External Injection at INFN-LNF

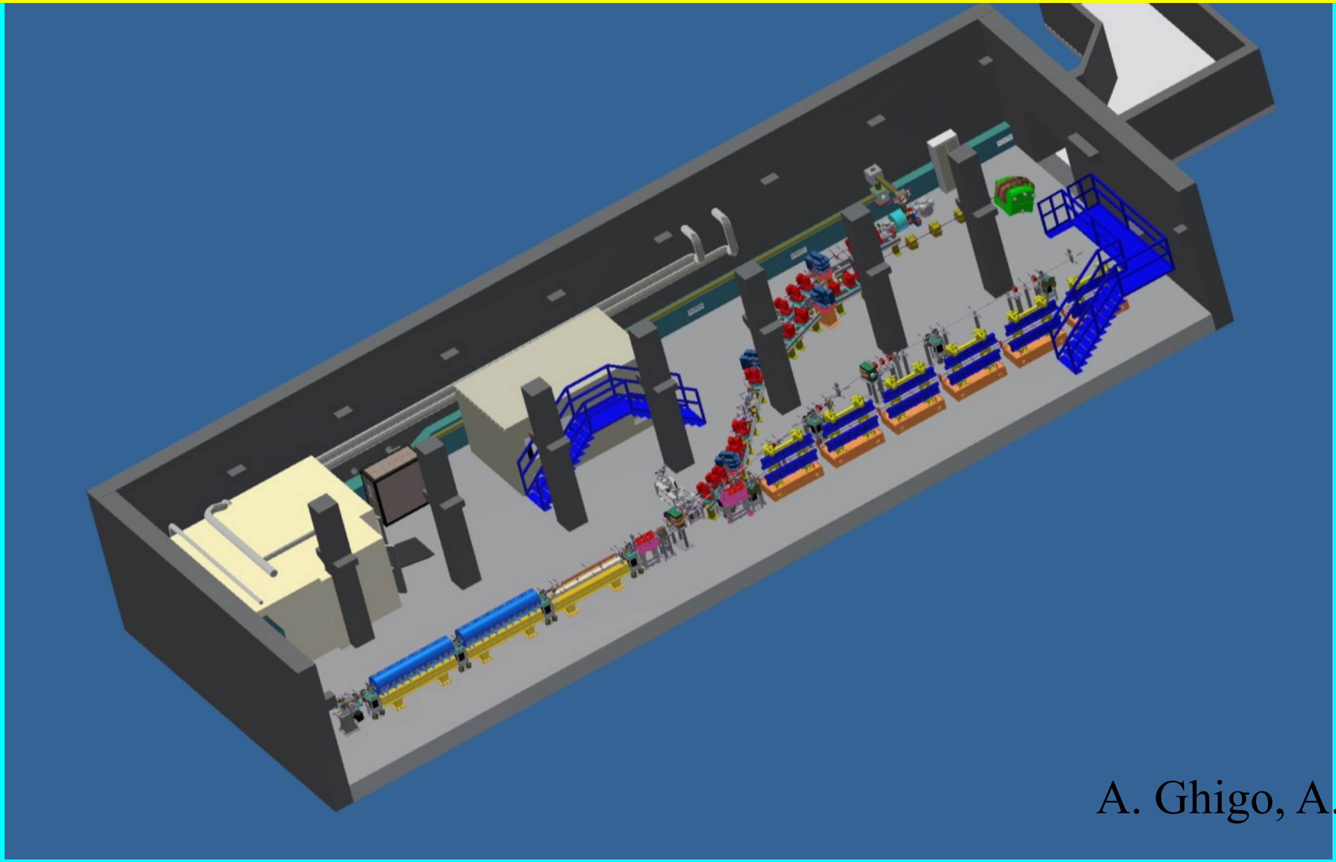
(*integrating RF photo-injectors with LWFA*)

Luca Serafini - INFN/Milano

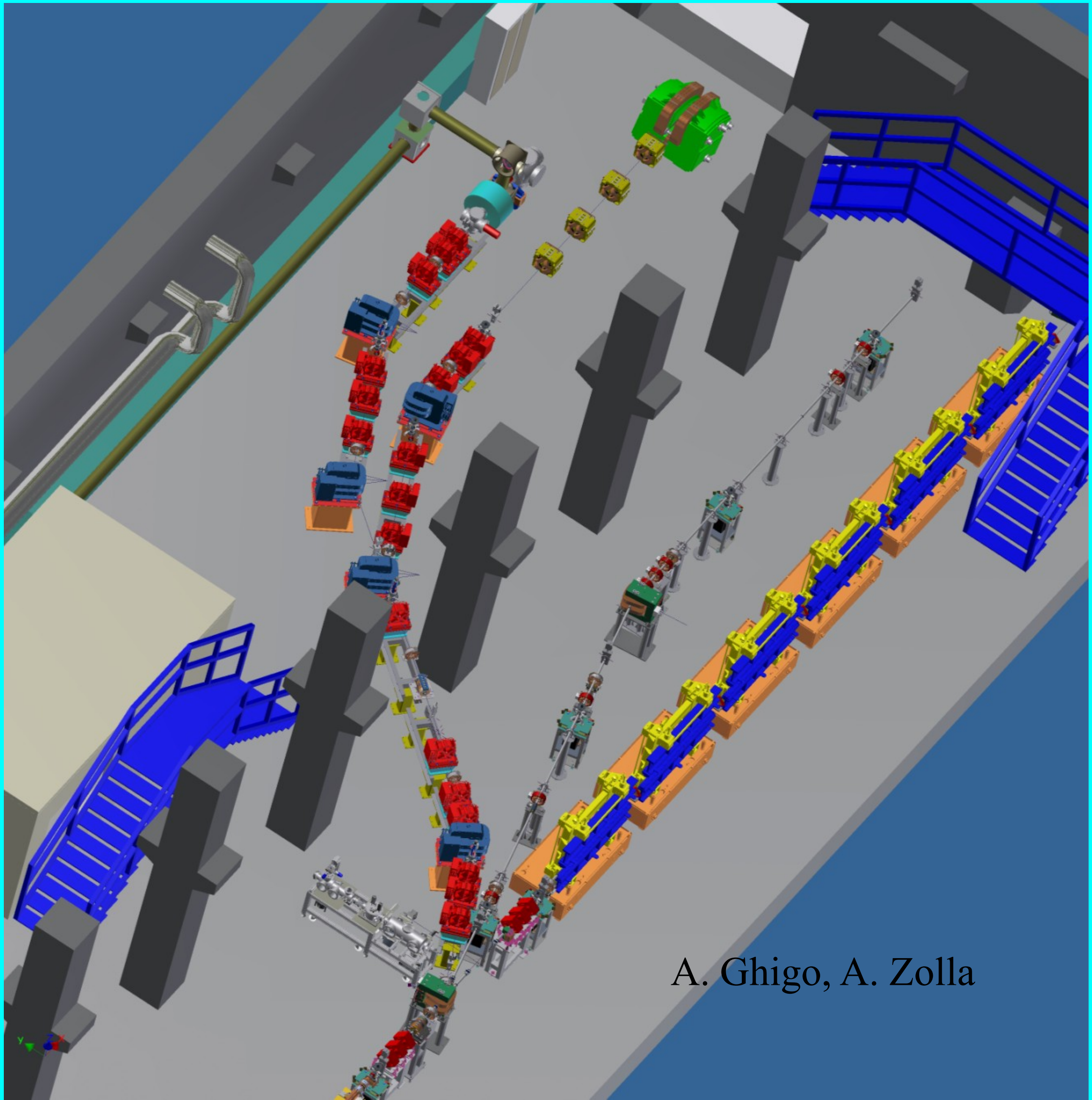
- **High Brightness Photoinjector SPARC – High Intensity (5 J, 300 TW) laser FLAME – both running at INFN-LNF**
- **Ongoing installation of electron and photon beam transport lines: 20-500 keV Thomson Source (2011) and Ext. Inj. Exp. in 2013 (-> PWFA COMB Exp., see M. Ferrario's talk)**
- **SPARC upgrade to 250 MeV (funded), using C-band techn., by 2012, and possible up to 750 MeV (SPARX-FEL program) by 2015: this will lead to second phase of PWFA experiments as well Compton γ-ray source (18 MeV) @ high spectral density**

Messa in Funzione Sorgente Thomson

200 fs electron bunch with low emittance exp. demonstrated at SPARC!
Simulations for 20 pC – 20 fs / 1 pC – 1 fs at 150 MeV

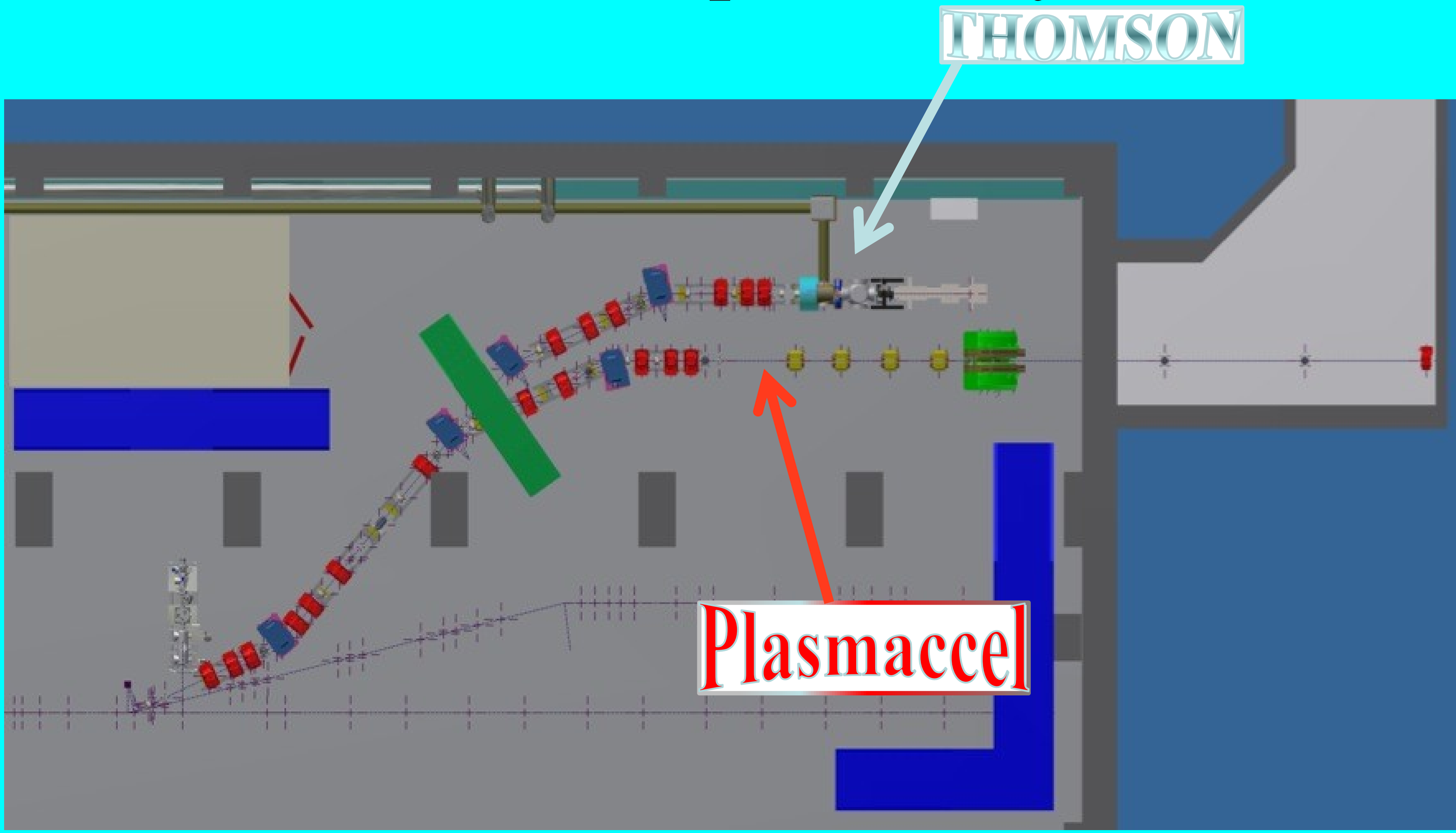


A. Ghigo, A. Zolla

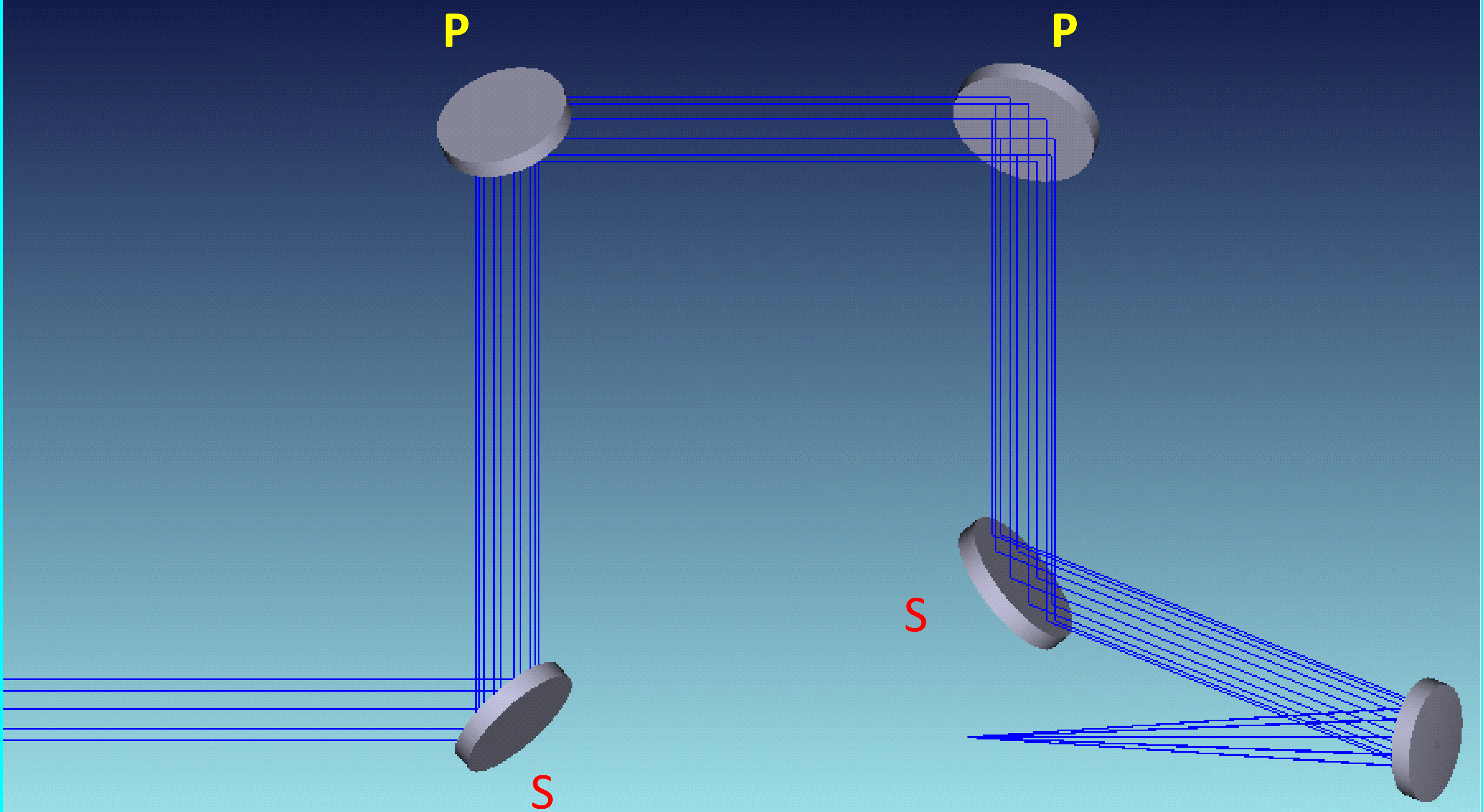


A. Ghigo, A. Zolla

Thomson & Plasma Acceleration beamlines updated layout



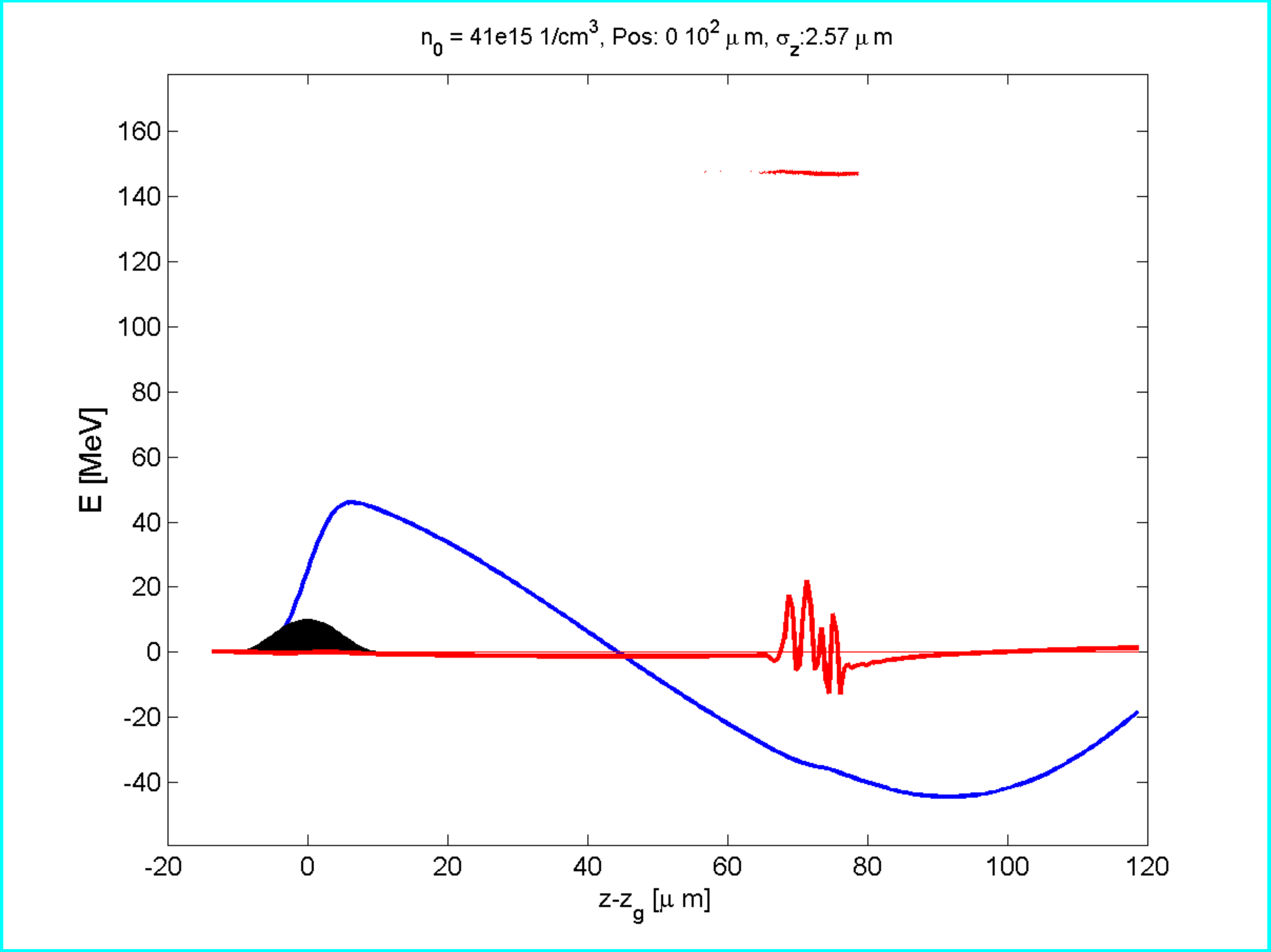
C. Vaccarezza



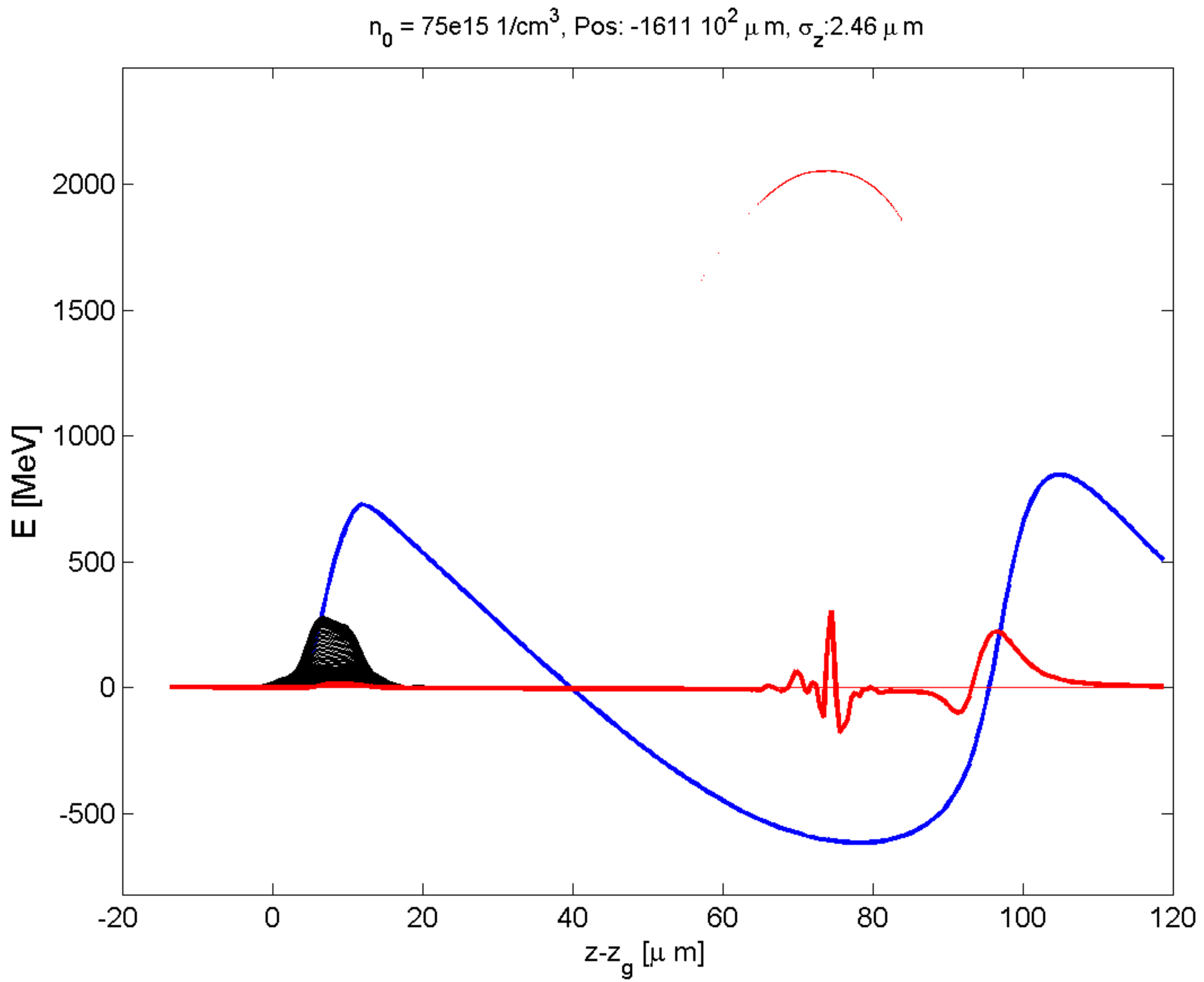
A. Ghigo, G. Gatti

External Injection Experiment

- **Injected Bunch**: 13pC, 150MeV, 0.6 mm·mrad, 3.0 μm rms spot, 2.4 μm rms rms length [circa 1KA]
- **Laser**: 7J in 35fs, w_0=32.5 μm, w_{0_inj}=135 μm, guided over 30 Z_R.
- **Plasma**: Density between $0.6 \cdot 10^{17}$ cm^{-3} and $0.8 \cdot 10^{17}$ cm^{-3} , guided laser pulse. Simulated acceleration length circa 15 cm.
- **Numerica**: Mobile Window at v=c, sampling at 46 mesh points / λ_p and 26 m.p./w. Bunch sampled by 40000 particles

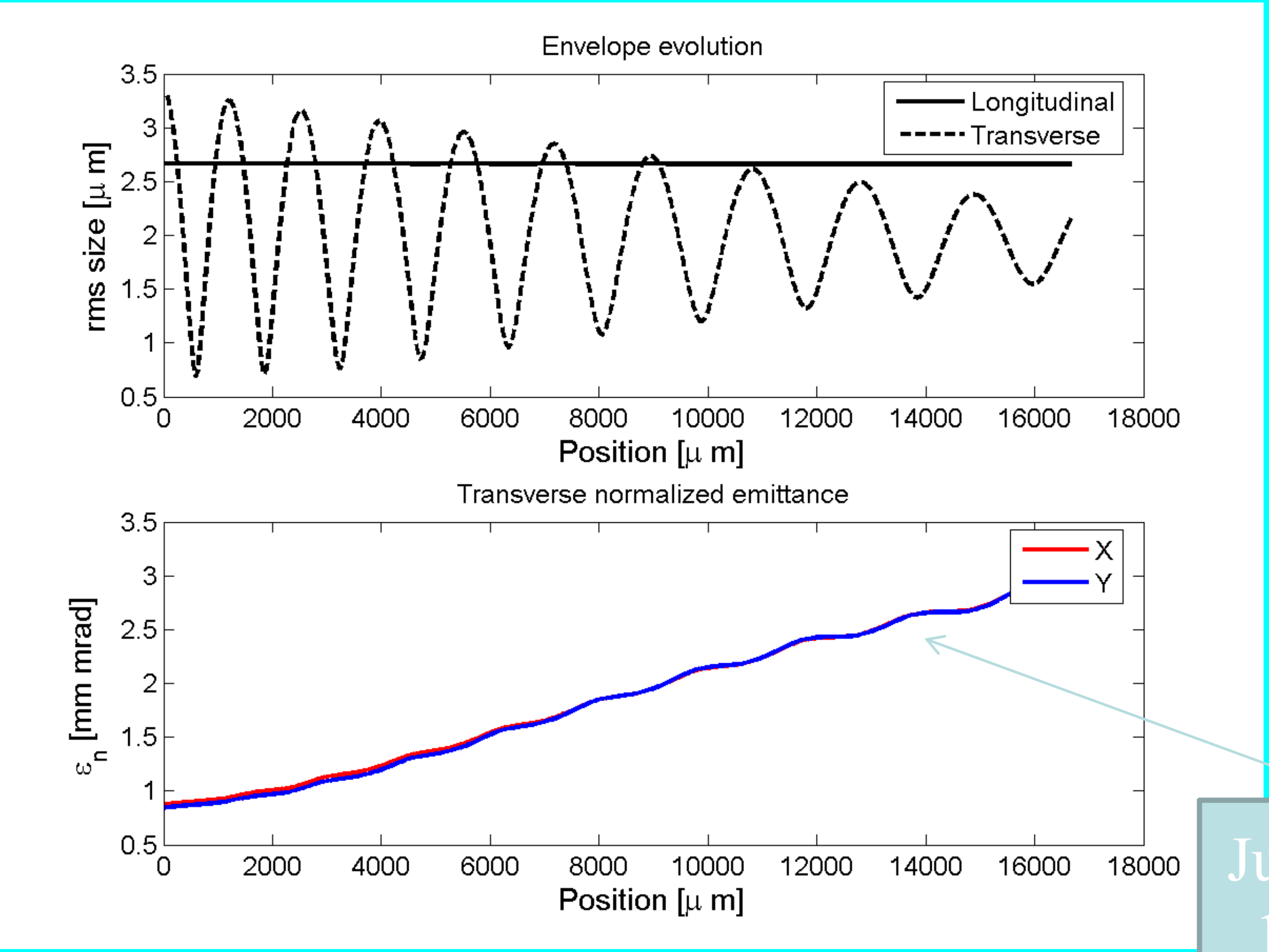


n0 = 41e15 1/cm3, Pos: 0 10^2 μ m, σz:2.57 μ m
E [MeV]
160
140
120
100
80
60
40
20
0
-20
-40
-20
0
20
40
60
80
100
120
z-zg [μ m]



n_0 = 75e15 1/cm^3, Pos: -1611 10^2 μ m, σ_z:2.46 μ m
E [MeV]
2000
1500
1000
500
0
-500
-20
0
20
40
60
80
100
120
$z-z_g$ [μ m]

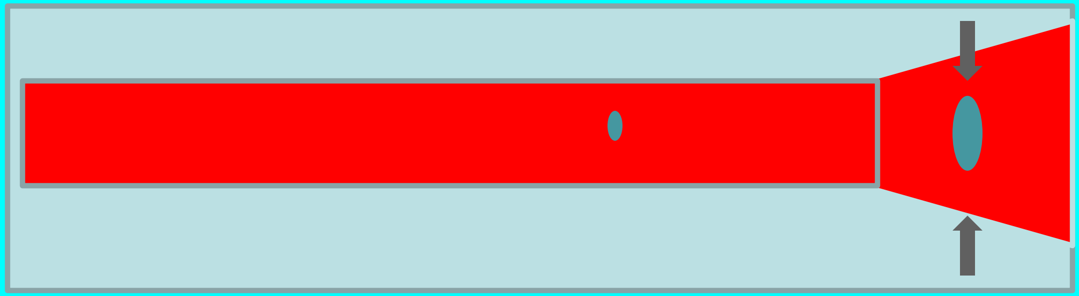
Emittance dilution for un-matched injection (transverse phase space rotation)



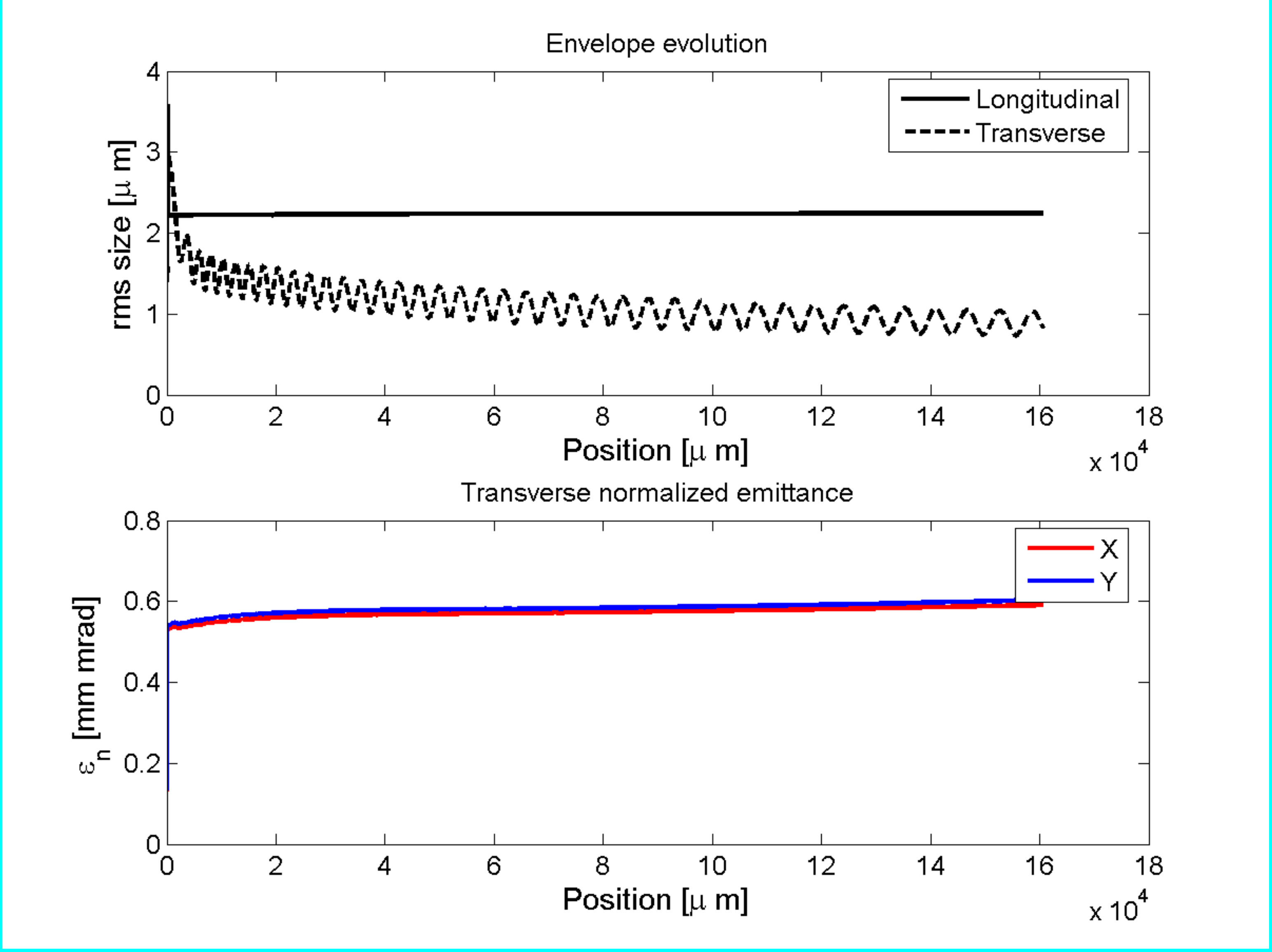
Just after 14 mm

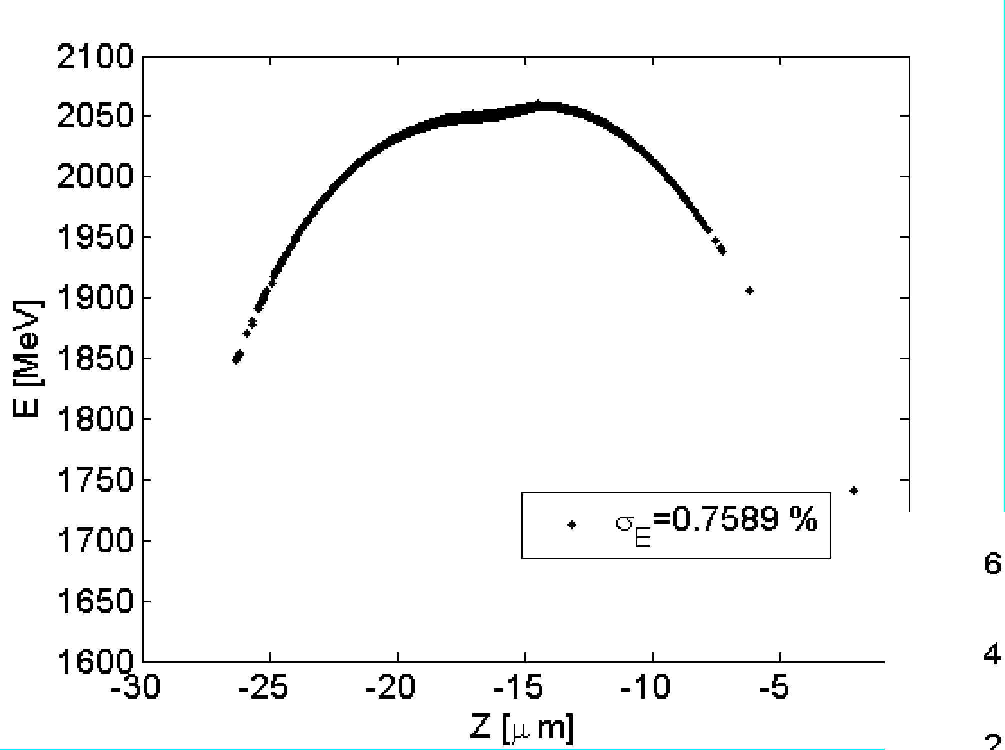
Matching of beam β-function with plasma betatron focusing: adiabatic matching

- Inject electron beam in capillary/plasma channel when laser pulse is still focusing (before waist).

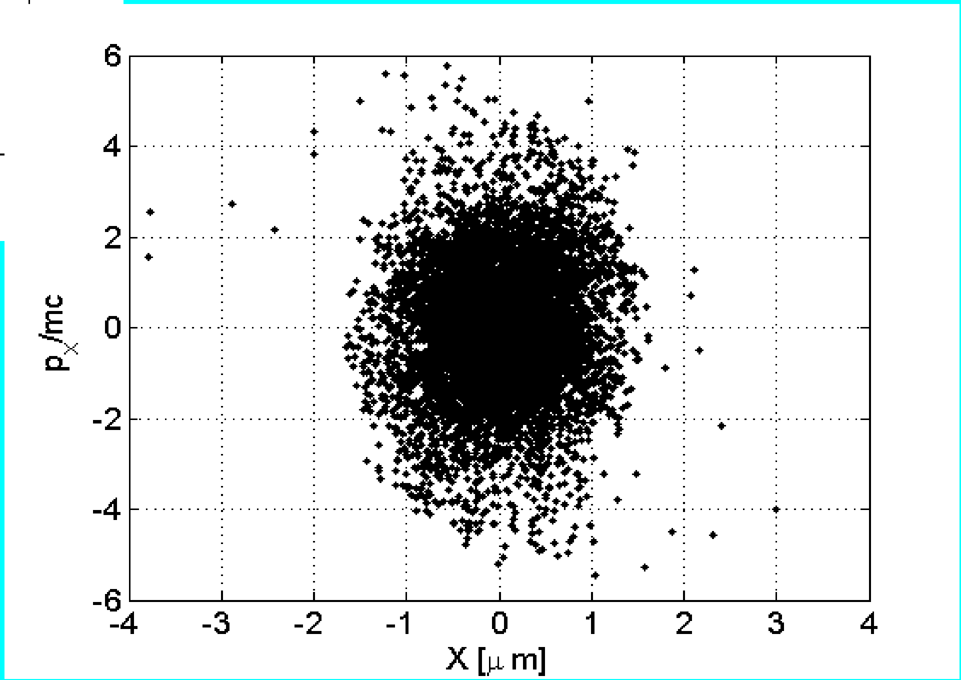


Adiabatic Matching into Plasma Channel





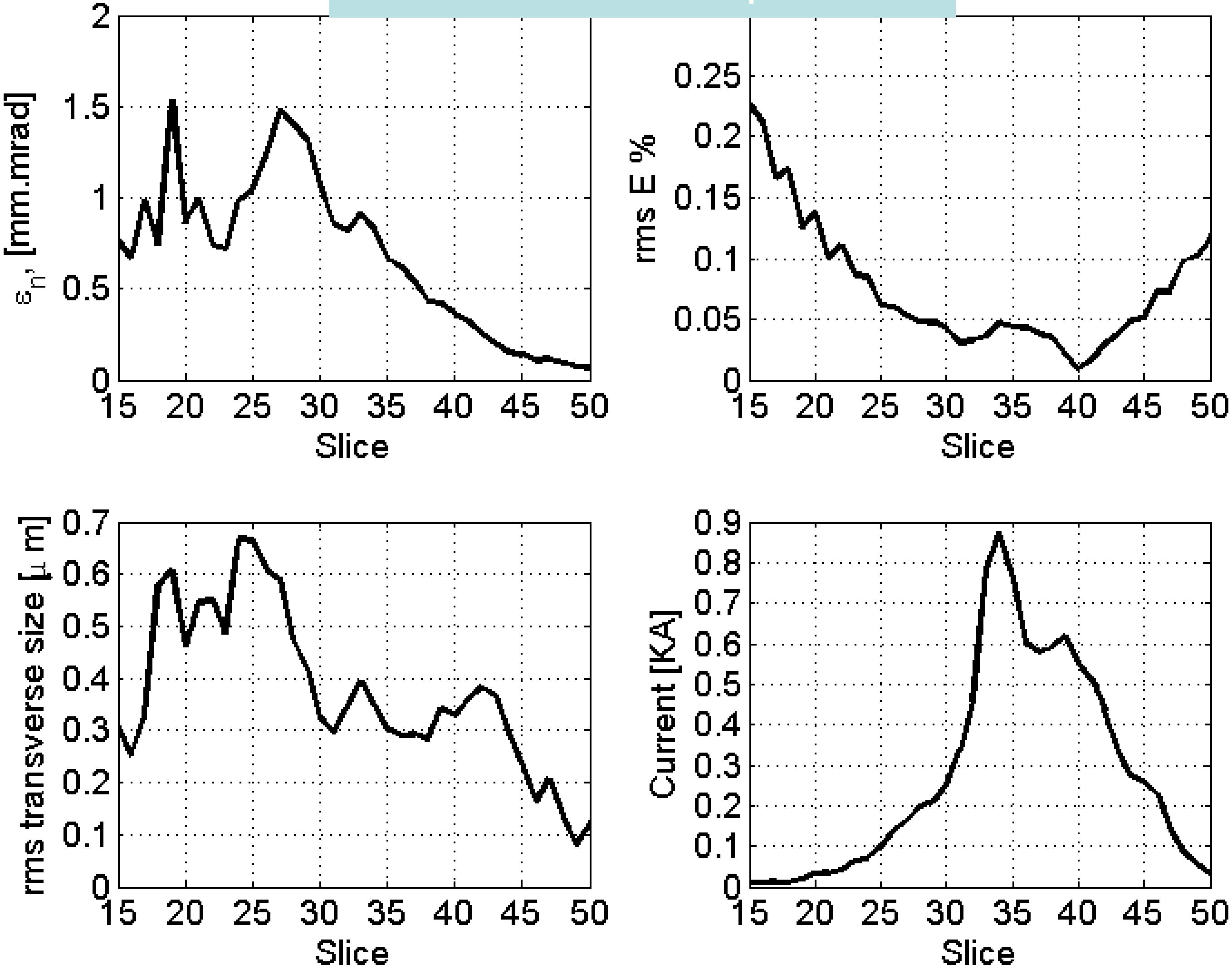
Output Beam
<E> = 2.01 GeV
$\Delta E/E$ = 0.8% *rms*
ε_n=0.6 μm



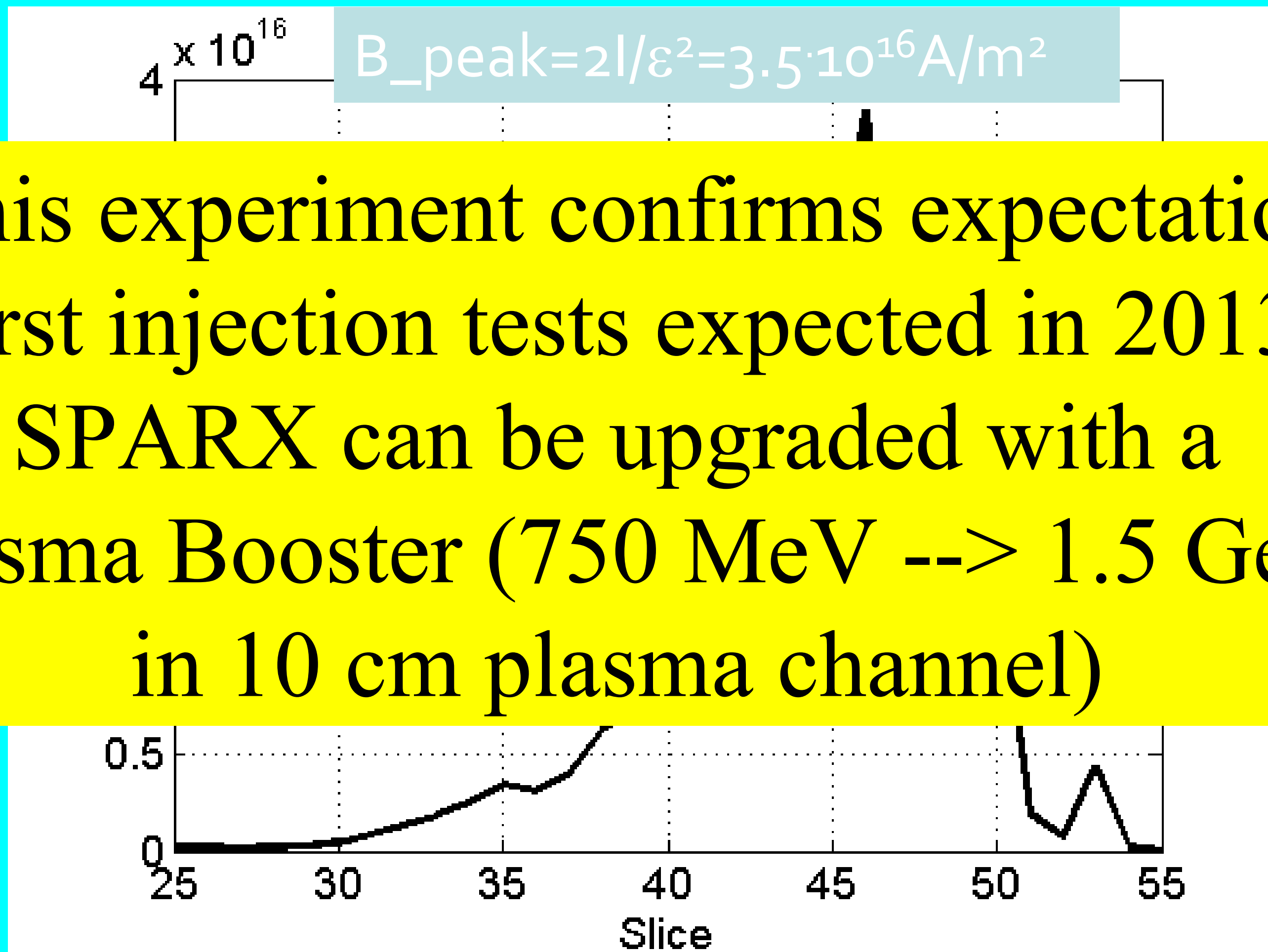
P. Tomassini (QFluyd2)

Slice Analysis

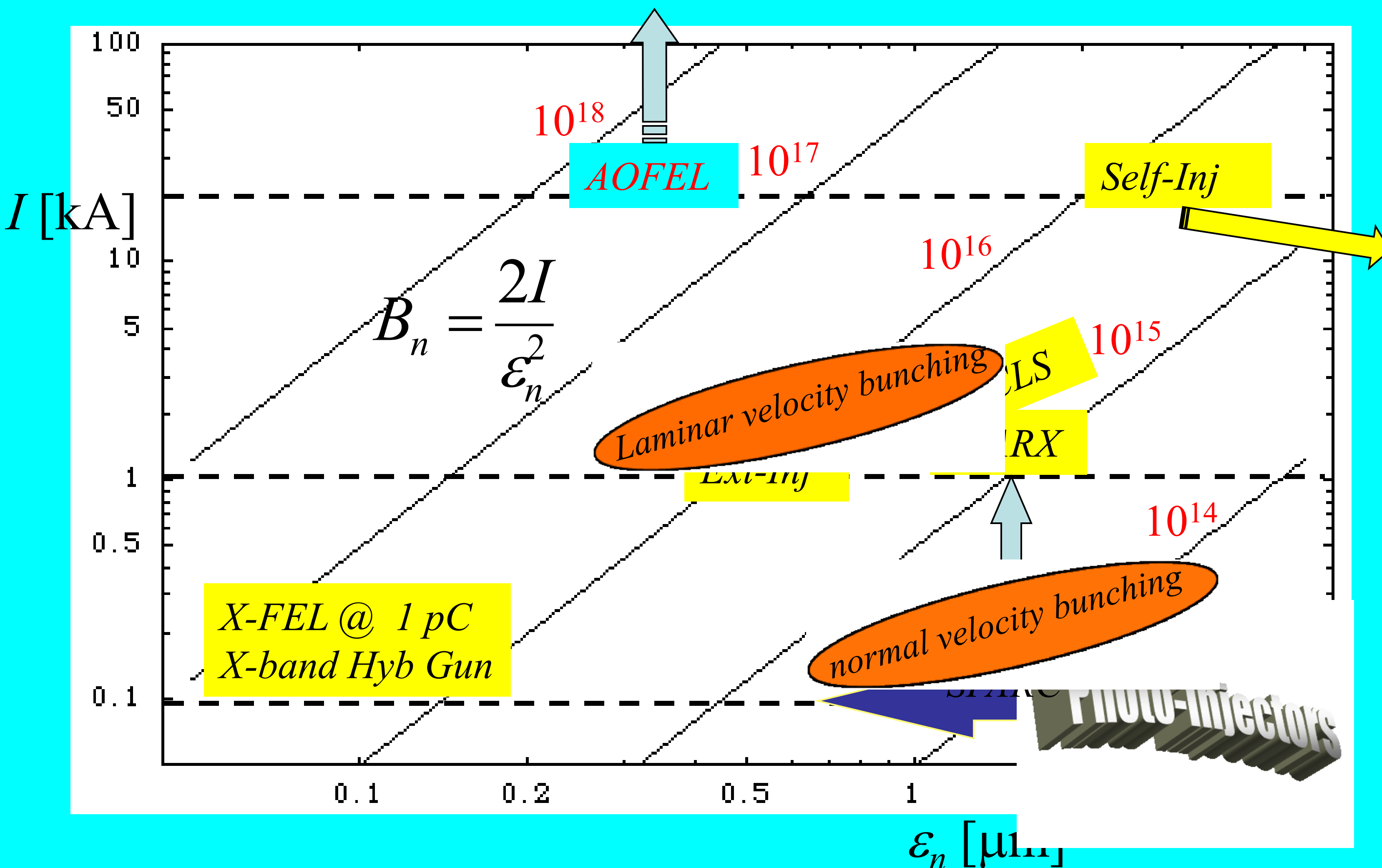
Slice thickness 400nm



Brightness good enough to drive a X-ray FEL

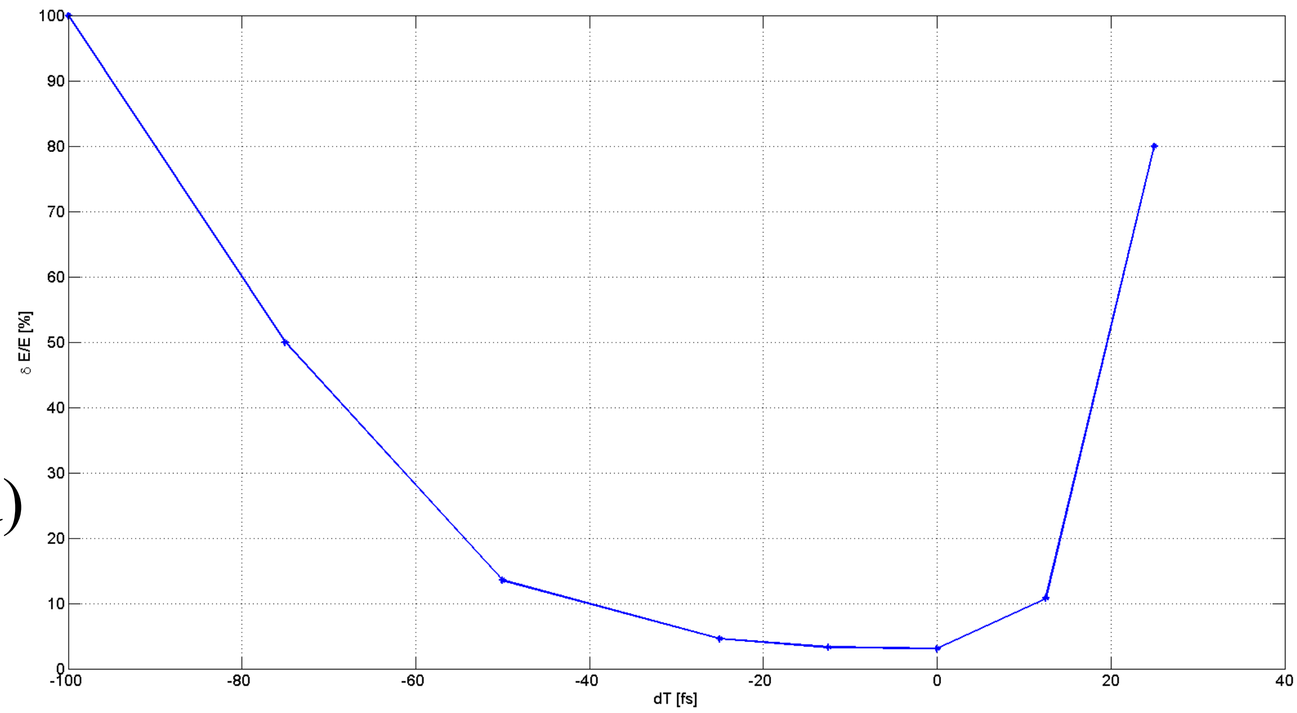


If this experiment confirms expectations (first injection tests expected in 2013) SPARX can be upgraded with a Plasma Booster (750 MeV --> 1.5 GeV in 10 cm plasma channel)



The Electron Beam Brightness Chart [A/(m·rad)^2]

Jitter



Total (correlated) en. spread (%)

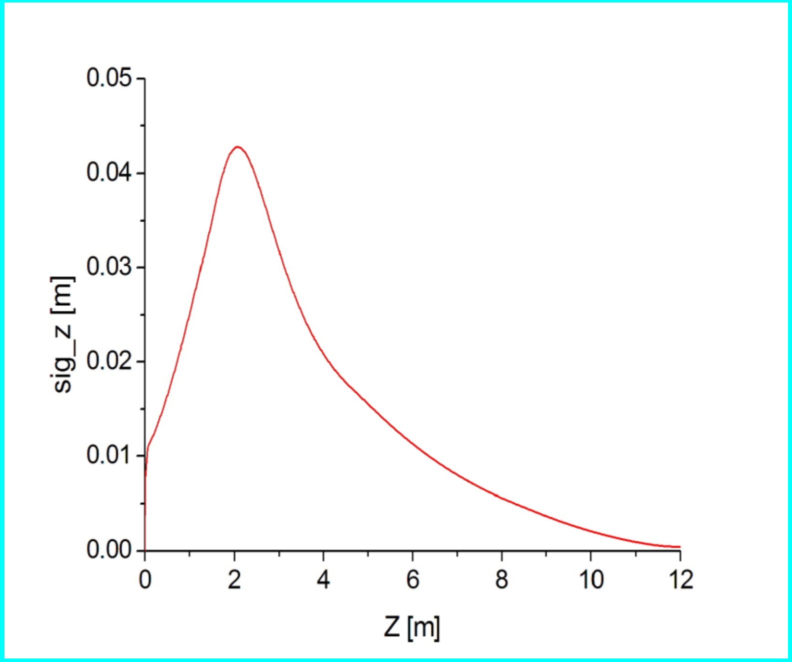
20 fs jitter (shot-to-shot @ 10 Hz) leads to 2.5 % en. spread increase
Present SPARC operation achieves 100-150 fs jitter – expected upgrade via O.M.O. (optical clock vs. RF clock) down to about 10-20…
for a test exp. survive with accepting lower effective rate of good shots out ot the nominal 10 Hz (single shot diagnostics)

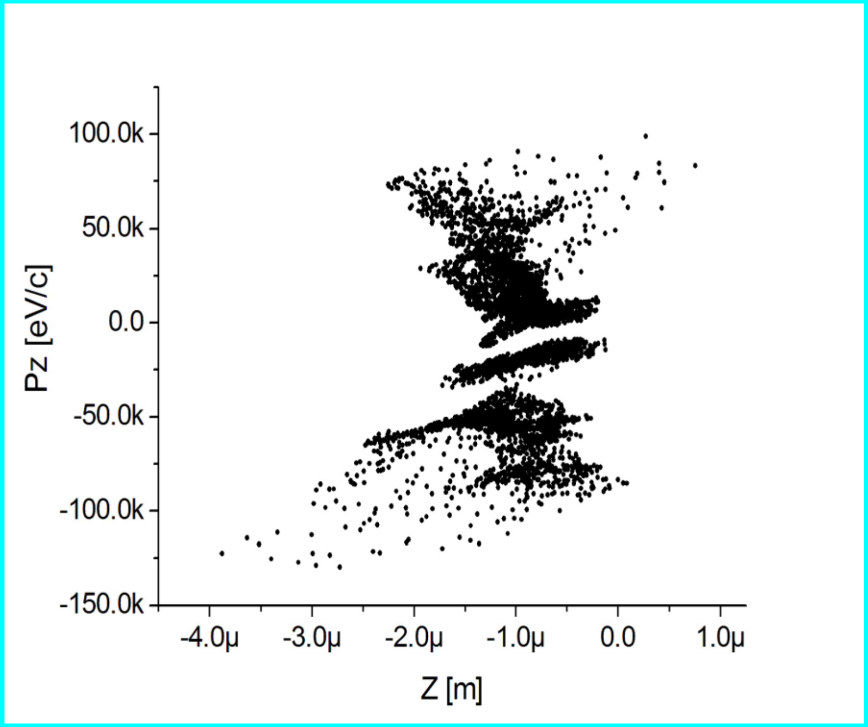
Sub-fs e^- 1 pC bunch @ SPARC -> fs γ-ray (A. Bacci, gen. algorithm & laminar vel.bunch.)

$$\sigma_t \cong 0.9 \ \ fs \ (0.28 \ \ \mu m)$$

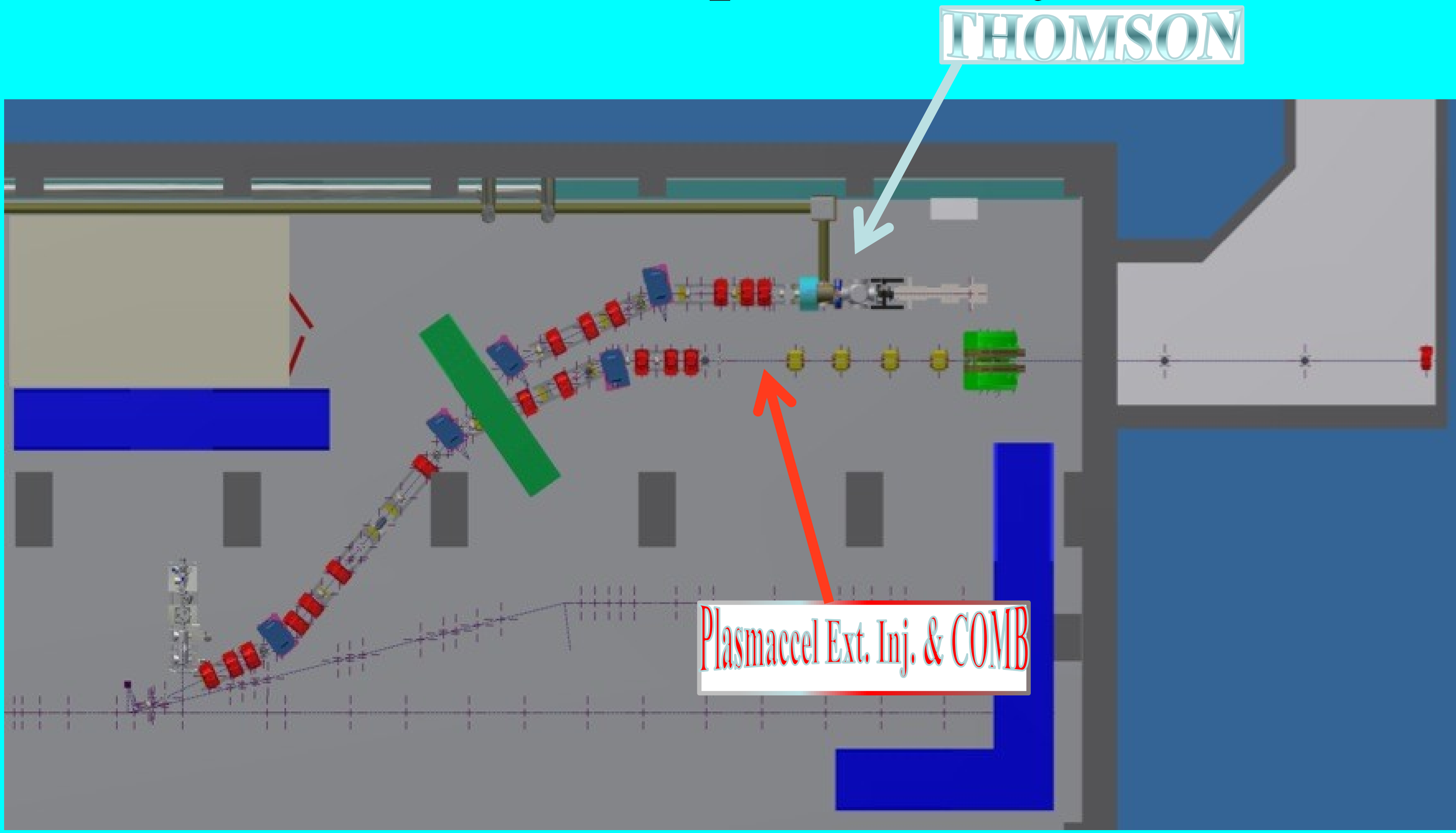
$$\frac{\Delta\gamma}{\gamma} \approx 0.1\%$$

$Comp \geq 100$!



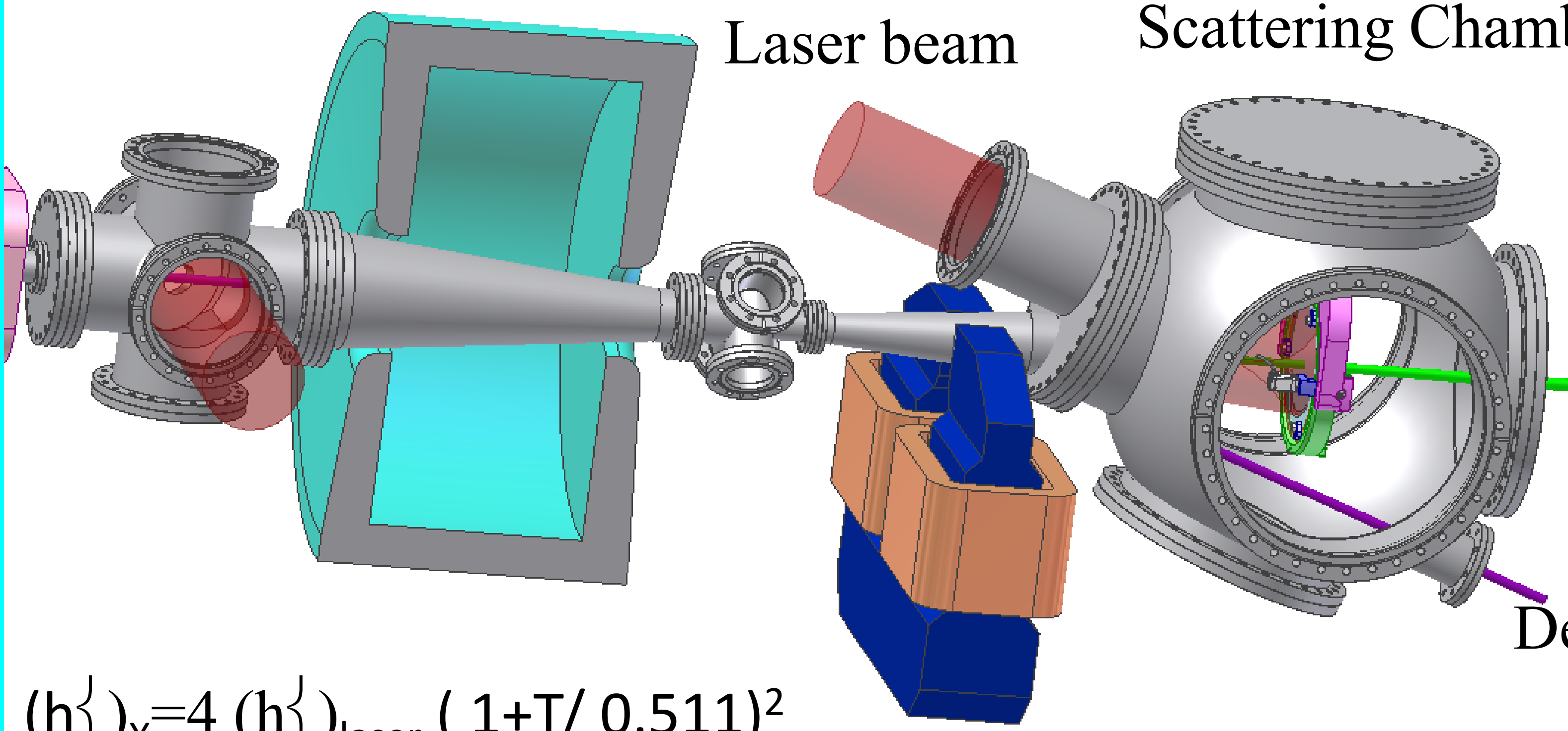


Thomson & Plasma Acceleration beamlines updated layout



C. Vaccarezza

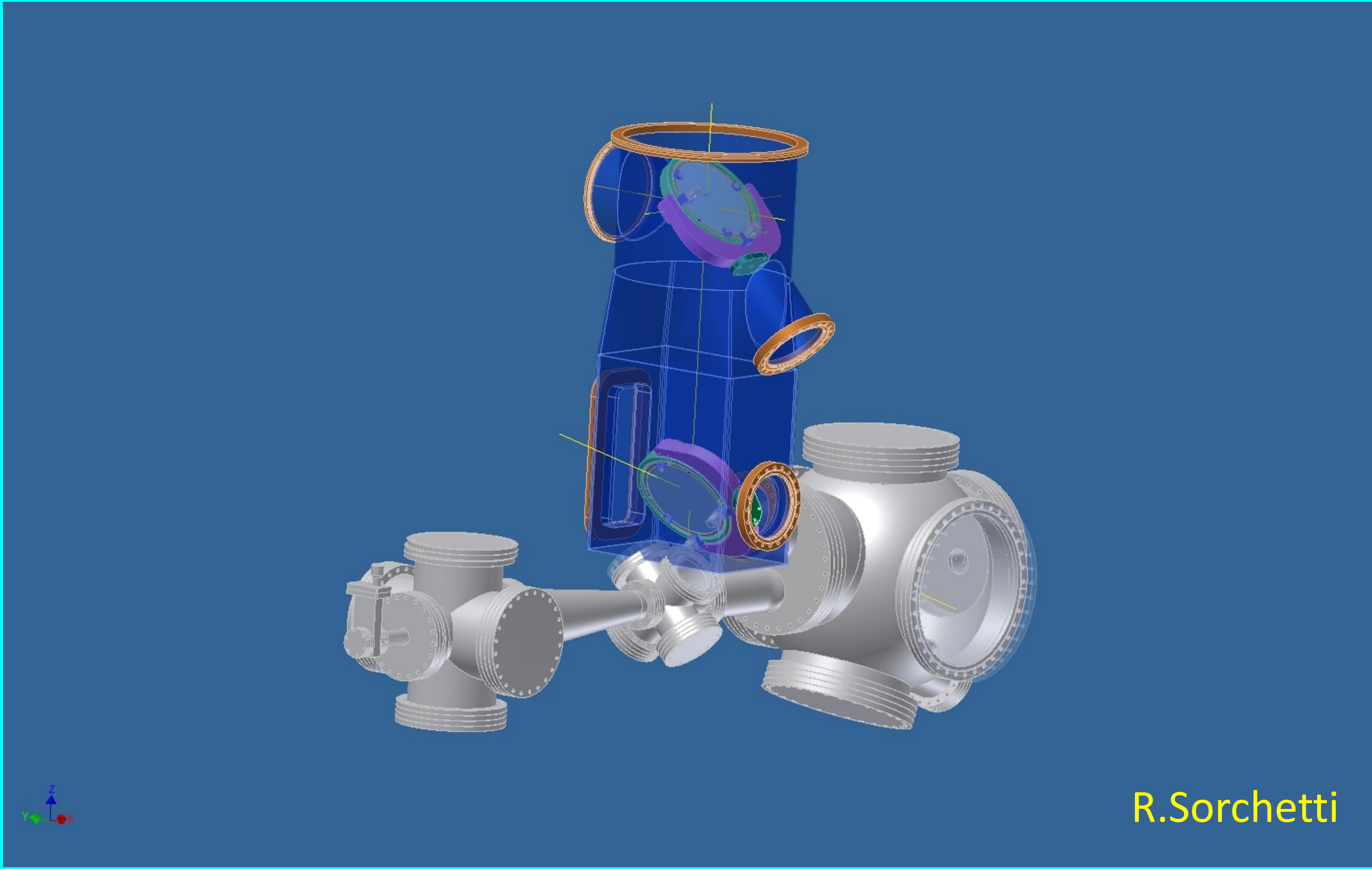
Thomson Source Interaction Region



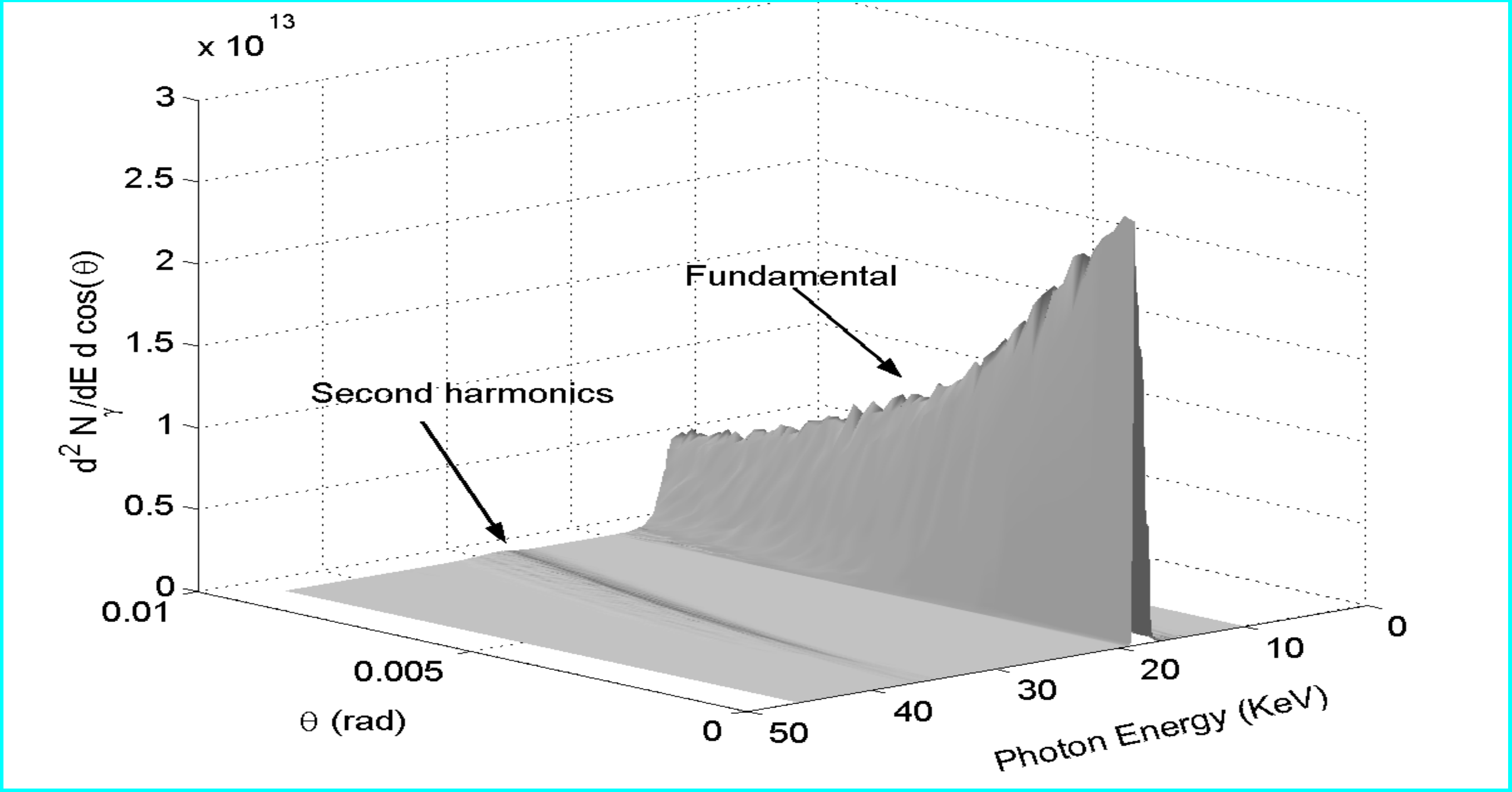
$$(h\nu)_X = 4\,(h\nu)_{laser}\,(1+T/0.511)^2$$

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

Laser pulse: 6 ps, 5 J
e^- bunch: 1 nC, 12 μm (rms)
X-ray: 10 ps, 10^9 photons per shot
α emission: 12 mrad


R.Sorchetti

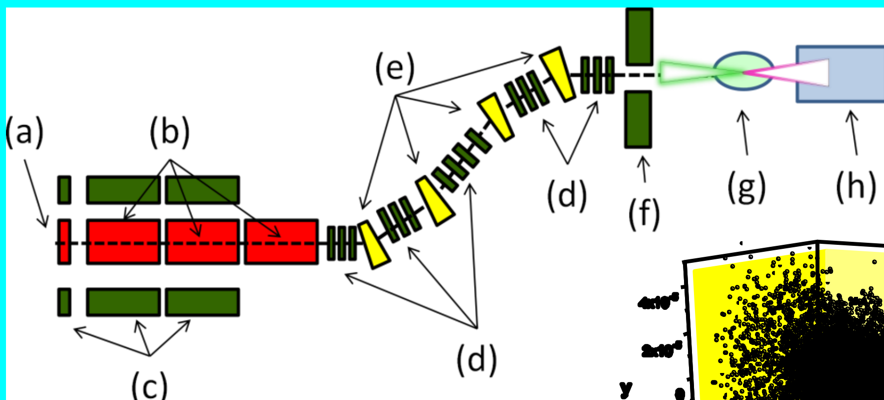
Angular and spectral distribution of the TS radiation in the case of 3 ps laser pulse (12.5 µm beam waist)
Linear Thomson Scattering



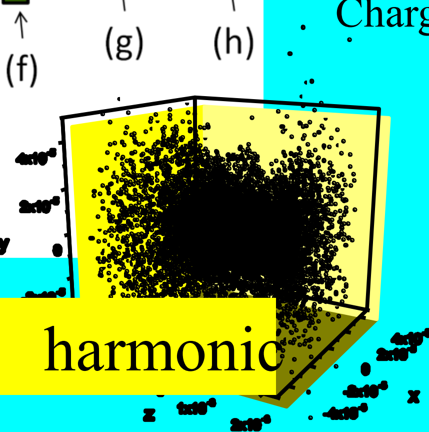
SPARC beamline at 150 MeV for production of X rays at about 500 KeV

Electron beam in the focal spot: σ_x=σ_y=10 um
Emit.=1.6 mm mrad
Energy= 150 MeV
En. spread=0.08 MeV
Charge = 1 nC

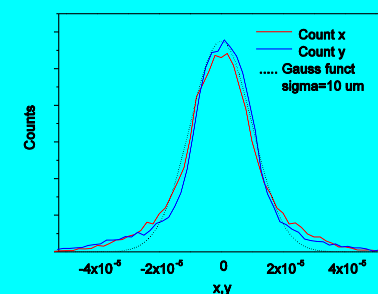
Laser parameters:
Lamda=0.8 μm
Energy=5J
Waist(diam)=15 μm
Temp. Duration=6ps



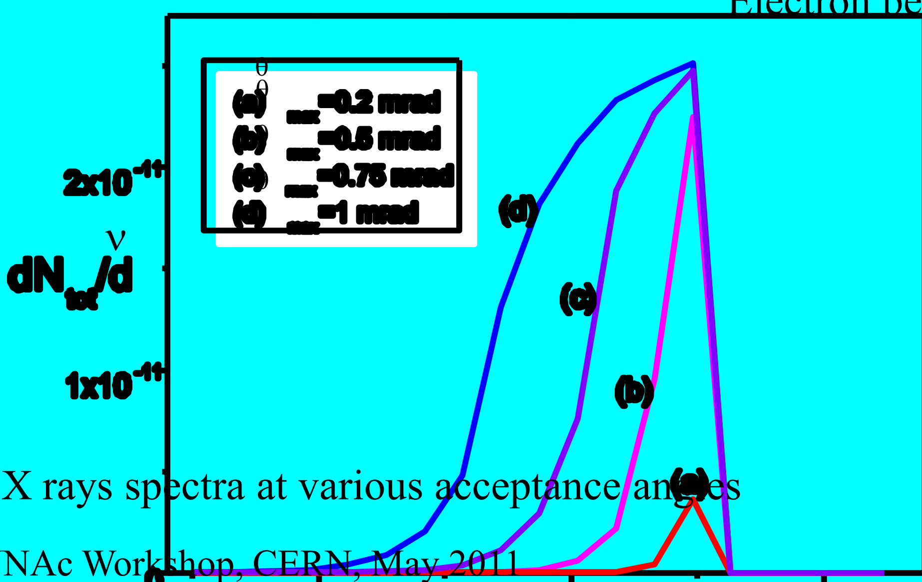
Option for 1 MeV with 2° harmonic



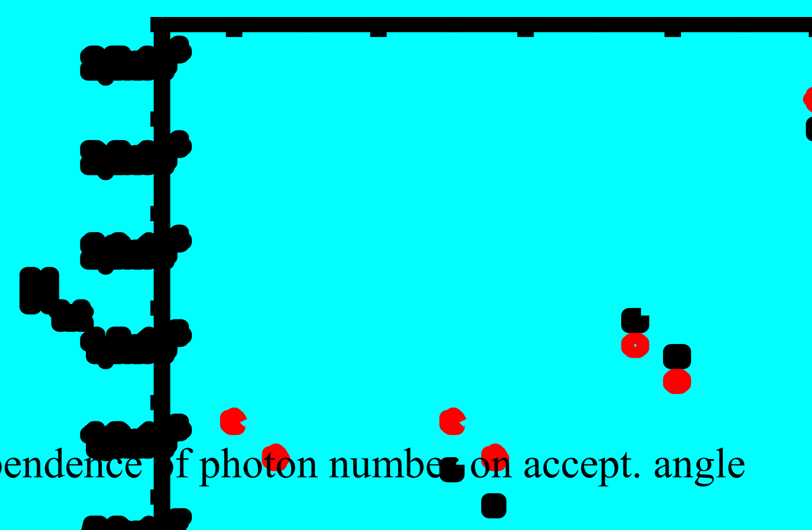
Electron beam



Electron transverse width



X rays spectra at various acceptance angles



Dependence of photon number on accept. angle

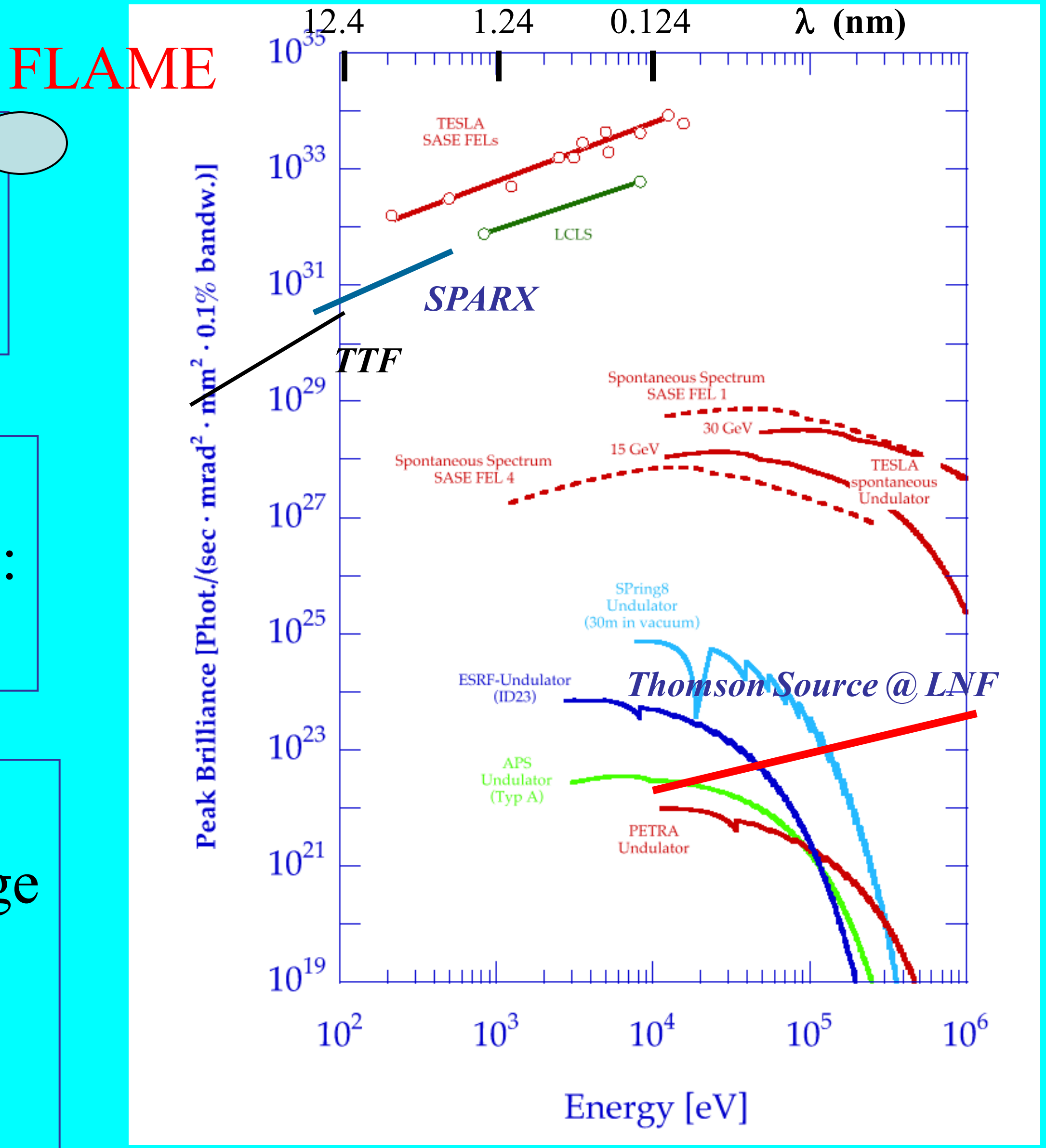
Brilliance of X-ray radiation sources

PLASMON X

SASE-FELs will allow an unprecedented upgrade in Source Brilliance

Covering from the VUV to the 1 Å X-ray spectral range: **new Research Frontiers**

Compact Thomson Sources extend SR to hard X-ray range allowing
Advanced Radiological Imaging **inside** Hospitals



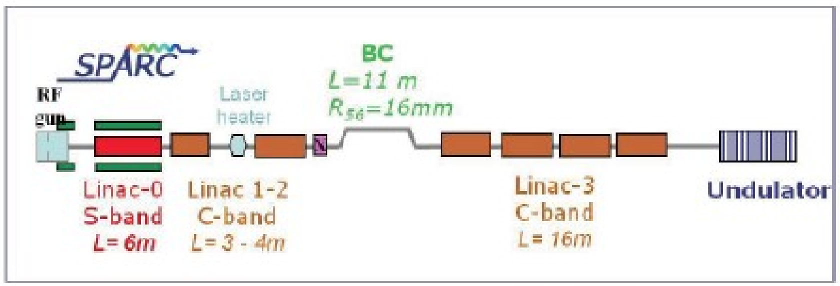
Acquisition of beam transport lines (magnets and related hardware, mirrors, diagnostics, etc) is ongoing

We expect to install all hardware inside SPARC bunker by july 2011

Starting of Thomson Source commissioning in september 2011

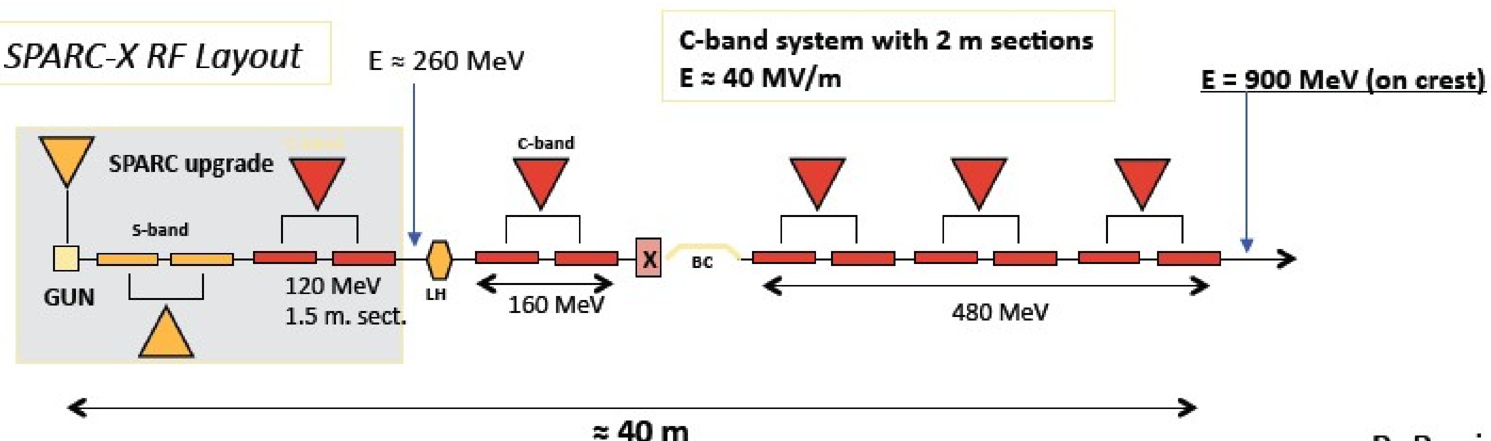
SPARC-X, Energy upgrade to 750 MeV

Following the successful result of the prototype power test, an average C-band RF gradient of 40 MV/m can be considered for the SPARC energy upgrade to 750 MeV.



General layout of SPARC-X-750

SPARC-X RF Layout



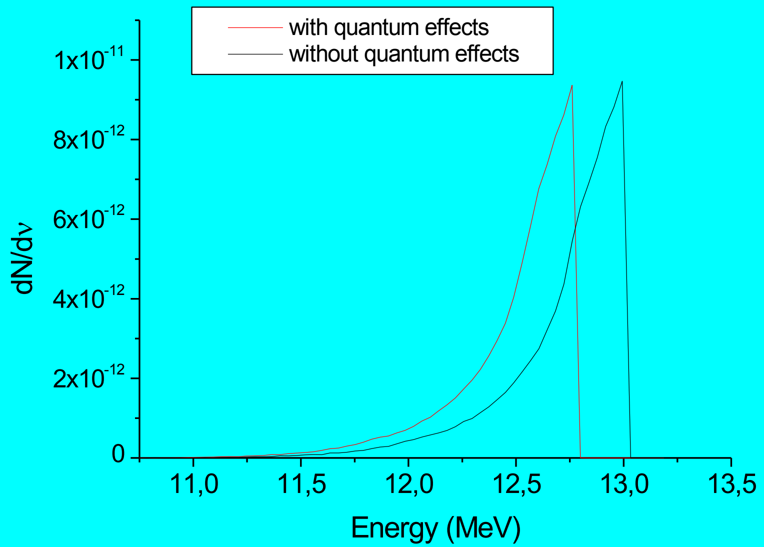
R. Boni

Production of 13 MeV gamma rays

Electron beam: Emittance=0.9 mm mrad,
σ_x=4 μm, σ_y=9 μm
Energy= 750 MeV
Energy spread=0,225 MeV
Charge =1 nC

Laser parameters
Energy 5J
Waist(diam)=10 μm
Temp. Dur.= 6ps

Spectrum for Acceptance angle=100μrad



Total photon number=7,7 10^8
Bandwidth=2,1%
Spectr. dens. = $3 \cdot 10^4$ ph/sec·eV

Aiming at spectral density of 10^4-10^5 ph/eV/sec
for nuclear photonics
best of brehmstrahlung sources is 1 ph/eV/sec

Total number vs beam transverse dimension

CONCLUSIONS

- **Thomson Source of mono-chromatic X-rays at high (peak) brilliance by 2011 at INFN-LNF, tunable within 20-500 keV. Upgrade to 2.8 MeV feasible in 2013 after SPARC upgrade to 250 MeV (2012).**
- **Acceleration of externally injected fs-class SPARC electron bunches into weakly non-linear plasma waves up to 1-2 GeV with FEL-class brightness/quality (2013)**
- **Possible Upgrade of SPARC up to 750-900 MeV by 2016 -> FEL program, PWFA (COMB) experiments, Compton Source of 5-18 MeV γ-Ray at 10^4-10^5 ph/eV/sec (10^{-2}-10^{-3} bandwidth)**