Nuove Tecniche di Accelerazione a SPARC_LAB

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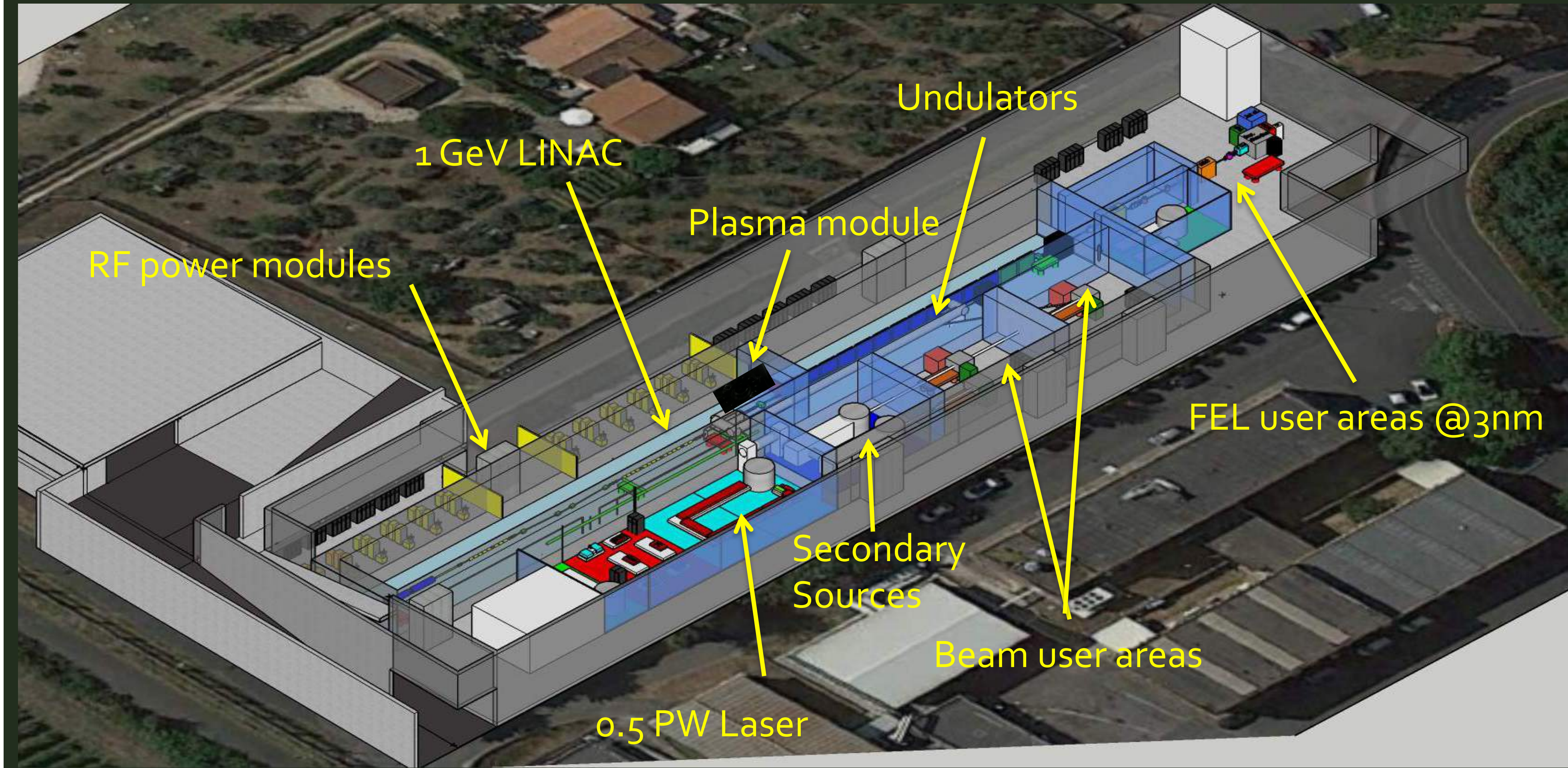
Giornata per Mario Calvetti ed Enrico Iacopini - Firenze 21 Giugno 2018

Future LNF Landscape

EuPRAXIA@SPARC_LAB



http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

D. Alesini[a], M. P. Anania[a], M. Artioli[b], A. Bacci[c], S. Bartocci[d], R. Bedogni[a], M. Bellaveglia[a], A. Biagioni[a], F. Bisesto[a], F. Brandi[e], E. Brentegani[a], F. Broggi[c], B. Buonomo[a], P. Campana[a], G. Campogiani[a], C. Cannaos[d], S. Cantarella[a], F. Cardelli[a], M. Carpanese[f], M. Castellano[a], G. Castorina[g], N. Catalan Lasheras[h], E. Chiadroni[a], A. Cianchi[i], R. Cimino[a], F. Ciocci[f], D. Cirrincione[j], G. A. P. Cirrone[k], R. Clementi[a], M. Coreno[l], R. Corsini[h], M. Croia[a], A. Curcio[a], G. Costa[a], C. Curatolo[c], G. Cuttone[k], S. Dabagov[a], G. Dattoli[f], G. D'Auria[l], I. Debrot[c], M. Diomede[a,g], A. Drago[a], D. Di Giovenale[a], S. Di Mitri[l], G. Di Pirro[a], A. Esposito[a], M. Faiferri[d], M. Ferrario[a], L. Ficcadenti[g], F. Filippi[a], O. Frasciello[a], A. Gallo[a], A. Ghigo[a], L. Giannessi[f,l], A. Giribono[a], L. A. Gizzi[e], A. Grudiev[h], S. Guiducci[a], P. Koester[e], S. Incremona[a], F. Iungo[a], L. Labate[e], A. Latina[h], S. Licciardi[f], V. Lollo[a], S. Lupi[g], R. Manca[d], A. Marcelli[a,m,n], M. Marini[d], A. Marocchino[a], M. Marongiu[g], V. Martinelli[a], C. Masciovecchio[l], C. Mastino[d], A. Michelotti[a], C. Milardi[a], M. Migliorati[g], V. Minicozzi[i], F. Mira[g], S. Morante[i], A. Mostacci[g], F. Nguyen[f], S. Pagnutti[f], L. Palumbo[g], L. Pellegrino[a], A. Petralia[f], V. Petrillo[o], L. Piersanti[a], S. Pioli[a], D. Polese[d], R. Pompili[a], F. Pusceddu[d], A. Ricci[m], R. Ricci[a], R. Rochow[l], S. Romeo[a], J. B. Rosenzweig[p], M. Rossetti Conti[o], A. R. Rossi[c], U. Rotundo[a], L. Sabbatini[a], E. Sabia[f], O. Sans Plannell[a], D. Schulte[h], J. Scifo[a], V. Scuderi[k], L. Serafini[c], B. Spataro[a], A. Stecchi[a], A. Stella[a], V. Shpakov[a], F. Stellato[i], P. Tomassini[e], E. Turco[d], C. Vaccarezza[a], A. Vacchi[j], A. Vannozzi[a], G. Vantaggiato[e], A. Variola[a], S. Vescovi[a], F. Villa[a], W. Wuensch[h], A. Zigler[q], M. Zobov[a]

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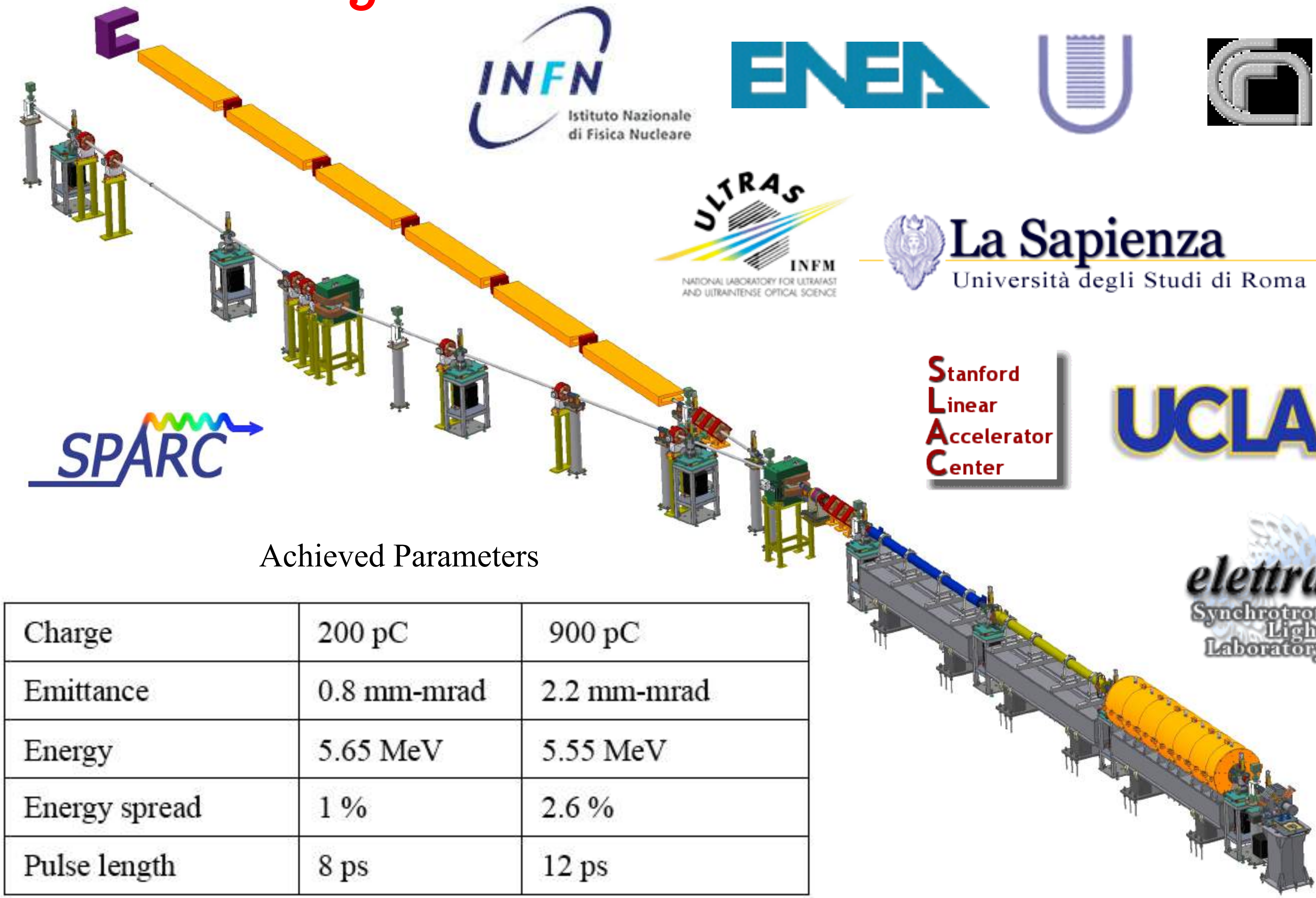
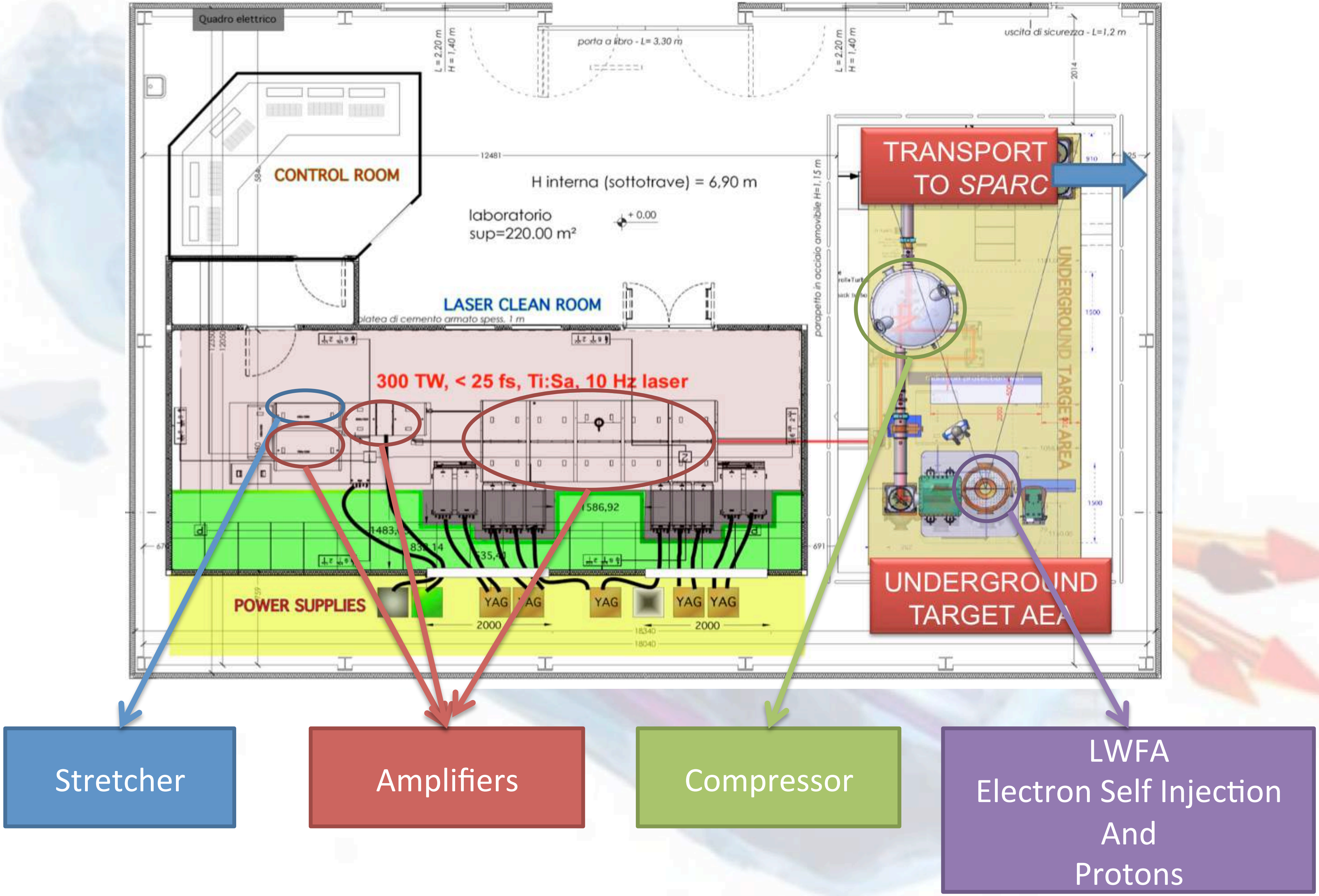
SPARC Injector + FEL



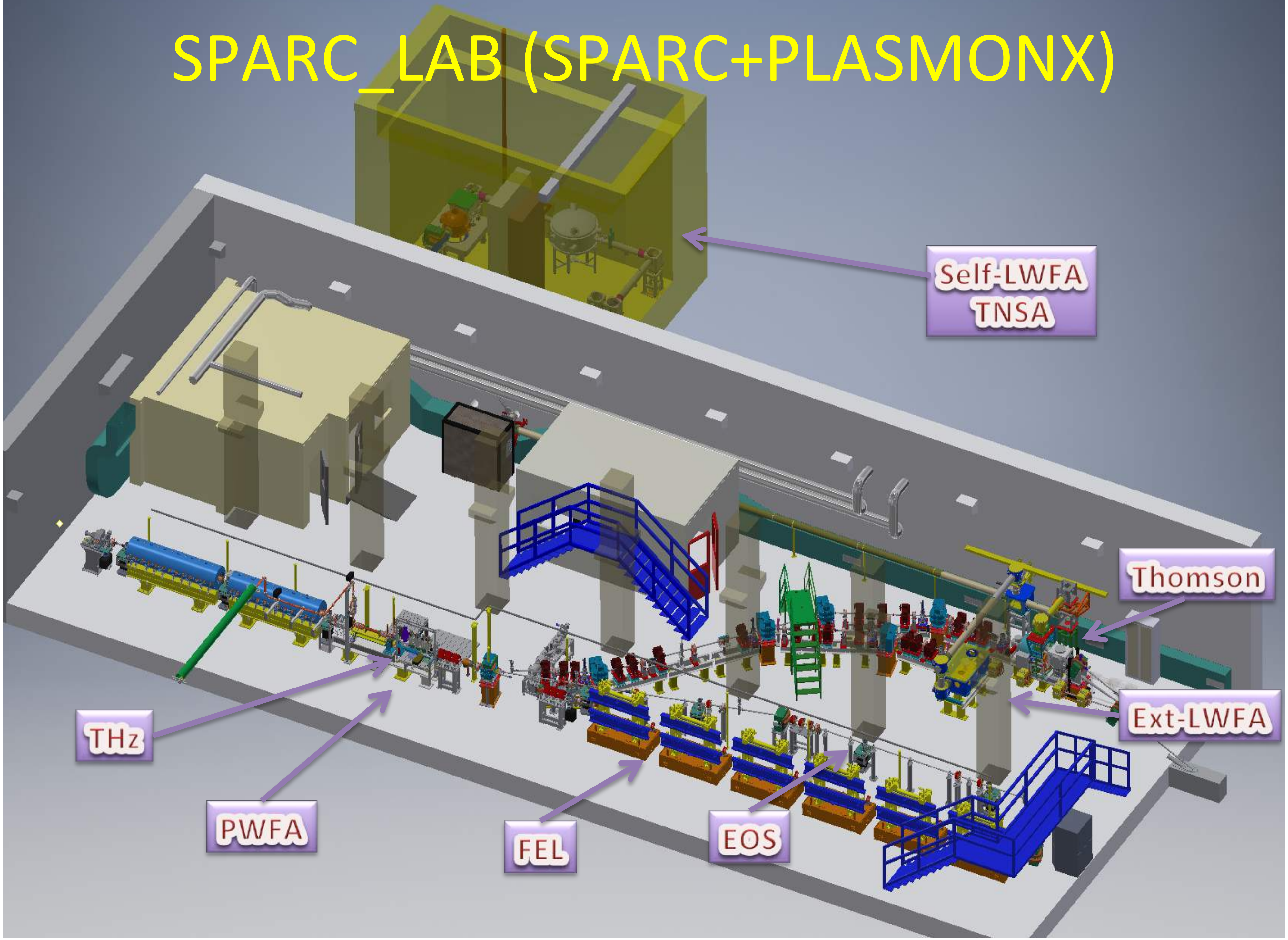
Achieved Parameters

Charge	200 pC	900 pC
Emittance	0.8 mm-mrad	2.2 mm-mrad
Energy	5.65 MeV	5.55 MeV
Energy spread	1 %	2.6 %
Pulse length	8 ps	12 ps

Ti:Sa FLAME laser (PLASMONX)



SPARC_LAB (SPARC+PLASMONX)



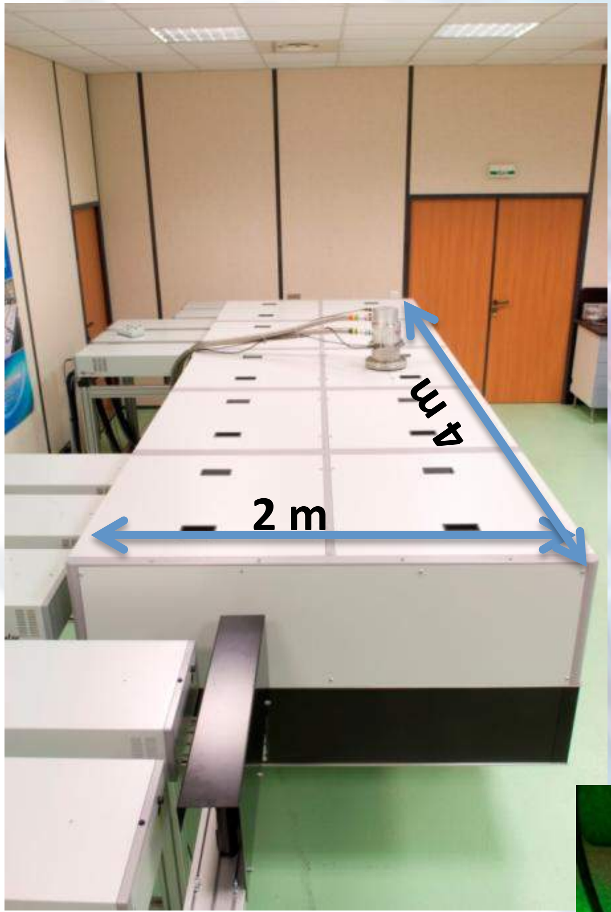
Il laser FLAME

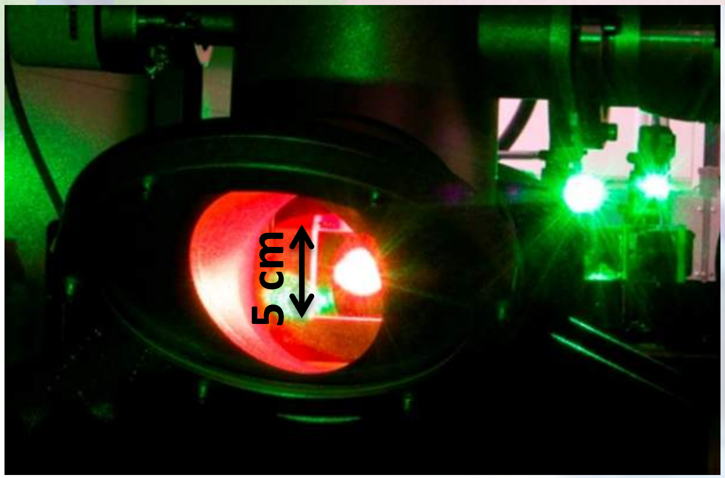
Frascati Laser for Acceleration and Multi-disciplinary Experiments

Il progetto su LWFA con self-injection a FLAME è stato istituito nel 2004 da una estesa collaborazione. Un technical design report è seguito all'intenso lavoro precursore di ricerca e sviluppo sull'interazione laser-plasma con gas-jet e LWFA all'Intense Laser Lab (CNR-Pisa), LOA (Palaiseau) e CEA (Saclay).

INFN Units: Pisa, Bologna, LNF-Frascati, Napoli, Roma1, LNS-Catania

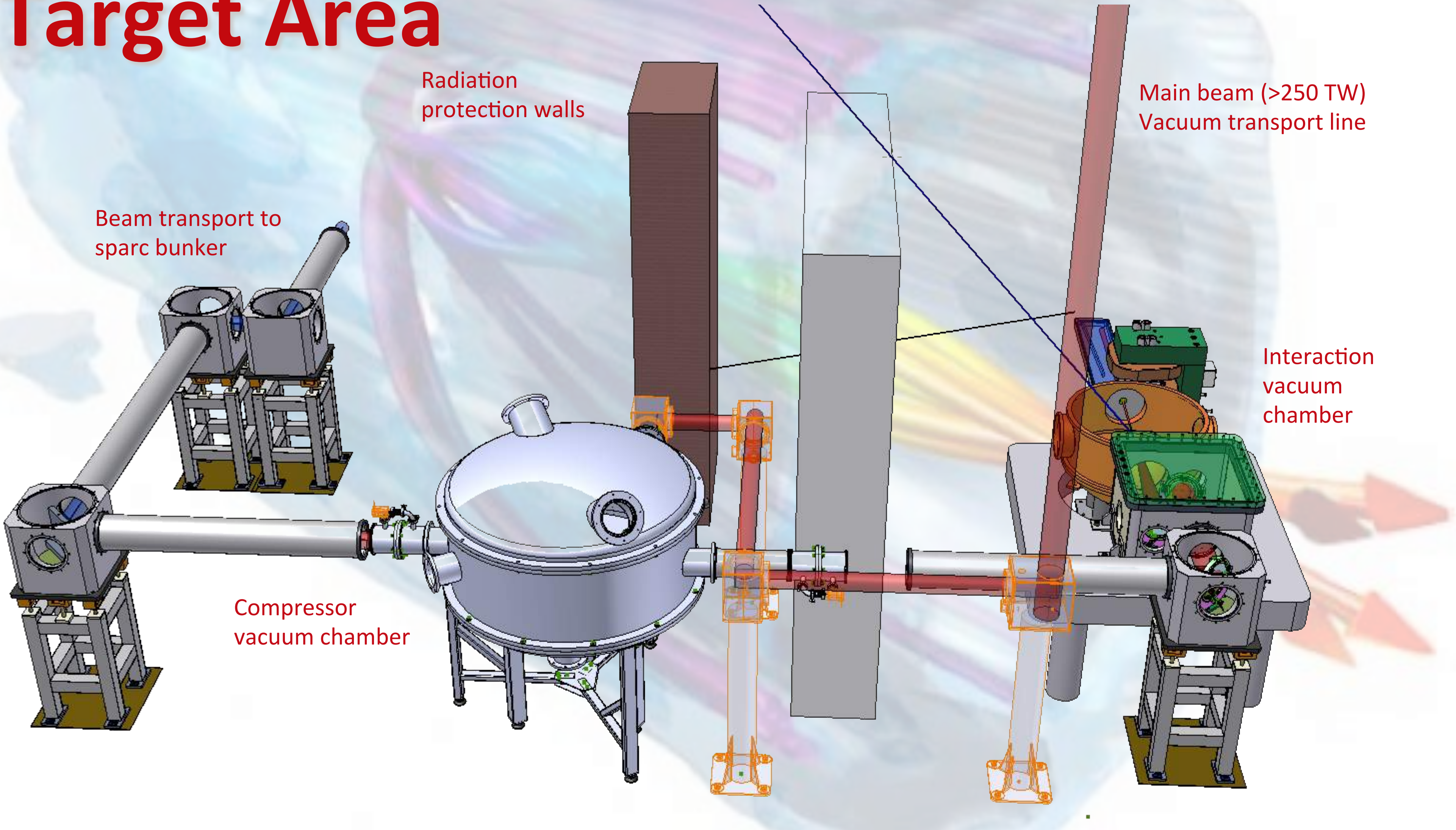
Il laser FLAME



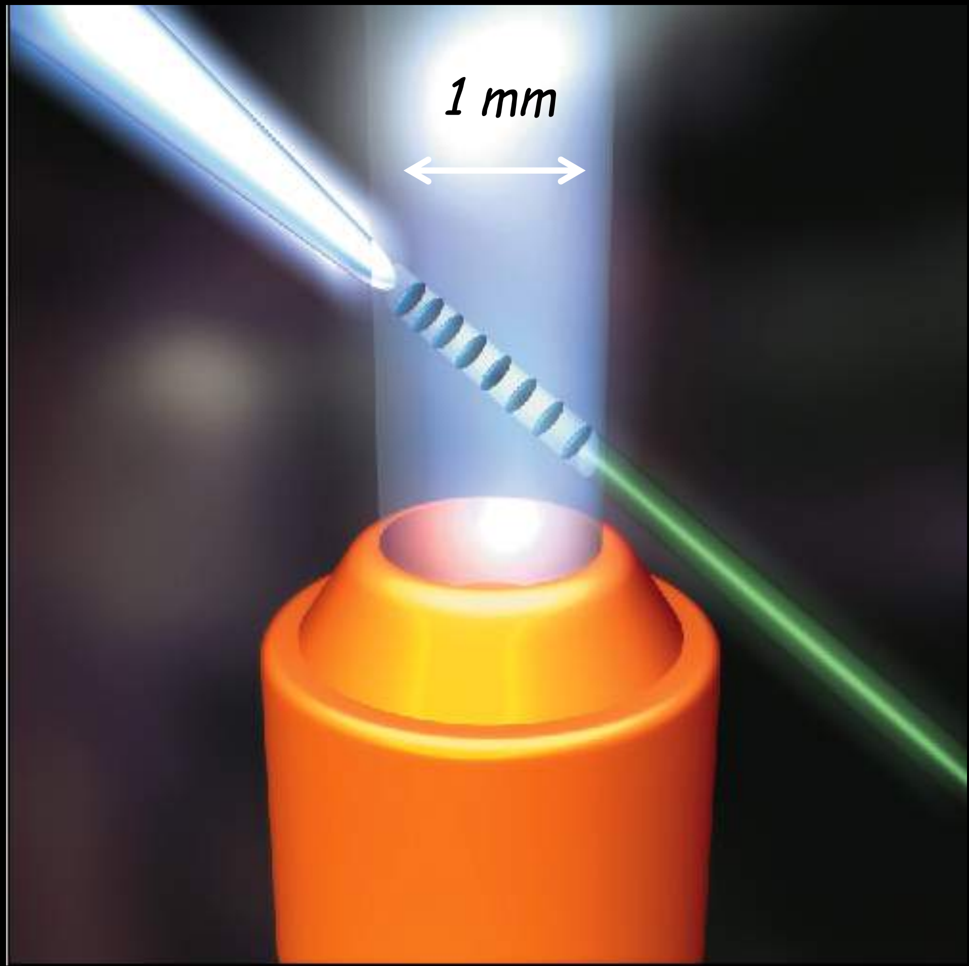


Esperimenti di auto-iniezione

Target Area



Direct production of e-beam

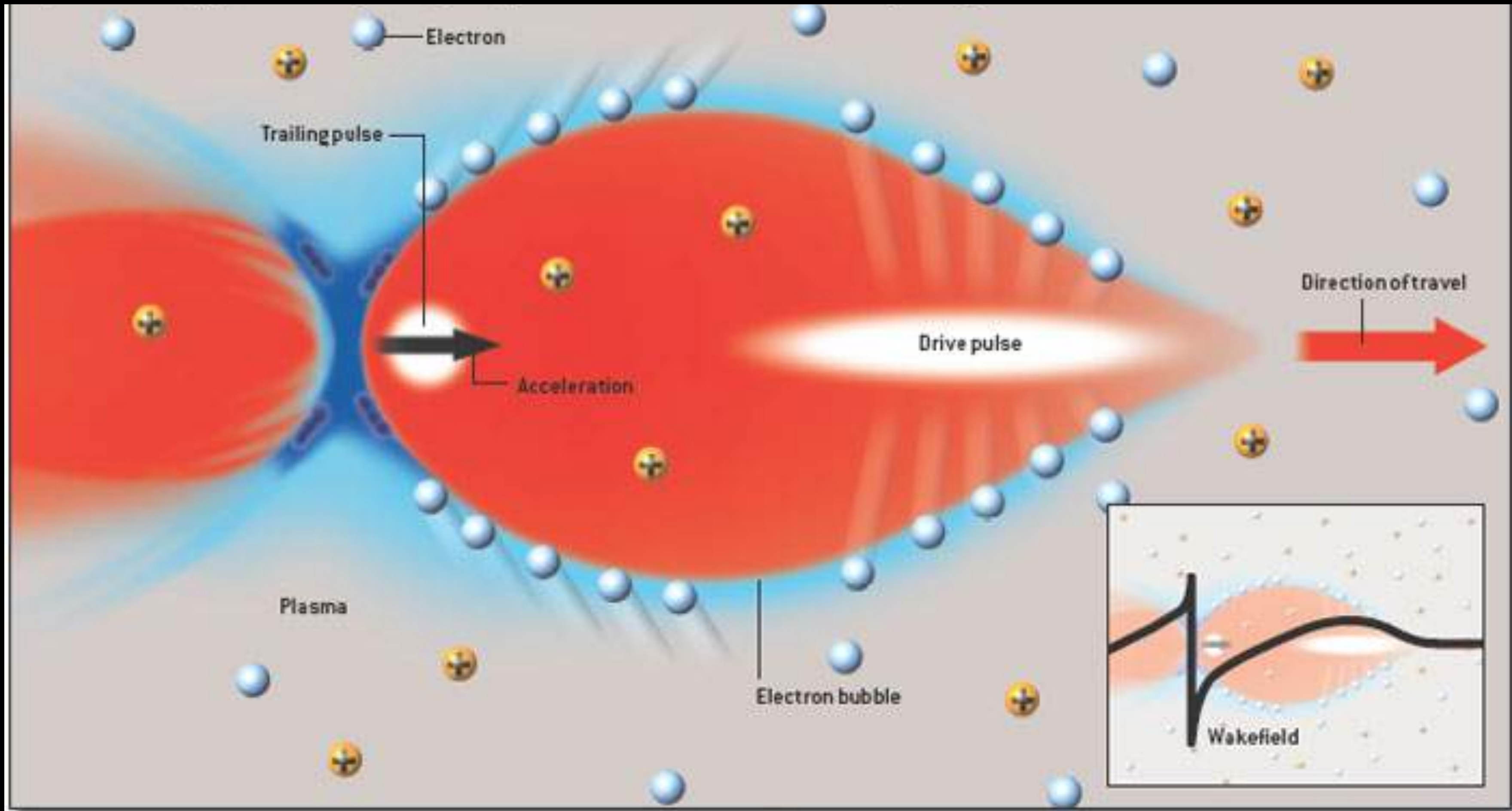


Electron beam

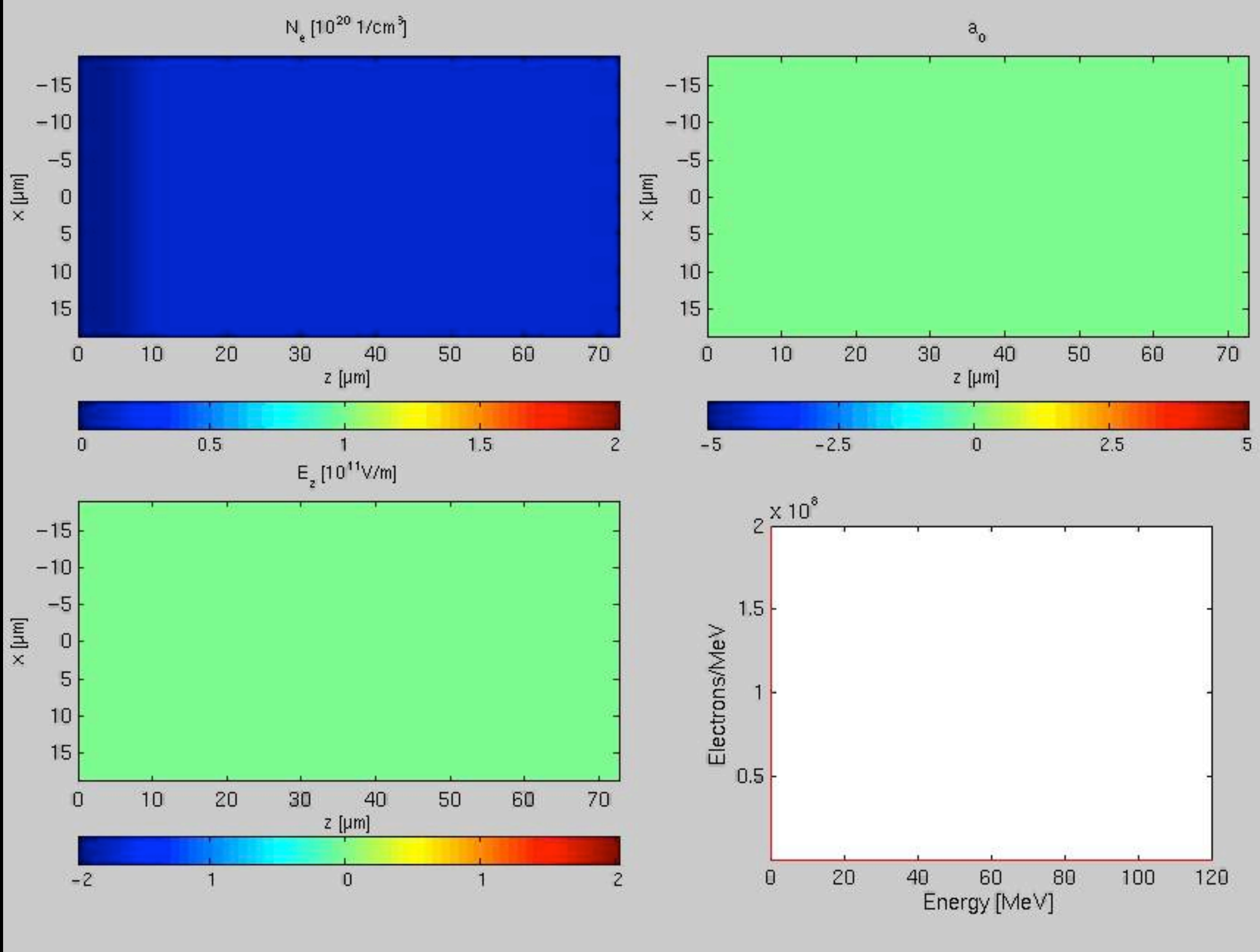
VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024
(Received 9 March 1979)



$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$



N_e [10^20 1/cm^3]
x [μm]
z [μm]
a_0
E_z [10^11 V/m]
x 10^8
Electrons/MeV
Energy [MeV]

FLAME RESULTS

- Plasma accelerators studies

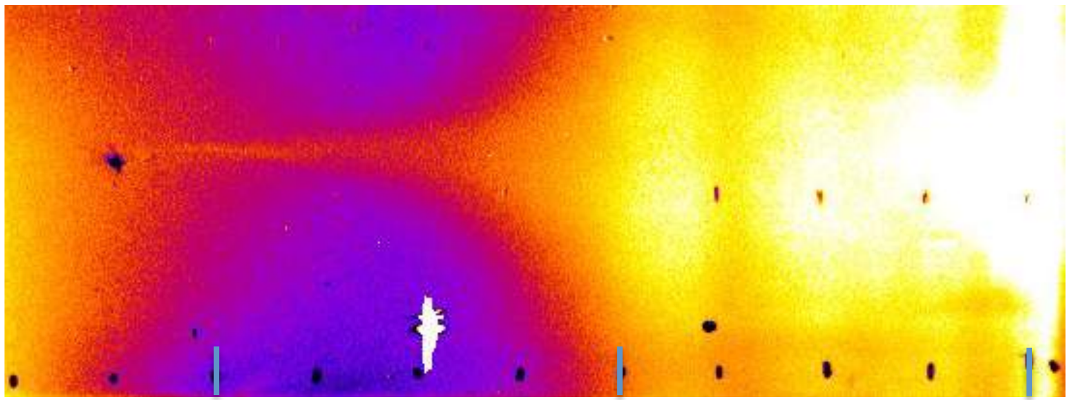
E_{laser}= 2J Laser length= 35-40 fs.

Accelerating length ≈ 2 mm (gas-jet)

E_{e-}= 350 MeV

Divergence = few mrad

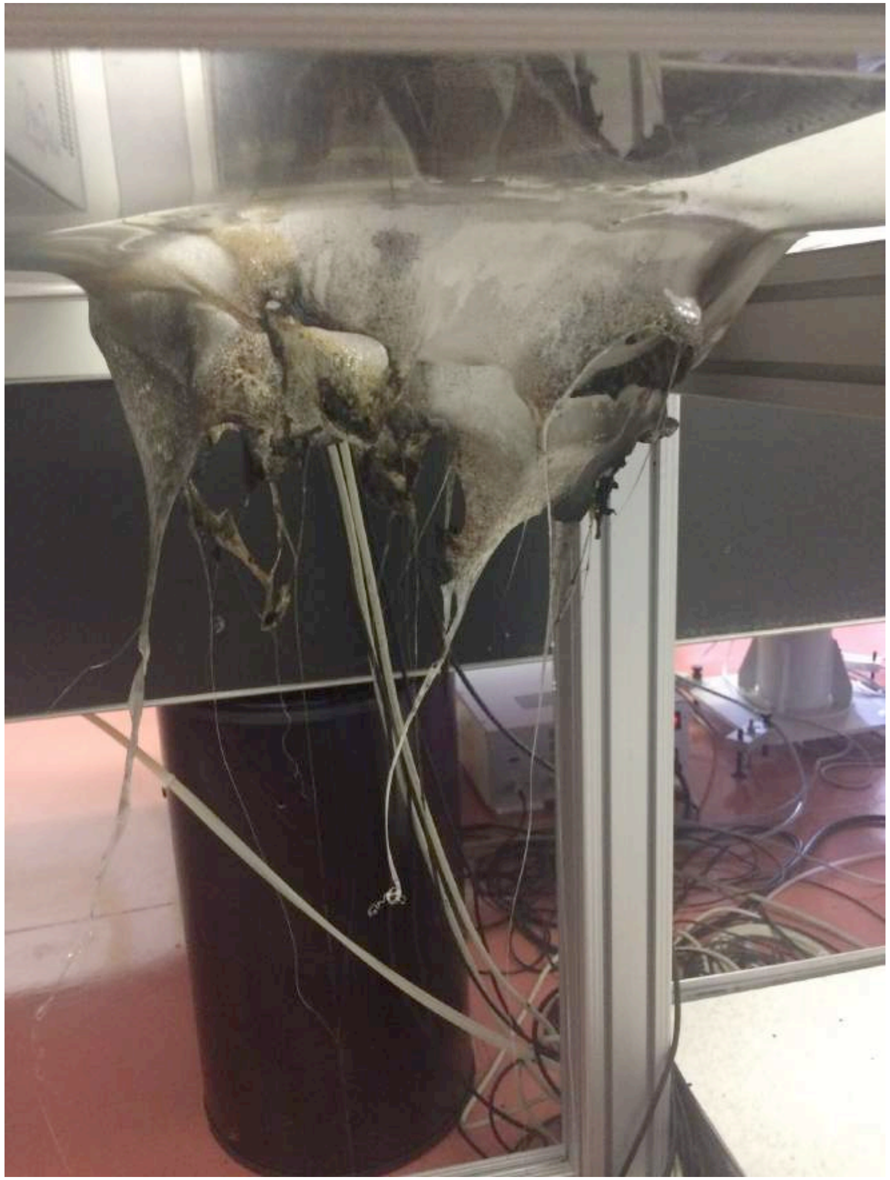
Integrated accelerating field ≈ 200 GV/m.



350 MeV 100 MeV 50 MeV

FLAME in FIAMME

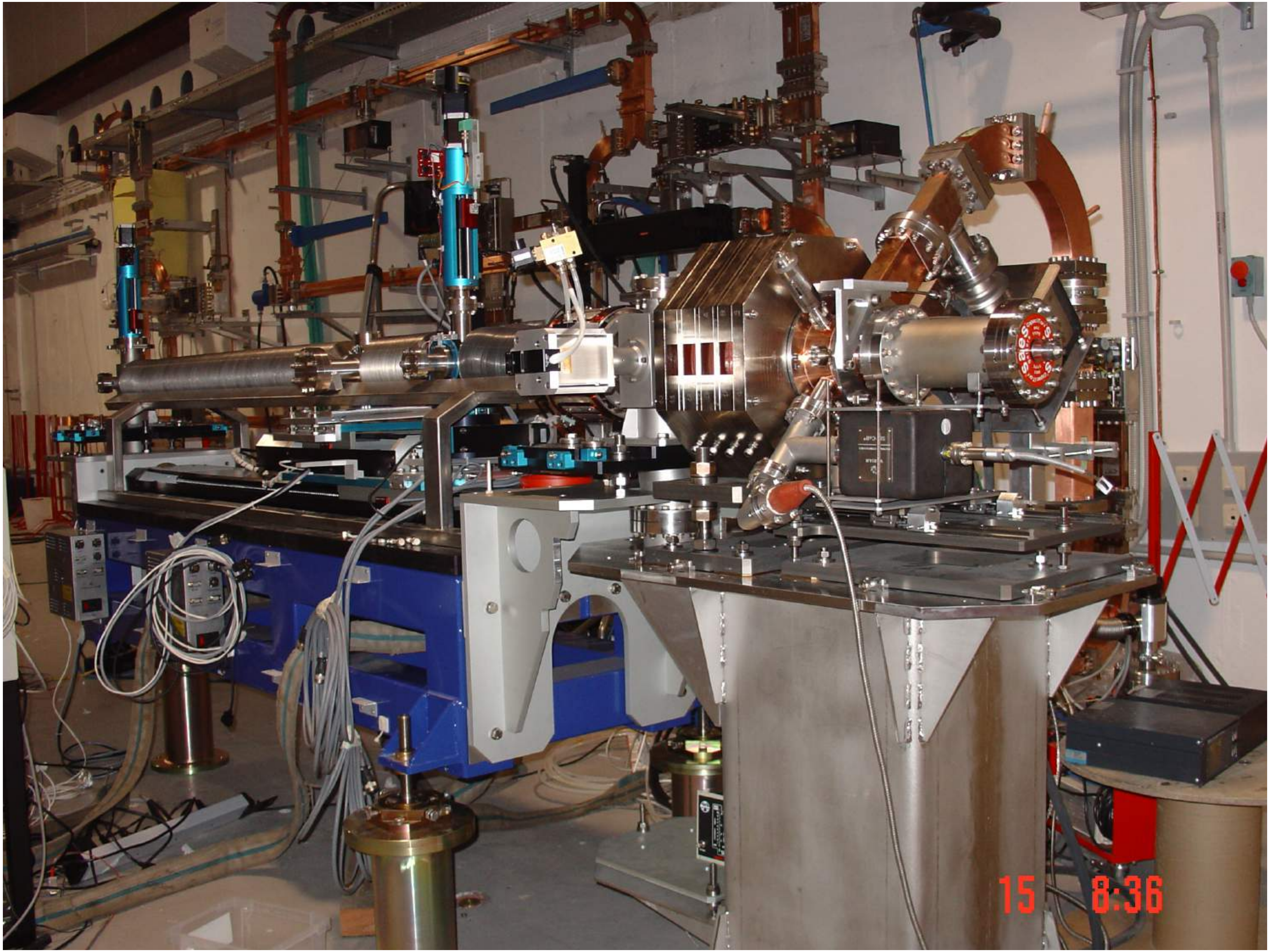
A fire accident has stopped suddenly FLAME operations…. **October 2016**



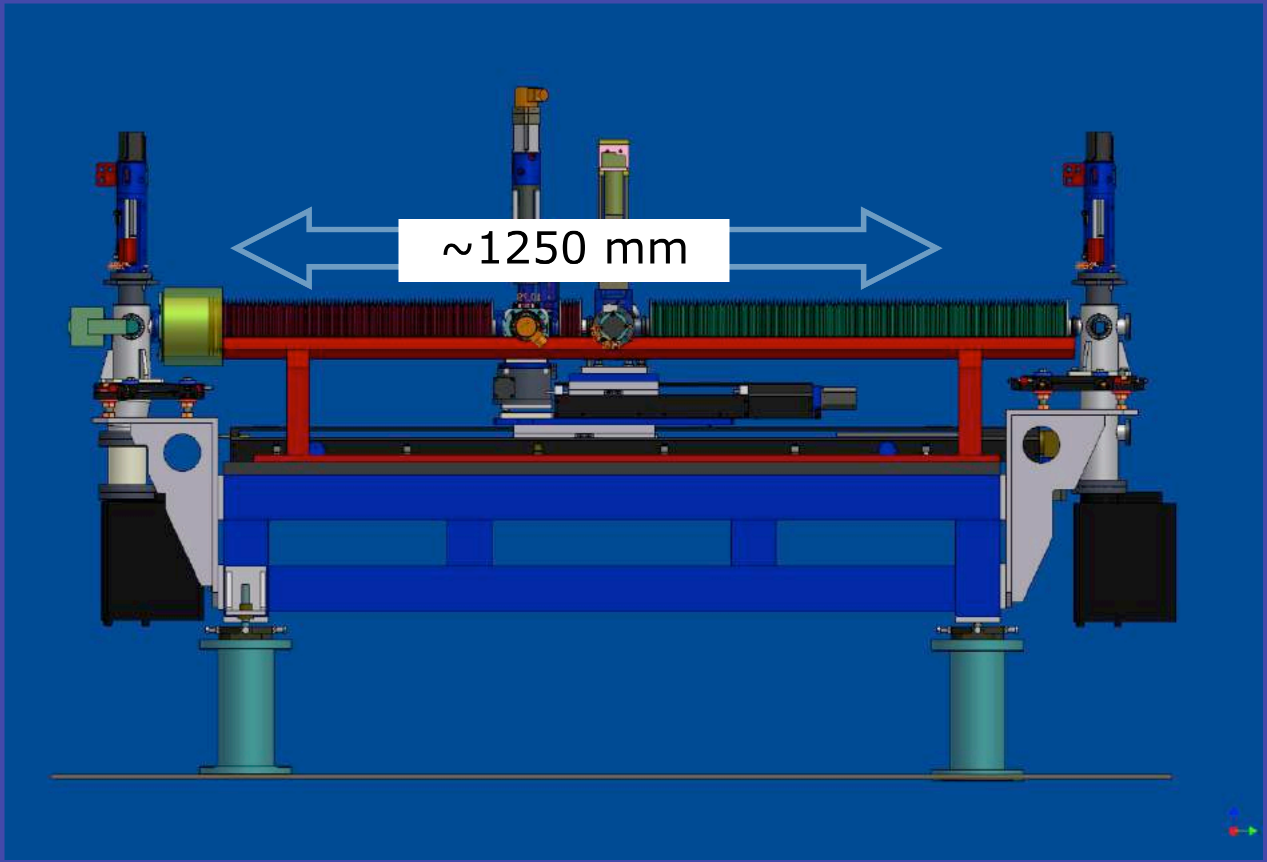
Ti:Sa FLAME laser

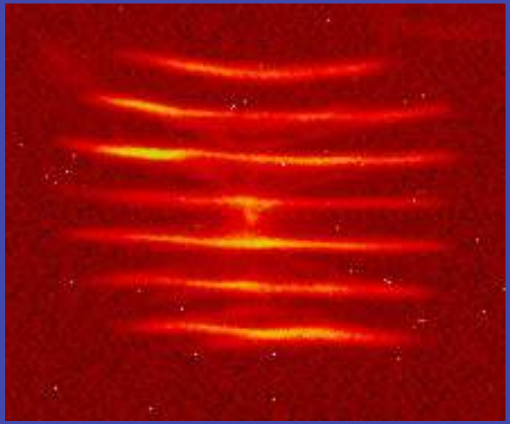
Final amplification stage from ~600 mJ to 6J

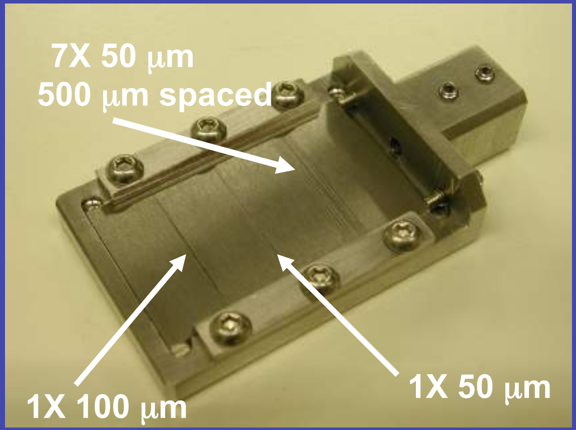
Energy	6 J
Duration	23 fs
Wavelength	800 nm
Bandwidth	60/80 nm
Spot @ focus	10 µm
Peak Power	300 TW
Contrast Ratio	10^{10}


15 8:36

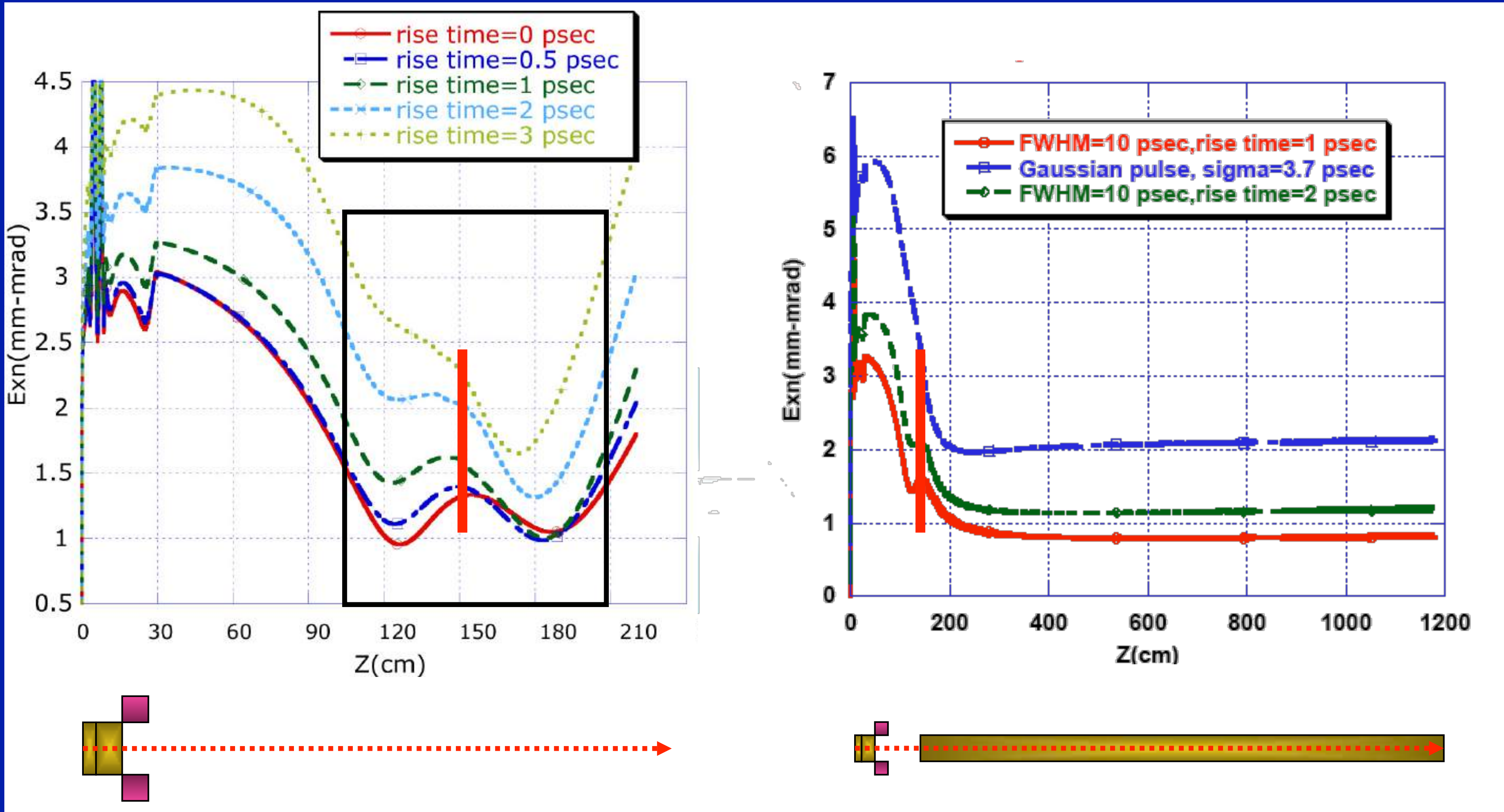
The SPARC Emittance Meter







Emittance evolution for different pulse shapes



Optimum injection in to the linac with:

$$\sigma' = 0$$

$$\gamma' = \frac{eE_{acc}}{mc^2} = \frac{2}{\sigma}\sqrt{\frac{I}{2\gamma I_A}}$$

PRL 99, 234801 (2007) PHYSICAL REVIEW LETTERS week ending 7 DECEMBER 2007

Direct Measurement of the Double Emittance Minimum in the Beam Dynamics of the Sparc High-Brightness Photoinjector

M. Ferrario,[1] D. Alesini,[1] A. Bacci,[3] M. Bellaveglia,[1] R. Boni,[1] M. Boscolo,[1] M. Castellano,[1] L. Catani,[2] E. Chiadroni,[1] S. Cialdi,[3] A. Cianchi,[2] A. Clozza,[1] L. Cultrera,[1] G. Di Pirro,[1] A. Drago,[1] A. Esposito,[1] L. Ficcadenti,[5] D. Filippetto,[1] V. Fusco,[1] A. Gallo,[1] G. Gatti,[1] A. Ghigo,[1] L. Giannessi,[4] C. Ligi,[1] M. Mattioli,[7] M. Migliorati,[5] A. Mostacci,[5] P. Musumeci,[6] E. Pace,[1] L. Palumbo,[5] L. Pellegrino,[1] M. Petrarca,[7] M. Quattromini,[4] R. Ricci,[1] C. Ronsivalle,[4] J. Rosenzweig,[6] A. R. Rossi,[3] C. Sanelli,[1] L. Serafini,[3] M. Serio,[1] F. Sgamma,[1] B. Spataro,[1] F. Tazzioli,[1] S. Tomassini,[1] C. Vaccarezza,[1] M. Vescovi,[1] and C. Vicario[1]

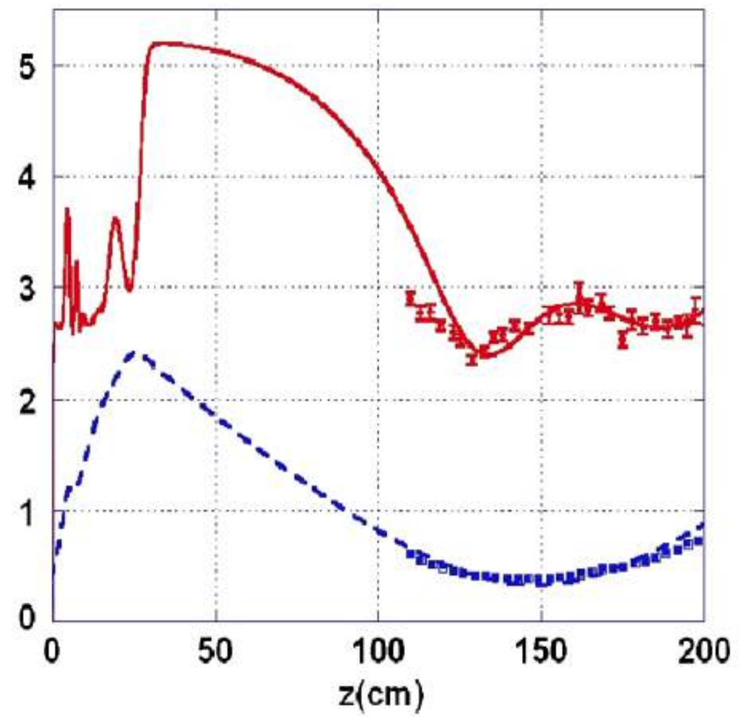
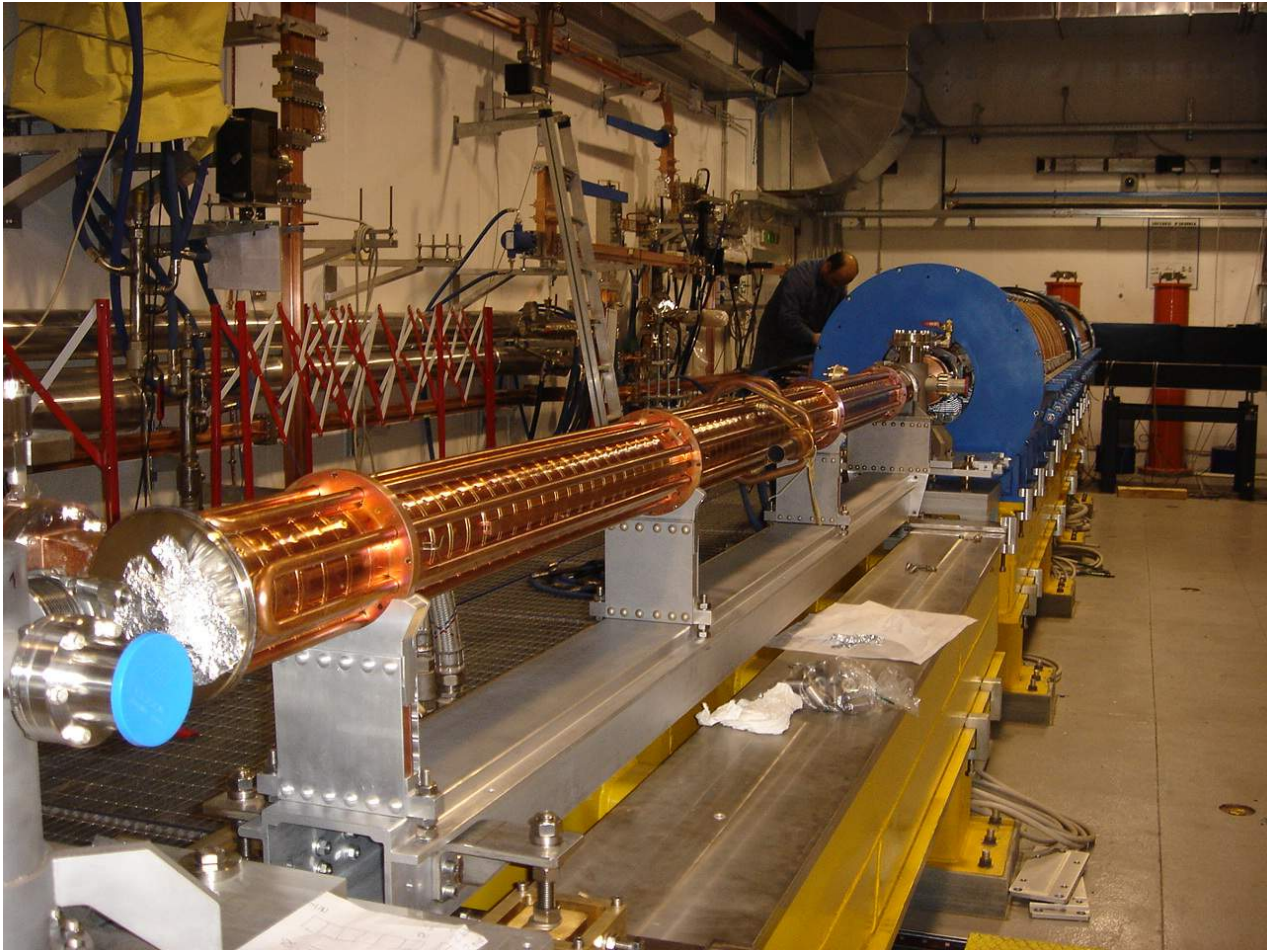
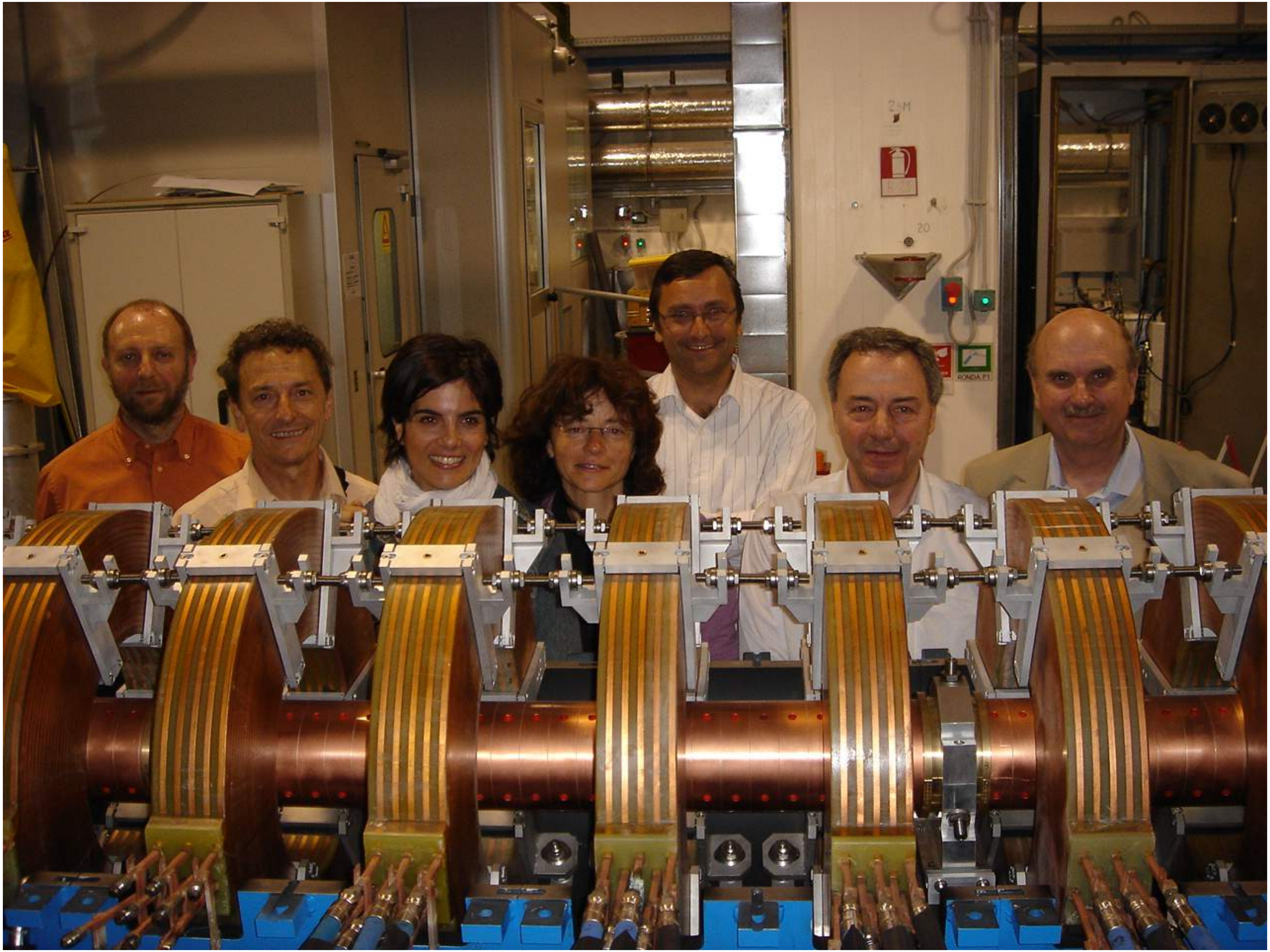
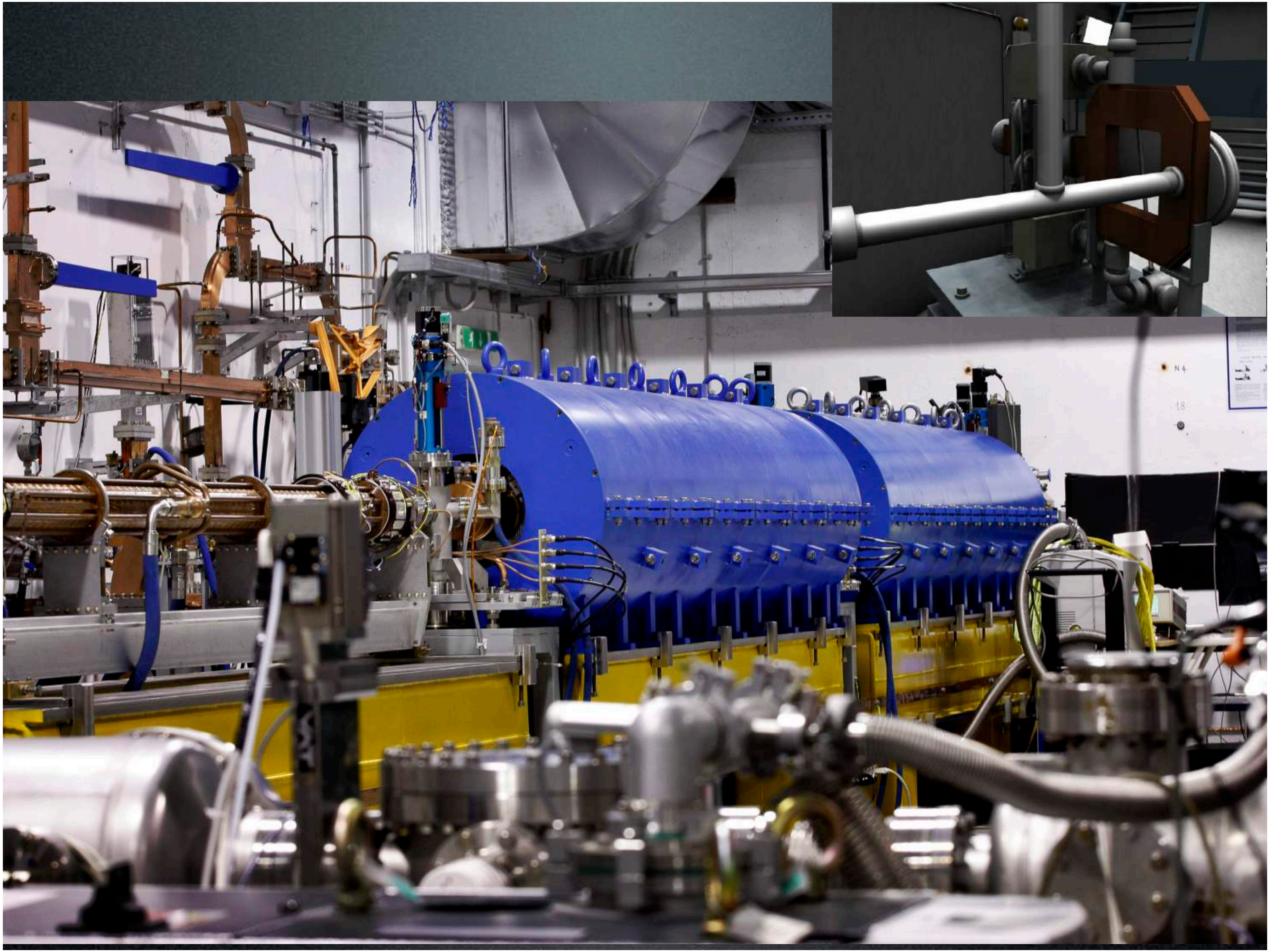


FIG. 6 (color online). rms envelope and rms norm. emittance evolution from the cathode up to the beam line end as computed by PARMELA, compared to measurements taken in the emittance-meter range.



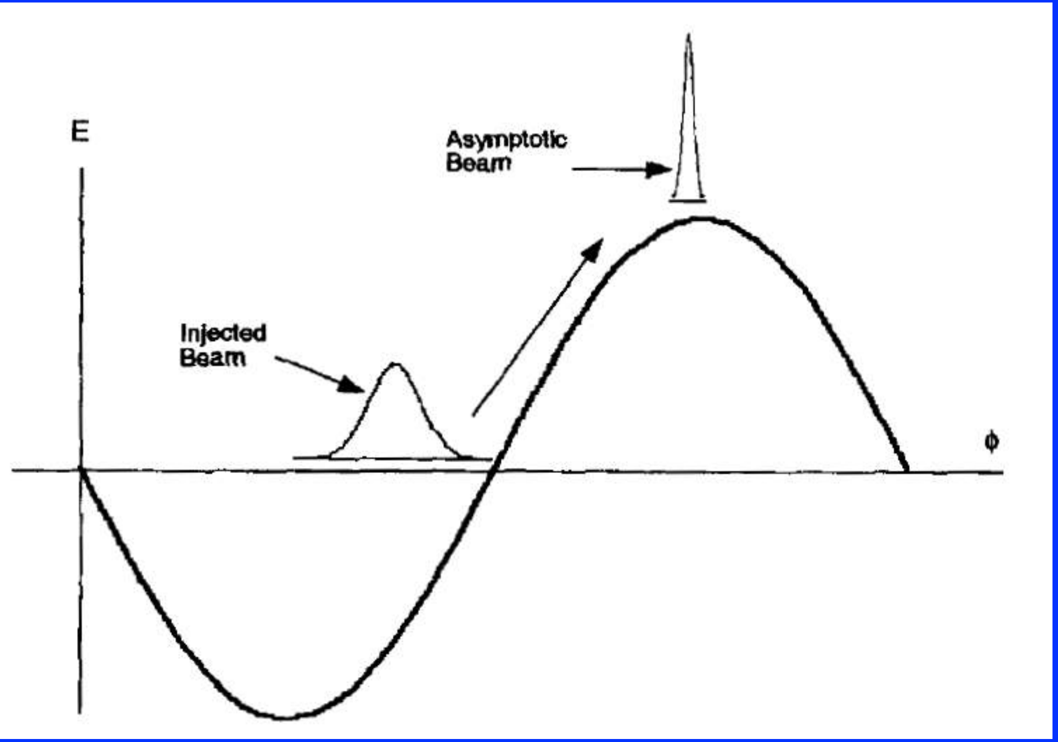




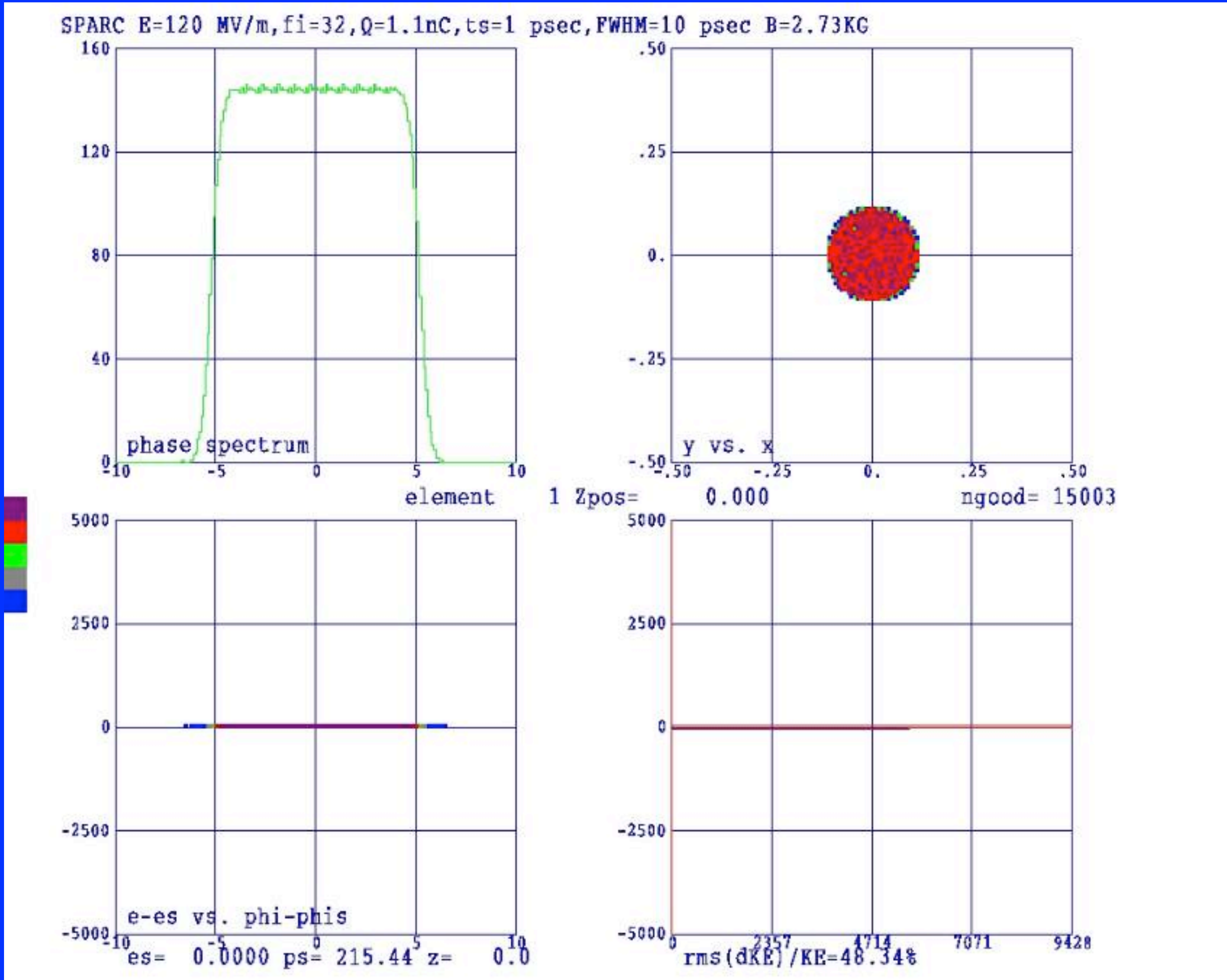
Velocity bunching concept (RF Compressor)

If the beam injected in a long accelerating structure at the crossing field phase and it is slightly slower than the phase velocity of the RF wave , it will slip back to phases where the field is accelerating, but at the same time it will be chirped and compressed.

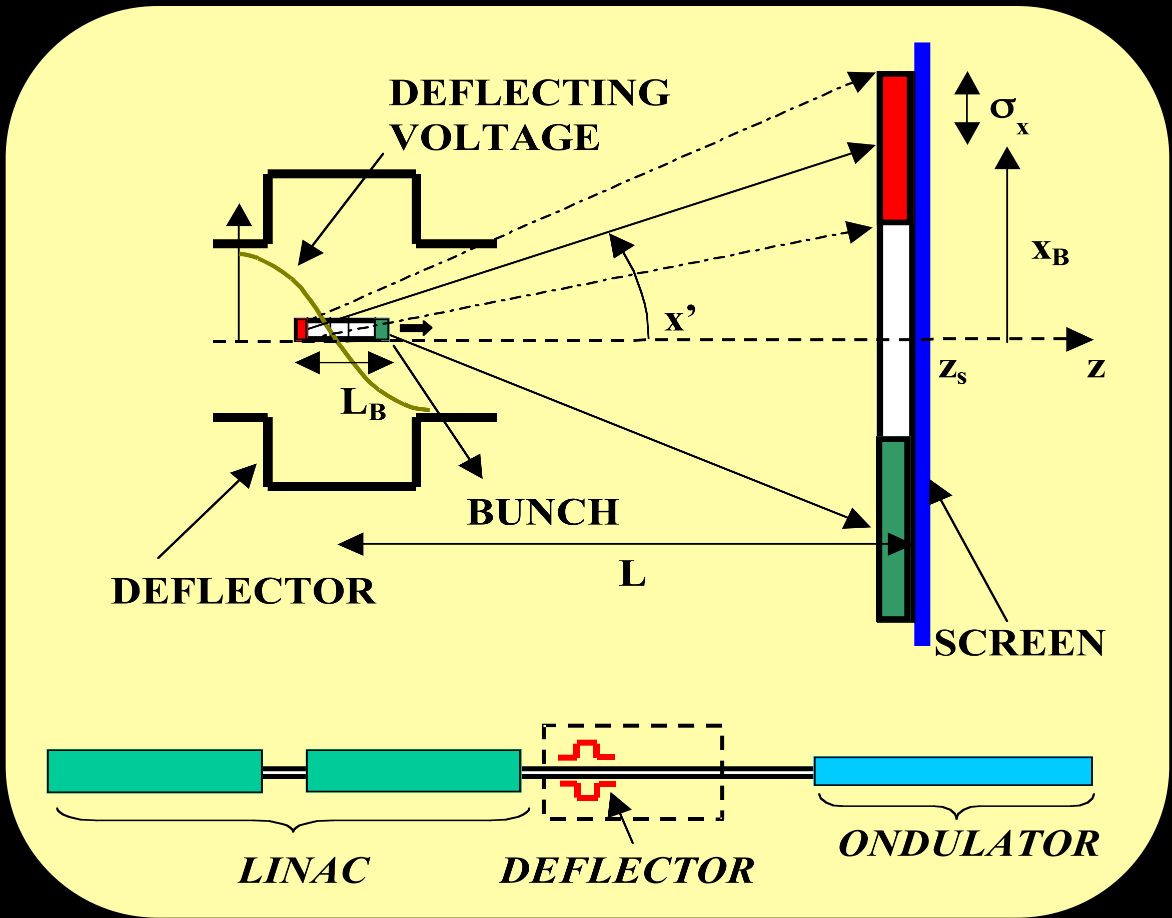
$$\varphi_o = -90$$
$$\varphi = 0$$



The key point is that compression and acceleration take place at the same time within the same linac section, actually the first section following the gun, that typically accelerates the beam, under these conditions, from a few MeV (> 4) up to 25-35 MeV.

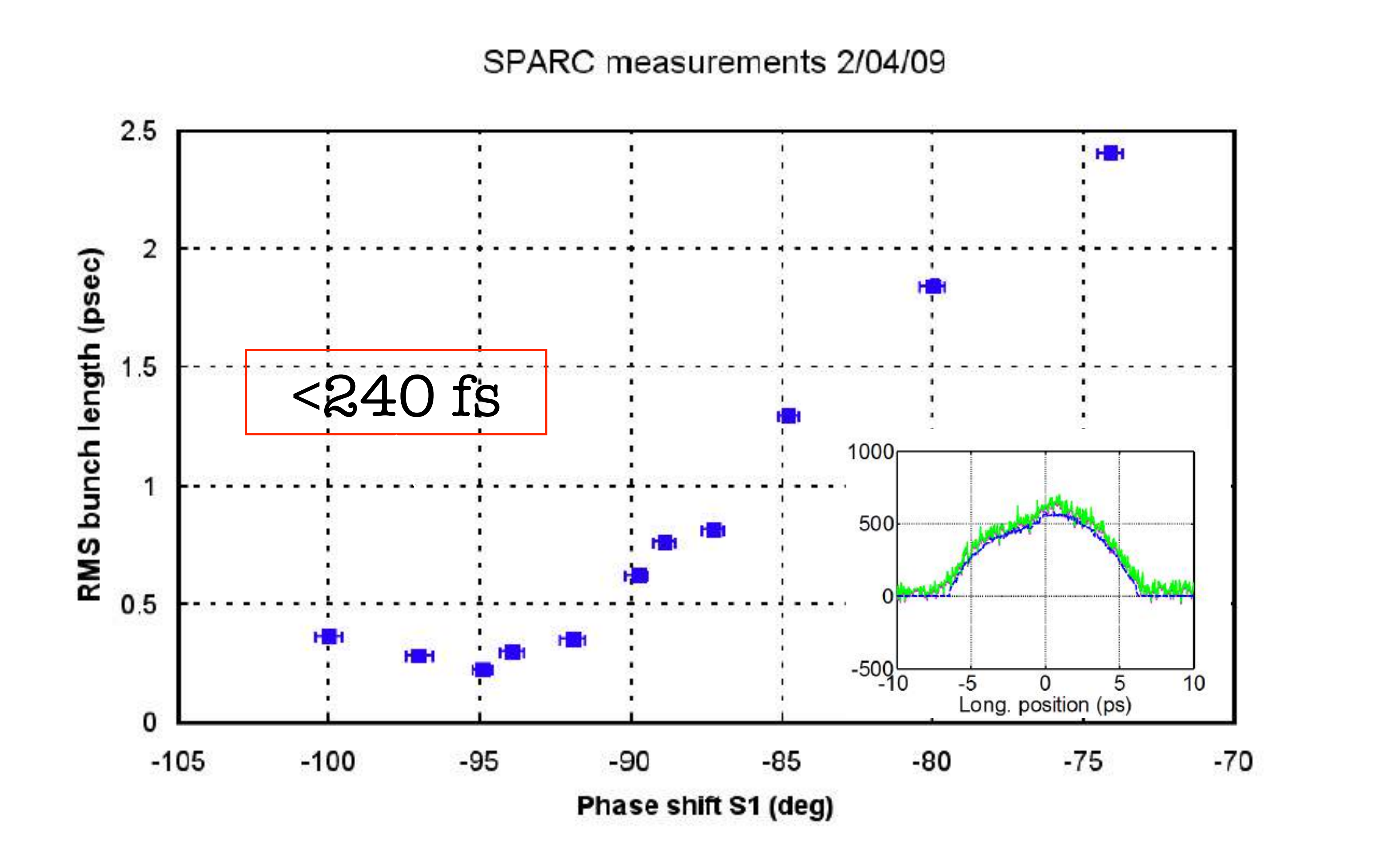

SPARC E=120 MV/m,fi=32,Q=1.1nC,ts=1 psec,FWHM=10 psec B=2.73KG
phase spectrum
y vs. x
element 1 Zpos= 0.000
ngood= 15003
e-es vs. phi-phis
es= 0.0000 ps= 215.44 z= 0.0
rms(dKE)/KE=48.34%

Bunch length measurement (RF Deflector)



$$x_B = \frac{\pi\ f_{RF} L L_B V_\perp}{cE/e}$$

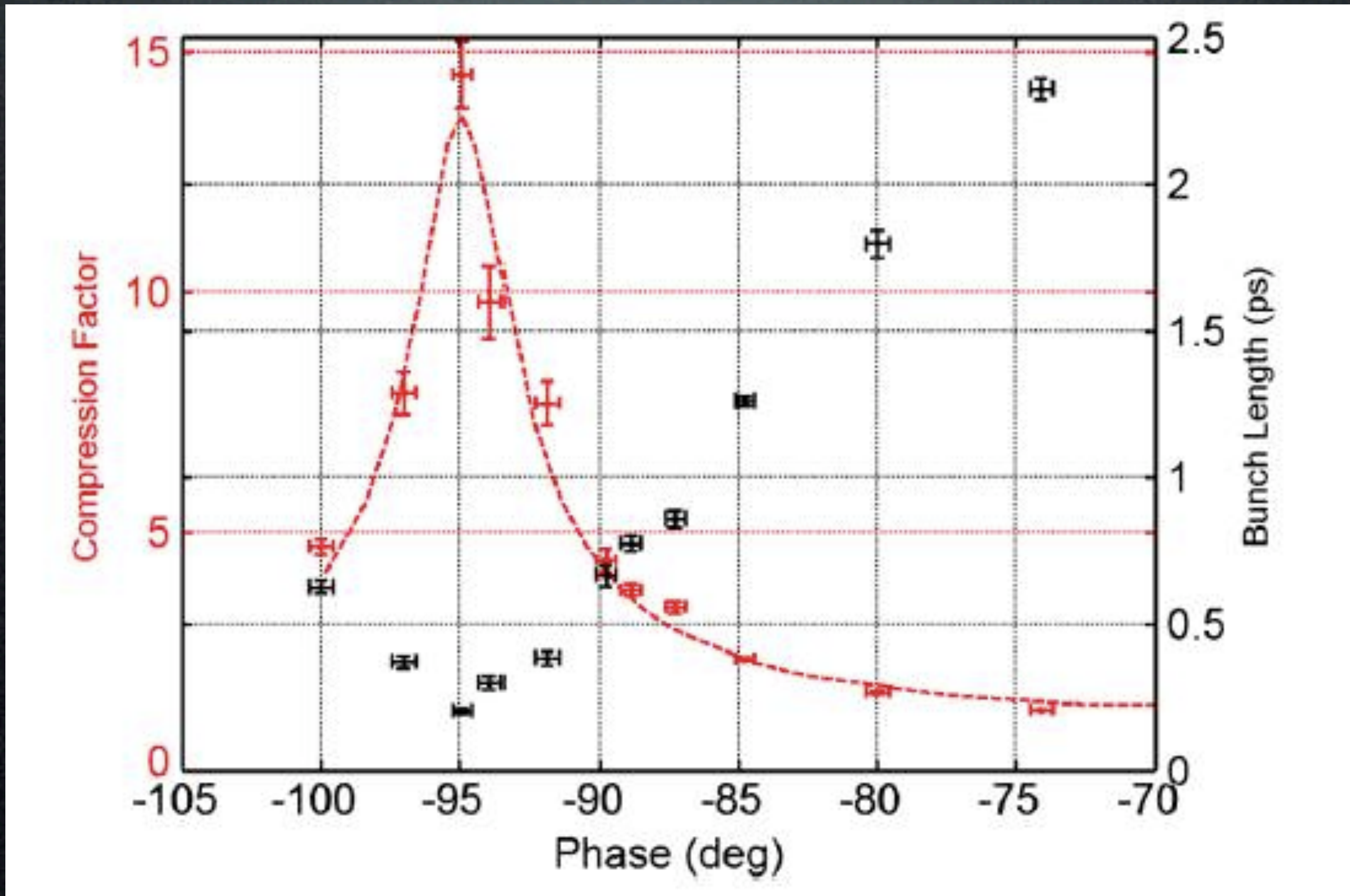
Pulse length versus Velocity Bunching phase

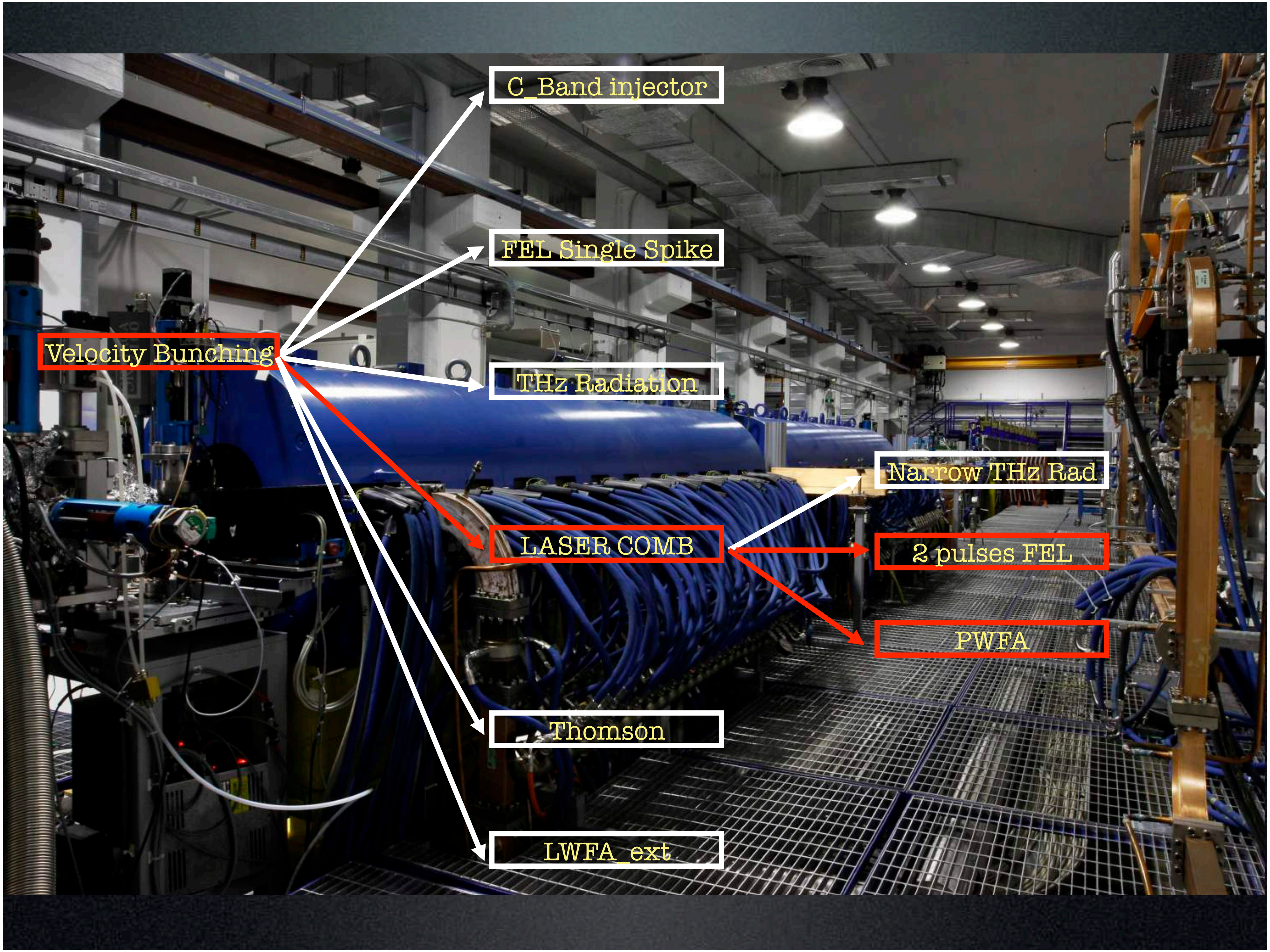


PRL 104, 054801 (2010) PHYSICAL REVIEW LETTERS week ending 5 FEBRUARY 2010

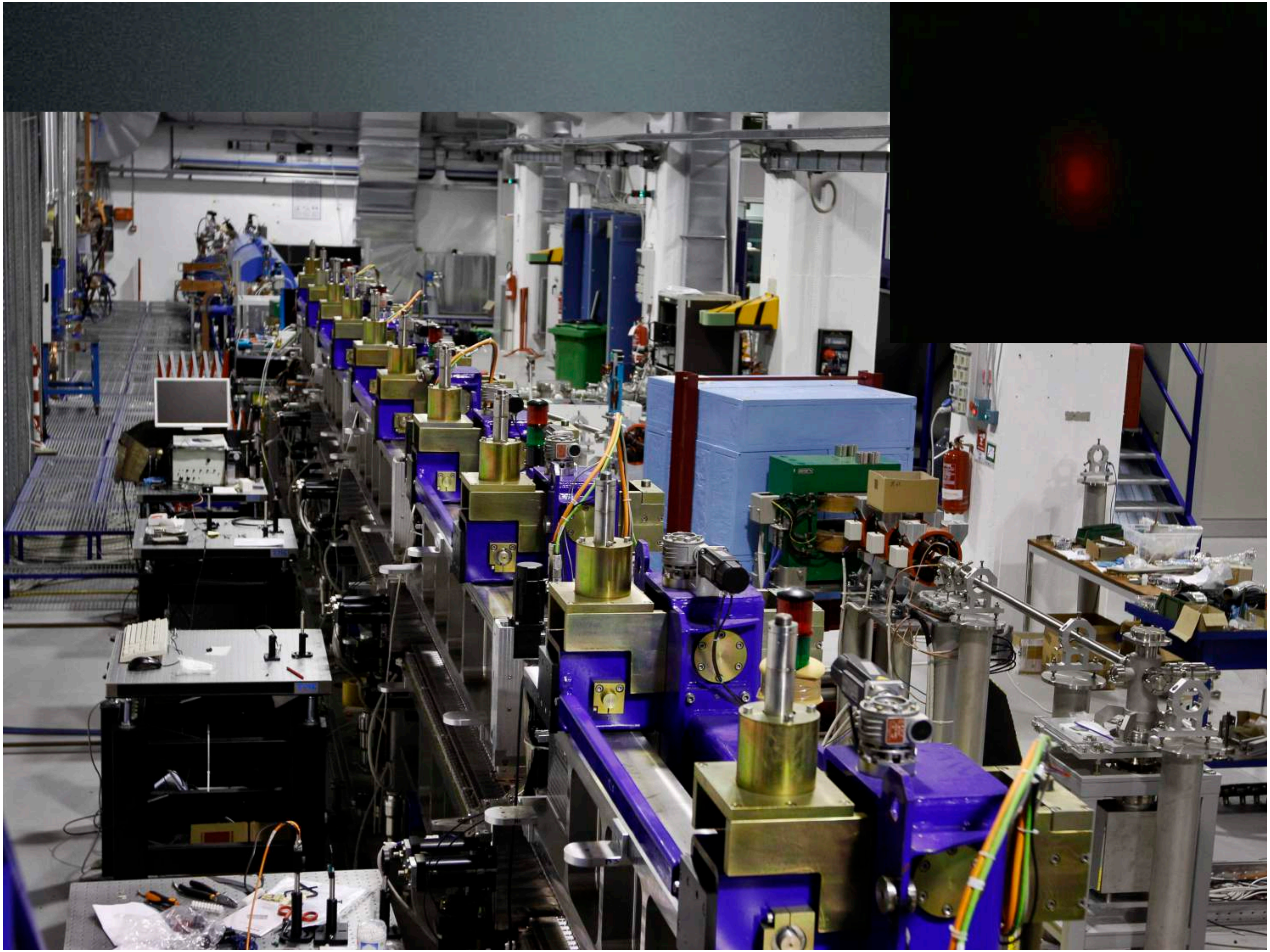
Experimental Demonstration of Emittance Compensation with Velocity Bunching

M. Ferrario,[1] D. Alesini,[1] A. Bacci,[3] M. Bellaveglia,[1] R. Boni,[1] M. Boscolo,[1] M. Castellano,[1] E. Chiadroni,[1] A. Cianchi,[2] L. Cultrera,[1] G. Di Pirro,[1] L. Ficcadenti,[1] D. Filippetto,[1] V. Fusco,[1] A. Gallo,[1] G. Gatti,[1] L. Giannessi,[4] M. Labat,[4] B. Marchetti,[2] C. Marrelli,[1] M. Migliorati,[1] A. Mostacci,[1] E. Pace,[1] L. Palumbo,[1] M. Quattromini,[4] C. Ronsivalle,[4] A. R. Rossi,[3] J. Rosenzweig,[5] L. Serafini,[3] M. Serluca,[6] B. Spataro,[1] C. Vaccarezza,[1] and C. Vicario[1]

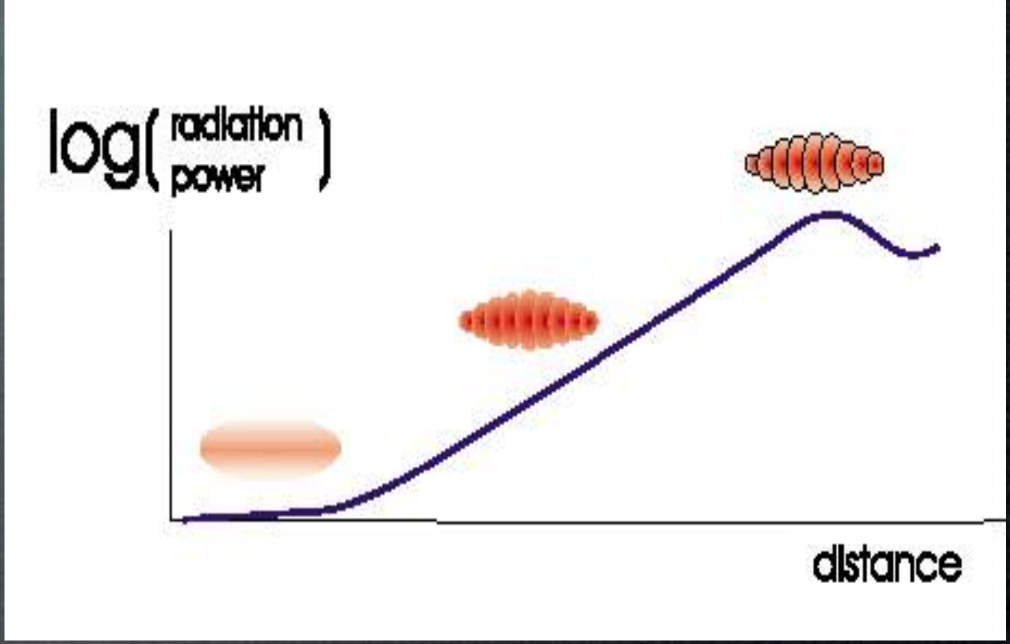




C_Band injector
FEL Single Spike
Velocity Bunching
THz Radiation
Narrow THz Rad
LASER COMB
2 pulses FEL
PWFA
Thomson
LWFA_ext



A Free Electron Laser is a device that converts a fraction of the electron kinetic energy into coherent radiation via a collective instability in a long undulator

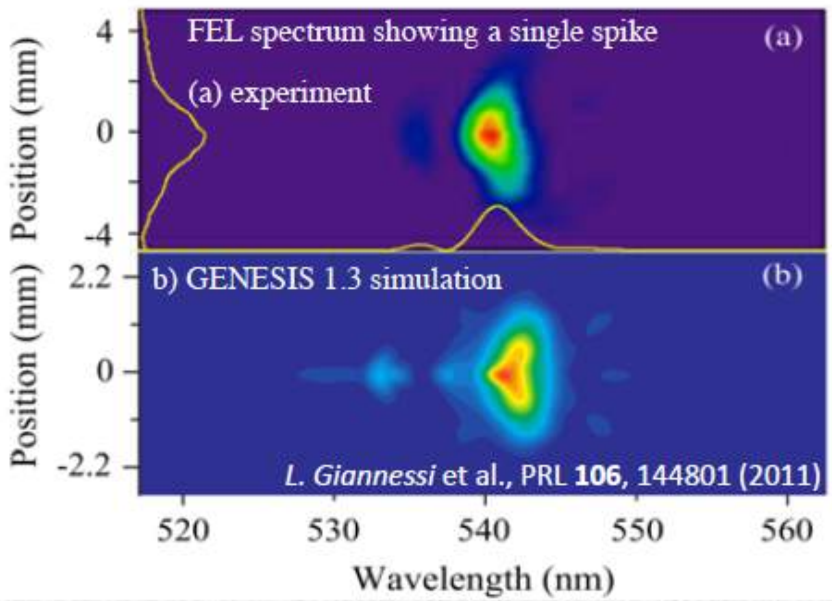


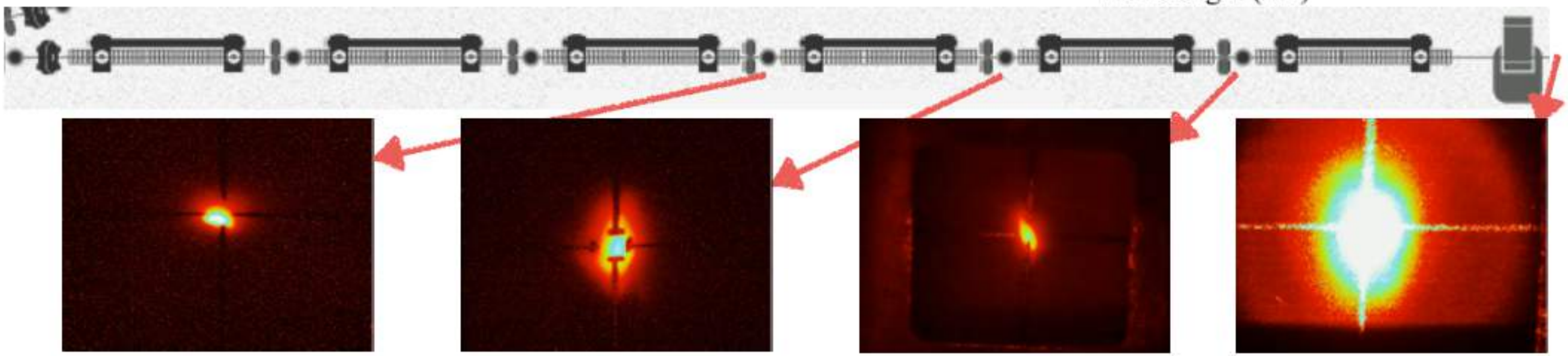
$$\lambda_{rad} \approx \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\vartheta^2\right)$$

(Tunability - Harmonics)

SPARC_LAB Achievements

- First experimental observation of emittance oscillation in a drift at low energy
  - Working point adopted in many photo-injector based user facilities
    - *Ferrario's working point*
- **SASE FEL exponential gain in single spike**





Electron beam image on view screens while the gap is closing. Weak FEL radiation already after the third module.

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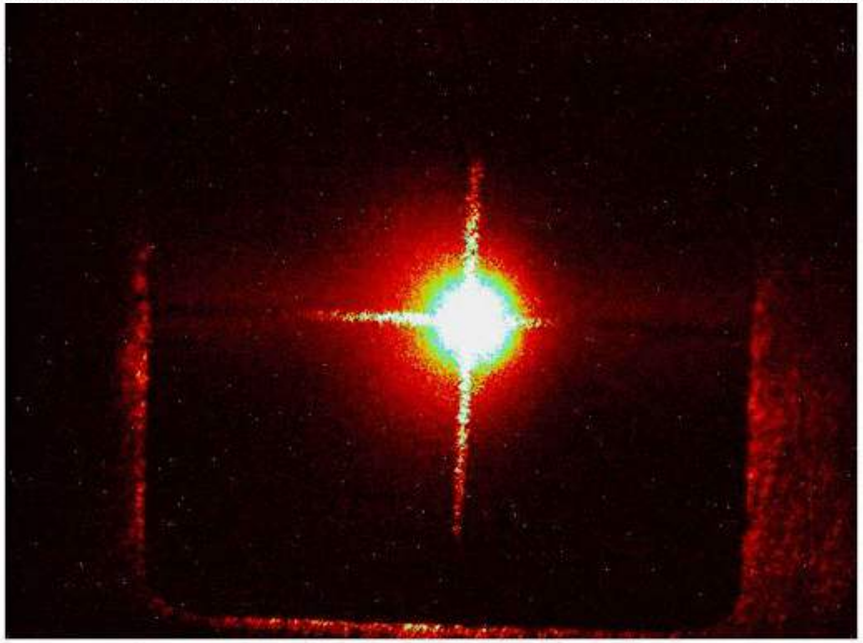
Single Spike FEL

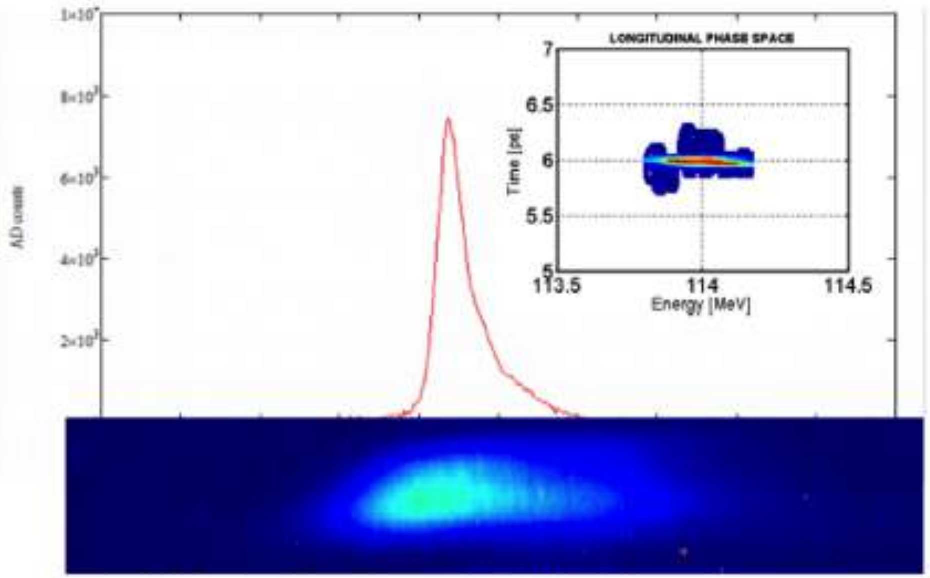
Short bunches compared to FEL Cooperation Length, have been sent into the SPARC FEL in the SASE regime **and Single Spike** behaviour lasing has been observed.

Bunch parameters

Charge (pC)	Energy (MeV)	Energy Spread (%)	Duration (fs)	Emittance (μm)	Peak current (A)
20	114	0.1	26	1.2	400



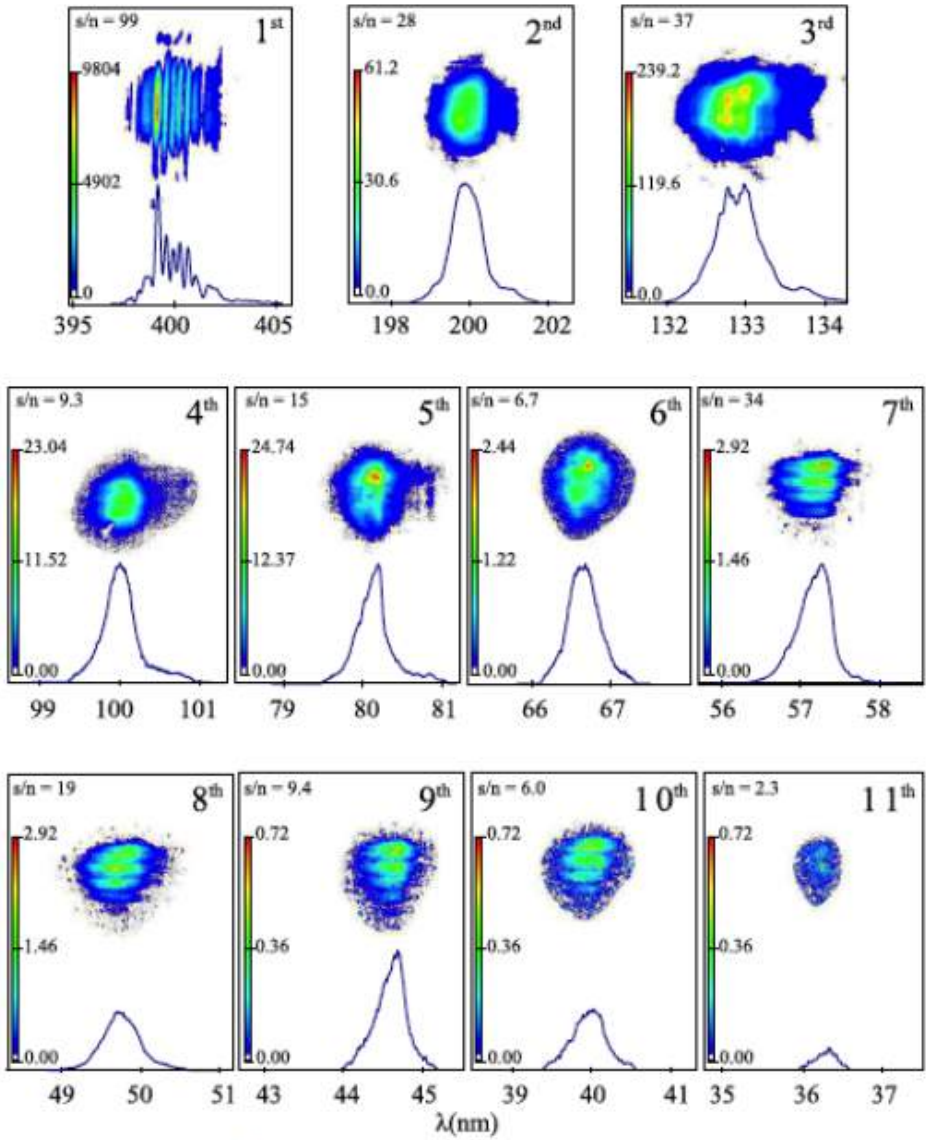
Single-spike FEL means high quality ultra-short beam!



Collected FEL light, 100 fs (rms), 40 μJ

SPARC_LAB Achievements

- First experimental observation of emittance oscillation in a drift at low energy
  - Working point adopted in many photo-injector based user facilities
    - *Ferrario's working point*
- SASE FEL exponential gain in single spike
- **First characterization of Advanced FEL schemes**
  - **FERMI@Elettra Seeded FEL user facility**



High order harmonic generation in a seeded FEL

L. Giannessi et al., PRL **108**, 164801 (2012)

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Laser Comb technique: generation of a train of short bunches

(Parmela code)

Charge vs. Time

Energy vs. Time

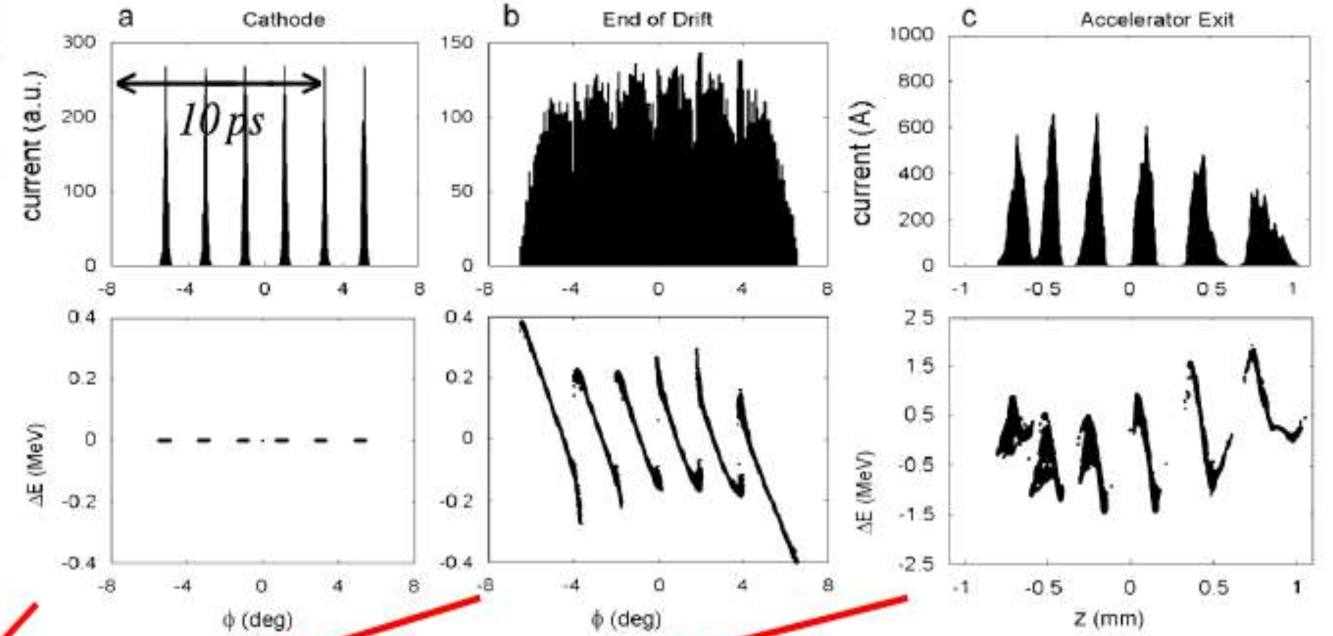
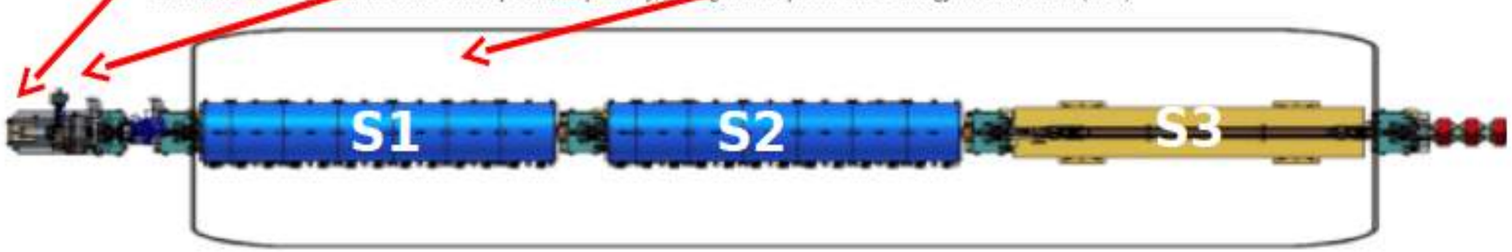
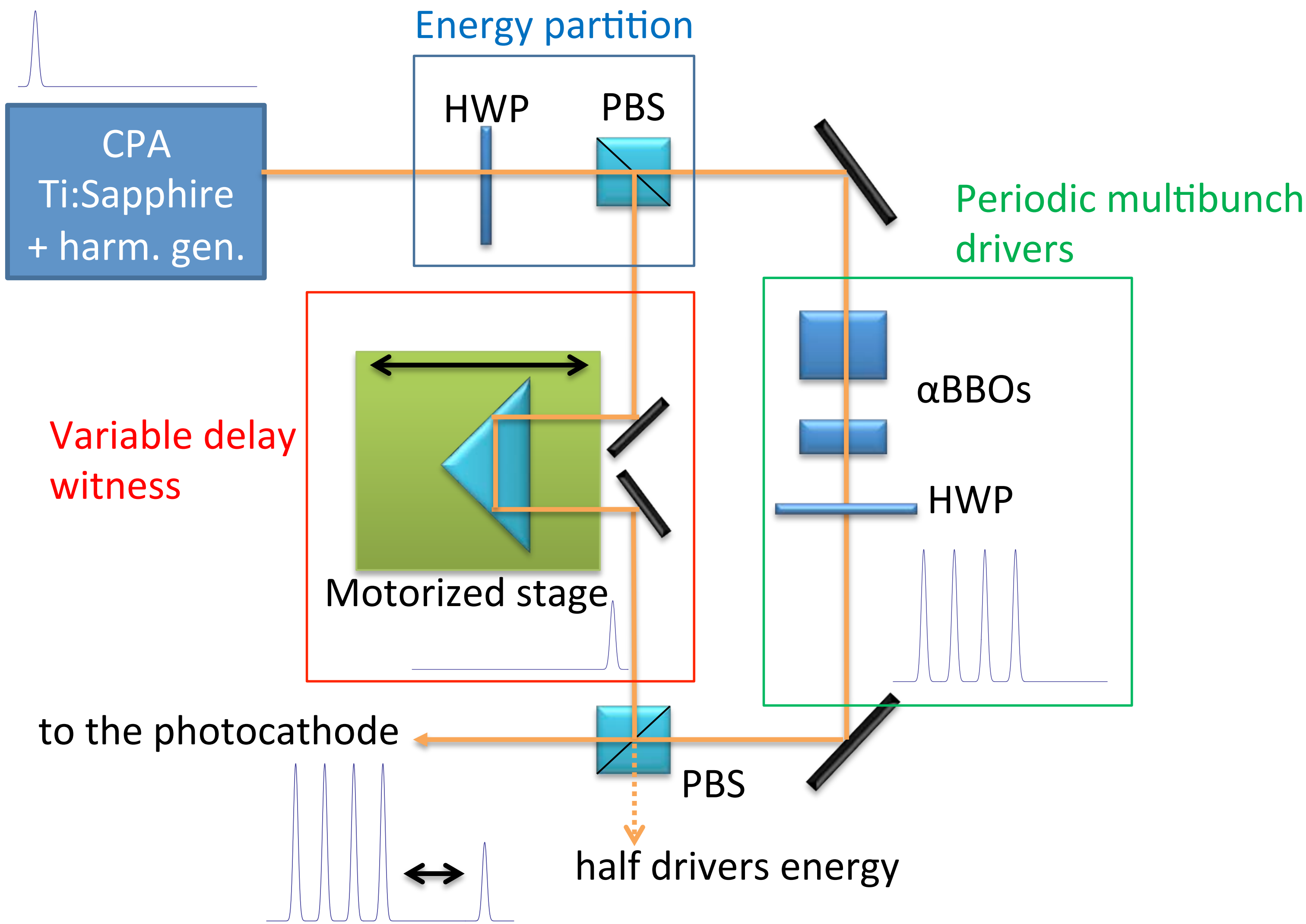


Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).

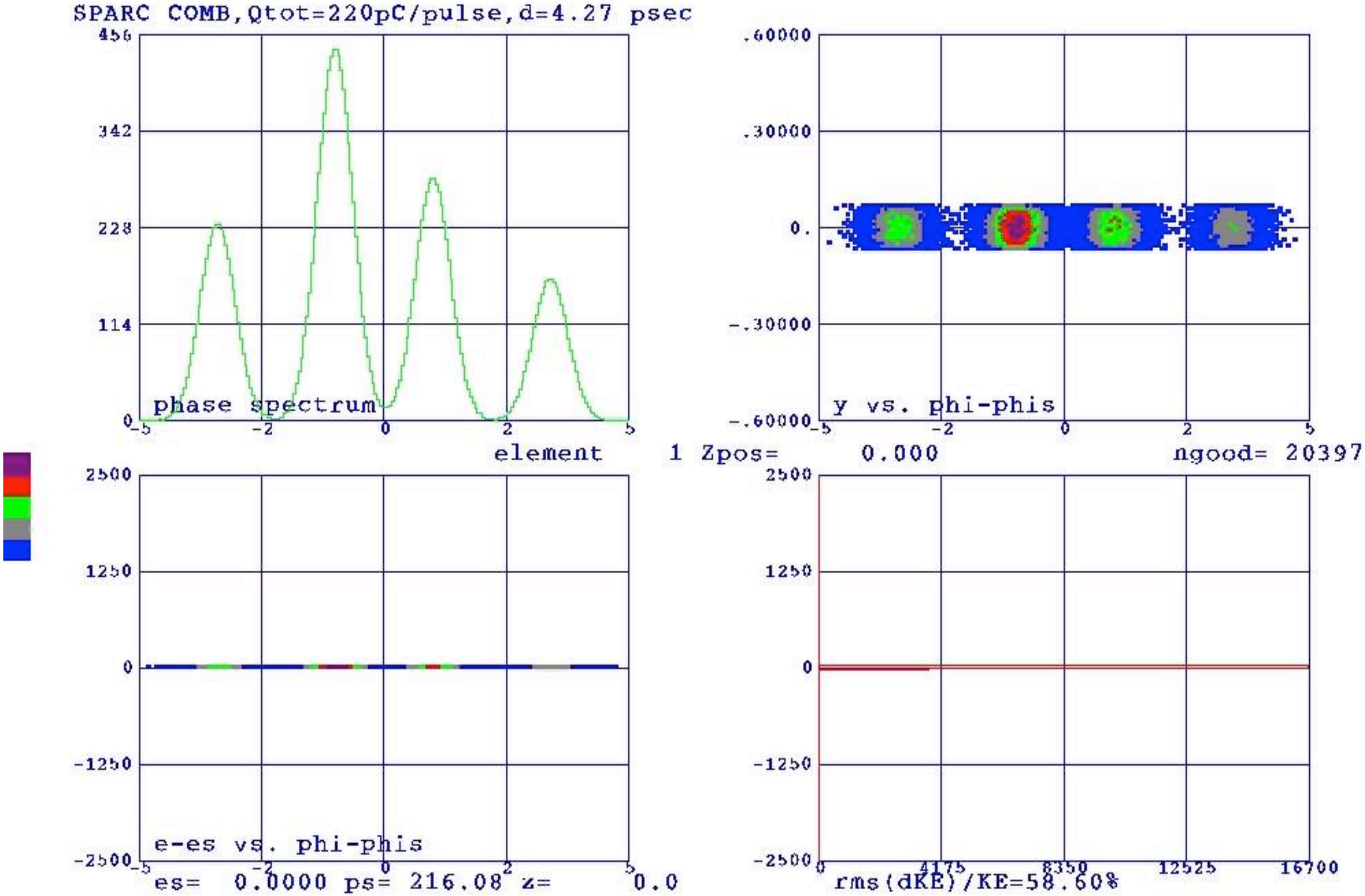


- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704. (Low charge regime only)
- M. Ferrario, M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (High charge, Beam Echo)

Driving and witness bunches generation

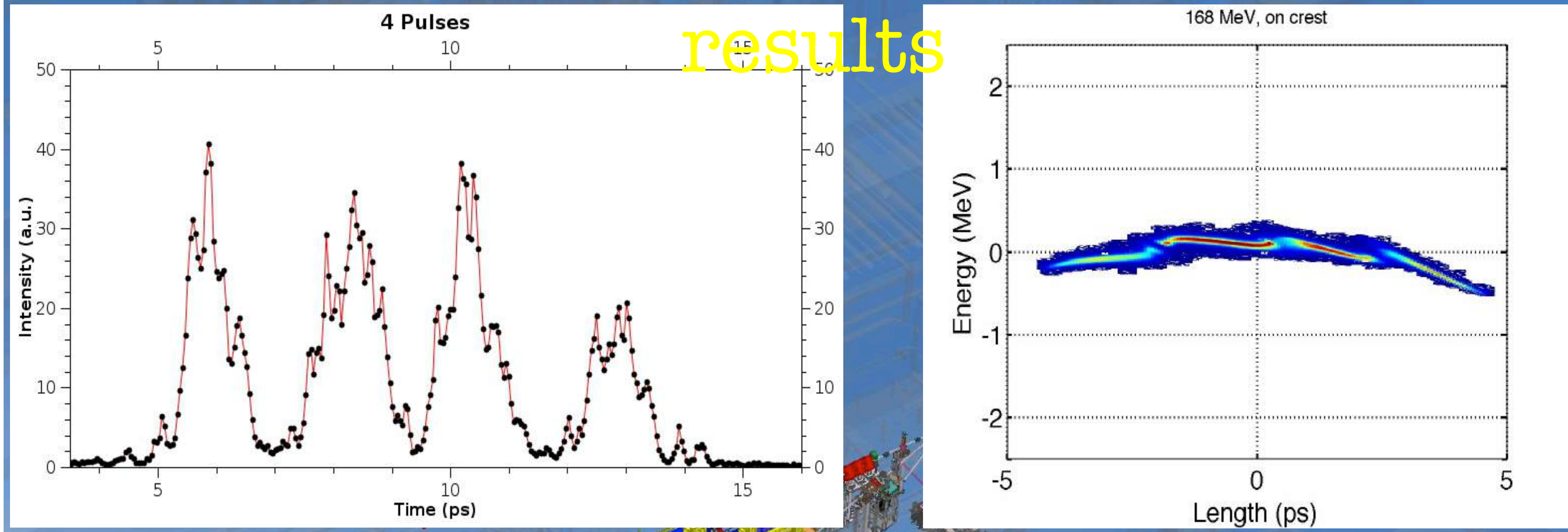


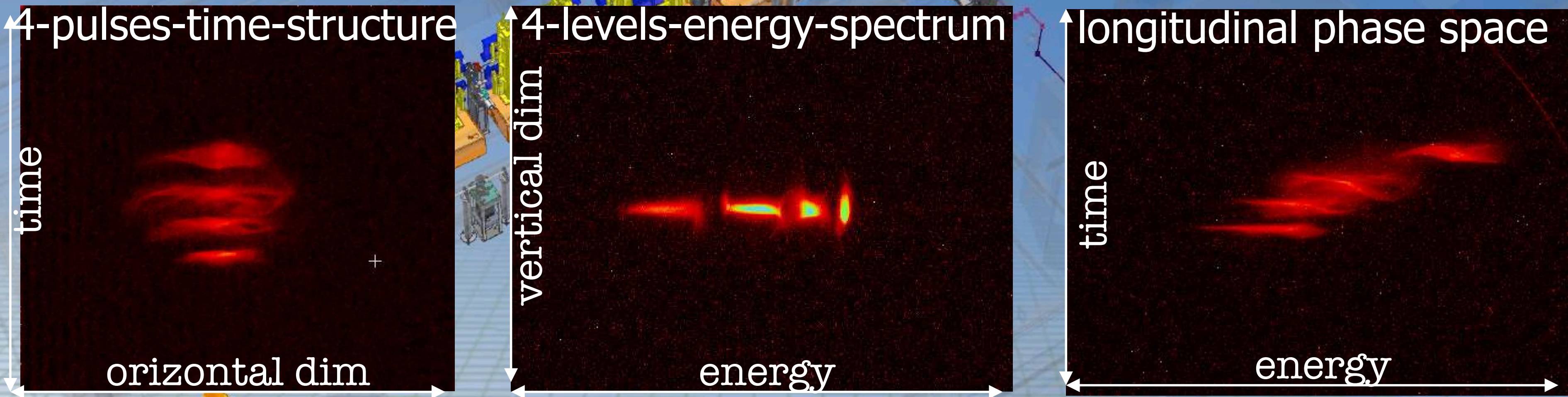
Laser Comb



SPARC COMB,Qtot=220pC/pulse,d=4.27 psec
phase spectrum
y vs. phi-phis
element 1 Zpos= 0.000 ngood= 20397
e-es vs. phi-phis
es= 0.0000 ps= 216.08 z= 0.0
rms(dKE)/KE=58.60%

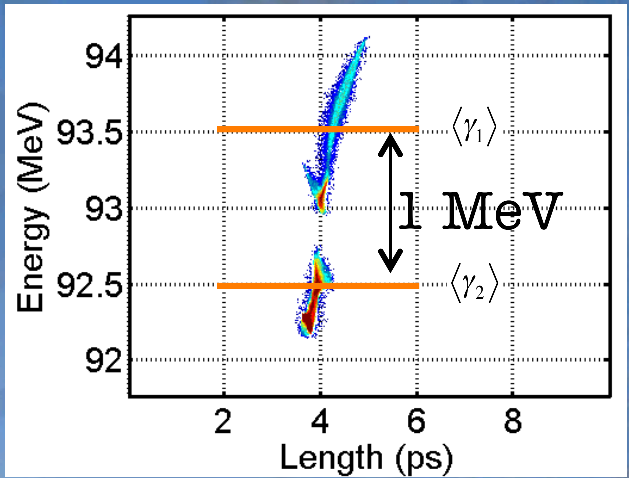
Laser COMB: experimental results





- M. Ferrario et al., Nucl. Inst. and Meth, A 637 (2011)
- A. Mostacci et al., Proc. of IPAC 2011, Spain

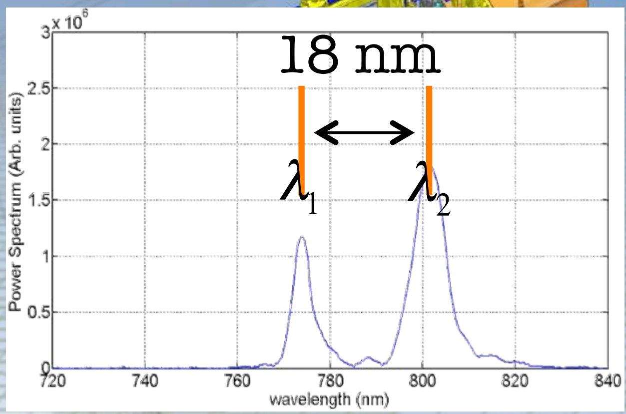
TWO COLORS SASE FEL



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

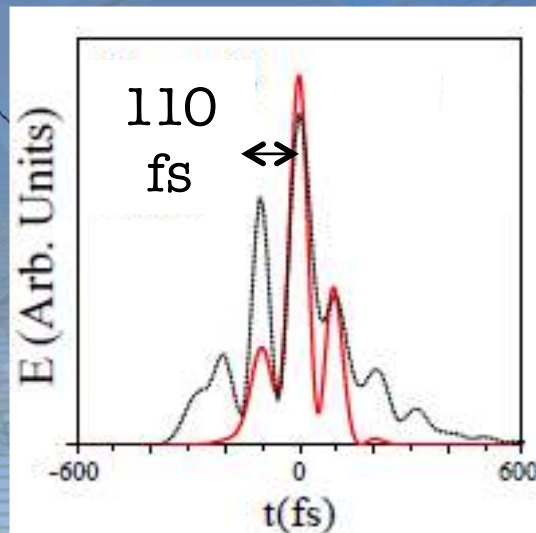
$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + K_{rms}^2\right)$$

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



produce two wavelength
SASE -FEL radiation
with time modulation

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



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]

Dual color X-rays from Thomson/ Compton sources

V. Petrillo[1,2], A.Bacci[1], C. Curatolo[1,2], M. Ferrario[3], G. Gatti[3], C. Maroli[2], J.V. Rau[4], C. Ronsivalle[5], L. Serafini[1], C. Vaccarezza[3], and M. Venturelli[2]*

[1] *INFN Milano ,Via Celoria, 16 20133 Milano, Italy*

[2] *Università degli Studi di Milano, Via Celoria, 16 20133 Milano, Italy*

[3] *LNF, INFN Via E.Fermi, 40 Frascati (Roma), Italy*

[4] *ISM-CNR Via del Fosso del Cavaliere, 100 00133 Roma, Italy and*

[5] *ENEA Via E.Fermi, 45 Frascati (Roma),Italy*

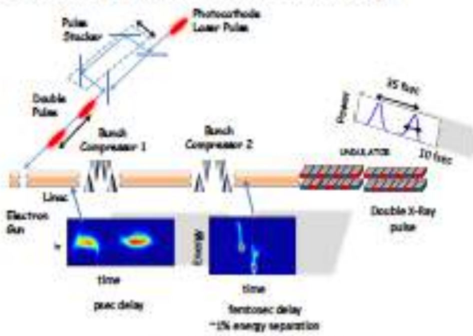
We analyze the possibility of producing two color X or gamma radiation by Thomson/Compton back-scattering between a high intensity laser pulse and a two-energy level electron beam, constituted by a couple of beamlets separated in time and/or energy obtained by a photoinjector with comb laser techniques and linac velocity bunching. The parameters of the Thomson source at SPARC_LAB have been simulated, proposing a realistic experiment.

Double-Bunch Operation at LCLS

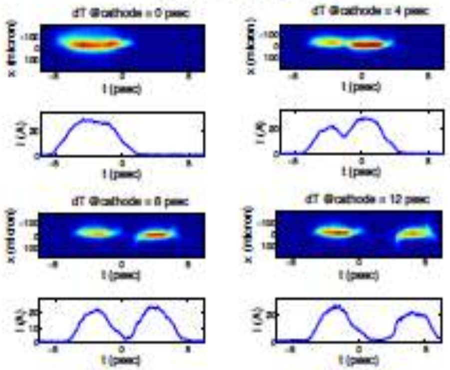
Generate double pulse at cathode and compress.
Similar concept demonstrated at SPARC in the Infrared [4]

Double-Bunch Operation at LCLS

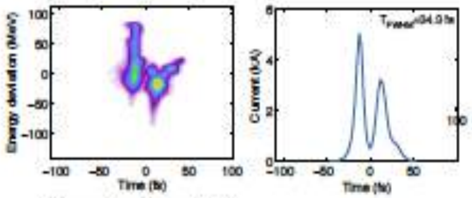
Generate double pulse at cathode and compress.
Similar concept demonstrated at SPARC in the Infrared [4]

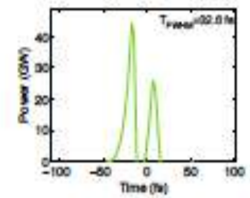


BEFORE COMPRESSION



AFTER COMPRESSION (2 STAGE)

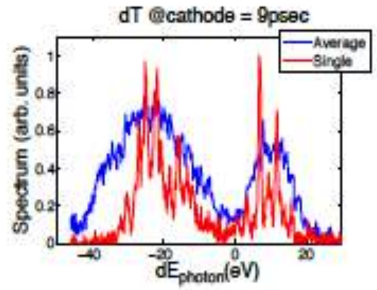




e-beam energy:15171 MeV

Bunch charge: 116 pC

X-ray pulse energy: 0.3 m



Spectrum around 9.1 keV
Spectrum clearly shows apperance of two separate spectral lines.
Tunability up to several tens of eV is a key feature for bio-imaging experiments based on MAD techniques.

Conclusions

The generation of multicolor X-FEL pulses with gain-modulation has been demonstrated experimentally. This technique has already been used in user experiments and has proved to be a valid alternative to 2-color SASE in cases in which full time overlap of the two colors is a crucial feature.

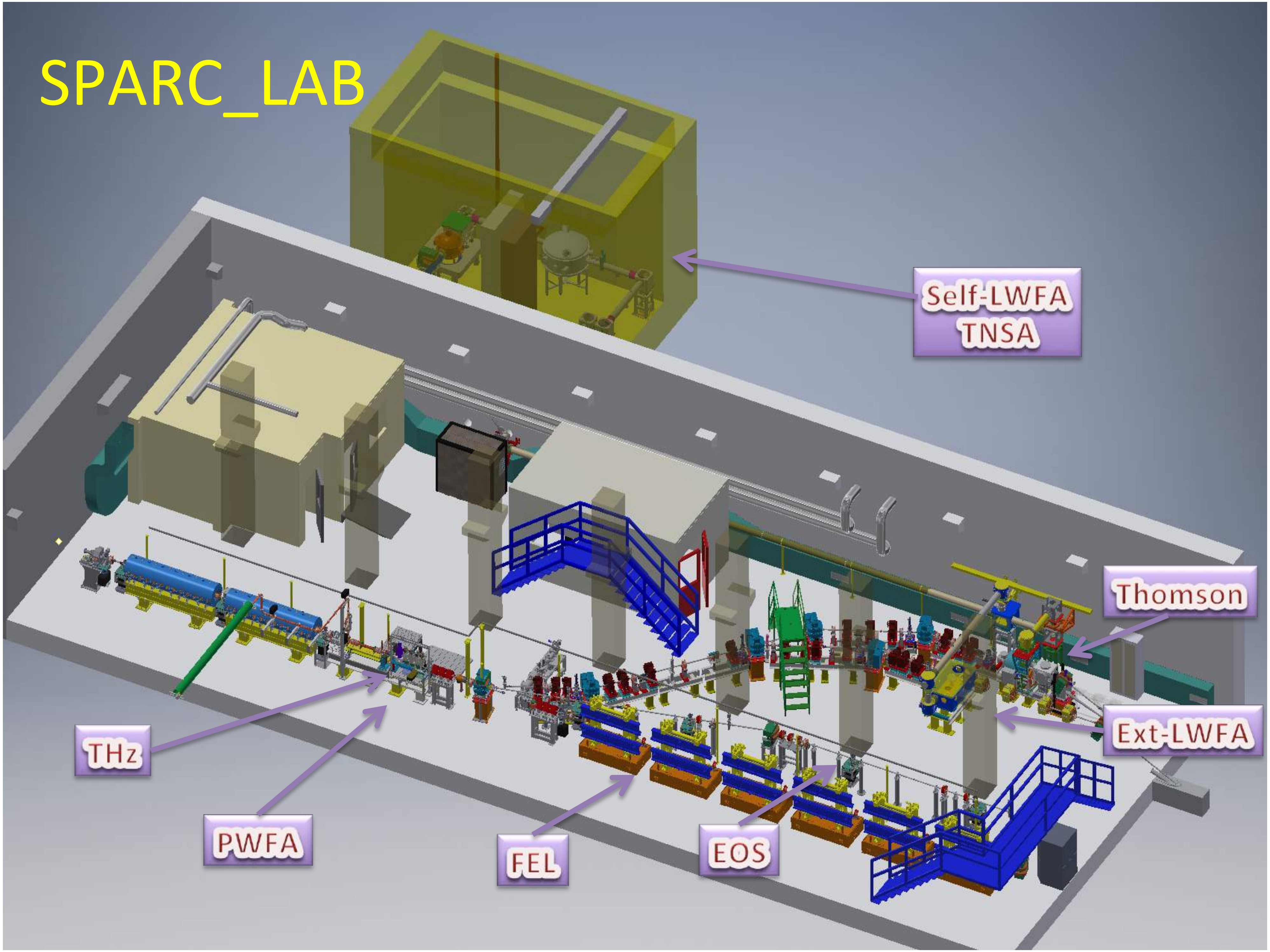
Two-bunch operation is currently under developement. Preliminary experimental results at hard x-rays show the key advantages of this method: full saturation power and possibility to diagnose the x-ray time structure with the x-tcav ona single shot base.

Bibliography

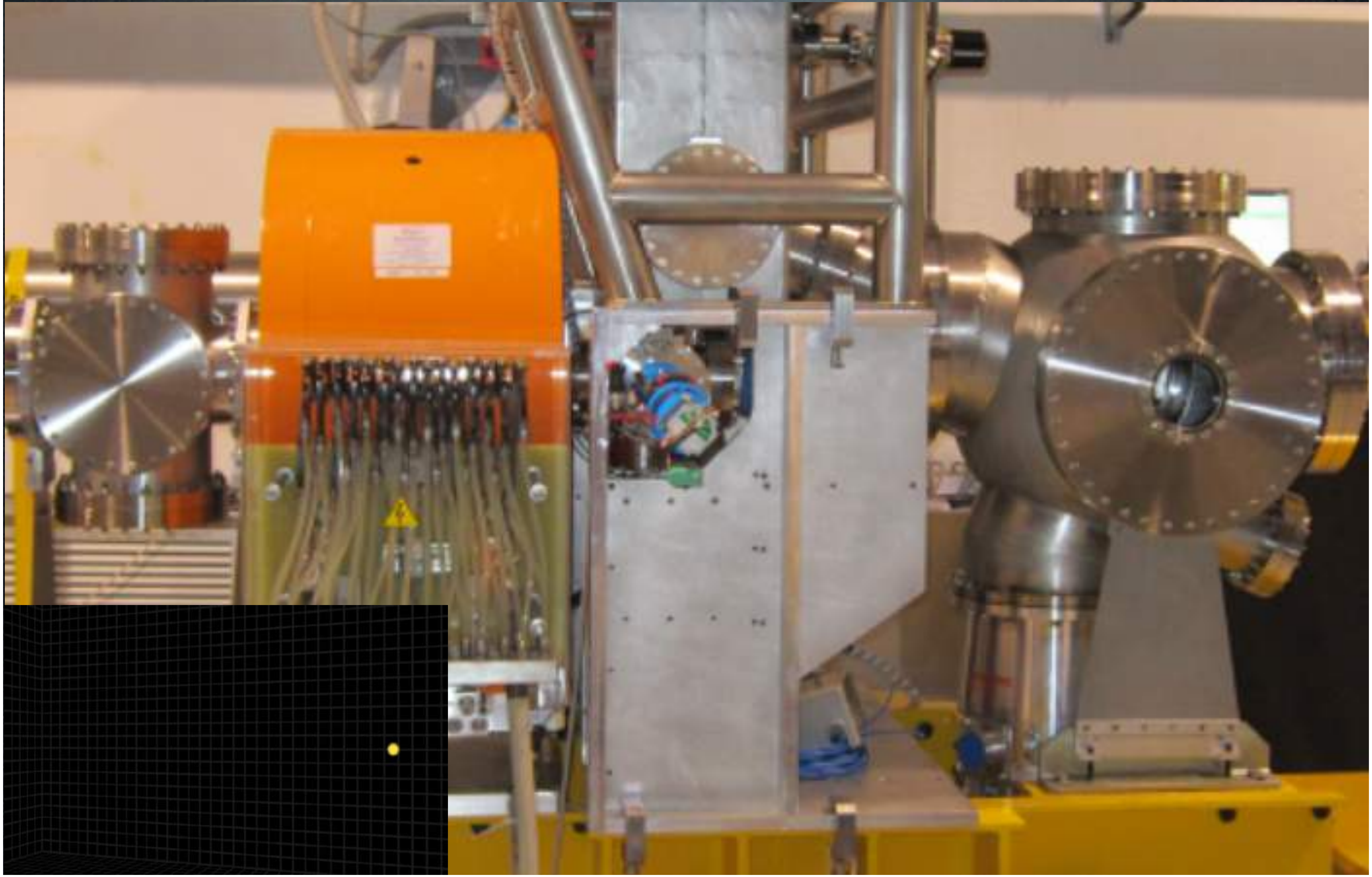
1) A. Lutman et al. *Experimental demonstration of femtosecond two-color x-ray free-electron lasers* Phys. Rev. Lett. 110, 134801 (2013).
2) G. De Ninno et al. *Chirped Seeded Free-Electron Lasers: Self-Standing Light Sources for Two-Color Pump-Probe Experiments* Phys. Rev. Lett. 110, 064801 (2013)
3) A. Marinelli et al. *Multicolor Operation and Spectral Control in a Gain-Modulated X-Ray Free-Electron Laser.* Phys. Rev. Lett. (In production)
4) V. Petrillo et al. *Observation of time-domain modulation of free-electron-laser pulses by multi-peaked electron-energy spectrum* Phys. Rev. Lett. (In production)


T.5

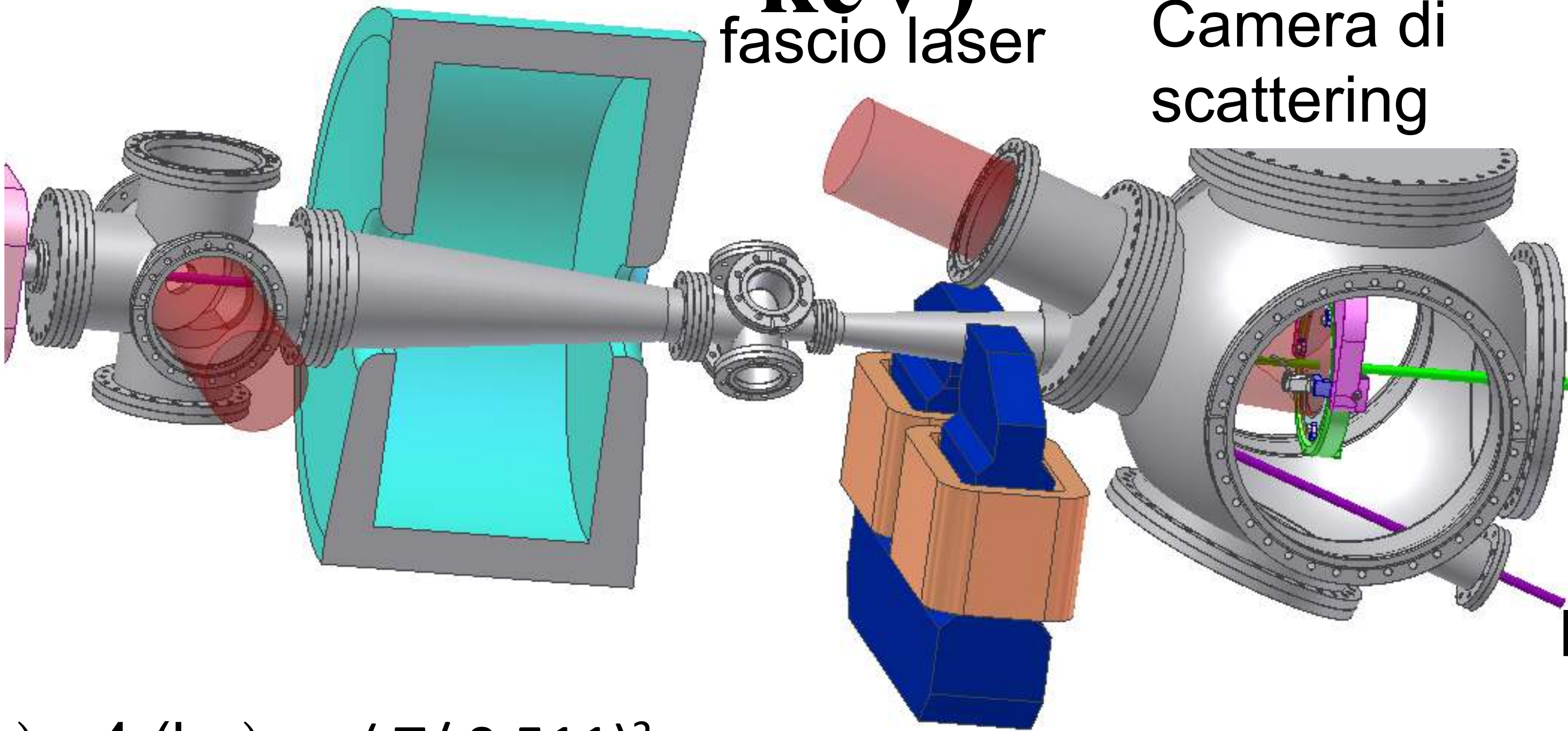
SPARC_LAB



Thomson back-scattering source



Thomson Interaction region (20-550 keV)



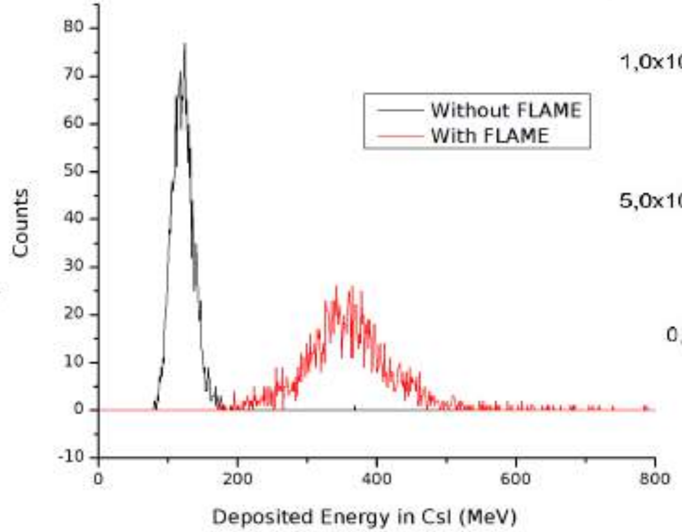
$(h\nu)_X = 4\ (h\nu)_{laser}\ (T/0.511)^2$

$(h\nu)_{laser}$ = 1.2 eV
T =30.28 MeV
$(h\nu)_X$ = 20 keV mammografia

Impulso laser: 6 ps, 5 J
pacchetto e^- : 1 nC , l: 2 mm (rms
Impulso X: 10 ps, 10^9 fotoni
α emissione: 12 mrad

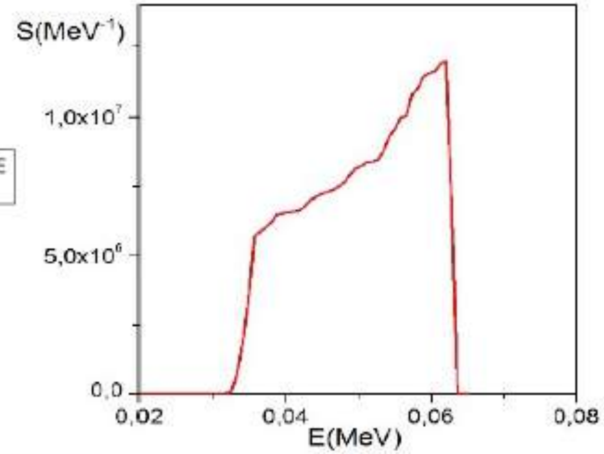
SPARC_LAB Achievements

- First experimental observation of emittance oscillation in a drift at low energy
  - Working point adopted in many photo-injector based user facilities
    - *Ferrario's working point*
- SASE FEL exponential gain in single spike
- First characterization of Seeded FEL schemes
  - FERMI@Elettra Advanced FEL user facility
- Multi-bunch generation
  - Laser comb technique
- First generation and characterization of two-color FEL radiation
  - LCLS scaling at X-rays to drive user experiments
- First user experiment with high peak power THz radiation
  - Implicazioni tecnologiche
- **γ-rays through Thomson-backscattering**
  - STAR project
  - ELI-NP



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

The number of photons per each pulse, coming from poor overlap conditions, and interacting with the detector sensitive area, is in average **6.7x10³**.



Spectral density S (MeV⁻¹) versus photon energy.

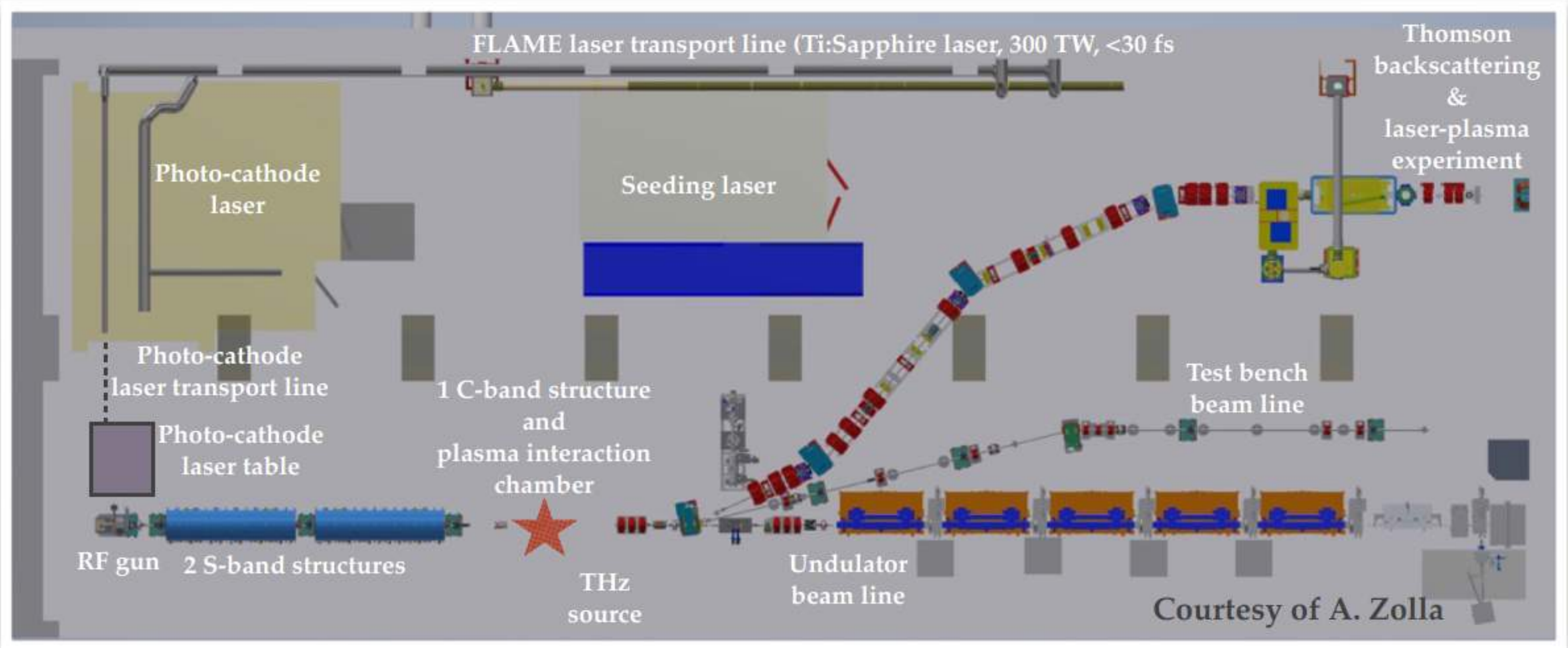
(50 MeV electron beam, with 200 pC charge, 5 mm mrad of emittance, 150 mm of rms beam transverse dimension, colliding with the laser with 500 mJ and 30 mm of waist, gives a number of photons of 2×10^5 in a bandwidth of about 19%.

The photon energy edge, given by $E_p \sim 4E_L g^2$, is about **63 keV.**

C. *Vaccarezza et al.*, NIM A **829** (2016) 237–242

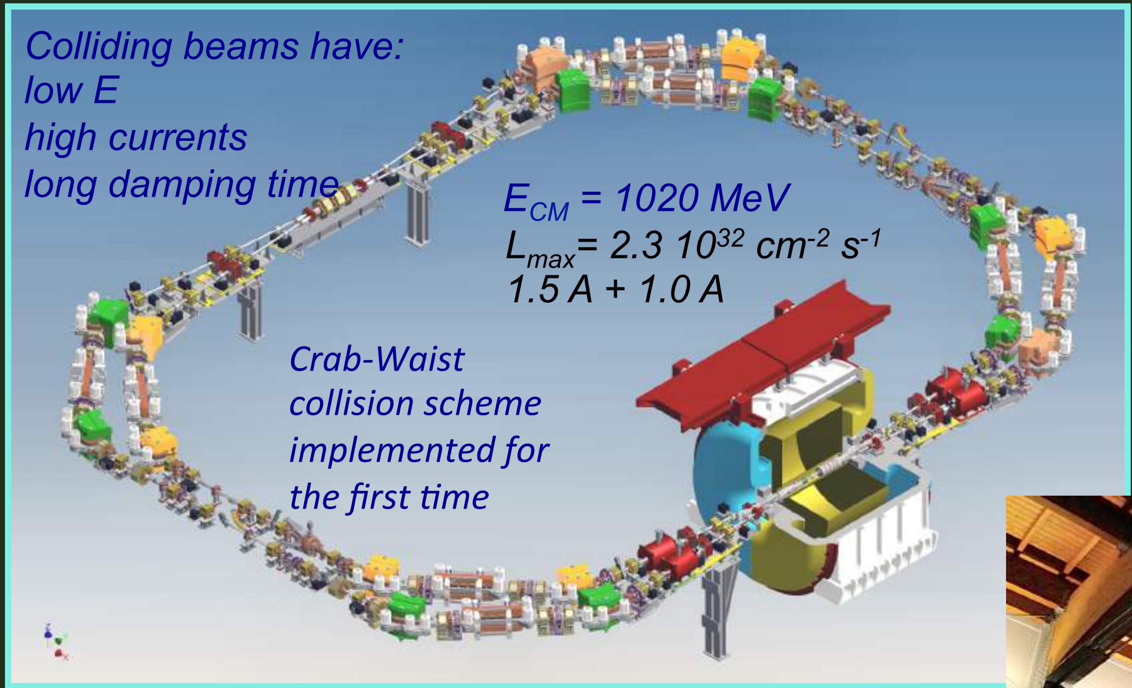
enrica.chiadroni@lnf.infn.it

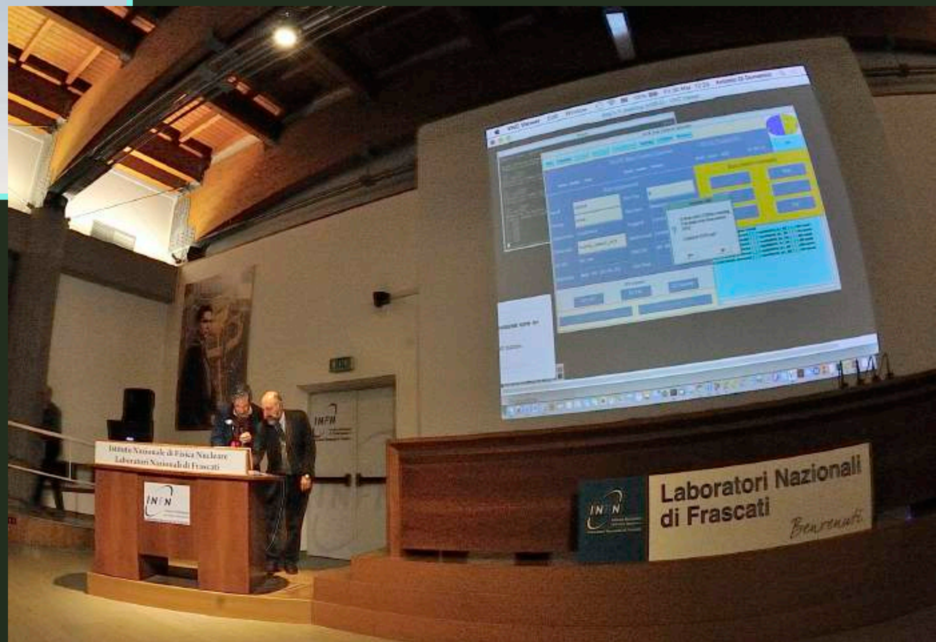
SPARC_LAB today



KLOE-2 data-taking closing ceremony

March 30th 2018 at 11:00 in the Bruno Touschek Auditorium



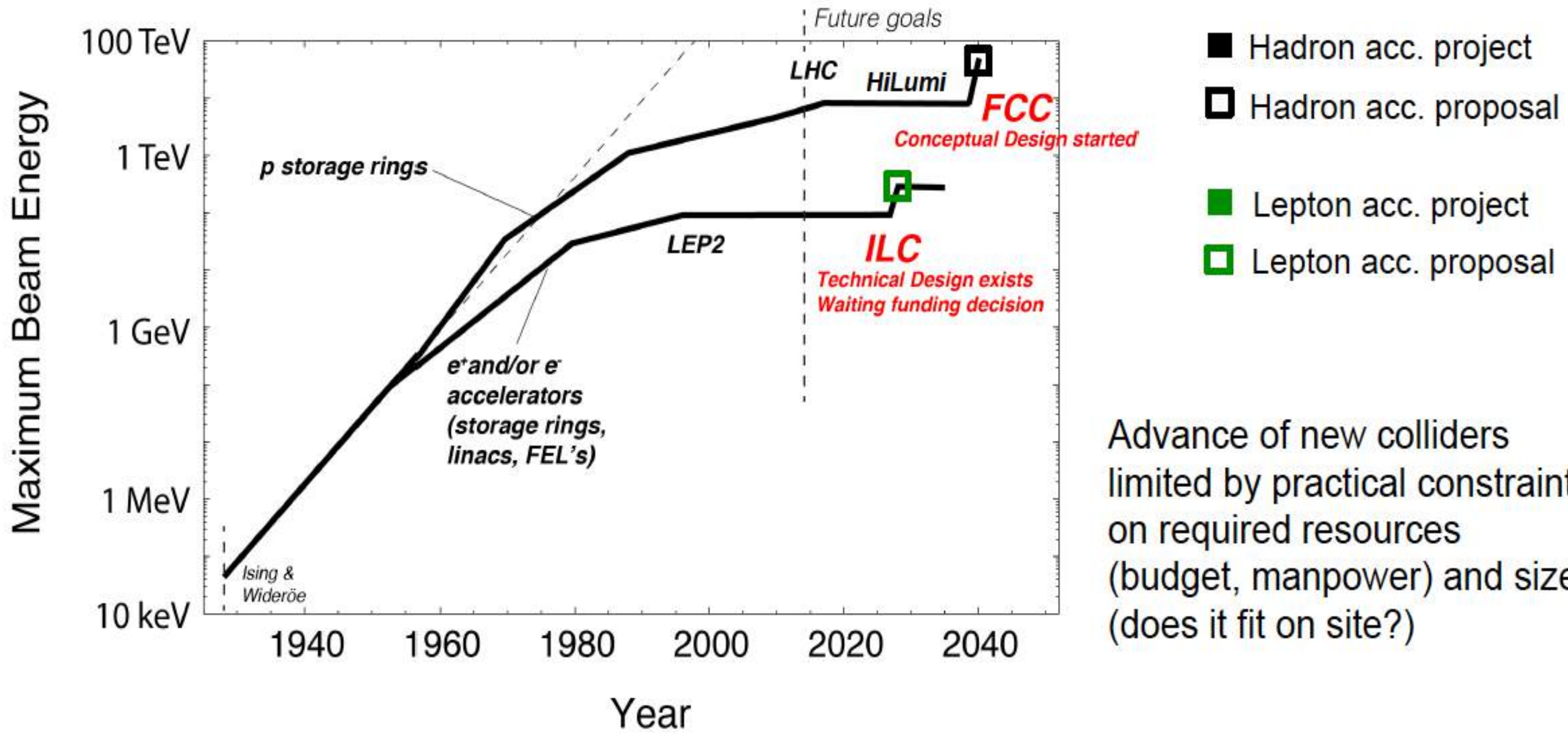


"What Next at LNF?"

is an often addressed question in many other labs
See for ex. SLAC, DESY, CERN

Slow-down in Energy Increase of Frontier Accelerators

Livingston plot leveling off – here our version, giving beam energy versus time



Advance of new colliders limited by practical constraints on required resources (budget, manpower) and size (does it fit on site?)

Courtesy R. Assmann, DESY

"How to advance?"

Hadron (p) circular collider

$$p = e \cdot R \cdot B_y$$

Increase bending field
SC bend magnet work (FCC-hh)

Increase radius = size (FCC-hh)

Lepton (e-,e+) circular collider

$$p \propto E_0 \cdot \sqrt[4]{\rho \cdot U_0}$$

Increase supplied RF voltage (FCC-ee)

Increase mass of acc. particle (muon)

Increase radius = size (FCC-ee)

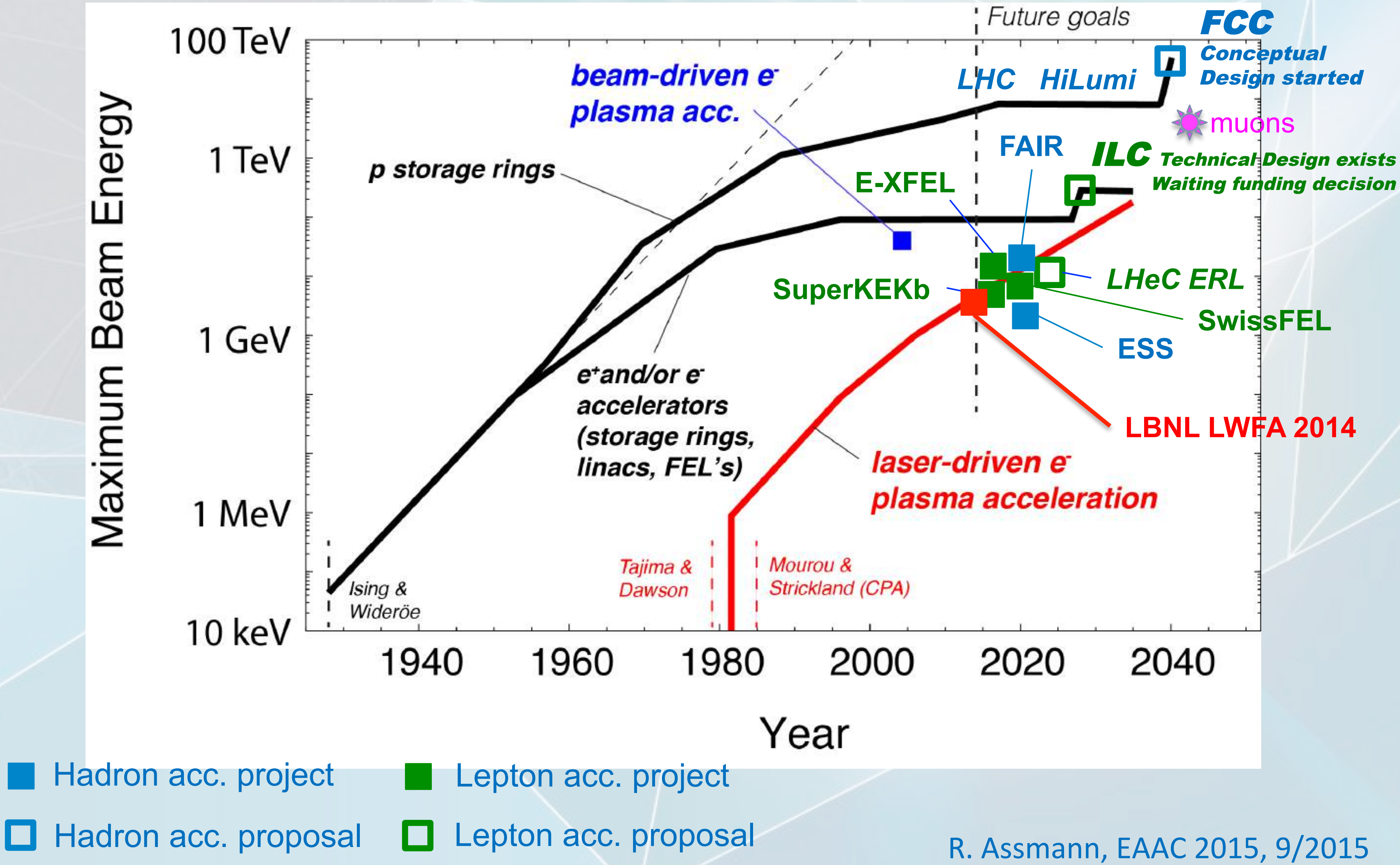
Lepton (e-,e+) linear collider

$$p = L \cdot G_{acc}$$

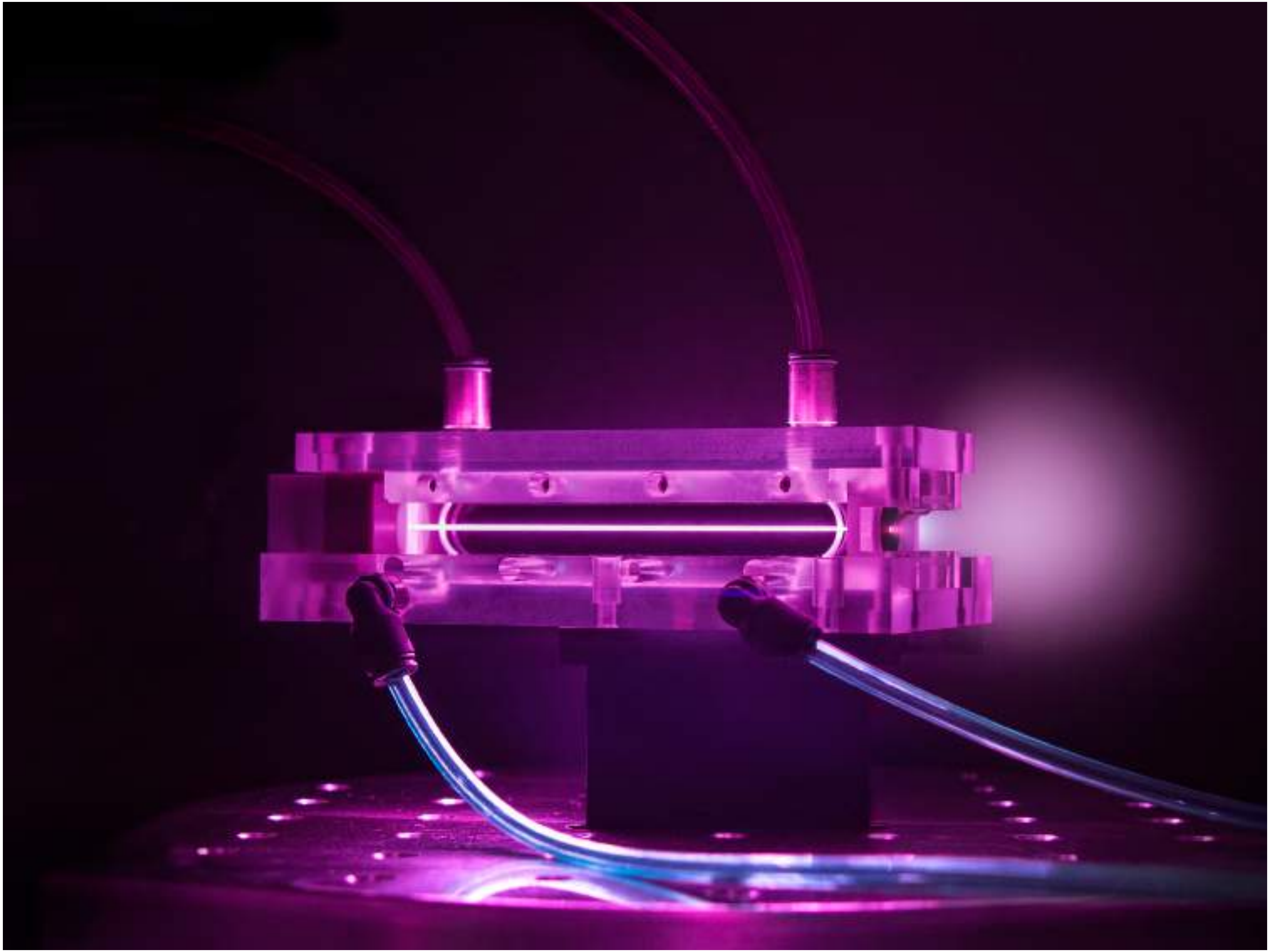
Increase accelerating gradient
(a) Pushing existing technology (ILC, CLIC)
(b) New regime of ultra-high gradients (plasma, dielectric accelerators)

Increase length (ILC, CLIC)

Future of Accelerators

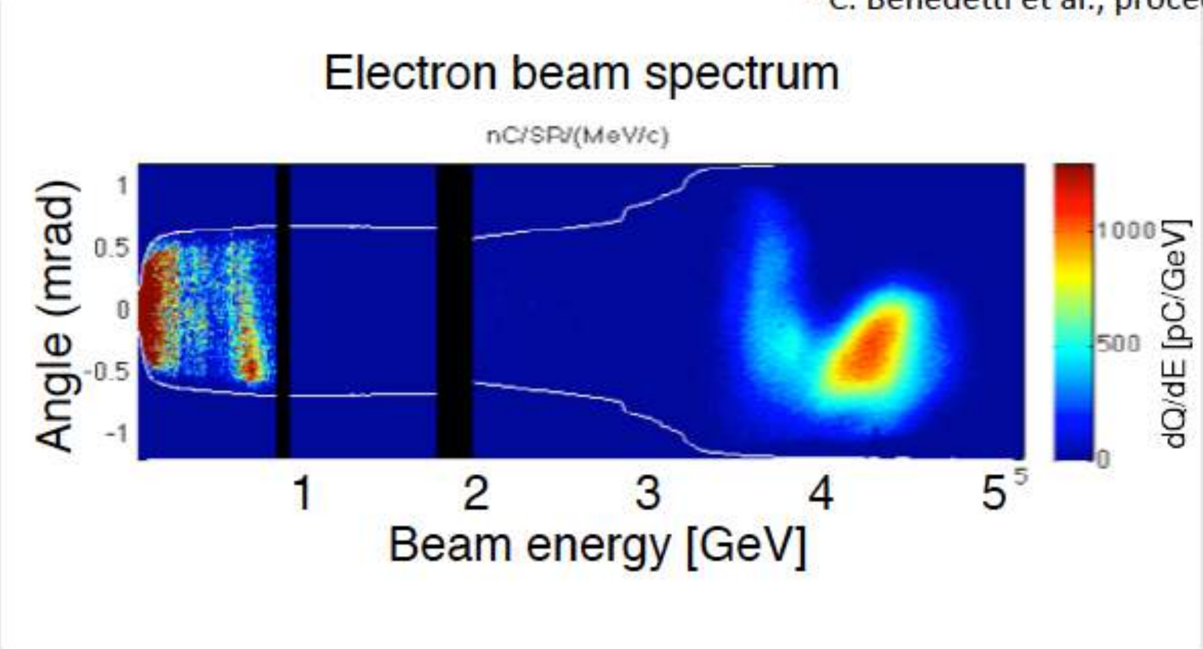


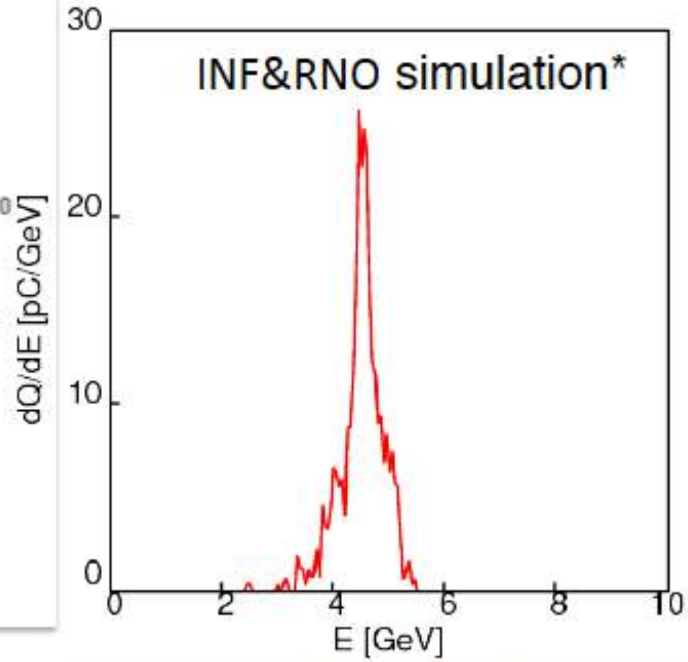
R. Assmann, EAAC 2015, 9/2015

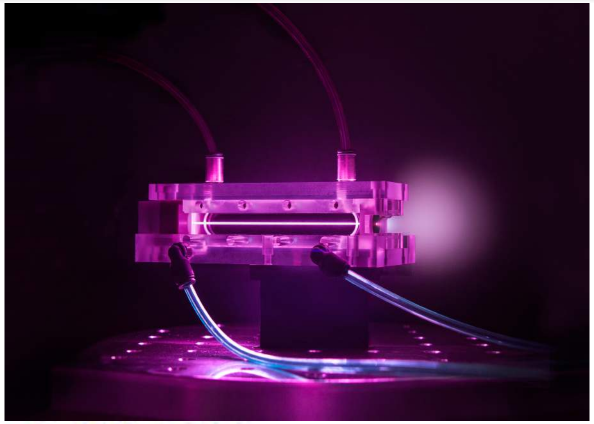


4.25 GeV beams have been obtained from 9 cm plasma channel powered by 310 TW laser pulses (15 J)

*C. Benedetti et al., proceedings of AAC2010, proceedings of ICAP2012







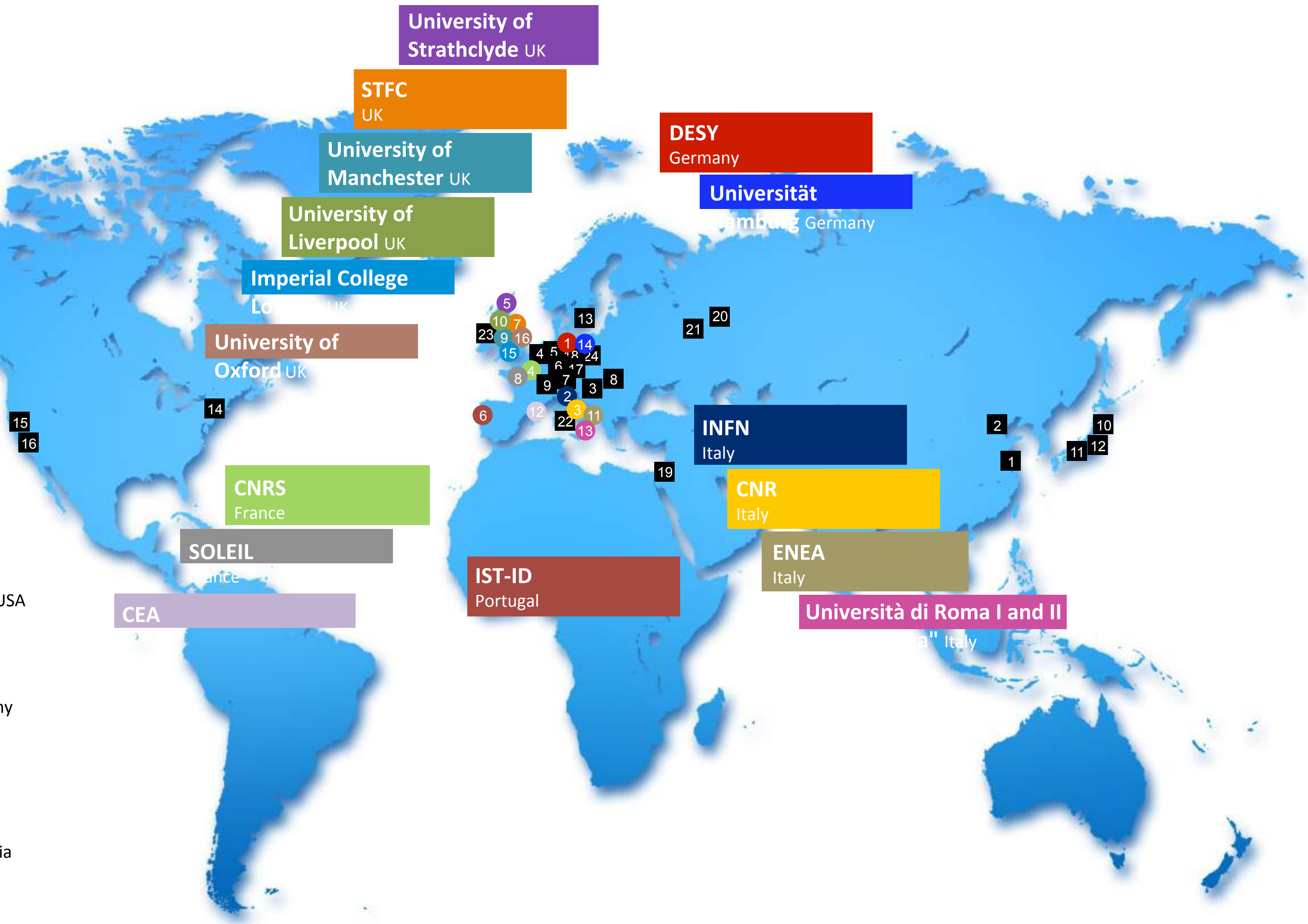
	Exp.	Sim.
Energy	4.25 GeV	4.5 GeV
ΔE/E	5%	3.2%
Charge	~20 pC	23 pC
Divergence	0.3 mrad	0.6 mrad

W.P. Leemans et al.,PRL 2014

Worldwide effort towards high quality plasma beams

Associated Partners
(as of December 2017)

1. **Shanghai Jiao Tong-University**, China
2. **Tsinghua University Beijing**, China
3. **ELI Beamlines**, International
4. **PHLAM, Université de Lille,** France
5. **Helmholtz-Institut Jena**, Germany
6. **HZDR (Helmholtz)**, Germany
7. **LMU München**, Germany
8. **Wigner Fizikai Kutatóközpont**, Hungary
9. **CERN**, International
10. **Kansai Photon Science Institute**, Japan
11. **Osaka University**, Japan
12. **RIKEN SPring-8**, Japan
13. **Lunds Universitet**, Sweden
14. **Stony Brook University & Brookhaven NL**, USA
15. **LBNL**, USA
16. **UCLA**, USA
17. **Karlsruher Institut für Technologie**, Germany
18. **Forschungszentrum Jülich**, Germany
19. **Hebrew University of Jerusalem**, Israel
20. **Institute of Applied Physics**, Russia
21. **Joint Institute for High Temperatures**, Russia
22. **Università di Roma 'Tor Vergata'**, Italy
23. **Queen's University Belfast**, UK
24. **Ferdinand-Braun-Institut**, Germany



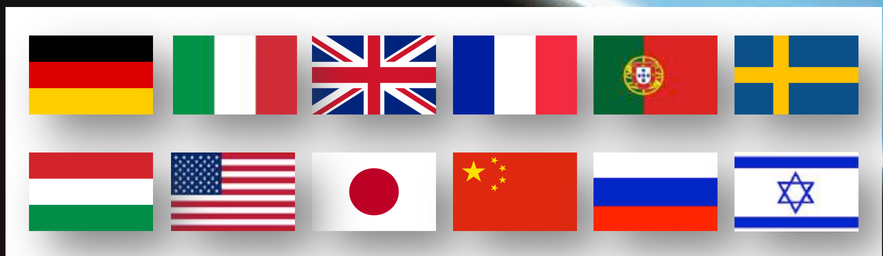
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

EuPRAXIA Design Study started on Novemebr 2015

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

Coordinator: Ralph Assmann (DESY)



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

http://eupraxia-project.eu

EuPRAXIA

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

Consortium

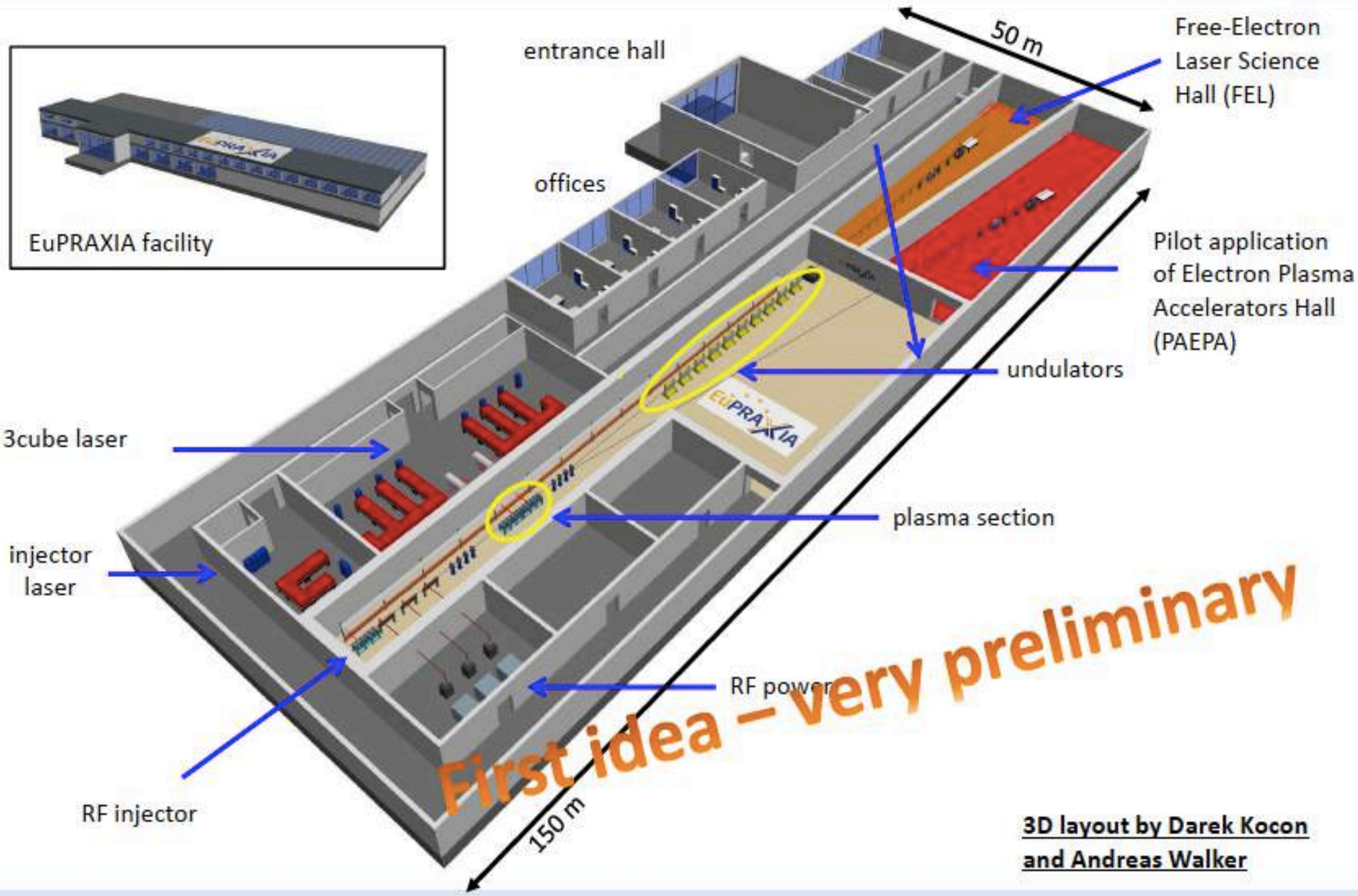
Horizon 2020

16 Participants

24 Associated Partners

(as of December 2017)

draft of facility layout



3D layout by Darek Kocon and Andreas Walker

Location of possible sites within EU

EuPRAXIA site studies:

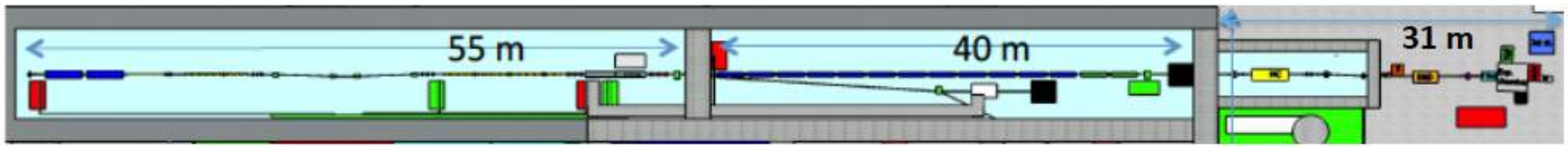
- Design study is site independent
- Five possible sites have been discussed so far
- We invite the suggestions of additional sites


Central Laser Facility
Didcot, United Kingdom


Eli Beamlines
Prague, Czech Republic

EuPRAXIA@SPARC_LAB

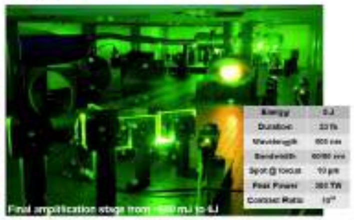
- **Candidate LNF to host EuPRAXIA (1 - 5 GeV)**
- The EuPRAXIA@SPARC_LAB Test User Facility will produce high brightness electron beams either by a **500 MeV X-band RF linac plus 500 MeV plasma** accelerator or by a **1 GeV X-band RF linac only** to drive
  - FEL user facility: 1 GeV – 3 nm
  - Advanced Accelerator Test Facility (LC + CERN)
  - Novel radiation sources facility, e.g. *THz radiation, γ-rays, neutron sources*



SPARC High Brightness Photo-injector

X-band linac

High power laser



Plasma-discharge capillary

Short-period undulator

EuPRAXIA@SPARC_LAB Conceptual Design Report is publicly available and can be downloaded from http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

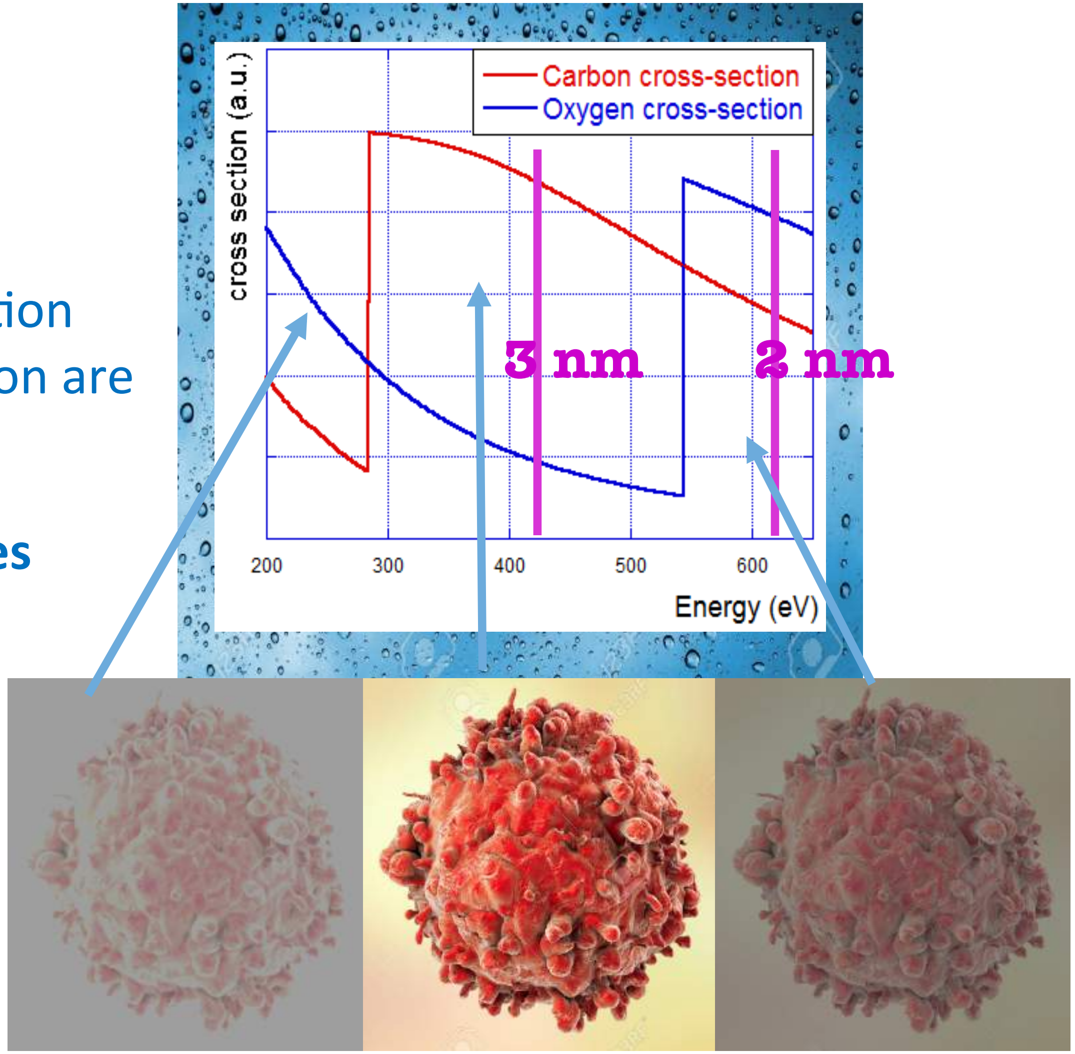
enrica.chiadroni@lnf.infn.it

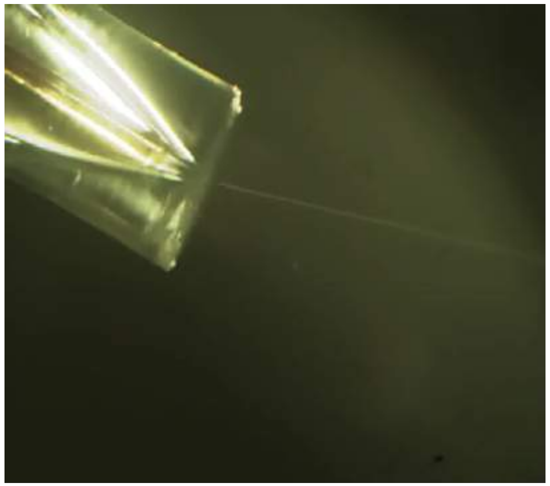
Water Window Coherent Imaging

Energy region between Oxygen and
Carbon K-edge 2.34 nm – 4.4 nm
(530 eV -280 eV)

Water is almost transparent to radiation in this range while nitrogen and carbon are absorbing (and scattering)

Coherent Imaging of biological samples living in their native state
Possibility to study dynamics





Courtesy F. Stellato, UniToV

R&D perspectives

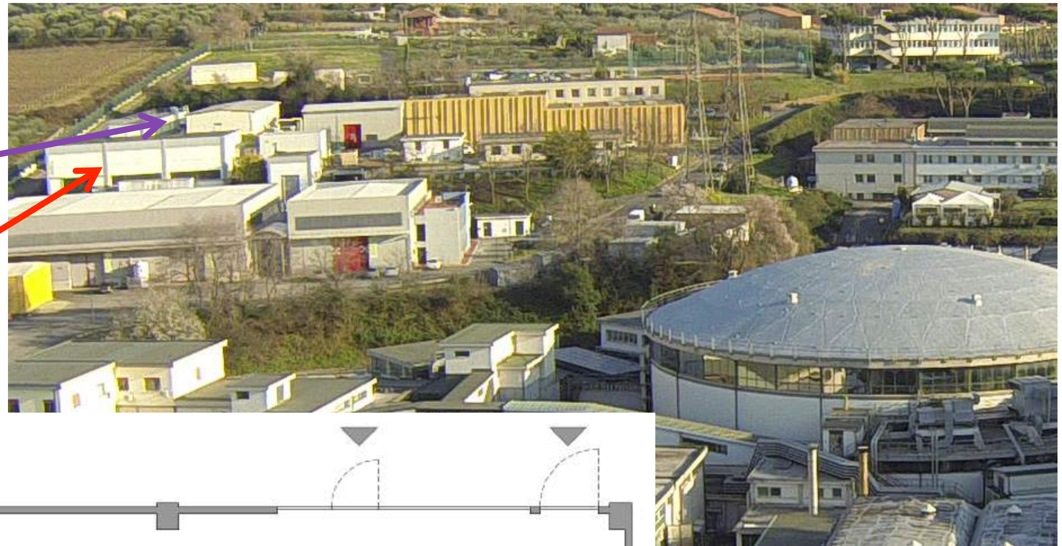
- X-band RF technology implementation,➔ CompactLight => CERN collaboration
- Science with short wavelength Free Electron Laser (FEL)
- Physics with high power lasers and secondary particle source
- Compact Neutron Source
- R&D on compact radiation sources for medical applications
- Detector development 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
- R&D in accelerator physics and industrial spin – off

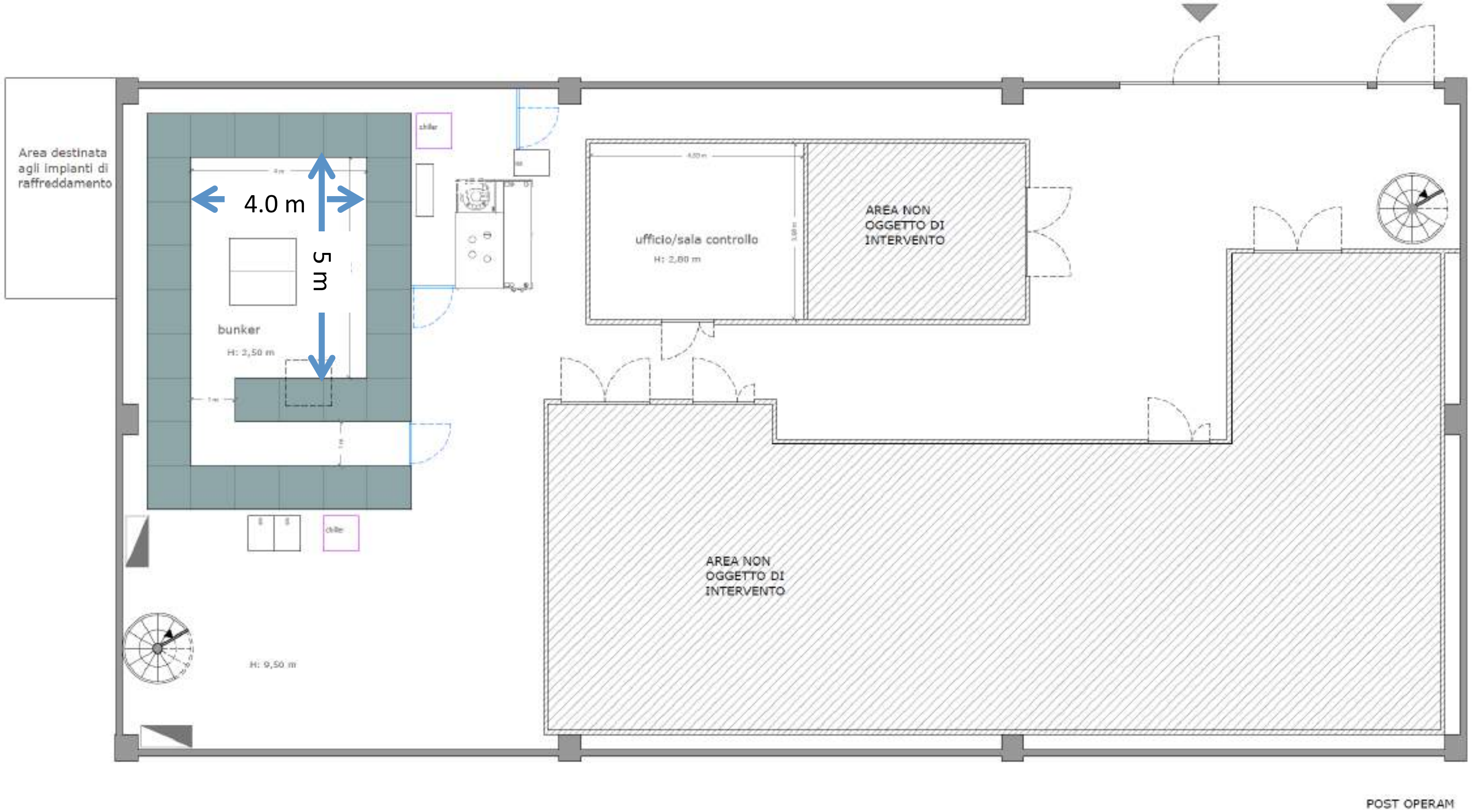
INFN – CERN official partnership on X-band RF development

The INFN Frascati X-box

SPARC_LAB

Building #7





it will be located in LNF building #7, very close to the SPARC_LAB area, formerly used for testing and conditioning of the DAFNE RF power plants and cavities

LNF building #7: the old bunker

LNF building #7: inside view

The INFN Frascati X-box

Pulsed Modulator: to be procured by INFN

OPERATIONAL PARAMETERS

		Unit	K2-3X	Notes
Pulse Output				
	Peak power to Klystron	MW	150.7	Peak power from Modulator
	Average power to Klystron	kW	17.3	Average power from Modulator
	Klystron Voltage range	kV	450	Nominal 410kV, see fig above
	Klystron Current range	A	335	Nominal 305A, see fig above
	Inverse Klystron Voltage	kV	<30	Reduced by the Solid State technology
	Pulse length	µs	1.5	Top of Klystron Voltage pulse
	Pulse length at 50%	µs	3,4	Of the Voltage Pulse
	RF duty cycle	%	0.0075	
	PRF range	Hz	1 - 50	
	Top flatness (dV)	%	<±0.25	Deviation from nominal voltage within the top of the pulse length
	Amplitude stability	%	<±0.1	
	Trig delay	µs	~1.2	See fig above
	Pulse to pulse jitter	ns	<6	
	Pulse length jitter	ns	<±10	
Filament Output				
	Klystron Max voltage DC	V	30	Nominal 10-30V
	Klystron Max current DC	A	30	Nominal 18-30A
	Kly. Fil. Current stability	%	<±1	
	Pre-heating period	min	60	Filament current is softly ramped to max value during pre-set time

VKX-8311A

X-band klystron: provided by CERN

Typical Operating Parameters		
Item	Value	Units
Beam Voltage	410	kV
Beam Current	310	A
Frequency	11.994	GHz
Peak Power	50	MW
Ave, Power	5	kW
Sat. Gain	48	dB
Efficiency	40	%
Duty	0.009	%

Pulse compressor: provided by CERN

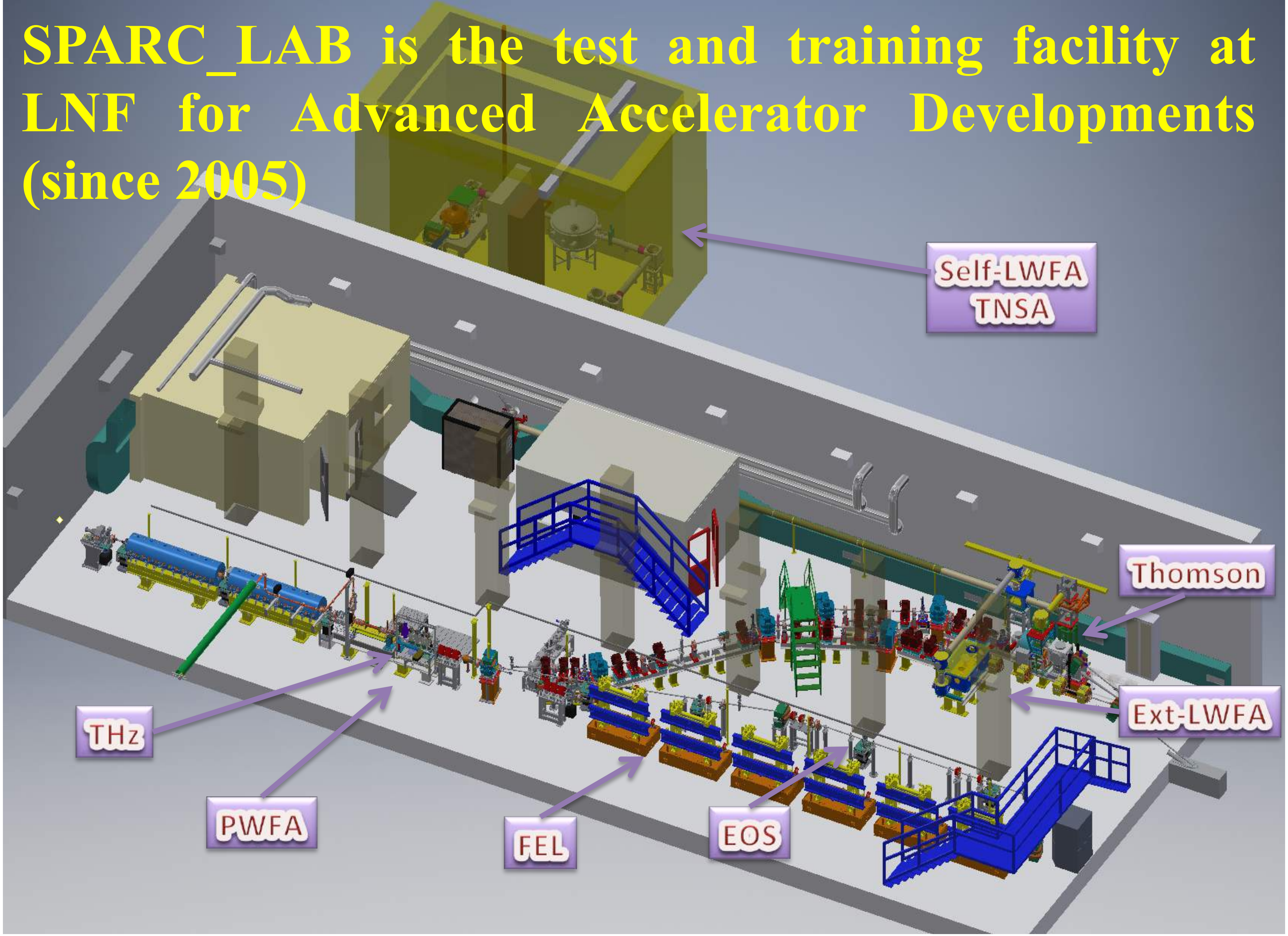
Other components:

- Low level RF and controls;
- RF driver amplifier;
- Rectangular waveguides;
- Ceramic windows;
- Vacuum pumps and power supplies;
- …

All components will be either provided by CERN or procured by INFN in full conformity with the original CERN X-box parts.

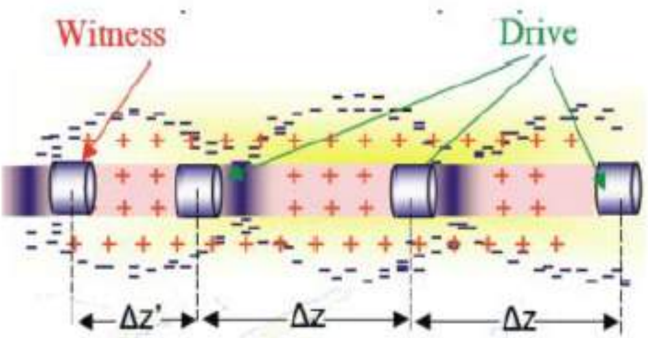
With the contribution of the **LATINO** project: a "Laboratory in Advanced Technologies for INnOvation" funded by Regione Lazio

SPARC_LAB is the test and training facility at LNF for Advanced Accelerator Developments (since 2005)



Plasma-based acceleration techniques

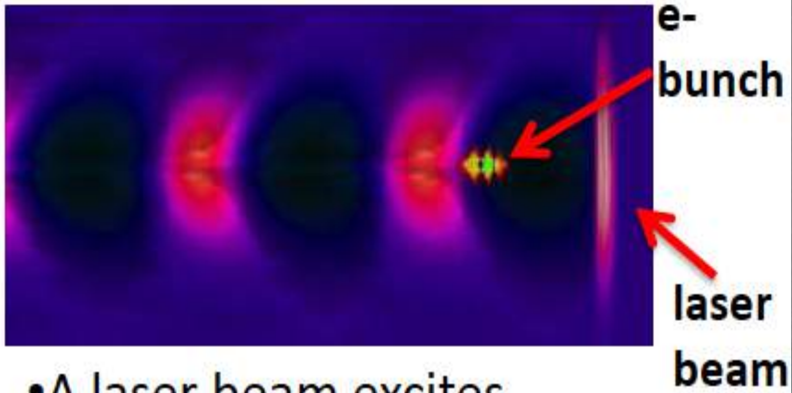
resonant-PWFA



- 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

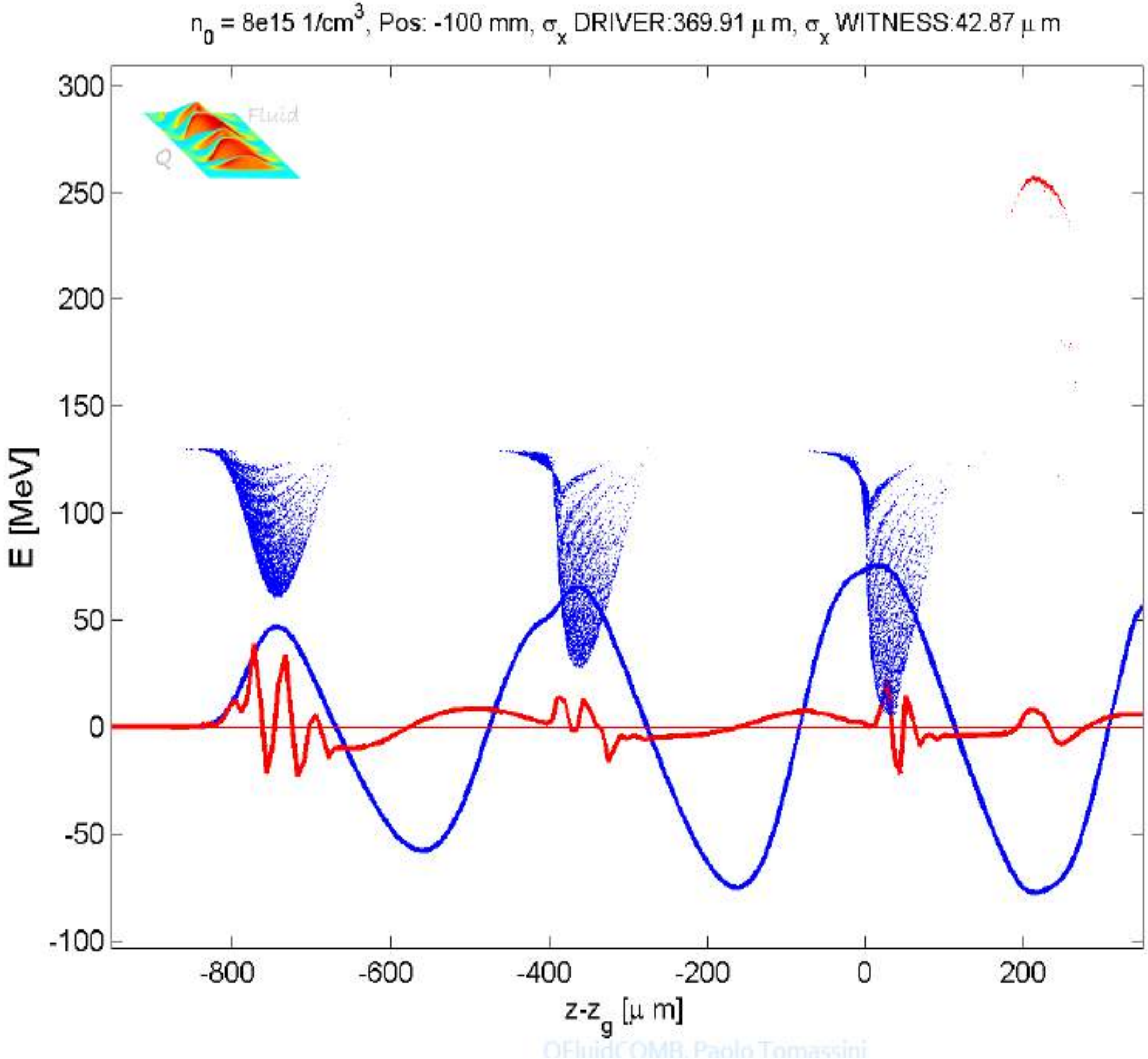
n_e = 2x10^{16} cm^{-3}
λ_p = 300µm
Capillary 1mm
Hydrogen

external injection LWFA



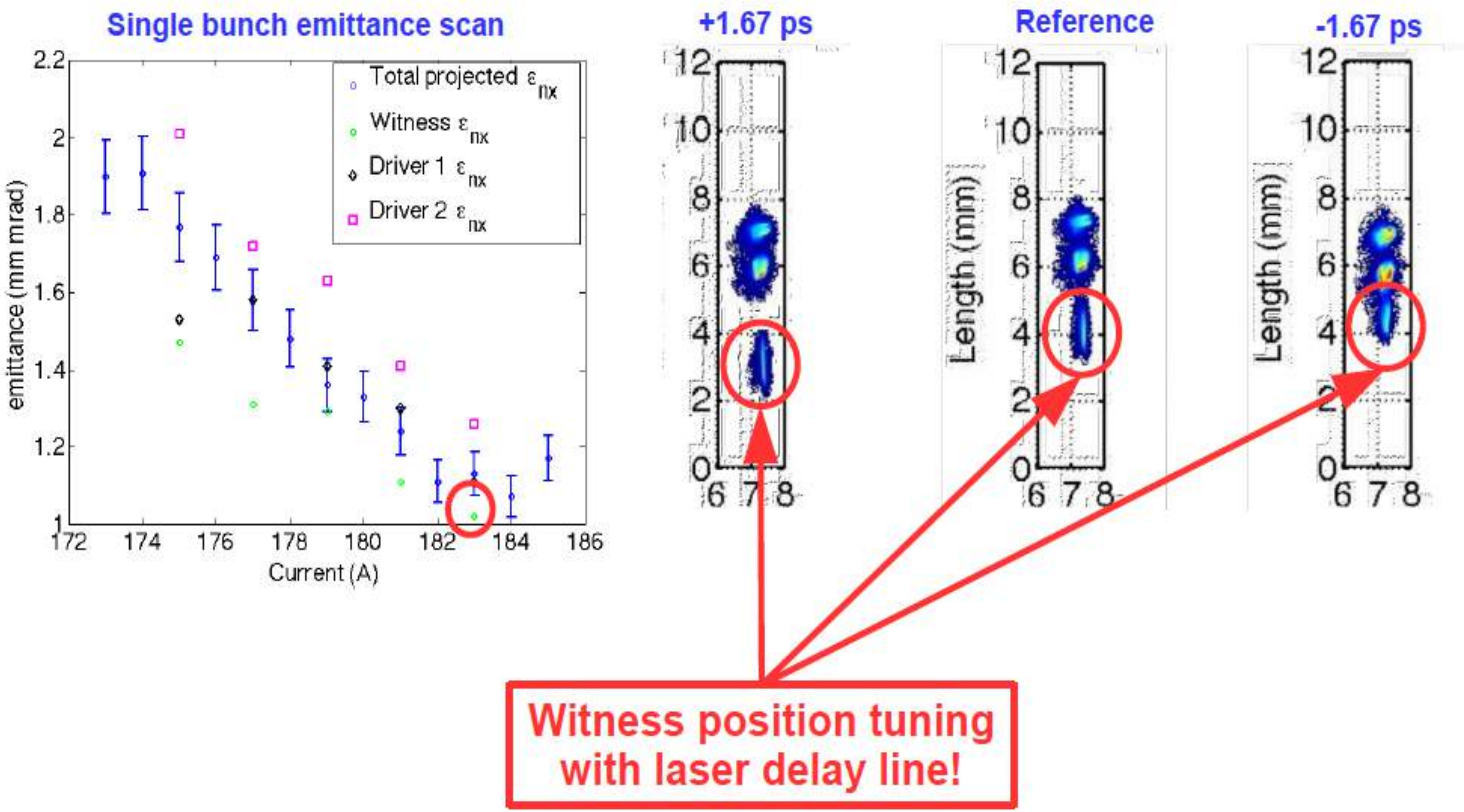
- A laser beam excites plasma waves in a capillary filled with gas
- A high brightness electron beam uses this wave to be accelerated

n_e = 1x10^{17} cm^{-3}
λ_p = 100µm
Capillary 100 µm
Hydrogen

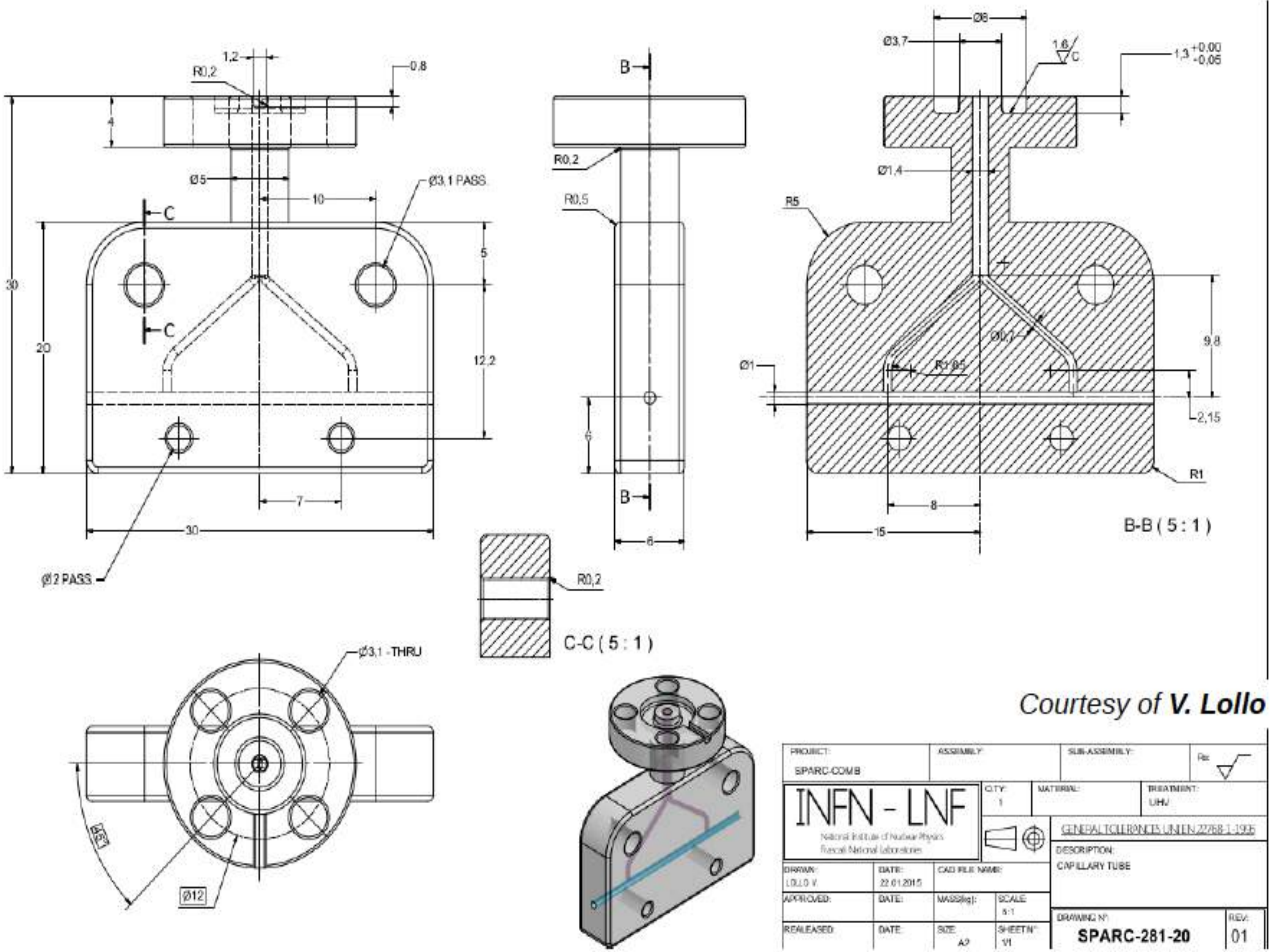


n_0 = 8e15 1/cm^3, Pos: -100 mm, σ_x DRIVER:369.91 μ m, σ_x WITNESS:42.87 μ m
E [MeV]
z-z_g [μ m]
300
250
200
150
100
50
0
-50
-100
-800
-600
-400
-200
0
200
QFluidCOMB Paolo Tomassini

Witness – tuning and characterization

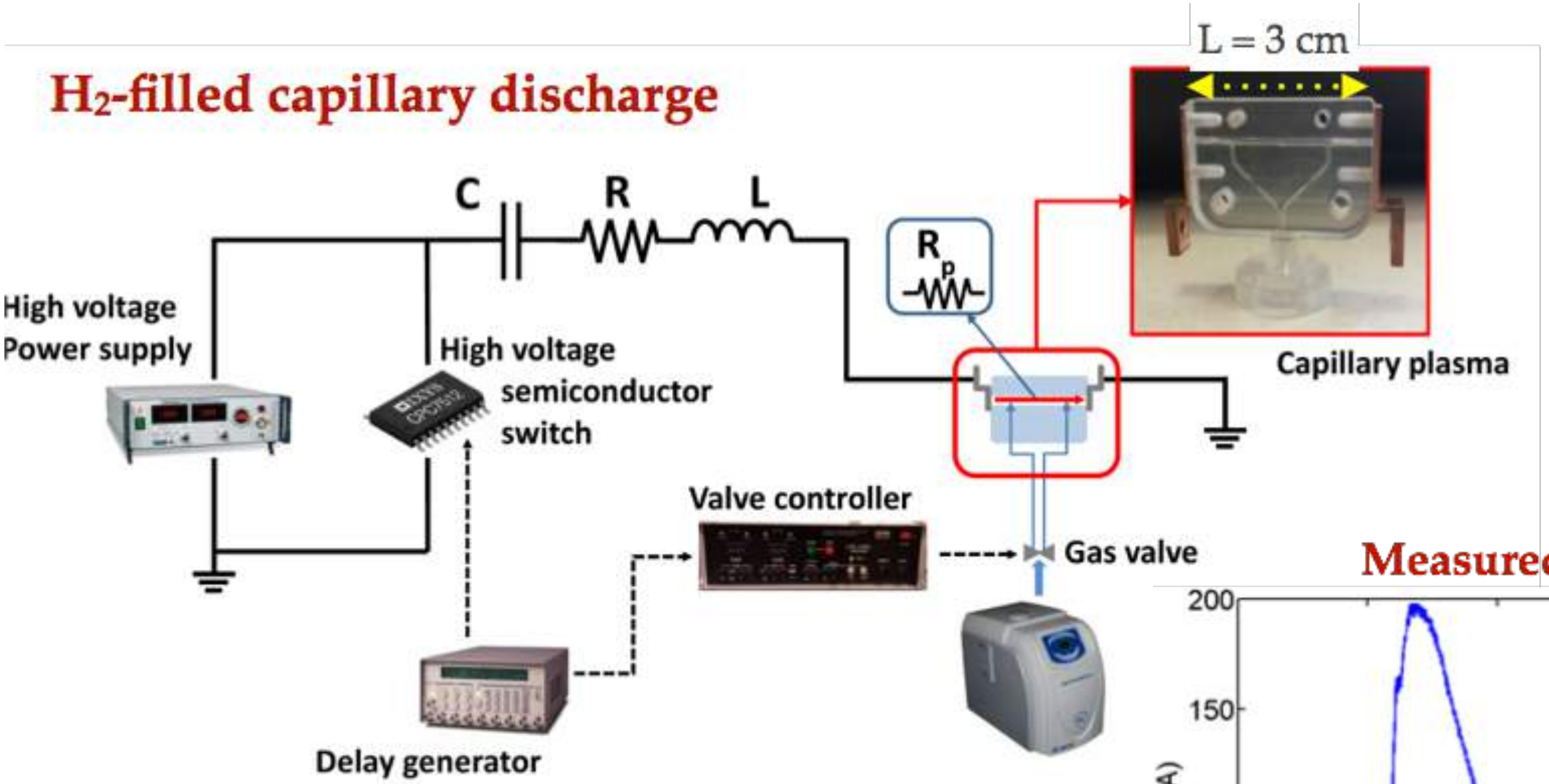


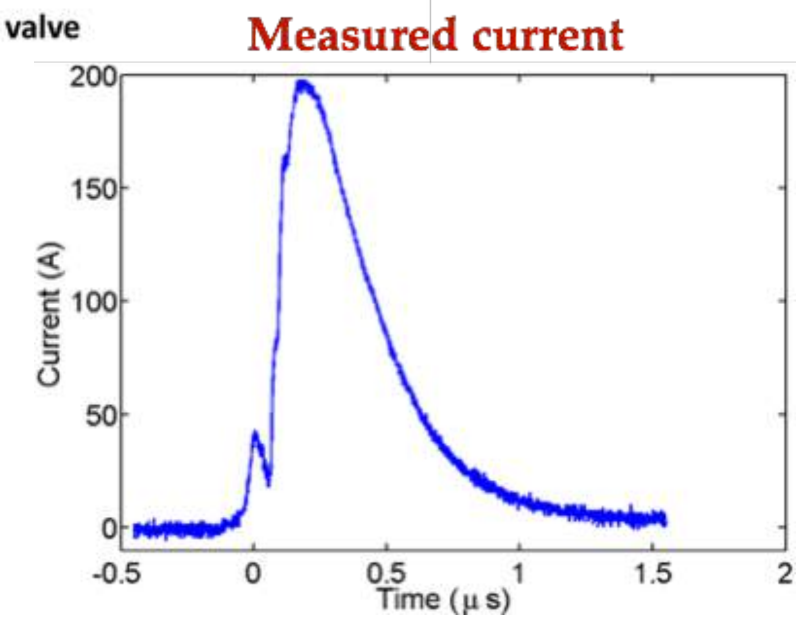
Plasma capillary



Courtesy of ***V. Lollo***

Plasma Source

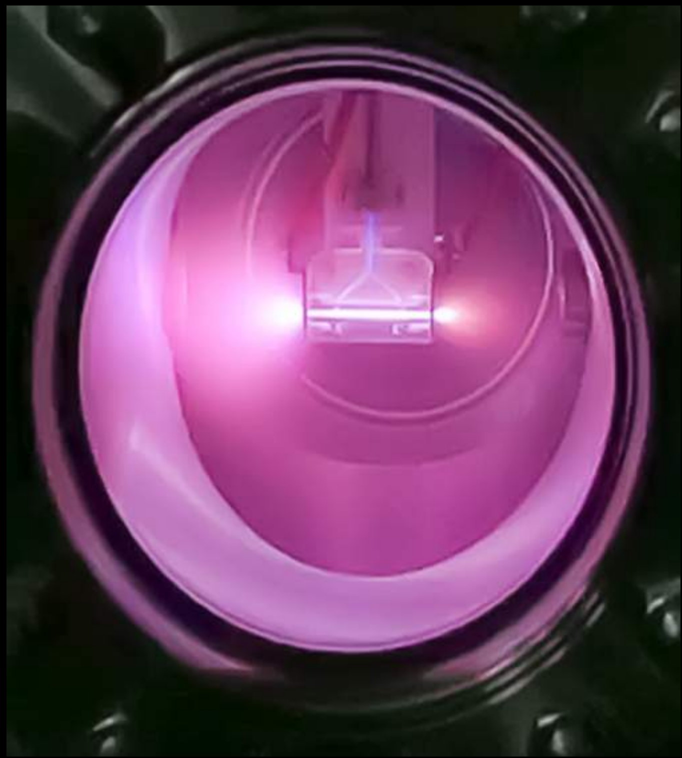




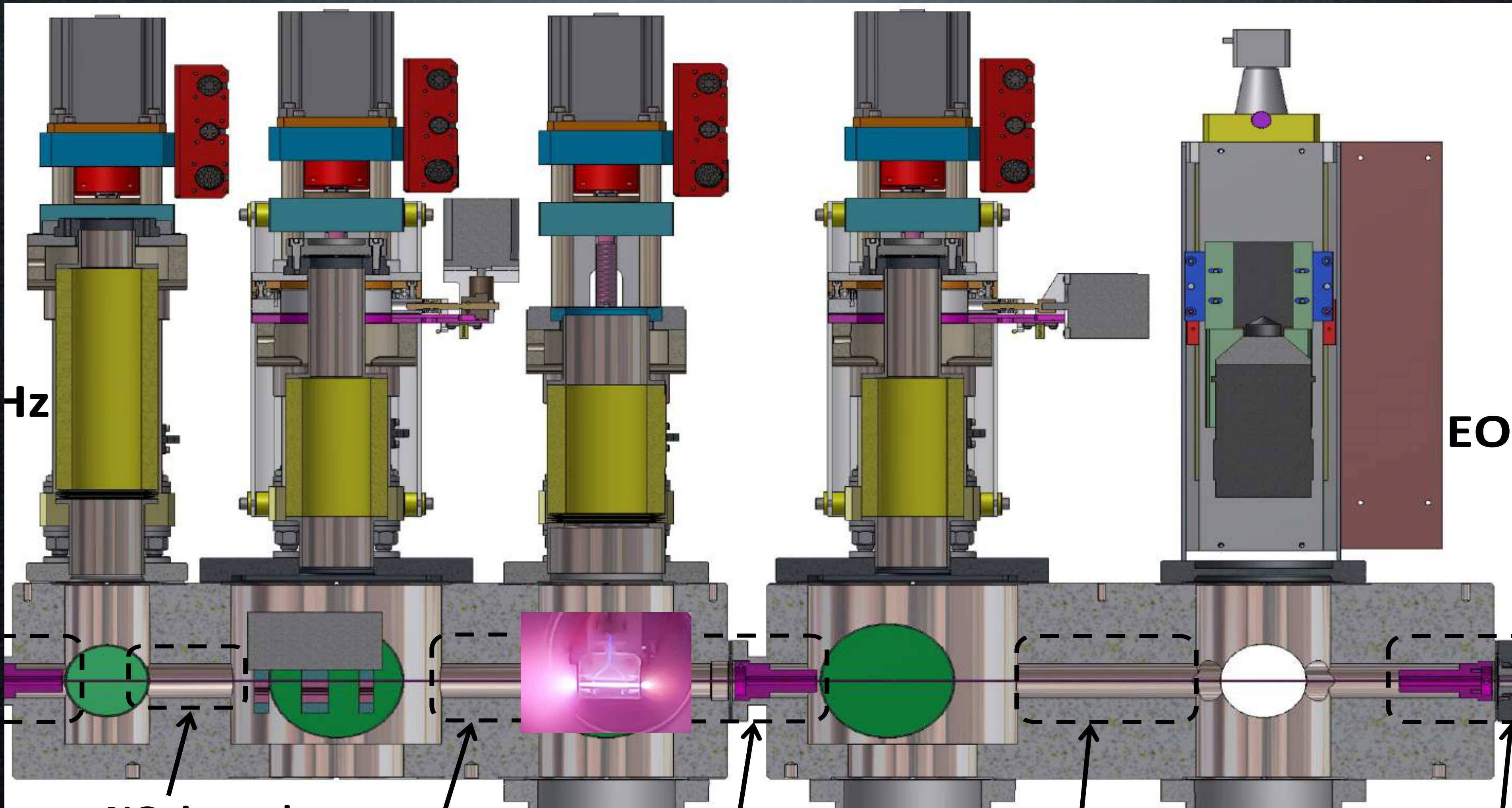
P_{H2} = 10 mbar
Total discharge duration: 800 ns
Voltage: 20 kV
Peak current: 200 A
Capacitor: 6 nF

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

Capillary Discharge at SPARC_LAB



PWFA - Particle Wake Field Accelerator

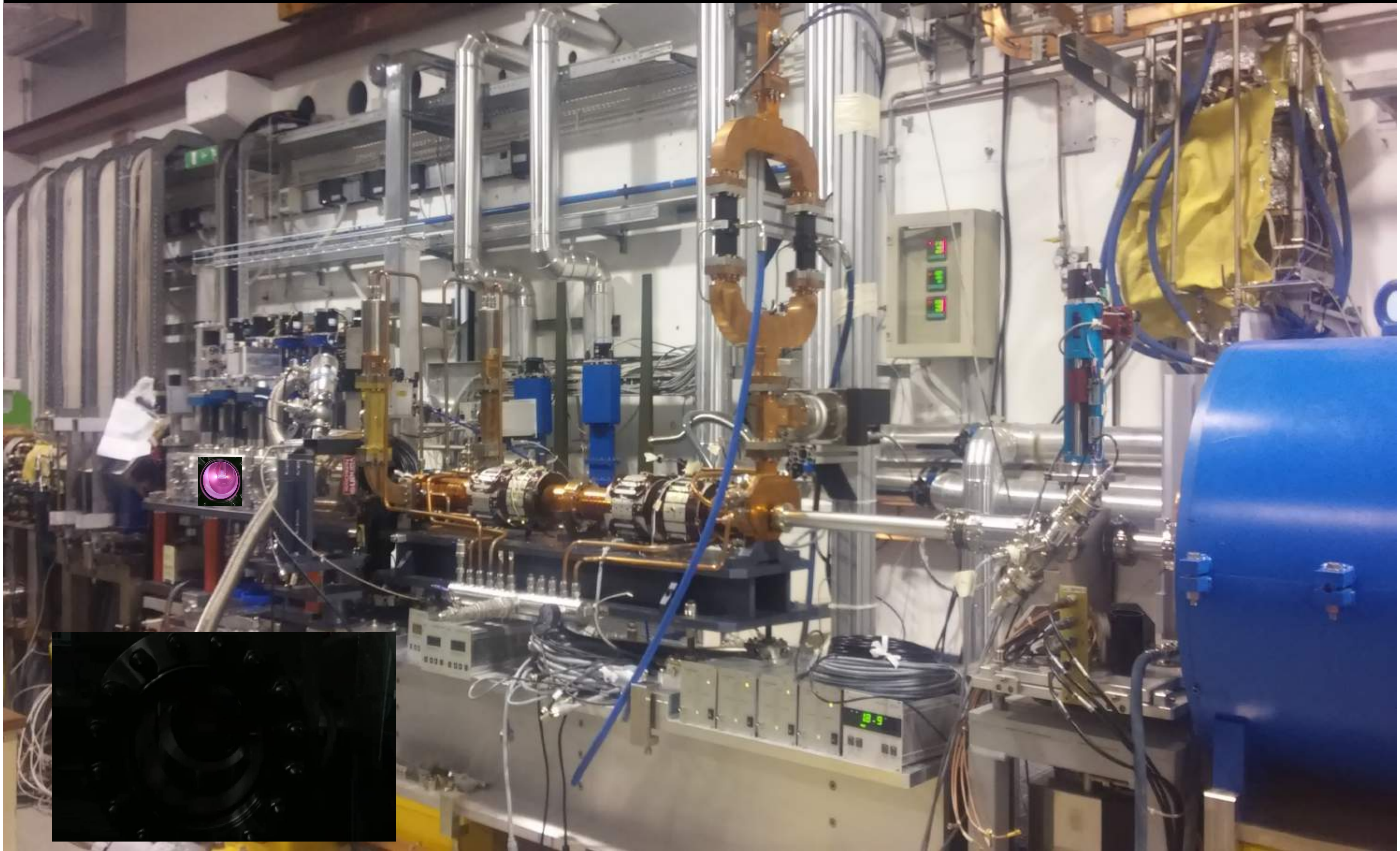


Focusing PMQ

PWFA module

Capture PMQ

PWFA vacuum chamber at SPARC_LAB



APPLIED PHYSICS LETTERS 110, 104101 (2017)

Experimental characterization of active plasma lensing for electron beams

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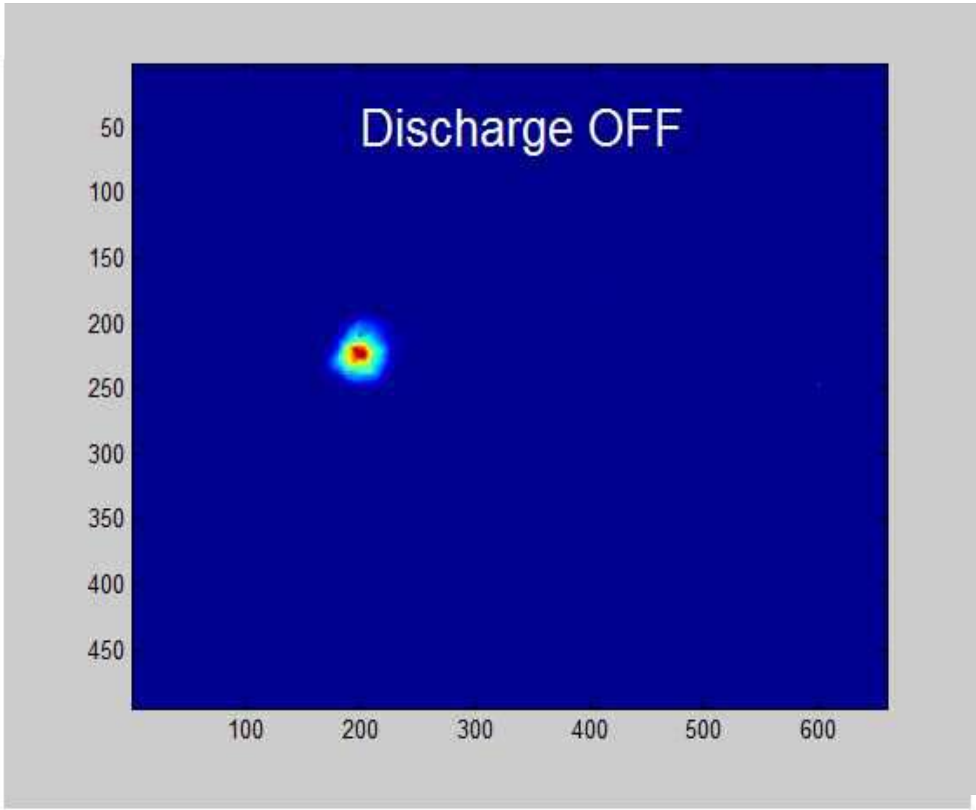

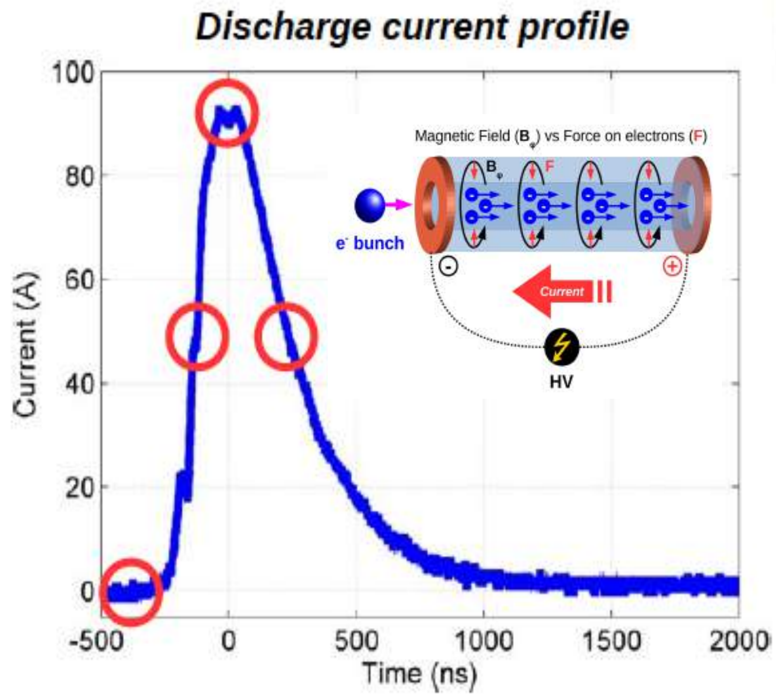


Grazie Mario
&
Grazie Enrico
Giornata per Mario Calvetti ed Enrico Iacopini - Firenze 21 Giugno 2018