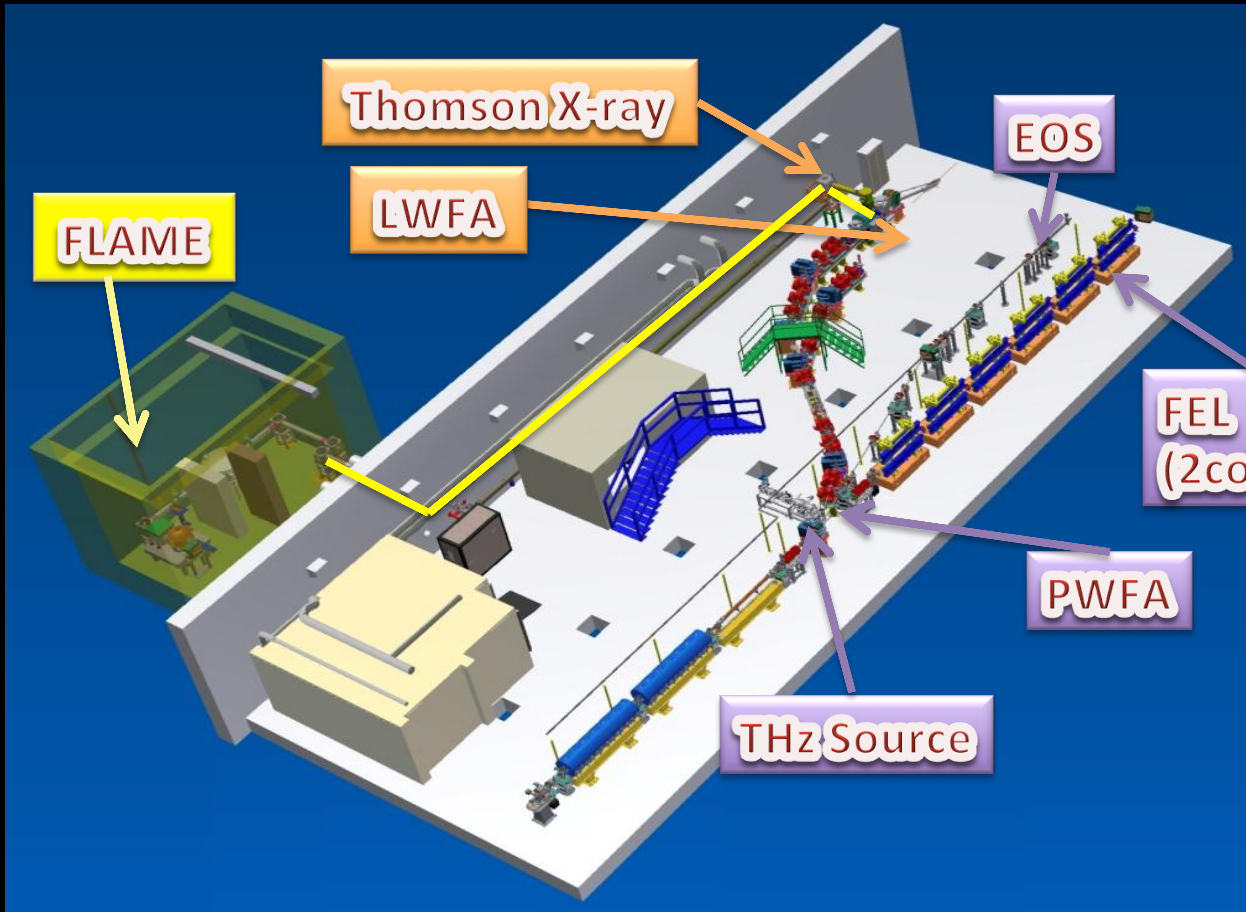
Summary of the SPARC_LAB activities

Massimo.Ferrario@LNF.INFN.IT
On behalf of the SPARC_LAB collaboration



LNF- November 12, 2014

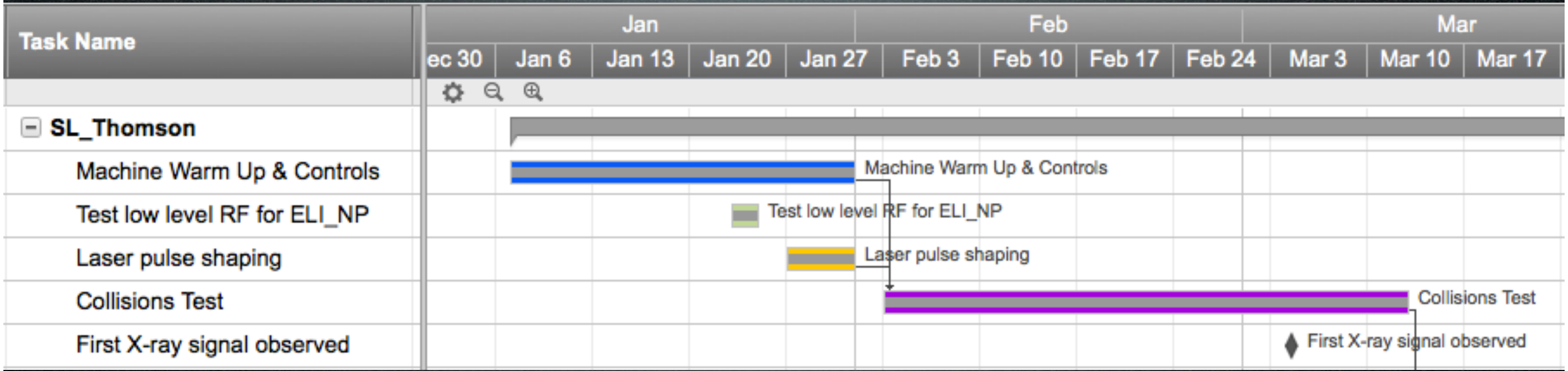
Outline

- First X-ray from Thomson source observed
- First Thz source external user made happy
- First seeded two colors FEL experiment done
- New short period undulator installed and tested
- Plasma interaction chamber off line test under way
- Linac and FLAME wide maintenance and upgrade needed
- More technical and prompt support needed
- 3 Horizon 2020 proposal submitted

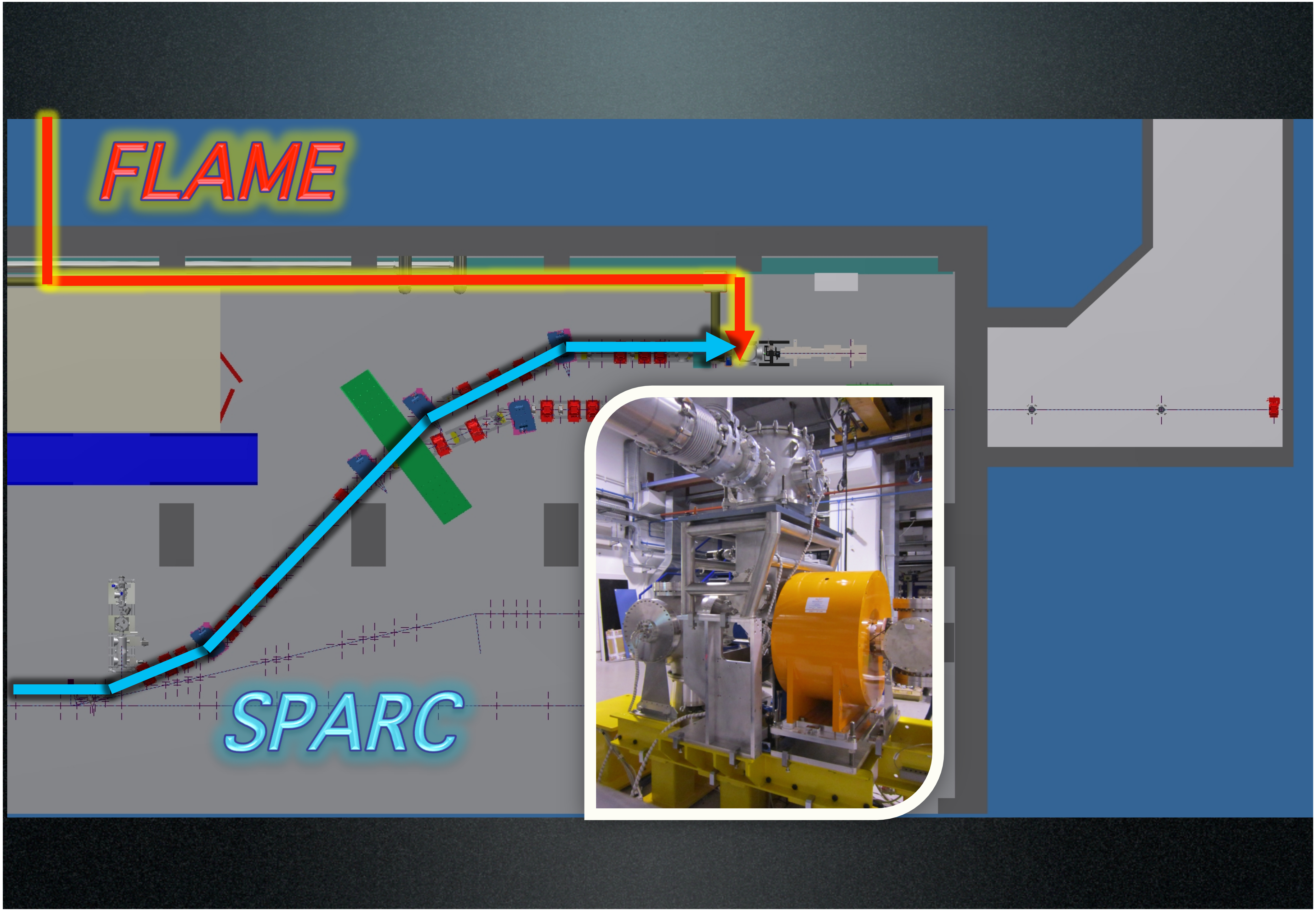
SPARC_LAB Welcomes:

- Prof. Arie Zigler (Hebrew University of Jerusalem) 1 year sabbatical
- Prof. Jamie Rosenzweig (UCLA) 7 months sabbatical
- Dr. Weiwei Li, PhD student from University of Science and Technology of China, 15 momths
- Dr. Alex Brynes, post doc from STFC, 3 months
- 3 new PhD students form University of Roma

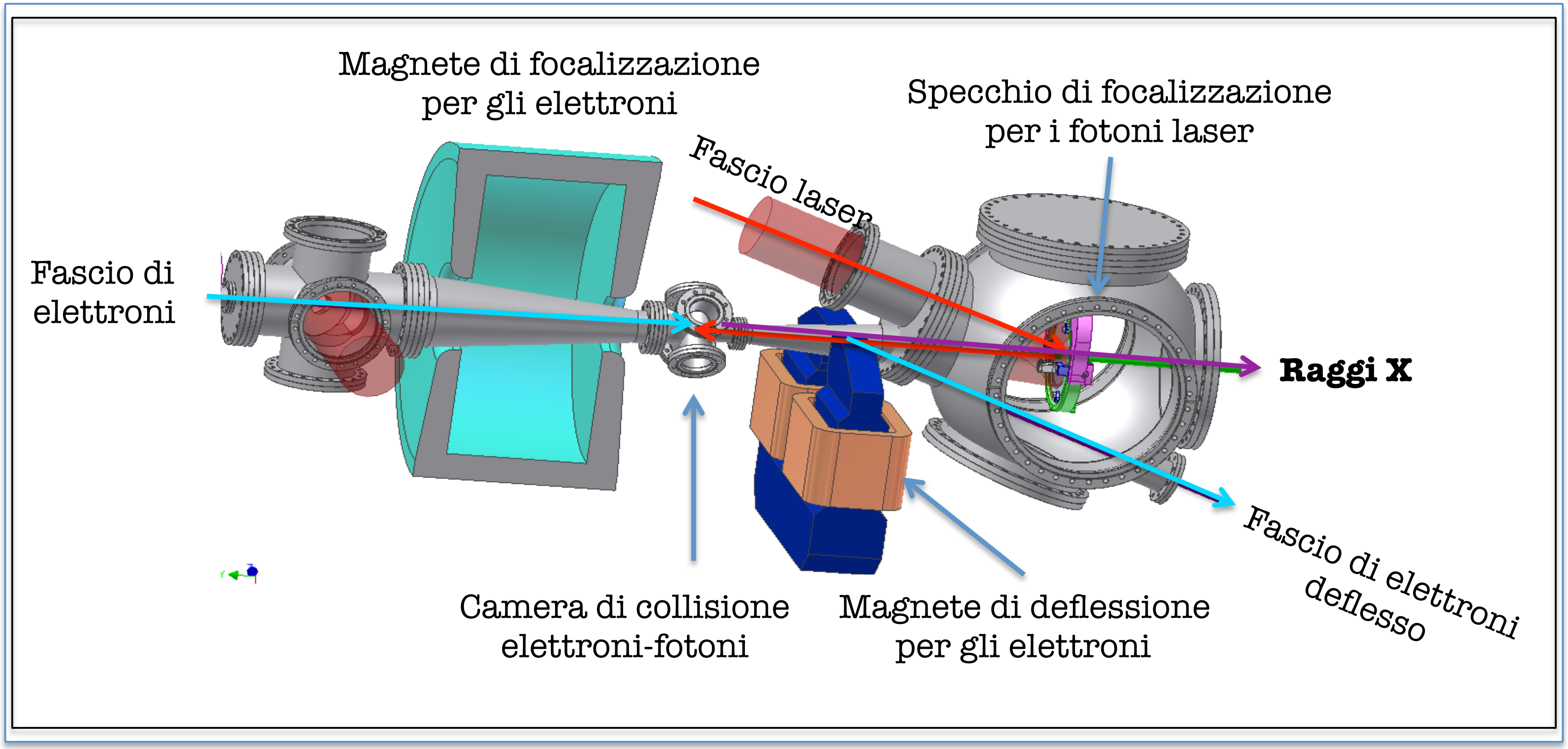
Thomson backscattering



Courtesy C. Vaccarezza

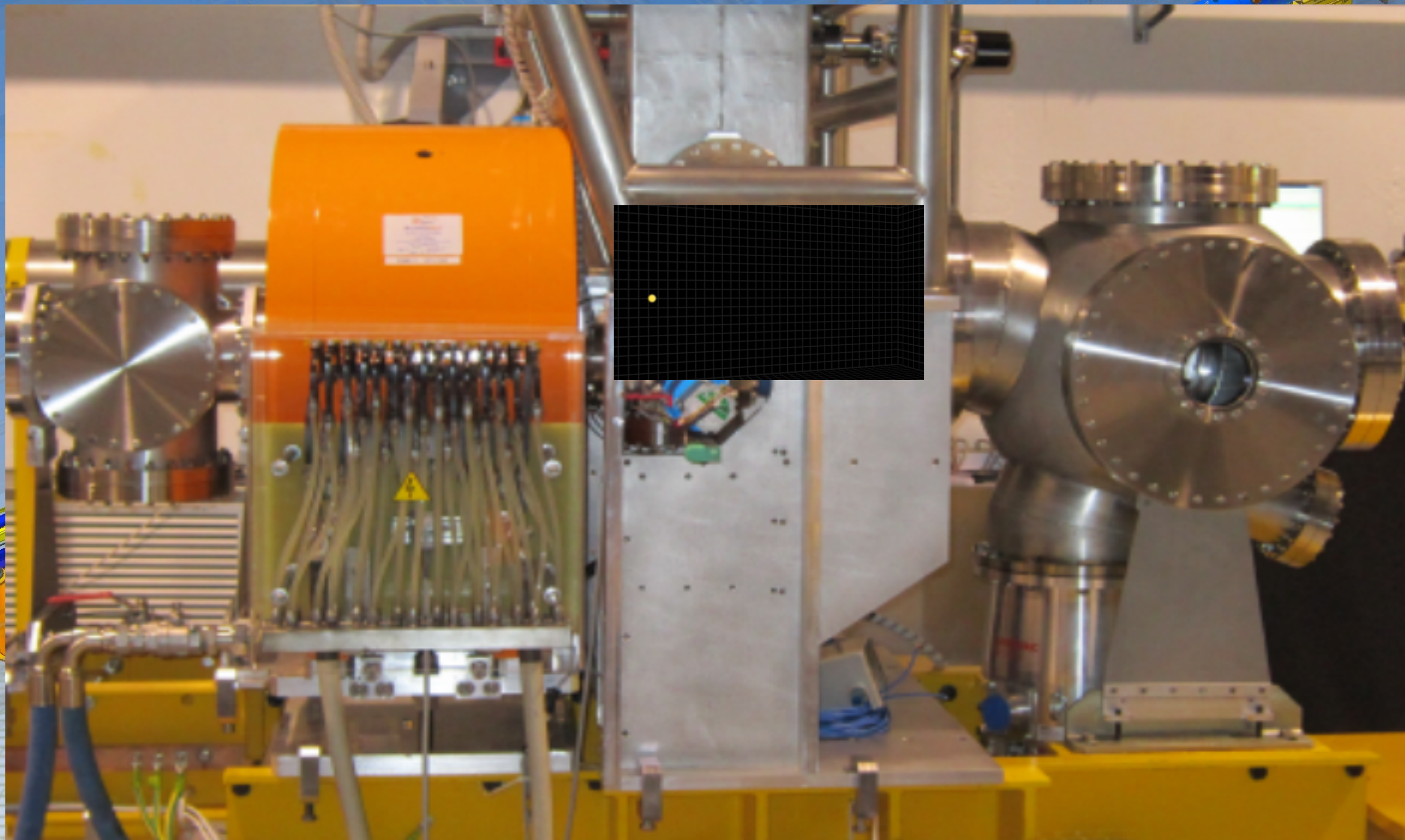

FLAME
SPARC

Thomson Interaction region (20-550 keV)



Thomson back-scattering source

carica (pC)	energia (MeV)	enx (mm mrad)	eny (mm mrad)	IP sigmax mm	IP sigmay (mm)
230	157	2.7	4.5	.50	.55
220 230	75 50	2.9 1.2	5 2.3	.28 .17	.36 .18

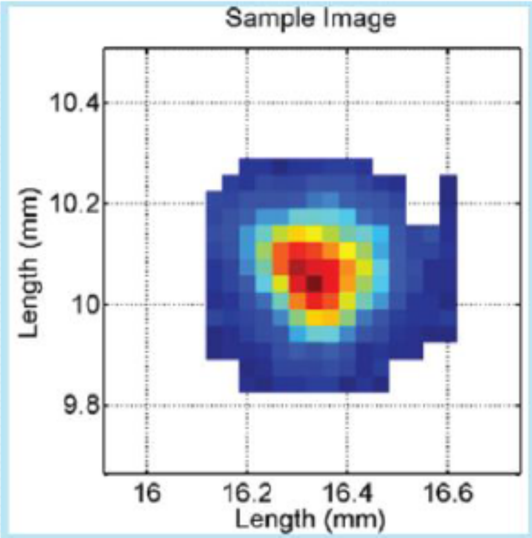


Working Point: electron beam and FLAME pulse

Electron Beam	Units	WP Parameters
Energy	MeV	50
Energy Spread	%	0.1 ± 0.03
Pulse Length	ps	3.1 ± 0.2
Spot Size	μm	90 ± 3
Charge	pC	200
Emittance	mm mrad	1.5 : 2.2 ± 0.2

FLAME laser pulse	Units	WP Parameters
Pulse Energy	J	0.5
Wavelength	nm	800
Pulse Length	ps	6
Spot Size	μm	10
Repetition Rate	Hz	10

- Electron beam spot size had to be of 50μm. Because of a limit in the magnet cooling system, the solenoid upstream the IP could be used at 70% of its nominal value.
  In this condition the minimum rms spot size was of about 90 μm.
- Best results obtained with σ_{x-y} = 240 : 160 ± 10 μm.



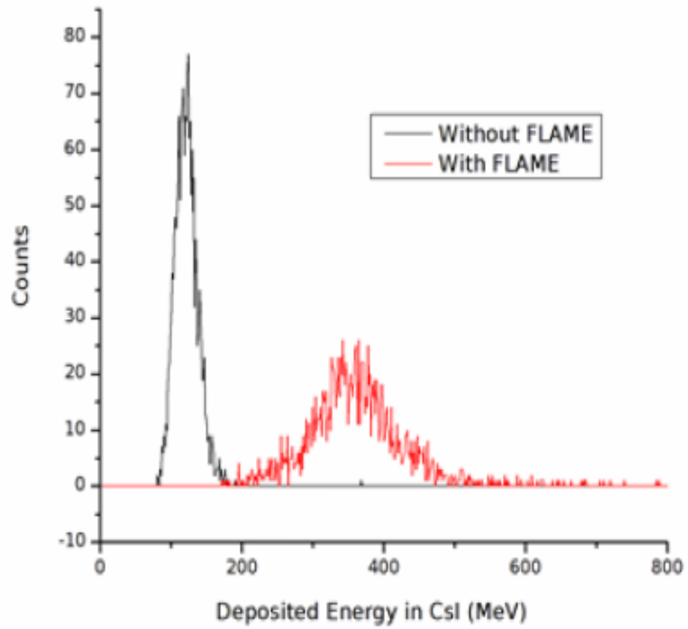
Emitted X-Rays: First Commissioning Results

Courtesy of
P. Cardarelli, P. Oliva,
G. Di Domenico INFN-FE
P. Delogu INFN-Pisa

- Two type of measurements of the X-Rays:
  1. 20 GHz BW oscilloscope for a fast response.
  2. Multichannel analyser to acquire an integral measurement over various interactions.

- Best results obtained with σ_{x-y} = 240 : 160 ± 10 μm
  1. Average Energy: 60 keV
  2. Number of photons for each pulse 6.7×10^3

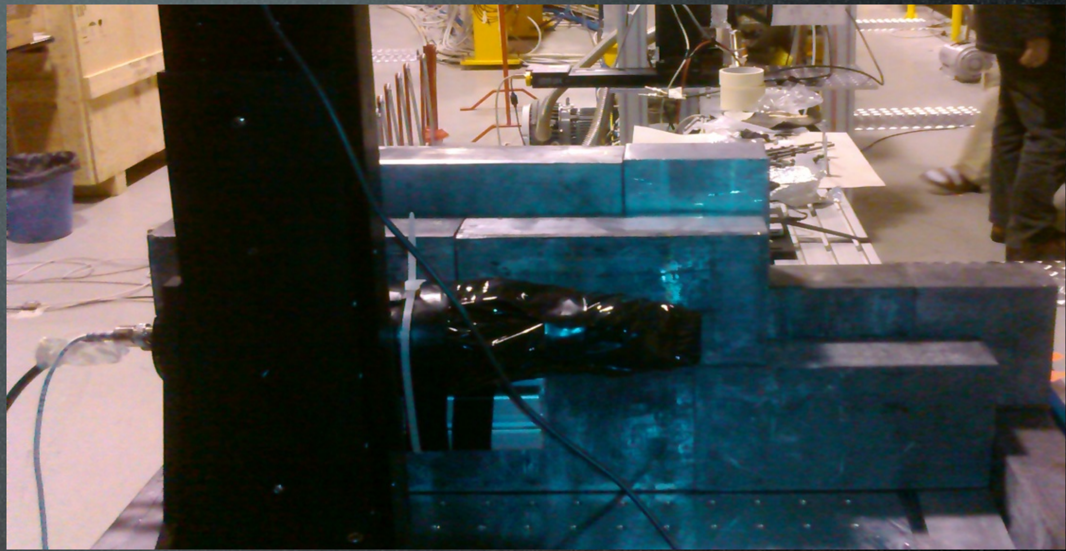
- Poor overlap conditions due to some misalignment of the interaction chamber can explain the difference between the measured number of photons for each pulse and the expected one.



Thomson x-rays signal in red, in black the electron background signal (without FLAME laser), integrated over 120 s (1200 pulses).

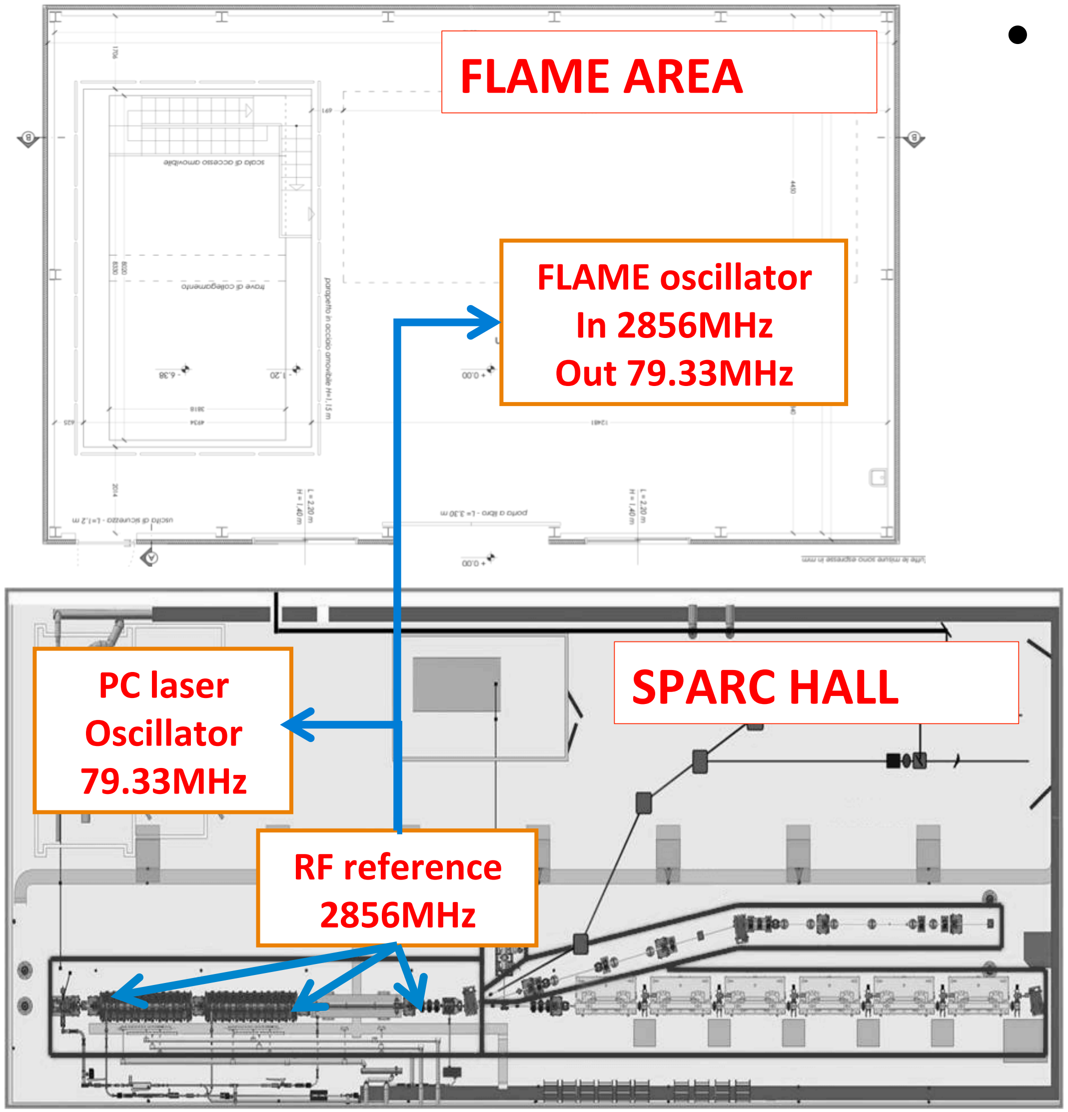
Detector: CsI scintillator (20x20x2 mm) + Photo Multiplier Tube

Front view (shielding)



Rear view (PMT)

SPARC_LAB synchronization system



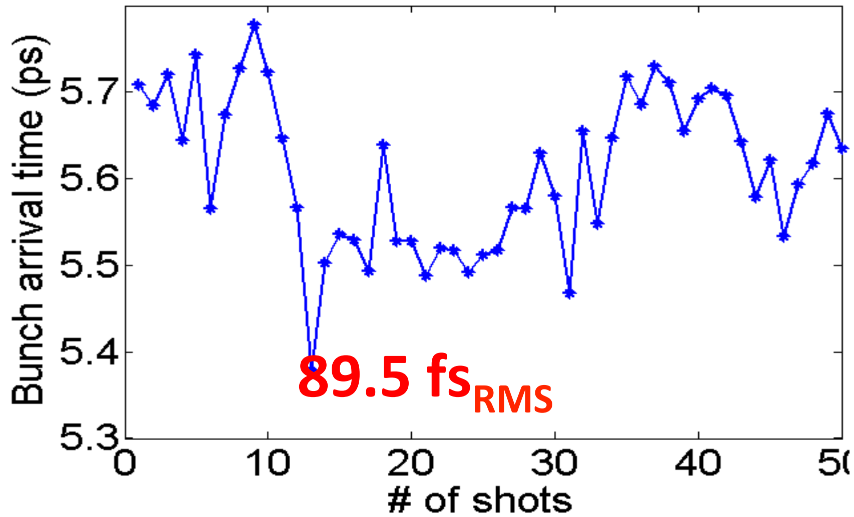
- Main RF Reference oscillator
  - RF system and laser oscillators locked to the reference through PLL
  - Electrical signal distributed through coaxial cable
  - Single sub-system VS reference time jitter $<50fs_{RMS}$
  - FLAME laser VS electrons time jitter (estimated) $<150fs_{RMS}$

Synchronization measurements

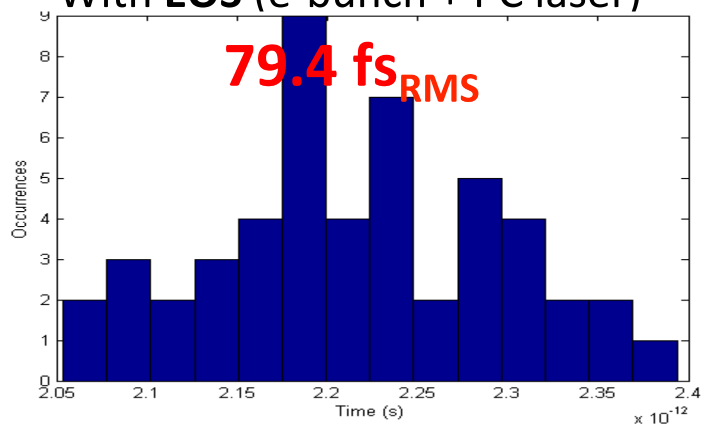
Electron bunch time of arrival

(2 bunch, max RF compression)

With **RF deflector** (e-bunch + deflecting field)



With **EOS** (e-bunch + PC laser)

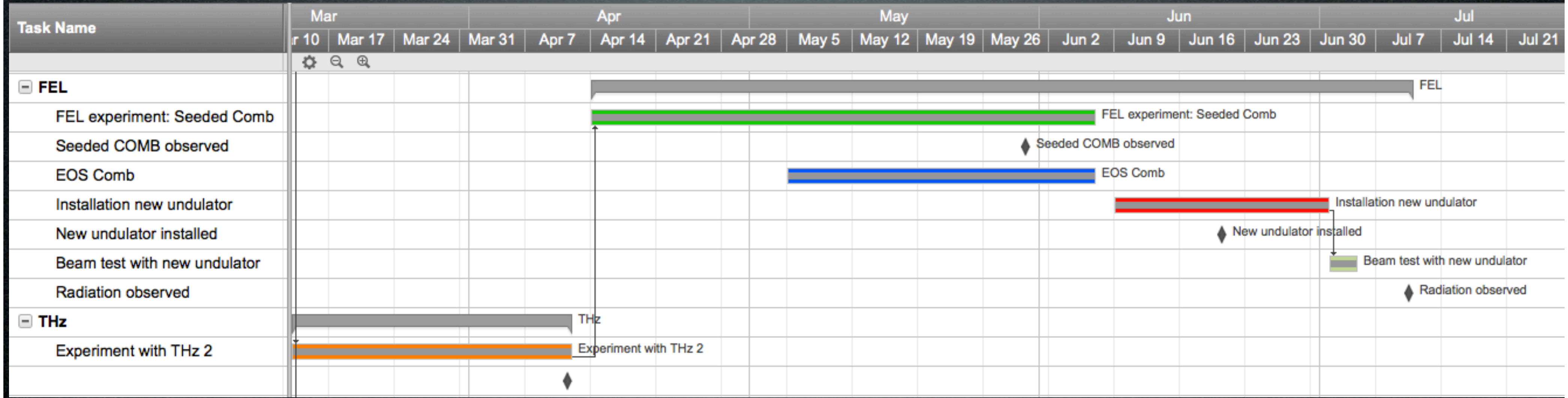


Conclusions and future experiments

- As VERY first commissioning results were obtained X-Rays with:
    1. Average energy: 60keV
    2. BW: 19%
    3. Number of photons per shot: 6.7×10^3

- In the shut-down were fixed some of the problems of the last experiment:
    1. Solenoid cooling system
    2. Re-alignment of the interaction chamber
    3. New electron dumping section was installed

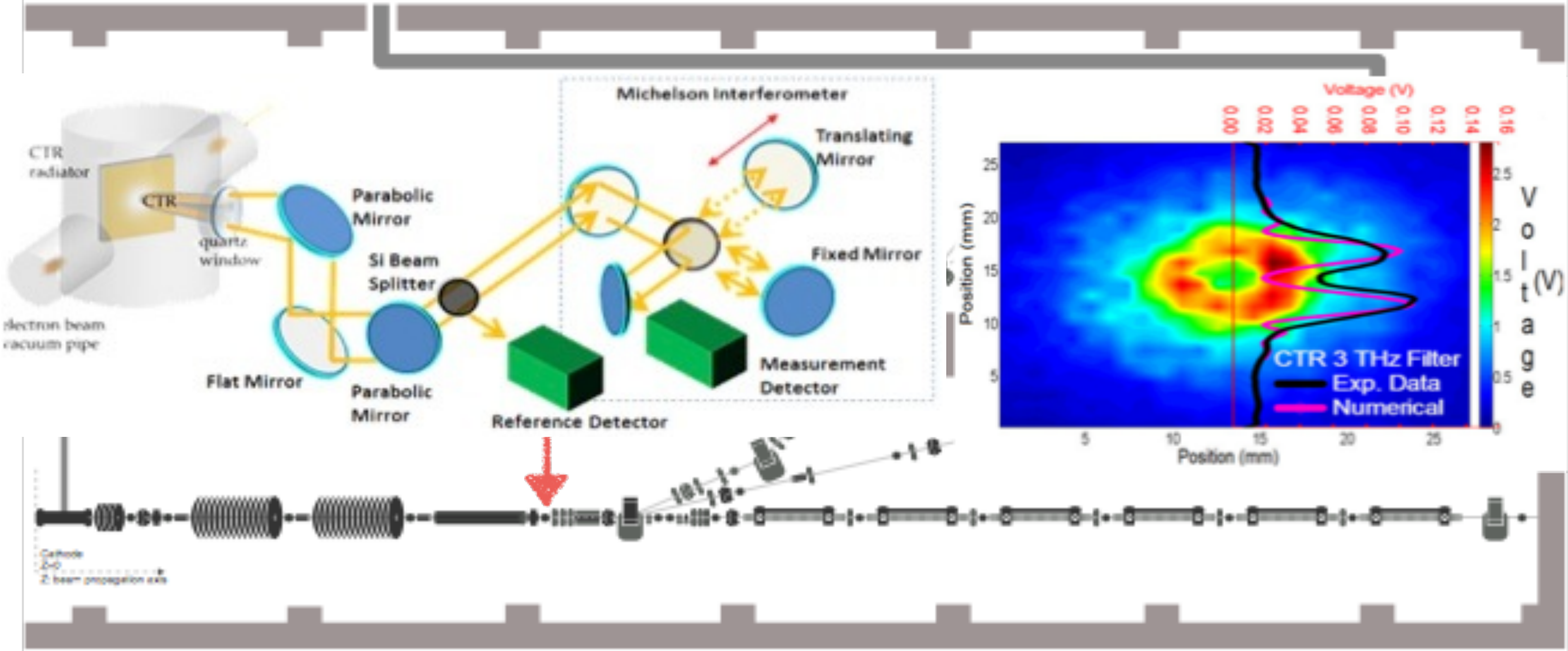
THz and FEL



Courtesy F. Villa

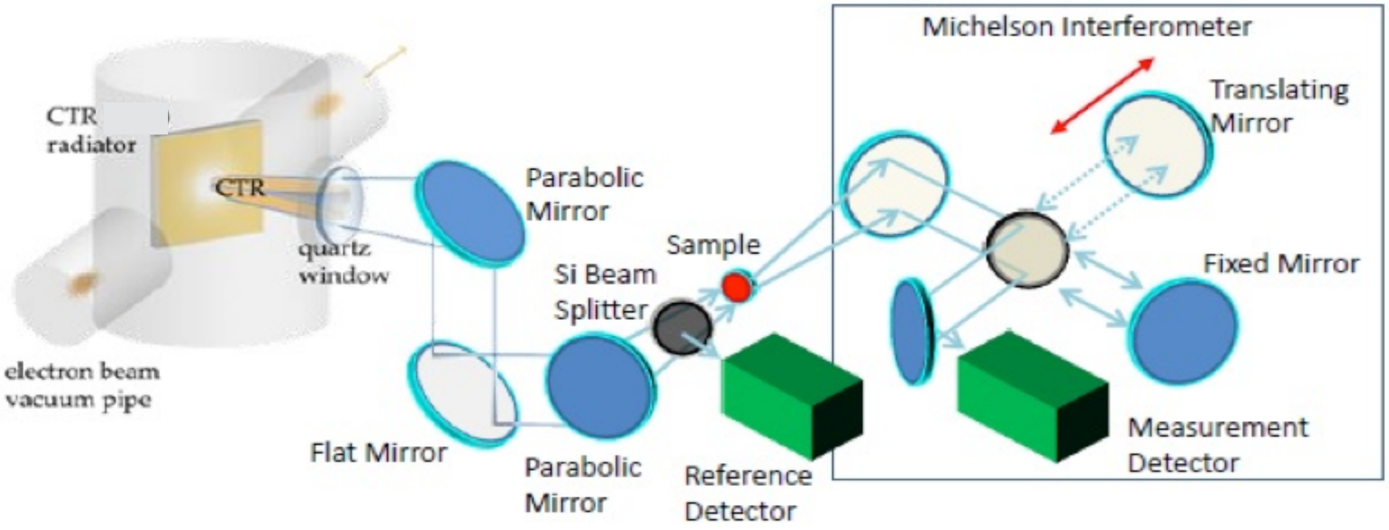
The THz Source

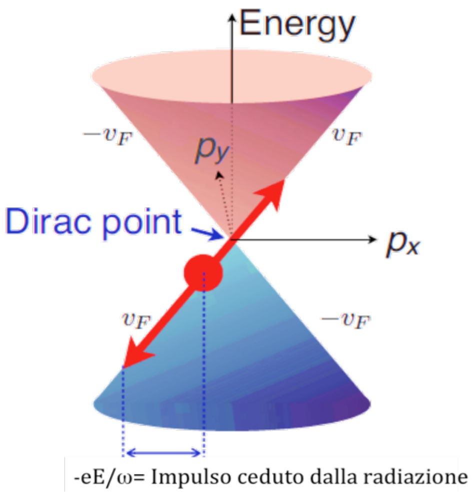
Coherent Radiation from an aluminum-coated silicon screen
(Courtesy E. Chiadroni)



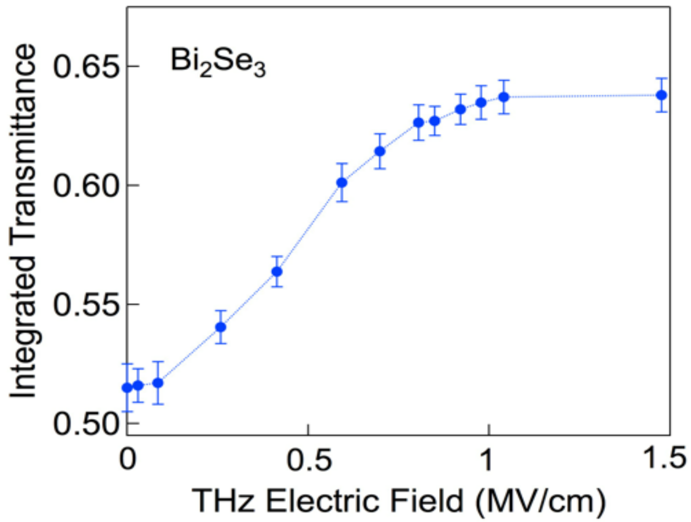
Beam energy (MeV)	Charge (pC)	Pulse length (fs)	Frequency BW (THz)	Pulse energy (uJ)	Electric field (MV/cm)
120	500	100	5	20	1.5

Non-Linear THz Experiments on Condensed Matter Physics



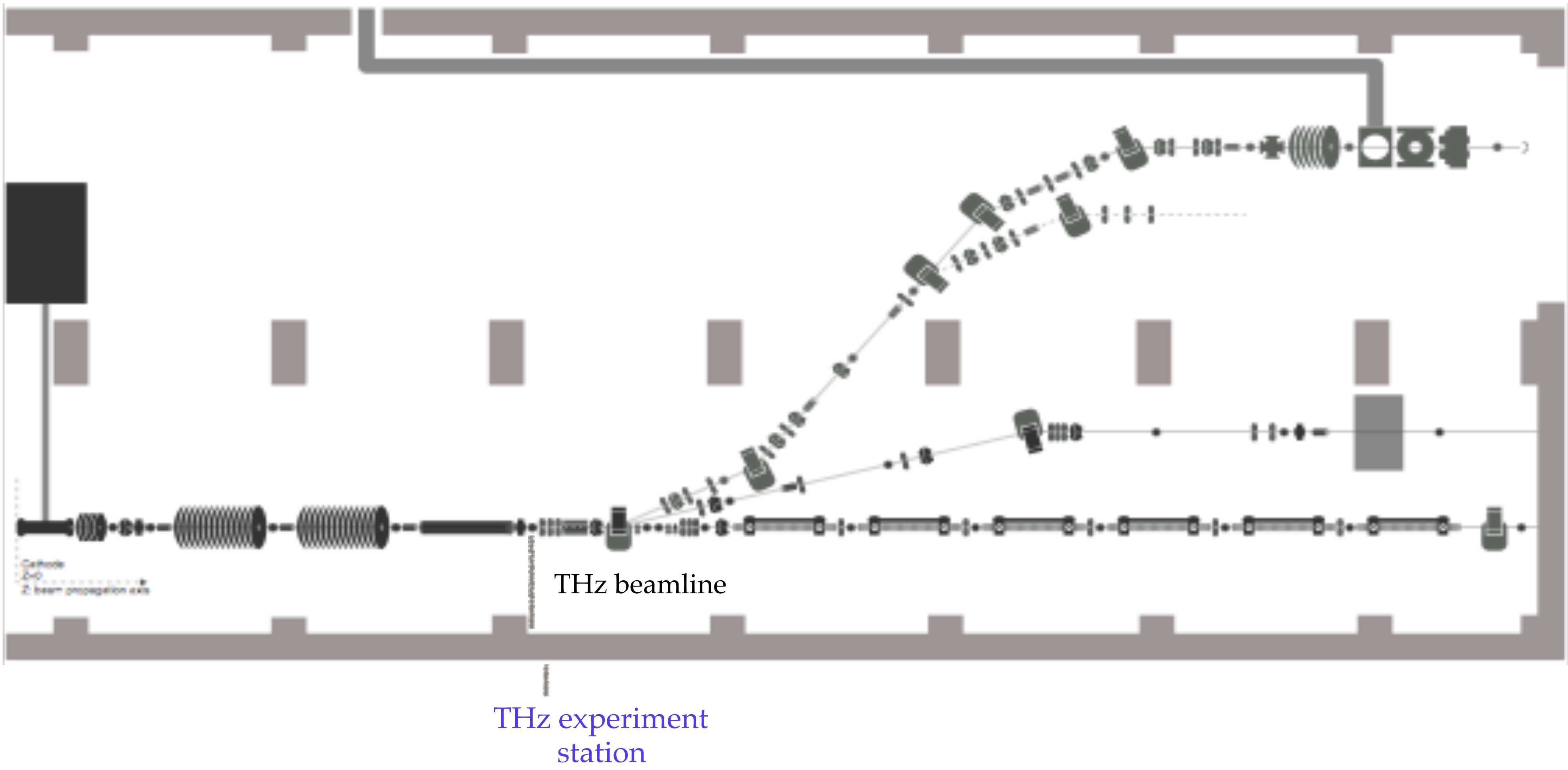


Strong THz non-linear response induced in a Dirac material by a high THz electric field

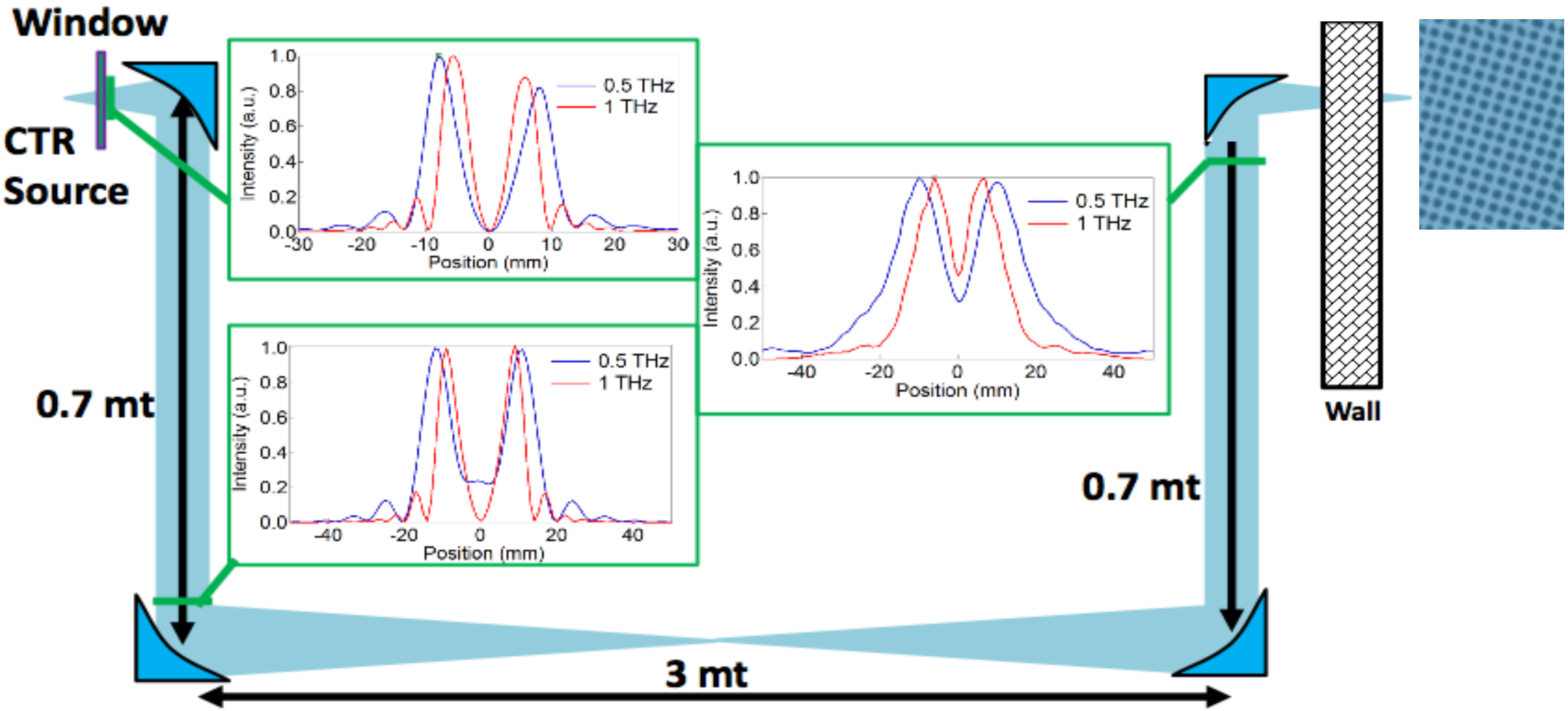


Collaboration with TeraLab group leaded by Prof. S. Lupi (Univ. of Rome *La Sapienza*)

The THz Beamline Upgrade

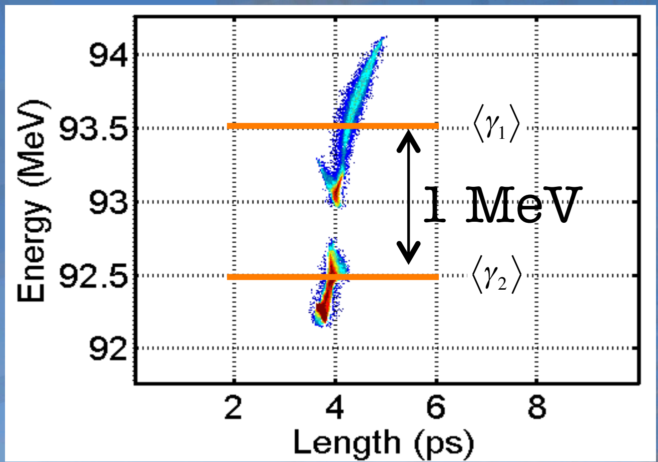


The THz Beamline Upgrade



- At 0.5 THz the radiation spot is all within 10 cm
    - custom parabolic mirrors with diameter of 15 - 20 cm
- Low vacuum is needed (10-2 mbar)

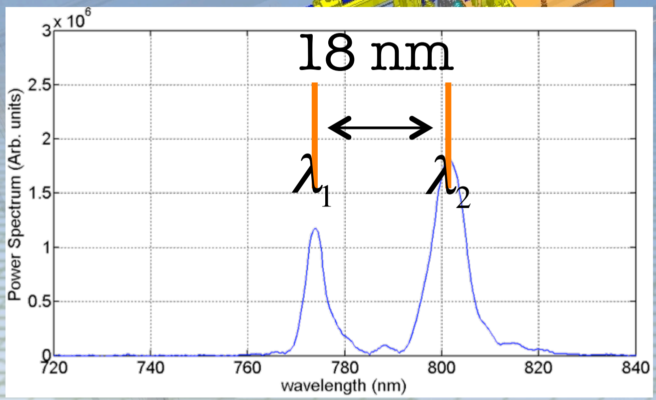
A train of fs FEL pulses



two bunches with
a two-level energy distribution
and time overlap (Laser COMB tech.)

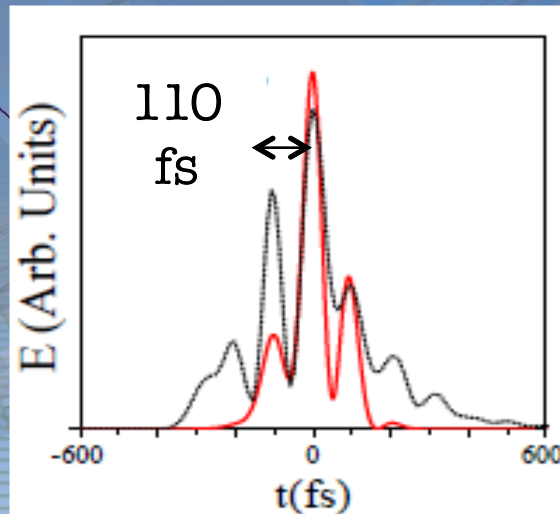
$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + K_{rms}^2\right)$$

$$\frac{\Delta\lambda_r}{\langle\lambda_r\rangle} = 2\frac{\langle\gamma_1\rangle - \langle\gamma_2\rangle}{\langle\gamma\rangle}$$

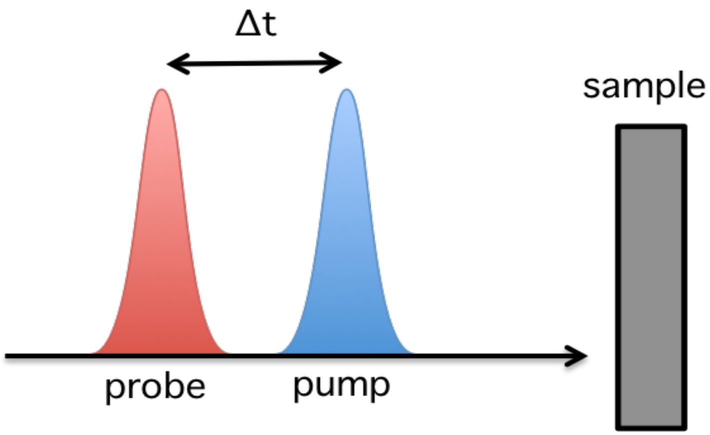


produce two wavelength
SASE -FEL radiation
with time modulation

$$\Delta t = \frac{\lambda_u\left(1 + K_{rms}^2\right)}{4c\langle\gamma\rangle\langle\gamma_1\rangle - \langle\gamma_2\rangle}$$



2 Color Free-Electron Lasers



2 pulses with

-tunable energy difference

-tunable arrival time

Many applications!

- x-ray pump/x-ray probe
- 2 color diffraction imaging

PRL 110, 134801 (2013) PHYSICAL REVIEW LETTERS week ending 29 MARCH 2013

Experimental Demonstration of Femtosecond Two-Color X-Ray Free-Electron Lasers

A. A. Lutman, R. Coffee, Y. Ding,* Z. Huang, J. Krzywinski, T. Maxwell, M. Messerschmidt, and H.-D. Nuhn
SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
(Received 13 December 2012; published 25 March 2013)

PRL 111, 134801 (2013) PHYSICAL REVIEW LETTERS week ending 27 SEPTEMBER 2013

Multicolor Operation and Spectral Control in a Gain-Modulated X-Ray Free-Electron Laser

A. Marinelli,[1,*] A. A. Lutman,[1] J. Wu,[1] Y. Ding,[1] J. Krzywinski,[1] H.-D. Nuhn,[1] Y. Feng,[1] R. N. Coffee,[1] and C. Pellegrini[2,1]

PRL 110, 064801 (2013) PHYSICAL REVIEW LETTERS week ending 8 FEBRUARY 2013

Chirped Seeded Free-Electron Lasers: Self-Standing Light Sources for Two-Color Pump-Probe Experiments

Giovanni De Ninno,[1,2] Benoît Mahieu,[1,2,3] Enrico Allaria,[2] Luca Giannessi,[2,4] and Simone Spampinati[2]

ARTICLE

Received 8 Sep 2013 | Accepted 12 Nov 2013 | Published 4 Dec 2013 DOI: 10.1038/ncomms3919

Two-colour hard X-ray free-electron laser with wide tunability

Toru Hara[1], Yuichi Inubushi[1], Tetsuo Katayama[2], Takahiro Sato[1,†], Hitoshi Tanaka[1], Takashi Tanaka[1], Tadashi Togashi[2], Kazuaki Togawa[1], Kensuke Tono[2], Makina Yabashi[1] & Tetsuya Ishikawa[1]

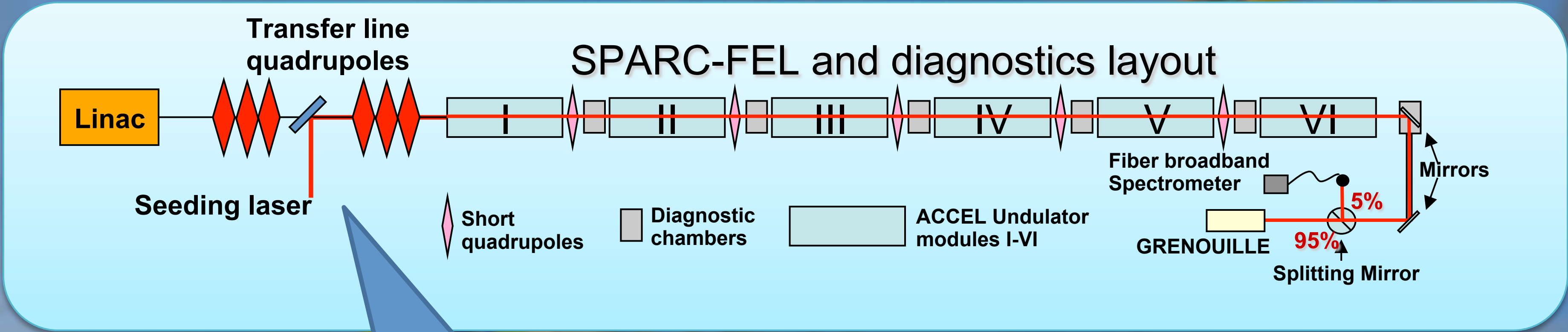
PRL 111, 114802 (2013) PHYSICAL REVIEW LETTERS week ending 13 SEPTEMBER 2013

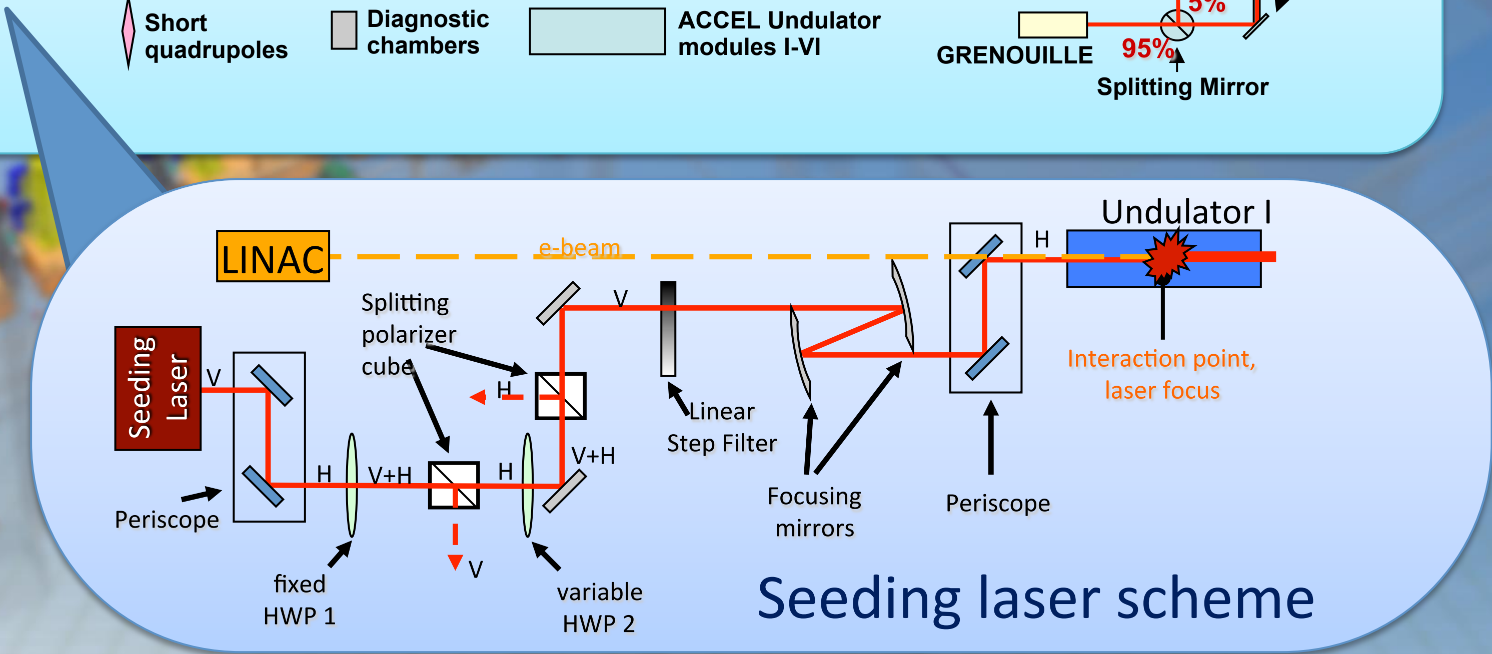
Observation of Time-Domain Modulation of Free-Electron-Laser Pulses by Multipeaked Electron-Energy Spectrum

V. Petrillo,[1] M. P. Anania,[2] M. Artioli,[3] A. Bacci,[1] M. Bellaveglia,[2] E. Chiadroni,[2] A. Cianchi,[4] F. Ciocci,[3] G. Dattoli,[3] D. Di Giovenale,[2] G. Di Pirro,[2] M. Ferrario,[2] G. Gatti,[2] L. Giannessi,[3] A. Mostacci,[5] P. Musumeci,[6] A. Petralia,[3] R. Pompili,[4] M. Quattromini,[3] J. V. Rau,[7] C. Ronsivalle,[3] A. R. Rossi,[1] E. Sabia,[3] C. Vaccarezza,[2] and F. Villa[2]

Two colors FEL: seeding

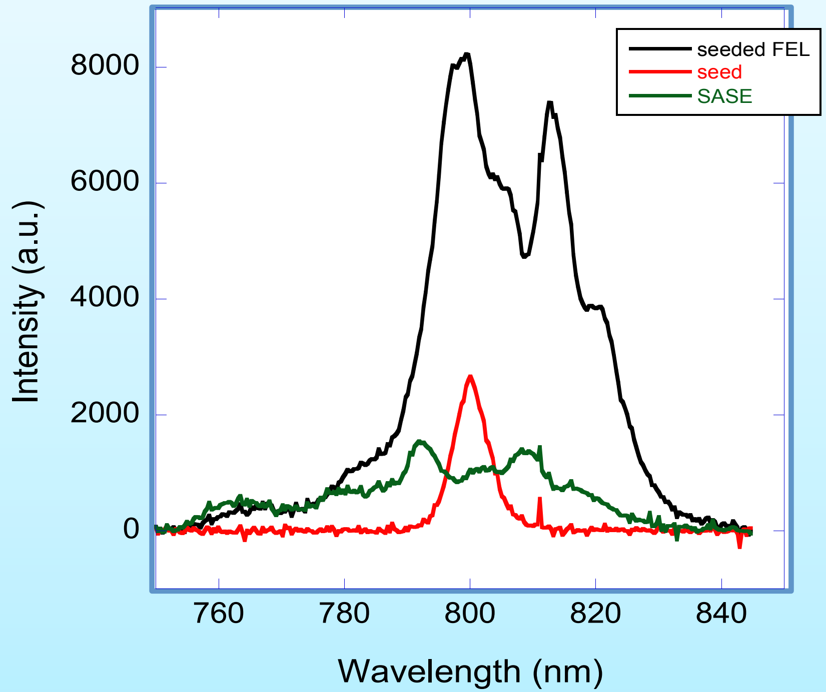
- To increase stability as well as intensity we added a laser seed at a wavelength at the average of the two FEL colors



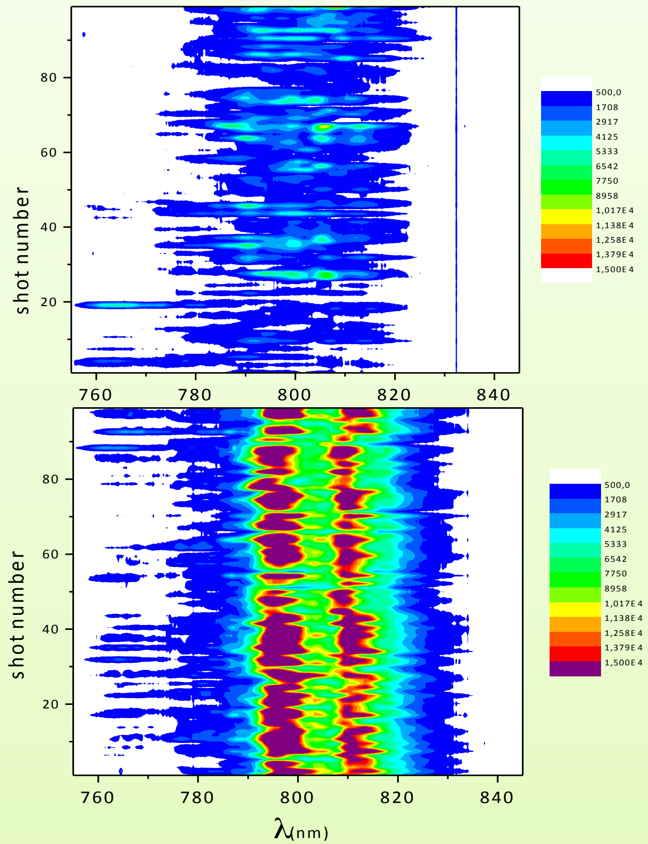


Two colors FEL: seeding

- With seeding we achieved increase stability and intensity



Averaged intensity of seed laser (red), SASE (green) and seeded FEL (black)



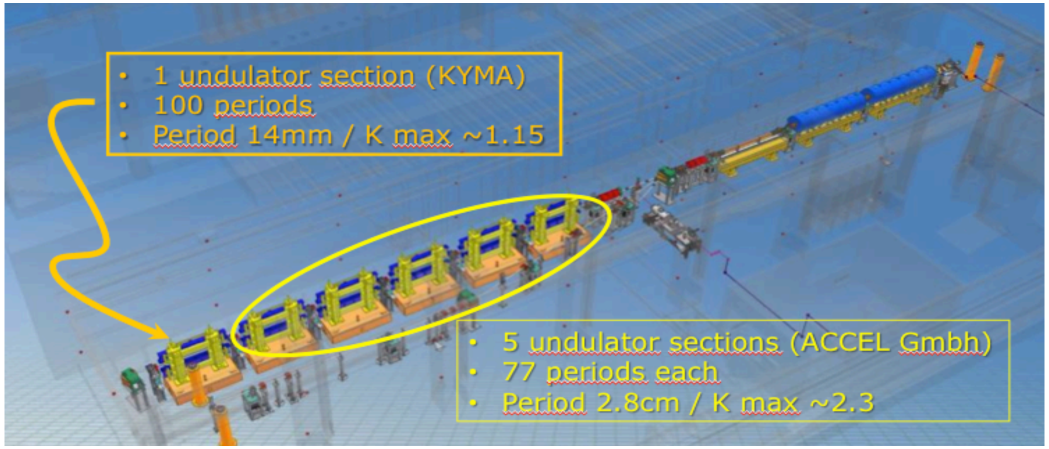
Spectral stability in time of SASE (top) and seeded FEL (bottom)

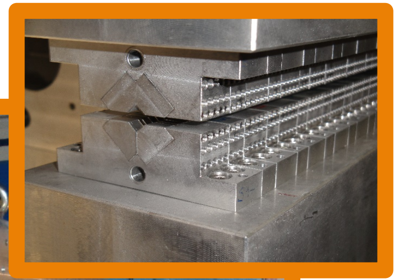
Test of multistage cascade FEL at SPARC F. Ciocci

- Installation and first test of short period undulator.
- Simulation work
- Preliminary report ready

DELTA like undulator λ_u = 14 mm, gap 5mm, Br = 1.22T

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

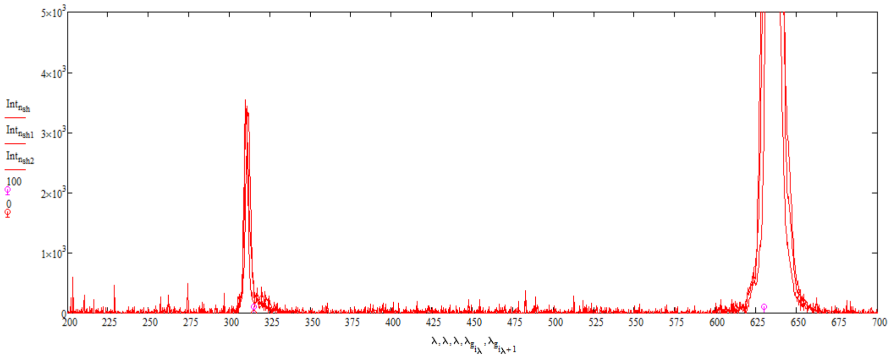


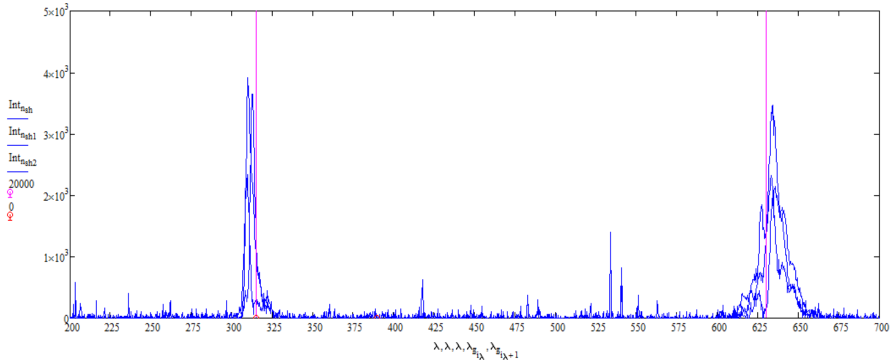


High-quality insertion devices
for light sources

Experiment. Example: Short period section used as “afterburner”

Two different group of spectra in the same acquisition run: the intensity of the emission from the first five undulators seems to marginally affect the intensity in the last undulator.

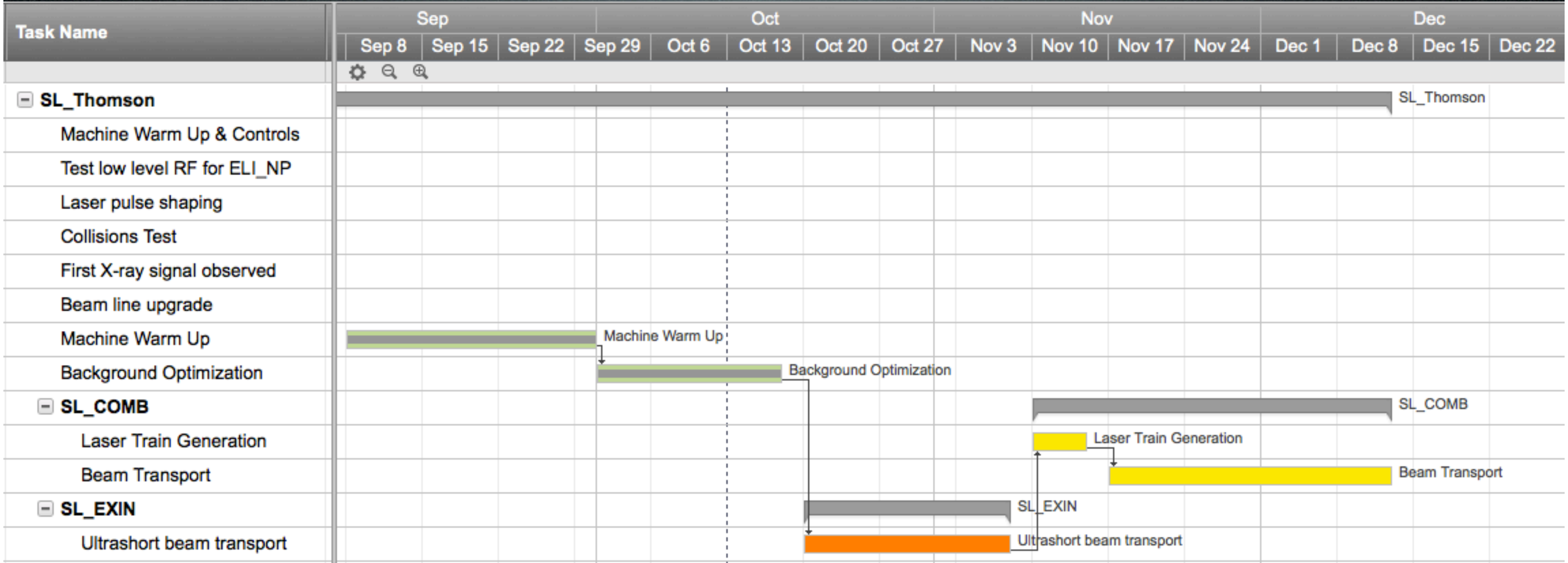


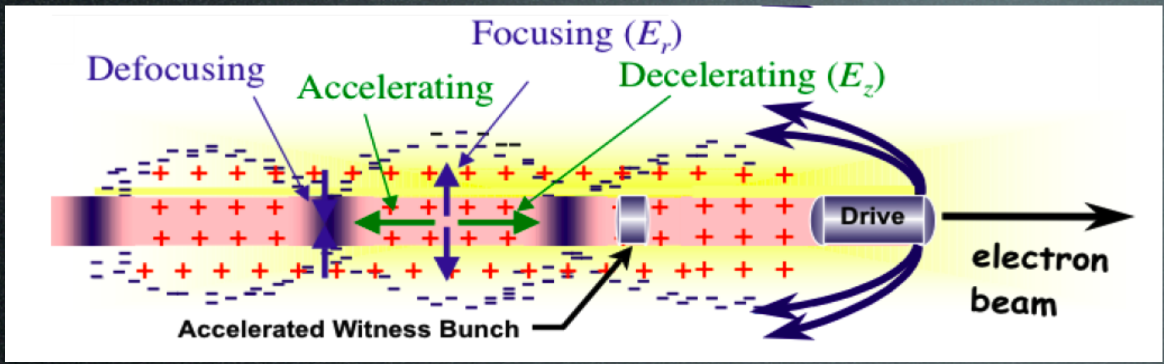


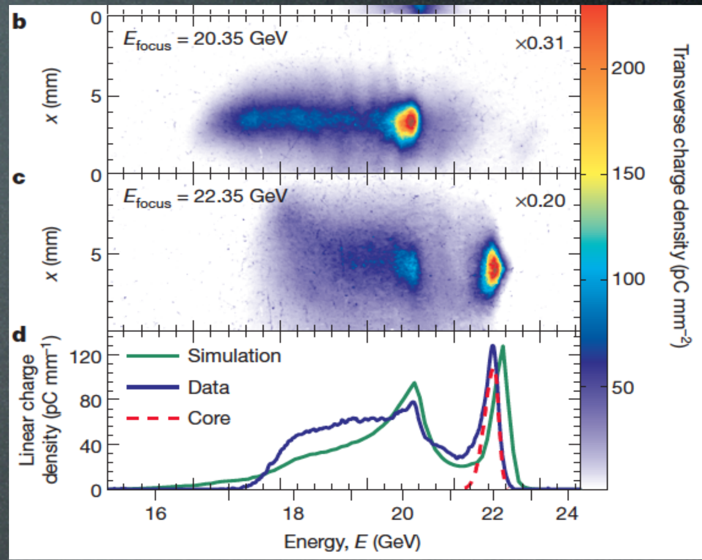
May be explained as an effect of electron beam mismatch in the first five sections connected to machine temporal drifts;

In the last section, the beam is always strongly focused in both directions and a mismatch at the entrance of this short section do not produce a significant reduction of the signal. Simulations show that other effects, such as variation of energy spread or electron bunches duration (with consequent variation of peak current) reduce in the same ratio both signals

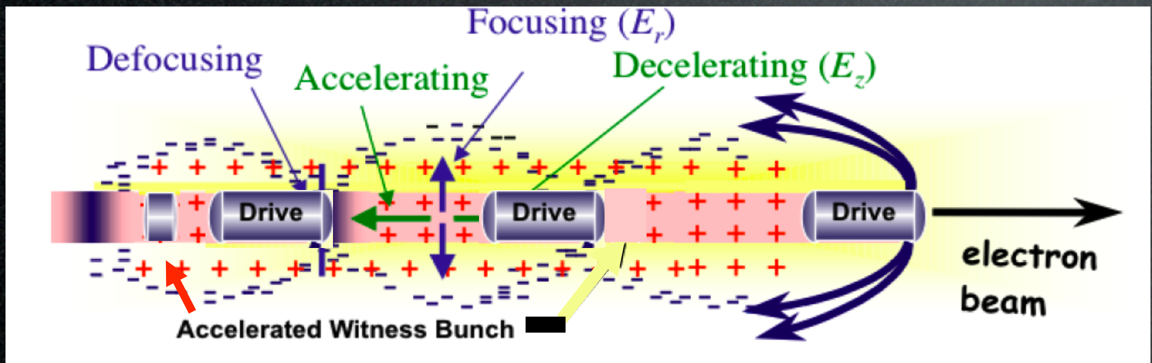
Beam dynamics studies for Plasma

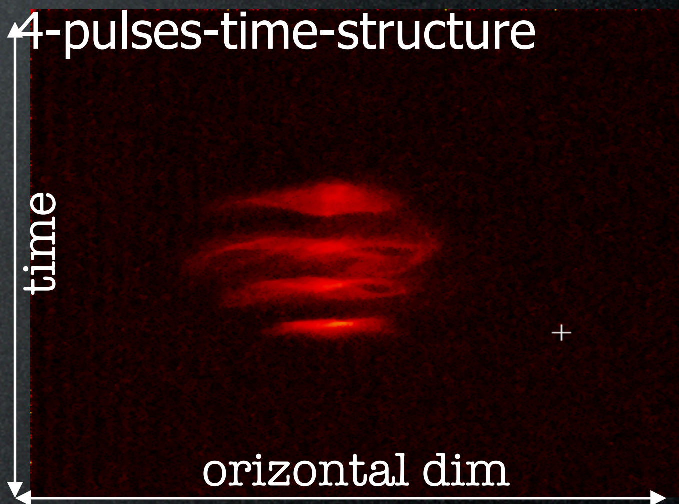






Litos, M. et al. *High-efficiency acceleration of an electron beamin a plasma wakefield accelerator*. **Nature** 515, 92-95 (2014).



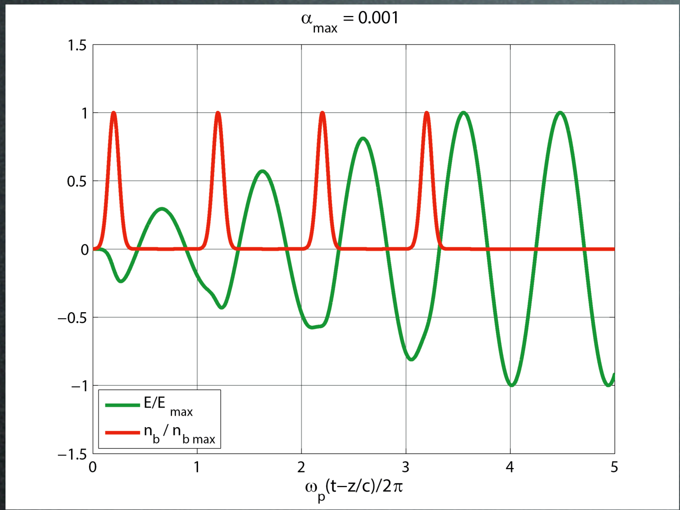


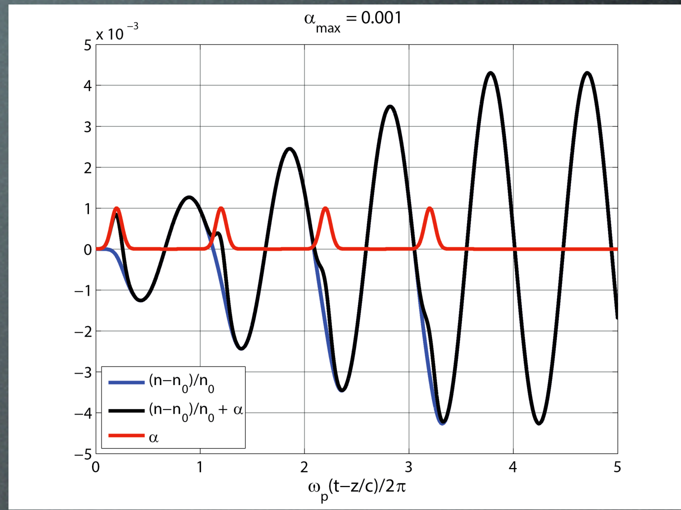
In progress also at SPARC_LAB

Submitted to HORIZON 2020 FET, (ELBA, M. Ferrario, E. Chiadroni, A. Cianchi)

Quasi-Non Linear regime

Linear

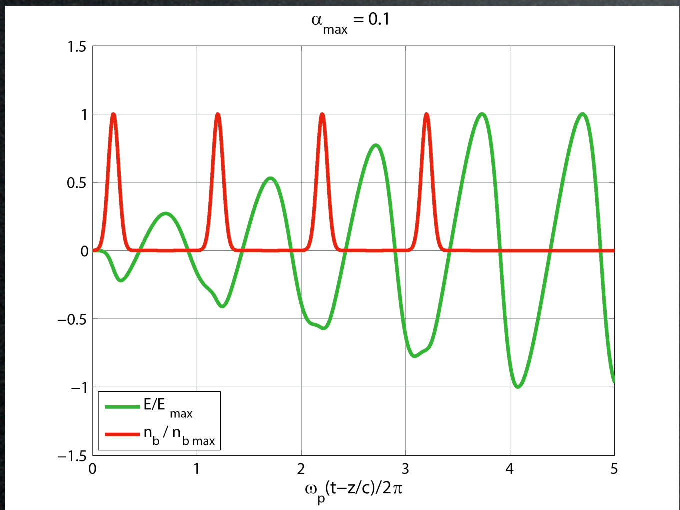


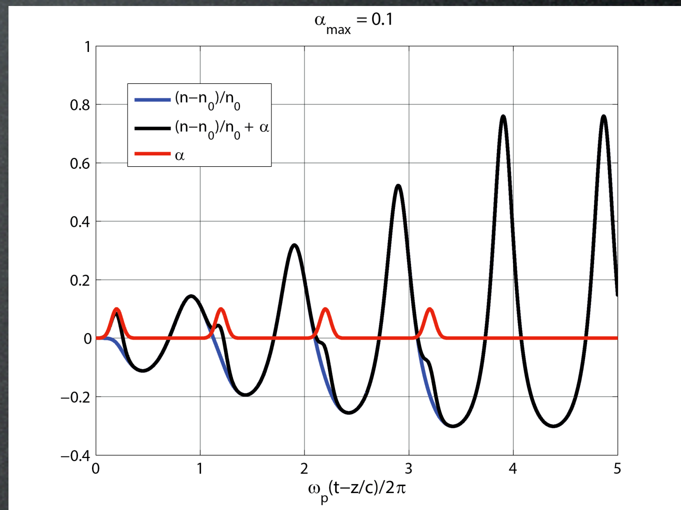


Accelerating field

Plasma density

Quais-Non Linear





Laser Comb technique: generation of a train of short bunches

(Parmela code)

Charge vs. Time

Energy vs. Time

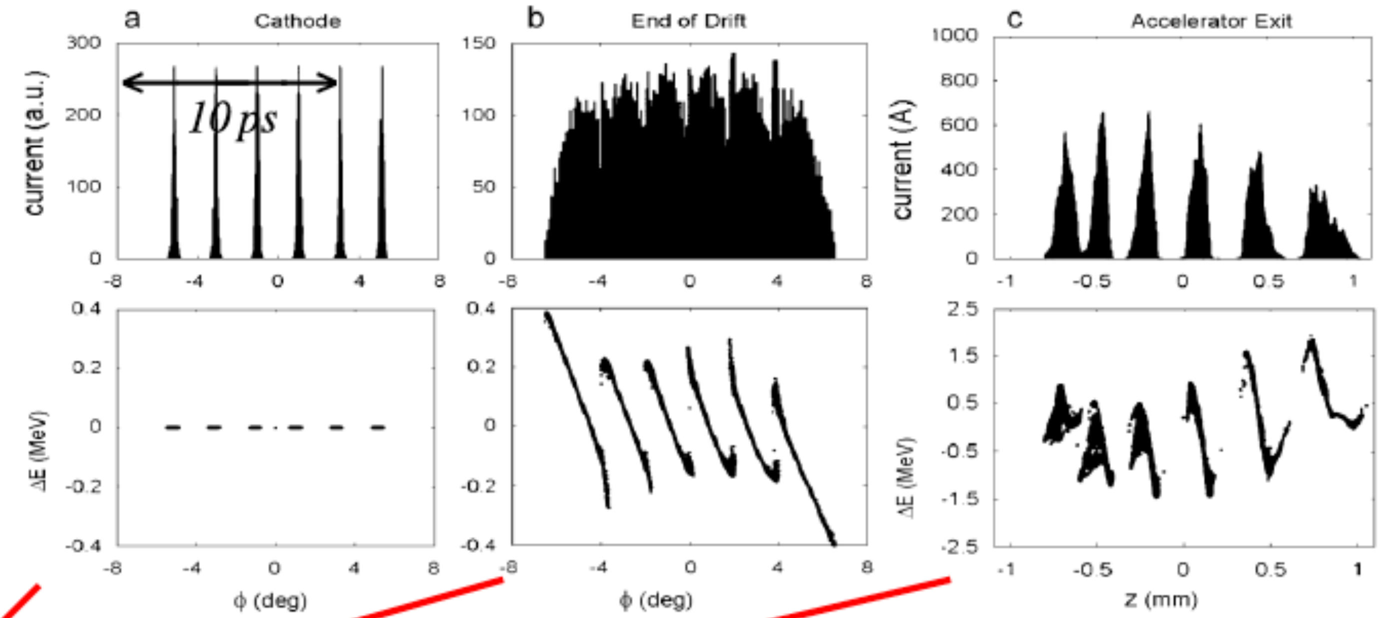
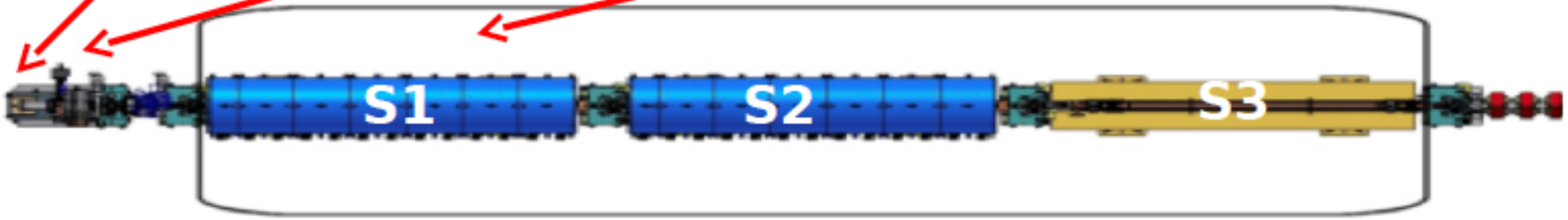
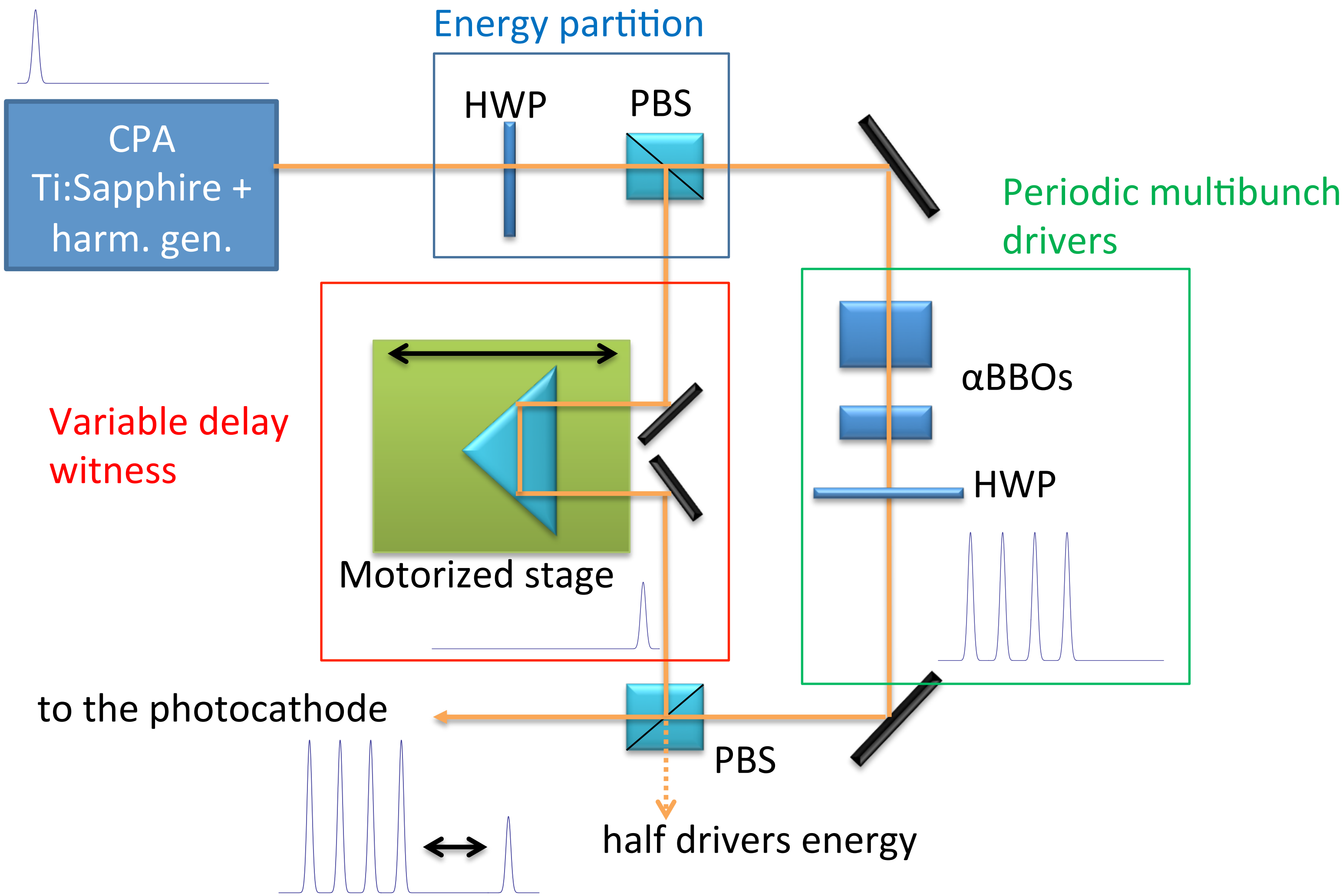


Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).



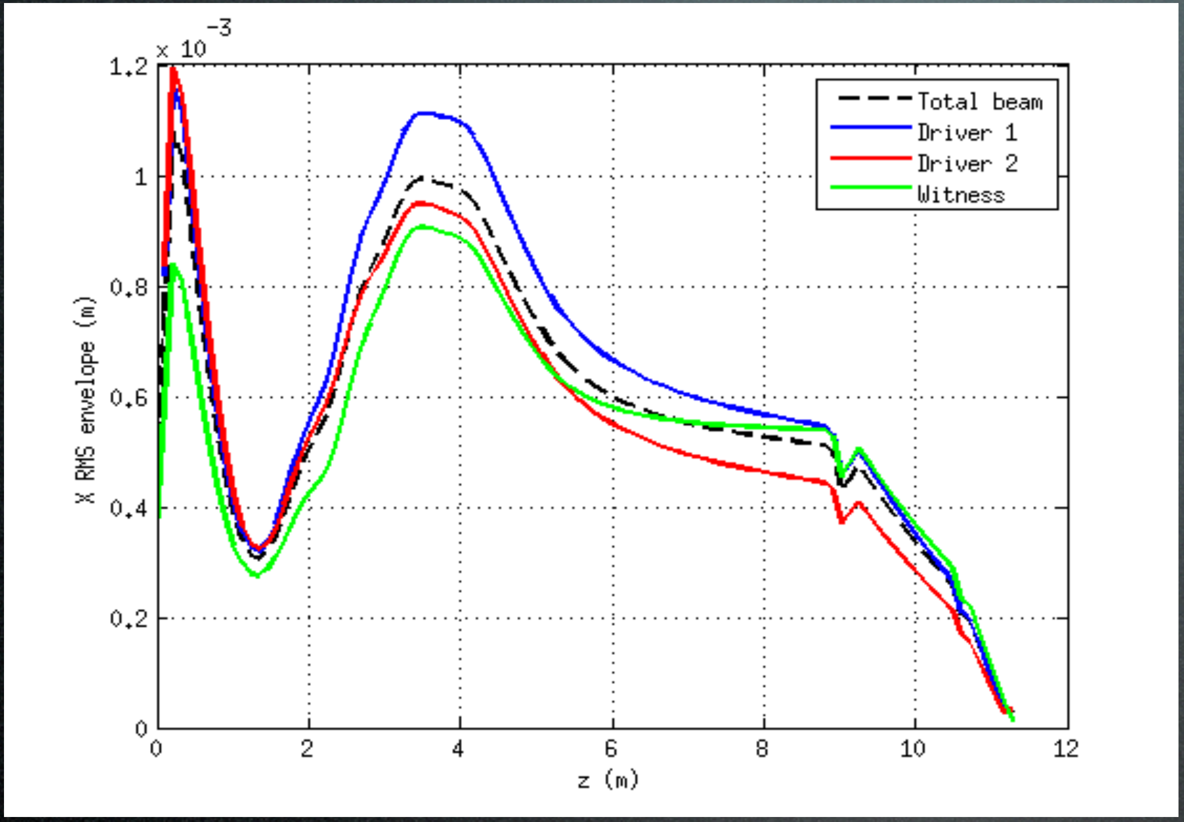
- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704. (Low charge regime only)
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (High charge, Beam Echo)

Driving and witness bunches generation

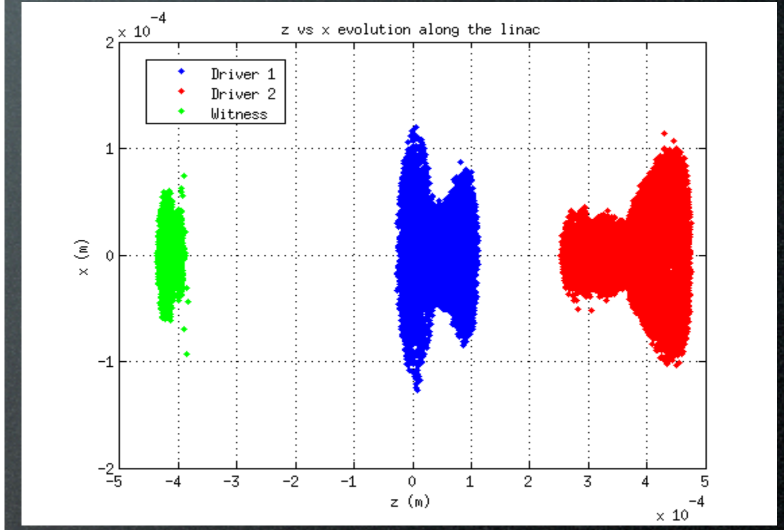


Courtesy F. Villa

•2x50 pc +1x25pC



•Plasma input beam



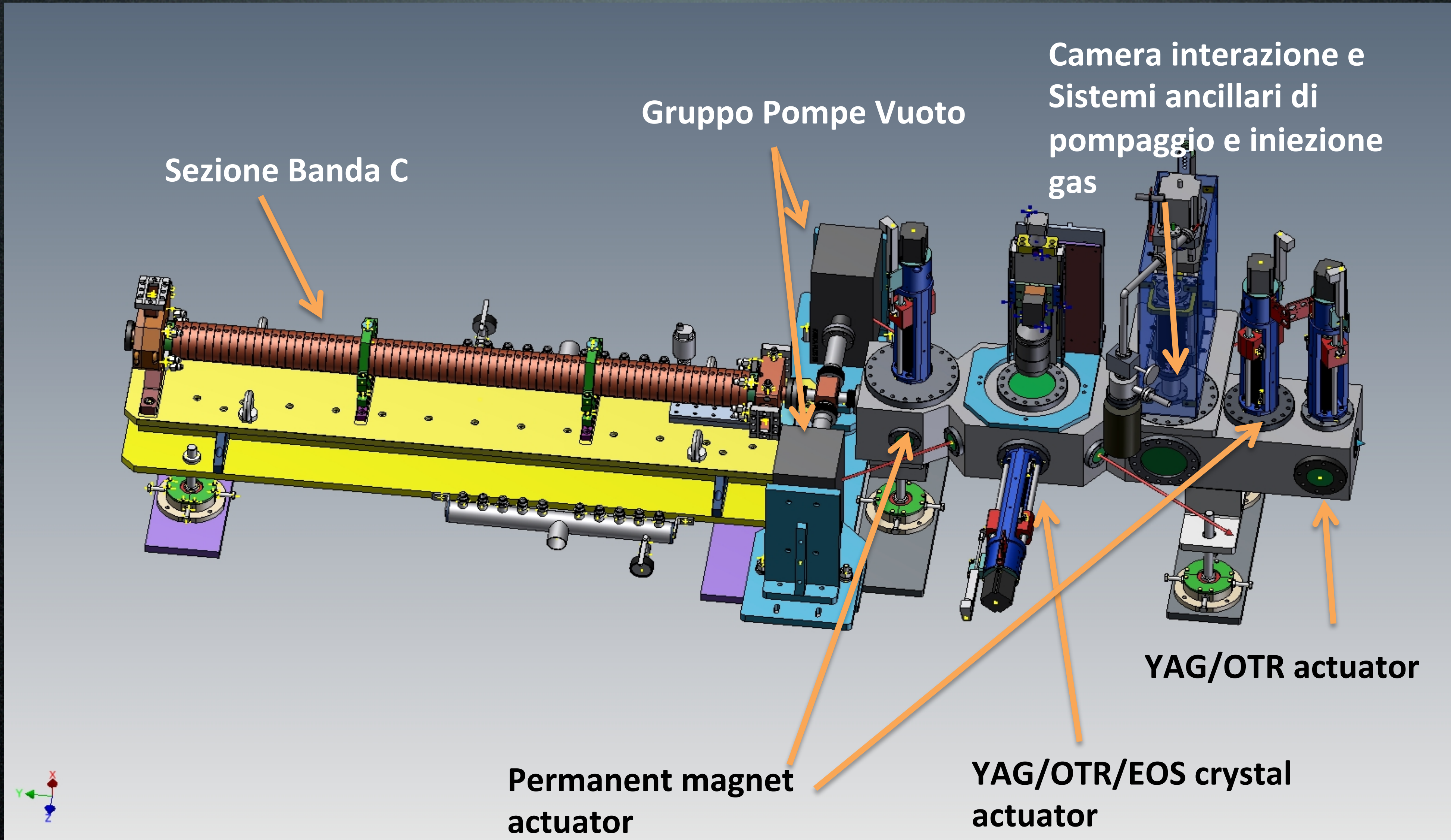
•rms spot: 33 um (driver 1 and driver 2), 13 um (witness)

•rms emittance: 2 um (driver 1), 1.6 um (driver 2), 1.2 um (witness)

•rms length: 31 um (driver 1), 55 um (driver 2), 7.4 um (witness)

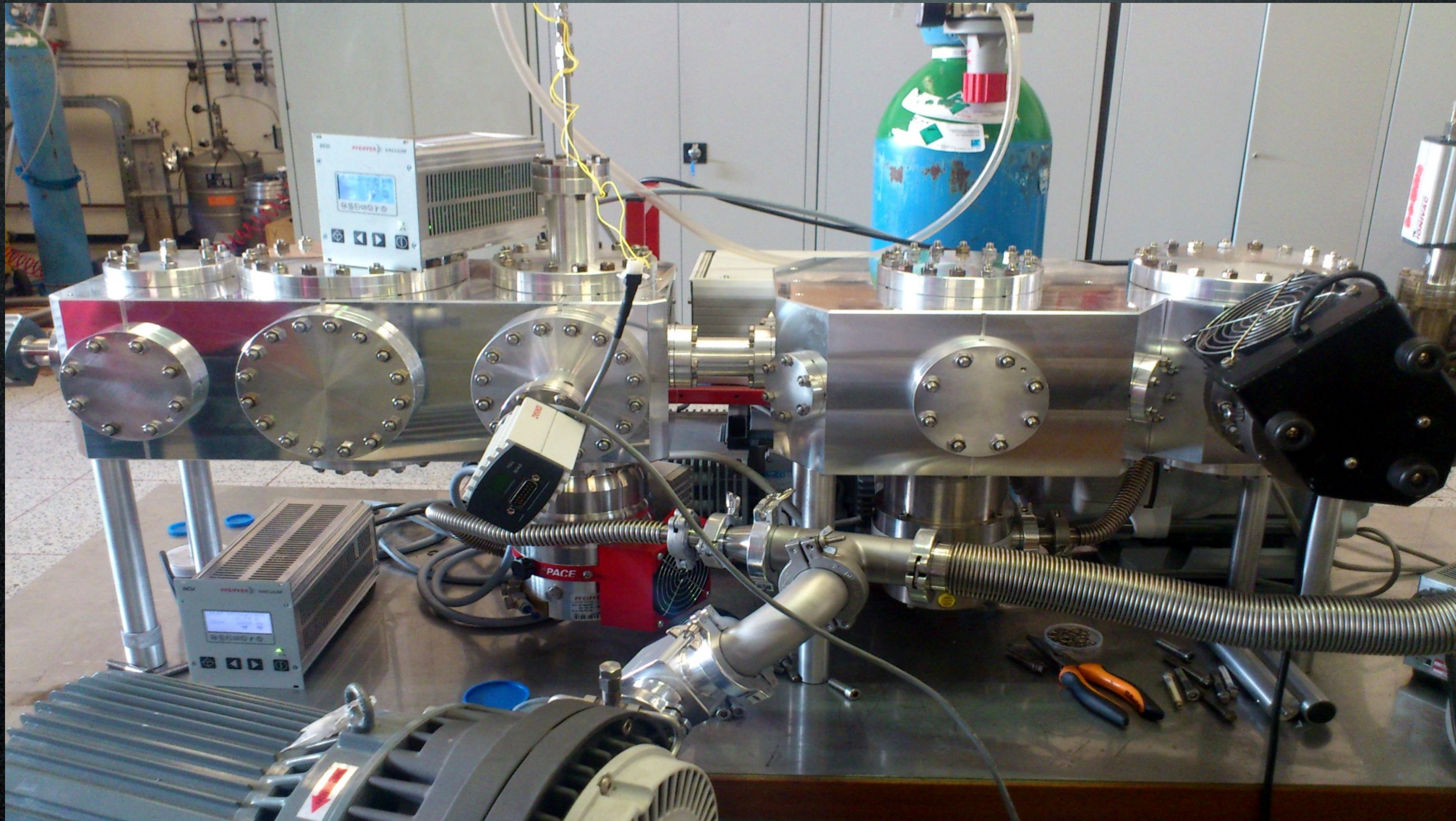
Courtesy R. Pompili

COMB plasma interaction chamber



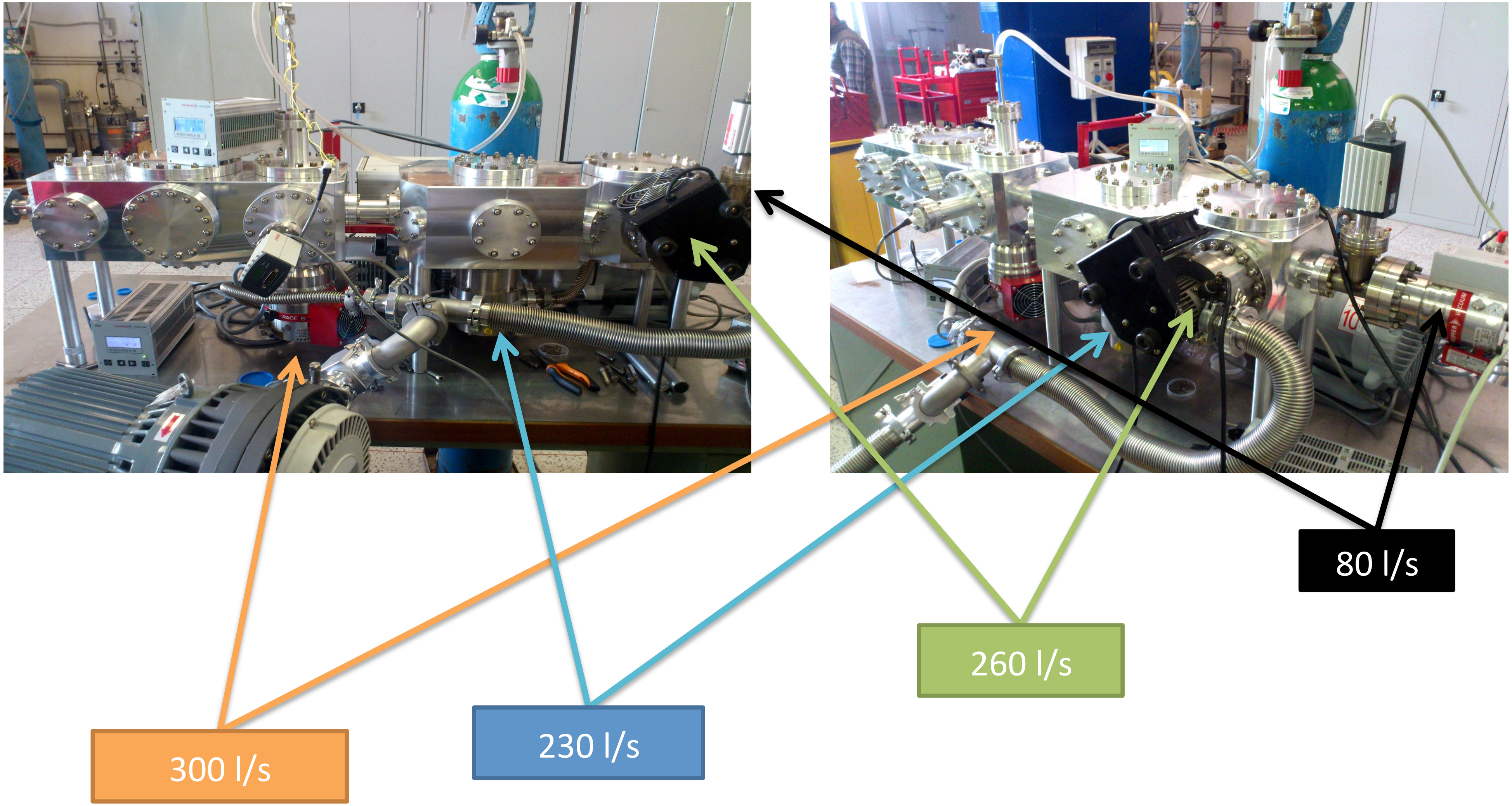
COMB interaction chamber delivered in July 2014

Dedicated plasma lab needed



Courtesy M. P. Anania

Camera layout: first test version!



Total pumping capacity: 870 l/s.

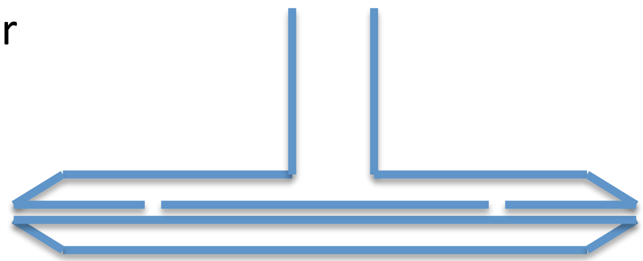
First test: Argon – new tests

Vacuum pumps: 4 turbo pumps and 3 scroll pumps.

Vacuum pre-shot: 6 – 8 x 10^{-9} mbar

Impedence: 5 mm diameter, 10 cm length.

Capillary: NEW DESIGN! 3 cm length, 1 mm inner diameter with 800 μm gas injection holes.



GOAL: shot-to-shot vacuum level below 9 x 10-7.

APPROCH: verify the vacuum level for different rep rate (1 – 5 and 10 Hz) and different electrovalve opening times (from 1 ms to 20 ms).

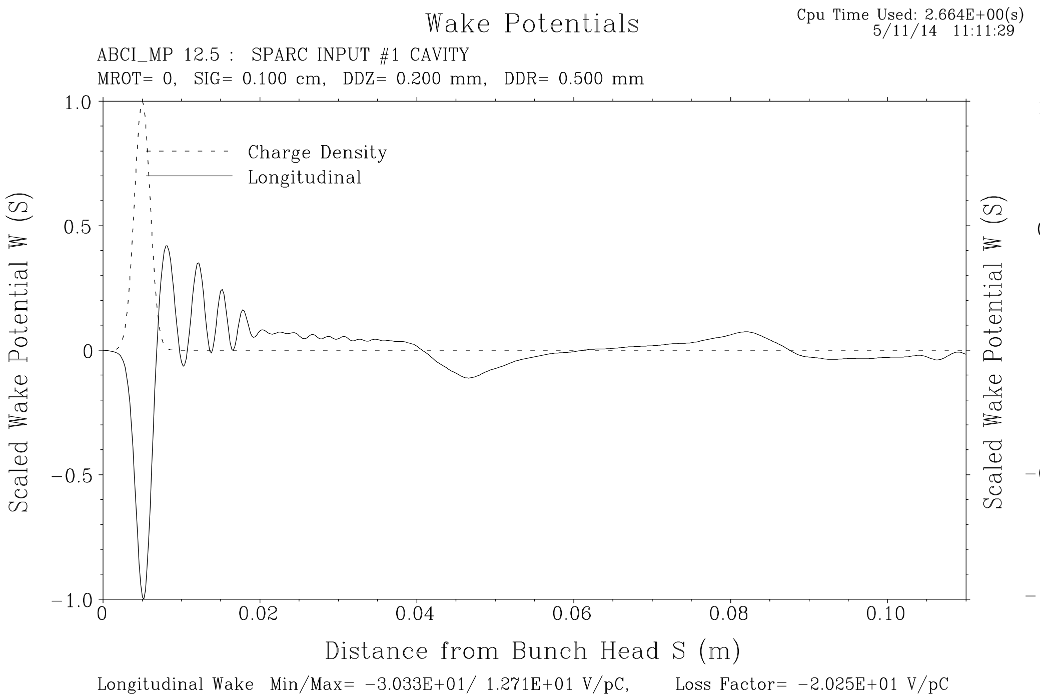
RESULTS: Way better than the last time! Vacuum level below 9*10-7 almost in all conditions. In particular, at 1 Hz rep rate, vacuum level is accettable with valve opening time up to 50 ms!!

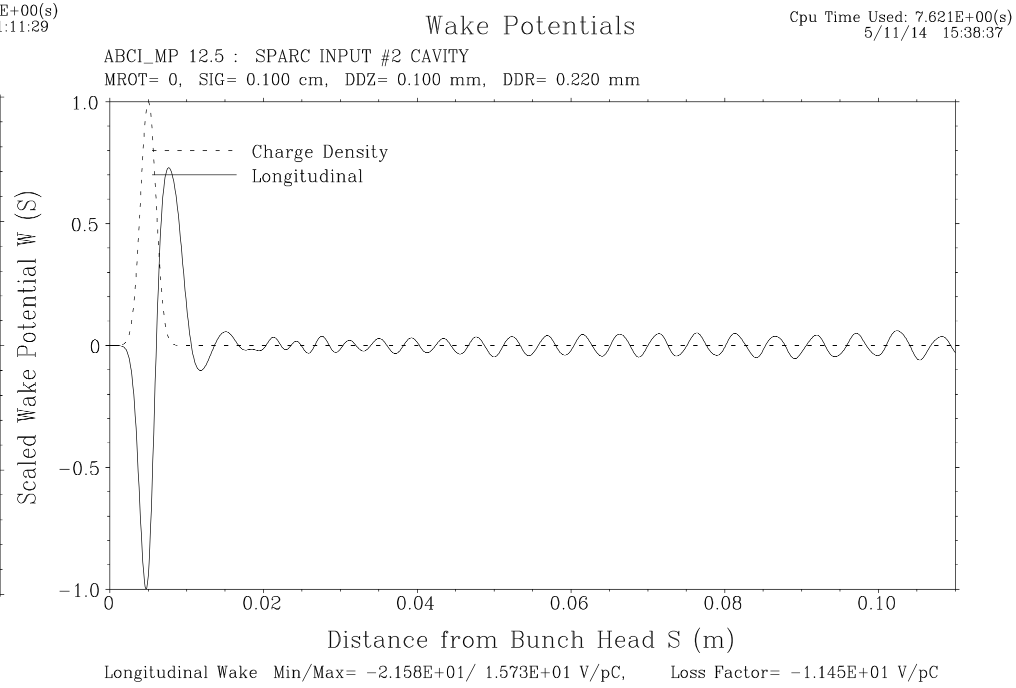
Helium – more close to H2.

Rep rate	Opening time	Vacuum level after shot [mbar] **Helium**	Vacuum level after shot [mbar] **Argon**
1 Hz	1 ms	7.0E-8	1.2E-8
	5 ms	2.0E-7	1.0E-7
	10 ms	5.5E-7	1.4E-7
	15 ms	1.0E-6	2.6E-7
	20 ms	1.5E-6	4.5E-7
5 Hz	1 ms	9.0E-8	2.9E-8
	5 ms	6.5E-7	1.7E-7
	10 ms	1.5E-6	3.6E-7
	15 ms	8.3E-6	5.6E-7
	20 ms	6.0E-6	7.6E-7
10 Hz	1 ms	1.7E-7	4.7E-8
	5 ms	2.0E-6	3.4E-7
	10 ms	7.6E-6	7.9E-7
	15 ms	2.6E-5	1.3E-6
	20 ms	1.0E-4	1.9E-6

Longitudinal Potentials (Courtesy A. Brynes and B. Spataro)

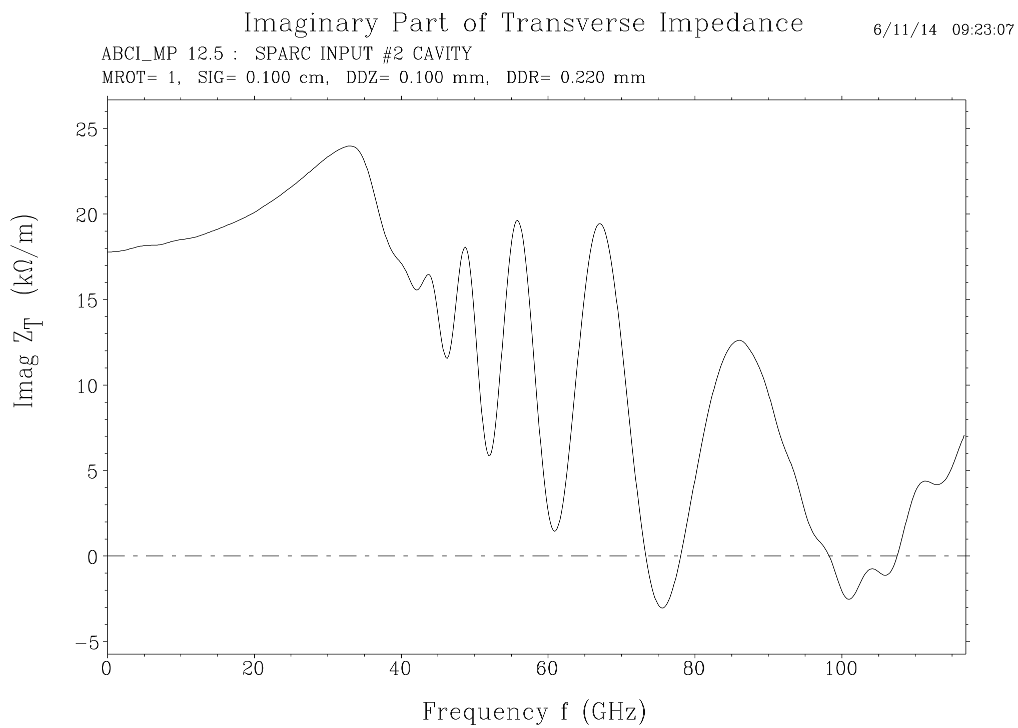
- As the distance behind the bunch is increased, we see that there are no trapped modes in the wake potential as the oscillations become damped as increases
- Below is the wake potential for cavities #1 and #2 up to



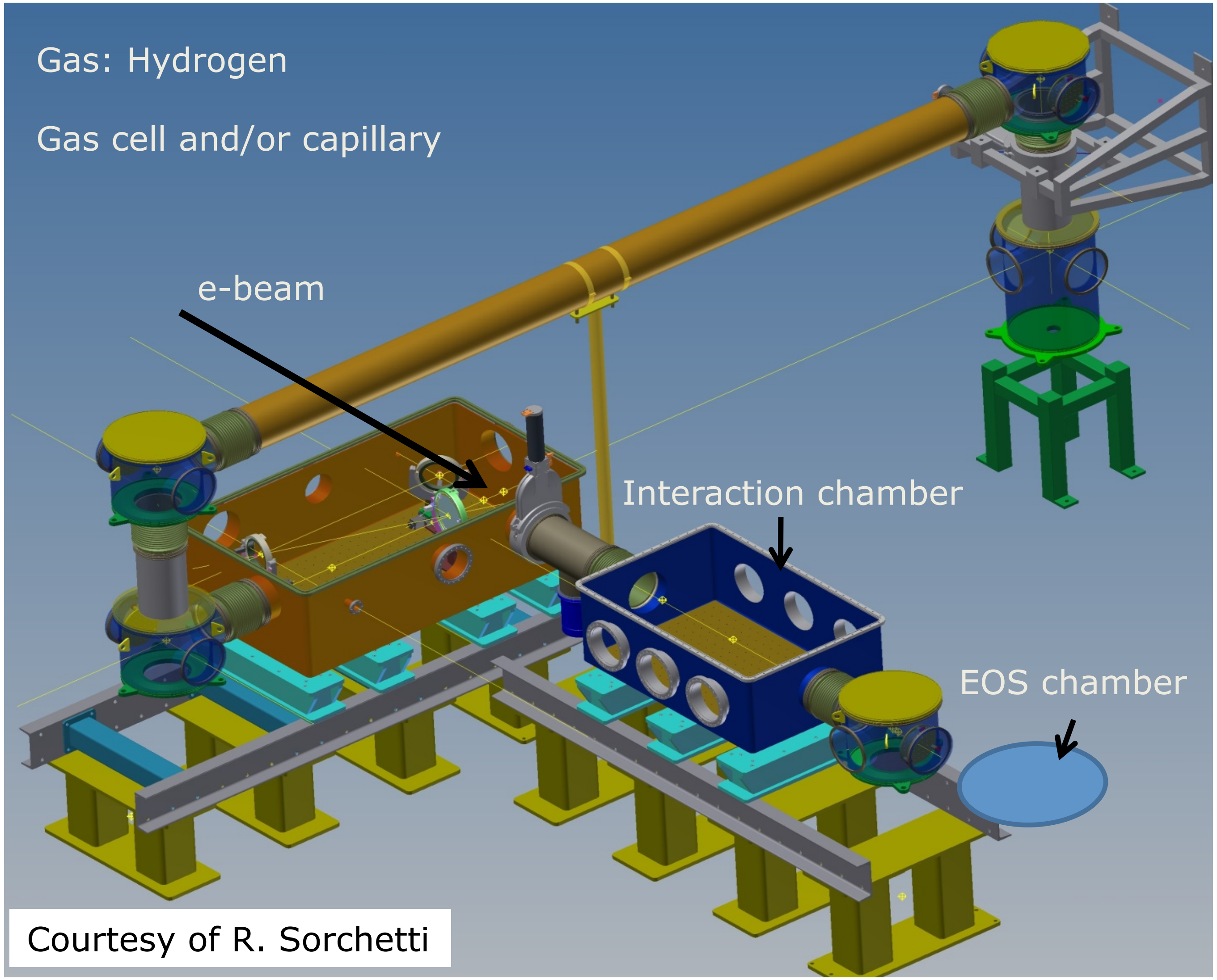


Transverse Wakes

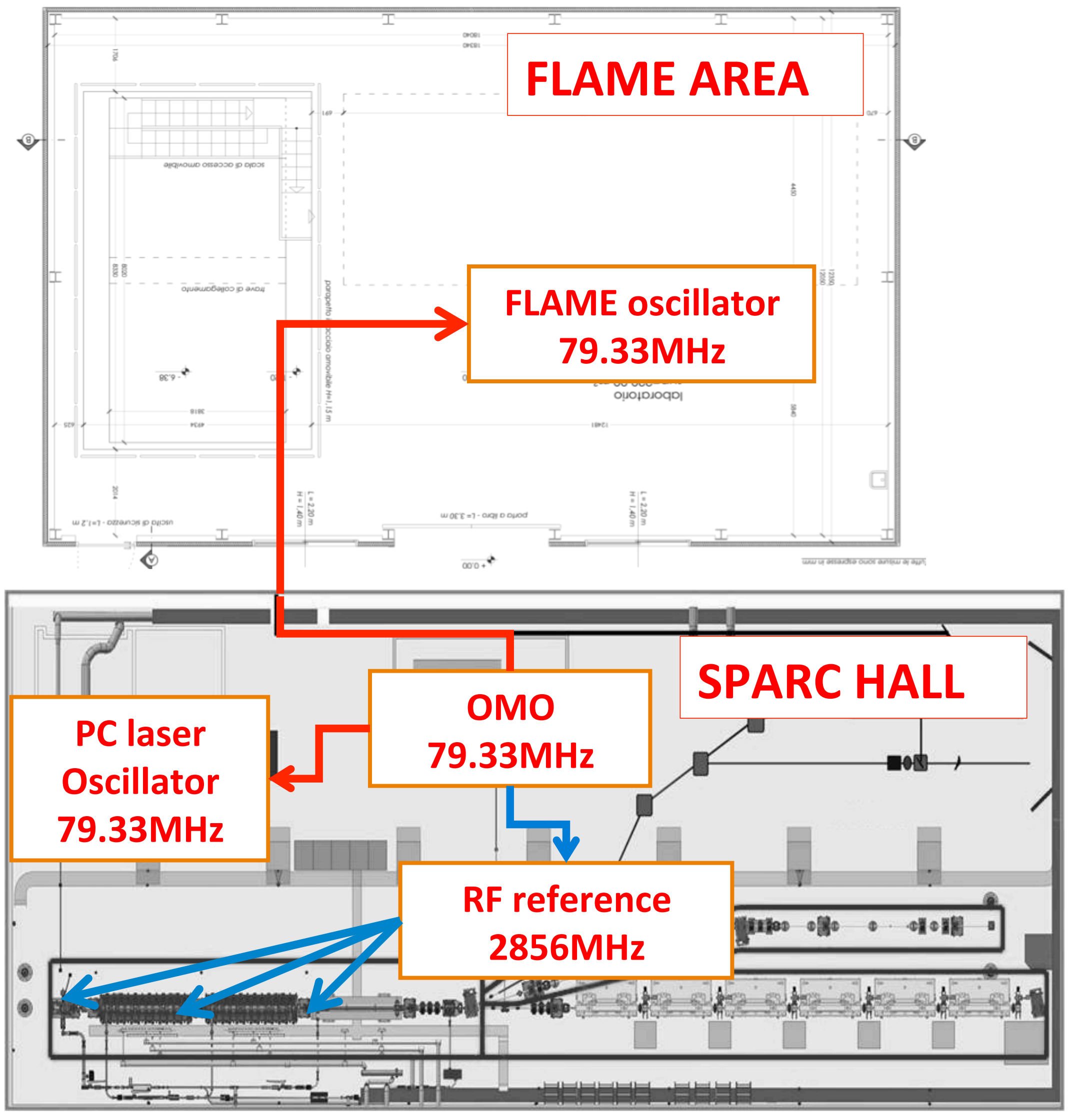
- Transverse impedance can be given as a function of transverse loss factor:
- E.g. – Cavity #2 gives
- So
- ABCI gives
- If , this is negligible, so transverse wakes do not have a large effect



Interaction Layout



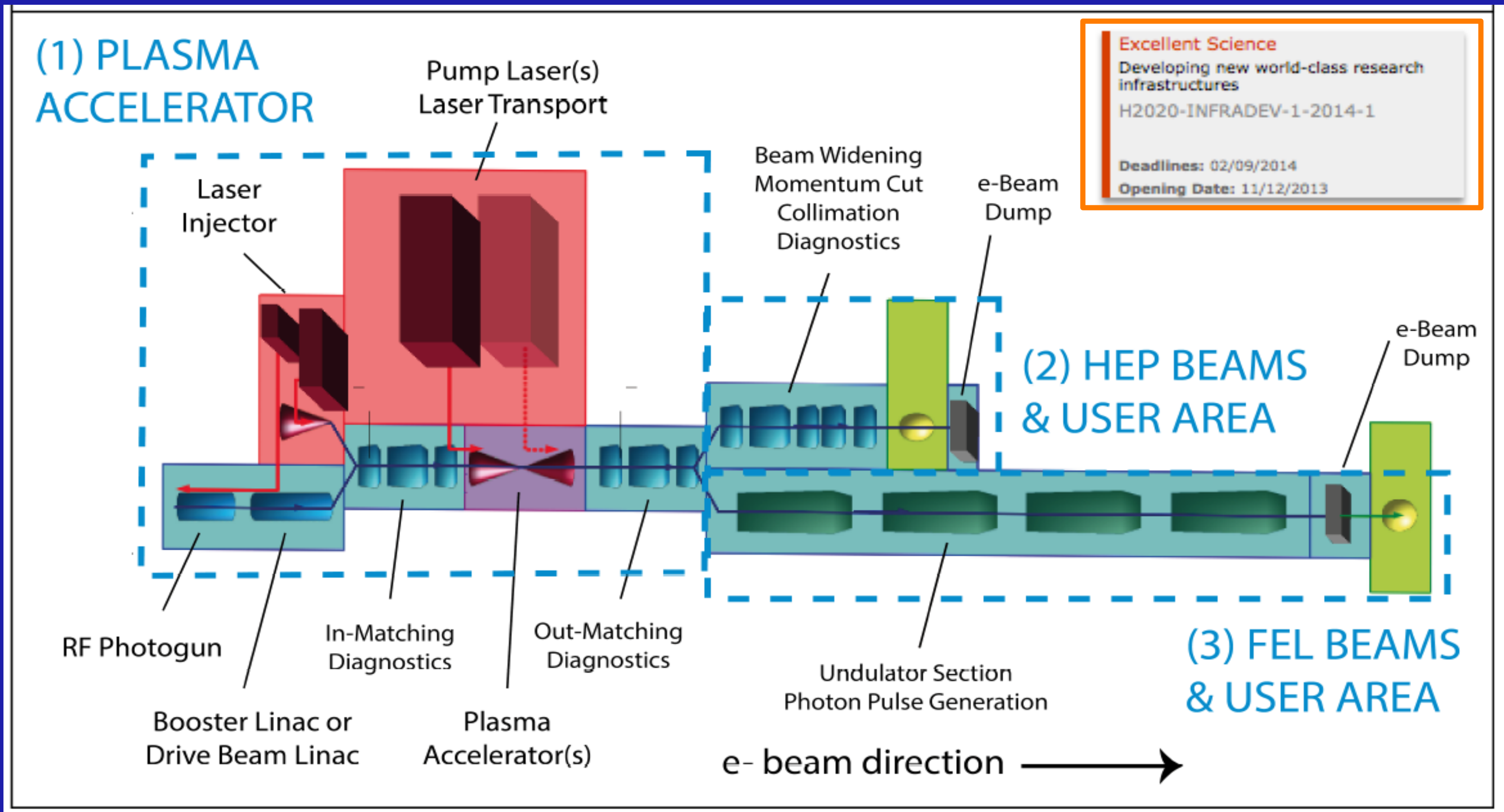
System upgrade



- Optical reference
  - RF reference will be substituted by fiber optical oscillator
  - Fiber laser OMO (Optical Master Oscillator) installed and tested
  - Systems locked through high resolution optical phase monitors (cross-correlators in house and ready to be tested)
  - Fiber link stabilization is ongoing (order placed) to distribute the reference signal
  - **FLAME laser VS electrons estimated time jitter <50fs$_{RMS}$**

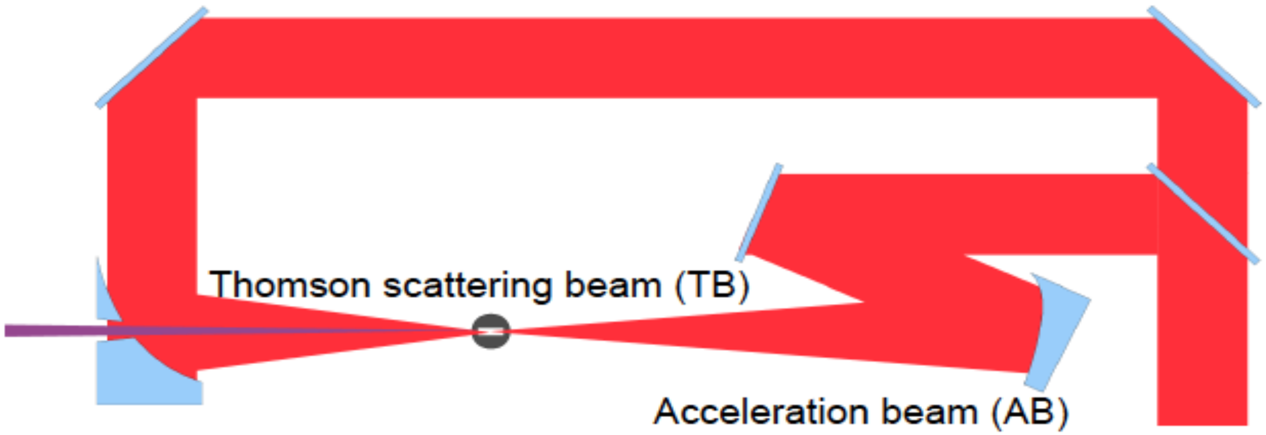
Design Study on the "European Plasma Research Accelerator with eXcellence In Applications" (EuPRAXIA)

Submitted to HORIZON 2020 INFRADEV, 4 years, 3 M€



TWO BEAM CONFIGURATION AT FLAME 1/2

A possible simple setup for Thomson scattering experiments with self-injected electrons [1/2] (~*compatible with existing setup*)

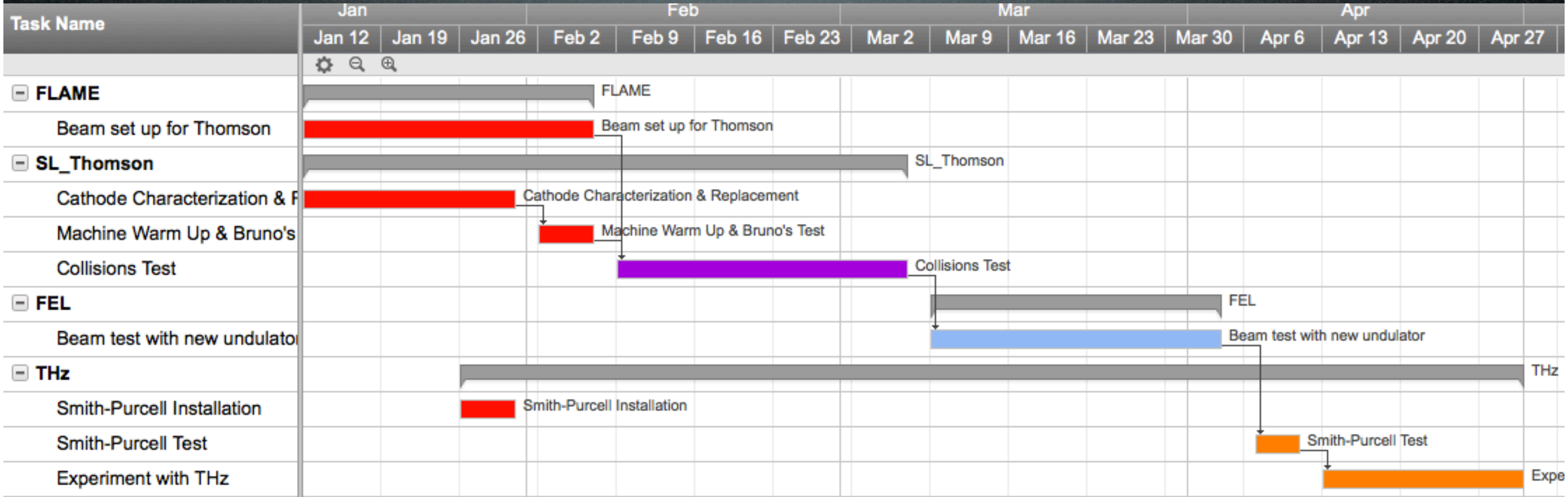


Main params:

- **AB** OAP: f/10, a_0~4-5
- **TB** OAP: to be defined (see below), a_0~0.5, but size (→ energy) depending on the e- beam emittance

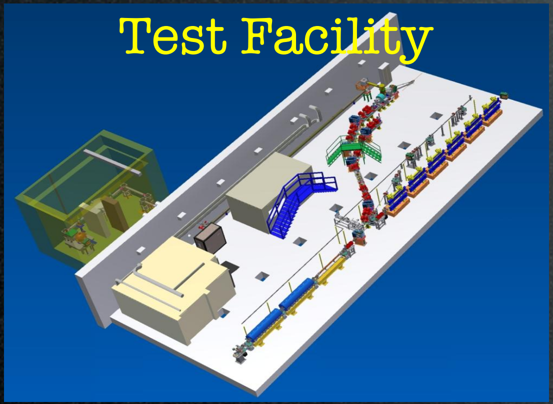
Submitted to HORIZON 2020 FET (AOX, F. Boscherini, G. Gatti, L. Gizzi)

Next year



Task Name
Jan
Feb
Mar
Apr
Jan 12
Jan 19
Jan 26
Feb 2
Feb 9
Feb 16
Feb 23
Mar 2
Mar 9
Mar 16
Mar 23
Mar 30
Apr 6
Apr 13
Apr 20
Apr 27
FLAME
Beam set up for Thomson
SL_Thomson
Cathode Characterization & F
Machine Warm Up & Bruno's
Collisions Test
FEL
Beam test with new undulato
THz
Smith-Purcell Installation
Smith-Purcell Test
Experiment with THz
FLAME
Beam set up for Thomson
SL_Thomson
Cathode Characterization & Replacement
Machine Warm Up & Bruno's Test
Collisions Test
FEL
Beam test with new undulator
THz
Smith-Purcell Installation
Smith-Purcell Test
Expe

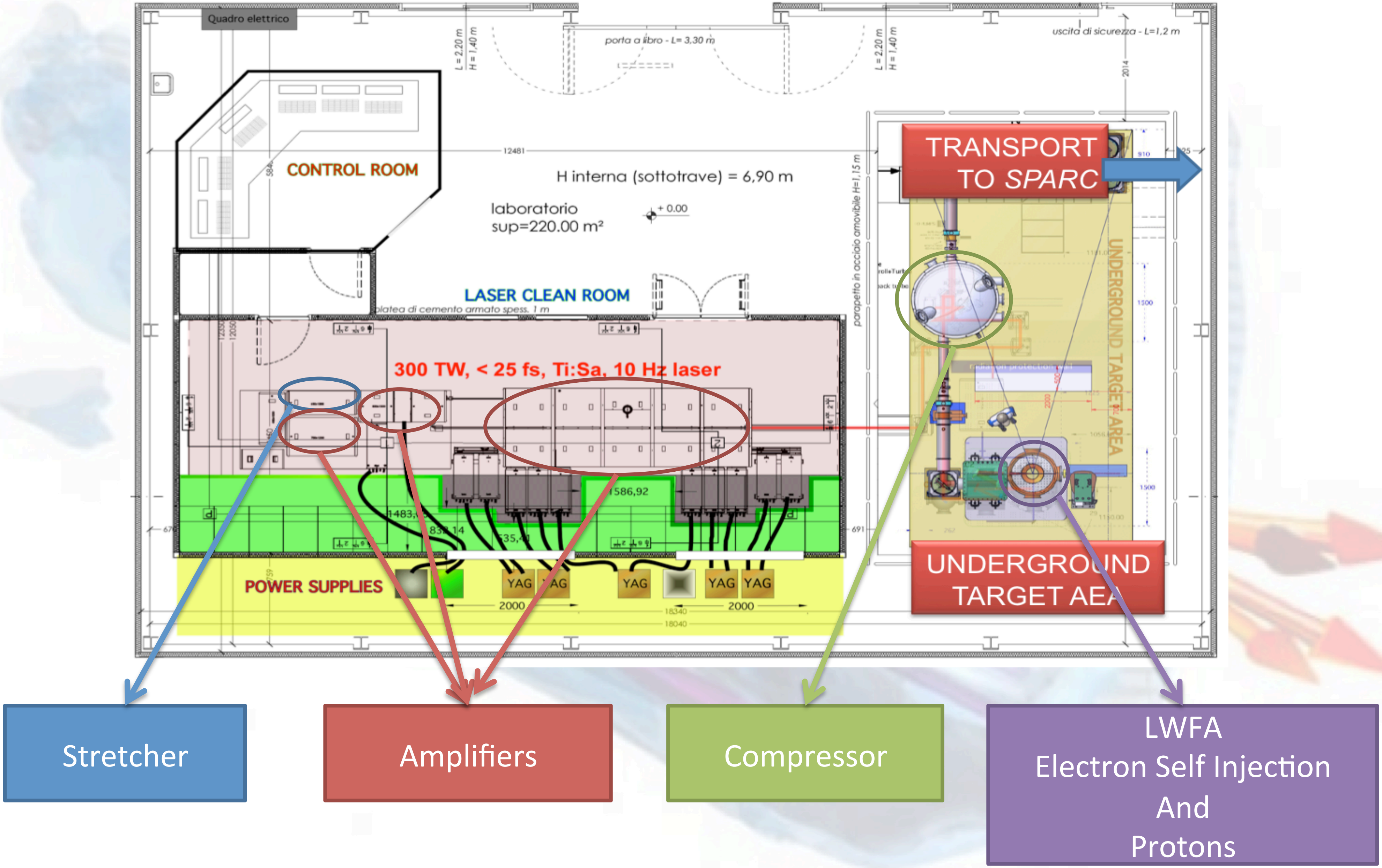
SPARC_LAB Consolidation started



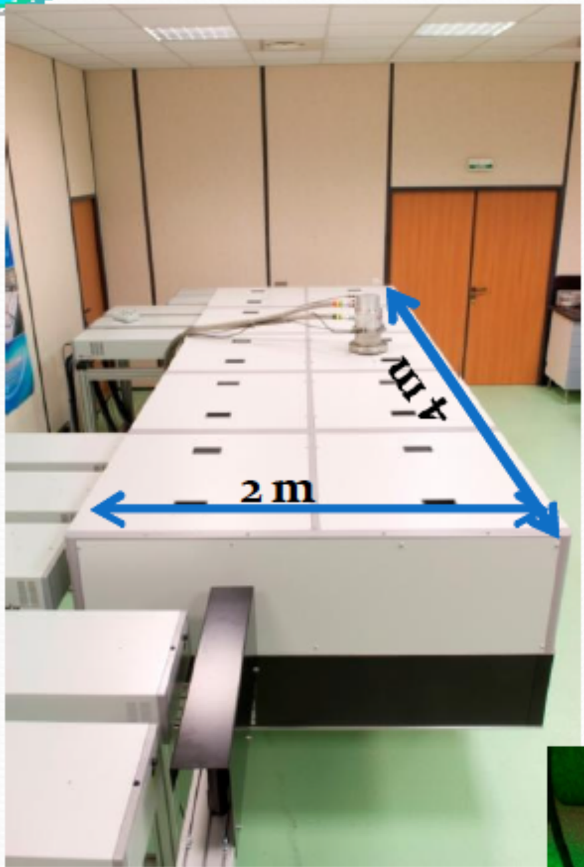
~3 years,~ 4 M€ allocated

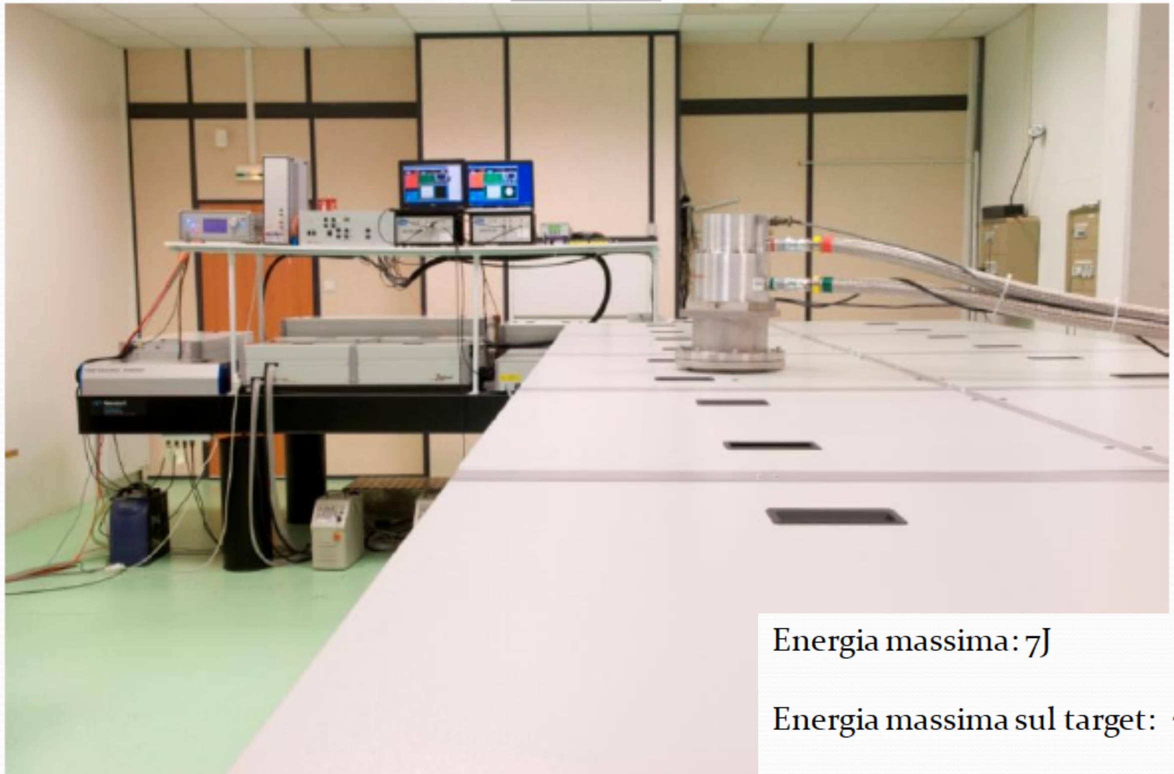
- FLAME maintenance
- Injector upgrade (C-band, X-band)
- THz user beam line upgrade
- Thomson and Plasma beam lines final commissioning
- FEL new undulator

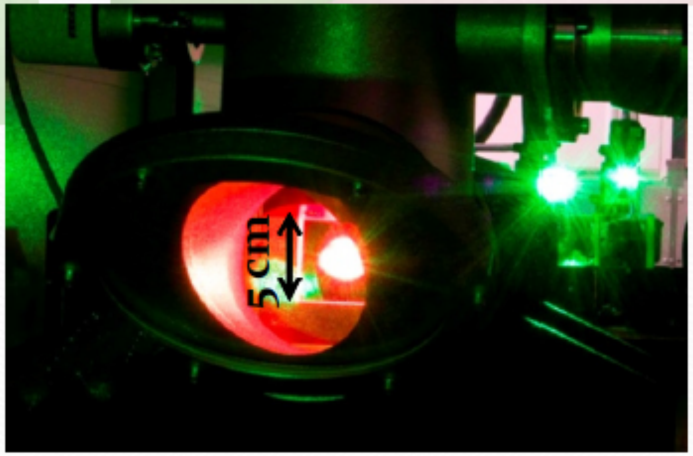
Ti:Sa FLAME laser



Il laser FLAME







Energia massima: 7J

Energia massima sul target: ~5J

Durata minima: 23 fs

Lunghezza d'onda: 800 nm

Larghezza di banda: 60/80 nm

Spot-size @ focus: 10 μm

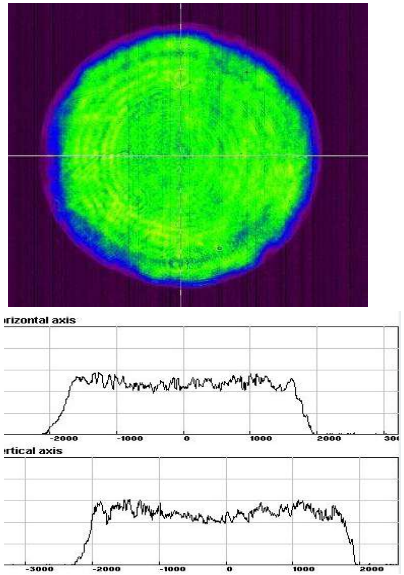
Potenza massima: ~300 TW

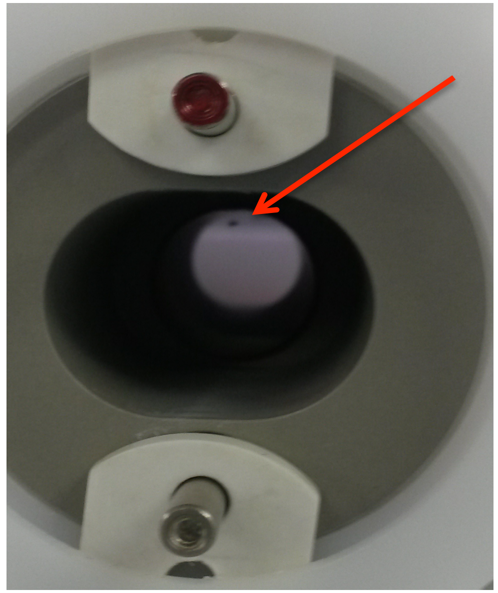
Contrasto: 10^{10}

Hardware situation

High power pumping critical:
Defective generation of Nd:Yags

Optical: Damage in the final amplifier of the pumps triggering othe damages in the chain





Electrical: Two power supply units failured

Cooling: One cooling unit failed
repaired in house

Chiller failure

Laser Issues: Almost exclusive vendor (Amplitude).
“Conventional Optics”: Most of items are not in stock
(almost 7 months waiting for large mirrors and Gratings).
Admin: Justify costing is getting more and more difficult. Orders of magnitudes high even for conventional manteinance.
13k€=1lamp replacement, 10k€ 1 Nd:Yag pumping chamber
10k€ 1 power supply, small grat. 13k€, big grat. 20k€

Further Upgrades Needed

New Compressor Chamber
about 80 K€
(+80k€ new gratings)

Very unconfortable chamber. Alignment very
Unfavorable. Chromatic effect not fixed by A.O.
arising (lateral colors). Grating supports not stable
Almost not tunable. Massive diagnostics is needed.
Preliminary design..waiting for news.

New Interaction Chamber
about 50 K€

Very limited range of upgrades and
Flexibility right now. Lot of experiments nearly
Impossible. Need of space for multi- purpose
bunker. Preliminary design…waiting for news.

New requests: final slides!

In vacuum camera

Trials still not satisfying: conventional cameras
survive but noise arises.
about 10 k€ for not specific camera..
otherwise much expensive.

PROPOSED SCHEME FOR SPARC: X-band structure for longitudinal phase space linearization + RF compressor

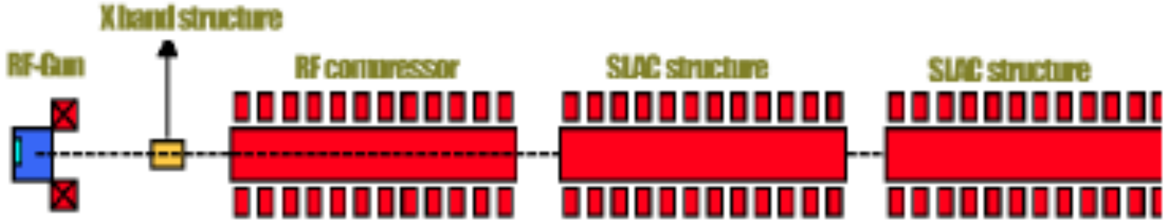
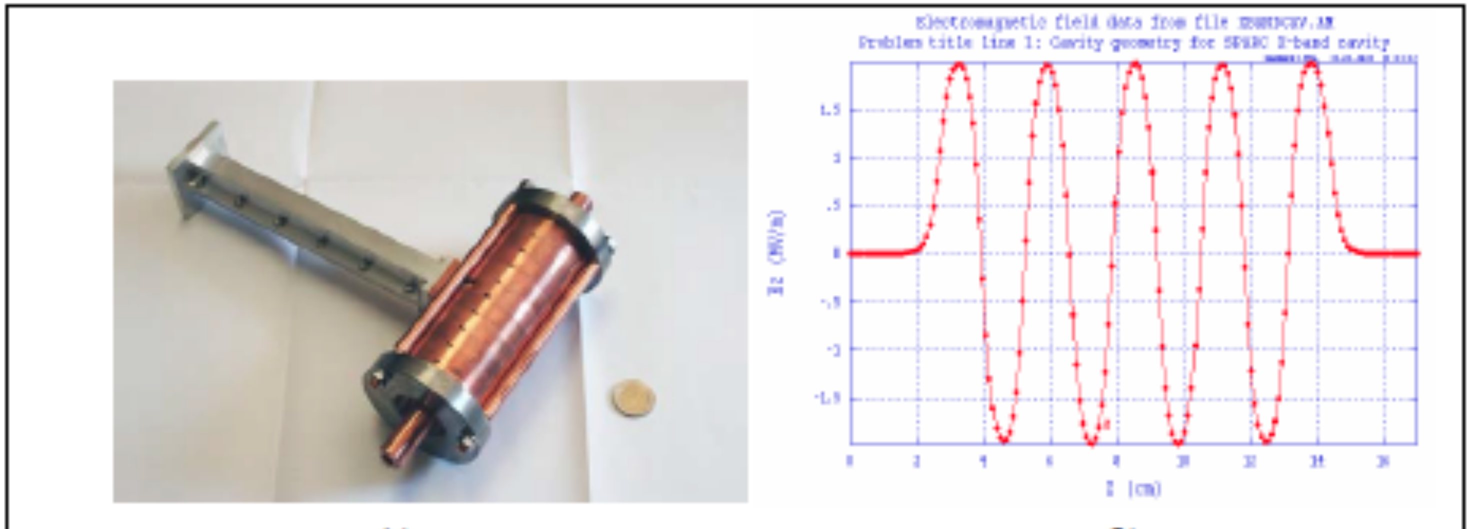


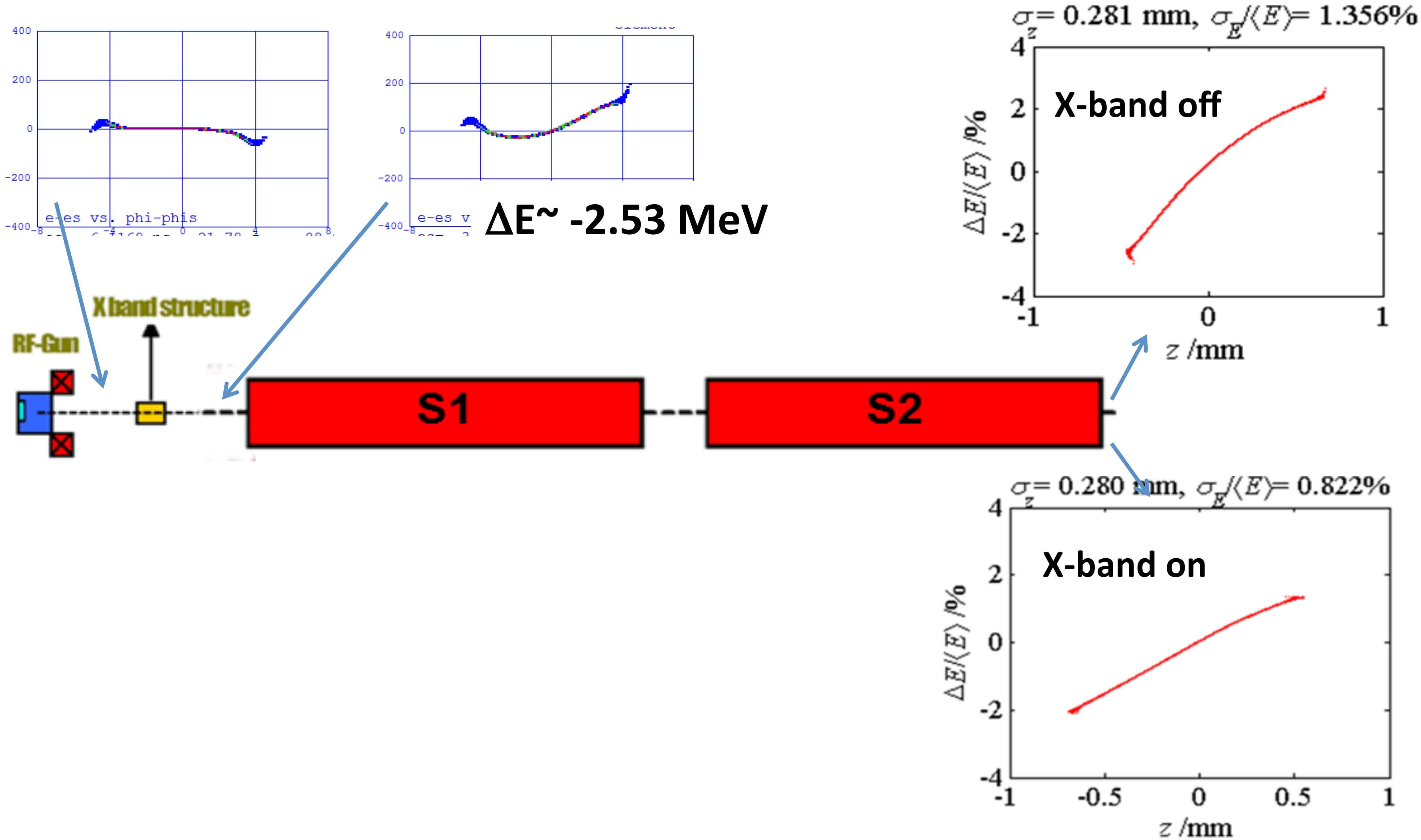
Fig.1 Sketch of SPARC-phase II layout



(a) *(b)*

Fig.2:a) Prototype of the SW X-band linac, b) Electric field distribution on the axis computed by SUPERFISH

LOW CHARGE (250 pC) CALCULATIONS



USE OF A LONGITUDINAL PHASE SPACE LINEARIZER @SPARC WITH A COMB BEAM (period 2010-2011)

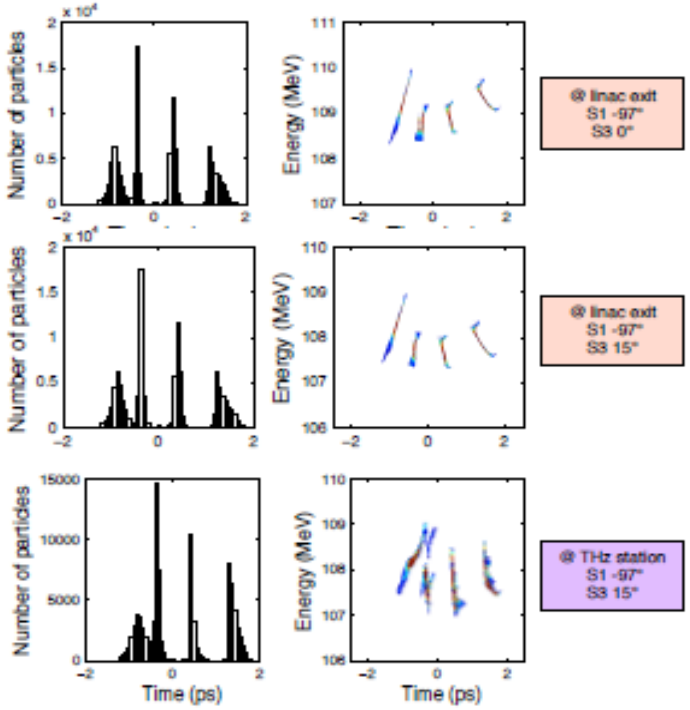


Figure 2.19: Longitudinal charge profile and phase space of the 4 pulses comb. The bunch has been over-compressed using S1 section. *On top:* comb at the exit of the linac it it travels on crest in the second and third accelerating sections. *In the middle:* comb at the exit of the linac if the S3's phase is used to compensate the energy difference between the four bunches. *On bottom:* same comb of precedent plot at the THz station; note that the length of each bunch has been modified by the dogleg (the first one is lengthened, the others are shortened) but their relative distance is almost the same.

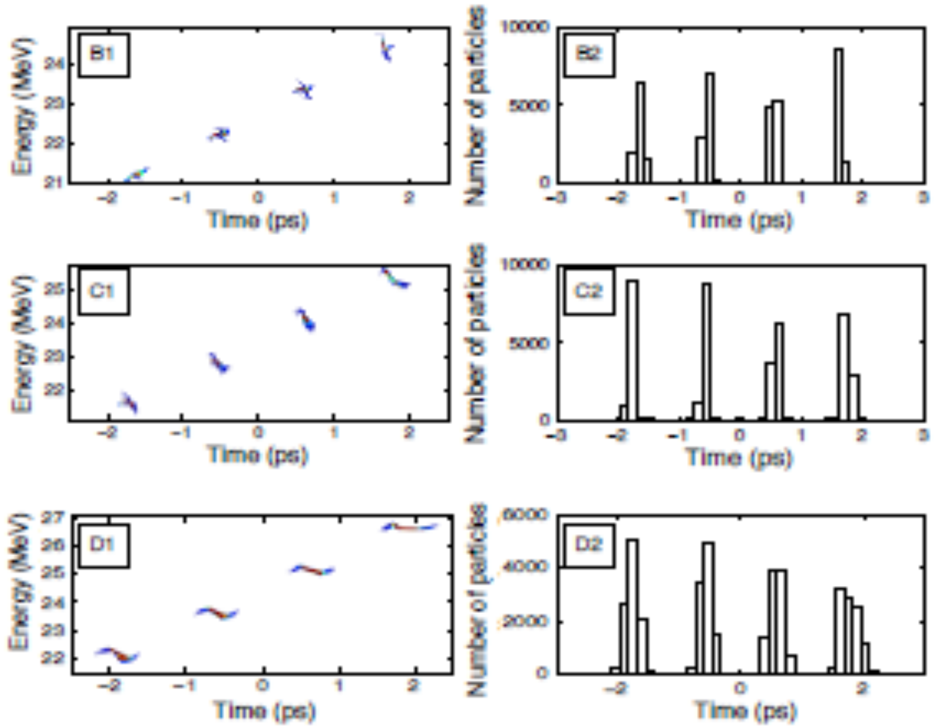


Figure 2.23: Longitudinal phase space and charge distribution of a 4 sub-pulses comb for different over-compression phases and correction of non-linearities by the fourth harmonic cavity discussed in the text. A: $S1 = -94°$; B: $S1 = -98°$; C: $S1 = -100°$; D: $S1 = -103°$.

RF compression without fourth harmonic correction

RF compression with fourth harmonic correction

B. Marchetti

Considerations

- The ongoing SPARC_LAB activities are being studied in several other laboratories, including SLAC, DESY, CERN and KEK with equally or even more ambitious research programs.

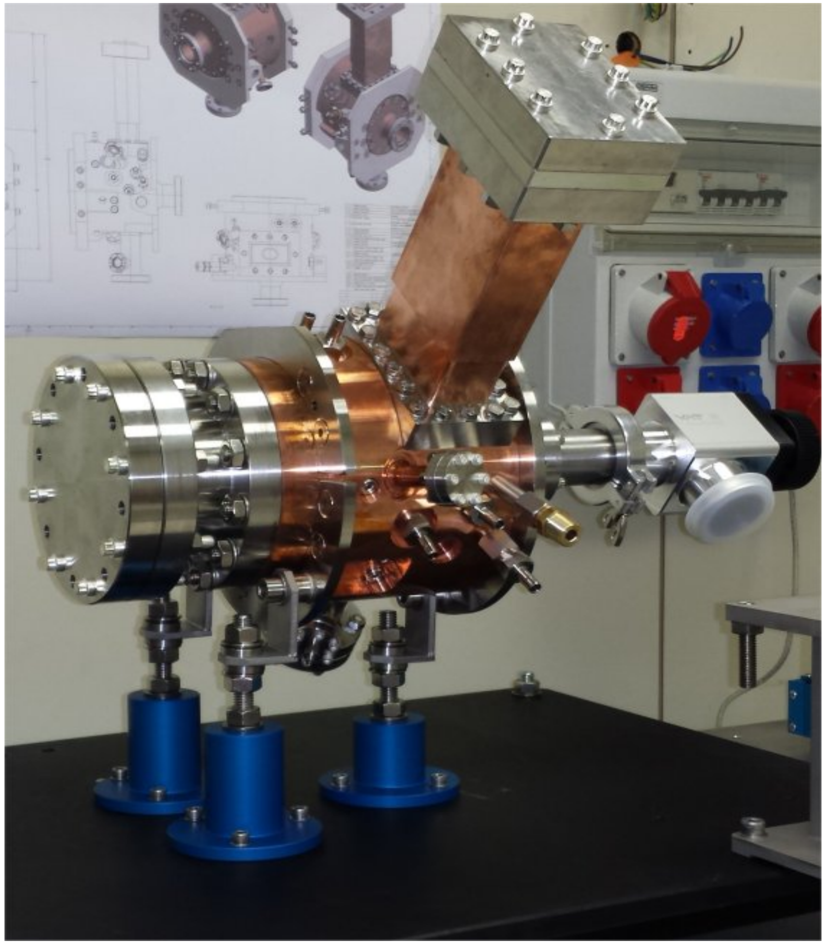
- Therefore the time factor becomes very important to remain at the research frontier and to produce results with high-impact on the international scientific community.

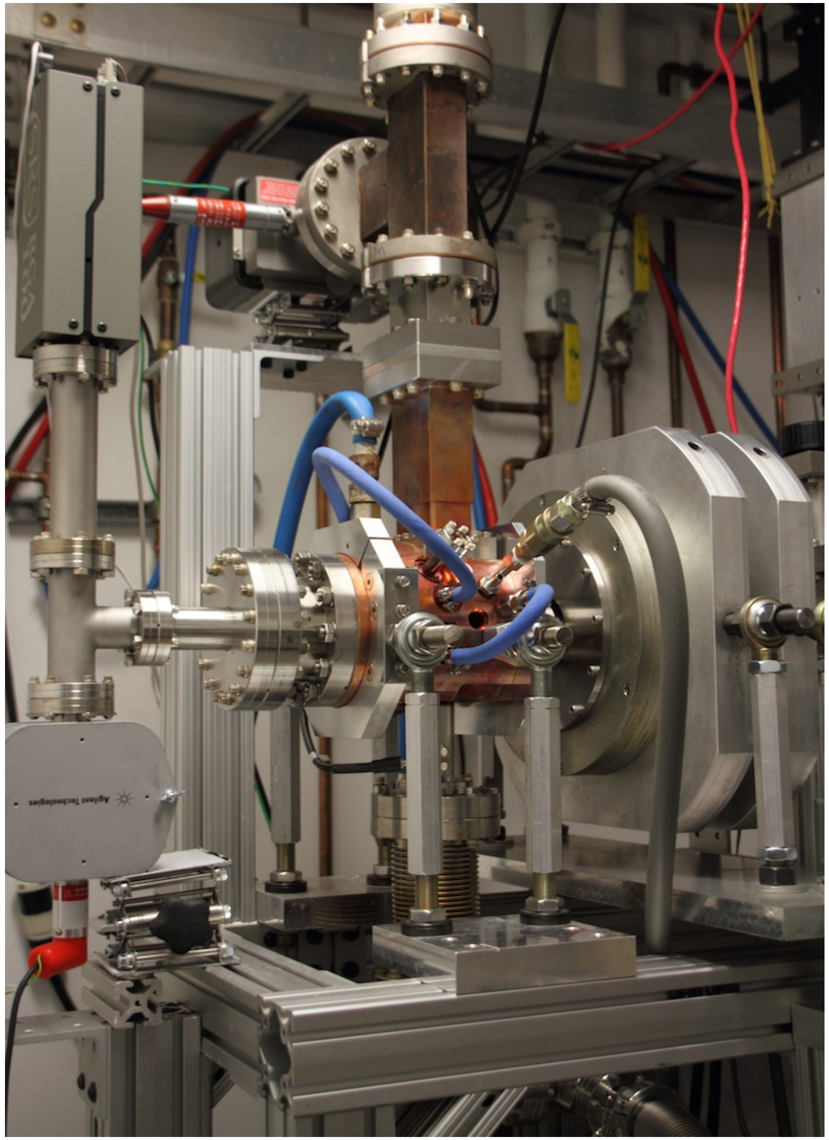
- A redefinition of the priorities inside LNF and an increase in the number of dedicated researchers and technician is an indispensable requirement to keep SPARC_LAB productive.

2014 References

- V. Petrillo et al., Dual color x rays from Thomson or Compton sources, PRST-AB17, 020706 (2014)
- Subiel, A . et al., Dosimetry of very high energy electrons (VHEE) for radiotherapy applications: using radiochromic film measurements and Monte Carlo simulationsPhys. Med. Biol. 59, 5811 (2014)
- Ronsivalle, C, et al., Large-bandwidth two-color free-electron laser driven by a comb-like electron beamNew Journal of Physics 16, 33018 (2014)
- Rossi, Andrea R.., The External-Injection experiment at the SPARC LAB NiM A 740, 60-66 (2014)
- Anania, M. P., et al., Design of a plasma discharge circuit for particle wakefield NIM A 740, 193-196 (2014)
- Pompili, R.., et al., First single-shot and non-intercepting longitudinal bunch diagnostics for comb-like beam by means of Electro-Optic Sampling NIM A 740, 216-221 (2014)
- Massimo, F. et al., Transformer ratio studies for single bunch plasma wakefield acceleration NIM A 740, 242-245 (2014)

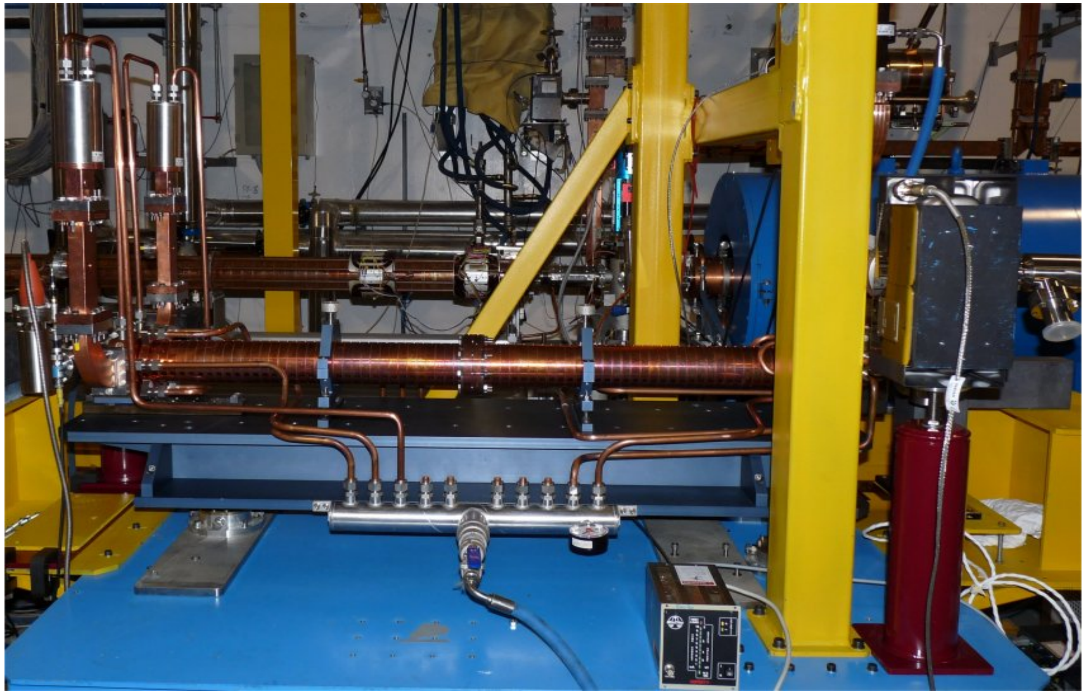
S Band GUN





-fabrication: OK
-tested at UCLA up to 92 MV/m: OK
-small modifications (supports and waveguides) to integrate the GUN into SPARC
(3 months of design and fabrication), 15 days for installation
-**BD simulations necessary prior to the installation**: solenoid position, new solenoid (ELI-NP style)?

C-Band Structures



-both structures tested at high power (35 MV/m reached)

-conditioning of the SKIP-SLED has to be done

-Modifications of C-band support (M. Del Franco): 2 months of design after receiving
information on quadrupoles dismensions. Fabrication time depends on final design.

-15-20 days for installation and alignment