



# Commissioning Status and Future Upgrade

## HIRFL-CSR

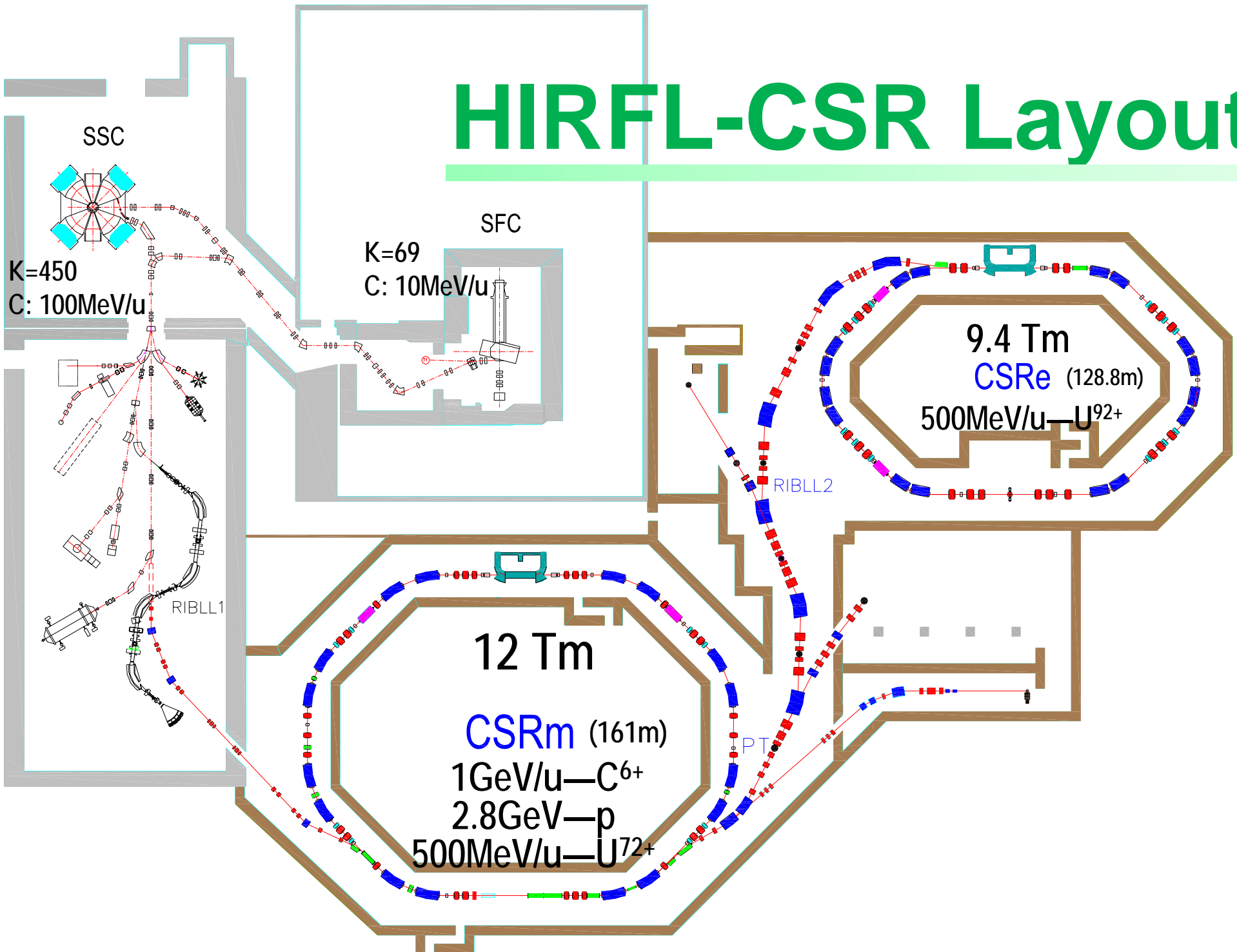
(Hheavy Ion Research Facilities in Lanzhou, Cooler Storage Rings)

**Yong Liu**    [y.liu@impcas.ac.cn](mailto:y.liu@impcas.ac.cn)

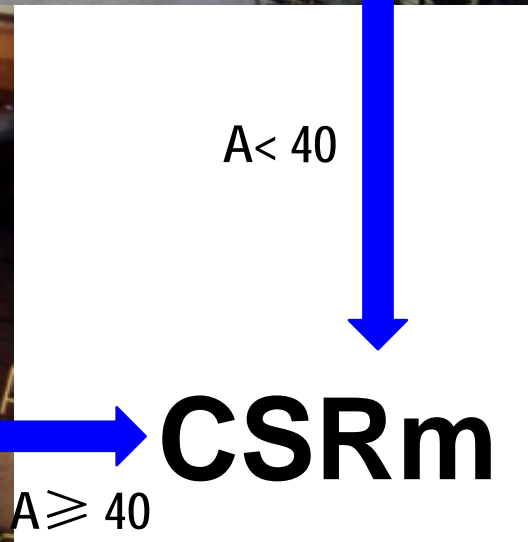
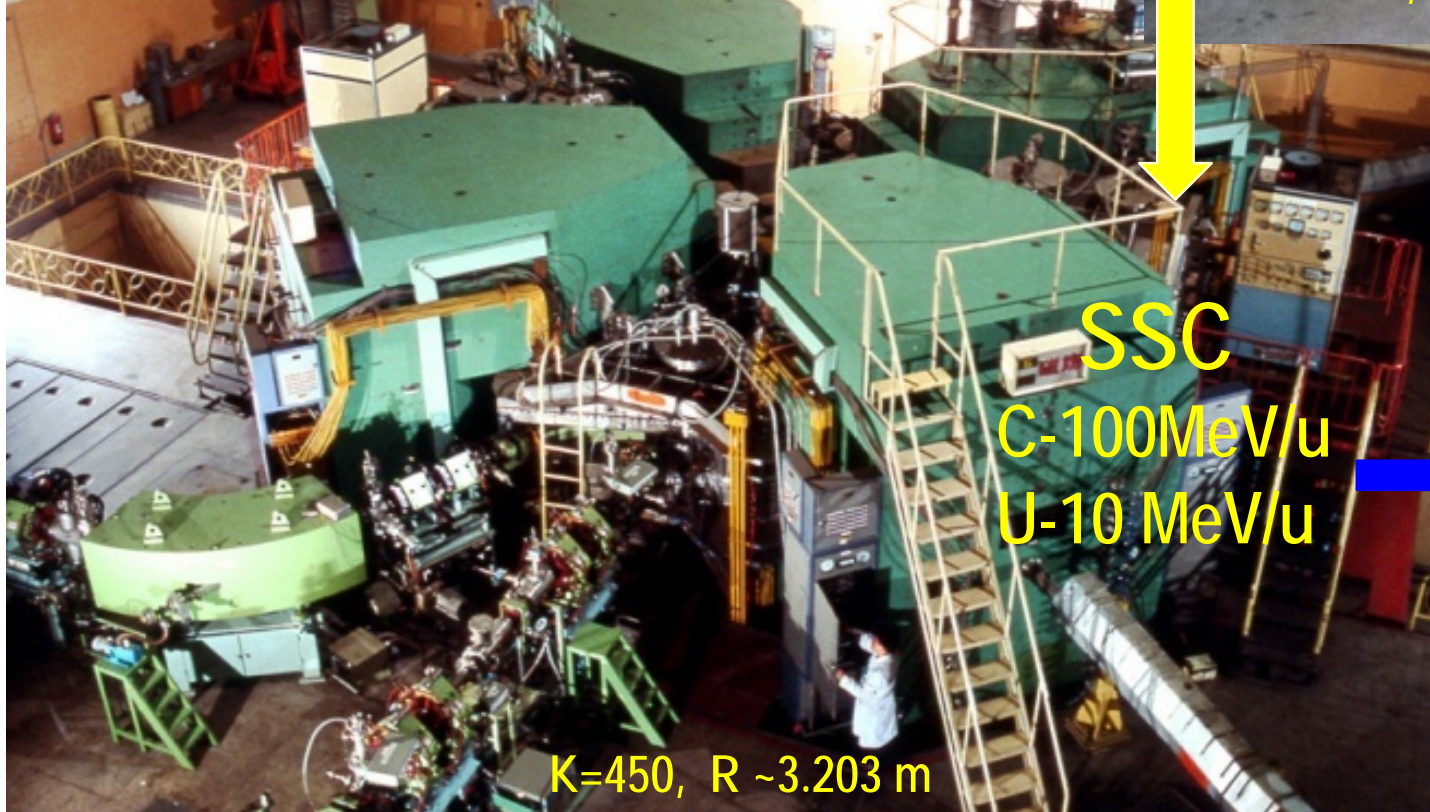
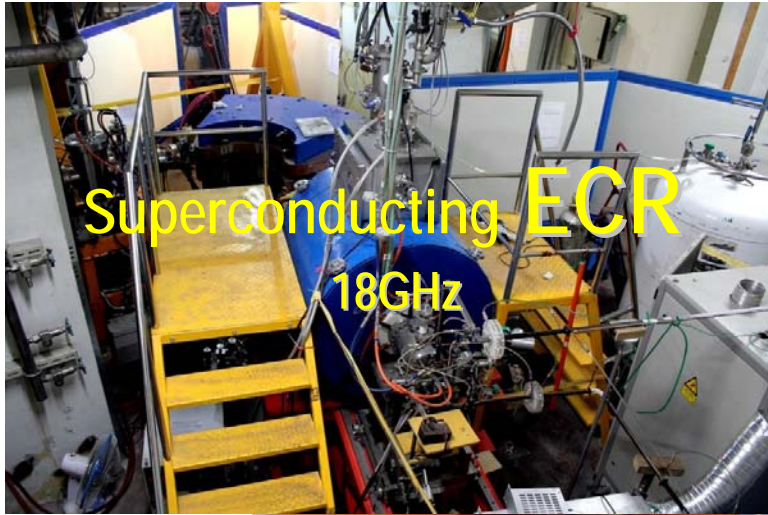
Institute Modern Physics, Chinese Academy of Sciences. Lanzhou

09 June. 2009, HIAT2009, Venice

# HIRFL-CSR Layout

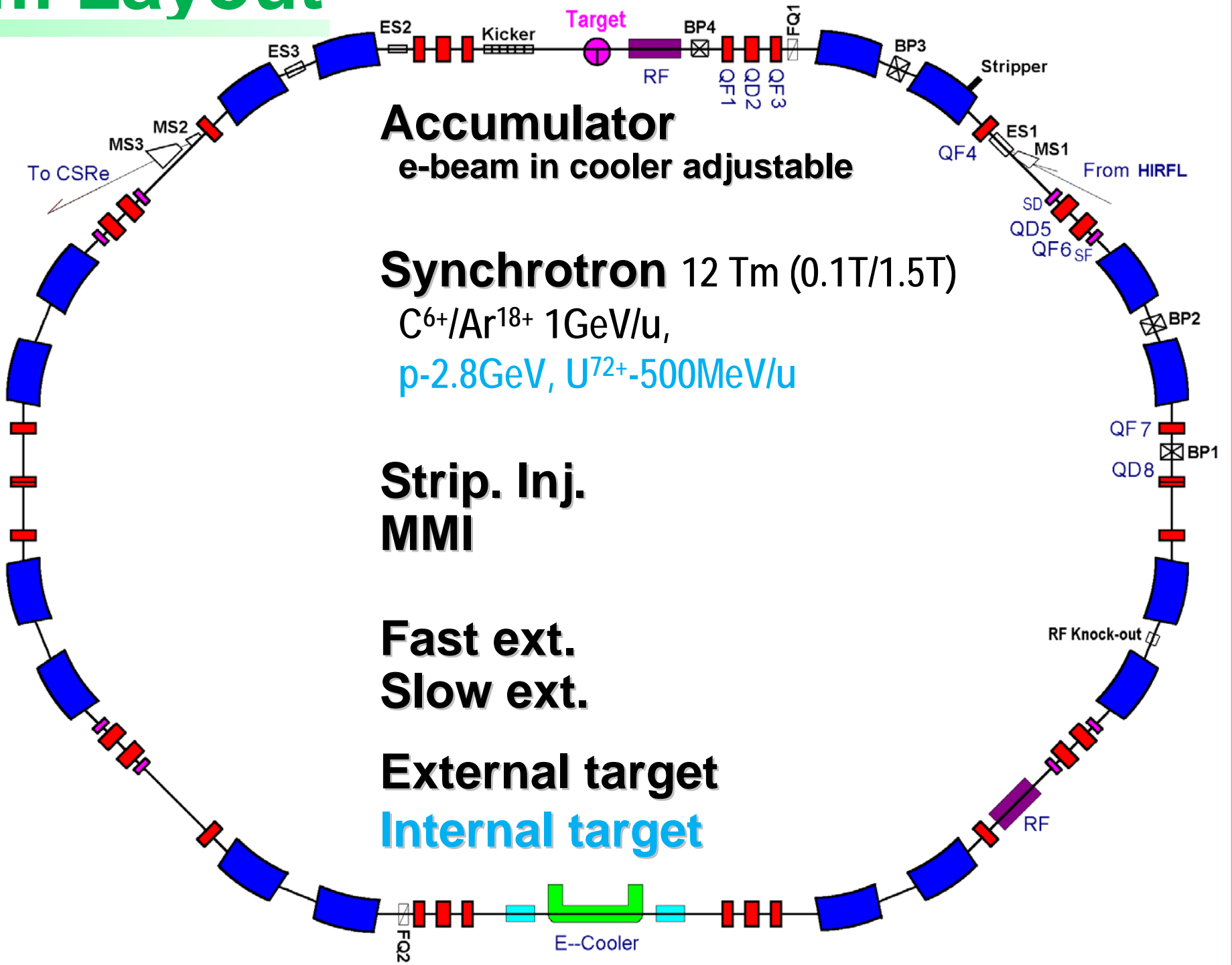


# Pre-accelerator system of CSR



**CSRm**

# CSRm Layout



**Accumulator**  
e-beam in cooler adjustable

**Synchrotron** 12 Tm (0.1T/1.5T)  
C<sup>6+</sup>/Ar<sup>18+</sup> 1GeV/u,  
p-2.8GeV, U<sup>72+</sup>-500MeV/u

**Strip. Inj.**  
**MMI**

**Fast ext.**  
**Slow ext.**

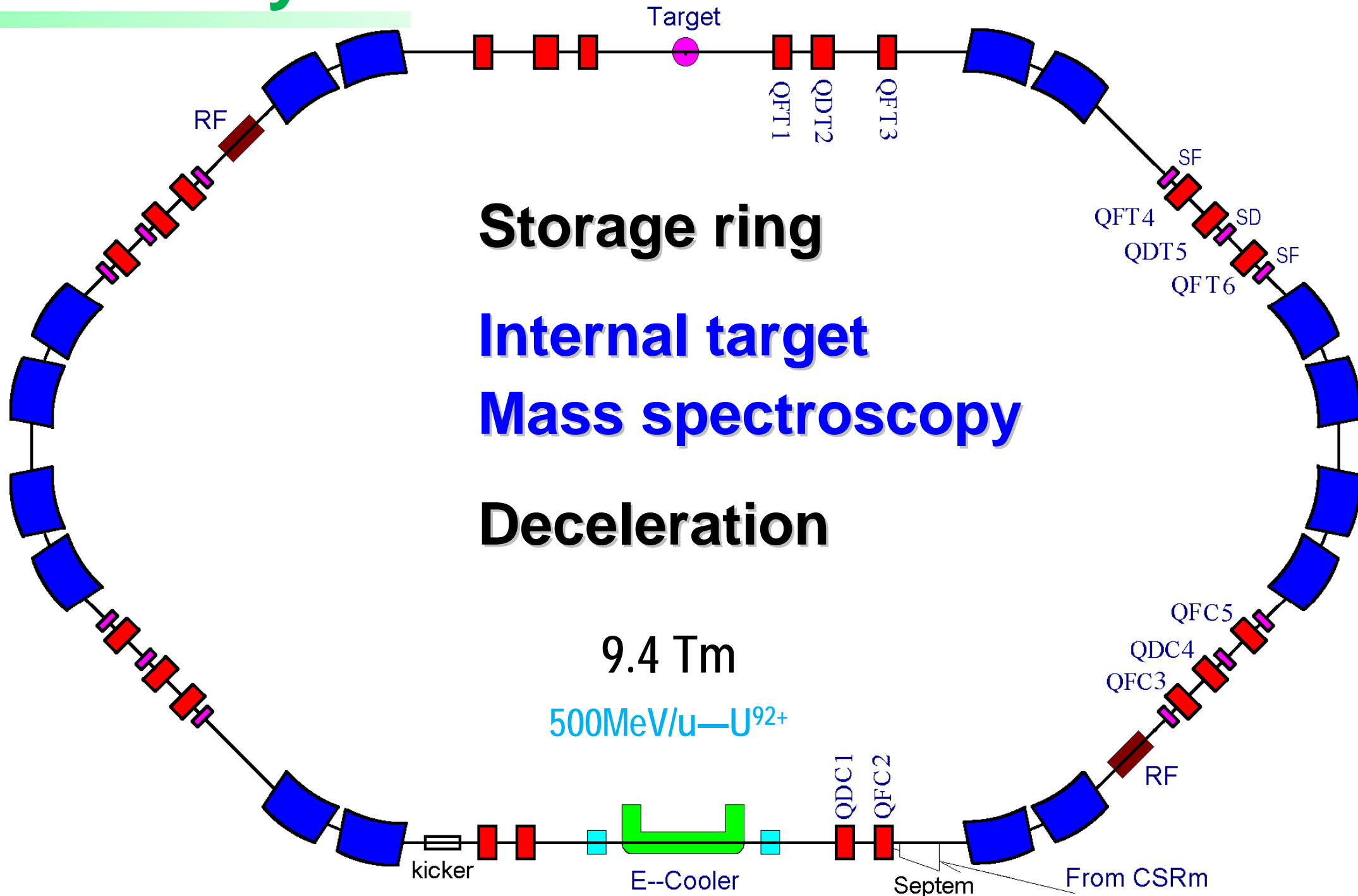
**External target**  
**Internal target**

E-Cooler

# CSRm Tunnel



# CSRe Layout



# CSRe Tunnel



B:34T



Internal Target



e-cooler  
300kv

2005.10



RF



Q:5T

**HIRFL-CSR**

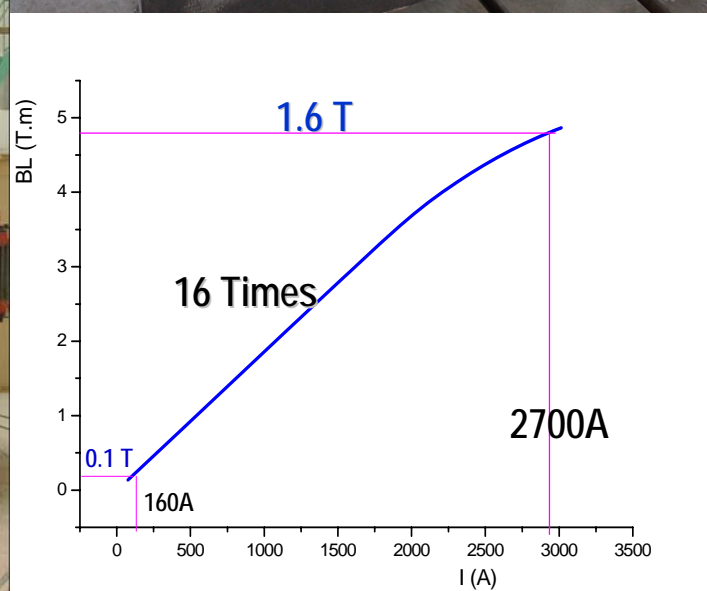
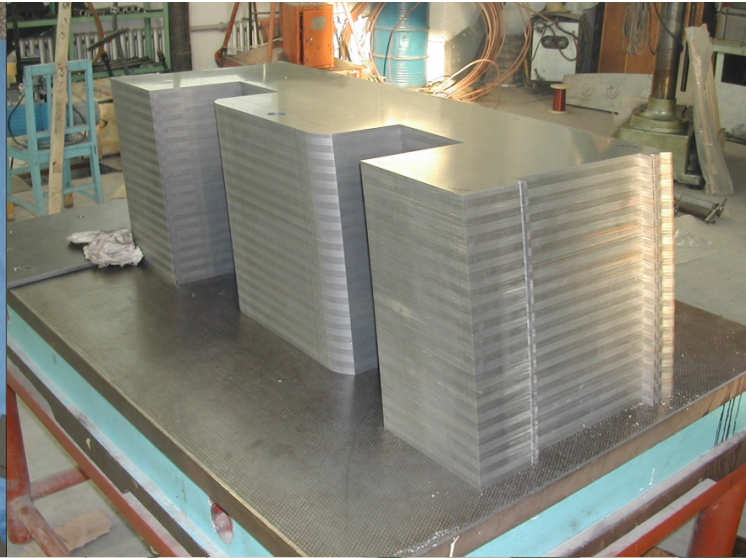
# Subsystems

**Construction: 2000--2005**

**→ Commissioning**

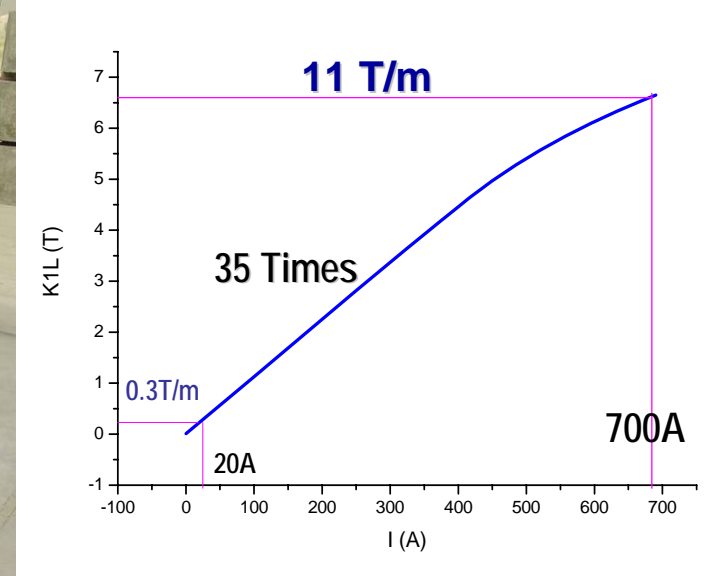
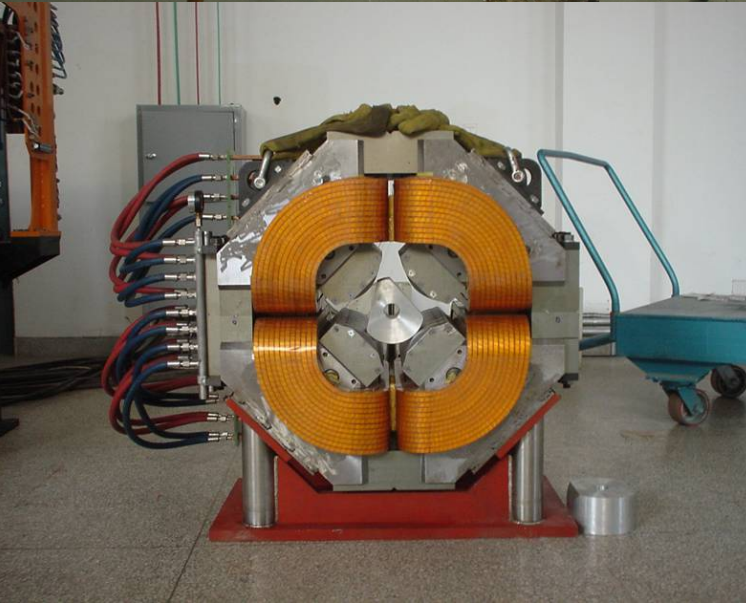


# CSRm-dipole Fabrication



H-Type, Angle=22.5°, Rbend, Radius=7.6m, Air Gap=80mm, Useful aperture=140×60mm<sup>2</sup>, Precision=3×10<sup>-4</sup>

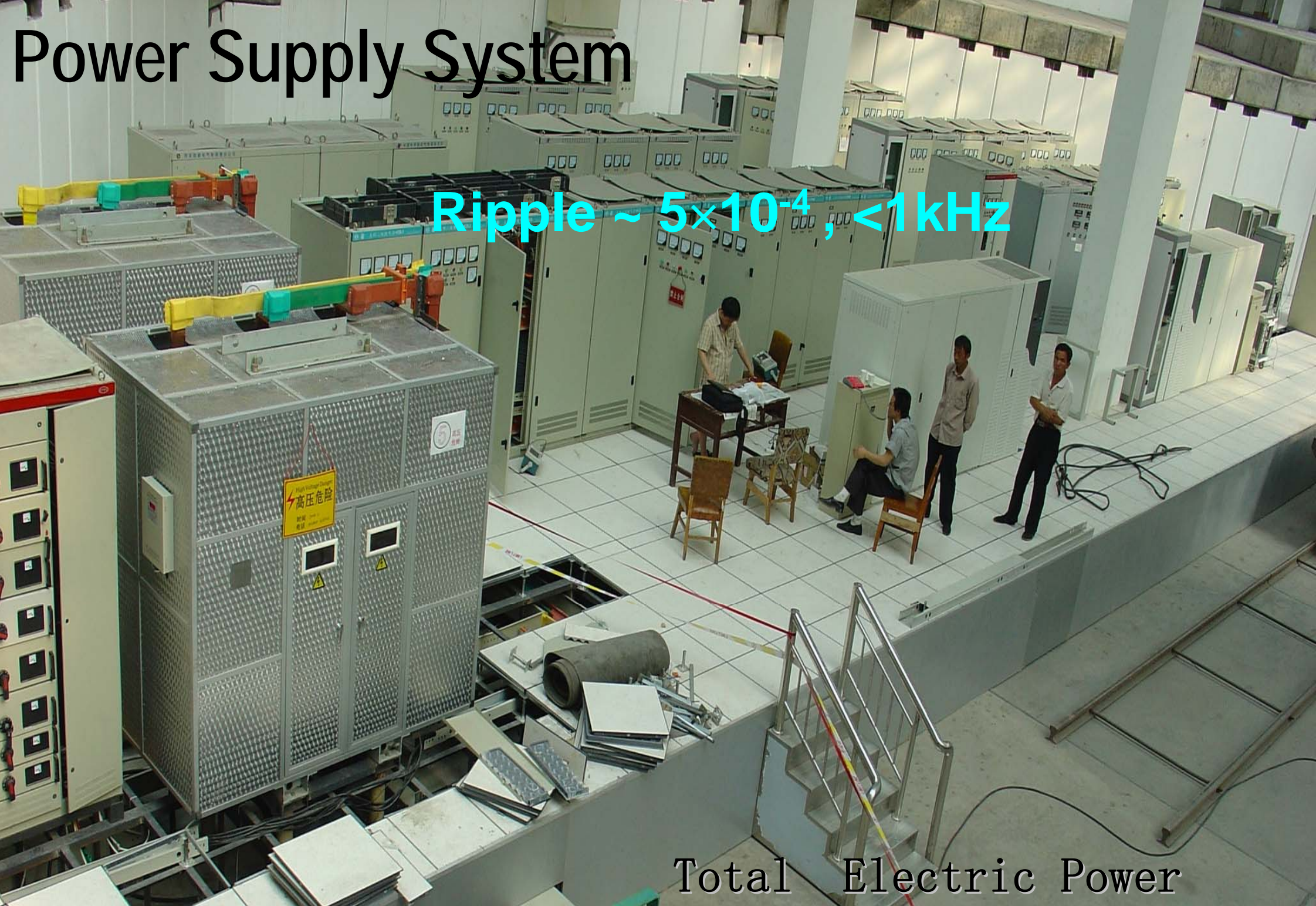
# CSRm-Quadrupole Fabrication



$L=0.5\text{m}, 0.65\text{m}, \Phi=170\text{mm}$ , Useful aperture=  $160\times 100\text{mm}^2$ , Precision=  $1.5\times 10^{-3}$

# Power Supply System

Ripple  $\sim 5 \times 10^{-4}$ ,  $< 1 \text{ kHz}$



Total Electric Power

# UHV System of CSR

Bake-out temperature: 250°C,  
Pressure:  $5 \times 10^{-12}$  mbar



# CSRm RF System



Cooperated with Novosibirsk BINP



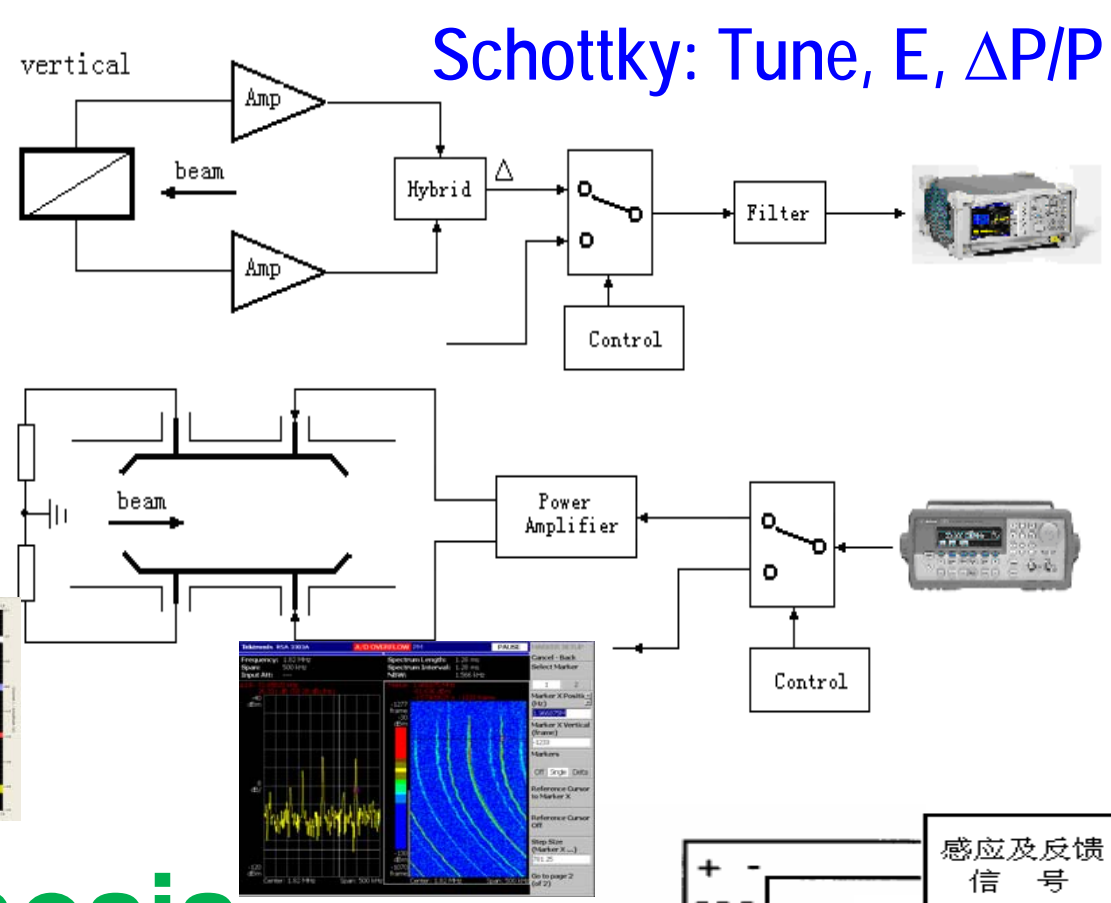
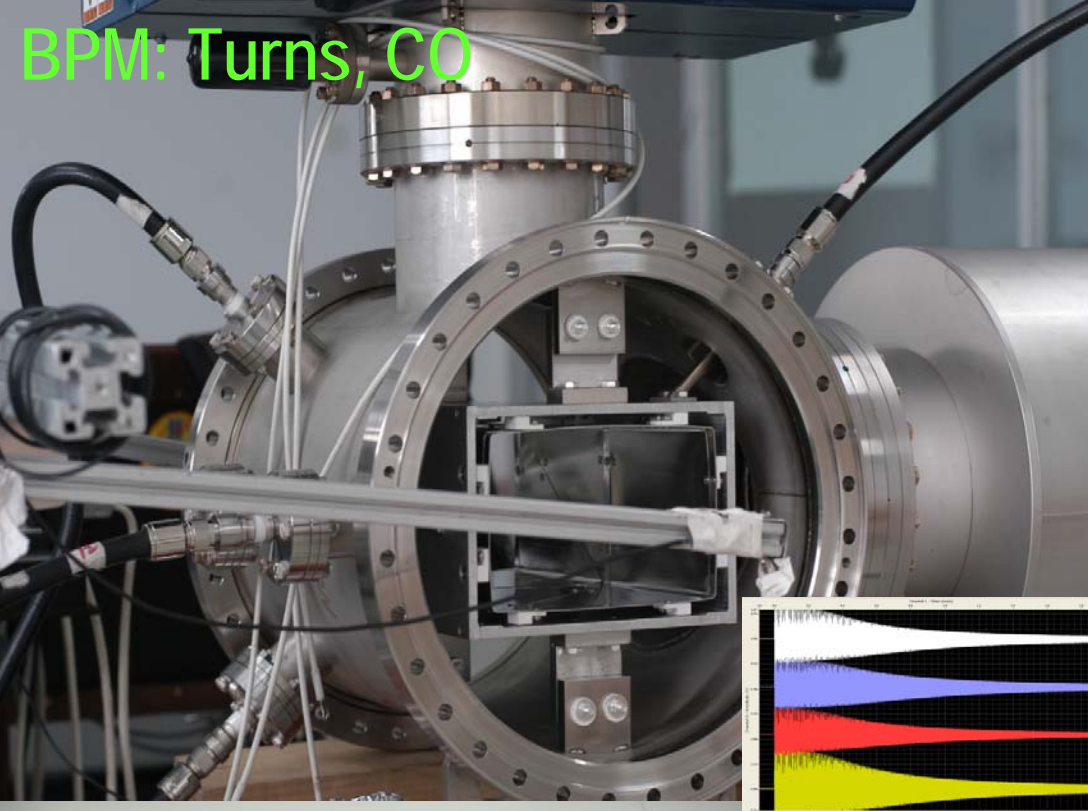
RF-station for acceleration

<sup>7.5 Times</sup>  
 $f = 0.24 \sim 1.81 \text{ MHz}, V_m = 7 \text{ kV}$

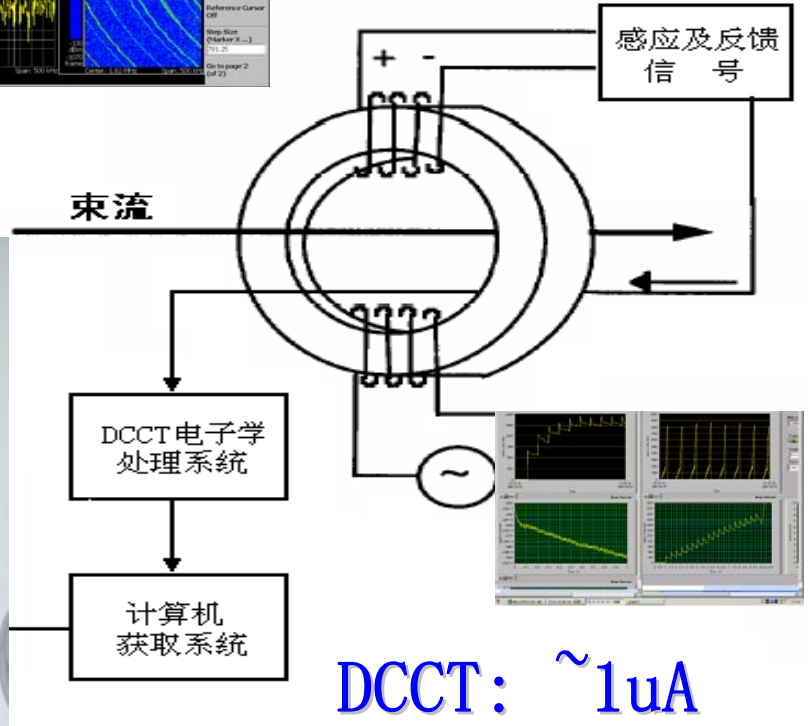


RF for beam accumulation

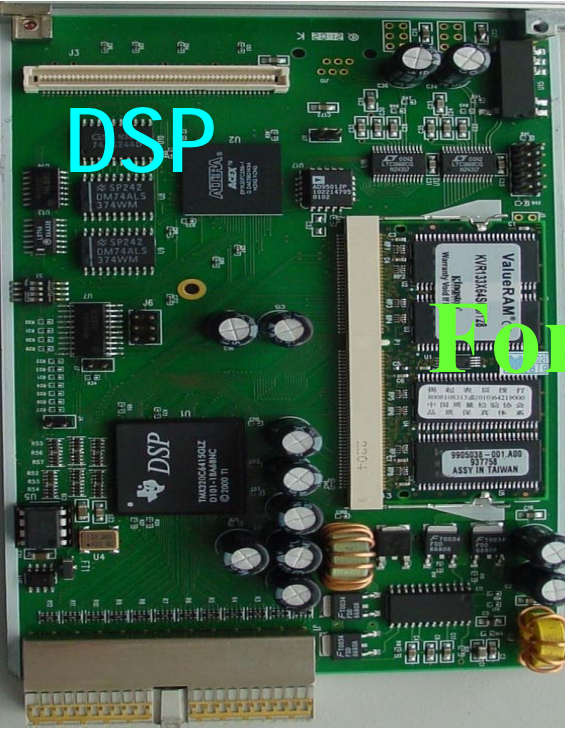
$f = 6 \sim 14 \text{ MHz}, V_m = 20 \text{ kV}$



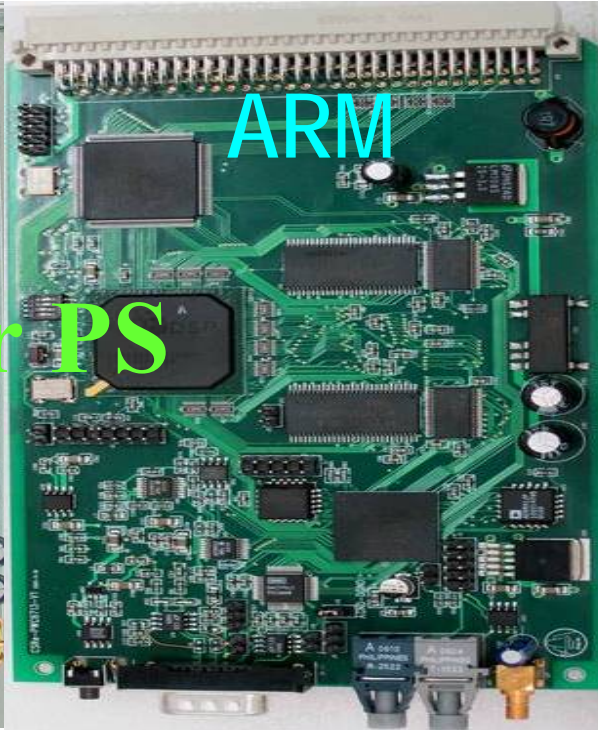
# Diagnosis



# Electronics Developments for CSR



DSP



ARM

For PS

ion: 36Ar18+ 21.65 Mev 19:34:57.592 07/04/20

DEV%	current(A)	dif(A)	DEV%	current(A)	dif(A)
1.25	34.69	-0.05629	2.179	34.8	0.03146
0.8423	53.08	-0.01011	0.7735	53.23	0.000374
0.6131	40.38	0.02591	2.819	40.31	-0.05053
3.364	33.86	0.02129	2.93	33.89	0.03303
0.6521	59.97	-0.02958	1.375	60.23	0.03519
1.17	64.21	0.1044	1.414	64.17	0.0706
2.716	43.78	-0.4198	55.43	0.9393	0.9393
1.096	62.7	0.002246	0.7779	285.1	1.145

DEV%	current(A) 2	dif(A)	DEV%	current(A)	dif(A)
0.8008	34.71	-0.09375	1.38	34.78	0.03013
2.46	53.09	0.05399	0.714	53.23	-0.01734
1.242	40.22	0.02194	1.722	40.42	0.04402
2.477	33.71	0.03611	2.558	33.9	0.00863
1.345	59.87	-0.0043	0.5773	60.07	-0.00871
1.196	63.82	0.001105	0.5451	64.07	0.00216
1.963	44.04	-0.0162	1.705	44.19	-0.0066
2.024	44.24	-0.01381	0.4588	1020	0

PS monitor

DEV%	current(A)	dif(A)	DEV%	current(A)	dif(A)	
1.00149	62.6894	-0.0105	22Q1	1.38	34.78	0.03013
			22Q2	0.714	53.23	-0.01734
			22Q3	1.722	40.42	0.04402
			22Q4	2.558	33.9	0.00863
			22Q5	0.5773	60.07	-0.00871
			22Q6	0.5451	64.07	0.00216
			22Q7	1.705	44.19	-0.0066
			23Q7	0.4588	1020	0
			23Q8			

Load Acc: 2 Particle 12 C 6 + of 6 碳 View DB Long Q strength Short Q strength

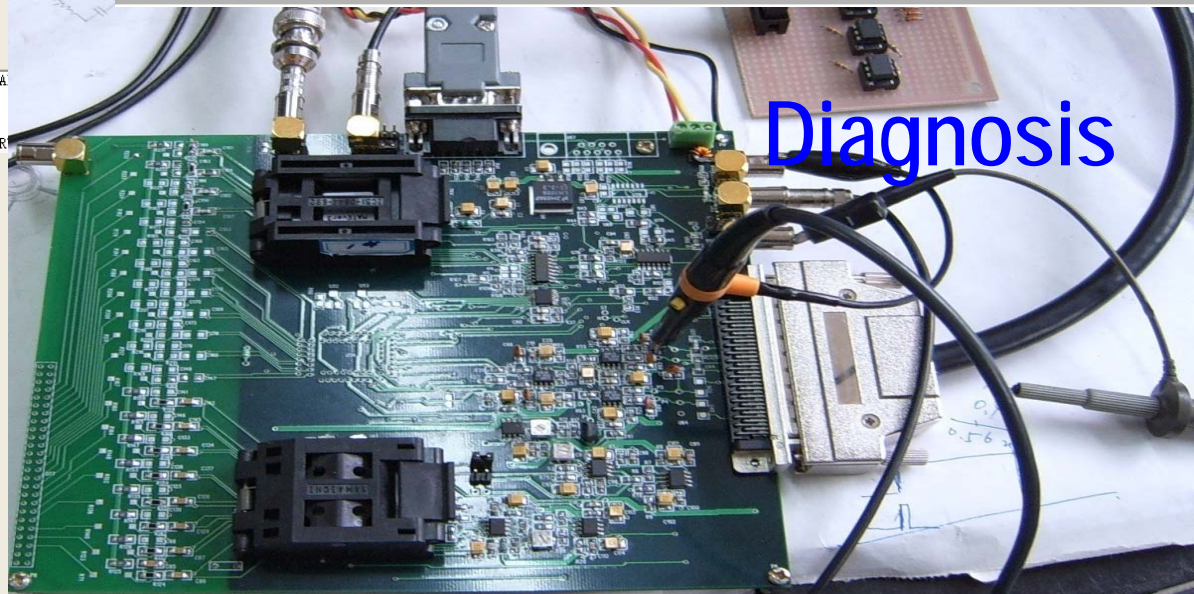
Save To: 0 Mass 11.996708518 数据准备 0.997 1.012

Injection	Mid Flat Top	Extraction
Energy[MeV/u] 7.0675	Energy[MeV/u] 50	Energy[MeV/u] 1000
Part_B_Rho[Tm] .7667438711	Part_B_Rho[Tm] 2.062677264	Part_B_Rho[Tm] 11.28495728
Delt R [mm] -2.2	Delt R [mm] -2.2	Delt R [mm] -2.2
RF Harmonic No. 2	Frequency[MHz] 1.173577590	RF Harmonic No. 1
Frequency[MHz] .4562004956	Vrf1(kV) 2	Frequency[MHz] 1.631340951
Vrf(kV) 2	Vrf2(kV) 3	Vrf(kV) 3
Qh 3.62	Qh 3.62	Qh 3.61
Qv 2.61	Qv 2.61	Qv 2.61
tau 0	tau 0	tau 0
Time Ext.[ms] 500	round sections 8	Command1
Time Meas.[ms] 250		

Calculate Dipole and RF Cavity Calculate Quadrupoles Other Correctors Coil Corrects

CYCLE\_STA MEASURE RAMP MID MEASURE RAMP\_STAR

Ramping interface



Diagnosis

# CSR Alignment



Accuracy ~0.1 mm



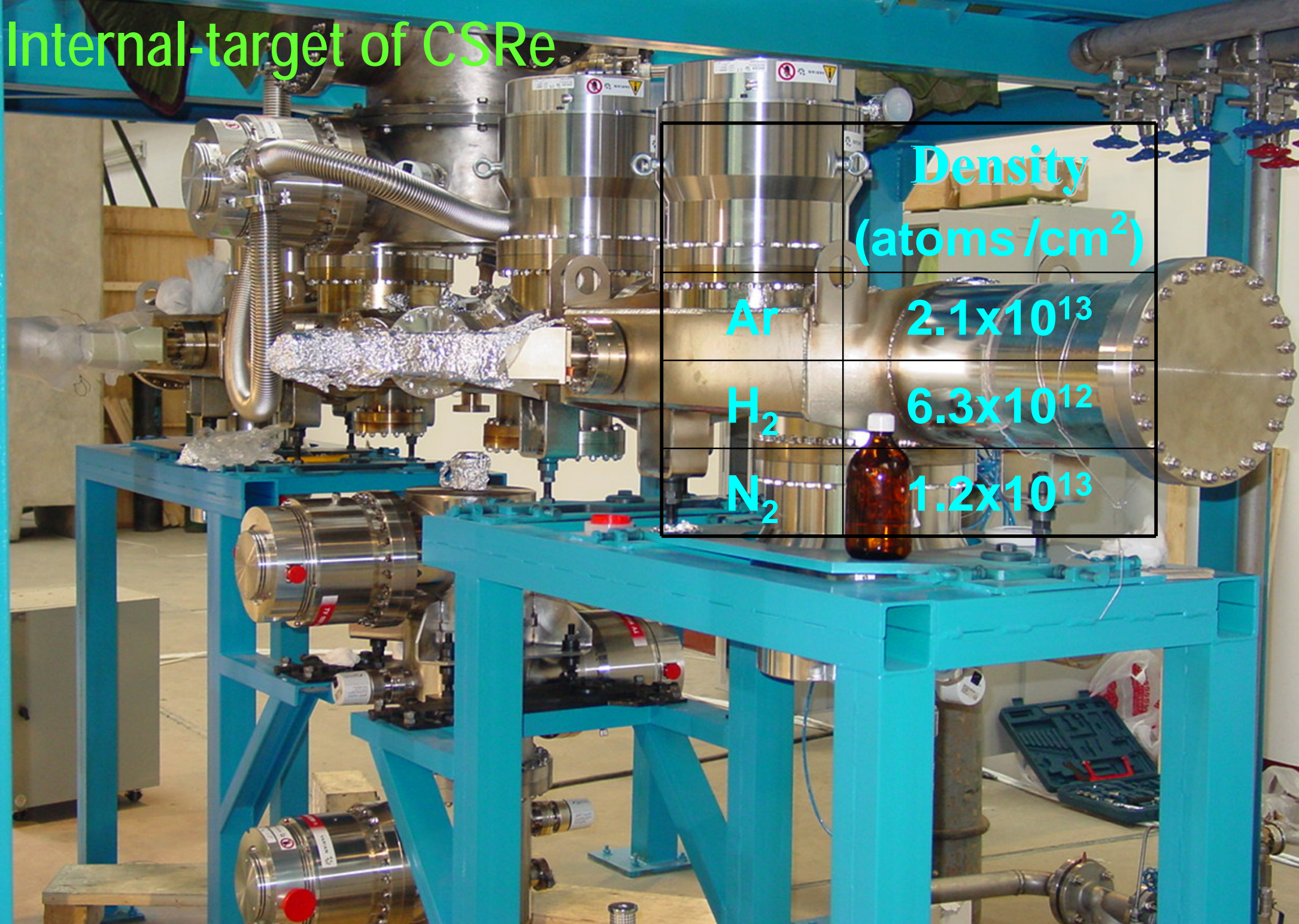
# Internal-target of CSRe

Density  
(atoms/cm<sup>2</sup>)

Ar  $2.1 \times 10^{13}$

H<sub>2</sub>  $6.3 \times 10^{12}$

N<sub>2</sub>  $1.2 \times 10^{13}$

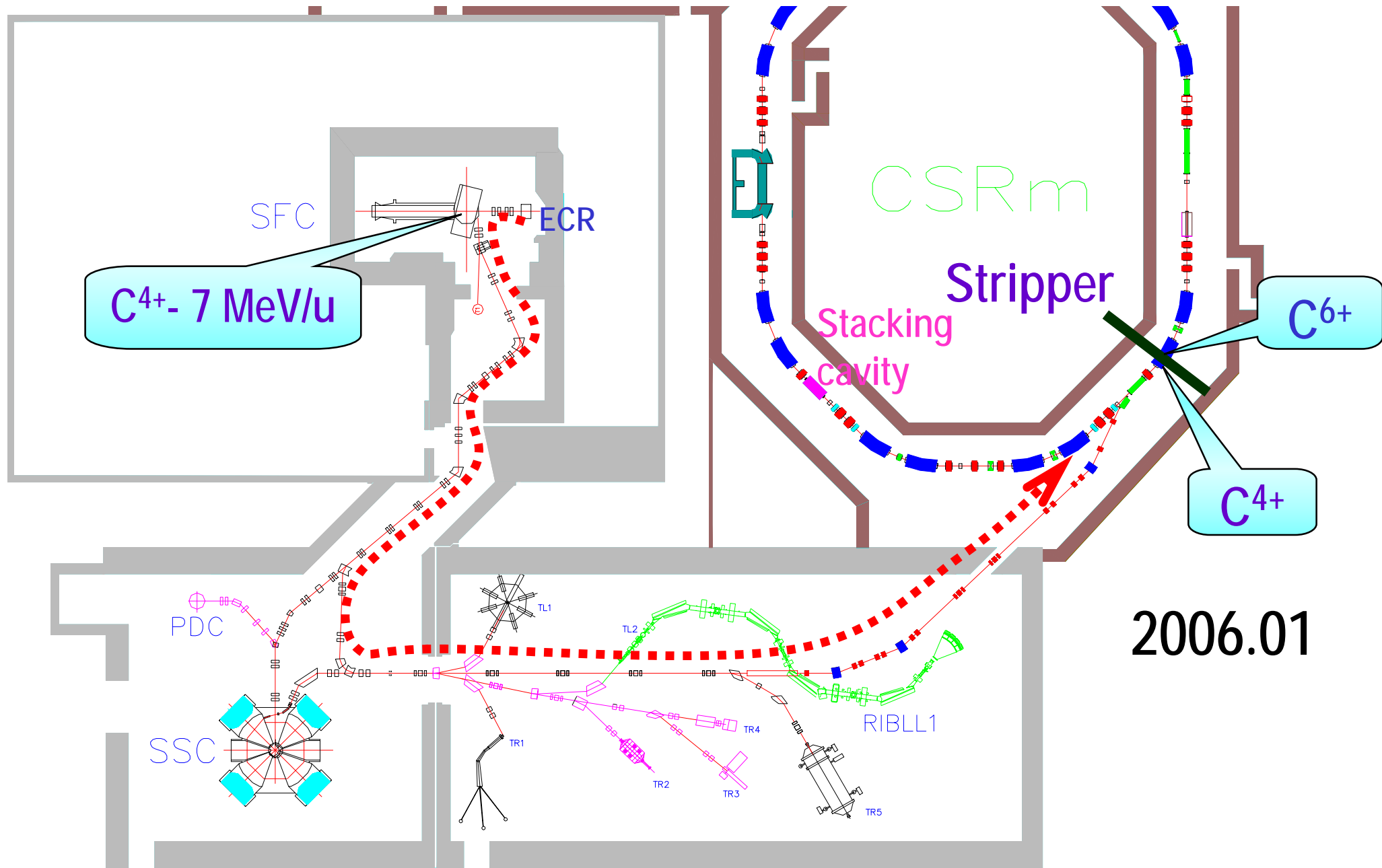


**HIRFL-CSR**

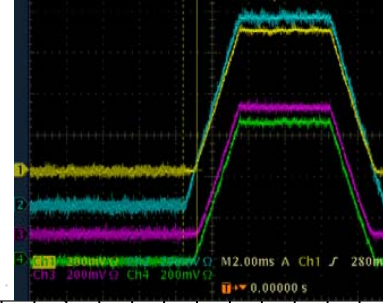
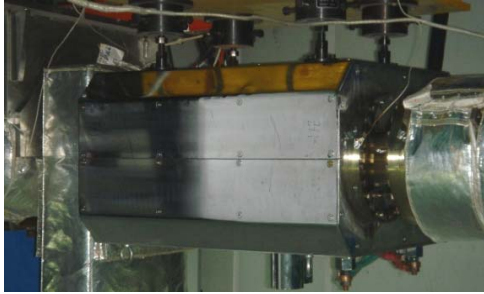
# Commissioning

**2006---2007**

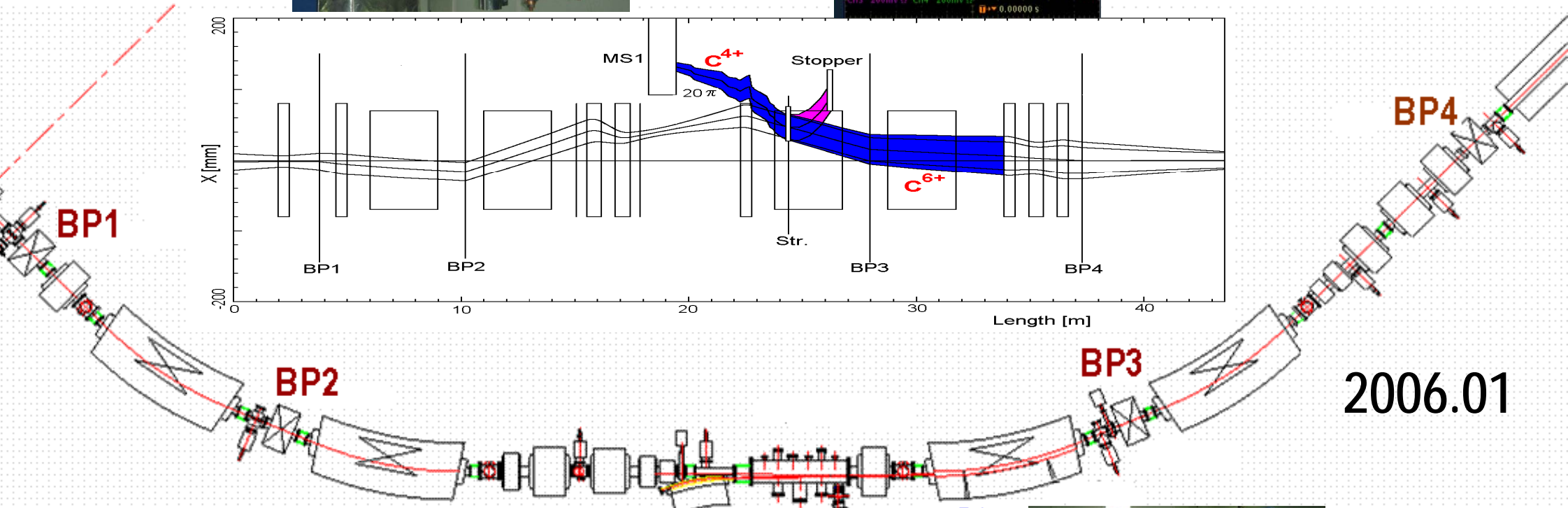
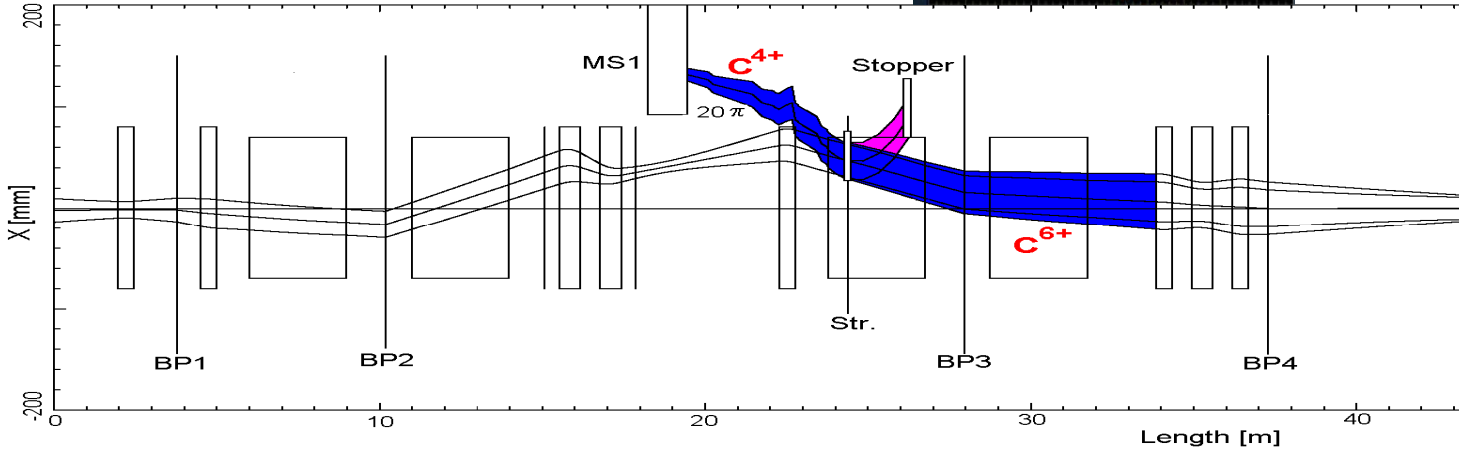
# Stripping Injection Scheme



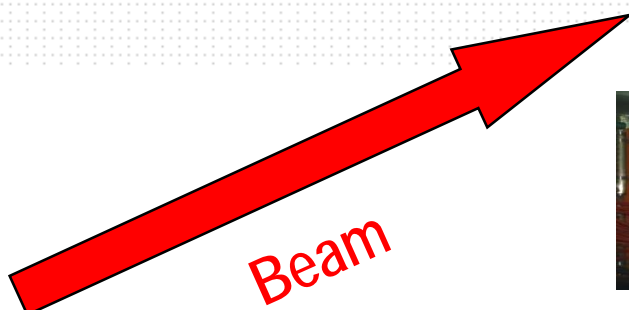
# Bump section for CSRm stripping injection



Bump-PS  
20 $\mu$ s  
3200A  
1600V



2006.01



2900A, 8600G



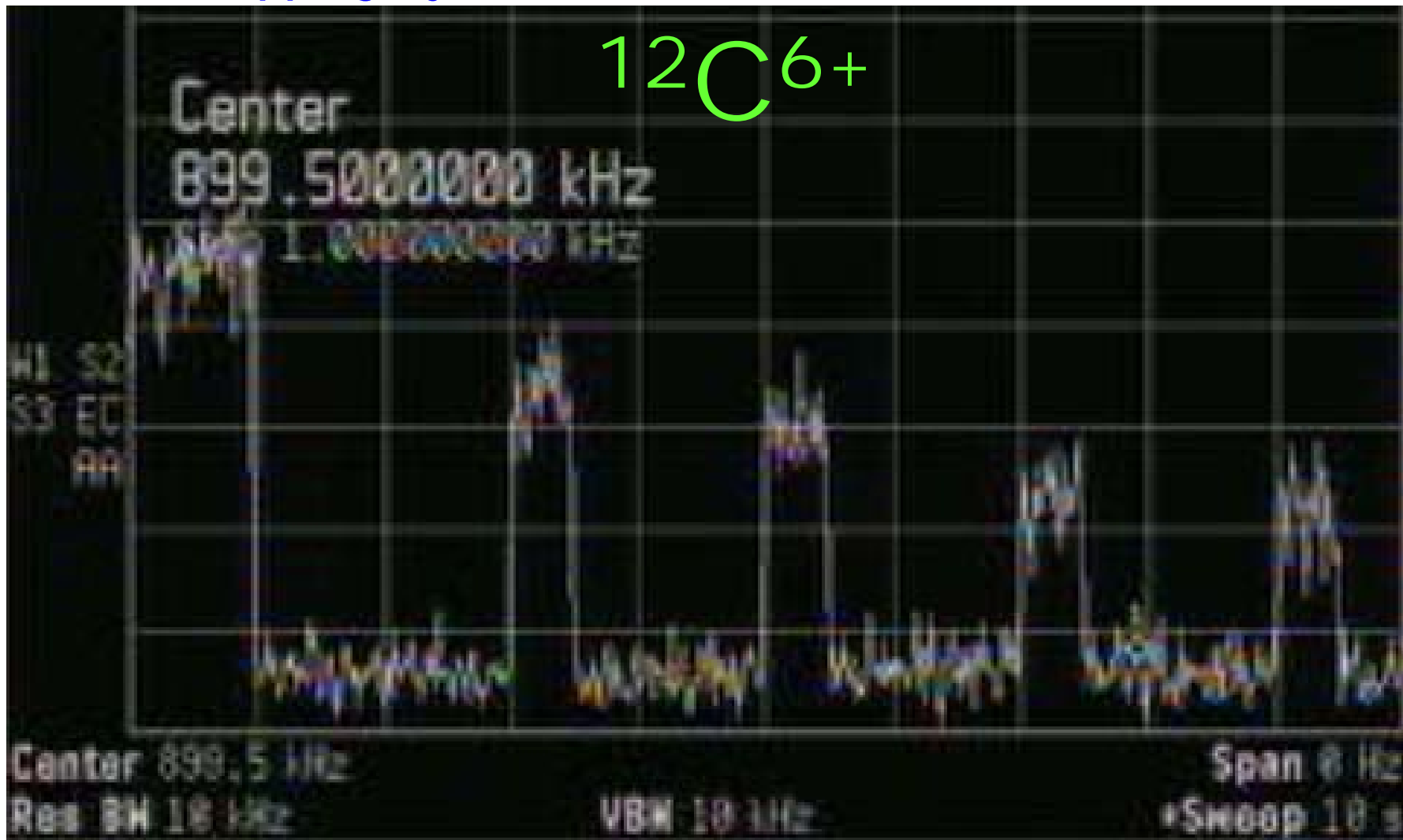
# First stored beam signal from spectrum analyzer in CSRm

Bumping orbit , RF modulation (1.3kV), Spe. Ana. in zero-span mode

Stripping injection

23Cy2 =7A 21D4 =0.5A

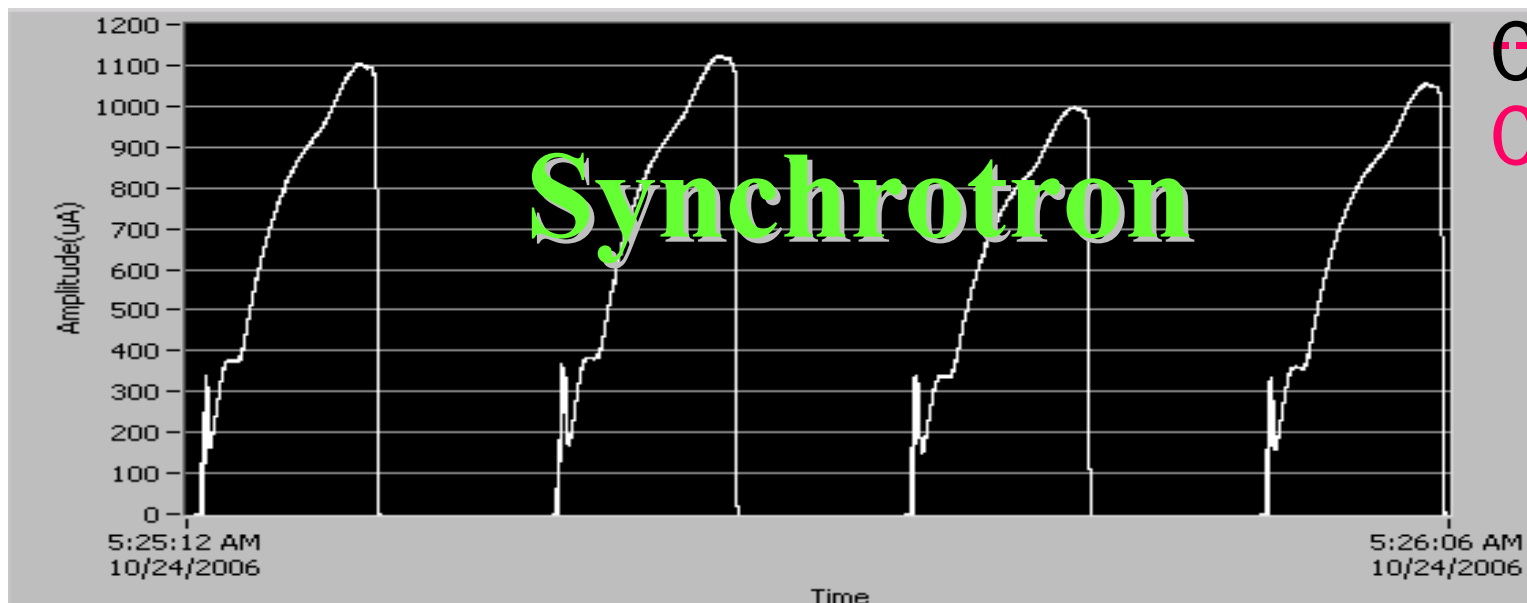
2006/1/23 22:47



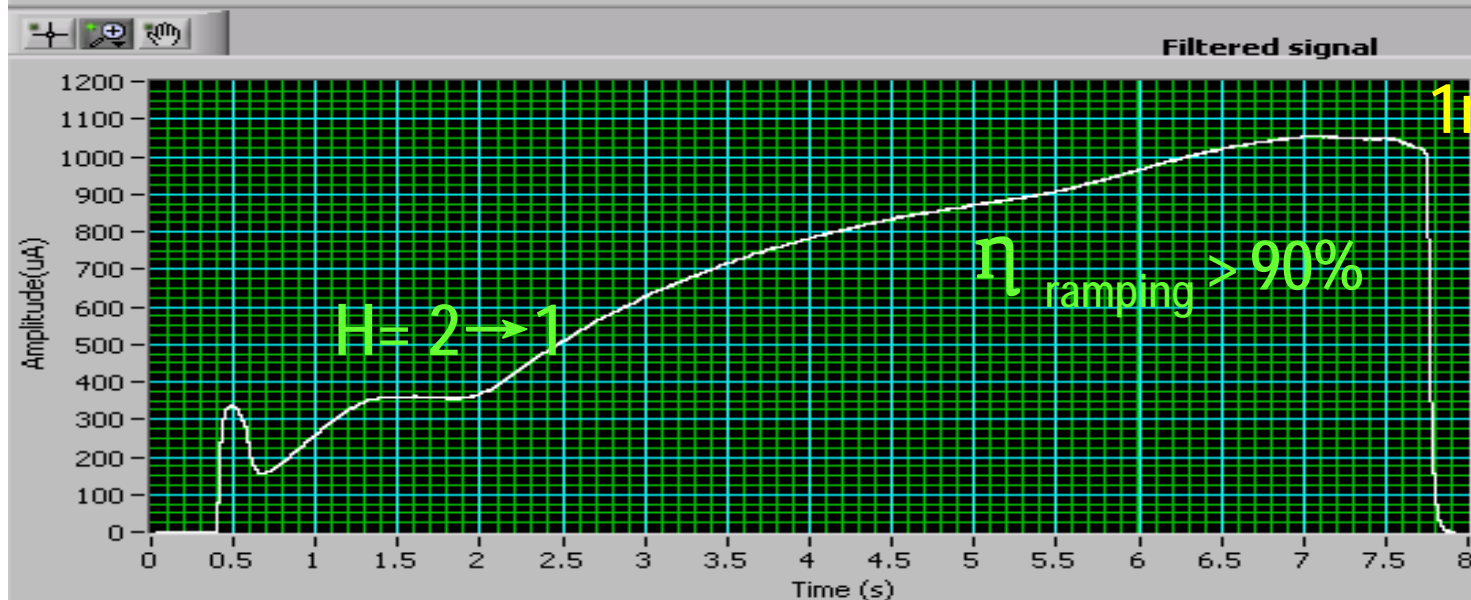
5 times of RF in 10s

# 7MeV/u $\rightarrow$ 1 GeV/u ( $C^{6+}$ ) Ramping

$H = 2 \rightarrow 1$ ,  $f_{rf} = 0.45 \rightarrow 1.63$  MHz,  $G = 11.3$  Tm



C  $\leftarrow$  50MeV/u  $\leftarrow$  SSC  
 $C^{4+}$  7MeV/u  $\leftarrow$  SFC

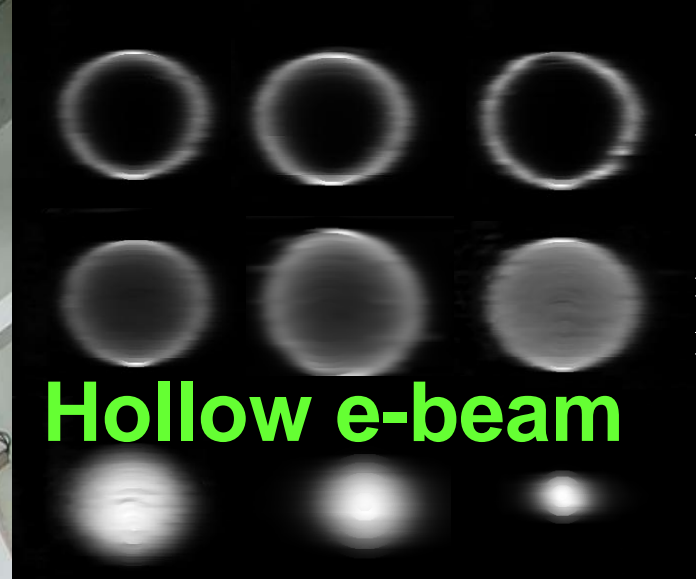


2006.12

Cooperated with BINP Novosibirsk

# e-cooler

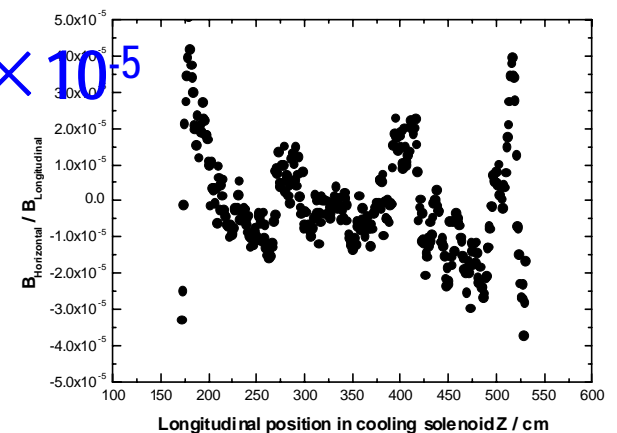
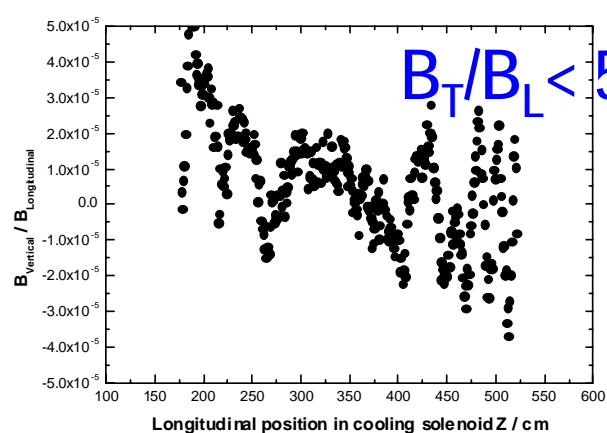
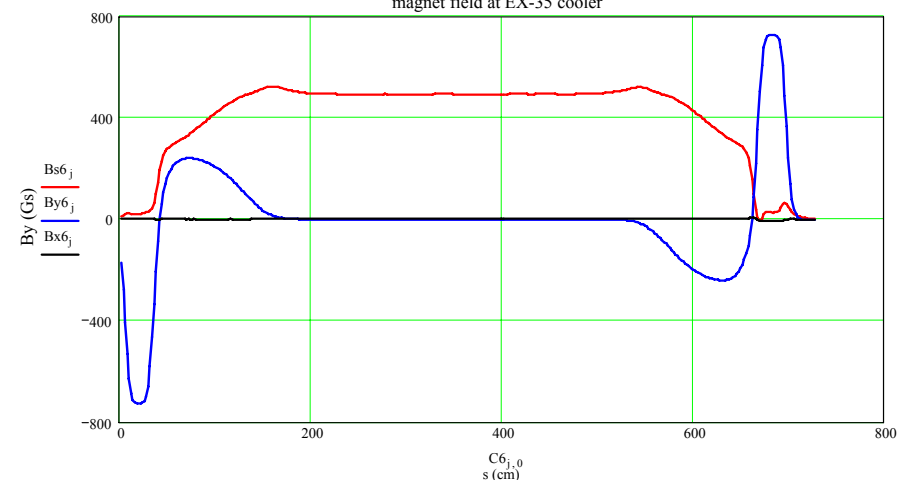
for ion cooling



Hollow e-beam

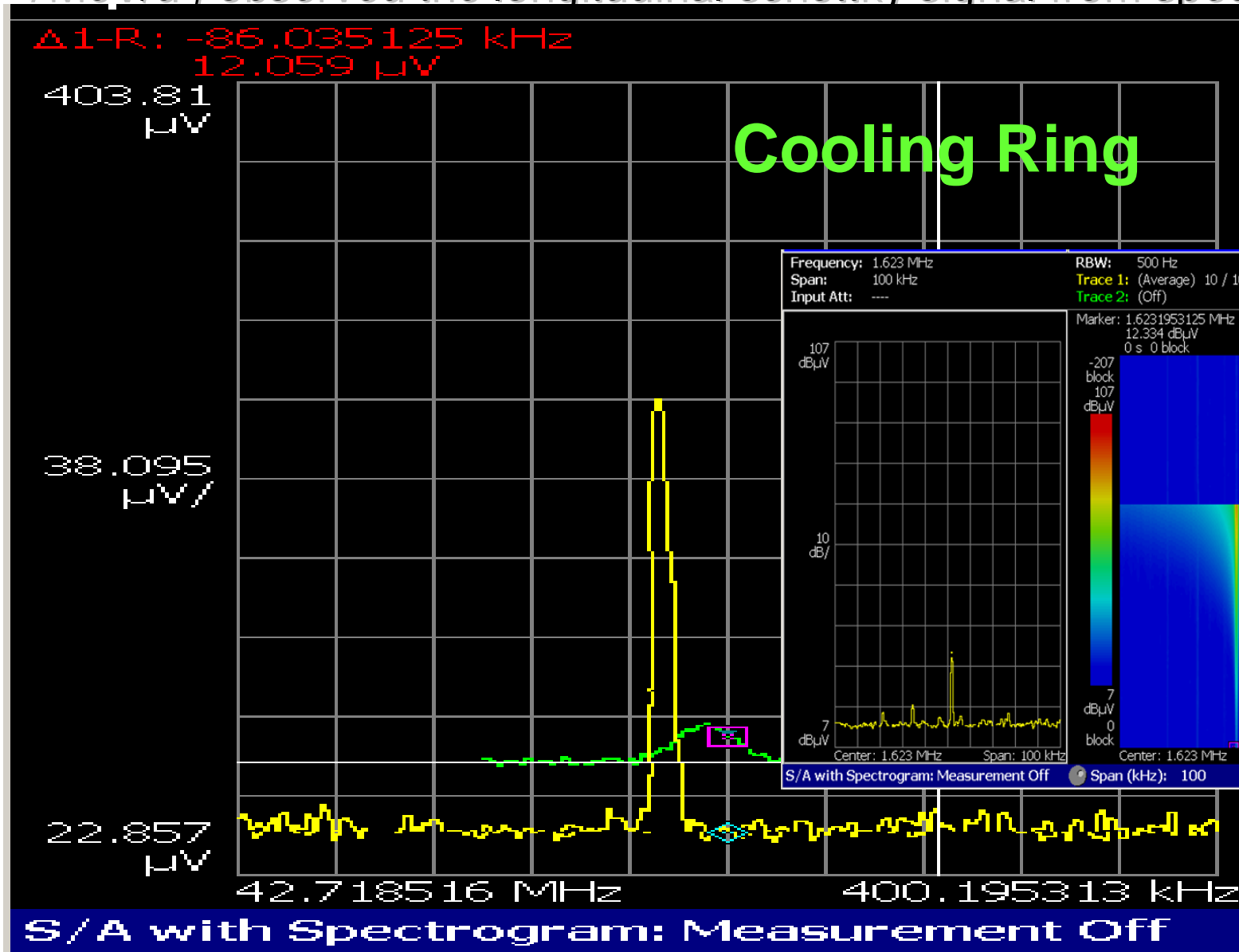


magnet field at EX-35 cooler



# e-cooling effect

$C^{6+}$ -7MeV/u, observed the longitudinal schottky signal from spectrum analyzer



06/12/27 08:15

$\Delta P/P$

$4 \times 10^{-3}$



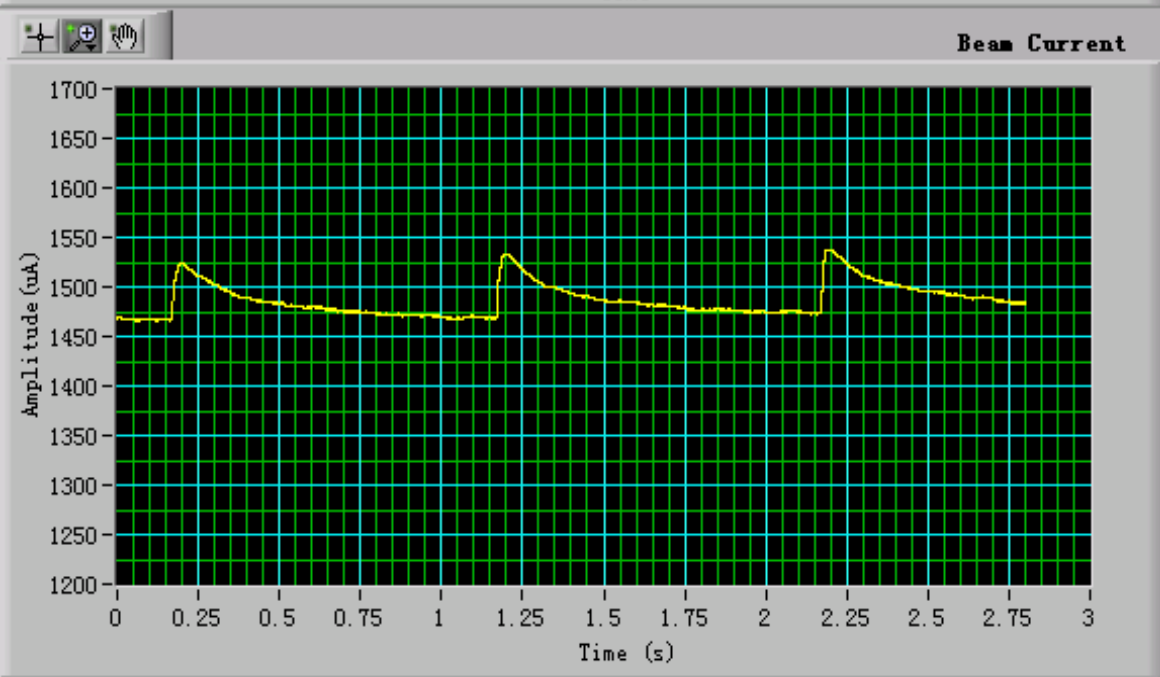
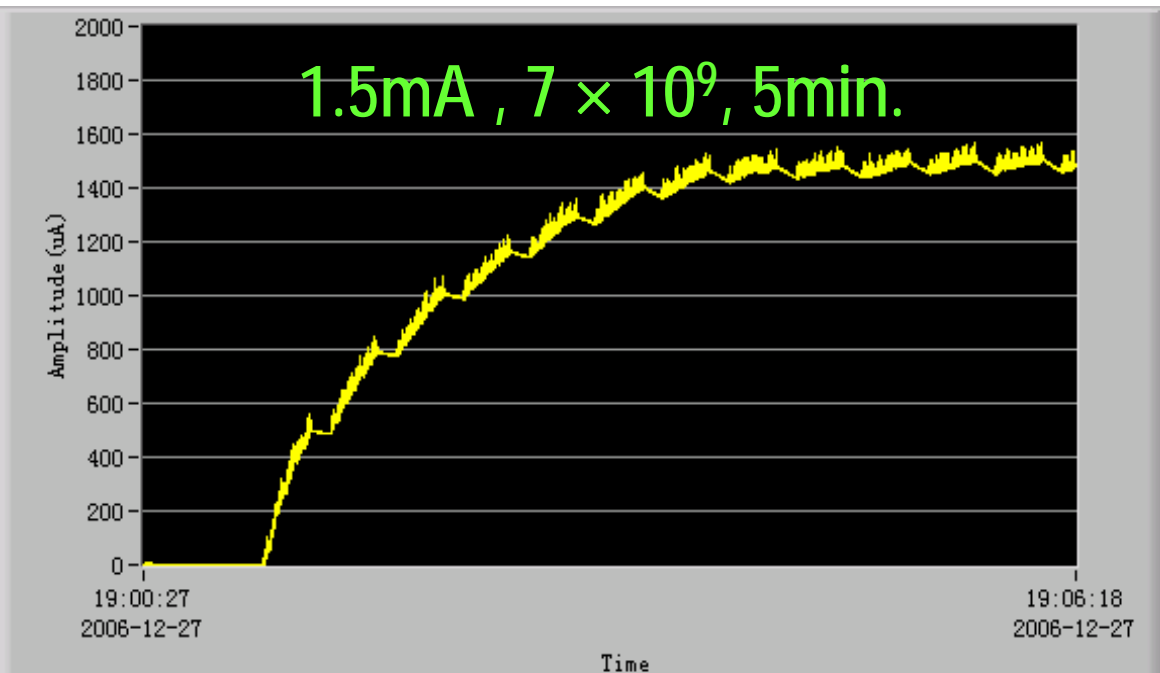
$2 \times 10^{-4}$



# Beam Accumulation with e-cooling in CSRm

2006/12/27 19:00

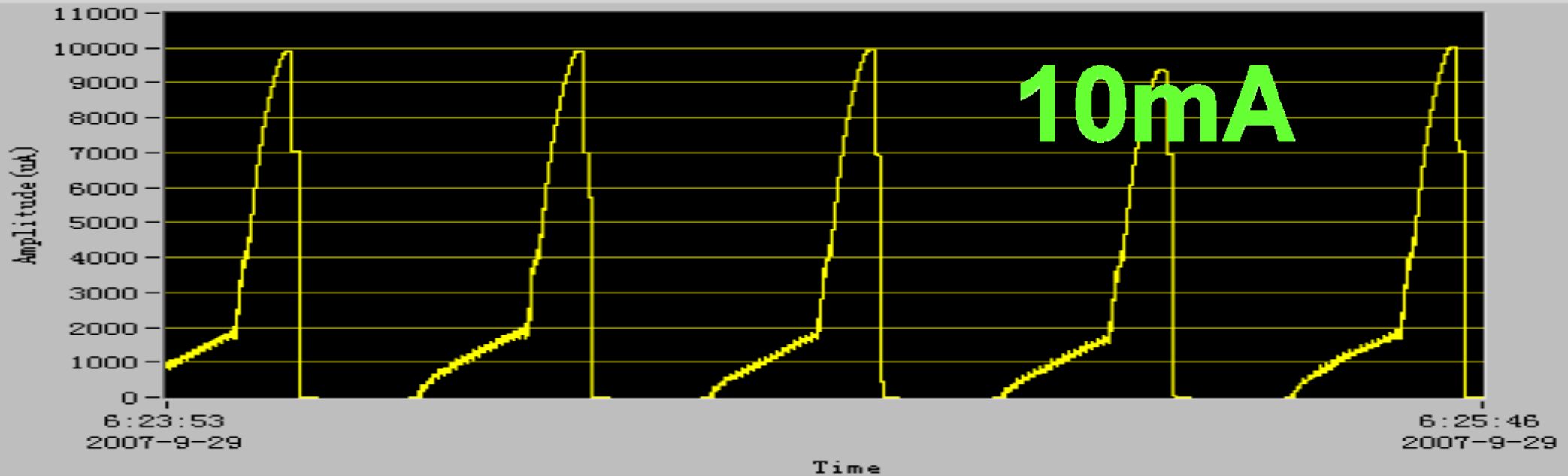
$C^{6+}$ -7MeV/u



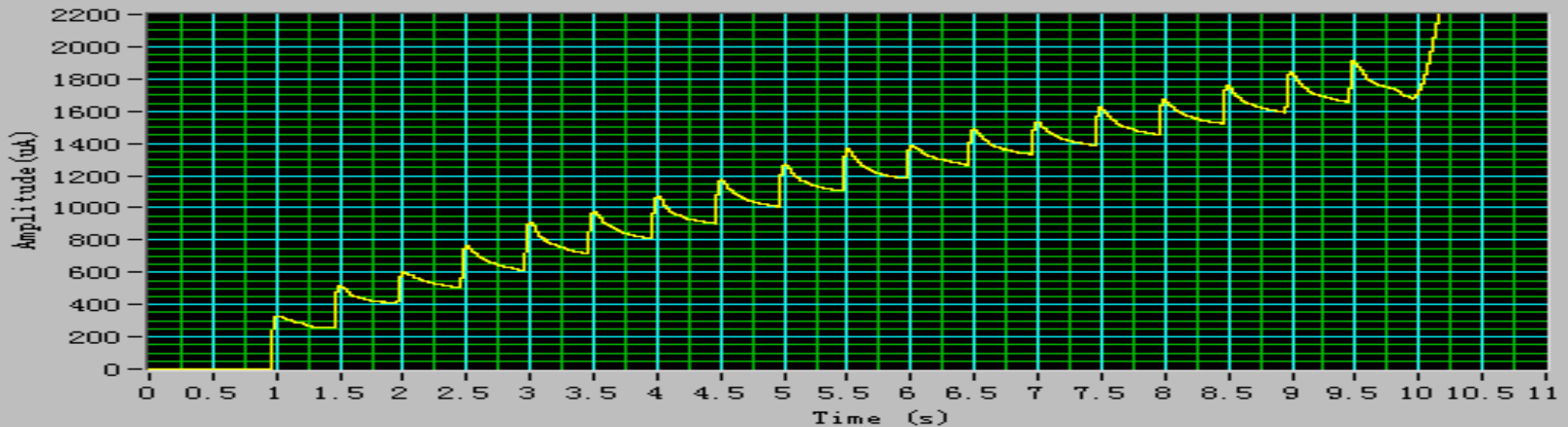
# C<sup>6+</sup>-600MeV/u Ramping in CSRm

2007/09/29 06:25

SFC-<sup>12</sup>C<sup>4+</sup>-7MeV/u,  $I_{inj.} = 11\mu\text{A}$ , STI, 1.8mA in 10s, 10mA on top,  $7 \times 10^9$



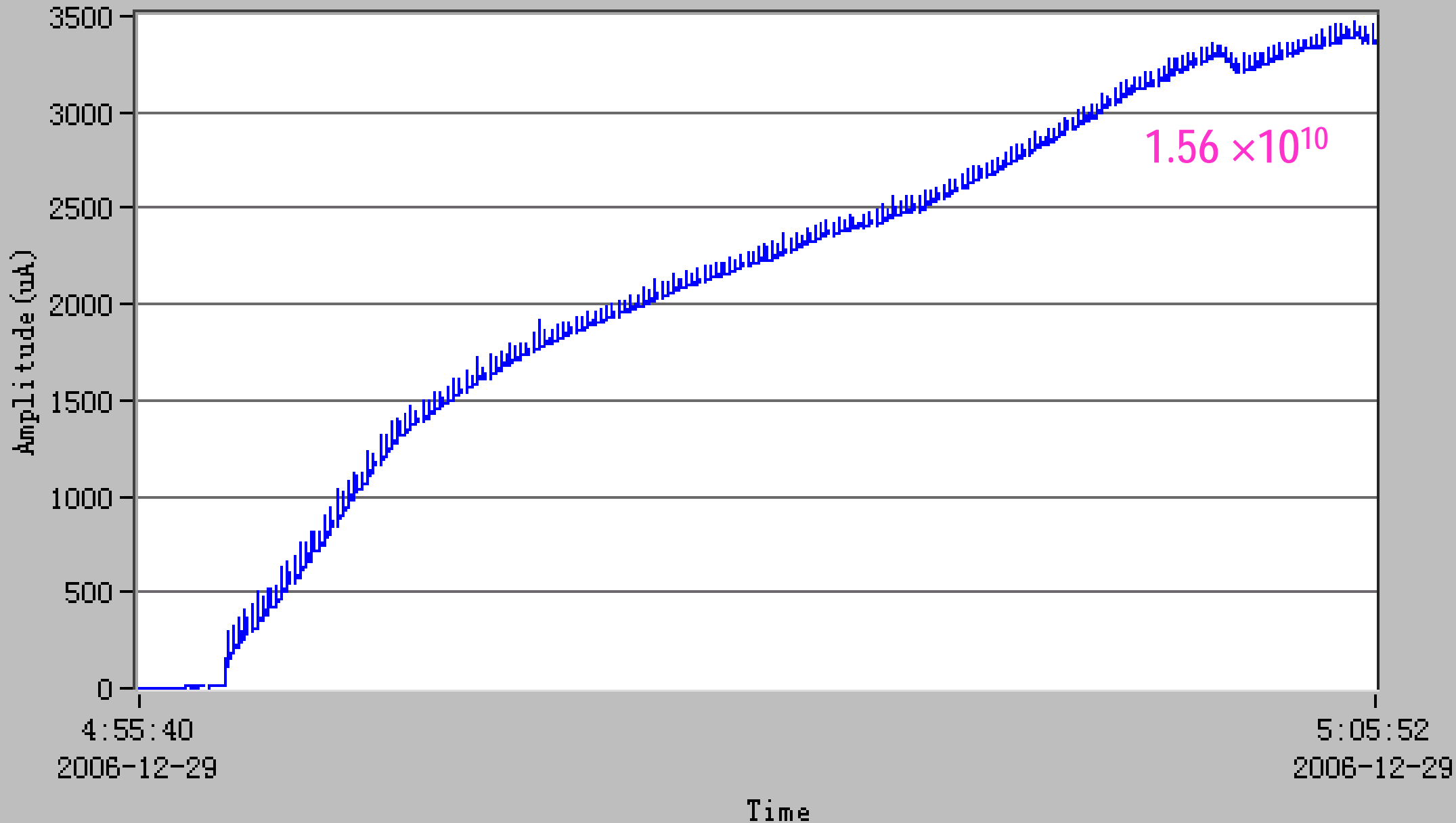
Beam Current



# STI for $C^{4+ \rightarrow 6+}$ -beam in CSRm with e-cooling

SFC- $^{12}C^{4+}$ -7MeV/u,  $I_{inj.} = 11\mu A$ , DCCT=3.4mA, Gain ~ 300

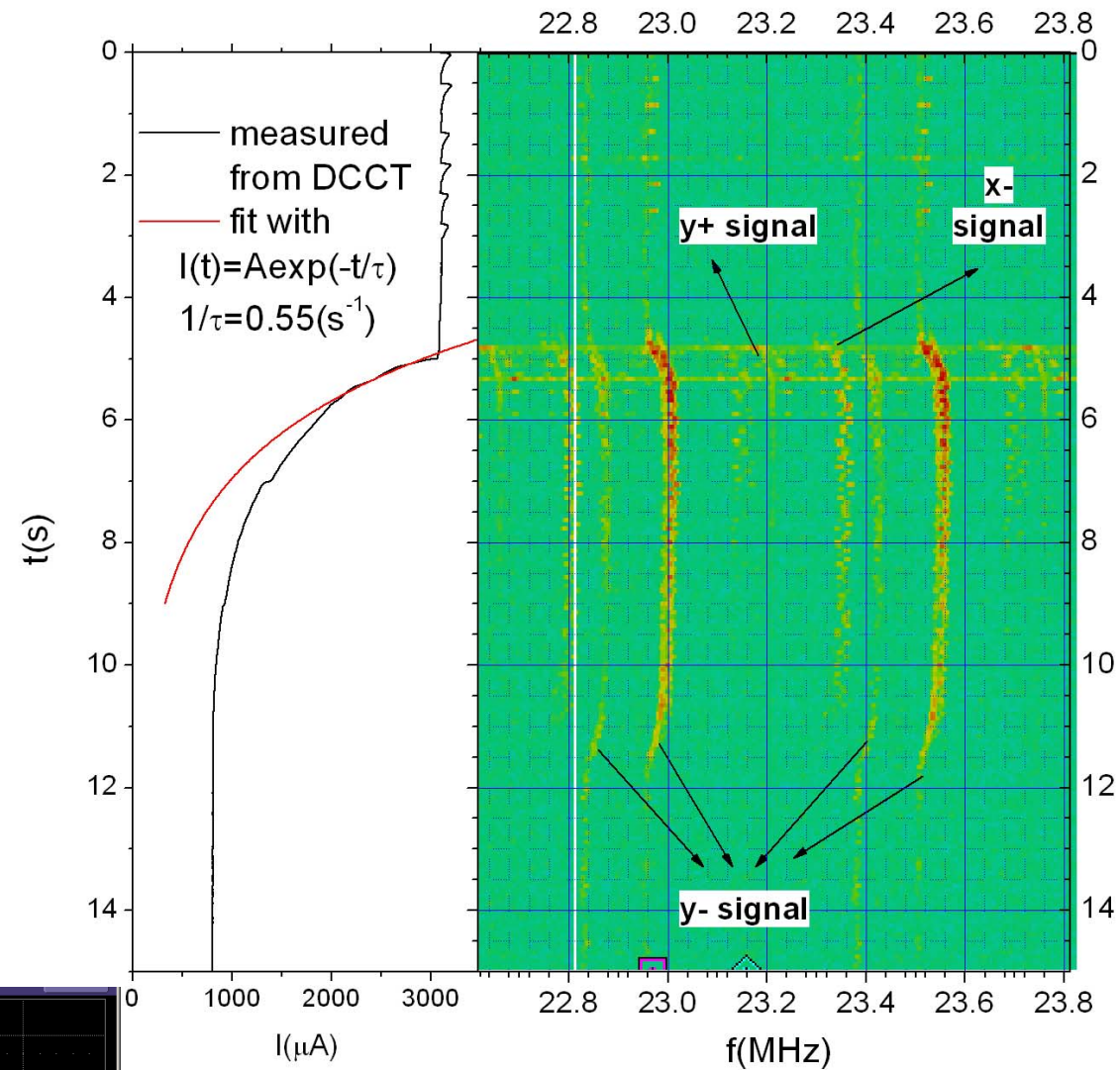
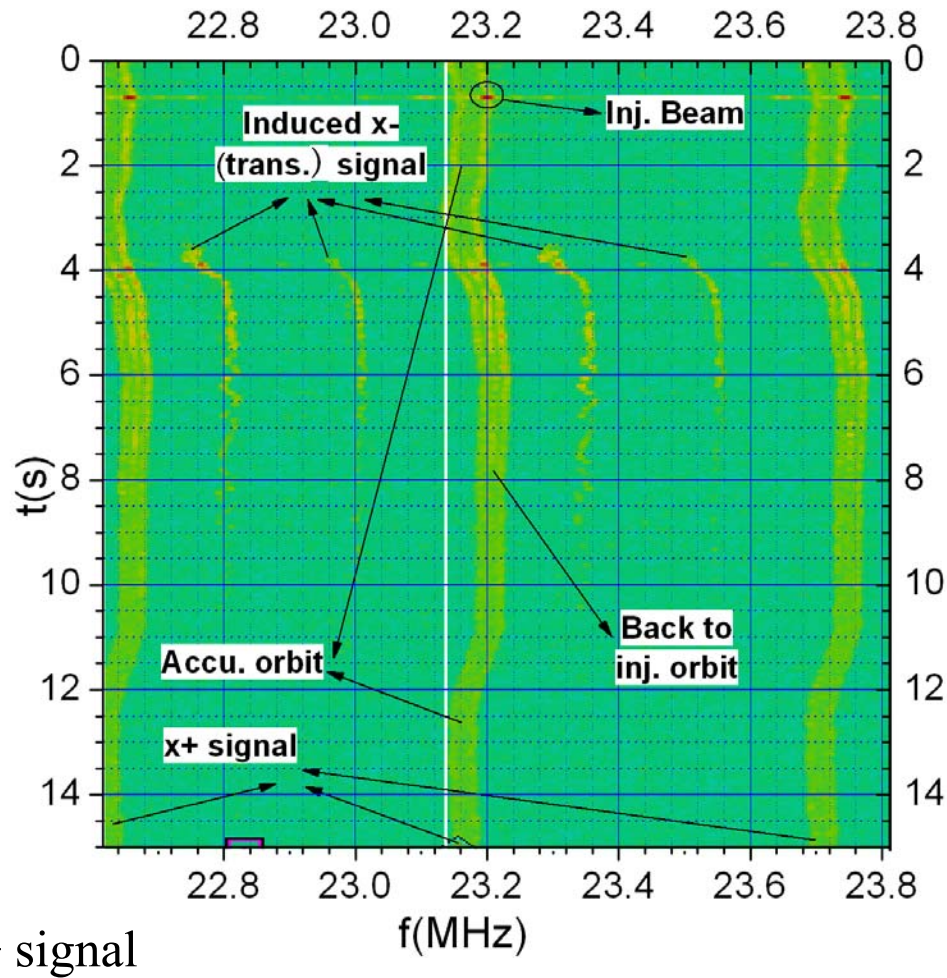
2006/12/29 23:20



# Current related beam break-up observed in CSR commissioning

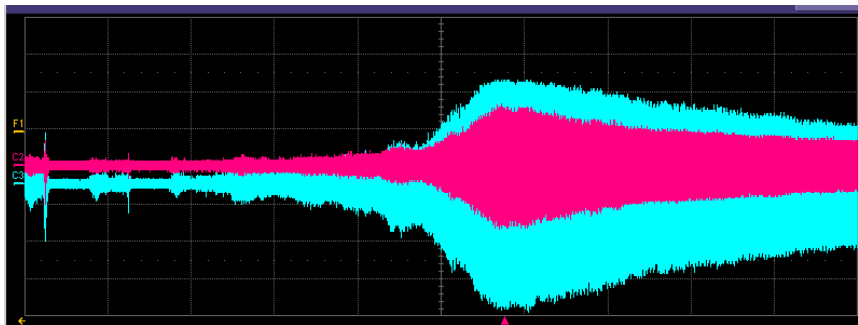
2007/09

7MeV/u  $^{12}\text{C}^{6+}$  strip inj.  $I \geq 2.5\text{mA}$  ( $1 \times 10^{10}$ ) . Just stop inj.



x+ signal

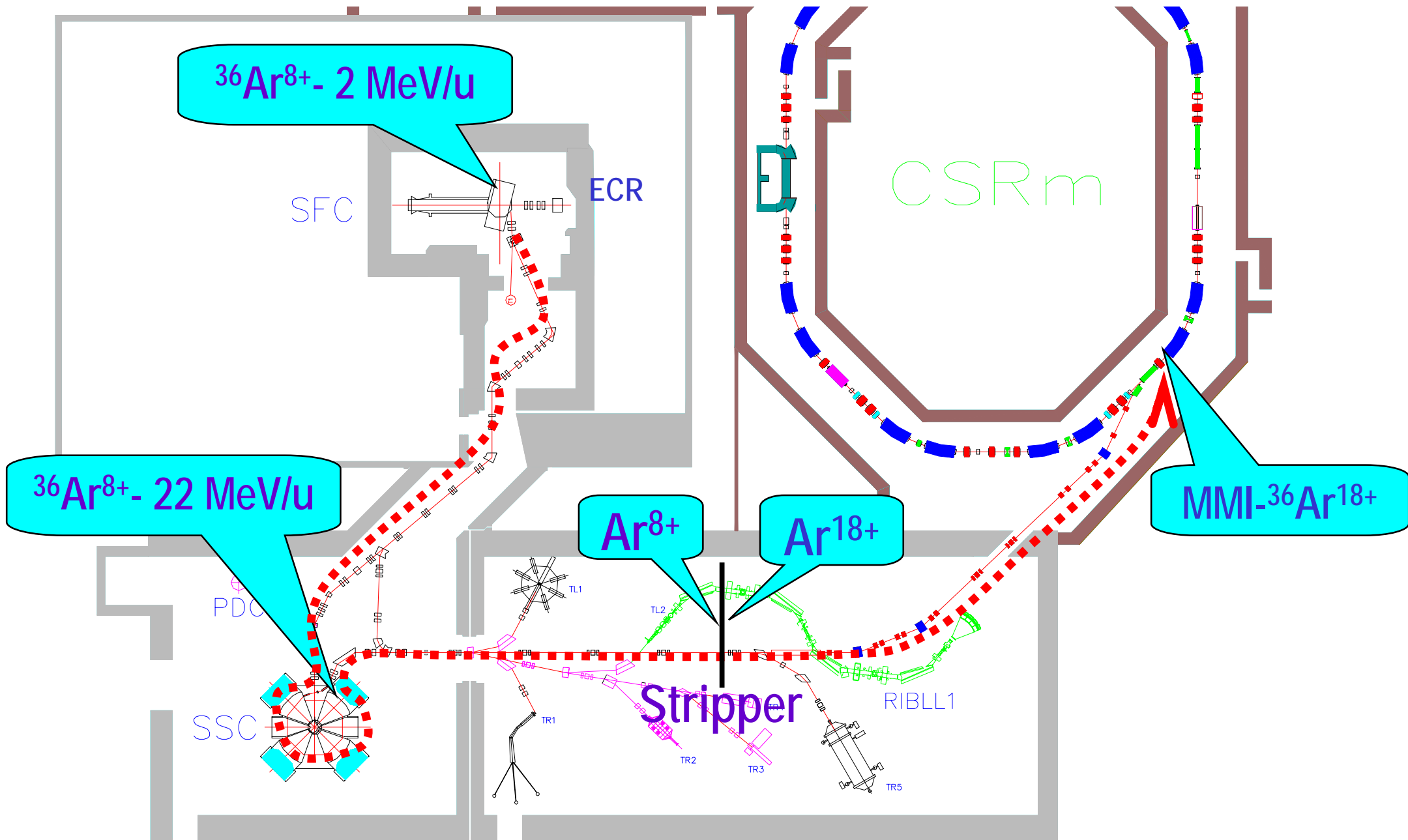
In time domain  
First 5s



DCCT and y- signal

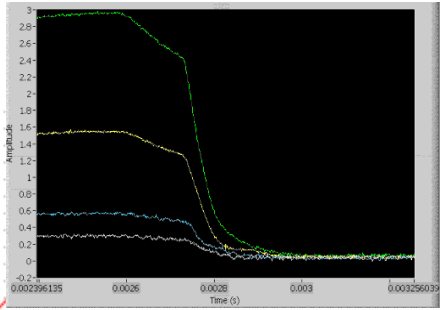
# Scheme of the MMI for Ar-beam in CSRm

2007/04/24

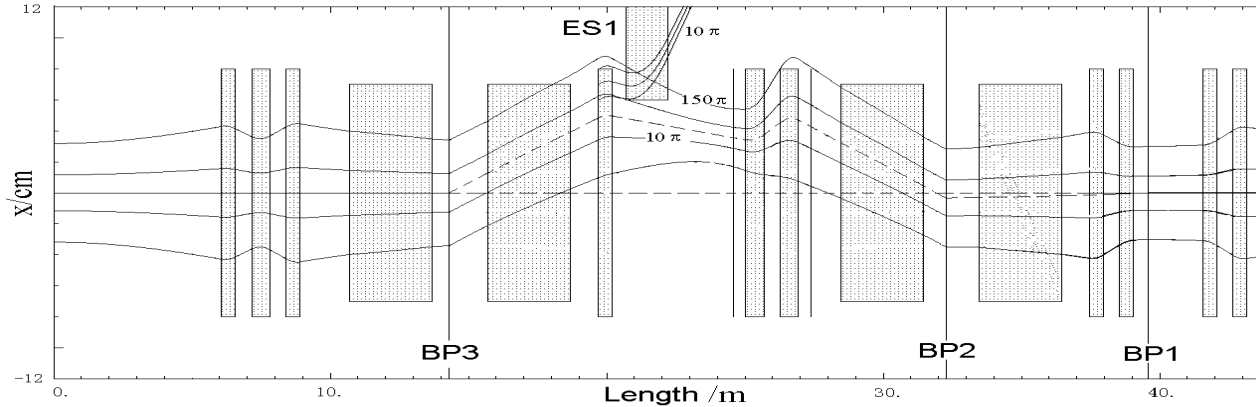


# Bump section for CSRm Multi-turn injection

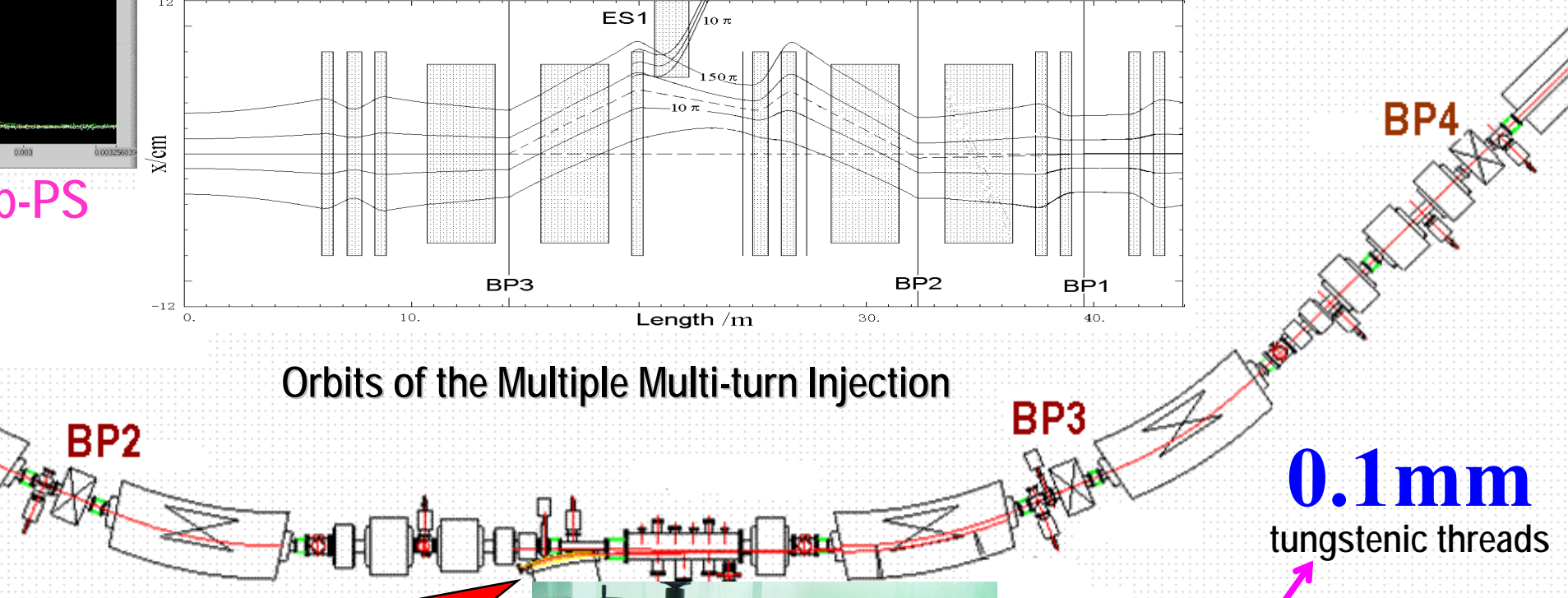
2007.03



Bump-PS



Orbits of the Multiple Multi-turn Injection



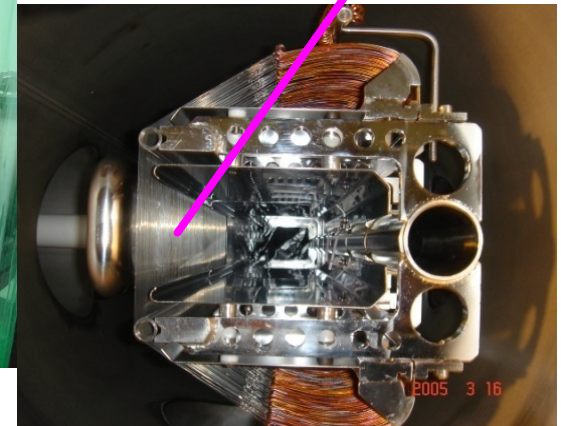
**0.1mm**  
tungstenic threads

Beam

$L = 2 \text{ m}$   
 $V_{\text{max.}} = 160 \text{ kV}$   
Gap=23mm



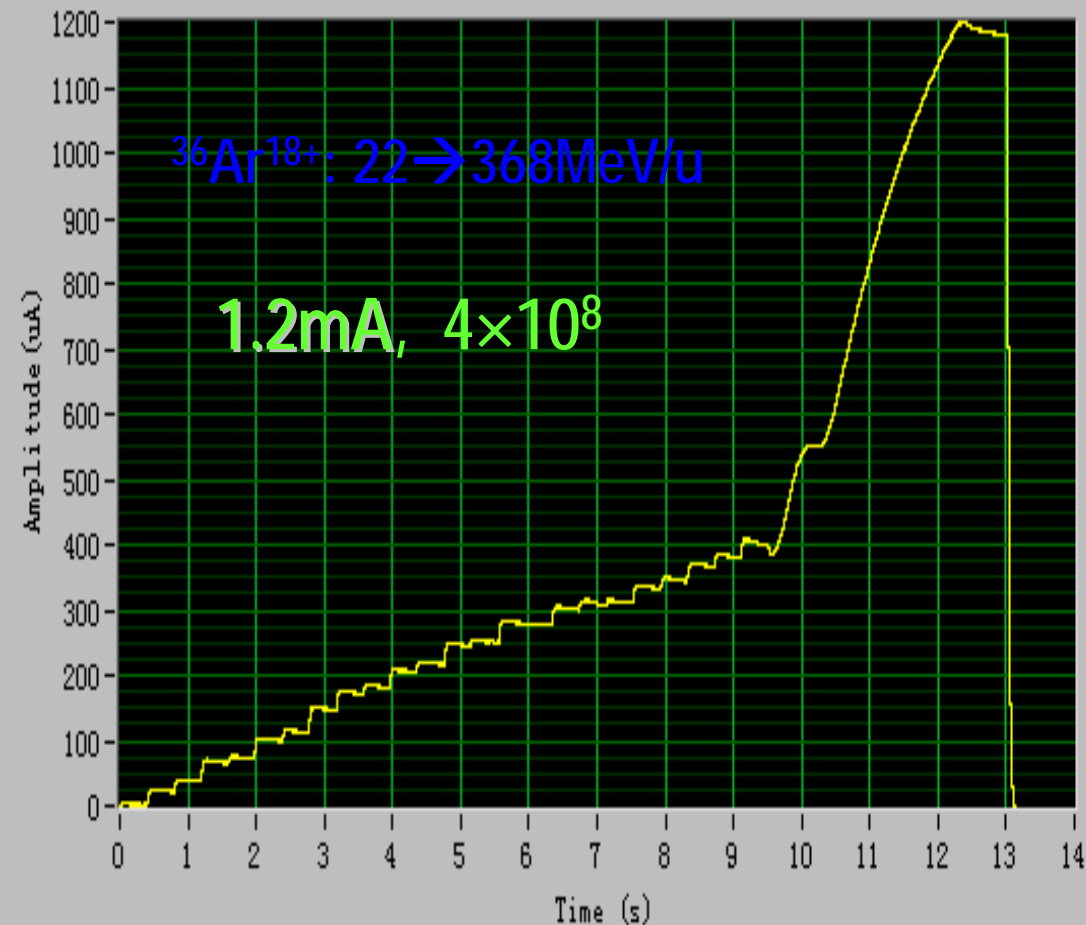
Inj. Electrostatic Deflector



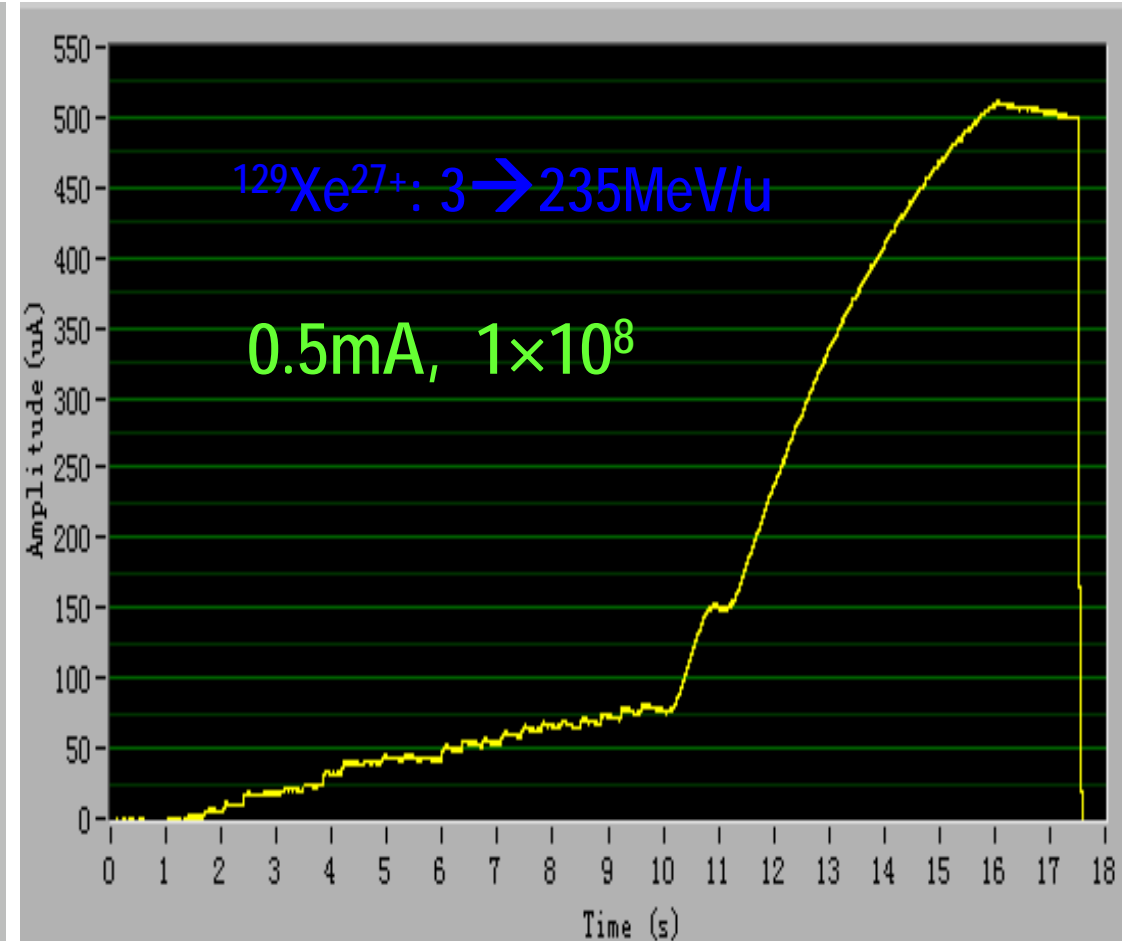
2005 3 16

# MMI + Ramping in CSRm

07/12/10 00:08



2007/06/25 07:20

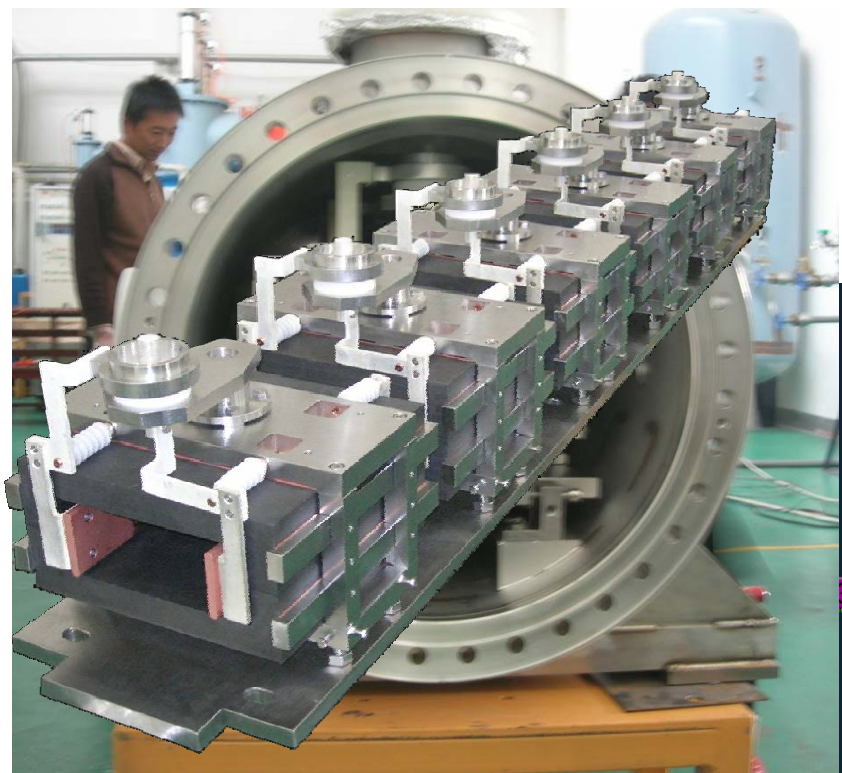
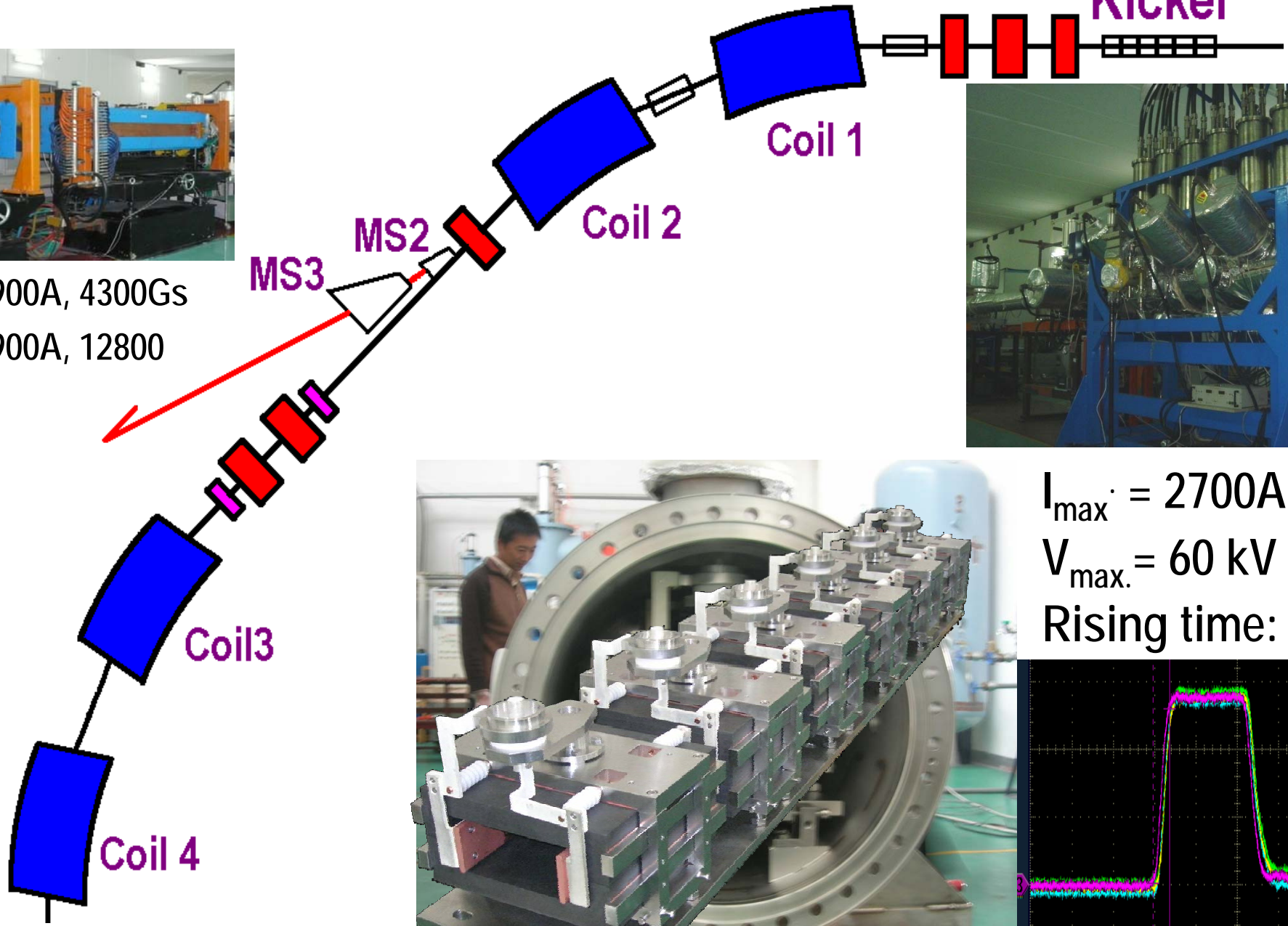


# Fast extraction section of CSRm

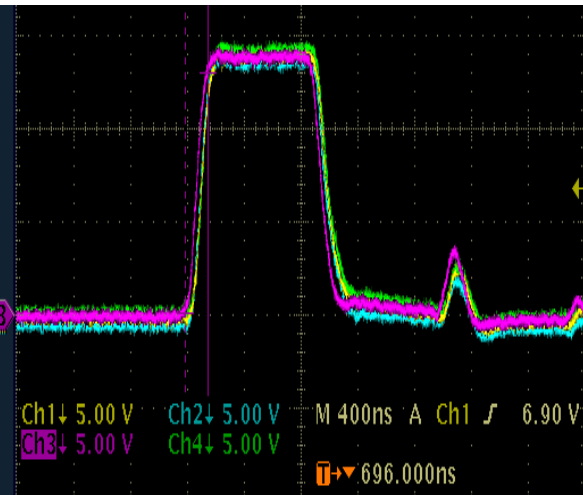
2007.08



MS2: 2900A, 4300Gs  
MS2: 2900A, 12800



$I_{max} = 2700A$   
 $V_{max.} = 60 kV$   
Rising time: **150ns**

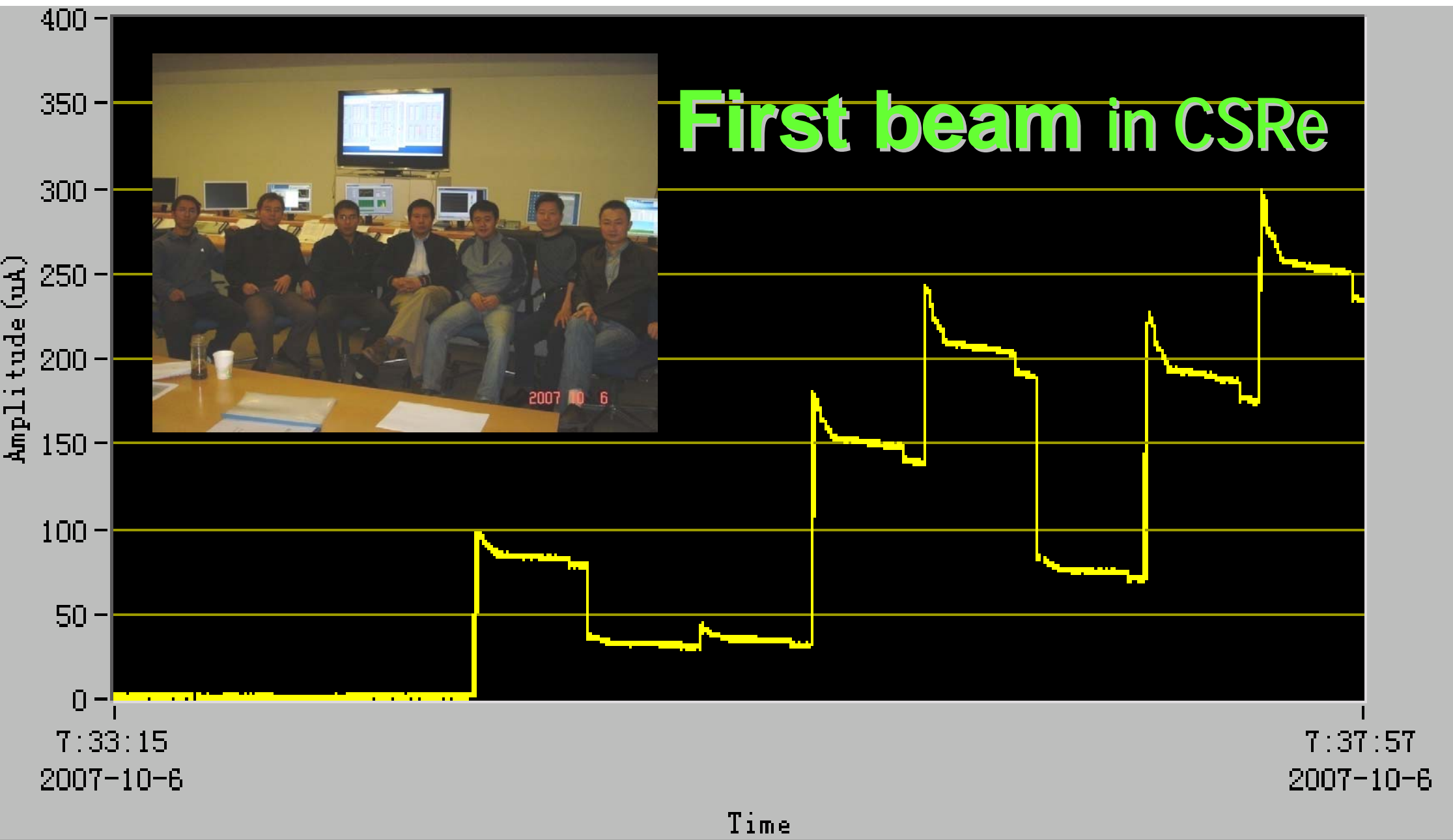




# Storage-beam for CSRe 1<sup>st</sup> Commissioning

$^{12}\text{C}^{6+}$ -600MeV/u

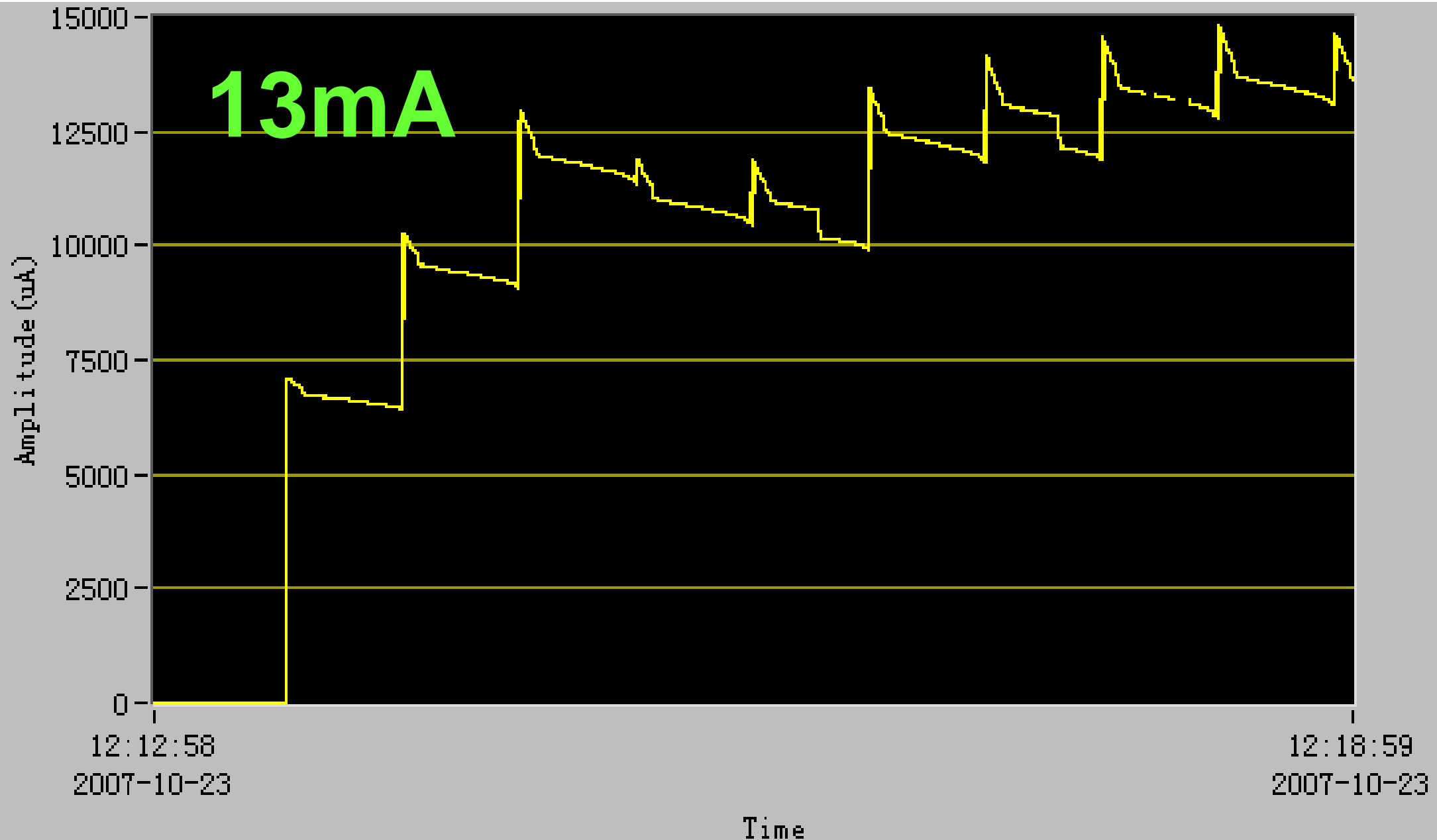
2007/10/06 07:40



# Multi-time Injection for CSRe 1<sup>st</sup> Commissioning

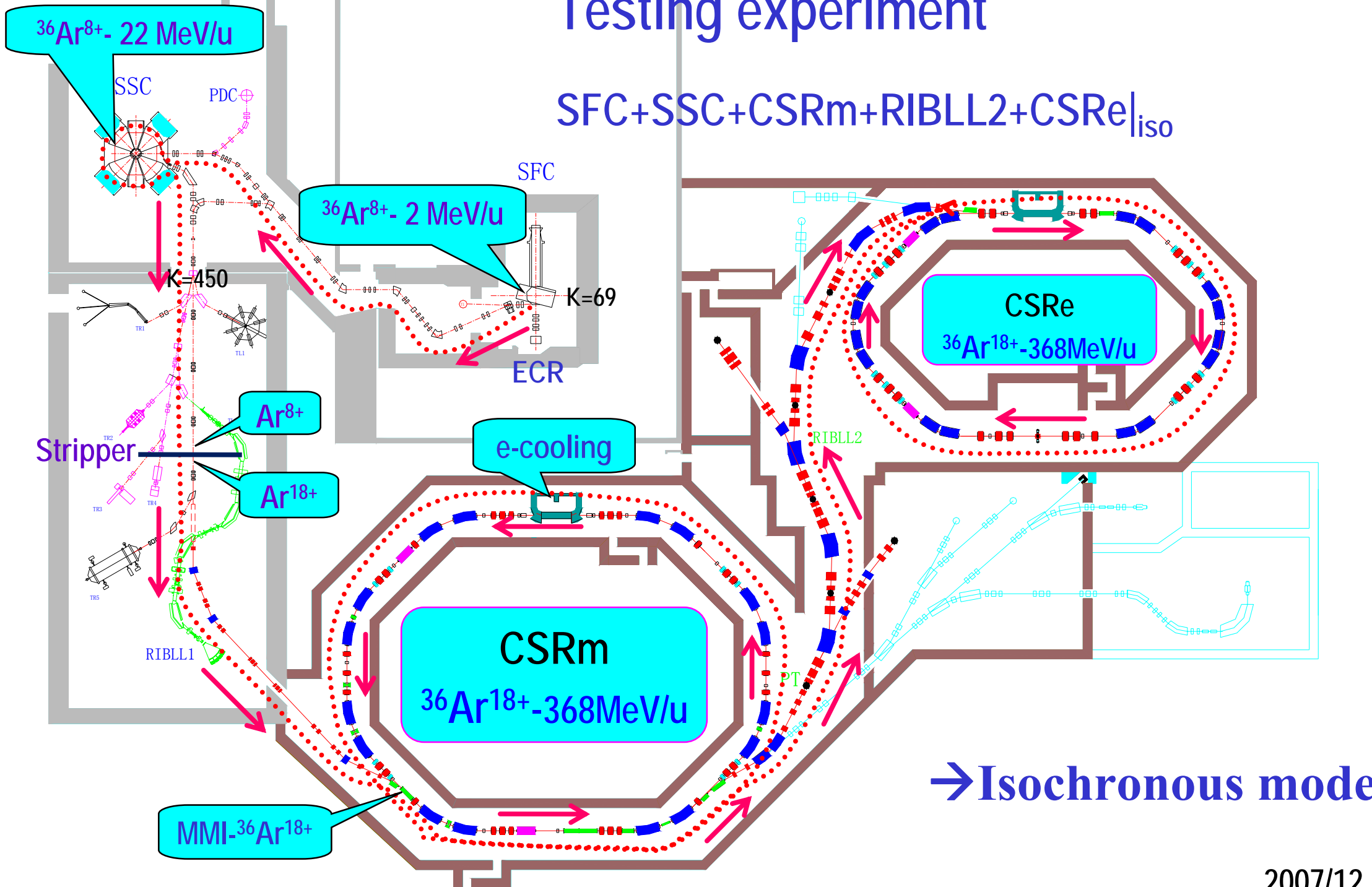
$^{12}\text{C}^{6+}$ -660MeV/u  $7 \times 10^9$

2007/10/23 12:18



# Testing experiment

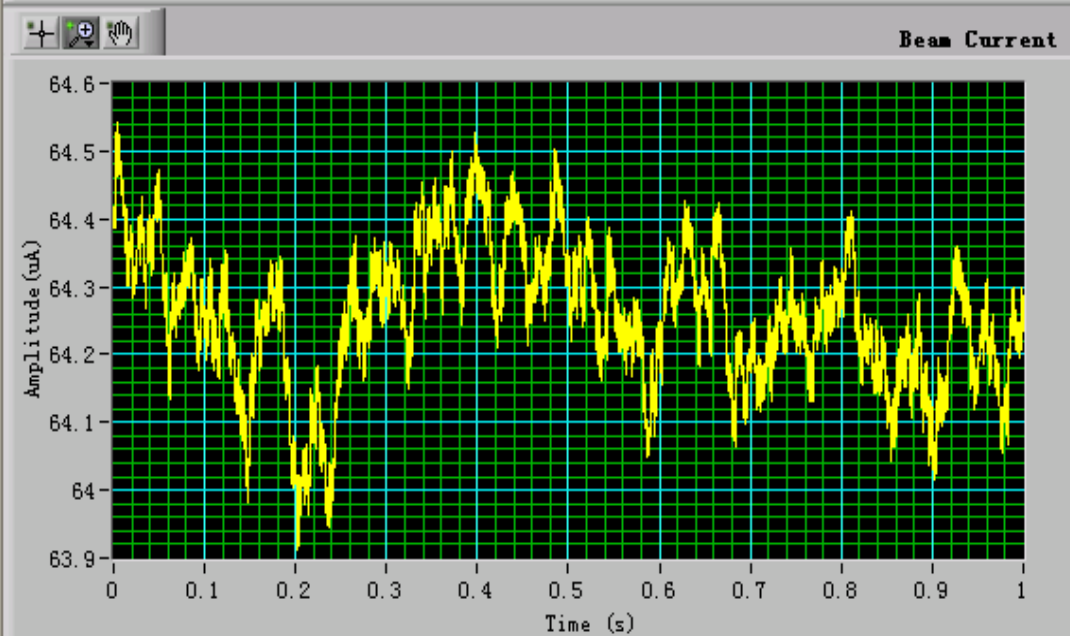
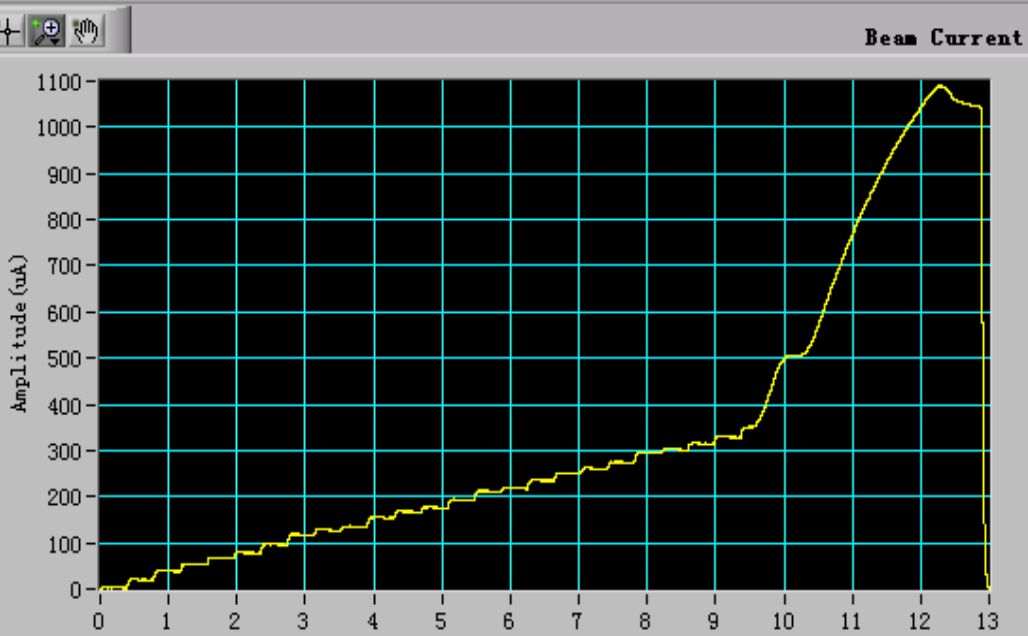
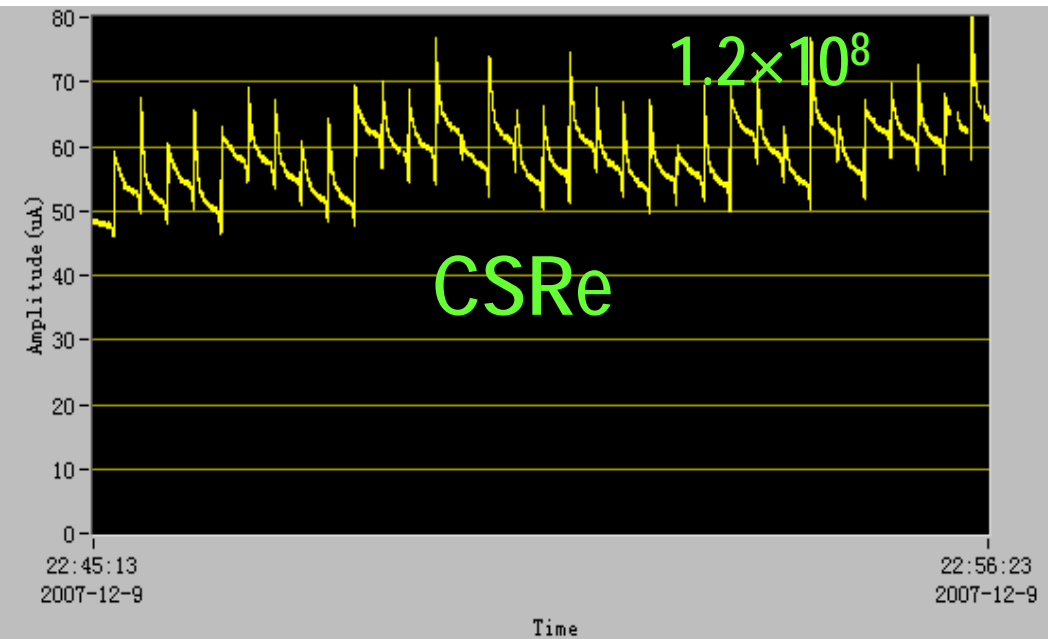
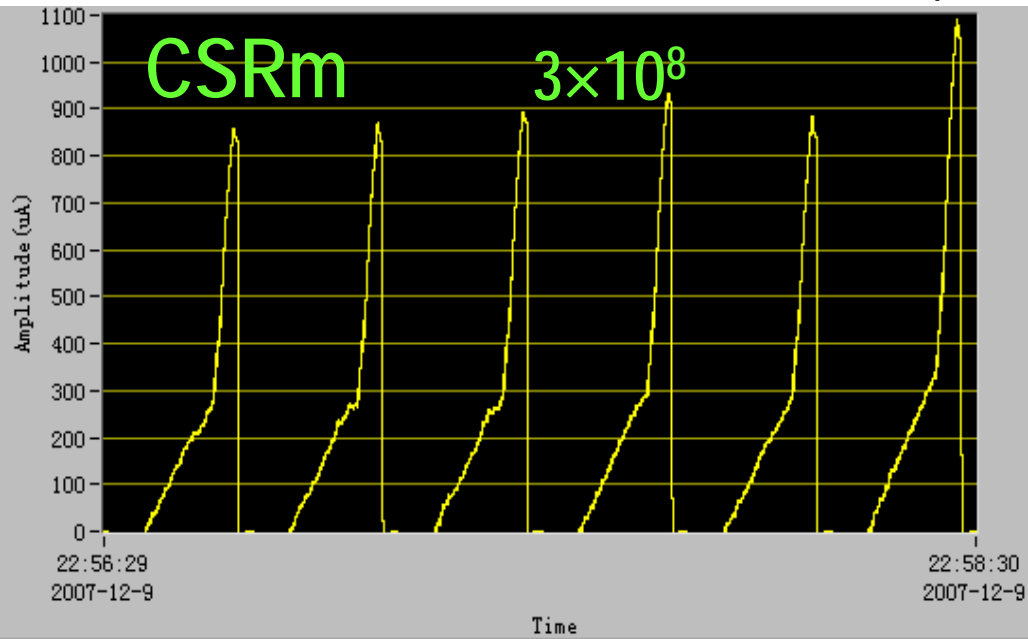
SFC+SSC+CSRm+RIBLL2+CSRe<sub>iso</sub>

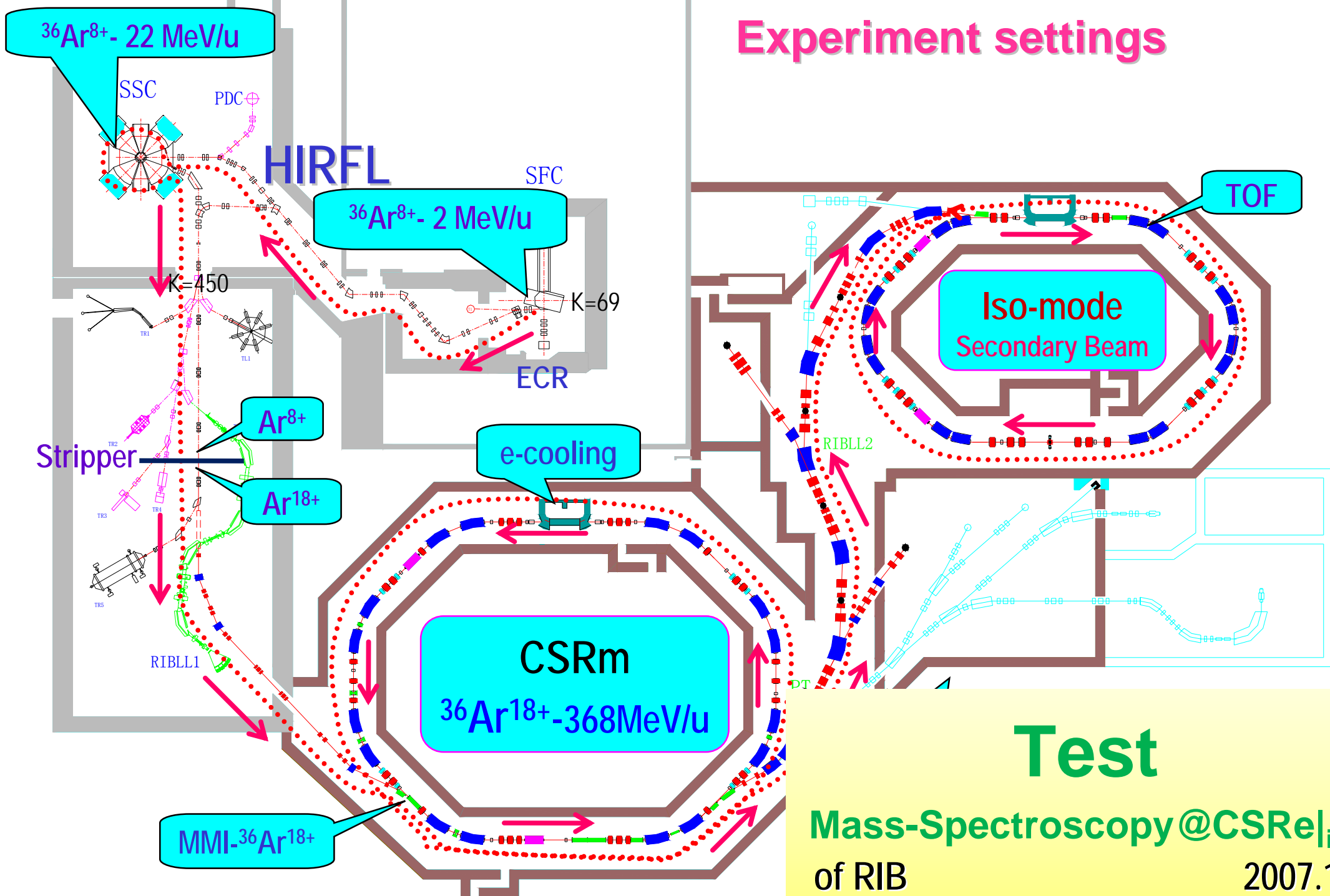


# Ar-beam in CSRm and CSRe

$^{36}\text{Ar}^{18+}$ -368MeV/u, Mode = **Isochronous**

2007/12/09 22:56



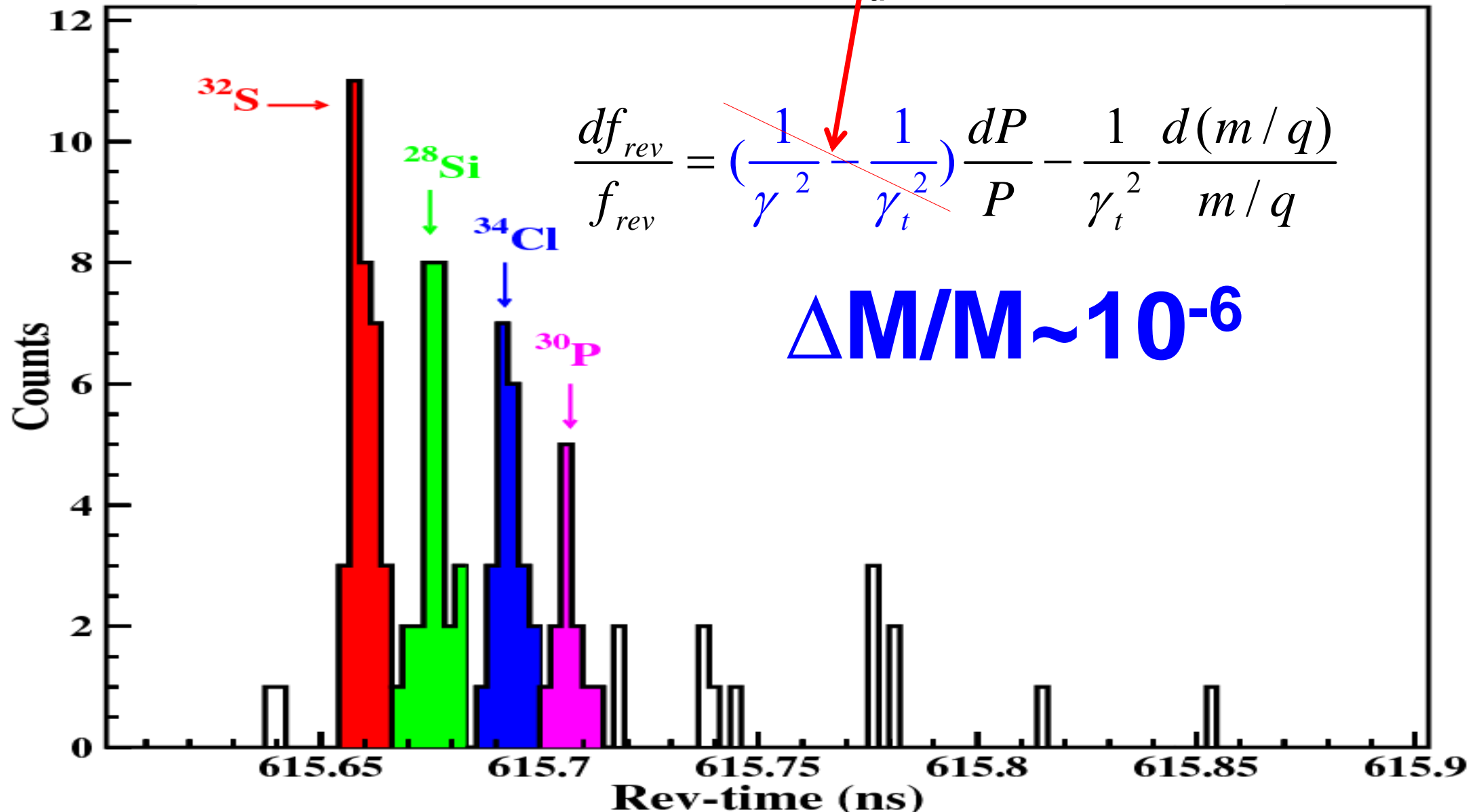


**Test**

**Mass-Spectroscopy@CSRe|<sub>iso</sub>**  
of RIB  
2007.12

# Mass Measurement of RIBs in CSRe

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



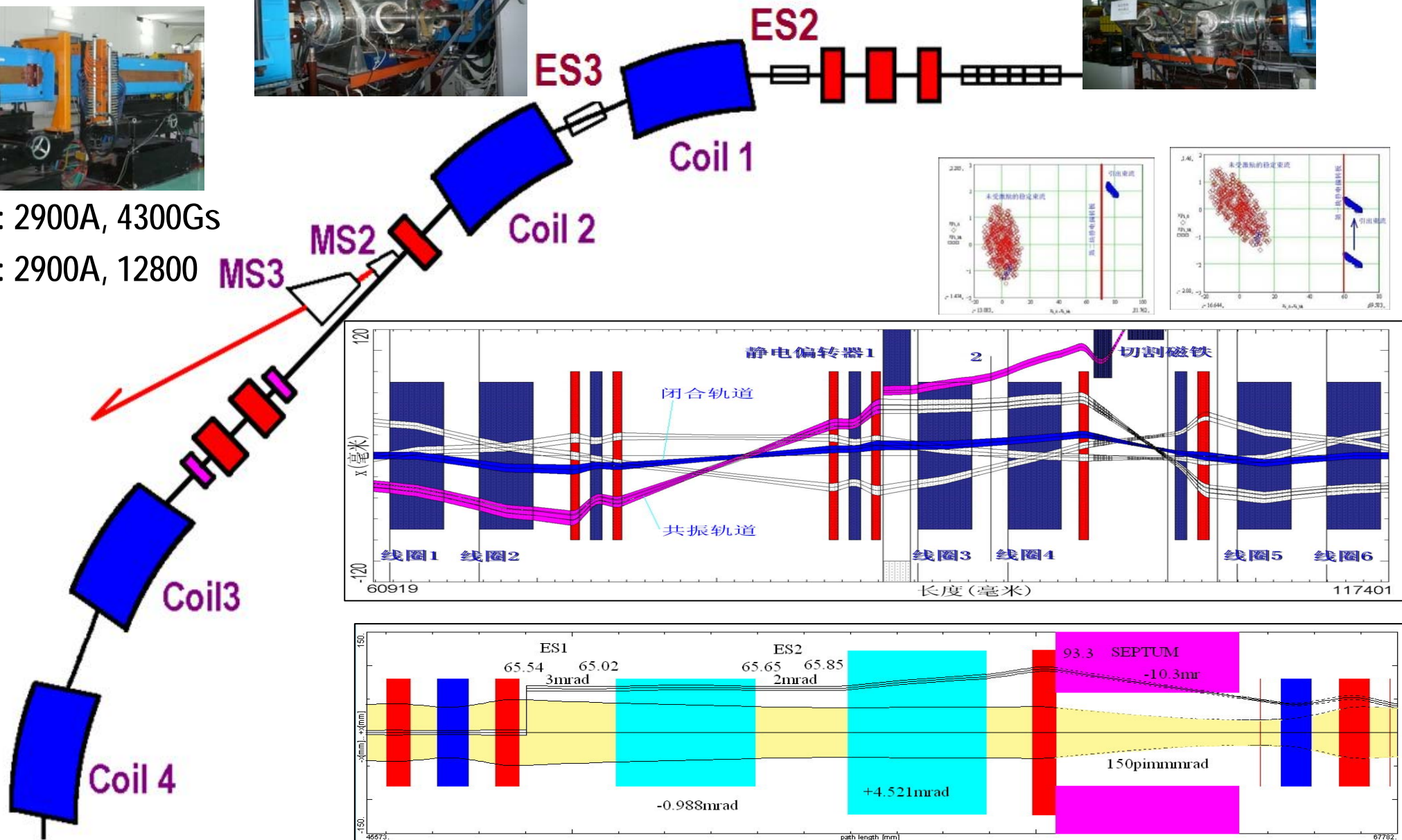
# Slow extraction of 1/3 Resonance in CSRm

2008.01.10



MS2: 2900A, 4300Gs

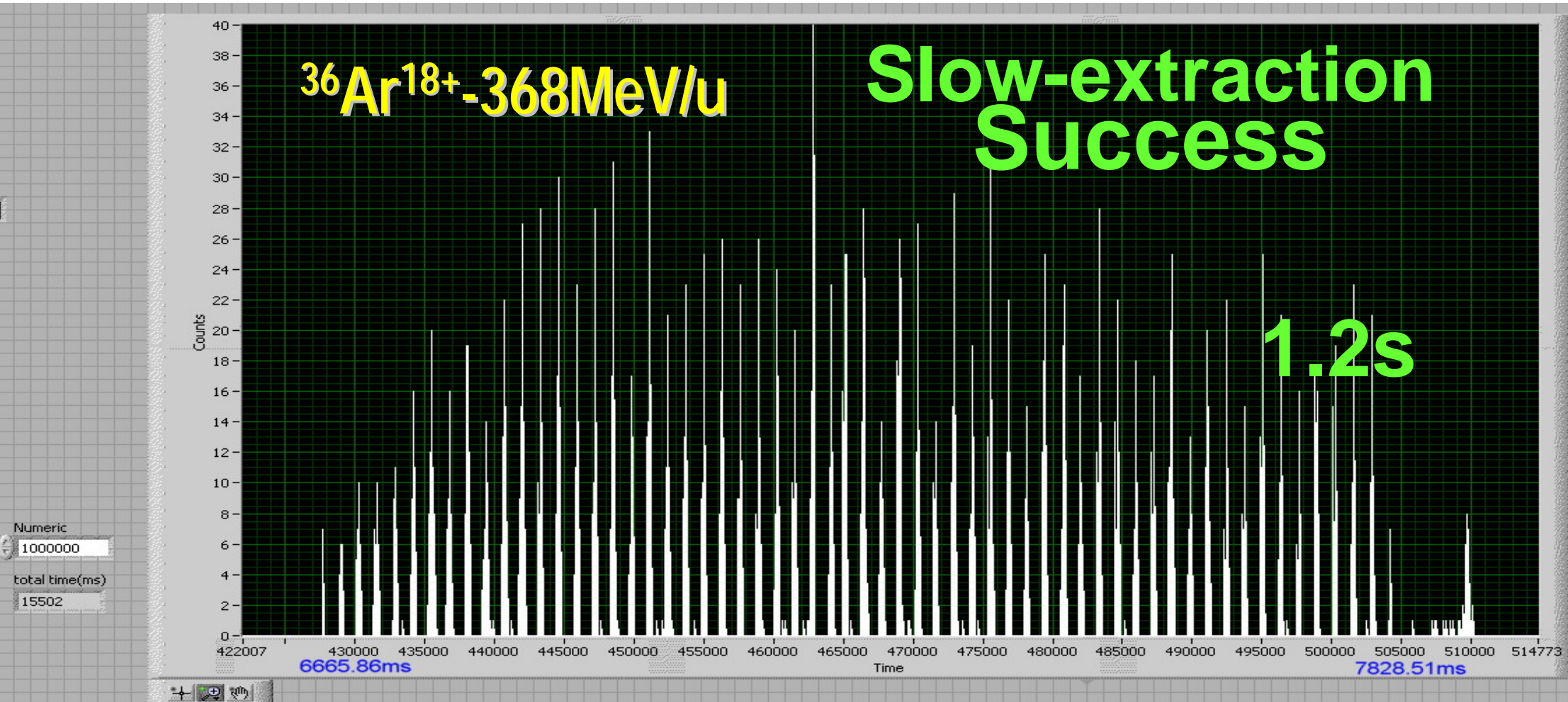
MS2: 2900A, 12800



# Beam signal for the first slow extraction in CSRm

From Scintillation Crystal Monitor

2008.01.10 15:00



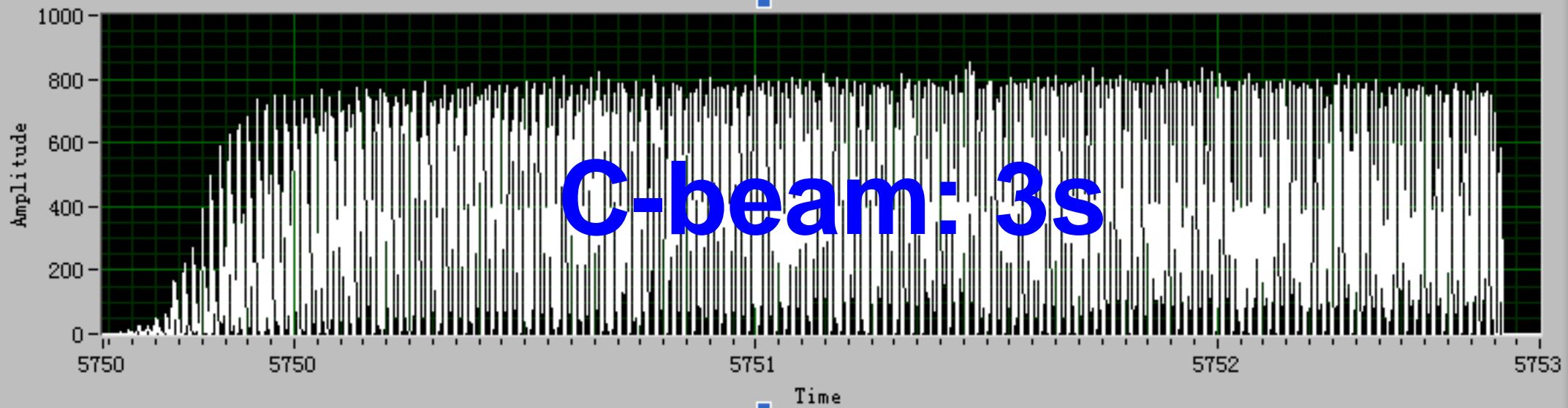
- Spill length: 1.2s
- Main frequency: 50Hz




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

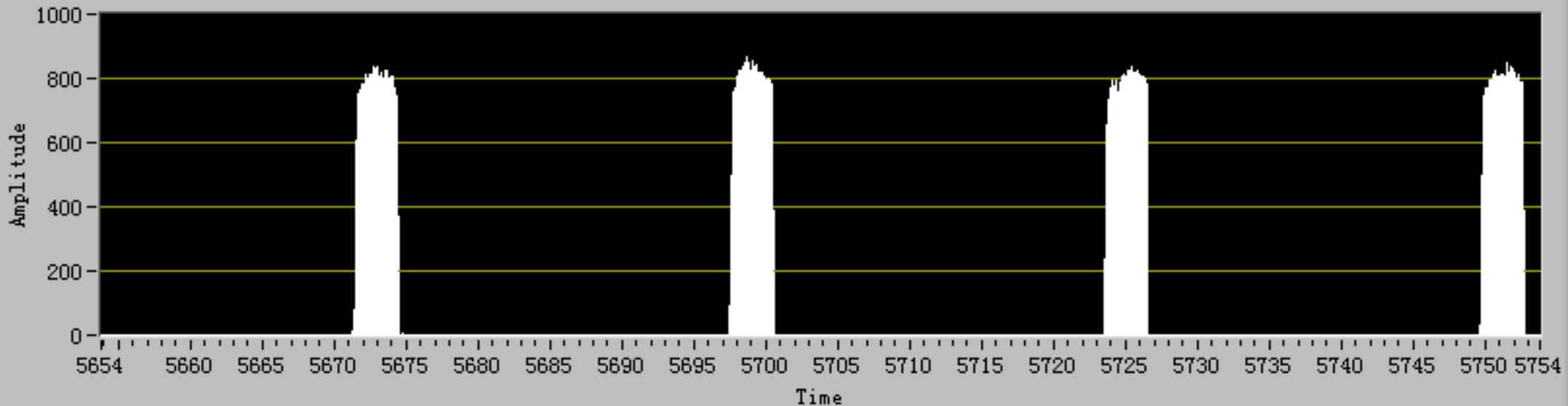
From Scintillation Crystal Monitor

2009.03



Waveform Chart

Plot 0 



**HIRFL-CSR**

**Operation & Experiments**

**2008---2009**

# HIRFL-CSR Control Room

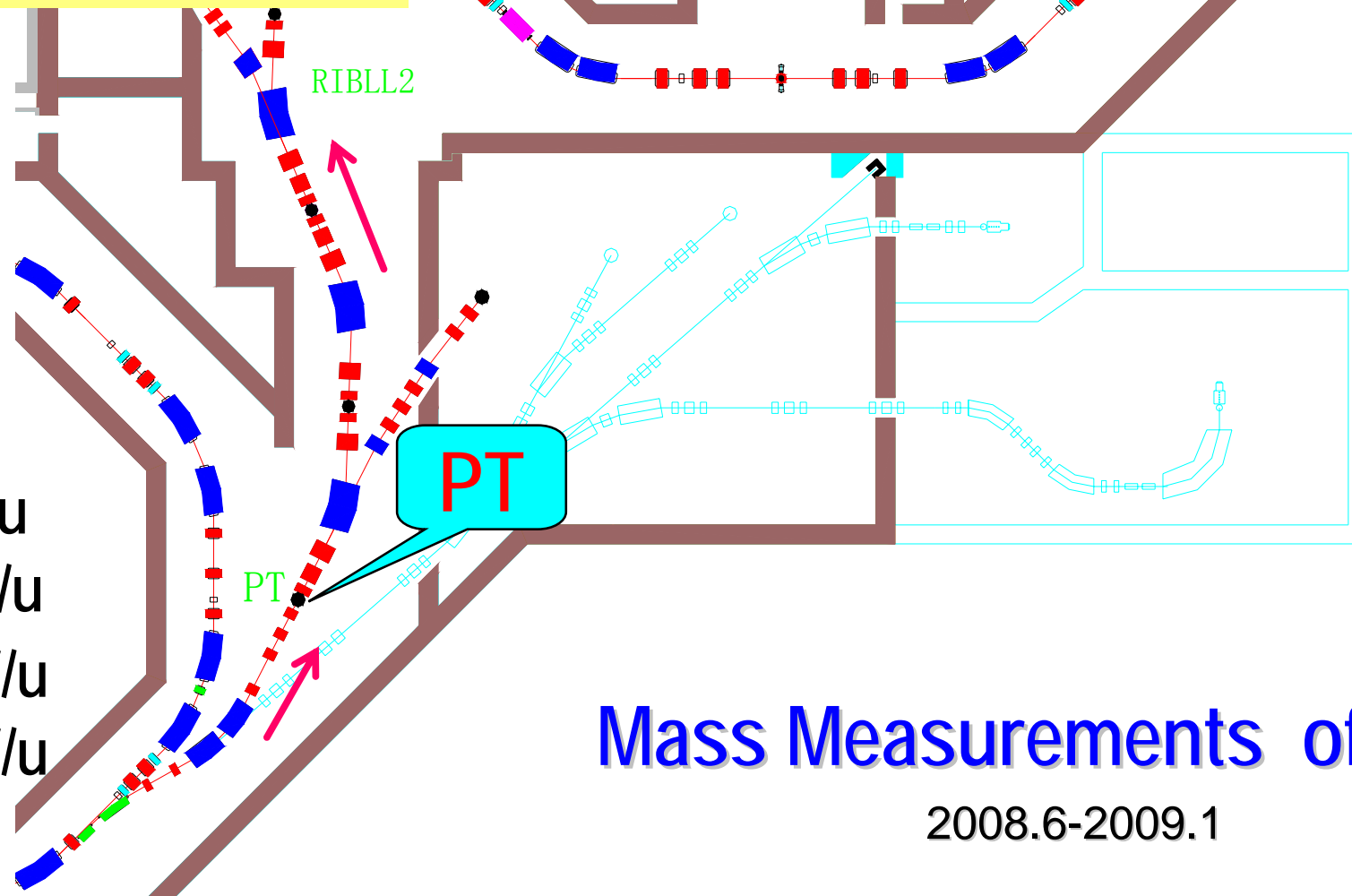
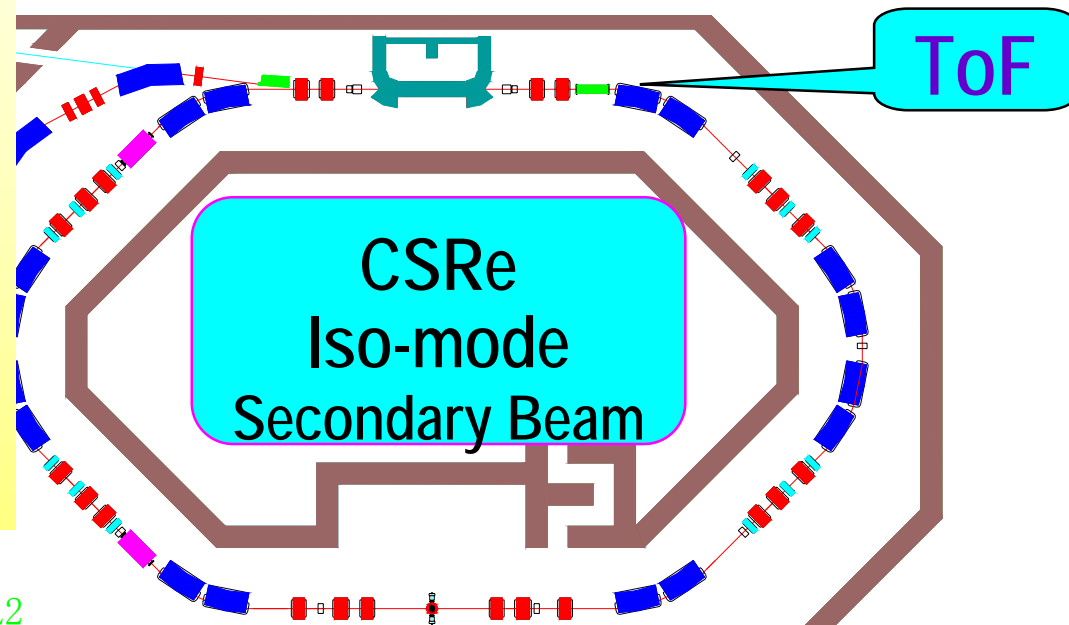


# “First” experiment

$^{78}\text{Kr} \rightarrow \text{Ge, As, Se} (2Z-1)$

2008.6-7

2008.10-2009.1



CSRm

$^{78}\text{Kr}^{28+}$

198.98 MeV/u

~371.71 MeV/u

~450.86 MeV/u

~499.78 MeV/u

## Mass Measurements of RIBs

2008.6-2009.1

# challenge

SC-ECR( $^{78}\text{Kr}^{19+}$ )

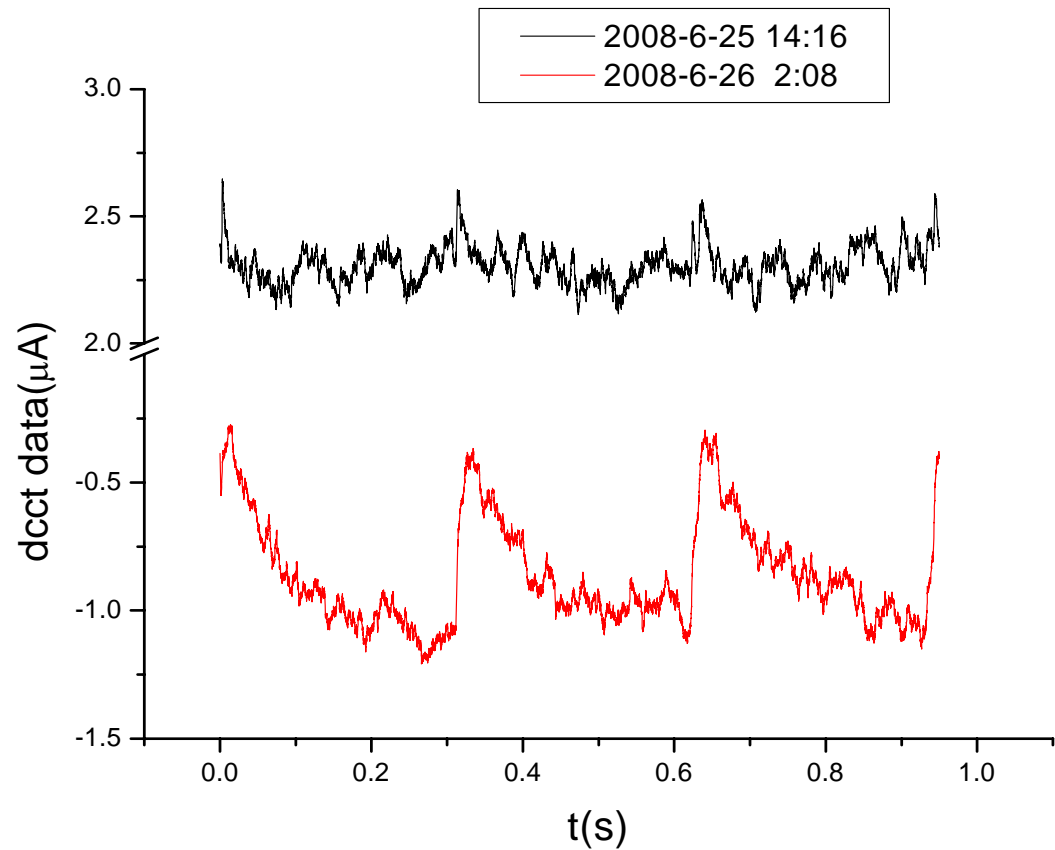
→ SFC( $^{78}\text{Kr}^{19+}$ , 4MeV/u)

→ BL2 ( $^{78}\text{Kr}^{28+}$ ), max.  $\sim 600\text{nA}$

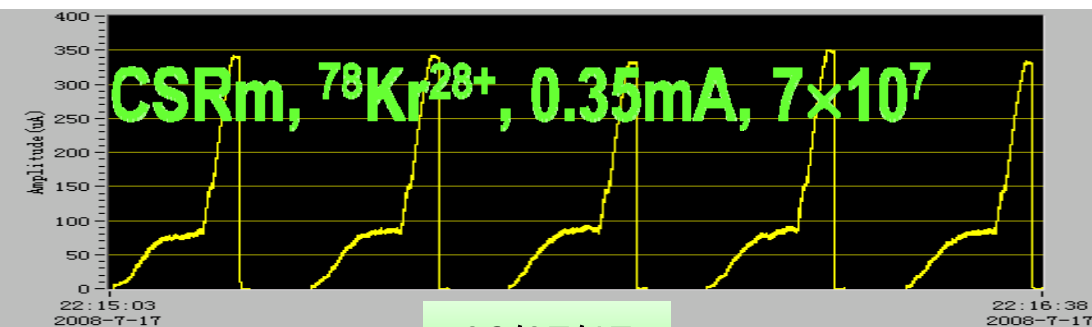
→ CSRm( $^{78}\text{Kr}^{28+}$ , 368-500MeV/u)

→ RIBLL2 ( $^{78}\text{Kr}^{28+}$  or  $^{78}\text{Kr}^{36+}$  or RIB)

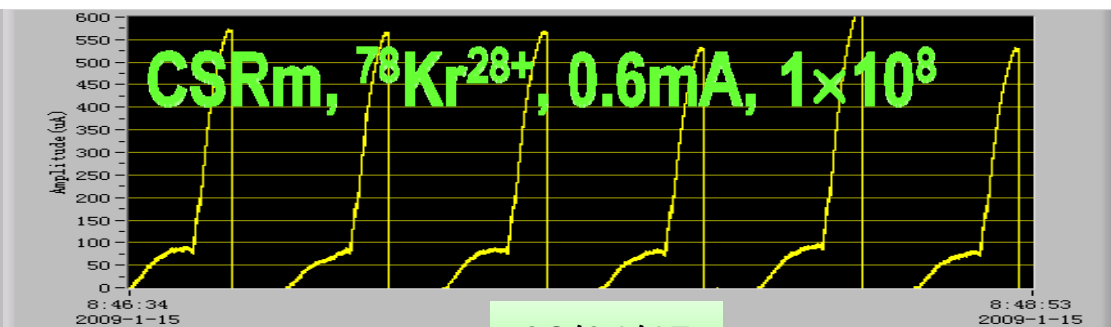
→ CSRe|<sub>iso</sub>



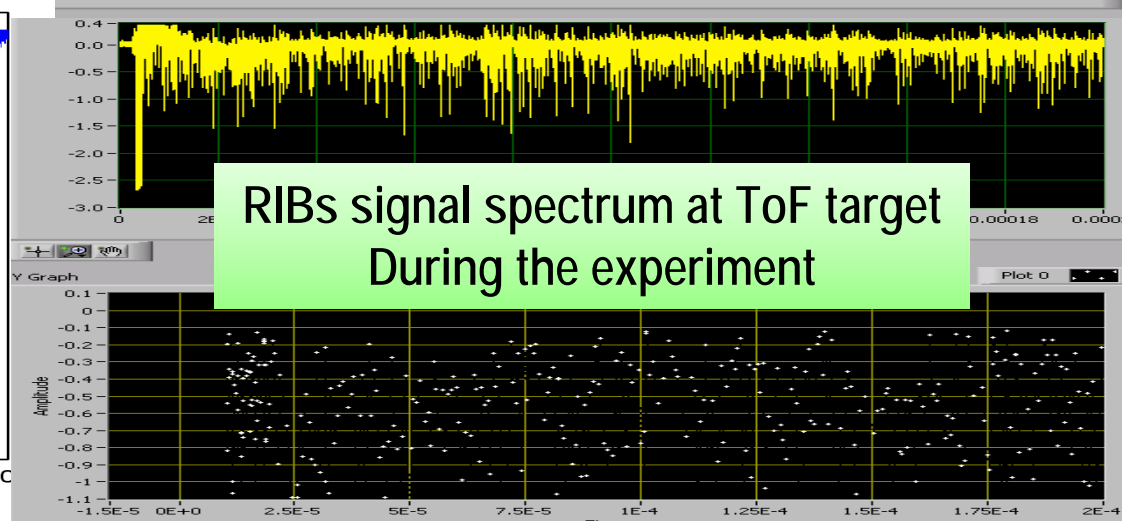
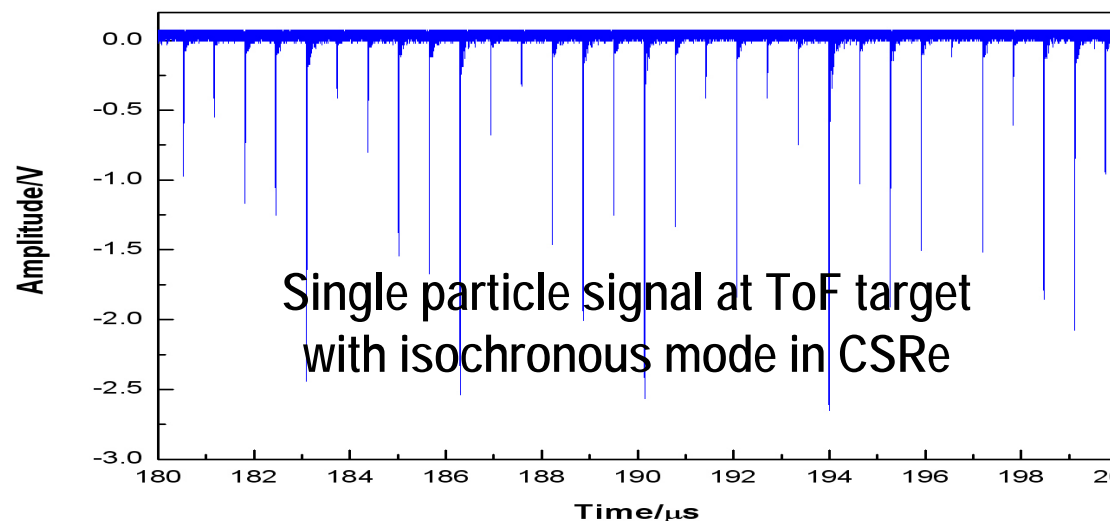
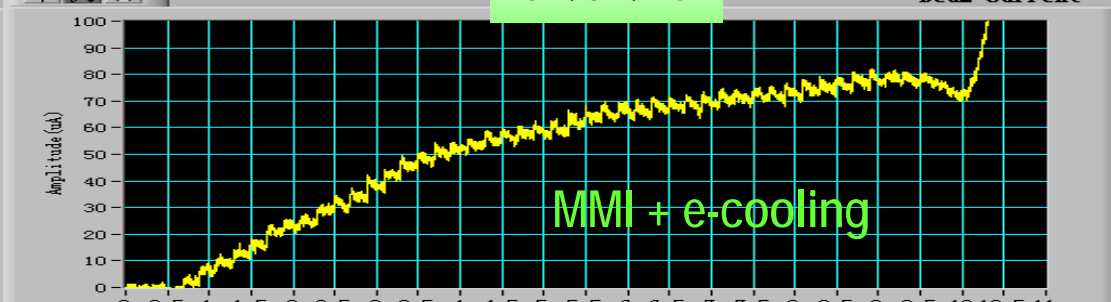
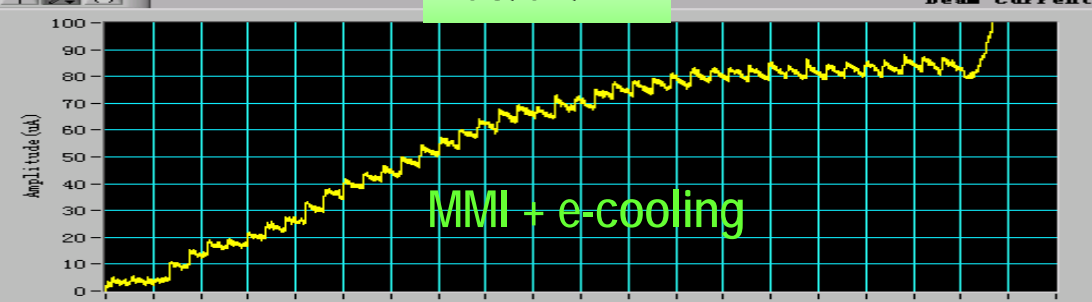
# Experiments for RIB mass spectroscopy



08/07/17

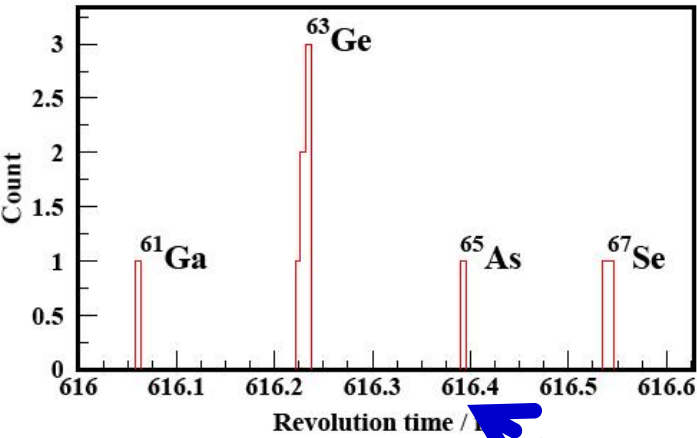


09/01/15

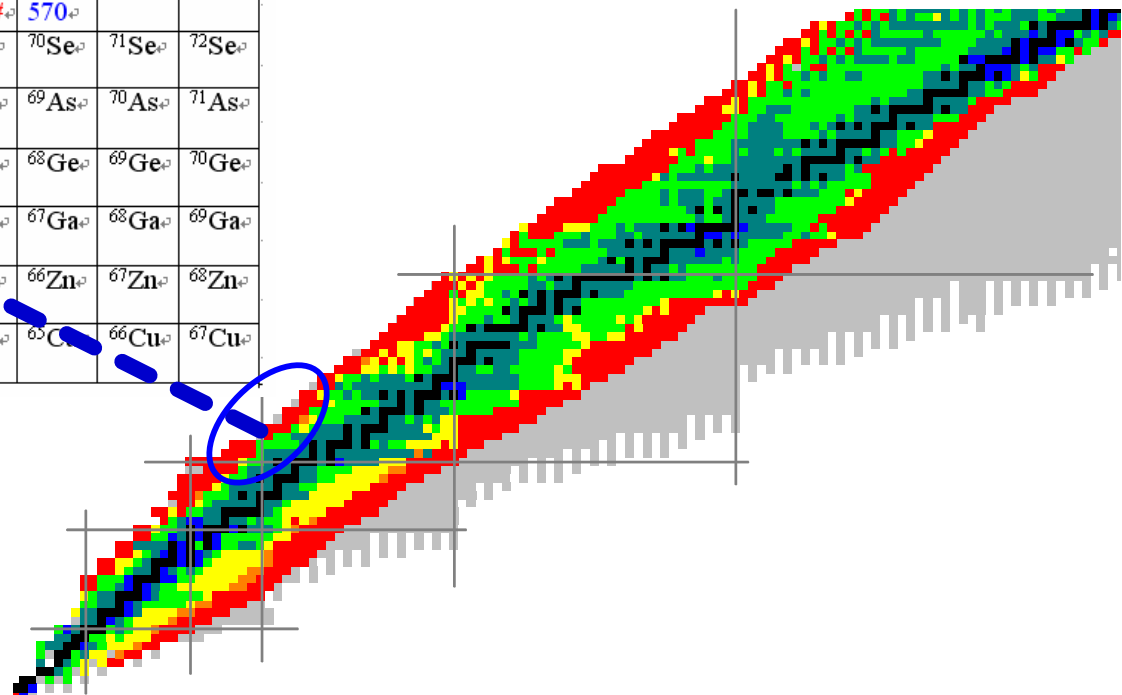


# Results of the RIBs mass-measurements (2008-2009)

For the 3 drip-line nuclei  $^{63}\text{Ge}$ ,  $^{65}\text{As}$ ,  $^{67}\text{Se}$  with the life-time of 100ms

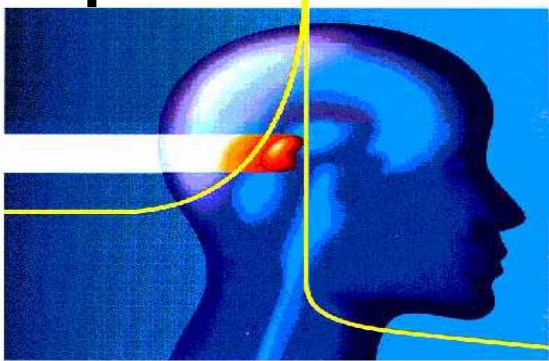


				$^{73}\text{Sr}$ 400#	$^{74}\text{Sr}$ 390#	$^{71}\text{Kr}$ 650#	$^{72}\text{Kr}$ 570#	$^{73}\text{Kr}$	$^{74}\text{Kr}$
						$^{70}\text{Br}$ 310#	$^{71}\text{Br}$ 570#	$^{72}\text{Br}$	$^{73}\text{Br}$
		$^{65}\text{Se}$ 600#	$^{66}\text{Se}$ 700#	$^{67}\text{Se}$ 200#	$^{68}\text{Se}$	$^{69}\text{Se}$	$^{70}\text{Se}$	$^{71}\text{Se}$	$^{72}\text{Se}$
		$^{64}\text{As}$ 300#	$^{65}\text{As}$ 300#	$^{66}\text{As}$ 680#	$^{67}\text{As}$	$^{68}\text{As}$	$^{69}\text{As}$	$^{70}\text{As}$	$^{71}\text{As}$
$^{61}\text{Ge}$ 300#	$^{62}\text{Ge}$ 140#	$^{63}\text{Ge}$ 200#	$^{64}\text{Ge}$	$^{65}\text{Ge}$	$^{66}\text{Ge}$	$^{67}\text{Ge}$	$^{68}\text{Ge}$	$^{69}\text{Ge}$	$^{70}\text{Ge}$
$^{60}\text{Ga}$ 110#	$^{61}\text{Ga}$	$^{62}\text{Ga}$	$^{63}\text{Ga}$	$^{64}\text{Ga}$	$^{65}\text{Ga}$	$^{66}\text{Ga}$	$^{67}\text{Ga}$	$^{68}\text{Ga}$	$^{69}\text{Ga}$
$^{57}\text{Zn}$ 100#	$^{58}\text{Zn}$	$^{59}\text{Zn}$	$^{60}\text{Zn}$	$^{61}\text{Zn}$	$^{62}\text{Zn}$	$^{63}\text{Zn}$	$^{64}\text{Zn}$	$^{65}\text{Zn}$	$^{66}\text{Zn}$
$^{55}\text{Cu}$ 300#	$^{56}\text{Cu}$ 140#	$^{57}\text{Cu}$	$^{58}\text{Cu}$	$^{59}\text{Cu}$	$^{60}\text{Cu}$	$^{61}\text{Cu}$	$^{62}\text{Cu}$	$^{63}\text{Cu}$	$^{64}\text{Cu}$



# Cancer Therapy with CSRm (2009.03-04)

6 patients, recrudescence after normal treatments! 3-10cm



In treatment:

$10^9$ pps required

100-250MeV/u

Energy degrader + multi-leaf-collimator

scan magnets  $\pm 5\text{cm} \times \pm 5\text{cm}$  uniformity 95%

Also tested

5MeV/u-step active change

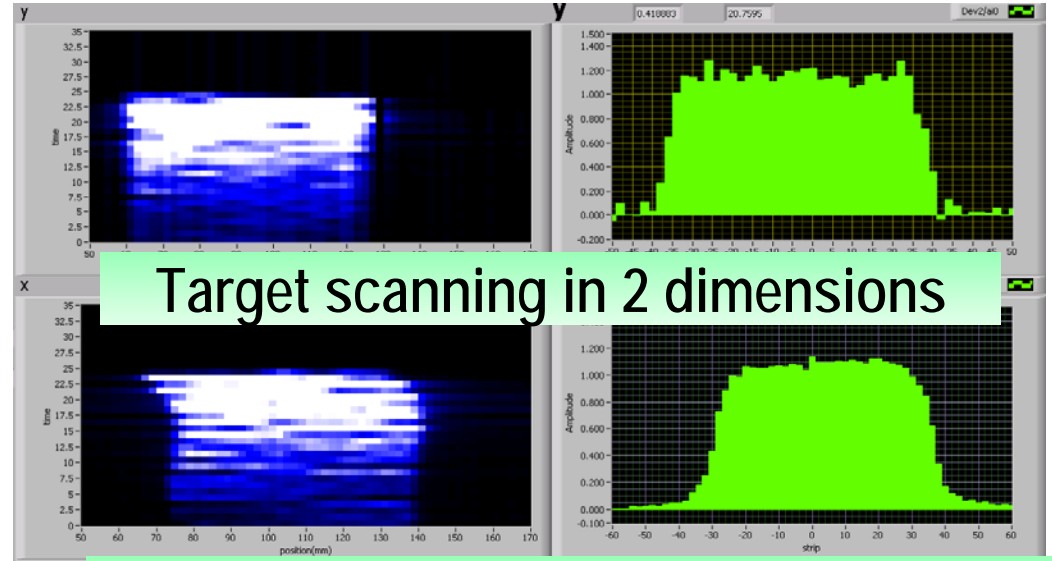
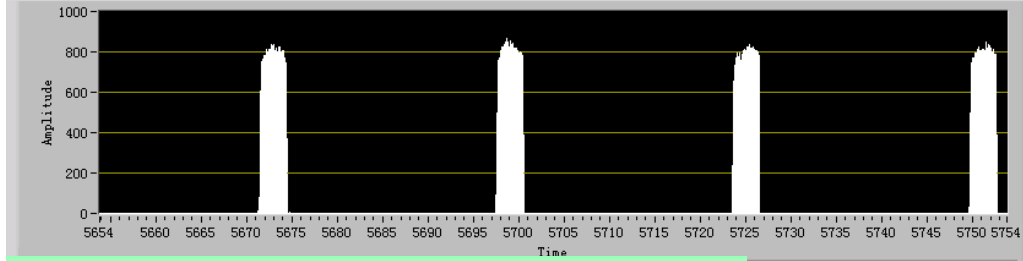
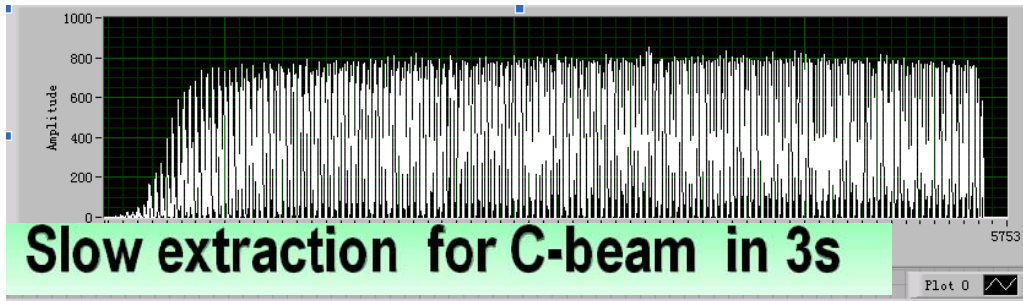
Optimized single stripping injection

preliminary  
clinic results: good

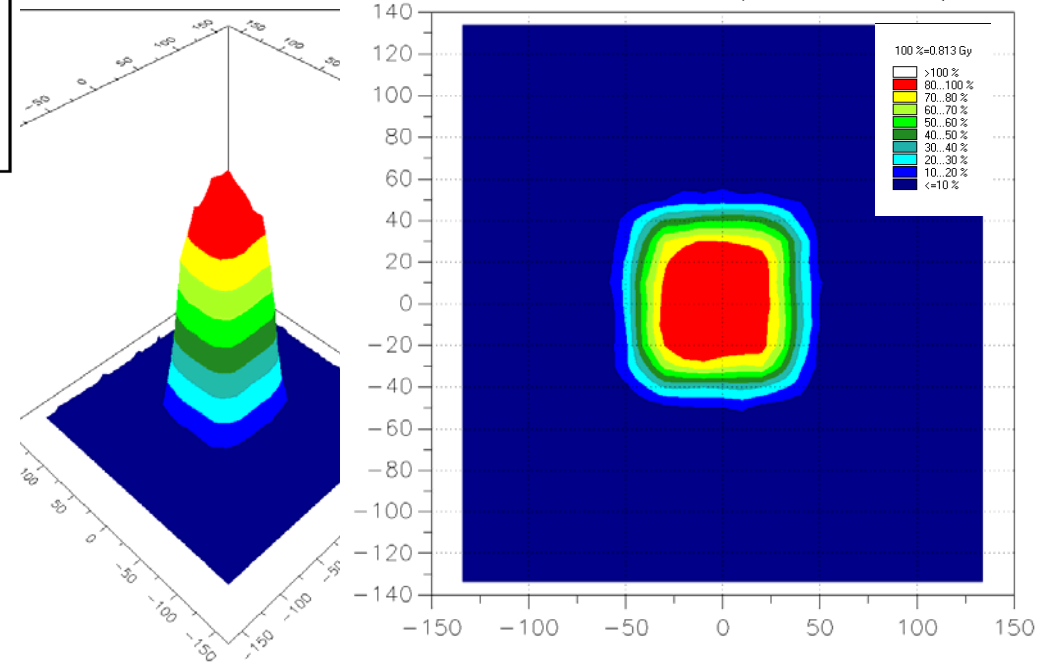
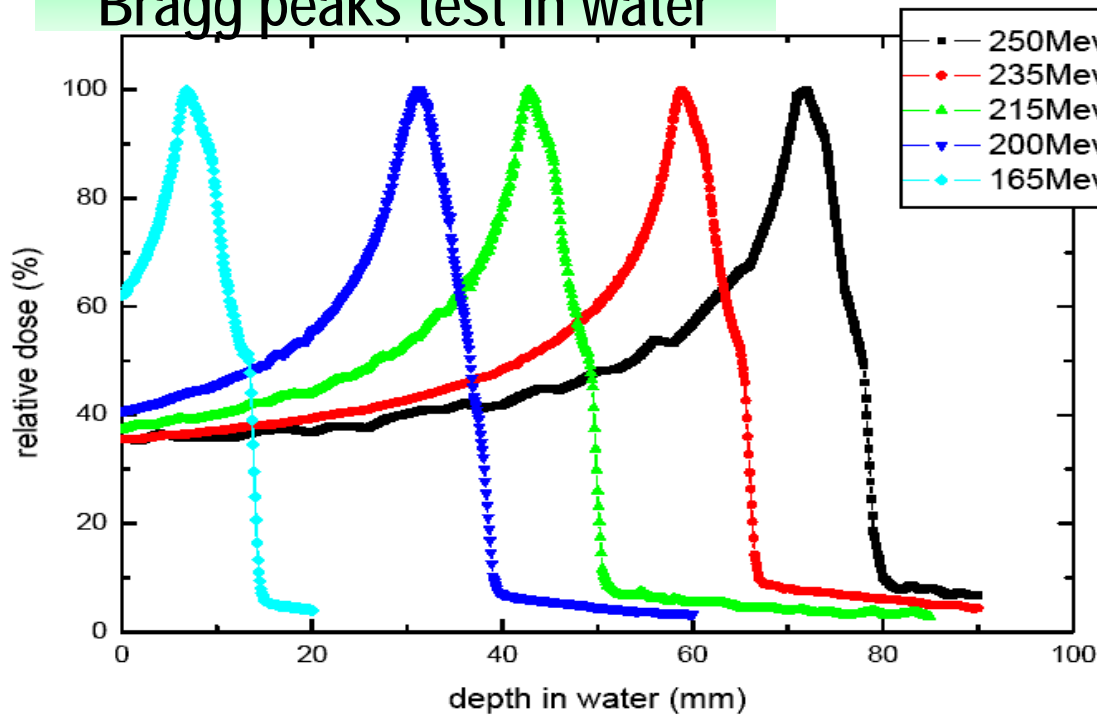




# Cancer Therapy with CSRm (2009.03-04)

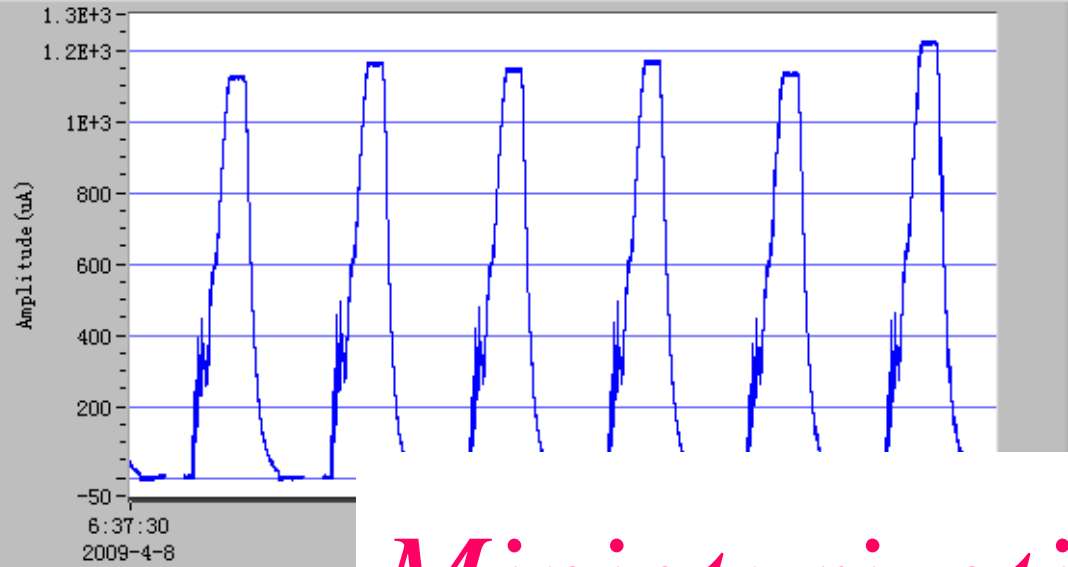


Irradiation field distribution (3D & 2D)

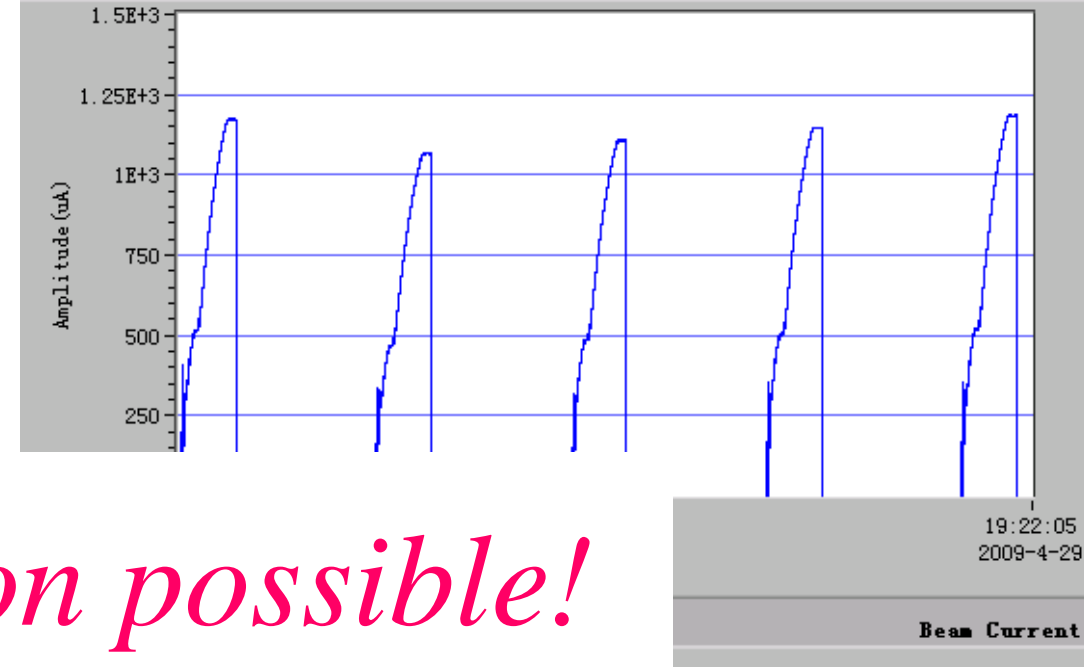


# *Test of single turn stripping injection*

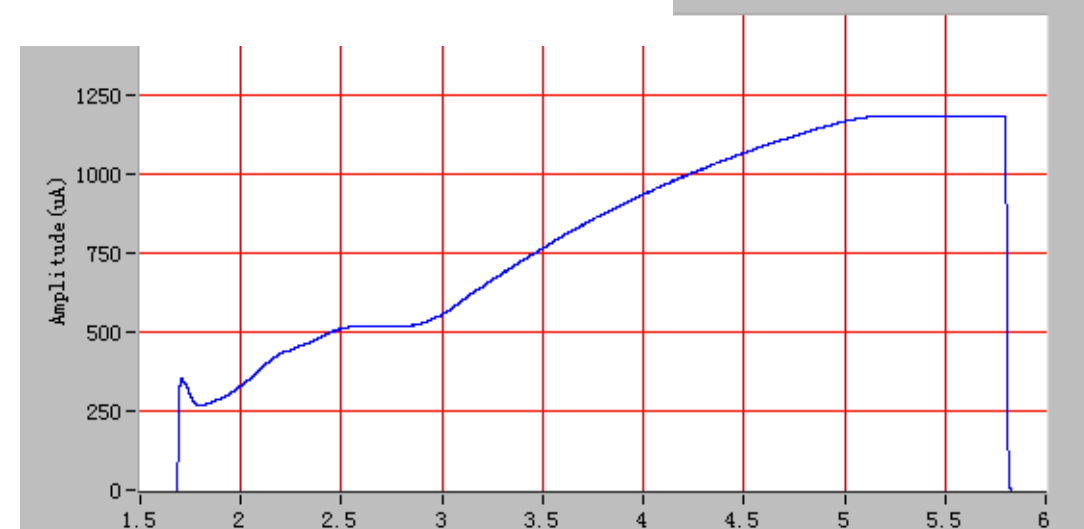
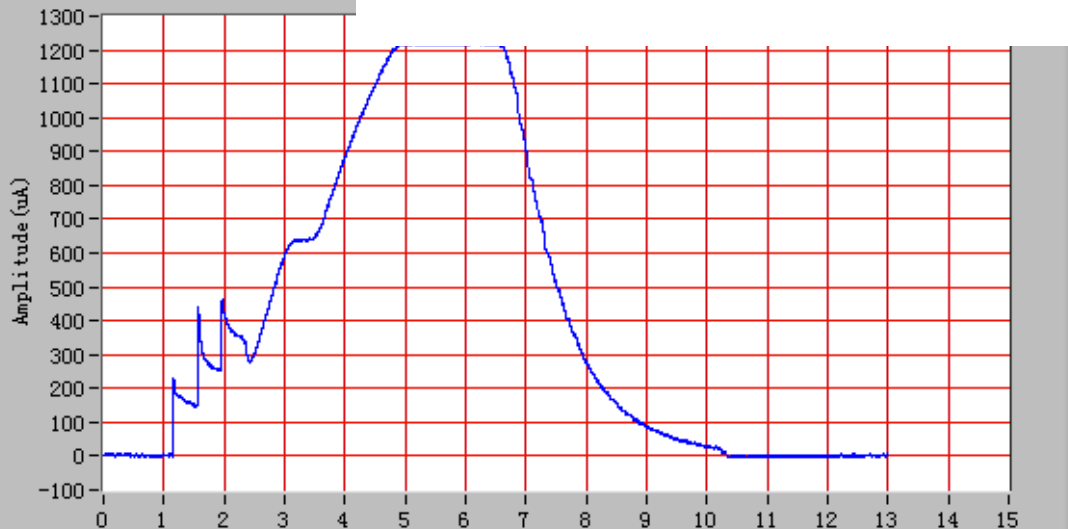
In treatment: multi-injection +e-cool



Optimized single stripping injection tested,  $>10^9$



*Miniaturization possible!*



# Summarize for CSR Beam Status

**Ion:**  $^{12}\text{C}^{6+}$ ,  $^{36}\text{Ar}^{18+}$ ,  $^{78}\text{Kr}^{28+}$ ,  $^{129}\text{Xe}^{27+}$

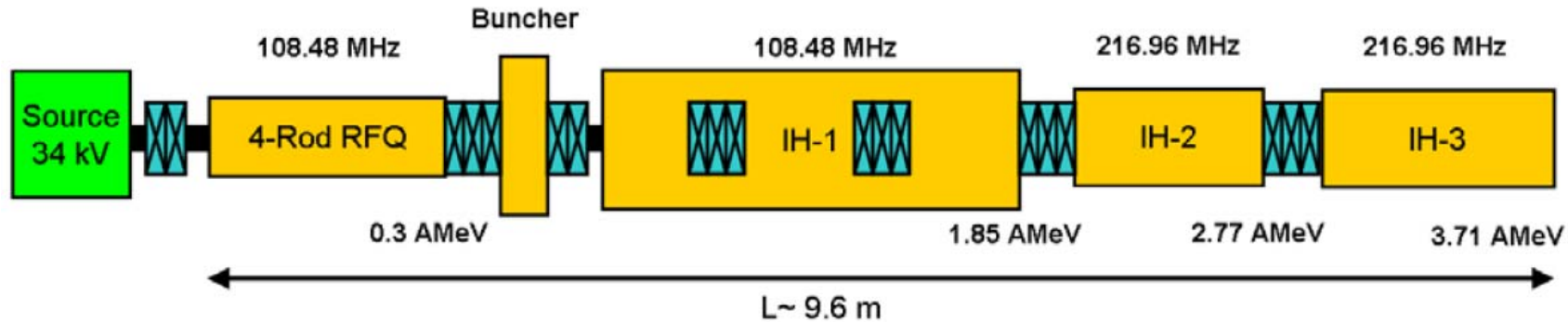
**Energy:** 1GeV/u for C & Ar in CSRm

**Intensity:** 10mA ( $7 \times 10^9$ ) for C-600MeV/u in CSRm  
1.2mA ( $4 \times 10^8$ ) for Ar-368MeV/u in CSRm  
0.6mA ( $1 \times 10^8$ ) for Kr-480MeV/u in CSRm  
0.5mA ( $1 \times 10^8$ ) for Xe-235MeV/u in CSRm  
15mA ( $8 \times 10^9$ ) for C-660MeV/u in CSRe

**Experiment:** RIBs mass-measurement, isochronous mode of CSRe,  $\Delta M/M \sim 10^{-6}$

**Slow-extraction:** For external-target experiments and cancer therapy

# Prospect of a new injector LINAC

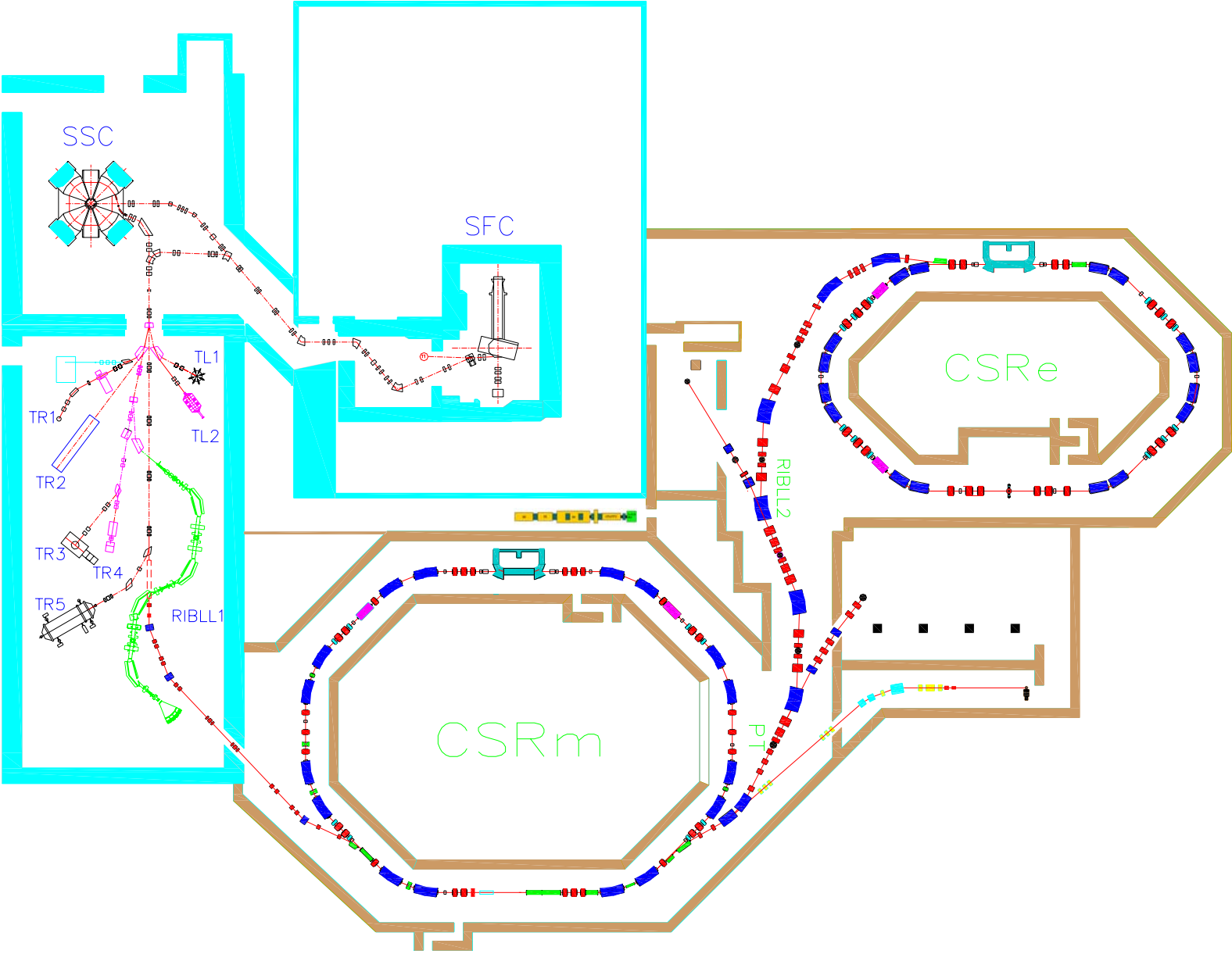


## Cooperation with IAP, Uni-Frankfurt

Ion source	Parameters
<b>Super-Conducting 28GHz ECR</b>	$^{12}\text{C}^{4+}$ , $^{40}\text{Ar}^{12+}$ , $^{129}\text{Xe}^{27+}$ , $^{208}\text{Pb}^{27+}$ , $^{238}\text{U}^{28+}$
<b>Beam Current (emA)</b>	<b>0.5 - 1.0</b>
<b>Charge-Mass Ratio(q/A)</b>	<b>1/8.5 - 1/3</b>
<b>Ext. Energy (MeV/u)</b>	<b>→3.5    →10</b>

50-100 times for C  
>1000 times for heavier ions

# *Future position of injector LINAC*



# Acknowledgement

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International Advisory Committee members of CSR:  
N. Angert, V.V. Parkhomchuk, D. Reistad, Y. Yano, T.  
Katayama, A. Goto, M. Steck, A.N. Skrinsky, J. Xu, S.Fang,

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GSI, Darmstadt

BINP, Novosibirsk

...

Community of Heavy Ion Accelerator Technology

HIAT Committees

*Thank you, and  
Welcome to Lanzhou*

