# Present Status of HIRFL Complex in Lanzhou

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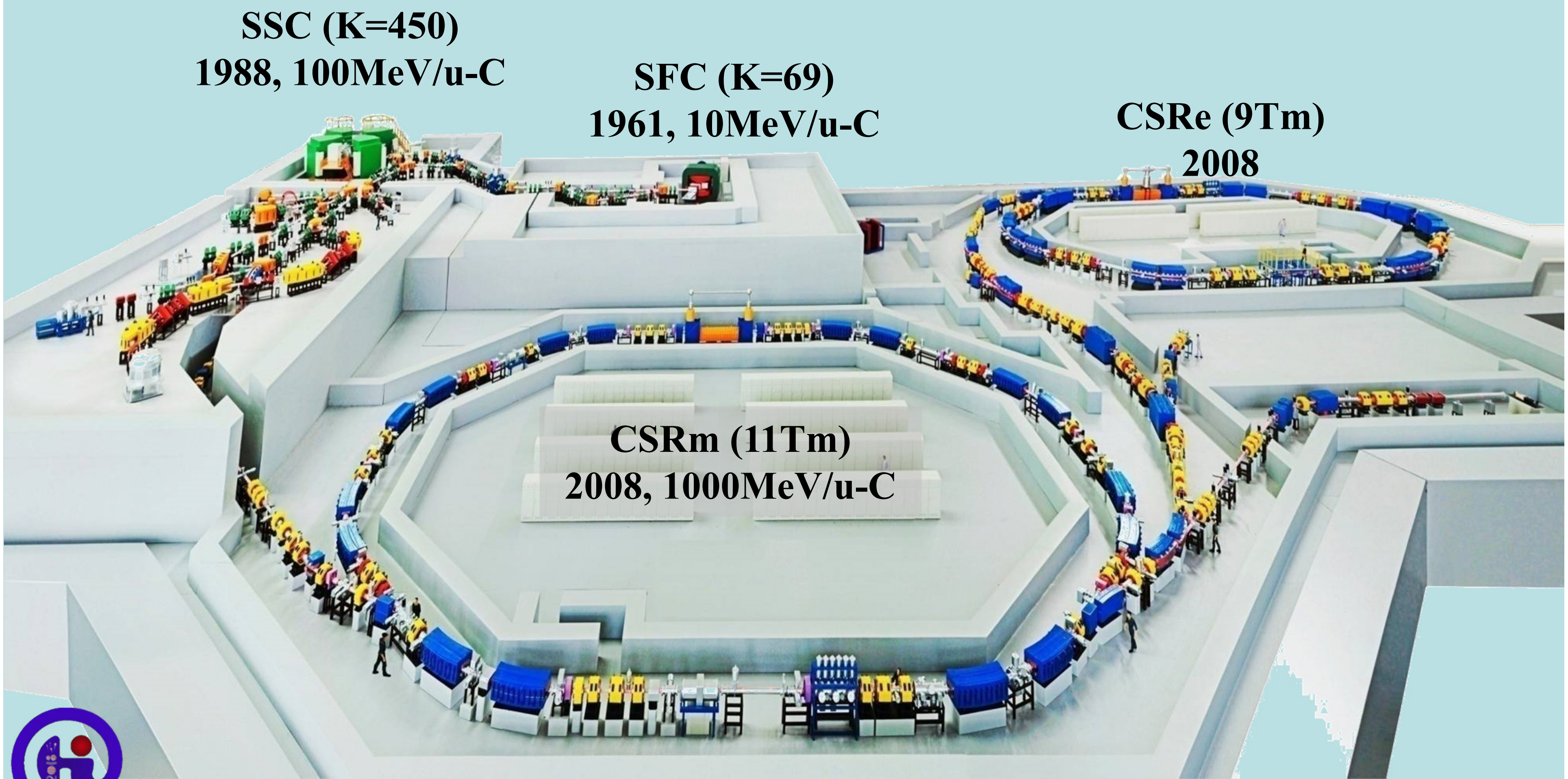
Lanzhou, China

# Heavy Ion Research Facility in Lanzhou (HIRFL)

The largest ion-accelerator complex in China

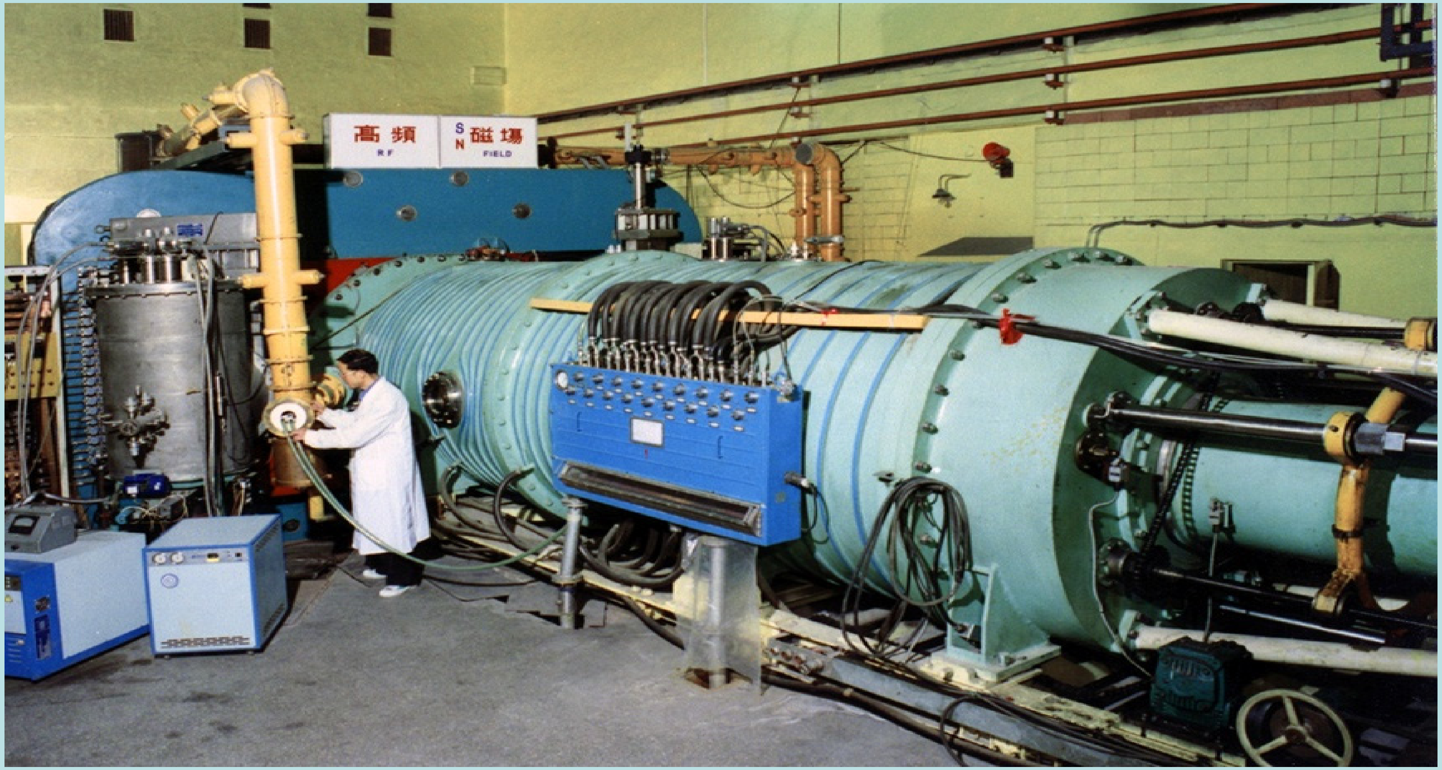


# The injector SFC

Built in 1961 with the assistance of the Soviet Union, H&He

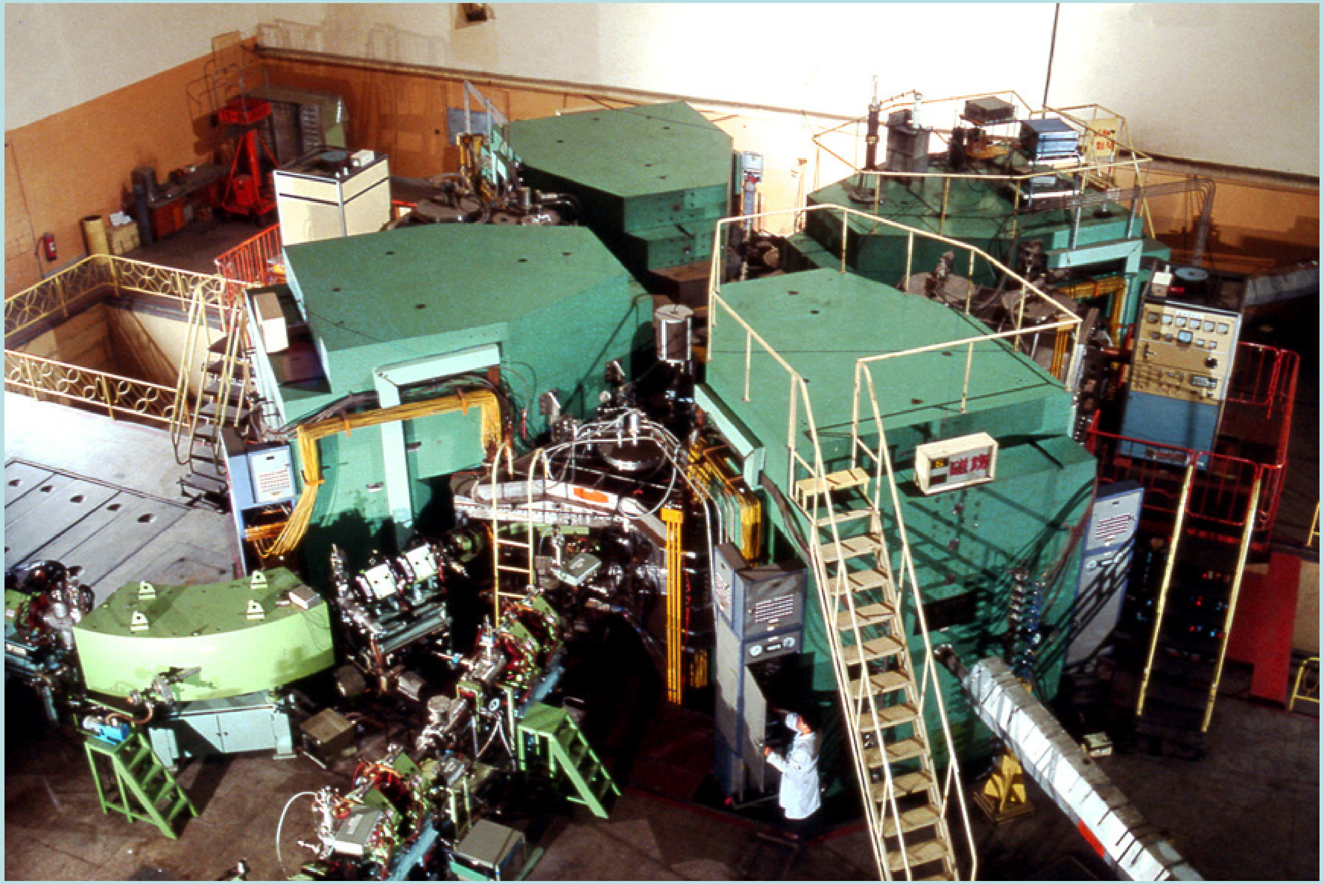
1970s, upgraded, Carbon~Uranium

K ~ 69, R ~0.75 m, E ~10 MeV(C), 1MeV/u(U)



# The main cyclotron SSC

1988, K ~ 450, R ~3.203 m, α~U, E : 100 MeV/u (C), 10 MeV/u (U)



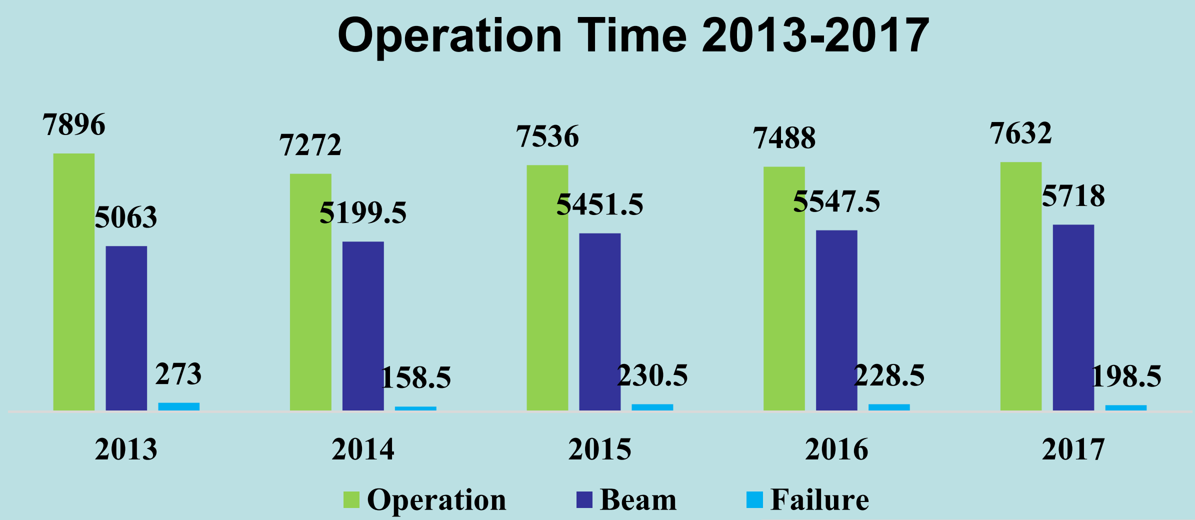
# Synchrotron and Storage Rings CSRm & CSRe

CSRm 161.0m, $G_{max}$=11.3 Tm

CSRe 128.8m, $G_{max}$=9.0 Tm

# Electron Coolers at CSRm&e


# HIRFL operation status 2013-2017



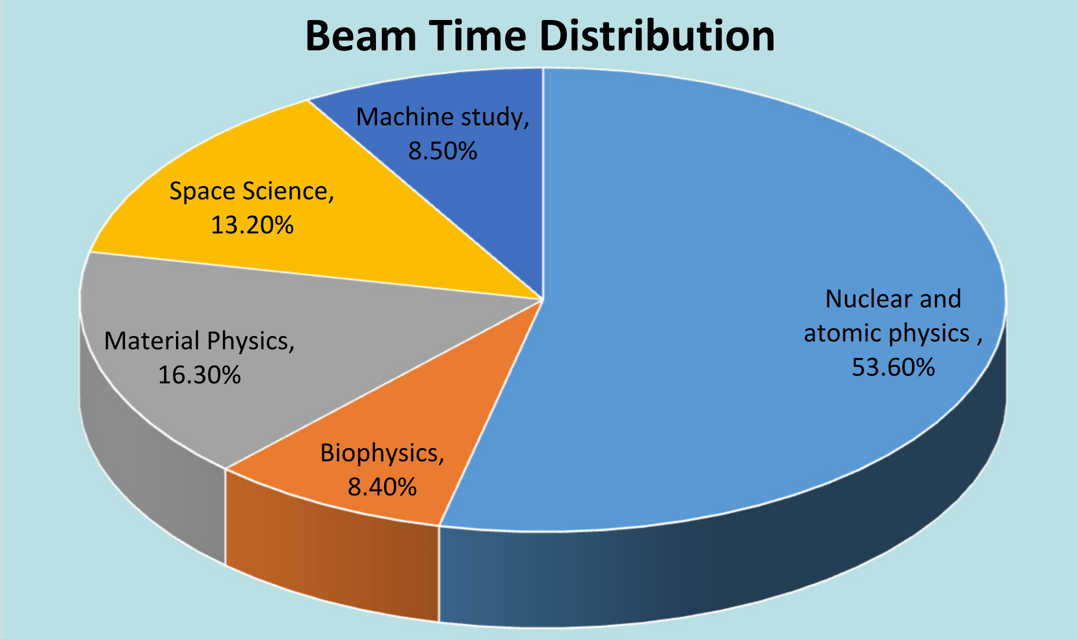

**Operation budget: 14.68 M$*5**

**Operation time/a: 7565 h**

**Beam Time/a: 5273 h**

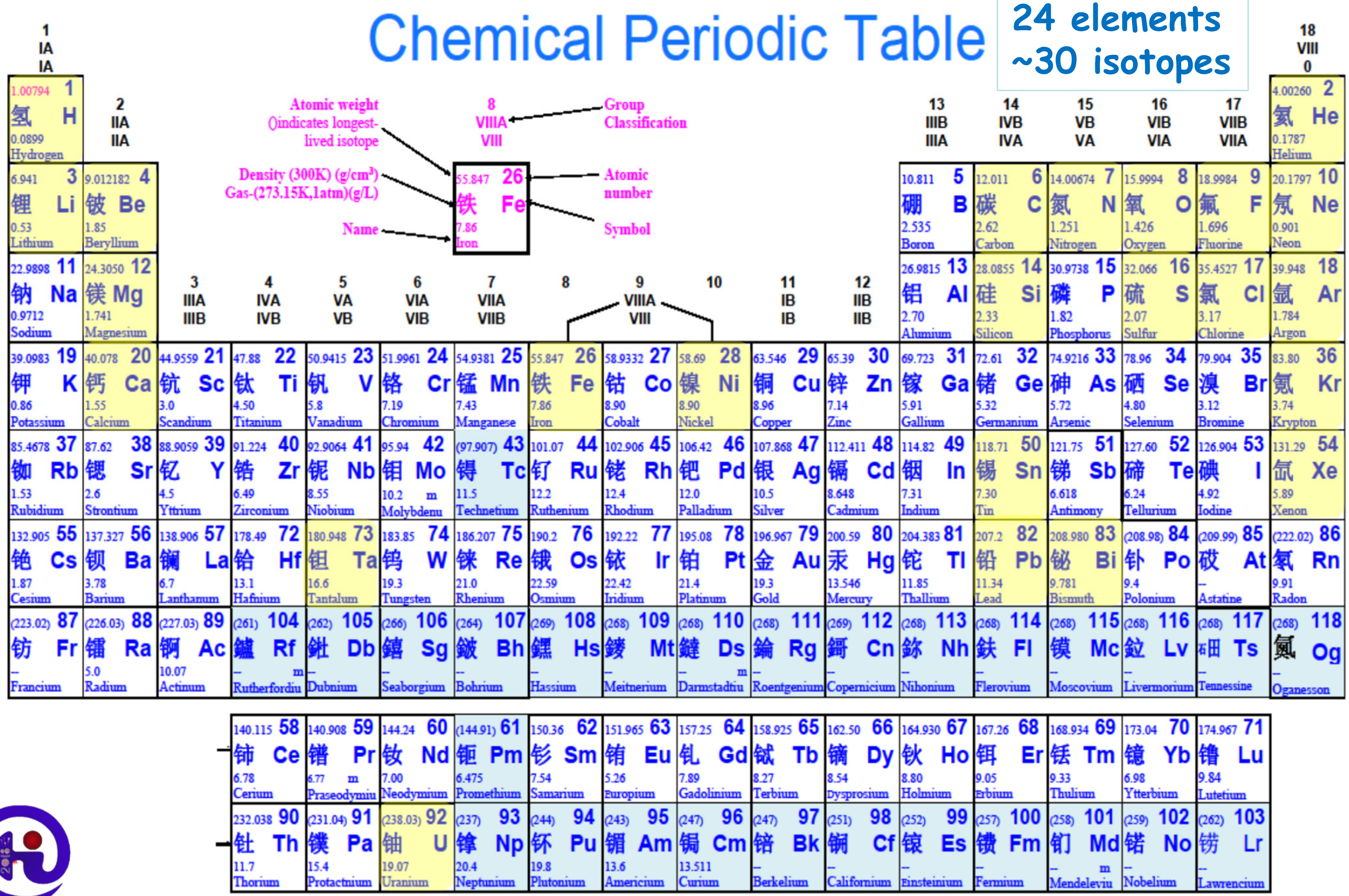
**No. Experiments: 910 (+31 MS)**

**User institutions: > 200**



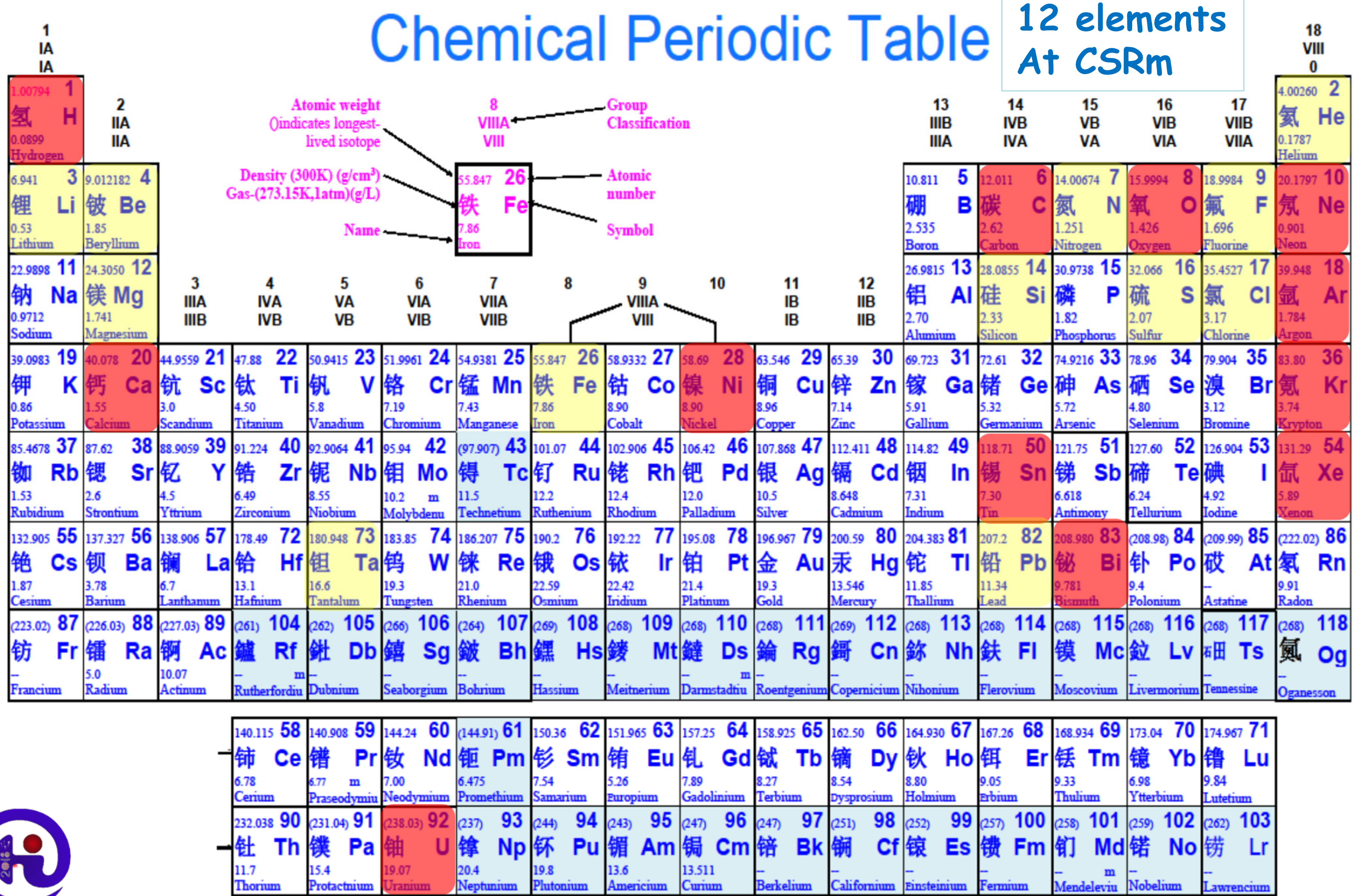
# Beams acc. by Cyclotrons

**24 elements**
**~30 isotopes**



# Beam by Cyc.s and CSRm

**12 elements At CSRm**



# Beam Availability of SFC and SSC

| | |
|---|---|
| 0 | Not available by SFC or SSC |
| 1 | Available by SFC alone |
| 2 | Available by SFC+SSC,same A/Q |
| | Limited by SFC-RF frequency <15.5 MHz |
| | Limited by SFC-B >1T |
| 1 | Available by SSC after stipping. |

$E_k$ (MeV/u)

| E(MeV/u) | SFC 0.4 | 0.6 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A/Qs | SSC 4.1 | 6.2 | 10.4 | 15.8 | 21.2 | 26.7 | 32.3 | 38.0 | 43.8 | 55.6 | 67.9 | 80.6 | 93.7 | 107.3 | 121.4 |
| 8 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.75 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.5 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7.25 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 2 | 2 | 1 | 0 | 0 | 0 | | | | | | | | | |
| 6.75 | 2 | 2 | 1 | 1 | 0 | 0 | | | | | | | | | |
| 6.5 | 1 | 2 | 2 | 1 | 0 | 0 | | | | | | | | | |
| 6.25 | 1 | 2 | 2 | 1 | 0 | 0 | | | | | | | | | |
| 6 | 1 | 2 | 2 | 1 | 0 | 0 | | | | | | | | | |
| 5.75 | 1 | 2 | 2 | 1 | 1 | 0 | | | | | | | | | |
| 5.5 | 1 | 2 | 2 | 1 | 1 | 0 | | | | | | | | | |
| 5.25 | 1 | 1 | 2 | 2 | 1 | 1 | | | | | | | | | |
| 5 | 0 | 1 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.75 | 0 | 1 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.5 | 0 | 1 | 2 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.25 | 0 | 0 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.75 | 0 | 0 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.5 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3.25 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 |
| 2.75 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 2.25 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 |
| 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 2 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| F-SFC | 5.59 | 6.85 | 8.84 | 10.82 | 12.49 | 13.95 | 15.28 | *16.50 | 5.88 | 6.57 | 7.19 | 7.76 | 8.28 | 8.78 | 9.25 |
| F-SSC | 8.39 | 6.85 | 8.84 | 10.82 | 12.49 | 13.95 | 7.64 | 8.25 | 8.82 | 9.85 | 10.78 | 11.63 | 12.43 | 13.17 | 13.87 |
| match | 0.5 | 1 | 1 | 1 | 1 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| * possibly availble by SFC-5.49MHz | | | | | | A/Q | SFC 11 | 12 | 14 | 16 | 18 | 20 | 23 | 26 | 30 |

| A/Q | SFC 11 | 12 | 14 | 16 | 18 | 20 | 23 | 26 | 30 |
|---|---|---|---|---|---|---|---|---|---|
| 2.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.25 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| F-SFC | 9.691 | 10.11 | 10.91 | 11.64 | 12.33 | 12.98 | 13.88 | 14.72 | 15.77 |

$F_{rf}$(MHz)

Present Status of HIRFL Complex in Lanzhou

# UPGRADING OF INFRASTRUCTURE

# Upgrading of Infrastructure

- **HIRFL was built-up in 3 periods, lasting about half century.**
- **Under strong support of the national maintenance and renovation budget for large scale fundamental science and technology facilities from CAS, many aspects of the infra-structure of HIRFL were upgraded or renewed to improve the operation stability and reduce the failure time:**
  - **Power station for SSC and beam lines to terminals**
  - **Water cooling system**
  - **Intranet**
  - **EMC environment of CSRe and RIBLL2**
  - **Environment control**
    - **The power supply rooms of CSR**
    - **New monitoring systems of water-cooling, power station and water leakage detection**
    - **Radiation protection system**

# New Power Station for SSC and beam lines to terminals


**New grid technology used to improve the reliability, safety and energy efficiency**

# Upgrade of Water Cooling

## Goals

- **Pressure stability ➔ ≤0.5kgf/cm2**
- **High water resistance ➔ ≥1MΩ•cm**
- **Real-time monitoring.**

## Actions

- **Replace packing pumps by vertical multistage centrifugal pumps**
- **Centralized management (3 in 1) of Frequency Conversion pumps by PLC**
- **New RO + EDI with Polishing Resin Bed.**

## Results

- **Pressure stability: ± 0.25, ± 0.1, ± 0.45 kgf/cm$^2$**
- **Inner water resistance: >2, 1.2, 3 MΩ·cm (SFC, SSC, CSRm)**
- **Space saved by 40% for inspection and maintenances**
- **Power consumption reduce by 11%**
- **Soft switch on & off of bumps**
- **Real time monitoring device status and parameters, failure alert……**

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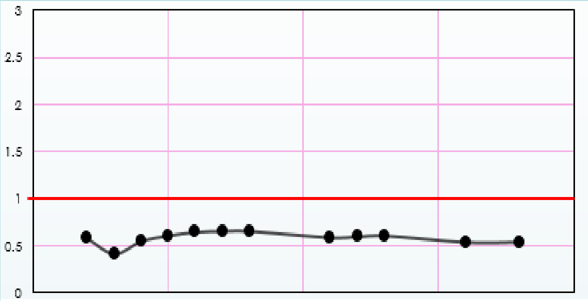
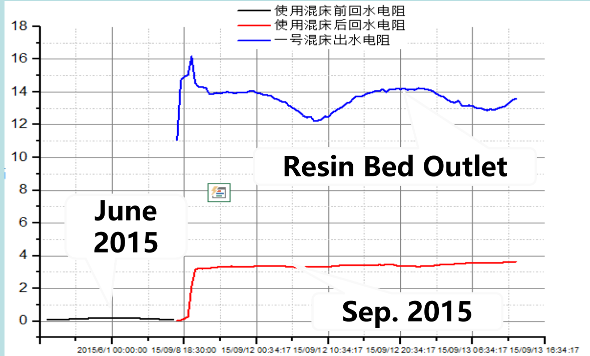
# Upgrade of Water Cooling

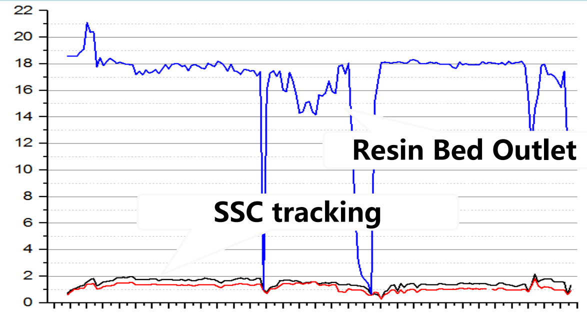
- **RO+EDI with Polishing Resin Bed → resistance improved obviously + Less water consumption**

Water resistance (MΩ.cm)

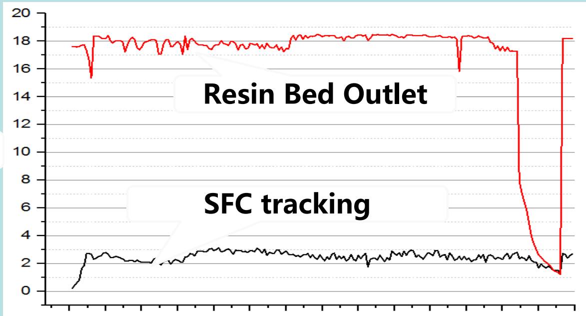


July 2014

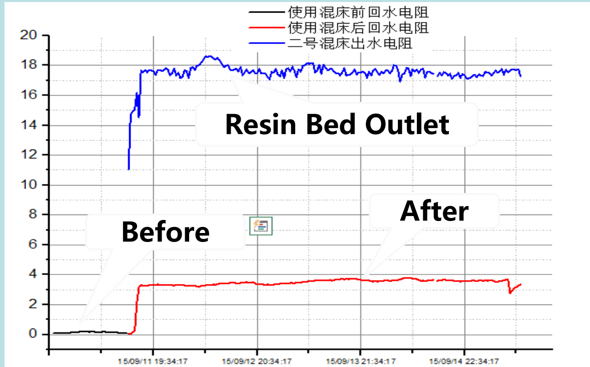



Sep. 2014




Sep. 2014




## SSC (1 resin bed)

- BEFORE：0.38 — 0.66 MΩ·cm。
- AFTER：1.2 — 1.7 MΩ·cm。

## SFC (1 resin bed)

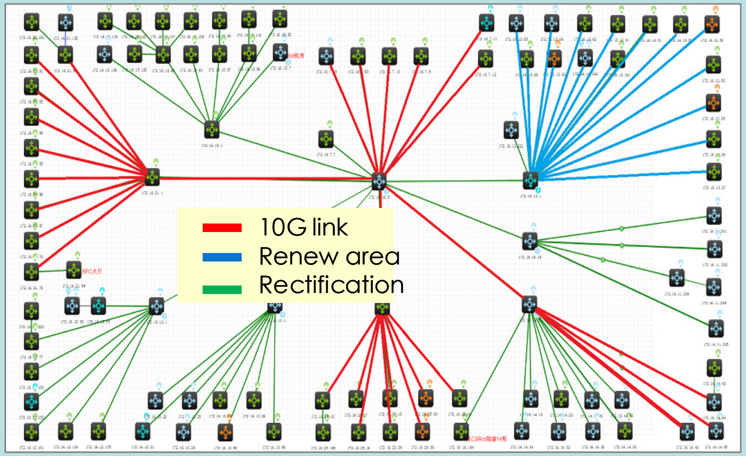
- BEFORE：0.4 — 0.72 MΩ·cm。
- AFTER：2.2 — 3.1 MΩ·cm。

## CSR (2 resin bed)

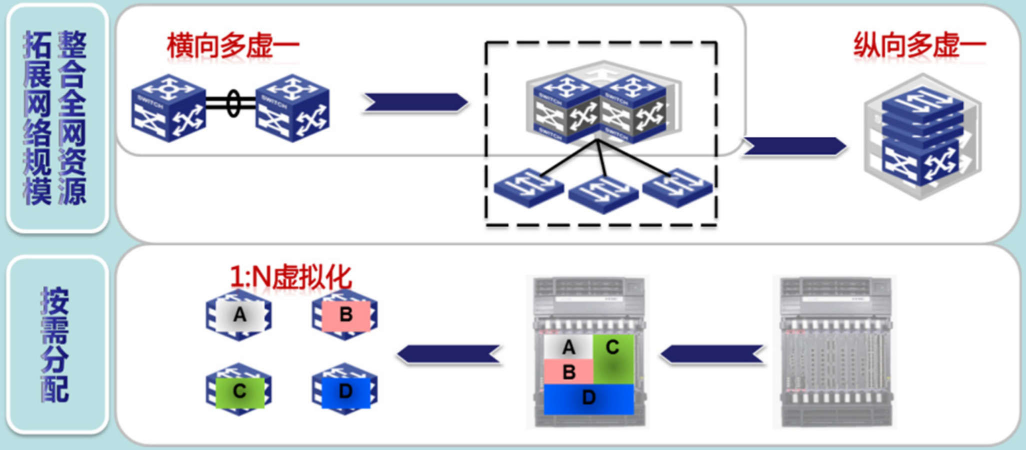
- BEFORE：0.08 — 0.12 MΩ·cm。
- AFTER：3.2 — 3.9 MΩ·cm。

# Upgrade of Intranet

- The backbone:100 M → 10 G bandwidth
- Physical link network topology optimization
- Network expansion with virtualization tech.




Physical link network topology

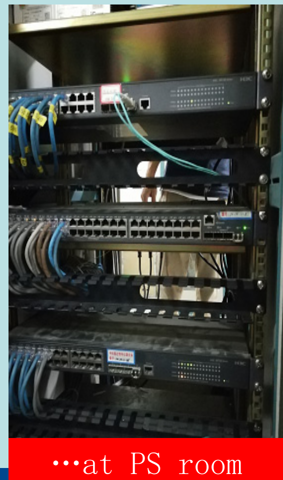



Virtualization technology

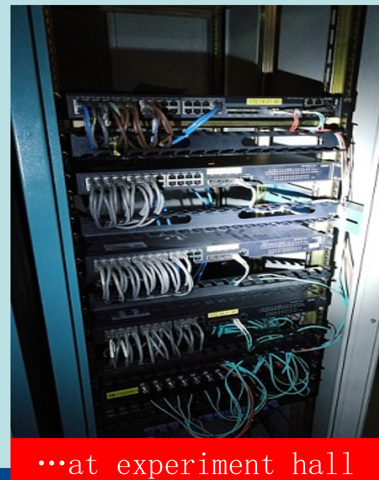
Control room

Cabinets at CR

…at SSC



…at PS room

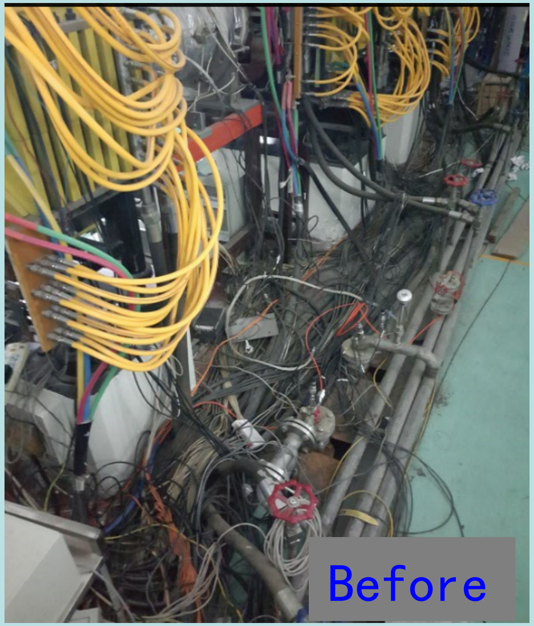


…at experiment hall

# Improving of EMC Enviro.

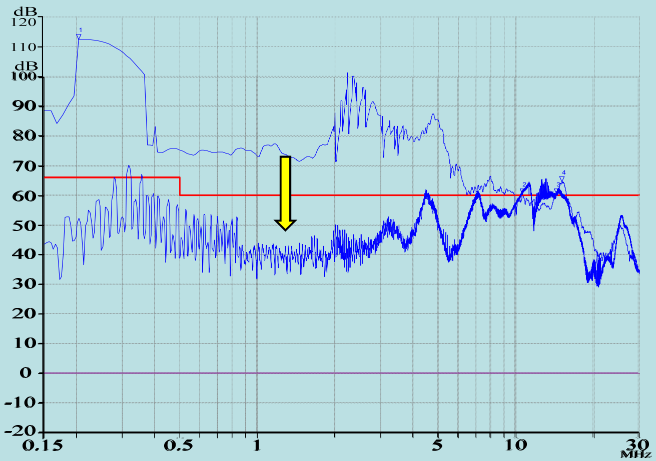
- **The signal cables and power cables of CSRe and RIBLL2 were rearranged and rewired to reduce the EMI and improve the EMC environment.**
- **The background noise levels of beam diagnosis and experiment detectors were reduced by more than one order.**

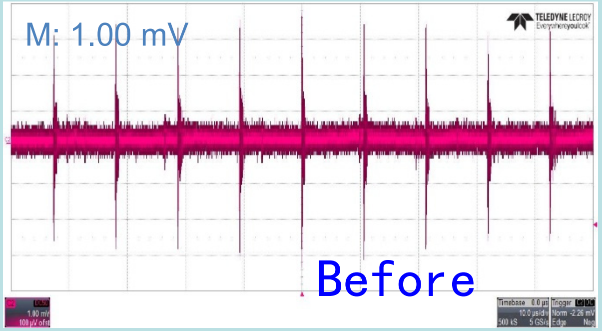
# EMC Enviro. at CSRe

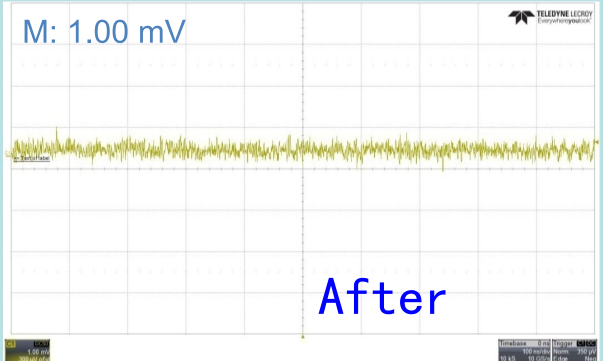





- ✓ Overall noise level < 0.5mV pp, reduces (30dB)
- ✓ VN-PE ~ 0 Volt



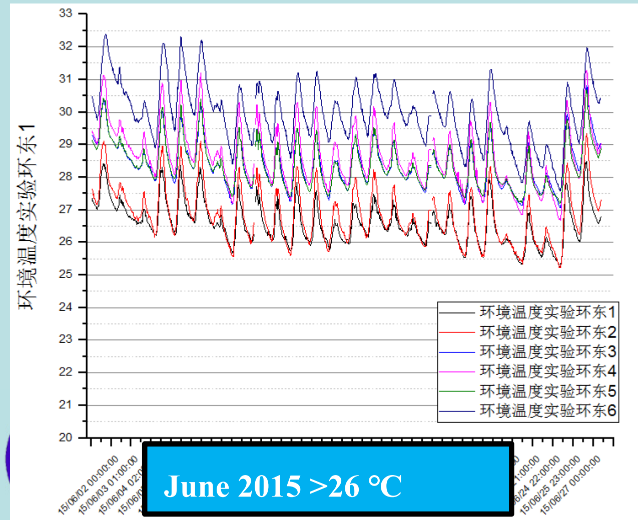



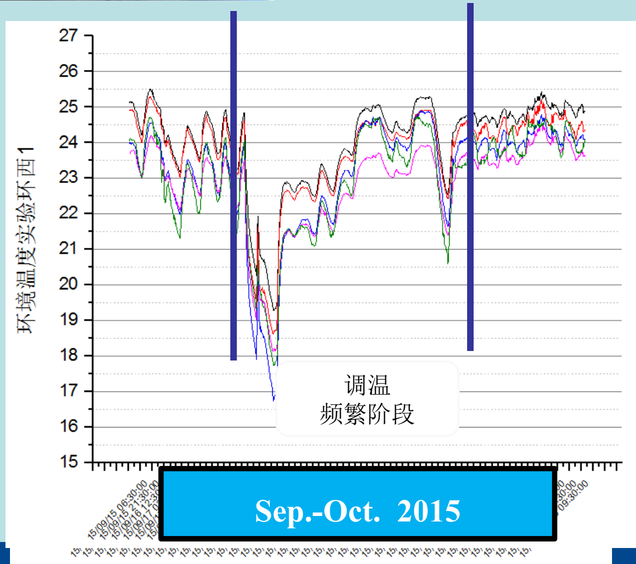
# Environment Control

- **New power supply rooms for CSRm and CSRe inside the CSR hall**
- **New monitoring systems of**
  - **water-cooling**
  - **power station**
  - **water leakage detection**
- **The radiation protection system partly rebuilt.**

# New CSRe PS Room



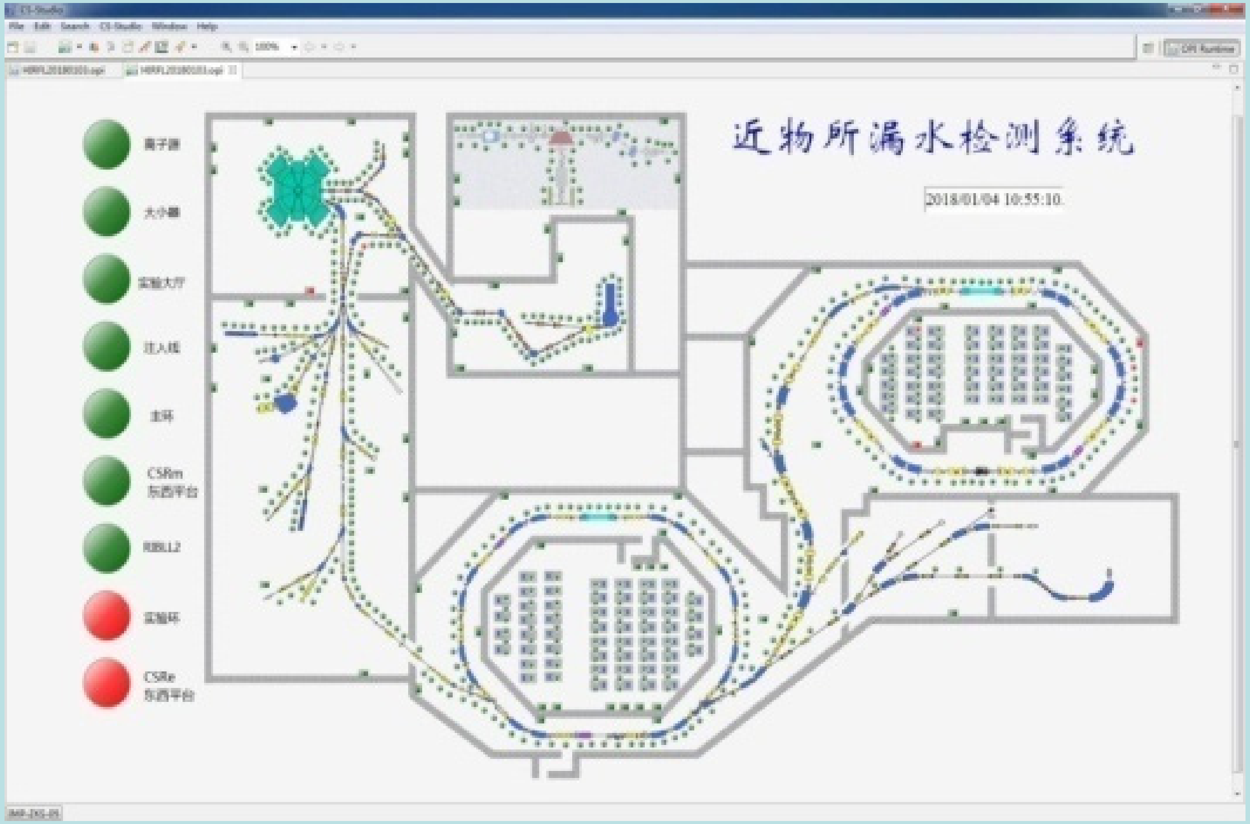



**Results T/24h**

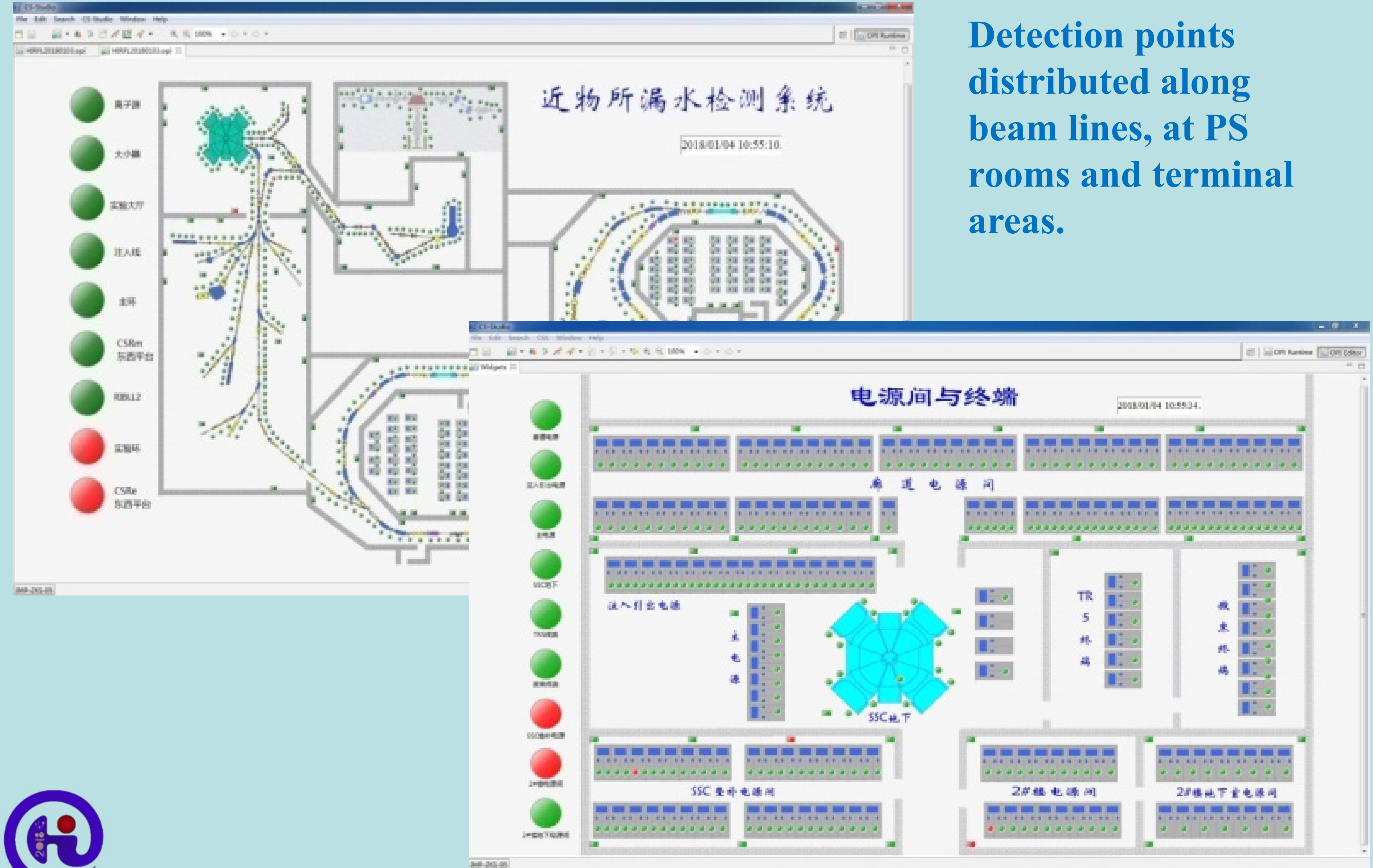
**Design: ±2°C**
**Before: ±2.5°C**
**After: ±1.5°C**

# Water Leakage Detection




**Detection points distributed along beam lines, at PS rooms and terminal areas.**

# Water Leakage Detection

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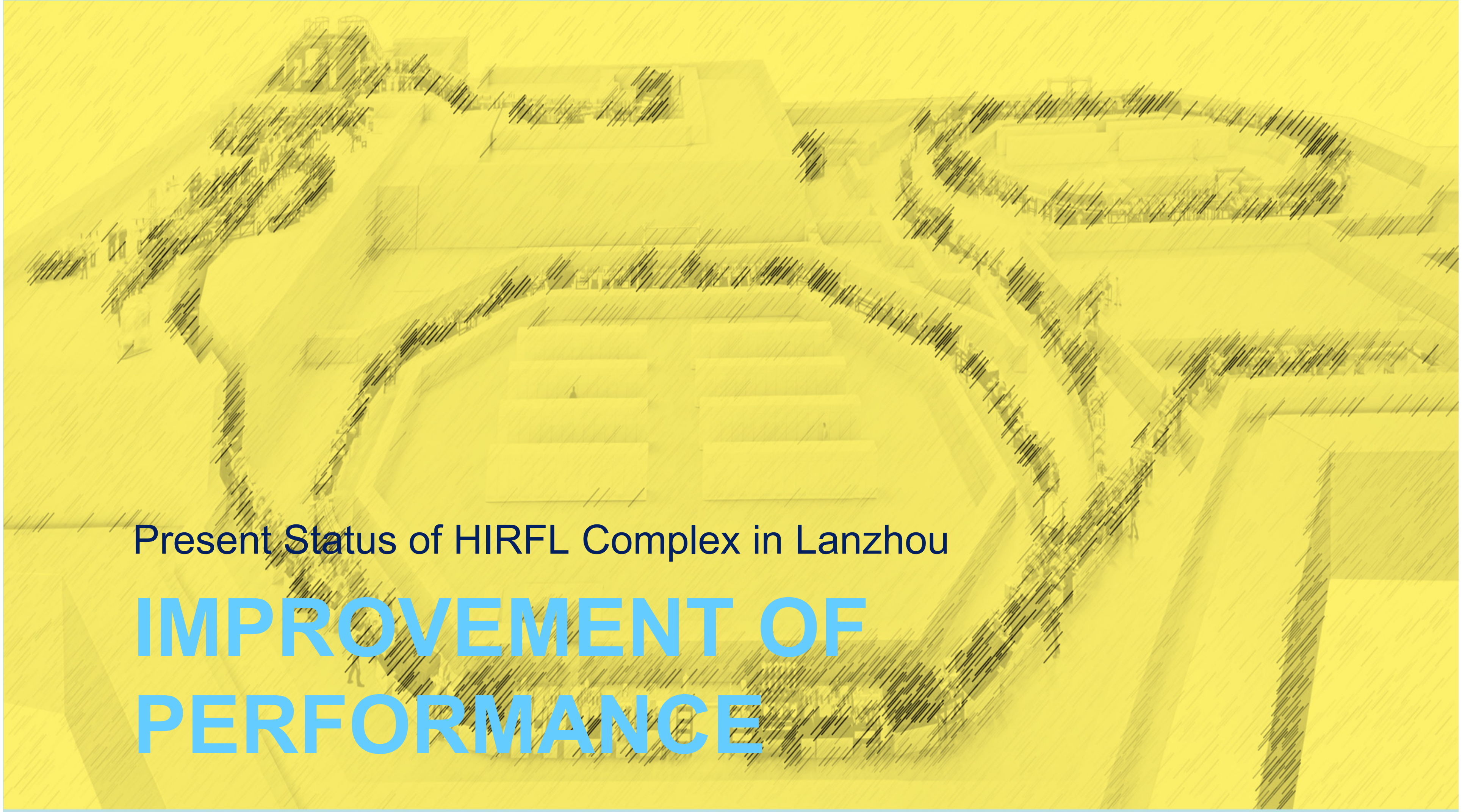
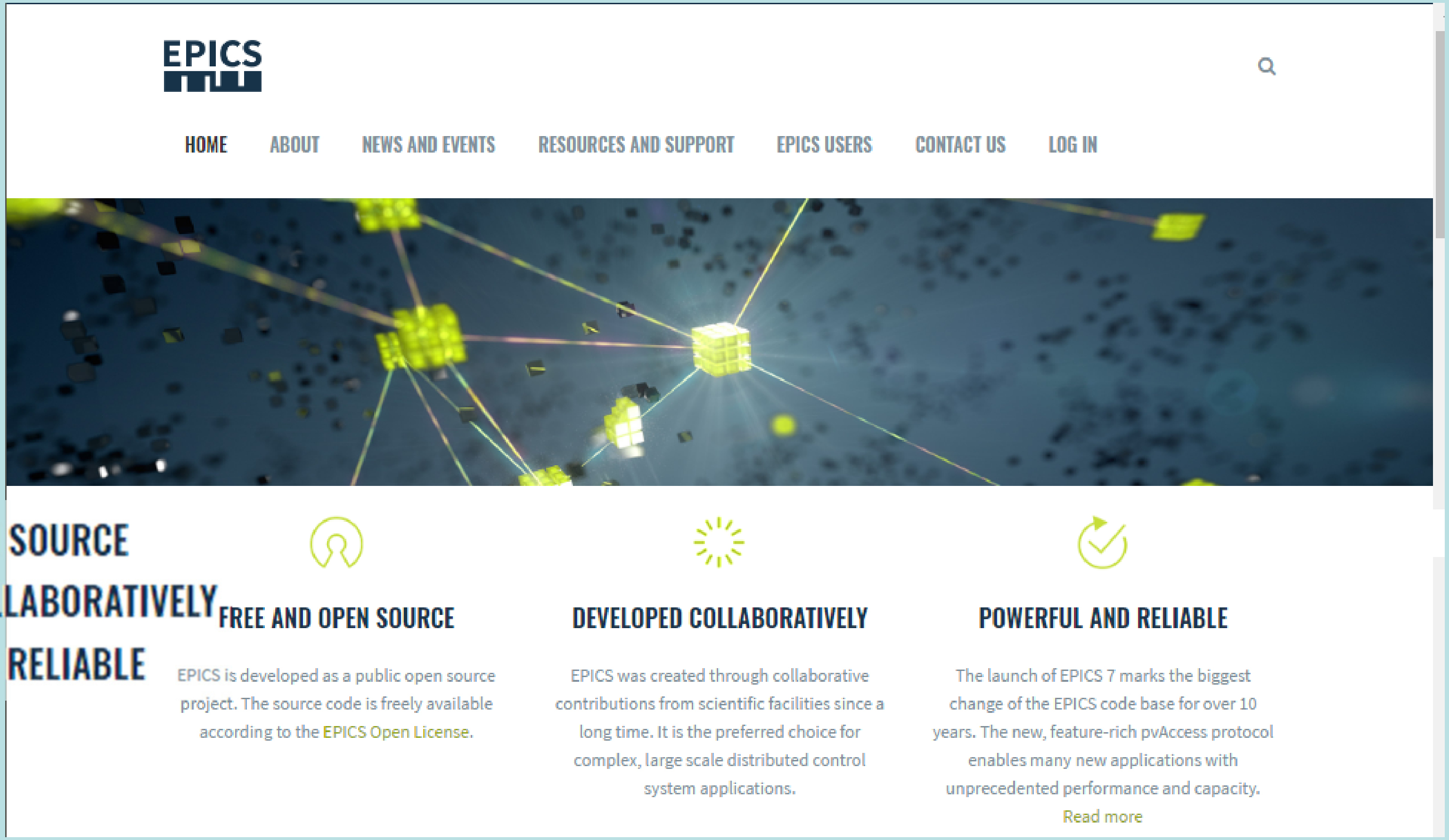


Present Status of HIRFL Complex in Lanzhou

# IMPROVEMENT OF PERFORMANCE

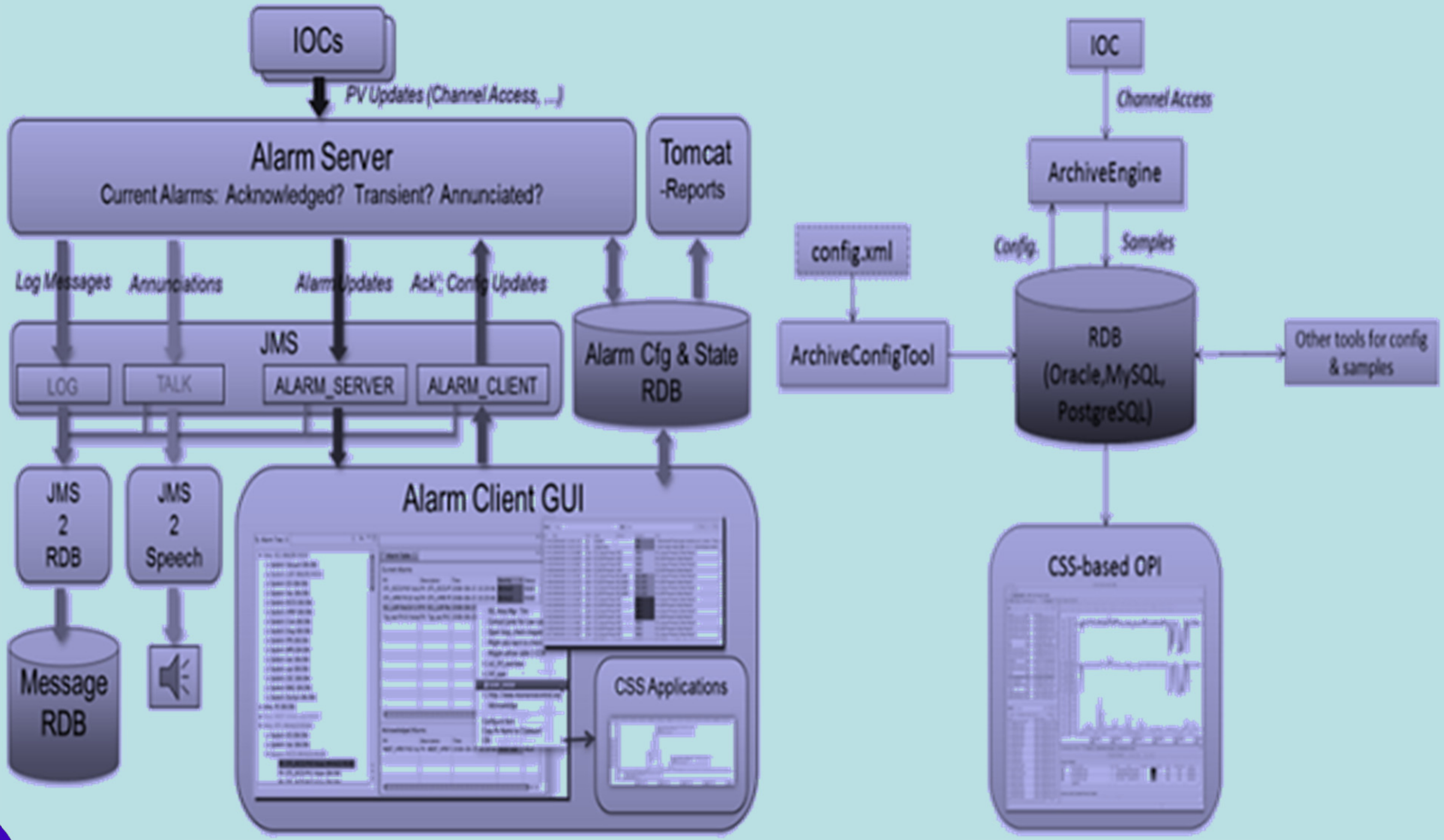
# New Control System

- The self-developed distributed control system of HIRFL was developed in many years part by part, and based on many kinds of platforms.
- In last years, the open-source Experimental Physics and Industrial Control System (EPICS), developed at LANL and ANL, was adapted to take over most of the control system of HIRFL.




FREE AND OPEN SOURCE
DEVELOPED COLLABORATIVELY
POWERFUL AND RELIABLE

# The structure of new control system

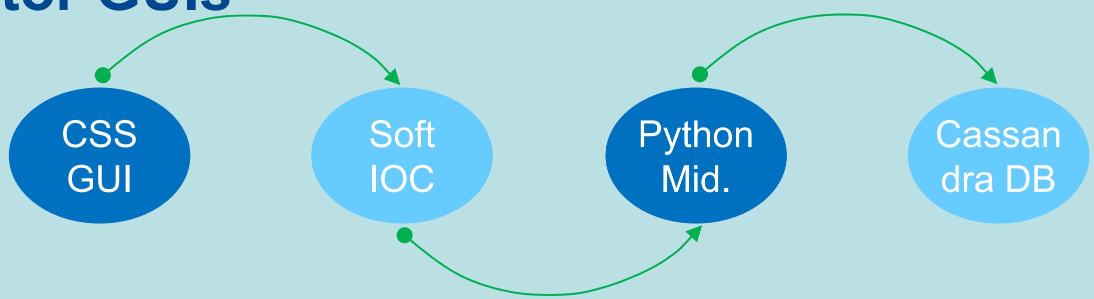



Control and monitor

Data Archive

# Properties and Results

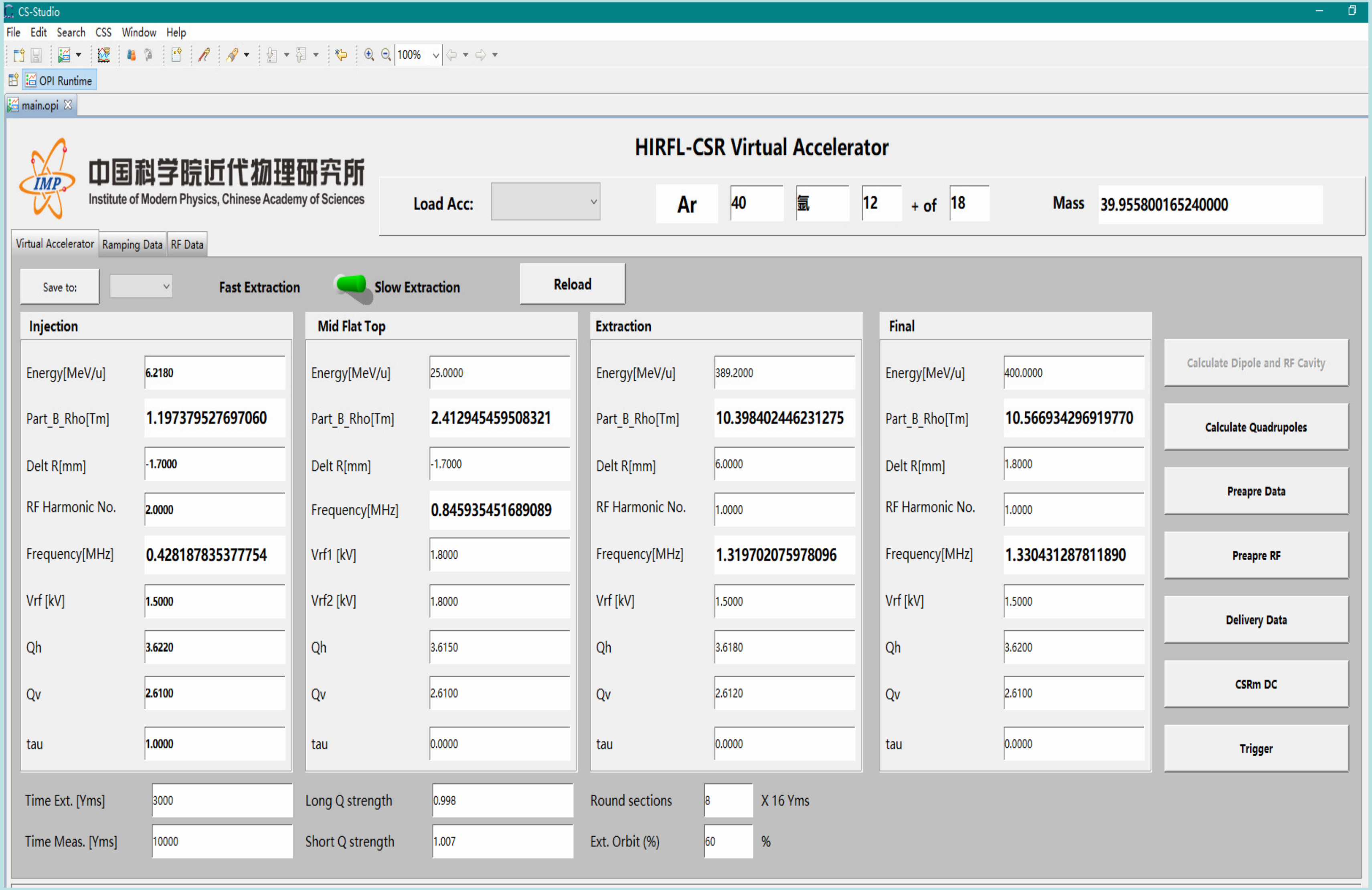
- Whole substitution of previous system
- Rearranged local controllers and rewire cables
- Big data volume transfer and monitor
- Direct data archive system based on MongoDB, no influence on operator GUIs




- New CSRm injection inflector and User Interface
- New control system for e-cooler instead of the hardware attached one
- The LLRF of cyclotron RF systems and new CSRm RF controller were rebuilt

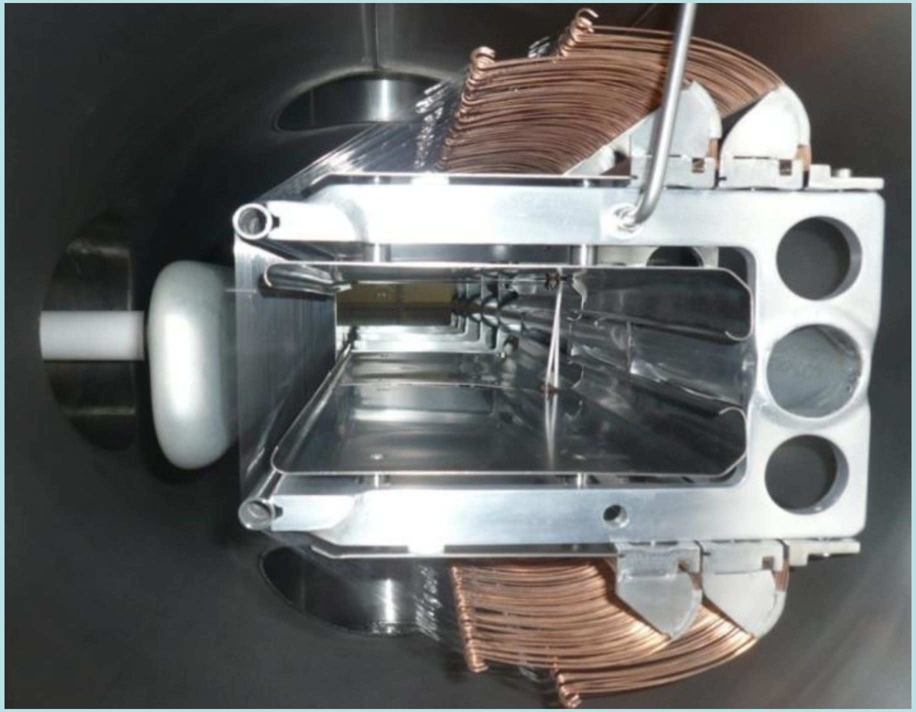
# Virtual Accelerator Software

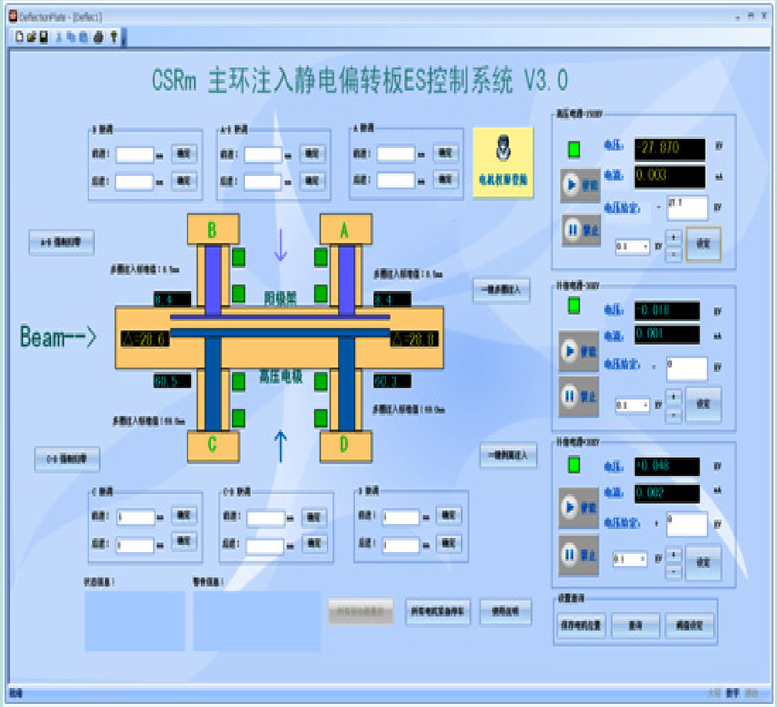
## CSS + Soft IOC + Python will replace previous VB Version



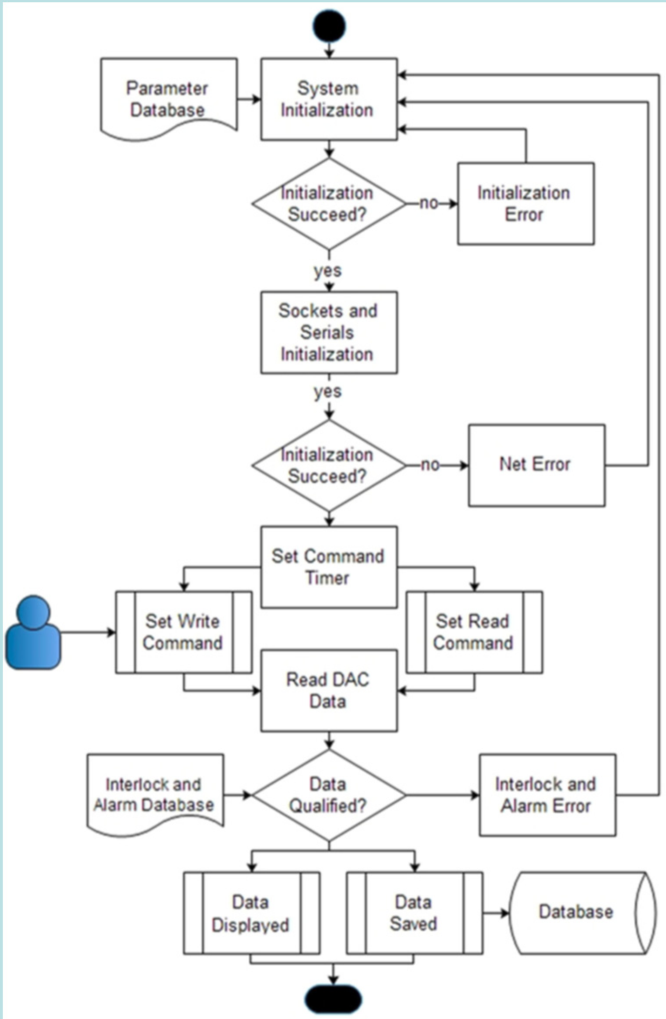
# New CSRm Inflector

- **New inflector for both MMI and CEI**
- **Saving time of breaking of vacuum (n*3 days/a)**

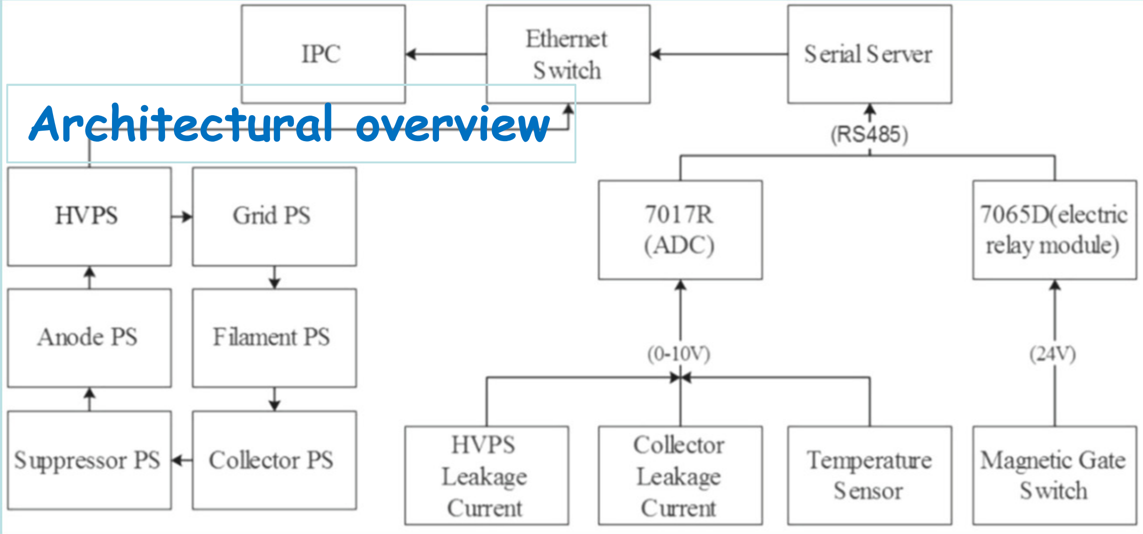




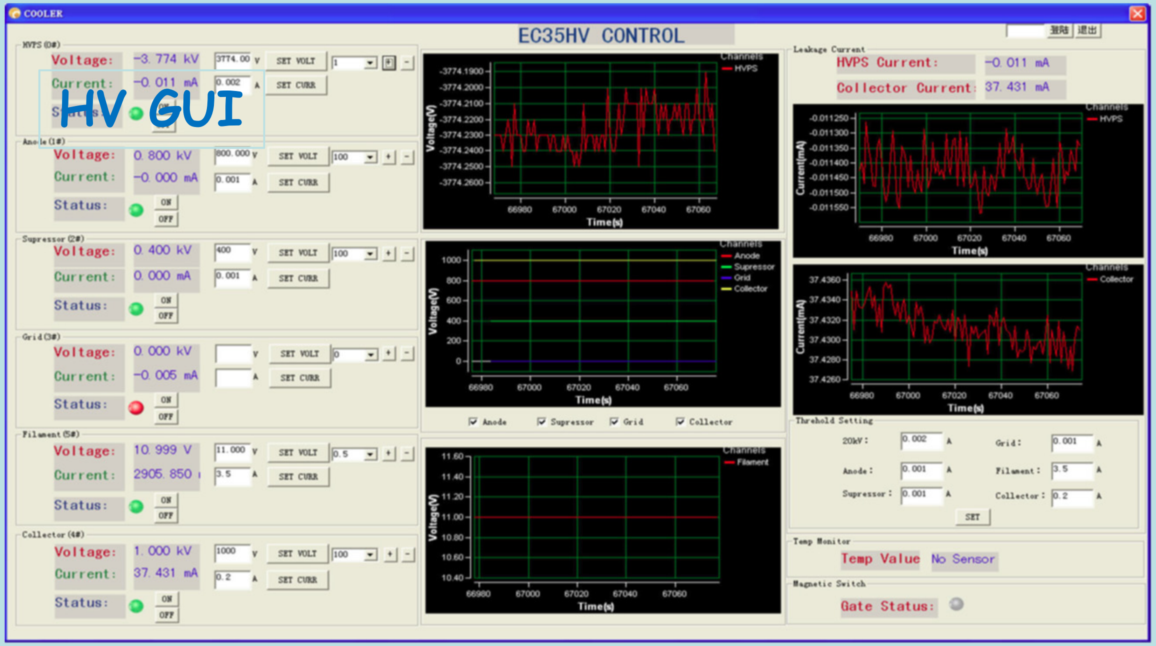
# New CS of e-Cooler@CSRm




Flowchart of software




Architectural overview




HV GUI

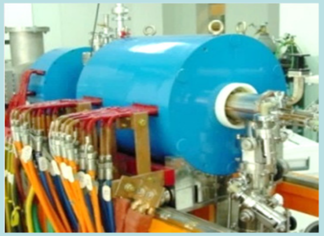
# New SC ECR Ion Source

- **A new generation superconductive ECR source-SECRAL-II as a back-up of the former SECRAL with better performance was constructed and will put into operation this year.**
- **With new structure, higher magnetic field and works at 18 GHz / 24 GHz microwave frequency, SECRAL-II sets a new beam current record of highly charged heavy ion beams.**

# New Full SC SECRAL-II

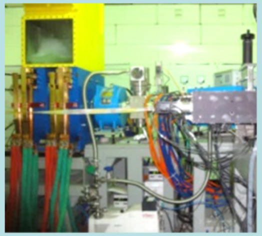
- Serial of ECR ISs. Keep the state of art IS technology and world records.
- New Full SC SECRAL-II as a backup under CAS support
- (maybe online this year!)


| SECRAL-II features（eμA） | | |
|---|---|---|
| Ion | SECRAL-II | SECRAL |
| $O^{6+}$ | 6700 | 2300 |
| $Ar^{14+}$ | 1040 | 846 |
| $Ar^{16+}$ | 620 | 350 |
| $Ar^{18+}$ | 15 | 0.2 |
| $Kr^{18+}$ | 1020 | 304 |
| $Kr^{28+}$ | 146 | 4 |
| $Xe^{30+}$ | 365 | 360 |
| $Xe^{38+}$ | 56 | 22.6 |
| $Xe^{45+}$ | 1.3 | 0.1 |
| $Ta^{30+}$ | 375 | / |
| $Ta^{38+}$ | 204 | / |

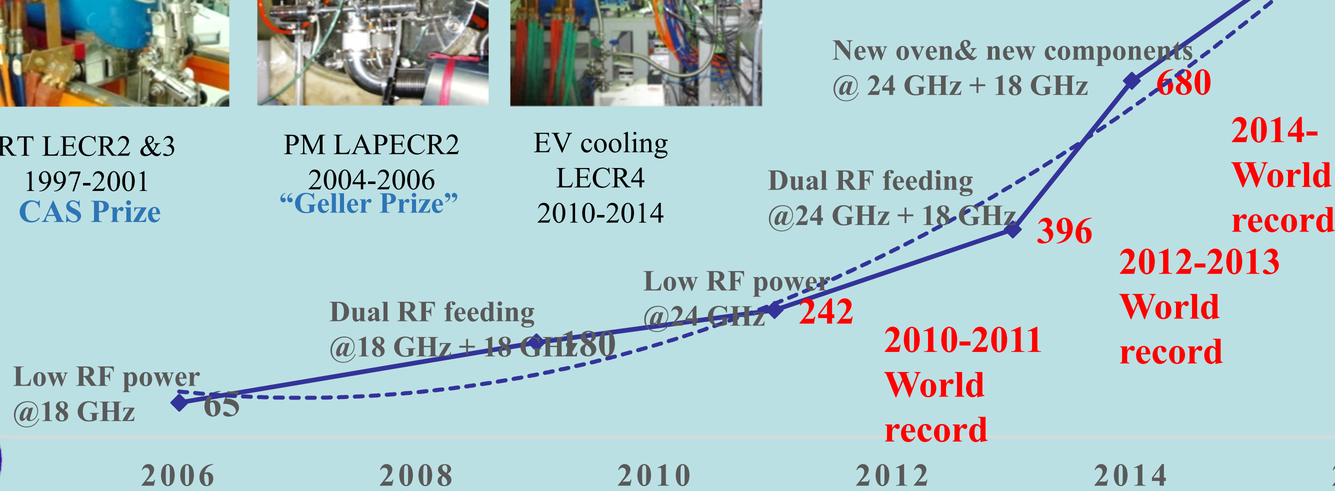


RT LECR2 &3
1997-2001
CAS Prize

PM LAPECR2
2004-2006
"Geller Prize"



EV cooling
LECR4
2010-2014




Full SC SECRAL I&II
2000-2006, 2012-2016
National Prize,
"Brightness Award"

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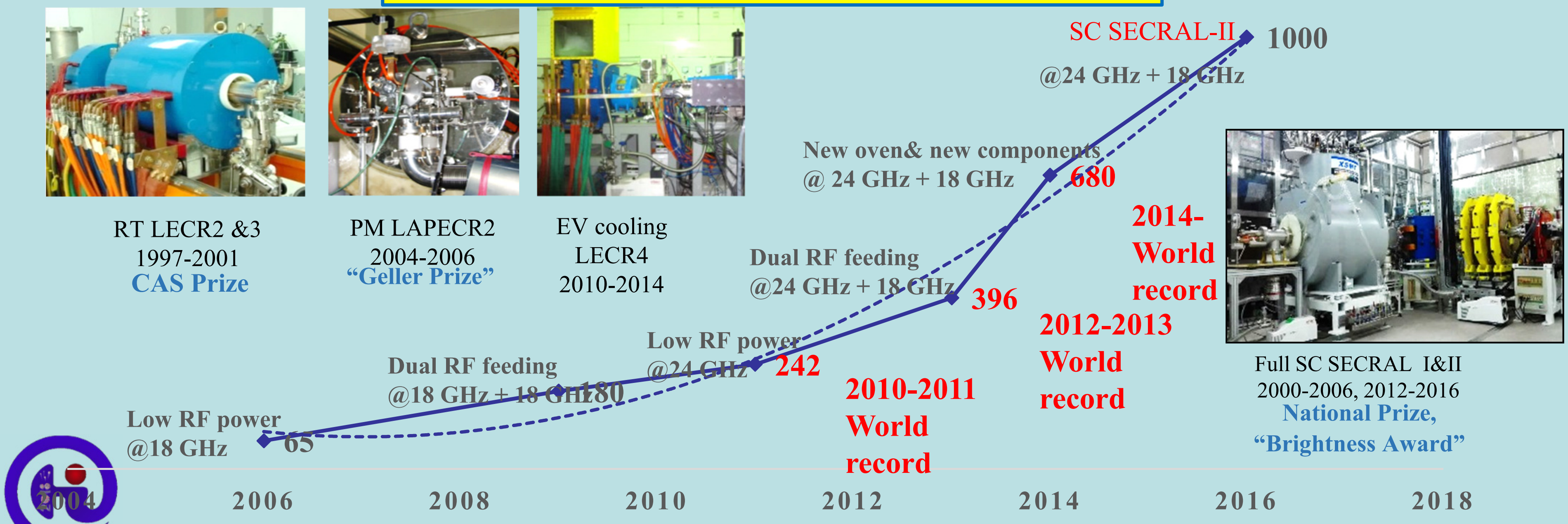
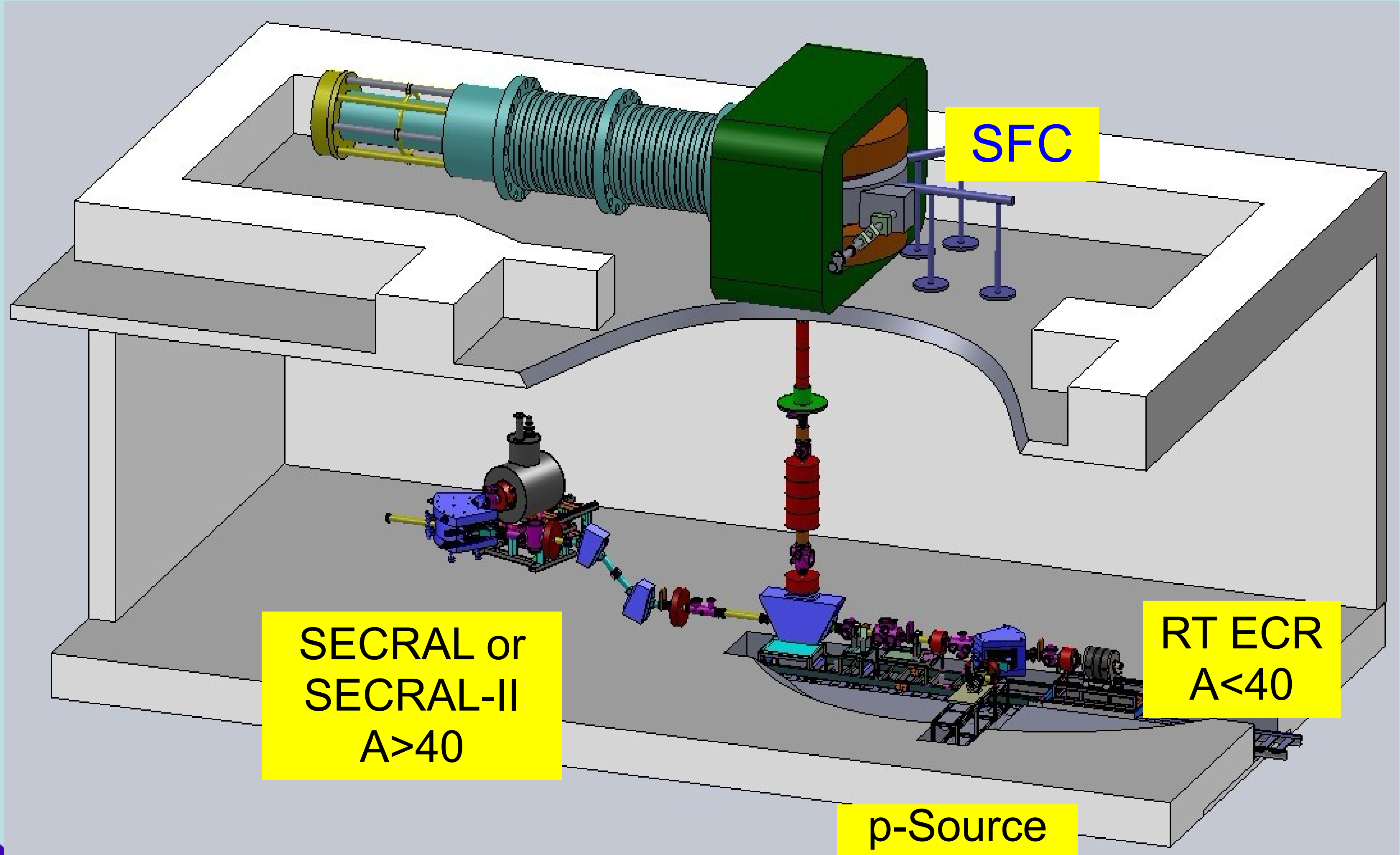
| $Xe^{30+}$ | 365 | 360 |
| $Xe^{38+}$ | 56 | 22.6 |
| $Xe^{45+}$ | 1.3 | 0.1 |
| $Ta^{30+}$ | 375 | / |
| $Ta^{38+}$ | 204 | / |

Highly charged ECR ion source development at IMP, L.T. Sun at this conference



# Ion Sources for SFC



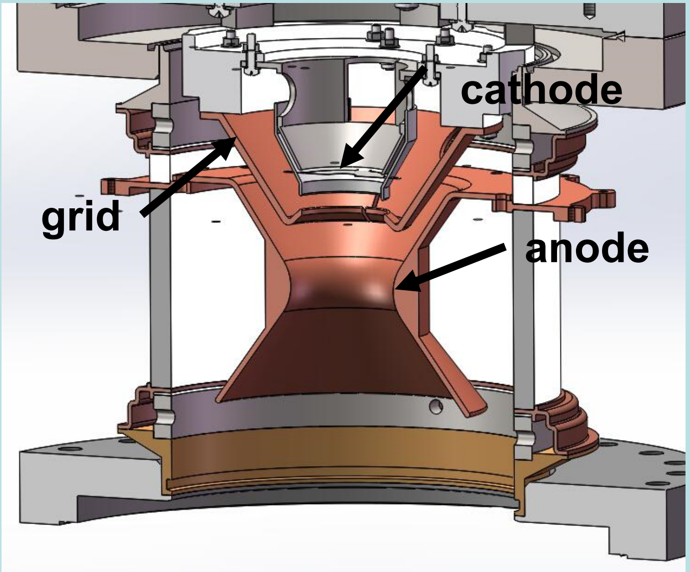
# e-Cool with Pulsed e-Beam

- **Pulsed Electron Cooling Experiments of electron cooling with pulsed electron beam are performed for the 1st time at CSRm.**
- **New phenomena were observed. Be explained in theory and proved by numeric simulations.**
- **Important for the cooling of high energy bunched ion beam with high peak current electron cooler, at future ion circular accelerator or colliders.**

# e-Cool with Pulsed e-Beam

## Pulsed e-Beam

- Grid voltage is used to switch on/off e-beam ➔ pulsed e-beam
- Timing system based on RF signal for synchronization
- DG535 is used to control the delay and pulse width



# e-Cool with Pulsed e-Beam

## Pulsed e-Beam

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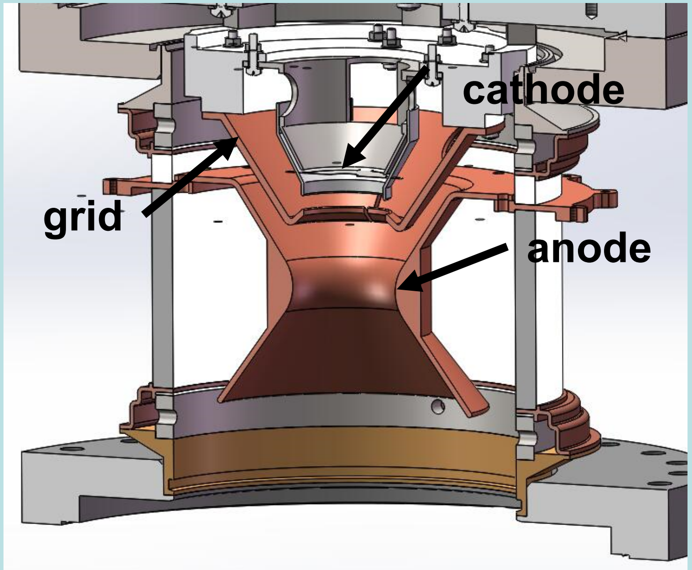
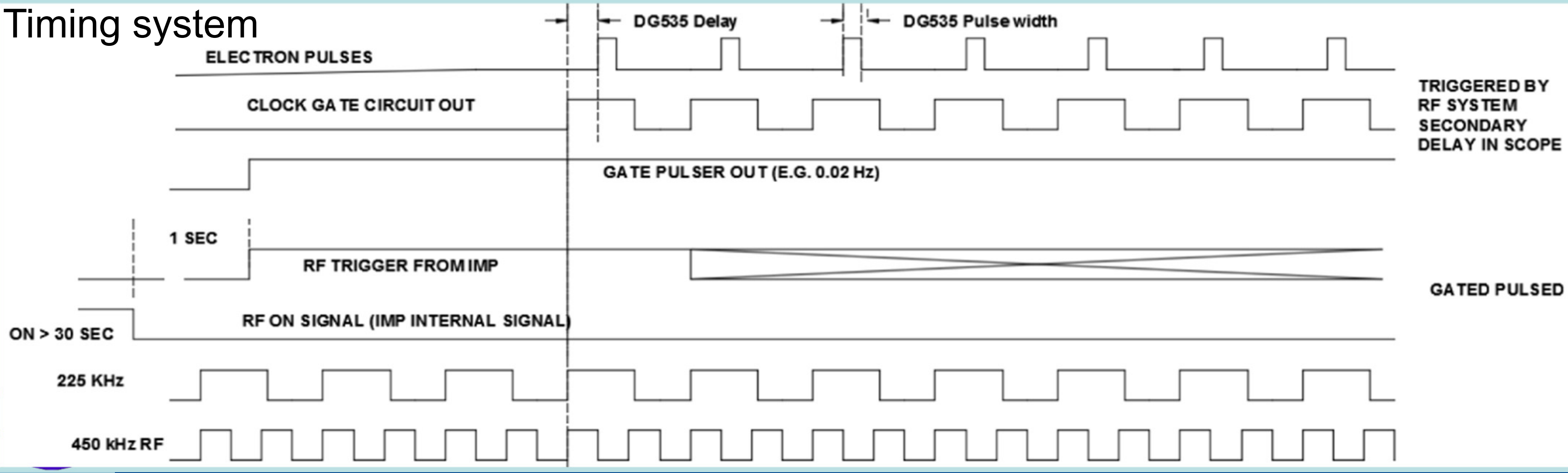



Timing system

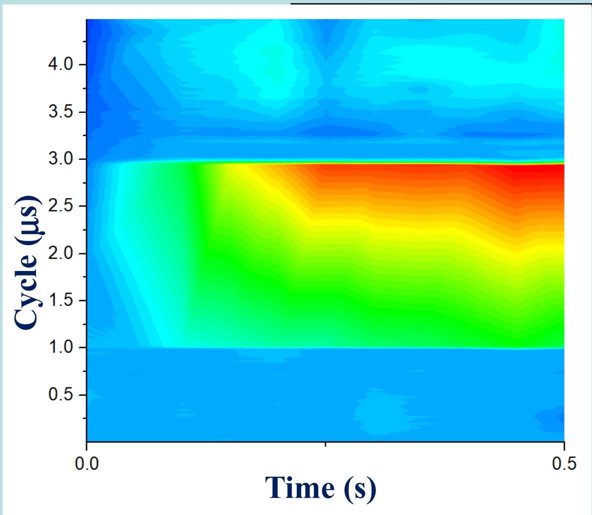


# e-Cool with Pulsed e-Beam

- **Coasting ion beam**
  - **Non synchronize heating effect – The freq. of e-beam should be int. or half int. of $F_{rev}$ ion beam for a stable beam.**
  - **Grouping effect – The ion beam cooled to a pulse with the same width of e-beam. The distribution is non-uniform.**
  - **Sidebands – sidebands appears, similar with the synchrotron sidebands.**

Exp. Parameters

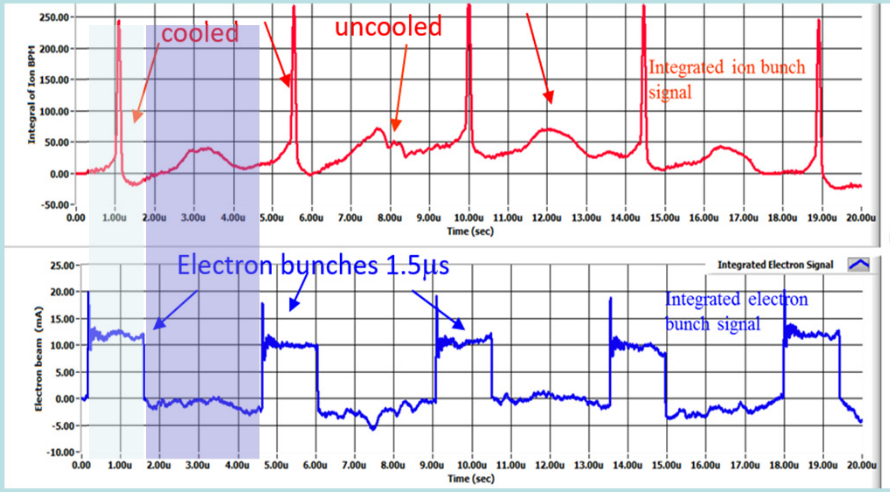
| 7.0 MeV/u $C^{6+}$ | Coasting | Bunched |
|---|---|---|
| Particle number | 5.0 x $10^8$ | 1.3 x $10^8$ |
| Emittance (RMS) | */* | */* |
| dp/p (RMS) | 2.0 x $10^{-4}$ | 7.0 x $10^{-4}$ |
| Bunch length (RMS) | * | ~135 ns |
| RF voltage | * | 1.0 kV |
| h | * | 2 |
| E-beam current (peak) | 30 mA | 65 mA |
| E-beam diameter | ~30 mm | ~25 mm |
| Pulse width | 0.5-3.0 μs | 0.5-3.0 μs |
| Rising/falling time | 10 ns | 10 ns |

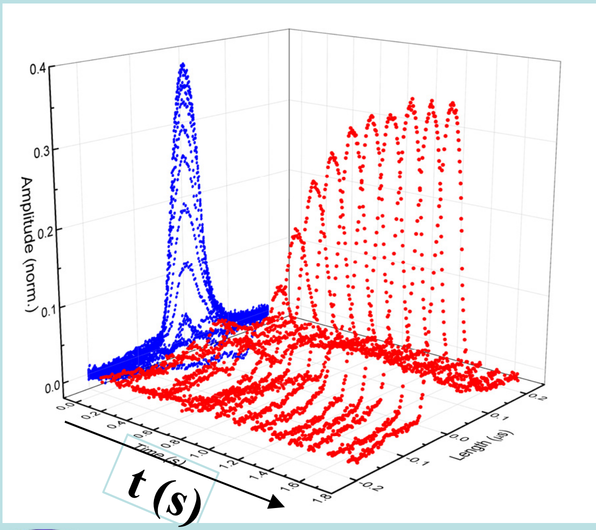



# e-Cool with Pulsed e-Beam

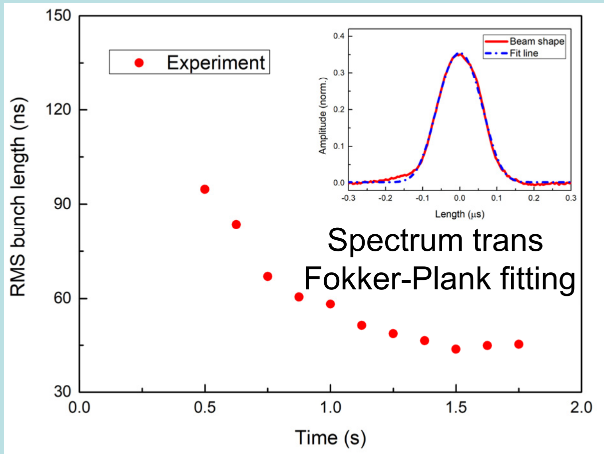
- **Bunched ion beam**
  - **Cooled and uncooled ions**
  - **The pulse width of e-beam is larger than the ion bunch length**
  - **Bunch shape evolution**

Integrated BPM signal

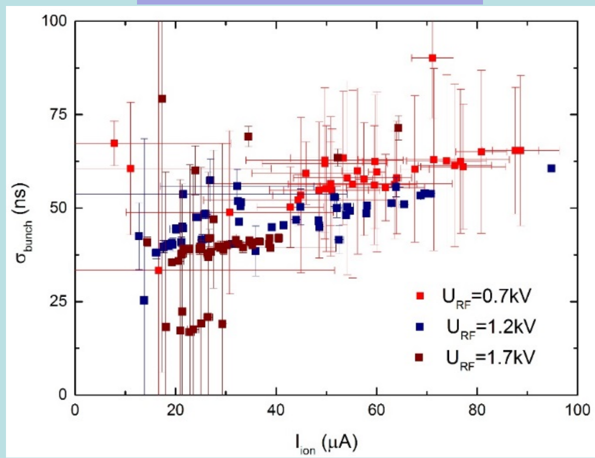



Cooling process



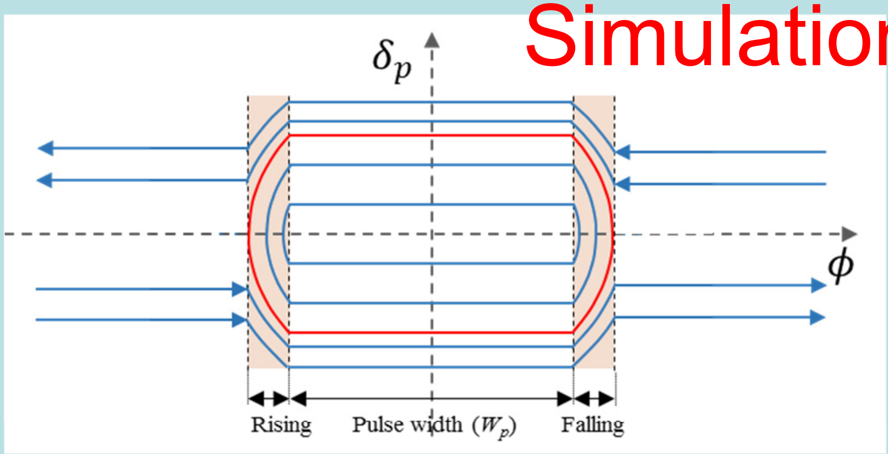

Final bunch length

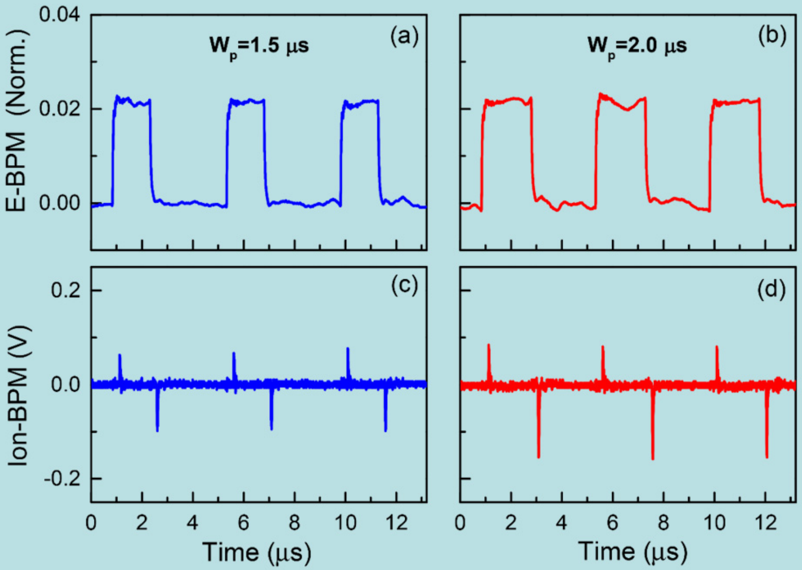


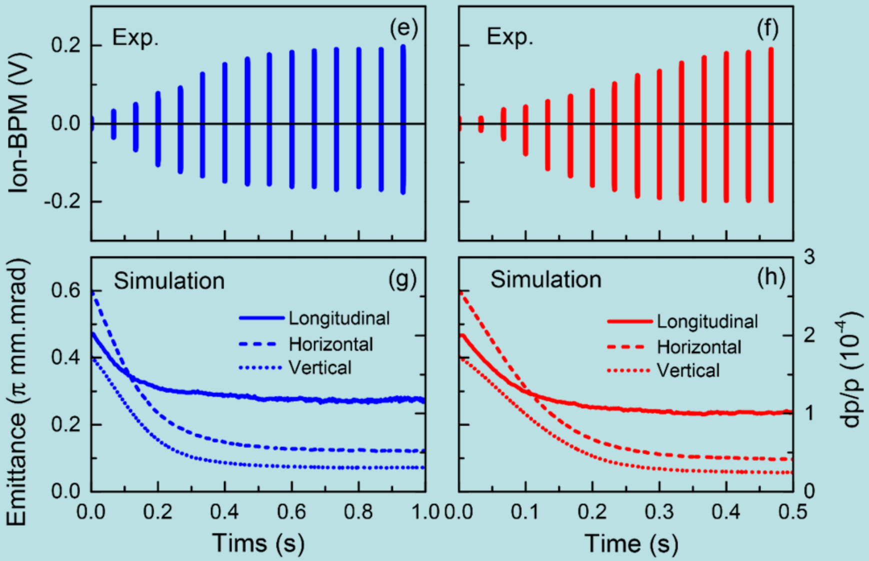
# e-Cool with Pulsed e-Beam

Simulation

- **Simulation on Coasting Beam**
  - **e-bunch formed a barrier-bucket-like potential well**
  - **BPM signals in one cycle used**
  - **Good agreement with the meas.**



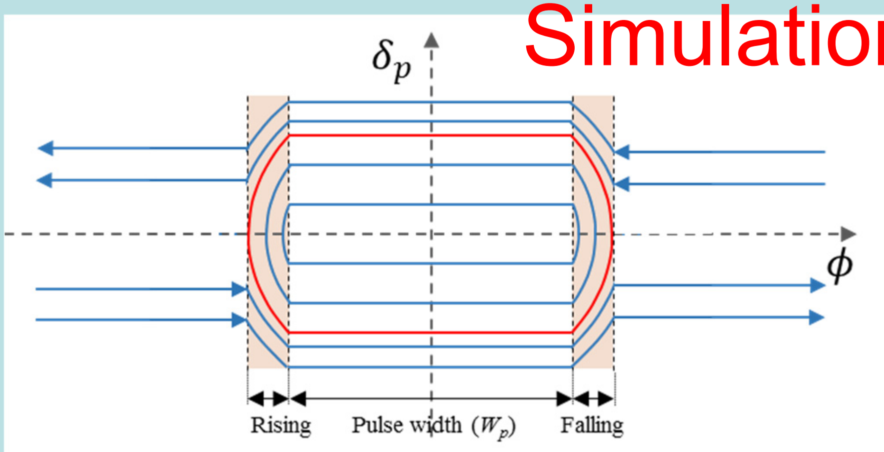



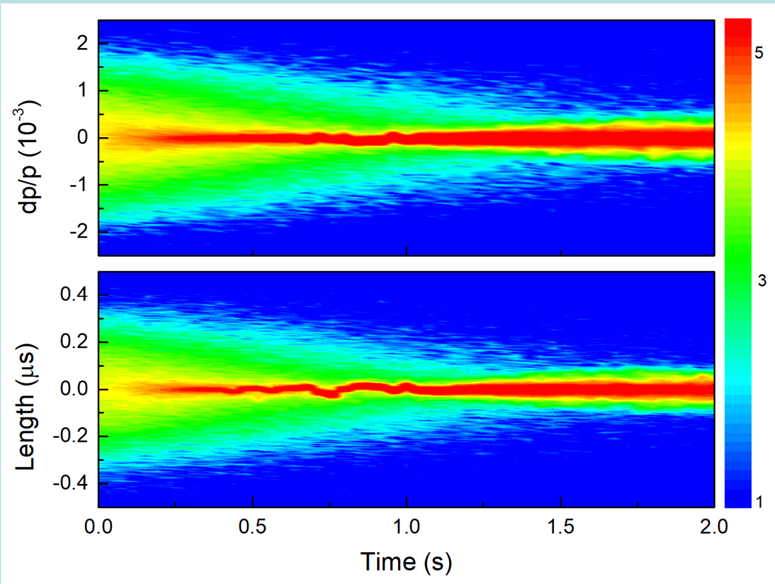



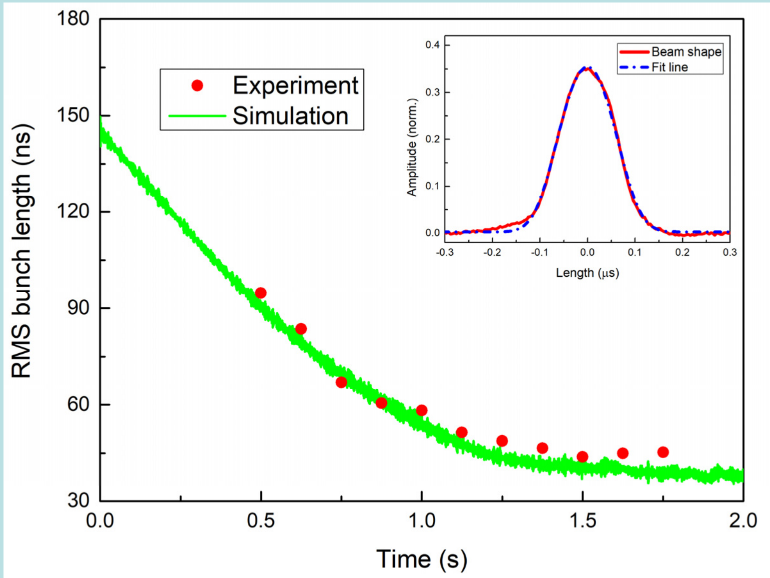
# e-Cool with Pulsed e-Beam

Simulation

- **Simulation on Bunched Beam**
  - **e-bunch formed a barrier-bucket-like potential well**
  - **Good agreement with the meas.**
  - **Similar cooling process with the exp. of DC e-beam cooling**



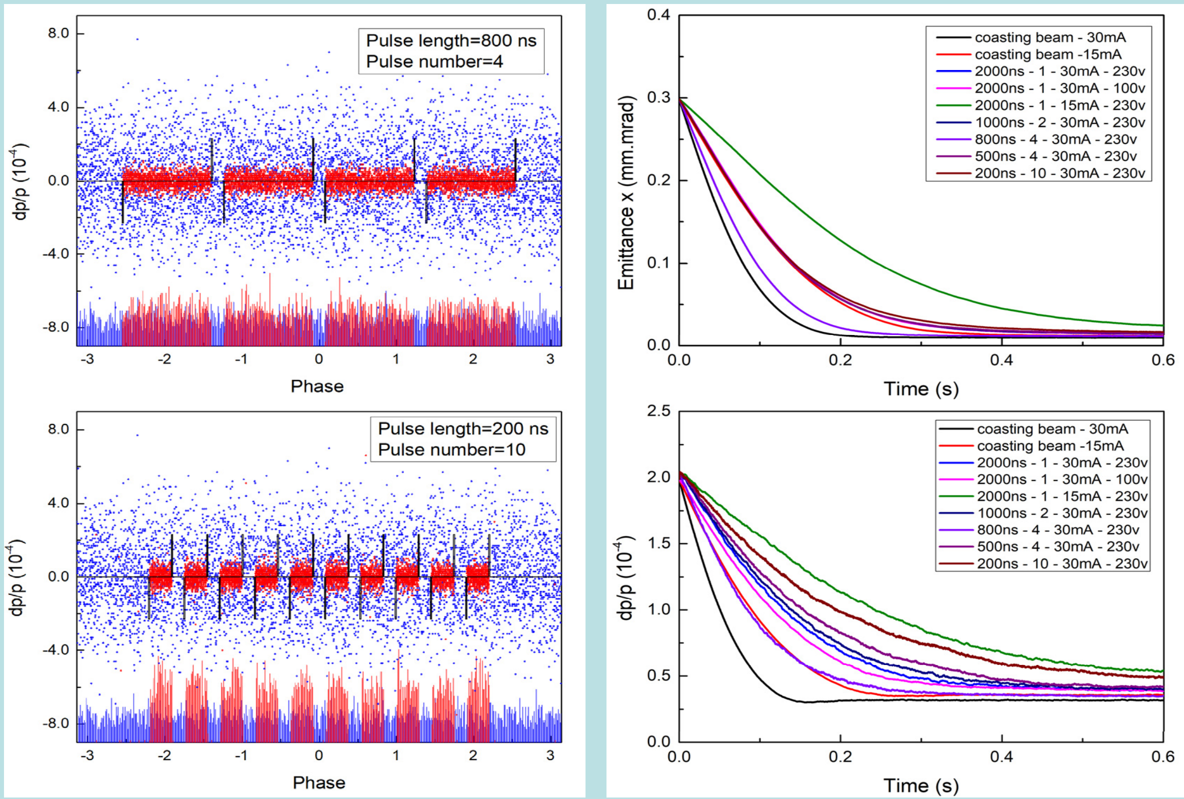



# e-Cool with Pulsed e-Beam

Simulation

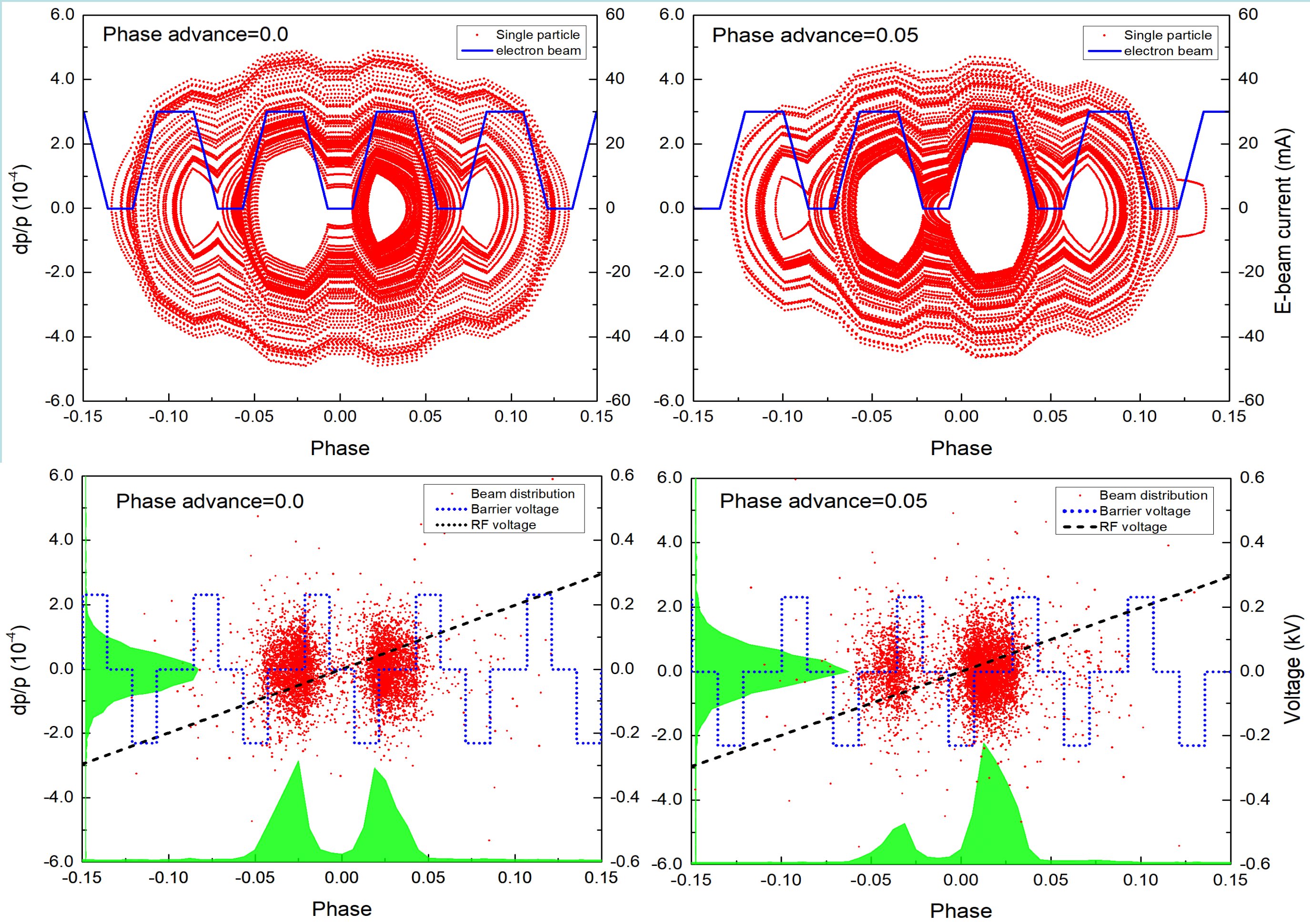
- **Multi-pulsed e-beam on coasting ion beam**
  - **The ion beam is been cooled to many pulses**
  - **The comparison between different pulsed e-beam (No. bunches, length, duty factor, e-current)**



# e-Cool with Pulsed e-Beam

Simulation

- **Short pulsed e-beam (15 ns) on bunched ion beam**
  - **RF bucket modulated by the barrier voltage of e-pulses**



# RIBLL2 Improvement

- **The performance of RIBLL2 as an in-flight separator of relativistic projectile fragments was gradually improved.**
- **There are 8 beam profile detectors newly installed along RIBLL2 for both horizontal and vertical profiles.**
- **In the joint efforts of experimental teams, RIBLL2-ETF is capable of identifying clearly all ions up to Z=30, with the combination of the TOF and the MUSIC detectors.**
- **Future upgrading of RIBLL 2 was planned.**

# Improve of RIBLL2

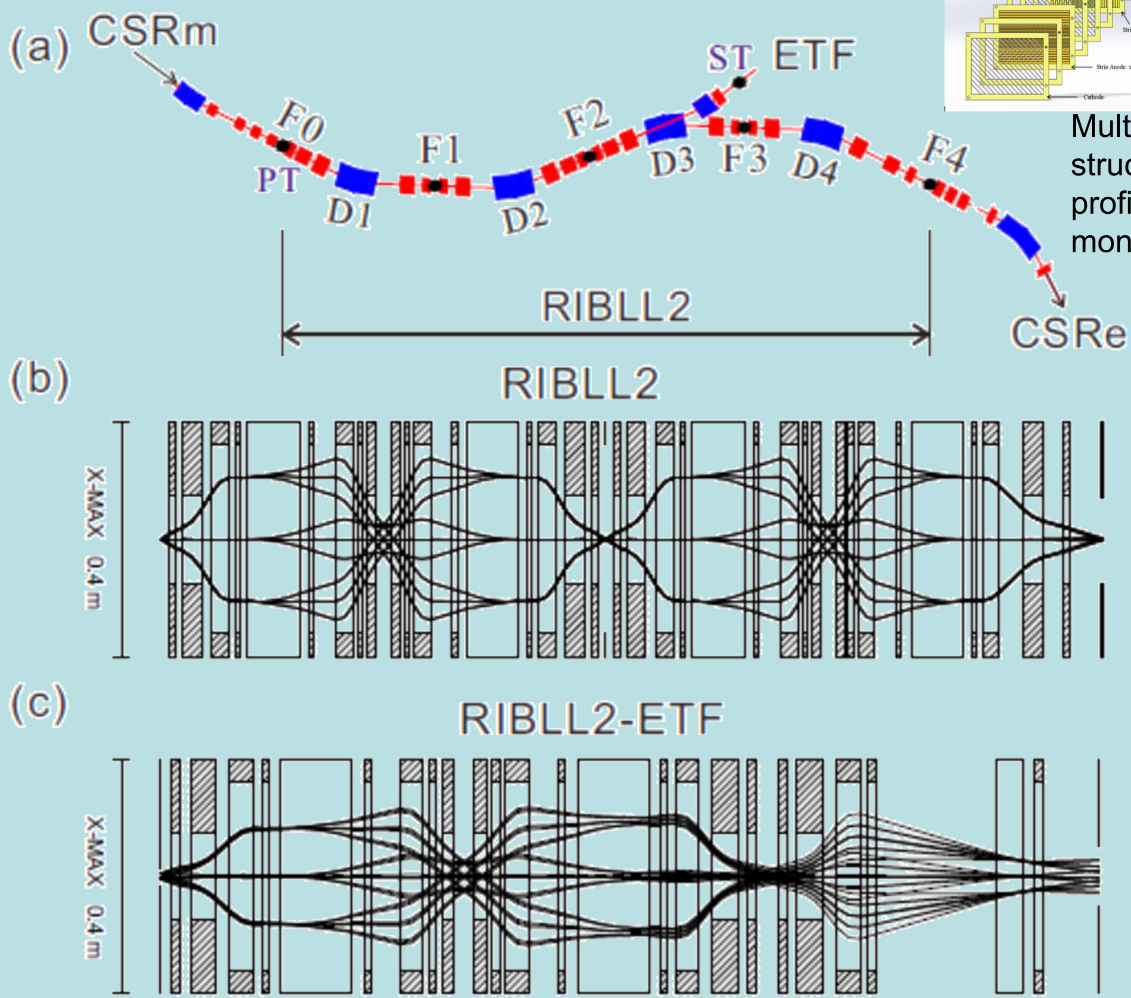
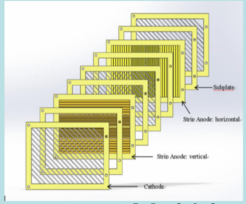



FIG. 1: (Color online) (a) A schematic layout of the RIBLL2



Multi-layer structure of profile monitor

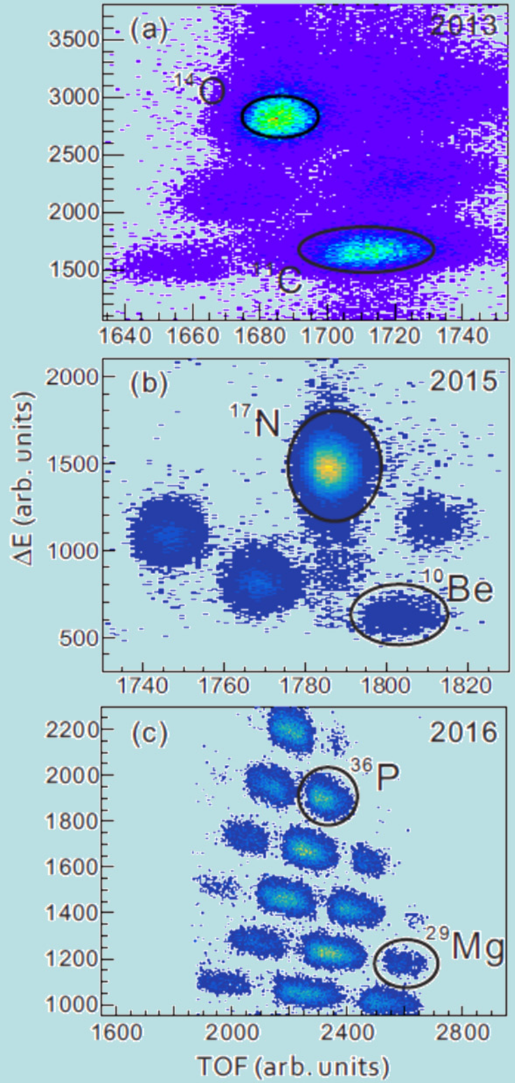
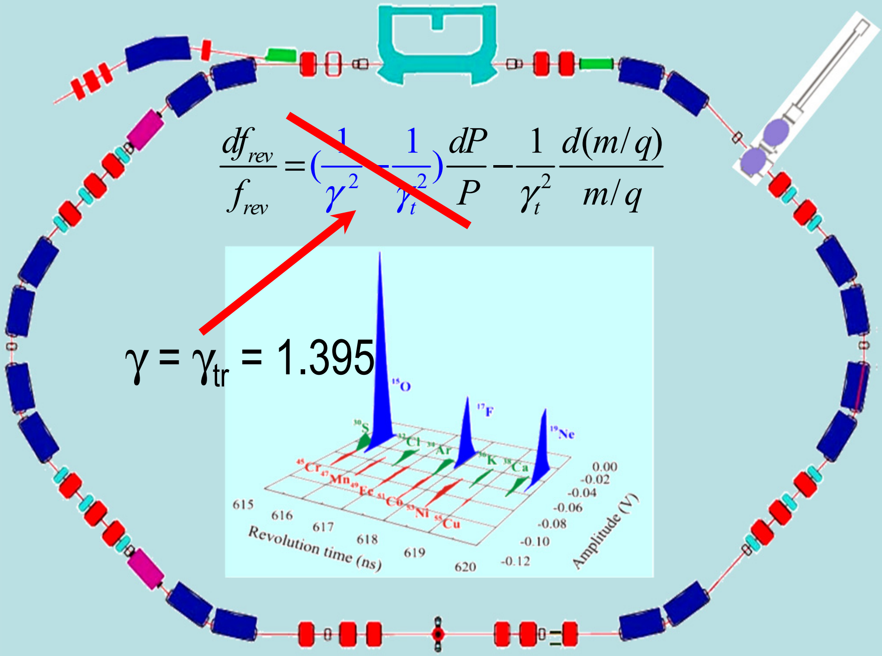



FIG. 2: (Color online) Typical particle identification plots of the $^{16}$O, $^{18}$O and $^{40}$Ar fragments in three experiments performed in 2013 (a), 2015 (b) and 2016 (c), respectively.

# Advanced Mass Spectrometry

- **State-of-art mass resolution of storage rings with unique two-TOF velocity measurement setups.**
- **Following the ISO mode mass spectrometry at ESR@GSI, we explored deeply the mass spectrometry at CSRe.**
- **With the improvement of EMC environment and new dipole PS at CSRe, the signal-noise ratio was significantly improved.**
- **With the new idea of two-TOF detector at storage rings (Unique) to measure the velocity of ions, the transition energy ($\gamma_t$), as a function of the closed orbit length or momentum deviation, can be measured precisely using the time spectra data of the ions cycling in CSRe.**
- **The transition energy function can be monitored and optimized online to ensure stable and good isochronous condition.**
- **With the quadrupole magnets and sextupole magnets corrections, a mass resolution of $1.71\times10^5$ (FWHM) was reached.**
- **Nonlinear optimization with higher order magnet field was planned.**

# Single TOF ISO mode mass spectrometry @CSRe

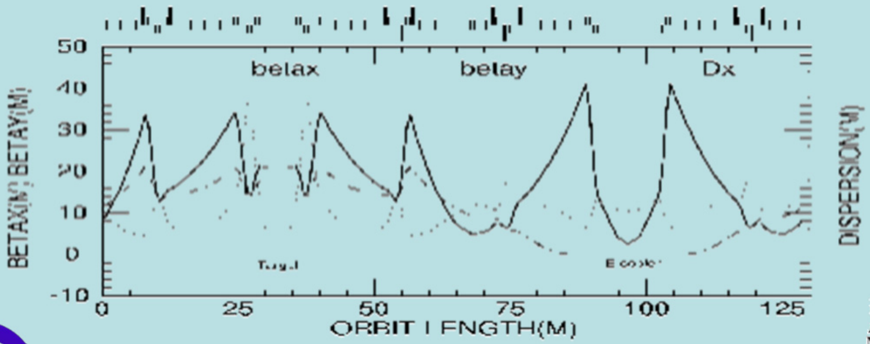


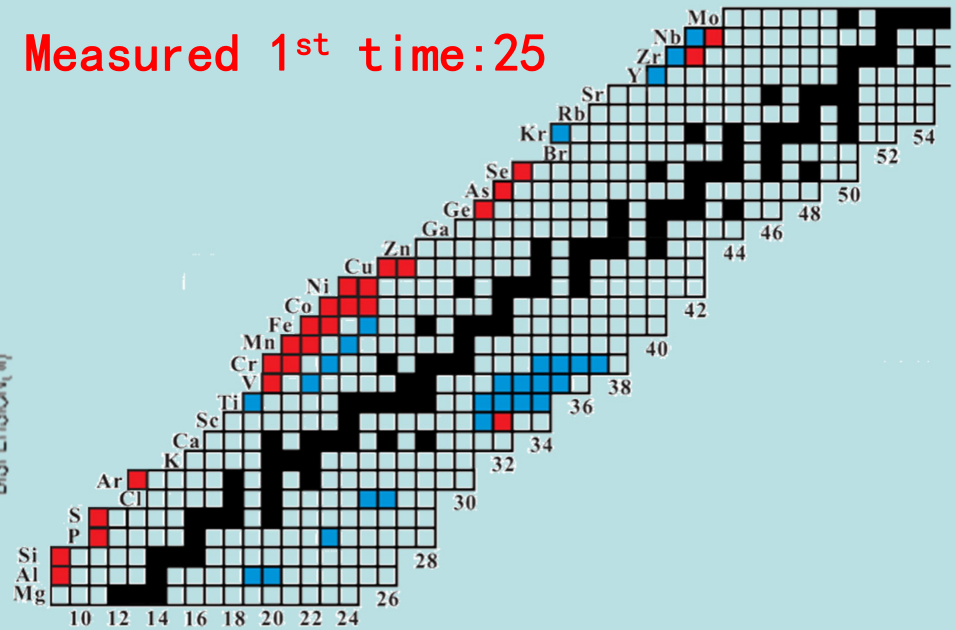

$$\frac{df_{rev}}{f_{rev}} = \left(\frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}\right)\frac{dP}{P} - \frac{1}{\gamma_t^2}\frac{d(m/q)}{m/q}$$

$\Delta m/m \sim 10^{-5} \sim 10^{-6}$

Precision improved:>50

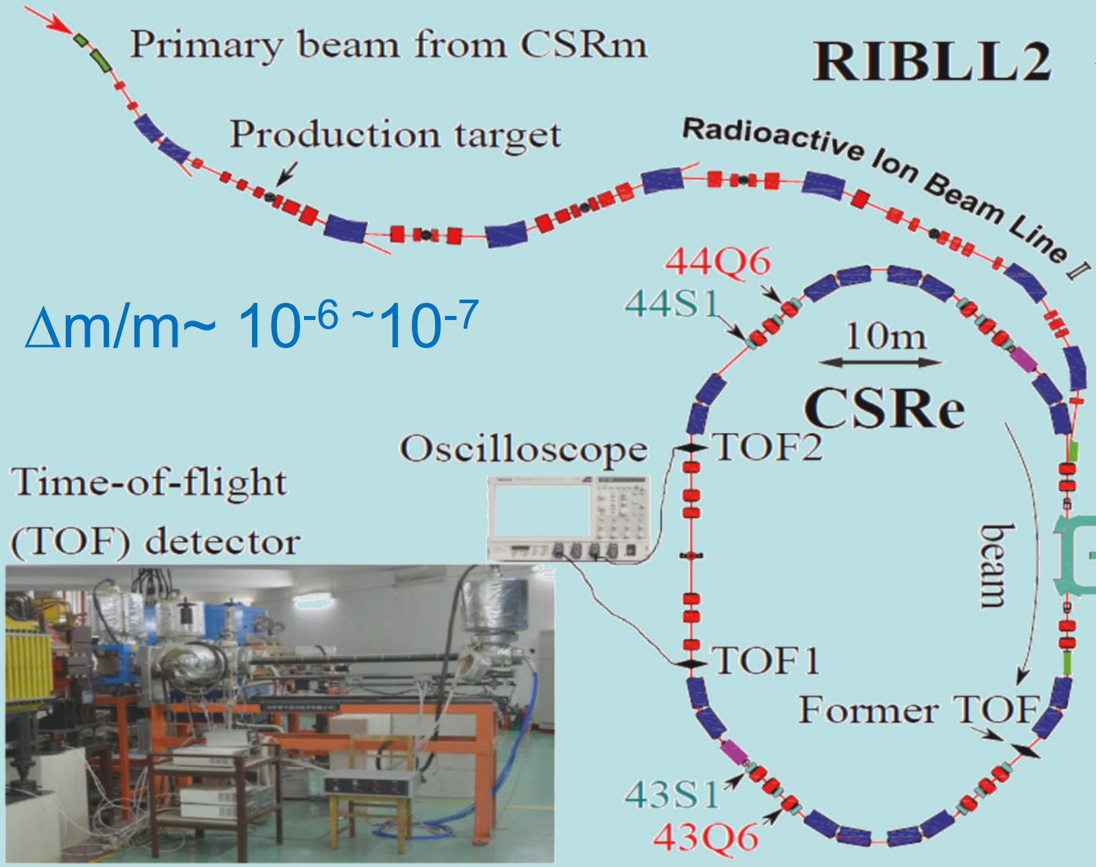
Measured 1st time:25



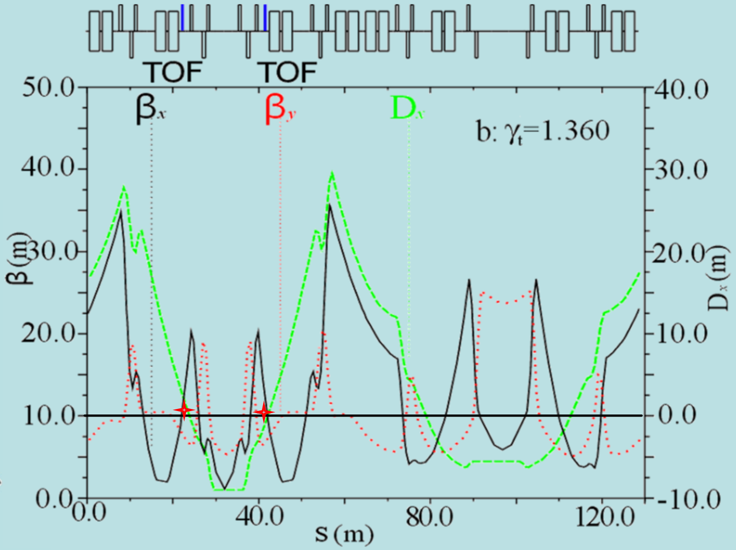



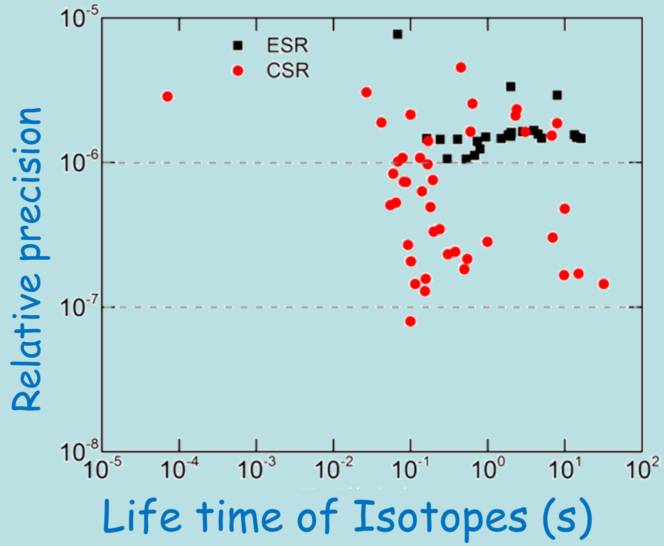
# Advanced Mass Spectrometry

**Unique** Double TOF ISO mode mass spectrometry
**Highest** mass precision in storage rings
**shortest** life time rare isotope with precise mass




$\Delta m/m \sim 10^{-6} \sim 10^{-7}$

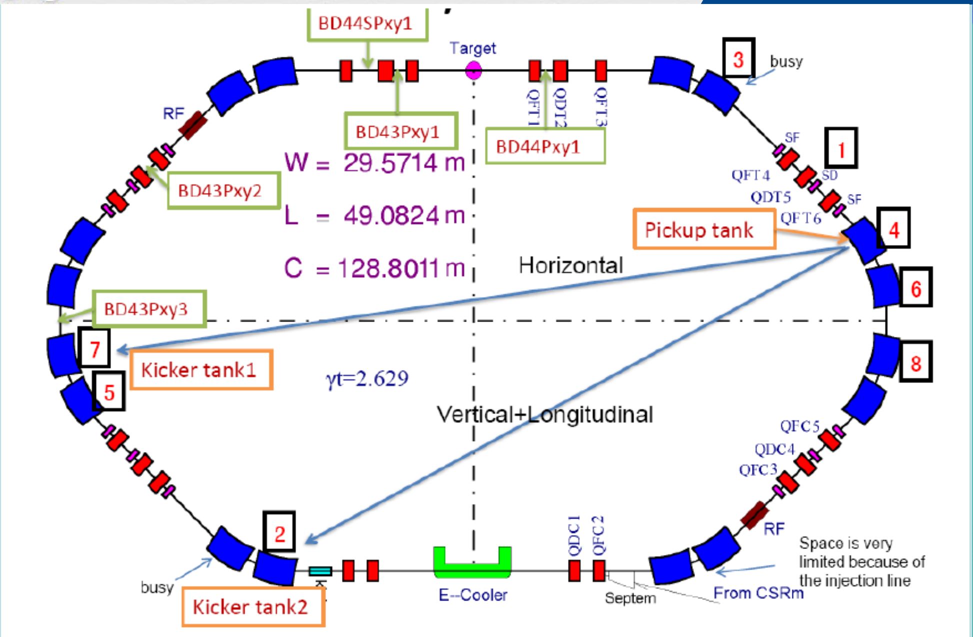


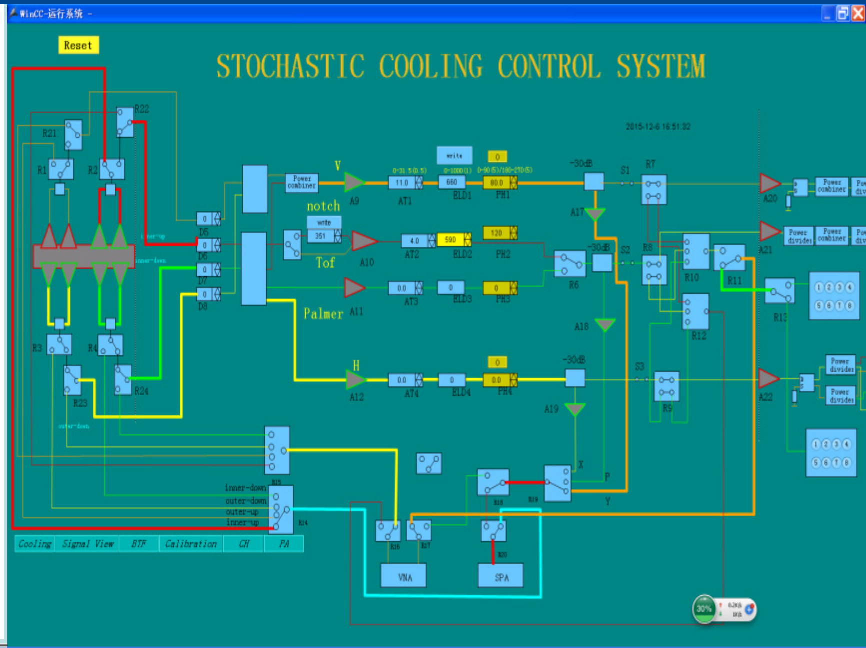



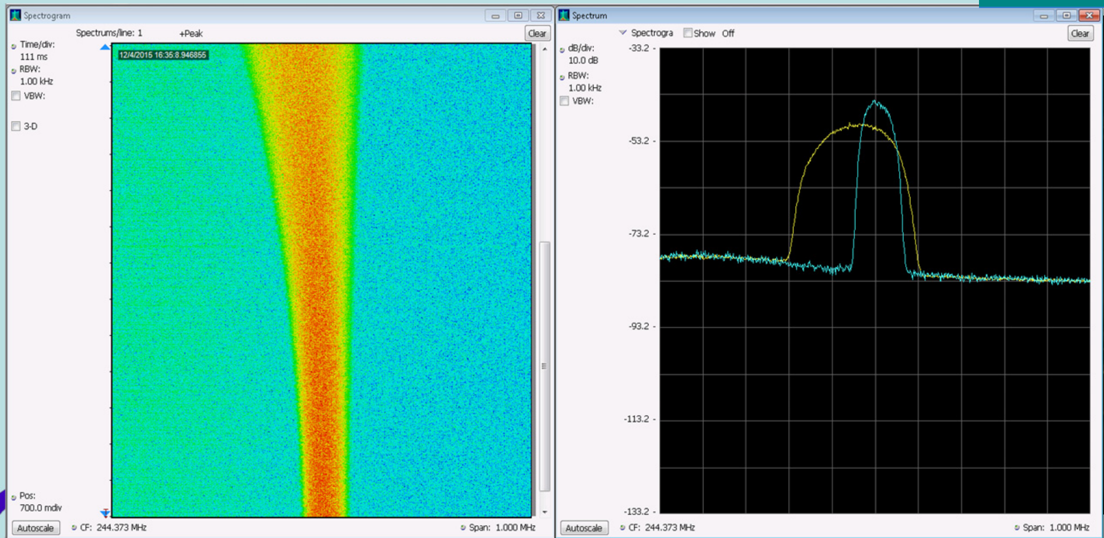
# Other Ion Cooling Systems

- **Stochastic Cooling and Laser Cooling are realized in CSRe, which will help to extend the research ability of nuclear and atomic physics at CSRe.**
- **The beam after target with large emittance and momentum spread can be cooled down in seconds by stochastic cooling with slot line pickup and kickers.**
- **Stochastic cooling will be used in the Schottky Mass Spectrometry (SMS) experiments.**
- **The relativistic Li-like $O^{5+}$ beam, with energy of 280 MeV/u, was cooled by CW laser of wavelength 220 nm recently. It's up to now heavy ions with highest charge state and highest energy that ever been laser cooled.**

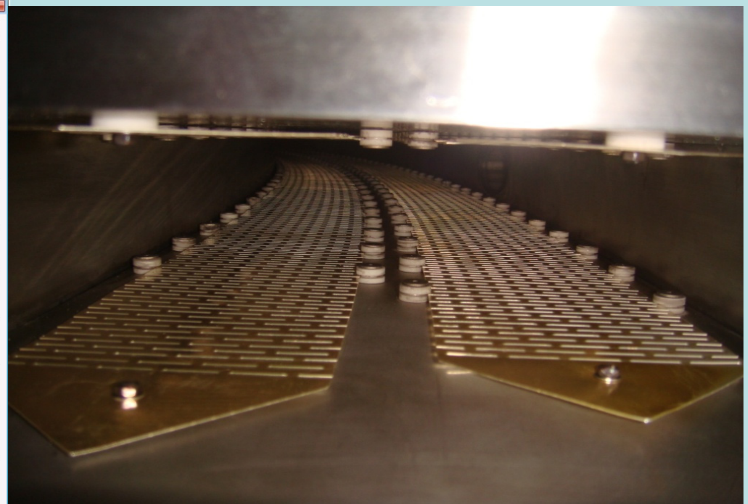
# CSRe with Stochastic Cooling



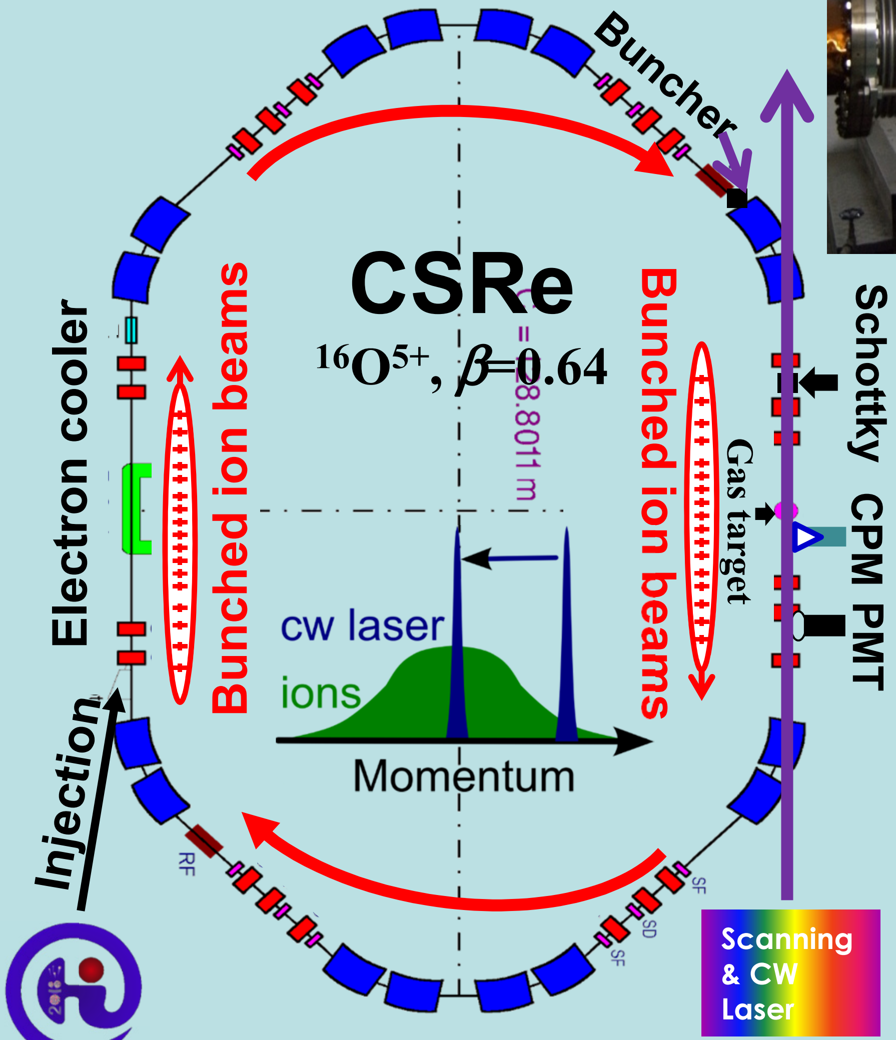

Longitudinal beam signal (380 MeV/u $^{12}C^{6+}$)

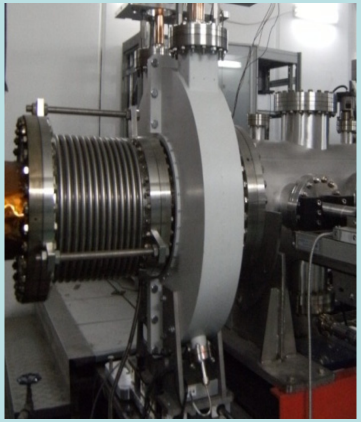


Pickup electrode

# CSRe with Laser Cooling

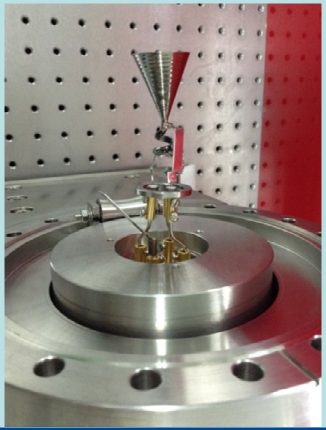
It's just a beginning…



F. Nolden, et al., NIMA,659(2011)69-77

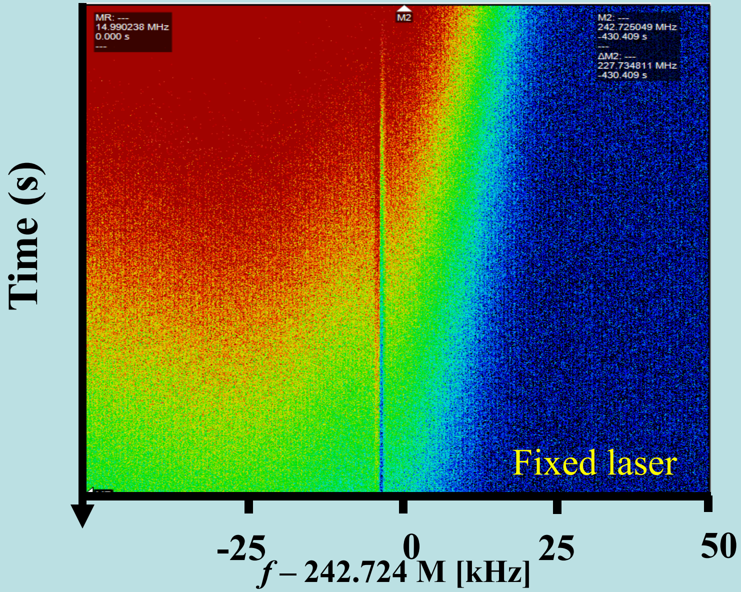
W. Wen et al., NIMA, 711(2013)90-95



| CSRe parameters | |
|---|---|
| Circumference | 128.80 m |
| Ion species | $^{16}O^{5+}$ |
| Beam energy | 275 MeV/u |
| Relativistic $\beta$, $\gamma$ | 0.64, 1.30 |
| Revolution frequency | 1.491 MHz |
| Transition energy $\gamma_t$ | 2.629 |
| Harmonic number $h$ | 10, 15 |
| **Laser system** | |
| Laser source | CW laser |
| Laser wavelength | $\lambda_{laser}$ = 220 nm |
| Laser power | $P_{laser}$ = 40 mW |
| Scanning range | $\Delta f_{laser}$= 20 GHz |
| **Cooling transition** | |
| $2S_{1/2}\rightarrow 2P_{1/2}$ | $\lambda_{rest}$ = 103.76 nm |
| $2S_{1/2}\rightarrow 2P_{3/2}$ | $\lambda_{rest}$ = 103.19 nm |

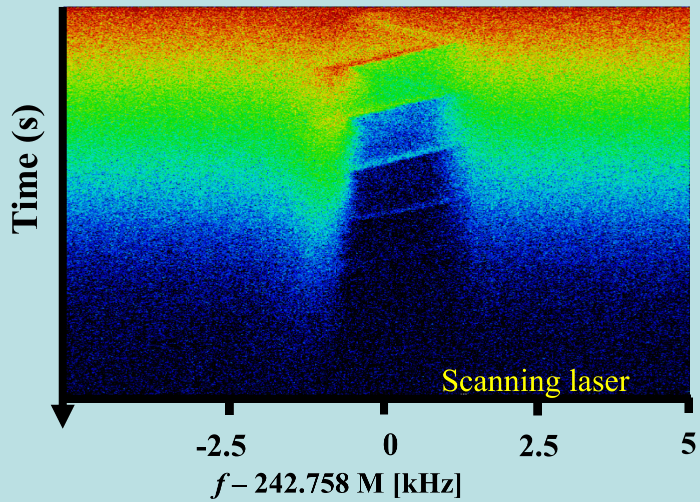
# CSRe with Laser Cooling

## Preliminary results: Coasting beam with fixed laser




Laser force range: $\triangle p/p \approx 1.0 \times 10^{-7}$

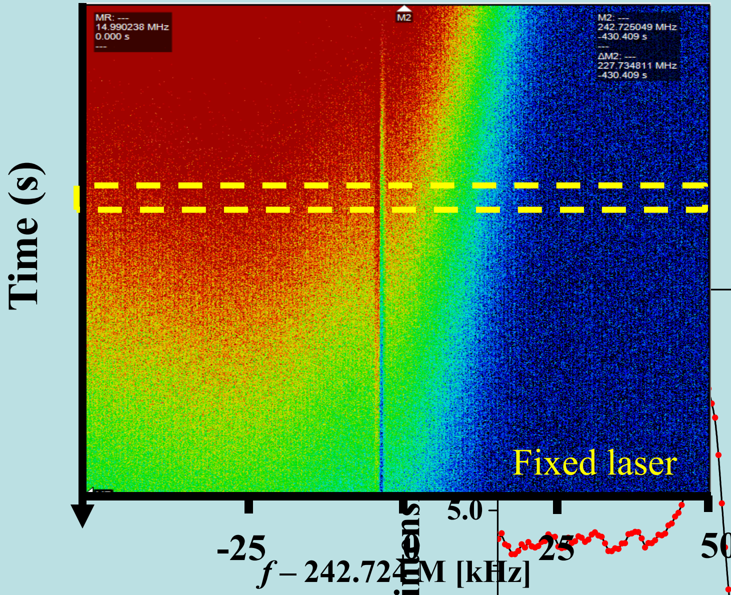
## Preliminary results: Coasting beam with scanning laser

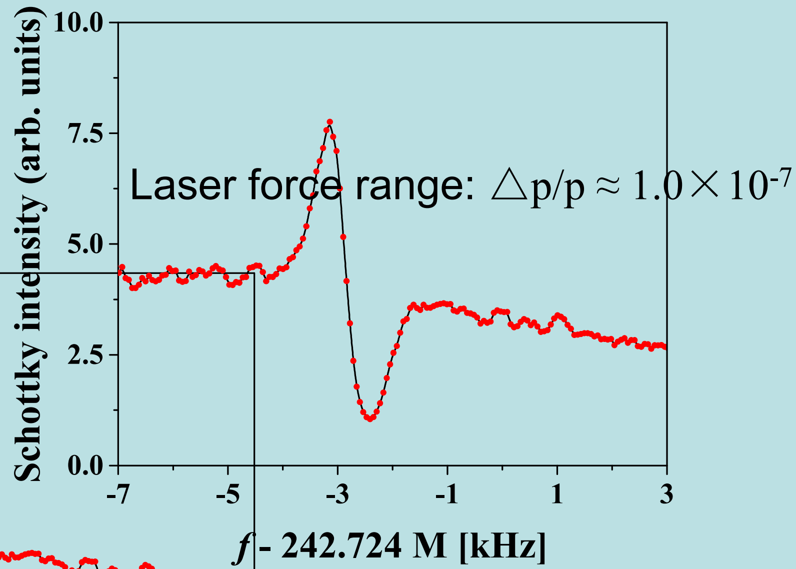



Laser scanning range: $\triangle p/p \sim 10^{-4}$

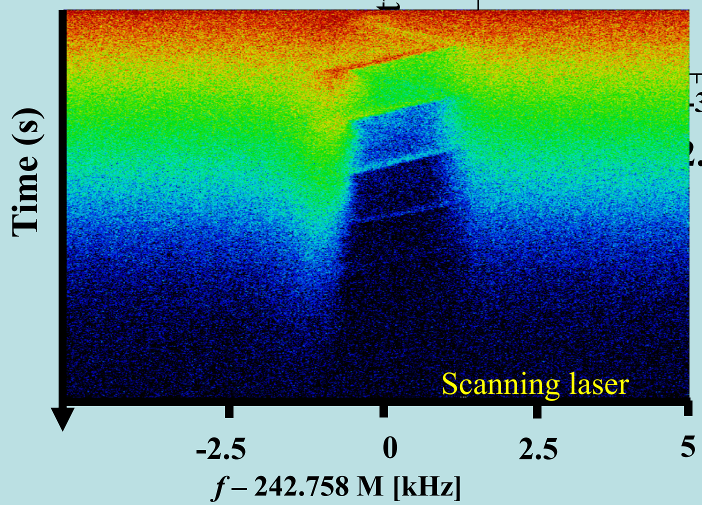
# CSRe with Laser Cooling

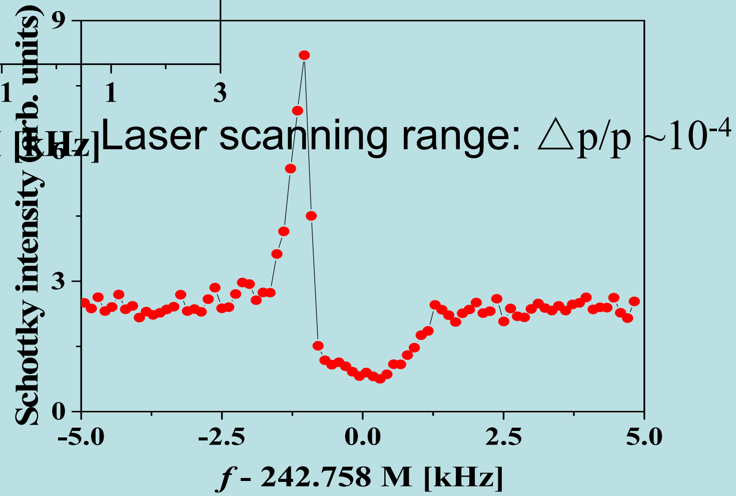
## Preliminary results: Coasting beam with fixed laser



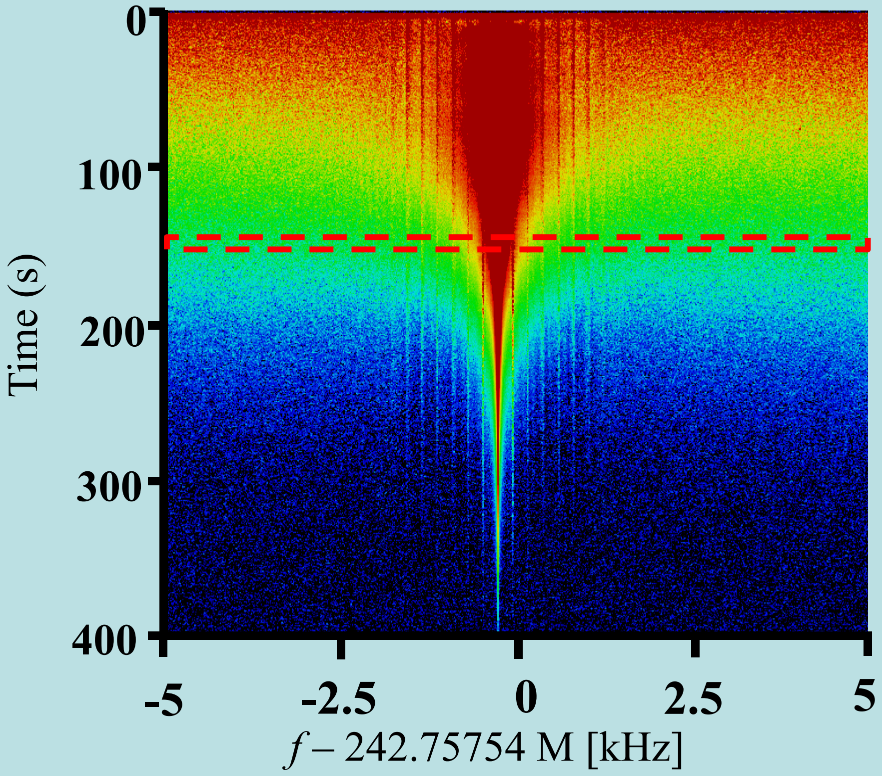

## Preliminary results: Coasting beam with scanning laser

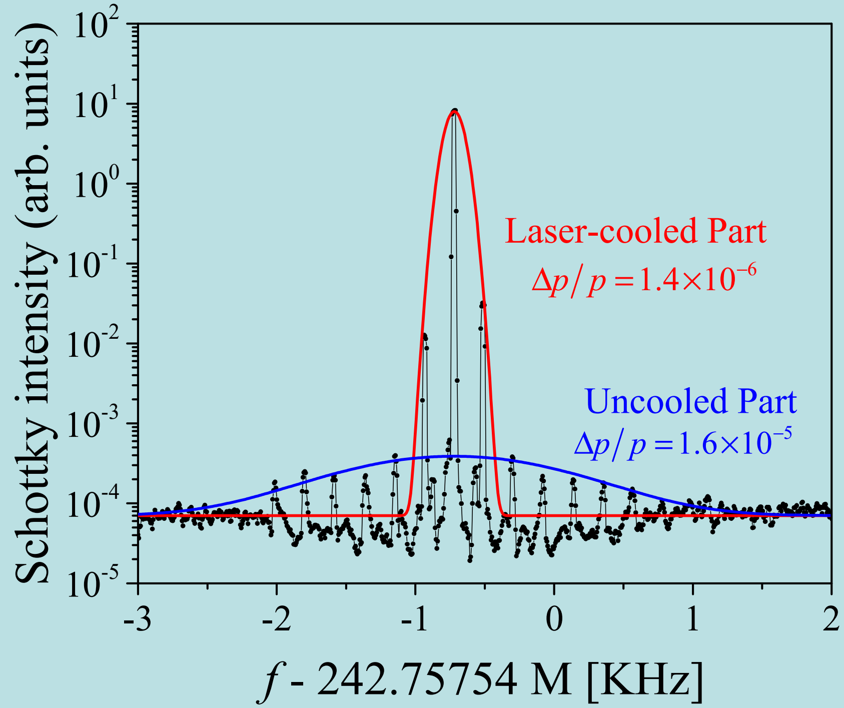


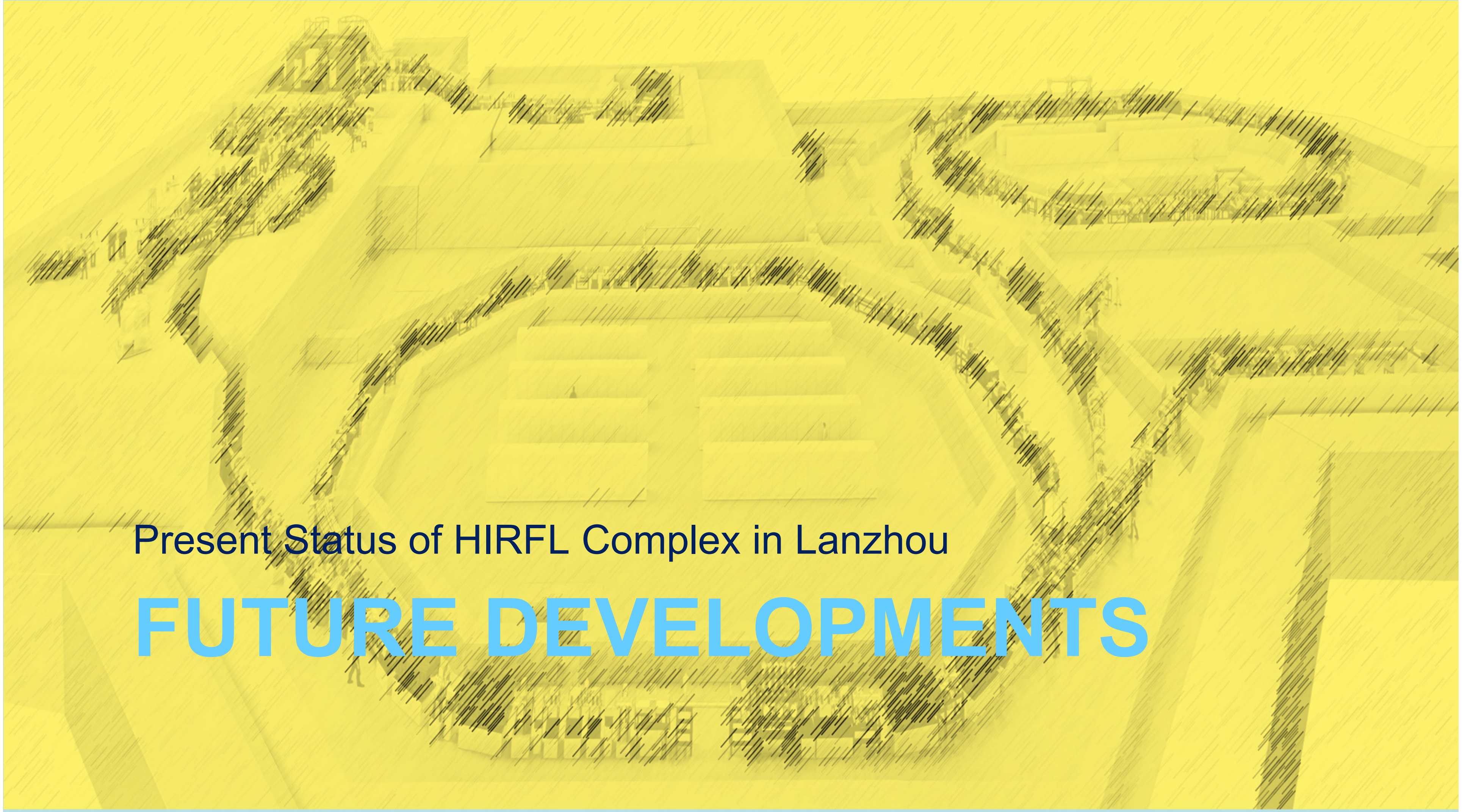
# CSRe with Laser Cooling

## Preliminary results: Laser cooling of bunched ion beams



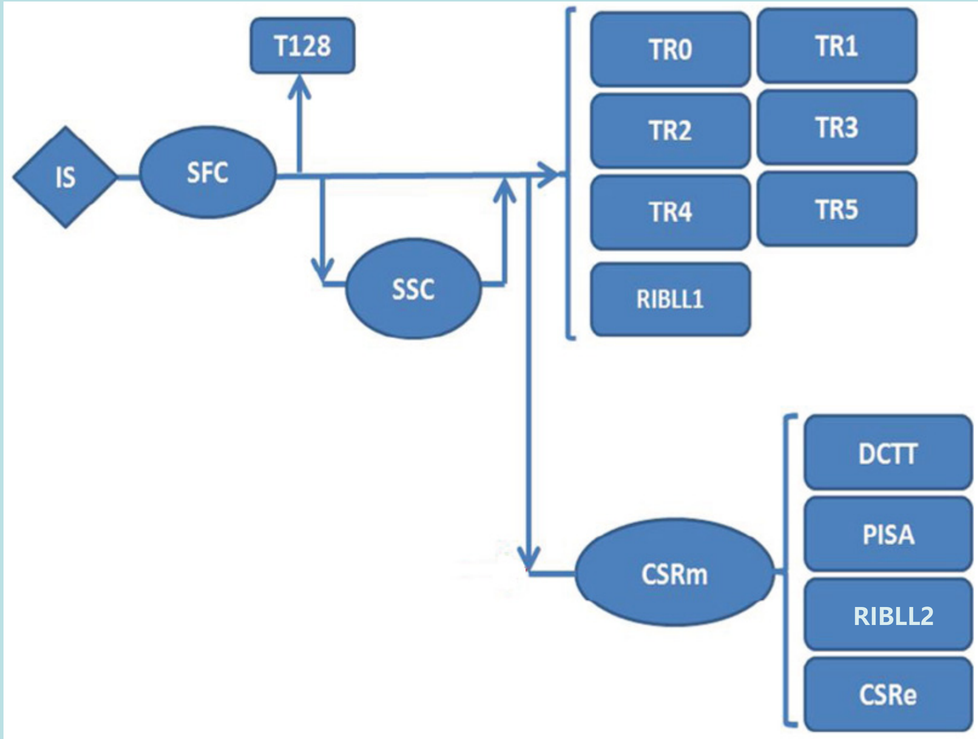

**Only part of the $^{16}O^{5+}$ ions were laser-cooled**



Present Status of HIRFL Complex in Lanzhou

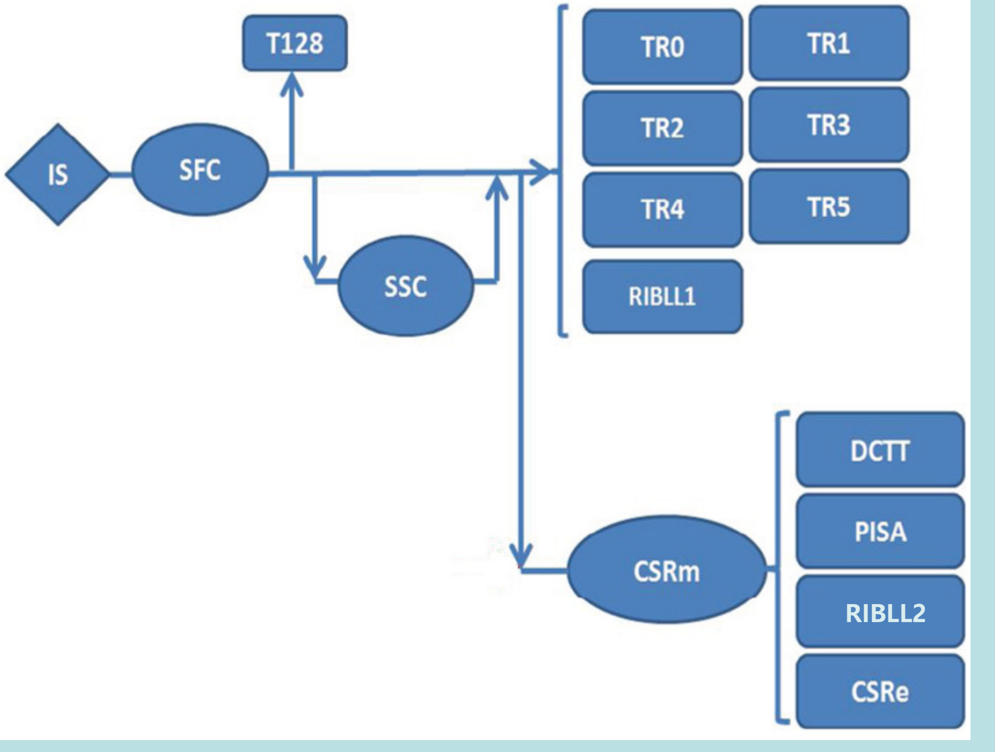
# FUTURE DEVELOPMENTS

# HIRFL with new injectors




Operation modes of HIRFL with new injectors

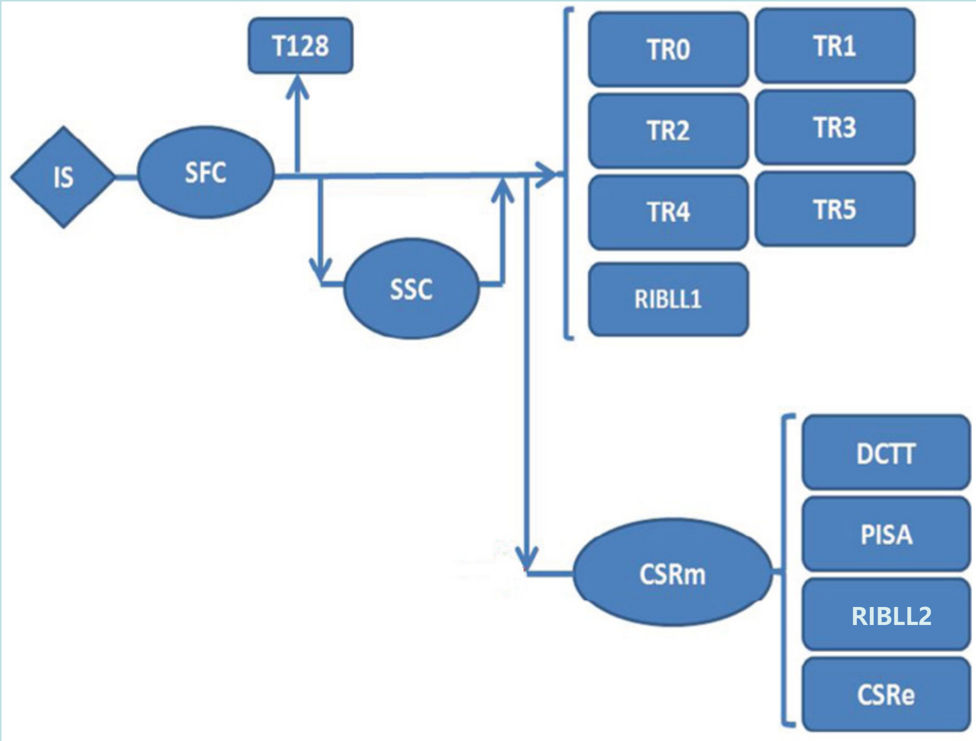
# HIRFL with new injectors




Operation modes of HIRFL with new injectors

# HIRFL with new injectors

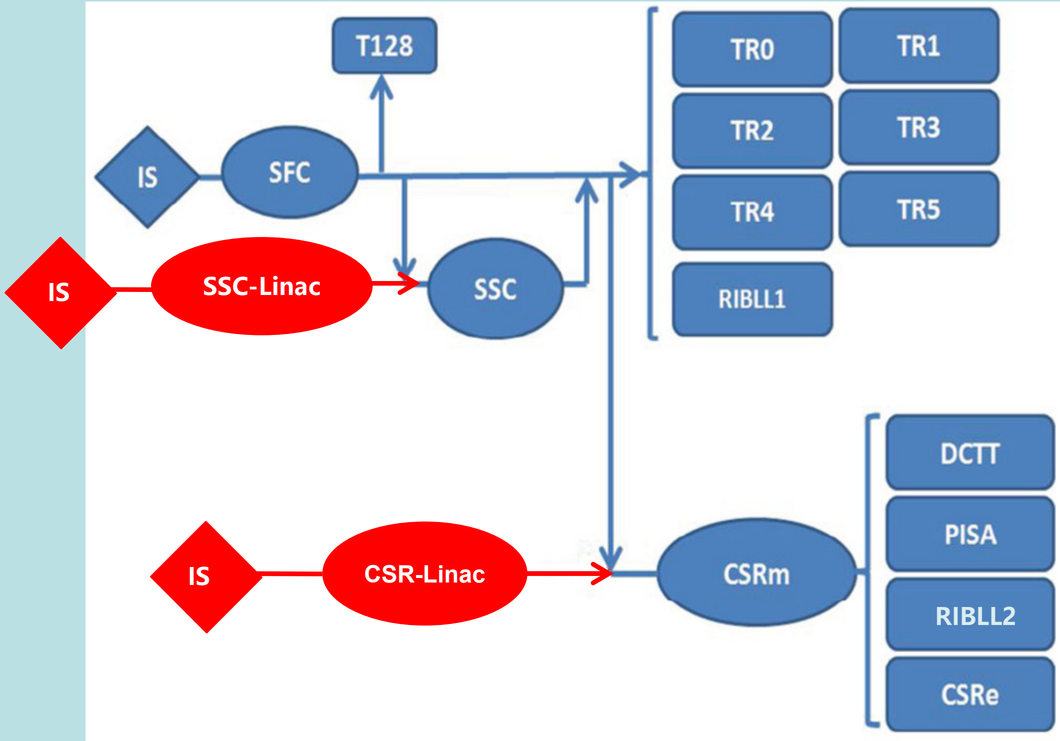
- Parallel operation modes of HIRFL.
  - Enough maintenance period for injectors
  - More total beam time




Operation modes of HIRFL with new injectors

# HIRFL with new injectors

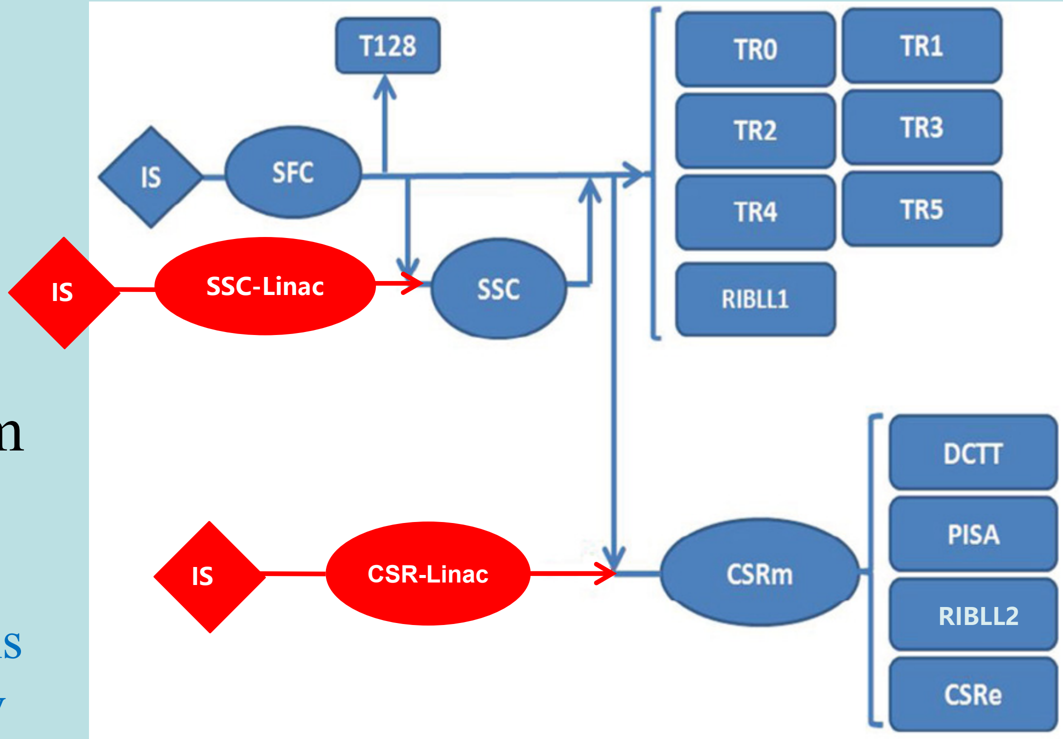
- Parallel operation modes of HIRFL.
  - Enough maintenance period for injectors
  - More total beam time




Operation modes of HIRFL with new injectors

# HIRFL with new injectors

- Parallel operation modes of HIRFL.
  - Enough maintenance period for injectors
  - More total beam time
- High beam transmission efficiency from IS  to CSRm and intensity.
  - Enough energy/ intensity to get highly charged heavy ions for higher accelerated energy by CSRm.
  - Short accumulation time → higher repetition rate of CSRm.
  -




Operation modes of HIRFL with new injectors

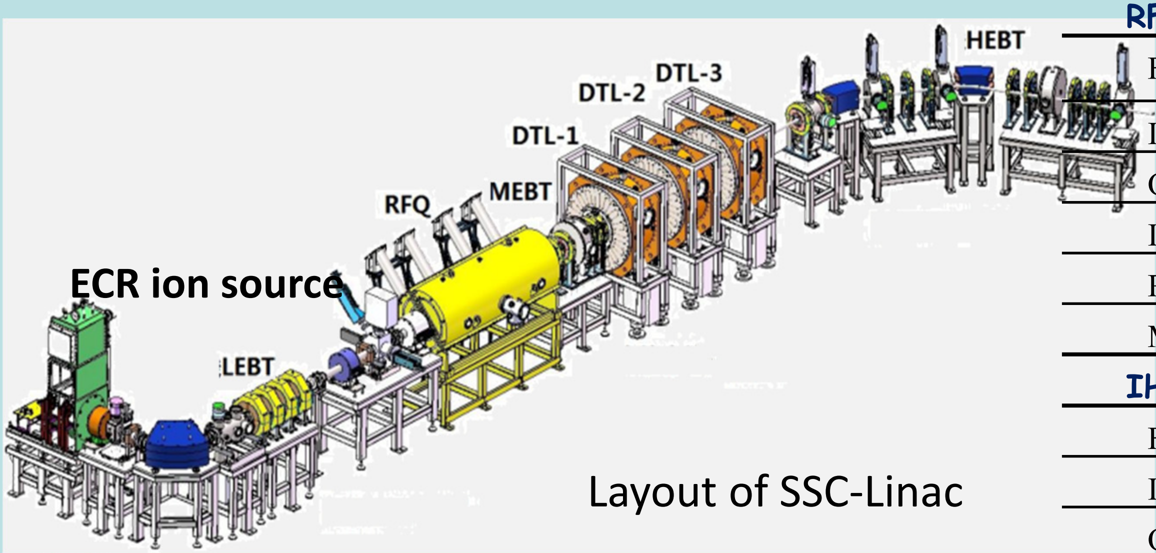
# SSC-Linac: Overview

## New high intensity heavy ion injector of SSC

- Extraction energy:
  1.025MeV/u→10.7MeV/u(SSC)→CSRm
  0.576 MeV/u → 5.97 MeV/u(SSC)→CSRm
- Beam current : 5~30eμA for various ions.
- Beam intensity: increase 1~2 order for SSC.
- $^{238}U^{35\text{-}72+}$ can be accelerated to 487MeV/u by CSRm after stripping.

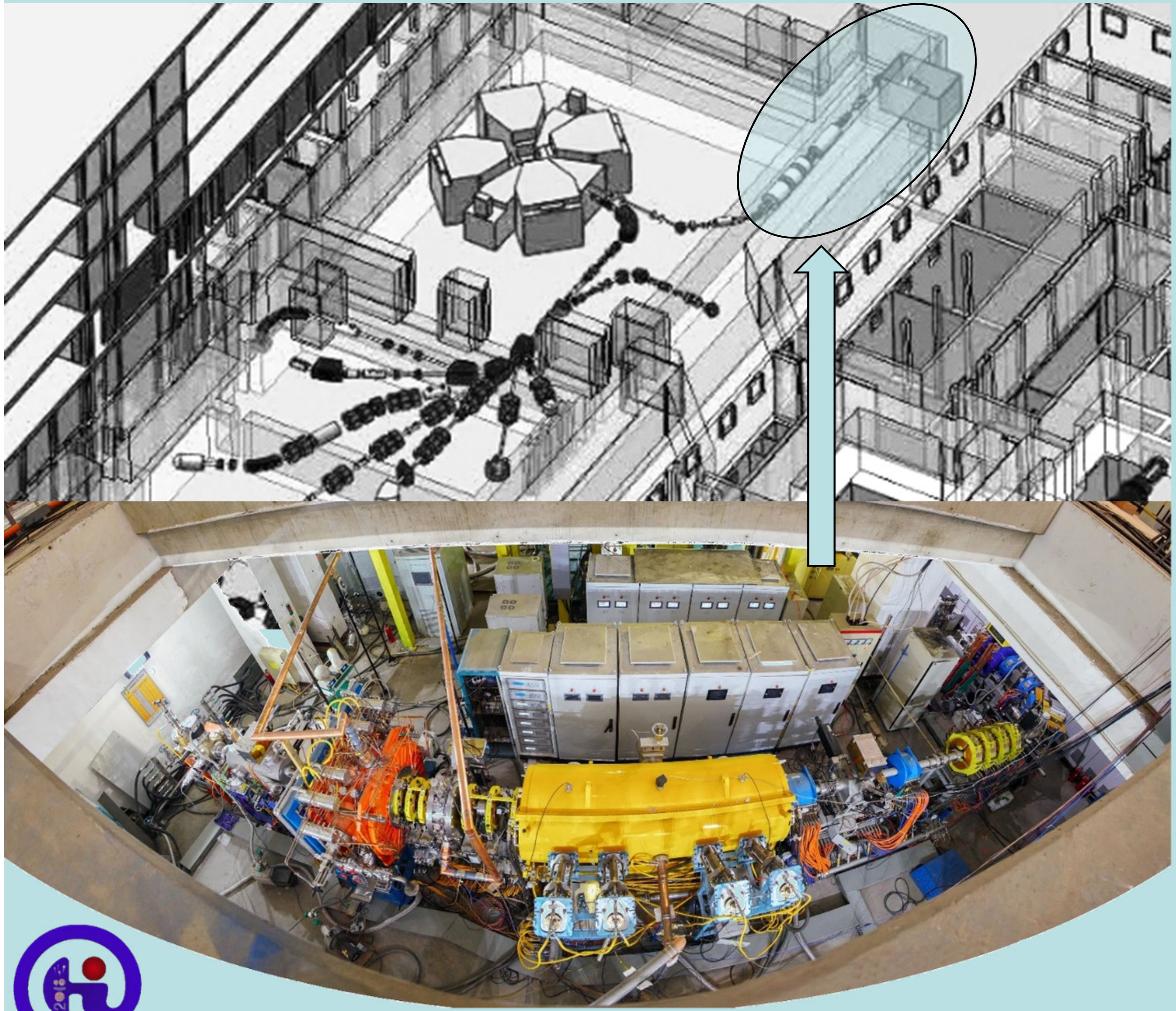
**Main parameters of SSC_Linac**

| Parameters | Values |
|---|---|
| **Design ion** | $^{238}U^{34+}$ |
| **ECR ion source** | |
| Extraction voltage | 25kV |
| Max. axial injection field | 2.3 T |
| Microwave frequency | 18GHz |
| **RFQ** | 4-rod |
| Frequency | 53.667MHz |
| Input energy | 3.728keV/u |
| Output energy | 143keV/u |
| Inter-electrode voltage | 70kV |
| RF power | 35kW |
| Max. current | 0.5emA |
| **IH-DTL** | KONUS |
| Frequency | 53.667MHz |
| Input energy | 0.143MeV/u |
| Output energy | 1.025MeV/u |




Layout of SSC-Linac

# SSC-Linac: Progress

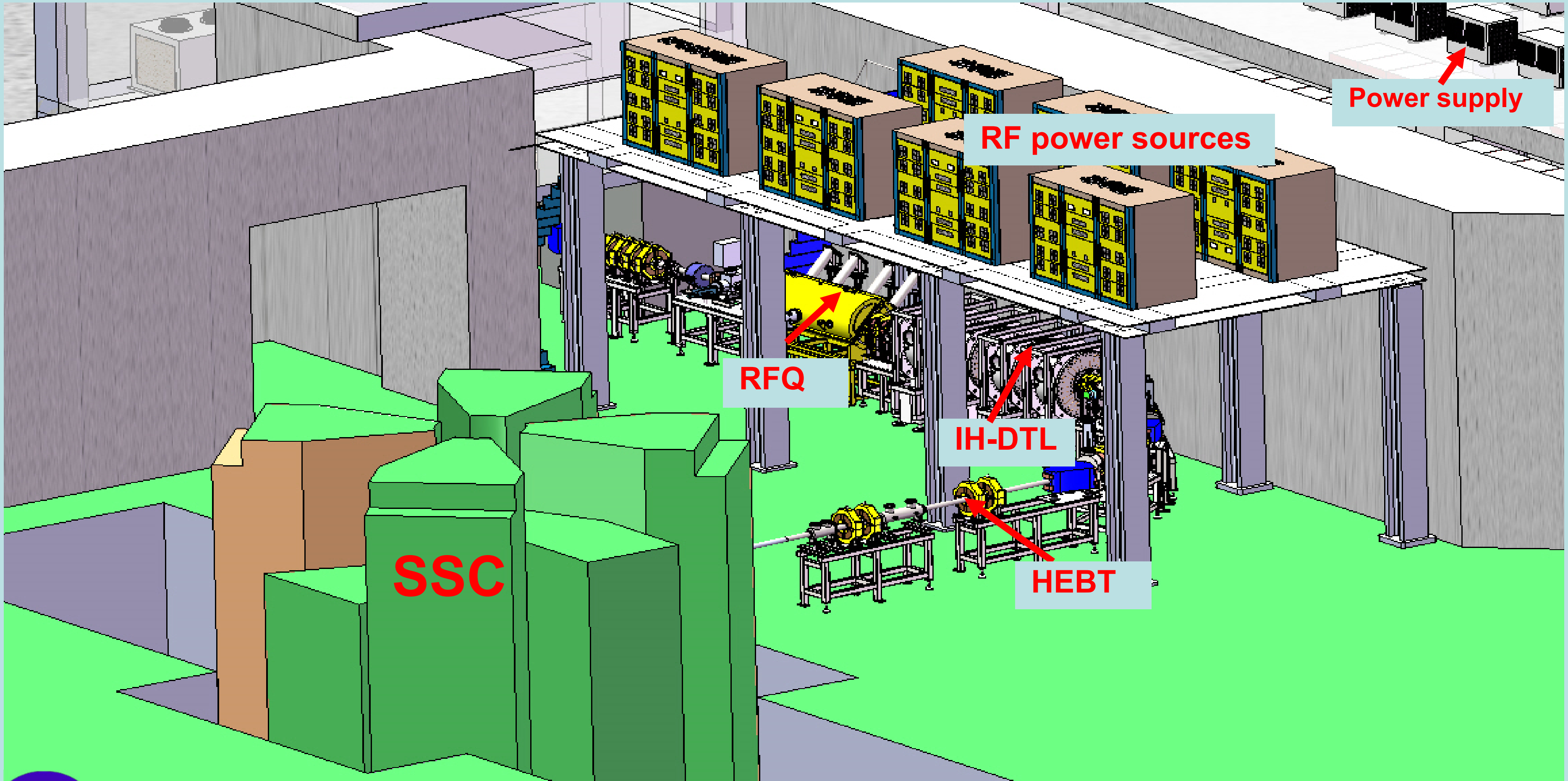


- Beam test of IS+LEBT+RFQ+DTL1 is done
- DTL2 be installed this month
- DTL34 ordered

- Civil construction start this summer
- Commissioning start by end of 2019

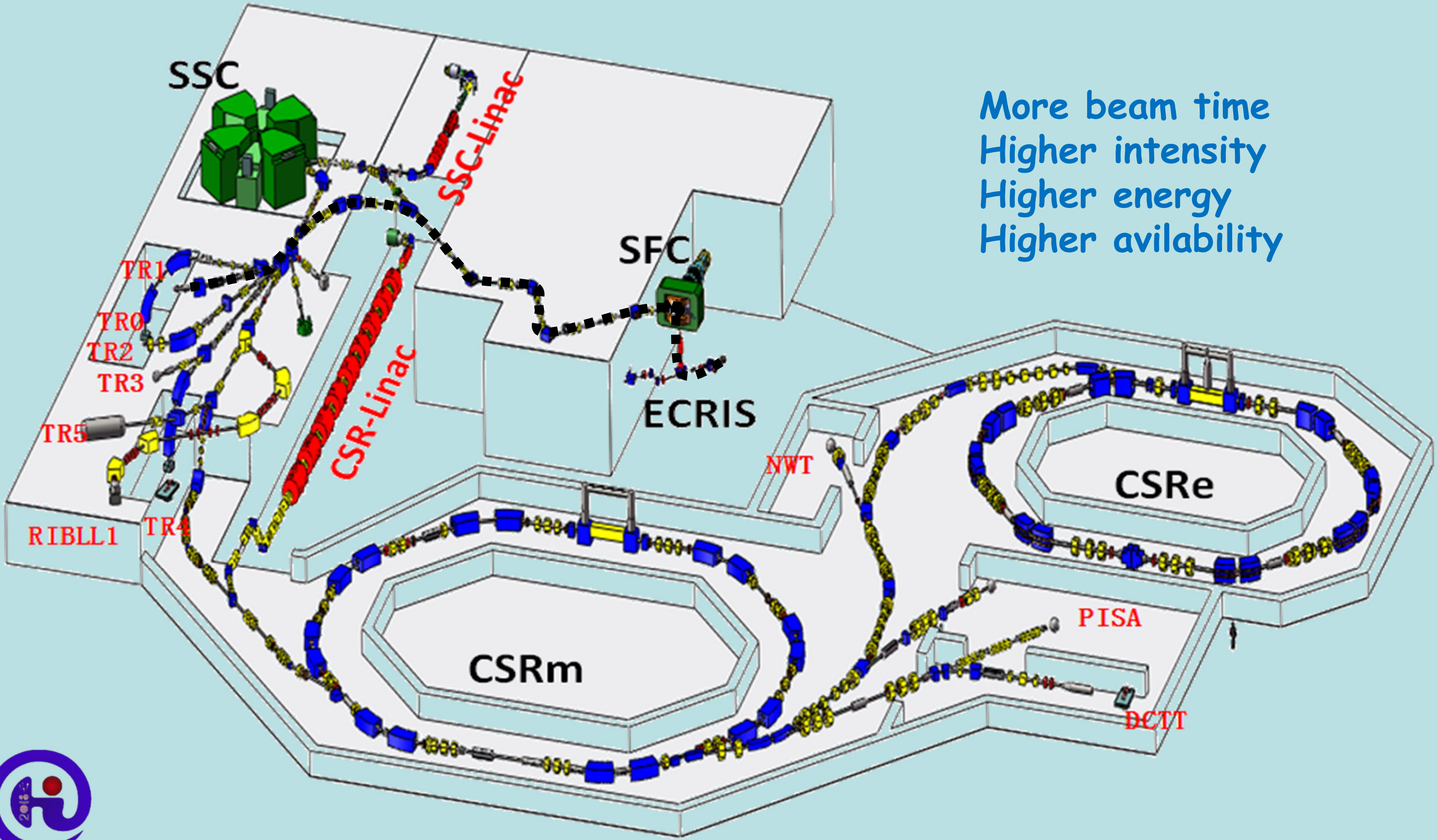
# Installation Site of SSC-Linac

- **Platform for RF generators, right up the cavities, 80 m$^2$**
- **New building outside SSC hall for PS, water cooling *etc*. ~400 m$^2$**



# HIRFL with new injectors

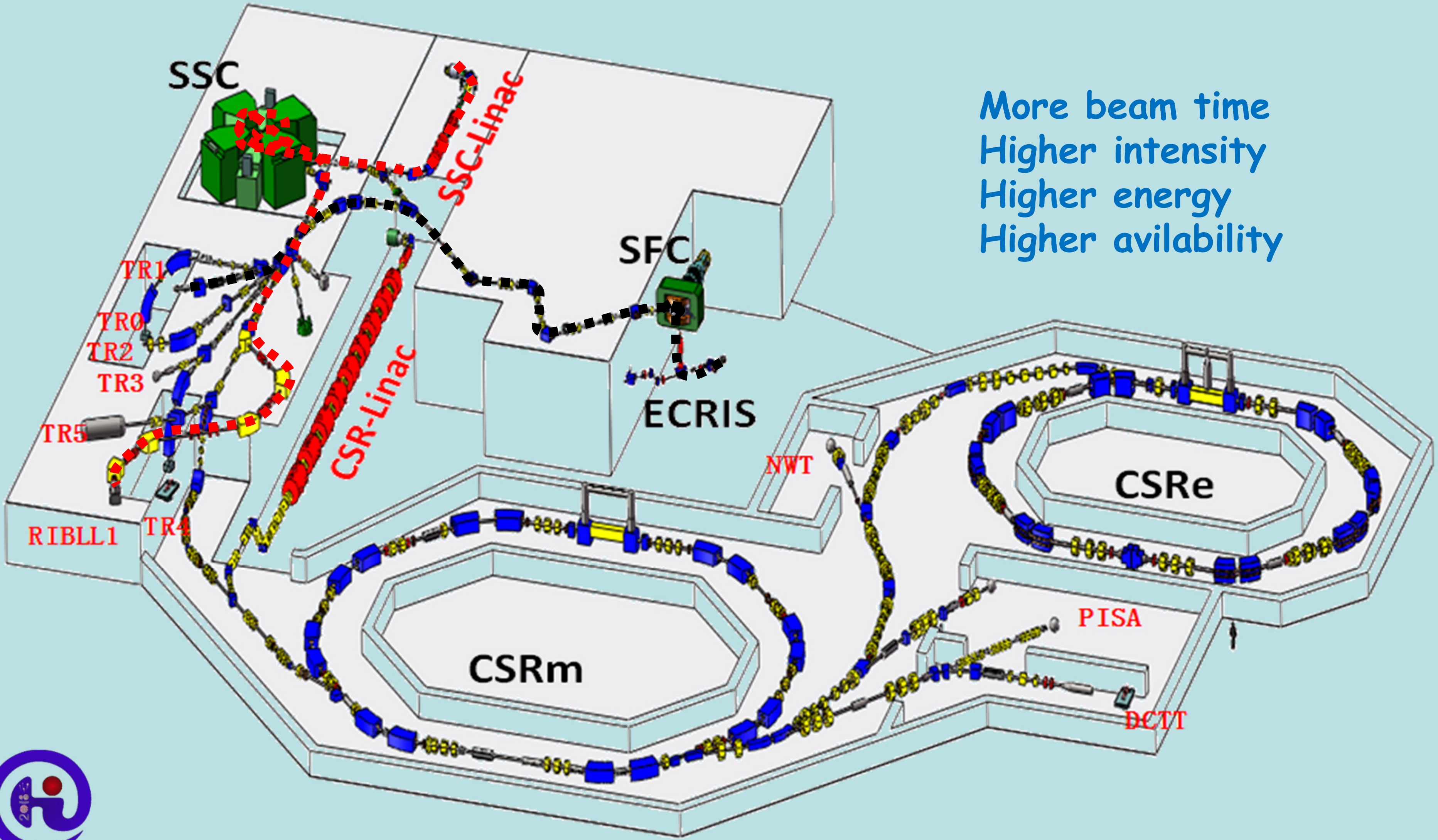
**SFC**




More beam time
Higher intensity
Higher energy
Higher avilability

# HIRFL with new injectors

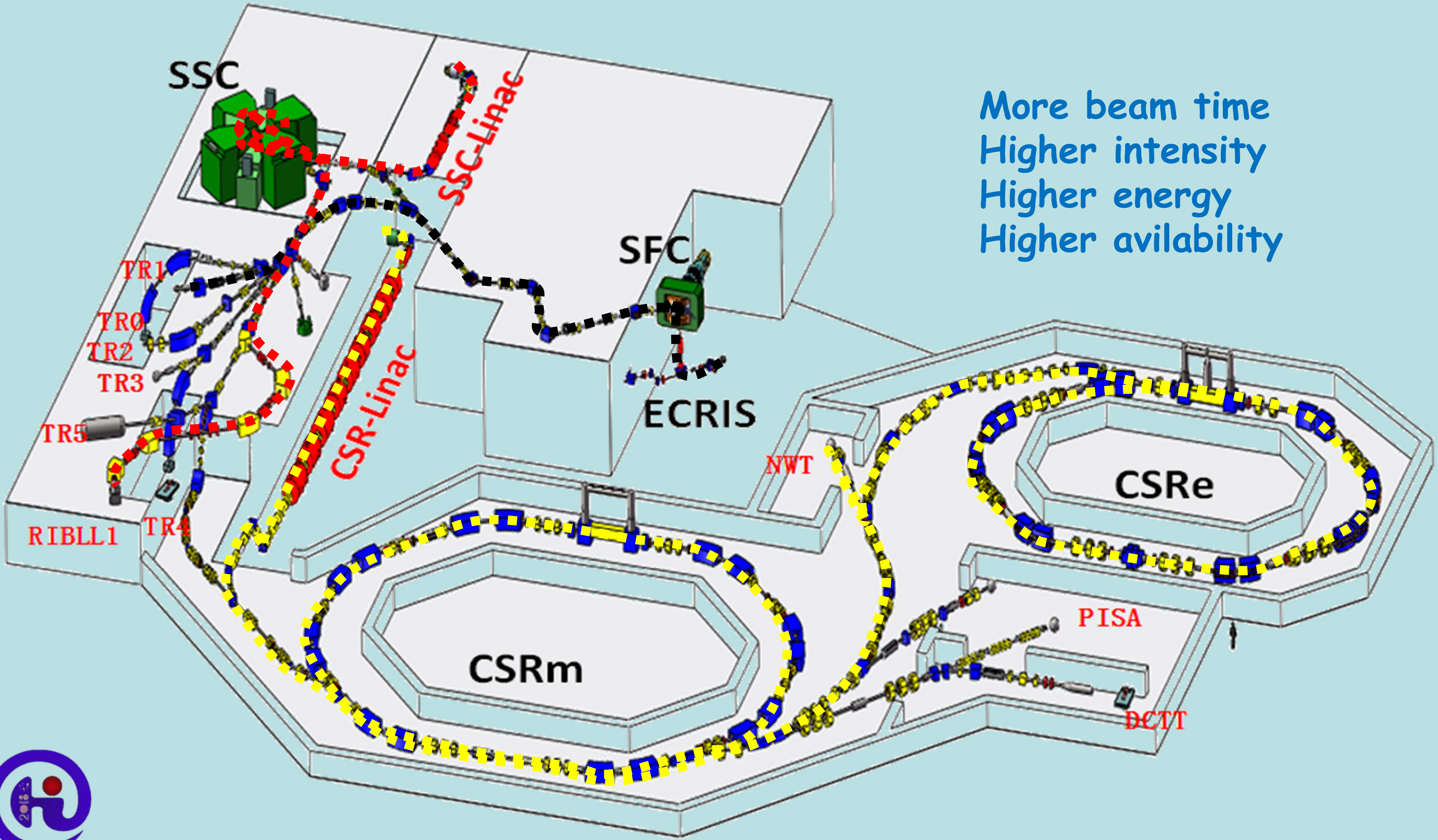
**SFC** **SSC-Linac**




More beam time
Higher intensity
Higher energy
Higher avilability

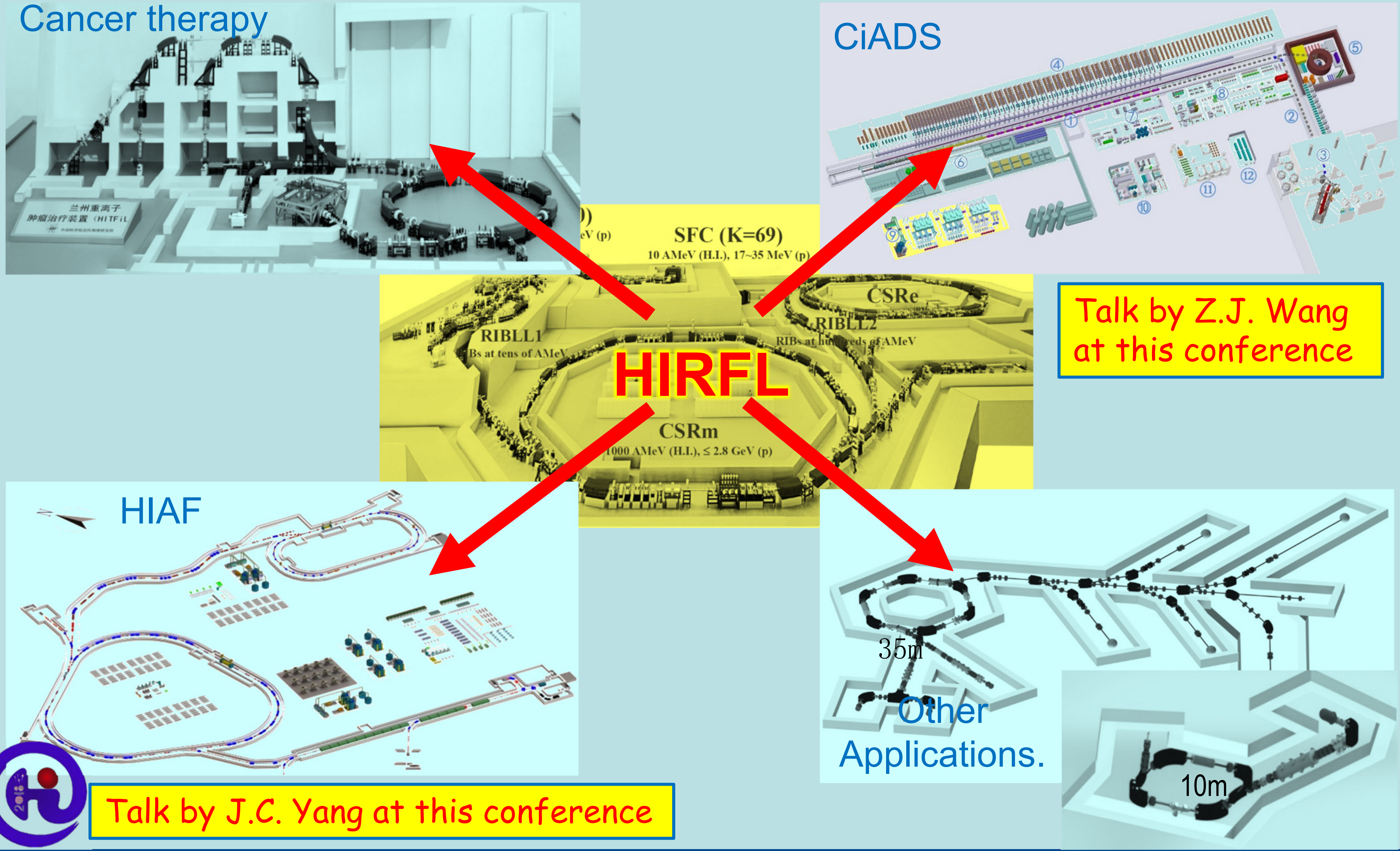
# HIRFL with new injectors

SFC SSC-Linac CSR-Linac




More beam time
Higher intensity
Higher energy
Higher avilability

# Recent and future projects based on HIRFL




Talk by Z.J. Wang at this conference

Talk by J.C. Yang at this conference

# Collaborations

## Thanks for the 50 years cooperations of all our friends!

HIRFL

**GSI**
- Electron cooling
- Beam optic
- Isochronous mass measurement
- Super conducting technology

**GANIL spiral2**
- Cyclotron

**Jefferson Lab**
- Electron Super conducting linac
- EIC

**BINP**
- E-cooling

**Peking University**
- Heavy ion linac

**Tsinghua University**
- Electron gun

**RIKEN**
- Cyclotron

**Brookhaven National Laboratory**
- Beam polarization

**Lanzhou University**
- Student training

**IHEP**
- Proton linac

**JINR**
- Ion source
- Cooling simulation

**Michigan State University**
- Beam injection method
- Target
- Super conducting heavy ion linac

**J-PARC**
- linac
- Beam Injection/Extraction method

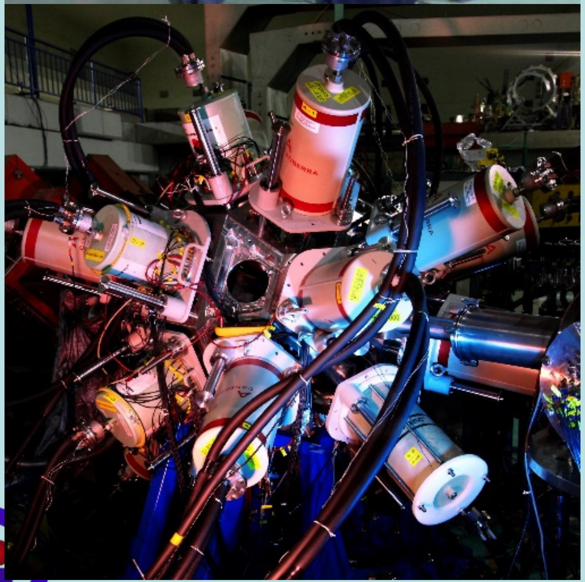
**CERN**
- High intensity dynamics
- Super conducting technology

# Present Status of HIRFL Complex in Lanzhou

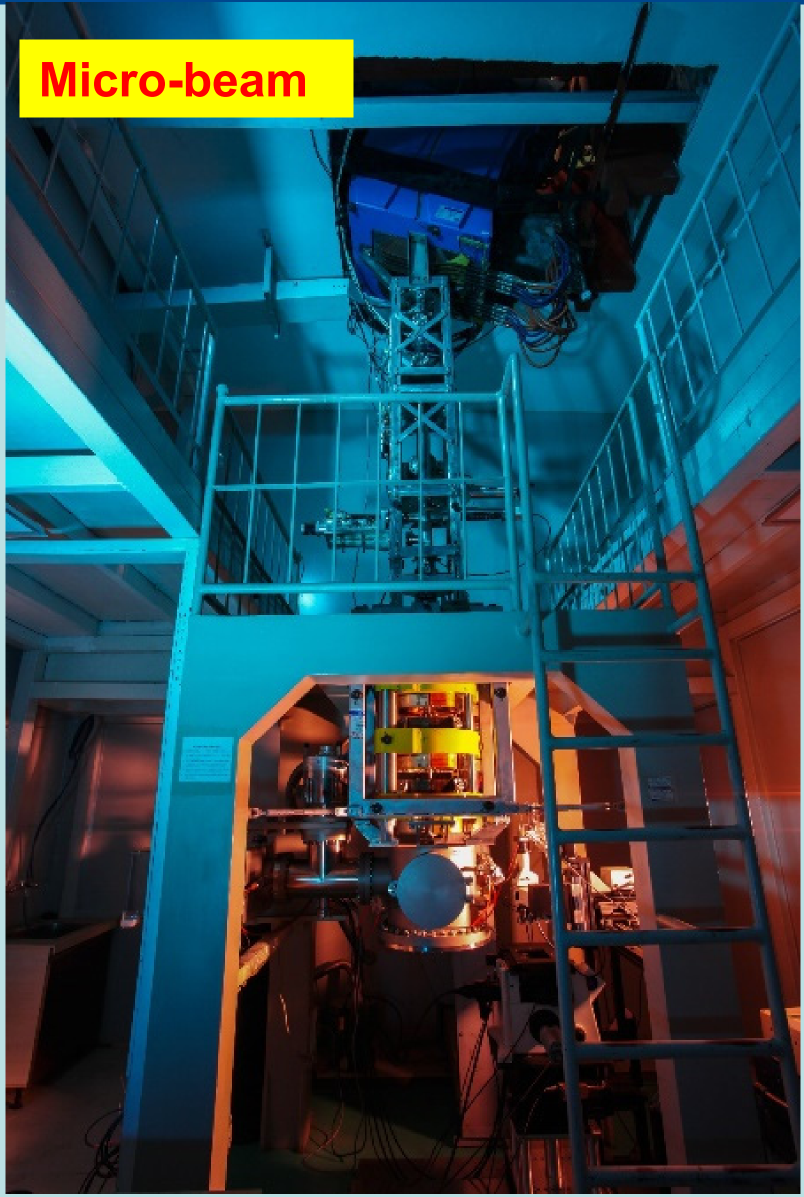
**Thanks for your attention!**

# Upgrading cyclotron terminals

RIBLL



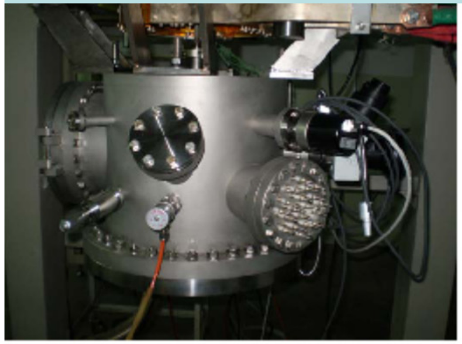
Online γ detector



Micro-beam

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

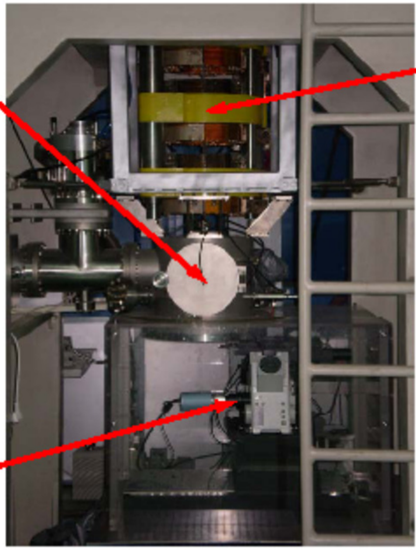
# Micro beam irradiation

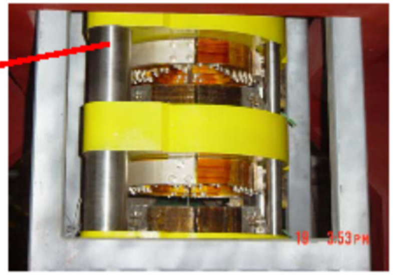


Microbeam facility on the first floor

(upper part )

Vacuum Chamber for material irradiation





Quadrupole triplet, Φ15mm
L = 100mm, G = 123 T/m

Inverted microscope for cell irradiation

Facility in the cellar

(lower part )

**Characteristics:**

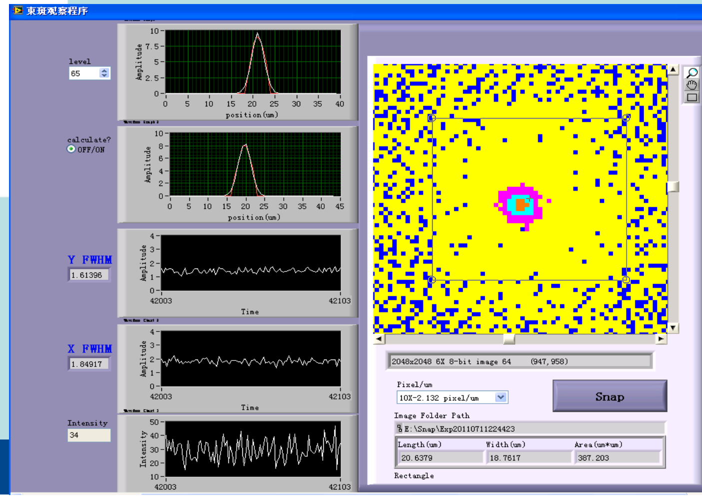
1. Energy selection
2. Vertical irradiation
3. Focusing micro beam
4. Two foci: one in vacuum the other in the air

$^{12}C^{6+}$ 80.55MeV/u

Ion hitting rate 1~1200/s controllable

FWHM beam spot <2μm in air

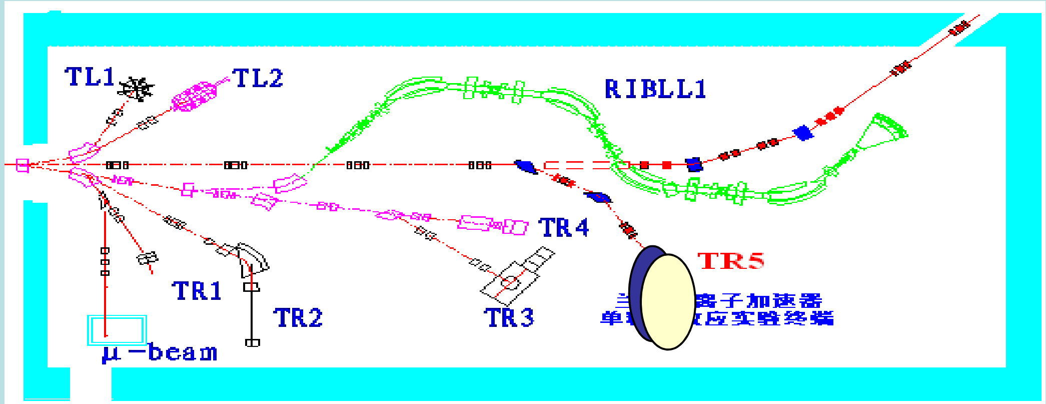
<1μm in vacuum



# New single event effects terminal

(2010-2014)

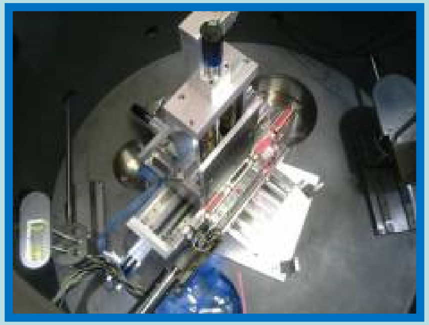
- 700 hours/year for SEE (Single Event Effects) researches
- Improving the accuracy and efficiency of ground simulation for space radiation
- Increasing reliability for electronic device evaluations




TR5 terminal for SEE research at the HIRFL experiment hall

Main Chamber

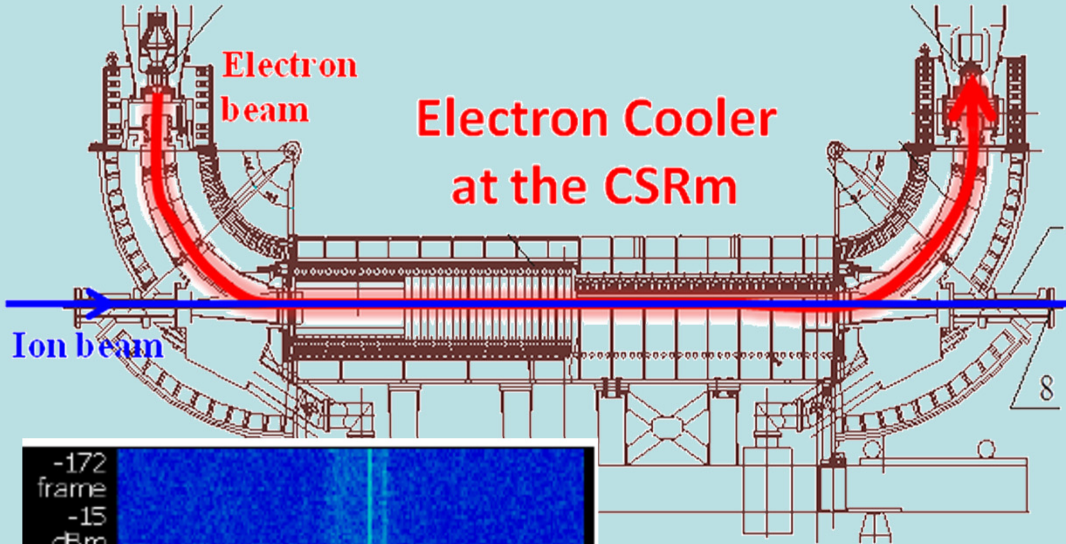
Pre-vac chamber



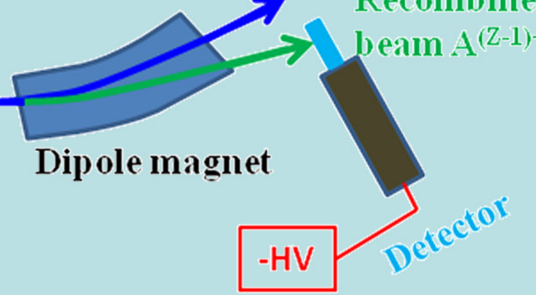
4-dimensional sample holder

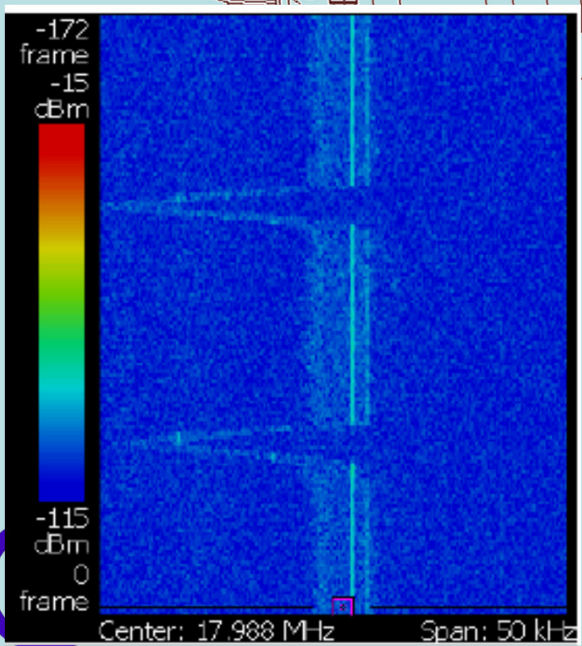
# DR experiment setup

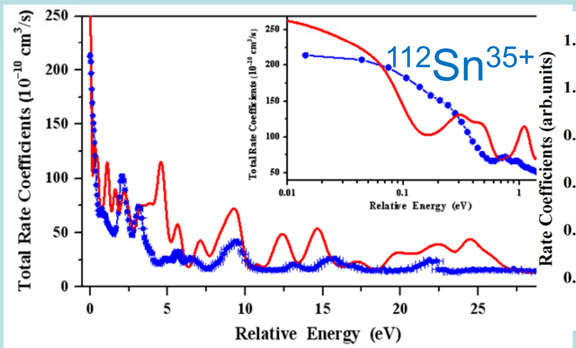
Operation mode：ECR+SFC+CSRm,  Beams: C, Ar , Xe, Sn…



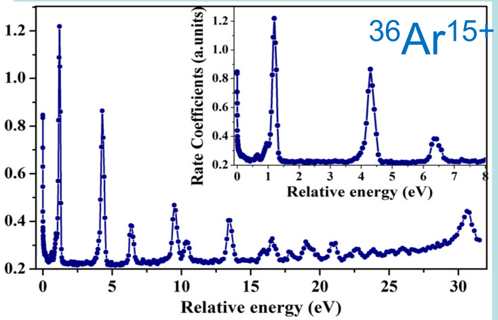

CSRm：Injection mode



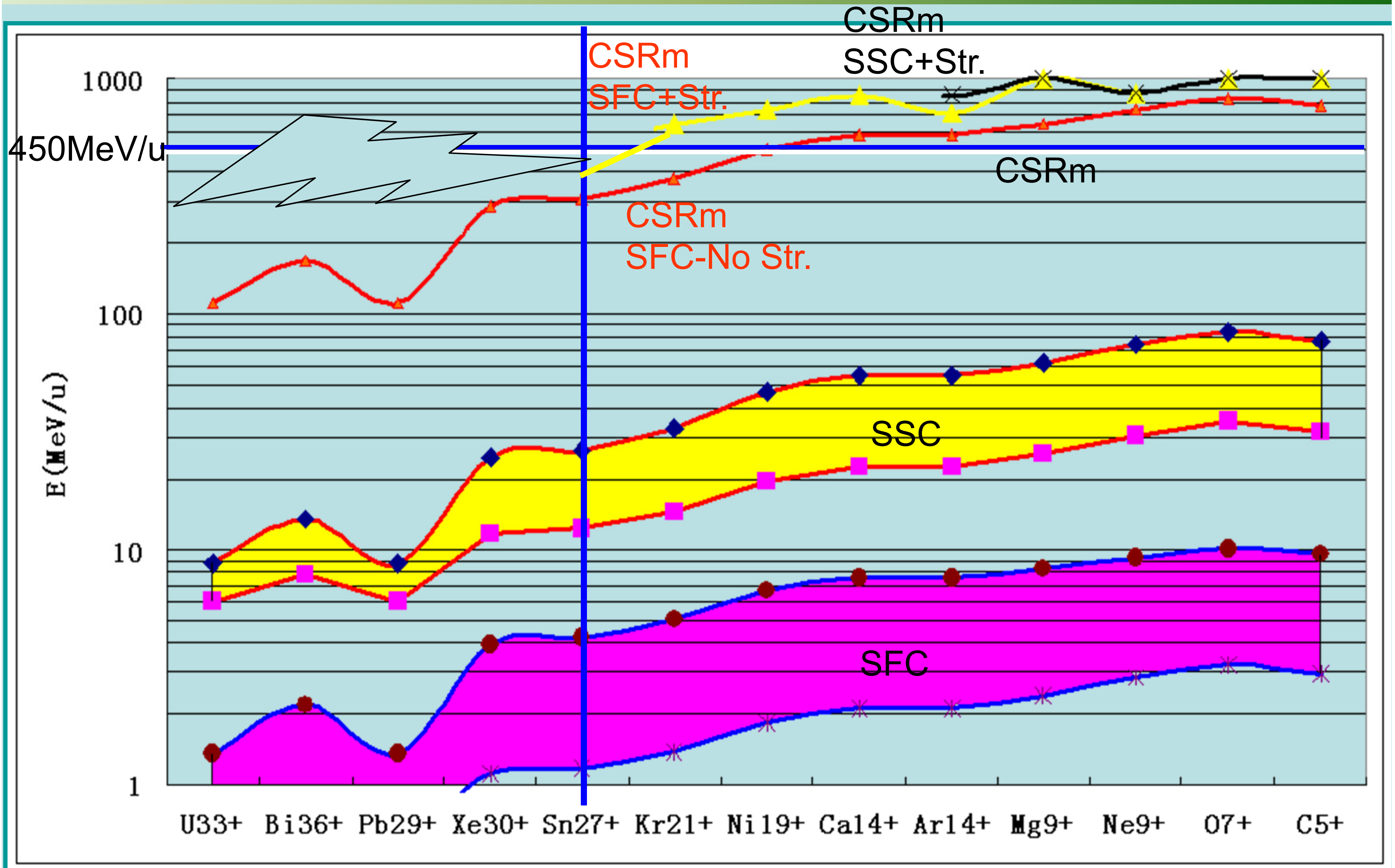

DR of $^{112}Sn^{35+}$, 10. 2012



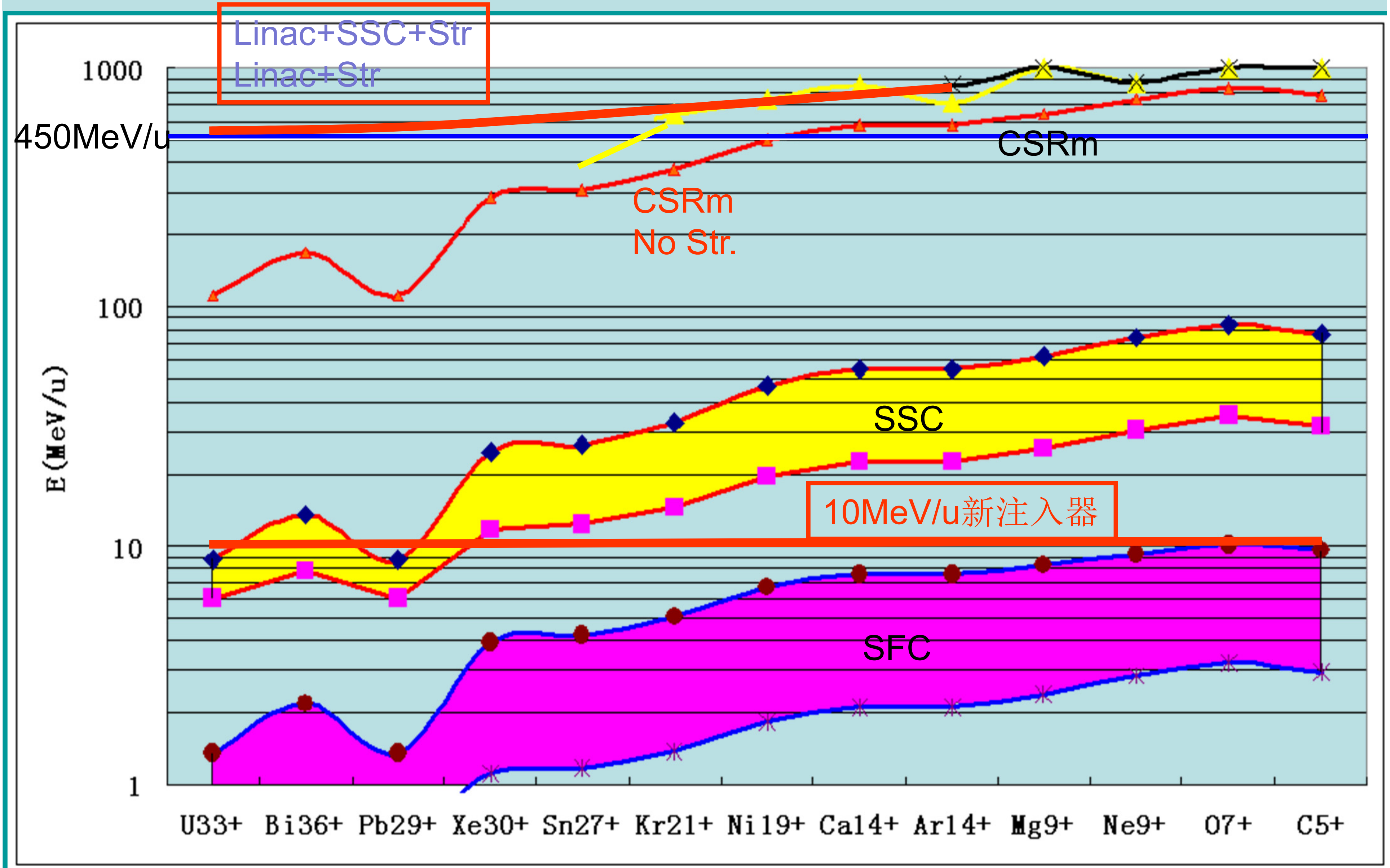

DR of $^{36}Ar^{15+}$, 07. 2014

Detuning e-energy for DR cross section measurement

# Energy range of HIRFL

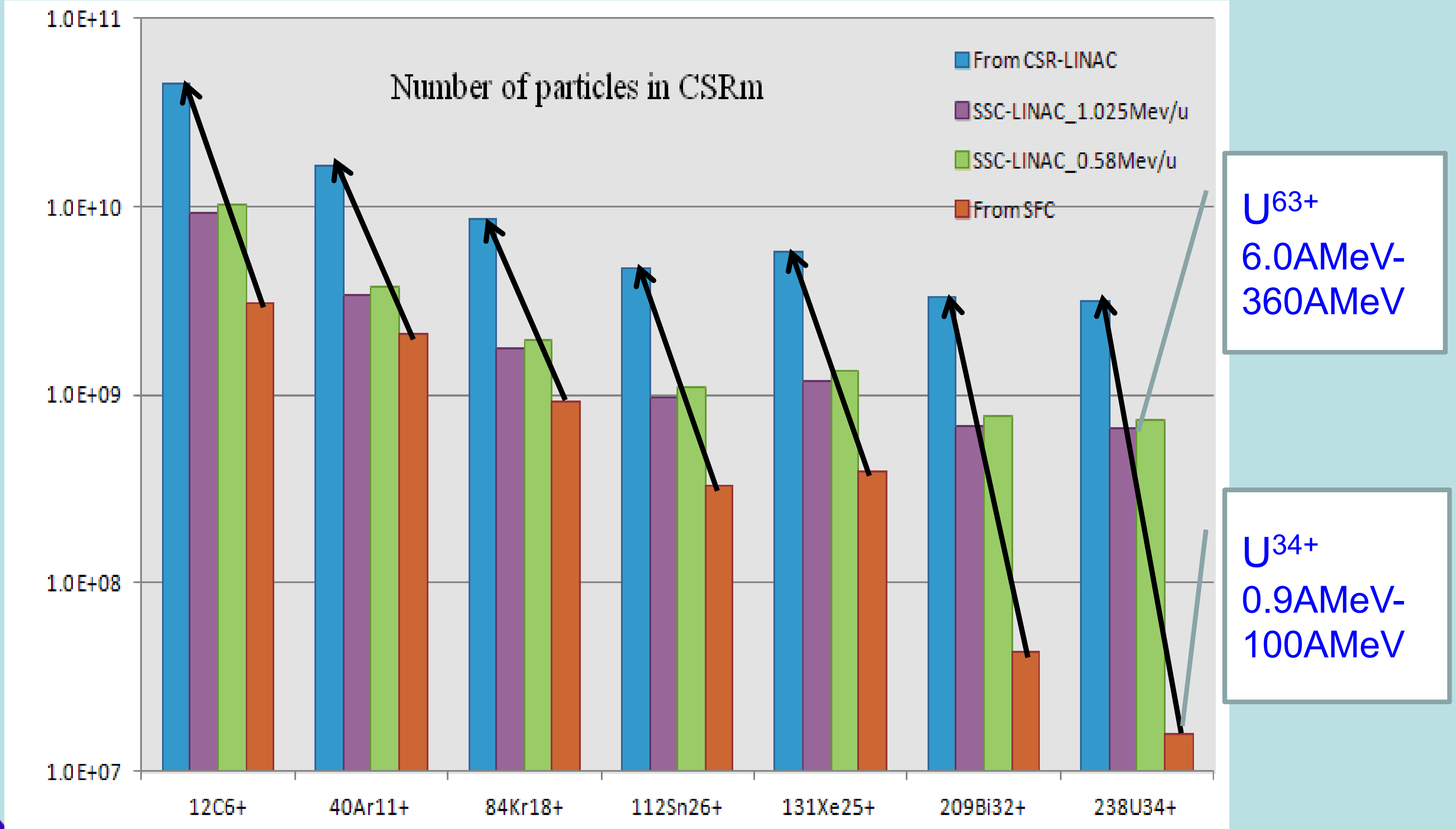


# HIRFL+10MeV/u new injector



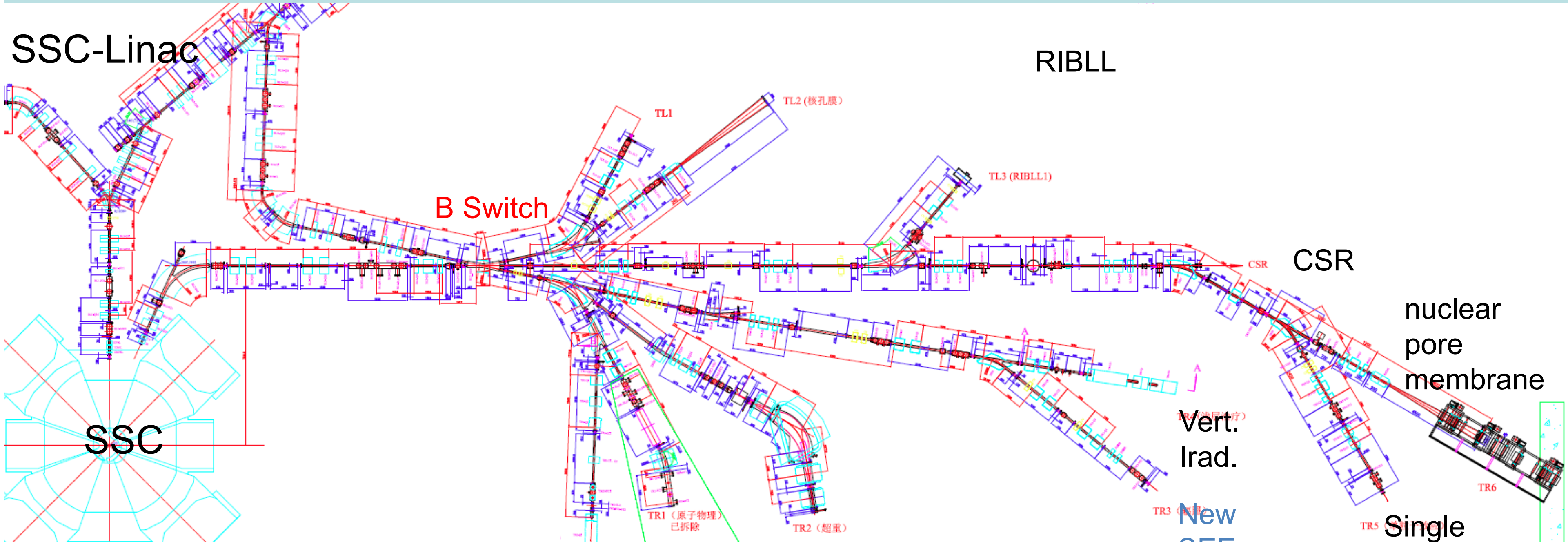
# CSRm bunch particles

- The number of ions in CSRm can be increased by 10~200 times
- The repetition cycle time can be reduced by ~30%




Estimated maximum number of stored particles at CSRm with various injectors

# Layout of HIRFL (part)



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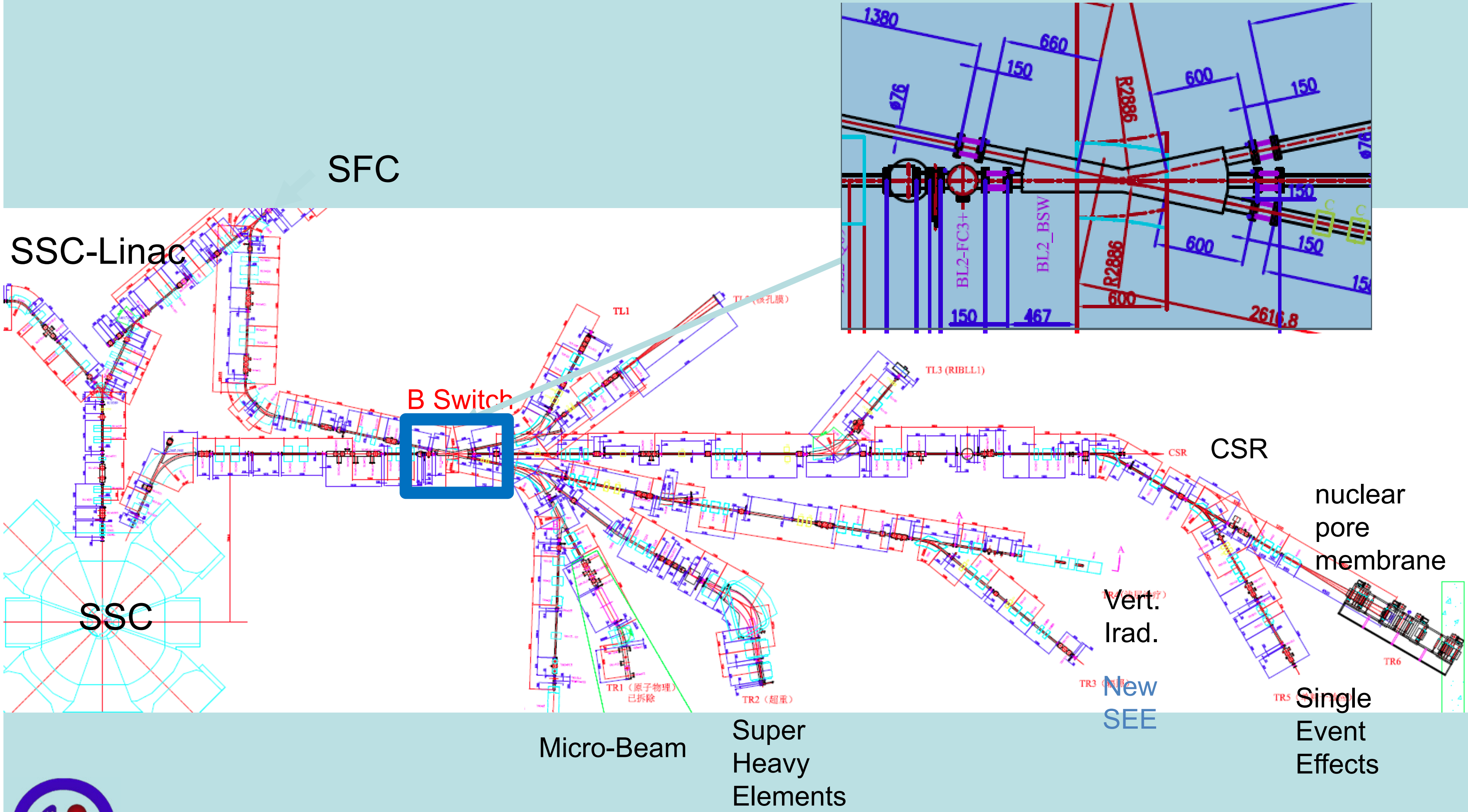
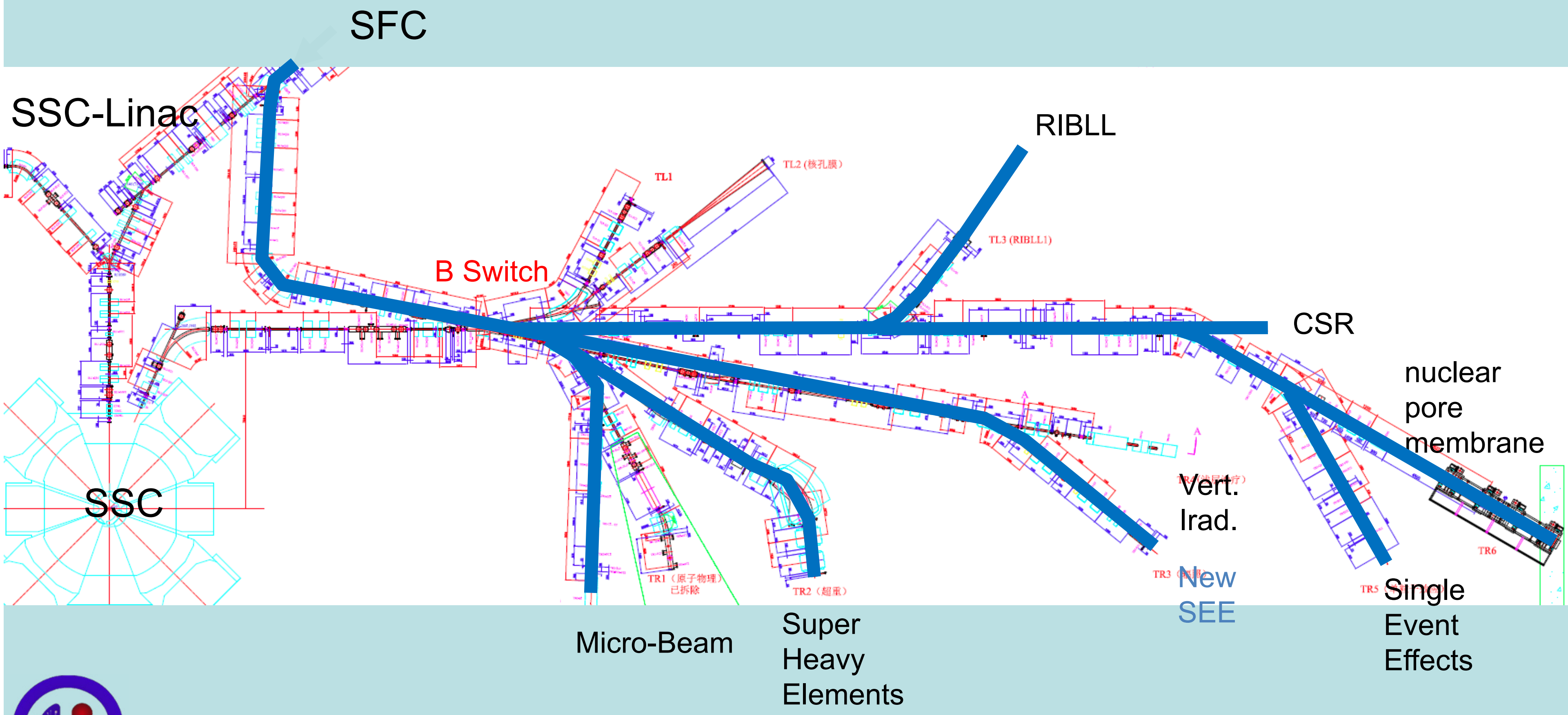
Institute of Modern Physics, Chinese Academy of Sciences

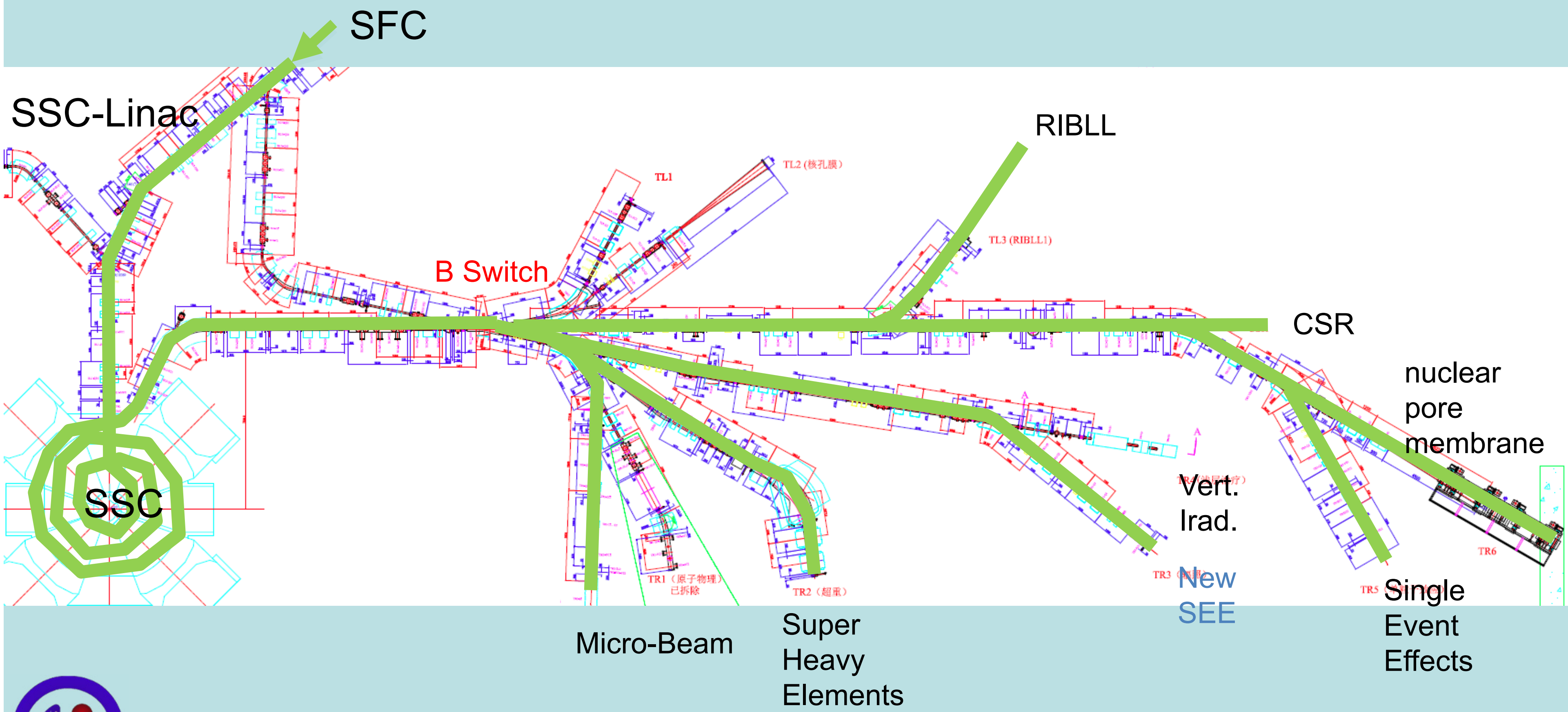
# Layout of HIRFL (part)



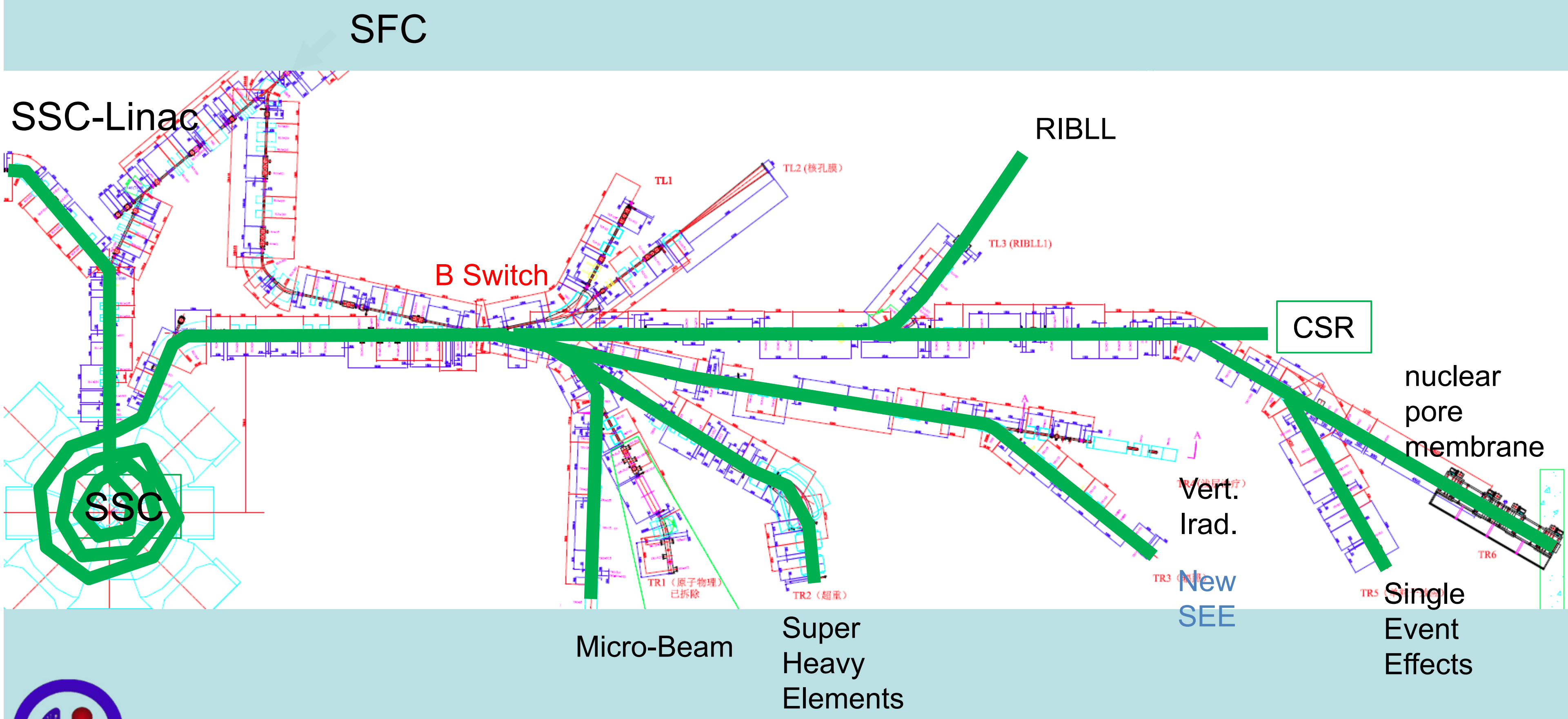
# SFC Injector Alone



# SFC + SSC

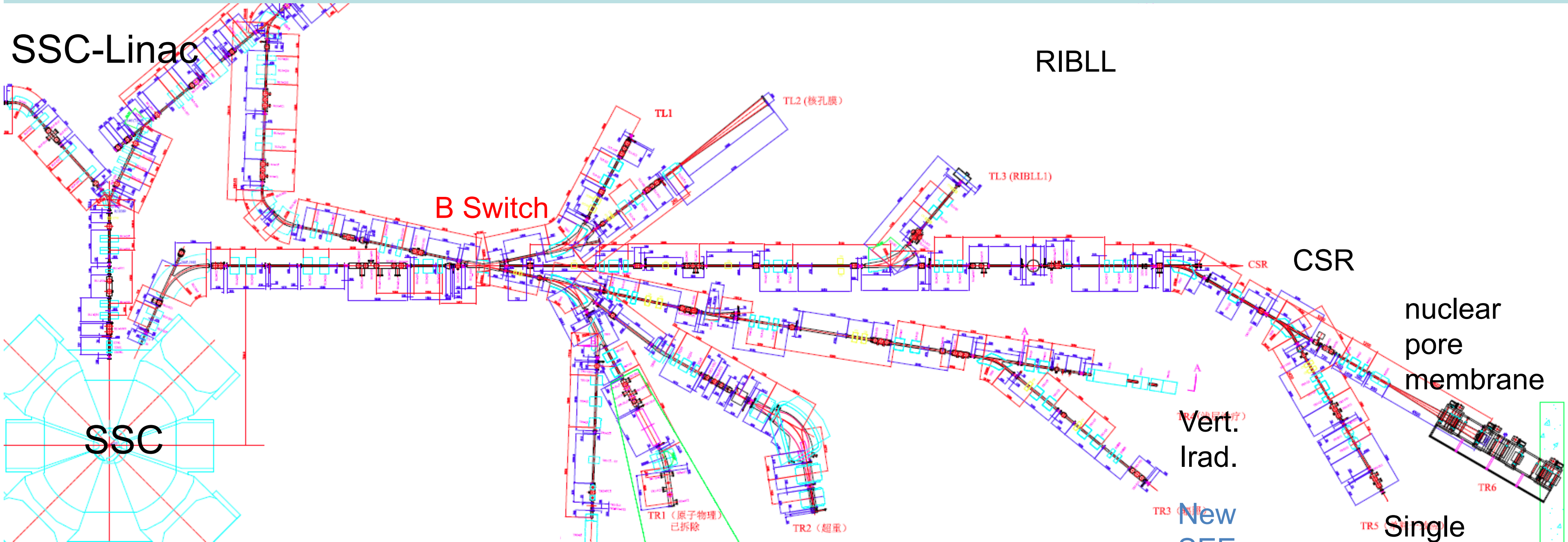

SFC
SSC-Linac
SSC
B Switch
TL1
TL2 (核孔膜)
TL3 (RIBLL1)
RIBLL
CSR
nuclear pore membrane
Vert. Irad.
New SEE
TR1 (原子物理) 已拆除
TR2 (超重)
TR3
TR5
TR6
Micro-Beam
Super Heavy Elements
Single Event Effects

# SSC-Linac + SSC



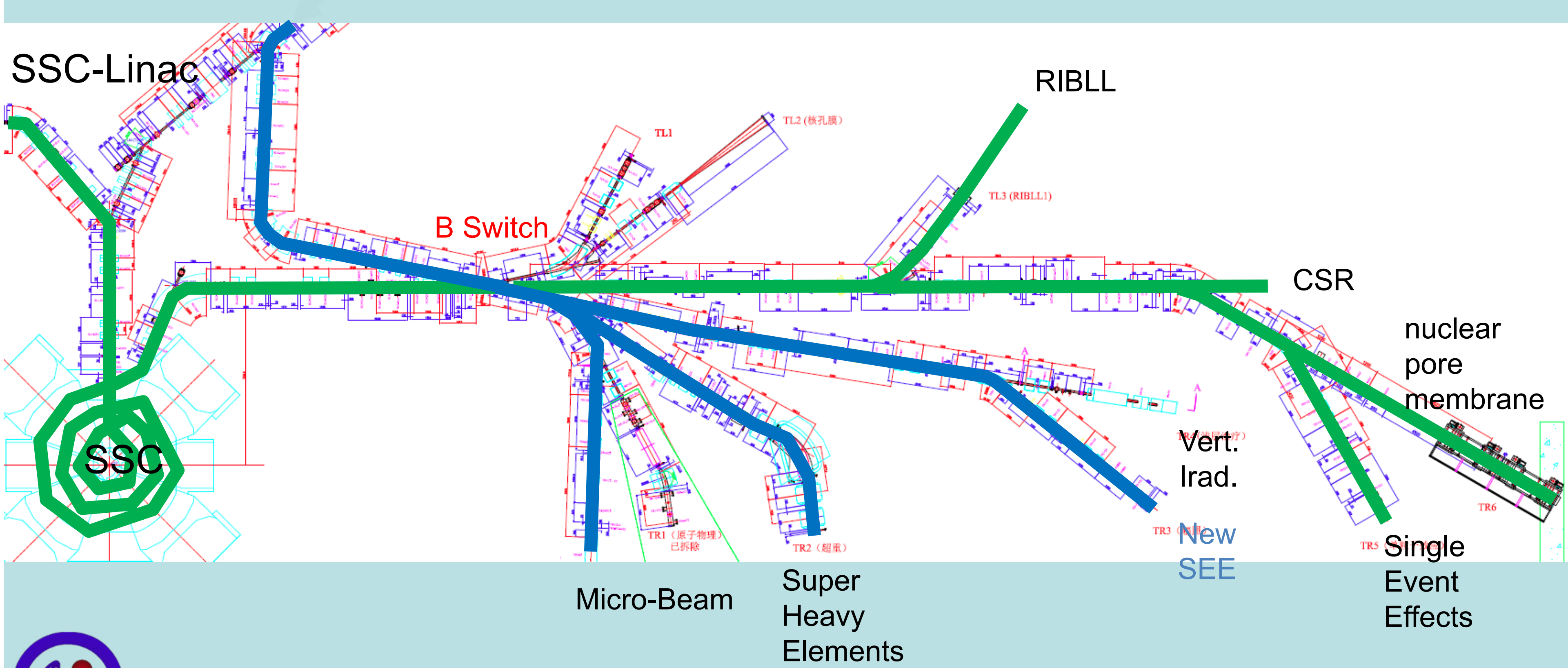
# Parallel Operation with 2 Injectors

SFC alone + (SSC-Linac+ SSC)



# Parallel Operation with 2 Injectors

SFC alone + (SSC-Linac+ SSC)



# THE END