HIRFL-CSR Facility Status and Development

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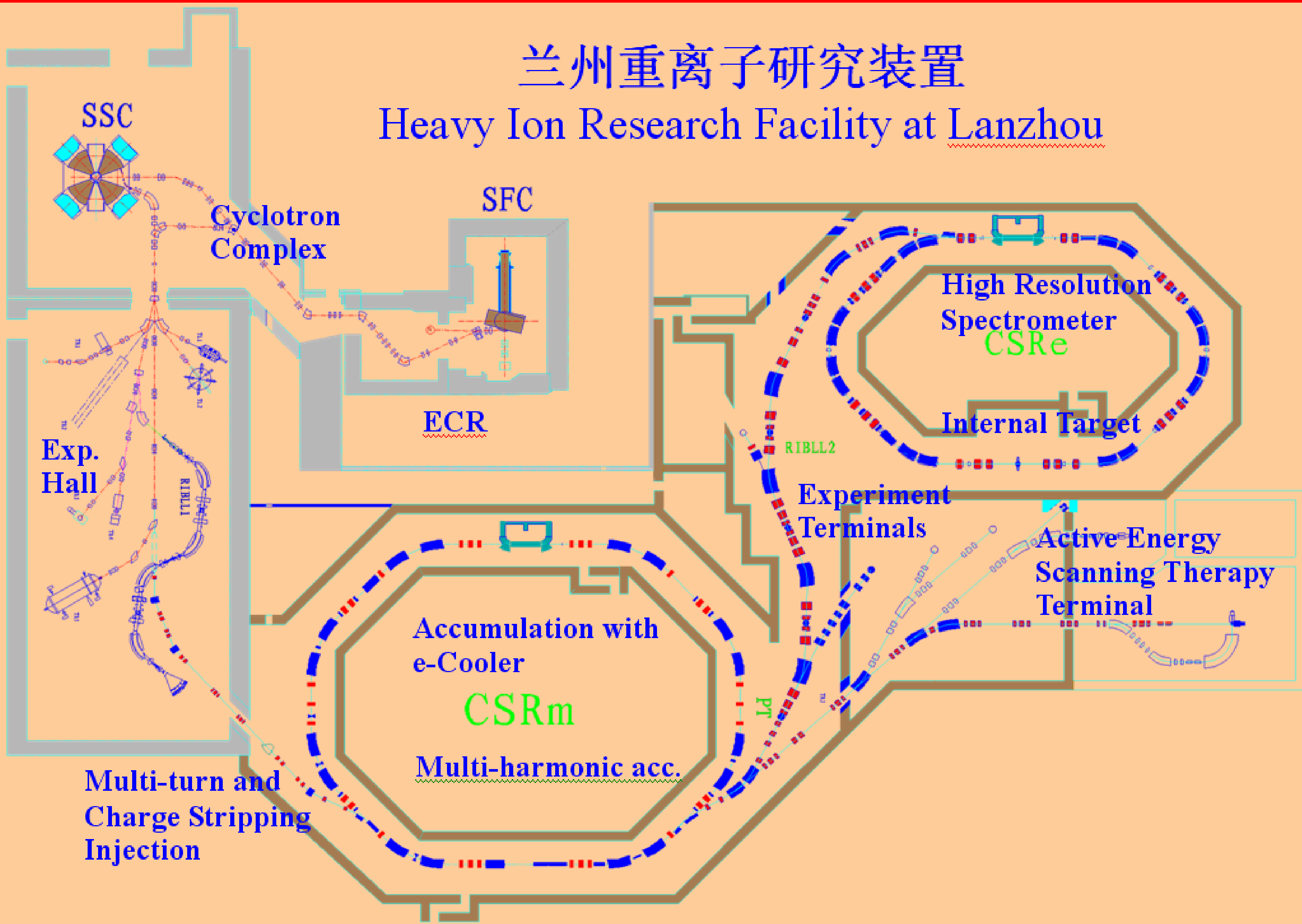
Topics

- Introduction to HIRFL-CSR
- Operation with slowly extracted beam
- Operation of CSRe mass spectrometer
- Operation of electron cooler and experiments of atomic physics
- The injector complex
- Other aspects

INTRODUCTION TO HIRFL-CSR

Major parameters and performance

兰州重离子研究装置
Heavy Ion Research Facility at Lanzhou



Major Parameters of CSR

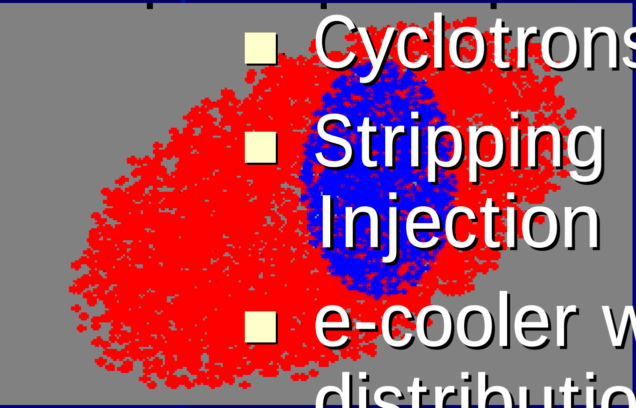
	CSRm	CSRe
Length	161.0m	128.8m
Ion species	Carbon~Uranium	Carbon~Uranium
Magnet rigidity	0.7~11.5Tm	0.6~9.4Tm
Acceptance		Normal mode
ε_x (π mm-mrad)	200($\Delta P/P = \pm 0.15$ %) 50($\Delta P/P = 1.25\%$)	150($\Delta P/P = \pm 0.5\%$) 10($\Delta P/P = \pm 1.3\%$)
ε_y (π mm-mrad)	30	75
Tunes	3.63/2.62	2.53/2.58
e-Cooler	2-35kV (3-50MeV/u)	50-300kV (70-420MeV/u)
Vacuum Pressure	$<6\times10^{-11}$mbar	$<6\times10^{-11}$mbar
RF cavity	0.24~1.7MHz / 7kV	0.5~2MHz / 2×10kV
Injection	Multi-turn / Charge exchange	Single turn
Extraction	Fast / Slow (RF KO)	-

Major Parameters of CSR Operation

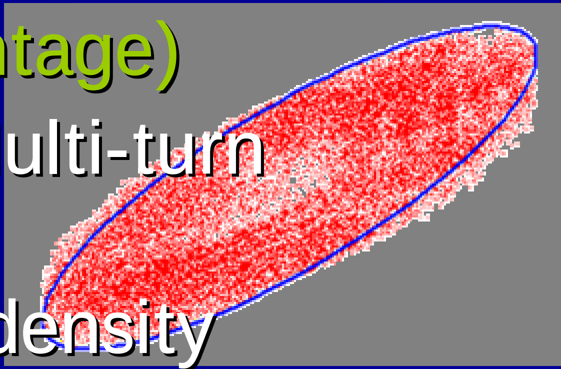
Beam	$^{12}C^{6+}$	$^{36}Ar^{18+}$	$^{78}Kr^{28+}$	Xe^{27+}
Injector	SFC	SFC+SSC	SFC	SFC
Accumulation Scheme	Charge exchange	Multi-turn	Multi-turn	Multi-turn
Energy (MeV/u)	150~300 / 600	368~500	300~500	197~ 235
Extraction Scheme	Slow Fast extraction	Fast ext.	Fast ext.	Fast ext.
Intensity (ppp)	$2\times10^8/7\times10^9$	4×10^8	2×10^8	1×10^8
Exp. Terminal	Cancer Therapy Neutron Wall	CSRm CSRe mass spect.	CSRe mass spect.	CSRe internal target

Key points of HIRFL-CSR

CSRm



- Cyclotrons as injector (disadvantage)
- Stripping Injection + Multiple Multi-turn Injection
- e-cooler with variable electron density distribution
- Low energy injection (multi-Hs acc.)
- Slow / fast extraction
- Virtual Machine and energy stepping



Key points of HIRFL-CSR

RIBLL2 & CSRe

- RIBLL2 as fragment separator and transfer line
- Isochronous mode Mass spectrometer
- Shottky Mass spectrometer later
- Internal target / electron target

OPERATION WITH SLOWLY EXTRACTED BEAM

- Basic Design and Performance
- Beam Spot and Improvement
- Single-time Stripping Injection
- Conformal Ion Beam Treatment
- Neutron-Wall Experiment

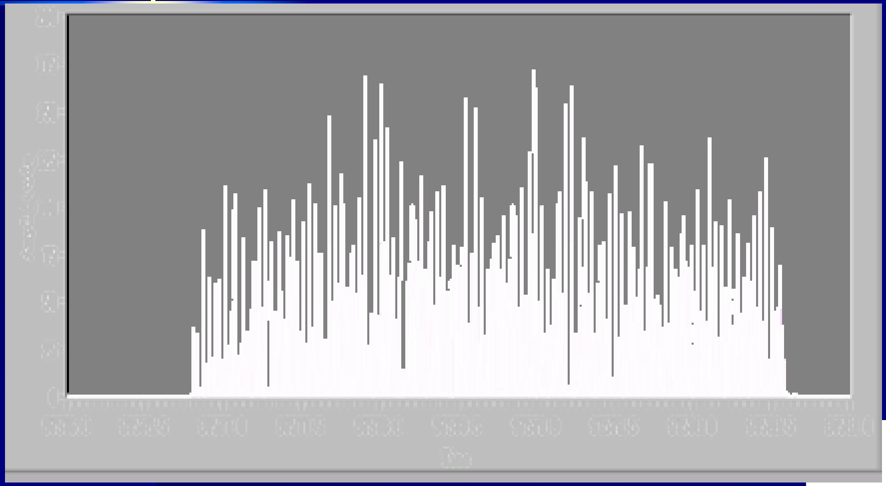
Basic Design

- 1/3 integer resonance
- Chromaticity corrected to 0(?)
- Excited by RF Knock-out method (~100V/cm)
- Stable area before extraction ~13π mm mrad.

Performance

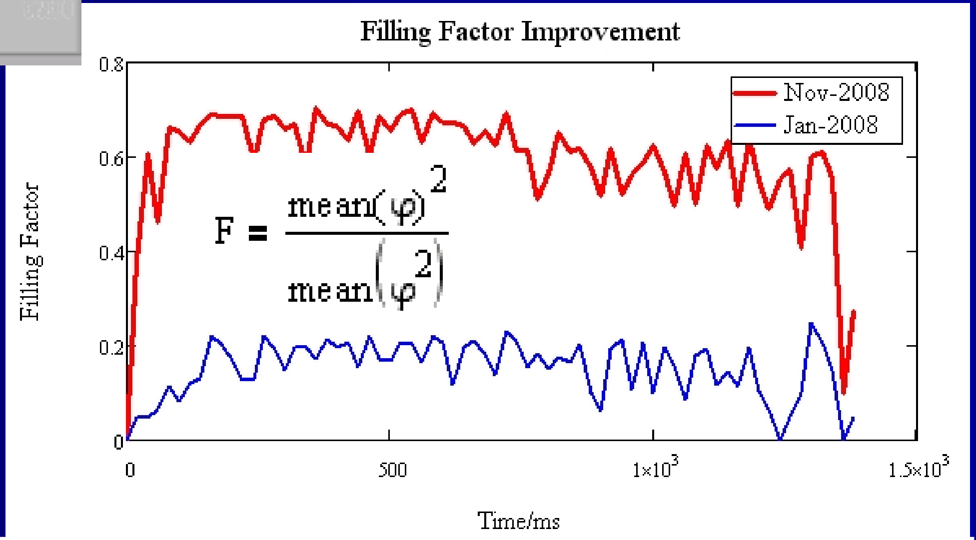
- RF-KO strength is modulated to make rectangular spill
- 3s spill length on 5s flattop for stable position←PS overshoot.
- Main frequency of spill is 50Hz ←PS ripple, filling factor~0.6. A feedback system *is* being developed to fix it.
- Extraction efficiency normally ~15%, recently ~60%

Performance



Spill Structure

Filling Factor

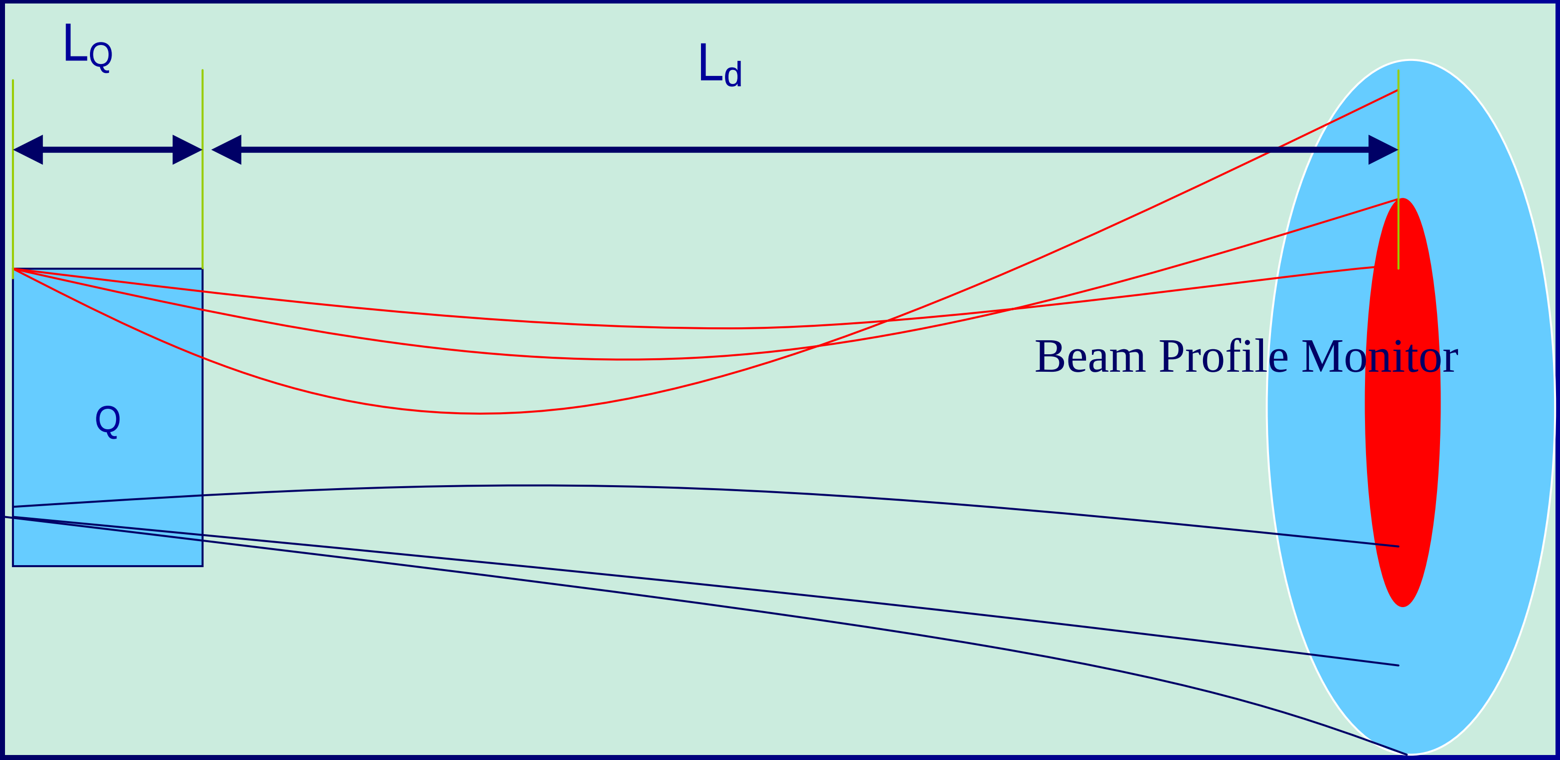


Beam Spot and Improvement

- FWHM of beam spot is usually ~20mm
- Dispersion contributes lot to spot size
- Multi-Gradients method is being introduced to measure the beam parameters (ε, β, α, D, dp/p) → direct the commissioning to get higher efficiency and small spot size.

Multi-Gradients Method

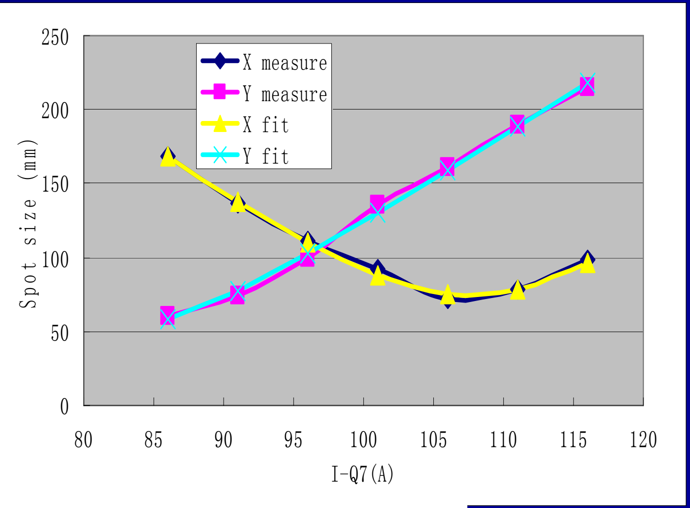
Layout

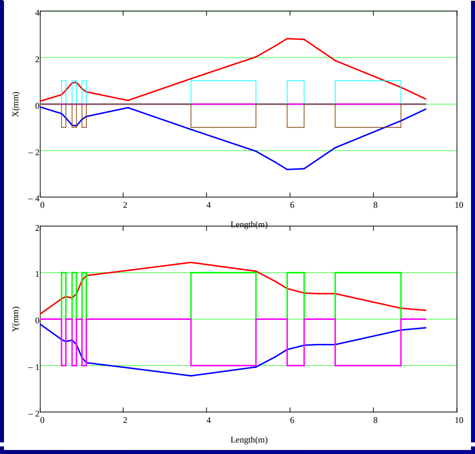


Multi-Gradient Method

Procedure

- Get spot sizes for both directions with different strength of Q
- Fit K~FWHM curves to get the beam parameters (ε, β, α, D, dp/p)
- Reconstruction the beam profile along the transfer line
- Optimize the beam line



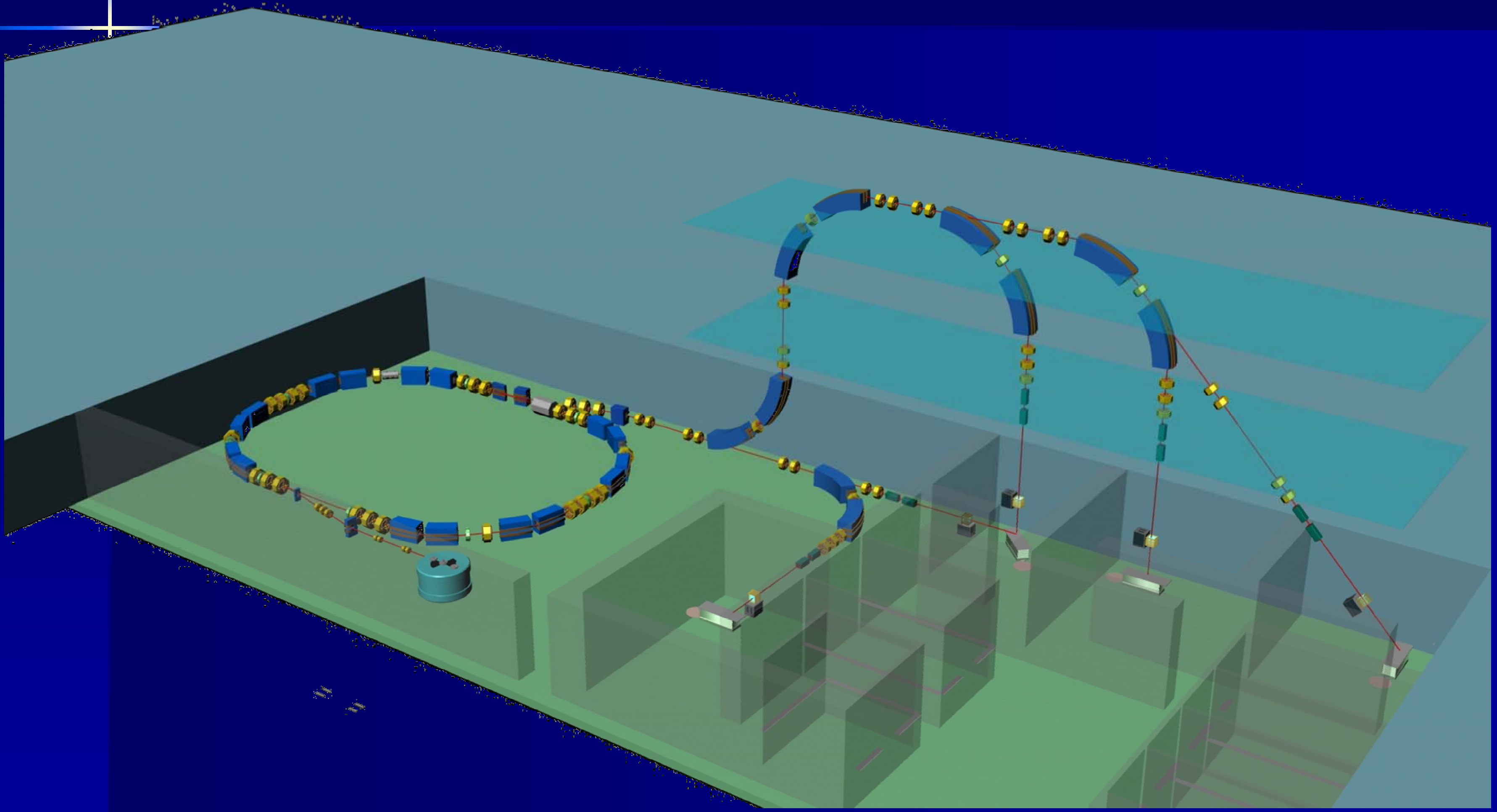


Single-time Stripping Injection

- For each machine cycle, beam injection time ~1ms
- Beam injected into RF bucket with certain area during the adiabatic capture procedure
- no electron cooling
- Gain factor is about 50, >10^9 carbon particles injected with beam intensity 2pμA from SFC(7MeV/u)
- possibility of using cyclotron as injector of cancer therapy machine HITFiL

HITFiL

Heavy Ion Therapy Facility in Lanzhou



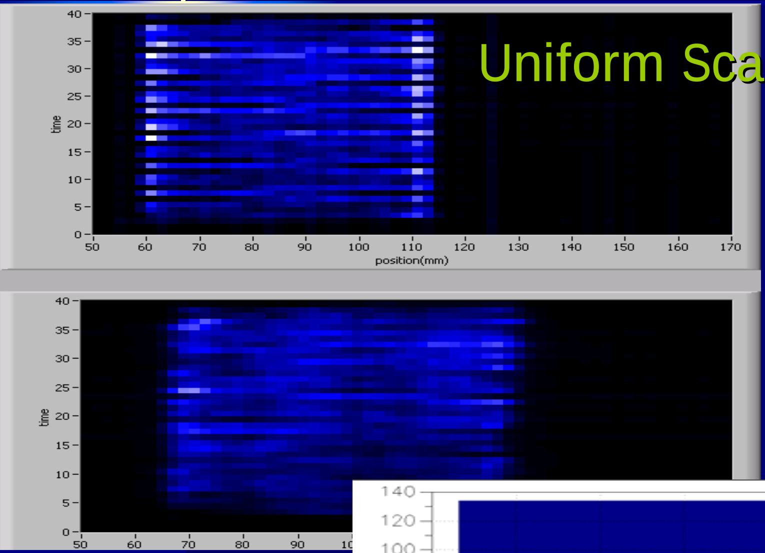
Conformal Ion Beam Treatment

- Two batches including 8 patients were treated
  - Depth 3 ~ 10cm
  - Passive energy variation longitudinally and uniform scanning transversely, usually
- The active energy variation and c technologies are developed and being tested.
  - 255 steps
  - Energy range of 100~430MeV/u (2cm to 34cm)
- The hysteresis effect of magnet field influenced the injection field level (~1%) and efficiency with larger energy step

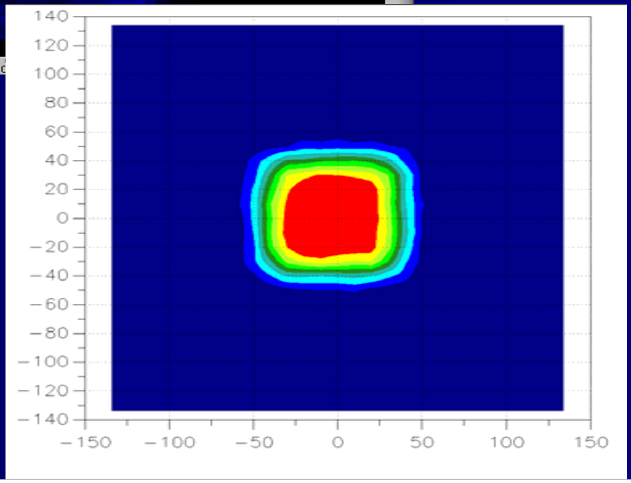
Conformal Ion Beam Treatment

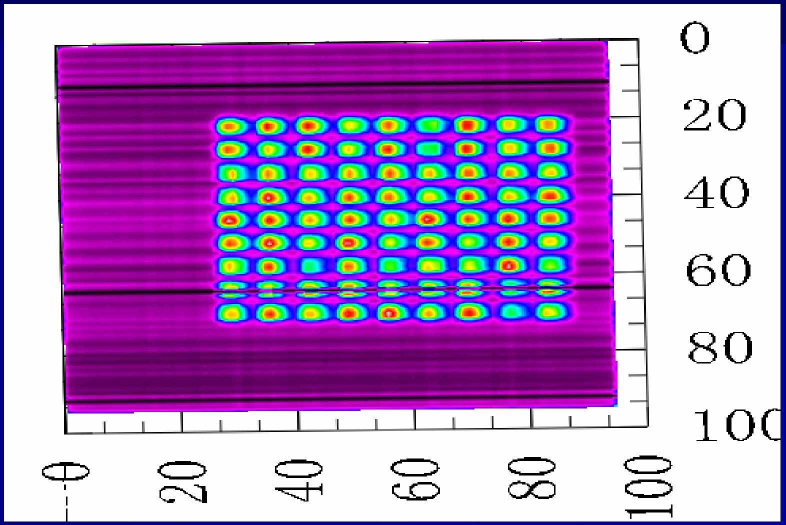
- Good position precision (<1mm) and dose distribution (>80%)
- Online dose distribution monitor using 2 sets of slitting ionization chambers (2mm resolution) for both horizontal and vertical direction was built up.

Conformal Ion Beam Treatment

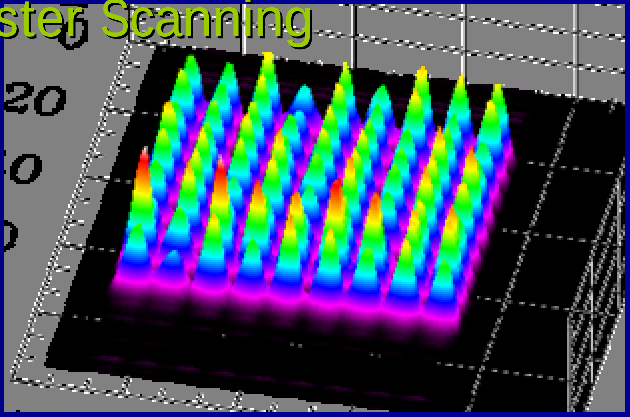


Uniform Scanning



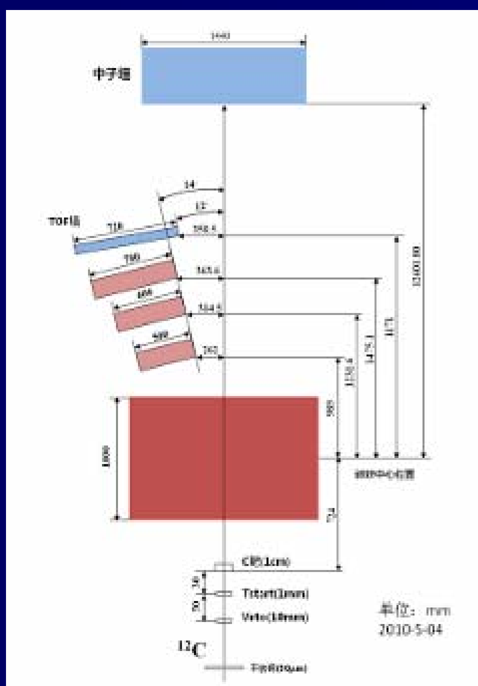


Raster Scanning

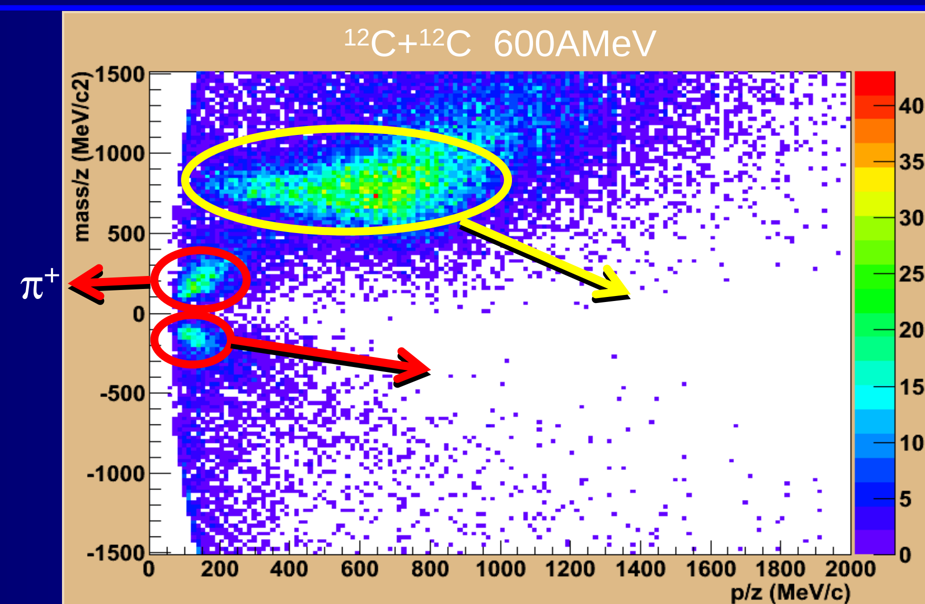


Neutron-Wall Experiment

600, 400 and 200AMeV ^{12}C



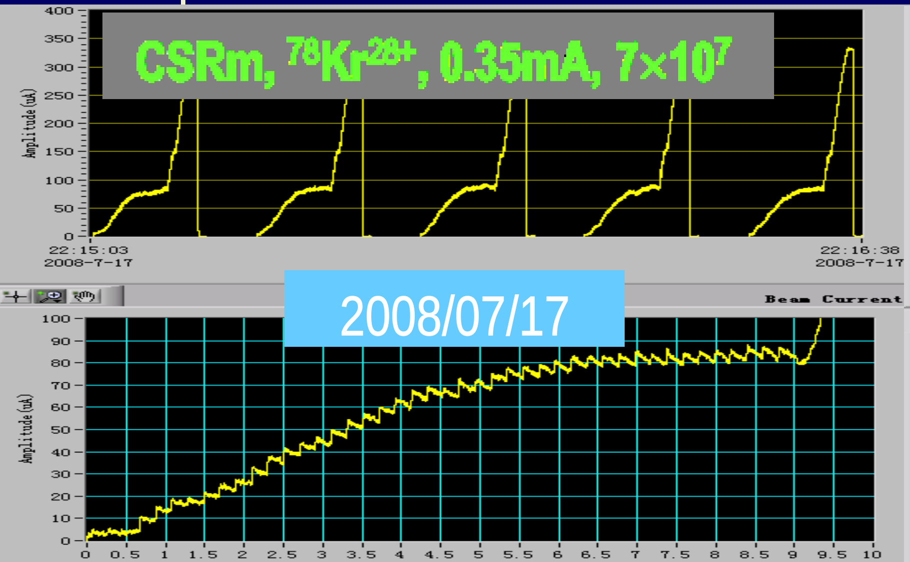
The detectors works well.
The production rate of π+ and π- verified theoretical calculation.

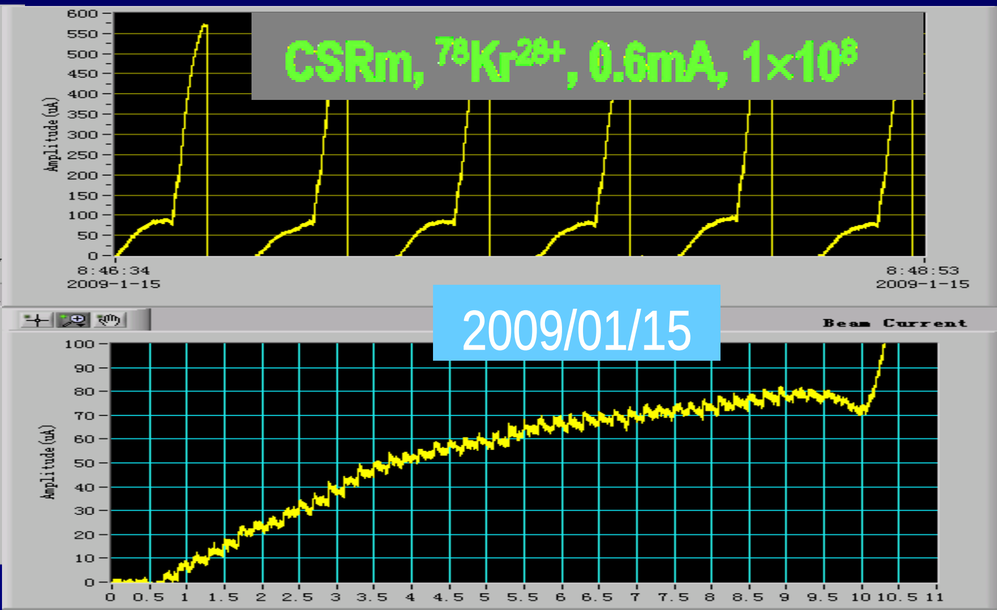


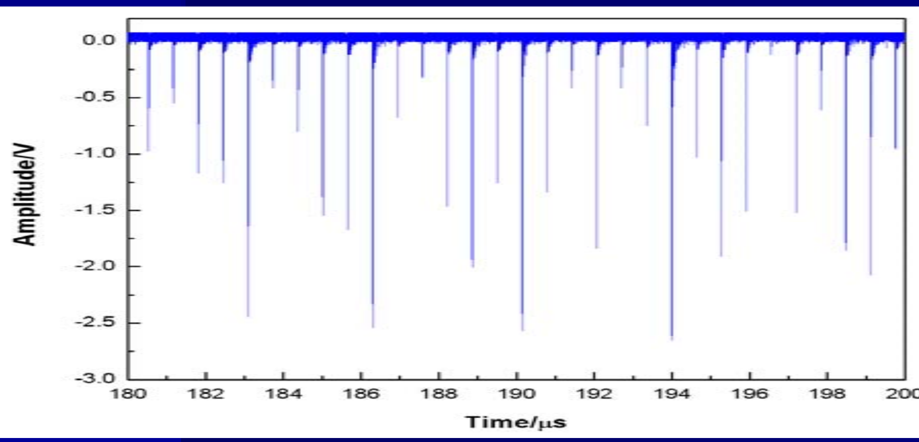
OPERATION OF CSRE MASS SPECTROMETER

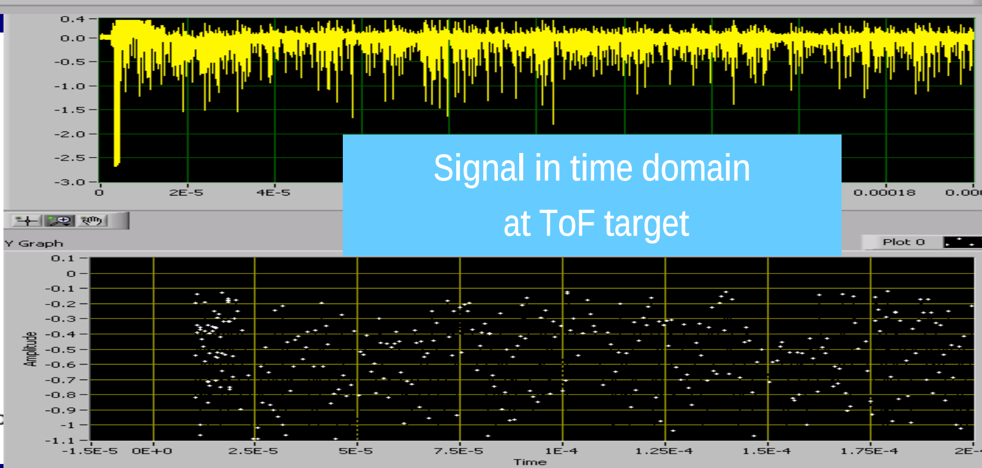
- Mass measurement with 78Kr
- Isochronous mode study

Mass Measurement with 78Kr









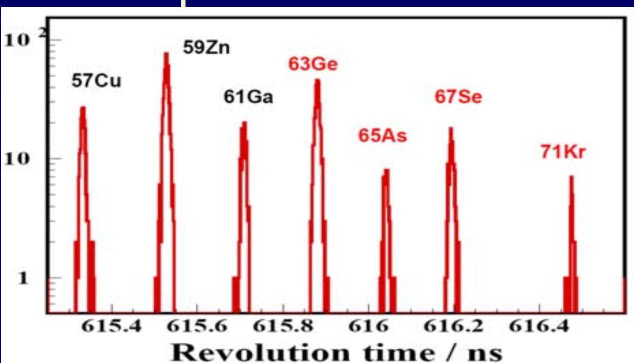
Results of the RIBs mass-measurements

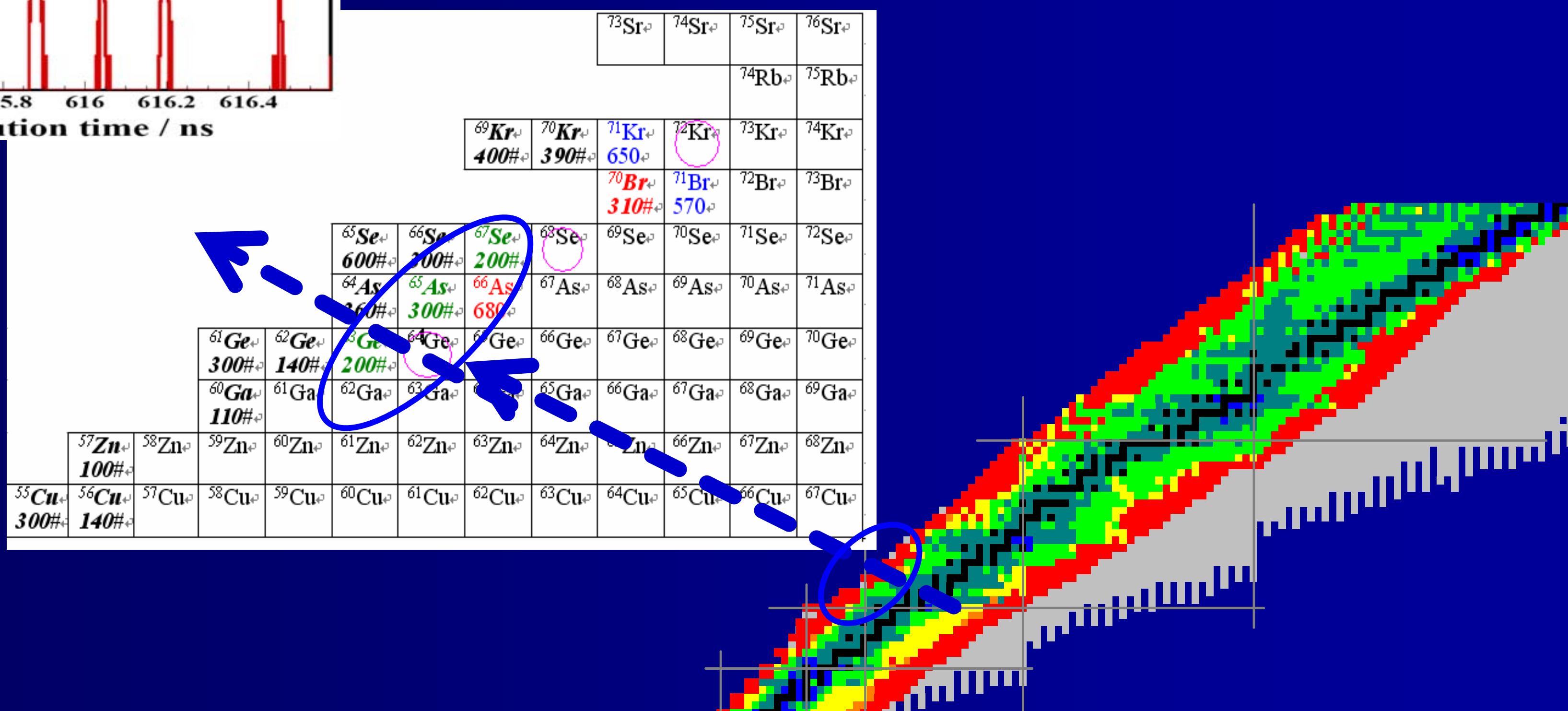
For the 9 drop-line nuclei with the life-time of 100ms

A=2Z-1: ^{63}Ge、^{65}As、^{67}Se、^{71}Kr

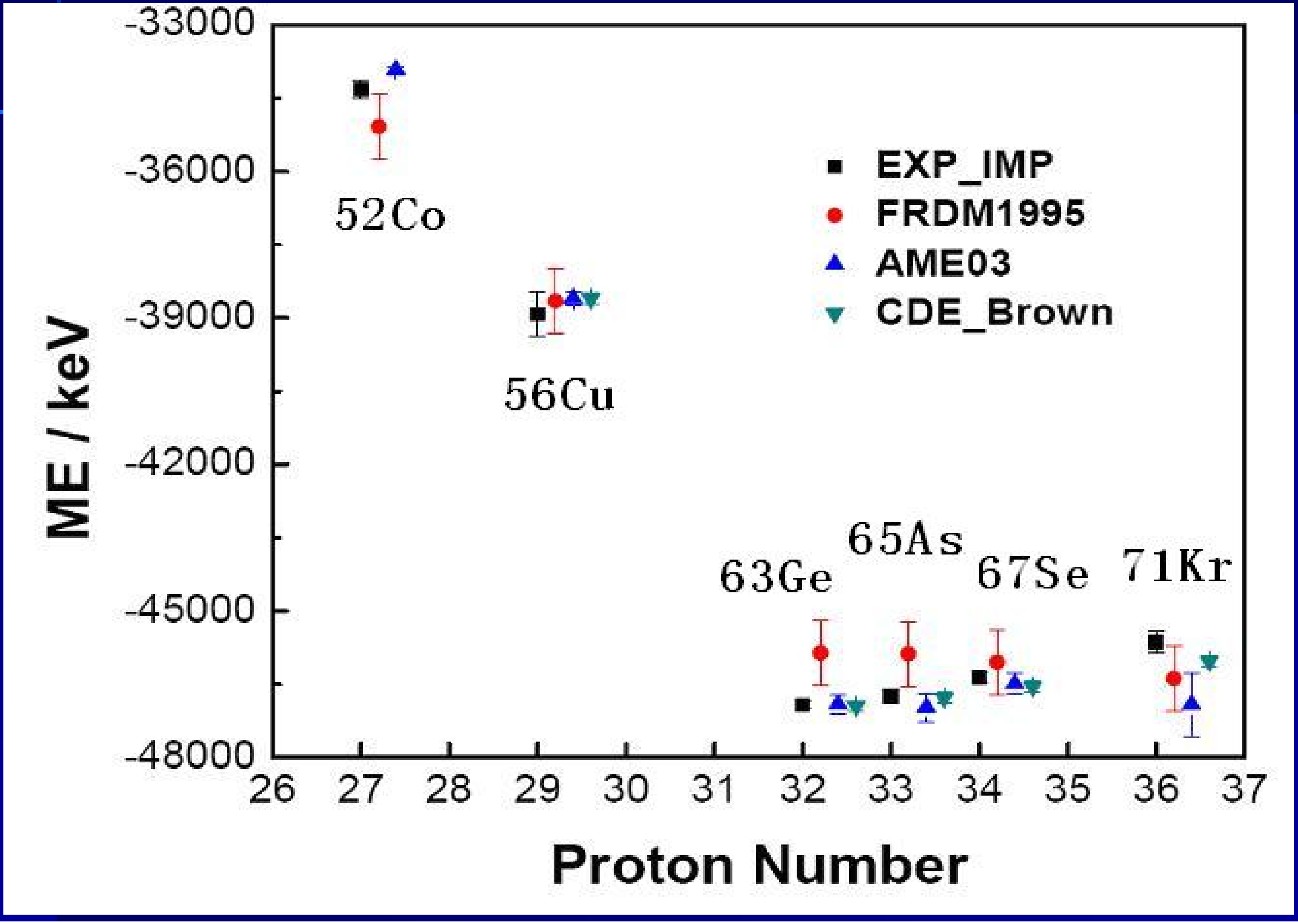
A=2Z-2: ^{56}Cu、^{52}Co

A=2Z-3: ^{43}V、^{49}Fe、^{53}Ni





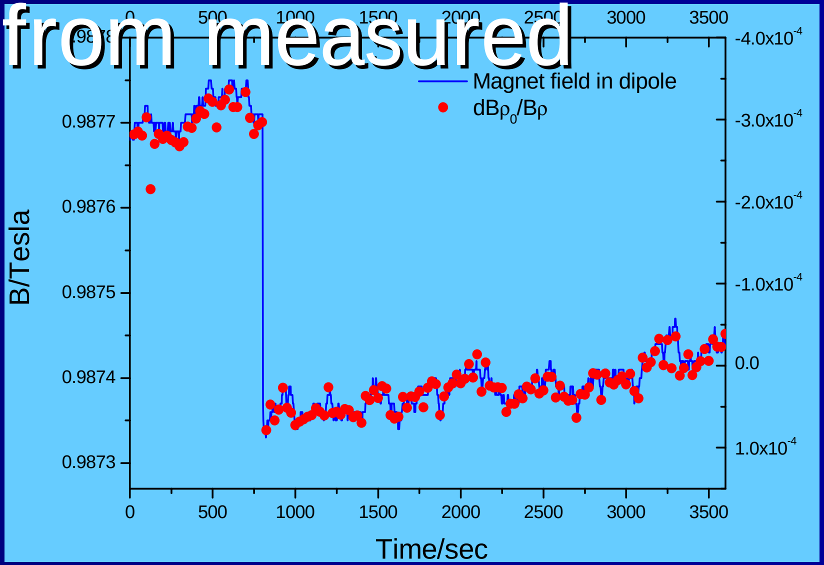
Mass Resolution ΔM/M: $3 \times 10^{-6} \sim 1 \times 10^{-7}$



Isochronous Mode Study

$$\frac{df}{f} = -\frac{dT}{T} = \eta\frac{dB\rho}{B\rho} = \left(\frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^{\ 2}}\right)\frac{dB\rho_1}{B\rho} + \left(\frac{1}{\gamma^2}\right)\frac{dB\rho_0}{B\rho}$$

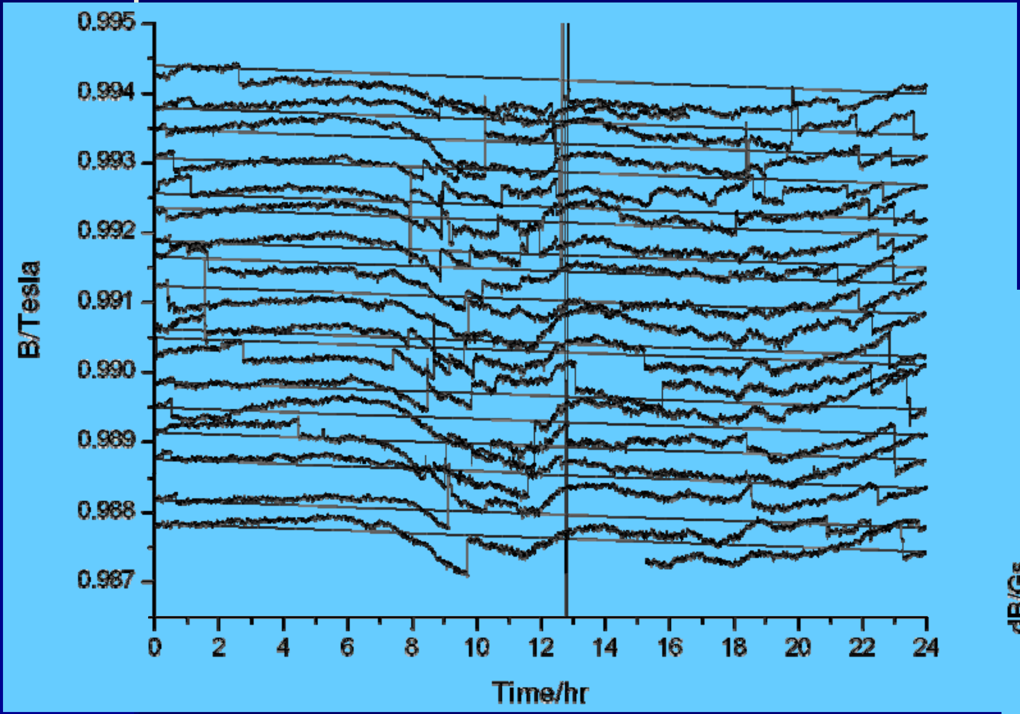
- Influence of magnet field drift on the period found out from measured spectrum of time



Coherence of magnet field drift and the rigidity of center orbit

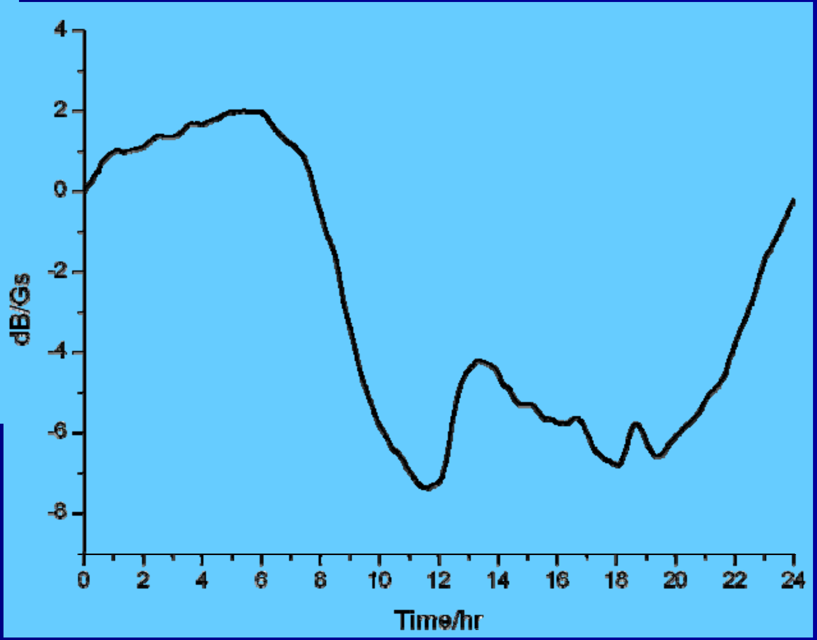
Isochronous Mode Study

Magnet field drift in dipoles



Water fall plot of magnet field in 15 days

Periodicity from midnight to midnight

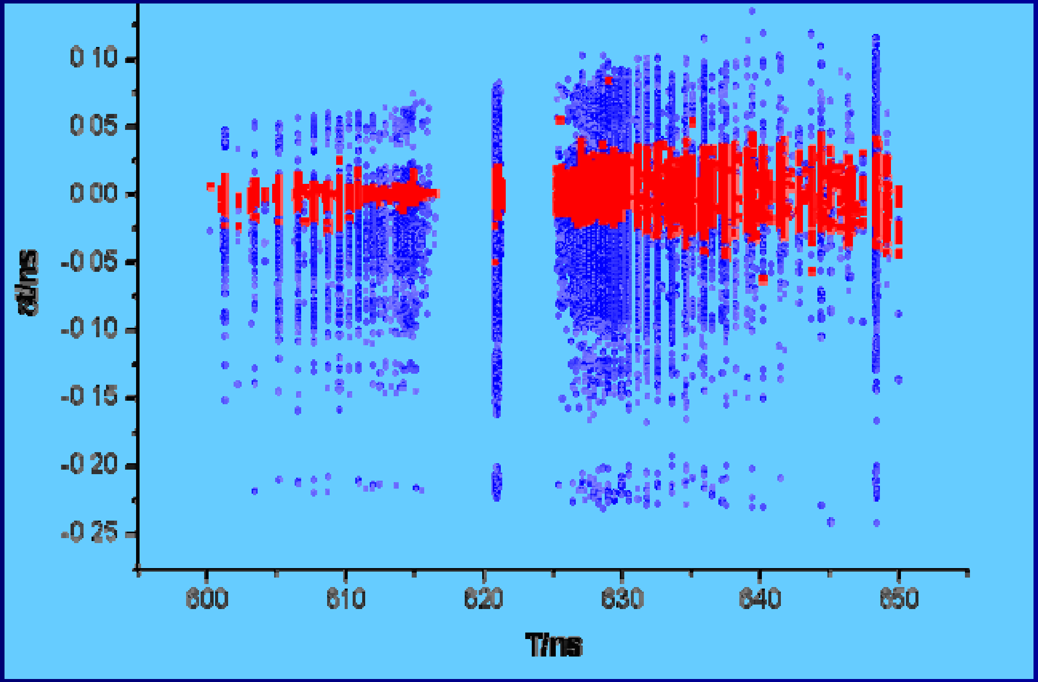


Isochronous Mode Study

Systematic error correction

- The system error induced by magnet field drift can be corrected!

Data of the measured periods in 9 hrs(blue) and
the distribution after reconstruction (red).



Isochronous Mode Study

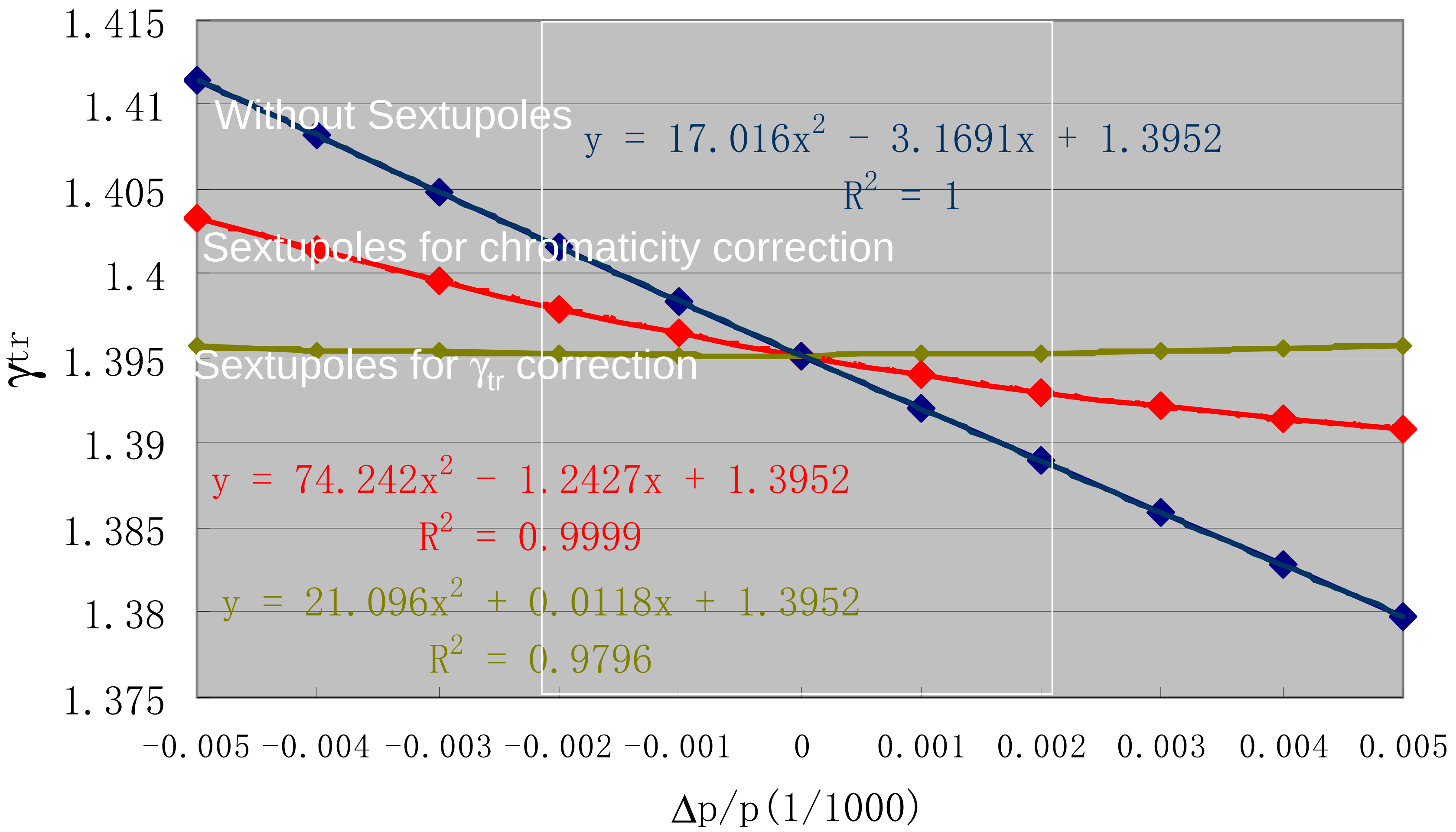
Momentum dependence of transition energy

- The γ_{tr} is depend on momentum of particles without nonlinear correction

The dependence of γ_{tr} on momentum offset at different conditions

Isochronous Mode Study

Momentum dependence of transition energy



Isochronous Mode Study

Momentum dependence of transition energy

- The time resolution of target nuclei can be improved by ~100 times with nonlinear correction

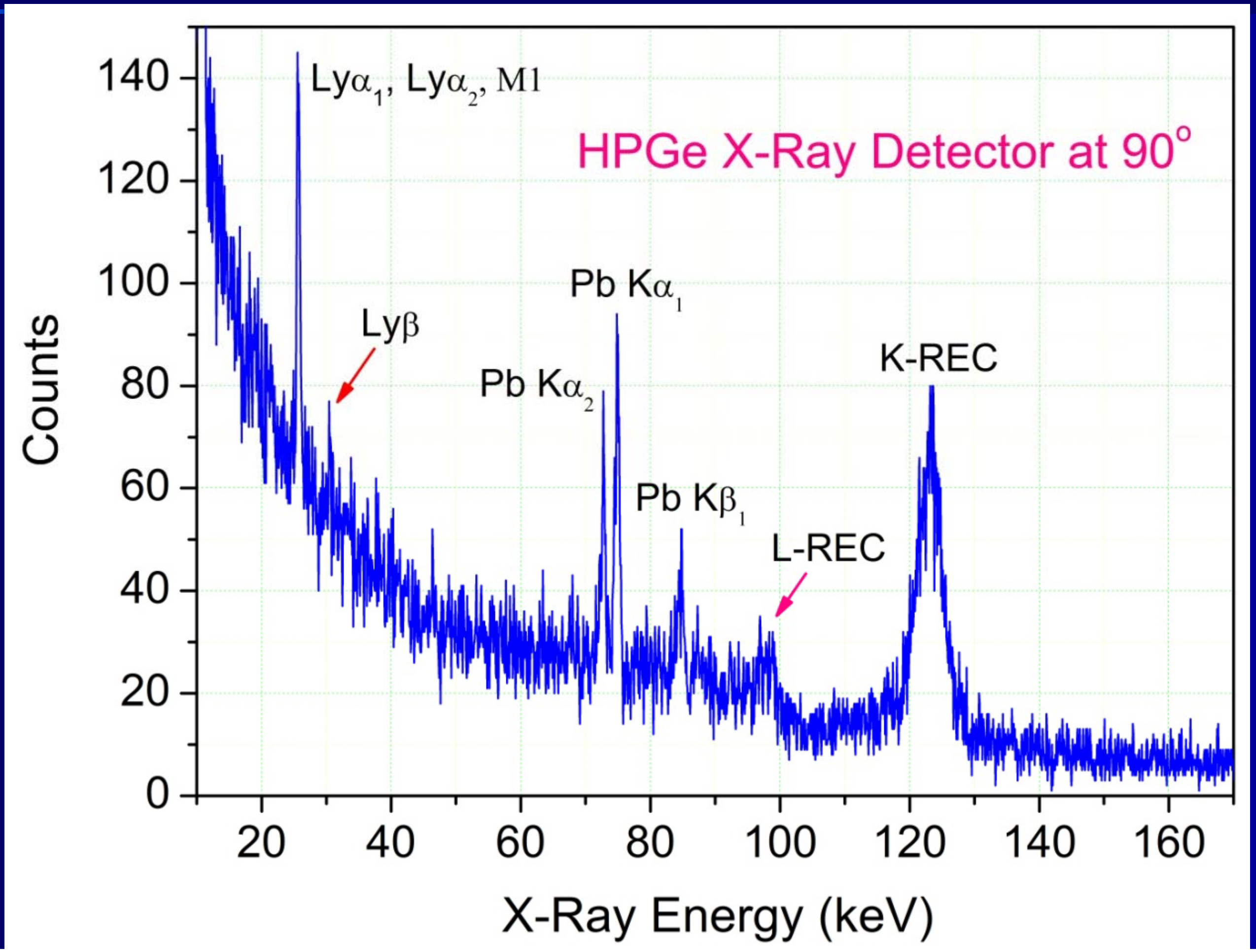
With / out Sextupoles

	SF/SD (10^{-9})	$\gamma_{tr}(\delta p/p)$	Xi_h/Xi_v	$(\Delta\gamma_{tr}/\gamma_{tr0})$ $(\Delta p/p=0.4\%)$
1	0 0	17.016x2 - 3.1691x + 1.3952	-0.8773 -1.1064	0.009
2	-32.6 78.3	$74.242x^2$ - 1.2427x + 1.3952	-0.0562 -0.0089	0.0036
3	-5.9 0	23.544x2 - 0.1264x + 1.3952	0.2363 -1.3437	0.00036
4	-5.9 -0.7	22.523x2 + 0.0118x + 1.3952	0.284 -1.3652	0.000077

OPERATION OF ELECTRON COOLER AND EXPERIMENTS OF ATOMIC PHYSICS

E-Cooler and Atomic Physics

- Both e-coolers work well, except for
  - Vertical positioning are difficult
  - 250kV to 300kV for e-cooler in CSRe
- Upgrading of control system for experiments of atomic physics→ fast e-energy shifting
- Test experiments with electron beam and internal gas-jet target


Lyα1, Lyα2, M1
HPGe X-Ray Detector at 90°
Lyβ
Pb Kα1
Pb Kα2
K-REC
Pb Kβ1
L-REC
Counts
0
20
40
60
80
100
120
140
160
X-Ray Energy (keV)

THE INJECTOR COMPLEX

– Major Tasks
– SSC efficiency study
– New Injector for SSC

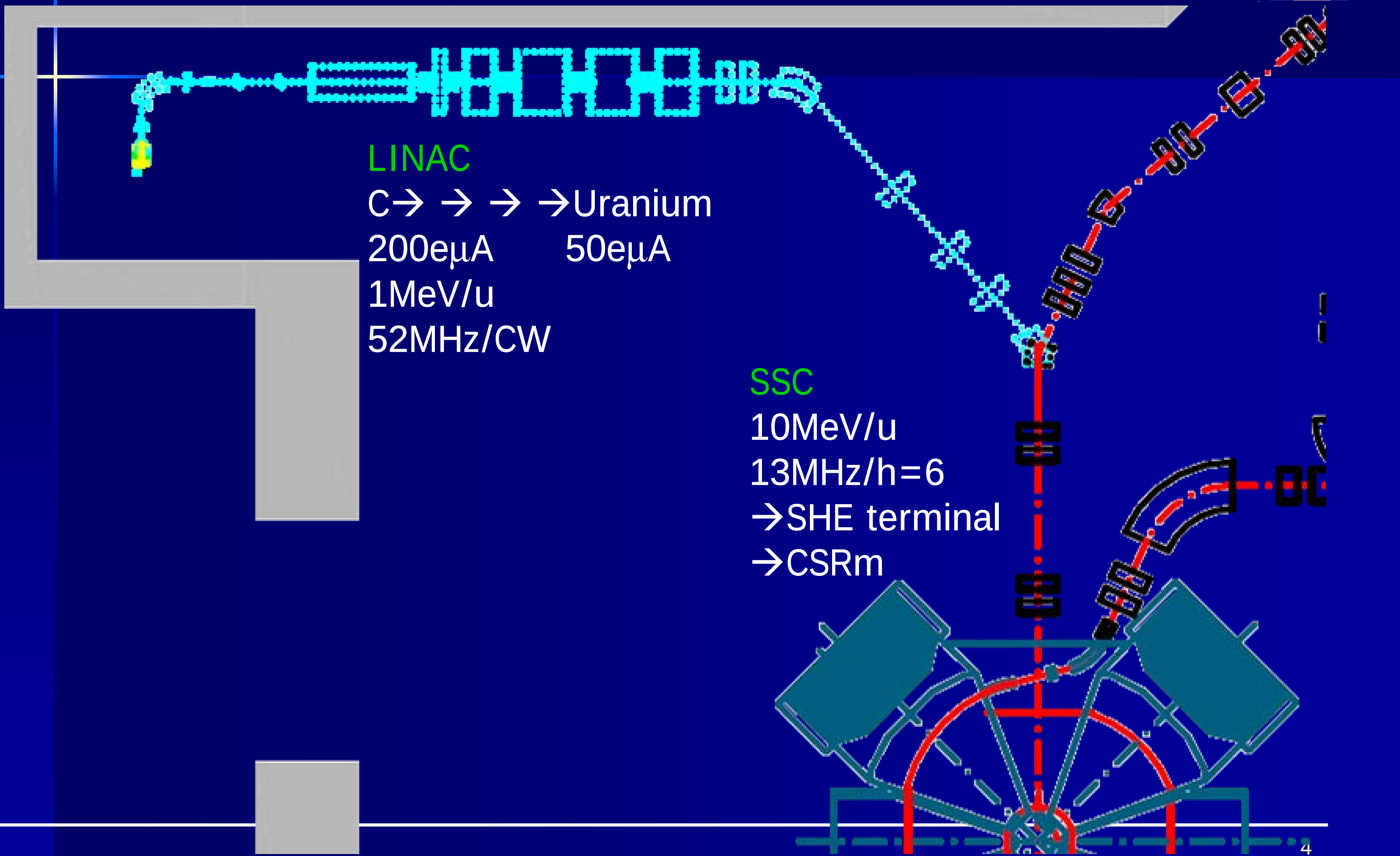
Major Tasks

- Increase the beam intensity of cyclotron complex especially for the heavy ions
- Improve of the overall performance → stability, efficient operation, time sharing

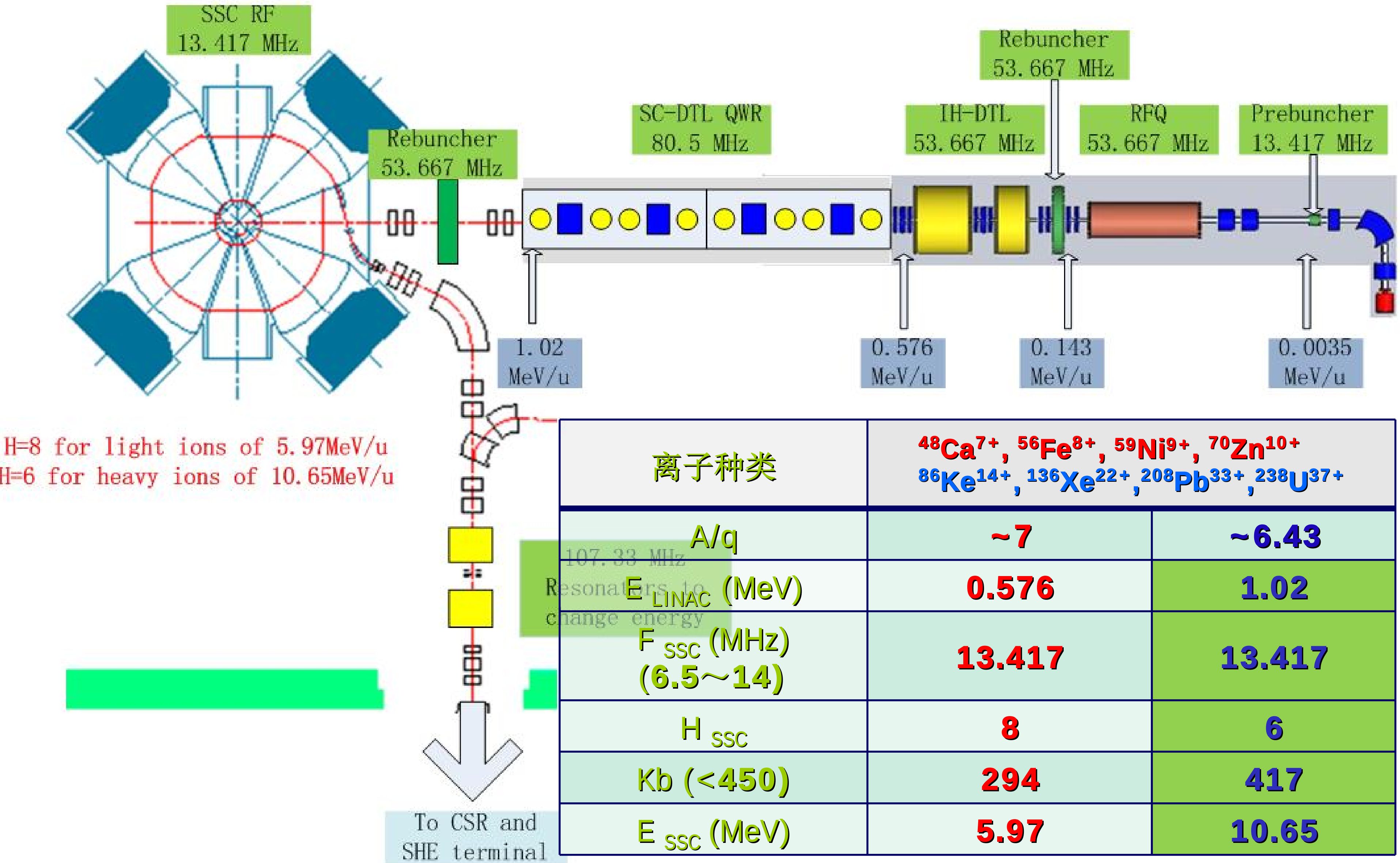
SSC efficiency study

- Urgent need for heavy ions with higher intensity and charge state to be injected into CSRm(~1emA for 238U72+ for example)
- Full path particle tracking with measured magnet field distribution
- Upgrading of the injection and extraction tunnel
- Important for the new injector SSC-LINAC

New Injector for SSC



New Design of SSC-LINAC



离子种类	$^{48}Ca^{7+}$, $^{56}Fe^{8+}$, $^{59}Ni^{9+}$, $^{70}Zn^{10+}$	$^{86}Ke^{14+}$, $^{136}Xe^{22+}$, $^{208}Pb^{33+}$, $^{238}U^{37+}$
A/q	~7	~6.43
E_{LINAC} (MeV)	0.576	1.02
F_{SSC} (MHz) (6.5～14)	13.417	13.417
H_{SSC}	8	6
Kb (<450)	294	417
E_{SSC} (MeV)	5.97	10.65

OTHER ASPECTS

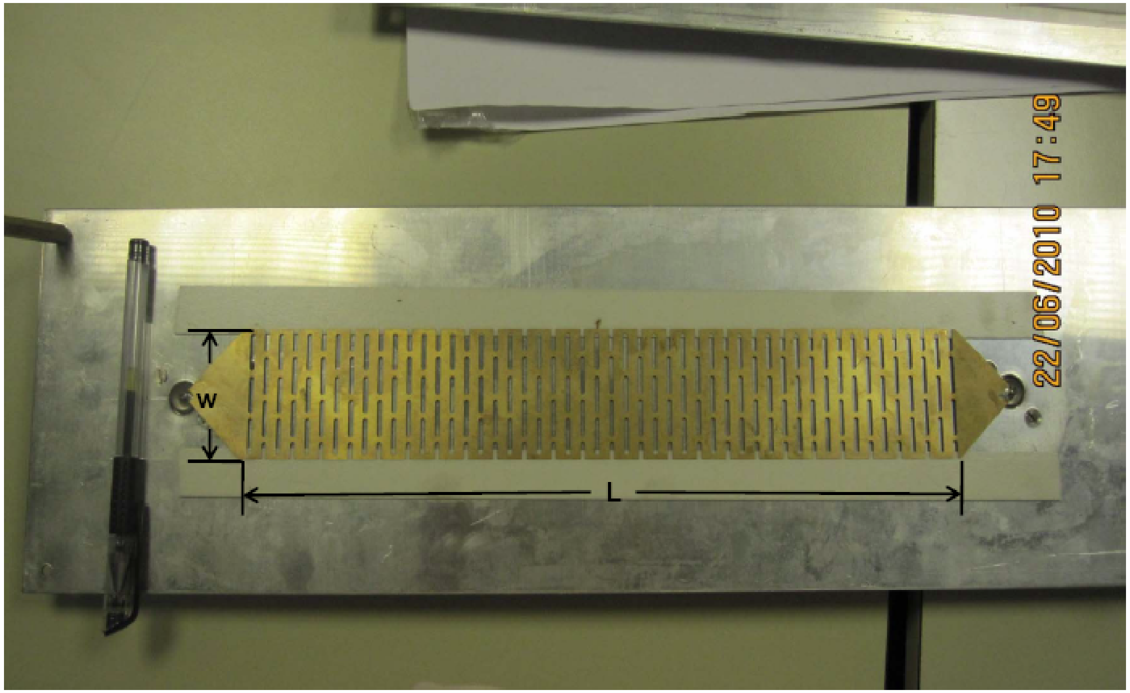
- Stochastic Cooling in CSRe
- Molecular Ions Research Facility

Stochastic Cooling in CSRe

- Cooperation with GSI, CERN and T. Katayama
- Project proposed to CAS (3 yrs)
- A new lattice is designed to reduce the flipper factor η to about 0.2
- Cooling time is estimated ~4s / 10^7ppp
- Energy range 300~500MeV/u

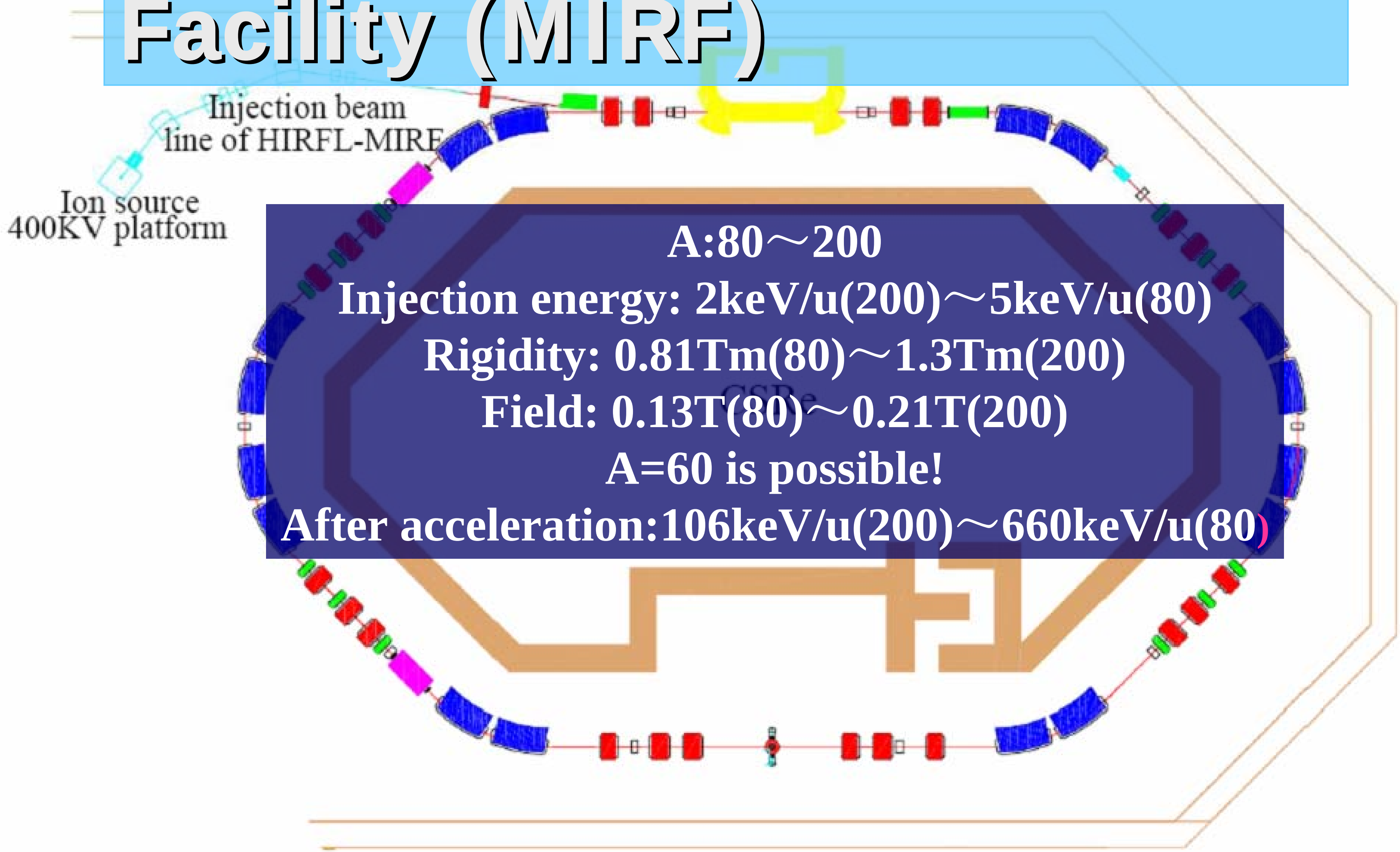
Possible pickup electrode

Fritz's slot type electrode



Slot type
The width W is about 53 mm
and the length L is the total length of 25 periods about 300 mm.

Molecular Ions Research Facility (MIRF)



A:80～200

Injection energy: 2keV/u(200)～5keV/u(80)

Rigidity: 0.81Tm(80)～1.3Tm(200)

Field: 0.13T(80)～0.21T(200)

A=60 is possible!

After acceleration:106keV/u(200)～660keV/u(80)

Other Topics

- Single particle Schottky detector in CSRe, for advanced mass spectrometer
- Barrier bucket stacking in CSRe, for accumulation of secondary beam

Thank You for Your Attention!