Technical Aspects of SESAME

Maher Attal (*Technical Director of SESAME)*
On Behalf of SESAME Technical Sector

SESAME is the only synchrotron light source in the region

There are more than 50 synchrotron light sources in the world, however SESAME is only one in the Middle East and the region.

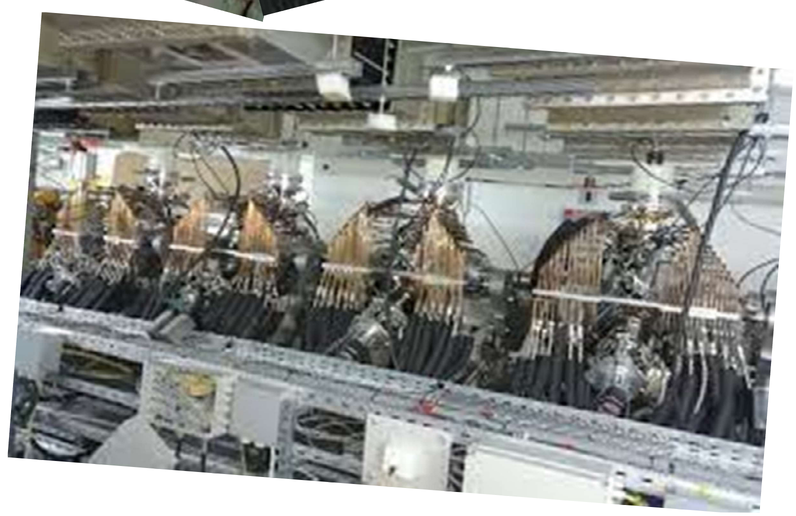
SESAME as a synchrotron light source

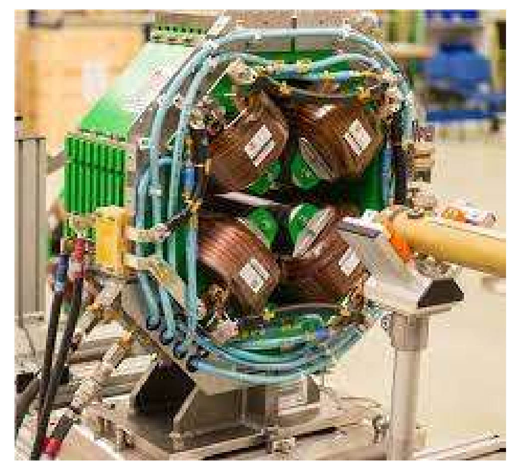
- SESAME produces a ***synchrotron light (radiation)***:

  A very intense light emitted by free electrons moving at high speed (close to speed of light) whenever their trajectory is deflected.

- Synchrotron light has many valuable features that make it a unique for the scientific research.

SESAME from Technical Point of View

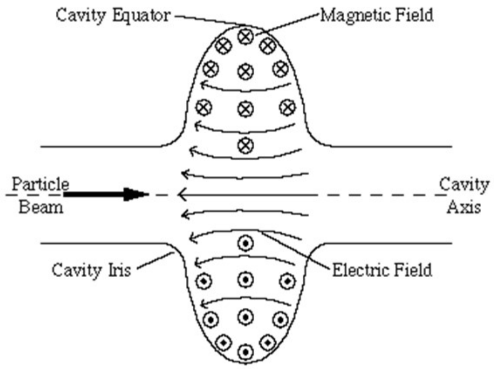




SESAME is an electron accelerator

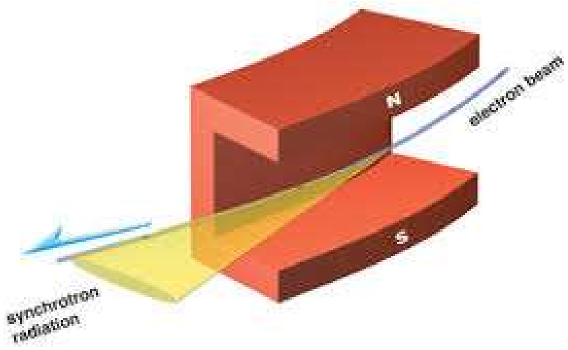
To produce synchrotron light, SESAME machine (Accelerators) do the following:

- Extract electrons from the source (LaB6 crystal) (Using ~ 4μs voltage pulse)



- Increases the electrons' speed to an **ultra-relativistic value** using Radio Frequency (RF) system. (*the microwave electric component is used to accelerate electrons*)

- **Deflects trajectory** of the relativistic electrons (central acceleration) using magnetic field.



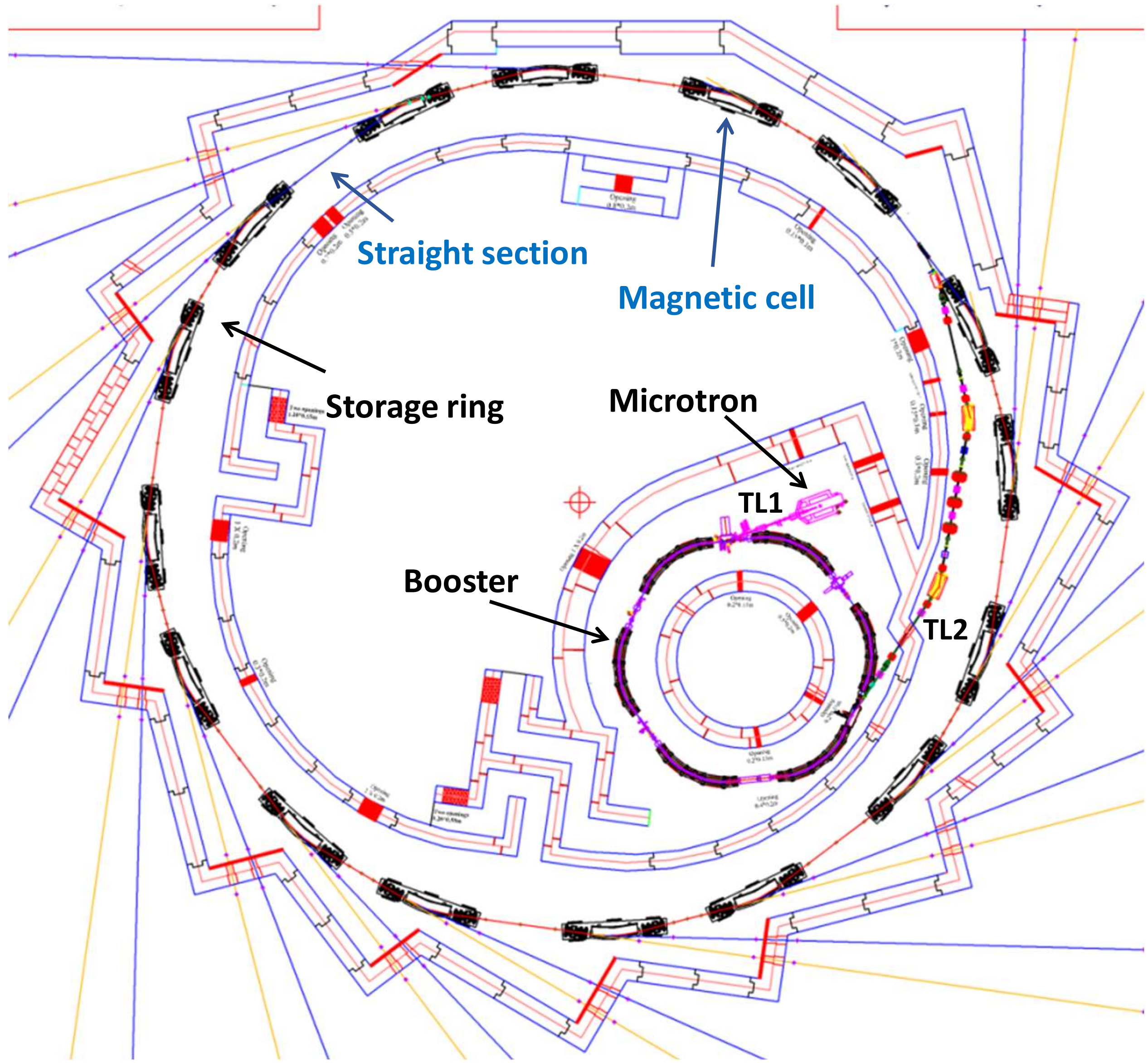
Other systems required to do the job

- **Vacuum system**: reduces the gas molecules in the way of the rotating e-beam which offers it more stability and longer lifetime.
- **Control system**: provides safe, synchronized, and controlled machine operation.
- **Diagnostics system**: characterizes the different parameters of e-beam like position, size, shape, and current value.
- **Power supplies system**: feeds the magnetic system with highly stable electrical power
- **Cooling system**: absorbs the power load on the vacuum chamber components, magnets, …

Layout of SESAME machine (Accelerators)

SESAME machine is composed of:

- 800MeV Injector
  - Microtron
  - Booster
  - Microtron-Booster transfer line (TL1)
- Booster-Ring transfer line (TL2)
- 2.5GeV storage Ring

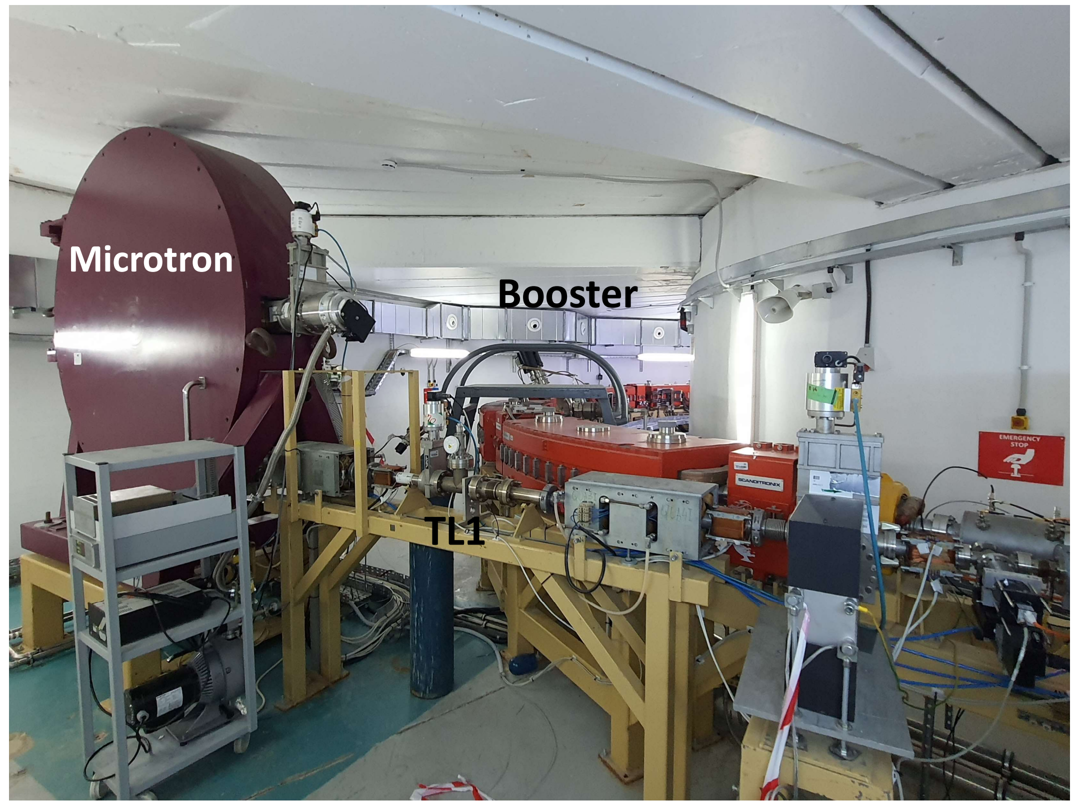


The 800MeV SESAME Injector

Originally from BESSY I machine. It composes:

- 20 MeV classical Microtron
  - Electrons emitted and accelerated to 20MeV
  - RF source is Magnetron (f = 3GHz)
  - Magnetic flux = 0.112 T
  - Accelerated electrons are sent to Booster through TL1.

- 800 MeV Booster synchrotron
  - 38.4m circumference
  - composed of 6 magnetic cells (2 dipoles + 3 quadrupoles each)
  - RF system source is SSA (f = 500MHz)
  - Accelerates electrons to 800MeV and sends them to storage ring through TL2.

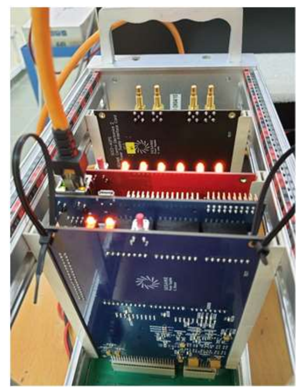


Upgrades on the Injector

- *All critical parts of the Microtron system are upgraded to new and modern ones*

The control rack replaced with a new PLC-based one

The auxiliary gun power supply replaced with a new one ***designed in-house***



The controller is completely SESAME design

The Thyratron-based Modulator replaced with two new SSMs (donated by INFN & PSI)

- *Booster injection septum is more stabilized and Microtron & TL1 old power supplies replaced with new ones*

Booster injection septum is refurbished and brought to higher level of stability

All power supplies of Microtron and TL1 replaced with new and modern ones

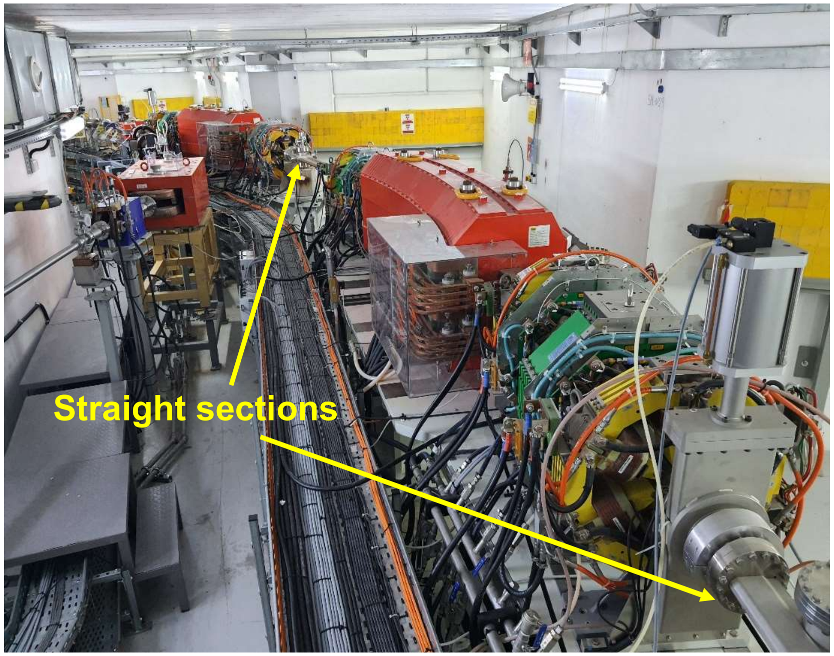
As a result,

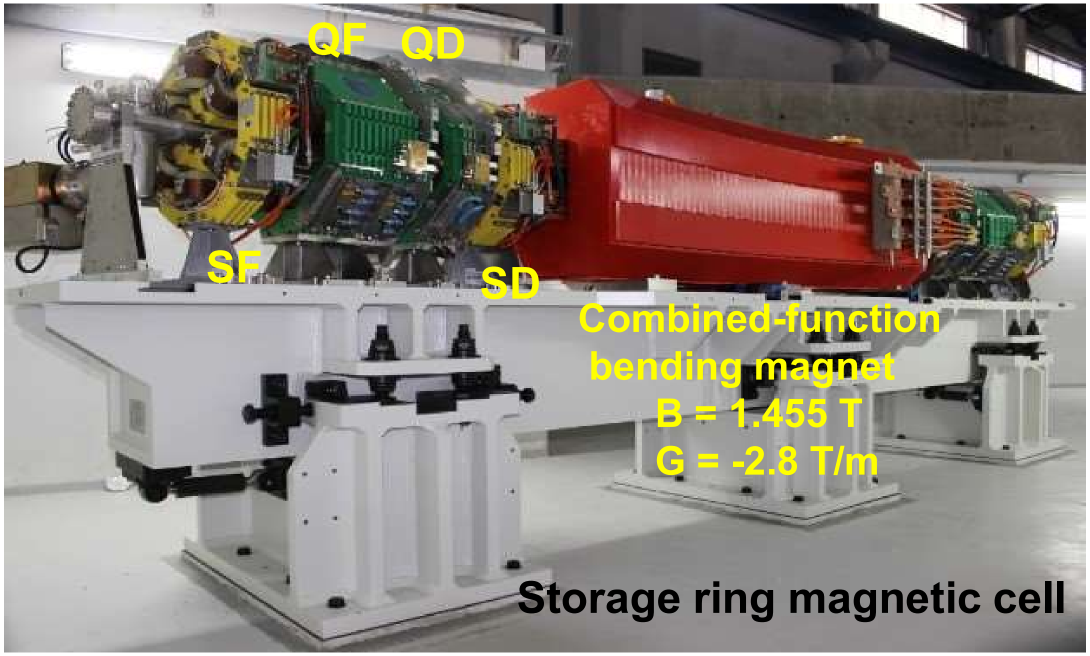
- Microtron system is at higher level of reliability and performance
- Higher average current in the booster
- Faster filling of the storage ring

The 2.5 GeV Storage Ring

- Storage ring magnetic structure is compact offering 16 cells & 16 straight sections in a 133.2m circumference.
  (*Bending magnets are combined-function ones & all correctors are included in the sextupole magnets*)

- The magnetic structure type (DBA) with combined-function dipoles could offer an emittance of 26nm.rad in such short circumference.

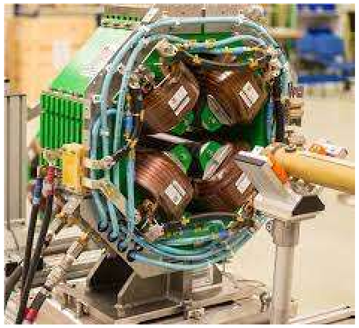




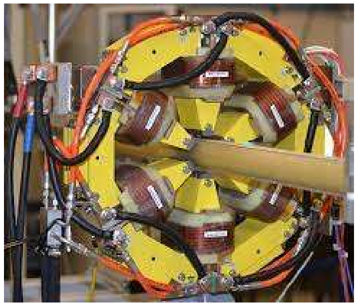
SESAME member countries joined construction of storage ring magnets

- Storage ring magnets are constructed through CESSAMag project in the frame of SESAME-CERN/EU collaboration.

- Bending magnets:
  - constructed by TESLA (UK)
  - magnetically measured at ALBA light source (Spain).



- Quadrupole magnets:
  - their bodies constructed by Elytt (Spain)
  - their coils constructed by STS (**Turkiye**)
  - tested and magnetically measured at CERN.



- Sextupole magnets:
  - their bodies constructed by CNE (**Cyprus**) & HMC-3 (**Pakistan**) (*equally shared*).
  - their coils constructed by SEF (France)
  - tested and magnetically measured at CERN

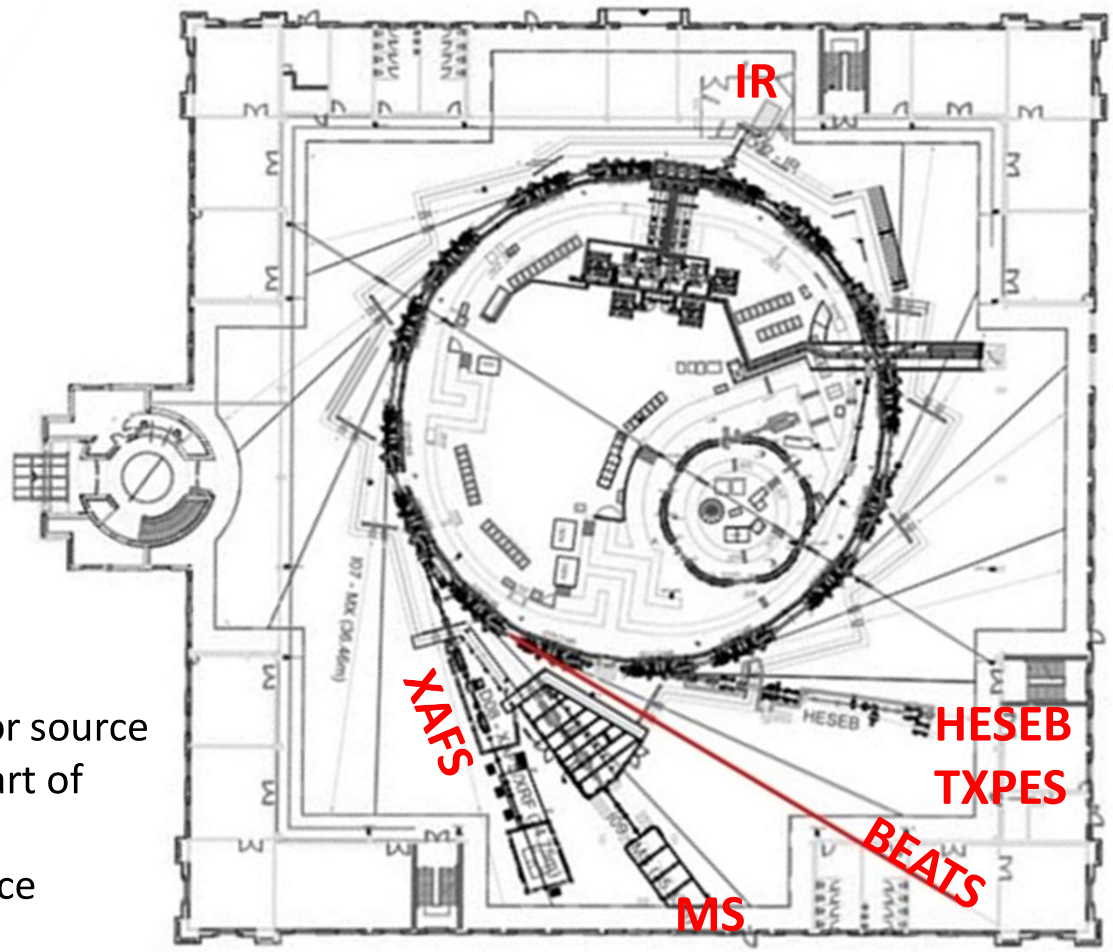
SESAME member countries joining construction of beamlines

SESAME

SESAME beamlines

- **Three operational beamlines:**
  - **XAFS/XRF beamline**: A bending magnet source
  - **IR beamline**: A bending magnet source
  - **MS/XPD beamline**: A 1.38T wiggler source

- **Three beamlines under commissioning/ construction:**
  - **HESEB** (**Soft X-ray) beamline:** APPLE II undulator source
  - **TXPES (Soft X-ray) beamline:** shares the first part of HESEB beamline.
  - **BEATS** (**Tomography beamline):** A 3T 3PW source



SESAME member countries joining construction of beamlines

- **HESEB beamline:** HESEB Helmholtz-SESAME Soft X-Ray Beamline für SESAME

- Funded by **Helmholtz Gemeinschaft** institution**.**

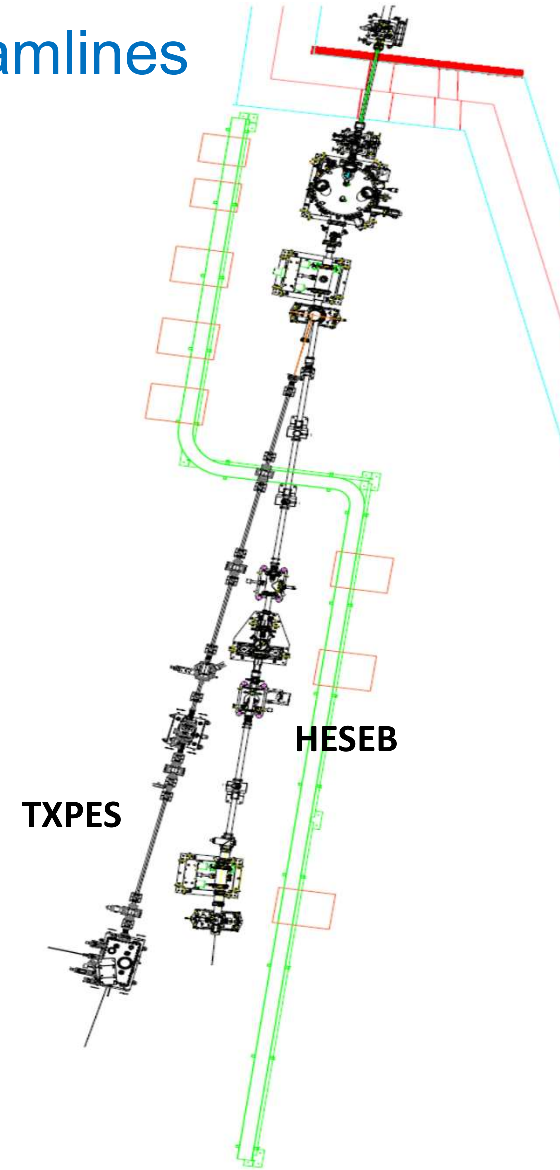
- The project is done in collaboration with Helmholtz facilities:

DESY. JÜLICH FORSCHUNGSZENTRUM HZB Helmholtz Zentrum Berlin HZDR KIT

- **TXPES beamline:** in collaboration with many **Turkish institutions**

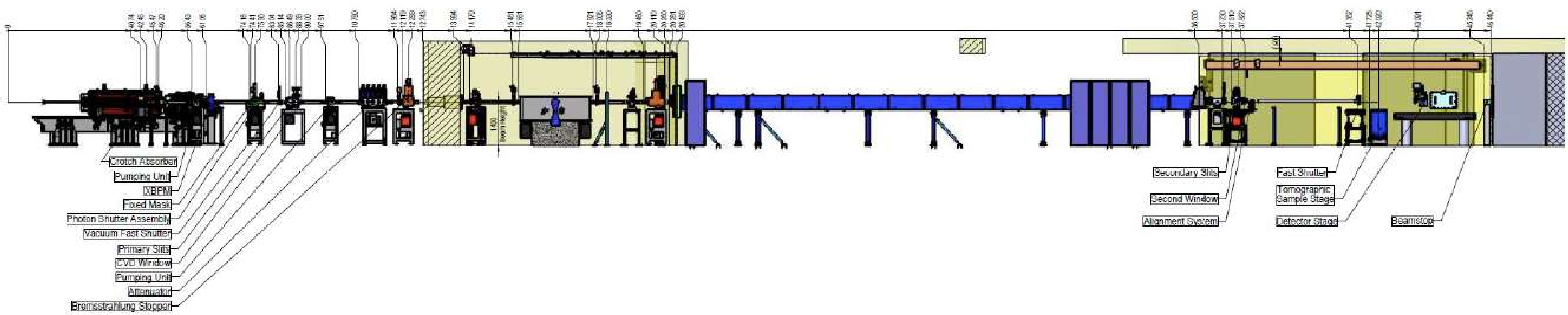
TXPES TENMAK İhsan Doğramacı Bilkent University TARLA Turkish Accelerator and Radiation Laboratory in Ankara KOÇ UNIVERSITY

- Funded by **Turkiye**.



BEATS (BEAmline for Tomography at SESAME) beamline

- Funded by the **<u>EU's H2020</u>** framework program under grant agreement n°822535
- The project is done in collaboration among many facilities:
- Expected to be ready for users by end 2023.



Photon sources at SESAME

The bending magnet (B = 1.455T, G = -2.8 T/m)

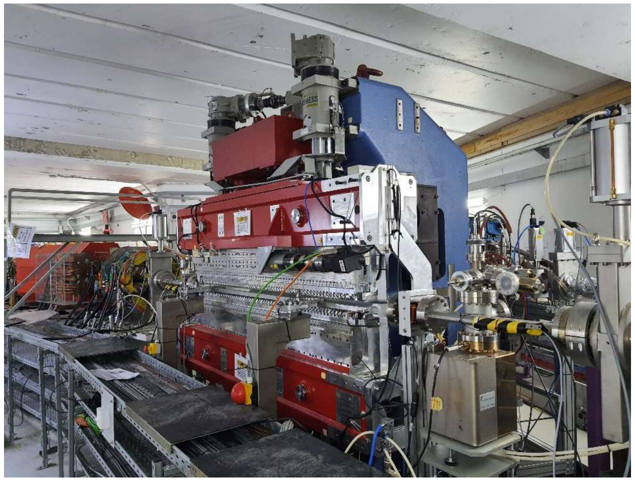
- The basic photon source in the storage ring
- A photon source for XAFS and IR beamlines.
- Delivers a wide photon spectrum from IR – hard X-ray with critical energy = 6keV.
- Electron beam size (@6.5deg) σ_x / σ_y = 232 / 81 μm

Multipole wiggler (B = 1.38T @ min. gap = 12mm)

- Photon source of material science powder diffraction beamline.
- It is composed of 33 periods of 60.5mm length and delivers a hard X-ray photon beam
- Electron beam size at middle of wiggler σ_x / σ_y = 826 / 21 μm

Photon sources at SESAME

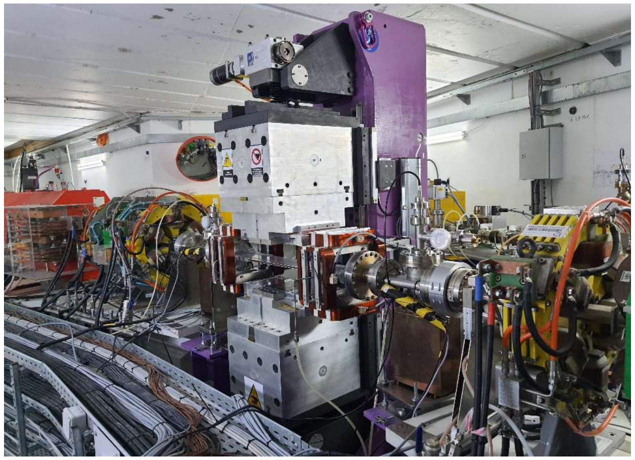
APPLE II-type undulator (B = 1T @min gap = 13.4mm & zero shift)



- Photon source of HESEB & TXPES beamlines.
- It has different operation modes (horizontal, circular, and vertical) delivering a soft X-ray photon beam of a tunable polarization
- Electron beam size at middle of undulator σ_x / σ_y = 826 / 21 μm

New: commissioned in June, 2022

Three-pole wiggler (B = 3T @min gap of 11.15mm)



- Photon source of BEATS beamline
- Delivers a single source hard X-ray photon beam
- Electron beam size at middle of wiggler σ_x / σ_y = 821 / 14 μm

New: commissioned in September, 2022

First Accelerator in the World Powered by Renewable Energy

- A 6.5MW solar power plant funded by the European Union (US$ 7.143 M)
- Yearly saving of 6.0 – 7.5 Tons of CO_2

SESAME Vacuum System

By Abid Ur Rehman, Vacuum group

Vacuum Pumps

SESAME

Diaphragm

Scroll

<u>Roughing Pumps</u>

Low Vacuum

Pressure Range: atm. to 10^{-3} mbar

<u>Turbomolecular Pumps</u>

High Vacuum

Pressure Range: 10^{-3} to 10^{-10} mbar

<u>Ion Pumps</u>

Ultra High Vacuum

Pressure Range: 10^{-7} to $<10^{-10}$ mbar

Vacuum Valves/ Components

All-Metal Angle Valves

All-Metal Gate Valves

Vacuum Components

Vacuum Gauges & Controllers

Low Vacuum Gauges
(atm. to 10^{-3} mbar)

High/Ultra High
Vacuum Gauges
(10^{-3} to 10^{-11} mbar)

Full Range Gauges
(atm. to 10^{-9} mbar)

Gauge Controllers

Ion Pump Controllers

Vacuum Leak Detection & RGA

Helium Leak detector

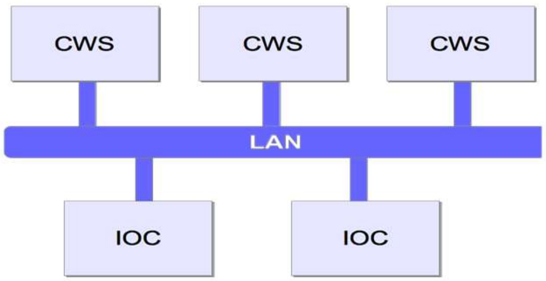
Helium Leak Detector

Residual Gas Analyzer (RGA)

SESAME Control System

By A. Abbadi, Control group

- SESAME control system utilizes ***Experimental Physics and Industrial Control System*** (**EPICS**) toolkit for both Machine and Beamlines.

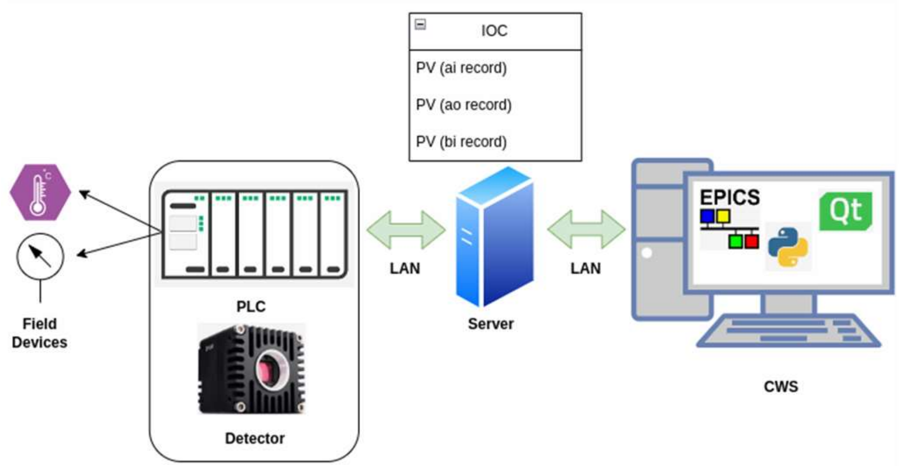


EPICS-based control system has basic components:

- **IOC** (Input/Output Controller): serves as the I/O server, and acts as a middle layer between various devices (instruments, sensors, detectors, ..) and other EPICS tools and clients (GUI, Python script, MATLAB script, ..)

- **CWS** (Client WorkStation): a computer (or server machine) that can run various EPICS tools and client applications.

- **LAN** (Local Area Network): a standard Ethernet-based (or wireless) communication network that allows the IOCs and CWSs to communicate.



Reference: https://docs.epics-controls.org/

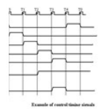
- Control system allows: access, monitor and control over the different devices from computers (workstations) located in the accelerators' control room and beamlines' control hutches.
- The role of control system can be summarized as the following:

Accelerators' Control

- Manages operation of the accelerators (for example, it controls Radio Frequency (RF) system, magnets, beam diagnostics system, ...etc)

Beamlines' Control

- Ensures the control over beamlines' components, such as mirrors, slits, monochromators , and detectors.



Timing System

- Synchronizes the operation of different accelerators and triggered subsystems.

Safety Systems

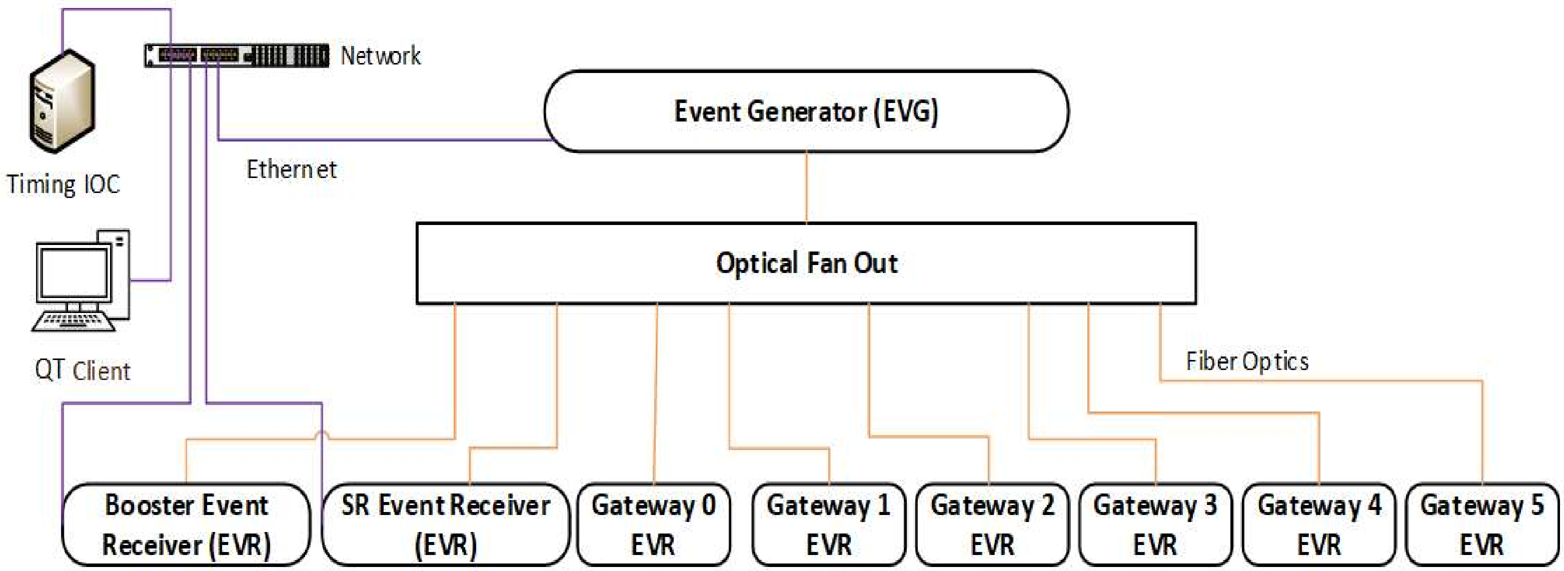
- The Personnel Safety System (PSS) controls the access into the shielded areas for radiation protection.
- The Machine Protection System (MPS) monitors various parameters, such as vacuum levels, temperature, water flow and triggers appropriate actions to protect the machine.

Graphical User Interface

- It offers a friendly graphical user interfaces (GUIs), for scientists and operators to interact with the beamlines and machine components.

Timing System

It generates and distributes hardware trigger signals and synchronization clocks around the accelerator facility to control the injection, acceleration, extraction, and any triggered equipment.



System structure:

- VME Based Event Generator/Receiver System.
- Signal distribution via fiber-optic links.
- 500 MHz reference clock (Master Oscillator).

Features and Functions:

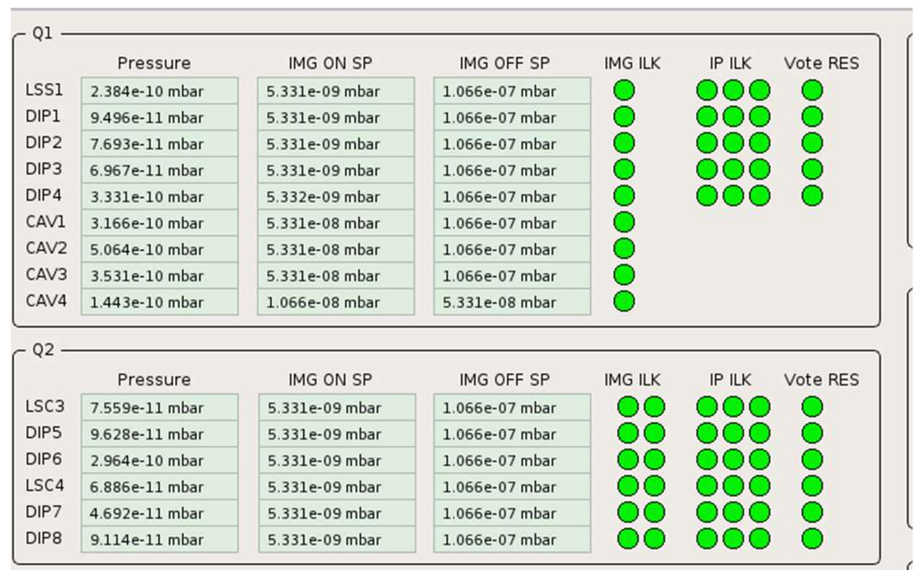
- Provides highly stable reference (clocks).
- Synchronization of different subsystems.
- Controls Beam Injection and Extraction.

Safety system - Machine Protection System

Machine Protection System (MPS) is implemented using SIEMENS S7-300 PLCs

It protects machine components from abnormal conditions:

- Low water flow
- High temperature
- High gas pressure (or bad vacuum)
- Large deviation in e-beam position (> ± 1mm)
- Protects insertion devices against hazardous motion
- Controls the photon shutters in case of an emergency.



Q1

	Pressure	IMG ON SP	IMG OFF SP	IMG ILK	IP ILK	Vote RES
LSS1	2.384e-10 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP1	9.496e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP2	7.693e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP3	6.967e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP4	3.331e-10 mbar	5.332e-09 mbar	1.066e-07 mbar			
CAV1	3.166e-10 mbar	5.331e-08 mbar	1.066e-07 mbar			
CAV2	5.064e-10 mbar	5.331e-08 mbar	1.066e-07 mbar			
CAV3	3.531e-10 mbar	5.331e-08 mbar	1.066e-07 mbar			
CAV4	1.443e-10 mbar	1.066e-08 mbar	5.331e-08 mbar			

Q2

	Pressure	IMG ON SP	IMG OFF SP	IMG ILK	IP ILK	Vote RES
LSC3	7.559e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP5	9.628e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP6	2.964e-10 mbar	5.331e-09 mbar	1.066e-07 mbar			
LSC4	6.886e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP7	4.692e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			
DIP8	9.114e-11 mbar	5.331e-09 mbar	1.066e-07 mbar			

Safety system - Personnel Safety System

PSS Functions

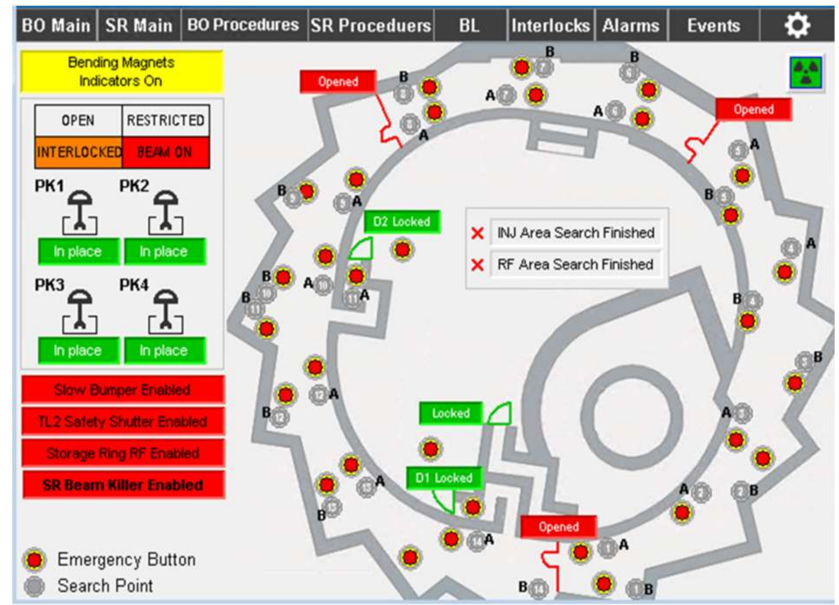
Personnel evacuation procedure from radiation area before accelerator operation

Audible and visual warning

Protect people from entering the radiation area during operation

Shut off the e-beam in emergency case.

Shut off e-beam when a high radiation detected in occupied area (Signal from radiation monitors)



Human Machine Interface (HMI) provides real-time information on various aspects (status of emergency buttons & search buttons, tunnel status, personal keys status, doors status)

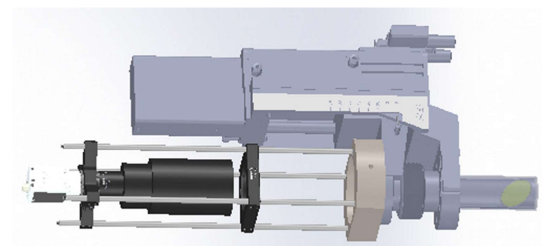
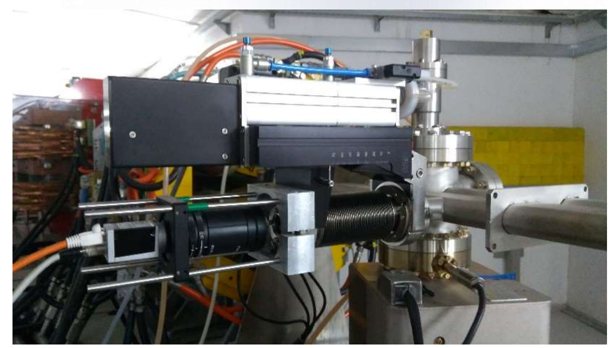
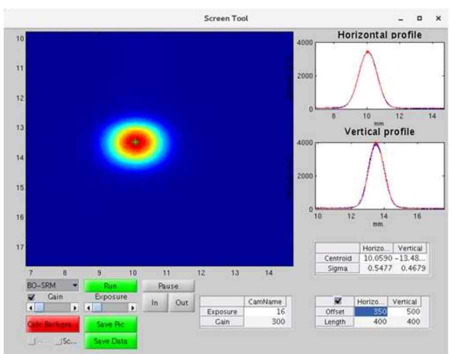
SESAME Diagnostics System

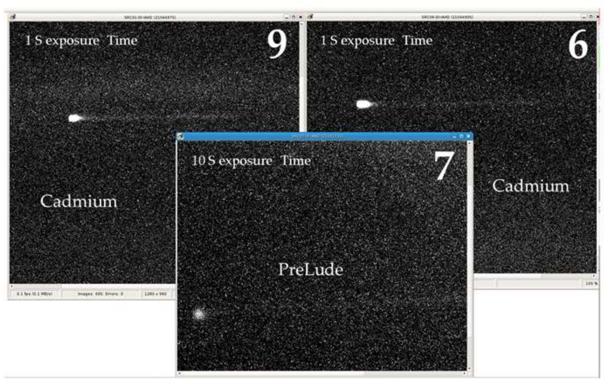
By H. Al-Mohammad, Diagnostics group

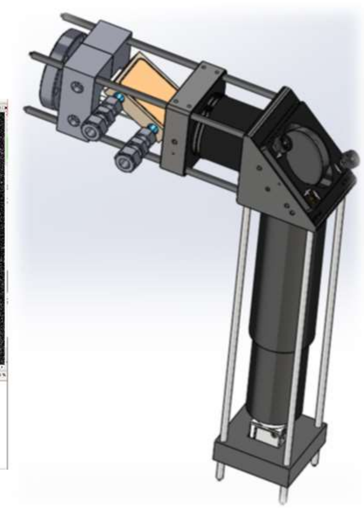
Florescent / Scintillator Screens

- Fixed on Pneumatic and stepper motor actuators
- Screens used: Al_2O_3, $CdWO_4$ (Cadmium Tungstate), YAG:Ce, Phosphor screens P43, PreLude
- The cameras used:
  - CCD (Charged Coupled Device) camera
  - CMOS (Complementary Metal-Oxide Semiconductor) PoE HW triggered camera (1/3” sensor 3.75x3.75um pixel size)





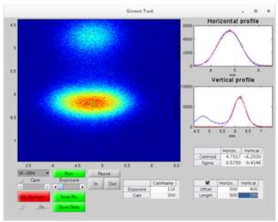


SESAME

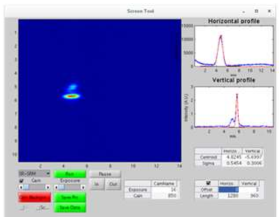
Beam Profile Measurement

- **Visible light method**: by **dirt imaging** and **interferometry** method.

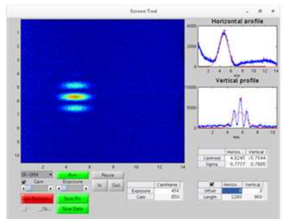
  Photon beam extracted using in-vacuum mirror.



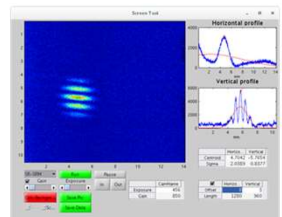
Direct Imaging ND(1)
10% 126mA 2.5GeV ROI



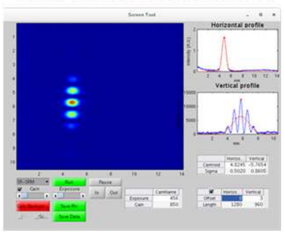
Direct Imaging ND(0.5)
32.62% 35mA 2.5GeV



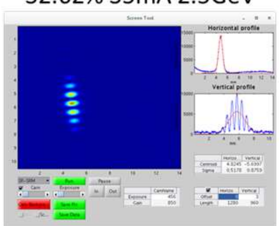
D-Slit Holes 3mm
35mA 2.5GeV



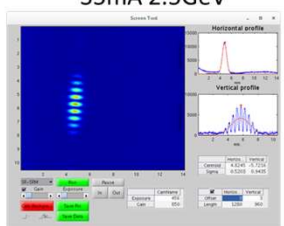
D-Slit Holes 4mm
35mA 2.5GeV



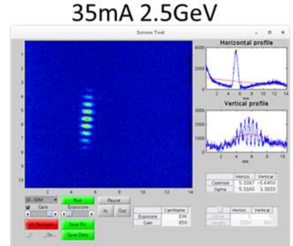
D-Slit Slot 3mm
35mA 2.5GeV



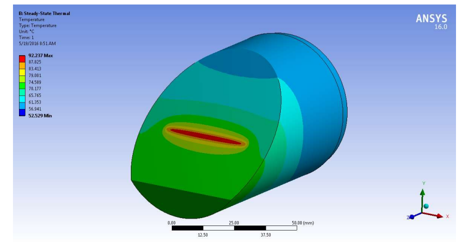
D-Slit Slot 4mm
35mA 2.5GeV

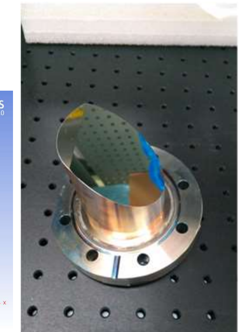


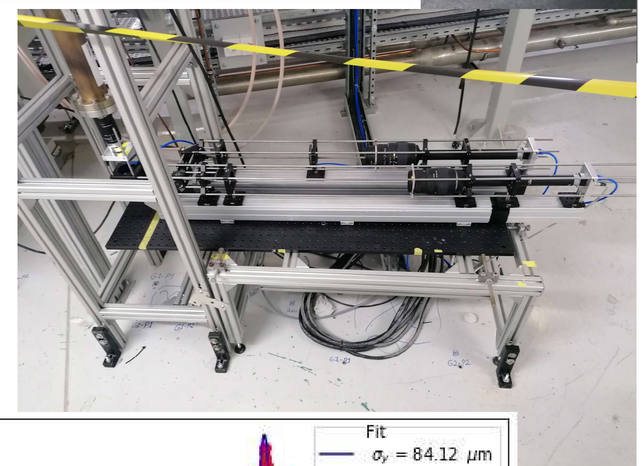
D-Slit Slot 5mm
35mA 2.5GeV

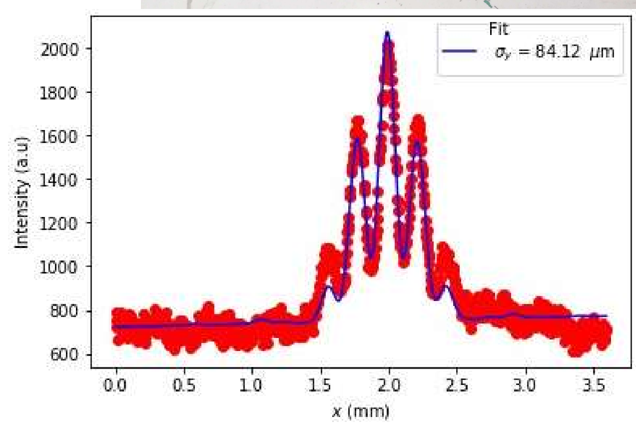


D-Slit Slot 5mm
6mA 0.8GeV





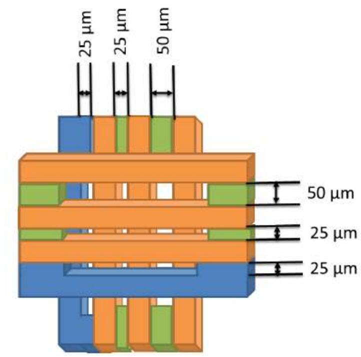


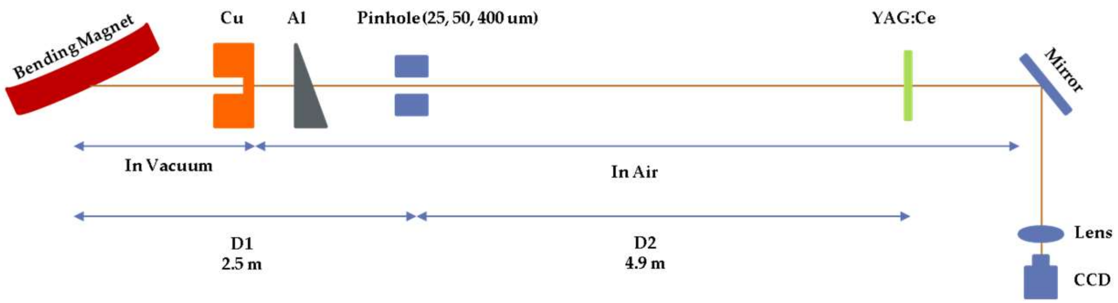


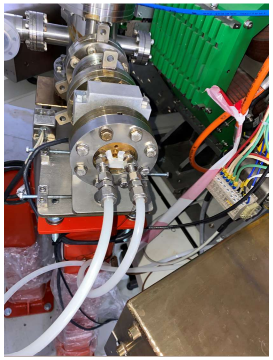
- Measured vertical beam size ~ 84µm (theoretical value ~ 81µ)

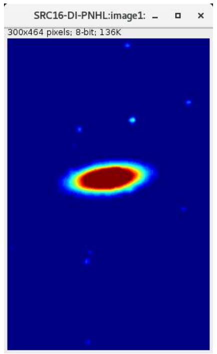
Beam Profile Measurement

- **X-ray method**: using a pinhole camera with very small hole sizes *10*10µm - 400*400µm* (the *25*25µm* adopted for operation).



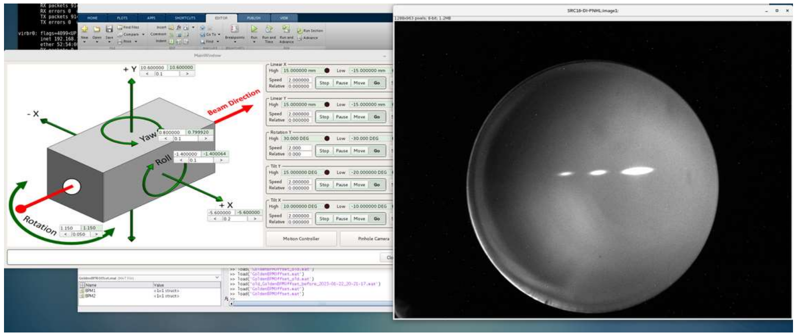






- The pinhole assembly controlled by 5 degree transition stage with micro-stepping motor.

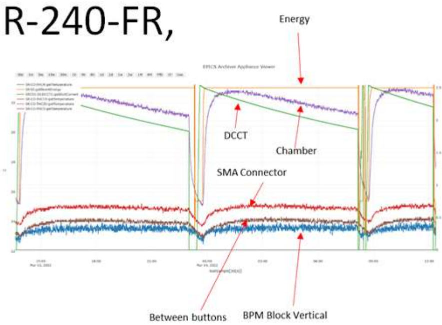
- The measured vertical beam size ~ 76µm.

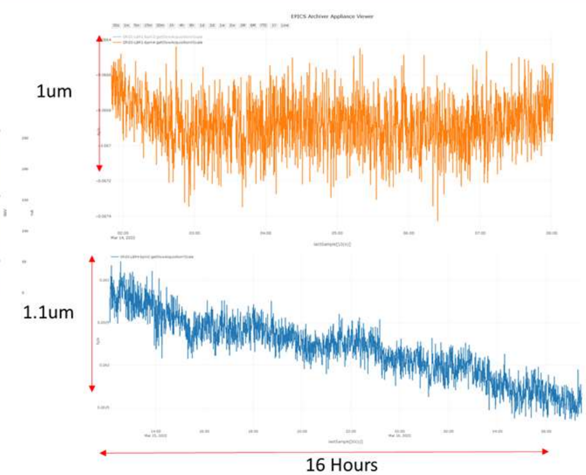


Beam Position Measurement

- Done using beam position monitor (BPM) connected to advanced electronics, **Libera Brilliance+,** based on µTCA.0 modular technology (*Each Libera device hosts up to 4 BPM modules*).

- **Different types of data obtained**: Raw ADC acquisition, turn-by-turn acquisition (2.25MHz), slow acquisition (10Hz) to fast acquisition (10kHz).
- **Fast acquisition (FA) data (10kS/s)**: provided through inserted GDX module.
- **Fiber connection between instruments**: offers fast data exchange.
- **Well calibrated coaxial cables**, with low attenuation LMR-240-FR, with phase matching.
- **Extremely low temperature drift (RMS)**: 0.2 µm/C for slow data, 0.5µm/C for turn-by-turn, and 0.07µm/C for FA.

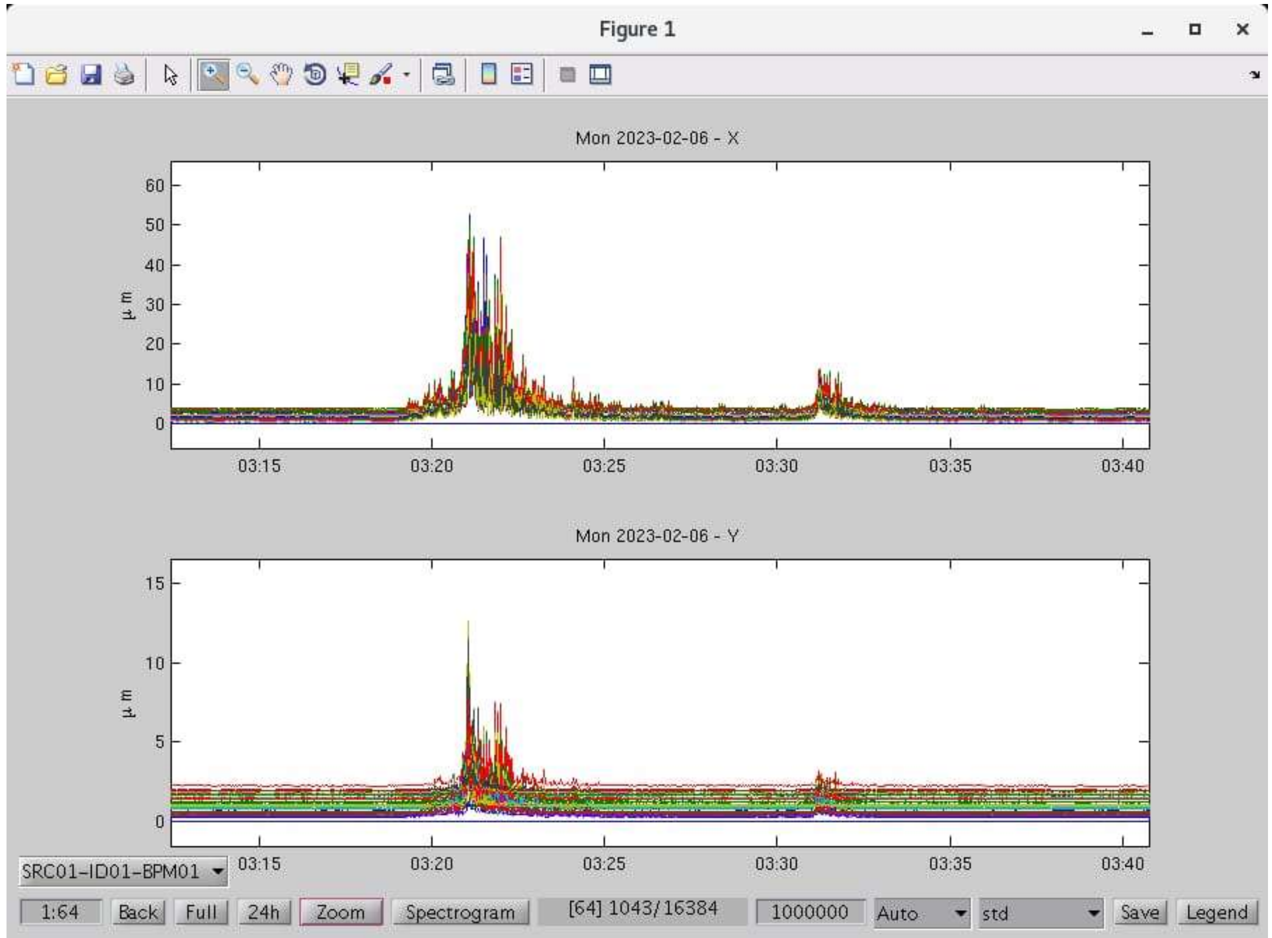




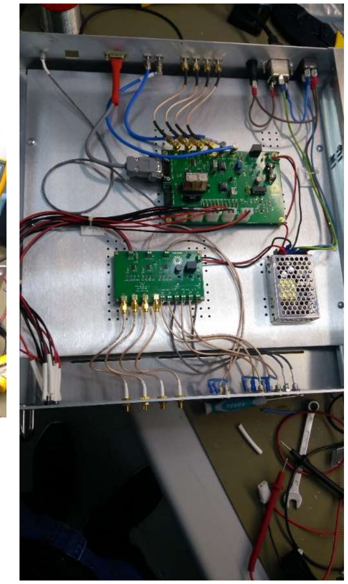
Beam Position Measurement

- Beam position measured with a resolution **1μm**

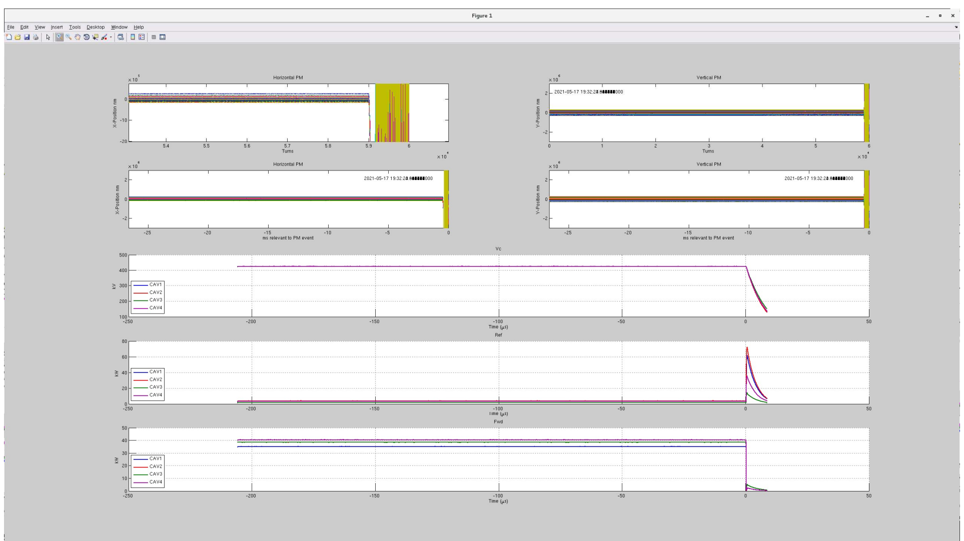
- Very sensitive to vibration: Turkish earthquake detected by our BPMs.



Hardware Fast Orbit Interlock Built in-House

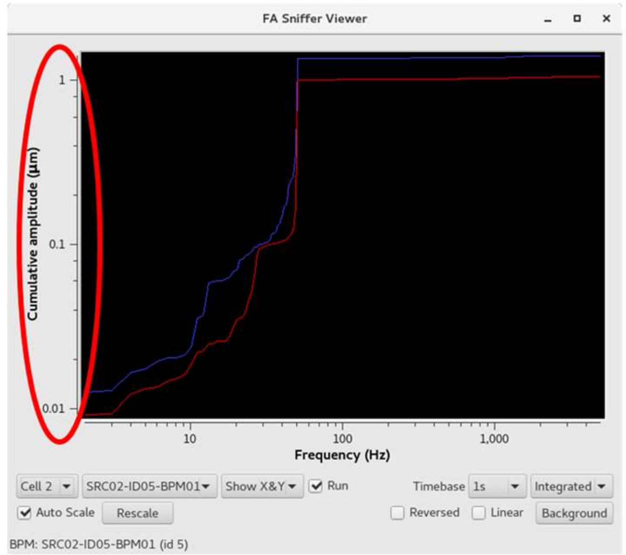


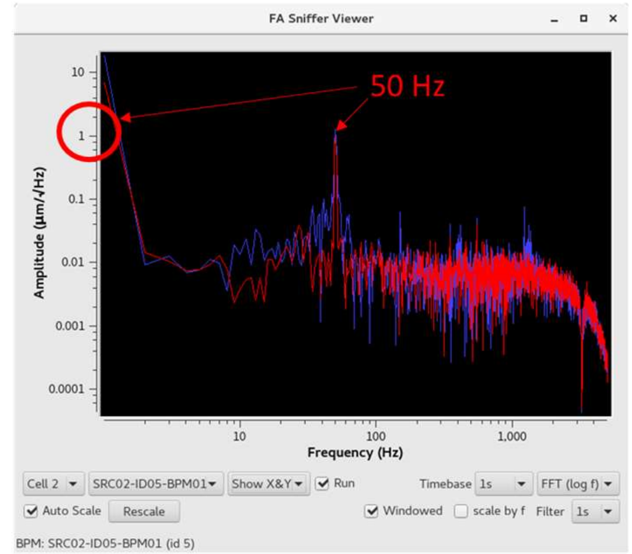
- A simple, robust and low cost hardware Fast Interlock system and Post Mortem **designed and assembled in-house**.
- Used to protects the machine from e-beam.
- It acts very fast:
  - o the system latency < 22μs
  - o the overall process to dump the e-beam takes ~ **1.8ms**

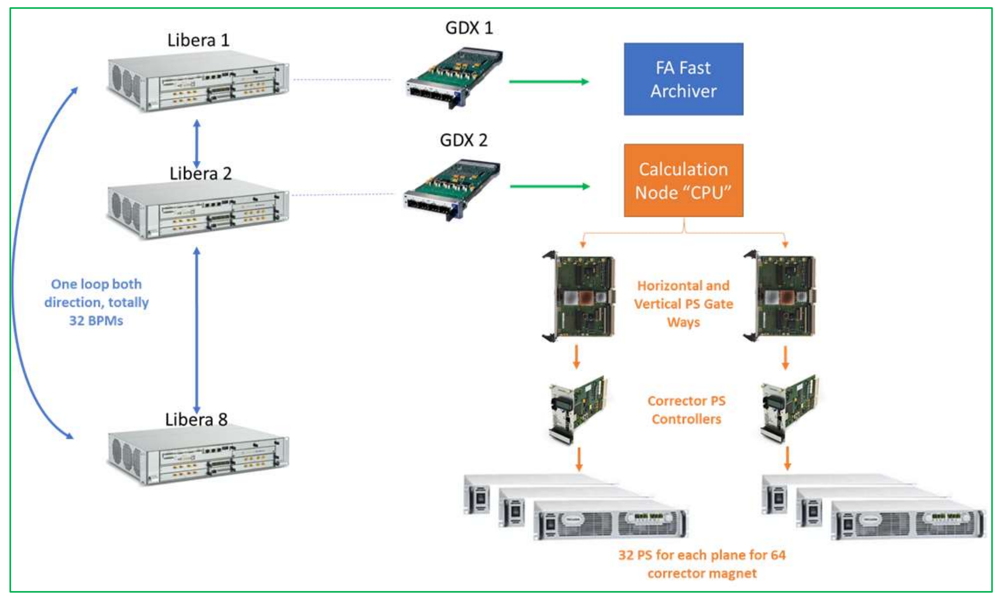


Beam stability at SESAME

- The e-beam orbit is stabilized using only a Slow Orbit Feedback system (orbit correction rate 0.2Hz).
- Sufficient beam stability achieved < 4µm (i.e. < 5% of beam size)
- The work on Fast Orbit Feedback system is ongoing (orbit correction rate > 50 Hz)

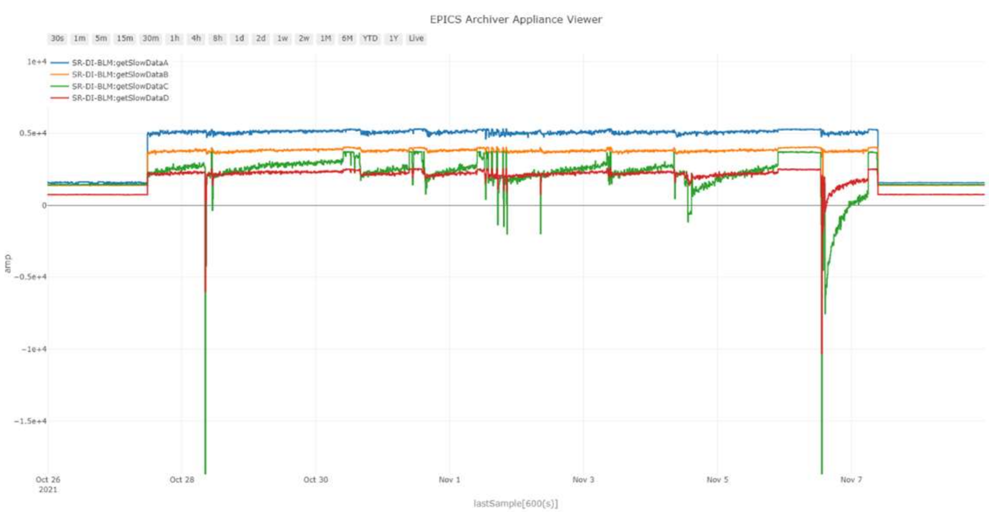


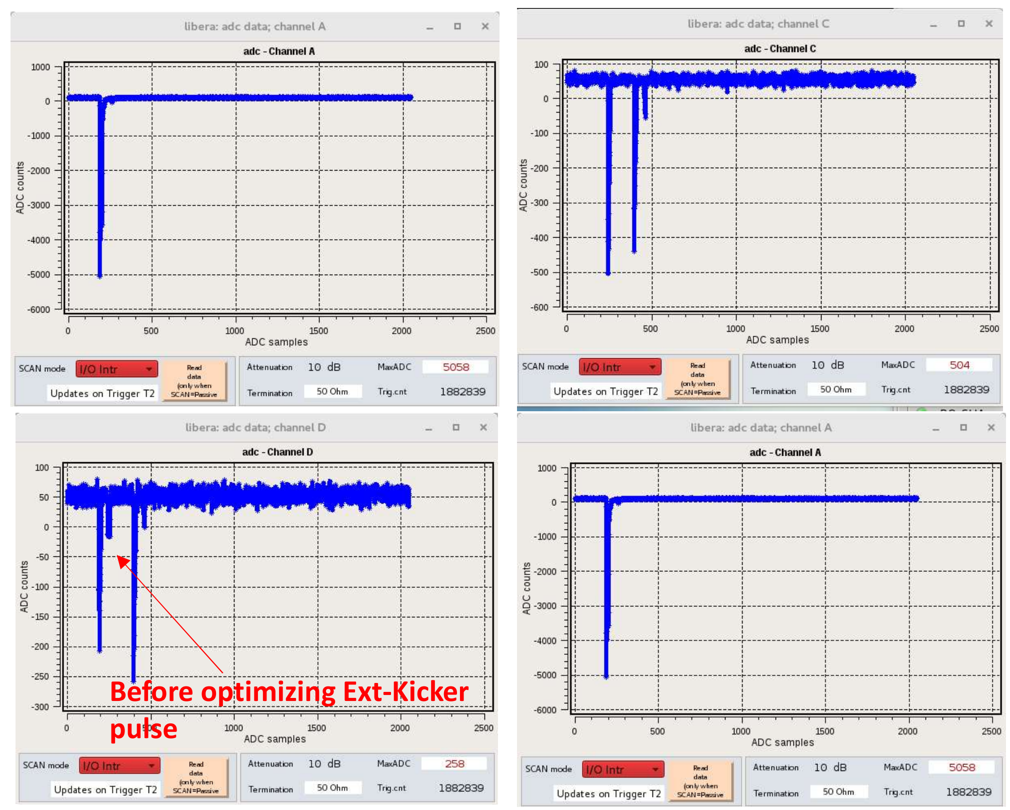




Beam Loss Detection

- Four Beam Loss Detectors (BLD) installed in the machine and connected to one Beam Loss Monitor (BLM).
- The detectors from I-Tech, EJ-200 with Hamamatsu 10721-110 PMT , are very fast and sensitive
- Very useful in machine studies (extraction, transmission, injection, ID commissioning, …etc)

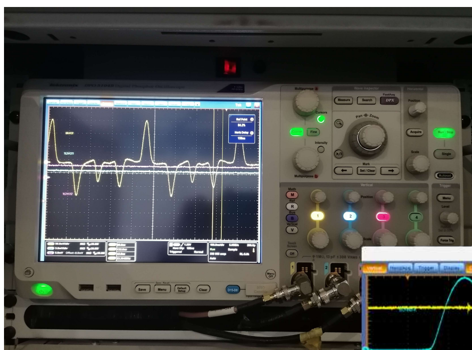




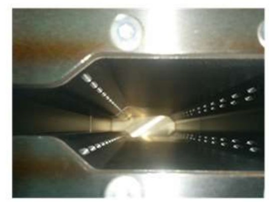
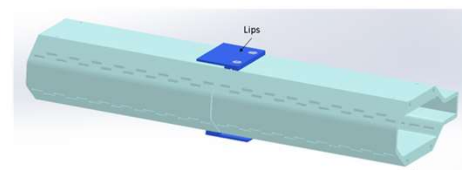
Beam Current Measurement

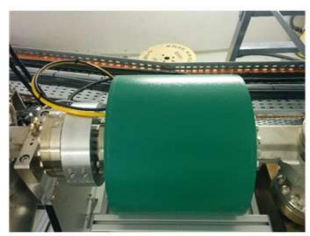
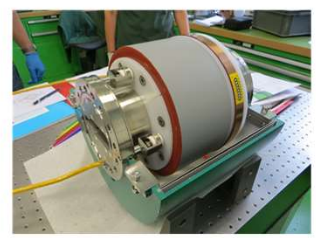
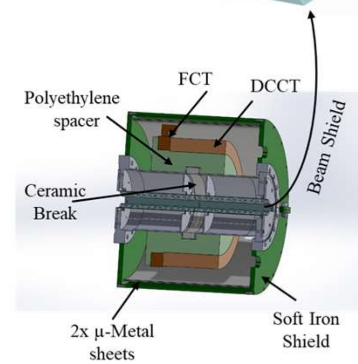
- Done using Fast Current Transformers (FCT) and DC Current Transformers (DCCT) from Bergoz, with radiation hardness heads.
- FCT has high sensitivity 2.5V/A, with 1.7GHz cutoff frequency, connected to 1GHz Tek scopes (20GS/s).

- DCCT resolution < 1μA(RMS)/sqrt(Hz) , response time < 50μs, linearity error < 0.1% (in the range 20mA to 20A), connected to 6.5 digit Keysight DMM.
- Measurements of filling pattern, extraction, transmission and injection efficiencies done with FCTs.





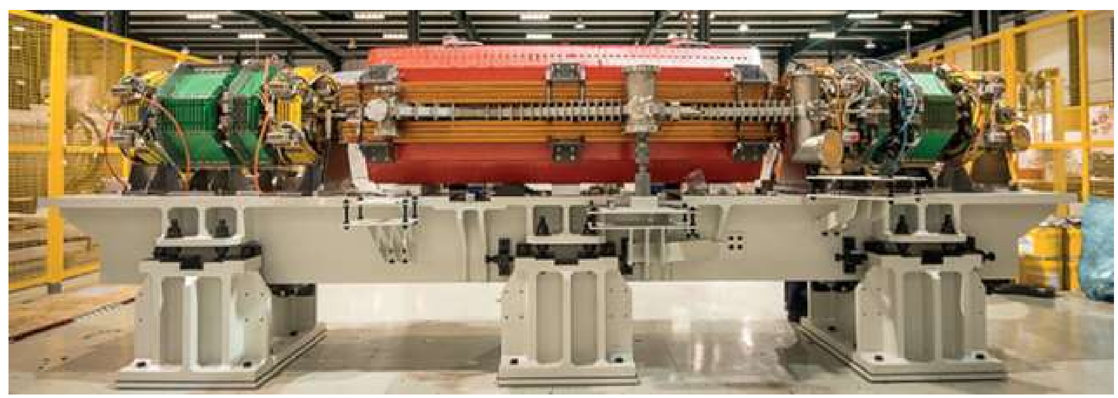
SESAME Power Supplies System

By S. Jafar, Power Supplies group

DC Power Supplies

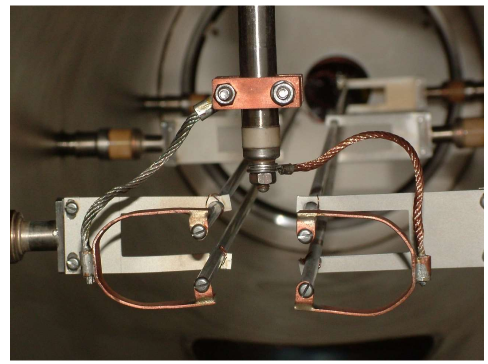
- Required for driving DC electromagnets of the machine
- Current Regulated power supplies
- High Precision (50-100ppm)
- High Stability (100ppm/8h)

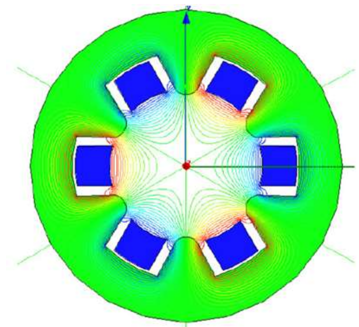
- **Technologies used**:
    - o 12-24 pulse rectification
    - o Switched mode power supplies
    - o DCCT
    - o High precision ADC / DAC
    - o Thermal regulation
    - o Realizes EMC/ Safety standards



Pulsed Magnets' Power Supplies

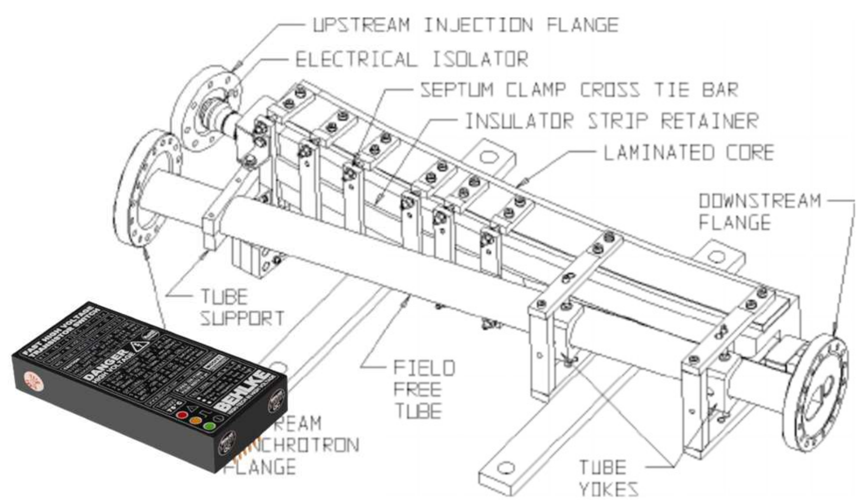
- Required to drive pulsed electromagnets (Kickers and Septums) used to transfer electron beam from accelerator to another
- High Speed (1μs-100μs)
- High Voltage (30kV)
- High Current (5kA)





- Technologies used in pulsed magnets:

  - o Magnetic Design and analysis.
  - o μm Thick Titanium Coating.
  - o Precision Machining.
  - o PFL/PFN Energy Transfer.
  - o Thyratron (high power switch).
  - o High Voltage Solid State Switches.

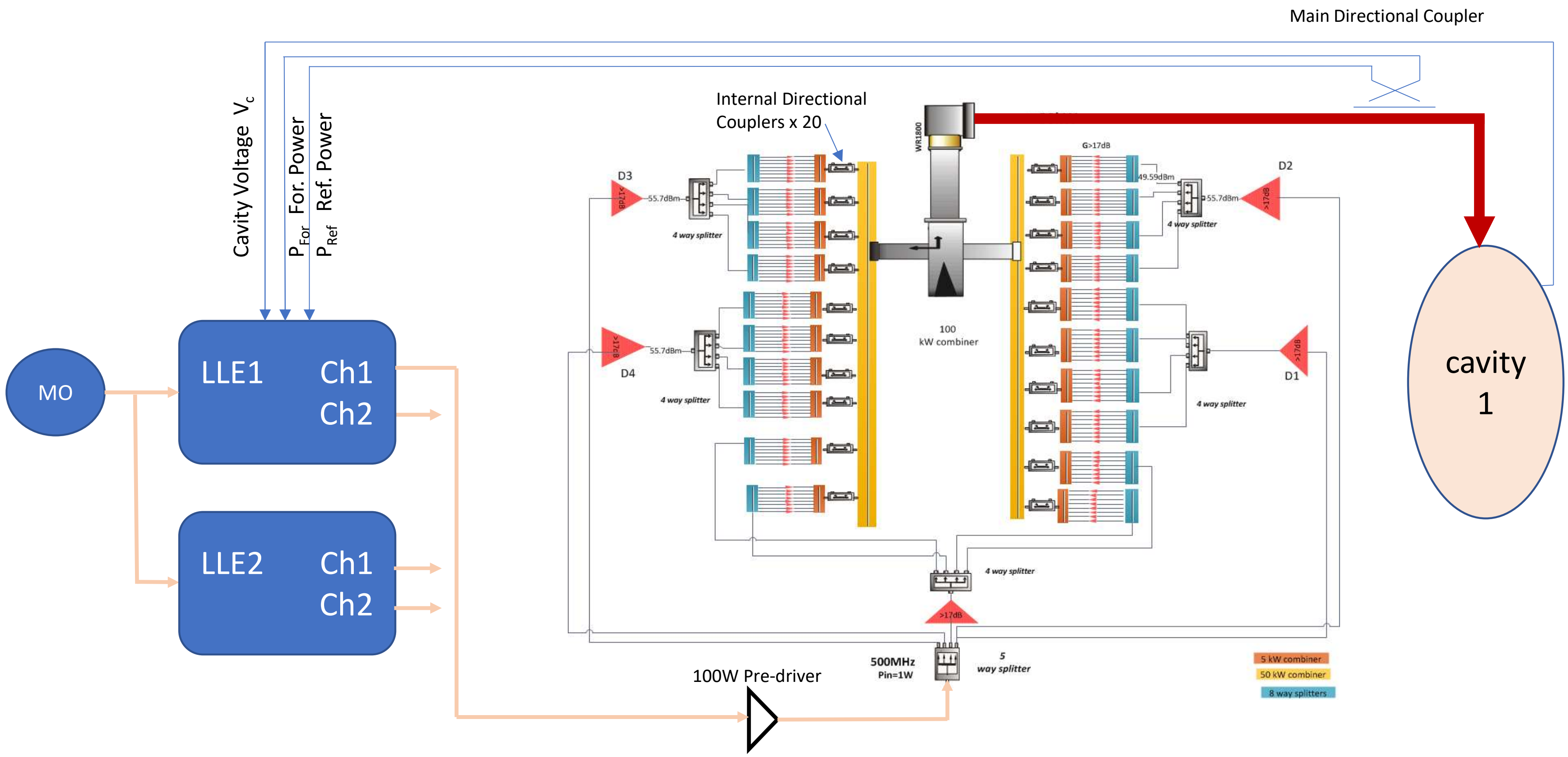


SESAME Radio Frequency System

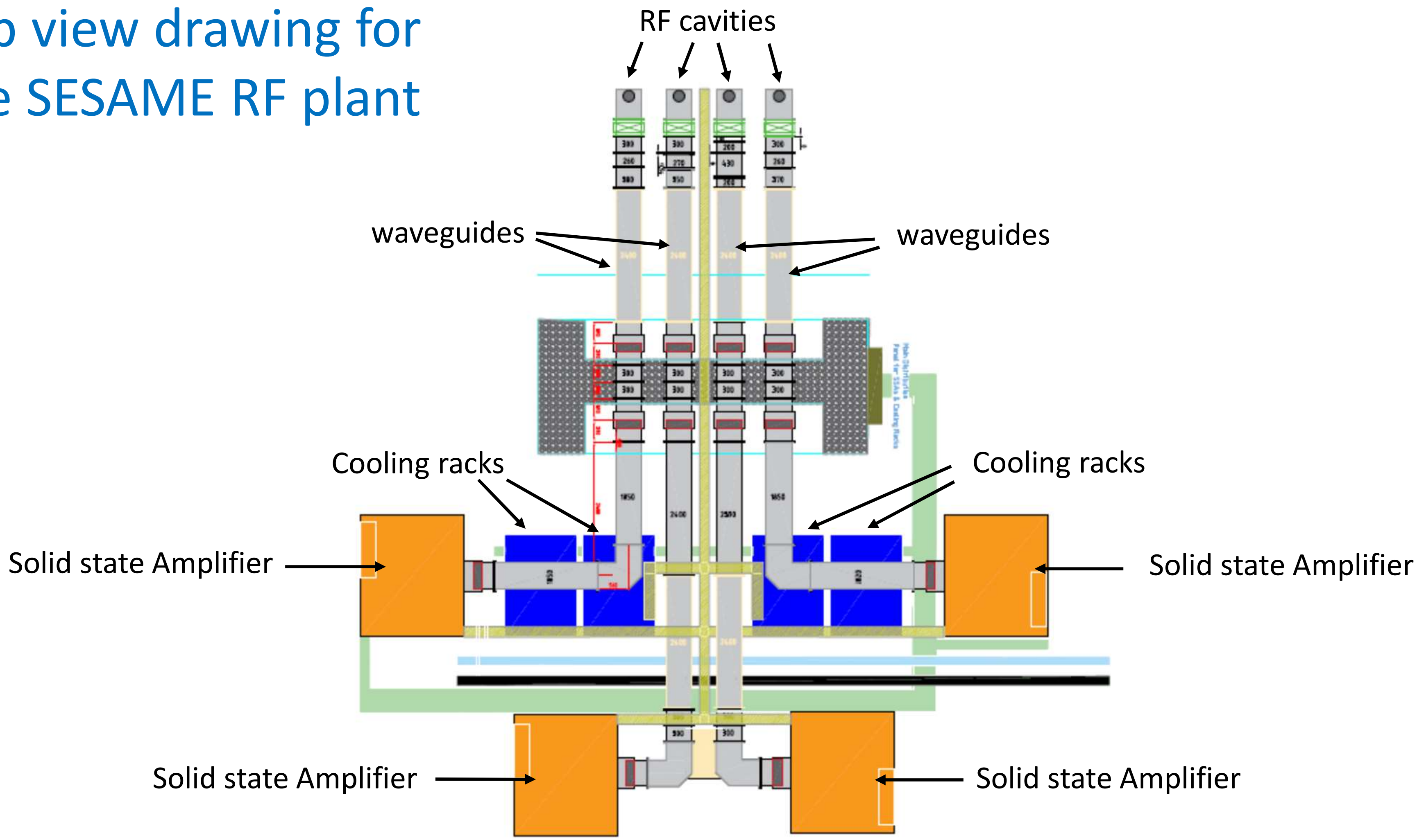
By D. Foudeh, RF group

SESAME RF Main Block Diagram

- MO: 500MHz master oscillator, synchronizes the whole machine systems & provides the driving signal to the RF stations.
- LLE: Low Level Electronics, responsible for regulating the voltage, phase and frequency inside the RF cavity.
- SSA: Solid State Amplifier, amplifies the corrected driving signal and provide a power up to 85KW.
- Cavity: Accommodate the resonant electric field to accelerate electron bunches with proper phase and magnitude.



Top view drawing for the SESAME RF plant



SESAME RF SSAs

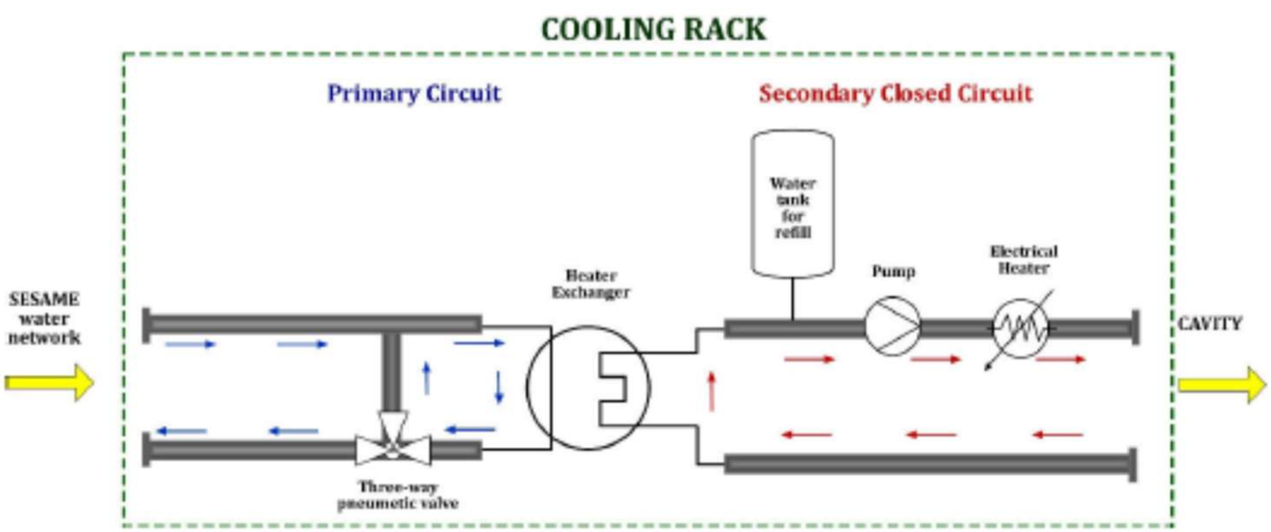
Radio Frequency Cavity

- Elettra-type RF Cavity.
- Free oxygen copper made with elliptical shape.
- The fundamental mode 499.654MHz can be tuned to ± 1MHz by axial compression/decompression.
- Max. input power at coupler is 110KW.

Four RF cavities in the SESAME storage ring

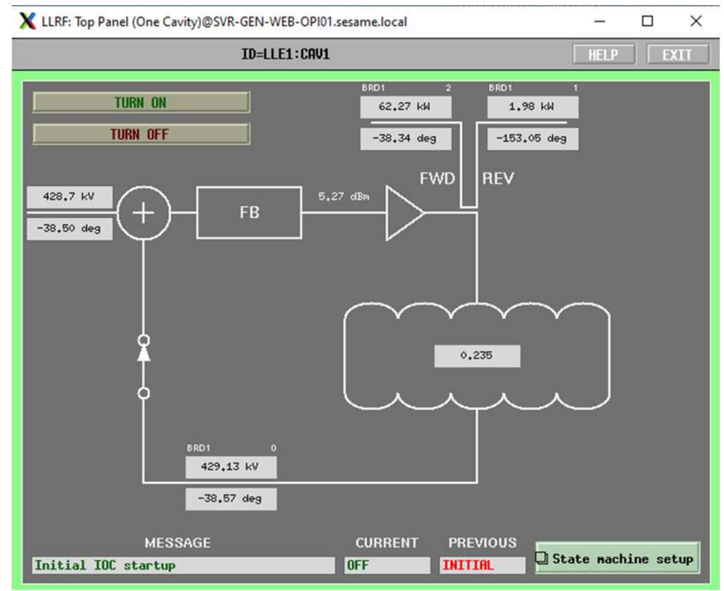
Cavity Cooling Rack

- Keeps temperature of the RF cavity to a pre-defined value (30 – 75)°C.
- Design accuracy ±0.05°C (achieved ±0.2°C).
- Primary circuit works at 7.5bar and 5m³/h while the secondary circuit works at 8bar and 12m³/h.



Low Level Electronics

- LLE (LLRF9/500) is FPGA based system programmed to control RF parameters (taking e-beam loading into account).
- All RF main parameters are presented by the LLE such as Forward and Reflected power, cavity voltage, phase errors, driving power, …etc
- Each LLE unit can control two cavities.
- EDM (Enthought Deployment Manager) panels are used to interact with the LLE and all data are exchanged via EPICS control system.



SESAME

Alignment System & Mechanical Engineering

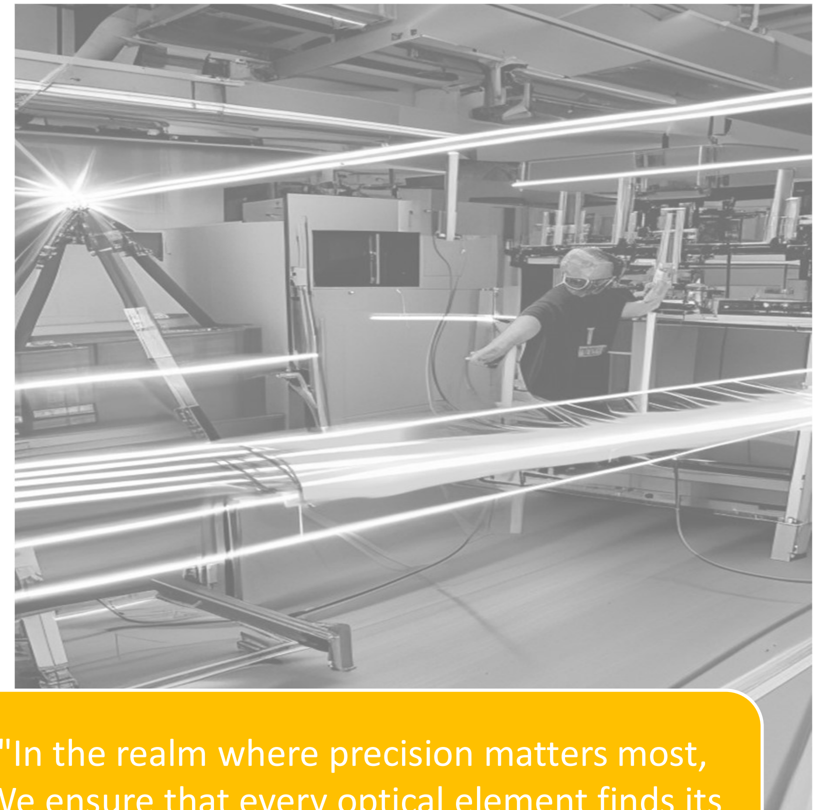
By A. Hasoneh & M. Shehab, Mechanical Engineering group

Alignment at SESAME

- Alignment:
  A) Rough Alignment. (in mm)
  B) Accurate alignment. (in micro meter)

- Mechanical inspection & Reverse Engineering.

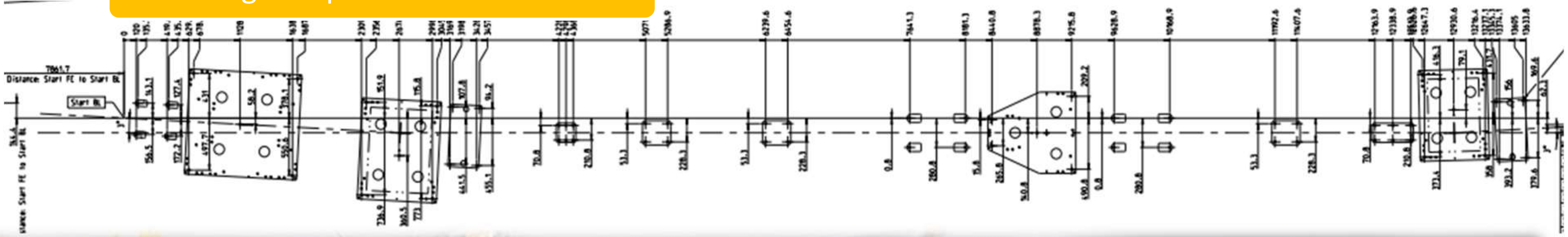
- Tools and Instruments used:
  - Laser Tracker 402 Leica.
  - TDA 5005
  - Optical LEVEL NA2 Leica.
  - Accurate water levels.
  - Laser Lines.



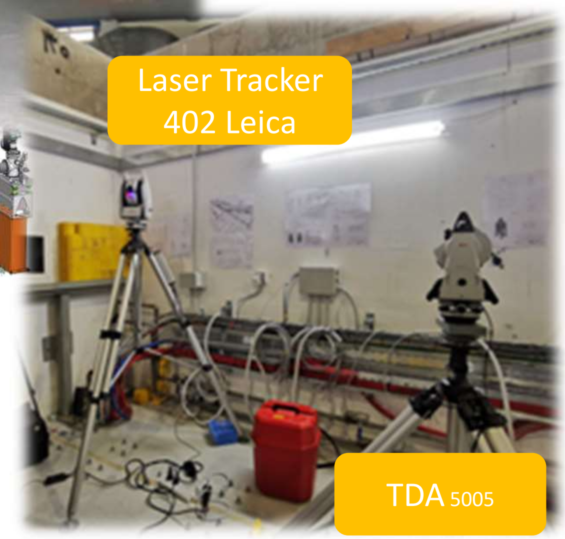
"In the realm where precision matters most, We ensure that every optical element finds its perfect place in the Synchrotron facility."

A) Rough Alignment (in mm)

Tracing Components on the floor



Installation and Positioning of Optical Components

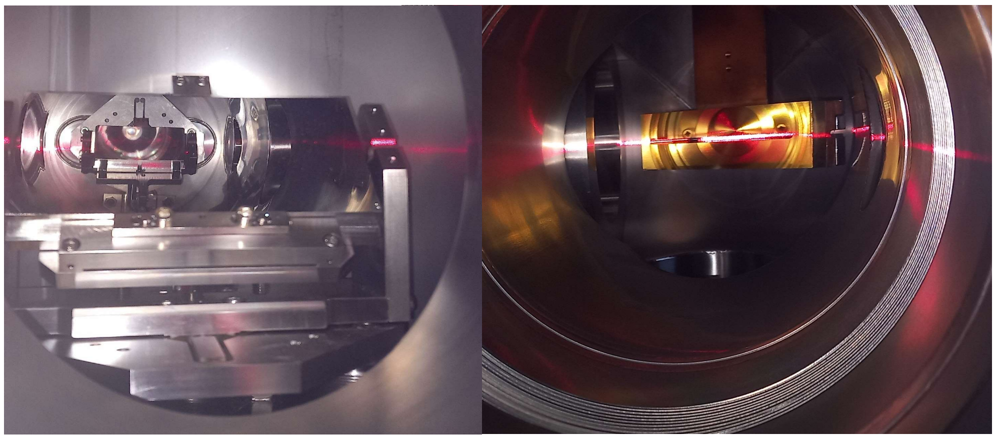


Laser Tracker 402 Leica

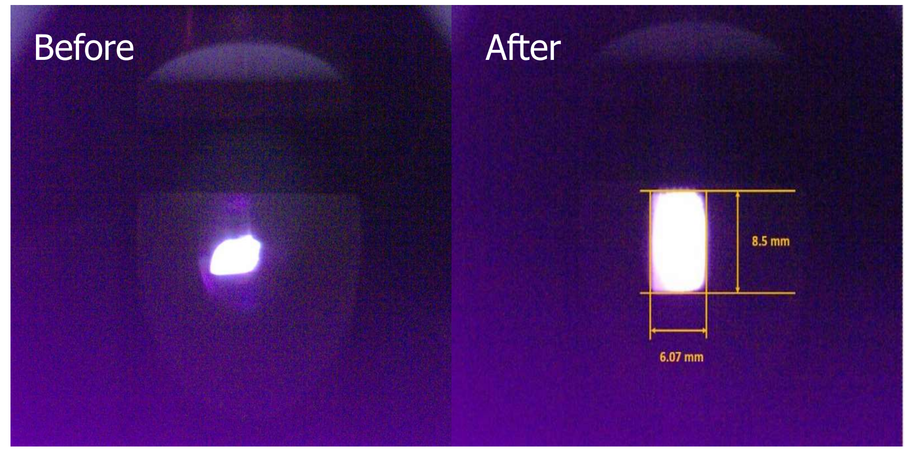
TDA 5005

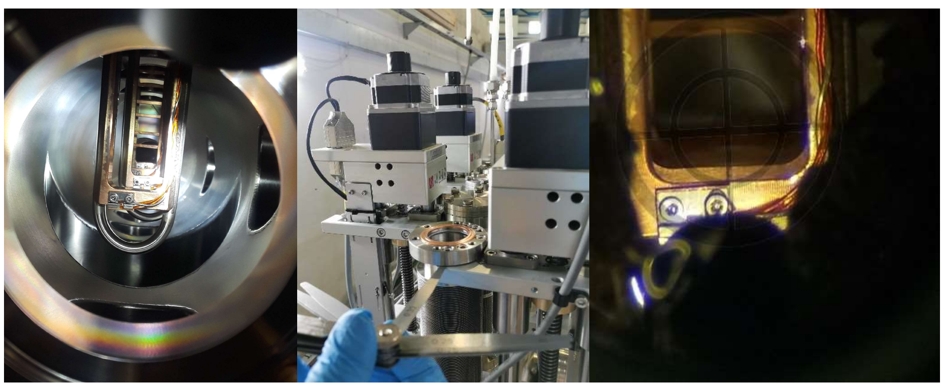
B) Accurate alignment (in μm)

Slots, Pinholes and Absorbers alignment



Mirrors Collimation and Alignment

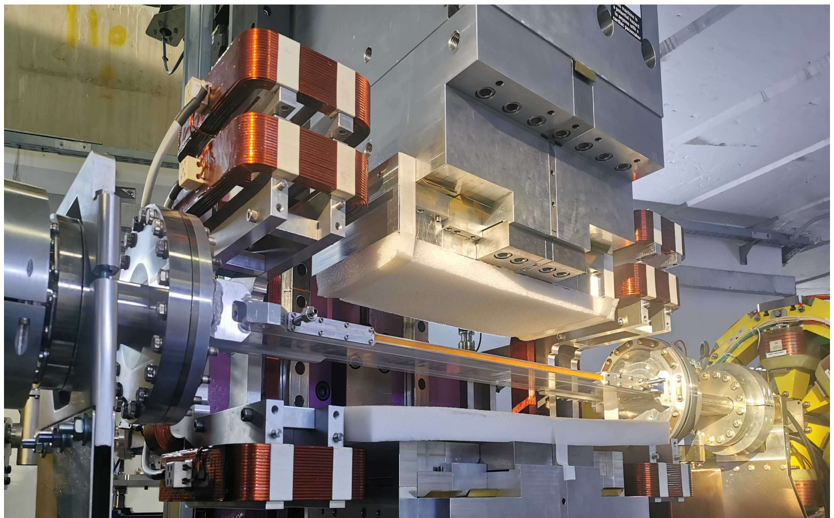




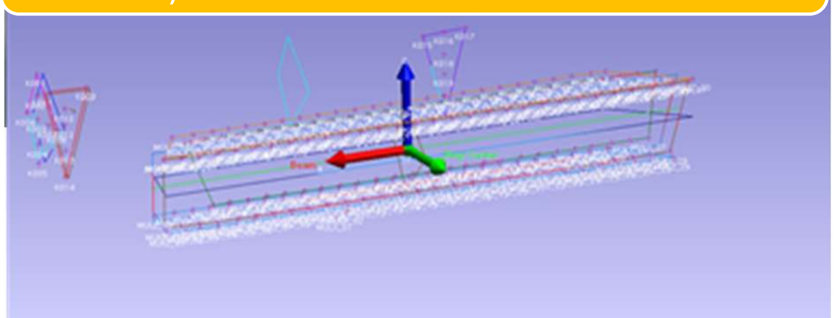
Multi layers filter and End stations alignment

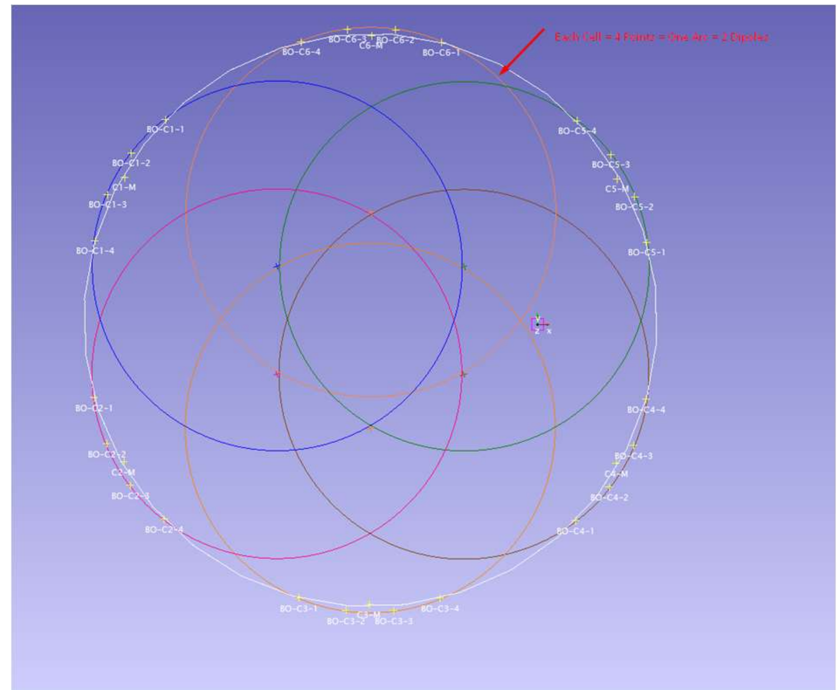
B) Accurate alignment (in μm)

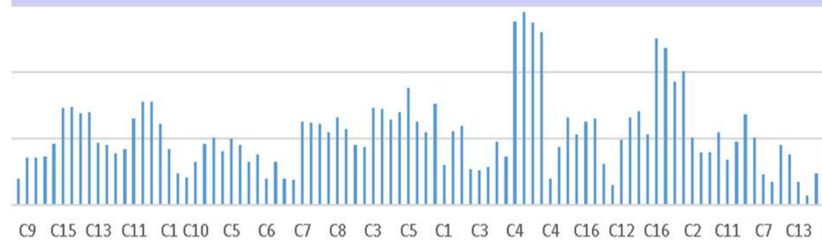
Using Laser Tracker Network for monitoring and Best fit positioning for continuous optimization of components in BOOSTER & SR



Results of chamber alignment (Maximum waviness) 0.05mm.

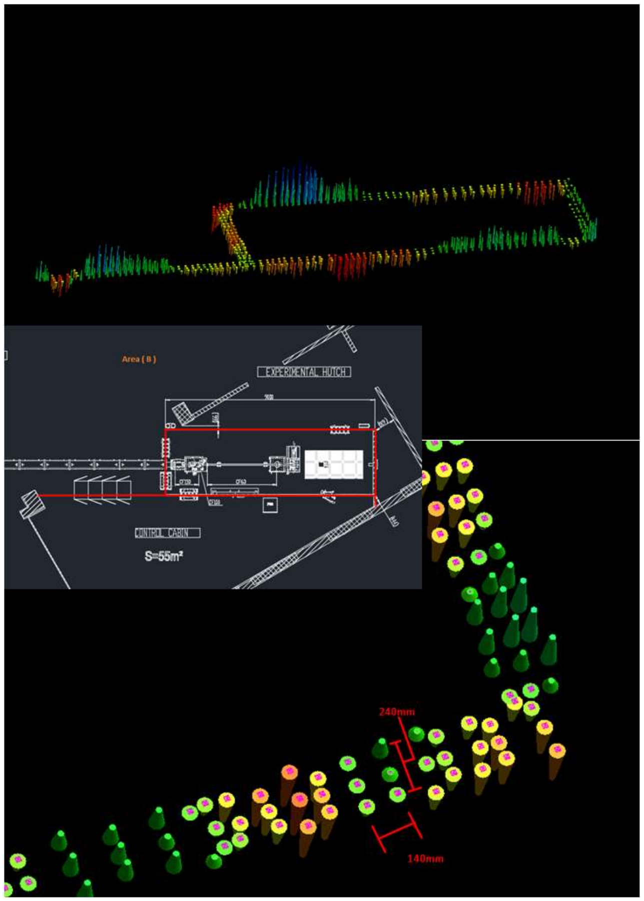




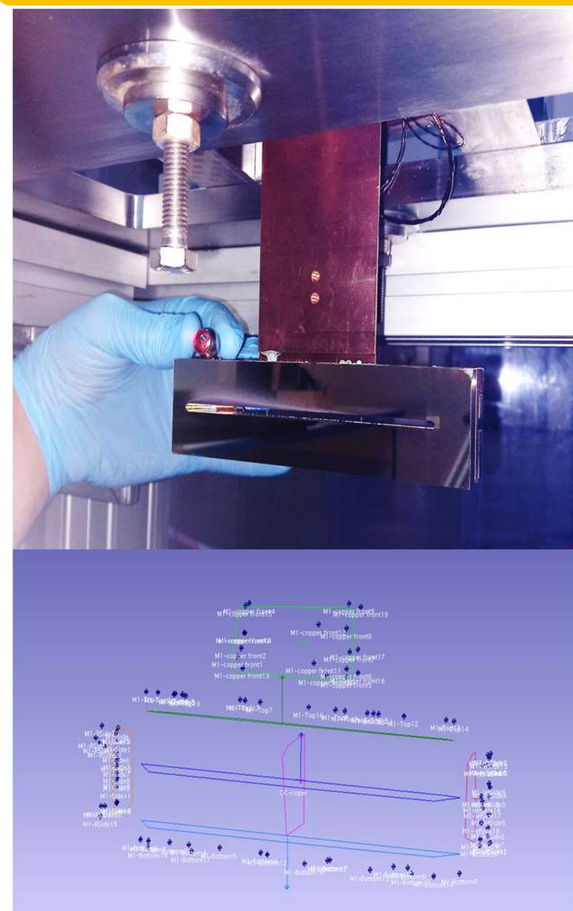


Mechanical inspection & Reverse Engineering

Large Area Scanning for flatness inspection



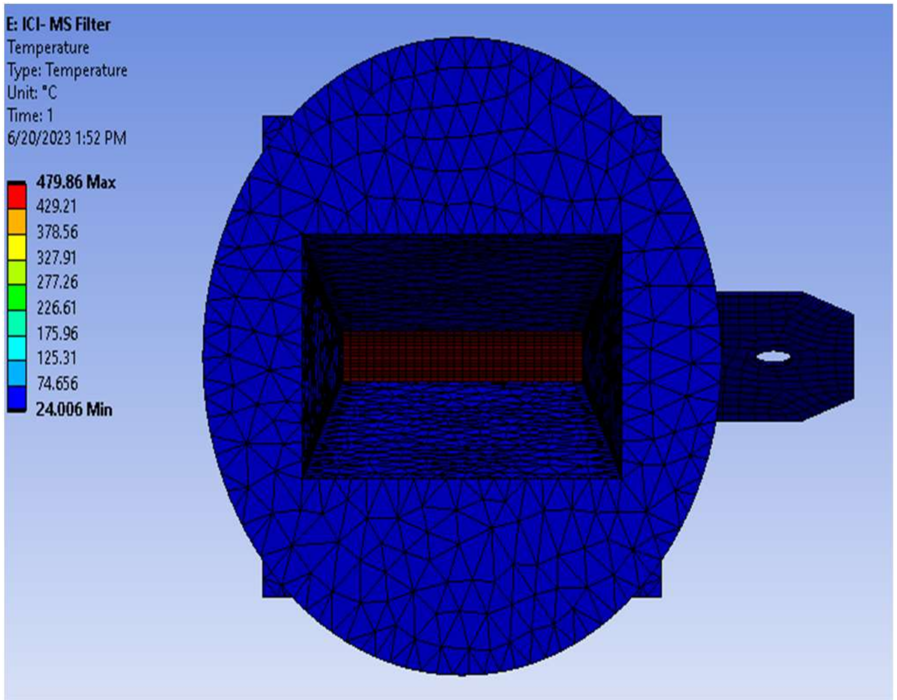
Mirror scanning and Fiducialization

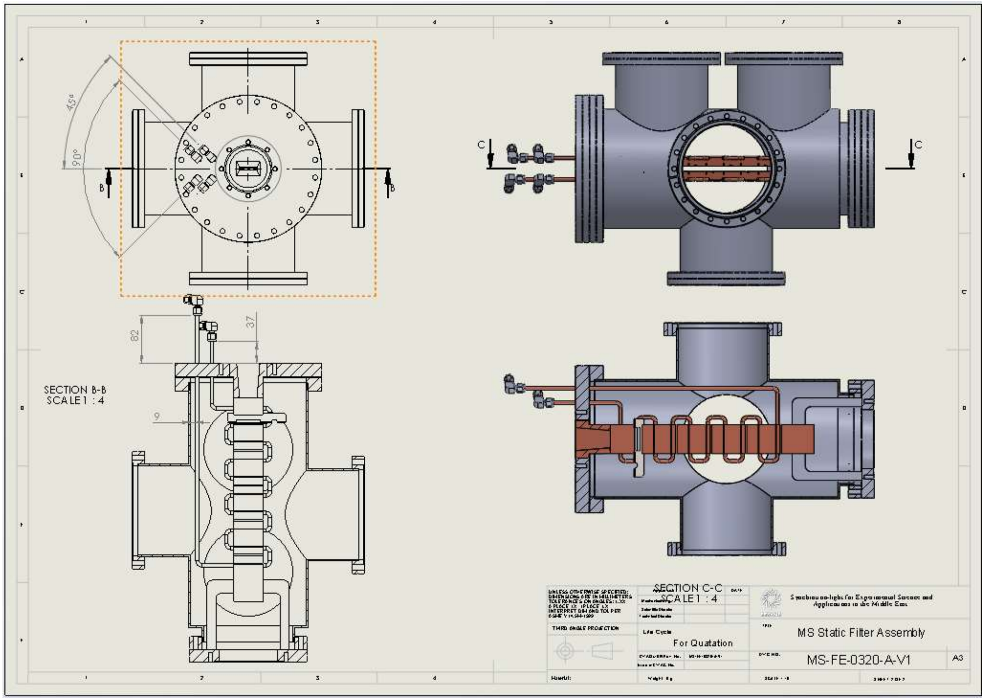


Photogrammetry scanning for BEATS H-Slit

Mechanical Design Work

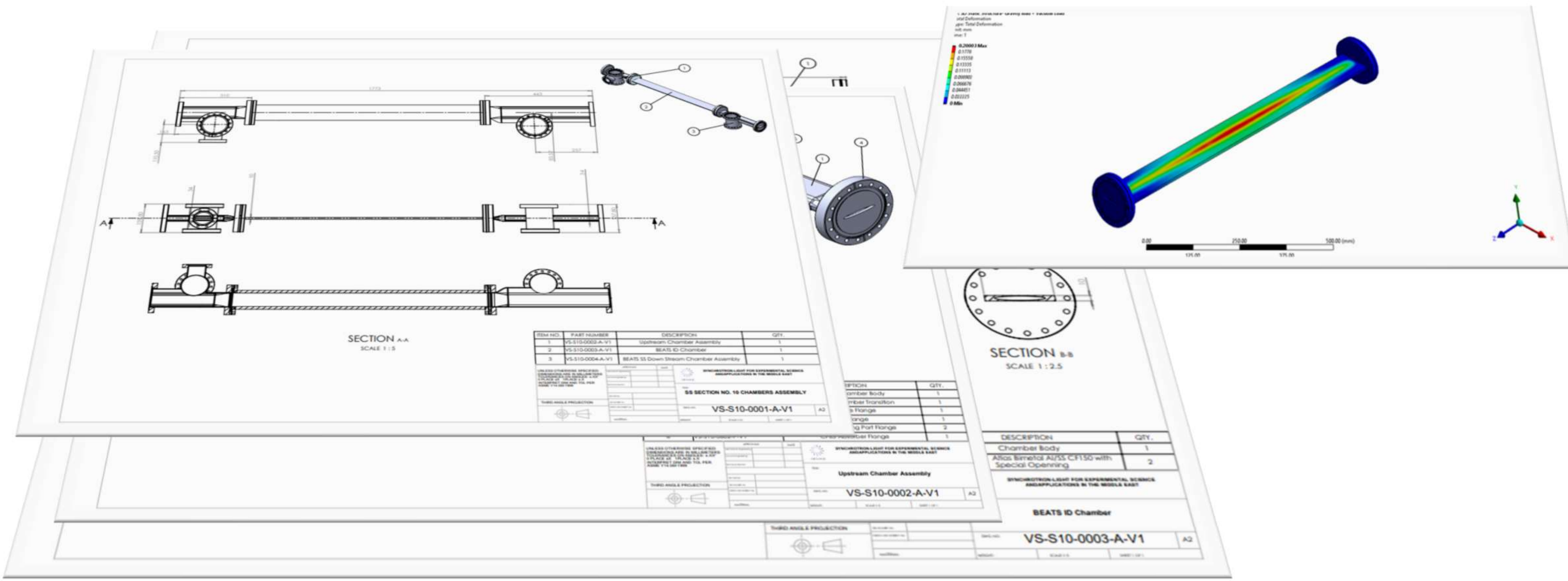
- Examples
  - o Static filter for MS/XPD Beamline





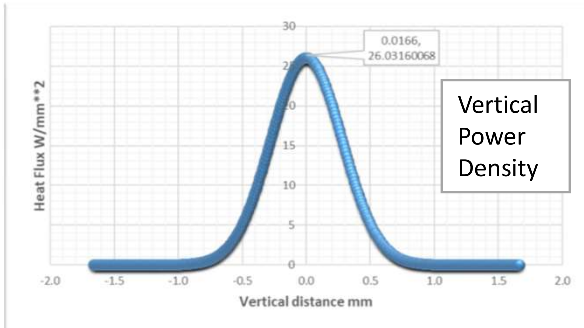
ME Design Support For New Beamlines

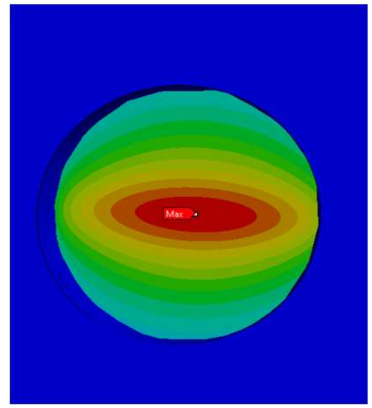
- BEATS Insertion Device chamber including up stream and down stream sections

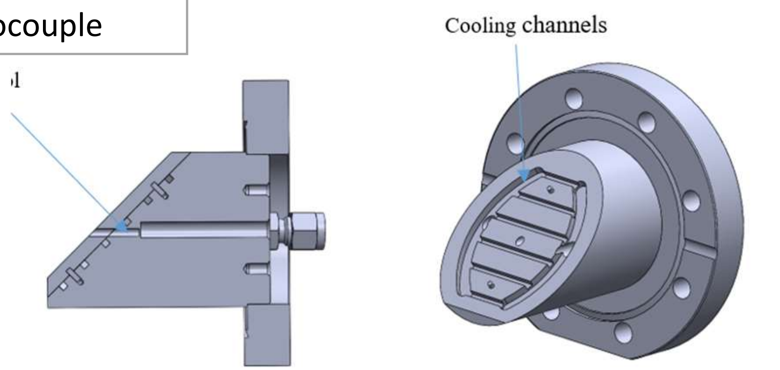


Projects - Pinhole Camera Beamline

Threaded Hole added
For thermocouple



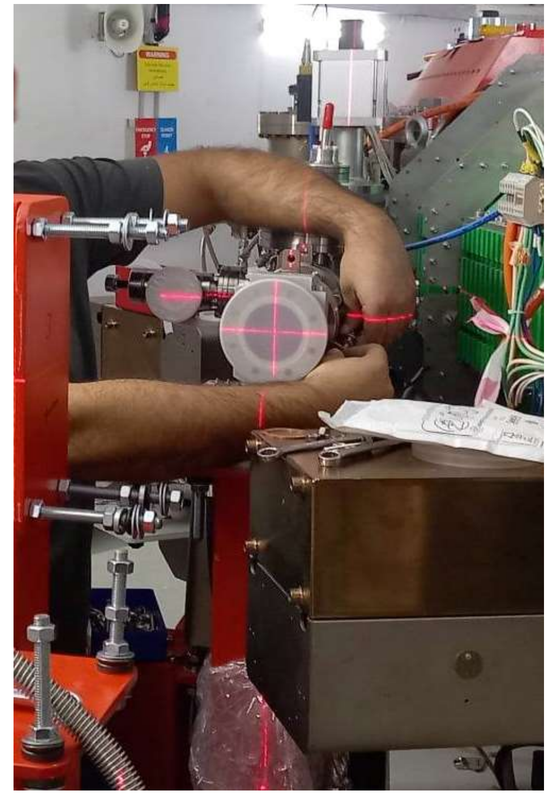




a: Sectional View

b: 3D View with cooling channe

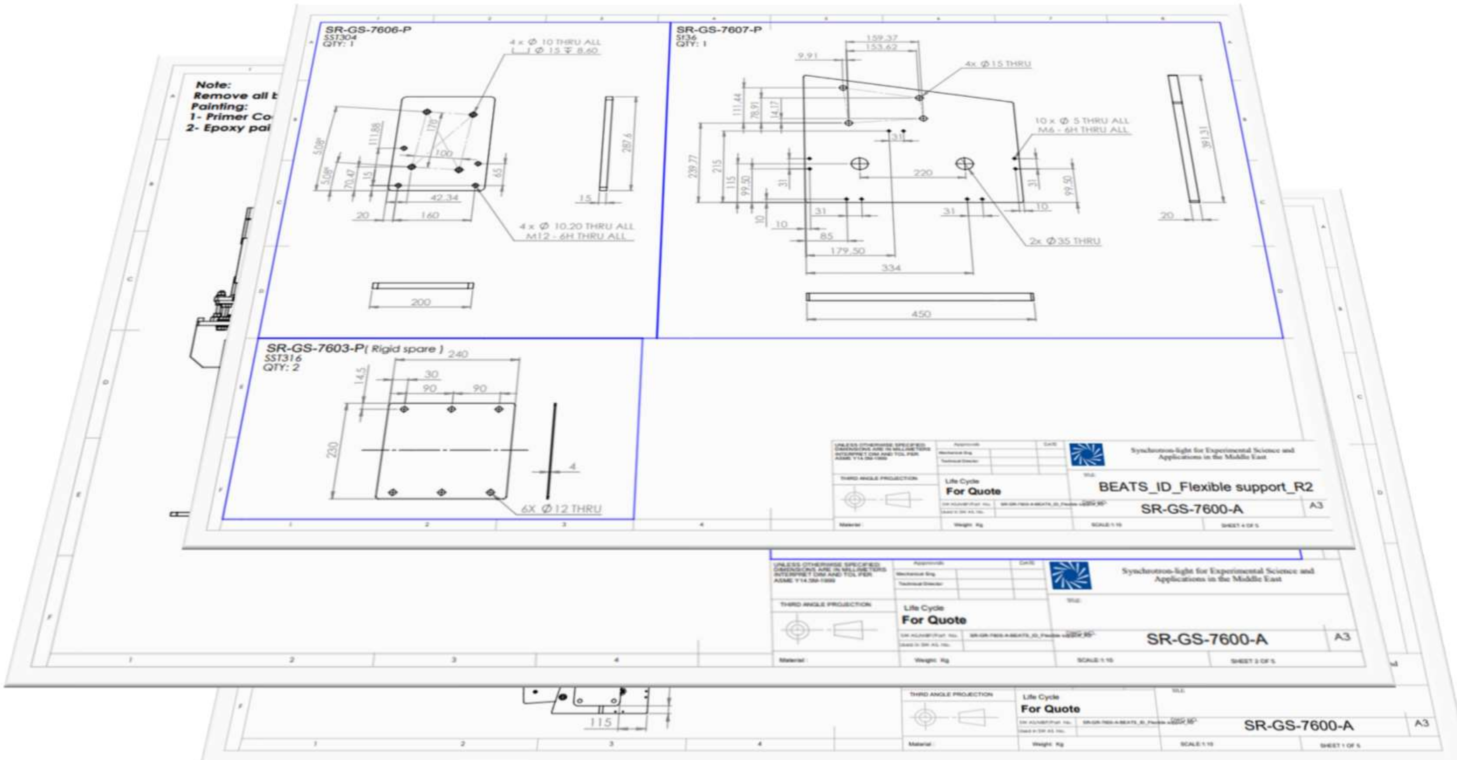
Modifications study on SRM Mirror for Pinhole filter. (Thermal, Strength Machinability)



- In Vacuum section installed & Aligned.
- Camera + Scintillator installed and aligned.

SESAME

Projects - Supports of BEATS ID section vacuum pumps



Thank you