Advanced Acceleration at SPARC_LAB

Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams

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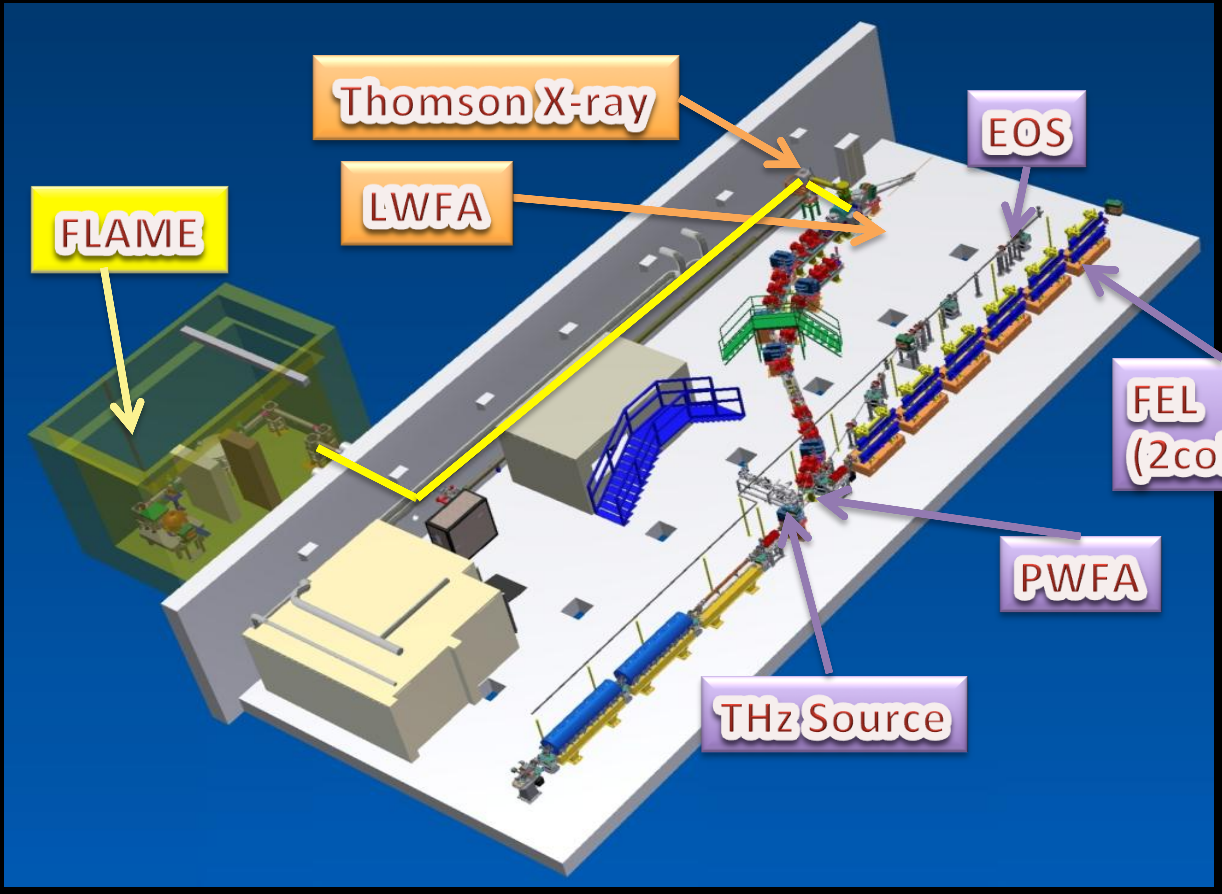
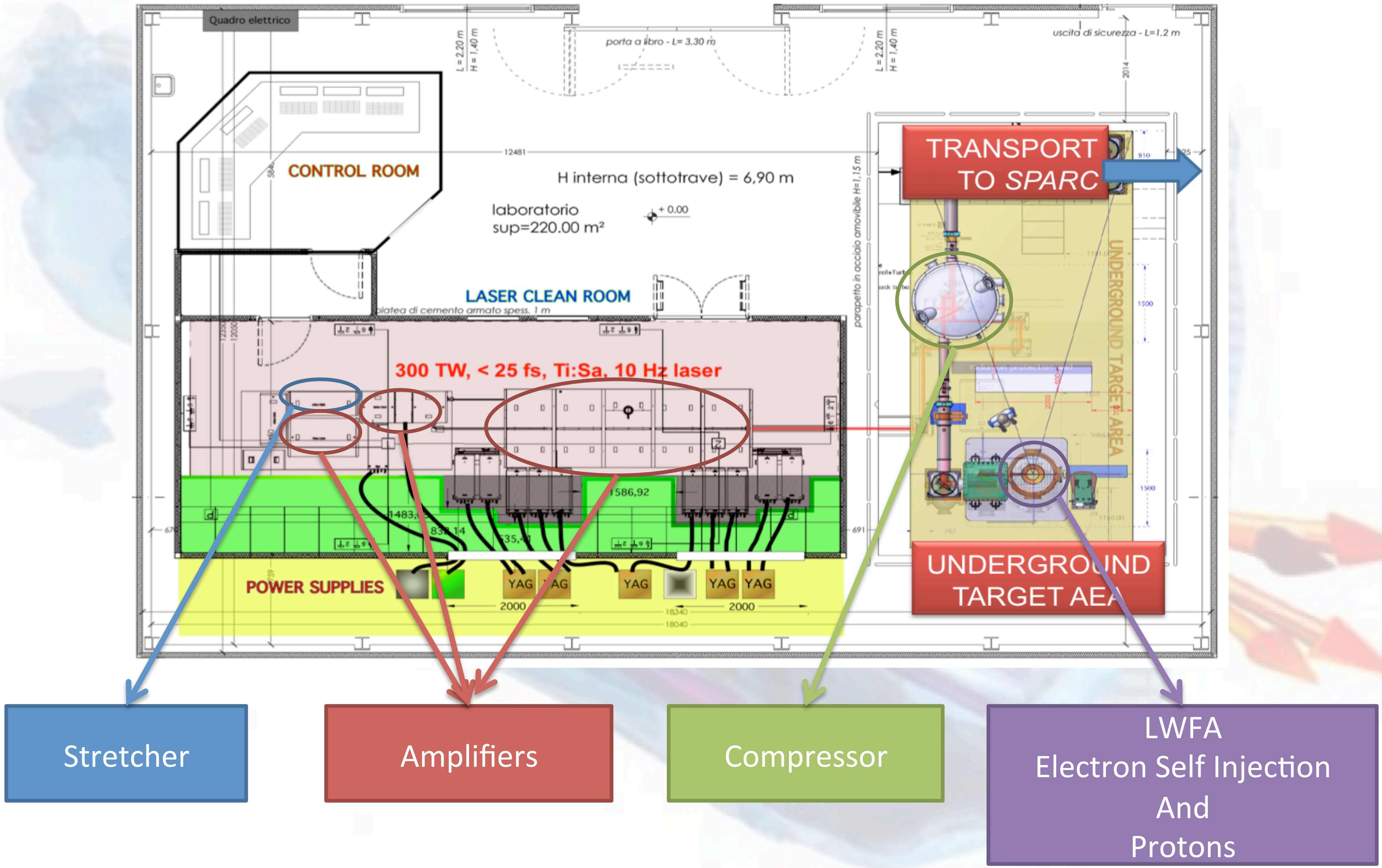
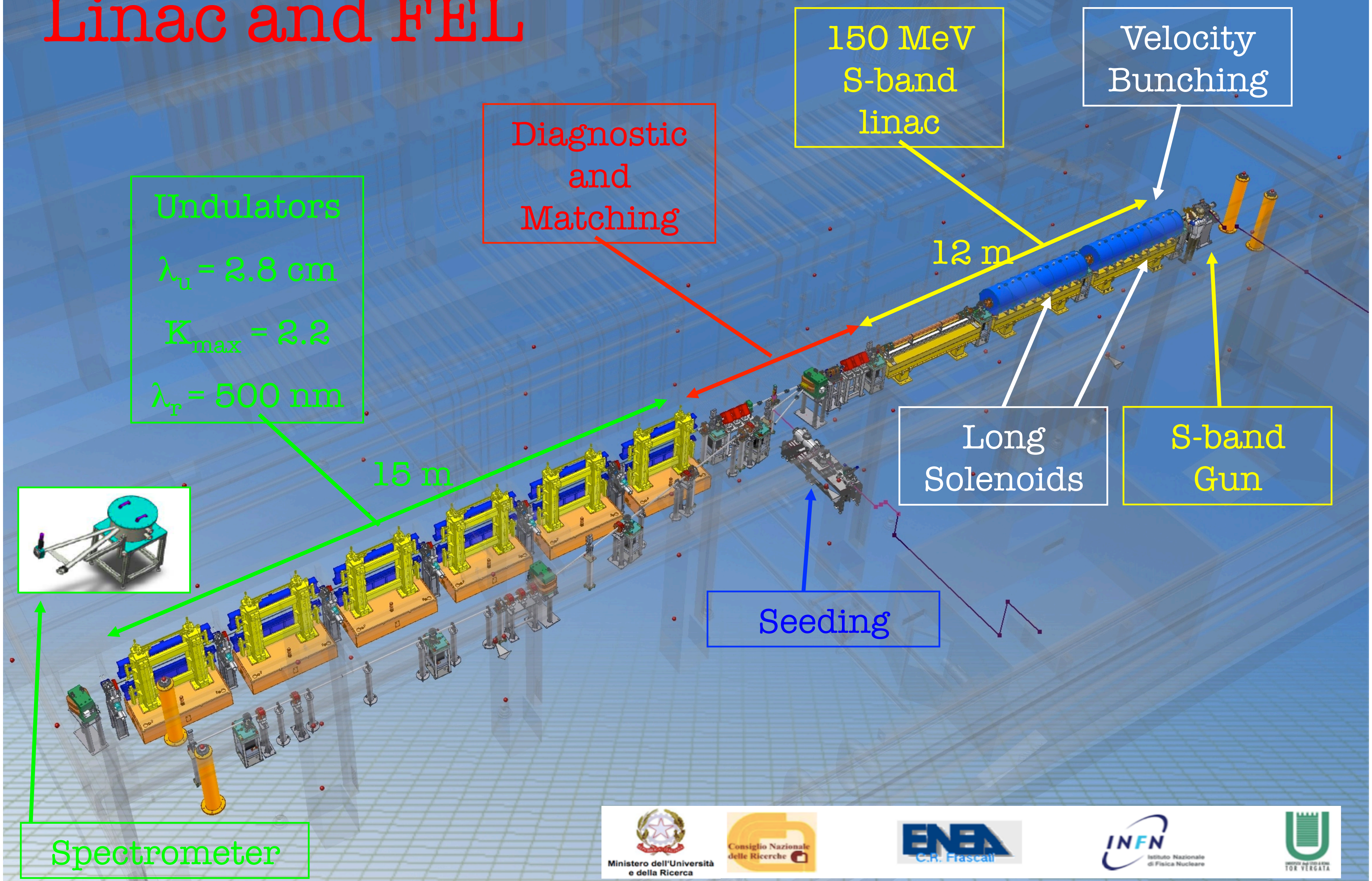


Virtuelles Institut PWFA – Hamburg, May 21, 2014

Ti:Sa FLAME laser



Linac and FEL



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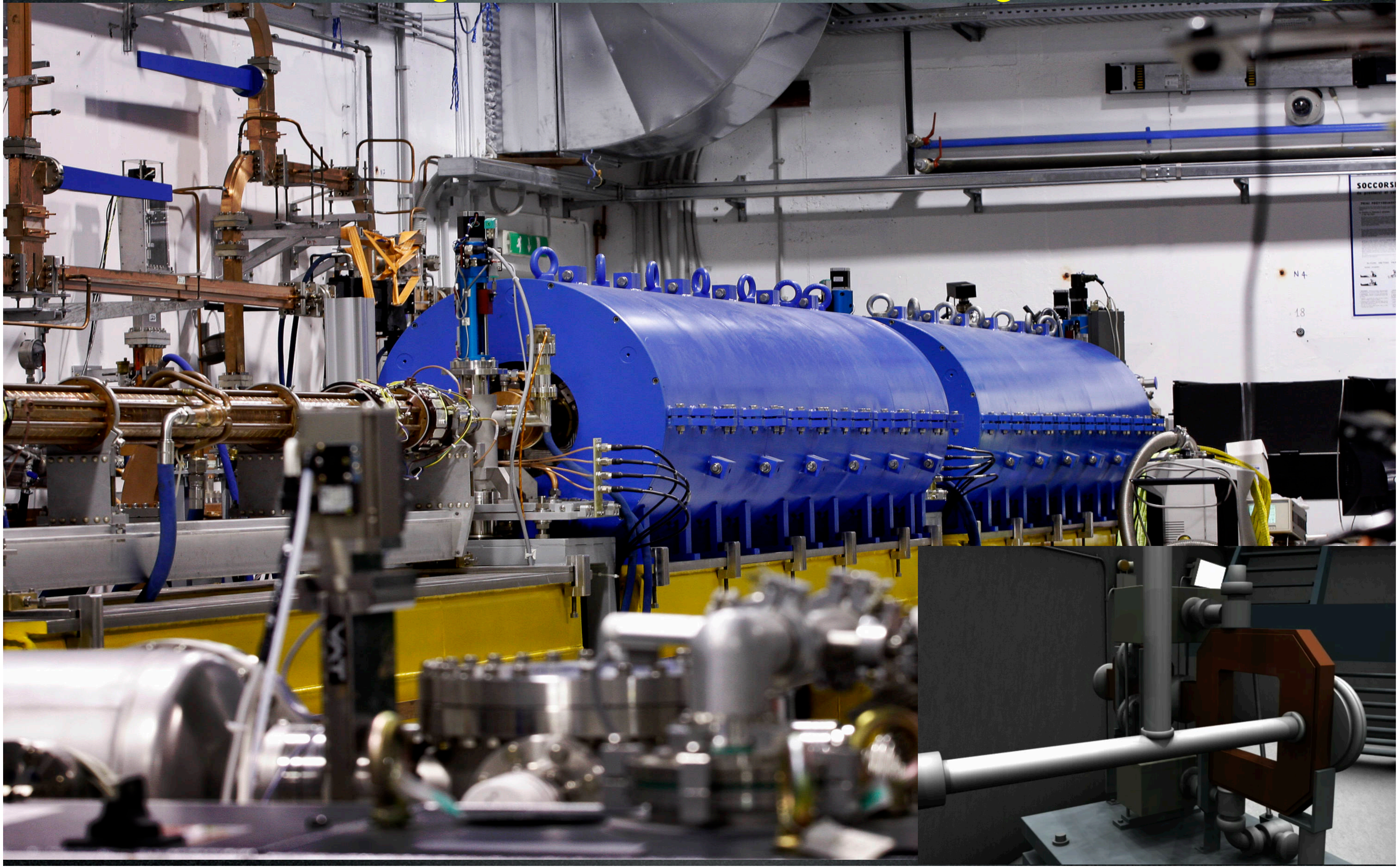
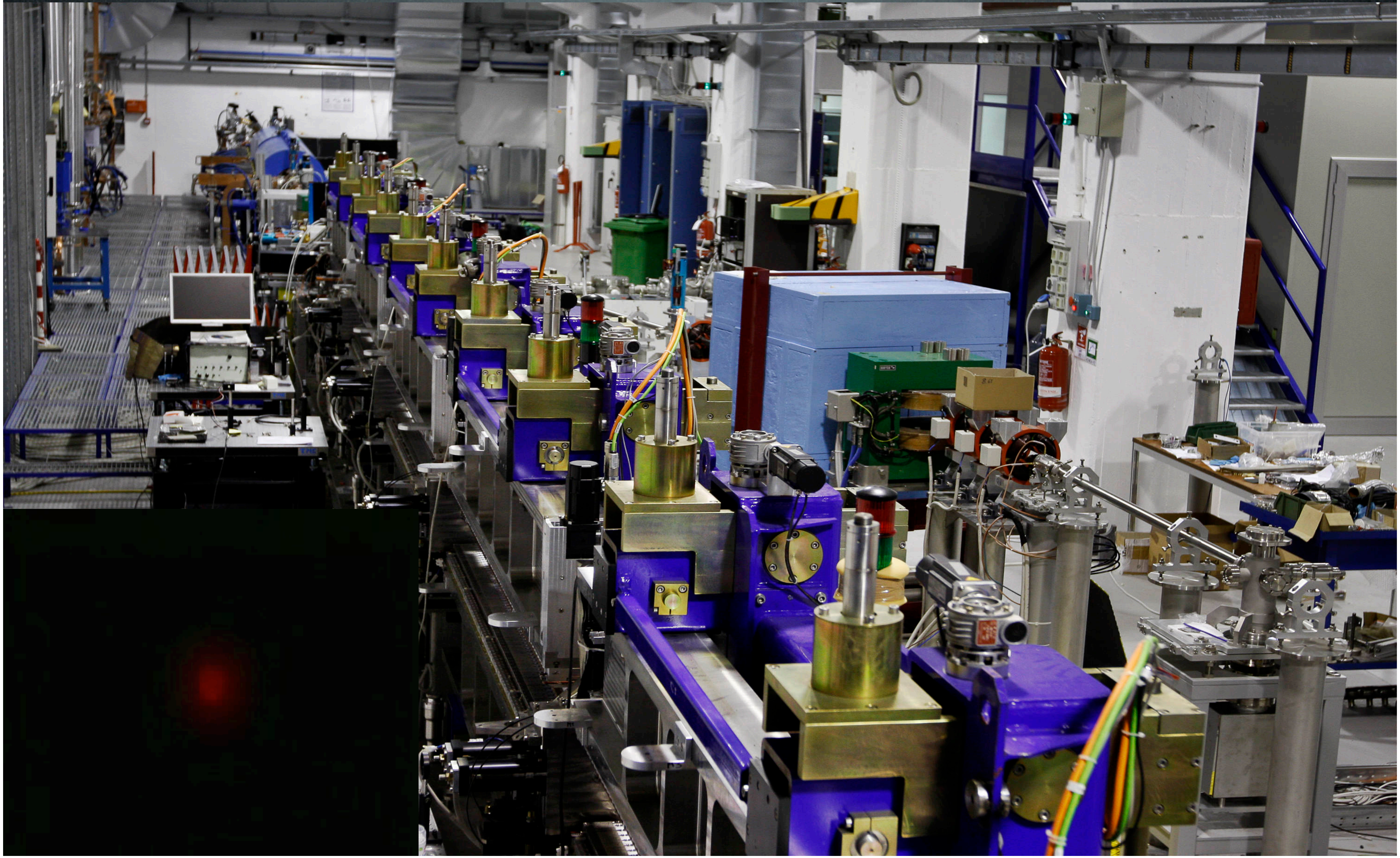
ENEA C.R. Frascati
INFN Istituto Nazionale di Fisica Nucleare

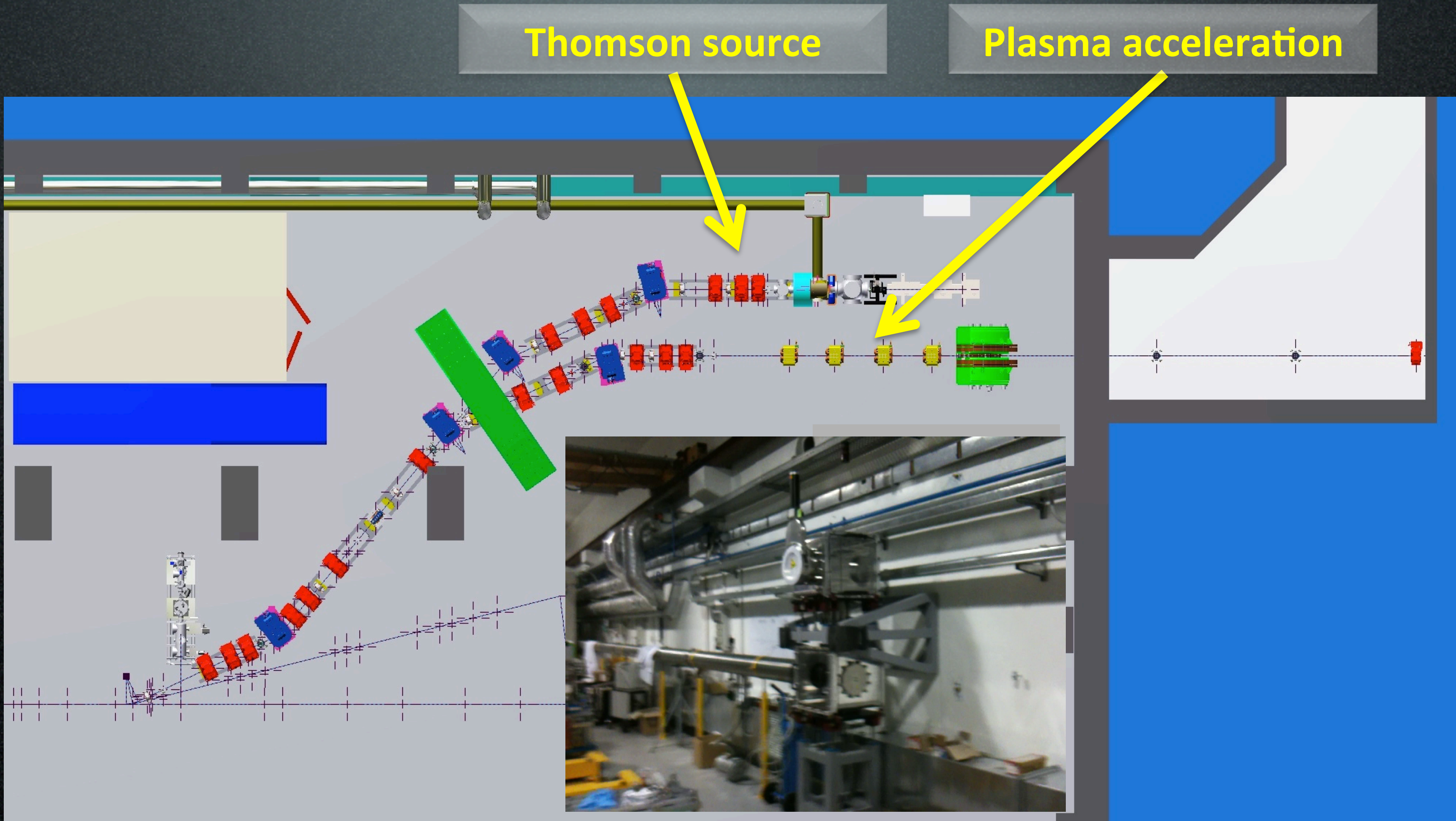
HB photo- injector with Velocity Bunching



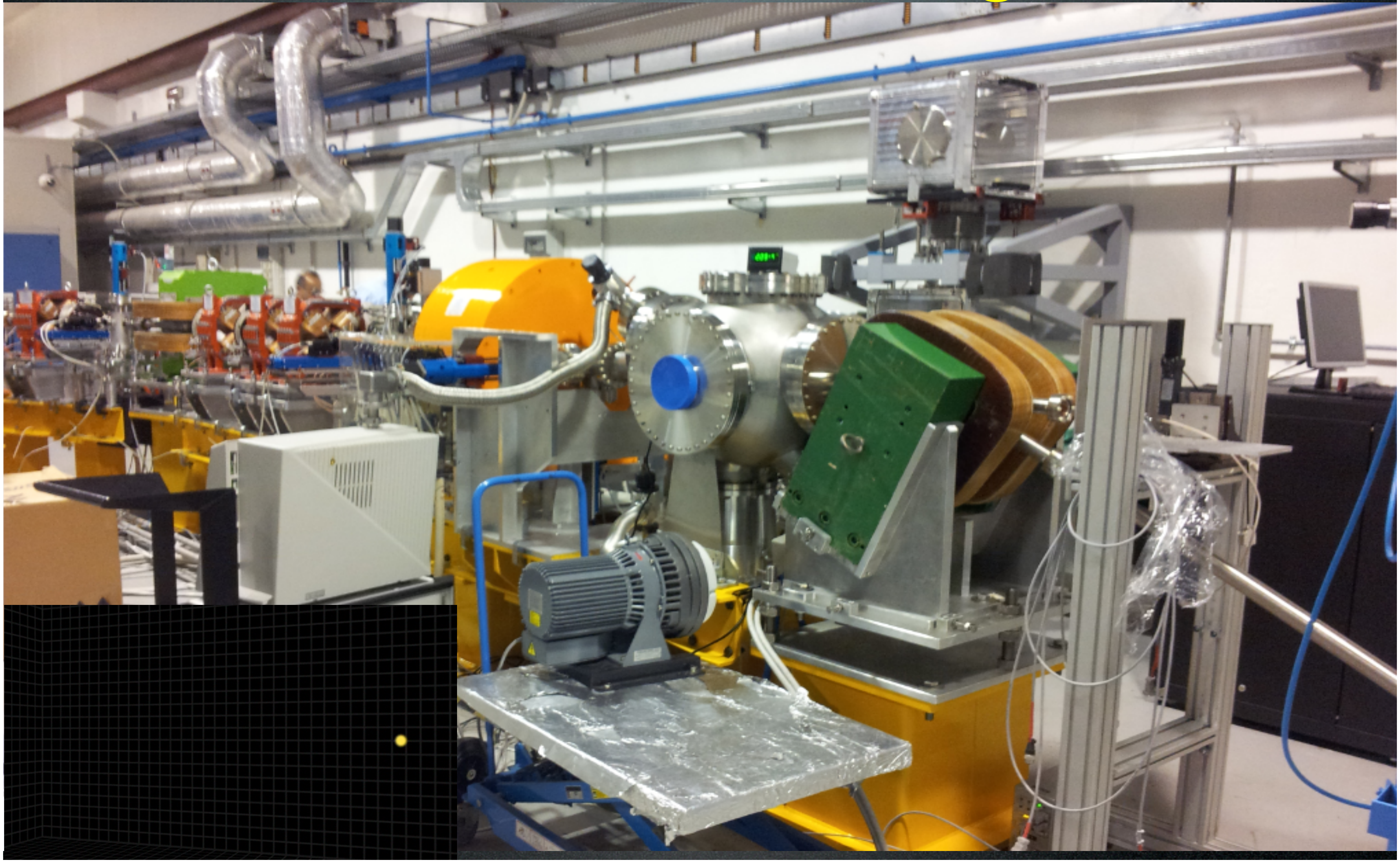
Free Electron Laser



New installations



Thomson back-scattering source

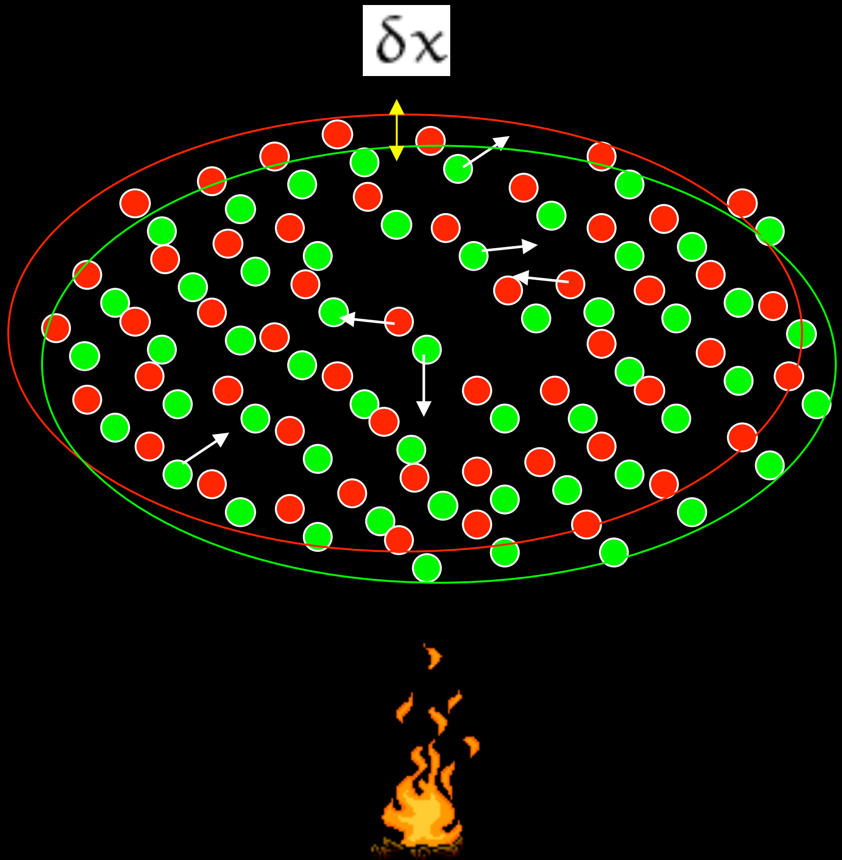


Space Charge induced emittance oscillations in a laminar beam

Neutral Plasma

Surface charge density

$$\sigma = e\, n\, \delta x$$



Surface electric field

$$E_x = -\sigma/\epsilon_0 = -e\, n\, \delta x/\epsilon_0$$

Restoring force

$$m \frac{d^2 \delta x}{dt^2} = e\, E_x = -m\, {\omega_p}^2\, \delta x$$

Plasma frequency

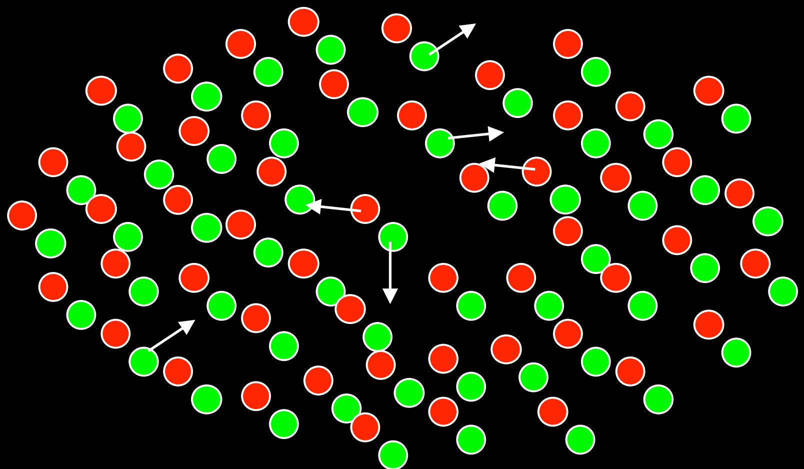
$$ {\omega_p}^2 = \frac{n\, e^2}{\epsilon_0\, m}$$

Plasma oscillations

$$\delta x = (\delta x)_0 \cos(\omega_p\, t)$$

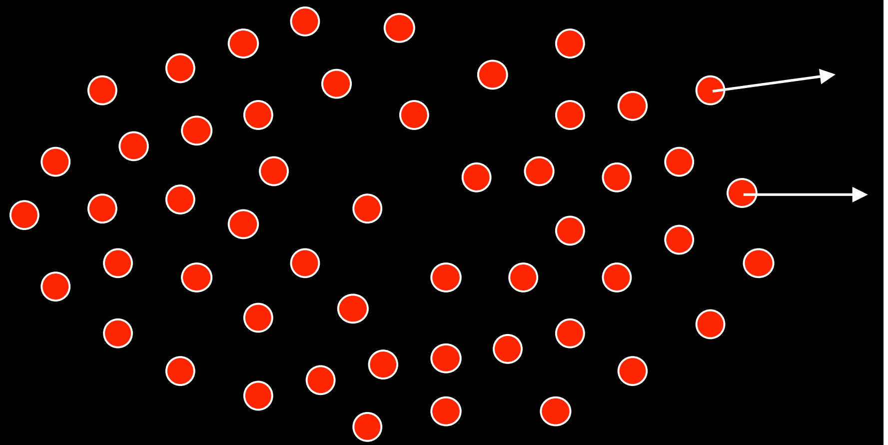
Neutral Plasma

- Oscillations
- Instabilities
- EM Wave propagation



Single Component Cold Relativistic Plasma

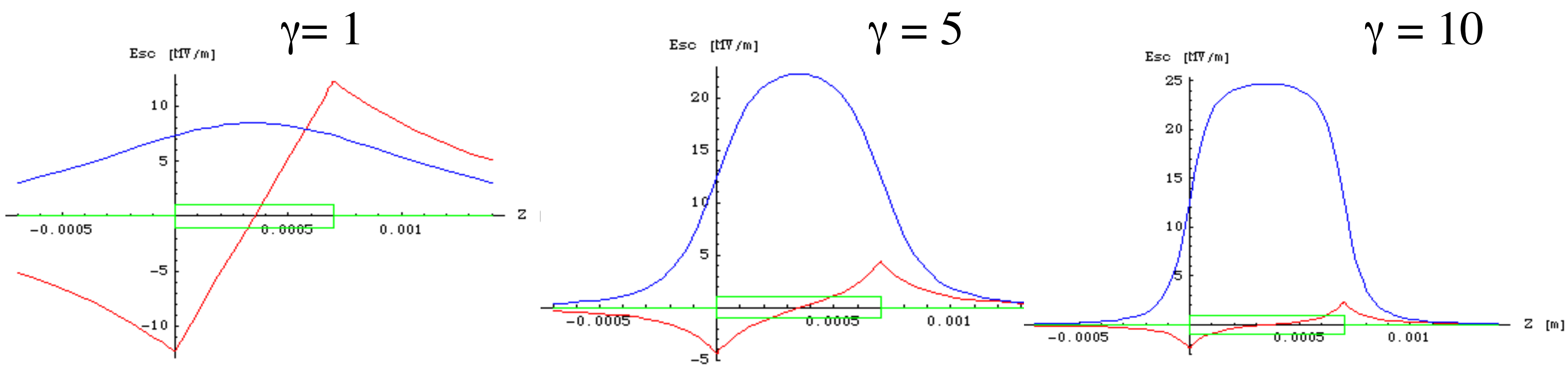
Magnetic focusing



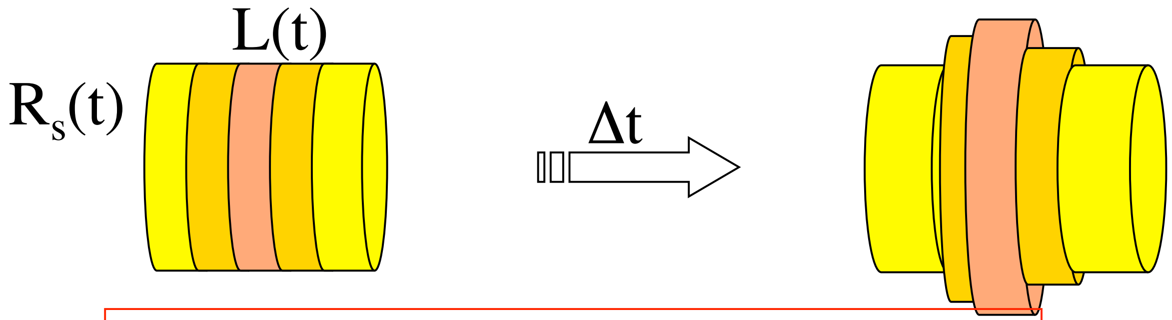
Magnetic focusing

$$E_z(0,s,\gamma) = \frac{I}{2\pi\gamma\varepsilon_0 R^2 \beta c} h(s,\gamma)$$

$$E_r(r,s,\gamma) = \frac{Ir}{2\pi\varepsilon_0 R^2 \beta c} g(s,\gamma)$$



$$F_r = \frac{eE_r}{\gamma^2} = \frac{eIr}{2\pi\gamma^2\varepsilon_0 R^2 \beta c} g(s,\gamma)$$



$$\sigma_x'' + \frac{(\beta\gamma)'}{\beta\gamma}\sigma_x' + k^2\sigma_x = \frac{\varepsilon_n^2}{(\beta\gamma)^2\sigma_x^3} + \frac{k_{sc}(s,\gamma)}{\sigma_x}$$

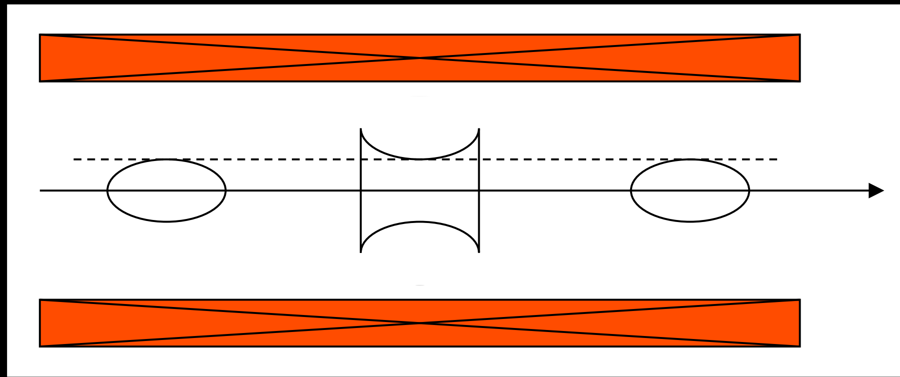
Single Component Relativistic Plasma

$$\sigma'' + k_s^2\sigma = \frac{k_{sc}(s,\gamma)}{\sigma}$$

$$k_s = \frac{qB}{2mc\beta\gamma}$$

Equilibrium solution:

$$\sigma_{eq}(s,\gamma) = \frac{\sqrt{k_{sc}(s,\gamma)}}{k_s}$$



Small perturbation:

$$\sigma(\zeta) = \sigma_{eq}(s) + \delta\sigma(s)$$

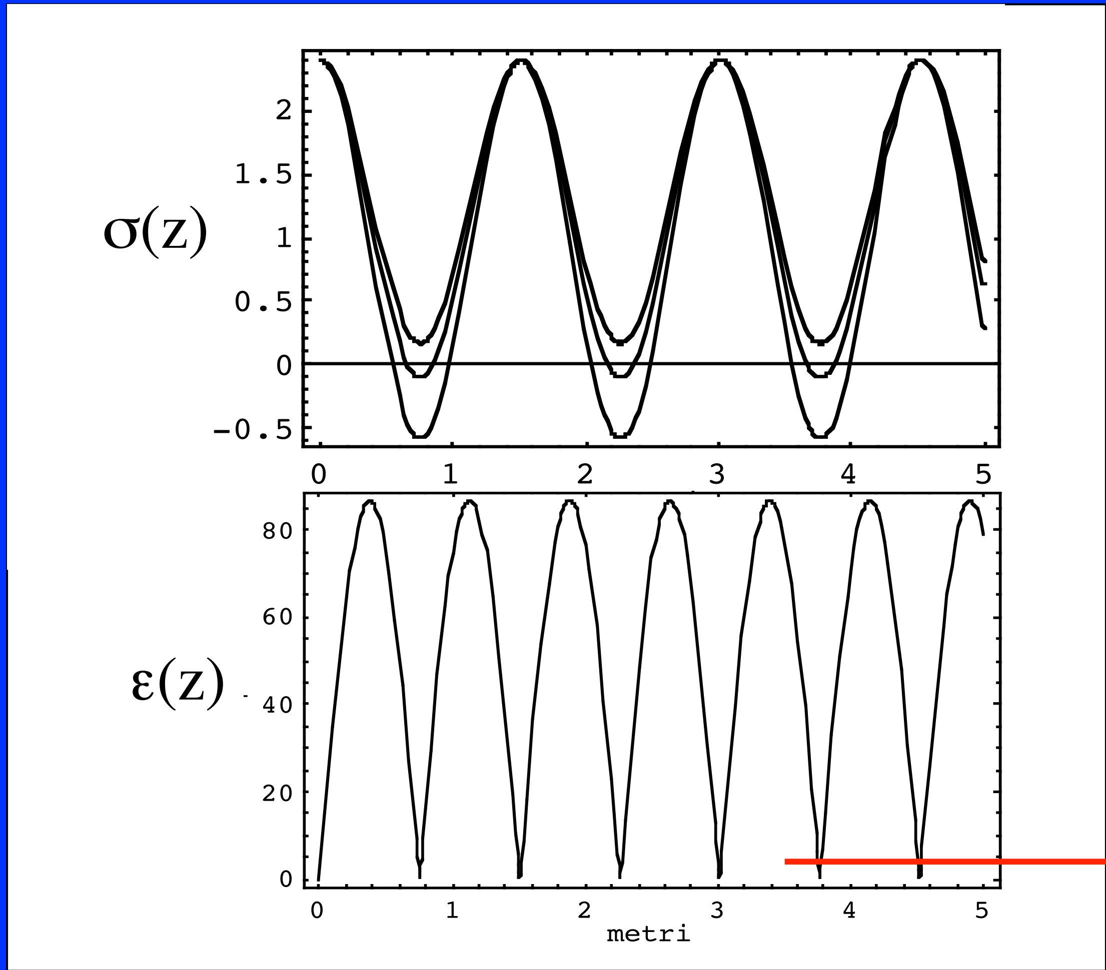
$$\delta\sigma''(s) + 2k_s^2\delta\sigma(s) = 0$$

$$\delta\sigma(s) = \delta\sigma_o(s)\cos\left(\sqrt{2}k_s z\right)$$

Perturbed trajectories oscillate around the equilibrium with the same frequency but with different amplitudes:

$$\sigma(s) = \sigma_{eq}(s) + \delta\sigma_o(s)\cos\left(\sqrt{2}k_s z\right)$$

Envelope oscillations drive Emittance oscillations



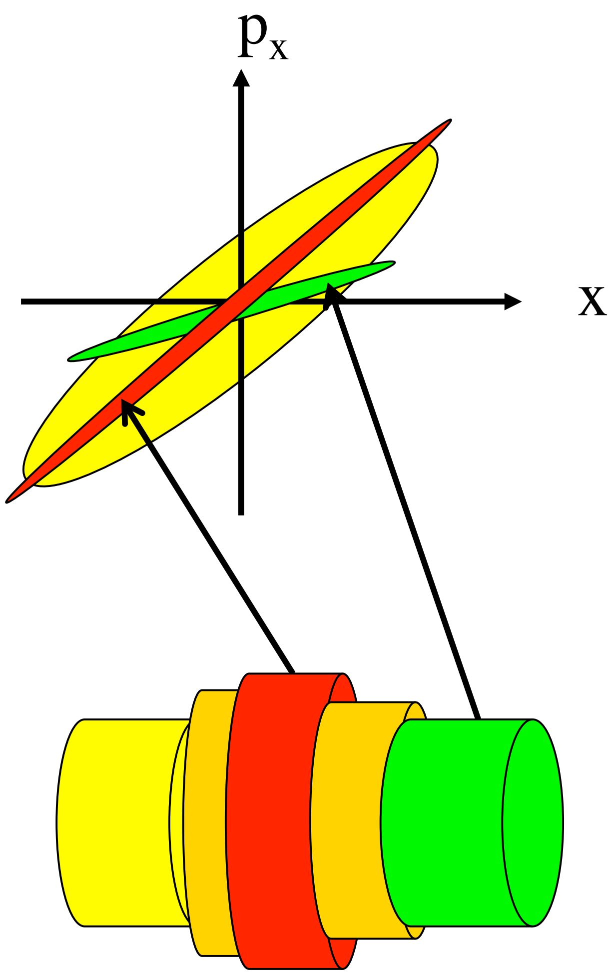
$$\frac{\delta\gamma}{\gamma} = 0$$

$$\sigma' = 0$$

$$\varepsilon_{rms} = \sqrt{\sigma_x^2 \sigma_{x'}^2 - \sigma_{xx'}{}^2} = \sqrt{\left(\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2\right)} \approx \left| sin\left(\sqrt{2} k_s z\right) \right|$$

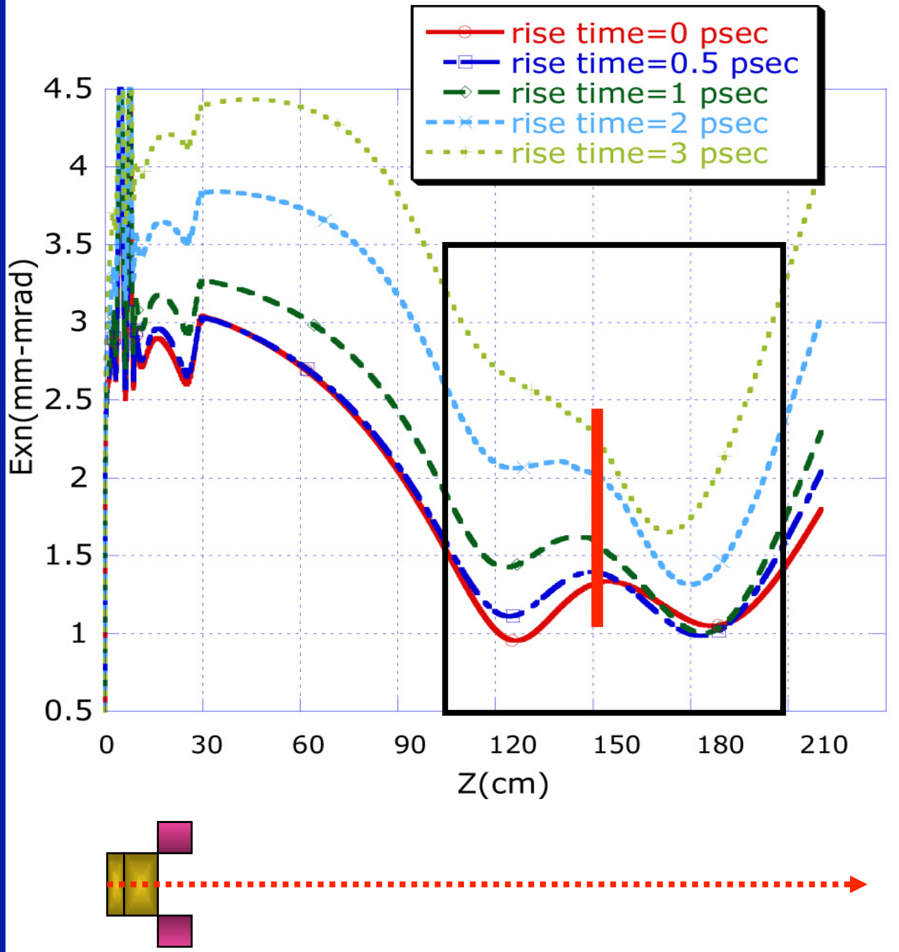
Emittance Oscillations are driven by space charge differential defocusing in core and tails of the beam

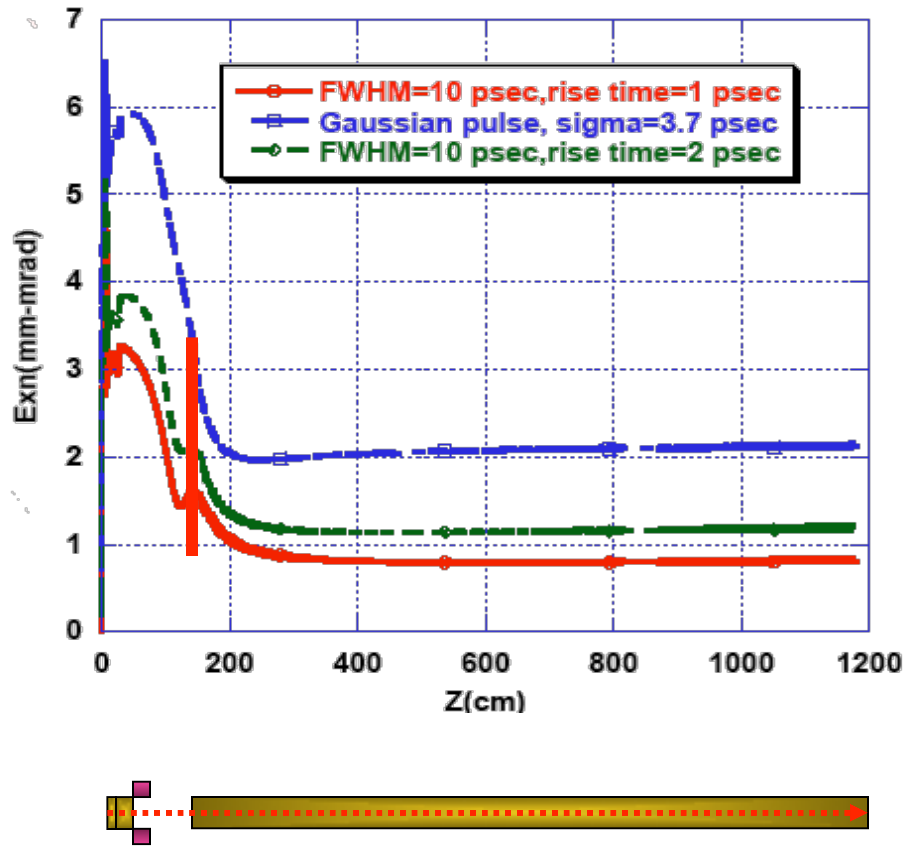
Projected Phase Space



Slice Phase Spaces

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]

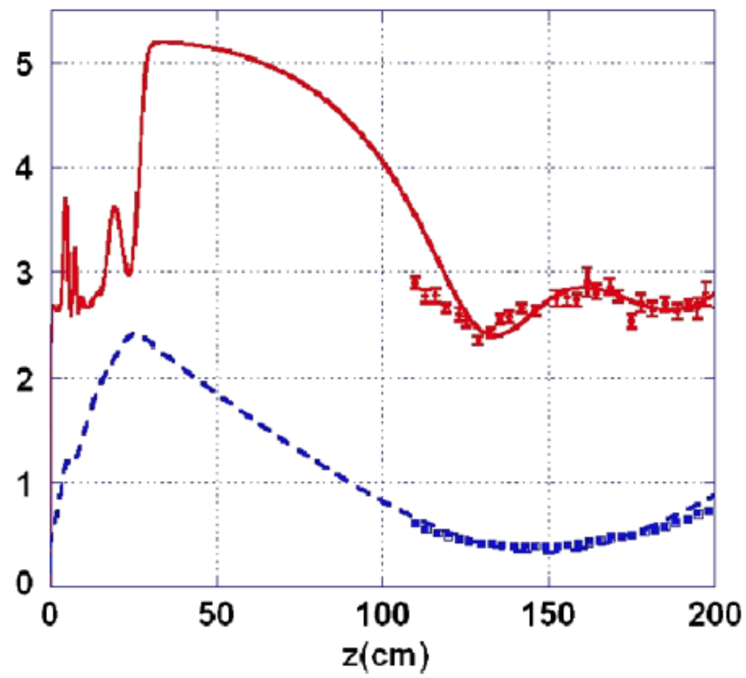


FIG. 6 (color online). rms envelope and rms norm. emittance evolution from the cathode up to the beam line end as computed by PARMELA, compared to measurements taken in the emittance-meter range.

Velocity Bunching

Bunch length in the moving frame S'

More interesting is the bunch dynamics as seen by a moving reference frame S', that we assume it has a relative velocity V with respect to S such that at the end of the process the accelerated bunch will be at rest in the moving frame S'. It is actually a deceleration process as seen by S'

Inverse Lorentz transformations:

$$\begin{cases} ct' = \gamma\left(ct - \frac{V}{c}z\right) \\ z' = \gamma(z - Vt) \end{cases}$$

leading for the tail particle to:

$$\begin{cases} t'_{o,t} = t_o = 0 \\ z'_{o,t} = z_{o,t} = 0 \end{cases}$$

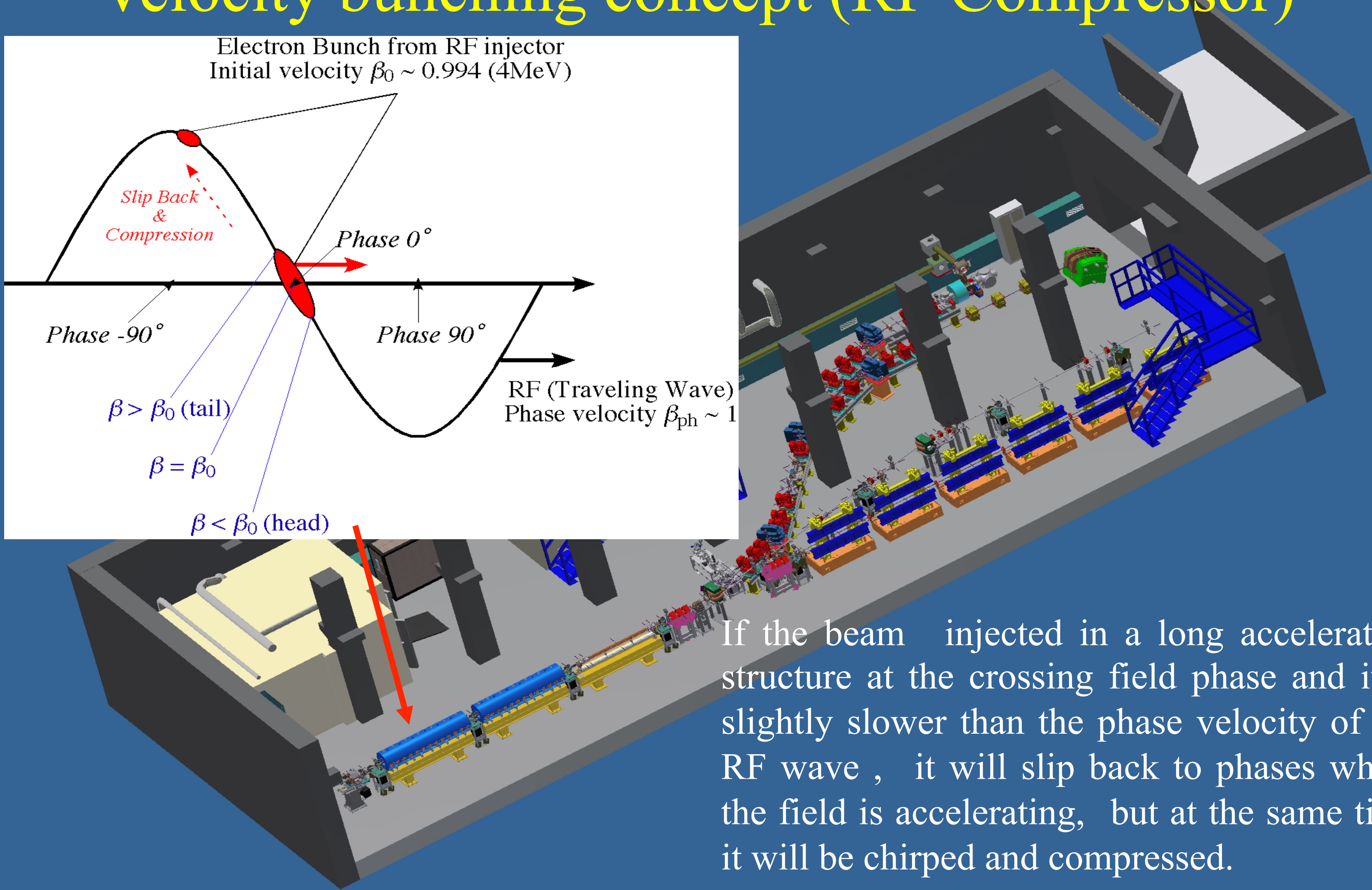
and for the head particle to:

$$\begin{cases} t'_{o,h} = -\frac{V}{c}\gamma'_o L_o < t_o \\ z'_{o,h} = \gamma'_o L_o > z_{o,h} \end{cases}$$

The key point is that as seen from S' the decelerating force is not applied *simultaneously* along the bunch but with a *delay* given by:

$$\Delta t'_o = t'_{o,h} - t'_{o,t} = -\frac{V}{c}\gamma'_o L_o < 0$$

Velocity bunching concept (RF Compressor)

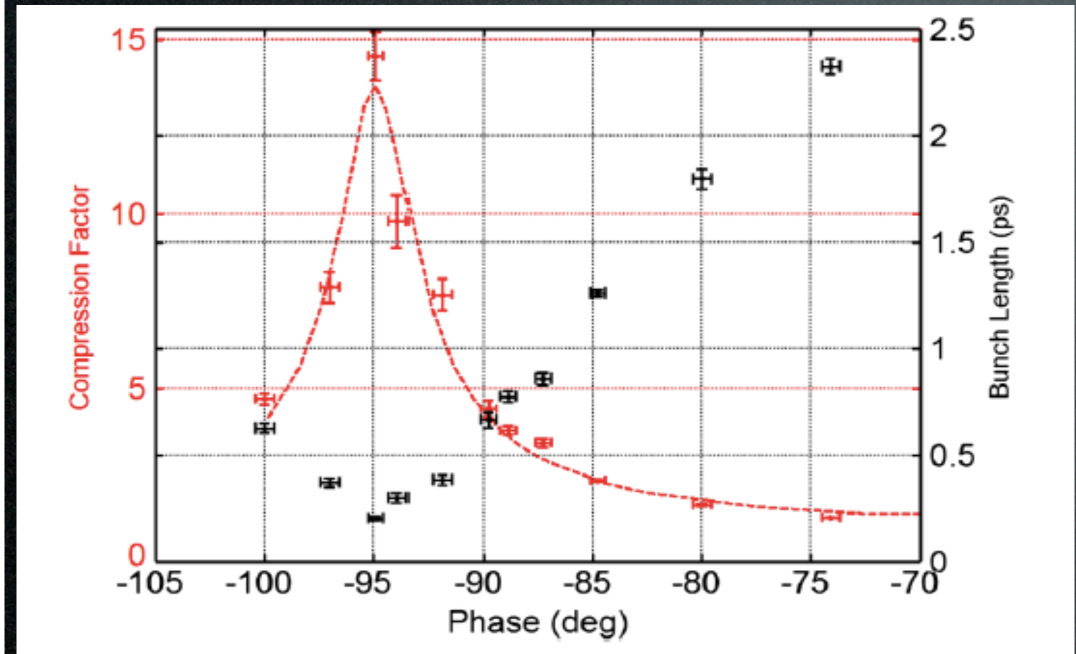


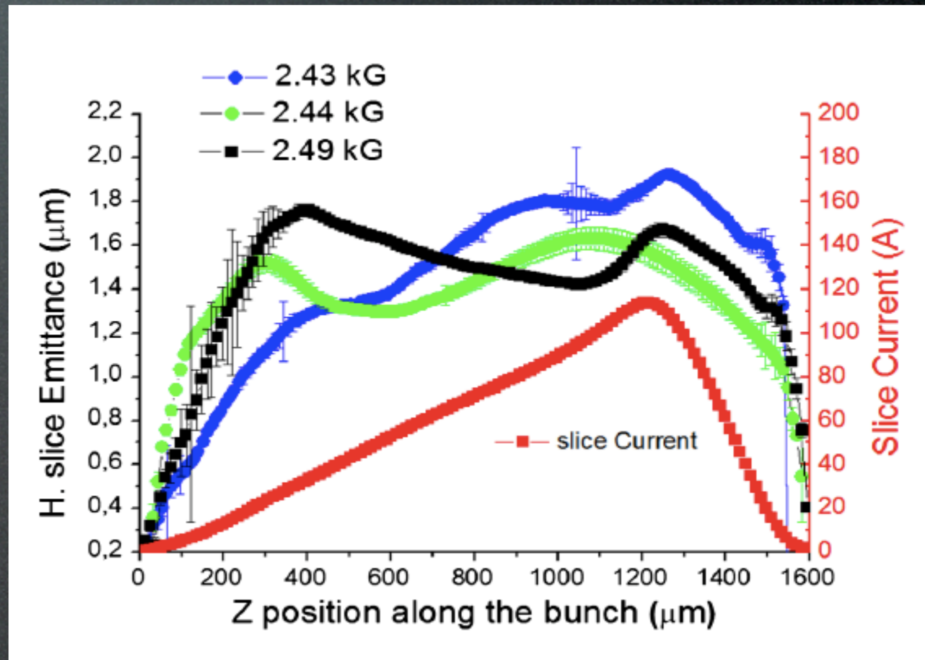
If the beam injected in a long accelerating structure at the crossing field phase and it is slightly slower than the phase velocity of the RF wave , it will slip back to phases where the field is accelerating, but at the same time it will be chirped and compressed.

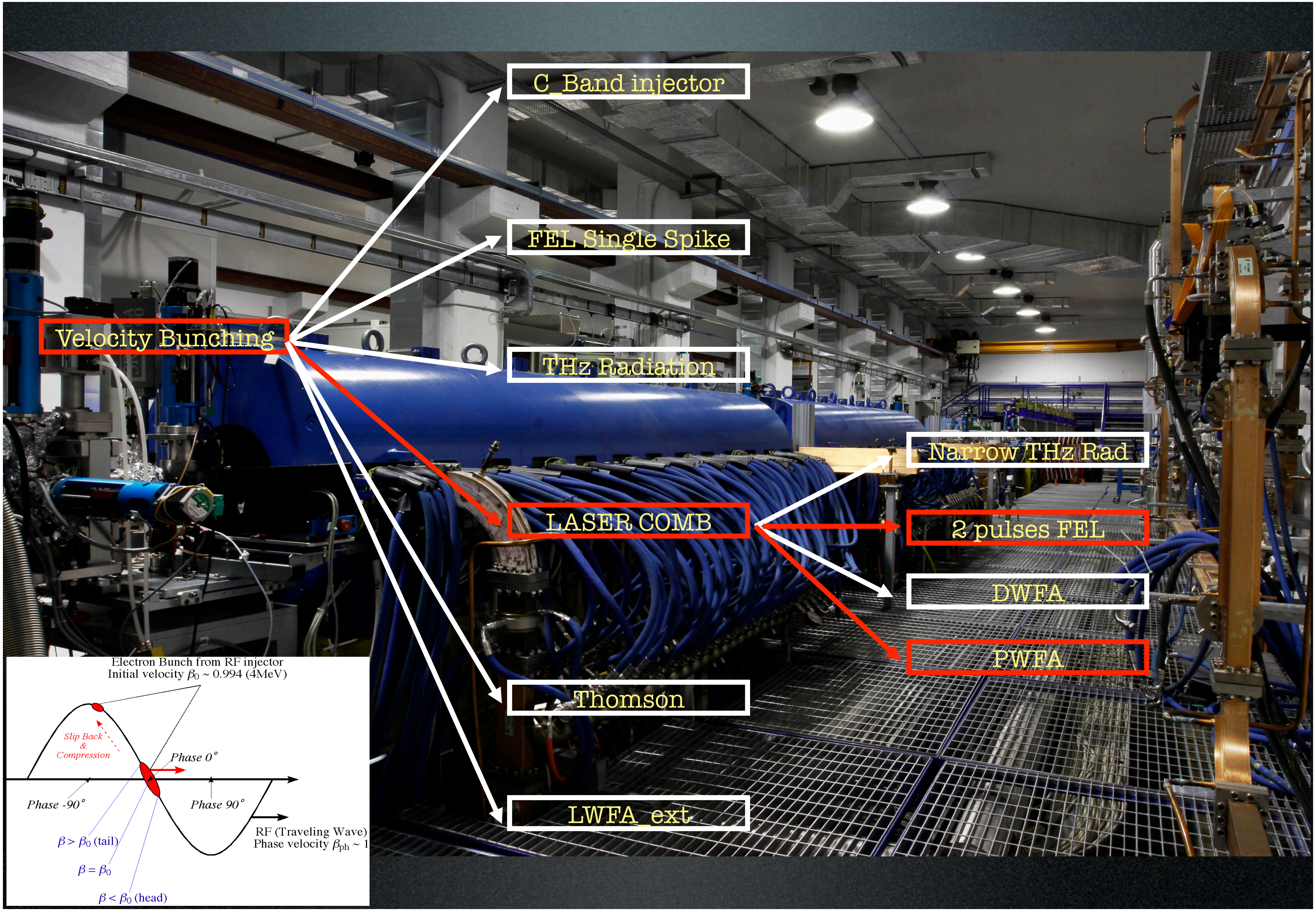
PRL **104,** 054801 (2010) PHYSICAL REVIEW LETTERS week ending 5 FEBRUARY 2010

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
DWFA
PWFA
Thomson
LWFA_ext
Electron Bunch from RF injector
Initial velocity $\beta_0 \sim 0.994$ (4MeV)
Slip Back & Compression
Phase 0°
Phase -90°
Phase 90°
RF (Traveling Wave)
Phase velocity $\beta_{ph} \sim 1$
$\beta > \beta_0$ (tail)
$\beta = \beta_0$
$\beta < \beta_0$ (head)

Laser Comb Technique

Laser Comb technique: generation of a train of short bunches

(Parmela code)

Charge vs. Time

Energy vs. Time

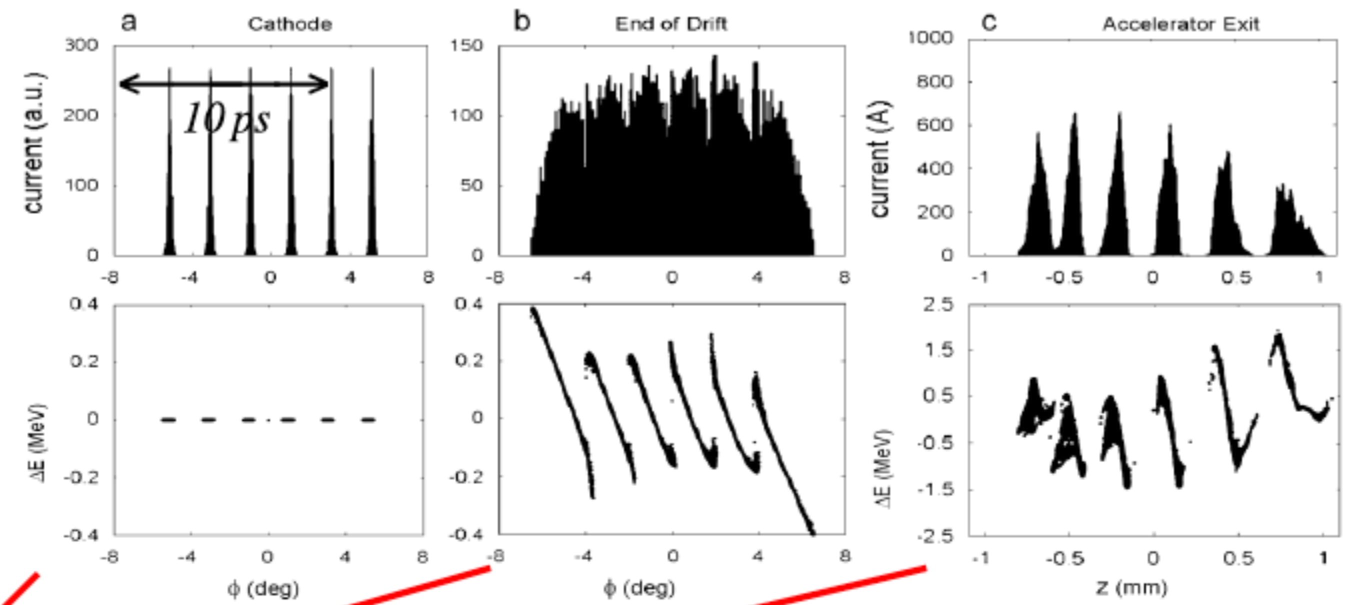
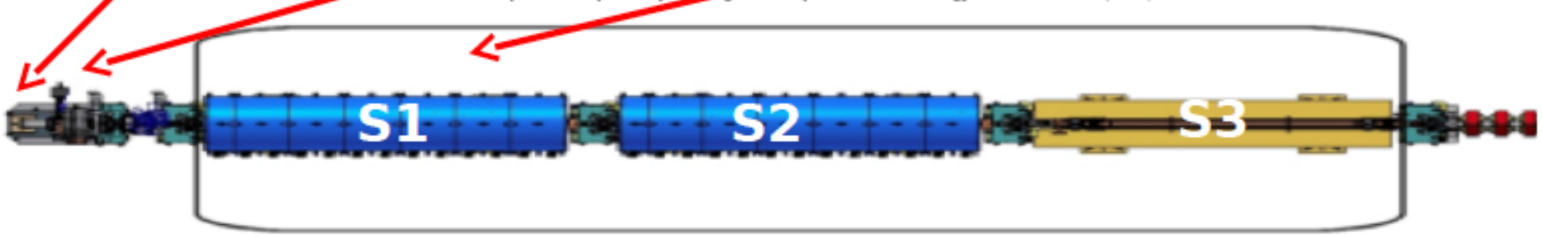
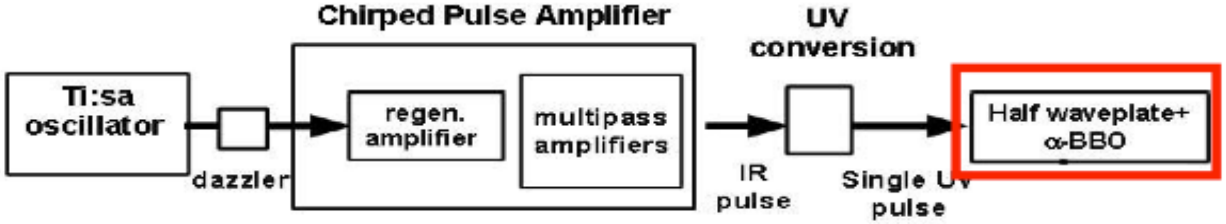


Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).

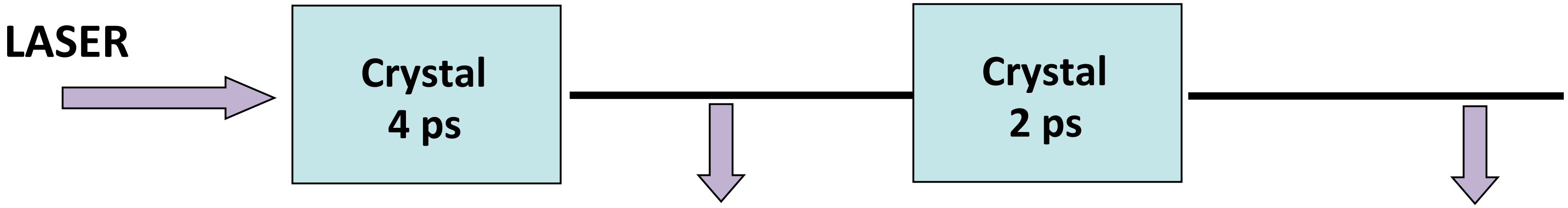


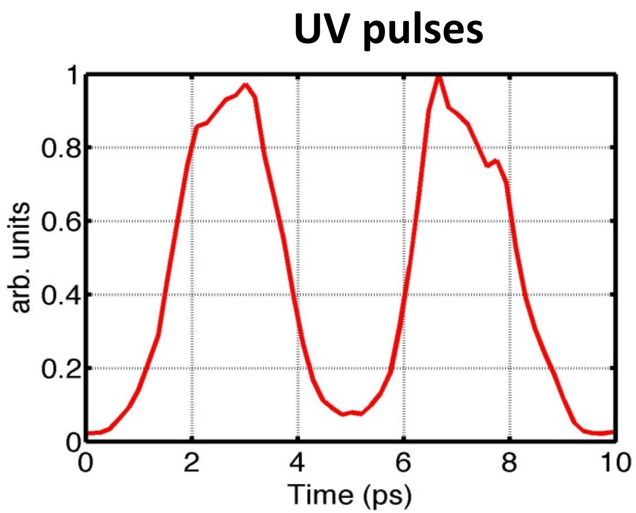
- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704. (Low charge regime only)
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (High charge, Beam Echo)

Laser Pulse Train Generation

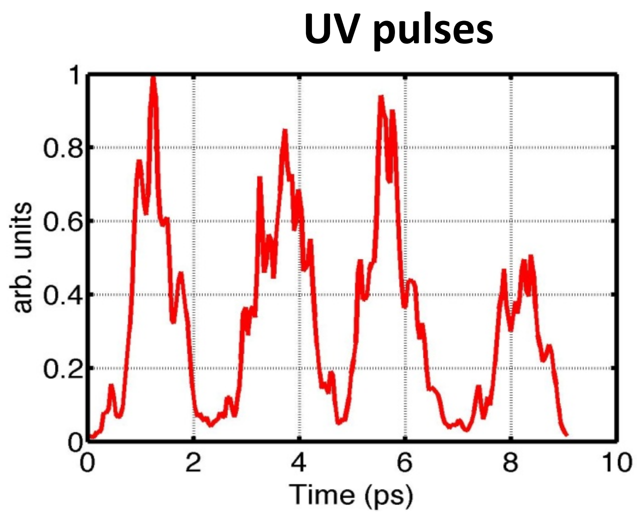


$$\Delta\tau = \left|\frac{1}{v_{ge}} - \frac{1}{v_{go}}\right| L_{crystal}$$



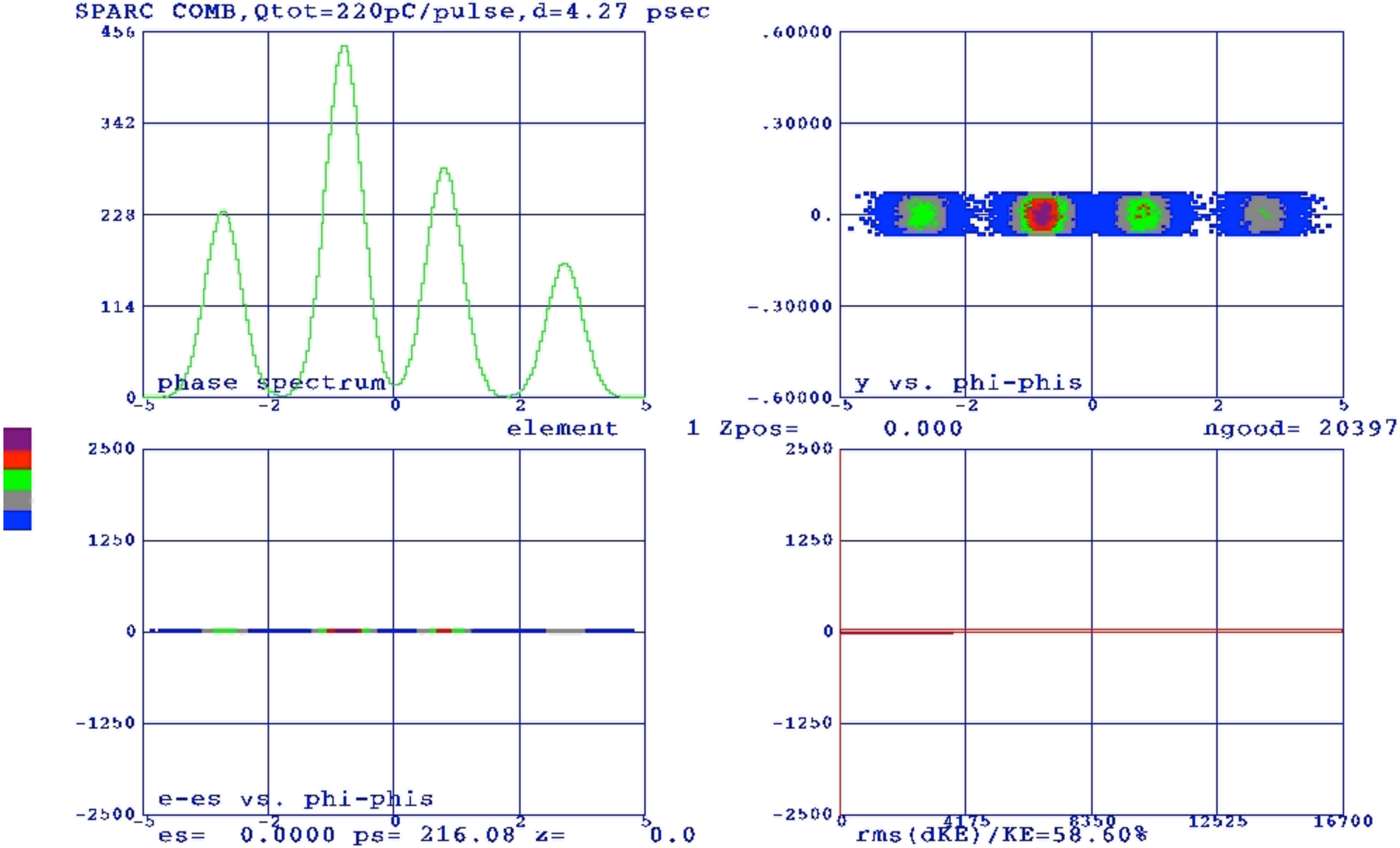


Streak camera

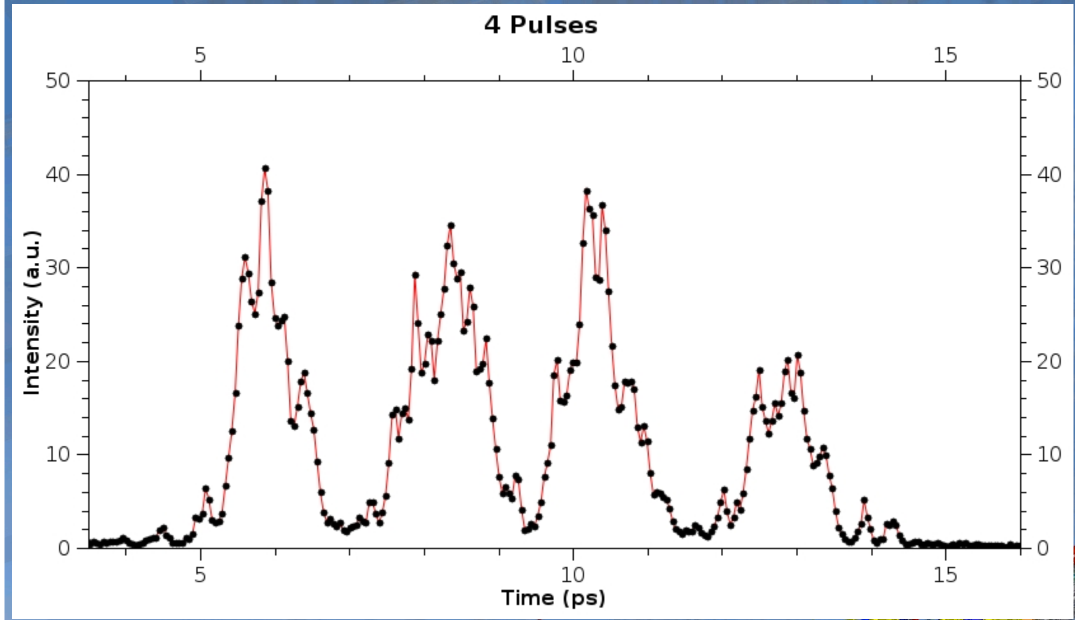


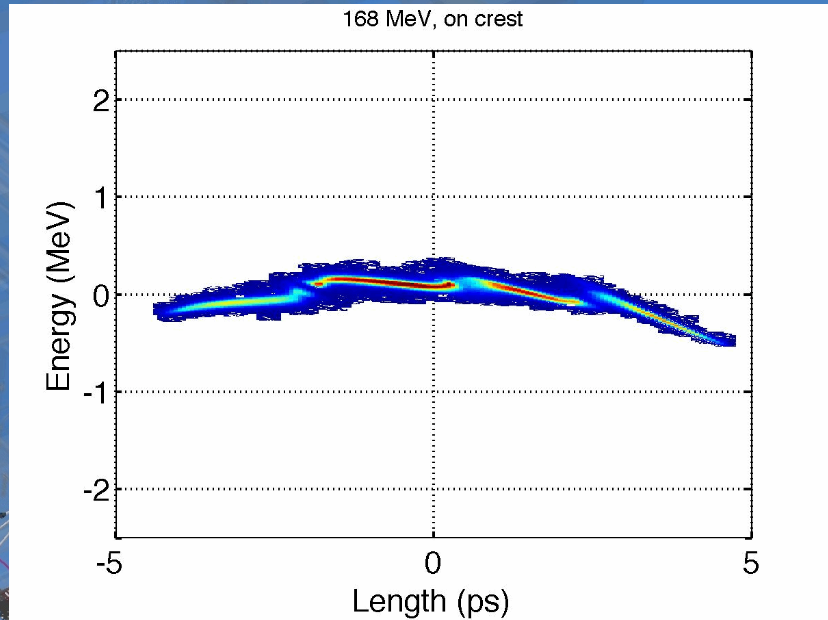
Streak camera

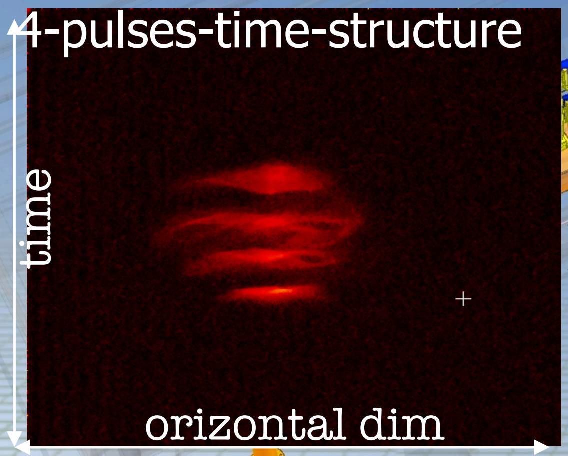
Overcompression

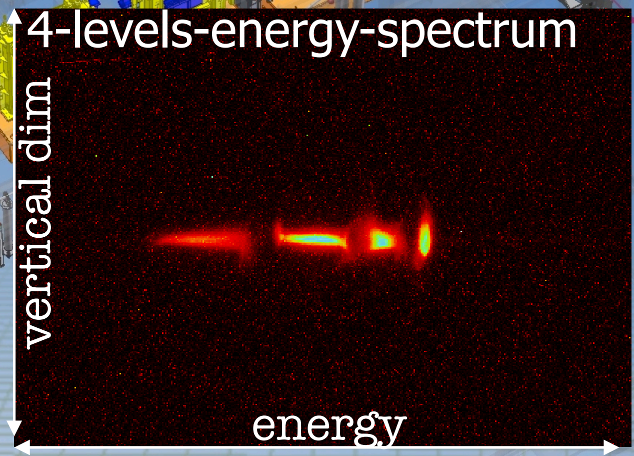


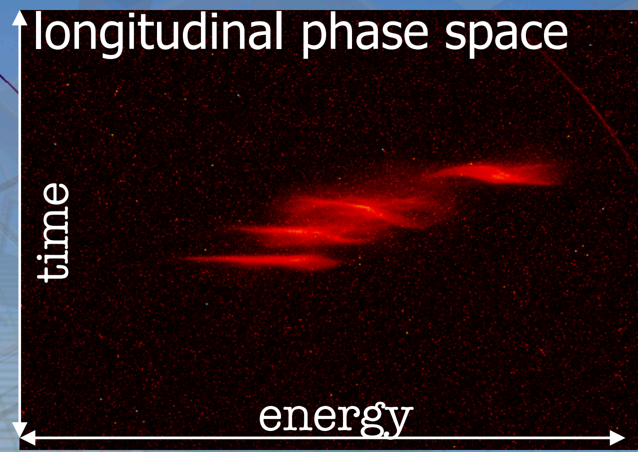
Laser COMB: experimental results







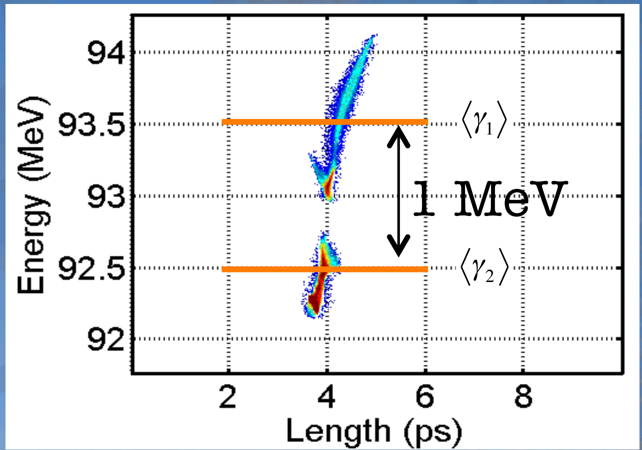




- M. Ferrario et al., Nucl. Inst. and Meth, A 637 (2011)
- A. Mostacci et al., Proc. of IPAC 2011, Spain

TWO COLORS FEL

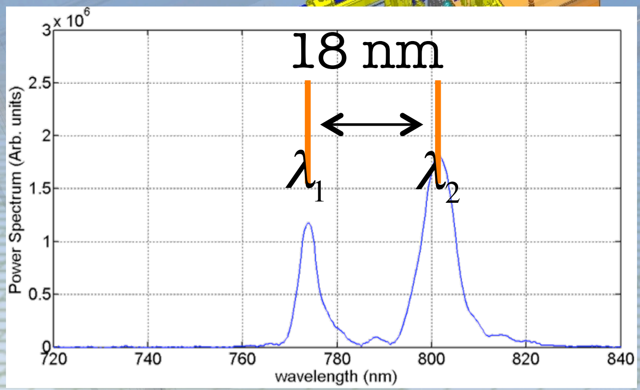
NEW: TWO COLORS SASE FEL



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

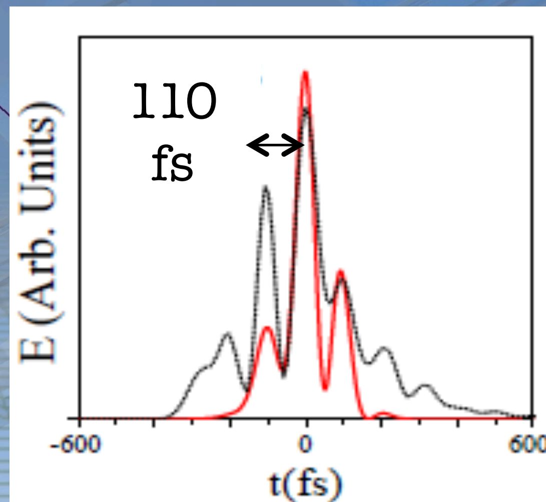
$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + K_{rms}^2\right)$$

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

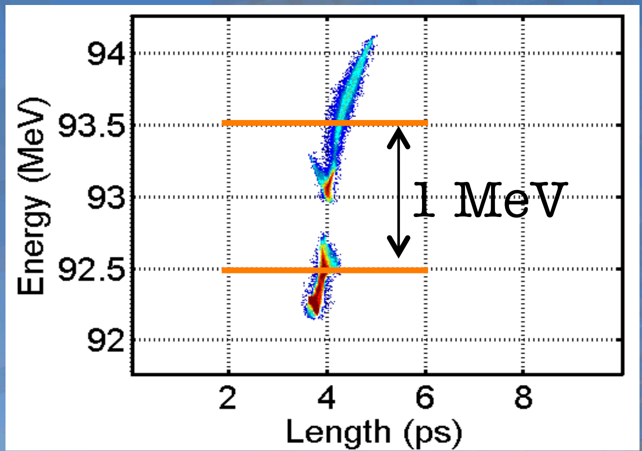


produce two wavelength
SASE –FEL radiation
with time modulation

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



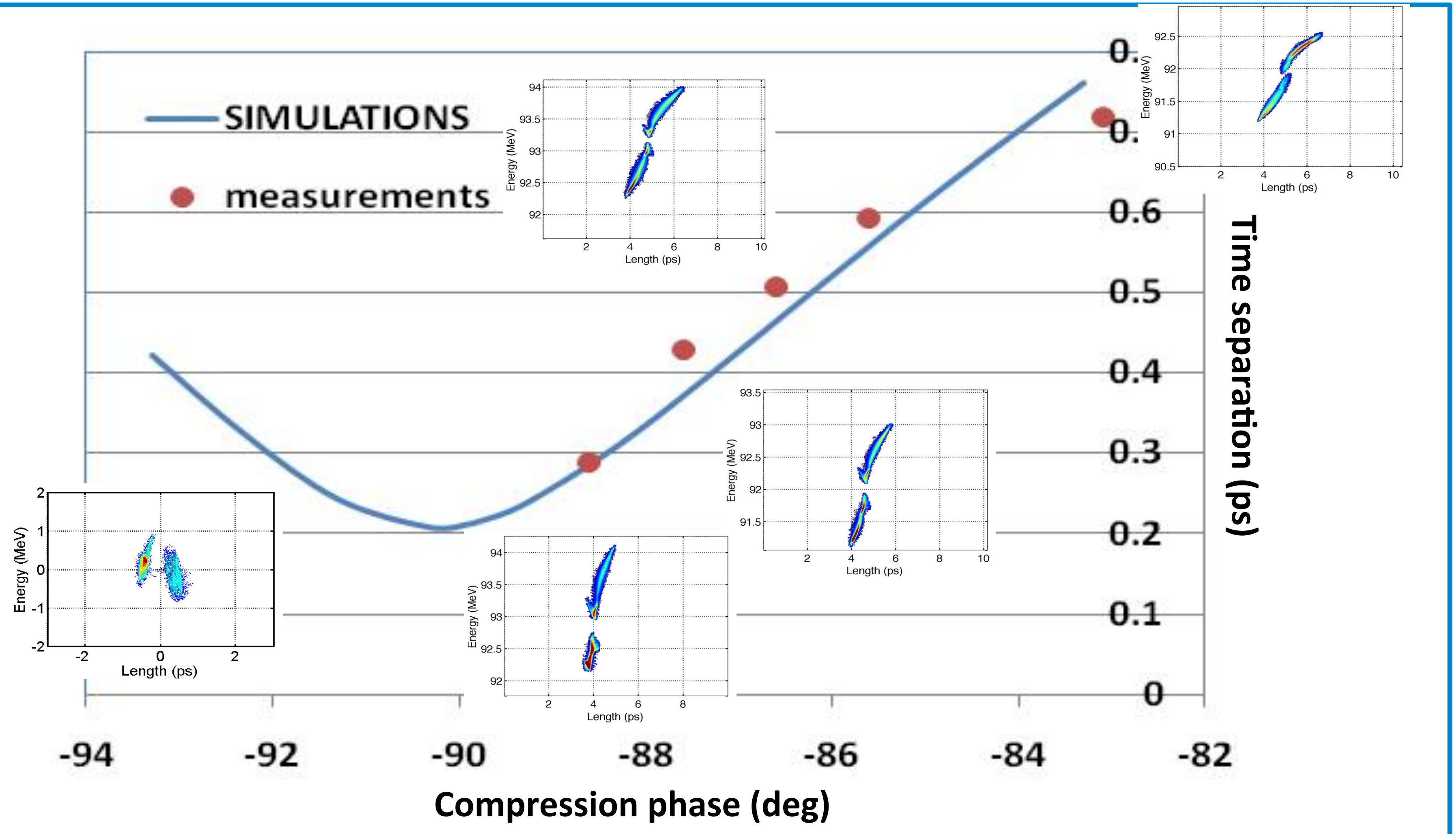
Electron beam requiremetns



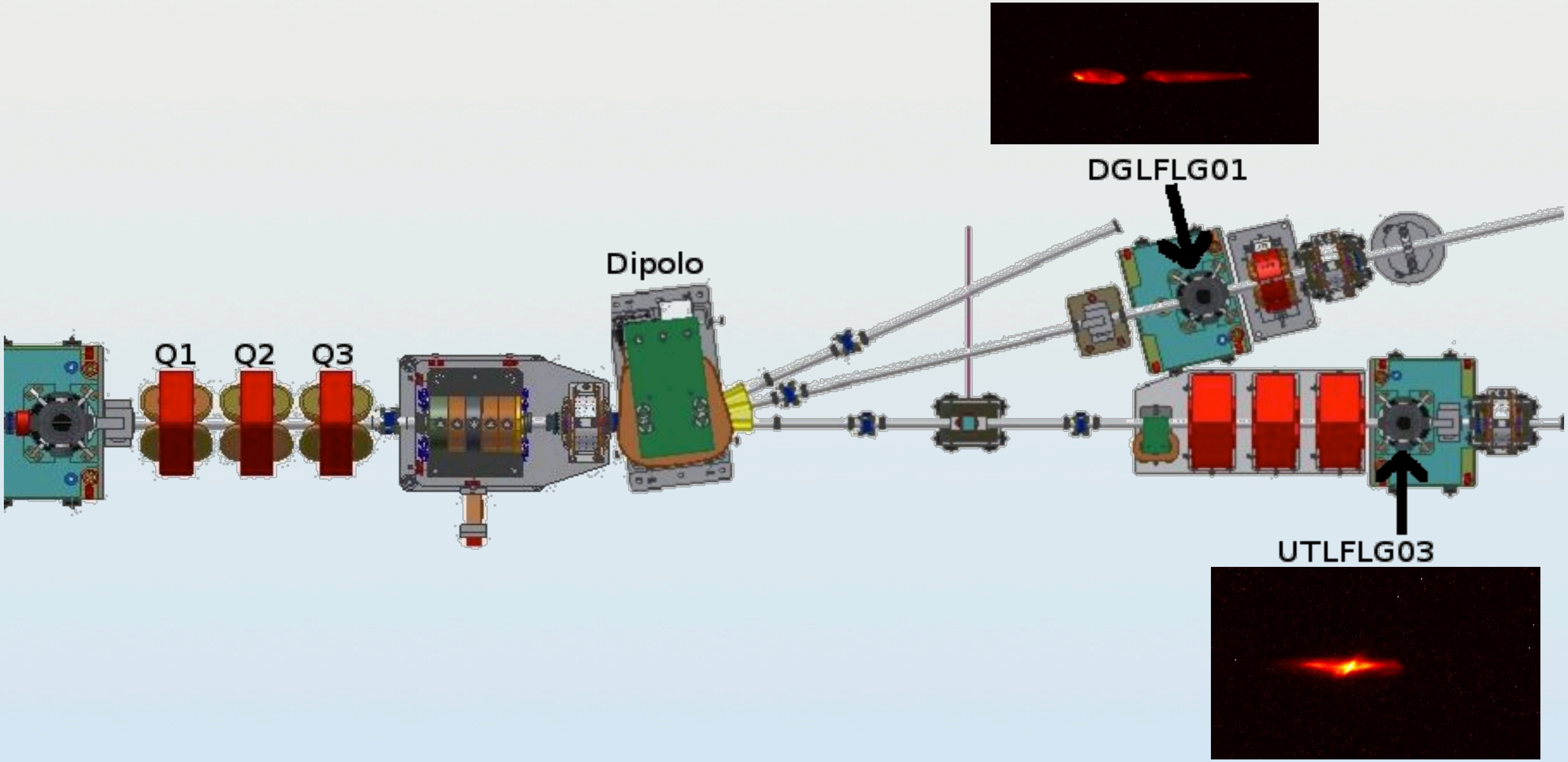
two bunches with
a two-level energy distribution
and time overlap (Laser COMB tech.)

- Lasing condition: $$\frac{\delta\gamma_{1,2}}{\langle\gamma_{1,2}\rangle} < \rho$$
- To prevent mode competition: $$\frac{\langle\gamma_1\rangle - \langle\gamma_2\rangle}{\langle\gamma\rangle} > \rho$$
- Single spike condition: $$l_b \approx L_{coop} = \frac{\lambda_r}{4\pi\sqrt{3}\rho}$$

Measured 2 bunches distance versus VB phase



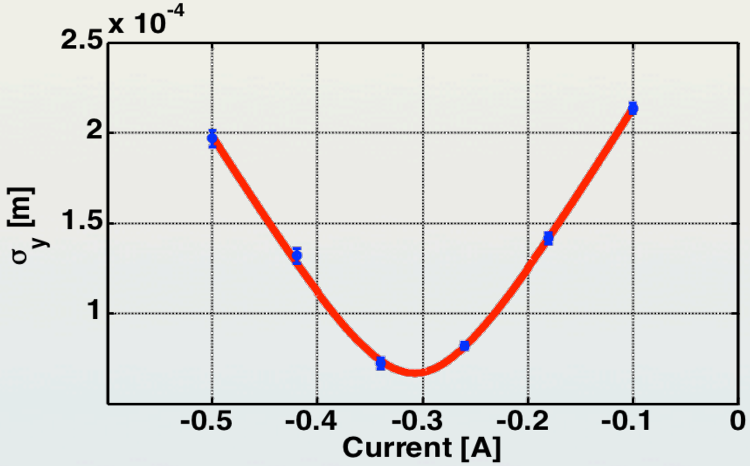
Measuring single beam properties

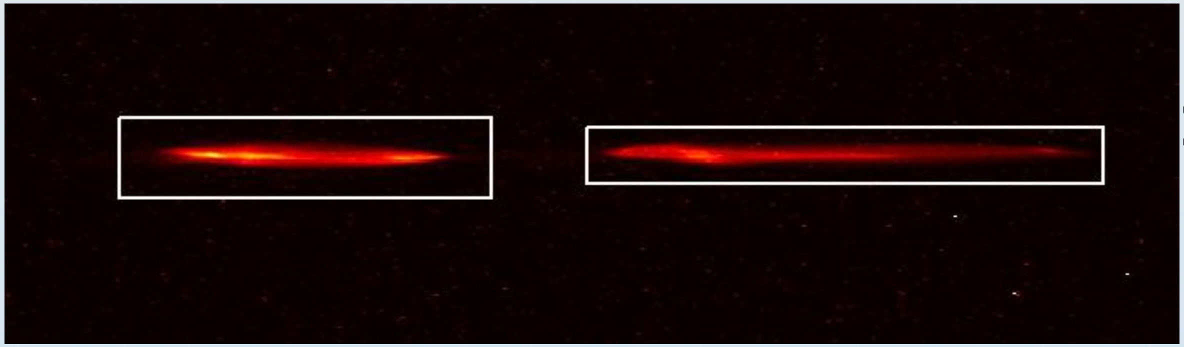


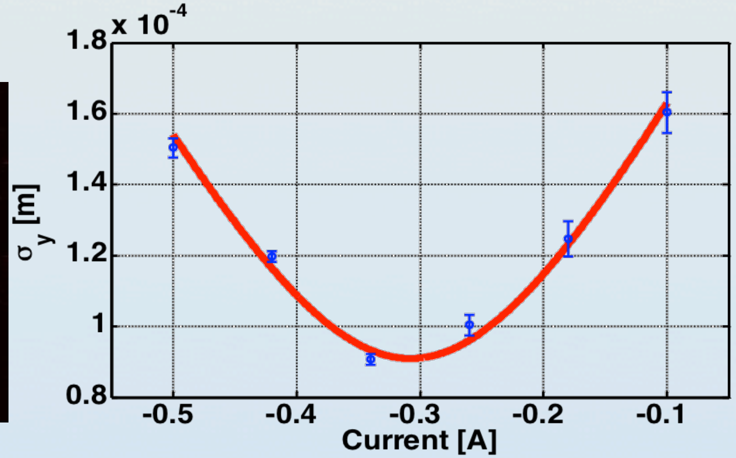
Emittance measurements comb beams

First bunch	$\varepsilon = (1.77 \pm 0.05)$ mm mrad $\alpha = -2.1 \pm 0.1$ $\beta = (27 \pm 1)$ m

Second bunch	$\varepsilon = (1.62 \pm 0.04)$ mm mrad $\alpha = -0.94 \pm 0.05$ $\beta = (13.4 \pm 0.5)$ m

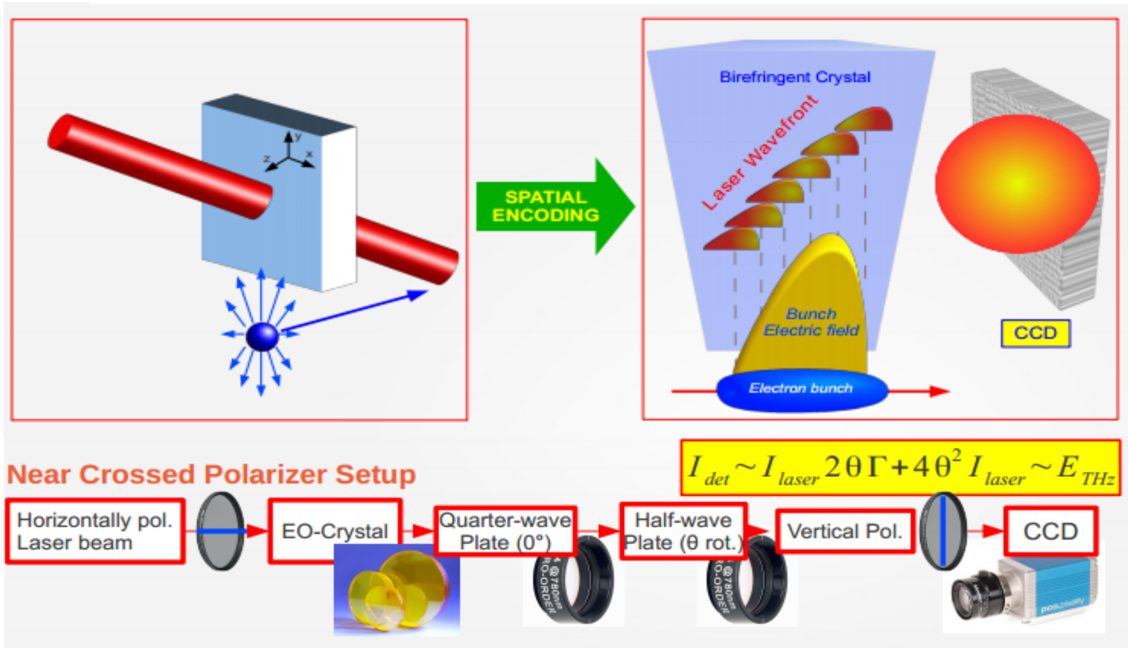


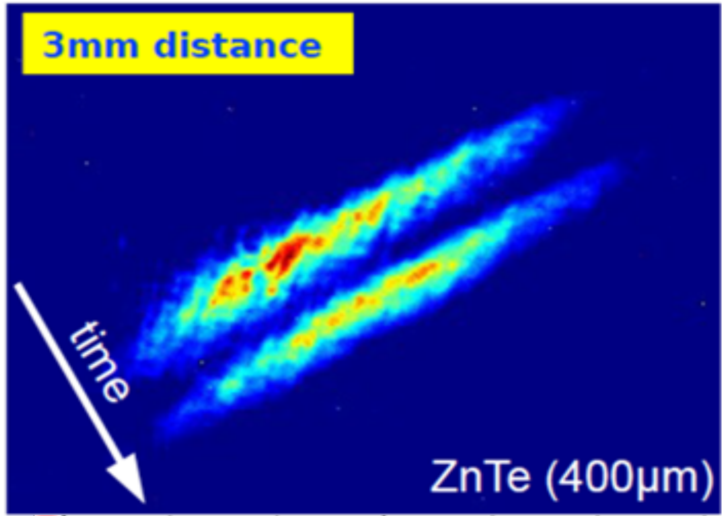


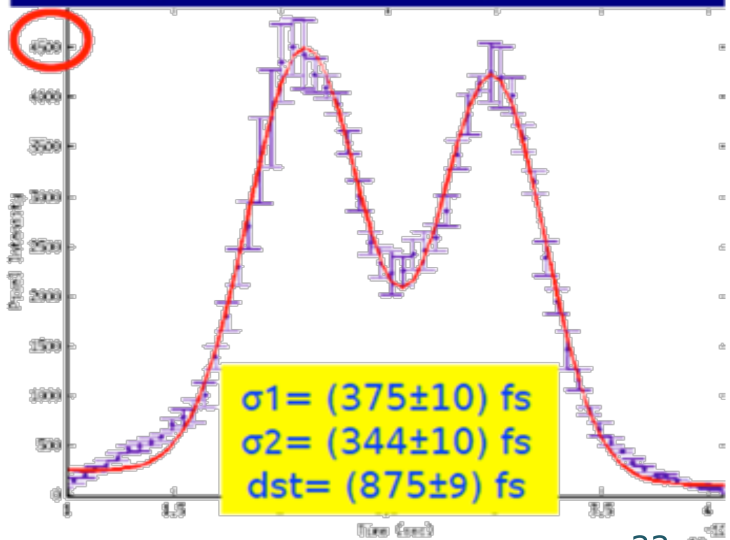


L. Innocenti

Electron Beam Diagnostics







- Laser crosses the crystal with an incident angle of 30deg
  - one side of the laser pulse arrives earlier on the EO crystal than the other by a time difference ΔT
- Coulomb field inducing birefringence is encoded in spatial profile of laser pulse

R. Pompili et al., NIM A **740**, 216–221 (2014)

Achieved Electron Beam Performances

Whole beam

- Peak current: 300 A (with 160 pC)
- Bunch duration: 300 fs
- Normalized emittance: 1.7 (0.1) mm mrad
- Energy spread: 0.6%
- Energy: 93.04 (0.03) MeV

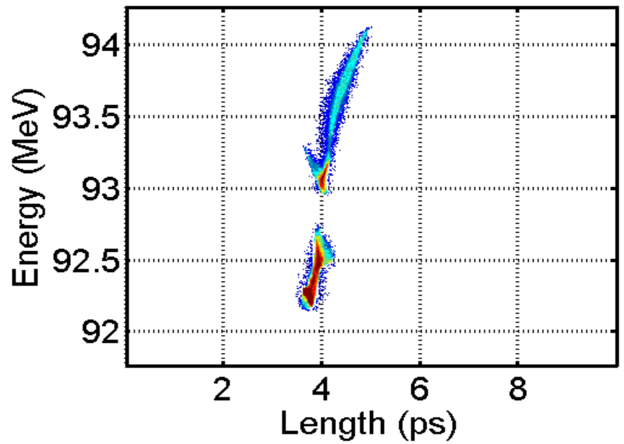
Single bunch

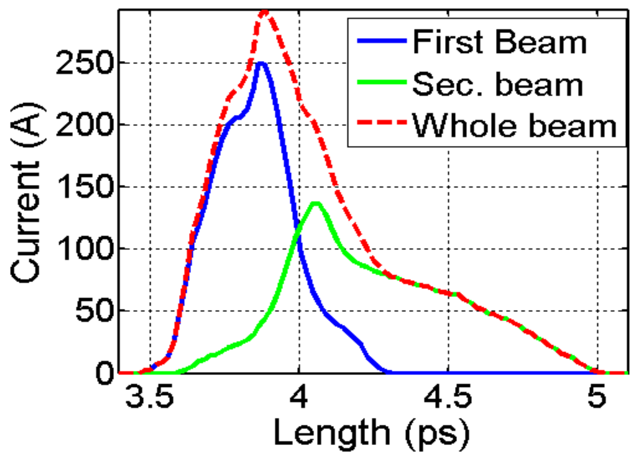
- Energy spread: 0.2% / 0.3 %
- Bunch duration: 100 fs / 250 fs

Energy separation: 1.07 (0.05) MeV

Time separation: 0.42 (0.03) ps

FEL parameter ρ: 6.7×10^{-3}

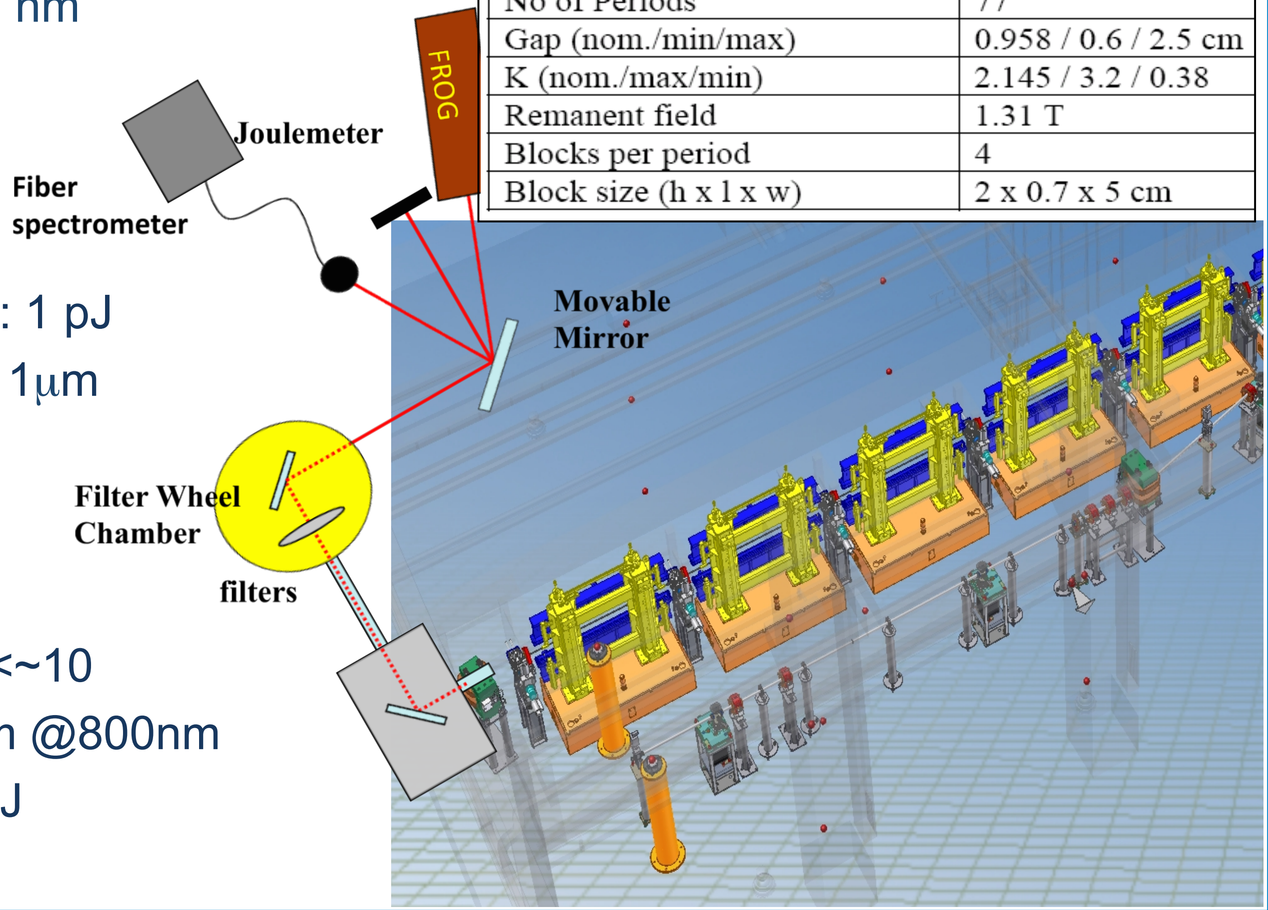




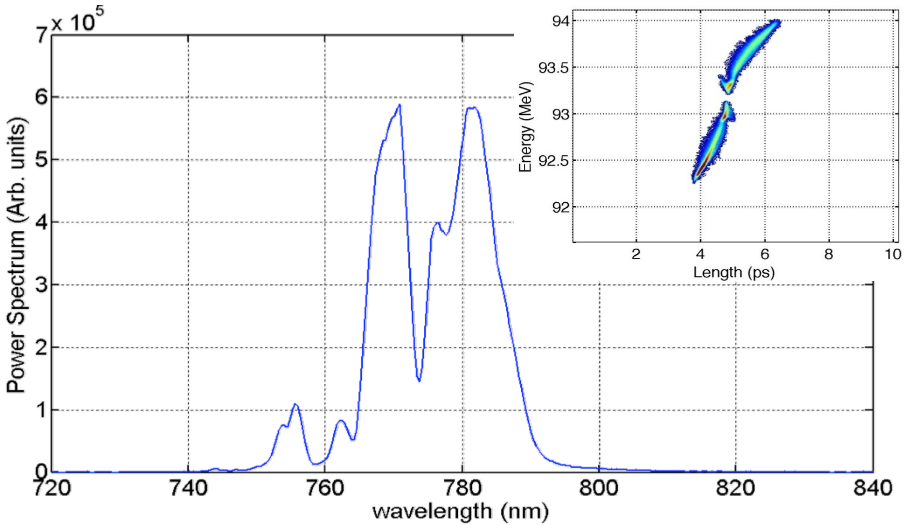
FEL Photon Diagnostics

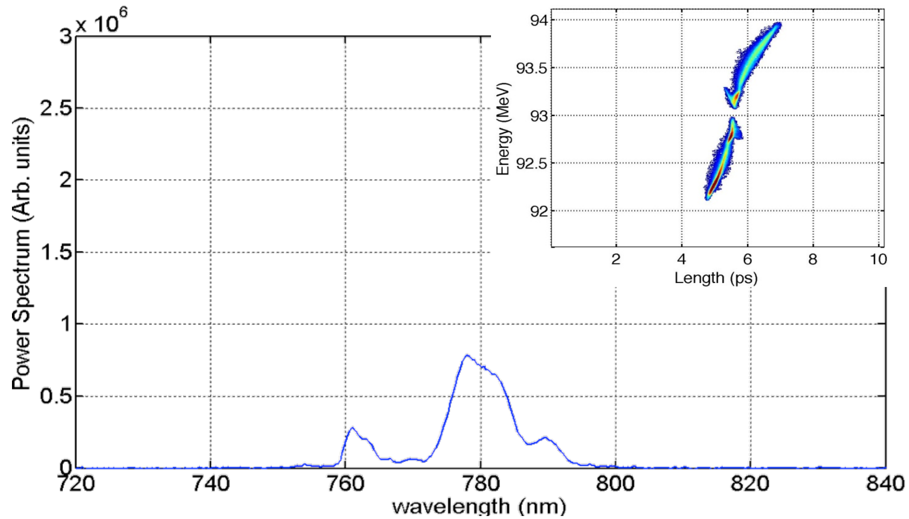
- **Fiber Spectrometer**
  - Resolution: 1.2 nm @ 800 nm
  - Window: 200-840 nm
- **Joulemeter**
  - Minimum detected energy: 1 pJ
  - Calibration: 5.96e8 V/J @ 1µm
  - Optical density filters
- **FROG:** NIR-Grenouille
  - Time-bandwidth product: <~10
  - Spectral resolution: 0.7 nm @800nm
  - Single shot sensitivity: 1 µJ

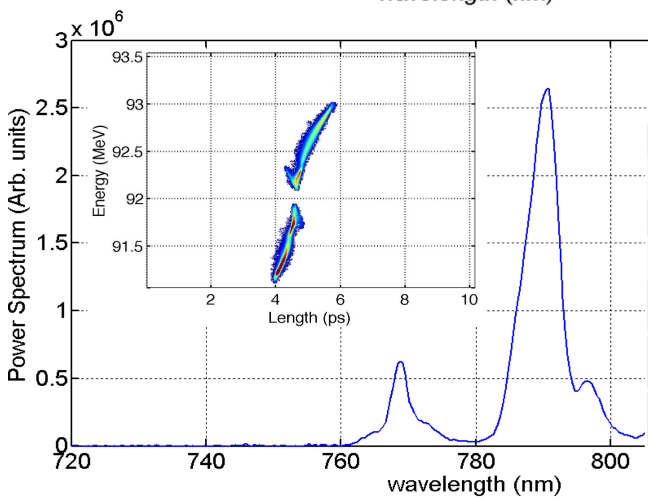
Period	2.8 cm
Undulator length	2.156.m
No of Periods	77
Gap (nom./min/max)	0.958 / 0.6 / 2.5 cm
K (nom./max/min)	2.145 / 3.2 / 0.38
Remanent field	1.31 T
Blocks per period	4
Block size (h x l x w)	2 x 0.7 x 5 cm



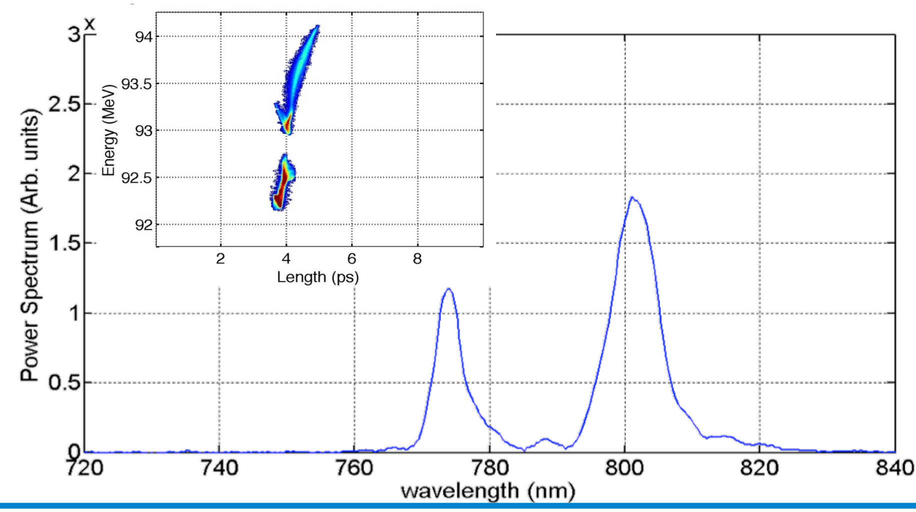
FEL Experiments: Two-levels radiation spectra



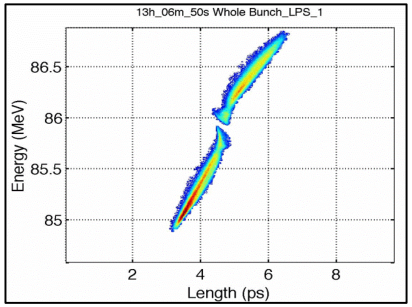




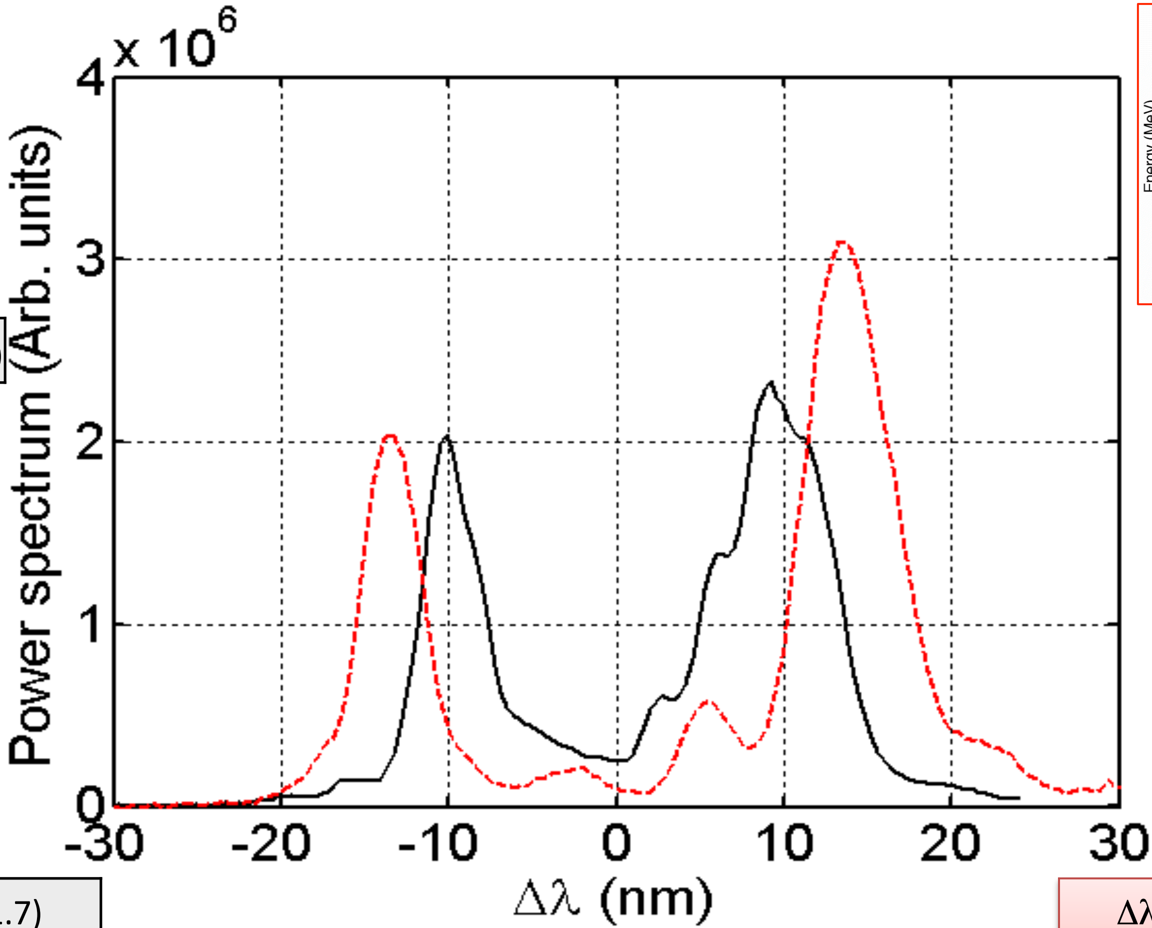
λ_{min} (nm)	769.8 (2)
$BW_{\lambda min}$ (%)	0.5
λ_{Max} (nm)	788.6 (1.3)
$BW_{\lambda Max}$ (%)	0.7
$\Delta\lambda$ (nm)	18.8 (2.9)
ΔE (MeV)	1.1 (0.17)
FEL Energy	> 37 μJ

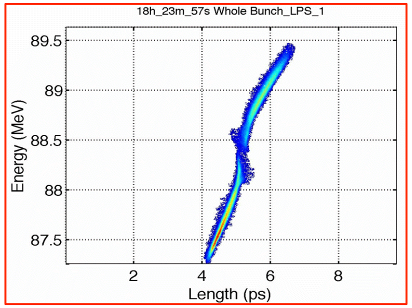


FEL EXPERIMENTS: Two-color tunability



ΔE(MeV)	-1.01 (0.03)





ΔE(MeV)	-1.14 (0.06)

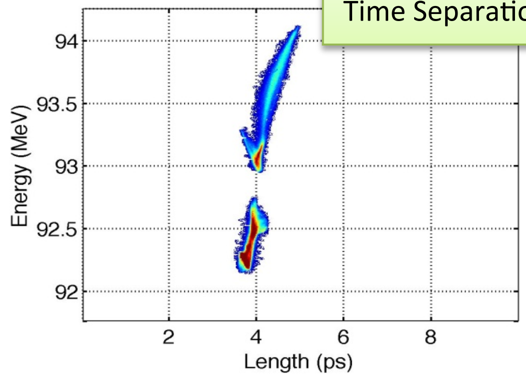
Δλ (nm)	20.7 (1.7)
ΔE (MeV)	1.066 (0.086)

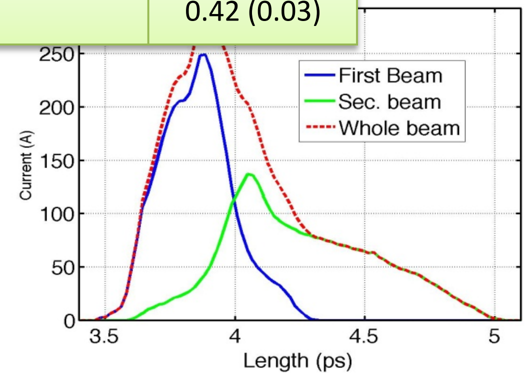
Δλ (nm)	26 (3)
ΔE (MeV)	1.35 (0.14)

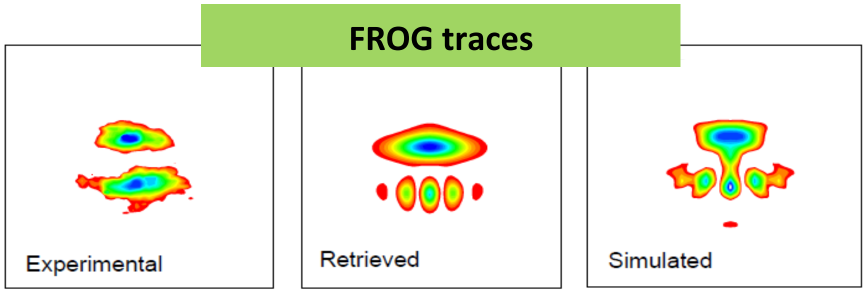
FEL Experiments: Time-modulated pulses

	Energy (MeV)	En. Spread (%)	Length (ps)	Charge (pC)
First Beam	92.515 (0.033)	0.174 (0.005)	0.147 (0.002)	82.15 (1.58)
Second Beam	93.588 (0.033)	0.317 (0.005)	0.283 (0.003)	77.85 (1.56)
Whole Beam	93.038 (0.032)	0.631 (0.003)	0.305 (0.004)	160.00 (3.10)

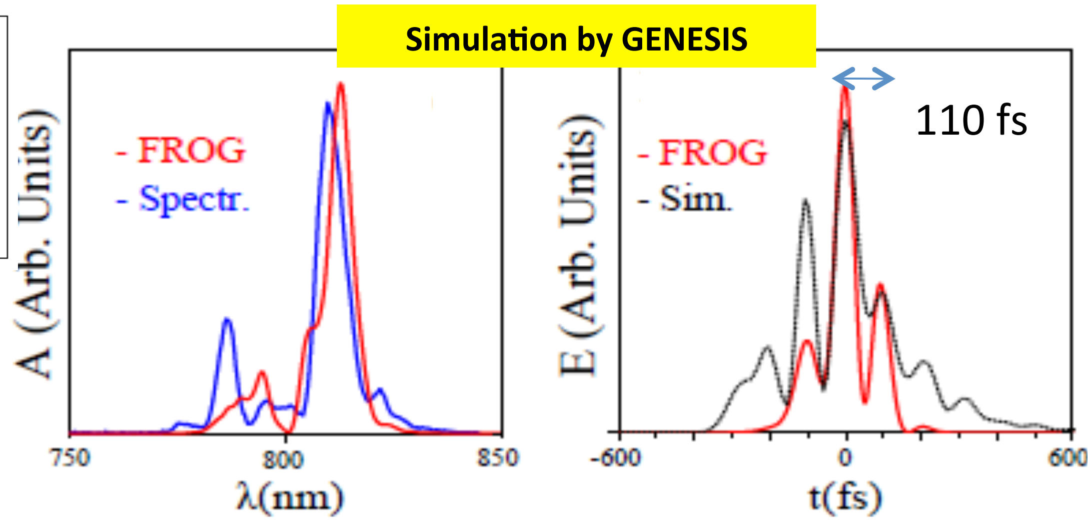
Energy Separation (MeV)	1.07 (0.05)
Time Separation (ps)	0.42 (0.03)



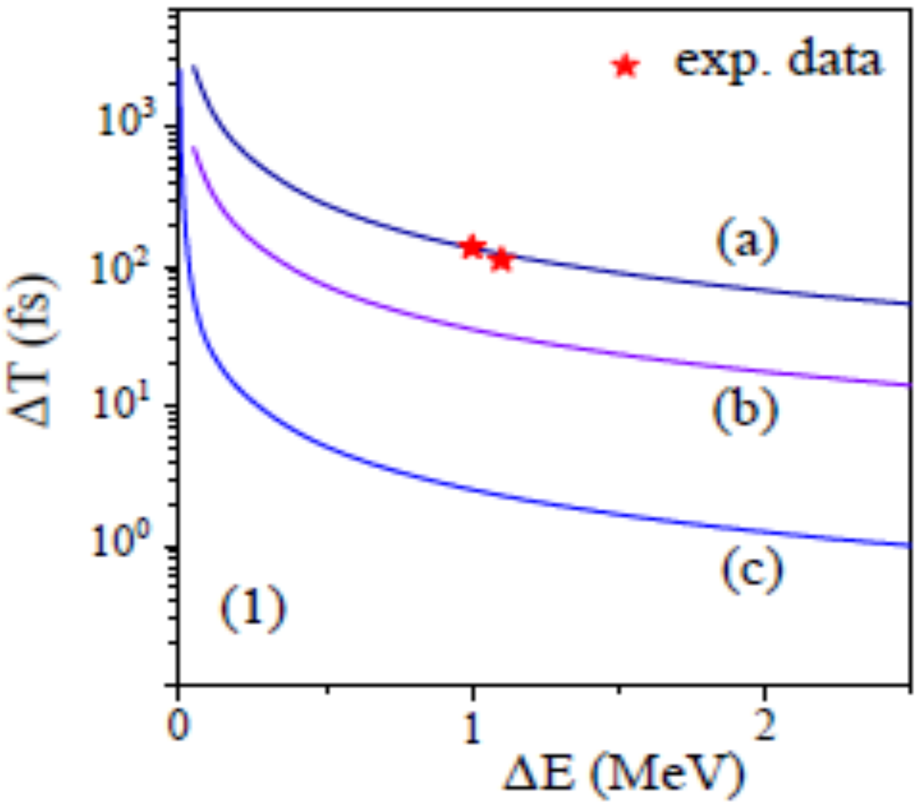




Δλ(nm)	BW (%)	RMS Time duration (fs)	Time separation (fs)
18	0.86	80	110



Expected time modulation at shorter wavelength



$$\Delta t = \frac{\lambda^2}{c(\lambda_2 - \lambda_1)} = \frac{\lambda_u(1 + K_w^2/2)}{4c\gamma\Delta\gamma}$$

(a) SPARC case.

(b) $\lambda = 30\,nm$

(c) $\lambda = 0.15\,nm$

CONCLUSIONS

- Production of a two-pulse beam with **time and energy separation tunable** with linac settings
- Demonstration of the possibility to control time and energy separation
- Achievement of beam quality necessary for FEL applications
- Generation of a two-pulse beam, each pulse shorter than the L_c, acting as independent radiation source in a quasi-single spike regime
  - Production and characterization of a two-color FEL spectrum and of a train of short FEL pulses
- Different techniques:
  - Chirped seeding ➔ G. De Ninni et al., PRL 110, 064801 (2013)
  - Alternate K undulator → A. A. Lutman et al., PRL 110, 134801 (2013)

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*
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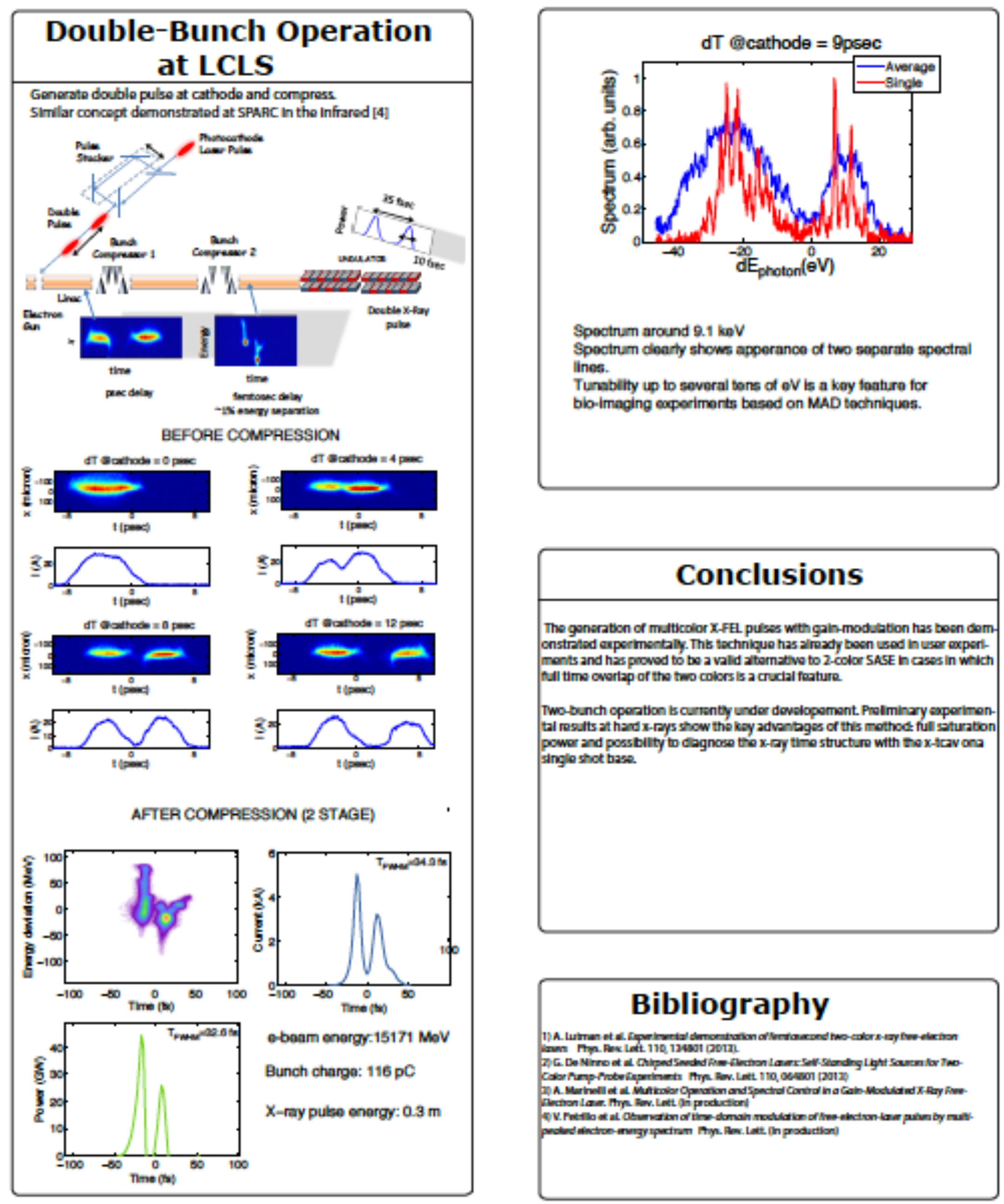
[3] *LNF, INFN Via E.Fermi, 40 Frascati (Roma), Italy*
[4] *ISM-CNR Via del Fosso del Cavaliere, 100 00133 Roma, Italy and*
[5] *ENEA Via E.Fermi, 45 Frascati (Roma),Italy*

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.

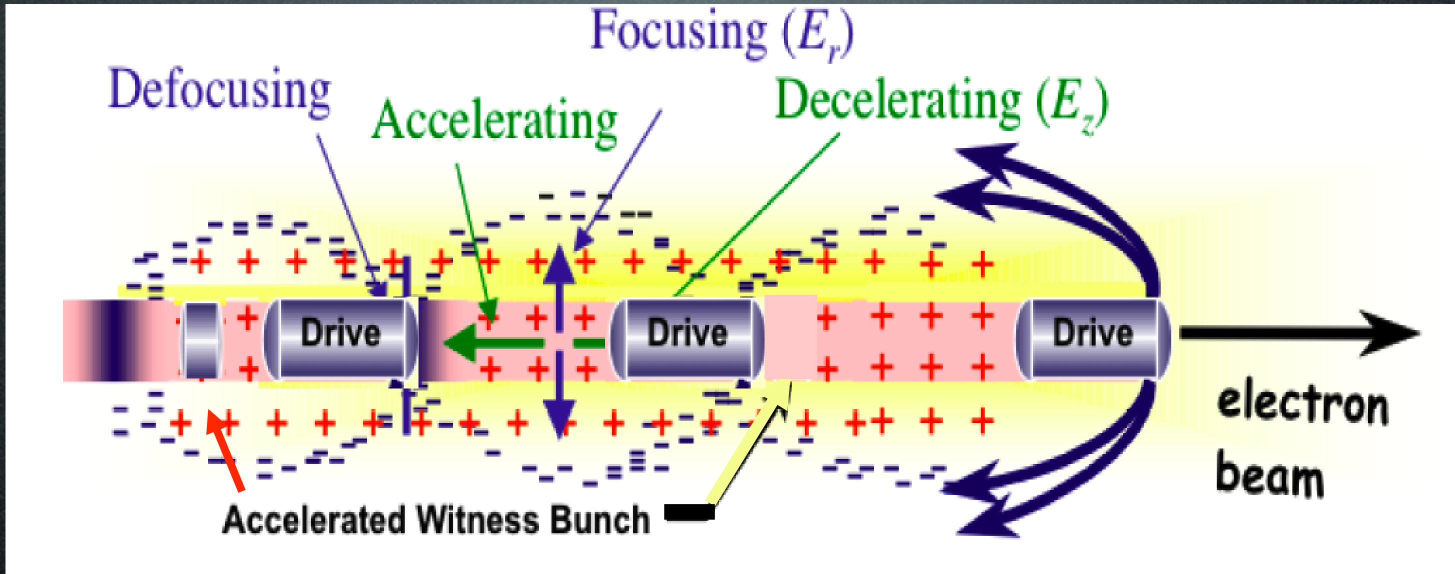
Double-Bunch Operation at LCLS

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



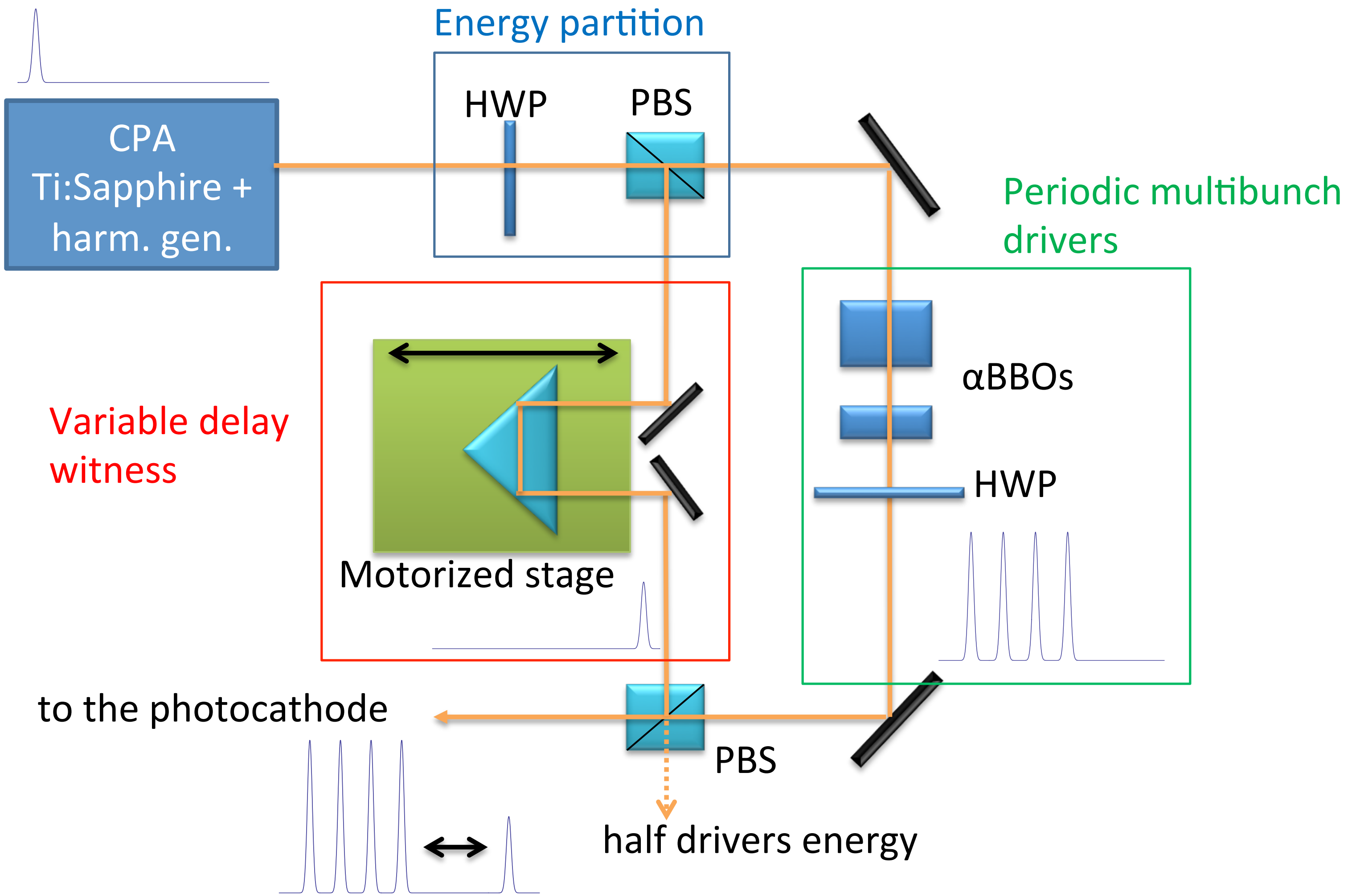
Particle Wake Field Acc.

Resonant plasma excitation by a Train of Bunches



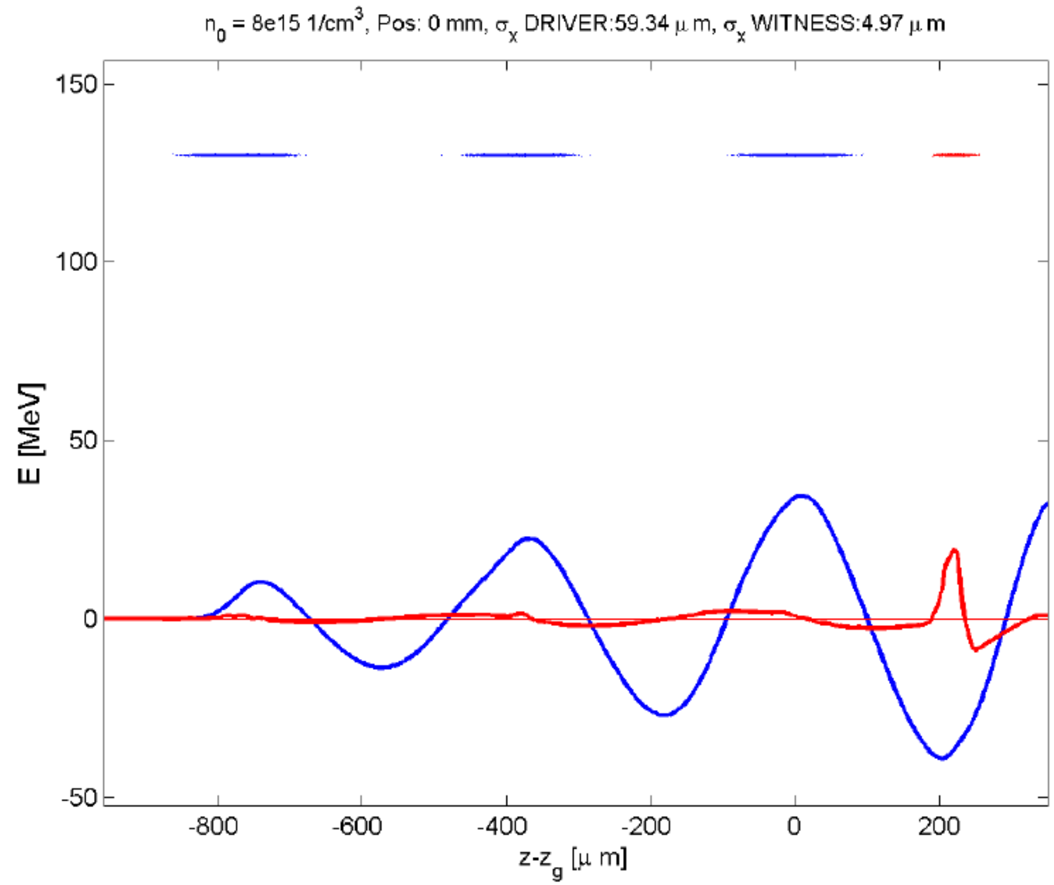
- **Weak blowout regime** with resonant amplification of plasma wave by a train of high Brightness electron bunches produced by **Laser Comb** technique?
- **Ramped bunch train configuration** to enhance tranformer ratio?
- **High quality bunch** preservation during acceleration and transport?

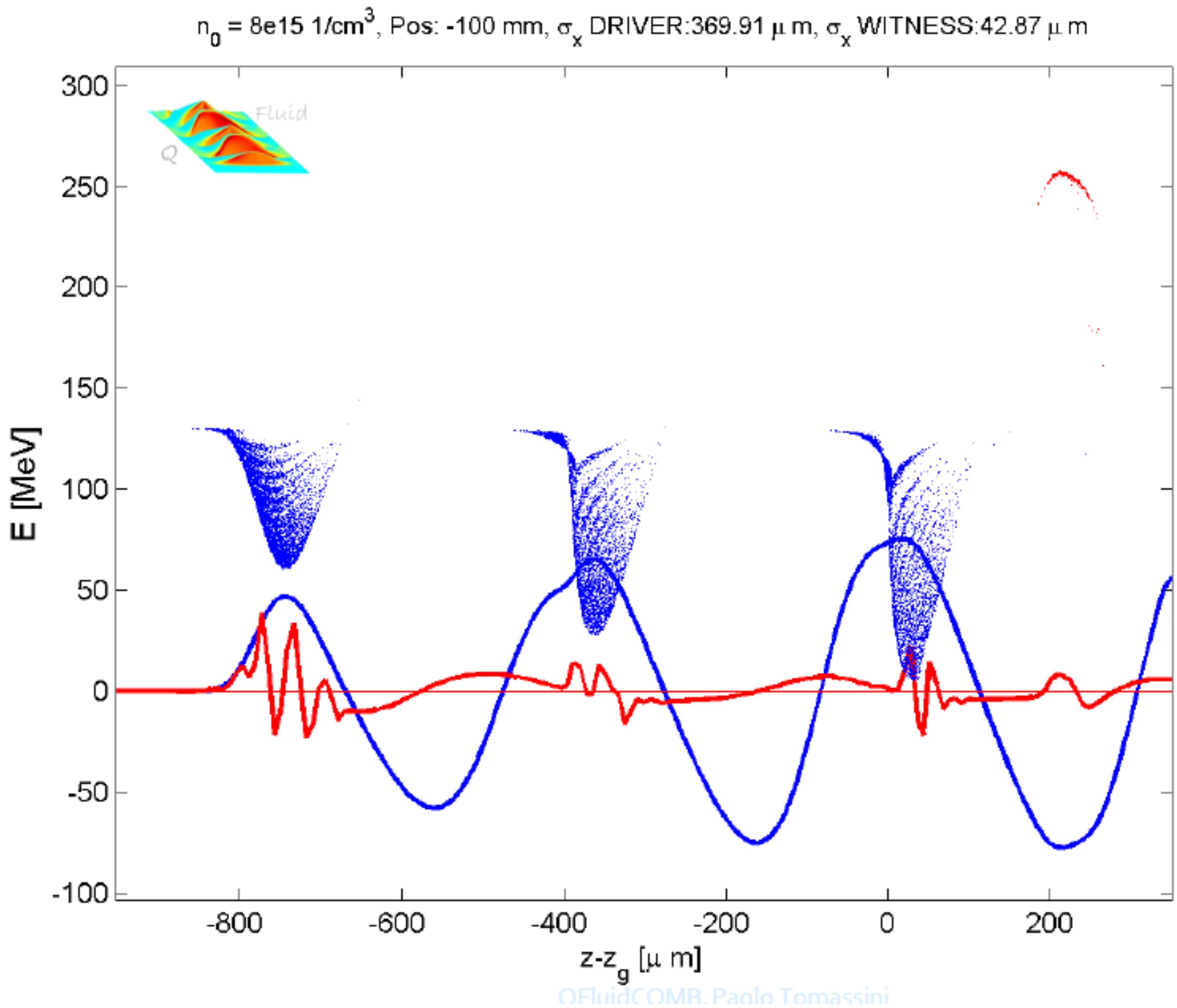
Driving and witness bunches generation



no=0.75e16 1/cm^3 Lambda_p=383 um, Lacc=10cm <u>Ez=1.2GV/m</u>

	DRIVER (each, pC)	WITNESS
Charge (pC, each)	200	20
sigma_x (um)	**60**	**5**
Sigma_z (um)	25	10

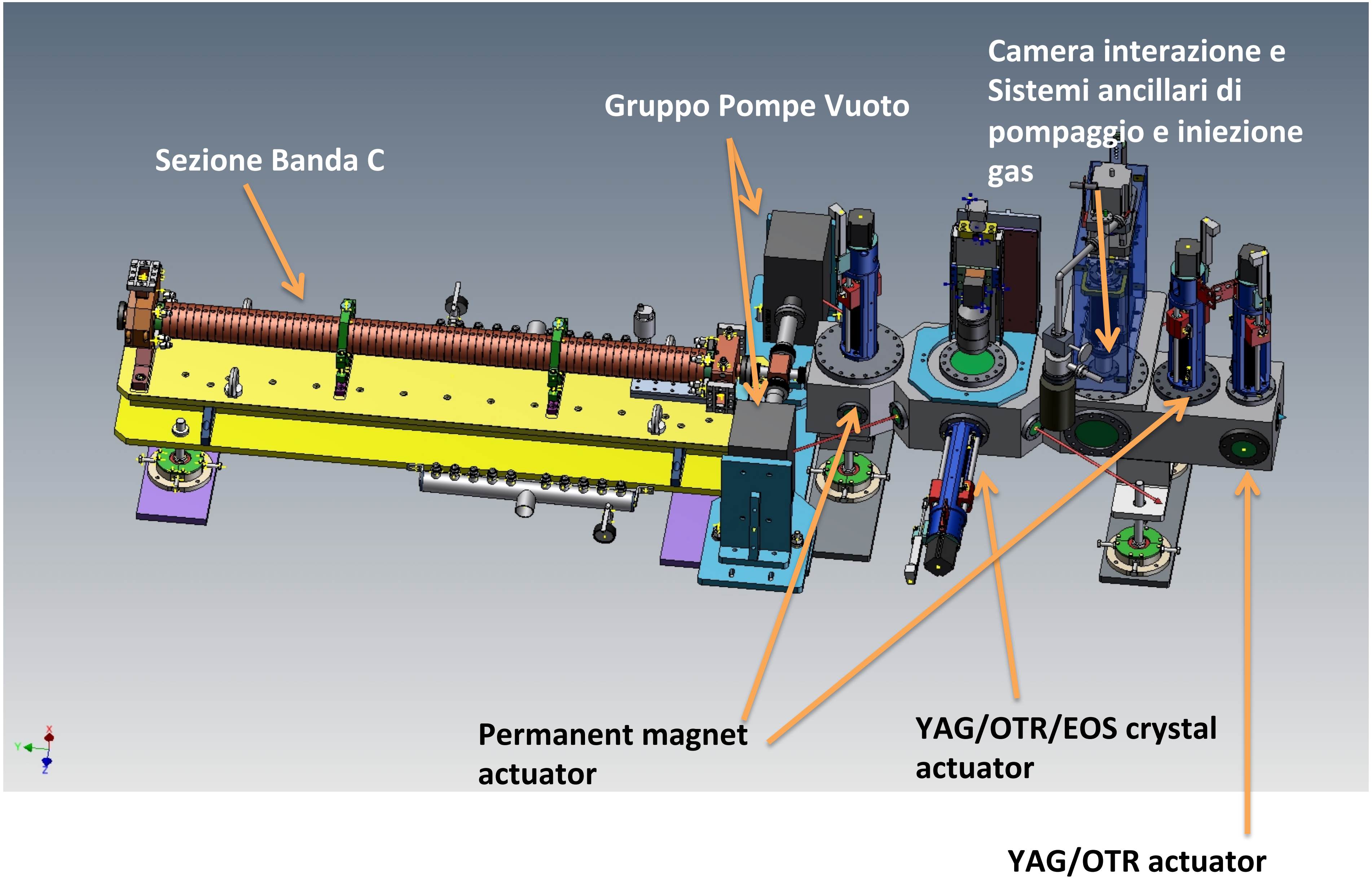


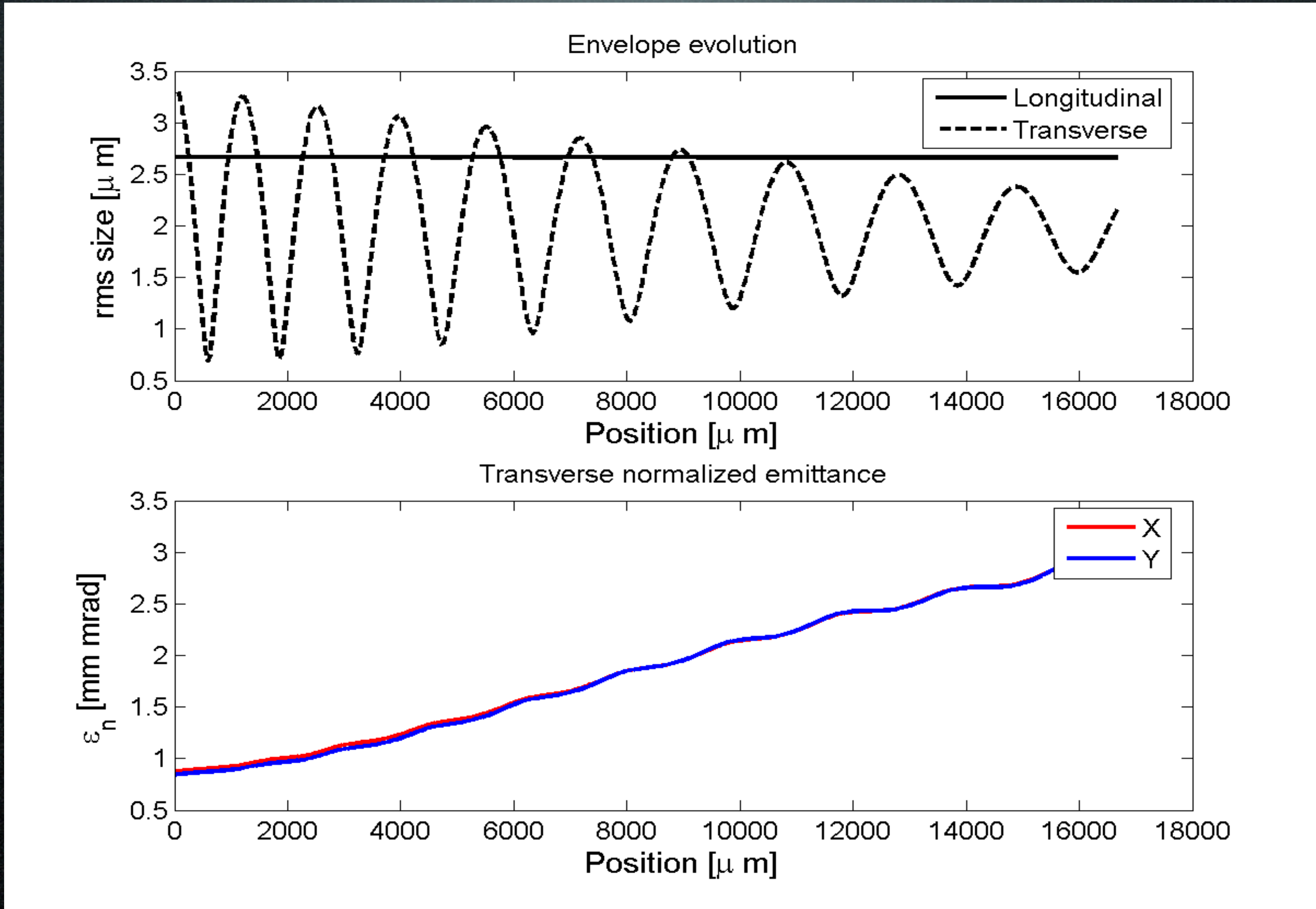


n_0 = 8e15 1/cm^3, Pos: -100 mm, σ_x DRIVER:369.91 μ m, σ_x WITNESS:42.87 μ m
E [MeV]
300
250
200
150
100
50
0
-50
-100
-800
-600
-400
-200
0
200
z-z_g [μ m]
Fluid
Q
QFluidCOMB. Paolo Tomassini

	DRIVER (each, pC)	WITNESS
energy (mean, MeV)	90	255
energy spread	35	0.9%
norm. emittance (um)	303	1.6
sigma_x (um)	370	3.5

COMB plasma interaction chamber





Courtesy P. Tomassini

When $\eta = \frac{4\gamma k_p^2}{3\gamma'^2} >> 1$ $\rho = \frac{k_{sc}^0 \sigma_x^2}{\gamma_o \varepsilon_n^2} << 1$

$\gamma'' = 0$

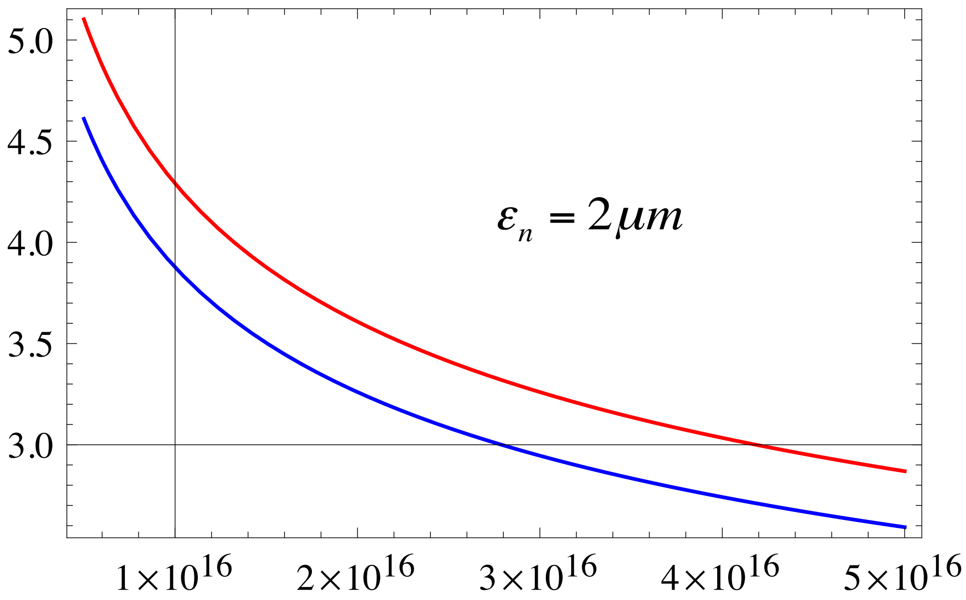
$\gamma' \neq 0$

$$\sigma_x'' + \frac{k_p^2}{3\gamma}\sigma_x = \frac{\varepsilon_n^2}{\gamma^2 \sigma_x^3}$$

matching condition with acceleration:

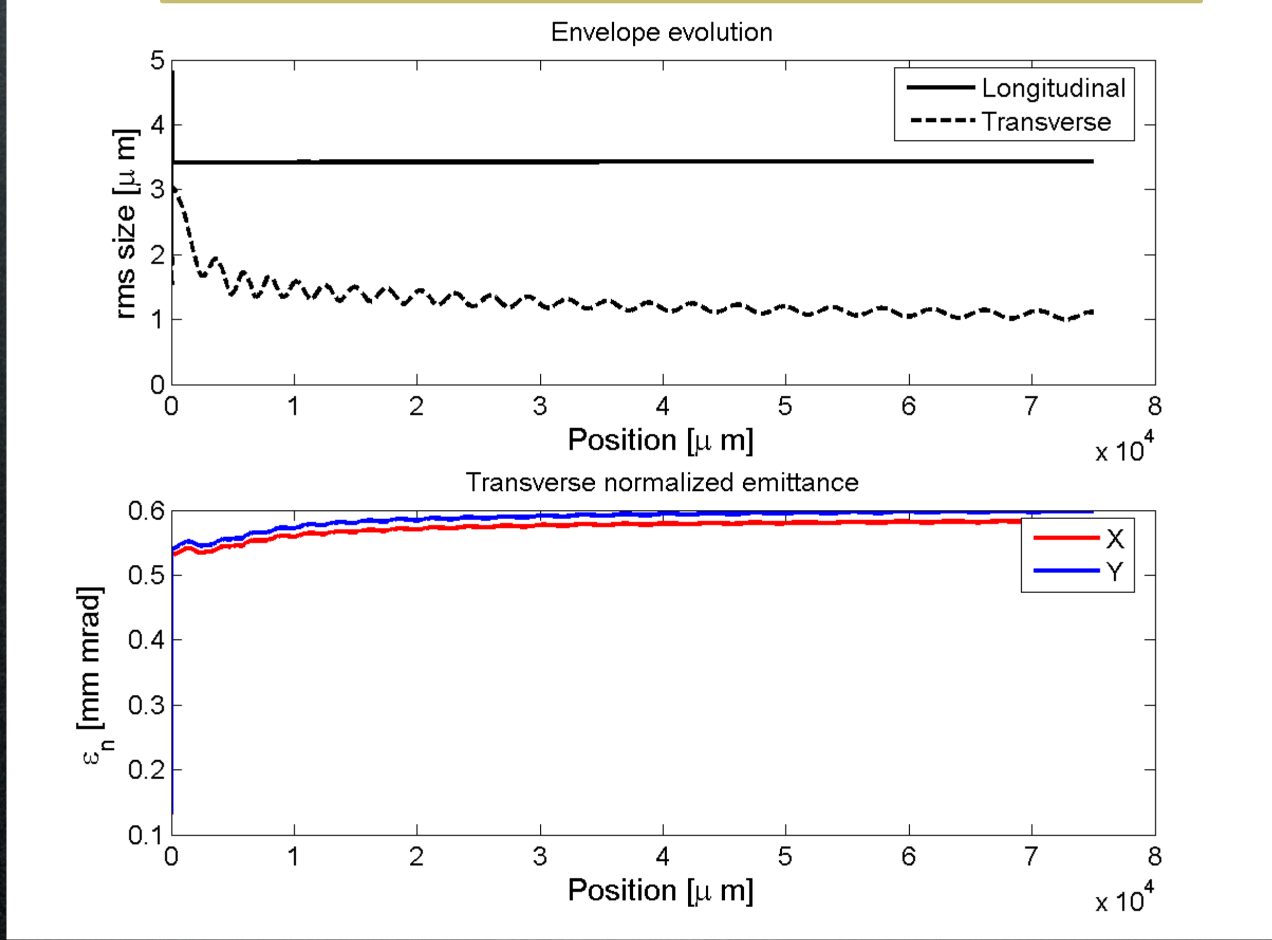
$$\sigma_\varepsilon = \sqrt[4]{\frac{3}{\gamma}}\sqrt{\frac{\varepsilon_n}{k_p}}$$

sigma_r [um]



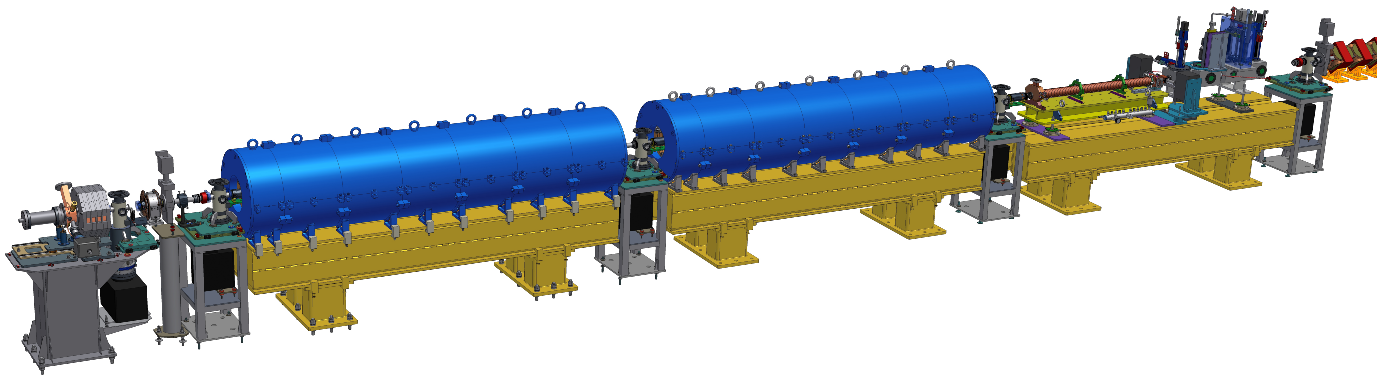
n [cm−3]

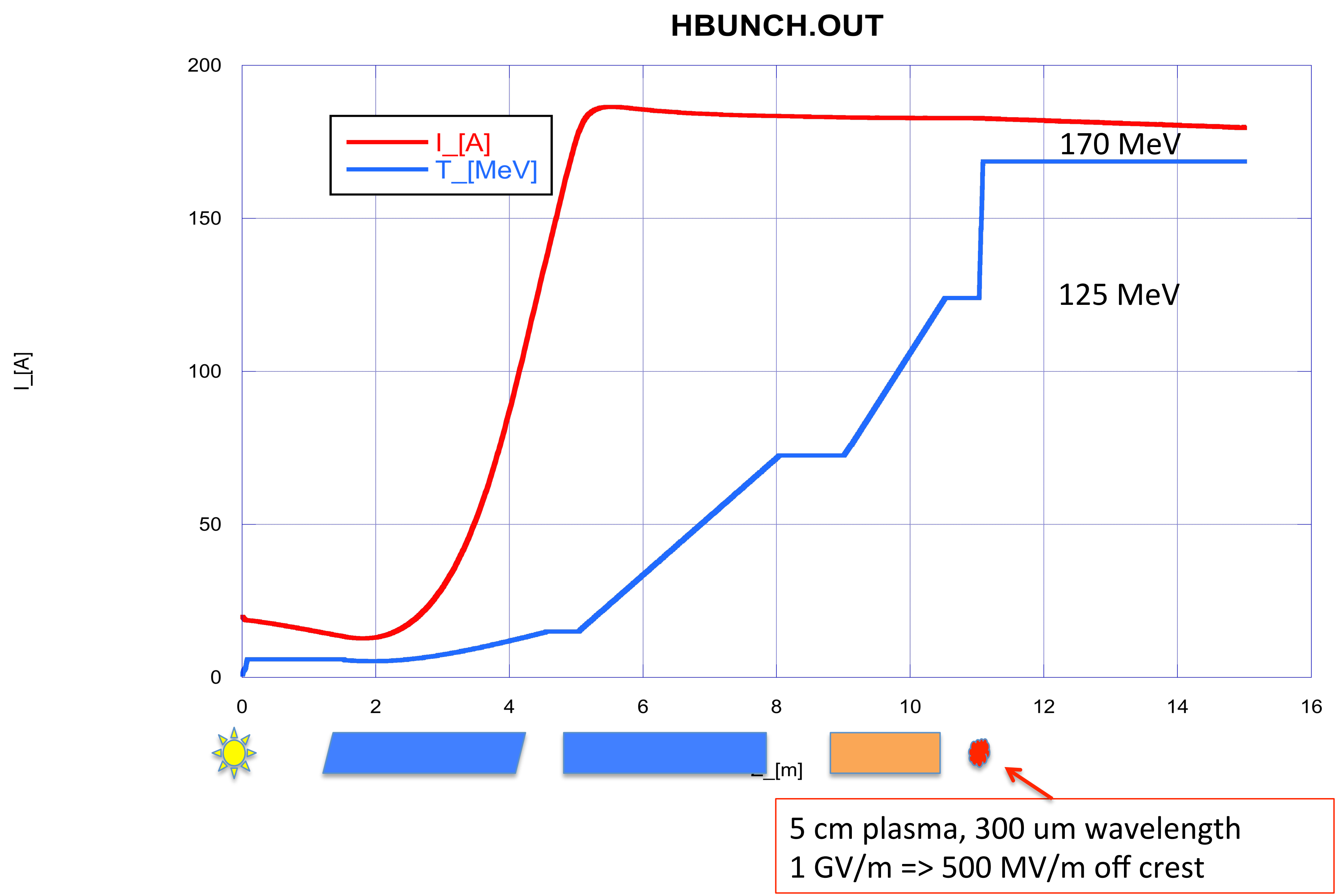
$$\sigma_\varepsilon = \sqrt[4]{\frac{3}{\gamma}}\sqrt{\frac{\varepsilon_n}{k_p}}$$

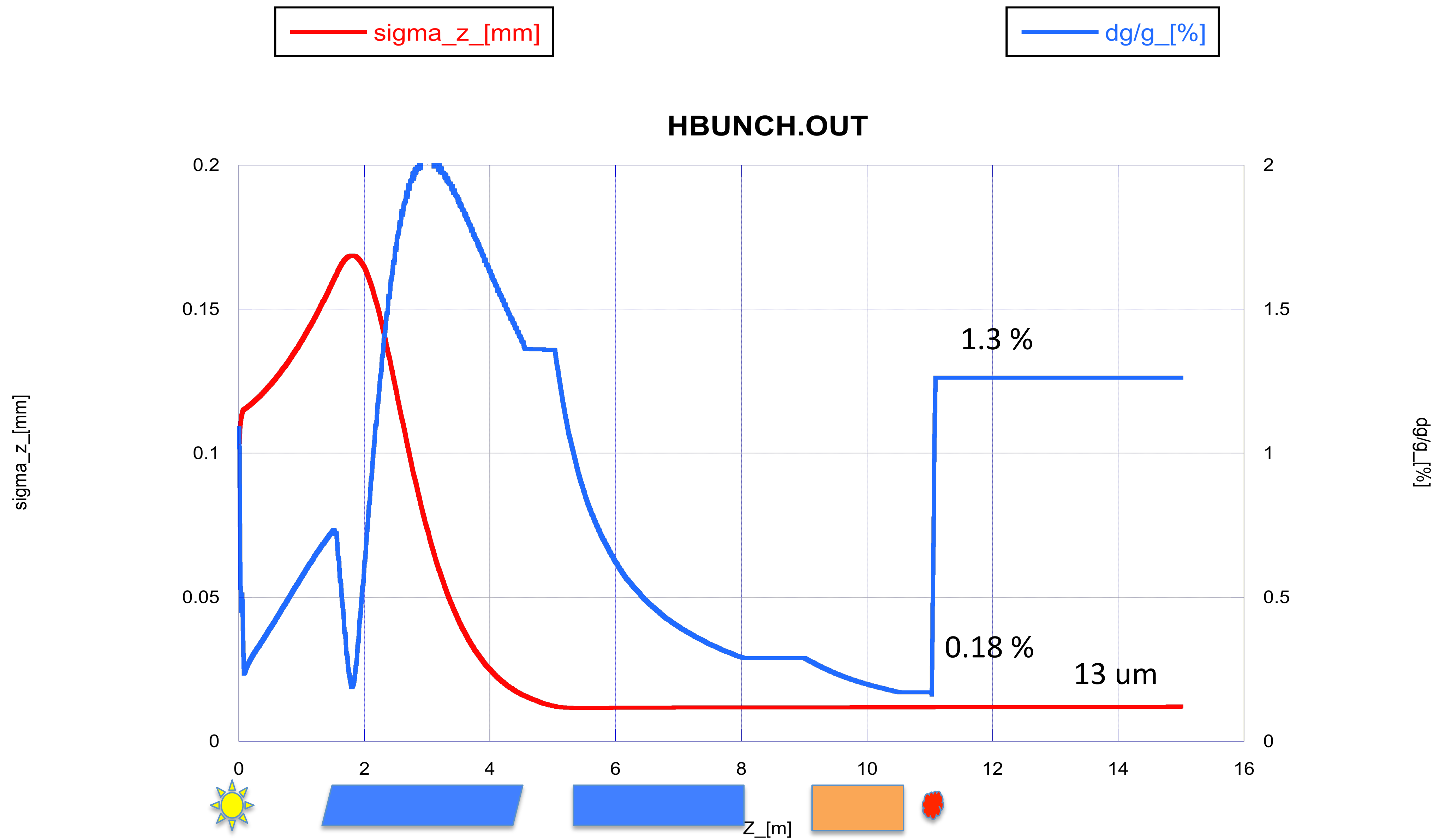


Homdyn preliminary simulations

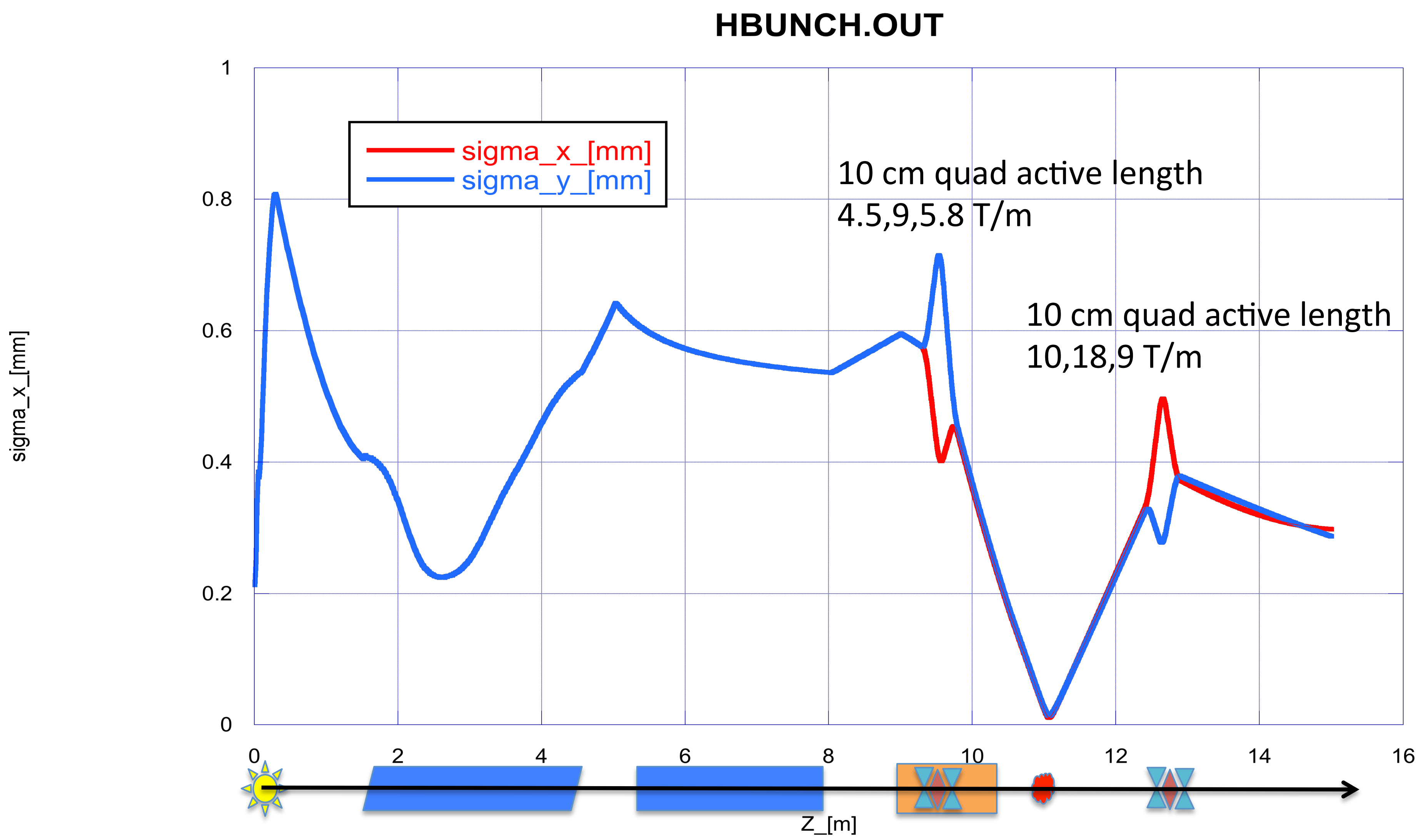
- Charge 25 pC
- Laser pulse length 300 fs FWHM
- Spot at cathode 370 um
- Gradients 20,20,35 MV/m



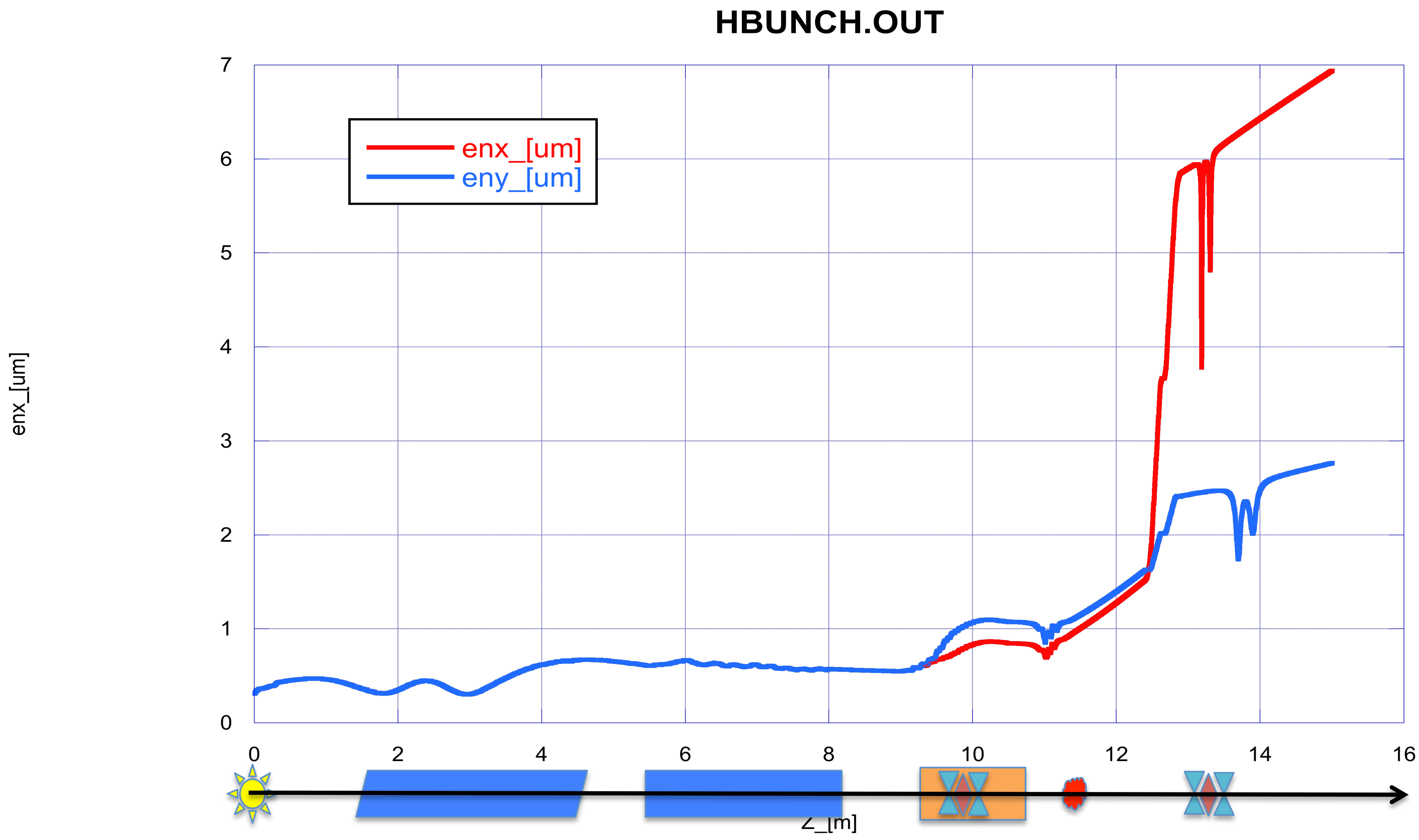

HBUNCH.OUT
I_[A]
T_[MeV]
170 MeV
125 MeV
200
150
100
50
0
I_[A]
0
2
4
6
8
10
12
14
16
_[m]
5 cm plasma, 300 um wavelength
1 GV/m => 500 MV/m off crest



sigma_z_[mm]
dg/g_[%]
HBUNCH.OUT
0.2
0.15
0.1
0.05
0
2
1.5
1
0.5
0
0
2
4
6
8
10
12
14
16
Z_[m]
sigma_z_[mm]
dg/g_[%]
1.3 %
0.18 %
13 um

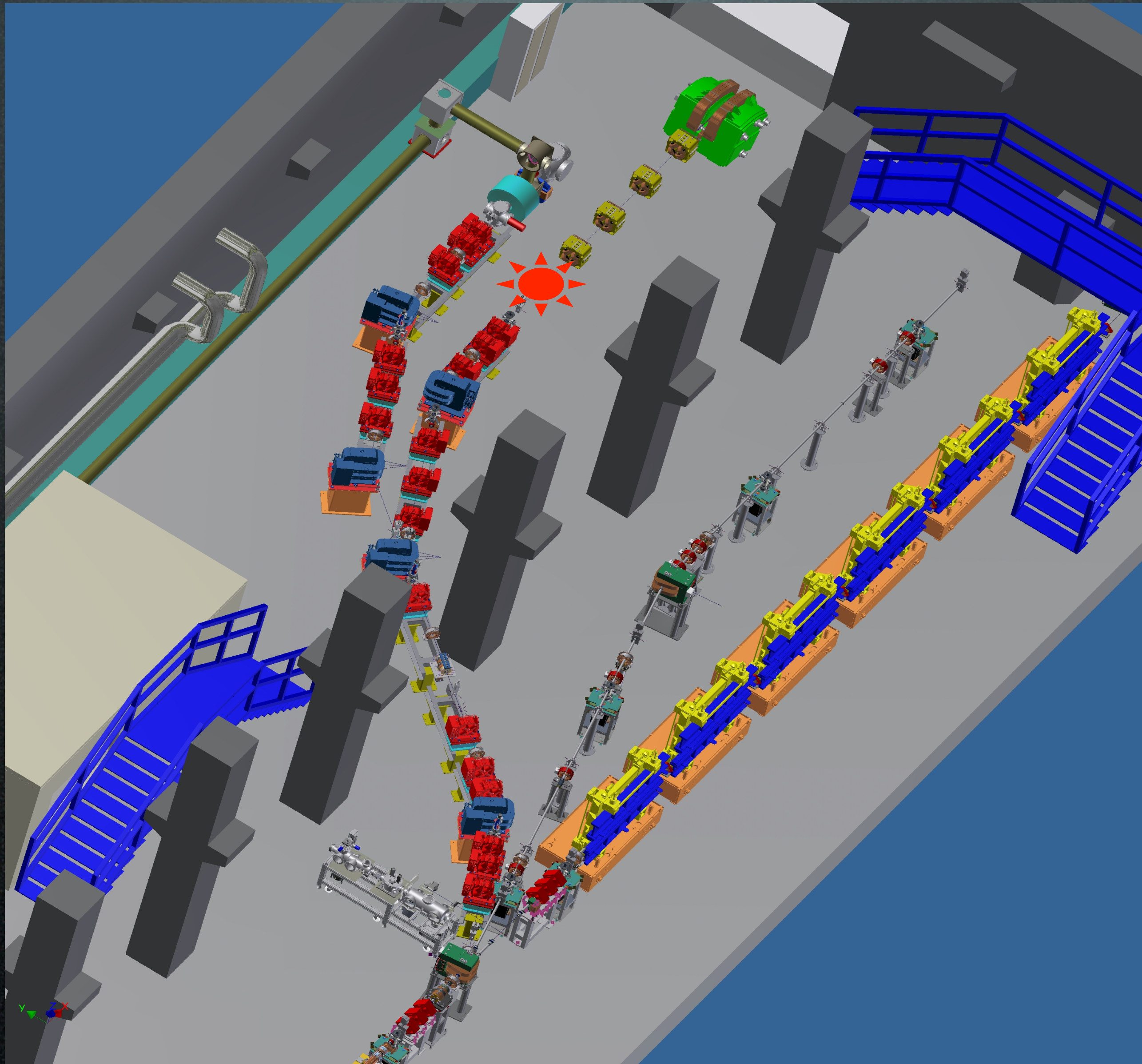


HBUNCH.OUT
sigma_x_[mm]
sigma_y_[mm]
10 cm quad active length
4.5,9,5.8 T/m
10 cm quad active length
10,18,9 T/m
sigma_x_[mm]
Z_[m]
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
12
14
16

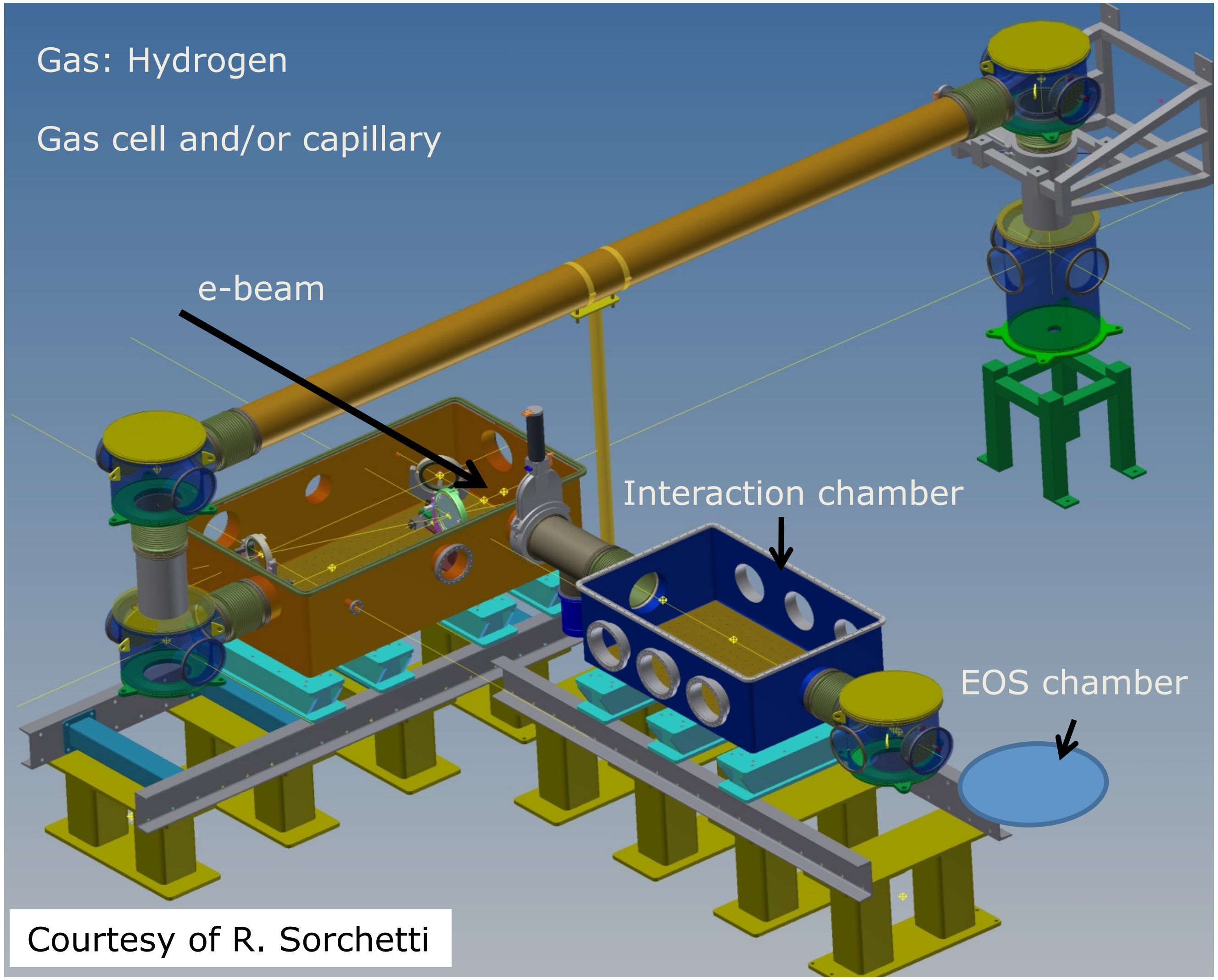


$$\Delta\varepsilon_{n,rms} = \langle\gamma\rangle \left| \left(\sigma_\gamma k_q l_q + \sigma'_o\right)\sigma_o^2 + \sigma_o \sigma'_o \right|$$

Laser Wake Field Acc.



Interaction Layout



Start-to-End Simulations

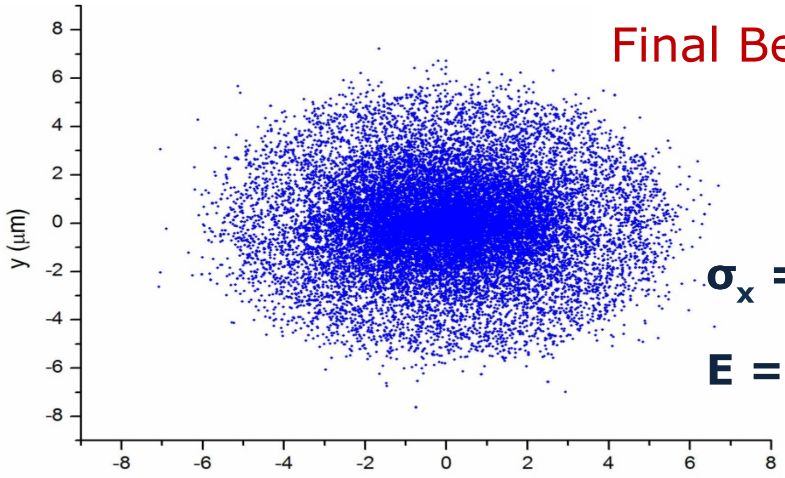
Start-to-end simulations for the External-Injection experiment are performed using three different numerical codes
- ASTRA for the bunch generation at the photocathode and acceleration down to the linac end (by A. Bacci)
- ELEGANT for the transport inside the dogleg (by C. Vaccarezza)
- QFLUID2 for the acceleration in plasma (by P. Tomassini)

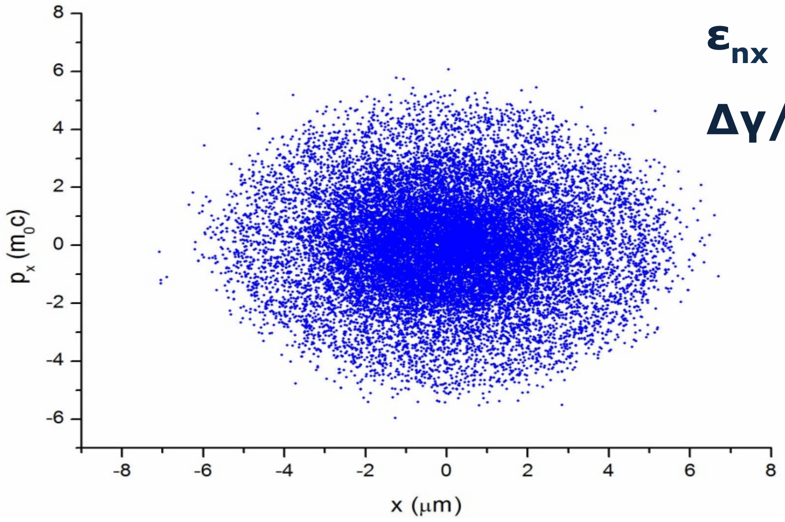
The simulation geometry is a capillary

Beam parameters
$\sigma x \approx \sigma y$=12.7 μm,
εx= 2.7 μm, **εy**= 0.4 μm, **E**= 78 MeV,
$\delta\gamma/\gamma$= 0.2%.
Total compression factor = 16
(8 by VB and 2 by dogleg).
Non particular optimization in dogleg
X emittance overestimated!

Start-to-End Simulations

Final Beam parameters



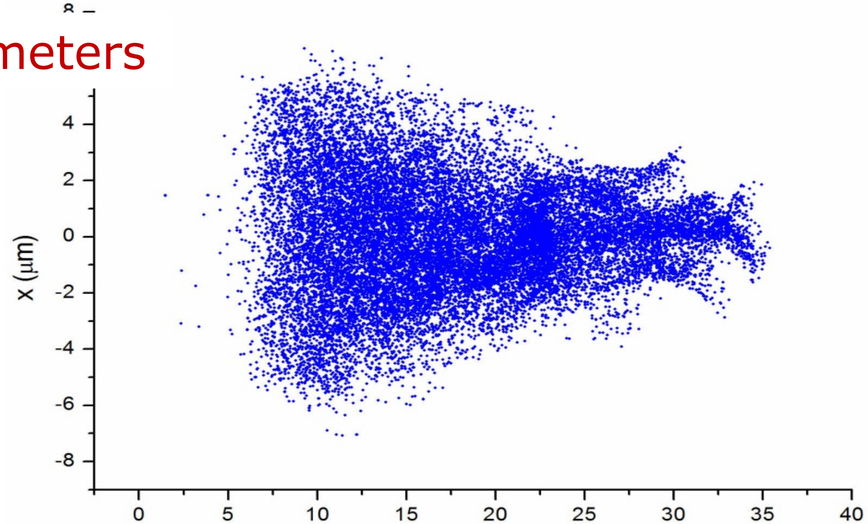


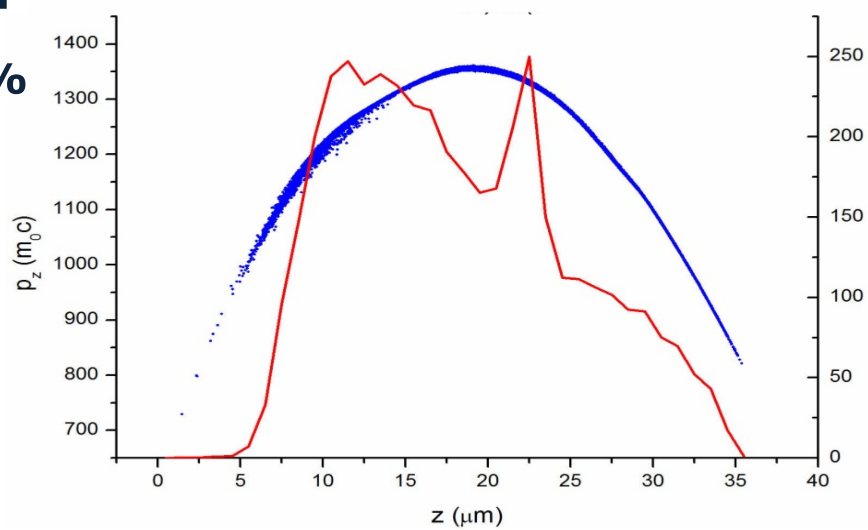
σ_x = 2.0 μm

E = 630 MeV

ε_{nx} = 3.5 μm

$\Delta\gamma/\gamma$= 7.7 %

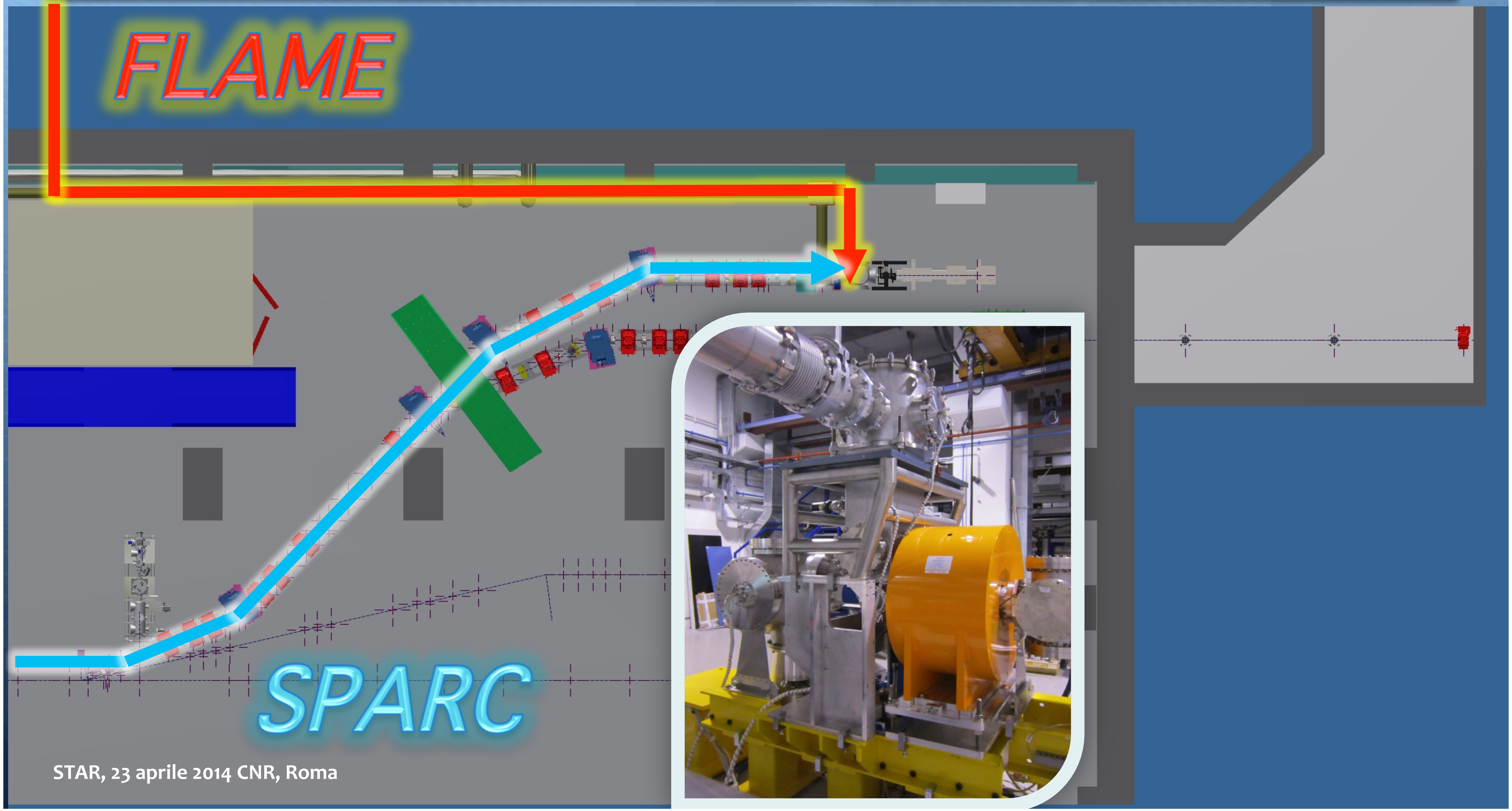




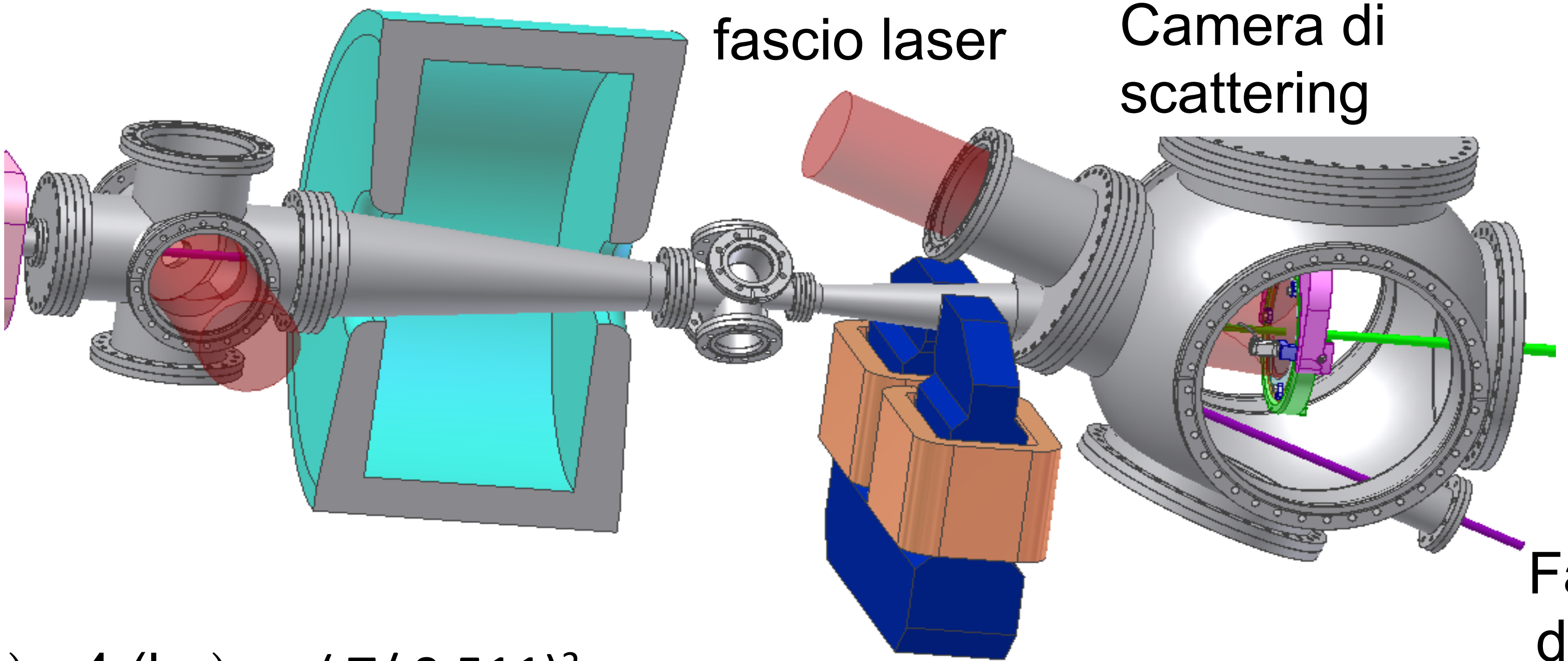
A. R. Rossi et al., NIM A **740**, 60-66 (2014)

Thomson backscattering

SL-Thomson Source at SPARCLAB



Thomson Interaction region (20-550 keV)



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

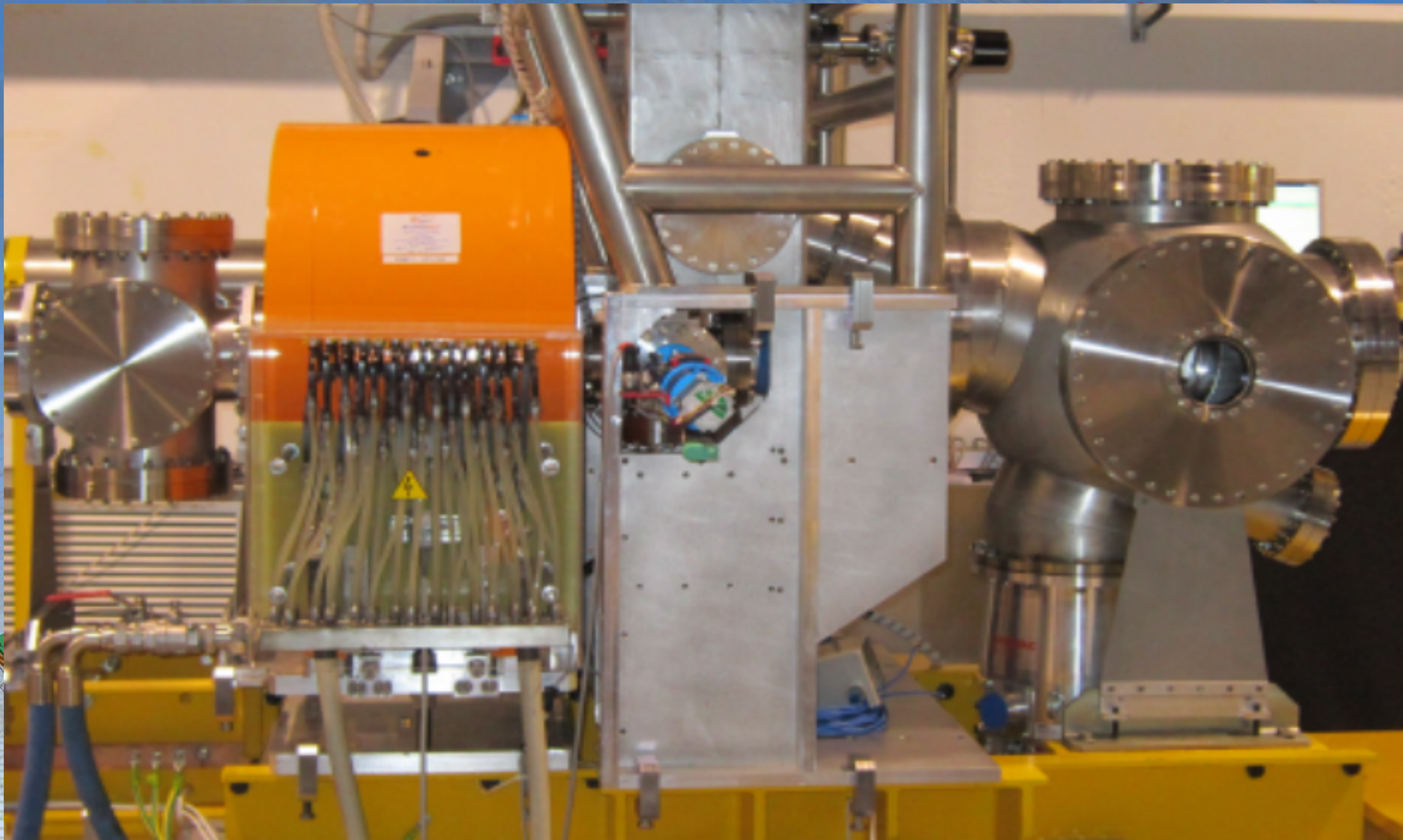
$(h\nu)_{laser}$ = 1.2 eV

T =30.28 MeV

$(h\nu)_X$ = 20 keV mammografia

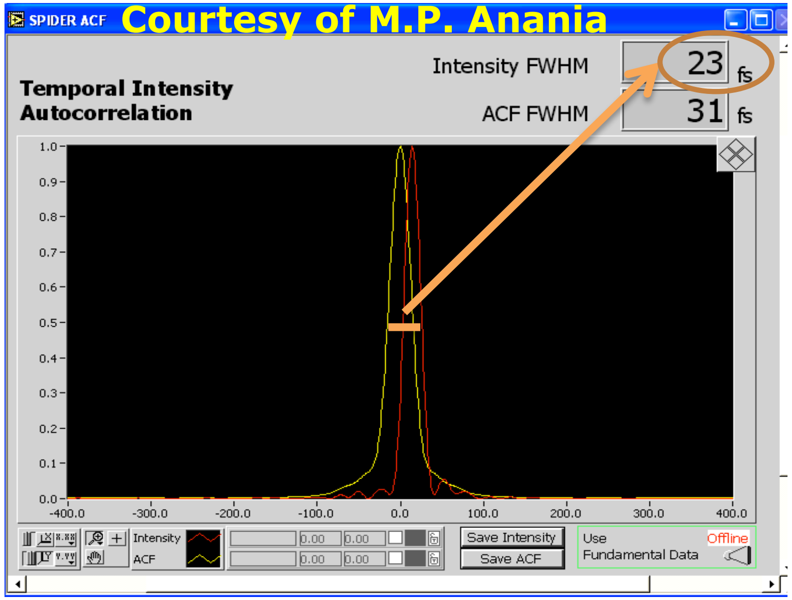
Impulso laser:	6 ps, 5 J
pacchetto e^- :	1 nC , l: 2 mm (rms)
Impulso X:	10 ps, 10^9 fotoni
α emissione:	12 mrad

Thomson back-scattering source

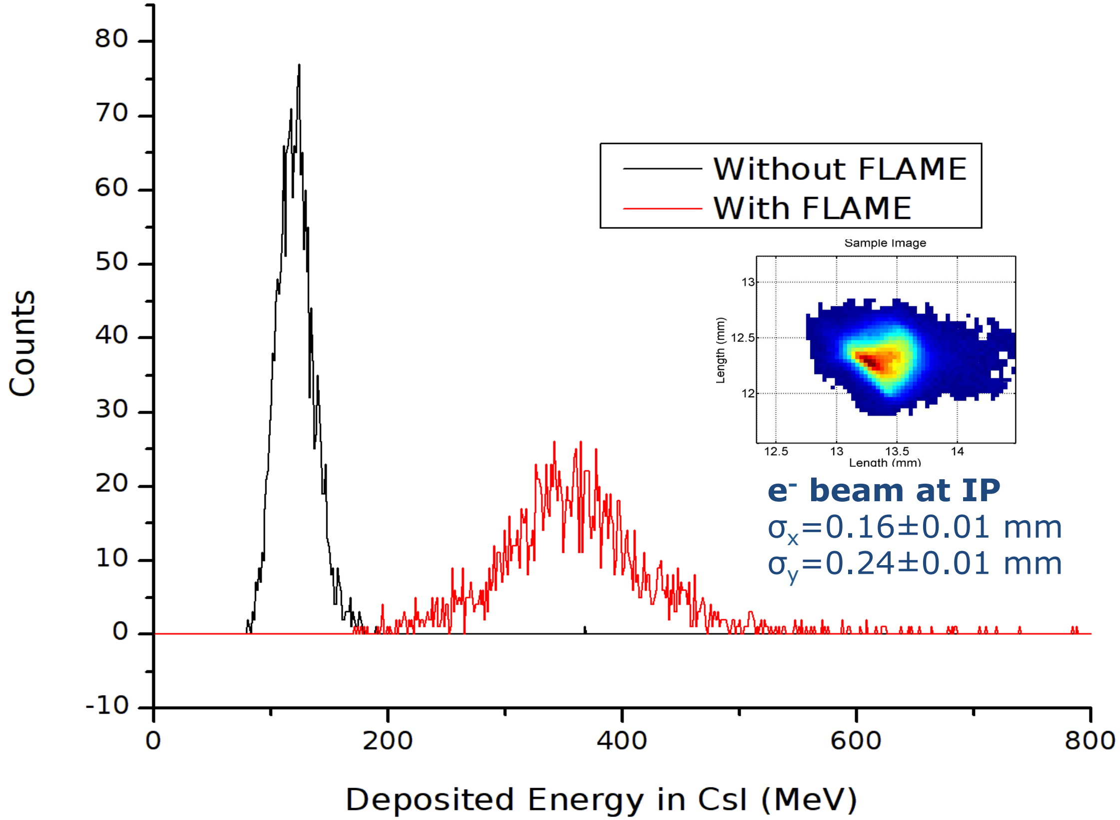


Electron Beam Experimental Studies

- Thomson backscattering experiments



Max energy: 7J
Max energy on target: ~ 5J
Min bunch duration: 23 fs
Wavelength: 800 nm
Bandwidth: 60/80 nm
Spot-size @ focus: 10 μm
Max power: ~ 300 TW
Contrast ratio: 10^{10}

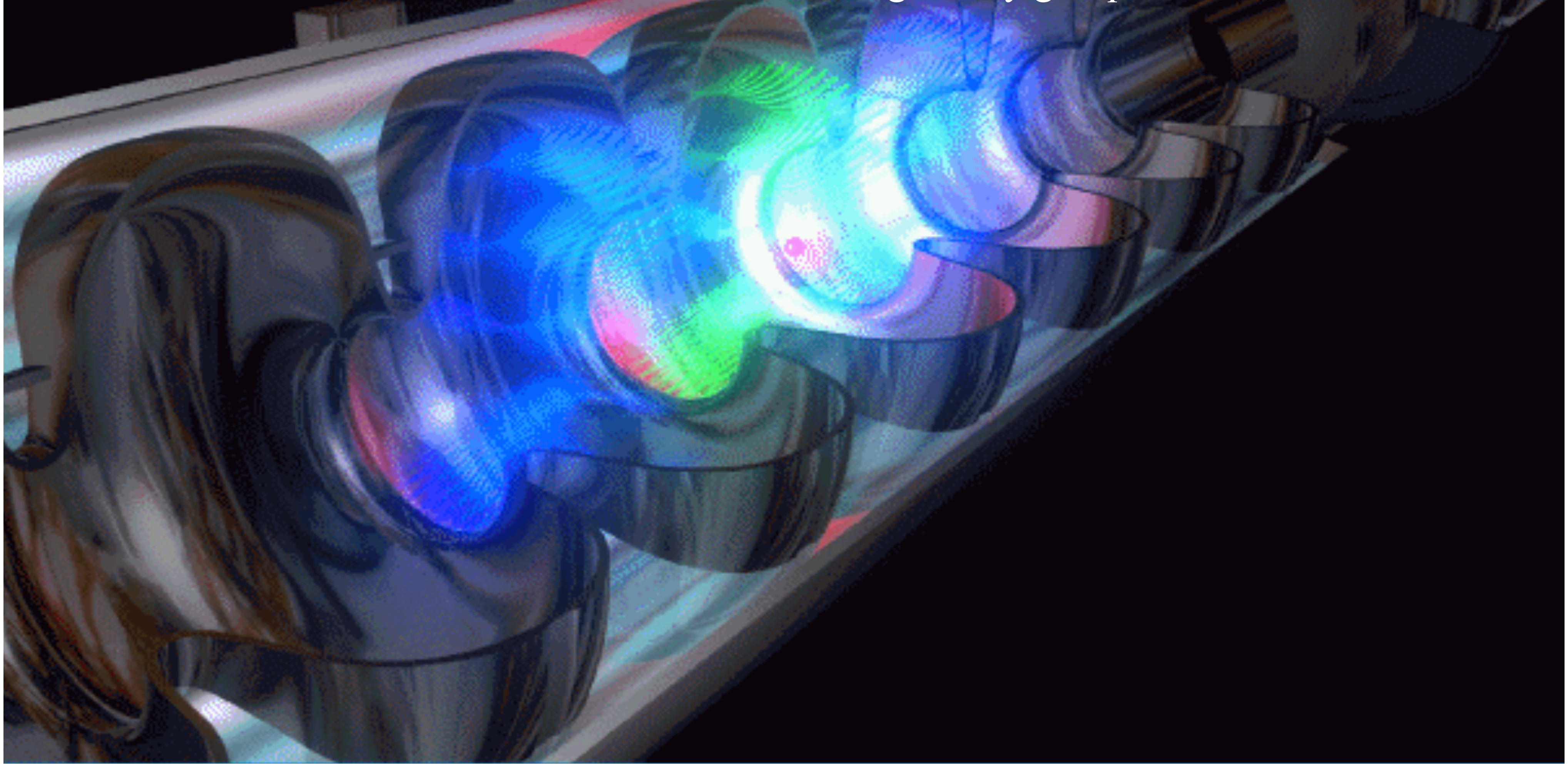


e^- beam at IP
σ_x=0.16±0.01 mm
σ_y=0.24±0.01 mm

I R I D E

Interdisciplinary Research Infrastructure with Dual Electron linacs

Massimo.Ferrario@lnf.infn.it
on behalf of the IRIDE design study group



IRIDE aims and potentials

- Science with Free Electron Lasers (FEL) from infrared to X-rays,
- Nuclear photonics with Compton back-scattering g-rays sources,
- Science with THz radiation sources,
- Advanced Neutron sources by photo-production,
- Fundamental physics investigations with low energy linear colliders
- Physics with high power/intensity lasers,

- R&D on advanced accelerator concepts including plasma accelerators and polarized positron sources
- ILC technology implementation
- Detector development for X-ray FEL and Linear Colliders
- R&D in accelerator technology and industrial spin – off

Nuclear Instruments and Methods in Physics Research A 740 (2014) 138–146

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IRIDE: Interdisciplinary research infrastructure based on dual electron linacs and lasers

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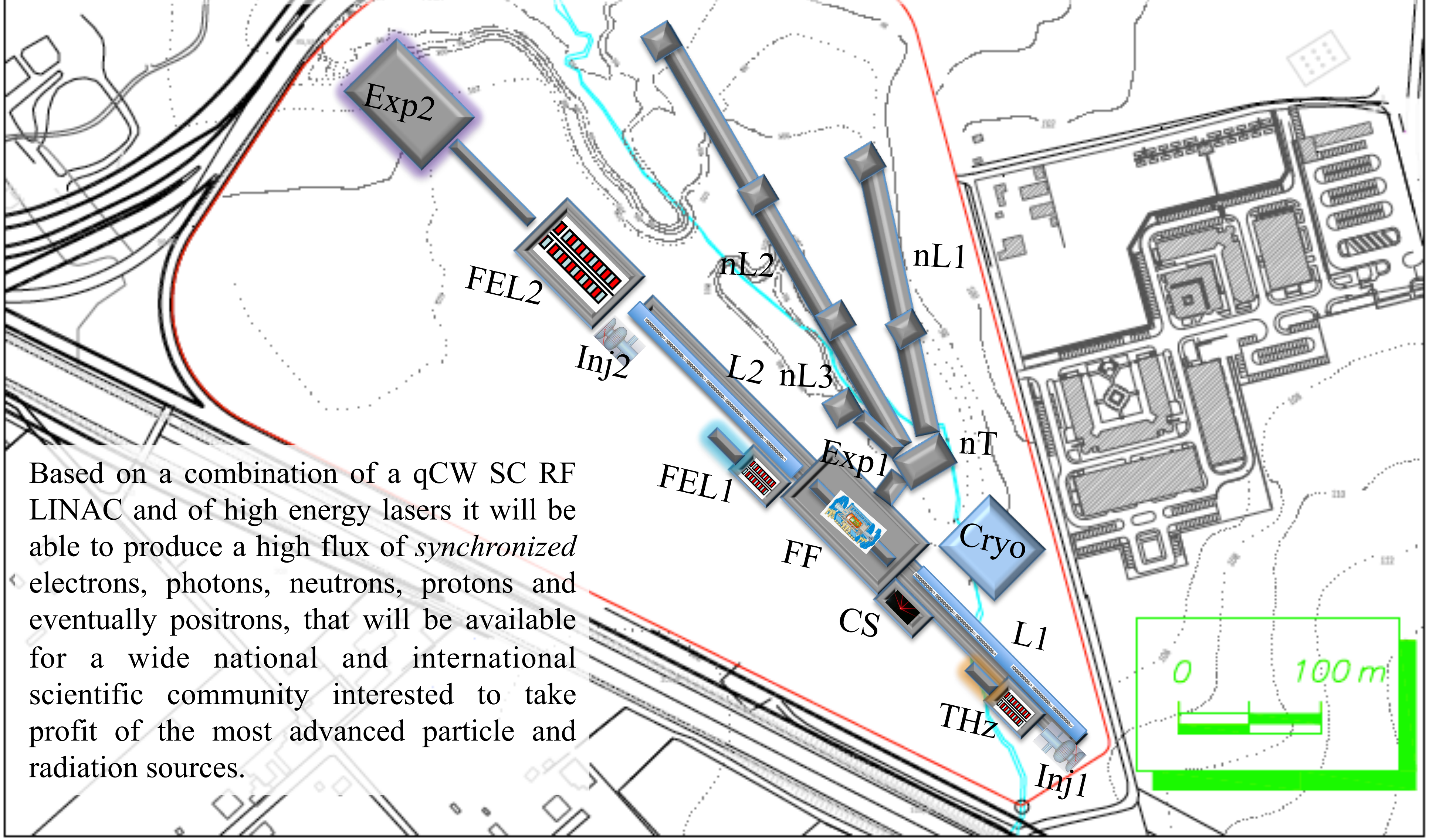
Wide collaboration among Italian and Euopean research institutes !!

Istituzione	# persone	# sezioni
INFN	104	15
CNR	20	6
ENEA	28	2
Altri (Italiani)	40	20
Altri (Stranieri)	43	19

IRIDE White Book delivered on July 17, 2013 available at:

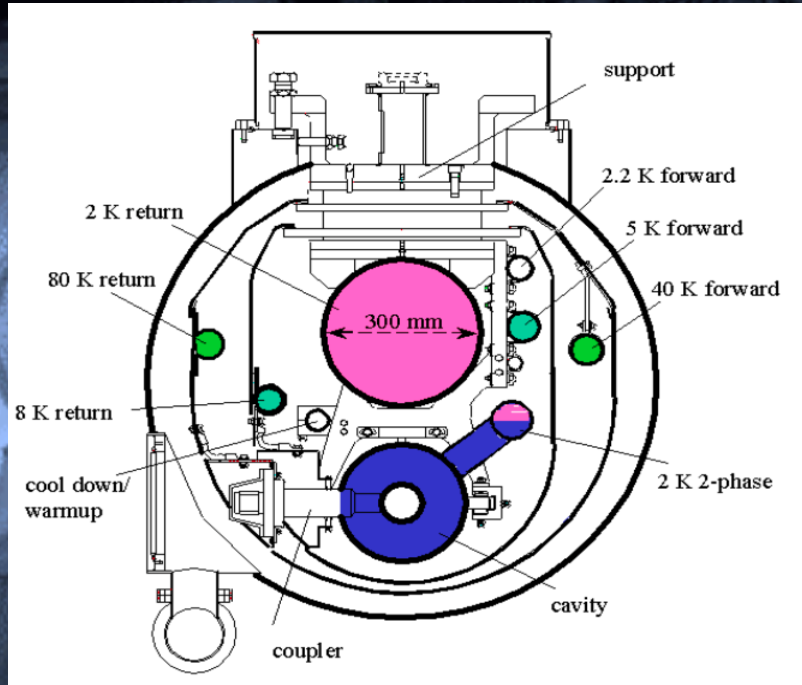
arXiv:1307.7967 [physics.ins-det].

I R I D E is a proposal for large infrastructure for fundamental and applied physics research. Conceived as an innovative and evolutionary tool for multi-disciplinary investigations in a wide field of scientific, technological and industrial applications, it will be a high intensity “particle beams factory”.



Based on a combination of a qCW SC RF LINAC and of high energy lasers it will be able to produce a high flux of *synchronized* electrons, photons, neutrons, protons and eventually positrons, that will be available for a wide national and international scientific community interested to take profit of the most advanced particle and radiation sources.

INFN is in a leading position in the SC RF technology, with knowledge and strong capabilities in the design, engineering and industrial realization of all the main component of a superconducting radiofrequency accelerator.

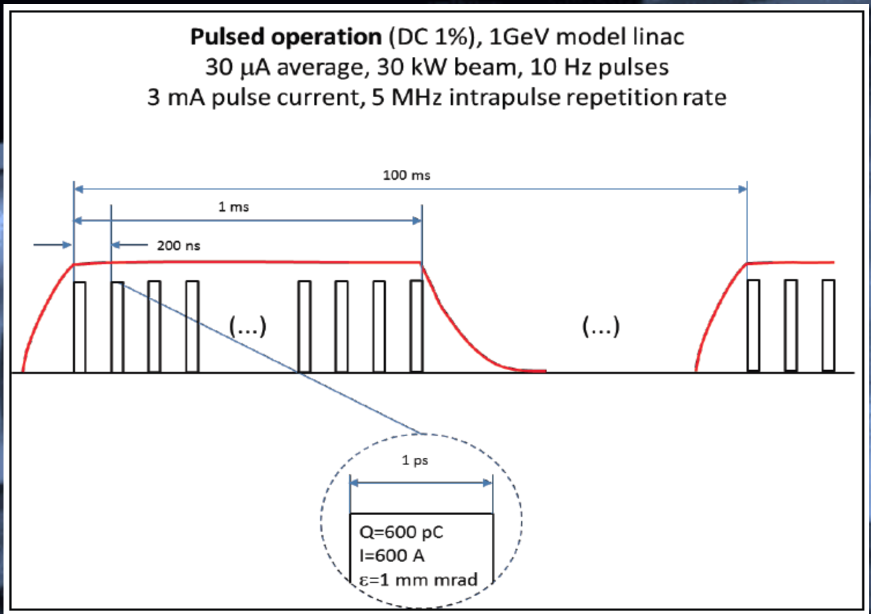


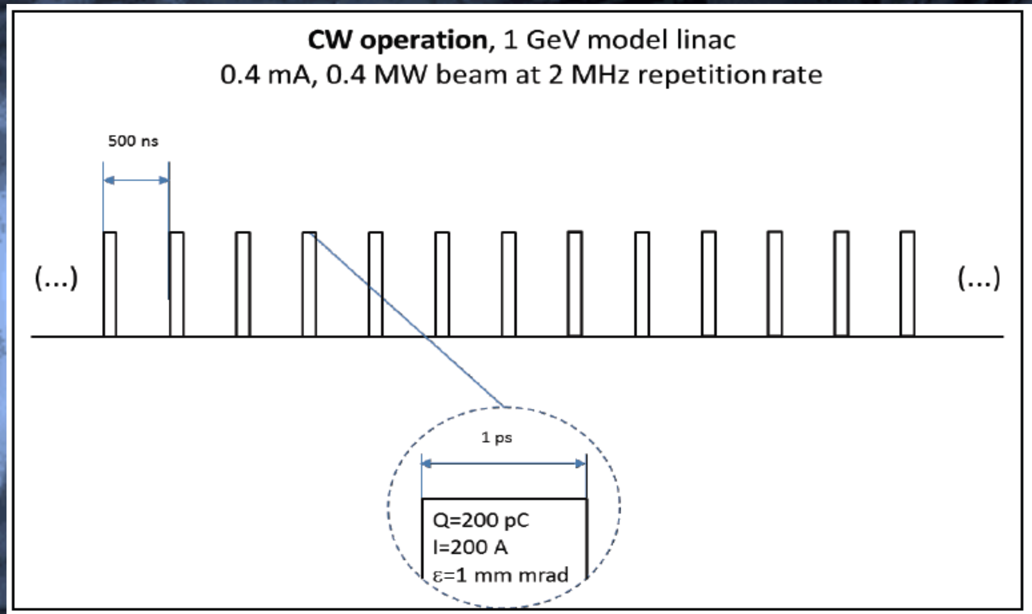
XFEL Italian In-Kind contribution

- 400/800 of the 1.3 GHz cavities
- 45/100 of the cryomodules
- High QE photocathode preparation/transport system
- Cavities/Cryomodule for the 3.9 GHz linearizer

i.e. the main components for a 9 GeV SC linac

The main feature of a SC linac relevant for IRIDE is the possibility to operate the machine in continuous (CW) or quasi-continuous wave (qCW) mode with high average beam power (>1 MW) and high average current (>300 μA).





The CW or qCW choice, combined with a proper bunch distribution scheme, offers the most versatile solution to provide bunches to a number of different experiments, as could be envisaged in a multi-purpose facility.

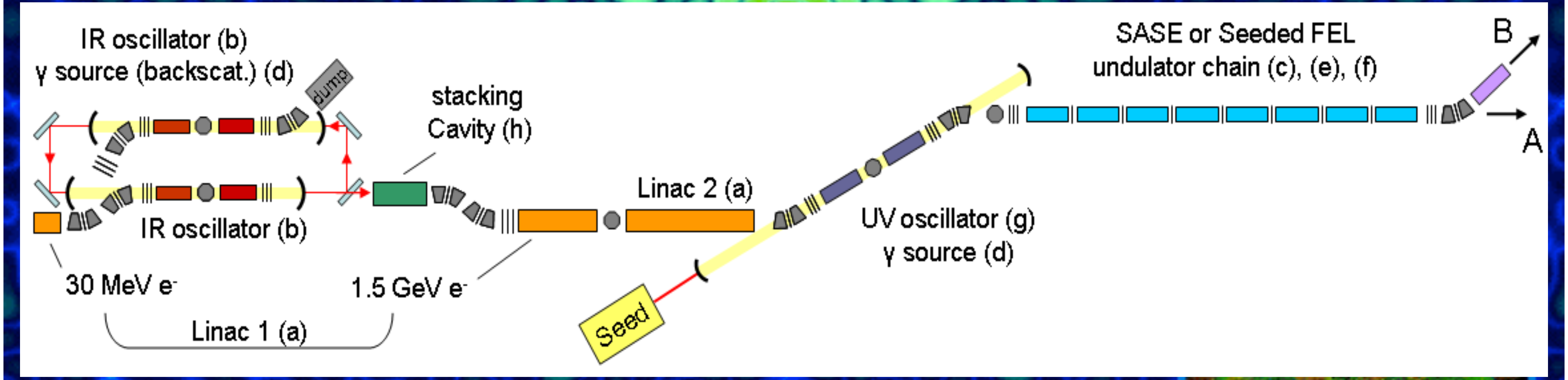
IRIDE linac parameters flexibility (for each linac)

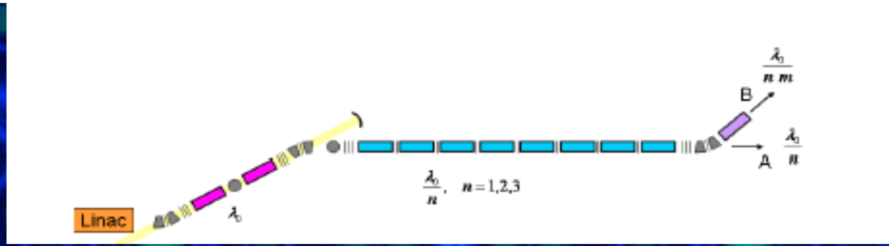
Table 1: Possible SC linac parameters

	Pulsed	qCW	CW
Energy [GeV]	2	2	1.5
I (within pulse) [mA]	2.5	0.26	
I (average) [mA]	0.17	0.16	0.35
RF pulse duration [ms]	1.5	1000	CW
RF Duty cycle [%]	15	60	100
E_{acc} [MV/m]	20	20	15
$Q_0 \times 10^{10}/Q_{ext} \times 10^6$	2/4	2/40	2/40
N. of cavities/N. of modules	96/12	96/12	96/12
Beam average power [kW]	334	309	525

IRIDE Free Electron Lasers

The IRIDE project will provide a new concept of FEL facility by merging the two technologies of FEL oscillators and fourth generation radiation sources by developing a facility providing radiation from IR to EUV to the nm region down to Å level using a mechanism of emission already successfully tested at SPARC.



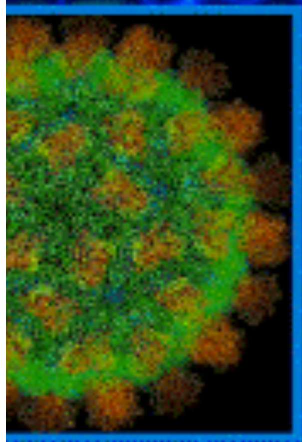


1.5 Gev electron beam energy

	Fundamental	3° harmonic	5° harmonic
λ(nm/KeV)	4/0.413	1.33/1.23	0.8/2.07
peak flux (n/s/- 0.1%BW)	$2.7*10^{26}$	$2.5*10^{24}$	$1.9*10^{23}$
Peak brilliance	$1.56*10^{30}$	$1.4*10^{28}$	$1.1*10^{27}$
photon/bunch	$5.94*10^{13}$	$5.5*10^{11}$	$4.18*10^{10}$

3.0 Gev electron beam energy

	Fundamental	3° harmonic	5° harmonic
λ(nm/KeV)	1/1.24	0.3/3.72	0.2/6.2
peak flux (n/s/- 0.1%BW)	$4.6*10^{25}$	$4.1*10^{23}$	$3.4*10^{22}$
Peak brilliance	$6.4*10^{31}$	$5.7*10^{29}$	$4.7*10^{28}$
photon/bunch	$1.01*10^{13}$	$9.02*10^{10}$	$7.48*10^{9}$



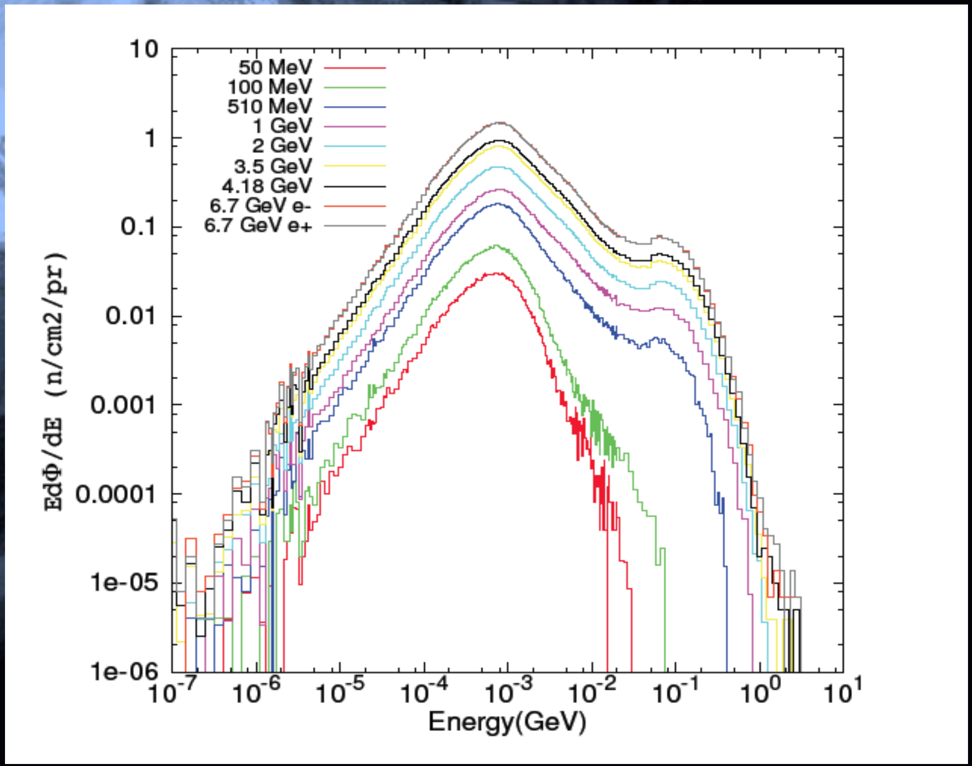
4.0 Gev electron beam energy

	Fundamental	3° harmonic	5° harmonic
λ(nm/KeV)	0.563/2.2	0.188/6.5	0.113/10.9
peak flux (n/s/- 0.1%BW)	$1.2*10^{25}$	$5.9*10^{22}$	$2.8*10^{21}$
Peak Brilliance	$1.92*10^{31}$	$1.8*10^{29}$	$1.2*10^{28}$
photon/bunch	$2.1*10^{12}$	$1.06*10^{10}$	$5.0*10^{8}$

Neutron Source

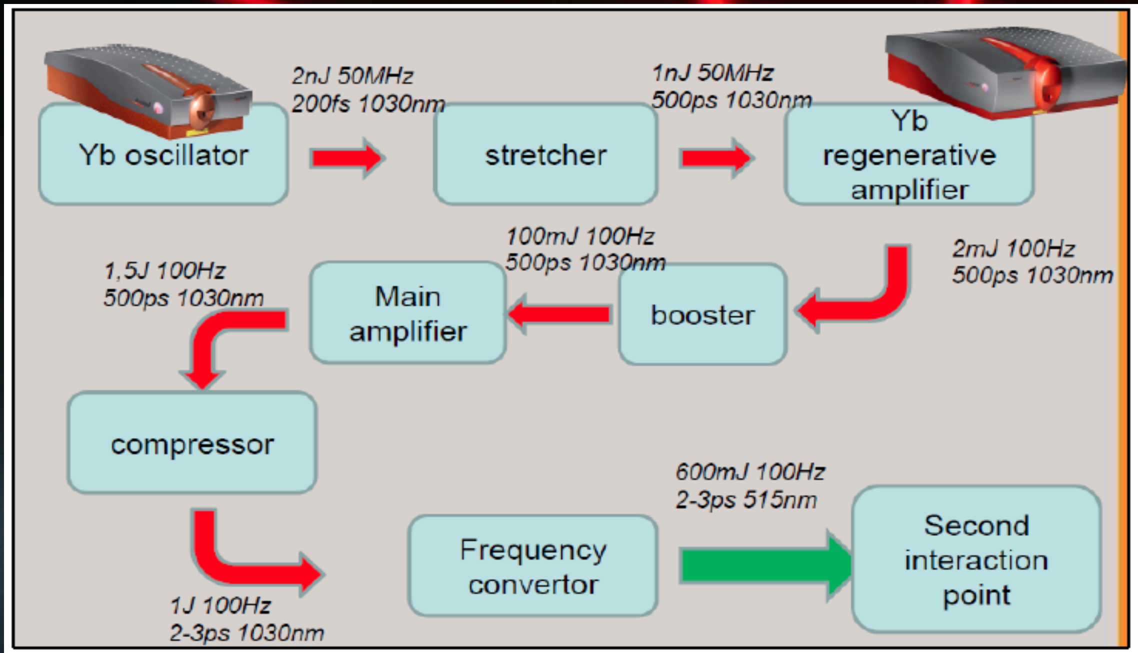
This source may be suitable for multiple applications, ranging from material analysis for industrial and cultural heritages purposes to chip irradiation and metrology. These applications envisage the development of properly designed beam lines with neutron moderation and possibly cold/thermal neutron transport systems. The proposed new facility will represent a great opportunity for research and development of neutron instrumentation (e.g. detectors) as well as training of young scientist in the use and development of neutron techniques.

Deposited Power [kW]	Primary Electron Energy [GeV]	Expected Average Neutron Emission rate [n/s]
30	1	1.3 E+14
250	1	1.0 E+15
400	1	1.7 E+15
30	3	4.3 E+13
250	3	3.3 E+14
400	3	5.6 E+14



Advanced γ-ray Compton Source

The state of the art in producing high brilliance/spectral density mono-chromatic γ-ray beams will be soon enhanced, stepping up from the present performances (γ-ray beams with bandwidth nearly 3% and spectral density of about 100 *photons/s·eV*) up to what is considered the threshold for Nuclear Photonics, *i.e.* a bandwidth of the γ-ray beam lower than 0.3% and a spectral density larger than 10^4 *photons/s·eV*.



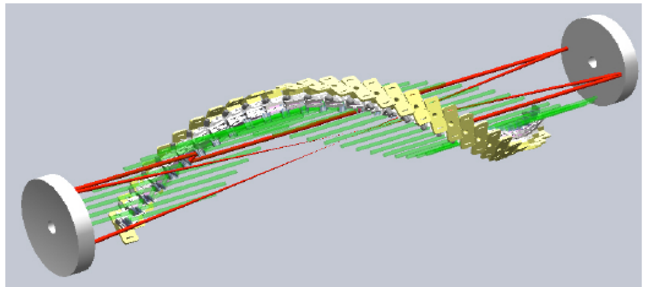


Fig. 133. Schematic view of the re-circulating principle

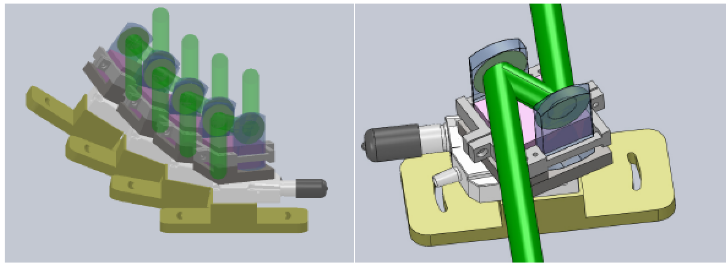


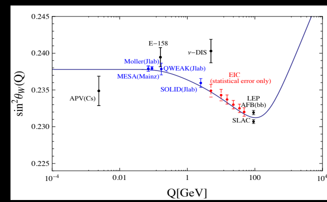
Fig. 134. Schematic view of the motorized mirror pairs used in the re-circulator

- colliding laser pulses to drive the back-scattering Compton (Yb:YAG, 100 W, 1 J, 0.1% bw)

Particle Physic Opportunities

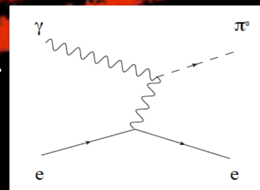
IRIDE facility can be a precision tool for the SM exploration at low- and medium-energy scales

ELECTRONS ON TARGET:

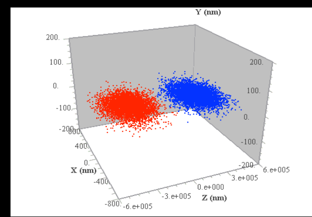


Utilizing the polarized electron beam dumped onto the proton target, one can measure the left-right parity violating asymmetry of electron-proton scattering at the per cent level, and thereby extract precisely the electroweak mixing angle.

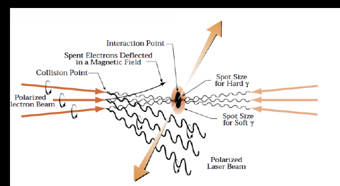
LINEAR COLLIDER CONFIGURATIONS:



γ-e The precise measurement of the π^0 width through the process $e\gamma \to \pi^0 e$ (*Primakoff effect*), and the search for light dark bosons in the energy region of few to hundreds MeV.



$e^- e^-$, $e^+ e^-$ An electron-positron collider with luminosity of 10^{32} $cm^{-2}s^{-1}$ with center of mass energy ranging from the mass of the φ-resonance 1 GeV up to ~3.0 GeV would allow one to measure the e^+e^- cross section to hadrons with a total fractional accuracy of 1%, with relevant measurements for the the *g*-2 of the muon and the effective fine-structure constant at the M_Z scale.



γ-γ We propose an experiment to observe photon-photon scattering in the range 1 MeV – 2 MeV CM energy, i.e., near the peak of the QED cross-section.