Development of a simulation code CISP and a control system PACS

for complicated beam dynamics in high intensity hadron accelerators

Speaker: Jie Liu

Jiancheng Yang, Jiawen Xia,

Yunpeng Zhu, Guimei Ma, Weiping Chai,

Guodong Shen, Shuang Ruan, Geng Wang, Fucheng Cai, et al.

Institute of Modern Physics, Chinese Academy of Sciences

Outline

1. Introduction

2. Development of simulation code CISP

3. CISP benchmarks and applications

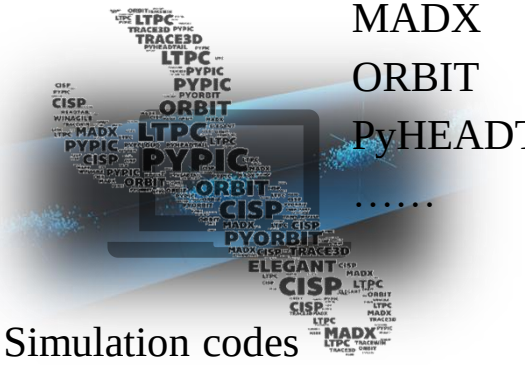
4. Development of control system PACS

5. PACS applications

6. Outlook

1. Introduction

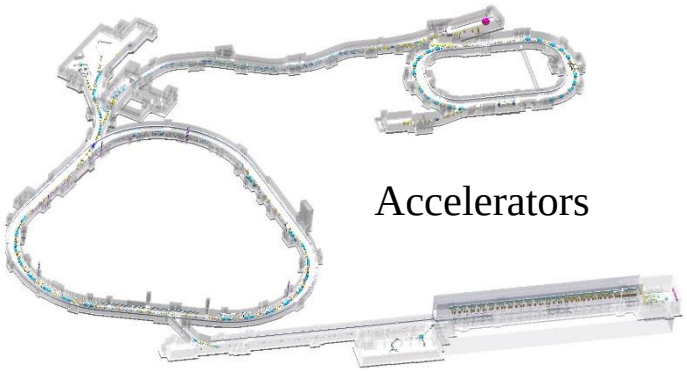
➢ **Simulation codes are essential tools to study complicated beam dynamics.**



Simulation codes

MADX
ORBIT
PyHEADTAIL
……

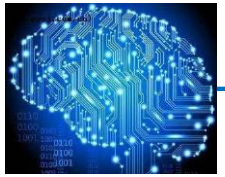
Massive beam dynamics research



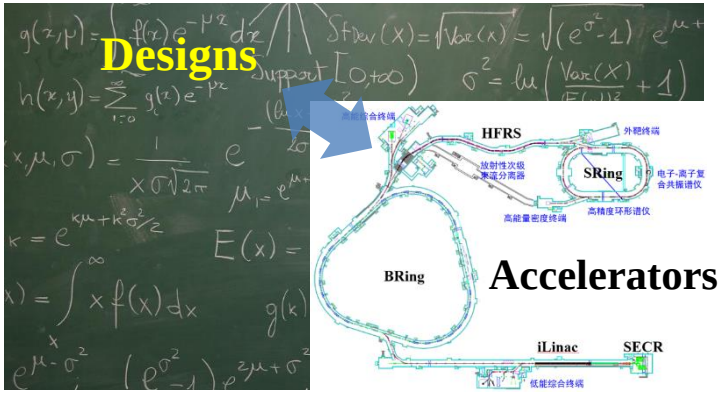
Accelerators

➢ **Control systems largely define accelerator performance.**

Core system of beam commissioning and operation



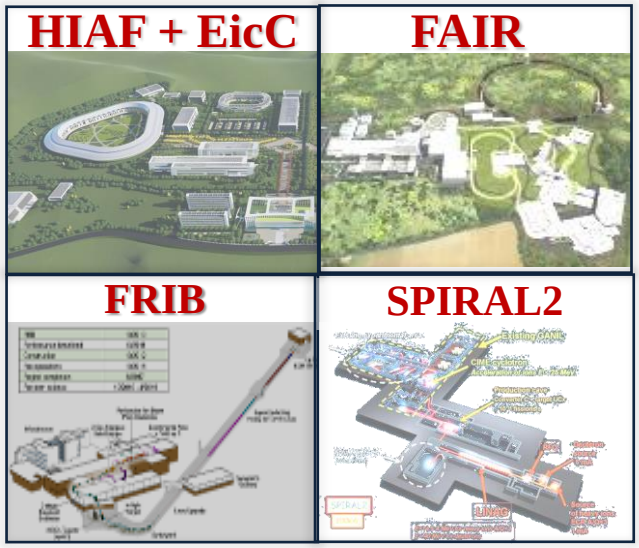
- Parameter Set Management
- Beam Dynamics Apps
- Control Var. ⟷ Physics Var.
- GUI…



Simulation codes and control systems are vital for design, research and operation!

1. Introduction

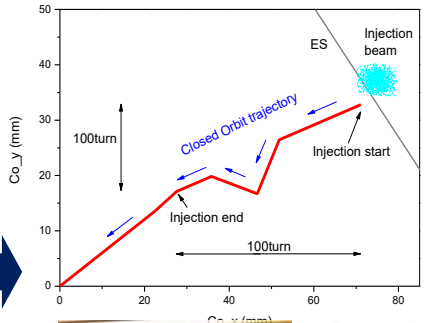
- Future hadron accelerators like HIAF and EicC … need **more advanced simulation codes and control systems**.



Go beyond limits

Higher intensity
Higher Power
Higher Luminosity
Higher Precision

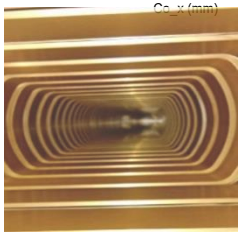
Two-plane painting injection based on tilted electrostatic septum



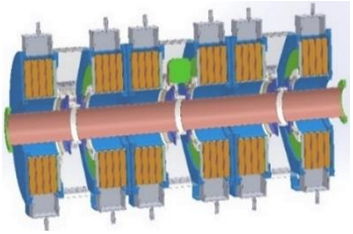
HIAF

New schemes

New technology



Ceramic-supported ultra-thin chamber



Broadband MA-loaded cavities

New simulation code and control system for HIAF

CISP 强流效应模拟平台

PACS 加速器物理控制

New beam dynamics schemes

More accurate offline and online models

High performance and high intelligence

2. Development of simulation code CISP

- Simulation Platform for Collective Instabilities (CISP) is a scalable multi-macroparticle simulation code built with C++ and Python.

CISP 强流效应模拟平台

CISP_Setup_7_1_0_stable.msi Easy to install

```
# sring.txt for sring simulations
# Jie Liu, liujie115@impcas.ac.cn, 18509312964

# ring parameters
ring: circumference=252.3270751, gammat=4.283426425|value, tunex = 5.16|v

# beam parameters
beam: id=0, bunch_num=1, n=238, a=92, e=92, particle_num=10000, ion_num=5

# elements
PhaseMonitor: name = phm1, interval = 50, rangex = 0.03, rangey=0.03, ran
ParaMonitor: name = pm1, switch=on, plot_switch=on
HRMonitor: name=hrm1, frequency=100, switch=on, plot_switch=on
RF: name=rf1, kind=uniform,length=0, voltage=0.1, h =1, phi =0, switch=on
oneturn:name=oneturn1,betax=7.7827715655203304,alphax=0,betay=18.76593517
wake:name=wake1,length=0,slice_num = 20000, orbitx=0,orbity=0,kind1=./sri

# beam line
beamline: pm1, phm1, hrm1, wake1, oneturn1, rf1

# simulation control
simulation:turns=10
```

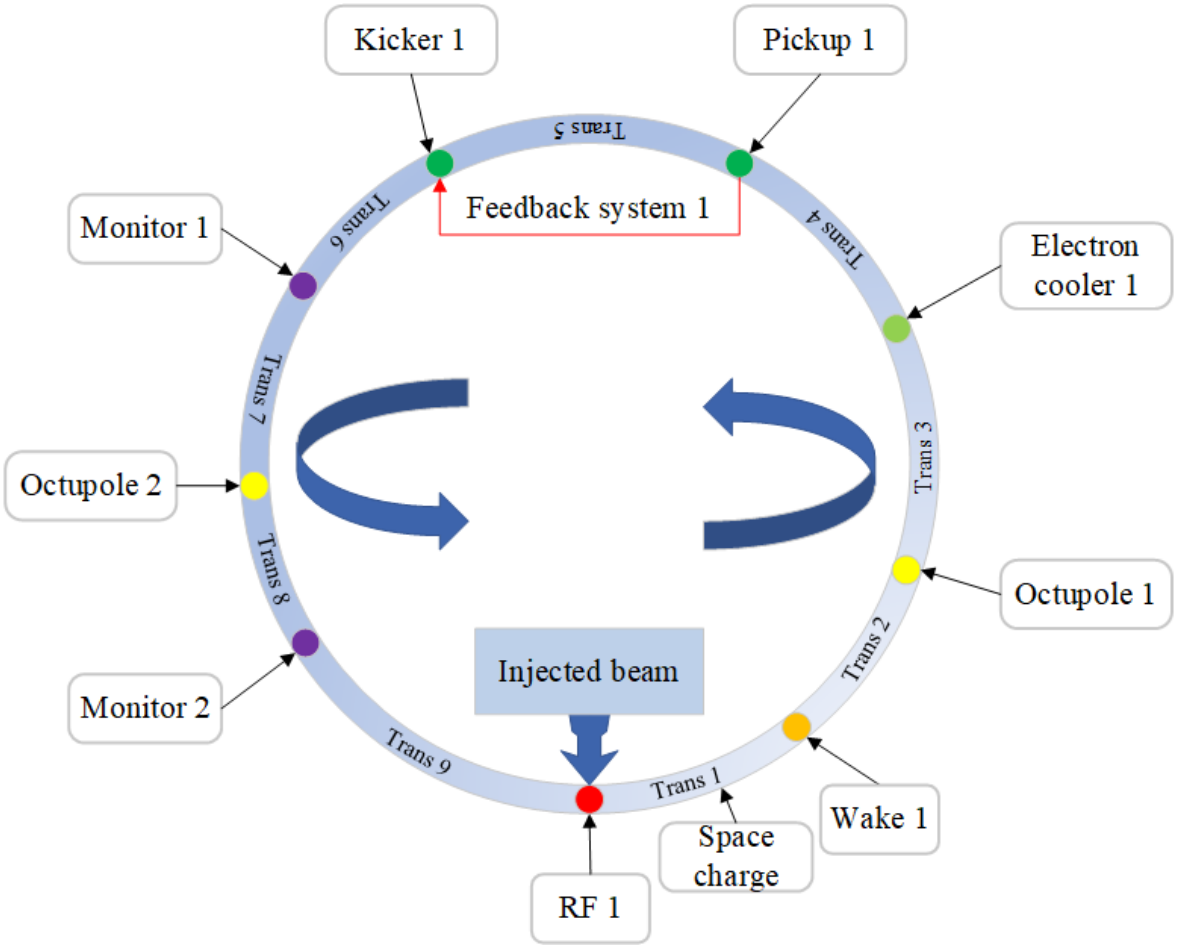
Build simulations with easy-to-use command file

- ✓ **Diverse multi-turn injection schemes**
- ✓ **Basic transverse and longitudinal linear dynamics**
- ✓ **Complicated longitudinal dynamics** like acceleration, bunch merging, barrier bucket bunch merging and so on
- ✓ **2.5D transverse and longitudinal space charge fields**
- ✓ **Dipole transverse wake and monopole longitudinal wake**
- ✓ **Sextupole and octupole magnets**
- ✓ **Broadband feedback systems**
- ✓ Intrabeam scattering effects
- ✓ DC electron cooler
- ✓ Slow extraction
- ✓ **Diverse apertures** close to real accelerators
- ✓ **10^6 macroparticles, 10^4 slices, 10^5 turns sim. in hours**

For more details and CISP installer, please visit CISP main website https://cisp.azurewebsites.net/ or contact cisp_support@163.com .

2. Development of simulation code CISP

- CISP employs **(beam transport + kicker) numerical model** to include previous diverse beam dynamics in a single simulation.



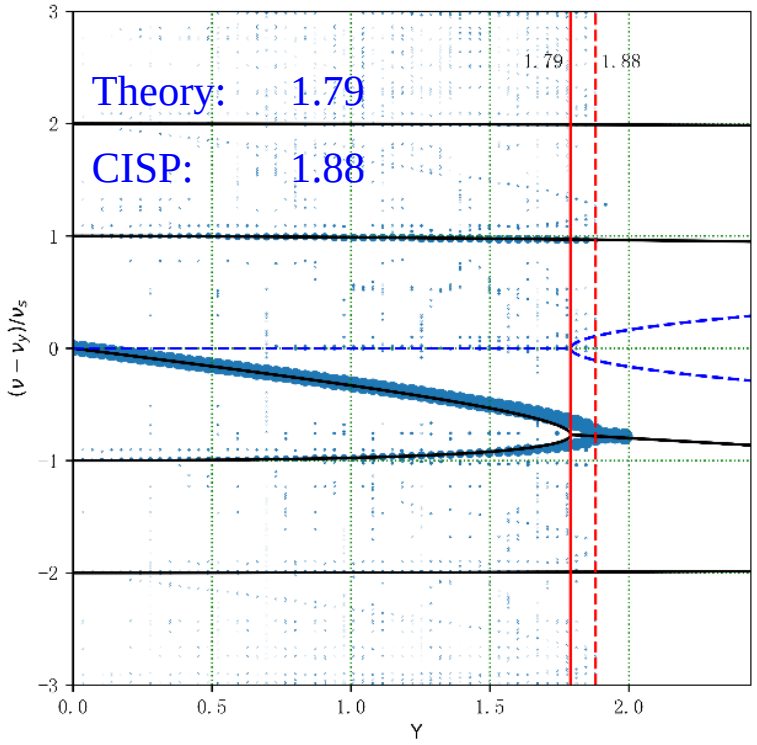
1. Place elements in an order to research a lot of beam dynamics

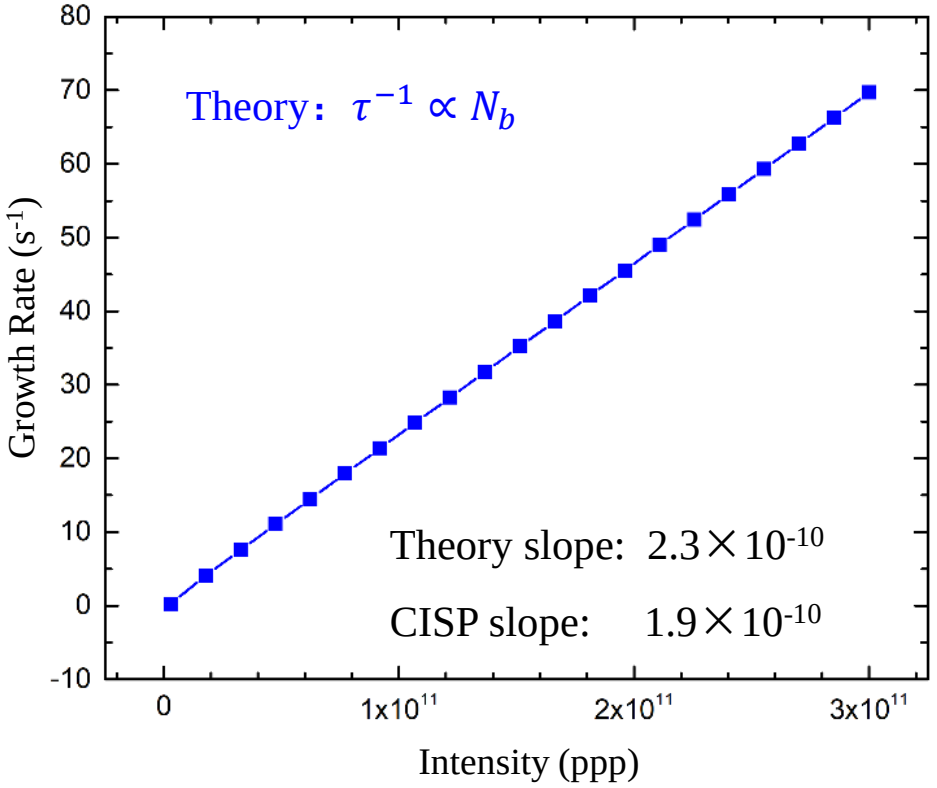
2. Elements are coded with OOP technology. Adding new elements (new beam dynamics) into CISP is very easy.

Better for development in the future …

3. CISP benchmarks and applications

- Transverse mode coupling and coupled-bunch instability benchmarks to theory



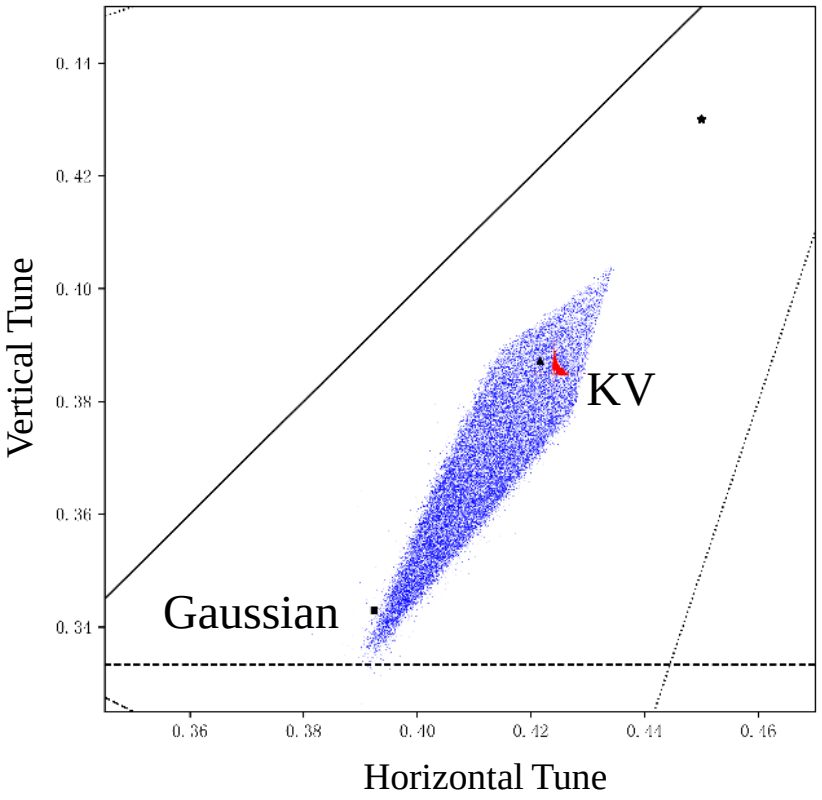


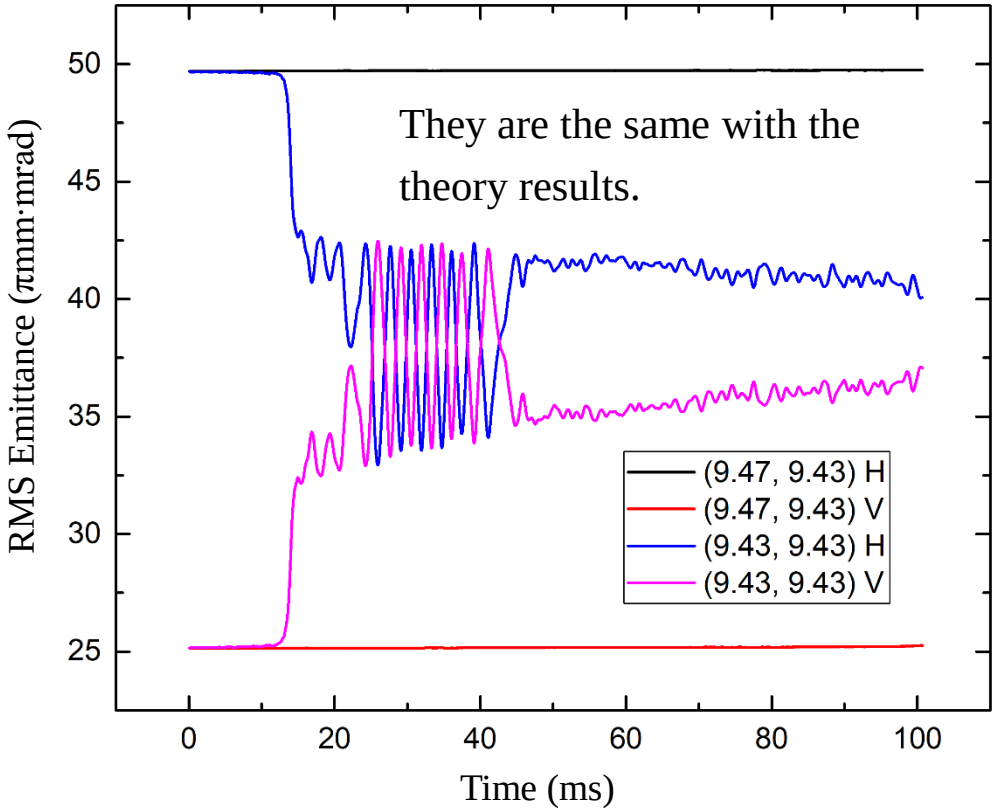
Mode frequency shift and threshold are very close to the theory in TMCI.

Growth rate increases at a linear function with intensity increase in TCBI.

3. CISP benchmarks and applications

- Space charge effect benchmarks to theory



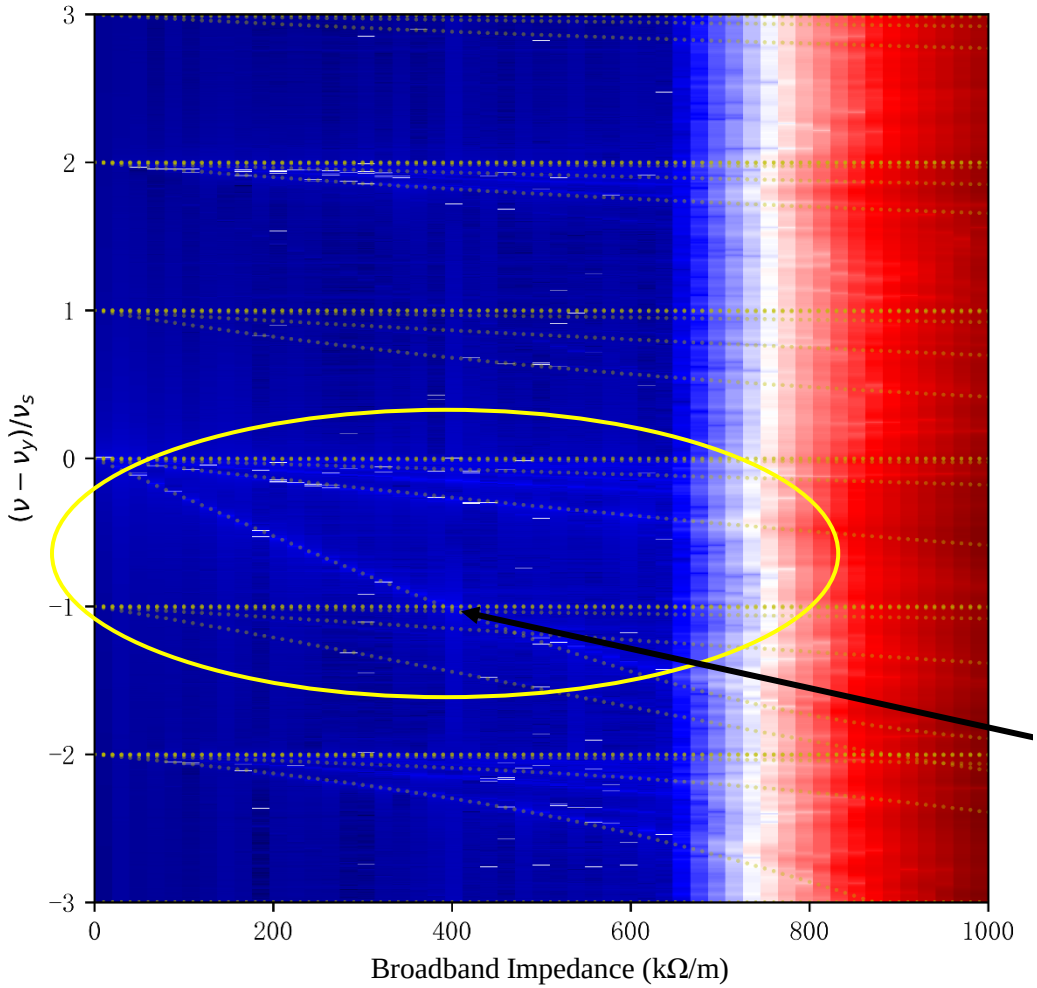


Tune spread simulation compared to theory.

Coupling between two transverse planes driven by space charge field itself in KV beam

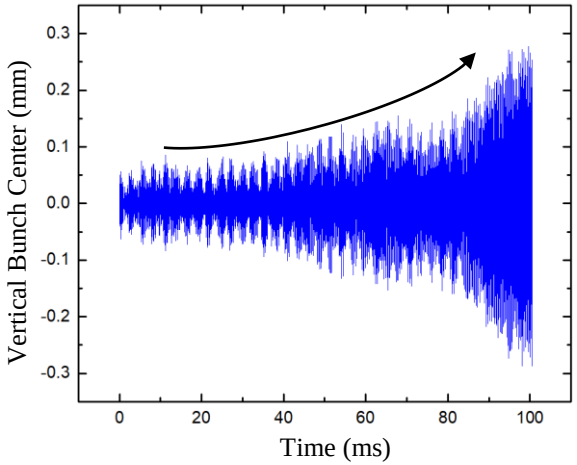
3. CISP benchmarks and applications

- TMCI benchmark to DELPHI code (CERN)



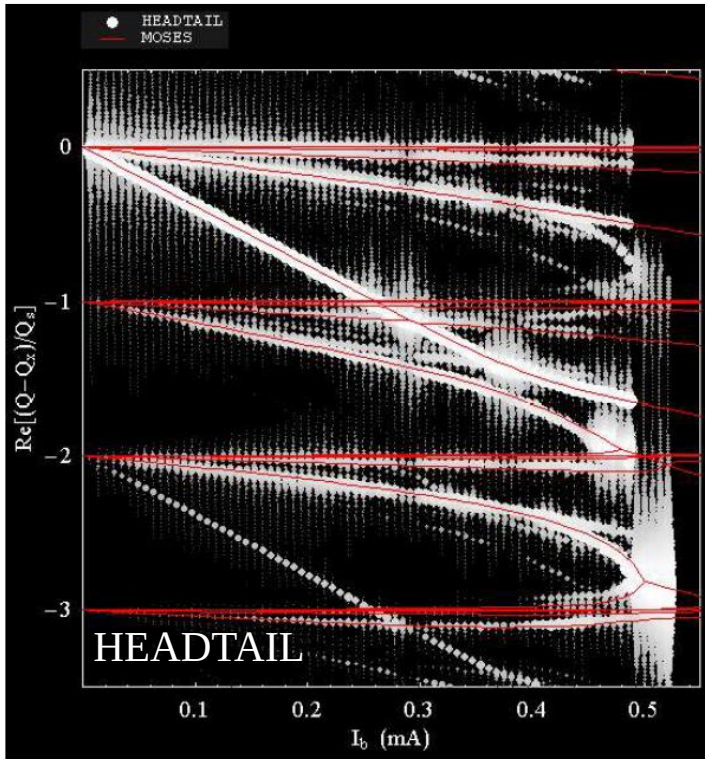
Results of simplified situation given by CISP and DELPHI (dots)

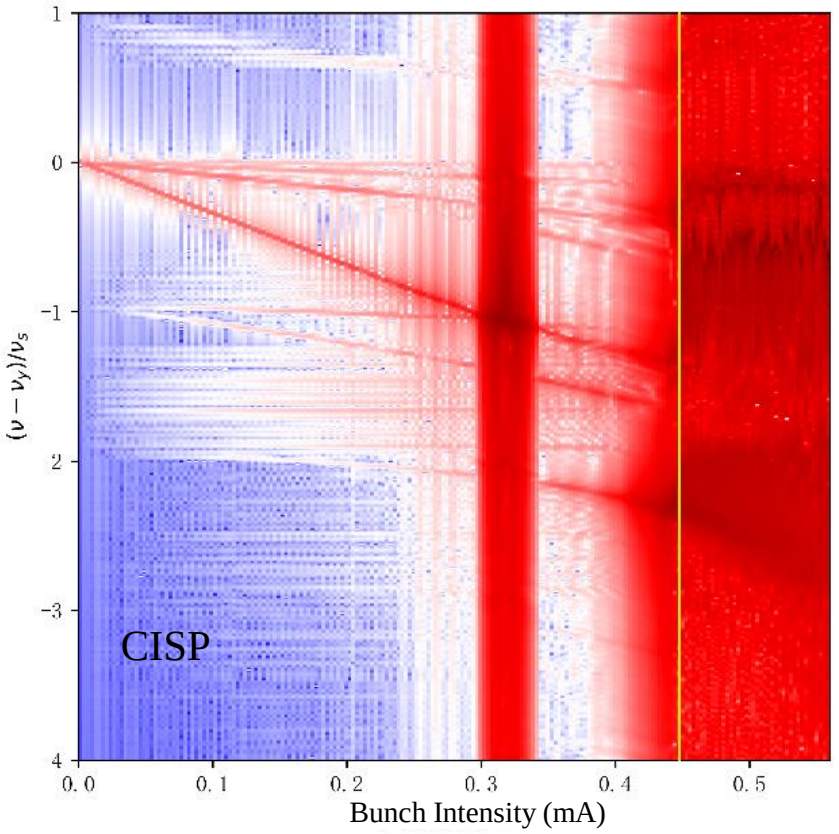
The frequency shifts and the intensity that introduces instability are the same.



3. CISP benchmarks and applications

- TMCI benchmark to HEADTAIL code (CERN)





Instability at 0.3mA and 0.46mA

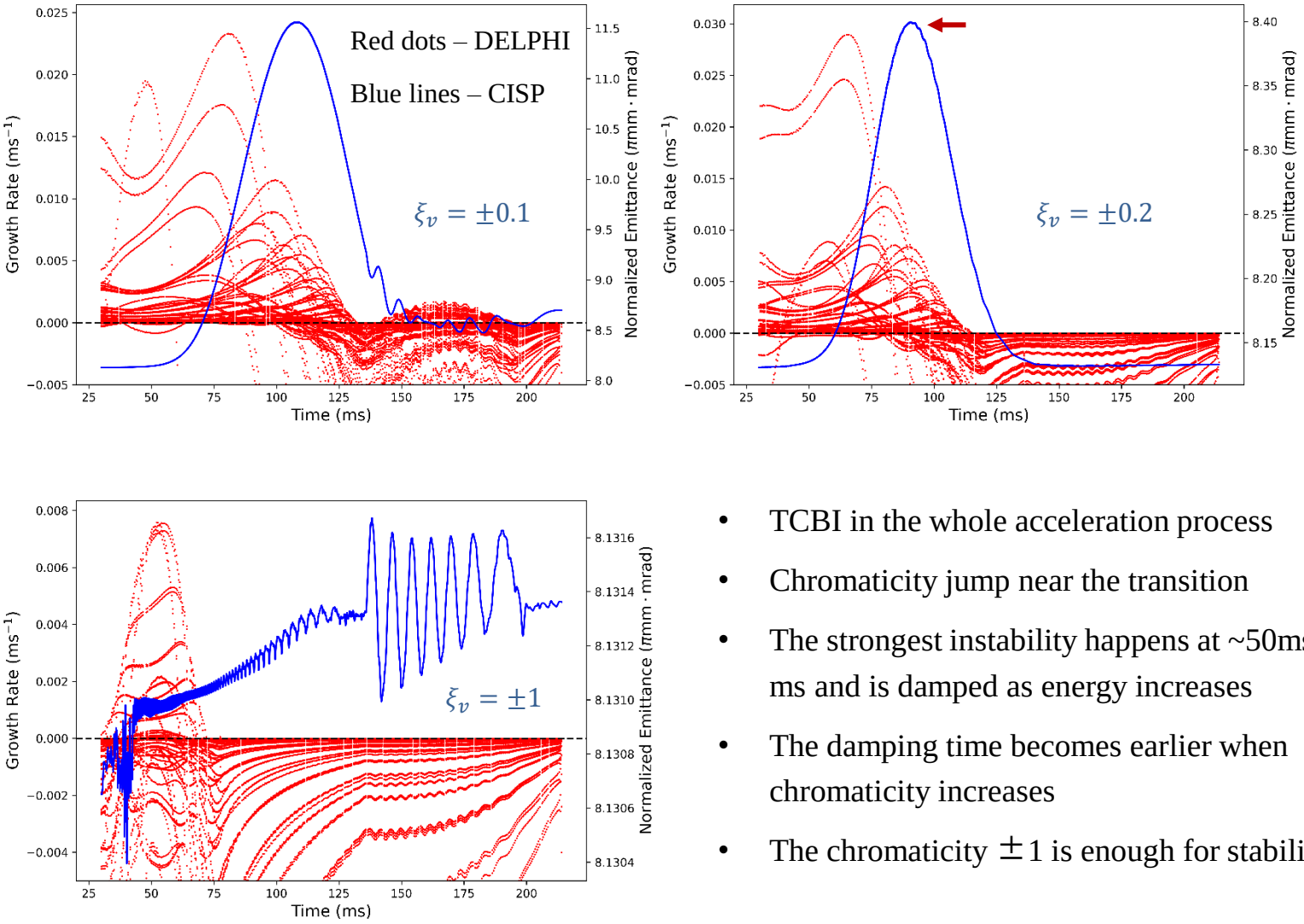
Results are very close

Instability at 0.32mA and 0.45mA

CISP is a useful tool for beam dynamics simulations in HIAF and other hadron accelerators.

3. CISP benchmarks and applications

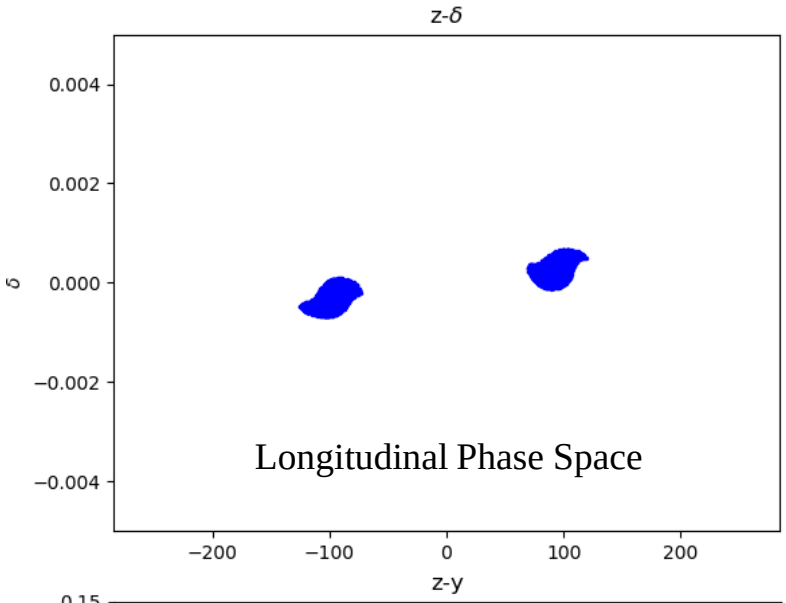
➢ TCBI and chromaticity effects in HIAF-BRing (proton @ 1.2×10^{13})

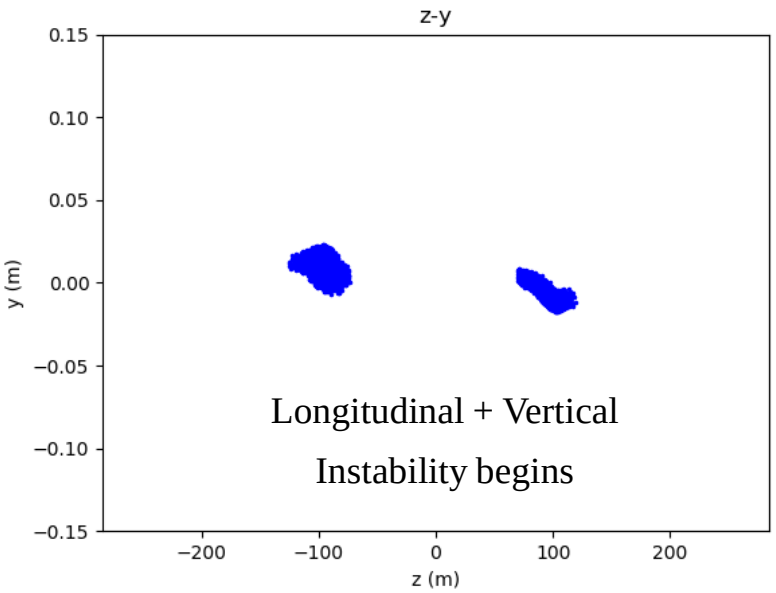


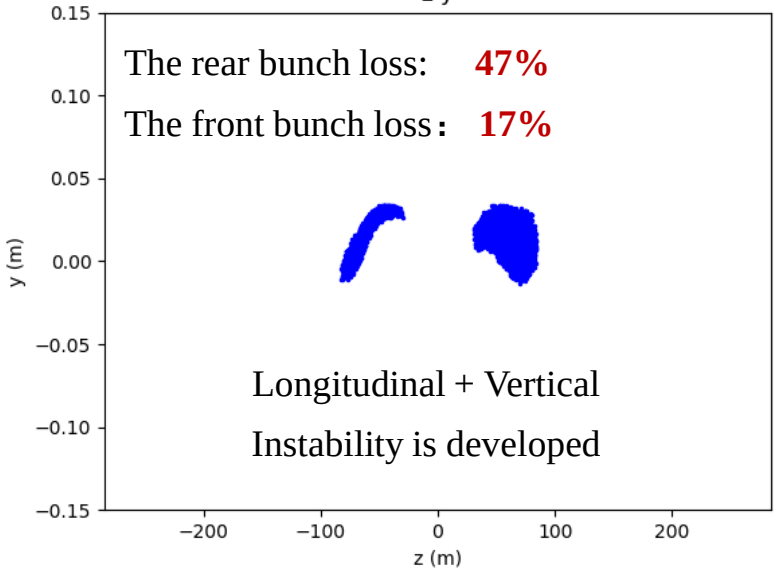
- TCBI in the whole acceleration process
- Chromaticity jump near the transition
- The strongest instability happens at ~50ms to 75 ms and is damped as energy increases
- The damping time becomes earlier when chromaticity increases
- The chromaticity ±1 is enough for stabilization

3. CISP benchmarks and applications

➢ TCBI in barrier bucket bunch merging of HIAF-BRing (proton @ 6×10^{12})



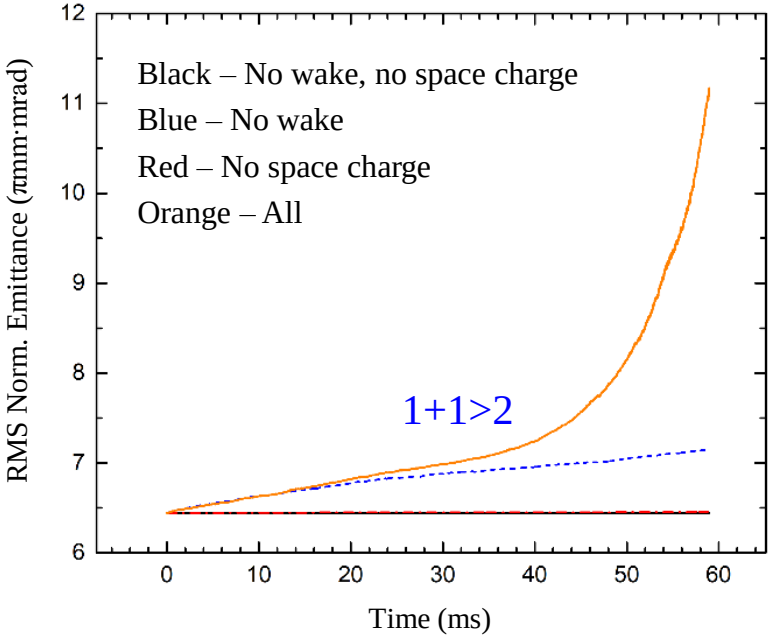


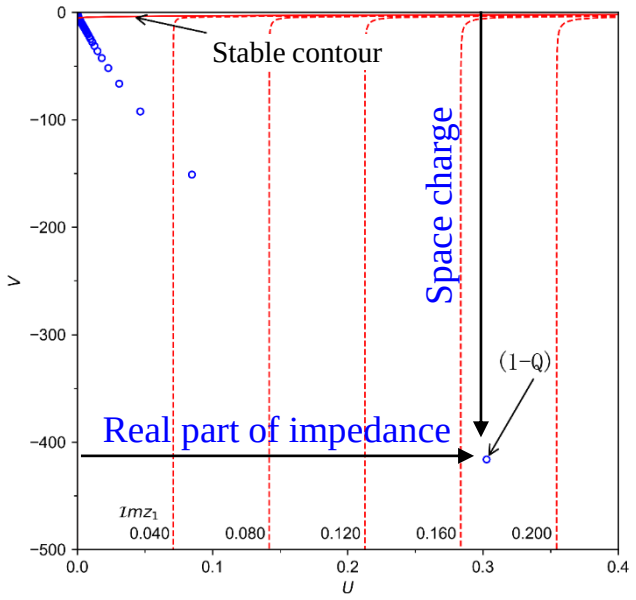


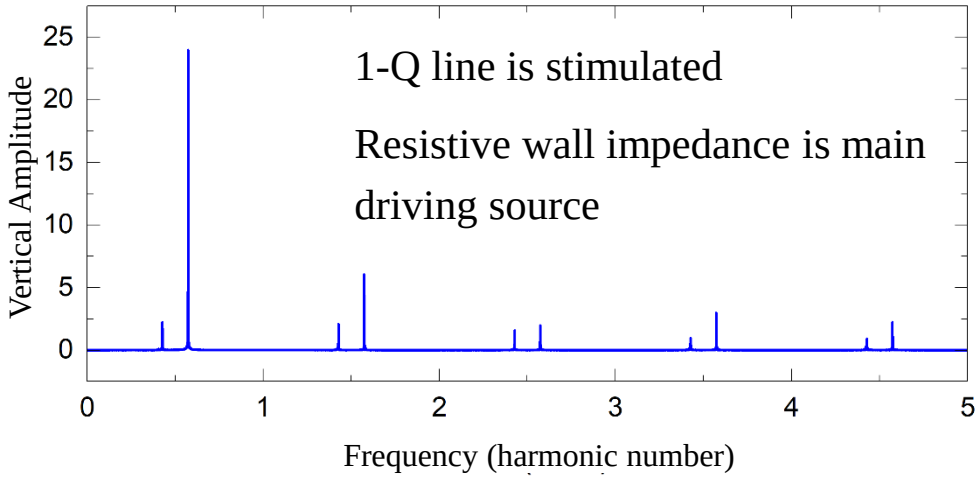
- Distortion of longitudinal distribution
- Bunches move close to each other continuously. No filling mode!
- It is difficult to analyze it in theory
- CISP can simulate TCBI in barrier bucket bunch merging …

3. CISP benchmarks and applications

- Combining effect of space charge and impedance in HIAF-BRing (Kr^{19+} @ 3×10^{11})



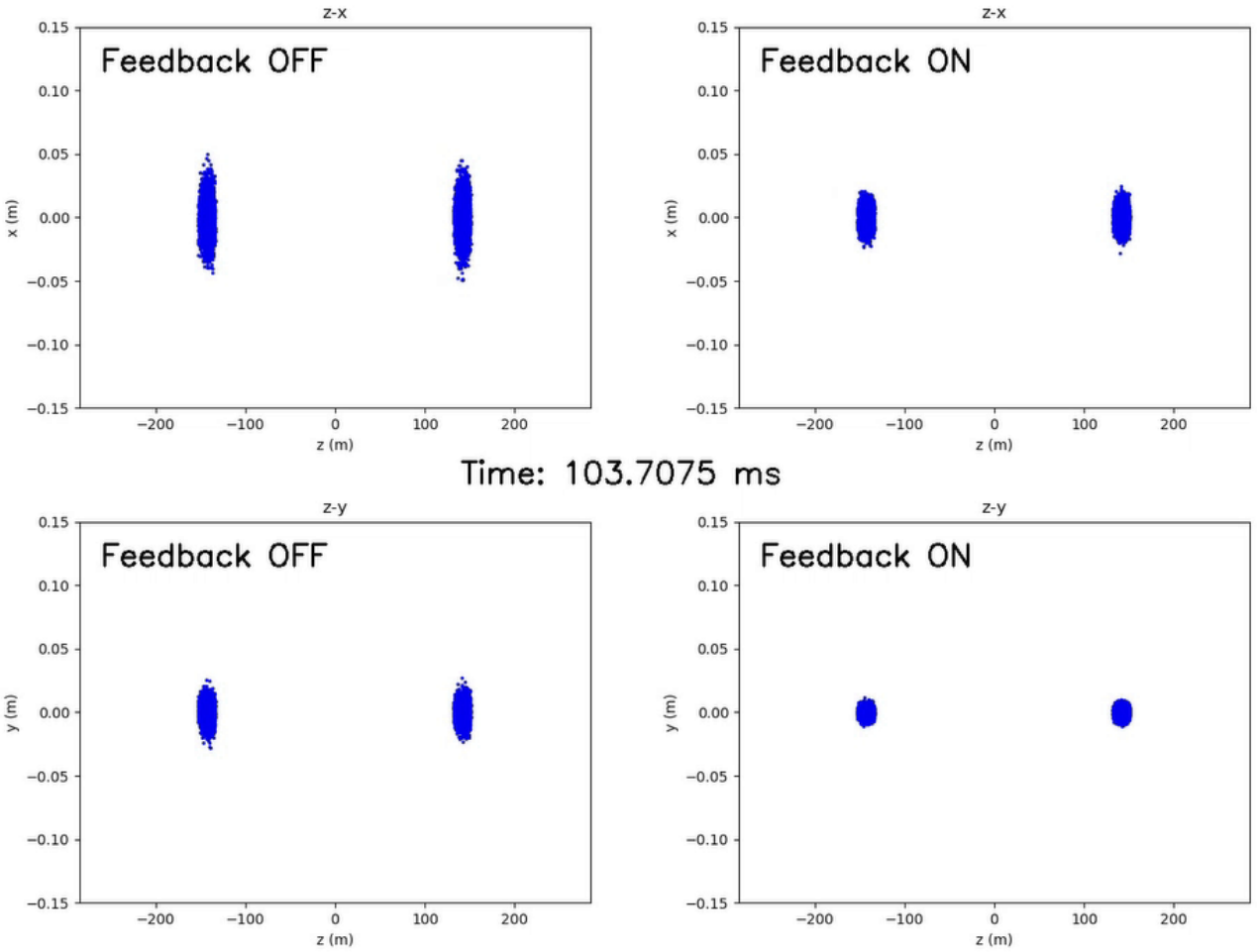




CISP can simulate space charge and wake simultaneously.

3. CISP benchmarks and applications

- Broadband feedback system simulation



Bandwidth

20 kHz ~ 100 MHz

Max. kicker

< 2.5 μrad

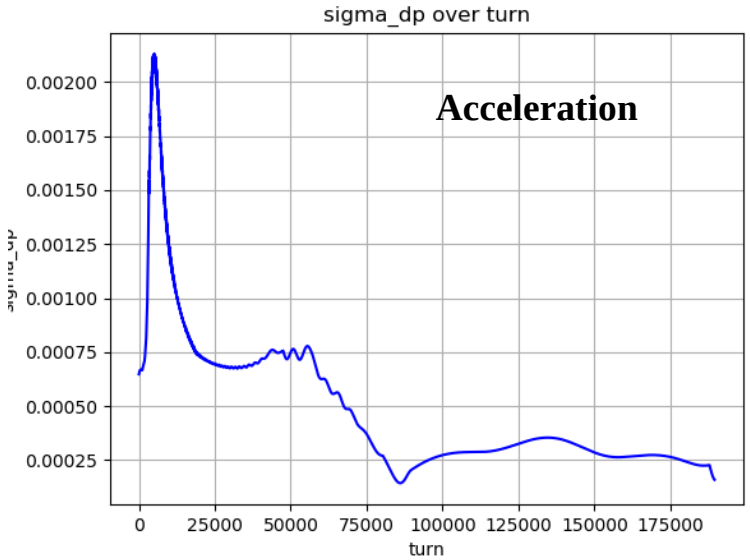
Power

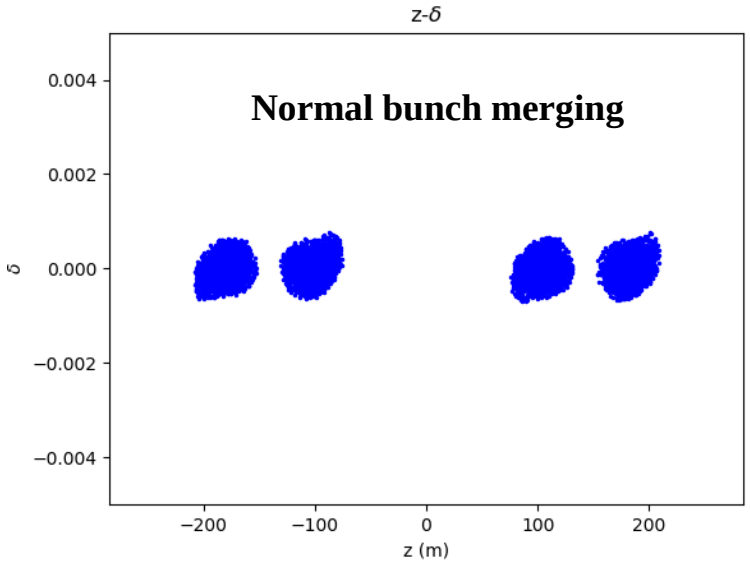
3.2 kW

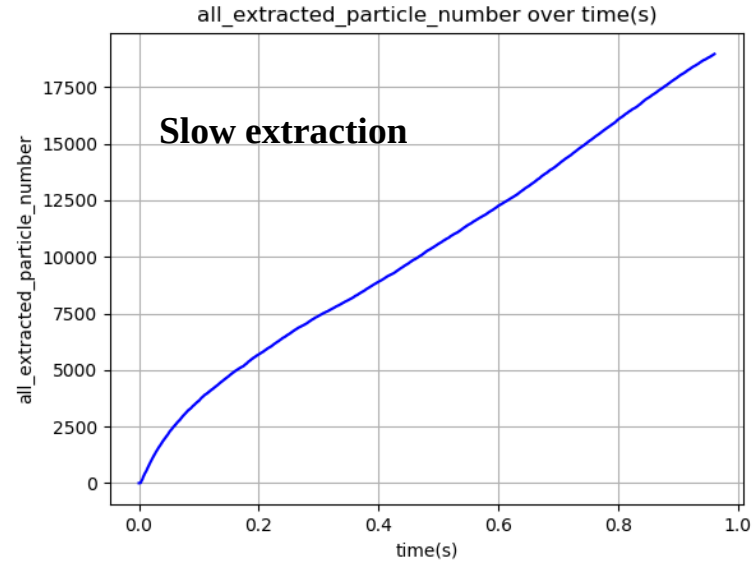
This broadband feedback system can stabilize intra-bunch instabilities in HIAF-BRing.

3. CISP benchmarks and applications

- Other beam dynamics simulations





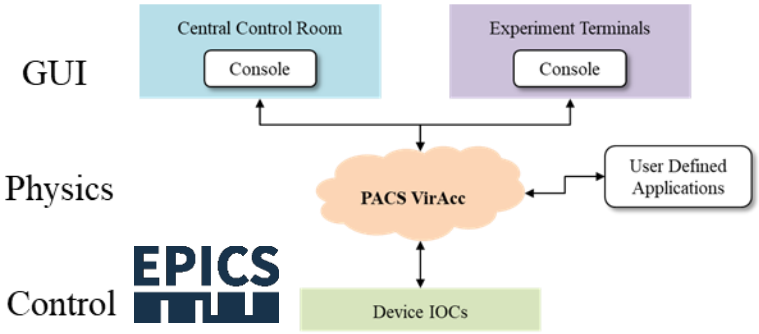


CISP
强流效应模拟平台

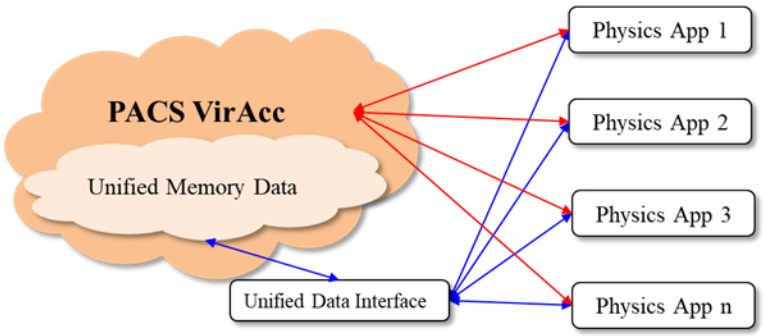
CISP is becoming a powerful simulation code for high intensity hadron accelerators which can simulate a lot of beam dynamics.

4. Development of control system PACS

- Physics-oriented Accelerator Control System (PACS) is a high-performance, high-reliability, high-scalability and high-intelligence accelerator high-level control system.

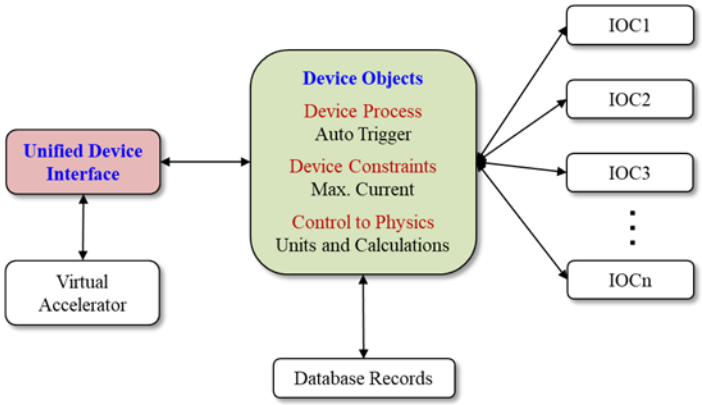


New three-layer framework

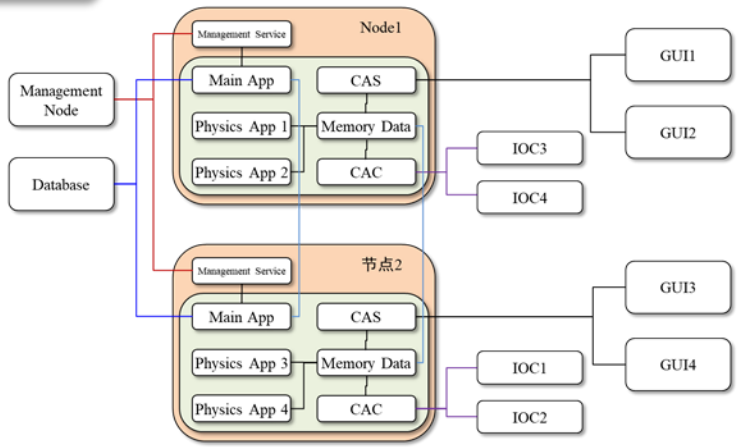


Arbitrary physics apps

Four key designs



Unified device access framework

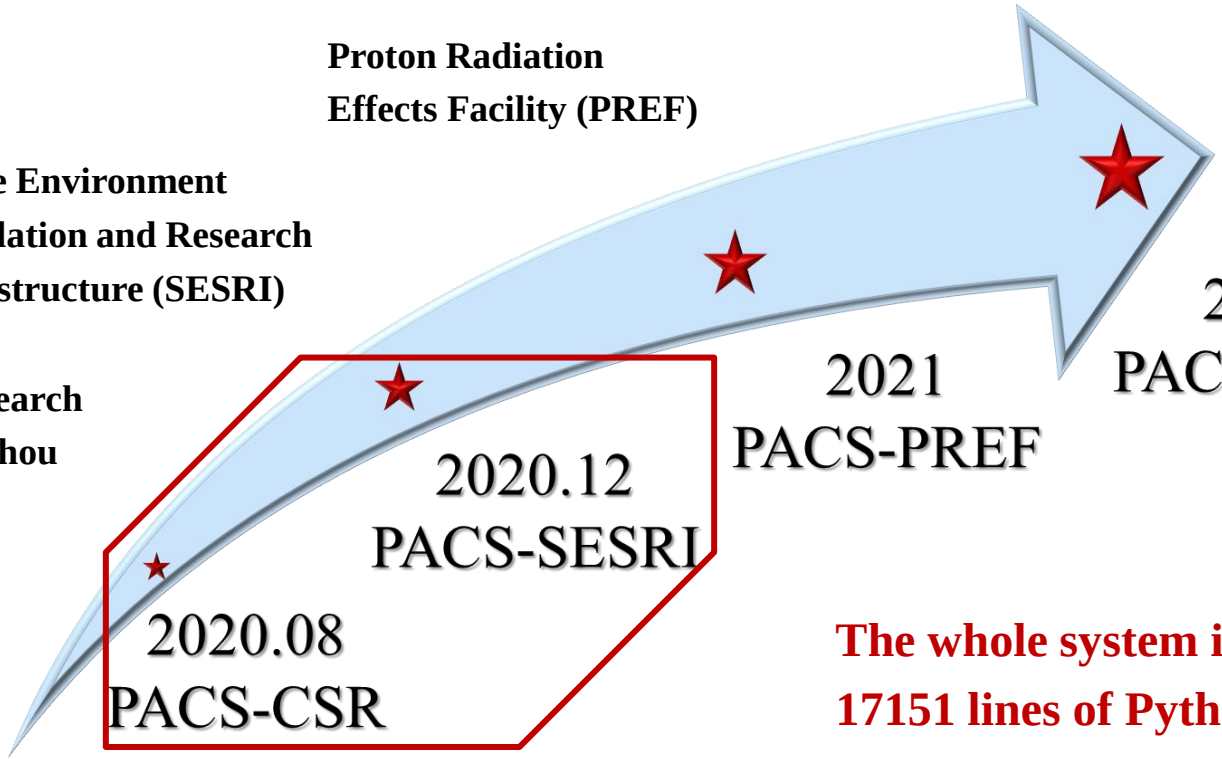


Real-time and high-performance computing grid

4. Development of control system PACS

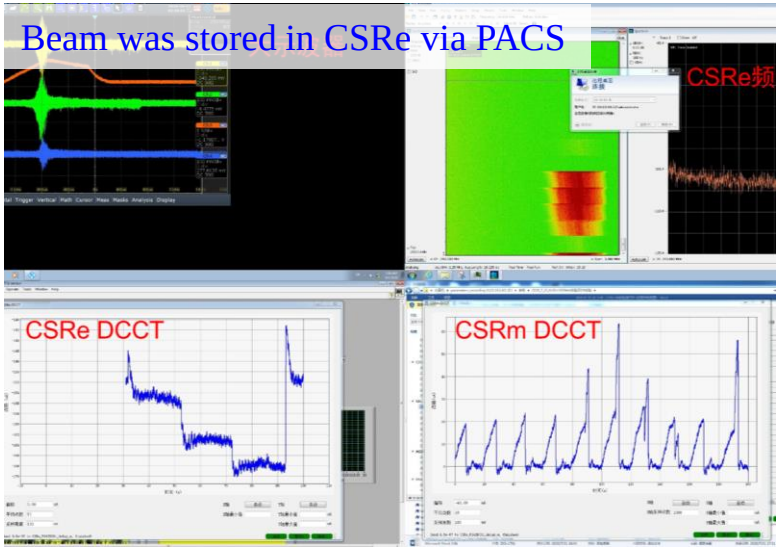
- Staging development and application plan

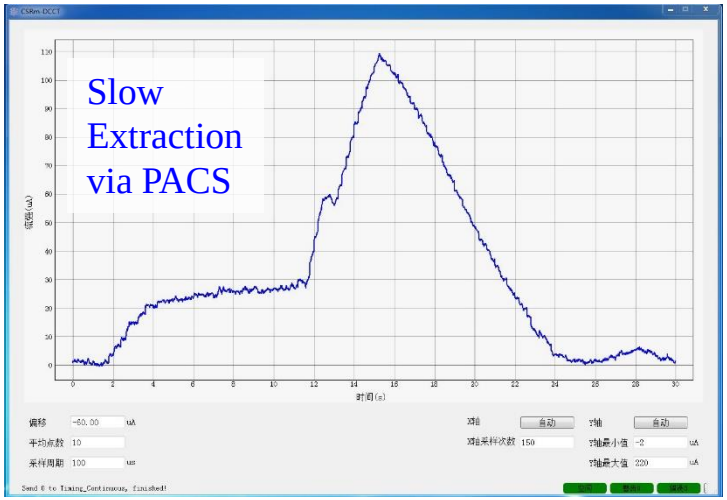
  - ✓ **Three national facilities in China**
  - ✓ **One collider in the future**

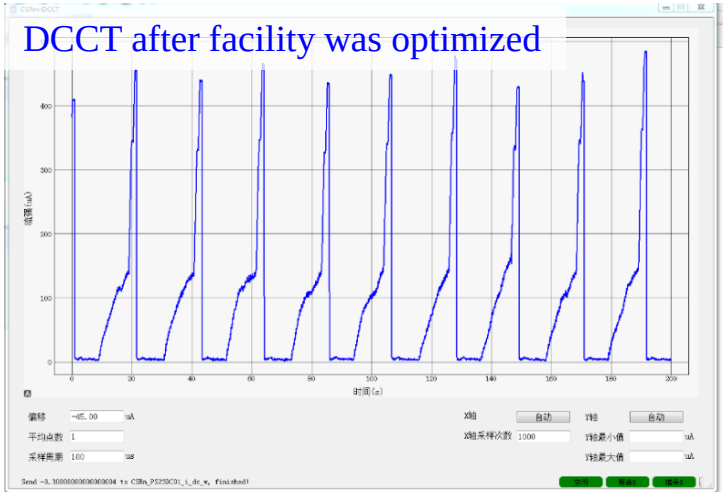


The whole system includes 17151 lines of Python code now.

5. PACS applications





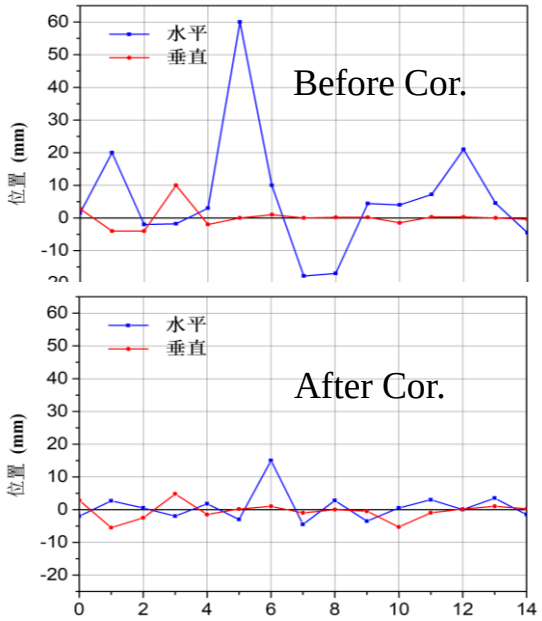


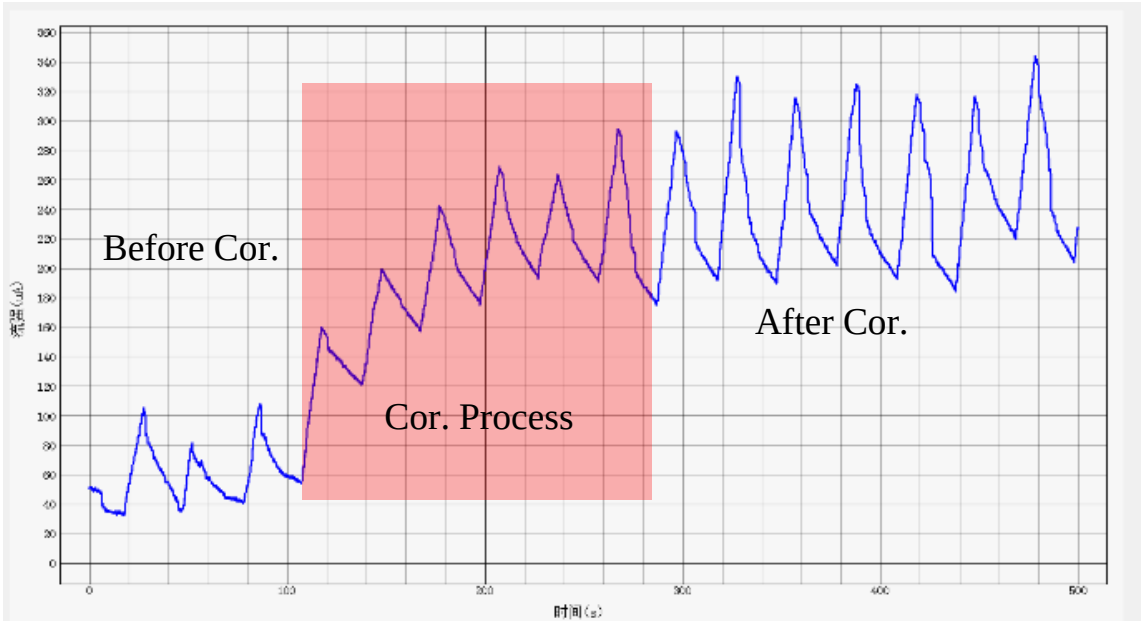
PACS itself has passed the tests and is deployed in HIRFL now!

5. PACS applications

- Application 1 – automatic closed orbit correction

Automatic processing app

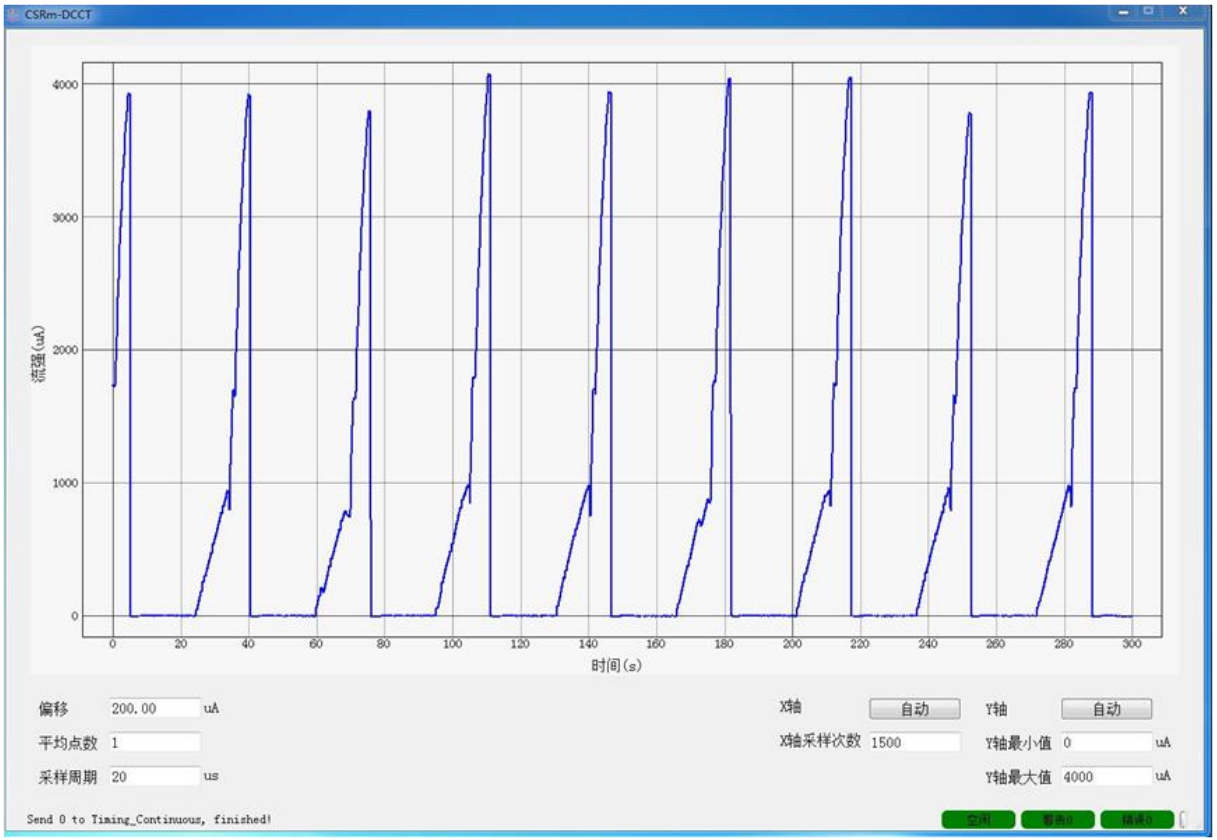




Automatic response matrix measurement and closed orbit correction were realized in HIRFL for the first time. After correction, the intensity increased by 2~3 times!

5. PACS applications

- Application 2 – beam optimization



Orbit, injection bumps, RF harmonic, RF voltage, RF frequency … are optimized

- ✓ Injection 1×10^{9} Kr^{26+}
- ✓ Extraction 6×10^{8} Kr^{26+}
- ✓ **20 times higher than the previous highest beam intensity record in HIRFL-CSR**

5. PACS applications

- Application 3 – PACS-SESRI development

Physics apps and devices are very different

2~3 months to finish the whole physics layer of PACS-SESRI


Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

The design of PACS (Physics-oriented Accelerator Control System) and its implementation in a heavy ion accelerator facility

G.M. Ma [a,b], J. Liu [a,*], J.C. Yang [a], W.P. Chai [a], S. Ruan [a,c], Y.P. Zhu [a,b], G. Wang [a,b], G.D. Shen [a,c], R.R. Wang [a,b]

[a] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Huizhou Research Center of Ion Science, Huizhou 516003, China

Reviewer: The idea of Physics based Controls, implementing Physics Theory to the Control System of a particular Physics Installation, is not new. However, **the level at which it is thought-out, developed, and implemented in this work looks very impressive**. It is specifically applied to the Ion/ Heavy Ion Accelerator Facilities of different scale, **but it can be easily adapted to almost any Physics Installation of any scale. It might be also a Plasma Installation, Proton Accelerators, Electron Accelerators, etc.**

The first stage of the PACS development is successful!

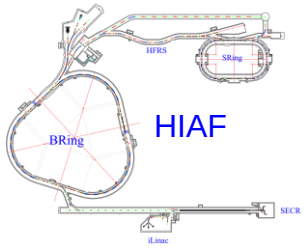
6. Outlook

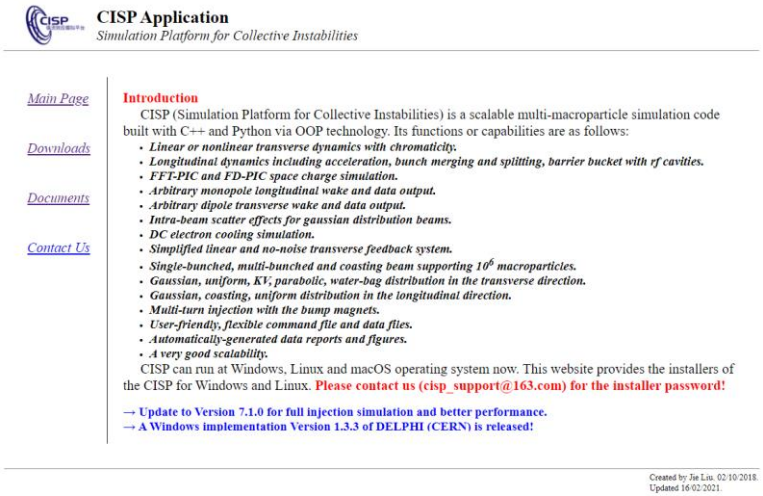
- The development of CISP and PACS have achieved initial success.

CISP 强流效应模拟平台

PACS @CSR 加速器物理控制

Full Featured
High Performance
High Scalability
Diverse Facilities





CISP Application
Simulation Platform for Collective Instabilities

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Introduction

CISP (Simulation Platform for Collective Instabilities) is a scalable multi-macroparticle simulation code built with C++ and Python via OOP technology. Its functions or capabilities are as follows:

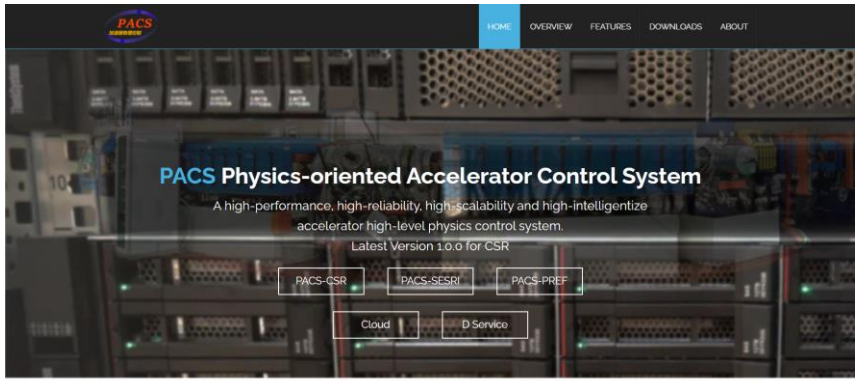
- *Linear or nonlinear transverse dynamics with chromaticity.*
- *Longitudinal dynamics including acceleration, bunch merging and splitting, barrier bucket with rf cavities.*
- *FFT-PIC and FD-PIC space charge simulation.*
- *Arbitrary monopole longitudinal wake and data output.*
- *Arbitrary dipole transverse wake and data output.*
- *Intra-beam scatter effects for gaussian distribution beams.*
- *DC electron cooling simulation.*
- *Simplified linear and no-noise transverse feedback system.*
- *Single-bunched, multi-bunched and coasting beam supporting 10^6 macroparticles.*
- *Gaussian, uniform, KV, parabolic, water-bag distribution in the transverse direction.*
- *Gaussian, coasting, uniform distribution in the longitudinal direction.*
- *Multi-turn injection with the bump magnets.*
- *User-friendly, flexible command file and data files.*
- *Automatically-generated data reports and figures.*
- *A very good scalability.*

CISP can run at Windows, Linux and macOS operating system now. This website provides the installers of the CISP for Windows and Linux. **Please contact us (cisp_support@163.com) for the installer password!**

→ Update to Version 7.1.0 for full injection simulation and better performance.
→ A Windows implementation Version 1.3.3 of DELPHI (CERN) is released!

Created by: Jie Liu. 02/10/2018.
Updated 16/02/2021.

CISP Website https://cisp.azurewebsites.net/

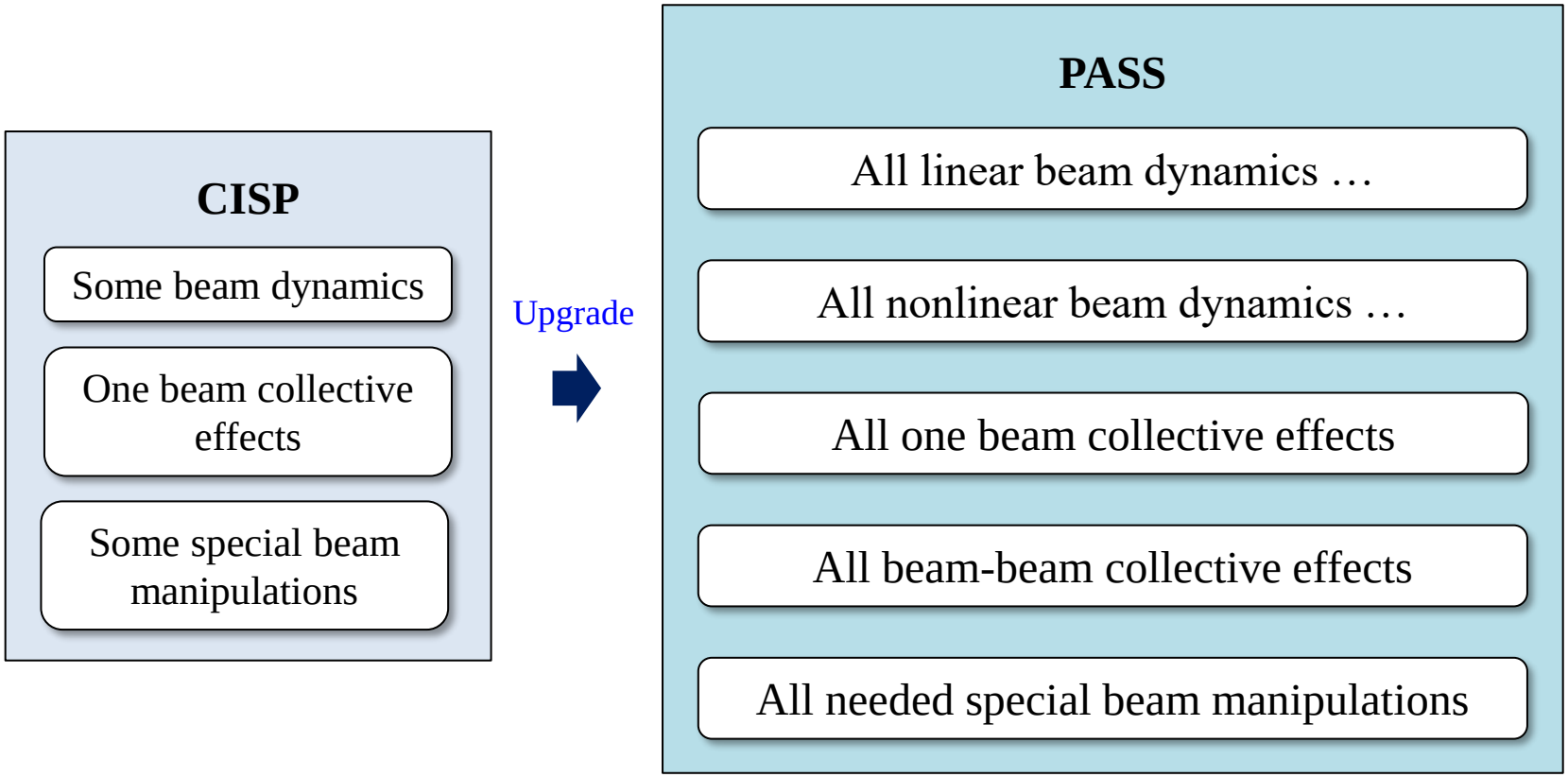


Overview

PACS Website (only available in our institute)

6. Outlook

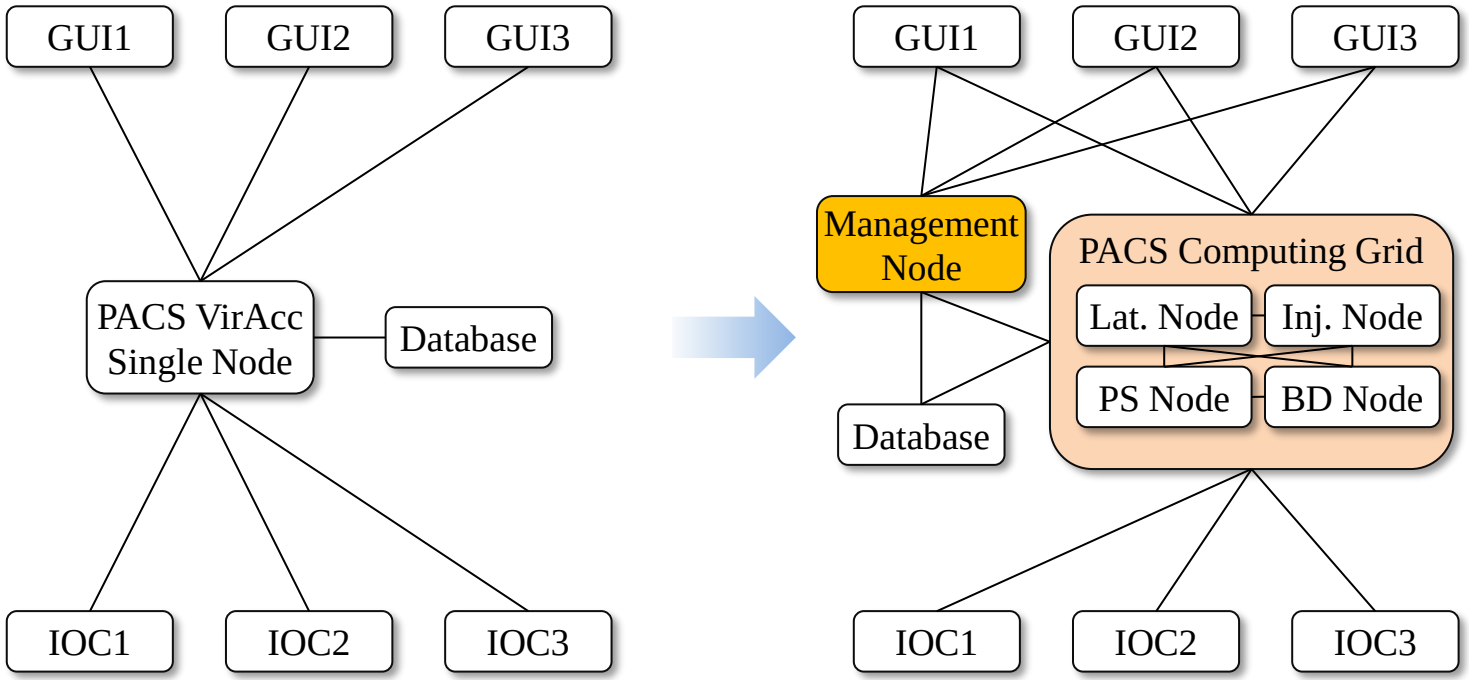
- PASS, a new beam dynamics simulation code, will extend CISP.



PASS（Particle Accelerator Simulation Studio）will become a powerful beam dynamics research software for hadron accelerators.

6. Outlook

- PACS-HIAF for large scale facilities will be developed.



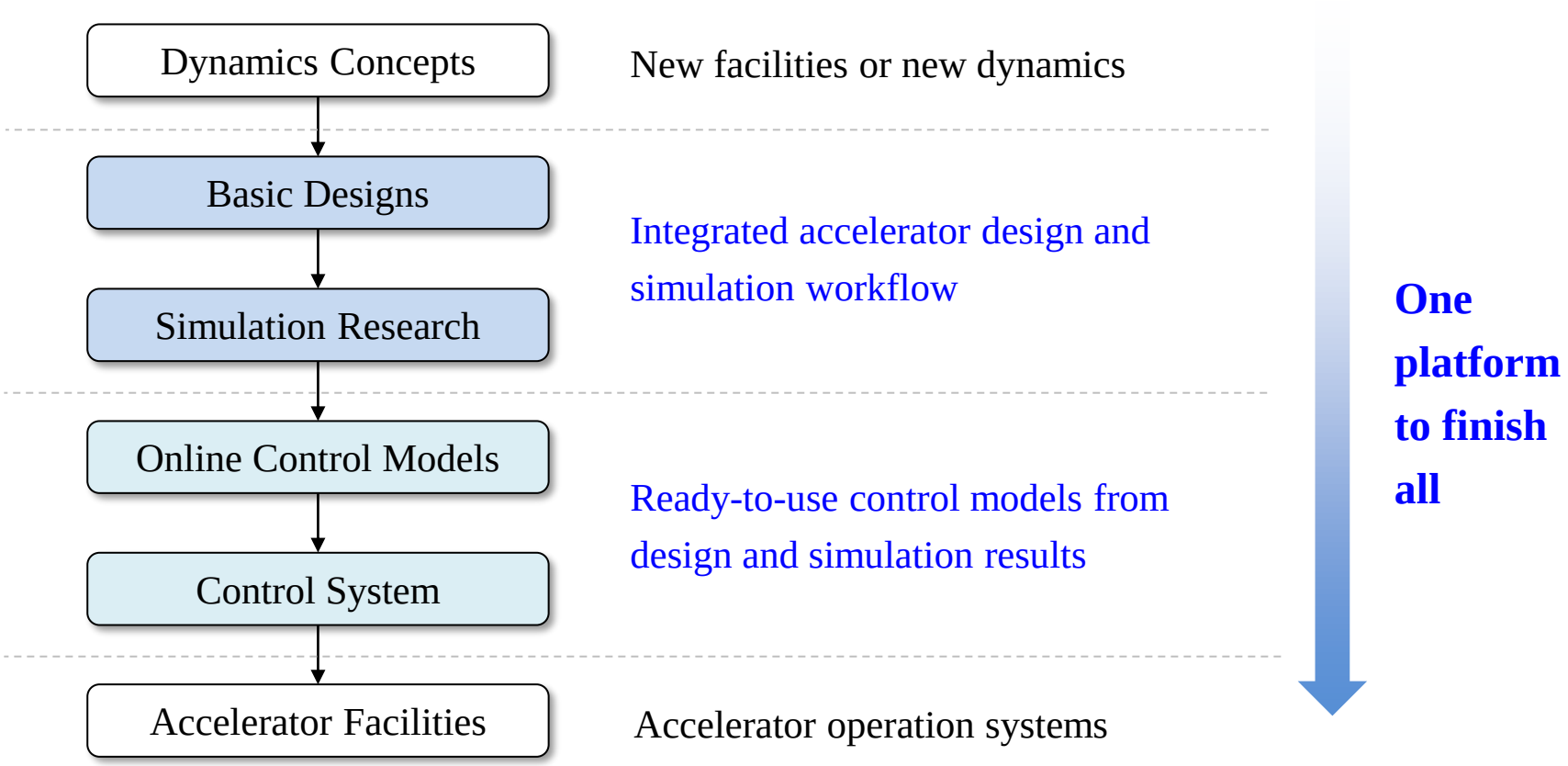
Employ a distributed computing grid to largely increase real-time performance.

PACS-HIAF will be finished in 2023.

It will become an advanced accelerator control system driven by big data technology!

6. Outlook

- PASS and PACS will be integrated into **a unified accelerator software platform**!



The integrated software platform will significantly improve the design and operation of the next-generation research and application accelerator facilities.

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- Thanks very much for the help from colleagues in general design group, IMP, CAS
- Thank the experts from IHEP, CAS for the help on collective instability calculations and simulations
- Thanks very much for the help from colleagues in other groups of accelerator technology center, IMP, CAS
- Thank the experts from CERN for the help on collective instability simulations

Thanks!