BEAM DYNAMICS IN THE FNAL PROTON DRIVER

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Argonne National Laboratory
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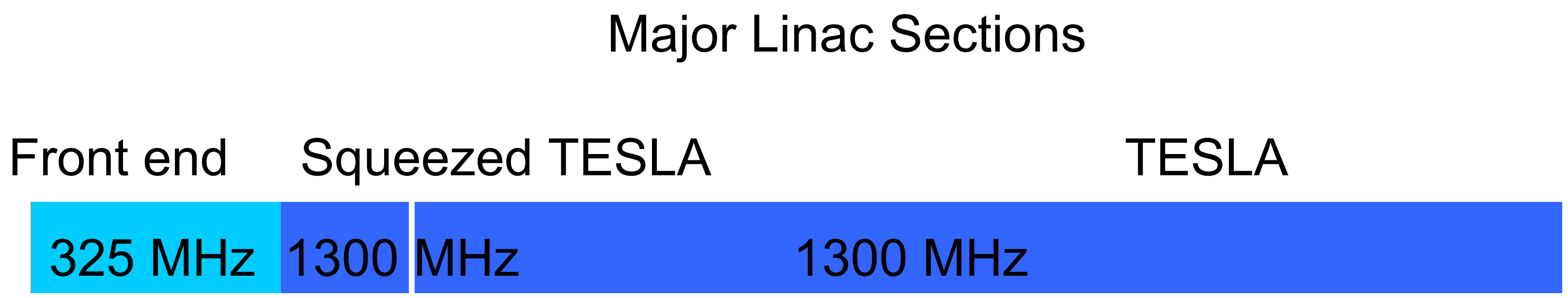
Office of Science
U.S. Department of Energy

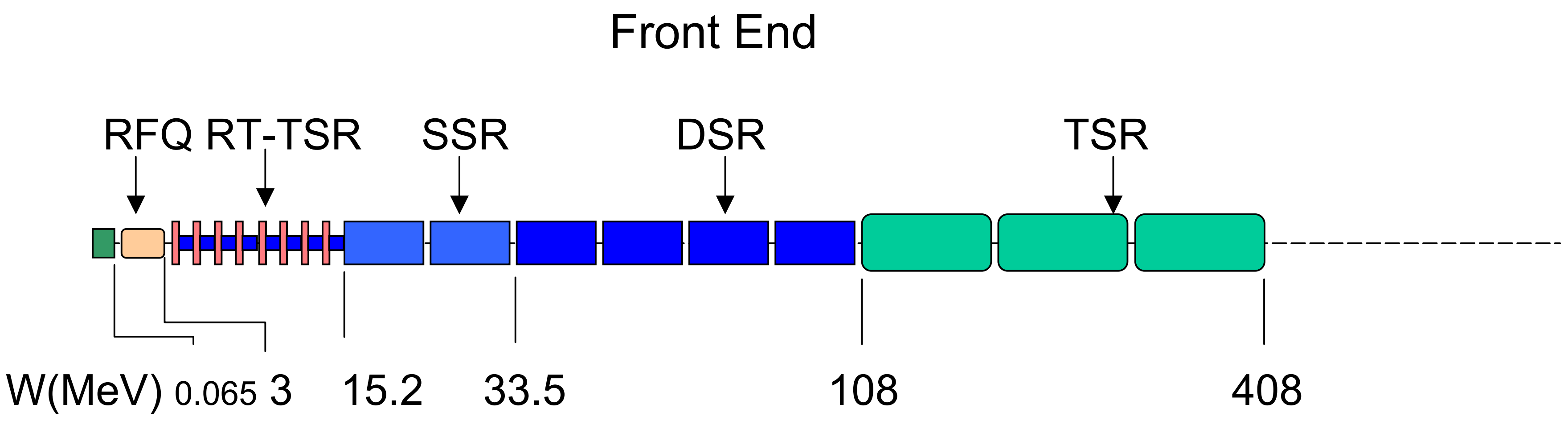
Outline

- **Lattice:**
  - Front End;
  - TESLA.
- **Preliminary analysis of the beam dynamics on the base of rms equations.**
- **Beam Dynamics Simulations.**
- **Current work.**

8-GeV linac



Major Linac Sections
Front end
Squeezed TESLA
TESLA
325 MHz
1300 MHz
1300 MHz

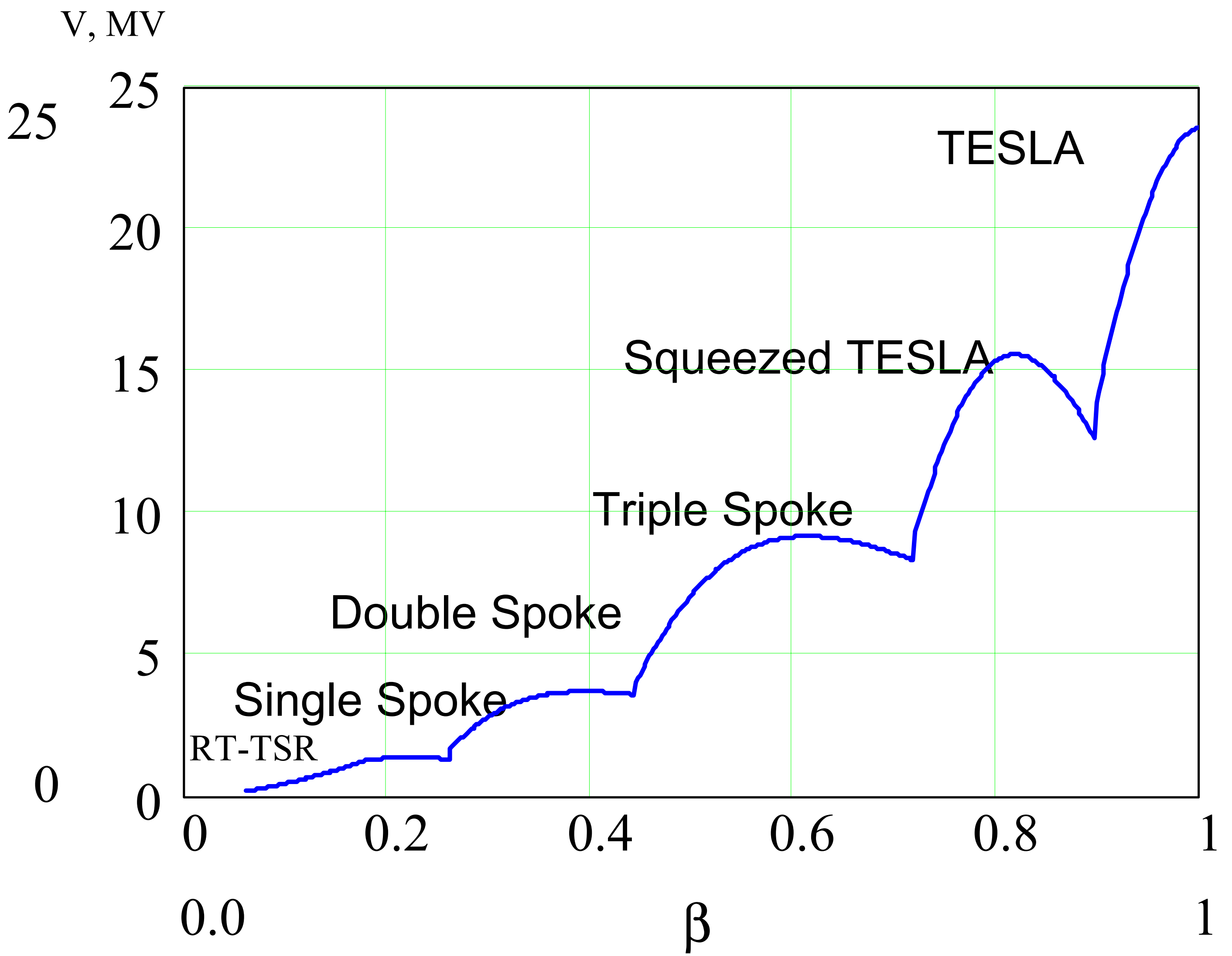


Front End
RFQ
RT-TSR
SSR
DSR
TSR
W(MeV)
0.065
3
15.2
33.5
108
408

Focusing lattice

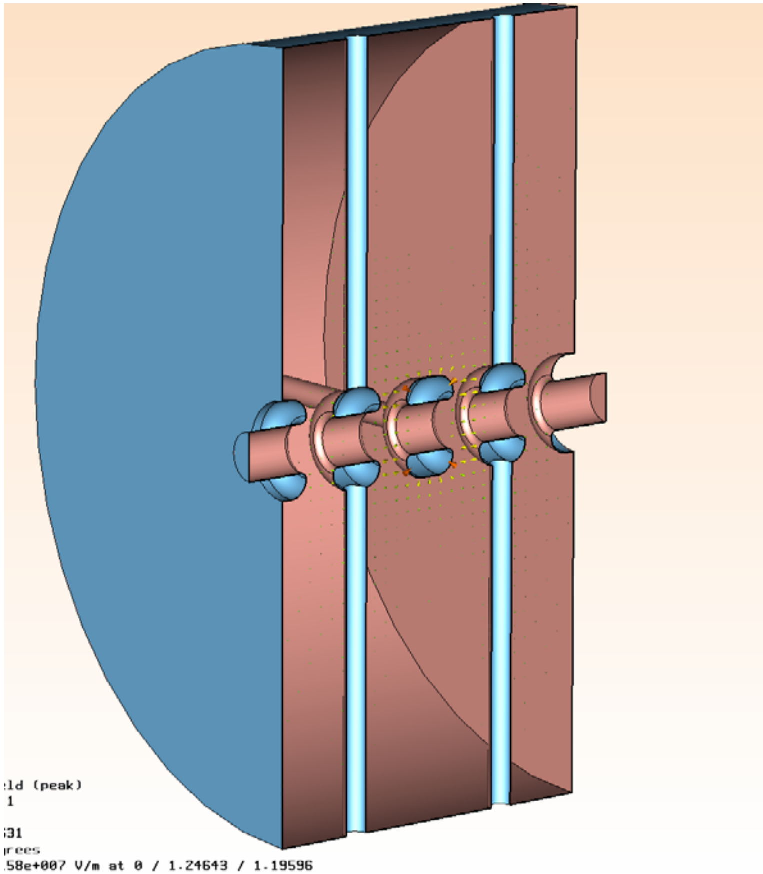
Section	Lattice	Length, m
RT-TSR	S+C S=solenoid, C=cavity	0.4-0.6
SSR	S+C	0.6
DSR	S+CC	1.435
TSR	F+C+D+C F=Fquad, D=Dquad	2.9
S-TESLA	F+CC+D+CC	6
TESLA	F+CCCCCCCC+D+CCCCCCCC	24

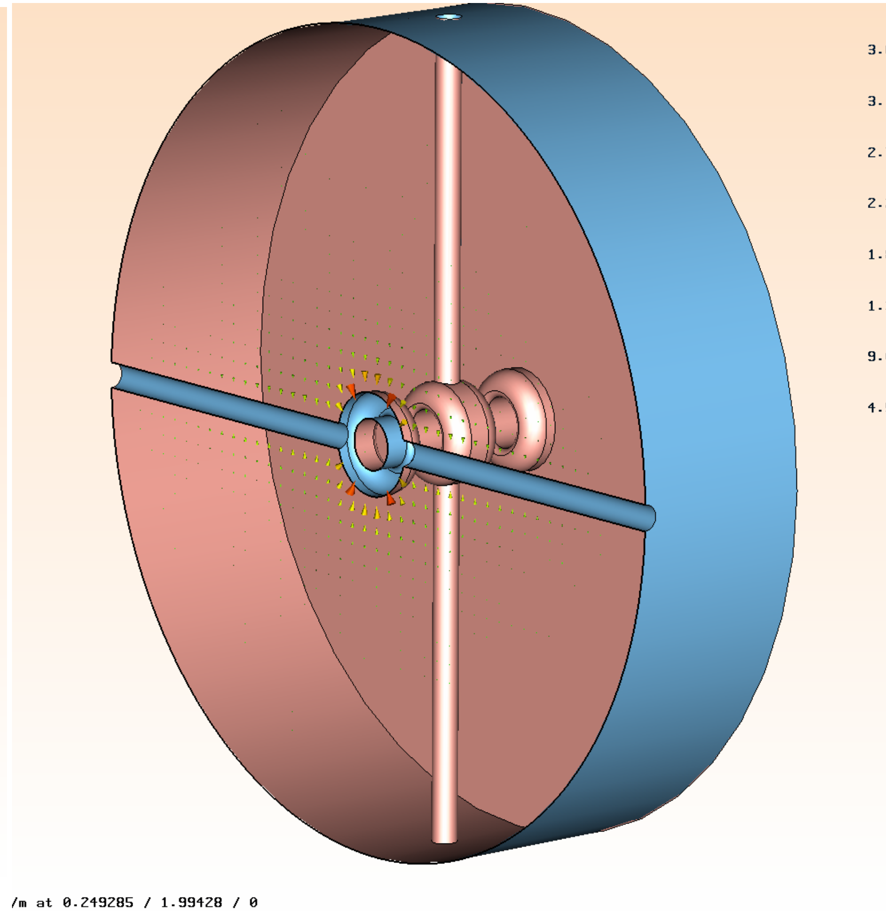
8-GeV linac



V, MV
25
25
20
15
10
5
0
0
TESLA
Squeezed TESLA
Triple Spoke
Double Spoke
Single Spoke
RT-TSR
0
0.2
0.4
0.6
0.8
1
0.0
β
1

Room Temperature TSR (Cross-bar H-type)





Shunt Impedance: 160 MΩ/m to 80 MΩ/m

Single- and double-spoke resonator

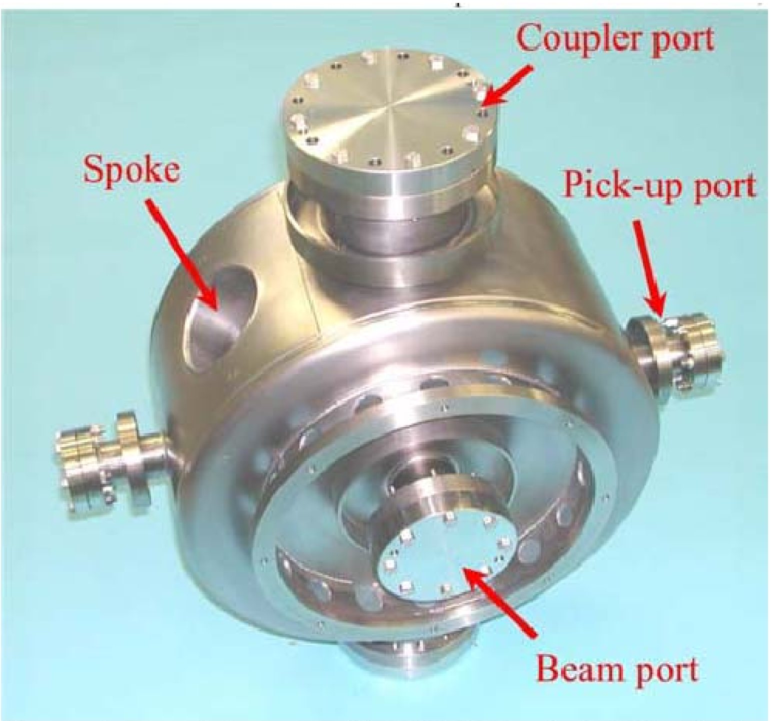


Figure 1: Los Alamos-built 350 MHz, β=0.175, single-spoke niobium cavity

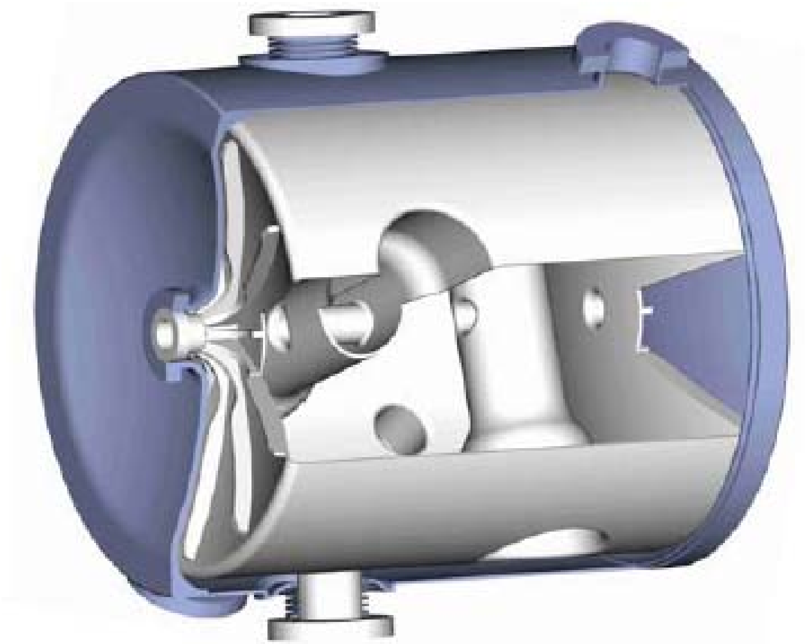


Figure 5: A 345 MHz, double-spoke, three-gap cavity for β=0.4. A niobium prototype has been built and tested at Argonne National Laboratory

Triple-spoke resonator

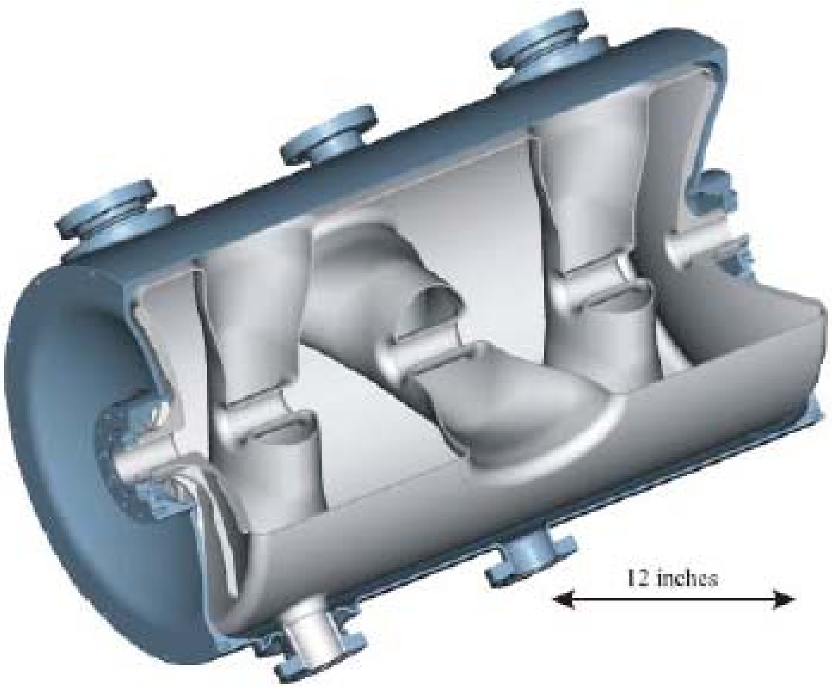
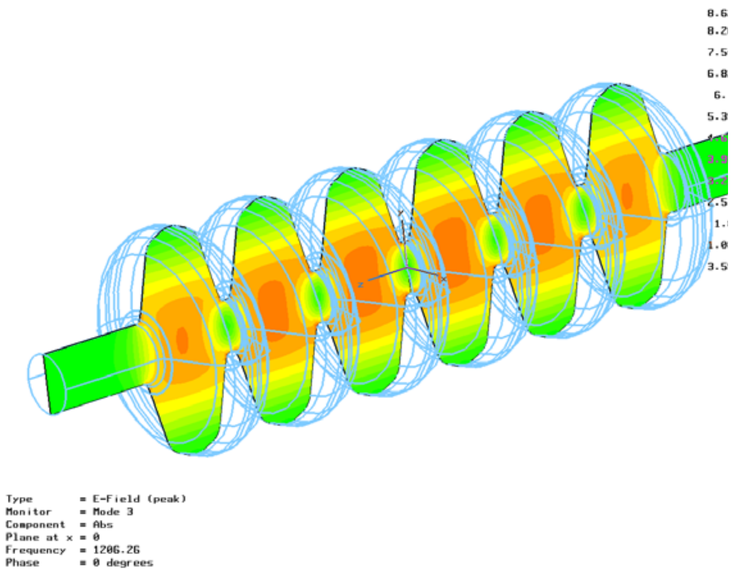
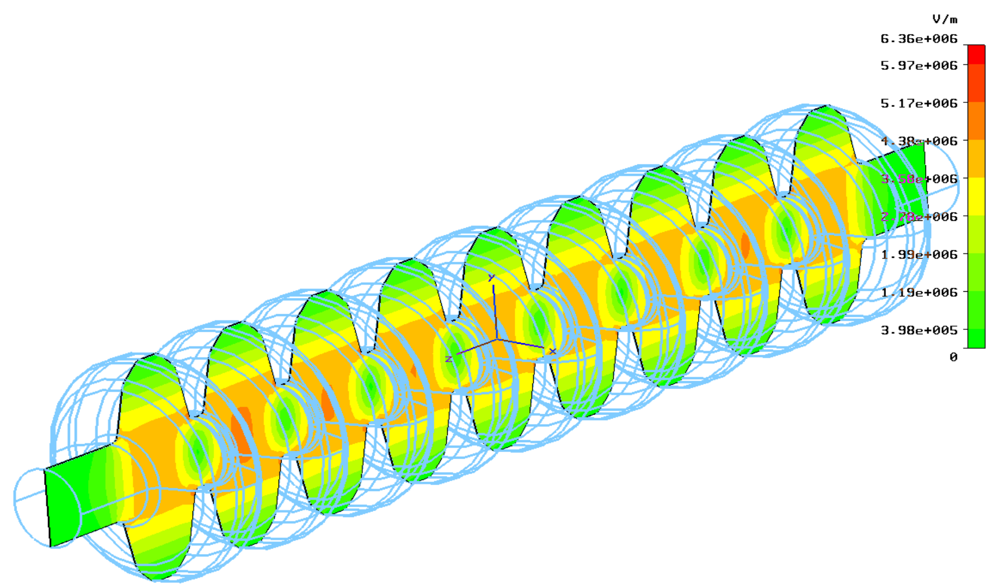


Figure 8: A 345 MHz, β=0.5 triple-spoke-loaded, four gap accelerating structure. A niobium prototype is under construction at Argonne National Laboratory.

Squeezed 6-cell (now 8-cell) and 9-cell TESLA cavities, 1300 MHz





Main parameters of the 8-GeV linac

	RT-TSR	SSR	DSR	TSR	S_TESLA	TESLA
Frequency, MHz	325	325	325	325	1300	1300
Beta geometrical	0.08-0.18	0.21	0.4	0.62	0.81	1.0
Number of cells	4	2	3	4	8	9
E_{peak}, MV/m	<20	30	30	30	45	45
E_{peak} /E_{acc}	3	3	3	3	2.15	2.0
Num. of res.	21	16	28	40	64	328
W_{out}, MeV	15.2	33.5	108	408.5	1032	8021
P_{beam}(I=26 mA), kW	27	30.5	84	221	337	588

Total number of klystrons ?
Total number of cavities (325 MHz) 84 + 21 RT-TSR
Total number of cavities (1300MHz) 392

Beam physics design

- **"Current independent" lattice**
  - Smooth k_{T0} and k_{L0} – avoid 'jumps' in the transition, very important in the SC linac
  - Avoid obvious resonances, such as $\sigma_{T0} = 90°$ and $\sigma_{L0} = \sigma_{T0}$; $\sigma_{L0} = 2\sigma_{T0}$; $\sigma_L = \sigma_T$; $\sigma_L = 2\sigma_T$
- **Front End**
  - At beam energy 3 MeV the length of the focusing period should be minimized: SC solenoids provide shortest focusing period;
  - No need in SC resonators up to ~15 MeV;
  - Frequency transition: at ~400 MeV
- **Space charge and higher order internal resonances**
  - Parameters should be close to equpartitioning;
  - Watch for higher order resonances
  - Final verification by multi-particle simualtions

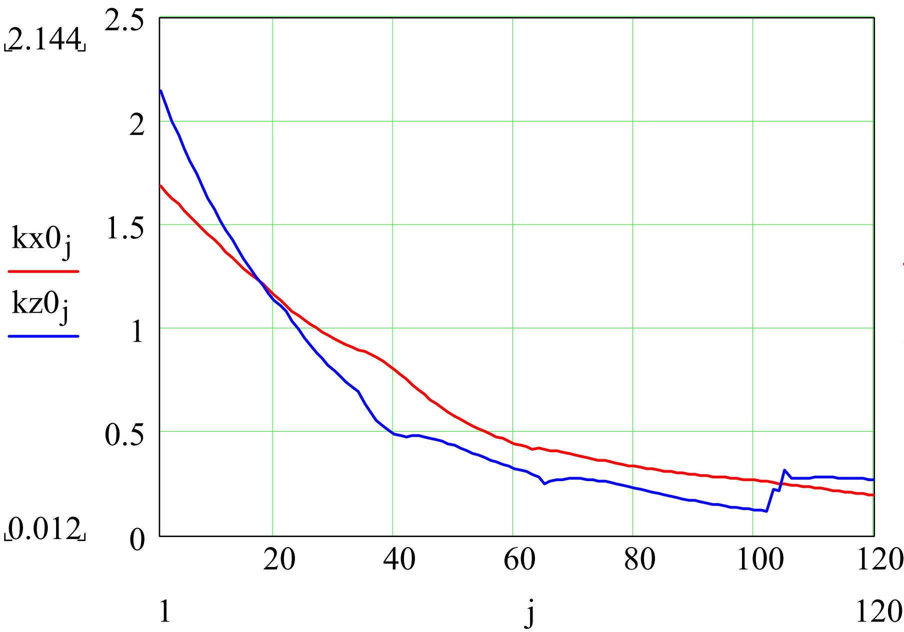
Beam physics design (cont'd)

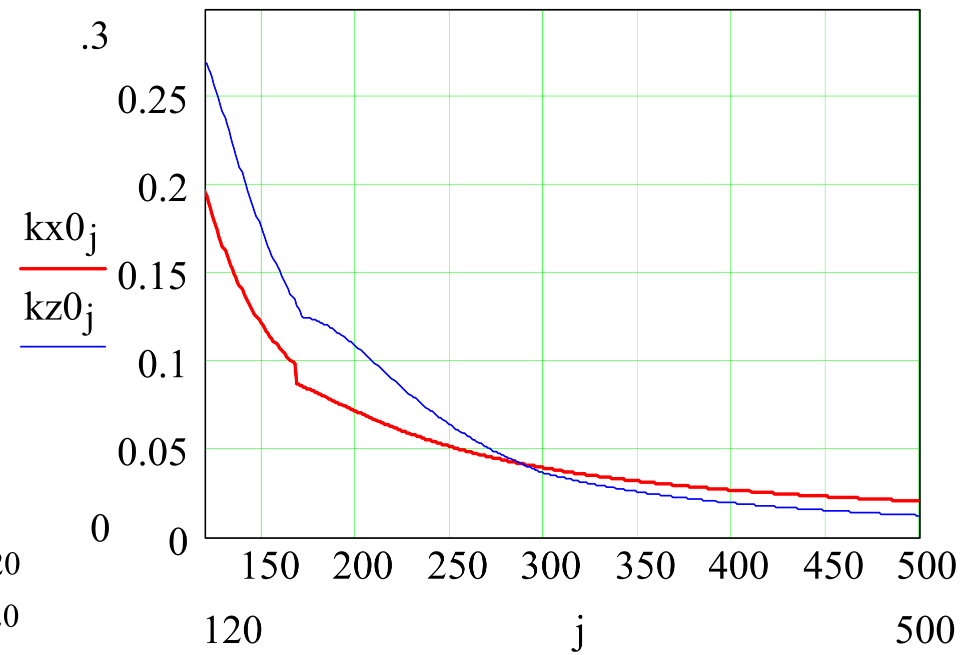
- SC solenoids: good up to ~100 MeV, limitation: H-minus stripping in the fringe field;
- ~100 MeV – transition to TSR and quadrupole FODO structure;
- Longitudinal matching in the transition from 325 to 1300 MHz

$$k_{z0} = \sqrt{\frac{2\pi \sin\varphi_s e E_0}{\lambda m_0 c^2 (\beta\gamma)^3}}$$

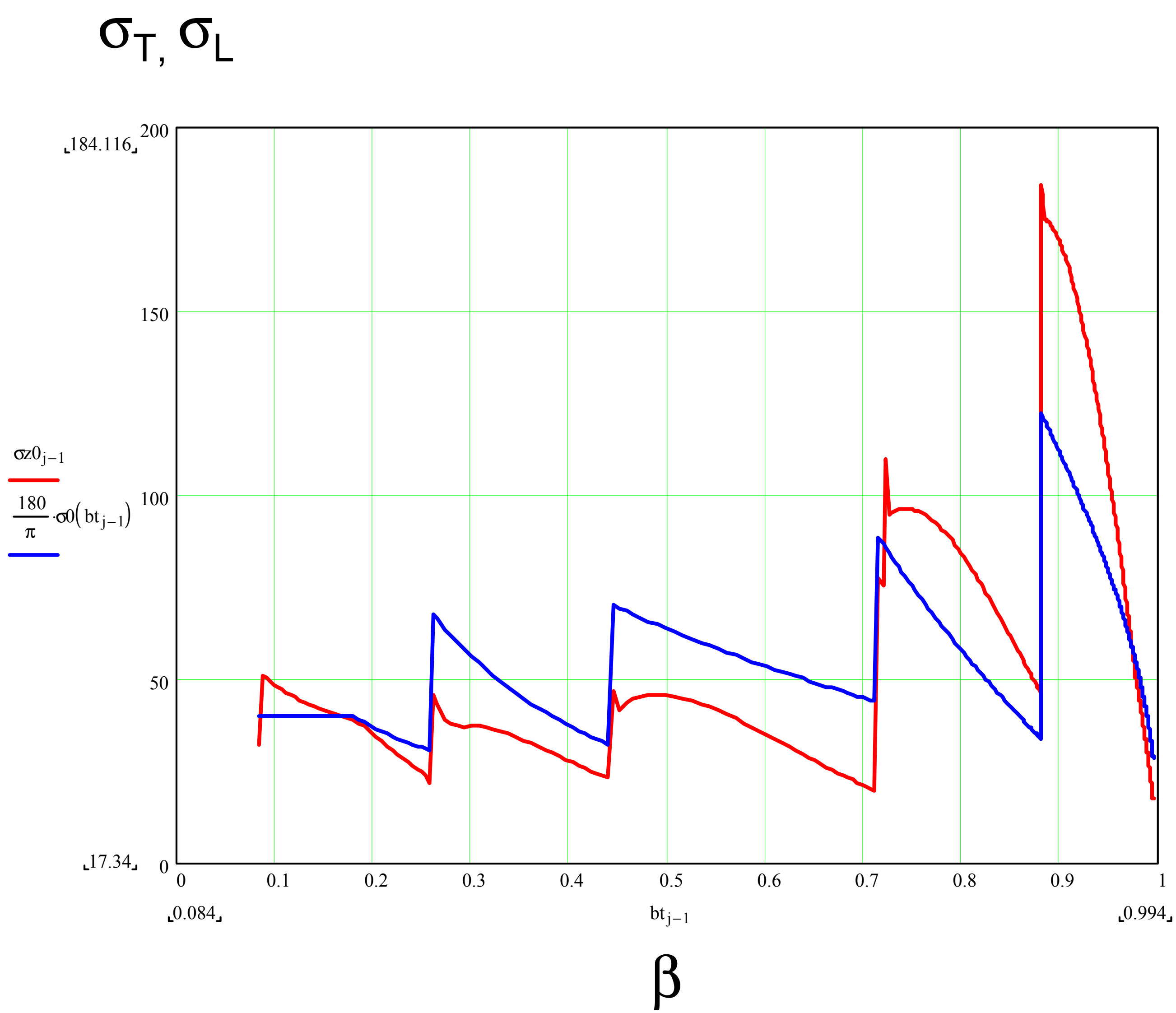
- High-energy section: avoid H-minus stripping. There are resonance crossings – should be studied by simulations.

RMS analysis: wavenumebrs of T- and L-oscillations



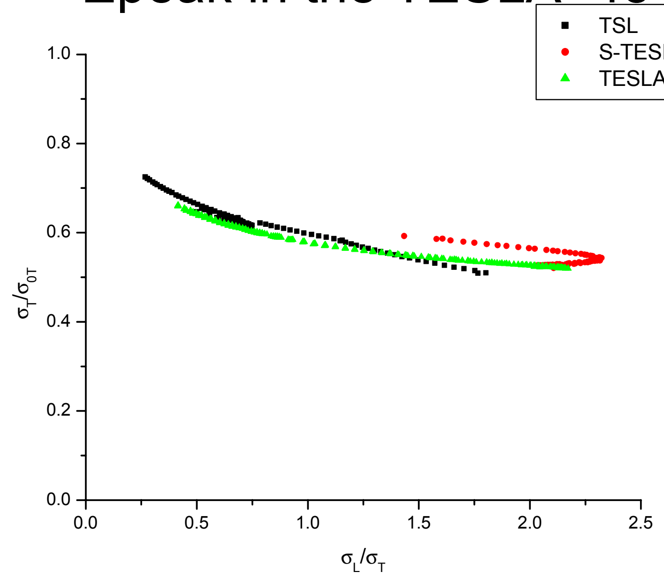


RMS analysis: Phase advance

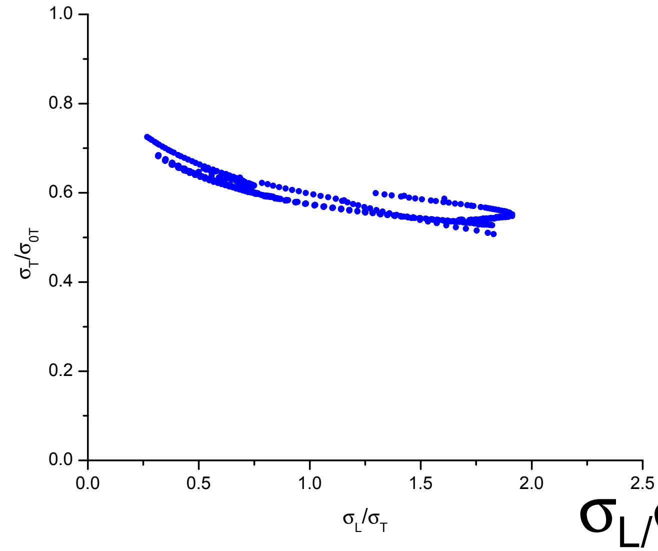


Tunes on Hofmann's Chart

Epeak in the TESLA=45 MV/m

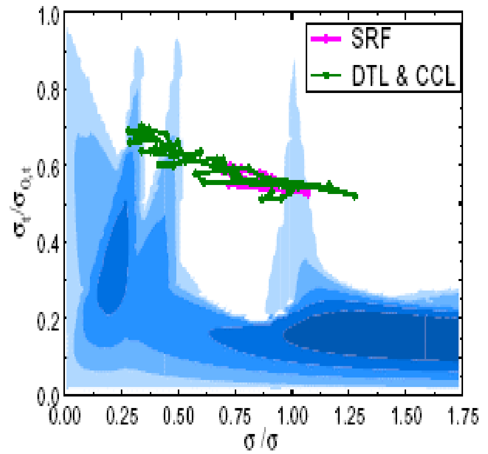


35 MV/m



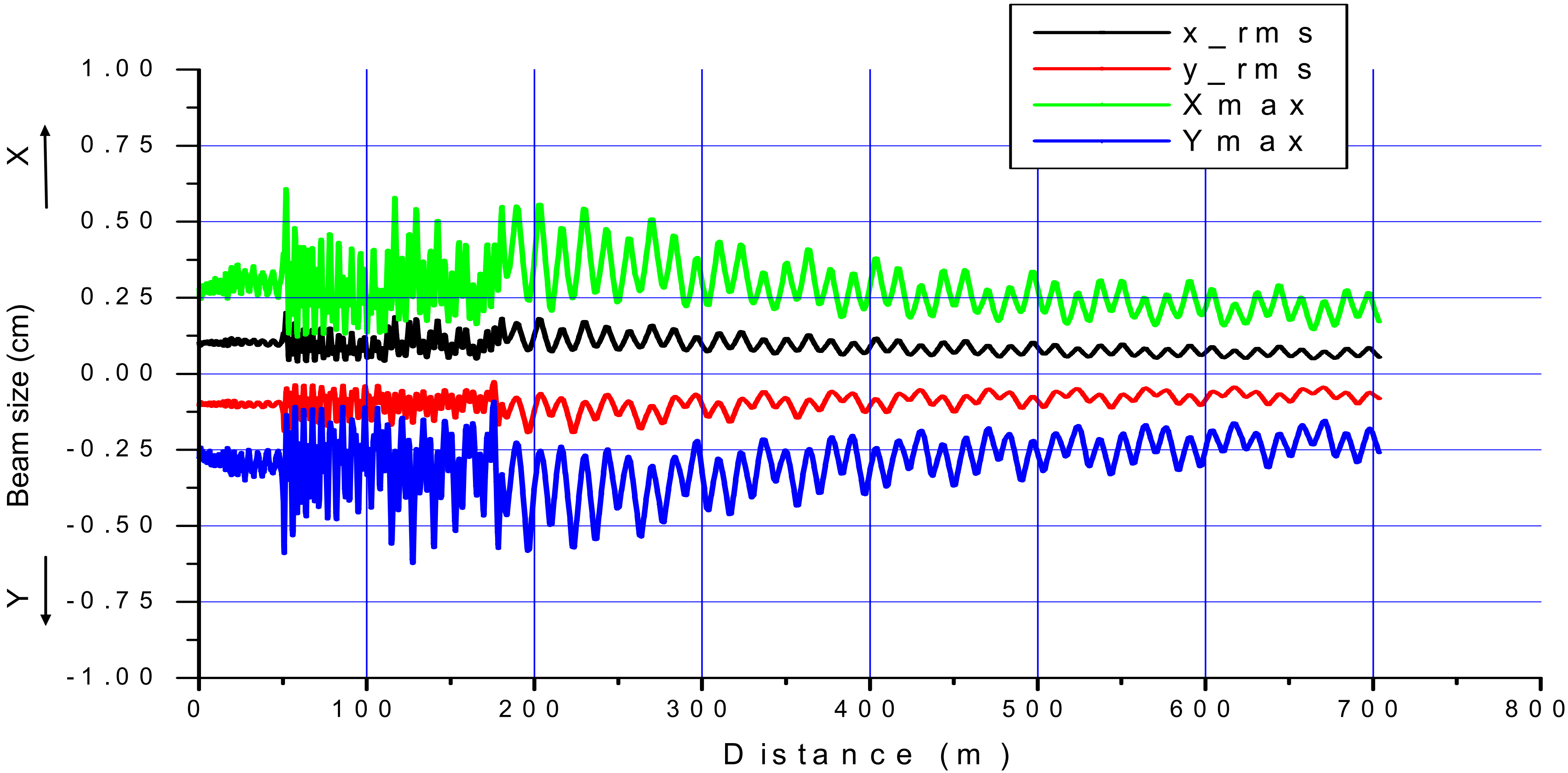
σ_L/σ_T

SNS 2-MW beam tunes

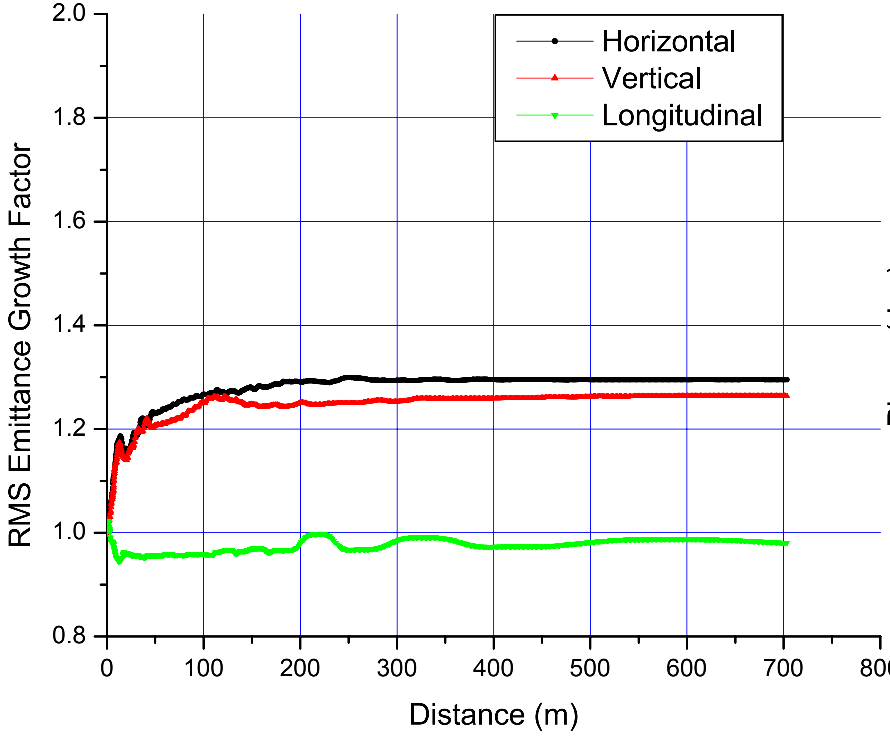


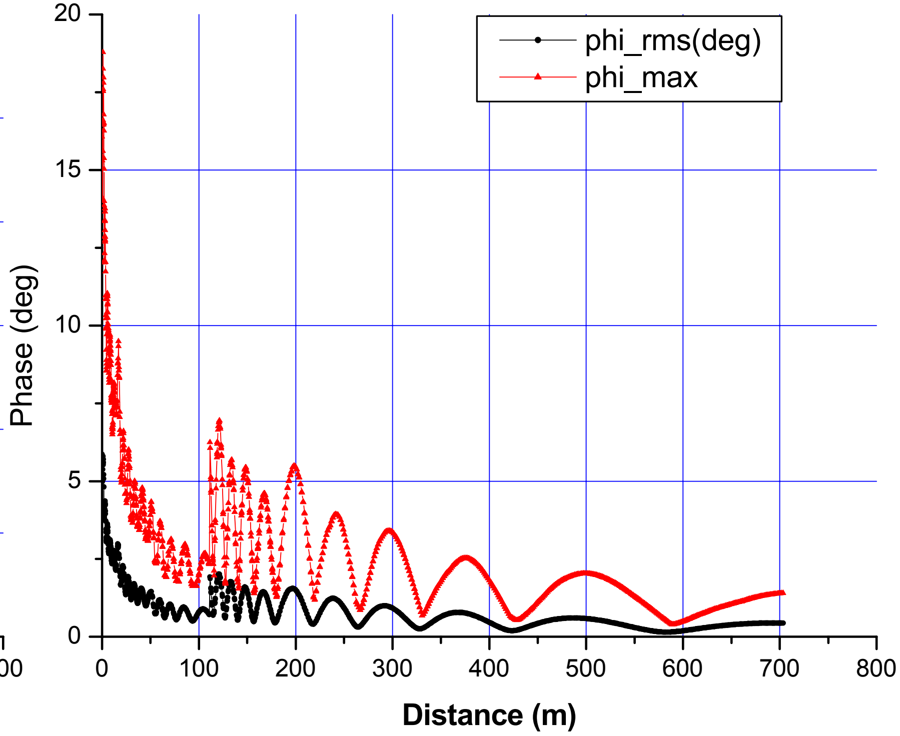
Beam envelope, rms and total (Iteration #1)

Simulation of $5 \cdot 10^4$ particles

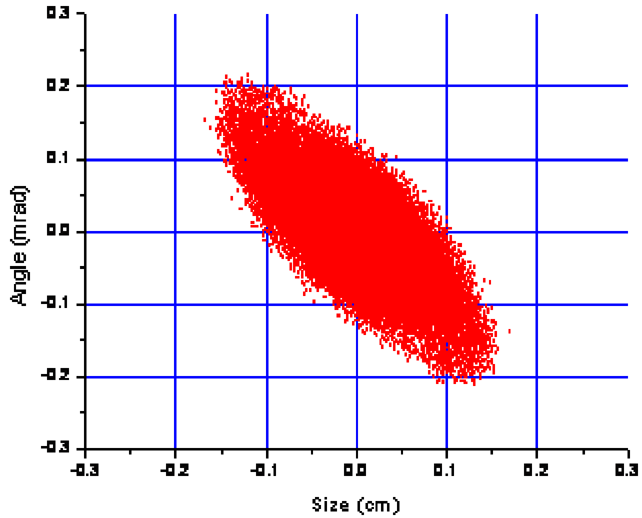


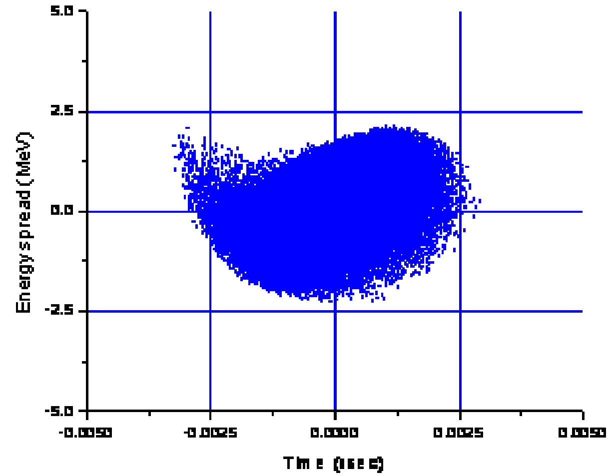
Emittance and phase width evolution (iteration #1)

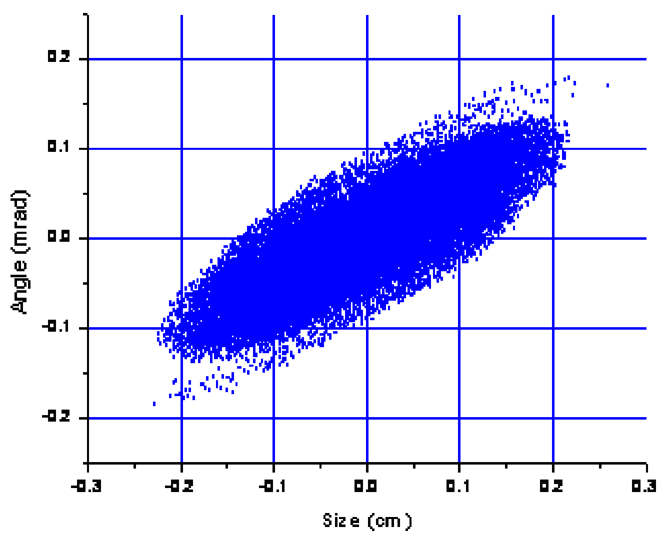




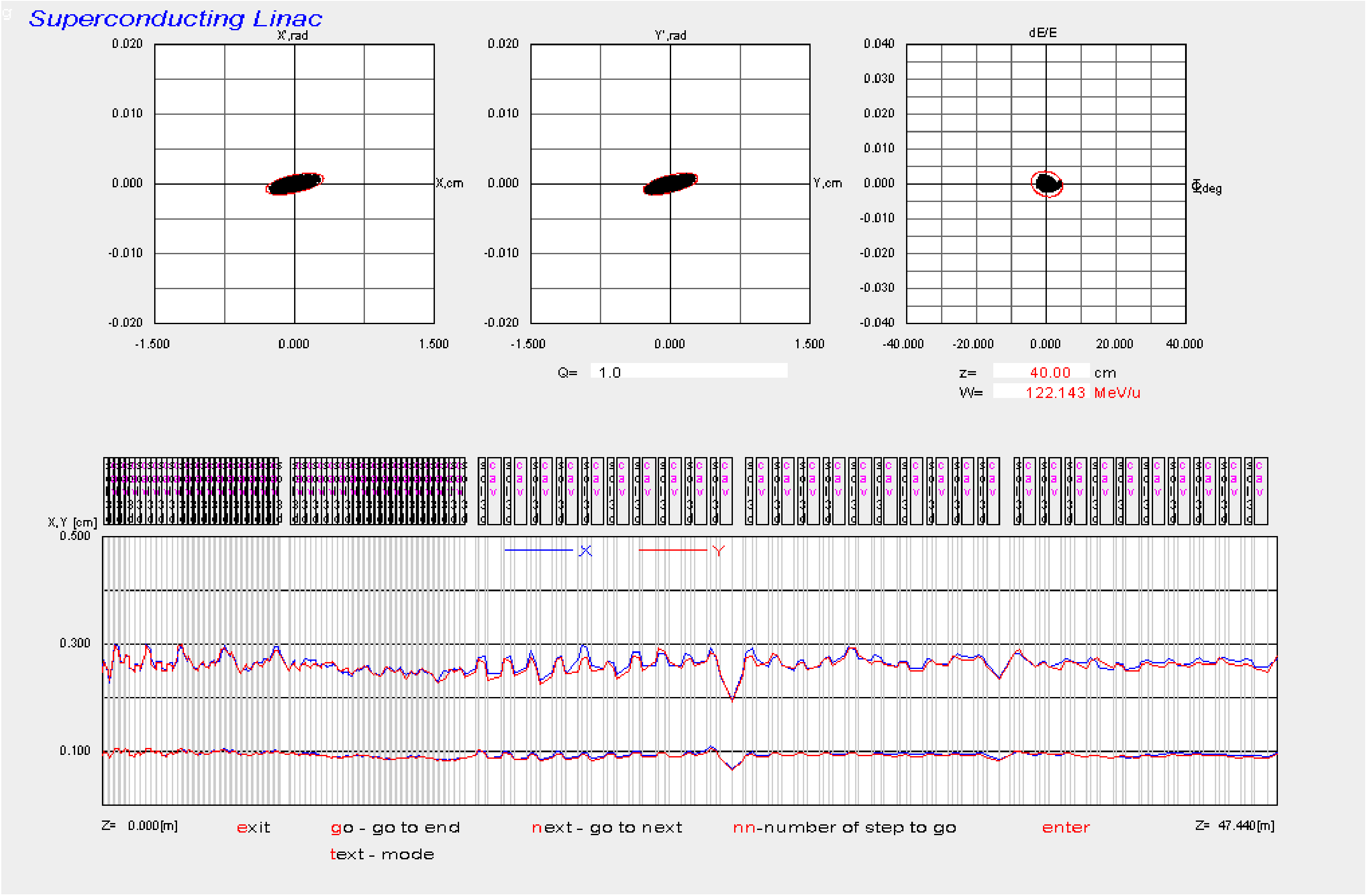
Phase space plots, 8 GeV (iteration #1)







Iteration #2, Front end



Conclusion

- **Iteration #1 does not show any significant problem in beam dynamics;**
- **We are in the process of the iteration #2**
  - RMS analysis is being completed;
  - 3D accelerating fields are being calculated in all resonators;
  - Smooth transition should be developed for 325 MHz to 1.3 GHz sections.
- **Study of high-order resonances with the tracking code;**
- **Finalizing of the lattice.**