The High Intensity Gamma-ray Souce (HIγS) at the DFELL.

The HIγS facility produces polarized near mono-energetic high intensity gamma rays through Compton back scattering. These back scattered gamma rays are the product of a collision between the stored electron beam in the DFELL storage ring and the FEL beam. This facility is currently undergoing an upgrade. The goal of the DOE funded upgrade of the accelerator complex at the DFELL is to create the capability of producing and delivering γ-ray beams of the intensity, polarization, energy resolution, and energy range required to conduct the proposed research program in photonuclear physics at the HIγS facility. A drawing of the conceptual design of the entire updated complex is shown in Figure 1. The upgrade has two main parts: (1) The development, installation, and commissioning of a 1.2 GeV booster synchrotron injector; and (2) accelerator reconfiguration to accept injection from the booster. An overview of the major components are described below.

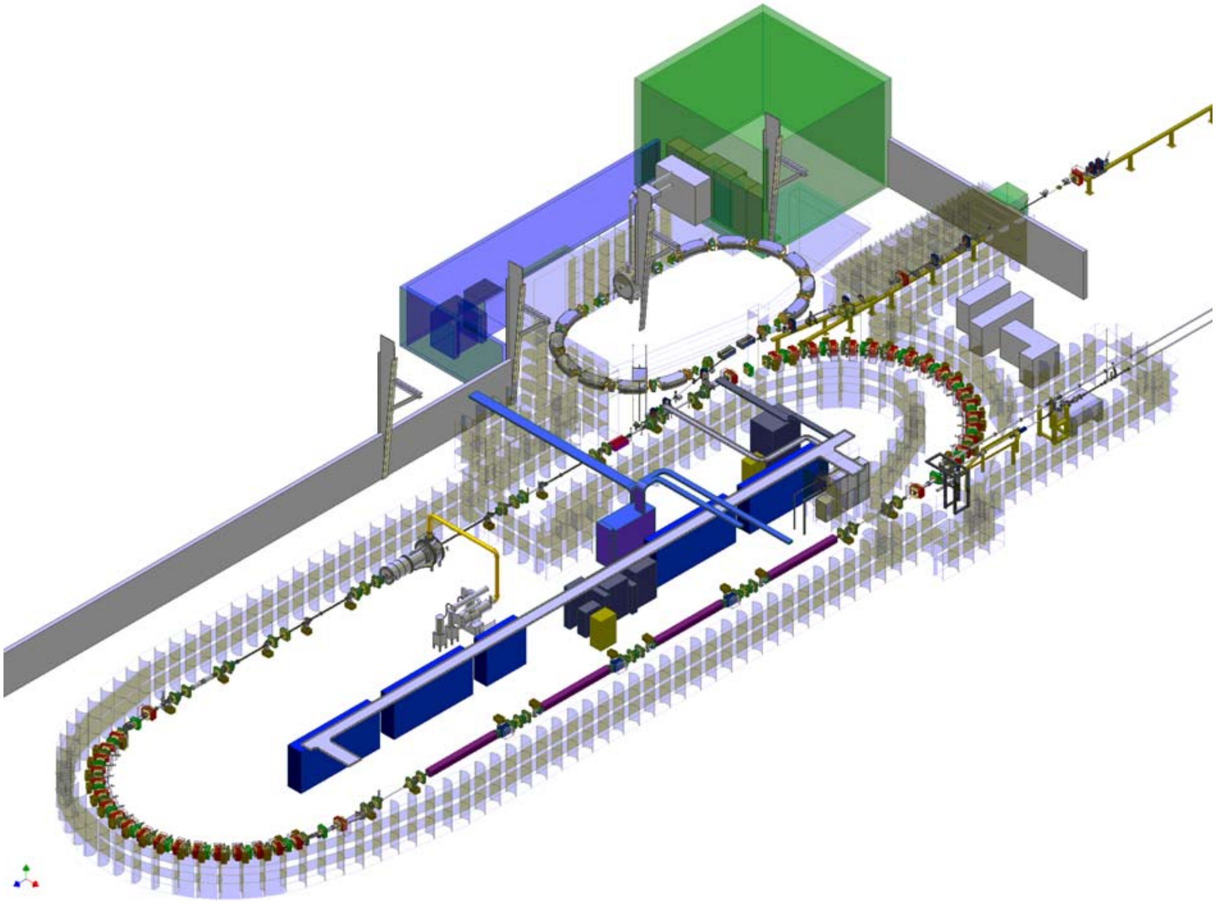


Figure 1. Conceptual design of upgraded accelerator facility for HIγS.

The performance parameters for the storage ring, the OK-5 FEL, and gamma-ray source after upgrade are given in Table 1. This table has been revised in the first quarter of 2004. The actual performance of the gamma-beam critically depends on the electron current capabilities of the storage ring and the realizable intra-cavity FEL power at various wavelengths. In particular, electron beam instabilities and FEL lasing below 190 nm present significant challenges. The challenge on beam instability is being met with the development of a transverse feedback system. The challenge on FEL lasing below 190 nm is being met by our active collaborative research with other laboratories and industry in developing reliable high reflectivity mirrors with radiation resistance in the 190nm to 100nm range.

Table 1. Performance parameters of the HIγS facility.

Storage Ring (demonstrated)	
Operating energy, E_e [GeV]	0.27 – 1.2
Max multi-bunch current (60 bunches) [mA]	270
Max single-bunch current [mA]	21
Typical two-bunch current for γ-operation [mA]	26 – 29
Natural emittance at 1 GeV, ε_x, ε_y, [nm rad]	18, <1
Beam size in OK-4 FEL, σ_x, σ_y, [mm]	0.2 – 0.5, 0.05 – 0.12
OK-5 FEL (projected)	
Tuning range, λ [nm]	126 – 800
Tuning range, E_{ph} [eV]	1.55 – 9.84
E-beam configuration for FEL	8 bunches, 20 mA each
Max average lasing power [W]	> 5
Max average intracavity power [W]	> 500
Linewidth (FWHM) [$\delta\lambda/\lambda$]	10^{-2} – 10^{-4}
Spatial distribution	TEM_{00}
HIγS Upgrade (projected)	
HOM-damped RF Cavity	support 8 bunches, 20 mA each
Booster synchrotron	top-off injection, 0.27 – 1.2 GeV
Single-bunch cycle time [s]	1.25
Multi-bunch cycle time [s]	2.5
Charge to storage ring [nC/s]	> 0.032
Compton γ-ray source (projected)	
E-beam configuration for γ-operation	8 bunches, 20 mA each
Energy of γ-rays, E_γ [MeV]	2 – 158(a)
Total flux [γ/sec]	
(a) No-loss mode (< 20 MeV)	
E_γ = 5 MeV	> 5 x 10^{8}(b)
E_γ = 10 MeV	> 1 x 10^{9}(b)
E_γ = 20 MeV	> 2 x 10^{9}(b)
(b) Loss mode (> 20 MeV)	
E_γ = 21 – 65 MeV	> 2 x 10^{8}(c)
E_γ = 66 – 95 MeV	> 1 x 10^{8}(d)
E_γ = 96 – 158 MeV	> 1 x 10^{8}(e)
Circular & linear polarizations	> 90%
Spatial distribution	pencil-like beam

(a) The maximum gamma energy will be limited by the availability of high reflectivity cavity mirrors at VUV wavelength.

(b) Using cavity mirrors with 99.5% reflectivity. Mirrors in the corresponding wavelength spectrum range and with this level of reflectivity are commercially available.

(c) Using a set of 245 nm mirrors (98.5% reflectivity) and 193 nm mirrors (96% reflectivity). These mirrors are commercially available and have been demonstrated for γ-ray production at HIγS.

(d) Using a set of 157 nm mirrors with 94% reflectivity. These mirrors are commercially available but have not been used for γ-ray production; mirror lifetime development might be necessary.

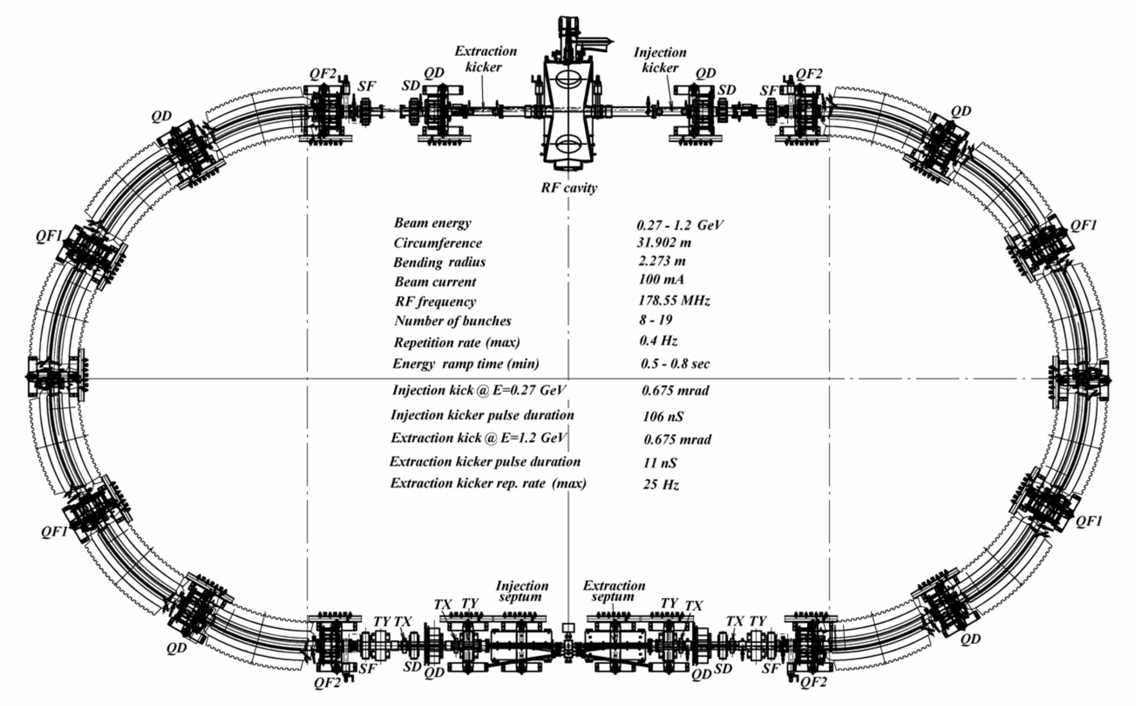
(e) Using a set of 126 nm mirrors with 93% reflectivity, which are under development.

1. Booster Injector

The booster synchrotron is designed to provide full energy injection into the storage ring over a wide energy range from 0.27 to 1.2 GeV. The top-off mode operation of the booster injector will enable continuous operation of the HIγS facility by replenishing the lost electrons in the so-called loss mode at relatively high gamma-beam energies.

The booster synchrotron is designed with the capability of delivering up to 4 nC/sec of electron beam into the storage ring in the top-off mode operation for high flux γ-ray beam production. The existing linac will be used to inject beam into the booster at an energy of 270 MeV. The extraction energy of the booster can vary from 270 MeV to 1.2 GeV. The booster is optimized for single bunch extraction. Using a common 178.5 MHz radio-frequency (RF) source, the booster and the storage ring are fully synchronized. The odd ratio of the harmonic numbers of the booster and ring, 19/64, provides for extraction of any individual electron bunch from the booster into any selected RF bucket of the storage ring.

The racetrack shaped booster is designed with two identical arcs separated by two 6.24 m long straight sections. The straight sections host the RF cavity, injection and extraction kickers, and injection and extraction septum magnets. Each arc consists of six bending magnets with parallel edges, four focusing quadrupoles, and four defocusing quadrupoles. This combination of magnets form three effective quadrupole triplets; one of which, located in the middle of the arc, uses the edge focusing of dipoles. The booster has a double bilateral symmetry. Figure 2 shows the general layout of the booster. Table 2 lists the major parameters of the booster.



Beam energy	0.27 - 1.2 GeV
Circumference	31.902 m
Bending radius	2.273 m
Beam current	100 mA
RF frequency	178.55 MHz
Number of bunches	8 - 19
Repetition rate (max)	0.4 Hz
Energy ramp time (min)	0.5 - 0.8 sec
Injection kick @ E=0.27 GeV	0.675 mrad
Injection kicker pulse duration	106 nS
Extraction kick @ E=1.2 GeV	0.675 mrad
Extraction kicker pulse duration	11 nS
Extraction kicker rep. rate (max)	25 Hz

Figure 2. Layout of the booster synchrotron.

Table 2. Accelerator design parameters of the booster synchrotron.

	single-bunch	multi-bunch
Maximum beam energy [GeV]	1.2	
Injection energy [GeV]	0.27	
Stored beam current [mA]	1.5 - 2	100
Circumference [m]	31.902	
Bending radius [m]	2.273	
RF frequency [MHz]	178.547	
Harmonic number	19	
Nominal operation cycle [sec]	1.2	2.5
Energy rise time, min [sec]	0.55	
At maximum energy E=1.2 GeV:		
Beam emittance ε_x, ε_y [nm·rad]	350/ 15	
Maximum β_x/ β_y/ η_x [m]	25.4/9.4/1.4	
Betatron tunes Q_x/Q_y	2.43/ 0.46	
Momentum compaction factor	0.153	
Natural chromaticity C_x/C_y	-1.7/ -3.7	
Damping times $\tau_{x,y}$/ τ_s [mS]	3.16 / 1.58	
Energy loss per turn [keV]	80.7	
Energy spread σ_E/E	$6.8\text{x}10^{-4}$	

2. Storage Ring Modifications

The upgrade of the HIγS facility includes significant modifications and upgrades of the existing storage ring light source. Two major storage ring upgrade projects are: (1) a new north straight section (NSS) lattice for booster injection, and (2) a high-order mode (HOM) damped radio frequency (RF) cavity system.

Presently, a linac injector is used to deliver electron beams with an energy of 270 MeV directly into the storage ring. The HIγS upgrade to the booster injector requires modifications to the storage ring injection lattice in the north straight section. This new injection scheme requires the relocation of the septum magnet downstream so that the injected beam from the booster can be accepted into the storage ring. Moreover, the injection with a booster requires the development of high voltage kickers for electron beams with energies up to 1.2 GeV. In addition, the modified NSS lattice must also accommodate the 3 m long HOM-damped RF cavity and insertion devices for future light sources.

The HOM-damped RF cavity supports the stable multi-bunch operation modes which are essential for higher gamma-flux. Very limited multi-bunch capabilities are available with the existing RF system without HOM damping; the only stable gamma-ray operation mode at the present time is a two-bunch operation with two symmetrically placed bunches in the storage ring. It is expected that with tuning, the new HOM-damped RF cavity would allow additional stable symmetric 4-bunch and 8-bunch operations, which will result in a higher stored current and more than one collision point, consequently, a higher gamma flux.

2.1. Modified North Straight Section Lattice

The present 34-m long NSS is an asymmetric lattice which hosts magnetic optics for injection, the RF cavity, an undulator light source, and various beam diagnostics. These functions need to be preserved in the modified NSS lattice for the HIγS upgrade. The basic requirements for the new NSS lattice are summarized as follows:

- high injection efficiency with the booster injector;
- minimizing the kicker strength for better reliability;
- accommodation of a 3-m long HOM-damped RF system;
- a bilaterally symmetric lattice for better beam dynamics and flexibility in lattice tuning;
- accommodation of existing beam diagnostics;
- reuse of existing hardware to save costs (quads, septum, etc.); and
- accommodation of future insertion devices.

For the booster injection, both vertical and horizontal injection schemes have been considered and studied. After careful evaluation of the available apertures and the required kicker strengths, we have chosen the horizontal injection scheme for the storage ring.

As required for the HIγS upgrade, the new north straight section lattice has been designed with bilateral symmetry and zero dispersion. A total of eighteen (18) quadrupoles are used in this 34-m long lattice. The first part of the lattice, sectors N01 to N06, is dedicated to injection, the HOM-damped RF cavity, and a future insertion device, as shown in Figure 3. The second part of the lattice, sectors N07 to N11, is dedicated to various diagnostics systems and a second future insertion device, as shown in Figure 4. The bilateral symmetry of the new NSS allows flexibility in lattice tuning. This is very important as this lattice has to provide a number of different functions. In particular, a flexible lattice allows adjustments to the injection scheme and betatron tune compensations for future insertion devices.

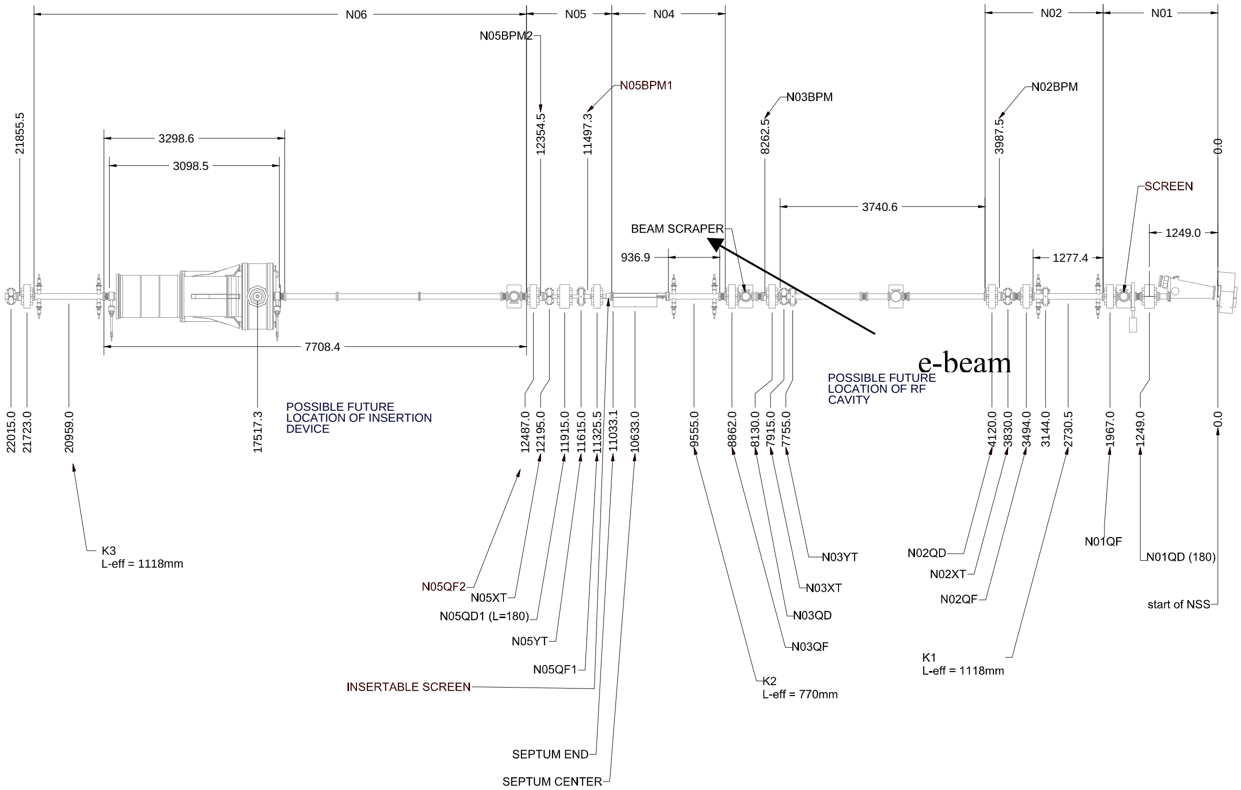


Figure 3. First half (N01-N06) of the lattice for the modified NSS.

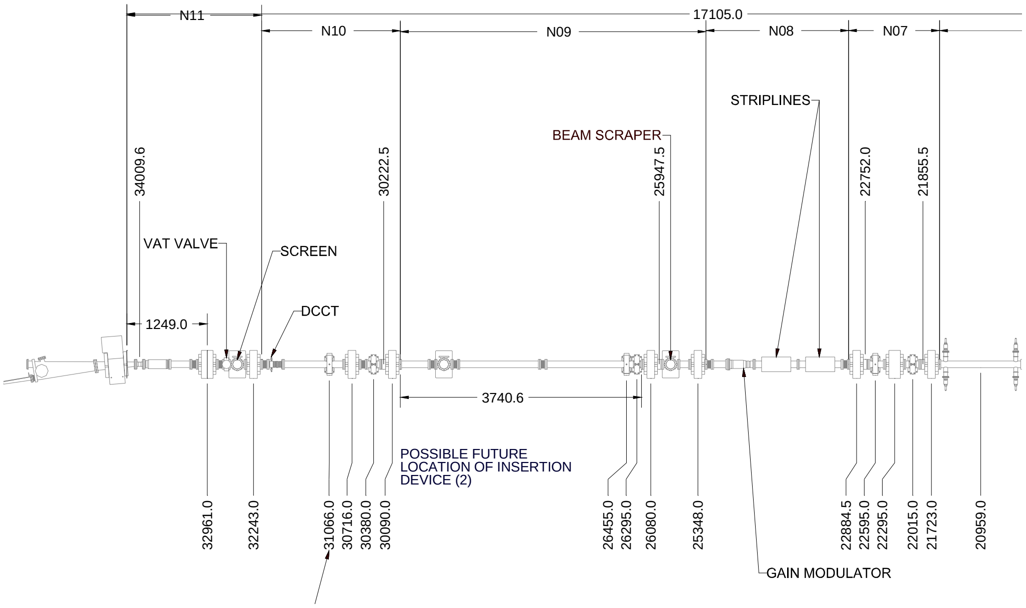


Figure 4. Second half (N07-N11) of the lattice for modified NSS.

2.2. Radio-Frequency System with High Order Mode Damping

The new radio frequency (RF) system consists of a high-order-mode (HOM) damped cavity, a larger output power transmitter, and the necessary control and interlock electronics. A general layout of this system is shown in Figure 5. The cavity will be installed in the north straight section of the storage ring and the transmitter will be installed inside the ring near the cavity.

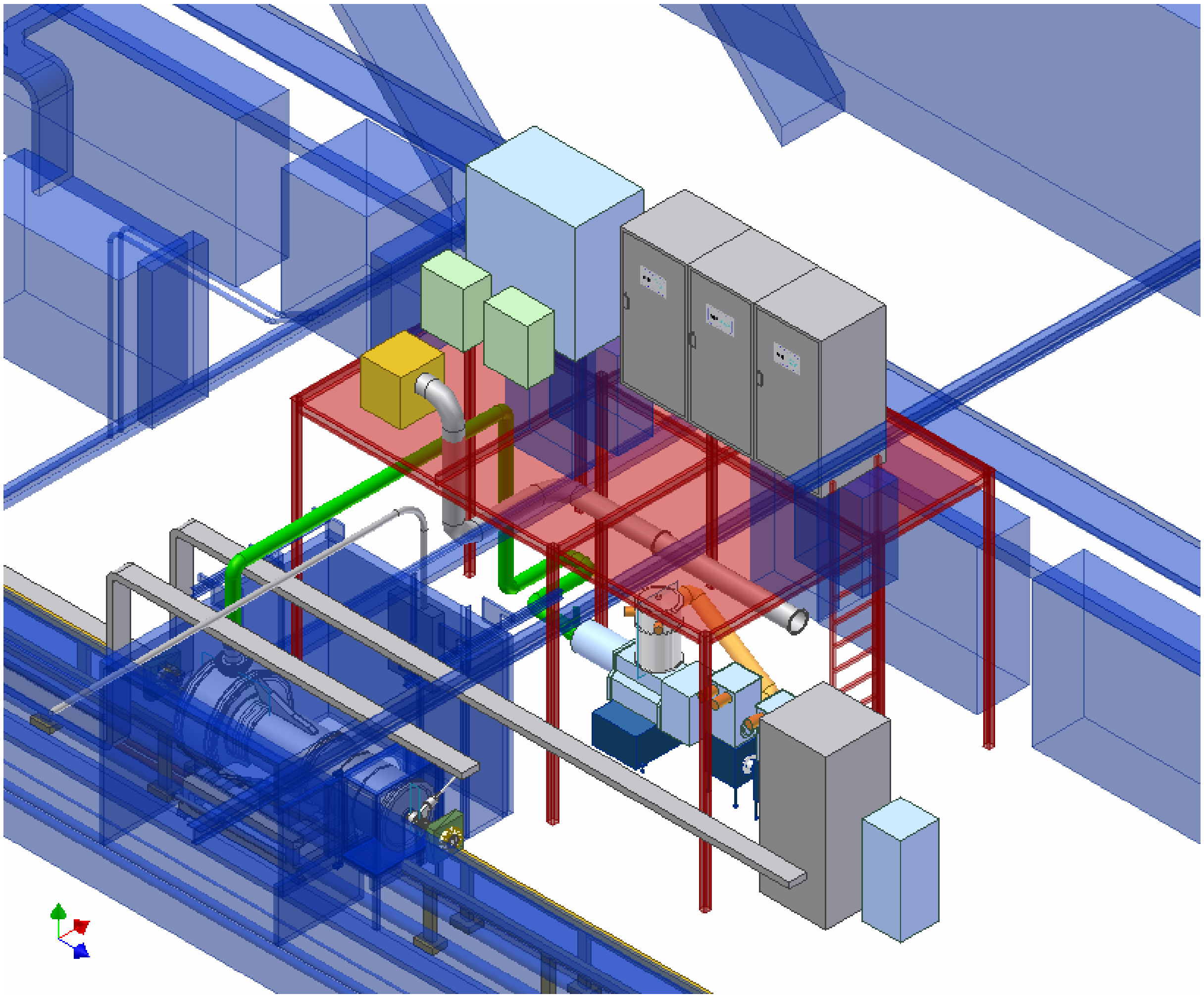


Figure 5. General layout of the HOM-damped RF system in the NSS.

The substantial reduction in the amplitudes of the HOMs in the new RF cavity should significantly reduce multi-bunch instabilities and allow more beam bunches to be stored in the ring with good stability, therefore increasing the multibunch capabilities of the storage ring. Symmetric 4-bunch and 8-bunch operation will result in multiple collision points to boost the gamma flux. The combination of the OK-5 FEL and the new RF system provides significant improvement in the gamma-beam capabilities of the Duke storage ring.