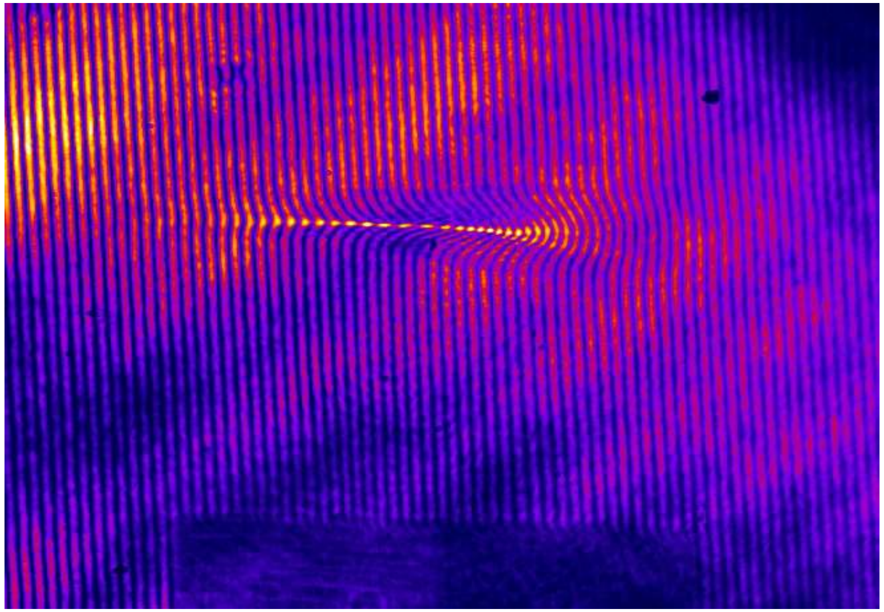
FLAME activities

Experimental set-up



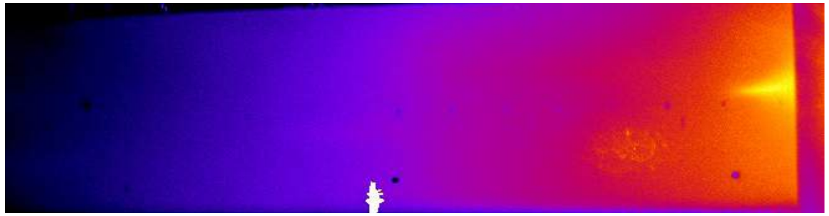


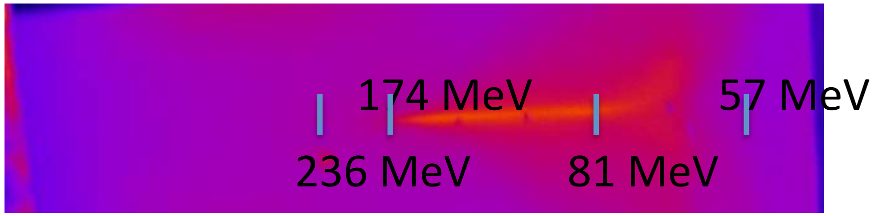
FLAME activities

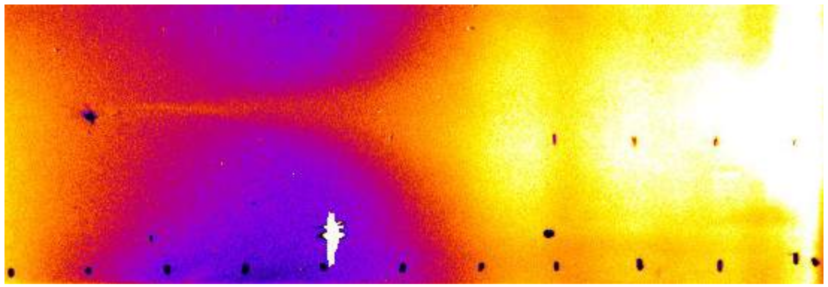


MachZender interferometer.

Density has been varied (with gas pressure) from $\approx 5*10^{18}$ to $\approx 2*10^{19}$, and electron energy has varied consequently.



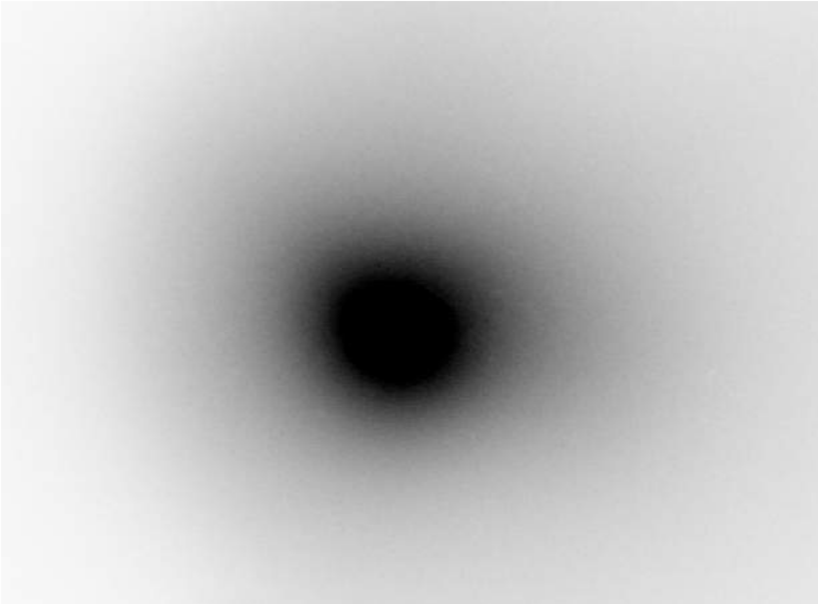




By scanning the plasma density, electron energy has been varied from 50 MeV, to 175 MeV and up to 300 MeV.

Tuning plasma density, energy spread has been reduced from 100% to 20%.

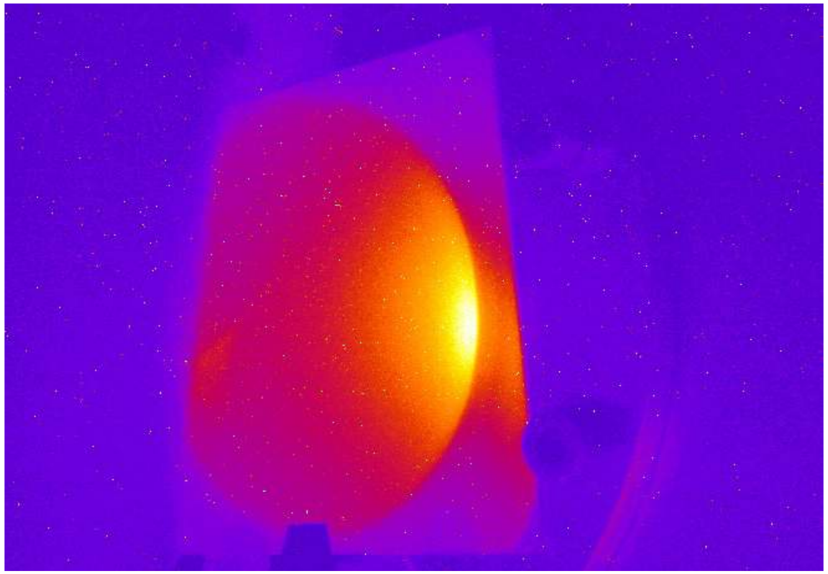
FLAME activities



In collaboration with ENEA (ABC group) we have been able to measure the charge of the bunches using image plates. Charge up to 10 pC in the core has been measured.

Using both x-ray lanex (to measure the divergence) and an x-ray camera, we have been able to characterize the betatron radiation.

Measured x-rays up to 20KeV.



FLAME activities

1. *LASER–CAPILLARY INTERACTION FOR THE EXIN PROJECT*, F.G. Bisesto et al., **NIM A (2016)**

2. *CHARACTERIZATION OF X-RAY RADIATION FROM SOLID SN TARGET IRRADIATED BY FEMTOSECOND LASER PULSES IN THE PRESENCE OF AIR PLASMA SPARKS,* A. Curcio et al. , **Laser and particle beams (2016)**

3. *THE SPARC_LAB THOMSON SOURCE,* C. Vaccarezza et al., **NIM A (2016)**

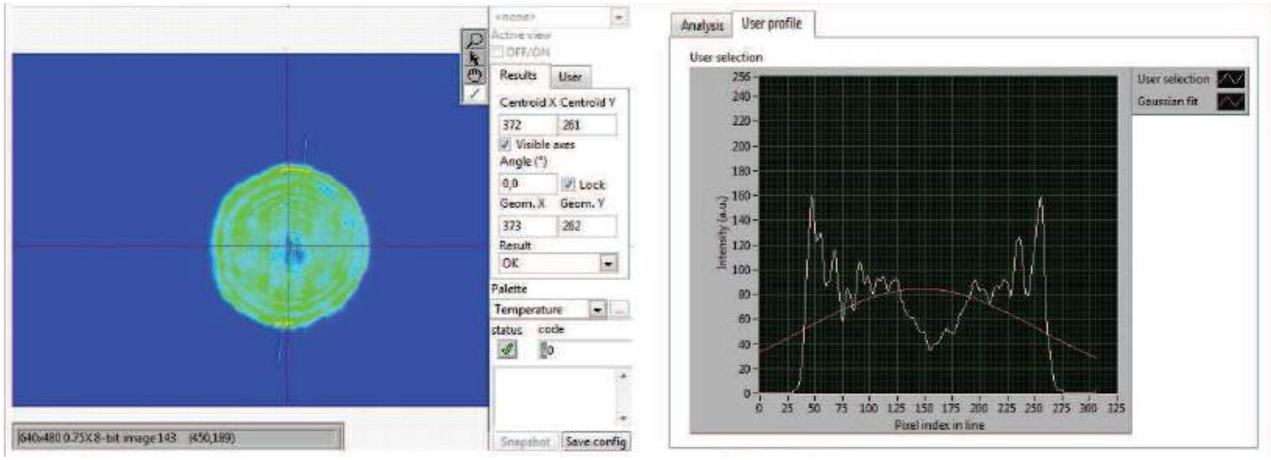
4. *FEMTOSECOND DYNAMICS OF ENERGETIC ELECTRONS IN HIGH INTENSITY LASER-MATTER INTERACTIONS,* R. Pompili et al., **Nature Scientific Reports (2016)**

5. *AN ULTRASHORT-PULSE RECONSTRUCTION SOFTWARE: GROG, APPLIED TO THE FLAME LASER SYSTEM,* M. Galletti, **Il Nuovo Cimento (2016)**

6. *SUB-PICOSECOND SNAPSHOTS OF FAST ELECTRONS FROM HIGH INTENSITY LASER-MATTER INTERACTIONS,* R. Pompiliet al., **Optics Express (2016)**

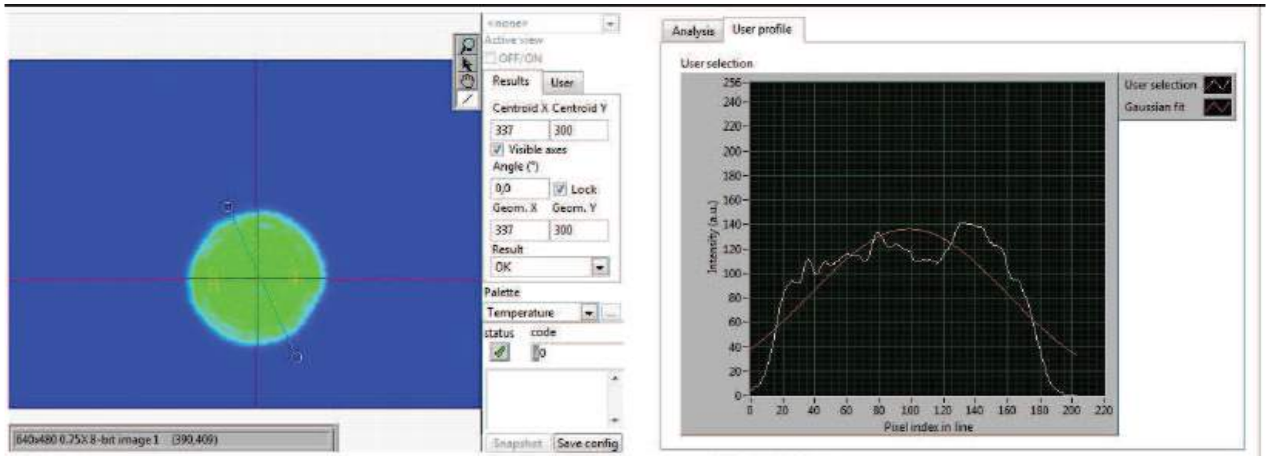
FLAME status

The first YAG has been upgraded, installed and checked. The beam profile has been highly improved and after 2 weeks of work no damages have been recorded.

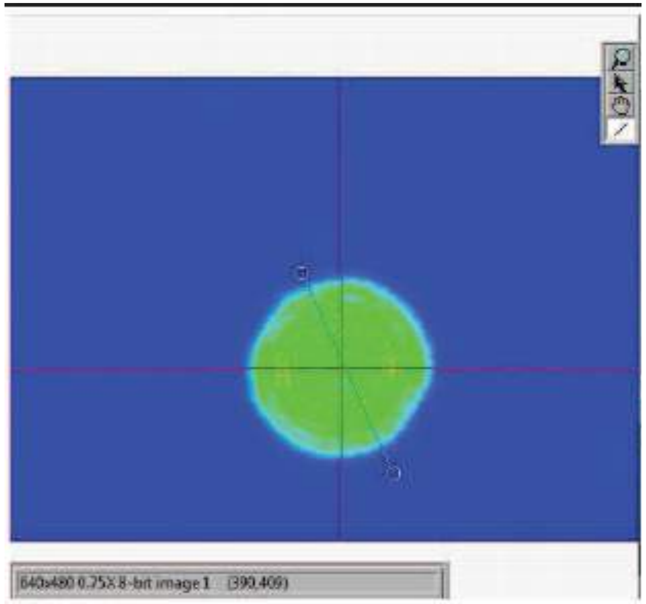


YAG profile before the upgrade

YAG profile after the upgrade

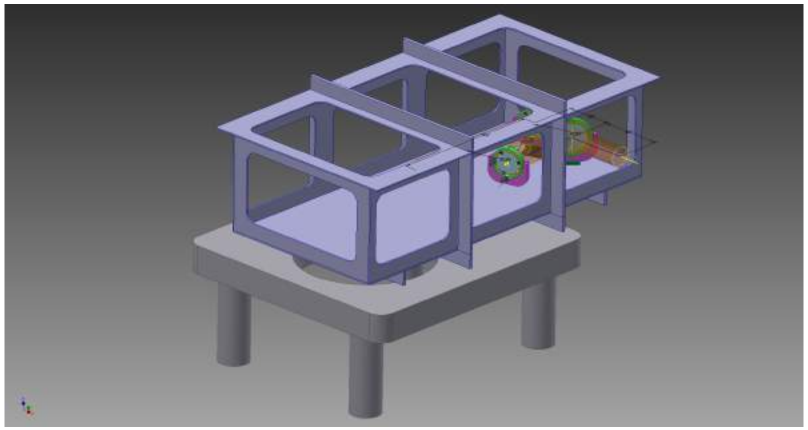


FLAME status



Order for the upgrade has been placed and we will have al the laser upgraded, installed and working by the summer (and hopefully also before, even if the upgrade of the 1st YAG has taken much longer then expected – from May to October, much more than the 1 week firstly promised from Amplitude!).

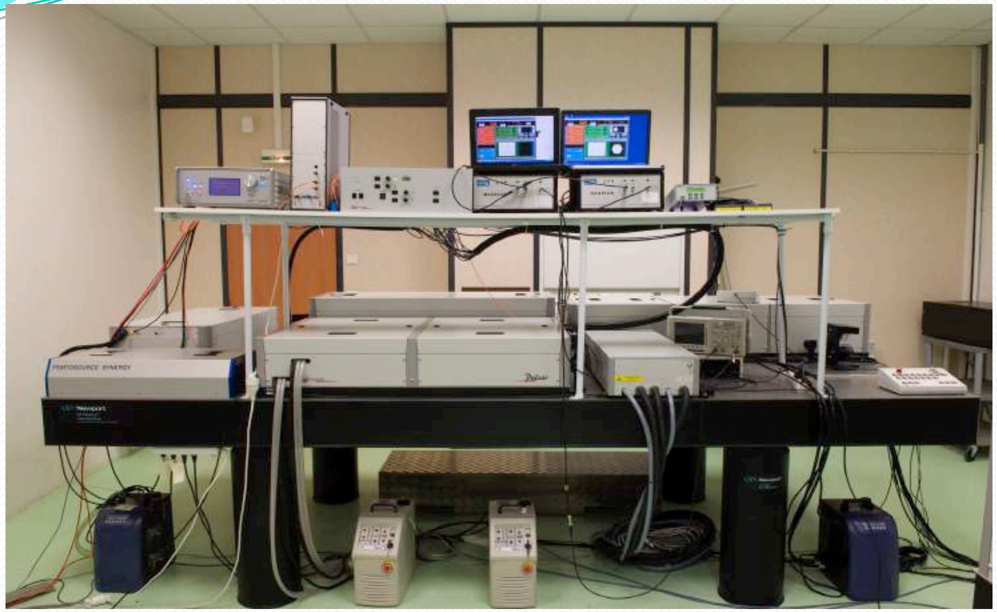
The new interaction chamber has been designed: it guarantees the maximum flexibility and space for diagnostic. With this new design, we will also be able to change parabola's focal length in order to have higher intensity.
The order for the new interaction chamber will be placed in march and the camera will be installed before summer.

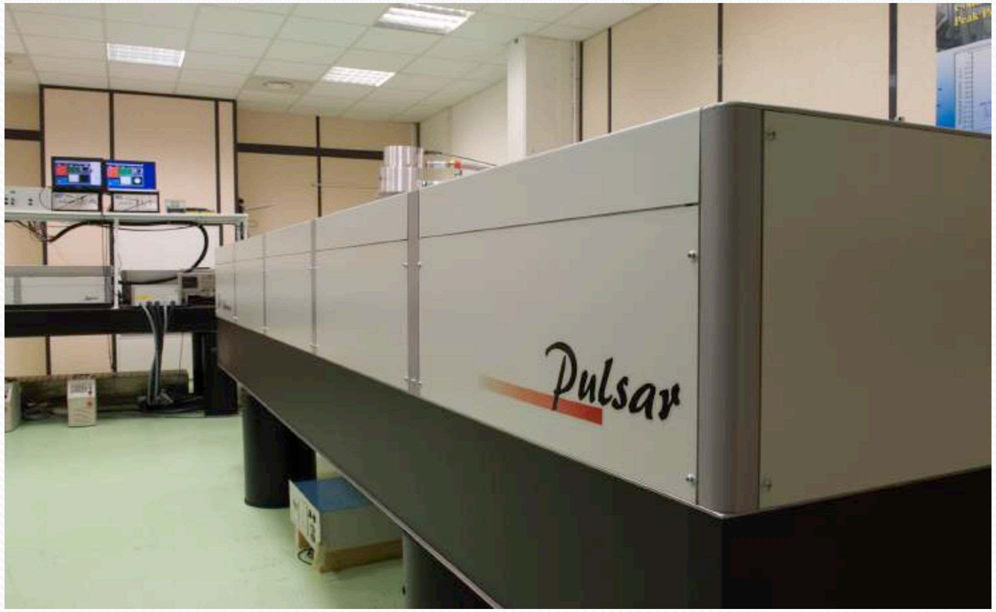


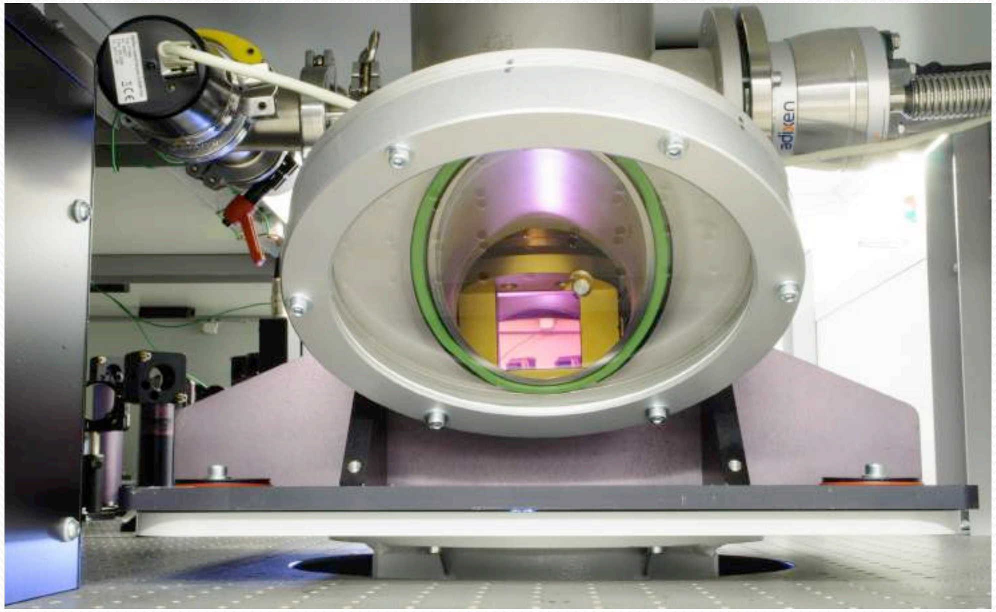
FLAME status

A fire accident has stopped suddenly FLAME operations….

FLAME @ SPARC_LAB

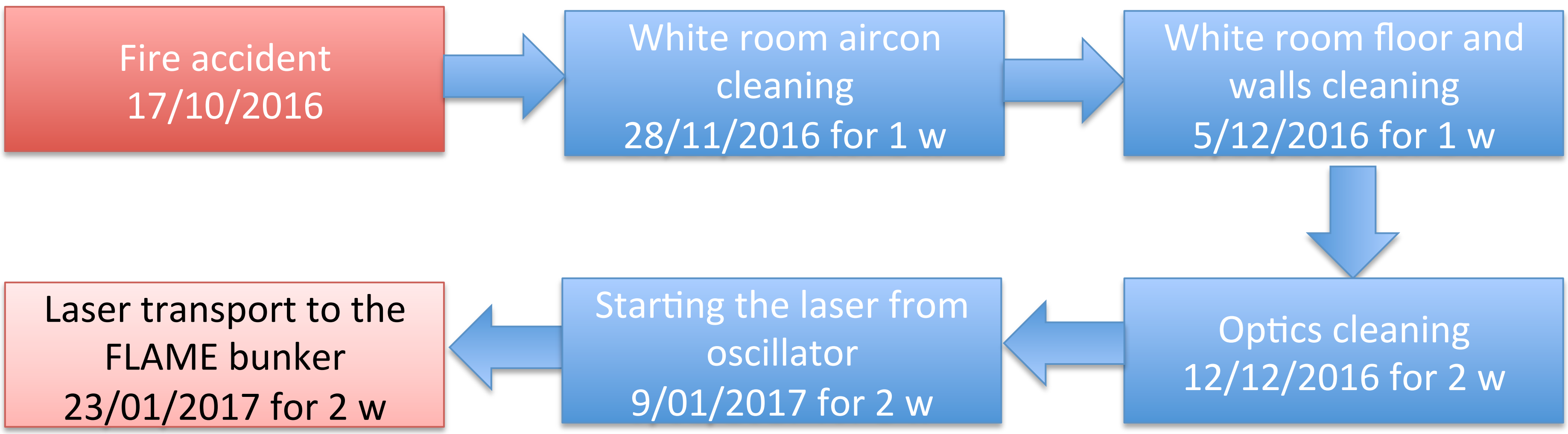






FLAME recovery roadmap

To restart the laser seems to be a very long path, since all the plastic burned during the fire have dirty not only the clean room, but also the air conditioning system, all the optics… Lot of time will be spent to clean optics one by one (even if from a 1st fast look at the laser optics they seem to be safe) and to realign all the laser from the beginning (consider that air conditioning has been working far from the normal conditions for 2 weeks to let the smoke and the smell out of the room).

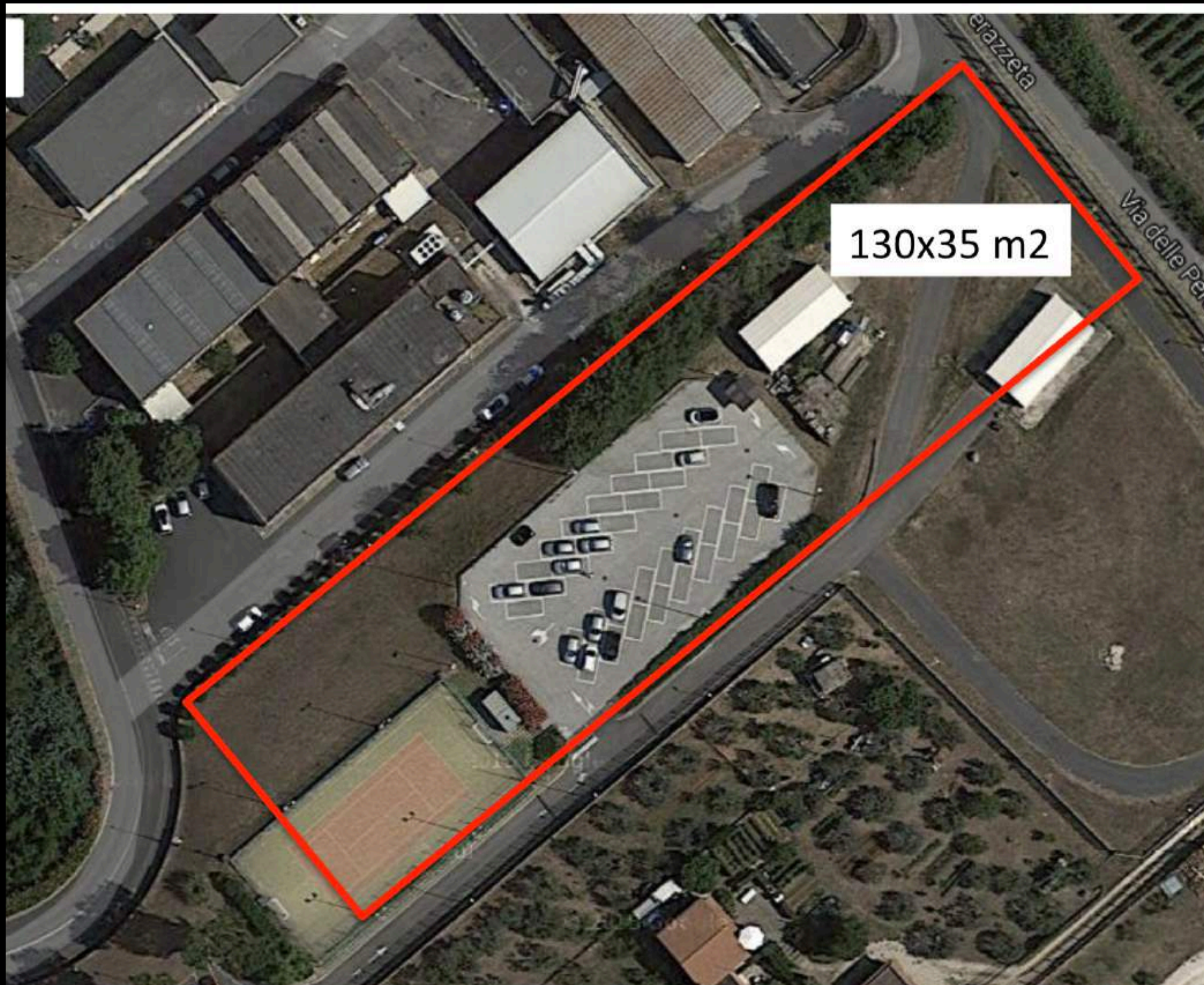


FLAME status: program

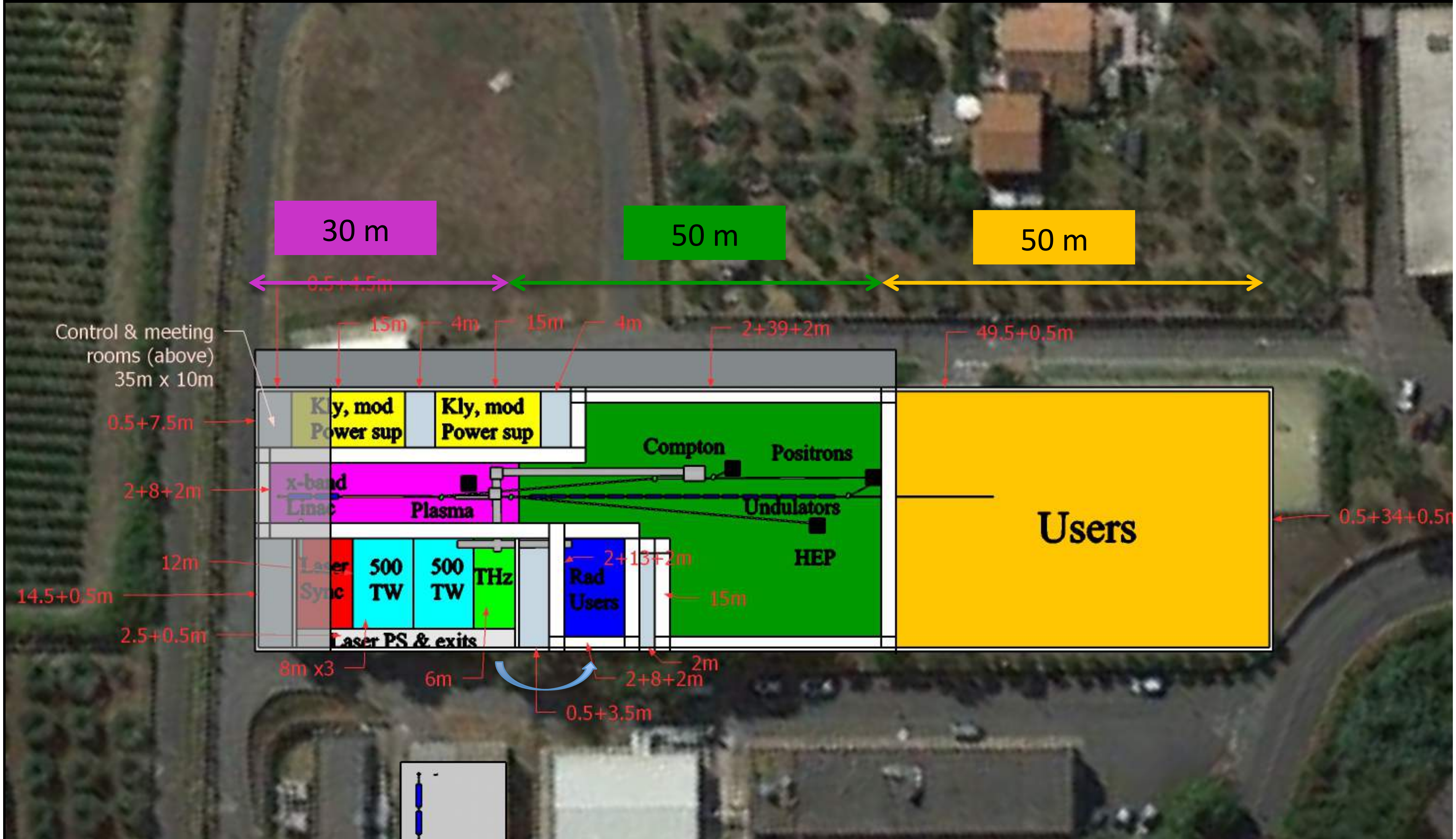
From now on.

Activity	Start date	End date
YAGs update – first 5 YAGs (upgrade, installation and test)	09/01/2017	23/01/2017
YAGs update – last 5 YAGs (upgrade, installation and test)	30/01/2017	13/02/2017
Laser restart	05/12/2016	03/02/2017
EOS experiment – phase 2 – set-up	09/01/2017	03/02/2017
1st Amplitude visit for YAG installation	06/02/2017	10/02/2017
2nd Amplitude visit for YAG installation	13/03/2017	17/03/2017
EOS experiment – phase 2 – experiment	13/02/2017	28/04/2017
Installation of the new interaction chamber	01/05/2017	12/05/2017
LWFA experiment – phase 2 – set-up	15/05/2017	09/06/2017
LWFA experiment – phase 2 – experiment	12/06/2017	04/08/2017
Capillary guiding and acceleration for EXIN @ FLAME – set-up	04/09/2017	30/09/2017
Capillary guiding and acceleration for EXIN @ FLAME – experiment	02/10/2017	22/12/2017

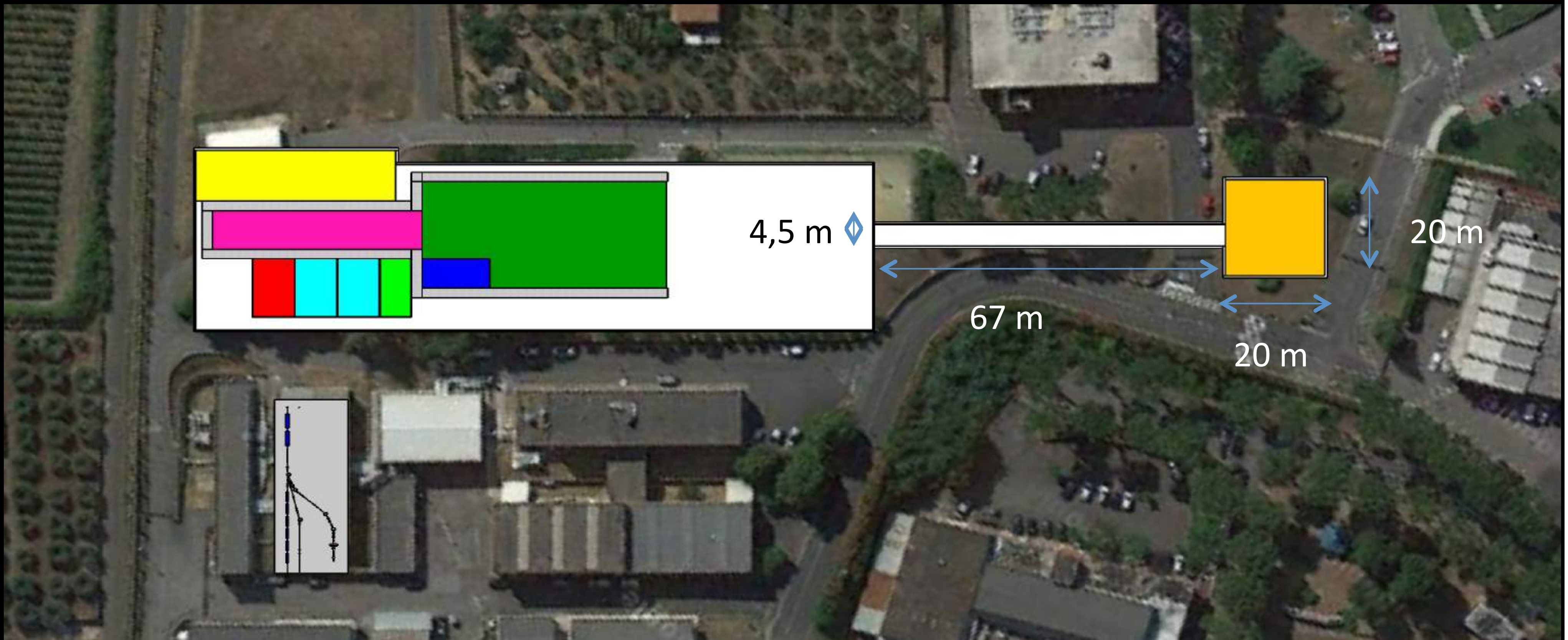
EUSPARC Design Study




SPARC
FLAME
Users

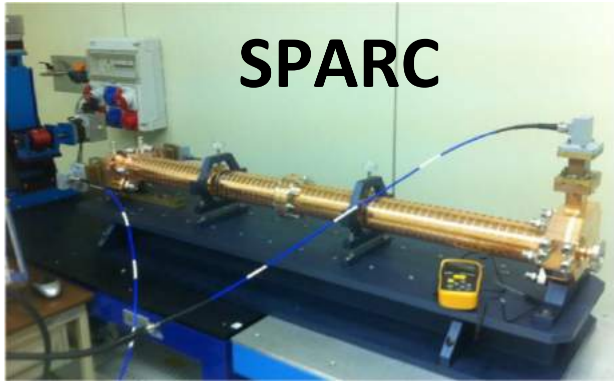


30 m
50 m
50 m
0.5+4.5m
Control & meeting rooms (above) 35m x 10m
15m
4m
15m
4m
2+39+2m
49.5+0.5m
0.5+7.5m
Kly, mod Power sup
Kly, mod Power sup
Compton
Positrons
x-band Linac
Plasma
Undulators
HEP
Users
2+8+2m
12m
Laser Sync
500 TW
500 TW
THz
Rad Users
2+13+2m
15m
14.5+0.5m
2.5+0.5m
Laser PS & exits
8m x3
6m
2m
2+8+2m
0.5+3.5m

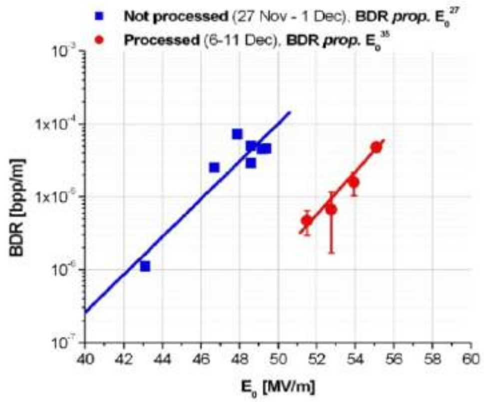

4,5 m
67 m
20 m
20 m

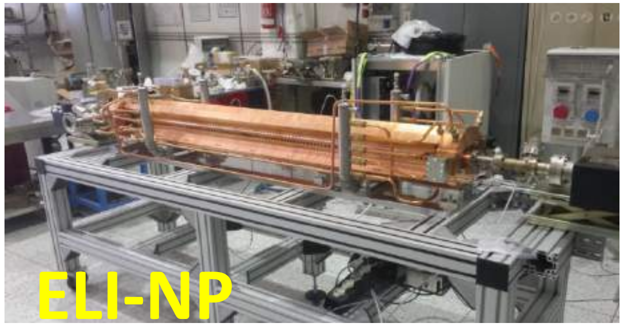
C !

SOME EXISTING C-BAND ACCELERATING STRUCTURES



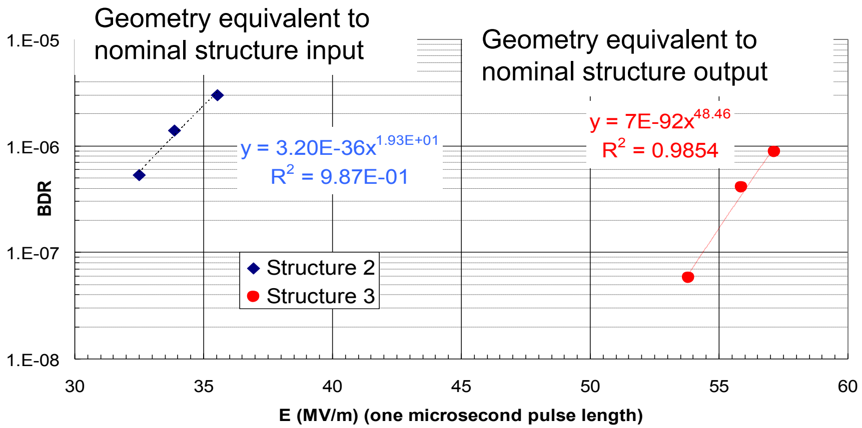
L=1.4 m, Tested to > 50 MV/m
(20 cells prototype)
Not efficient for high-gradient operation (too large RF output power)



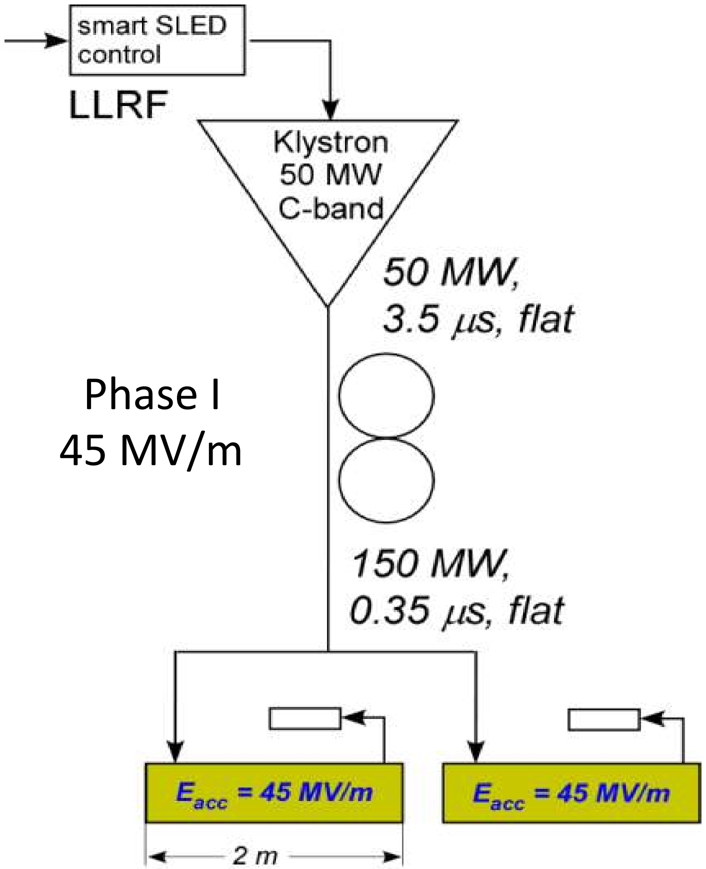


L=2m, Tested to > 33 MV/m, long pulse
HOM damped, unsuitable for single bunch operation

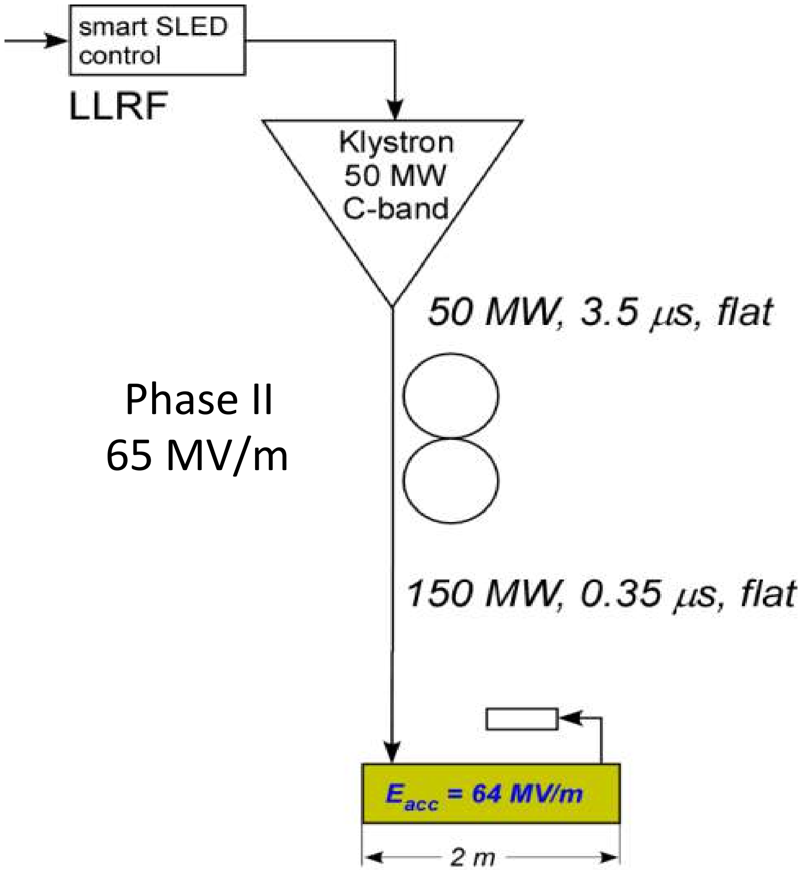
L=2m, short prototype tested to > 55 MV/m



Possible RF modules for an EUSparc C-band linac

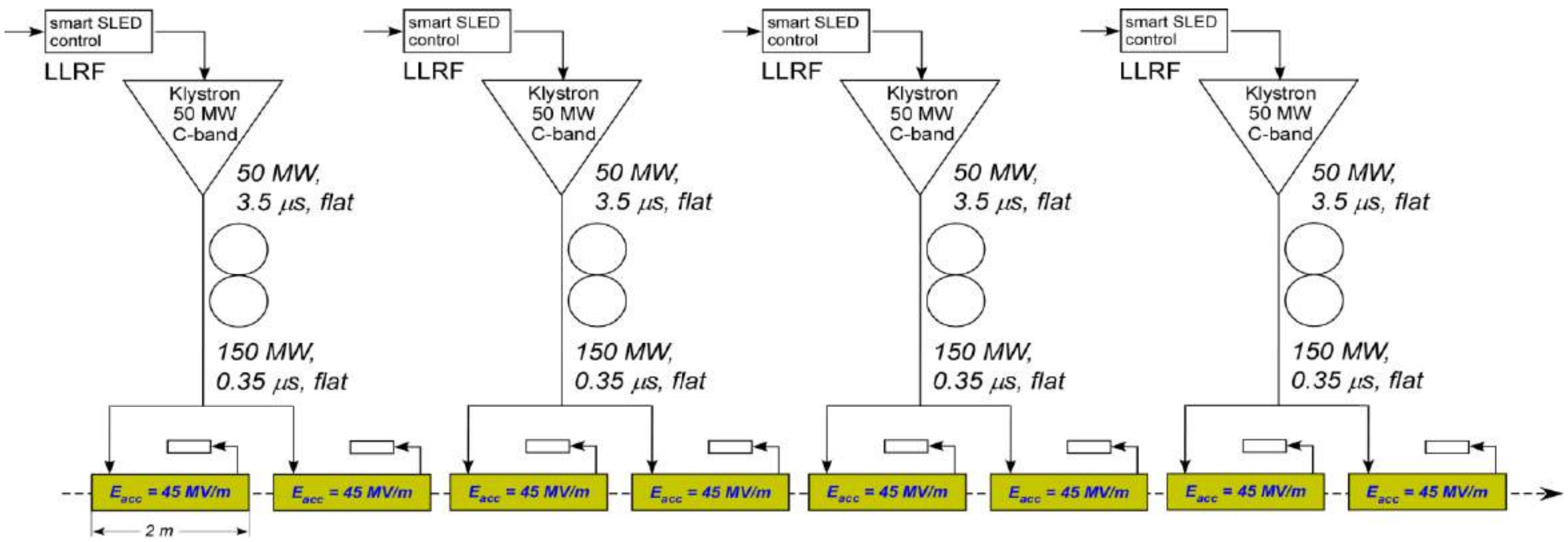


4 Klystrons, 4 SLEDs, 8 sections
≈ 16 m active length
≈ 720 MeV RF linac energy

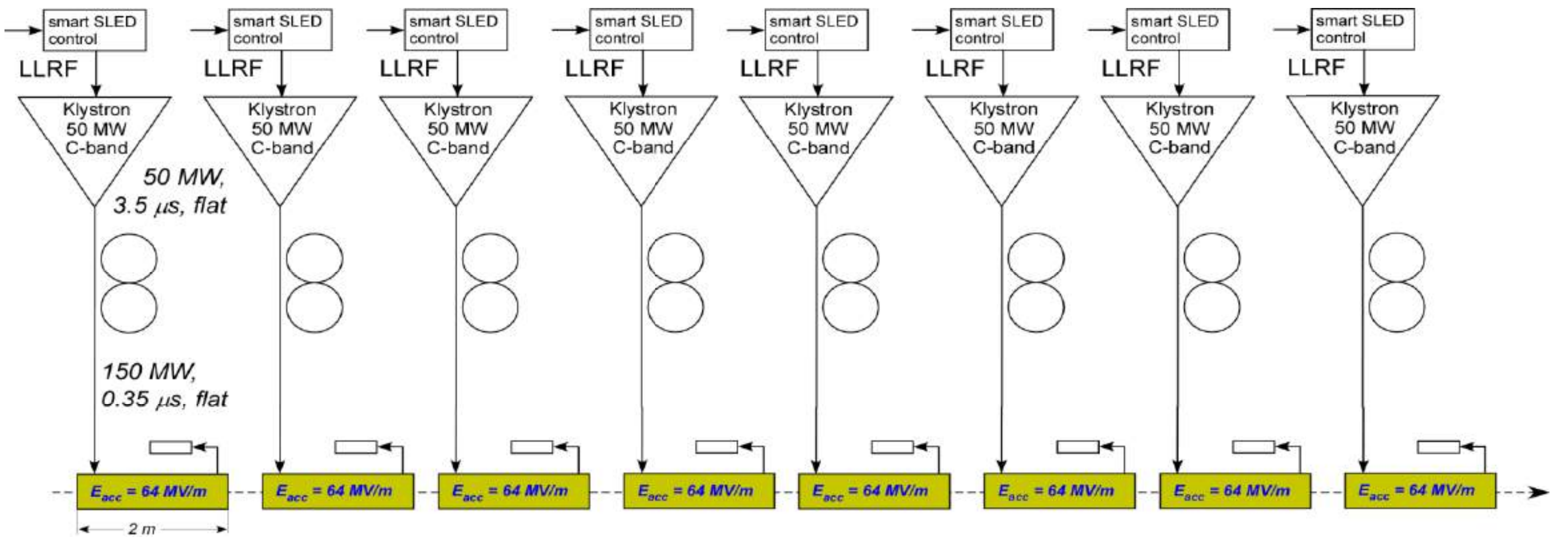


8 Klystrons, 8 SLEDs, 8 sections
≈ 16 m active length
≈ 1010 MeV RF linac energy

Possible configurations for an EUSparc C-band linac



Phase I
45 MV/m
E = 720 MeV
L ≈ 20 m



Phase II
64 MV/m
E = 1010 MeV
L ≈ 20 m

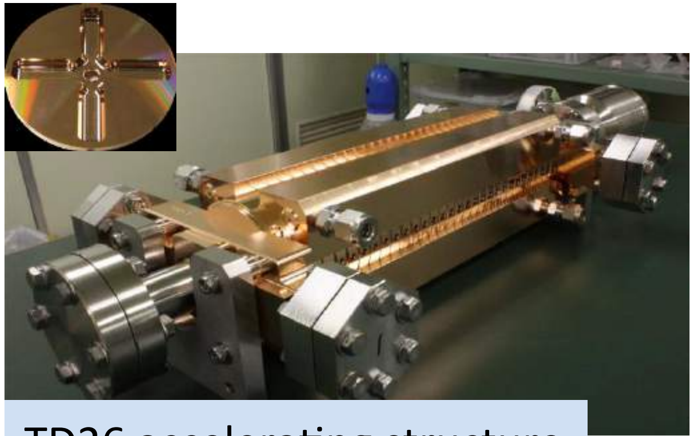
X !

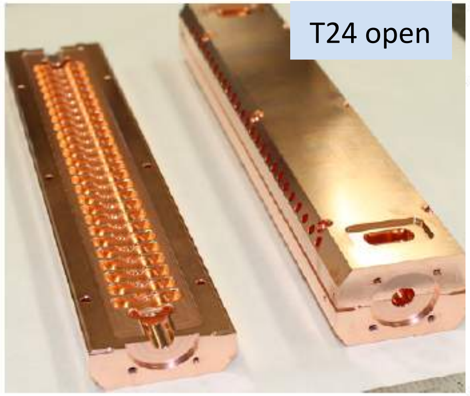
HIGH-GRADIENT RF DEVELOPMENT AND APPLICATIONS

W. Wuensch, CERN, Geneva, Switzerland

LINAC16, East Lansing, September 2016

In the CLIC baseline designs for all energy stages, the approximately **200 MW/m** of required peak 12 GHz power for the main linac is produced by decelerating a high-current, bunched drive beam.

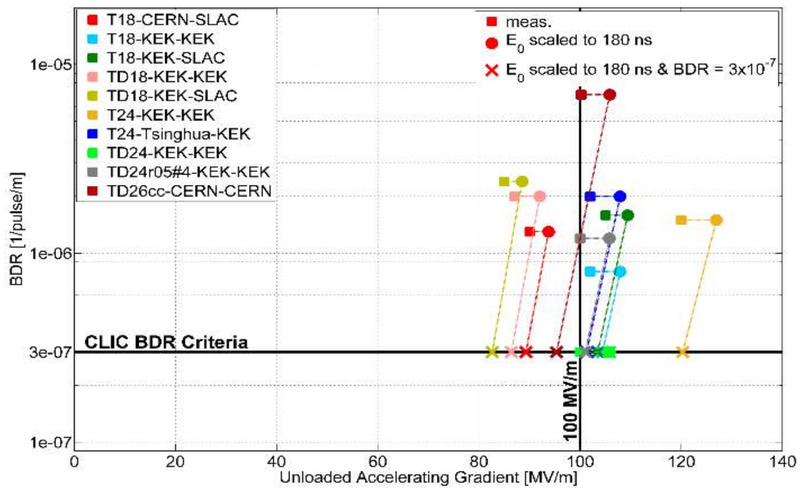




	T24-open	CLIC-G T24
Unloaded Gradient [MV/m]	100	100
Input/output radii [mm]	3.15/2.35	3.15/2.35
Group velocity [%c]	1.99/1.06	1.79/0.91
Shunt impedance [MΩ/m]	107/137	116/150
Peak input power [MW]	44.5	37.5
Filling time [ns]	49	57
Maximum E-field [MV/m]	268	222
Maximum Sc [MW/mm^2]	5.16	3.51
Maximum pulse heating temperature [K]	25	14

TD26 accelerating structure

Average loaded accelerating gradient	100 MV/m
Frequency	12 GHz
RF phase advance per cell	2π/3 rad
Input, Output iris radii	3.15, 2.35 mm
Input, Output iris thickness	1.67, 1.00 mm
Input, Output group velocity	1.65, 0.83 % of c
First and last cell Q-factor (Cu)	5536, 5738
First and last cell shunt impedance	81, 103 MΩ/m
Number of regular cells	26
Structure length including couplers	230 mm (active)
Filling time	67 ns
Peak input power	61.3 MW



Proceedings of FEL2015, Daejeon, Republic of Korea

THE X-BAND FEL COLLABORATION

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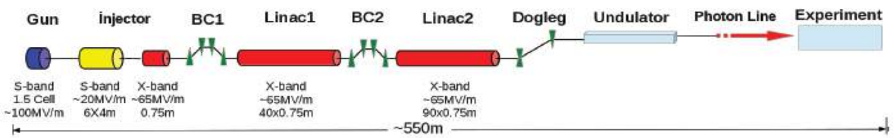
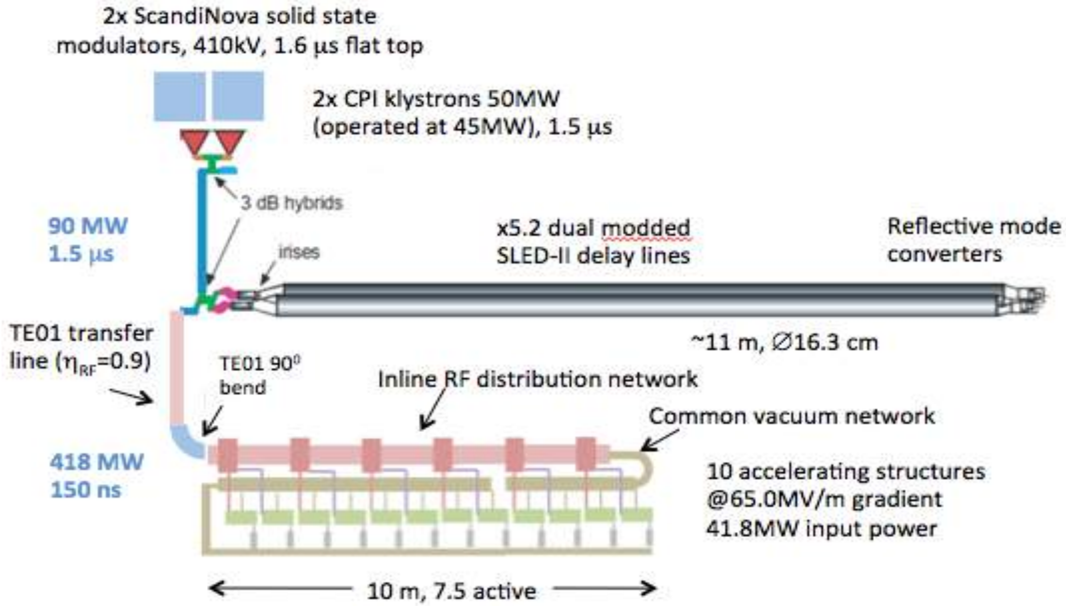
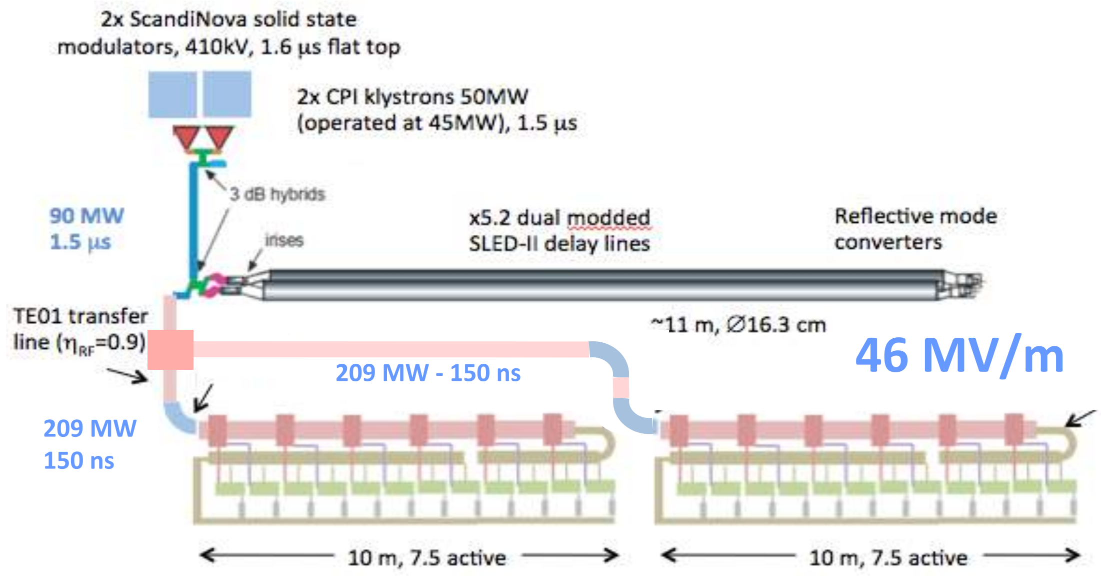


Parameter	CLIC-502		Optimum
Structures per RF unit	12	16	10
Klystrons per RF unit	2	2	2
Structure length (m)	0.23	0.23	0.75
a/λ	0.145	0.145	0.125
Operating gradient (MV/m)	77	67.5	65
Energy gain per RF unit (MeV)	213	248	488
RF units needed	27	23	12
Total klystrons	54	46	24
Linac active length (m)	74	84	88
Cost estimate (a.u.)	76.2	71.5	51.7

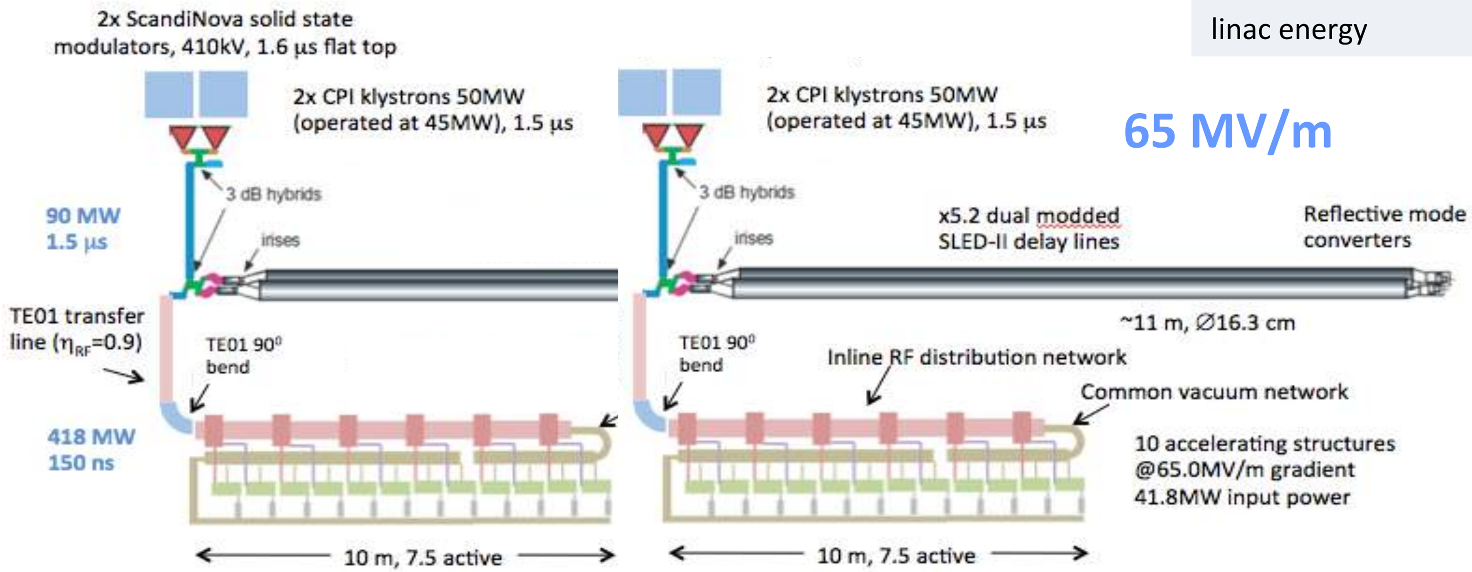


- No much info about this accelerating section (ever been prototyped and tested?). It might possibly be just an optimal scaling for the purpose.
- However the RF plant and the section properties fit the EUSPARC need, so the proposed RF basic block can be easily scaled to the EUSPARC case to draw some initial scenario.
- Filling factor is ≈ 75 %

EUSPARC scenario based on "X-band FEL collaboration" RF module



	Phase I	Phase II
RF gradient	46 MV/m	65 MV/m
# of sections	20	
# of modulators	1	2
# of klystrons	2	4
# of SLEDs	1	2
linac length	20 m (15 m active)	
section input power	21 MW	42 MW
linac energy	690 MeV	975 MeV



C band: pros

- technology well established, background of various projects (SFEL, SPARC, ELI-NP, …);
- synergic with other internal activities;
- all components already industrialized, well known suppliers;
- medium gradients (50 MV/m) already demonstrated.
- linearization possible (X band)

C band: cons

- relatively long pulses (300 – 400 ns);
- higher gradients require some R&D efforts;
- ultimate gradients realistically limited (< 80 MV/m)

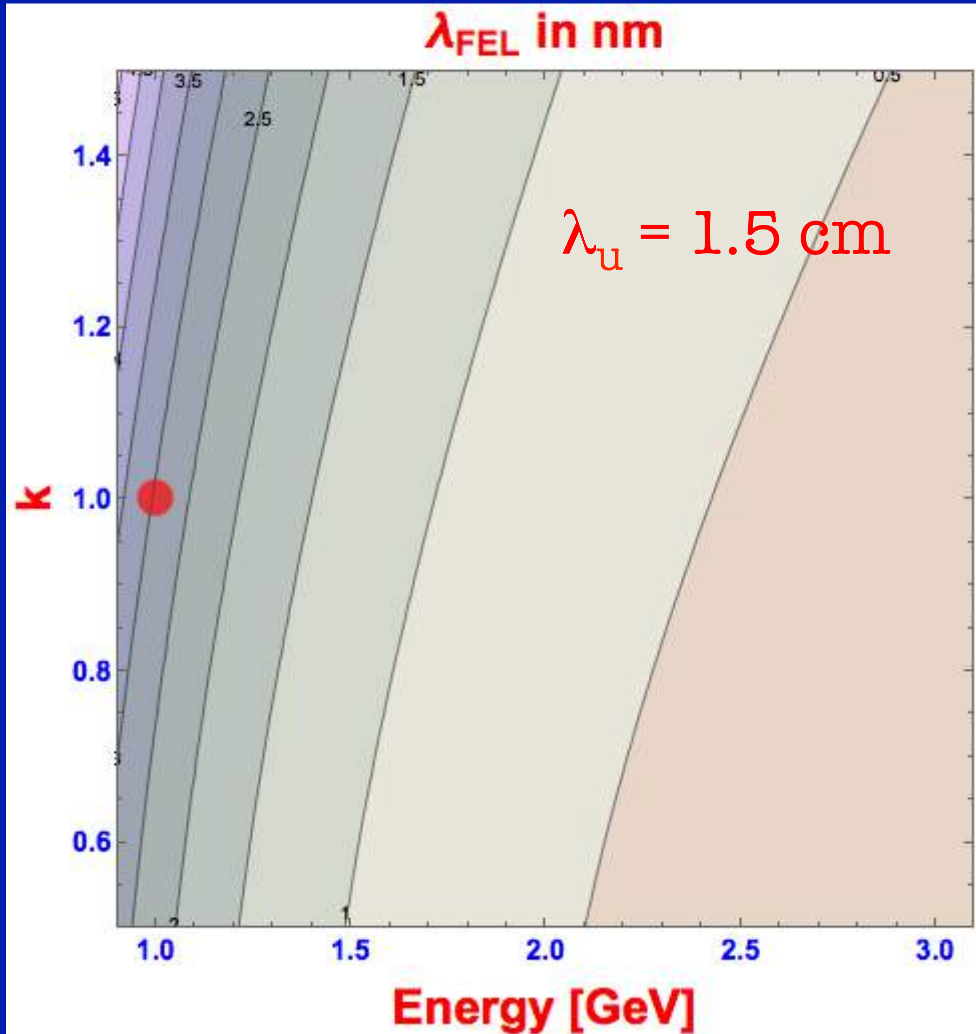
X band: pros

- short RF pulses (< 200 ns);
- about 40% larger efficiency;
- ultimate gradients in the > 100 MV/m range
- synergic with other european (CERN) and international efforts

X band: cons

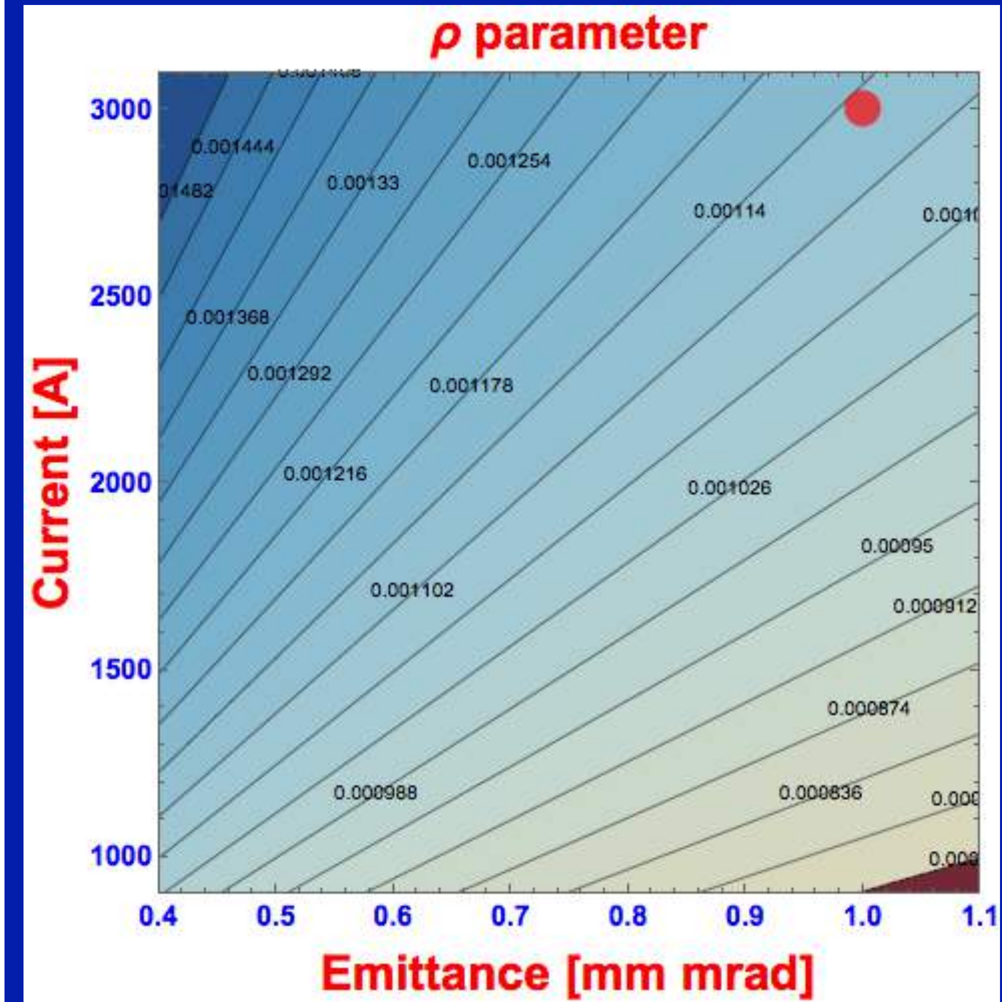
- klystron availability and cost;
- more complicated pulse compressors;
- critical RF transport and distribution;
- not all components industrialized;
- no LLRF commercially available;
- in general any part of the system requires R&D effort and a lot of manpower

SASE FEL studies

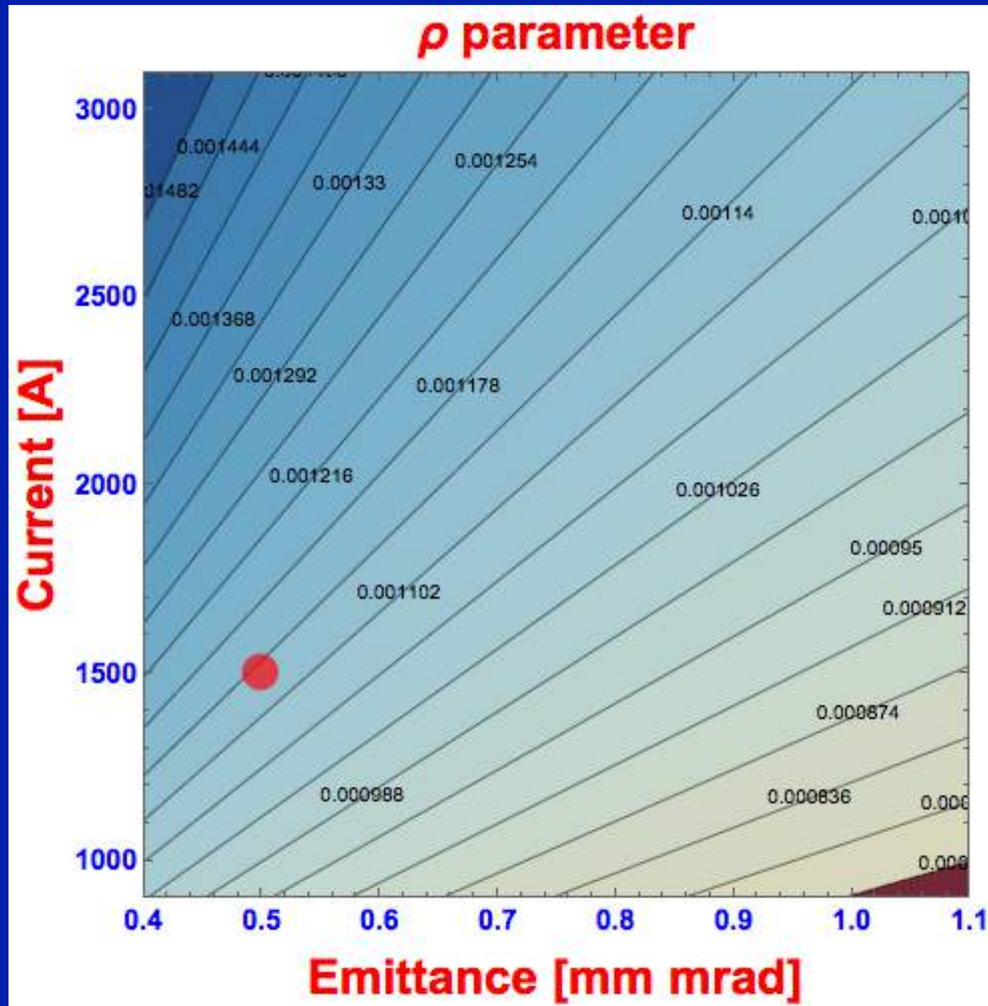


λ_u = 1.5 cm

1 GeV, 3 kA, 30 pC, 1 um, 0.1 %

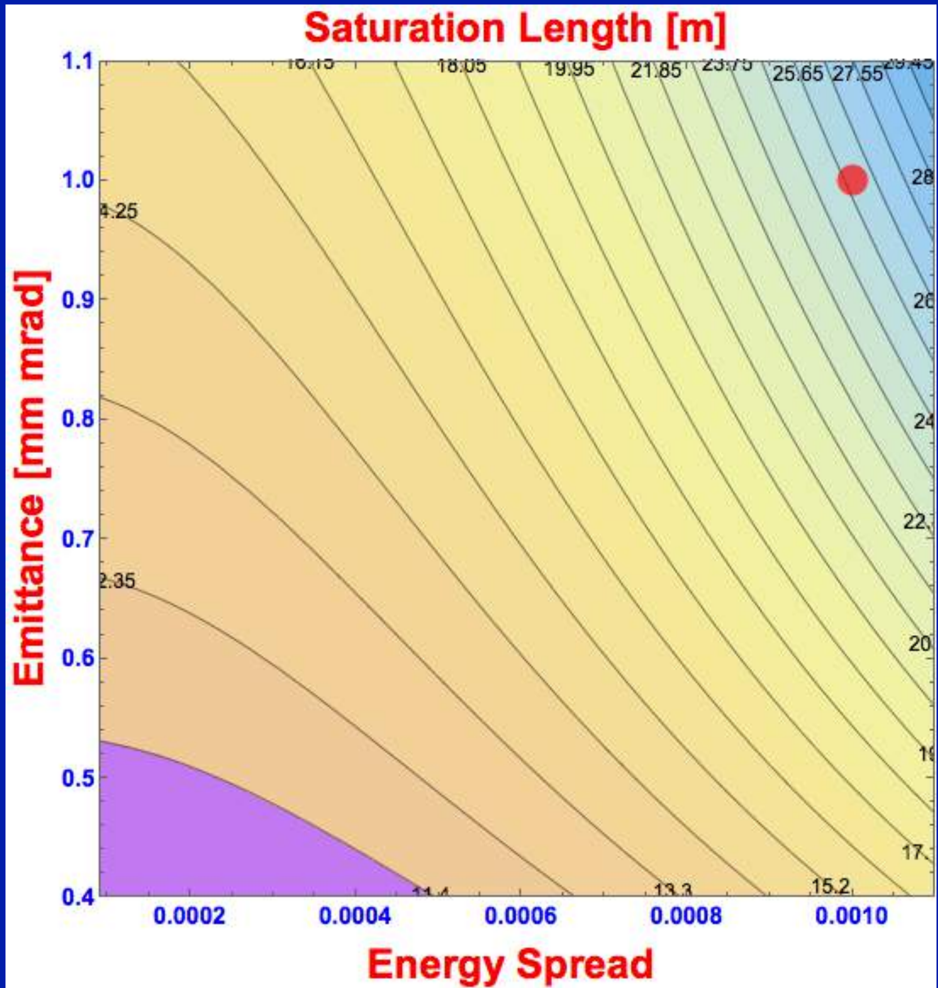


1 GeV, 30 pC, 1.5 kA, 0.5 um, 0.01 %

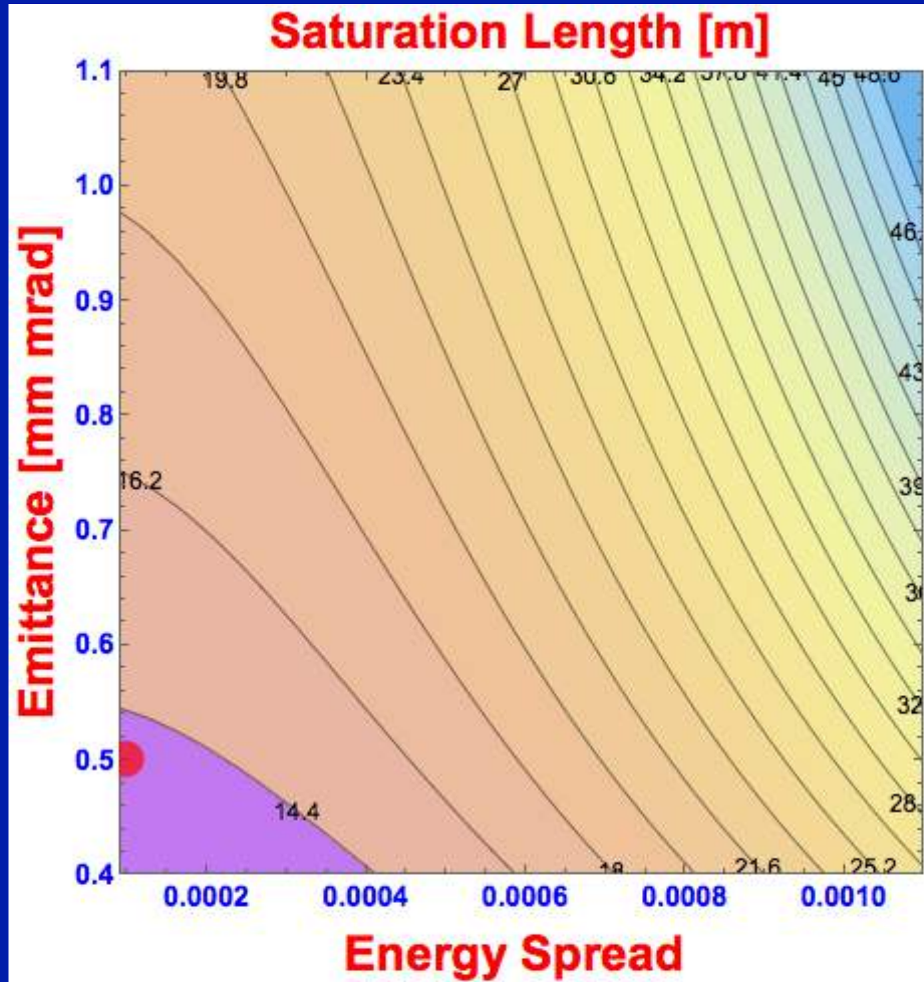


$\rho = 1.14\ 10^{-3}$

1 GeV, 3 kA, 30 pC, 1 um, 0.1 %

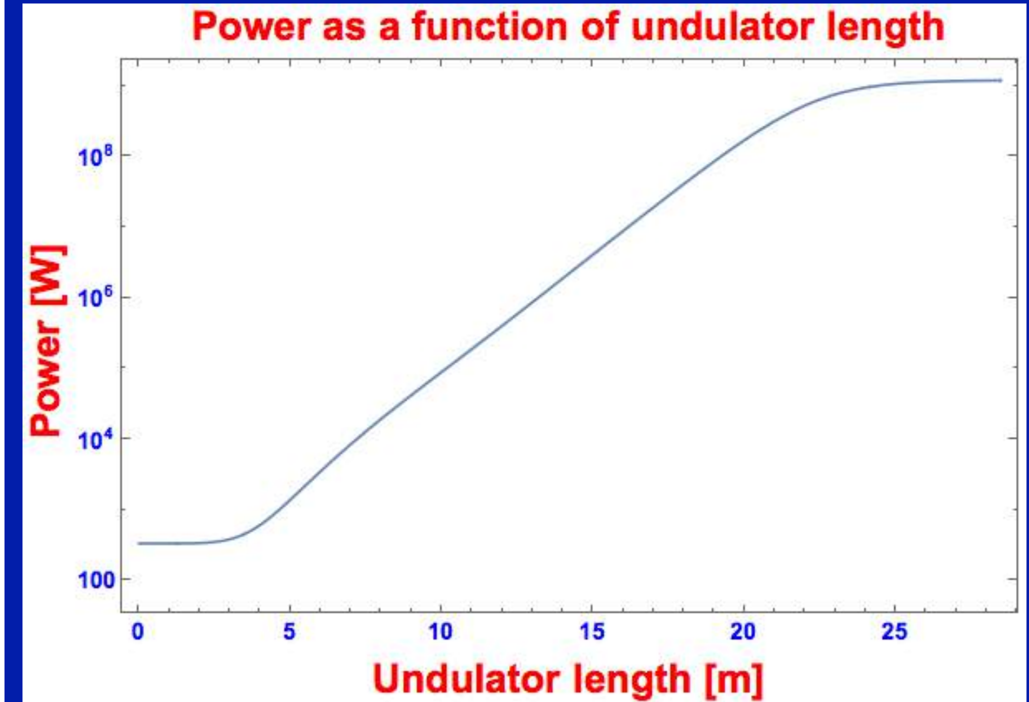


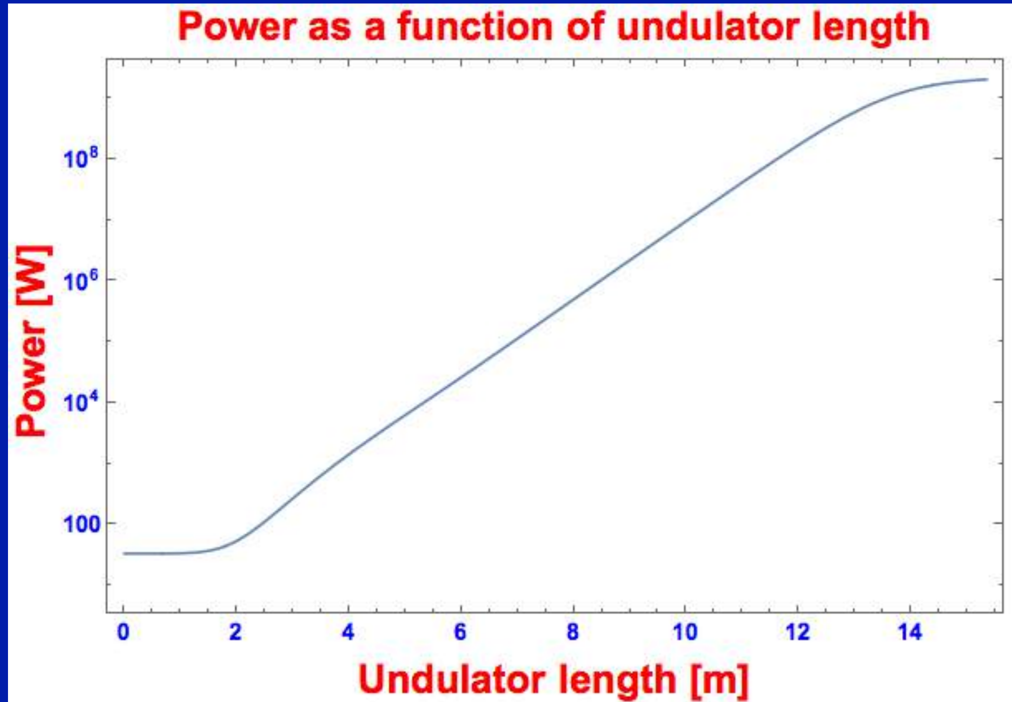
1 GeV, 30 pC, 1.5 kA, 0.5 um, 0.01 %



1 GeV, 3 kA, 30 pC, 1 um, 0.1 %

1 GeV, 30 pC, 1.5 kA, 0.5 um, 0.01 %





EUSPARC CDR Working Groups

WG 0 – Project Management (M. Ferrario)
- 0.1 Executive summary

WG 1 – Electron beam design and optimization
- 1.1 Advanced High Brightness Photo-injector (E. Chiadroni)
- 1.2 HB Linac options, design and parameters (A. Gallo)
- 1.3 – Machine layout

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. Cianchi)
- 3.2 LWFA beam line (A. R. Rossi)
- 3.3 Positron acceleration

WG 4 – FEL pilot applications
- 4.1 Plasma driven FEL (F. Villa)
- 4.2 Advanced FEL schemes (G. Dattoli)
- 4.3 FEL user applications (M. Benfattoi)

WG 5 – Radiation sources and user beam lines
- 5.1 Advanced dielectric THz source
- 5.2 Compton source (C. Vaccarezza)
- 5.3 User beam lines

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

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)

EuSPARC GANTT CHART

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M. Ferrario

SPARC_LAB Scientific Board
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Vacuum systems	D. Alesini
Laser systems	A. Ghigo

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Beam Diagnostics	A. Cianchi
Photon Diagnostics	E. Chiadroni
Timing & Synchr.	M. Bellaveglia
Lasers & Optics	F. Villa
Plasma Sources	M. P. Anania
Control system	G. Di Pirro
Undulators	A. Petralia
Electron-photon int.	V.Petrillo

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Electrical inst.	R. Ricci
Cooling plants	S. Cantarella


Thanks for your attention