FLS2023, Lucerne

Pyapas: A new framework for High-Level Application development at HEPS

Xiaohan Lu, Yi Jiao

2023/08/29

HEPS, Beijing

Content

- HLA development requirements of HEPS
- *Pyapas* for HLA development at HEPS
- HLA development based on *Pyapas*
- Conclusion

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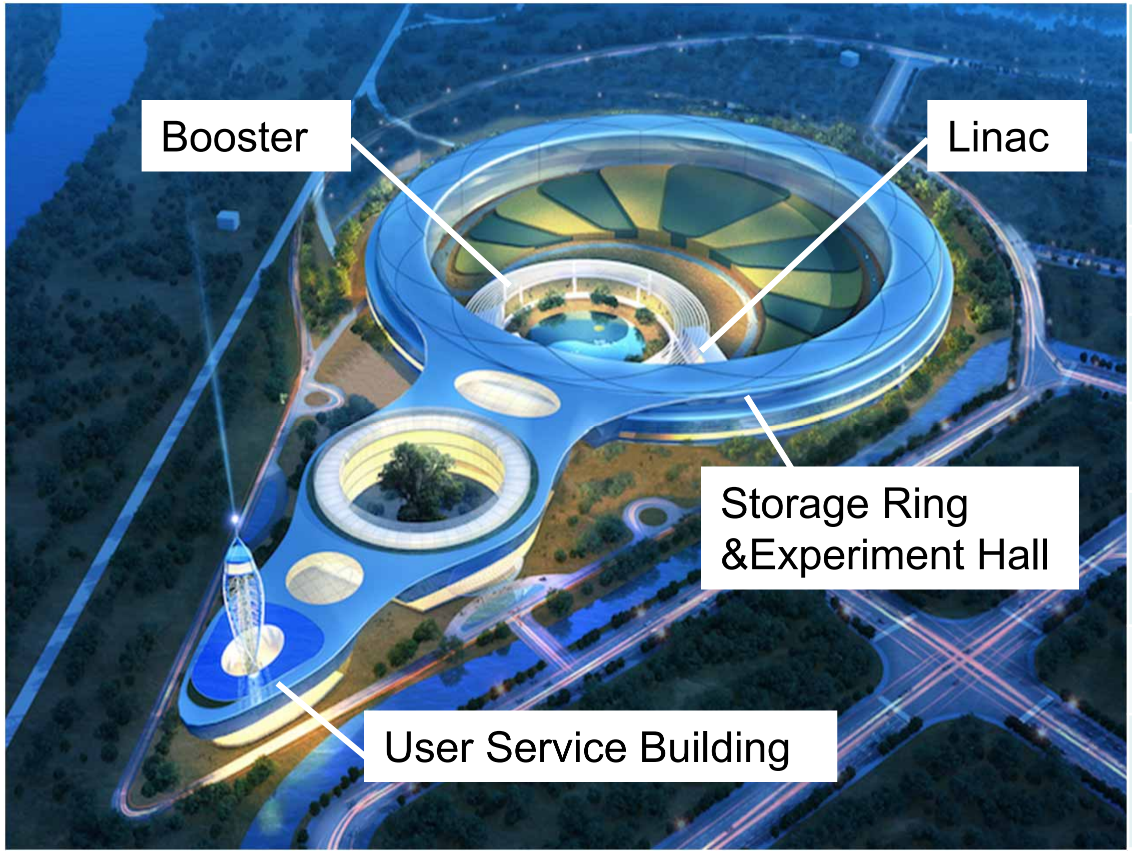
Introduction to HEPS

High Energy Photon Source

One of the world's brightest fourth-generation synchrotron light sources



	APS-U	ESRF-EBS	MAX-IV	Sirius	HEPS
E(GeV)	6	6	3	3	6
C(m)	1104	844.4	528	518	1360.4
Lattice	7BA	7BA	7BA	5BA	7BA
Cell	40	32	20	20	48
Emittance (pm*rad)	42	150	330	250	34
Brightness	$> 10^{22}$	$> 10^{22}$	$\sim 10^{21}$	$\sim 10^{21}$	$> 10^{22}$
Construction period	2018-2024	2015-2020	2010-2016	2015-2018	2019~2025

- ✓ The facility has the capacity for more than 90 high-performance beamlines and can provide X-rays with energy up to 300 keV
- ✓ The facility offers 10nm spatial resolution, 1MeV energy resolution, and picosecond time resolution for high-frequency dynamic detection

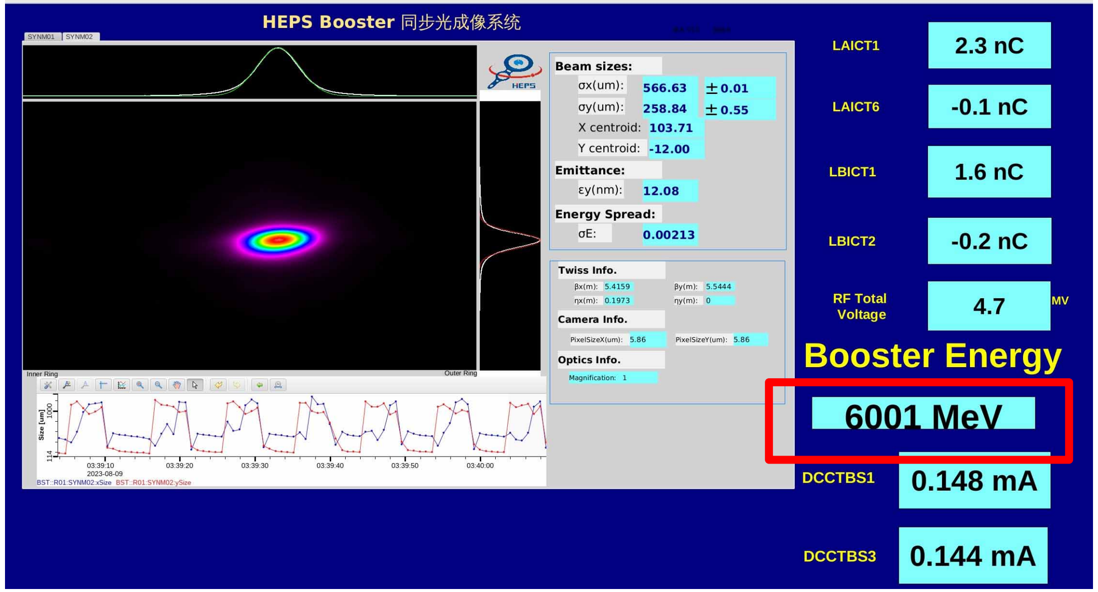
Milestones of HEPS Contruction and Beam Commissioning

- ✓ 2019.12, the physical design was frozen
- ✓ 2021.06, installation of the first equipment
- ✓ 2022.03, the tunnel installation of the Linac started
- ✓ pre-alignment installation of booster started
- ✓ 2022.05, Linac full-line vacuum sealing was completed
- ✓ 2022.08, the tunnel installation of the booster started
- ✓ 2022.09, high-power online conditioning completed
- ✓ 2023.01, booster full-line vacuum sealing was completed
- ✓ 2023.02, the ring tunnel installation started
- ✓ 2023.03, obtained radiation protection of the Linac and started beam commissioning
- ✓ 2023.06, completed process acceptance of the Linac
- ✓ 2023.07, beam commissioning of the booster started
- ✓ 2023.08, the energy of booster ramp to 6GeV

Cai Meng, this workshop, Poster ID: TU4P27

Comparsion of design and measurement parameters of Linac

Parameter	Unit	Design		Measurement	
		Mode1	Mode2	Mode1	Mode2
Pulse charge	nC	≥2.5	≥7.0	2.84±0.02	7.29±0.02
Energy	MeV	≥500	≥500	501.4	501.2
Energy spread	%	≤0.5	≤0.5	0.31	0.45
Energy stability	%	±0.25	±0.25	σ=0.014 peak-peak=0.04	σ=0.014 peak-peak=0.05
Repetition rate (Burst mode)	Hz	50	50	50 （10 pulse/s）	50 （10 pulse/s）
Geometric emittance	nm·rad	≤41	≤70	37.2（H） 36.9（V）	56.4（H） 58.5（V）



Courtesy of Cai Meng

The development requirements for HLA of HEPS

→The emittance is reduced by 1or 2 orders of magnitude, approaching the X-ray diffraction limit

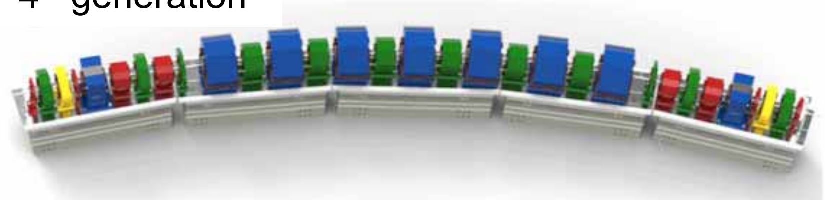
→The number of magnets increases by an order of magnitude

HEPS is currently the largest particle accelerator facility in the country.

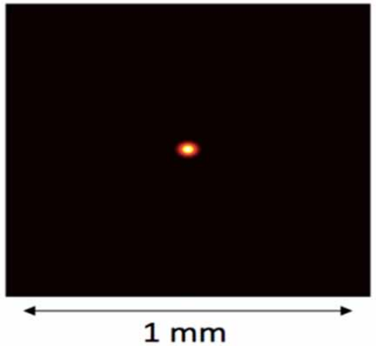
- High control complexity
- Large scale of control variables
- High precision control required
- Large number of HLAs required

3rd generation

4th generation

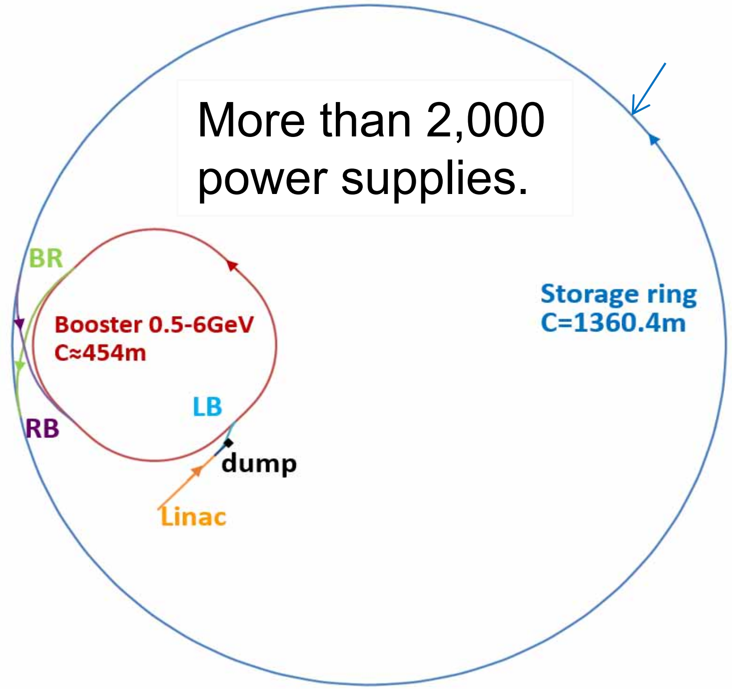


Layout



Beam Profile

More than 2,000 power supplies.

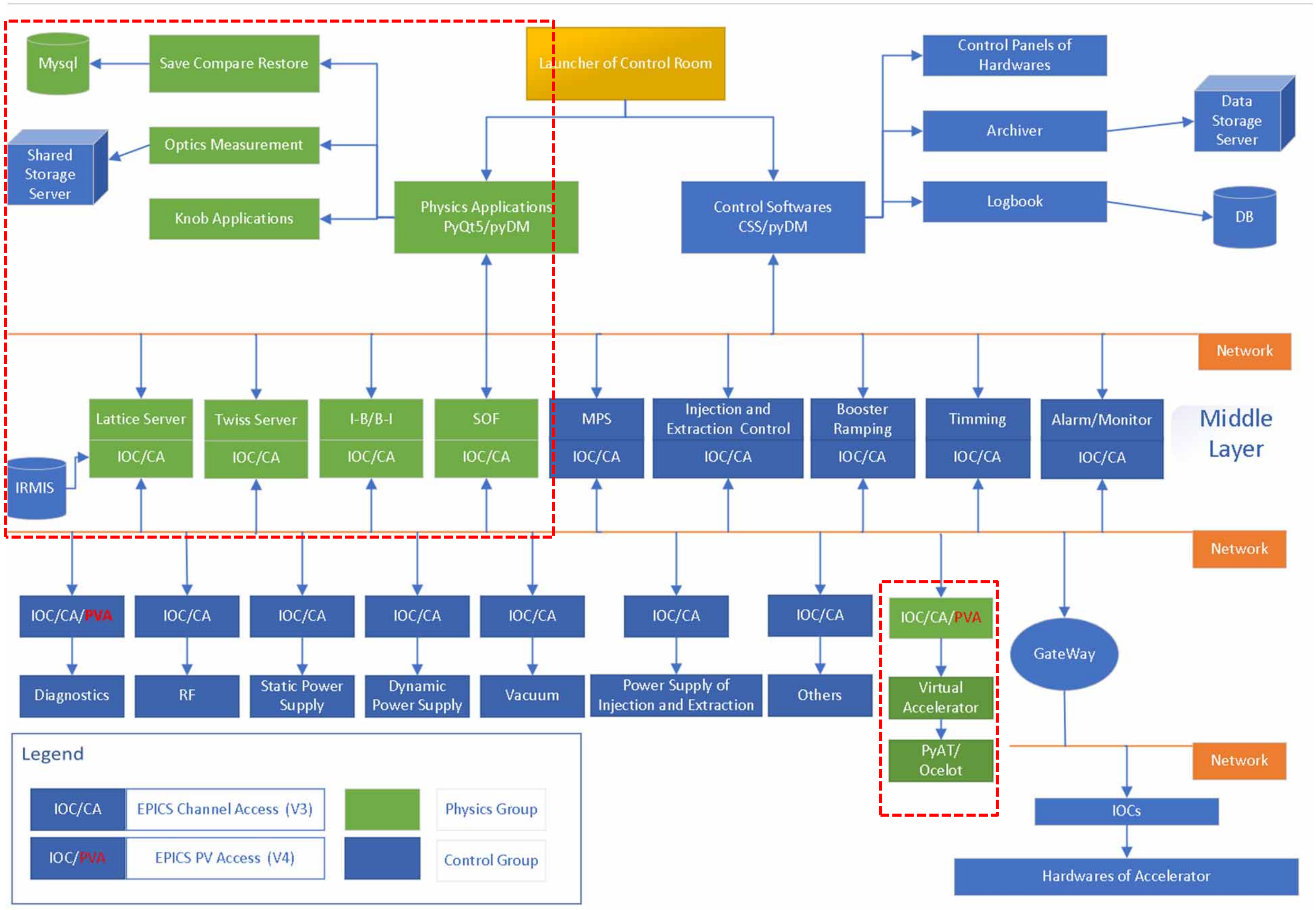


Overall control structure of HEPS

High level physical application focus more on physical process: optimization, simulation, feedback et.al.

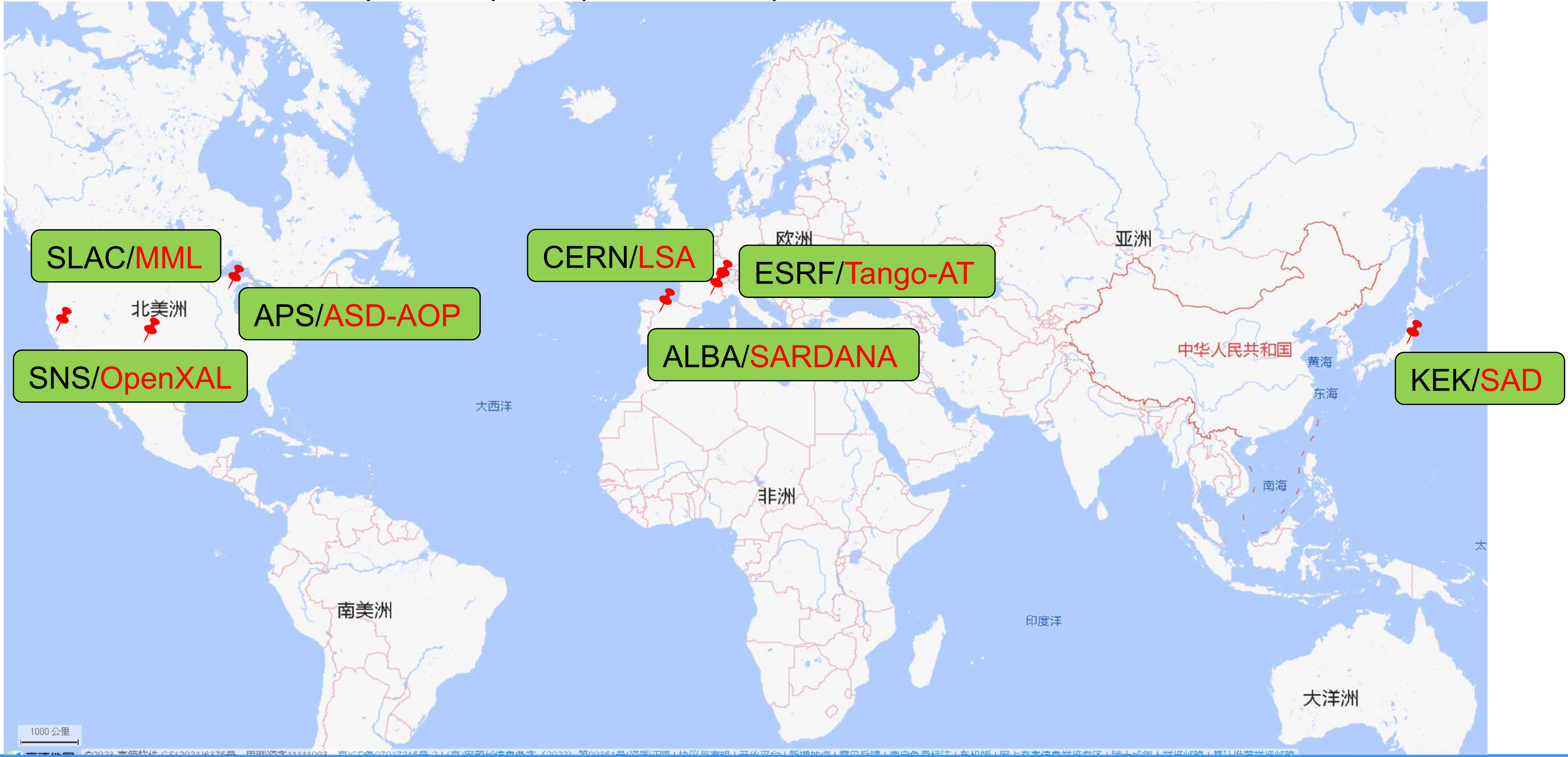
High Level Application (HLA)

- High control complexity
- Large scale of control variables
- High precision control required
- Large number of HLAs required
- **Focus on physical process**



Investigation on HLA Development Strategy

- ✓ Investigation of popular HLA strategies used by two or more laboratories over the past 20 years (not full list ..)



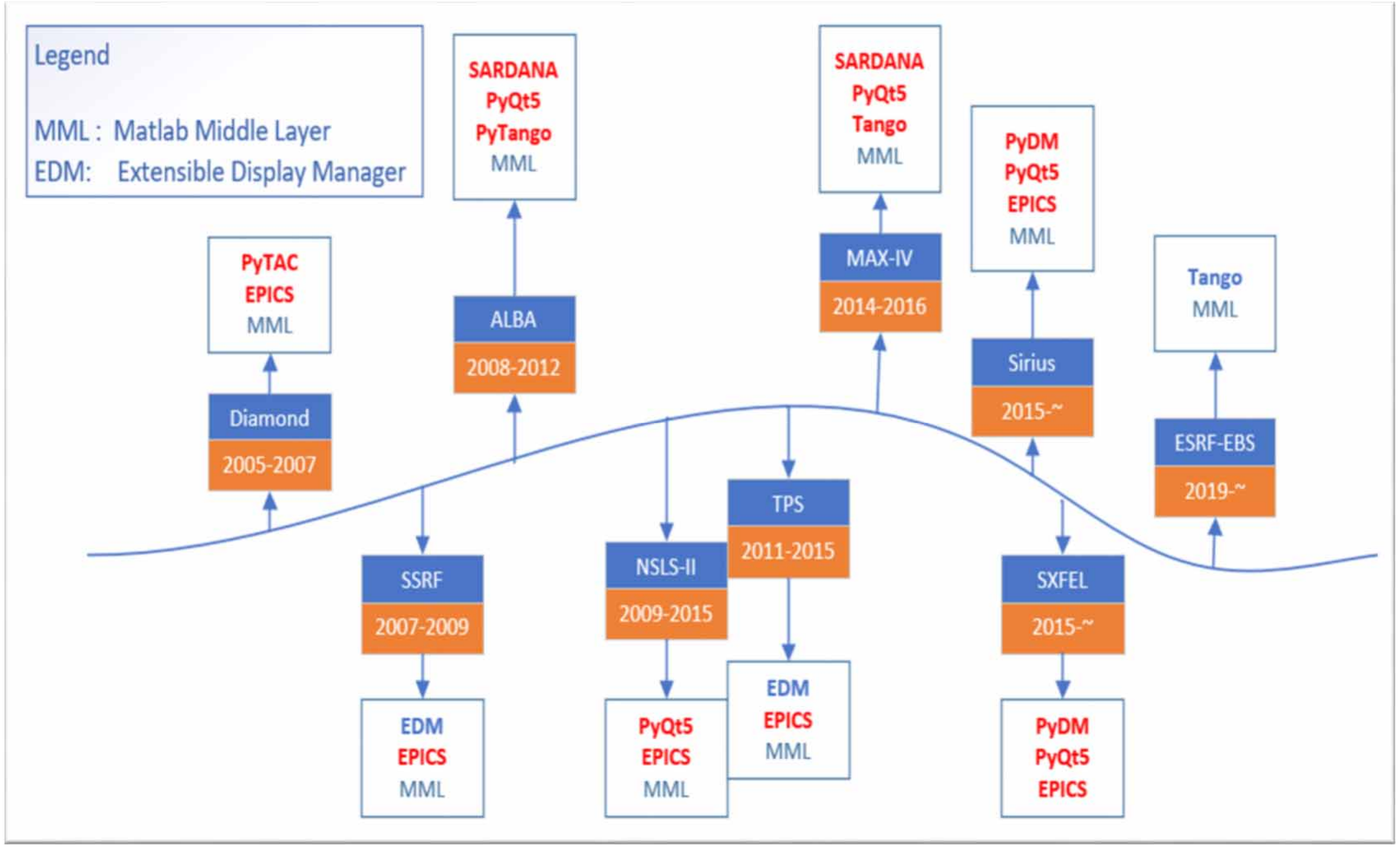
Investigation on HLA Development Strategy

Operational light sources of the world

SSRF
NSRL
BSRF

SXFEL

More and more control rooms are using Python



Source：https://lightsources.org/lightsources-of-the-world/

HLA development plan for HEPS

Stragety/ Framework	Language	GUI	Communication with Hardware	Physical model	Database	
ASD-AOP	C++/Fortran	Tk/Tcl	EPICS	Elegant	~	APS
SAD	C++/Fortran	Tk/Tcl	EPICS	SAD	~	KEK/**BEPC**
OpenXAL	Java	Swing	EPICS	Online model	Mysql	SNS/**CSNS**
LSA(CERN)	Java	Swing	EPICS	MAD	Oracle	CERN/DESY
MML-AT	Matlab	Matlab	EPICS	AT	Oracle	90% light source
Tango-AT	Java/Python	Swing/PyQt	Tango	AT	Mysql	ESRF/ALBA
SARDANA	C++/Python	Qt	Tango	AT	Mysql	ALBA/MAX-IV
						HEPS？？

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ASD-AOP	C++/Fortran	Tk/Tcl	EPICS	Elegant	~	APS
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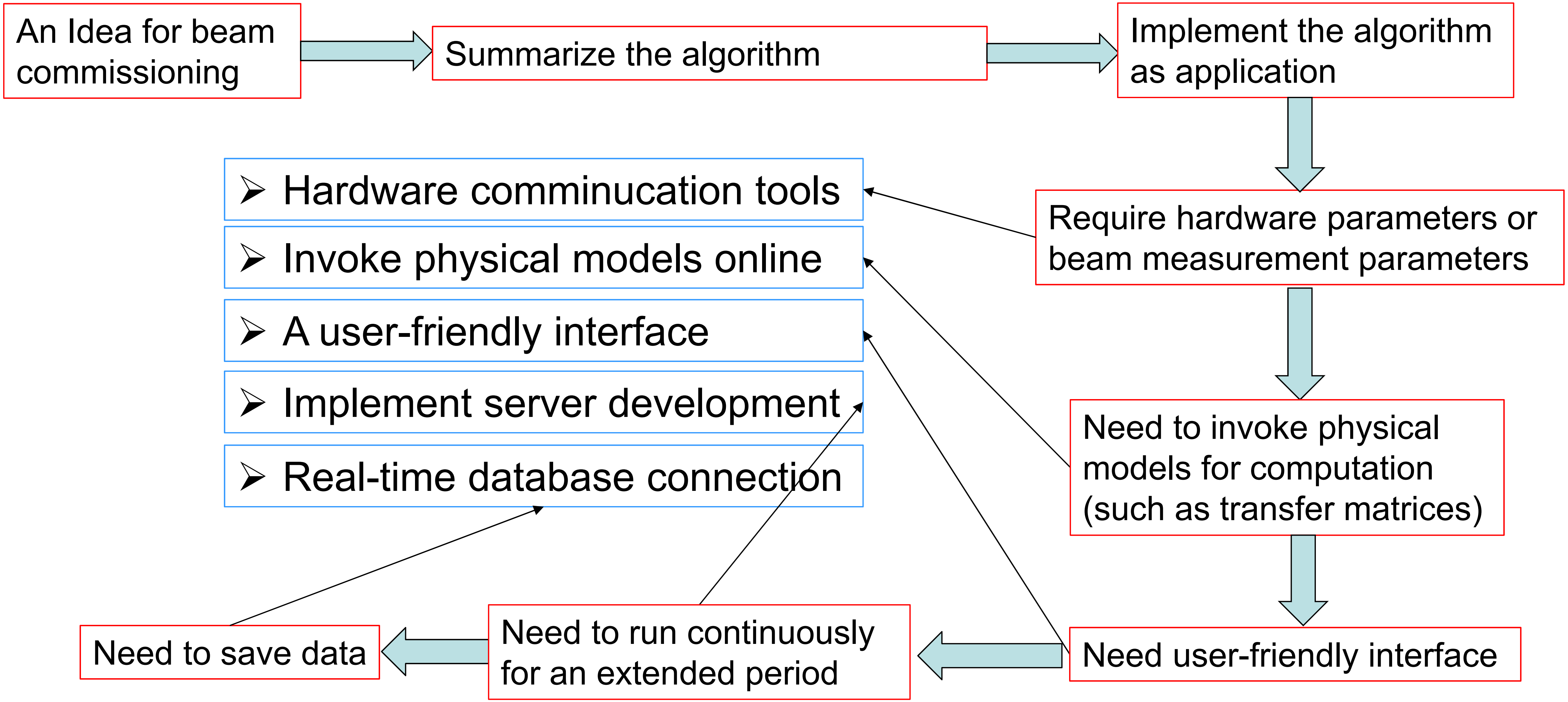
MML-AT	Matlab	Matlab	EPICS	AT	Oracle	90% light source
Tango-AT	Java/Python	Swing/PyQt	Tango	AT	Mysql	ESRF/ALBA
SARDANA	C++/Python	Qt	Tango	AT	Mysql	ALBA/MAX-IV
Pyapas	**Python**	**PyQt5**	**EPICS**	**Ocelot/pyAT**	**Mysql**	**HEPS**

- Porting the framework is almost as much work as building it from scratch with Python.
- MML is based on Matlab which is commercial software, not a budget-friendly option!
- **A Python-based framework will save lots of time.**

→ Develop a brand-new framework based on Python to develop HLA.

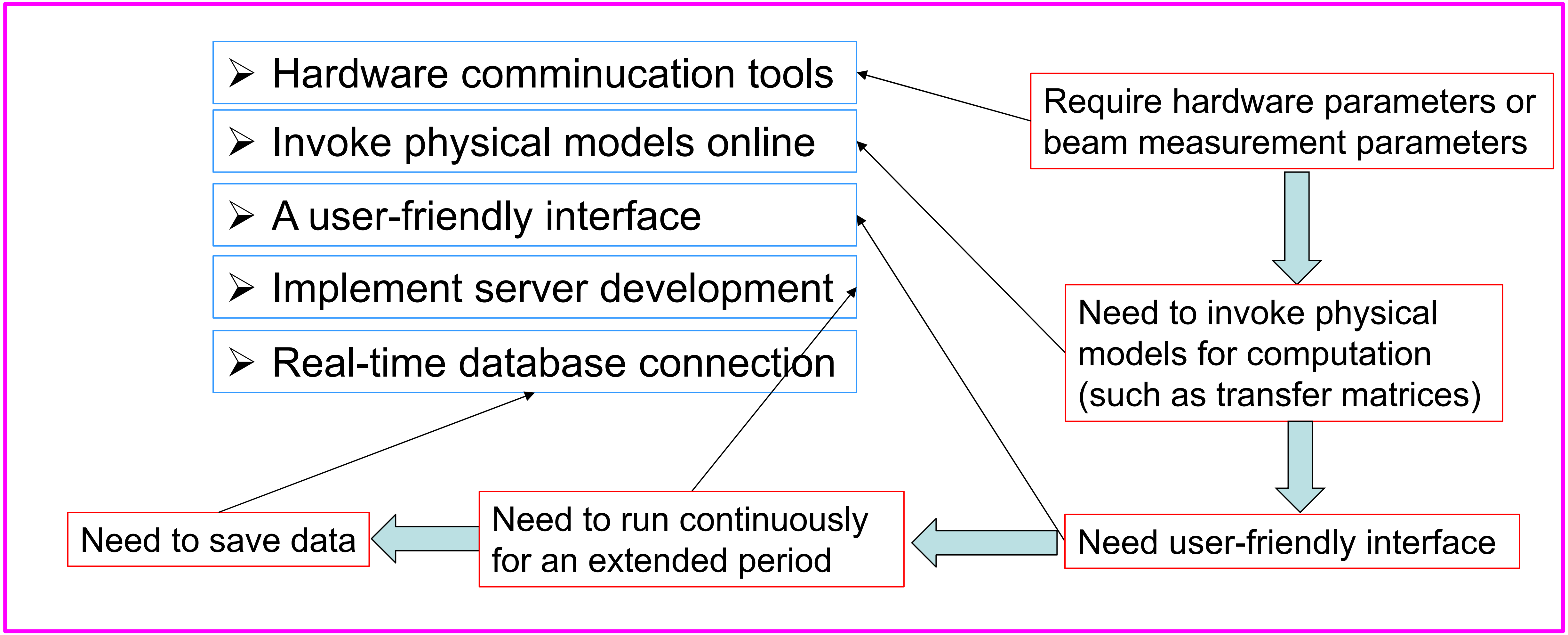
- HLA development requirements of HEPS
- *Pyapas* for HLA development at HEPS
- HLA development based on *Pyapas*
- Conclusion

HLA Requirements Analysis



HLA Requirements Analysis

For physics developers, the following steps are overly complex.
Independent development by each individual would be time-consuming



Strategy of HLA Development

An Idea for beam commissioning → Summarize the algorithm → Implement the algorithm as application

- Can physics developers focus only on these three steps?

↓

- Can the development process of HLA be simplified like this?

↓

- Design a new framework to handle the development process

↓

Pyapas

Strategy of HLA Development

- High control complexity
- Large scale of control variables

Efficient Real-Time Data Interaction System

Design a Singleton Factory Pattern for Real-Time Interaction Management

Algorithms

- Hardware comminucation tools
- Invoke physical models online
- A user-friendly interface
- Implement server development
- Real-time database connection

- Large number of HLAs required

Involves numerous tools, and the development process is time-consuming

Adopting modular design to save development time

- High control complexity
- High precision control
- Focus on physical process

Require various models for simulation

Low-coupling dual-layer physical module, capable of switching simulation algorithms

Physical application

- Focus on physical process

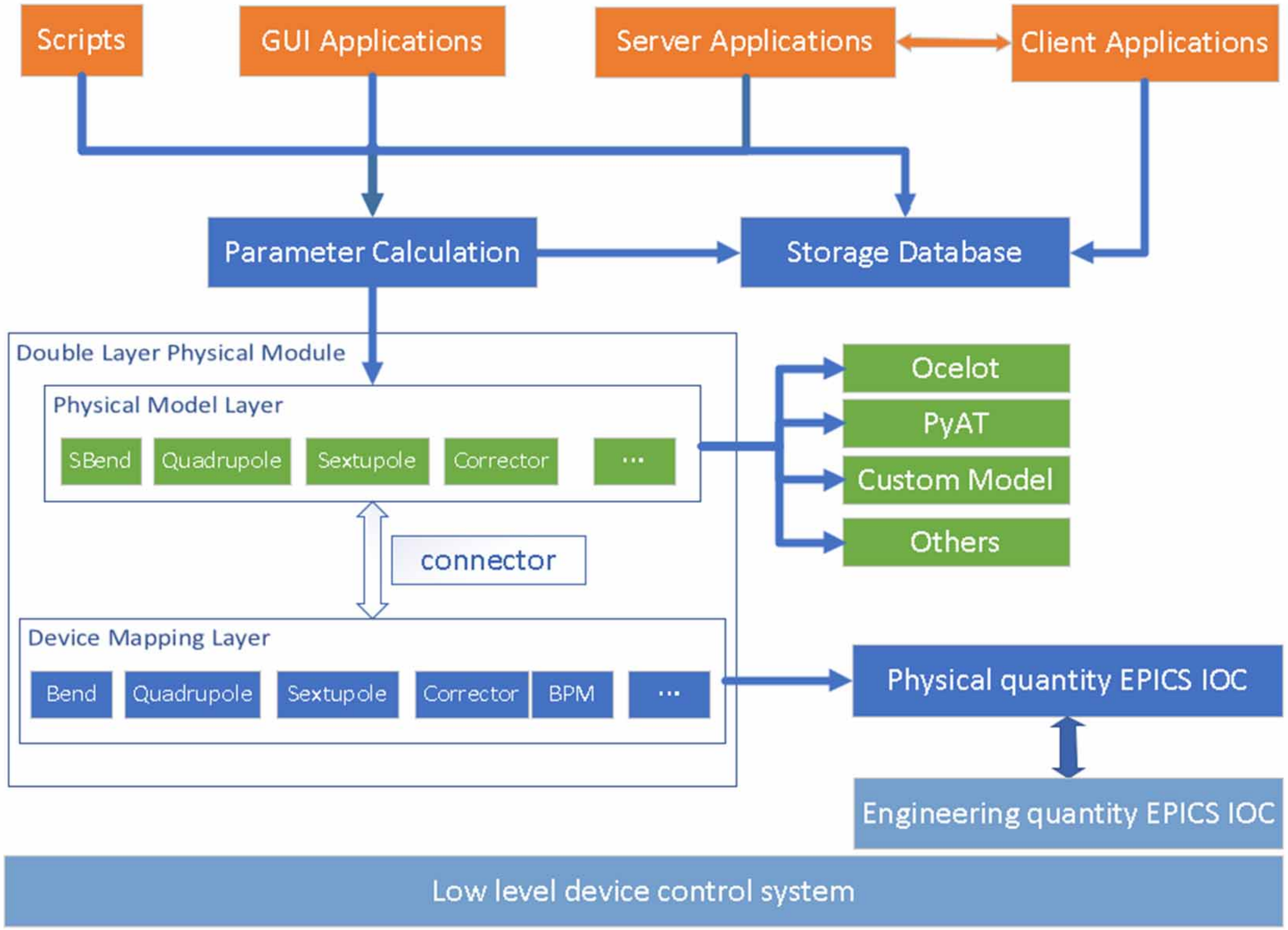
Physical application need to directly control physical quantities for more intuitive operation

Construct a conversion system from physical quantities to engineering quantities

Pyapas Architecture Design
(Python-based accelerator physics application set)

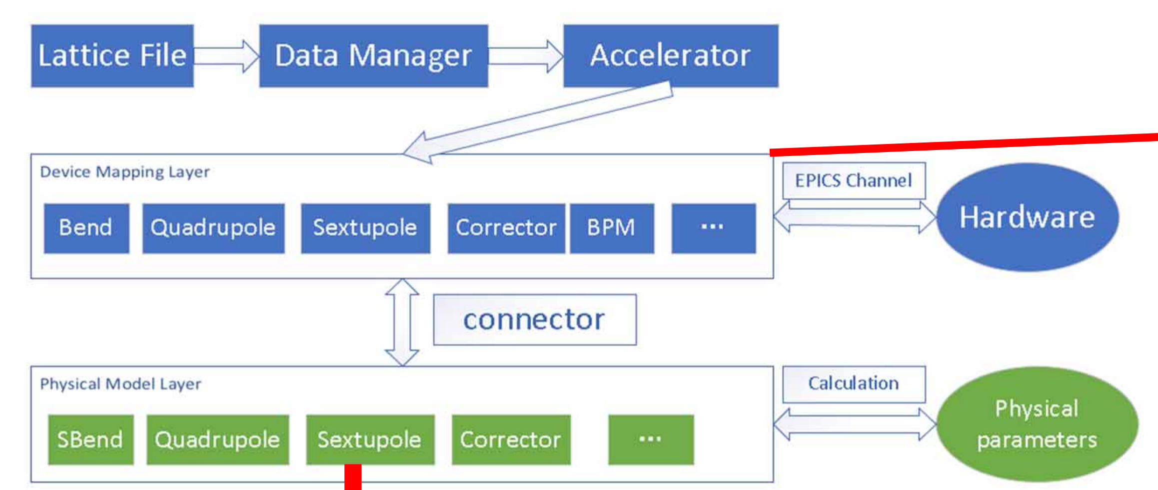
- ✓ Based on Physical Quantities
- ✓ Model-Based
- ✓ Modular Design

① Dual-layer physical module
② Friendly user interface module
③ Hardware communication module
④ Database connection module
⑤ Client-Server development module
⑥ Various phyiscal algorithm toolkits



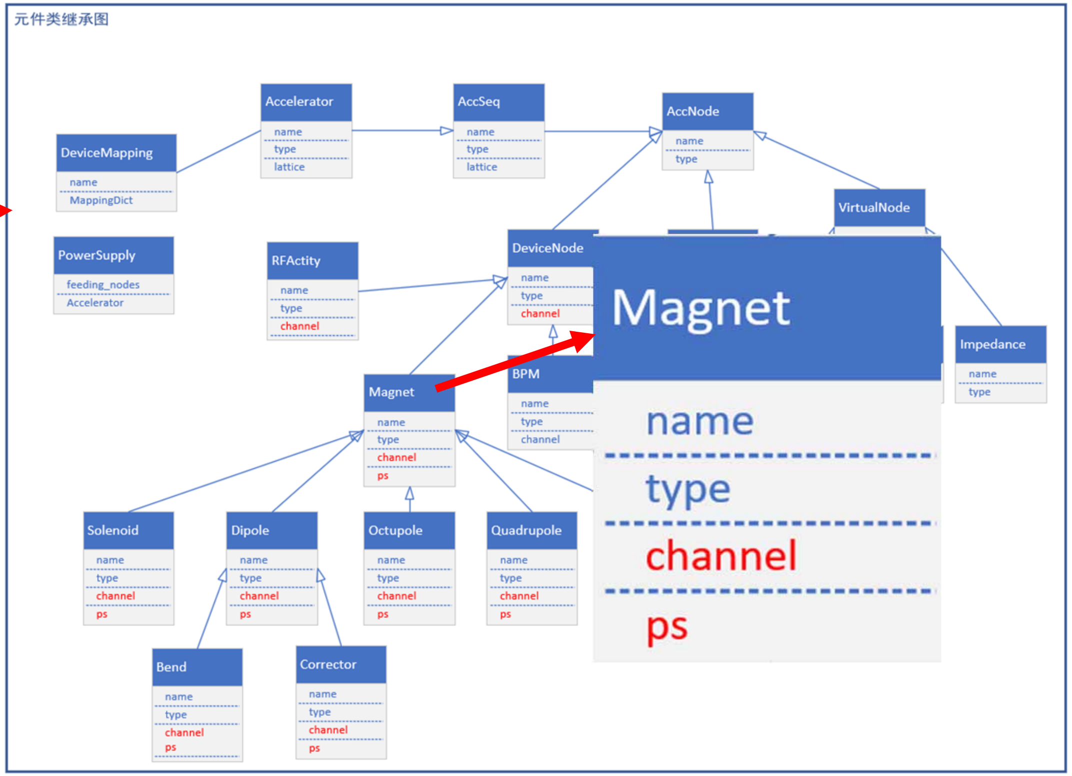
X. Lu et al., ICALEPCS2021, THPV047
X. Lu et al., IPAC2023, THPA125

Low-coupling dual-layer physical module



- Ocelot
- PyAT
- Custom model
- Others

The "Connector" is responsible for invoking simulation algorithms



The component class maps to the actual machine components

Not dependent on specific physical models, easy to extend

Physical model ⟷ Real machine

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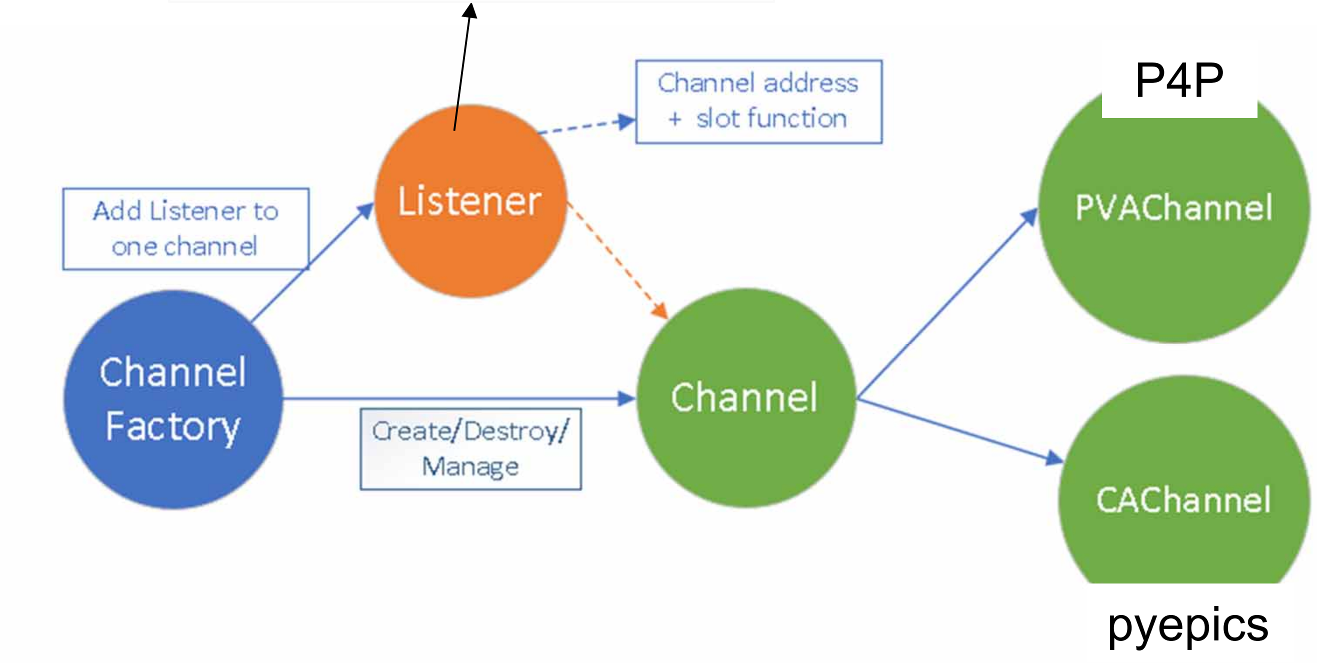
Real-time Data Interaction System

- Combining the design philosophies of **pydm** and **openxal**, design the communication structure of *pyapas* (active and passive channel data acquisition) ）

Monitor a specific channel



The Channel class contains the EPICS communication interface responsible for specific communication with the IOC

- ✓ Combining PyQt's signal-slot mechanism to achieve efficient real-time interaction
- ✓ The 'Singleton Factory Pattern' centrally manages interaction channels in the program, avoiding redundant creation and improving interaction efficiency."
- ✓ The channel factory has namespace functionality

	NodeName	xAvgChannel	Value	yAvgChannel	
1	R01BPM01	R:BI:R01BPM01:x	-0.00024846263641131787	R:BI:R01BPM01:y	0.0
2	R01BPM02	R:BI:R01BPM02:x	-0.0007405004049405429	R:BI:R01BPM02:y	0.0
3	R01BPM03	R:BI:R01BPM03:x	-0.0003863998687952148	R:BI:R01BPM03:y	0.0
4	R01BPM04	R:BI:R01BPM04:x	-5.57367509261469e-05	R:BI:R01BPM04:y	0.0
5	R01BPM05	R:BI:R01BPM05:x	0.00019363297907922127	R:BI:R01BPM05:y	0.0
6	R01BPM06	R:BI:R01BPM06:x	0.0003999152633156065	R:BI:R01BPM06:y	0.0
7	R01BPM07	R:BI:R01BPM07:x	-0.0002012937695207042	R:BI:R01BPM07:y	0.0
8	R01BPM08	R:BI:R01BPM08:x	-0.0003712213026685325	R:BI:R01BPM08:y	0.0
9	R01BPM09	R:BI:R01BPM09:x	0.0003782940324338285	R:BI:R01BPM09:y	0.0
10	R01BPM10	R:BI:R01BPM10:x	0.000246271410320288	R:BI:R01BPM10:y	0.0
11	R01BPM11	R:BI:R01BPM11:x	0.00023493524065263668	R:BI:R01BPM11:y	0.0
12	R01BPM12	R:BI:R01BPM12:x	-0.0004448539000907493	R:BI:R01BPM12:y	0.0
13	R02BPM01	R:BI:R02BPM01:x	-0.0008175793579582362	R:BI:R02BPM01:y	0.0
14	R02BPM02	R:BI:R02BPM02:x	-0.00023626437779320208	R:BI:R02BPM02:y	0.0
15	R02BPM03	R:BI:R02BPM03:x	7.631787448949901e-06	R:BI:R02BPM03:y	0.0
16	R02BPM04	R:BI:R02BPM04:x	0.000971139202285528	R:BI:R02BPM04:y	0.0

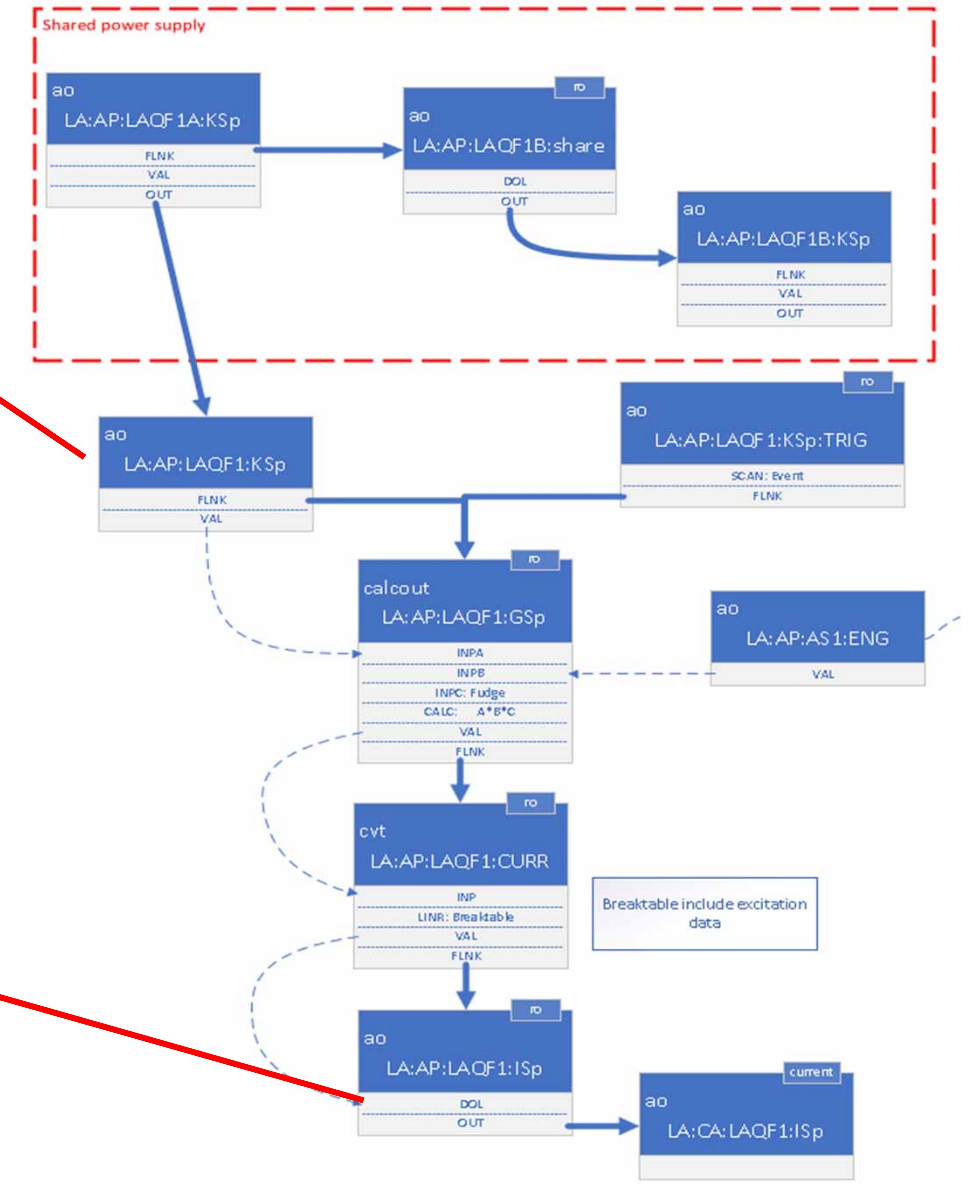
The same application can smoothly run while monitoring 10,000 PVs

Physical to Engineering Quantities Conversion System

Physical quantities:
Quadrupole K-value,
Corrector angle

cvt：
Excitation Data
Conversion

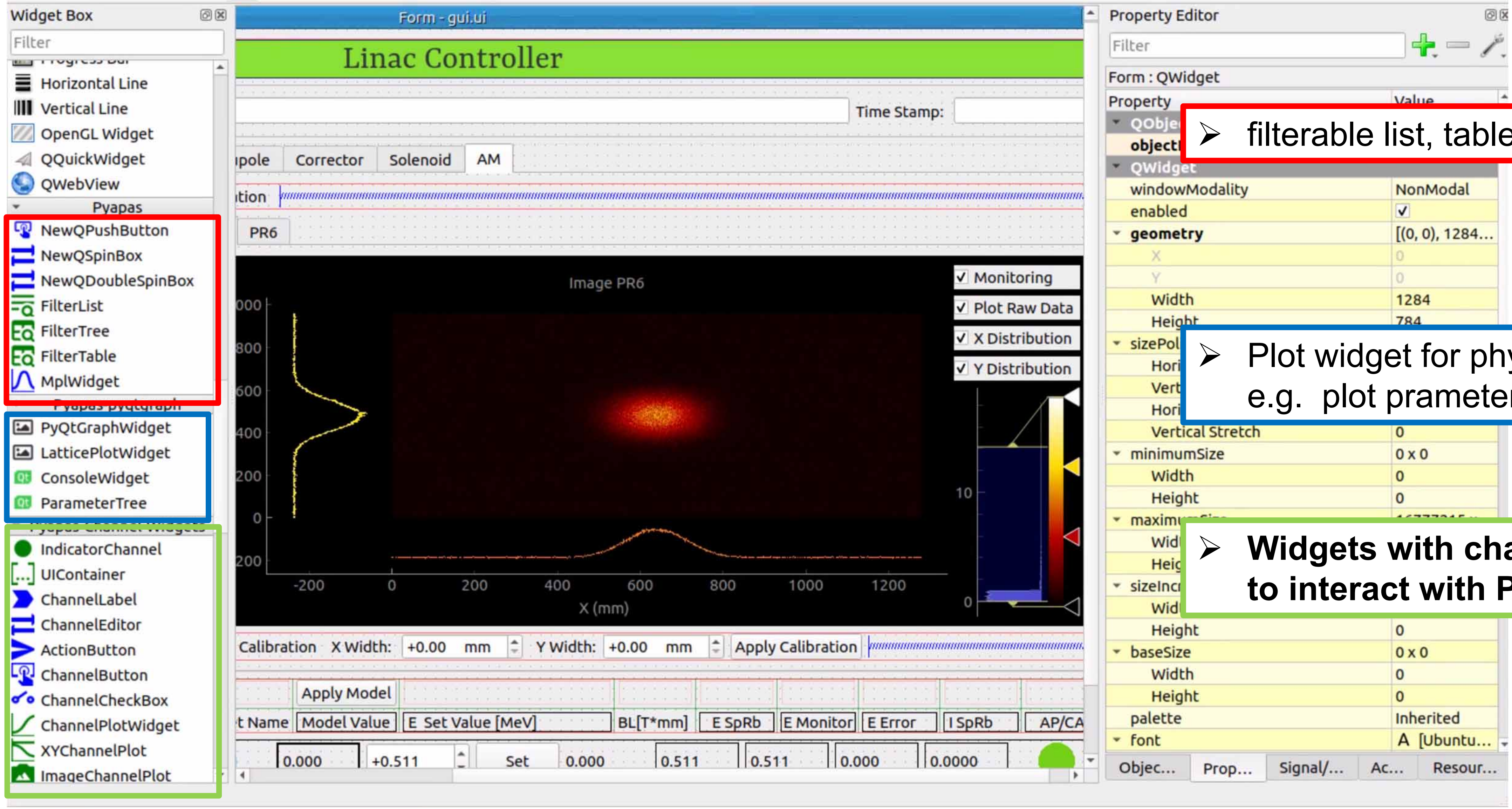
Engineering Quantity:
Power supply current



- ✓ **A new EPICS record type ‘cvt’ was developed**
- ✓ **Physical Quantities and Engineering Quantities are Interlocked**

User-friendly Interface developement

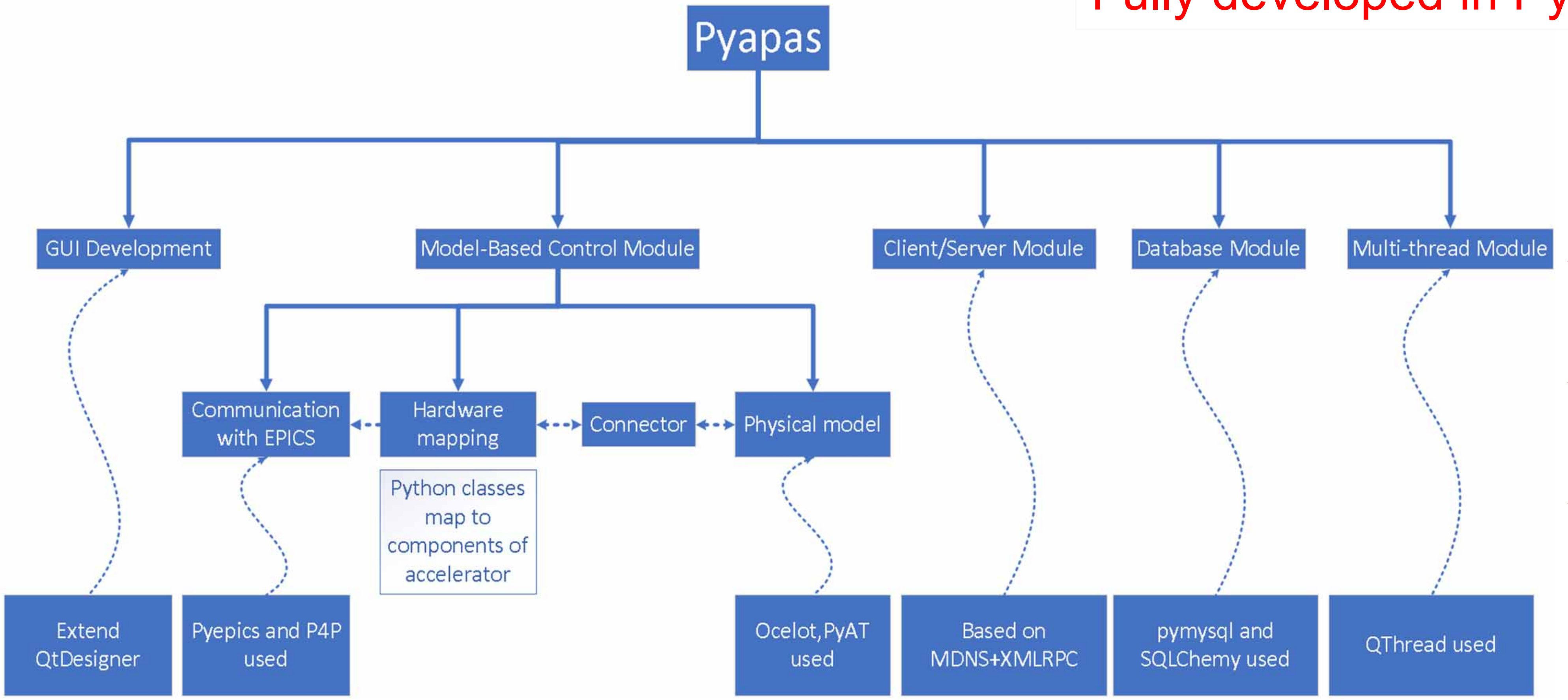
Extend QtDesigner → Customize widgets for HLA development



- filterable list, table, tree
- Plot widget for physical image, e.g. plot prameters with lattice
- **Widgets with channel property to interact with PV directly.**

The main modules of Pyapas are essentially complete

Fully developed in Python



- ✓ **User-friendly**
- ✓ **Efficient**
- ✓ **Stable**

The modules included in Pyapas basically meet all the requirements of HLA development for HEPS

- HLA development requirements of HEPS
- *Pyapas* for HLA development at HEPS
- HLA development based on *Pyapas*
- Conclusion

CPM of HLA Development for HEPS

2022 | 2023

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun

Linac

- Linac Virtual Accelerator ✓
- Transimission Efficiency ✓
- Emittance Measurement ✓
- Orbit Correction ✓
- Phase Scan ✓
- Energy Spread Measurement ✓
- Beam-based Alignment ✓
- Linac Control ✓

Transfer Line

- LB Virtual Accelerator ✓
- Emittance Measurement ✓
- Orbit Correction ✓
- Beam-based Alignment ✓
- Local Orbit Correction ✓

Booster

- Lattice Preparation ✓
- Booster Virtual Accelerator ✓
- First Turn Measurement ✓
- Dispersion Measurement ✓
- Chromaticity Measurement ✓
- Tune adjustor ✓
- Global Orbit Correction ✓
- Local Orbit Correction ✓
- Beam Lifetime ✓

Storage Ring

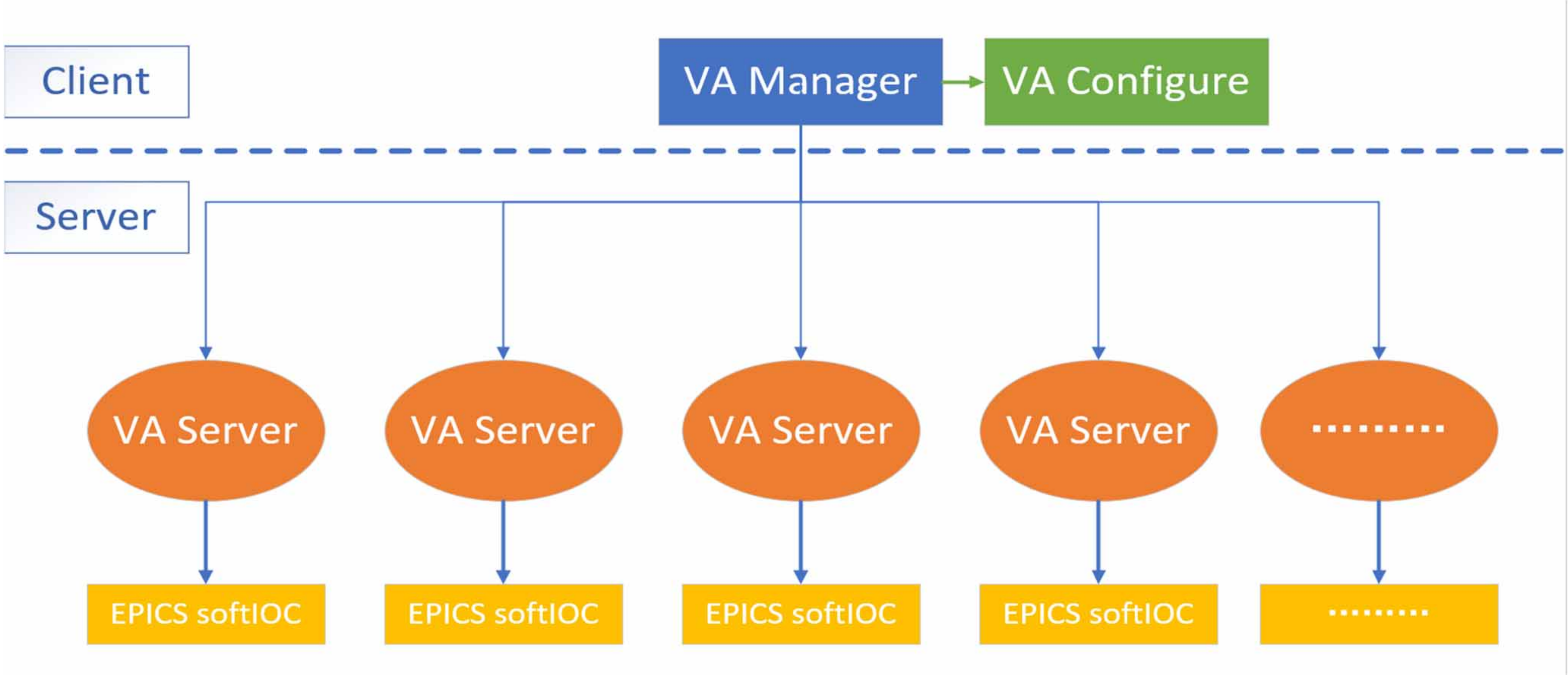
- Lattice Preparation ✓
- Booster Virtual Accelerator ✓
- First Turn Measurement ✓
- Dispersion Measurement ✓
- Chromaticity Measurement ✓
- Global Orbit Correction ✓
- Local Orbit Correction ✓
- Beam Lifetime ✓
- Orbit Display ✓
- Slow Orbit Feedback ✓
- K-Value adjustor ✓
- Fast BBA ✓

All the HLAs are developed based on *Pyapas*

Design of A Multi-User Virtual Accelerator

➢ Create virtual hardware to simulate real machines, providing corresponding PV channels and beam information

C/S Architecture

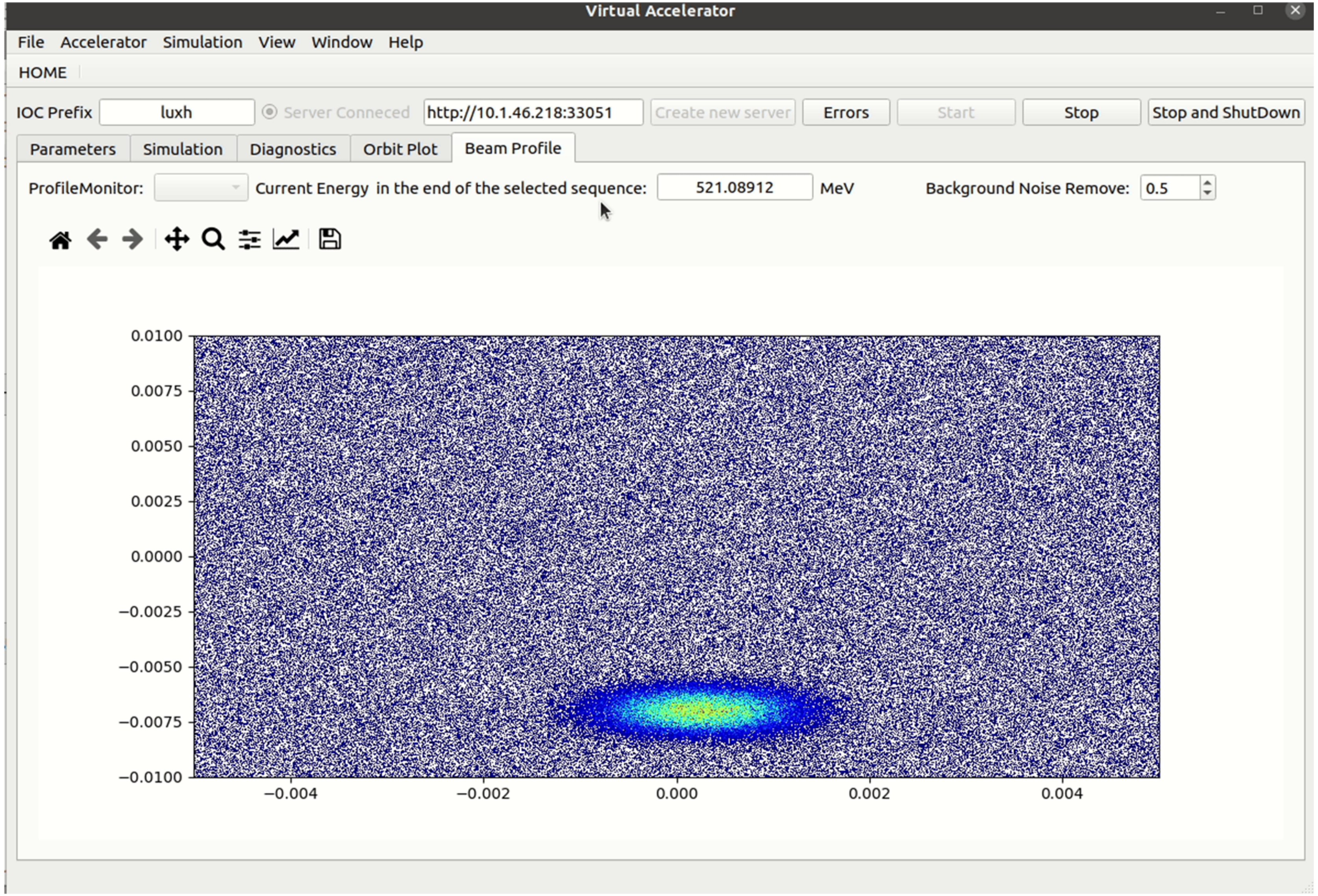


- ✓ **Multiple tasks running concurrently**
- ✓ **Multiple users operating simultaneously**
- ✓ **Unified management with one-click start and stop**

Within the same network environment or on the same server, any number of virtual accelerators can be launched without conflicting with each other

Virtual Accelerator of HEPS Linac

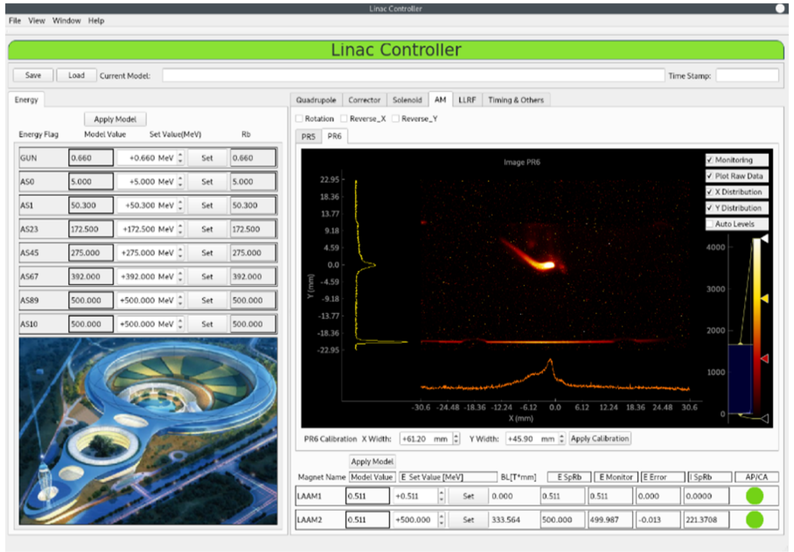
- Single Particle Tracking
- Multi-Particle Tracking
- Vritual PR
- Full feature IOC
- Errors included



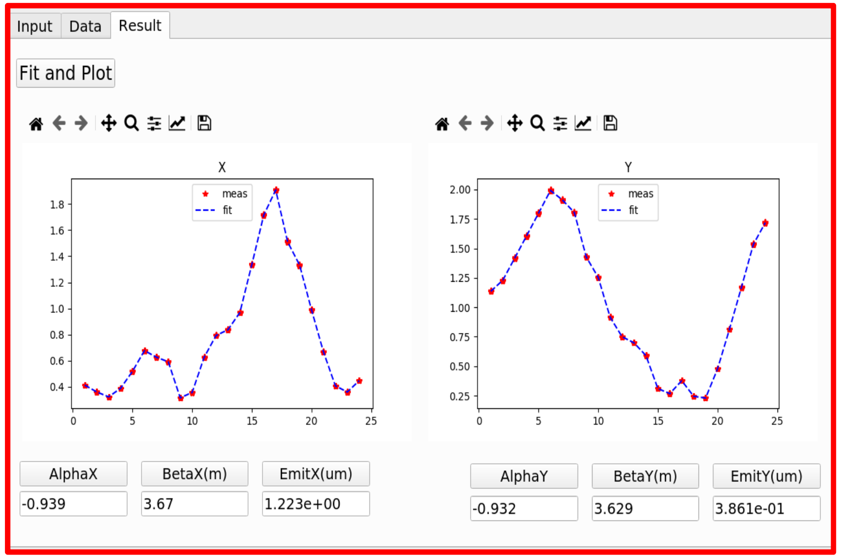
Generate 'real-time' data for testing HLAs

Part of HLAs for Linac

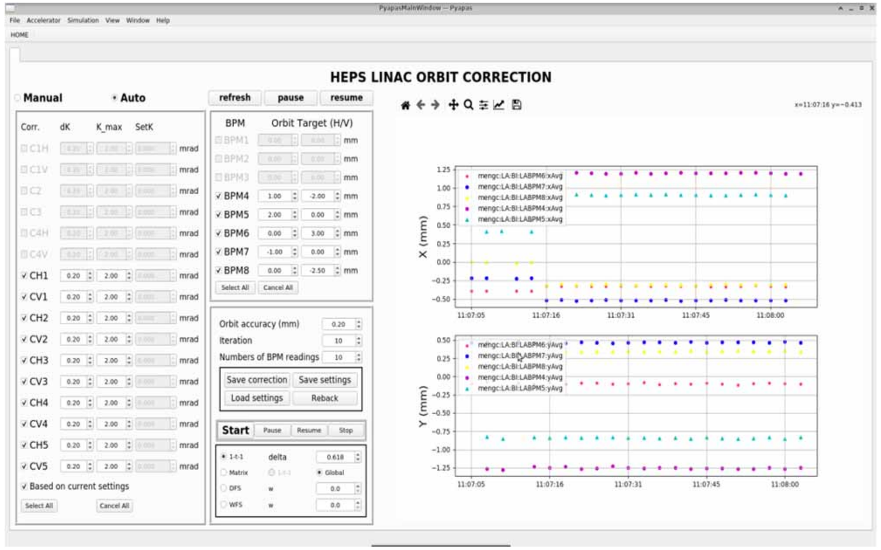
Linac control（Xiaohan Lu）



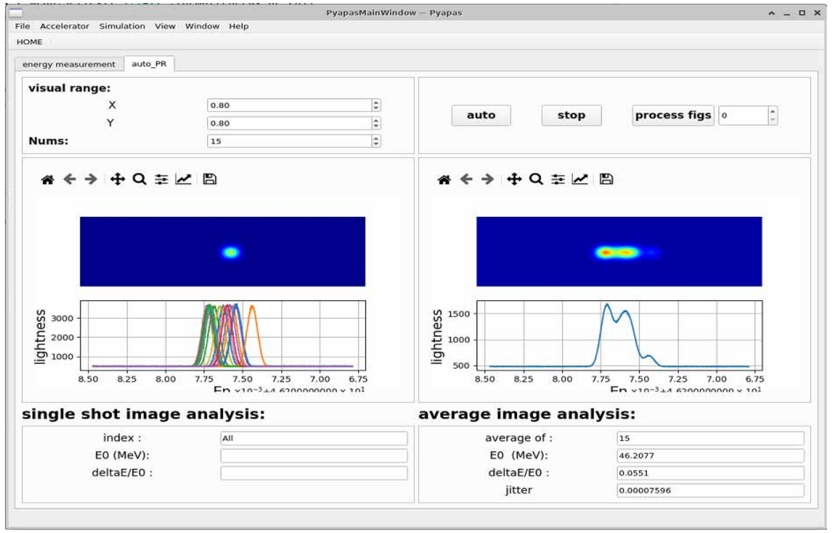
Emittance measurement（Yaliang Zhao）



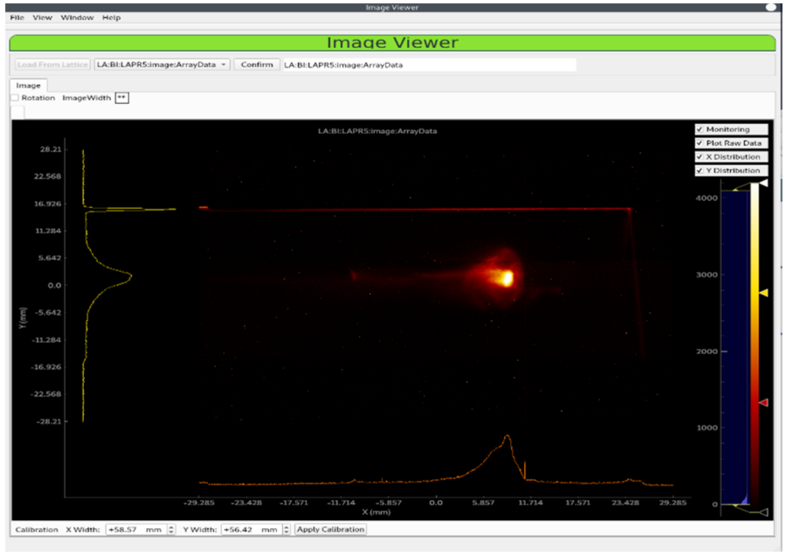
Orbit correction（Cai Meng）



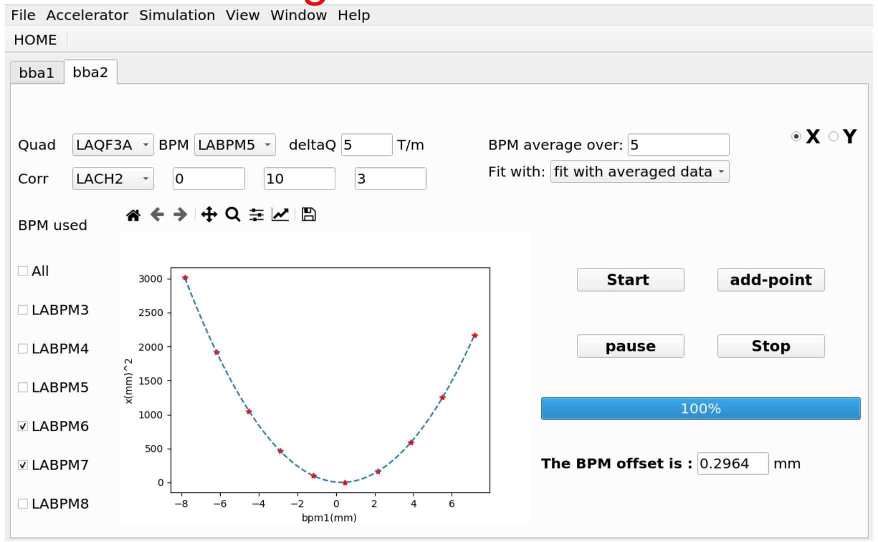
Energy spread measurement（Hongfei Ji）



PR analysis tool（Xiaohan Lu）



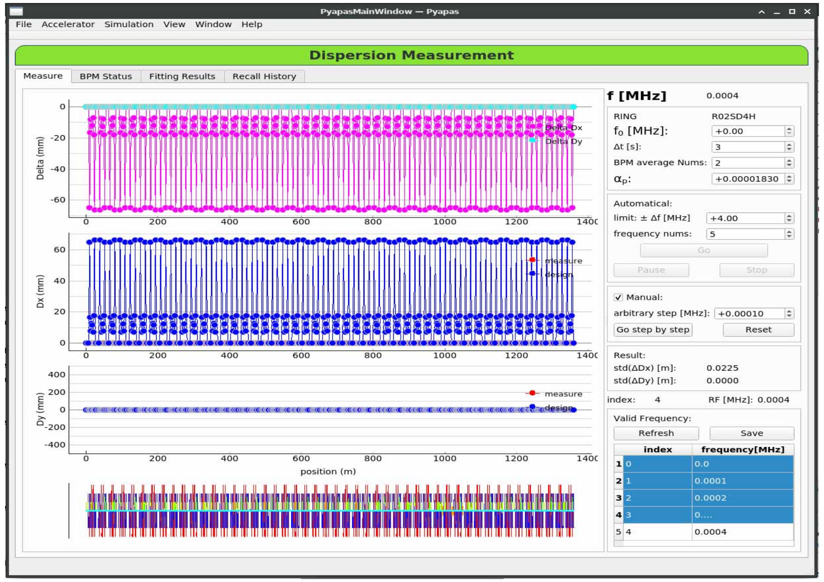
BBA（Yaliang Zhao）



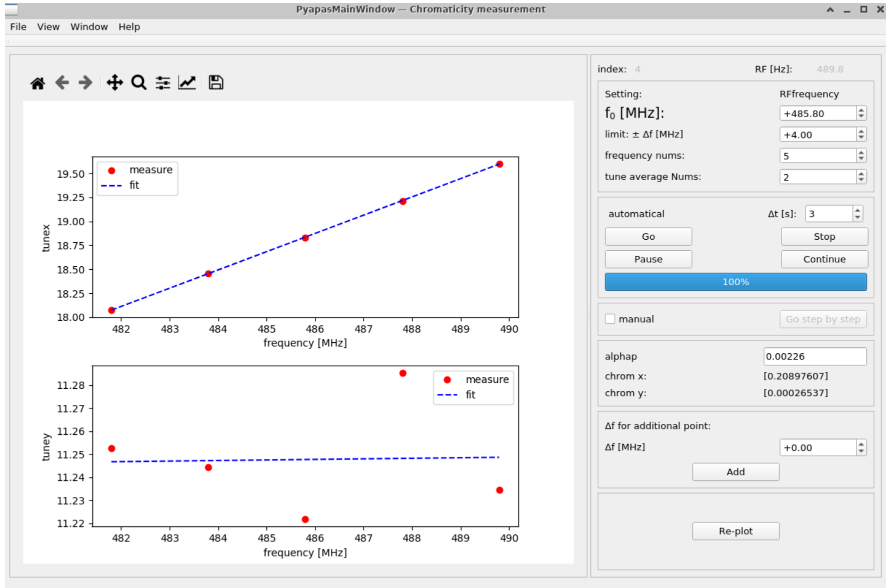
中国科学院高能物理研究所
Institute of High Energy Physics, Chinese Academy of Sciences

Part of HLAs for Booster and Storage Ring

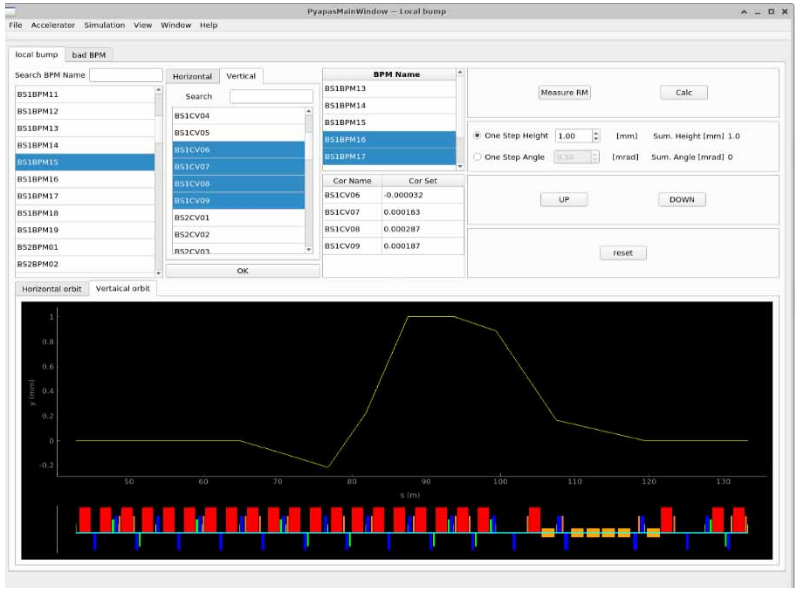
Dispersion measurement（Hongfei Ji）



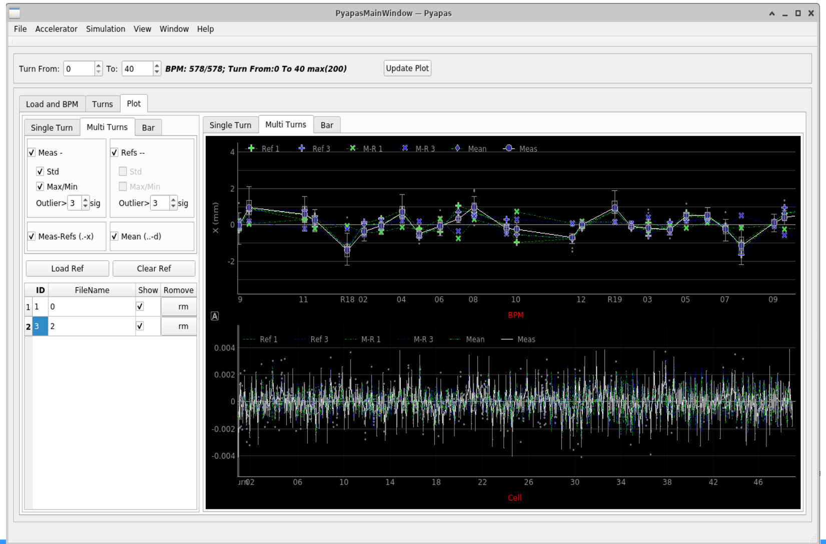
Chromaticity Measurement（Y. Wei）



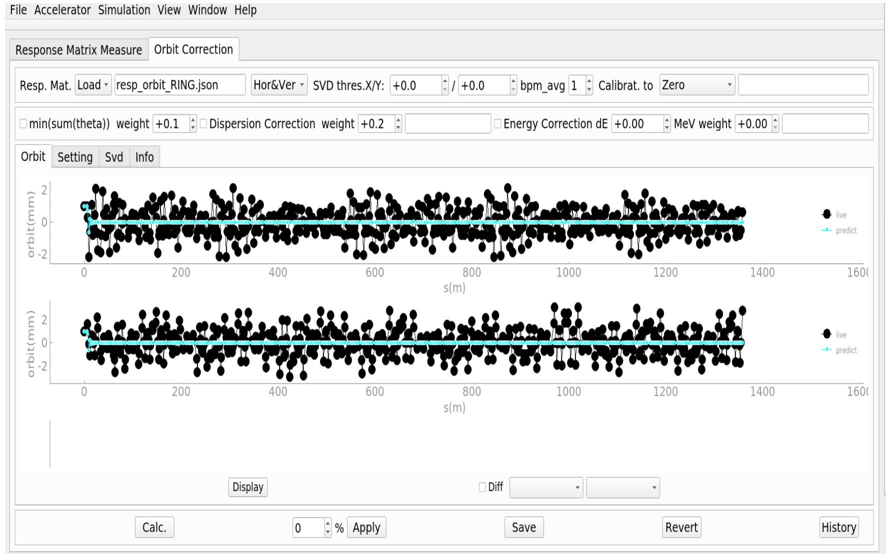
Local orbit correction（Y. Wei）



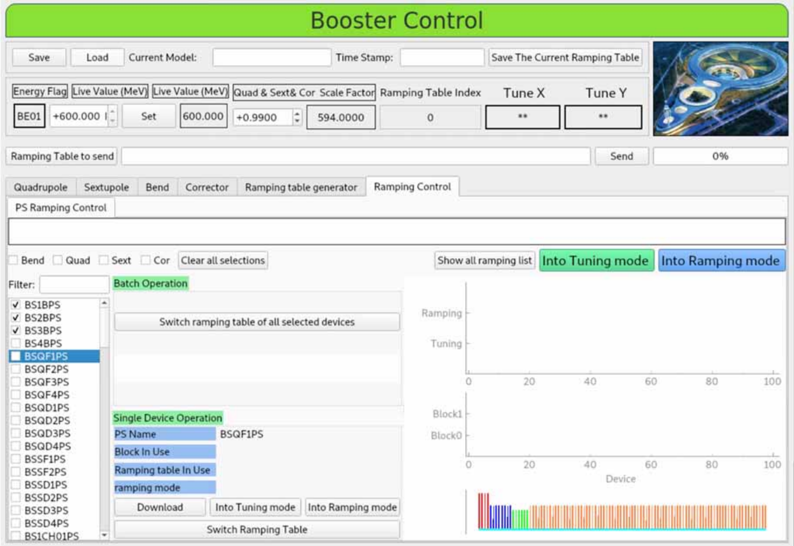
First turn data analysis（Daheng Ji）



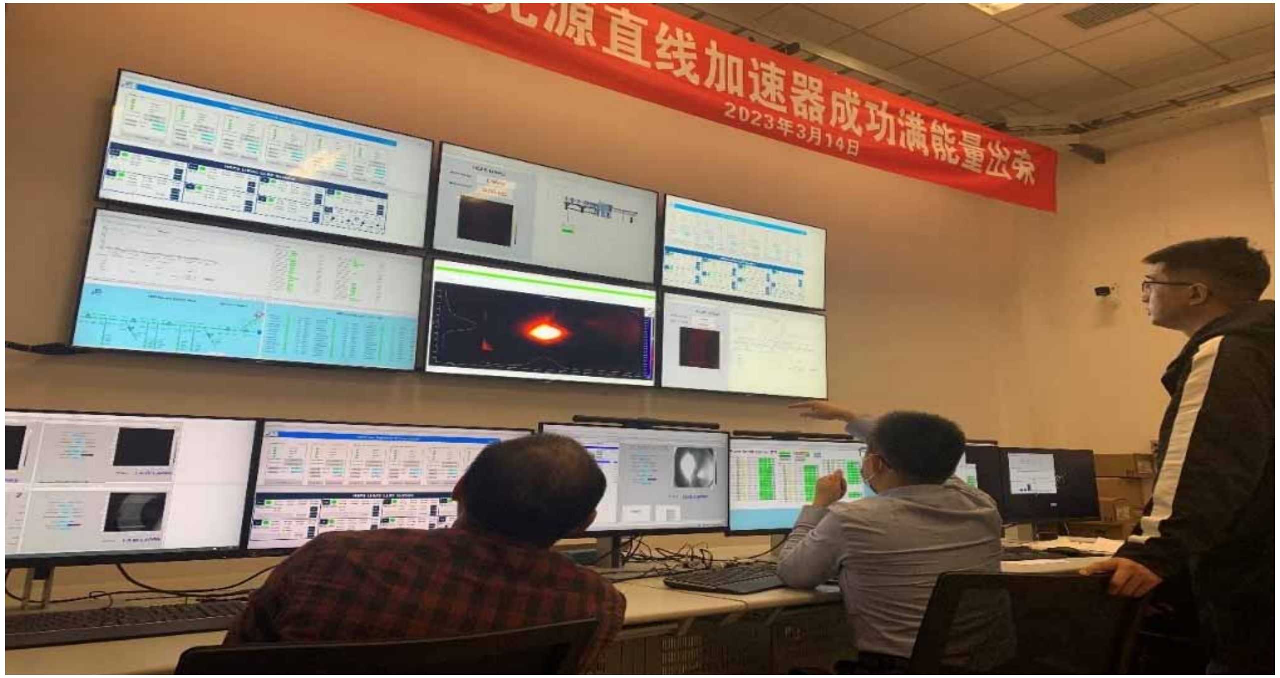
Global orbit correction（Yaling Zhao）



Booster Control（Xiaohan Lu）

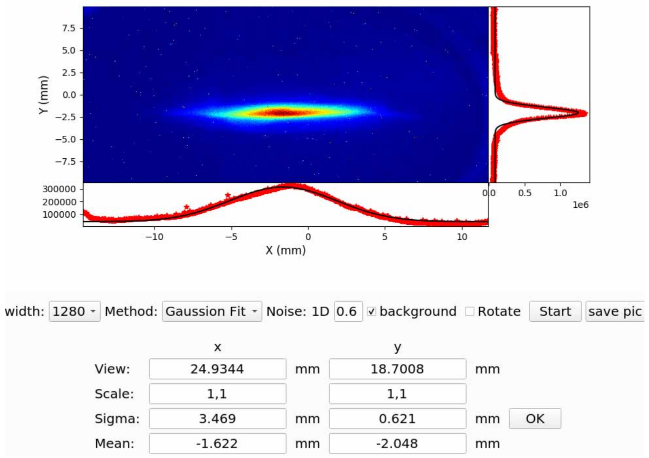


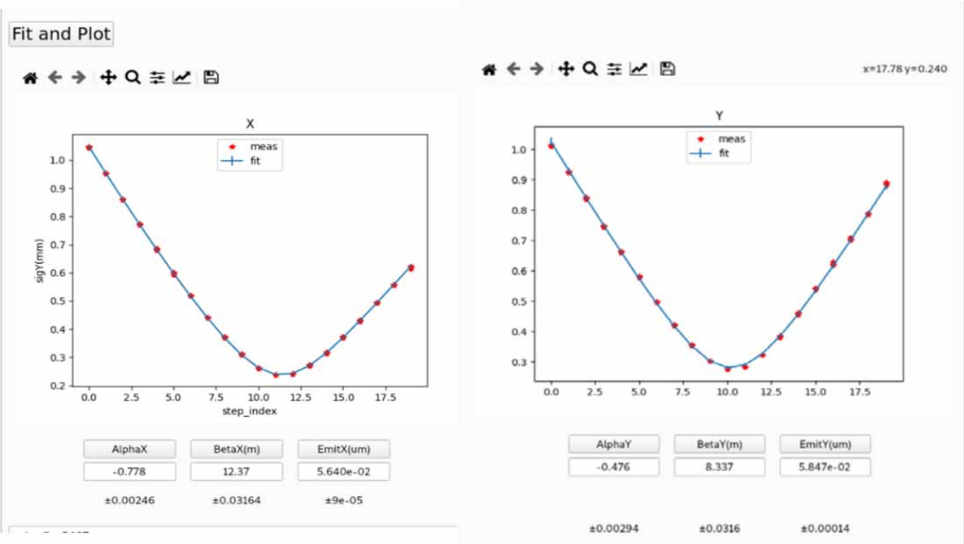
Pyapas in the Control Room

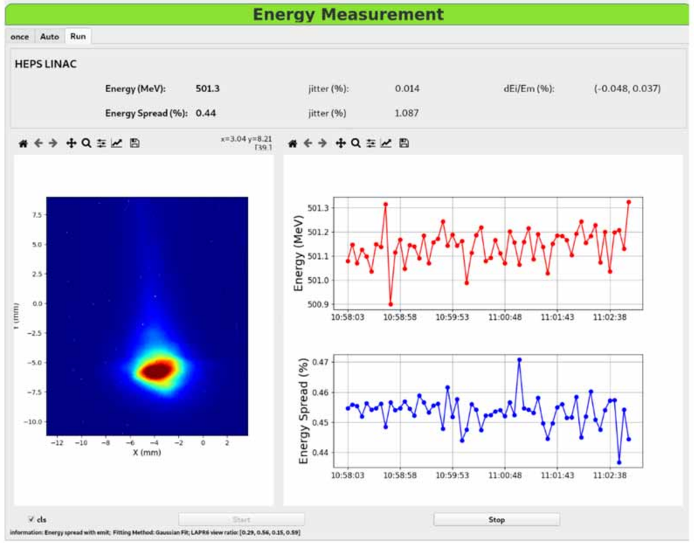


Pyapas has been successfully applied in beam commissioning of HEPS.

The practicality and reliability of *Pyapas* have been essentially verified







- HLA development requirements of HEPS
- *Pyapas* for HLA development at HEPS
- HLA development based on *Pyapas*
- Conclusion

Conclusion

- A brand-new framework, *Pyapas*, was developed based on Python to enhance the efficiency of HLA development.
- A multi-user virtual accelerator was developed based on *Pyapas* for testing the HLA.
- All the HLAs of HEPS were developed based on *Pyapas*
- We're looking to enhance *Pyapas* with more features and **welcome interested colleagues to join us in its development**

- https://code.ihep.ac.cn/heps-hla/pyapas.git luxh@ihep.ac.cn

Thanks for your attention !