EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

Coordinator: Ralph Assmann (DESY)

EuPRAXIA an Overview

Massimo Ferrario (INFN-LNF)
On behalf of the EuPRAXIA Collaboration

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

Motivations

Horizon2020

PRESENT EXPERIMENTS

Demonstrating **100 GV/m** routinely

Demonstrating **GeV** electron beams

Demonstrating basic **quality**

EuPRAXIA INFRASTRUCTURE

Engineering a high quality, compact plasma accelerator

5 GeV electron beam for the 2020's

Demonstrating user readiness

Pilot users from FEL, HEP, medicine, ...

PRODUCTION FACILITIES

Plasma-based **linear collider** in 2040's

Plasma-based **FEL** in 2030's

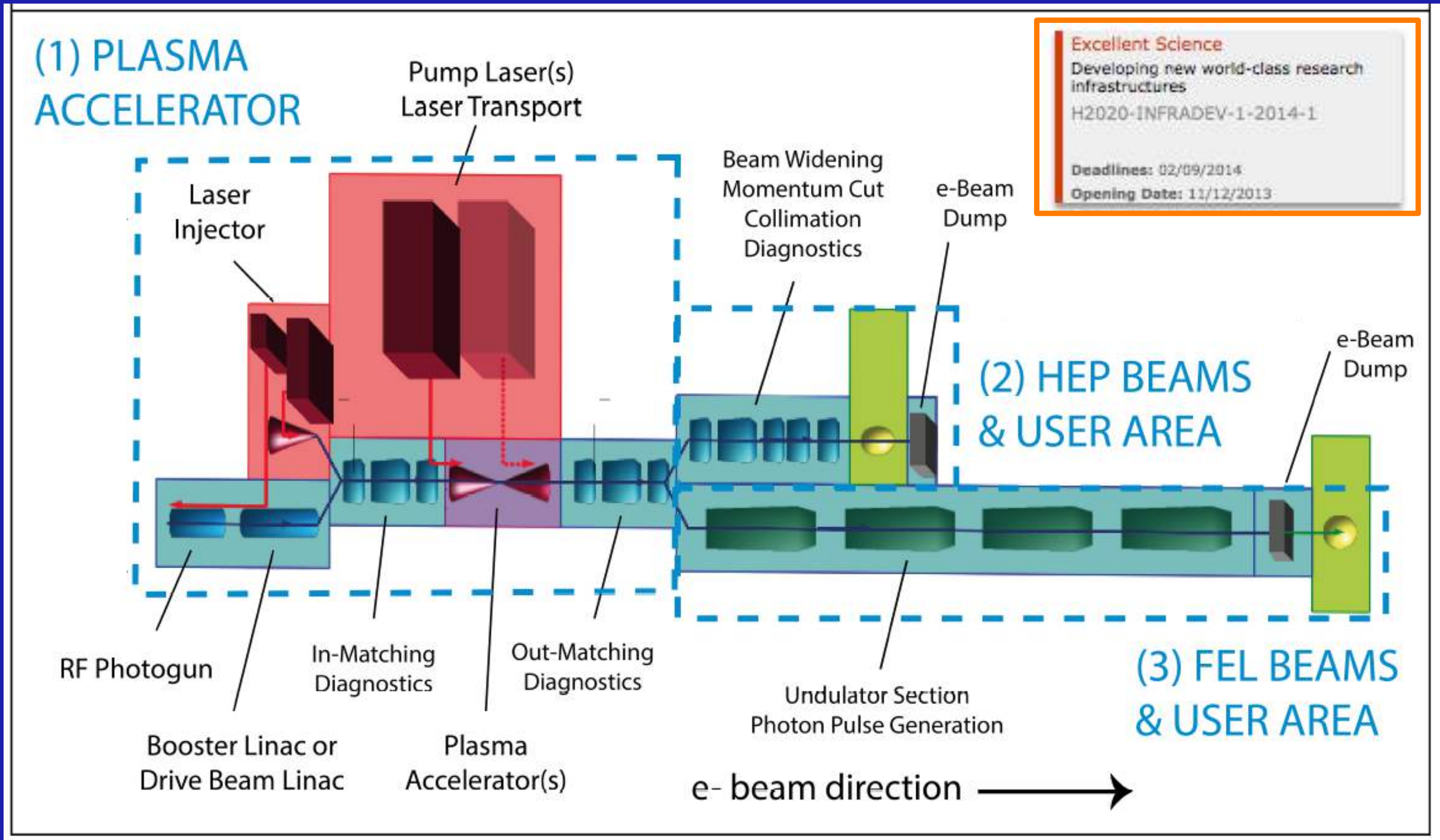
Medical, industrial applications soon

Courtesy R. Assmann

EuPRAXIA Design Study

Approved as HORIZON 2020 INFRADEV, 4 years, 3 M€

Coordinator: Ralph Assmann (DESY)



A 1 PW Ti: Sa laser laser driver or a high brightness 1 GeV electron beam linac could be adequate drivers for the EUPRAXIA plasma accelerator.

The foreseen parameters give access to:

(1) to an FEL in the EUV to X-ray regime (1 – 15 nm) and

(2) to short electron pulses with high brightness for HEP detector tests, material tests and other applications.

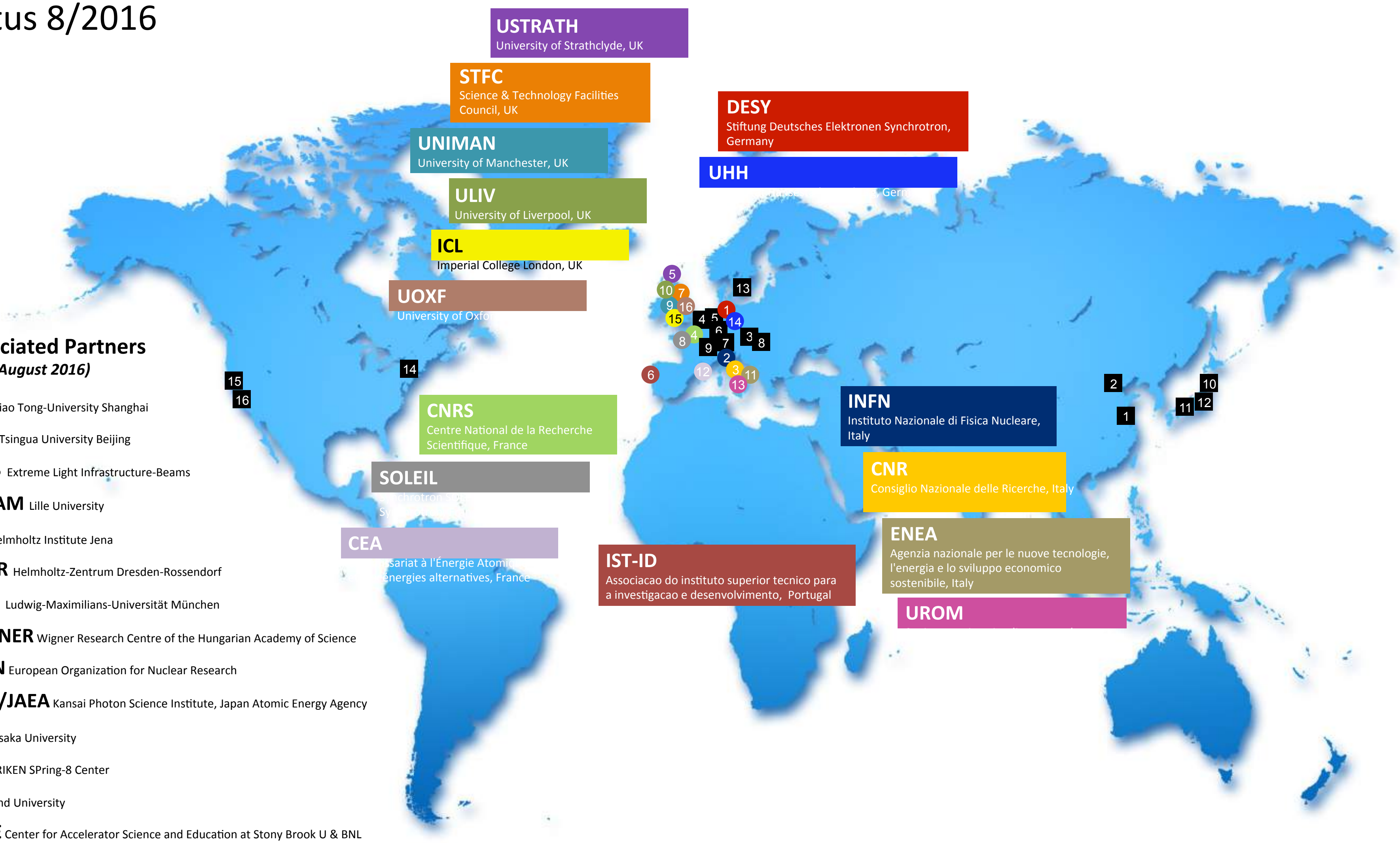
Beam Parameter	**Unit**	**Value**
Particle type	-	Electrons
Energy	GeV	1 – 5
Charge per bunch	pC	1 – 50
Repetition rate	Hz	10
Bunch duration	fs	0.01 - 10
Peak current	kA	1 – 100
Energy spread	%	0.1 – 5
Norm. emittance	mm	0.01 – 1
FEL wavelength	nm	1 - 15

Participating Institutions

16 beneficiaries, 16 associated partners

Horizon2020

Status 8/2016



Associated Partners

(as of August 2016)

1 **JUS** Jiao Tong-University Shanghai
2 **TUB** Tsingua University Beijing
3 **ELI-B** Extreme Light Infrastructure-Beams
4 **PHLAM** Lille University
5 **HIJ** Helmholtz Institute Jena
6 **HZDR** Helmholtz-Zentrum Dresden-Rossendorf
7 **LMU** Ludwig-Maximilians-Universität München
8 **WIGNER** Wigner Research Centre of the Hungarian Academy of Science
9 **CERN** European Organization for Nuclear Research
10 **KPSI/JAEA** Kansai Photon Science Institute, Japan Atomic Energy Agency
11 **OU** Osaka University
12 **RSC** RIKEN SPring-8 Center
13 **LU** Lund University
14 **CASE** Center for Accelerator Science and Education at Stony Brook U & BNL
15 **LBNL** Lawrence Berkeley National Laboratory
16 **UCLA** University of California, Los Angeles

New Partners
Industrial Participation

Horizon2020

Industry: involved through workshops and Scientific Advisory Board

Contacts still evolving, several cooperations under discussion

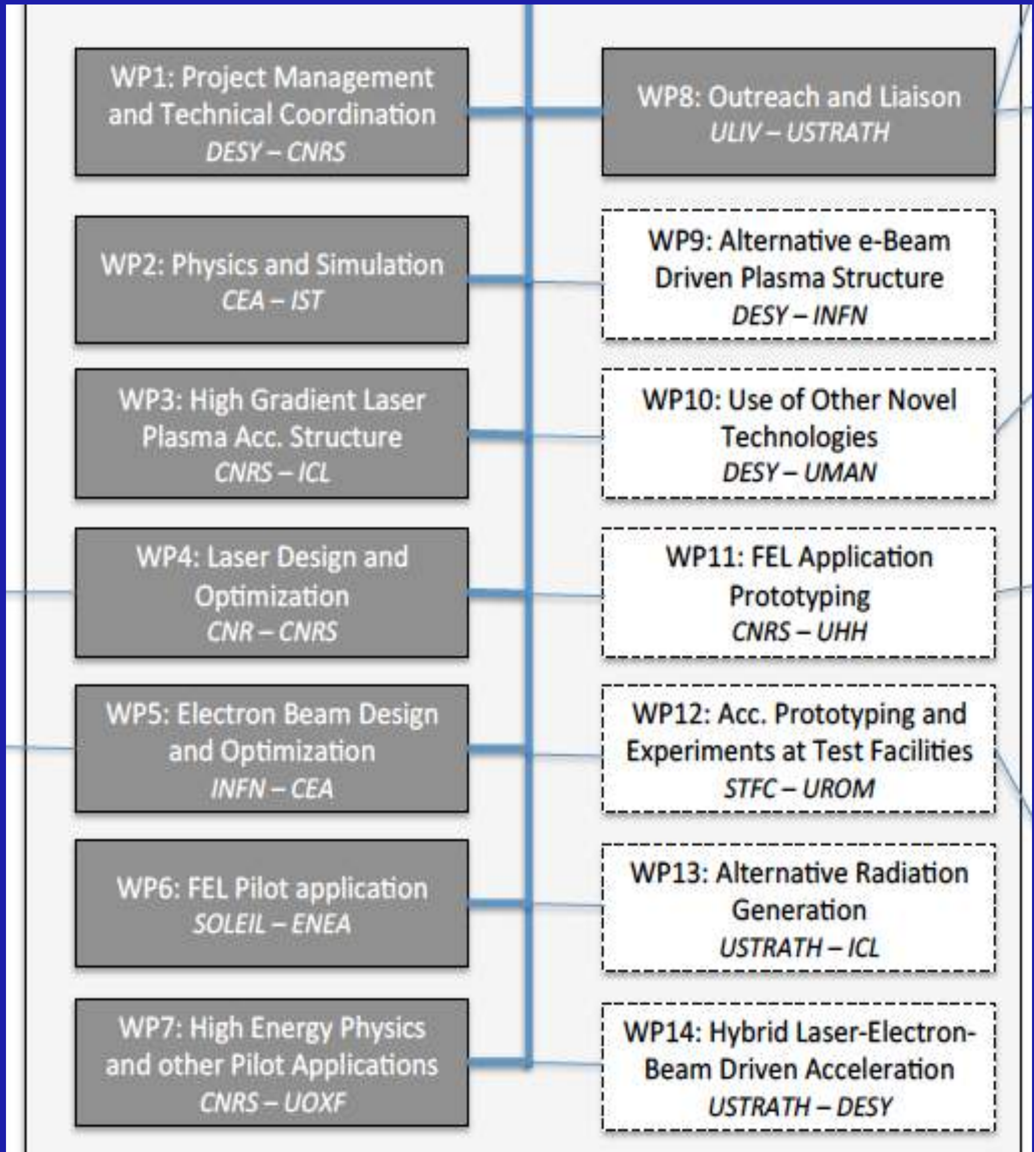
New associate partner candidates (documents complete – vote CB today):

1. Karlsruhe Institute of Technology, Germany
2. Hebrew University of Jerusalem, Israel
3. Institute of Applied Physics, Nizhny Novgorod, Russia
4. Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russia
5. University of Rome, Tor Vergata, Italy
6. Forschungszentrum Jülich, Germany

New associate partners (documents under preparation):

1) FNAL (Fermilab), US, 2) SLAC, US

Project Organization



MS4 : Electron beam baseline parameter for FEL application

Horizon 2020

MS4 (8 p) : Prospective cases

Based on these references, we recommend the following prospective scenarios for the EuPRAXIA FEL design:

- 1-1.5 GeV case, starting with one stage, 0.1 % energy spread, 1 mm.mrad emittance. Advanced beam manipulation to prepare the electron beam for the undulator section is advised. This can relax the requirements on the plasma acceleration stage.

- 3 GeV case , 0.1 % energy spread, 1 mm.mrad emittance

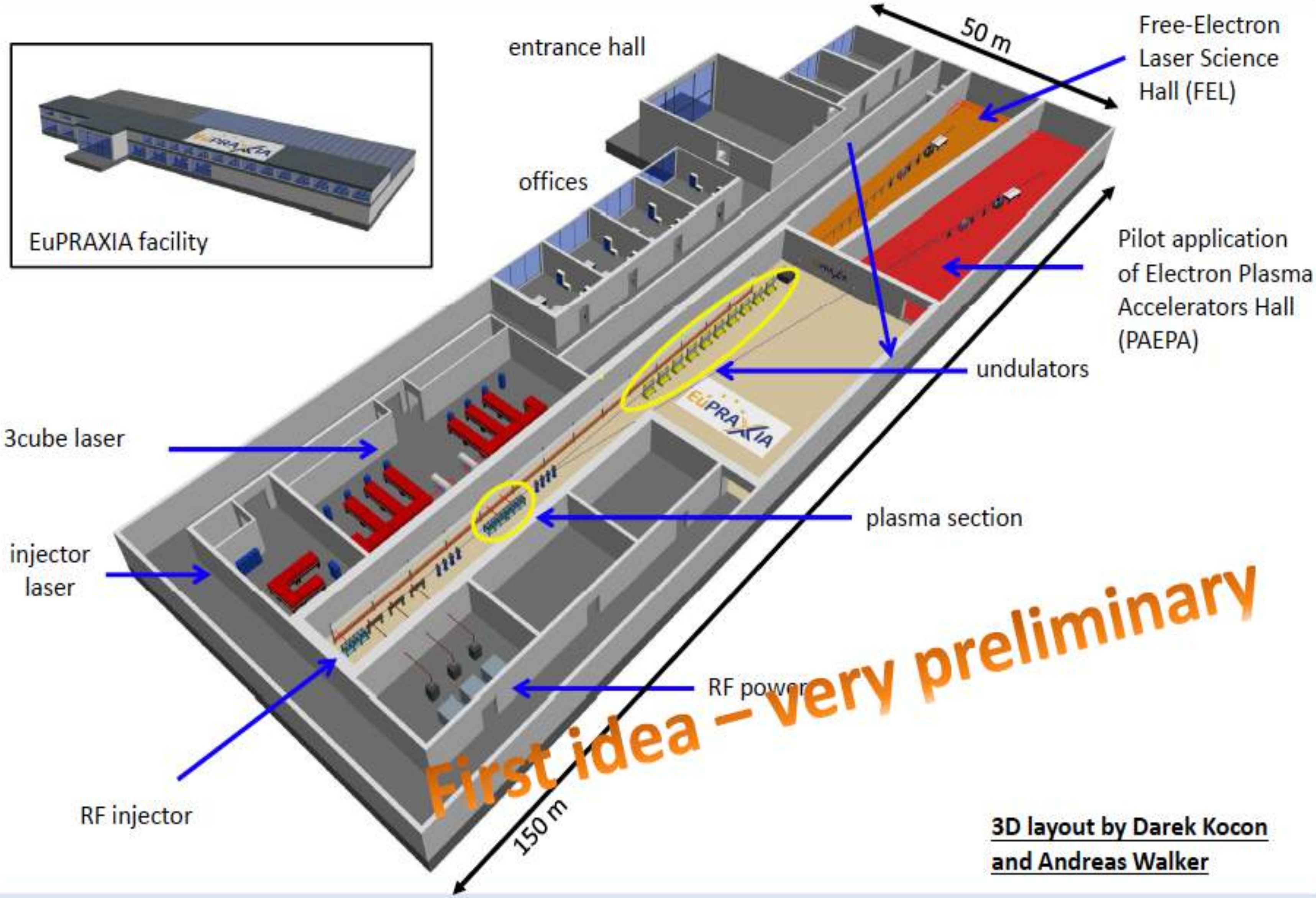
- 5 GeV case, 0.1 % energy spread, 1 mm.mrad emittance

The targeted current value (or charge) has still to be investigated. From these three series of data, one could define reasonable LPA parameter specification for the FEL application, providing the requirements to the other WP.

Courtesy M. E. Couprie

	Units	Xband FEL-SASE 1 GeV	EuPRAXIA FEL-CDR 1 GeV Witness bunch	
No.bunches		1 – (maybe 2)		
Bunch separation	ps	(maybe 83)		
Rep. rate	Hz	10 – (100)	10	
Injector energy	GeV	0.15	0.15	
Xband Acc. Gradient	MV/m	> 70	> 70	
Exit linac energy	GeV	1. – (1.5)	0.5	
			2016	**2017 ?**
Rms Energy Spread	%	<1.	<1	<1
Peak current	kA	2.	3	1.5
Bbunch charge	pC	100	30	10
Bunch length rms	μm (fs)	15 (50)	3 (10)	2 (7)
Rms norm. emittance	μm	< 1.	<1.5	<1
Slice Length	μm	0.7	0.75	0.75
Slice Charge	pC	4.5	7.5	3.7
Slice Energy Spread	%	0.1	0.1	0.1
Slice norm. emittance	μm	0.5	1	0.5
Undulator period	cm	1.5	1.5	1.5
K		1	1	1
ρ	$x\ 10^{-3}$	1.2	1.1	1.1
Radiation wavelength	nm (keV)	3. (0.4)	3. (0.4)	3. (0.4)
Saturation length	m	22	26	27
Saturation power	MW	940	1210	492
Energy	μJ	47	12	3.3
Photons/pulse	$x\ 10^{10}$	70	17.	4.8

draft of facility layout



3D layout by Darek Kocon and Andreas Walker

Officially started on November 1, 2015

Excellent Science
Developing new world-class research infrastructures
H2020-INFRADEV-1-2014-1
Deadlines: 02/09/2014
Opening Date: 11/12/2013

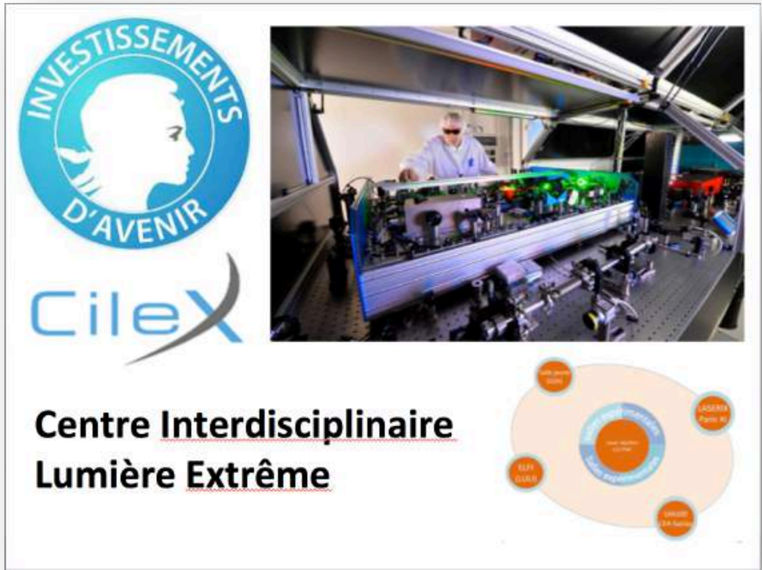
ESFRI European Strategy Forum on Research Infrastructures

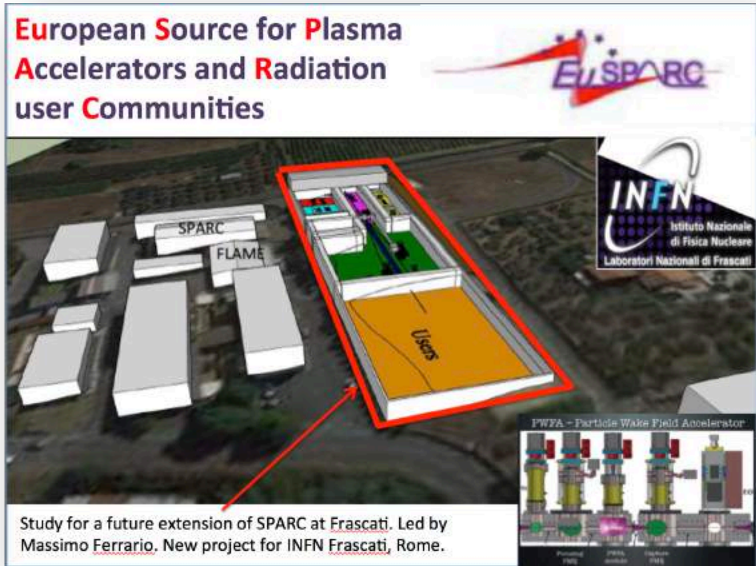
~200 M€

- Design Studies with at least 3 Countries,
- Cost. Schedule, Siting?
- What is the governance model?
- What is the intended user community?
- Will it be open access?
- Apply for H2020 preparatory phase (PP)?

- Support will be provided by Horizon2020 and MIUR for the implementation (PP) and operation of the research infrastructures listed on the ESFRI Roadmap and ERIC.

Examples upcoming and new facilities

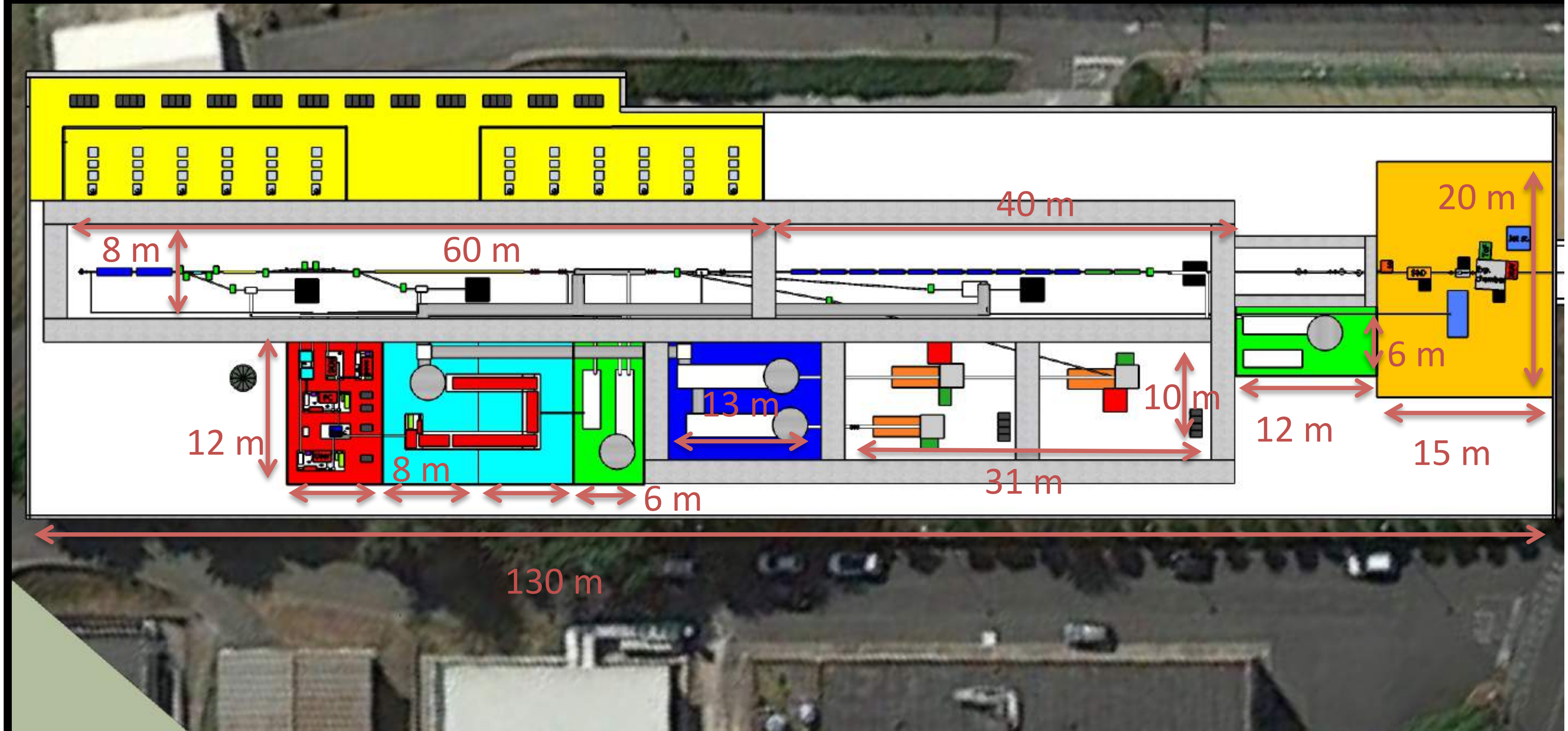




Exciting developments in various partner and associate partner labs.

EuPRAXIA@SPARC_LAB

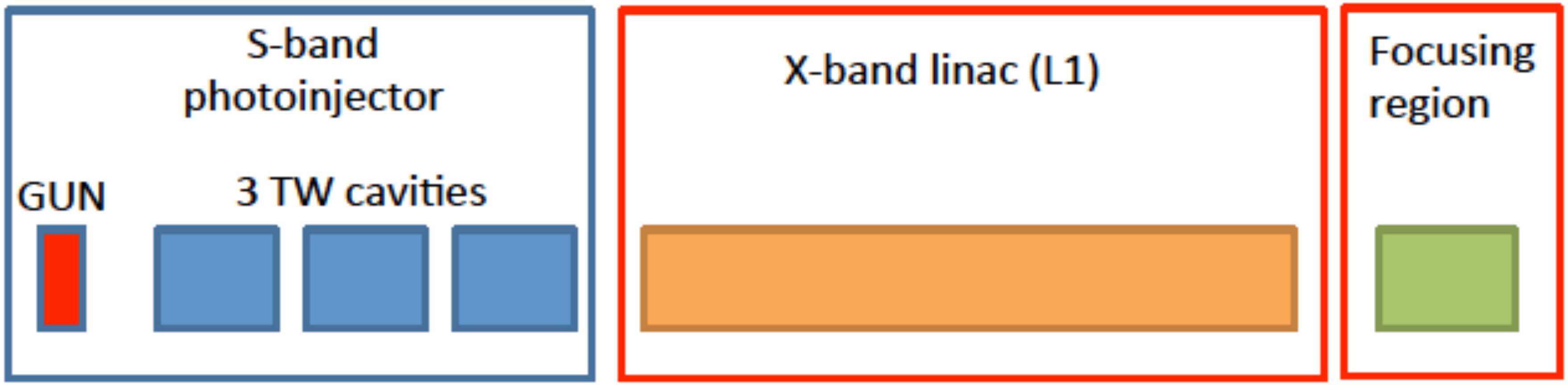

SPARC
FLAME
Users

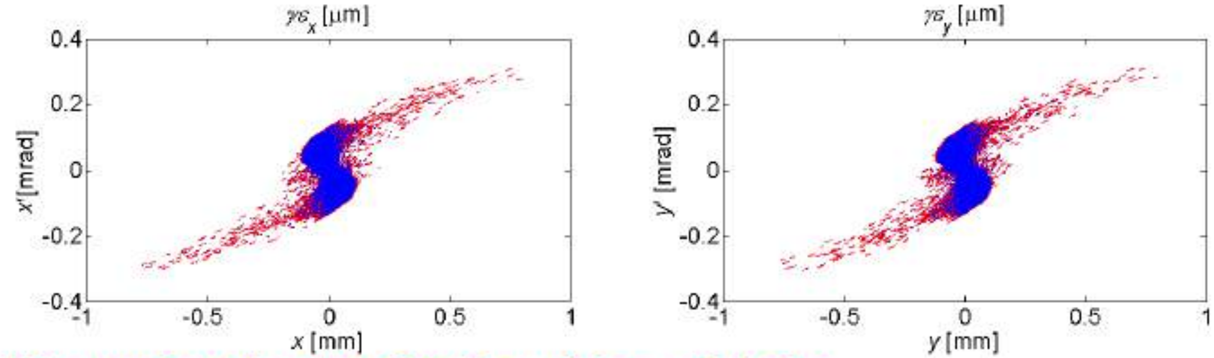


8 m
60 m
40 m
20 m
6 m
12 m
8 m
6 m
13 m
10 m
31 m
12 m
15 m
130 m

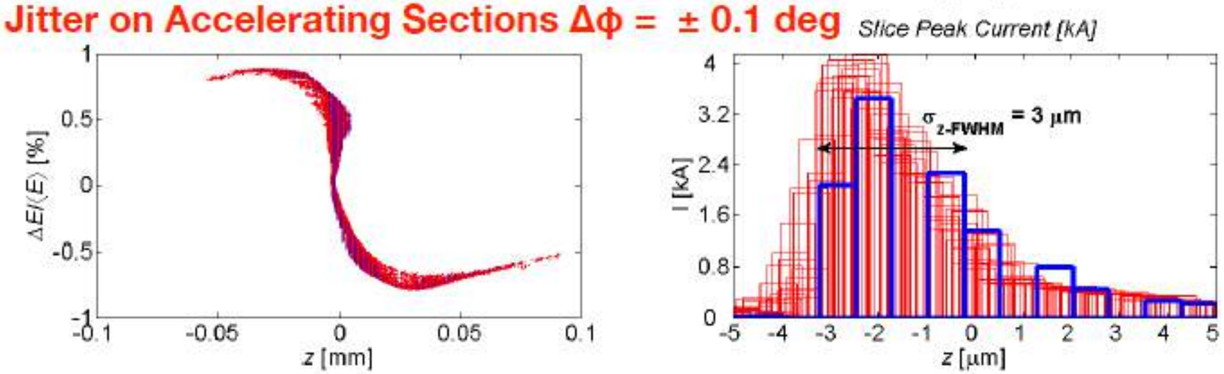
Witness Working Point

Stability studies by Anna Giribono (INFN-RM1)





Jitter on Accelerating Sections Δϕ = ± 0.1 deg



Beam parameters @Inj.Exit	
E [MeV]	98.8 ± 0.5
ΔE/E [%]	0.30 ± 0.01
$\varepsilon_{x,y}$ [mm mrad]	0.58 ± 0.02
$\sigma_{z\text{-rms}}$ [μm]	5.6 ± 0.1
$\sigma_{z\text{-FWHM}}$ [μm]	~ 3.0
$I_{peak-FWHM}$ [kA]	~ 3.0

Compact-Light Design Study just submitted

THE X-BAND FEL COLLABORATION

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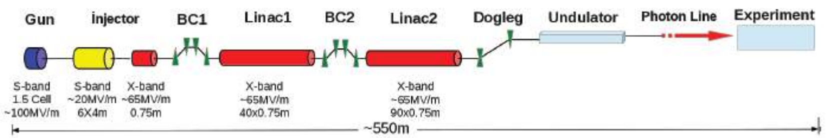
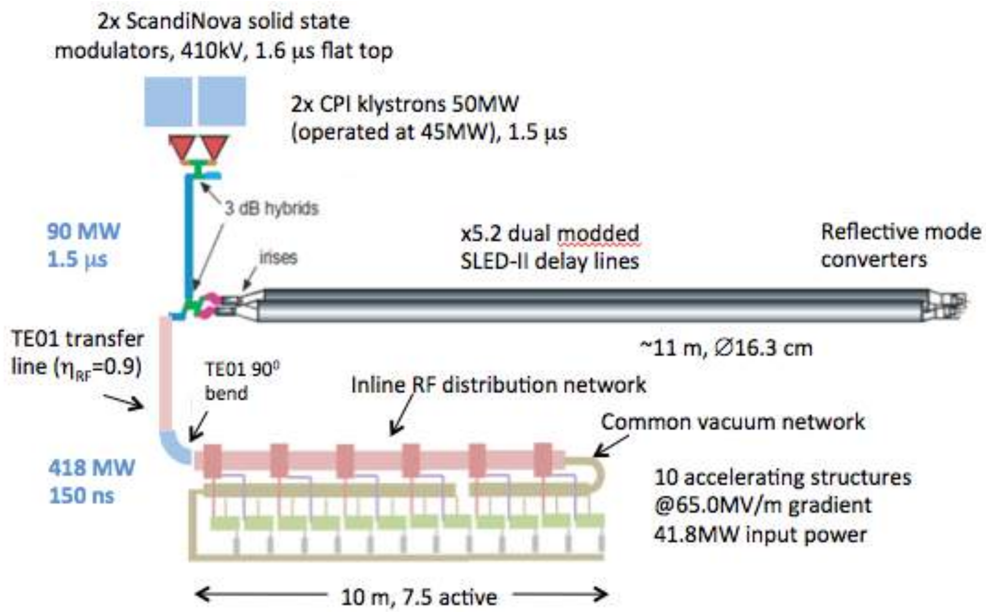




Parameter	CLIC-502		Optimum
Structures per RF unit	12	16	10
Klystrons per RF unit	2	2	2
Structure length (m)	0.23	0.23	0.75
a/λ	0.145	0.145	0.125
Operating gradient (MV/m)	77	67.5	65
Energy gain per RF unit (MeV)	213	248	488
RF units needed	27	23	12
Total klystrons	54	46	24
Linac active length (m)	74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

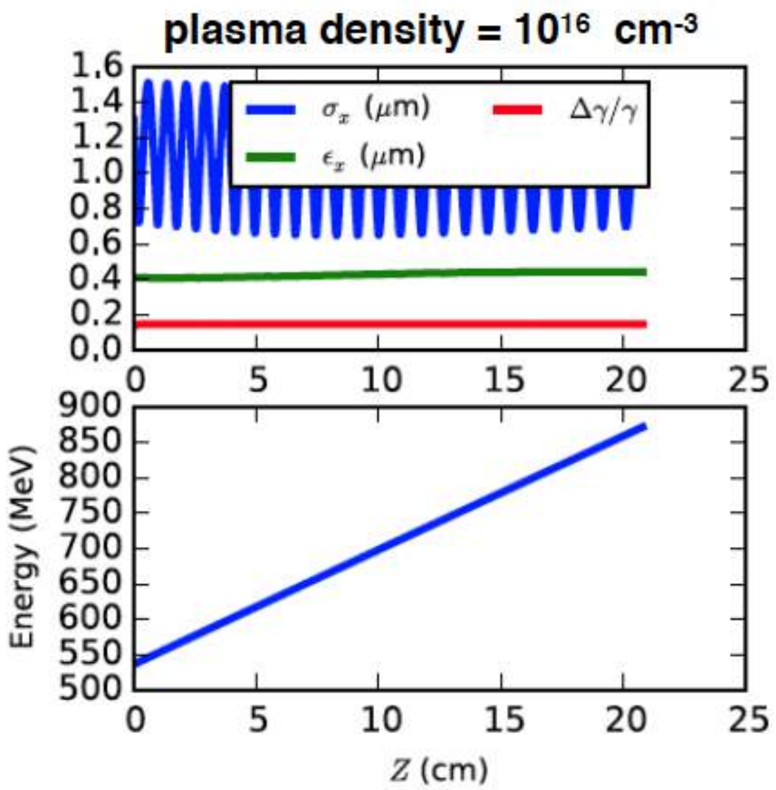
- No much info about this accelerating section (ever been prototyped and tested?). It might possibly be just an optimal scaling for the purpose.
- However the RF plant and the section properties fit the EUSPARC need, so the proposed RF basic block can be easily scaled to the EUSPARC case to draw some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

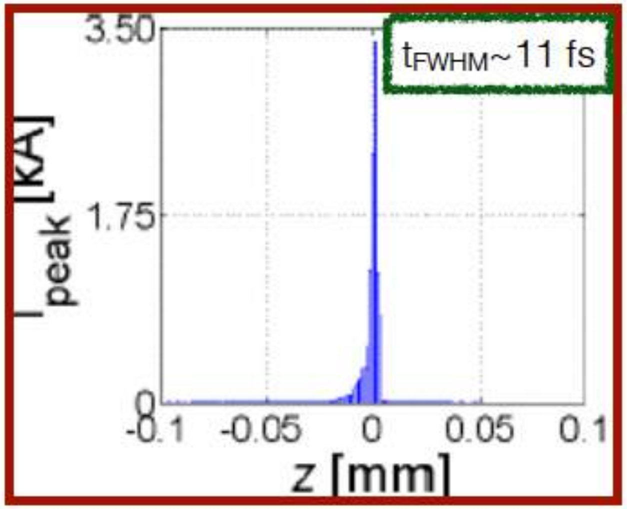
Witness Interaction in the Plasma

by Alberto Marocchino (INFN-LNF)

- Input witness beam from TSTEP-Elegant simulation
- Driver beam modeled in Architect*
- Witness interaction simulated in Architect

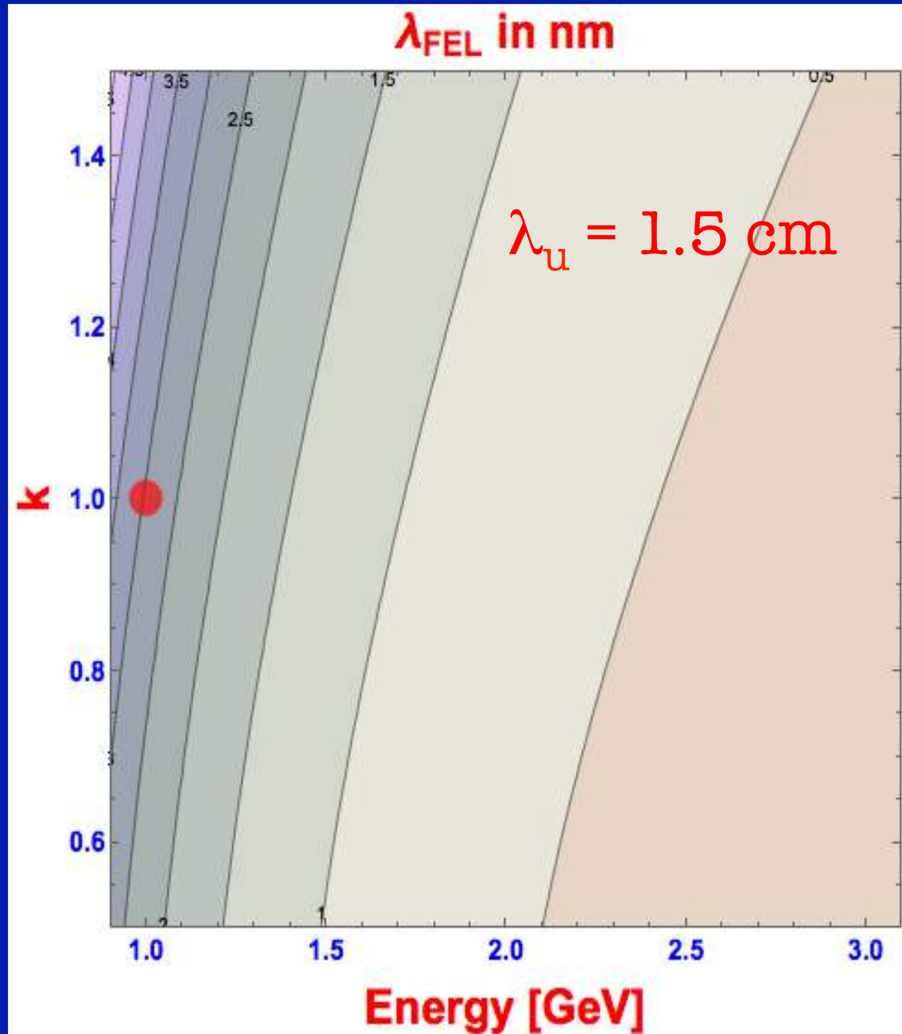
	Witness
E [MeV]	548.3
ΔE/E [%]	0.07
$I_{peak-FWHM}$ [kA]	~ 2.7
Q [pC]	30
$\sigma_{z\text{-}rms}$ [µm]	6.6
$\sigma_{z\text{-}FWHM}$ [µm]	~ 3.3
$\varepsilon_{x,y}$ [mm mrad]	0.6 – 1.0
$I_{peak-Slice}$ [kA]	3.5

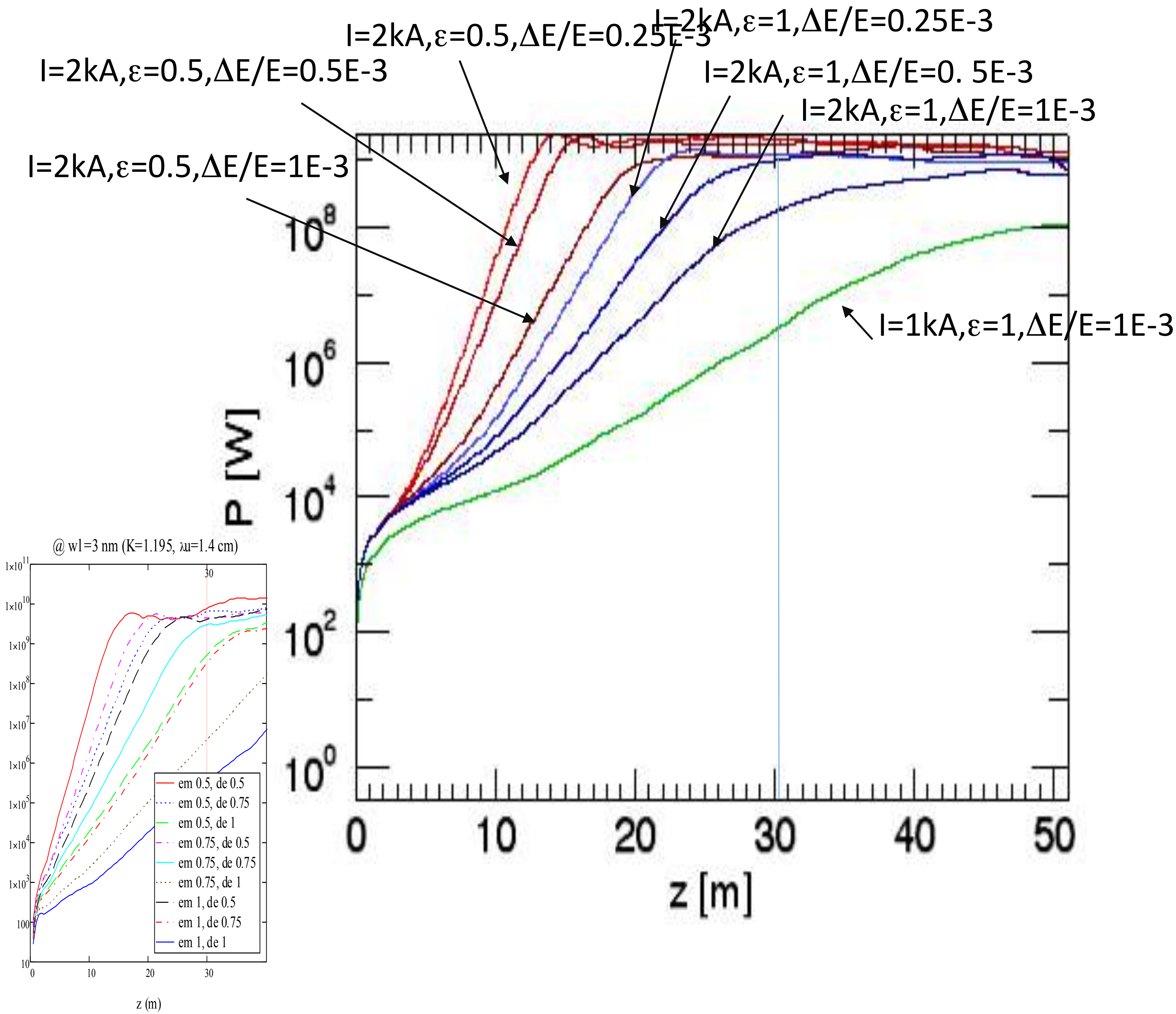




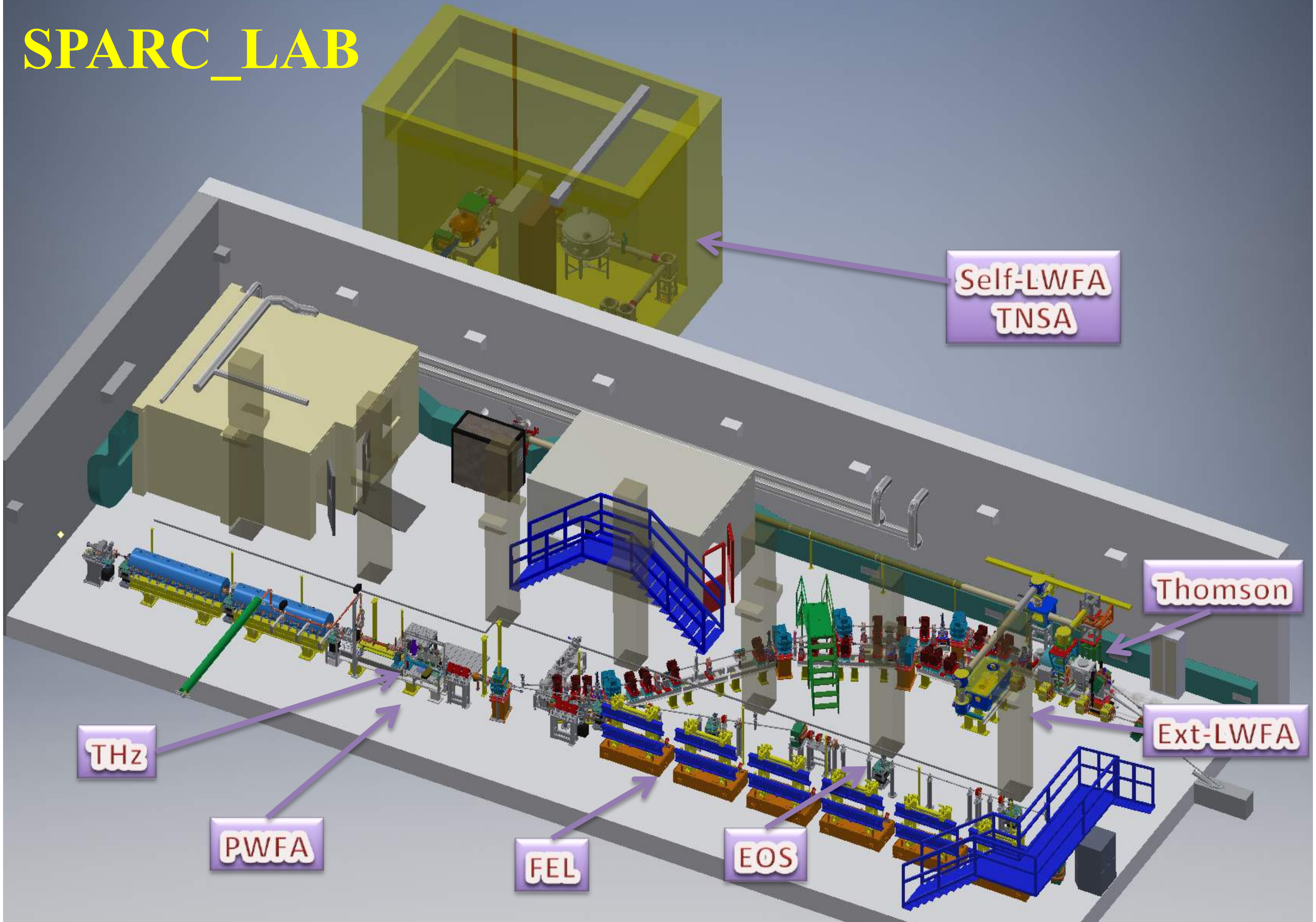
*A. Marocchino, F. Massimo, Architect: first release (Apr. 2016). doi:10.5281/zenodo.49572.

SASE FEL studies



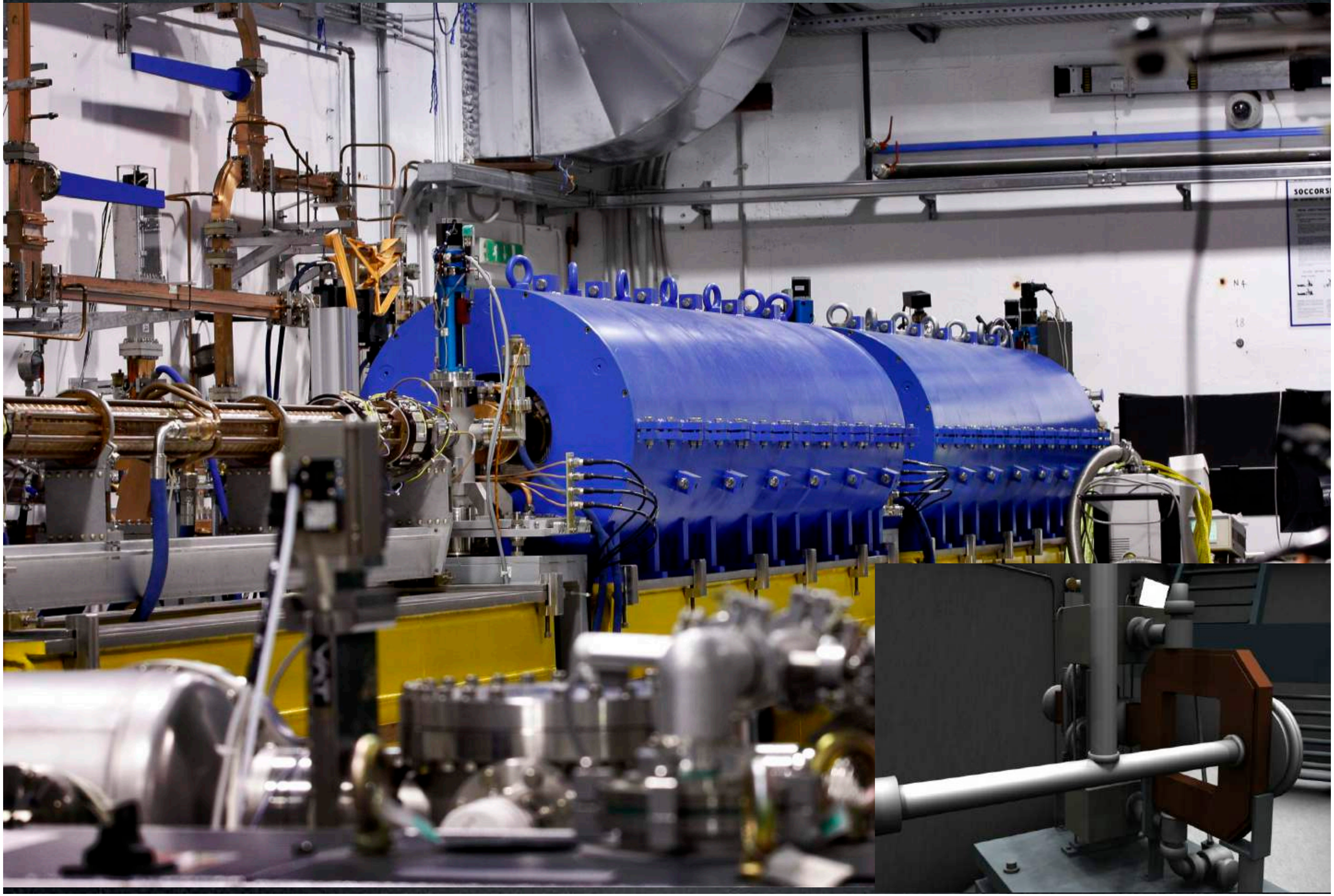

I=2kA,ε=0.5,ΔE/E=0.25E-3
I=2kA,ε=1,ΔE/E=0.25E-3
I=2kA,ε=0.5,ΔE/E=0.5E-3
I=2kA,ε=1,ΔE/E=0. 5E-3
I=2kA,ε=1,ΔE/E=1E-3
I=2kA,ε=0.5,ΔE/E=1E-3
I=1kA,ε=1,ΔE/E=1E-3
P [W]
z [m]
@ wl=3 nm (K=1.195, λu=1.4 cm)
em 0.5, de 0.5
em 0.5, de 0.75
em 0.5, de 1
em 0.75, de 0.5
em 0.75, de 0.75
em 0.75, de 1
em 1, de 0.5
em 1, de 0.75
em 1, de 1
z (m)

SPARC_LAB

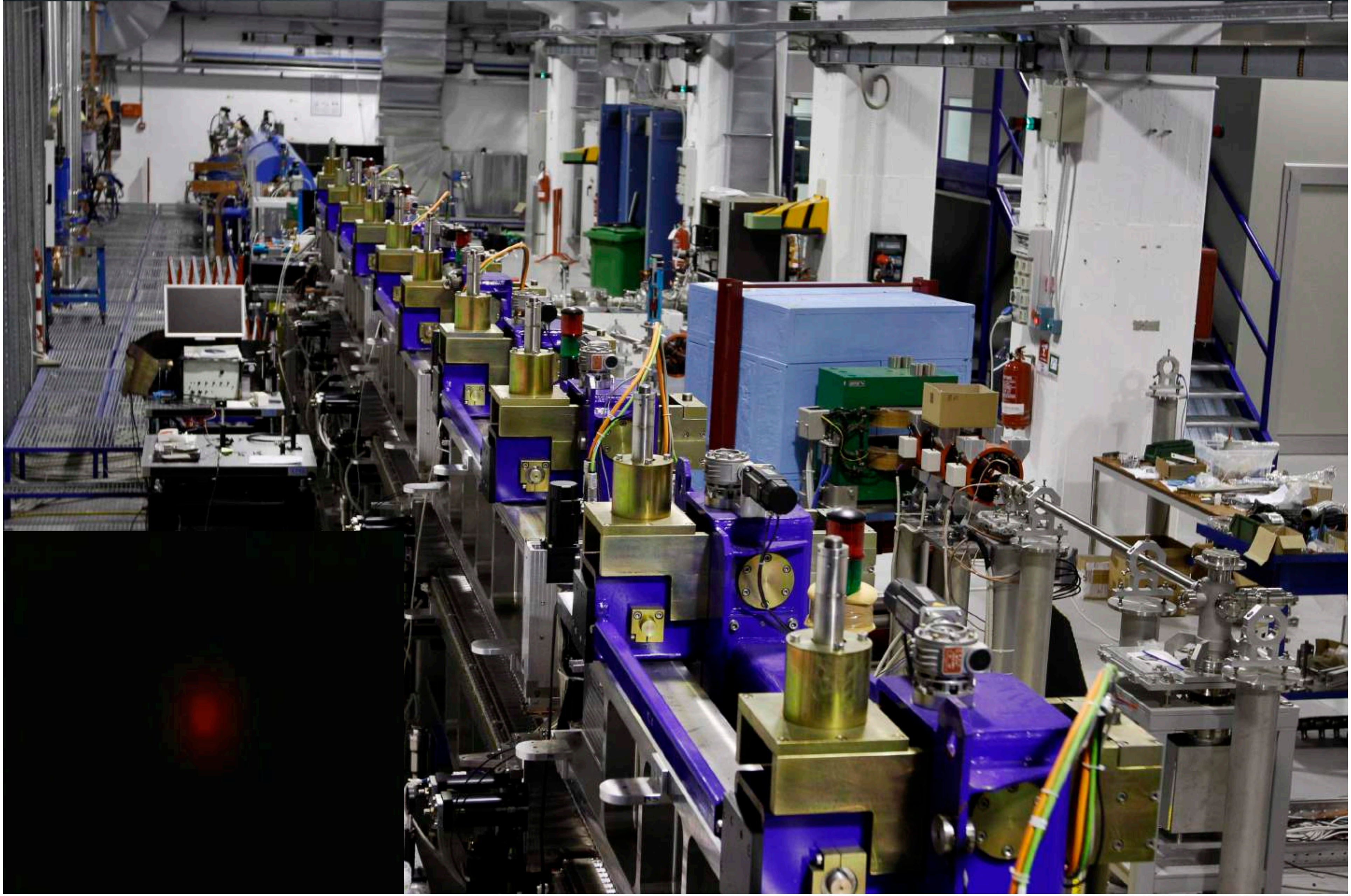


Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.

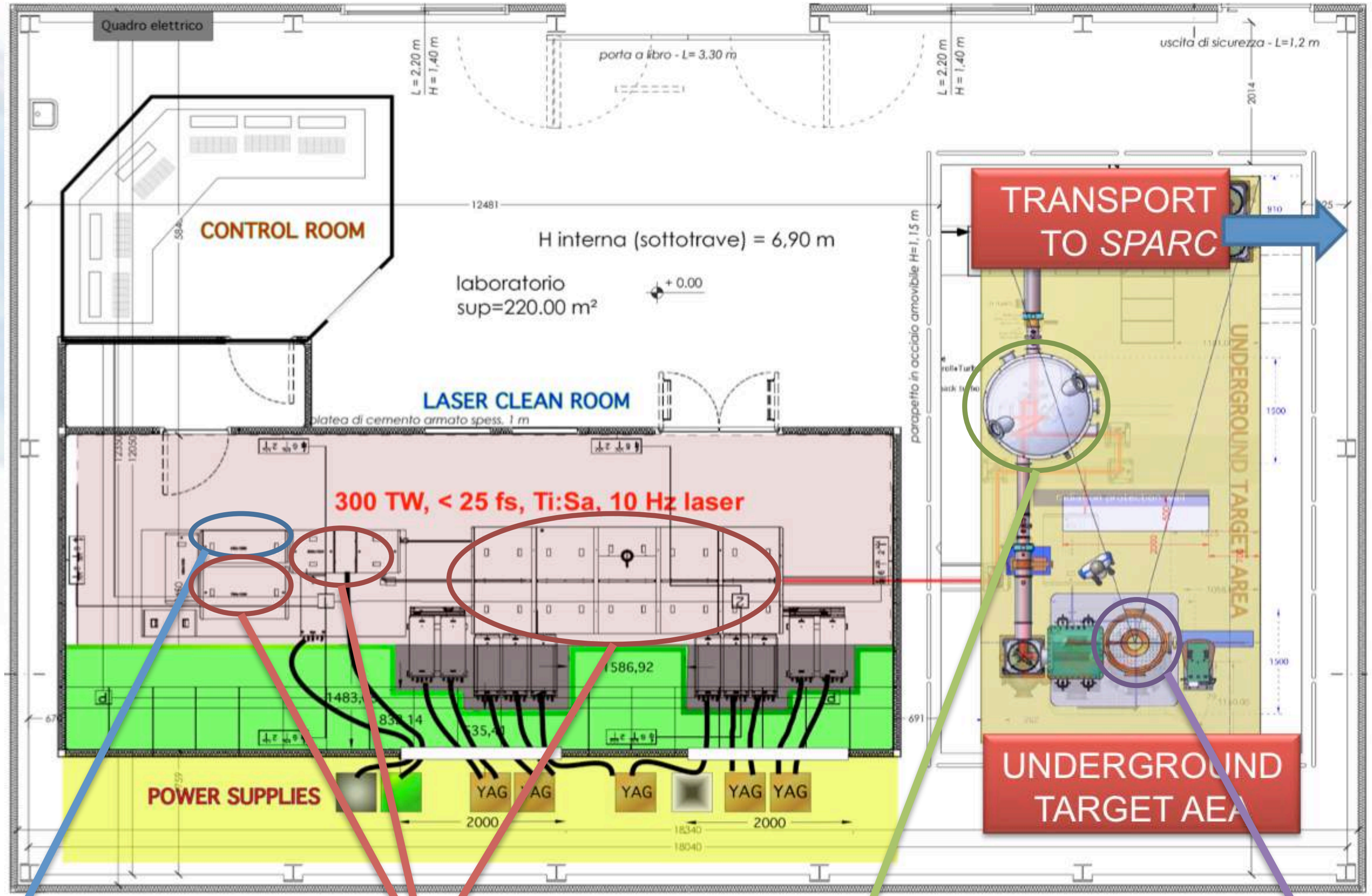
HB photo- injector with Velocity Bunching



Free Electron Laser



Ti:Sa FLAME laser



Stretcher

Amplifiers

Compressor

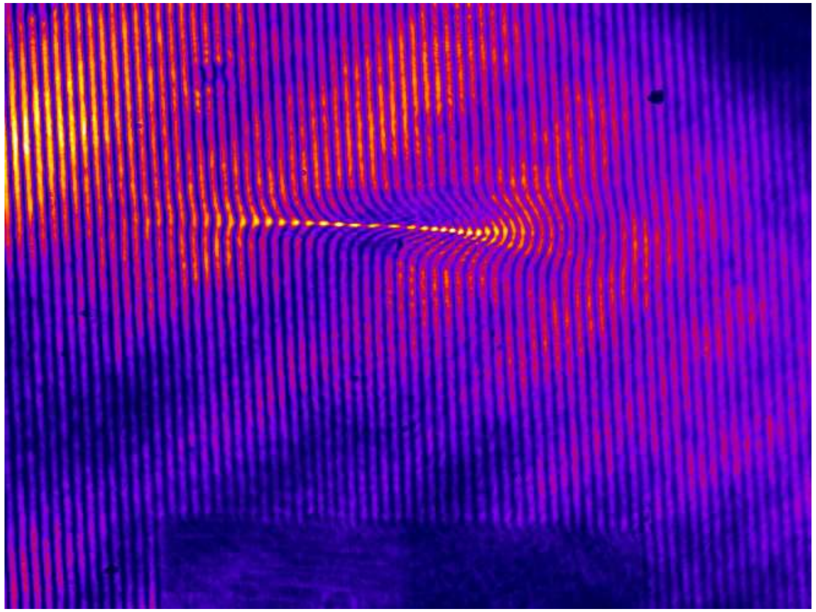
LWFA
Electron Self Injection
And
Protons

Ti:Sa FLAME laser

Final amplification stage from ~600 mJ to 6J

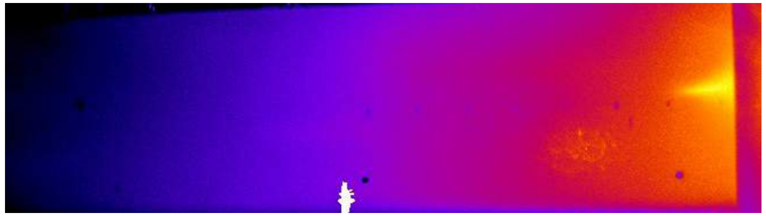
Energy	6 J
Duration	23 fs
Wavelength	800 nm
Bandwidth	60/80 nm
Spot @ focus	10 μm
Peak Power	300 TW
Contrast Ratio	10^{10}

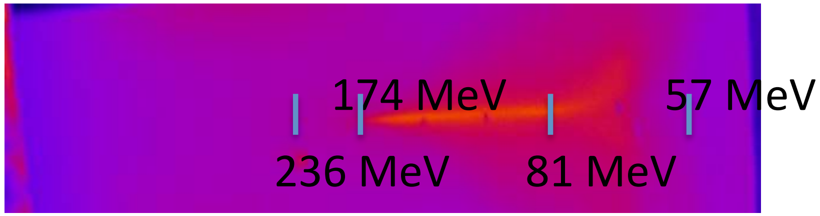
FLAME activities

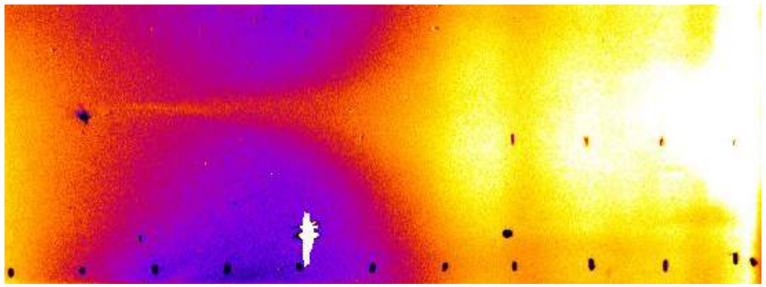


MachZender interferometer.

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





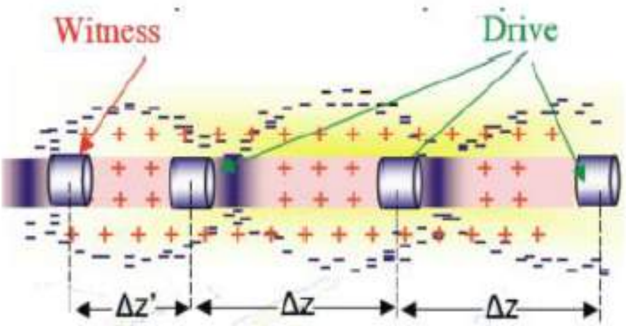


By scanning the plasma density, electron energy has been varied from 50 MeV, to 175 MeV and up to 300 MeV.

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

Plasma-based acceleration techniques

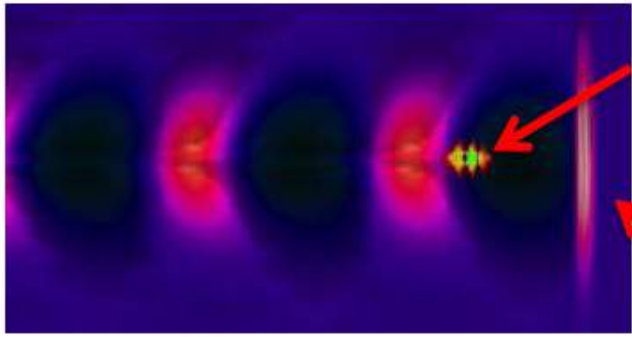
resonant-PWFA



•A train of three electron bunches (driver bunches) is sent through a capillary discharge
•A resonant plasma wave is then excited in plasma
•A fourth electron beam (witness beam) uses this wave to be accelerated

$n_e = 2x10^{16}$ cm^{-3}
$\lambda_p = 300\mu m$
Capillary 1mm
Hydrogen

external injection LWFA



•A laser beam excites plasma waves in a capillary filled with gas
•A high brightness electron beam uses this wave to be accelerated

$n_e = 1x10^{17}$ cm^{-3}
$\lambda_p = 100\mu m$
Capillary 100 µm
Hydrogen

GRAXIE

Courtesy A. Mostacci