INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES

UBA17

Electron Linear Accelerator Project in Iran

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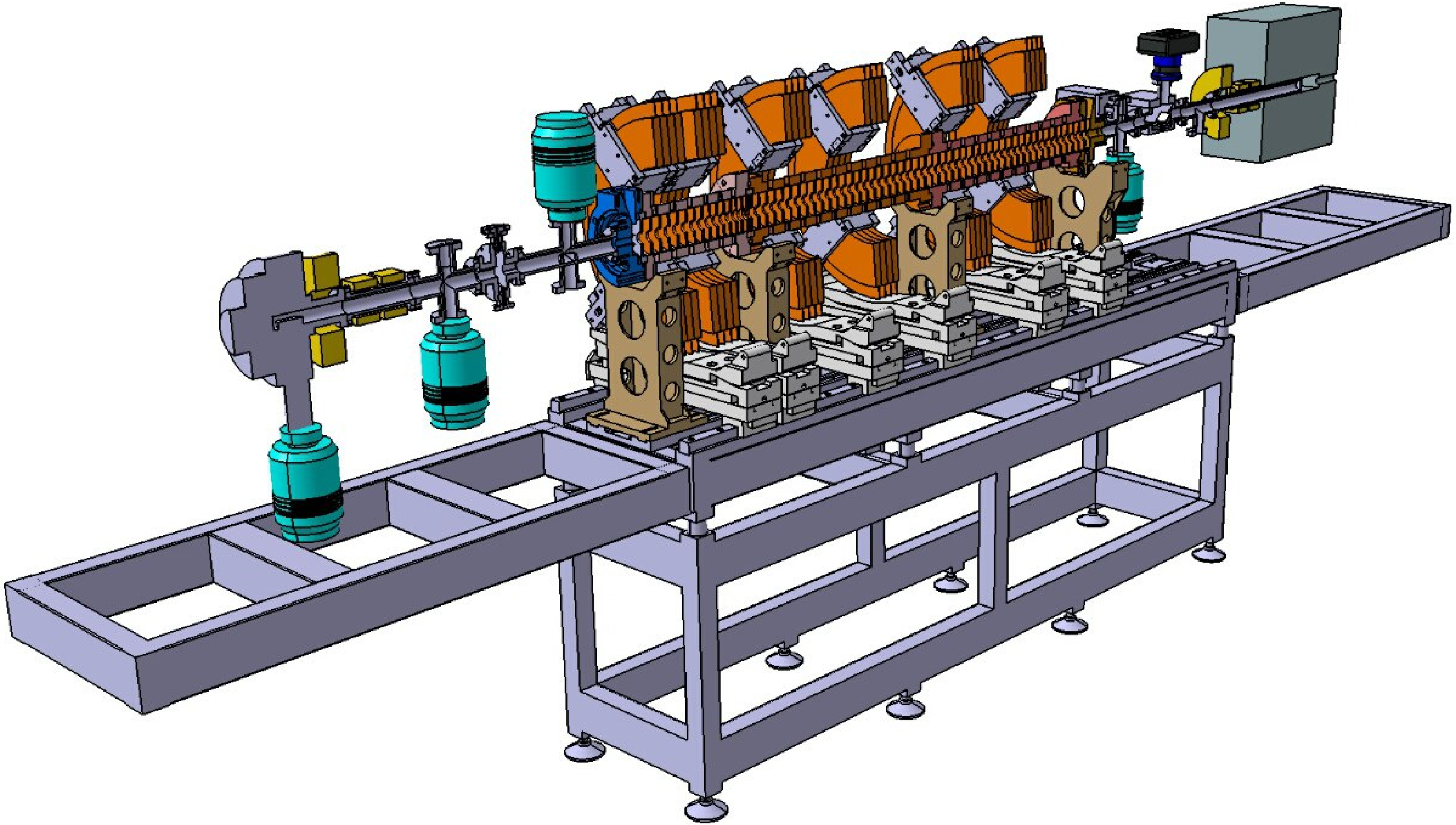
The RF Linear Accelerator as the first accelerator project in Iran

- The main goal of this project was to establish the accelerator knowledge inside the country then it was decided to build it based on the country technology and in the same time build and develop the infrastructure for the future accelerator projects. This decision also comes from the difficulties to access to the foreign companies. This project helped to establish two private companies, one build a compact 15MW modulator and the another one, was equipped to design and build the accelerating cavities. Another two private companies are in the way, one is for the RF components and another one to gather all of these companies to deign, build and commercialize the complete accelerators.

The Linac Layout



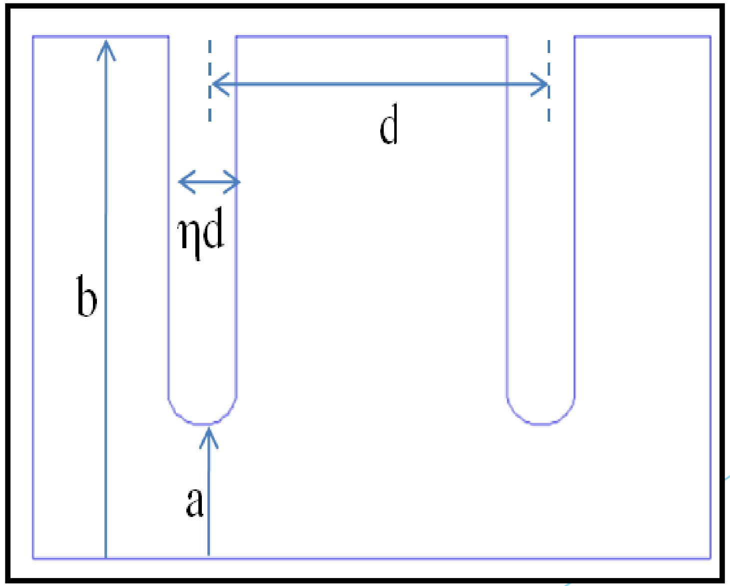
IPM Linac Parameters

Parameter	Magnitude	Unit
Electron Gun Output Energy	45	KeV
Electron Gun Maximum Current	10	mA
Working Frequency	2997.9	MHz
Phase Advance between cells	90	Degrees
RF input peak power	2	MW
Maximum Repetition Rate	250	Hz
Maximum Pulse Length	7	µs
Buncher output beam energy	1.4	MeV
Buncher Length	30.8	cm
Accelerating Tube Length	60	cm
Final Energy (two / three tubes)	8 / 11	MeV
Cells Quality Factor	11000	

The design starts

- The SLAC Two Mile machine was a standard for future electron linear accelerators in the world but based on our capabilities we found the SLAC Mark III is more suitable for us and there was a very good report it. The pi/2 mode and 100mm wavelength was selected.

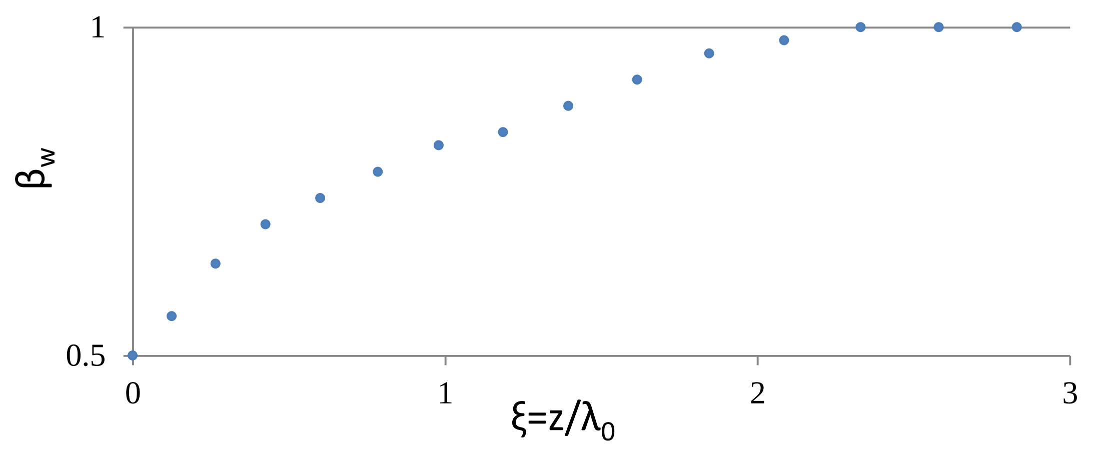
Disk thickness (ηd)	5mm
Cell Inner Diameter (2b)	78.5mm
Cell length (d)	25mm
Working Frequency	2997.9 MHz
Phase/Group velocity	1.0c/0.011c
Main Harmonic axial Electric Field	7.4 MV/m @ 2 MW input power



Low Gradient vs High Gradient

- We had an access to a 2MW klystron build inside the country. Also at that time we are limited to the high vacuum level(~1e-6 Torr) that forced us to start from the low gradient regime. But it was also a good opportunity to us. The low gradient structure is an ideal structures for the bunching system. Historically, after the SLAC Mark III machine the bunching system was mostly forgotten because of going to the higher RF power and higher gradients and the bunching efficient became less important. Our team in IPM also used the knowledge attained in the bunching system design at the CLIC Drive Beam Injector and the final result was about one order better than previous designs. As another example, looking deeply to the bunching mechanism led to the high efficiency klystrons studies by the HEIKA group.

Beam Dynamic Study - I

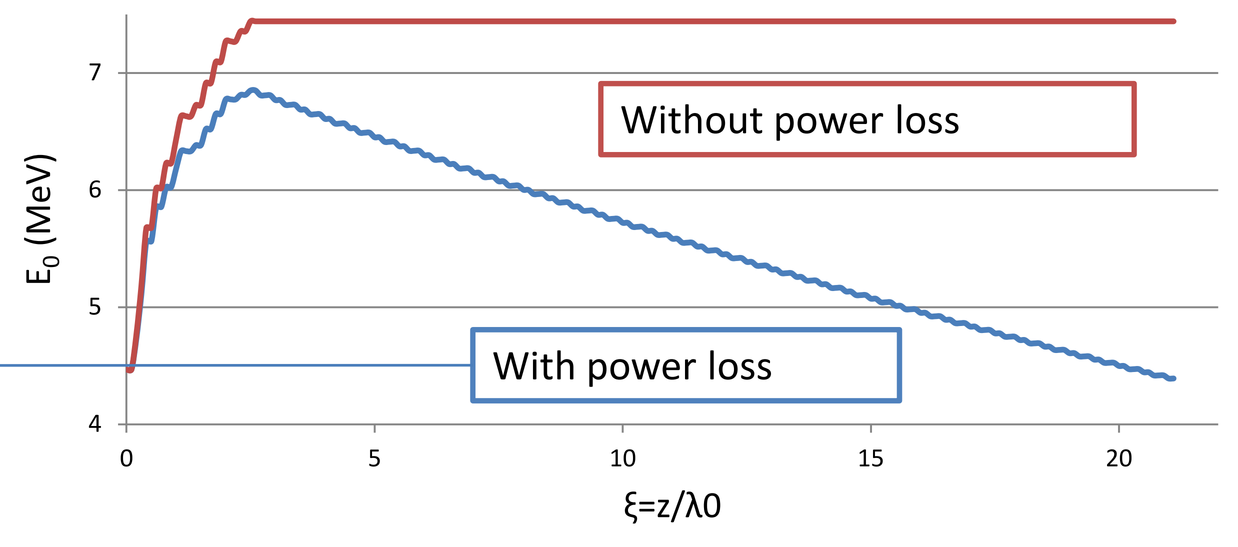


Inside the buncher, phase velocity increases smoothly to reach to the velocity of light.

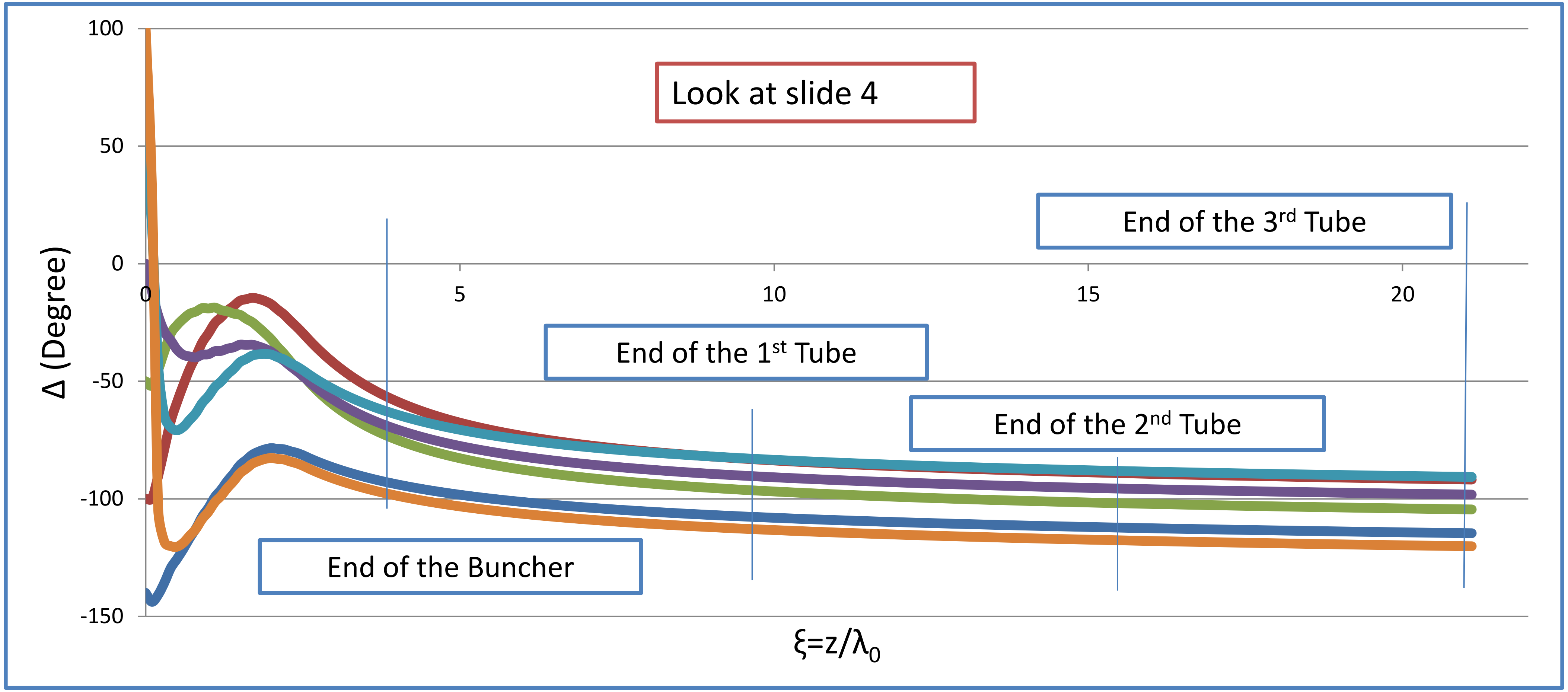
$$\begin{cases} \dfrac{a^4 \alpha^2}{\beta_w} f(k_r a) = constant\ ;\ \alpha = \dfrac{E_0 e \lambda_0}{m_0 c^2} \\ f(k_r a) = \dfrac{8}{(k_r a)^2}\left[J_1{}^2(k_r a) - J_0(k_r a) J_2(k_r a)\right] \end{cases}$$

After choosing phase velocity inside the buncher, the accelerating field (without loss)is calculated using this equation. The disk hole radius(a) is equal to 10.00 mm.

$$\begin{cases} E(z) = E_0(z) e^{-Iz} \xrightarrow{z=L=2.1195m} E(L) = 0.59 E_0(L) \\ \Rightarrow \dfrac{P_f}{P_i} = 0.59^2 = 0.35 \Longrightarrow P_f = 700\ kW \\ I = \dfrac{\omega}{2 v_g Q} = \\ \dfrac{2\pi \times 2997.92\ MHz}{2 \times 0.01158 \times 2997.92 \times 10^5 \times 10908.9} = 0.2487\ (\dfrac{1}{m}) \end{cases}$$



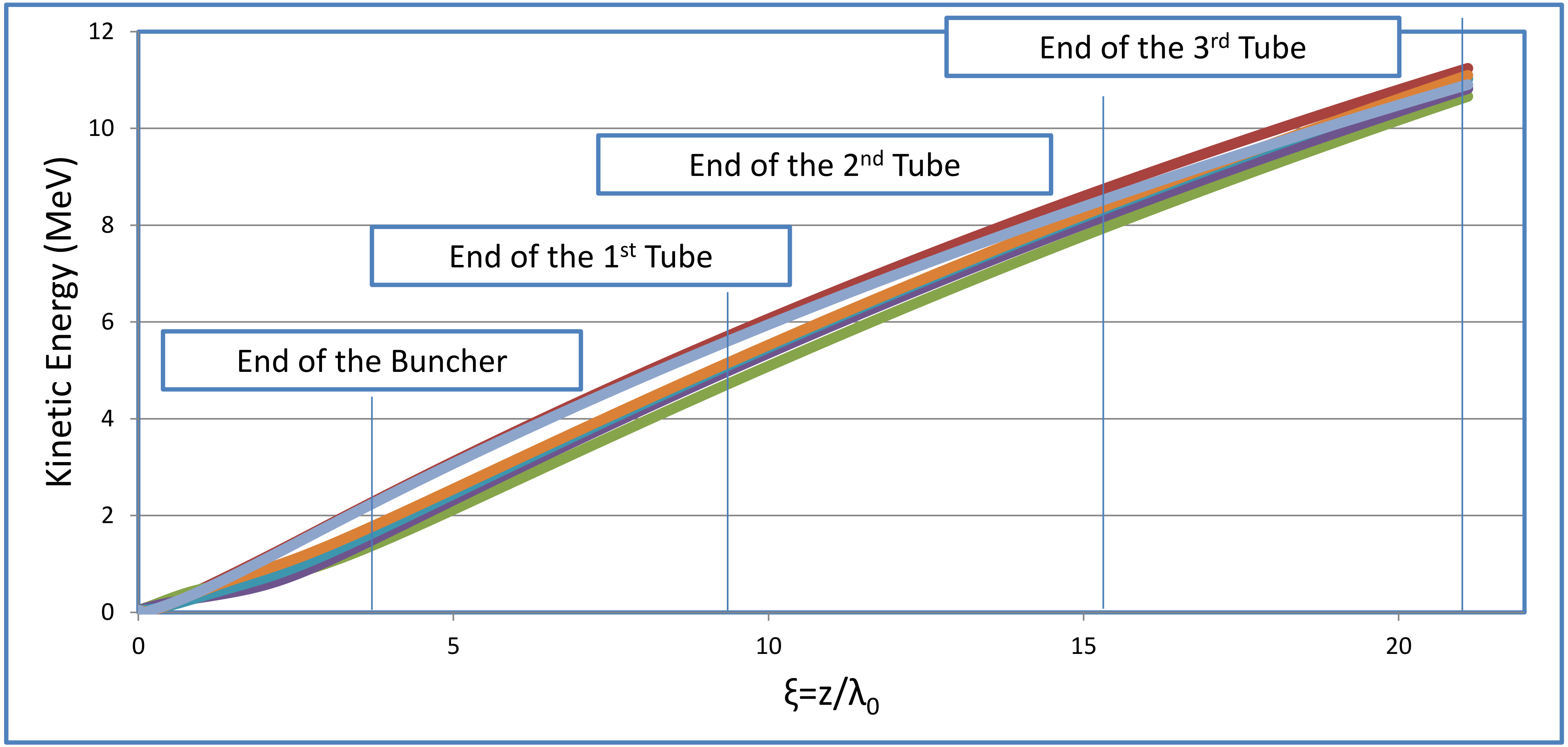
Beam Dynamic Study - II



$$\begin{cases} \dfrac{d\Delta}{d\xi} = 2\pi\left(\dfrac{1}{\beta_w} - \dfrac{1}{\beta_e}\right);\ \xi = \dfrac{z}{\lambda_0} \\ \dfrac{d\gamma}{d\xi} = -\alpha \sin(\Delta)\ ;\ \gamma = \dfrac{1}{(1-{\beta_e}^2)^{\frac{1}{2}}} \end{cases}$$

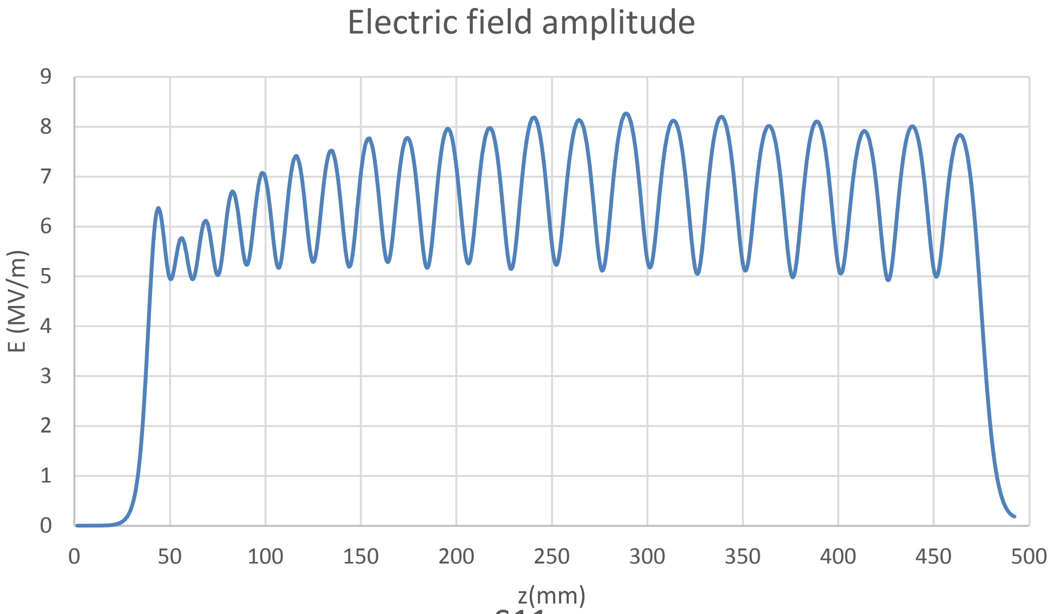
-97.24±7.54 deg (final distribution) ≈ 4.2 mm bunch length
Capturing: -142 … 102 : 244 deg (68%)
Continues beam is entered: No pre-buncher is assumed.

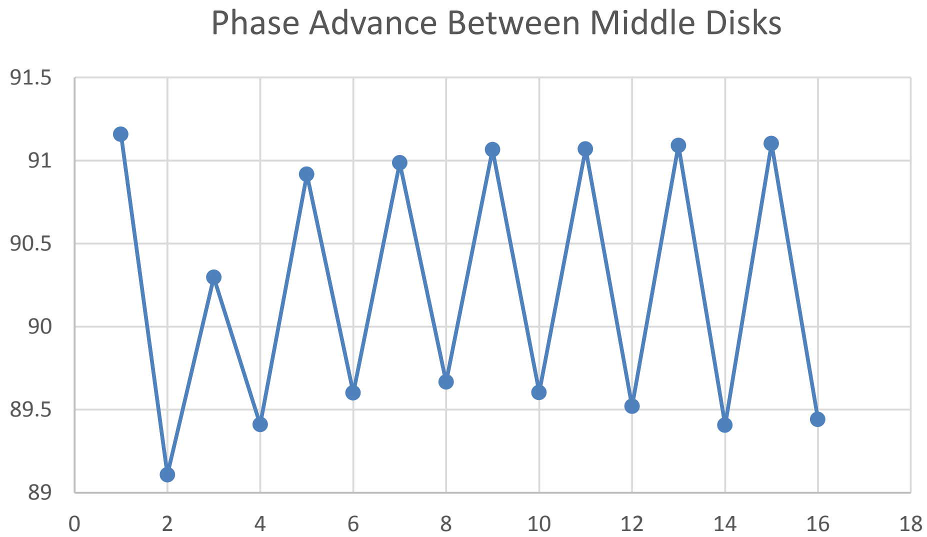
Beam Dynamic Study - III

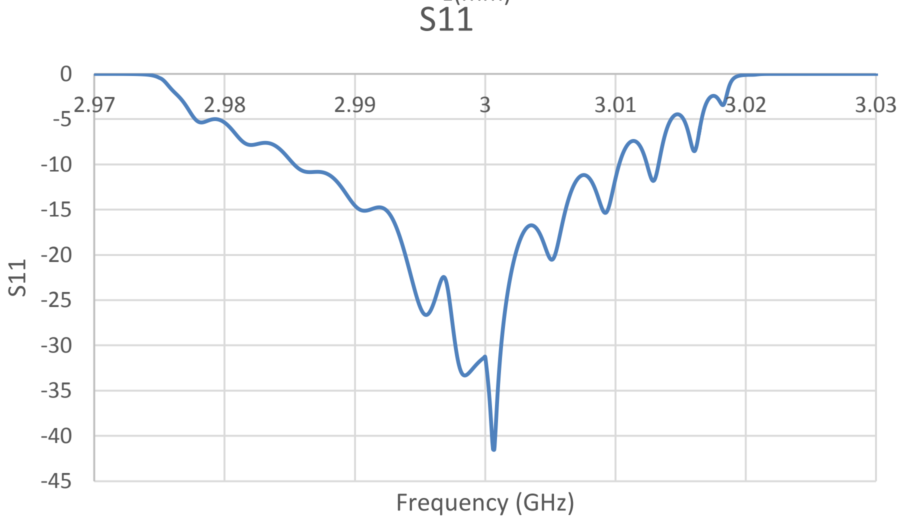


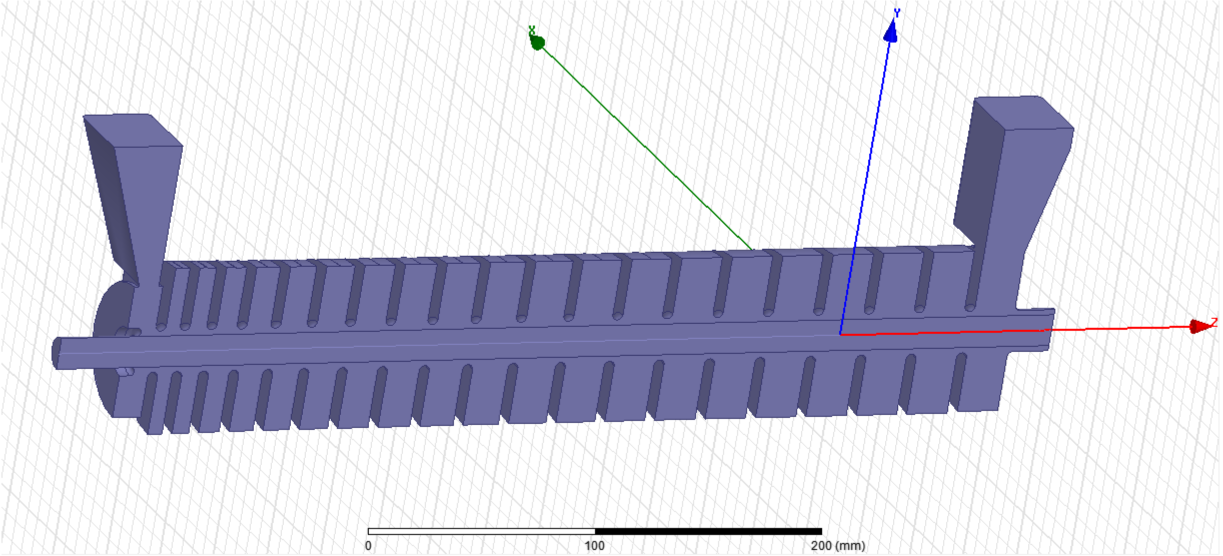
Final Kinetic Energy: 11.04±0.26 MeV or 2.3% Energy Spread

RF Structure Design



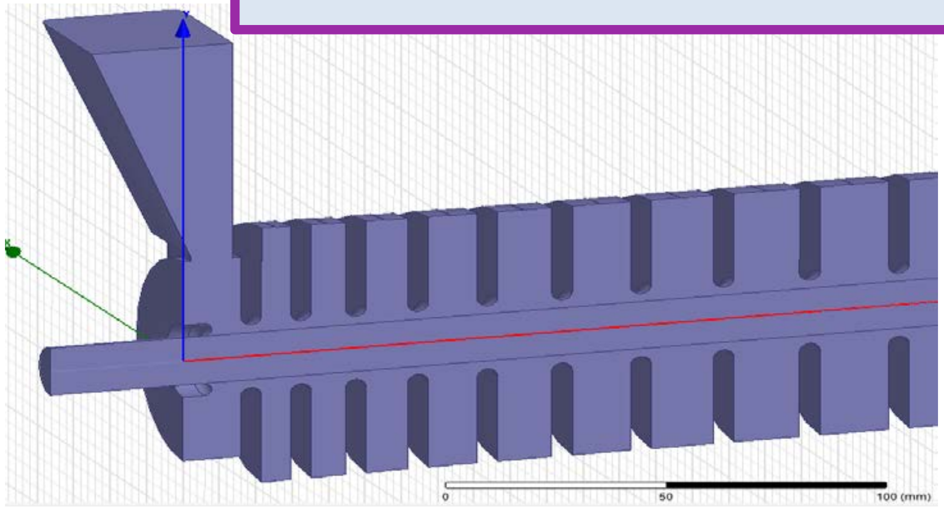


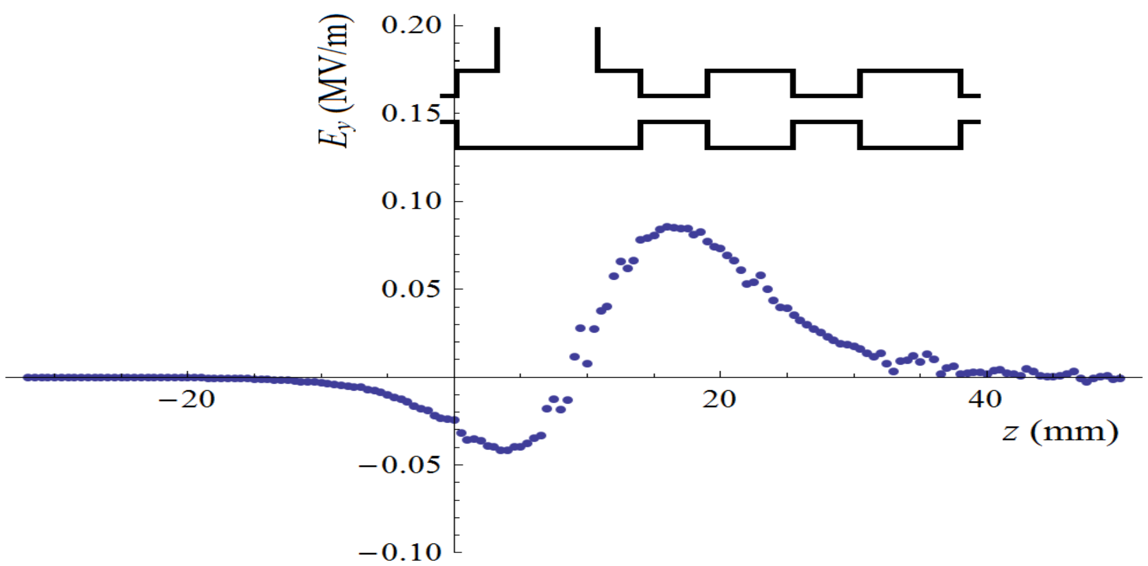


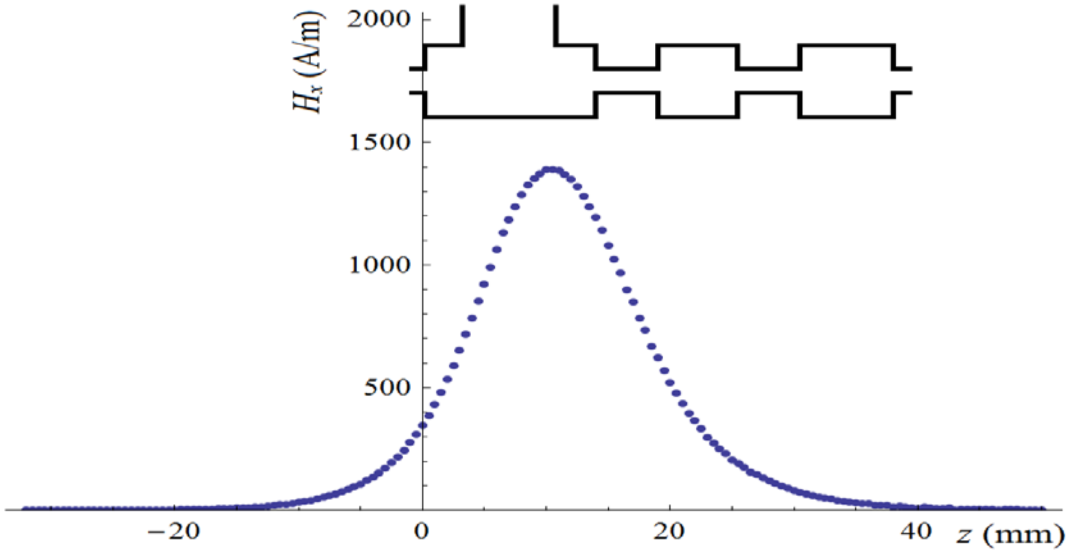


1.1 Induced kick

Necessity of 3D modeling ⟹ **ASTRA**



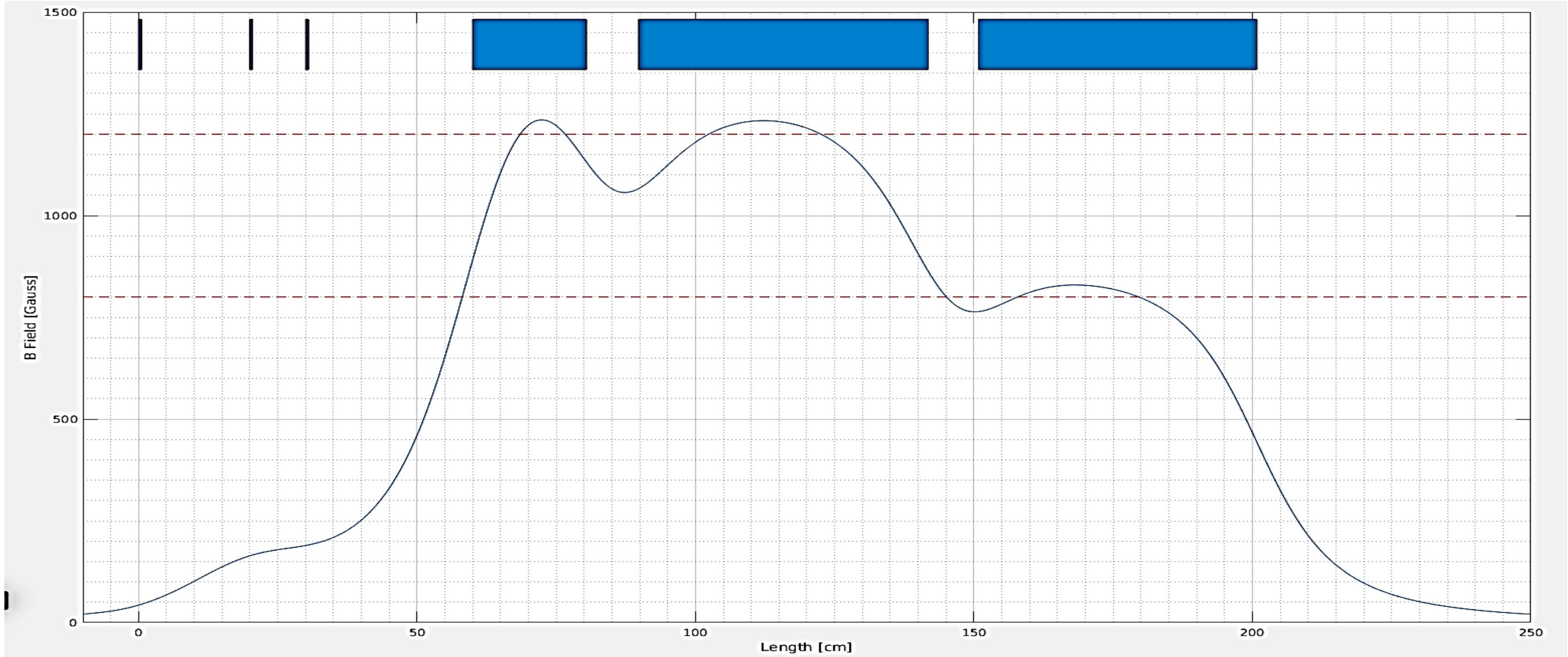




3.3 Misalignment Studies

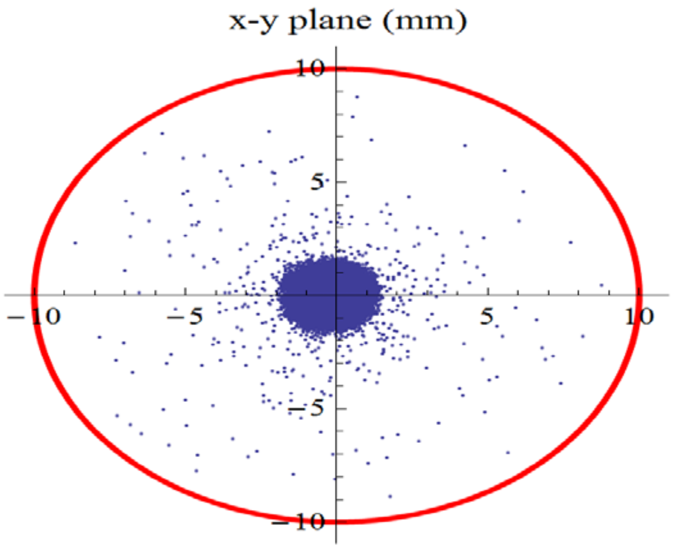
➢ What to do?

1. Extend the strange buncher field sligthly more. Then the beam dynamics will be less sensitive to misalignments!

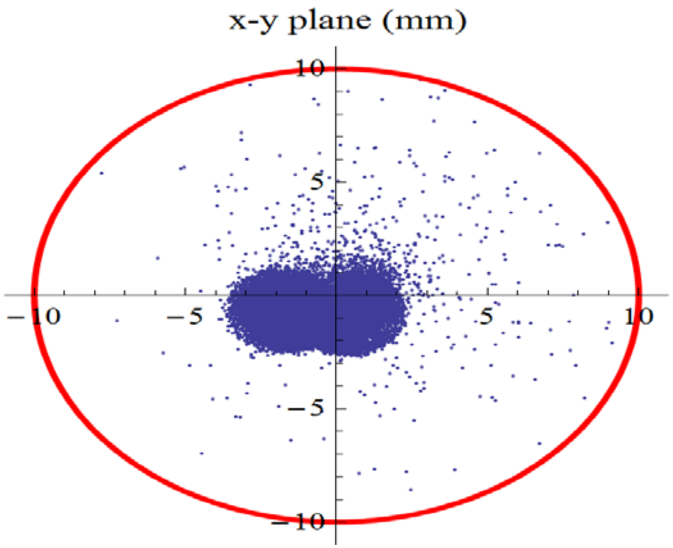


3.3 Misalignment Studies

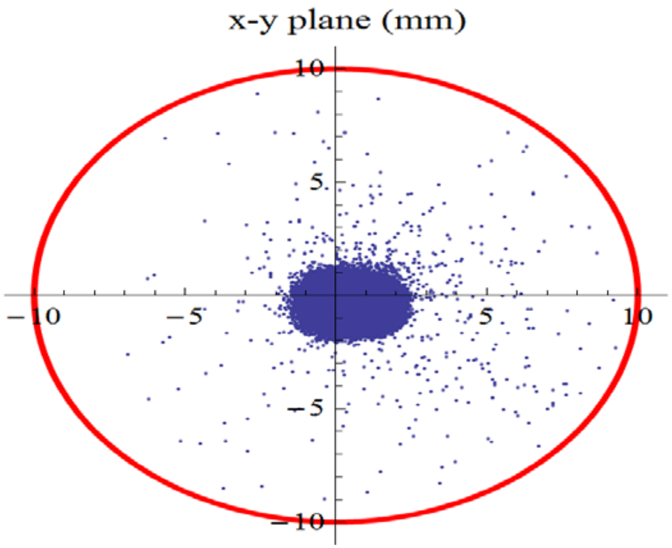
- $B \approx$ 1200-800 G



No misalignment
$\varepsilon \sim 5$ mm-mrad



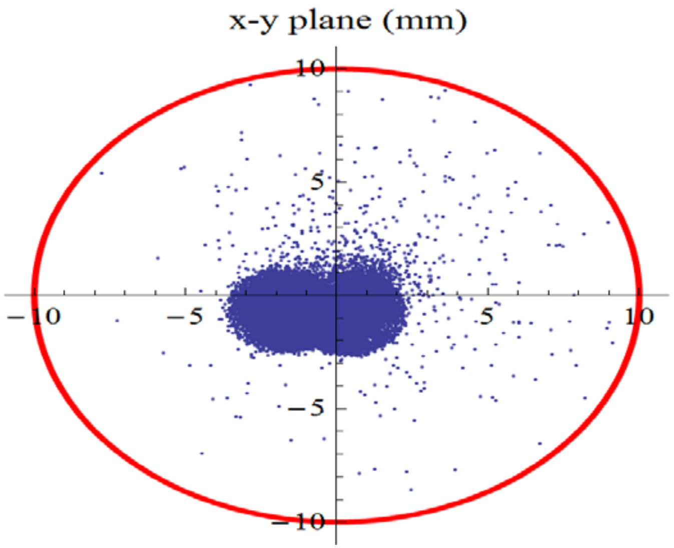
Offset
$\varepsilon \nearrow$ 500%



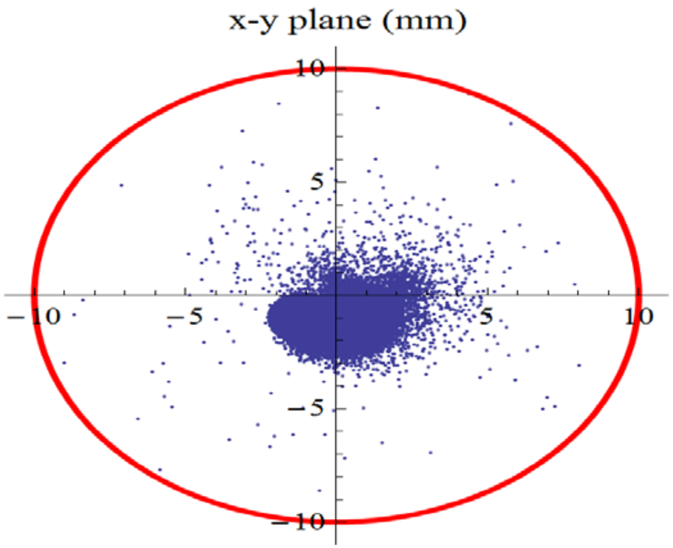
Tilt
$\varepsilon \nearrow$ 300%

3.3 Misalignment Studies

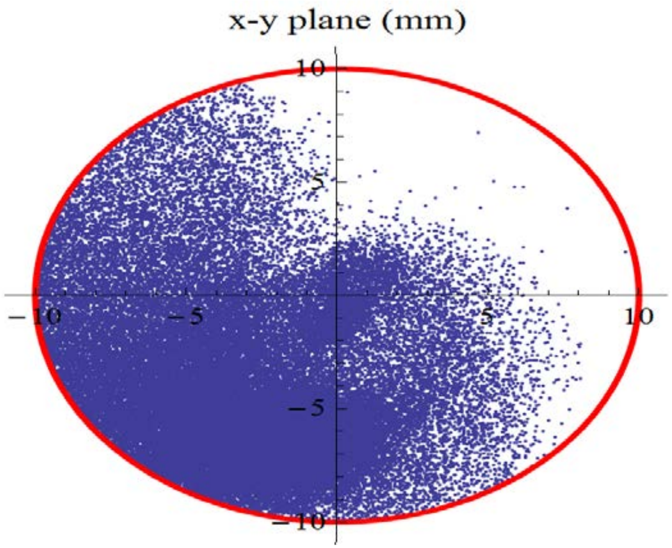
- Offset



$B \approx$ 1200-800 G



B ↙ 20% (≈ 1000-650 G)

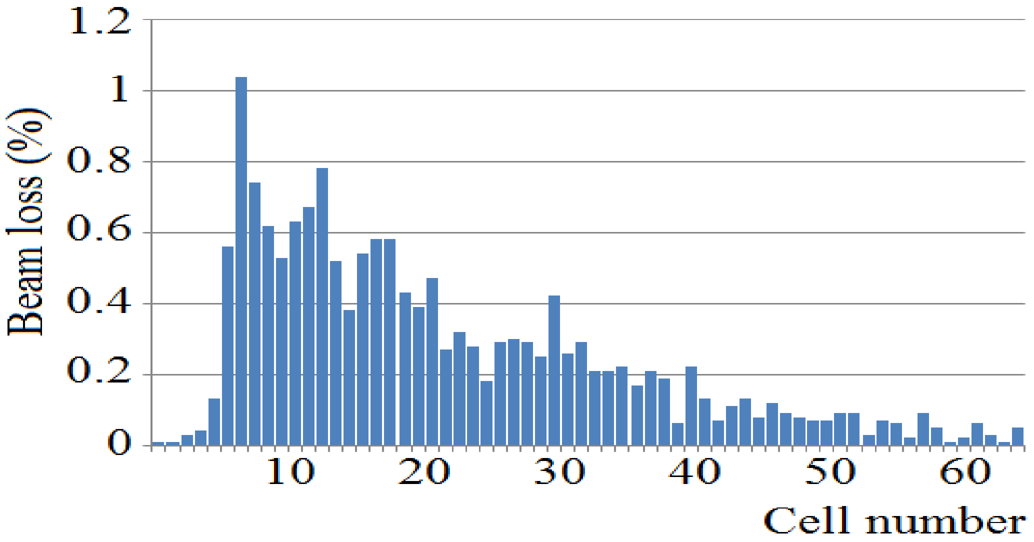


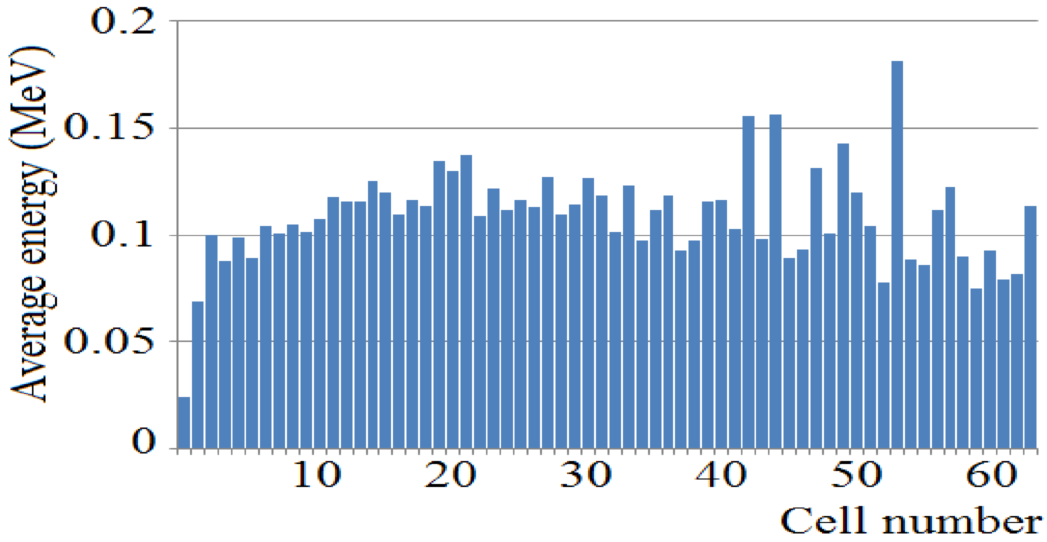
B ↙ 40% (≈ 700-500 G)
55% Beam loss

Target beam size of 0.5 mm & 1 mm & 2 mm

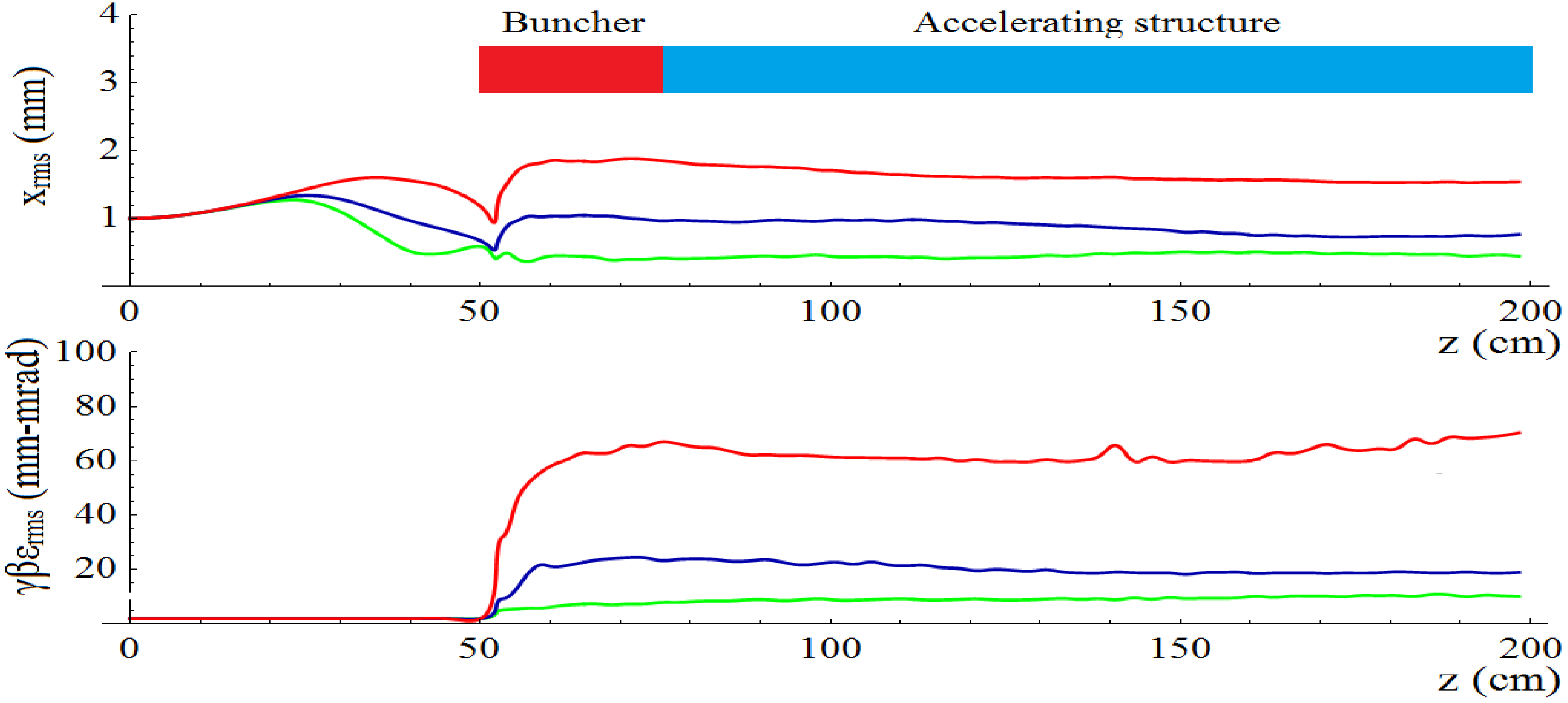
Target beam size	0.5 mm	1 mm	2 mm
Beam loss	3.6%	16%	22%
Average Magnetic field	1400 G	835 G	689 G
Final emittance	10 mm-mrad	19 mm-mrad	70 mm-mrad

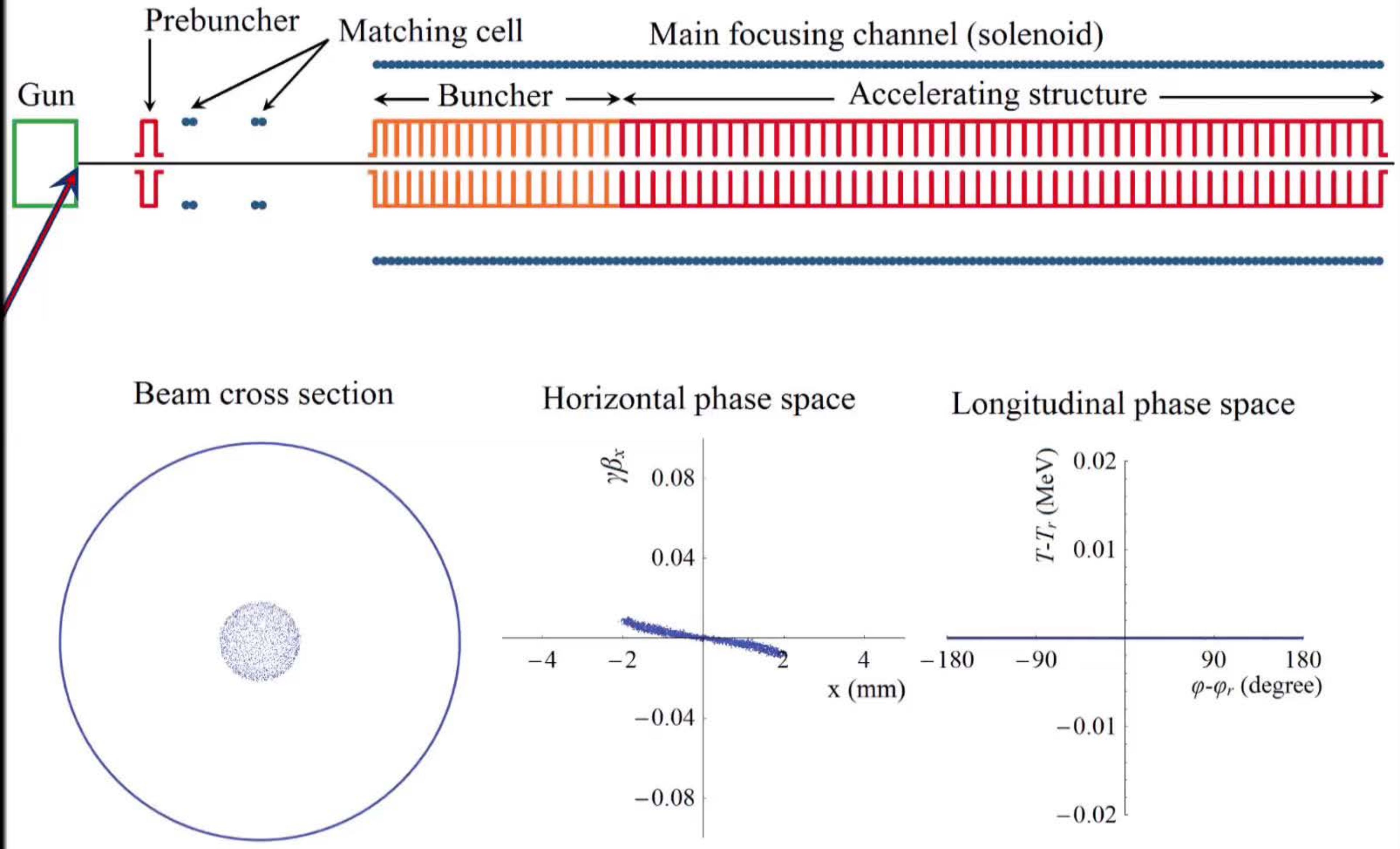
Beam loss distribution





Target beam size of 0.5 mm & 1 mm & 2 mm





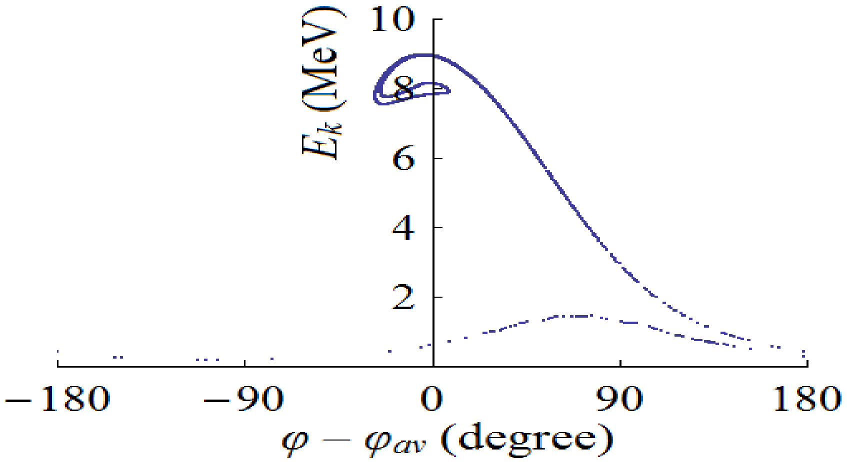
Prebuncher
Matching cell
Main focusing channel (solenoid)
Gun
Buncher
Accelerating structure
Beam cross section
Horizontal phase space
Longitudinal phase space
γβx
0.08
0.04
−0.04
−0.08
−4
−2
2
4
x (mm)
T-Tr (MeV)
0.02
0.01
−0.01
−0.02
−180
−90
90
180
φ-φr (degree)

New buncher design

> **Good bunching system is an alternative to the Photocathode RF Gun without laser costs and difficulties especially for multi-bunches operation. We are working on it.**

1. The need for a new buncher

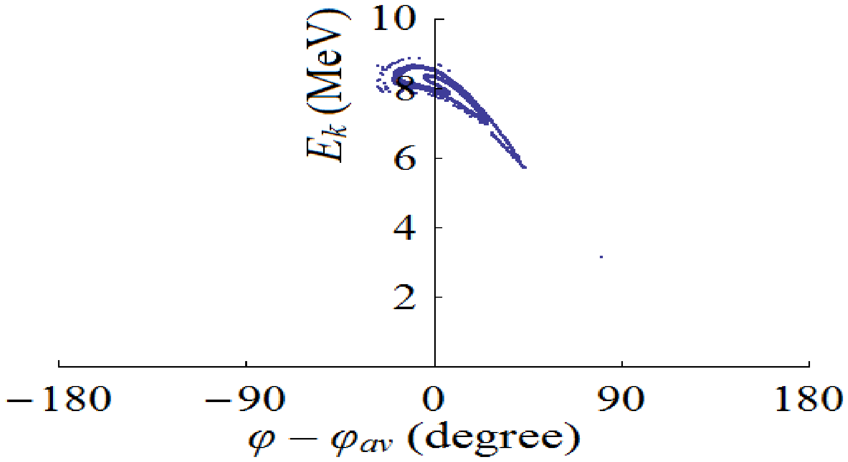
- History of the buncher design.



$\sigma_\varphi = 15.2°$

$\sigma_{E_k} = 0.61\ Mev$

$L_B = 40\ cm$



$\sigma_\varphi = 11.3°$

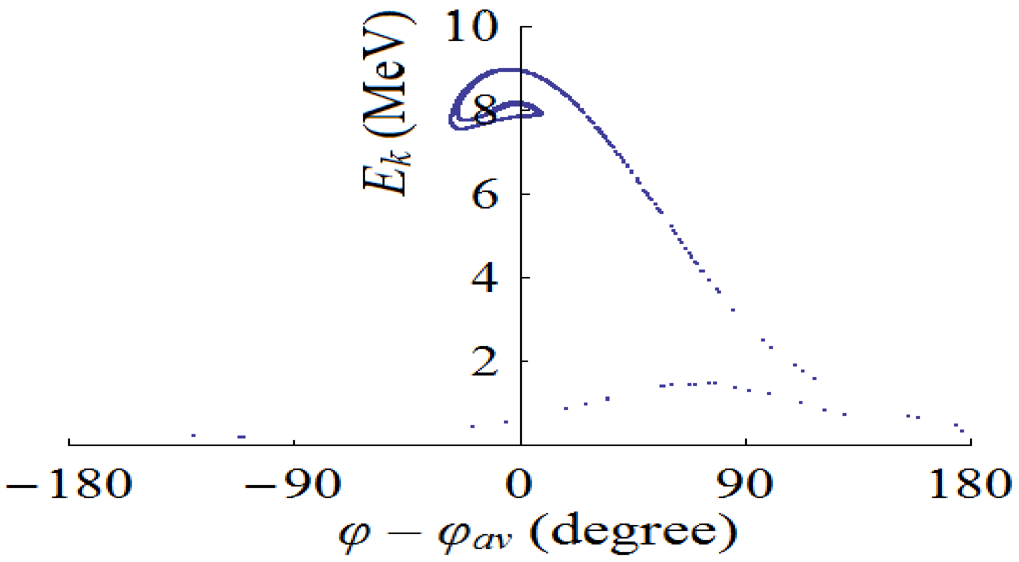
$\sigma_{E_k} = 0.41\ Mev$

$L_B = 50\ cm$

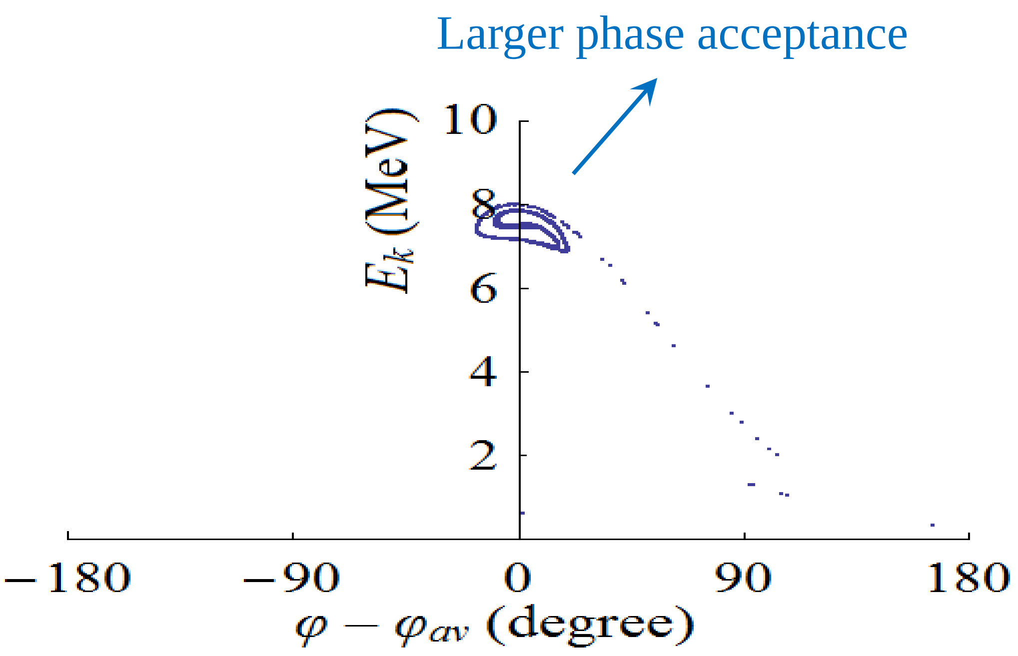
- Distortion of the geometry of some cells of the existing buncher through the fabrication process.
- The feasibility of cavity fabrication using the brazing techniques.
- Looking for a new design with higher performance (higher beam quality) and no kick.

2.1 New buncher

- Beam parameters and comparison with previous designs
  - ✓ L = 40 cm (Pre-buncher included)



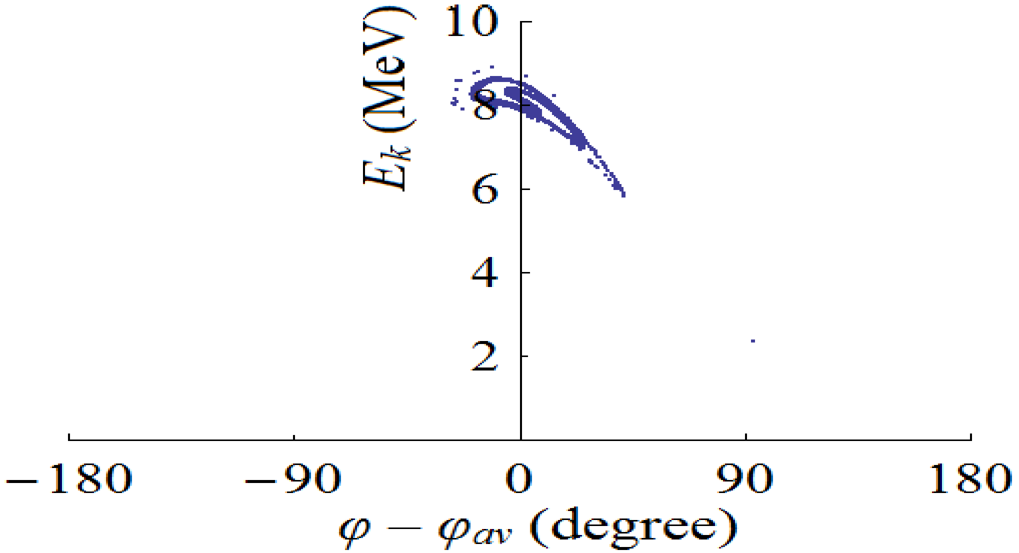
$\sigma_\varphi = 9.2°$
$\sigma_{E_k} = 0.30\ MeV$
$E_{av} = 8.0\ MeV$



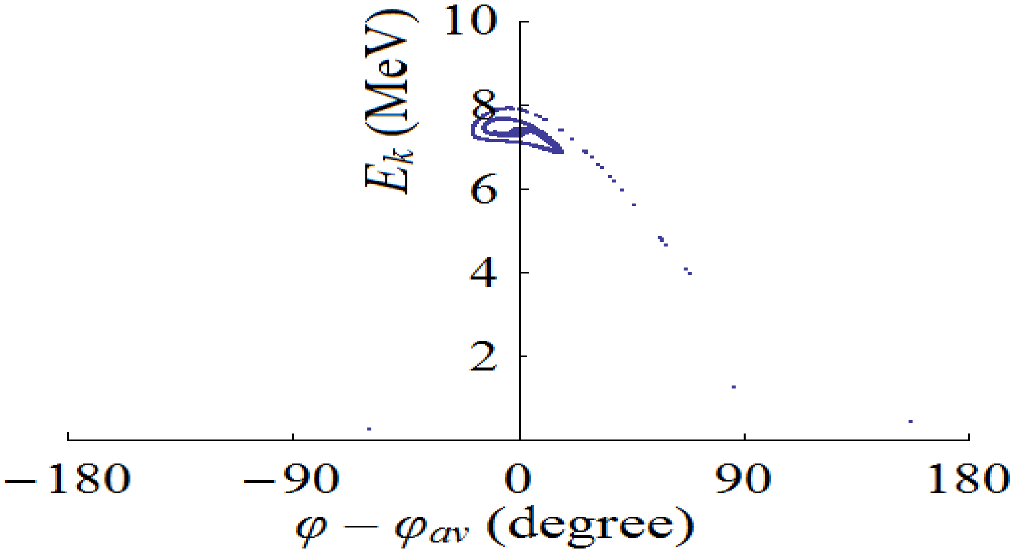
$\sigma_\varphi = 7.0°$
$\sigma_{E_k} = 0.17\ MeV$
$E_{av} = 7.5\ MeV$

2.2 New buncher

- Beam parameters and comparison with previous designs
  - ✓ L = 50 cm (Pre-buncher included)

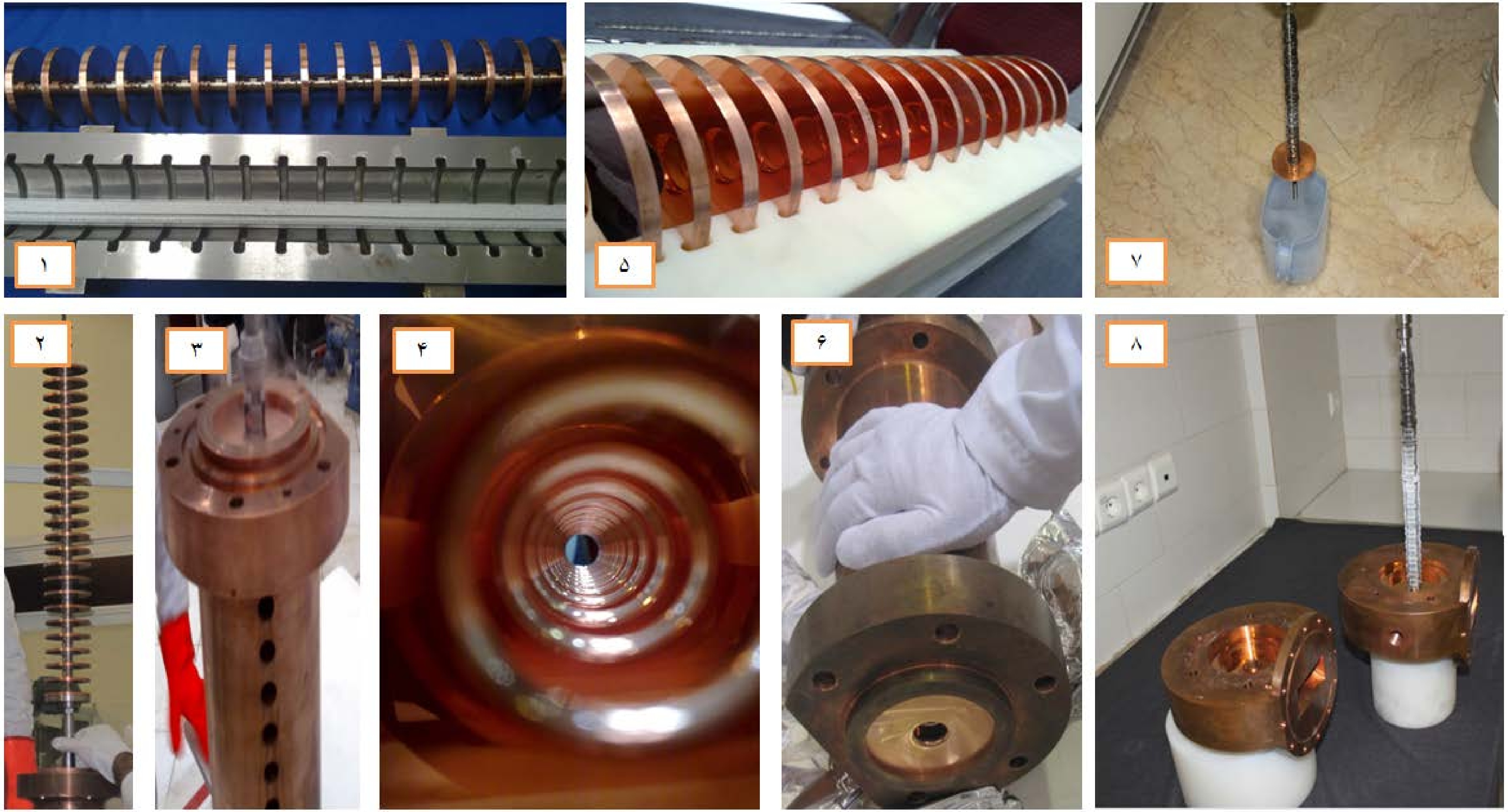


$\sigma_{\varphi} = 6.8°$
$\sigma_{E_k} = 0.27 MeV$
$E_{av} = 8.1\ MeV$



$\sigma_{\varphi} = 5.9°$
$\sigma_{E_k} = 0.12\ MeV$
$E_{av} = 7.3\ MeV$

Cavities Fabrication

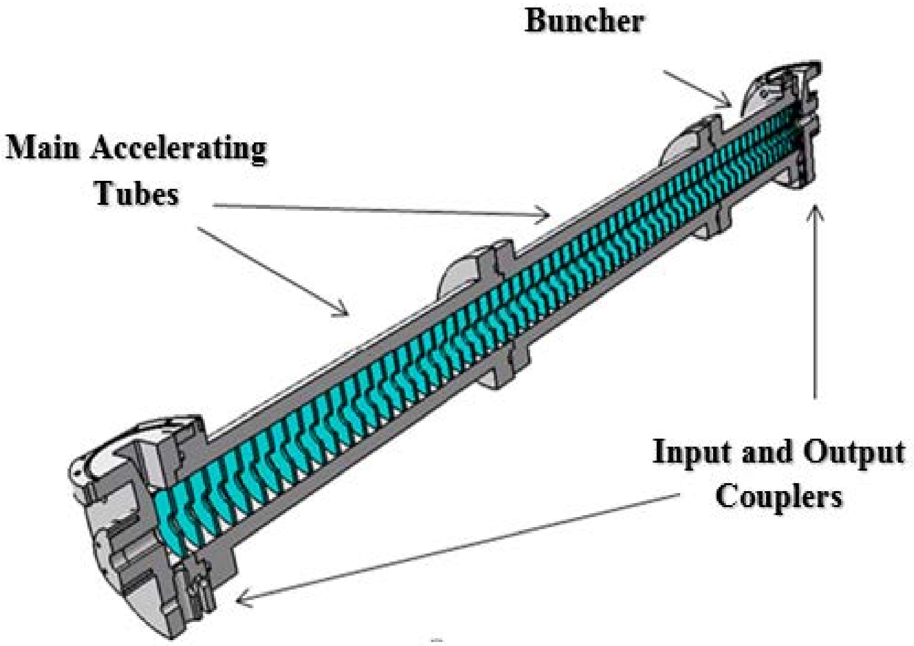


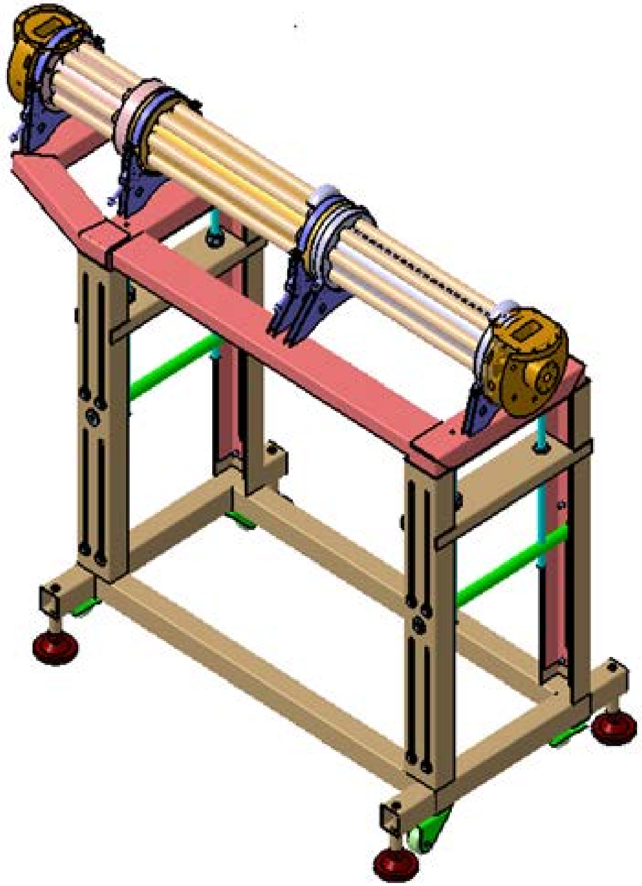
مراحل مونتاژ قسمت‌های تیوب شتابدهی به روش انقباضی؛ ۱- بستن دیسک‌ها بر روی فیکسچر و جدا کردن آن‌ها از پایه صفحه‌ها برای مونتاژ تیوب دوم، ۲- هم‌ترازی فیکسچر و تیوب دوم، ۳- جازدن صفحه‌ها در تیوب دوم، ۴- تصویری از داخل تیوب بعد از جدا کردن فیکسچر(صفحه‌ها بخوبی مشخص‌اند)، ۵- پایه نگه‌دارنده صفحه‌های بانچر(صفحات بانچر قطرها و فاصله‌های متفاوت از یکدیگر دارند)، ۶- بانچر پس از جازدن صفحه‌ها، ۷- فیکسچر تک‌صفحه‌ای برای جازدن صفحه کوپلرها، ۸- جازدن صفحات در کوپلرها

Why shrinking fit method?

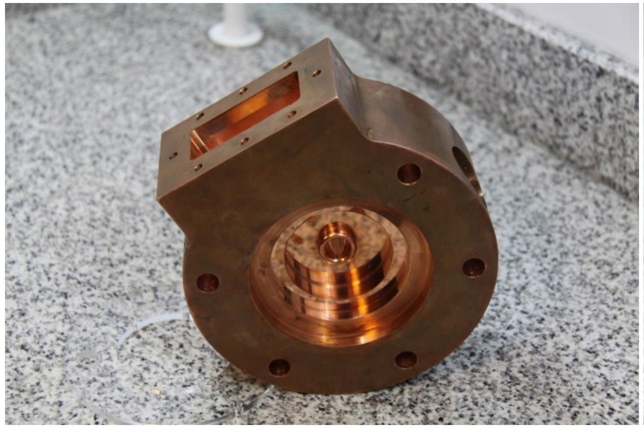
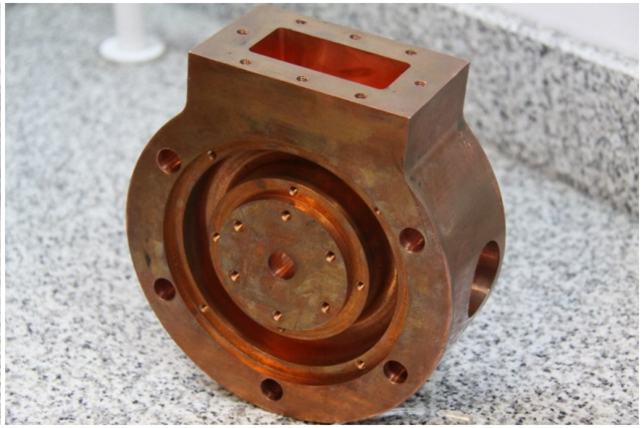
- It’s an old method but not bad at all.
- Difficulty to access the OFHC.
- Poor knowledge about the vacuum brazing at that time.
- Now, we build a small structure by the vacuum brazing method and our next accelerating structure will be build by this method.
- Also there are some interests to the non-brazing method to keep the copper hard and to reduce the cost.

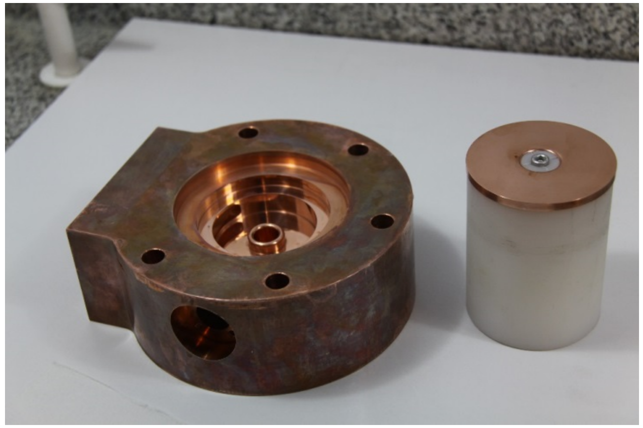
The accelerating tube layout

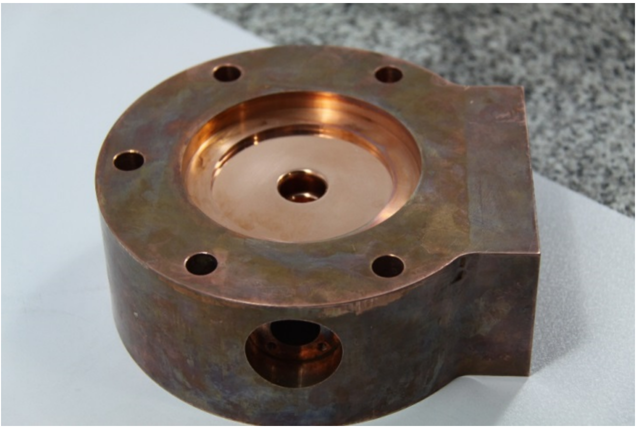
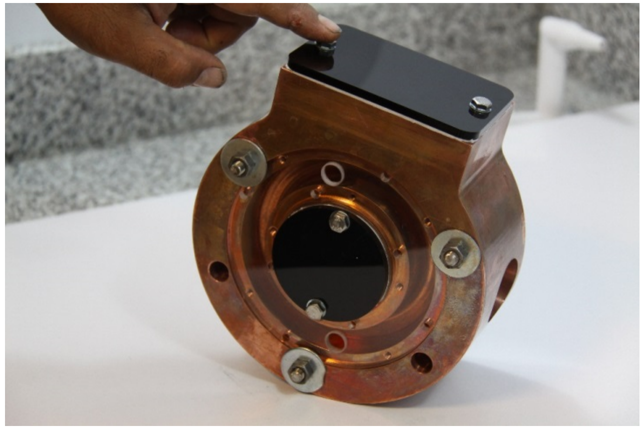




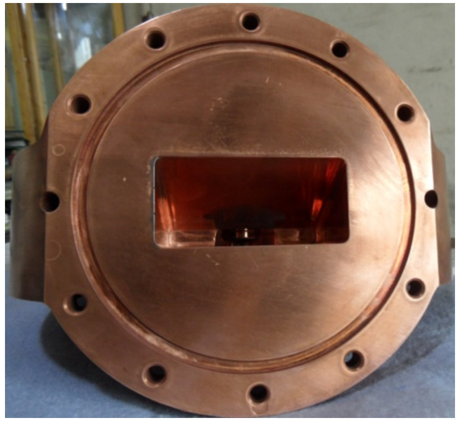
Buncher Coupler

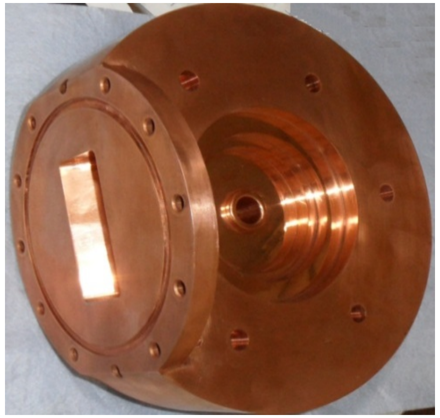





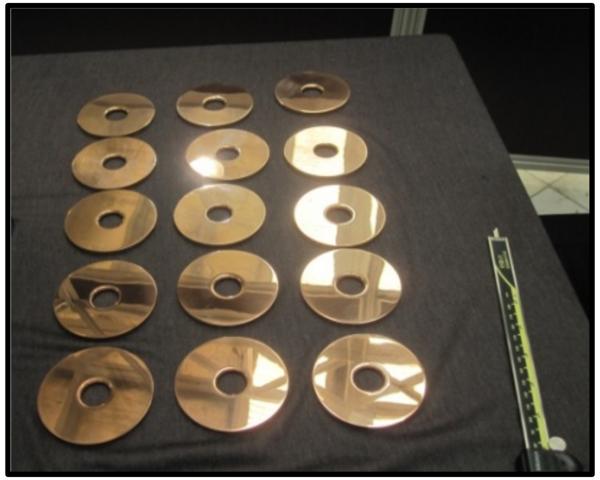
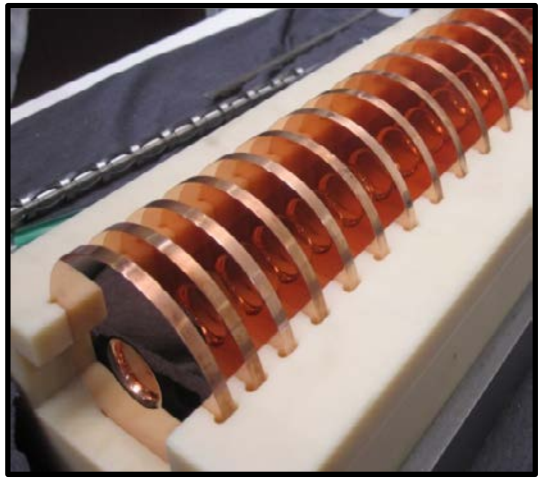
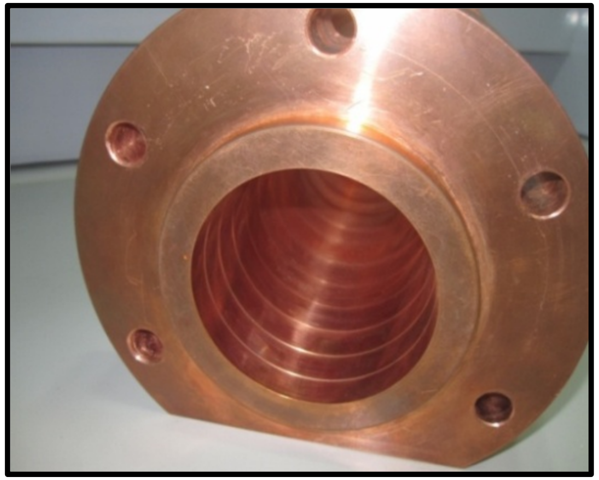
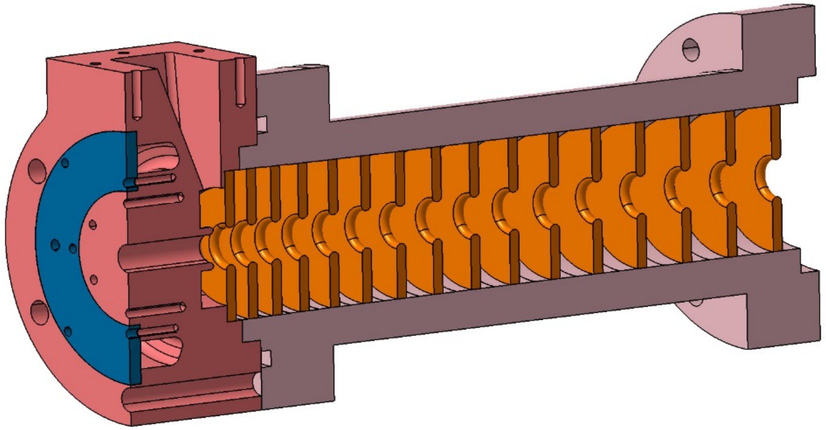
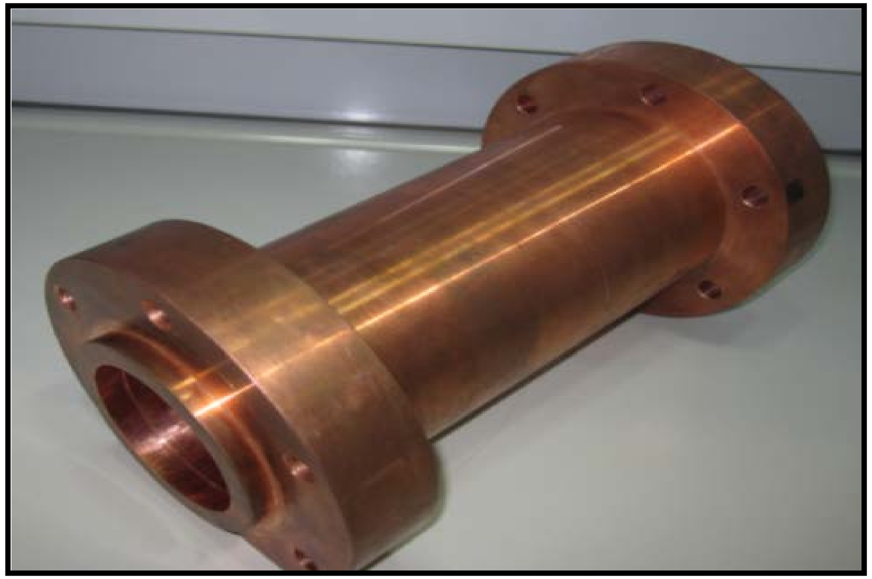




Accelerating Structure (Tube) Coupler





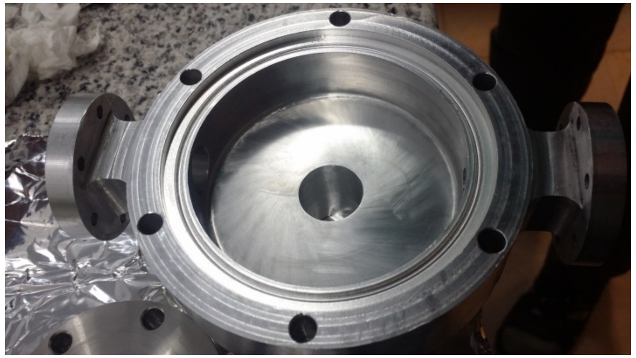
Buncher

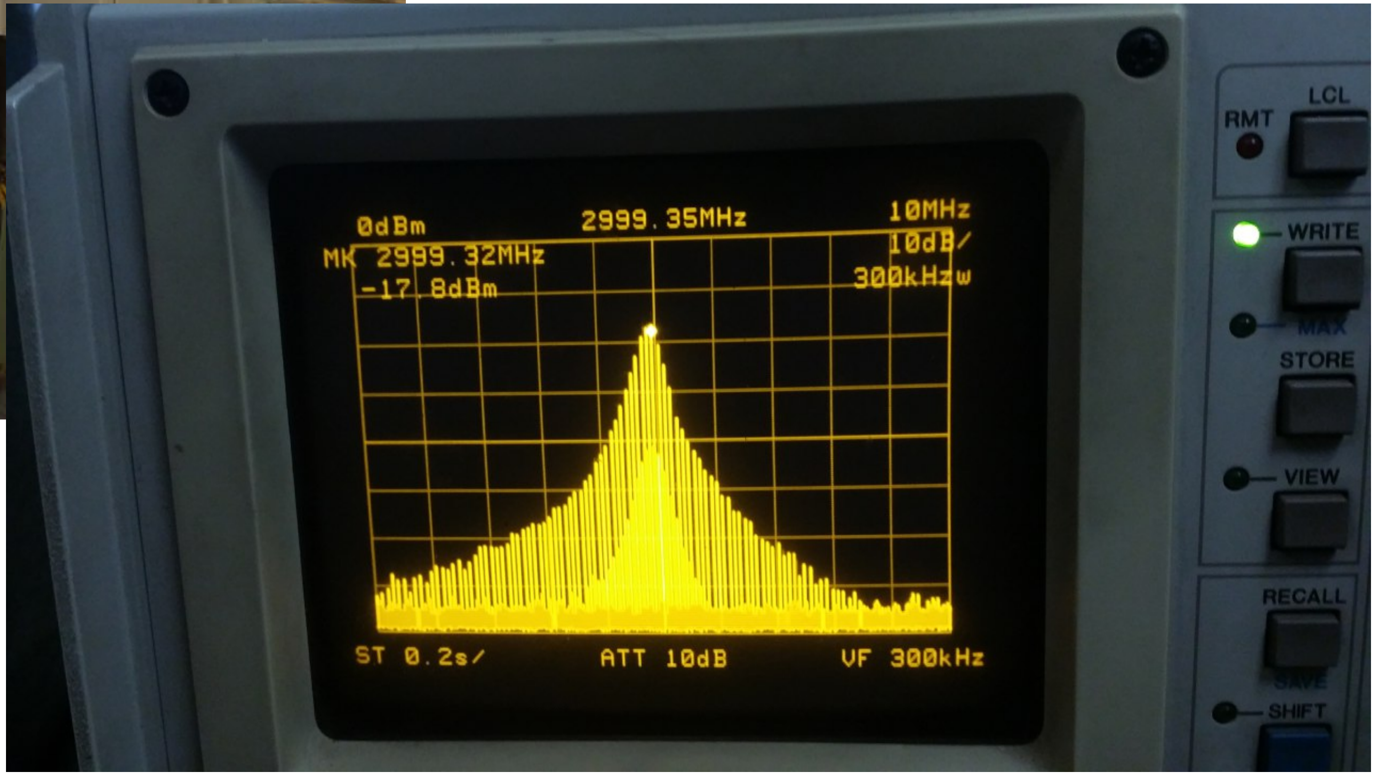
Accelerating Structure (Tube)

Three units was constructed

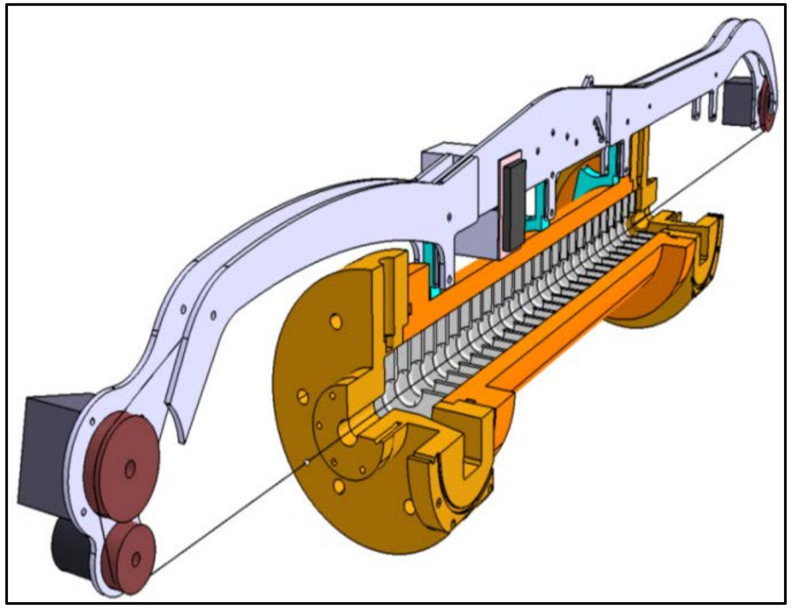
Pre-Buncher

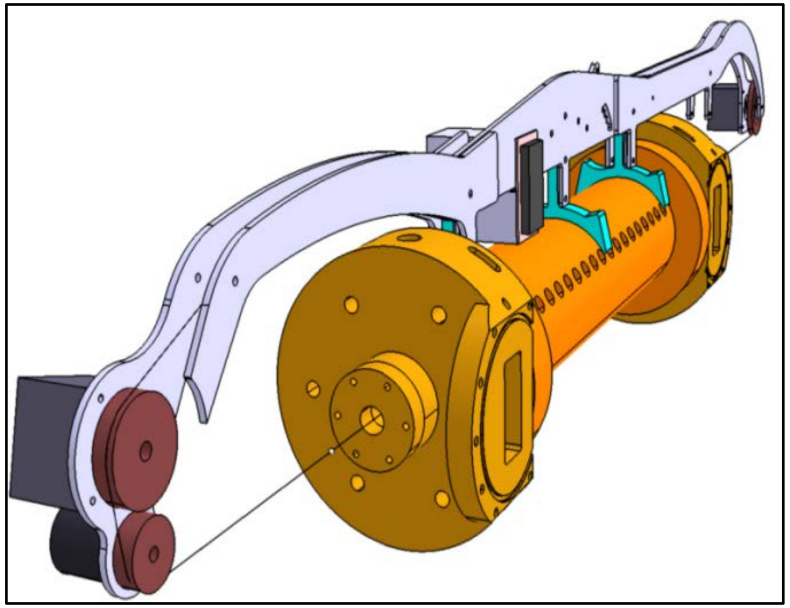


Pre-Buncher Test by Beam

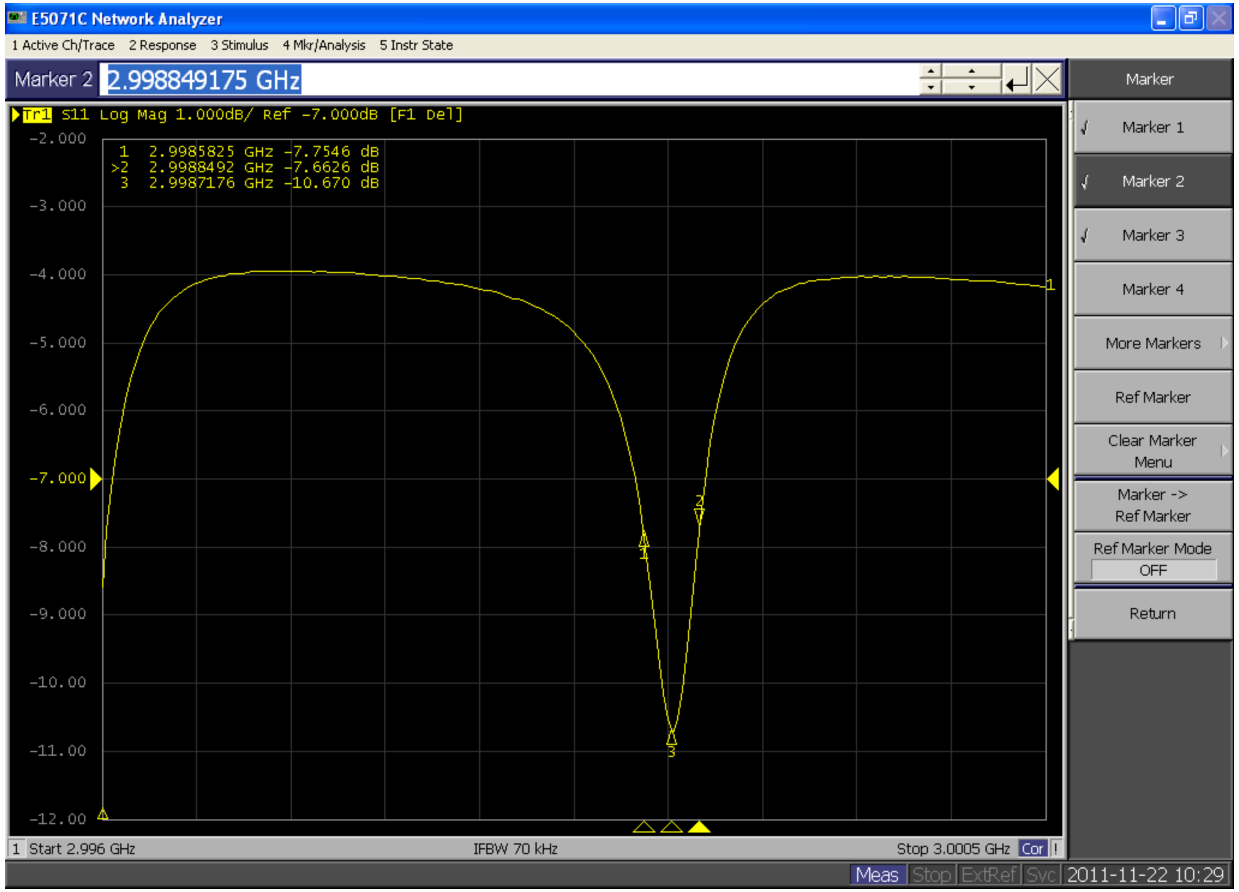


Measurement – How much the structure is good





Frequency Quality factor measurement



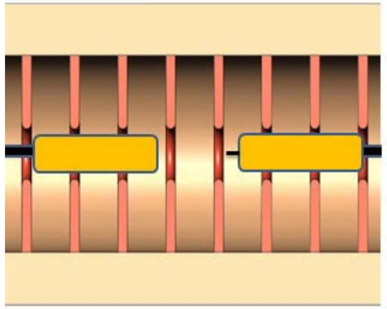
$$Q_L = \frac{f_0}{\Delta f\ (for\ 3db)} = \frac{2998.72\ MHz}{2998.85 - 2998.58} \approx 11100$$

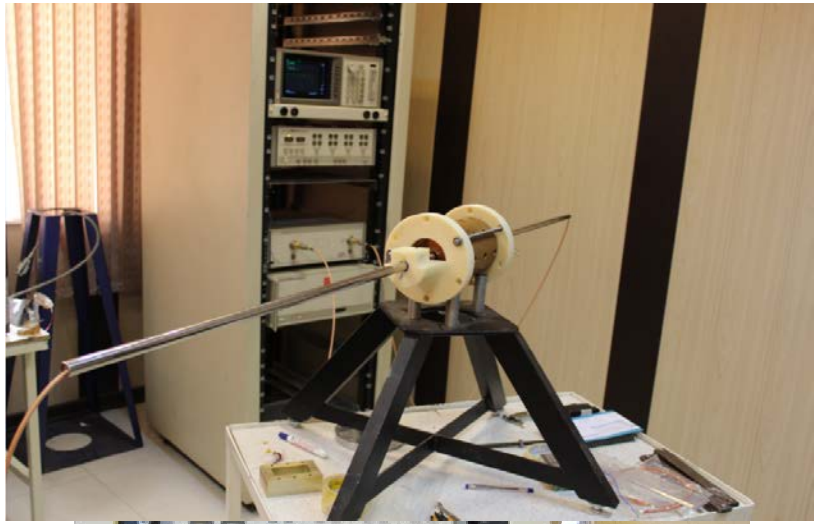
In this measurement we have a weak coupling ($\beta<<1$) then $Q_0 \approx Q_L$= 11100±500 ≈ 10909. It means that structure is close to nominal case.

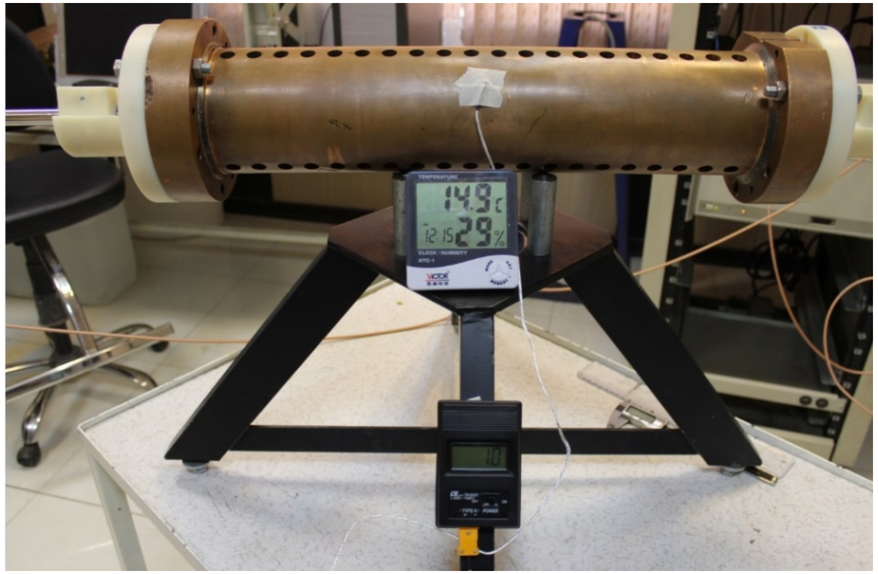
Good Achievement

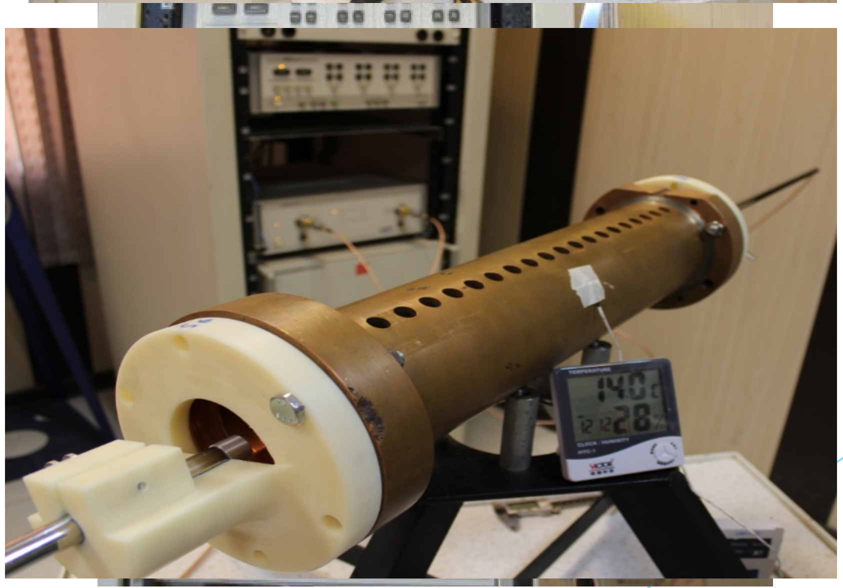
This frequency is 0.8 MHz more than nominal case (2997.92 MHz) but the nominal case is for vacuum and 25° C. This measurement is done at air and around 15° C .

Frequency Measurements-Direct Method

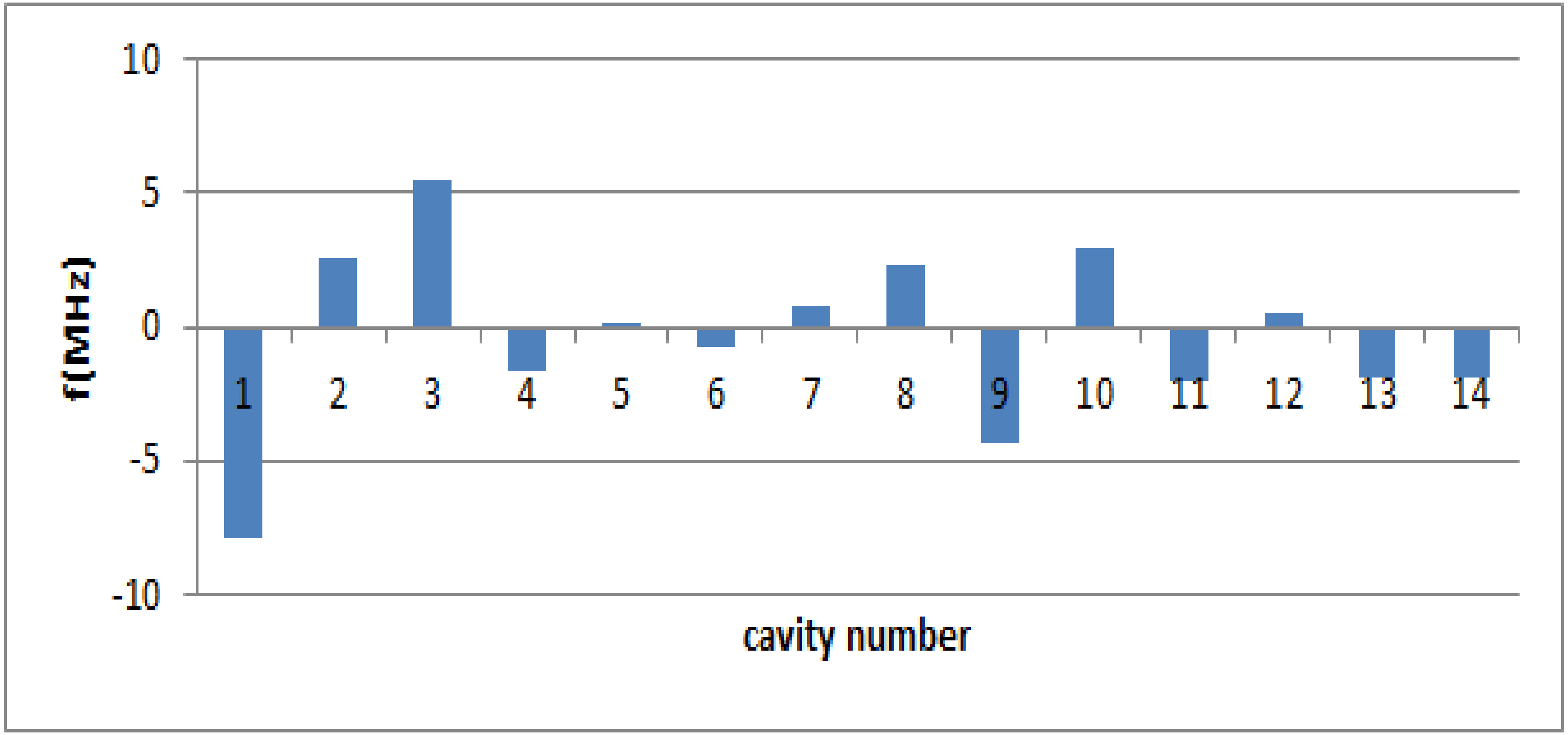








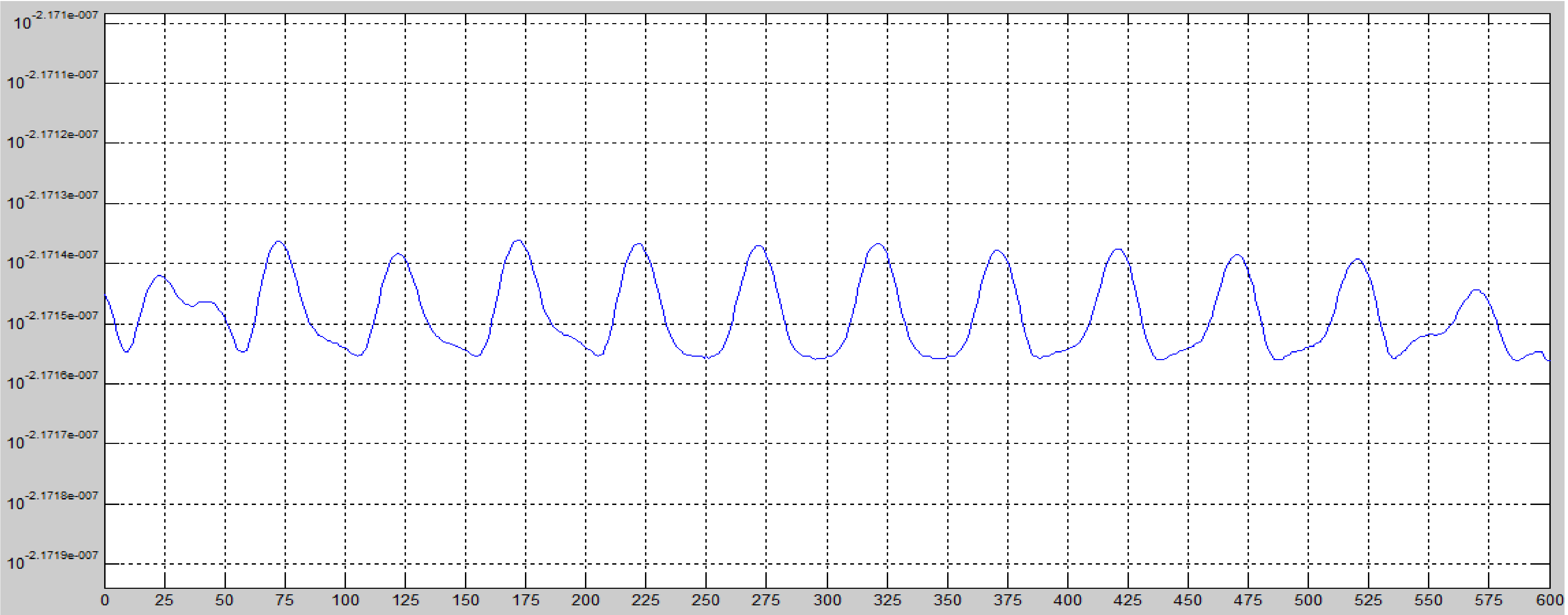
Buncher Measurement result before tuning



تفاوت فرکانس کاواک‌های بانچر با مقدار طراحی axis

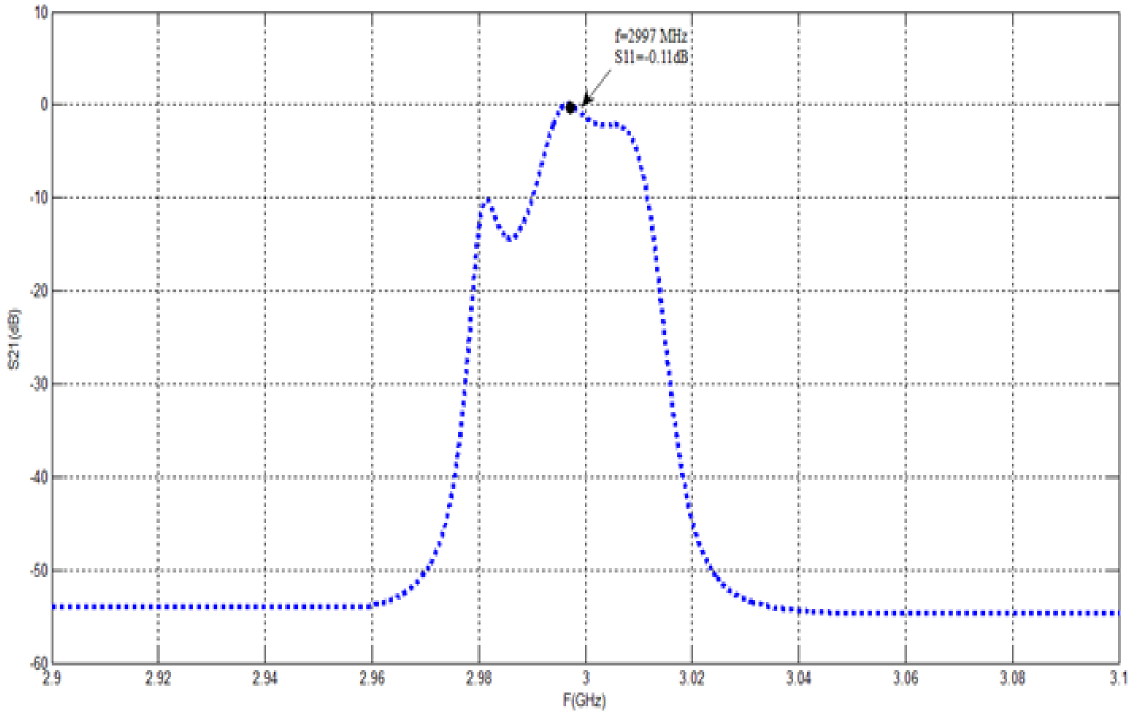
اندازه‌گیری فرکانس تک‌تک کاواک‌های بانچر با استفاده از پلانگر

Accelerating Tube Measurement result before and after tuning



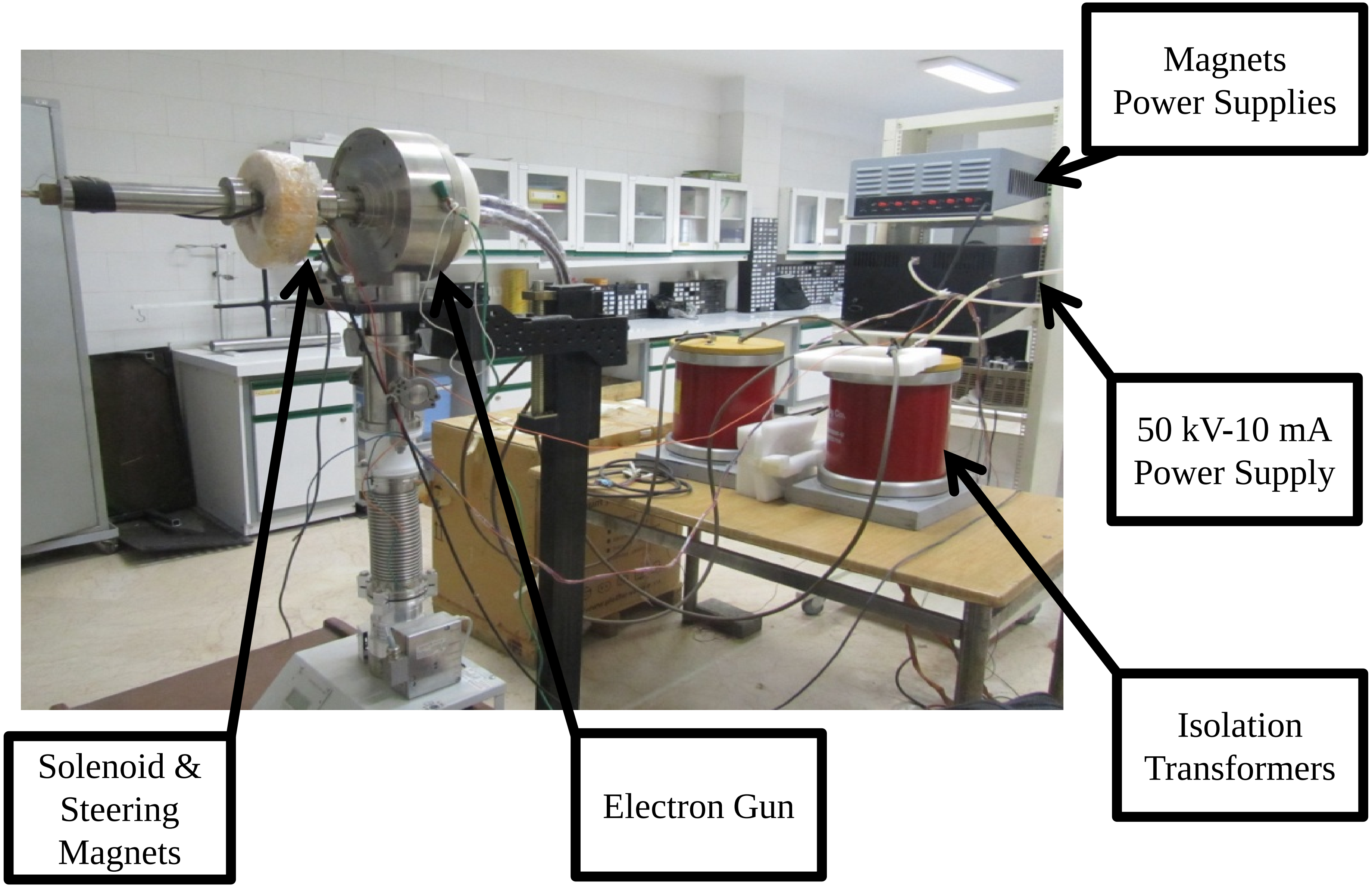
فرکانس اندازه‌گیری شده برای کاواک‌ها: ستون‌های آبی - قبل و قرمز-بعد از تیون

Output Couplers Tuning



S12 value result

Electron Thermionic Gun and its components



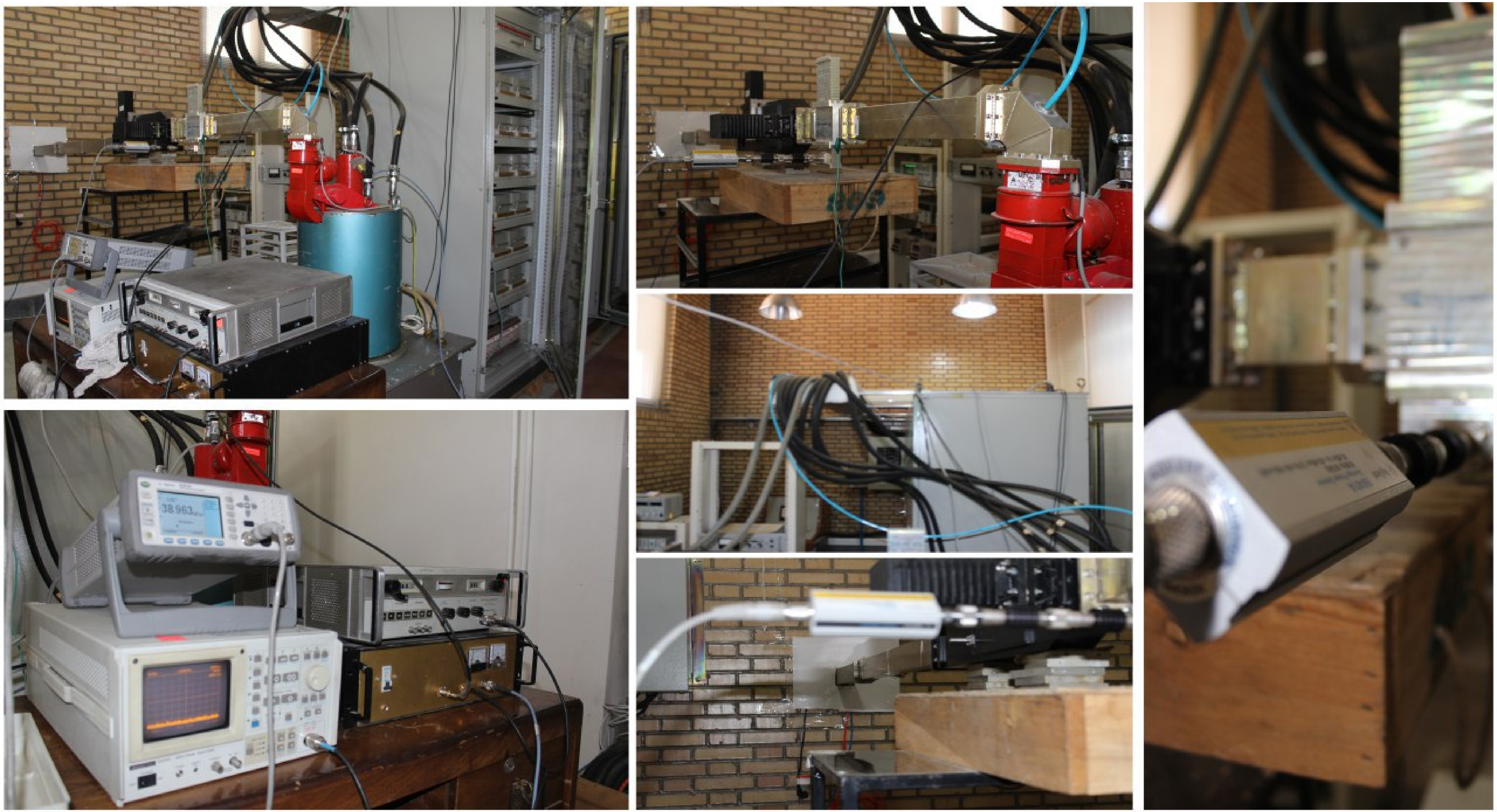
Klystron Gallery

Installing the 7 MW modulator






RF amplifier and other RF components



Cleaning by Nitrogen and Co2

Disassembling of the Electron Gun

Radiation Protection Shielding

Accelerator Table