STATUS OF TAC SASE-FEL PROJECT

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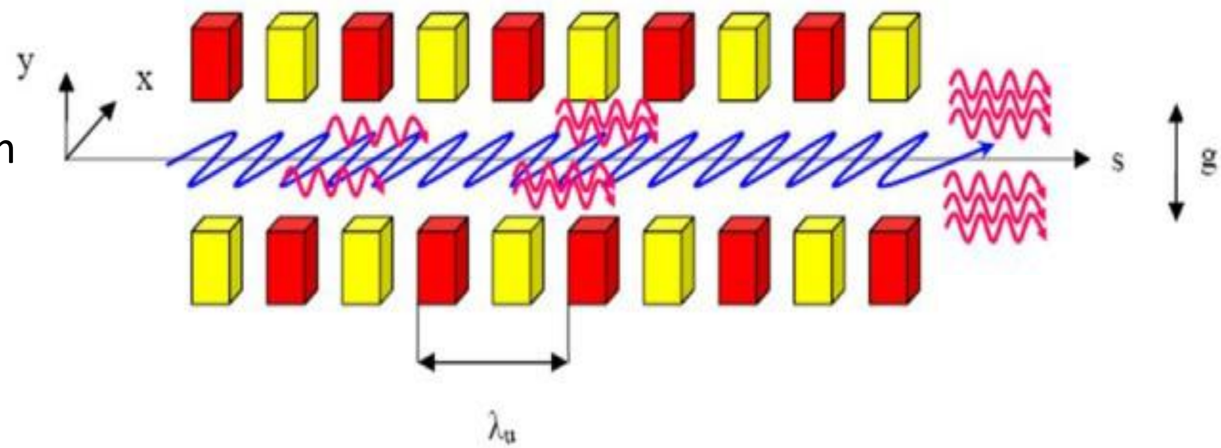
2nd International Conference on Particle Physics
in Memoriam Engin Arık and Her Colleagues
Doğuş University, İstanbul, Turkey
20 - 25 June 2011

OUTLINE

- SASE-FEL Production
- SASE-FEL user Potential
- TAC SASE-FEL Gun studies,
- TAC SASE-FEL Beam Dynamics studies,
- TAC SASE-FEL Undulator studies,
- TAC SASE-FEL Laser Optimization studies,
- Conclusion

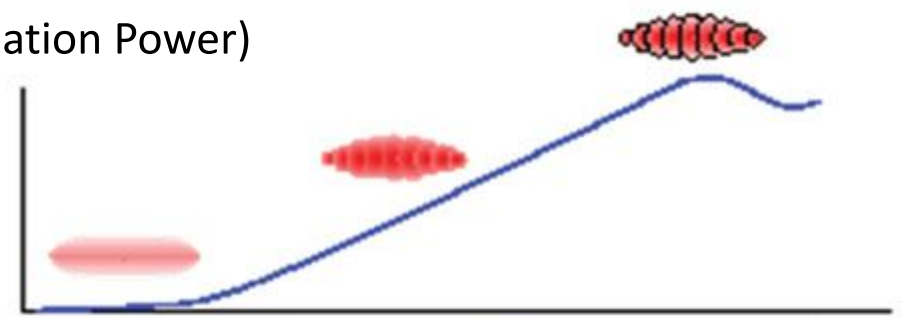
SELF-AMPLIFIED SPONTANEOUS-EMISSION FREE ELECTRON LASER (SASE-FEL)

Electron Beam

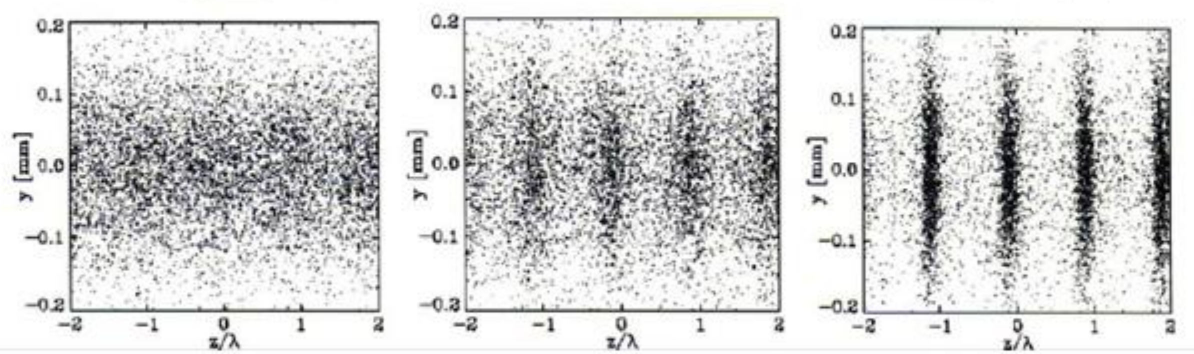


photon

Log (Radiation Power)



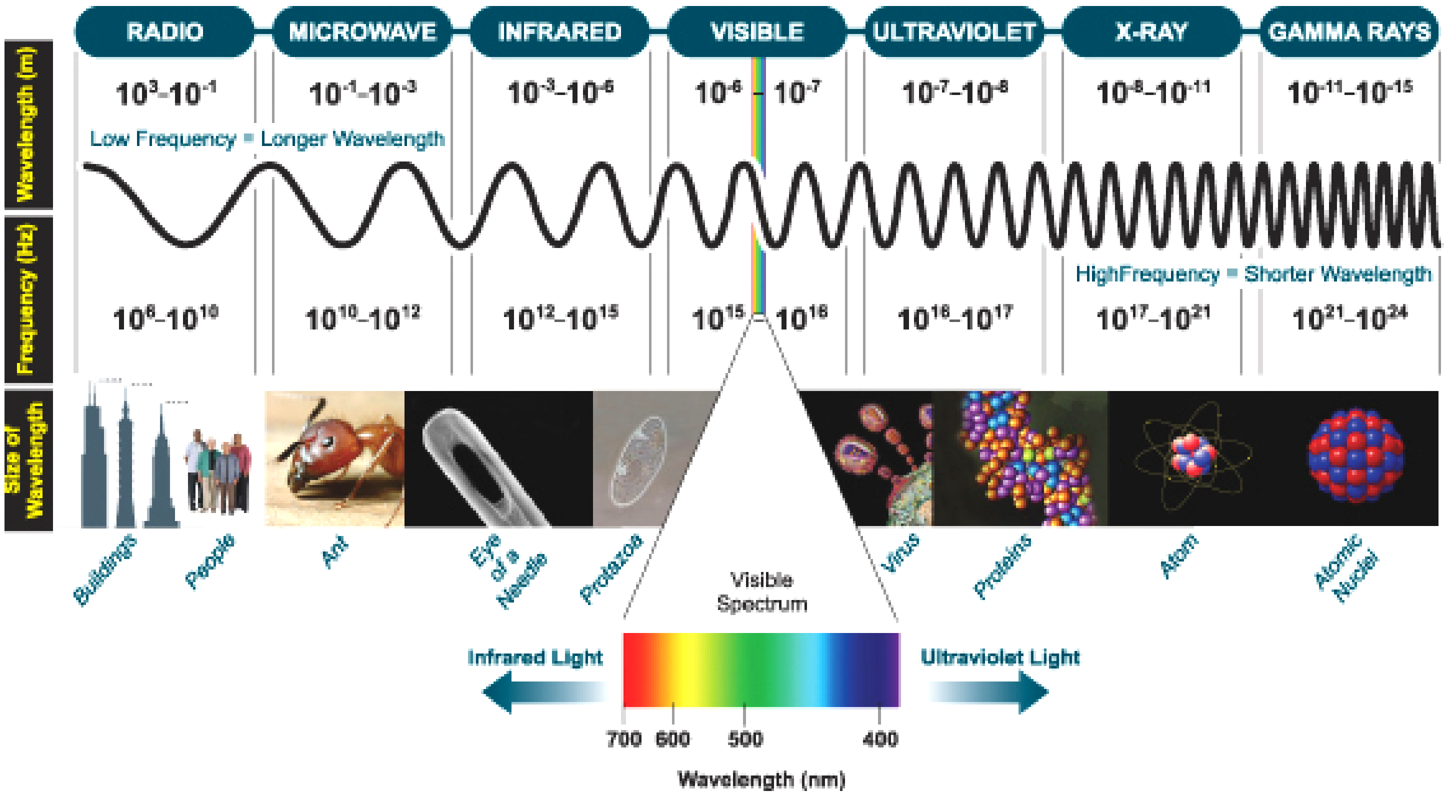
length



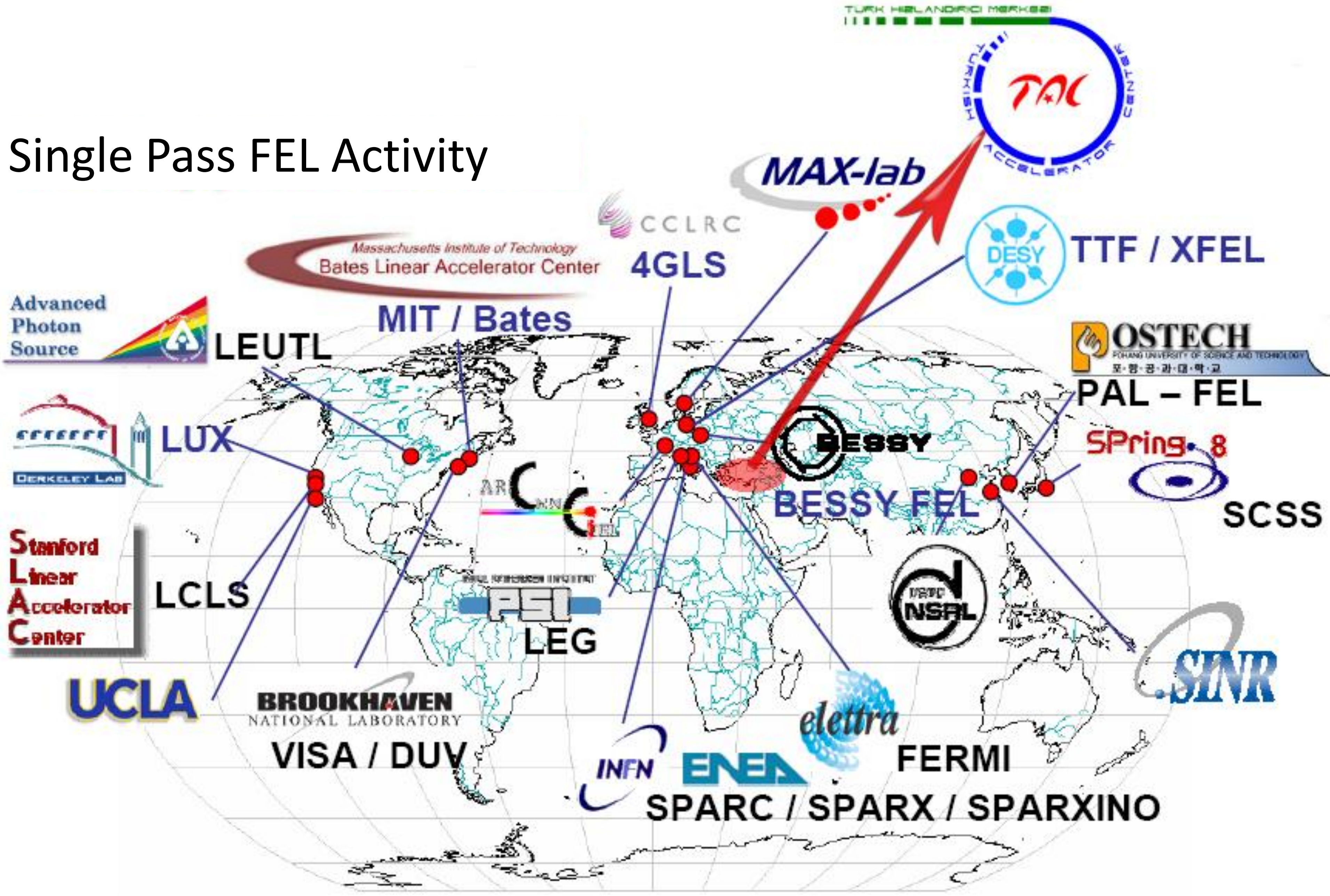
Motivation to Design the SASE-FEL

- Benefits of FEL are very important and indispensable
  - FEL's are tunable, i.e. they can output different wavelengths during operation.
  - FEL's can be designed to produce a range of wavelengths, from microwaves to X-rays.
  - FEL's can scale to very high power because they use a vacuum for their medium they are not affected by heat problems that are common in other lasing techniques.
  - FEL's are efficient, generally a FEL can transform 10% of its energy into a LASER
  - FEL's are reliable in that they can run for long periods of time.
  - Coherent and brillant
- There is not any FEL Facility in Turkey yet.

By using 1 GeV electron beam, 3-60 nm Wavelength laser production is aimed at TAC SASE-SEL Facility .



Single Pass FEL Activity



SCIENTIFIC APPLICATIONS OF SASE-FEL

Atoms, moleculas and clusters

- Multi-ionization,many photon events
- Spectroscopy of stimulated level and prodcution(atomic holes, laser energy levels,
- Dynamics, electrical and geometric structure of atomic clusters

Plasma physics

- Intense plasma prodcution
- Plasma diagnostics

Solis State Physics

- Ultra speed dynamics
- Electronic structures
- Soft matter and disordered materials

Materyal Science

- Dynamics of rigid materials
- Dynamics and structures of Nanomateryals

chemistry

- Reaction dynamics of solid state, Fluid systems
- Analytical Solid State Chemistry
- Hetorojen catalysis

Structural Biology

- Single and molecular imaging
- Biomoleculas dynamics

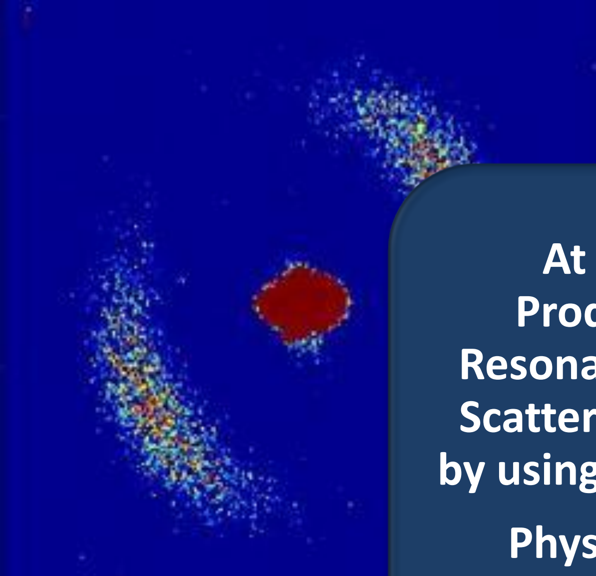
Optic and non-linear subjects

- Nonlinear effect for atoms and solid state
- High field sicence

Ultra short pulse   Pulse power   Coherency   Average brightness

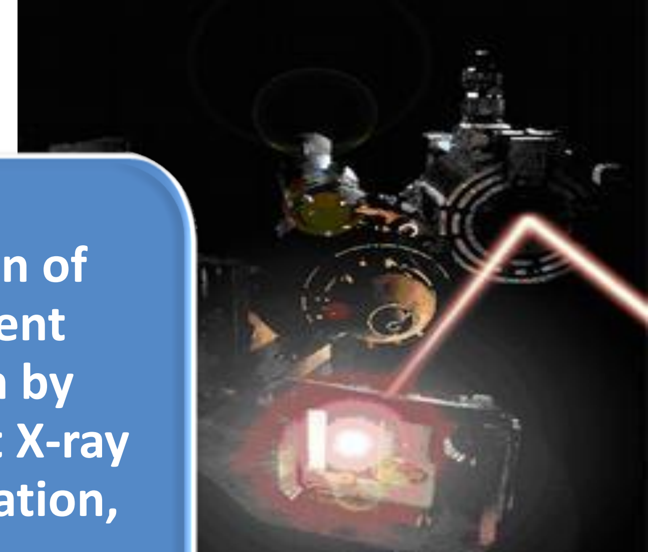
General Applications of SASE-FEL

Adhesive	Agriculture	Atomotive	battery	Biotechnology
Potting	Catalyst	Ceramics	Chemicals	Computers
Cosmetic	Electronic	Environmental Engineering	Fabrication	Food
Fuel cells	Geology	Glass Industry	Laser	Light
Oiling, greasing	Magnetic Memory	Mineralogy	mining, excavation	Nuclear
Nanotechnology	packing	paper and wood	boards	Polymer Coating
Plastic	printer	recording devices	Semiconductor	Steel
Textile Industry	Thin	film coating	Welding	



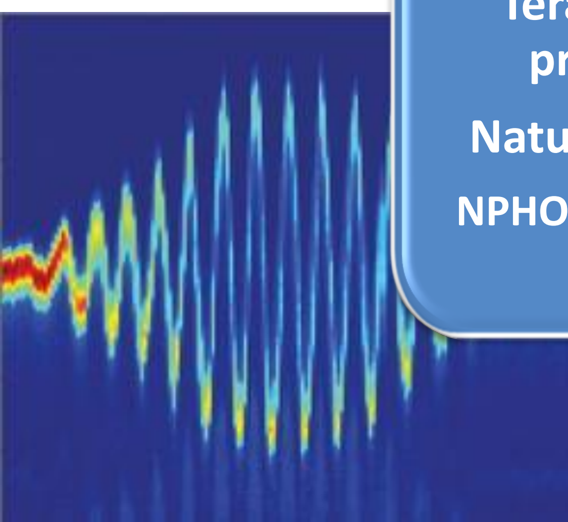
At 1.59 nm Production of Resonant Magnetic Scattering from FEL by using soft fs pulse,

Phys Rev B 79, 212406 (2009)



Production of transparent aliminum by intense soft X-ray photoionization,

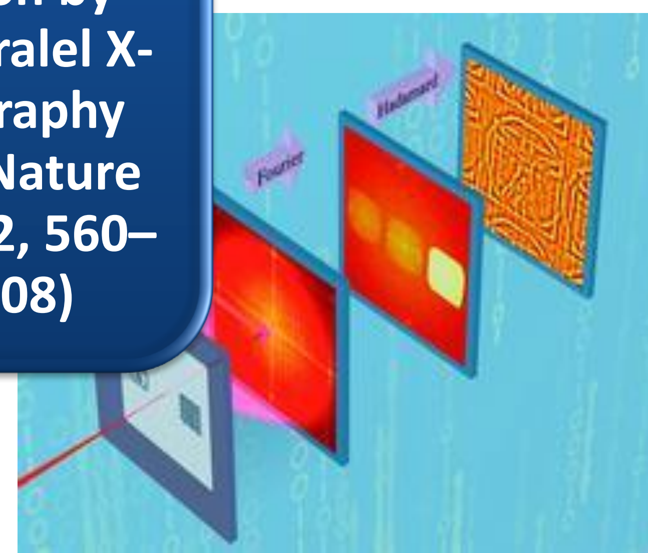
Nature Physics



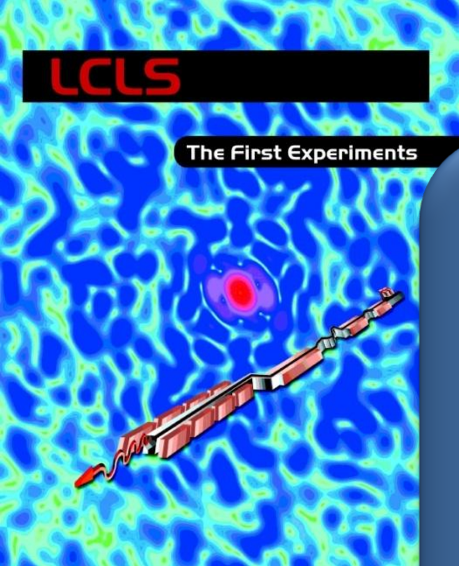
By using X-ray camera, single hit Terahertz field production,

Nature Photonics

NPHOTON.2009.160.



Graphic Production by intense paralel X-ray holography method /Nature Photonics 2, 560–563 (2008)



--Collisions in Nano dimensions

--İmaging of Single molecula and nano particles

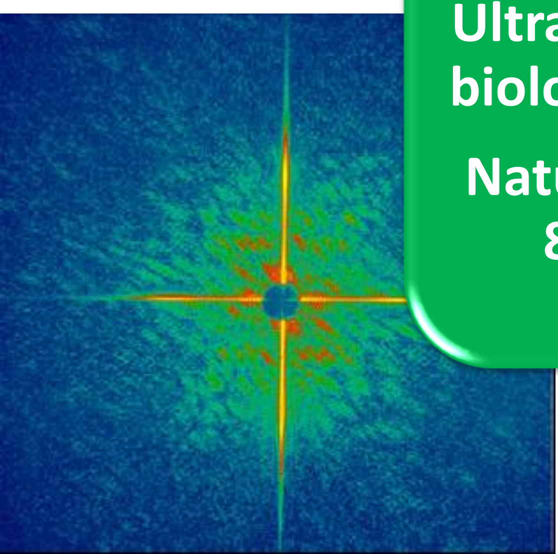
--Femtochemistry and biomolecule studies

Chip Production at required 10 kW Ultraviyole SASE-fEL Laser

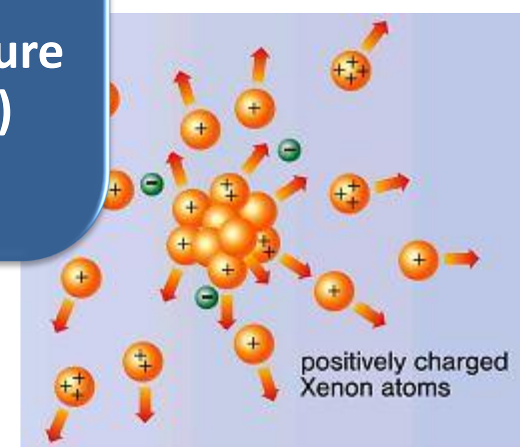
NIM in Physics Research A 475 (2001) 391–396

Imaging of Ultrafast coherent biological samples

Nature Physics 2, 839 (2006)



Multi-ionization of Atomic clusters-catalyzor production / Nature 420, 482 (2002)



TAC SASE-FEL Organizations

Coordinator – Dr. Hatice DURAN YILDIZ

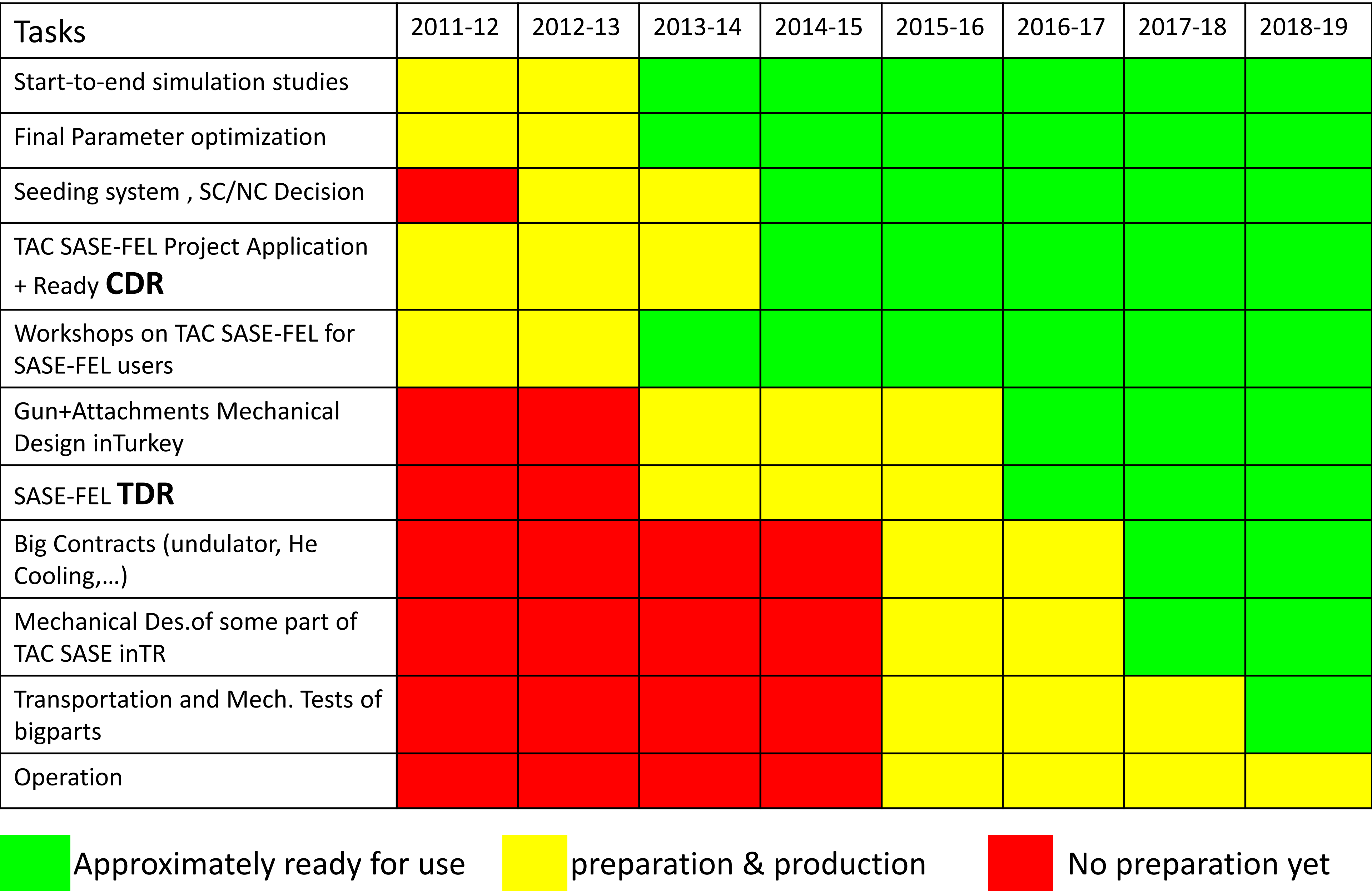
Co-Coordinator – Dr. İlhan TAPAN

Tasks	Researchers
Gun	G. Coşkun, M. Tural Gündoğan
Beam Dynamics	H. Duran Yildiz, A. Aksoy, G. Coşkun
Eletron Beam Diagnostics	Z. Nergis
Vacuum System	H. Aksakal
Control System	M. Aydar, G. Coşkun
Photon Beam Diagnostics	İ. Tapan, Ö. Şahin
Undulator System	H. Duran Yildiz, B. Ketenoğlu
Laser Optimization	H. Duran Yildiz, B. Ketenoğlu
Cooling systems	C. Kaya
Water Cooling	İ. Yildiz, E. Bozkurt
Radiation Protection	A. Bat
User Potentials	İ. Yildiz

Total

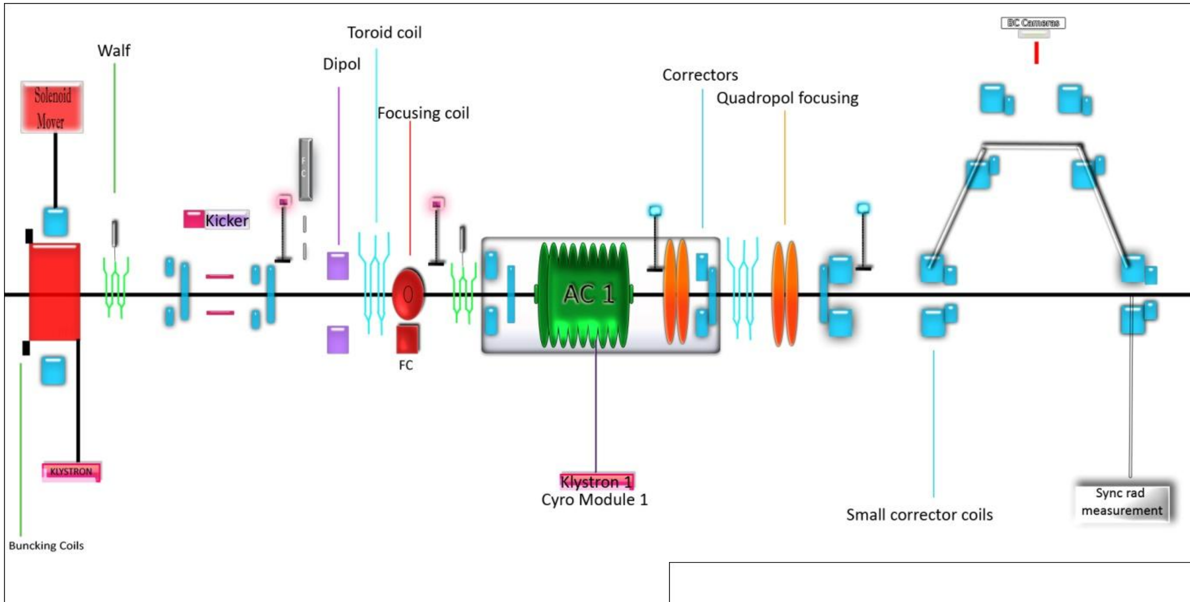
14 Physicists with 5 PhD

Draft Gantt Chart for TAC SASE-FEL



Proposed TAC SASE-FEL Studies

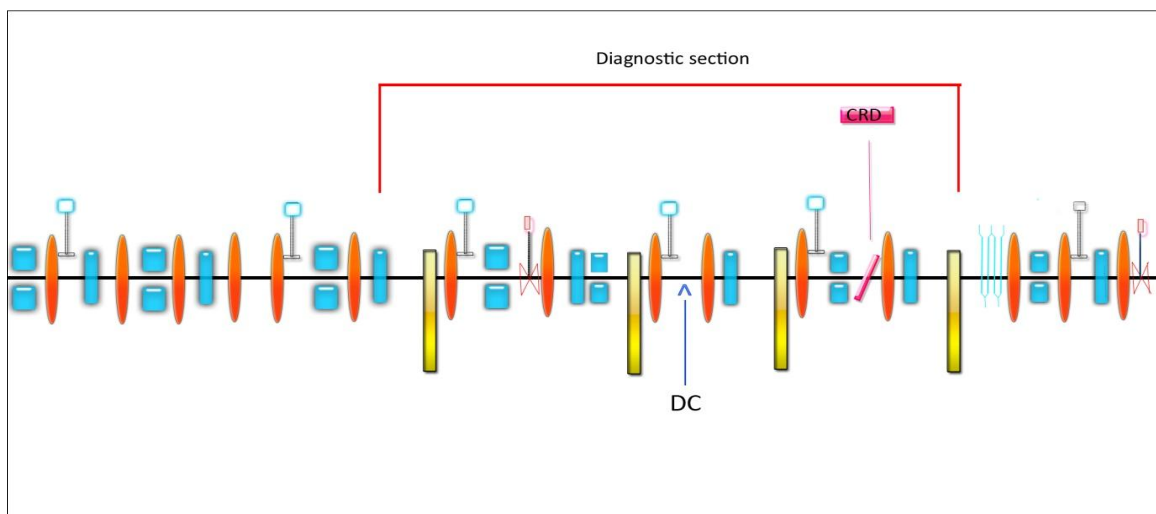
Proposed TAC SASE-FEL Layout



Charge from gun output could be around 10 pC.

In order to take out electron from gun, Nd:YLF laser can be used.

Gun and around have to have 10^{-11} vacuum value.

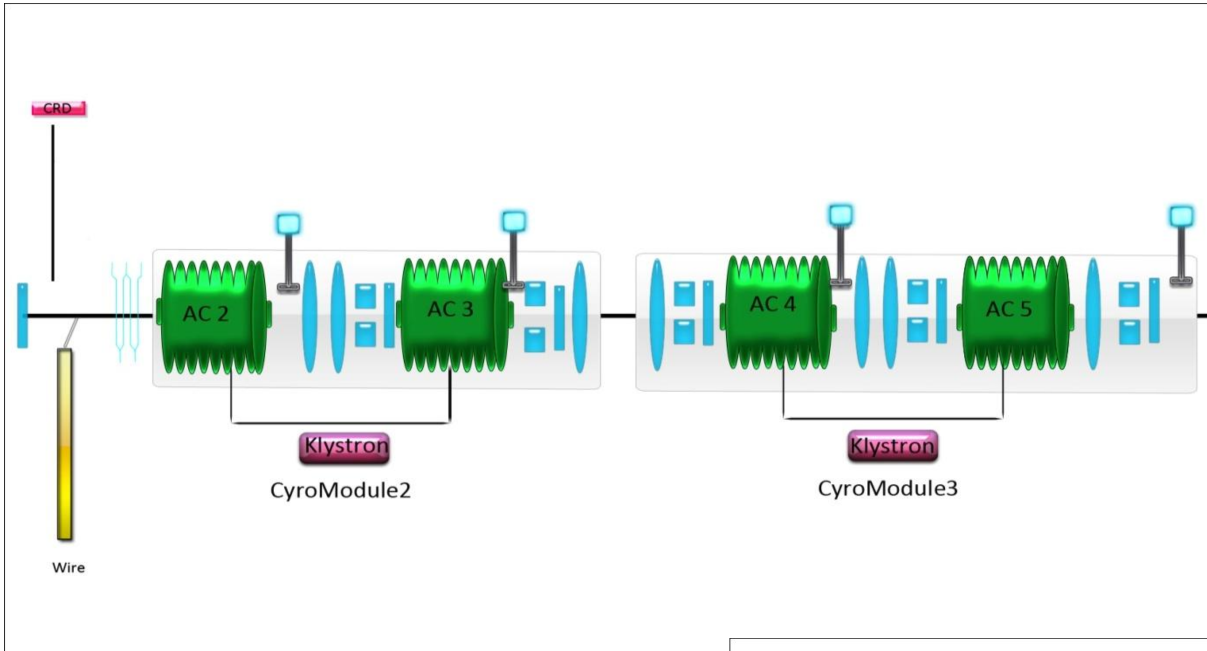


To compensate the magn. Field at the Cathode, backing coil is placed

Solenid mover can be used for alignment purpose respect to gun

NC RF gun can be chosen with Cs_2Te Cathode.

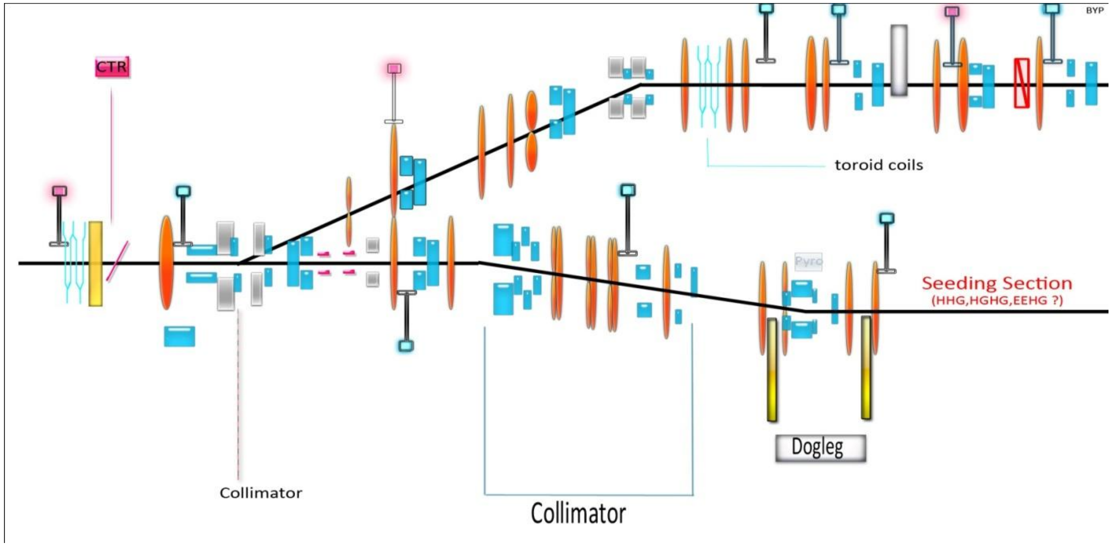
Accelerator and seeding section in propsed TAC SASE-FEL

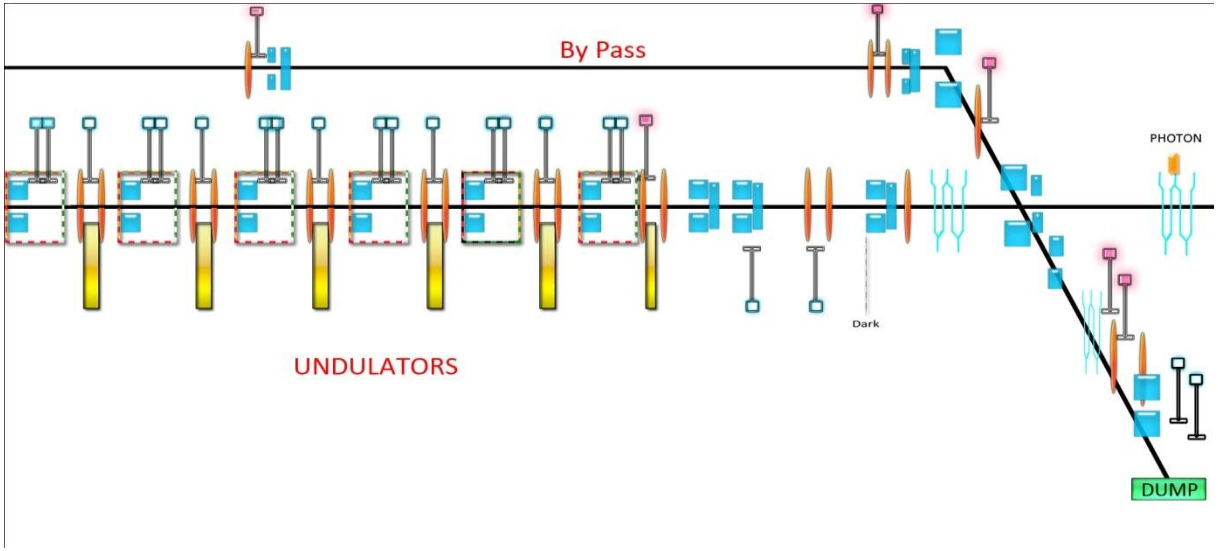


Accelerator section, collimator (beam need to squeeze to prevent any problem in the undulator, collimator is made up of Cu with the shape of block tubes) and the seeding section is displayed

In the case of choosing SC, we can Use 3 Module system to reach 1 GeV beam energy. These Modules need to feed by Klystron and transformed to produce high voltage.

If we choose NC, should be more number of modules





Proposed TAC SASE-Layout. Similar order with Flash [1]

Undulator gap is considered around 12 mm. Each undulator can be around 5 m. If we use 6 undulator as in the layout, 5x6=30 m total undulator section length. Hybrid with iron can be used for undulator material.

But in vacuum case, undulator gap could be go down to 8 mm or even less.

Beam dump, inner area should be coated with carbon, the aliminum, and Cu follows carbon. Cu is needed for resistance. The shape can be cylindirical tube.

PROPOSED TENTATIVE TAC SASE-FEL PARAMETERS

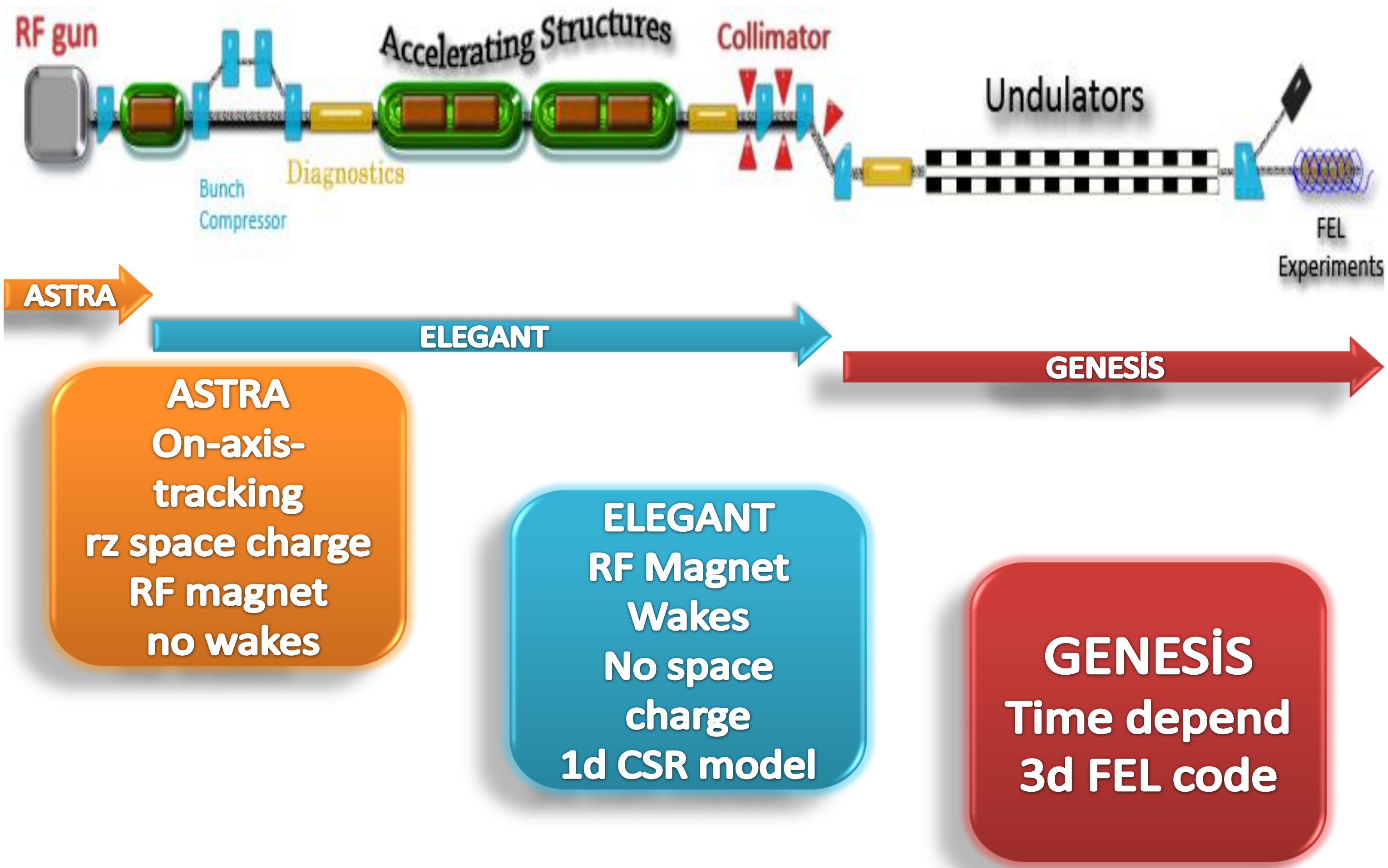
Proposed Electron Beam Parameters for TAC SASE-FEL are shown in the following Table 1. 1 GeV electron gun is proposed for TAC SASE-FEL. Peak current is considered 2 kA, while the transverse emittance 3.2 nm.

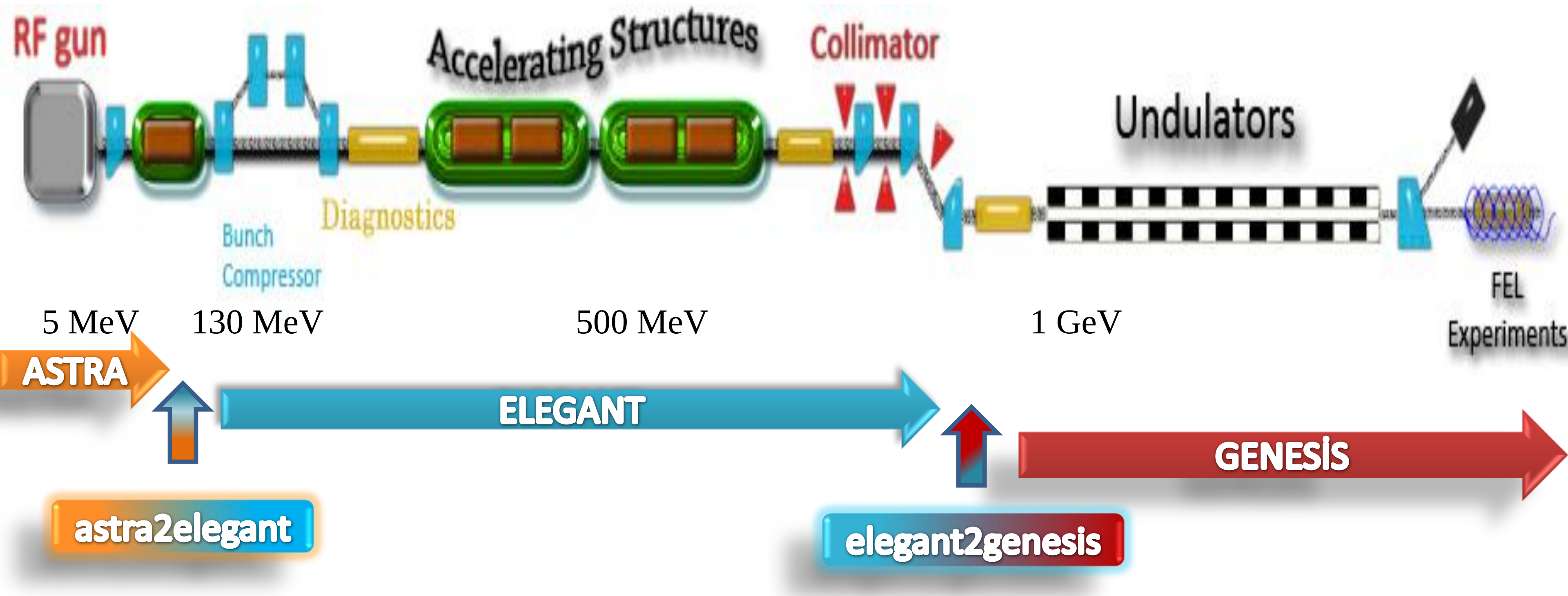
Parameter, [Symbol]	Unit	Value
Electron beam energy, [E_{beam}]	GeV	1
Bunch charge, [Q]	nC	1
Normalized emittance, [ε_N]	π mm.mrad	< 2
Transverse emittances, [$\varepsilon_{x,y}$]	nm	3,2
FWHM bunch length, [σ_z]	µm	150
Transverse bunch sizes, [$\sigma_{x,y}$]	µm	180
Peak current, [I_{peak}]	kA	2
Beta functions, [$\beta_{x,y}$]	M	10
Energy spread, [ΔE/E]	-	< 0.02
Beam peak power, [P_{beam}]	TW	2
Macropulse Repetition Rate	Hz	10

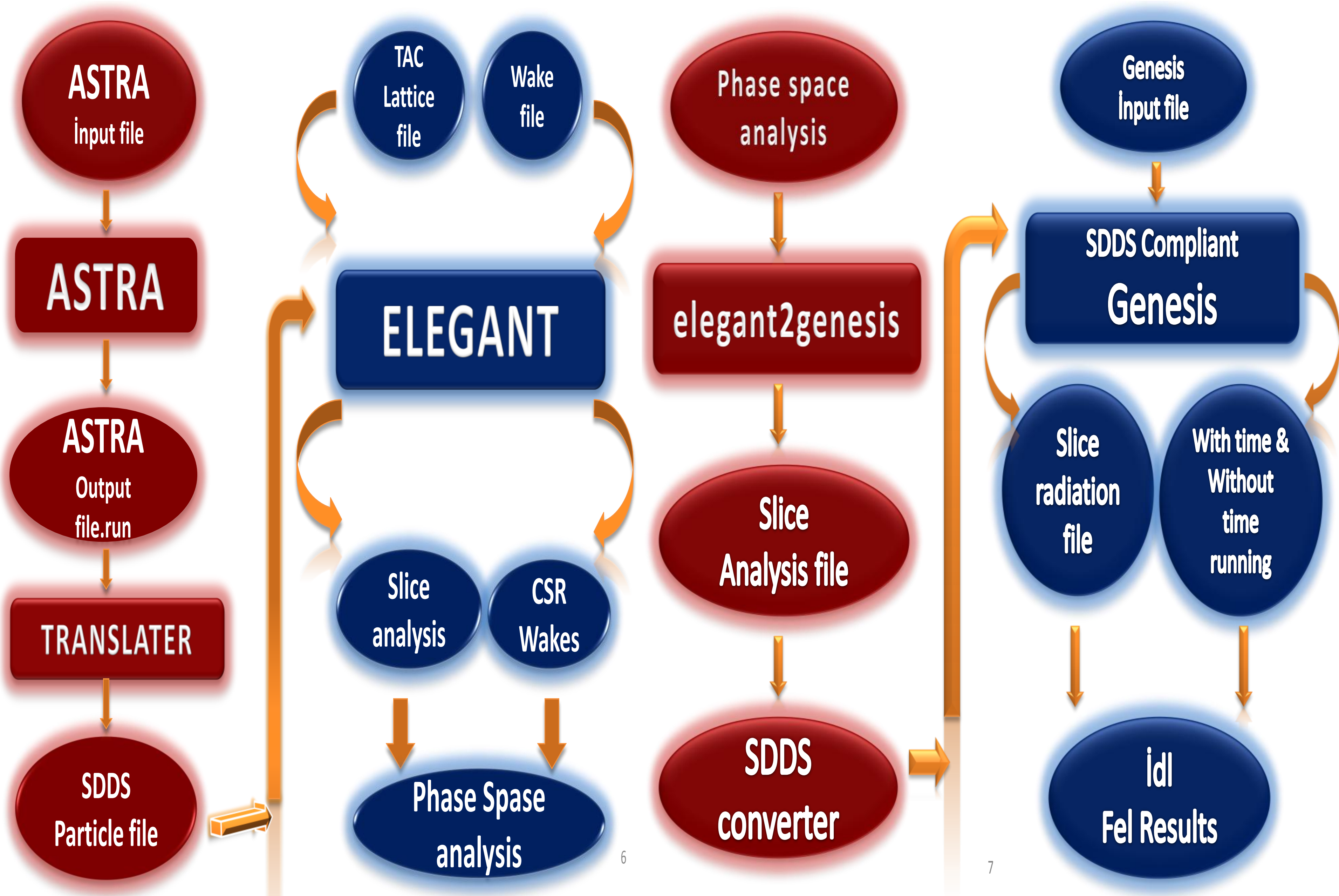
Linac Beam Dynamics Simulation:

After a realistic bunch distribution was generated using ASTRA to optimize parameters up to the end of the firs linac module AC1, he bunch should be converted and read into Elegant for tracking through the linac and CSRTrack for the bunch compressors.

At the start of the Elegant tracking the bunch properties should agree astra results.



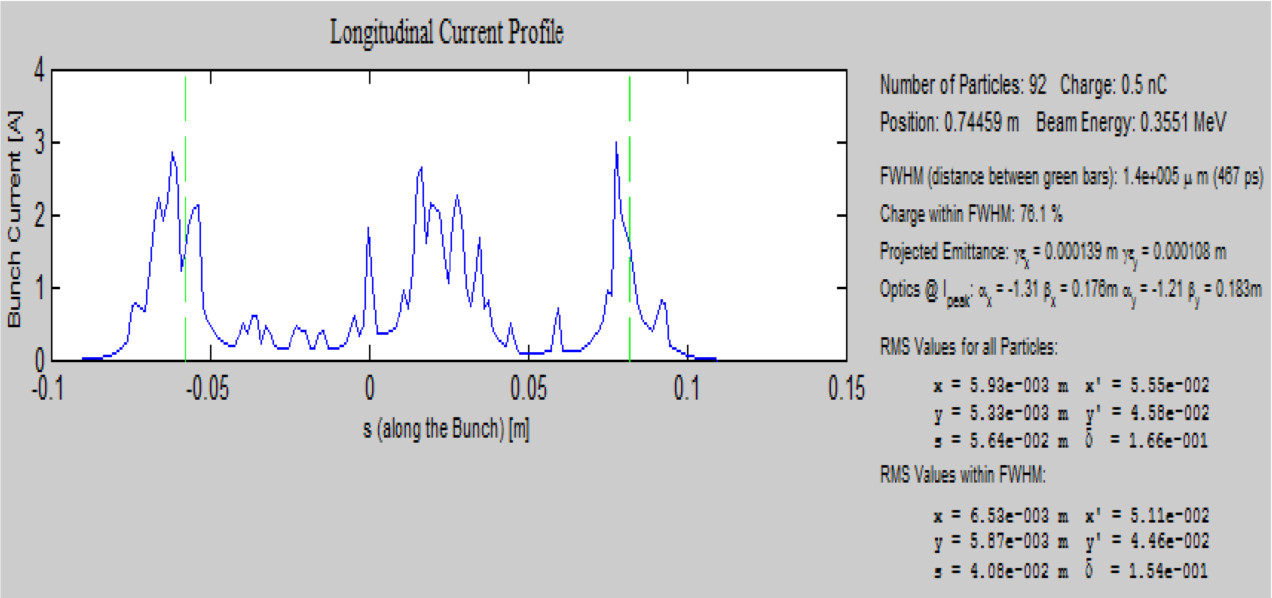

RF gun
Bunch
Compressor
Diagnostics
Accelerating Structures
Collimator
Undulators
FEL
Experiments
5 MeV
130 MeV
500 MeV
1 GeV
ASTRA
ELEGANT
GENESİS
astra2elegant
elegant2genesis


ASTRA
İnput file
ASTRA
ASTRA
Output
file.run
TRANSLATER
SDDS
Particle file
TAC
Lattice
file
Wake
file
ELEGANT
Slice
analysis
CSR
Wakes
Phase Spase
analysis
6
Phase space
analysis
elegant2genesis
Slice
Analysis file
SDDS
converter
7
Genesis
İnput file
SDDS Compliant
Genesis
Slice
radiation
file
With time &
Without
time
running
İdl
Fel Results

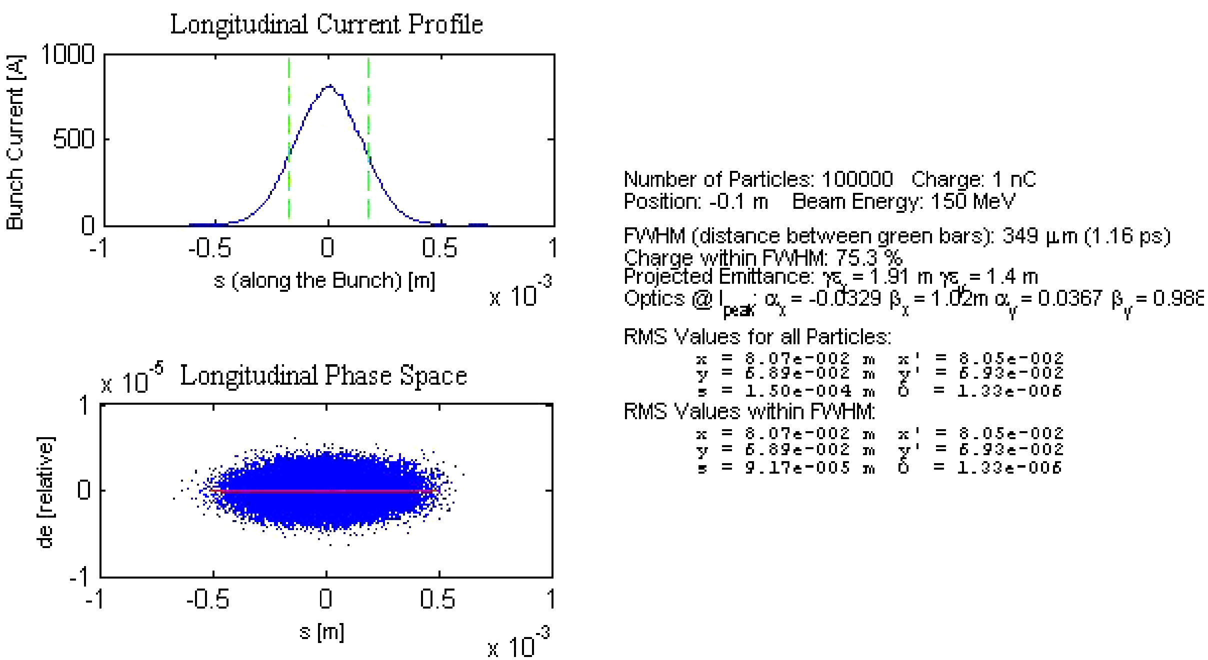
Using Astra Code[2]:

TAC SASE-FEL is considered as 1 GeV electron beam energy while accelerating RF field, 1.3 GHz RF gun.

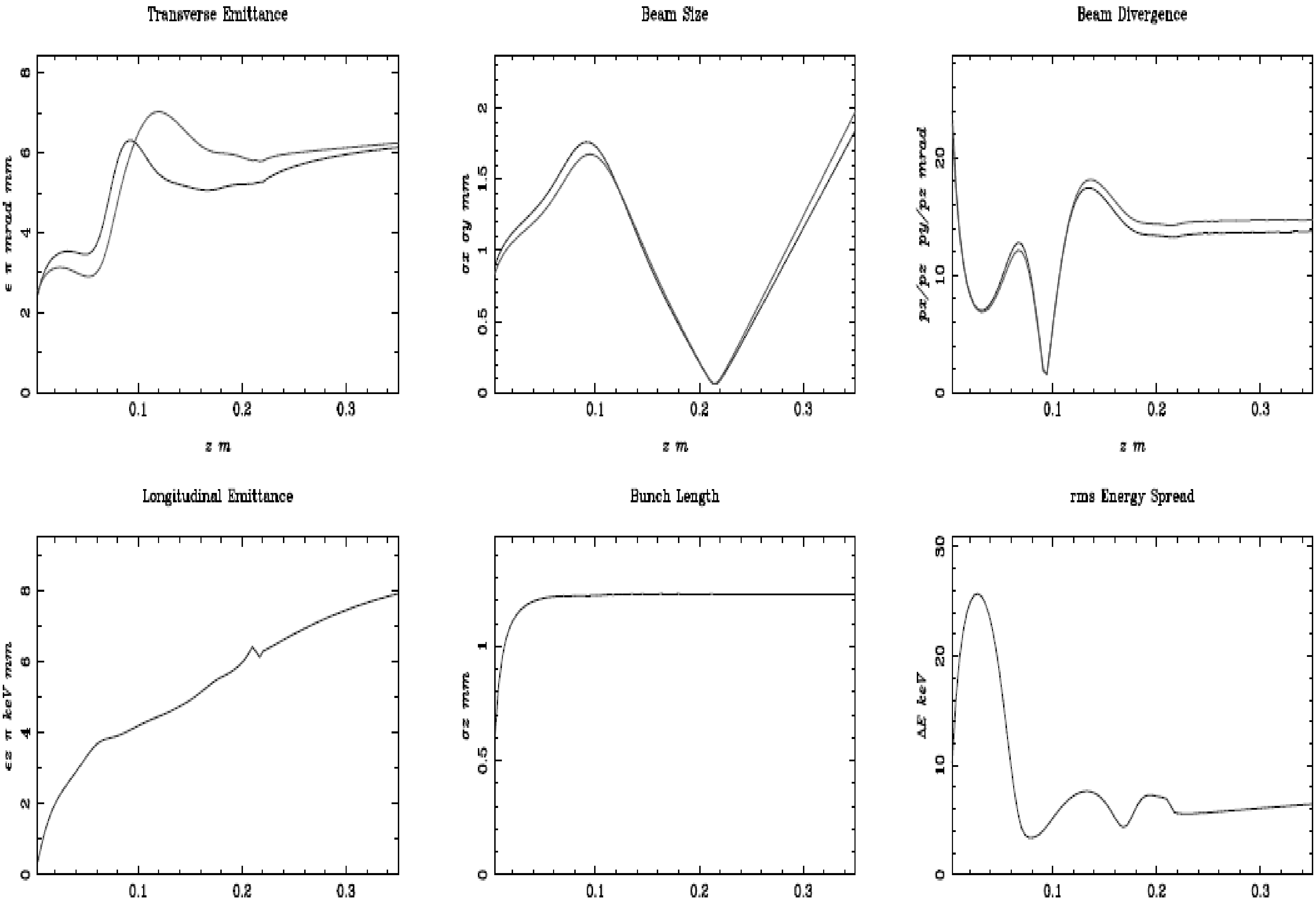
Solenoid's magnetic field is considered as 0.2260 T and length is taken 35 cm.

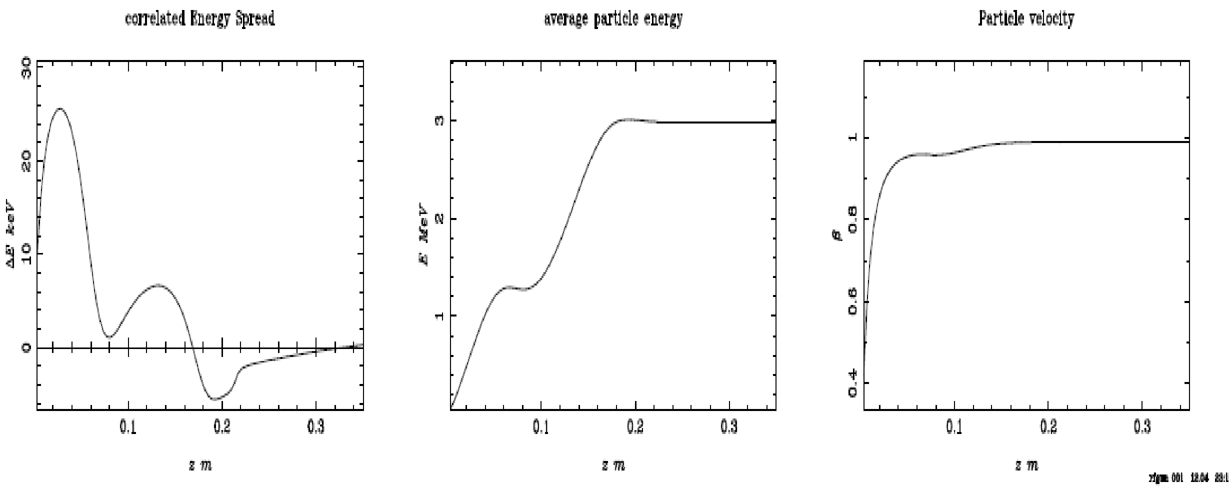


For 1 nC, 100000 number of particle, after the particles released from the gun, Bunch current vs along the bunch (m) is displayed in the following graphs. Current should be
Gaussian shape. Since Astra is space charge tracking algorithm, charge thus in a time, current behaves gaussian shape statistically.



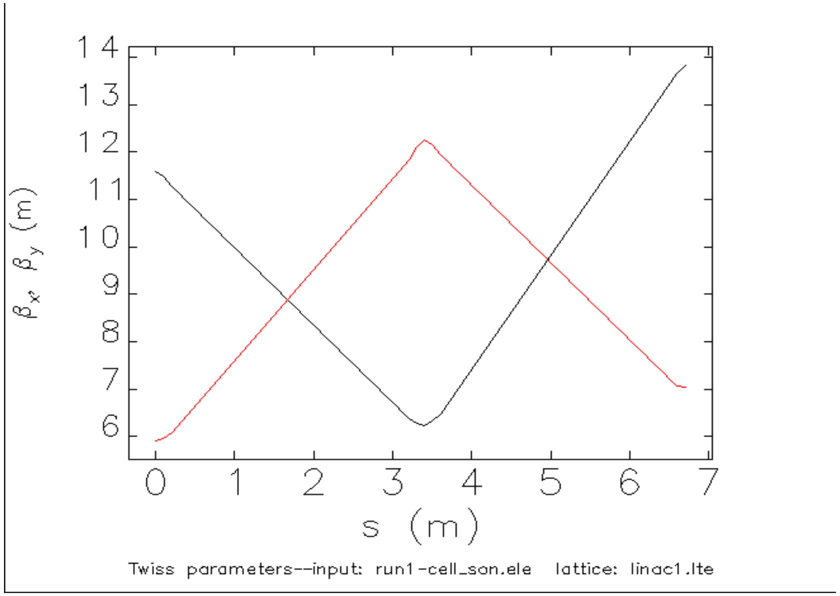
Evolution of rms beam parameters along the beamline is displayed in the following figures: An initial bunch was produced with both the gun & linac operating on-crest.

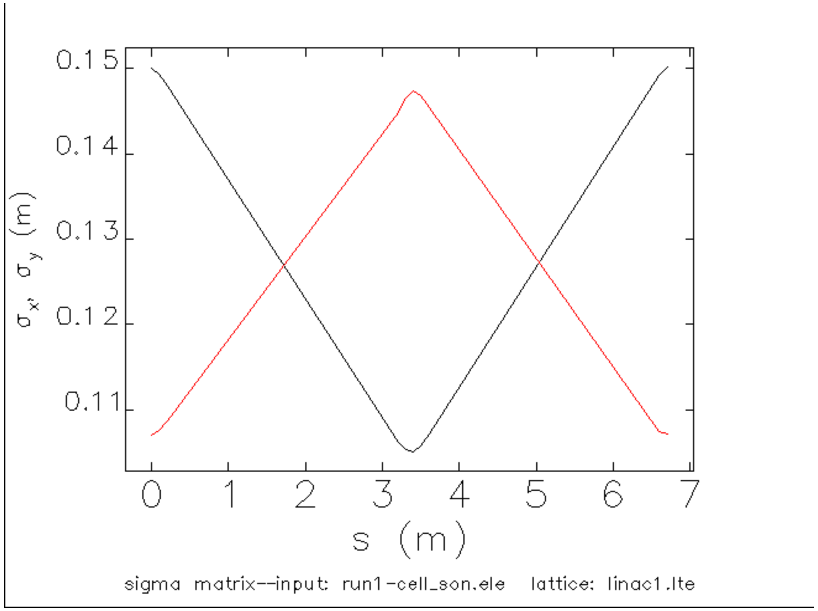




For further studies, we obtain laser spot parameter, laser pulse width, initial thermal energy, gun peak field by using ASTRA.

	TESLA Structure	S Band Linac
Frequency (GHz)	1.3	3
Gradient (MV/m)	30	30
Input power (MW)	10	25
Pulse Length (μs)	~10	~10
Number of Structure	35	12
Linac length (m)	~ 100	45





In the above figures shows that elegant
results for beta function and transverse beam size

$\sigma = \sqrt{}$ emittance x β/γ

Elegant[3] results give .output, .sig, .twi parameters

We define lattice, magnet strength parameters, voltages, current values,… all the beam way through the beginning of the undulator

Undulator Modelling and Laser Optimisation

- After we obtained Elegant output files, by using SDDS and using binary converters, we need to prepare output file to Genesis.
- Seeding ??
- In vacuum ??
- After converting elegant output, we start constructing Genesis beam file.
- In this beam file, lattice, electron beam, radiation field steps needed to determined. External magnetic field input should be supplied.

Undulator Material:

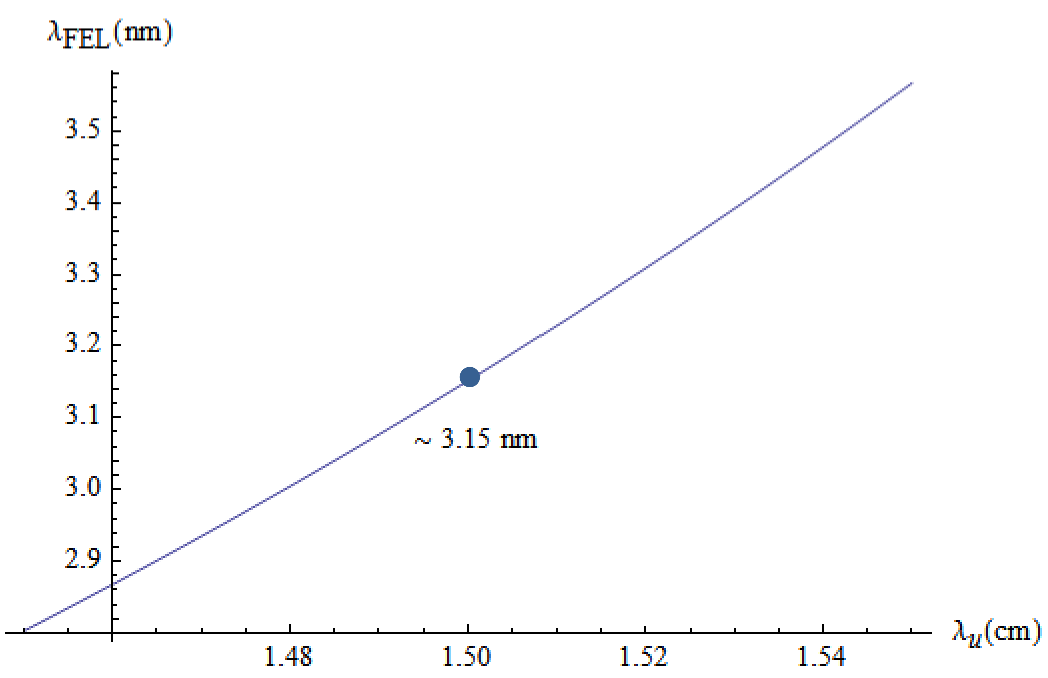
$$B_{peak} = aExp\left(b\frac{g}{\lambda_u} + c\left(\frac{g}{\lambda_u}\right)^2\right)$$

Case	Definition	a	b	c	Gap
A	PPM*, Planar, Vertical Magnetic Field	2.076	-3.24	0	$0.1 < g / \lambda_u < 1$
B	PPM*, Planar, Horizantal Magnetic Field	2.4	-5.69	1.46	$0.1 < g / \lambda_u < 1$
C	PPM*, Helical Magnetic Field	1.614	-4.67	0.62	$0.1 < g / \lambda_u < 1$
D	Hybrid with Vanadium Permendur	3.694	-5.068	1.52	$0.1 < g / \lambda_u < 1$
E	**Hybrid with Iron**	**3.381**	**-4.73**	**1.198**	$\mathbf{0.1 < g / \lambda_u < 1}$
F	Superconducting, Planar, Gap = 1.2 cm	12.42	-4.79	0.385	1.2 cm $<\lambda_u<$ 4.8 cm
G	Superconducting, Planar, Gap = 0.8 cm	11.73	-5.52	0.856	0.8 cm $<\lambda_u<$ 3.2 cm
H	Electromagnet, Planar, Gap = 1.2 cm	1.807	-14.3	20.316	4 cm $<\lambda_u<$ 20 cm

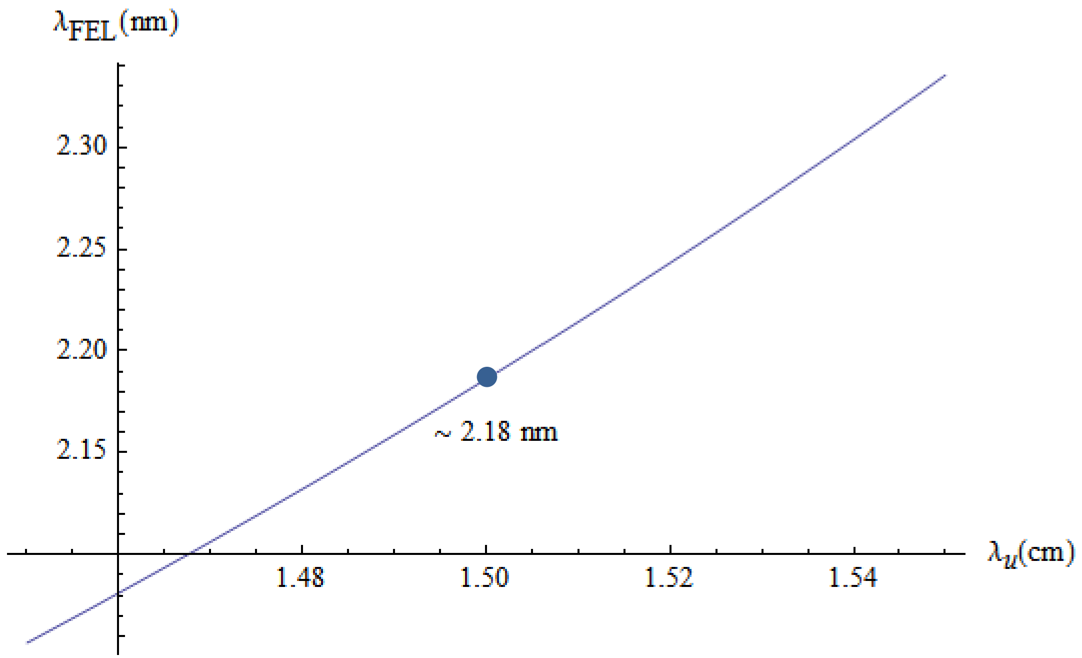
In vacuum Case:

Parameter, [Symbol]	Unit	Value
Undulator gap, [g]	cm	0,8
Undulator period, [λ_u]	cm	1,5
Peak magnetic field, [B_{peak}]	T	0,787
K parameter	-	1,1
Number of undulator periods, [N_u]	-	1580
Undulator length, [L_u]	m	23,7

Keeping same undulator period (1.5 cm) Two different undulator gaps are used. g= 8 mm and g= 12 mm keeping SC planar. Niobium (SC) alloys are used as undulator material. [4]



Parameter, [Symbol]	Unit	Value
Undulator gap, [g]	cm	1,2
Undulator period, [λ_u]	cm	1,5
Peak magnetic field, [B_{peak}]	T	0,344
K parameter	-	0,482
Number of undulator periods, [N_u]	-	2598
Undulator length, [L_u]	m	38,97



Laser Parameters:

Laser parameters for SASE, such as gain length, saturation power can be obtained by using [6]:

$$F_1(K)=\frac{K^2}{\left(1+\frac{K^2}{2}\right)^2}\left(BesselJ\left[0,\frac{\frac{K^2}{4}}{\left(1+\frac{K^2}{2}\right)}\right]-BesselJ\left[1,\frac{\frac{K^2}{4}}{\left(1+\frac{K^2}{2}\right)}\right]\right)^2$$

$$K=0.934\lambda_u aExp\left[b\frac{g}{\lambda_u}+c\left(\frac{g}{\lambda_u}\right)^2\right]$$

$$\lambda_{FEL}=\frac{\lambda_u}{2\gamma^2}\left\{1+\frac{\left[0.934\lambda_u aExp\left(b\frac{g}{\lambda_u}+c\left(\frac{g}{\lambda_u}\right)^2\right)\right]^2}{2}\right\}$$

$$\rho=\left(\frac{\gamma\left(\lambda_{FEL}\right)^2 r_e n_e}{8\pi}\frac{K^2}{\left(1+\frac{K^2}{2}\right)^2}\left(BesselJ\left[0,\frac{\frac{K^2}{4}}{\left(1+\frac{K^2}{2}\right)}\right]-BesselJ\left[1,\frac{\frac{K^2}{4}}{\left(1+\frac{K^2}{2}\right)}\right]\right)^2\right)^{\frac{1}{3}}$$

$$P_{sat}\approx\rho P_{beam}=1.6\rho\left(\frac{L_{G,1D}}{L_{G,3D}}\right)^2 P_{beam}$$

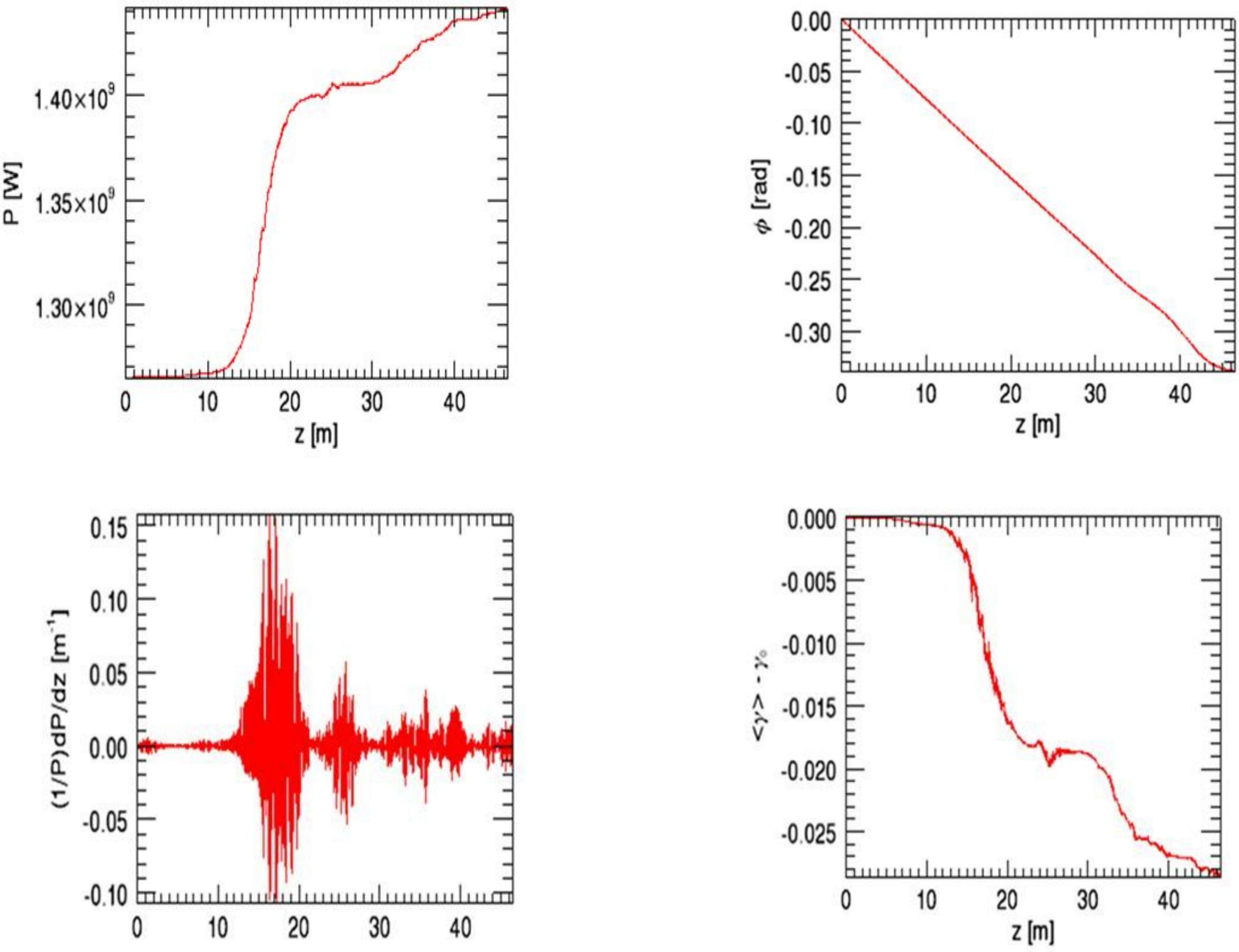
$$L_{G,1D}=\frac{\lambda_u}{4\pi\sqrt{3}\rho}\qquad L_{G,3D}=(1+\eta)L_{G,1D}\qquad \eta=a_1\eta_d^{a_2}+a_3\eta_\varepsilon^{a_4}+a_5\eta_\gamma^{a_6}+a_7\eta_\varepsilon^{a_9}+a_{10}\eta_d^{a_{11}}\eta_\gamma^{a_{12}}+a_{13}\eta_d^{a_{14}}\eta_\varepsilon^{a_{15}}+a_{16}\eta_d^{a_{17}}\eta_\varepsilon^{a_{18}}\eta_\gamma^{a_{19}}$$

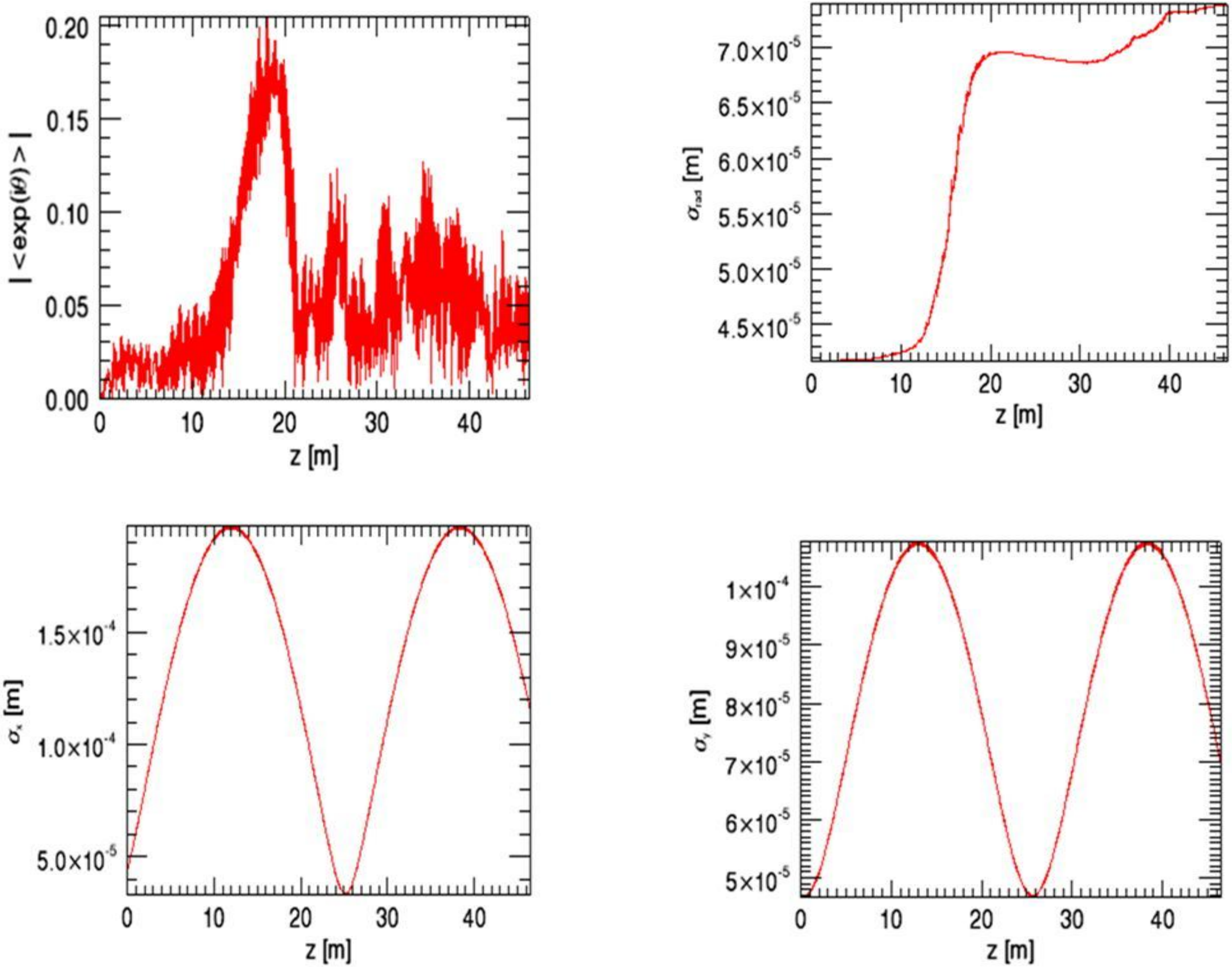
Genesis Results:

- In Genesis [5],
- 1 GeV electron beam energy is considered
- Peak current - curpeak $2x10^3$
- Slice number is considered 8192, …

- We obtain power, pondoramative phase, radiation growth rate, energy, growth of bunching (current profile), radiation size (photon beam size), vertical and horizontal sigma.

- Power is obtained around 10^9 W and
- Saturation Length is around 21 m.


P [W]
1.40×10^9
1.35×10^9
1.30×10^9
0
10
20
30
40
z [m]
ϕ [rad]
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
0
10
20
30
40
z [m]
(1/P)dP/dz [m^-1]
0.15
0.10
0.05
0.00
-0.05
-0.10
0
10
20
30
40
<γ> - γ₀
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
0
10
20
30
40
z [m]



| <exp(iθ)> |
0.00
0.05
0.10
0.15
0.20
0
10
20
30
40
z [m]
σ_rad [m]
4.5×10^-5
5.0×10^-5
5.5×10^-5
6.0×10^-5
6.5×10^-5
7.0×10^-5
z [m]
σ_x [m]
5.0×10^-5
1.0×10^-4
1.5×10^-4
z [m]
σ_y [m]
5×10^-5
6×10^-5
7×10^-5
8×10^-5
9×10^-5
1×10^-4
z [m]

There are three different tentative laser parameter are shown. Gap 8 mm, gap 12 mm with İn vacuum case and gap 12 mm without vacuum case

Parameter, [Symbol]	Unit	Value
q quantity	-	9,047
Rho parameter, [ρ]	-	$6{,}327.10^{-4}$
1D gain length, [$L_{G,1D}$]	M	1,089
3D gain length, [$L_{G,3D}$]	m	2,659
Rayleigh length, [L_R]	M	129,196
Saturation length, [L_{sat}]	M	21,816
FEL wavelength, [λ_{FEL}]	nm	3,151
Saturation power, [P_{sat}]	GW	1,265
FEL energy, [E_{FEL}]	keV	0,392

Parameter, [Symbol]	Unit	Value
q quantity	-	7,02
Rho parameter, [ρ]	-	$3{,}847.10^{-4}$
1D gain length, [$L_{G,1D}$]	m	1,79
3D gain length, [$L_{G,3D}$]	m	13,821
Rayleigh length, [L_R]	m	186,245
Saturation length, [L_{sat}]	m	31,991
FEL wavelength, [λ_{FEL}]	nm	2,186
Saturation power, [P_{sat}]	GW	0,769
FEL energy, [E_{FEL}]	keV	0,565

Laser Parameters	
Wavelength Range [nm]	3 or 6 – 60 nm
Maximum Peak Power (GW)	1.3
Peak Brillance (photons/s/mrad^2/mm^2/0.1%bw)	$\sim 10^{29}$
Peak Energy (μJ)	130

Conclusion

- Choosing SC/NC acceleration modules ??
  - → Crymodules, price, manpower, electricity
- ERL/Linac Case ??
  - → Beam energy need to be determined, the able to decide
- Why we choose 3-60 nm
  - → 3-60 nm laser wavelength
  - → Partly, we can discuss laser wavelength in the summer workshop
    http://physics.dogus.edu.tr/tac-sr/

For beam energy enchancment, first we would like to learn in more detail all part of the system either simulation or mechanically by going other laboratories in the world and also bringing some experts here and work sometime together. In Turkey, conventional x-ray or UV sources are used but no laser lab. that produce laser in this region that can be used.

References

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