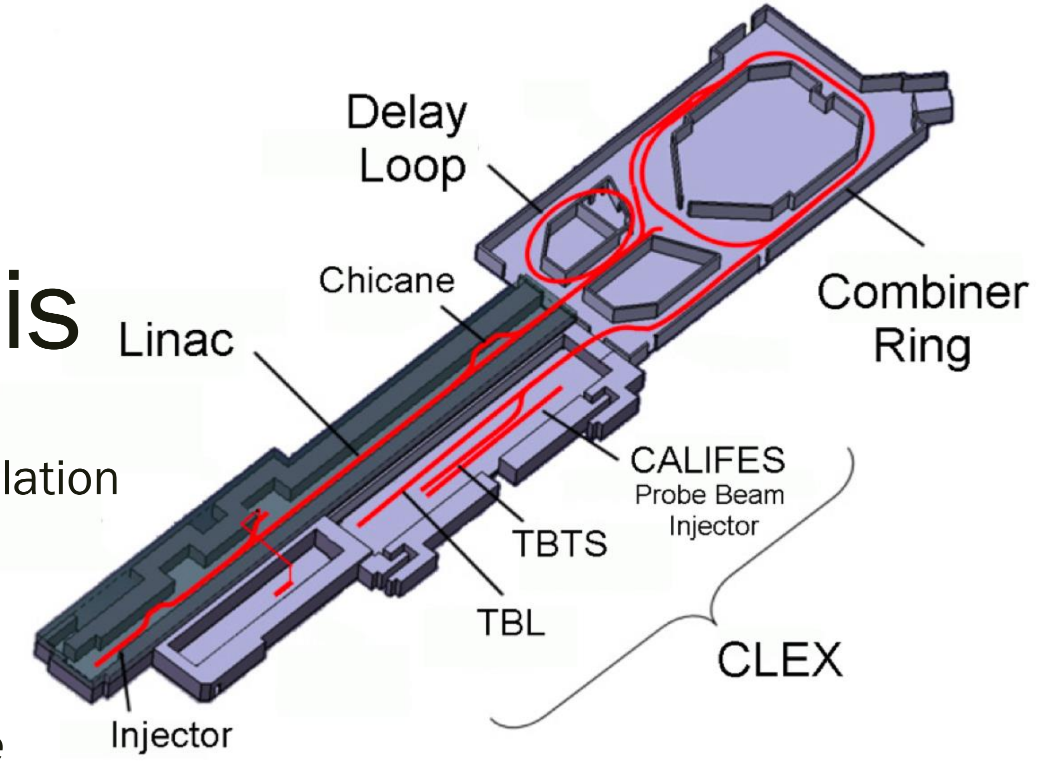
A BRIEF REVIEW OF MY EXPERIENCES IN THE CLIC AND THE IRANIAN LINAC PROJECTS

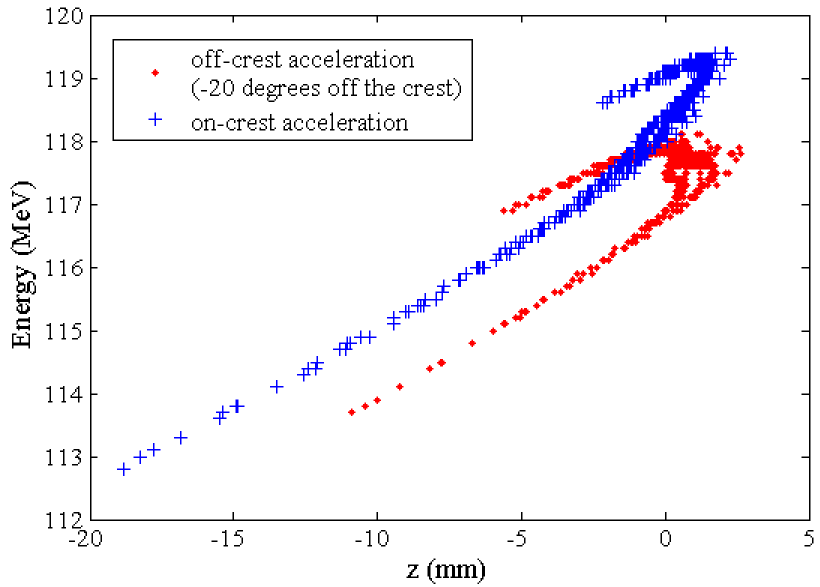
Hamed Shaker
PITZ - DESY, Zeuthen

CLIC Project

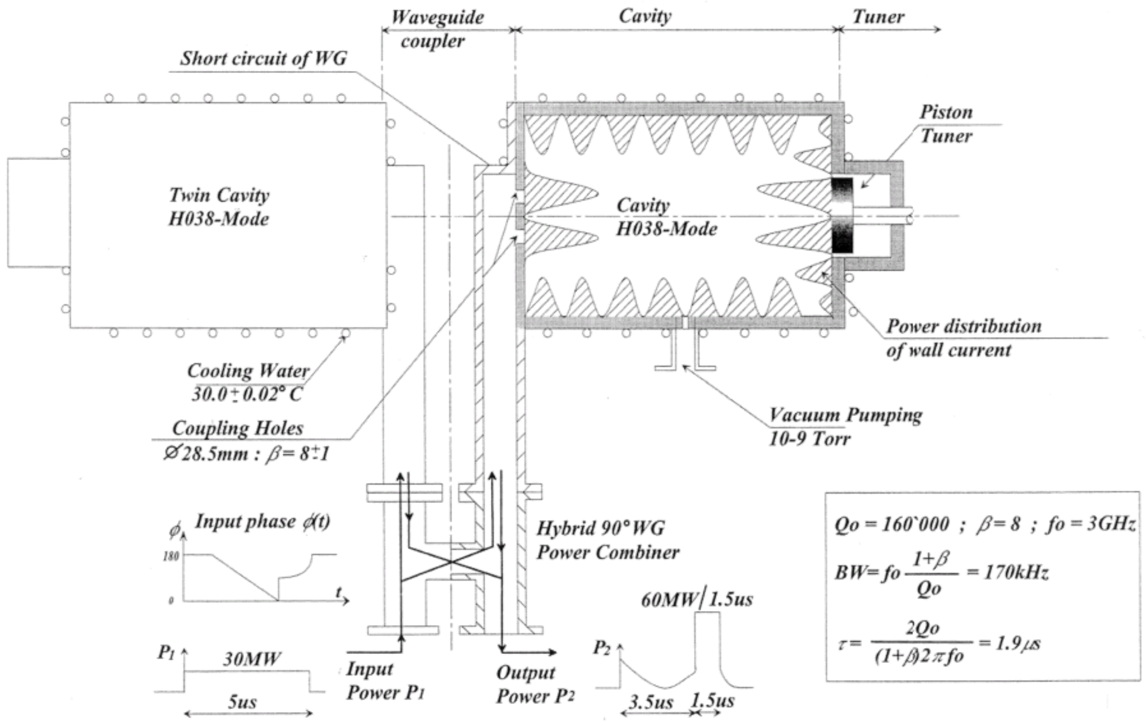
CLIC Test Facility 3
2006-2008 , Ph.D. Thesis

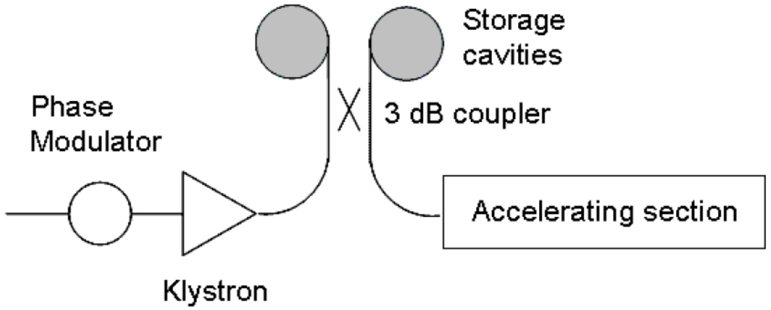


- Pulse Compressors output flattening by phase modulation
- Longitudinal Beam Dynamic study
  - *Space-charge effect in injector*
  - *Short-Range Wakefield using K. Bane Model*
  - *Coherent Synchrotron Radiation in the Chicane*
    Implemented in the PLACET code by E. Adli
  - *Bunch Shortening/Lengthening by Magnetic Chicane (Bunch Compressor/Decompressor)*
  - *1-D and 3-D modeling, MathCAD, PLACET*
- Bunch Length Measurement
- Supervisor : Roberto Corsini

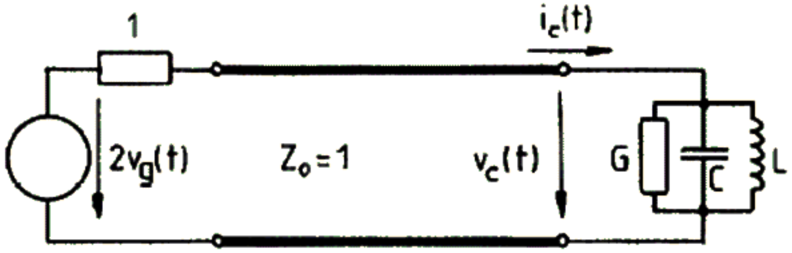


Pulse Compressor/ Phase Modulation





"A SLED type pulse compressor with rectangular pulse shape", A. Fiebig et al.



Introducing a specific detuning to minimize the phase variation during a pulse as proposed by R. Bossart et al. and was implemented in the circuit model by me.

$$\begin{cases} \alpha V_g = V_c + \tau \dot{V}_c \\ \alpha = \dfrac{2\beta}{1+\beta} \\ \tau = \dfrac{2Q_0}{\omega_0(1+\beta)} \end{cases}$$

$$\begin{cases} \alpha V_g = V_c(1 + i\tau\Delta\omega) + \tau \dot{V}_c \\ \Delta\omega = \omega_g - \omega_c \end{cases}$$

$$V_{c,n+1} = V_{c,n-1} + \frac{2\Delta t}{\tau}[\alpha V_{g,n} - V_{c,n}(1+i\tau\Delta\omega)] + O(\Delta t^3)$$

Numerical form to use for simulation

Pulse Compressor Control

“Low Level RF Including a Sophisticated Phase Control System for CTF3”, J. Mourier et al.

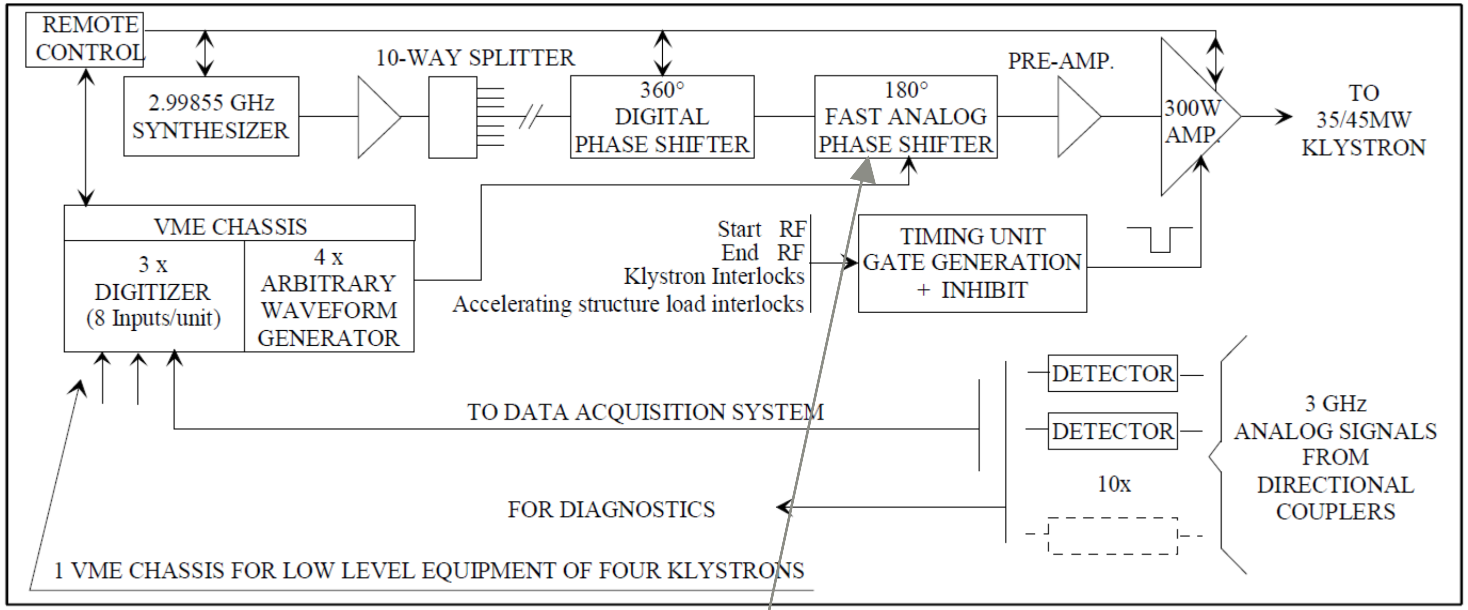
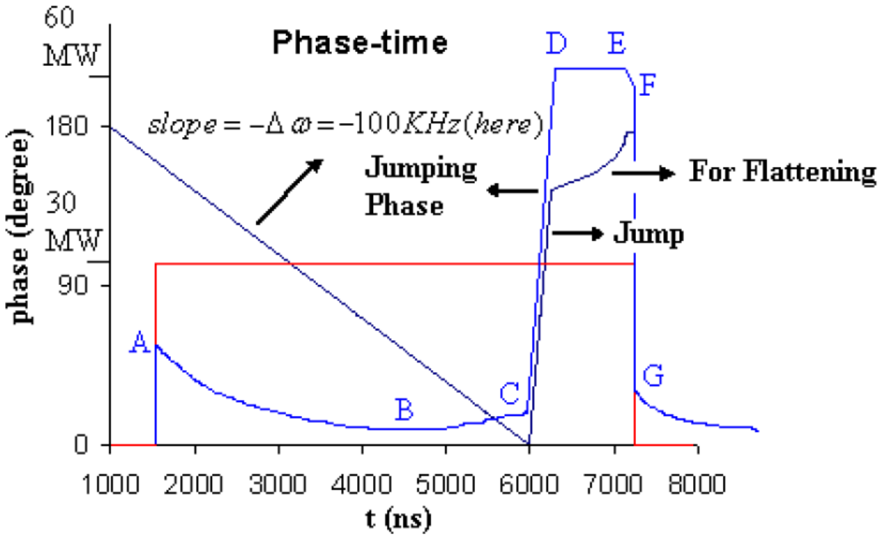
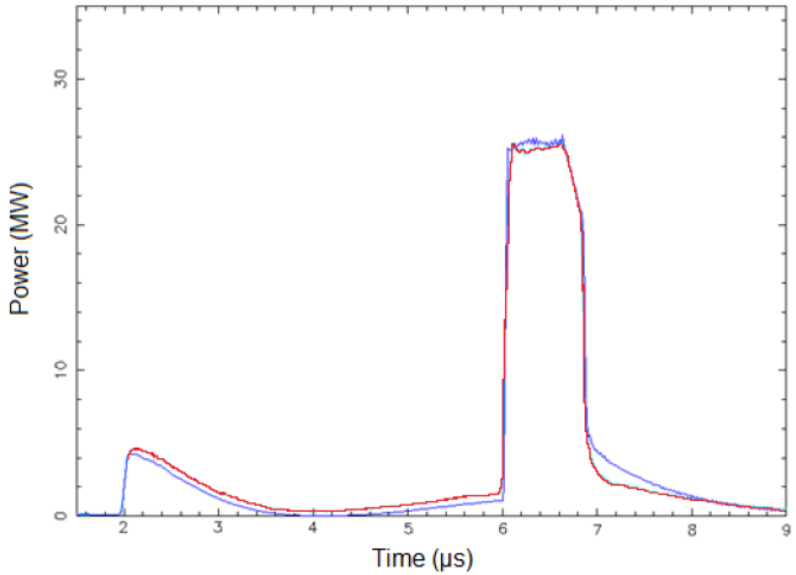


Figure 1: Simplified block diagram of low level system.

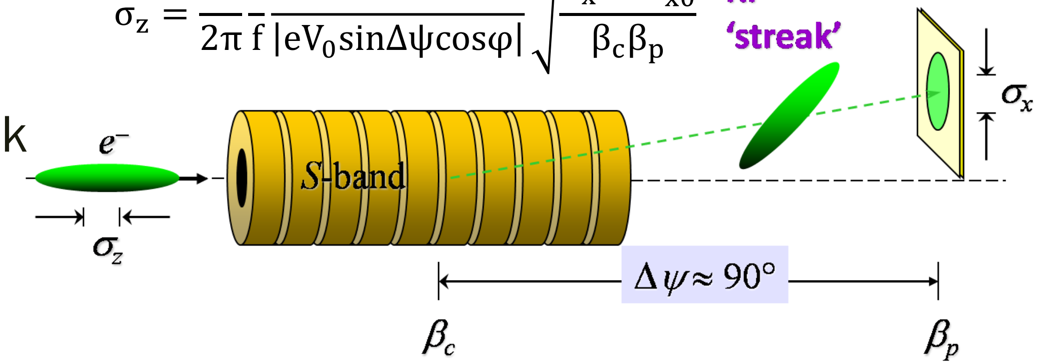




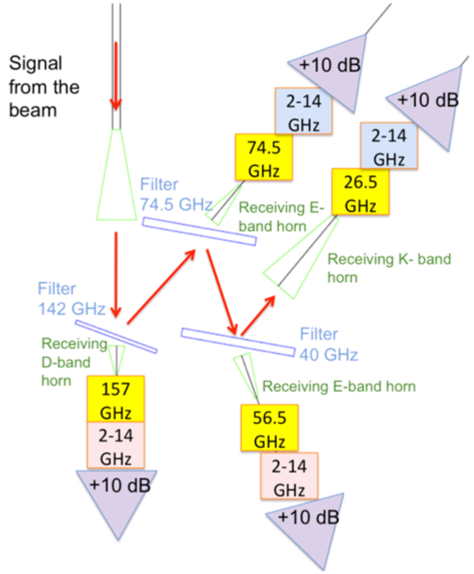
Write a Code with C++ to simulate the pulse compressor based on the real klystron output and control the pulse output flatness by sending the calculated phase to the fast analog phase shifter. Also get the new output as a feedback to correct the input phase

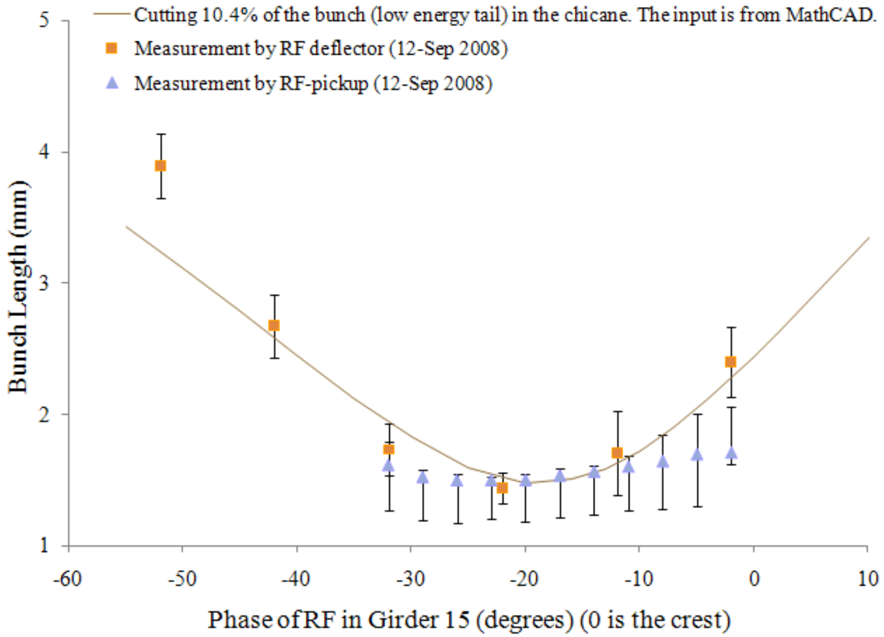
Bunch Length or/and longitudinal profile measurement

$$\sigma_z = \frac{1}{2\pi}\frac{c}{f}\frac{E}{|eV_0 \sin\Delta\psi \cos\varphi|}\sqrt{\frac{\sigma_x^2 - \sigma_{x0}^2}{\beta_c \beta_p}}$$



- A TDS (1.5 GHz RF deflector mainly used to kick *the bunches inside the delay loop)*
  + OTR screen downstream the line
  By help of T. Lefevre
- RF Pickup Cavity Spectrometer
  Done by A. Dabrowski and
  I helped her
  - *The bunch length is dependent inversely to the intensities of induced HOMs*



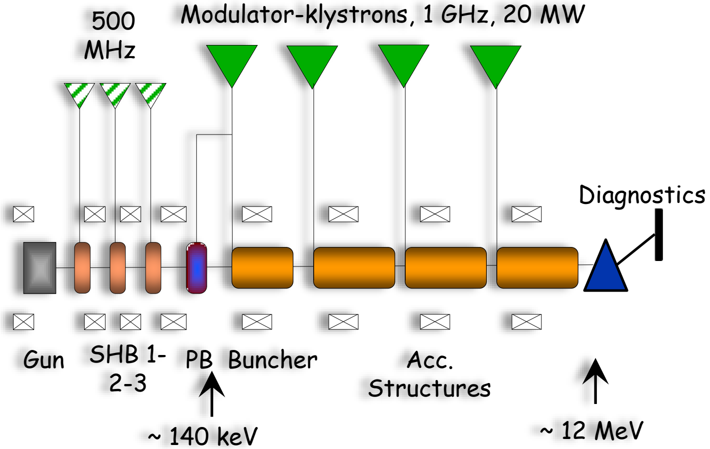


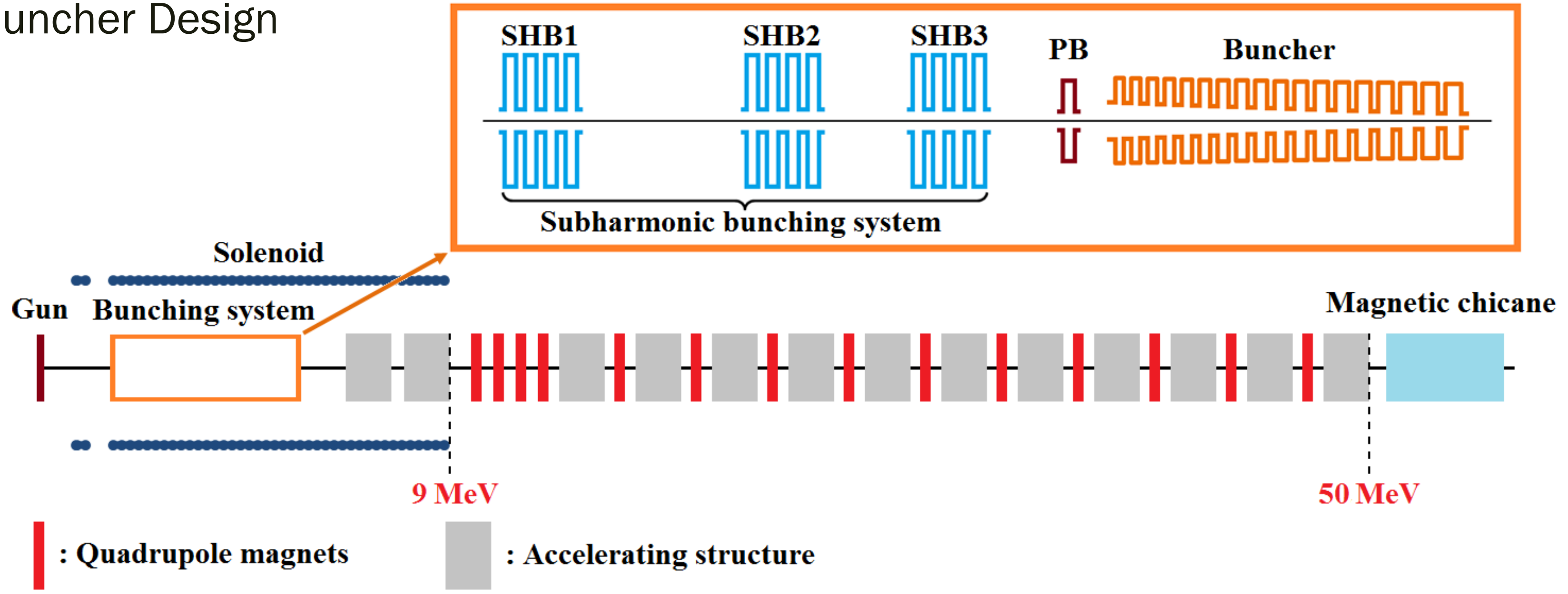
CLIC Drive Beam Injector 2011-2015

Further work shows it can be reduced to 3.5μm/1% with no beam loss by new cathode/gun design, introducing 4th SHB and use higher solenoid fields.

Electron Gun Energy / Current	140 KeV/5A
Main Working Frequency	999.5 MHz
Sub Harmonic Bunchers (SHBs) working frequency	499.75 MHz
SHBs Bandwidth	60 MHz (12%)
SHBs input power/Maximum Voltage	20-100KW/15-45KV
Repetition Rate/Pulse Length	50 Hz/140 μs
TW Buncher Length / Output Beam Energy	1.6 m/2.4 MeV
Final Emittance/Satellite population	20 μm / 2 %
Final Beam Energy / Energy Spread	50 MeV / 1 %
Bunch Charge	8.4 nC

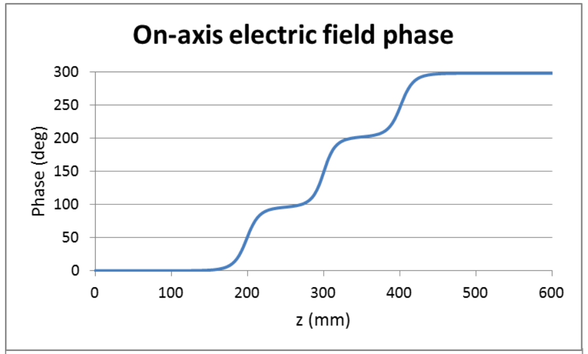
- Beam and RF design of CLIC Drive Beam Injector
  - *TW SHBs and TW Buncher*
  - *Co–Supervising with Steffen Doebert*
    - Beam Design
    - DC Gun & Prebuncher Design

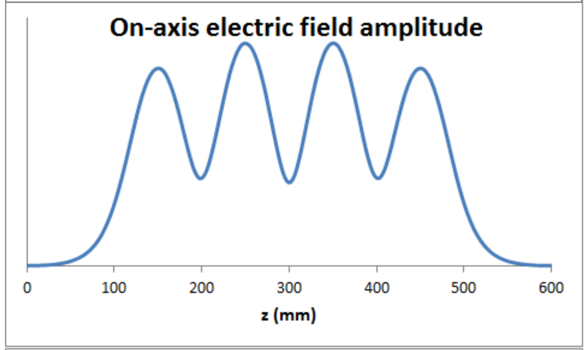


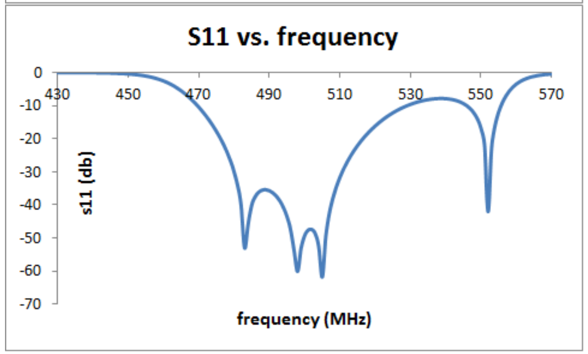


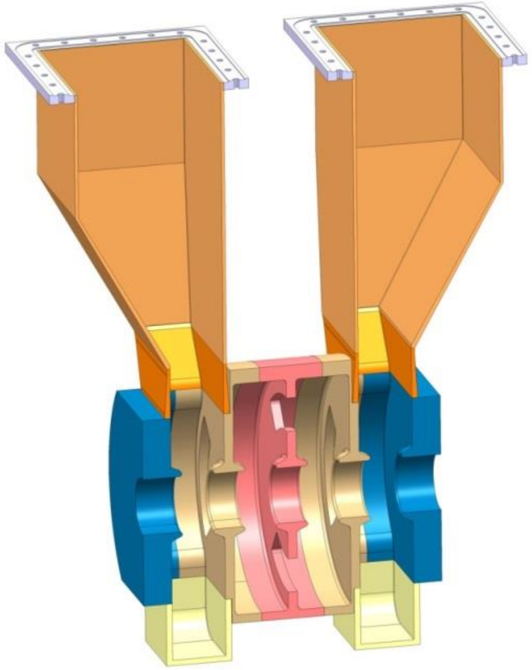
Sub Harmonic Bunchers

- 500 MHz Backward TW SHBs , β=0.62
- Wideband (60 MHz) to capable for
  180°phase switch in 10ns
- High-shunt impedance
- Beam-loading and HOMs compensation
- Coupler cells asymmetry compensation
  by using the shorted waveguide
- RF design based on complicated
  beam/cavity Interactions
- Contributing in the Mechanical Design
- RF Measurement

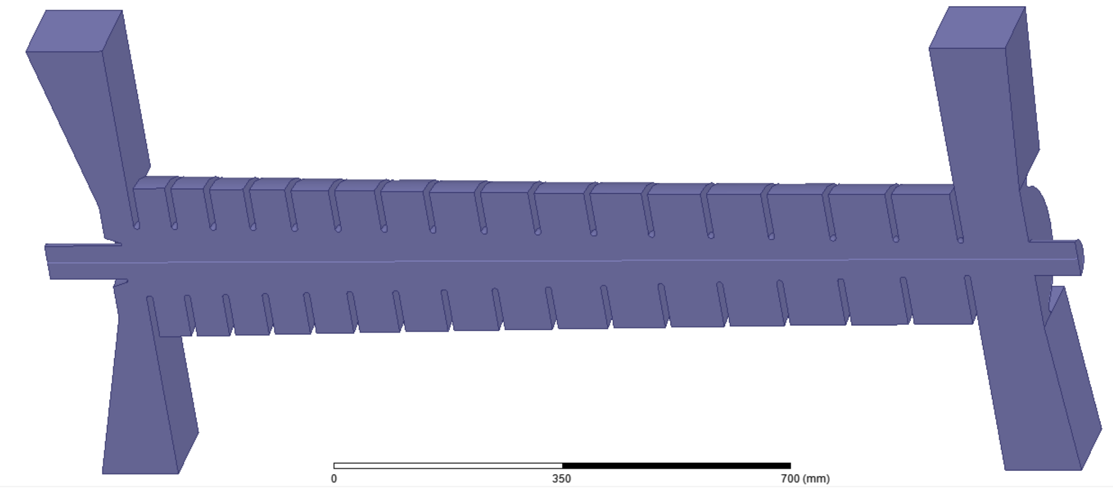




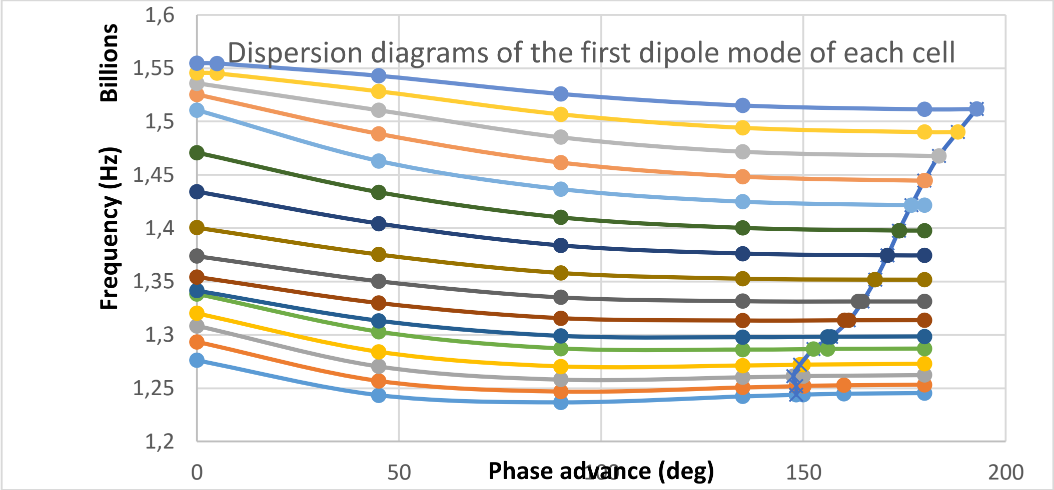




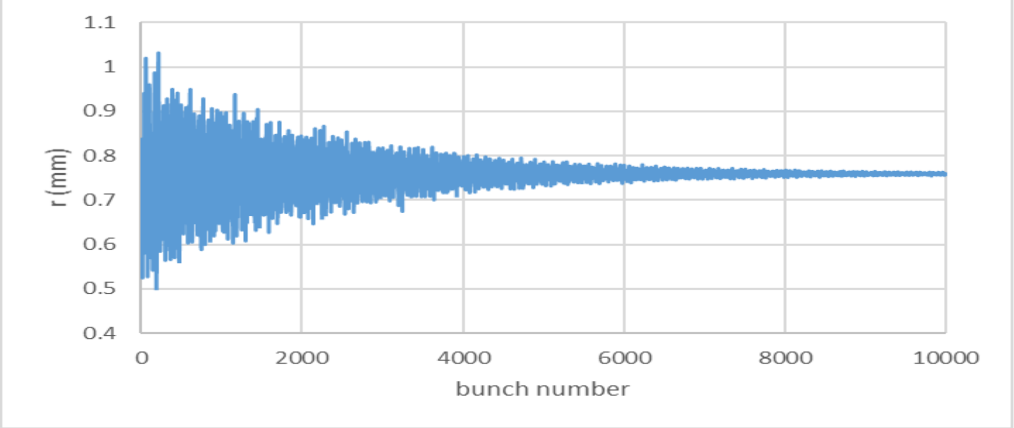
TW Buncher



- 1 GHz TW tapered disk-loaded waveguide
  - *So efficient bunching > 99% with SHBs+PB*
  - *Low surface loss < 4 %*
  - *Double feeding to reduce the emittance growth*
  - *Nose-cone in the input coupler cell to reduce the beam loss, emittance growth and energy spread*
- HOMs damp naturally and no dampers are needed based on
  - *1-D code developed to track the successive Bunches based on the kicks in each cell*
  - *Near-Relativistic long-range wakefields*

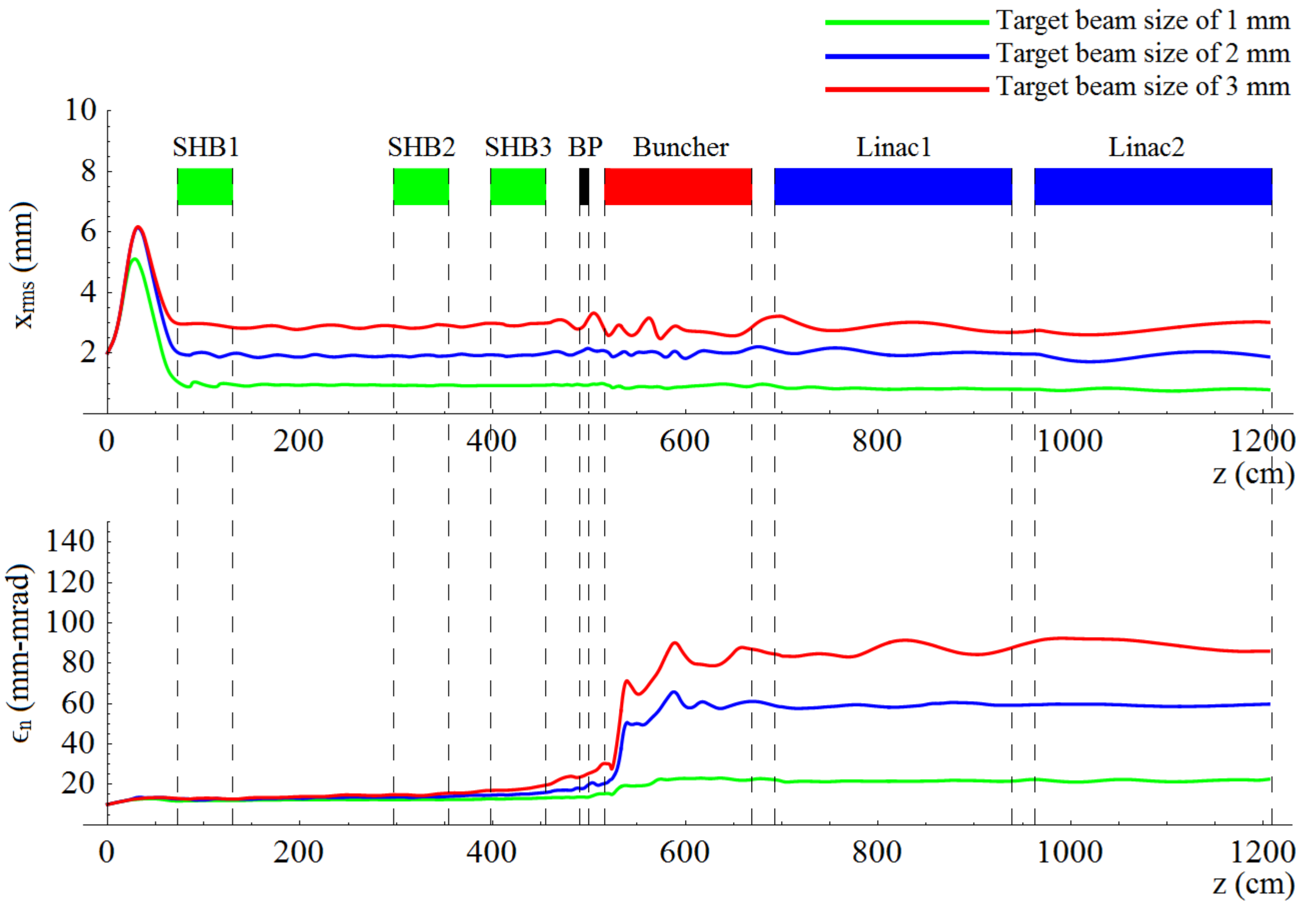


Bunch offset after kick



Beam Design (Supervising)

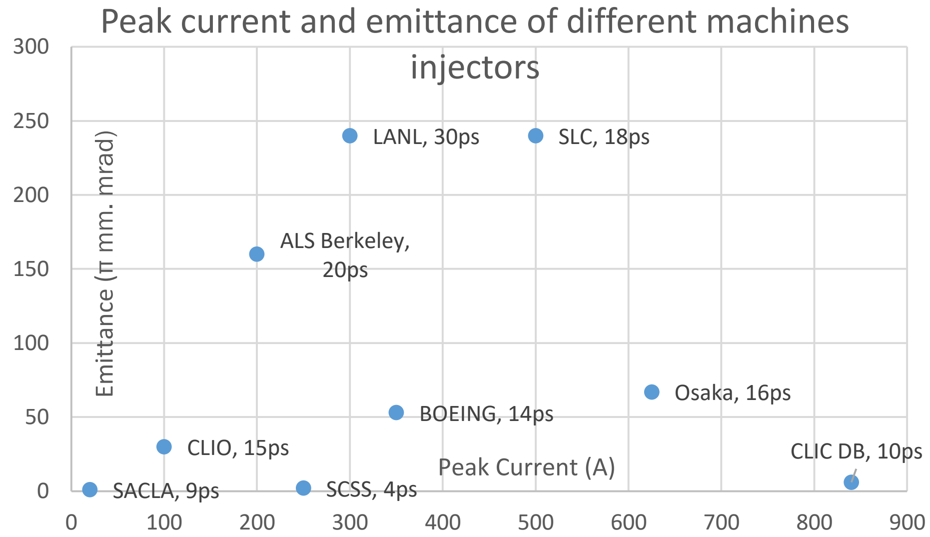
- Longitudinal Beam Dynamics
  - *Efficient bunching and low energy spread with variable voltages SHBs and the tapered buncher*
- Transverse Beam Dynamics
  - *Solenoids channels to reduce the emittance growth*



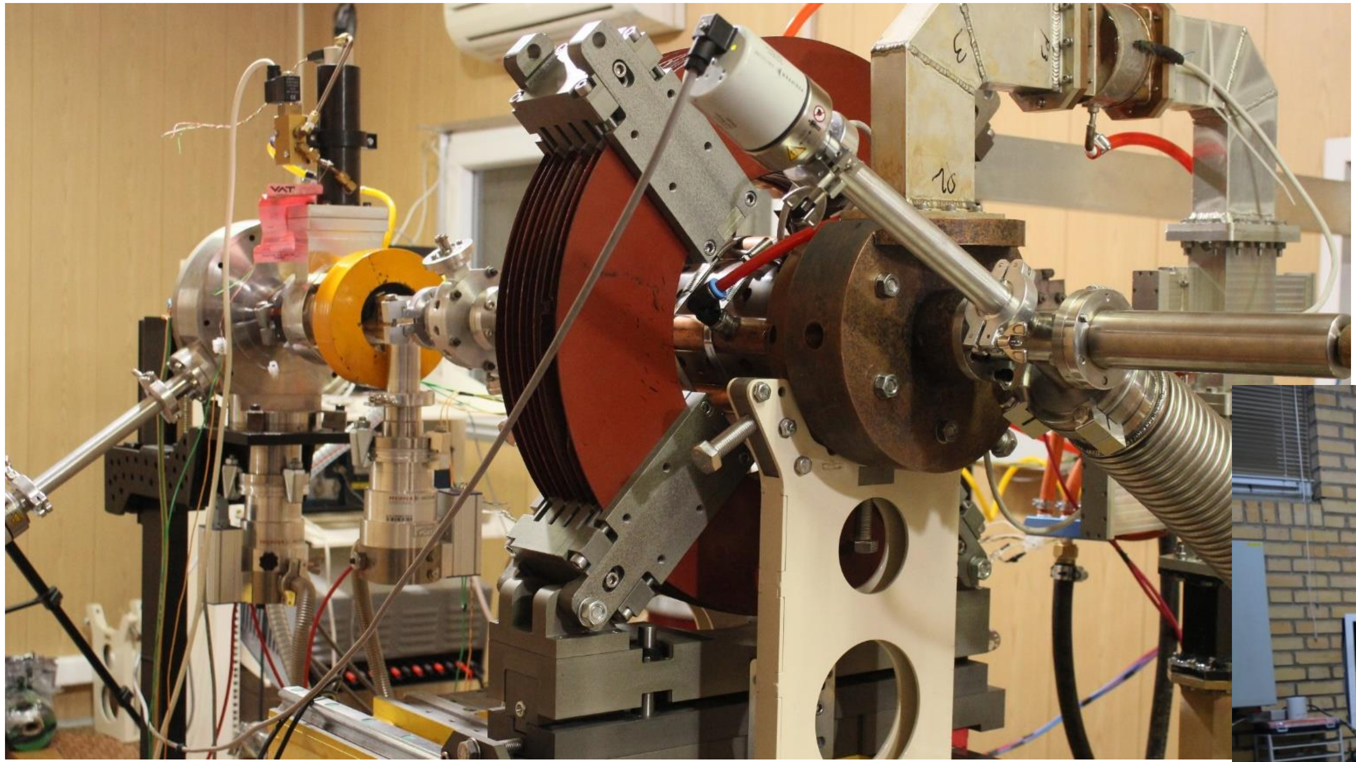
Discuss about the DC gun and Photoinjector based options

- DC Gun and bunching system
  - *By significantly improving compared to the last design met all the required beam properties*
  - *Very good alternative for high duty cycle injectors*

    With very short time intervals
- Photo-Injector based CLIC DB Injector
  - *140 μs, 50 Hz (0.007 duty cycle)*
  - *8.4 nC bunch charge*
  - *Multi-shots laser with 2ns interval*
  - *Good to avoid complicated bunching system and space-charge dominated region but there are problems with cathode-life and various laser jittering*

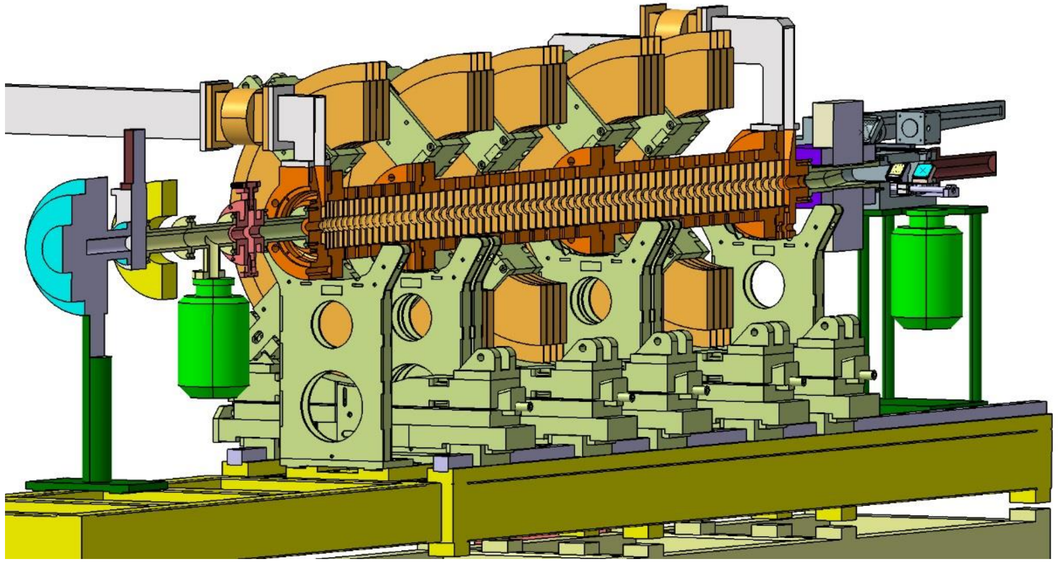


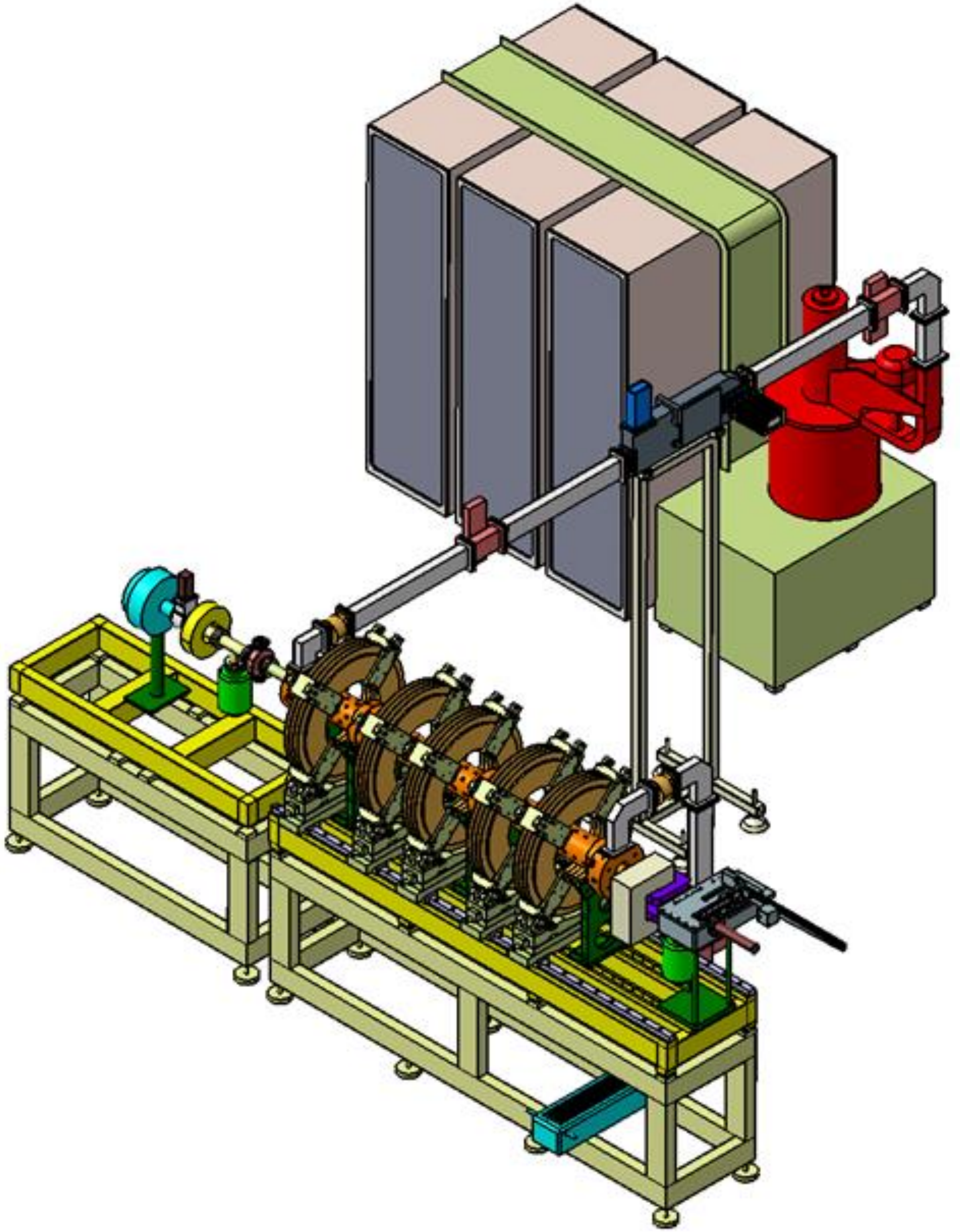
Iranian Electron Linac Project



3D Layout

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	255	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	





Timeline of particle accelerators in Iran

- 1956: Was bought a Van de Graaff by university of Tehran from High Voltage Eng. Corp. , US
- 1971: Started to work and was used for the Particle-Induced X-ray Emission (PIXE) analysis
- 1978: A few Iranian physicist made a wish during a workshop to have a national accelerator laboratory for the particle physics research
- 1996-1997: Was bought a Rhodotron for irradiation applications and a Cyclotron for the radio-isotope production from IBA, Belgium.
- 2001: General agreement for the collaboration between Iran and CERN
- 2001: A Electron Linac project was started as the first step to the national accelerator
- 2003: Iran Joined the SESAME based on the idea of using BESSY-I in the middle east
- 2009: Iranian Light Source Facility was started; The choice for the national accelerator
- 2017: We detected the first accelerated beam from the tapered buncher of Electron Linac and the opening ceremony by the president of Iran
- Also was bought several medical and cargo inspection Linacs.

Accelerator group, Department of Particles and Accelerators, IPM (Institute for Research in Fundamental Sciences)

Establish the sub-groups and train people to fit efficiently

- Beam Dynamic
- Radio-Frequency
- Beam Diagnostic
- Electron Guns & Ion Sources
- Magnet
- Vacuum
- Radiation Protection
- Control and Safety
- Mechanical Engineering
- Electronics
- Civil Engineering
- Novel Accelerators

Members

- 9 Post-docs
- 5 Researchers
- 2 Faculties
- 3 Engineers
- 1 Ph.D student

Proposal

Study of non-brazed high gradient S-Band cavities based on the shrinking fit method which was supported by the CLIC team.

Collaborations

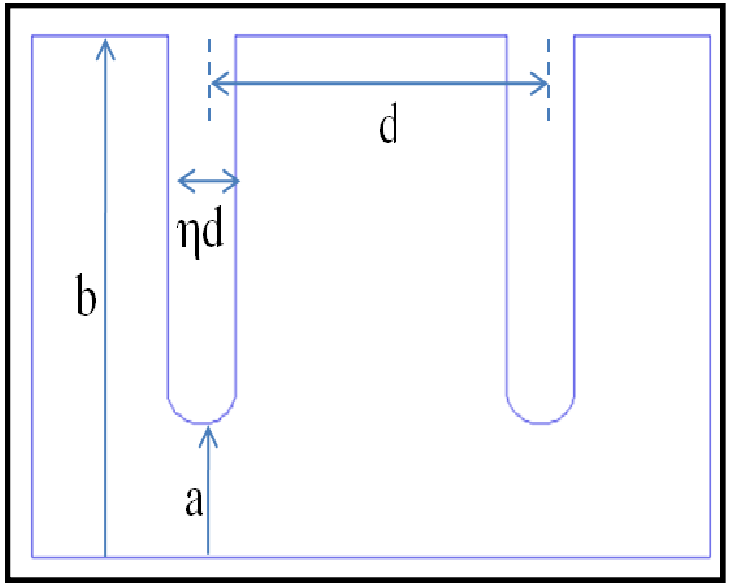
- Working with several national companies, institutes and universities.
- Working with CERN in the CLIC, LINAC4 and AWAKE project
- Good progress to start a new collaboration with DESY

Projects

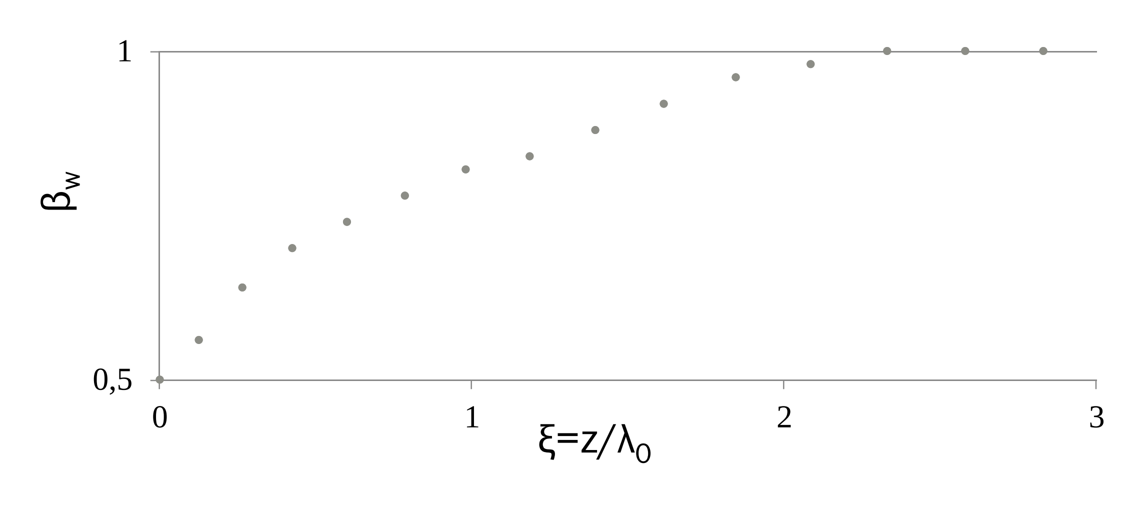
- IPM Electron Linac
- Photo-Cathode RF Gun
- Pulse Compressors
- New buncher design
- And more upgrade design

Accelerating Structure/Constant Impedance

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



TW Tapered Buncher

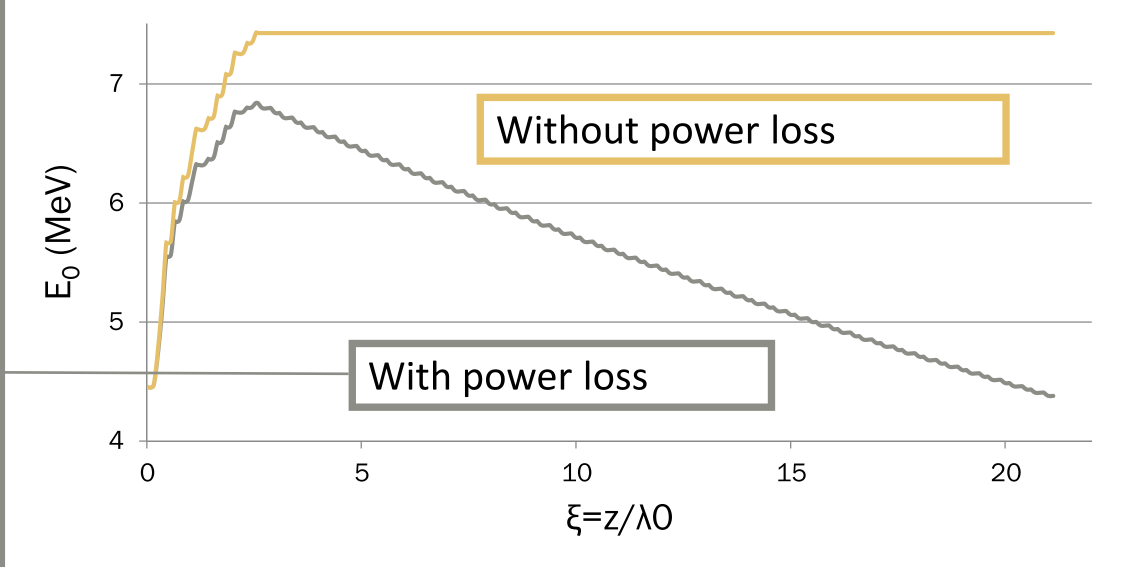


Inside the buncher, phase velocity increases smoothly to reach to the velocity of light.

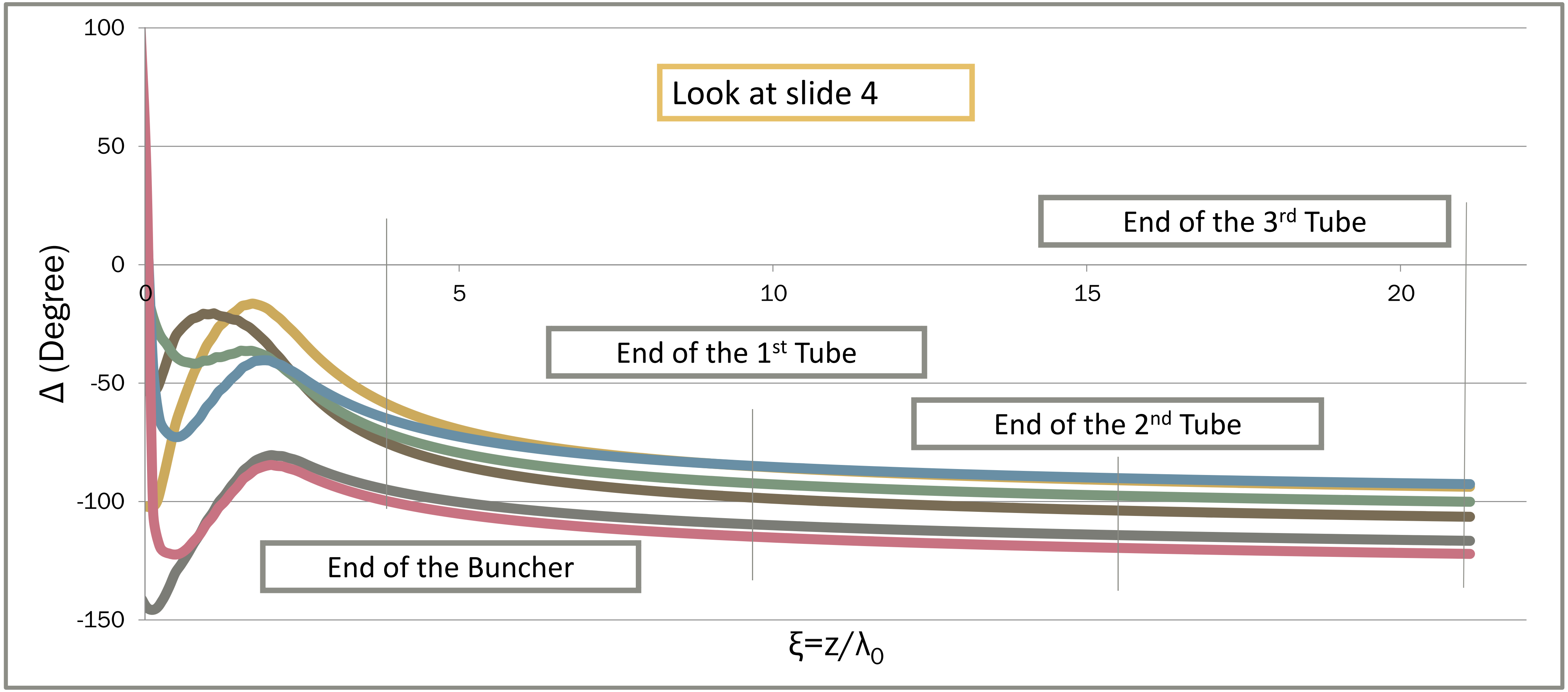
$$\begin{cases} \frac{a^4\alpha^2}{\beta_w} f(k_r a) = constant\,;\ \alpha = \frac{E_0 e \lambda_0}{m_0 c^2} \\ f(k_r a) = \frac{8}{(k_r a)^2}\left[J_1{}^2(k_r a) - J_0(k_r a) J_2(k_r a)\right] \end{cases}$$

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.

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



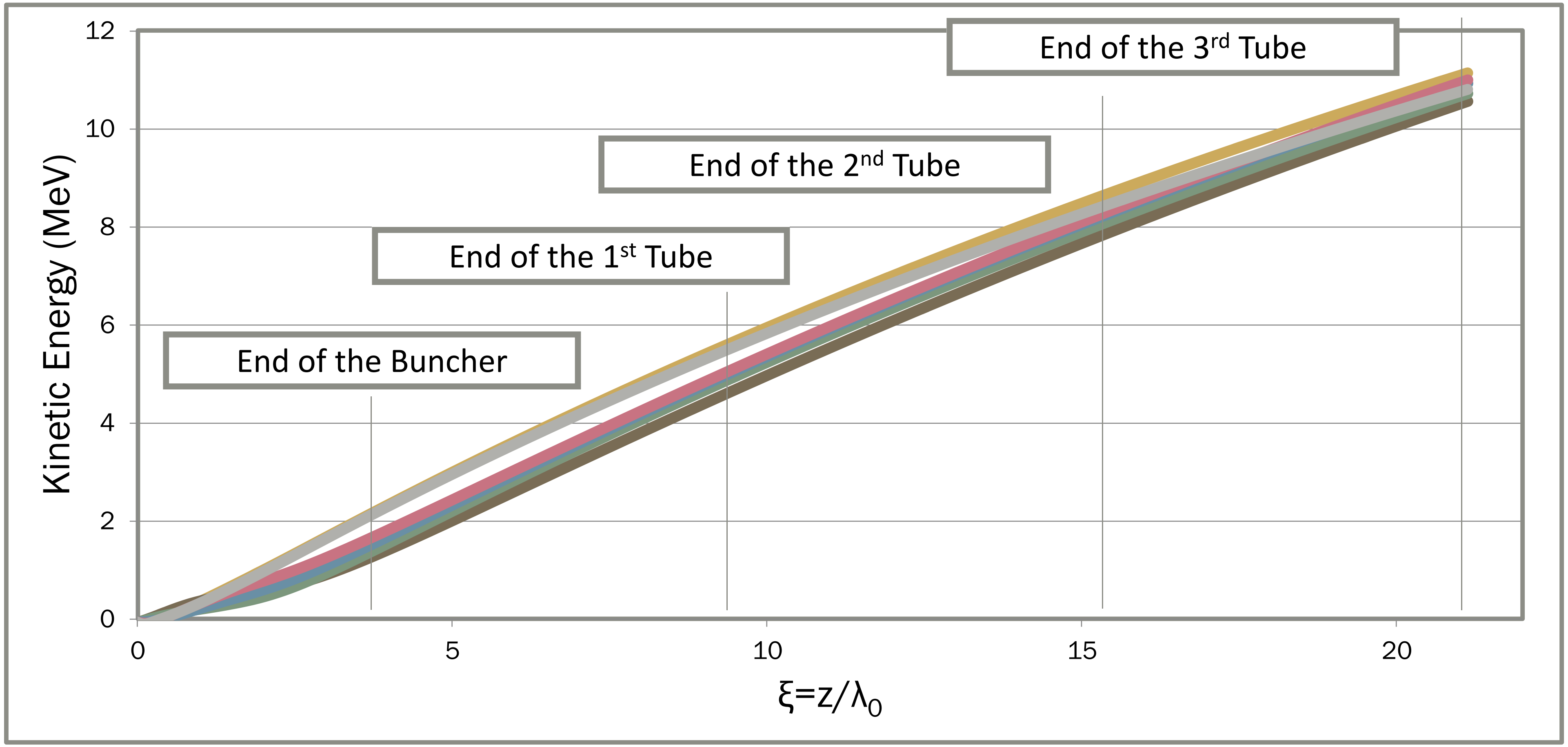
Phase Evolution



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

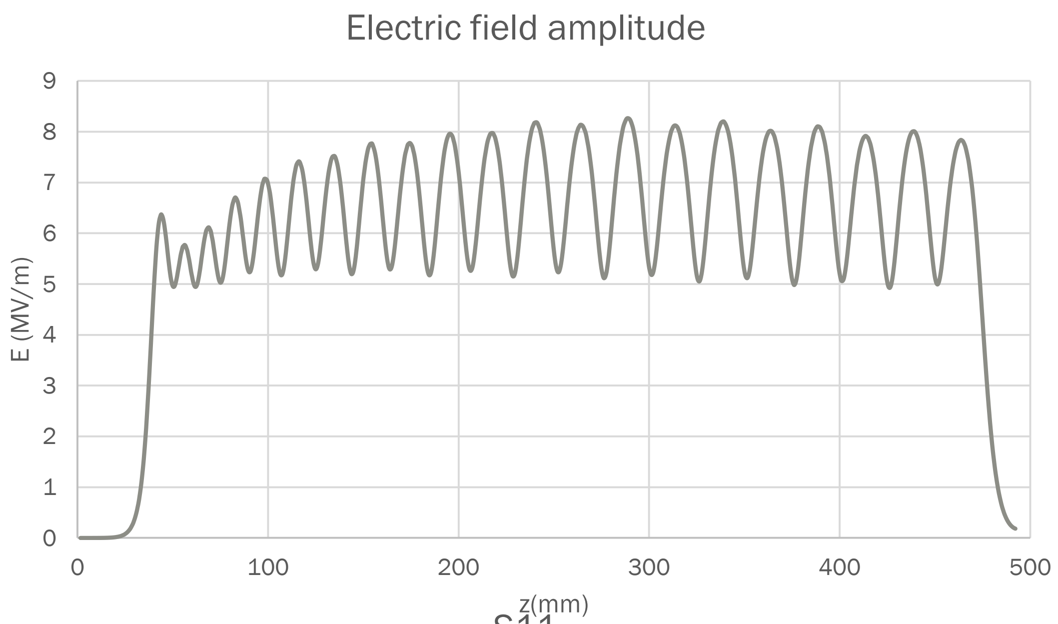
-97.24±7.54 deg (final distribution) ≈ 4.2 mm bunch length
Capturing: -142 … 102 : 244 deg (68%)
Continues beam is entered: No pre-buncher is assumed.

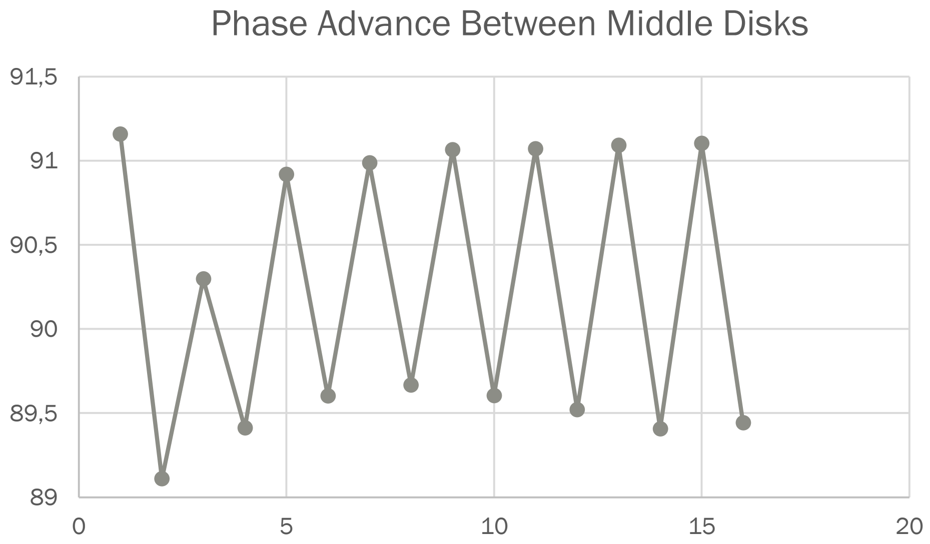
Energy Evolution

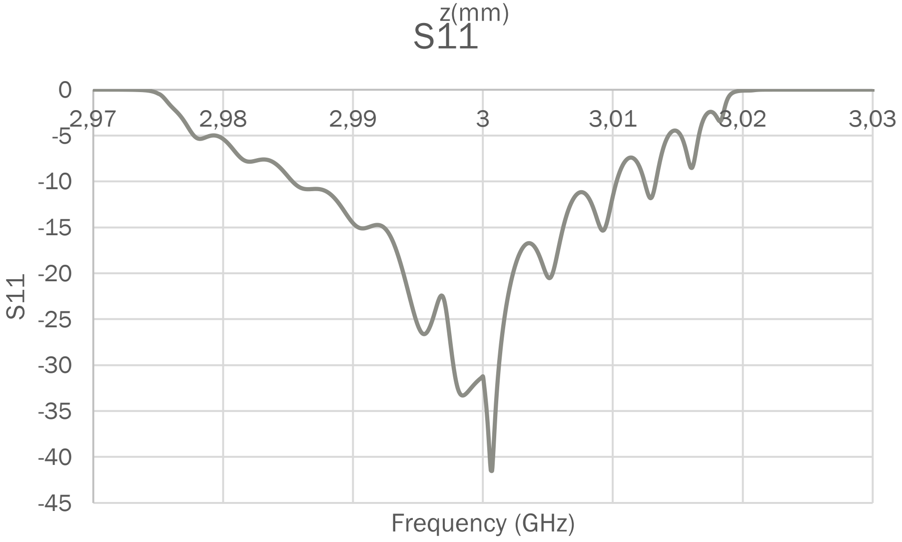


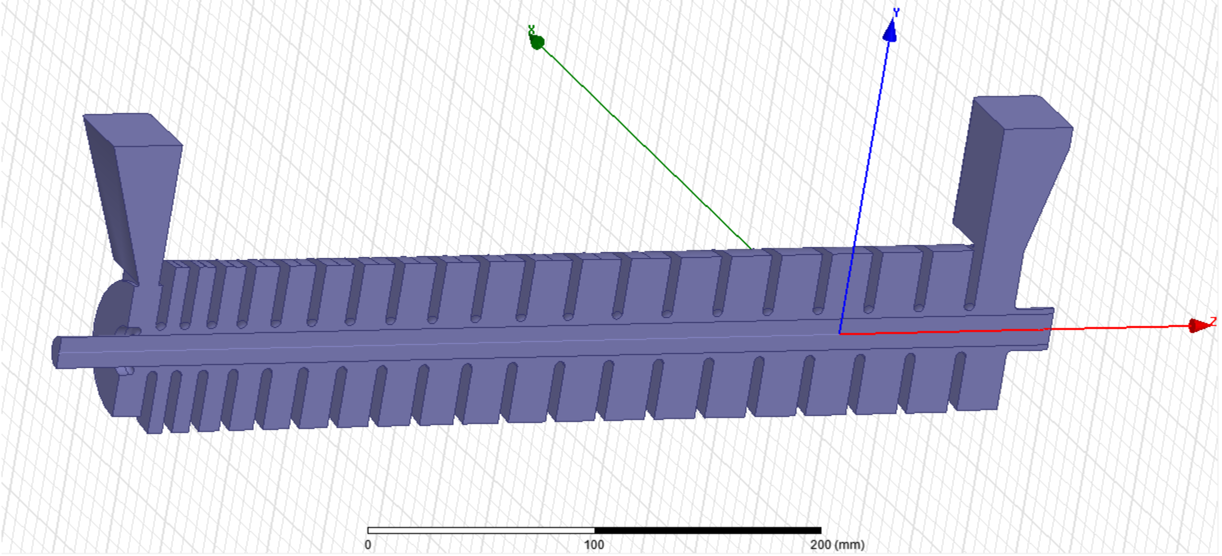
Final Kinetic Energy: 11.04±0.26 MeV or 2.3% Energy Spread

Coupler Design and RF responses







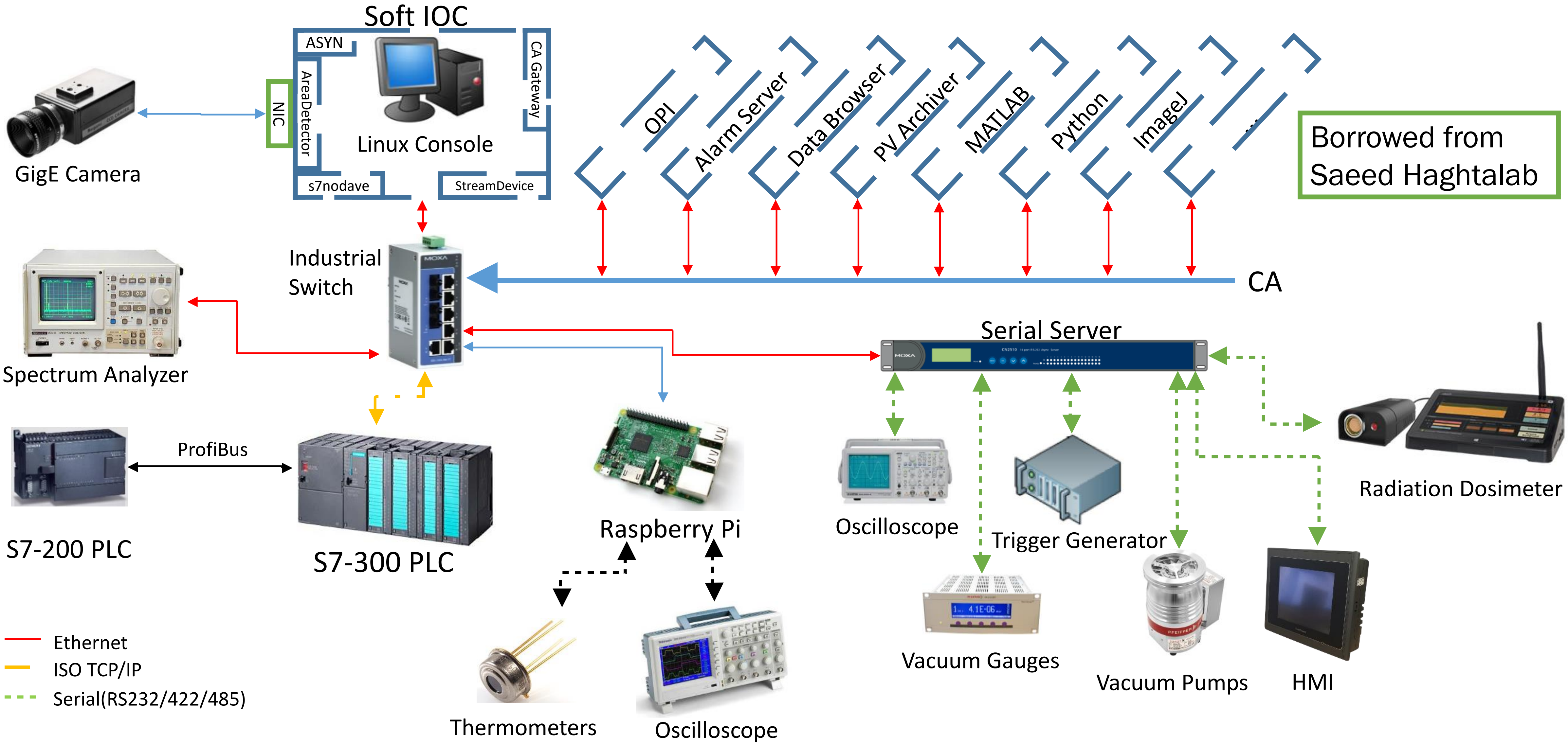


Cavity Assembly – Shrinking Fit method

Borrowed from
Farshad Ghasemi

مراحل مونتاژ قسمت‌های تیوب شتابدهی به روش انقباضی؛ ۱- شمایی از نحوه جازدن صفحه‌ها، ۲- تهیه ازت مایع به میزان کافی، ۳- تست و بستن فیکسچر نگه‌دارنده صفحه‌ها، ۴- سوارکردن صفحه‌ها برروی پایه تثبیت فاصله و بستن فیکسچر، ۵- مونتاژ تیوب پلی‌اتیلنی، ۶- تست اولیه هم‌ترازی و ۶- مونتاژ نهایی تیوب

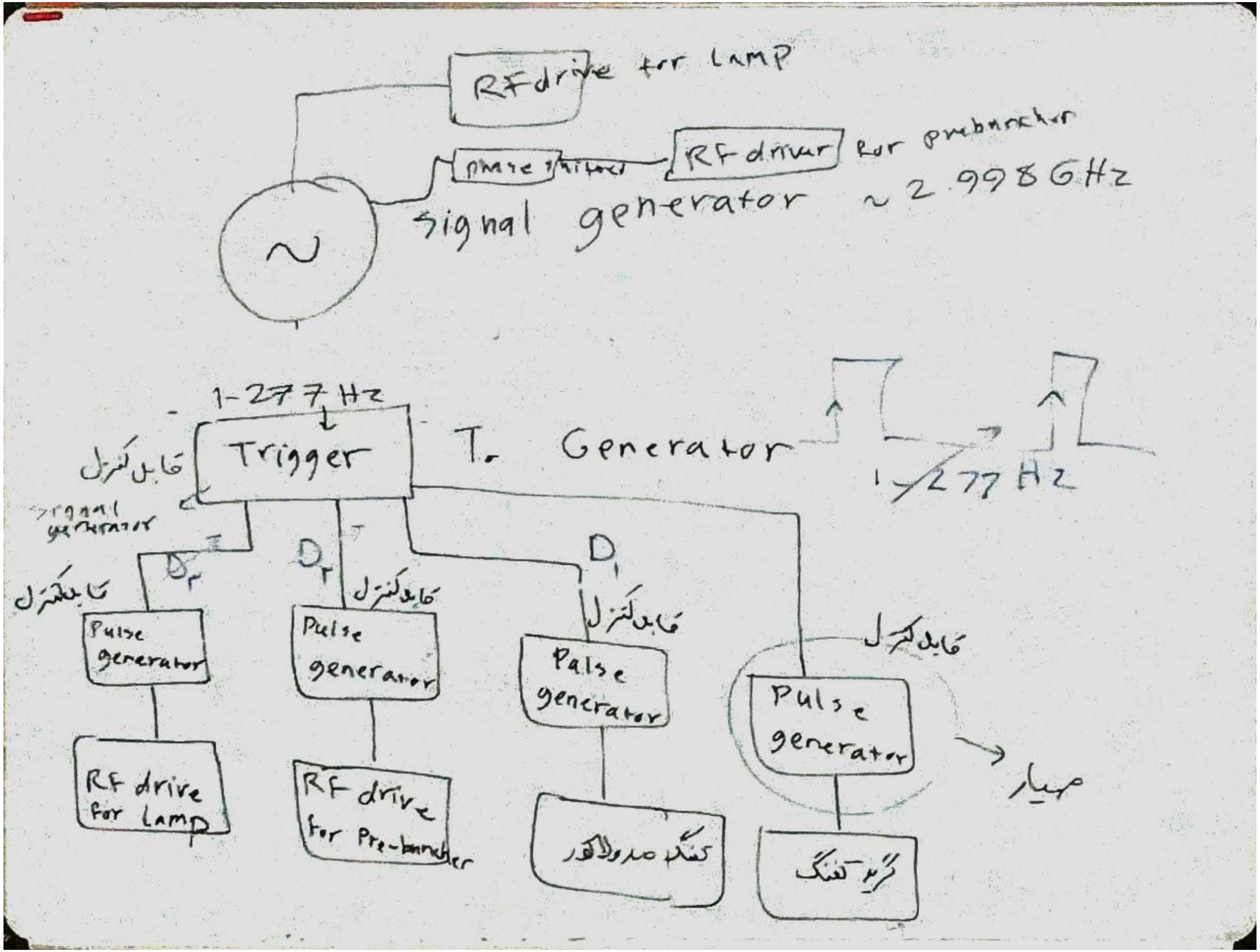
Control System



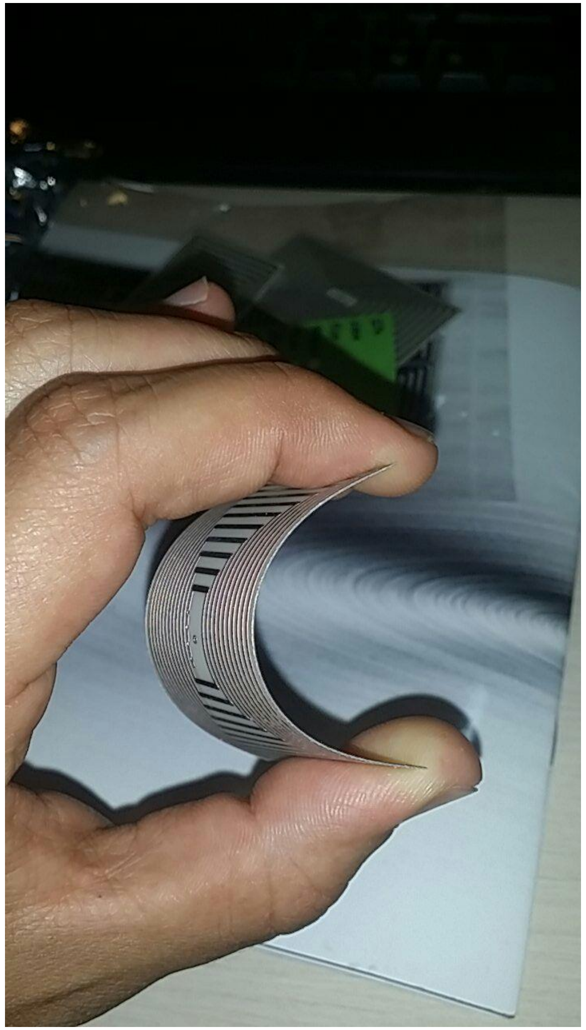
Borrowed from Saeed Haghtalab

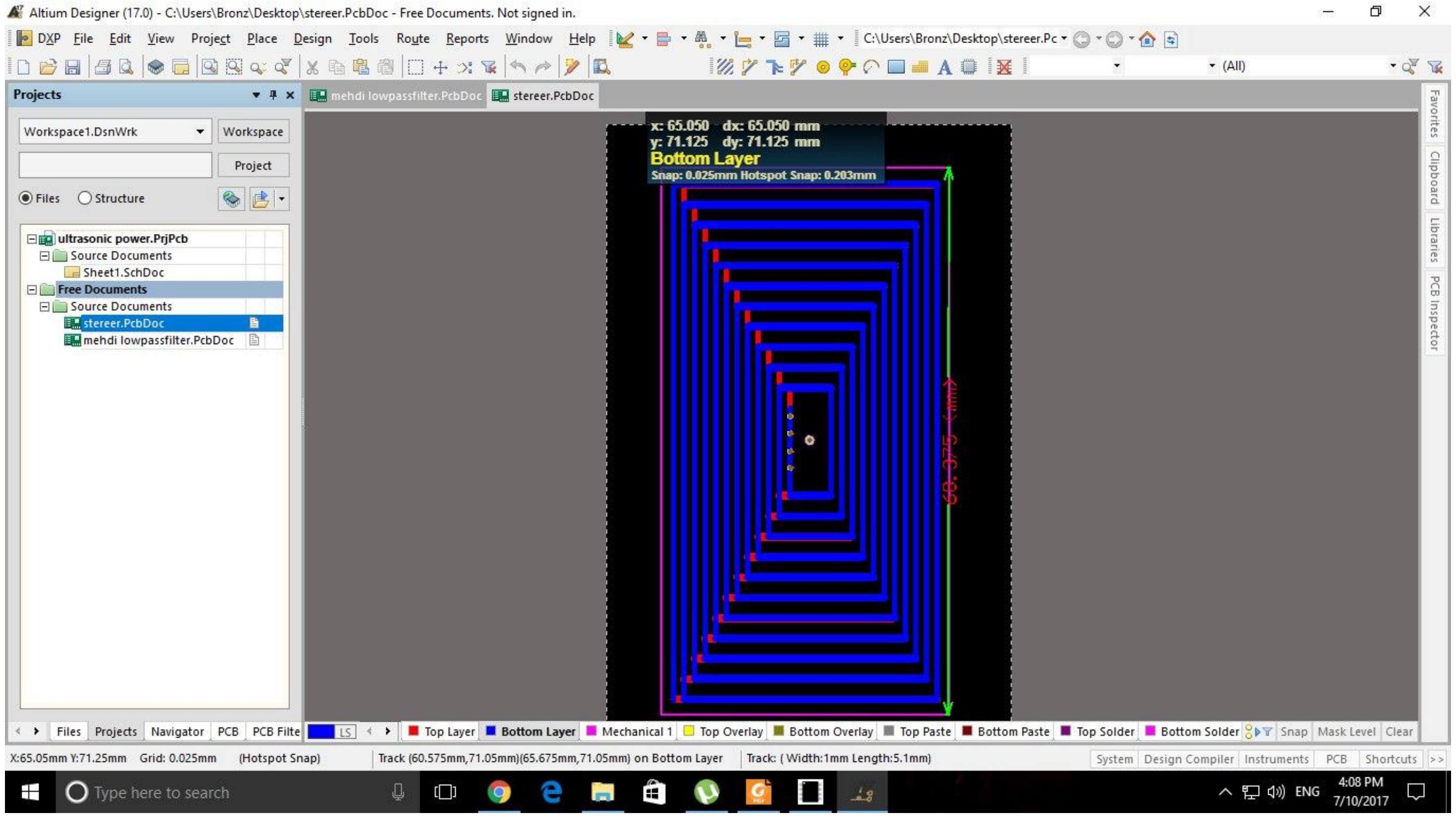
Cleaning by Nitrogen and CO_2

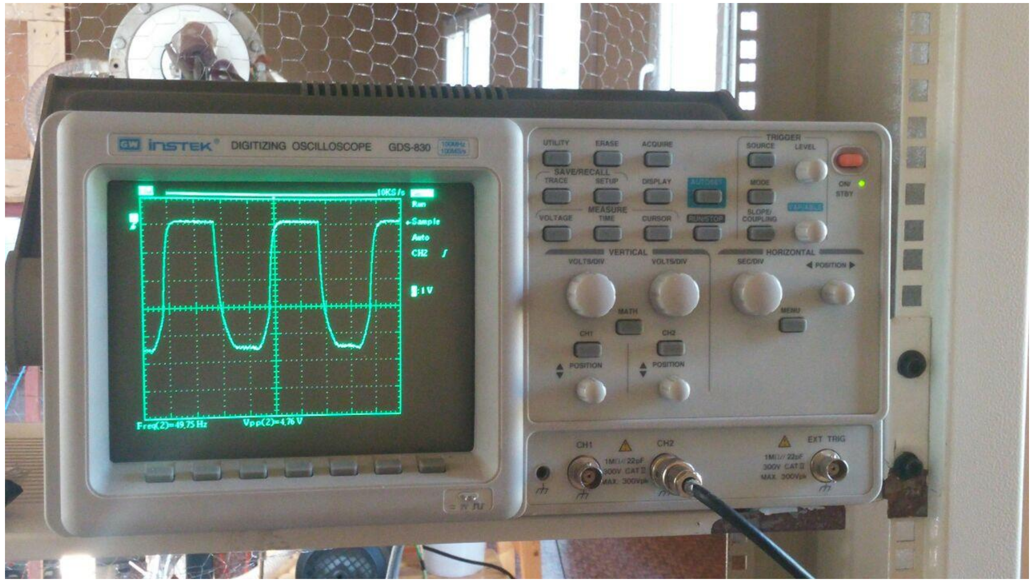
Disassembling of the Electron Gun



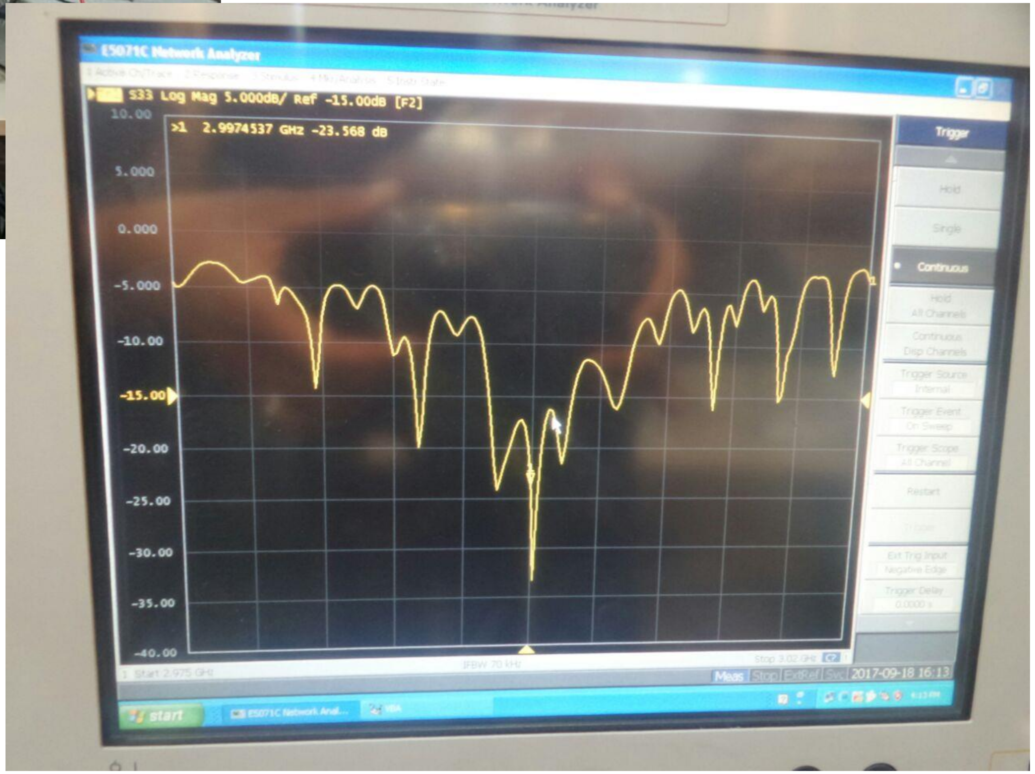
RF drive for lamp
RF driver for prebuncher
signal generator ~2.998 GHz
Trigger
T. Generator
قابل کنترل
D1
D2
D3
Pulse generator
Pulse generator
Pulse generator
Pulse generator
RF drive for Lamp
RF drive for Pre-buncher

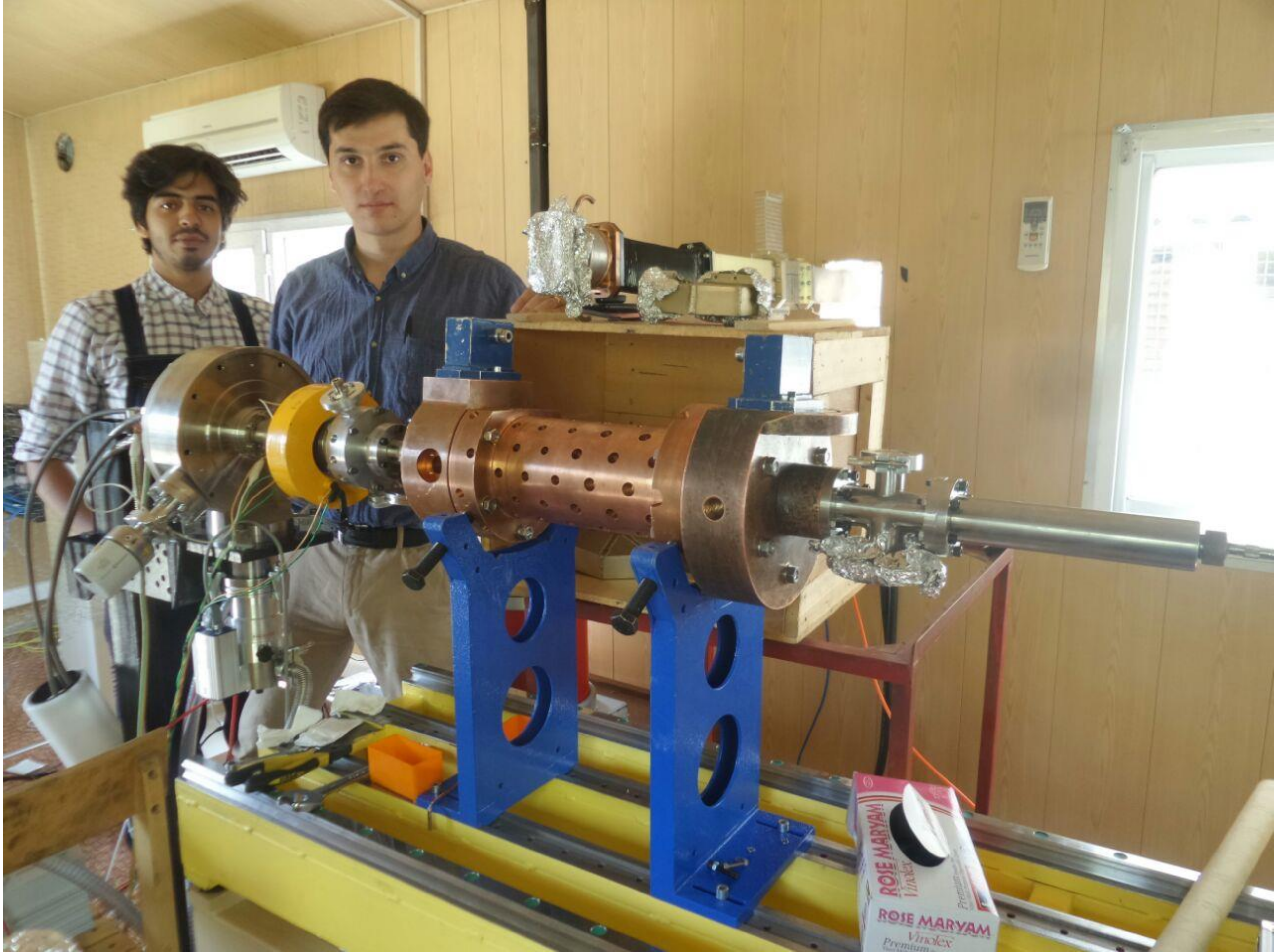



Altium Designer (17.0) - C:\Users\Bronz\Desktop\stereer.PcbDoc - Free Documents. Not signed in.
DXP File Edit View Project Place Design Tools Route Reports Window Help
Projects
mehdi lowpassfilter.PcbDoc
stereer.PcbDoc
Workspace1.DsnWrk
Workspace
Project
Files
Structure
ultrasonic power.PrjPcb
Source Documents
Sheet1.SchDoc
Free Documents
Source Documents
stereer.PcbDoc
mehdi lowpassfilter.PcbDoc
x: 65.050 dx: 65.050 mm
y: 71.125 dy: 71.125 mm
Bottom Layer
Snap: 0.025mm Hotspot Snap: 0.203mm
Files Projects Navigator PCB
Top Layer
Bottom Layer
Mechanical 1
Top Overlay
Bottom Overlay
Top Paste
Bottom Paste
Top Solder
Bottom Solder
Snap
Mask Level
Clear
X:65.05mm Y:71.25mm Grid: 0.025mm (Hotspot Snap)
Track (60.575mm,71.05mm)(65.675mm,71.05mm) on Bottom Layer
Track: (Width:1mm Length:5.1mm)
System
Design Compiler
Instruments
PCB
Shortcuts
Type here to search
ENG
4:08 PM
7/10/2017

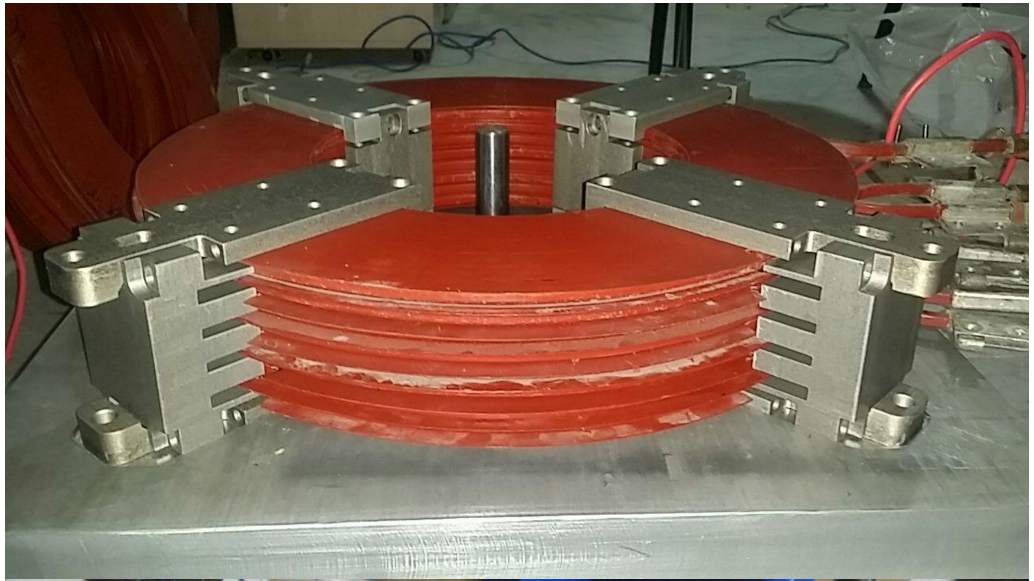
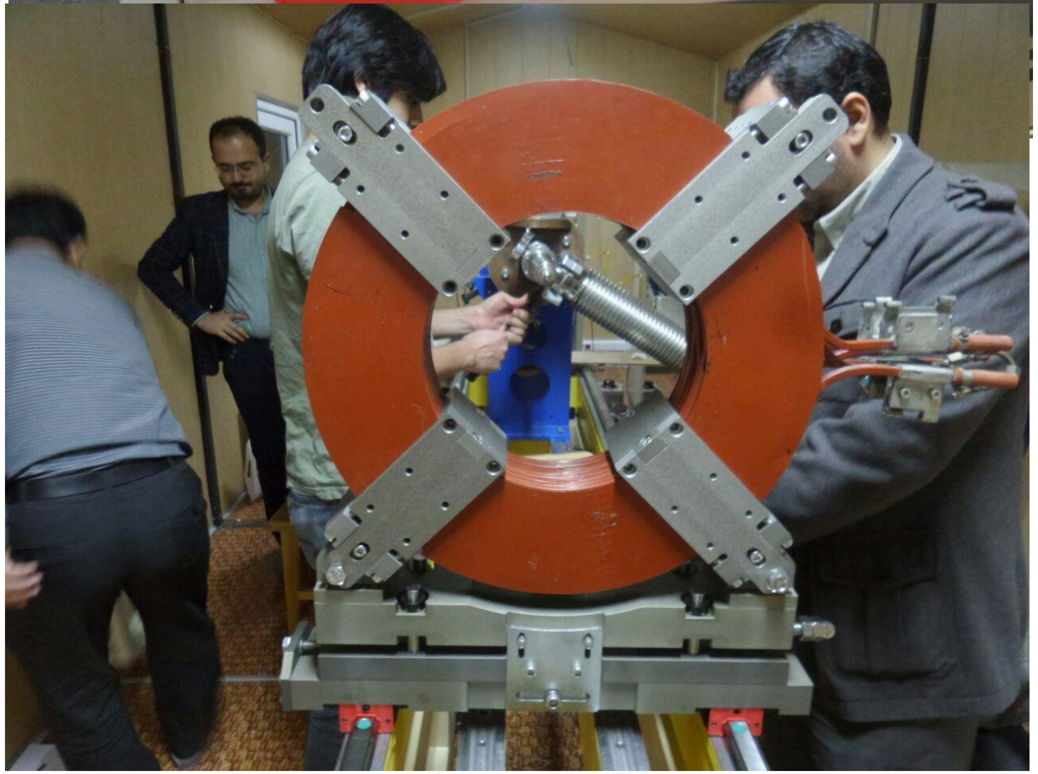
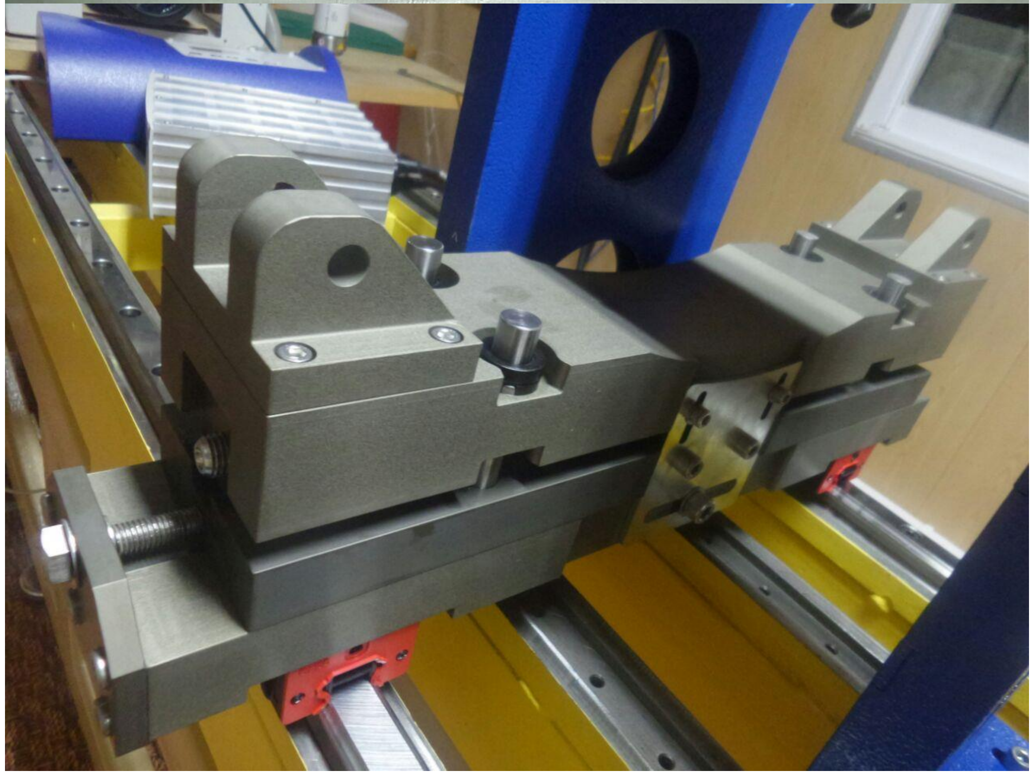

instek
DIGITIZING OSCILLOSCOPE
GDS-830
Freq(2)=49.75 Hz
Vpp(2)=4.76 V
TRIGGER
VERTICAL
HORIZONTAL
CH1
CH2
EXT TRIG

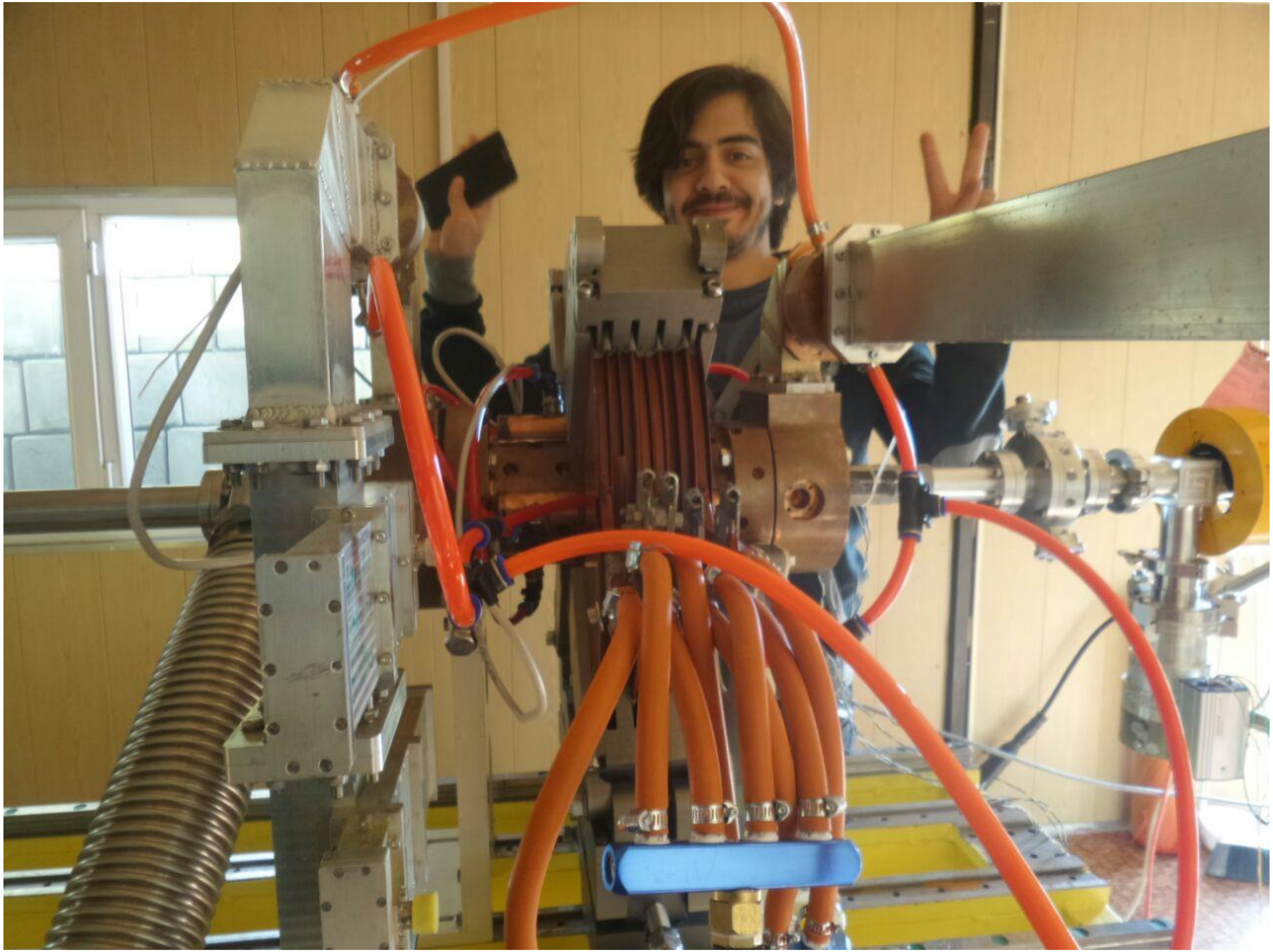

شروع اندازه گیری
02/09/2017


E5071C Network Analyzer
S33 Log Mag 5.000dB/ Ref -15.00dB [F2]
>1 2.9974537 GHz -23.568 dB
Trigger
Continuous
2017-09-18 16:13

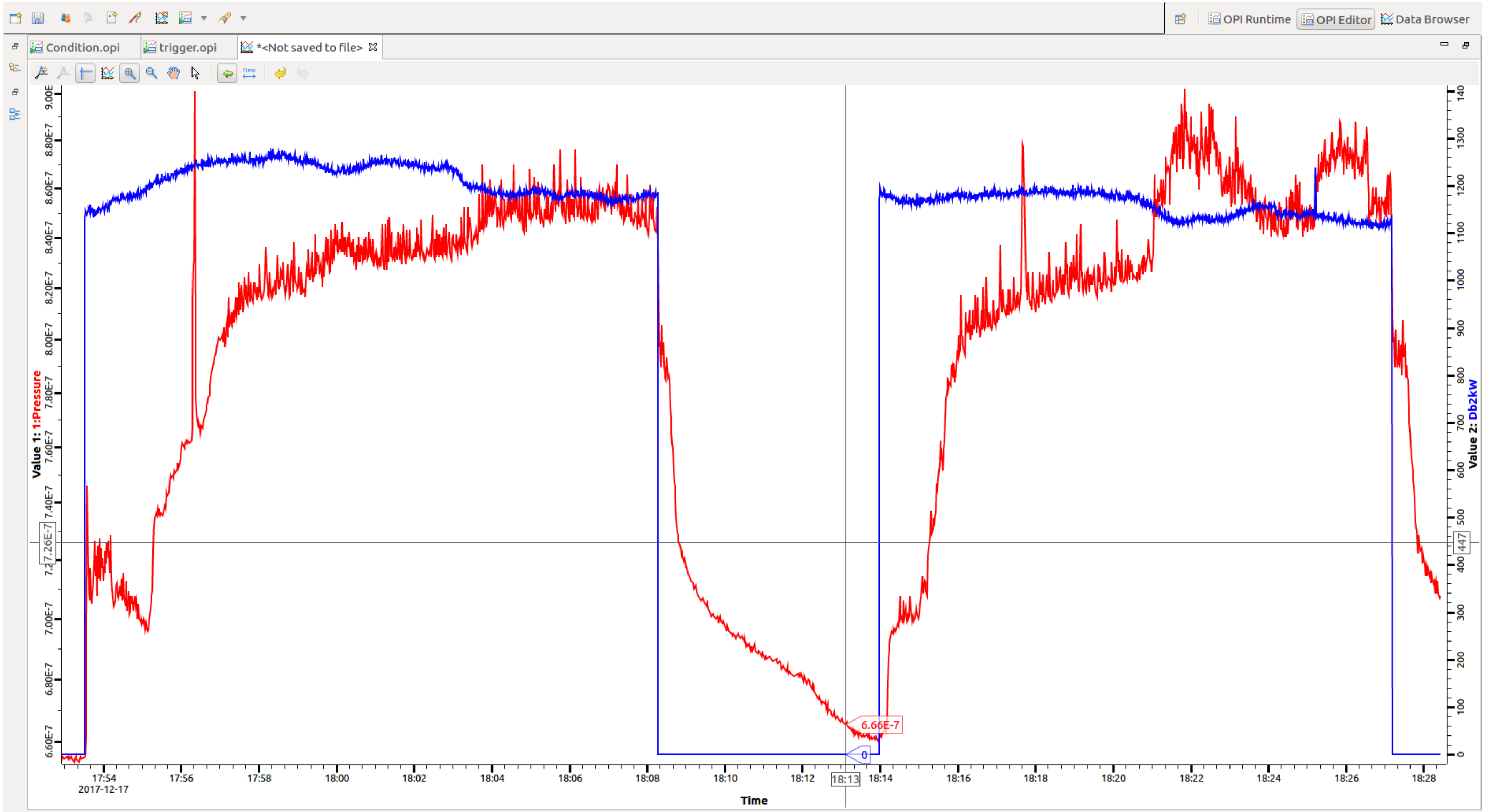

ROSE MARYAM
Vinolex
ROSE MARYAM
Vinolex

Shielding Blocks



Conditioning



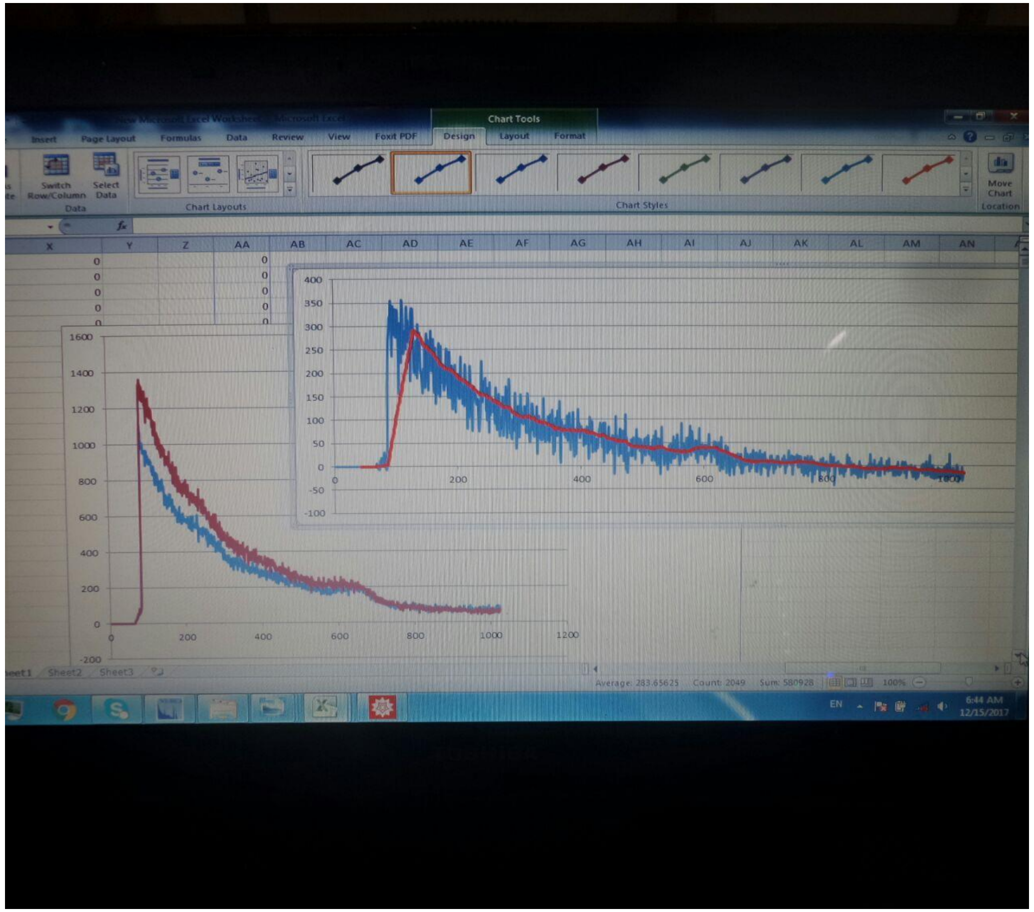
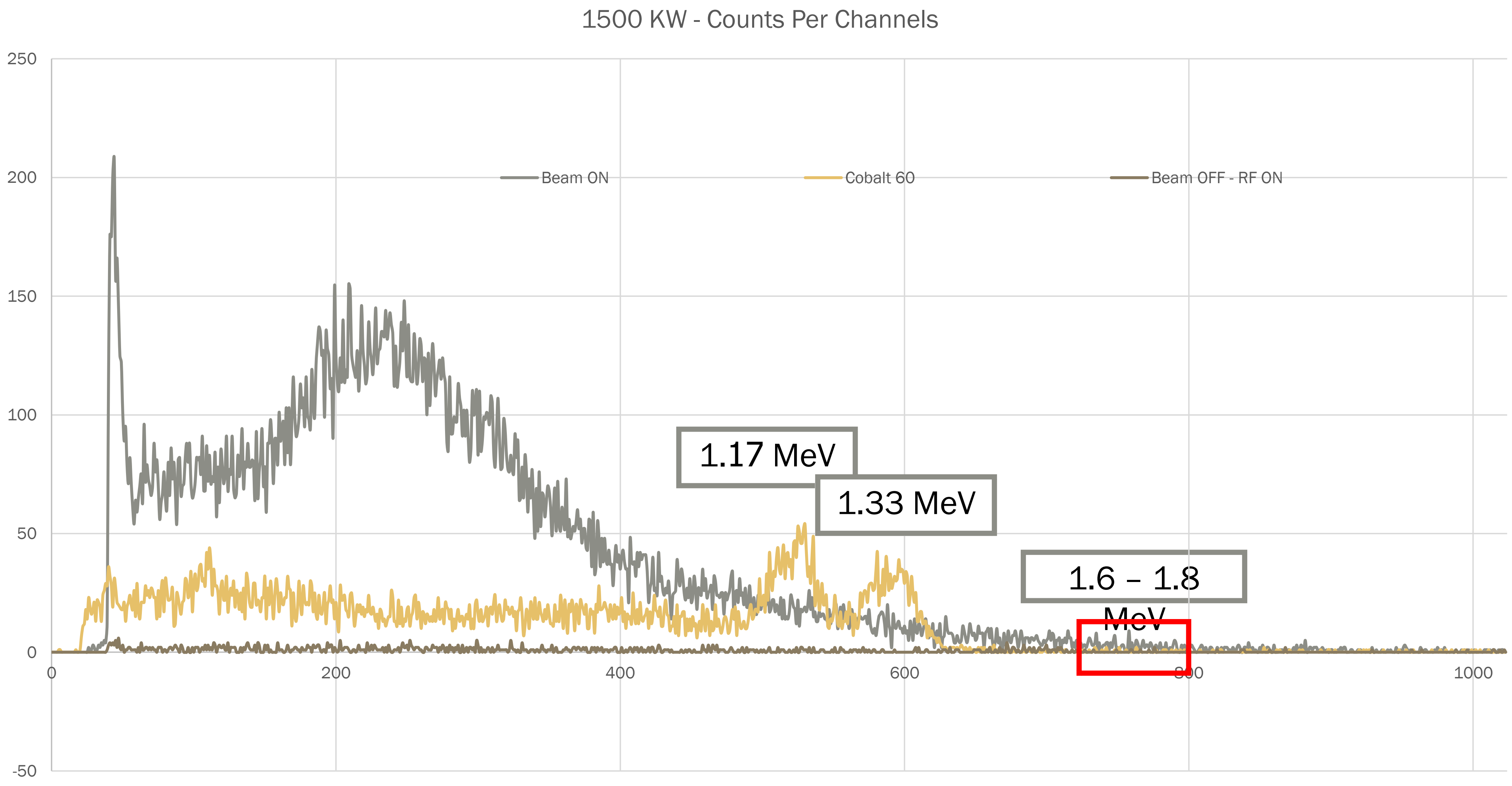


Chart Tools
Insert
Page Layout
Formulas
Data
Review
View
Foxit PDF
Design
Layout
Format
Chart Layouts
Chart Styles


ASUS
Time

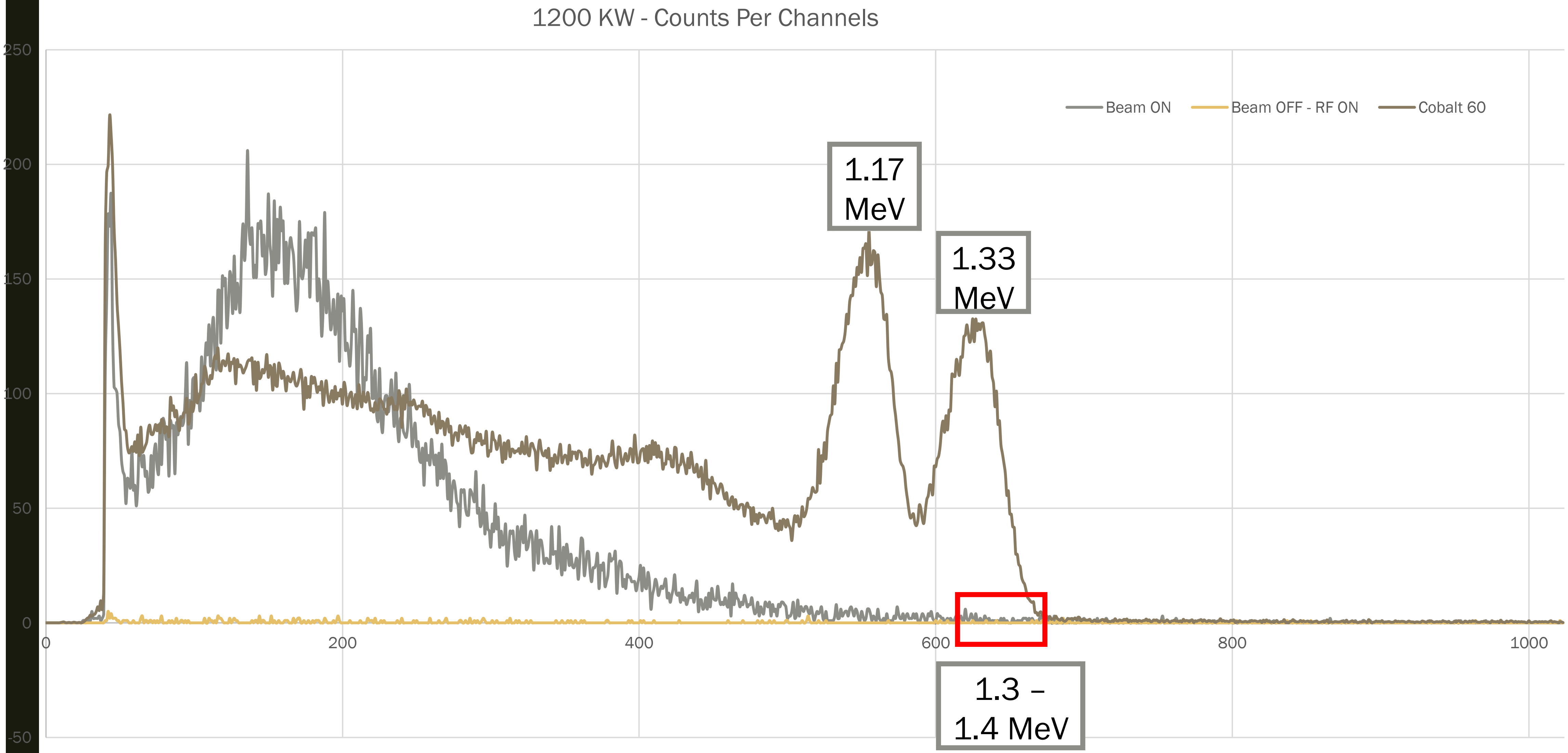
Measurement Setup - I

For 1.5 MW input power

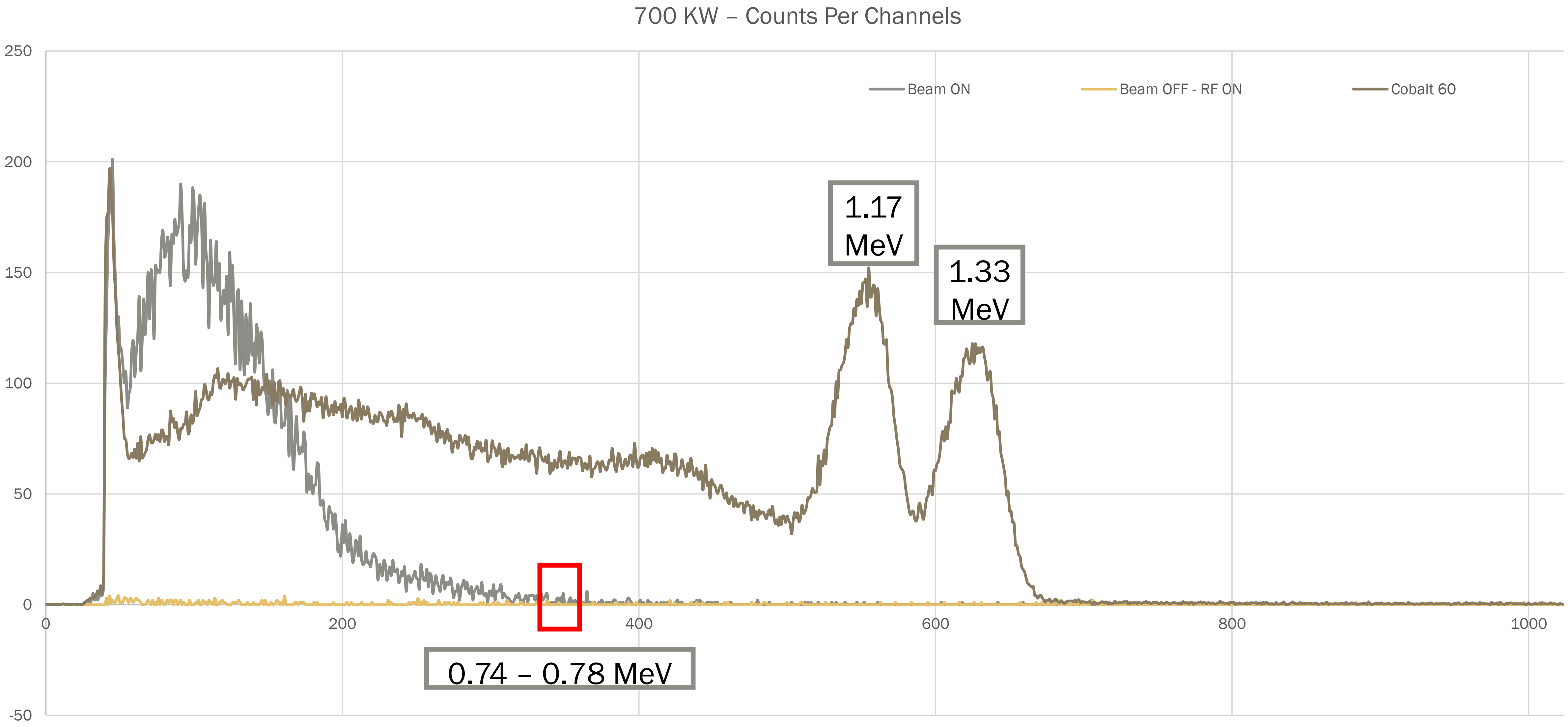


Measurement setup - II

For 1.2 MW input power



For 0.7 MW input power



Non-Brazing S-Band High-Gradient Proposal

The non-brazing structures are attractive because of two reasons: the capability for lower cost fabrication and the capability to use hard copper that behaves better in the high-gradient regime. At the moment the shrinking fit method - we used in our Linac - and the clamping method - proposed by David Alesini in INFN - are two candidates of this study. Initially, a single cell structures with proper removable power coupler will be designed as suggested by Walter. This first model will be brazed to use as the reference to compare to next non-brazing models. Next models will be fabricated/assembled by non-brazing methods and will be send to CERN for high power tests and breakdown studies with the CLIC project facilities (S-Box). S-Box is already used for the BTW structures for TULIP.

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

CERN
GENEVE, Suisse
GENEVA, Switzerland

Dr. Roberto Corsini and Dr. Walter Wuensch
CERN
BE Department
CH-1211 GENEVA 23

Geneva, 3 November 2017

To whom it may concern,

We would like to give our strong support to Hamed Shaker's proposal to investigate innovative assembly techniques for high-gradient accelerating cavities and we encourage its approval.

Electron linacs are used in a wide variety of scientific and industrial applications and recent demonstration of high, 100 MV/m-range, gradients by the CLIC collaboration open the possibility for even more applications. However high-gradients currently require rather complex and expensive assembly techniques which limits the spread of the technology. The Shaker proposal has the real potential to develop and validate new, less expensive cavity assembly techniques which are equally capable of supporting high gradients. Such a development would contribute to the spread of high-gradient technology, a very important goal for our collaboration.

In order to support the Shaker proposal, CERN is willing to provide access to the so-called SBox facility at CERN in order to carry out high-gradient testing on completed cavities. Tests of cavities in this facility will provide essential performance data, validating the ideas and providing guidance for further development. CERN will make the infrastructure available for the testing and provide operational support. We also welcome the participation of IPM experts and students during the high-gradient tests. Some local subsistence support can be envisaged. It will also be possible for the IPM group to apply for funding under the ARIES Transnational access of the facility. In addition CERN radio frequency experts can provide guidance for the technology development.

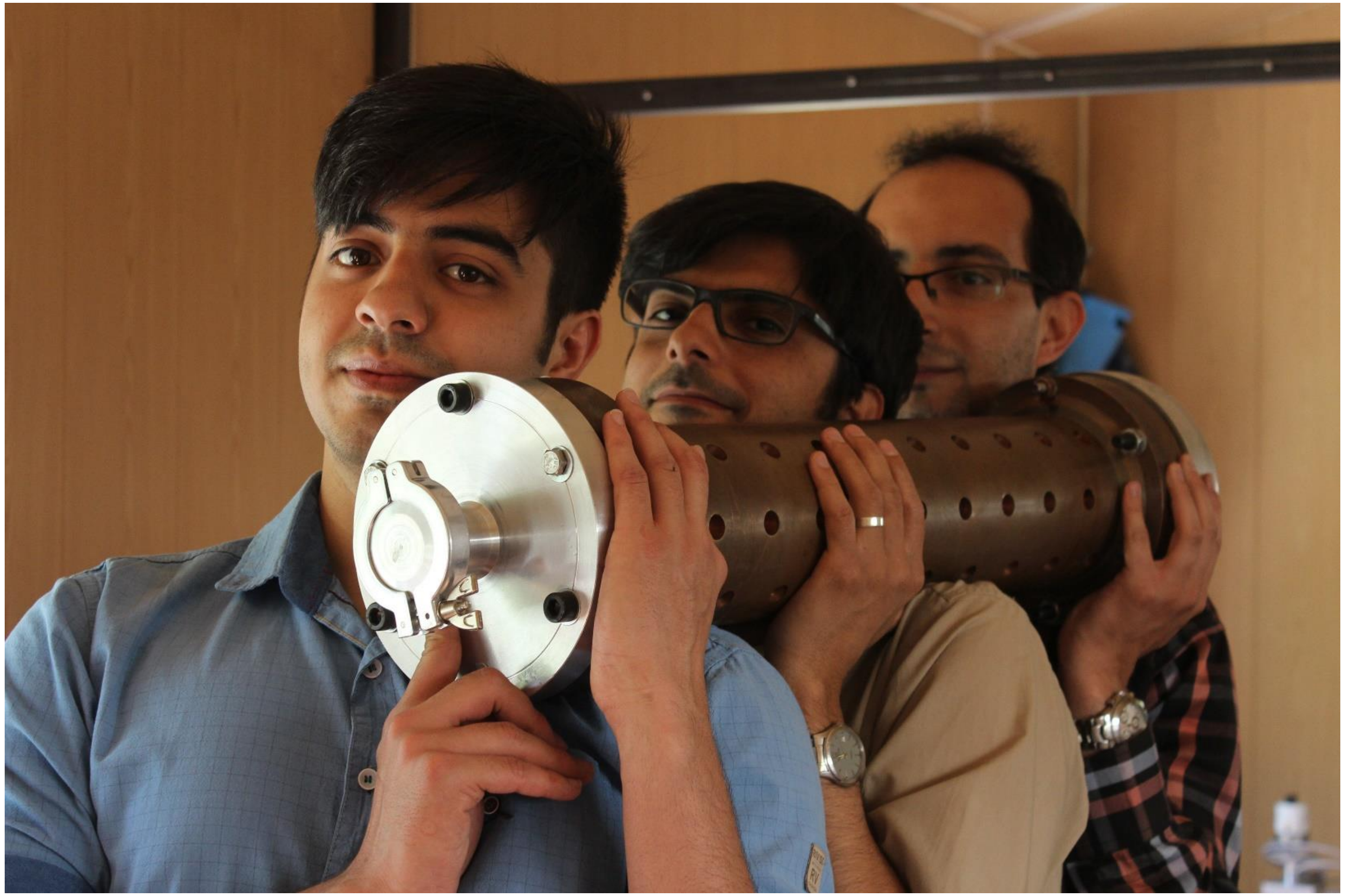
The IPM institute has made important contributions to the CLIC study and has proven its capabilities. Consequently we would like to support continuation of our collaboration and expansion into the field of high-gradient cavity development and testing.

Sincerely,

Dr. Roberto Corsini
CLEAR Facility coordinator
BE/ABP/LAT section leader

Dr. Walter Wuensch
Head of the CLIC rf development program

Thanks for your attention

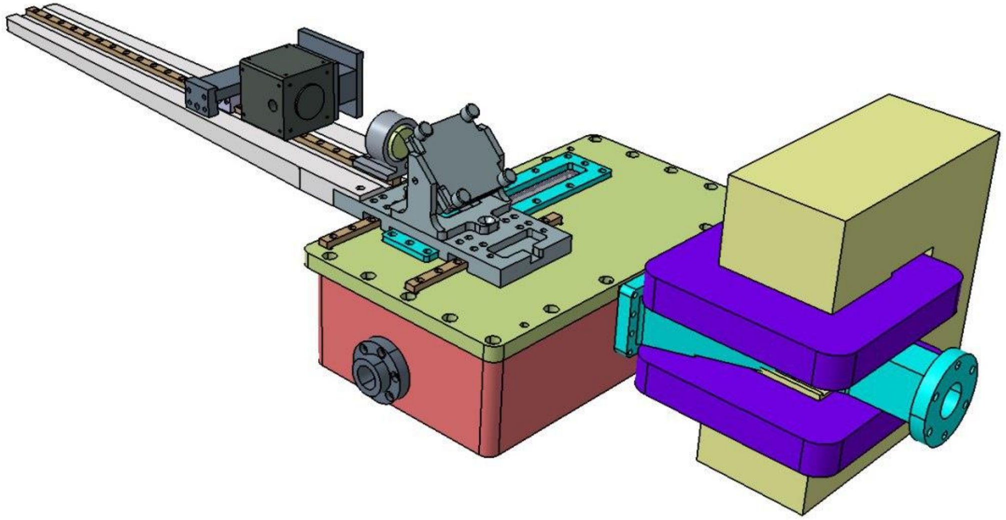


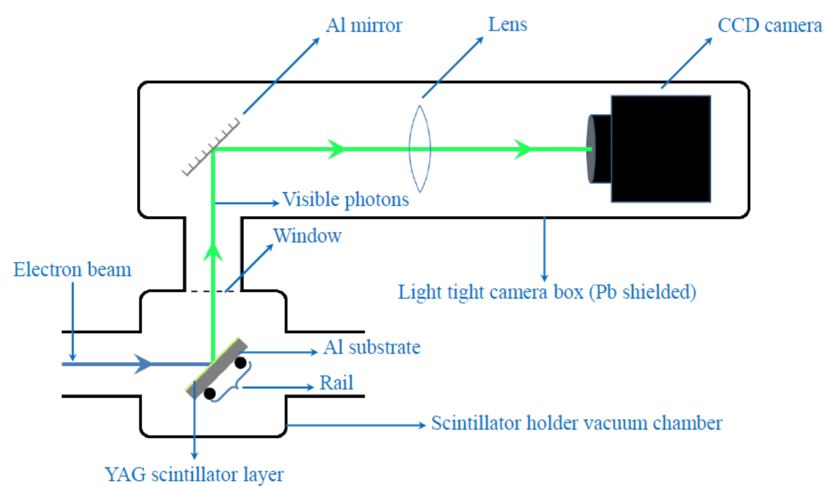
Brief Procedures on Cavities

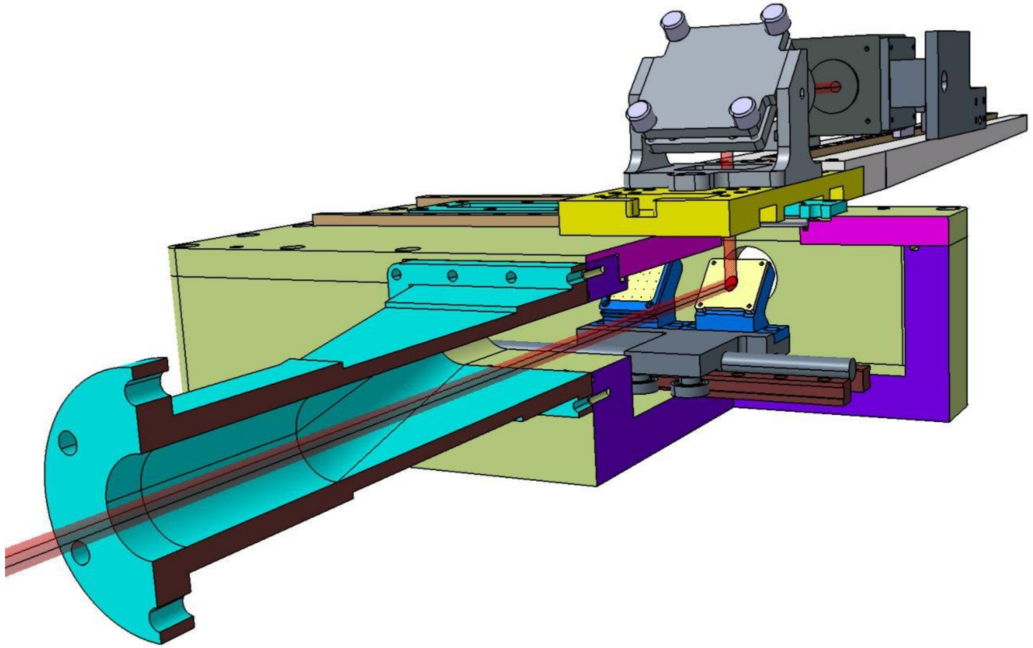
- Cold RF measurement
  - *Bead-pull measurement for electric and phase advancing profile*
  - *Quality factors and other parameters*
- Dry-ice cleaning based on the DESY's experiences
- Vacuum test
- Conditioning
- 1.8 MW, 255 Hz, 7μs Input power
- 1.5 MeV electron extracted from the TW buncher on 17th December 2017

Beam Diagnostic Box (Supervising)

- Beam Profile Monitor
- Energy Spectroscopy
- Emittance measurement
- Current measurement



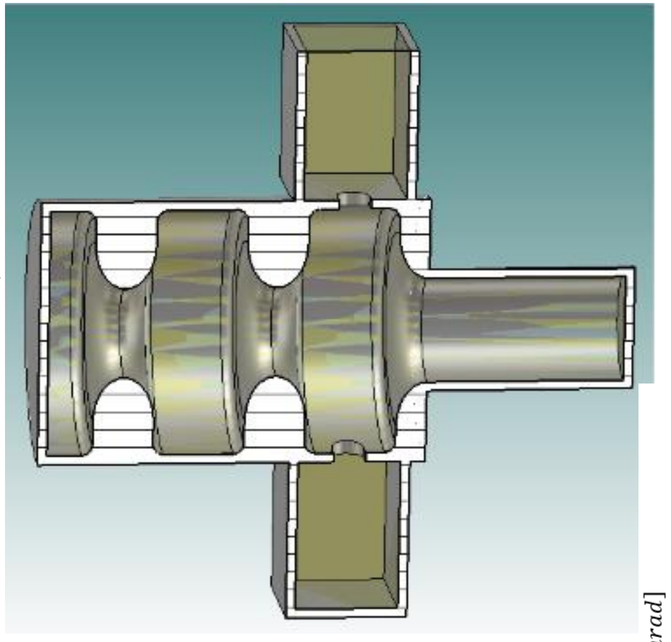


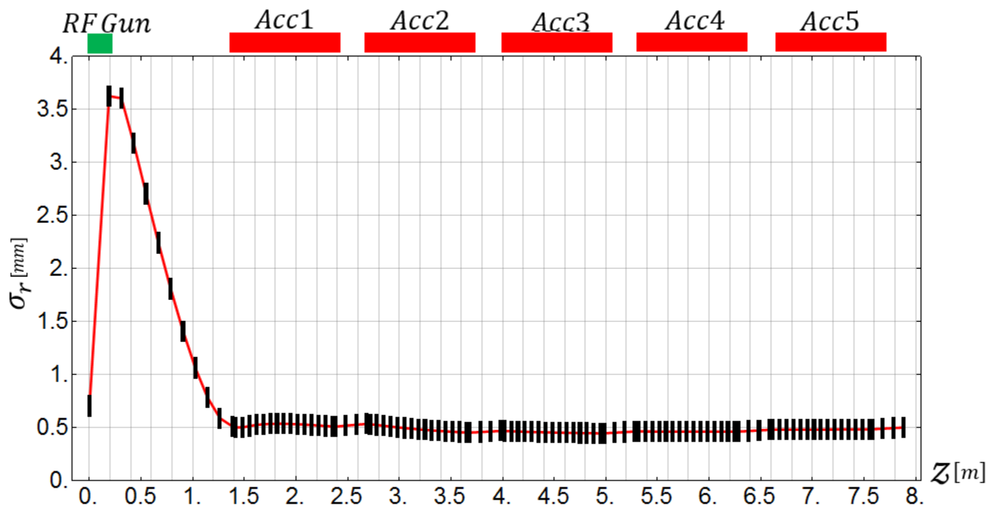


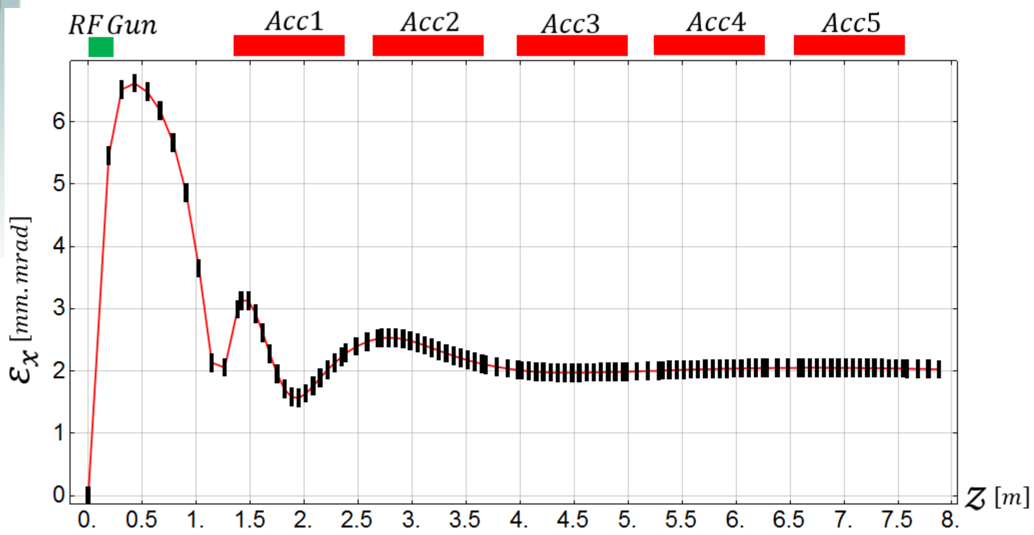
Initial design of a Photo-Injector for upgrading (Supervising)

- 2998 MHz
- 6 MW input power
- 74 MV/m on Cathode
- 5 MeV injector energy
- 2 μm emittance
- 0.2% energy spread

  in 50 MeV







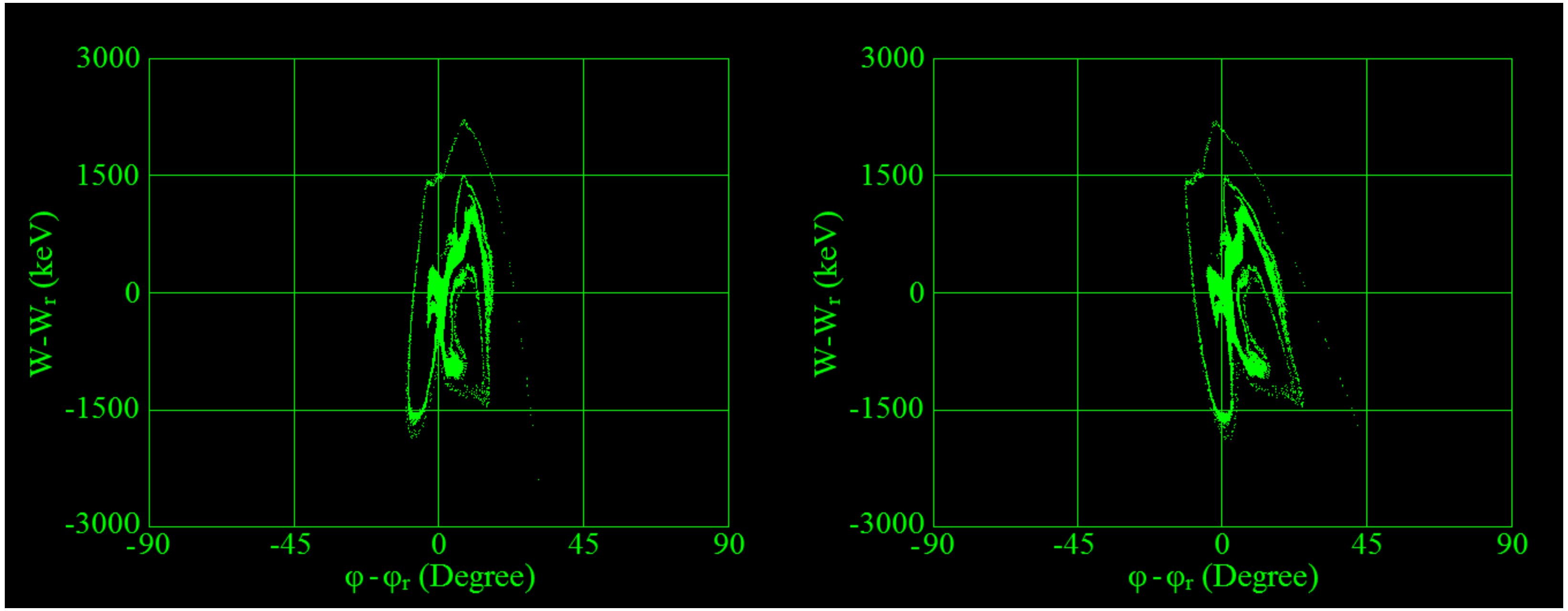
Beam parameters without a chicane

Parameters	Bunch length	Energy spread
Required value	3 mm	< 0.5 MeV
CDR model	9 mm	1.3 MeV
New model	3 mm	0.53 MeV

Adjusting the phase of ACC1: 3.3 mm 0.5 MeV

… to optimize the magnetic chicane to operate as a bunch compressor as well.

Bunch compression at chicane



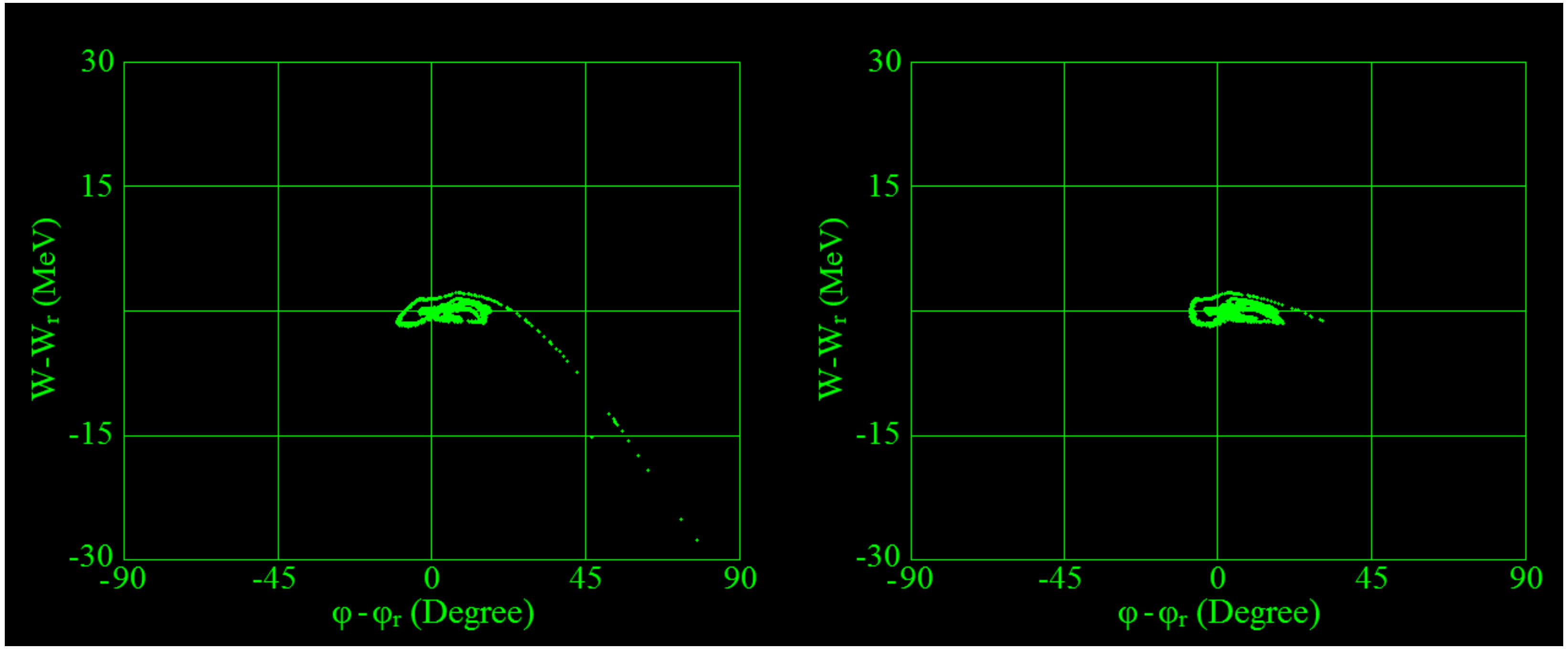
Before chicane After chicane

Bunch length reduction: ~ 20 %

Chicane and the injector performance

- Beam loss reduction (10% bunch length increase):

$$\sigma_L: 10\% \nearrow \quad \Longrightarrow \quad \frac{\sigma_W}{W_{av}} < 1\% \quad \Longrightarrow \quad \textit{No loss } (\lesssim 0.1\%)$$



Before chicane After chicane

Conclusion

A new model for the CLIC Drive Beam injector.
A significant improvement of the injector performance compared to the CDR model.

- **Longitudinal dynamics:**
  - ✓ Satellite population is reduced from 4.9% to 2.1%.
    - ○ The 4^{th} SHB: 1% Satellite population.
  - ✓ The energy spread is reduce by a factor 3.

    ⟹ Beam loss: 24%⟶0.1%.

  - ✓ **Transverse dynamics:**
  - ✓ Constant beam size: limiting the emittance growth.
  - ✓ Variable beam size: reducing the need for solenoidal field.
  - ✓ The quadrupole focusing could be started from the end of ACC2.

- **Magnetic chicane:**
  - ✓ No need to chicane.
  - ✓ Improving the injector performance.