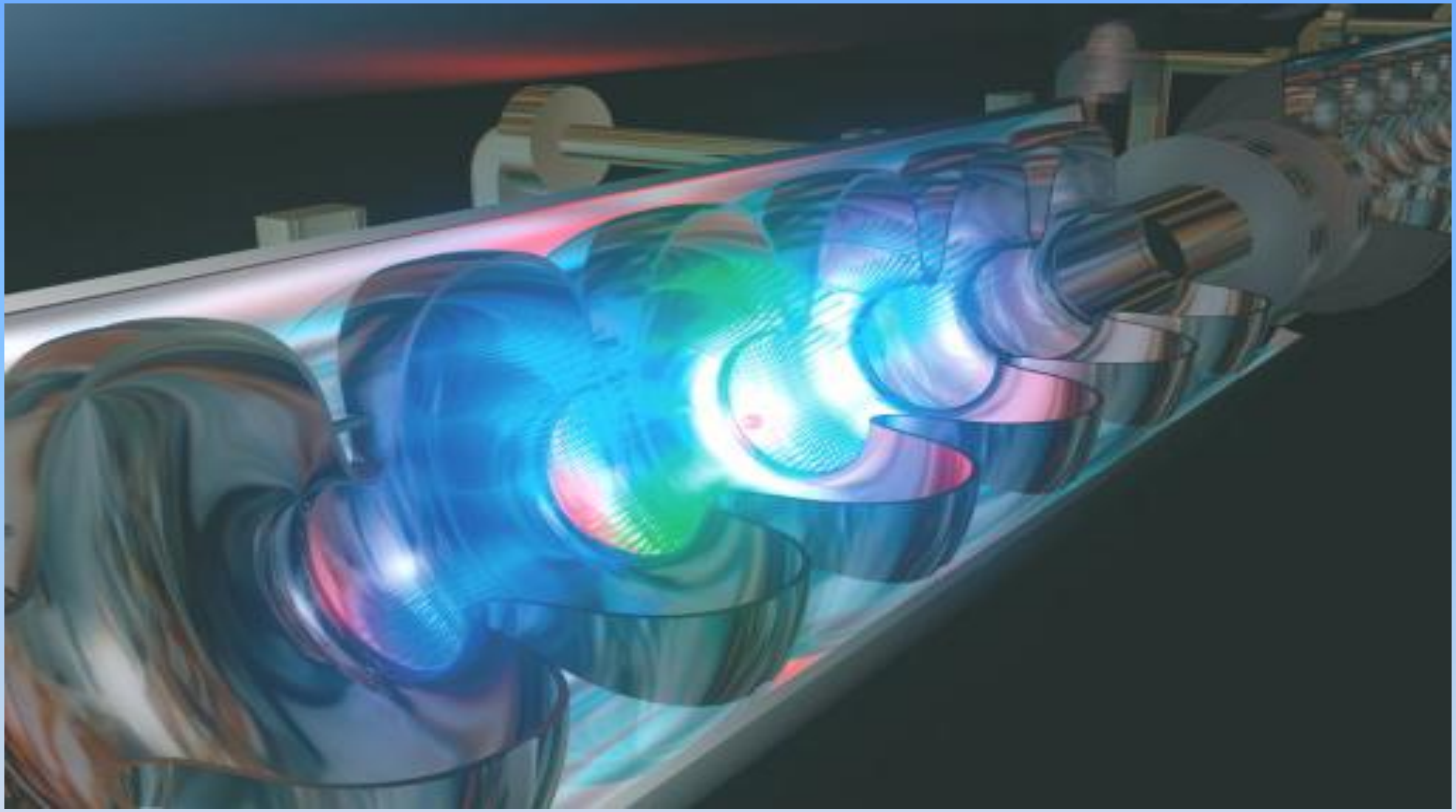
GUN, MAIN LINAC DESIGN SIMULATIONS AND BEAM DYNAMICS AT LINEAR COLLIDERS



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ANKARA HIGH ENERGY PHYSICS DAYS
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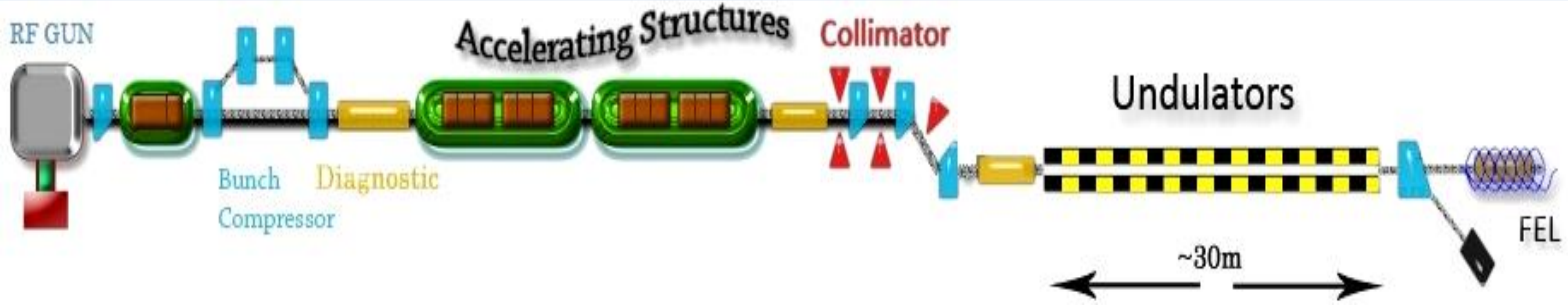
Contents

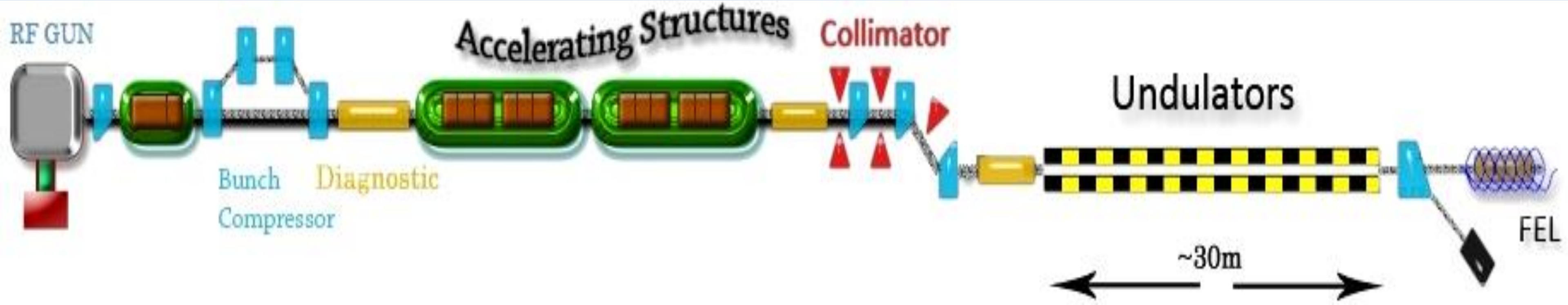
▪ Linear Accelerator System -1

- A compact beam,
- Superconducting Cavities to accelerate the beam,
- Helium cooling system to keep low tempreature cavities,
- Nitrogen system to keep Helium system in low temperature,
- Water cooling
- Control system,
- Vacuum System
- Radiation system

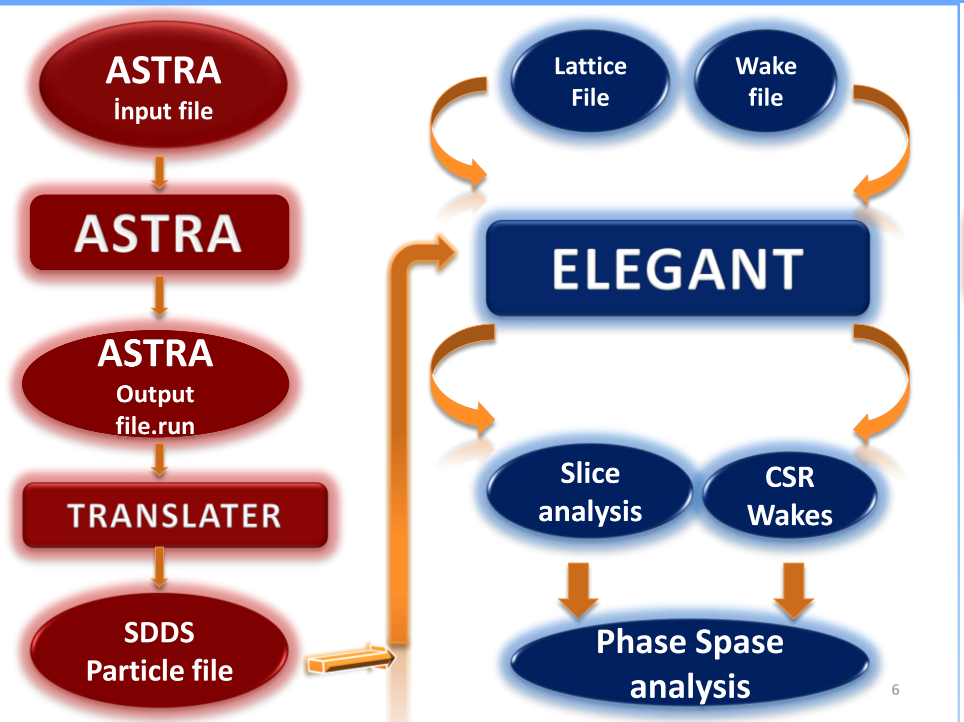


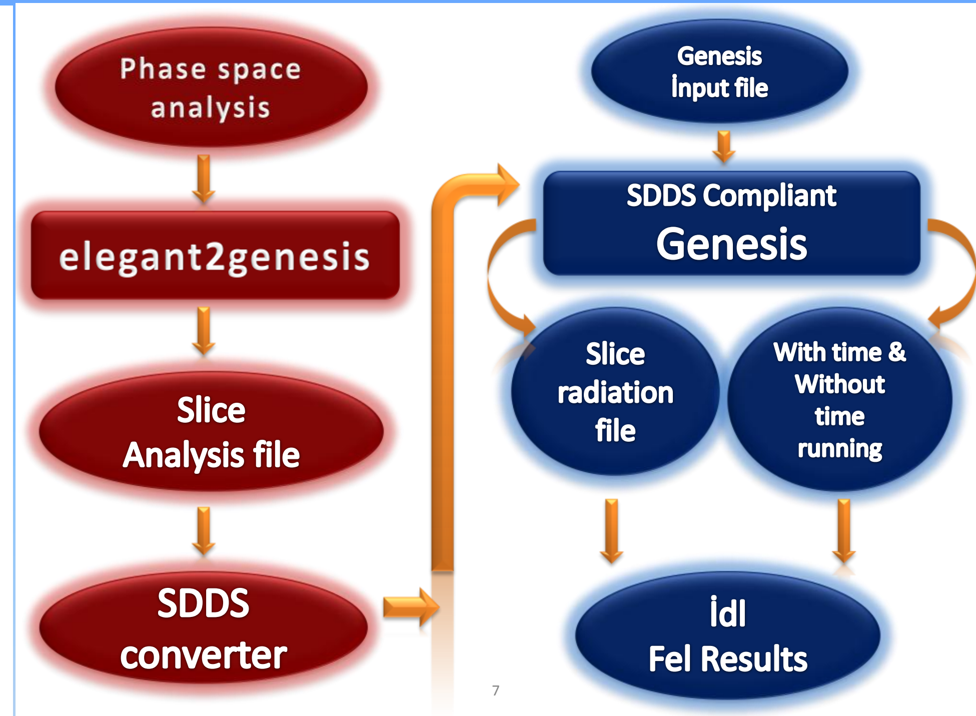
▪ Linear Accelerator System -2

- Bunch Compressor,
- Diagnostics system (BPM, OTR, CRD, various cameras to diagnose the beam)
- RF System (Low Level RF, High Level RF)
- Collimators
- Magnets (Dipol magnets, quadrupol magnets, steering magnets, bending magnets)
- Cables and oscilloscopes



Used codes for whole laser system



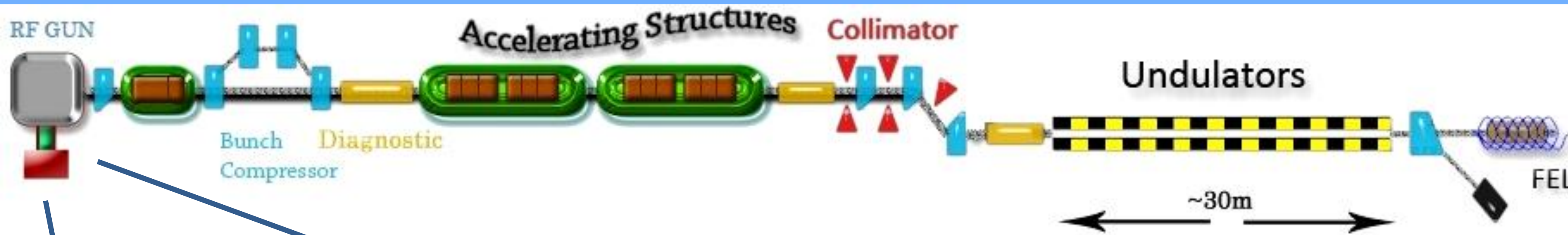


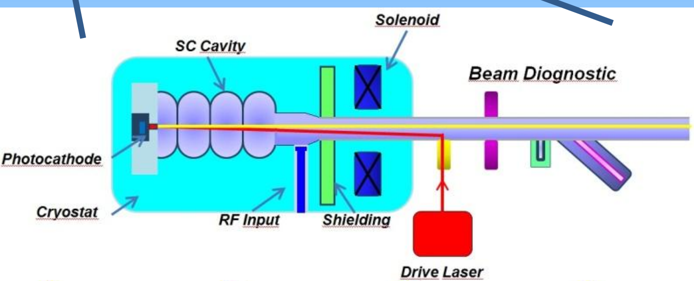
+

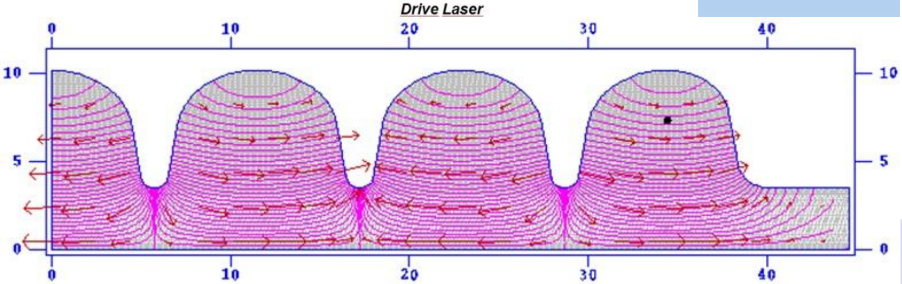
- Poisson / Superfish Programs
- CST MWS (Microwave Studio Computer Simulation Technology)
- CST PS (Particle Studio Computer Simulation Technology)
- Mathematica
- Ps Wiever
- FLUKA Monte Carlo Method

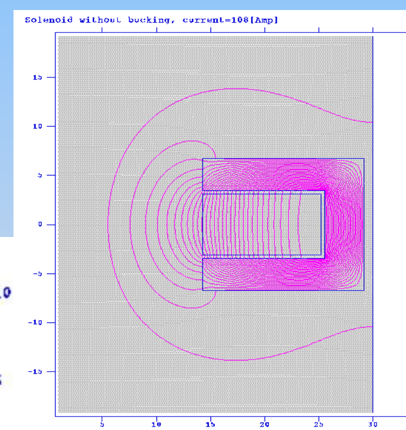
SASE-FEL Simulation Studies

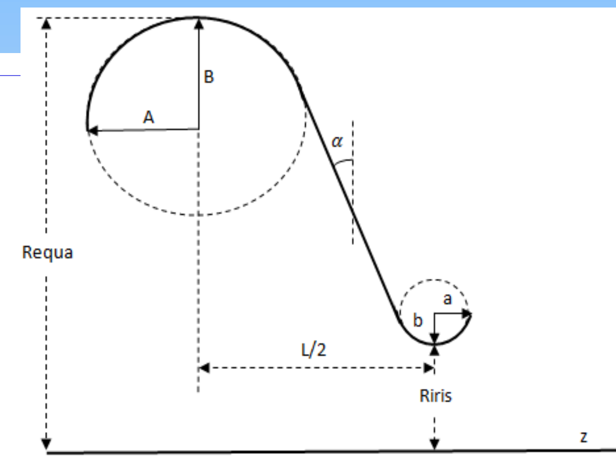
- Gun and Injector simulation studies











→ Astra simulations are done by taking 260 000 particles. Gun and solenoid field maps are obtained. For the initial Astra simulations it was assumed that the gun will be operated with an on-axis peak electric field of 48 MV/m for 3½ - cell cavity

Injector simulation studies

→ **SC has been considered for both gun cavity and main linac cavities.**

→ **SC cavity has high quality factor, low power dissipation on cavity wall, low surface resistance, problems can be minimize when we compare with NC.**

→ **NC cavity case is also under consideration as an MSc thesis of one of the student.**

Current Studies:

→ **Enjector studies: Gun → 3.5 – cell**
1.5 – cell gun cavity

→ **After gun →6+3 – cell,**
4+3 – cell, and
3+3 – cell enjector cavity considered

→ **Main Linac → 9 x 9 – cell → 1.4 GeV**
12 X 9 – cell → 1.6 GeV Energy has been reached.

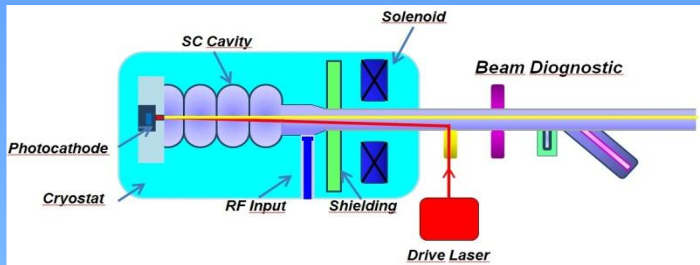
→ **Undulator (in vacuum, w/out vacuum)**

→ **Laser Optimisation 1, 3, 5, and 6 GeV are considered for simulations.**

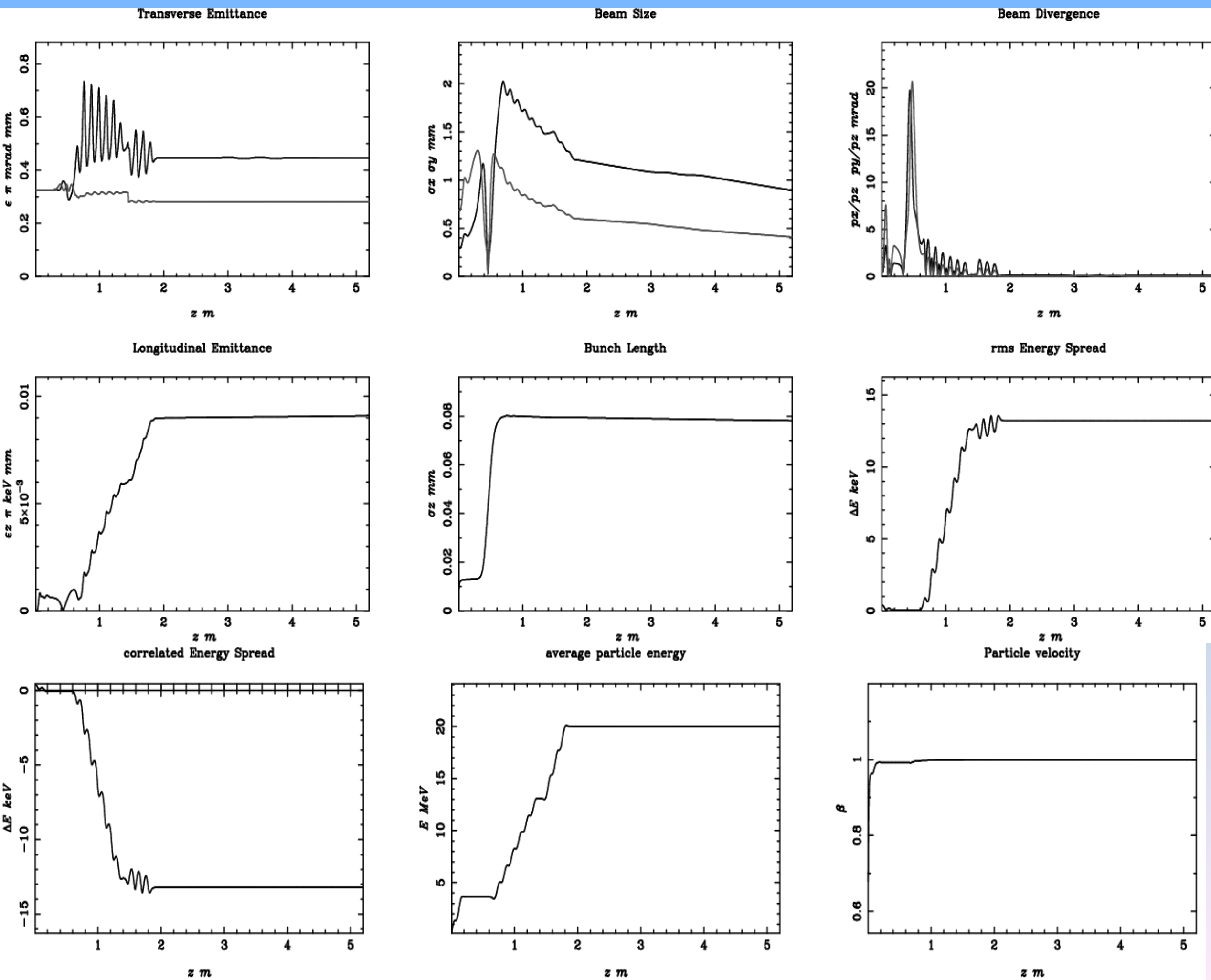
RF Phases in Cavities

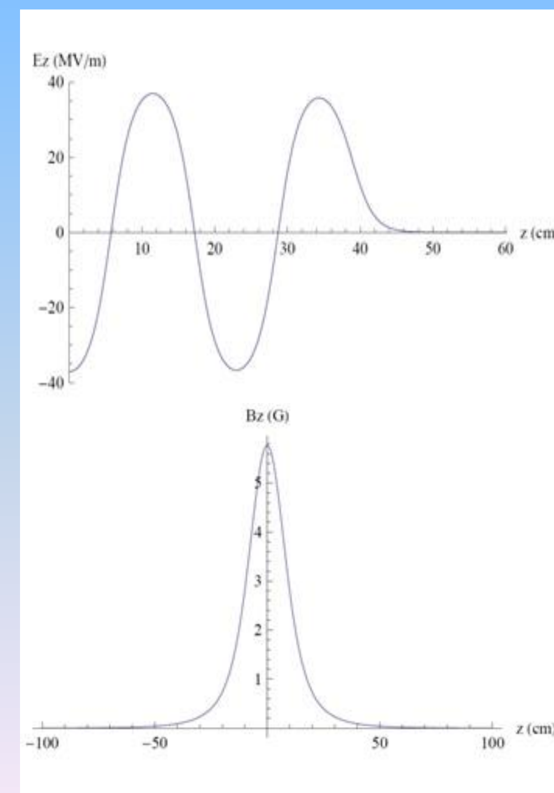
	3½ - cell	3+3	4+3	6+3	8X9 (for 6+3)
Energies (MeV)	3.95	17	20	22	> 1250
Phases (deg)	-2.104	-2.104 -32.05 -12.5	-1.2 -28.00 -14.7	-1.02 -27.3 -2.80	-1.02 for 1½ -cell -27.3 for 6-cell -2.80 for 3-cell 6.40 -136.62 -25.62 -25.62 for 9-cell 0.0 0.0 0.0 0.0
Maximum E_{peak} (MV/m)	38.8	38.8 38.5234 38.5234	38.8 46.070 38.5234	38.8 30.7087 38.5234	38.8 30.7087 38.5234 40.70 35.55 33.75 48.62 42.60 42.60

Injector simulation studies, 3.5-cell gun cavity – Superfish Code

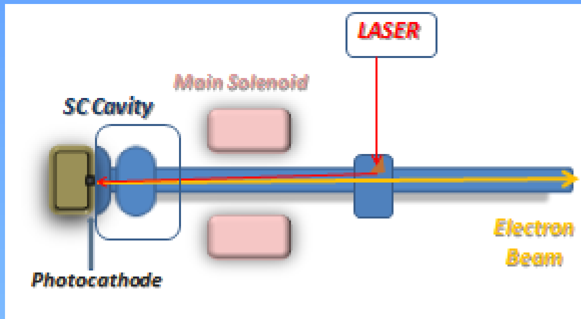


Parameter and Unit	Value
Solenoid Field (T)	0.523
Gradient (MV/m)	23
Peak current, $[I_{peak}]$ (kA)	2
Electron beam energy, $[E_{beam}]$(GeV)	≥ 1.5
Bunch charge, [Q] (nC)	1
Normalized emittance,$[\varepsilon_N]$(πmm.mrad)	≤ 0.5
Frequency(GHz)	1.3
Gun UHV (mbar)	10^{-10}-10^{-11}





Injector simulation studies, 1.5-cell gun cavity



a) GUN cavity (1.5 – cell Nb)

b) Electric field distribution inside the gun cavity (≈ 35MV/m)

c) Magnetic field distribution inside the gun cavity

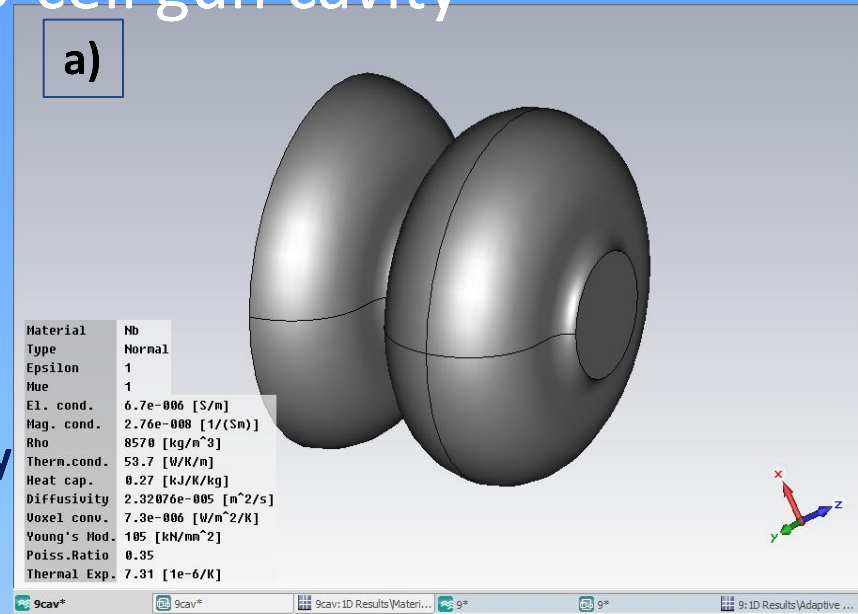
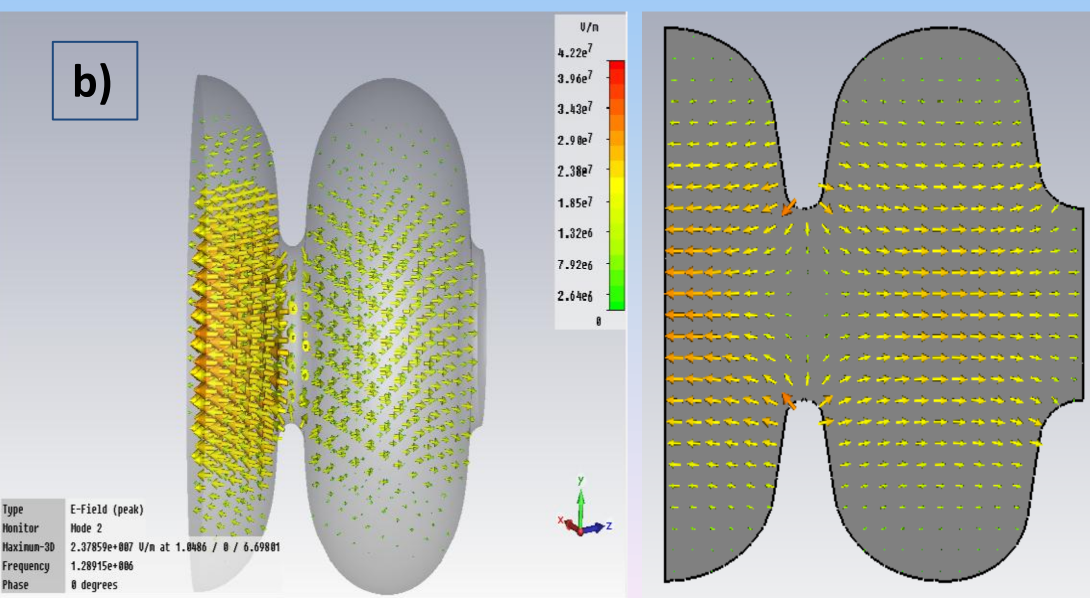
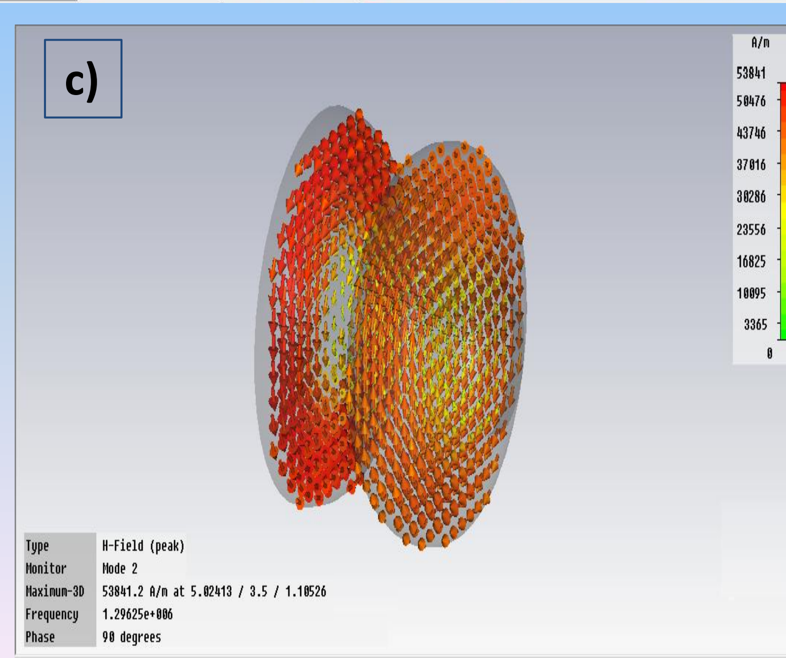
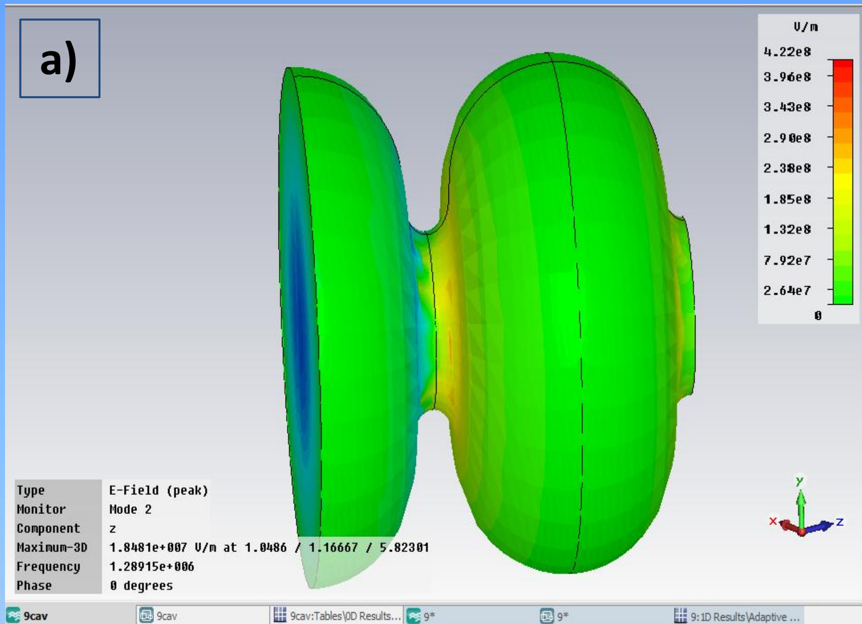


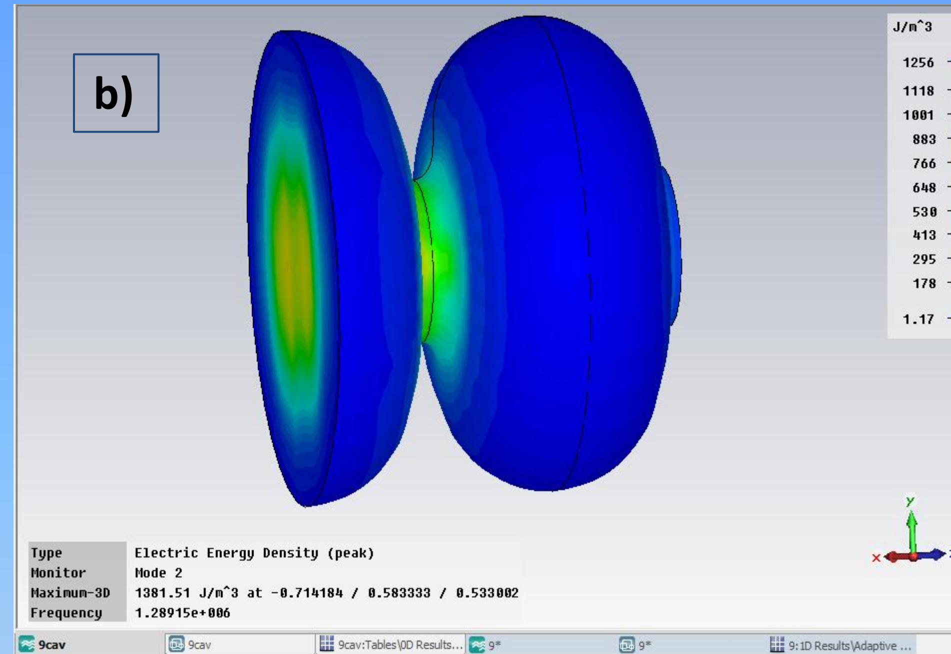
Figure -1 a), b), c)





Injector simulation studies, 1.5-cell gun cavity





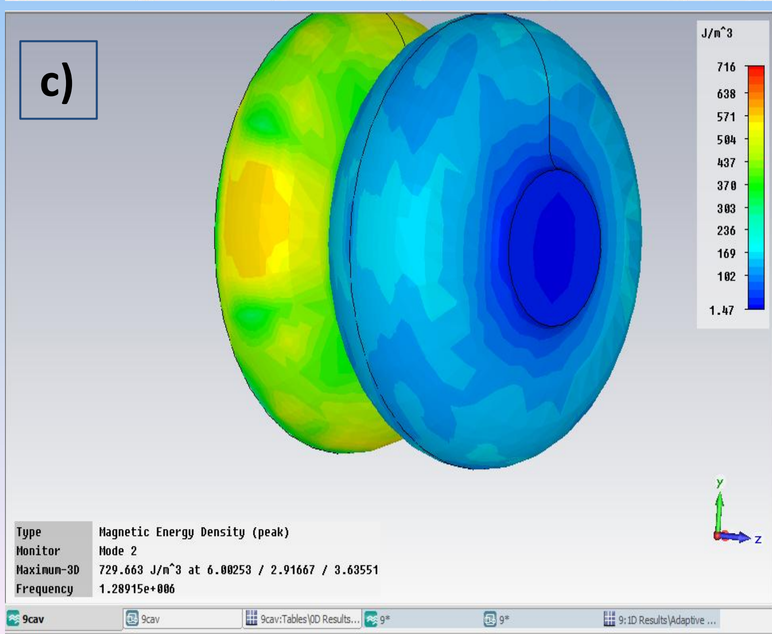


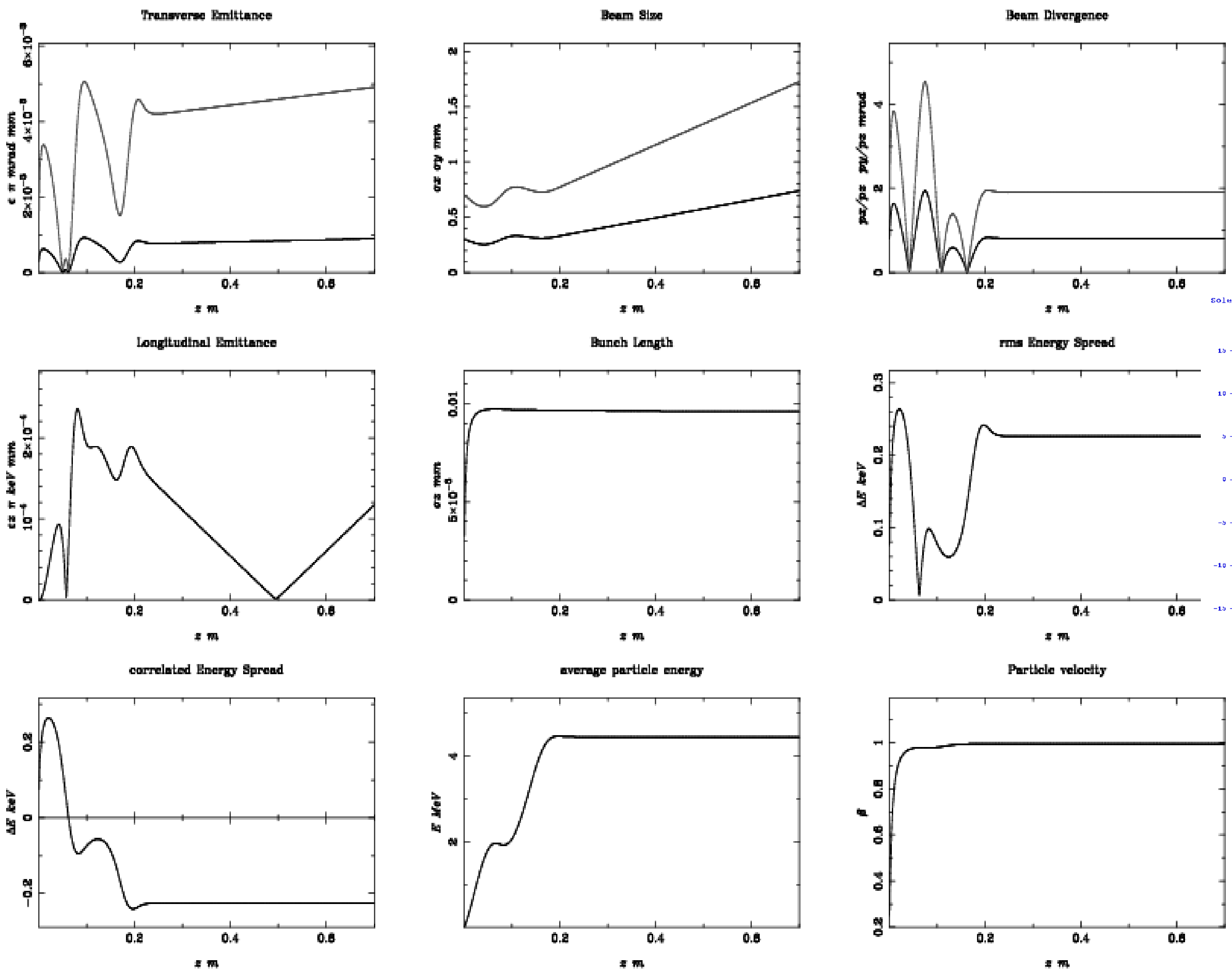
Figure- a), b),c)

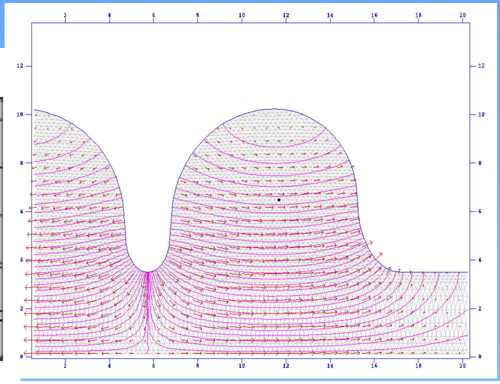
a) E_{peak} through the beamline (z)

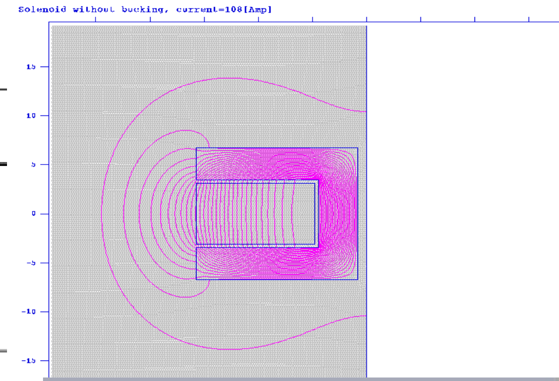
b) Electrical energy distribution on 1.5-cell gun-cavity

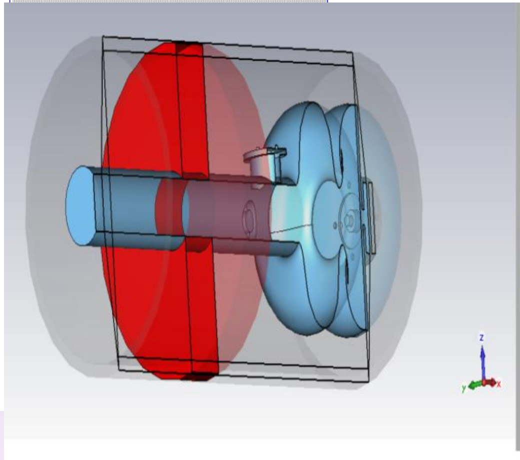
c) Magnetic energy distribution on 1.5-cell gun cavity

1.5 cell gun cavity







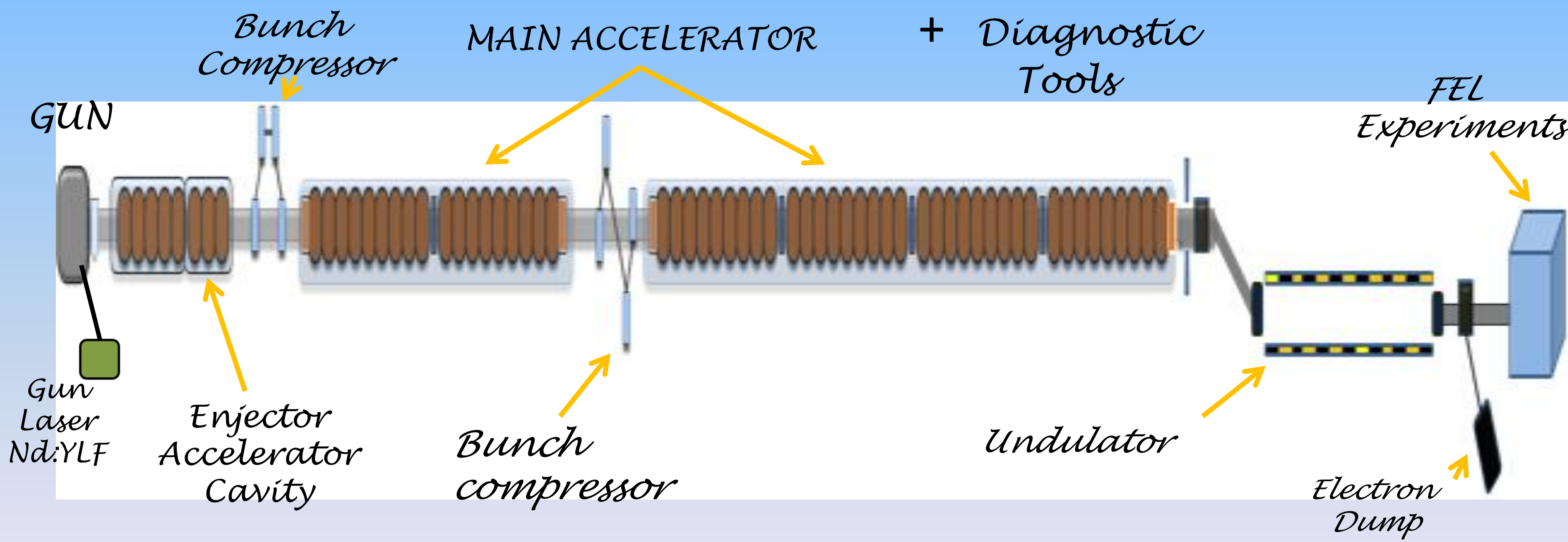


Injector simulation studies,

3+3,

6+3,

4+3 – cell cavities



	Unit	Value
Number of Particle	N	260.000
Total Charge	nC	1
RF Frequency	GHz	1.3
Solenoid Field	T	0.15
Cavity Length	m	1.26 m for 9-cell
Solenoid Length	m	0.13
Quadrupole Length	m	0.20
Quadrupole K Value		2.867
Cavity Temperature	K	2
Pressure	Torr	10^{-11}

Parameters for gun and enjector superconducting cavities

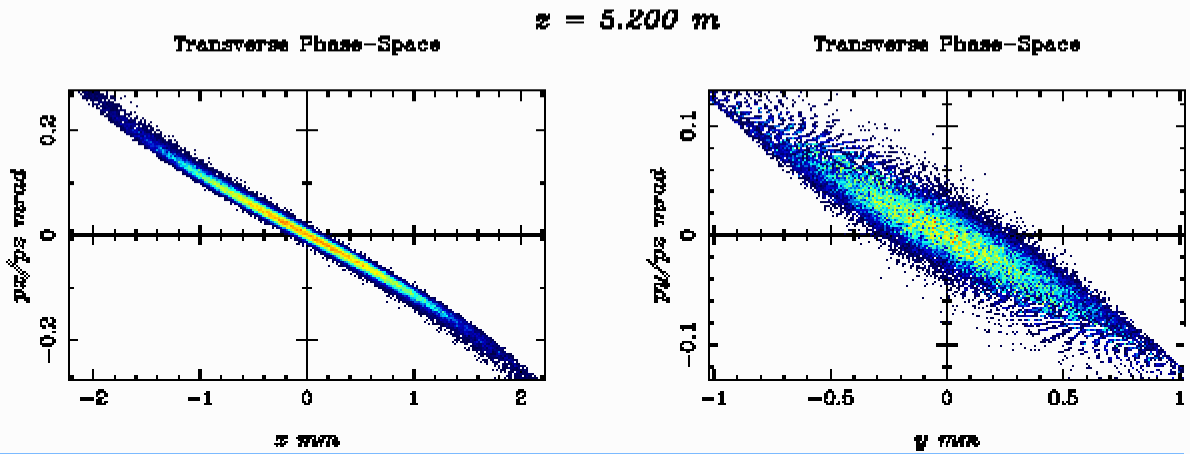
Coupler properties input and HOM antenna

Electrical conductivity	S/m	5.96e+007
Thermal conductivity	W/K/m	401.0
Meterial density	kg/ m^3	8930.0
Young's modulus	GPa	120
Poisson's ratio	-	0.38

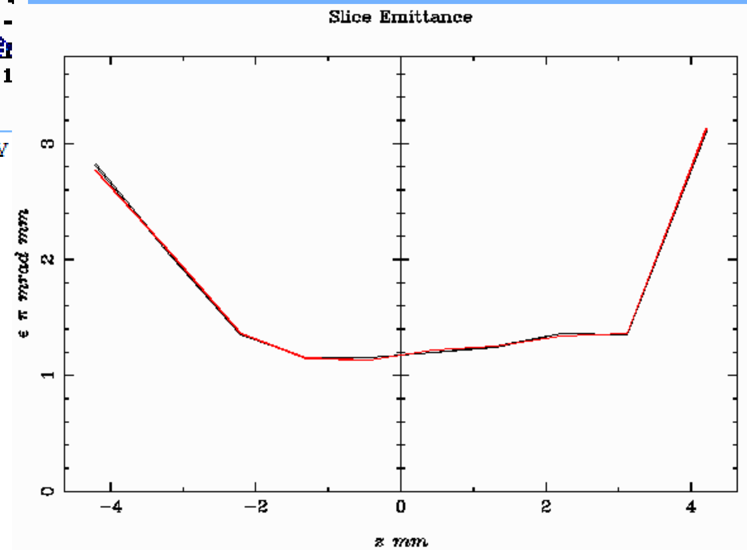
Electrical conductivity	S/m	6.7e6
Magnetic conductivity	1/Sm	2.76e-8
Thermal conductivity	W/K/m	53.7
Heat capacity	kJ/K/kg	0.27
Thermal diffisuvity	m^2/s	2.32076e-005
Young's modulus	GPa	105
Poisson's ratio	-	0.35
Meterial density	kg/ m^3	8570

Niobioum properties used as Cavity material

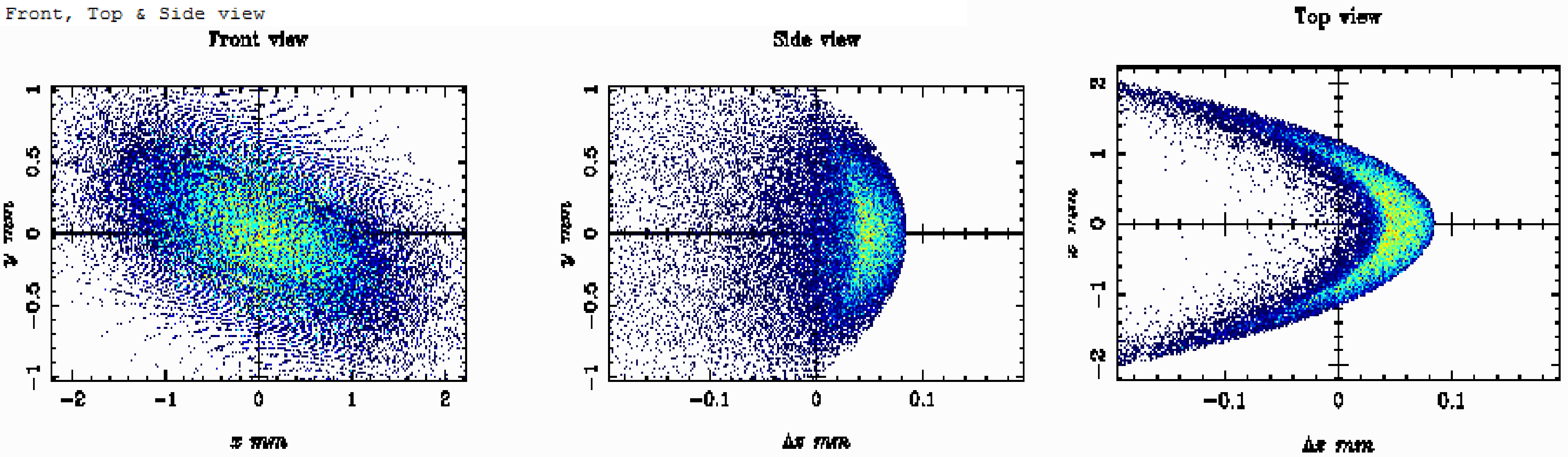
6+3 – cell injector Beam behaviour with only space charge effect is included for slice emittance figure

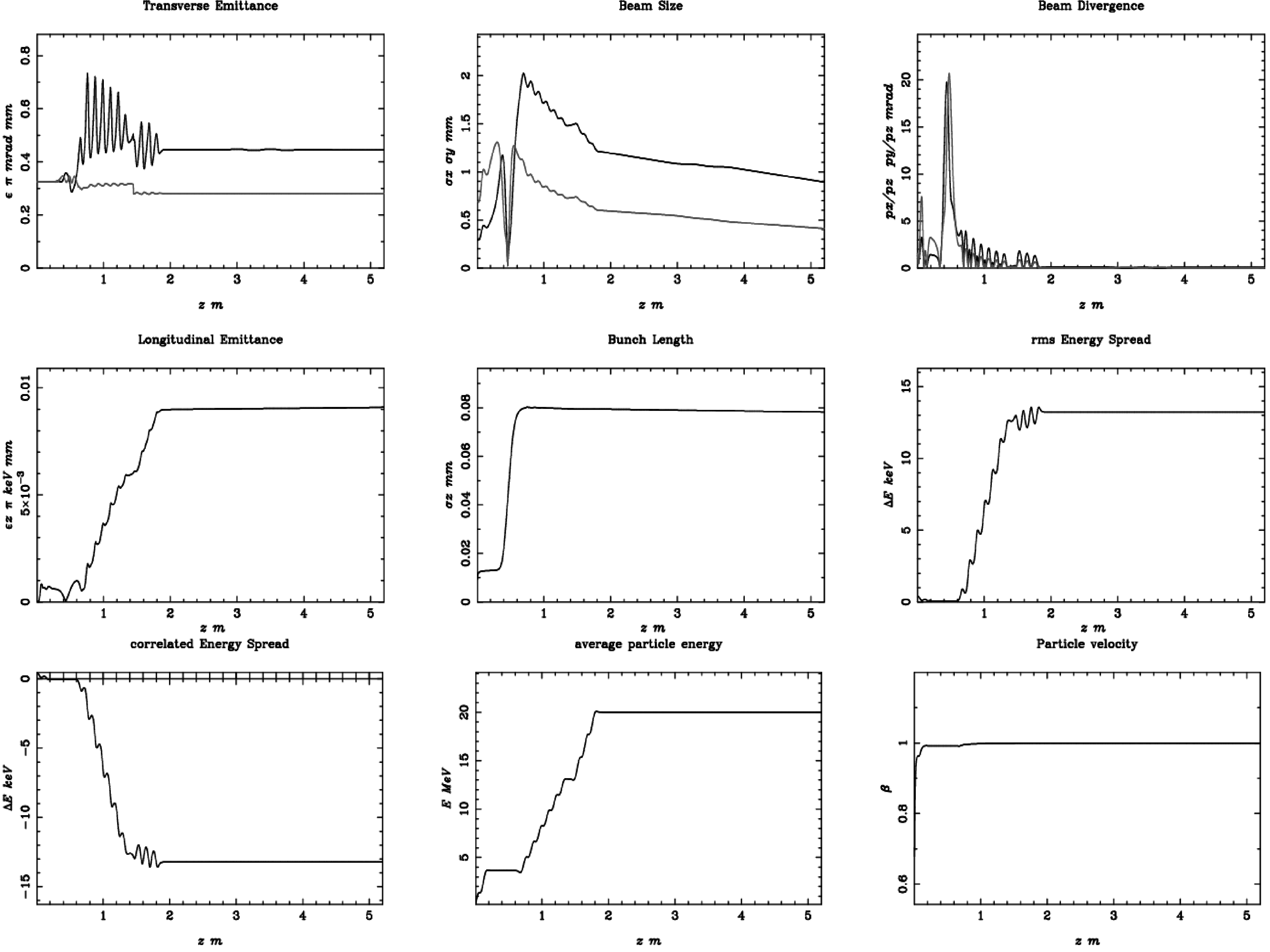


Slice	Charge	beta x	alpha x	zeta x	beta y	alpha y	zeta y
	nC	m			m		
1	1.000E-02	90.5	12.0	1.33	21.1	2.22	1.08
2	1.000E-02	127.	15.3	1.20	21.8	2.50	1.02
3	1.000E-02	103.	12.1	1.21	23.7	2.90	1.00
4	1.000E-02	87.6	10.1	1.23	26.2	3.34	1.01
5	1.000E-02	78.0	8.83	1.28	28.4	3.70	1.04
6	1.000E-02	70.6	7.92	1.31	30.9	4.08	1.07
7	1.000E-02	67.3	7.49	1.35	32.2	4.28	1.09
8	1.000E-02	64.5	7.13	1.38	33.4	4.48	1.12
9	1.000E-02	61.7	6.78	1.40	34.9	4.69	1.14
10	1.000E-02	58.5	6.37	1.45	36.8	4.98	1.17
Average values:							
		80.9	9.40	1.31	28.9	3.72	1.07



Front, Top & Side view

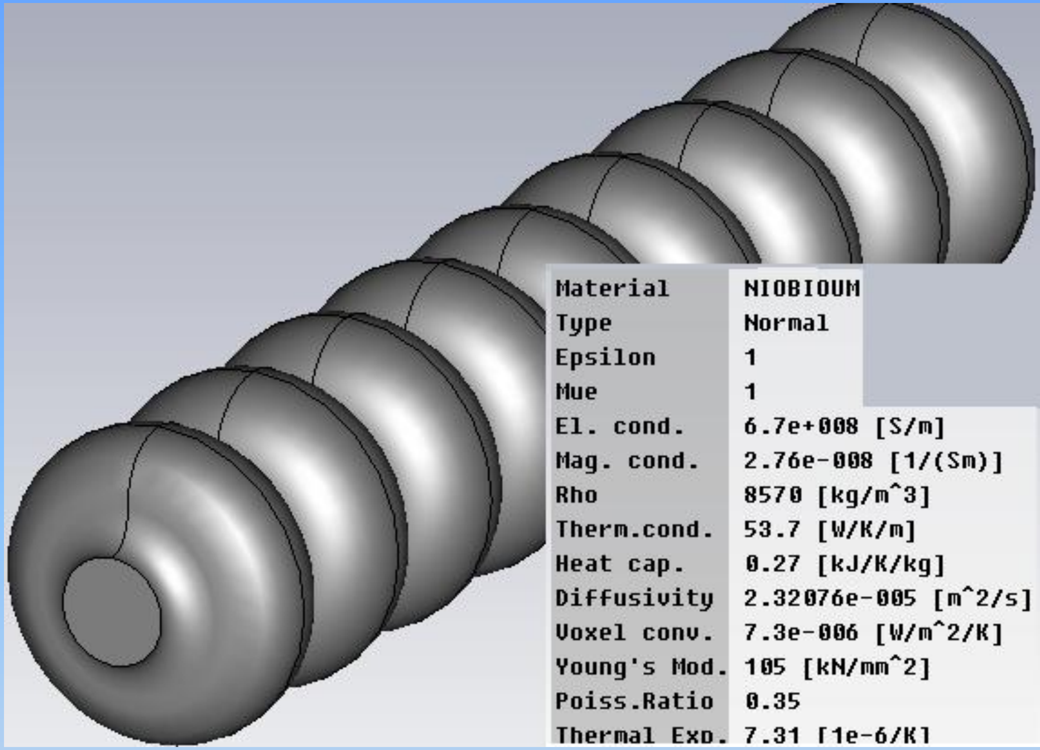


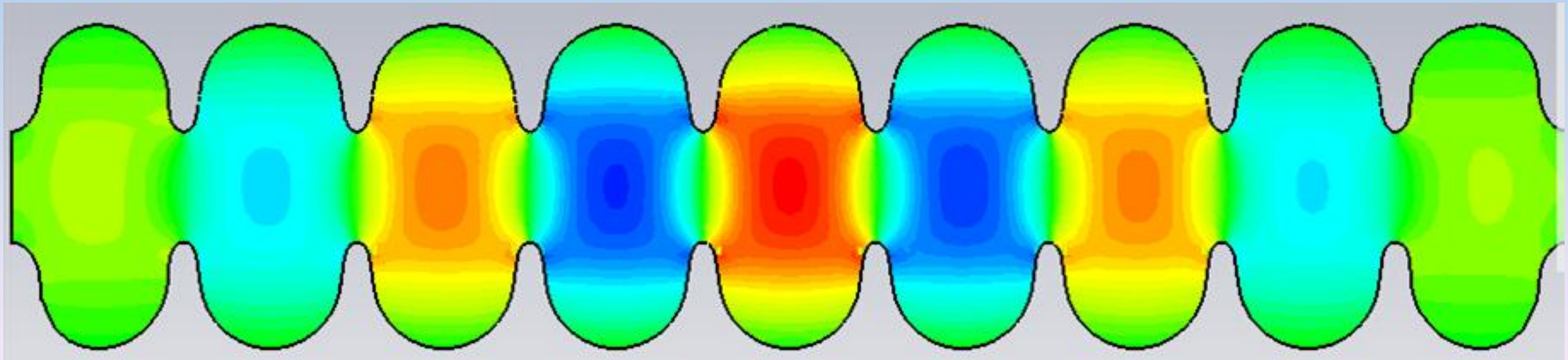


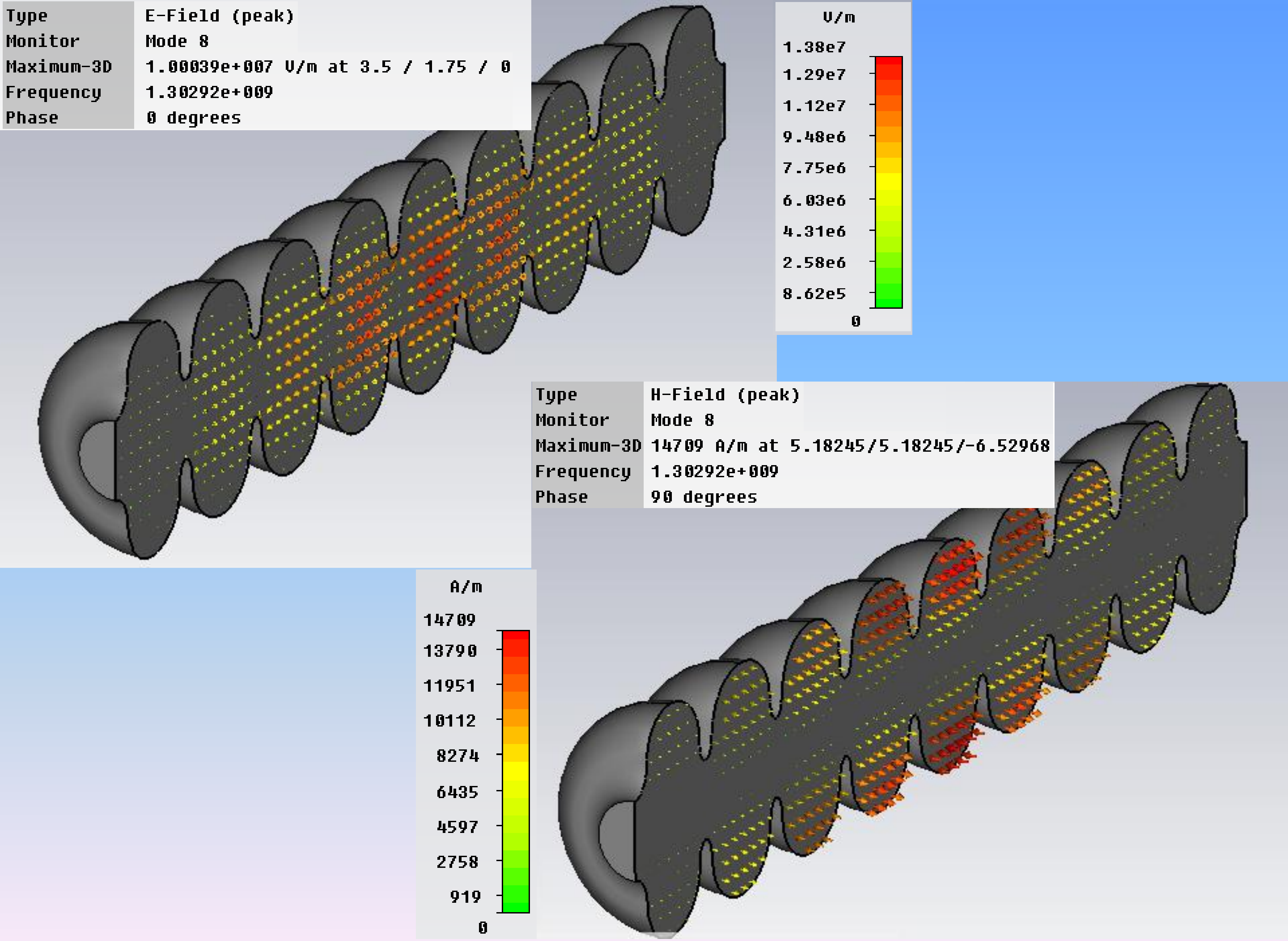
Transverse Emittance
ε π mrad mm
z m
Beam Size
σx σy mm
z m
Beam Divergence
px/pz py/pz mrad
z m
Longitudinal Emittance
εz π keV mm
z m
Bunch Length
σz mm
z m
rms Energy Spread
ΔE keV
z m
correlated Energy Spread
ΔE keV
z m
average particle energy
E MeV
z m
Particle velocity
β
z m

Main Linac Studies 9-cell cavities

Electric field distribution inside the 9-cell superconducting cavity

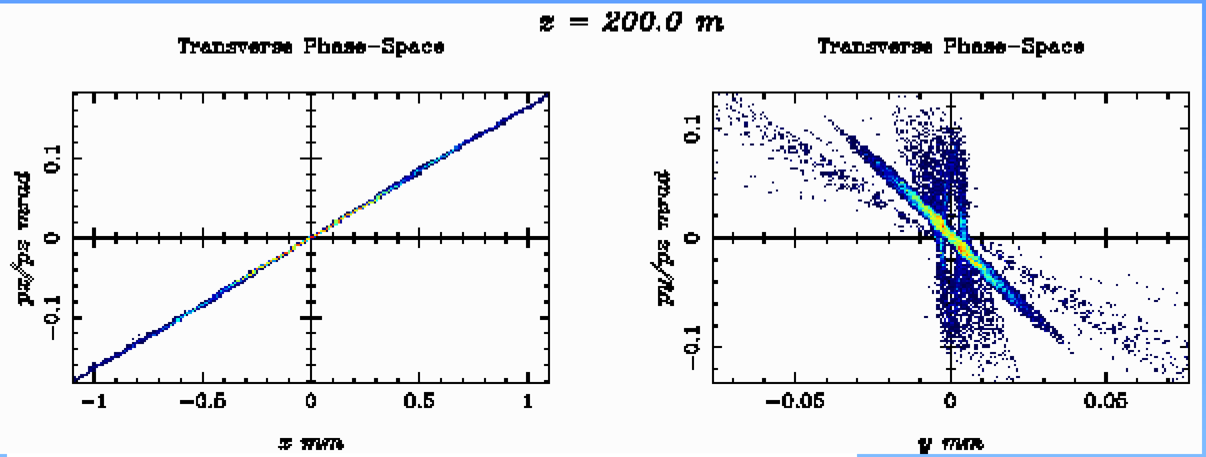


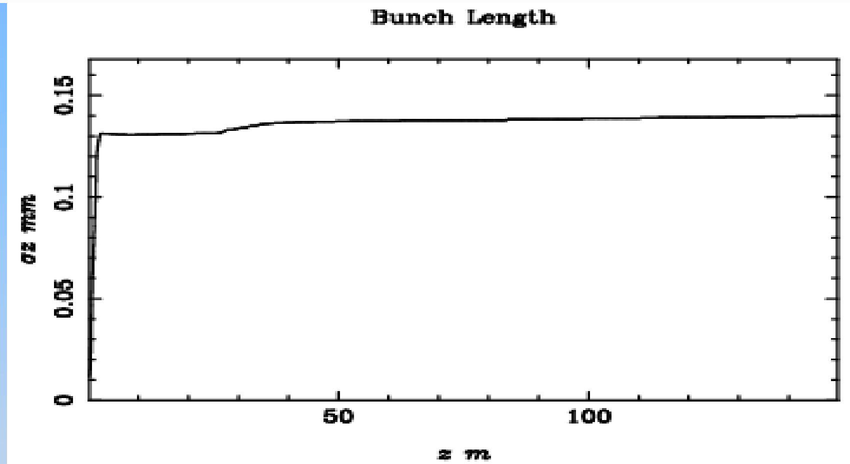


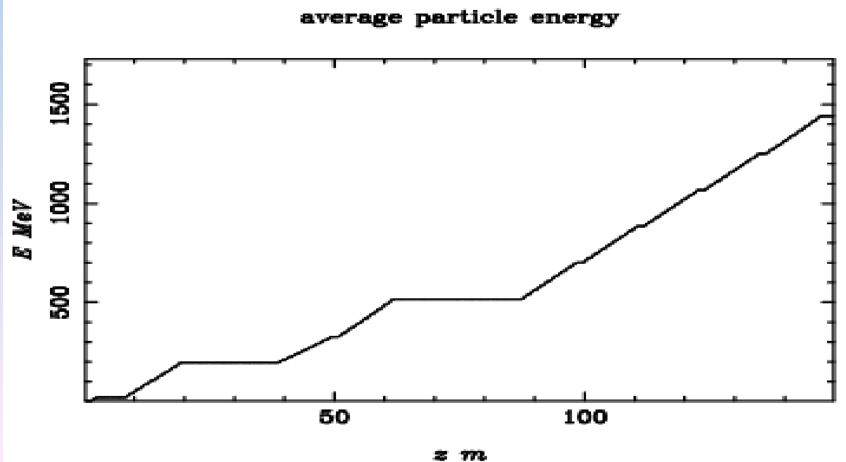


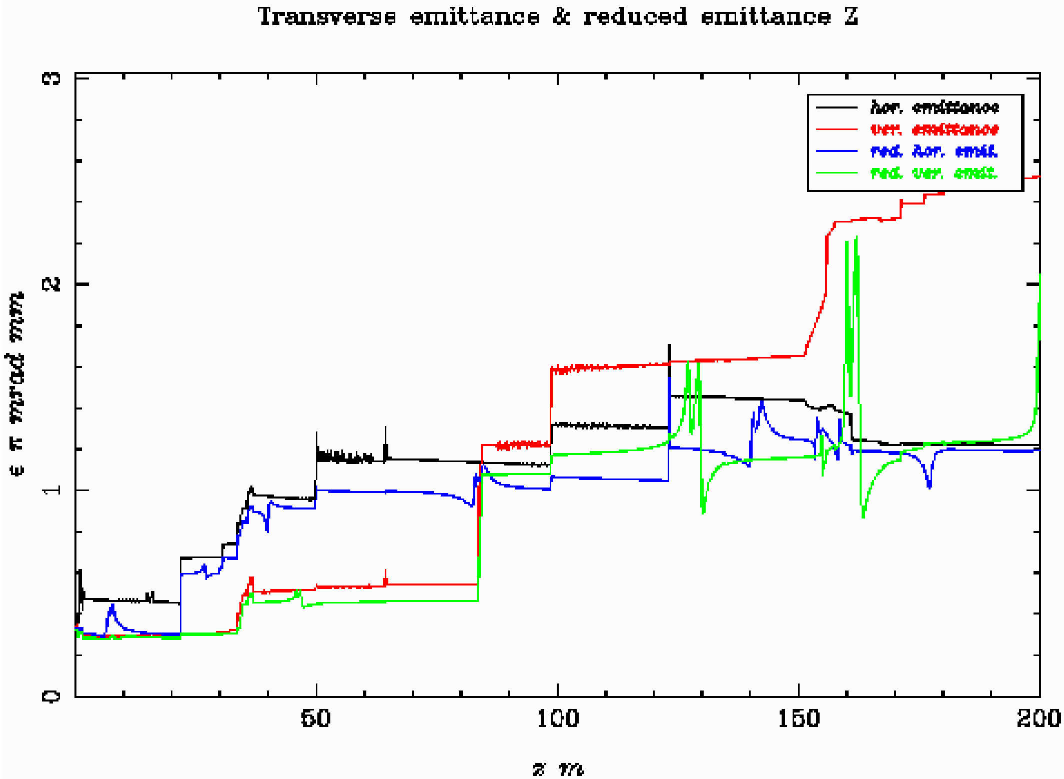
Type
E-Field (peak)
Monitor
Mode 8
Maximum-3D
1.00039e+007 V/m at 3.5 / 1.75 / 0
Frequency
1.30292e+009
Phase
0 degrees
V/m
1.38e7
1.29e7
1.12e7
9.48e6
7.75e6
6.03e6
4.31e6
2.58e6
8.62e5
0
Type
H-Field (peak)
Monitor
Mode 8
Maximum-3D
14709 A/m at 5.18245/5.18245/-6.52968
Frequency
1.30292e+009
Phase
90 degrees
A/m
14709
13790
11951
10112
8274
6435
4597
2758
919
0

After the main linac, Whole System





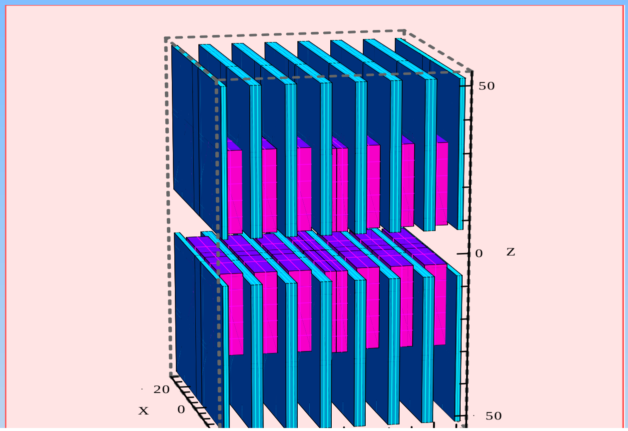


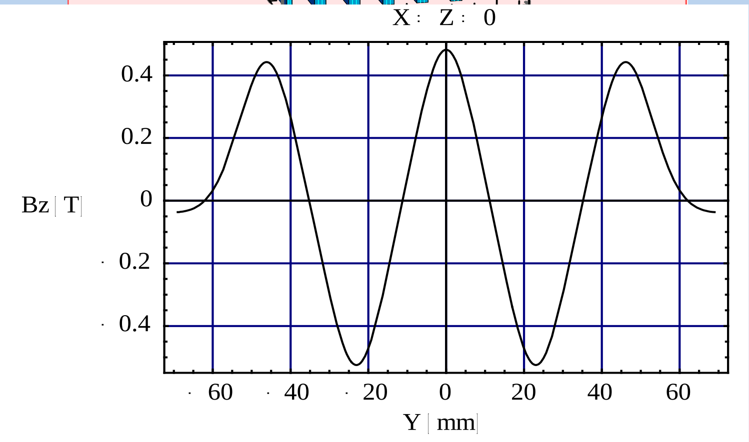


Undulator Modelling and Laser Optimisation

- Seeding ??
- In vacuum ??
- Astra file converted to elegant [3] files. Then, elegant output file is converted to Genesis beam file. In the beam file, lattice, electron beam, radiation field steps needed to determined. External magnetic field input should be supplied.

Undulator Material:





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

P. Ellaume et all.

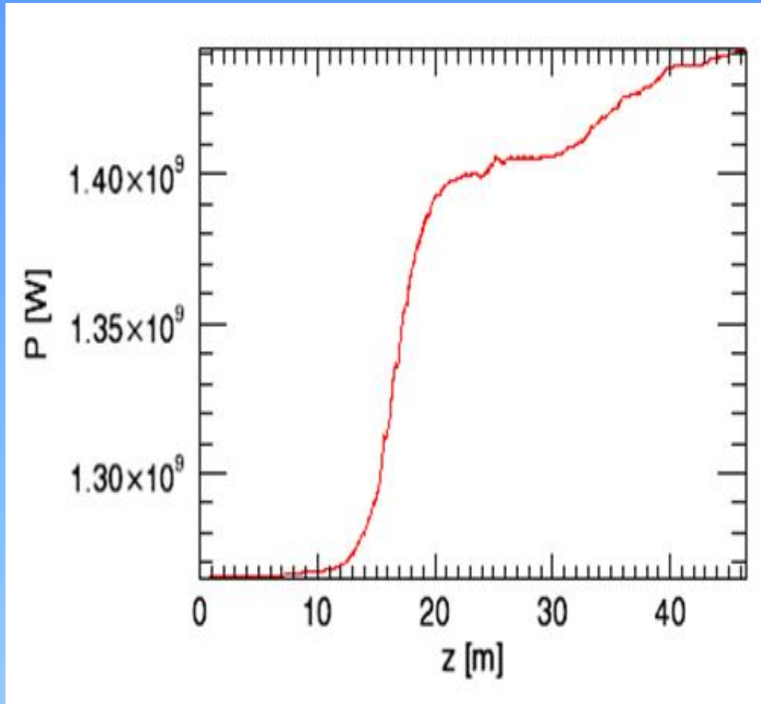
Case	Definition	a	b	c	Gap
A	PPM*, Planar, Vertical Magnetic Field	2.076	-3.24	0	$0.1 < g / \lambda_u < 1$
B	PPM*, Planar, Horizantal Magnetic Field	2.4	-5.69	1.46	$0.1 < g / \lambda_u < 1$
C	PPM*, Helical Magnetic Field	1.614	-4.67	0.62	$0.1 < g / \lambda_u < 1$
D	Hybrid with Vanadium Permendur	3.694	-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

Genesis Results:

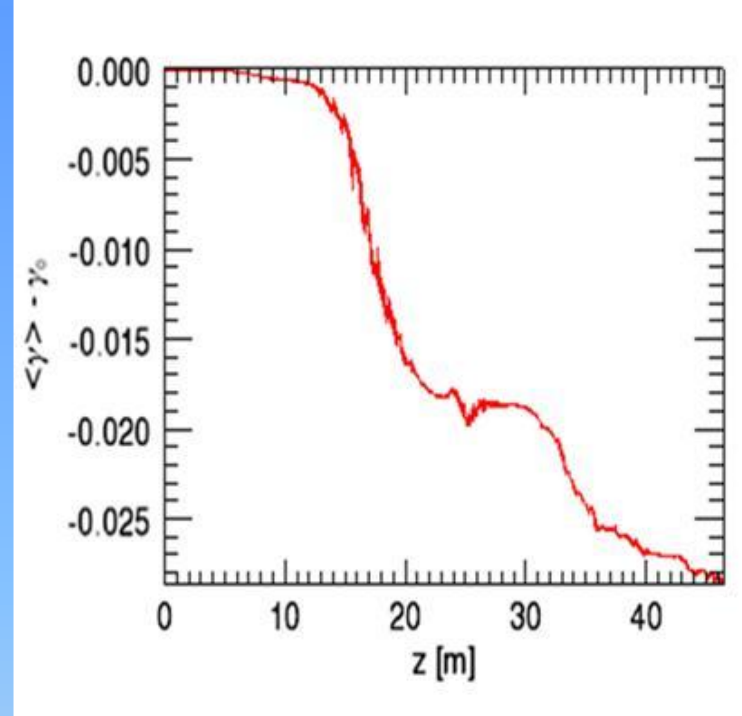
- In Genesis,
- 1.6 GeV electron beam energy is considered
- Peak current-curpeak $2x10^{3A}$
- Slice number is considered 8192, …

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

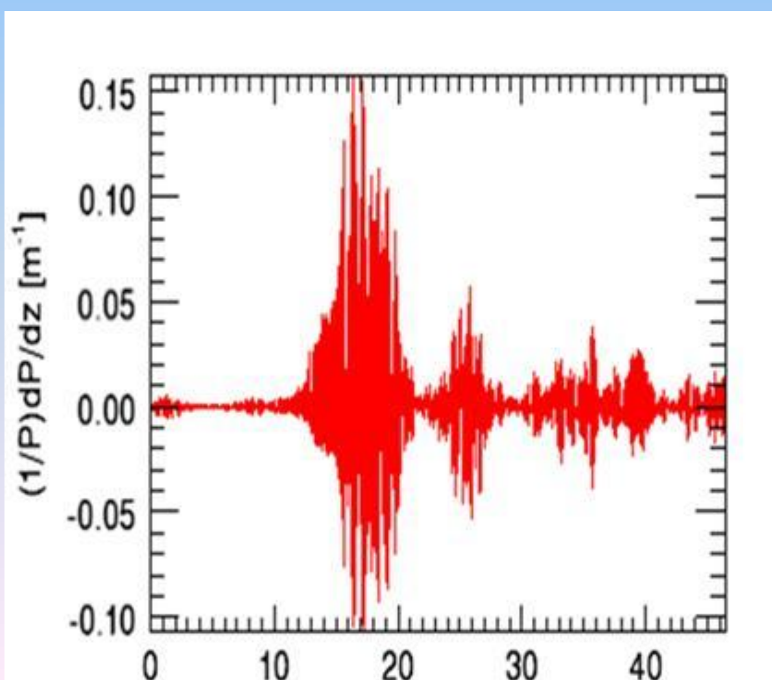
- Power is obtained around 10^9 W and
- Saturation Length is $\geq$ 21 m.



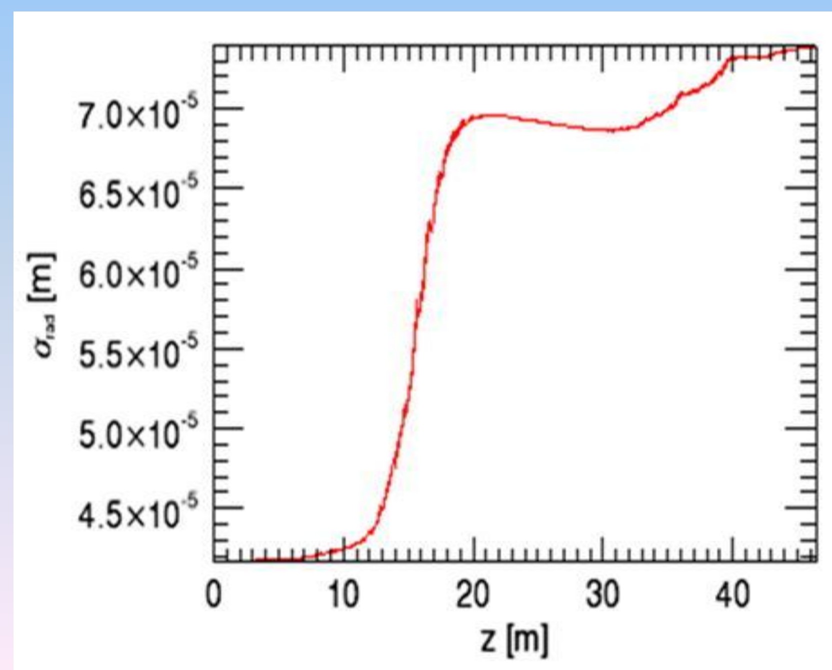
P [W]
1.40×10^9
1.35×10^9
1.30×10^9
0
10
20
30
40
z [m]



<γ> - γ₀
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
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



σ_rad [m]
7.0×10^-5
6.5×10^-5
6.0×10^-5
5.5×10^-5
5.0×10^-5
4.5×10^-5
0
10
20
30
40
z [m]

References

- http://laacg.lanl.gov/laacg/services/download_sf.phtml
- https://www.cst.com/
- CST Microwave Studio, CST GMbH, Buedinger Str. 2a, D-64289, Darmstadt, Germany, http://www.cst.com/Content/Products/MWS/Overview.aspx
- Astra—K. Flöttmann, Astra homepage, http://www.desy.de/~mpyflo
- http://genesis.web.psi.ch/ and http://pbpl.physics.ucla.edu/Computing/Code_Overview/#genesis