Status of the EUSPARC proposal

Massimo.Ferrario on behalf of the EuSparc team

Istituto Nazionale di Fisica Nucleare

June 25, 2016

Report on the EUSPARC design study at LNF

(European Source for Plasma Accelerators and Radiation user Communities)

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on behalf of the SPARC_LAB - EUSPARC collaboration

Sptember 14, 2016

If the proposed SPARC_LAB upgrade, named EUSPARC and discussed in the following paragraphs, will be completed within the next 6 years, we believe it will be possible to strongly candidate LNF to host the EuPRAXIA European Facility.

In order to meet the EuPRAXIA requirements some important preparatory steps must be set up at LNF:

- Consolidating the existing infrastructure in order to qualify SPARC_LAB with significant experimental results in the field of plasma accelerators and FEL.
- Consolidating in the very short term the existing expertise with staff positions for at least: 3 accelerator researchers (Plasma, Diagnostics and FEL Physics), 2 high power laser experts and 2 laser technicians.
- Investigating the availability of a large infrastructure at LNF or build a new experimental hall able to host the EUSPARC facility.
- Provide within one year a Conceptual Design Report with a scientifically exciting program for EUSPARC itself.

A number of significant improvements of the existing SPARC_LAB facility are underway, mainly funded by MIUR via the EUROFEL_MIUR and "Premiale" contracts with an additional INFN contribution:

- FLAME maintenance and consolidation up to the nominal 300 TW power,
- Injector upgrade for ultra-high brightness beams with a new RF gun,
- THz user beam line installation in the upper aisle,
- Thomson and External injection plasma beam lines final commissioning and operation,
- FEL short period undulator test and R&D on RF and optical alternatives including Quantum FEL studies.

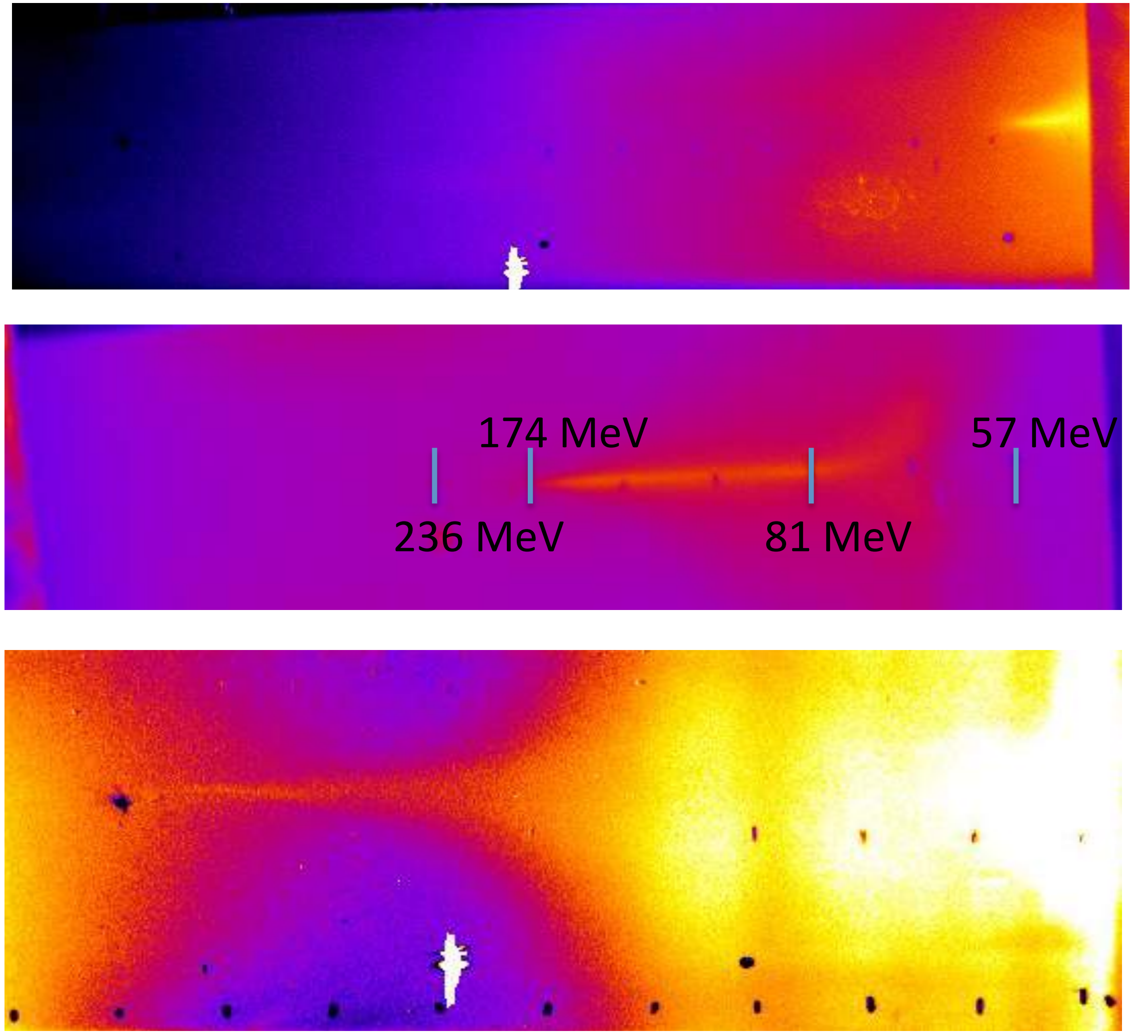
In parallel to the facility consolidation actions listed above, a number of significant experiments are foreseen with the existing SPARC_LAB facility, focused in achieving some of the fundamental requirements enabling the EuPRAXIA program. Within the next 5 years the SPARC_LAB Work Program foresees:

FLAME – Self Injection experiments

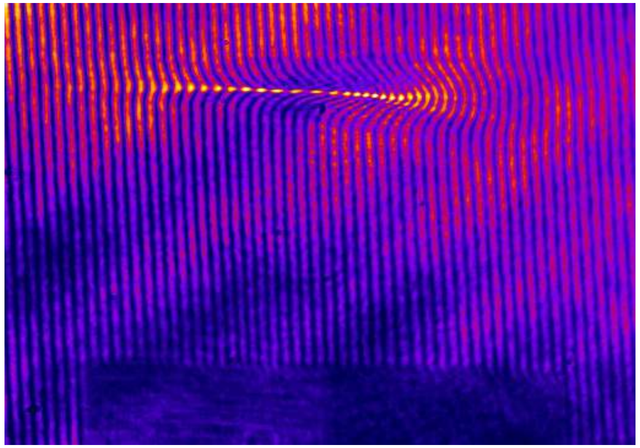
Parametric study of the laser and plasma performances.

So for example by scanning the plasma density, electron energy has been varied from 50 MeV, to 175 MeV and up to 300 MeV.

Also by tuning plasma density, energy spread has been reduced from 100% to 20%.



- **Plasma Diagnostics**

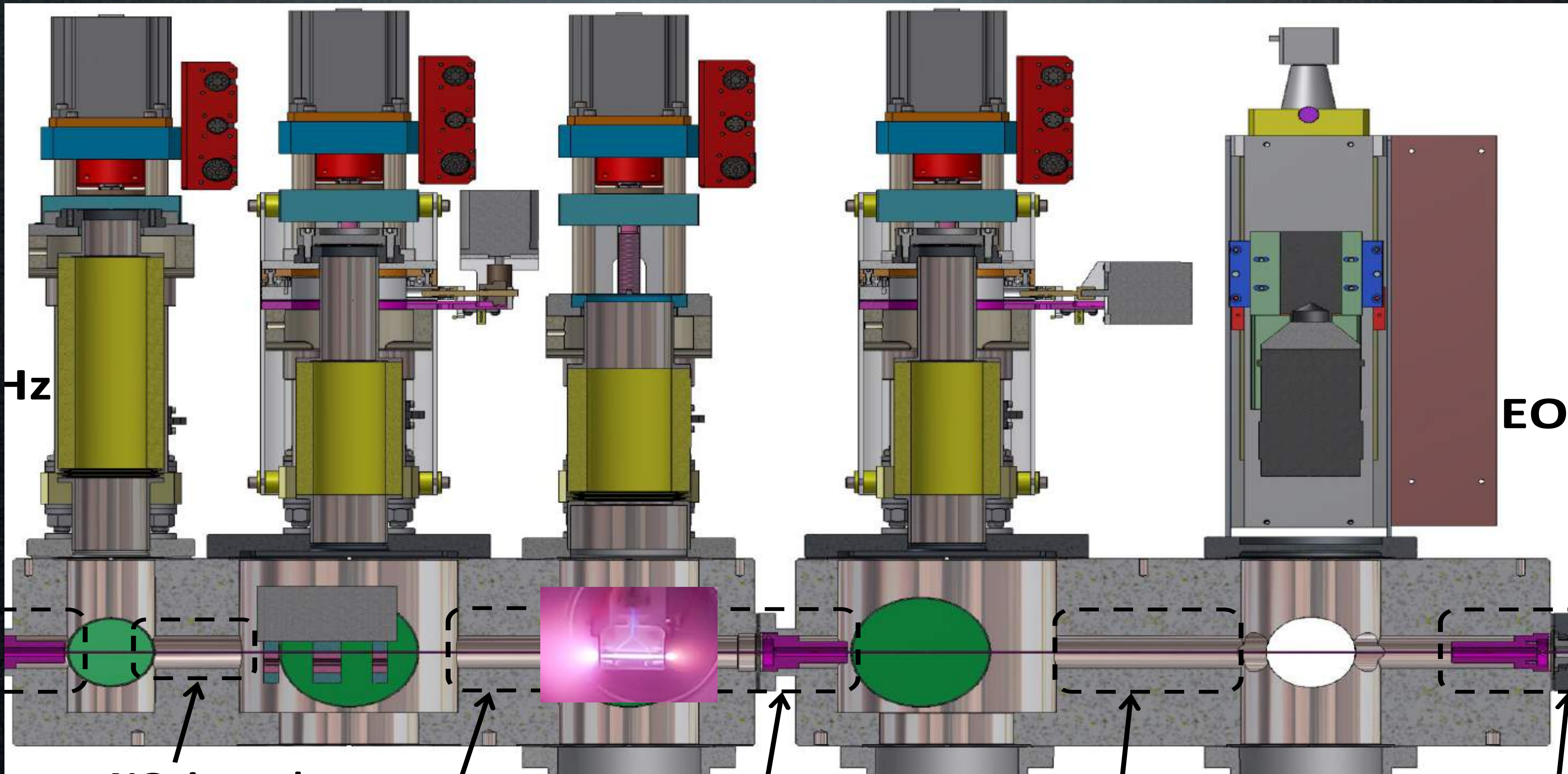


MachZender interferometer to measure the plasma density.

Using this diagnostic we have shot to shot measurement of the density and the total accelerating length.

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

PWFA – Particle Wake Field Accelerator

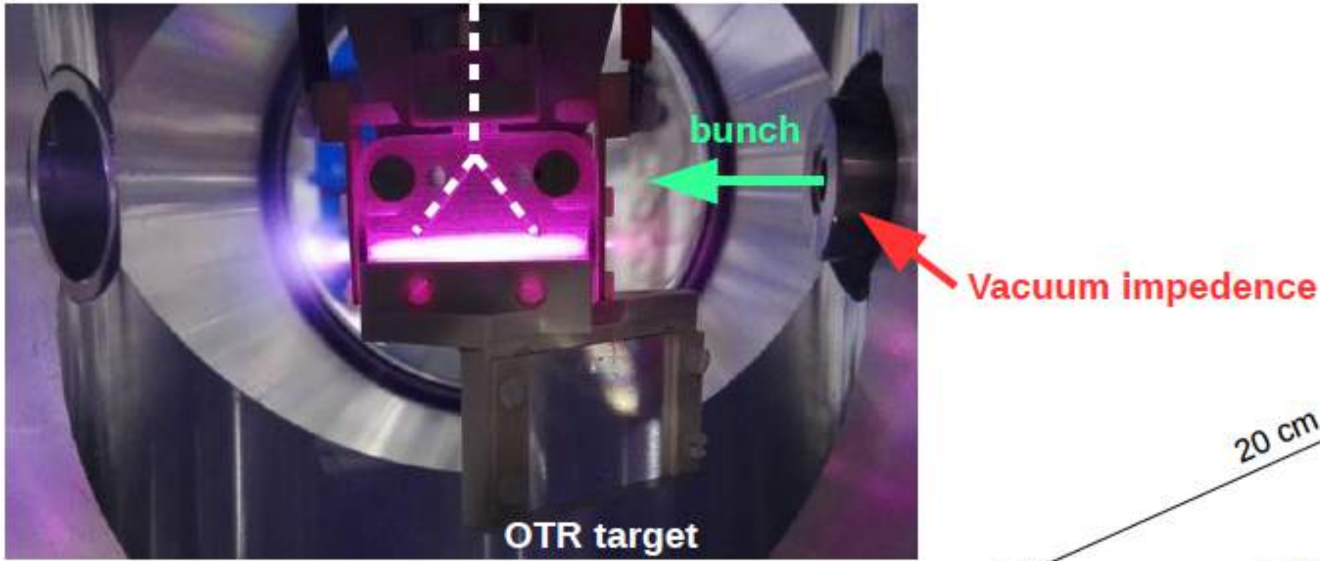


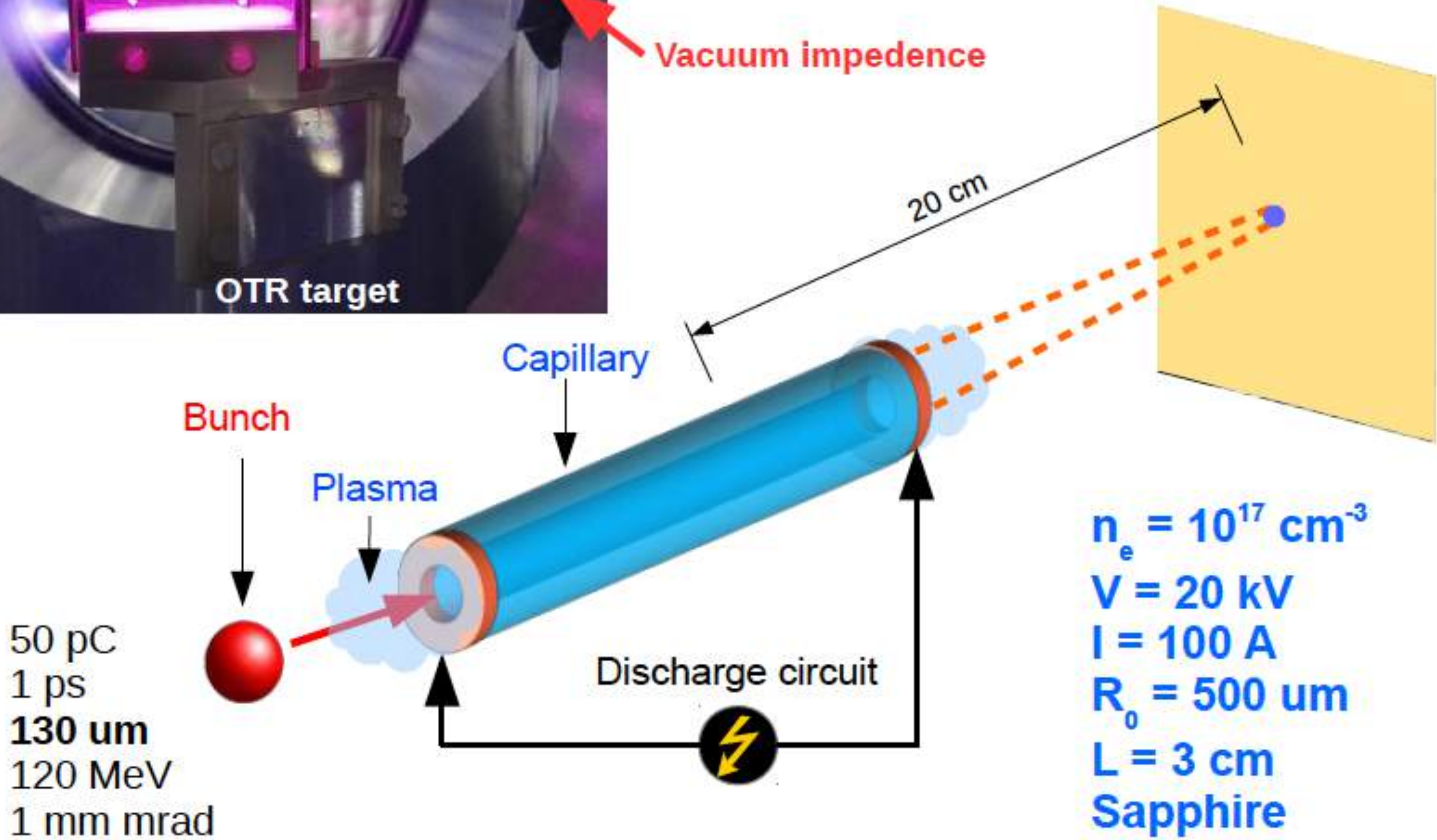
Focusing PMQ

PWFA module

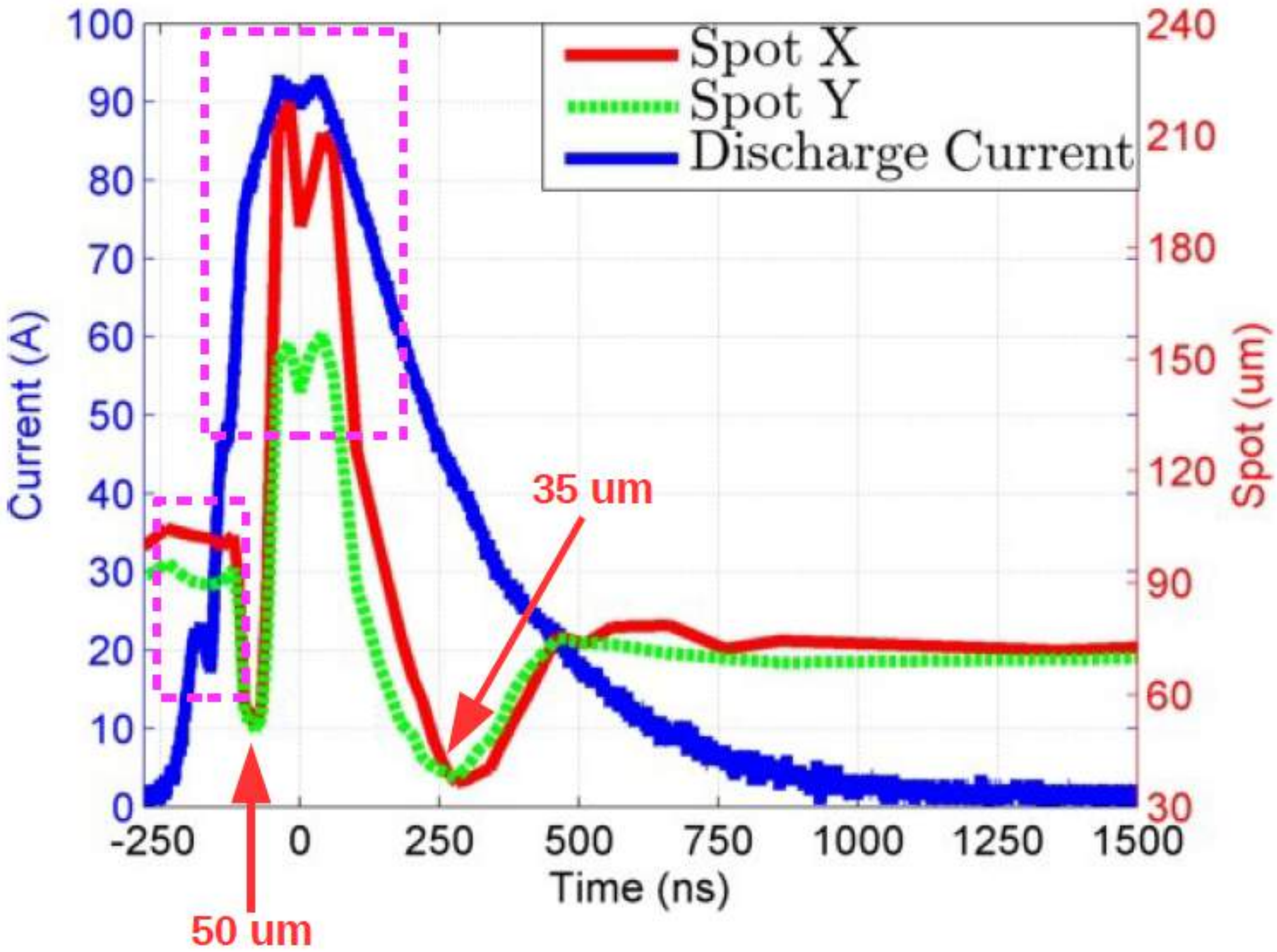
Capture PMQ

Experimental layout





Preliminary results



4 - EUSPARC SCIENTIFIC PROGRAM

The EUSPARC scientific program has three main directions:

- High gradient acceleration techniques for the next FEL and e+e- collider generations.
- Advanced radiation sources for photon science (FEL, Betatron, Compton, Channeling).
- Physics of high field interactions with matter.

The main required actions enabling the accomplishment of such a program are:

- The FLAME laser upgrade up to 1 PW
- The RF Linac upgrade up to 1 GeV

EUSPARC TDR 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

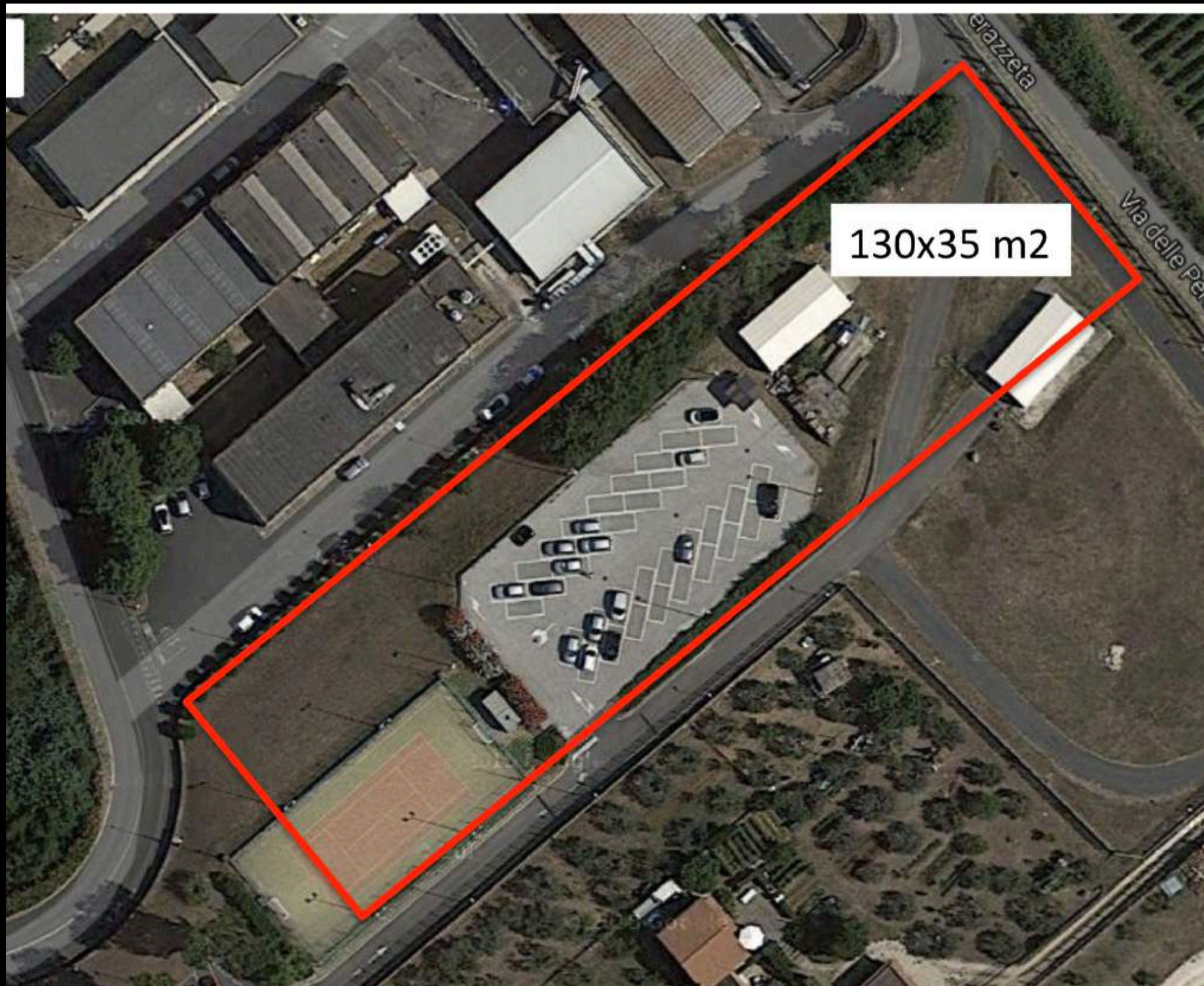
WG 4 – FEL pilot applications
- 4.1 Plasma driven FEL (F. Villa)
- 4.2 Advanced FEL schemes (G. Dattoli)
- 4.3 FEL user applications (M. Benfattoi)

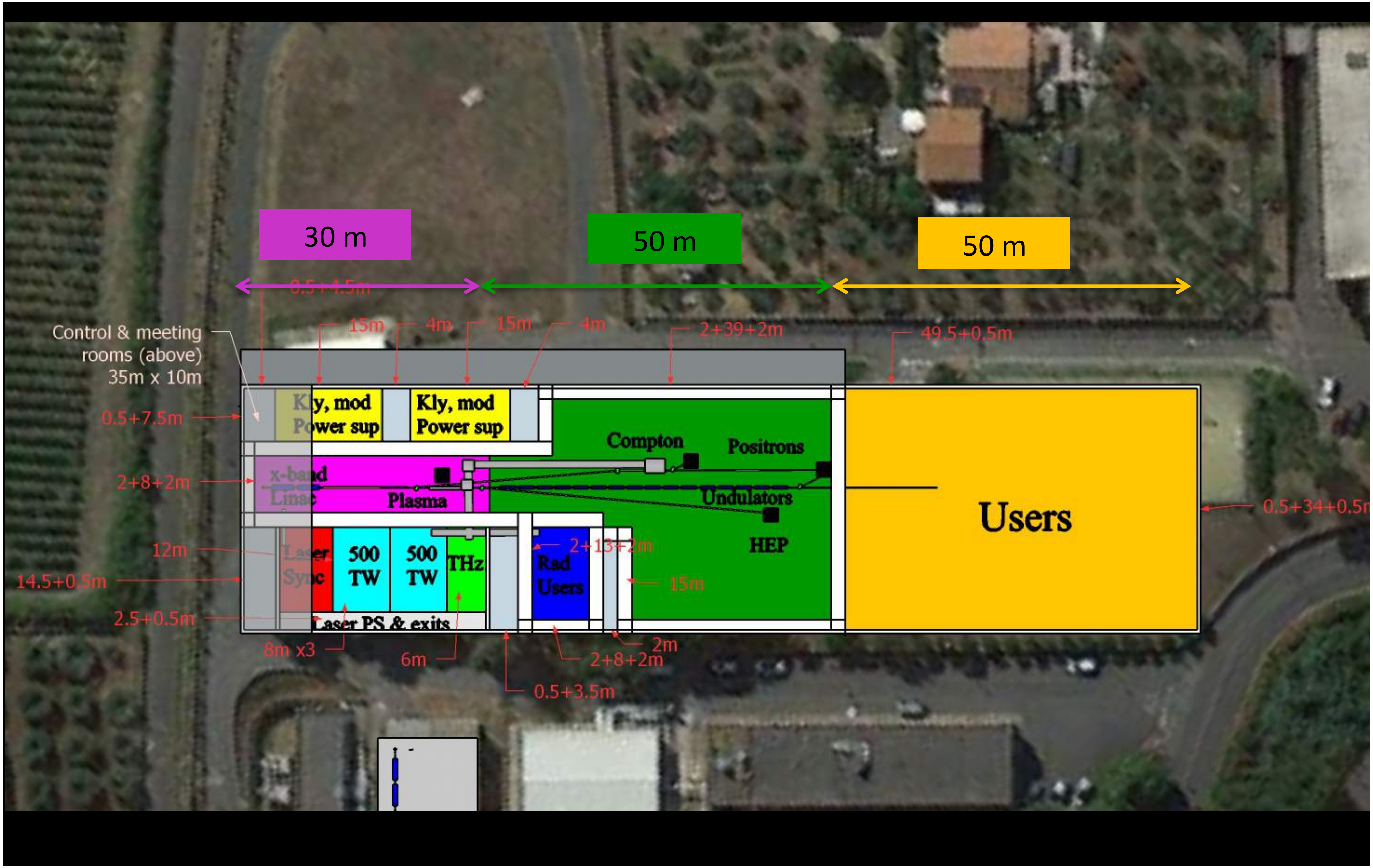
WG 5 – Radiation sources and user beam lines
- 5.1 Advanced dielectric THz source
- 5.2 Compton source (C. Vaccarezza)
- 5.3 User beam lines

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 Civil Engineering





Equipped new building 130x35 m^2	20. M€

Advanced RF Acceleration, X-band and Beyond

Sami G. Tantawi, Valery Dolgashev, Michael Fazio, Aaron Jensen, Mark Kemp, Zenghai Li, Jeff Neilson, and Collaborators

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Summary- Solid Foundation for Extending to Higher Frequency and Gradient

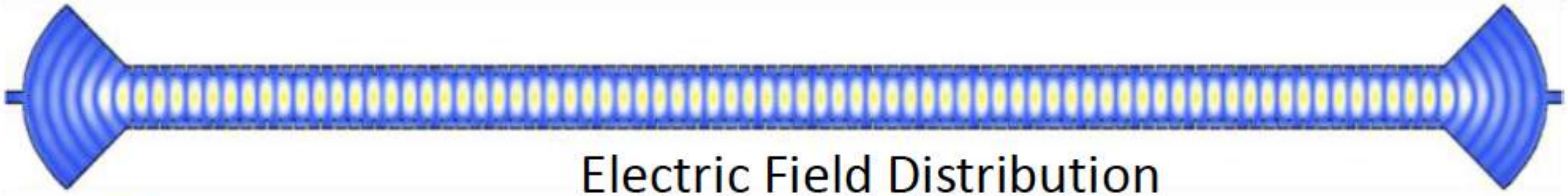
SLAC

- Gradients increased by factor of ~3, from 65 MV/m to > 170 MV/m
- *Very high shunt impedance* can improve RF to beam efficiency
- New Structure Topologies could go beyond 200 MV/m ***efficiently***:
  - ***Pave the way for future high energy colliders***
  - ***Revolutionize proton accelerators***
  - ***Provide an economical driver for plasma wakefield accelerators***
- New RF source designs improve efficiency and lower voltages:
  - Efficient modulators with short rise and fall times
  - Eliminate pulse compression for much higher system efficiency
  - Klystrons with no electromagnets and cost effective depressed collectors
- High efficiency allows NCRF operation beyond 10 KHz
- Many other applications - light sources, medical linacs, ...

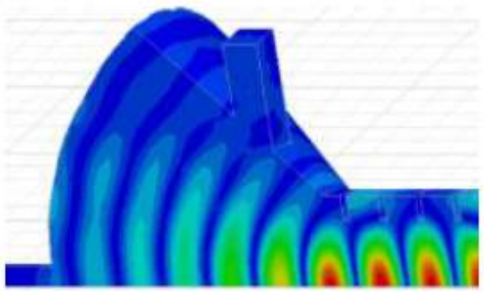
RF Undulator Example

- Corrugated waveguide structure

Undulator Mechanical Structure



Electric Field Distribution



Corrugation Period=0.4254 λ
Inner Radius=0.75 λ
Outer radius= 1.01293 λ
Corrugation Thickness= λ/16
Number of periods =98

RF λ = 26.24 mm (11.4 GHz)
Undulator Period = 13.93 mm
Power required (for linearly polarized, K=1) = 48.8 MW
Q0=94,000

High quality beam driven acceleration up to 1GeV @Eu_SPARC

Stefano Romeo
(stefano.romeo@lnf.infn.it)

on behalf of SPARC_LAB collaboration

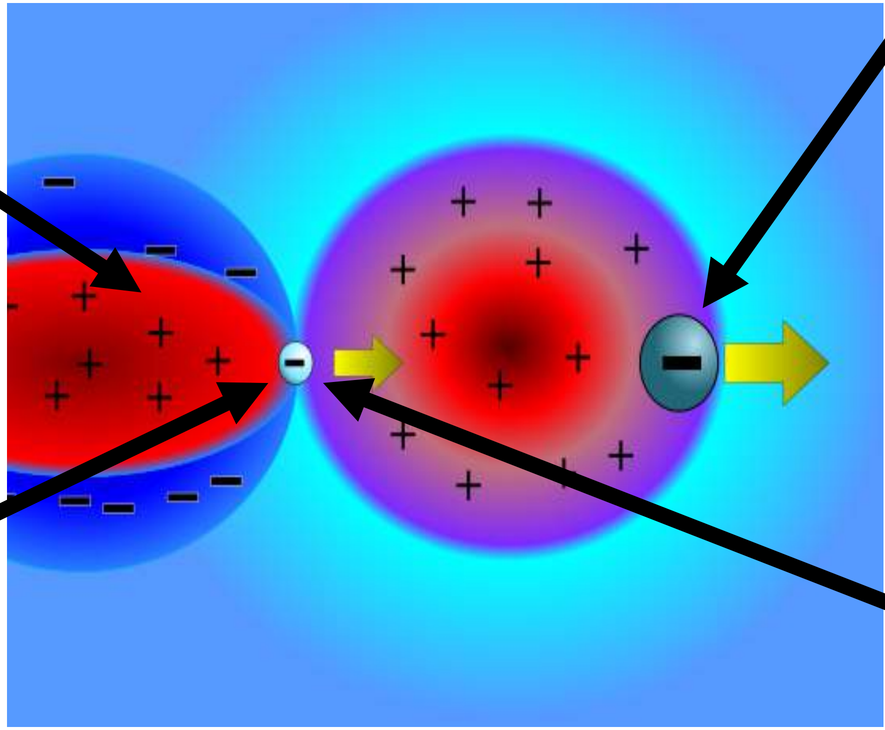
2016-07-12

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

New concept: surfing bubble

The field generated by the witness is non linear

Simple matching



The driver generates a linear field

The witness can be injected in the zone of maximum field

The focusing is guaranteed by a beam loading effect

Increased witness stability

The injection is performed on the crest of linear field

Minimum energy spread
Maximum gradient

Simulation parameters

- Plasma density $n_0 = 2\cdot 10^{16}$
- **Driver:**
  - Energy $\gamma = 500$
  - Charge $Q = 200pC$
  - Length $\sigma_z = 1/k_p$
  - $\alpha = 0.5$
  - Emittance $\varepsilon_n = 10\ mm\ mrad$
- **Witness:**
  - Energy $\gamma = 500$
  - Charge $Q = 15pC$
  - Length $\sigma_z = 3\mu m$
  - Spot size $\sigma_r = \sqrt[4]{1/\gamma}\ \sqrt{2\varepsilon_n / k_p}$
  - Emittance $\varepsilon_n = 0.3\ mm\ mrad$
  - Injection distance $\Delta z = 0.4\lambda, 0.45\lambda_p$

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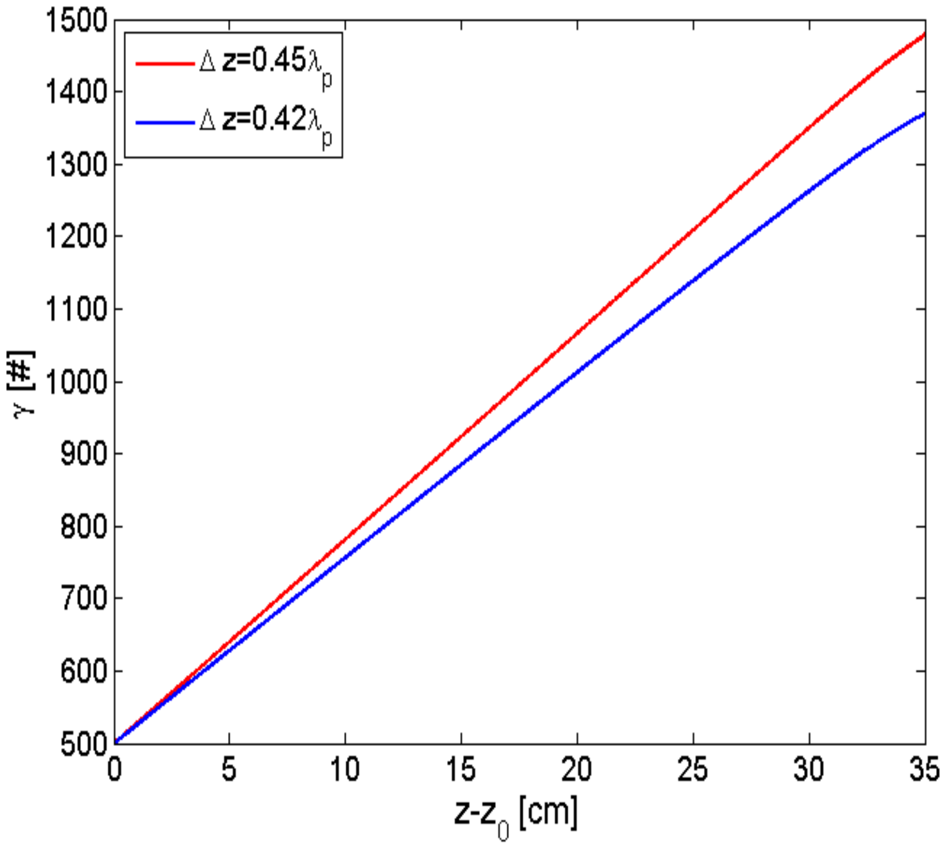
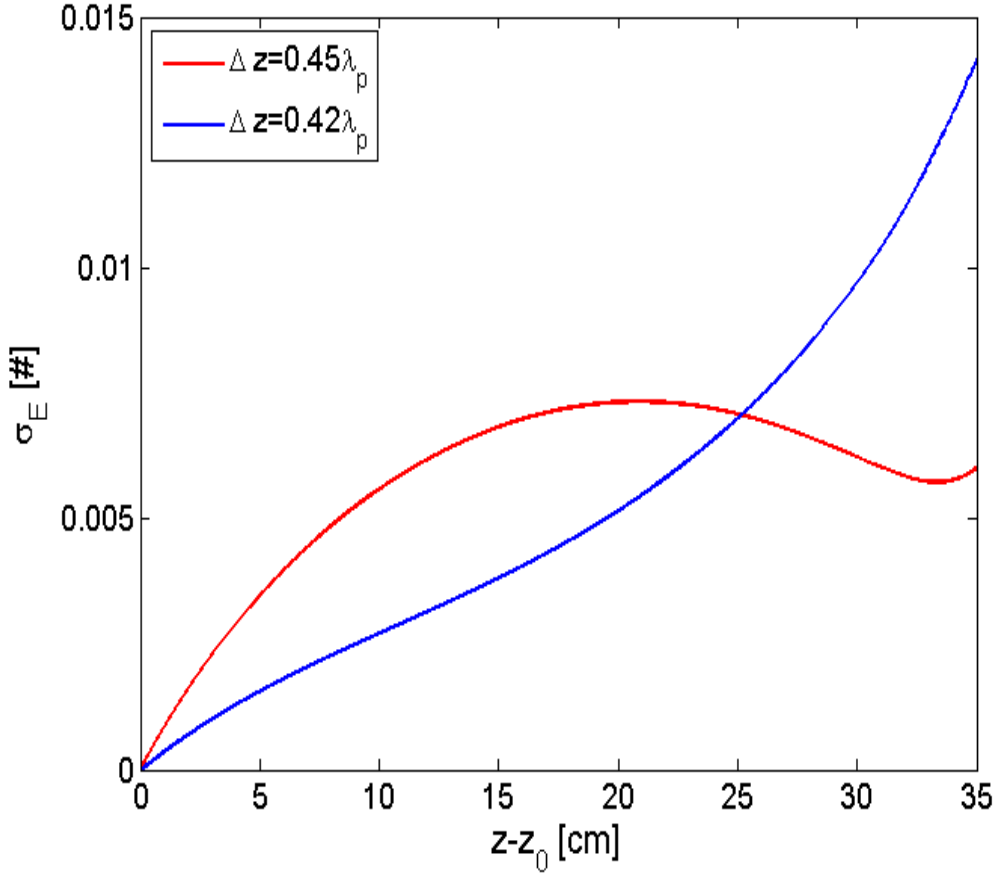
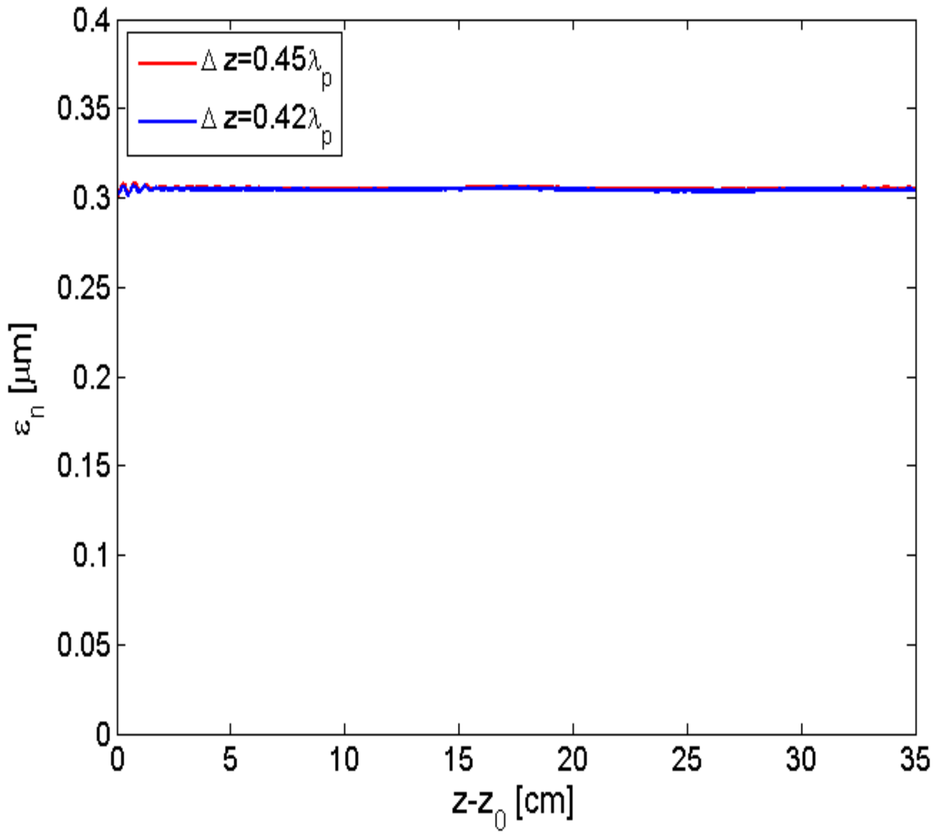
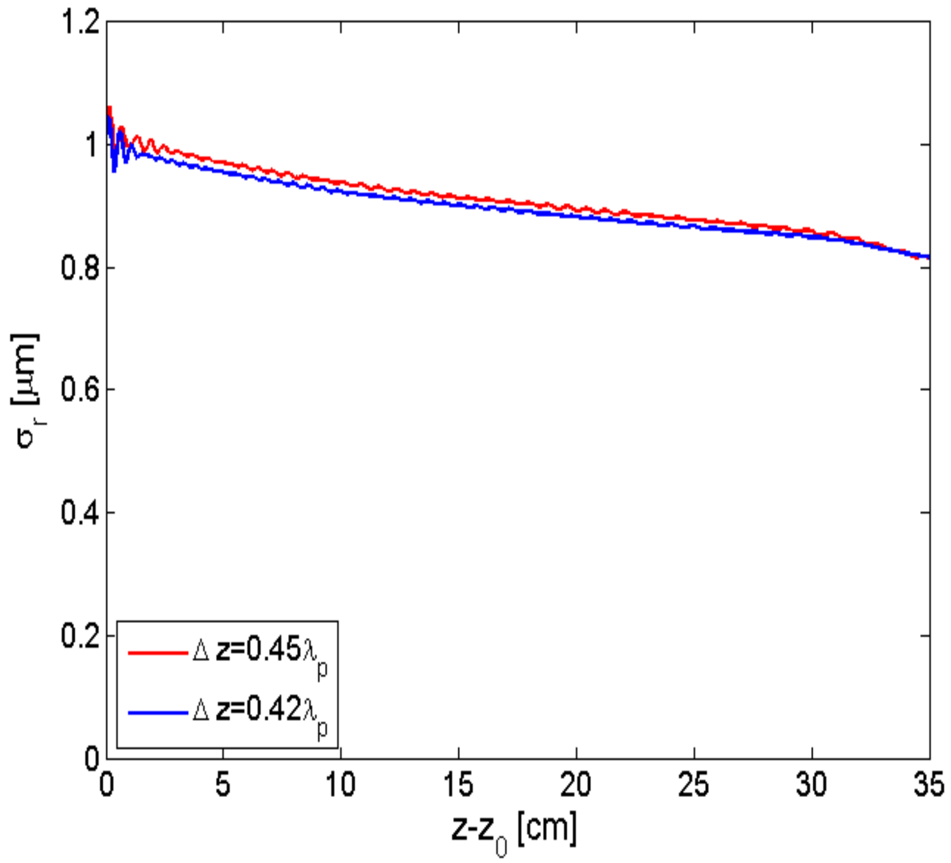
Energy and energy spread





Envelope and emittance





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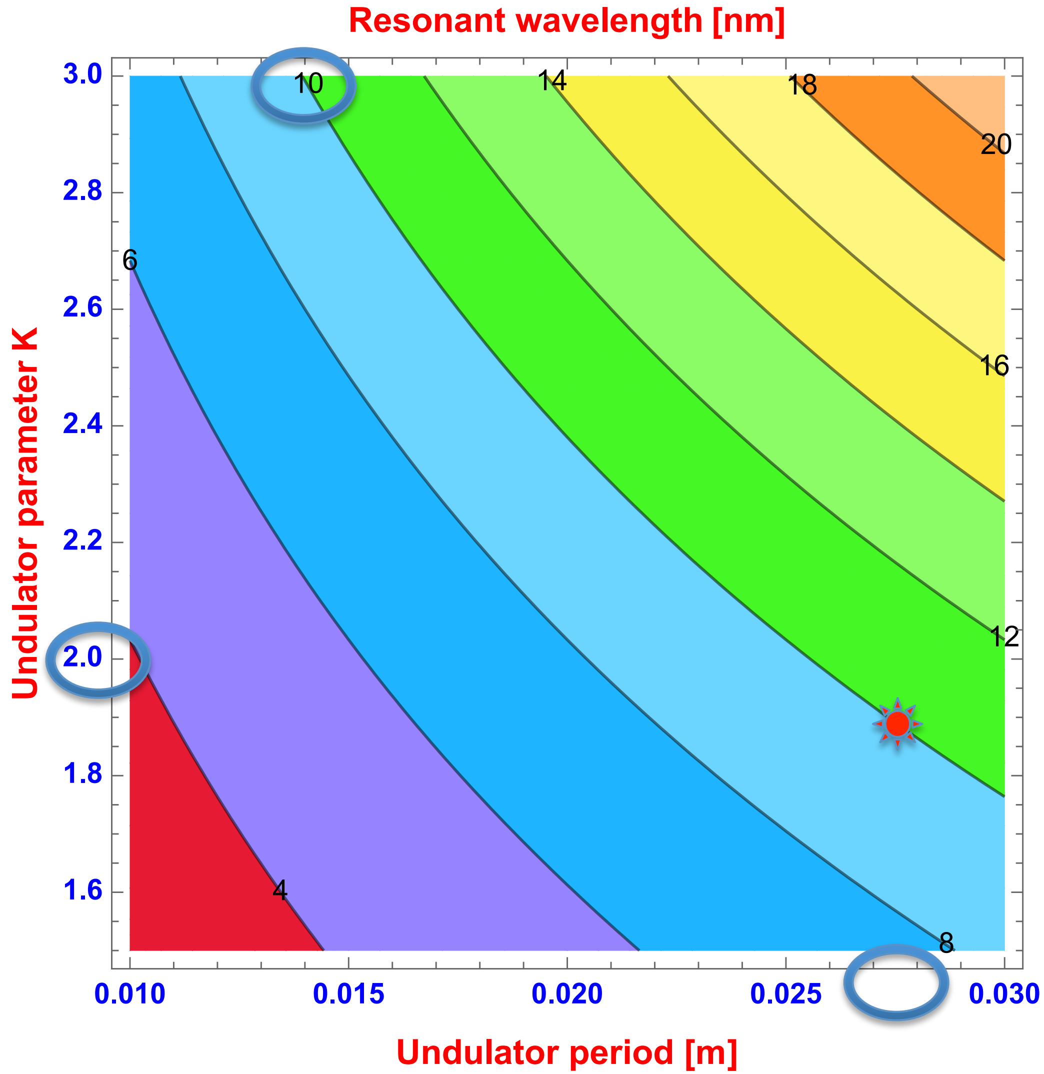
Preliminary parameter list discussed

- 1 GeV, 0.1 %, 0.5 um, 1kA
- 2.8 cm , k=2 , rho 10^-3 => 10 nm in 20 m und
- Cooperation length ~ 2 um
- Dedicated meeting at LNF on OCTOBER 3rd about parameter and possible test experiments (DESY, INFN et al.)

FEL resonant wavelength

Energy=1GeV

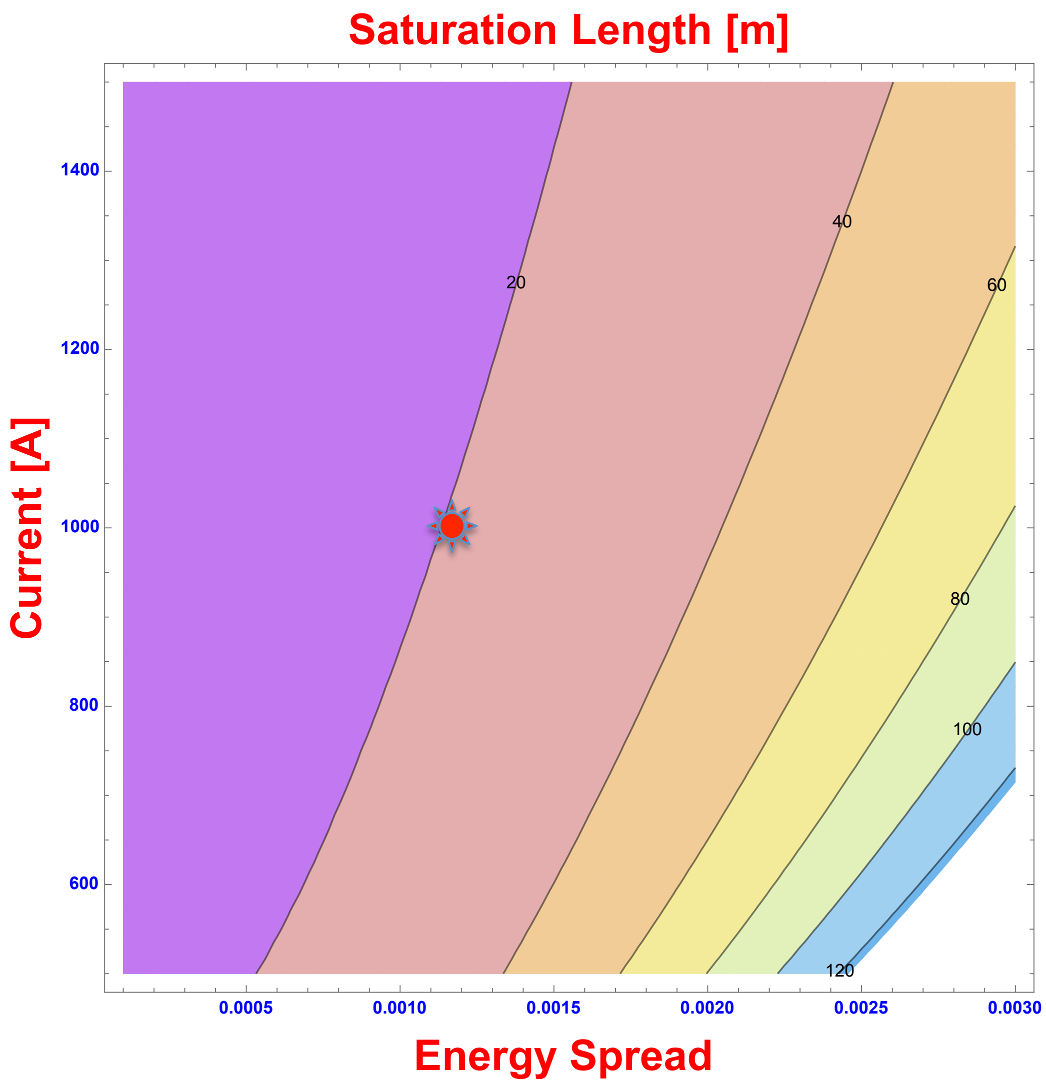
$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$



Saturation length

ε_n=1. um

$$L_g \approx \frac{\lambda_u}{4\pi\sqrt{3}\rho}$$



WP COMPTON SOURCES

C.VACCARREZZA

IN DETAIL:

With a 2.3 eV laser beam and:

- 75-740 MeV Linac → 2-19.5 MeV γ beam:

  GDR (Giant Dipole Resonance)

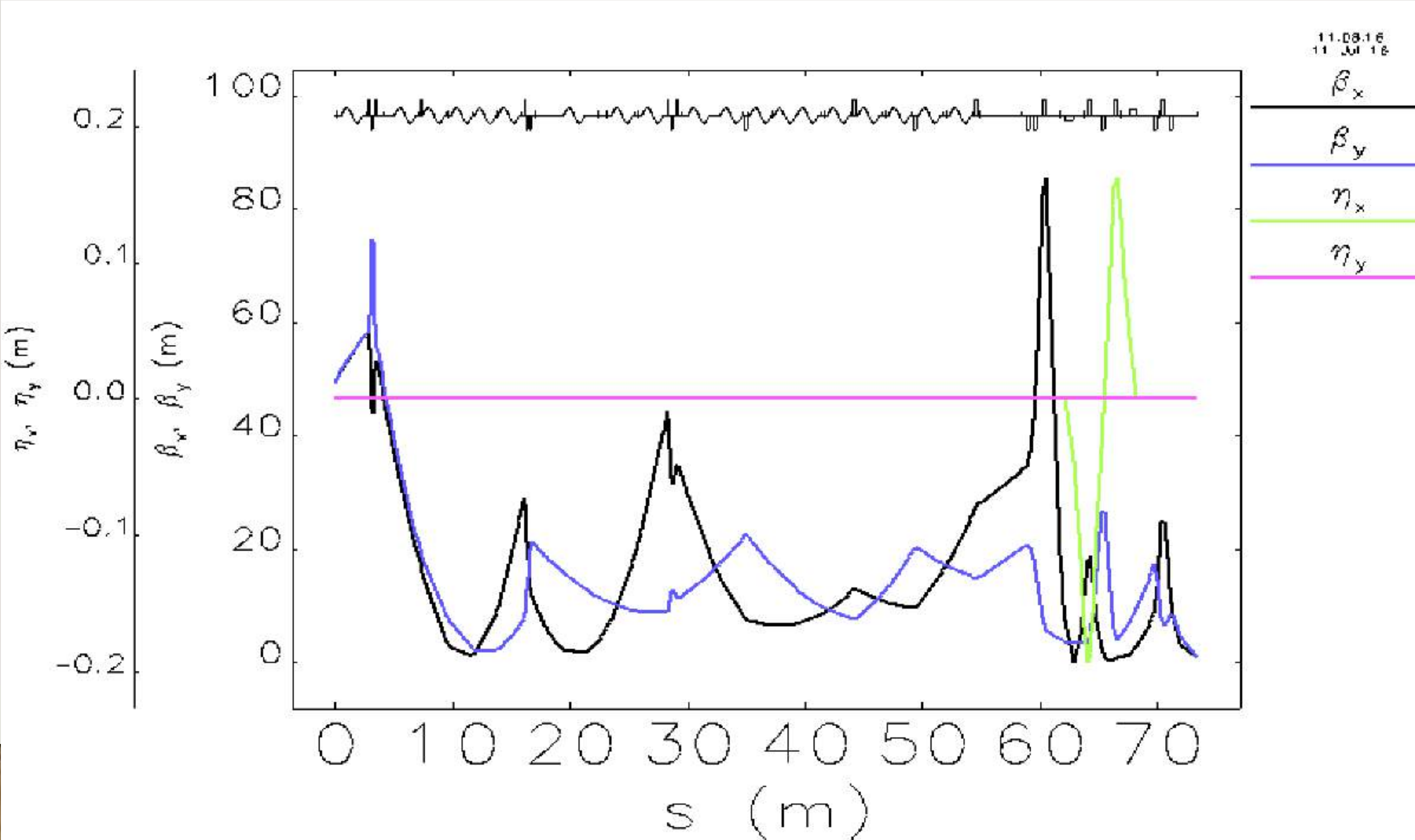
- 1.1 GeV Linac → 45 MeV γ beam:

  2nd harm. GDR effects (never observed up to now)

- 1.35 GeV Linac → 60 MeV γ beam:

  Polarized Positron Source by ICS polarized photons (P. Musumeci& L. Serafini provate comm., Omori NIM A 500,232, 2003)

1 GEV e^- BEAM FOR EUSPARC
(6 more C-band sections)



Laser-Plasma Astrophysics

Esperimenti di Astrofisica in Laboratorio utilizzando un laser di potenza (1 PW)

Scalando opportunamente i parametri fisici è possibile simulare e investigare fenomeni astrofisici come:

- Supernovae
- Resti di Supernova
- Astrophysical Jets (γray bursts)
- Origine dei raggi cosmici e meccanismi di accelerazione
- Produzione di antimateria (positroni)

etc. etc.

Laser-Plasma Astrophysics

Prima riunione su Astrofisica in Laboratorio l'8 Luglio (coinvolti: Anania, Bisesto, Cianchi, Filippi, Gatti, Gizzi, Marocchino).

Obiettivi gruppo di lavoro:

- Individuare possibili esperimenti laser-plasma (in particolare con connessioni con fisica INFN, almeno un caso forte)
- Individuare la comunità di riferimento
- Individuare richieste per laser e diagnostica

Piano di Lavoro:

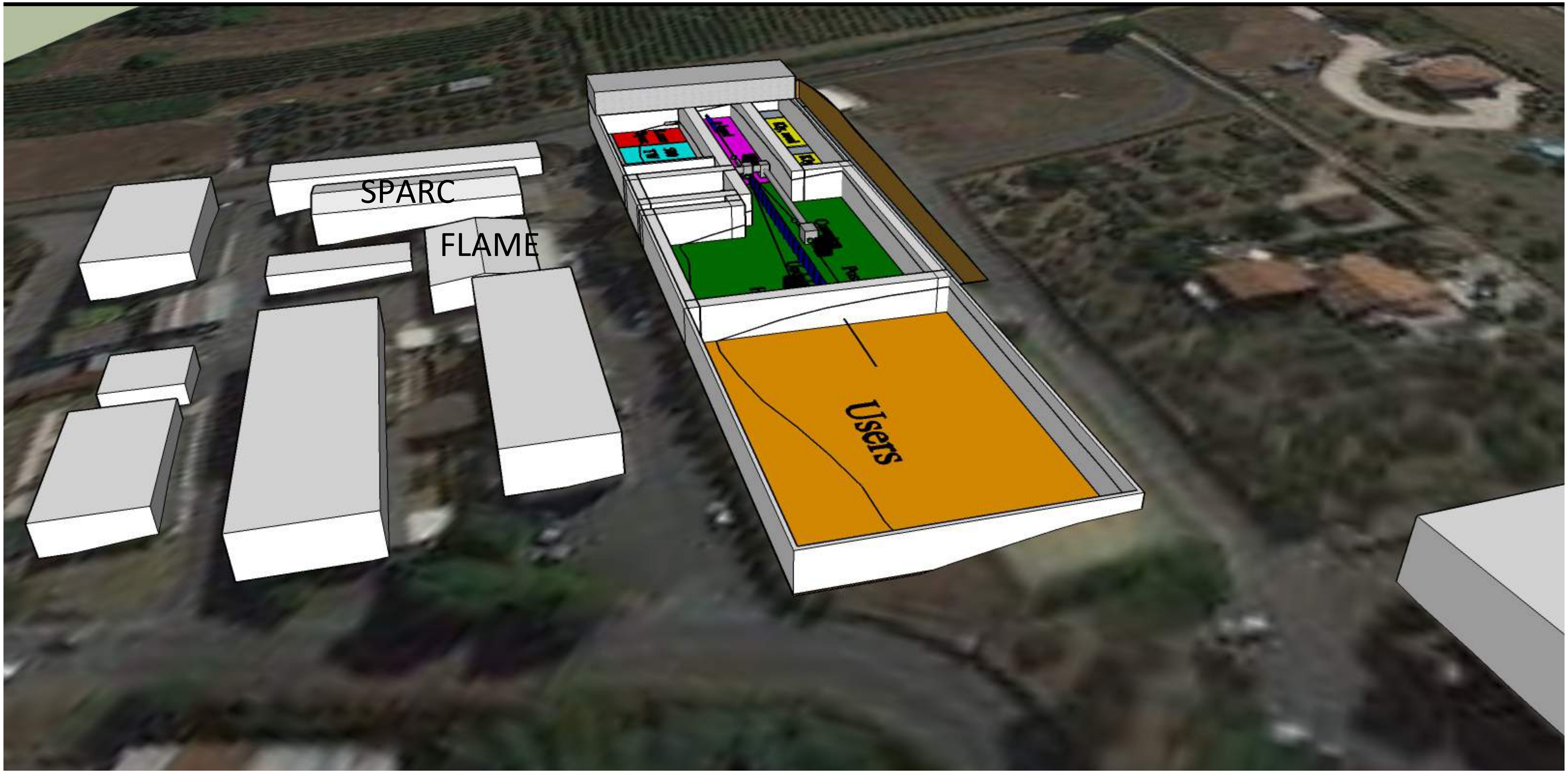
- Ricerca in letteratura esperimenti in corso
- Individuare casi di interesse
- Organizzare una giornata di discussione e confronto con esperti del campo
- Scrivere un report per fine anno

EUSPARC CDR timetable and milestones

- CDR expected delivery: end of March 2017
- Regular monthly meeting with the WPs coordinators

Month	October	November	December	January	February2	March
WG-7 -Infrastructure						
Civil Engineering and conventional plants	Define Civil Engineering	Tender ready	Tender open		Optimized layout	Chapter ready
Radiation Safety	Preliminary evaluations	Beam Dumps			Optimized layout	Chapter ready
Control System					Chapet ready	
WG-1 Electron beam design and optimization						
Advanced HB photoinjector design	Conventional/Ctyogenic Gun	Beam dynamics simulations S band	Injector fixed		Chapet ready	
HB Linac options, design and parameters	Investigation C-X bands options	Beam dyn. simulations C/X band	RF Linac frequency fixed	RF Powery Systems Optimisation	Chapet ready	
Linac layout			Beam extraction lines	Linac layout Optimisation	Chapet ready	
WG-2 Laser design and optimizations						
FLAME upgrade 500 TW design			Upgraded FLAME layout		Chapet ready	
Advanced Laser systems				Dual Beam Configuration	Chapet ready	
WG- 3 – Plasma Accelerator						
PWFA beam line			Beam dynamics simulations PWFA	Beam Line Layout	Chapet ready	
LWFA beam line			Beam dynamics simulations LWFA	Beam Line Layout	Chapet ready	
Positron acceleration test			Beam dynamics simulations Positrons	Beam Line Layout	Chapet ready	
WG-4 – FEL pilot applications						
Plasma driven FEL	Undulator Options	Undulator Fixed	FEL simulations	Start to End simulations	FEL layout	Chapter ready
Advanced FEL schemes			RF Undulator investigation	Compact Undulators	Chapet ready	
FEL user applications			FEL users without plasma	FEL users at 1-10 nm with plasma		Chapter ready
WG 5 – Radiation sources and user beam lines						
Advanced dielectric THz source					Chapet ready	
Compton source					Chapet ready	
User beam lines					Chapet ready	
WG 6 – Low Energy Particle Physics						
Advanced positron sources					Chapet ready	
Fundamental physics experiments , Lab-Astro					Chapet ready	
Plasma driven photon collider					Chapet ready	

EUSPARC GANTT CHART



EUSPARC total costs estimate

New infrastructure	20. M€
FLAME upgrade to 1 PW and related beam line	9.5 M€
Beam energy upgrade ~1 GeV and related experiments	16. M€
Grand Total	**45.5 M€**

Cost estimate

Upgrade of the front-end (currently 0.5J) to higher energy (>1J), short <15 fs pulse duration and high ns and ps contrast	1.5
Upgrade of the existing main amplifier for beam 1 at ≈1 PW	3.5
Installation of a new amplifier for beam 2 at 0.2 PW	3.0
Upgrade (and relocation) of the new compressor for beam 1	0.75
Installation of a new compressor set-up for beam 2	0.5
New layout of the target area, including fully shielded ceiling and dual beam target chamber	0.25
Total	**9.5** M€

Cost estimate

Beam energy upgrade ~1 GeV	10. M€
PWFA modules and diagnostics	1. M€
Short period undulator development	3. M€
Positron beam line	2. M€
Total	**16. M€**