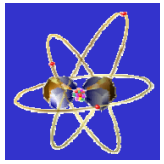
Status of HIRFL-CSR

Youjin Yuan



Institute of Modern Physics (IMP)

Chinese Academy of Sciences (CAS)

RuPAC'08,Zvenigorod

9/29/2008

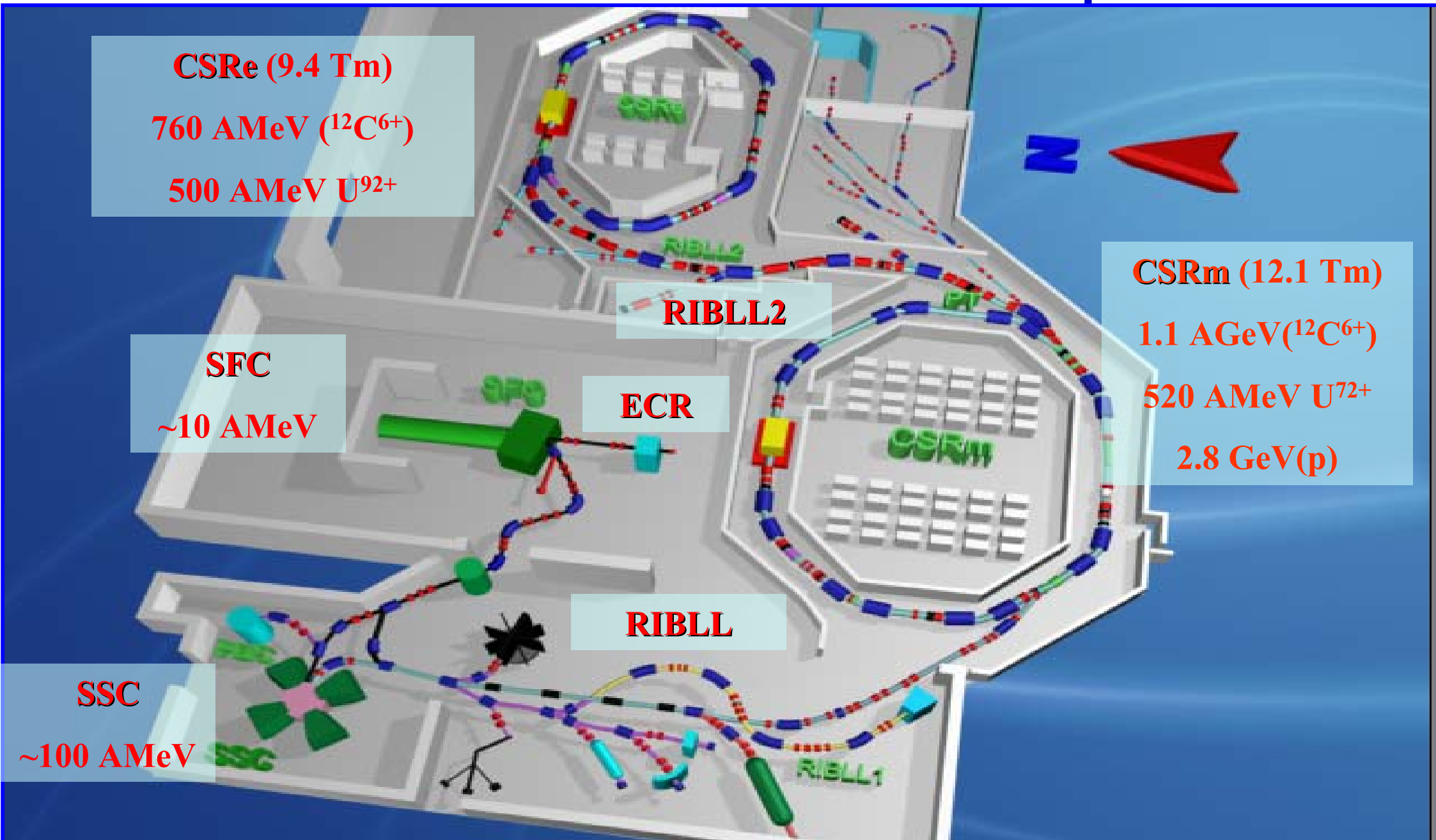
Brief introduction of CSR Project

Heavy-ion Cooler Storage Ring project
Heavy-Ion Research Facilty in Lanzhou
National Laboratory of Heavy-Ion Accelerators in Lanzhou

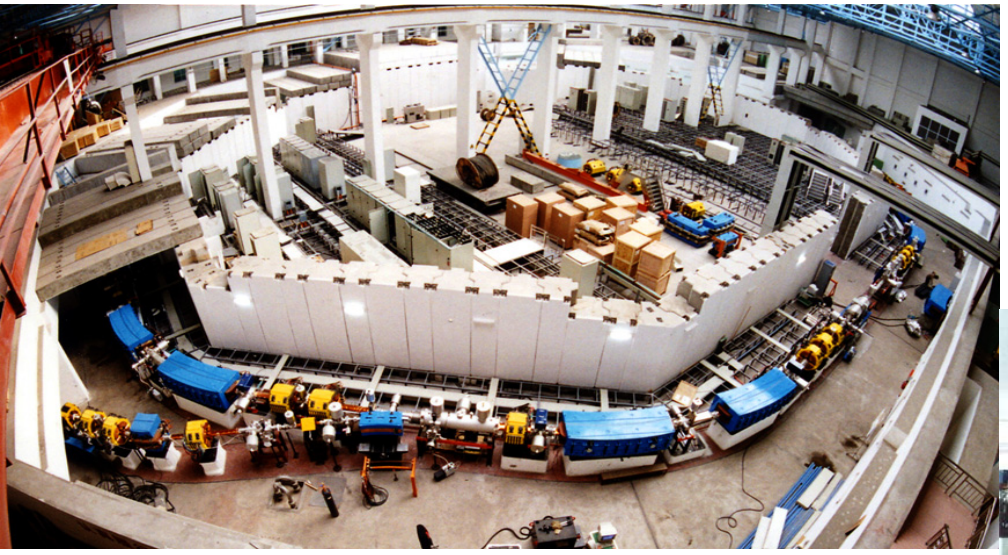
1993	Original idea
1996	Proposal
1998	Approved
2000-2005	Construction
2006-2007	Commissioning
2008	Operating

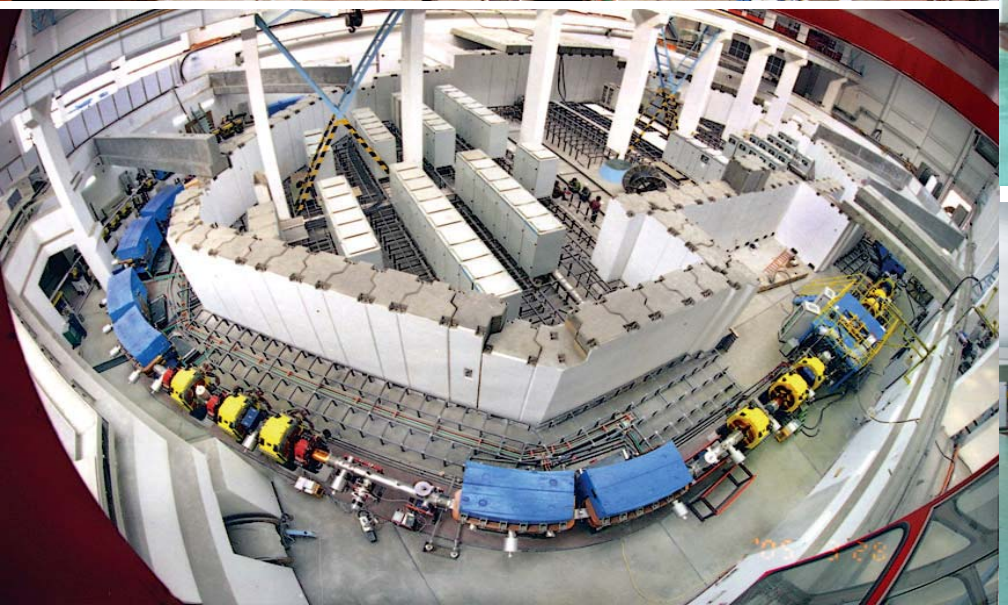
Layout of HIRFL

ECR+SFC+SSC+CSRm+CSRe complex



HIRFL-CSR





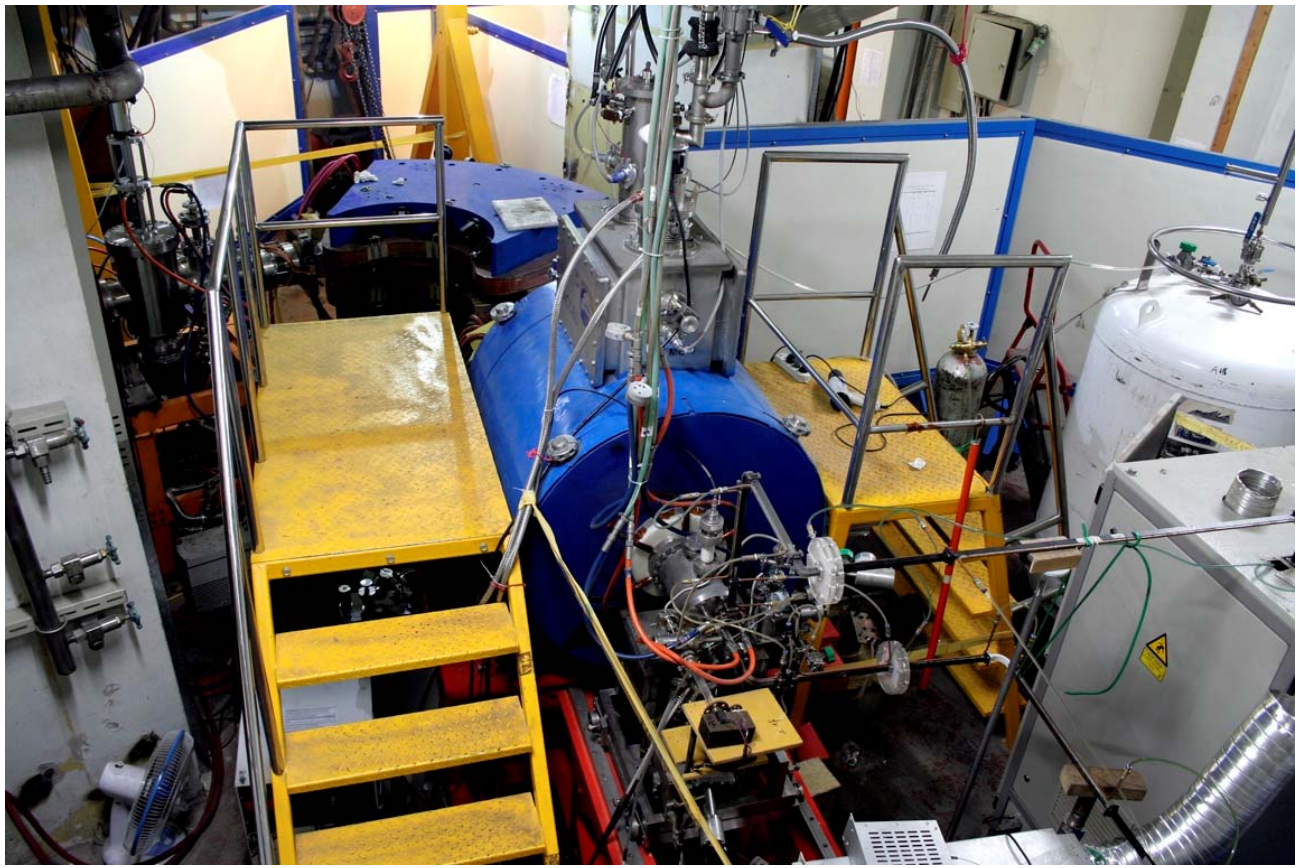
Main Physics Goals at HIRFL-CSR

- **Nuclear Structure and Decay Property**
- **Heavy Element and New Nuclide Synthesis**
- **EOS of Nuclear Matter**
- **Hadron-Nucleon Physics in E <1.1 AGeV HI & <2.88GeV (3.7GeV/c) Proton**
- **High Charge State of Atomic Physics**
- **Large Molecule Ions Fragmentation**
- **High Energy Density Physics**
- **Nuclear Astrophysics**
- **Applications: Material, Biology, Cancer Therapy, Microelectronics and Space Industries**

Superconducting ECR Source made in IMP

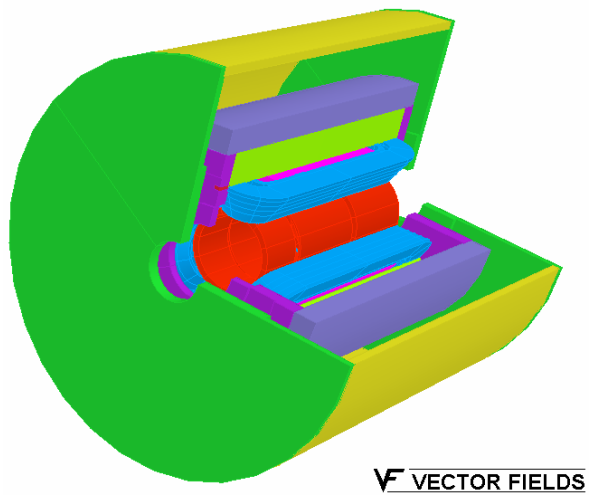
Results (eμA) at 18GHz SECRaL

^{16}O	6^+	2300
	7^+	810
^{40}Ar	11^+	810
	12^+	510
	14^+	270
	16^+	73
	17^+	8.5
^{129}Xe	20^+	505
	26^+	410
	27^+	306
	30^+	101
	31^+	68
^{40}Ca	16^+	75
	19^+	2.25
Pb	30^+	90
	34^+	18



33+ 31
37+ 5
38+ 2.4

SECRAL



Injector SFC (Sector Focus Cyclotron)

Many β-delayed new nuclei were synthesized at SFC

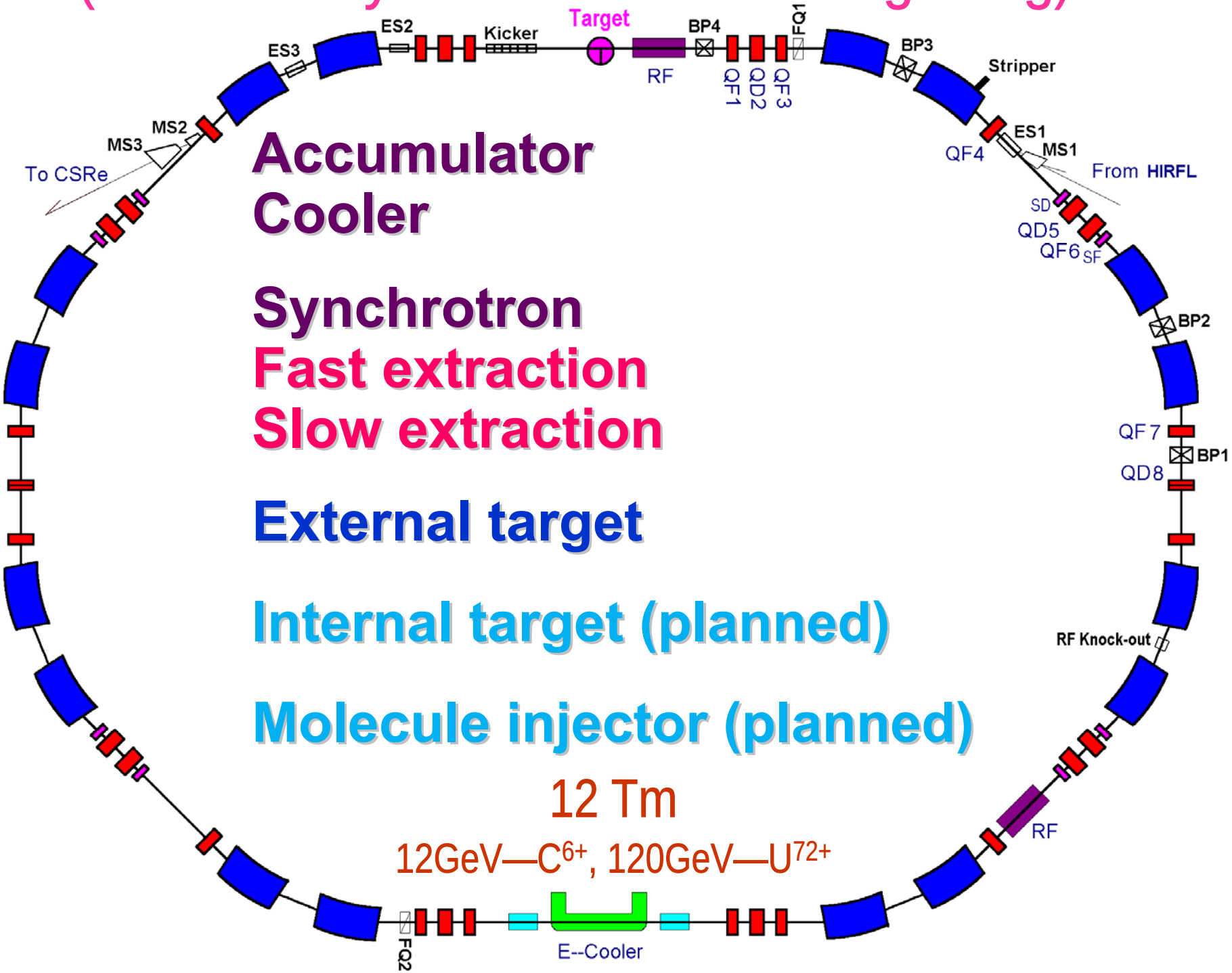
K ~ 69, R ~0.75 m, E ~10 MeV/u(C), 1 MeV/u(U), ε~20 π mm mrad, ΔP/P ~ ±0.5%

Injector SSC (Separated Sector Cyclotron)

82 shallow-seated tumor patients have been treated at SSC

K ~ 450, R ~3.2 m, E ~100 MeV/u(C), 10 MeV/u(U), ε~10 π mm mrad, ΔP/P ~ $\pm$0.15%

CSRm (The main synchrotron and storage ring)



Accumulator Cooler

Synchrotron
Fast extraction
Slow extraction

External target

Internal target (planned)

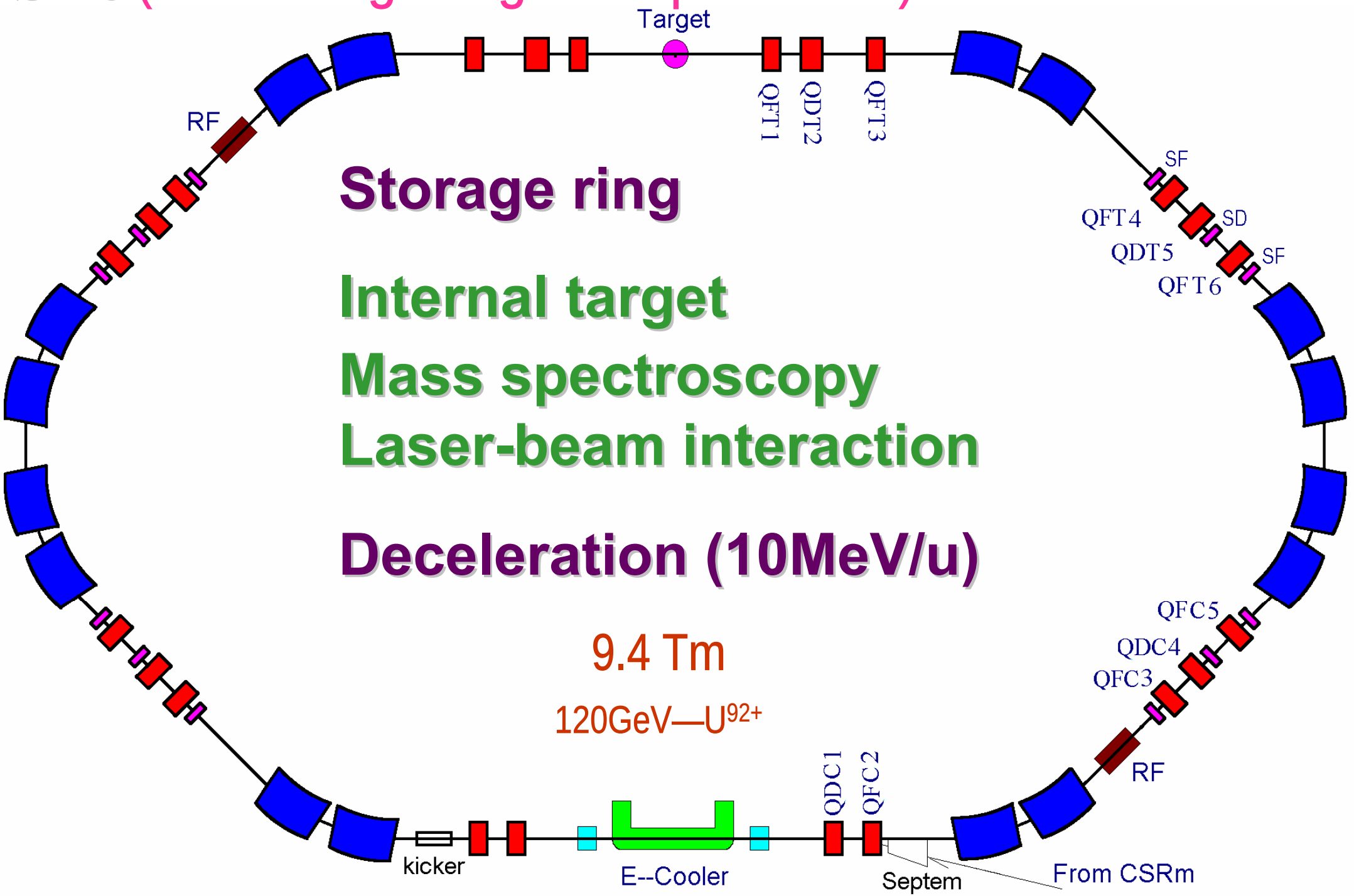
Molecule injector (planned)

12 Tm

12GeV—C^{6+}, 120GeV—U^{72+}

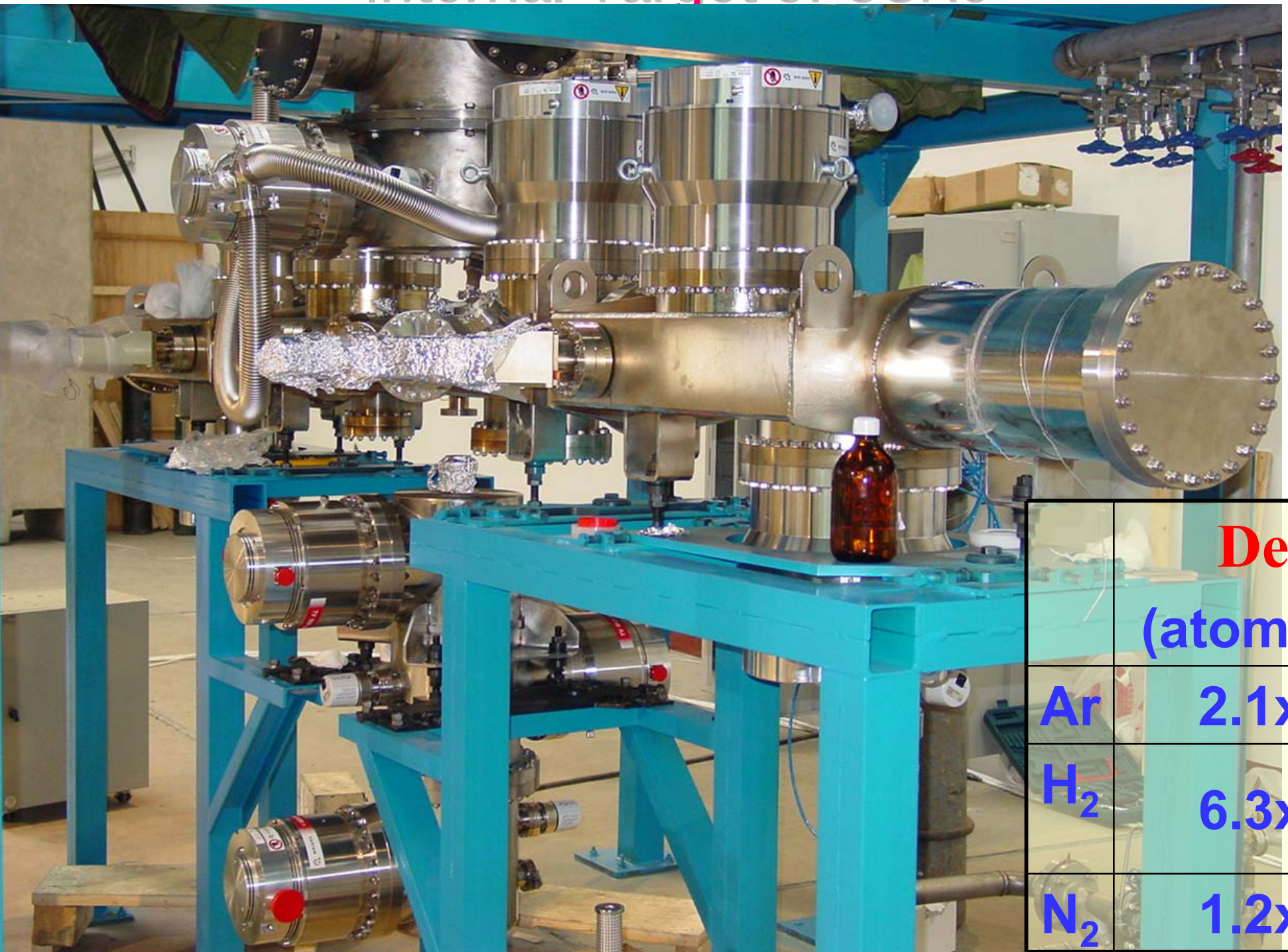
CSRm Tunnel

CSRe (The storage ring for experiments)



CSRe Tunnel

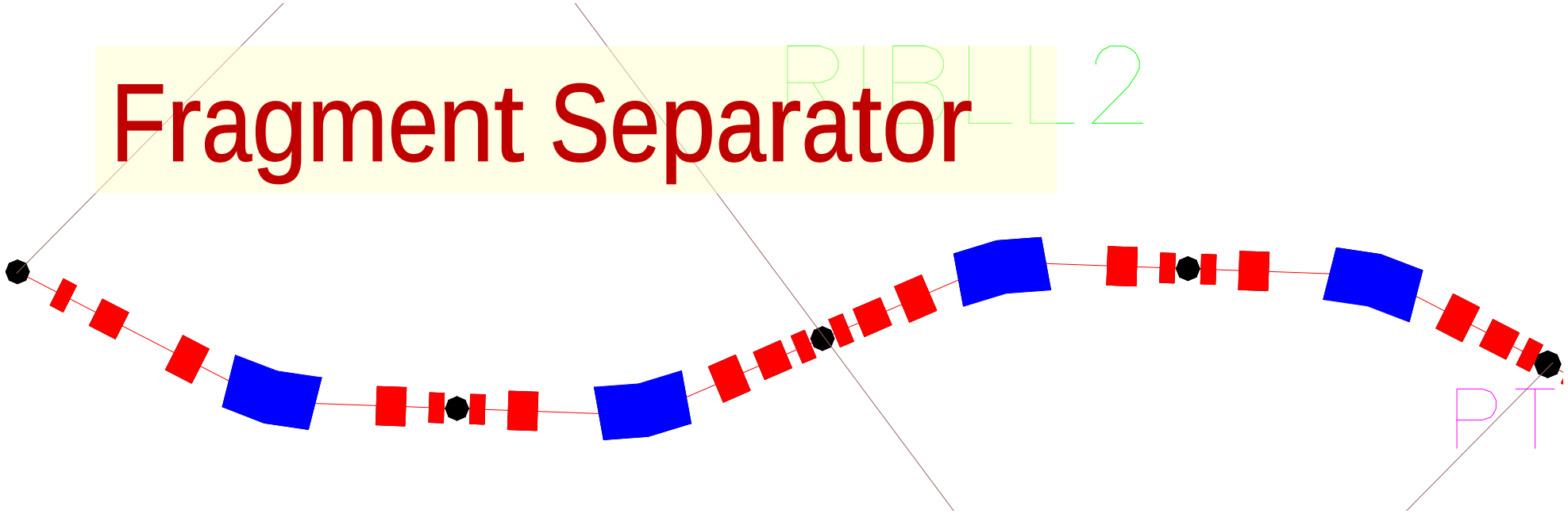
Internal-Target of CSRe



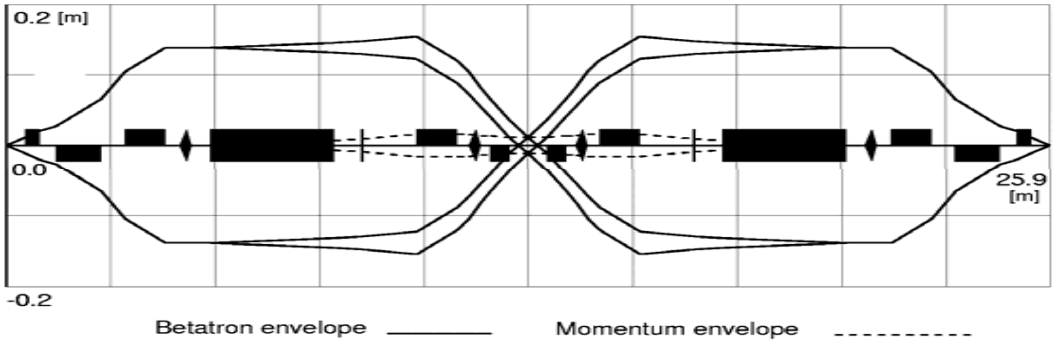
	Density (atoms /cm^2)
Ar	2.1x10^{13}
H_2	6.3x10^{12}
N_2	1.2x10^{13}

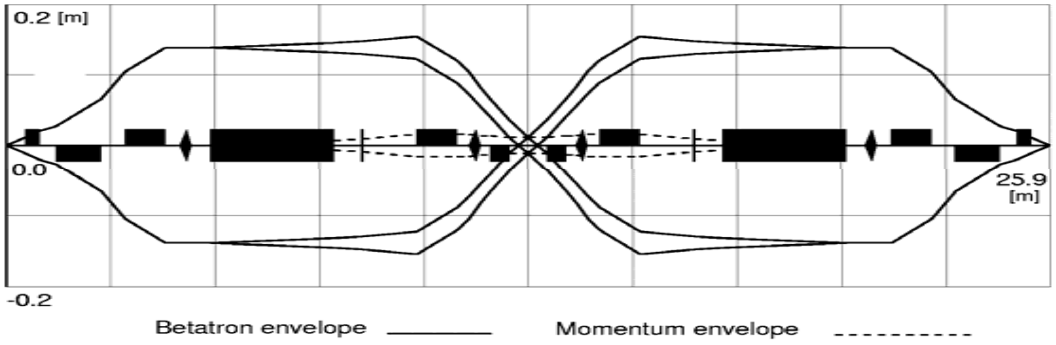
Radioactive Ion Beam Line between CSRm and CSRe

Fragment Separator



ΔP/P = ±1% , Emittance = 25π mm-mrad





RIBLL2 Tunnel

CSRm Injection Schemes

C to Ar, A<40, E = 7~10 MeV/u

SFC + CSRm

Stripping Injection + E-cooling →→ $I=10^{8\sim9}$

C to U, E = 3~25 MeV/u

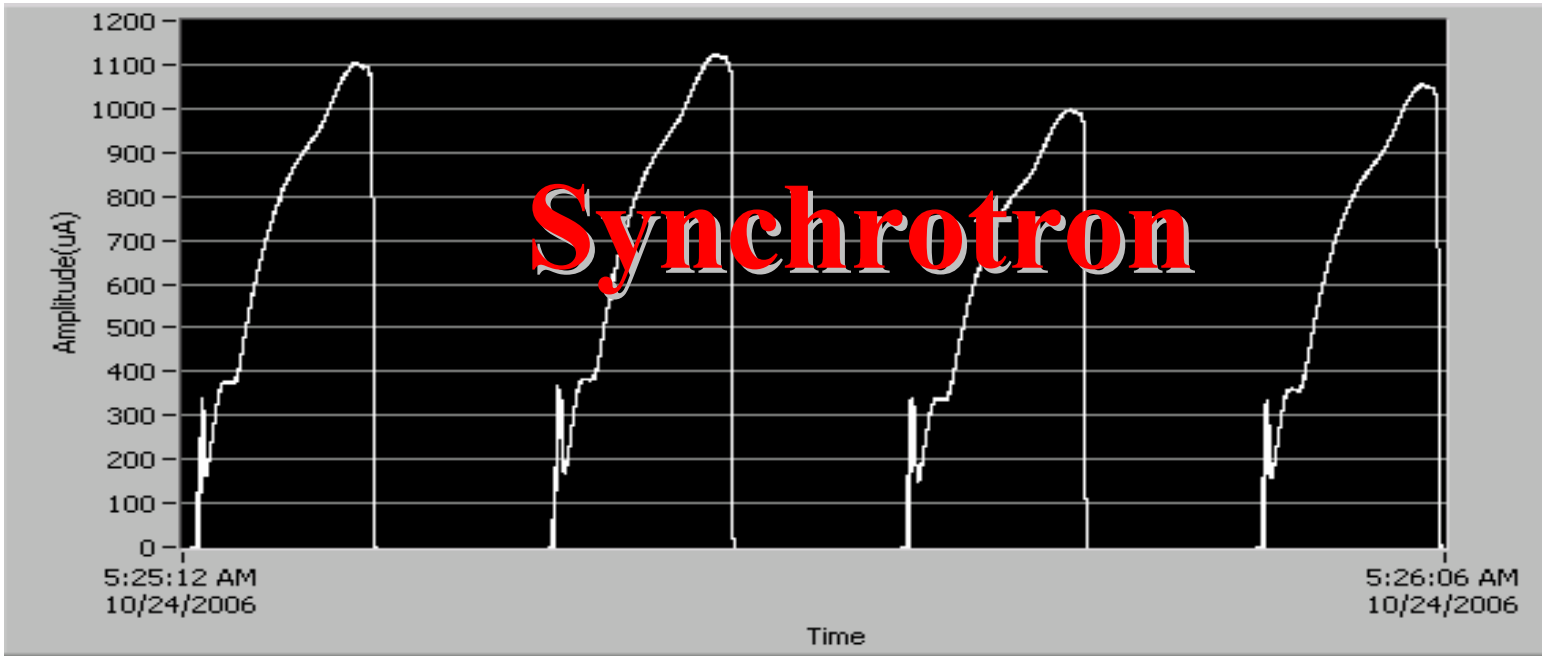
SFC + SSC + CSRm

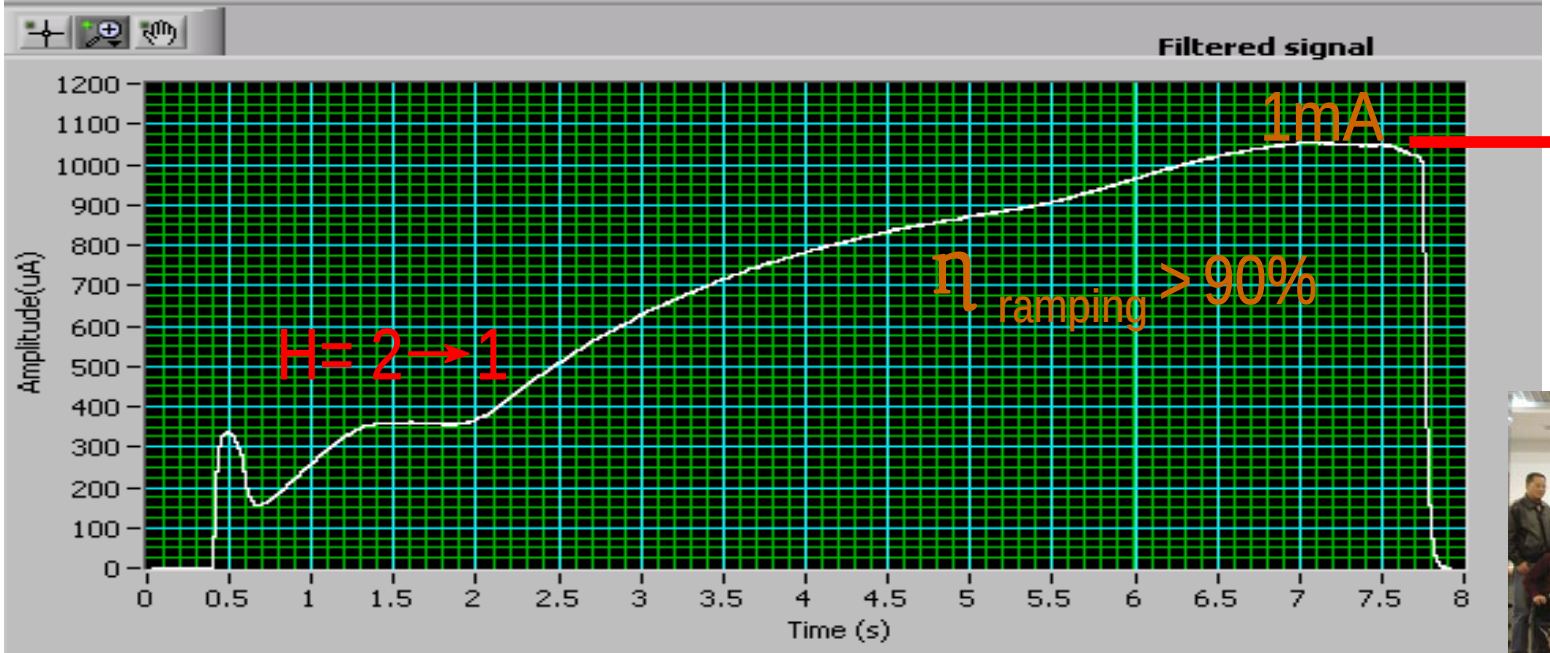
Multiple Multi-turn Injection + E-cooling →→ $I=10^{7\sim8}$

7AMeV→1AGeV (C^{6+}) STI + Ramping in CSRm

06/10/24 05:19

Mode: SFC+CSRm, STI, H = 2→1, f_{rf} = 0.45→1.63MHz, G = 11.3Tm

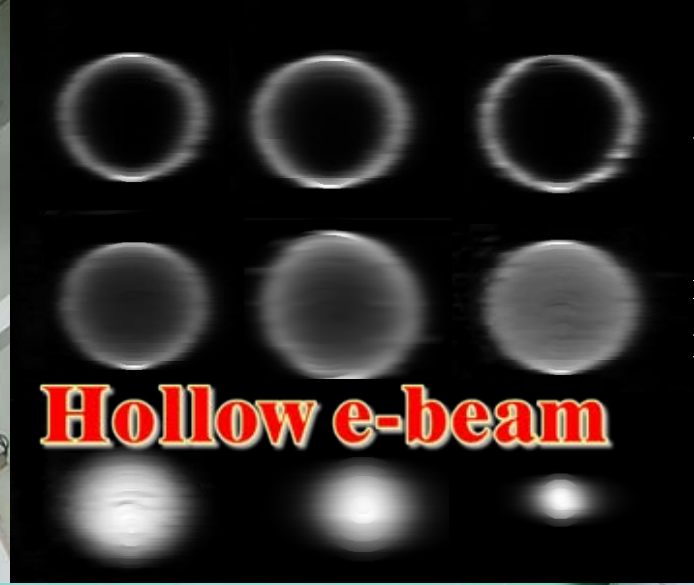


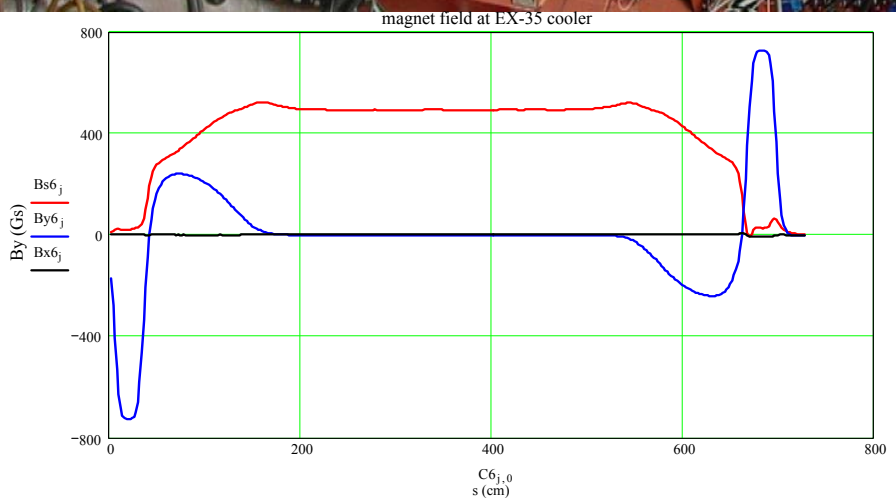


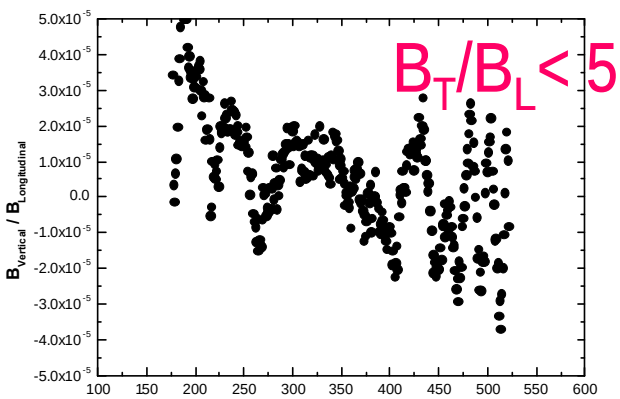
2006.12

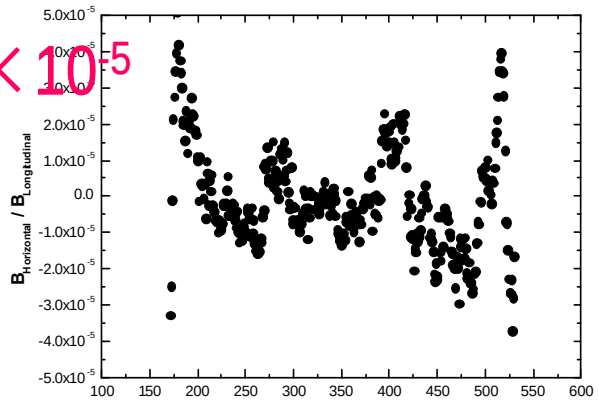
e-cooler

for ion cooling



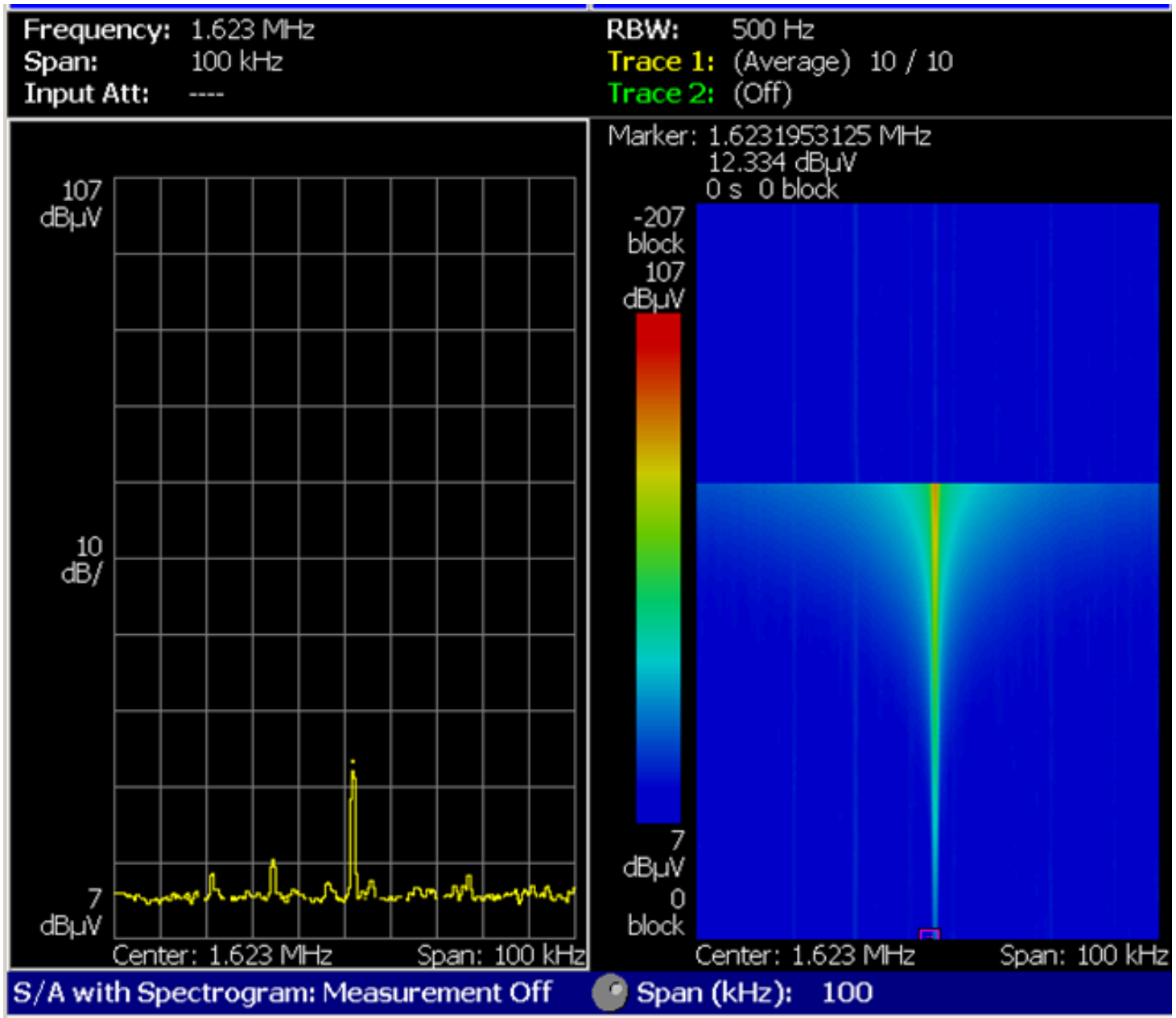






e-cooling effect

C^{6+}-7AMeV , observed the longitudinal Schottky signal from spectrum analyzer



Δ P/P

4×10^{-3}

↓

↓

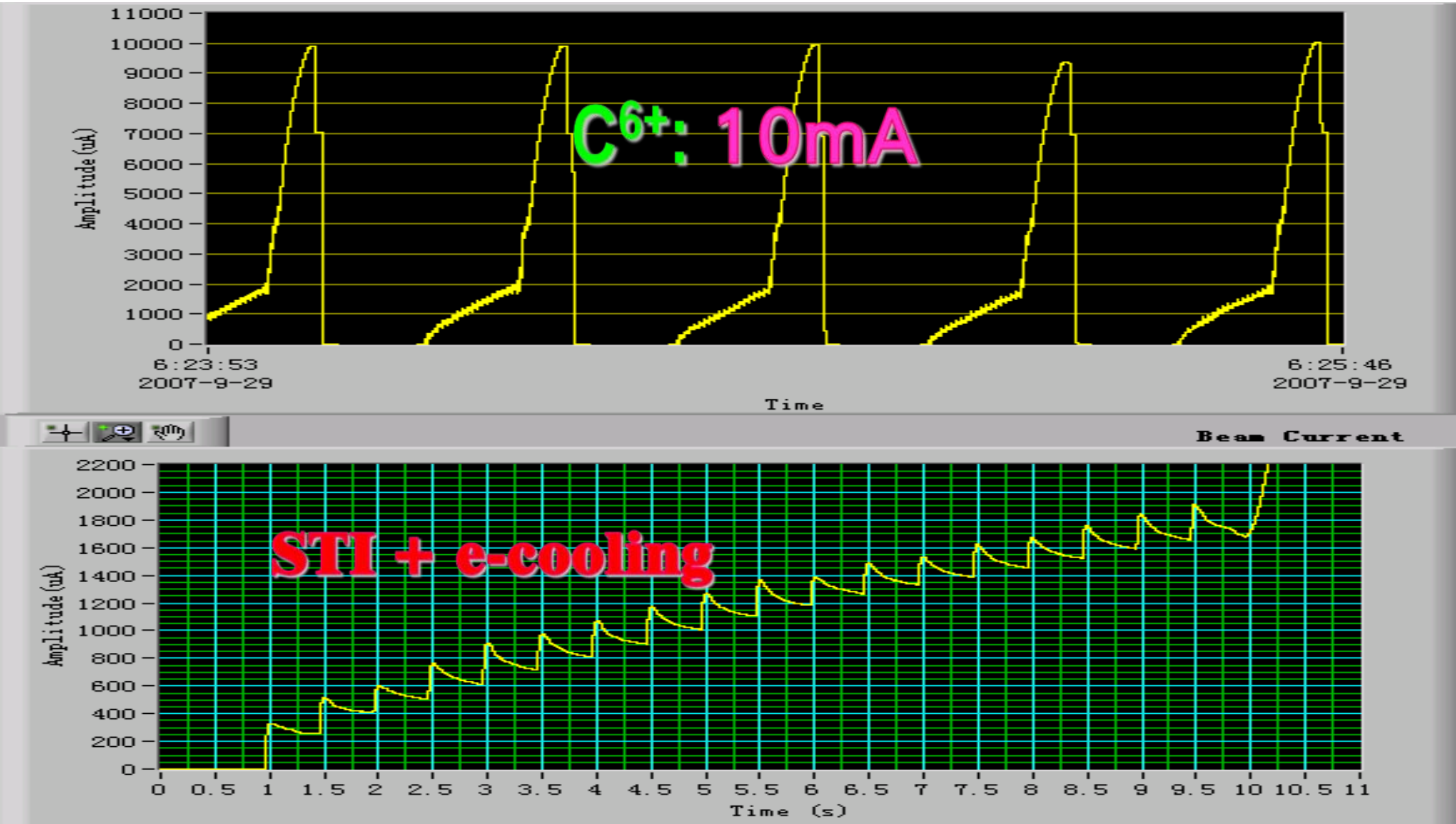
↓

2×10^{-4}

C^{6+}–600AMeV Ramping in CSRm

07/09/29 06:25

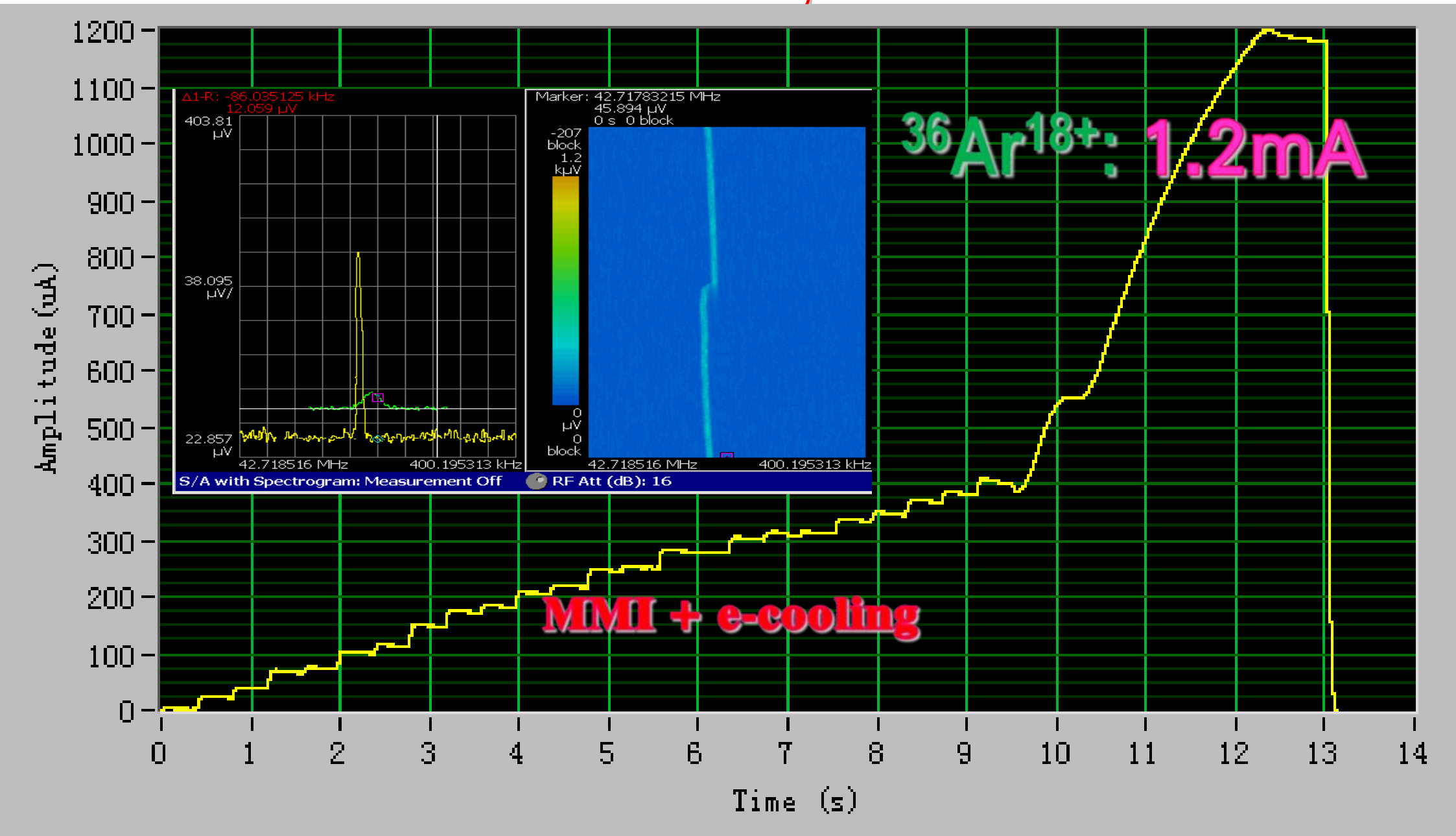
SFC-$^{12}C^{4+}$-7AMeV, $I_{inj.}$= 11uA, STI, 1800uA in 10s, 10000uA on top, 7 ×10^9



MMI + Ramping ($^{36}Ar^{18+}$-1AGeV) in CSRm

Mode: SFC+SSC+CSRm, 4×10^8

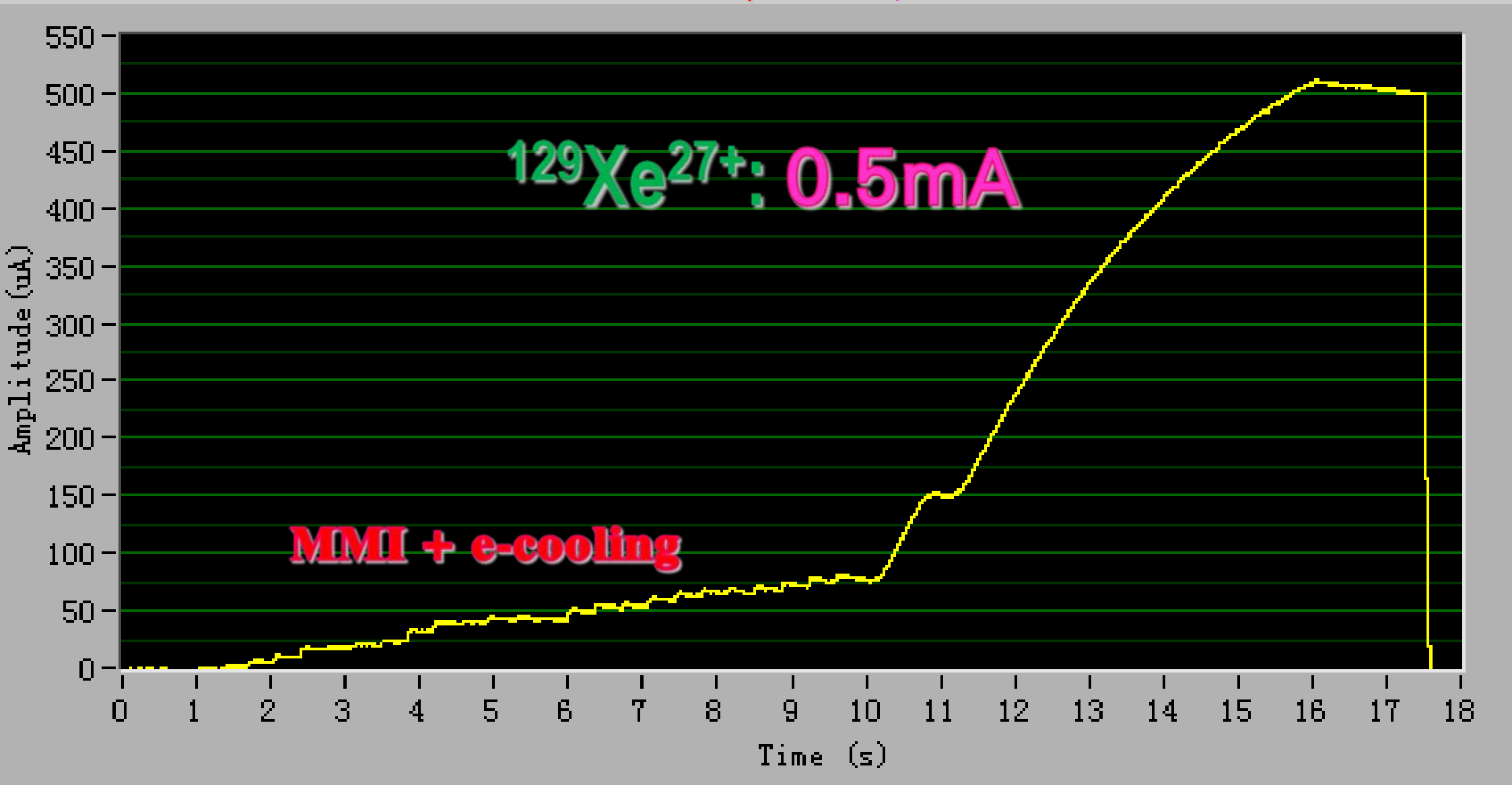
07/12/10 00:08



MMI + Ramping ($^{129}Xe^{27+}$-235AMeV) in CSRm

Mode: SFC+CSRm, 1×10^{8}, η =83%

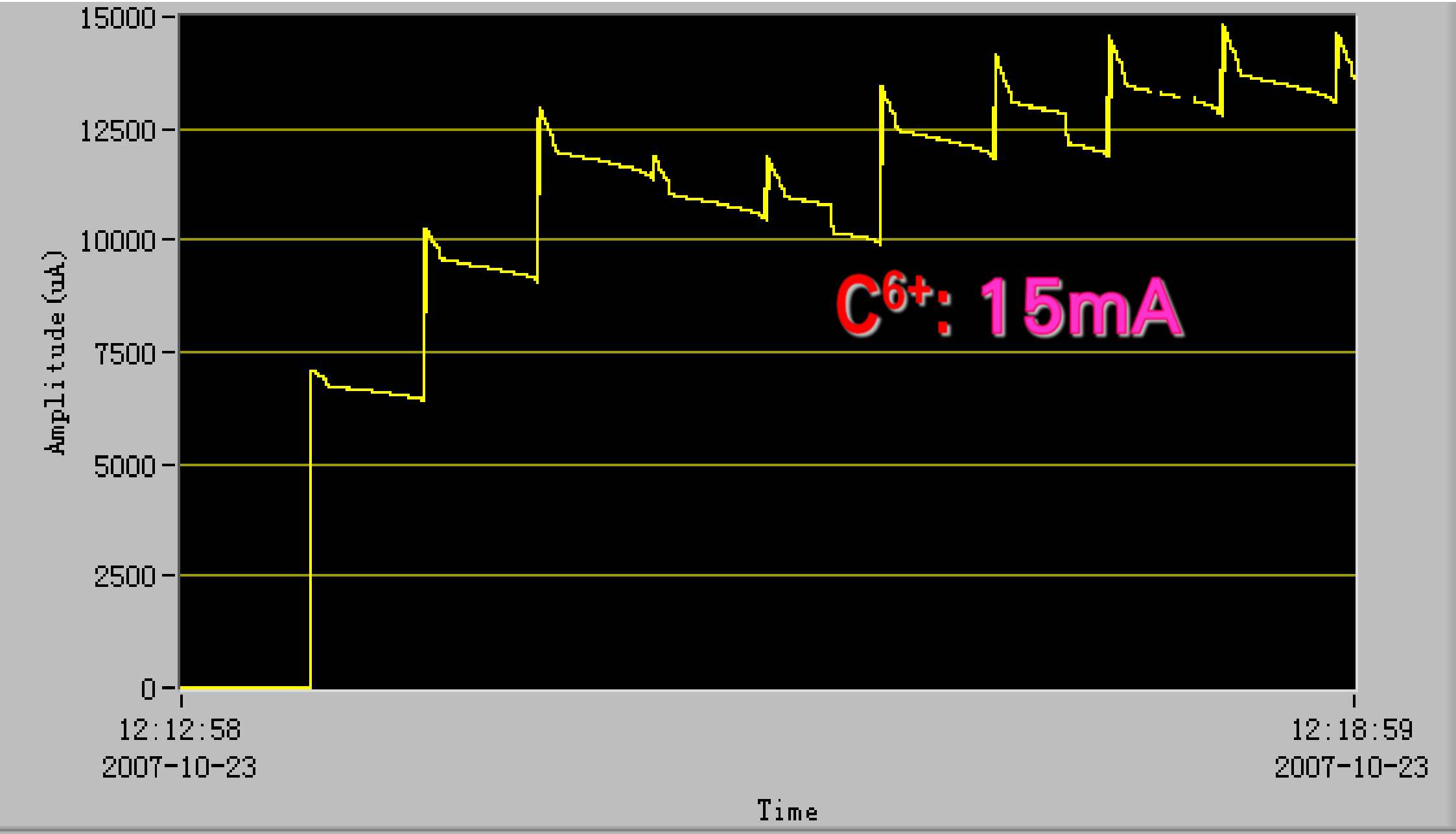
07/06/25 07:20



Multi-time Injection for CSRe 1st Commissioning

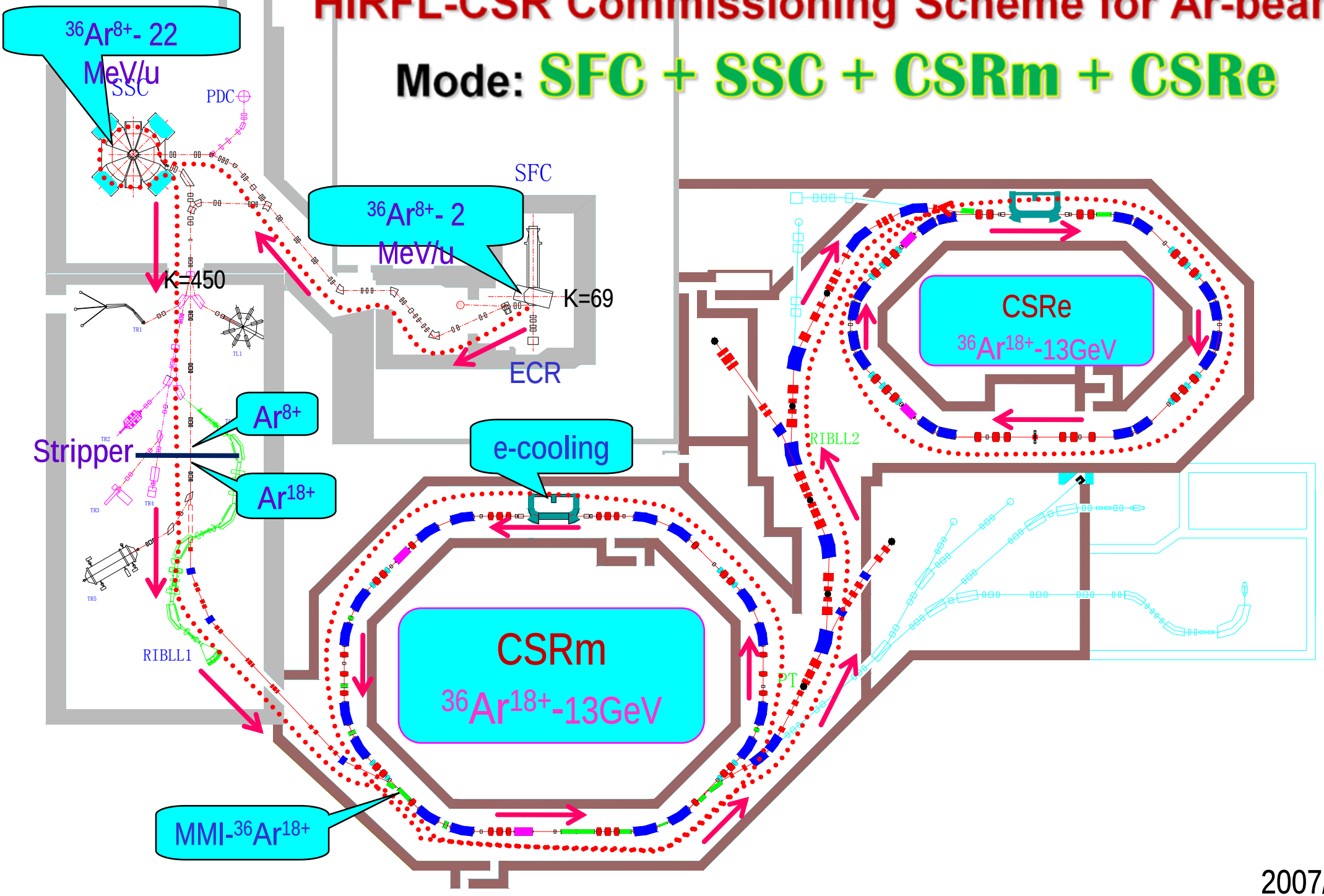
Mode: SFC+CSRm+CSRe, STI, $^{12}C^{6+}$-8GeV

07/10/23 12:18



HIRFL-CSR Commissioning Scheme for Ar-beam

Mode: SFC + SSC + CSRm + CSRe

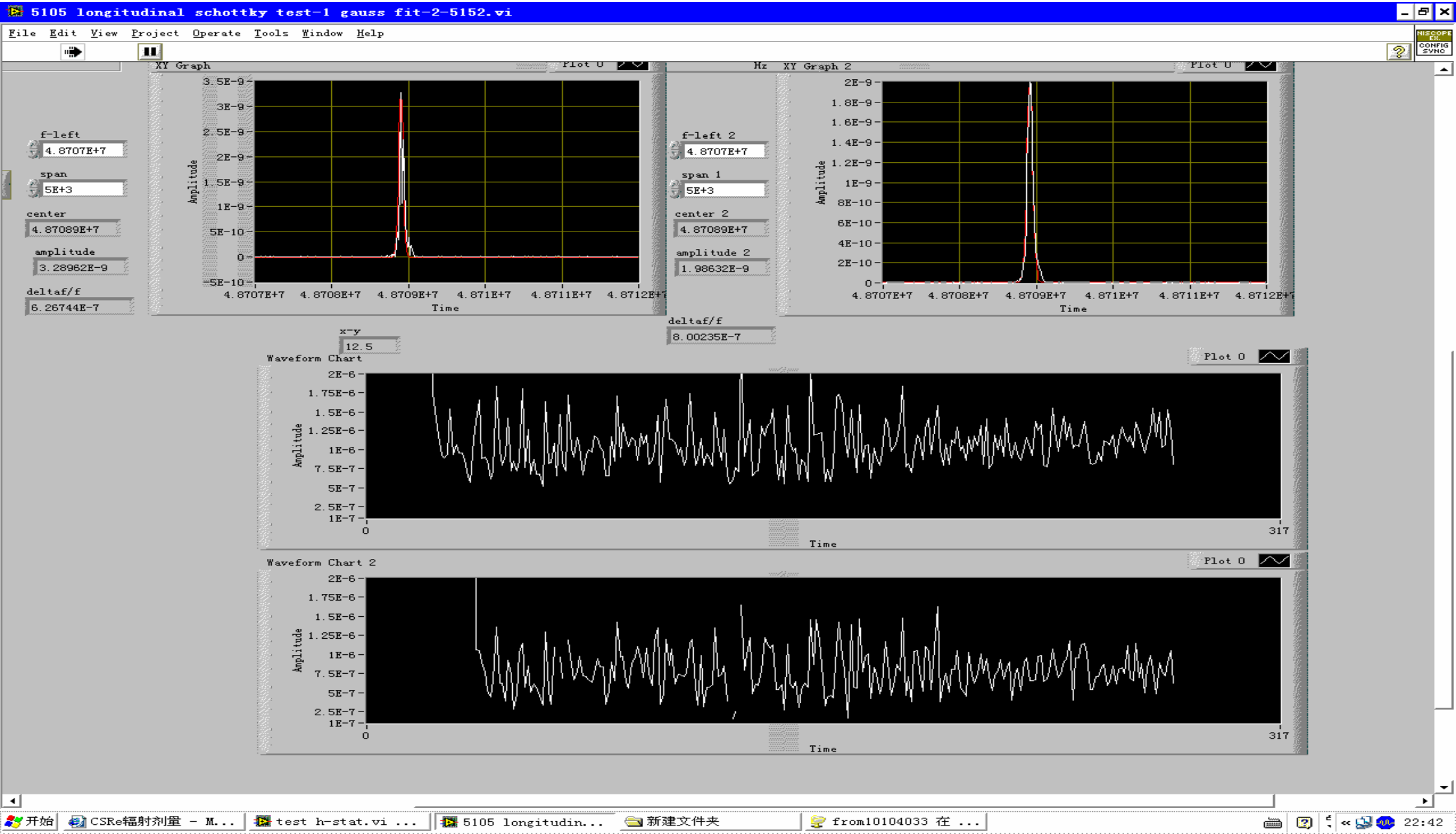


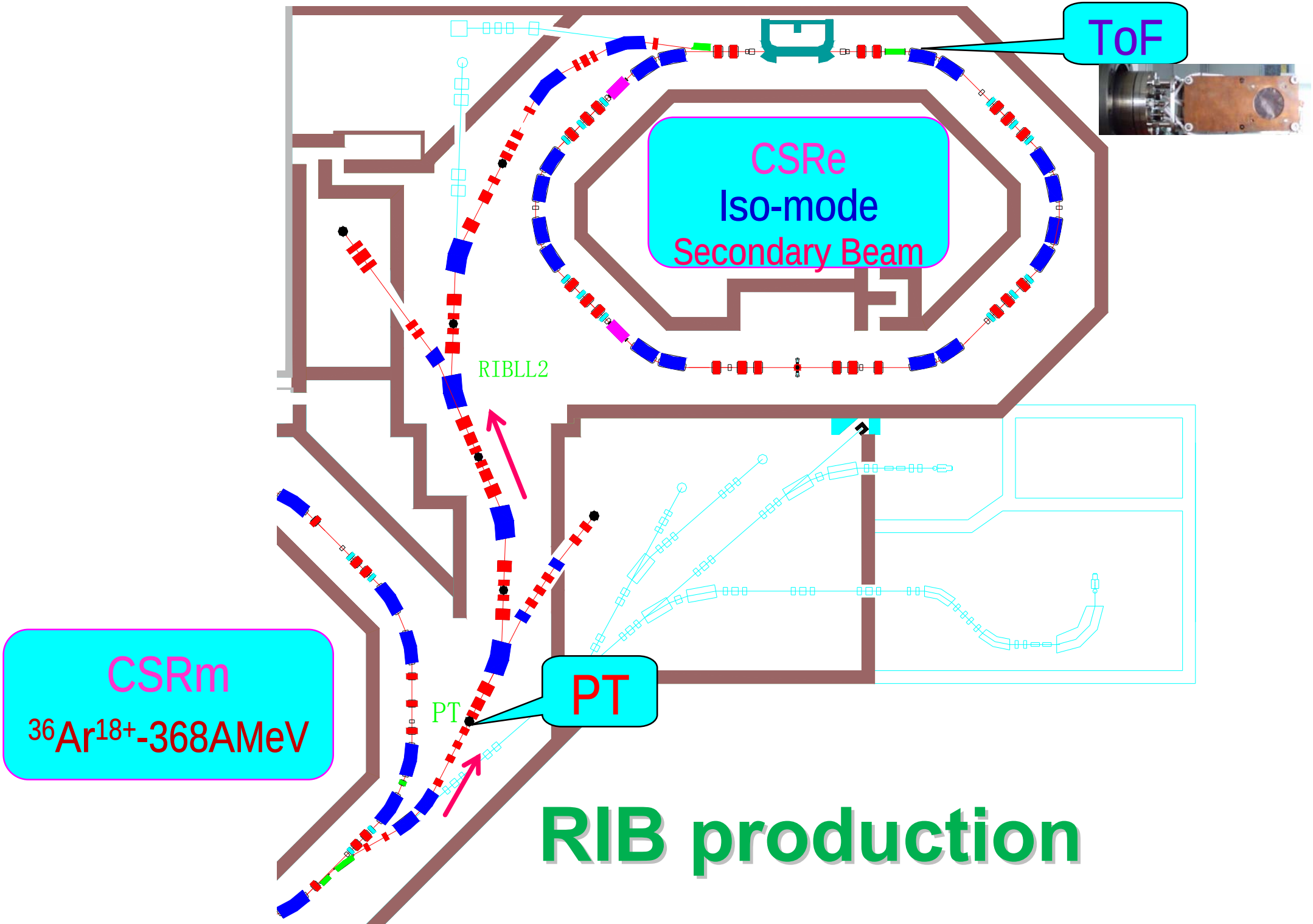
2007/12

Isochronous Mode in CSRe, $\Delta f/f \sim 10^{-7}$

$^{36}Ar^{18+}$-368AMeV

07/12/08 22:44



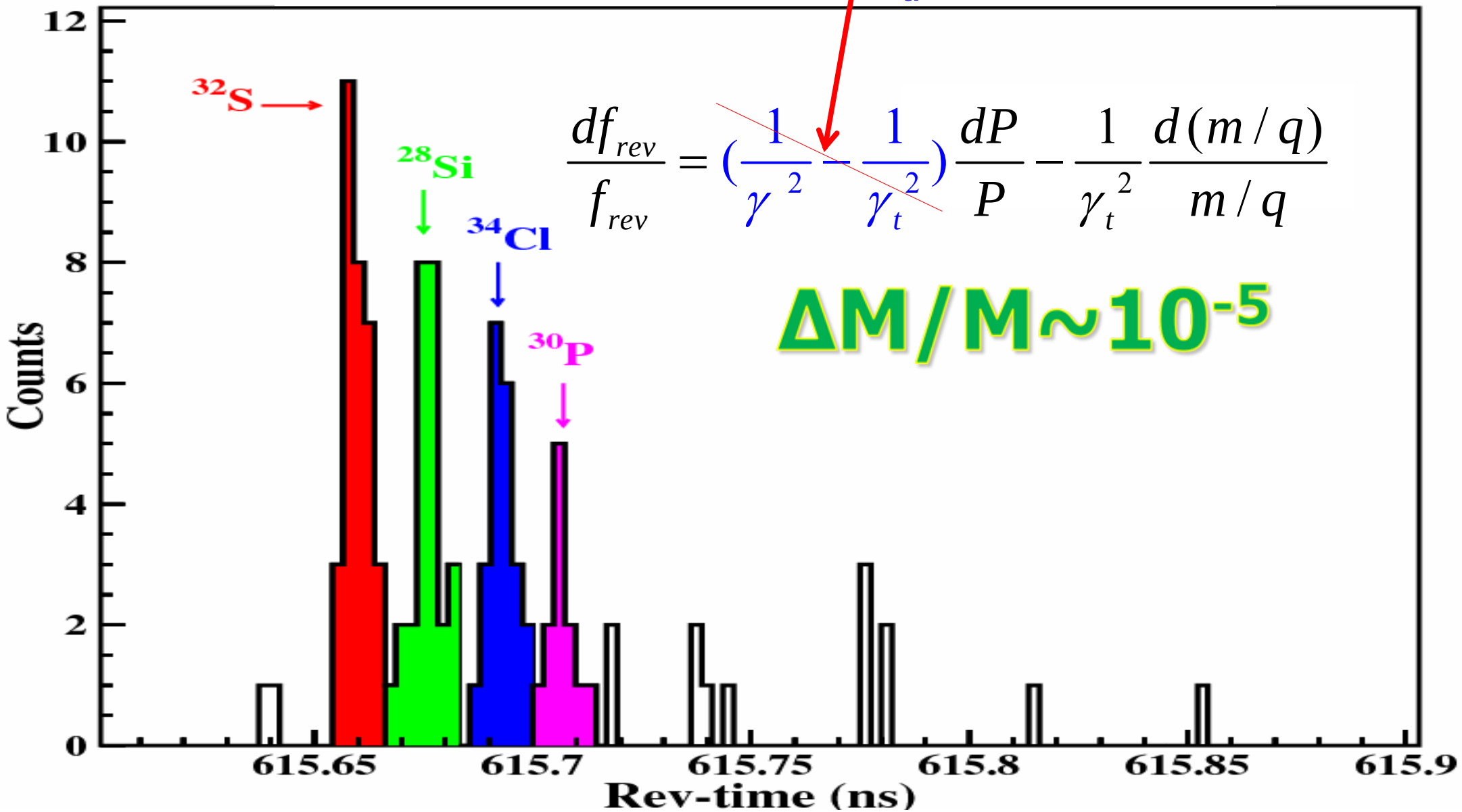


RIB production

2007.12.07

Mass Measurement of RIBs in

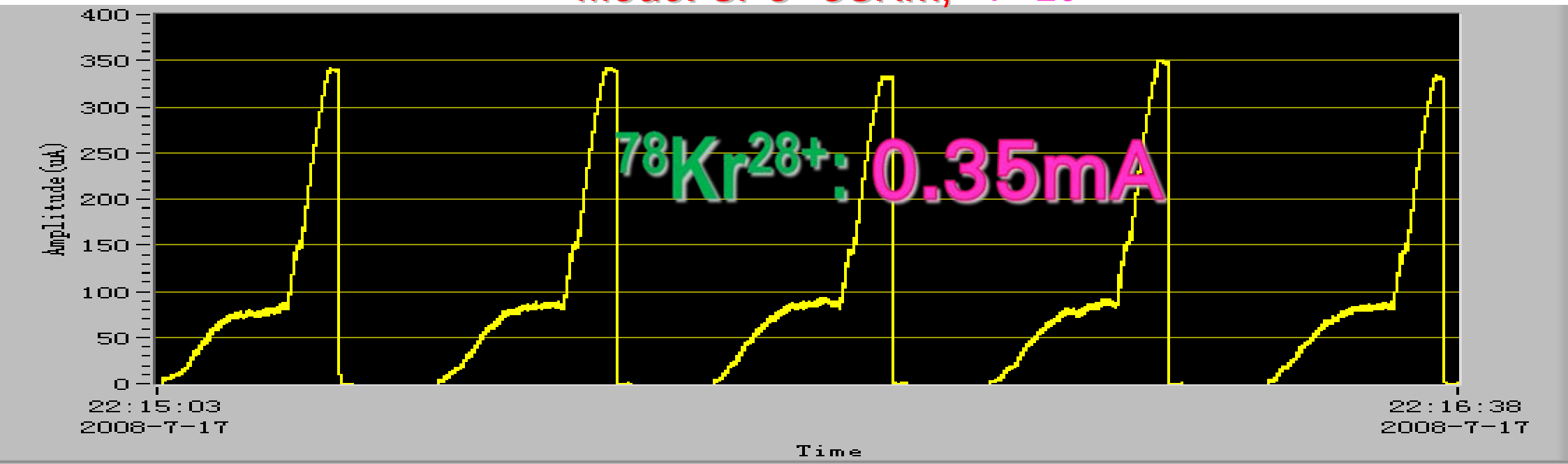
Isochronous Mode: $\gamma = \gamma_{tr} = 1.395$, ToF

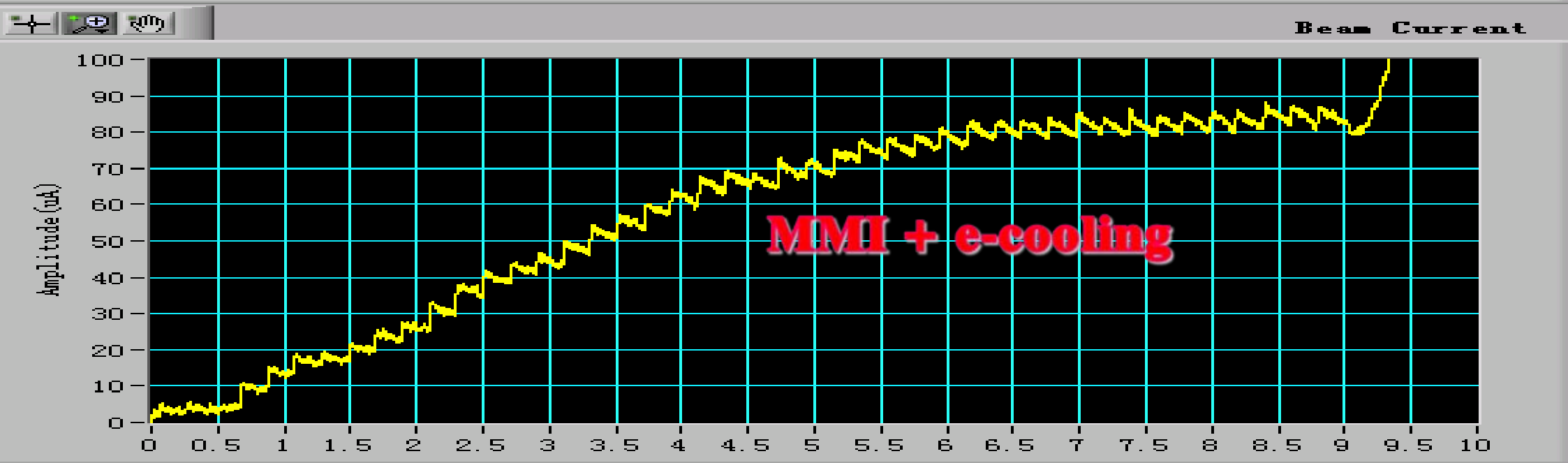


MMI + Ramping ($^{78}Kr^{28+}$--4~204.7AMeV) in CSRm

Mode: SFC+CSRm, 7×10^7

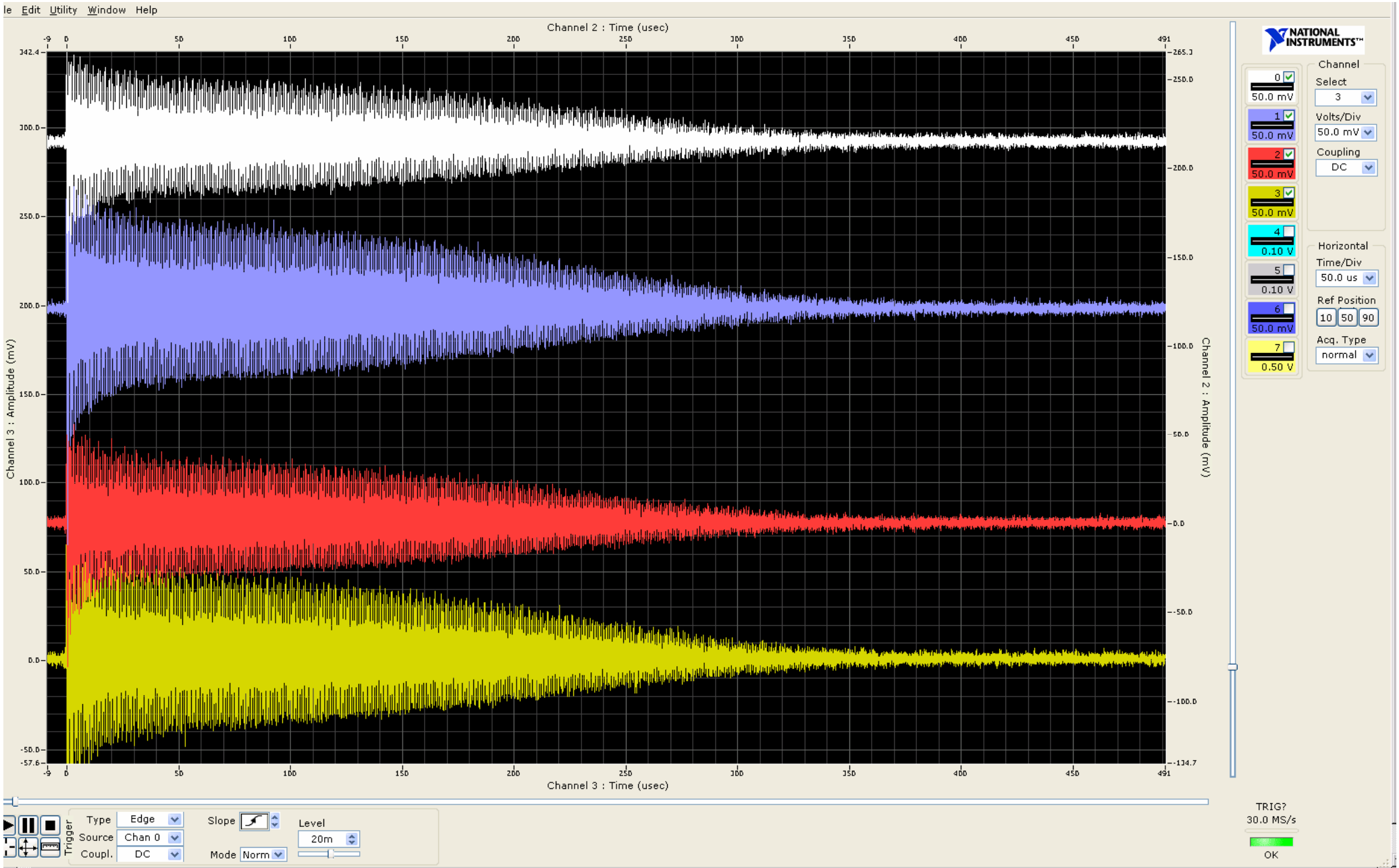
08/07/17 22:11





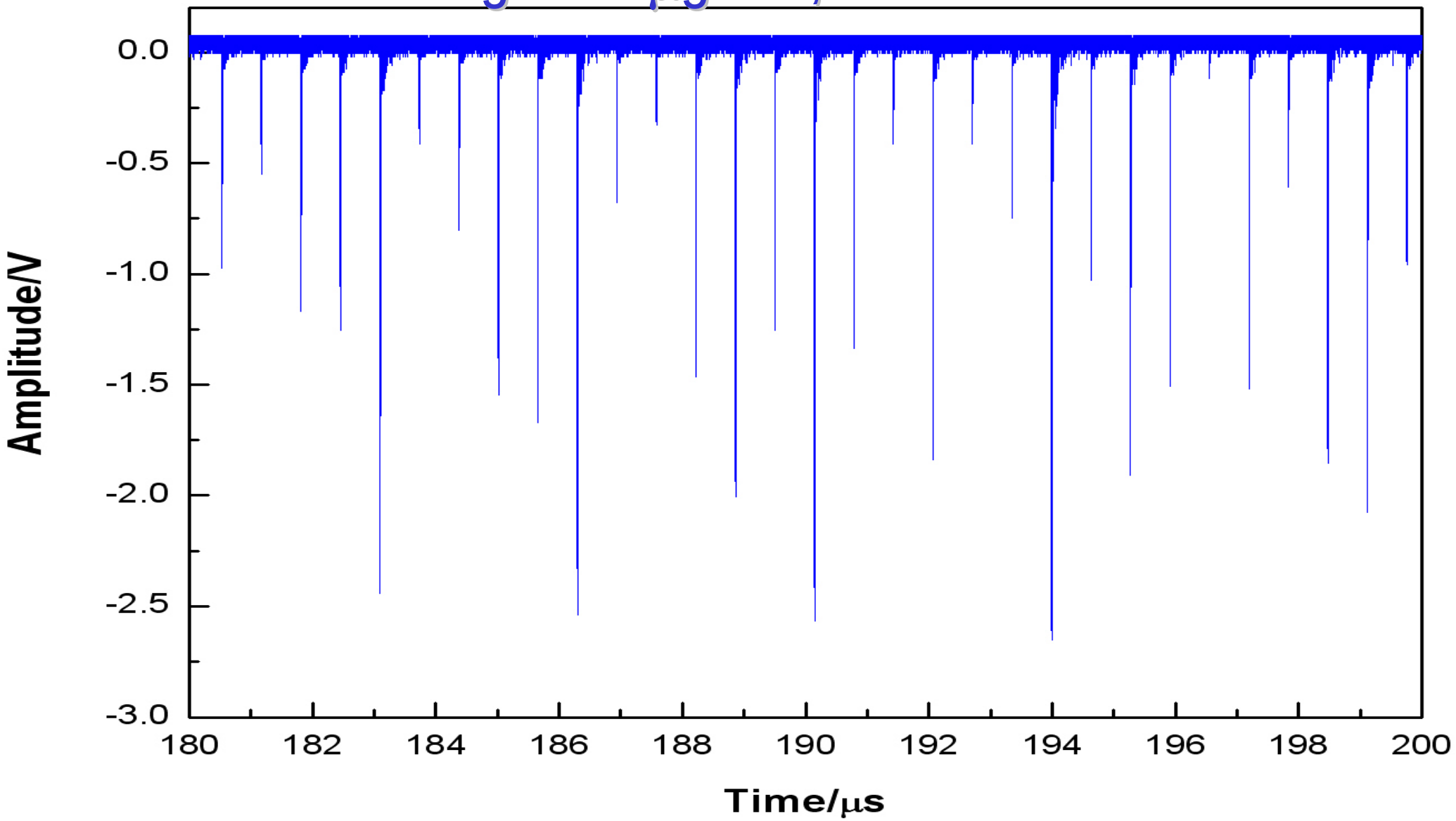
Multi-turns of $^{78}Kr^{36+}$-404.5AMeV from BPM in CSRe

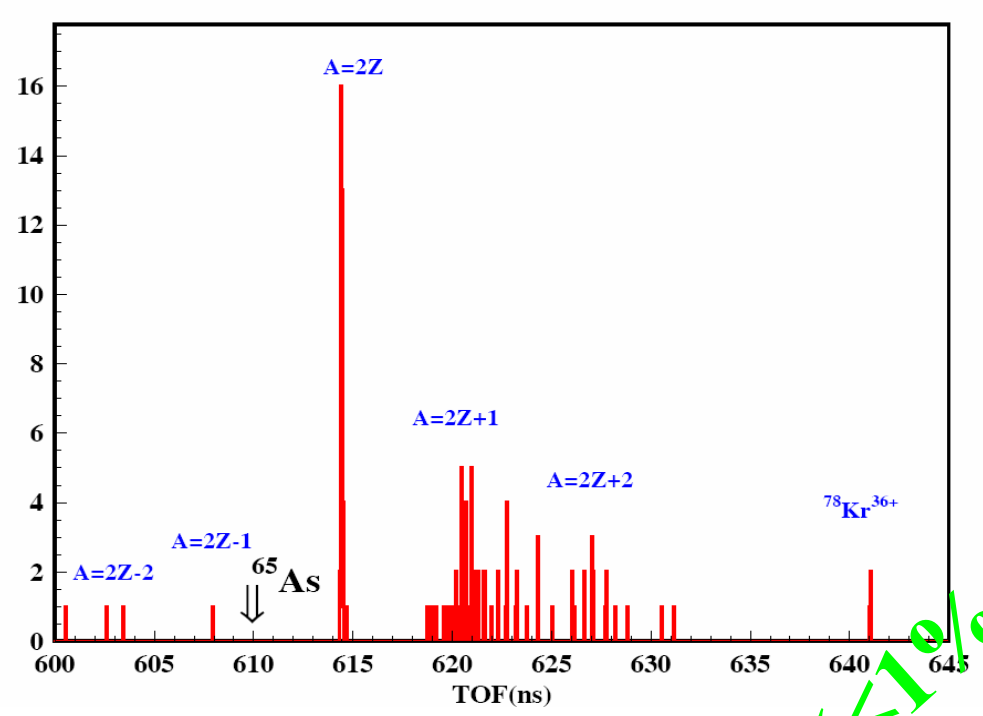
TOF Target : In , Mode : Isochronous, 600 turns 08/07/17 22:11

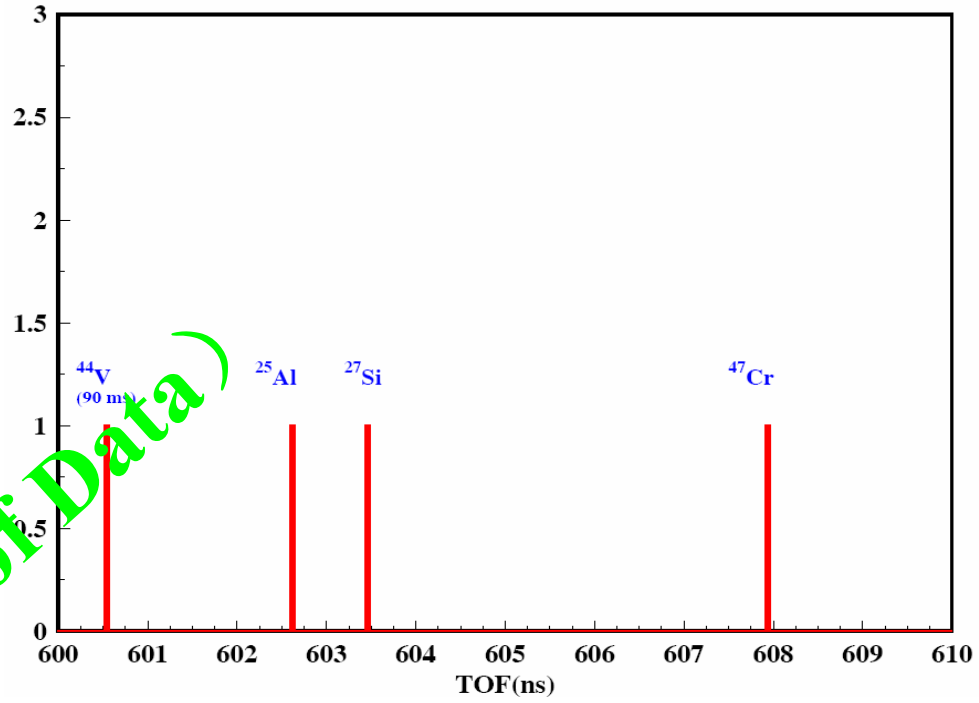


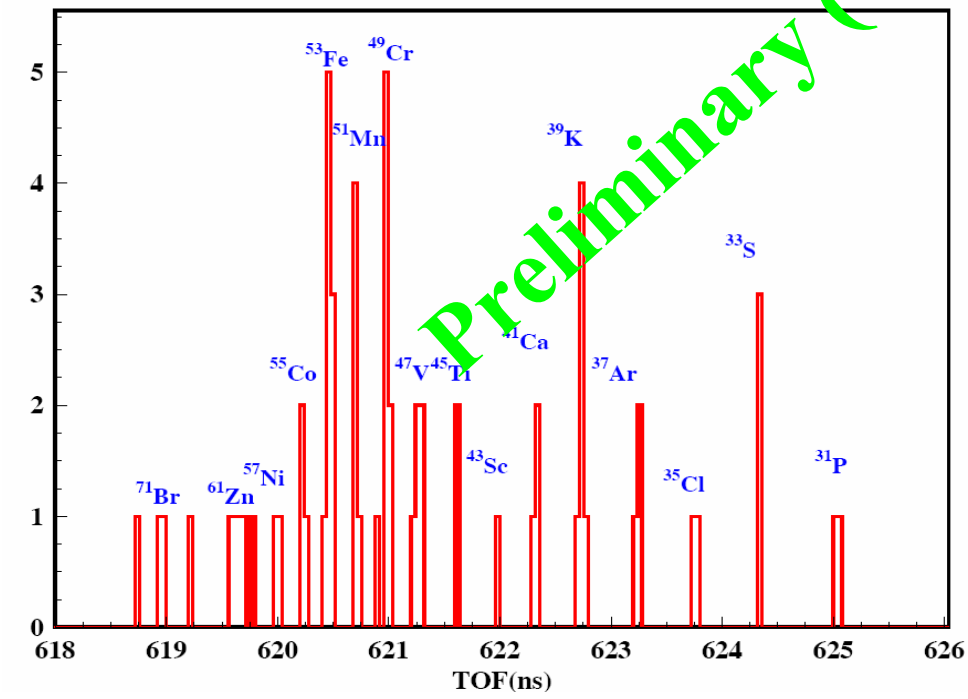
Turn by Turn Signals of Single Particle of 451.1AMeV $^{78}Kr^{28+}$ on 10mg/cm^2 Beryllium Target

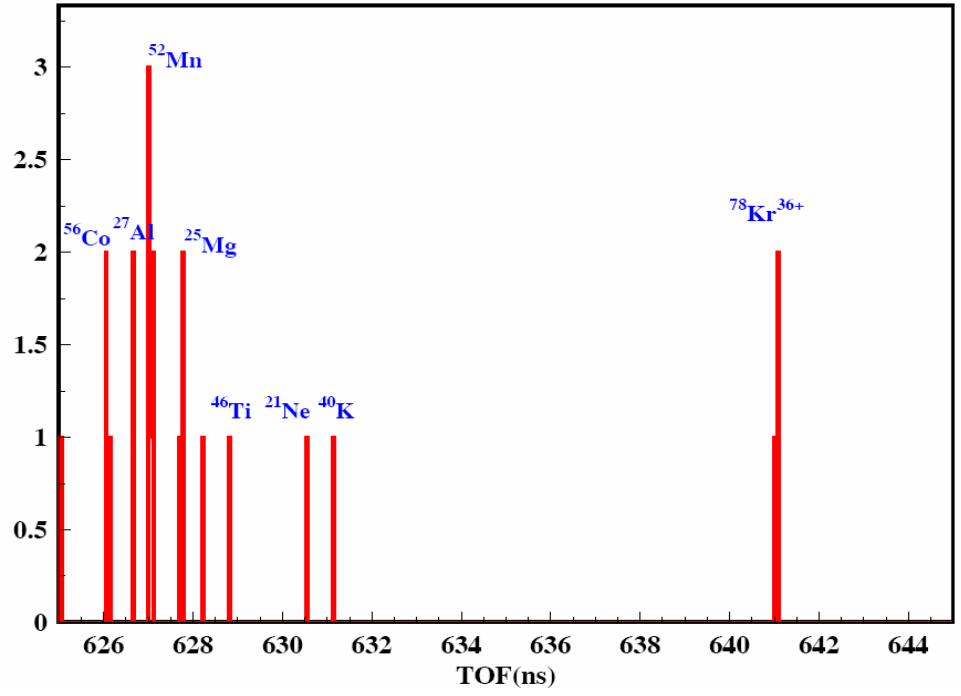
ToF Target : 15μg/cm^2, Isochronous Mode





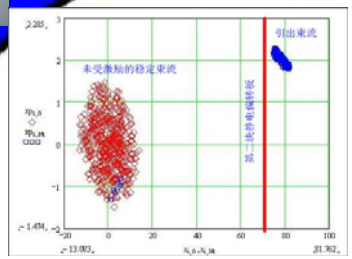


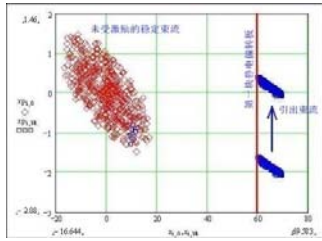




Slow extraction of 1/3 Resonance in CSRm

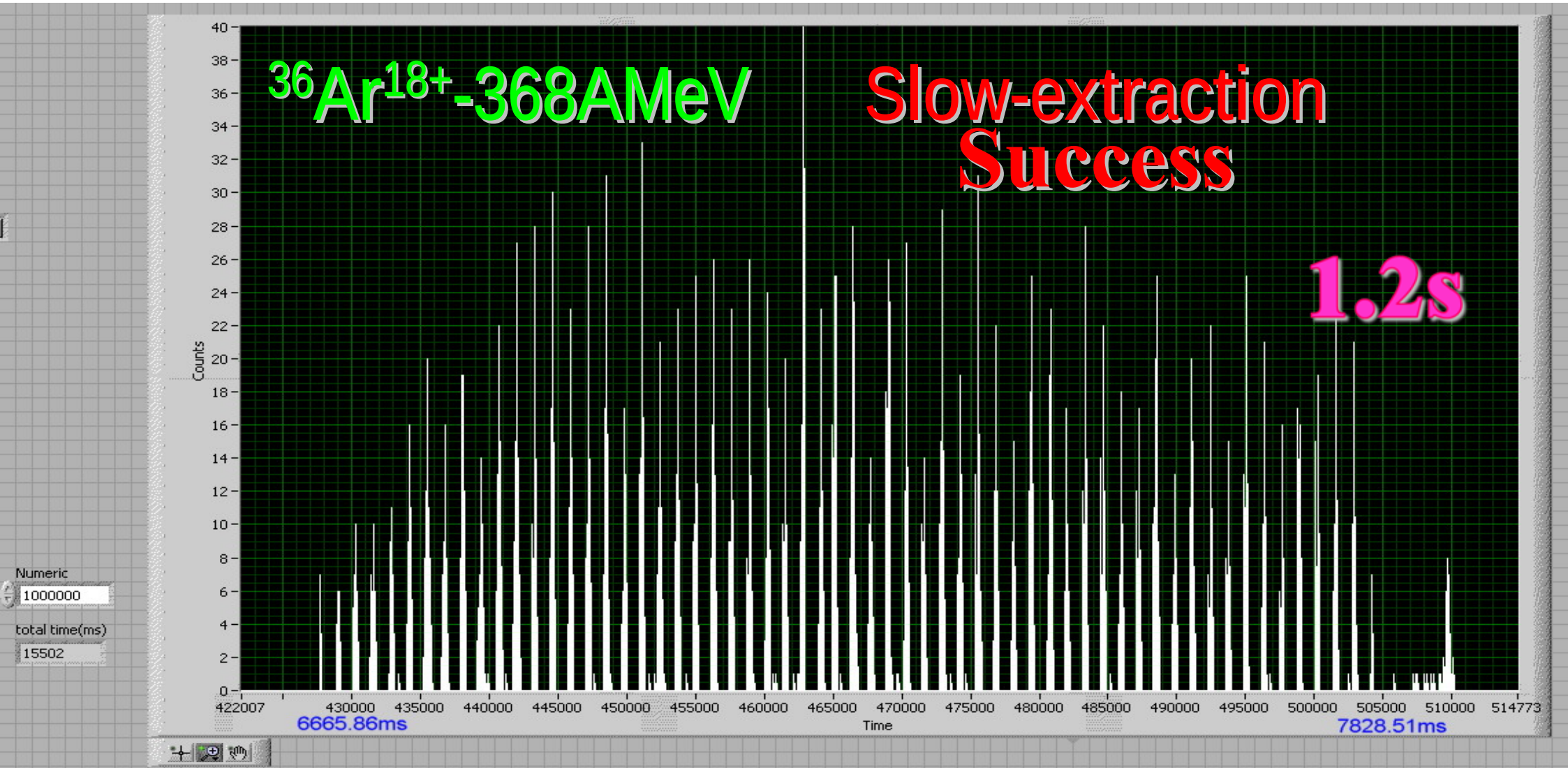
2008.01.10





Beam signal for slow extraction in CSRm

2008.01.10 15:00

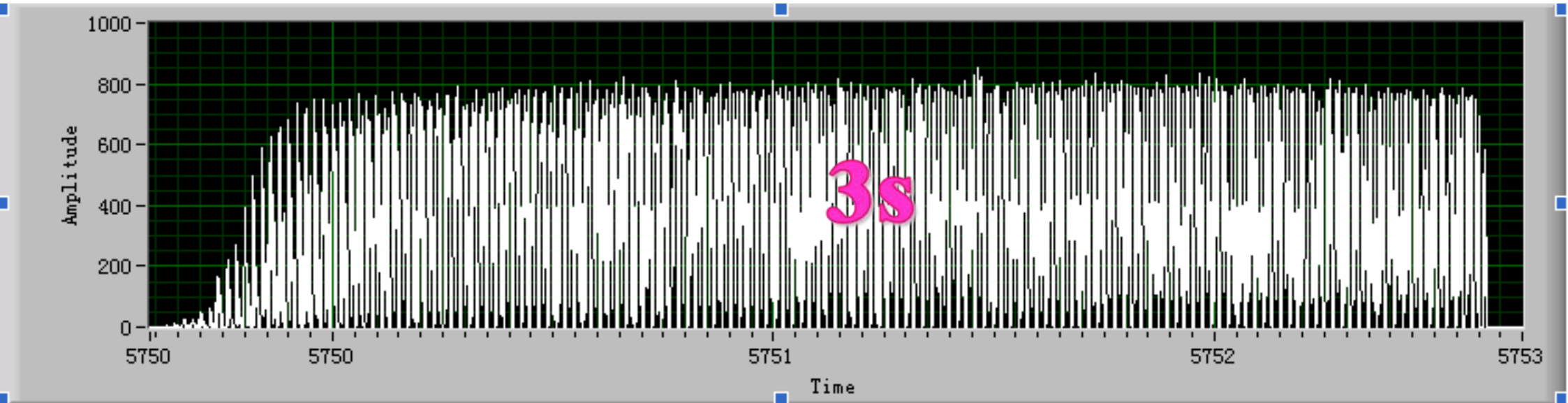


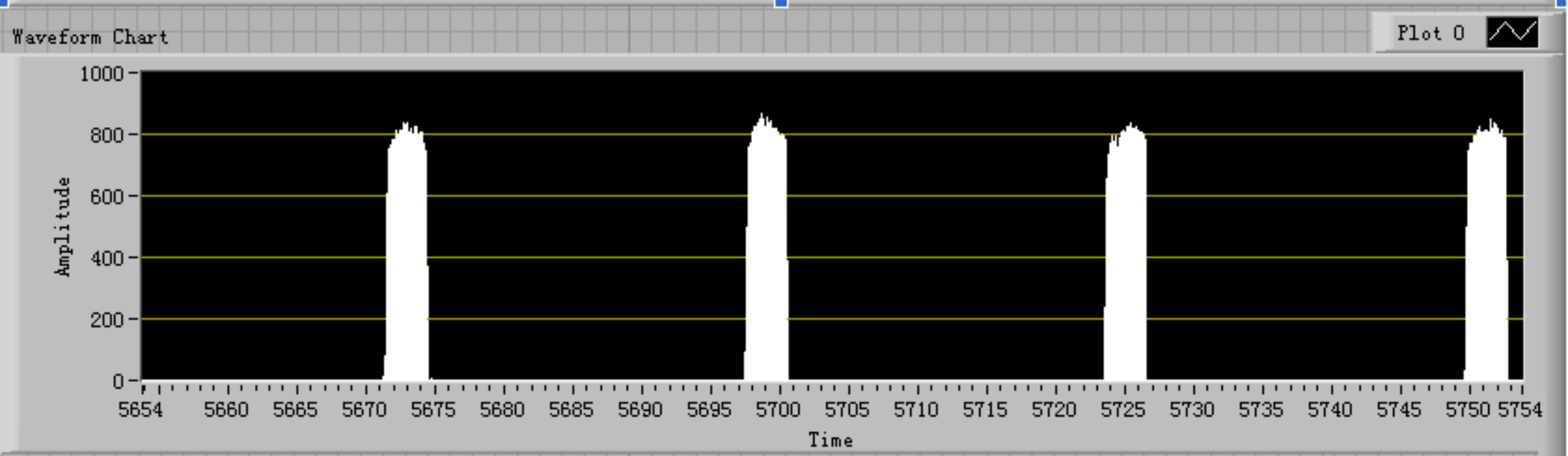
- Spill length: 1.2s
- Main frequency: 50Hz

Slow extraction for $^{12}C^{4+}$-300MeV/u in CSRm

From Scintillation Crystal Monitor

2008.05.21 03:31





Status of Coolers in CSR Project

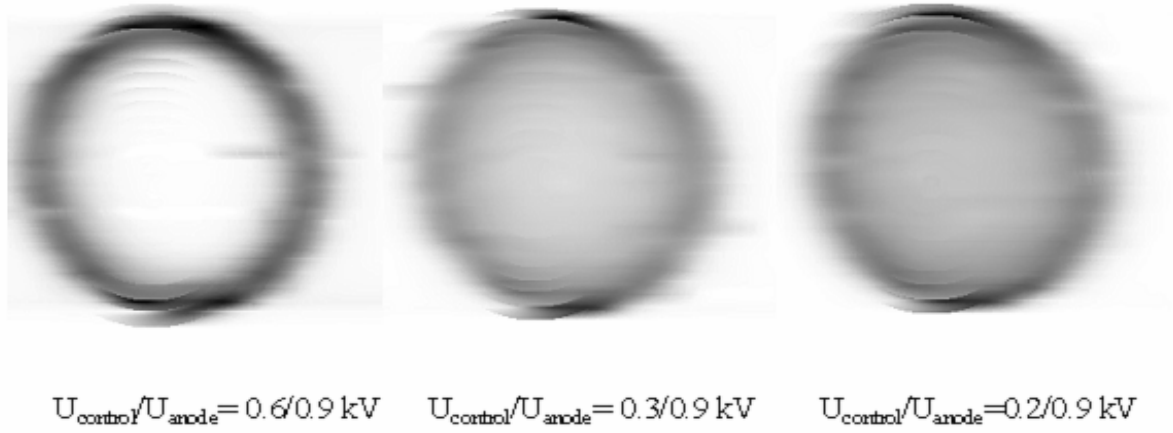
- CSRm Cooler
  - 35kV←→60AMeV for accumulation
- CSRe Cooler
  - 300kV←→500AMeV for experiments

What we have done on CSRm Cooler

- $^{12}C^{6+}$ 7MeV/u $U_{grid}/U_{anode}=0.33$
- $^{12}C^{4+}$ 7MeV/u $U_{grid}/U_{anode}=0.2$
- $^{36}Ar^{18+}$ 22MeV/u $U_{grid}/U_{anode}=0.2$
- $^{129}Xe^{27+}$ 2.9MeV/u $U_{grid}/U_{anode}=0.2$
- $^{12}C^{5+}$ 8.26MeV/u $U_{grid}/U_{anode}=0.2$
- $^{78}Kr^{28+}$ 4.04MeV/u $U_{grid}/U_{anode}=0.224$

0.33

0.67



0.22

$U_{control}/U_{anode}$= 0.6/0.9 kV $U_{control}/U_{anode}$= 0.3/0.9 kV $U_{control}/U_{anode}$=0.2/0.9 kV

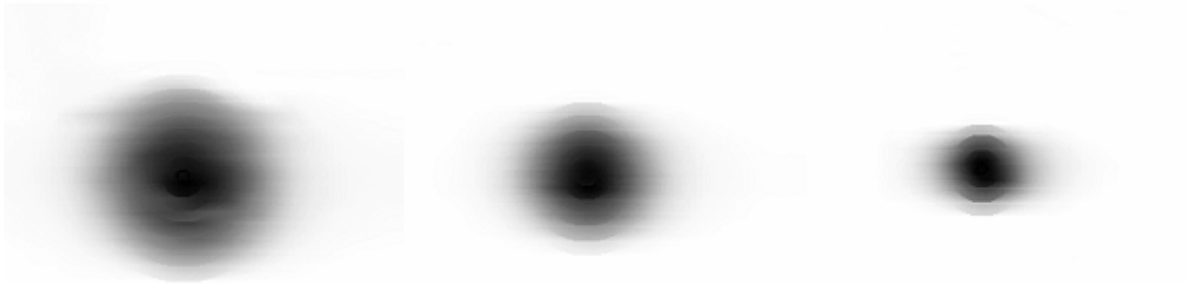
0.11

0

$U_{control}/U_{anode}$=0.1/0.9 kV $U_{control}/U_{anode}$= 0.05/0.9 kV $U_{control}/U_{anode}$= 0/1.4 kV

Electron beam Profile
U_{grid}/U_{anode}

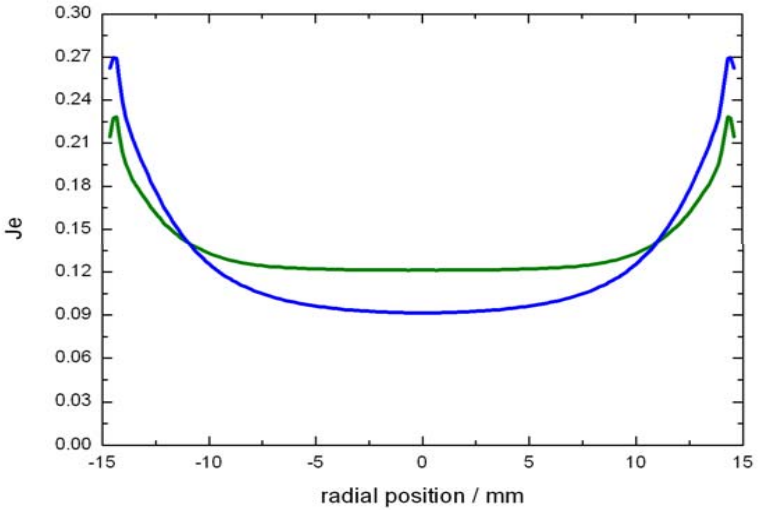
-0.07



-0.2

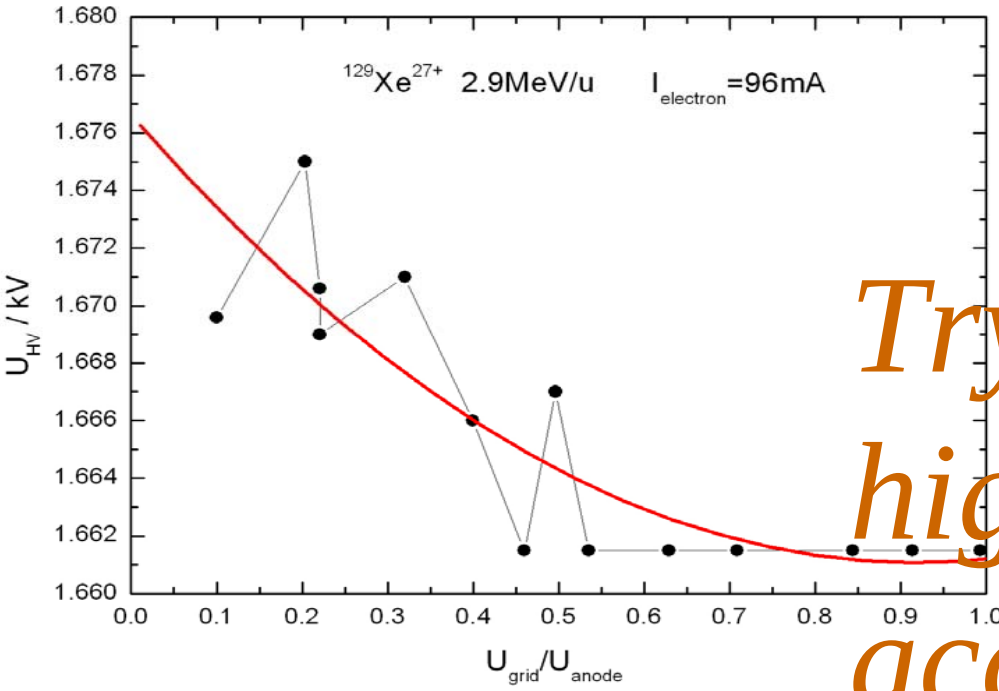
$U_{control}/U_{anode}$=–0.2/2.8 kV $U_{control}/U_{anode}$= -0.4/2.8 kV $U_{control}/U_{anode}$=–0.6/2.8 kV

-0.14

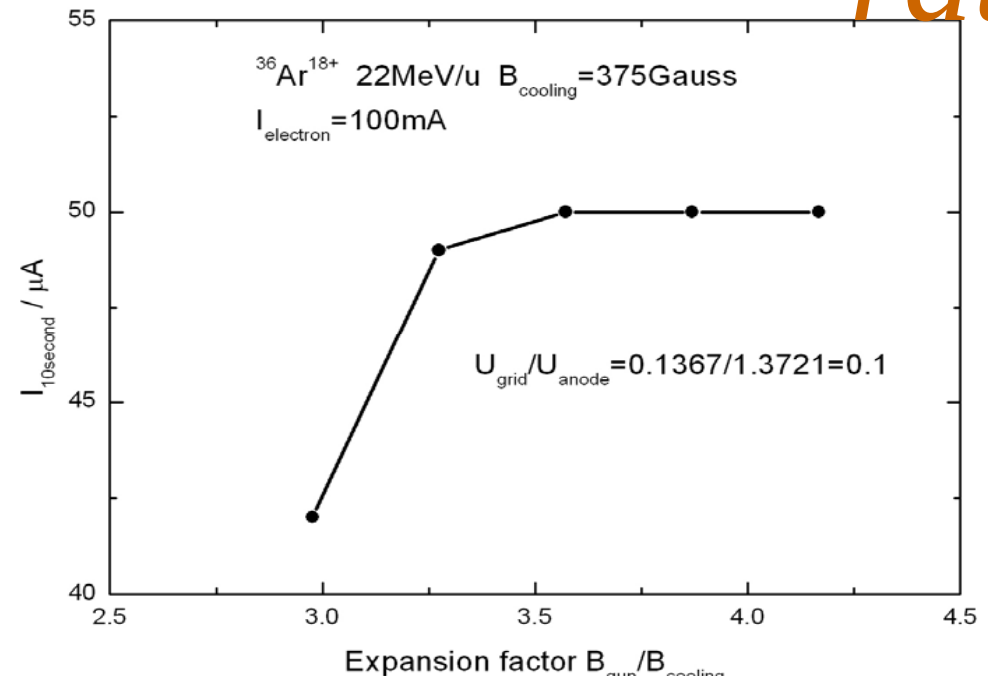


$U_{control}/U_{anode} = 0.3/0.9$ kV

$U_{control}/U_{anode} = 0.2/0.9$ kV

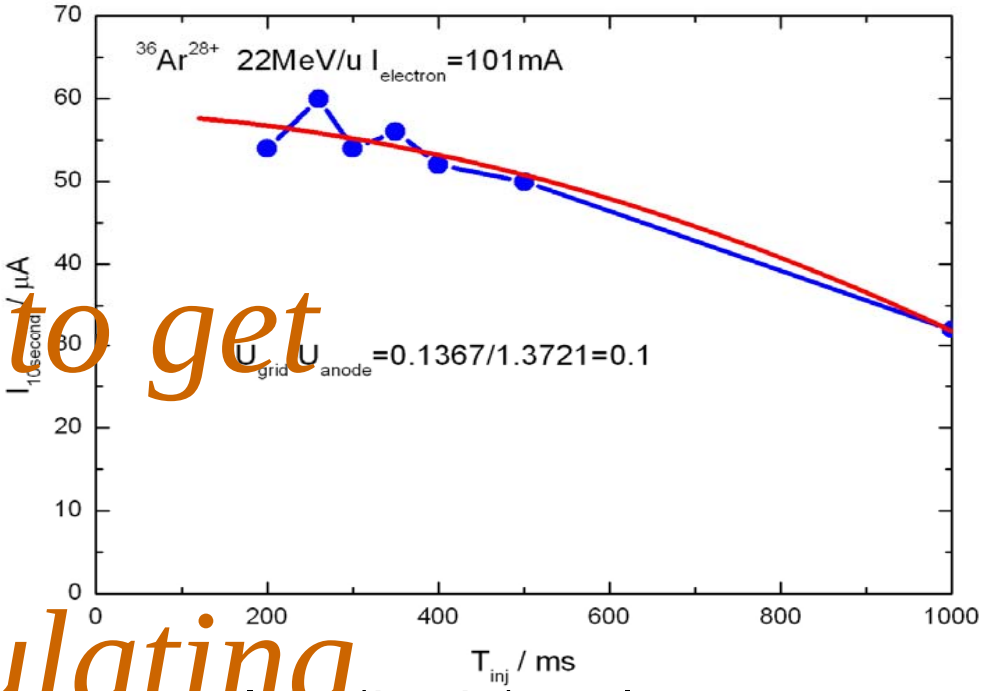


Electron energy



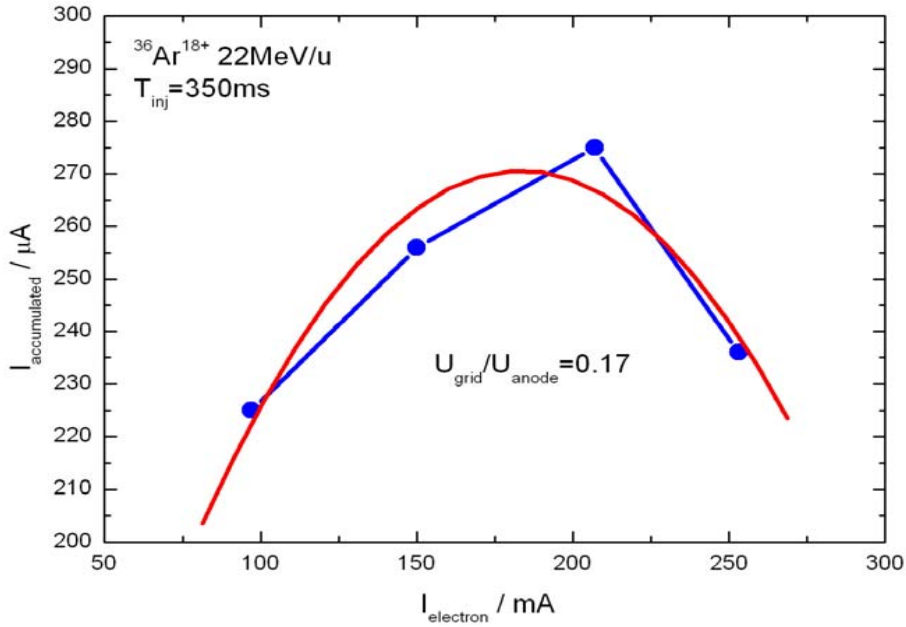
Expansion factor

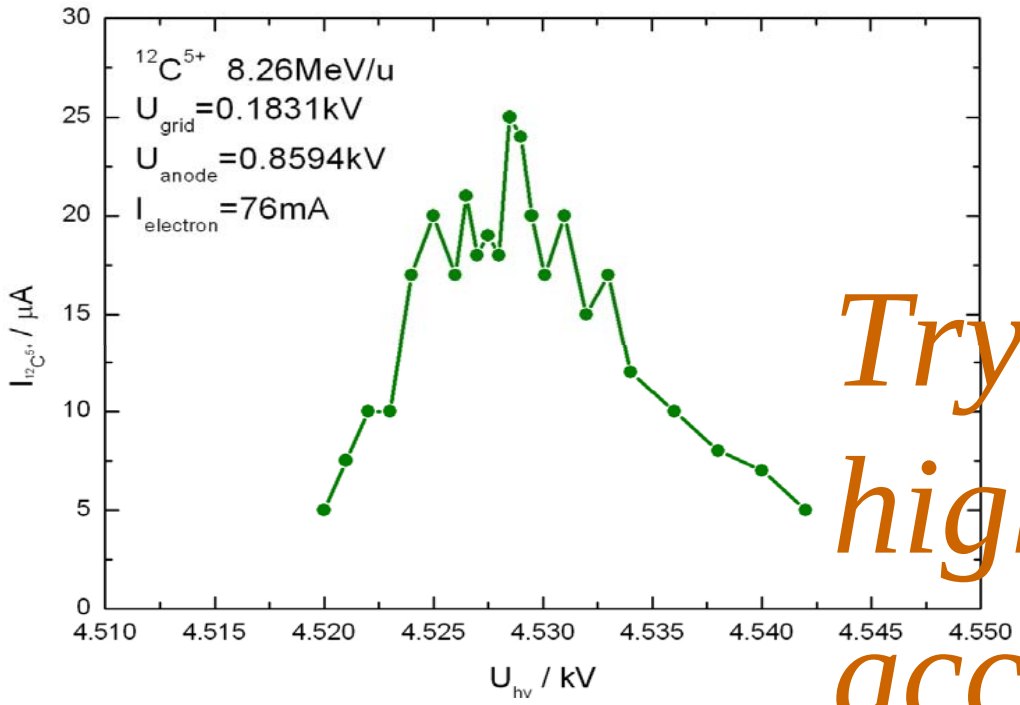
Trying to get higher accumulating rate



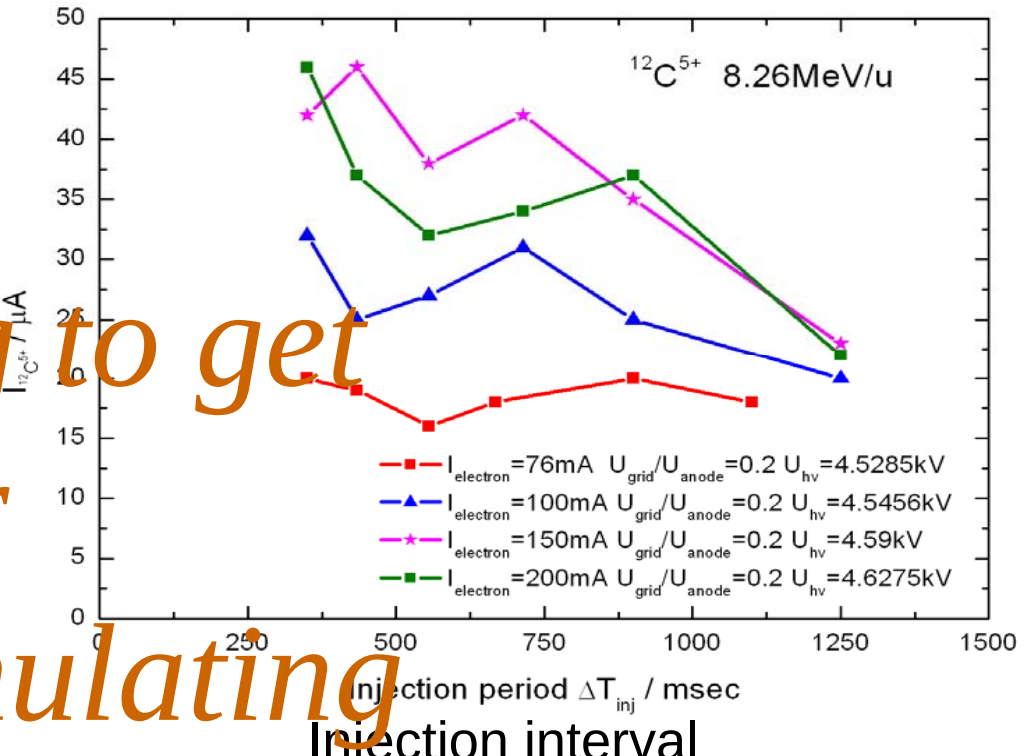
Injection interval

Electron beam current



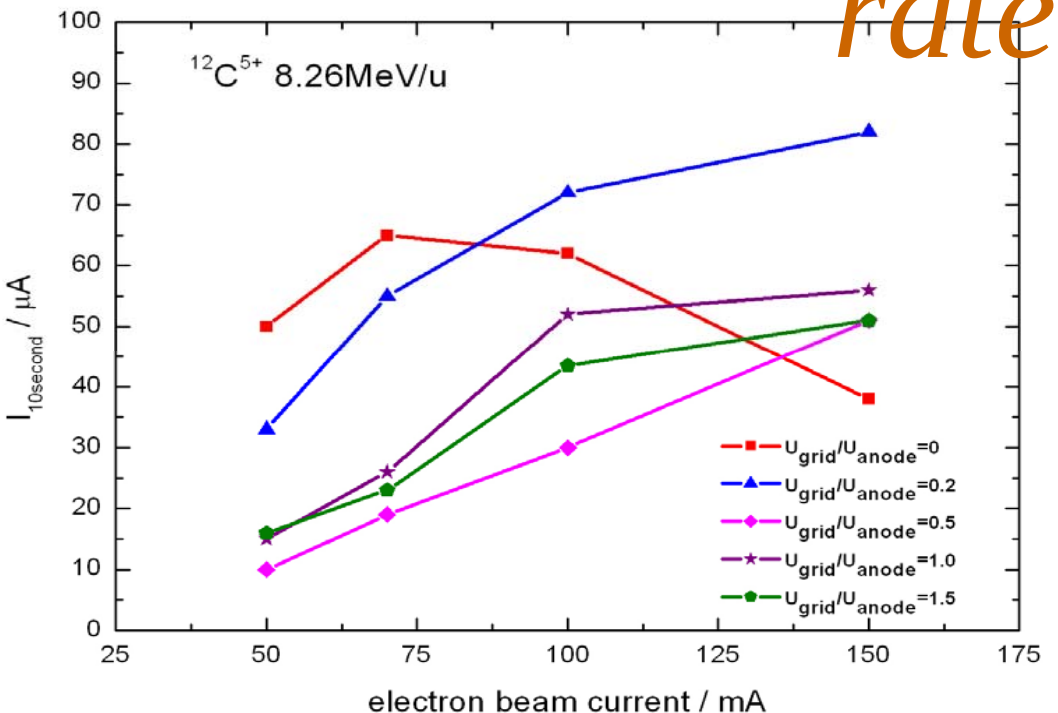


Trying to get higher accumulating rate



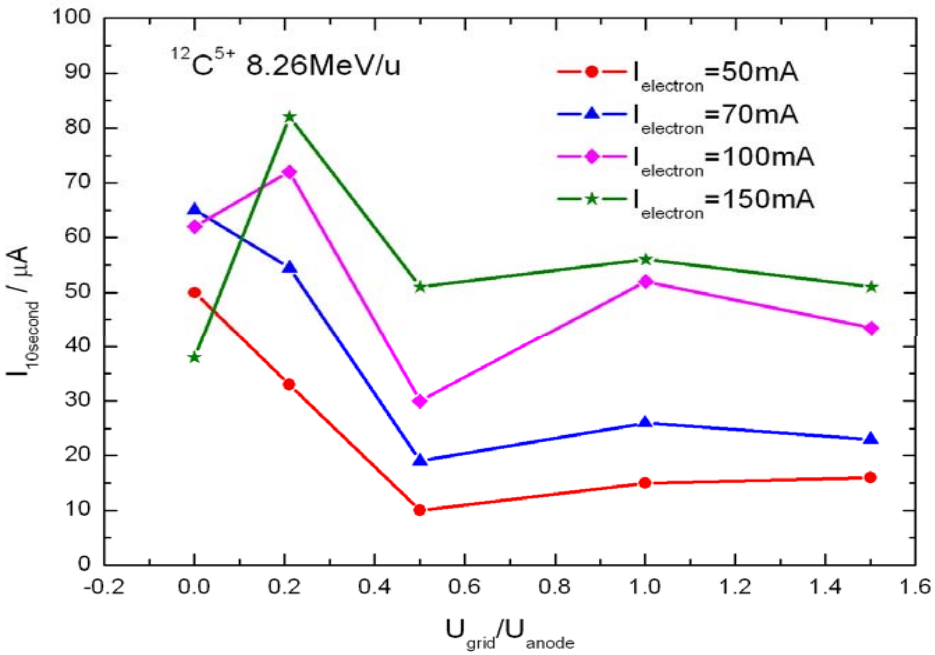
Electron energy

Electron current



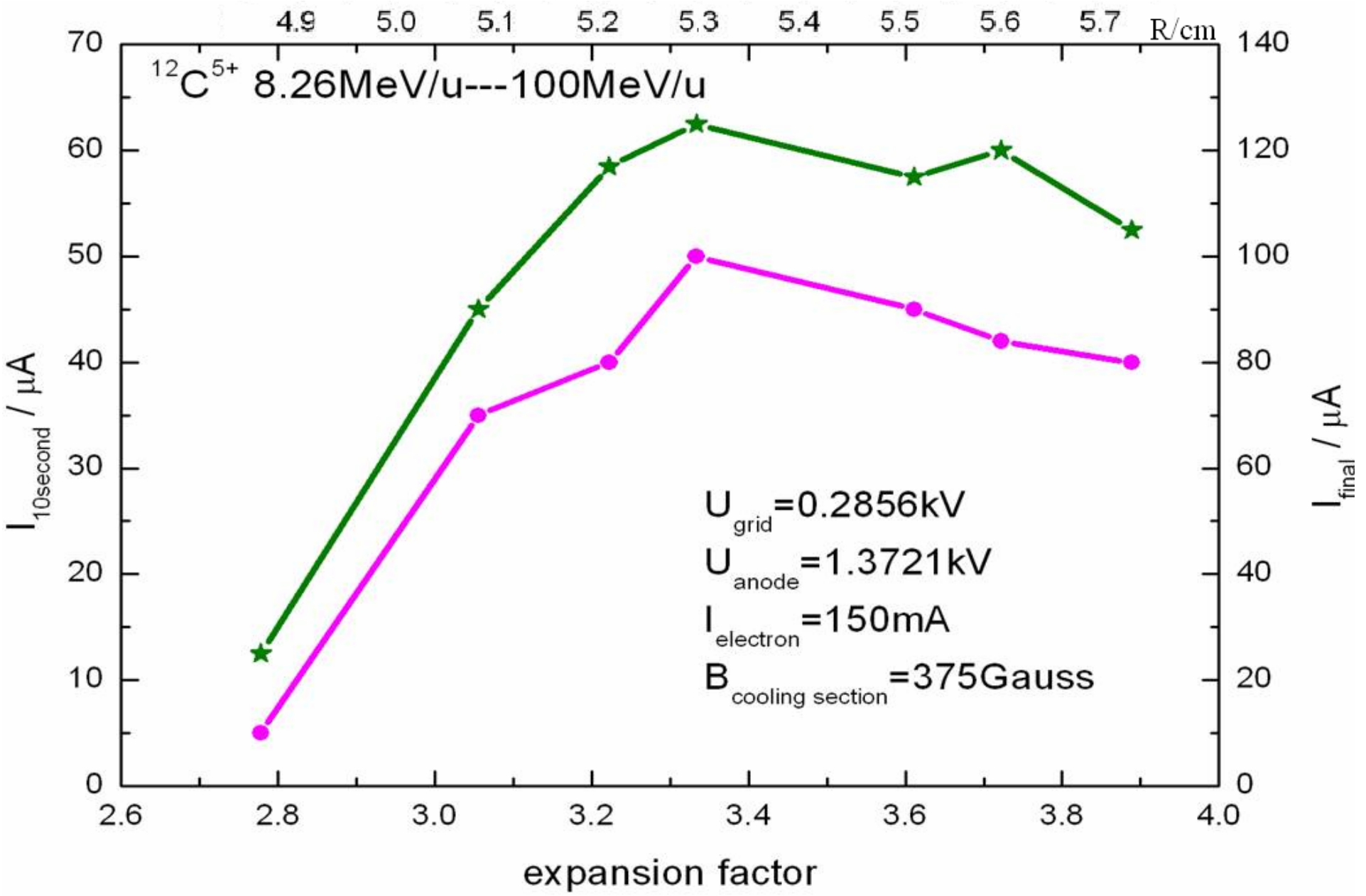
Injection interval

Electron beam shape

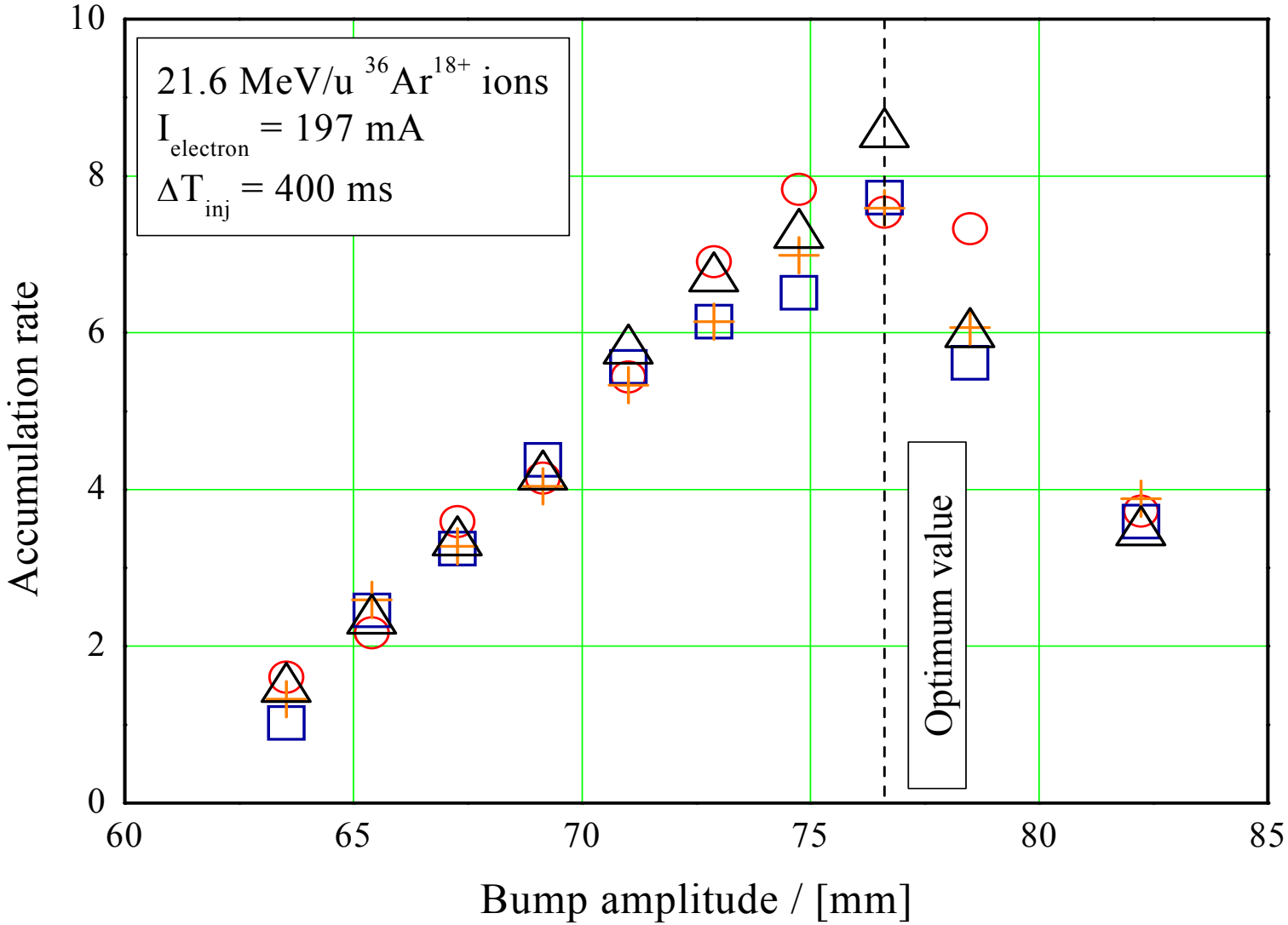


Electron beam diameter

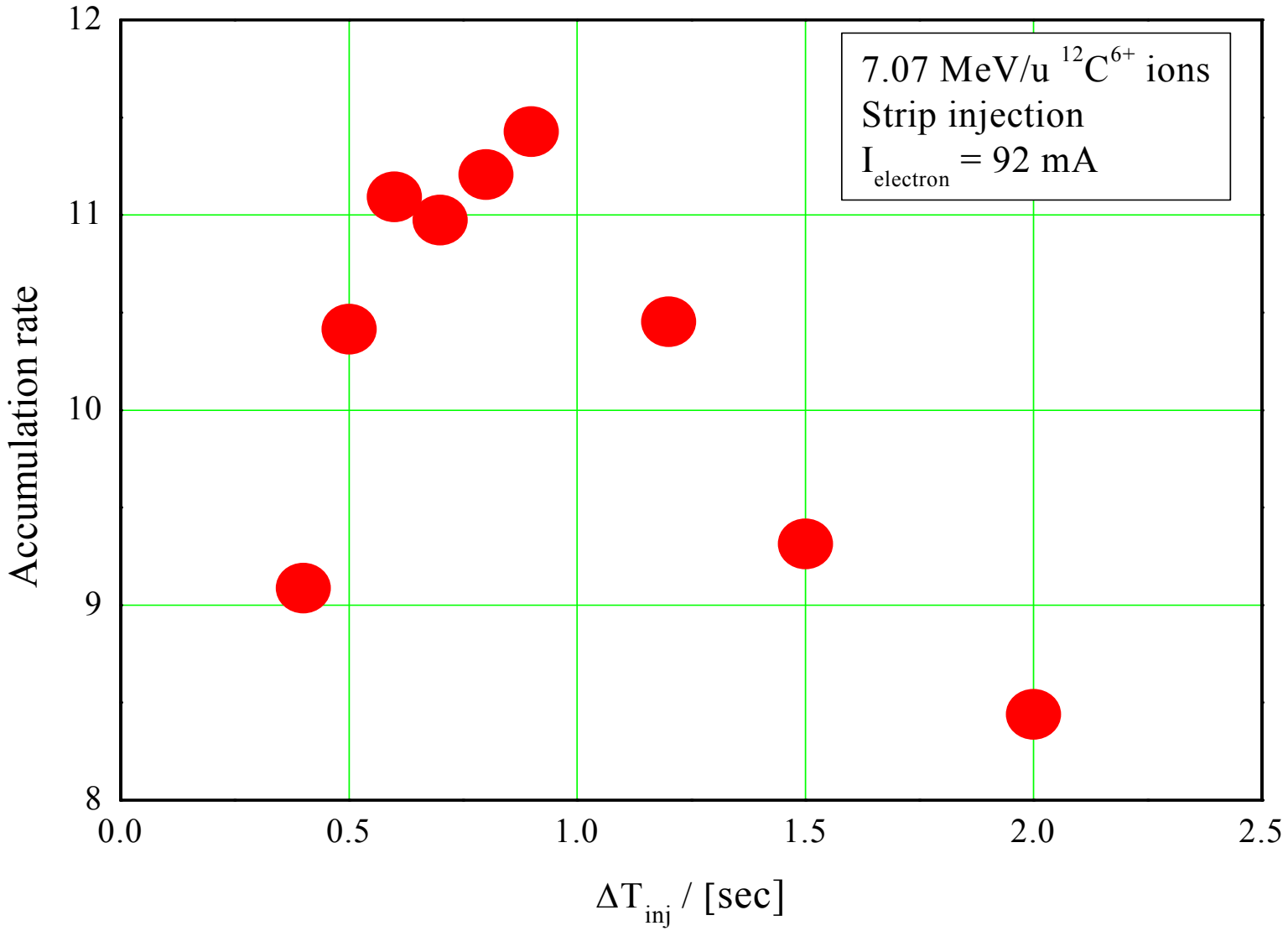
The electron beam current was fixed.



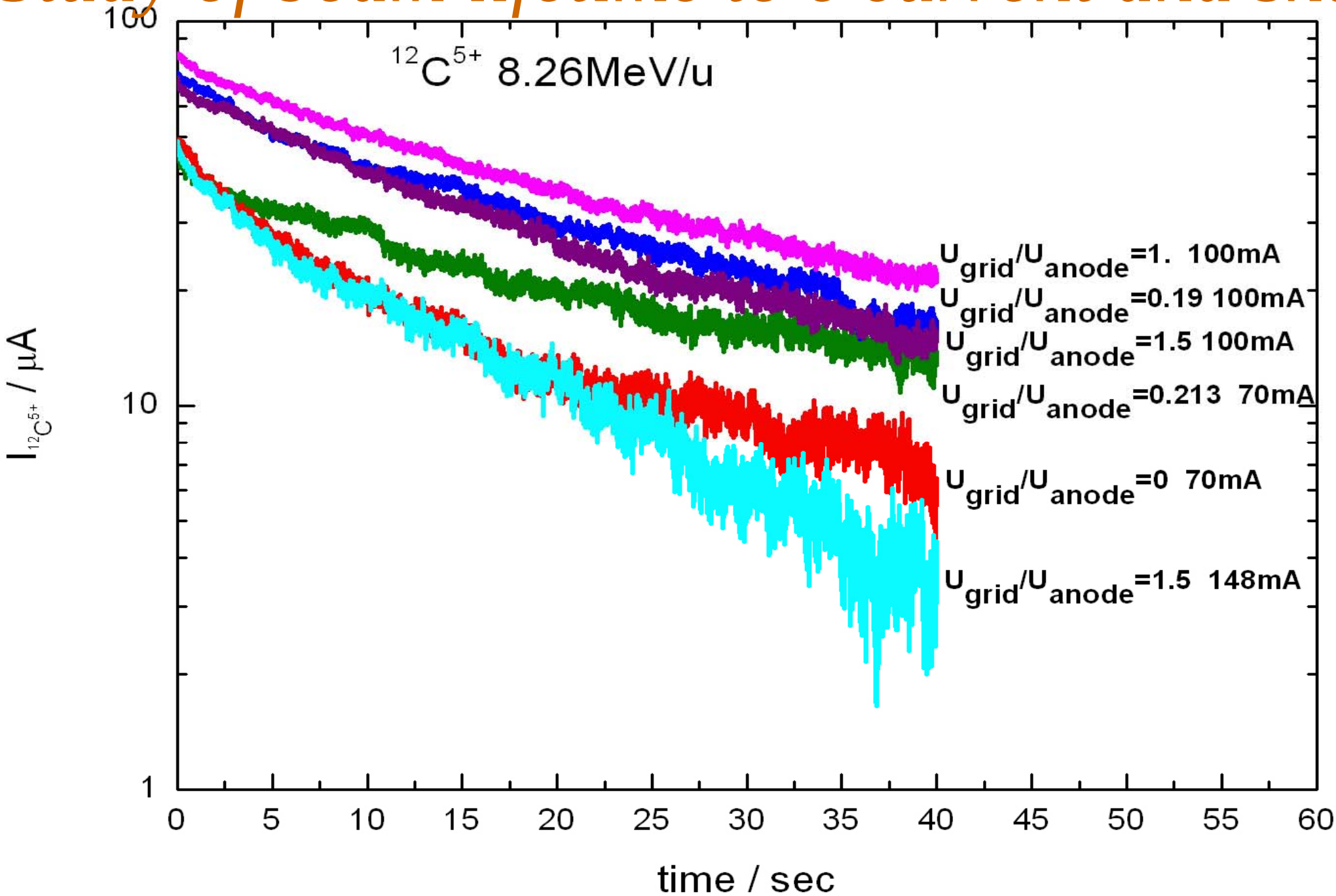
Study of accumulating rate to bump amplitude

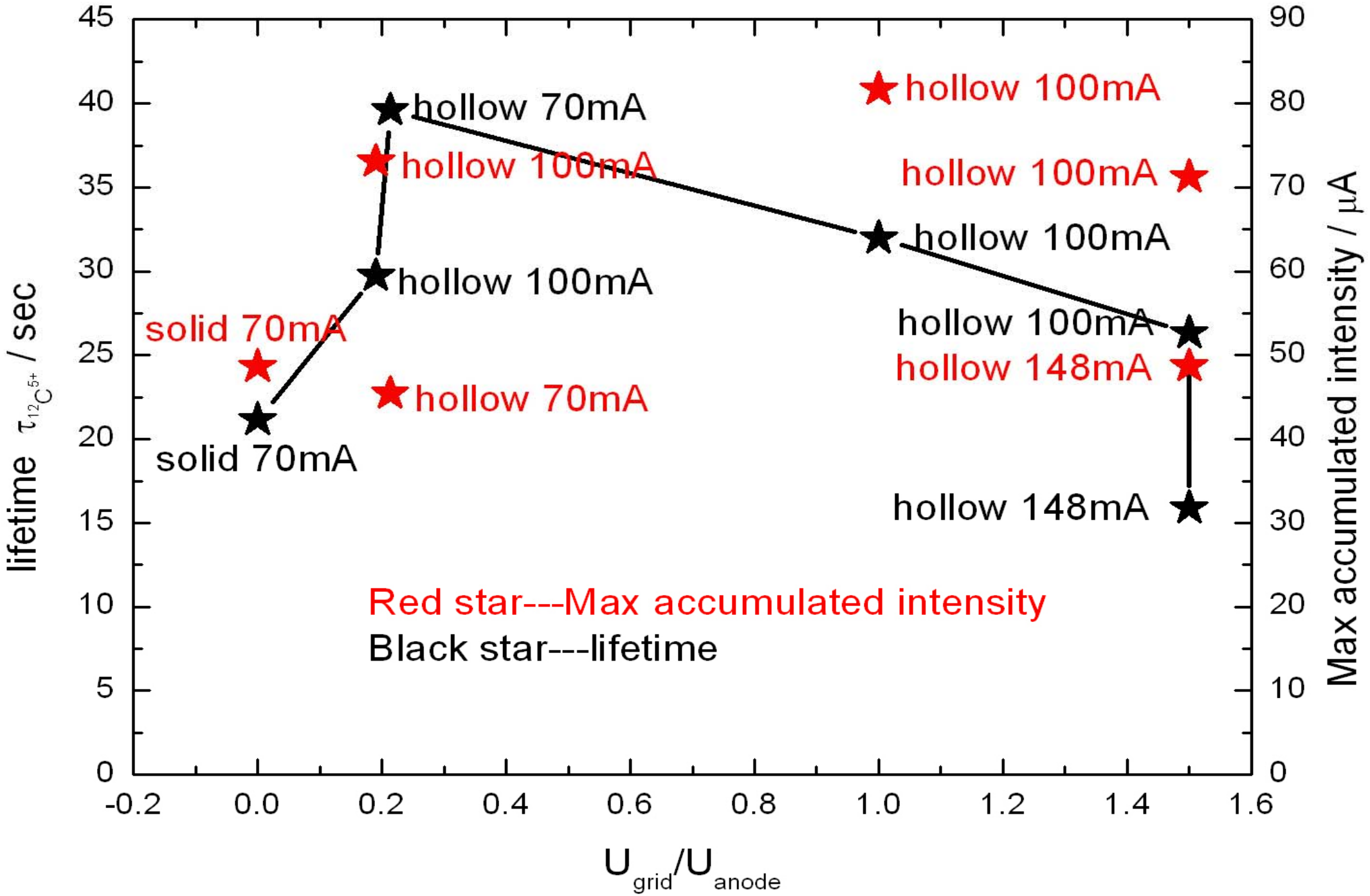


Study of accumulating rate to injection interval



Study of beam lifetime to e current and shape




lifetime $\tau_{^{12}C^{5+}}$ / sec
Max accumulated intensity / μA
U_{grid}/U_{anode}
hollow 70mA
hollow 100mA
hollow 100mA
hollow 100mA
hollow 100mA
hollow 100mA
hollow 100mA
hollow 148mA
hollow 148mA
solid 70mA
solid 70mA
hollow 70mA
Red star---Max accumulated intensity
Black star---lifetime

Study of momentum spread of cooled beam

Parameters of Electron Cooler

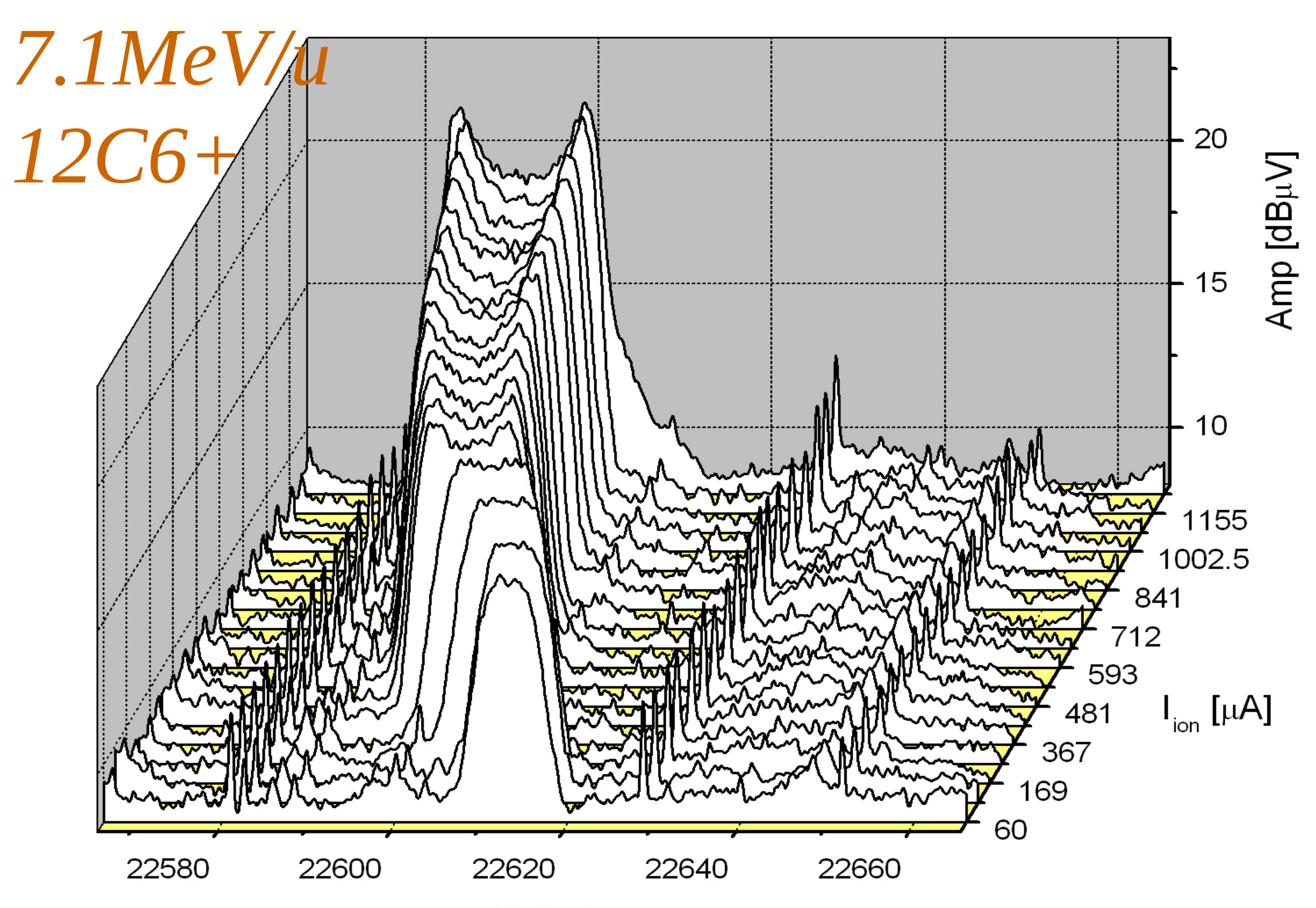
- U_{grid}=0.18kV
- U_{anode}=0.81kV
- U_{grid}/U_{anode}=0.222
- U_{HV}=3.890kV
- $I_{electron}$=92mA

$I_{gun\ solenoid}$=690A(1380G)

I_{toroid}=198A(375G)

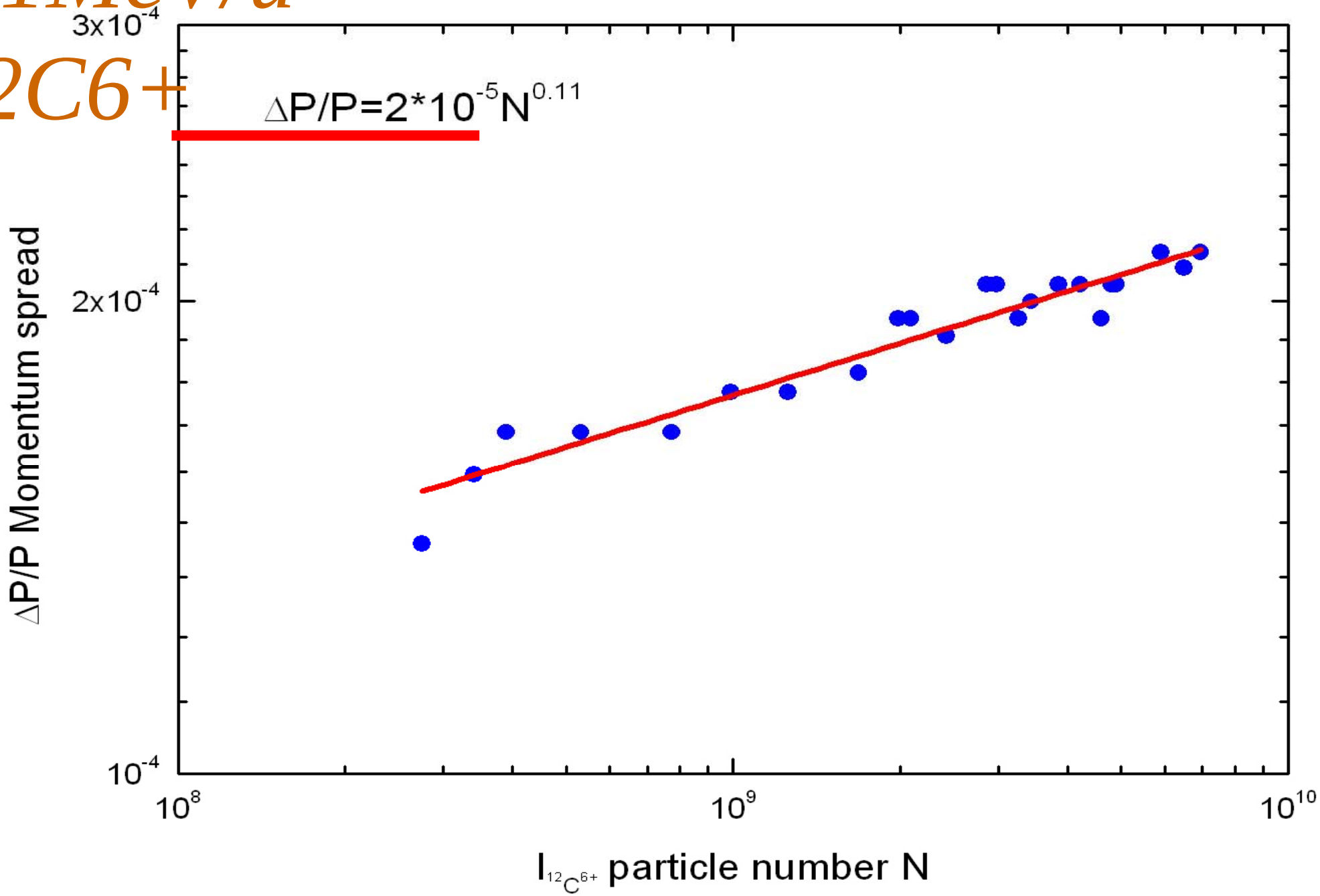
$I_{main\ solenoid}$=48A(375G)

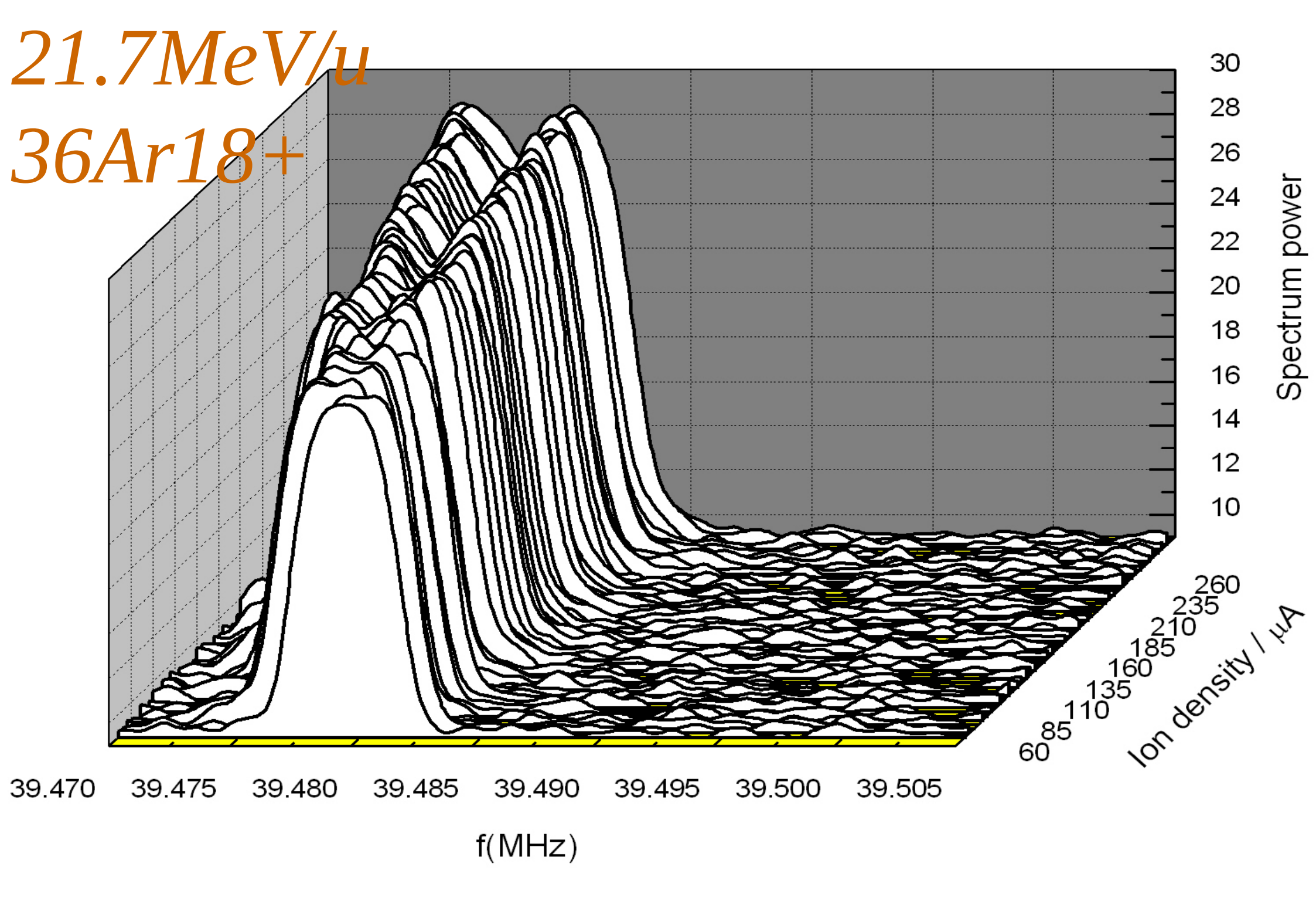
$U_{bending}$=380V


7.1MeV/u
12C6+
20
15
10
Amp [dBμV]
1155
1002.5
841
712
593
481
367
169
60
I ion [μA]
22580
22600
22620
22640
22660

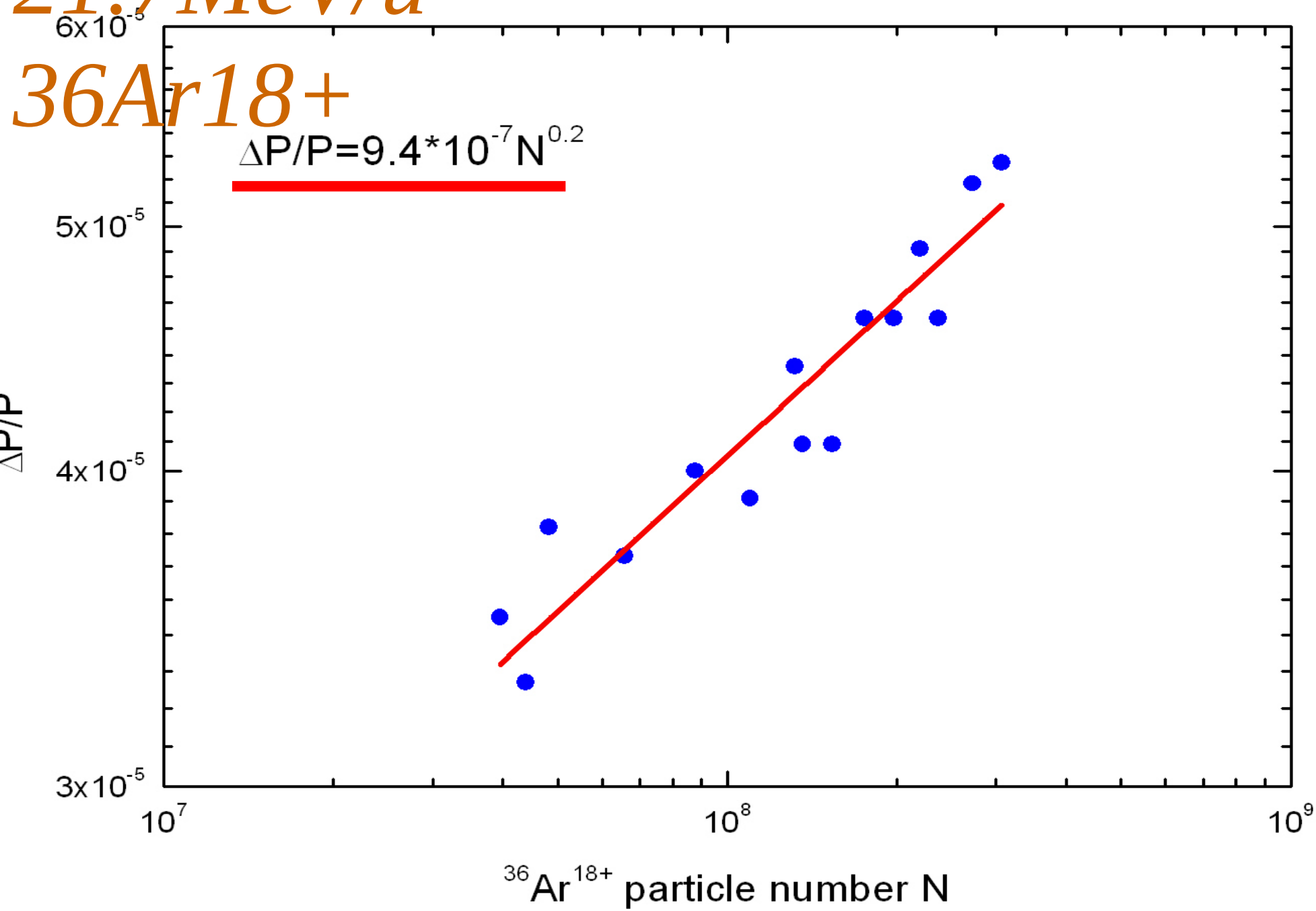
7.1MeV/u

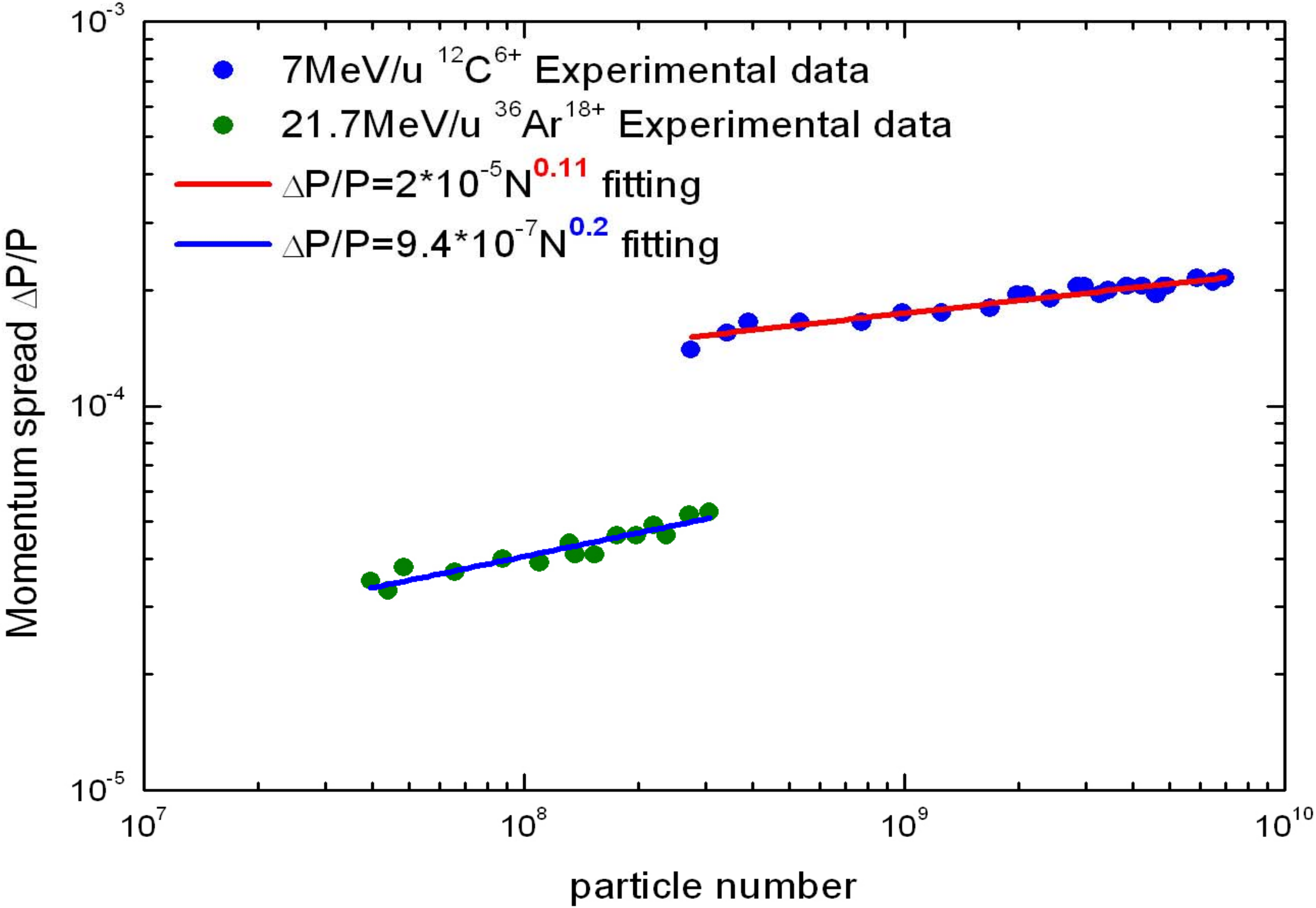
12C6+


3x10^-4
2x10^-4
10^-4
ΔP/P=2*10^-5N^0.11
ΔP/P Momentum spread
10^8
10^9
10^10
I12C6+ particle number N


21.7MeV/u
36Ar18+
30
28
26
24
22
20
18
16
14
12
10
Spectrum power
260
235
210
185
160
135
110
85
60
Ion density / μA
39.470
39.475
39.480
39.485
39.490
39.495
39.500
39.505
f(MHz)

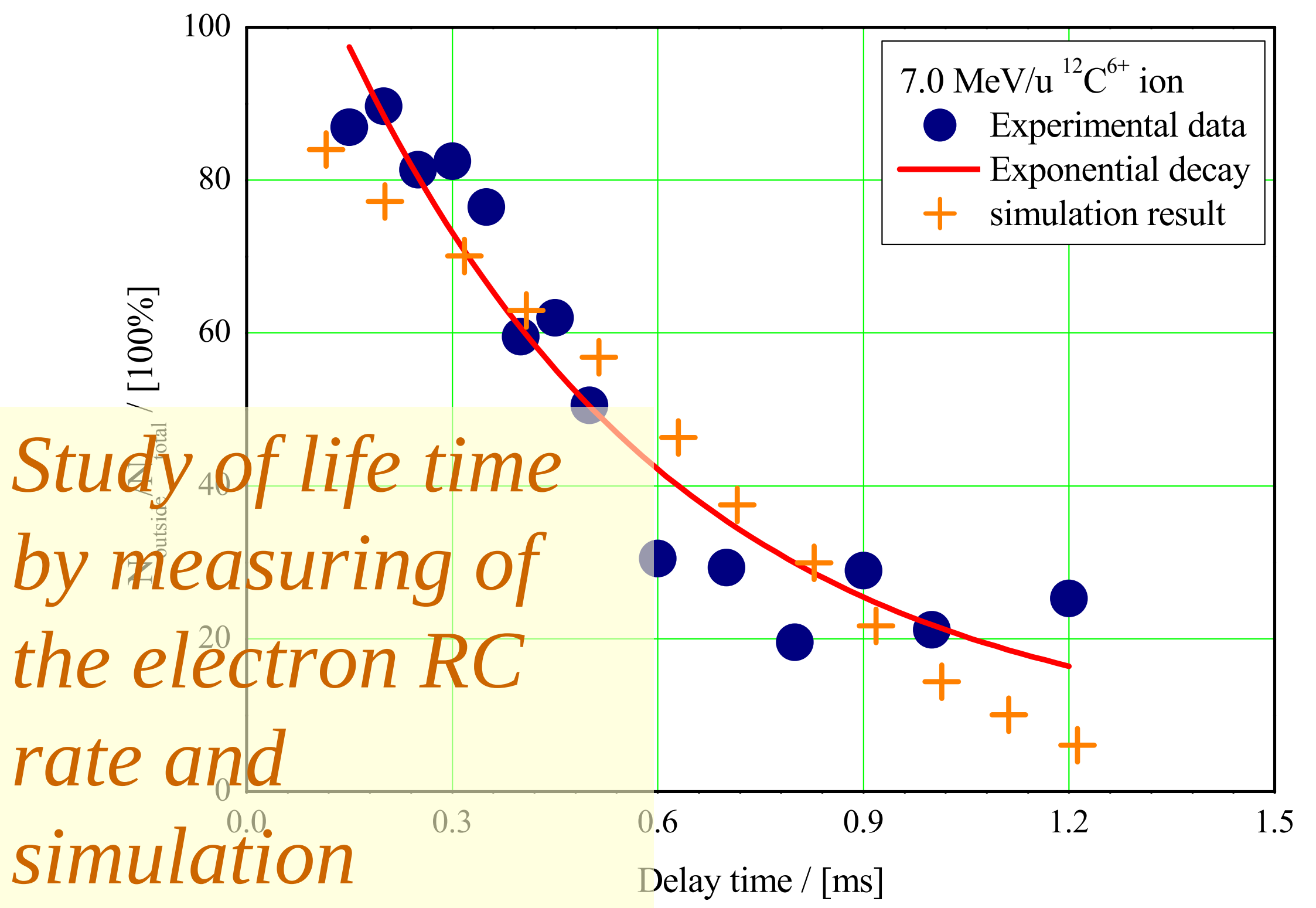
21.7MeV/u
36Ar18+



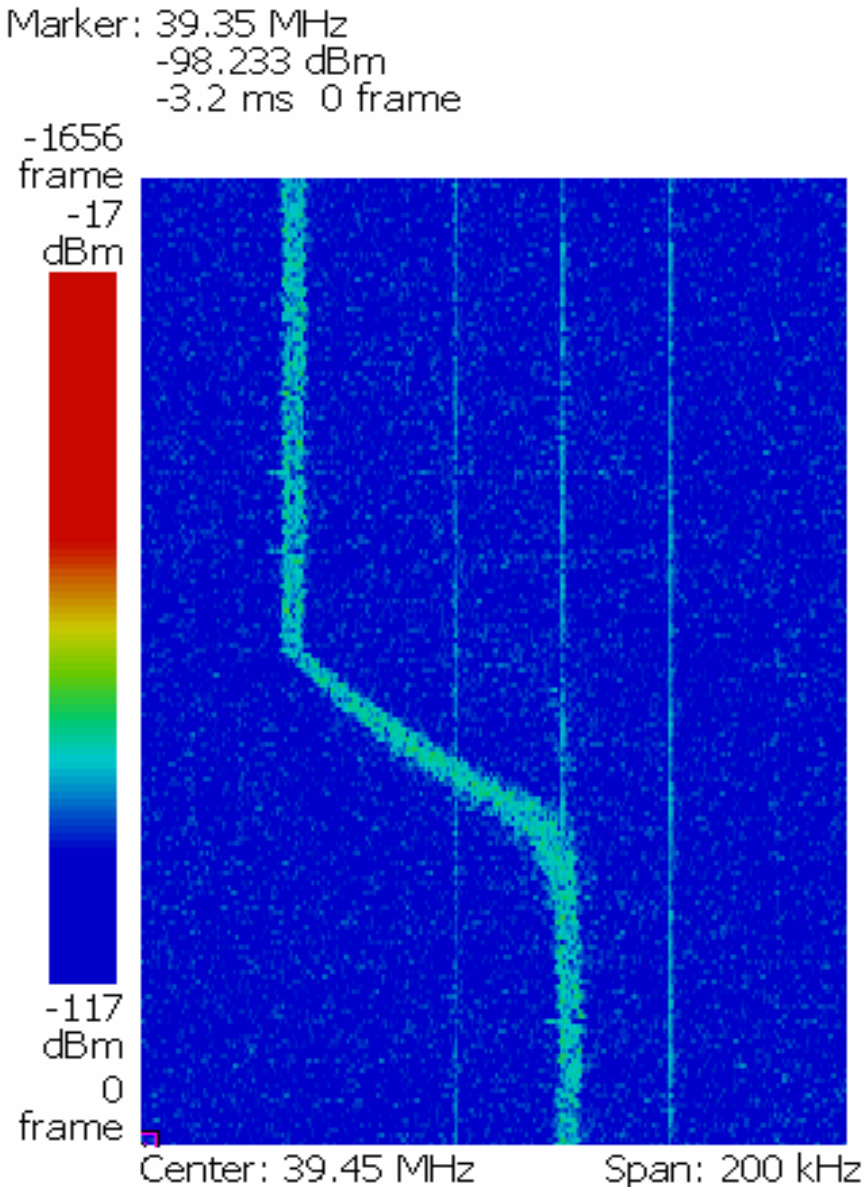

7MeV/u $^{12}C^{6+}$ Experimental data
21.7MeV/u $^{36}Ar^{18+}$ Experimental data
$\Delta P/P=2*10^{-5}N^{0.11}$ fitting
$\Delta P/P=9.4*10^{-7}N^{0.2}$ fitting
Momentum spread $\Delta P/P$
particle number
10^{-3}
10^{-4}
10^{-5}
10^{7}
10^{8}
10^{9}
10^{10}

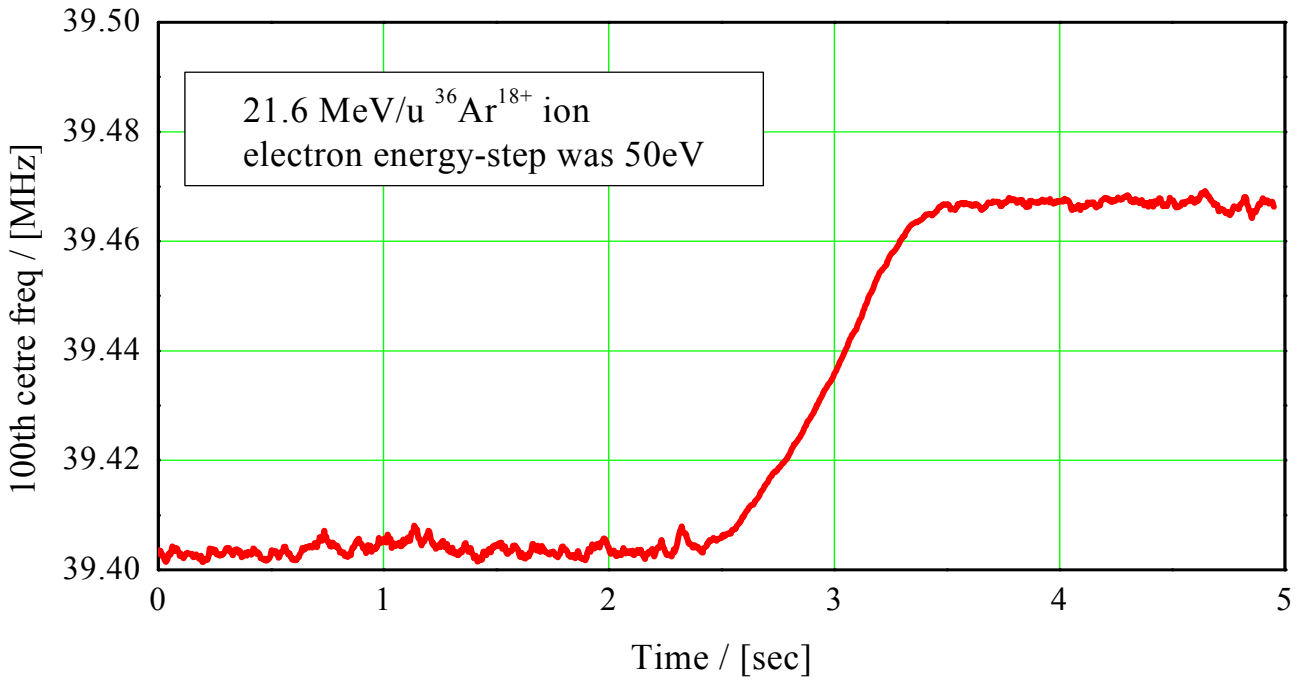
What we are doing on CSRm cooler

- Cooling time measurement
- Cooling force measurement
- BETACOOL simulation
- Electron Recombination

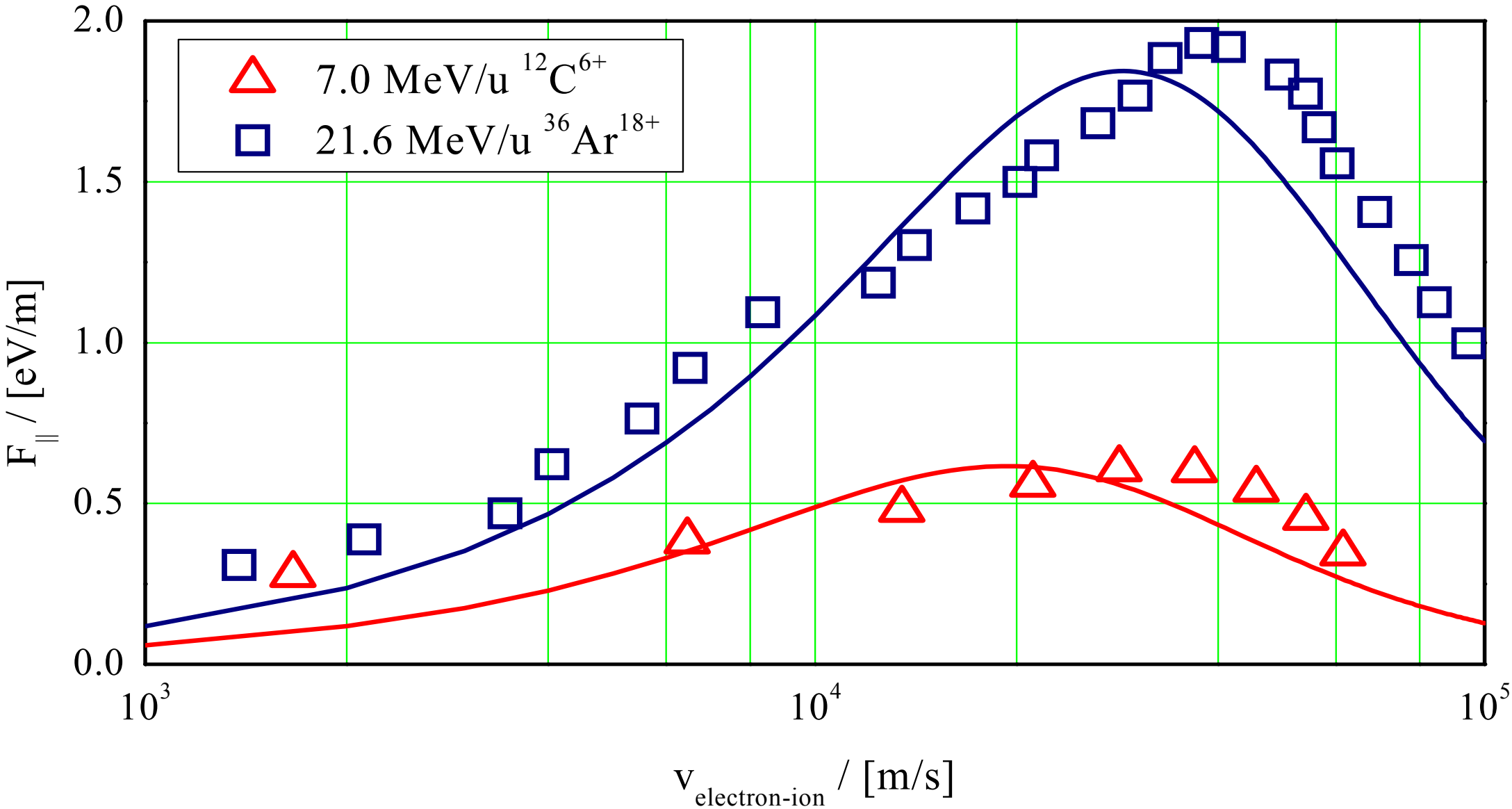

7.0 MeV/u $^{12}C^{6+}$ ion
Experimental data
Exponential decay
simulation result
100
80
60
40
20
0
0.0
0.3
0.6
0.9
1.2
1.5
Delay time / [ms]
/ [100%]
Study of life time by measuring of the electron RC rate and simulation

Study of longitudinal cooling force by swift shifting of energy center

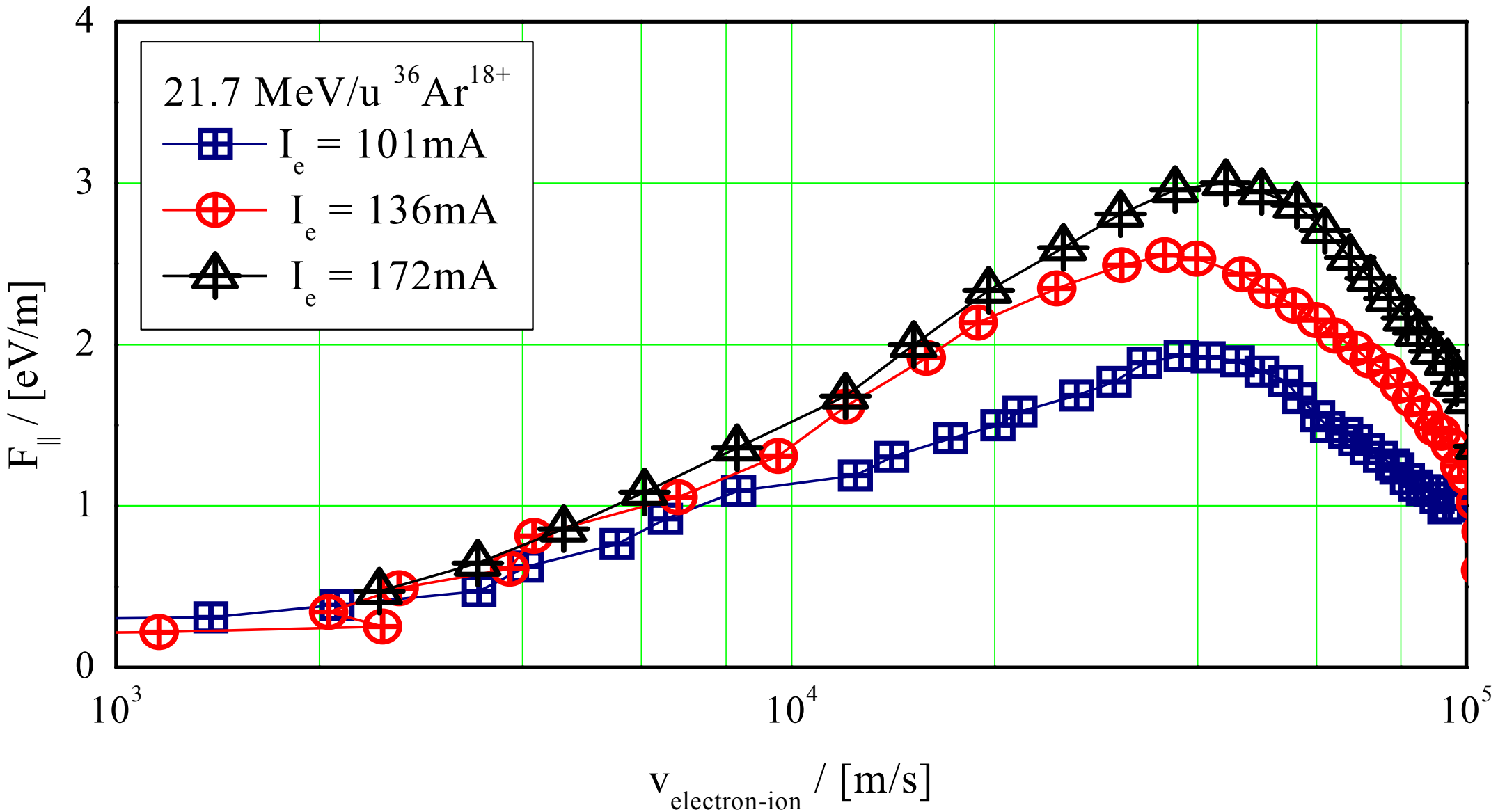




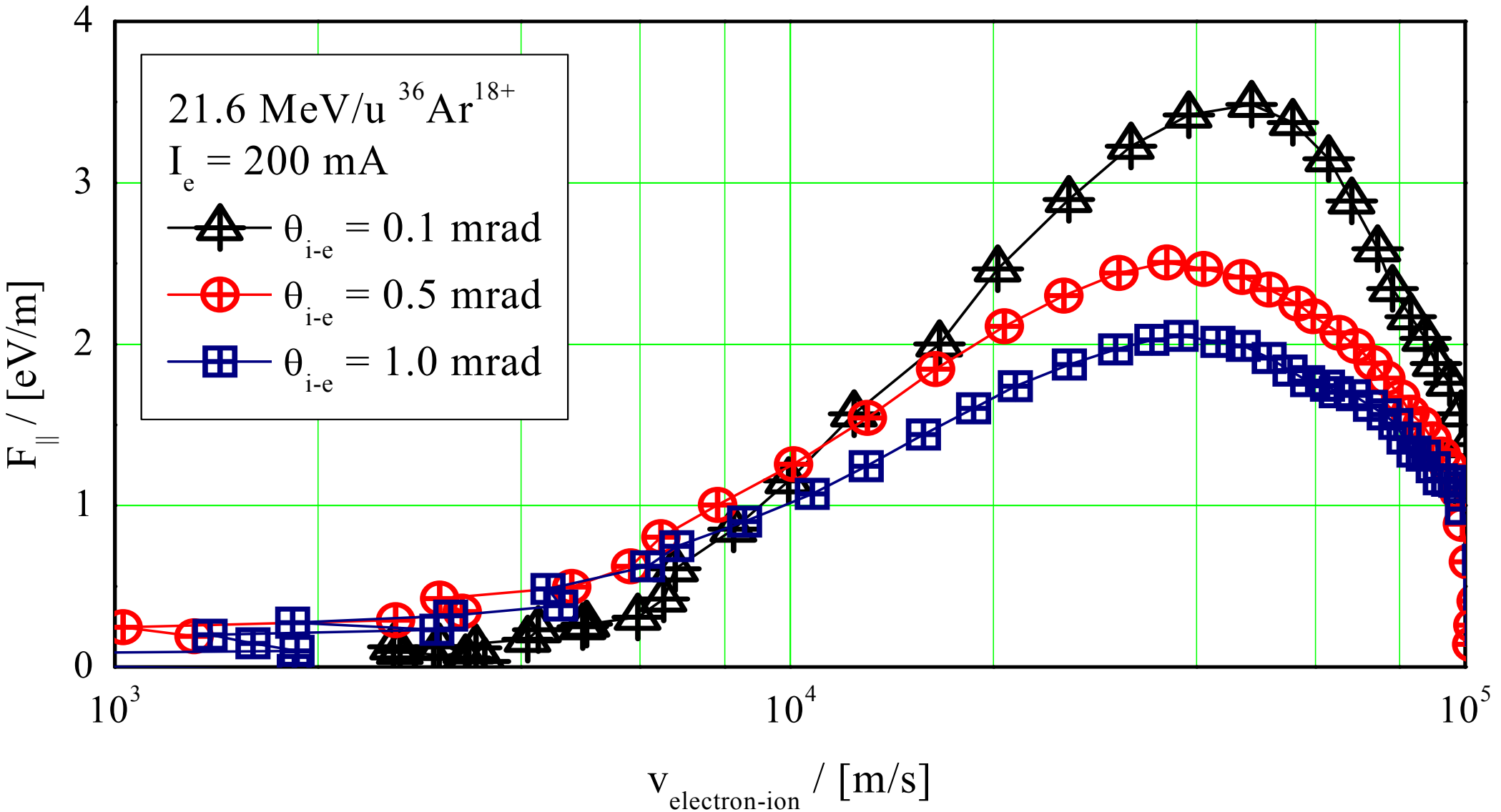
Study of cooling force for C and Ar



Study of cooling force for Ar with different e-currents



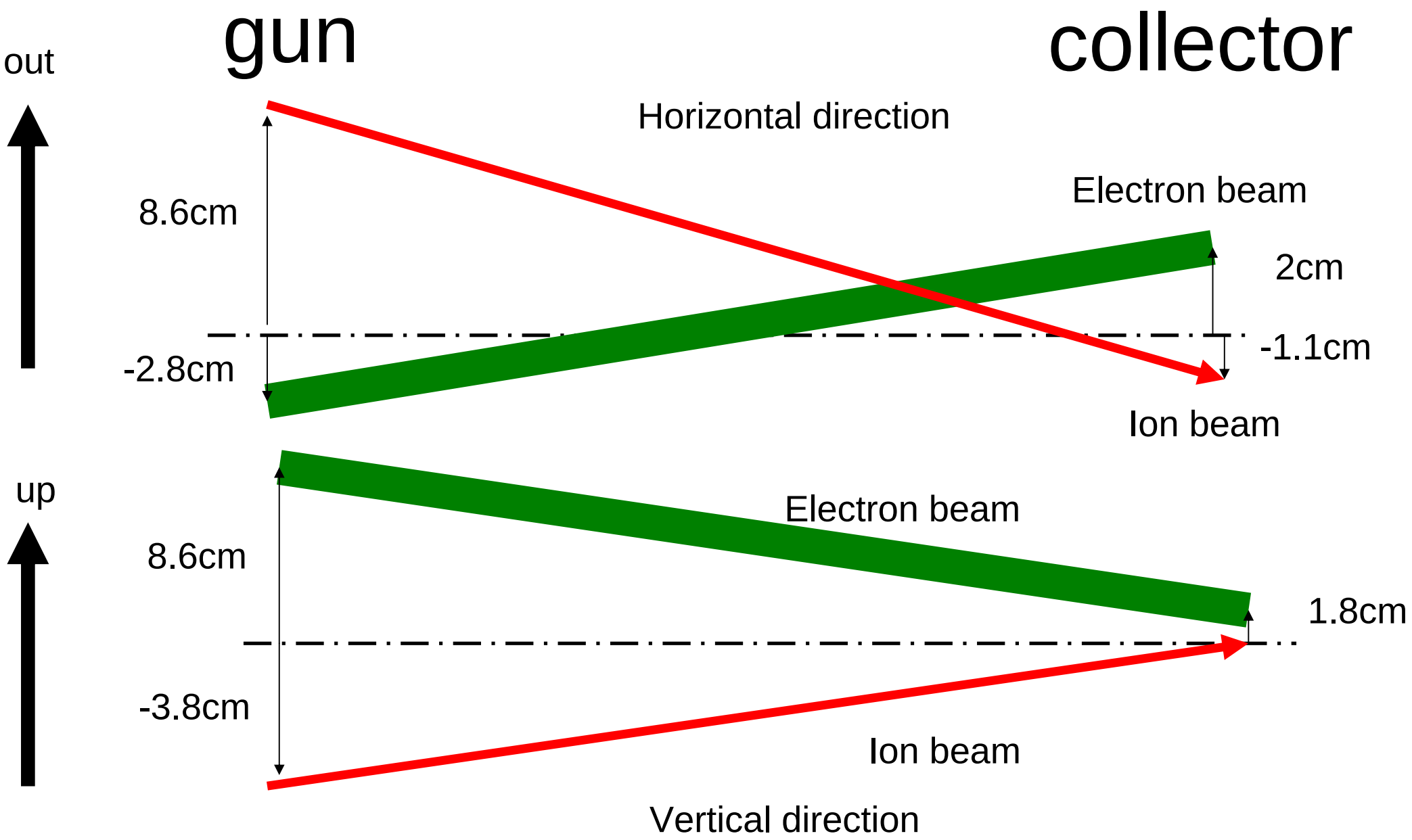
Study of cooling force for Ar with different crossing angle



CSRe Cooler

- Reached 230kV, 300mA(400MeV/u)
- Electron beam position problem:

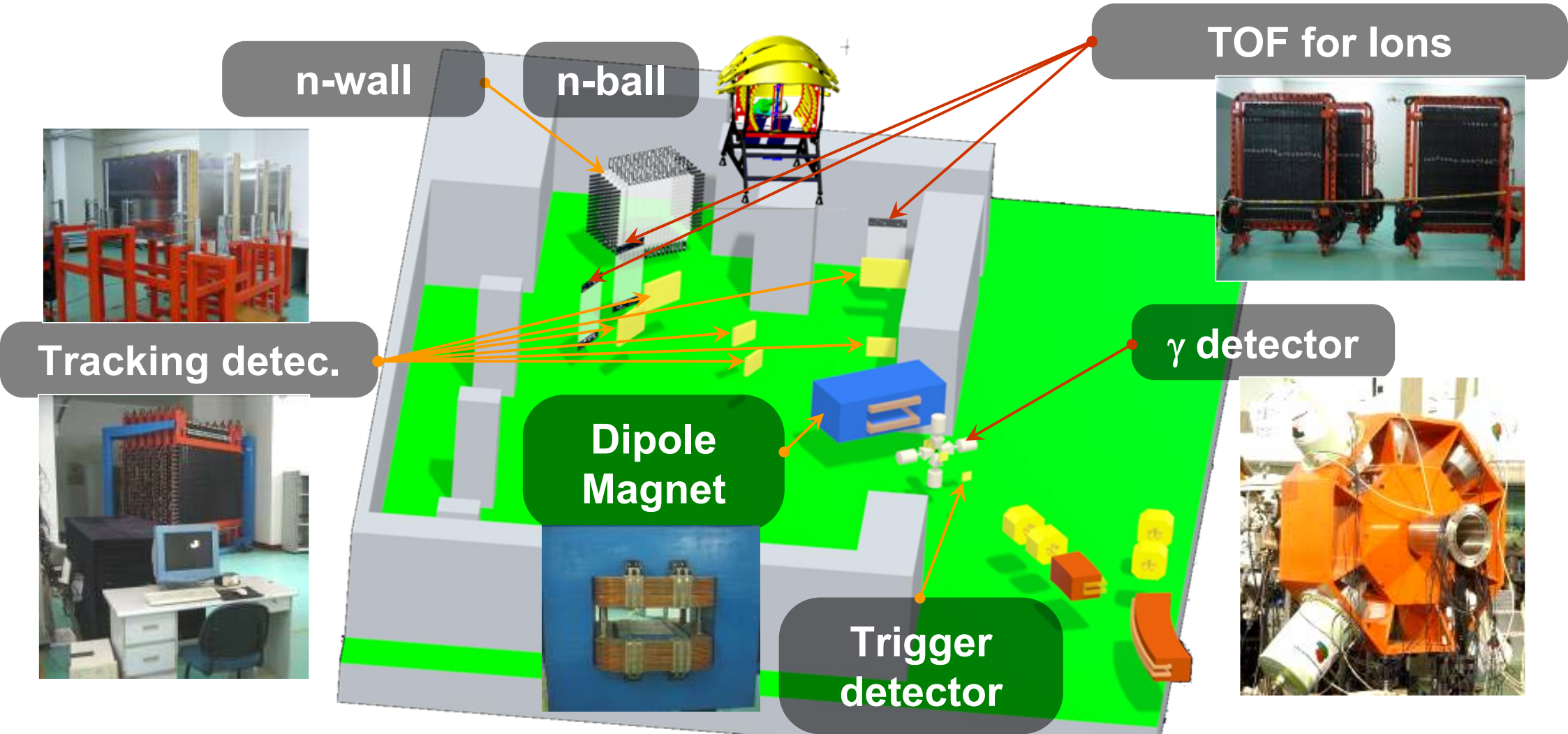
  electron beam is not parallel to ion beam presently


gun
collector
out
Horizontal direction
8.6cm
Electron beam
2cm
-2.8cm
-1.1cm
Ion beam
up
Electron beam
8.6cm
1.8cm
-3.8cm
Ion beam
Vertical direction

Other Tasks in Progress:

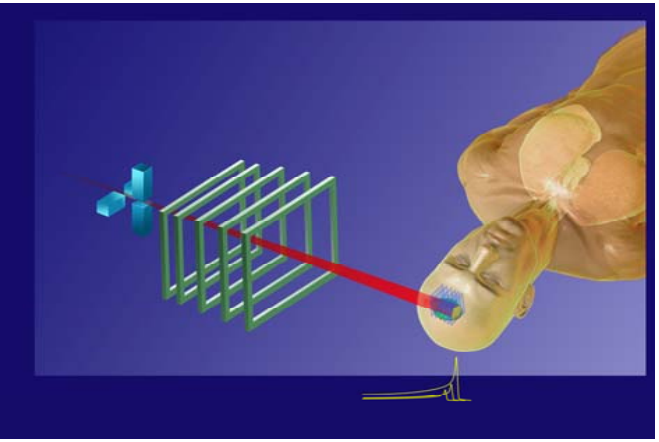
- External target
- Tumor Therapy study
- FAIR Project
- Upgrading of CSR project

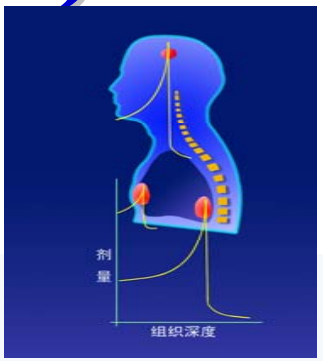
External Target Experiments collaborated with several groups

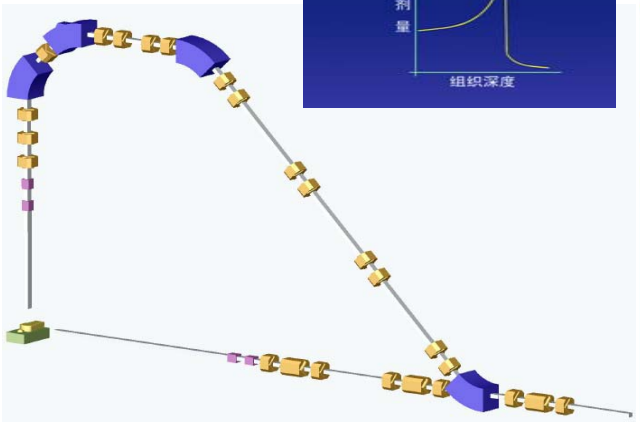


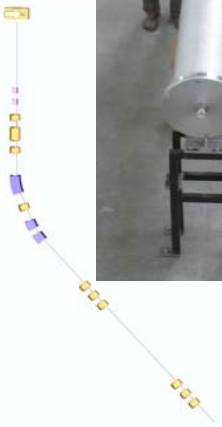
Deep-seated Tumor Therapy at HIRFL-CSR

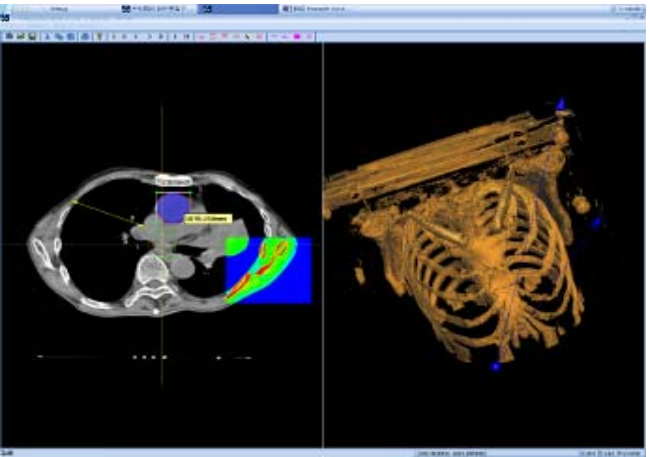
Treatment Ports
(horizontal, vertical+horizontal)

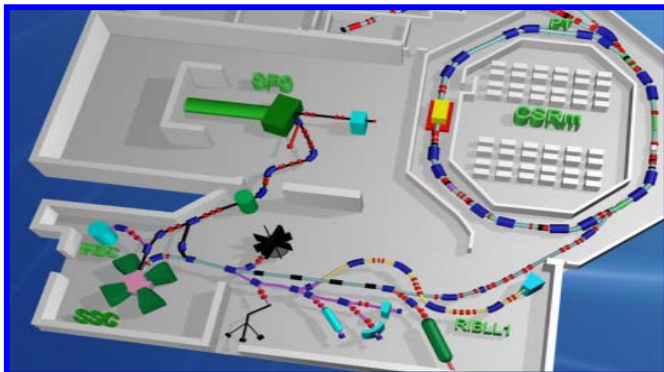






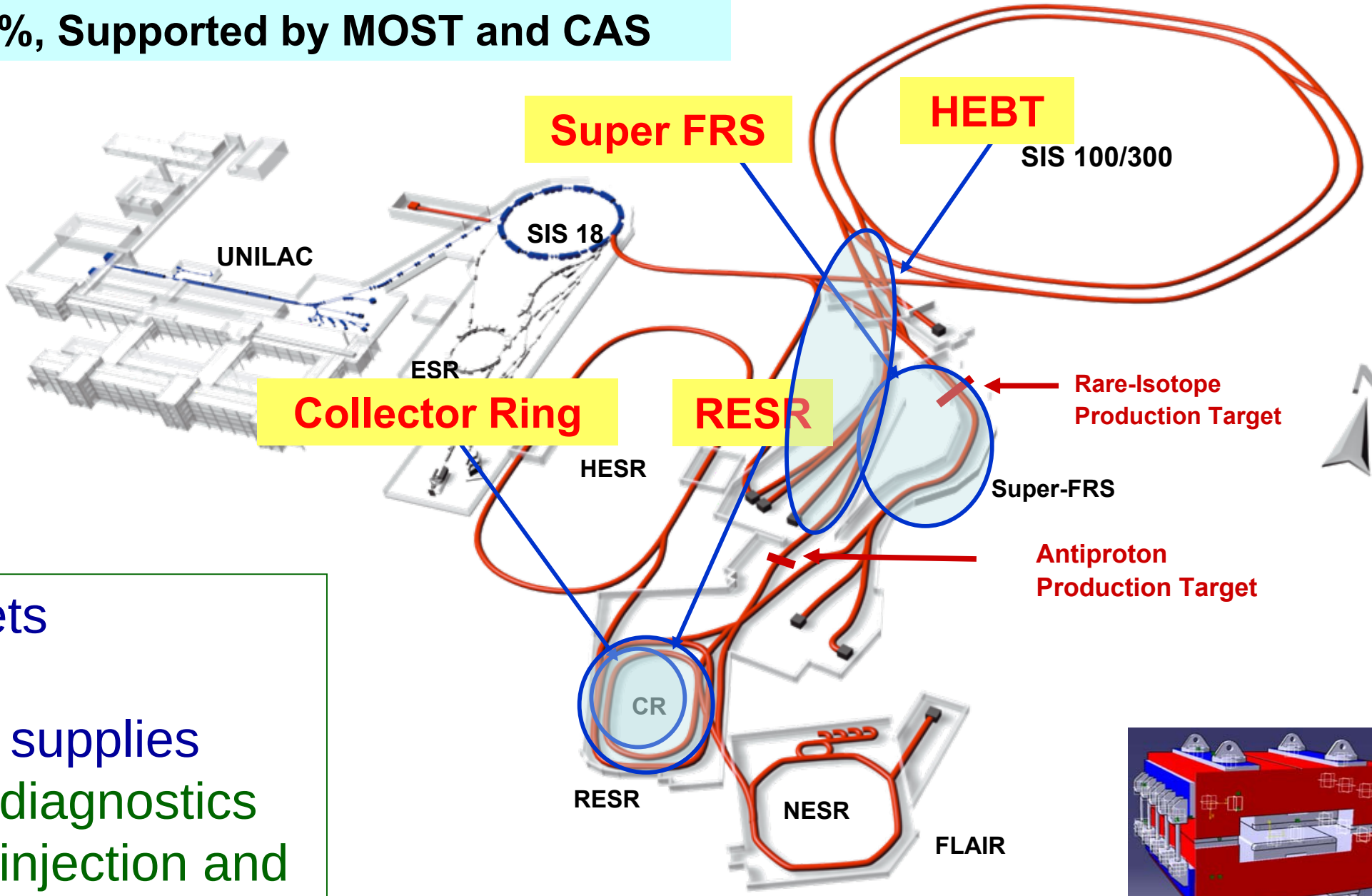






FAIR Project —Accelerator part

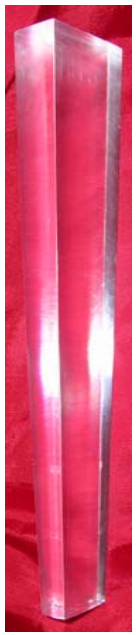
China >1%, Supported by MOST and CAS



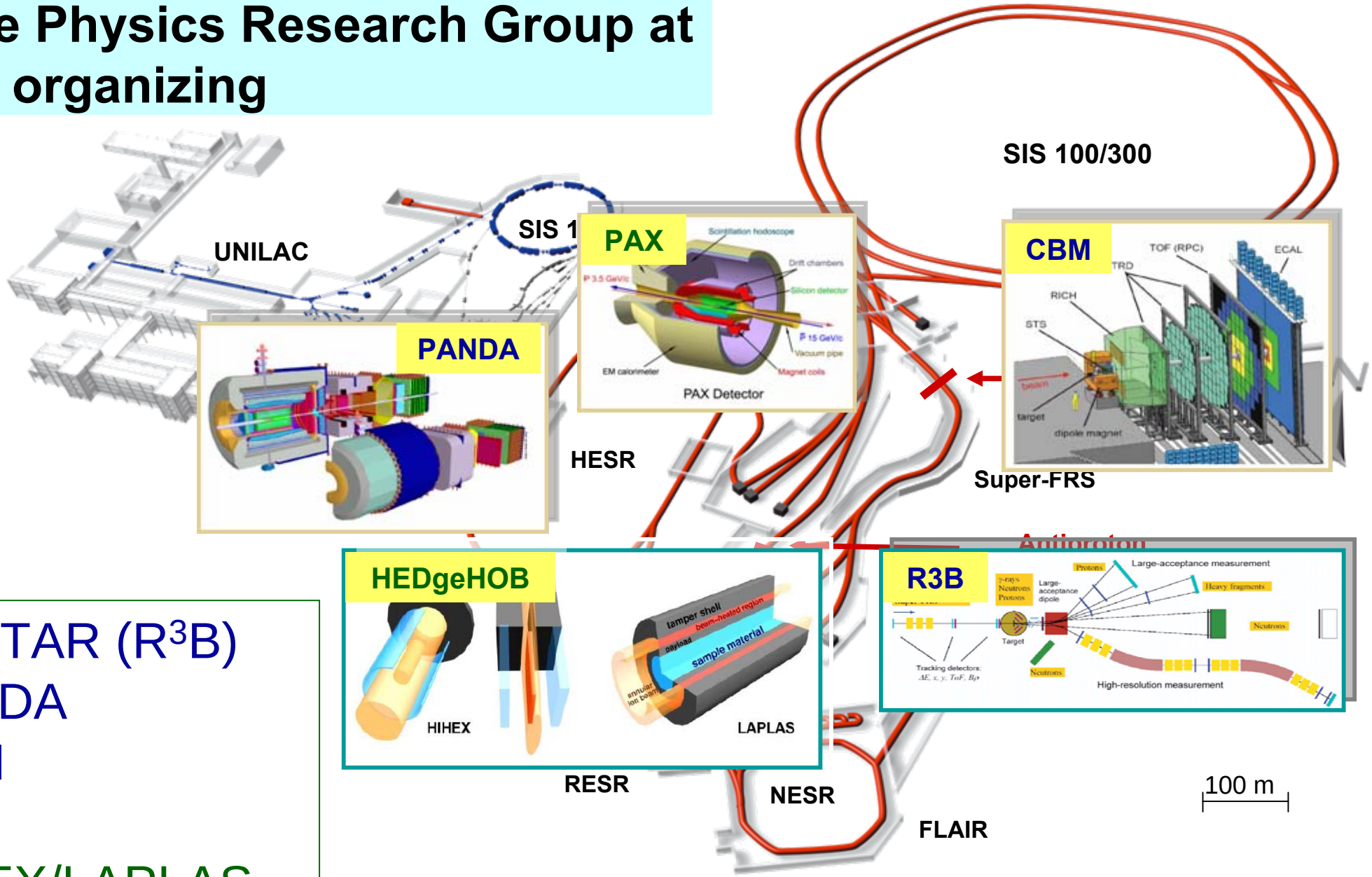
- Magnets
- UHV
- Power supplies
- Beam diagnostics
- Beam injection and extraction elements

FAIR Project – Detectors part

Chinese Physics Research Group at FAIR is organizing

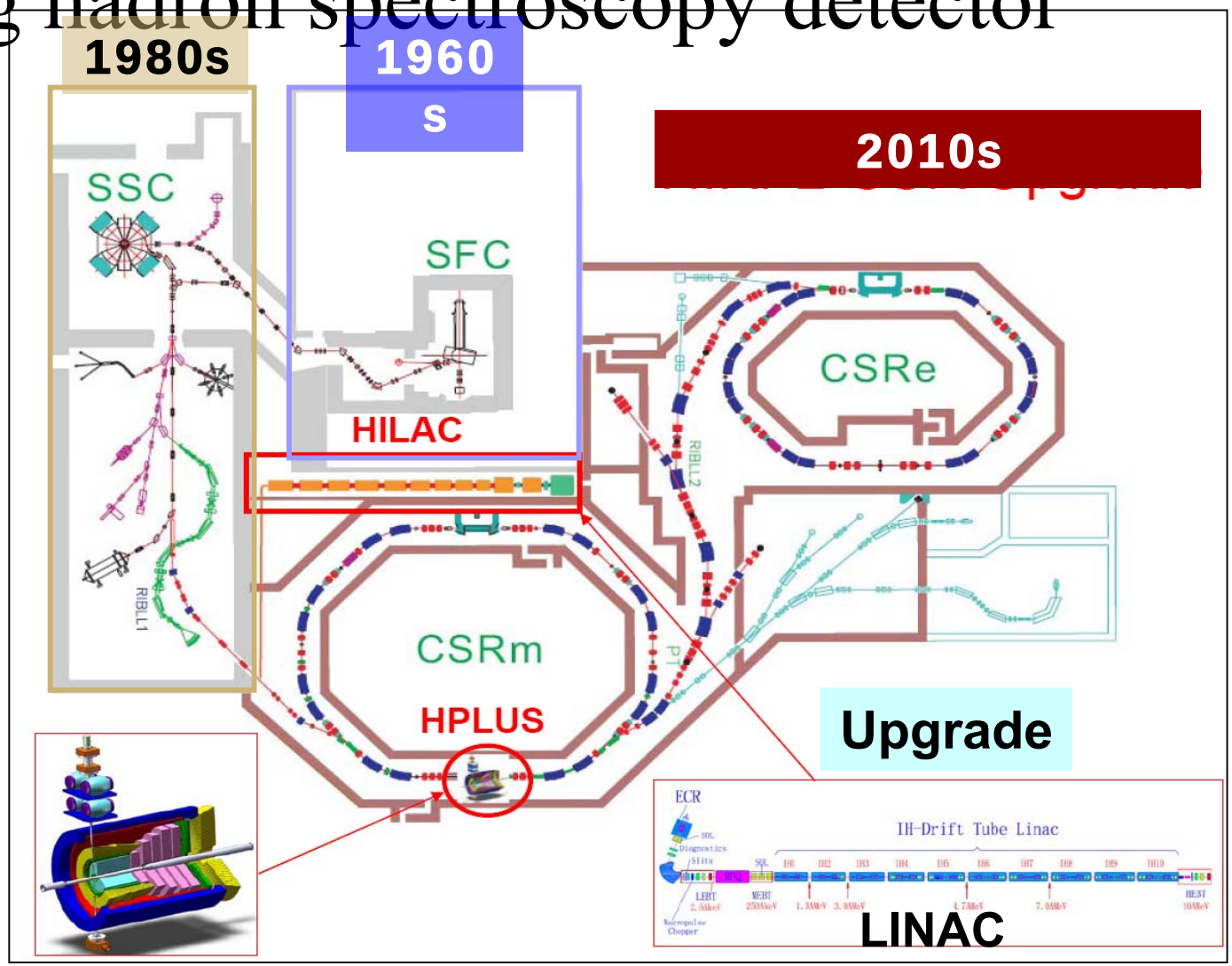


- NUSTAR (R^3B)
- PANDA
- CBM
- PAX
- HIHEX/LAPLAS



Upgrade of HIRFL-CSR

- Increasing beam intensity, beam species
- Building hadron spectroscopy detector

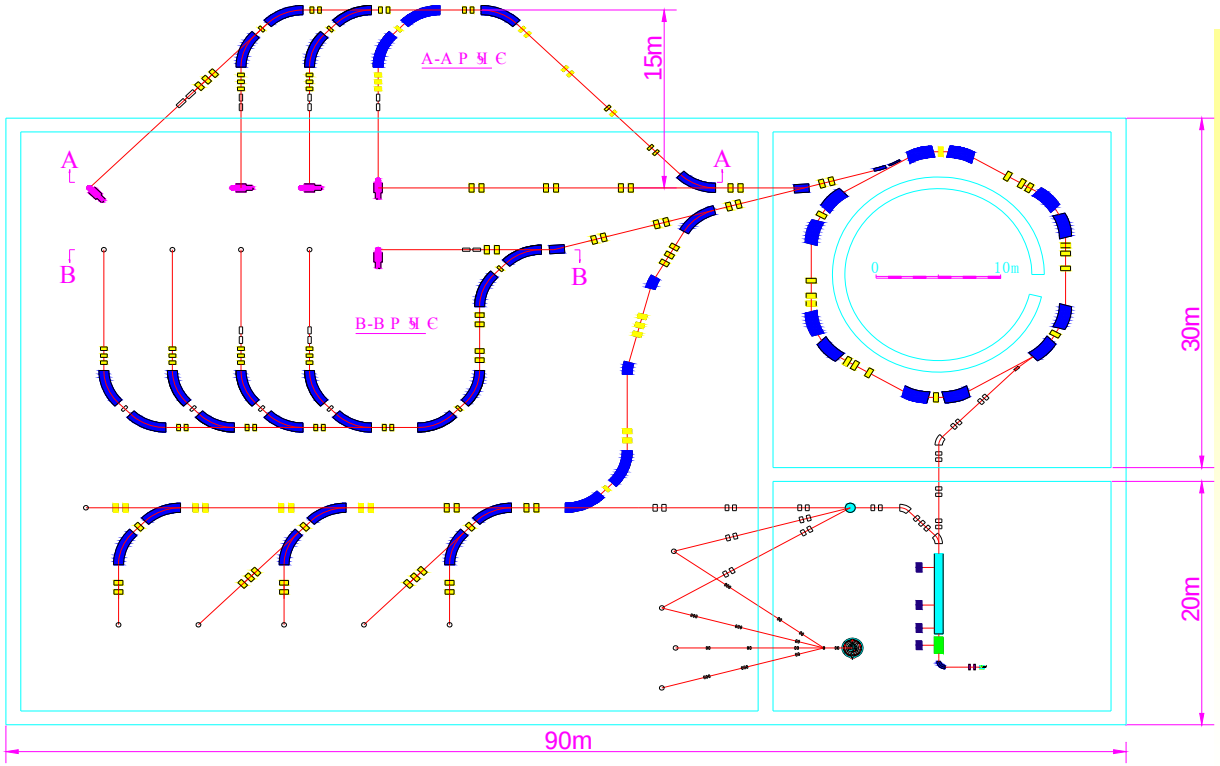


Possible Future Projects:

- Facility of Heavy Ion Beam Application Research
- Compact Cancer Therapy Accelerator
- New facility in the future (2020-2035)

➢New project was proposed (2011-2015)

Facility of Ion Application Research in Lanzhou



p~Xe ions, C(430MeV/u)

Focused on:

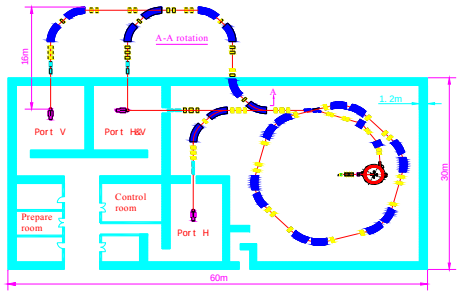
- **➢Cancer therapy**
- **➢Space industries**
- **➢Material sciences**
- **➢Mutation breeding**
- **➢Beam analysis&imaging**

Total budget: 850 M¥

Compact facilities

for therapy centers in China

Several in recent years are possible

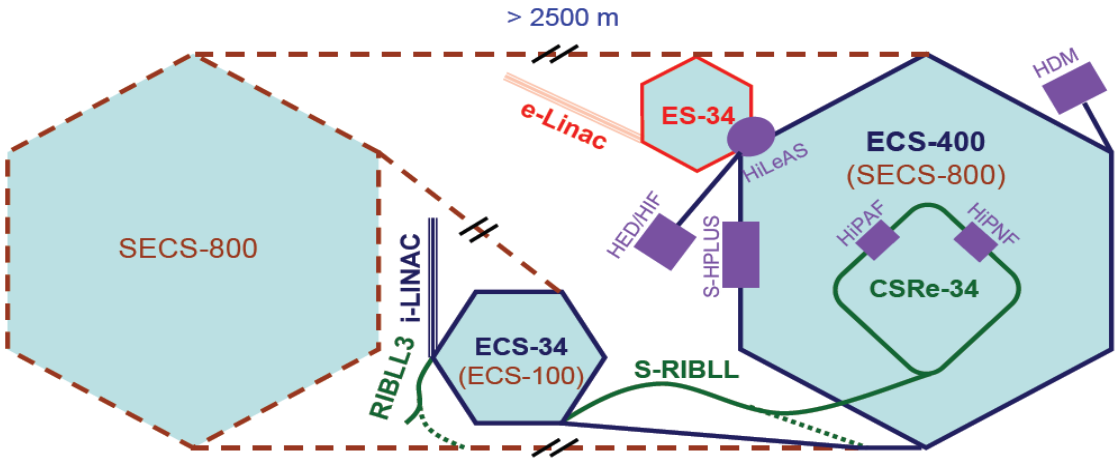


New facility in the future (2020-2035)

Facility of Ion, Electron and Beta Beams (FIEB2)

(2015)

FAIR Project



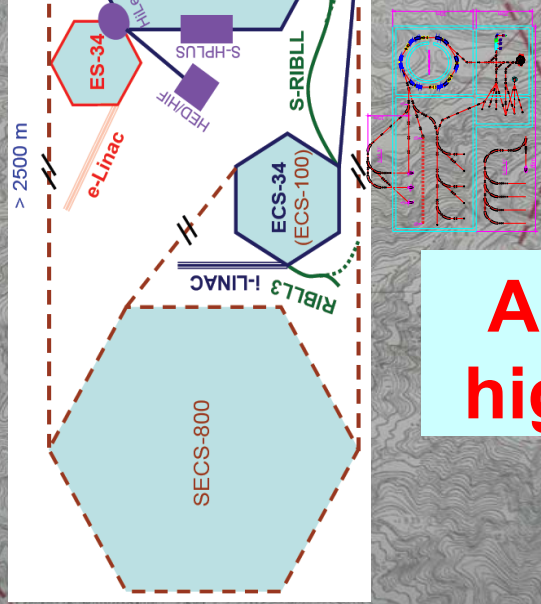
High Energy Density Physics and Nuclear Matter Facility

New Place for future facilities

Present place is limited

Building national research center in Lanzhou

4 km²



Airport highway

10 min by car from IMP


Thanks!