Iranian Light Source Facility Accelerators

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On behalf of my colleagues at ILSF

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INTRODUCTION – Accelerators design review

- Design of the ILSF accelerators was commenced in the middle of 2010.

- Regarding the proposed budget and user's requirements, several types of lattice with different configurations of the magnets have been explored for the ILSF storage ring.

- To fill up the ILSF storage ring, many scenarios of the injection systems have been investigated and as the consequence, a full energy booster synchrotron fed by small Linac sections is frozen as the main injector of the ILSF storage ring.

INTRODUCTION – Accelerators design review

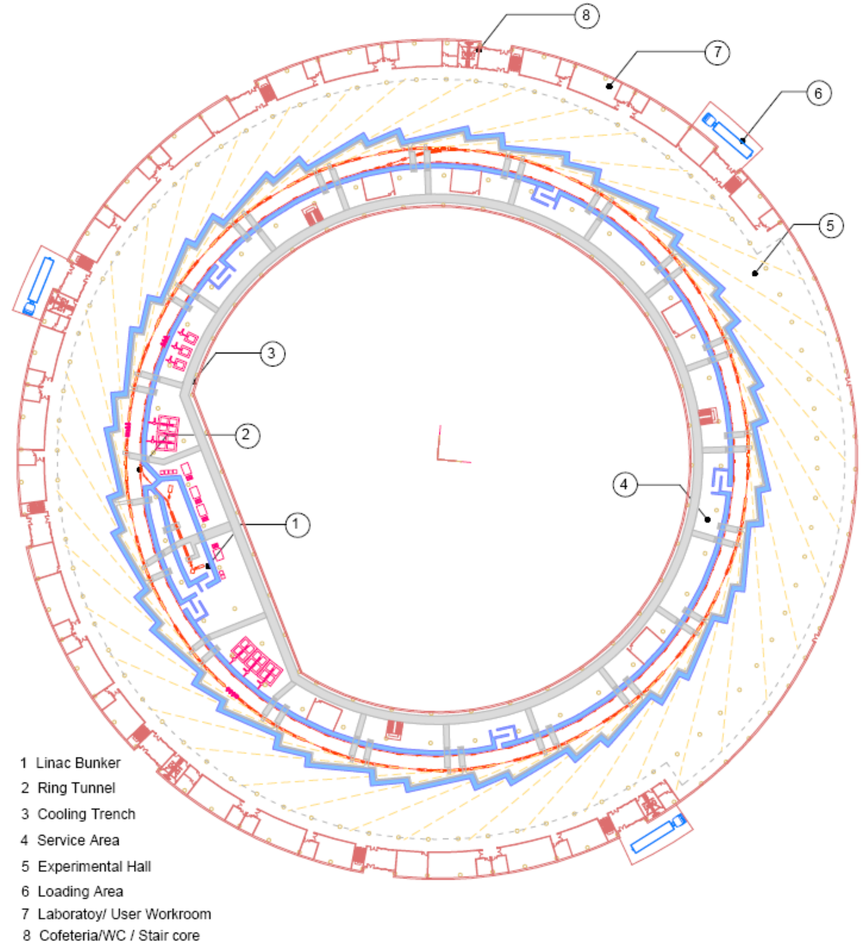
- Two approaches were studied for design of the booster.
  - In the first approach, the booster with small circumference was designed to place in a separated tunnel as storage ring.
  - In the second, a low emittance large booster was designed to be in the shared tunnel with storage ring.
- In spite of the concerns regarding the risk associated with interference in installation, testing and commissioning of both machines placed in the shared tunnel as well as future booster troubleshooting, significant higher construction cost of the additional tunnel for the case of separated tunnel booster motivated us to accept the risk and thus **the choice of booster in the shared tunnel with ring is frozen**.
- As a consequence of this decision, the booster becomes as large as storage ring but most of the booster circumference is in use with small stainless steel vacuum pipe.
- Based on housing both booster and storage ring in the shared tunnel, maintenance cost is expected to reduce during the ILSF operation phase.
- Due to the low value of beam emittance in the large booster; more efficient beam injection would be obtainable.

INTRODUCTION – Main buildings

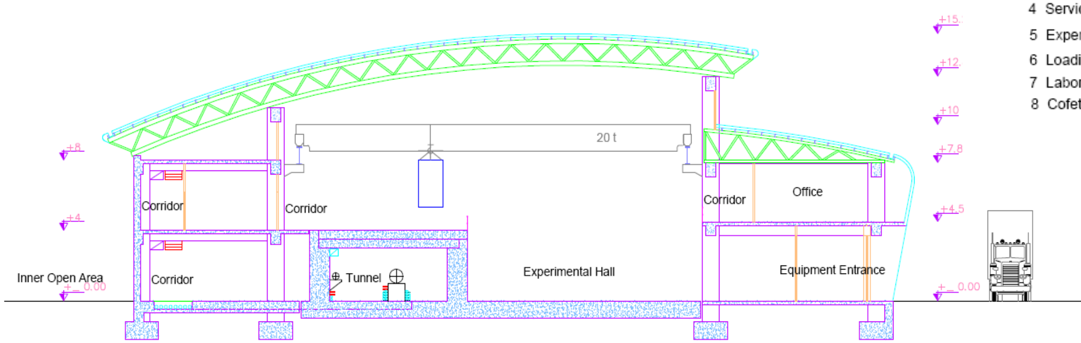
- ❑ The main building consists of
  - o two floors service area
  - o Linac bunker
  - o shared storage ring and booster tunnel
  - o experimental hall and access corridors

❑ The typical width of the service area is 10 m and the experimental hall accommodates beamlines with length of 60 m long.

❑ Outboard of the experimental hall is the access corridor with 2.5 m width. The supplemental laboratories would be next to them.



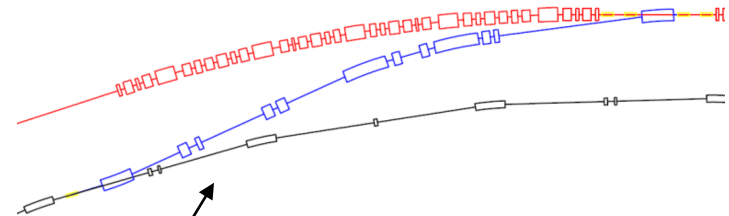
Main Building Ground Floor Layout

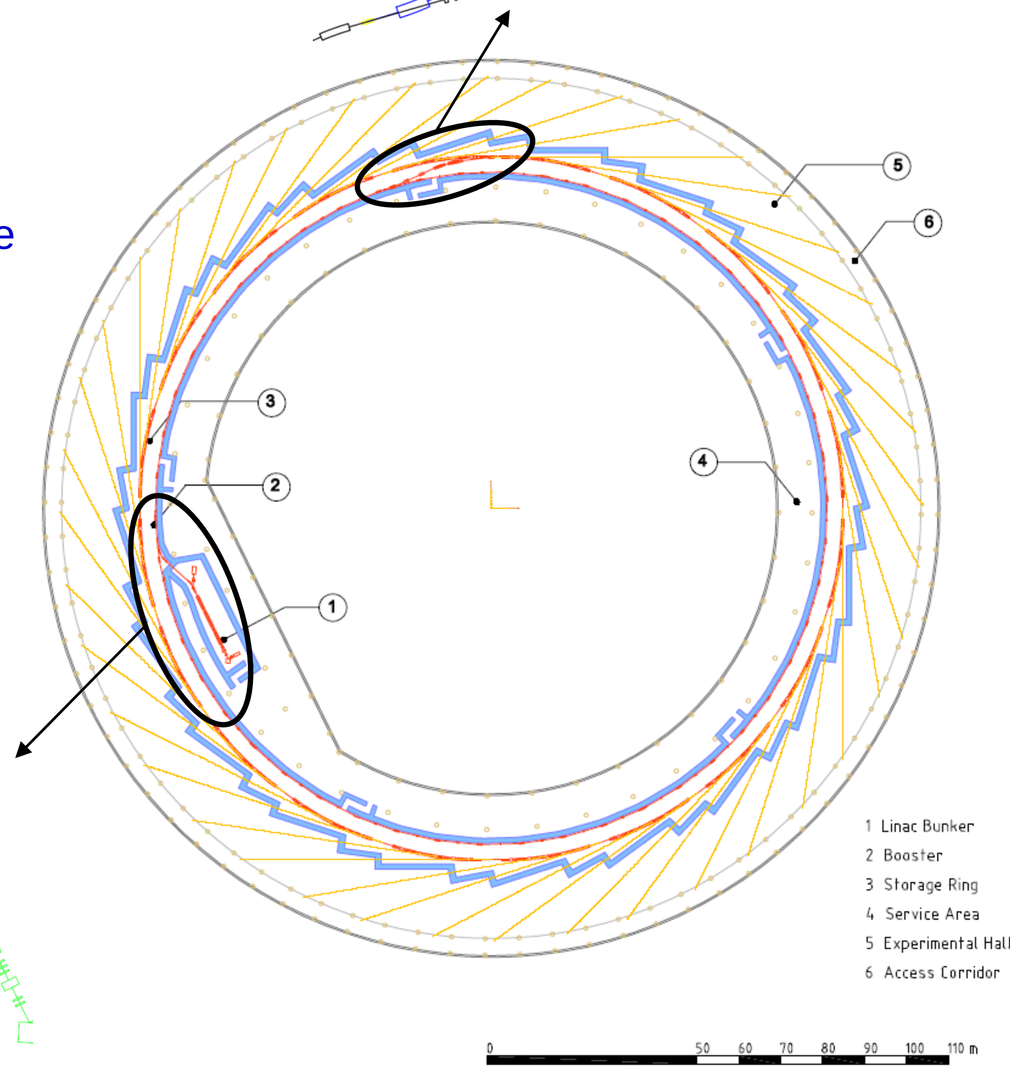


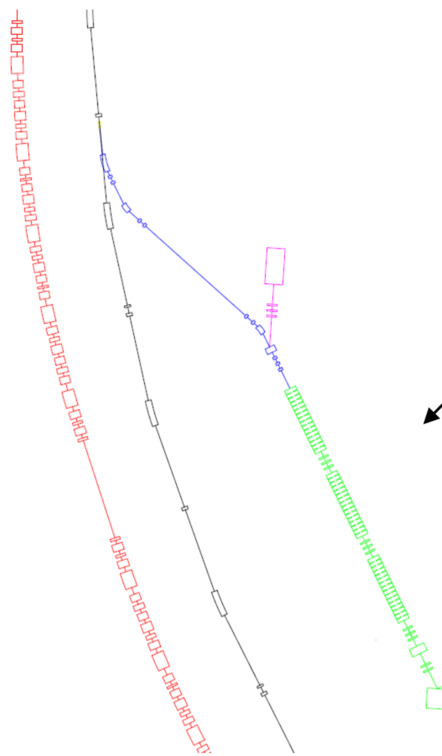
INTRODUCTION – Layout of Accelerators

The ILSF accelerators consist of five main systems;

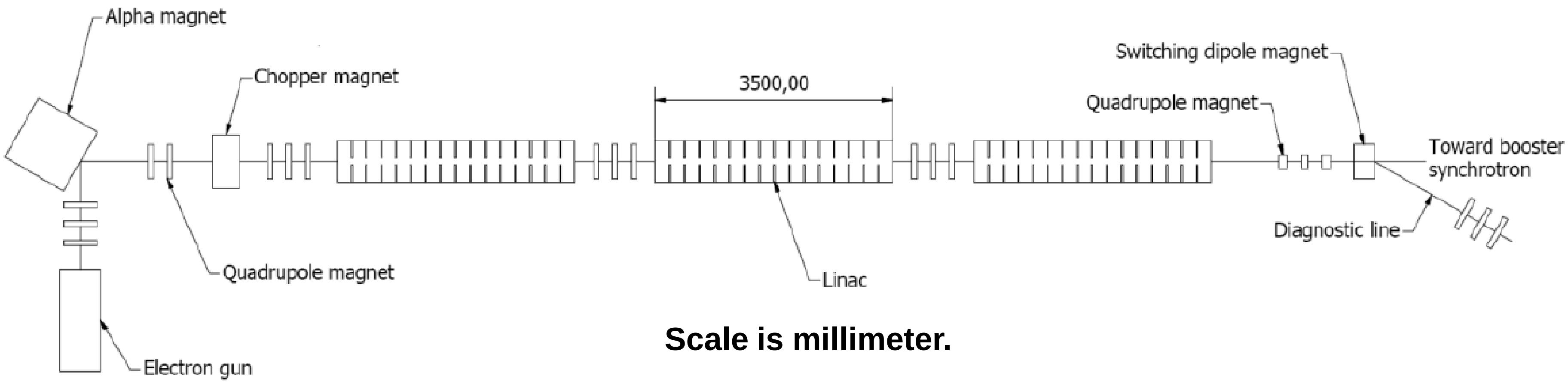
- Pre-injectors
- Linac to booster (LTB) transfer line
- Booster synchrotron
- Booster to storage ring (BTS) transfer line
- Storage ring







PRE-INJECTORS

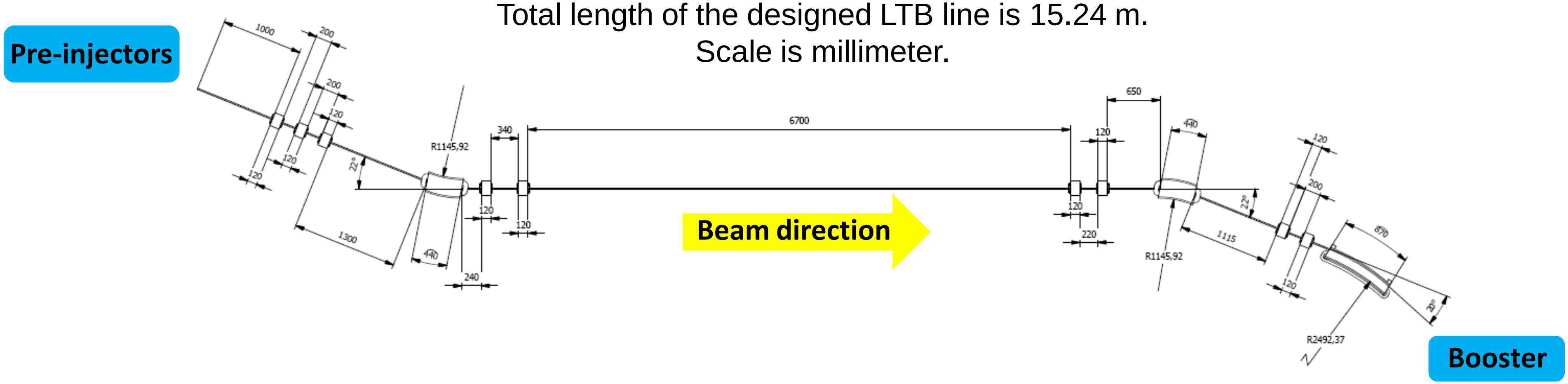


Scale is millimeter.

- The electron bunches are produced from a thermionic RF gun.
- They go through the alpha and chopper magnets for bunch accumulation.
- Then they move toward 3 travelling wave linear accelerator sections which each section with length of 3.5 m accelerates the bunched electrons to the energy of 50 MeV and totally 150 MeV.
- The triplet quadrupoles are used in the different locations in pre-injector section for transverse focusing.

LINAC TO BOOSTER (LTB) TRANSFER LINE

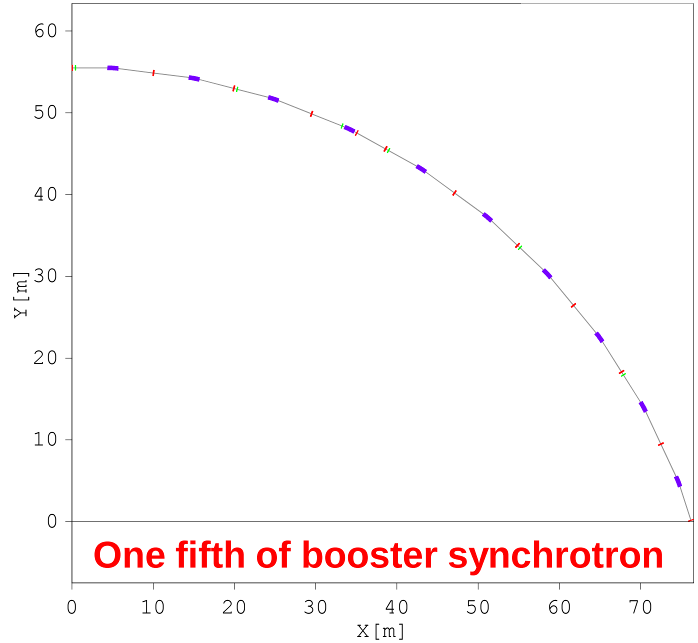
Total length of the designed LTB line is 15.24 m.
Scale is millimeter.



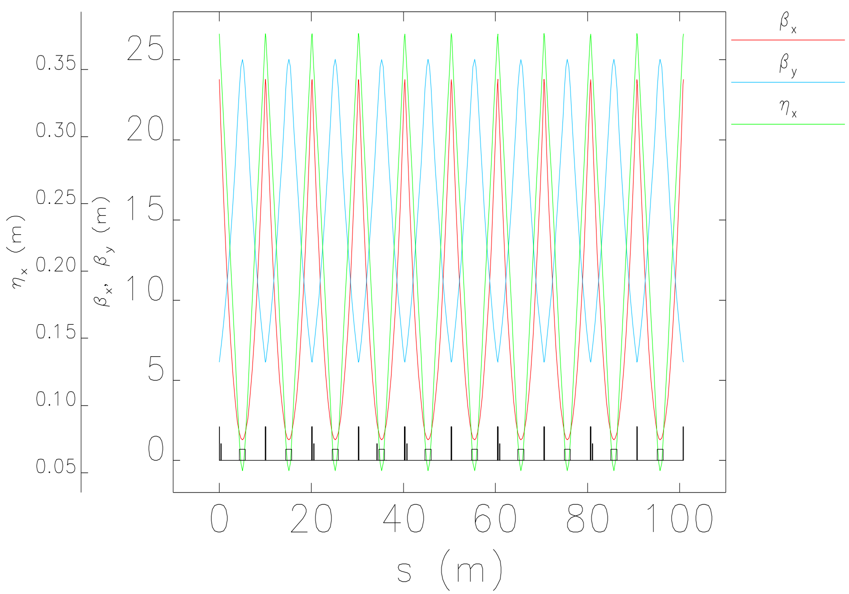
- ❑ LTB transfer line guides 150 MeV bunches to the booster synchrotron.
- ❑ It starts at the exit of pre-injectors and ends at the exit of the injection septum.
- ❑ Two dipole magnets with the same specifications are employed to guide the electrons to the straight section of the booster. One of them firstly bends the beam negatively (anticlockwise) and the other one gives a positive deflection (clockwise) to the electrons. They include no field gradient, have the length of 440 mm and the bending field of 436 mT.
- ❑ A long distance of 6.7 m is considered between the dipoles to cover requirements of the building structural design.
- ❑ Matching of the optical functions was performed in the six dimensional phase spaces by the use of 9 quadrupoles all with the length of 120 mm.

BOOSTER SYNCHROTRON

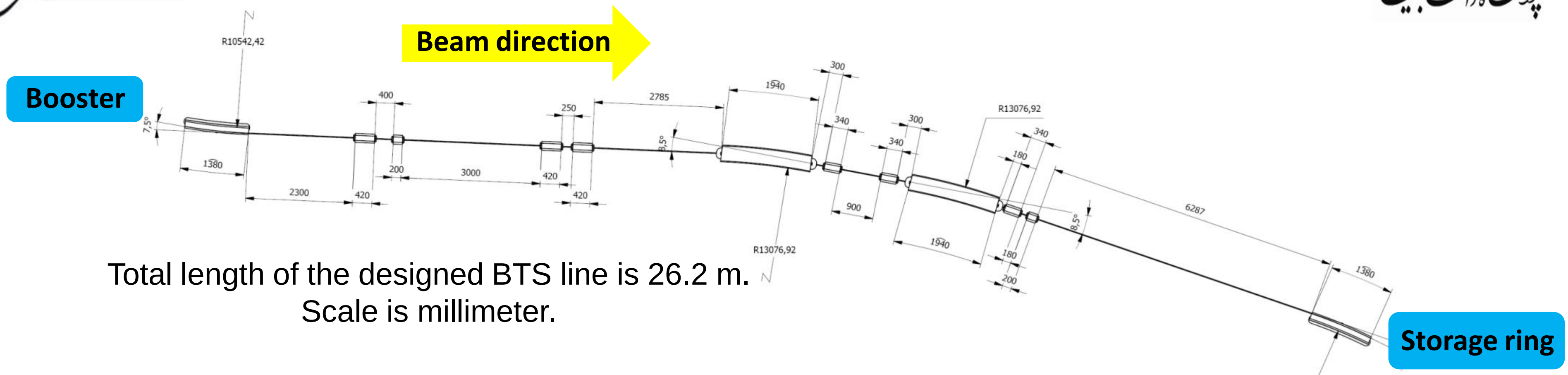
Parameter	Unit	Value
Injection energy	MeV	150
Extraction energy	GeV	3
Maximum beam current	mA	5
Circumference	m	504
Lattice structure	-	FODO
Natural emittance at ext. energy	nm rad	3.50
Repetition rate	Hz	2
RF frequency	MHz	100



- ❑ Booster lattice is based on FODO lattice structure.
- ❑ There are 50 combined function dipoles each with length of 1.3 m, maximum field of 1 T and bending angle of 7.2 degrees in the booster.
- ❑ As a part of pole geometry, all dipoles include of quadrupole field components to provide vertical focusing.
- ❑ The horizontal focusing is performed by the use of 50 weak one role quadrupole magnets in the booster.



BOOSTER TO STORAGE RING (BTS) TRANSFER LINE



Total length of the designed BTS line is 26.2 m.
Scale is millimeter.

- The BTS transfer line links the booster synchrotron to the storage ring of the ILSF. Due to being both booster and storage ring in a shared tunnel, geometric constrains have been utilized in design of BTS.
- BTS magnets have been carefully arranged along to avoid transversely interfere of their yokes with the yokes of the ring magnets.
- The extracted bunches with the horizontal displacement of 24 mm from the booster ideal orbit come into the septum and septum with the length of 1.38 m bends the bunches 7.5 degrees anticlockwise to the BTS transfer line.
- Two uniform bending dipoles are employed to compensate the 16 degrees rotation between booster and storage ring straight sections. These two dipoles have the length of 1.94 m and each bends the bunches 8.5 degrees clockwise.
- There are three long drift spaces between them which allows people and equipment passage by bending below the beam pipe.
- The optical matching has been done with use of 8 quadrupole.

STORAGE RING

- Several intensive efforts have been performed in the design of the third generation synchrotron light sources around the world to meet future demands of the users for having super bright radiation from ultralow electron beam emittance.

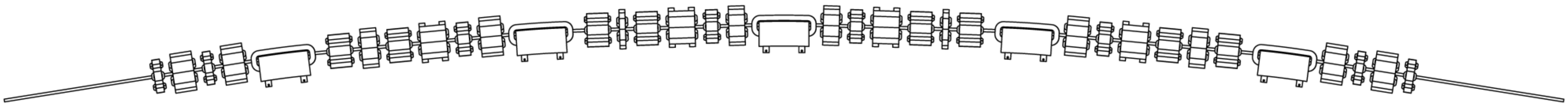
- The beam emittance is defined by the structure of magnets in the lattice. it is proportional directly to the square of beam energy and inversely to the third power of number of dipoles.

- Horizon of the ultralow emittance storage rings is based on the multibend achromat (MBA) lattice structure which improves the brightness 2 to 3 orders of magnitude higher than nowadays synchrotron radiation light sources.

- ILSF storage ring lattice follows design trend of modern 3rd generation synchrotron light source facilities.

- In order to avoid large storage ring circumference and to have a large number of beam lines, the designed lattice is optimized to be as compact as possible.

STORAGE RING



- The ILSF storage ring is based on 5 bend achromat lattice structure.
- It's composed of 20 super periods and provides 20 straight sections each with the length of 5.11 m.
- One of them will be occupied with the injection equipment, two of them are reserved for the RF cavities; the remain straight sections are considered for installation of the insertion devices with the length up to 4 m.
- Expected number of beamlines:37

Parameter	Unit	Value
Energy	GeV	3
Maximum beam current	mA	400
Circumference	m	528
Lattice structure	-	5BA
Number of super period	-	20
Length of str. sect.	m	5.110
Natural emittance	pm rad	476.62
Betatron tune	-/-	43.28/14.25
Natural chromaticity	-/-	-99.43/-52.86
Natural energy spread	-/-	7.03×10^{-4}
Damping times	ms/ms/ms	19.71/19.72/9.86
Natural energy loss/turn	keV	535.98
Revolution time	µs	1.76
RF frequency	MHz	100
Harmonic number	-	176

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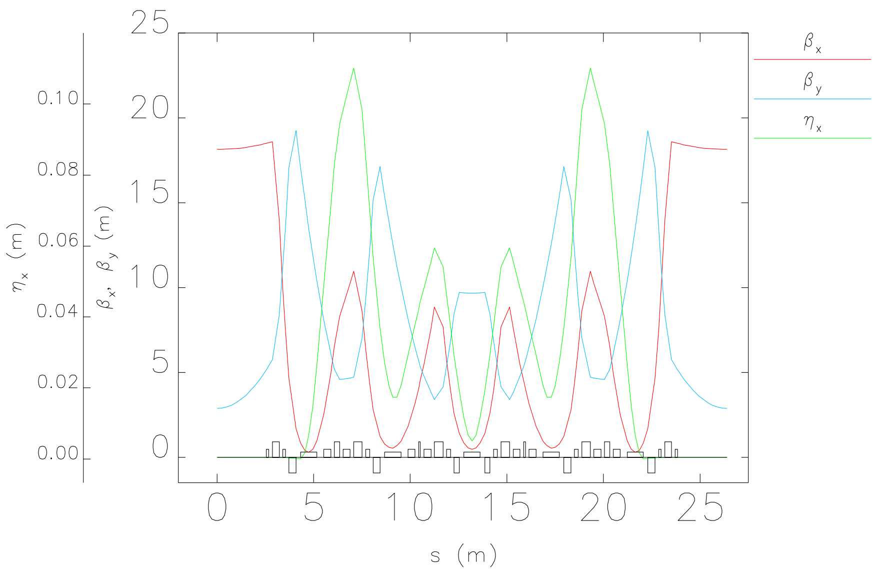
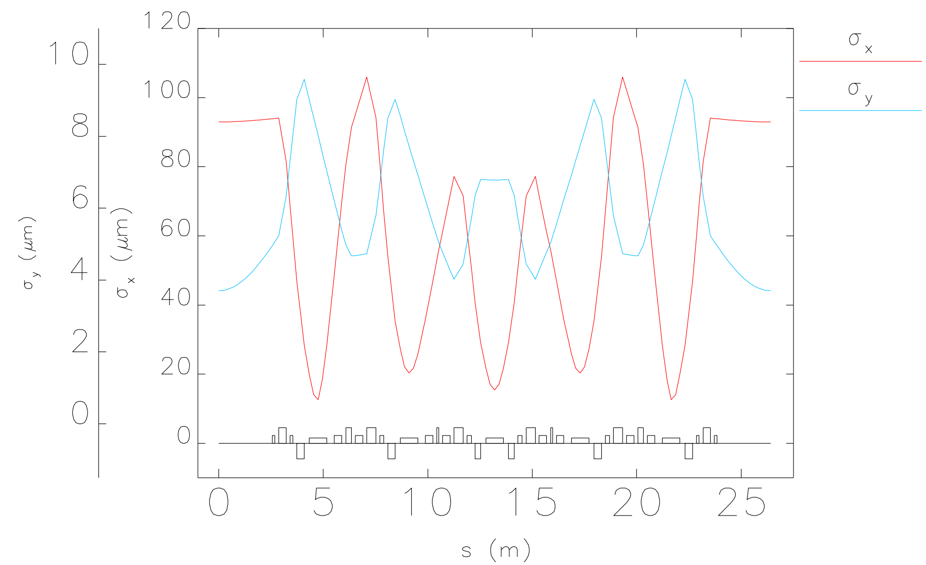
STORAGE RING-LATTICE

- ❑ 100 pure dipoles (length: 0.84 m, Field: 0.75 T, Bending angle: 3.60 Degrees)

- ❑ Focusing is performed with the use of 16 quadrupoles grouped in 8 families. There are totally 320 quadrupoles with maximum strength of 25 T/m and pole radius of 26 mm.





Parameter	Straight section	Central dipole
β_x(m)/β_y(m)/η_x (mm)	18.15/2.83/0.00	0.48/9.03/4.90
<β_x>/<β_y>(m/m)	7.58/8.06	
η_{xMin}/η_{xMax}>(cm/cm)	0.00/11.062	
σ_x(μm)/σ_y(μm)	92.99/3.703	15.41/6.79

With use of such relaxed weak magnets in the lattice design, an extraordinary natural emittance of about 0.48 nm rad is achieved.

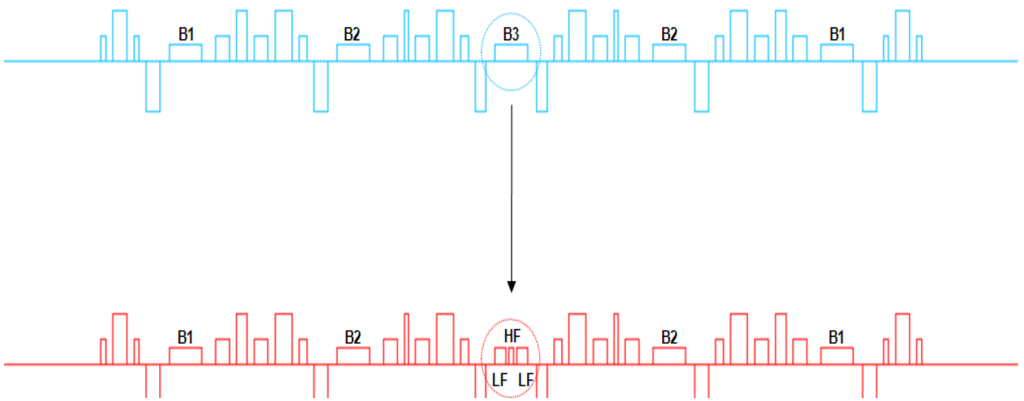
STORAGE RING-SUPER BEND MAGNET

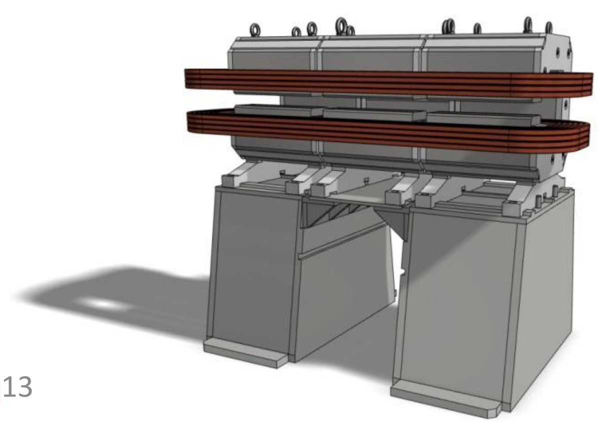
- Due to using low field dipoles, the radiated beam critical energy is limited to 4.48 keV at 3 GeV. This photon beam energy is useful for several experiments in the soft x-ray region but it is low for the experiments which require high energy hard x-ray.

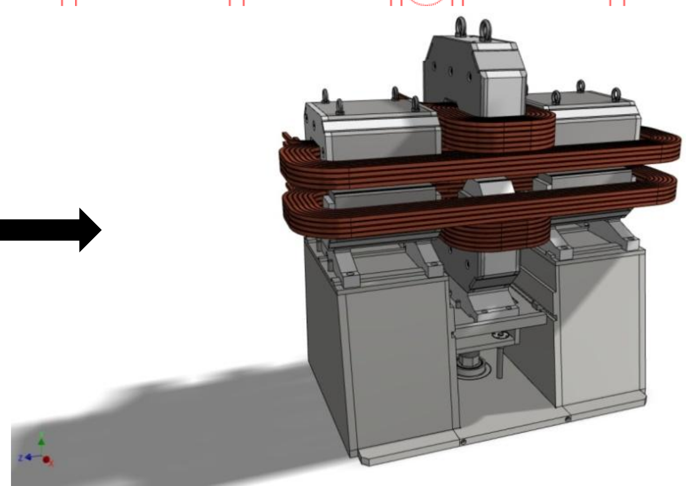
- To reach super bright high energy radiation from the dipoles, the central low field bending magnet (B3) in the lattice is replaced with a combination of a thin high field (HF) dipole magnet which is sandwiched between two low field (LF) dipoles.

- All the low field bending sections are the same in the length (28 cm) and the deflection angle (1.2 degrees).

- The middle low field section is removable. It can be taken out and replaced with the thin high field dipole.

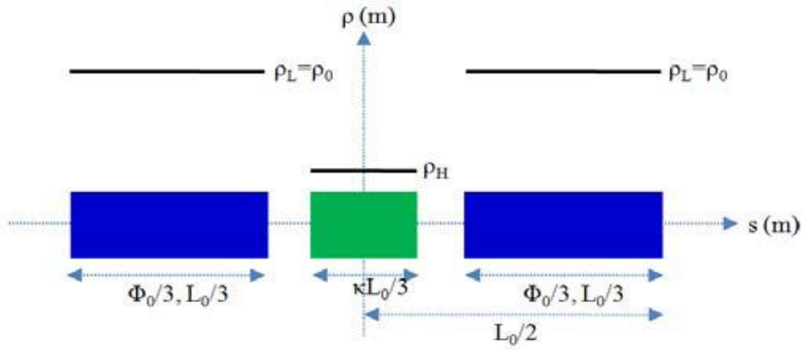






STORAGE RING-SUPER BEND

- ❑ The longitudinal gradient provided with the super-bend magnet helps beam emittance reduction.

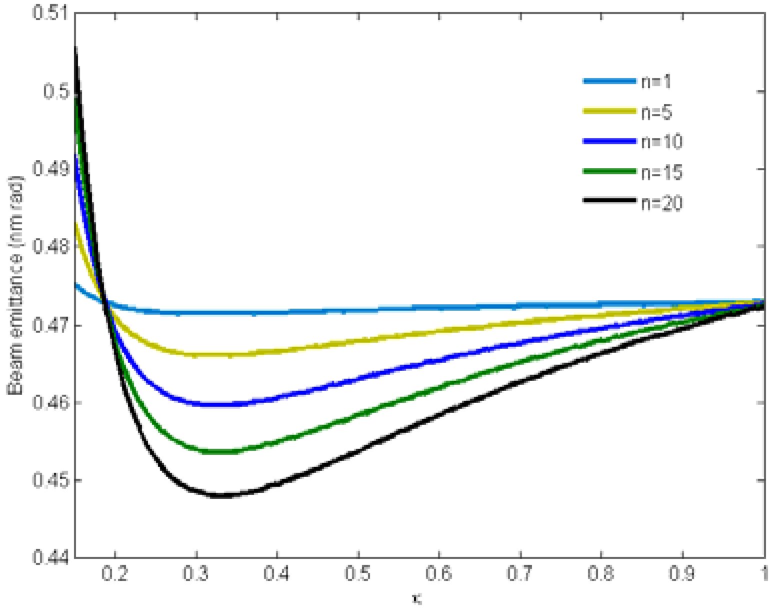


$$\varepsilon=\frac{C_q\gamma^2}{J_x}\cdot\left[\frac{2Nh_0^3\left(\int_0^{L_0}(H_1+H_2)ds\right)+(N-n)h_0^3\int_0^{L_0}H_3ds+2nh_0^3\int_0^{\frac{L_0}{3}}H_{LF}ds+n\left(\frac{h_0}{\kappa}\right)^3\int_0^{\frac{\kappa L_0}{3}}H_{HF}ds}{4Nh_0^2L_0+(N-n)h_0^2L_0+2nh_0^2\frac{L_0}{3}+n\left(\frac{h_0}{\kappa}\right)^2\frac{\kappa L_0}{3}}\right]$$

L_0 and h_0 are the length and the curvature of the low field dipoles (B1 or B2 or B3) in the bare lattice respectively. The κ factor represents length ratio of high field (HF) and low field (LF) dipoles ($L_H=\kappa L_0/3=\kappa L_F$) and indicates how far the high field section can be extended. N is the number of super period, n is the number of high field inserted dipole.

- ❑ It reveals that the beam emittance lower than 0.45 nm rad would be achievable for the κ=0.33 when highest numbers of the high field sections are used.

- ❑ However, due to the saturation of locally available low carbon steel at 1.8 T, the κ factor is set to 0.43, which indicates 12 cm for the length of high field inserted dipole.

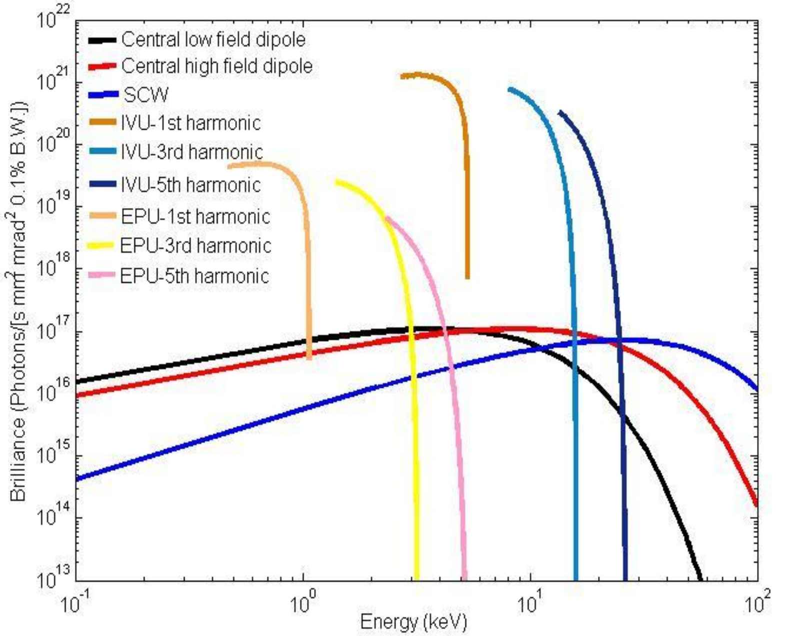


STORAGE RING-RADIATION PERFORMANCE

- To see performance of designed ring, below IDs have been considered;

Parameters	Unit	SCW	EPU	IVU
Number of ID period	-	20	30	140
Period length	cm	6	8	1.6
Magnetic field	T	3.50/0.00	0.90/0.50	0.85/0.00
Length of ID	m	1.20	2.40	2.24
K parameter	-	19.61/0.00	6.73/3.74	1.27/0.00
Radiation loss	keV	83.79	14.50	9.23
Power	kW	8.38	1.45	0.92

Parameters	Unit	Value
Beam current	mA	100
RF voltage	MV	1.100
Beam emittance	nm rad	0.413
Beam energy spread	-	0.835×10^{-3}
Coupling (%)	-	1
Bunch length	mm	9.677
Momentum acceptance (%)	-	4.386
IDs	-	4HF+SCW+3IVU+2EPU
Radiation loss per turn	keV	656.855
Parasitic loss	keV	30



Announcement:

First ILSF Machine Advisory Committee (MAC) meeting will be held in IPM, Tehran, Iran from 7-9 June 2015.

http://ilsf.ipm.ac.ir/ilsfnews.jsp#MAC

THE END

Thank you!