Status and Upgrades of HIRFL

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- Status of HIRFL
- Activities of Upgrading
  - SSC-Linac injector
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  - Electron cooling at CSR
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  - Stochastic cooling at CSRe
  - Vacuum collimation at CSRm
- HIAF project

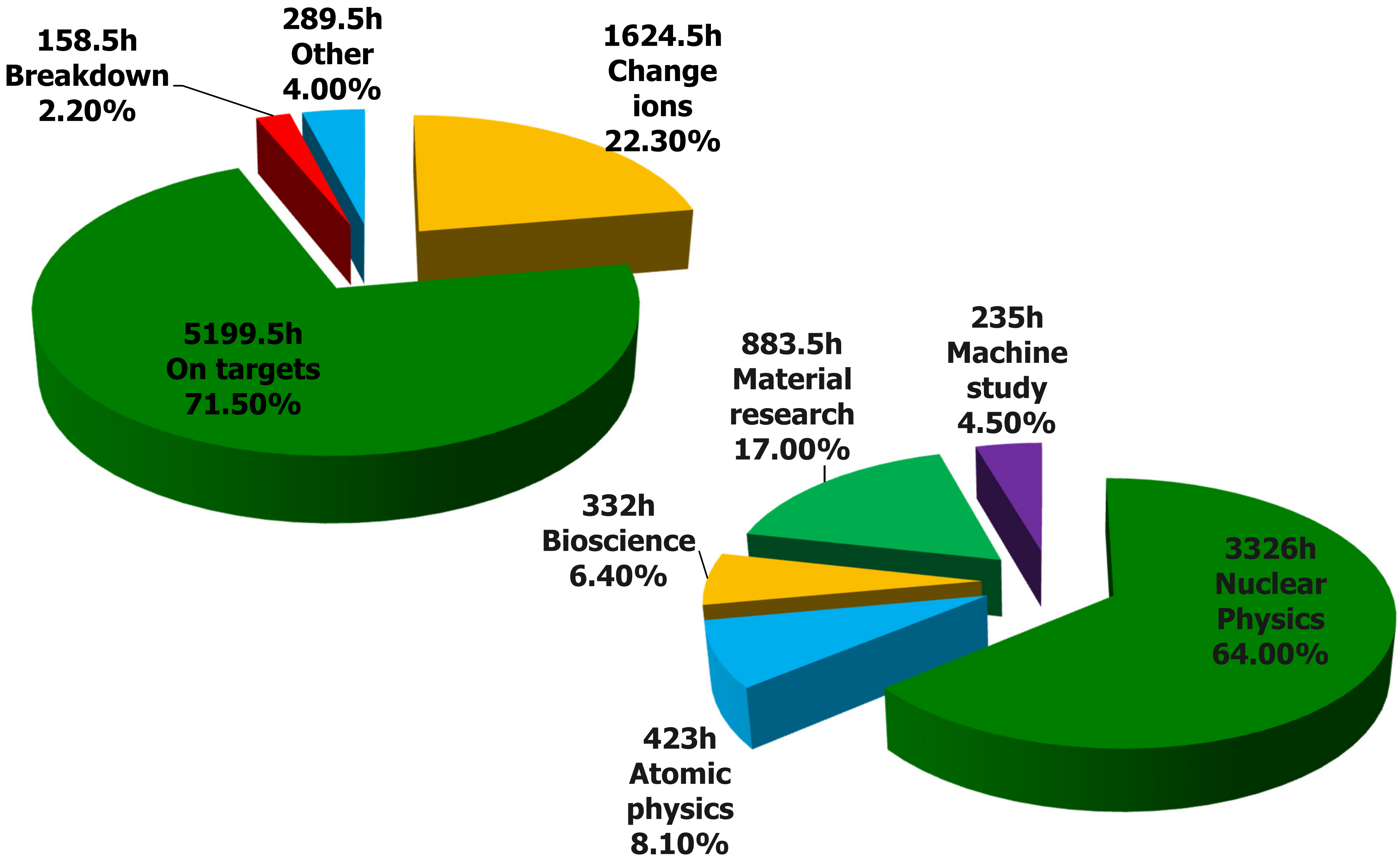
Status of HIRFL: overview

Heavy Ion Research Facility in Lanzhou (HIRFL)

Operation in 2014

No.	SFC			SSC		CSR			
	Ion	Energy MeV/u	Current uA	Energy MeV/u	Current uA	Charge State	Energy MeV/u	Current @ CSRm (uA)	Current @ CSRe (uA)
1	$^{78}Kr^{19+/28+}$	4	4.2				432.5,487	600	Secondary beams
2	H_2^+	10	4				250	30-50	
3	$^{40}Ar^{11+}$	4.8	3. 2						
4	$^{16}O^{6+}$	7	8.5			8+	265,360	600-1000	
5	$^{12}C^{4+/6+}$	7	2.3	80.55	0.17				
6	$^{40}Ar^{12+/17+}$	6.17	5	70	0.45				
7	$^{16}O^{6+/8+}$	6.17	5.9	70	0.45				
8	$^{12}C^{4+/6+}$	5.361	2.8	60	0.24				
9	$^{209}Bi^{31+}$	0.911	0.6	9.5	0.04				
10	$^{58}Ni^{19+/25+}$	6.17	1.2	70	0.07				
11	$^{32}S^{9+}$	3.9	1.7						
12	$^{40}Ar^{9+/15+}$	2.794	3	30	0.05				
13	$^{20}Ne^{7+}$	6.17	3.8						
14	$^{16}O^{6+}$	7.5	2						
15	$^{22}Ne^{8+}$	7.5	2.2						
16	$^{86}Kr^{17+/26+}$	2.345	4.5	25	0.13				
17	$^{12}C^{4+/6+}$	4.906	5	54.5	0. 35				
18	$^{36}Ar^{15+}$	8.5	1.9				8.5	300	
19	$^{14}N^{4+}$	4.5	2.8						
20	$^{40}Ca^{12+}$	5	2						
21	$^{12}C^{3+}$	4.2	5				122.375	270	200
22	$^{12}C^{4+}$	7	10				165， 300	1500	
23	$^{40}Ca^{12+}$	4.825	2						
24	$^{209}Bi^{31+}$	0.911	0.3	9.5	0.01				
25	$^{58}Ni^{19+}$	6.3	1.2				467等多种	280	Secondary beams

Operation in 2014



- **Status of HIRFL**
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  - ***SSC-Linac injector***
  - **Electron cooling at CSR**
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  - **Stochastic cooling at CSRe**
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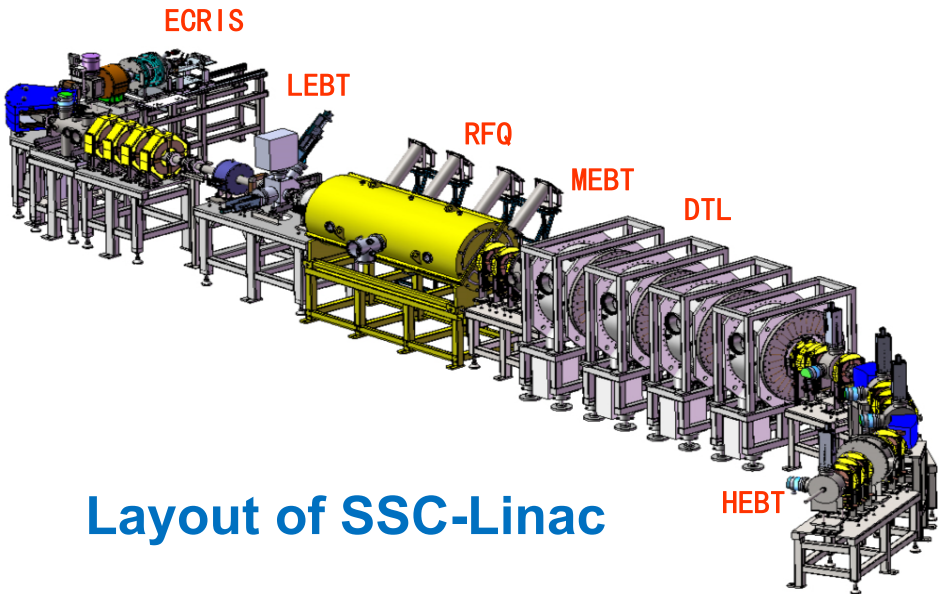
  - **Vacuum collimation at CSRm**
- **HIAF project**

SSC-Linac injector: 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)
- Beam current : 5~30eμA for various ions.
- Beam intensity: increase 1~2 order for SSC.
- $^{238}U^{72+}$ can be accelerated to 487MeV/u by CSRm after stripping.

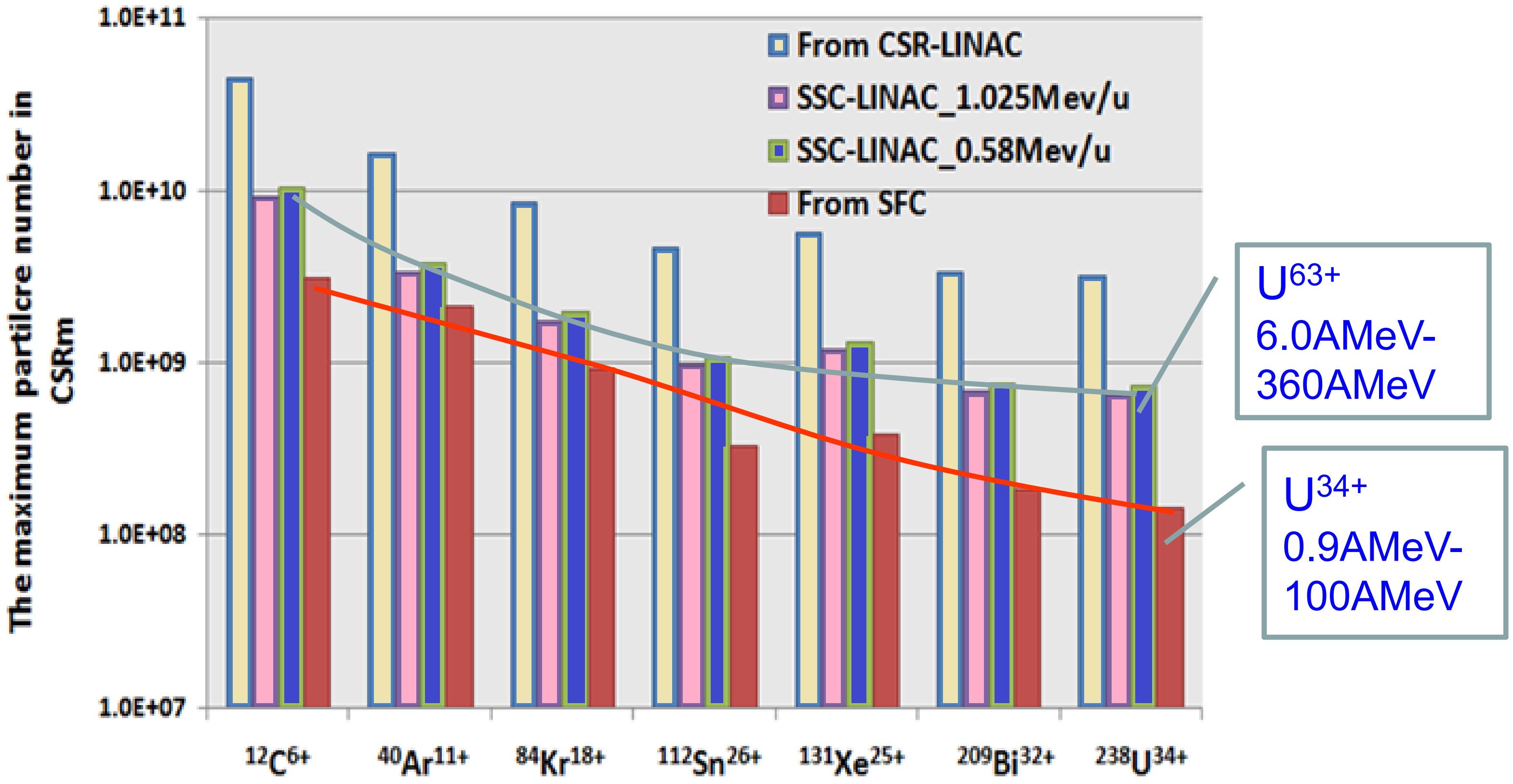


Layout of SSC-Linac

Main parameters of SSC_Linac

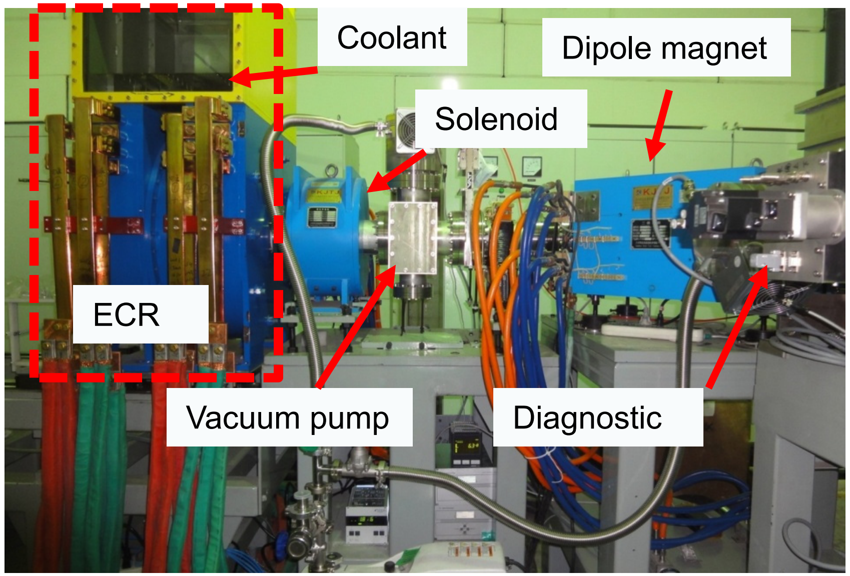
Parameters	Values
Design ion	$^{238}U^{34+}$
ECR ion source	
Extraction voltage	25kV
Max. axial injection field	2.3 T
Microwave frequency	18GHz
RFQ	4-rod
Frequency	53.667MHz
Input energy	3.728keV/u
Output energy	143keV/u
Inter-electrode voltage	70kV
RF power	35kW
Max. current	0.5emA
IH-DTL	KONUS
Frequency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

SSC-Linac injector: Goal

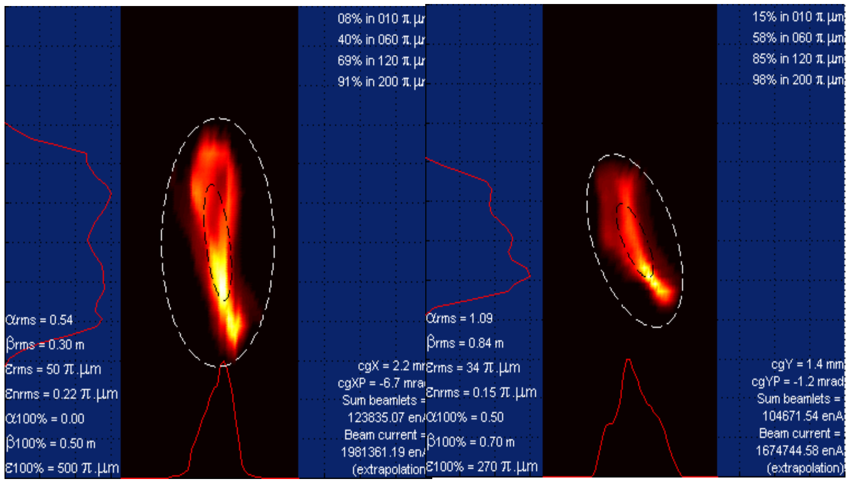


For planned linac injectors, the maximum stored particle numbers in CSRm will be 2 to 5 times the case of the cyclotron injector SFC.

SSC-Linac injector: Ion Source



ECR ion source



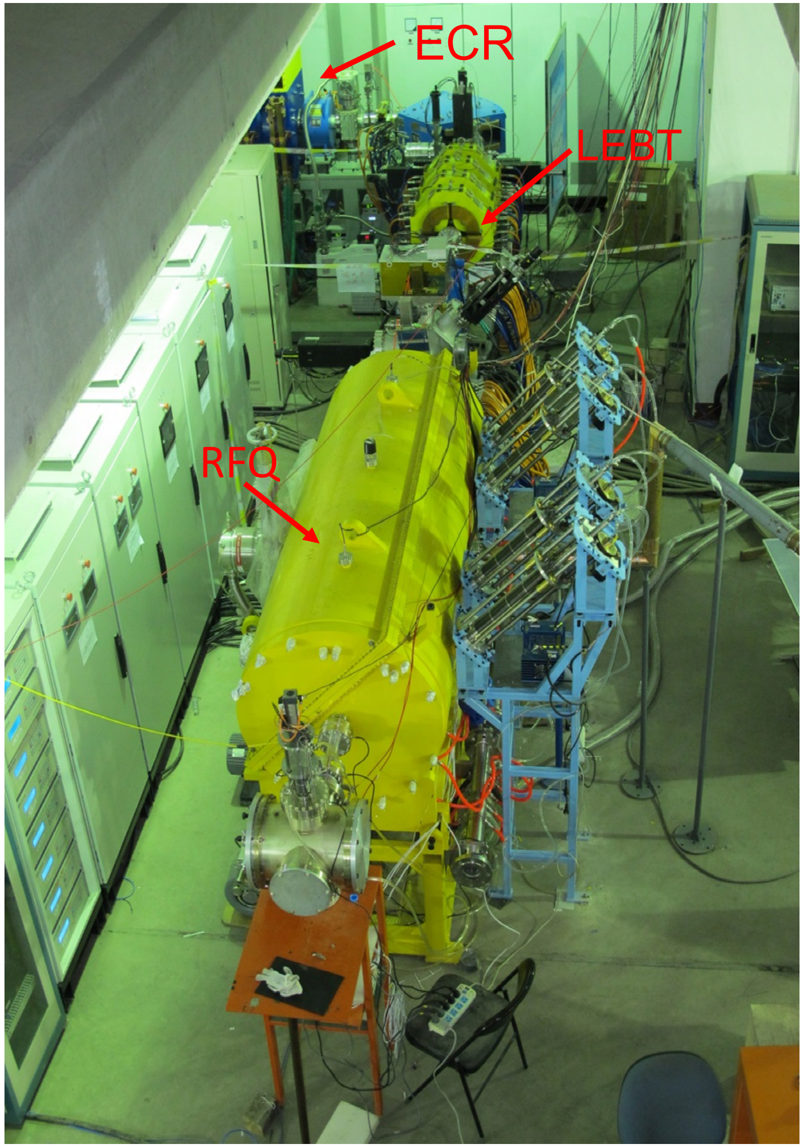
Measured transverse emittance

- High intensity HCI ECR ion source
- Evaporative cooling technology

Beam test results of Ion source

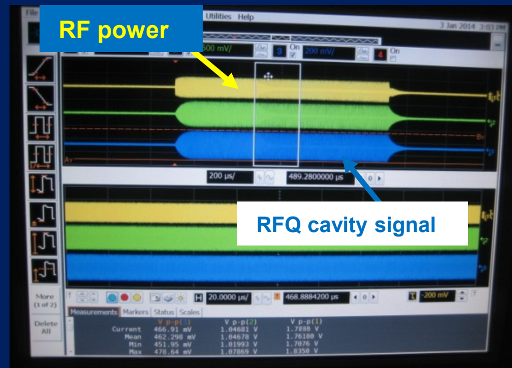
LECR4		
Ion	**charge state**	**I(eμA)**
^{16}O	6^+	2110
	7^+	560
^{40}Ar	8+	1717
	9^+	1230
	14+	185
^{129}Xe	20+	430
	27+	135

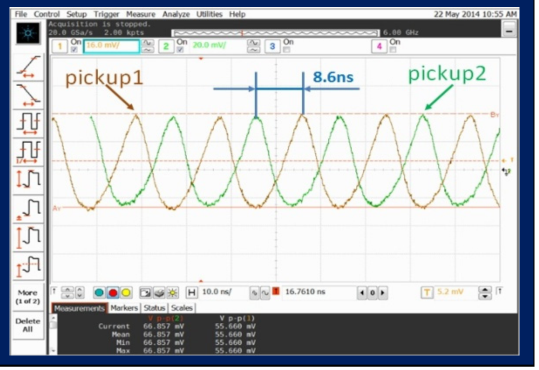
SSC-Linac injector: Layout and front end testing



Front end of SSC-Linac

- 35kW in CW mode has been fed into RFQ successfully.
- $^{40}Ar^{8+}$ ion beam, E=142.8keV/u, I= 198eμA.
- Beam transmission efficiency is 94%.





IH-DTL

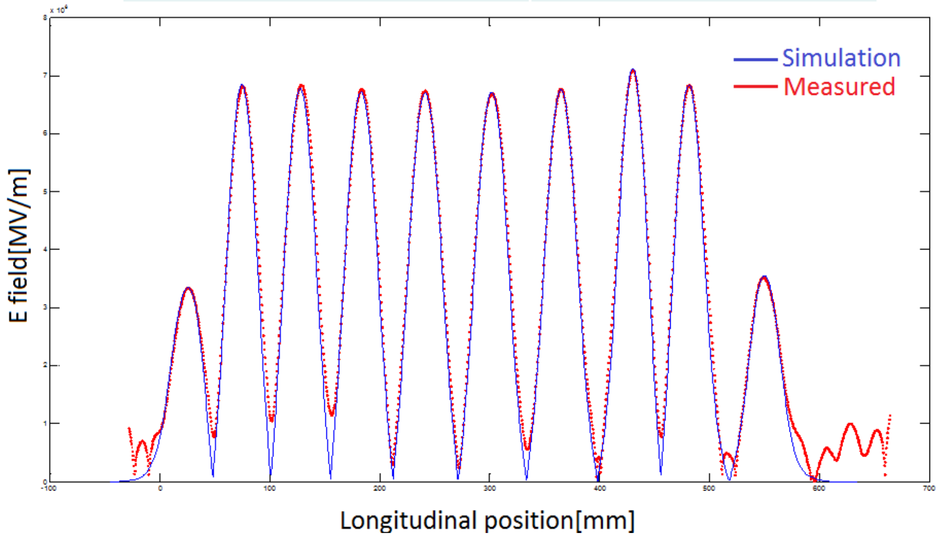
IH-DTL1

RF measured resualts

Frequency[MHz]	53.667
Q0	10200 (Designed 12400)
Fixed tuner[mm]	150
Tuning range[MHz]	1.4
Moveable tuner[mm]	100
Tuning range[kHz]	140
Power[kW]	18.2(Calculated)

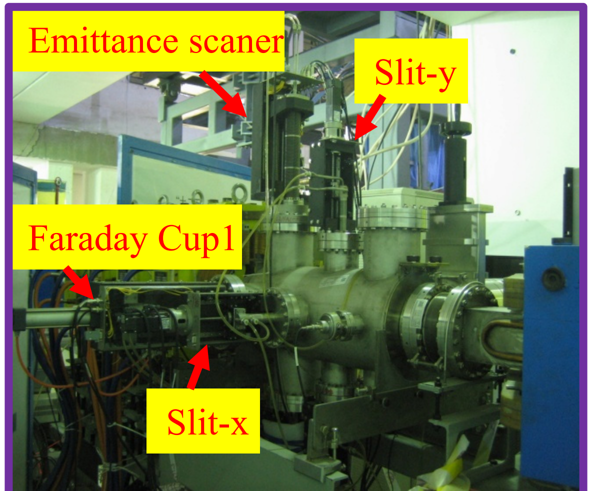
RF coupler

Movable Tuner

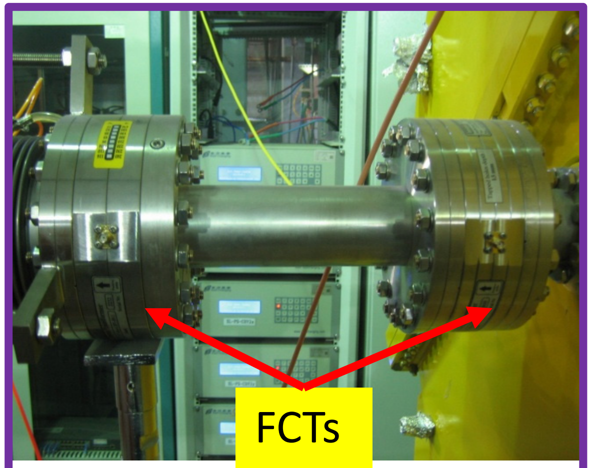


Field distribution along the tank

Beam diagnostic instruments



The transverse emittances are measured by scanners located at the downstream of the analyzing magnet.

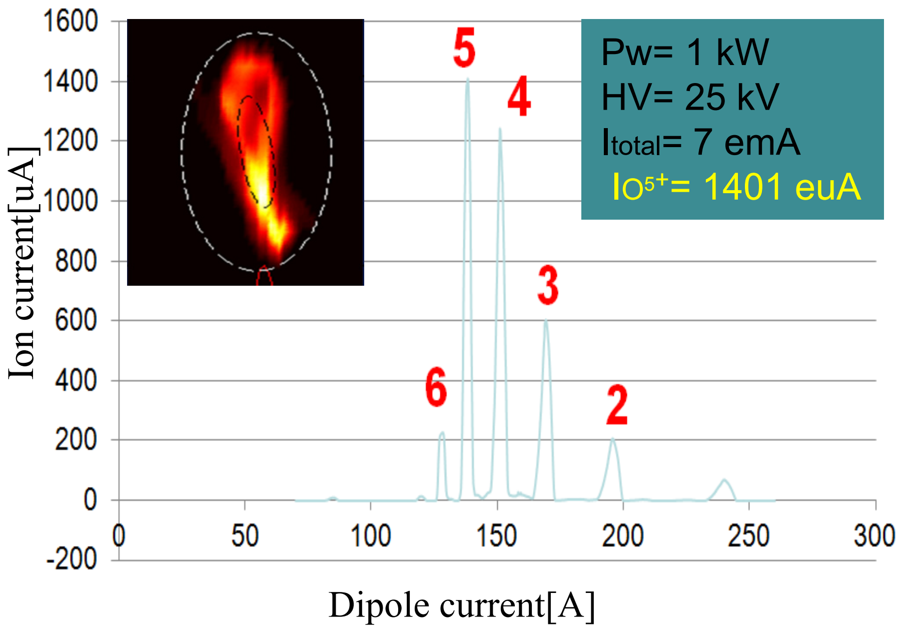


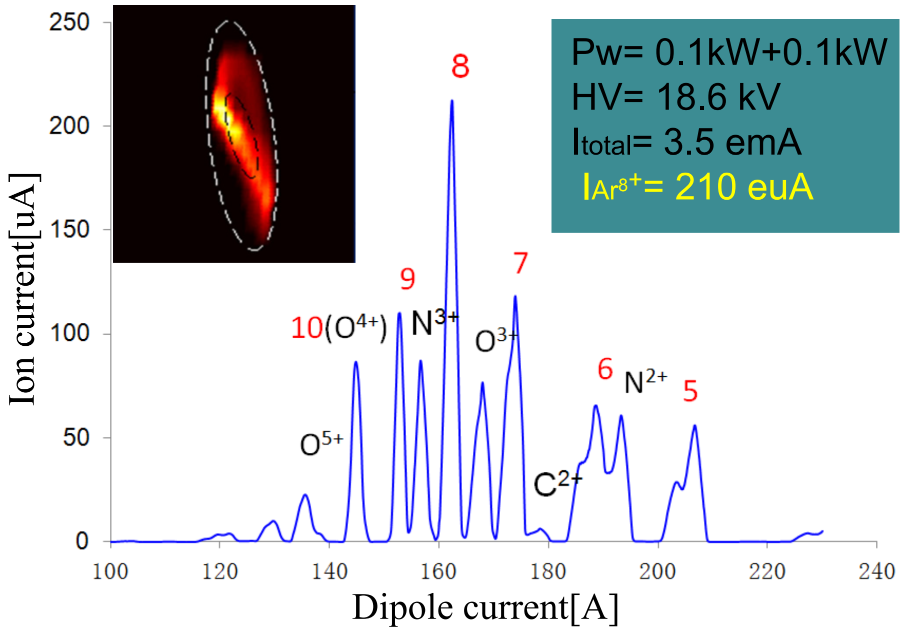
The beam energy is measured using the time of flight (TOF) method with two FCTs (Fast Current Transformer) installed after RFQ.

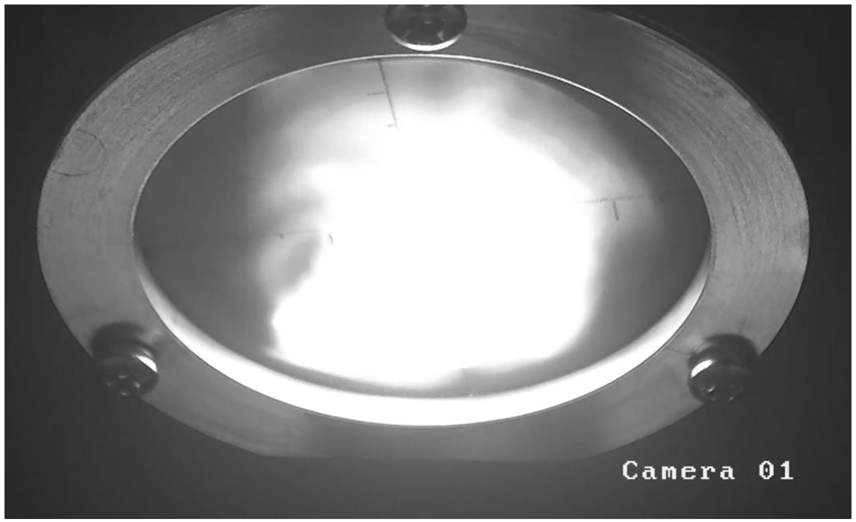
The beam current and transmission are measured by three Faraday cups.

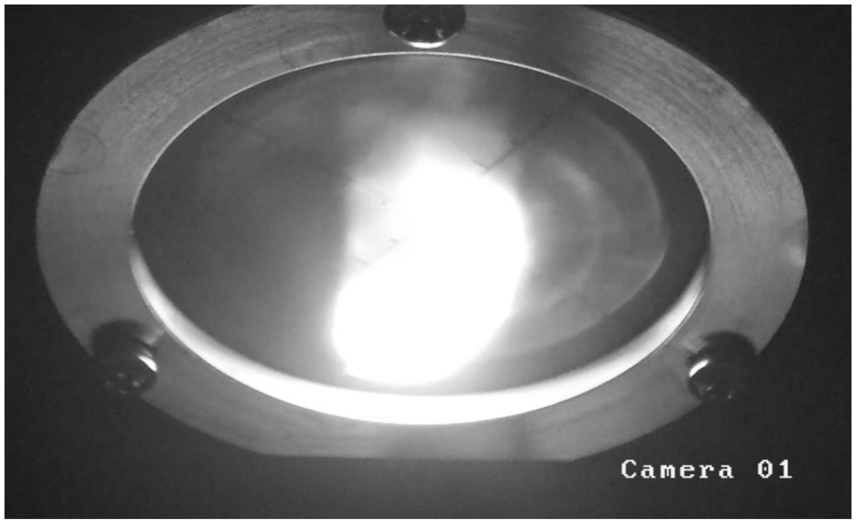
Some beam instruments were developed and applied in the beam commissioning. However, many elements and beam instruments were omitted since the limited funds. The analyzing dipole magnet system and the electrics system for the wire scanner, which were used to measure the energy spread and beam section profile, are not yet available.

Solid core beam of O^{5+}, Ar^{8+}



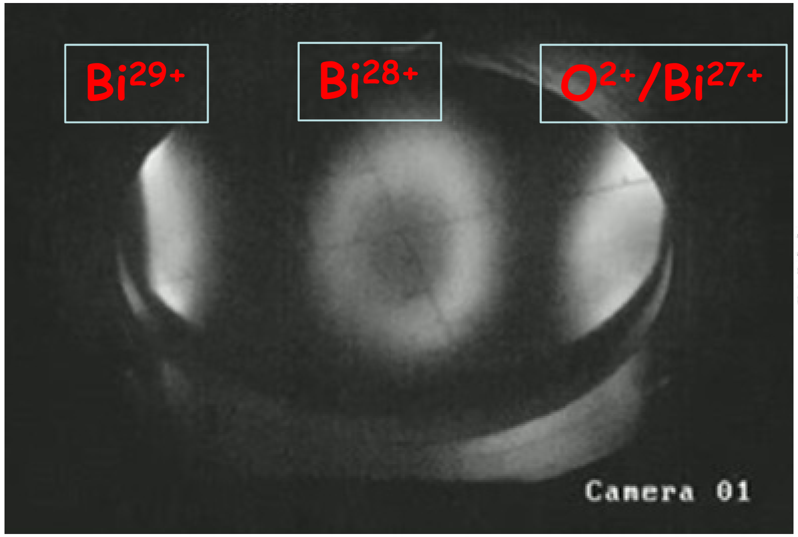


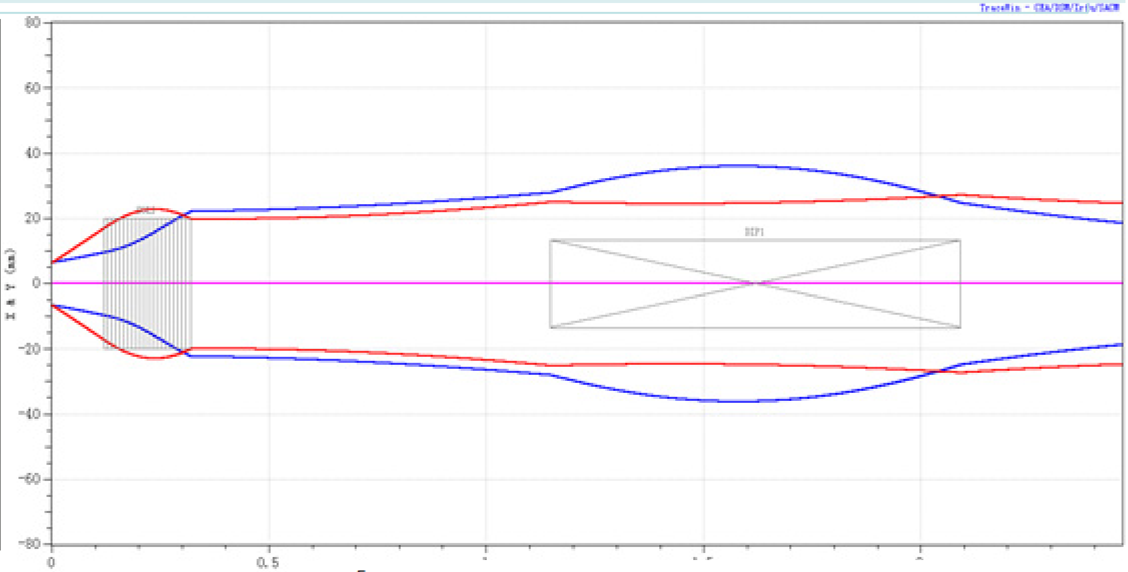




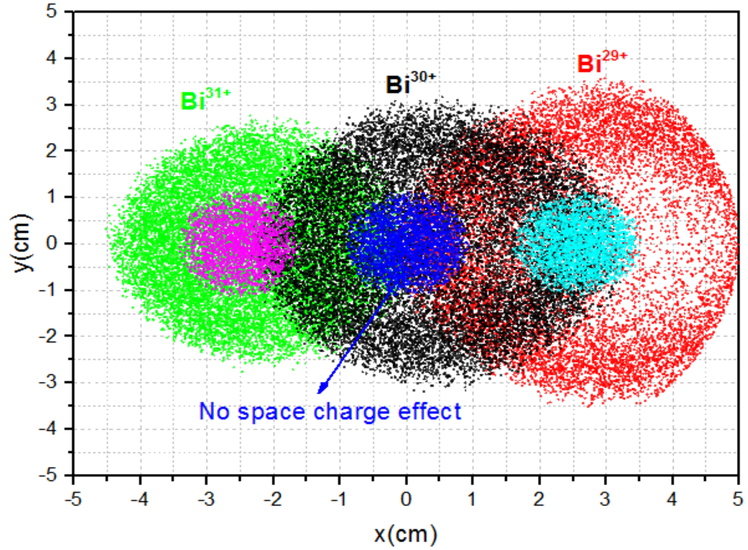
SSC-Linac injector: LEBT

LEBT hollow beam phenomenon and redesign with PIC multiple beam transmission simulation



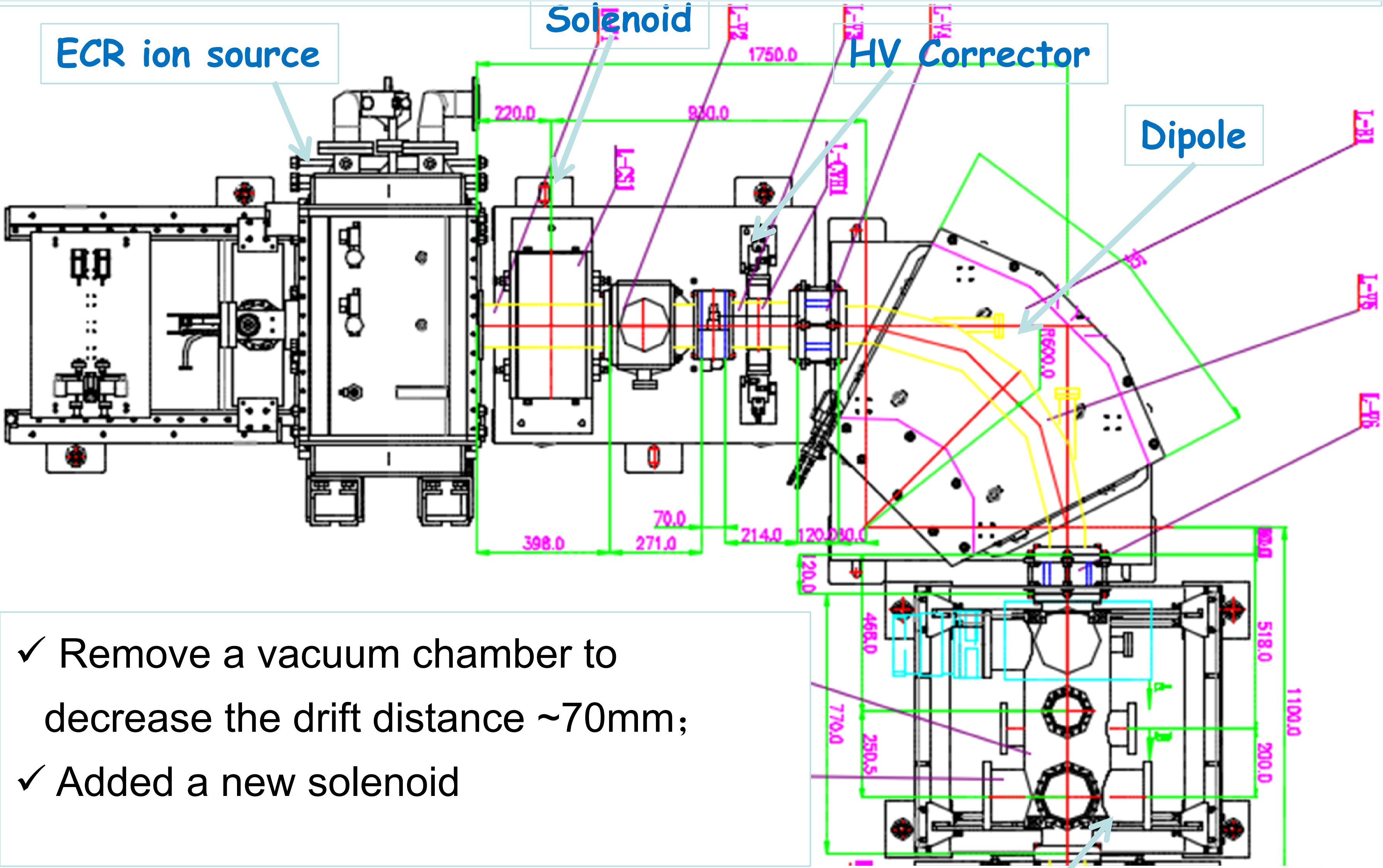


- High charge state
- High intensity Ion beam with multiple ion species and charge states
- High current space charge effect
- Extraction voltage: 23 kV
- I_{total}= 2.4 emA, $I_{Bi^{28+}}$= 20 euA



SSC-Linac injector: LEBT

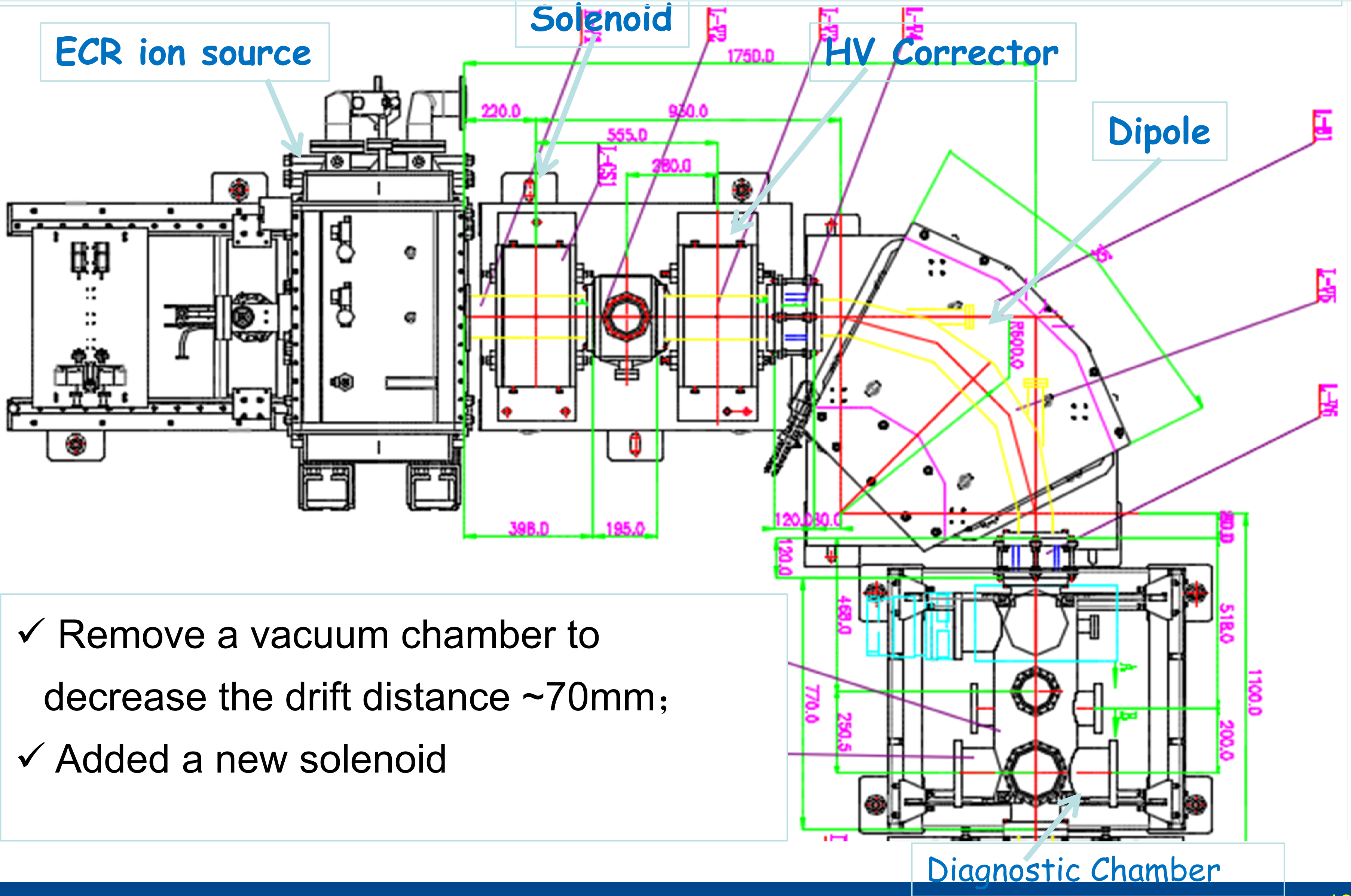
Optimization of LEBT



- ✓ Remove a vacuum chamber to decrease the drift distance ~70mm;
- ✓ Added a new solenoid

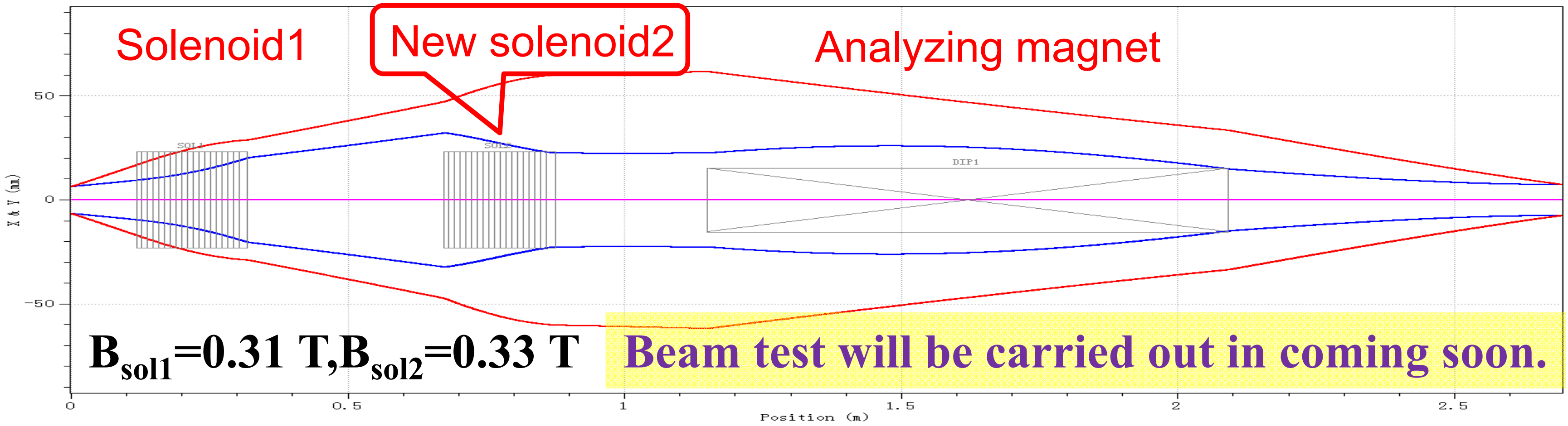
SSC-Linac injector: LEBT

Optimization of LEBT



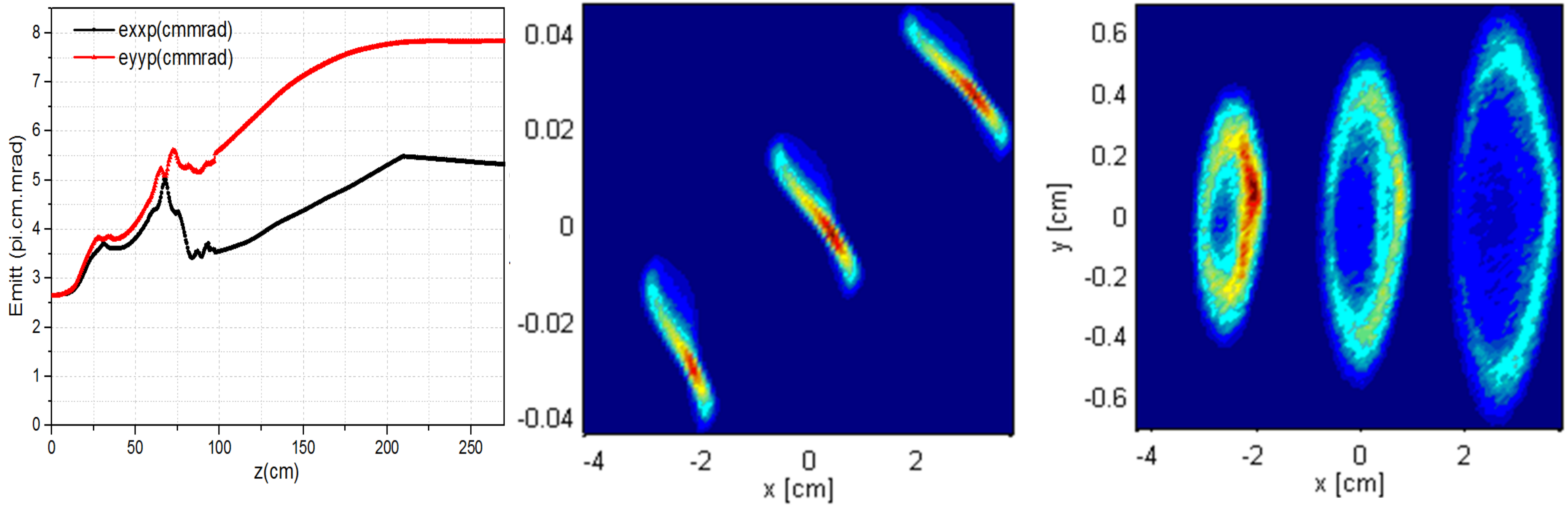
- ✓ Remove a vacuum chamber to decrease the drift distance ~70mm;
- ✓ Added a new solenoid

SSC-Linac injector: New LEBT



B_{sol1}=0.31 T,B_{sol2}=0.33 T

Beam test will be carried out in coming soon.



Simulation after optimization of LEBT

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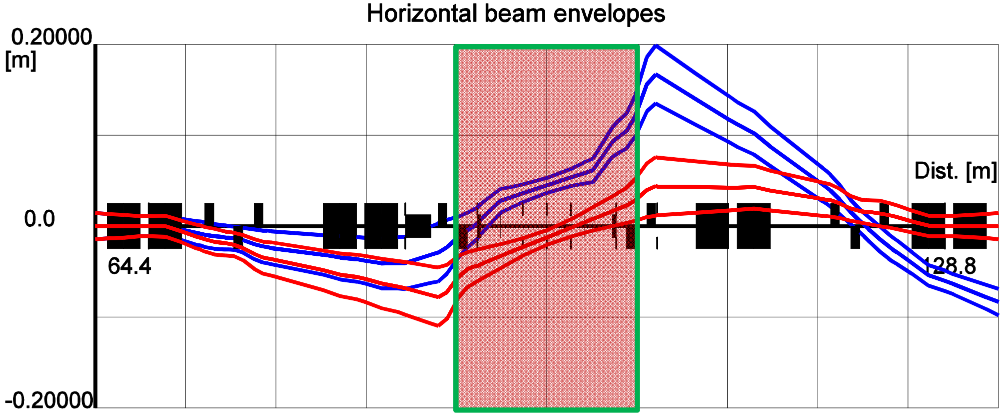
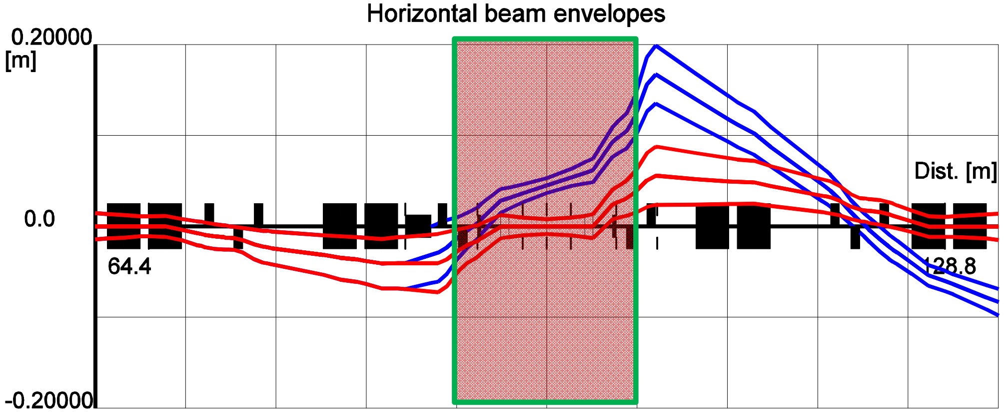
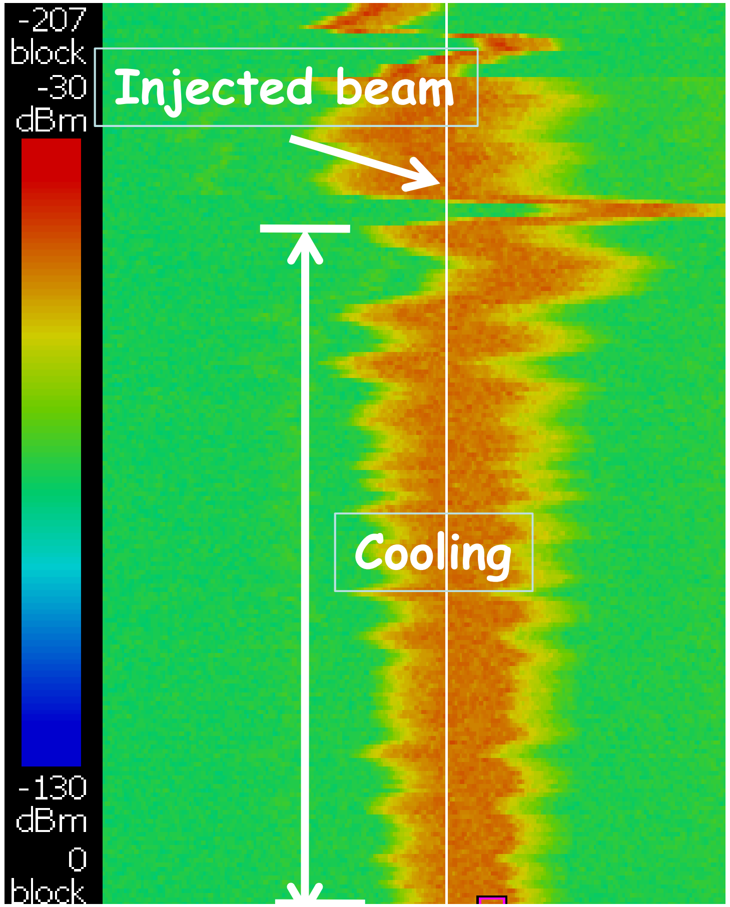
Beam Cooling at CSRe

A new beam orbit correction is used to ensure an overlap coaxially between electron and ion beam







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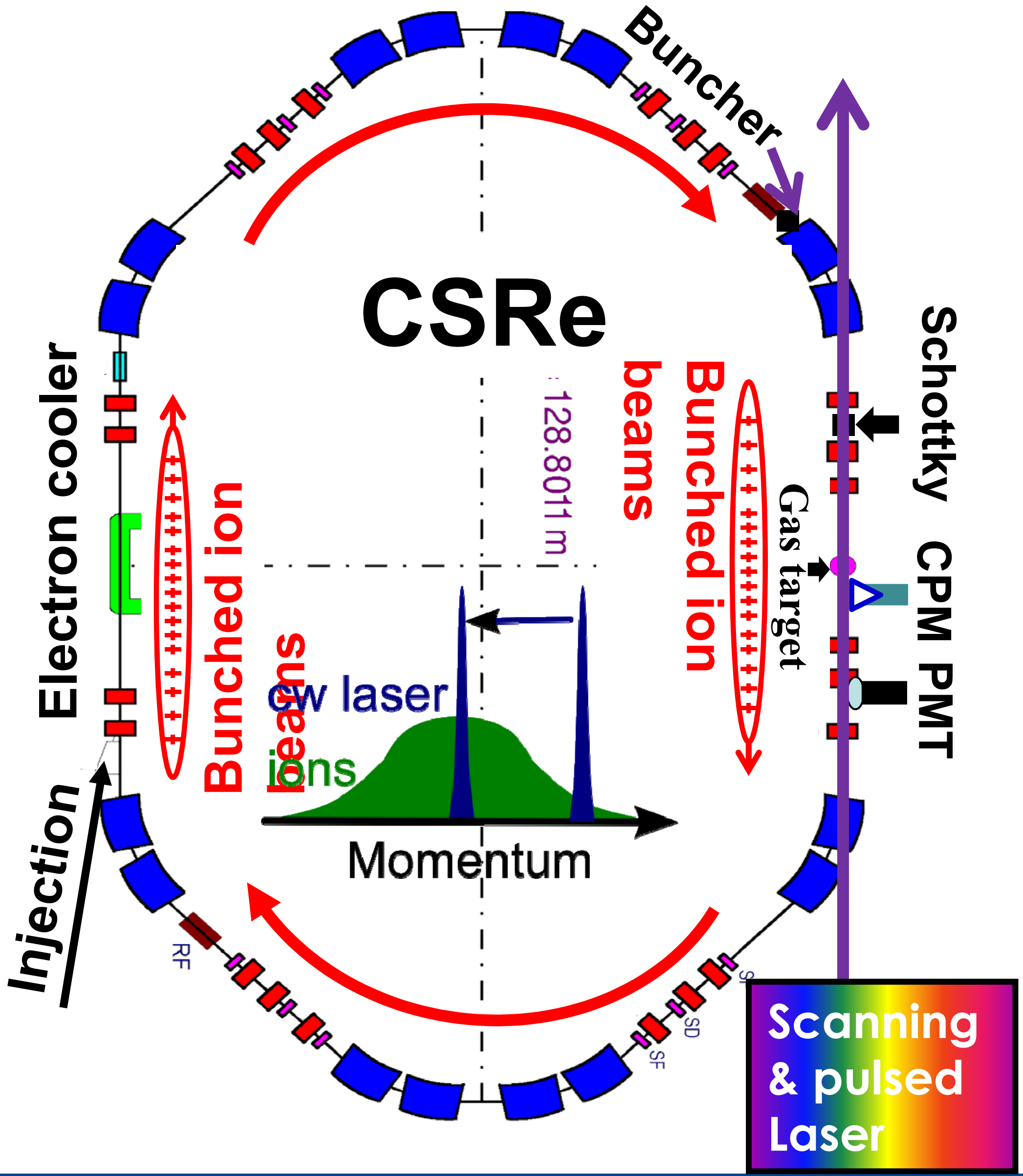
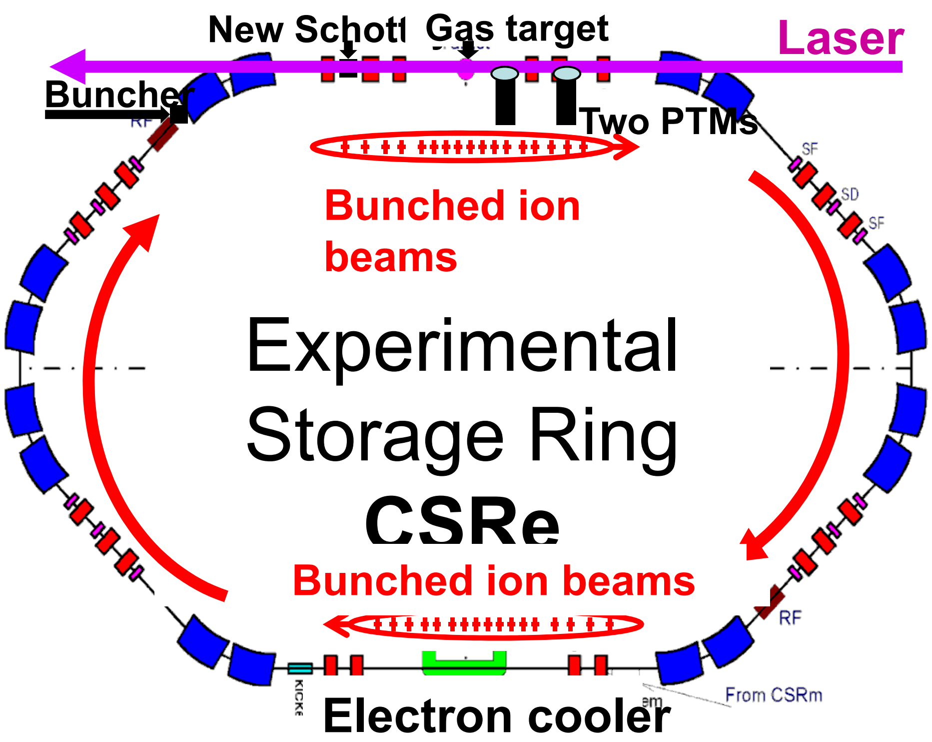
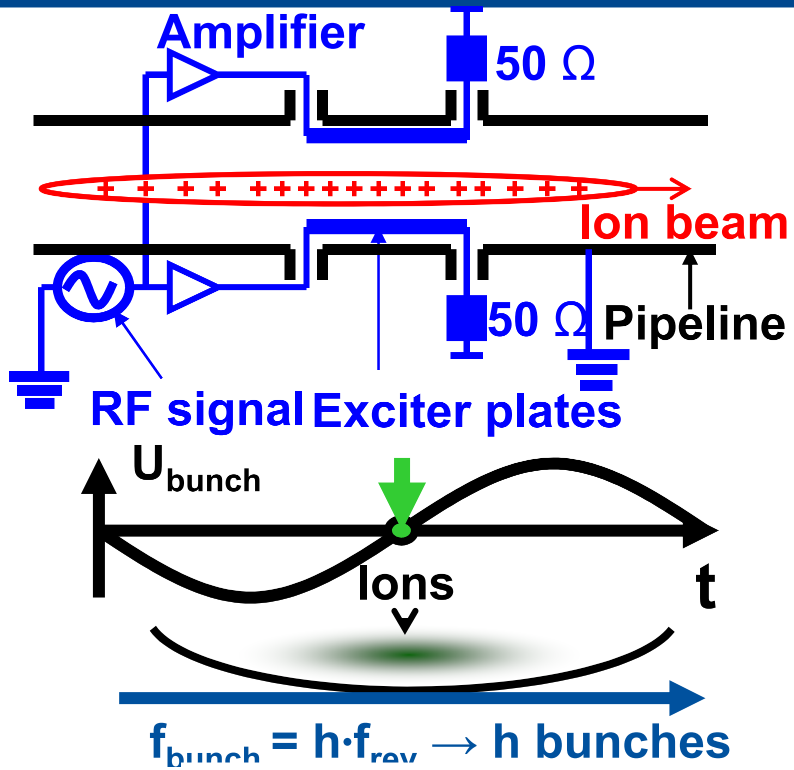
Main parameters



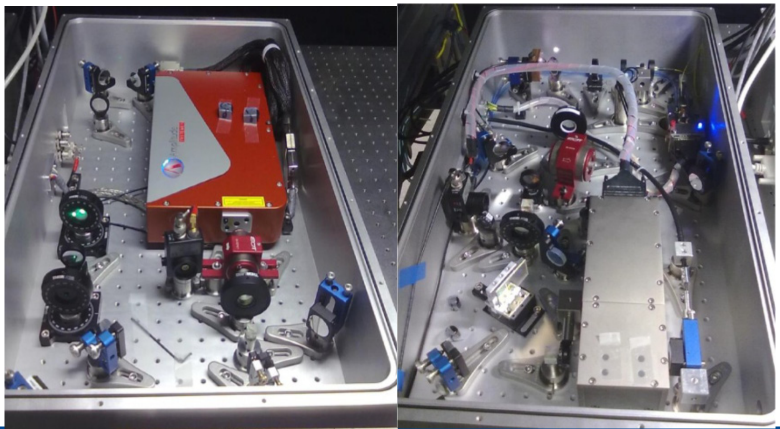
CSRe parameters	
Circumference	128.80 m
Ion species	$^{12}C^{3+}$
Beam energy	122 MeV/u
Relativistic β, γ	0.47, 1.13
Revolution frequency	1.088 MHz
Transition energy γ_t	2.626
Lifetime of ion beam	~ 20 s
Harmonic number h	10,15, 25
Laser system	
Laser source	cw & pulsed laser
Laser wavelength	$\lambda_{laser} = 257.5$ nm
Cooling transition	
$2s_{1/2} \rightarrow 2p_{1/2}$	$\lambda_{rest} = 155.07$ nm
$2s_{1/2} \rightarrow 2p_{3/2}$	$\lambda_{rest} = 154.81$ nm

Experimental setup

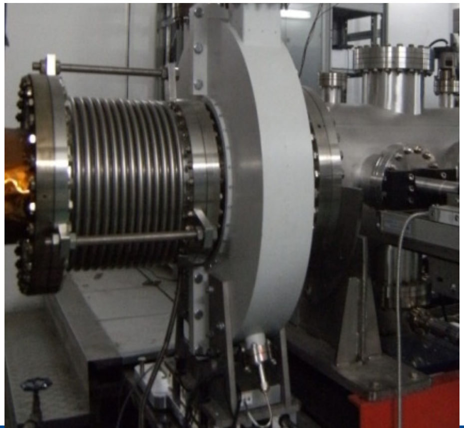




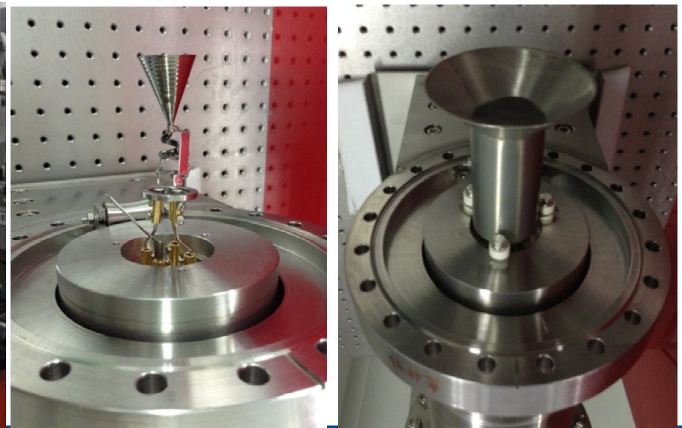
Pulse laser system, HZDR



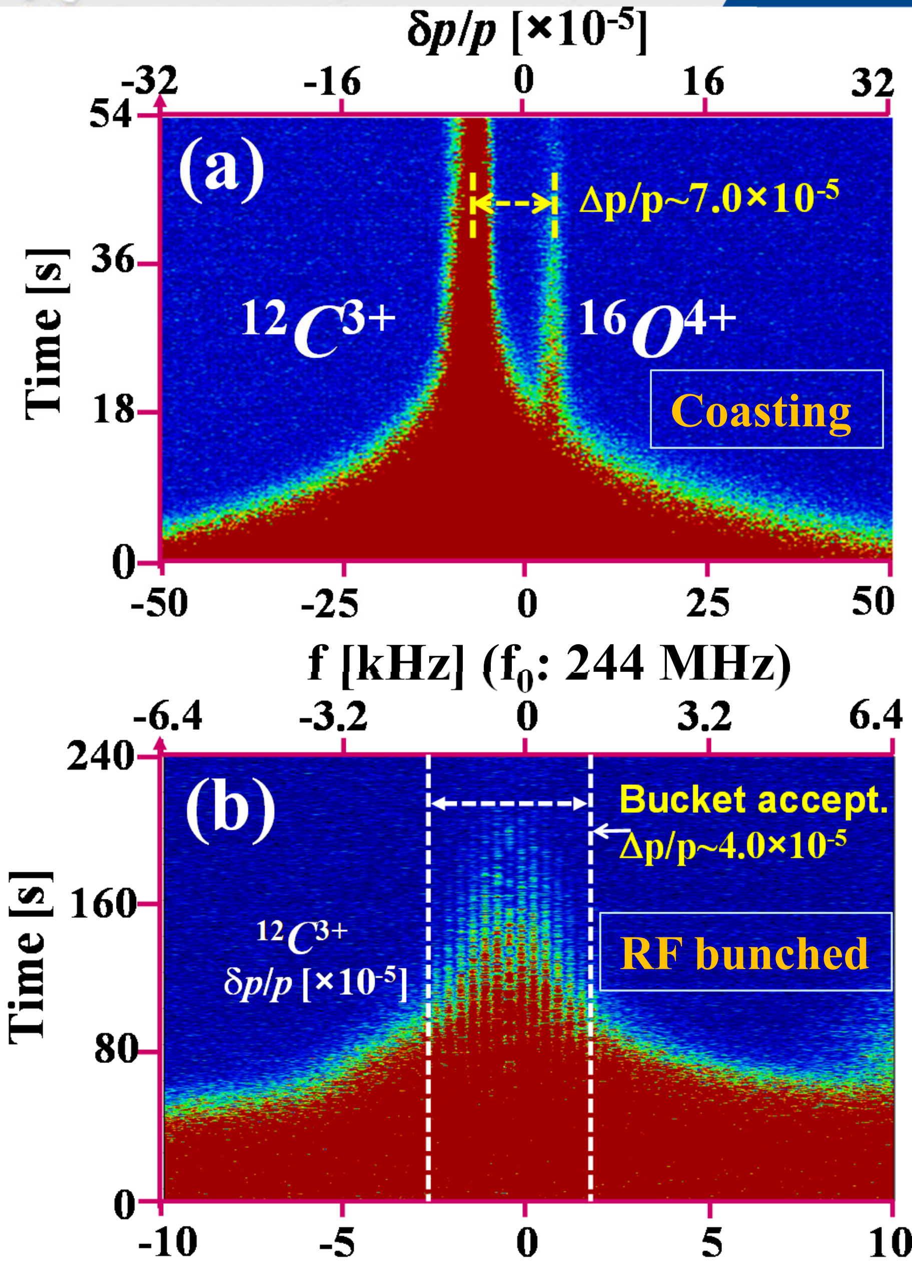
Resonant Schottky



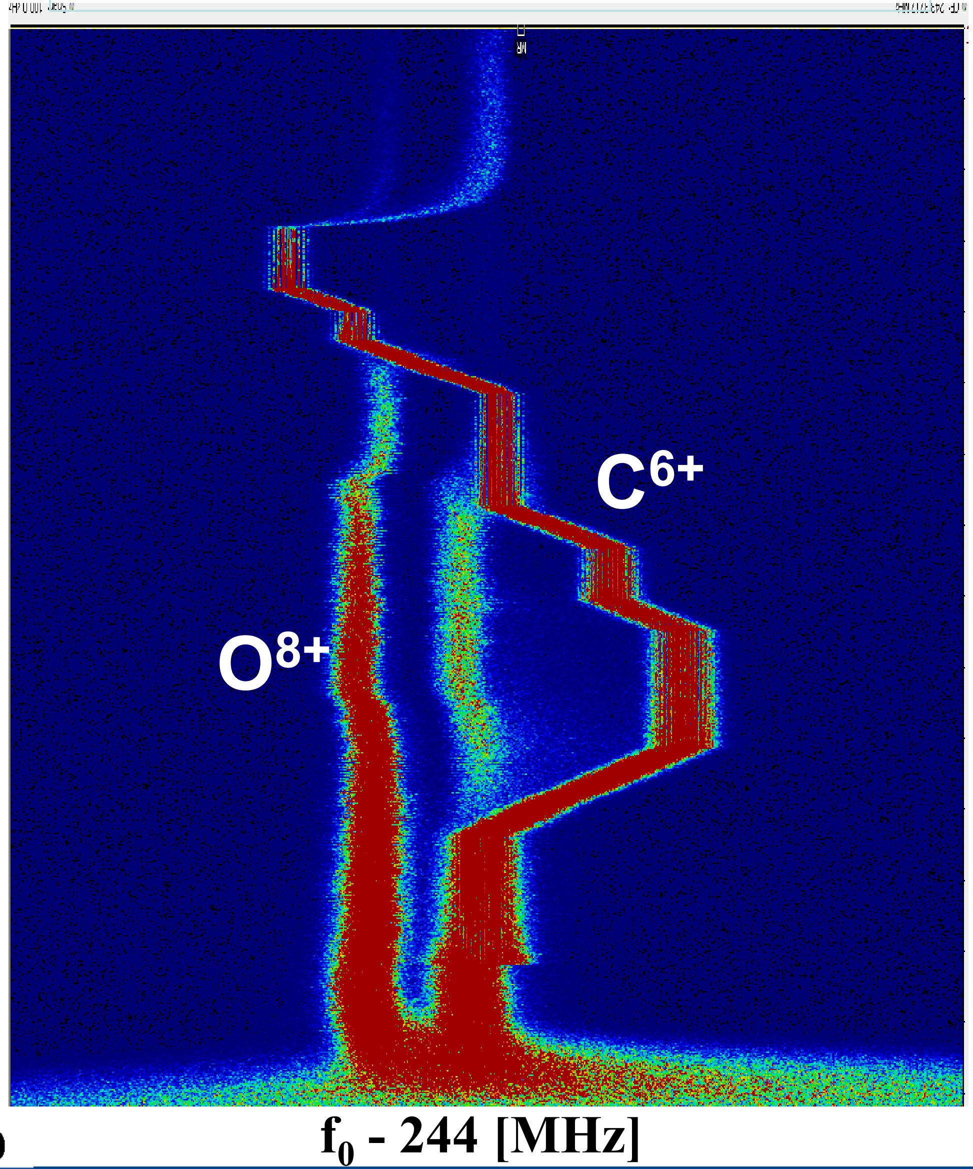
UV-sensitive Channeltron



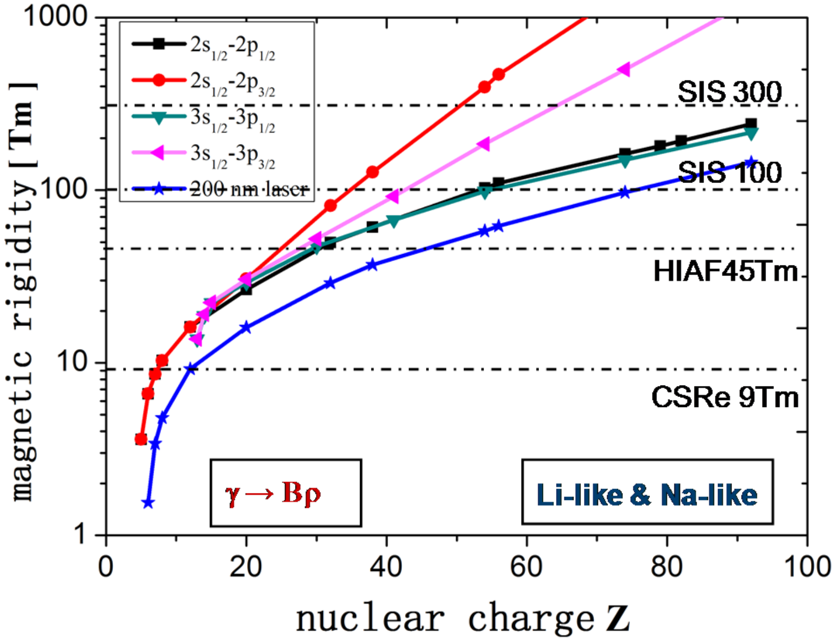
Schottky spectrum



Moving ion energy with RF buncher



Experimental setup test



Lorentz transformation

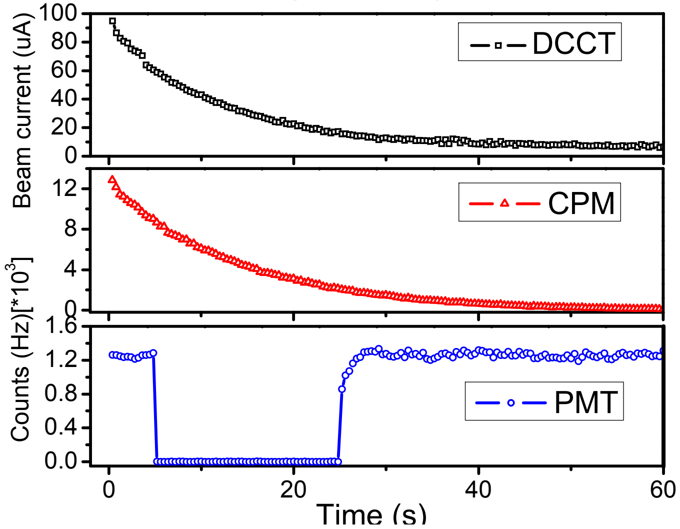
a) access to ground state transitions of heavy ions by huge Doppler shift (@ λ_{UV} = 257nm)

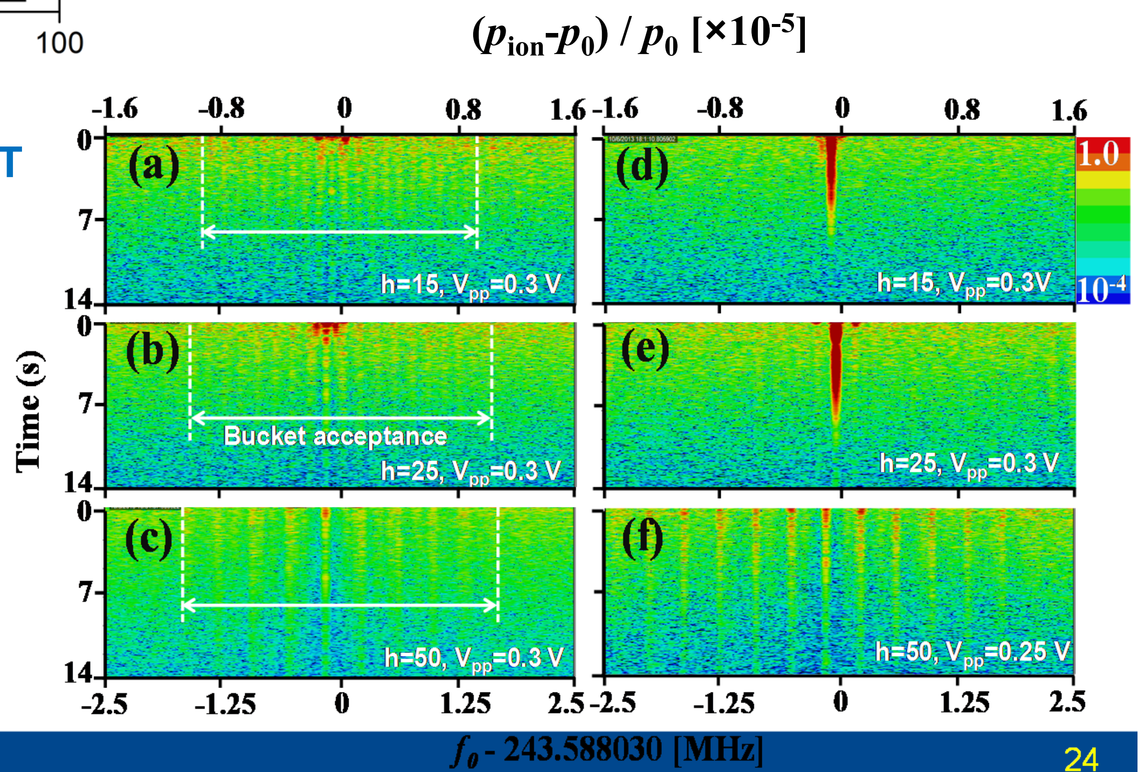
b) one laser for many ion species

c) Laser cooling force increases with beam energy

d) laser spectroscopy is "free"

Florescence signals by CPM and PMT





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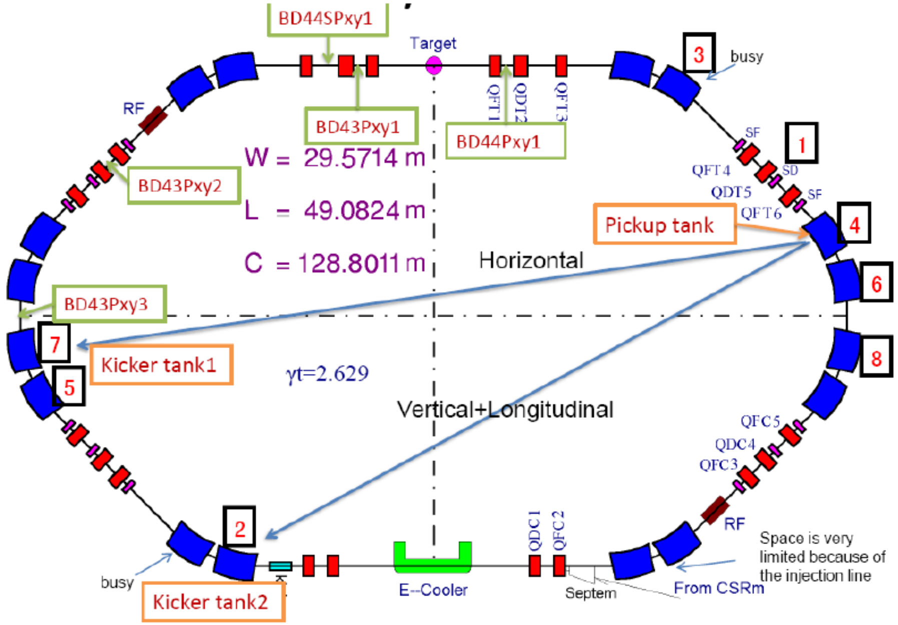
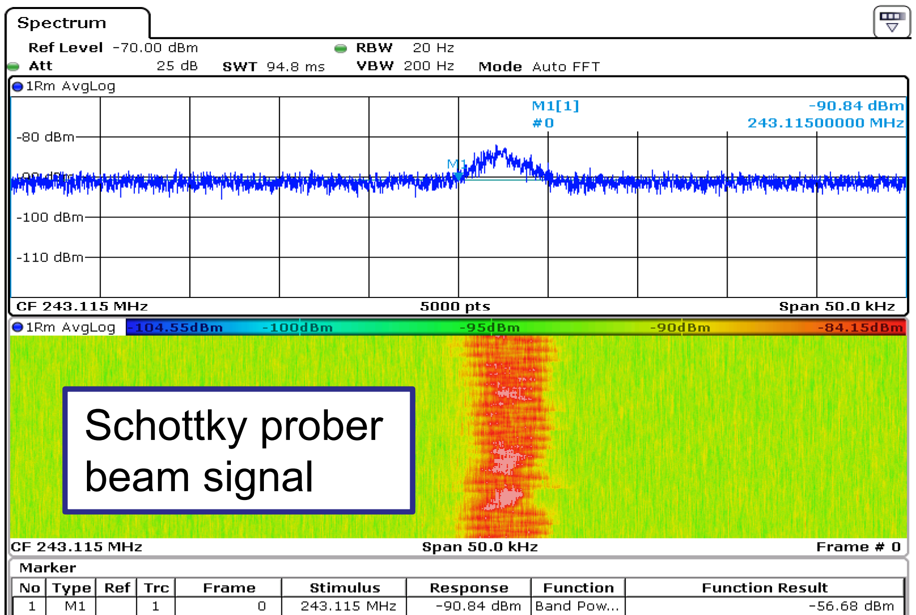
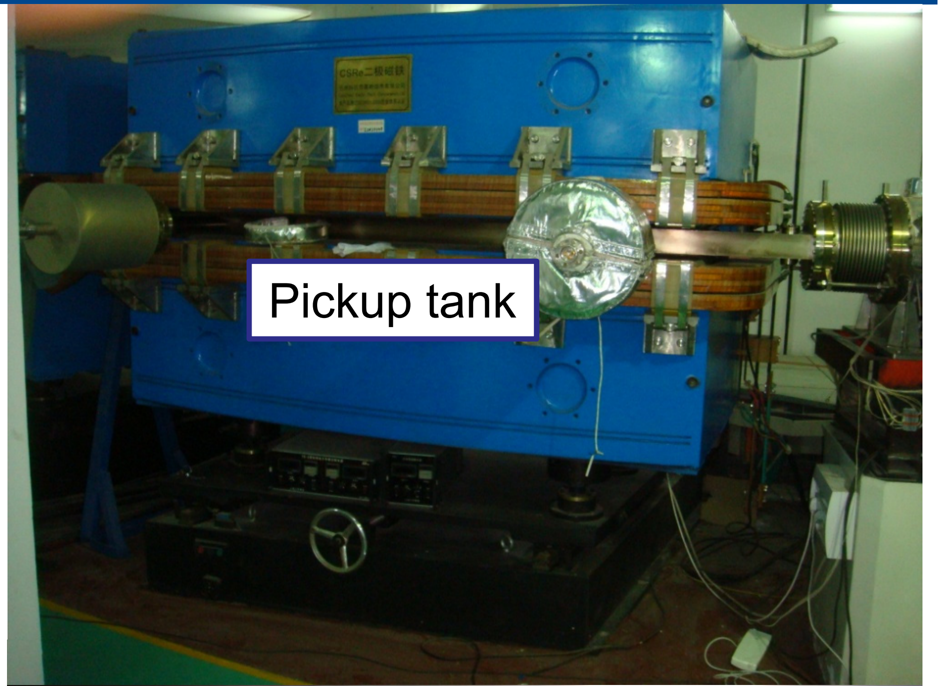
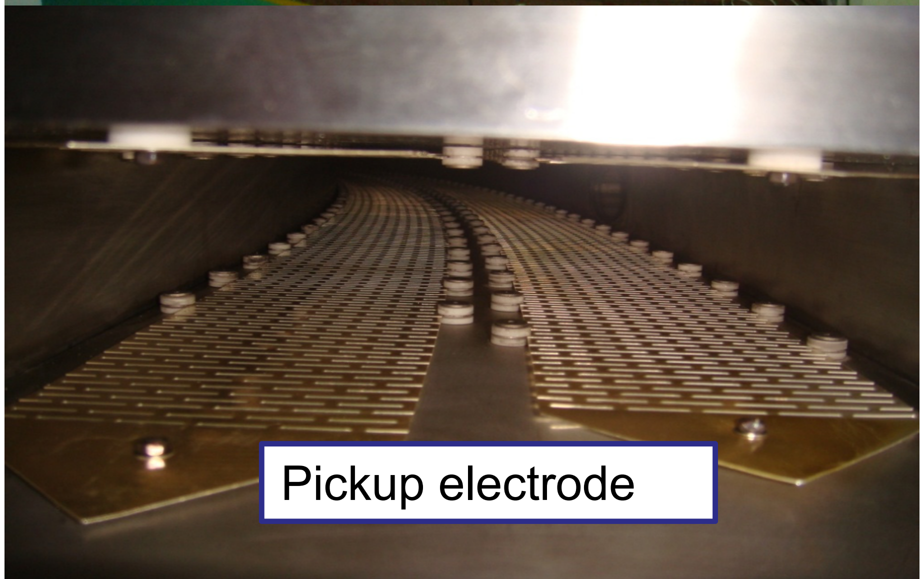
Overview

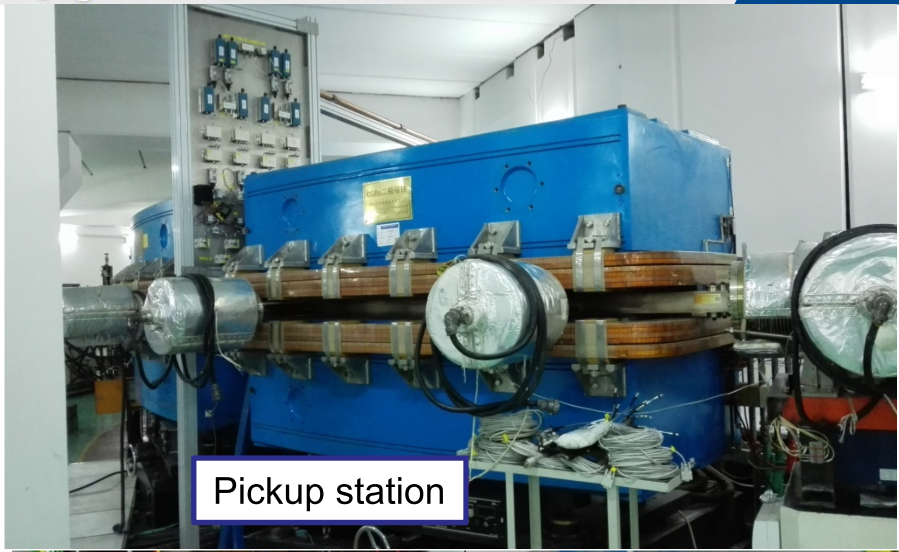

BD44SPxy1
Target
busy
3
RF
BD43Pxy1
QFT1
QDT2
QFT3
BD44Pxy1
SF
1
QFT4
SD
QDT5
SF
QFT6
BD43Pxy2
W = 29.5714 m
L = 49.0824 m
C = 128.8011 m
Pickup tank
4
Horizontal
6
BD43Pxy3
7
Kicker tank1
8
5
γt=2.629
Vertical+Longitudinal
QFC5
QDC4
QFC3
RF
2
QDC1
QFC2
Space is very limited because of the injection line
busy
Kicker tank2
E--Cooler
Septem
From CSRm


Spectrum
Ref Level -70.00 dBm
RBW 20 Hz
Att 25 dB
SWT 94.8 ms
VBW 200 Hz
Mode Auto FFT
1Rm AvgLog
M1[1] -90.84 dBm
#0 243.11500000 MHz
-80 dBm
-100 dBm
-110 dBm
CF 243.115 MHz
5000 pts
Span 50.0 kHz
1Rm AvgLog
-104.55dBm
-100dBm
-95dBm
-90dBm
-84.15dBm
Schottky prober beam signal
CF 243.115 MHz
Span 50.0 kHz
Frame # 0
Marker
No Type Ref Trc Frame Stimulus Response Function Function Result
1 M1 1 0 243.115 MHz -90.84 dBm Band Pow... -56.68 dBm

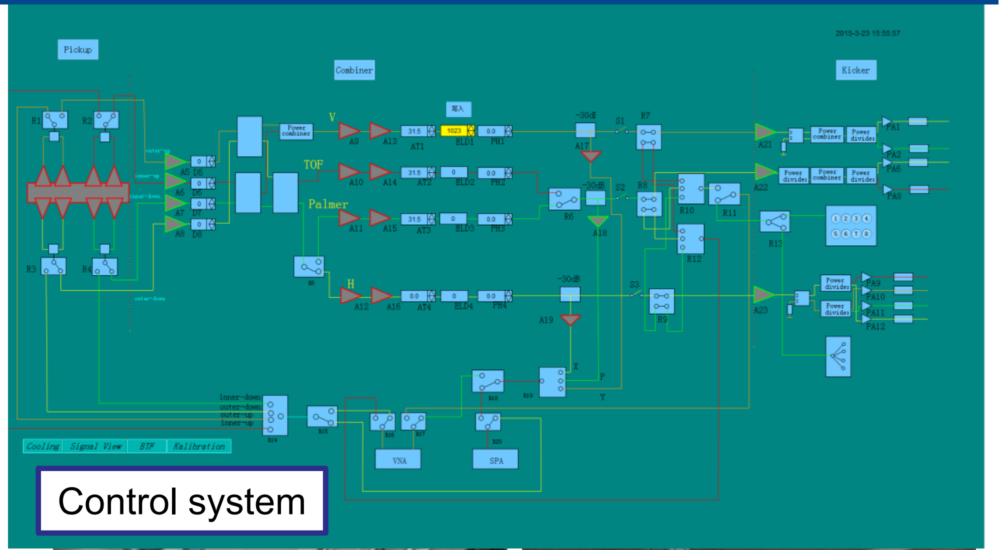

Pickup tank


Pickup electrode

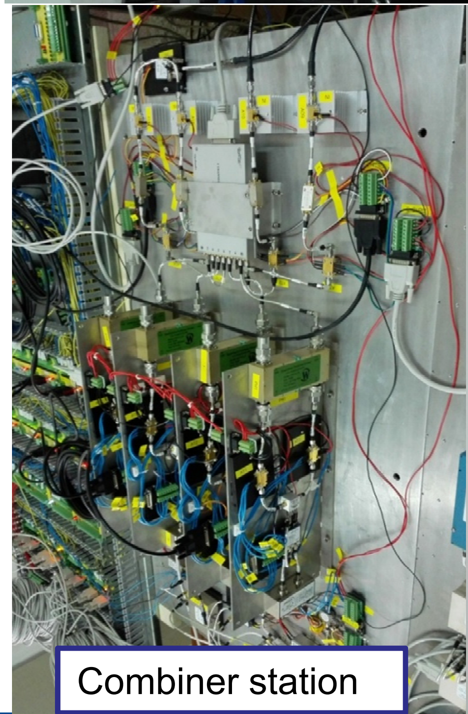
Experimental setup



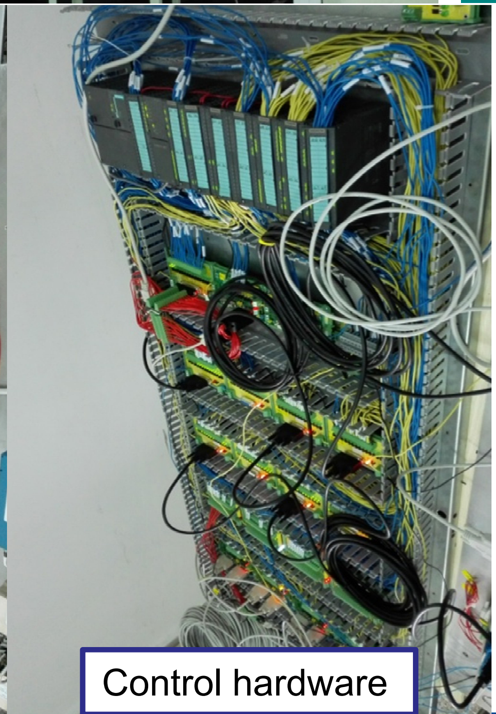
Pickup station



Control system



Combiner station



Control hardware

Transmission line

Power amplifier

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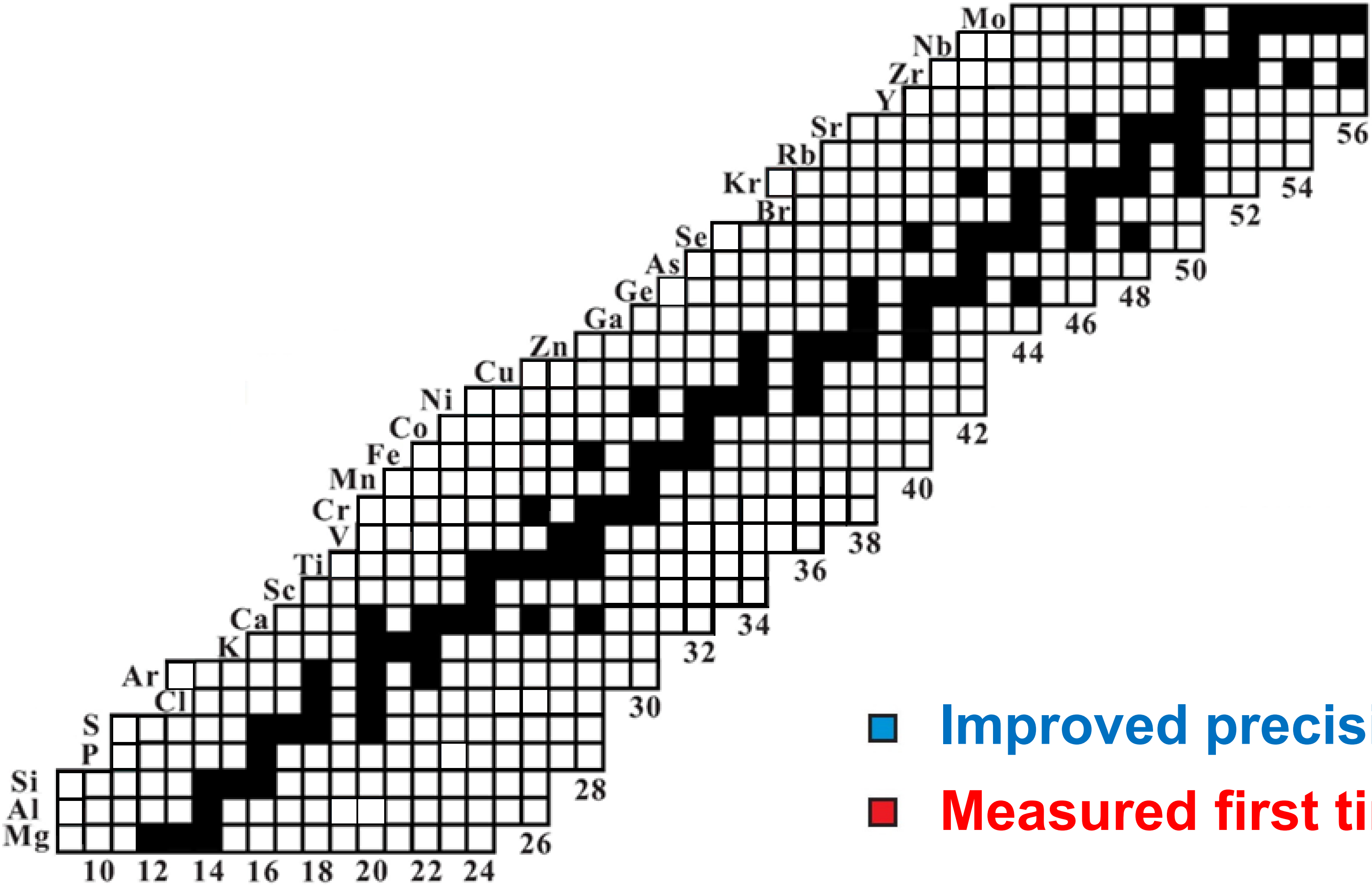
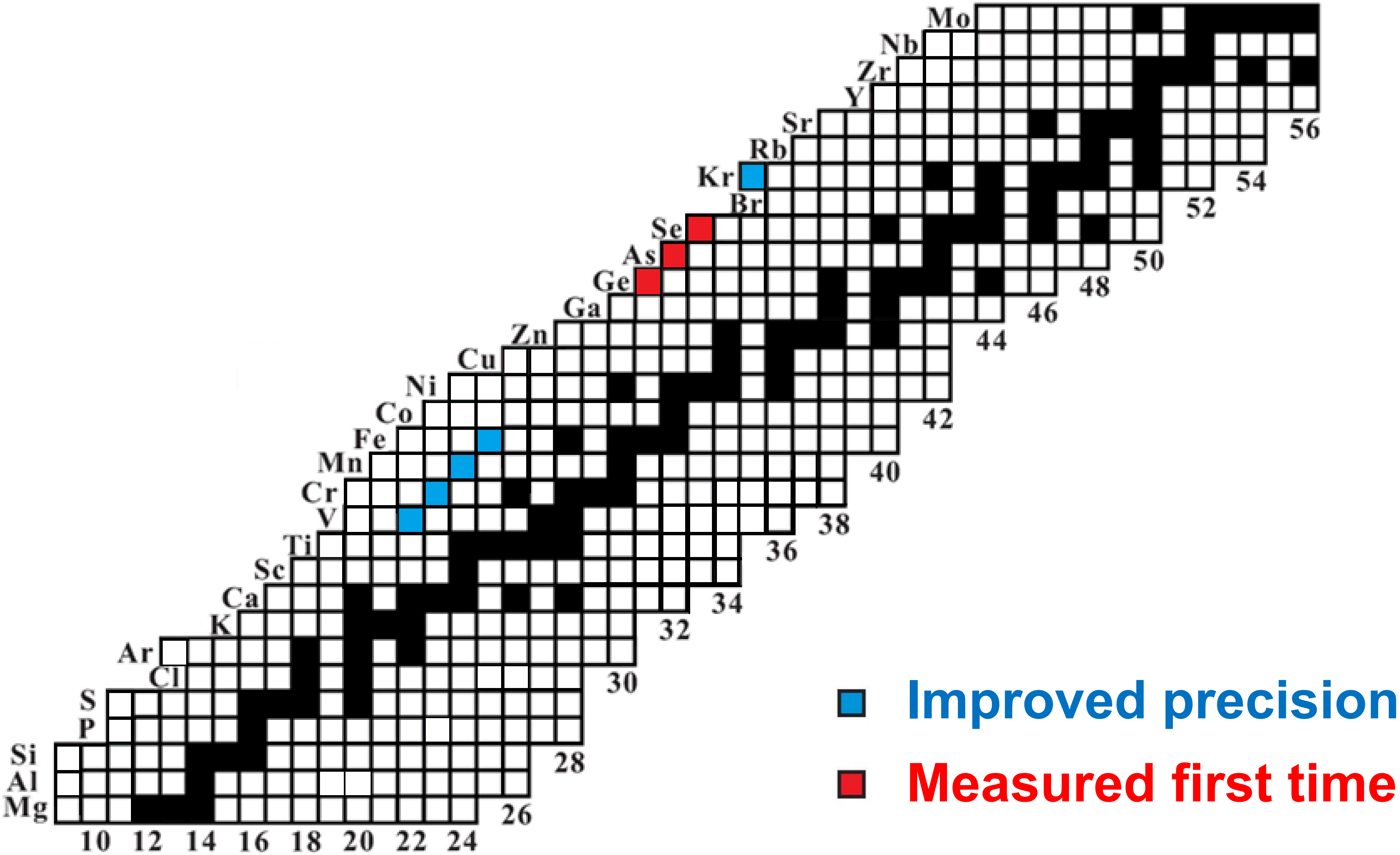
Overview of experimental results



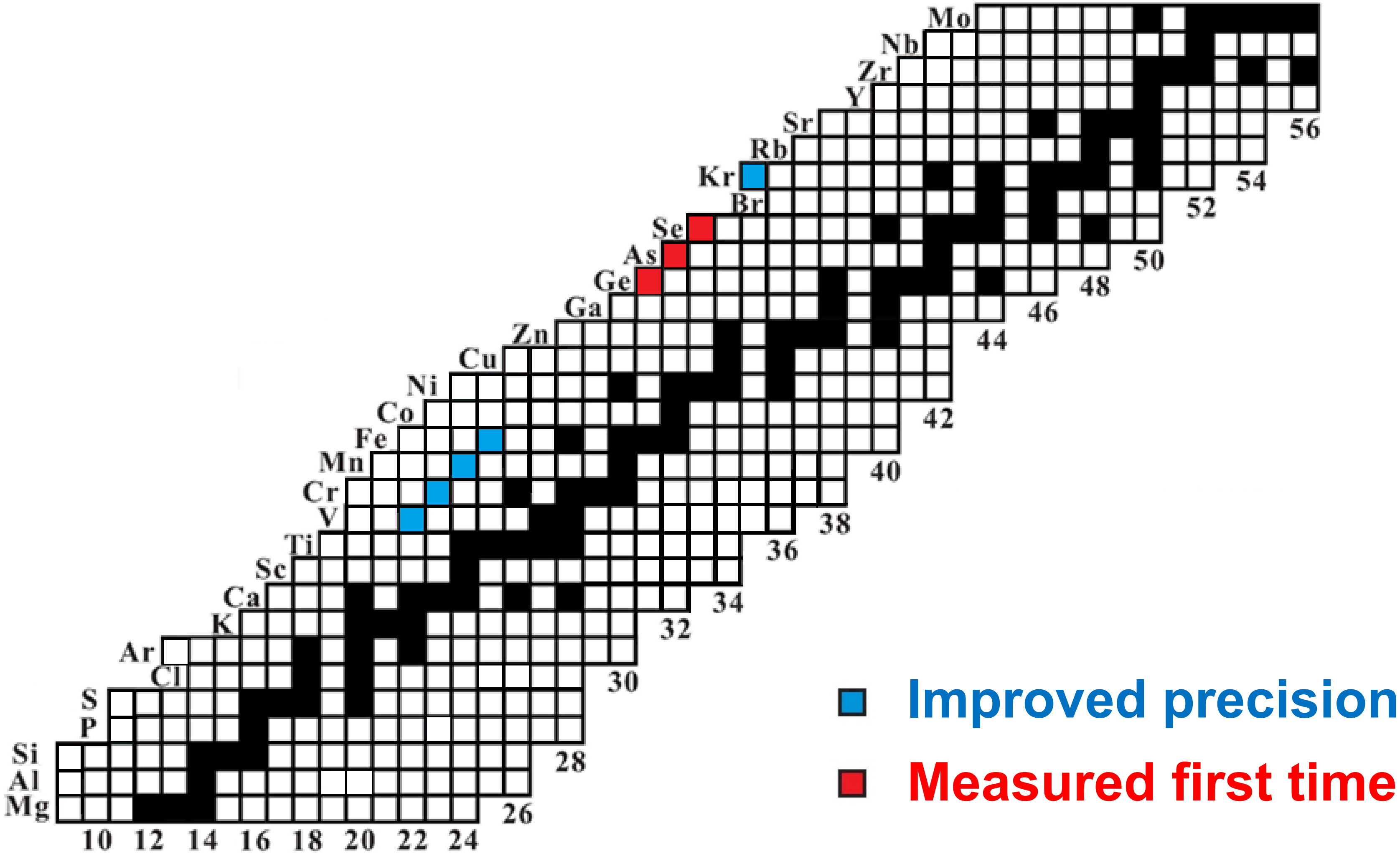
- Improved precision
- Measured first time

Overview of experimental results



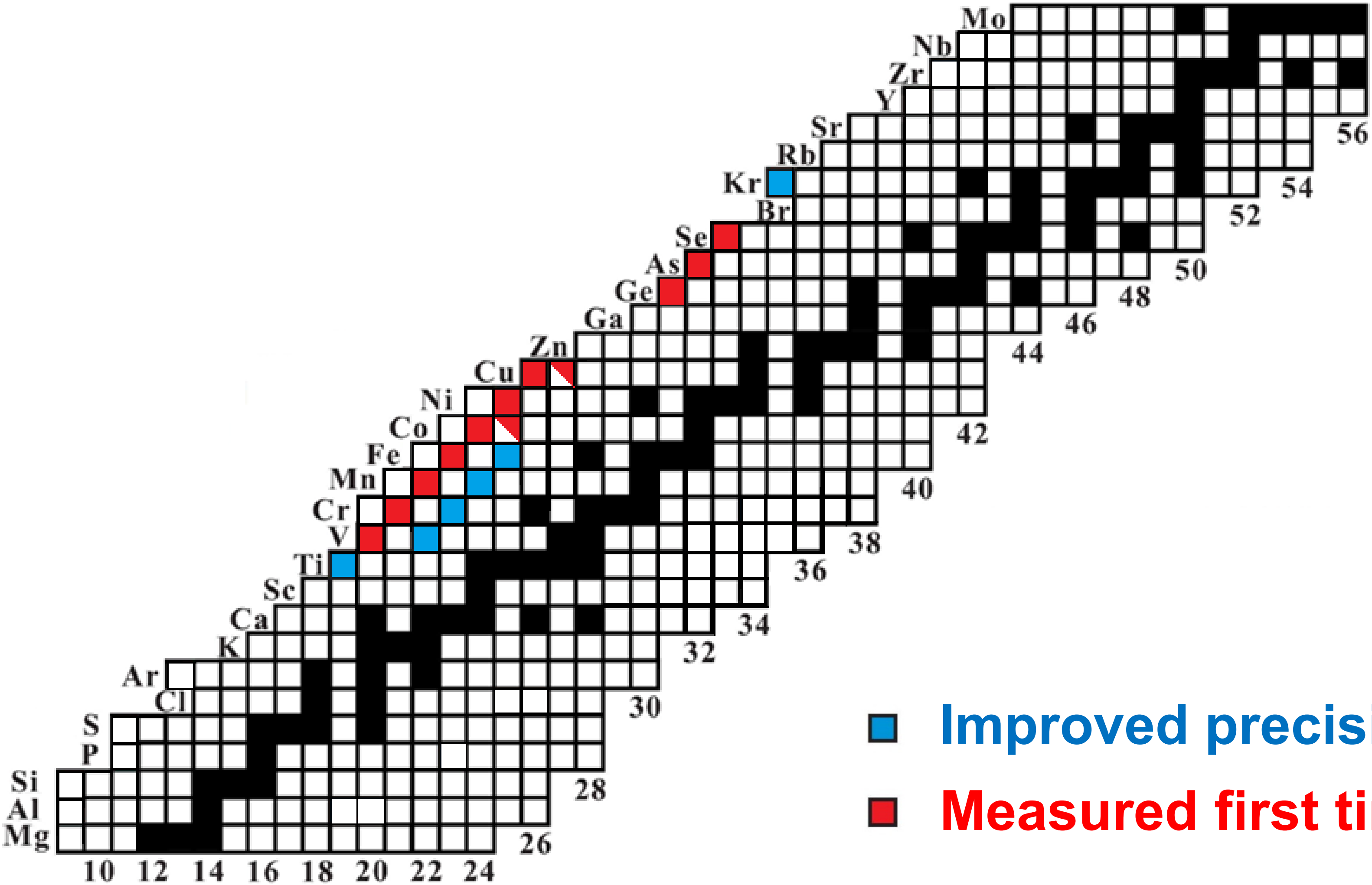
Overview of experimental results

Beams: **^{78}Kr,**



Overview of experimental results

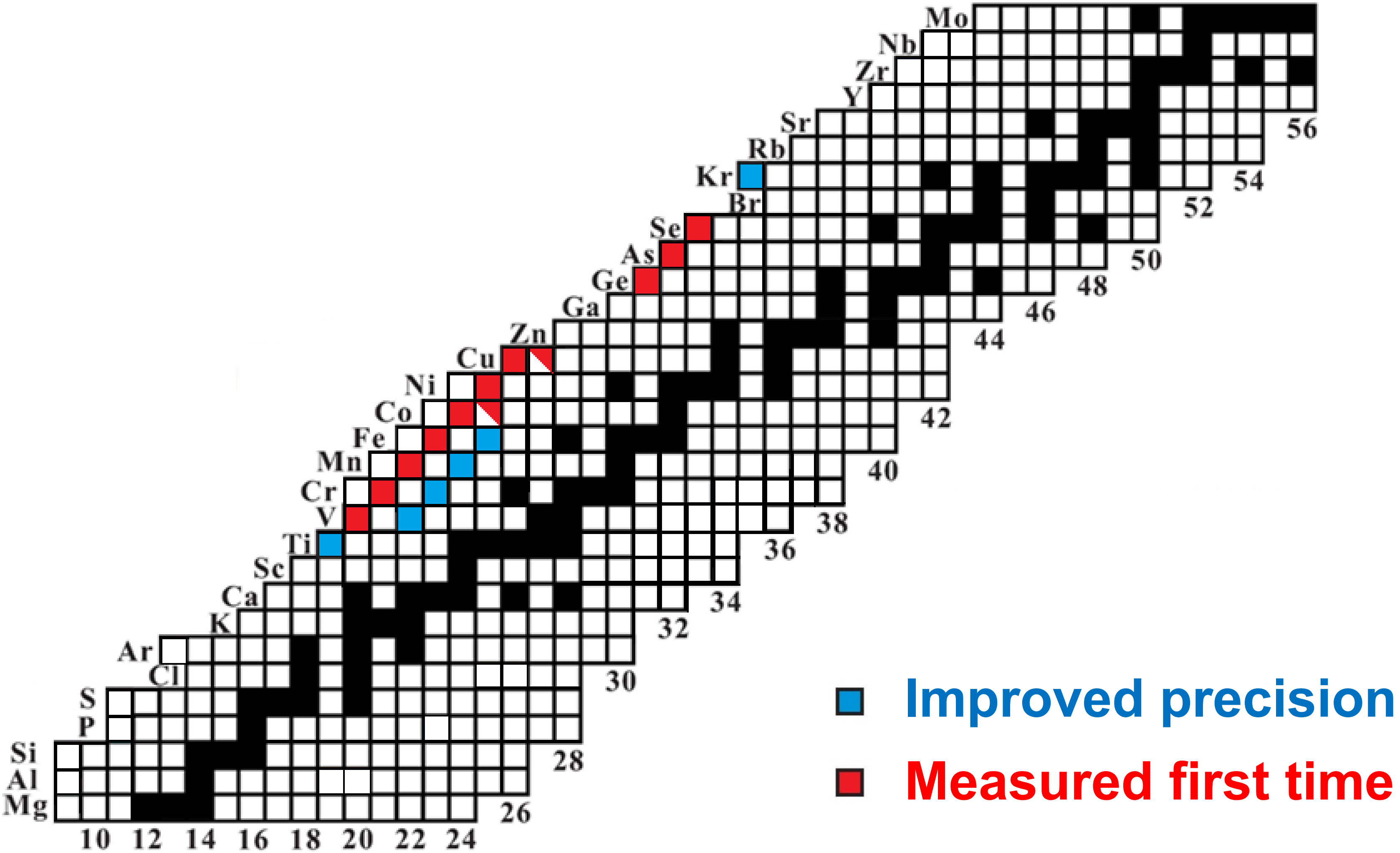
Beams: ^{78}Kr,



- Improved precision
- Measured first time

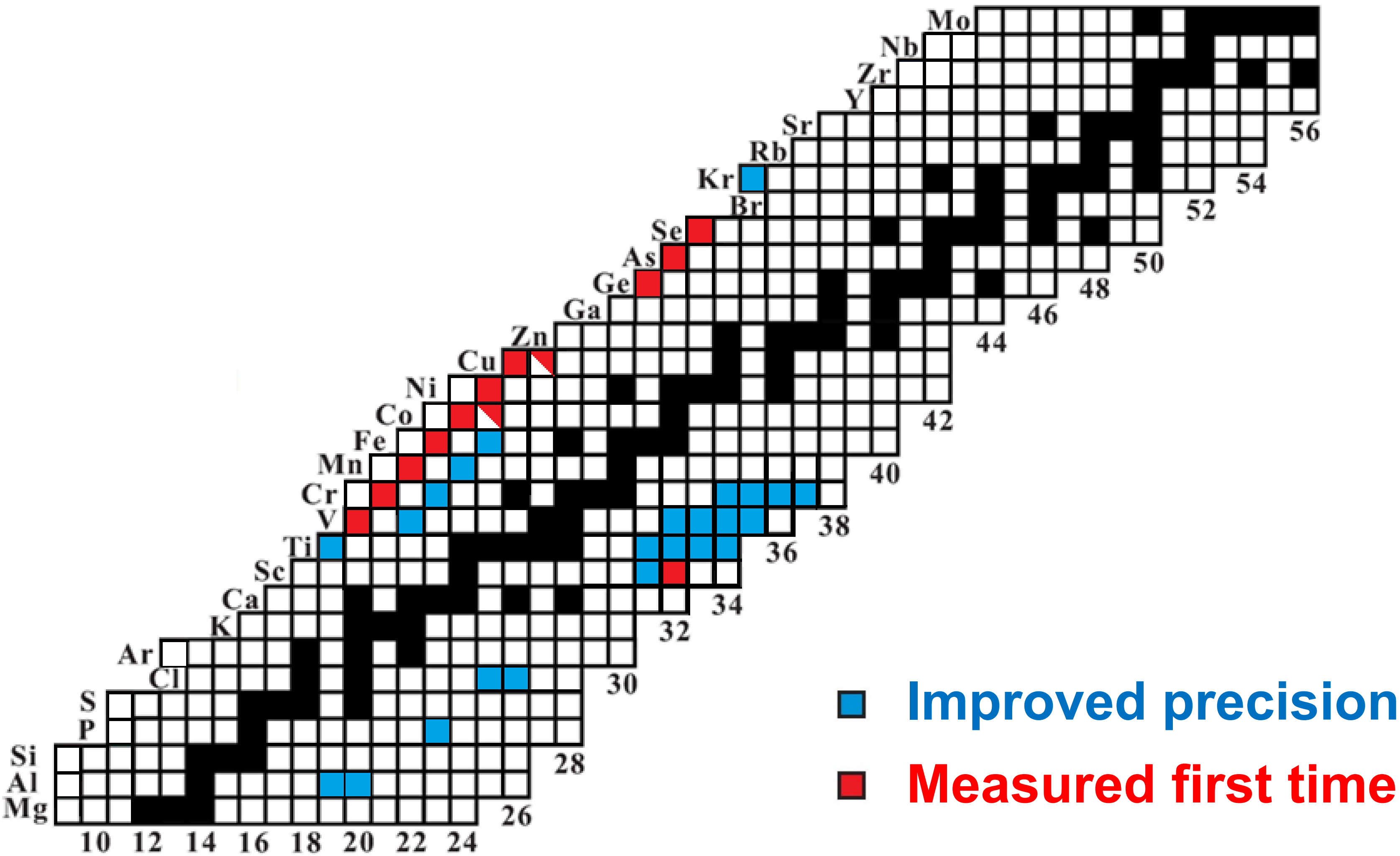
Overview of experimental results

Beams: ^{58}Ni, ^{78}Kr,



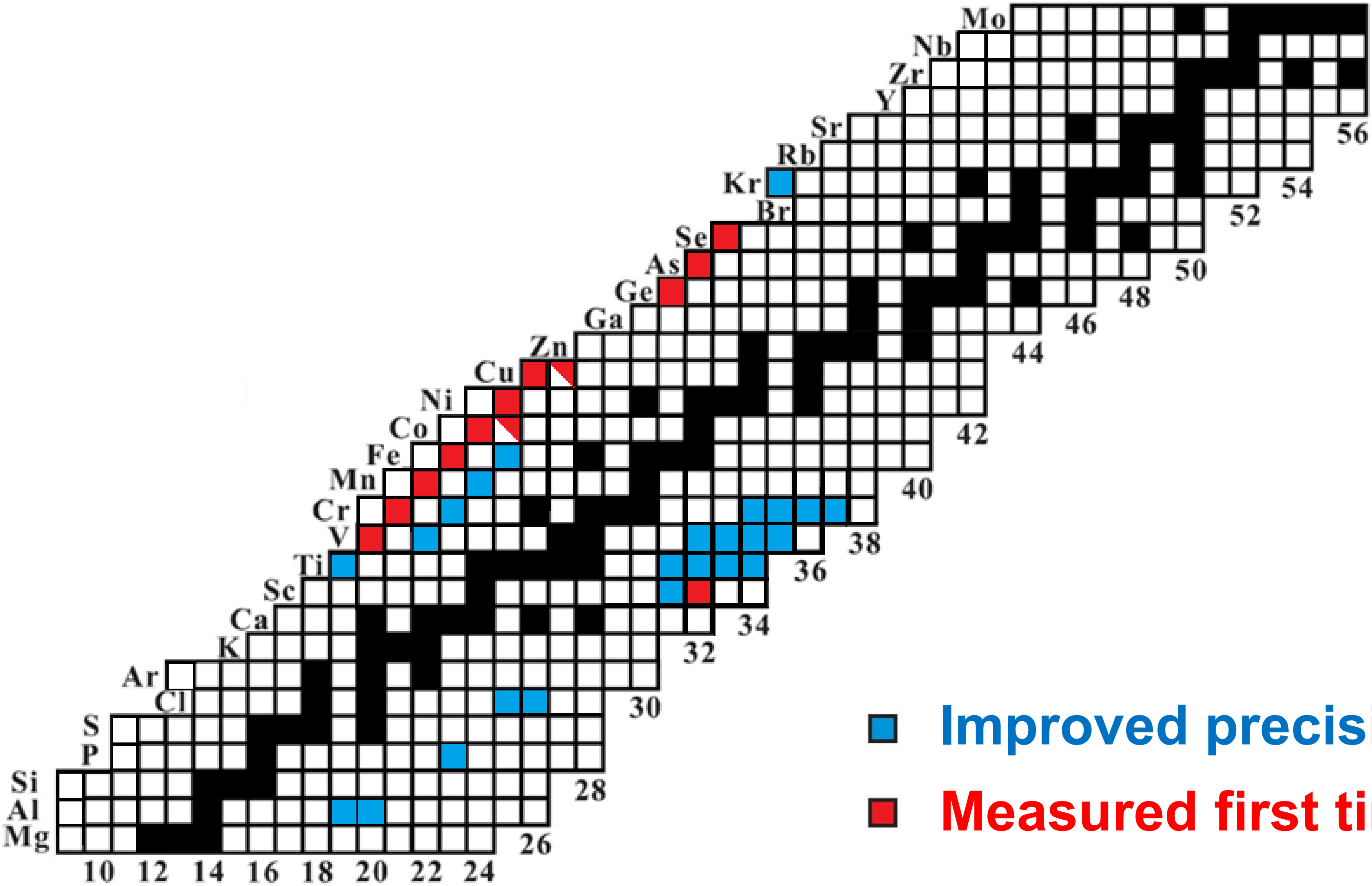
Overview of experimental results

Beams: ^{78}Kr, ^{58}Ni,



Overview of experimental results

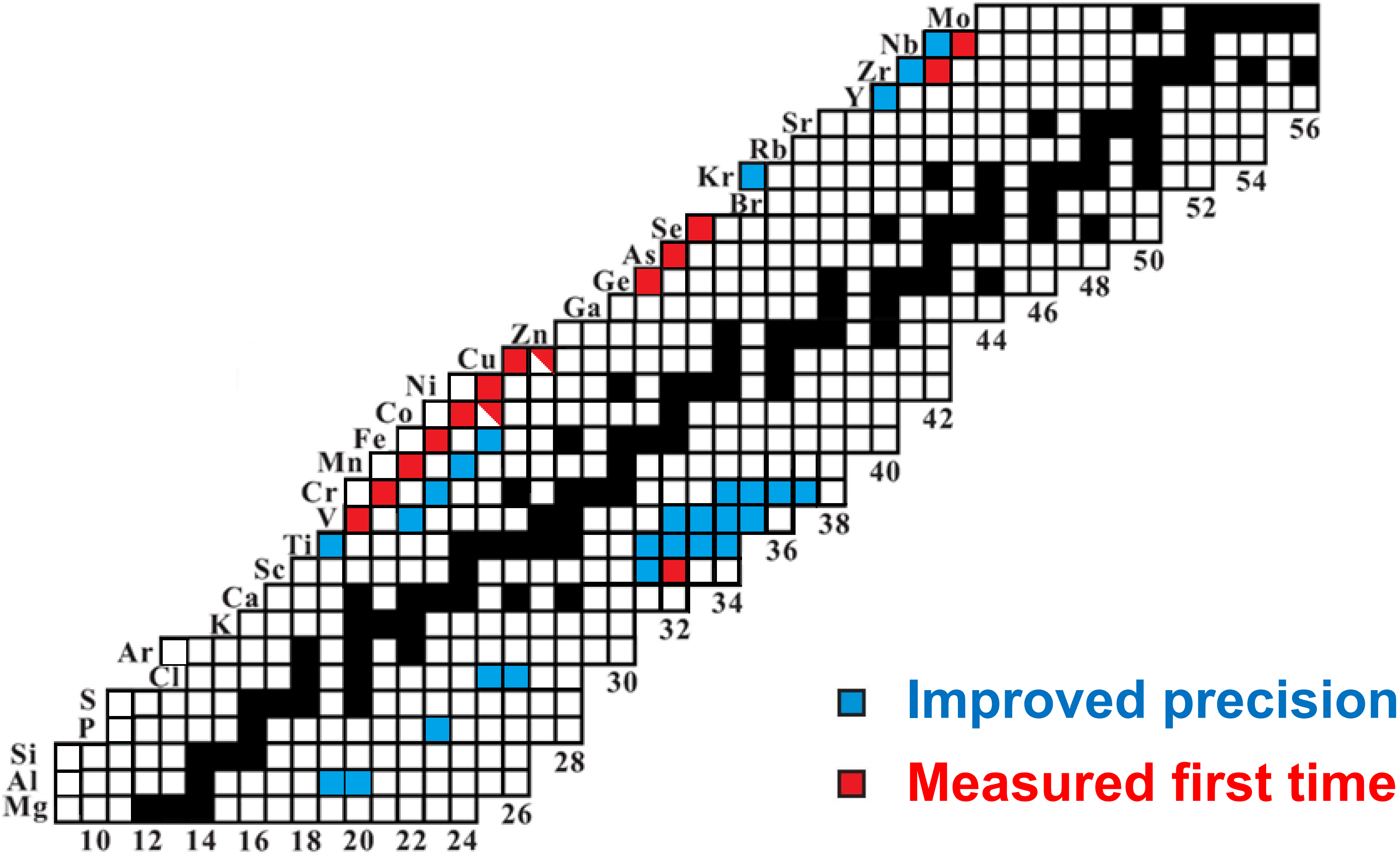
Beams: ^{78}Kr, ^{58}Ni, ^{86}Kr,



- Improved precision
- Measured first time

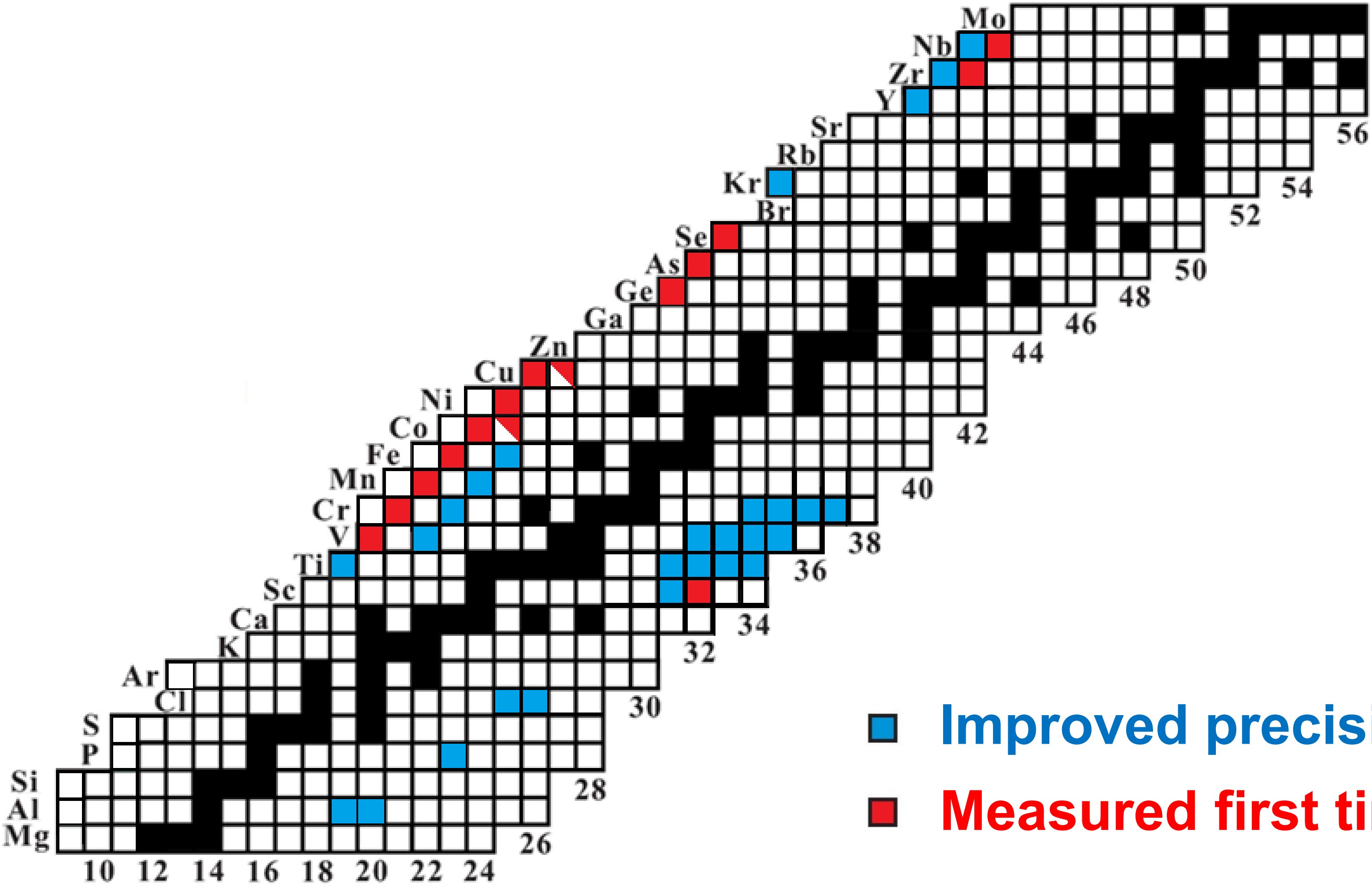
Overview of experimental results

Beams: ^{78}Kr, ^{58}Ni, ^{86}Kr,



Overview of experimental results

Beams: ^{78}Kr, ^{58}Ni, ^{86}Kr, ^{112}Sn,

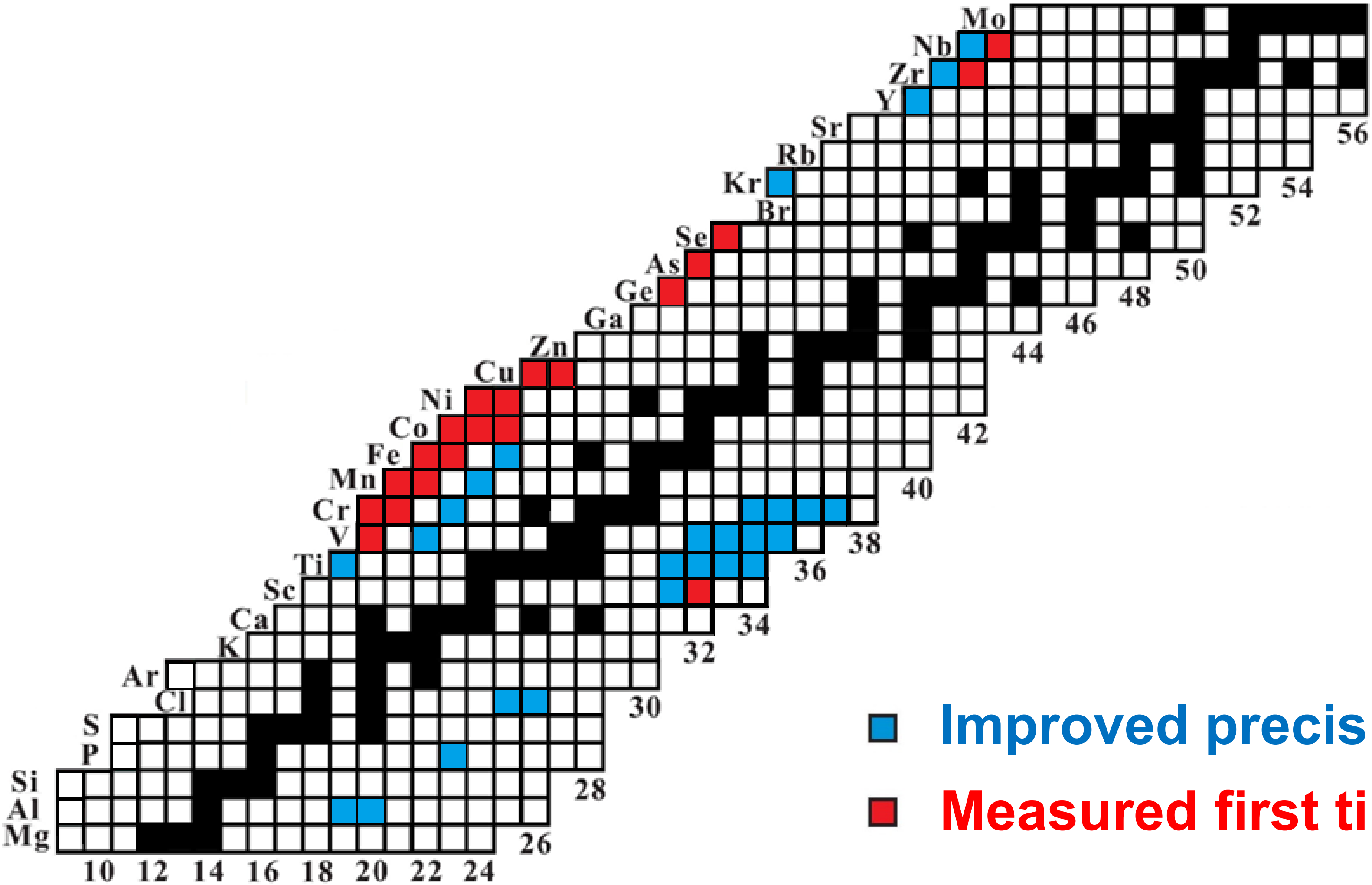


■ Improved precision

■ Measured first time

Overview of experimental results

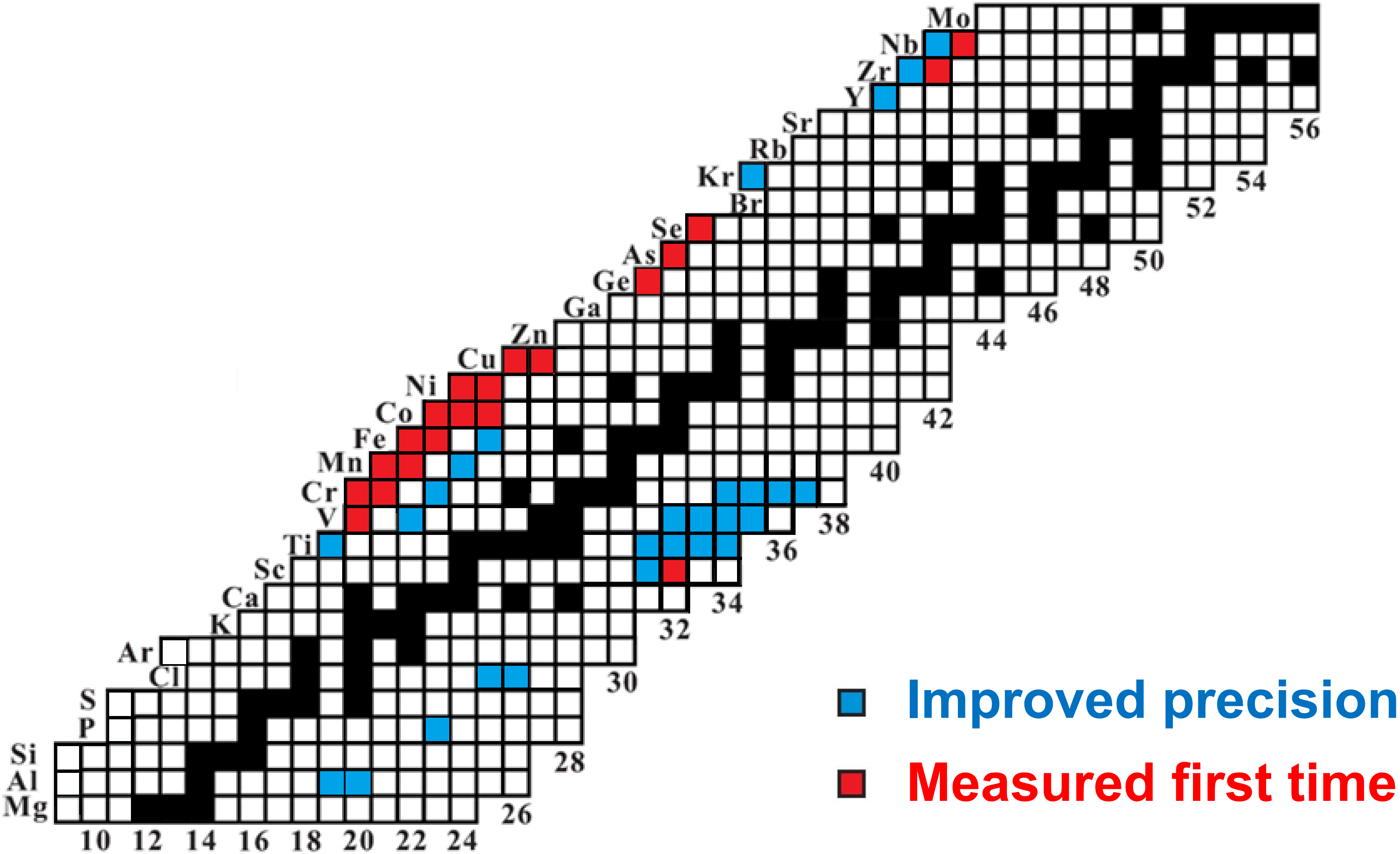
Beams: ^{78}Kr, ^{58}Ni, ^{86}Kr, ^{112}Sn,



- Improved precision
- Measured first time

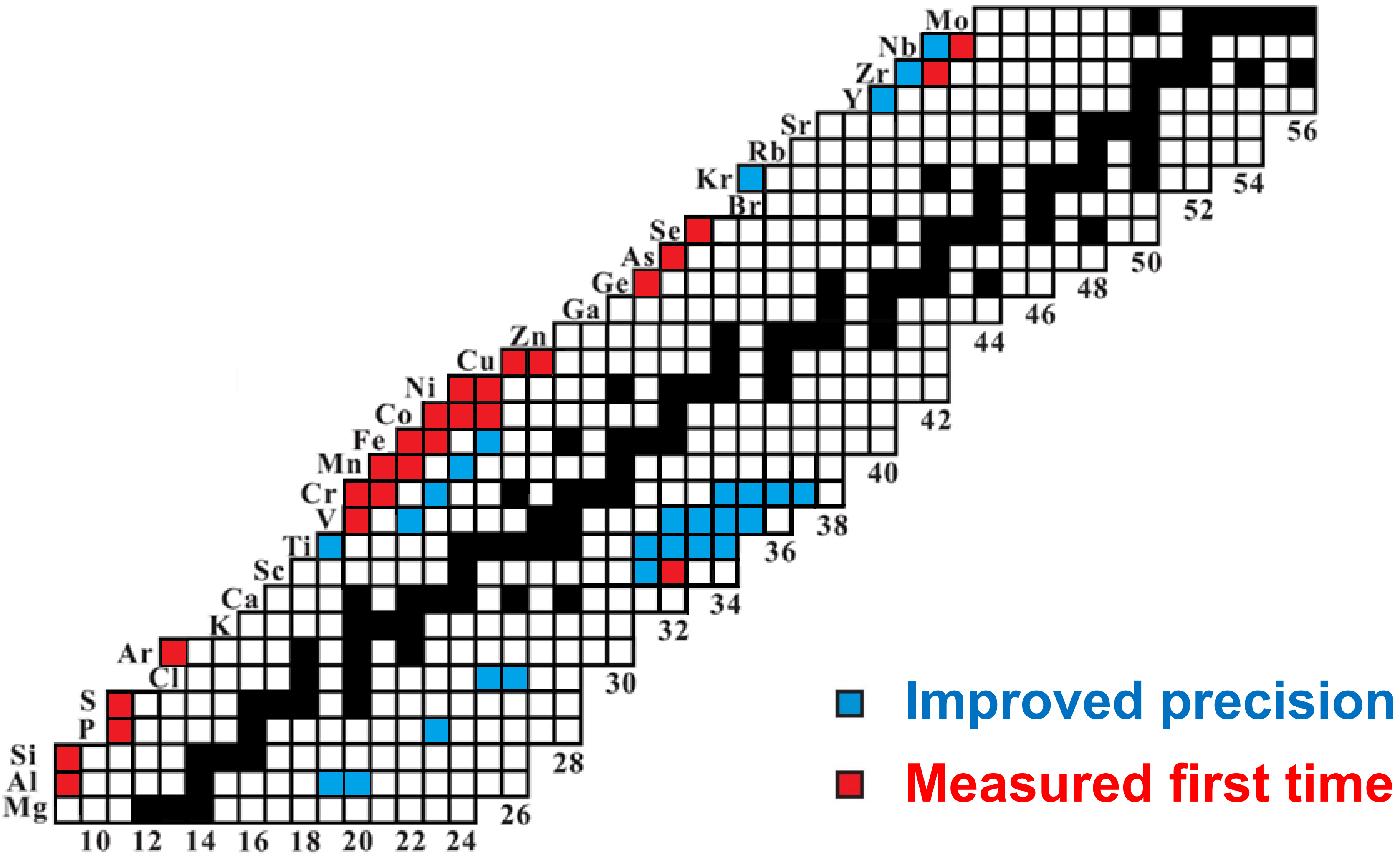
Overview of experimental results

Beams: ^{78}Kr, ^{58}Ni, ^{86}Kr, ^{112}Sn, ^{58}Ni,



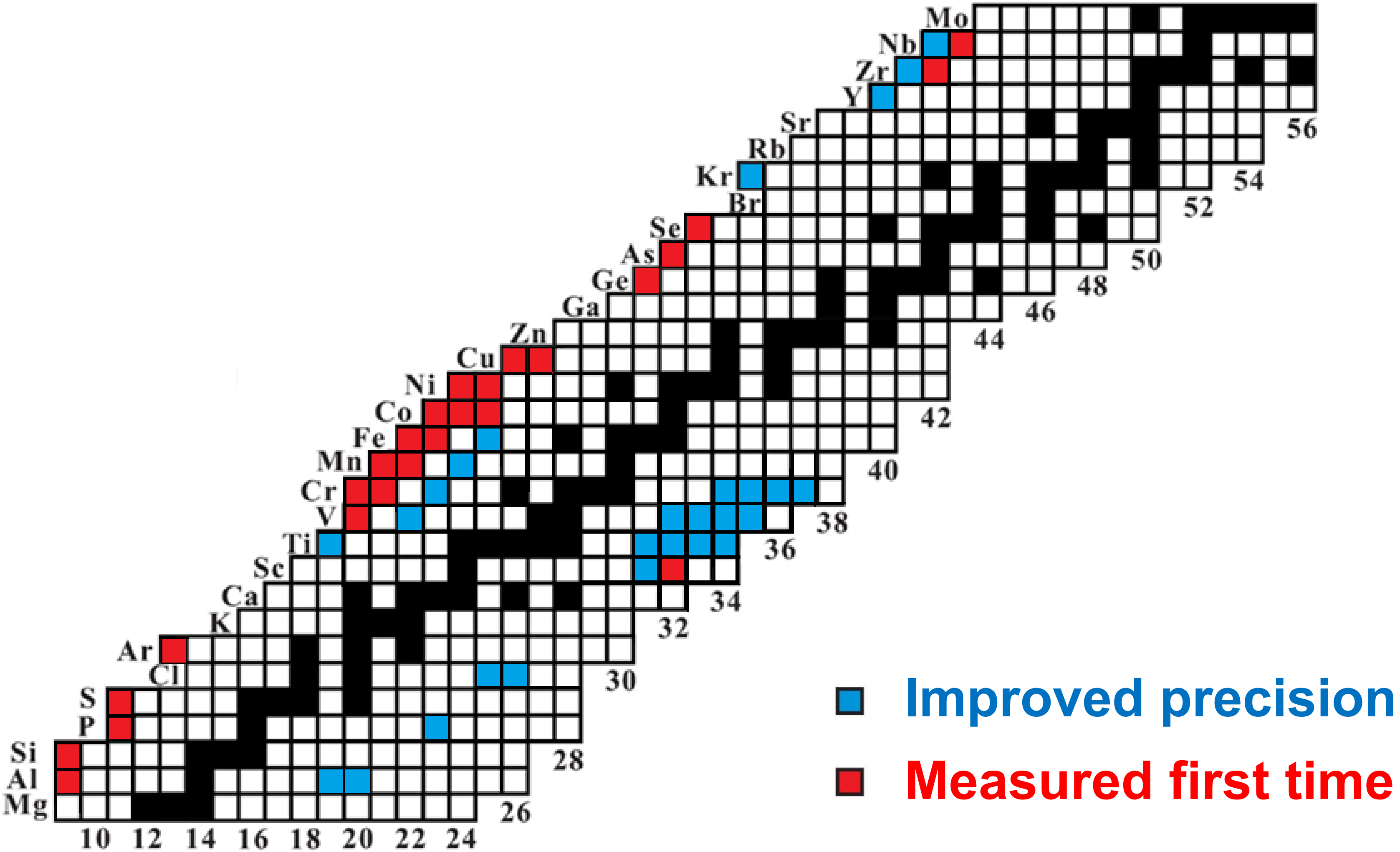
Overview of experimental results

Beams: **^{78}Kr, ^{58}Ni, ^{86}Kr, ^{112}Sn, ^{58}Ni,**



Overview of experimental results

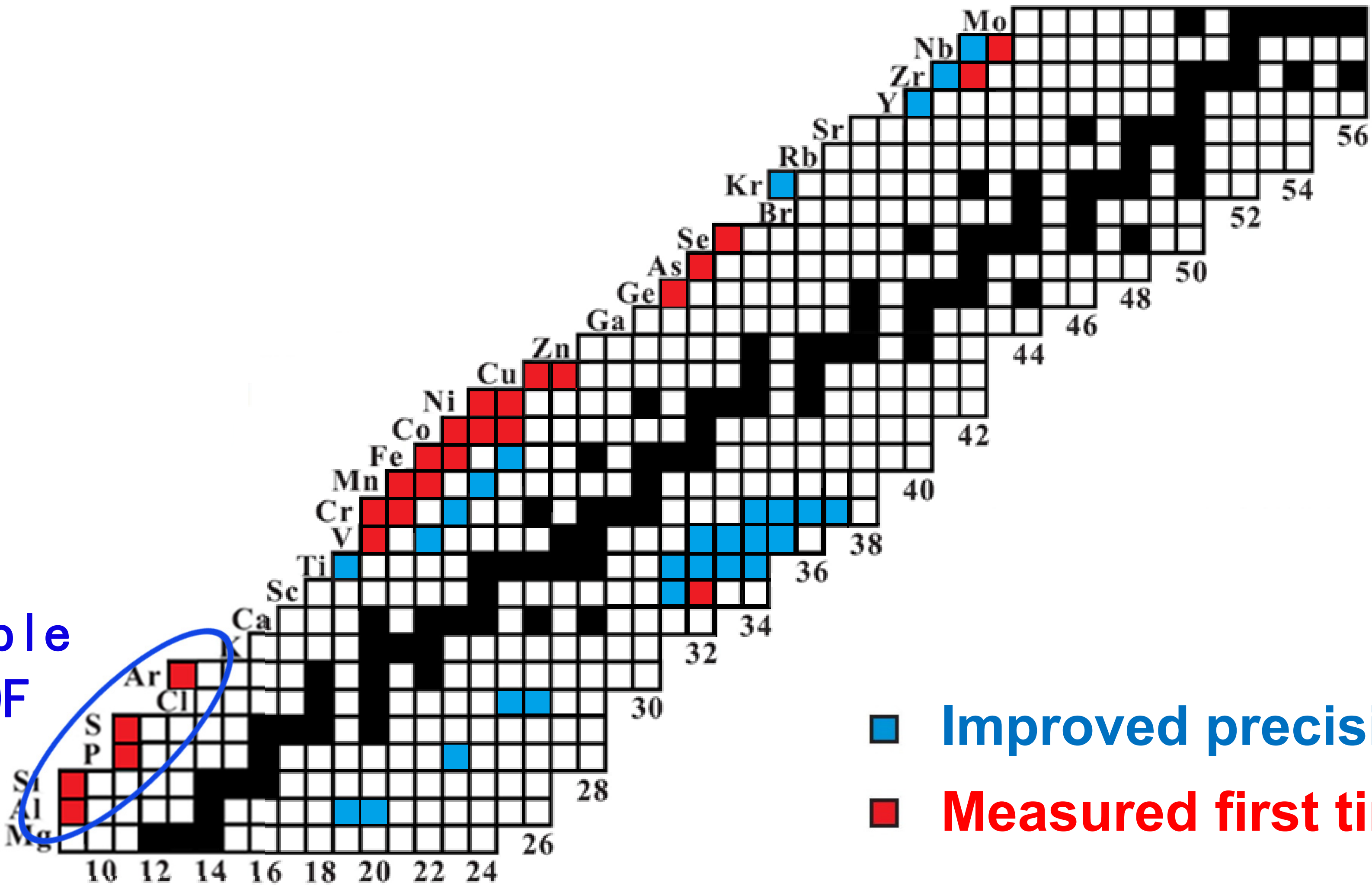
Beams: ^{78}Kr, ^{58}Ni, ^{86}Kr, ^{112}Sn, ^{58}Ni, ^{36}Ar



Overview of experimental results

Beams: ^{78}Kr, ^{58}Ni, ^{86}Kr, ^{112}Sn, ^{58}Ni, ^{36}Ar

Double TOF



- Improved precision
- Measured first time

Overview of experimental results

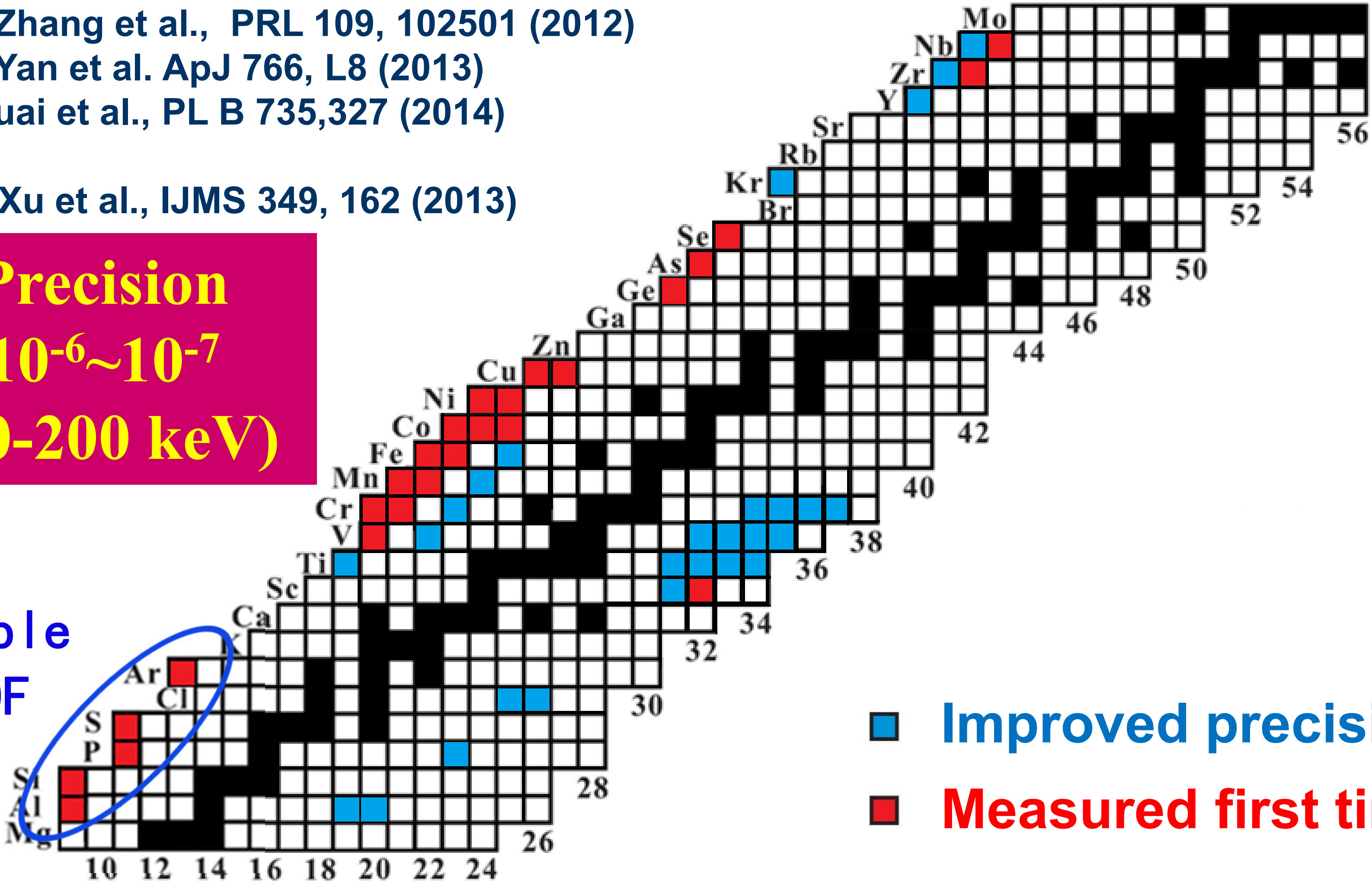
Beams: ^{58}Ni, ^{86}Kr, ^{112}Sn, ^{58}Ni, ^{36}Ar, ^{78}Kr,

X. L. Tu et al., PRL 106, 112501 (2011)
Y. H. Zhang et al., PRL 109, 102501 (2012)
X. L. Yan et al. ApJ 766, L8 (2013)
P. Shuai et al., PL B 735,327 (2014)

H. S. Xu et al., IJMS 349, 162 (2013)

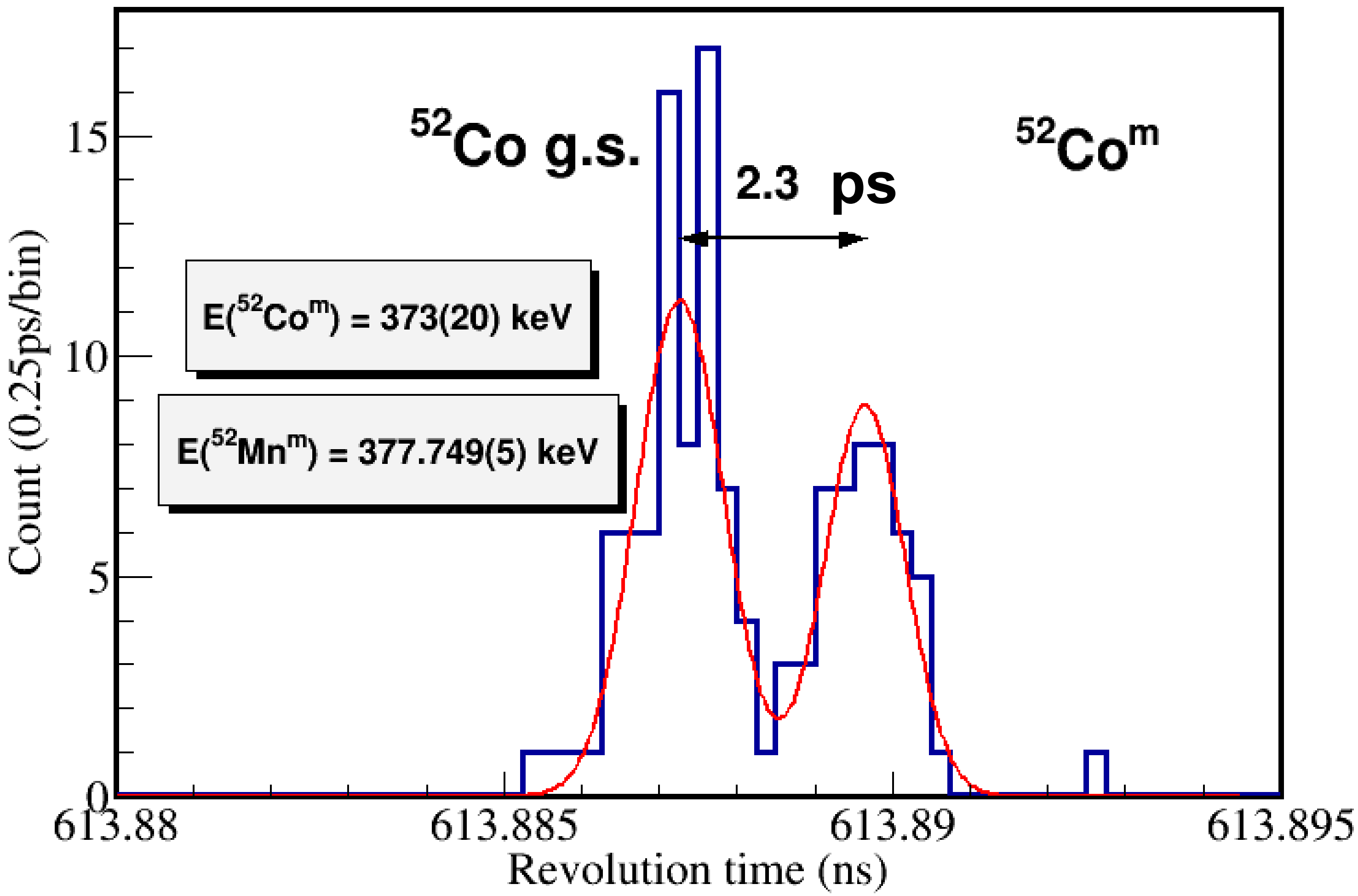
Precision
10^{-6}~10^{-7}
(20-200 keV)

Double TOF



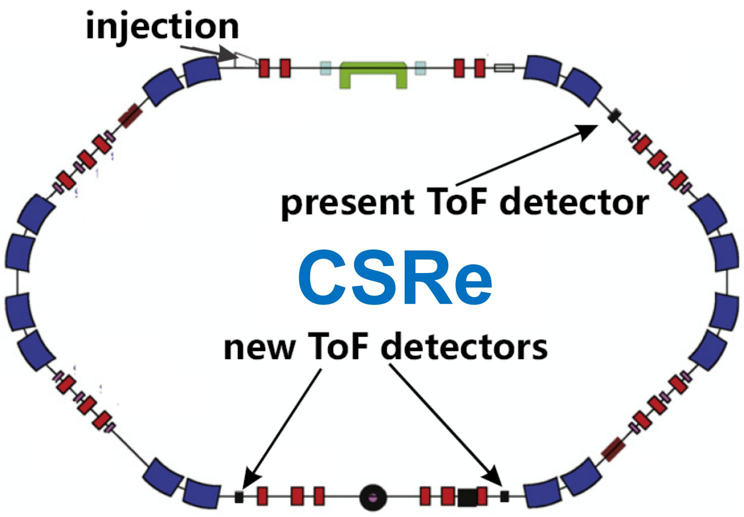
■ Improved precision
■ Measured first time

Highest resolving power of single ToF IMS

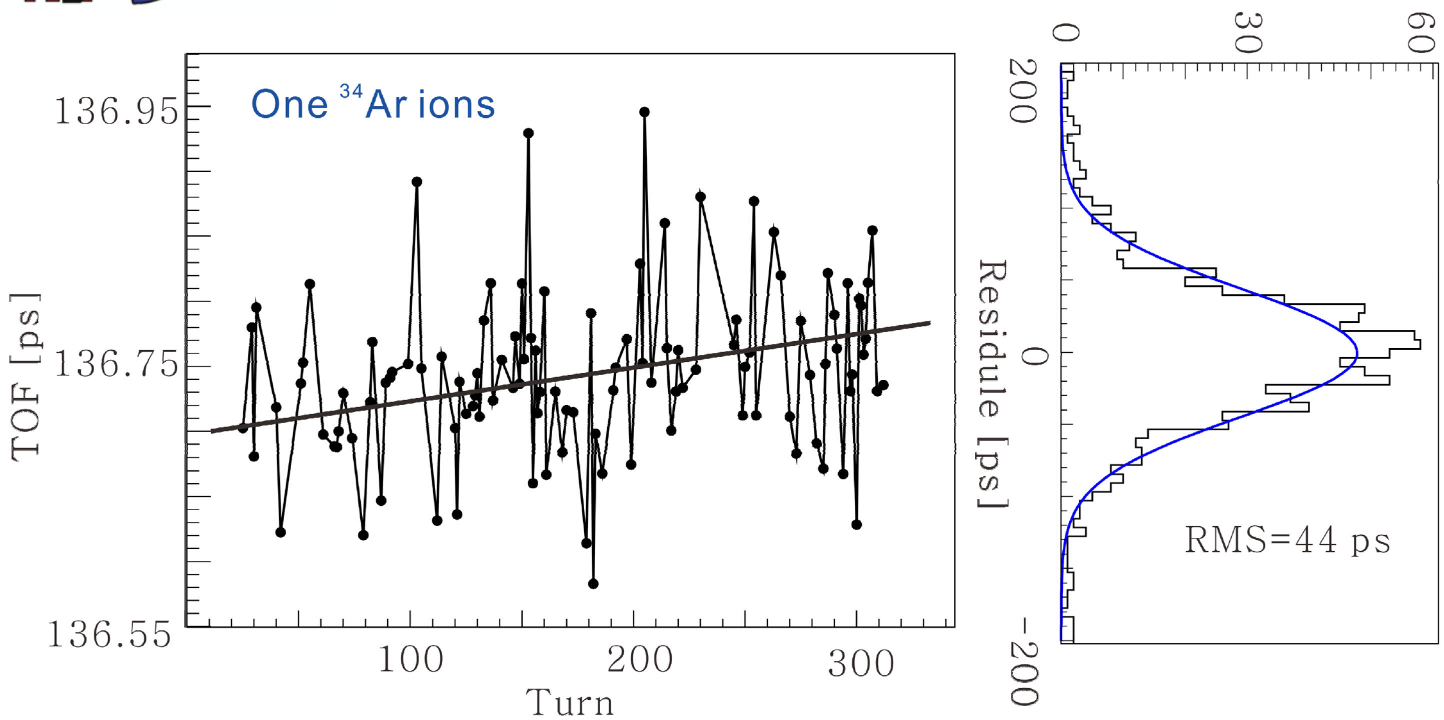


$$\frac{m}{\Delta m_{(FWHM)}} = 250{,}000$$

Preliminary results of double ToF IMS



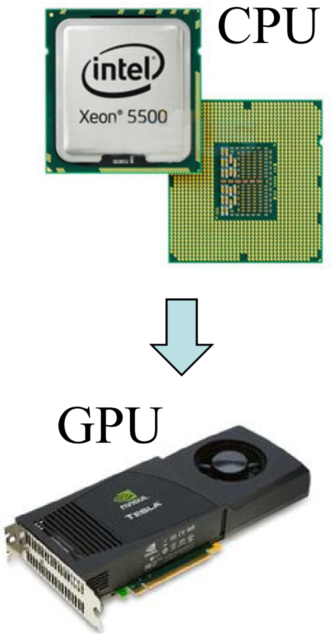
1. intrinsic resolution of TOF detector: **30 ps**
2. accuracy of velocity measurement: $\mathbf{10^{-4}}$

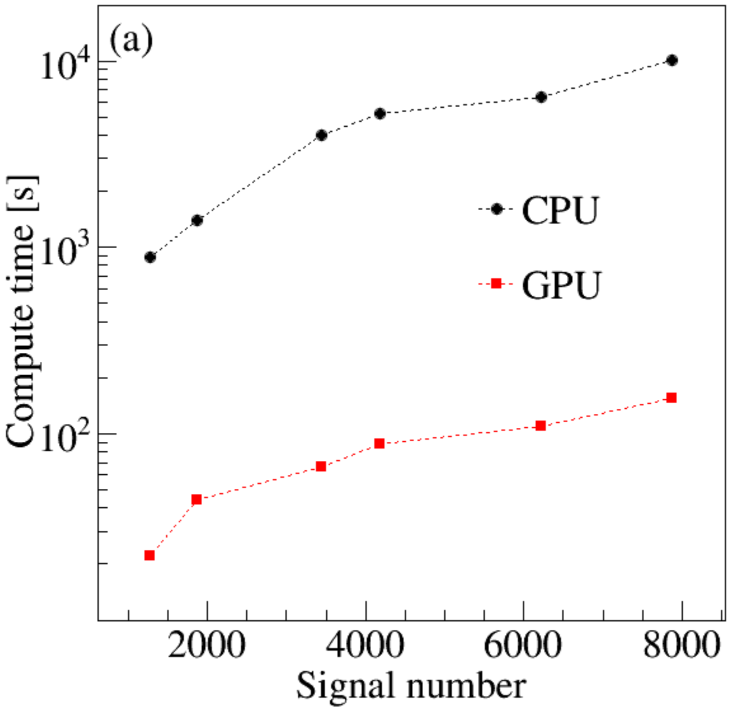


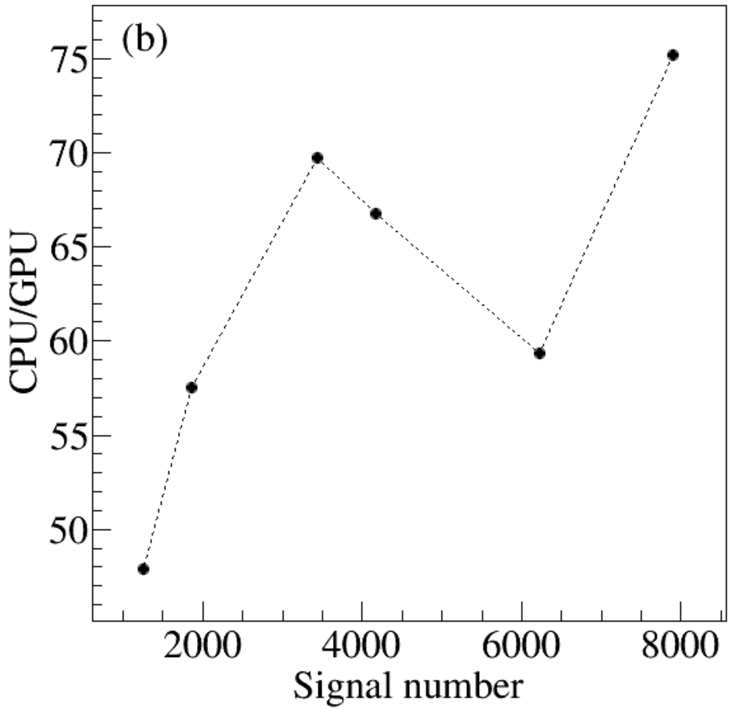
Upgrade data analysis with GPU

Realize real-time data analysis for each injection.

	1272 signals	1870 signals	3543 signals	4177 signals	6232 signals	7896 signals
CPU	862	1380	3972	5208	6406	10066
GPU	18	24	57	78	108	134





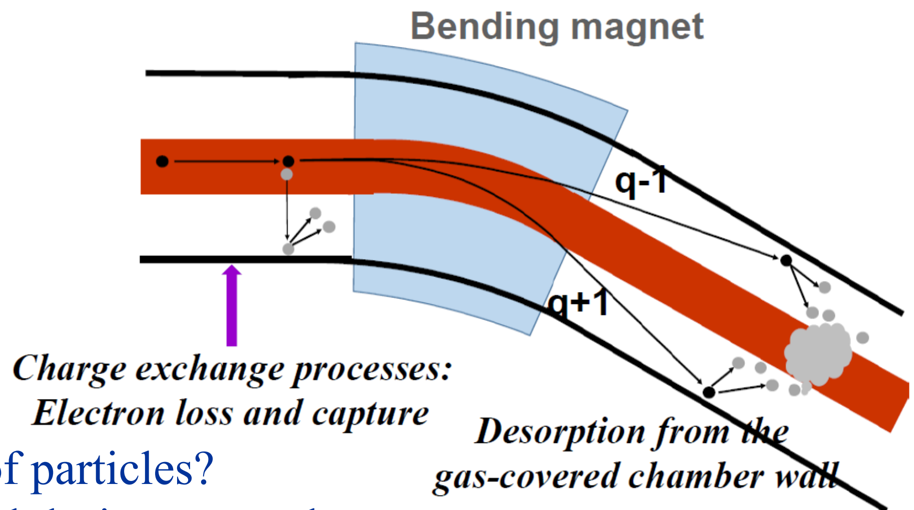


- **Status of HIRFL**
- ***Activities of Upgrading***
  - **SSC-Linac injector**
  - **Electron cooling at CSR**
  - **Laser cooling at CSRe**
  - **Stochastic cooling at CSRe**
  - **Isochronous mass spectrometry**
  - ***Vacuum collimation at CSRm***
- **HIAF project**

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

Vacuum Collimation at CSRm

To maintain extra-low and stable vacuum pressure



Beam loss mechanism:

Charge exchange of intermediate charge state ions ($^{238}U^{34+}$) **due to collision**

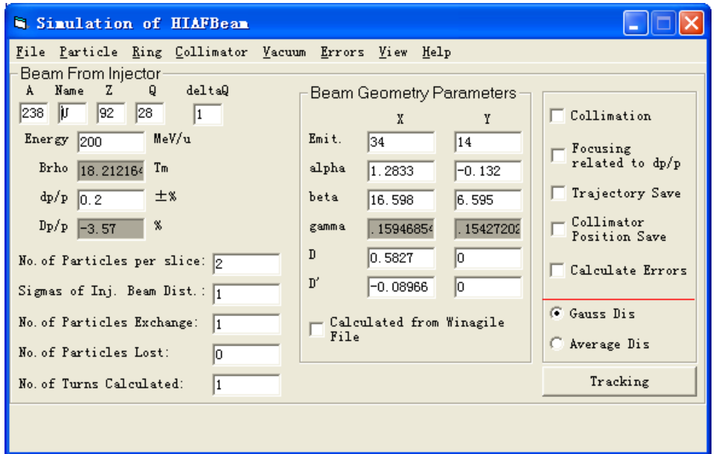
$U^{34+} + X^{n+} \rightarrow U^{35+} + X$ Stripping

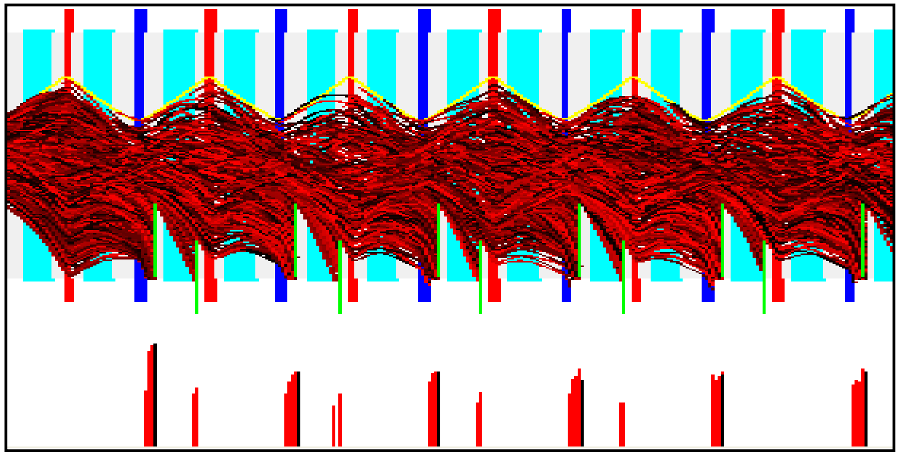
$U^{34+} + X^{n+} \rightarrow U^{33+} + X$ Capture

Challenges:

- How to get the high collimation efficiency?
- How to optimize lattices for different types of particles?
- How to design the collimator? the mechanical design, control system, vacuum system test.

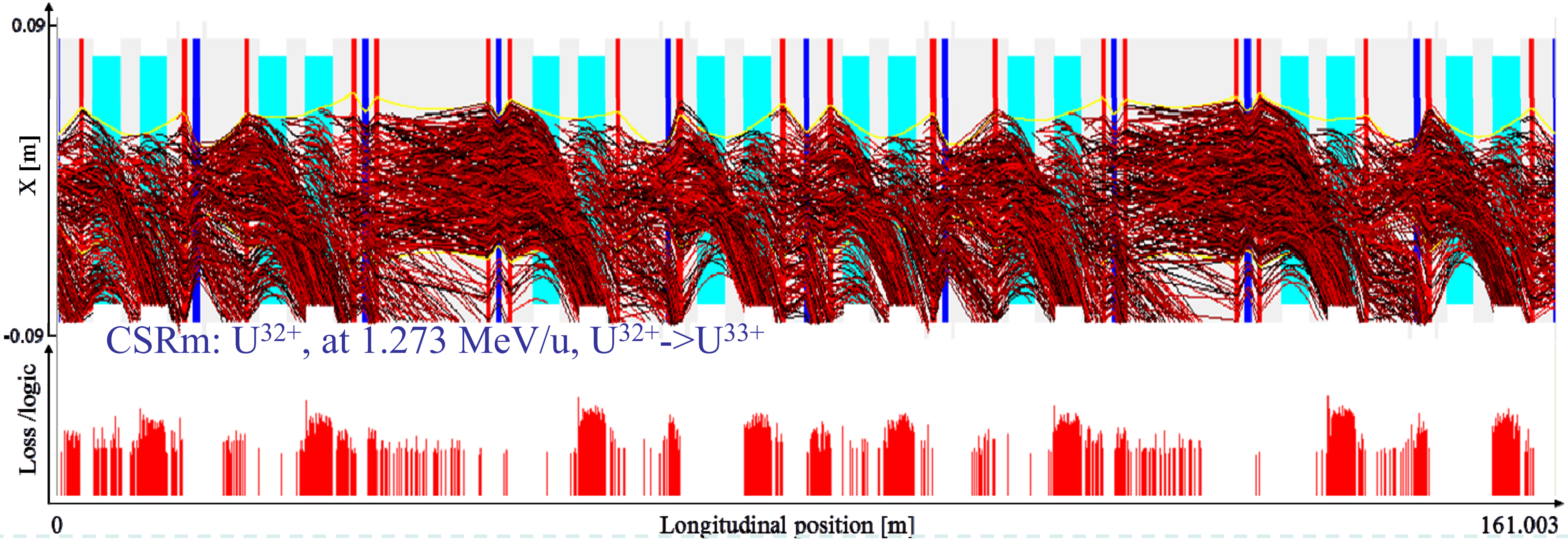
A dedicated dynamic vacuum simulation code HIAF-DYSD has been developed for the optimization of dynamics design.



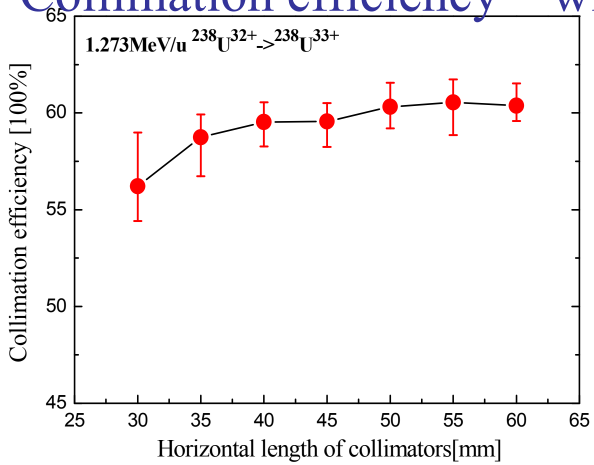


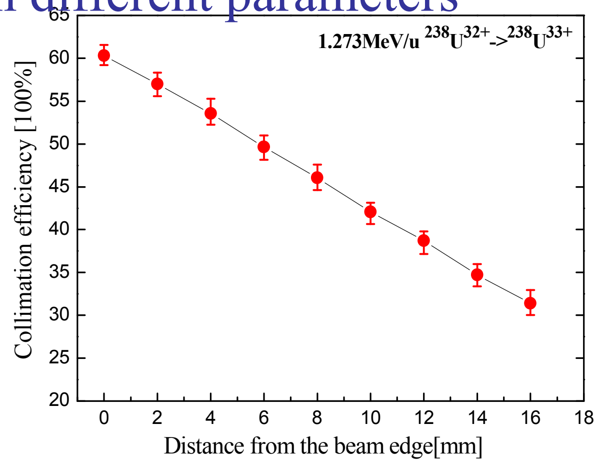
Vacuum Collimation at CSRm

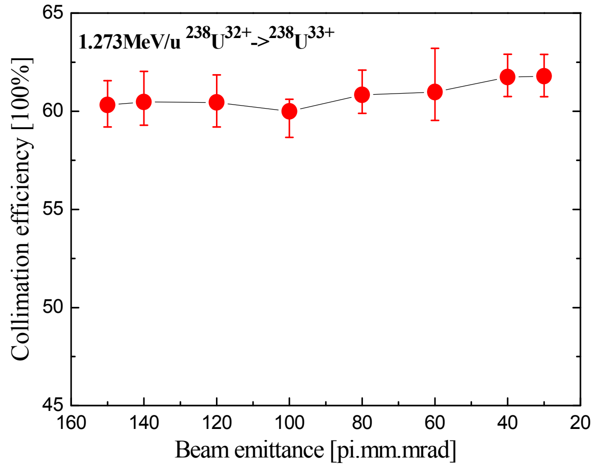
Study of collimation efficiency with different parameters



Collimation efficiency – with different parameters







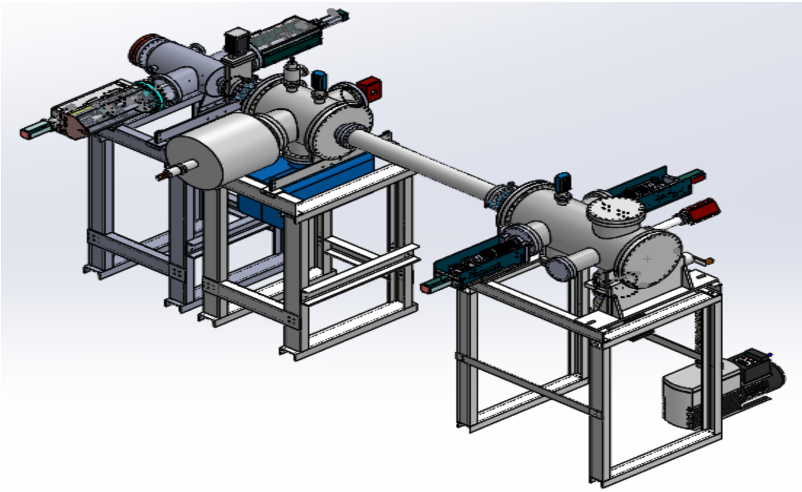
Collimation at CSRm

Preparation of desorption and collimation study experiments

First step - Test platform

Desorption measurement

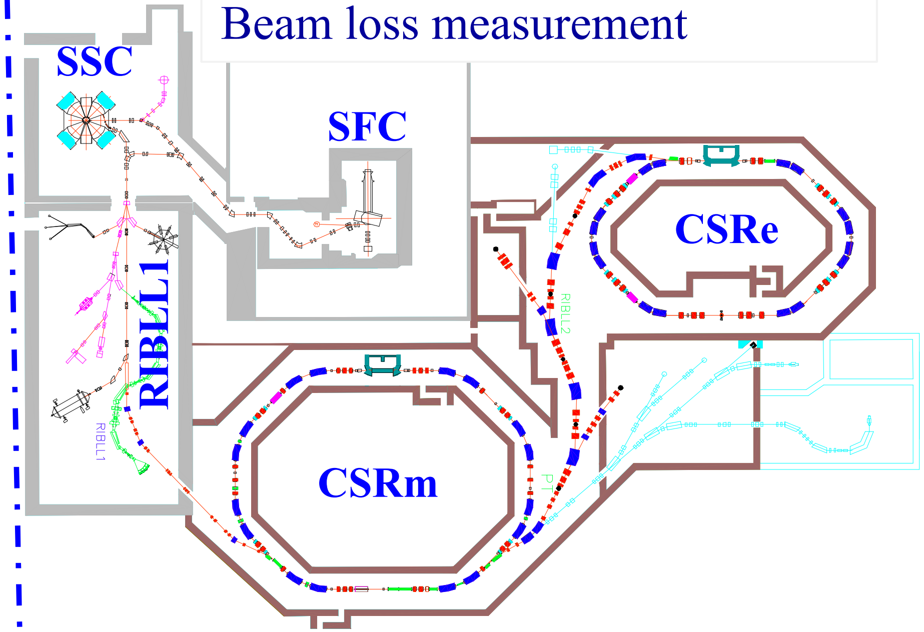
Install at PISA or E-point



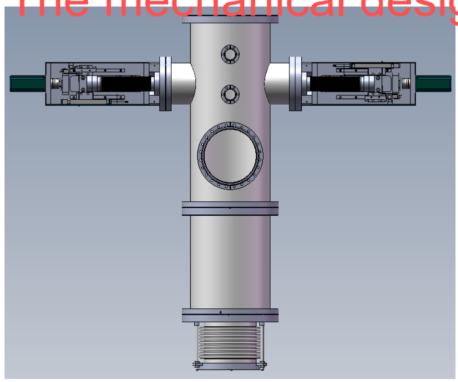
Second step –

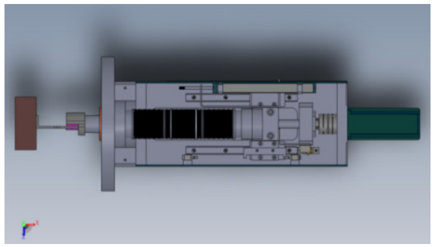
Collimator prototype of CSRm

Beam loss measurement

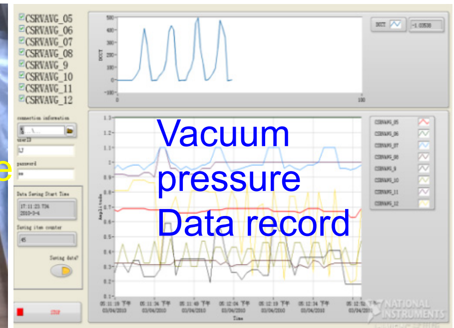


The mechanical design has been finished





Fabrication of hardware components



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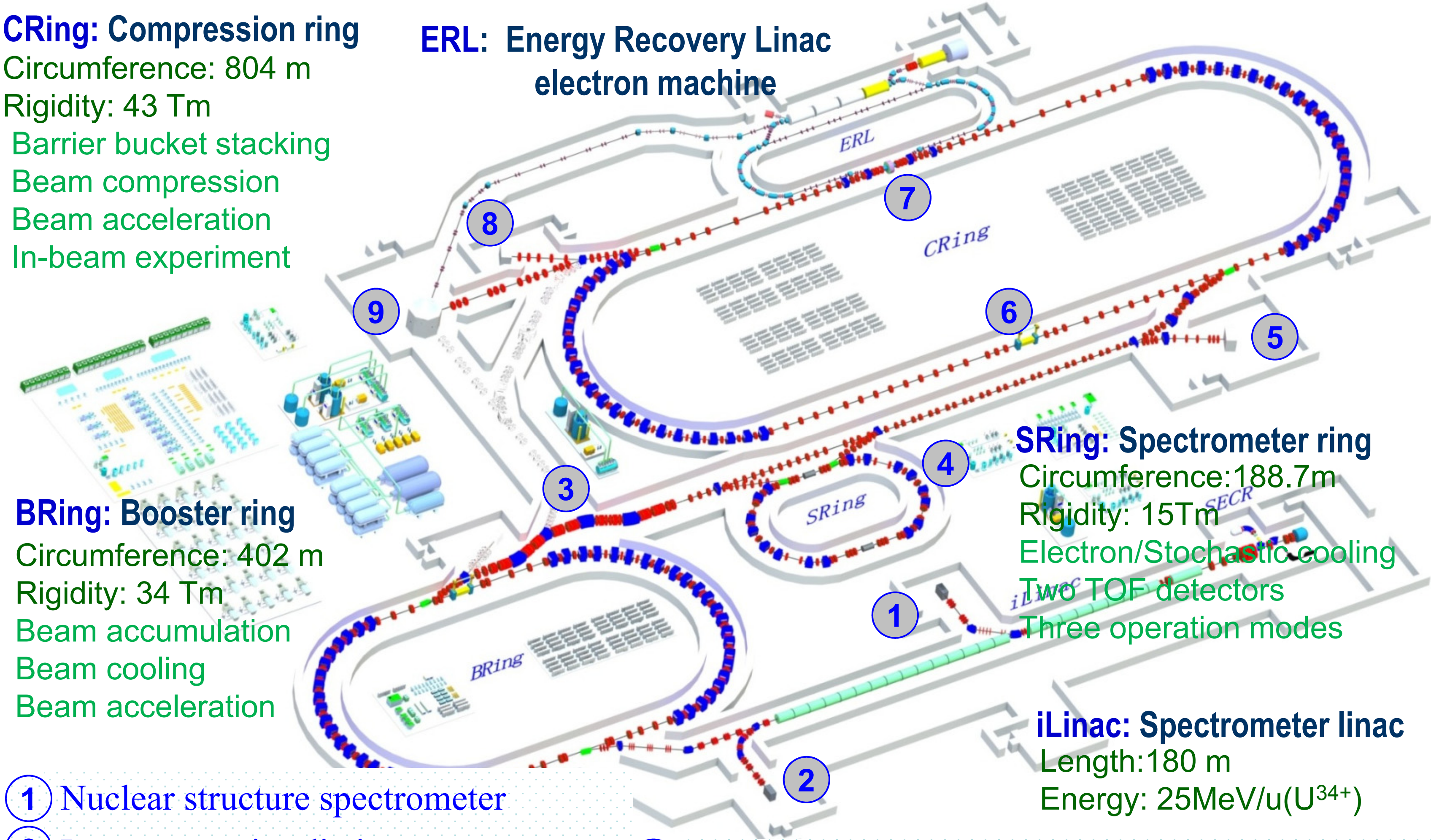
- ***HIAF project***

Layout of HIAF

CRing: Compression ring
Circumference: 804 m
Rigidity: 43 Tm
Barrier bucket stacking
Beam compression
Beam acceleration
In-beam experiment

ERL: Energy Recovery Linac electron machine



SRing: Spectrometer ring
Circumference:188.7m
Rigidity: 15Tm
Electron/Stochastic cooling
Two TOF detectors
Three operation modes

BRing: Booster ring
Circumference: 402 m
Rigidity: 34 Tm
Beam accumulation
Beam cooling
Beam acceleration

iLinac: Spectrometer linac
Length:180 m
Energy: 25MeV/u(U^{34+})

1. Nuclear structure spectrometer
2. Low energy irradiation target
3. RIBs beam line
4. High precision spectrometer ring
5. External target station
6. Electron-ion recombination spectroscopy
7. Electron-Nucleus Collision (ENC)
8. High Energy Density Physics target
9. High energy irradiation target

Main Parameters of HIAF

Unprecedented beam Intensity(Comparison with HIRFL):

- Primary beam intensity increases by x 1000 – x 10000
- secondary beam intensity increases by up to x 10000

Precisely-tailored beams

- beam cooling (*Electron, Stochastic, laser; high quality, very small spot*)
- Beam compression (*Ultra-short bunch length: 50-100ns*)
- super long period slow extraction (*Super long, high energy, quasi-continuous beam*)

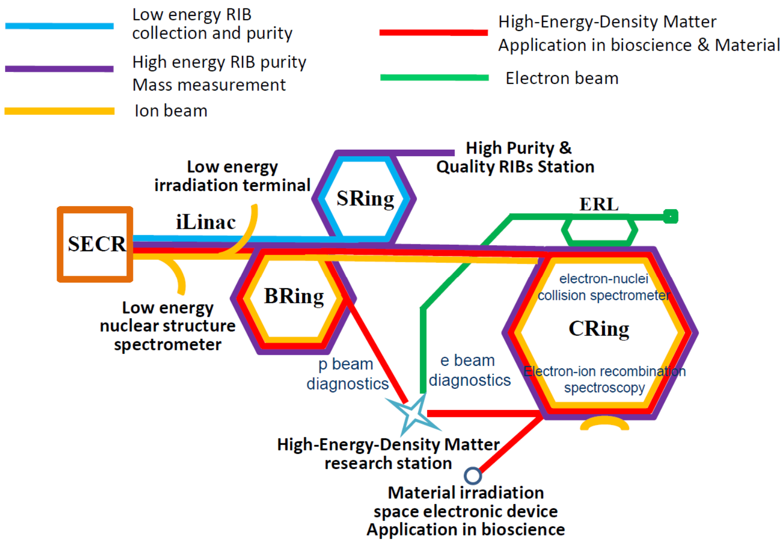
Wide beam Energy:

- heavy-ion energy : x 10 – x 15

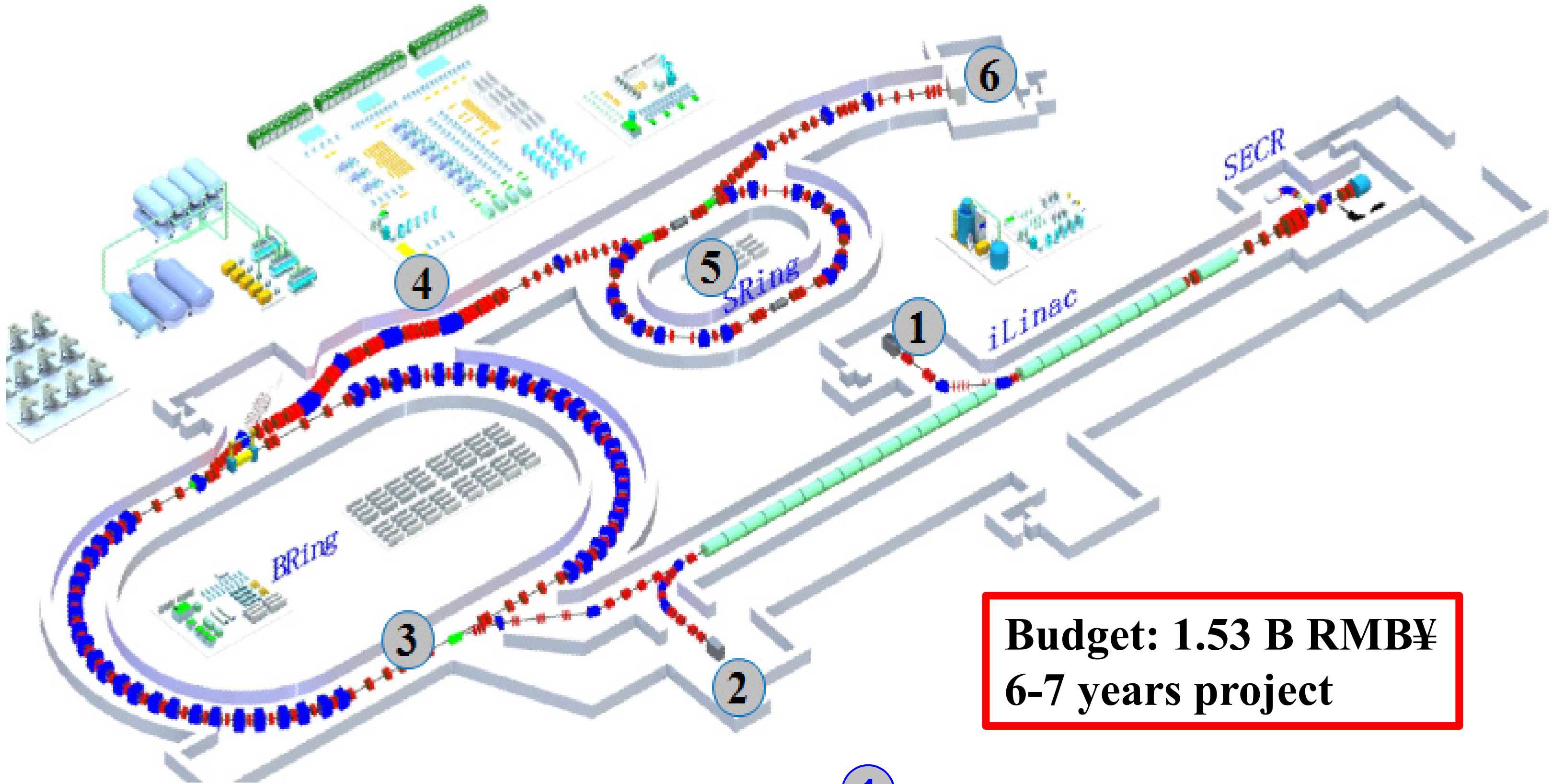
Versatile operation modes:

- parallel operation, beam splitting (*increase of target time, high integrated luminosity*)

	Ions	Energy	Intensity
SECR	U^{34+}	14 keV/u	0.05 pmA
iLinac	U^{34+}	25 MeV/u	0.028 pmA
BRing	U^{34+}	0.8 GeV/u	~1.4×10^{11} ppp
CRing	U^{34+}	1.1 GeV/u	~5.0×10^{11} ppp
	U^{92+}	4.1 GeV/u	~2.0×10^{11} ppp



First phase of HIAF



Budget: 1.53 B RMB¥
6-7 years project

	Ions	Energy	Intensity
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iLinac	U^{34+}	17 MeV/u	0.028 pmA
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Thanks for your attention!