RF gun based on parallel coupled accelerating structure for high charge and low emittance

A.M. Barnyakov, D.A. Nikiforov, A.E. Levichev

Ultrafast Beams and Applications
04-07 July 2017, CANDLE, Armenia

05.07.2017

nikdanila@bk.ru

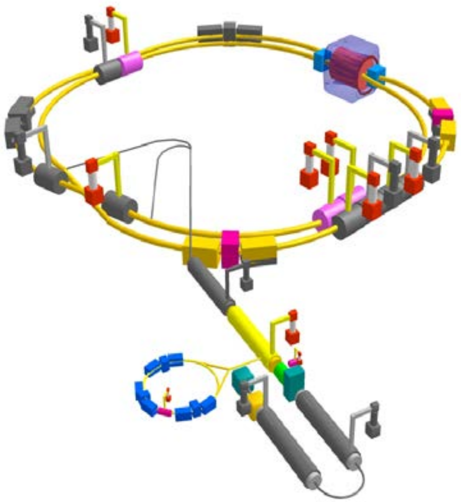
Outline

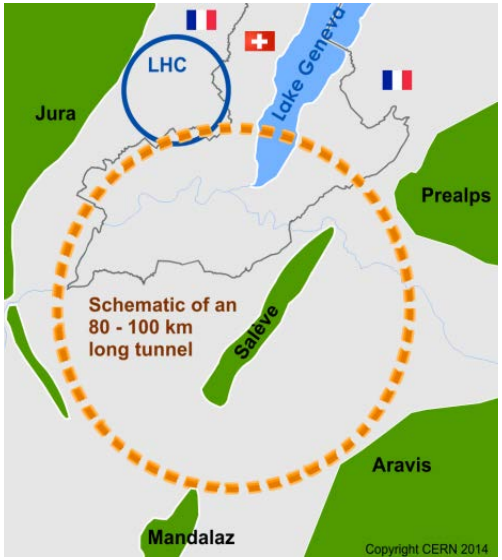
- Motivation and requirements
- RF gun for SuperKEKB
- Parallel coupling accelerating structure (PCS)
- RF gun based on (PCS)
- Beam dynamics for PCS gun
- Experience of operation of the electron linear accelerator based on PCS
- Conclusion

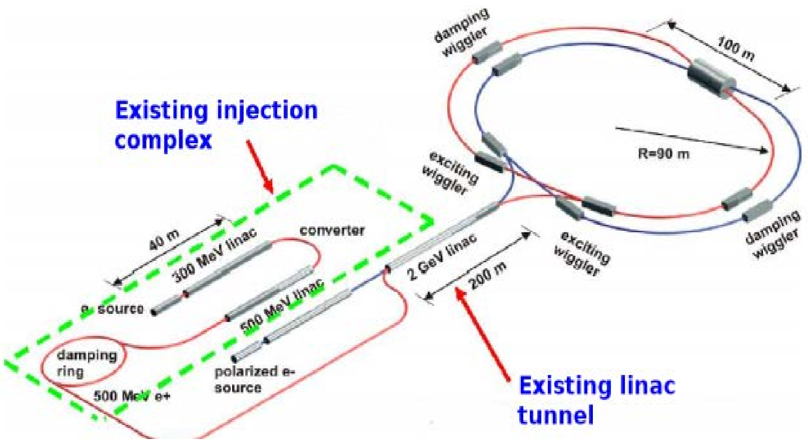
Motivation

Photocathode rf guns are considering today as the most advanced type of electron injectors for modern electron-positron colliders.

Super KEKB (Japan) **FCC (CERN)** **Super-c-τ-factory (BINP)**







Typical RF gun parameters

Parameters	Value
Energy (MeV)	9-11
Charge (nC)	6.5 (**FCC**), 5 (**SuperKEKB**)
Horizontal emittance (mm mrad)	<7 (**FCC**), <20(**SuperKEKB**)
Vertical emittance (mm mrad)	<10(**FCC**),<50 (**SuperKEKB**)
Longitudinal sigma (mm)	~1.3
Transverse sigma (mm)	1-2
RMS Energy spread	<1%

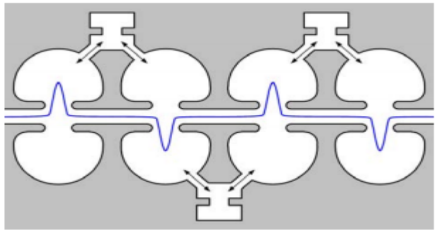
- To extract such a big charge, beam size will be too large , due to space charge limit (several mm)
- Focusing magnetic field along the cavities or/ strong RF focusing are needed to preserve or decrease transverse beam dimensions.

But…

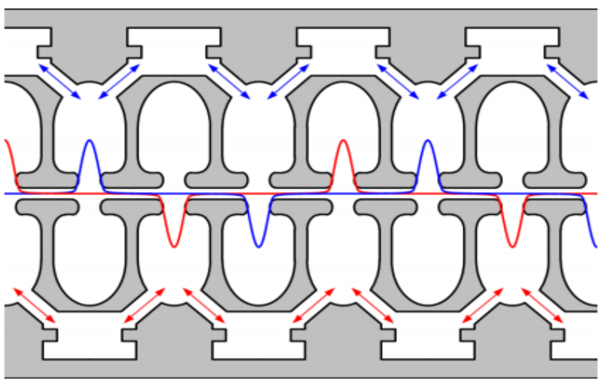
- The focusing solenoid along rf gun leads to magnetic field on the cathode and additional cavities heating

RF gun for SuperKEKB

RF gun for SuperKEKB

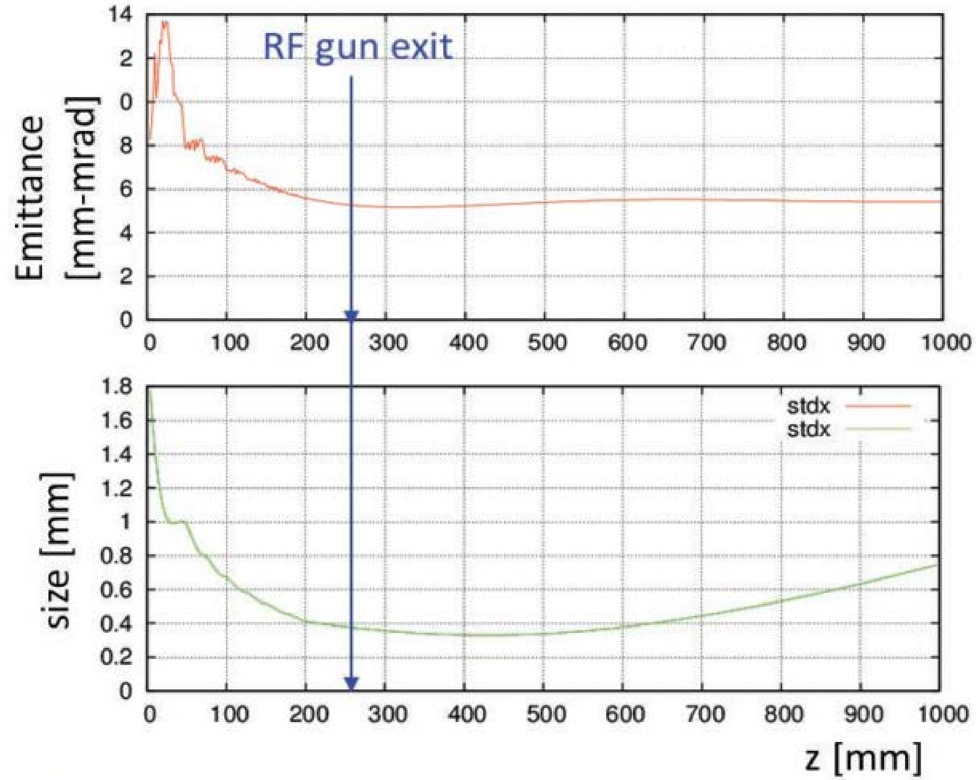


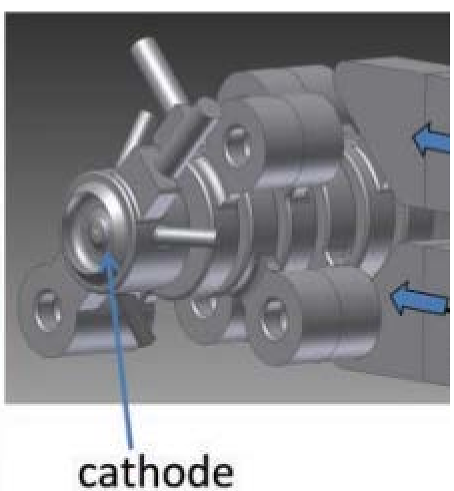
(a) Normal side coupled cavities



(b) Quasi traveling wave side coupled cavitie

Figure 1: Structure of the quasi traveling wave ca





QE=1 × 10^{-4} @266nm

Long lifetime

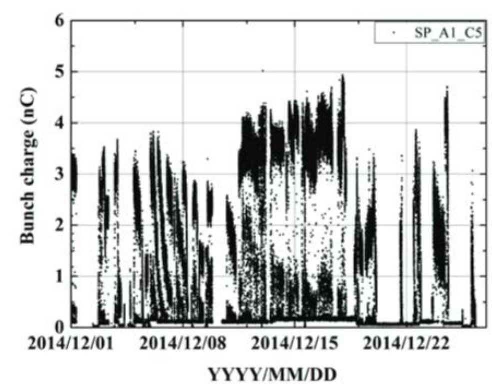
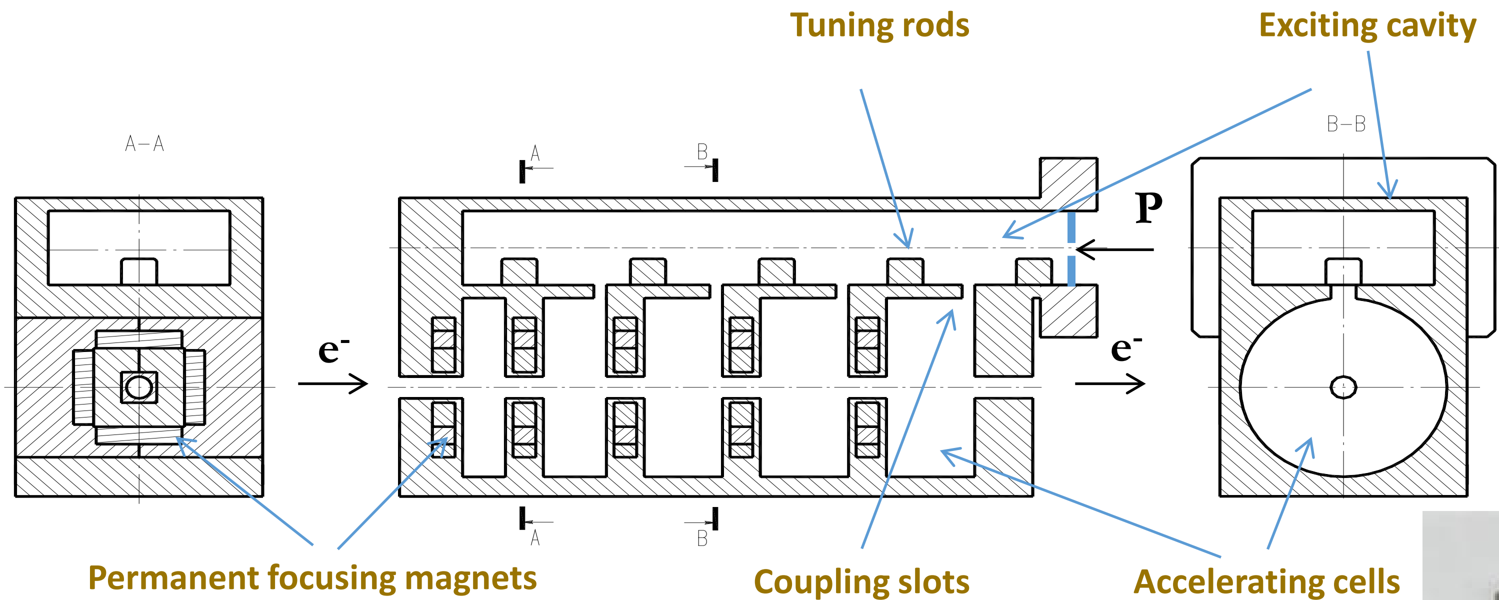


Figure 6: Beam charge of RF gun.

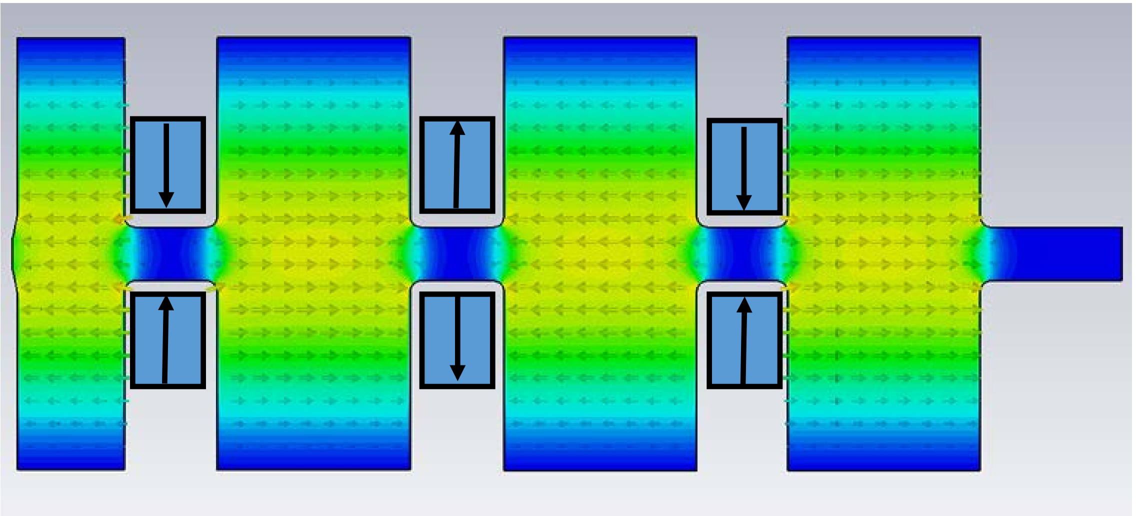
Parallel coupling accelerating structure

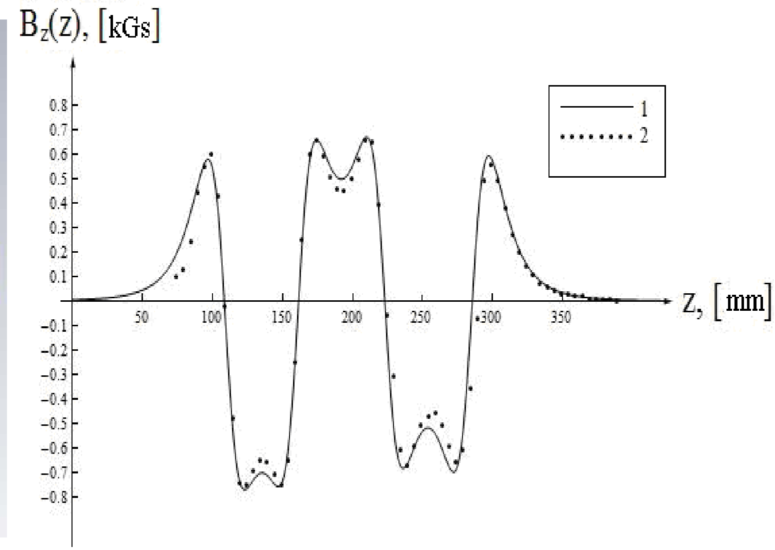


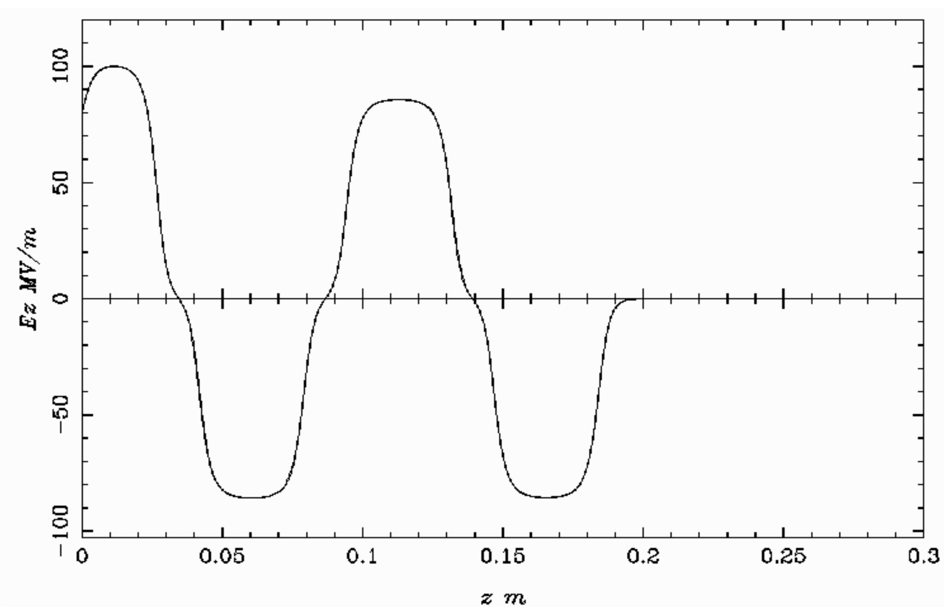
Features:

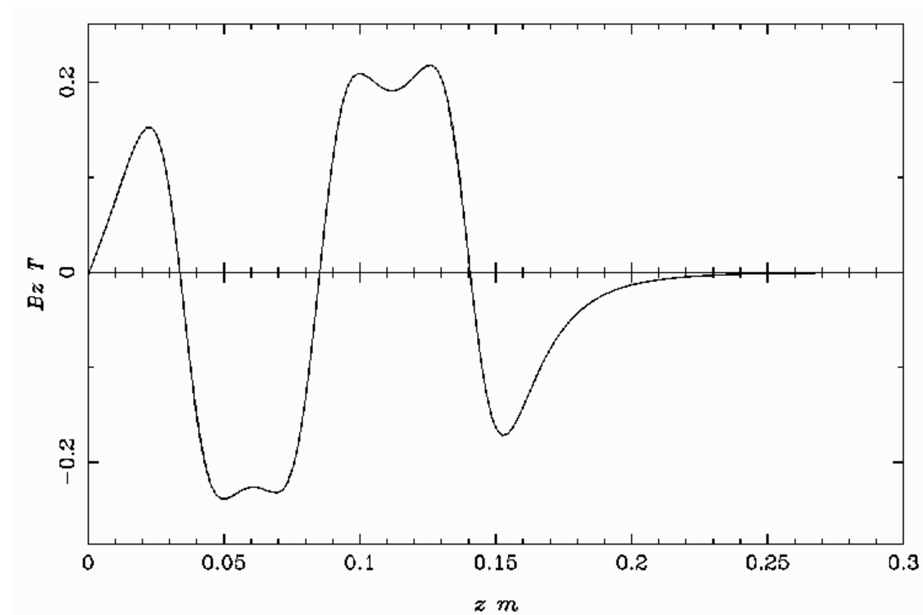
1) Parallel RF power feeding.
2) Cavities are not connected with each other by RF power: process in one cavity doesn’t influence on every cavities
3) Organization of the free electric field distribution along the structure can be obtained by changing the individual coupling slot
4) In order to develop 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.**

RF gun based on (PCS)





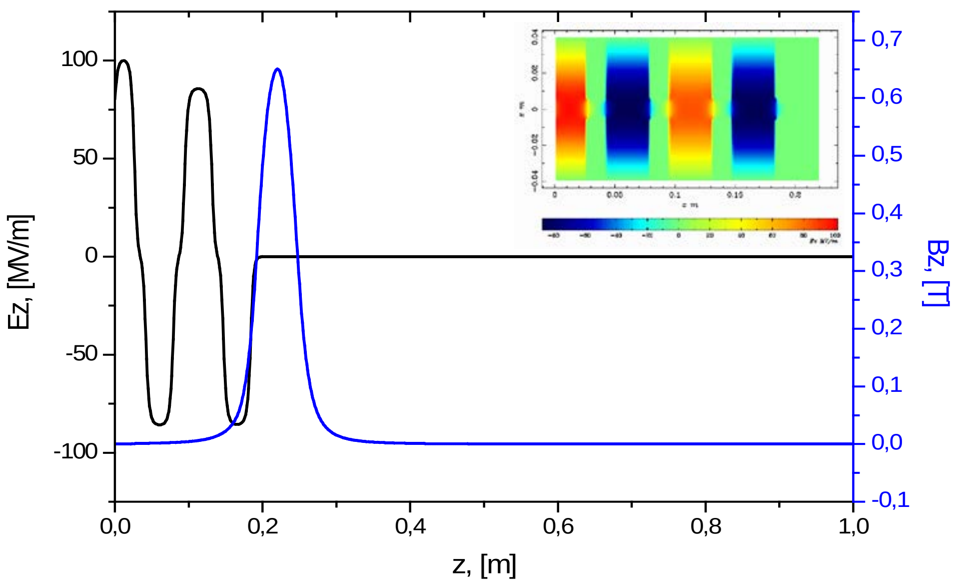




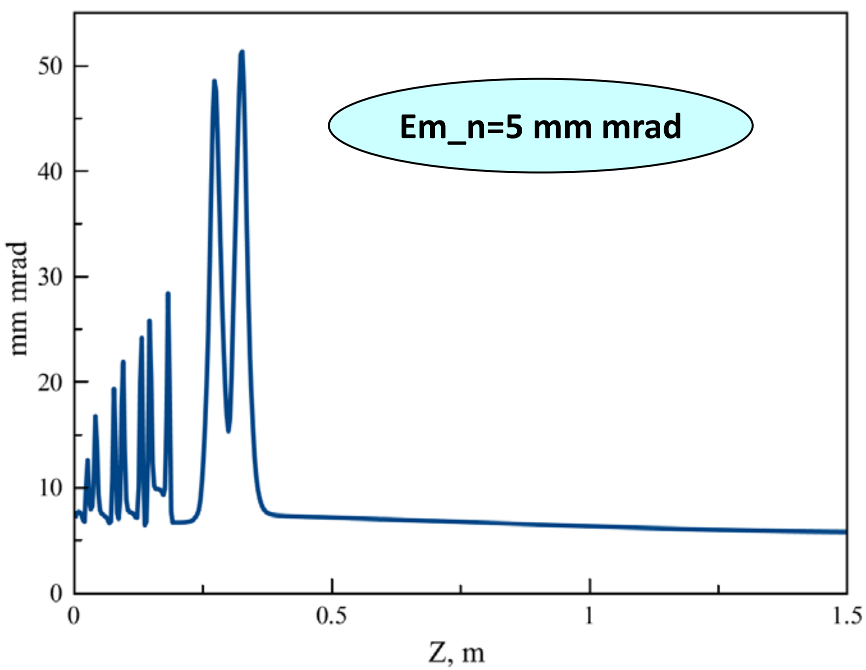
Beam dynamics for PCS gun

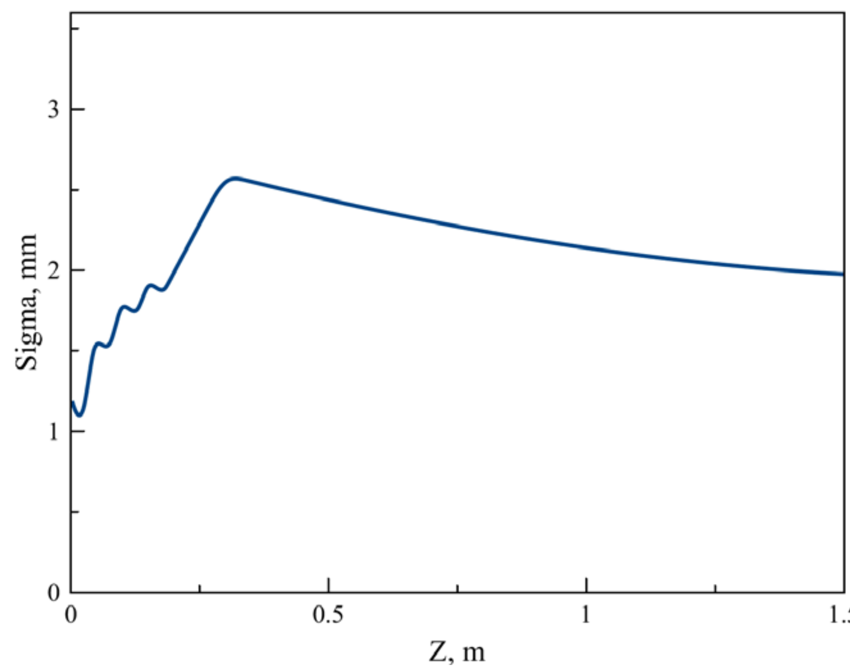
ASTRA simulation parameters	
Initial emittance	1.2 mm mrad
Initial kinetic energy	0.6 eV
Total charge	6.5 nC
Cathode spot size	5 mm
Initial distribution	Rad. Uniform
Laser pulse duration	8 ps
Laser injection phase	variable
Magnetic field on the cathode	0 T
Peak accelerating field	100 MV/m
Focusing solenoid field	0.5 T

Beam dynamics for PCS gun

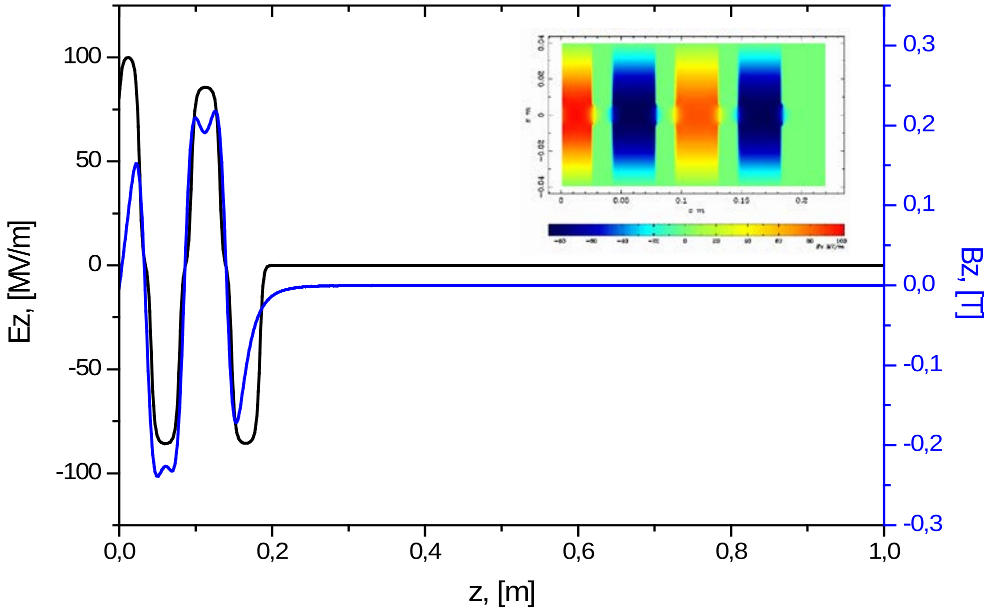


Parameter	Value
Beam length (sigma, mm)	1.5
Norm tr. Emittance (mm mrad)	5
Energy (MeV)	9.8
Energy spread (%)	0.6%
Injection phase (deg)	200

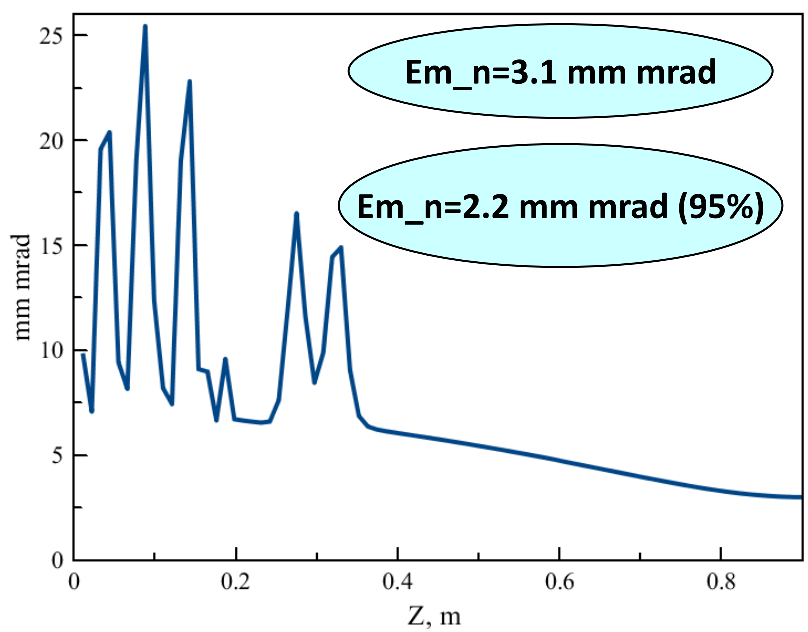


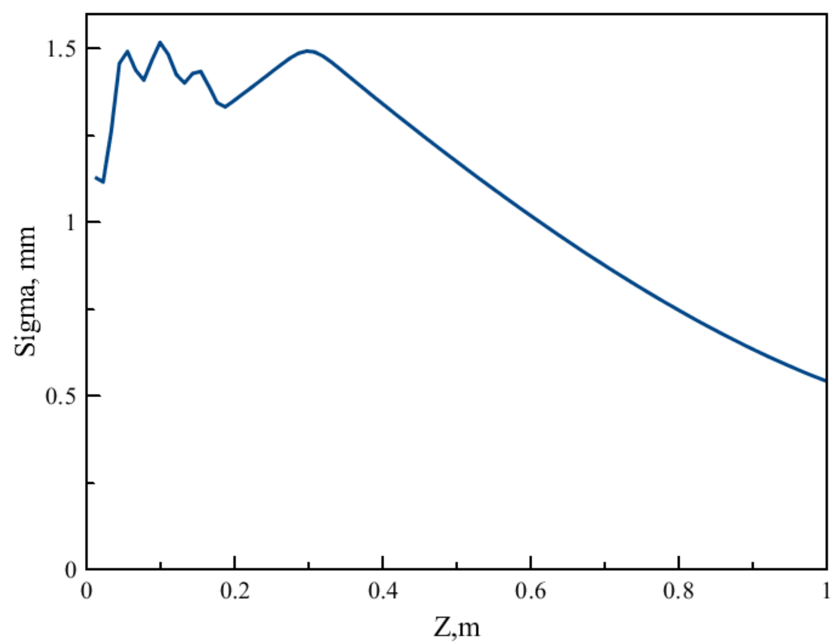


Beam dynamics for PCS gun

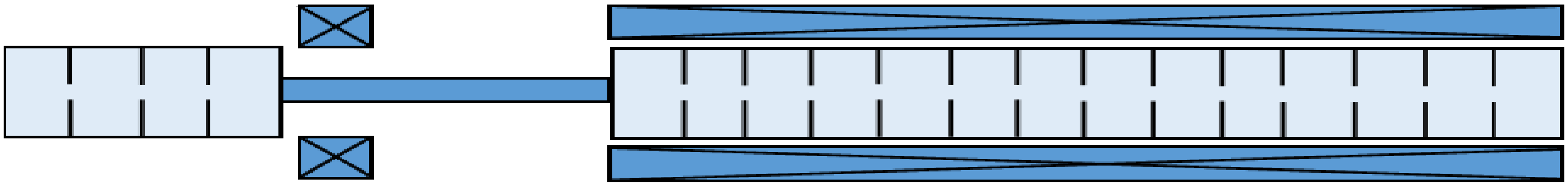


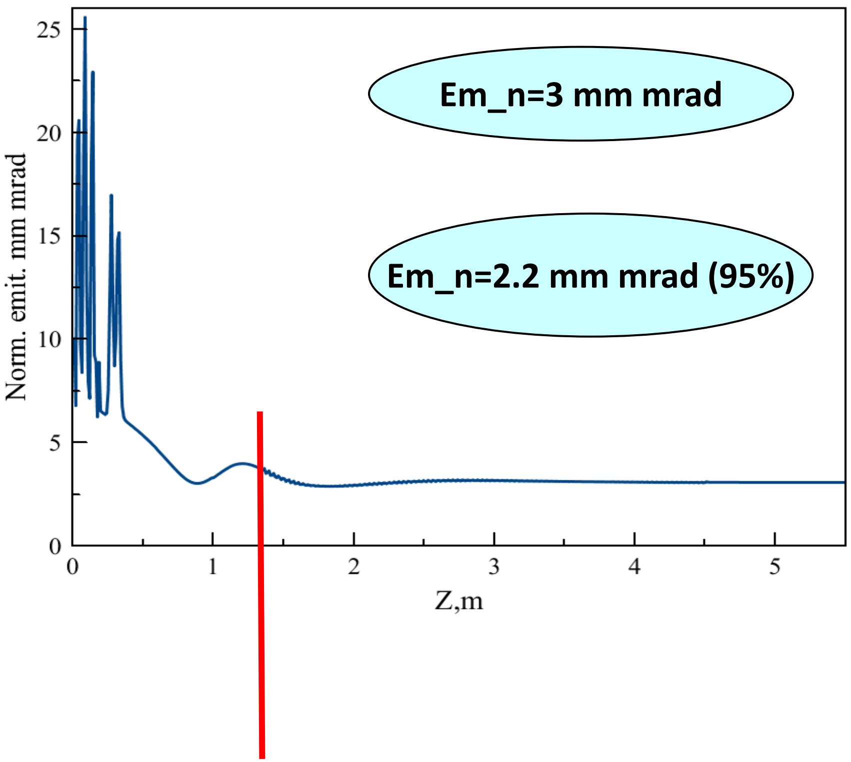
Parameter	Value
Beam length (sigma, mm)	1.5
Norm tr. Emittance (mm mrad)	3
Energy (MeV)	9.8
Energy spread (%)	0.6%
Injection phase (deg)	200



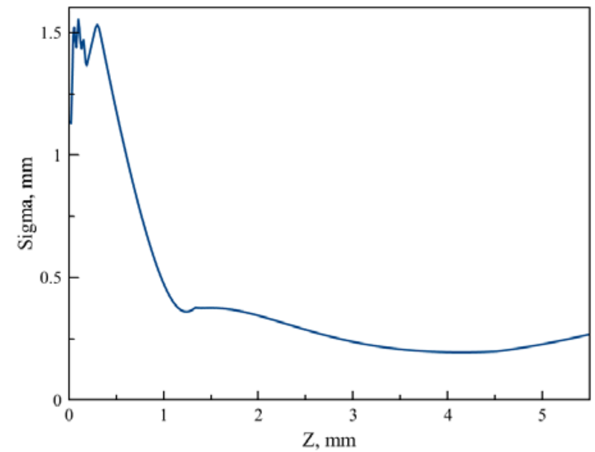


Beam dynamics for PCS gun



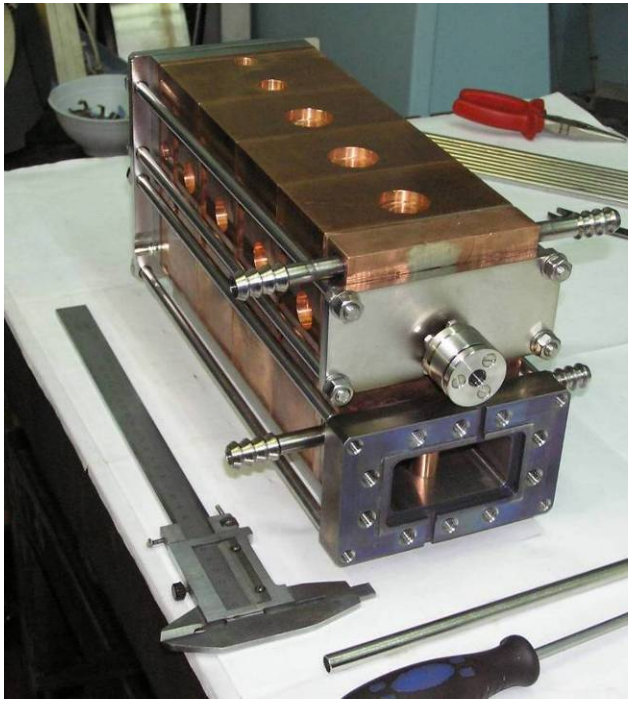


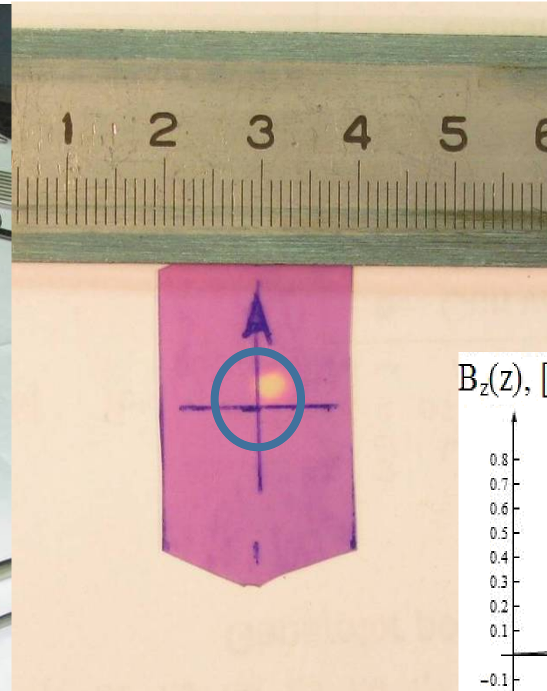
3 m. long SLAC type acc. structure

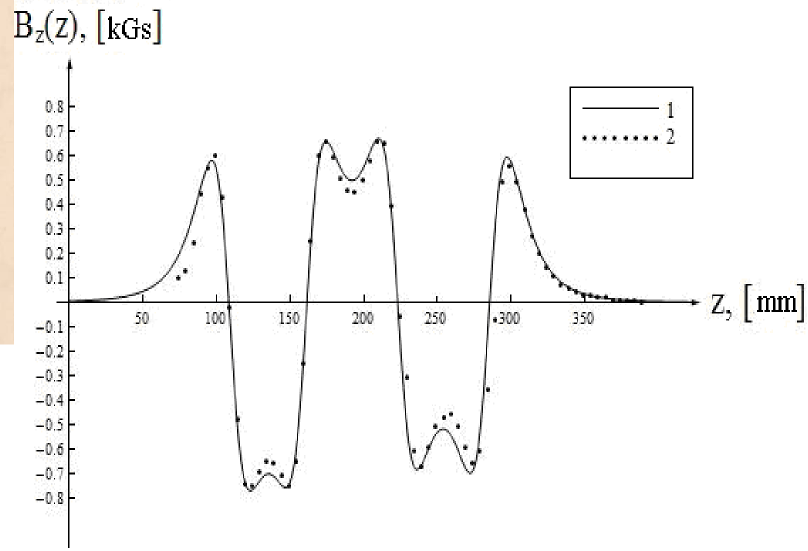


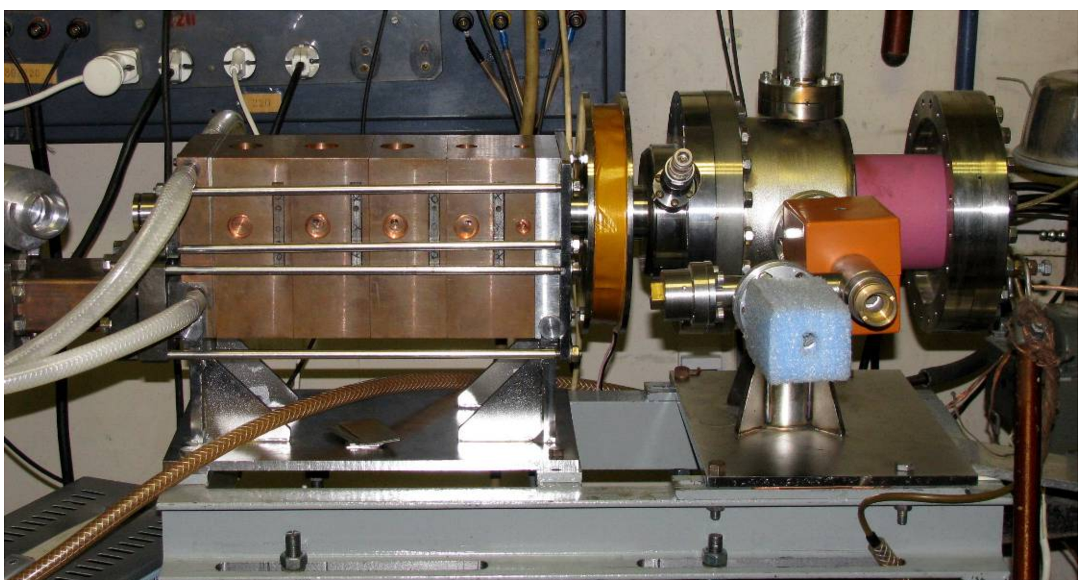
Parameter	Value
Beam length (sigma, mm)	1.5
Norm tr. Emittance (mm mrad)	3
Energy (MeV)	9.8
Energy spread (%)	0.7%
Injection phase (deg)	293

Prototype of parallel coupled accelerating structure with 2450 MHz



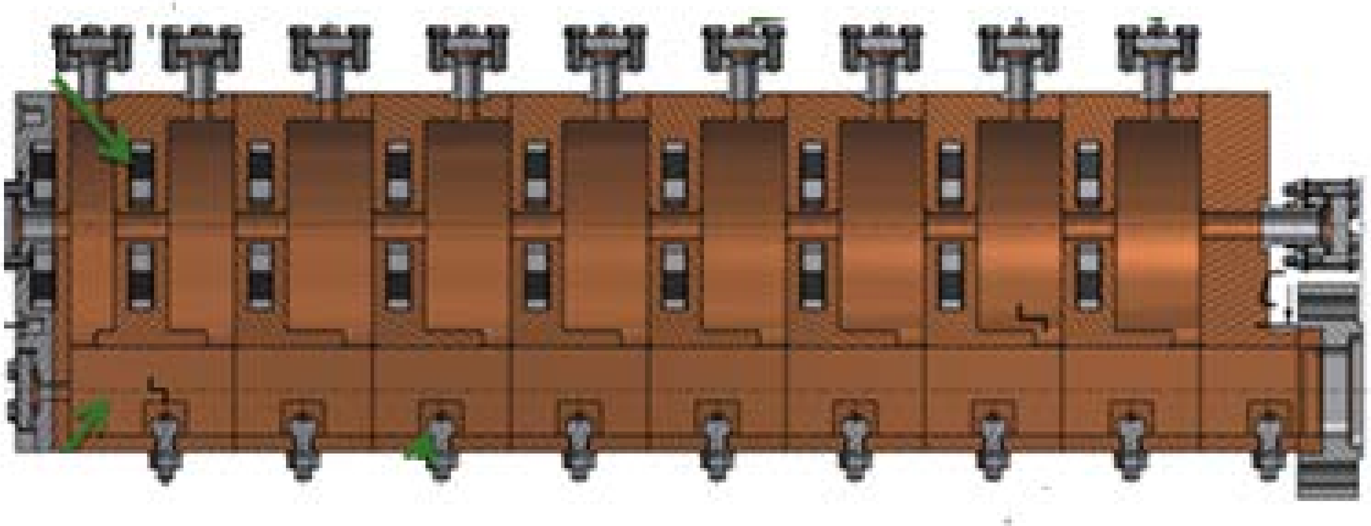


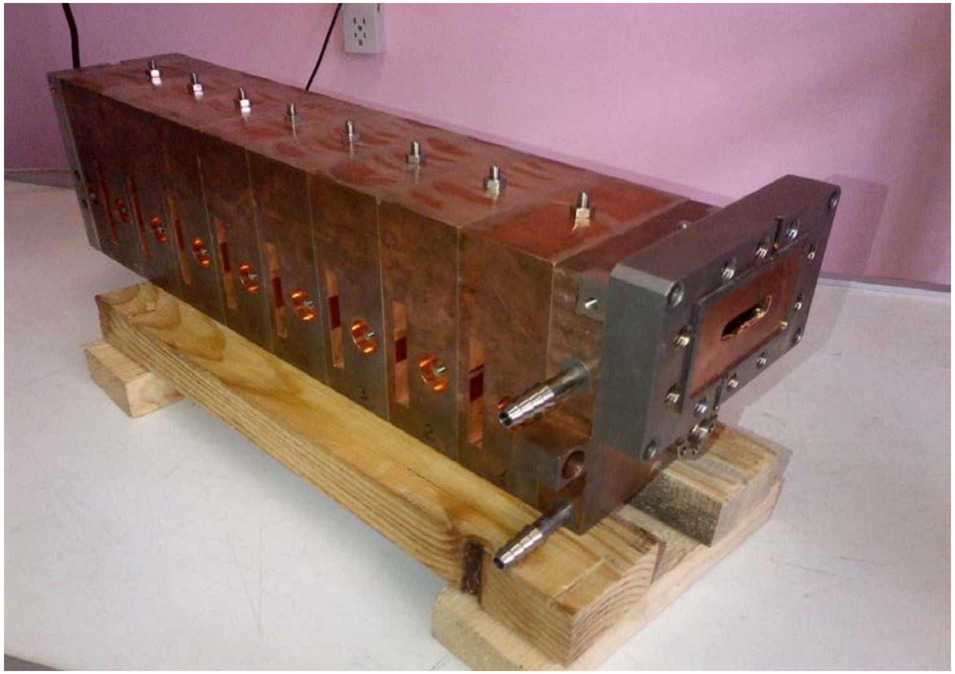


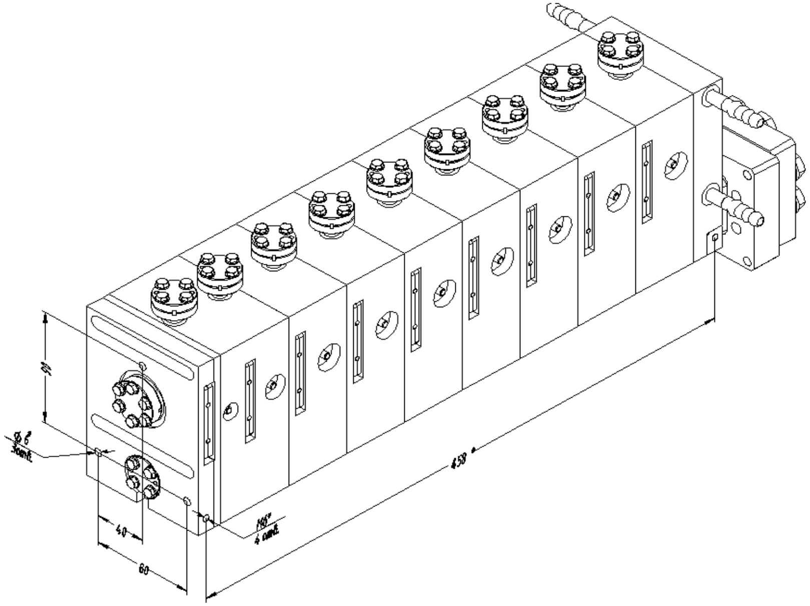


Beam current is about 500 mA, duration is 2.5 ns, energy is 4.5 MeV

Prototype of parallel coupled accelerating structure with 2856 MHz





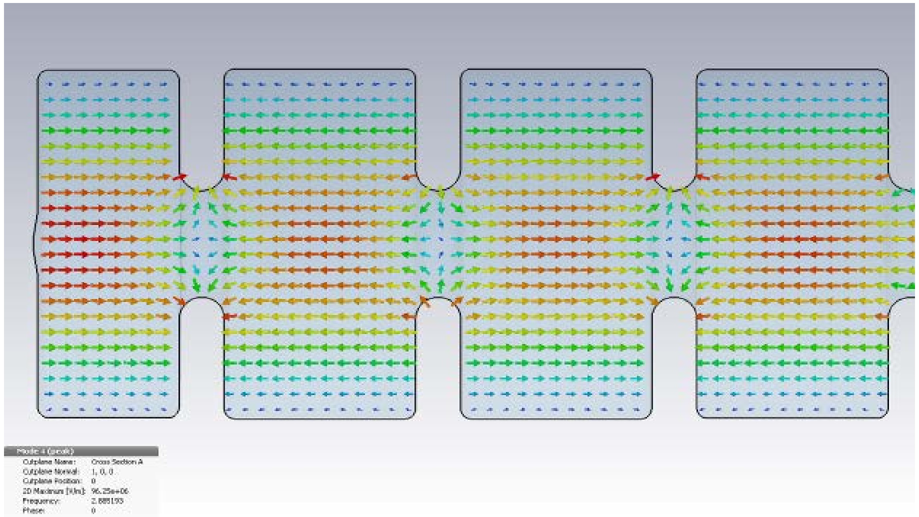


Conclusion

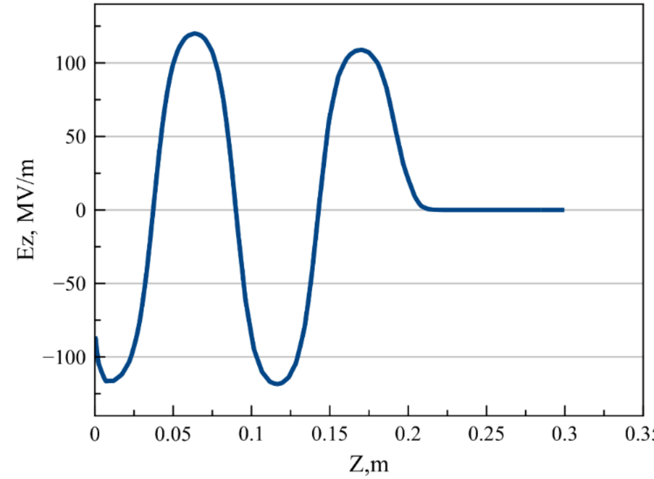
1. The design of parallel coupled accelerating structure allows using the permanent focusing magnets and create the strong magnetic field along the cavities and save the beam size.
2. The travelling tube aperture can be decreased as significantly as it allows the beam dynamics.
3. This design of the RF gun allows us to consider the cavities as independent. The length and field amplitude can be tuned separately for every cavity.
4. Preliminarily results of beam dynamic simulations gave reason to hope that this construction is acceptable solution for high charge generation.
5. 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 and successfully tested.
6. It is currently planned to perform tests the new parallel coupled accelerating structure with 2856 MHz .

But:
There is need for a more detailed analysis of these results.

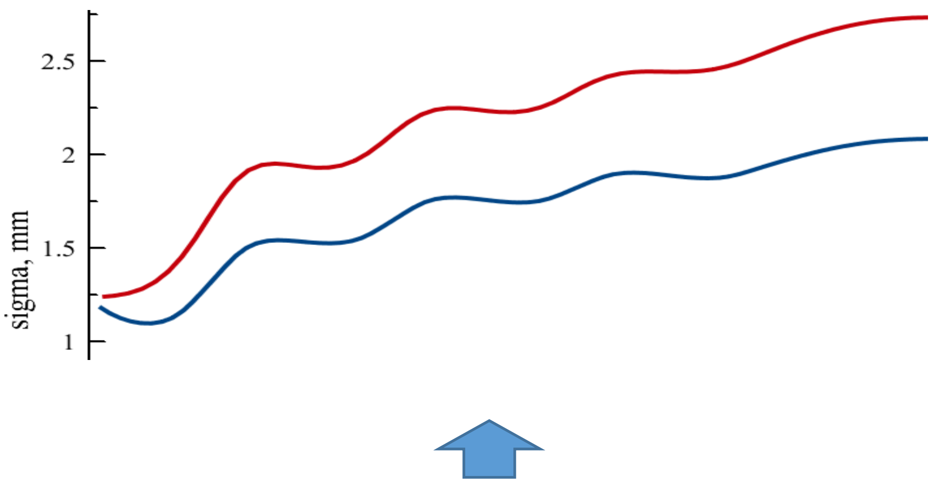
Thank you for attention



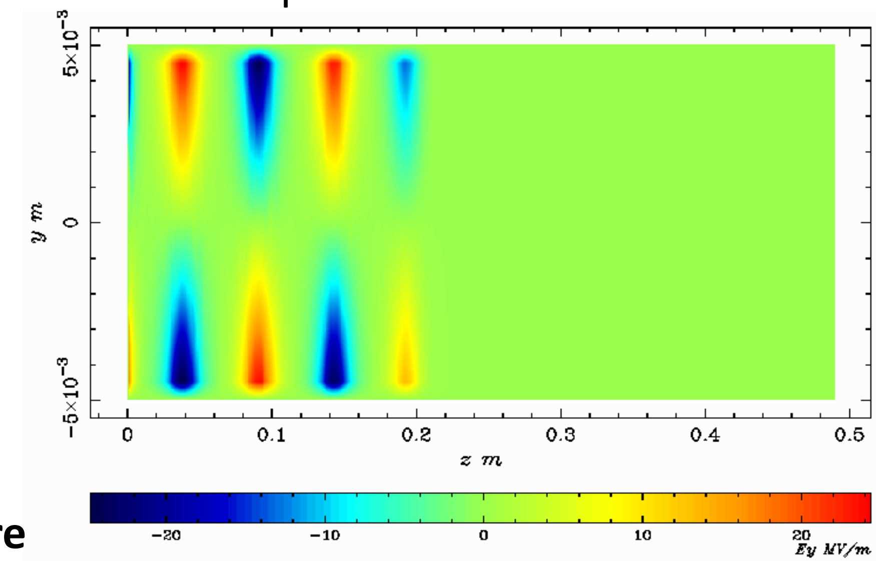
Electric field on axis



Beam envelope along the gun

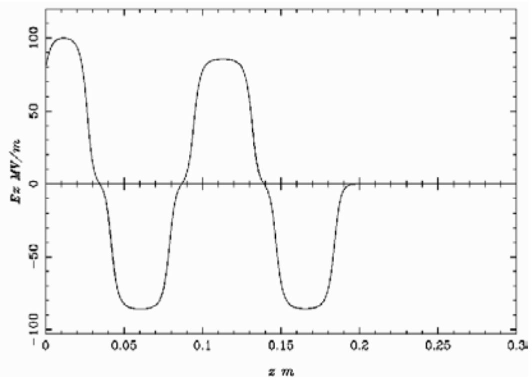


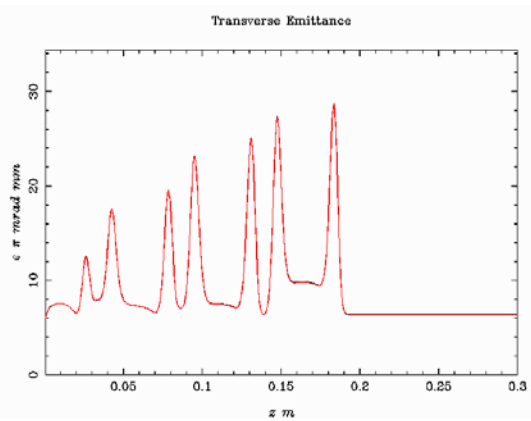
Distribution of the vertical electrical field component near the beam axis

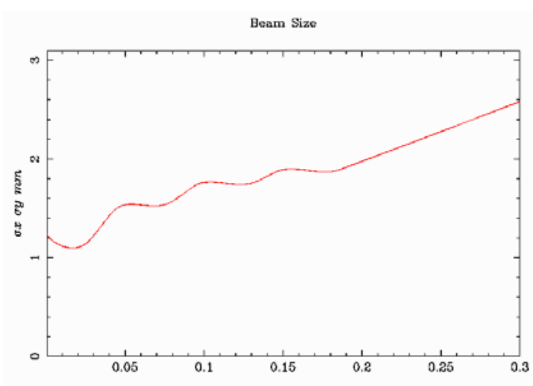


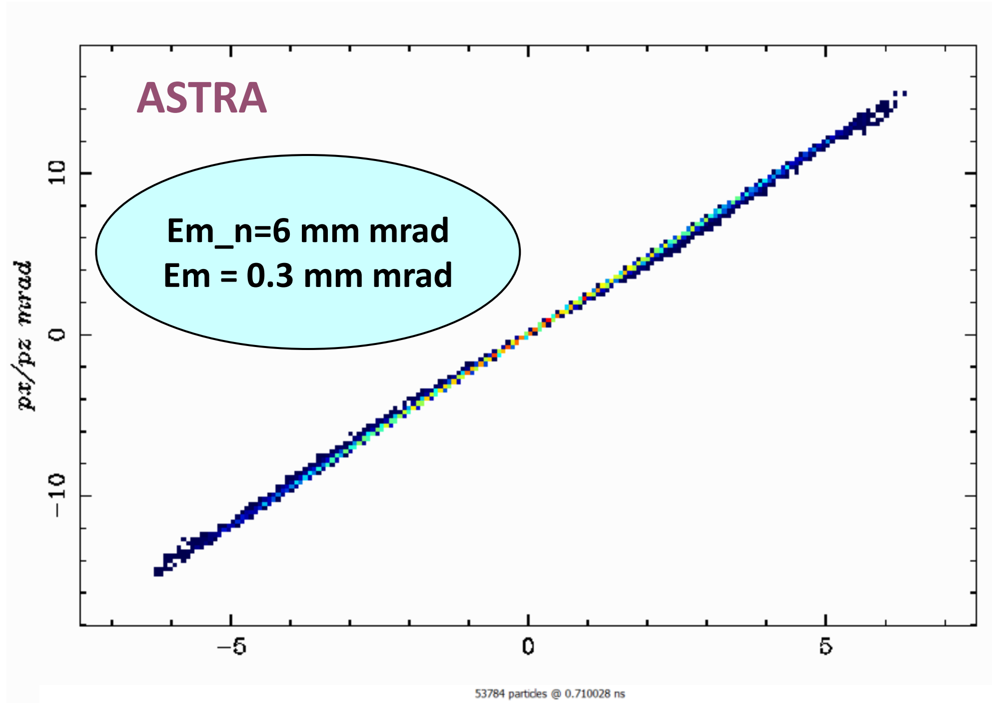
In the last cell beam can occupy a half of aperture

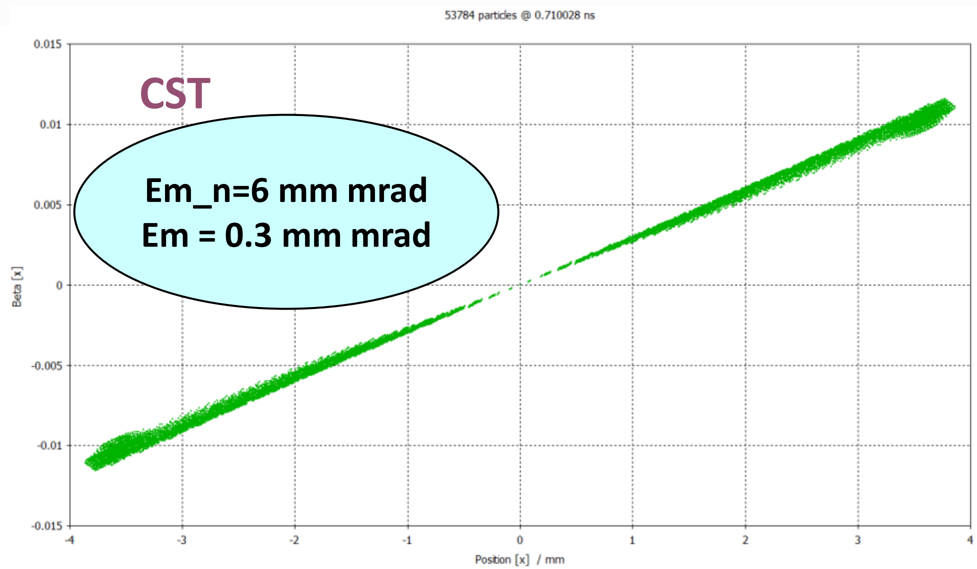
Beam dynamics in the gun without any magnetic fields



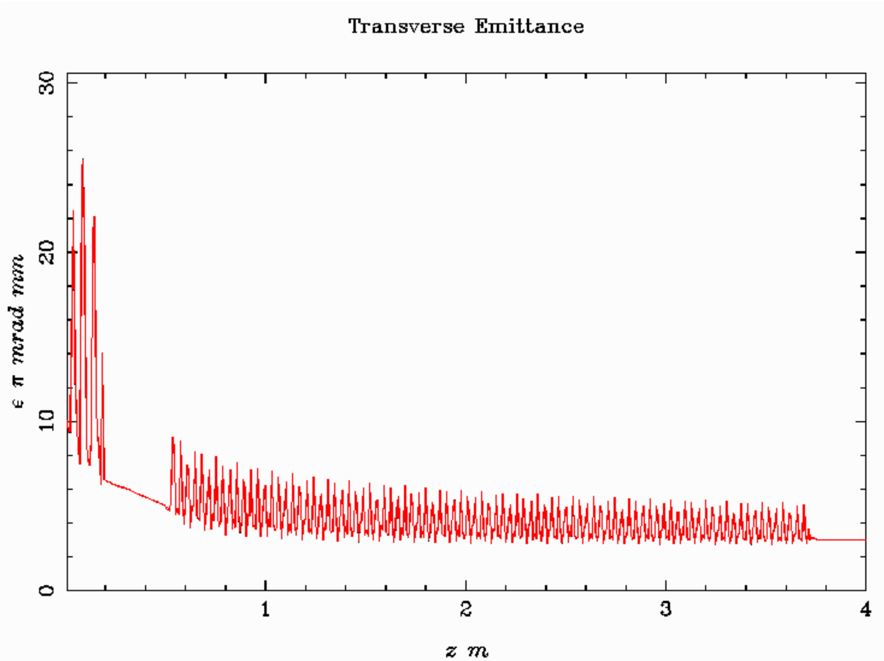


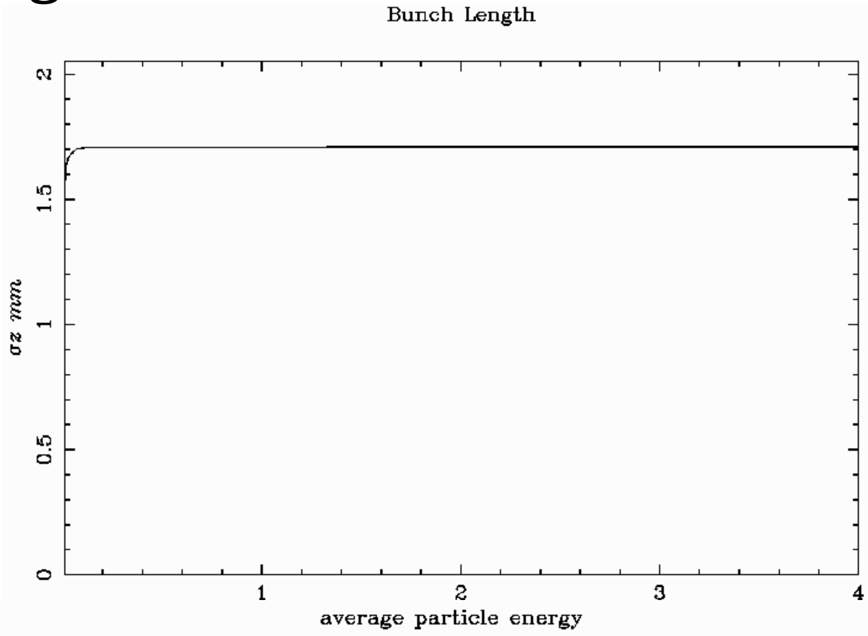


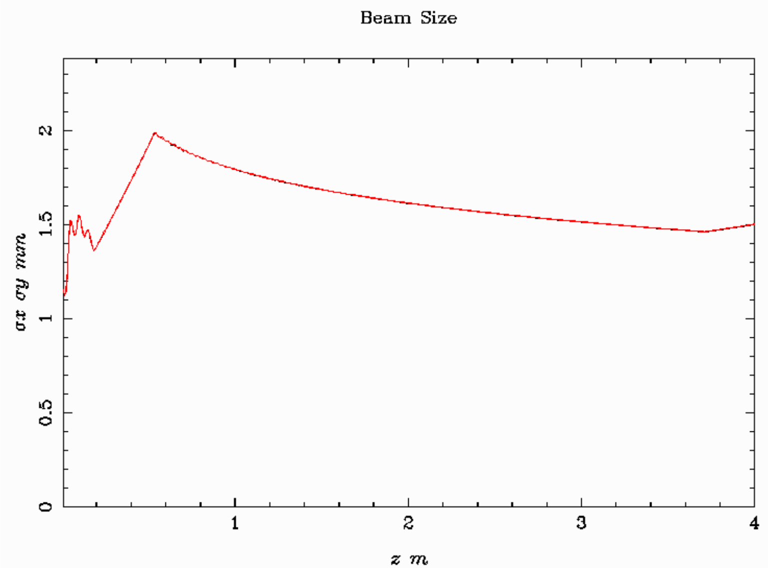


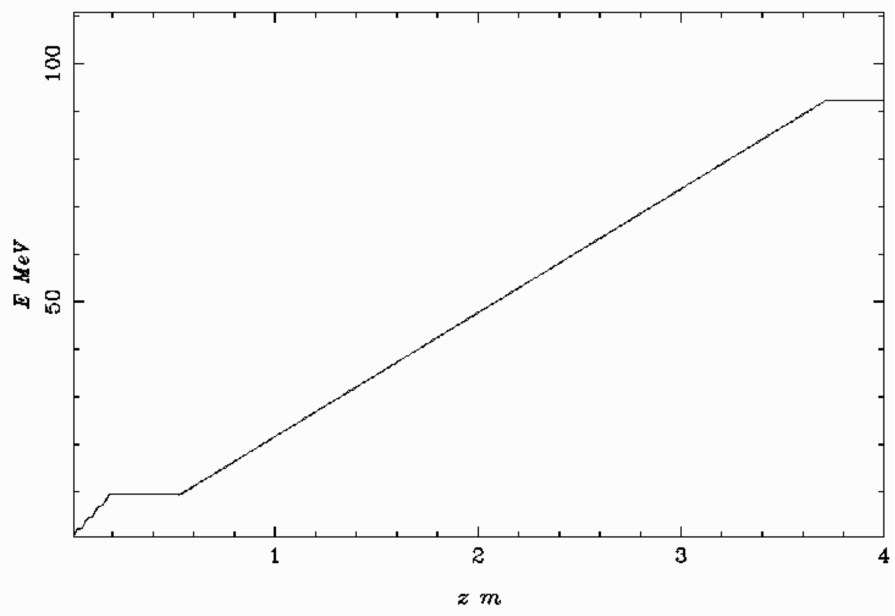


Beam dynamics with permanent magnets and 3 m long TW accelerating structure

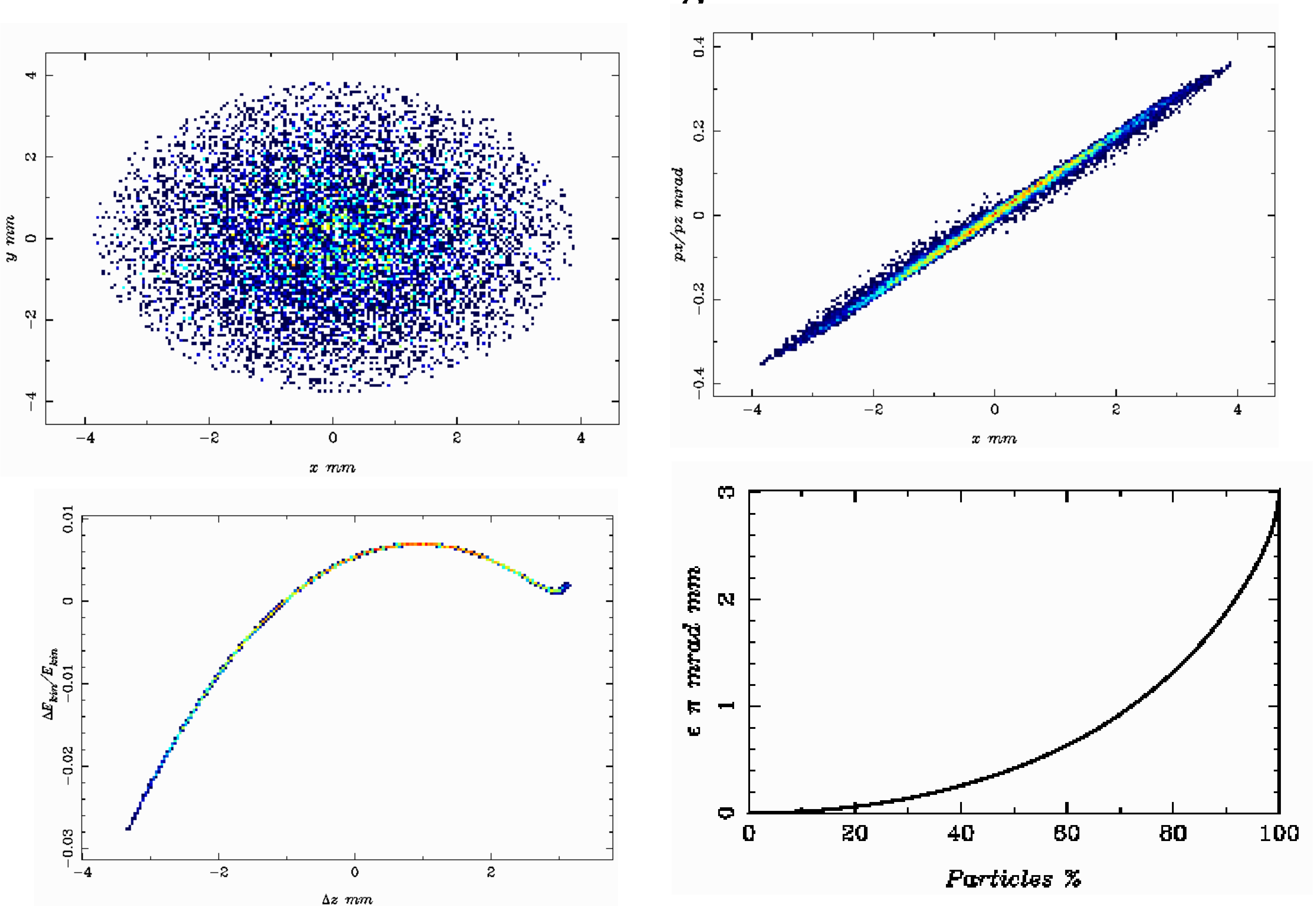








Beam dynamics with permanent magnets and 3 m long TW accelerating structure



IrCe photocathode

D. Satoh and et. al. DEVELOPMENT OF BETTER QUANTUM EFFICIENCY AND LONG LIFETIME IRIDIUM CERIUM PHOTOCATHODE FOR HIGH CHARGE ELECTRON RF GUN. Proceedings of IPAC2013, Shanghai, China

We have been developing a new photocathode material as an electron source for the SuperKEKB electron linac. This injector is required to obtain a low emittance and high charge electron beams in order to achieve the highest luminosity all over the world. The required properties of a new photocathode are reasonably high quantum efficiency (**QE > 10-4**) and high laser durability to achieve a **longterm (> 1 year)** accelerator operation. We succeeded in developing an iridium cerium (**Ir5Ce**) **photocathode** which has a reasonably high QE **(~ 9.1×10-4 @213nm at room temperature**) and long **lifetime** (> **LaB6**). Furthermore, the QE of Ir5Ce photocathode was increased to a maximum value of **2.70×10-3 by heating at 1006 °C**. These great advantages of Ir5Ce photocathode led to generate the electron beams with a maximum charge of **4.4 nC/bunch using a new-type RF gun** at a test bench of KEK electron linac.

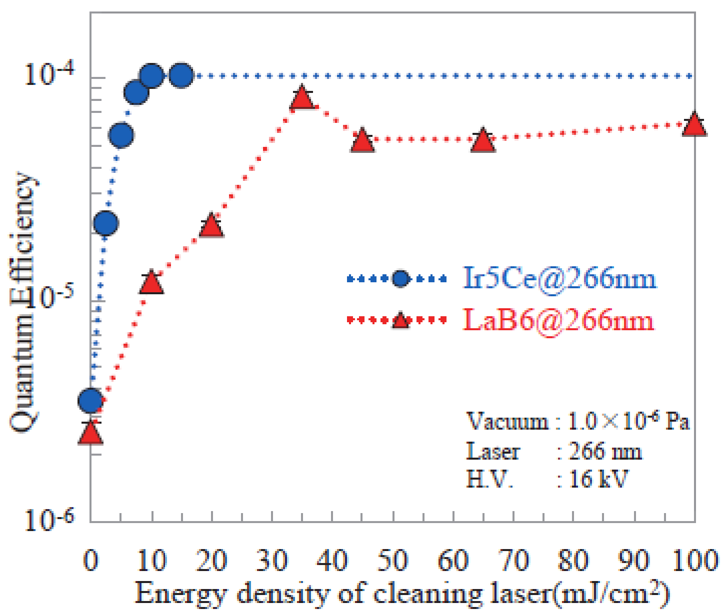


Figure 2: The QE as functions of the scanned energy density of cleaning laser.

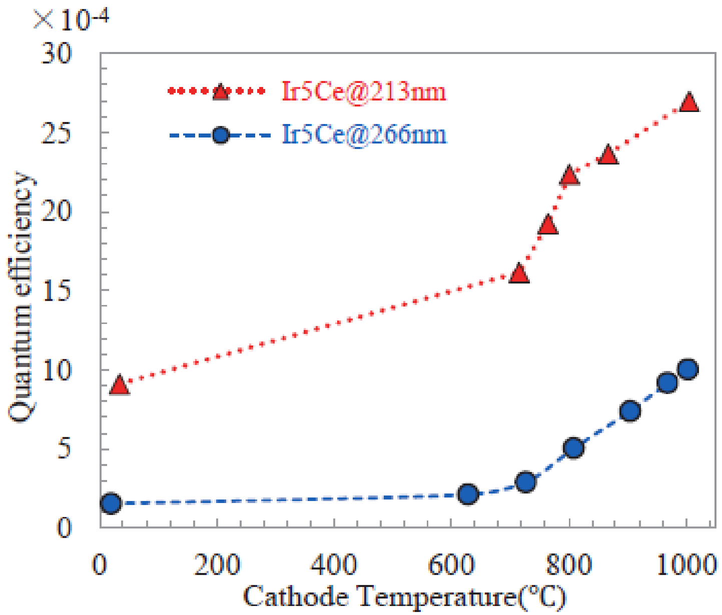
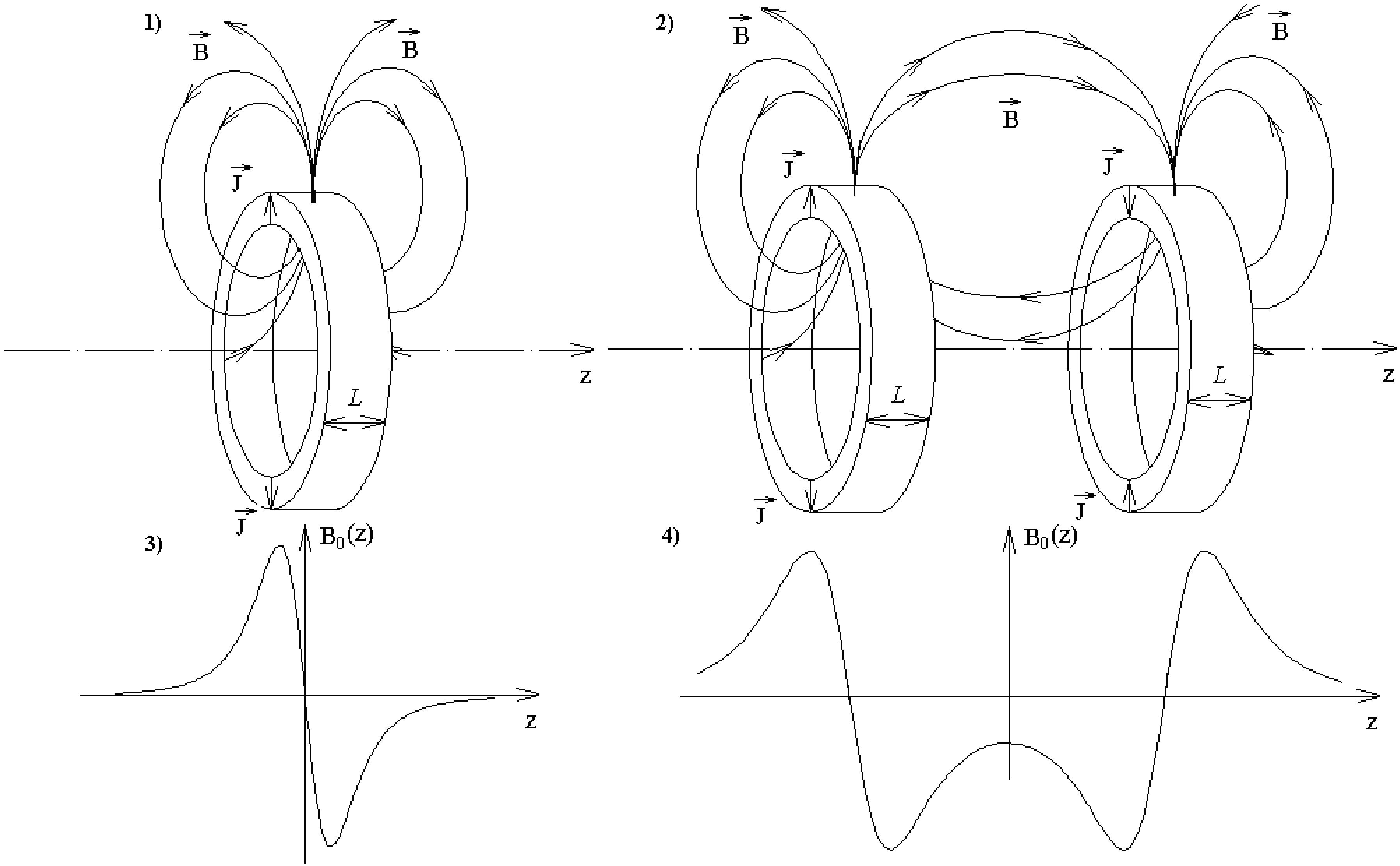


Figure 4: The QE of the Ir_5Ce photocathode as functions of the surface temperatures.


1)
B
B
J
J
L
z
2)
B
B
B
J
J
J
J
L
L
z
3)
B0(z)
z
4)
B0(z)
z