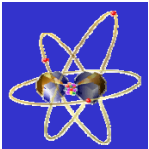


Lanzhou Cooler Storage Ring Commissioning

Jiawen Xia, Youjin Yuan (Speaker)

CSR Group



Institute of Modern Physics (IMP), Chinese Academy of Science (CAS)



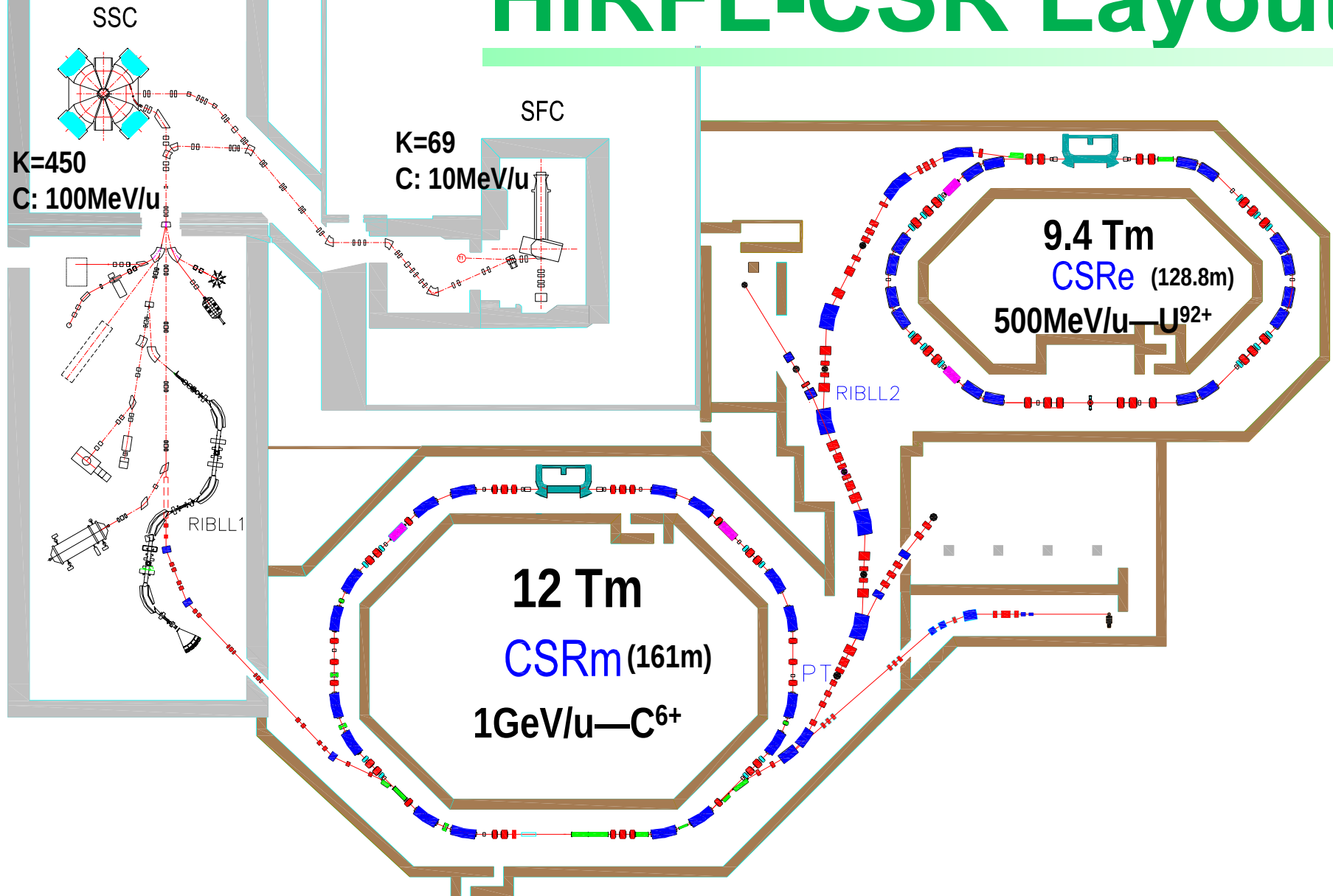
Lanzhou, China

History of CSR

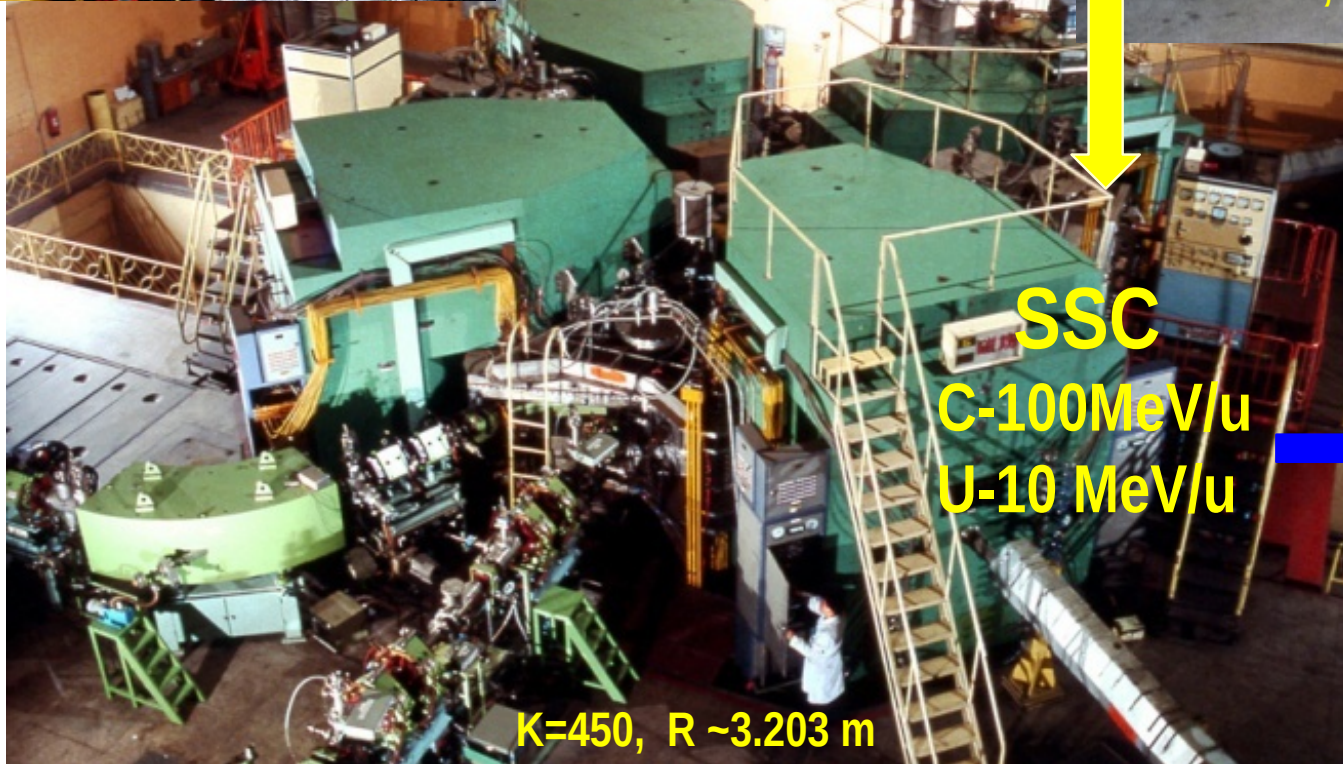
Heavy-ion **C**ooler **S**torage **R**ing & Synchrotron in Lanzhou

1993	Original idea
1996	Proposal
1998	Approved
2000-2005	Construction
2006-2007	<i>Commissioning</i>
2008-2010	Operating & Experiments

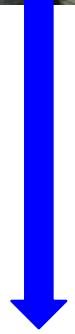
HIRFL-CSR Layout



Pre-accelerator system of CSR



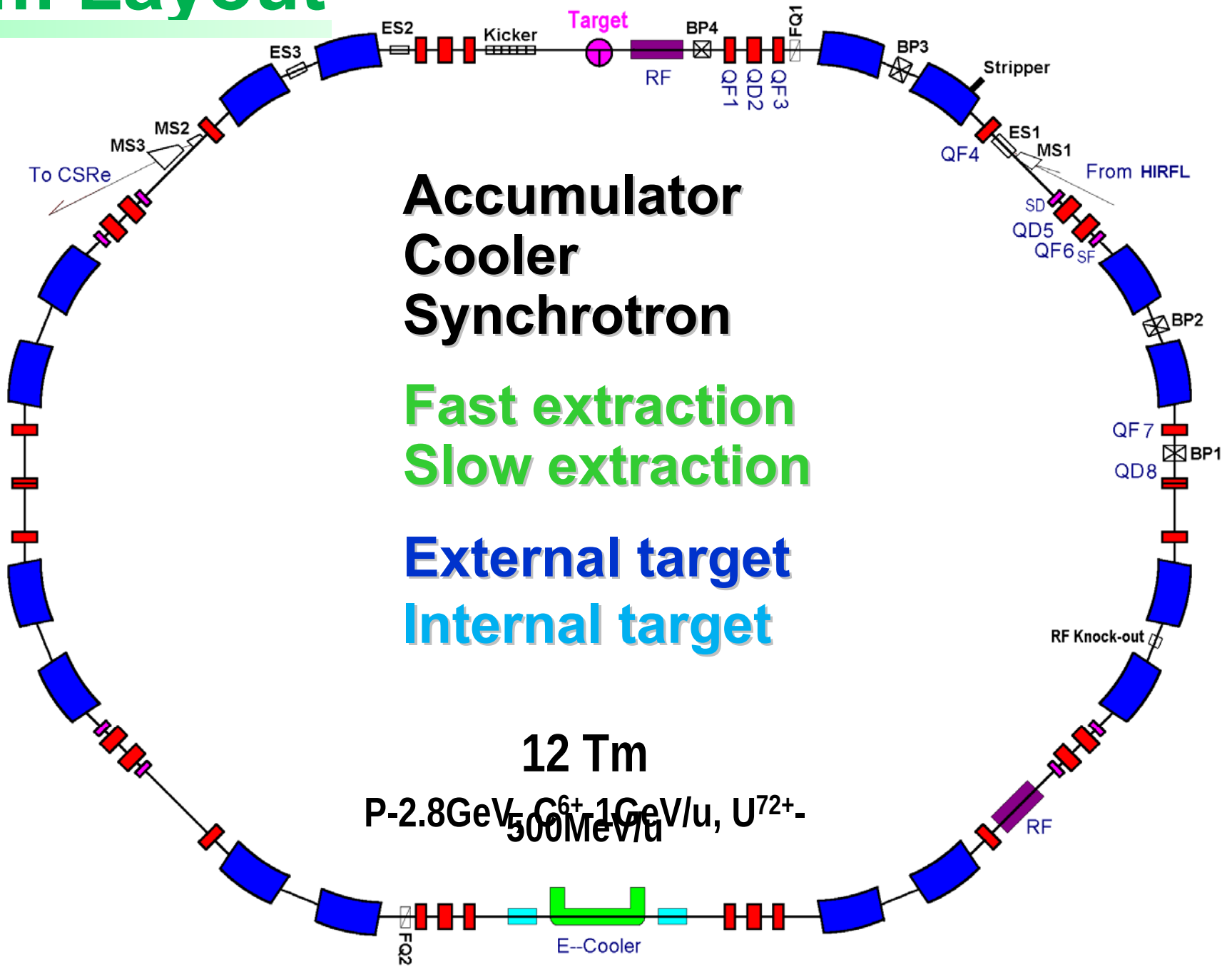
$A < 40$



$A \geq 40$

CSRm

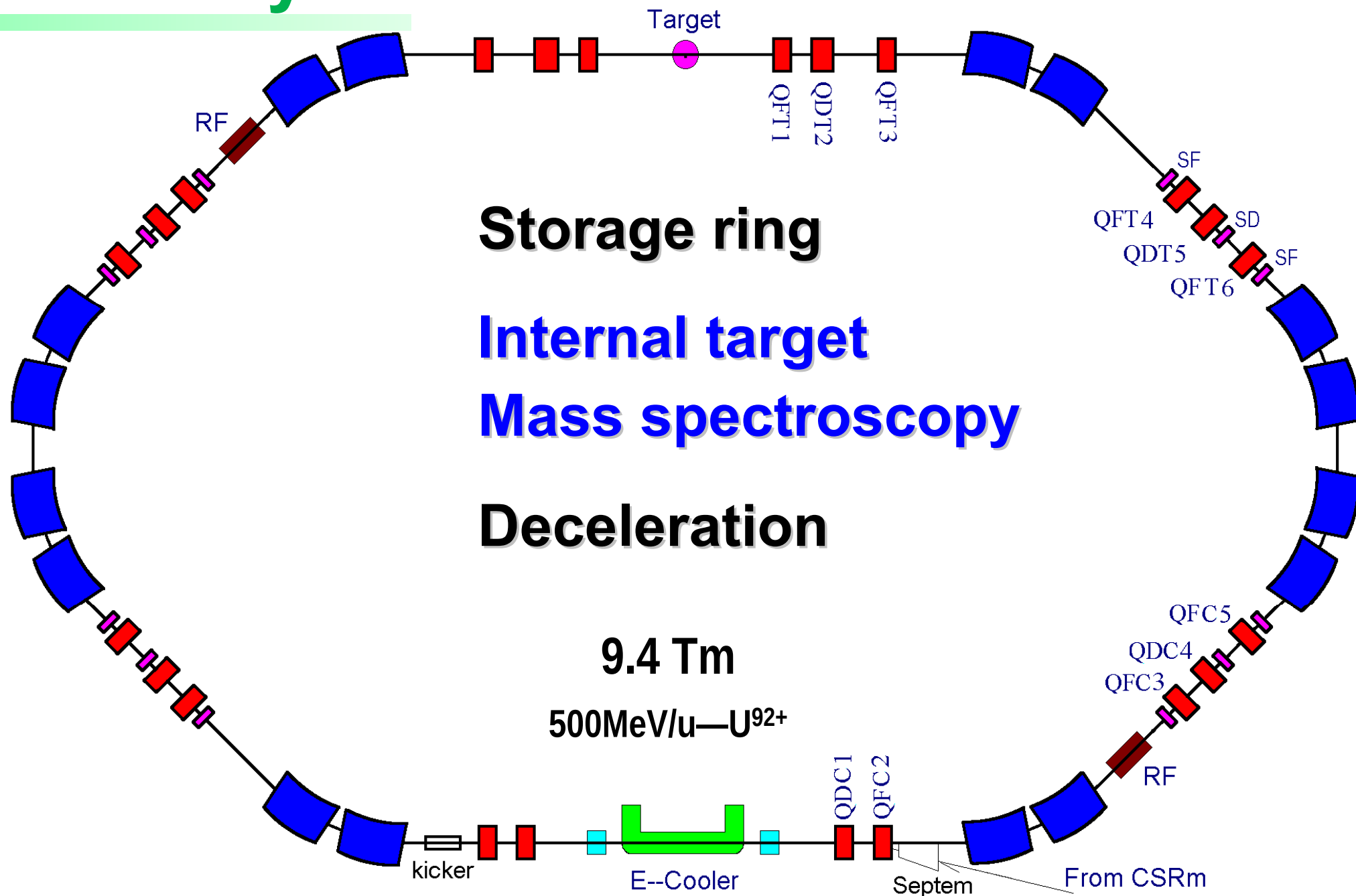
CSRm Layout



CSRm Tunnel



CSRe Layout

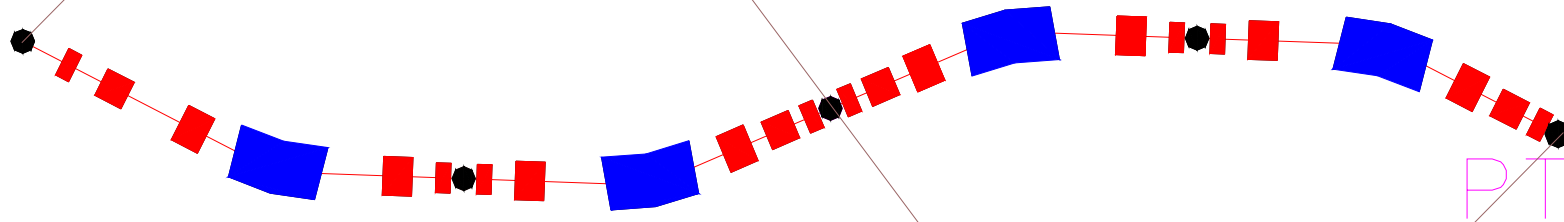


CSRe Tunnel

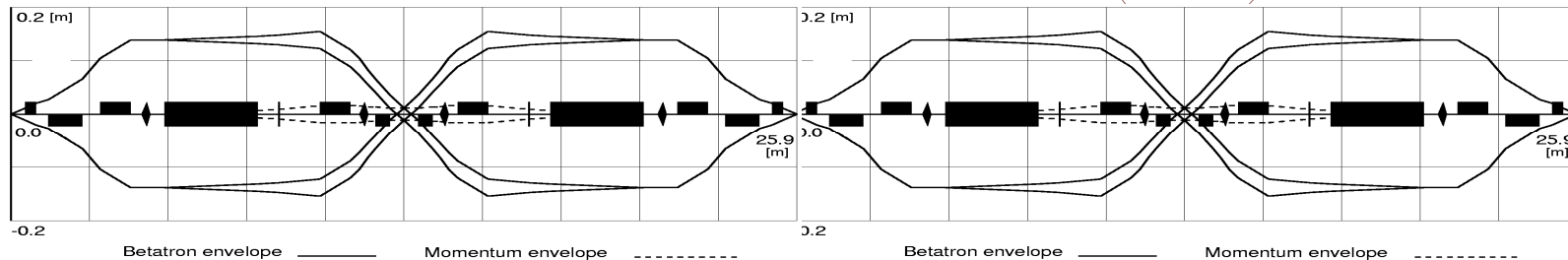


Radioactive Ion Beam Line **RIBLL2** between CSRm and CSRe

Double Separator



$$\Delta P/P = \pm 1\% , \text{ Emittance} = 25\pi \text{ mm-mrad}$$



RIBLL2 Tunnel

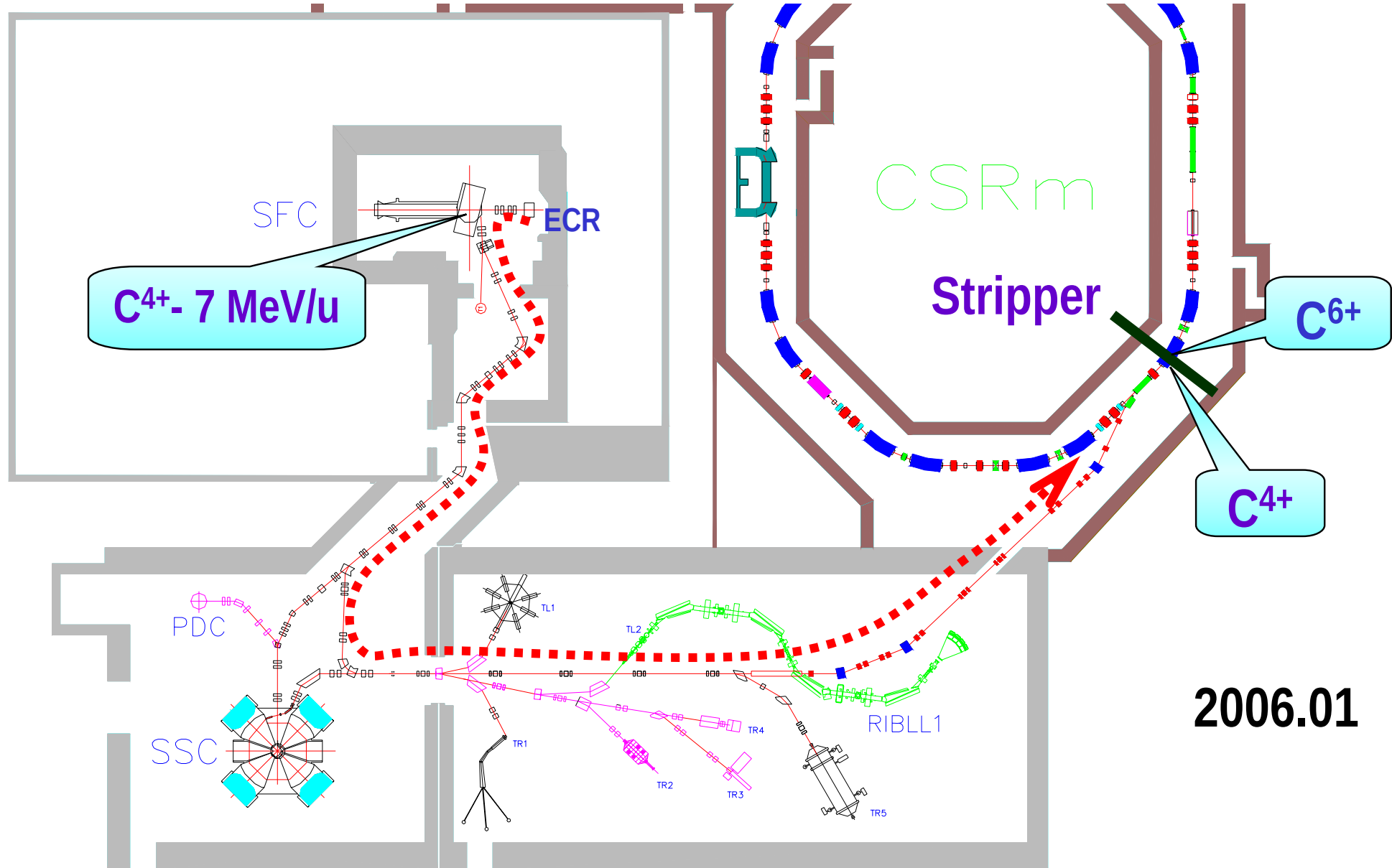


HIRFL-CSR

Commissioning

2006---2007

Stripping Injection Scheme

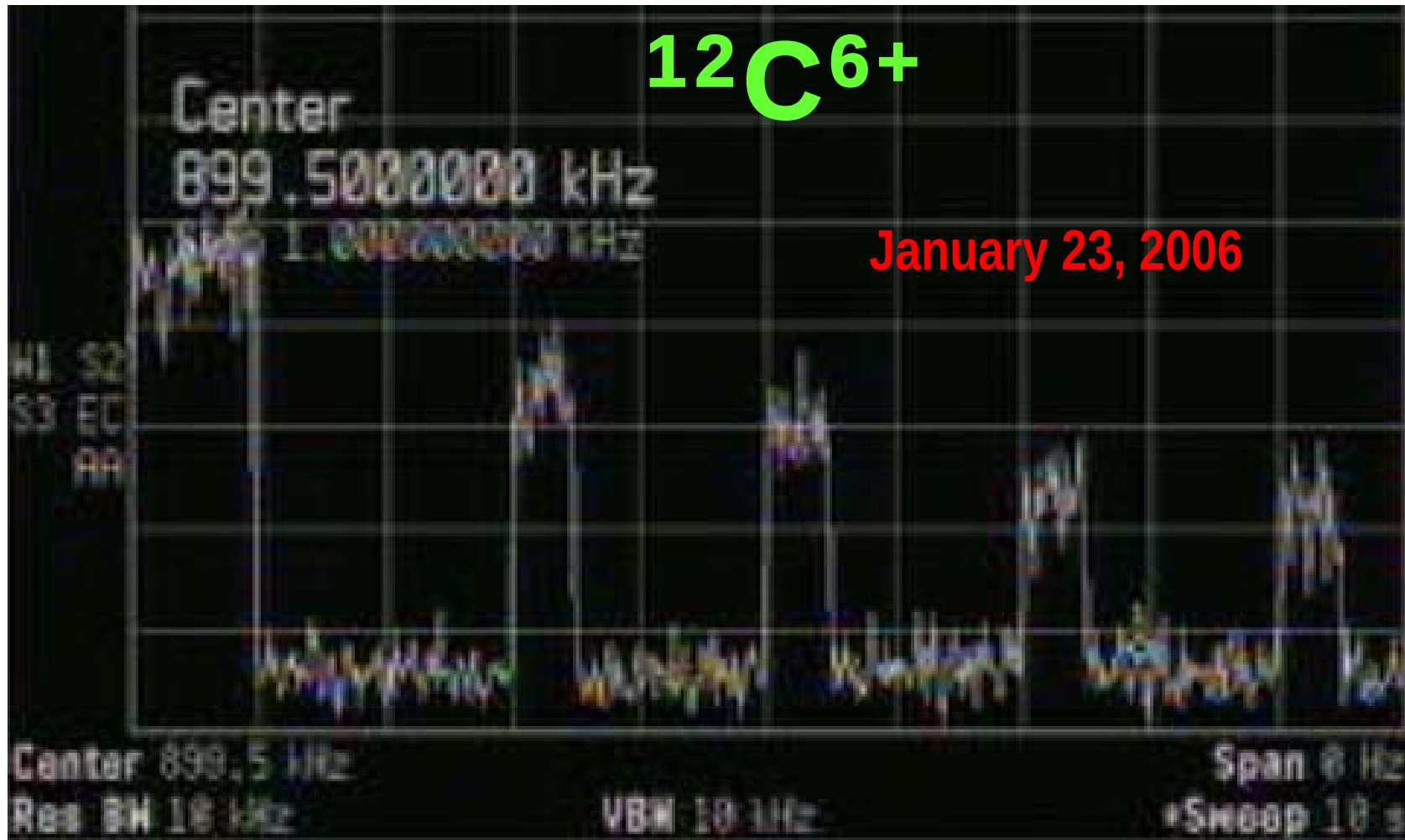


First stored beam signal from spectrum analyzer in CSRm

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

Stripping injection

23Cy2 =7A 21D4 =0.5A

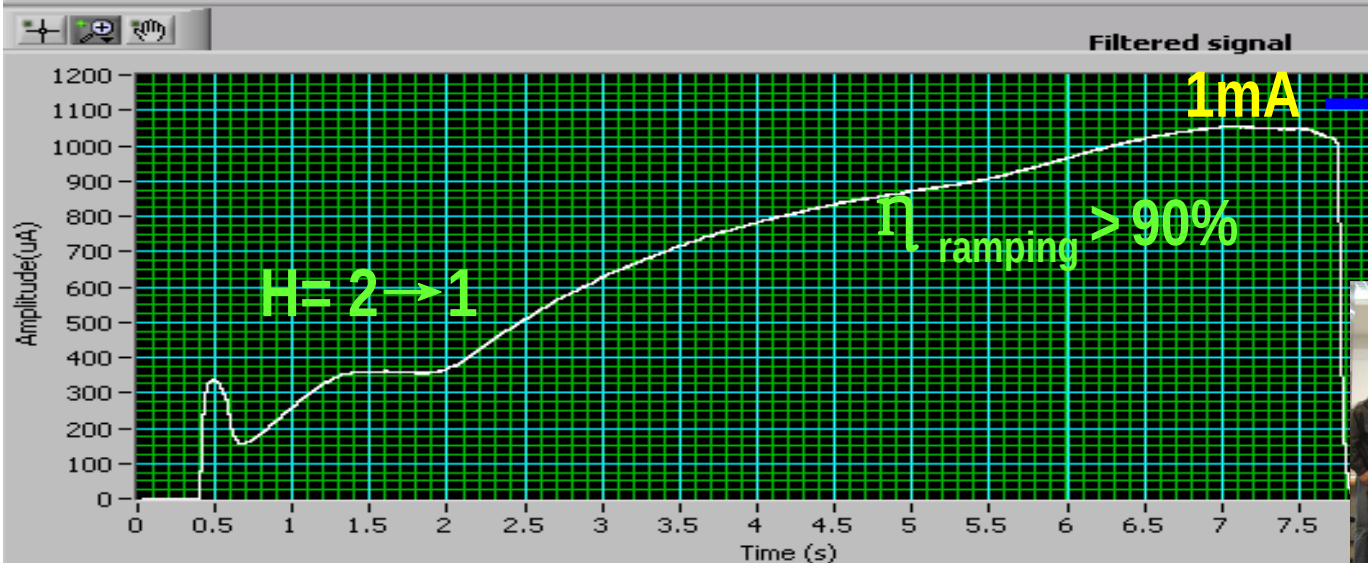
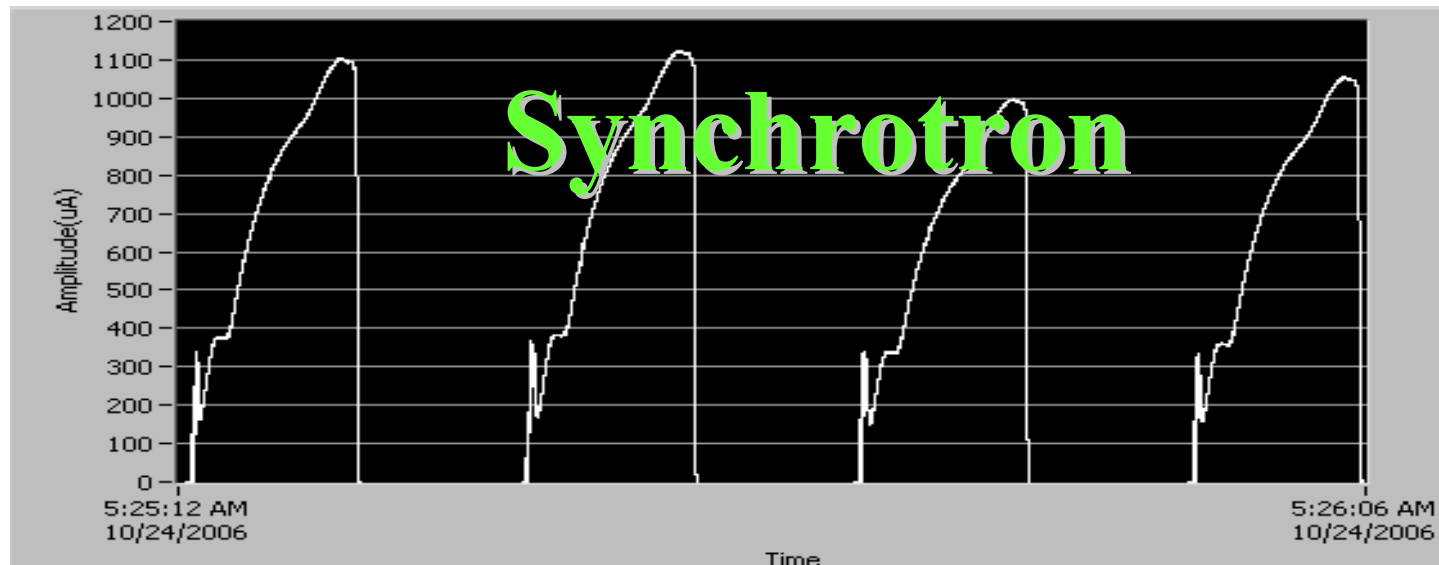


5 times of RF in 10s

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

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

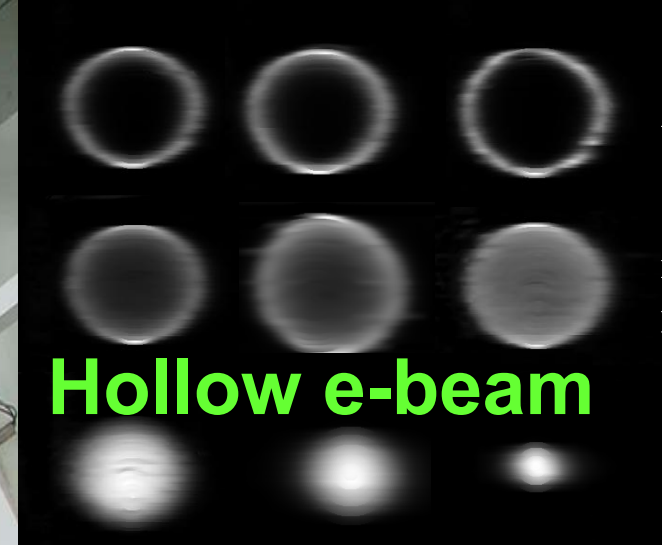
Oct. 24, 2006



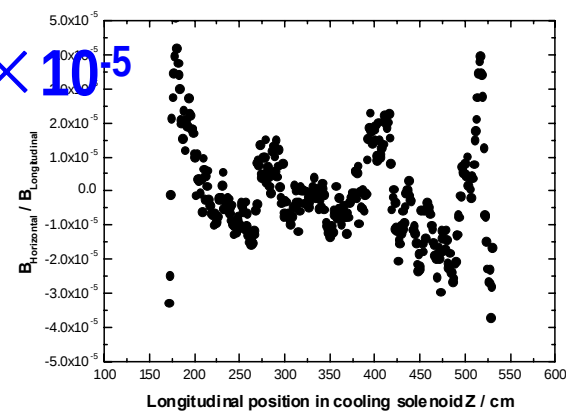
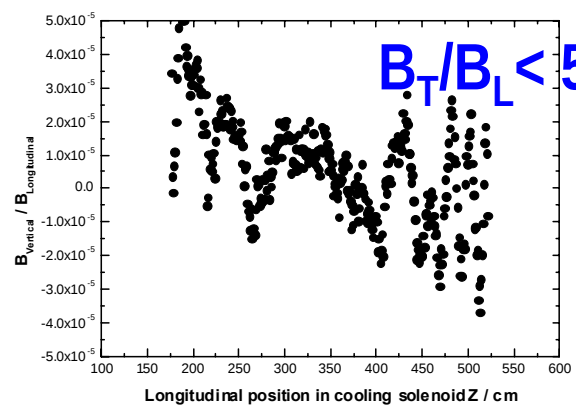
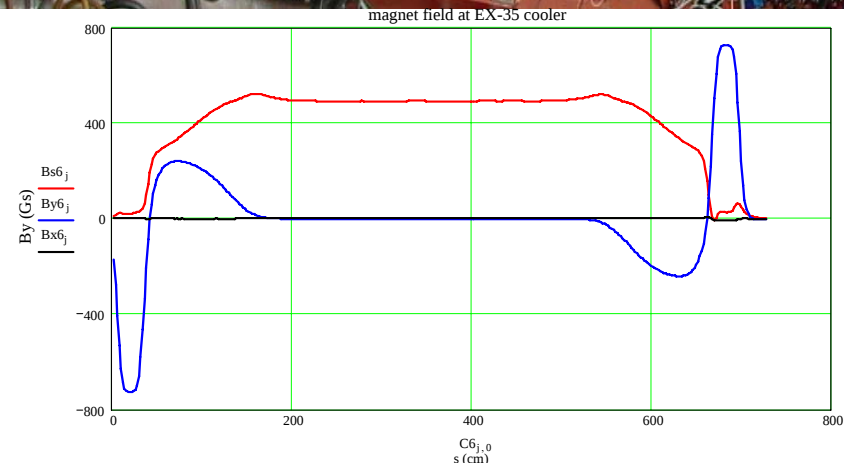
2006.12



e-cooler
cooling for beam stacking

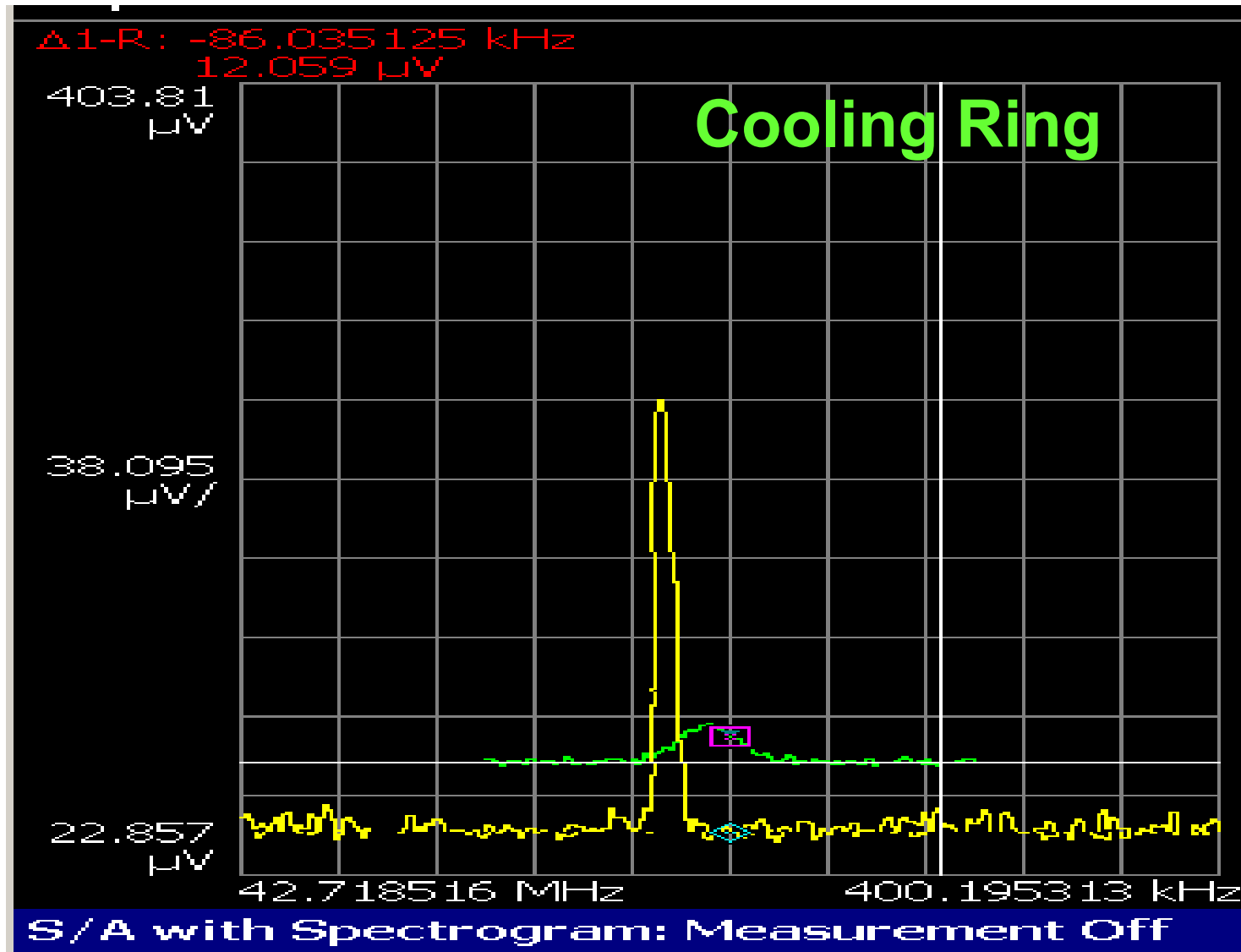


Hollow e-beam



First e-cooling effect in CSRm

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



Dec. 27, 2006

$\Delta P/P$

4×10^{-3}

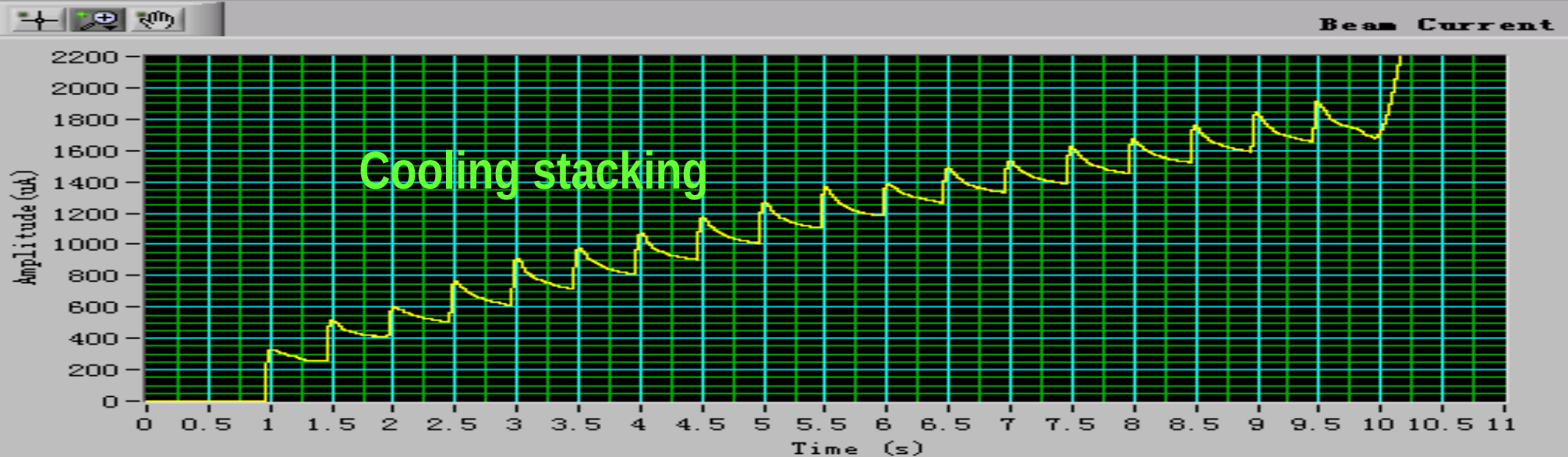
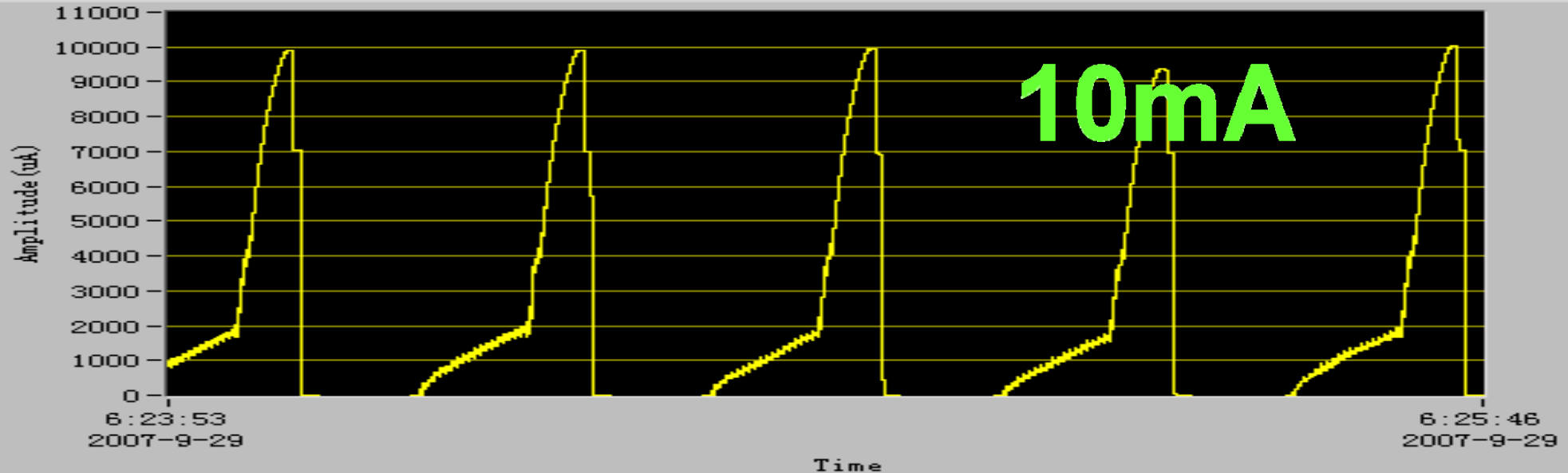


2×10^{-4}

C^{6+} -600MeV/u Ramping in CSRm

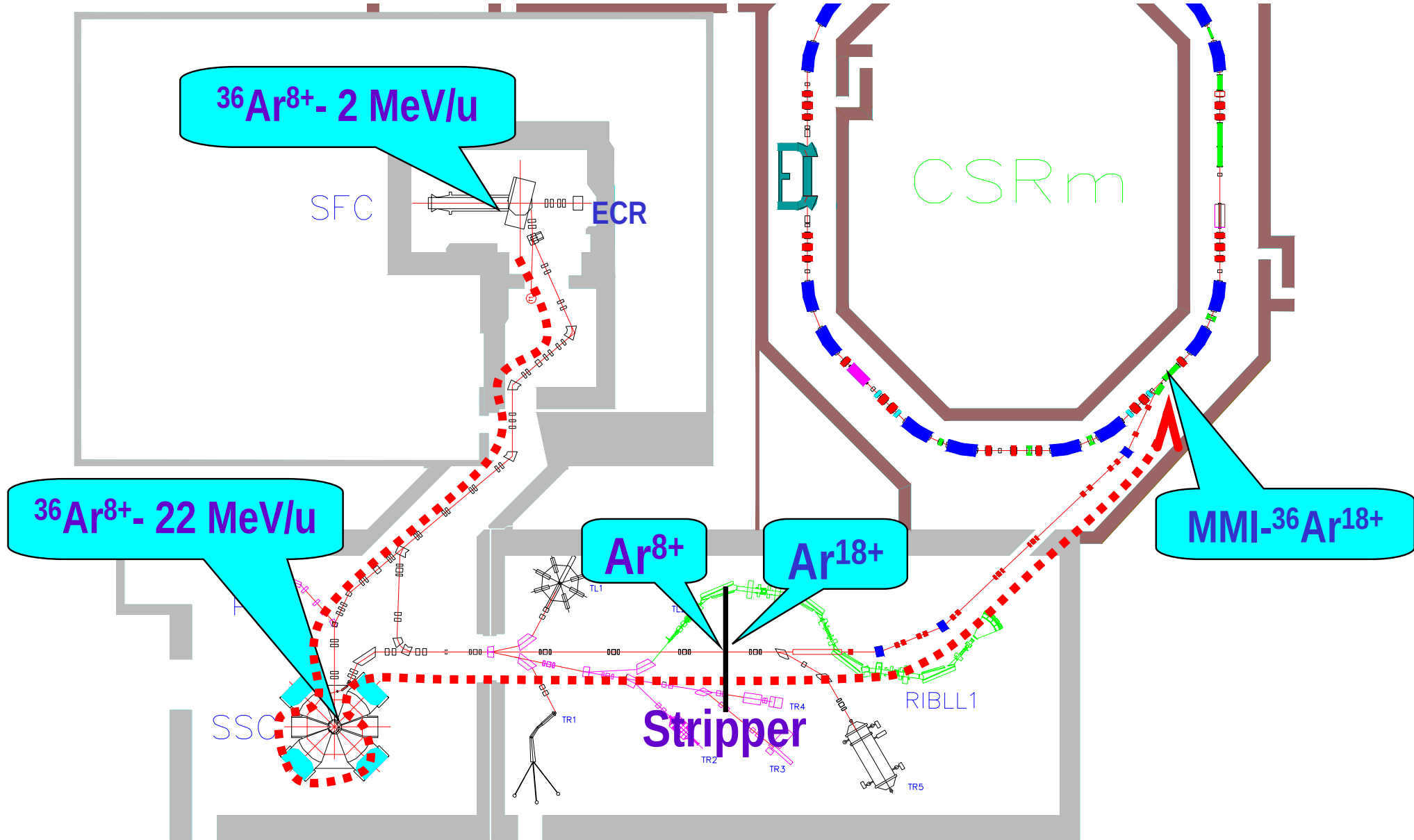
07/09/29 06:25

SFC- $^{12}C^{4+}$ -7MeV/u, $I_{inj.} = 11\mu A$, STI, 1800 μA in 10s, 10000 μA on top, 7×10^9



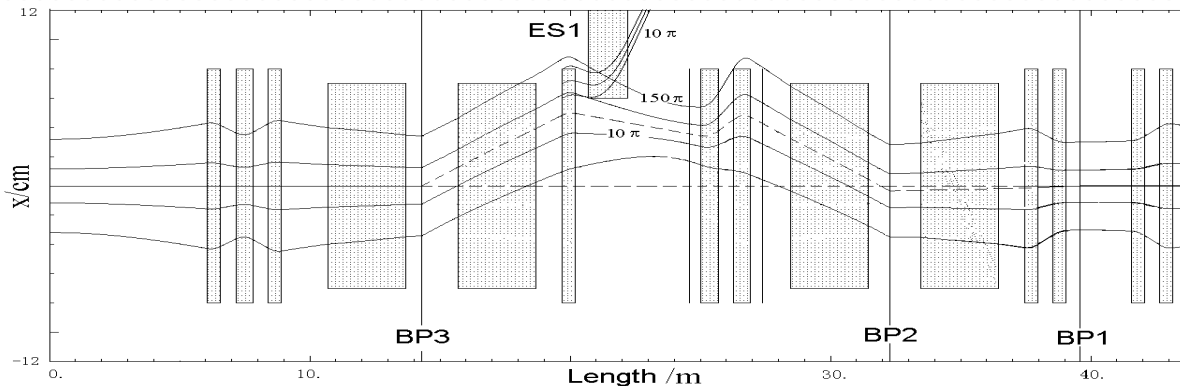
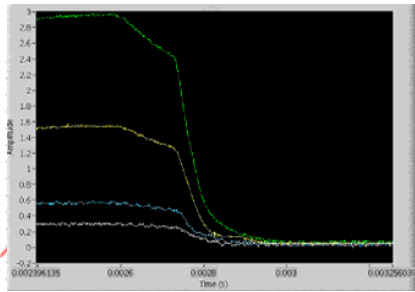
Scheme of the MMI for Ar-beam in CSRm

07/04/24

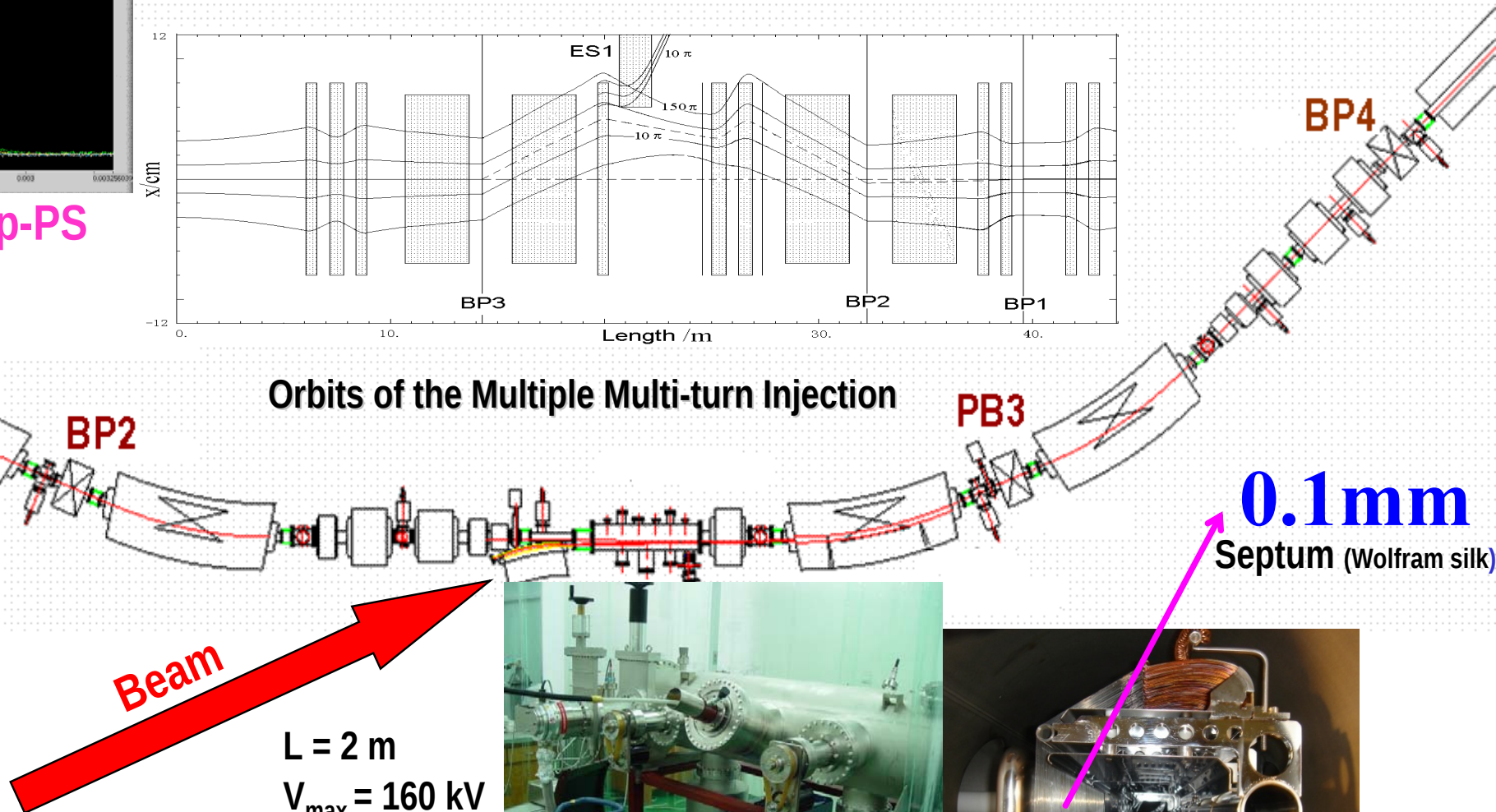


Bump section for CSRm Multi-turn injection

20007.03



Orbits of the Multiple Multi-turn Injection

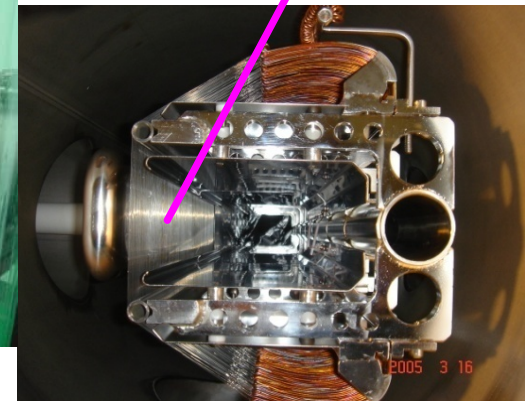


0.1mm
Septum (Wolfram silk)

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



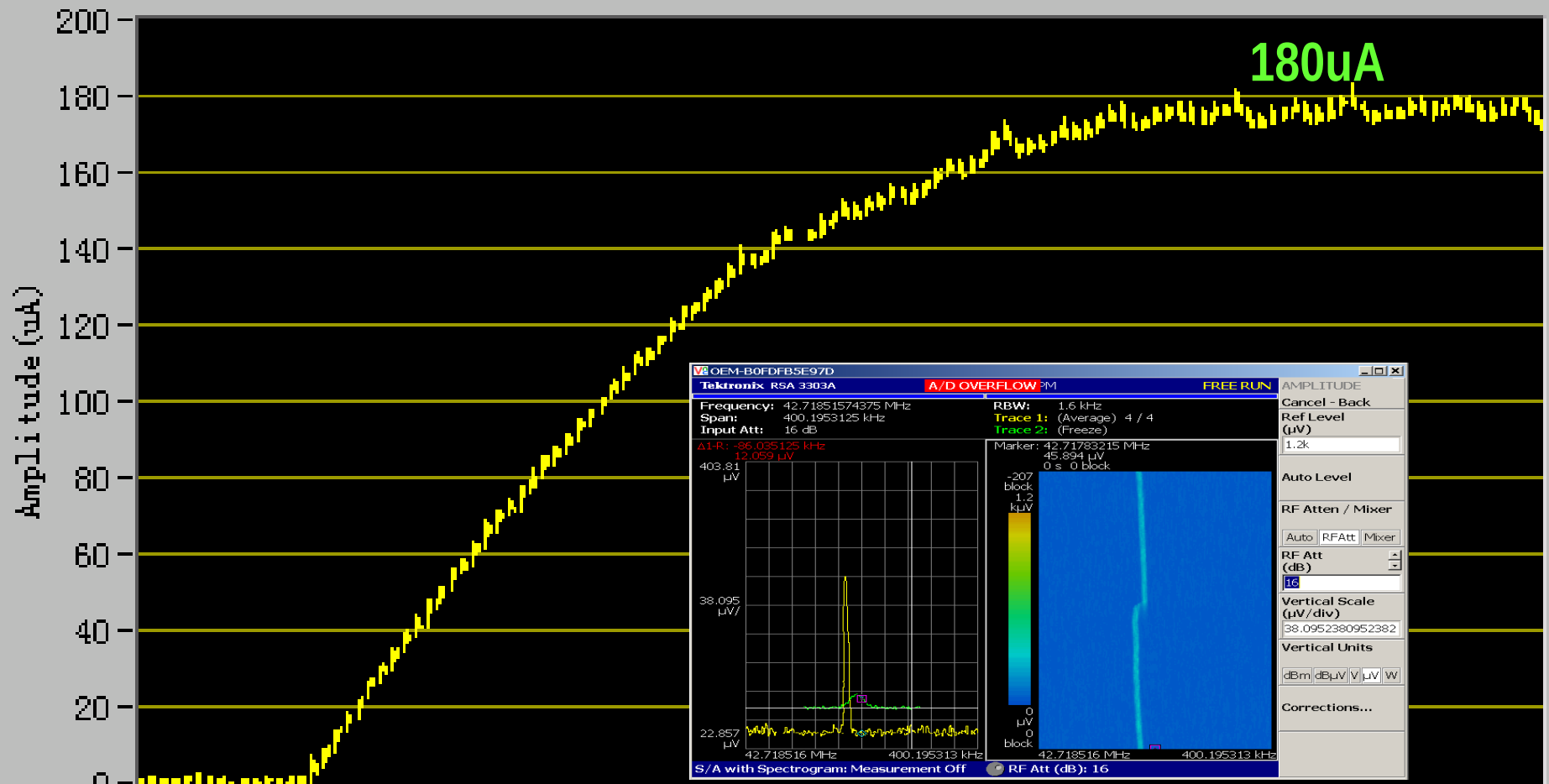
Static-electric septum



MMI for Ar-beam in CSRm with e-cooling

SSC-Ar-22MeV/u, $I_{inj.} \sim 2\mu\text{A}$, DCCT $\sim 180\mu\text{A}$, Period=2min., Gain ~ 90

07/04/25 06:00



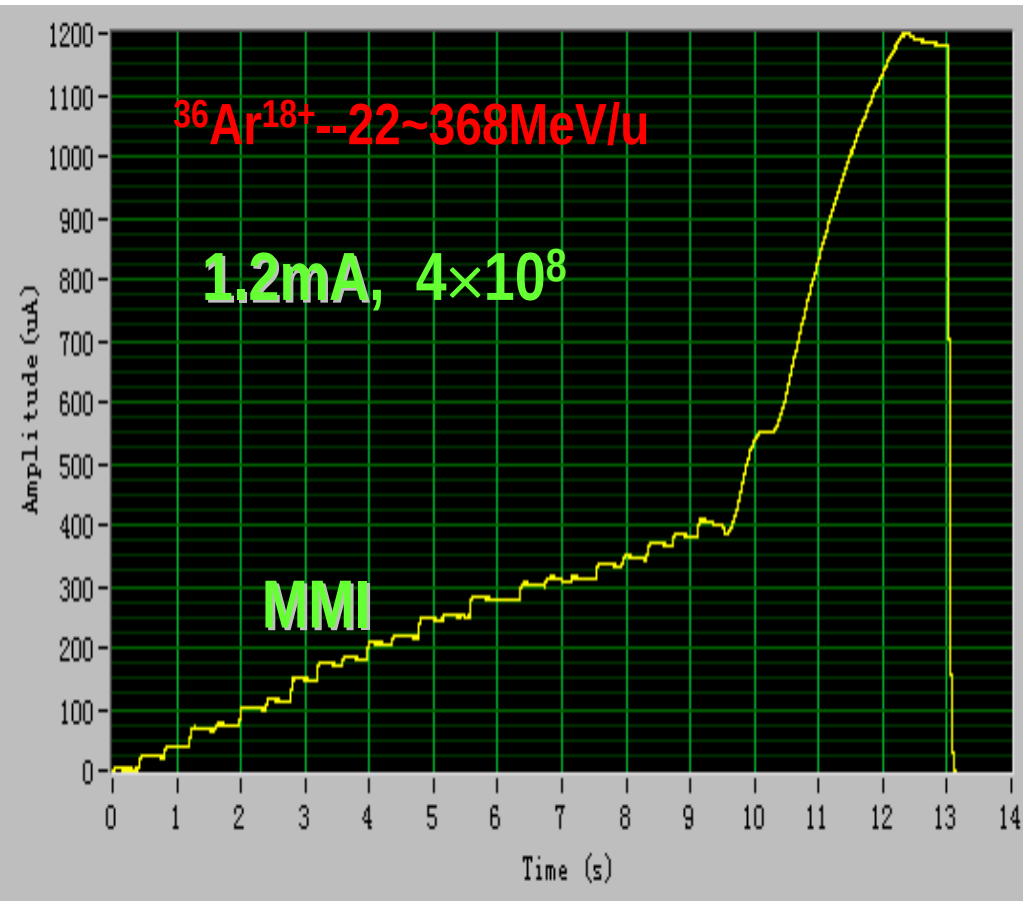
5:50:33
2007-4-25

5:54:59
2007-4-25

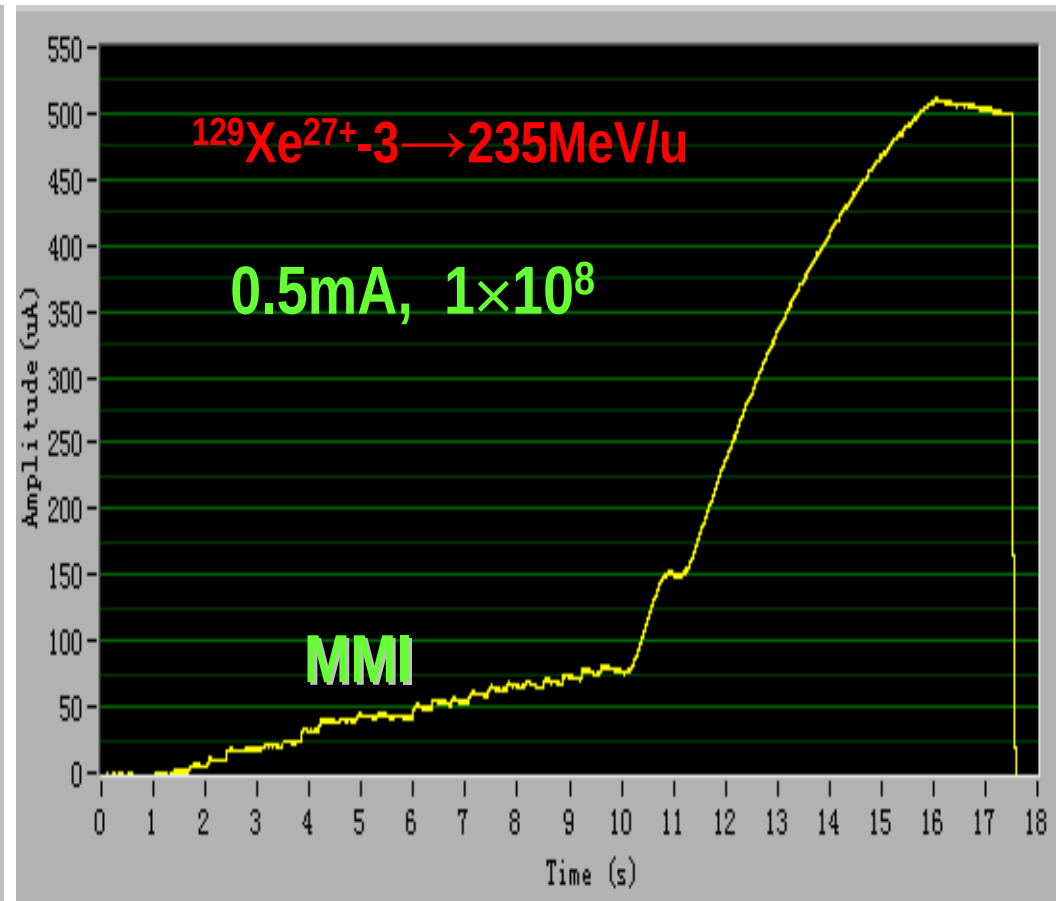
Time

MMI + Ramping in CSRm

07/12/10 00:08



07/06/25 07:20



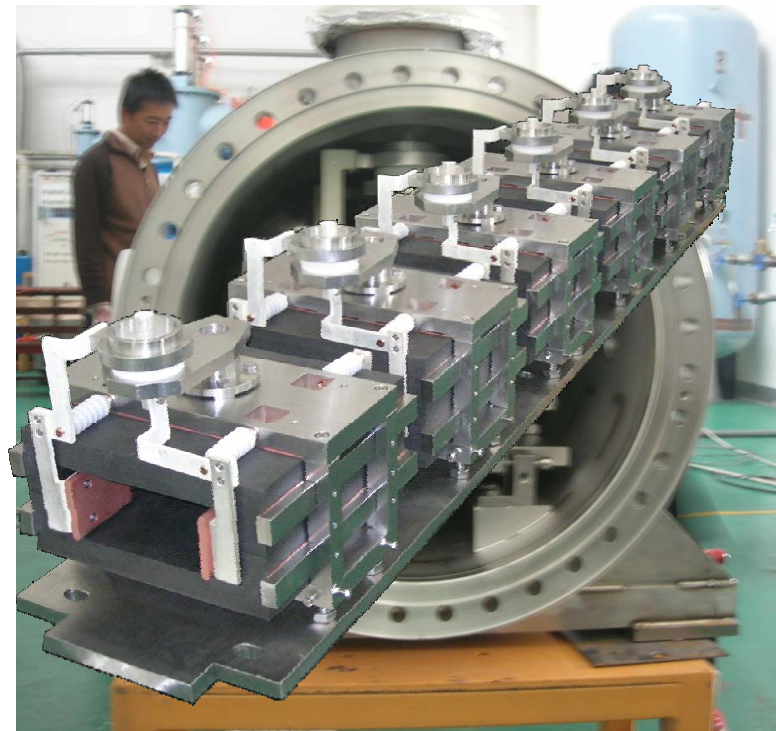
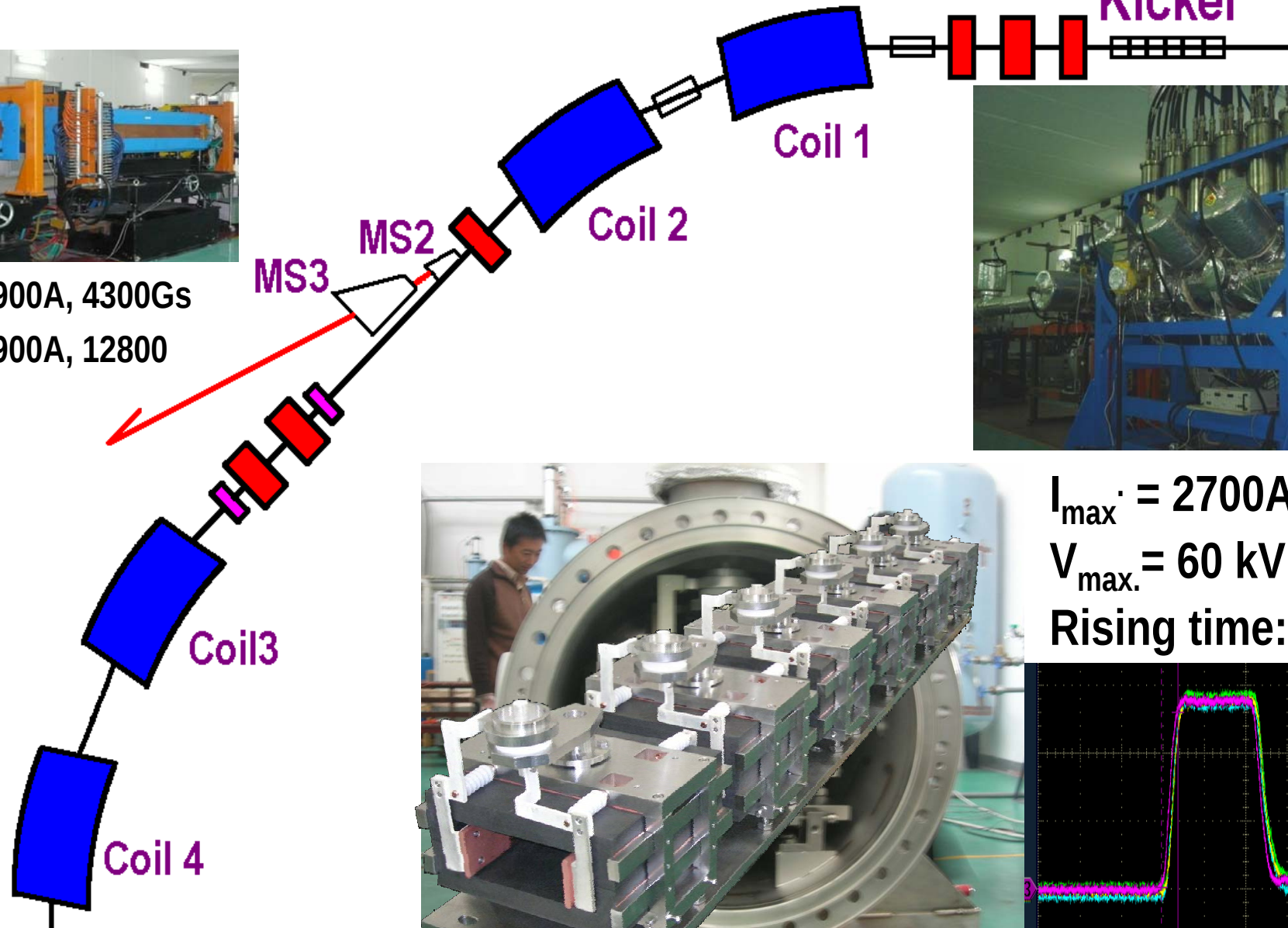
Fast extraction section of CSRm

07/08



MS2: 2900A, 4300Gs

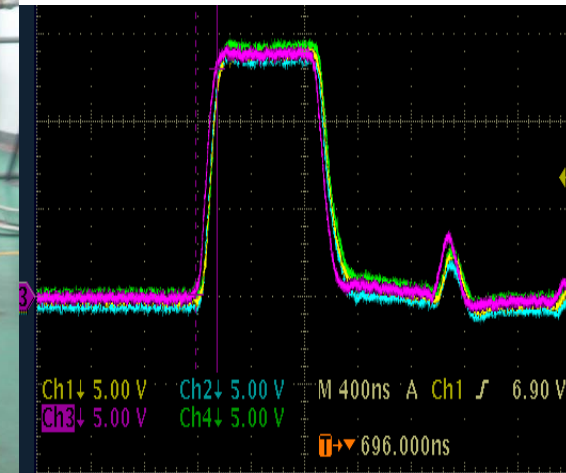
MS2: 2900A, 12800



$I_{\max} = 2700\text{A}$

$V_{\max.} = 60\text{ kV}$

Rising time: **150ns**





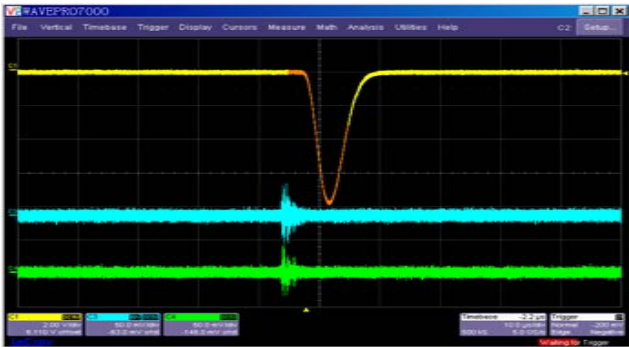
Fast-extraction from CSRm
Success

07.8.4

PT

30FC1

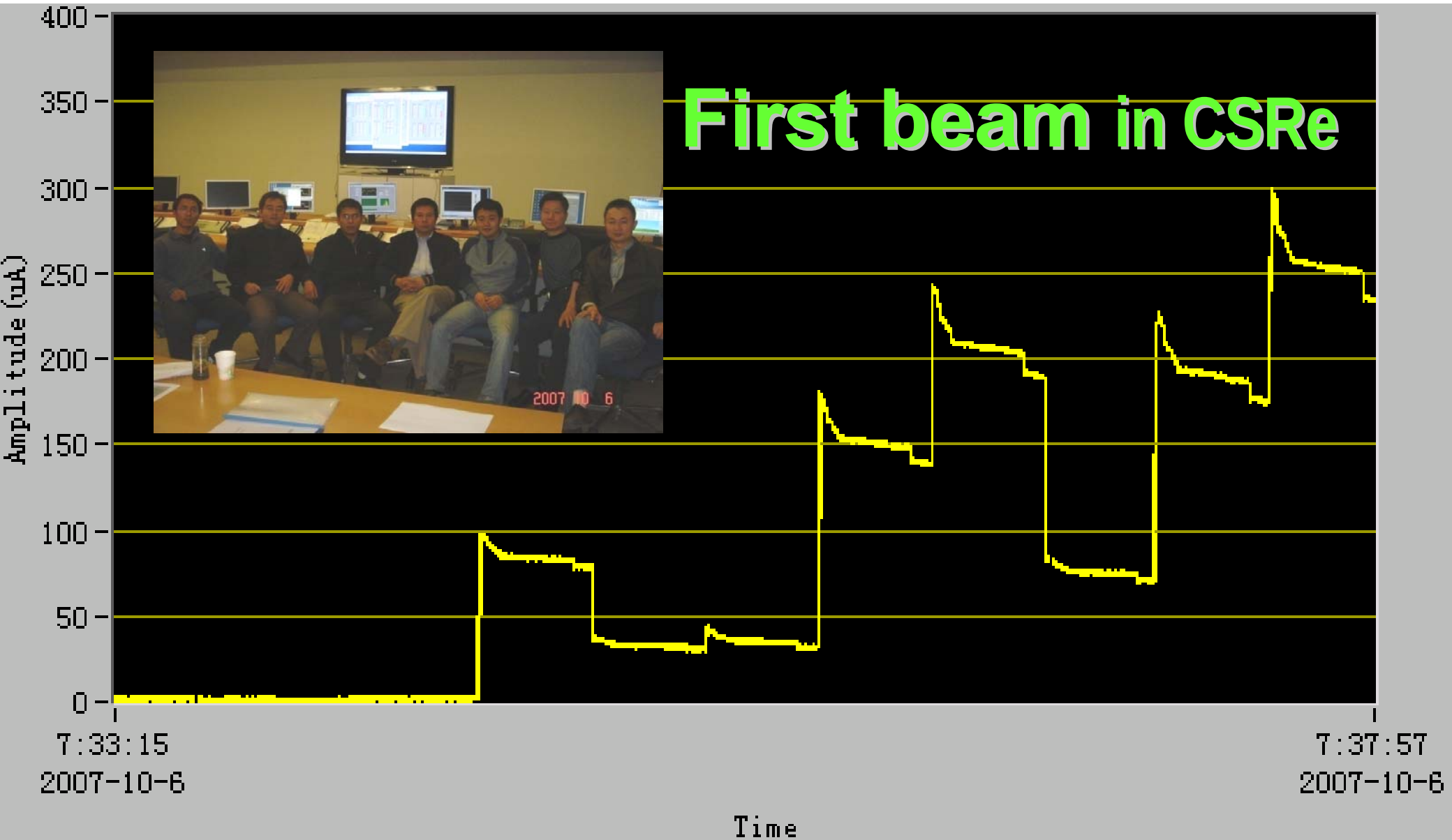
30VS2



Storage-beam for CSRe 1st Commissioning

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

07/10/06 07:40

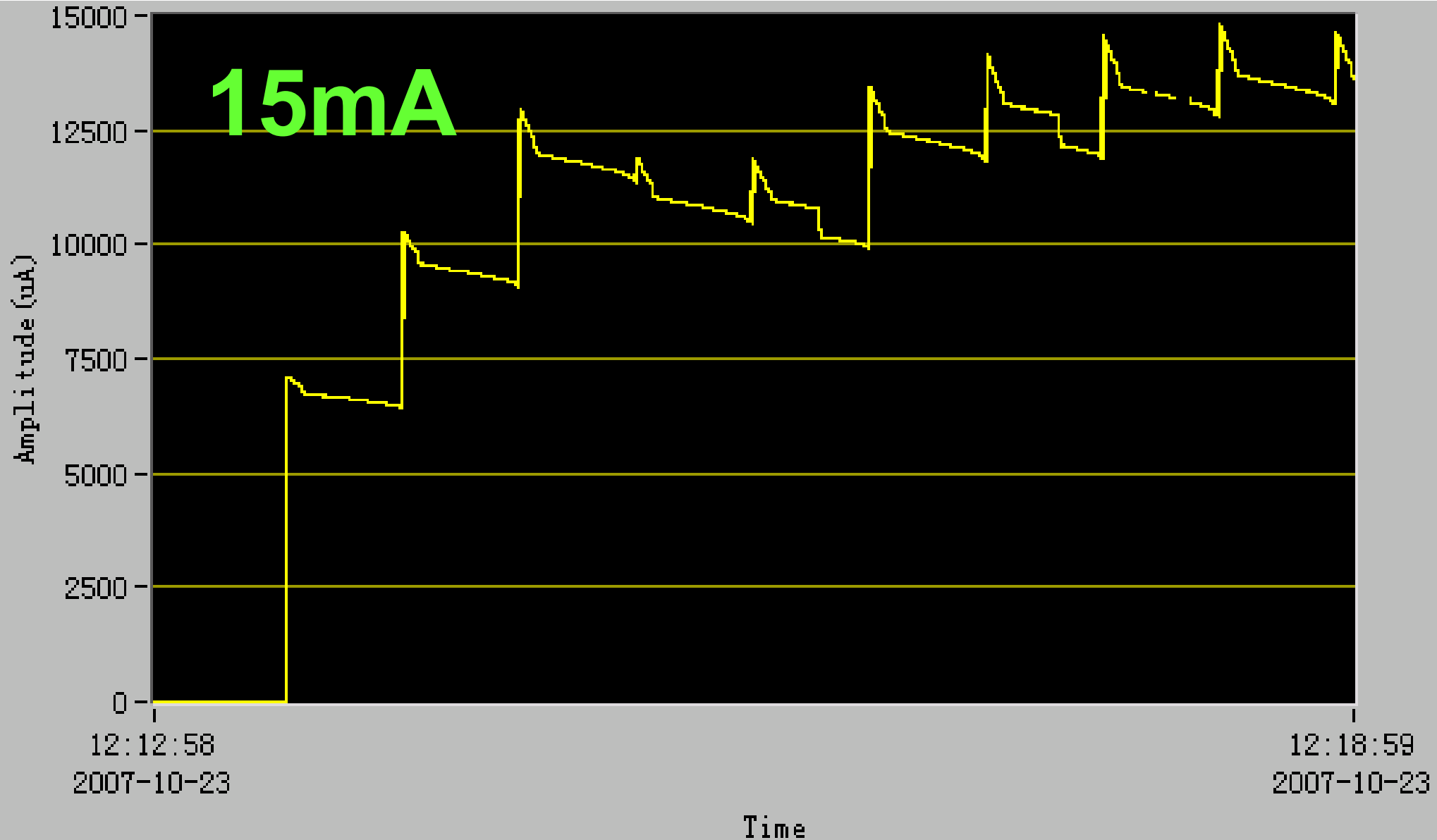


Multi-time Injection for CSRe 1st Commissioning

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

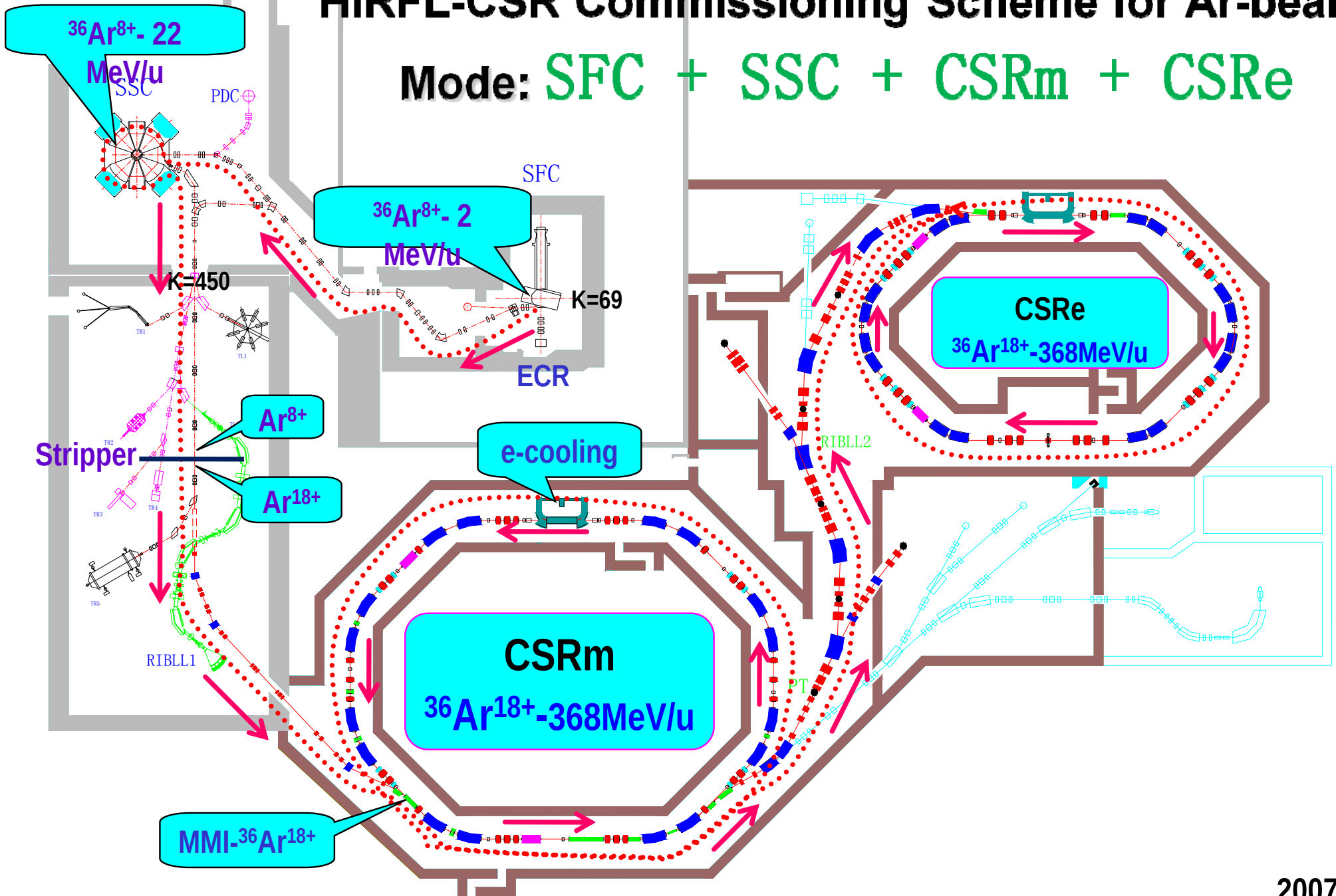
07/10/23 12:18

15mA



HIRFL-CSR Commissioning Scheme for Ar-beam

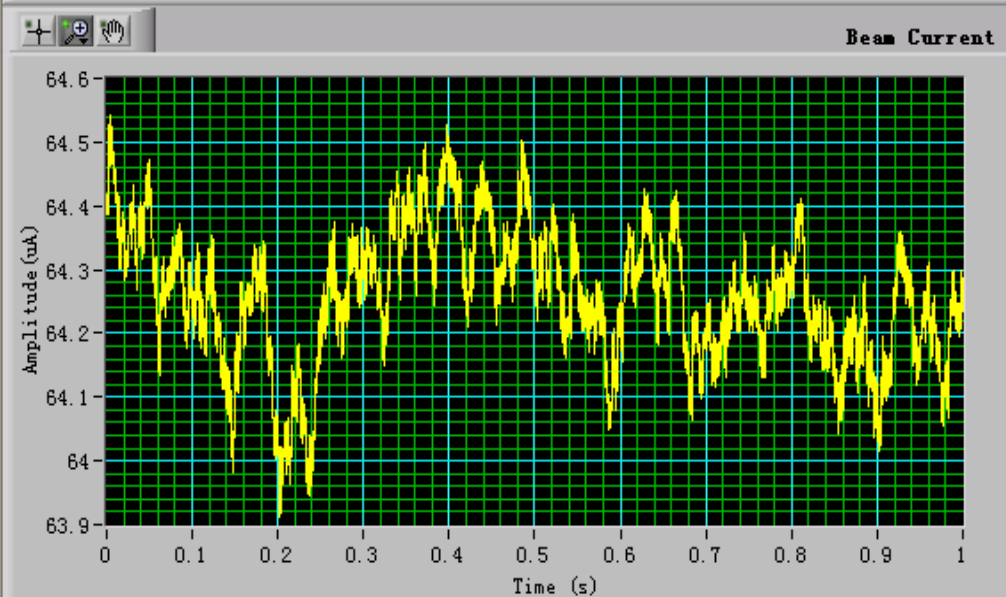
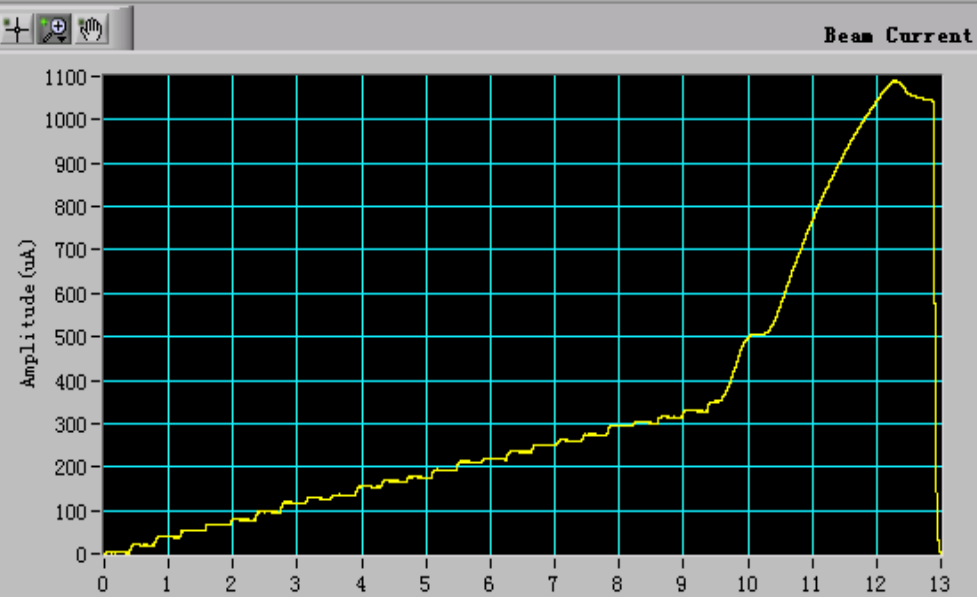
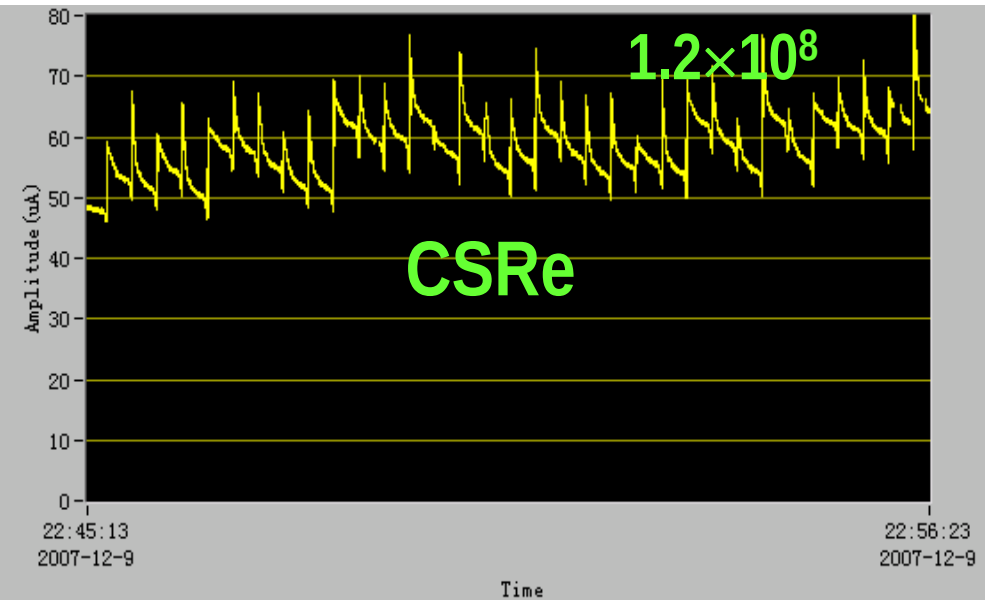
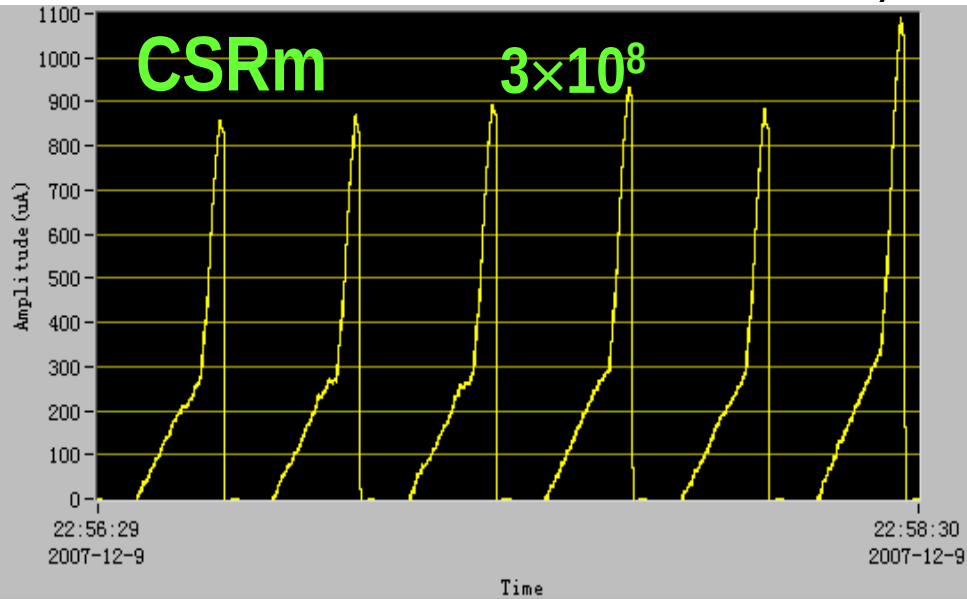
Mode: **SFC** + **SSC** + **CSRm** + **CSRe**



Ar-beam in CSRm and CSRe

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

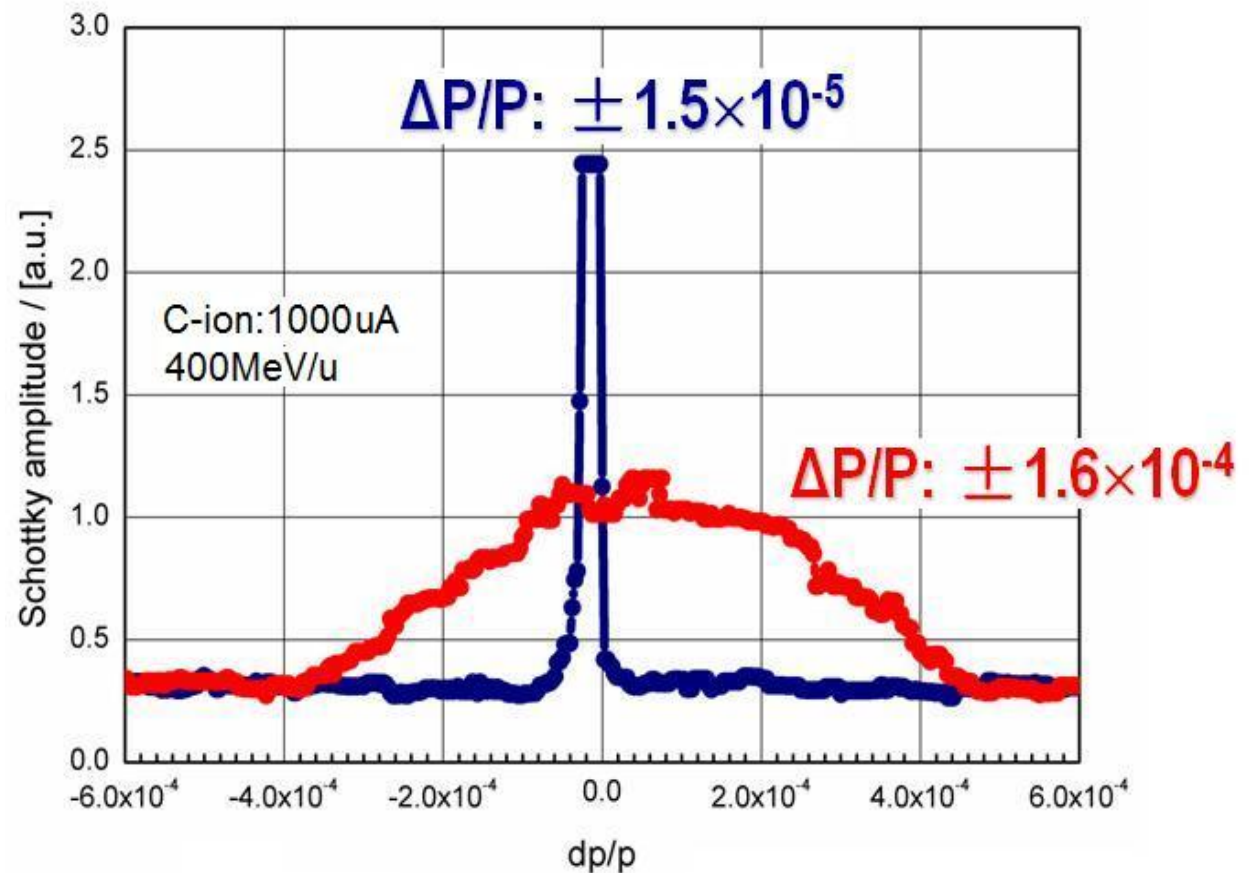
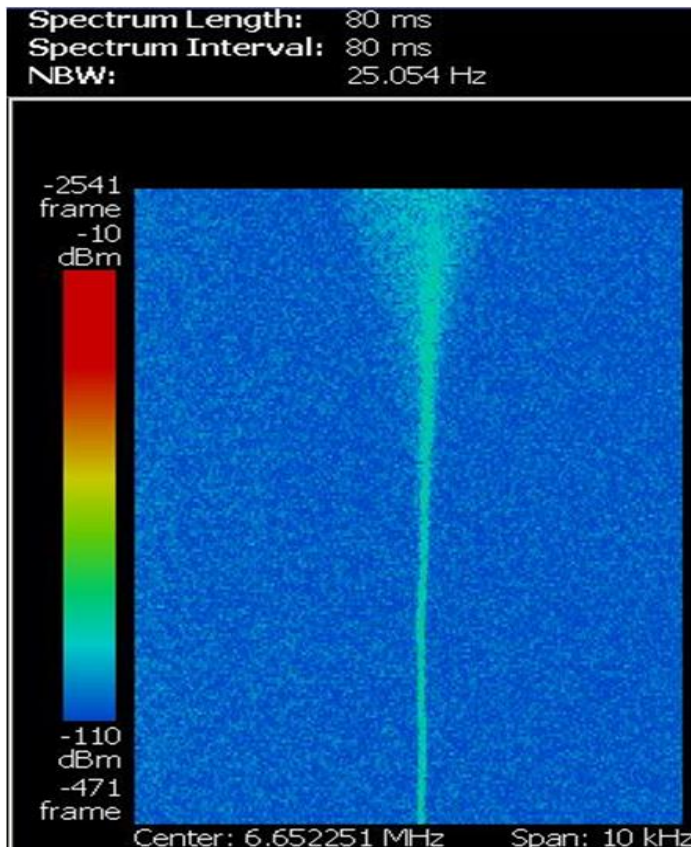
07/12/09 22:56



E-cooling in CSRe

C^{6+} -400MeV/u , 1000uA, longitudinal schottky signal from spectrum analyzer

April, 2009



HIRFL-CSR

Operation & Experiments

2008---2010

HIRFL-CSR Control Room



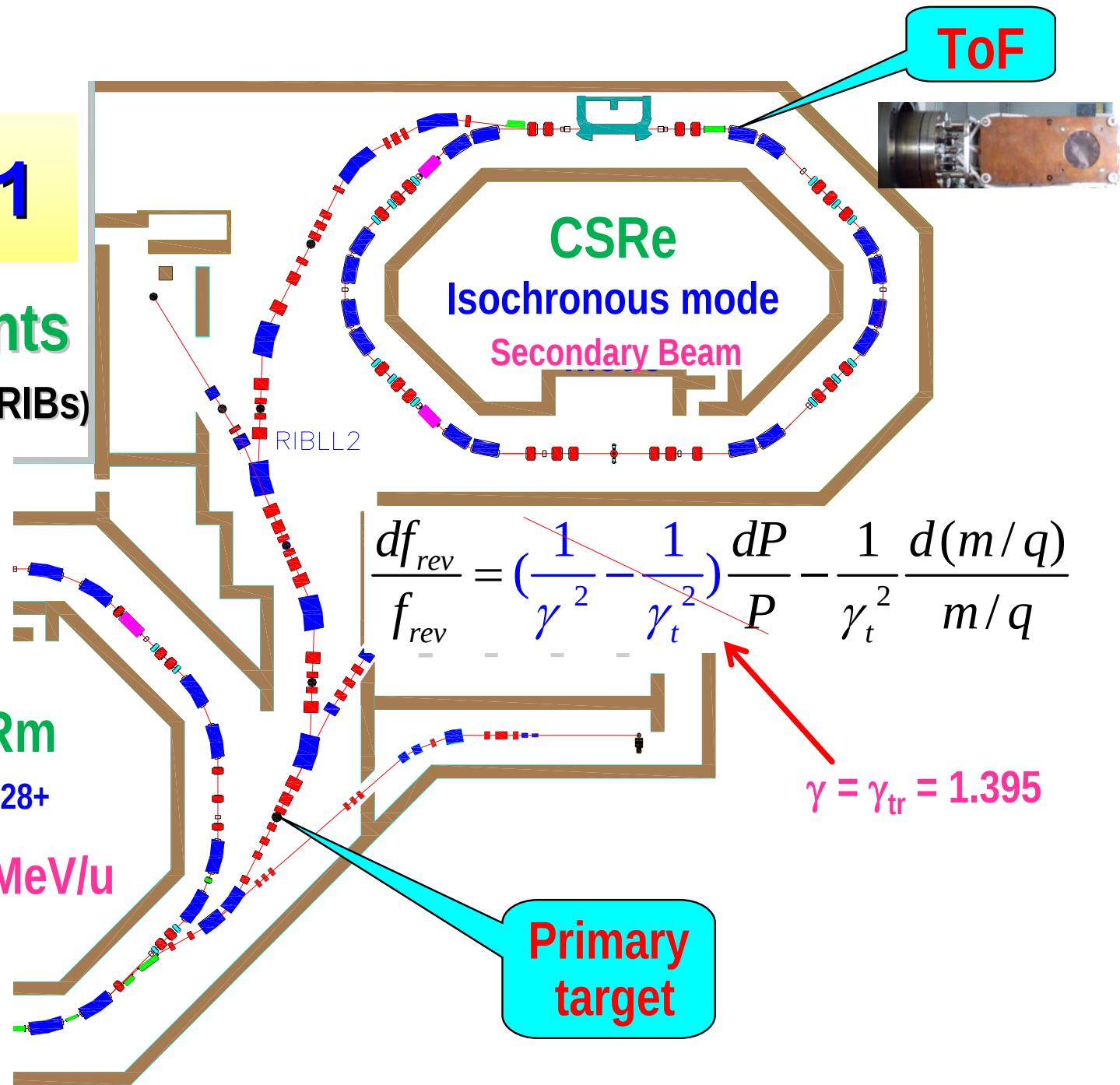
Experiments-1

Mass Measurements

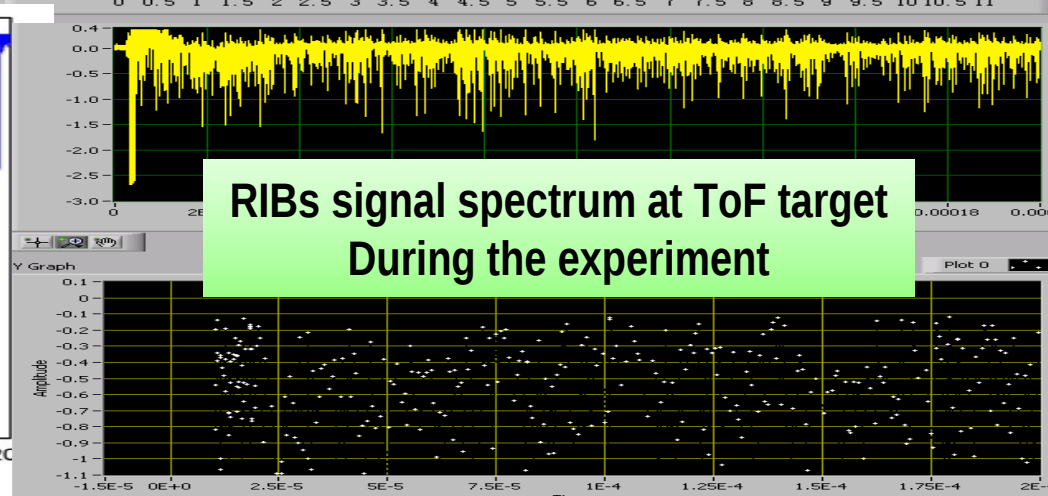
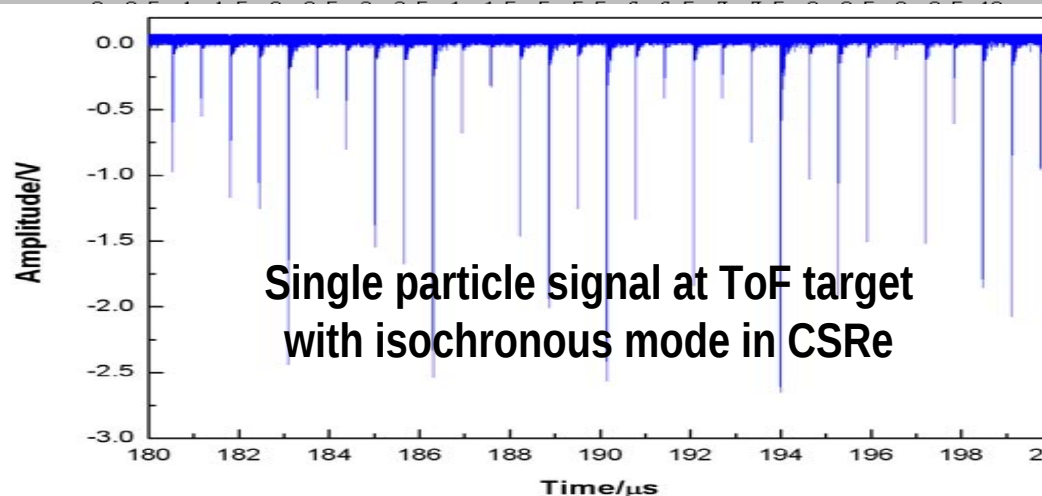
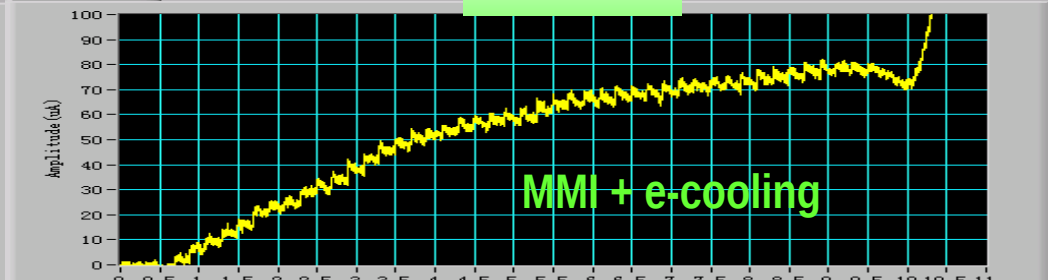
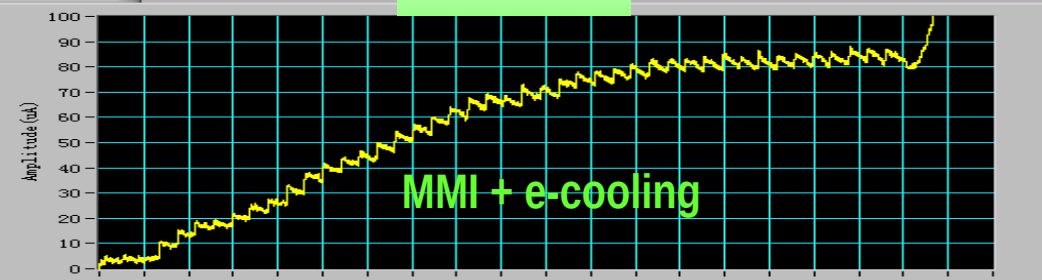
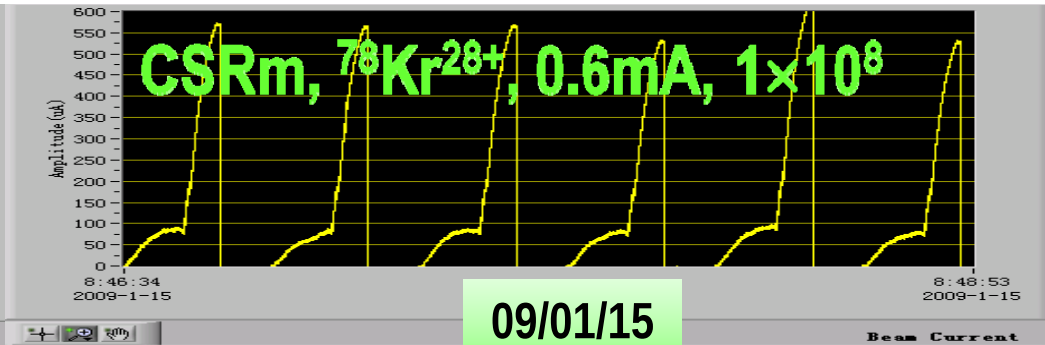
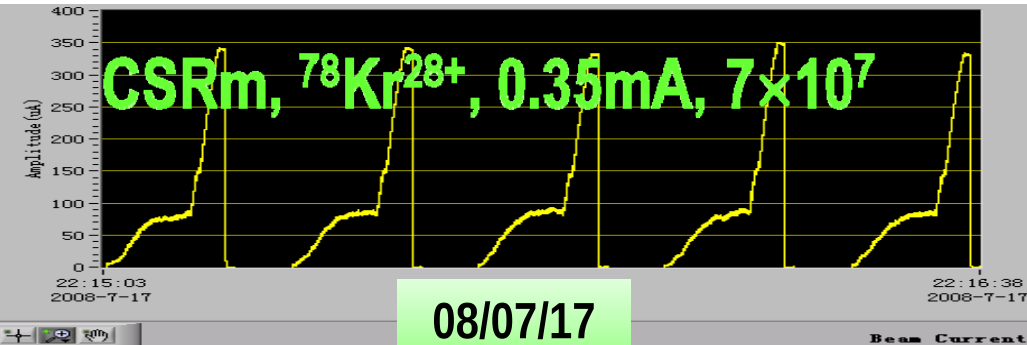
for Radioactive Ion Beams (RIBs)

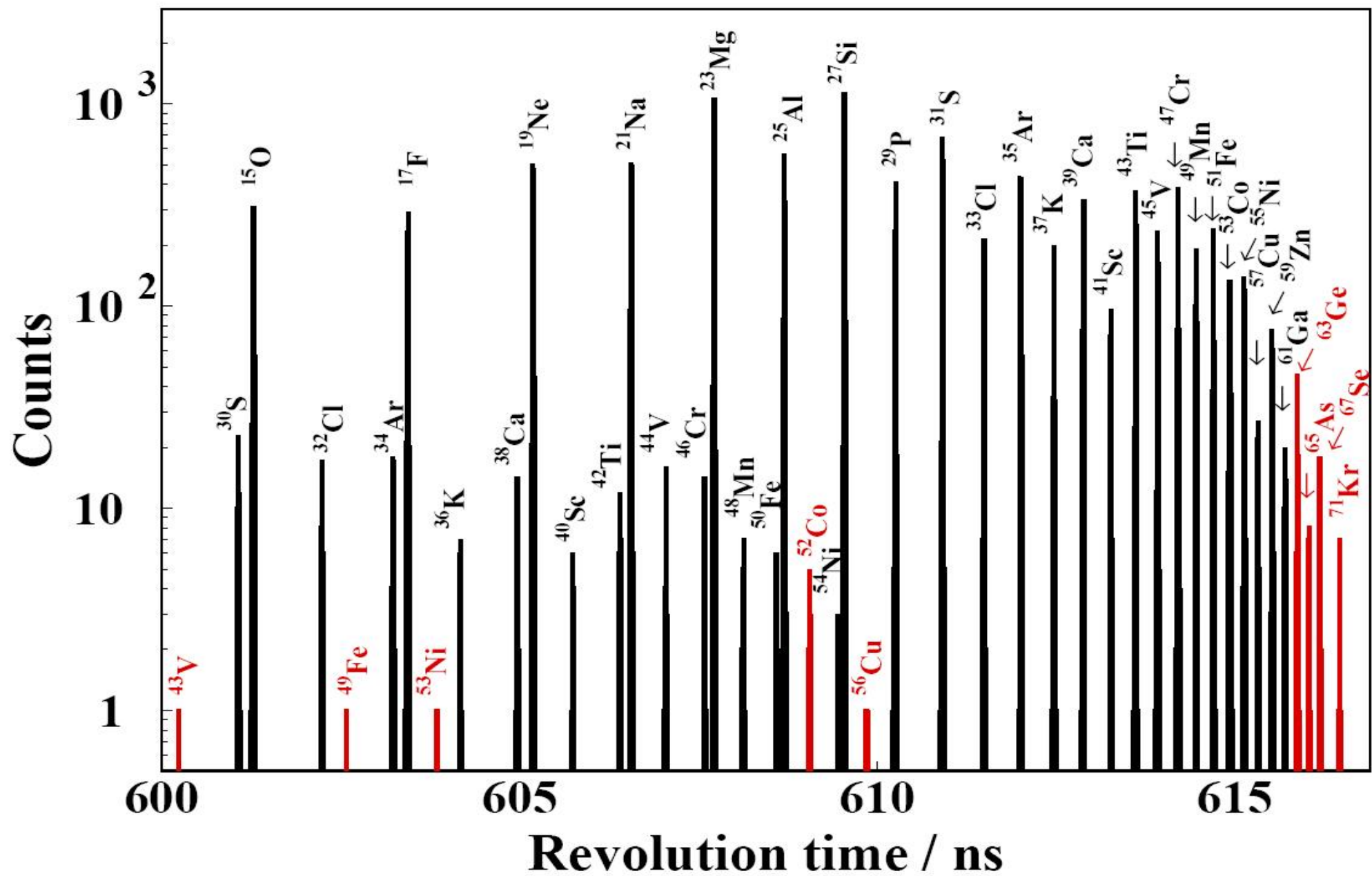
2008 & 2009

CSRm
 $^{78}\text{Kr}^{28+}$
481.88 MeV/u



Experiments for RIBs spectroscopy





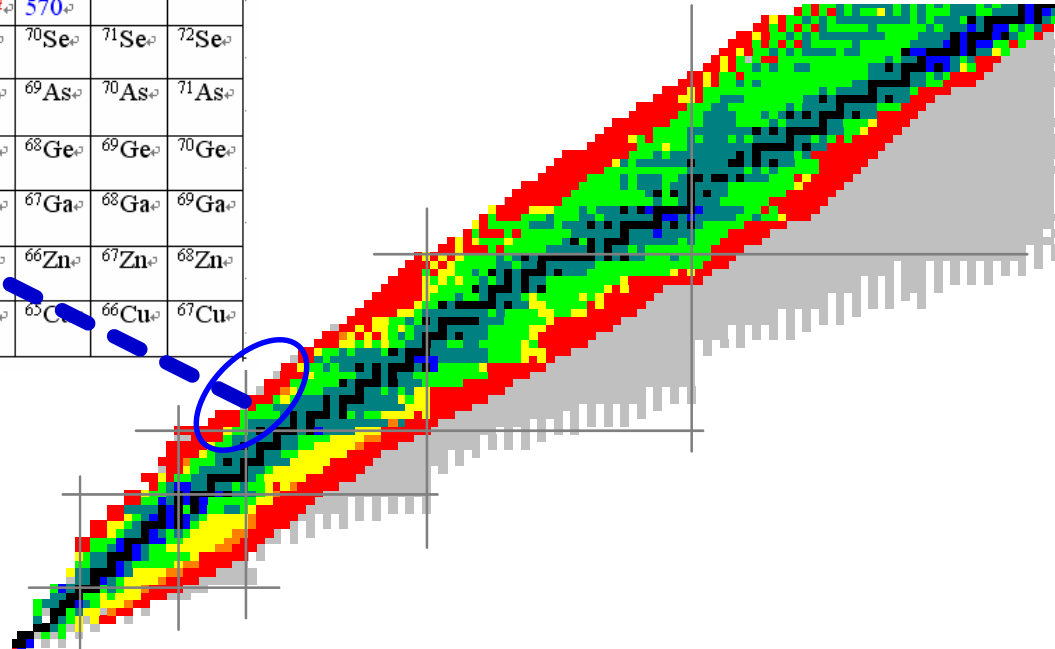
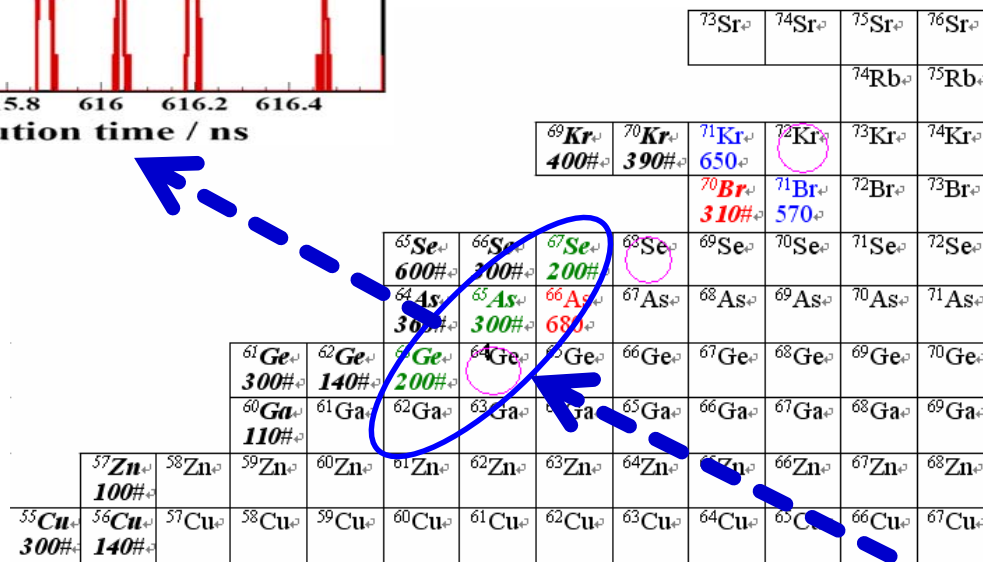
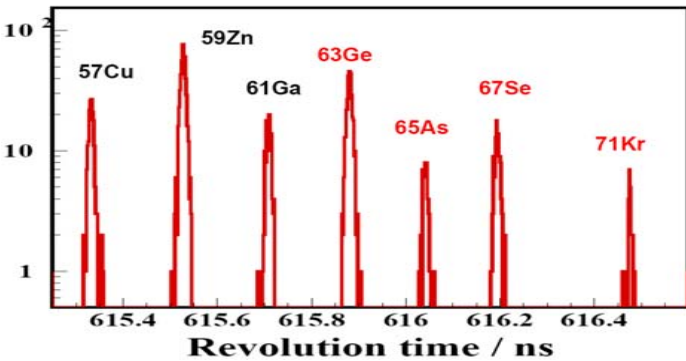
Results of the RIBs mass-measurements (2008-2009)

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

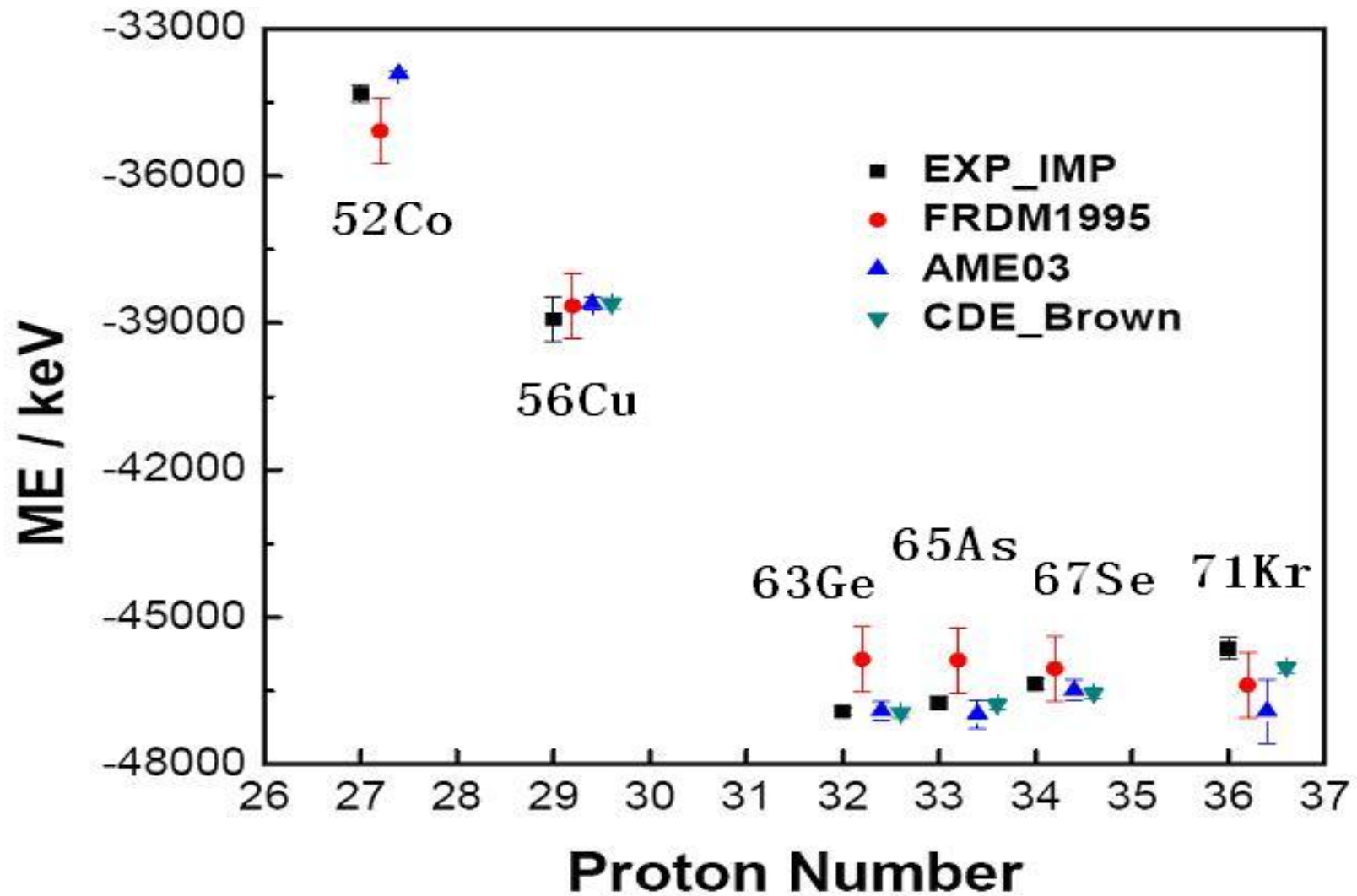
$A=2Z-1$: ^{63}Ge , ^{65}As , ^{67}Se , ^{71}Kr

$A=2Z-2$: ^{56}Cu , ^{52}Co

$A=2Z-3$: ^{43}V , ^{49}Fe , ^{53}Ni



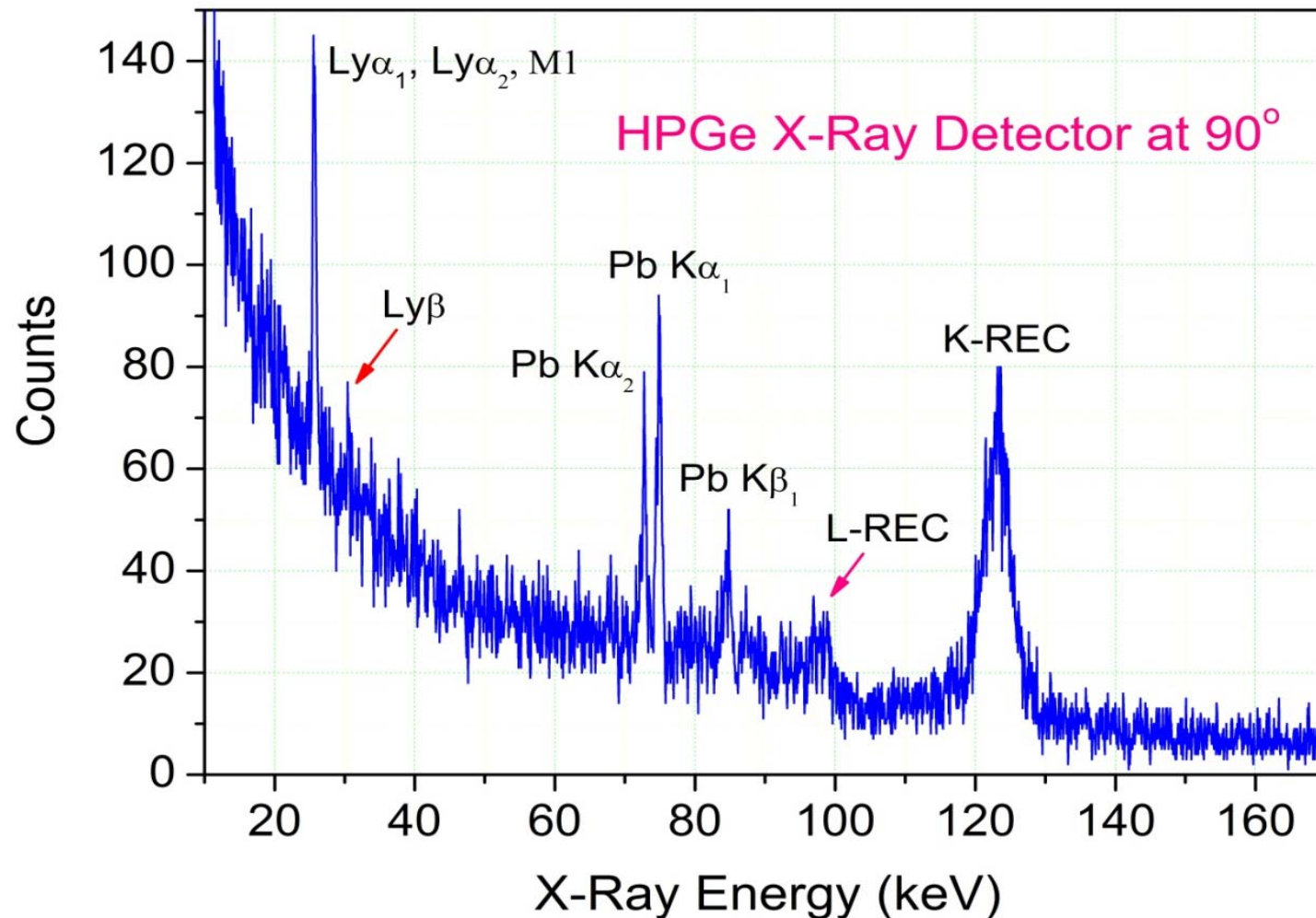
Mass Resolution $\Delta M/M$: $3 \times 10^{-6} \sim 1 \times 10^{-7}$



Experiments-2

Radioactive Electron Capture (REC) experiment for atomic physics

Xe^{54+} -beam ,197MeV/u, crossed with the N_2 -jet at internal target of CSRe



SFC-CSRm

Cancer therapy with c-beam

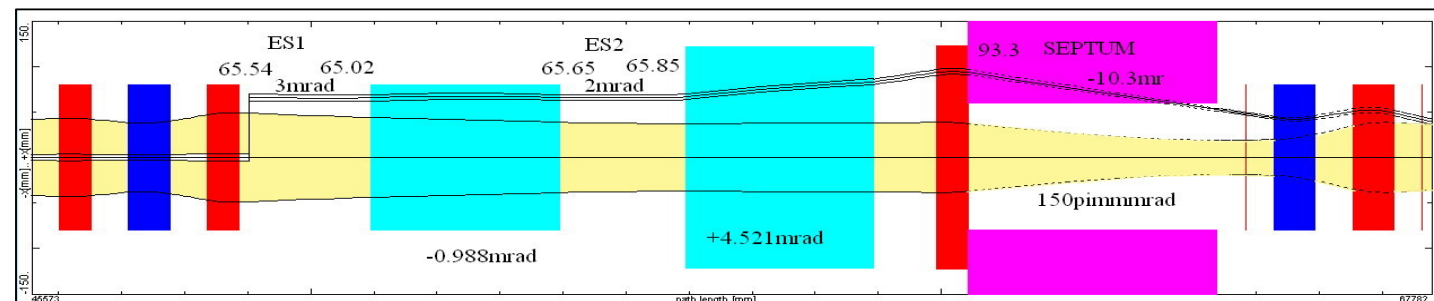
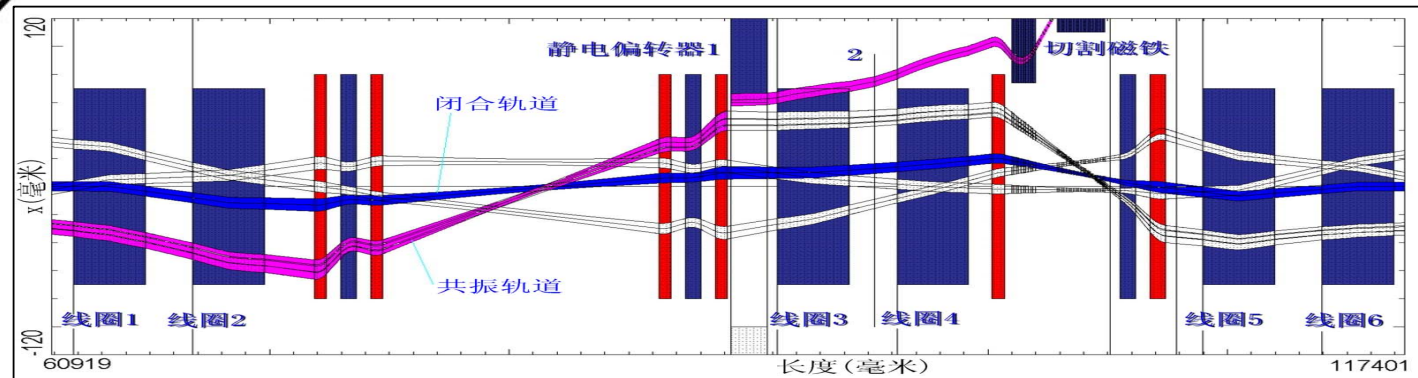
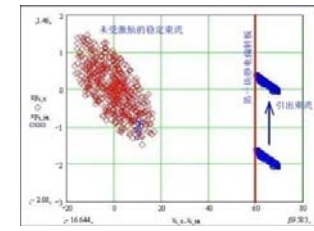
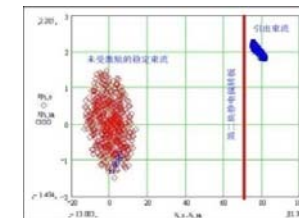
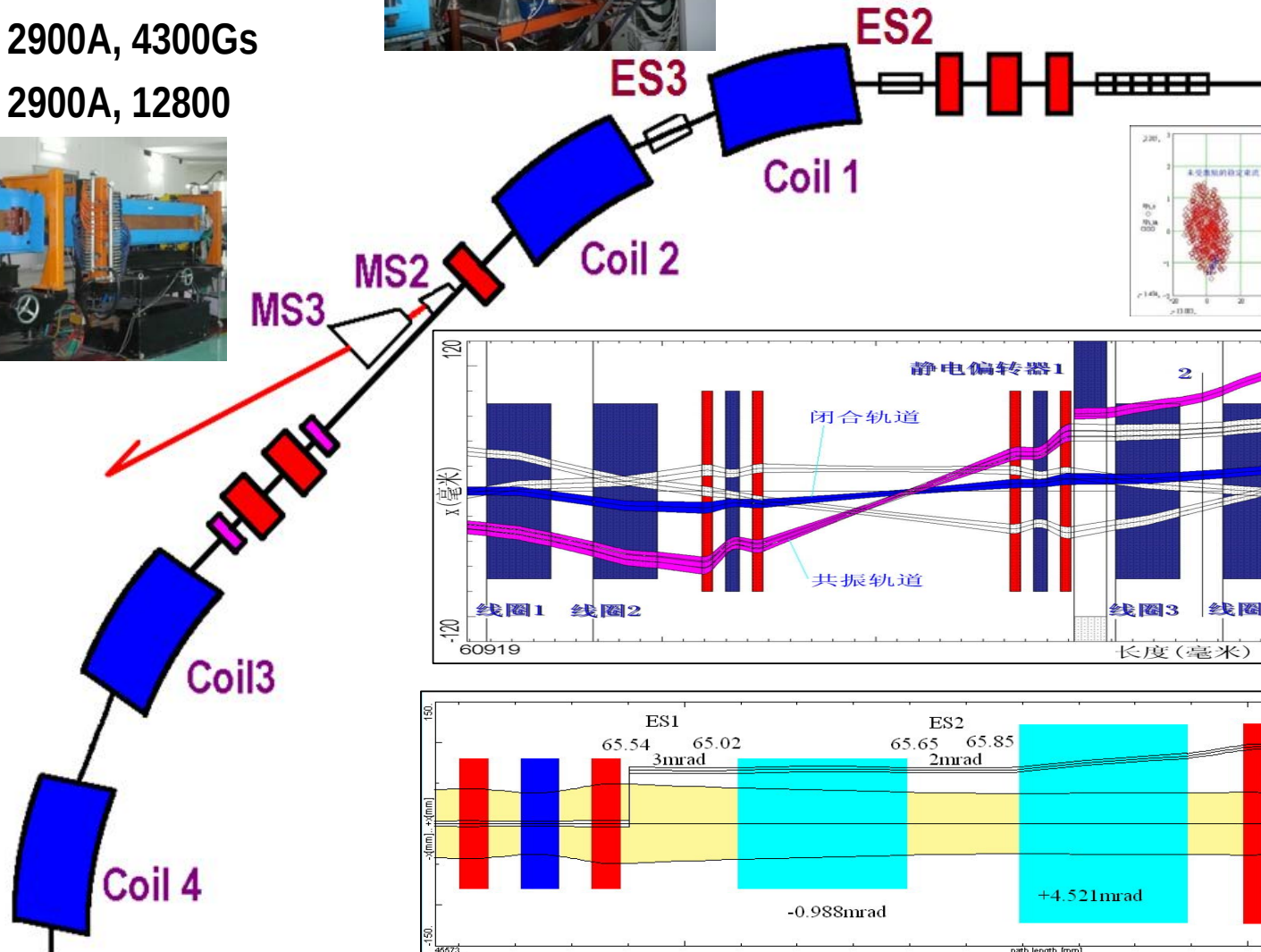
2008---2010

Slow extraction of 1/3 Resonance in CSRm

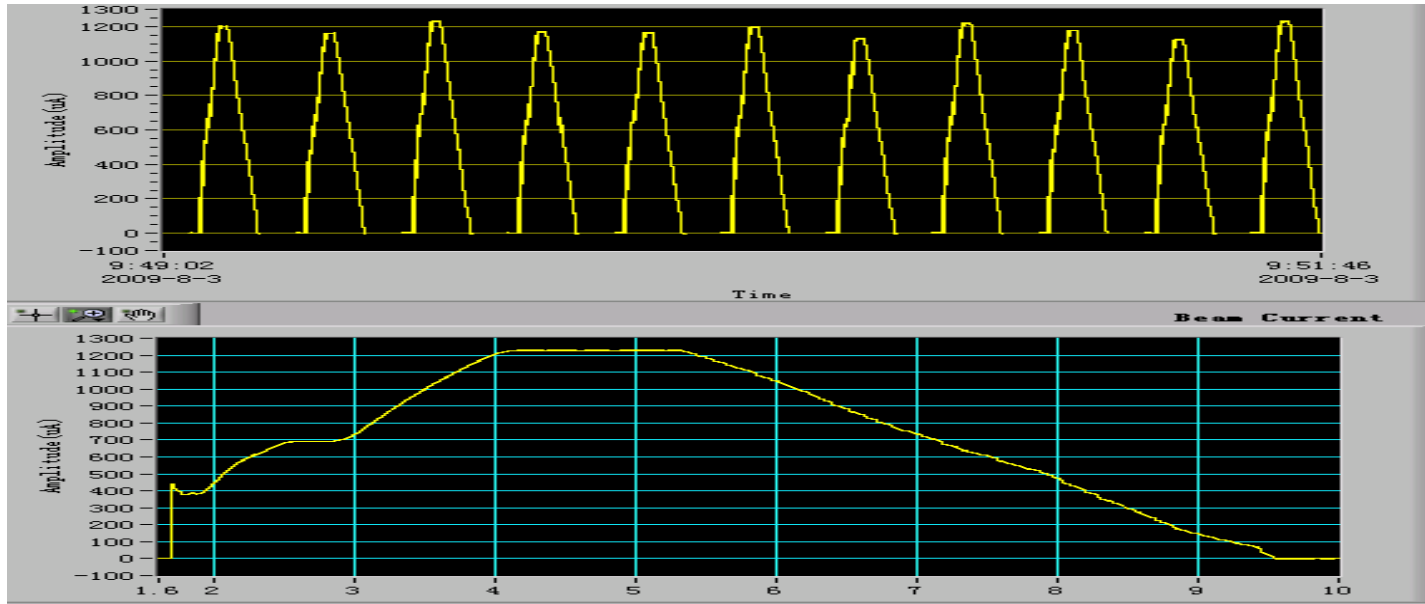
2008.01.10

MS2: 2900A, 4300Gs

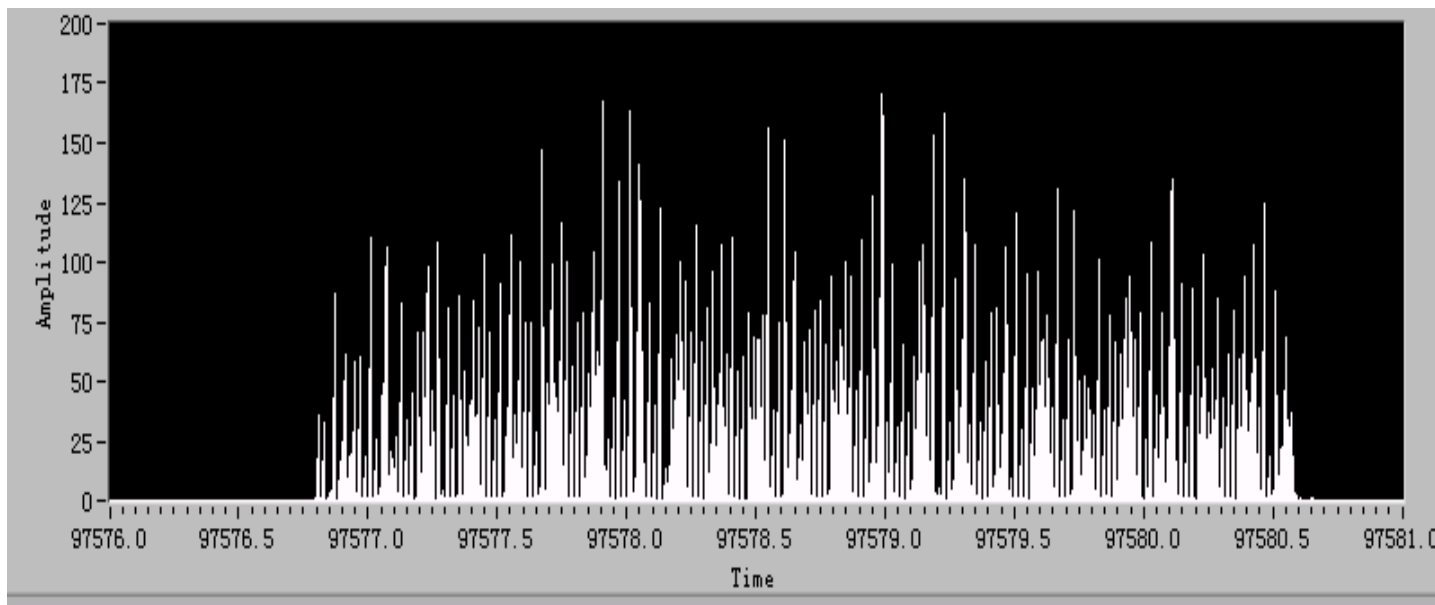
MS2: 2900A, 12800



Slow extraction for $^{12}\text{C}^{6+}$ -200MeV/u in CSRm

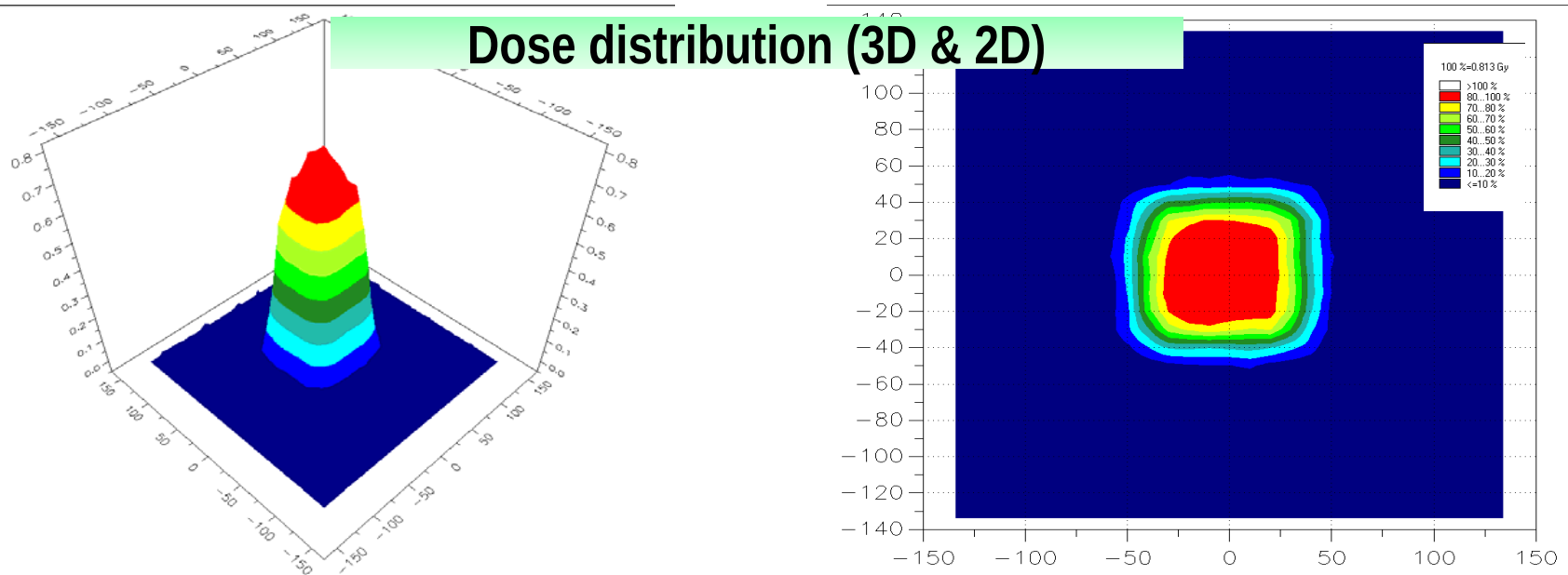
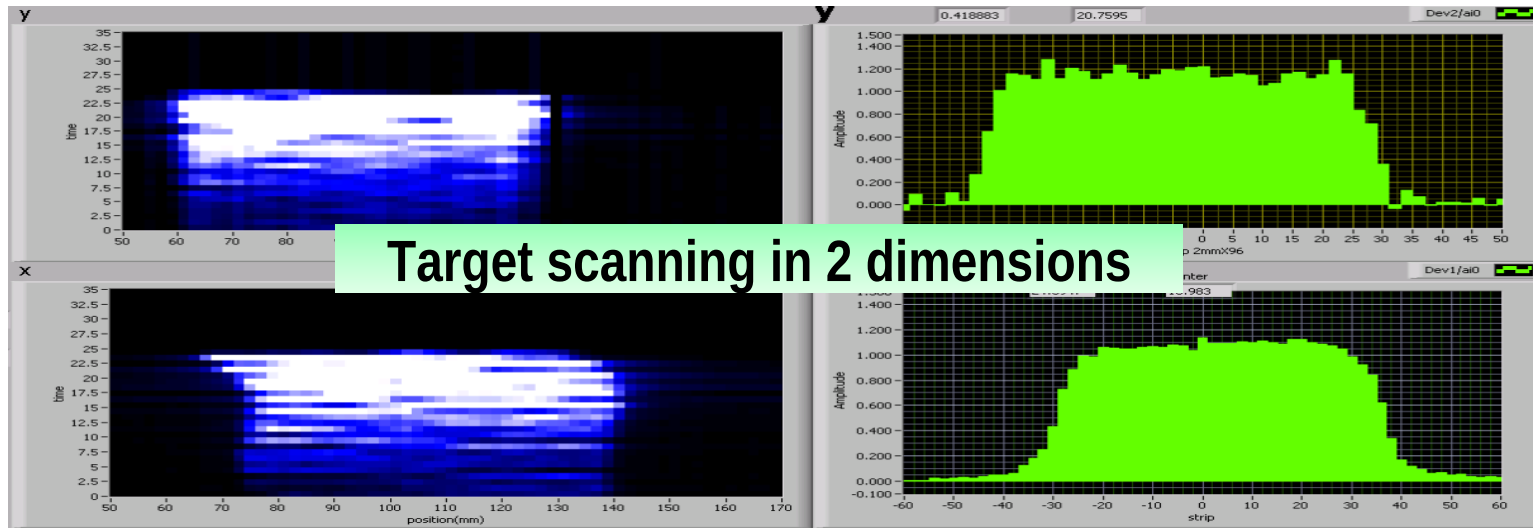


DCCT beam signal
in CSRm



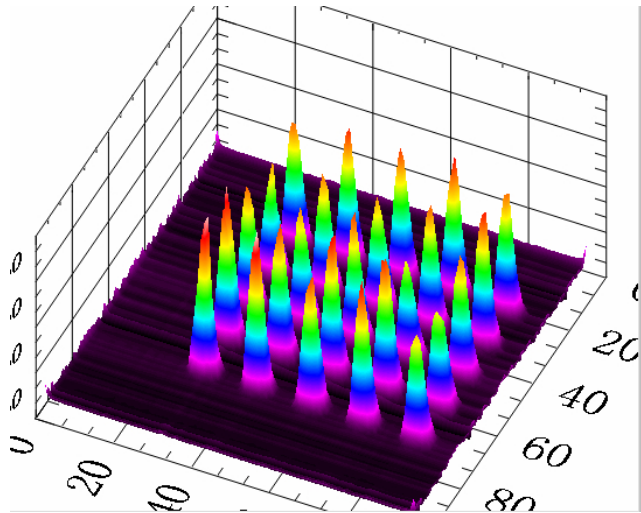
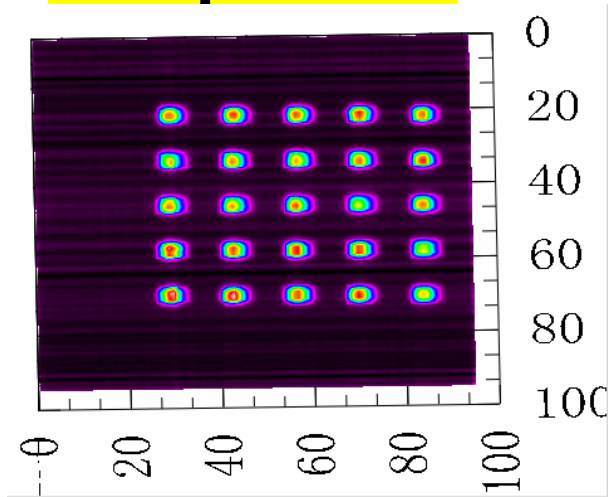
AIC beam signal at
therapy terminal

Uniform Scanning for Cancer Therapy

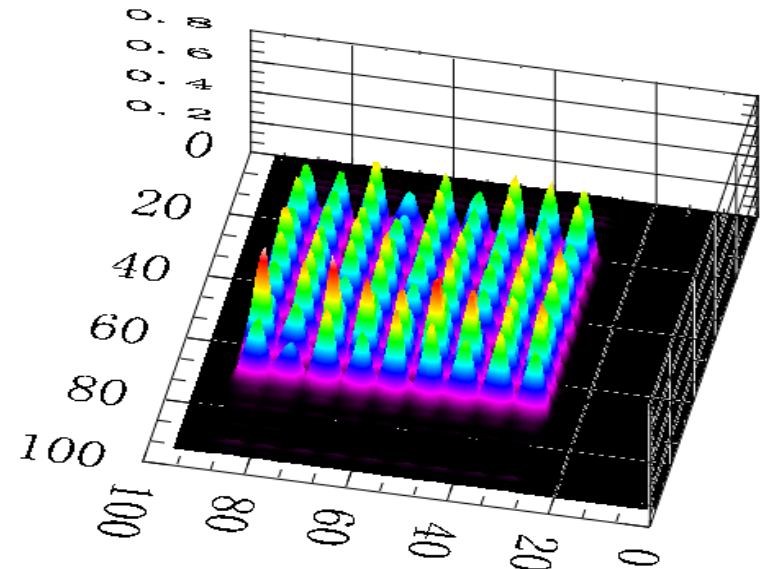
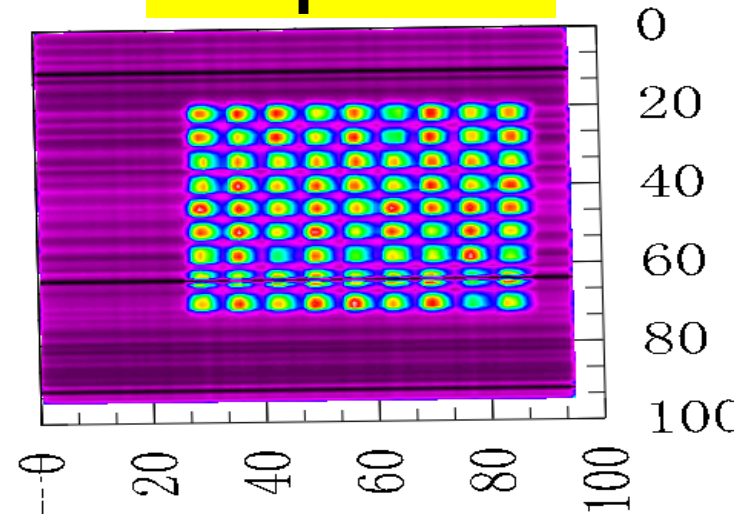


Raster Scanning for Cancer Therapy

25 points

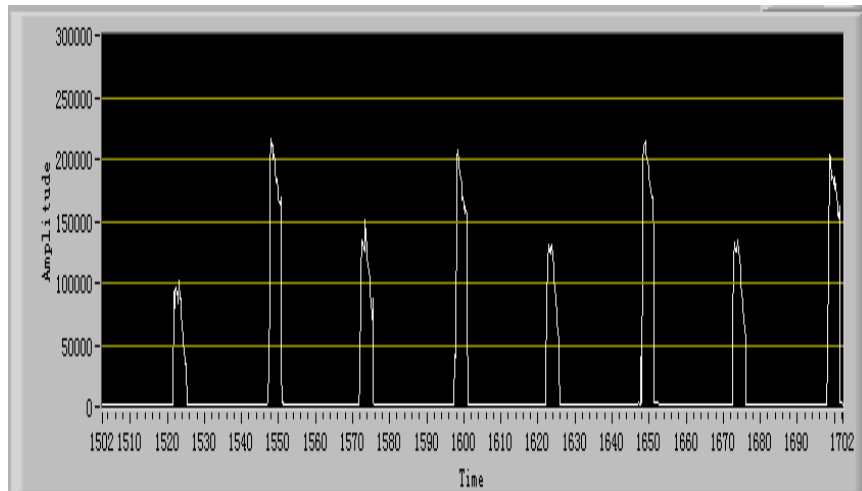
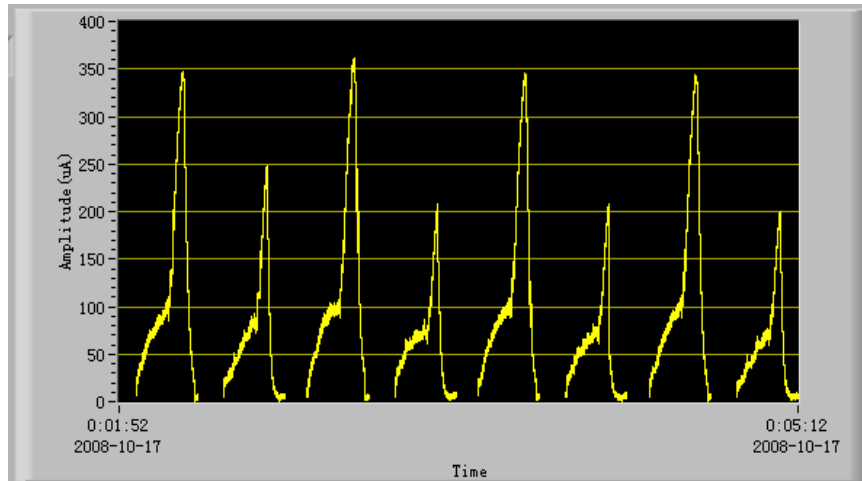


81 points

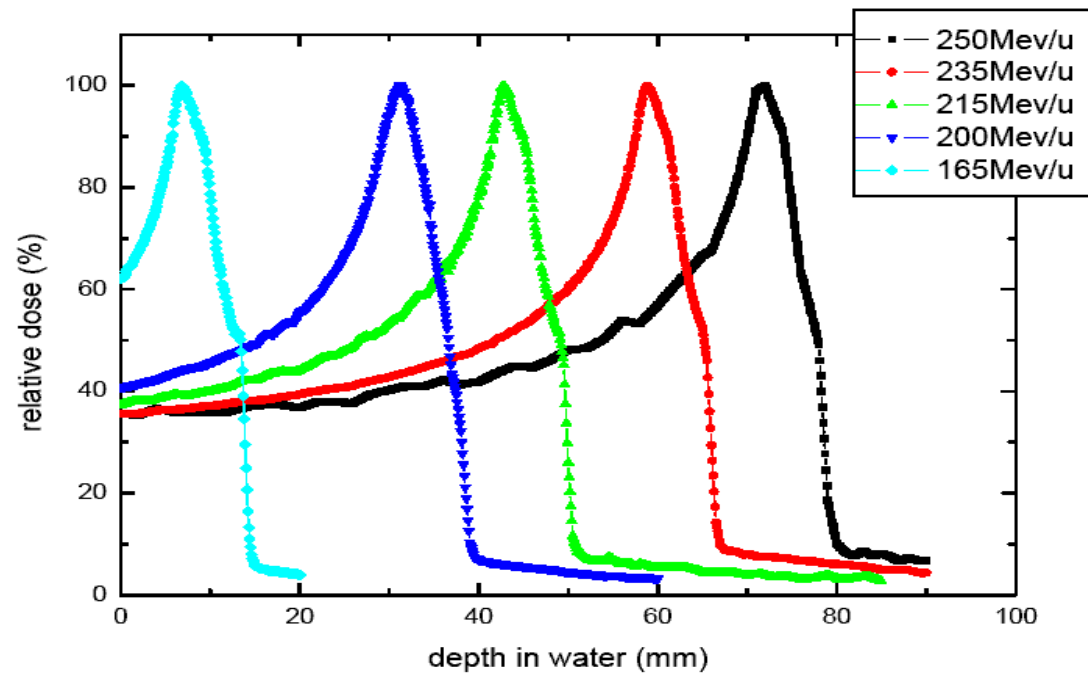


Varying-energy slow extraction for cancer therapy

Beam energy of each cycle can be changed

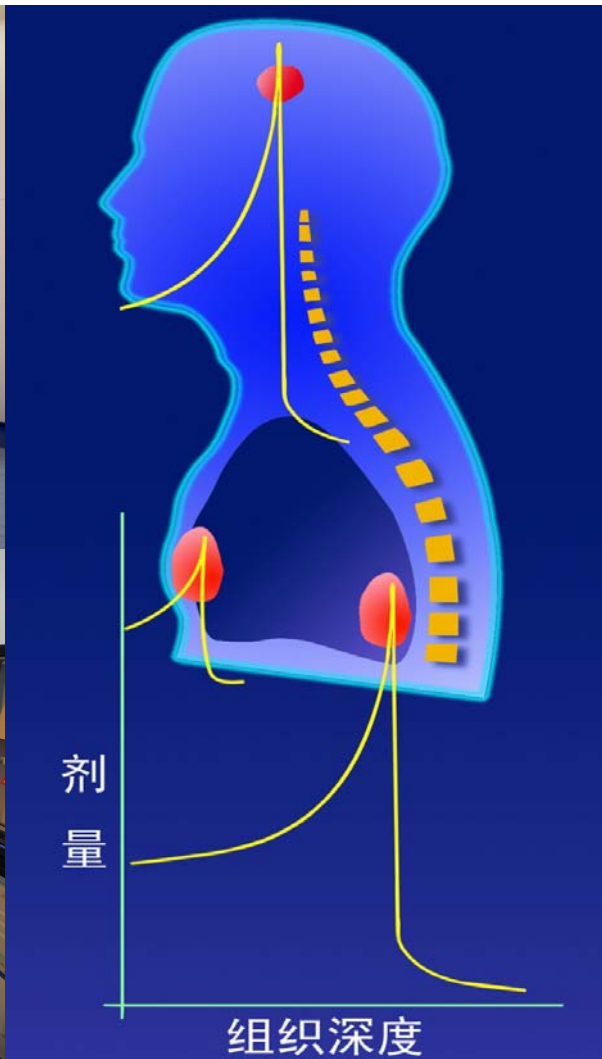


Bragg peaks in water with 5 energy spills



Cancer Therapy with CSRm (2008-2010)

Two batches: 8 patients



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 (7×10^9) for C-600MeV/u in CSRm
1.2mA (4×10^8) for Ar-368MeV/u in CSRm
0.8mA (2×10^8) for Kr-480MeV/u in CSRm
0.5mA (1×10^8) for Xe-235MeV/u in CSRm
15mA (8×10^9) 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

Thanks

