Particle Accelerators Projects in Iran (Focused on the IPM recent and future projects)

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History

- During 90s, the idea of founding of a particle accelerator national laboratory and to participate in the international particle accelerator projects was born among a few Iranian physicists. At the beginning of this century, this dream turned to reality, mostly under the IPM's umbrella. At 2001 and 2005, respectively, the official collaboration with CERN and SESAME was signed. At 2003, a low energy TW electron linear accelerator project was started which aimed at a proof of principle and using as an injector for other accelerators at the one hand and for the industrial and clinical applications at the other hand. At 2004, the accelerator physics Ph.D. program was started at IPM and 12 students were graduated up to now. At 2009, the national particle accelerator laboratory was founded aimed at to build a light source although the initial idea was a collider.

Institute for Research in Fundamental Science (IPM)

The Institute was founded on 1989 and it is comprised of nine schools:

- Astronomy
- Biological Sciences
- Cognitive Sciences
- Computer Science
- Mathematics
- Nano-science
- **Particles and Accelerators**
  - Collaboration with CERN
    - CMS
    - CLIC
    - LINAC4
  - TW Low Energy Electron Linac
  - Ph.D. Programs: Was started from 2004 and 12 students were graduated.
- Philosophy
- Physics
- National Projects
  - **Iranian Light Source Facility (ILSF)**
  - Observatory
  - GRID

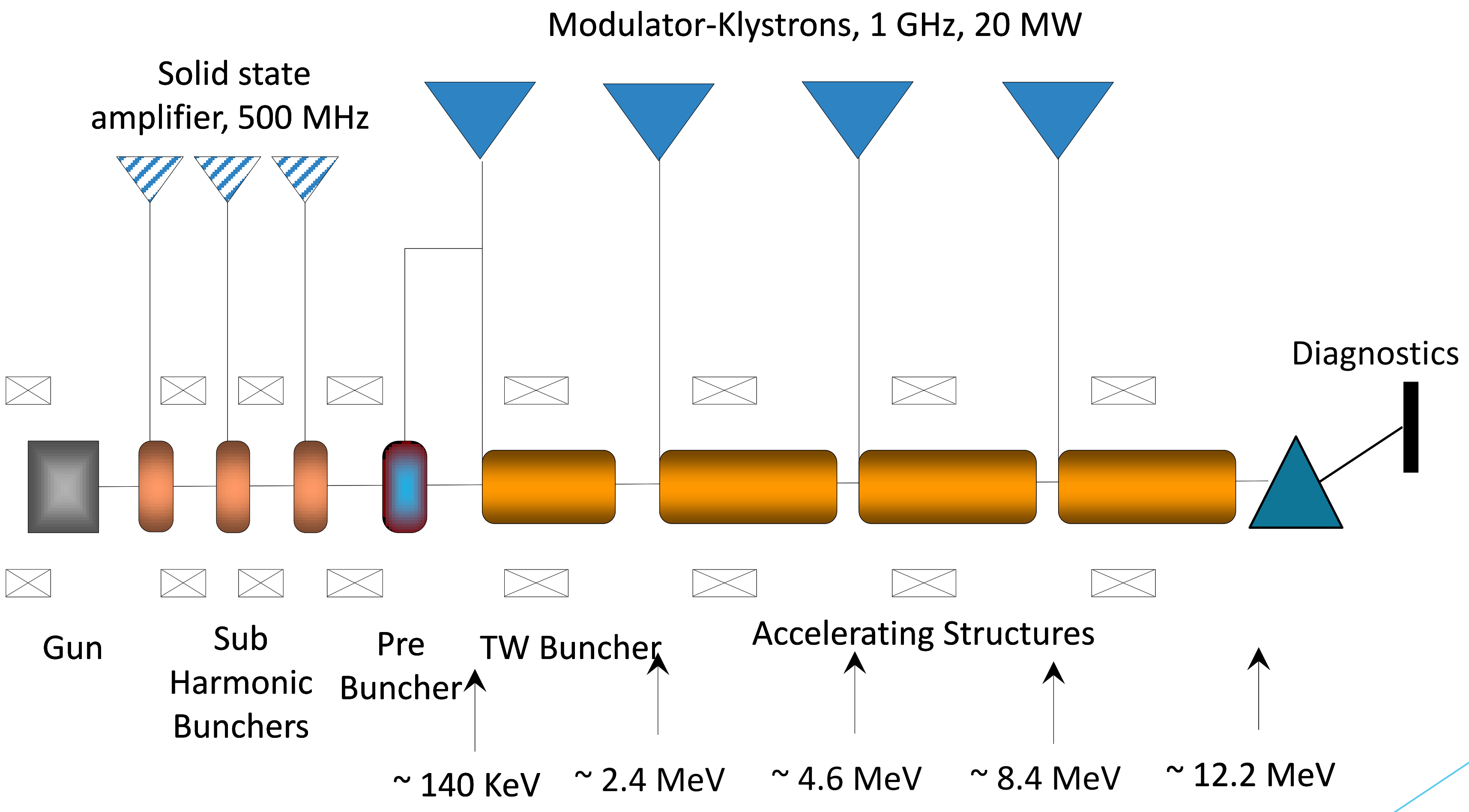
LINAC4

- Ph.D. Thesis:
  - Beam dynamic & commissioning
  - Magnetic measurements
  - DTL RF cavity bead pull measurements and tuning

CLIC

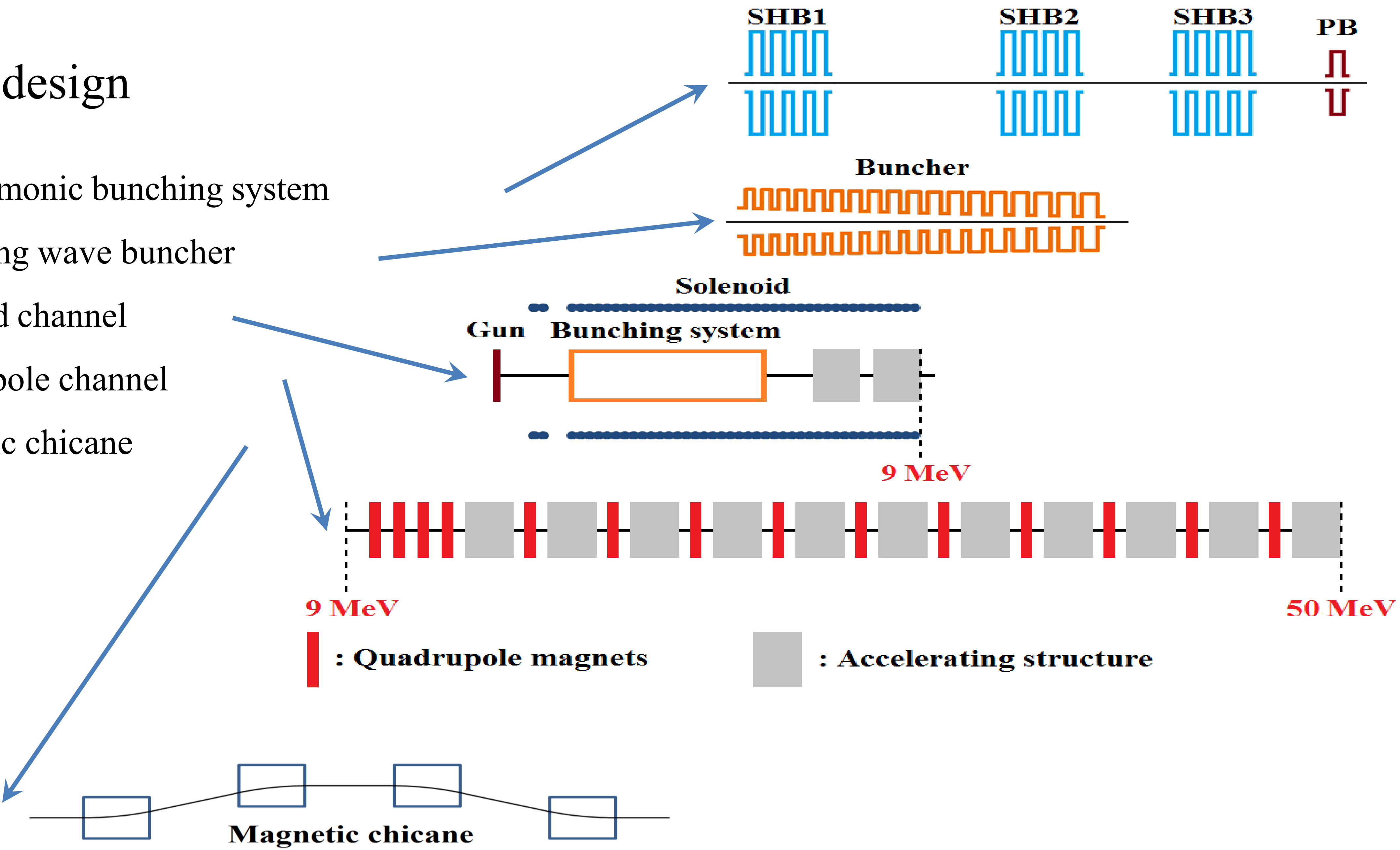
- Ph.D. Thesis:
  - CLIC Drive Beam Injector
    - Beam Dynamics Study
    - Pre-Buncher RF Design
    - Thermionic and Photo-Cathode RF Gun Design
  - CTF3 Longitudinal Beam Dynamics Study and Bunch Length Measurement
  - CTF3 Pulse Compressors Control
- Post-Doctoral Researches:
  - RF Design of Sub-Harmonic Bunchers (First one has been machined in the CERN Workshop)
  - RF Design of Traveling Wave Buncher
  - Damping Ring Study

CLIC Drive Beam Front-End Layout

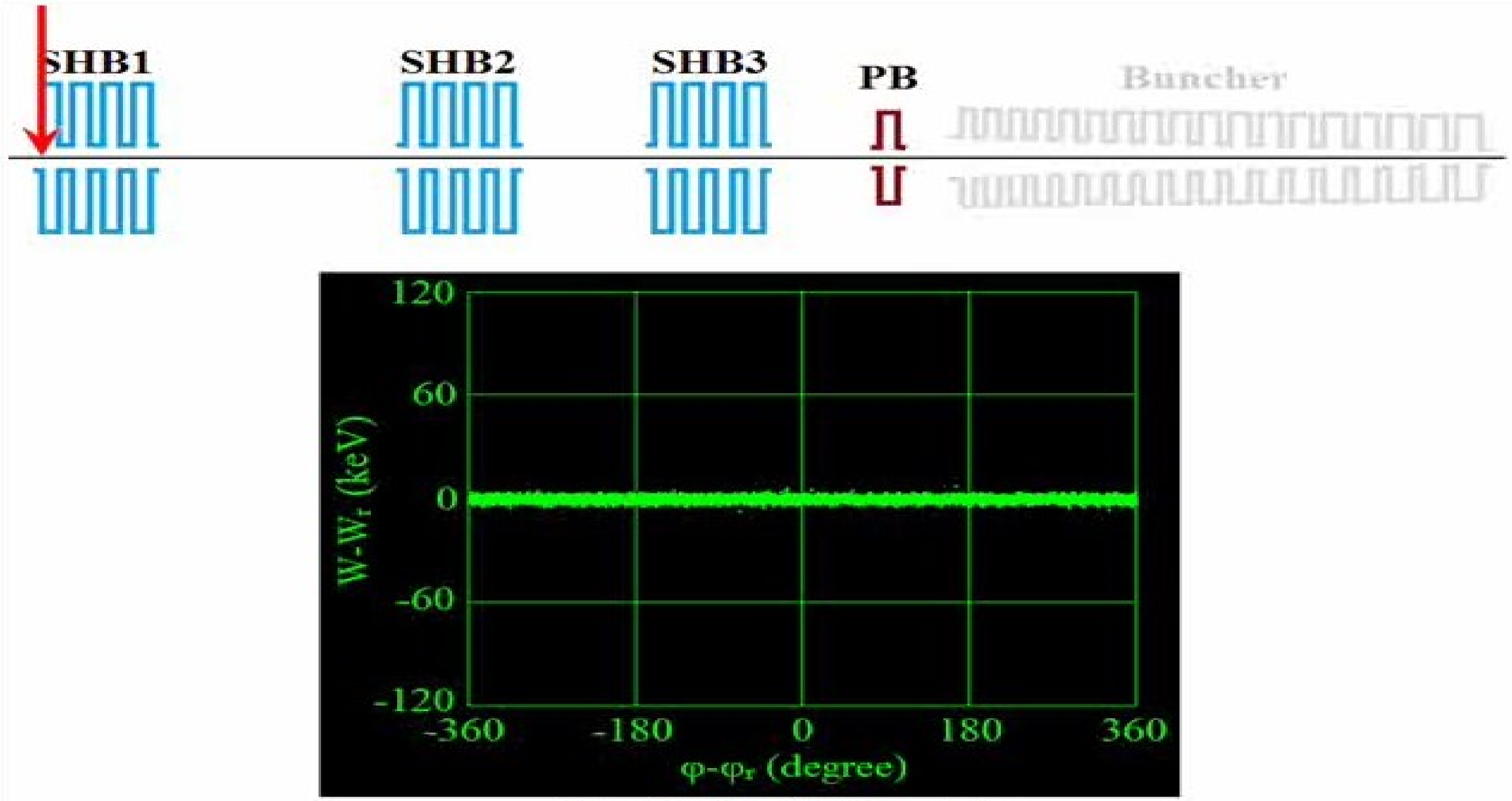


Injector design

- ✓ Sub-harmonic bunching system
- ✓ Travelling wave buncher
- ✓ Solenoid channel
- ✓ Quadrupole channel
- ✓ Magnetic chicane

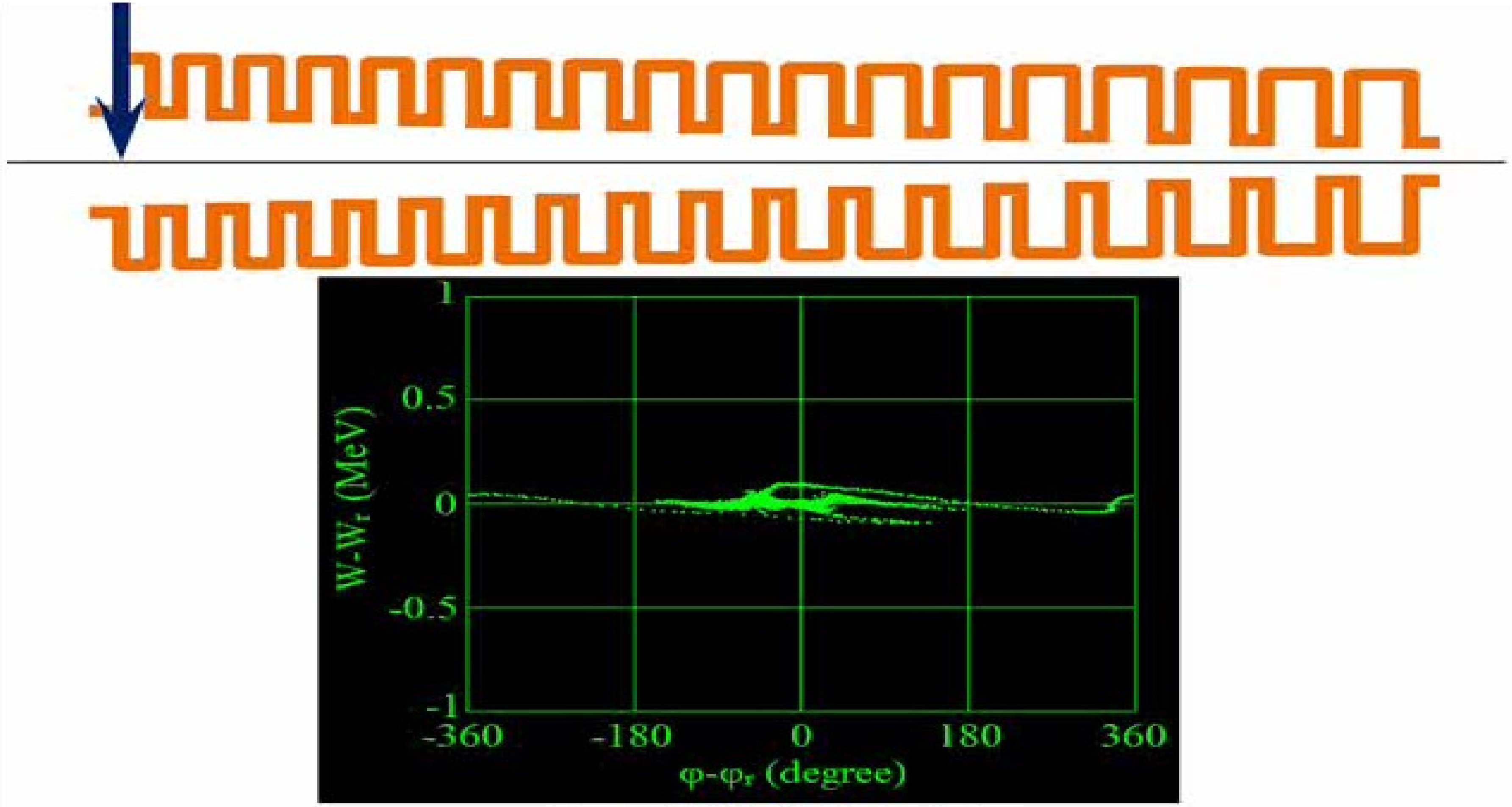


Longitudinal phase space evolution: SHB



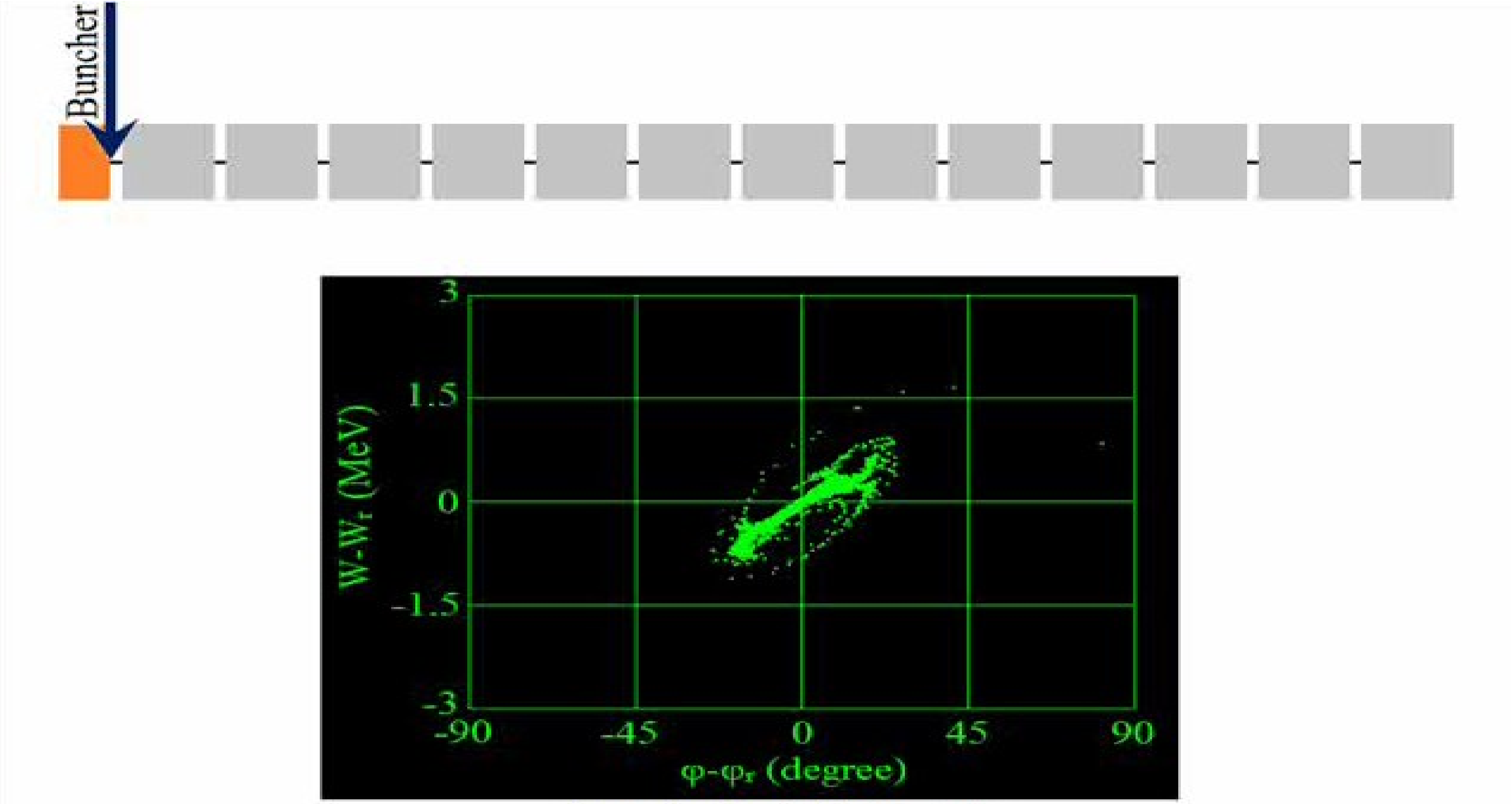
Longitudinal phase space

Longitudinal phase space evolution: TW Buncher



Longitudinal phase space

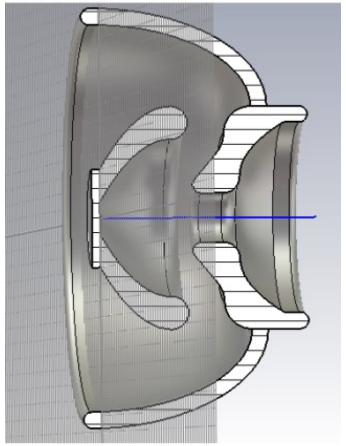
Longitudinal phase space evolution: Accelerating structures



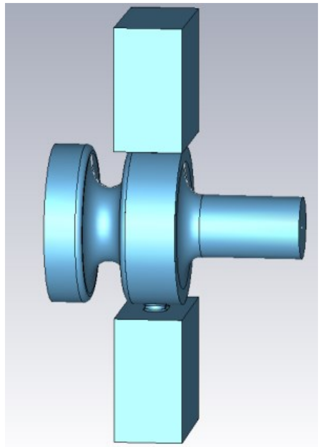
Longitudinal phase space

CLIC Drive Beam Injector – Electron Guns and Prebuncher

Low Emittance Thermionic Gun

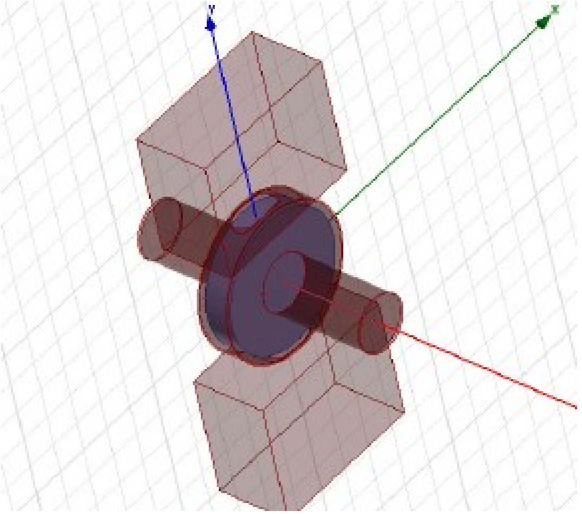


Low Emittance Photo-Cathode RF Gun

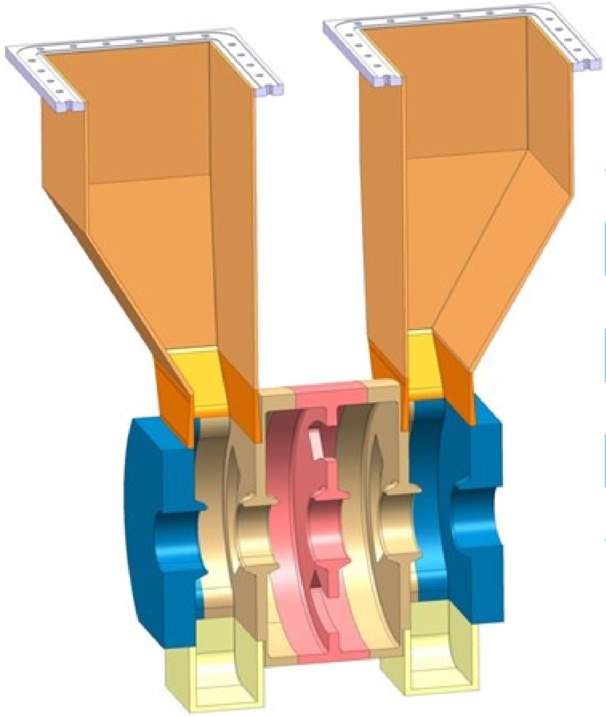


Frequency [GHz]	1
Bunch Frequency [GHz]	0.5
Current [A]/Charg[nC]	4.2/8.4
RMS Bunch Length [ps]	5
Pulse Repetition Rate [Hz]	50
Input Power [MW]	20,30,40
Pulse Length [μS]	140

Pre-Buncher



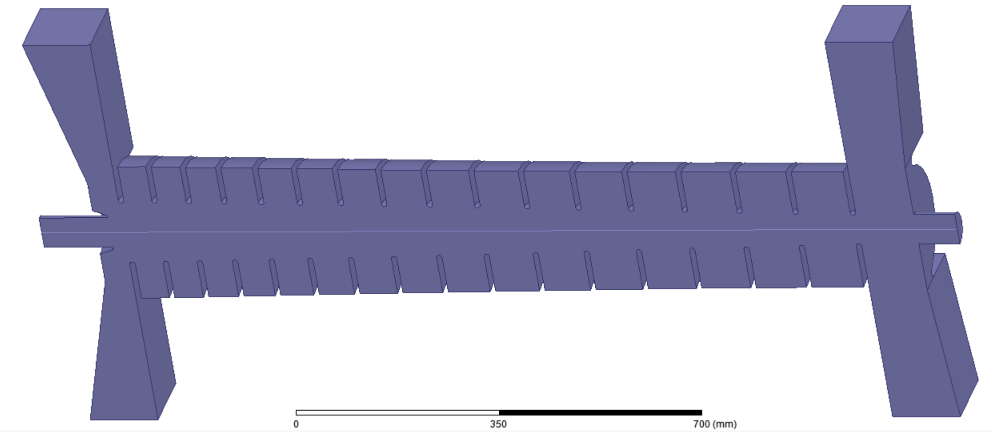
CLIC Drive Beam Injector – Sub Harmonic Bunchers

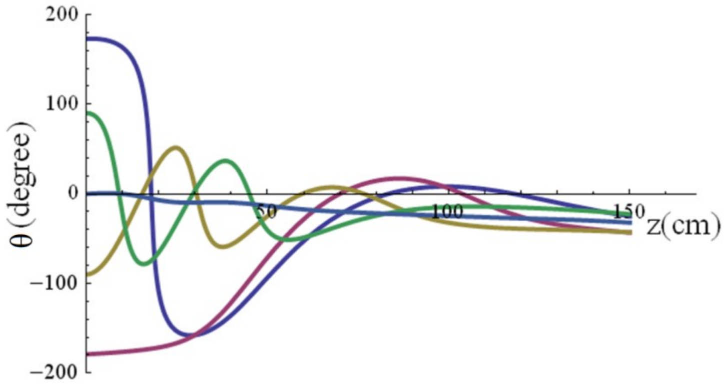


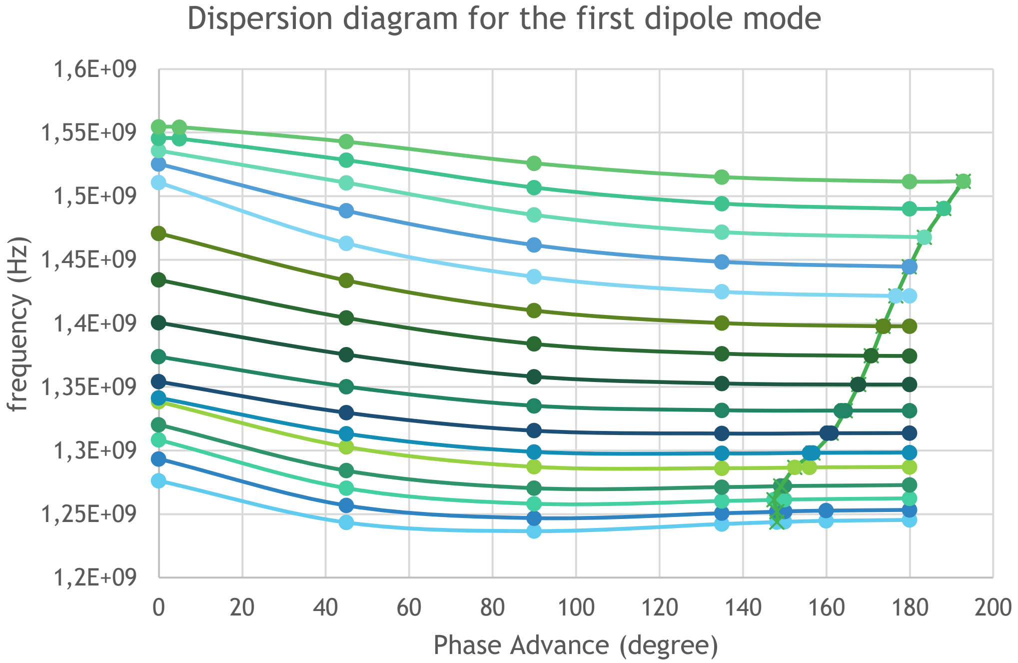
Frequency [MHz]	499.75
Bandwidth [MHz]	~60
Filling time [ns]	~10
Input Power [KW]	~20-100
Maximum Voltage [KV]	15-45
Phase advance [Deg]	~108
Phase/Group Velocity	0.62c/0.14c

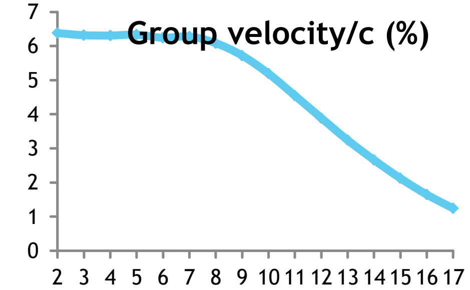
- Low filling time (wideband structure)
- Coupler asymmetrical field compensation
- Beam Loading Compensation
- Reduced required input power: For a FTW structure about 1MW is needed for 40KV voltage

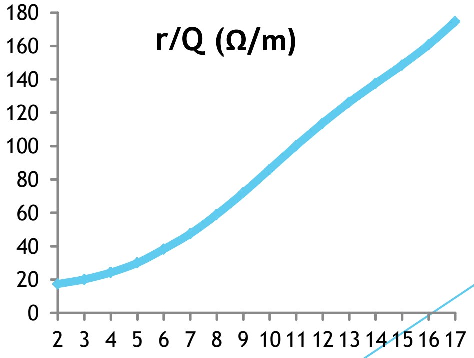
CLIC Drive Beam Injector – TW Buncher







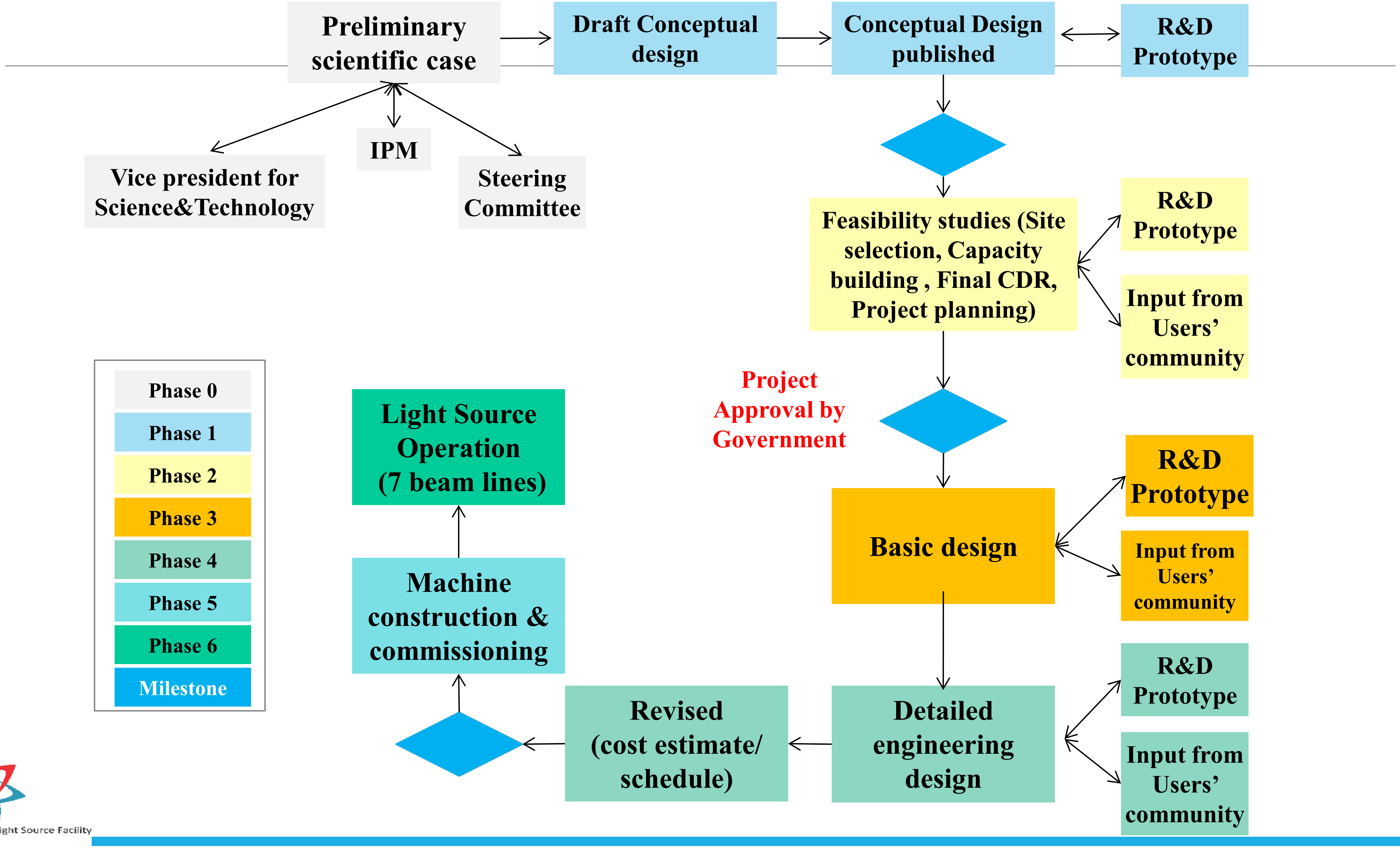




Iranian Light Source Facility (ILSF)

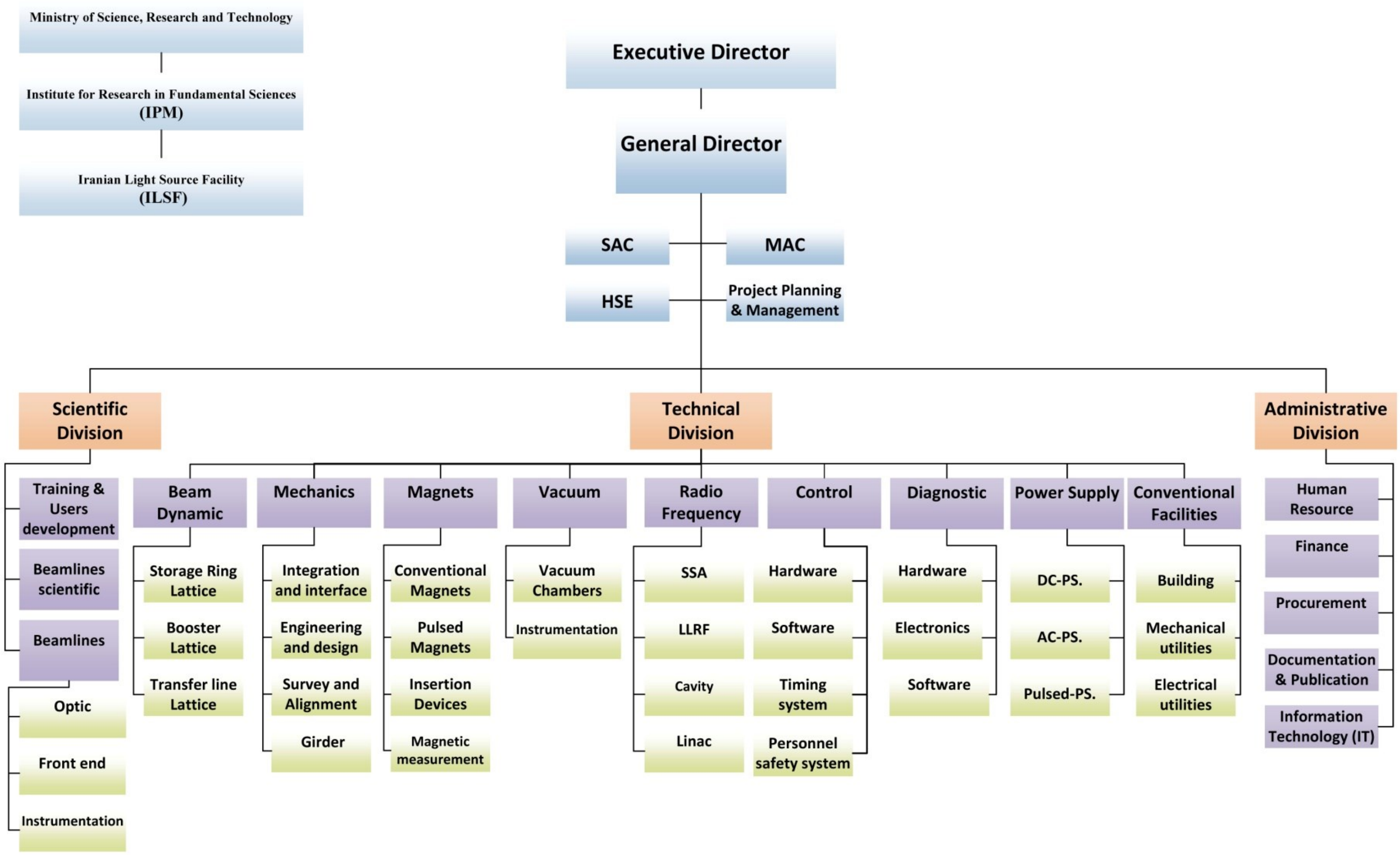
7th Users' Meeting , 20-21 April2015, Qazvin, Iran

Project Milestones



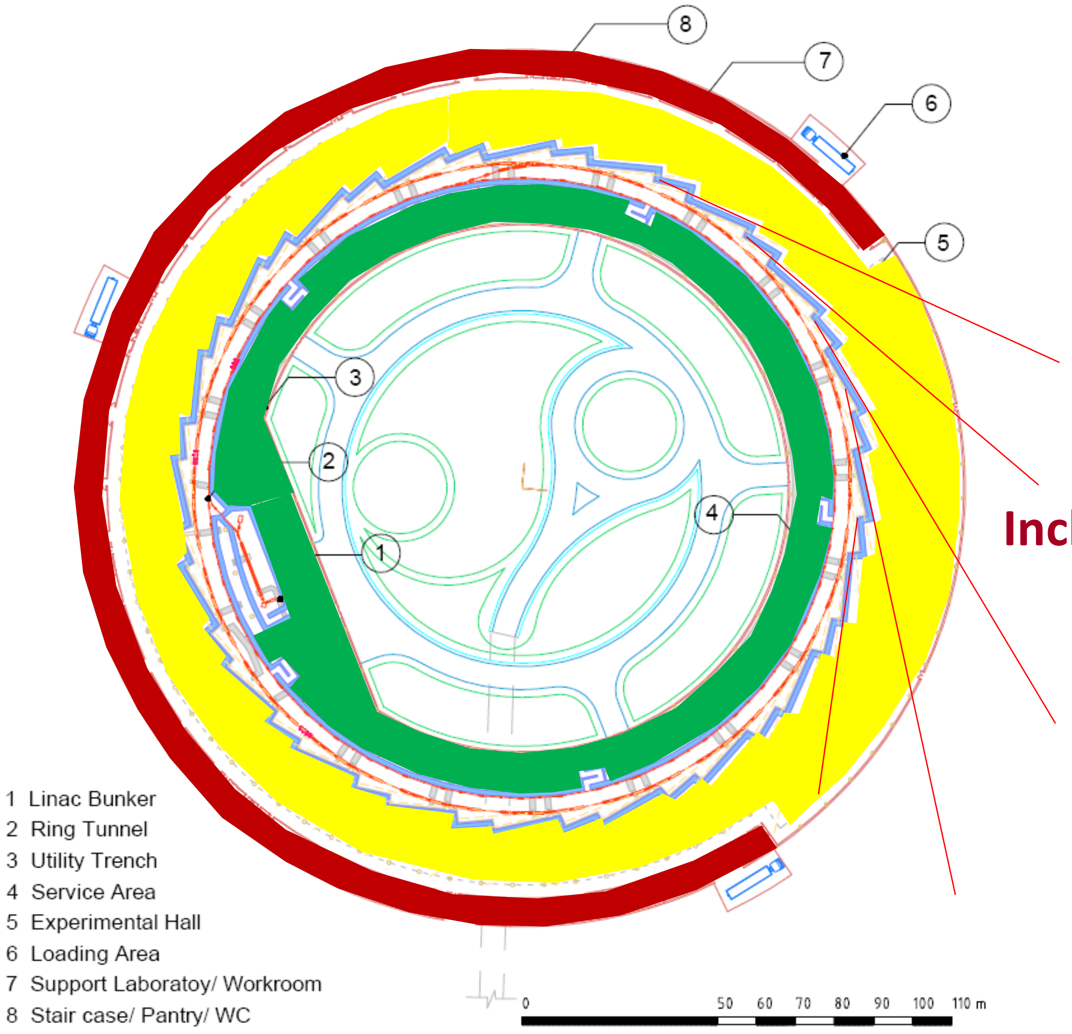
Iranian Light Source Facility

ILSF Organization Chart



MAC : Machine Advisory Committee
SAC: Scientific Advisory Committee
HSE: Health, safety & Environment
SSA: Solid State Amplifier
LLRF: Low Level Radio Frequency

Main Building Architecture - Ground Floor



Main Building Ground Floor Layout

Ground Floor Overall information:

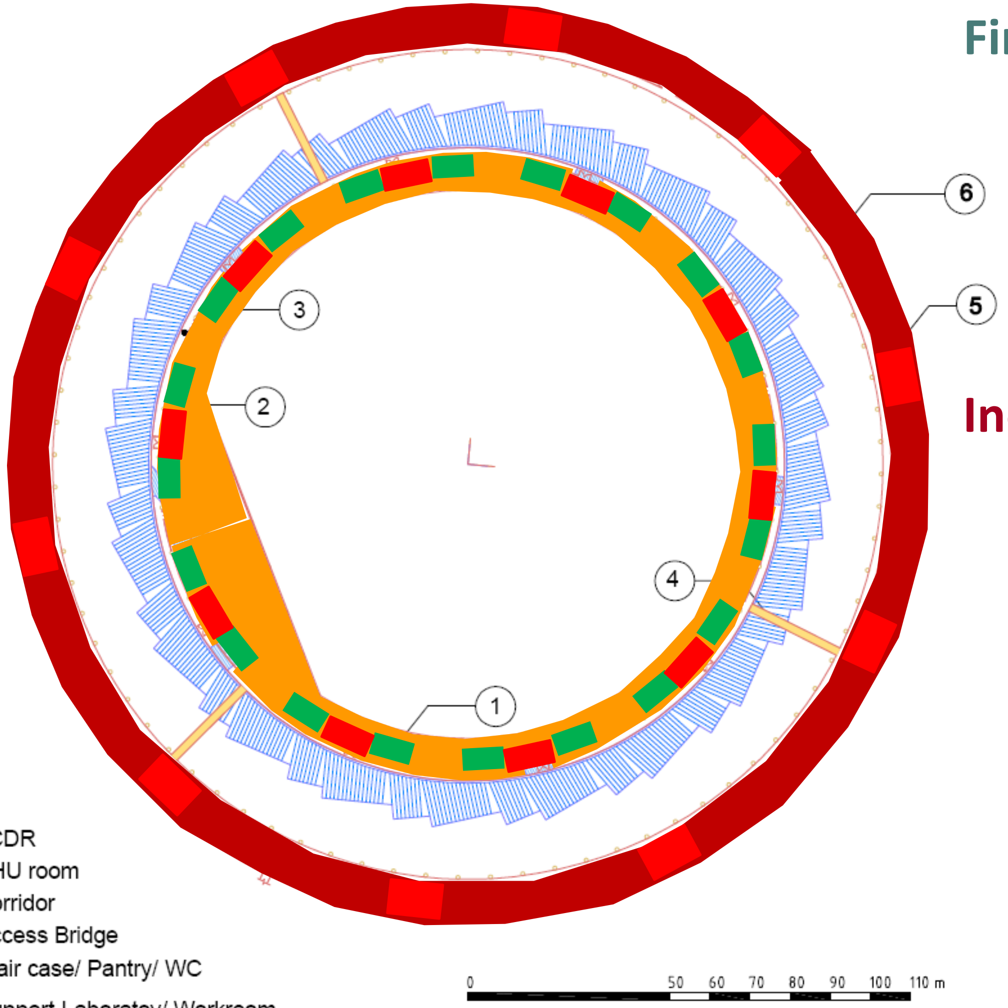
- Total area: 26320 m^2
- Experimental Hall: 9700m^2
- Accelerator Tunnel: 5550m^2
- Service area:4975m^2
- Access Corridors: 2323m^2
- Support Labs/work offices… :3785m^2

Including:

- 22 Support Laboratories/Work offices
- 4 meeting rooms
- 10 entrances including 3equipment entrance from outer perimeter
- 5 equipment entrance from inner yard
- Stair cases/Washrooms/Pantries/WCs

Iranian Light Source Fac

Main Building Architecture - First Floor



1 PCDR
2 AHU room
3 Corridor
4 Access Bridge
5 Stair case/ Pantry/ WC
6 Support Laboratoy/ Workroom

Main Building 1 Floor Layout

First Floor Overall information:

- Total area: 12650 m^2
- Service area:4525m^2
- Access Corridors: 2285m^2
- Support Labs/work offices… :5840m^2

Including:

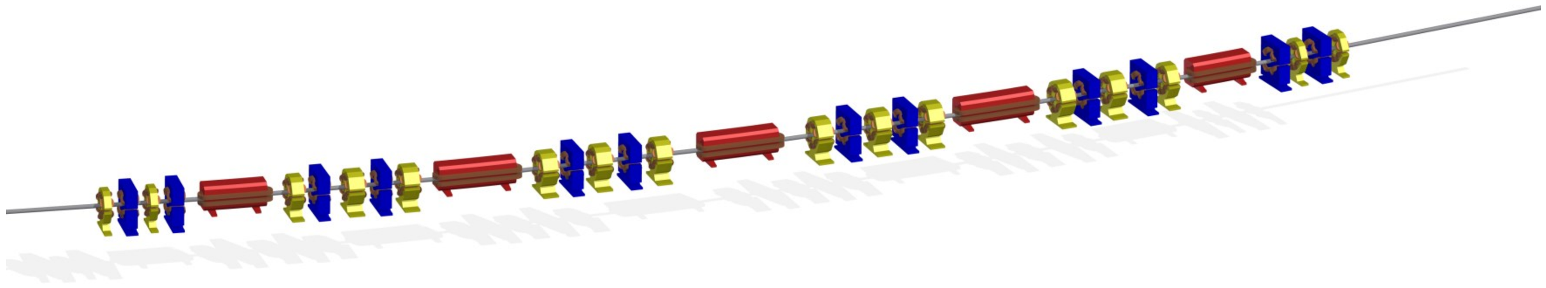
- 27 Support Laboratories/Work offices
- 1 meeting room
- Control room
- 20 PCDR (power supply, control & diagnostic instrument room)
- 20 AHU rooms
- 5 Switchgear rooms
- 3 Access bridge
- Stair cases/Washrooms/Pantries/WCs

ILSF Site Ground

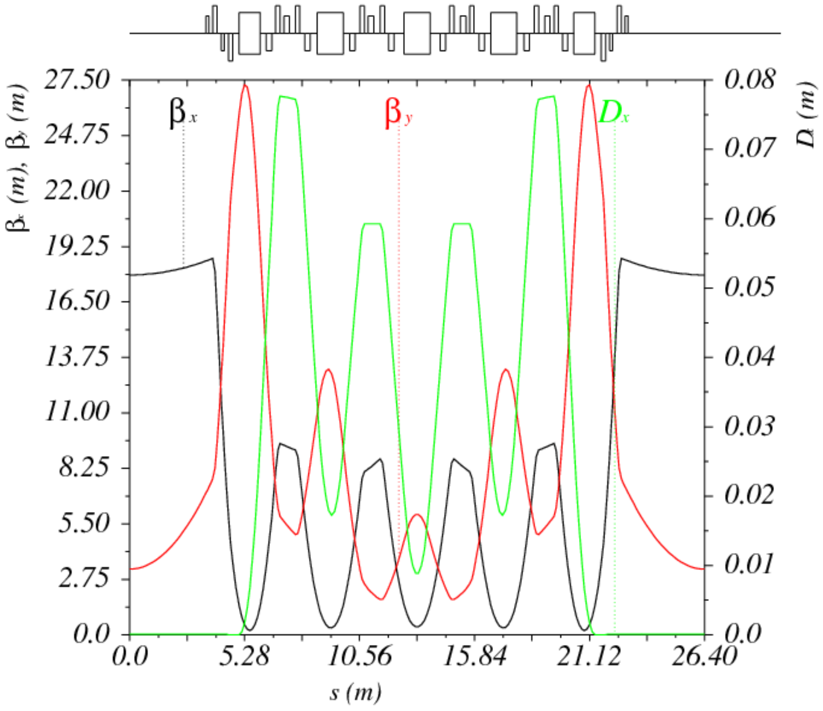
Site Layout - Buildings Schedule

No.	Building	Area(m^2)
1	Main building	38000
2	Administration building	3500
3	R&D Laboratory	3000
4	Utility building	4500
5	Workshop	1000
6	Canteen building	500
7	Mosque	250
8	Guesthouse	3000
9	Amphitheater & Library	1500
10	Recreation complex	1500
11	Gridiron	-
12	HSE building	150
13	Fire station	200
14	Power generator building	500
15	Nitrogen production unit	500
16	Water tanks	500
17	Pump house	250
18	Rainwater harvesting tank	500
19	Warehouse	1500
20	Substation building	150
21	Passage post building	150
22	Gas pressure reduction station	100
23	Security building	300
24	East Guardhouse	75
25	South Guardhouse	75
	Total	61700

ILSF storage ring lattice design

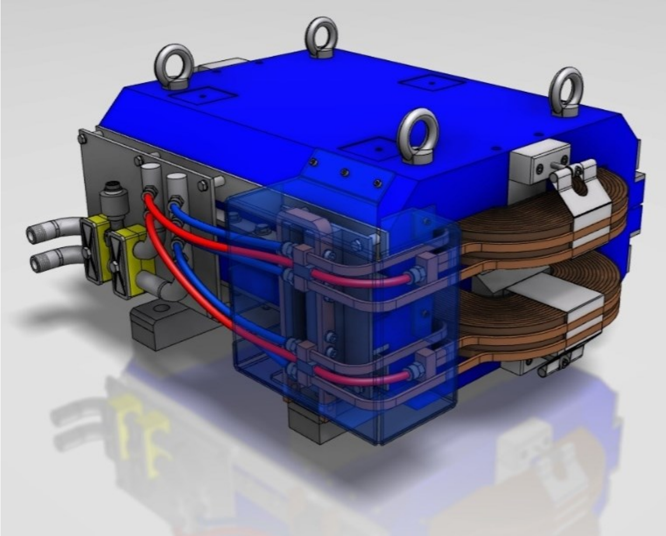


Parameter	Unit	Value
Energy	GeV	3
Maximum beam current	mA	400
Circumference	m	528
Length of straight section	m	7.0
Natural emittance	pm rad	275
Betatron tune (Q_x/Q_y)	-/-	44.20/16.23
Natural chromaticity (ξ_x/ξ_y)	-/-	-108.30/-61.54
Natural energy loss/turn	keV	406
RF frequency	MHz	100

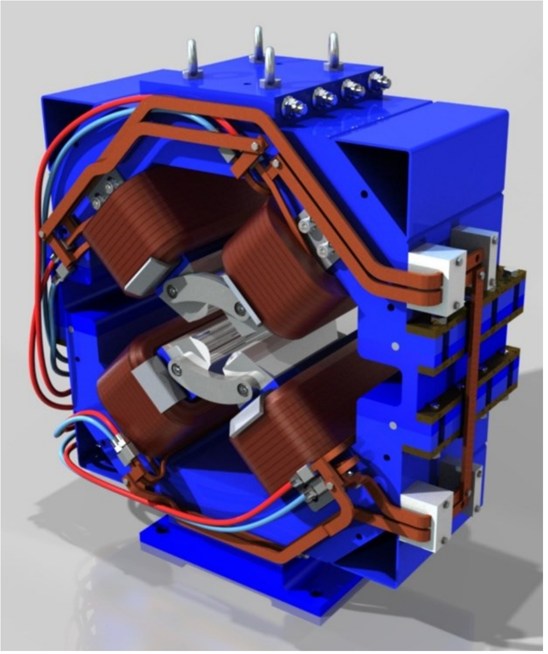


ILSF R&D Laboratory

Designed Prototype Magnets



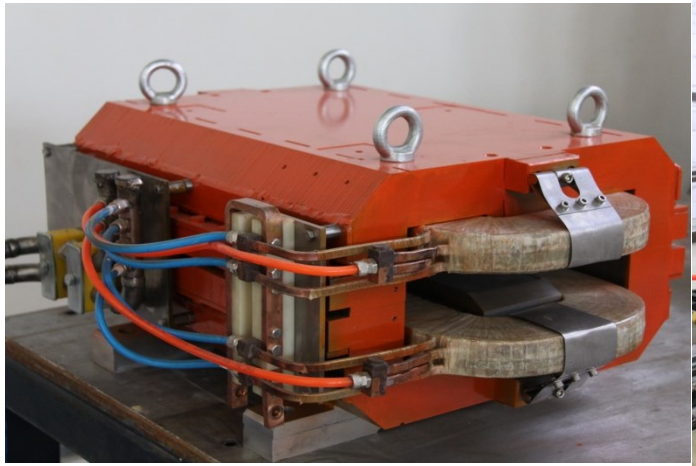
Dipole-H



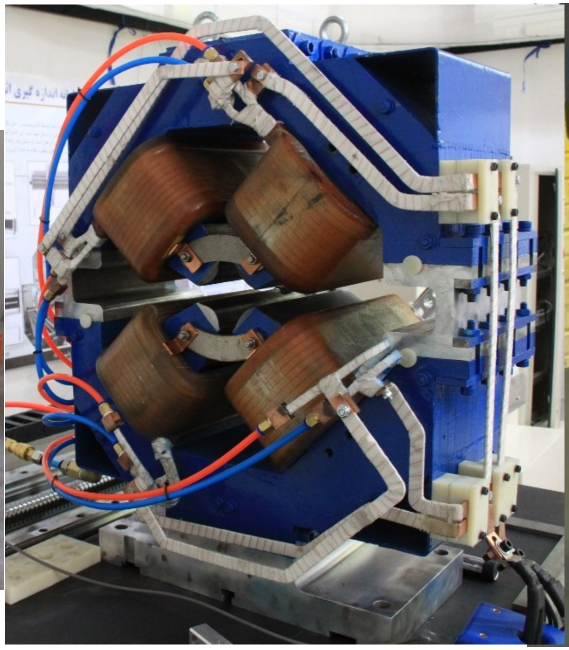
Quadrupole

Alpha magnet

Constructed Prototype Magnets



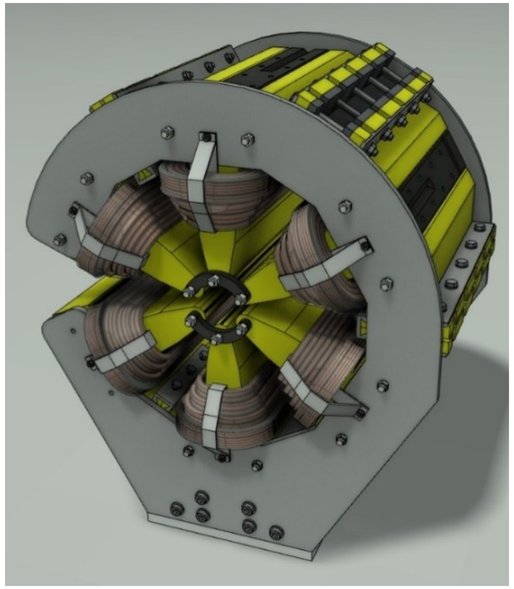
Dipole-H



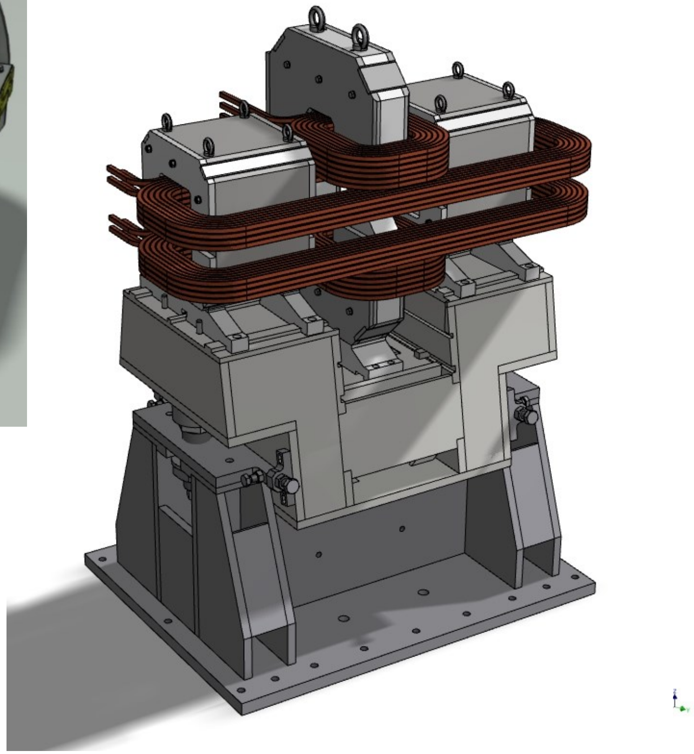
Quadrupole

Alpha magnet

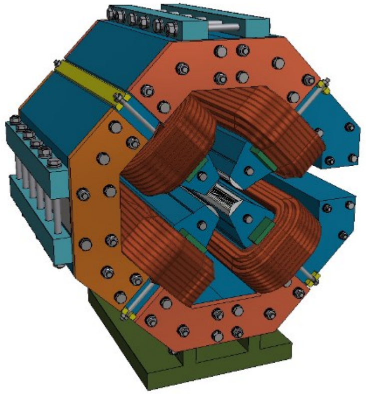
Ongoing Prototypes construction



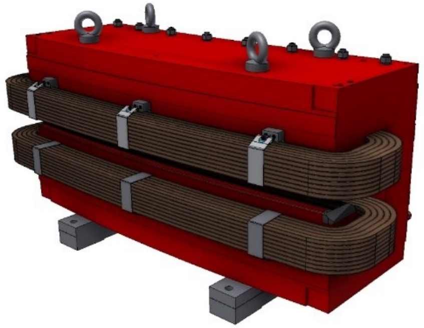
Sextupole



High Field Insert Dipole + Special Girder



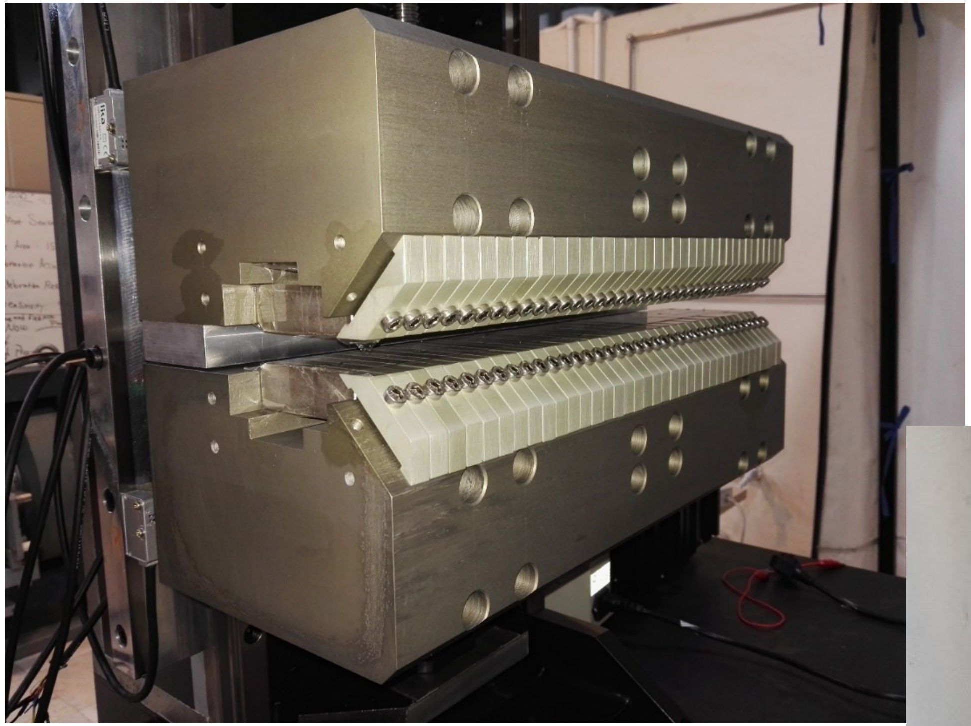
Quadrupole



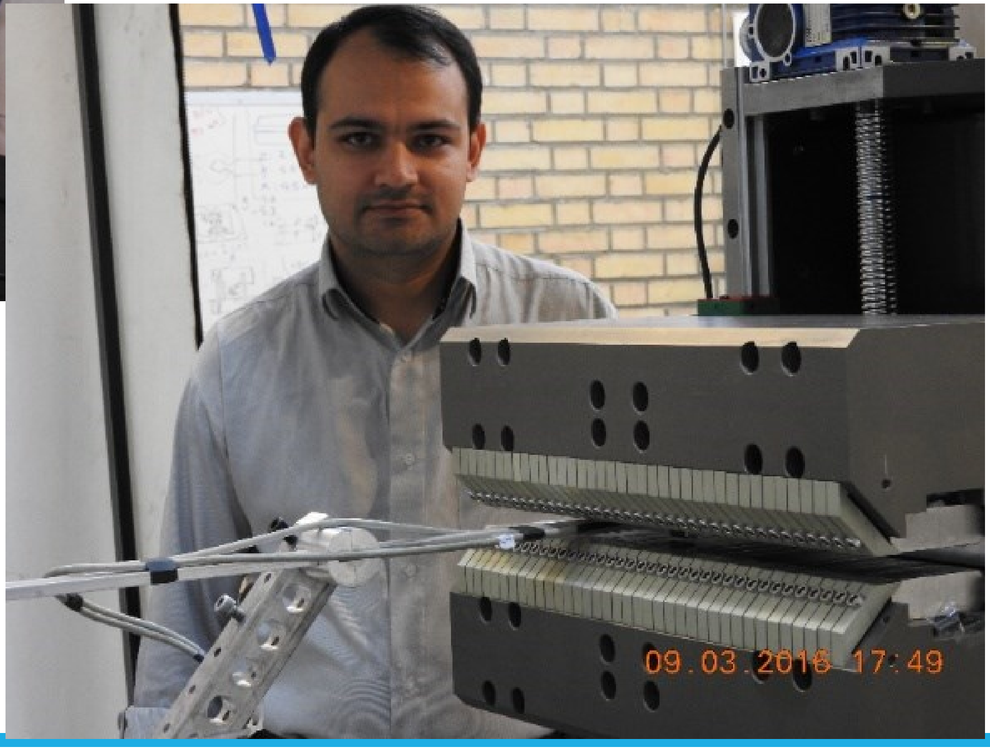
Dipole

چشمه نور ایران Iranian Light Source Facility

Insertion Device Prototype



- ILSF First Undulator Prototype (Permanent Magnets)
- Probe Measurement System
- @gap=15mm, $B_{y,max}$=0.75T



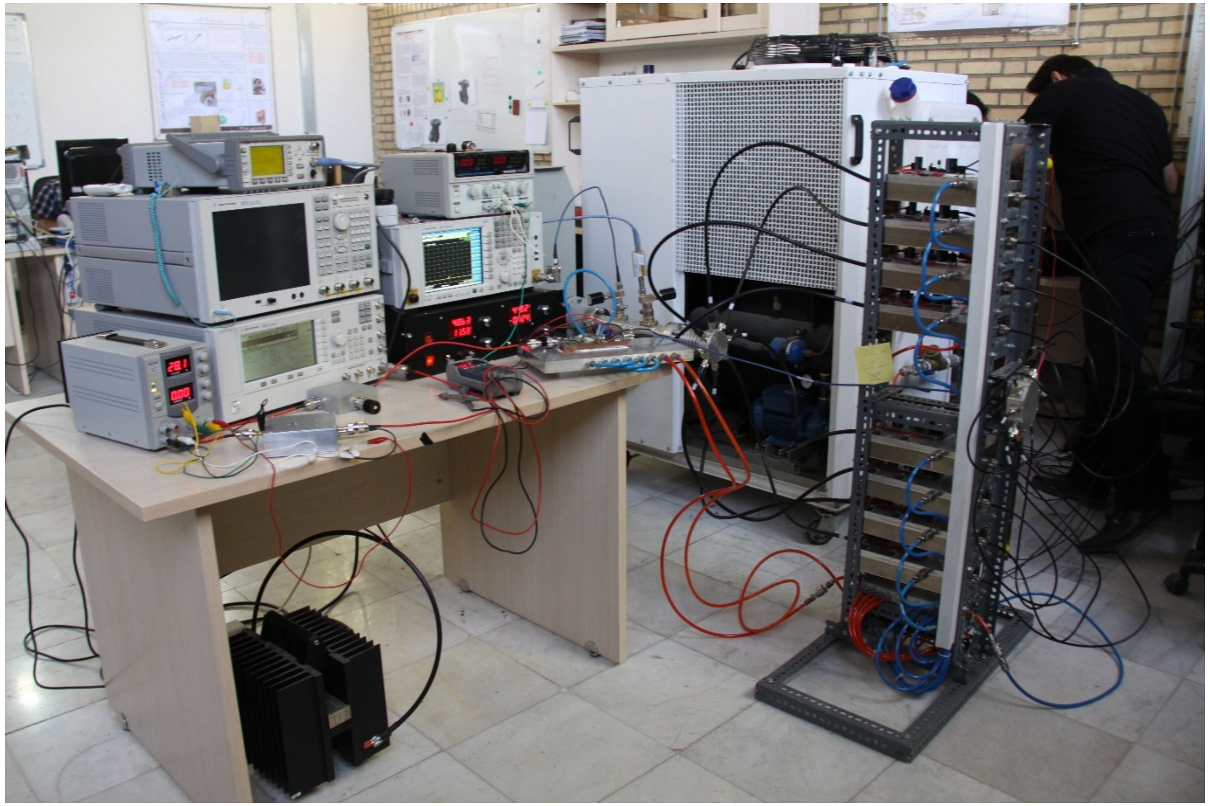
Temperature controlled hutch for magnet measurements

RF R&D Status

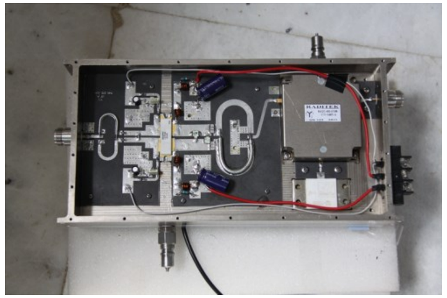
High Power RF Amplifier

✓ 4kW 500MHz SSA prototype

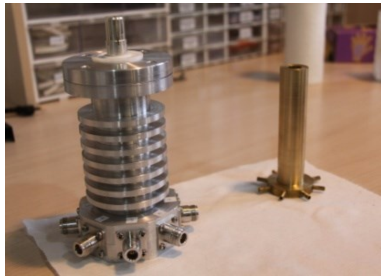
(developed successfully, 59% efficiency)



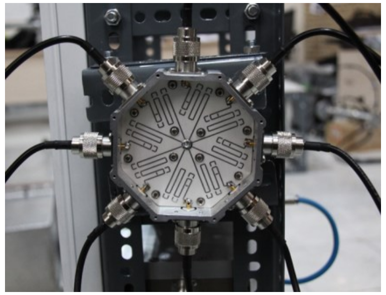
Amplifier Module
(Based on BLF578 Transistor)



8:1 Combiner



1:8 Divider



➤ 30kW 100MHz SSA prototype as one forth of 120kW (under investigation)

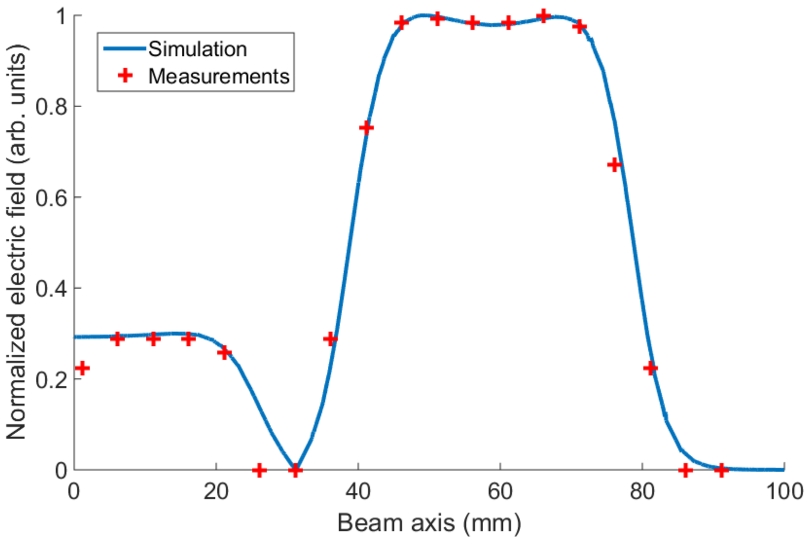
RF gun prototype for low power measurements

Built with normal copper material and joined together using screws and conductive paste.

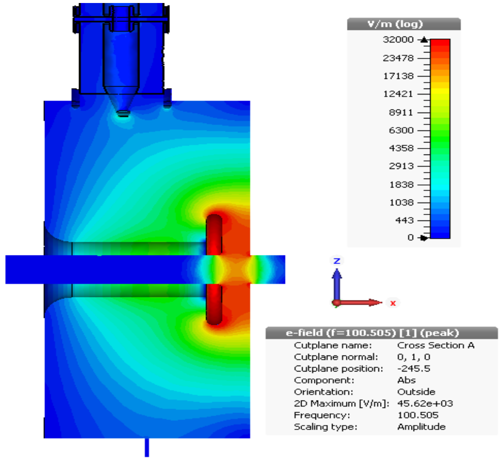
Final gun will be built with OFHC and will be brazed together.

Simulation and measurement results

Parameter	Unit	Simulation	Measurement
Resonance frequency	MHz	2859.38	2859.57
Unloaded quality factor	-	13200	9300
Shunt impedance	MΩ/m	86.2	60.4
unloaded coupling (S11)	dB	-20	-19.6

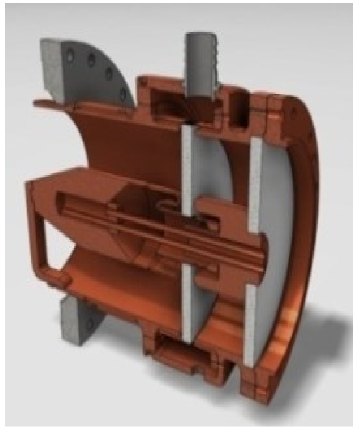


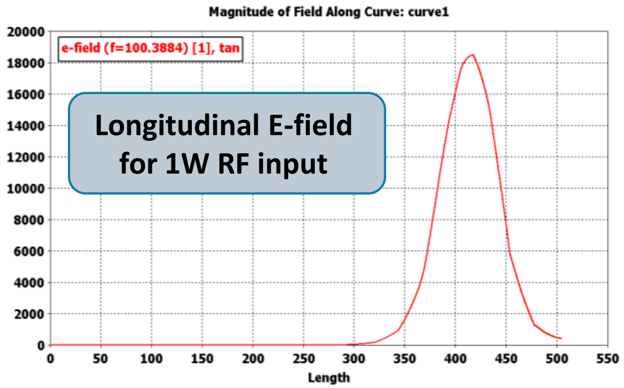
100 MHz Cavity under construction by local industry

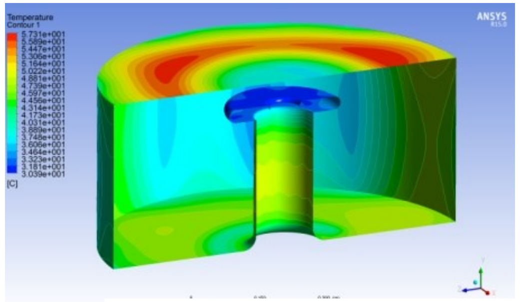


100 MHz Cavity

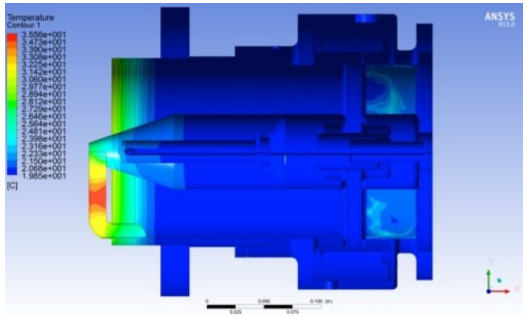
- ✓Electromagnetic & mechanical design
- ✓Feasibility study & RFP preparation
- ➢Fabrication is initiated.







cavity body thermal analysis



cavity coupler thermal analysis

Cavity simulation results comparison

Parameter	SuperFish	HFSS	CST
Resonant frequency	99.8 MHz	101.427 MHz	100.388 MHz
Q factor	20425	21434	21390
Shunt impedance	2.16 MΩ	1.75 MΩ	1.75 MΩ

Iranian Light Source Facility

List of beam instrumentations

Instrument Name	Detecting Parameters	Required Number	Estimated Cost $
Beam Position Monitor	Position	400	3,800,000
Stripline BPM		7	126,000
Faraday Cup	Current-Charge	1	10,000
Fast Current Transformer		12	180,000
Wall Current Monitor		8	8,000
Beam Charge Monitor		5	75,000
DC Current Transformer		2	100,000
Annular Electrode		2	20,000
Fluorescent Screen/OTR	Profile-Size	13	50,000
Visible Synch.Rad.Monitor		3	250,000
X-Ray Synch.Rad.Monitor		1	10,000
Beam Loss monitors	Beam loss	129	129,000
Scrapers	Beam halo-others	4	20,000
		Total Estimated Cost	5,000,000$

Almost 80% costs of the instrumentations are for BPMs!!

Iranian Light Source Facility

Beam position Monitor of ILSF

Beam size is 60×6 μm^2

Beam displacement is less than 20 µm

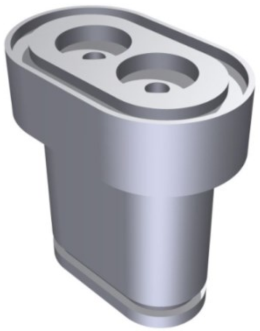
BPM resolution should be at least 1 µm

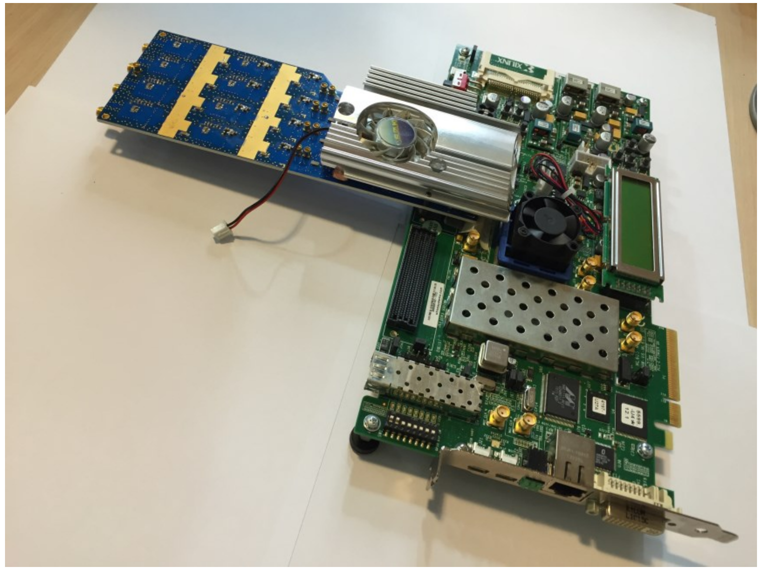
BPM

- Button
- Test Stand
- Electronic Readout

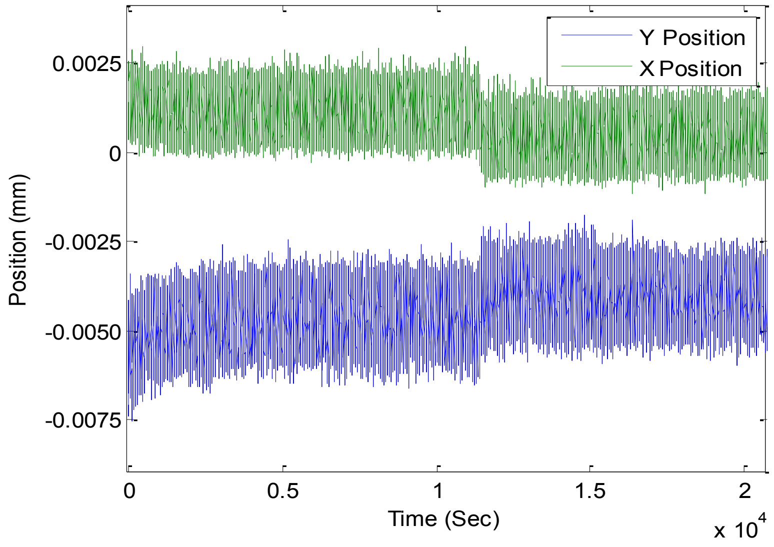
Design & Fabrication done successfully

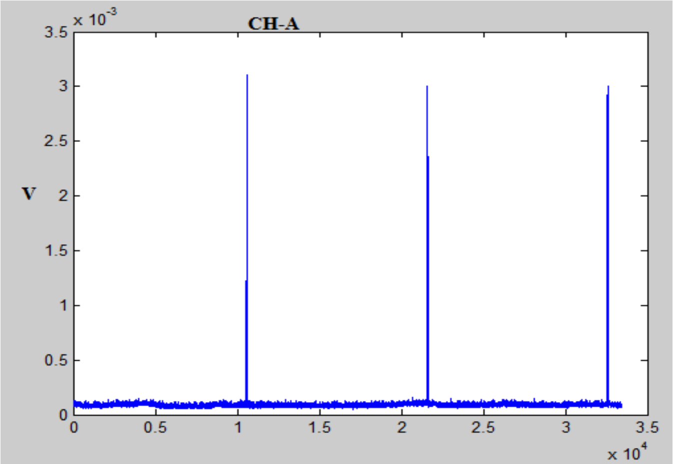
Design is done successfully





Test of electronic system in ALBA





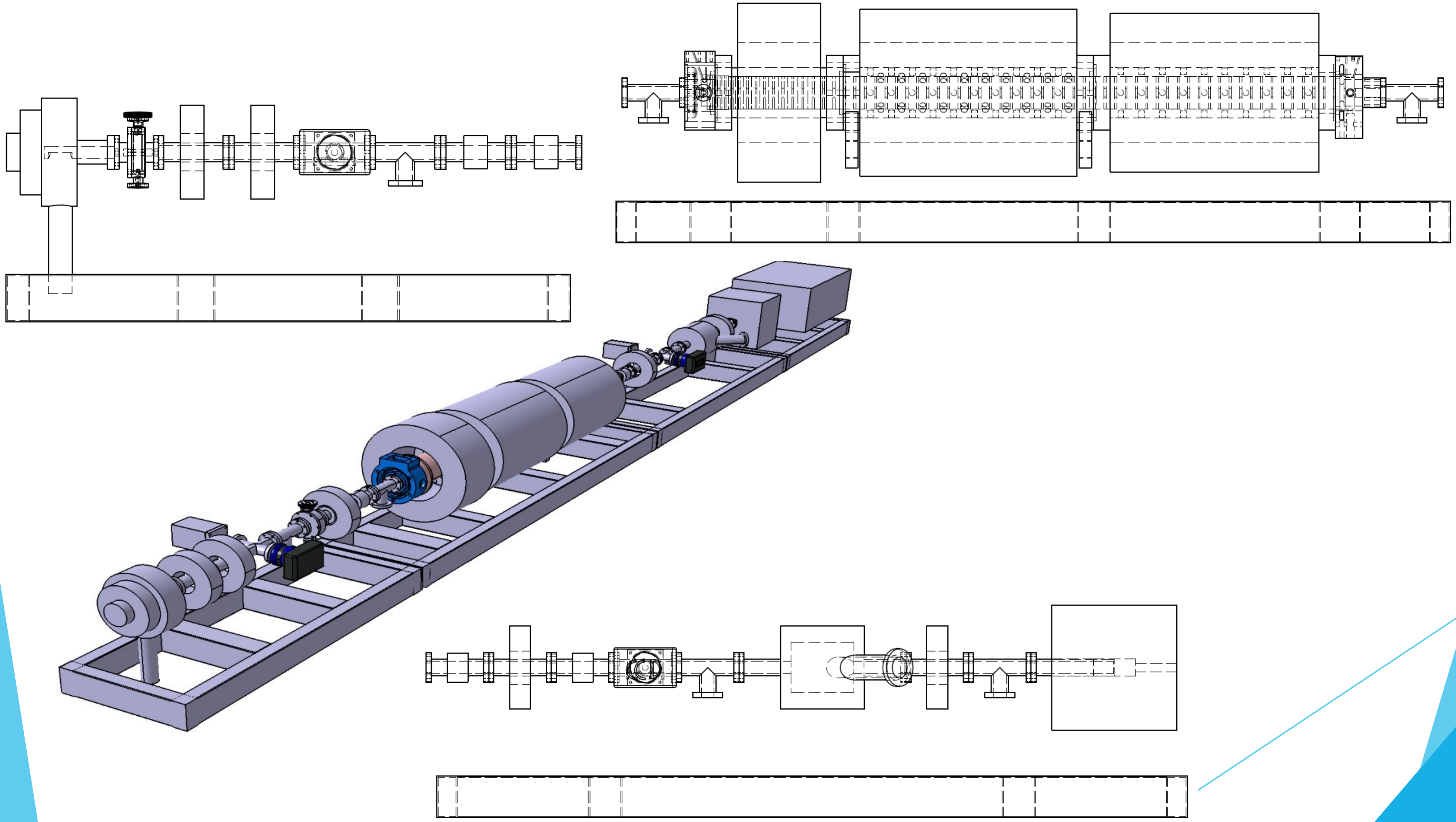
Our Target is improving Precision to 0.1µm

1.2 µm precision for readout system which tested on real beam at storage ring of ALBA (Picture shows 1µm displacement of beam)

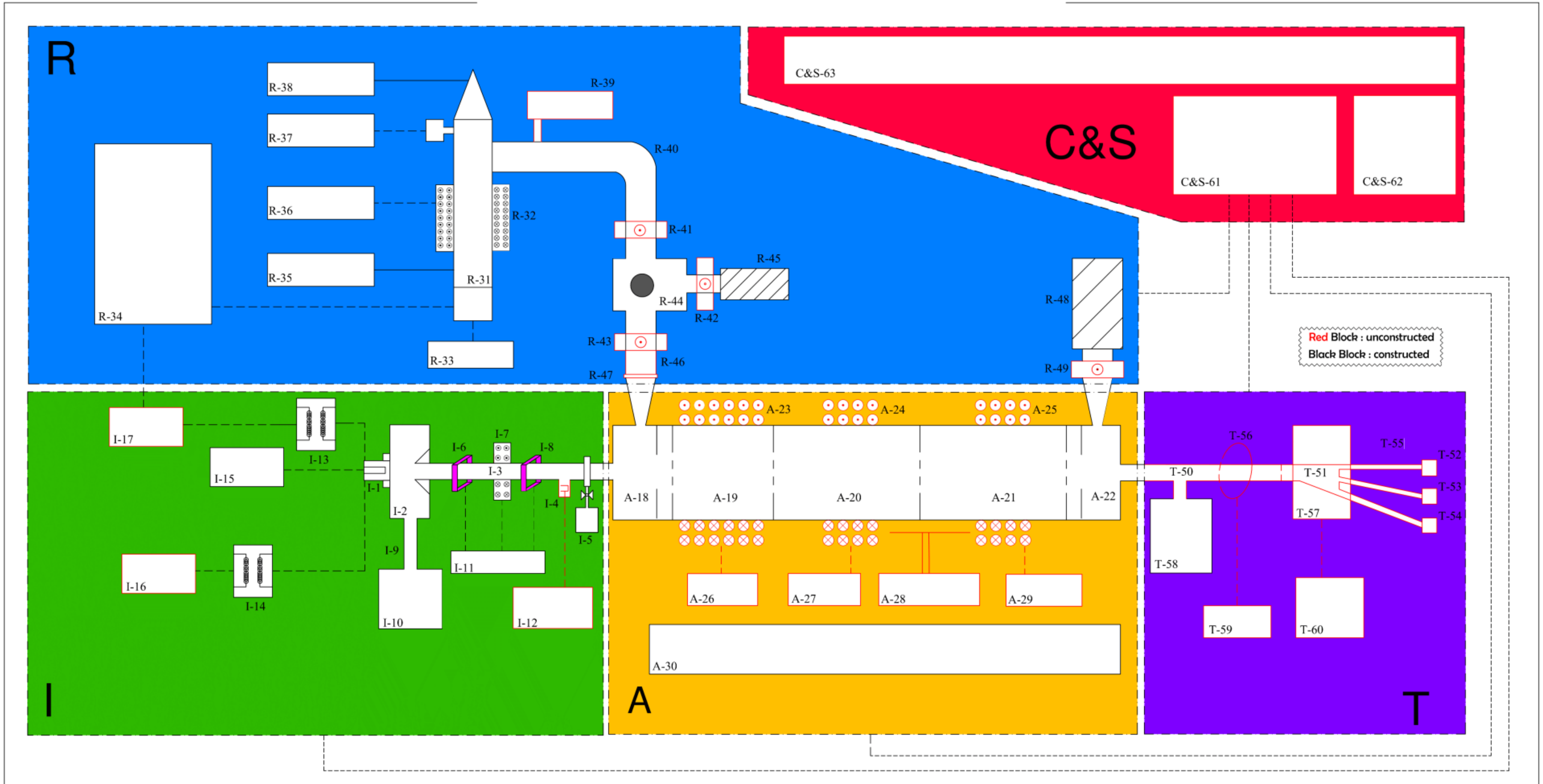
Detection of beam position in Booster of ALBA at top-up mode with 1.5mA injection at each 20 minutes!

Iranian Light Source Facility

Low Energy TW Linear Accelerator



IPM LINAC Layout

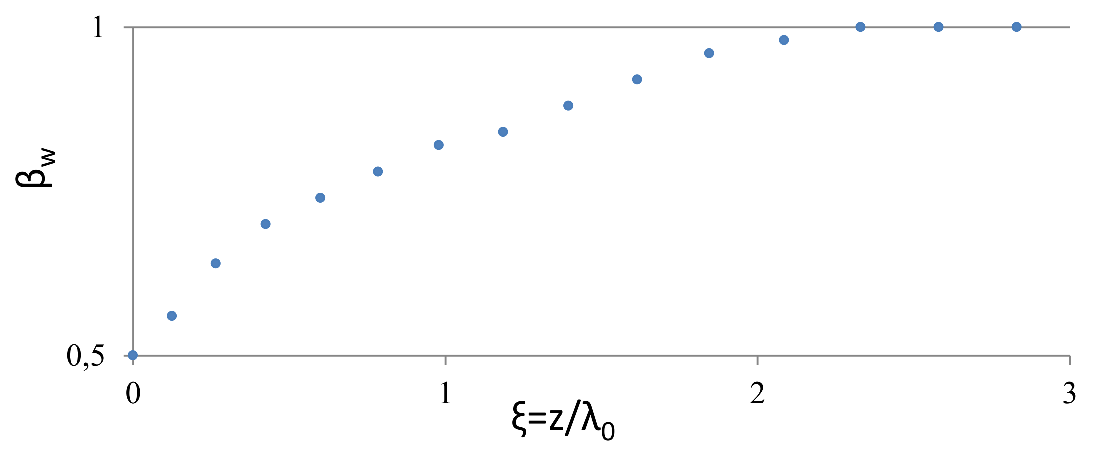


IPM e-Linac Project Layout

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	MHz
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	

Beam Dynamic Study - I

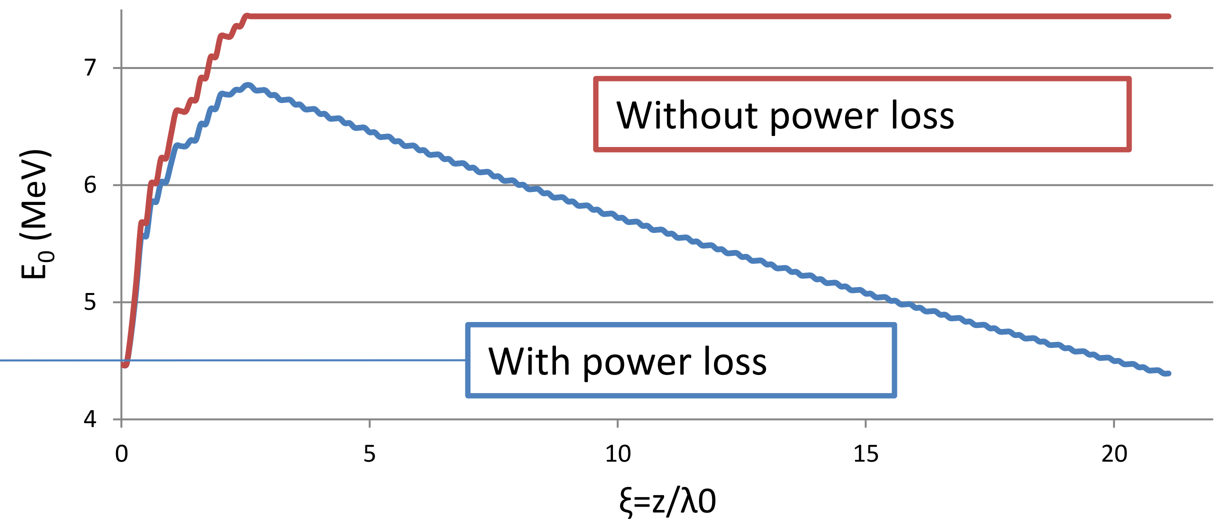


Inside the buncher, phase velocity increases smoothly to reach to the velocity of light.

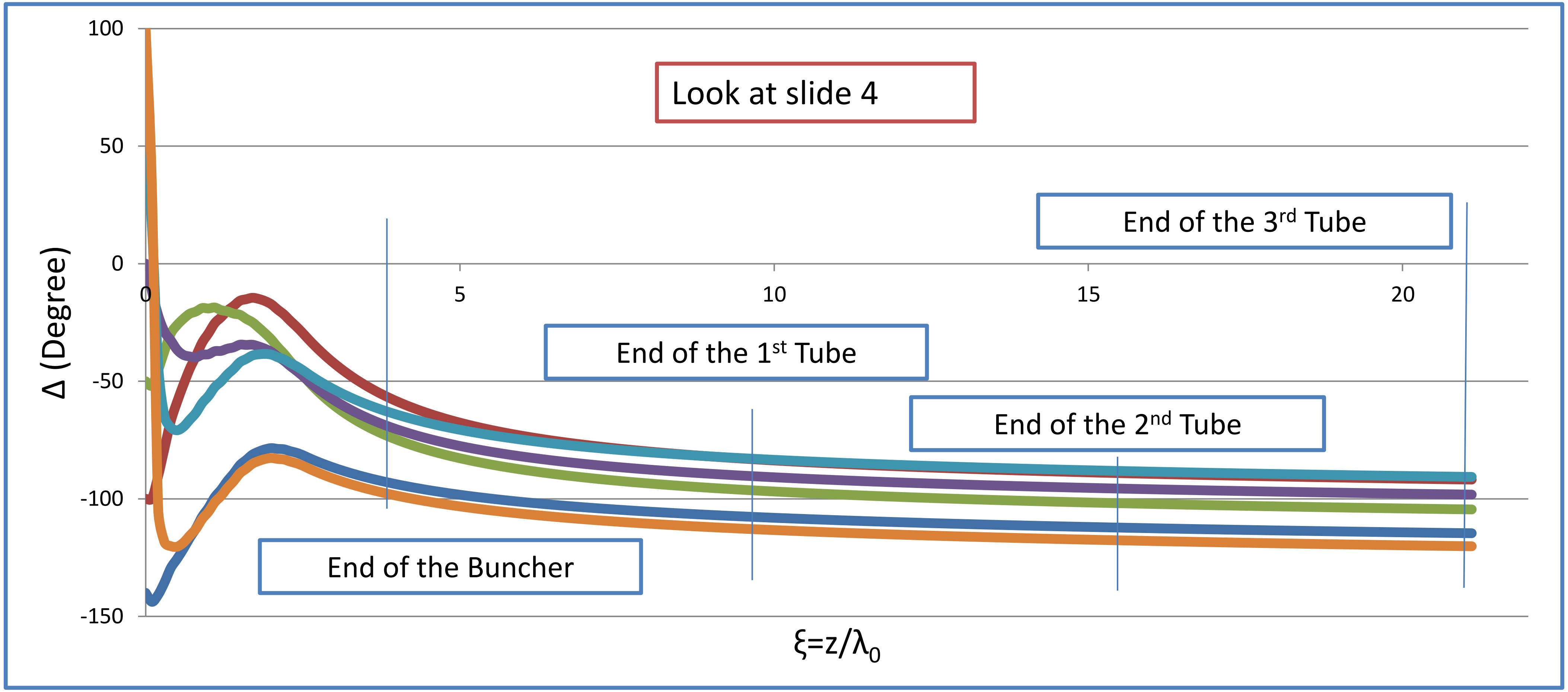
$$\begin{cases} \dfrac{a^4\alpha^2}{\beta_w} f(k_r a) = constant\,;\ \alpha = \dfrac{E_0 e \lambda_0}{m_0 c^2} \\ f(k_r a) = \dfrac{8}{(k_r a)^2}\left[J_1{}^2(k_r a) - J_0(k_r a) J_2(k_r a)\right] \end{cases}$$

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.

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



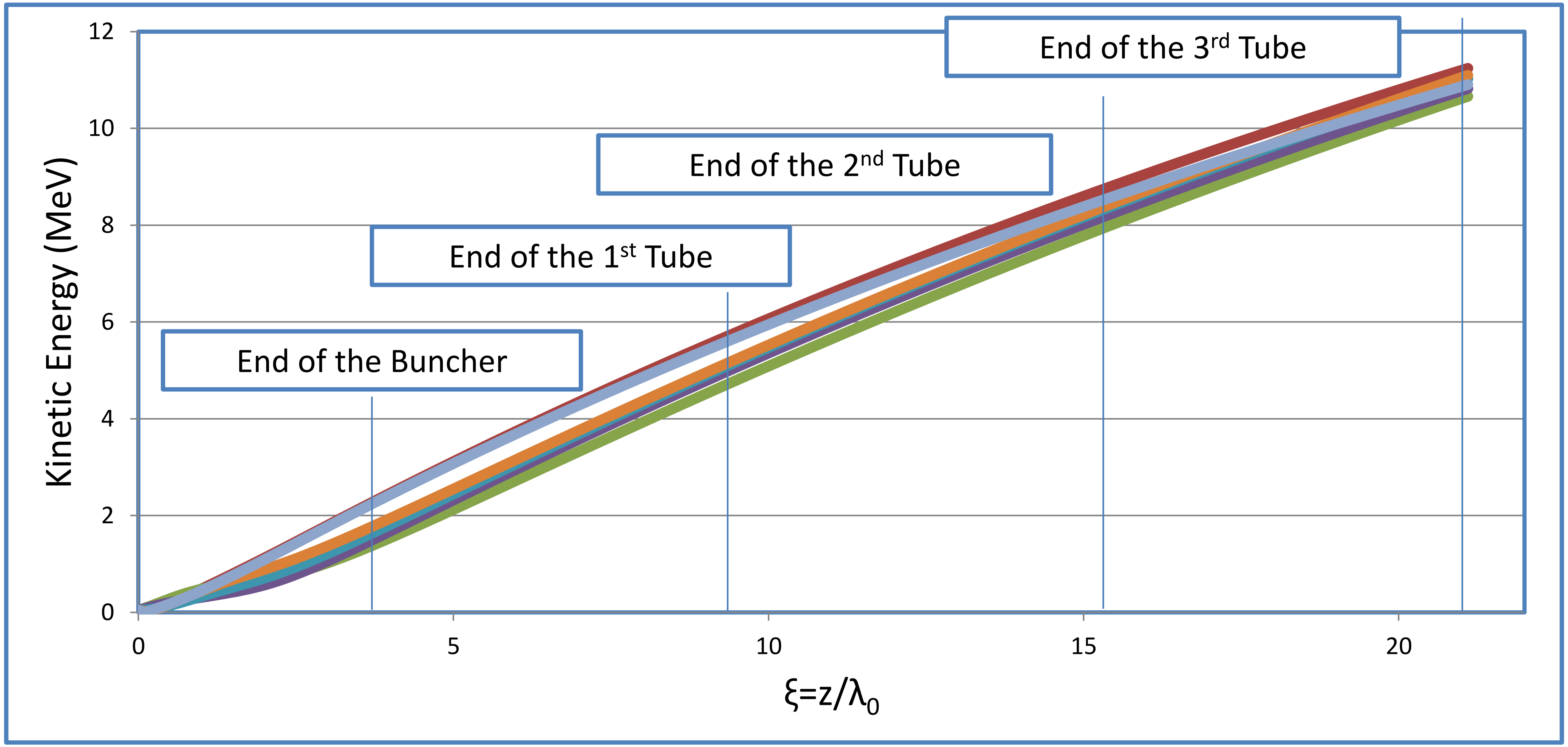
Beam Dynamic Study - II



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

-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.

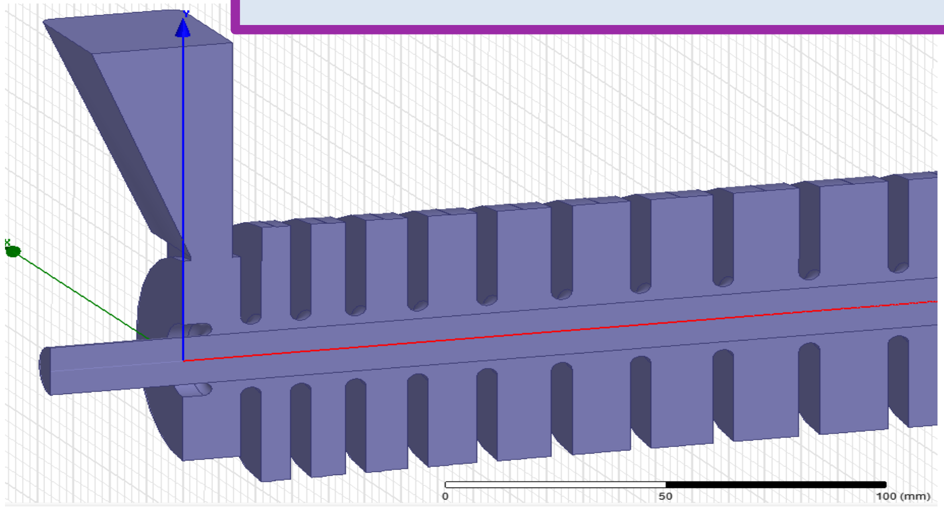
Beam Dynamic Study - III

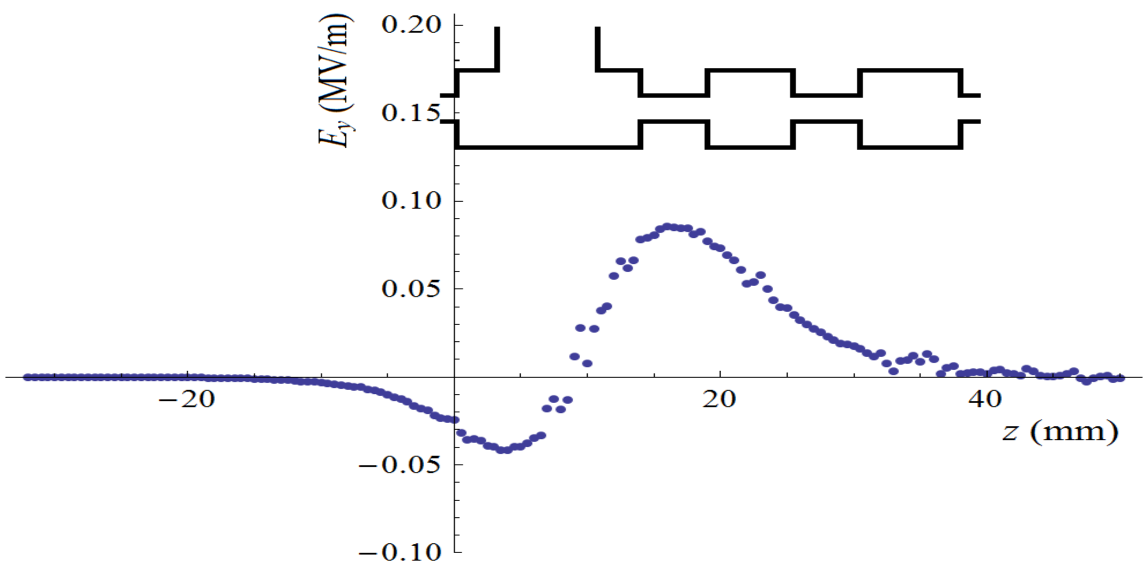


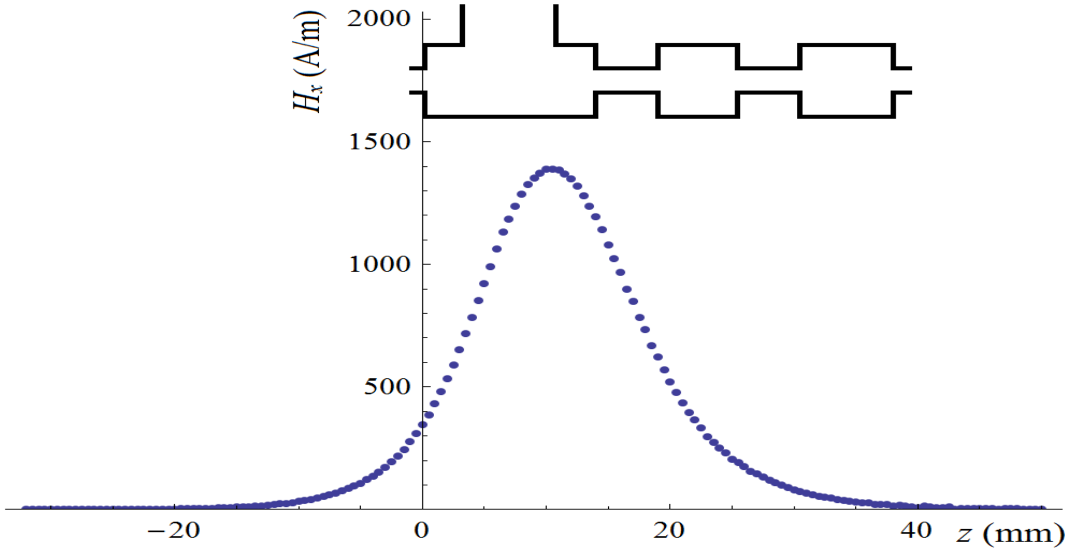
Final Kinetic Energy: 11.04±0.26 MeV or 2.3% Energy Spread

1.1 Induced kick

Necessity of 3D modeling ⟹ **ASTRA**

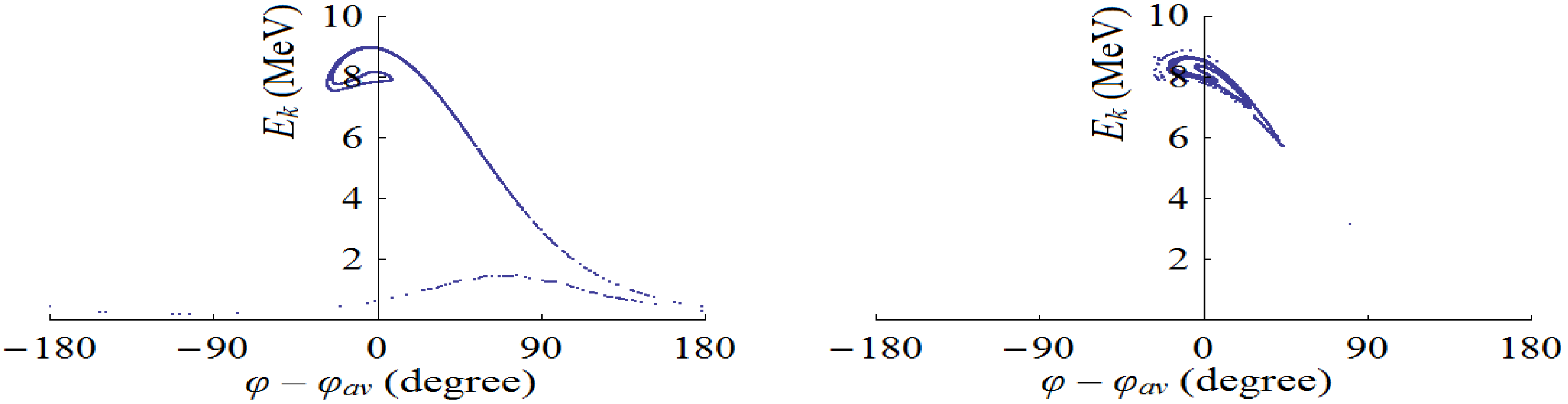






2.1 The need for a new buncher

- History of the buncher design.



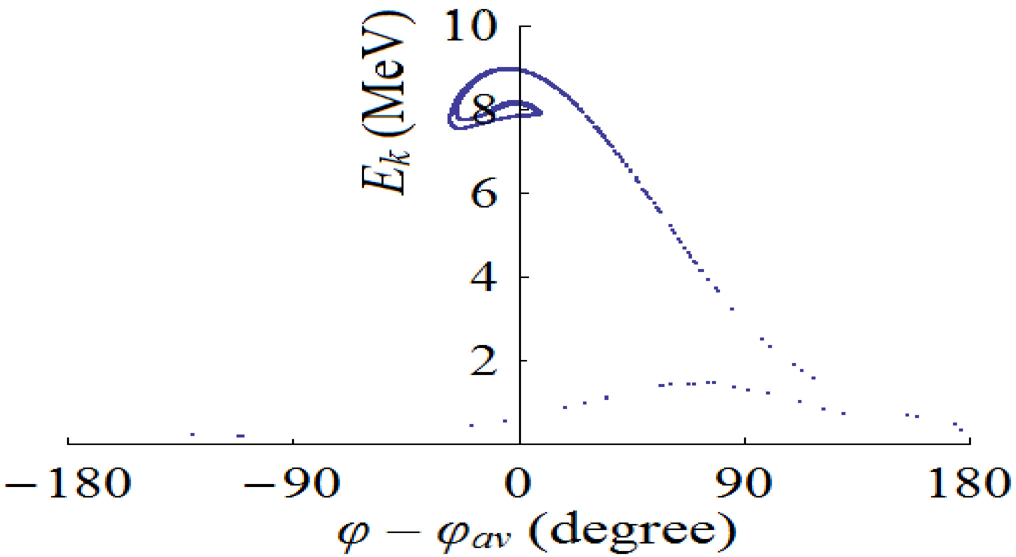
$\sigma_\varphi = 15.2°$
$\sigma_{E_k} = 0.61\ Mev$
$L_B = 40\ cm$

$\sigma_\varphi = 11.3°$
$\sigma_{E_k} = 0.41\ Mev$
$L_B = 50\ cm$

- 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.

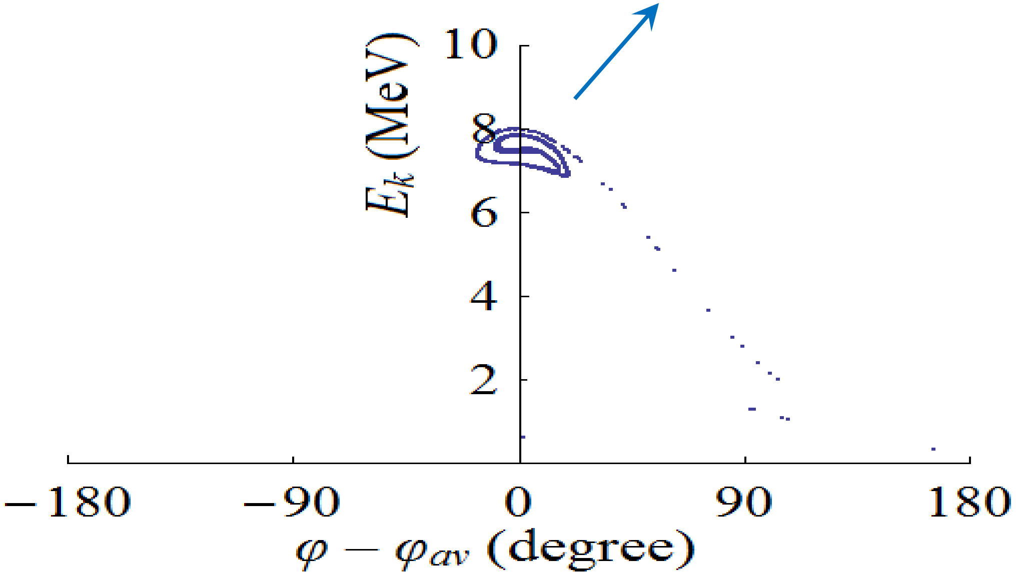
2.3 New buncher

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



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

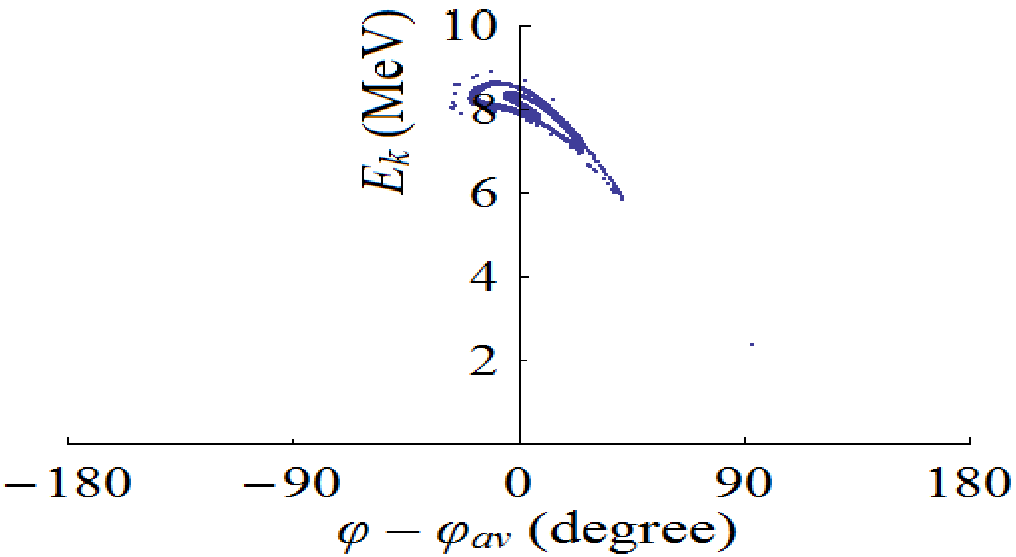
Larger phase acceptance



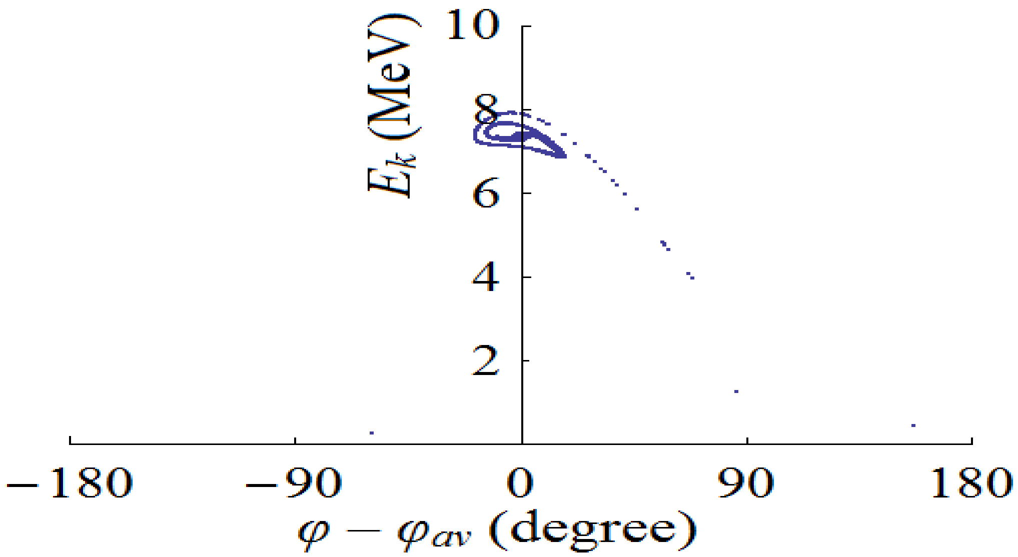
$\sigma_\varphi = 7.0°$
$\sigma_{E_k} = 0.17\ MeV$
$E_{av} = 7.5\ MeV$

2.3 New buncher

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



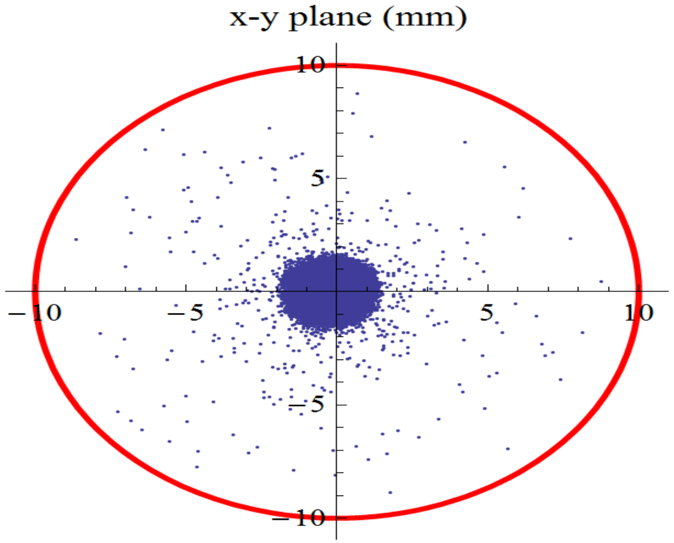
$\sigma_\varphi = 6.8°$
$\sigma_{E_k} = 0.27 MeV$
$E_{av} = 8.1\ MeV$



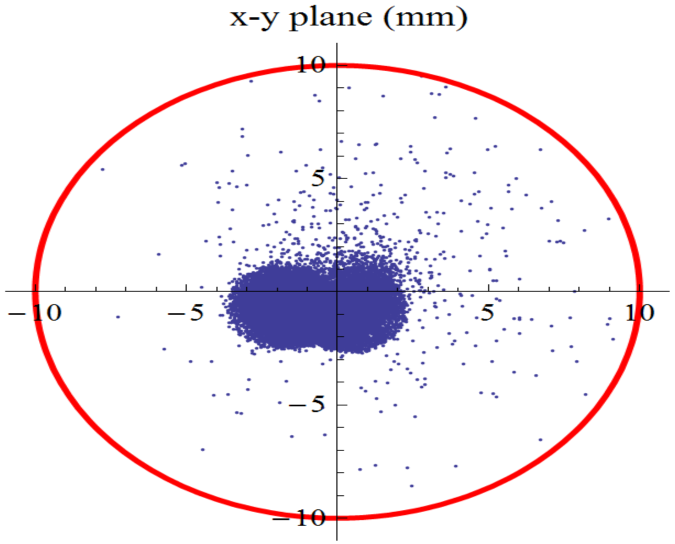
$\sigma_\varphi = 5.9°$
$\sigma_{E_k} = 0.12\ MeV$
$E_{av} = 7.3\ MeV$

3.3 Misalignment Studies

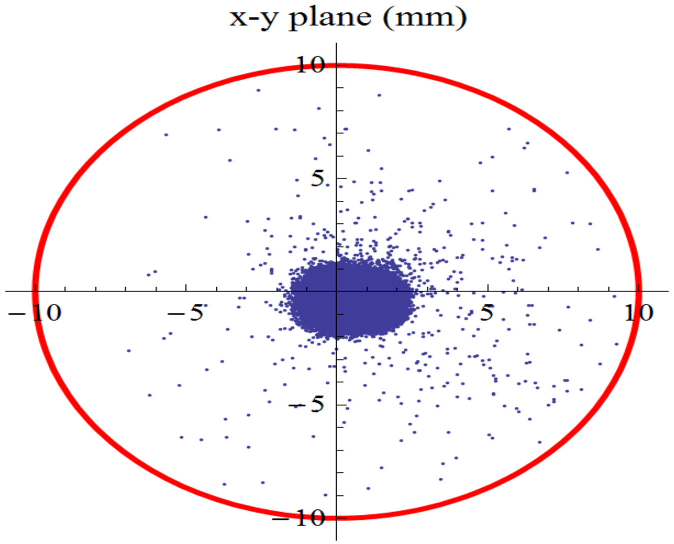
- $B \approx$ 1200-800 G



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



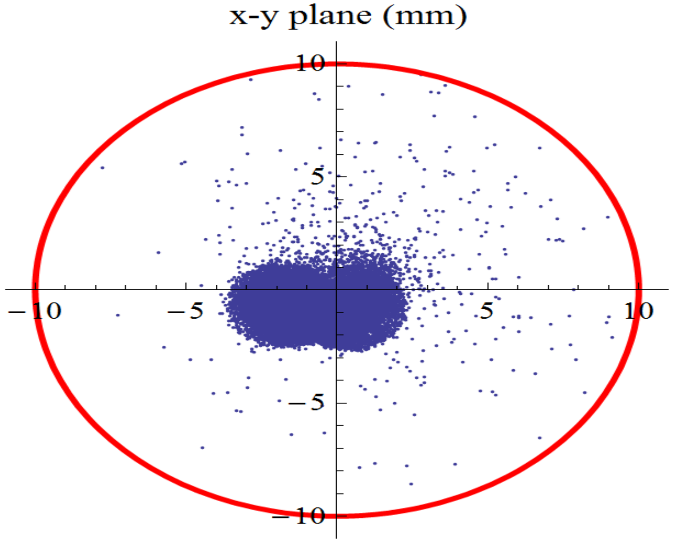
Offset
$\varepsilon \nearrow 500\%$



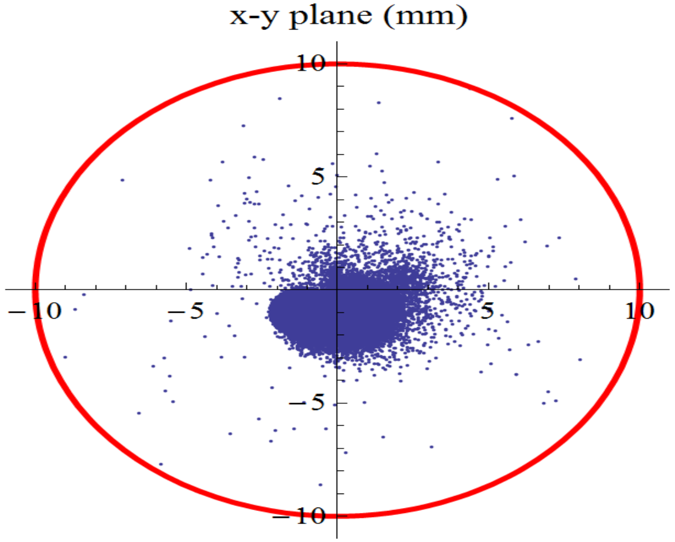
Tilt
$\varepsilon \nearrow 300\%$

3.3 Misalignment Studies

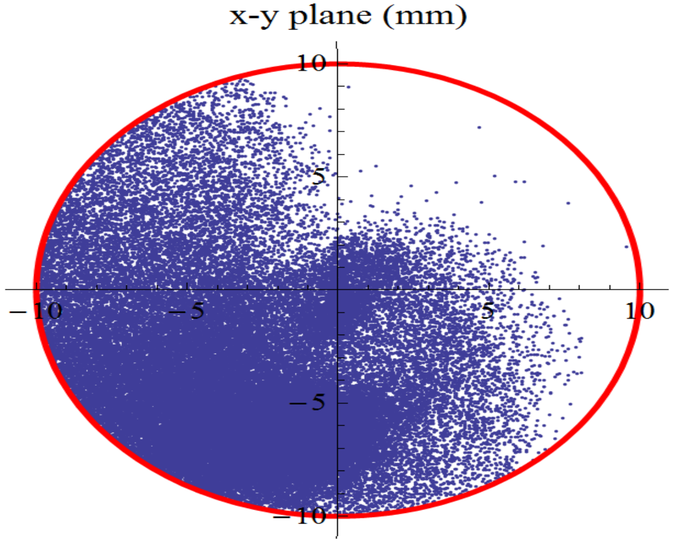
- Offset



B ≈ 1200-800 G



B ↙ 20% (≈ 1000-650 G)

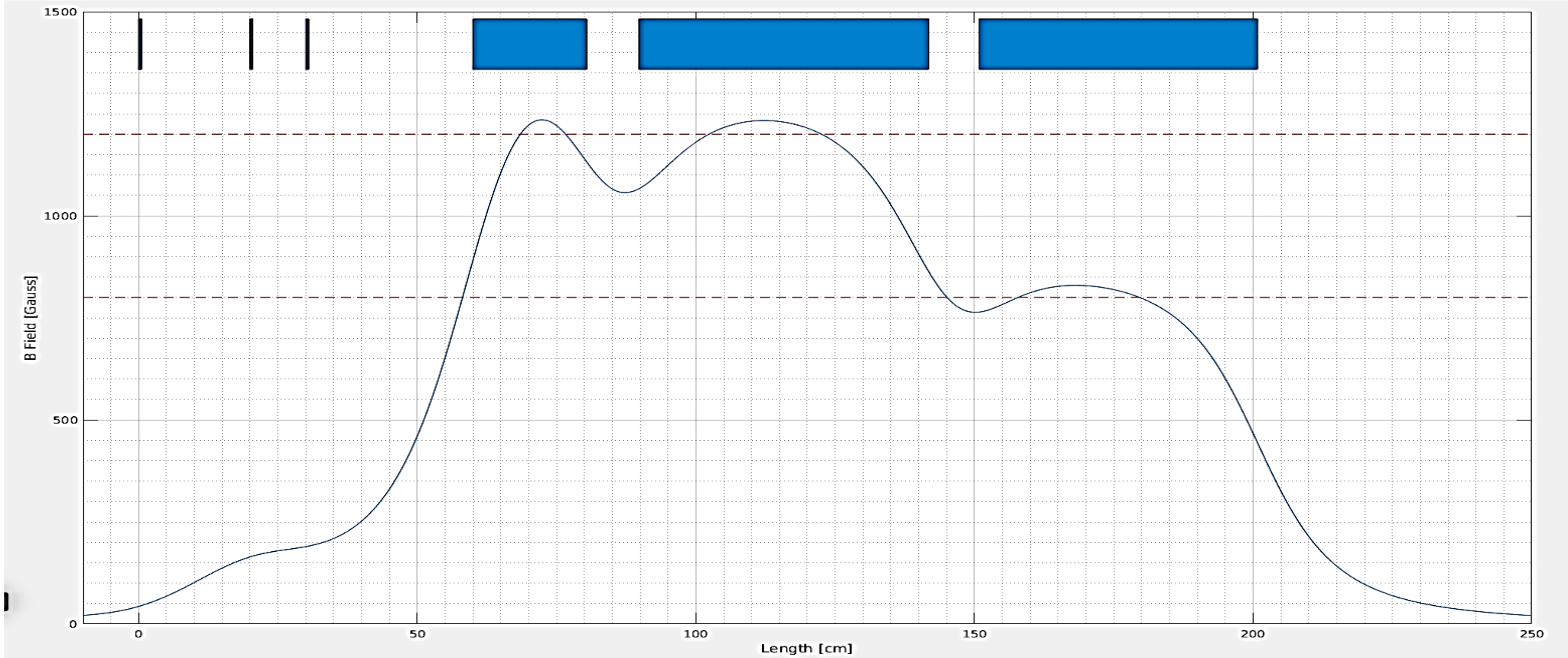


B ↙ 40% (≈ 700-500 G)
55% Beam loss

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!

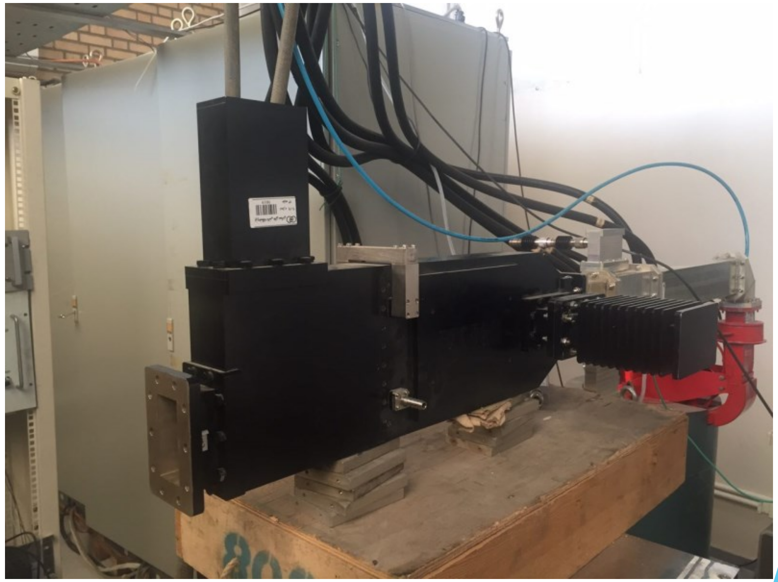


Electron Gun

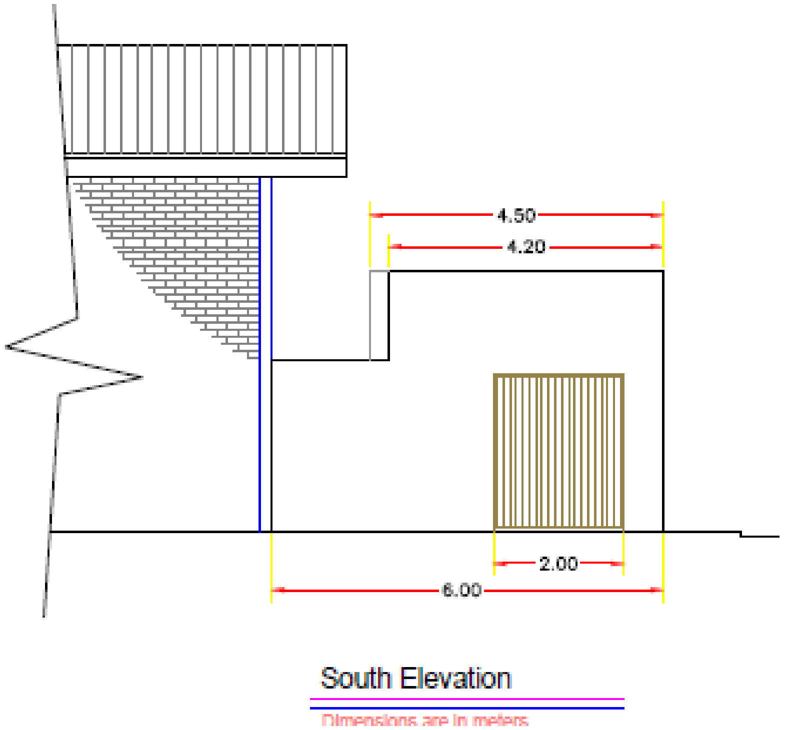
RF (Klystron, Modulator, Waveguide)

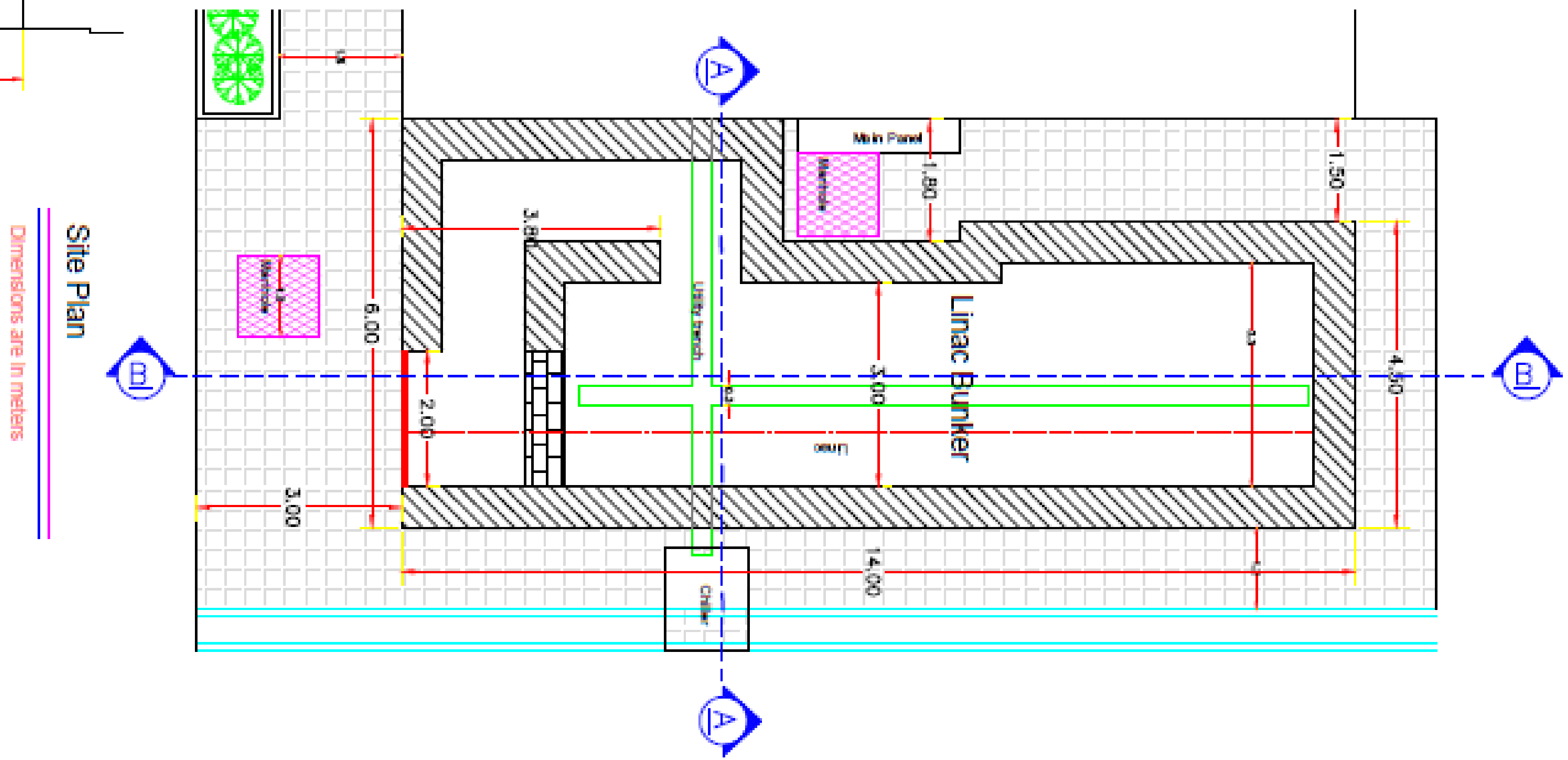
Linac Laboratory at IPM

RF Transmission Components

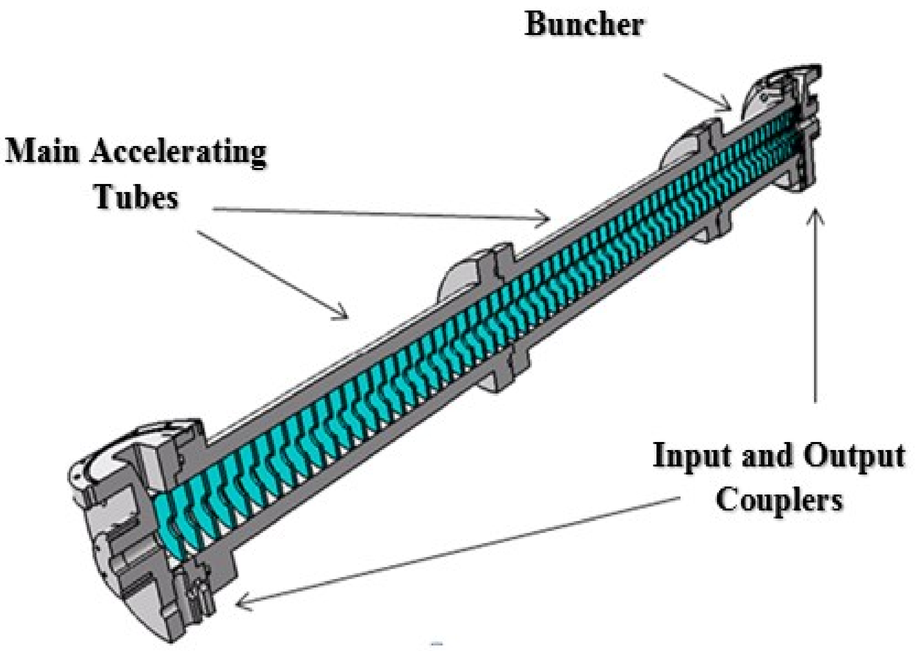


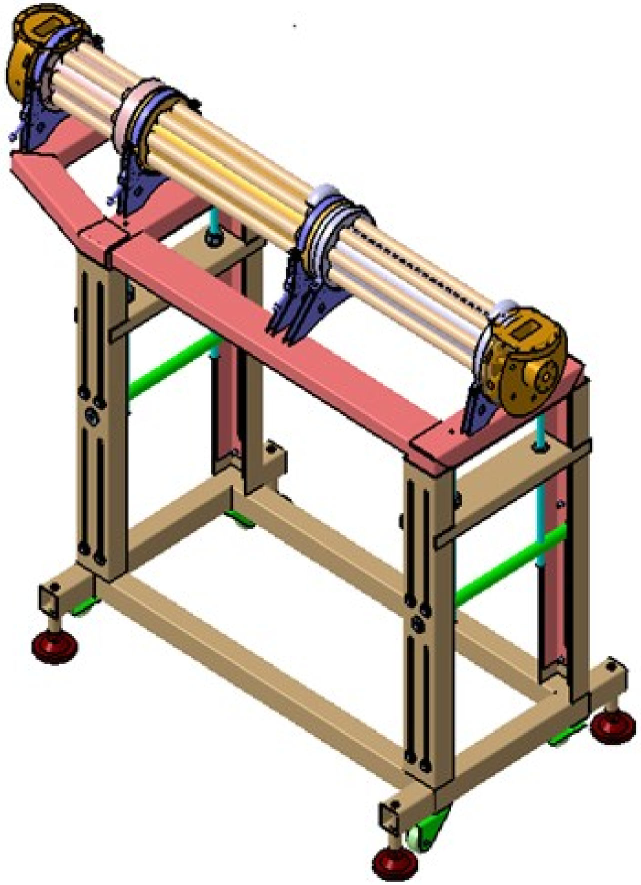
The Linac Bunker



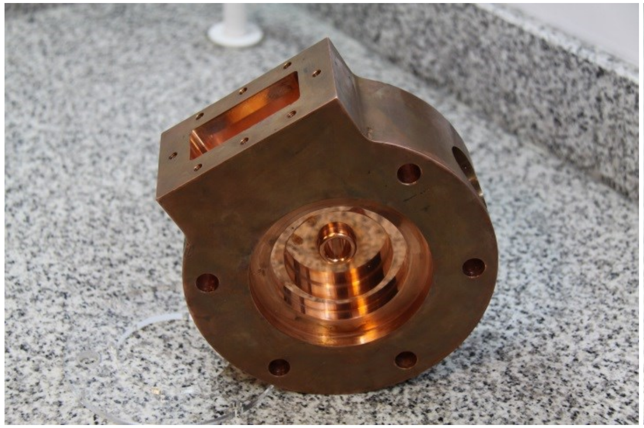
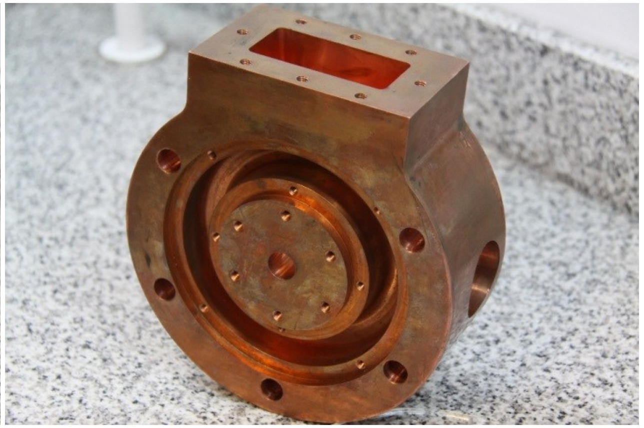


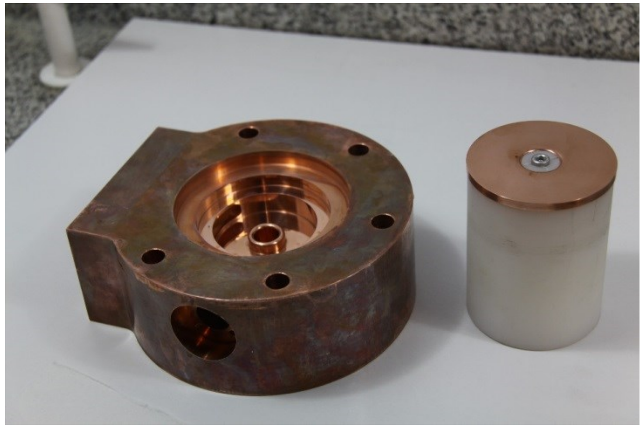
The accelerating tube layout

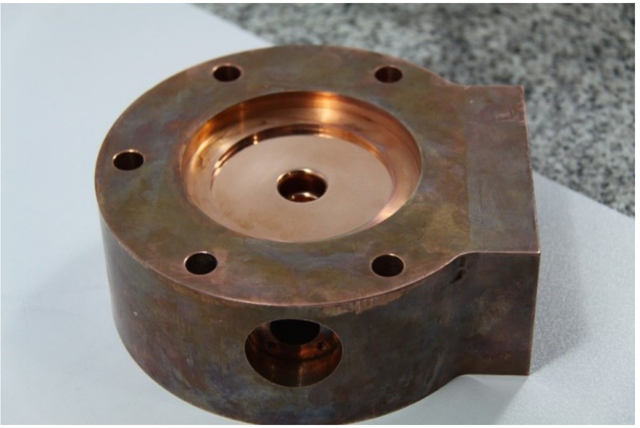
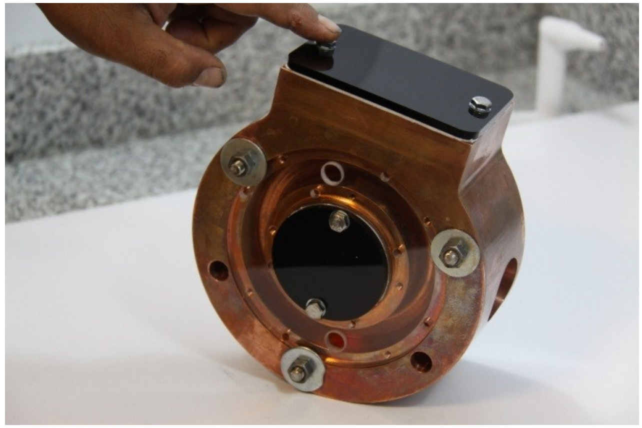




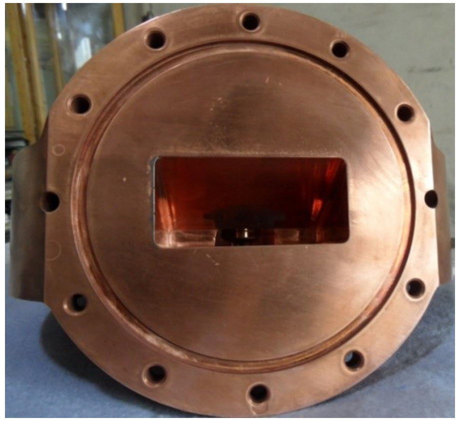
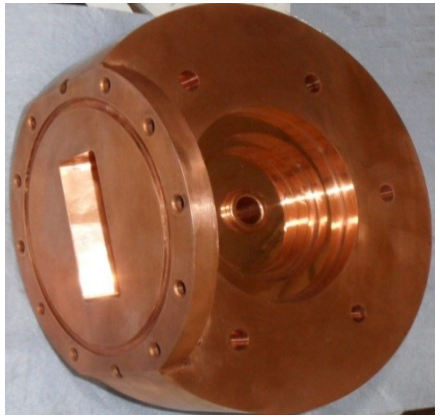
Buncher Coupler

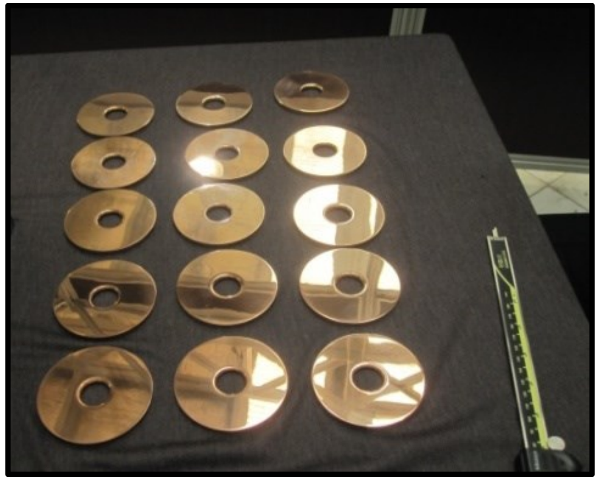


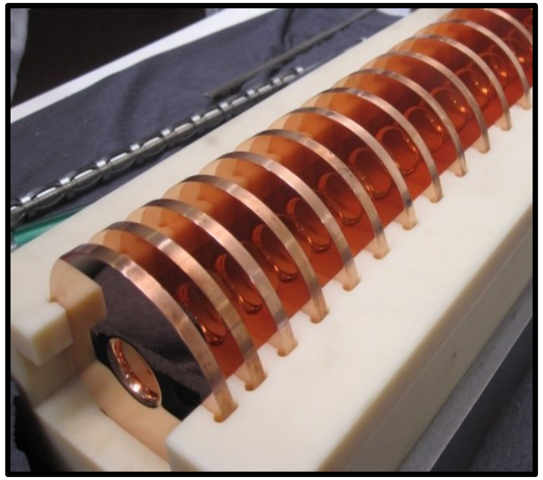




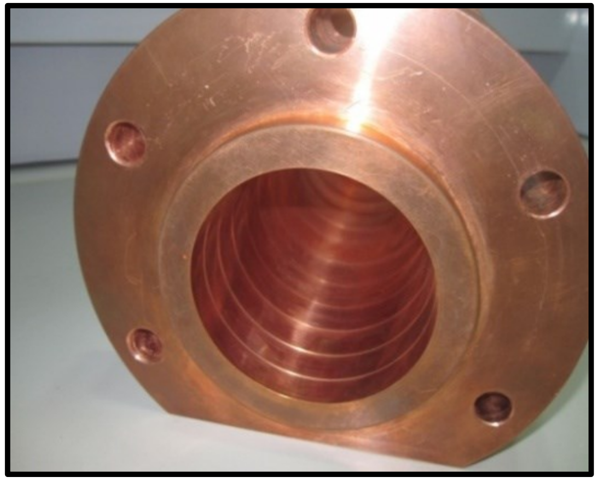
Accelerating Structure (Tube) Coupler

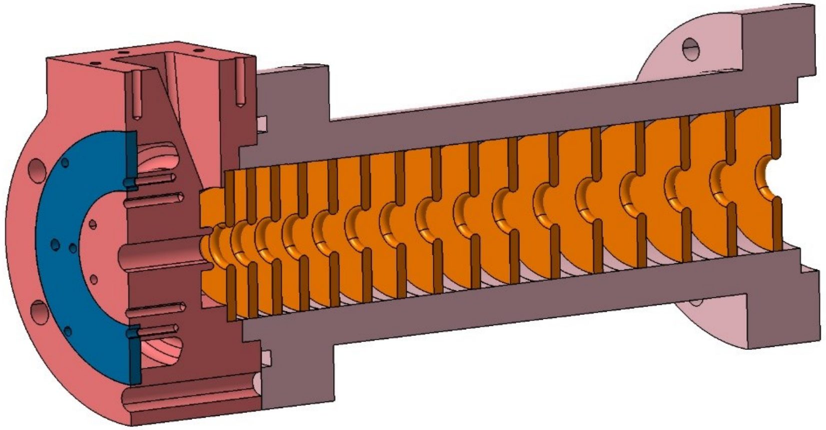



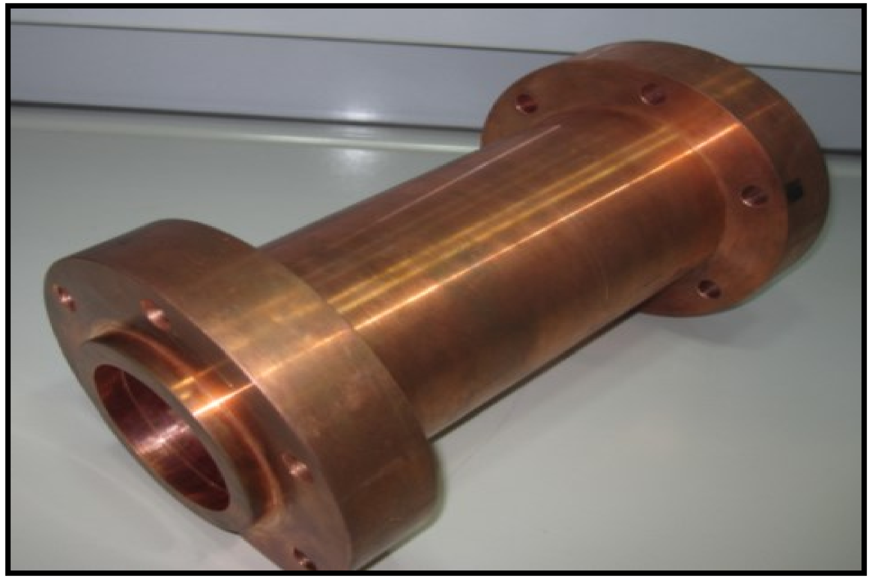

Buncher



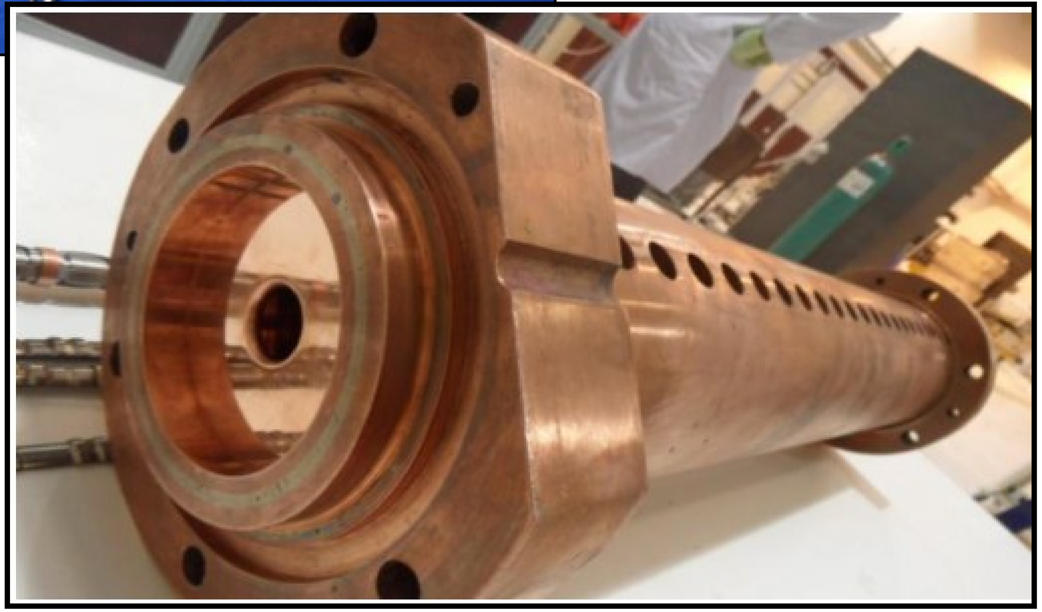








Accelerating Structure (Tube)



Three units was constructed

Bead-Pull Measurements

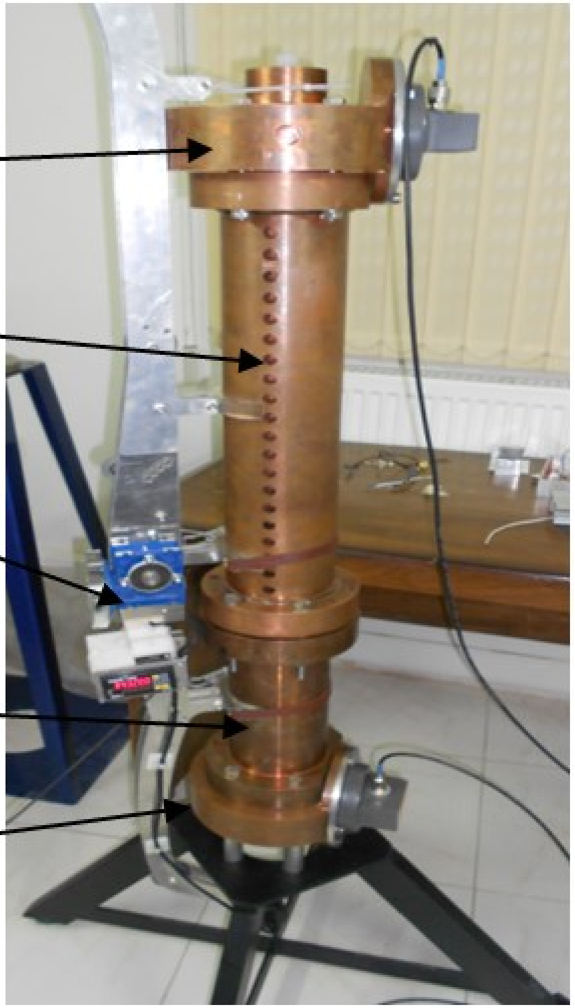
Output Coupler

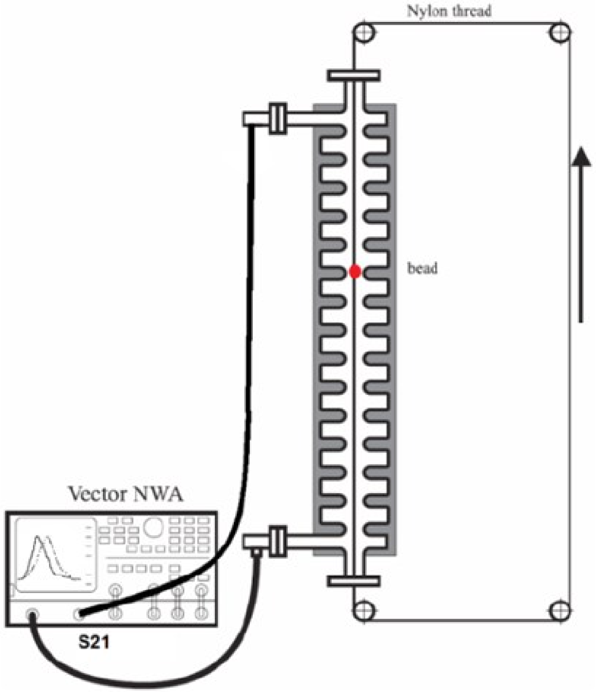
Accelerating tube

Bead-pull measurement structure

Buncher

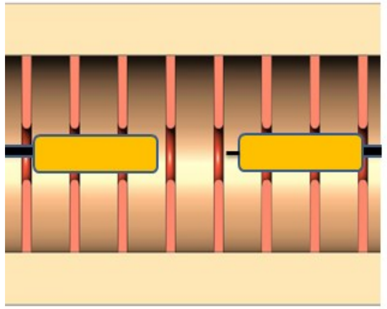
Input Coupler

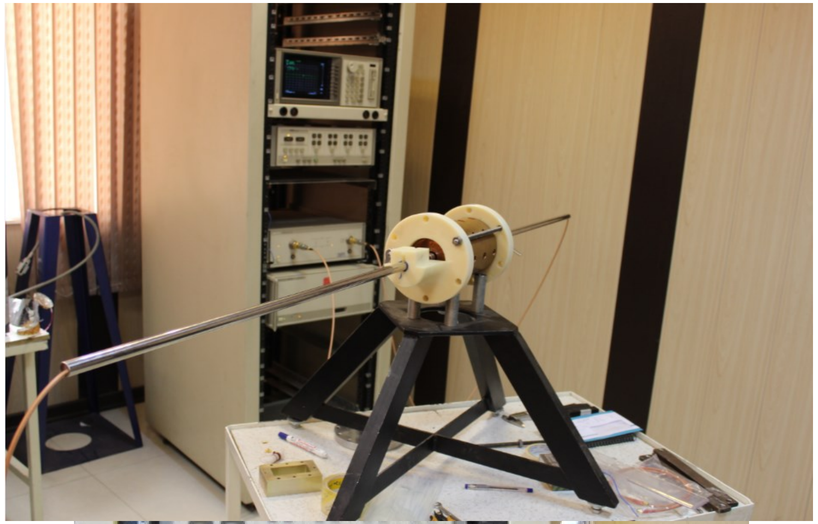


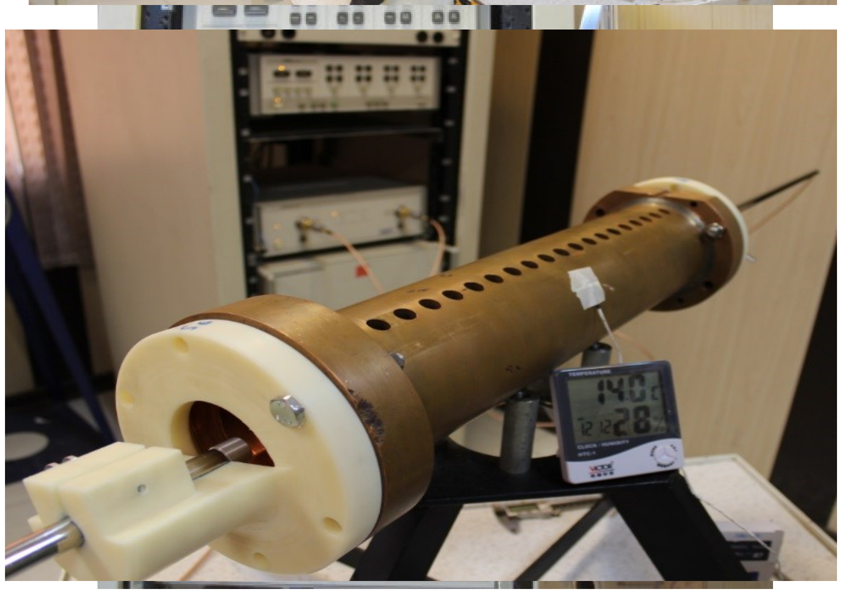


Bead pull measurement

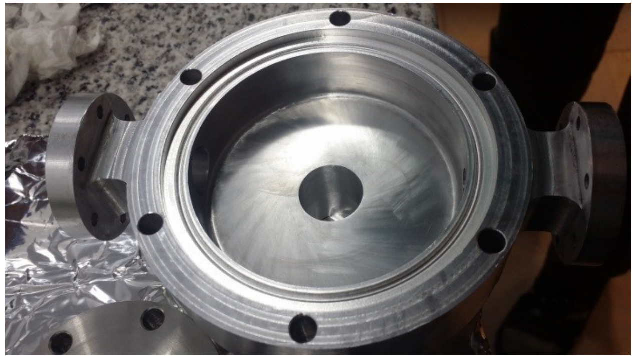
Frequency Measurements-Direct Method







Pre-Buncher

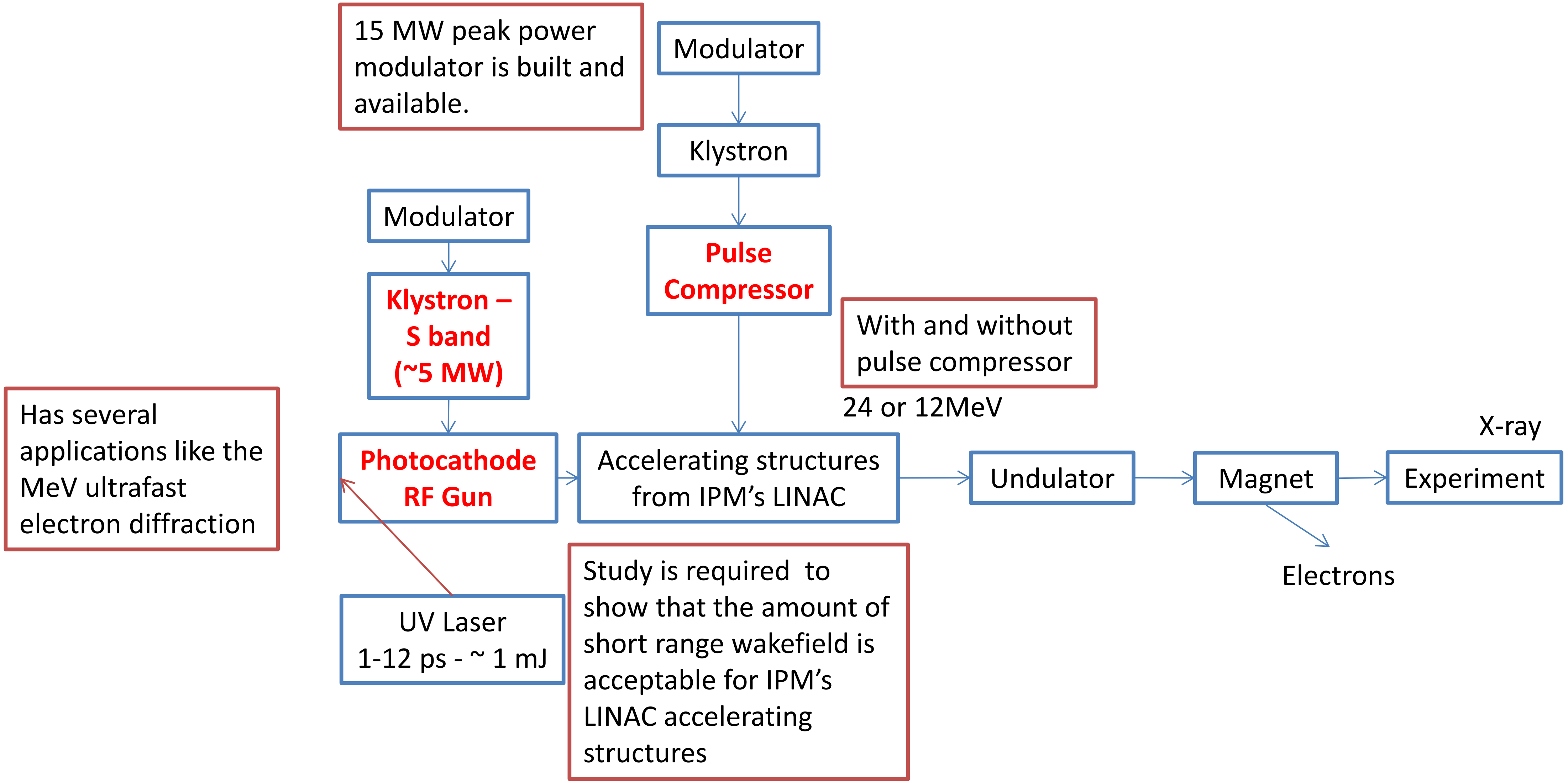




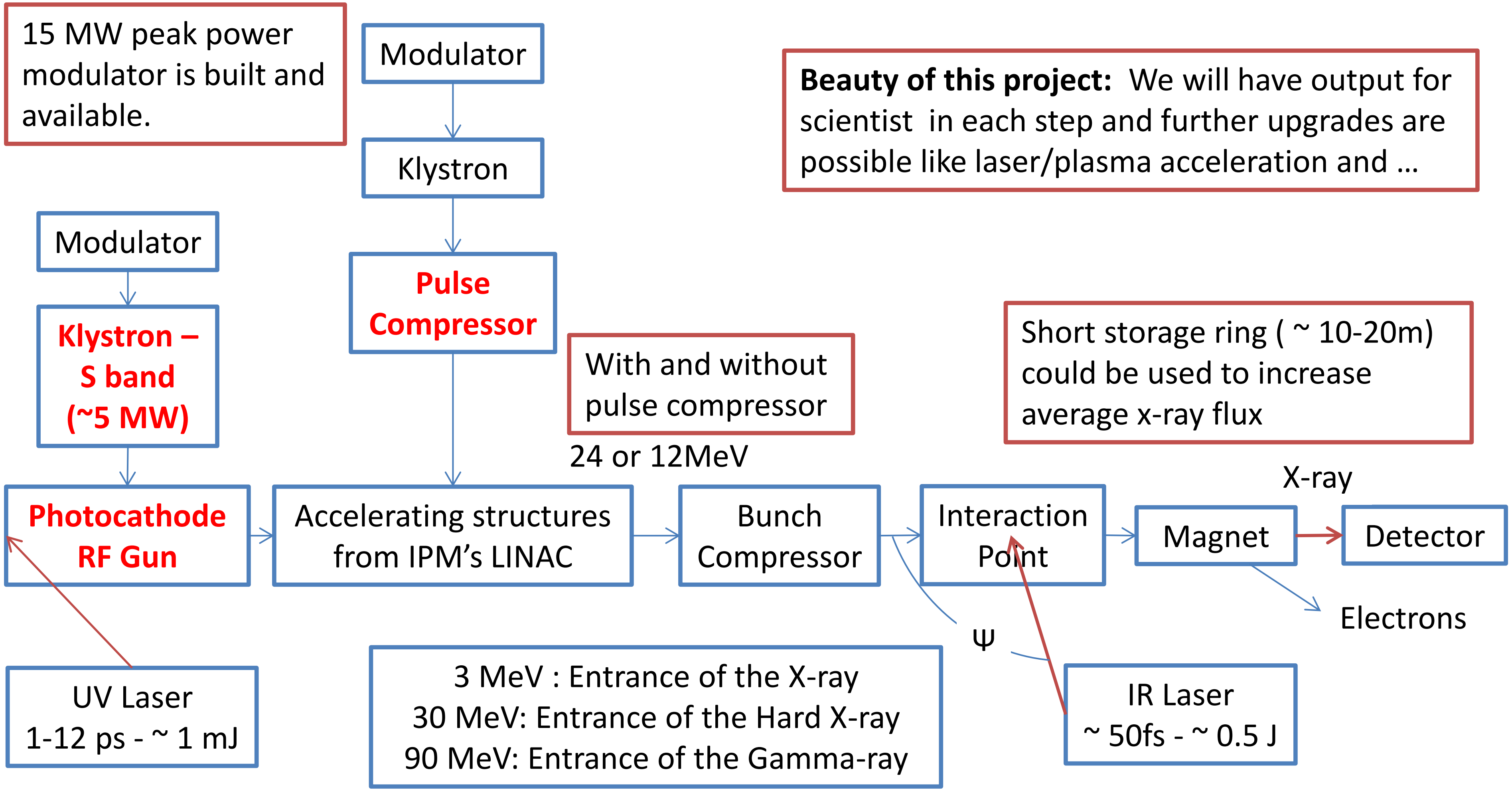

Ideas for the future projects

- Photo-Cathode RF Gun
- THz Source
- Inverse-Compton Scattering

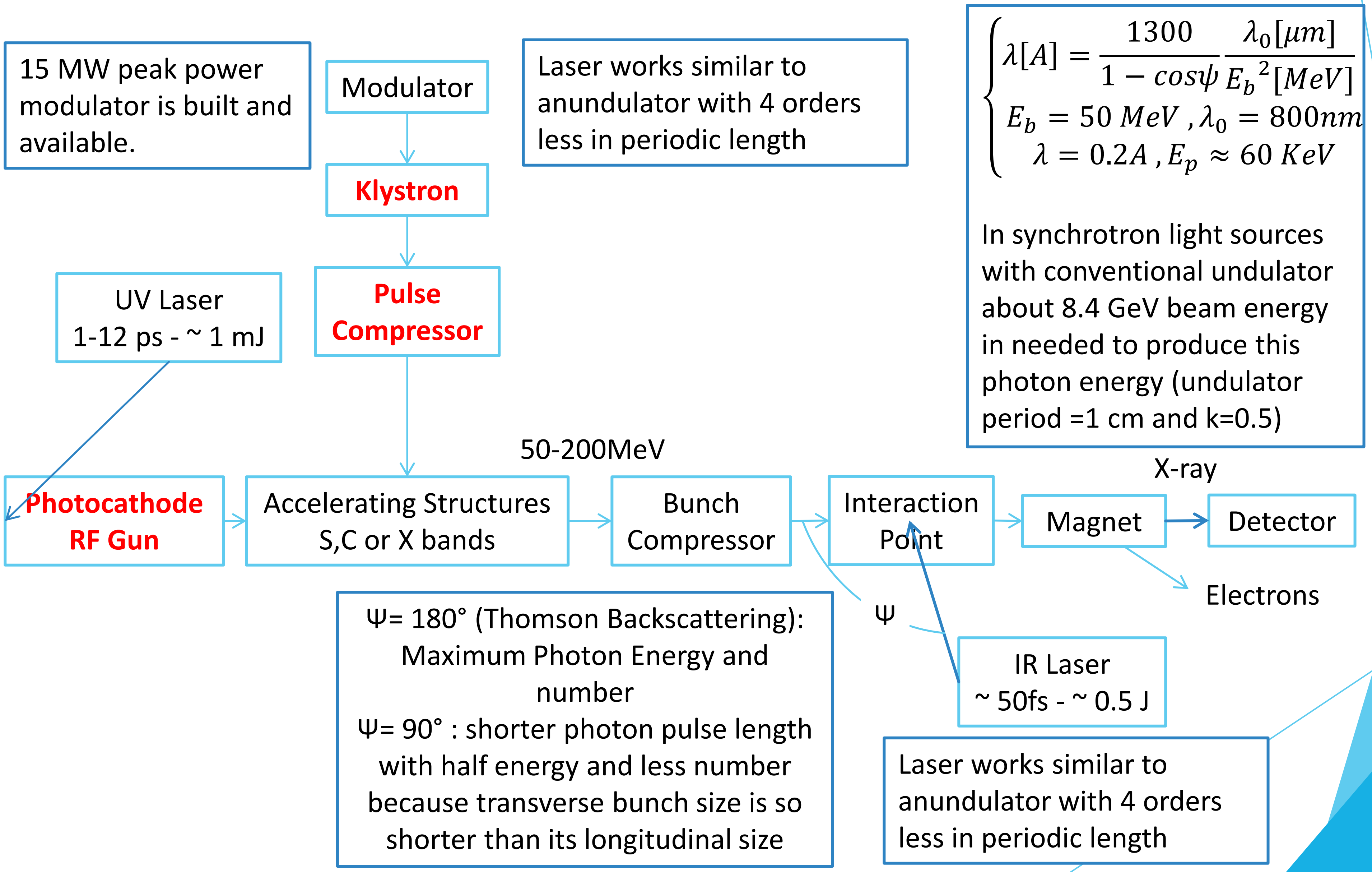
Project in the Progressive Stages
Photo-Cathode RF Gun and THz Source



Project in the Progressive Stages
Inverse-Compton Scattering X-Ray Source



Inverse-Compton Scattering X-ray source

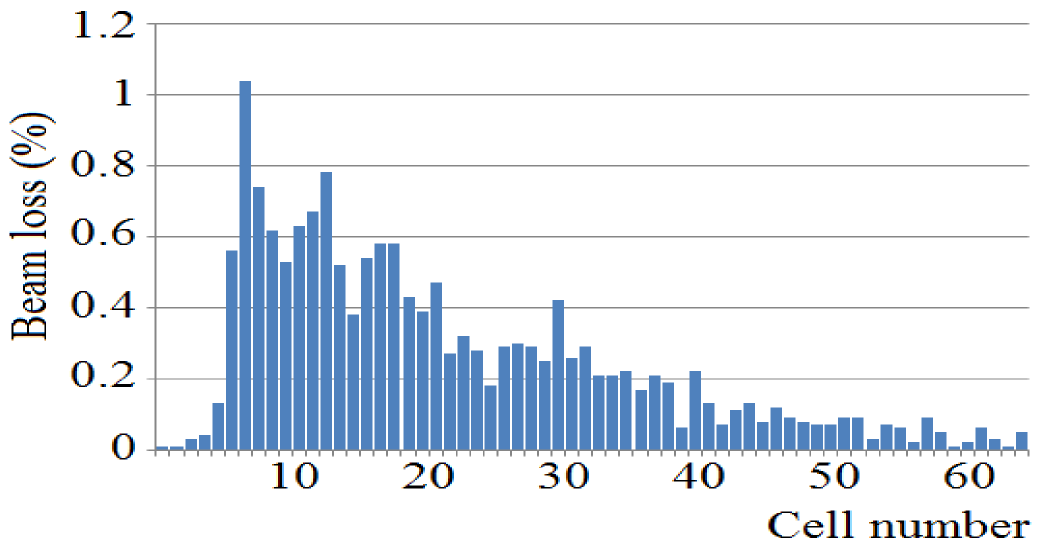


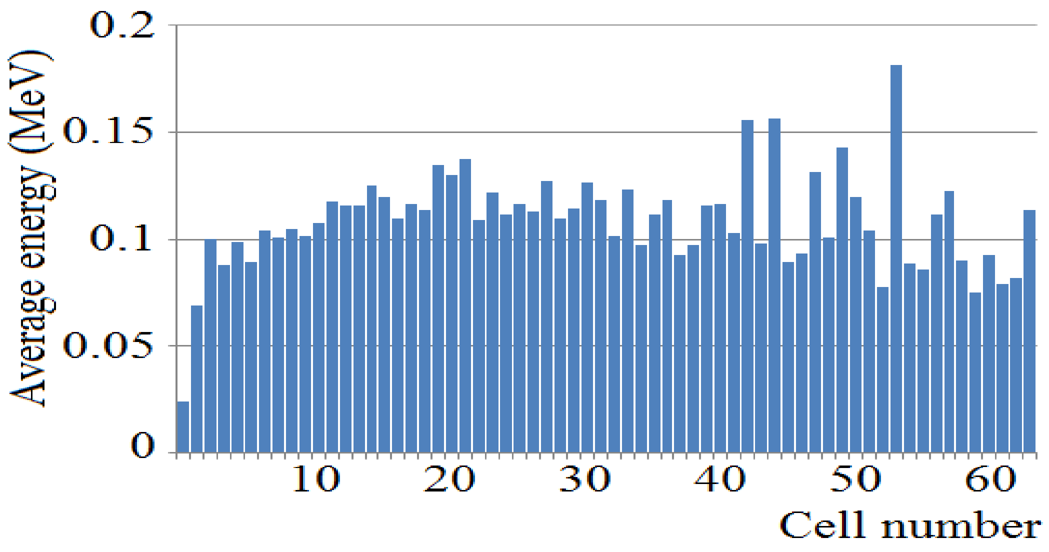
Thanks for your attention

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