RF gun based on new type accelerating structure

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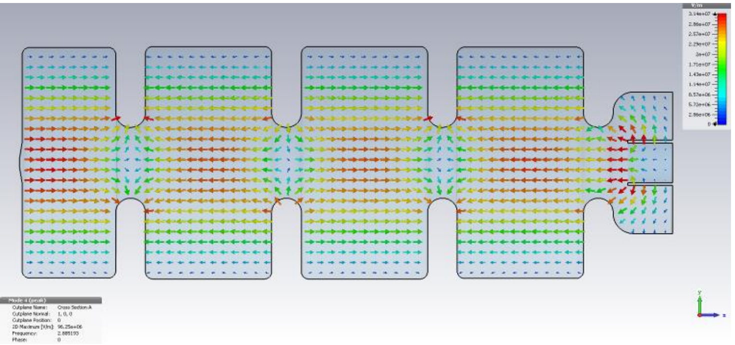
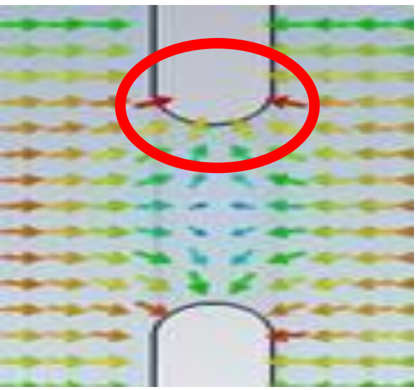
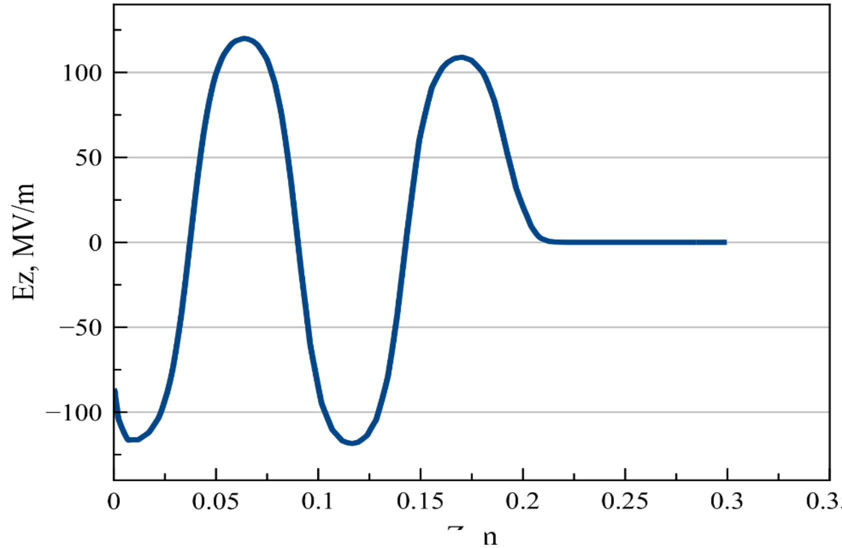
Outline

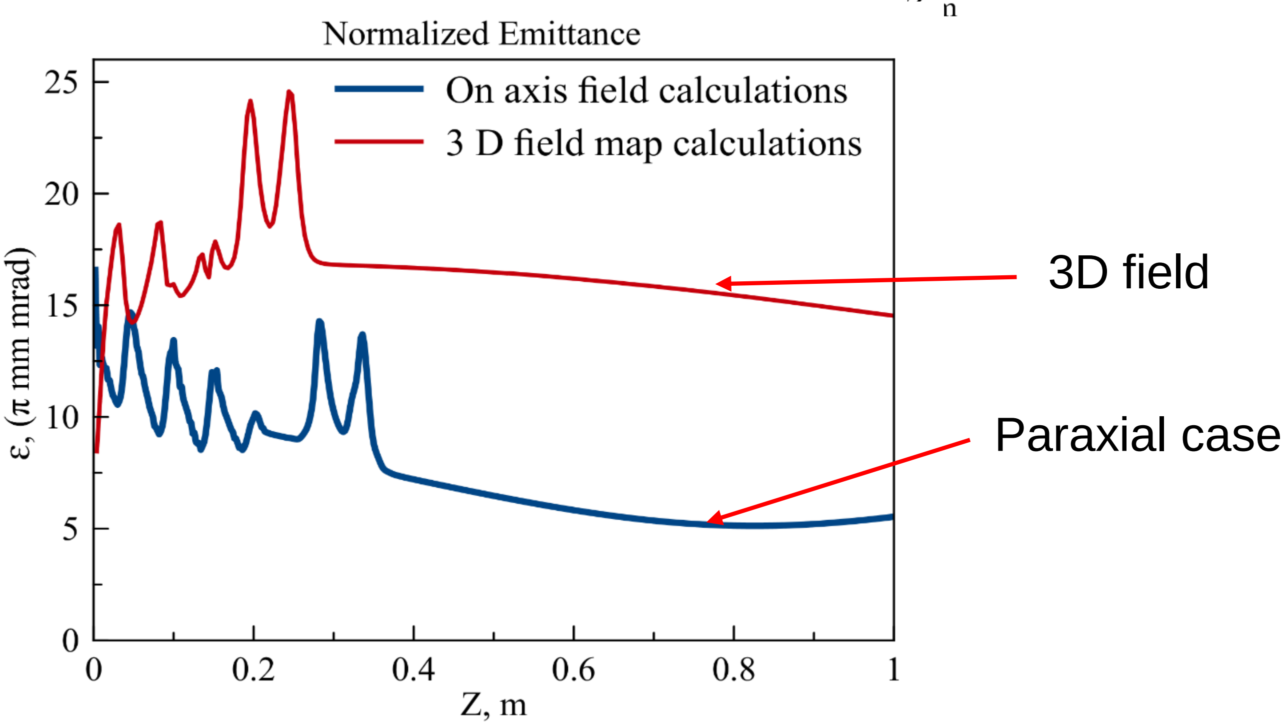
- Last simulations
- Emittance analytical estimations
- New ideas
- Injector SKEKB
- New design
- ASTRA and CST simulation of RF gun
- Comparison with previous simulations
- Beam dynamics
- Conclusions

Previous simulation based on usual RF gun design









Analytical emittance predictions

Emittance-generating factors:

$$\epsilon_{n,rf} = \frac{eE_{rf}}{2mc^2}\sigma_x{}^2\sigma_\phi\sqrt{cos^2\phi_e + \frac{\sigma_\phi{}^2}{2}sin^2\phi_e}$$

ϕ_e - Bunch rf phase at the gun exit

σ_ϕ - Rms bunch length in radians

σ_x - Rms bunch size

$$\epsilon_{n,chromatic} = \sigma_{x,sol}{}^2\frac{\sigma_p}{mc}K|\sin KL + KL\cos KL|$$

$K \equiv \frac{eB(0)}{2p} = \frac{B(0)}{2(B\rho)_0}$

L - Effective length of solenoid

$(B\rho)_0 = 33.356\,p\left(\frac{GeV}{c}\right)kG\cdot m$ - Magnetic rigidity

$B(0)$ - Peak field of the solenoid

$$\epsilon_{n,geometric} = 0.0046\left(\frac{microns}{mm^4}\right)\sigma_{x,sol}{}^4(mm)$$

$$\varepsilon_{n,photo} = \sigma_x\sqrt{\frac{\hbar\omega - \phi_{eff}}{3mc^2}}$$

$$\varepsilon_{n,s} = \frac{\pi}{4}\frac{1}{\alpha k}\frac{1}{\sin\varphi_0}\frac{I}{I_A}\mu_i(A)$$

α - Dimensionless rf strength

I - Peak current

I_A - Alfven current

$\mu_i(A)$ - Fields form factors

$A = \frac{\sigma_x}{\sigma_x}$ - Aspect ratio

Analytical emittance predictions

$$\varepsilon_{total} \sim \sqrt{\varepsilon_{photo}{}^{2} + \varepsilon_{n,sc}{}^{2} + \varepsilon_{n,rf}{}^{2} + \varepsilon_{n,chromatic}{}^{2} + \varepsilon_{n,geometric}{}^{2}}$$

$$\varepsilon_{total} \sim 5.18\, mm mrad$$

Main previous conclusions

1. Nonlinear electric field components significantly influence on the emittance
2. Difference between simulation with the 3D fields and the paraxial case is about 3 times

How to make gun in order to work with paraxial dynamics

1.Beam size has to be as small as possible
2.Nonlinear field components have to be decreased

In what case the beam size and nonlinear components can be decreased?

1. Beam size can be decreased in the strong solenoidal magnetic field
2. Nonlinear field components are zero in the cavity without travelling tubes (ideal cylindrical cavity)

Hereby

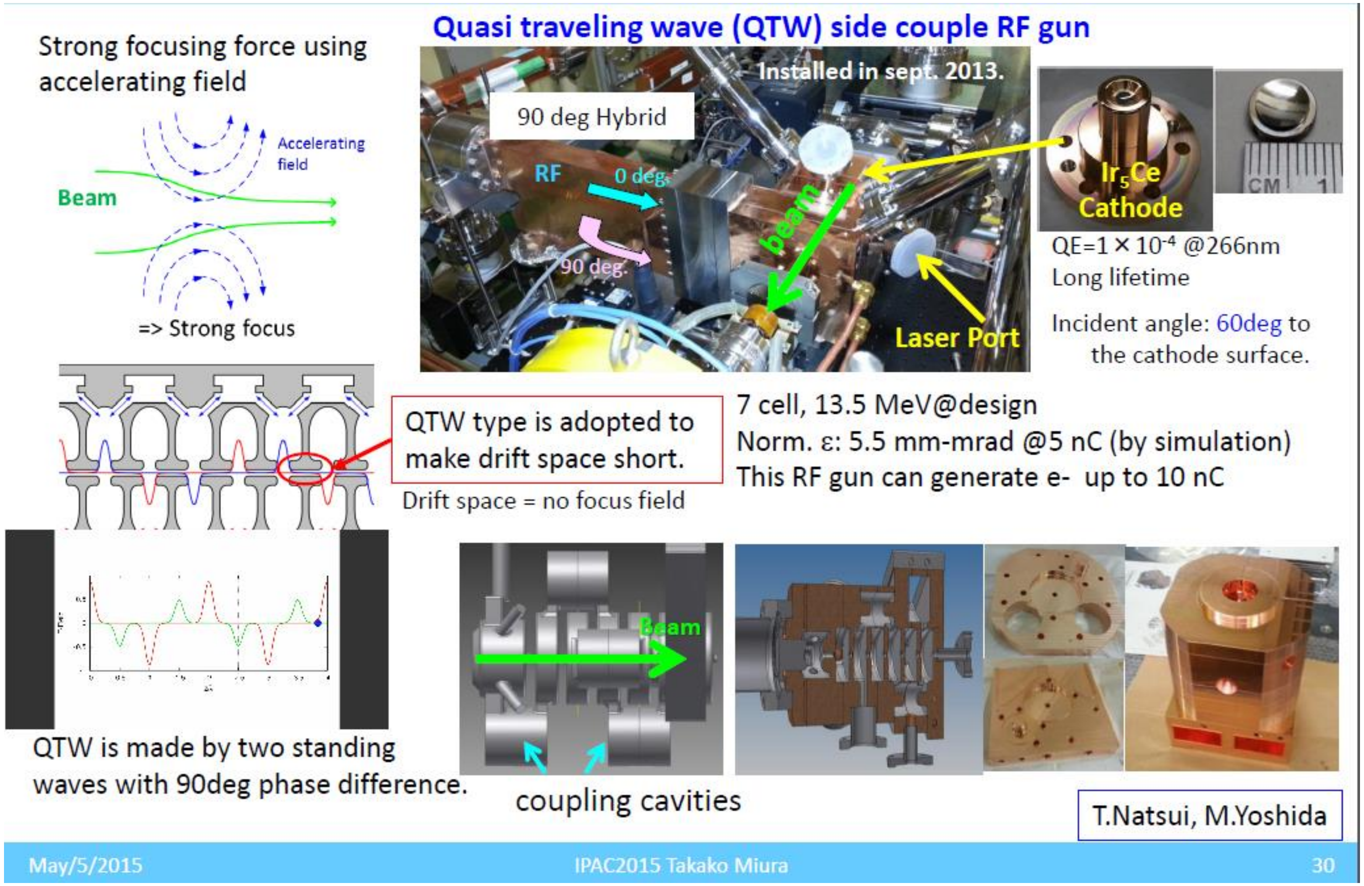
1. We need the focusing magnetic field along the cavities or/with strong RF focusing
2. We need very small aperture for the travelling tubes

But

1. Aperture of RF gun based on the disk loaded waveguide depends on the oscillation mode
2. Magnetic field along the cavities in the basis with the focusing solenoid leads to magnetic field on the cathode and additional cavities heating

Possible solutions

RF gun based on the structure with external coupling cavities:
SuperKEKB design



Advantages:

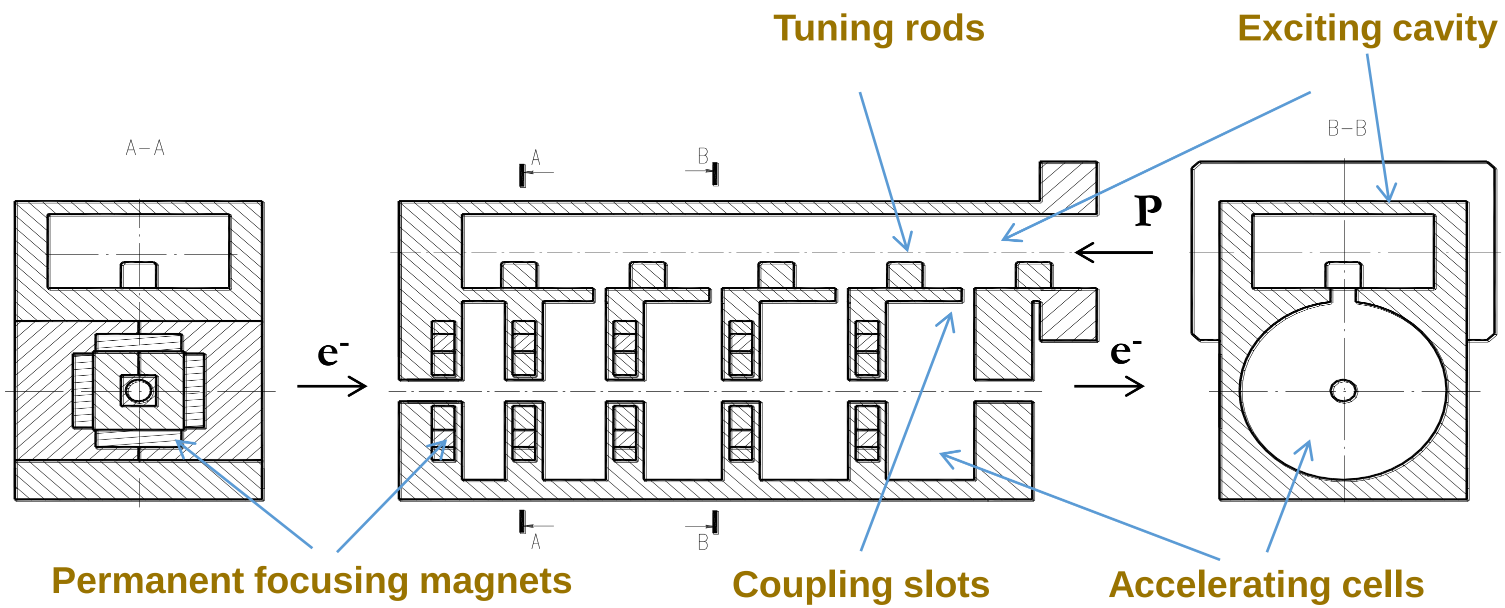
1. Small apertures
2. π mode
3. Strong focusing RF forces

Disadvantages:

1. Complex design
2. Impossible using of the magnetic fields along the cavities
3. Nonlinear components from the fields due to relatively large coupling slots

Possible solutions

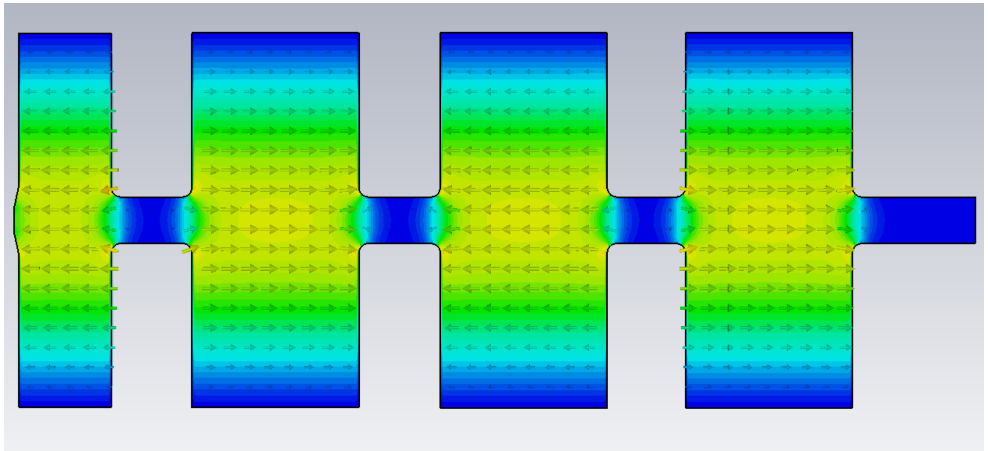
RF gun based on the parallel coupled accelerating structure

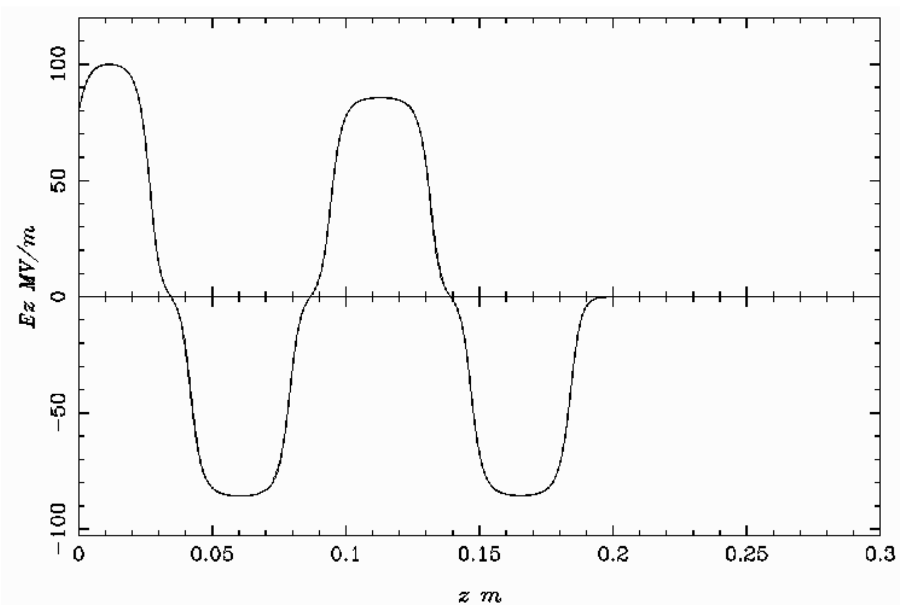


Features:

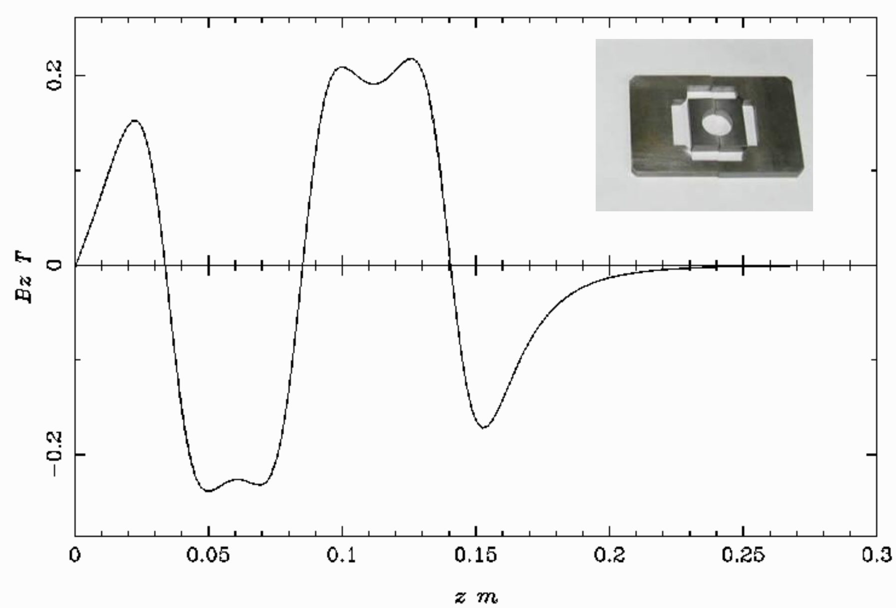
1) Parallel RF power feeding.
2) Cavities are not connected with each other by RF power: process in one cavity doesn't influence on every cavities
3) Organization of the free electric field distribution along the structure can be obtained by changing the individual coupling slot
4) In order to develop accelerating structure only one accelerating cells have to be calculated due to absence of the cavities connection by electromagnetic field
5) Aperture of the structure is defined by only beam motion and can be considerably reduced
6) Design of the structure allows using internal permanent focusing magnets.

Fields



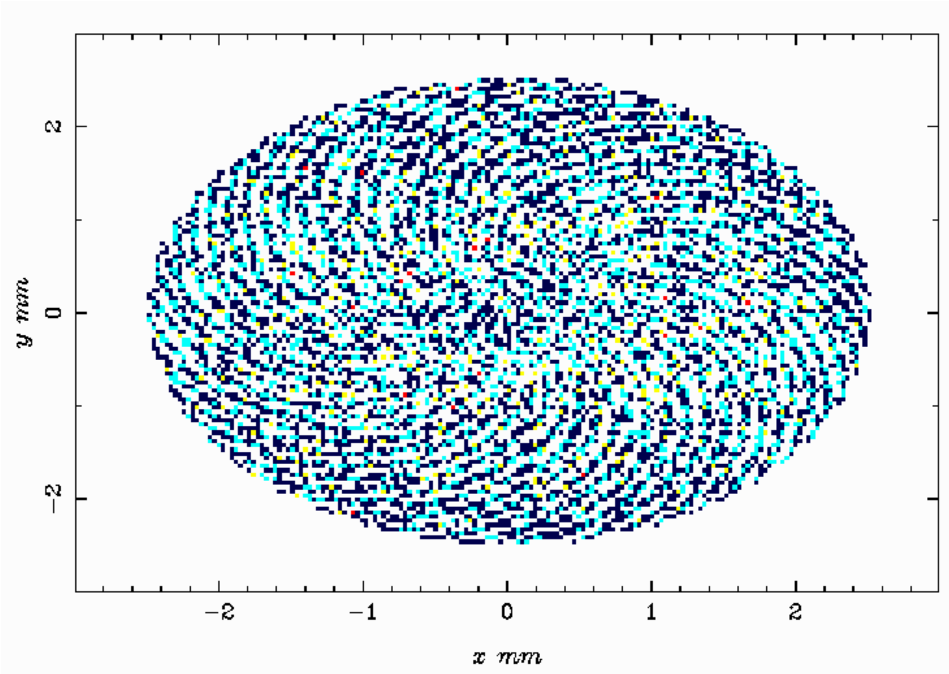


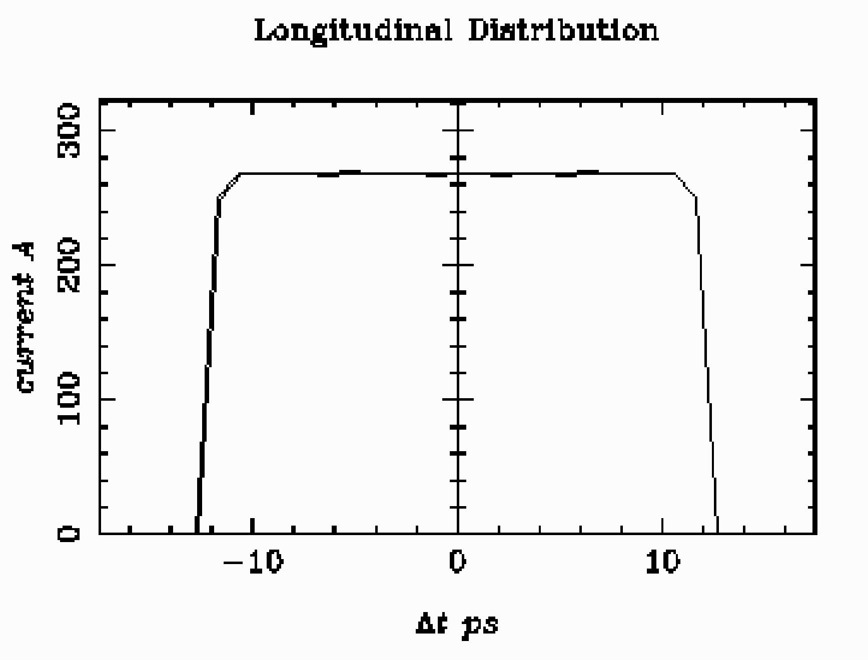
Ez MV/m
100
50
0
−50
−100
0
0.05
0.1
0.15
0.2
0.25
0.3
z m

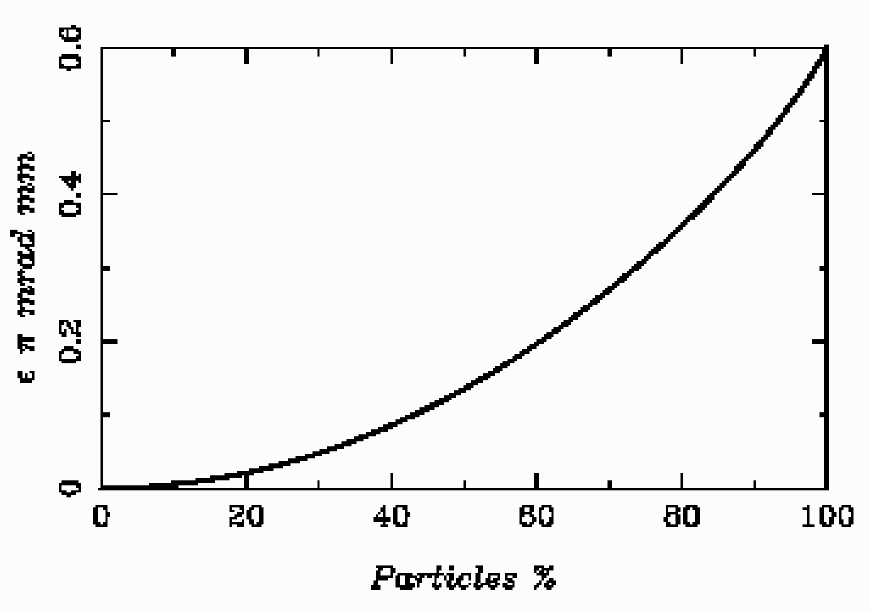


Bz T
0.2
0
−0.2
0
0.05
0.1
0.15
0.2
0.25
0.3
z m

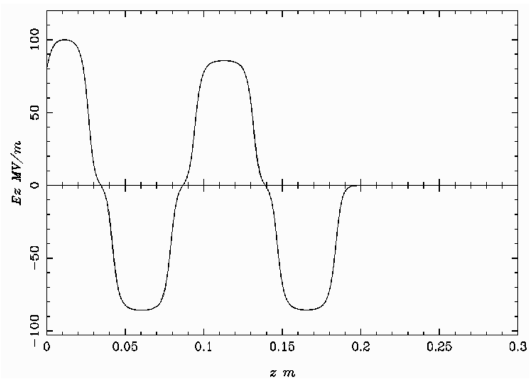
Initial beam

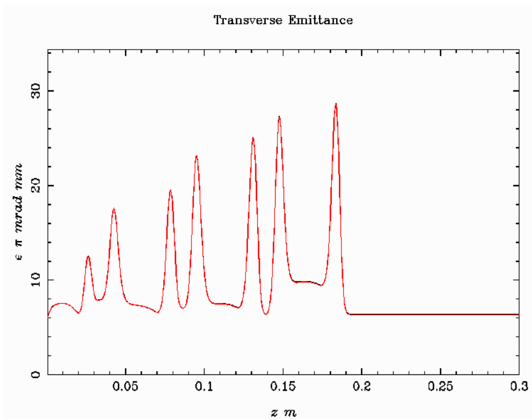


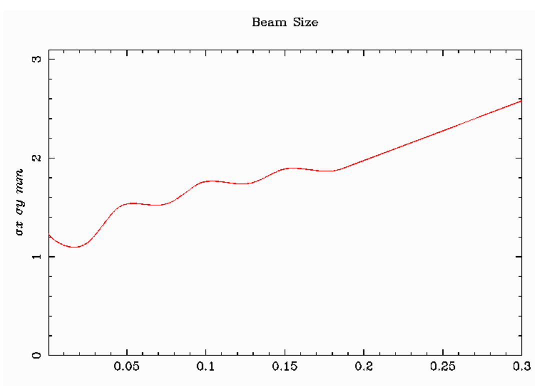


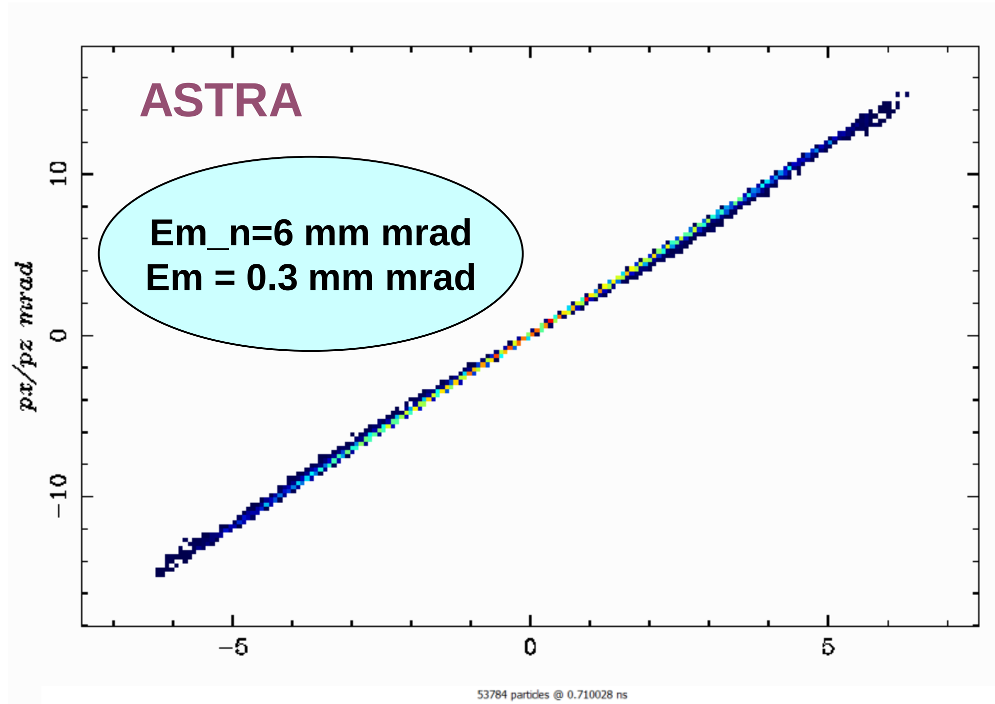


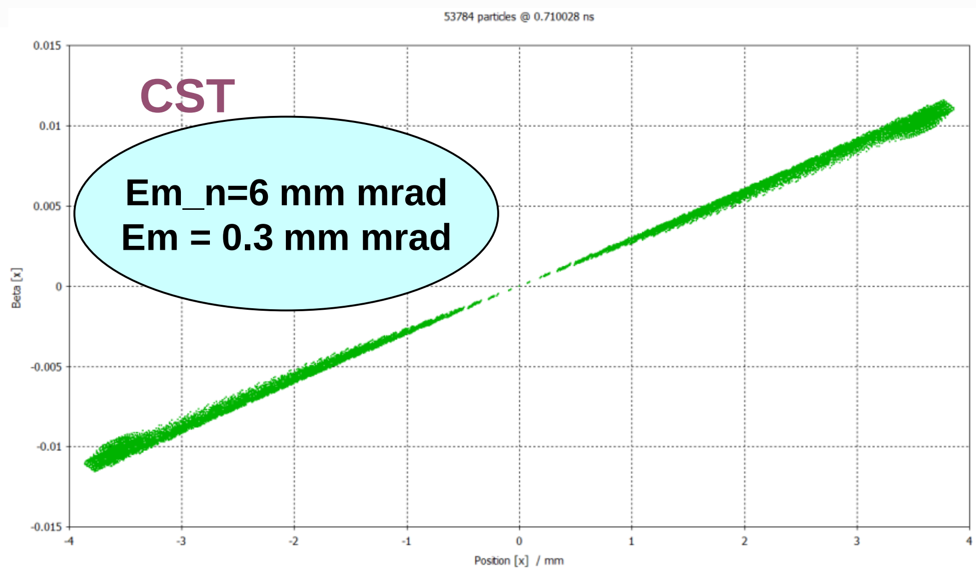
Beam dynamics in the gun without any magnetic fields



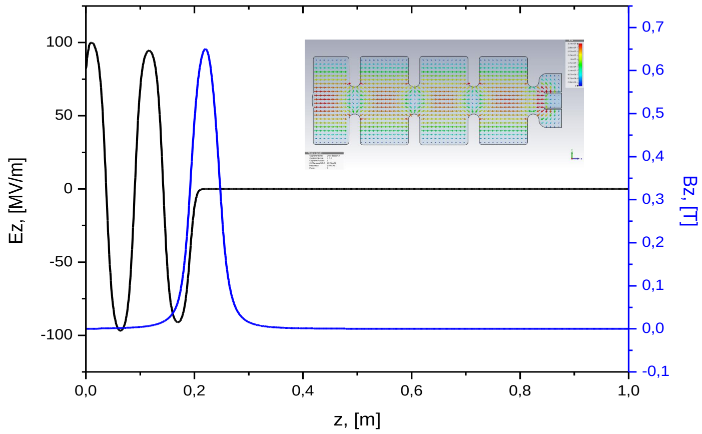


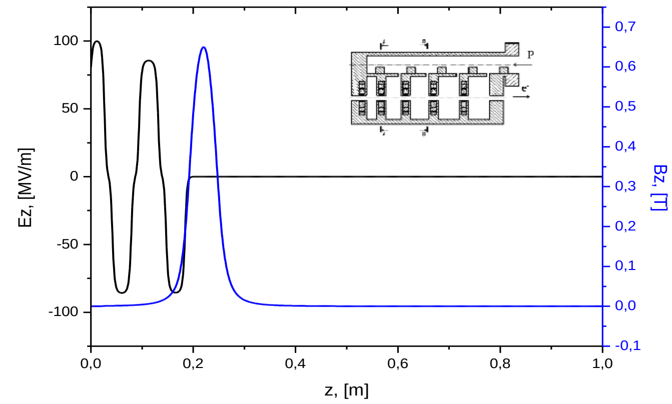


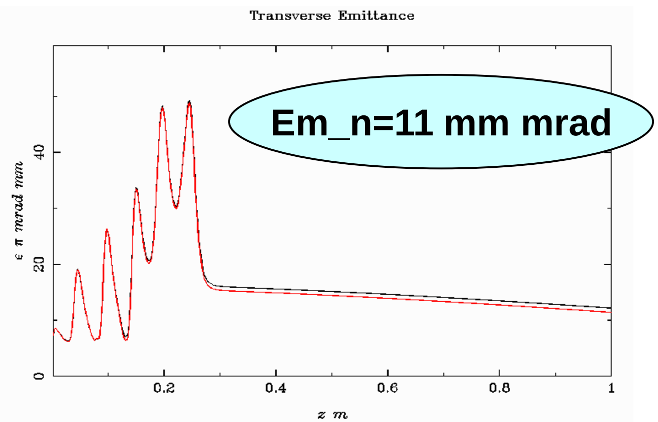


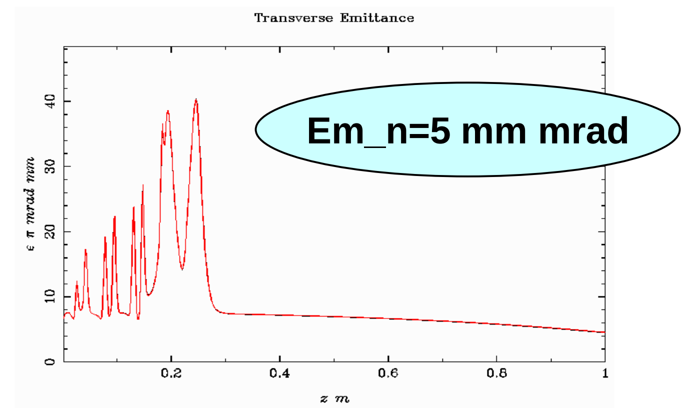


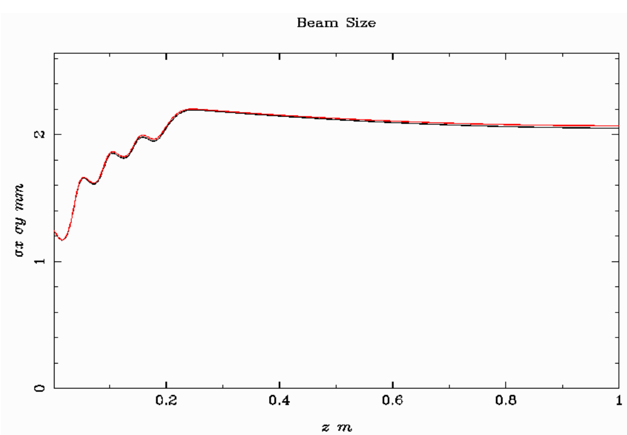
Comparison with previous design

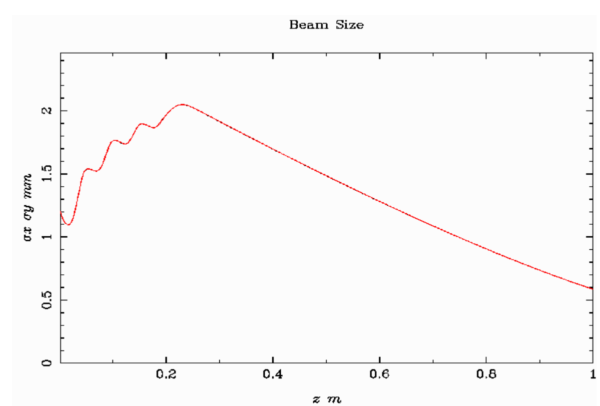




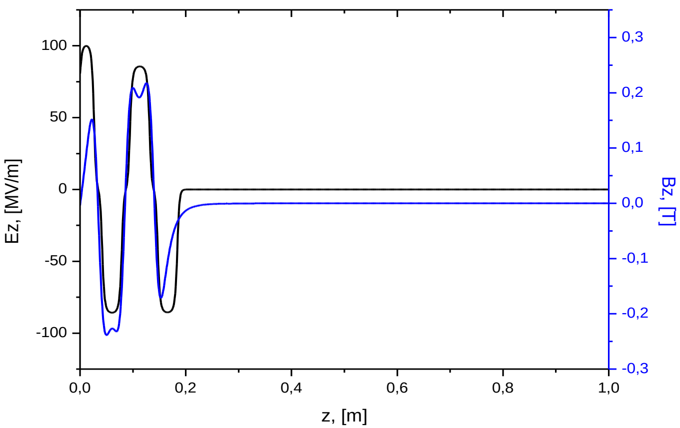


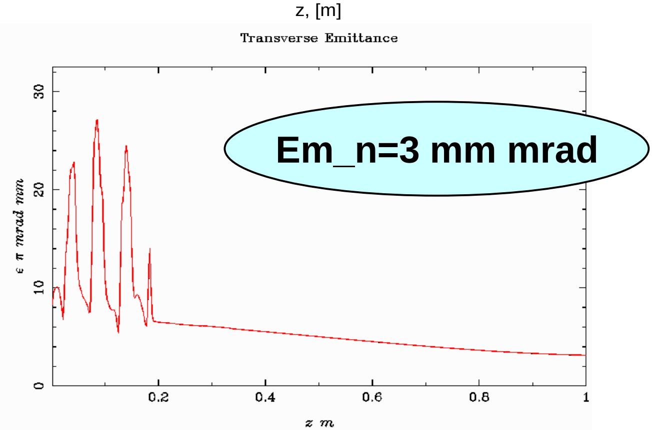


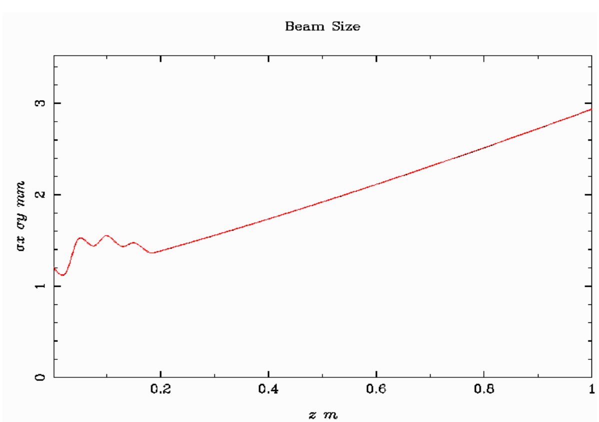


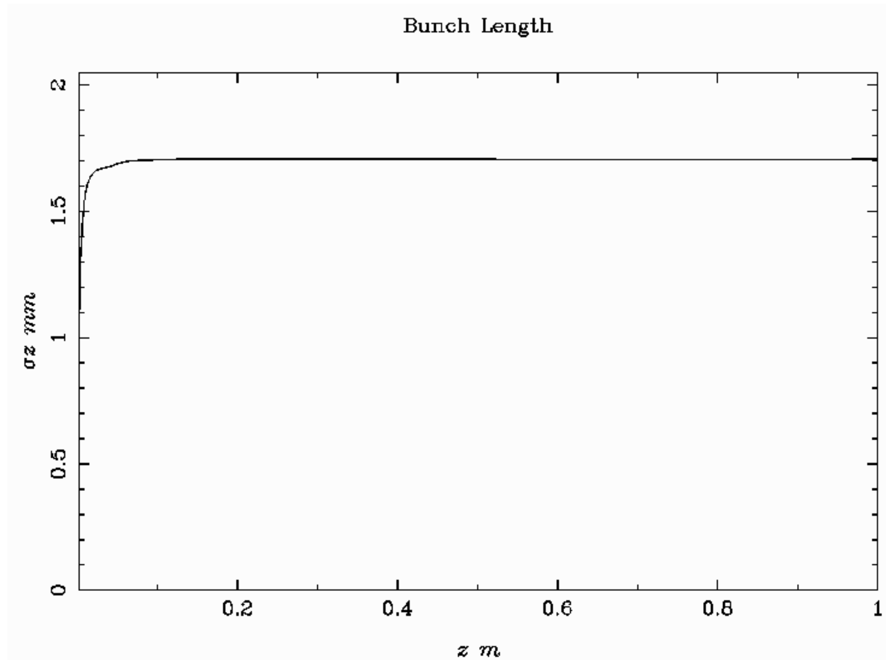


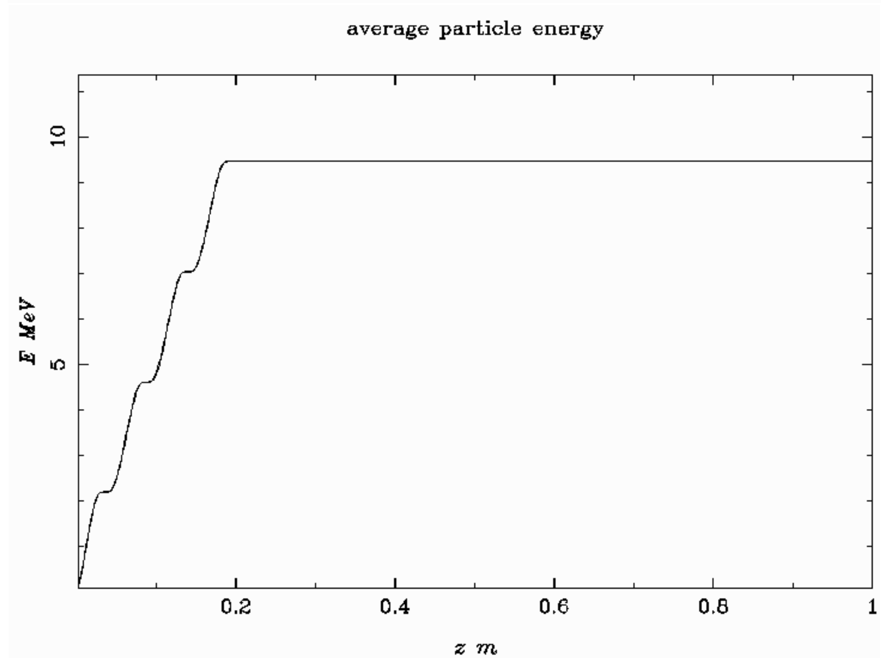
Beam dynamics with permanent magnets











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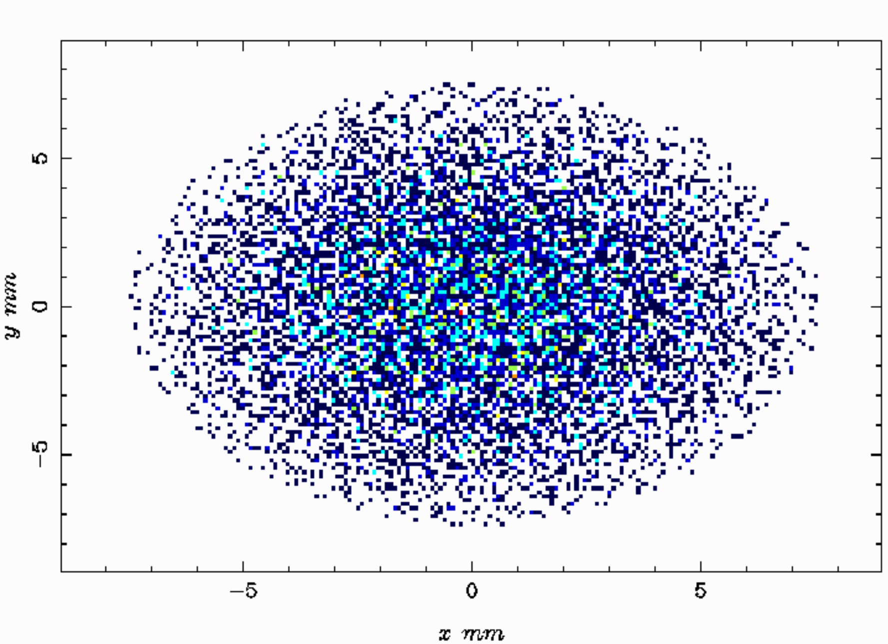
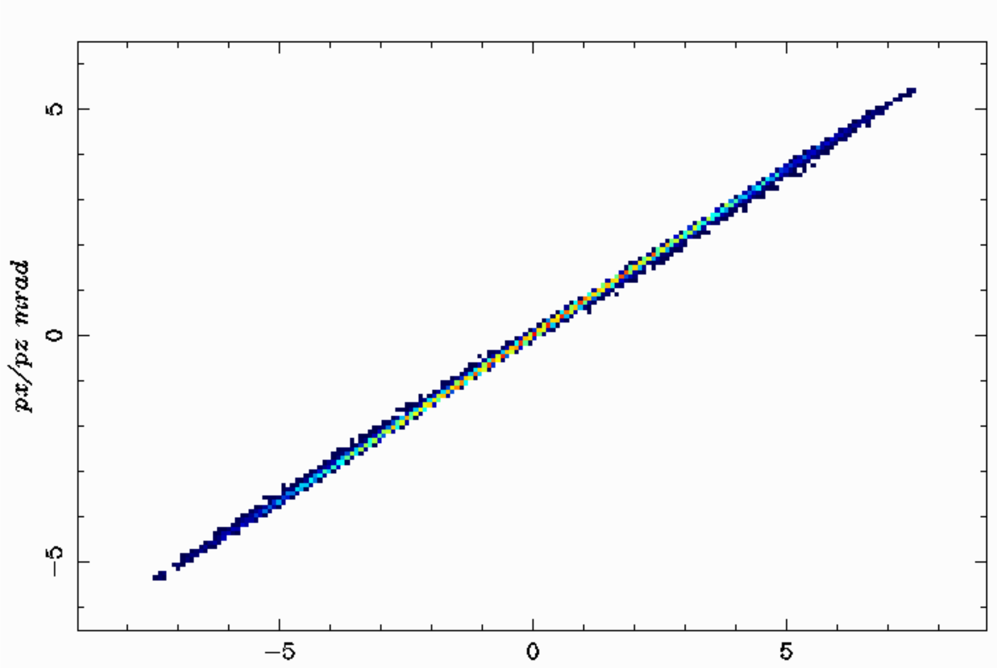
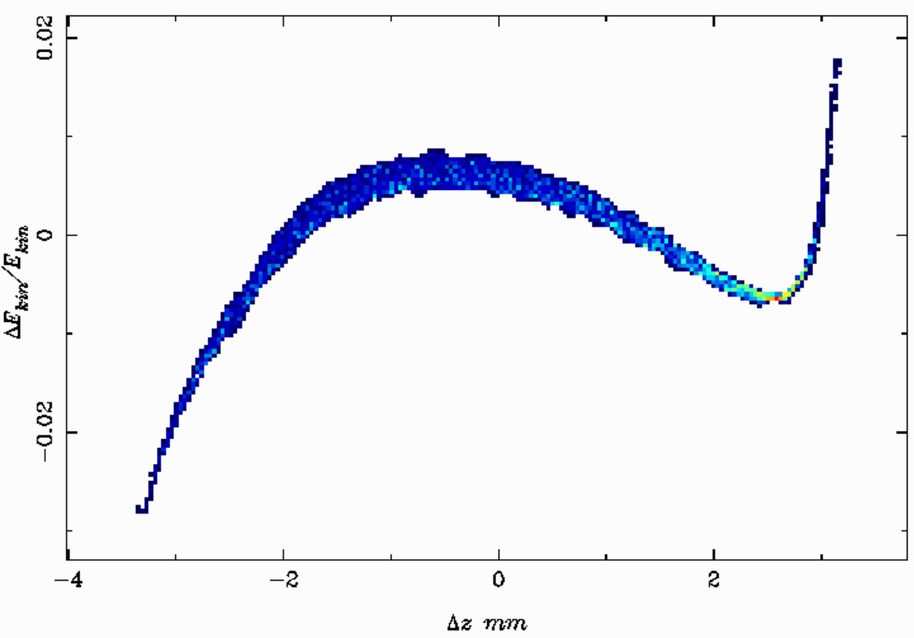
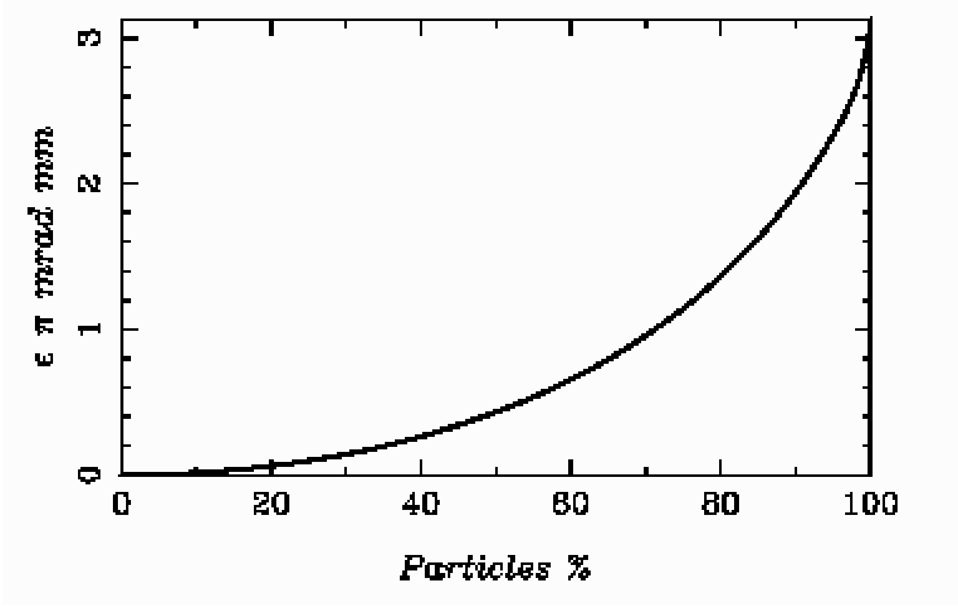
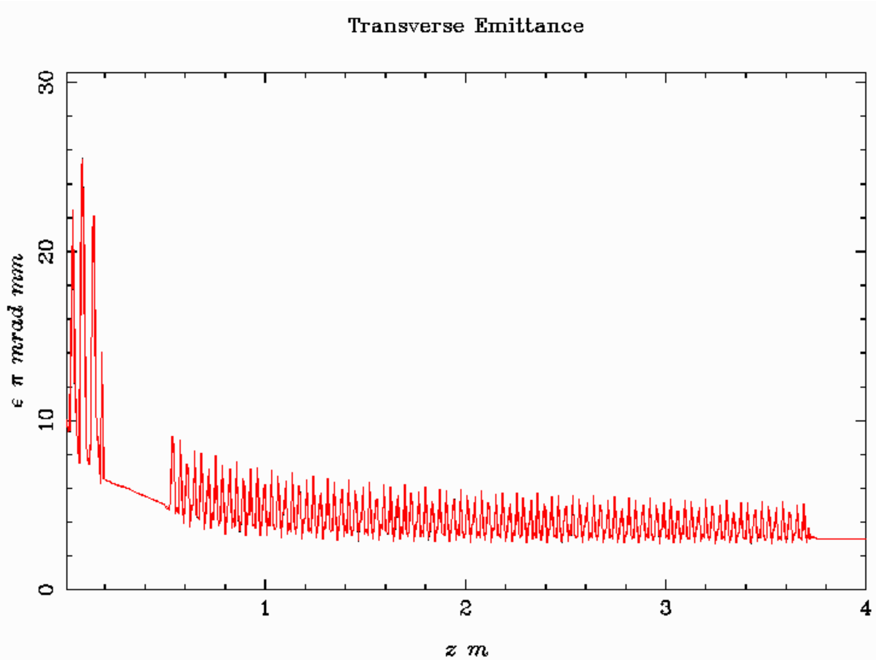


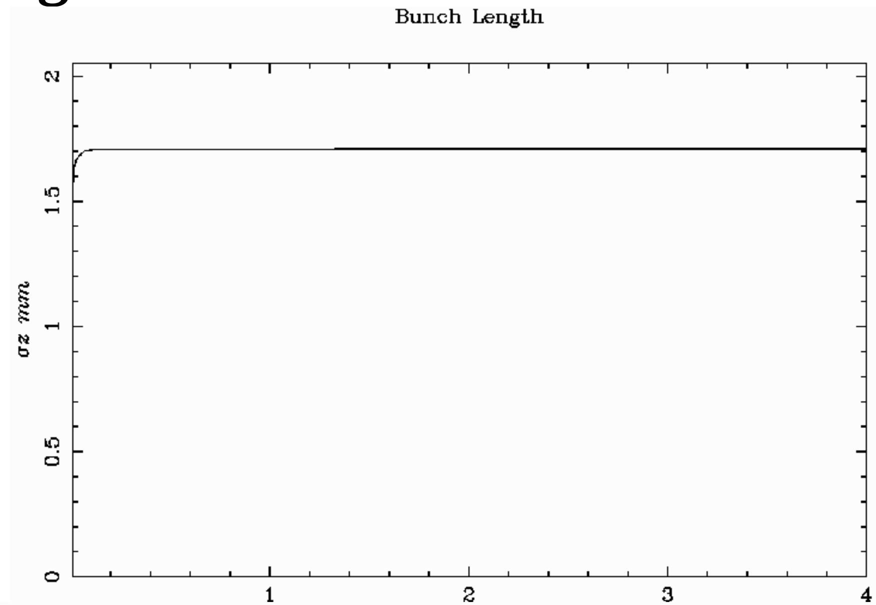


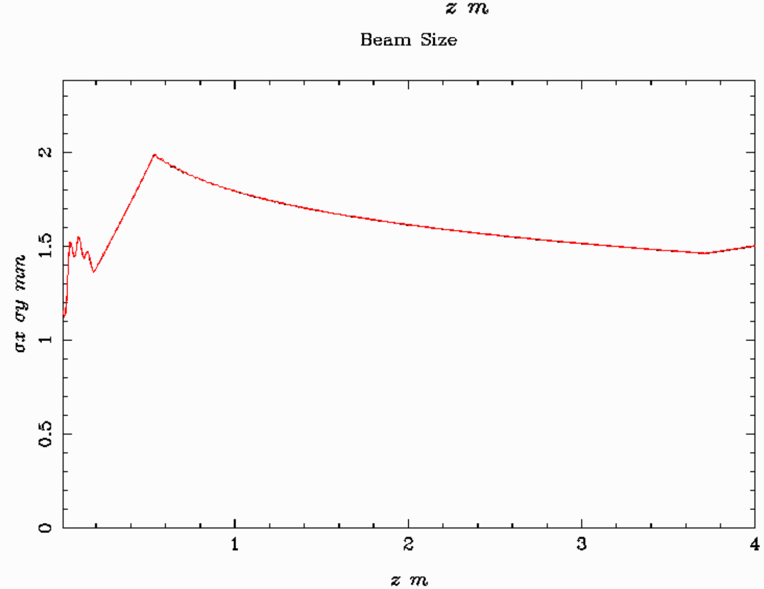


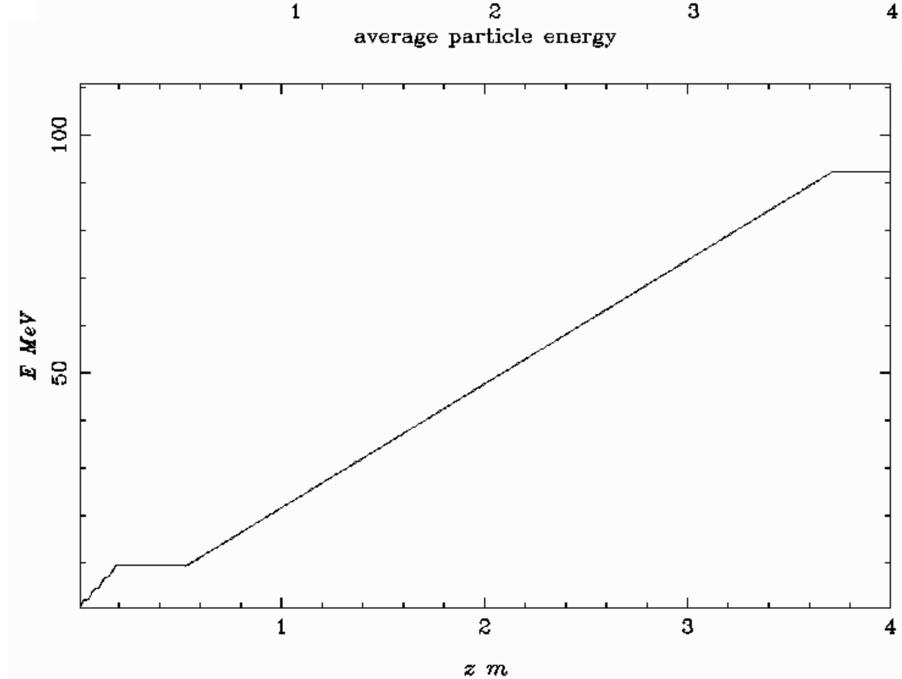


Beam dynamics with permanent magnets and 3 m long TW accelerating structure









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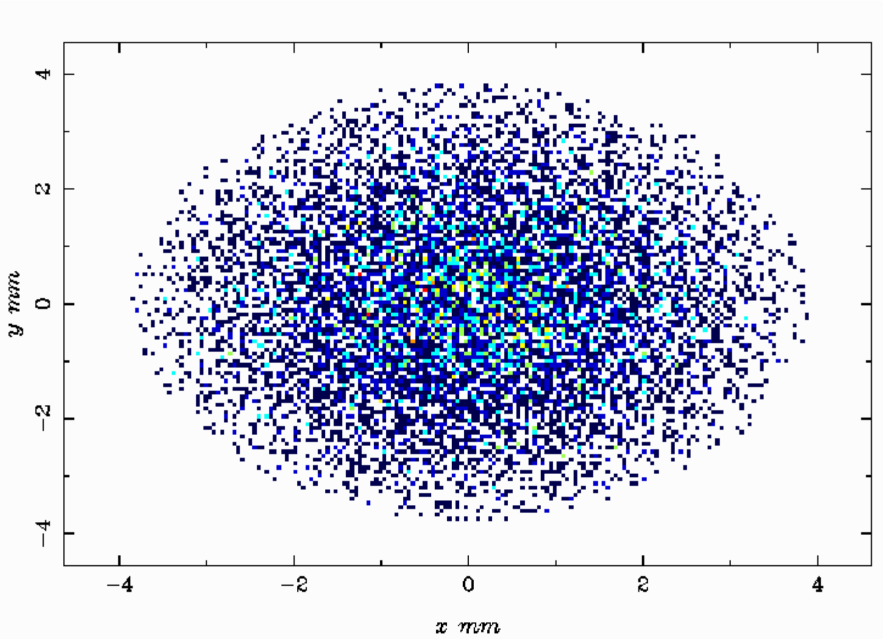
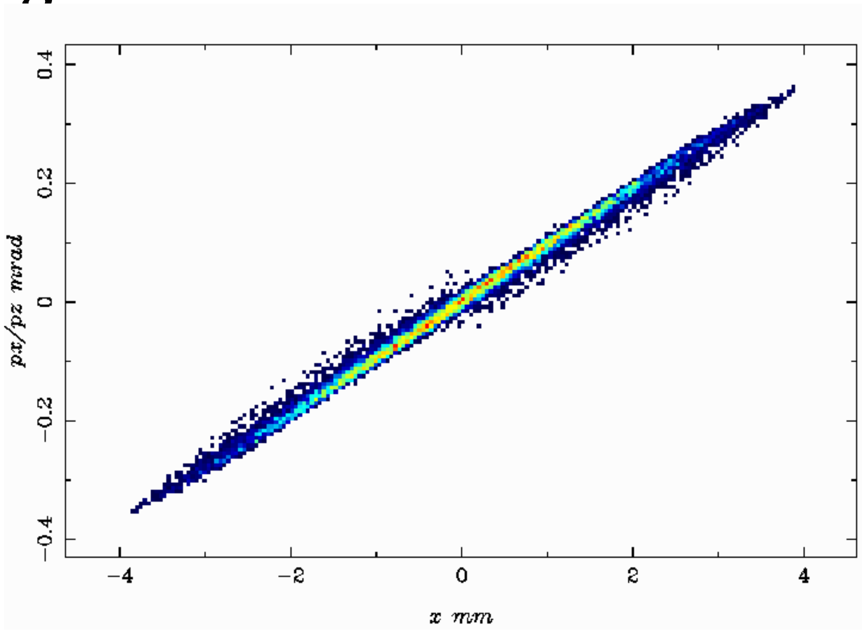
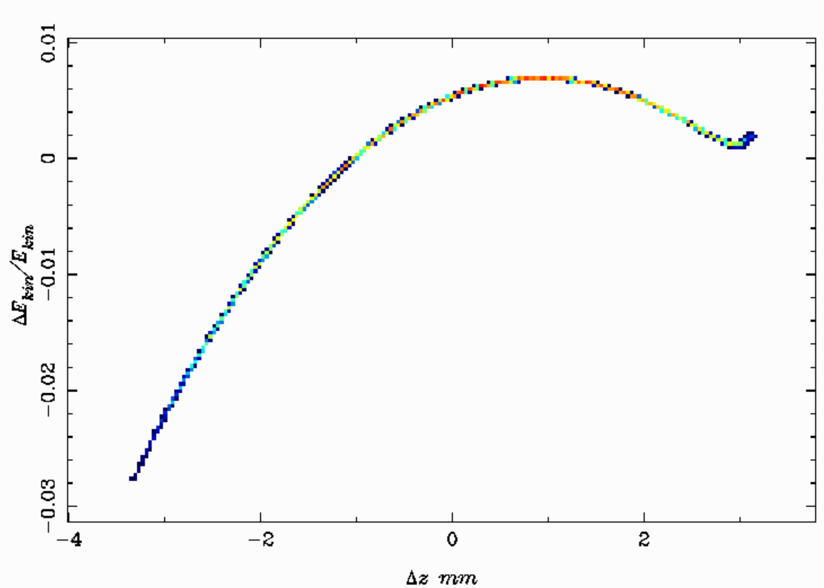
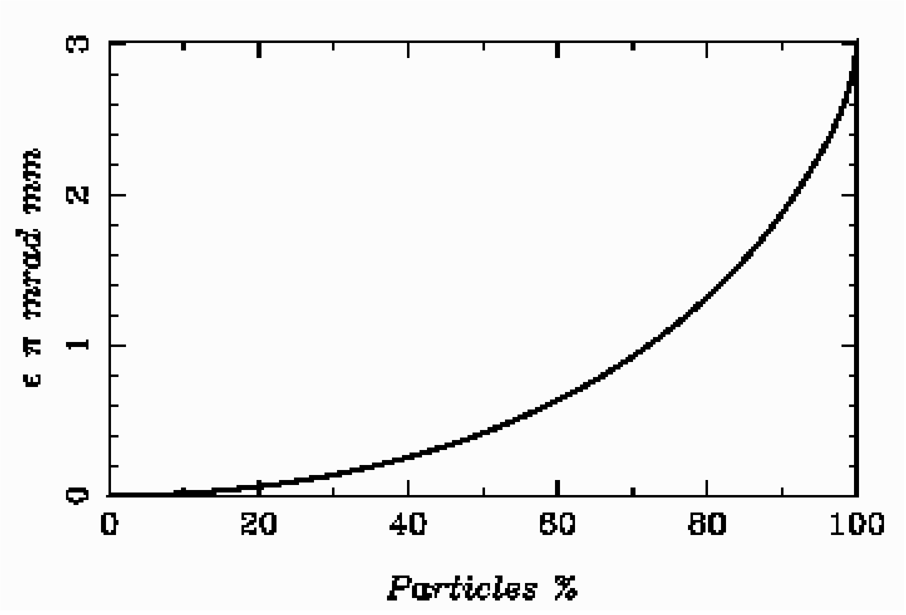
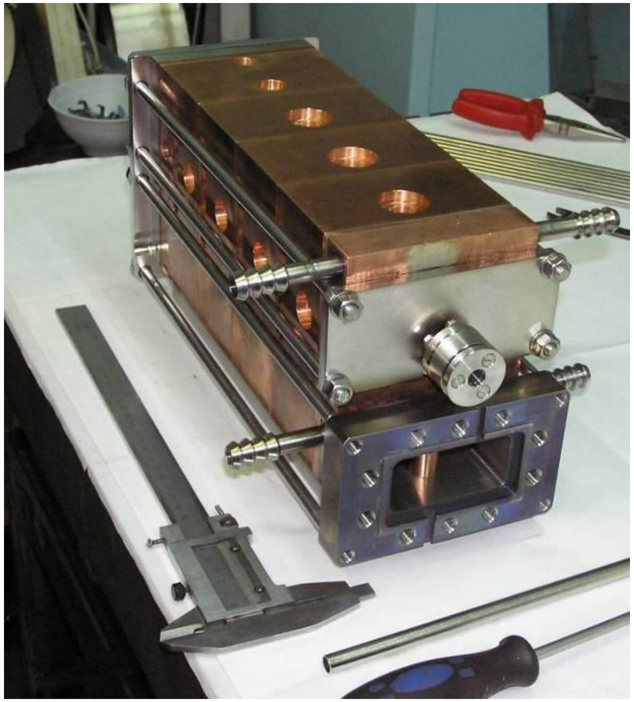


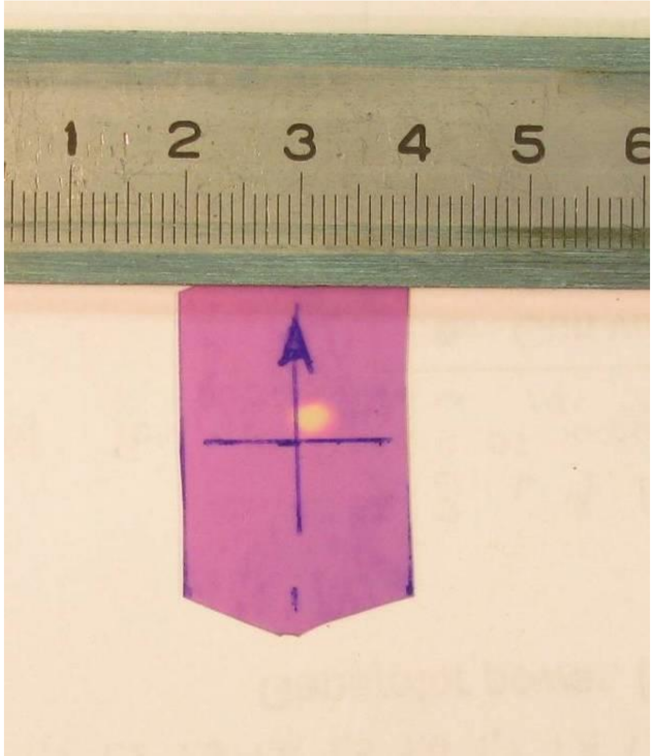


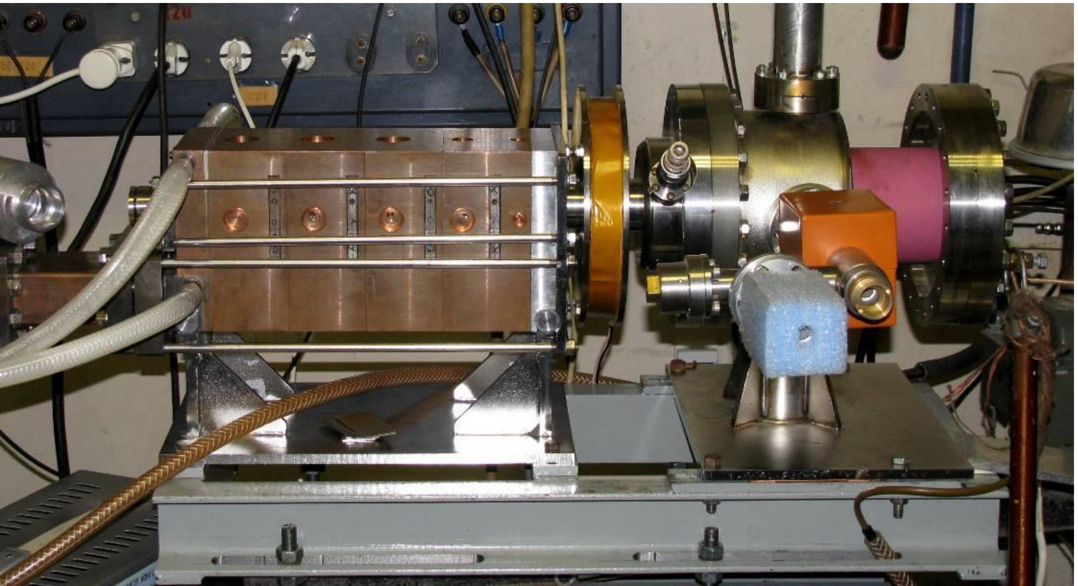




Prototype parallel coupled accelerating structure with 2450 MHz

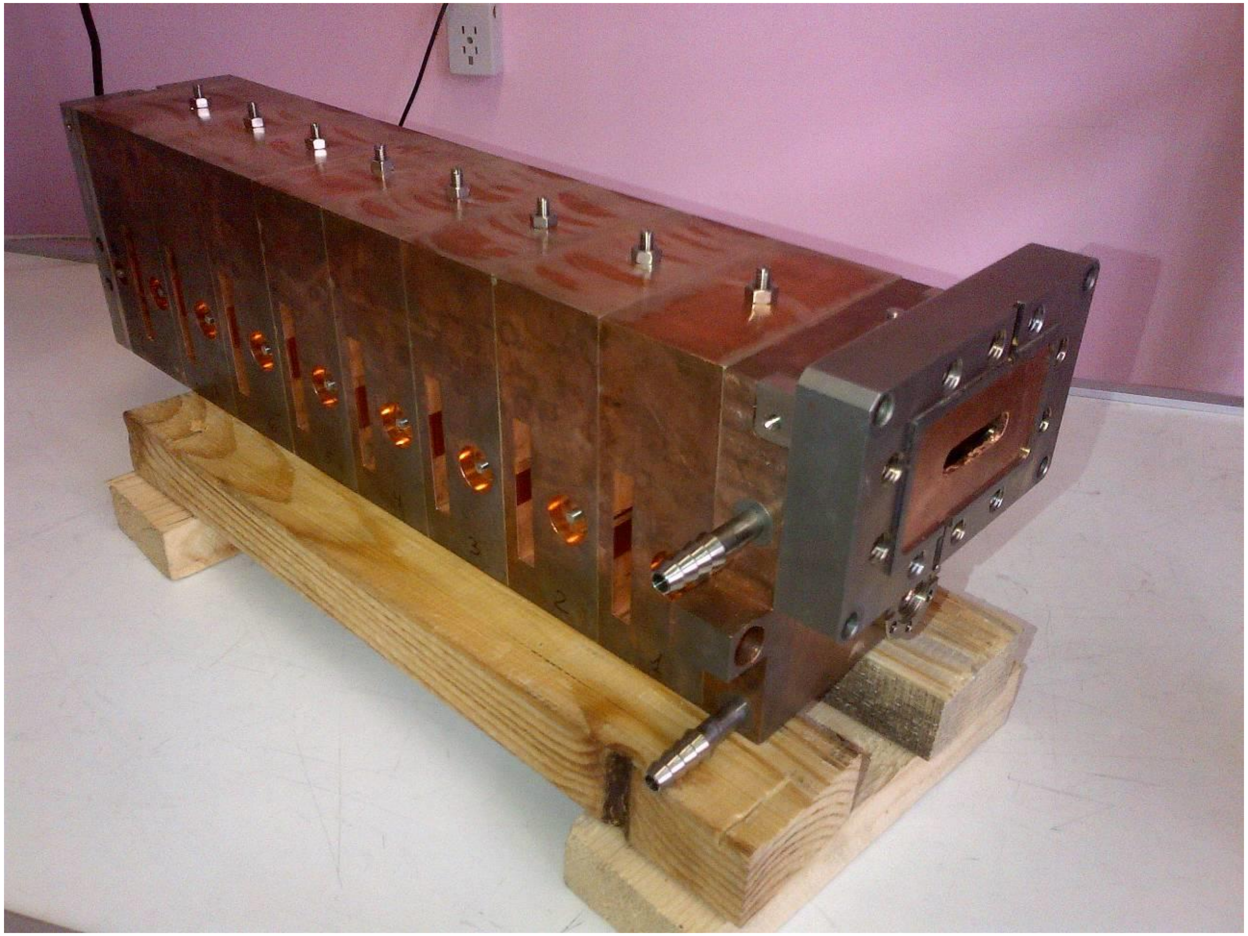






Beam current is about 300 mA, duration is 2.5 ns, energy is 4 MeV

Prototype parallel coupled accelerating structure with 2856 MHz



Accelerating stand is under developing

Conclusion

1. Decreasing of the travelling tube apertures is right solution
2. Save small beam size along the cavities of RF gun is also right solution
3. In the solenoidal magnetic field the emittance is oscillated and there is the point when the emittance will have the local minimum. If the next accelerating structure is placed in this point, the emittance can be decreased. Thus, using right focusing elements allows reducing the emittance.
4. New design of the RF gun allows us to consider the cavities as independent. The length and field amplitude can be tuned separately for every cavity.
5. The travelling tube aperture can be decreased as significantly as it allows the beam dynamics.
6. New design also permits using the permanent focusing magnets and create the strong magnetic field along the cavities and save the beam size.
7. All of these can reduce the beam emittance.
8. The prototype of the accelerating structure based on new design with parallel coupling between the cavities have been produced in BINP with operating frequency of 2450 MHz. At present we are developing new test facility stand based on the linear accelerator. Test of the new parallel coupled accelerating structure with 2856 MHz is one of the tasks of this stand.

Following steps:

1. Analysis of new results
2. Check ASTRA results with CST-studio
3. Work with technical questions

Thank you for attention