

# LEHIPA: A Control System Perspective

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**ACSS,LEHIPA,IADD,BARC**

# Plan of Talk

- **Introduction to LEHIPA**
- **LEHIPA Control System**
- **EPICS in LEHIPA Control System**
- **Future Plans**

# LEHIPA

- **Low Energy High Intensity Proton Accelerator (LEHIPA)**
- **20 MeV 10 mA Proton beam**
- **Front end of Accelerator Driven System(ADS)**
- **Successfully commissioned on August 2023**
- **EPICS is used in the Control System.**

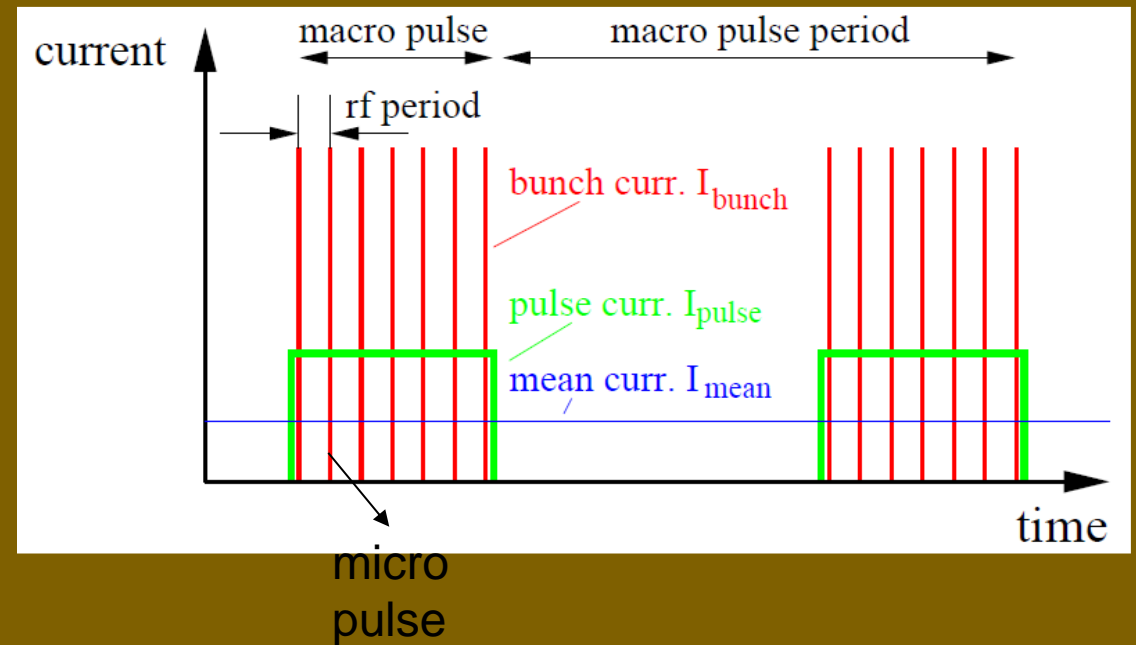
# LEHIPA – Important Parameters

Maximum Proton Beam Energy :	21 MeV.
Maximum Beam Power(Average) :	52.5 W.
Maximum RF Pulse Width:	250 us.
Ion Source Maximum Pulse Width:	1 ms.
RFQ RHVPS Pulse Width & Max Rep Rate	400 us / 2 Hz
DTL RHVPS-2 and RHVPS-3 Maximum Pulse Width & Max Rep Rate	200 ms / 4 Hz.
Maximum Peak RF Power for RFQ klystron	700 kW.
Maximum RF Power for DTL 1&2 klystron:	900 kW.
Maximum RF Power for DTL 3&4 klystron:	900 kW (Peak Power)
Maximum Forward Power Per Coupler(Peak Power):	350 kW
Maximum Peak Proton Current in RFQ and DTL	5 mA (Accelerated).
RHVPS Voltage:	Min: 60 kV , Max 95 kV
Vacuum:	RFQ and DTL $1 \times 10^{-7}$ Torr or better. Elsewhere $1 \times 10^{-6}$ Torr or better.

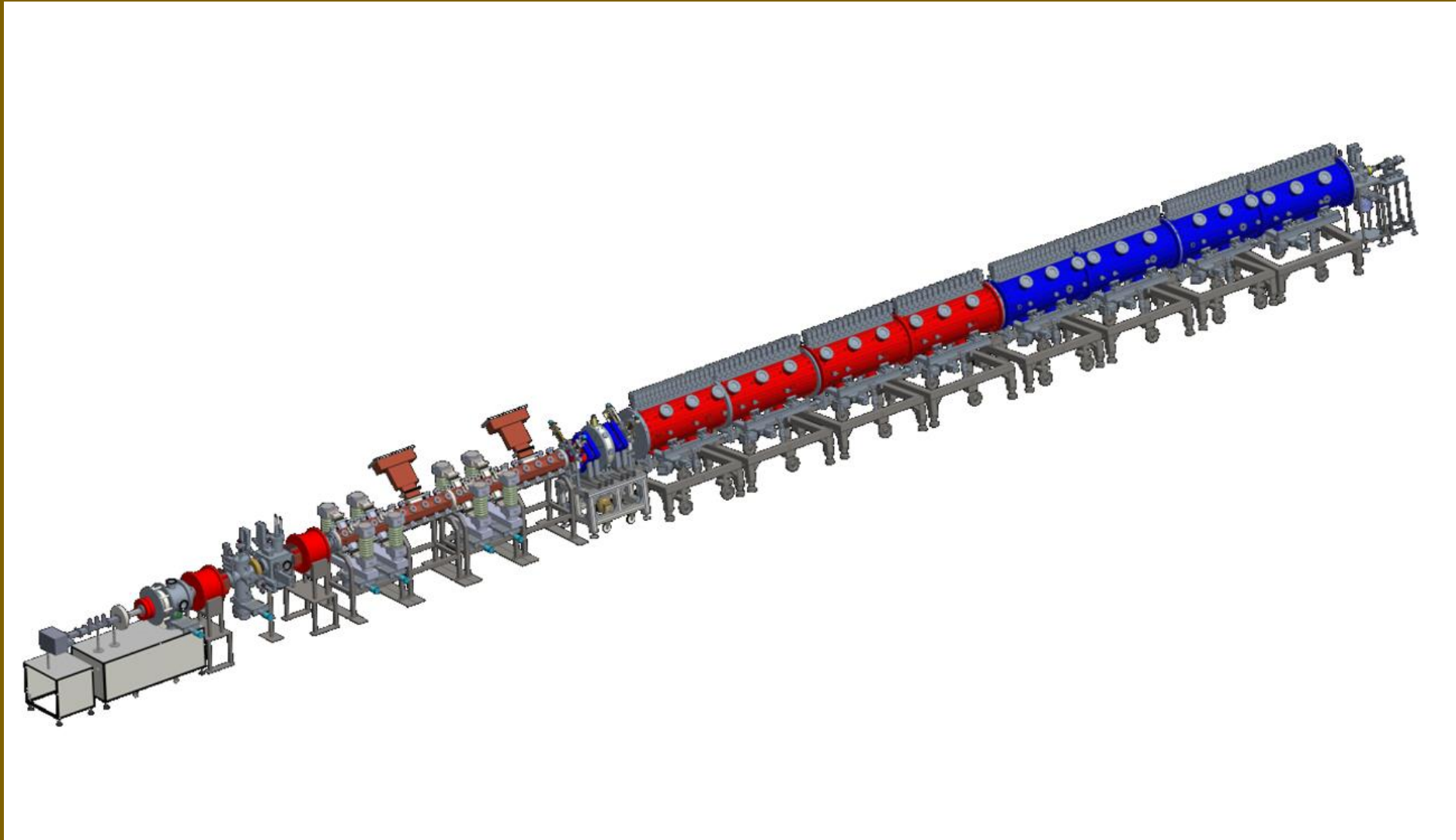
# LEHIPA

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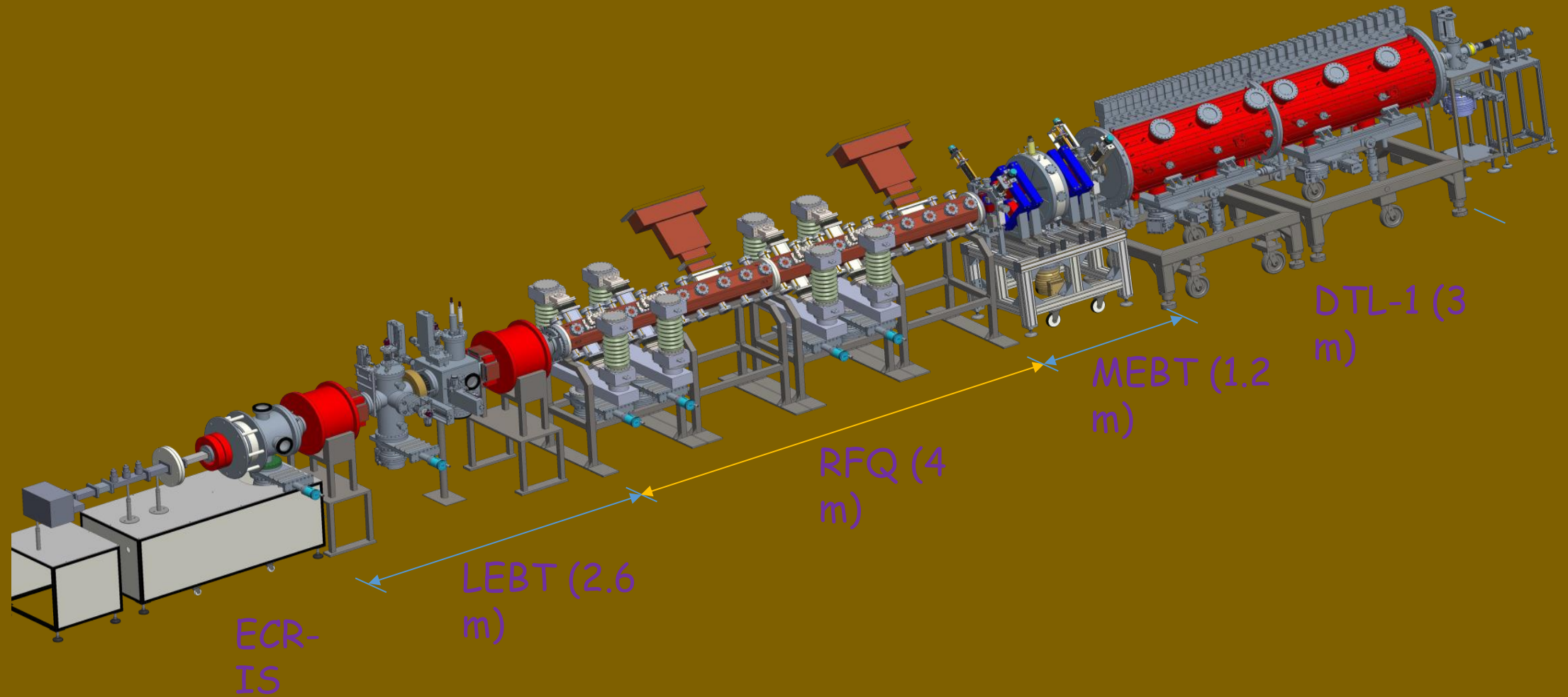
Parameter	Value
$T_{RF}$ (352 MHz)	2.8 ns
Macro pulse width	100 $\mu$ s
Synchronous Phase, $\Phi_s$	$-30^\circ$
Micro pulse (Bunch) width	$\leq 710$ ps
RMS bunch width	$\sim 150$ ps



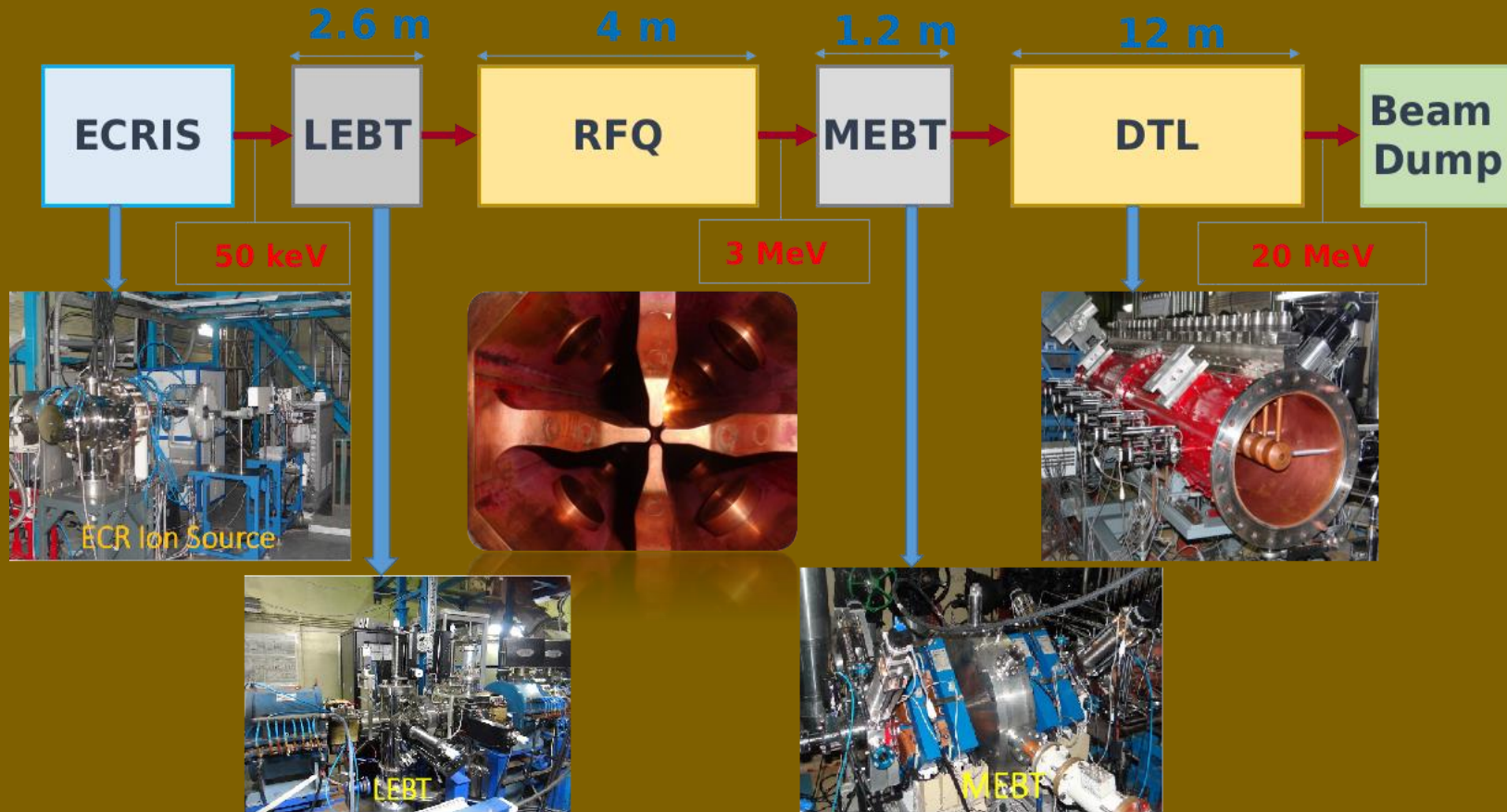
# Layout of 20 MeV LEHIPA Facility



# Layout of 20 MeV LEHIPA Facility



# LEHIPA Subsystems



1. Ion Source
2. LEBT
3. RFQ
4. MEBT
5. DTL
6. BDS
7. Timing System
8. HPRF
9. SSRF
10. LLRF
11. LCW
12. VCIS
13. RHVPS
14. FPIS
15. OPIS



# LEHIPA Auxiliary Subsystems

## 1. Vacuum System

- **1E-7 Torr throughout the length without beam**
- **1E-6 Torr with beam**
- **TMP with roots pump as backing pump and SIP is used for pumping**
- **Vacuum Control and Interlock information system is dealing with vacuum interlocks.**

## 2. Cooling Water System

- **Low conductivity cooling water system is used to cool the components.**

## 3. RF Power Generation System

- **352 MHz,1 Mw klystron generates RF power**
- **Waveguide system transport the power to fed it in cavities.**

## 4. DC Supply for RF Power Generation

- **Pulse modulator**
- **Regulated High Voltage Power System**

## 5. Beam Diagnostic System

- **Faraday Cup**
- **Wire Scanner**

# Subsystems of LEHIPA facility

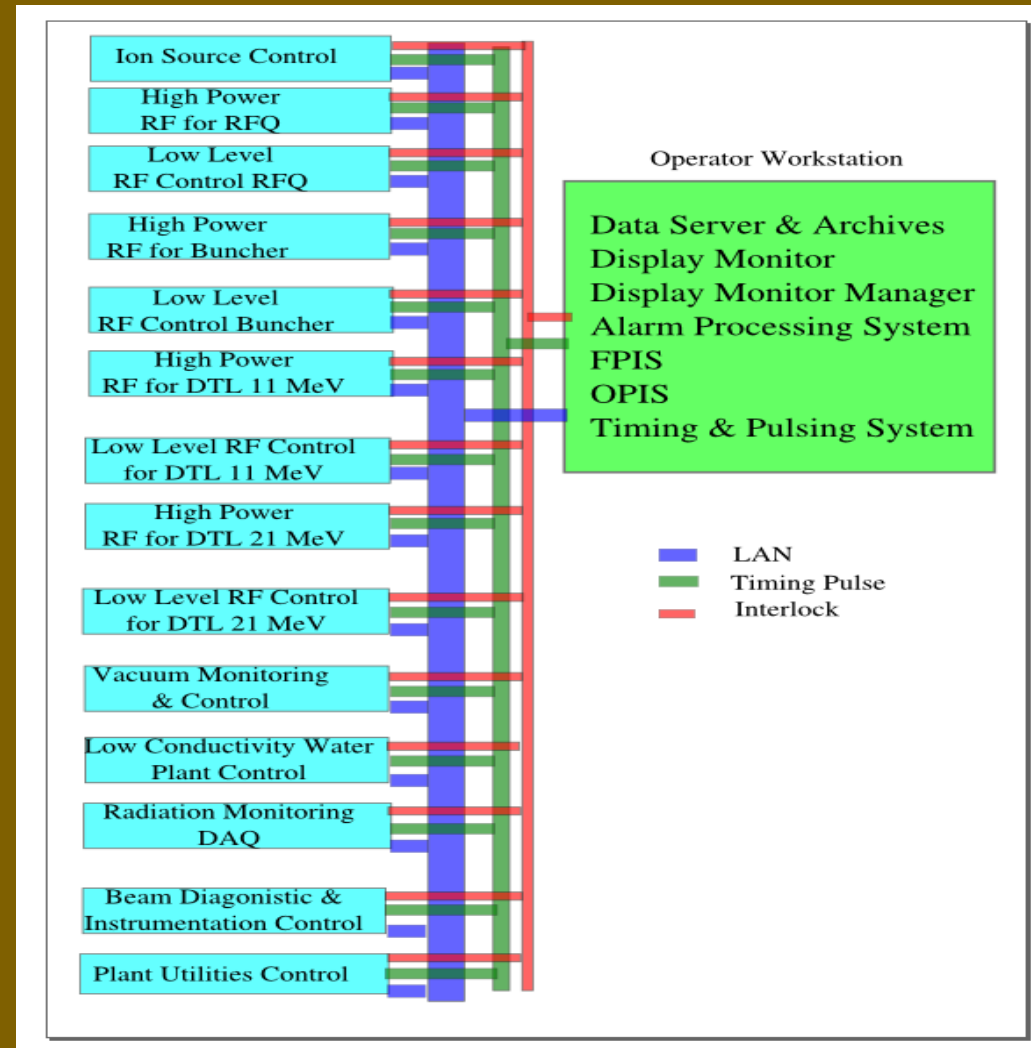


# LEHIPA Control System

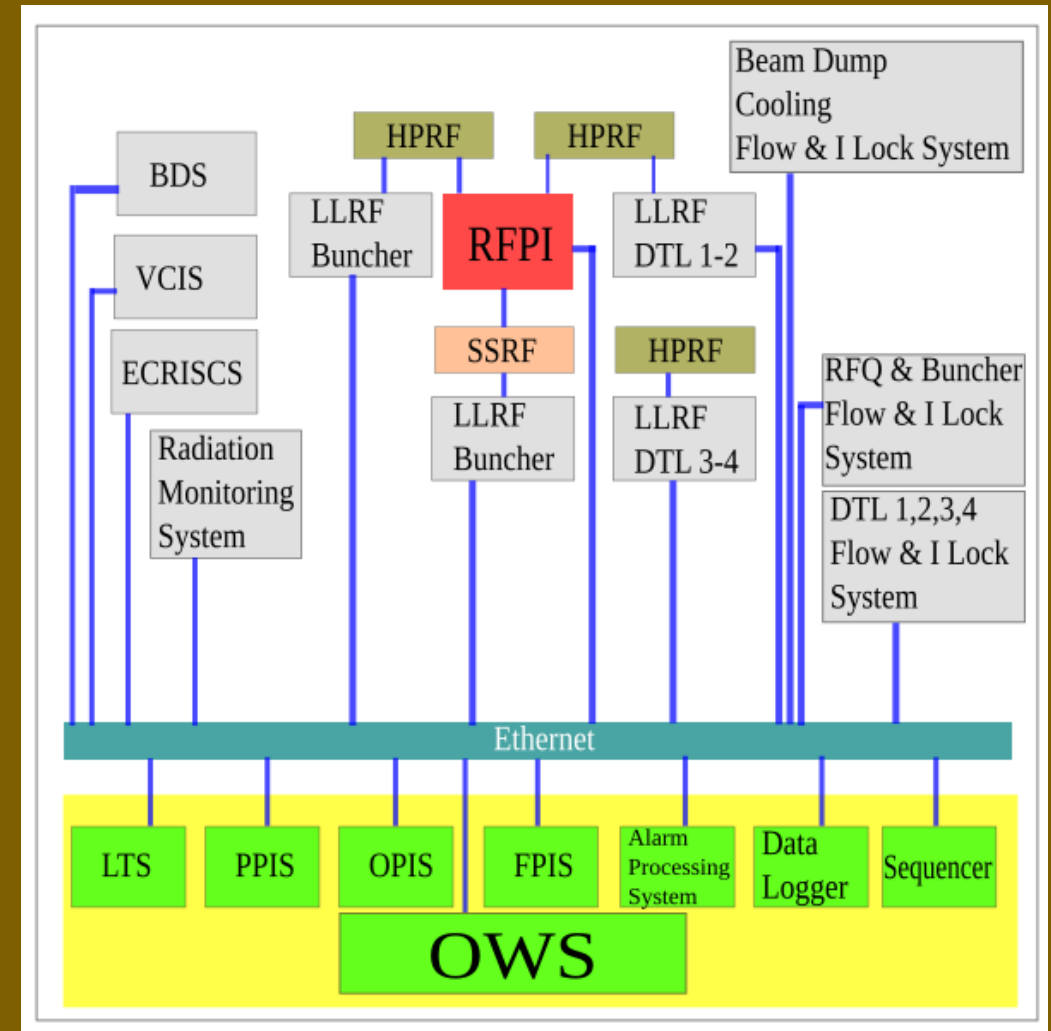
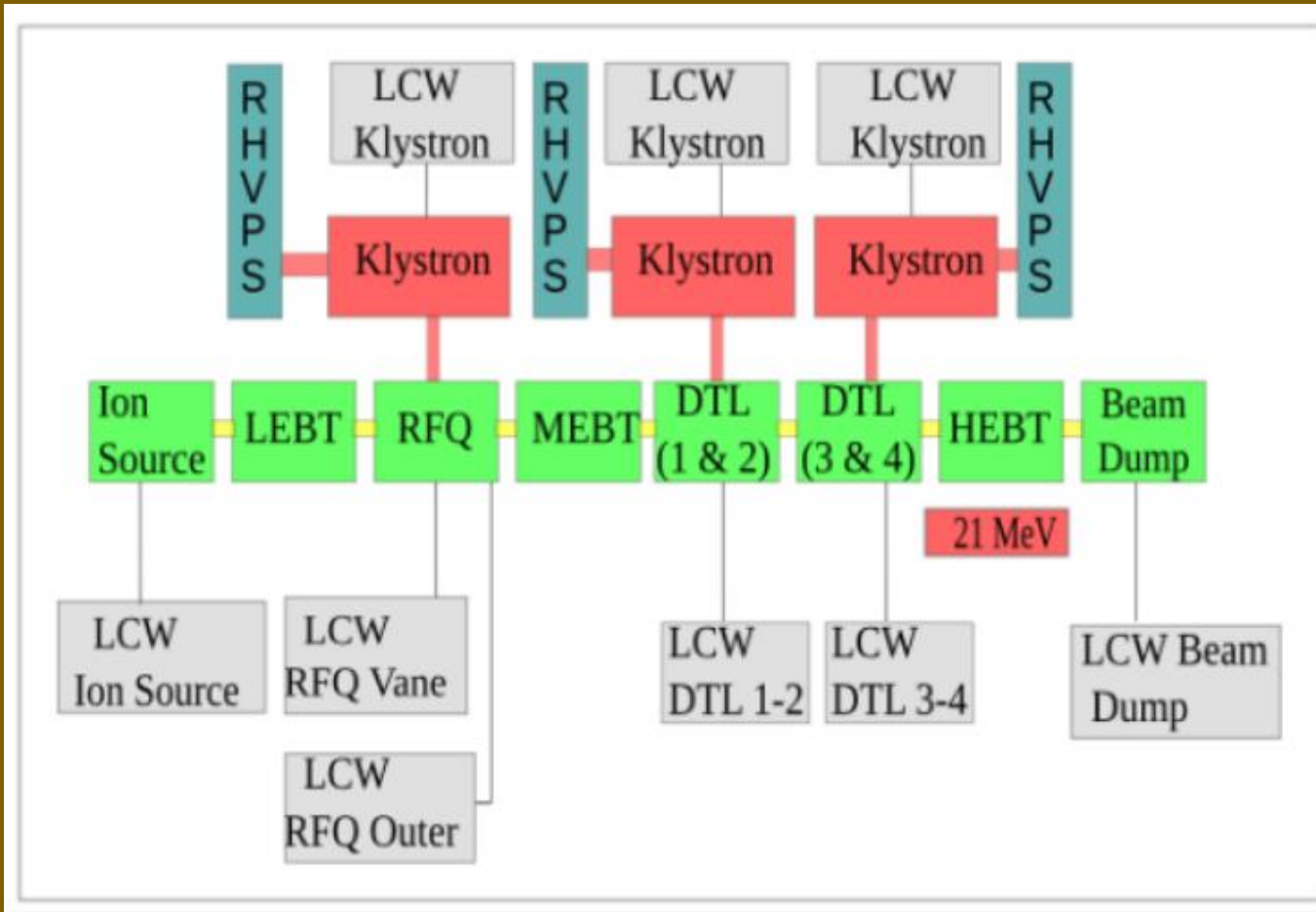
LEHIPA Control System is responsible for

1. Maintaining stable electric field in the cavity.
2. Timing system to synchronize activities for beam acceleration
3. Data acquisition and presentation of data to operator and user
4. Implementation of operator actions on field devices.
5. Generation of alarm for operator.
6. Acquiring and presenting beam diagnostic data to operator.
7. Machine protection system
  - Fast Protection
  - Slow Protection
8. Personnel Protection System
  - Search and Secure System
9. CCTV monitoring system of LEHIPA
10. Archiving of machine data during operation
11. E Logbook

# Architecture of the LEHIPA Control System



# Functional Schematic of the LEHIPA Control System



# General Specification of the LEHIPA Control System

Sr No	Parameter	Value
1	Classification	Distributed Control System(DCS)
2	Software Platform	Linux,muc OS
3	Programming Language	C/C++,Qt,EPICS Qt,Python
4	Digital Hardware	cPCI,VME,TPLC,RioPLC
5	SCADA	EPICS
6	Communication Protocol	EPICS CAS,MODBUS over TCP/IP,SCPI
7	Response Time	<b>5 microseconds</b> for fast protection system to switch of RF Power <b>200 microseconds</b> for Beam switch off

# EPICS & LEHIPA

Experimental Physics and Industrial Control System(EPICS) is an open source system which is widely used in acclerators across the world.

LEHIPA Control System uses EPICS to

- Switch on and off all the power supplies remotely.
- Set current and voltage in the high voltage and high current power supplies.
- Read back RF power, temperature, humidity, Vaccum value, Valve status
- Set and readback of timing pulses.
- Ensure interlock of Klystron by reading back parameters of the klystron.
- Acquiring and presenting beam diagonistic data
- Sequencing complex repeatative actions

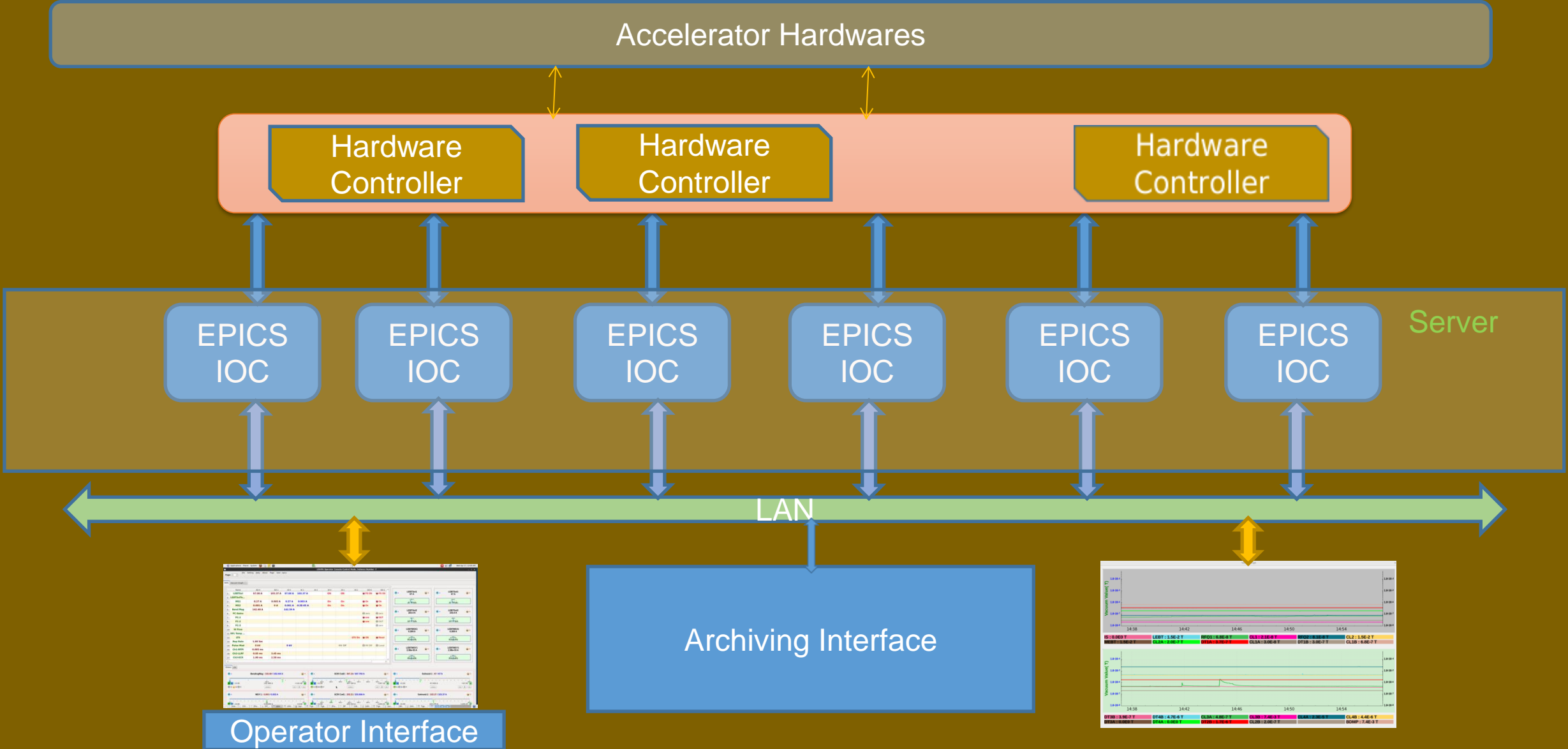
# EPICS & LEHIPA

LEHIPA Control System uses EPICS to achieve distributed control

- Each subsystem has its own IOC, which is running in the Raspberry Pi / cPCI crate or linux PC.
- LEHIPA operator interface is custom SCADA for LEHIPA. It is a customized EPICS tool which interacts with field IOCs to set the field values applied by the operator and present the readback to the operator in a meaningful way.
- Development is in an advanced stage to deploy EPICS Sequencer to automate RF conditioning in RFQ.



# LEHIPA Architecture



# EPICS Statistics

Sr No	Parameter	Count
1	EPICS Version	3.14
2	Number of IOCs	12
3	Number of Pvs	>150
4	Protocols	Modbus over TCP/IP, SCPI
5	Data acquisition mode	Periodic Scanning and IO Interrupt

# EPICS in use :LEHIPA Timing System

LTS Version2

## LEHIPA Timing System

Edit     ENABLE Timing System     Reset    Trip: **High**

Master ON / OFF    ON    Time Period: 1.00    1.00 sec    Rep. Rate: 1.00 Hz

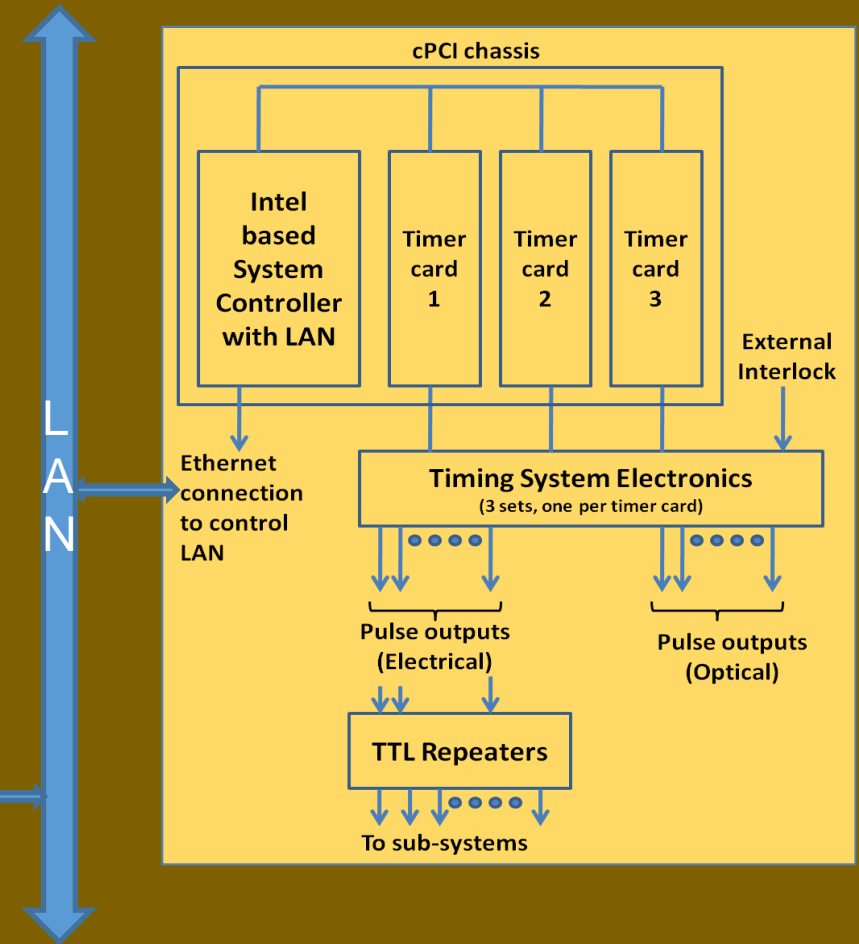
	Delay	Delay (RB)	On Time (Set)	On Time (RB)
<input checked="" type="checkbox"/> RHVPS2    ON	2.00	2.00 msec	300.00	300.00 msec
<input checked="" type="checkbox"/> RHVPS3    ON	2.00	2.00 msec	300.00	300.00 msec

Common Delay: 280.00    280.00 msec

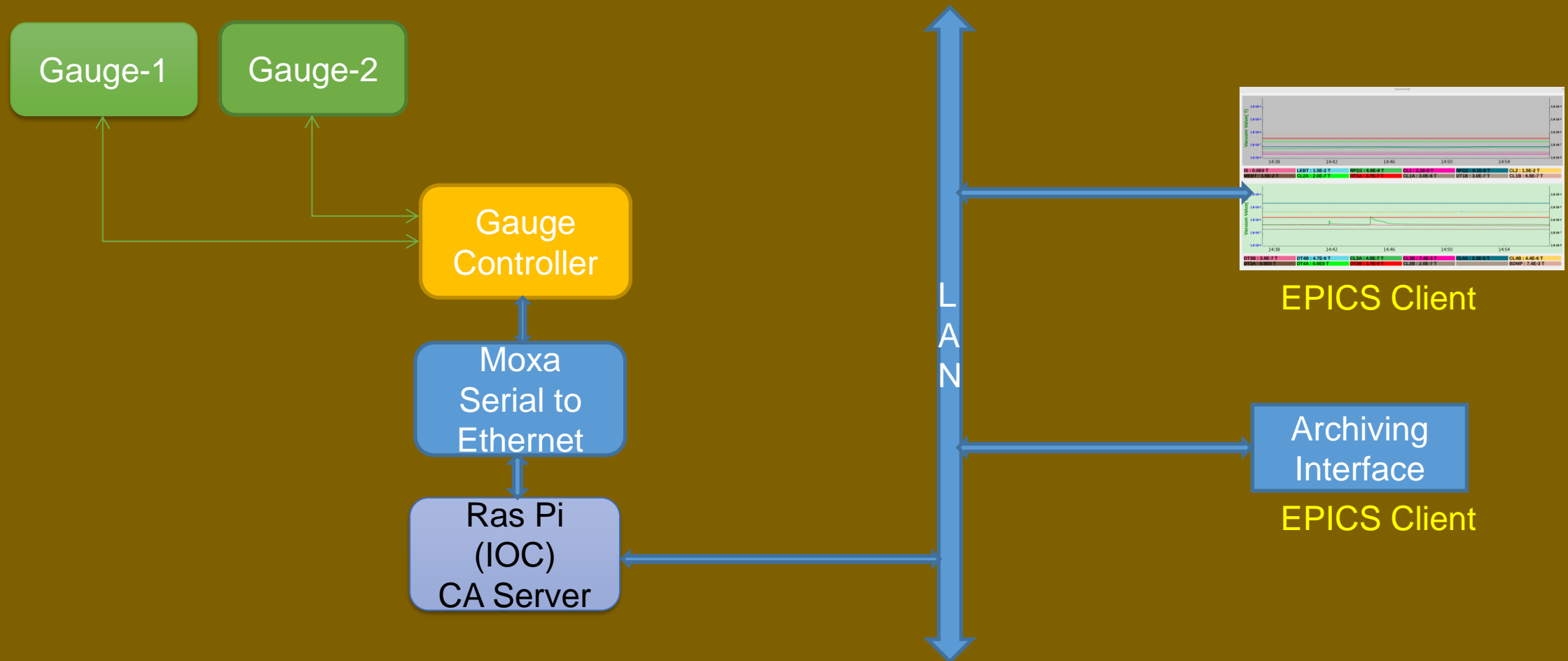
	Additional Delay	Effective Delay	On Time
<input checked="" type="checkbox"/> Pul-Mod    ON	0.001	280.001 msec	0.400    0.400 msec
<input checked="" type="checkbox"/> Ion Source    ON	0.001	280.001 msec	1.000    1.000 msec
<input checked="" type="checkbox"/> RFQ RF    ON	0.001	280.001 msec	0.010    0.010 msec
<input checked="" type="checkbox"/> Buncher RF    ON	0.001	280.001 msec	0.050    0.050 msec
<input checked="" type="checkbox"/> DTL-10 RF    ON	0.001	280.001 msec	0.050    0.050 msec
<input checked="" type="checkbox"/> DTL-20 RF    ON	0.001	280.001 msec	0.050    0.050 msec

Settings Files

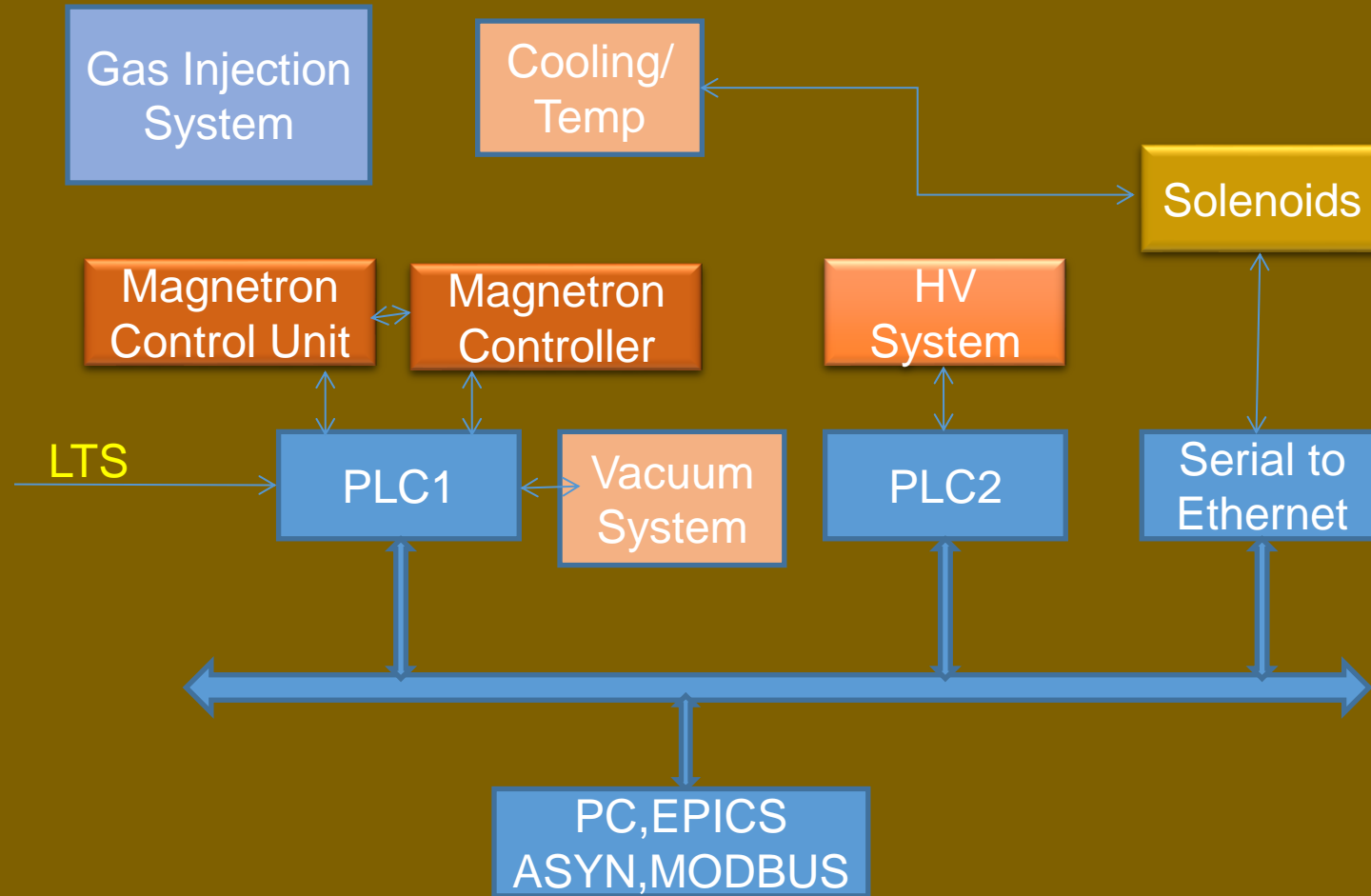
Contact Deepak Mathad(26893) for hardware issues, A Basu(23473) for software issues. Program running since : Fri Mar 10 16:19:32 2023



# EPICS in use : Vacuum Gauge Reading



# EPICS in use : Ion Source Control



# EPIC in use: Klystron Protection System – interface with PLC

HPRFA-3 Interlock System (on powermonitor.dhcp)

### STATE

1 2 3 4 5

1 - DO0 Shutdown/IPOK

2 - DO1 LCW OK

3 - DO9 EMPS OK

4 - DO3 Fil OK

5 - DI8 HVOK & RF Enabled

IPS Fault Status DO11

RESET (DO6)

### EMPS-1

DevID: LAMBDA,GEN300-11

Status: ON

Set Voltage: 266.37 V

Output Voltage: 243.49 V

Set Current: 9.64 A

Output Current: 9.64 A

### EMPS-2

DevID: LAMBDA,GEN300-17

Status: ON

Set Voltage: 237.86 V

Output Voltage: 195.18 V

Set Current: 8.60 A

Output Current: 8.60 A

Live	Parameters	Latched
	Ion Pump PS status	
8.633	Collector Flow	
2.407 Unit	RF Load Flow	
	Body LCW Flow	
	Cavity LCW Flow	
	Circulator LCW Flow	
2.373 Unit	LCW IL Temp	
2.490 Unit	Body OL Temp	
8.714 Unit	EMPS-1 Current	
5.029 Unit	EMPS-2 Current	
6.521 Unit	Filament Current	
6.692 Unit	Filament Voltage	
	RHVPS-3 Status	
	Reserved	

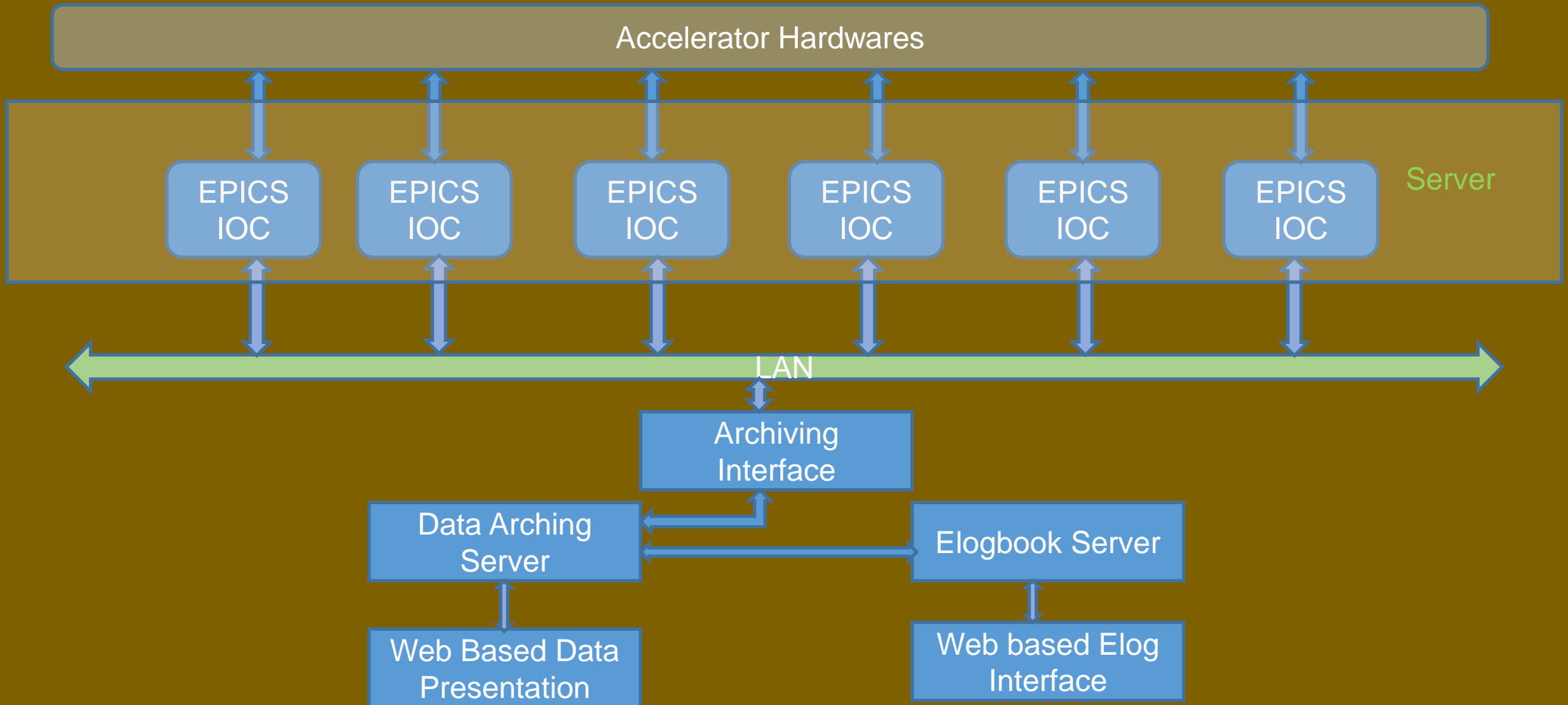
## EPICS in Use: LEHIPA Data Archiver

EPICS provide a data archiver as a part of its application toolkit.

However a custom data archiver is developed in LEHIPA

- It is written in Python using pyEPICS.
- MongoDB is used as the database
- Currently time series data is being archived.
- An event base archiving scheme is under design.

# LEHIPA Data Archiver Architecture





# LEHIPA Data Archiver-Salient Points

- Data is archived in a RAID server. Server is a 2 X 8 TB Network Attached Storage(NAS) with RAID level 1 ( data mirroring).
- The storage disk is hot swappable.
- Server runs on Cent OS-8.
- MongoDB is used as the NoSQL database.
- Database system is configurable by the system admin to add new parameters as and when required.
- Data is saved as BSON format in database.
- Currently it takes approximately 35 millisecond to access 120 PV and push them in the mongoDB database.
- A web-based data retrieval system is designed in node.js . This system is multiuser and is used to access vital data via browser.

# EPICS Client-LEHIPA Operator Interface

LEHIPA Operator Console-Control Mode. Instance Number -7

Page: 2

Hello Vacuum Graph

	Name	AO-0	AO-1	AI-0	AI-1	AI-2	DI-0	DI-1	DI-2	DO-0	DO-1
1	ECR Coi11				205.16 A			ON		ON	REM
2	ECR Coi12				362.29 A			ON		ON	REM
3	ECR 6kv	2.03 kV		2.04 kV			HVOn	VMode		HVOn	
4							Ok	NoFault		Remote	
5	ECR 60kv	50.08 kV		50.07 kV			HVOn	VMode		HVOn	
6							Ok	NoFault		Remote	
7											
8	VAC IS				5.4E-06 Torr						
9	FIL MTRN						Ready			Fil On	
10	PWR MT...	0.50 kW					Mwave On			Mtron On	
11	RST MTRN						Mtron No Fault			No Reset	
12	Vac Viv1						Check PLC			Closed	
13	IN TEMP			15.69							
14	OUT TEMP			18.51							
15											
16											
17											

LEBTSol1 60.68 A

LEBTSol2 104 A

LEBTMSX1 0.2161 A

LEBTMSY1 0.08497 A

Sliders LTS

BendingMag : 148.08 / 146.729 A

Solenoid-1 : 60.68 / 60.68 A

Solenoid-1 : 60.68 / 60.68 A

MTRON PWR Level : 2.5 / 0.5 kW

Solenoid-2 : 104.01 / 104.01 A

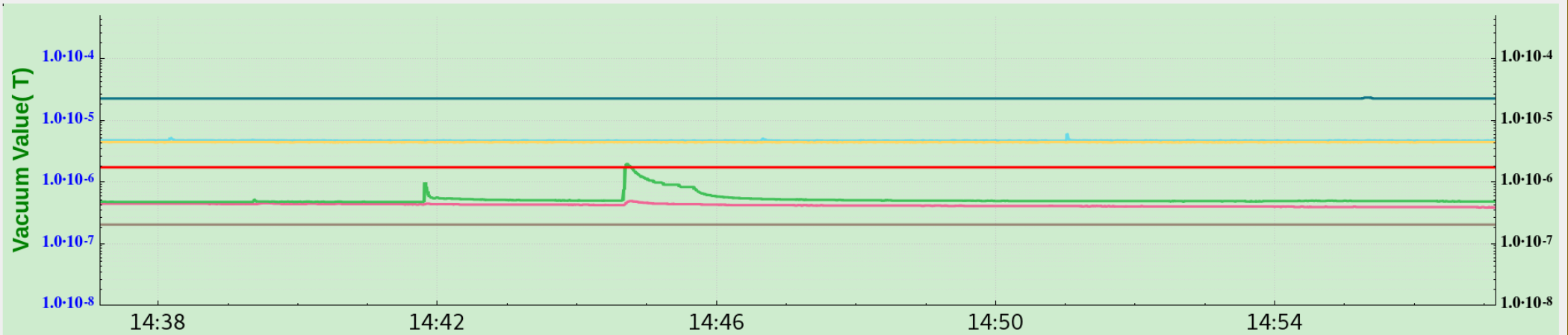
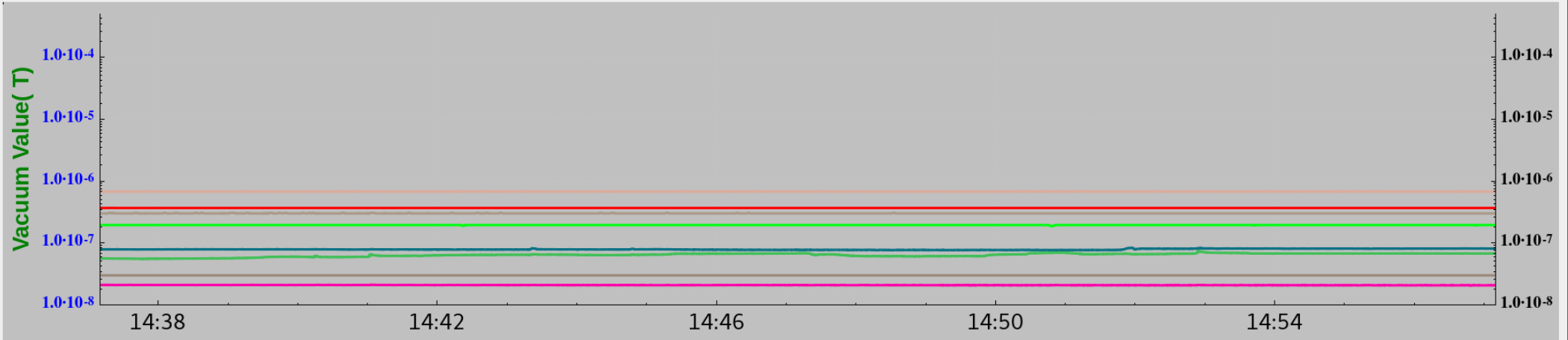
MSX-1 : 0.216 / 0.216 A

RF Po... [Interl... [CS-St... [Progr... [FP\_R... [LEHIP... [LEHIP... [epics... [LEHIP... [Tiger... [Tiger... [LEHIP... [Tiger... [Tiger... [Scre... [accel...

1. Built Using EPICS-Qt
2. Tables, sliders and buttons are fully configurable in every aspect

# EPICS Client Vacuum Data Chart

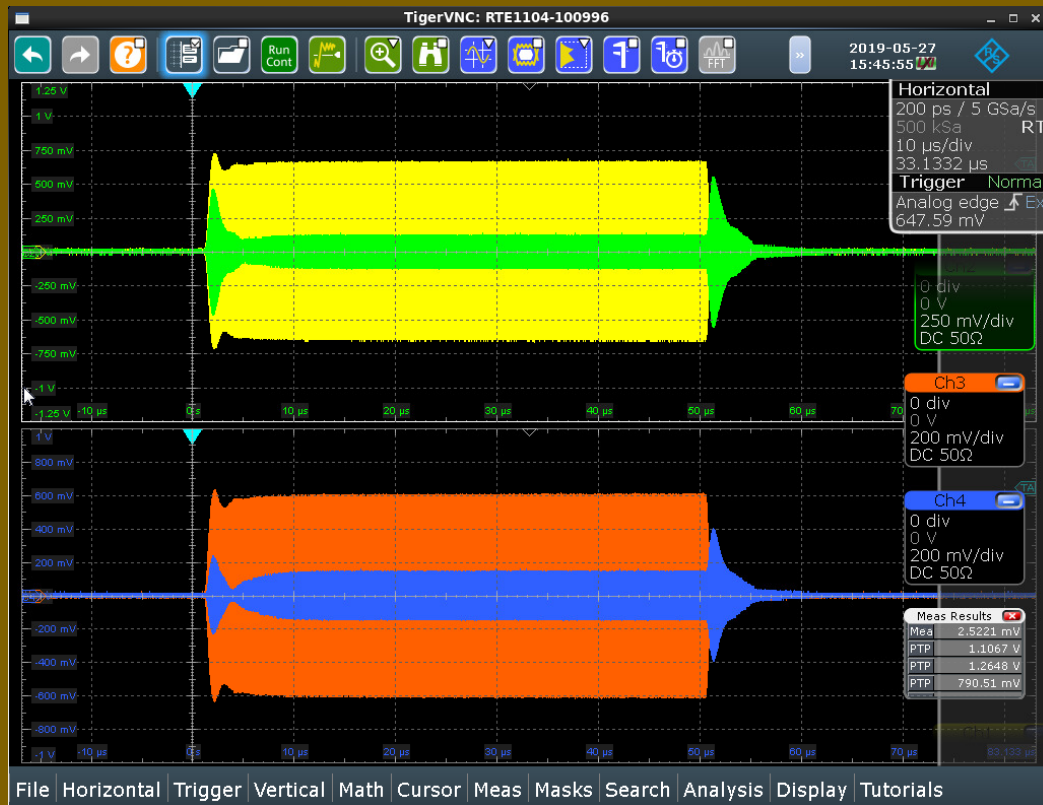
VacuumGraph



## EPICS Sequencer in LEHIPA

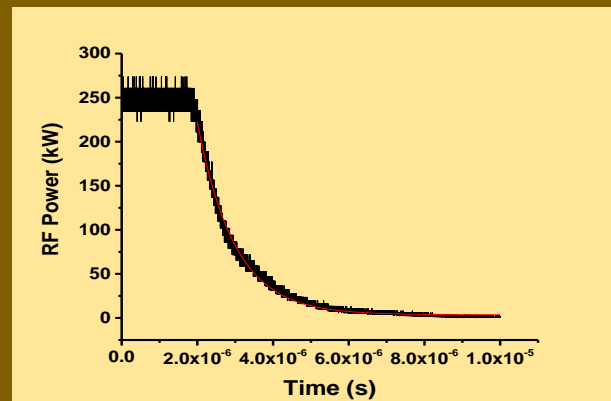
- Sequencer is a very powerful feature of EPICS
- Many of the regular acclerator operations can be automated using EPICS sequencer.
- Automated operation enhances the safety of operation.
- LEHIPA is currently testing a EPICS sequencer to automatically RF condition the RFQ
- Upon successful deployment of the RF conditioning sequencer, more such sequencers will be developed and deployed.

# High power RF Conditioning of RFQ (Operator Driven)



- Required power level to be 520 kW to have nominal design voltage of 68 kV.
- Forward & Reflected powers are continuously monitored.

Parameter	Value
RF Pulse	352 MHz, 50 μs, 1 Hz
RFQ RF Power	600 kW (FP)-80 kW (RP)
$Q_L$	2200

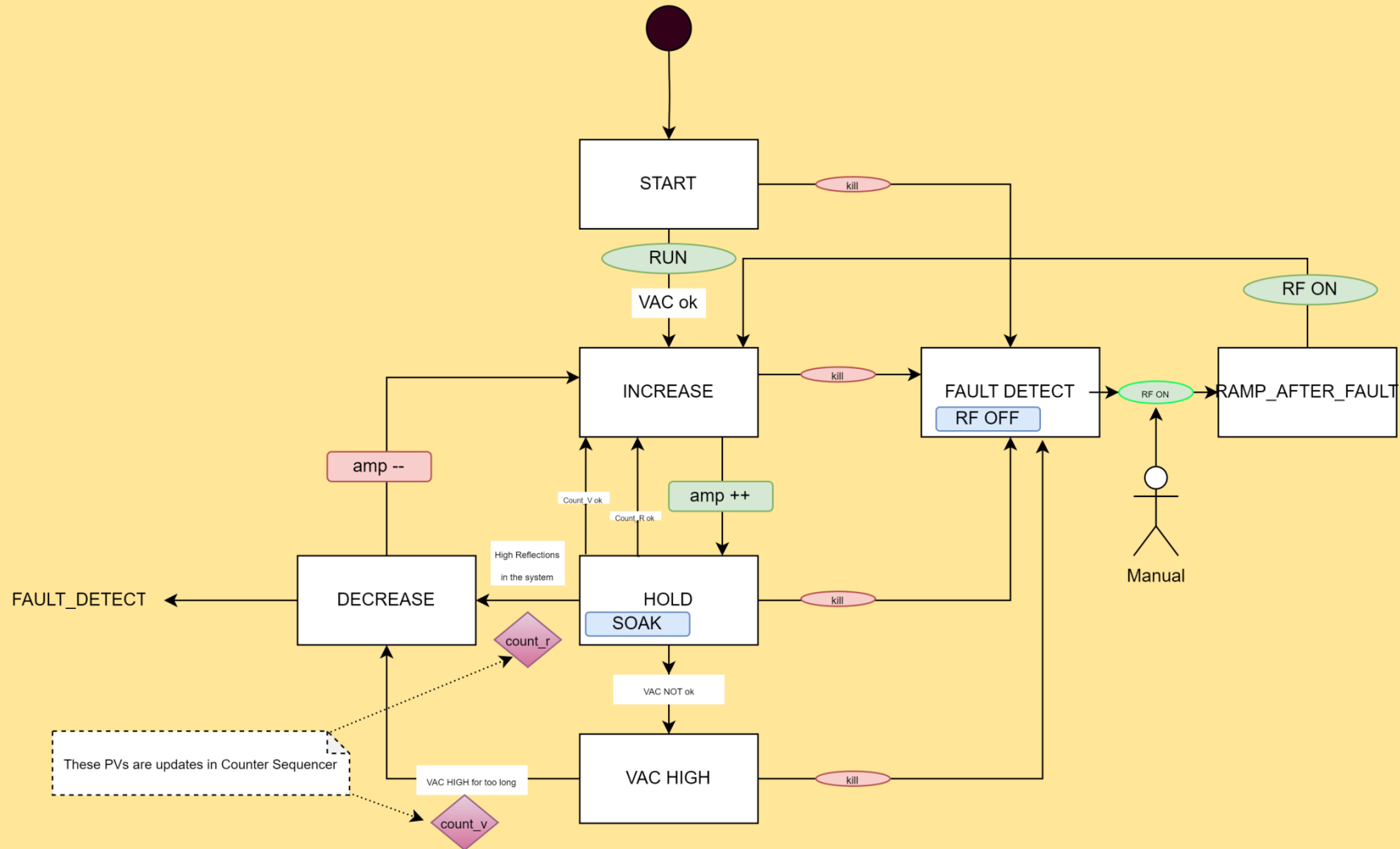


# LEHIPA Interlock Monitor

Interlock Monitor					
En/Disable	Chk Param	Relation	Setpoint	Action	Taget Param
<input checked="" type="checkbox"/> Enabled	LEBT	Select	1e-09	Sw Off	LTS Power
<input checked="" type="checkbox"/> Enabled	RFQ1	Select	1e-05	Sw Off	LTS Power
<input checked="" type="checkbox"/> Enabled	CPLR1	Select	5e-06	Sw Off	LTS Power
<input checked="" type="checkbox"/> Enabled	CPLR2	Select	1.6e-05	Sw Off	LTS Power
<input checked="" type="checkbox"/> Enabled	CPLR1_Fwd_Pwr	Select	300	Select	Select
<input checked="" type="checkbox"/> Enabled	CPLR1_Rfl_Pwr	Select	75	Select	Select
<input checked="" type="checkbox"/> Enabled	IS	Select	5e-05	Select	Select
<input checked="" type="checkbox"/> Enabled	MEBT	Select	1.6e-05	Select	Select

- **1) Acts as the soft interlock.**
- **2) It acts as the vacuum interlock.**
- 3) Essential during operator driven RF conditioning.

# LEHIPA RFQ Conditioning Sequencer

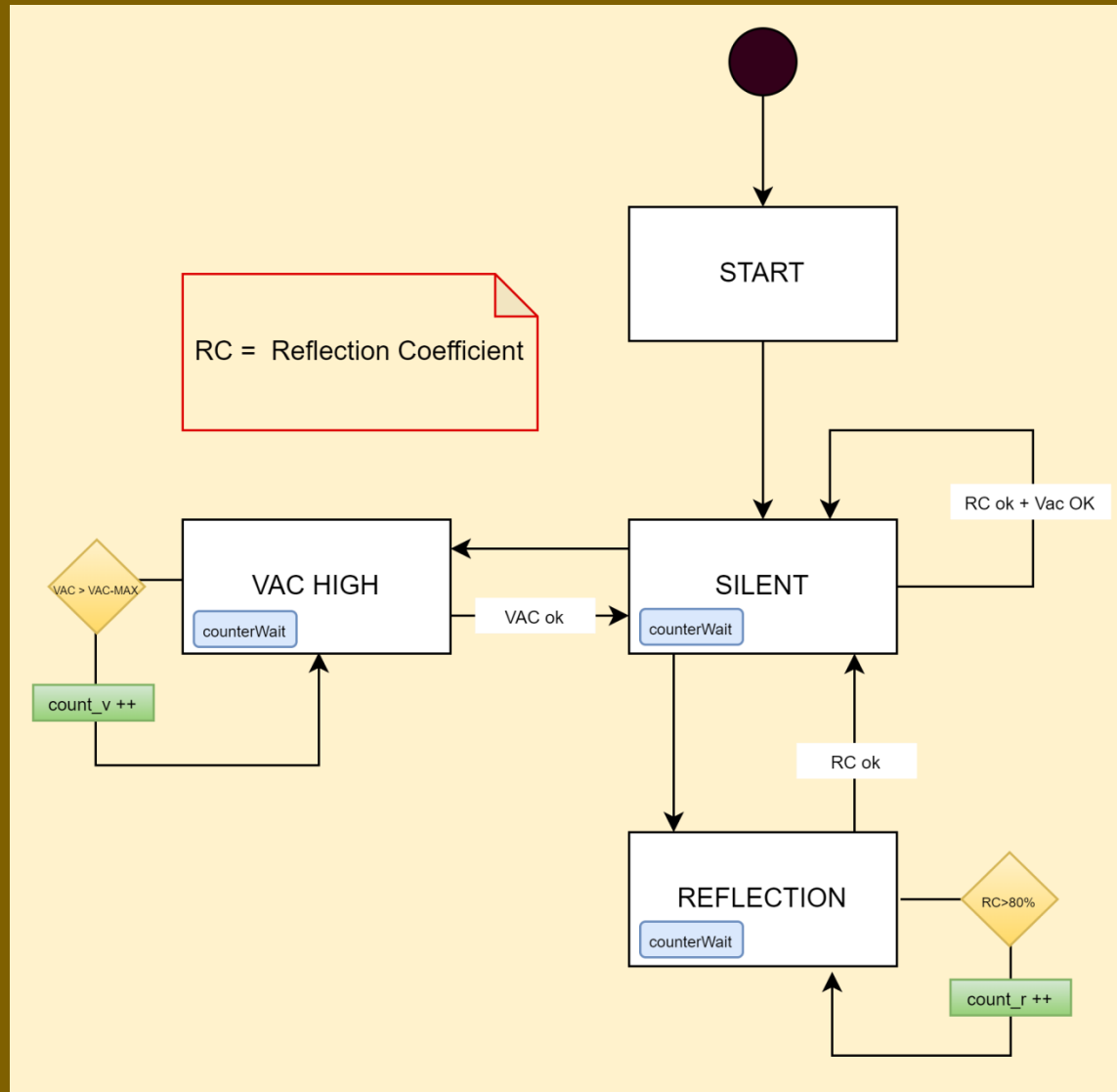


## MONITORING PV

Run, Kill  
 Count\_v  
 Count\_r  
 SoakTime  
 Amplitude –  
 SignalGenerator  
 RF enable  
 stepIncrement

Refresh Rate = SoakTime

# LEHIPA RFQ Counter Sequencer



**MONITORING PV**

- Count\_v
- Count\_r
- CounterWait
- Field Vacuum
- Field Reflected/Forward power

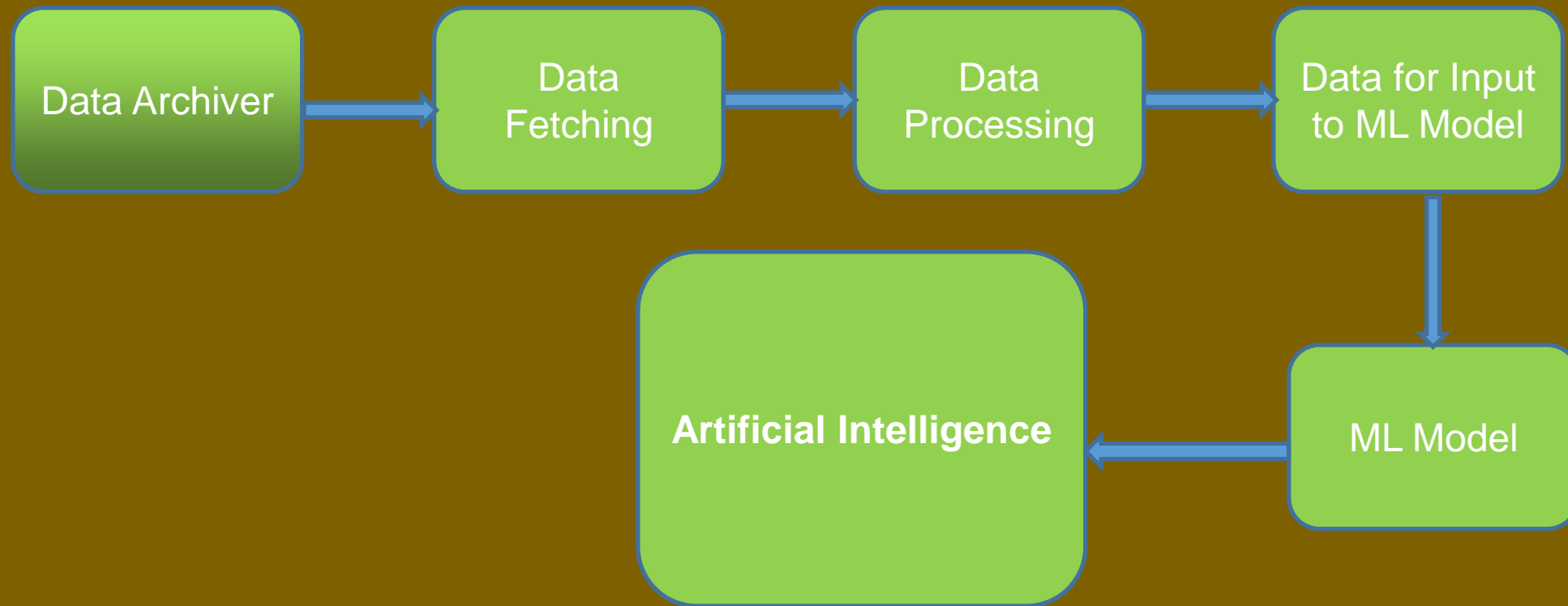
Refresh Rate = counterWait



# Future Plans

- IOC in docker container
- Hot standby redundant IOC
- Accessing radiation data in EPICS
- Accessing Camera data in EPICS
- AI/ML analysis of archived data
- AI/ML based beam tuning

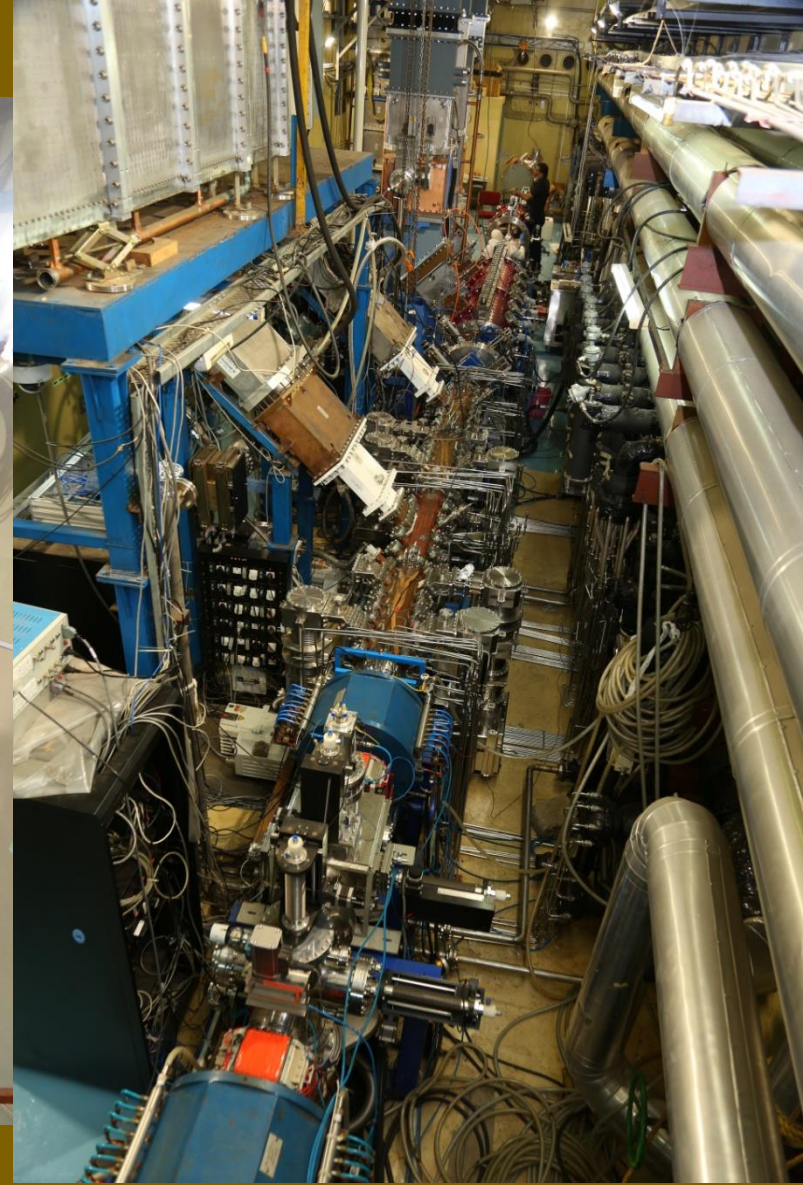
# AI ML Design in LEHIPA



# **Acknowledgement**

- 1) Shri Sudheer Kumar Singh**
- 2) Dr. Rajesh Kumar, Head IADD**
- 3) Deepak ,Bhumesh,Santhosh,Namrata,  
Laxman,Pravin**
- 3) Colleagues of IADD**
- 4) All the colleagues of the various other  
divisions of BARC**

# LEHIPA



**THANK YOU**