April 9, 2004, BNL

CSR Project

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A upgrading for the Heavy Ion Research Facility in Lanzhou

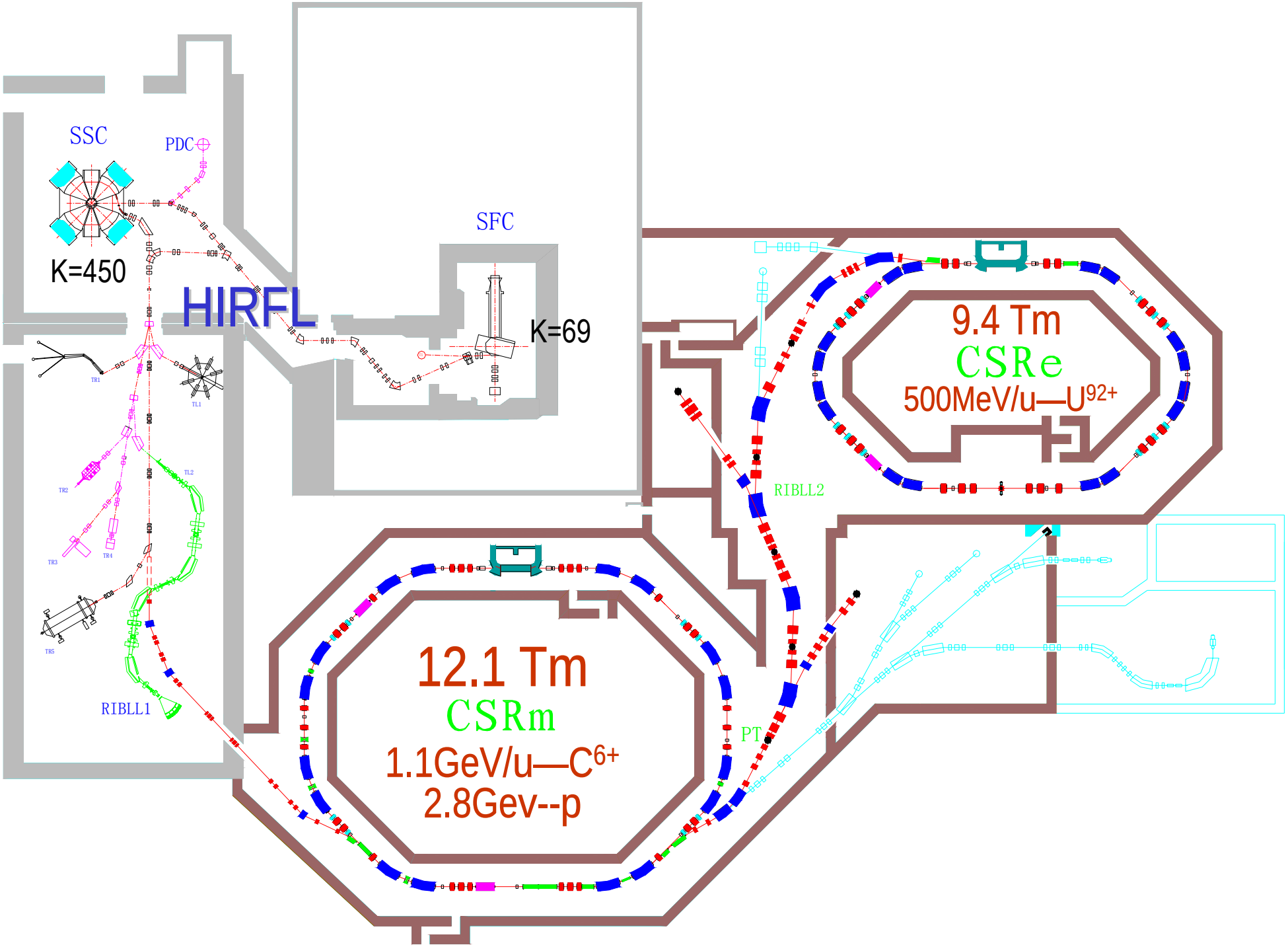
HIRFL- CSR Project

(Cooler-Storage Ring)

Total Budget ~ 400 million Chinese yuan

Construction time
2000 ------- 2005

HIRFL-CSR Layout



Physics Program of CSR

RIB physics

(With Radioactive Ion Beams)

Researches of hot nuclei

(With high-energy beams)

Atomic physics

(With highly charged heavy ions)

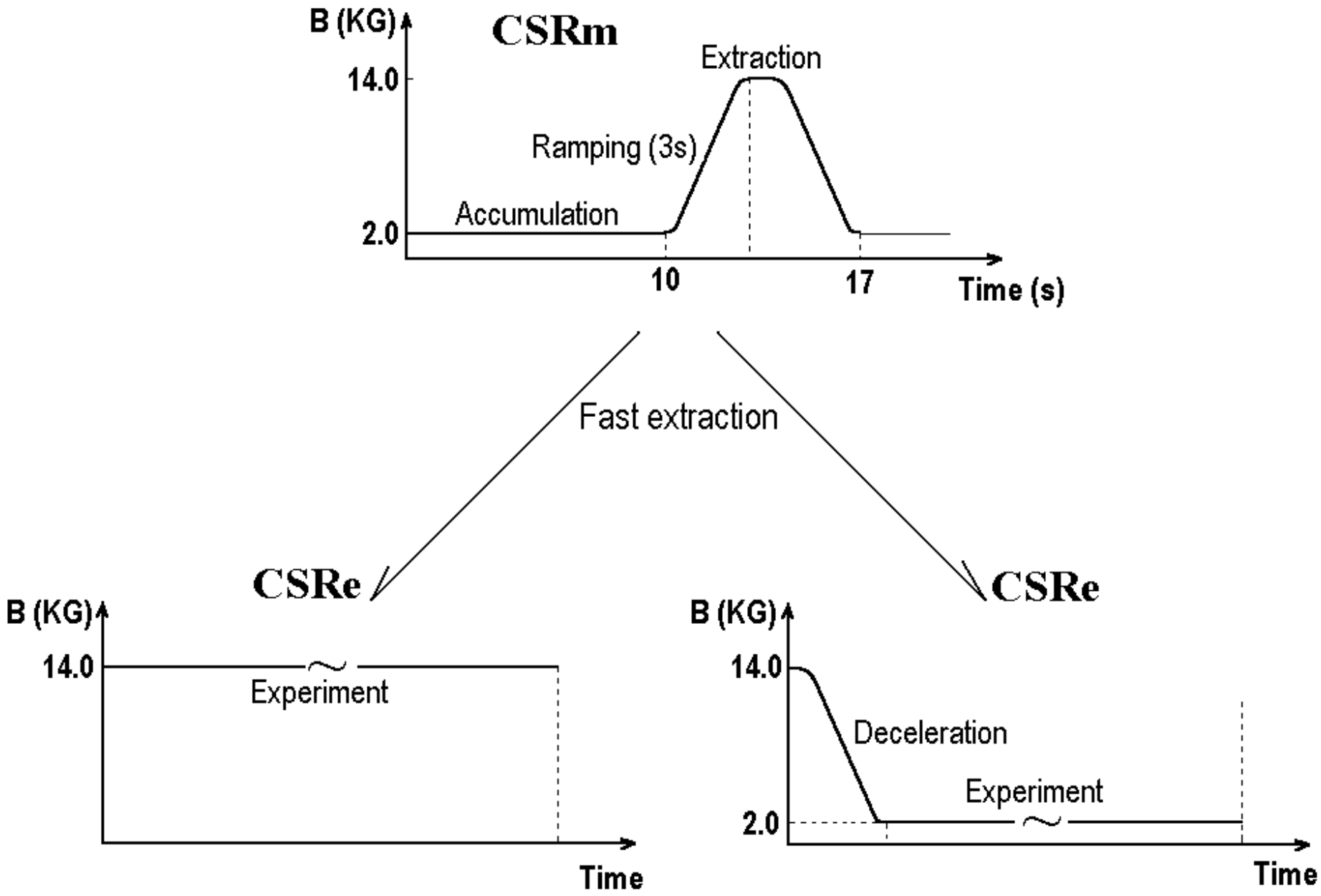
Related applications

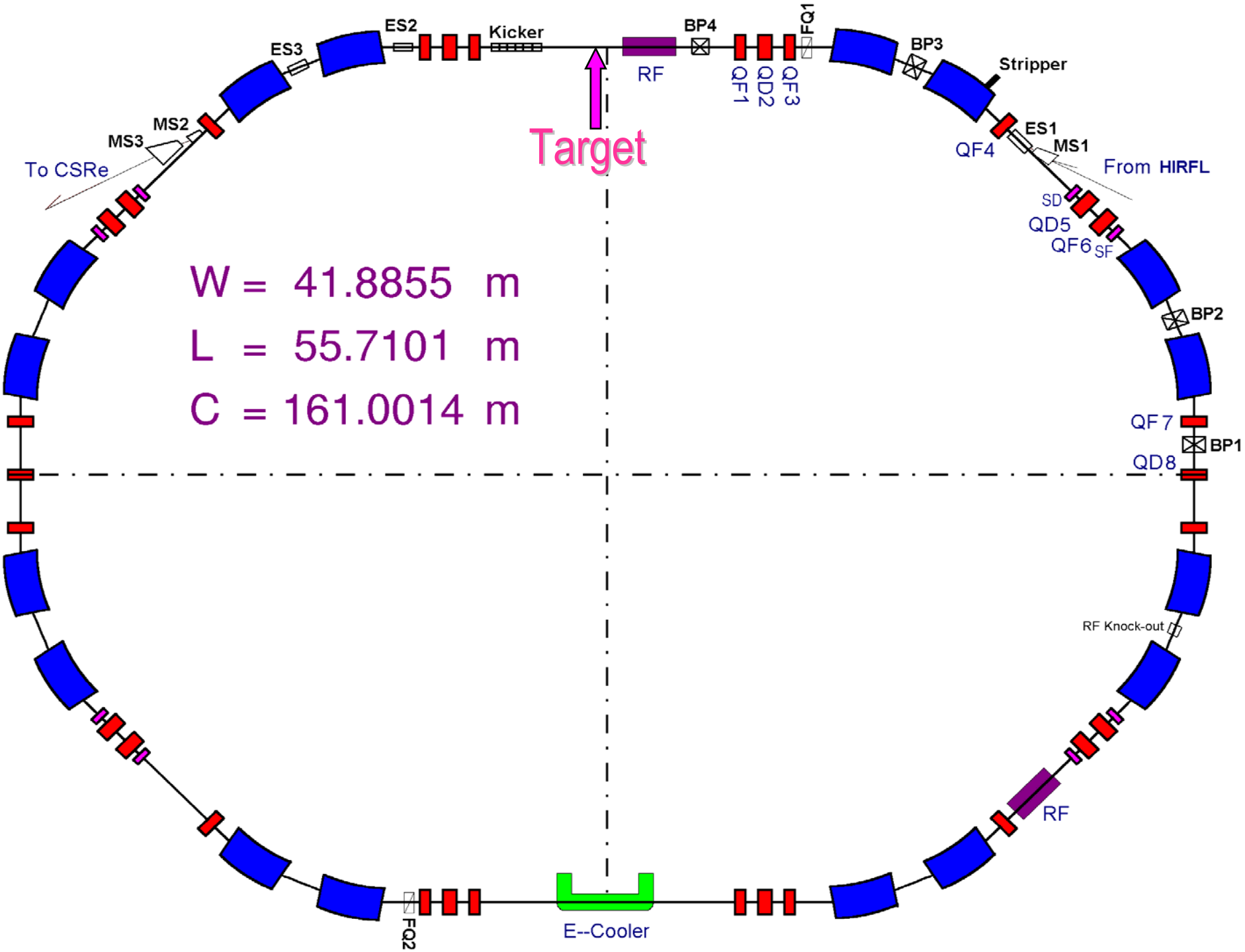
CSR major parameters

	CSRm	CSRe
rcumference (m)	161.0014	128.8011
verage radius (m)	$8R_{SSC}=34R_{SFC}=25.62416$	$4/5R_{CSRm}=20.499328$
eometry	Race-track	Race-track
ax. energy (MeV/u)	2800 (p) 1100 (C^{6+}) 500 (U^{72+})	2000 (p) 750 (C^{6+}) 500 (U^{92+})
ρ (Tm)	0.81/12.05	0.50/9.40
(T)	0.10/1.60	0.08/1.60
amping rate (T/s)	0.05 ~ 0.4	-0.1 ~ -0.2
epeating circle (s)	~17 (~10s for Accumulation)	
cceptance	Fast-extraction mode	Normal mode
A_h (π mm-mrad)	200 (Δp/p = ±0.3 %)	**150** (Δp/p =±0.5%)
A_v (π mm-mrad)	40	**75**
Δp/p (%)	1.4 (ε_h= 50 π mm-mrad)	**2.6** (ε_h= 10 π mm-mrad)

	CSRm		CSRe
E-cooler			
Electron energy (KeV)	35		300
Eff. cooling length (m)	3.4		3.4
RF system	Accel.	Accum.	Decelerati
Harmonic number	1	16, 32,64	1
f_{min}/f_{max} (MHz)	0.24/1.81	6.0 / 14.0	0.4 / 2.0
Voltages (n × kV)	1 × 7.0	1 × 20.0	2 × 10.0
Vacuum (mbar)	(3.0×10^{-11})		

CSR Operation Scheme





CSRm Lattice Layout

CSRm Lattice Modes

Fast extraction (Normal mode)

2.8GeV (P), 1.1GeV/u ($^{12}C^{6+}$), 500MeV/u ($^{238}U^{72+}$)

Providing beams for CSRe

External-target exp., Producing RIB,

Slow extraction

1GeV/u ($^{12}C^{6}$+, N, O)

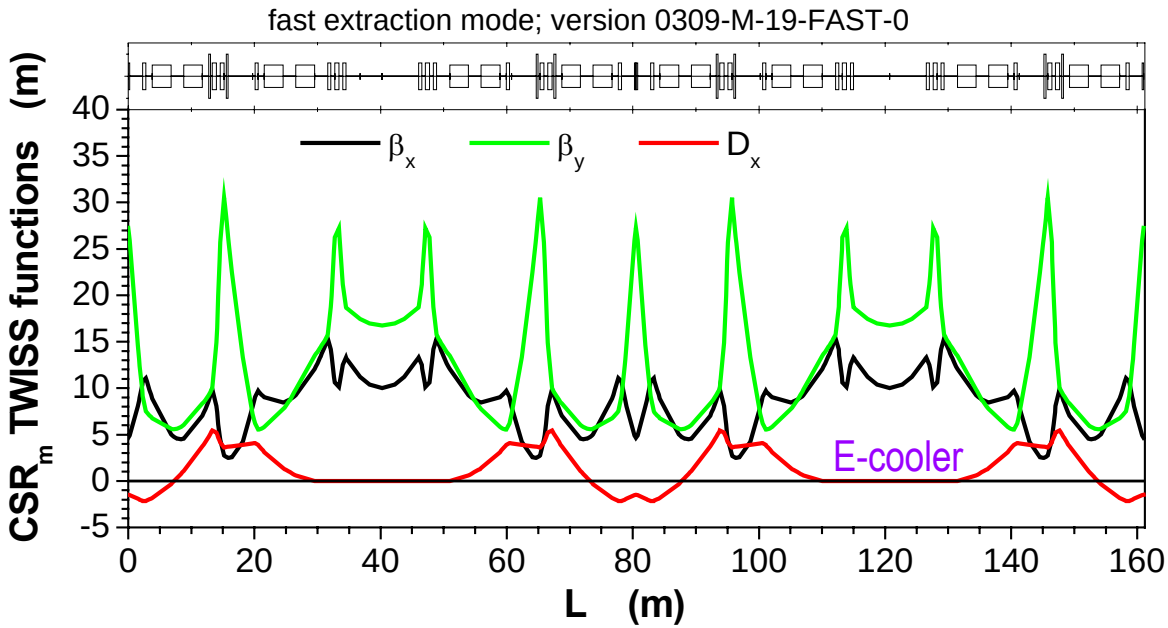
External-target exp., Cancer therapy research

Internal target (Unsymmetrical)

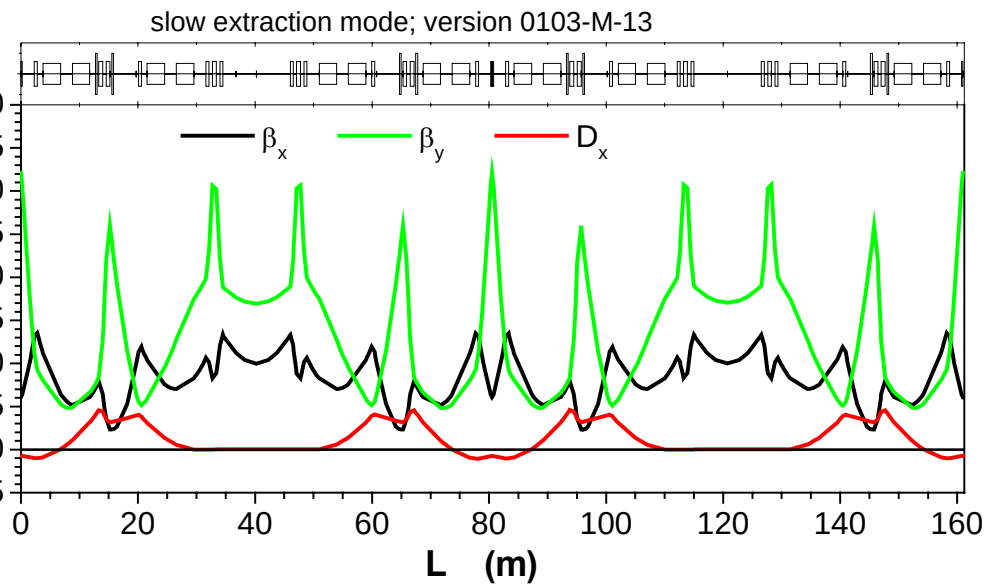
2.8GeV (P), 1.1GeV/u ($^{12}C^{6+}$)

Internal-target experiments

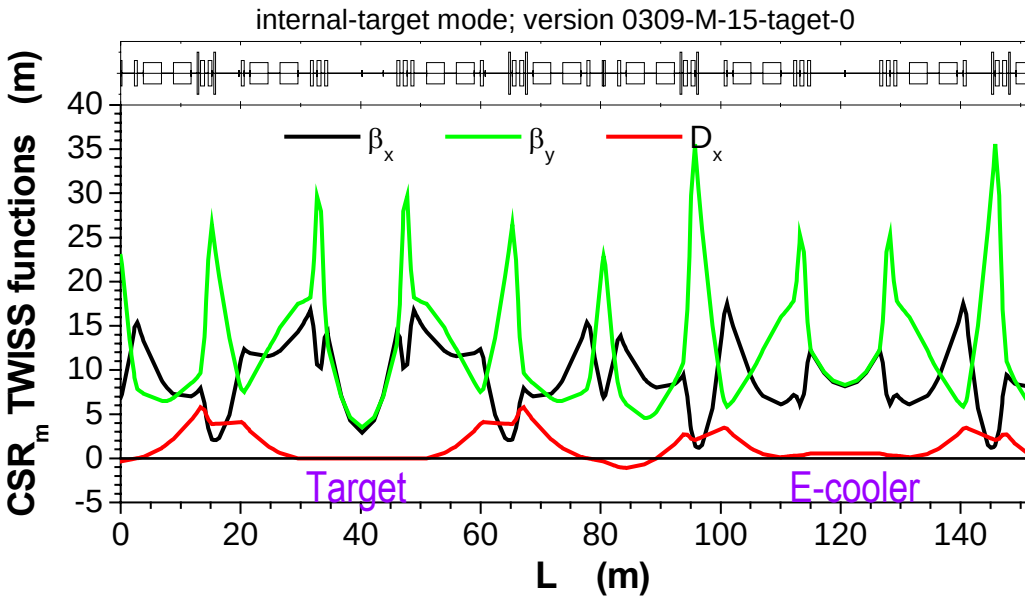
Twiss Functions of CSRm



Fast-extraction Mode



Slow-extraction Mode



Internal-target Mode

Unsymmetrical

Useful aperture of CSRm

Dipole	Quadruple
$140 \times 60\ mm^2$	$160 \times 100\ mm^2$
$B_{Max.} = 1.6\ T$	$K_{Max.} = 11\ T/m$

Beam Acceptance

Fast-extraction Mode	Slow-extraction Mode	Internal-target Mode
A_h=200 π mm-mrad ($\Delta P/P=\pm 0.3\%$)	A_h=200 πmm-mrad ($\Delta P/P=\pm 0.3\%$)	A_h=150 π mm-mrad ($\Delta P/P=\pm 0.3\%$)
A_v=40 π mm-mrad	A_v=30 π mm-mrad	A_v=30 π mm-mrad
$\Delta P/P$=1.4% (ε_h=50 π mm-mrad)	$\Delta P/P$=1.4% (ε_h=50 π mm-mrad)	$\Delta P/P$=1.3% (ε_h=50 π mm-mrad)

CSRm injection scheme

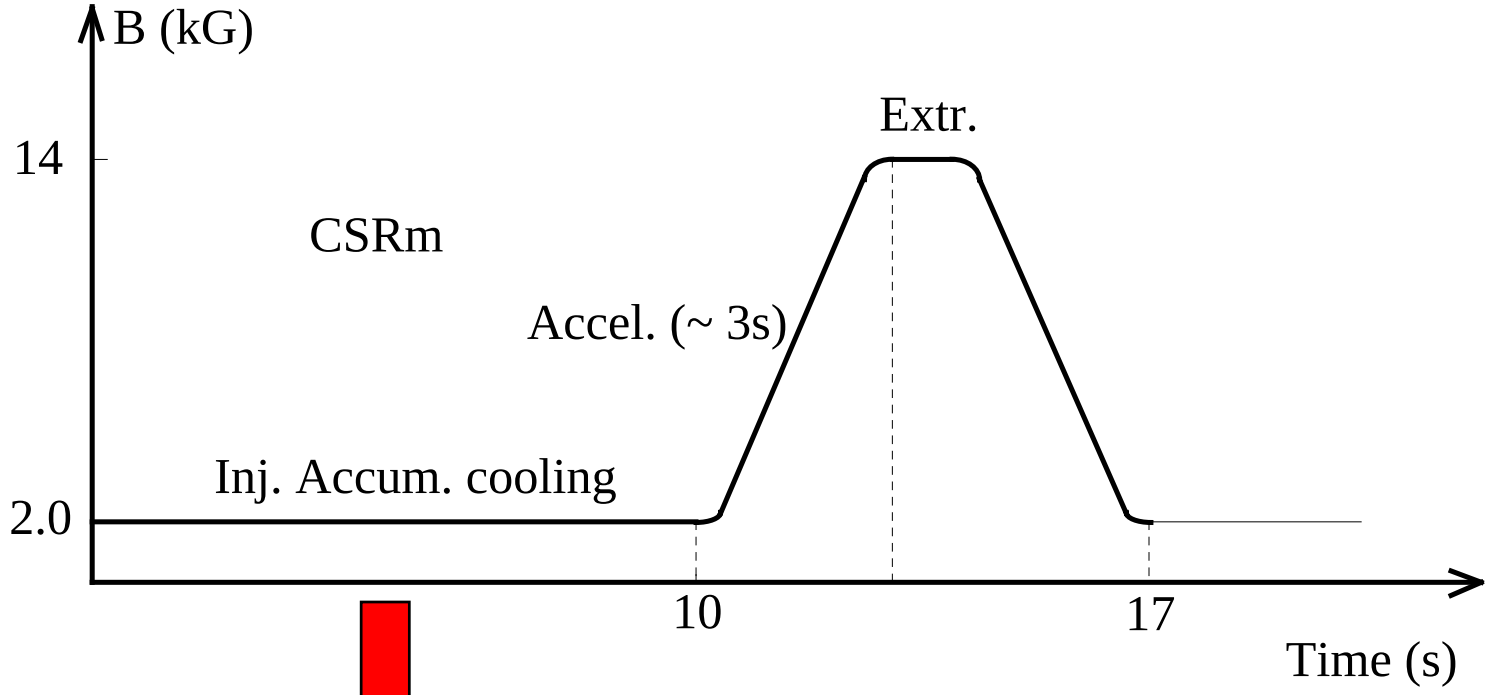
C, N, O, F, Ne, Ar, Ca, $A \leqslant 40$, E = 7---10 MeV/u

SFC + CSRm

Kr, Xe, Ta, Au, Pu, U, $A > 40$, E = 10---25 MeV/u

SFC + SSC + CSRm

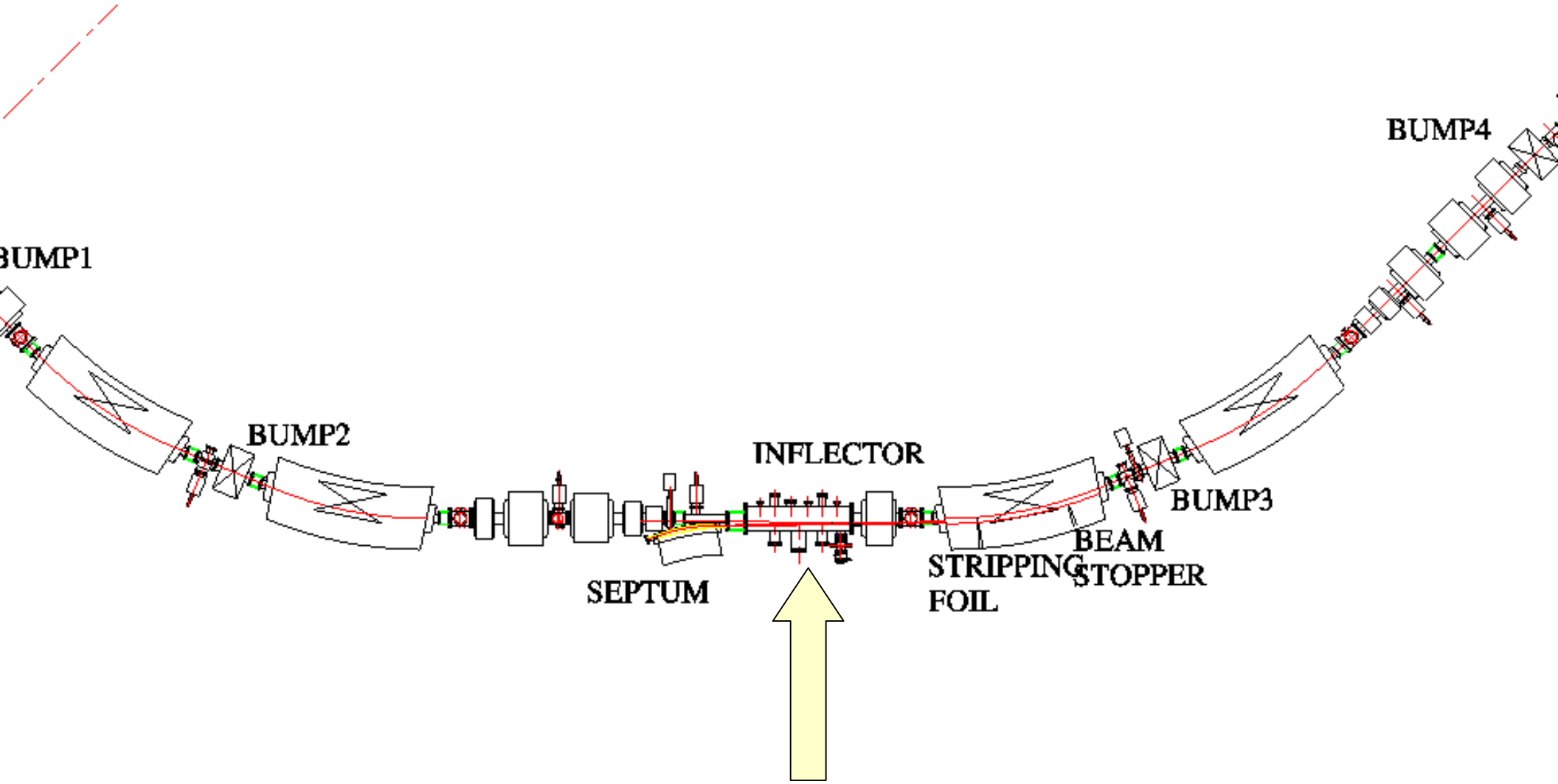
CSRm beam accumulation scheme



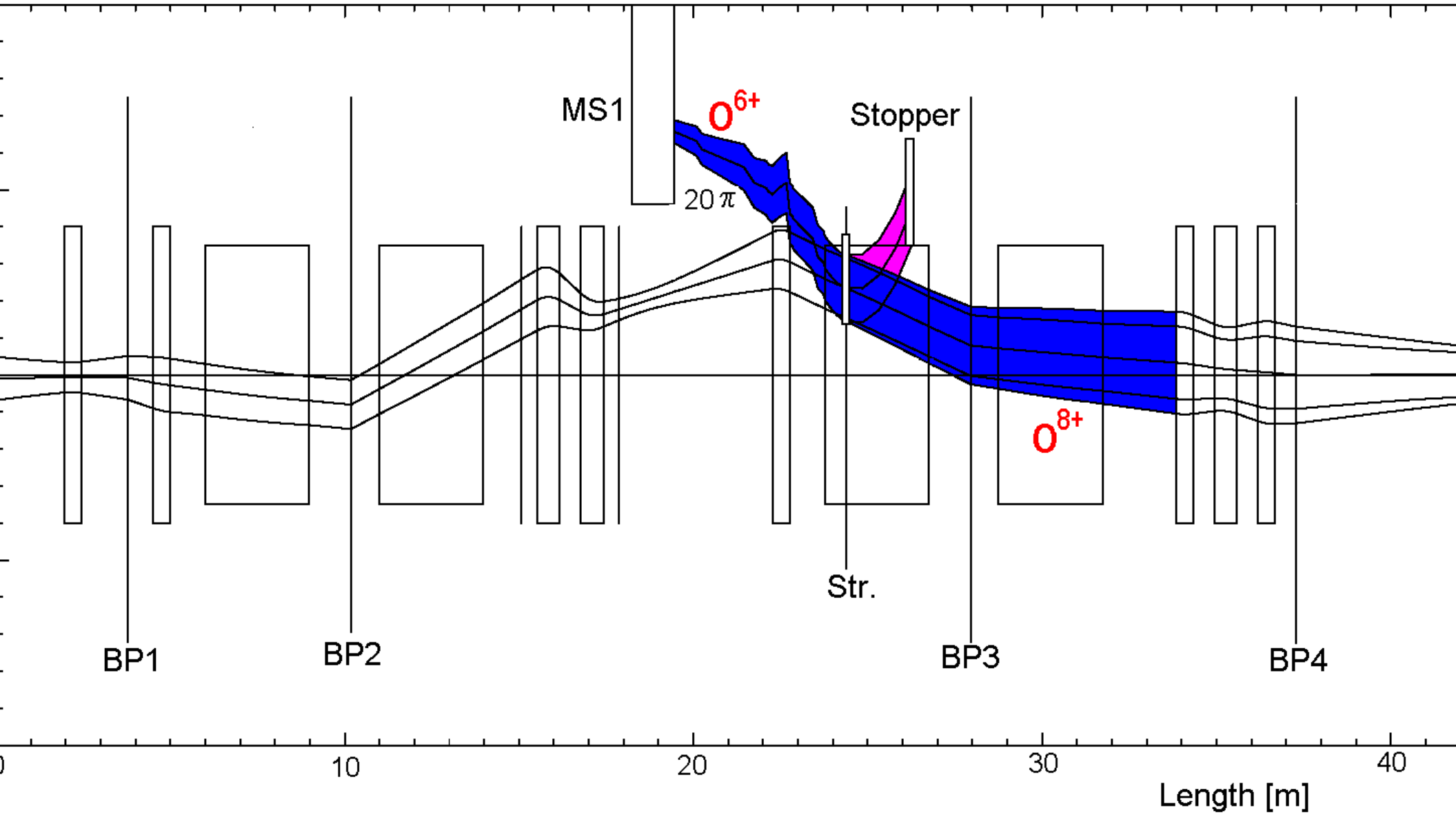
Three injection modes will be chose,

1) **Stripping injection (A≤20) + E-cooling →→ I=10^{10}**
2) **MMI + RF stacking + E-cooling (20⩽A⩽40) →→ I=10^{9}**
3) **MMI + E-cooling (A>40) →→ I=10^{7}**

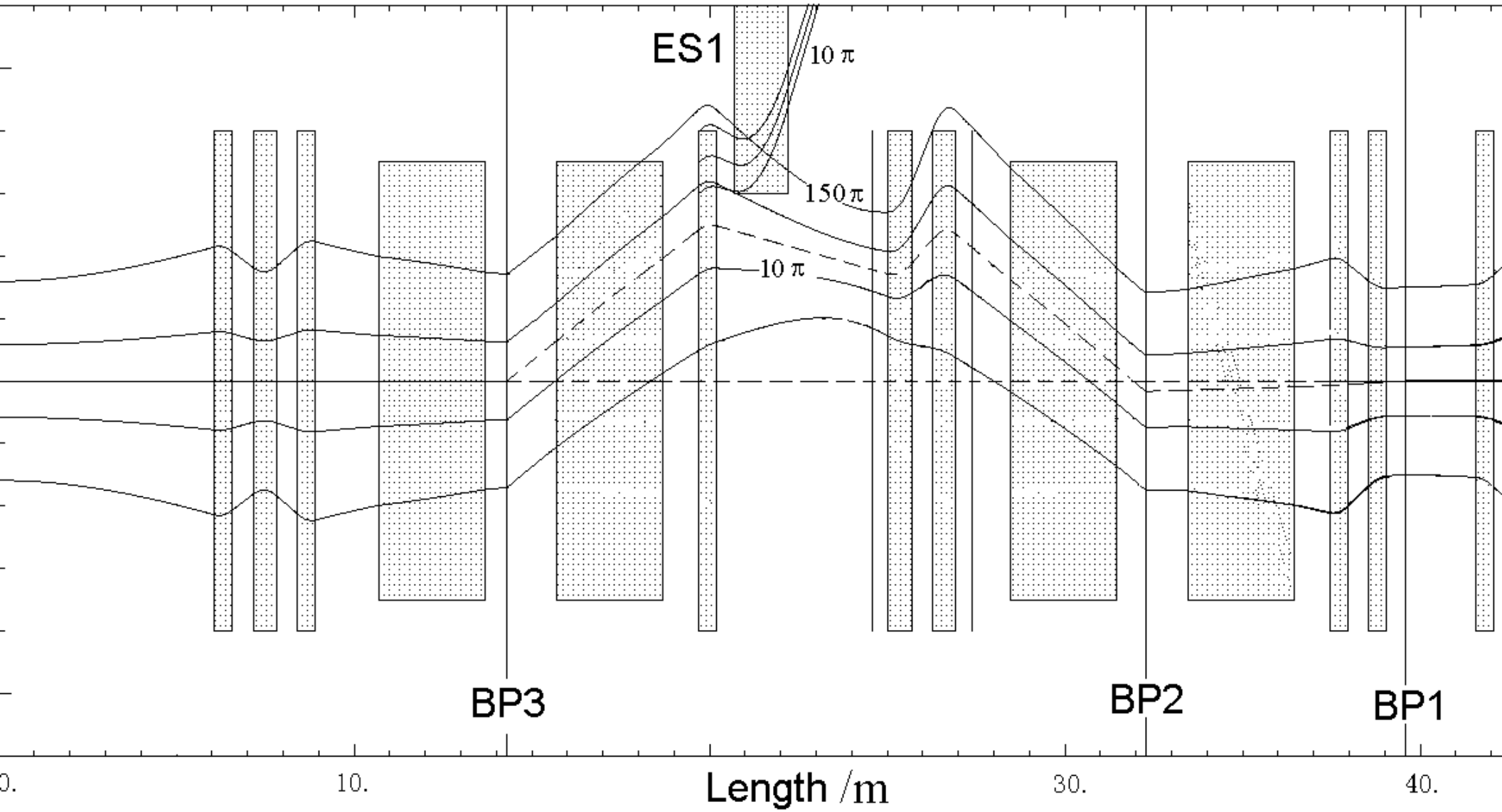
Injection section of CSRm



Move away while STI

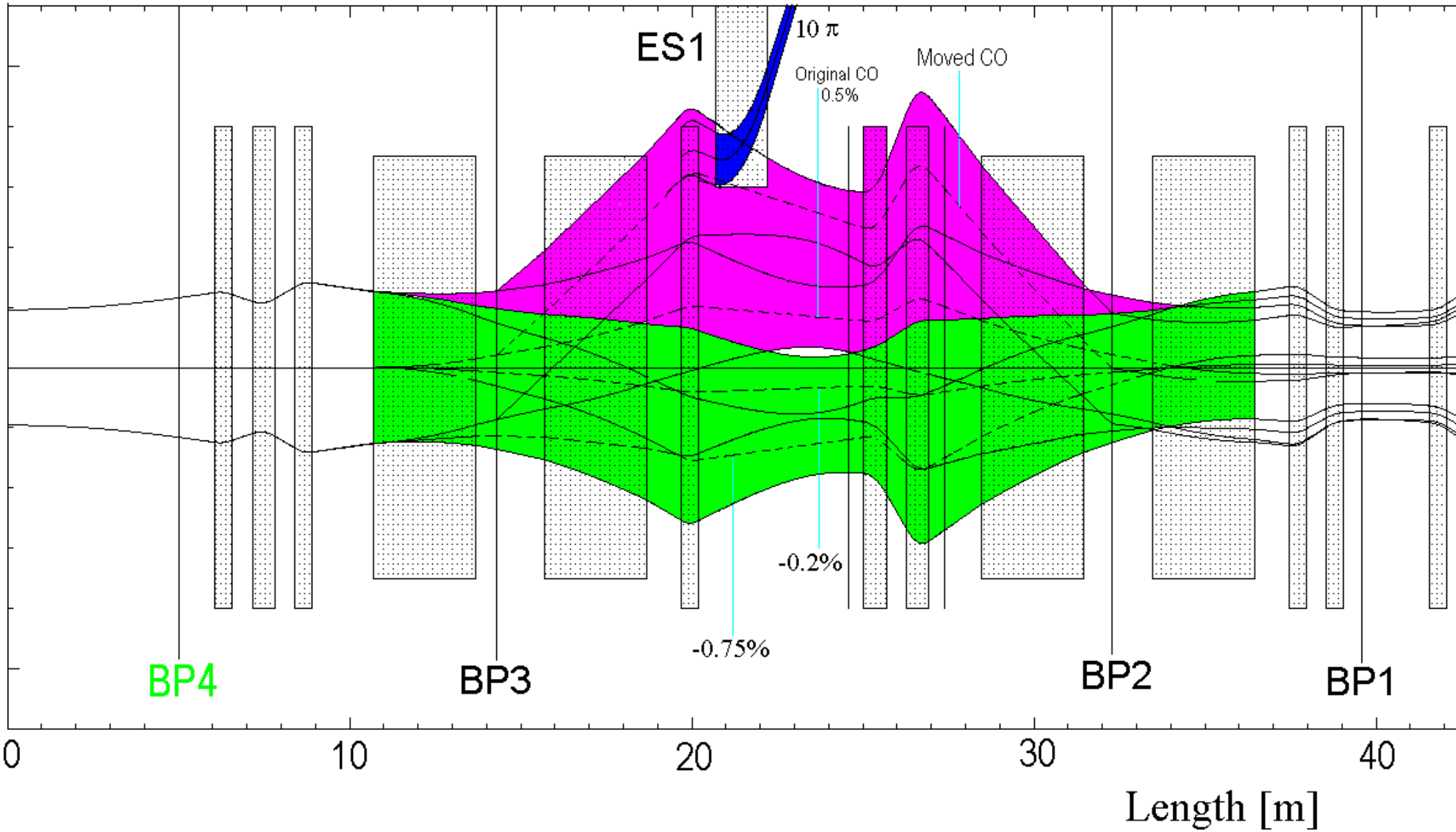


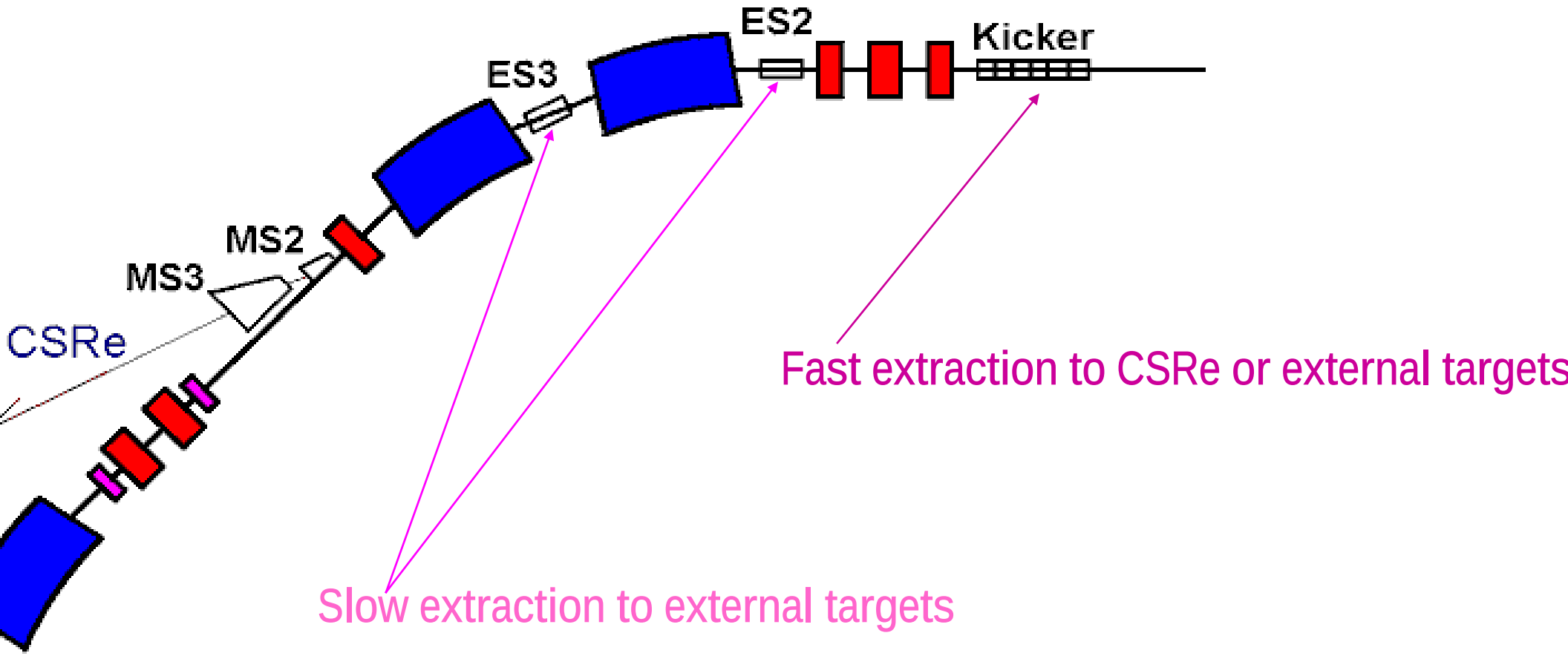
Orbits of the stripping injection in CSRm



Orbits of the Multiple Multi-turn Injection in CSRm

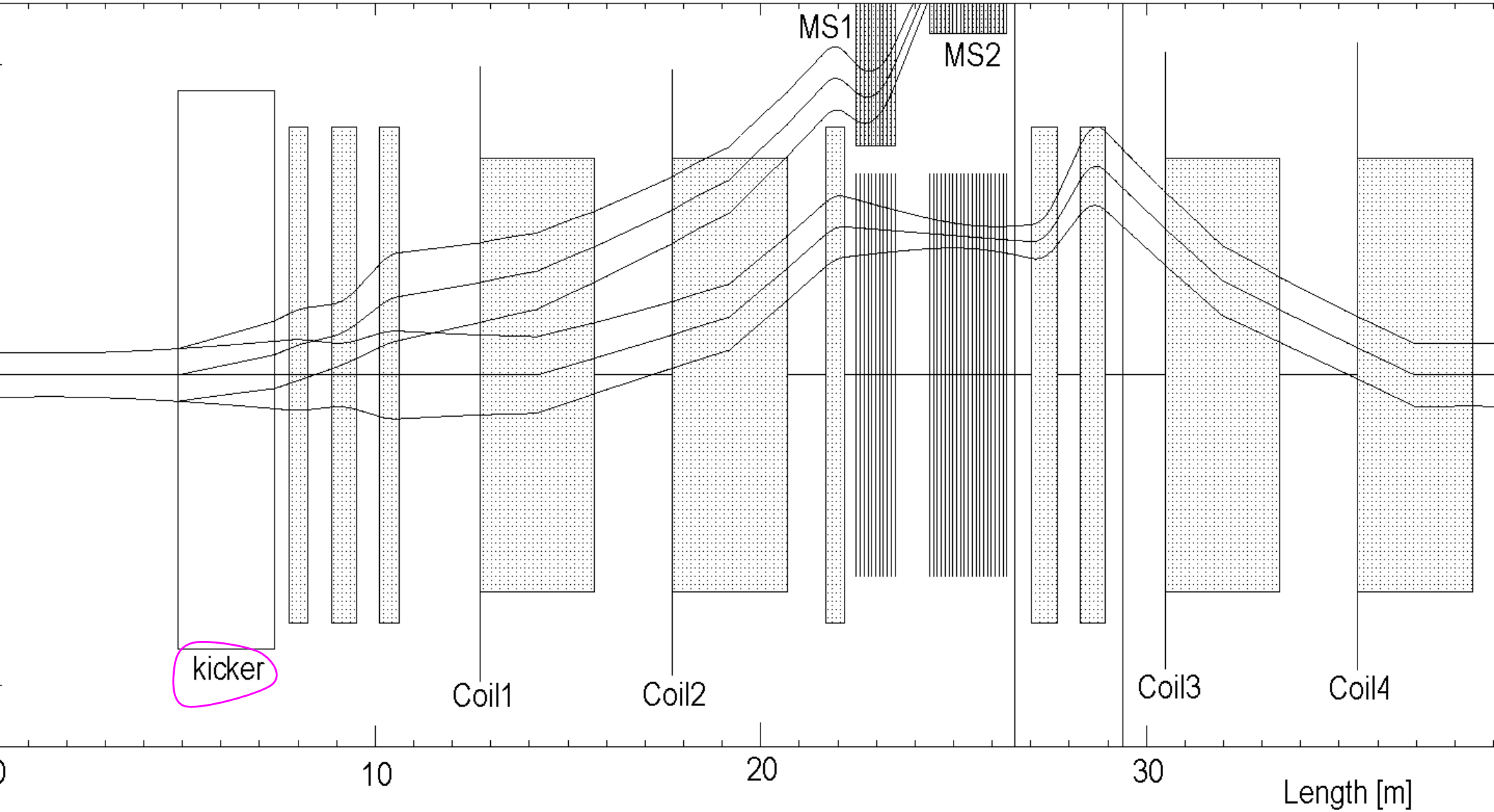
Orbits of the MMI+RF stacking in in CSRm



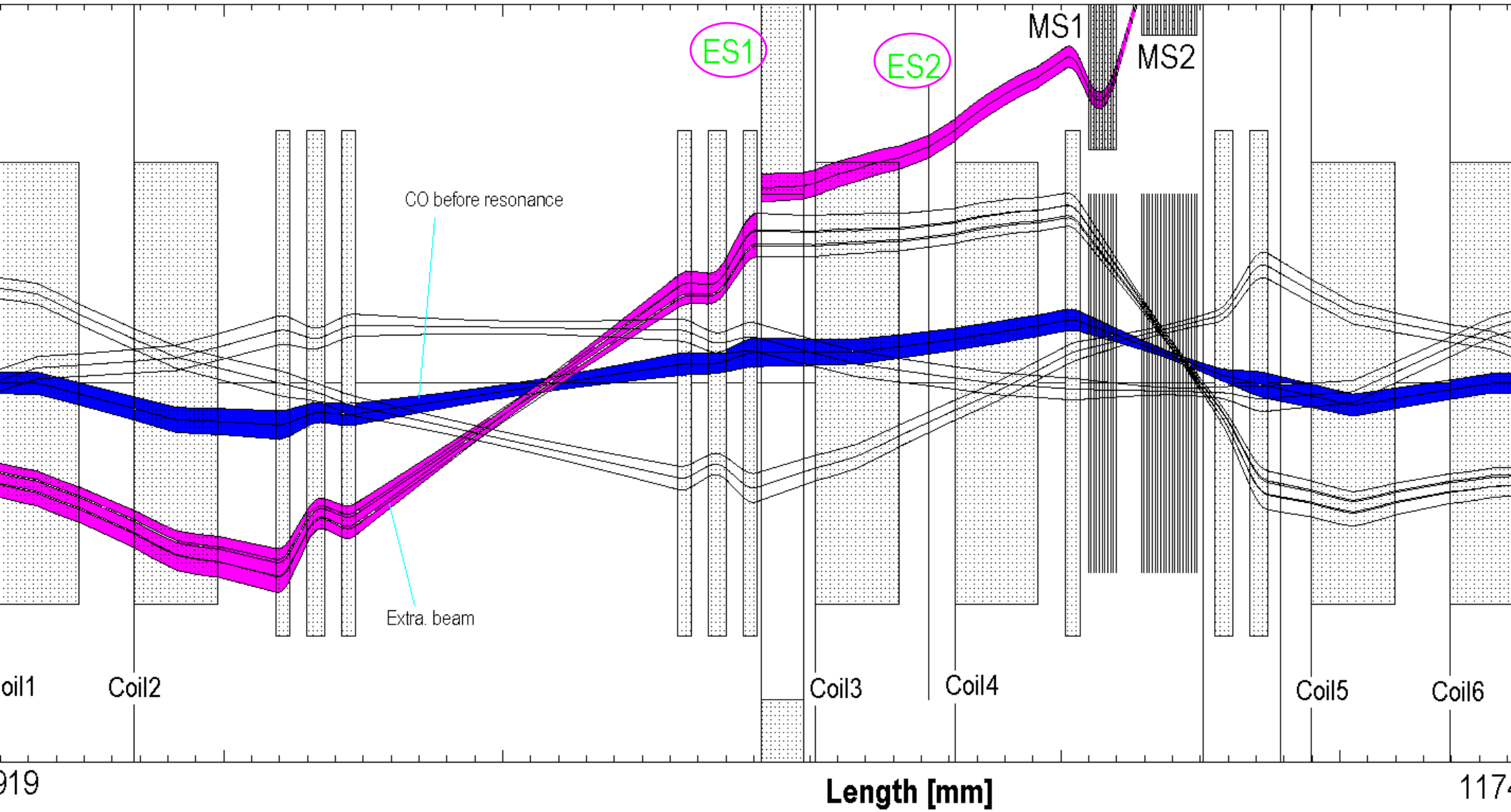


Extraction section of CSRm

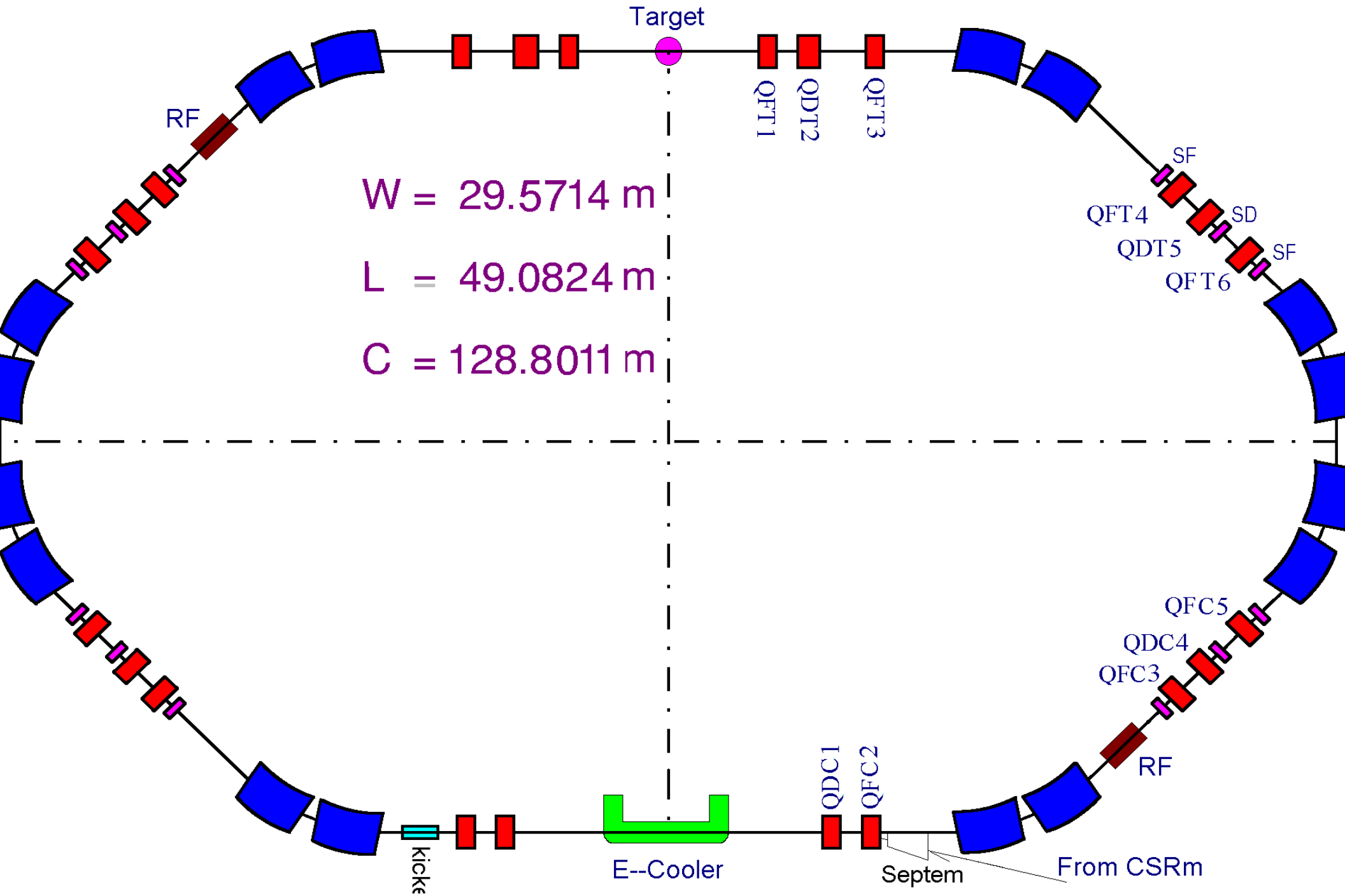
Orbits of the beam fast extraction in CSRm



Orbits of the slow-extraction with 1/3 resonance in CSRm



Blue one is the CO before resonance; the others are the orbits of the last three turns)



CSRe lattice layout

Three Lattice Modes of CSRe

- **Internal-Target Mode**

  Small β-amplitude in target point

  Large transverse acceptance for internal-target experiments

  A_h=150πmm mrad, A_v=75πmm mrad

- **Normal Mode**

  Large momentum acceptance, $\Delta P/P$ = 2.6%

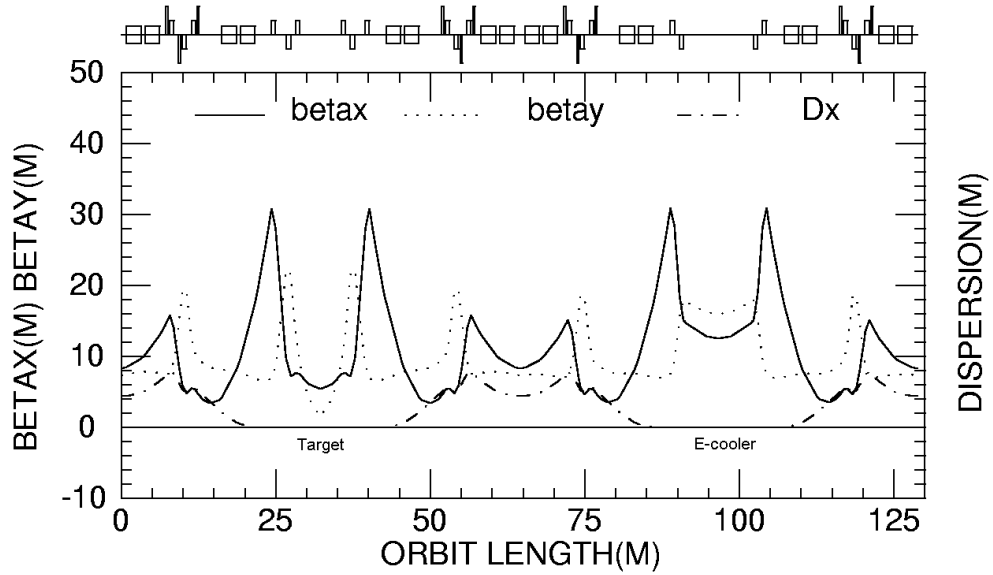
  For high-precision mass spectroscopy

- **Isochronous Mode**

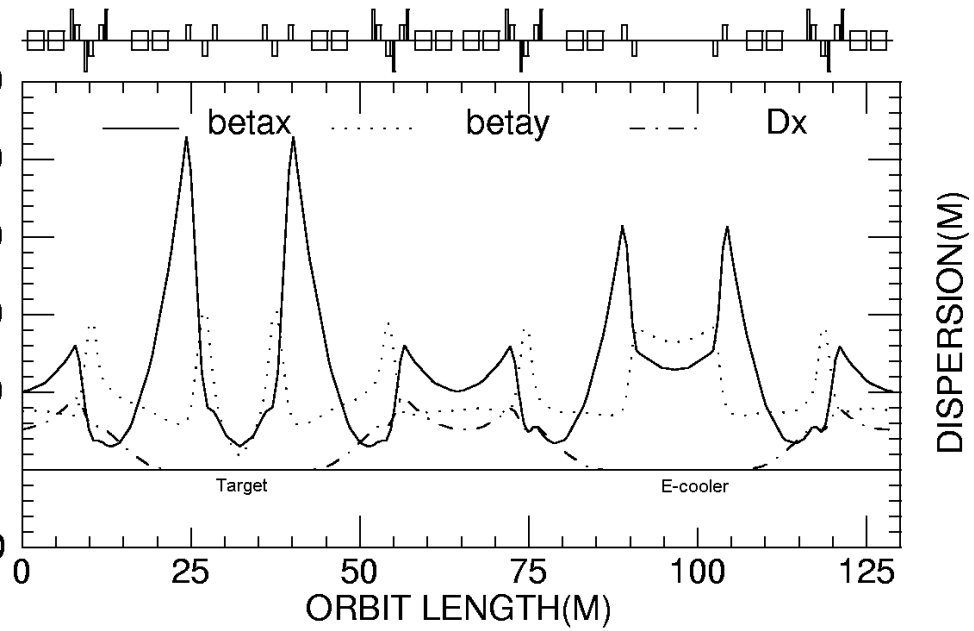
  Small transition γ_{tr} = Beam energy γ of several hundred MeV/u

  For the mass measurement of the short-life-time RIB with TOF.

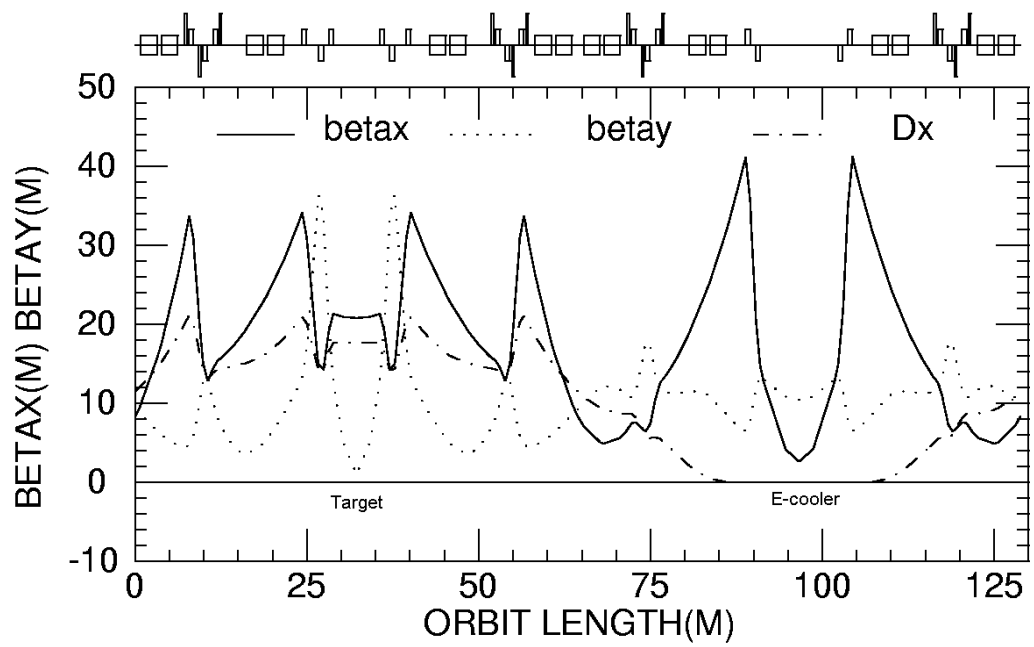
Twiss Functions of CSRe



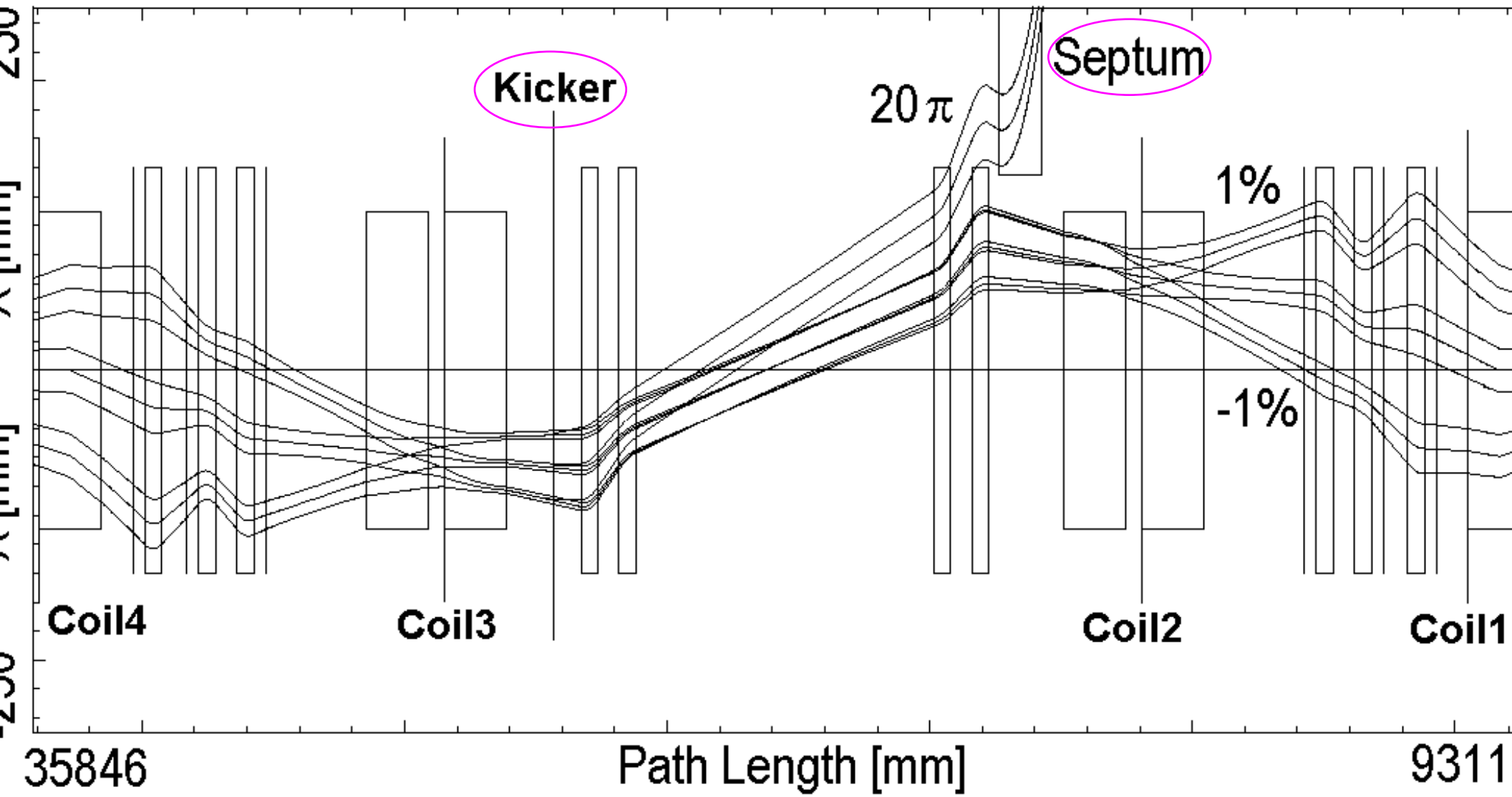
Normal Mode



Internal-Target Mode



Isochronous Mode



Single-turn injection orbit of CSRe

Beams from beam-line with $\Delta P/P \sim \pm 1\%$ can be accepted

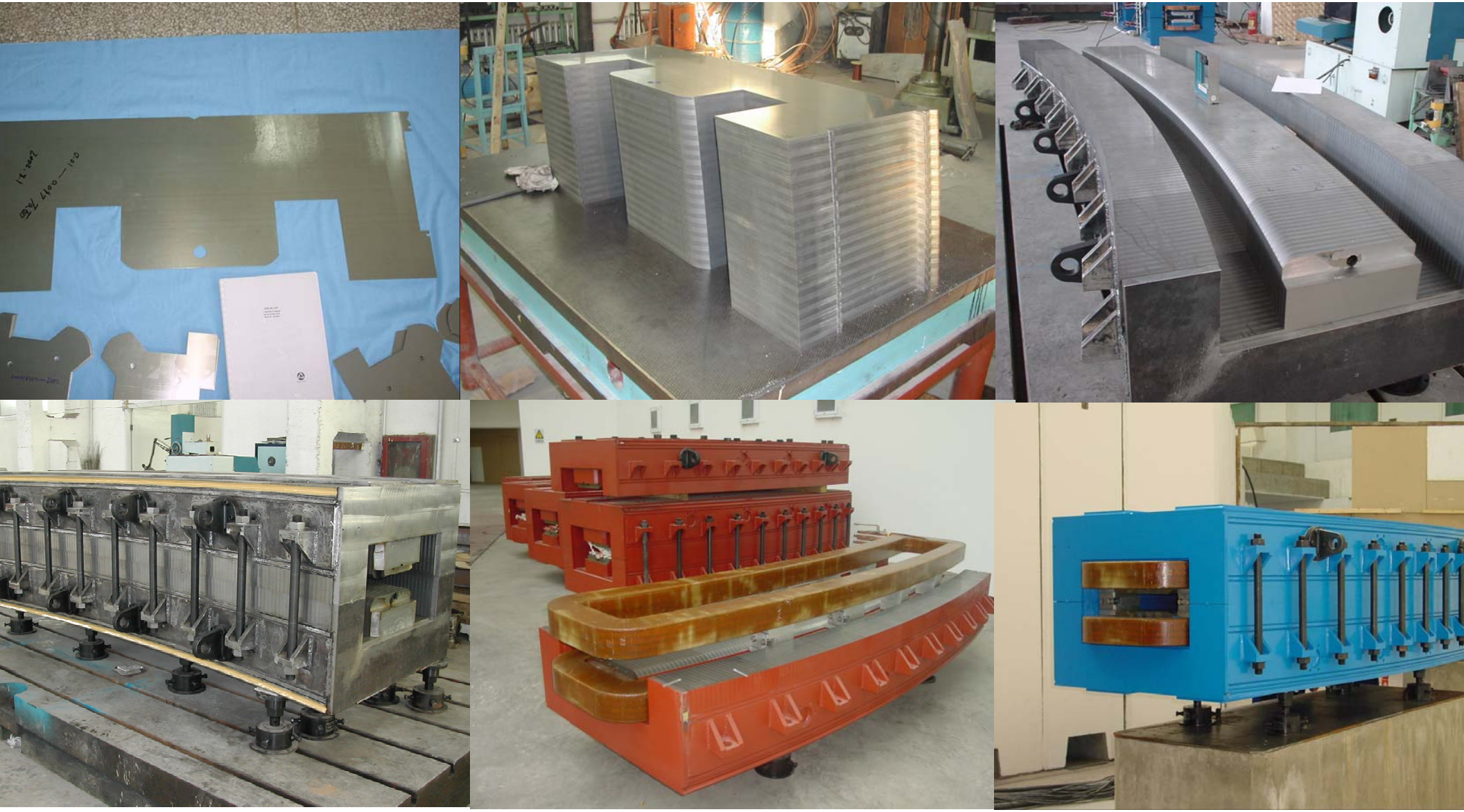
Useful aperture of CSRe

Dipole	Quadruple
$220 \times 70\ mm^2$	$280 \times 140\ mm^2$
$B_{Max.} = 1.6\ T$	$K_{Max.} = 7\ T/m$

Beam Acceptance

Internal-Target Mode	Normal Mode	Isochronous Mode
A_h=150 π mm-mrad ($\Delta P/P=\pm 0.5\%$)	A_h=150 π mm-mrad ($\Delta P/P=\pm 0.5\%$)	A_h=20 π mm-mrad ($\Delta P/P=0.7\%$)
A_v=75 π mm-mrad	A_v=80 π mm-mrad	A_v=20 π mm-mrad
$\Delta P/P=2.0\%$ (ε_h=10 π mm-mrad)	$\Delta P/P=2.6\%$ (ε_h=10 π mm-mrad)	$\Delta P/P=0.7\%$ (ε_h=20 π mm-mrad)

CSRm-dipole Fabrication



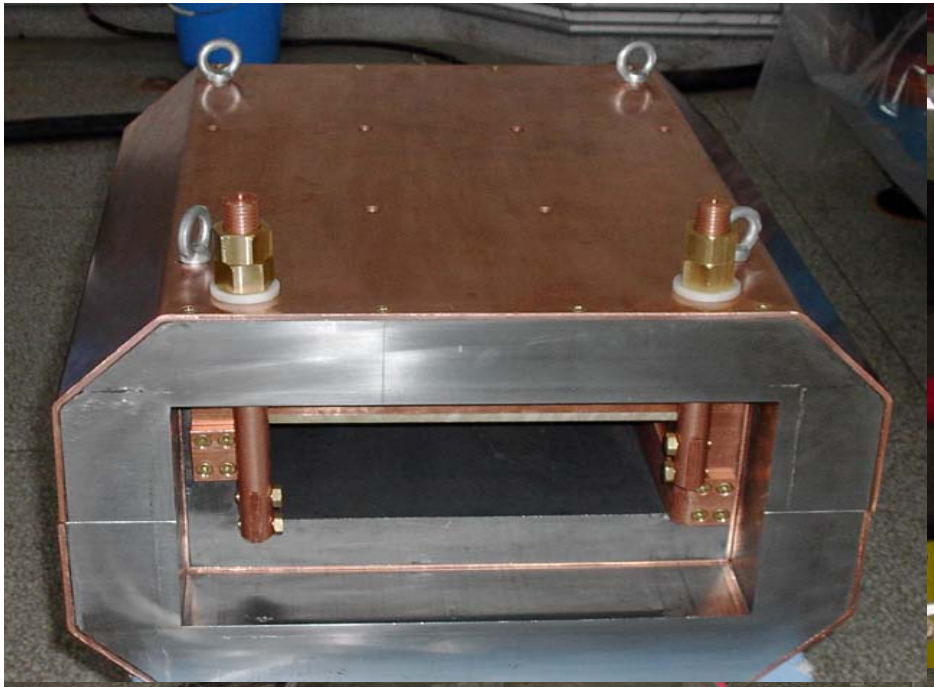
Angle=22.5^0, Radius=7.6m

CSRm-Quadruple Fabrication

L=0.5m, 0.65m, Φ=170mm

Special magnets of CSRm

mp

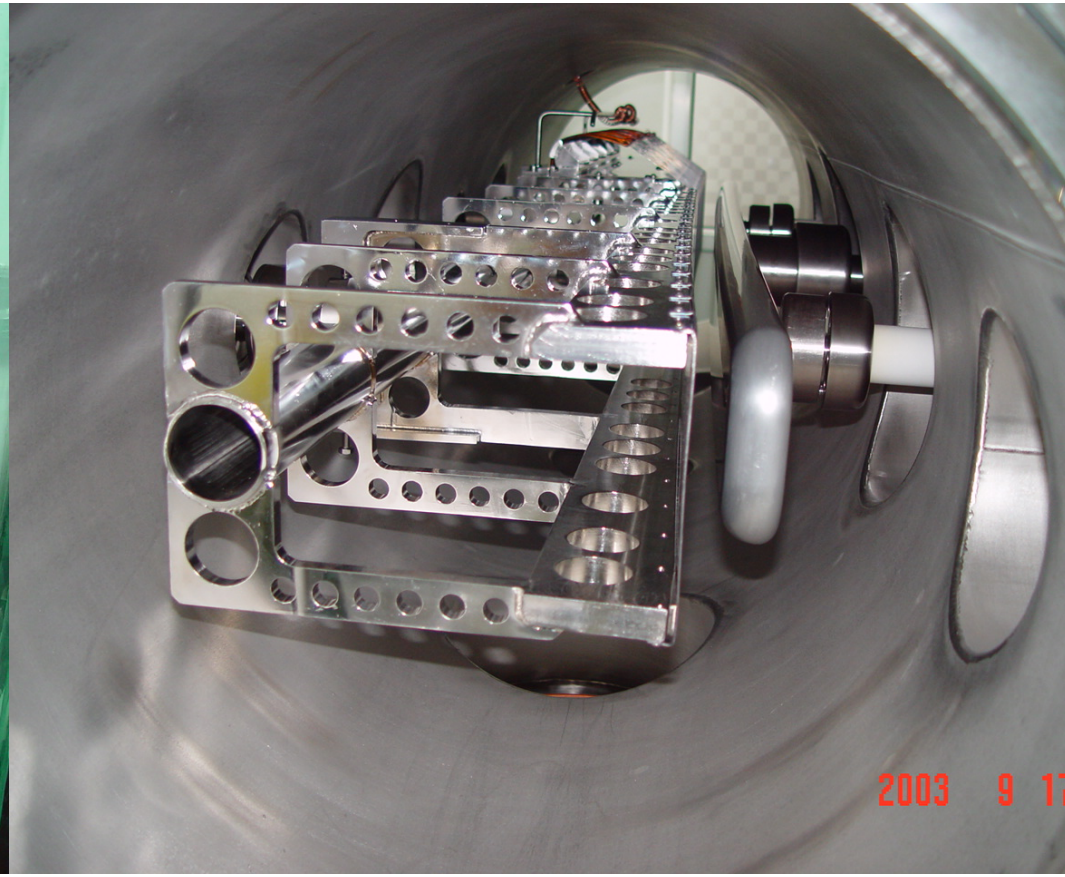


C

S

Septu

Static-electric septum (Injection)



L = 2 m, $V_{max.}$= 160 kV

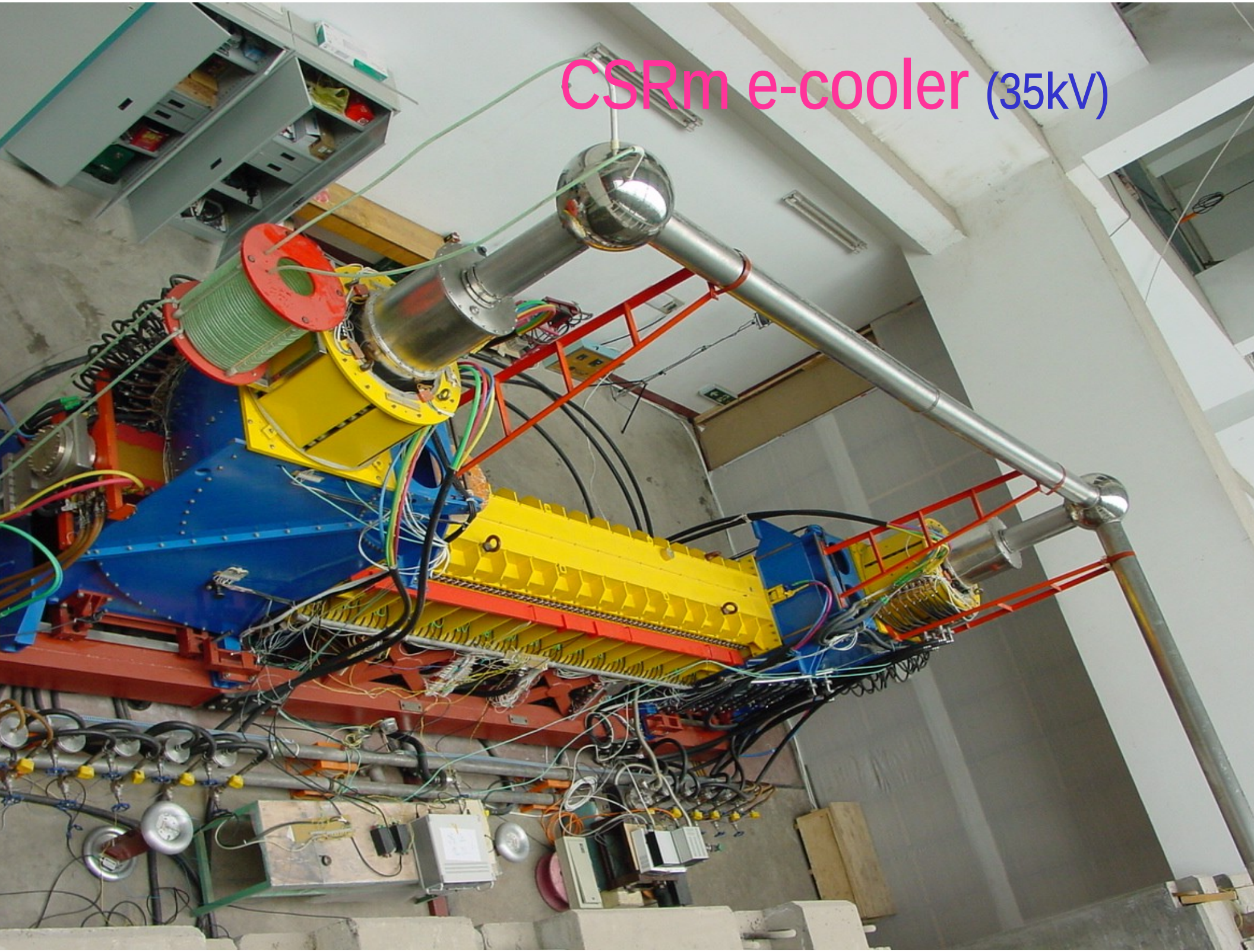
PS for quadruple

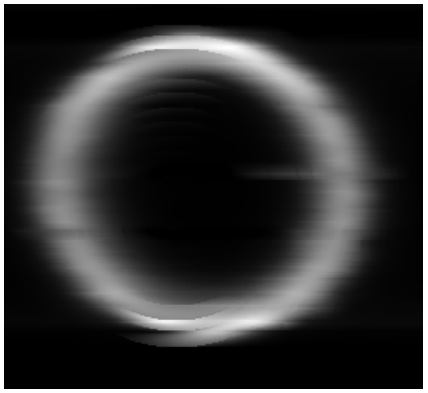
Ripple ~ 5×10^{-6} , <1kHz

UHV System of CSR

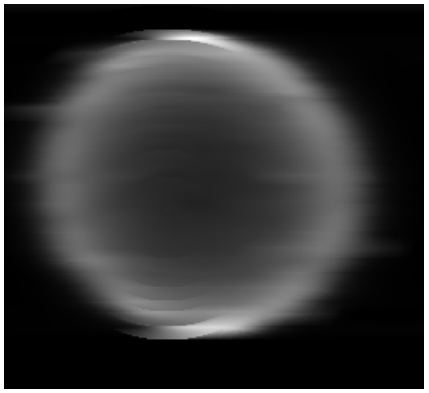
Bake-out temperature: 250°C, Pressure: 1.1×10^{-11} mbar

CSRm e-cooler (35kV)

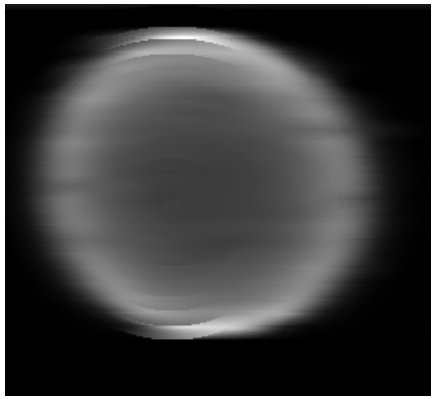




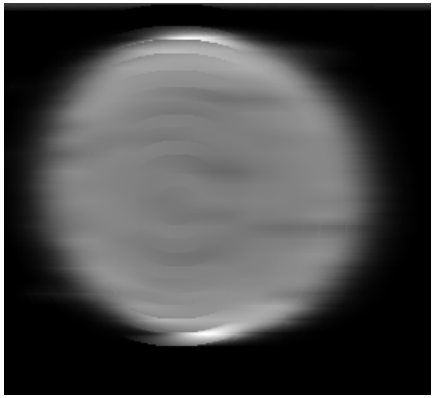
$U_{contrrol}/U_{anode}$= 0.6/0.9 kV



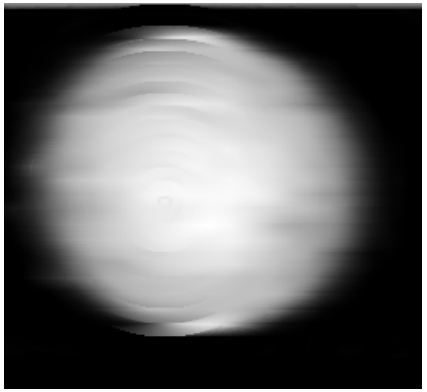
$U_{contrrol}/U_{anode}$= 0.3/0.9 kV



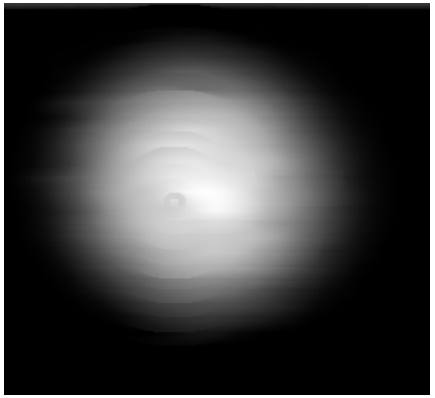
$U_{contrrol}/U_{anode}$=0.2/0.9 kV



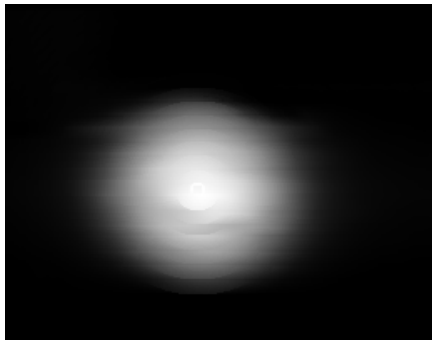
$U_{contrrol}/U_{anode}$=0.1/0.9 kV



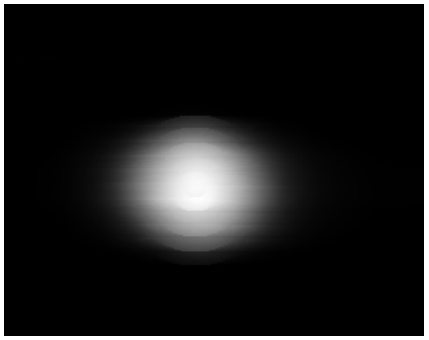
$U_{contrrol}/U_{anode}$= 0.05/0.9 kV



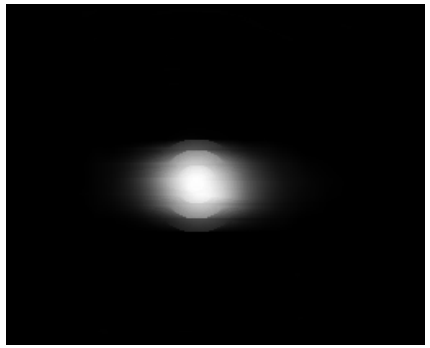
$U_{contrrol}/U_{anode}$= 0/1.4 kV



$U_{contrrol}/U_{anode}$= –0.2/2.8 kV

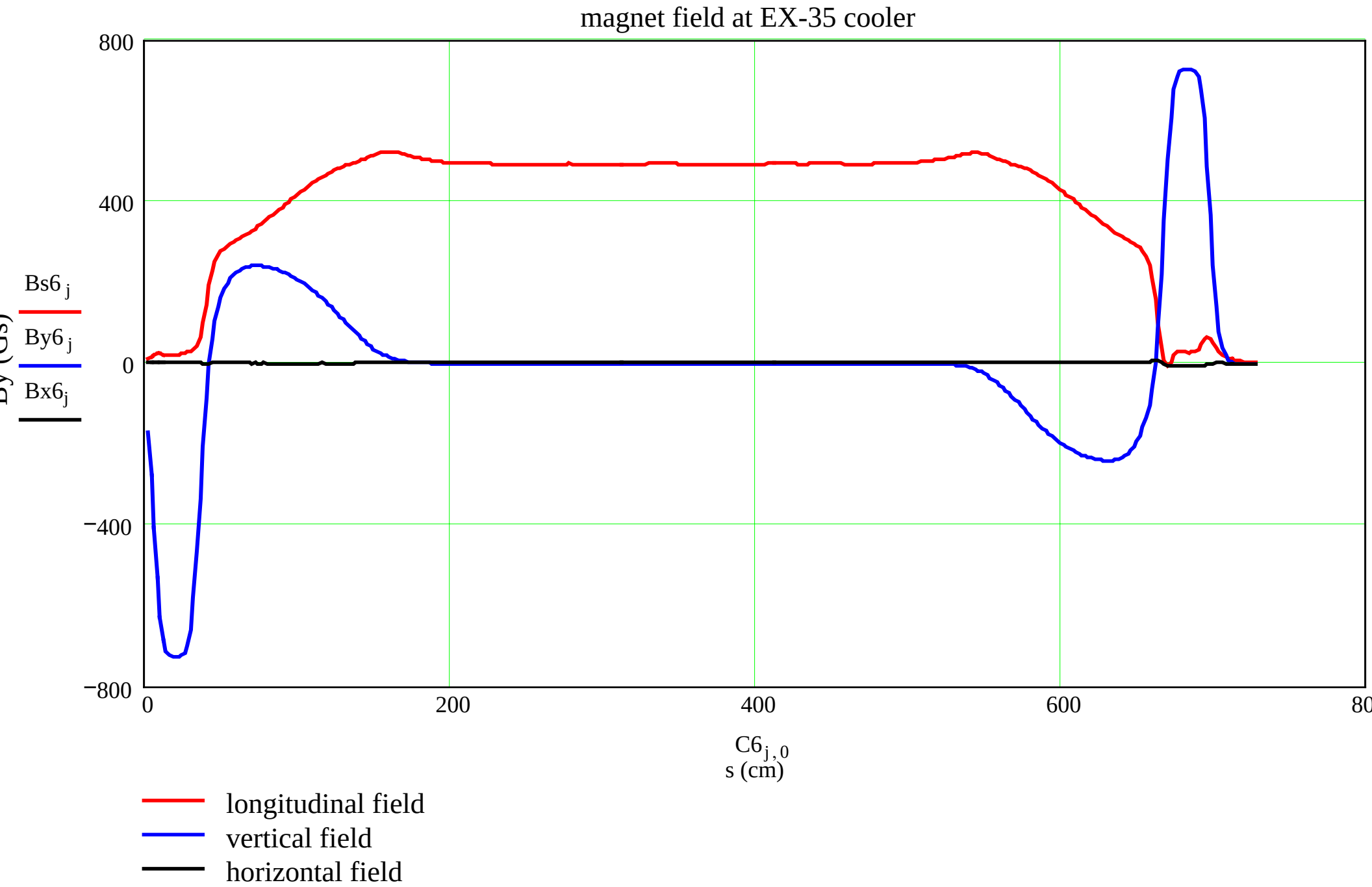


$U_{contrrol}/U_{anode}$= -0.4/2.8 kV

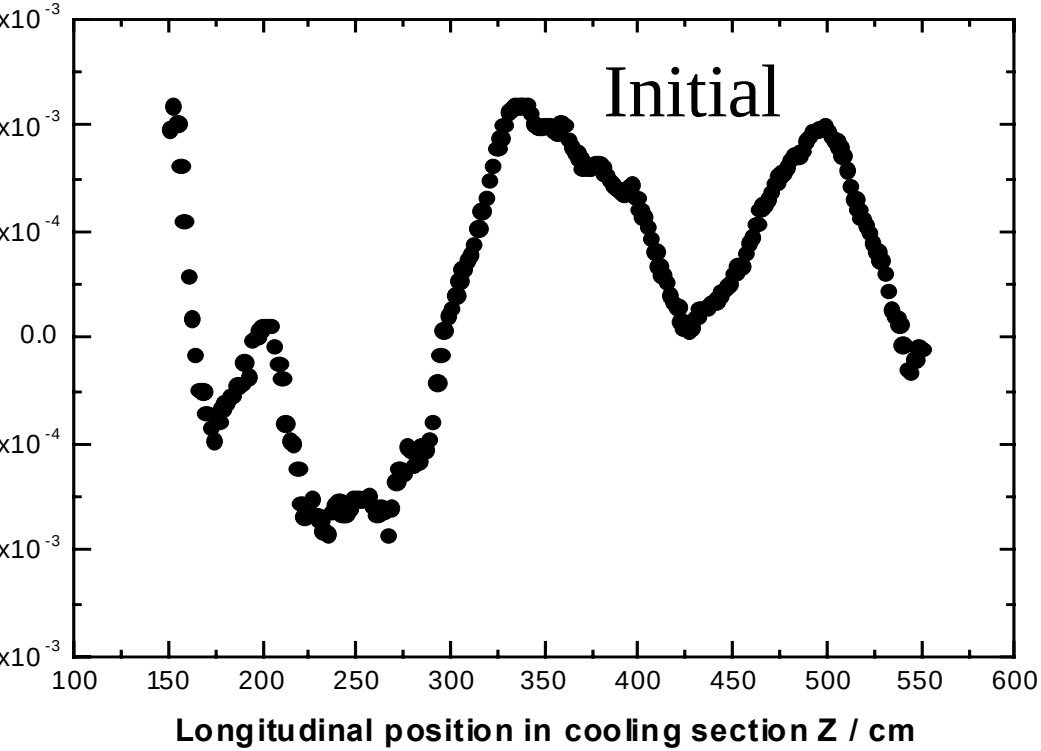


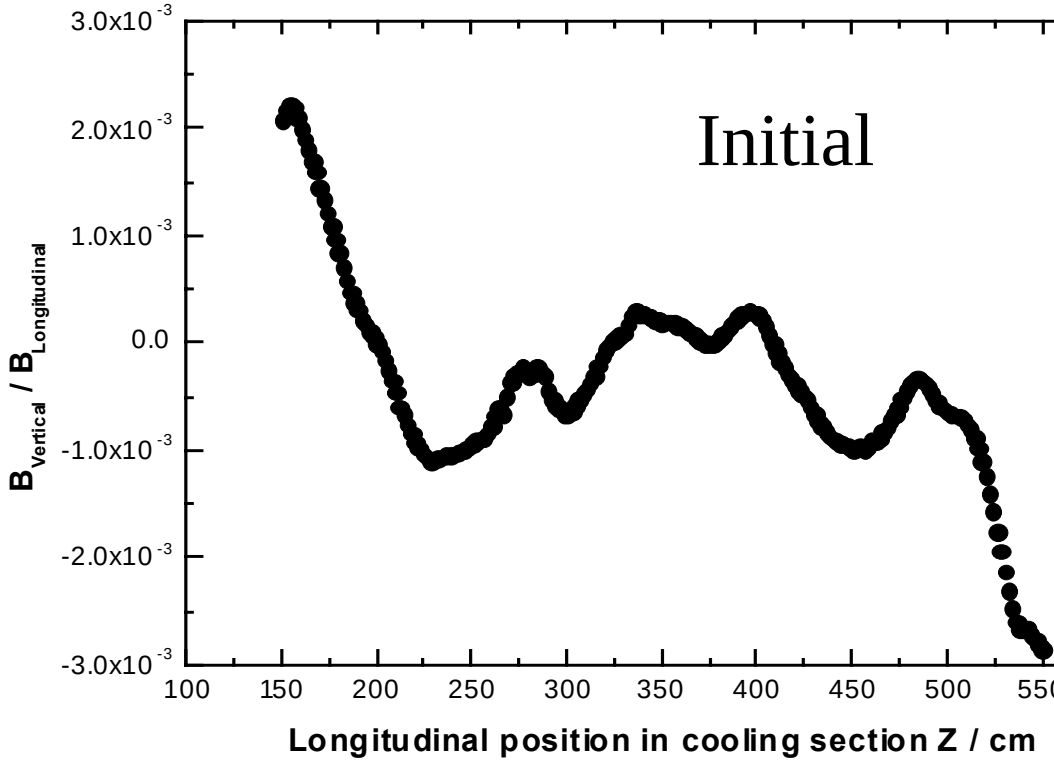
$U_{contrrol}/U_{anode}$= –0.6/2.8 kV

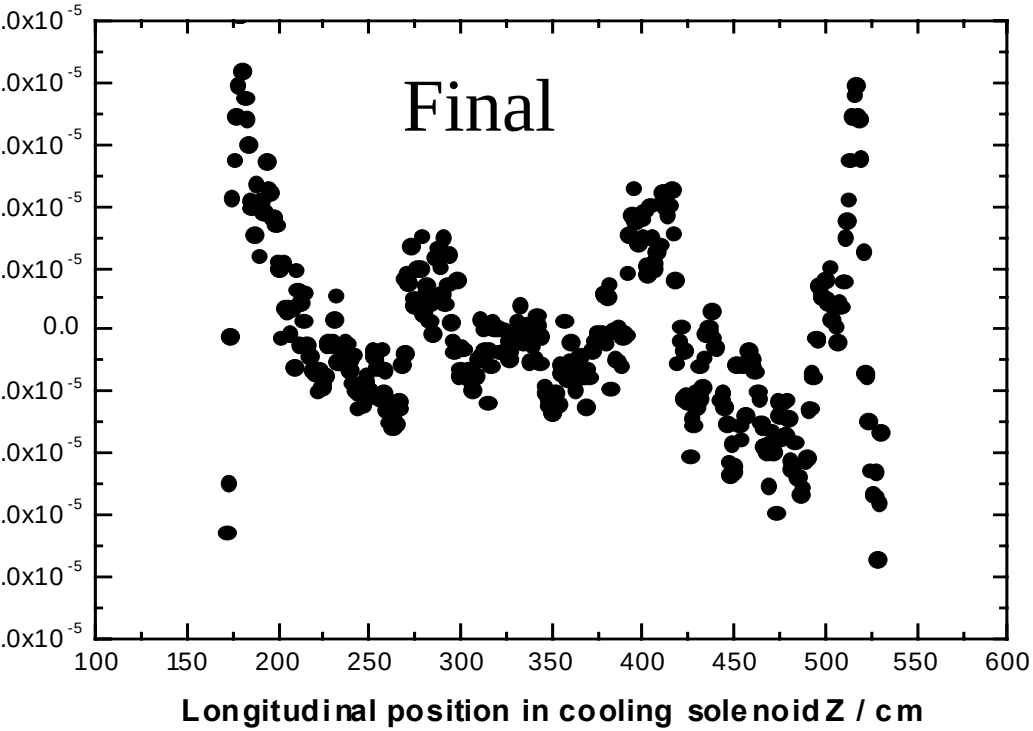
Electron beam distribution for different voltage on the control electrode and the anode

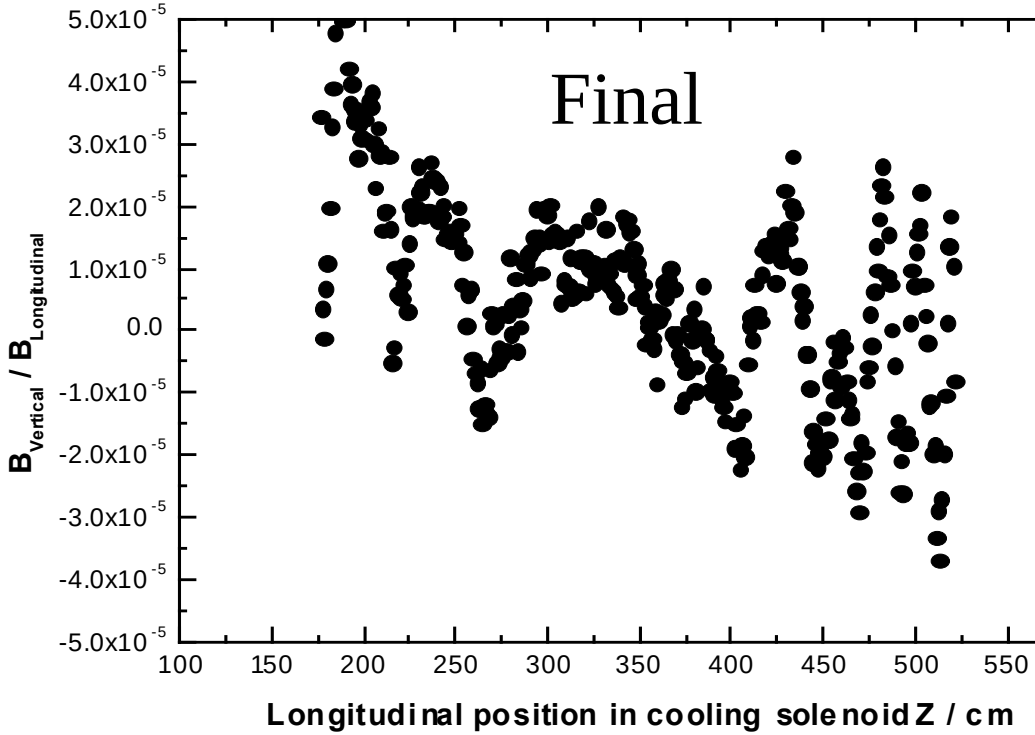


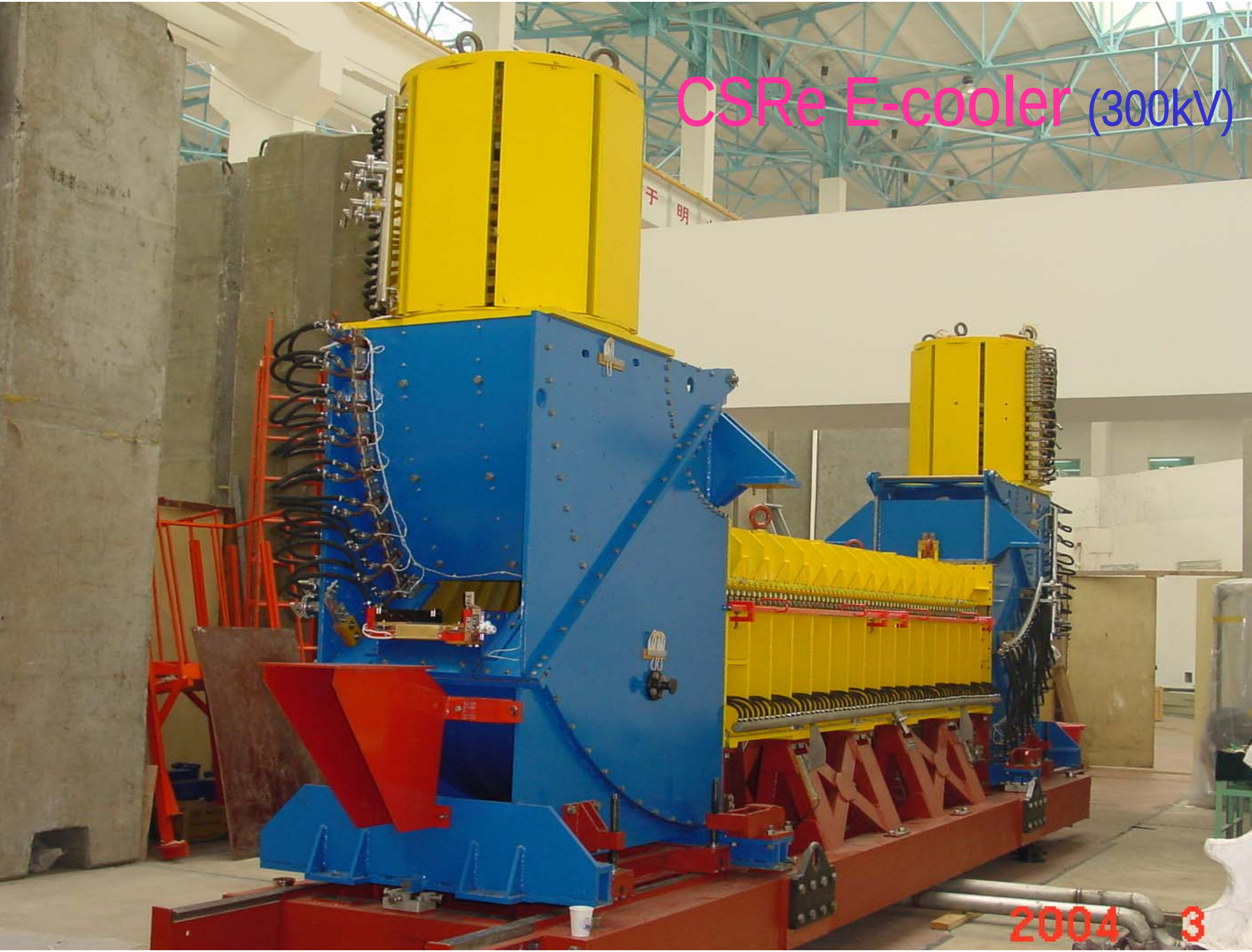
Magnetic-field measurement results in the cooling section


Initial
Longitudinal position in cooling section Z / cm


Initial
$B_{Vertical} / B_{Longitudinal}$
Longitudinal position in cooling section Z / cm


Final
Longitudinal position in cooling solenoid Z / cm


Final
$B_{Vertical} / B_{Longtudinal}$
Longitudinal position in cooling solenoid Z / cm


CSRe E-cooler (300kV)
2004 3

Budker Institute of
Nuclear Physics
f = 0.24 ~ 1.81 MHz
V = 7 kV
CSRm RF-cavity for acceleration
2004 3

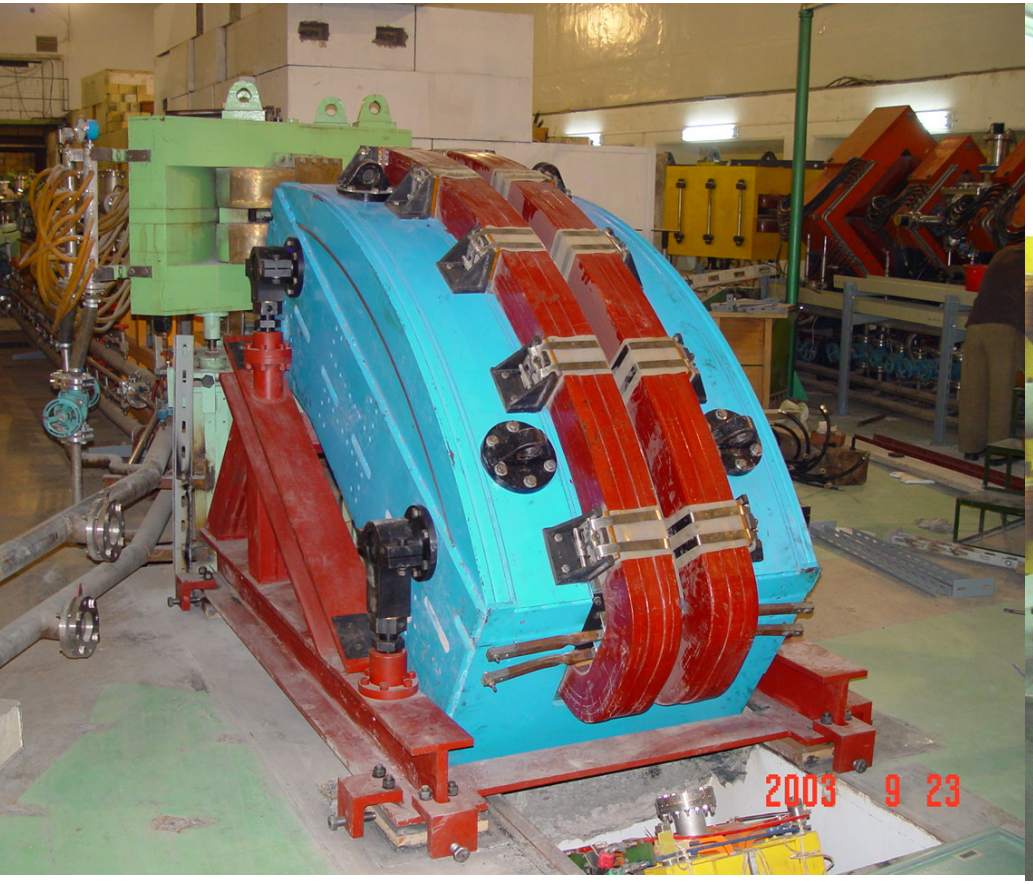
CSRm RF-cavity for accumulation

f = 6 ~ 14 MHz

V = 20 kV

Internal-target of CSRe

Injection-line bended underground



Injection beam-line bended to the storage-ring level

SRm injection-line channel
2004 3 2

Enter of CSRm
2004 3

SRm Hall

2004 3 2

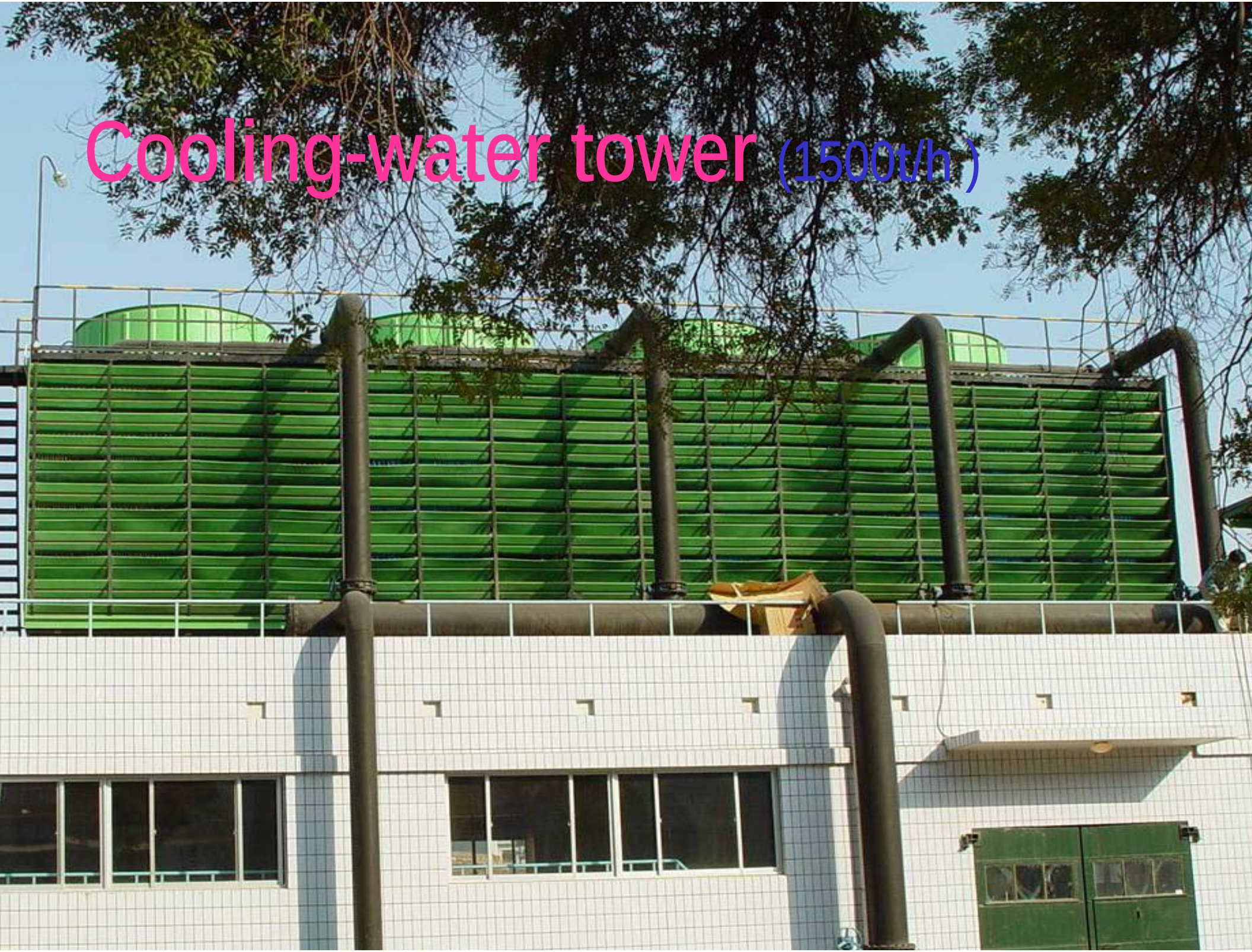
2004 3

2004 2 6

Power-supply system

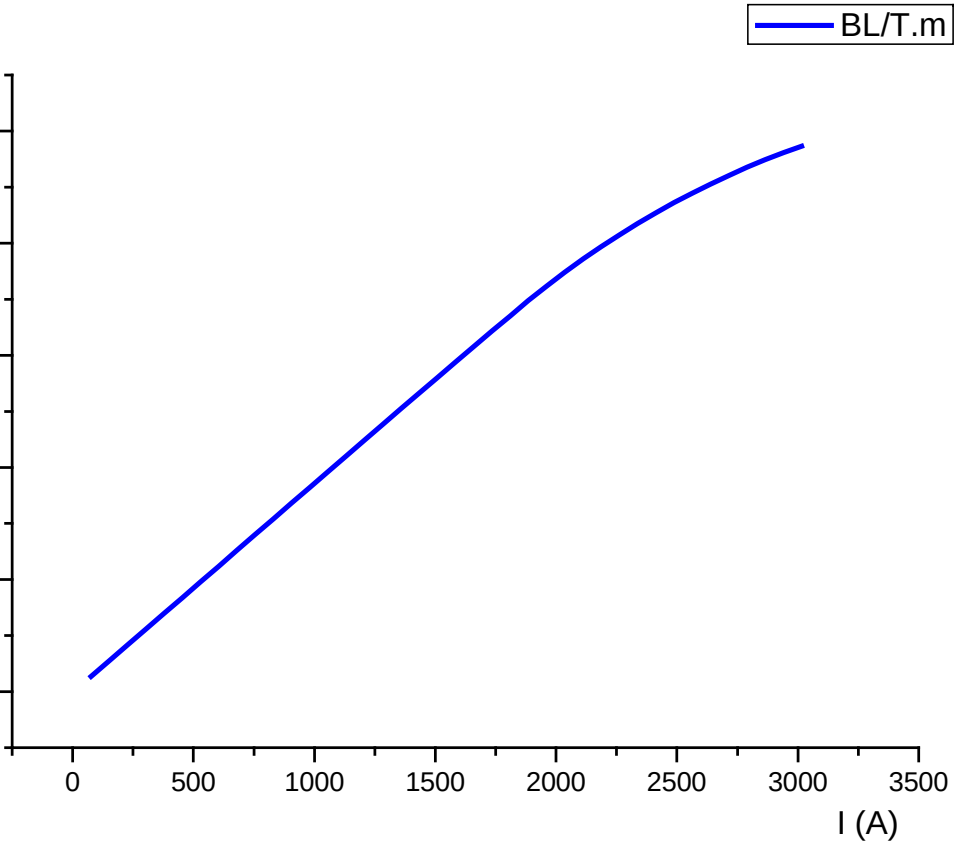
Total Net Power: 12MW

Cooling-water tower (1500t/h)

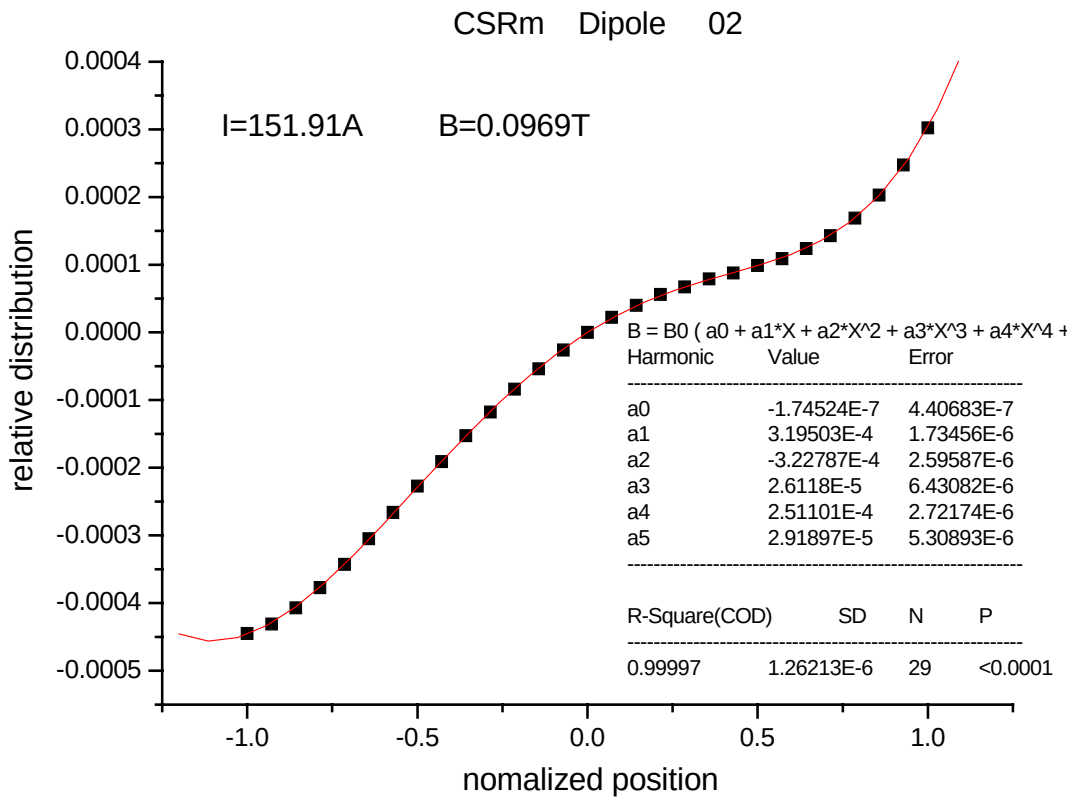


Measurements for the CSRm-dipole

Results of CSRm-dipole

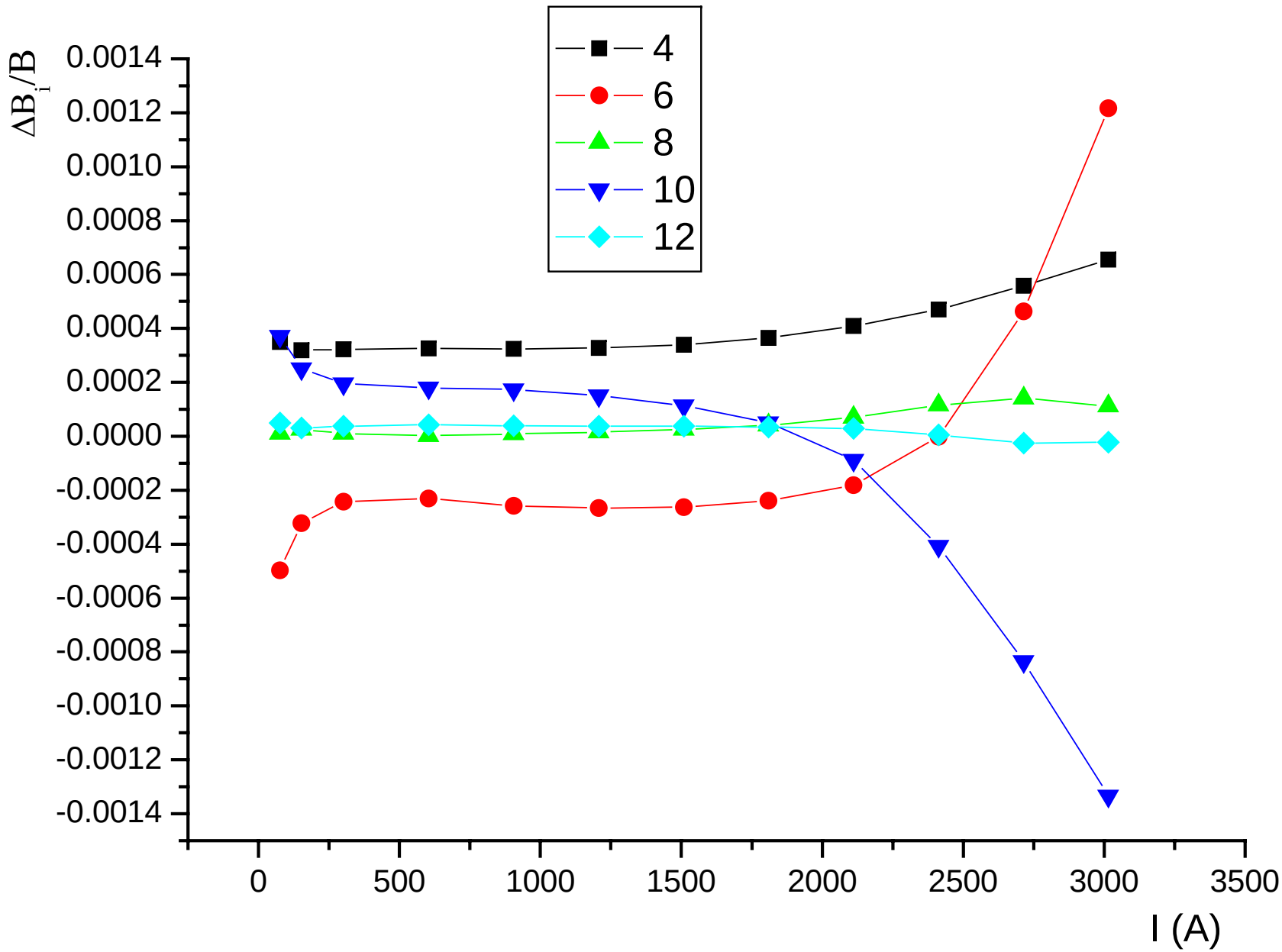


BL-I curve

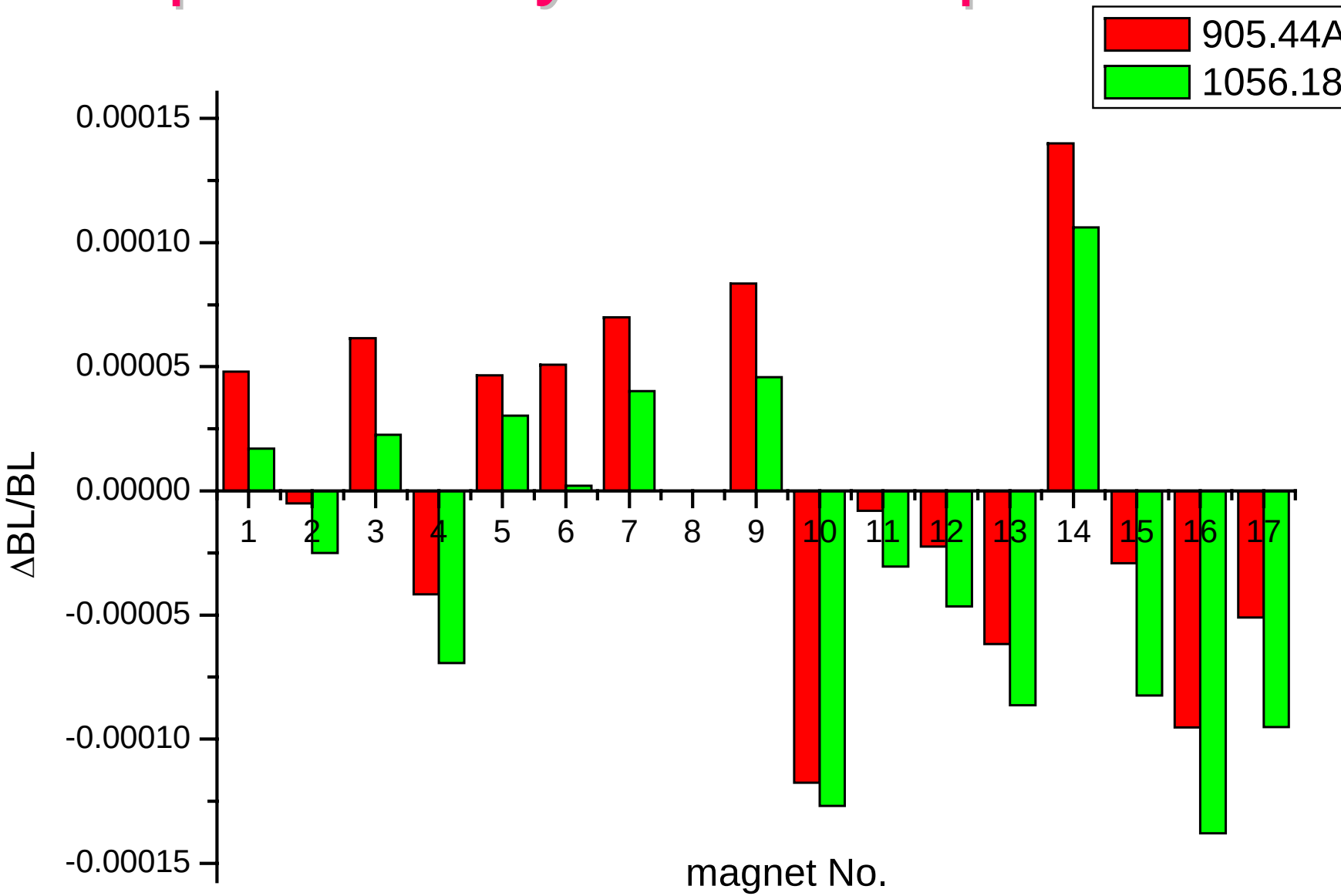


Width of the B-field at 150A (Injectio

Multipole components in CSRm-dipole

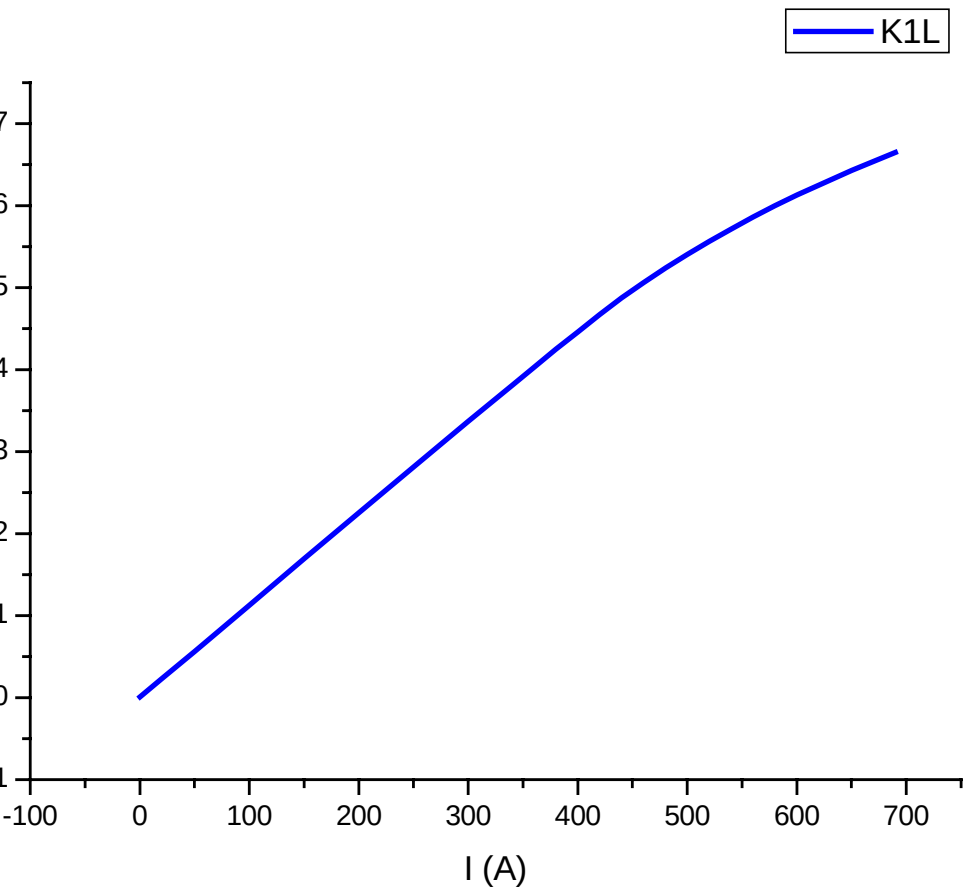


Reproducibility of CSRm-dipole

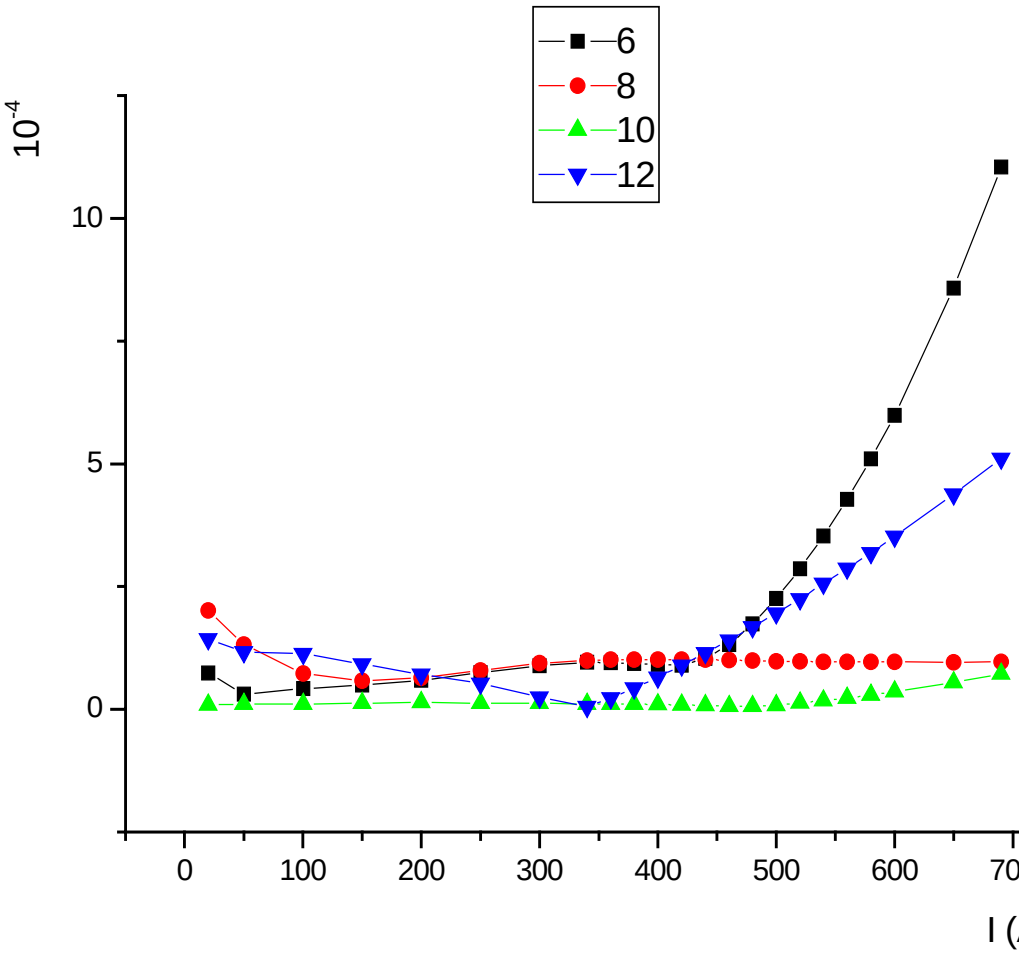


Measurements for the CSRm-quadrupole

Results of CSRm-quadrupole



BL-I curve

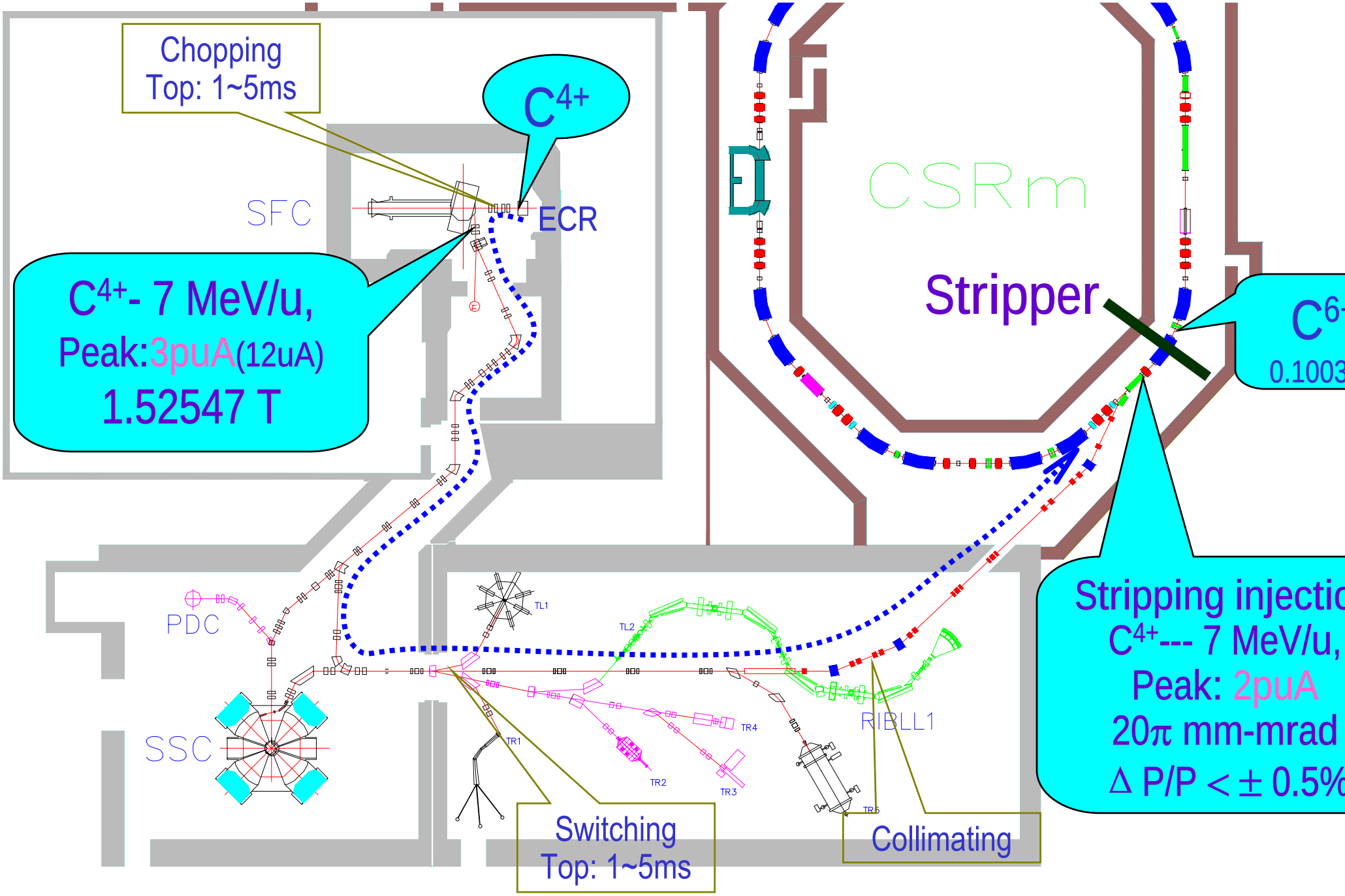


Multipole components

Schedule

1993 -----1996	Proposal
1998.7	Approved
1997 ----- 2001	R&D, Prototype
1999 ----- 2004	Construction & Fabrication
2003 ----- 2005	Installation
2004.5-7	Inject first beam in CSRm
2005	First commissioning

C^{4+} Injection for the CSRm 1st-commissioning



CSRm status

2004.03.18

Sub-system	Status
Magnet	Installation, ramping measurements
PS	Installation & tuning
Vacuum	Prepare baking
RF	Off-line tuning
E-cooler	Off-line operation
Inject. & Extra. elements	Installation, kicker on fabrication
Diagnosis	Test & assembling
Alignment	On going
Control	On going
Water & Power	Installation

Thank
s

CSRe can be used as a high resolution

Mass Spectrometer

$$\frac{df_{rev}}{f_{rev}} = \left(\frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}\right)\frac{dP}{P} - \frac{1}{\gamma_t^2}\frac{d(m/q)}{m/q}$$

$$R_q^{-1} = \left(\frac{\gamma_t^2}{\gamma^2} - 1\right)\frac{\Delta P}{P}$$

Normal mode : $\gamma \neq \gamma_{tr} \sim 2.624$

For those long lifetime nuclei (>5s)

E-cooling + Schottky Diagnosis

($\Delta P/P \sim 10^{-6}$) (Revolution frequency spectrum)

$R_q^{-1} \sim 4 \times 10^{-6}$

Momentum Acceptance : $\Delta P/P =$ 2.6 %

2) Isochronous mode : $\gamma = \gamma_{tr} \sim 1.395$ (E = 370MeV/u

For those short lifetime nuclei (μ s)

10 turns ~ 1km $t_{flight} \sim 5\mu s$

Time-Of-Flight --------→ $\Delta t/t \sim 10^{-5}$

Momentum Acceptance : $\Delta P/P =$ 0.7 %

Lattice parameters of CSRm

	Fast extraction mode	Slow extraction mode	Internal-target mode
Transition gamma	γ_{tr} = 5.418	γ_{tr} = 5.168	γ_{tr} = 5.119
Betatron tune	Qx / Qy = 3.64 / 2.61	Qx / Qy = 3.63 / 2.61	Qx / Qy = 3.695 / 2.73
Natural chromaticity	Q'_x / Q'_y = -3.17 / -5.37	Q'_x / Q'_y = -3.05 / -5.34	Q'_x / Q'_y = -3.73 / -5.78
Max. β-Amplitude	β_x/β_y =12.1/13.5 m (Dipole) β_x/β_y =15.4/30.5 m (Quadruple)	β_x/β_y =11.2/17.5 m (Dipole) β_x/β_y =13.5/32.2 m (Quadruple)	β_x/β_y =15.0/17.5 m (Dipole) β_x/β_y =17.5/35.6 m (Quadruple)
Max. Dispersion	$D_{max}(x)$=3.7m(Dipole, β_x=7.0m) $D_{max}(x)$=5.4m (Quad. , β_x=10.0m)	$D_{max}(x)$=3.2 m (Dipole, β_x=10.4m) $D_{max}(x)$=4.6m (Quad. , β_x=8.0m)	$D_{max}(x)$=4.3m (Dipole, β_x=7.0m) $D_{max}(x)$=5.7m(Quad. , β_x=8.0m)
Injection section	β_x= 8.0 m , D_x = 4.1 m (Septum) β_x= 9.7 m, D_x =3.9 m (Quadruple)	β_x= 10.0 m, D_x = 4.0 m (Septum) β_x= 11.9 m, D_x = 3.9 m (Quadruple)	β_x= 10.0 m , D_x =4.1 m (Septum) β_x= 11.4m, D_x = 4.1 m (Quadruple)
E-cooler section	β_x/β_y = 10.0/16.7 m , D_x = 0	β_x/β_y = 10.0/17.0 m , D_x = 0	β_x/β_y = 8.2/8.3 m , D_x = 0
Target	β_x/β_y = 10.0/16.7 m , D_x = 0	β_x/β_y = 10.0/117.0 m , D_x = 0	β_x/β_y = 3.0/3.5 m , D_x = 0
RF station section	β_x/β_y = 8.0/7.2 m , D_x = 4.0m	β_x/β_y = 10.0/6.4 m , D_x = 4..0m	β_x/β_y = 14.0/15.0m , D_x = 3.4m

Lattice parameters of CSRe

	Internal-target mode	Normal mode	Isochronous mode
Transition gamma	γ_{tr} = 2.457	γ_{tr} = 2.629	γ_{tr} = 1.395
Betatron tune	Qx / Qy = 2.53 / 2.57	Qx / Qy = 2.53 / 2.57	Qx / Qy = 1.695 / 2.72
Natural chromaticity	Q'_x / Q'_y = -3.70 / -3.55	Q'_x / Q'_y = -3.10 / -3.74	Q'_x / Q'_y = -1.57 / -3.25
Max. β-Amplitude	β_x/β_y =25.7/8.7 m (Dipole) β_x/β_y =43.0/20.4 m (Quadruple)	β_x/β_y =17.6/8.2 m (Dipole) β_x/β_y =30.9/22.3 m (Quadruple)	β_x/β_y =28.1/12.2 m (Dipole) β_x/β_y =41.2/36.4 m (Quadruple)
Max. Dispersion	$D_{max}(x)$=7.9m(Dipole, β_x=14m) $D_{max}(x)$=9.4m (Quad. , β_x=16m)	$D_{max}(x)$=6.5 m (Dipole, β_x=13m) $D_{max}(x)$=7.8m (Quad. , β_x=16m)	$D_{max}(x)$=18.5m (Dipole, β_x=28m) $D_{max}(x)$=21.2m(Quad. , β_x=34m)
Injection section	β_x= 30.8 m , D_x = 0 m (Septum) β_x= 31.4 m, D_x =0 m (Quadruple)	β_x= 30.4 m, D_x = 0 m (Septum) β_x= 30.9 m, D_x = 0 m (Quadruple)	β_x= 40.8 m , D_x = 0 m (Septum) β_x= 41.2m, D_x = 0 m (Quadruple)
E-cooler section	β_x/β_y = 12.9/16.5 m , D_x = 0	β_x/β_y = 12.5/16.0 m , D_x = 0	β_x/β_y = 2.6/10.5 m , D_x = 0
Target	β_x/β_y = 3.0/1.7 m , D_x = 0	β_x/β_y = 5.4/1.5 m , D_x = 0	β_x/β_y = 20.8/1.0 m , D_x = 17.7m
RF station section	β_x/β_y = 4.0/8.3 m , D_x = 4.6	β_x/β_y = 4.0/8.4 m , D_x = 4.5	β_x/β_y = 19.0/11.5m , D_x = 15.0m

Parameters of the beam accumulation in CSRm

	C^{4+}	O^{7+}	O^{7+}	Xe^{48+}	U^{72+}
Injector	SFC	SFC	SFC	SSC	SSC
Energy (MeV/u)	7	10	10	20	10
Peak current (p μ A)	2	0.5	0.5	0.01	0.01
Current (pps)	12×10^{12}	3×10^{12}	3×10^{12}	6×10^{10}	6×10^{9}
Particles / Turn	5×10^{7}	1×10^{7}	1×10^{7}	1.5×10^{5}	2×10^{4}
Efficiency of stripping	68%			19%	15%
Mode	STI	RFS	MMI	MMI	MMI
Injection pulse (ms)	1~5	0.1	0.1	0.1	0.1
Cooling cycle (ms)	2500	100	1000	250	100
Period (s)	3	10	10	10	10
Gain factor of MMI	30	2.8	5	5	5
Particles	1.5×10^{9}	2×10^{9}	4×10^{8}	5×10^{6}	1×10^{6}

What's functions of e-cooling in CSR

Accumulating heavy ion beam in CSRm

Cooling beam during the three injection mode.

Cooling beam in CSRe

Compensating the emittance growth

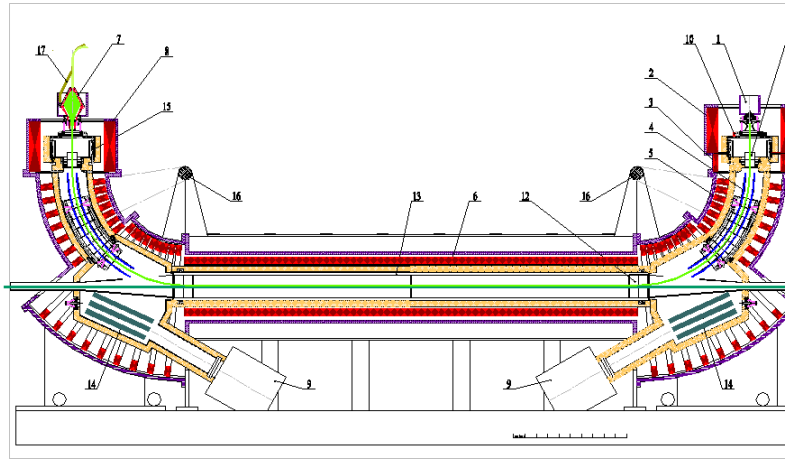
During internal-target experiment.

Obtaining $\Delta P/P \sim 10^{-6}$ in CSRe

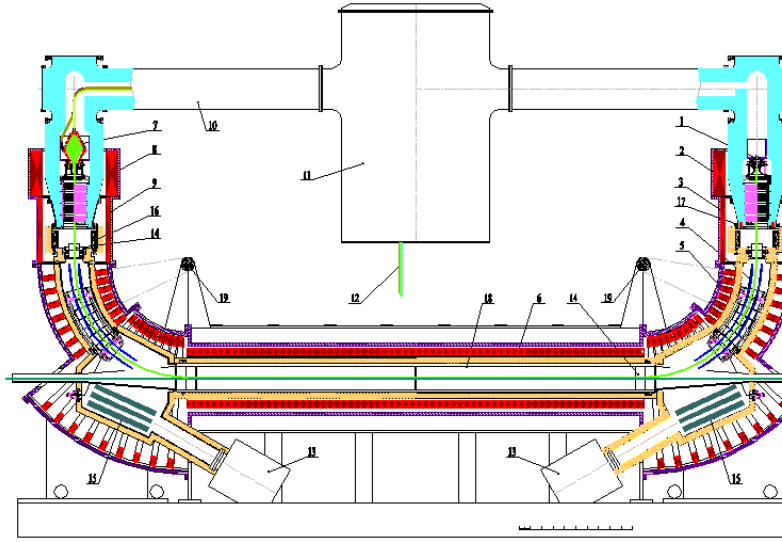
For the high-resolution mass spectrometer.

Major parameters of e-coolers

Parameters	CSRm	CSRe
Ion Energy [MeV/u] Electron Energy [keV]	8-50 4-35	25-400 10-300
Electron beam current [A]	3 (1.0A@5.5keV)	
Cathode radius [cm]	1.25	1.25
Magnetic expansion factor	1- 4	1- 10
Max. Field in gun region [kG]	2.4	5
Magnetic field in collector region [kG]	1.2	1.2
Magnetic field at cooling section [kG]	0.6-1.5	0.5-1.5
Length of installation [m]	7.2	7.2
Effective cooling section length [m]	3.4m	3.4m
Deflection angle of toroid [Deg.]	90°	90°
Deflection radius of toroid [m]	1.0	1.0

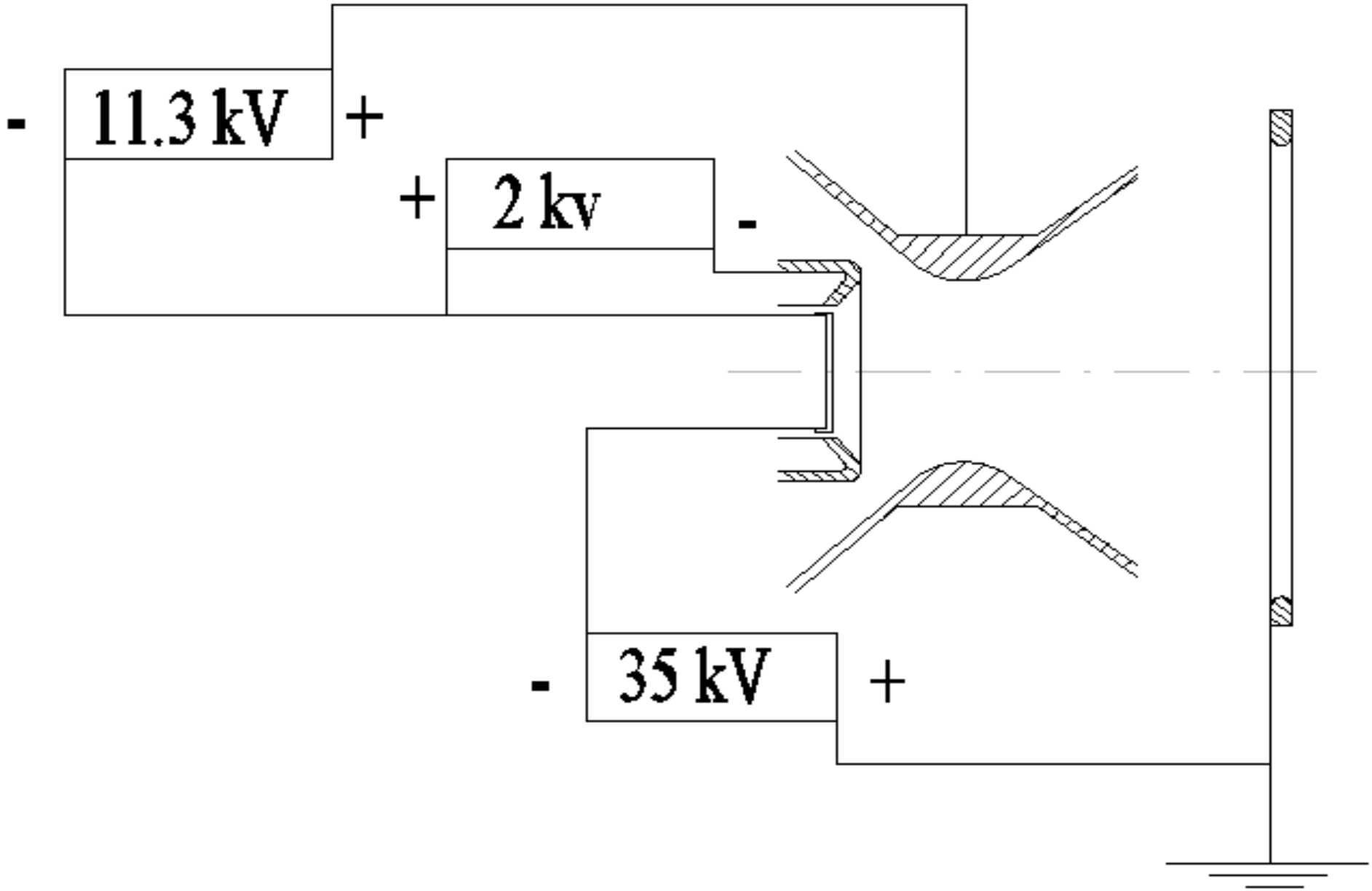


CSRm e-cooler



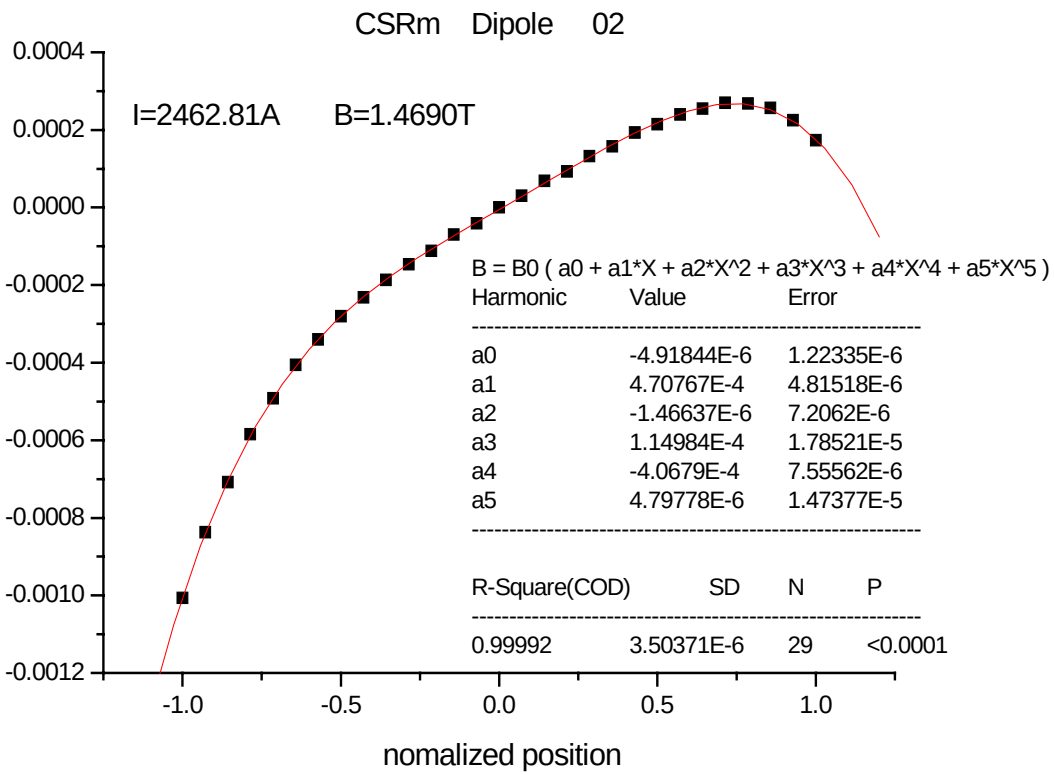
CSRe e-cooler

A new electron gun



The electron gun with cathode, control electrode and anode.

Width of the B-field at high levels



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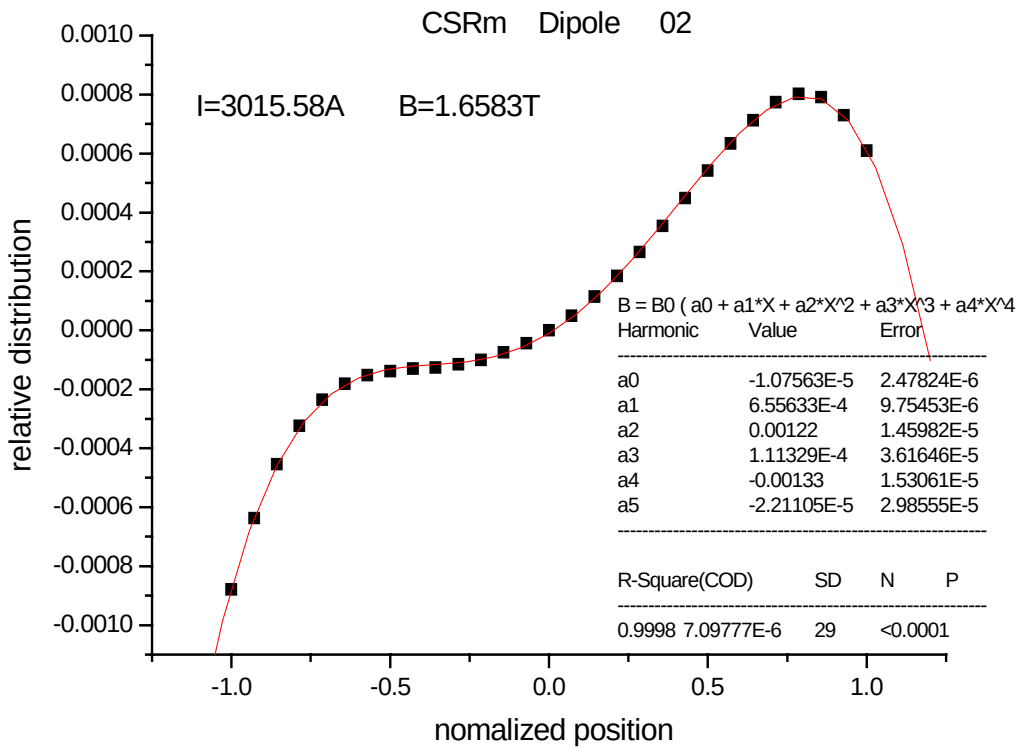

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