Study of Intense Beam Injection and Extraction of Heavy Ion Synchrotron

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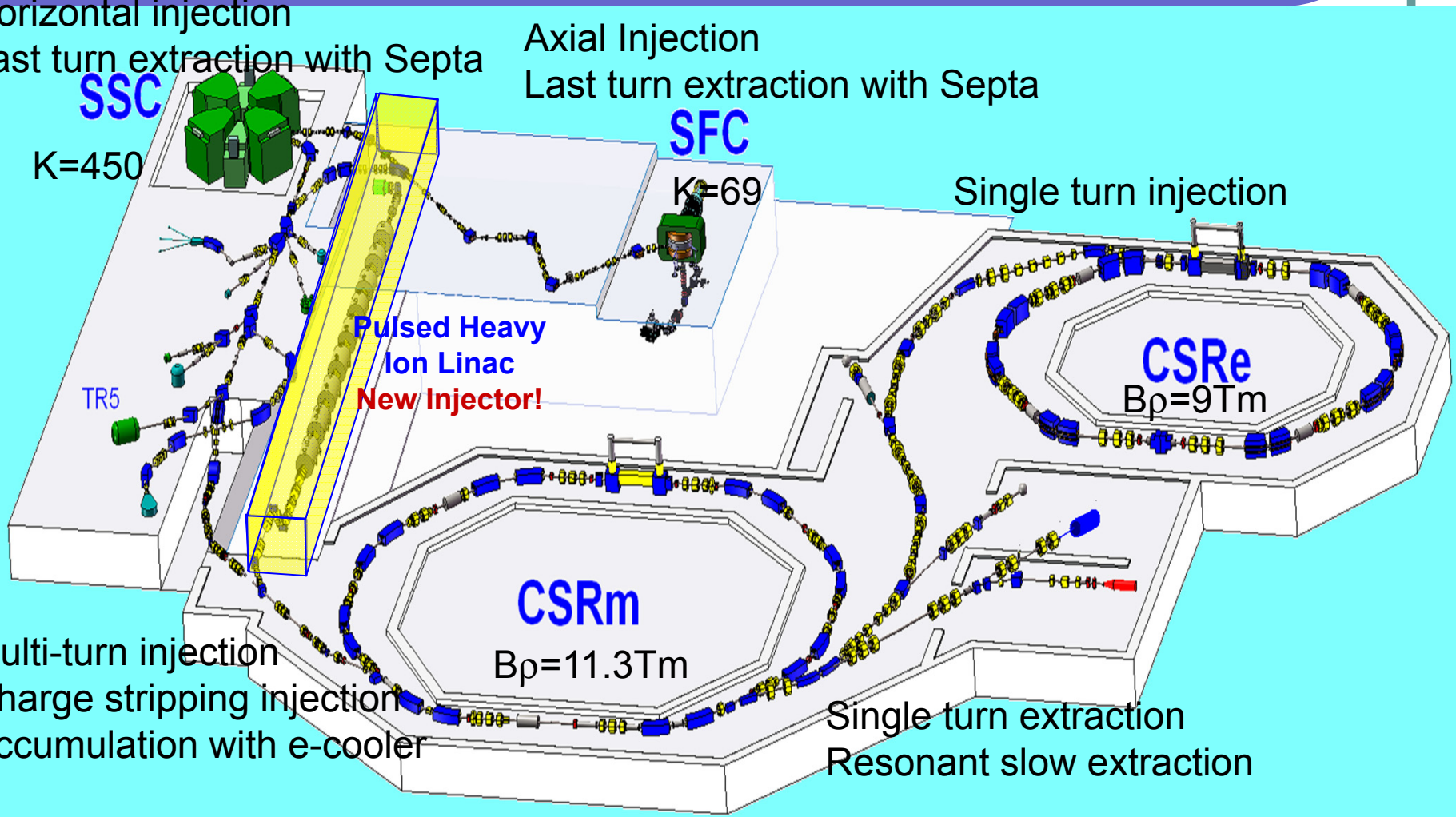
September 1, 2012

Introduction to HIRFL-CSR



The Cyclotron Injectors

- SFC (Spiral Sector Focusing Cyclotron)
  - K=69, $\varepsilon_{x,y}$~24π μm.rad,Δp/p~1%,$\Delta\psi$~30°.
  - provided H_2^+,$^{12}C^{4+}$, $^{18}O^{6+}$, $^{22}Ne^{7+}$, $^{58}Ni^{19+}$, $^{78}Kr^{19+}$, $^{129}Xe^{27+}$, $^{209}Bi^{36+}$, $^{238}U^{32+}$ for CSRm
- SSC (Separator Sectors Cyclotron)
  - K=450, $\varepsilon_{x,y}$~10π μm.rad,Δp/p~0.4%,$\Delta\psi$~15°.
  - provided $^{36}Ar^{8+}$||18MeV/u||3eμA for CSRm.

Injection and accumulation methods of HIRFL-CSR synchrotron CSRm

- Multi-turn injection (Horizontal phase space painting) is the fundamental method. →to make maximum use of the ring acceptance
- Charge stripping injection for light heavy ion beam. →to overcome Lowville theorem limit, condense the phase space.
- Accumulation with electron cooling for both of above. →to overcome Lowville theorem limit, condense the phase space.

Injection and Accumulation Schemes

For heavy ions: τ_{cool}<1s

- Multi-turn injection → MI is base of inj.
- MI + e-cooler → MMI

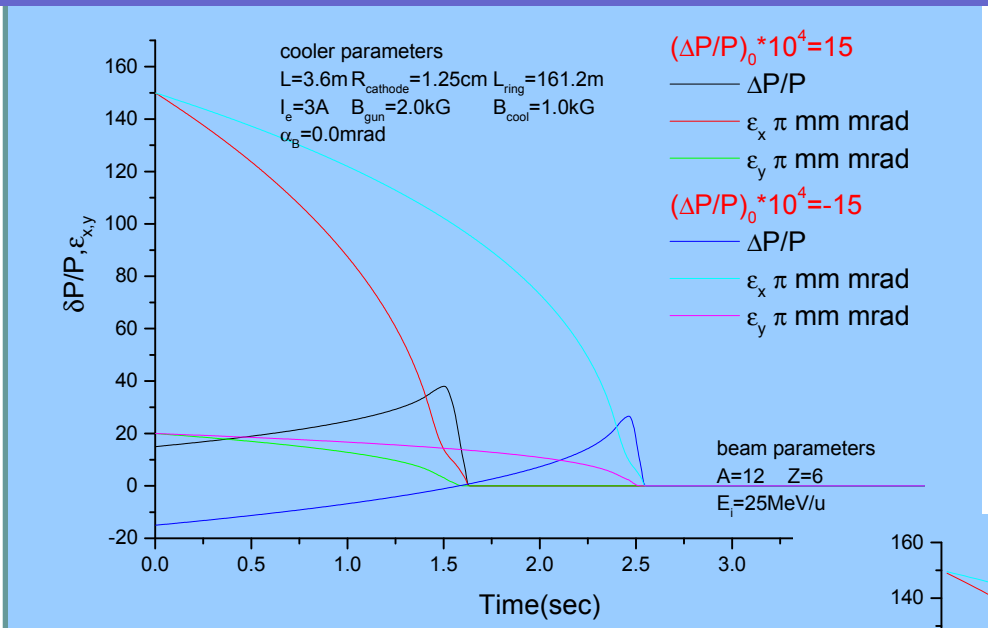
For Light ions: τ_{cool}>1s, $\eta_{str.}$>50%

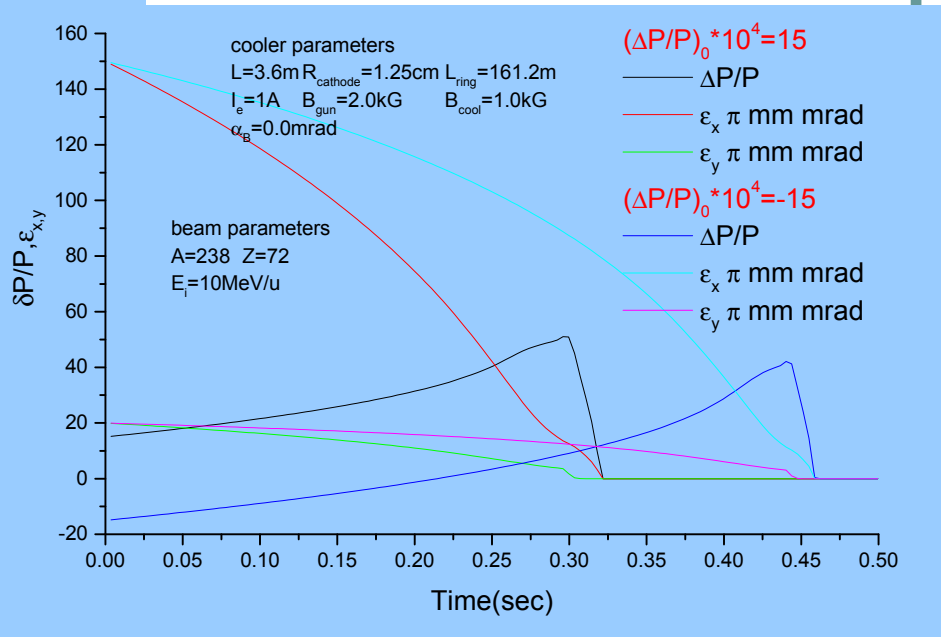
- Charge stripping injection → CI
- CEI + e-cooler → MCI
- RF Bucket-on Single CI → SCI for Cancer Therapy Facility

Electron Cooler for Accumulation

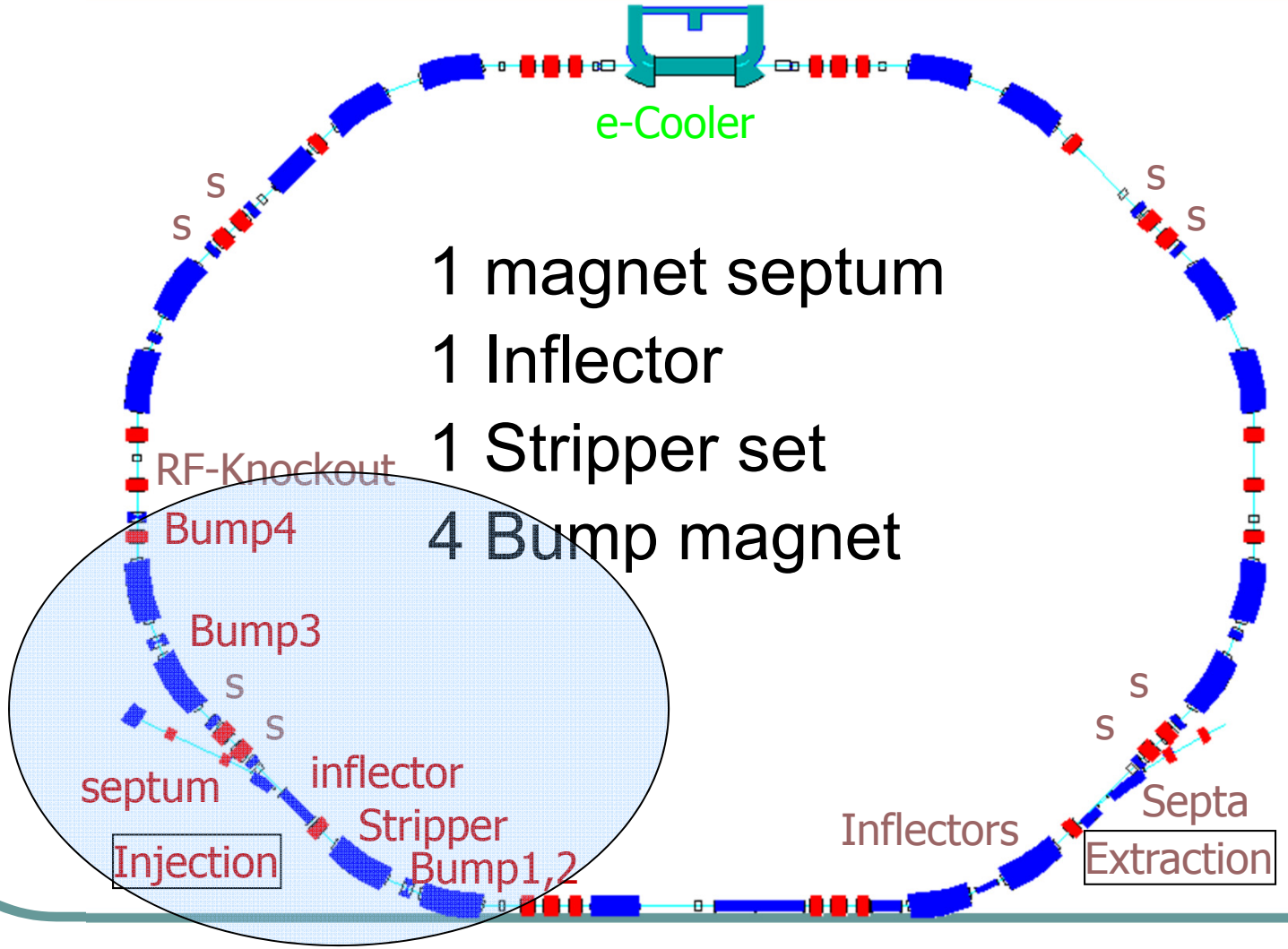
- First electron cooler with modifiable cross-section electron beam
- Parameters
  - V_{max}=35kV, I_e<1A, T_e~0.1eV
  - Diameter of electron beam : 60mm

Electron-Cooling Calculation

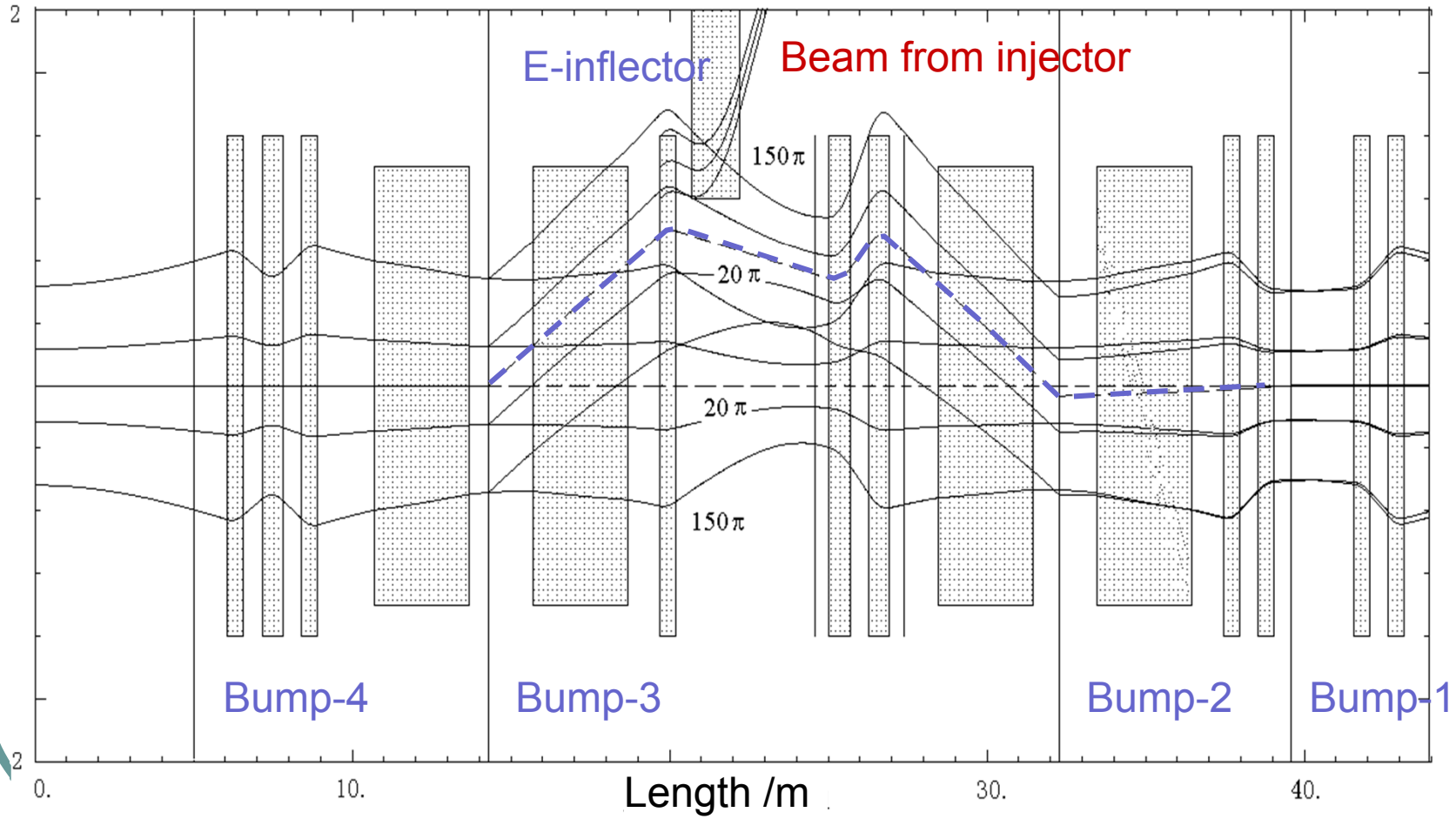




Layout of CSRm Injection

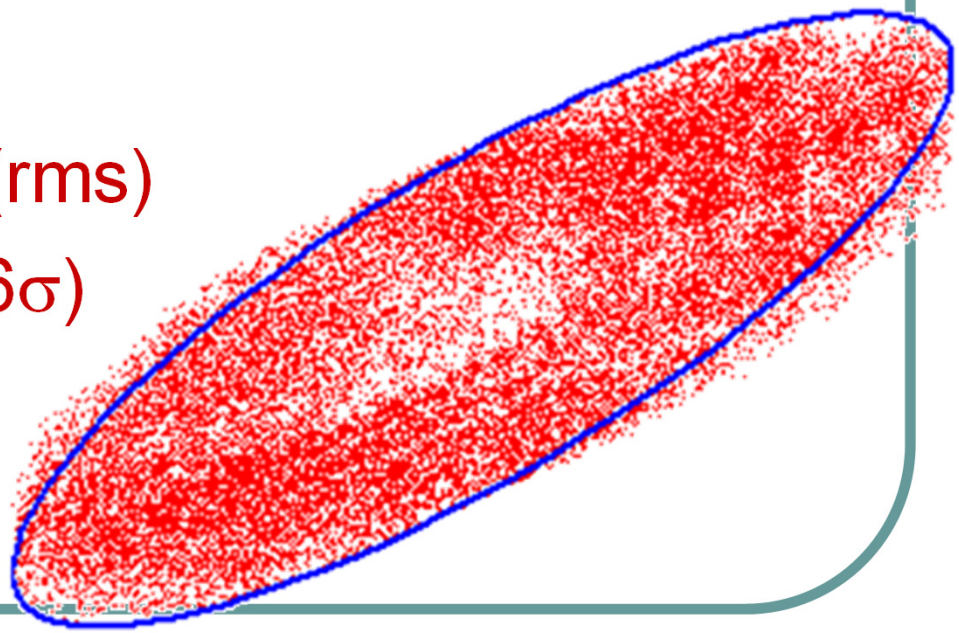


Injection Orbit And Beam Envelope of MI

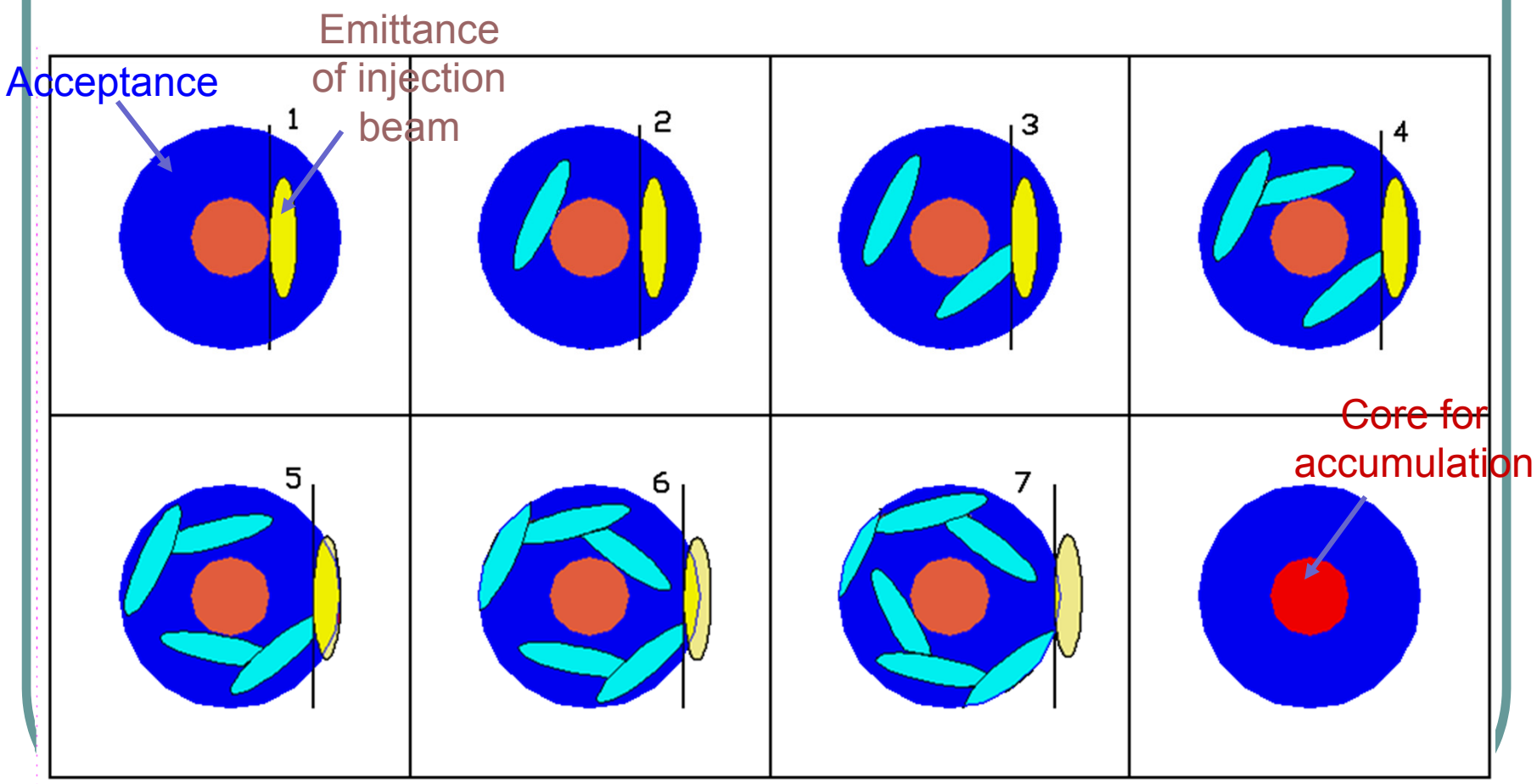


Phase Space of MI

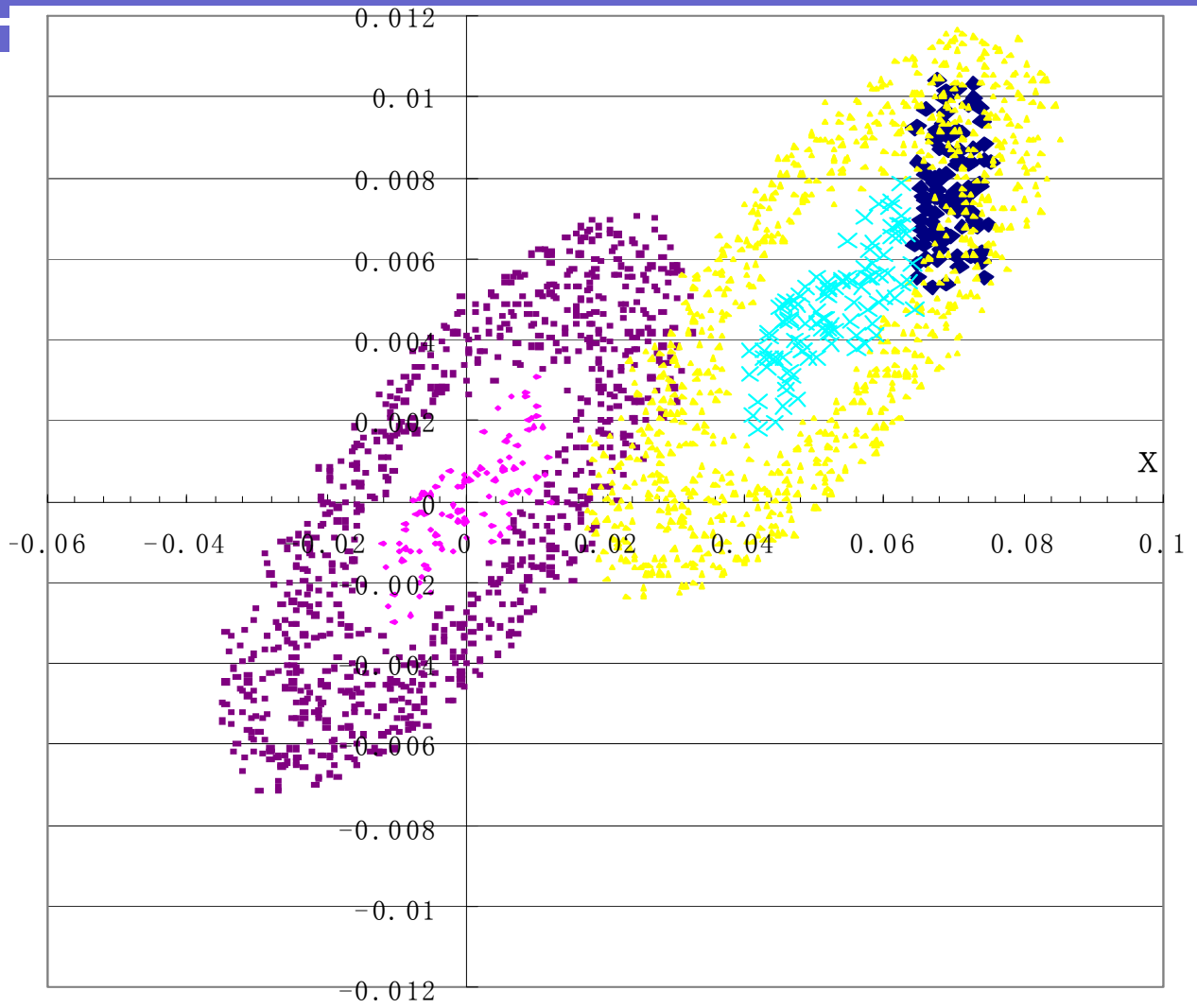
- X_{ES}=60mm Thickness d=0.1mm
- Gain Factor=8.7
- Beam from injector
  - Ax=150 πmmmrad
  - $\varepsilon_{x,y}$=2.5πmmmrad(rms)
  - $\delta p/p=\pm 0.5\%(2.236\sigma)$



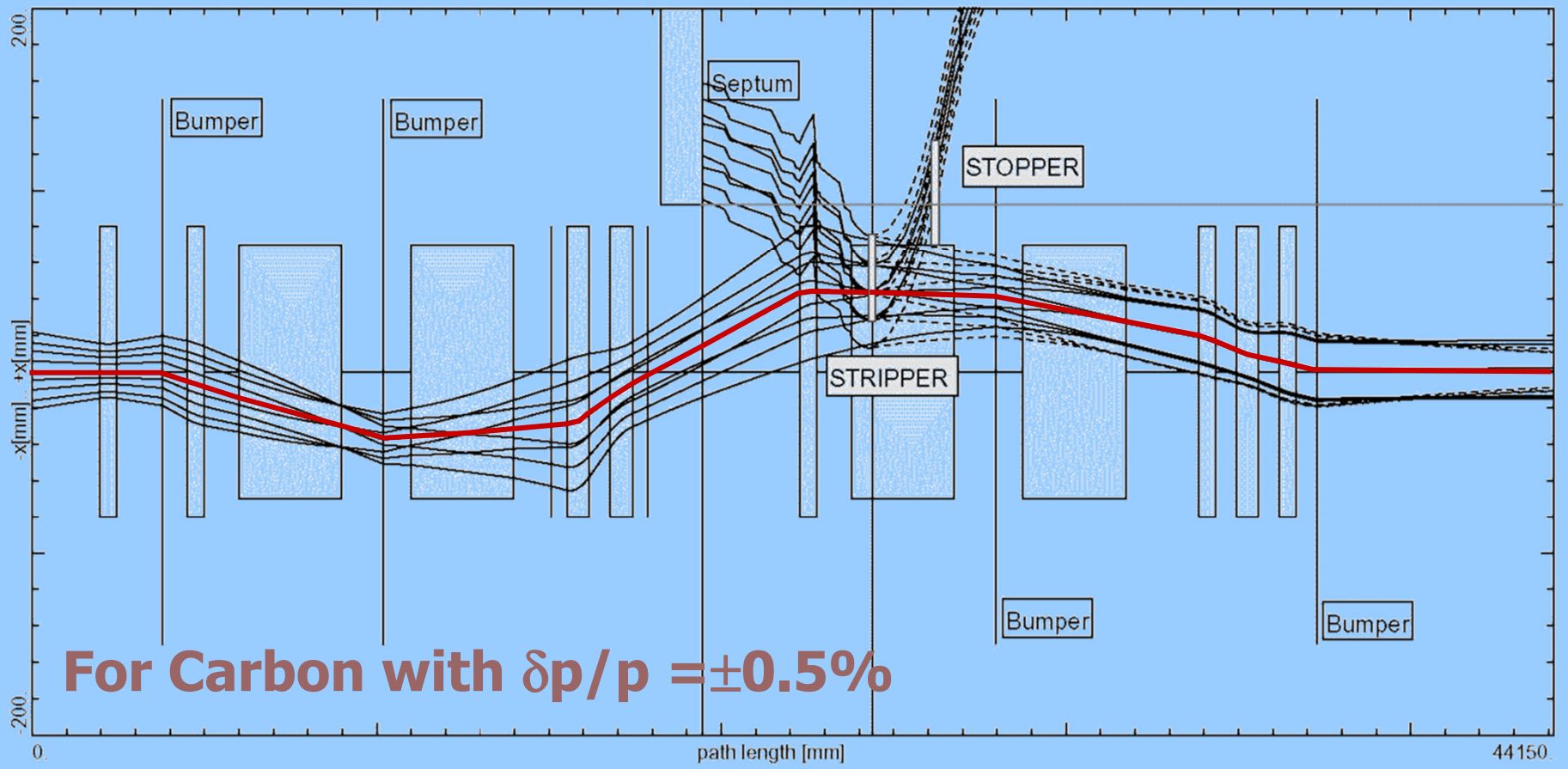
MI and Accumulation with e-Cooler



Phase Space of MI

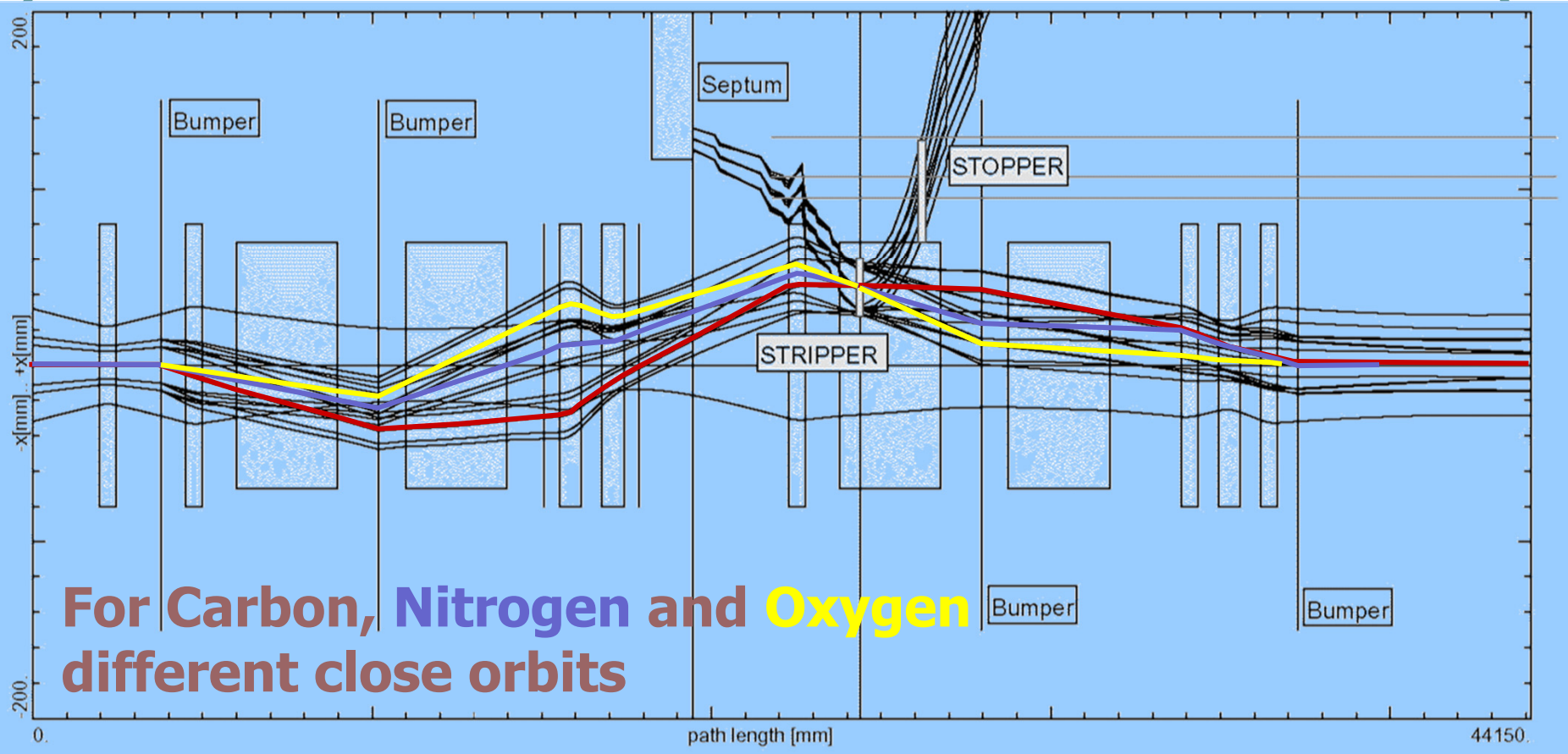


Injection Orbit and Beam Envelope of CI

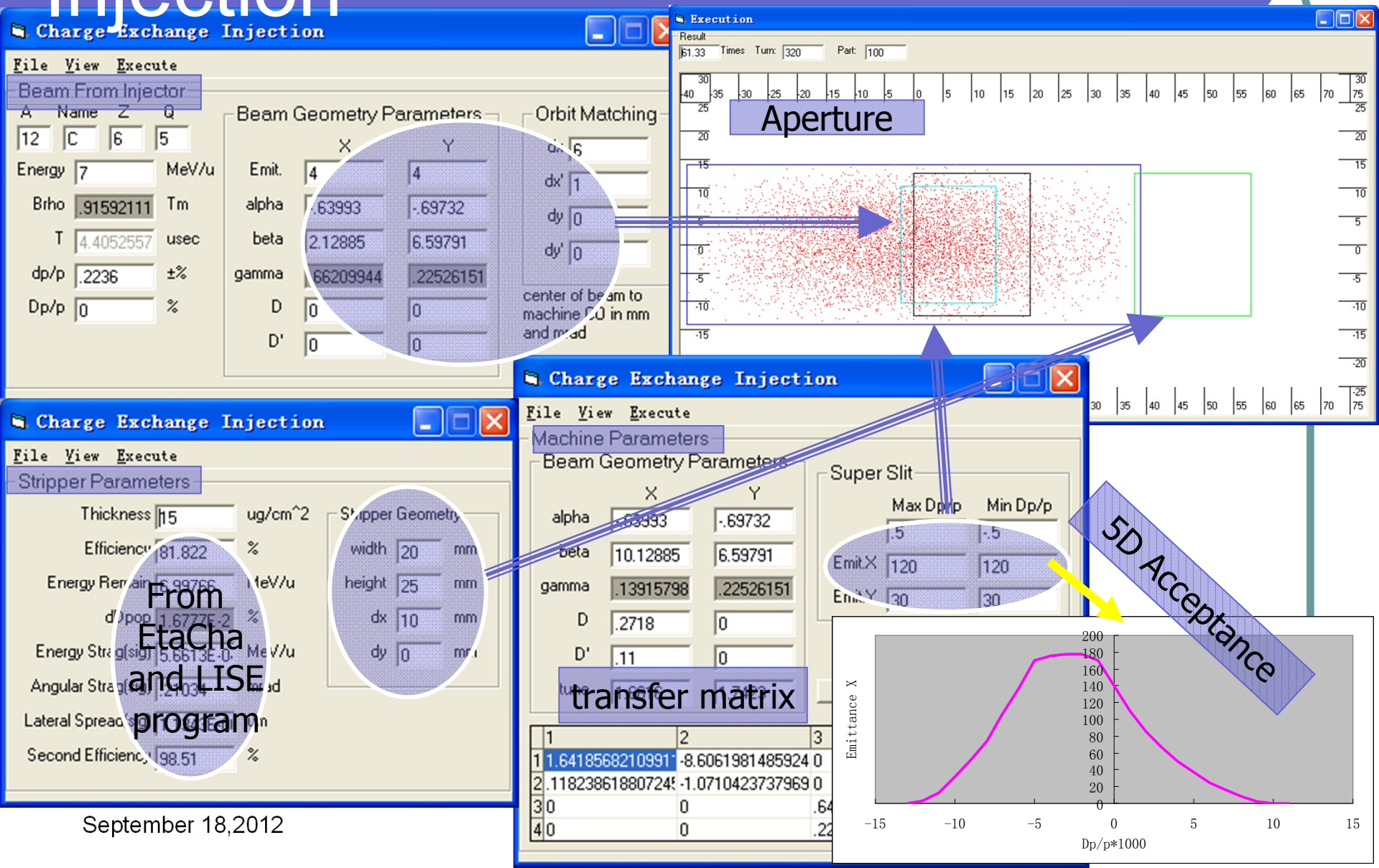


For Carbon with $\delta p/p = \pm 0.5\%$

Injection Orbit And Beam Envelope of CI

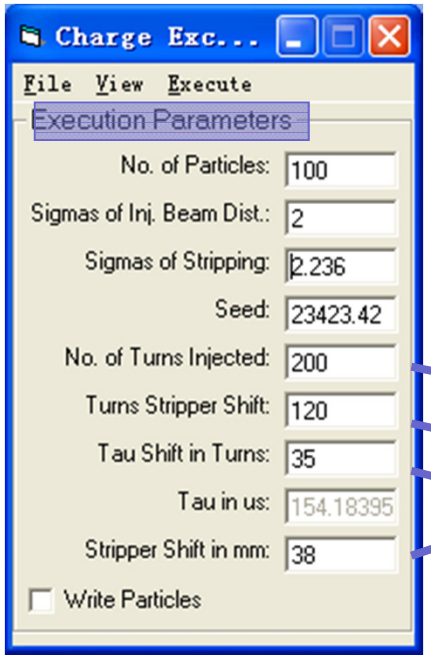


Simulation Program for Stripping Injection

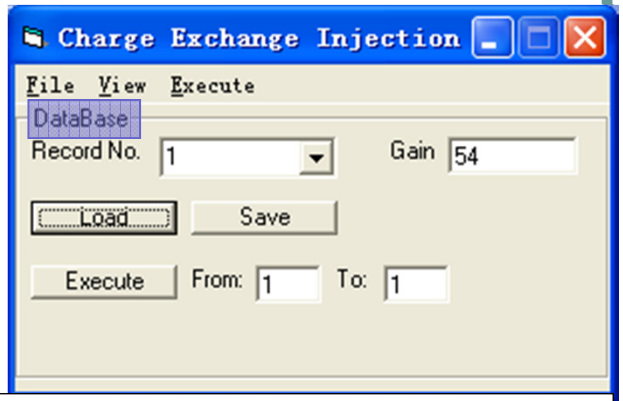


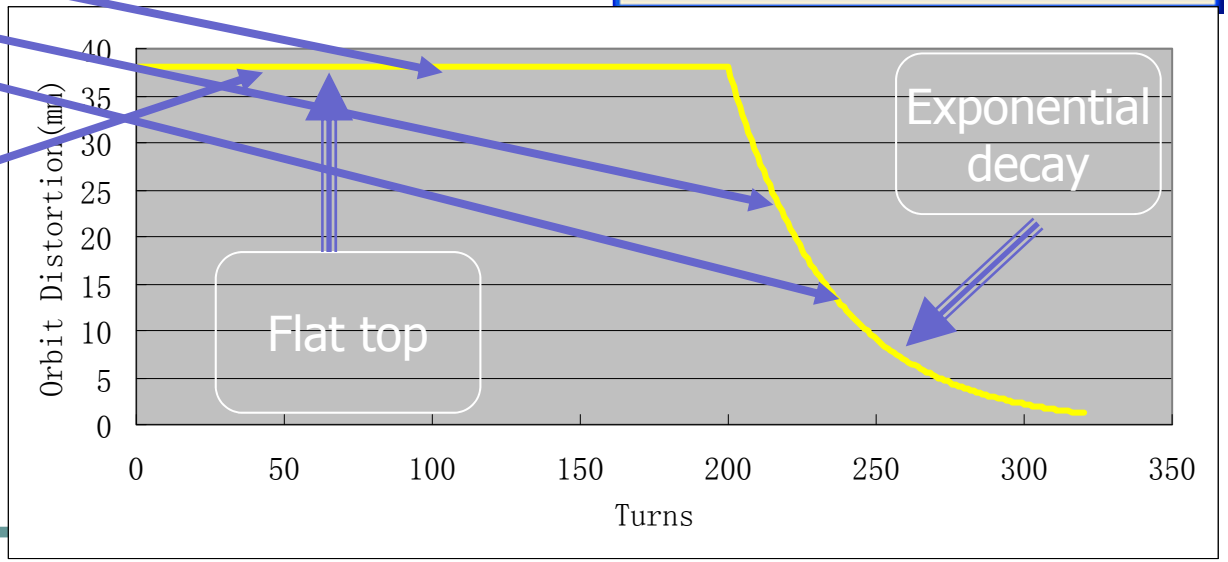
Simulation Program for Stripping Injection

Injection procedure control

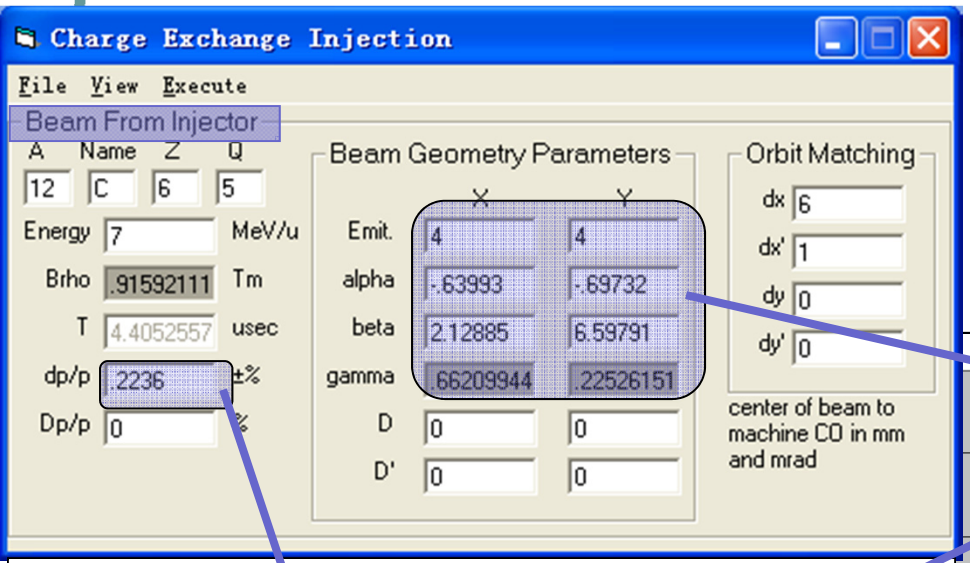


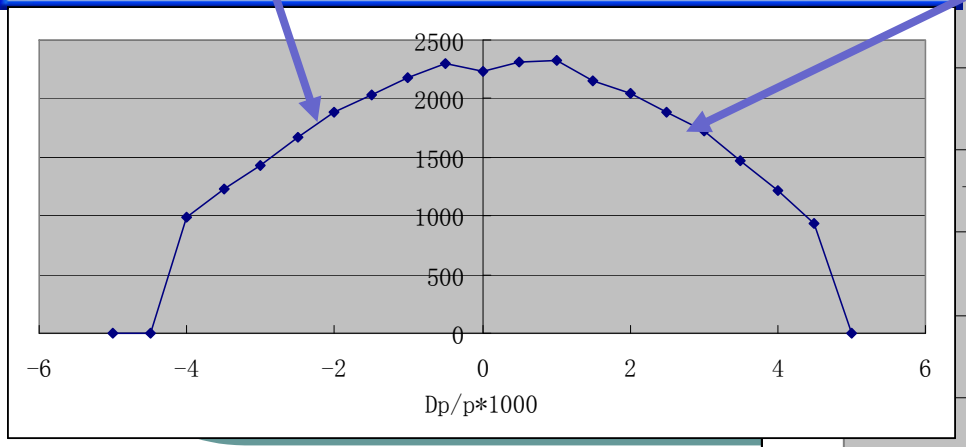
Parameters are stored in database or in files.





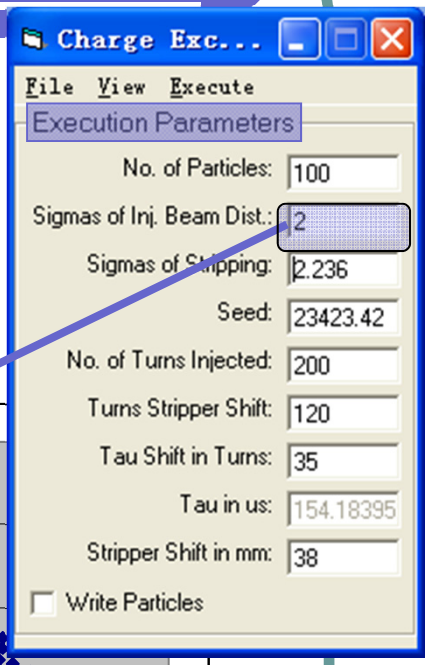
Injection Particles

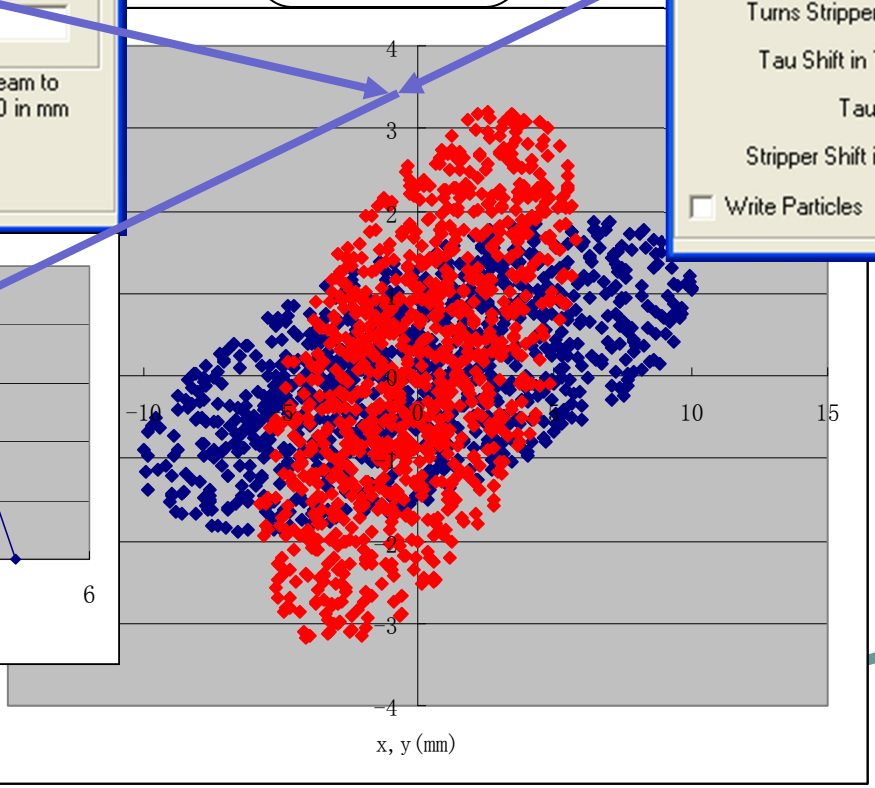




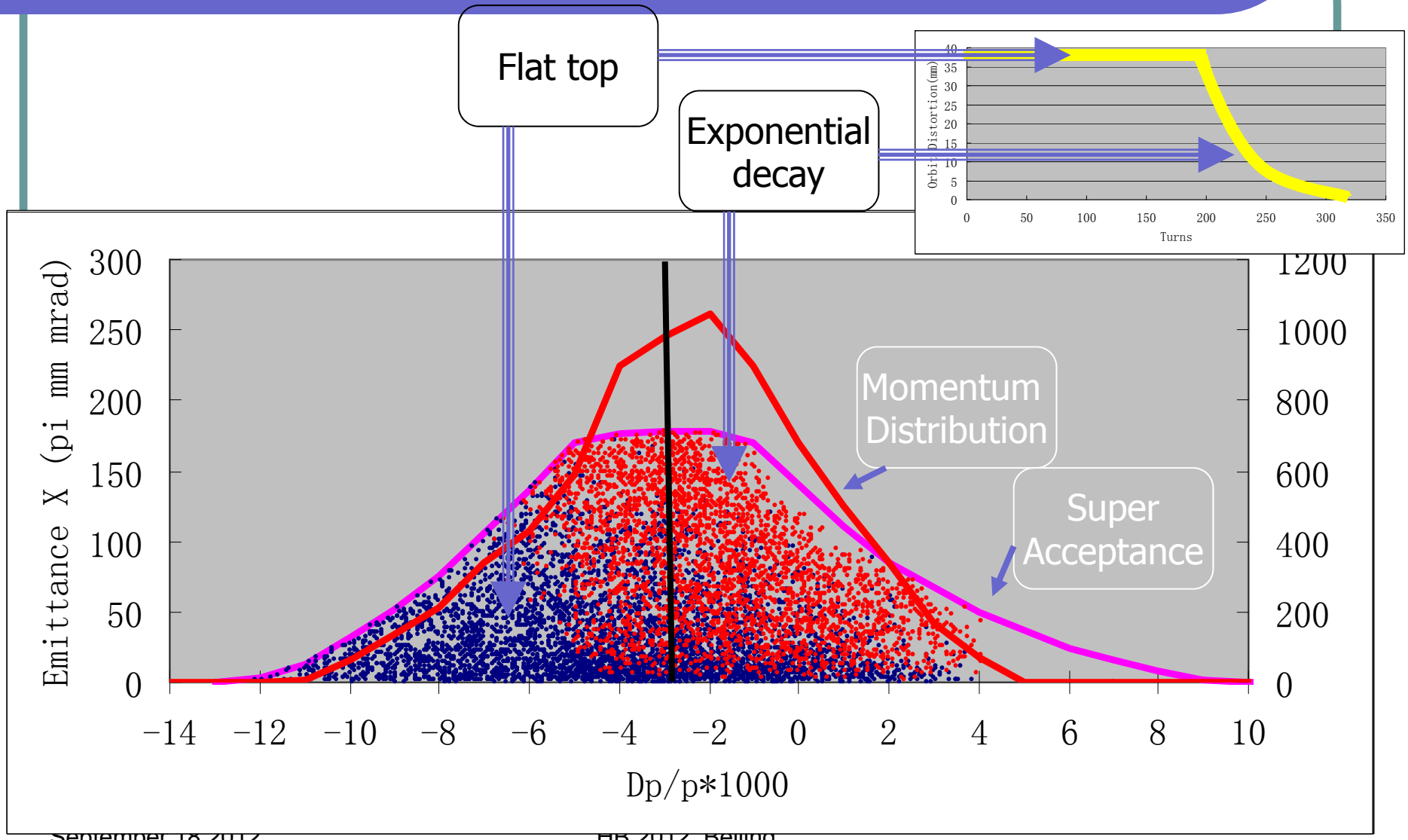
5D phase space of injection beam

Gaussian Distribution and cut

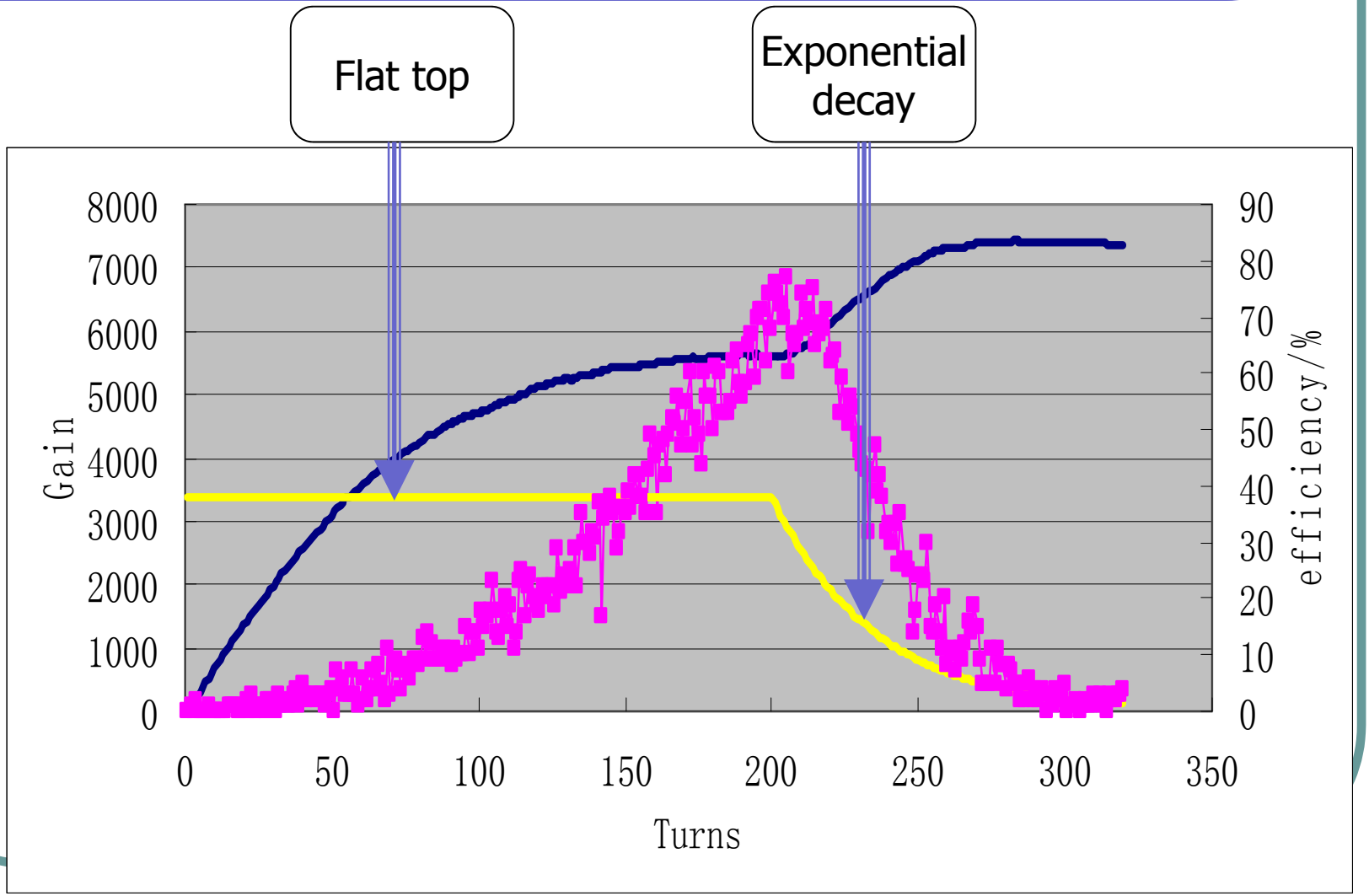




Injected Beam Distribution

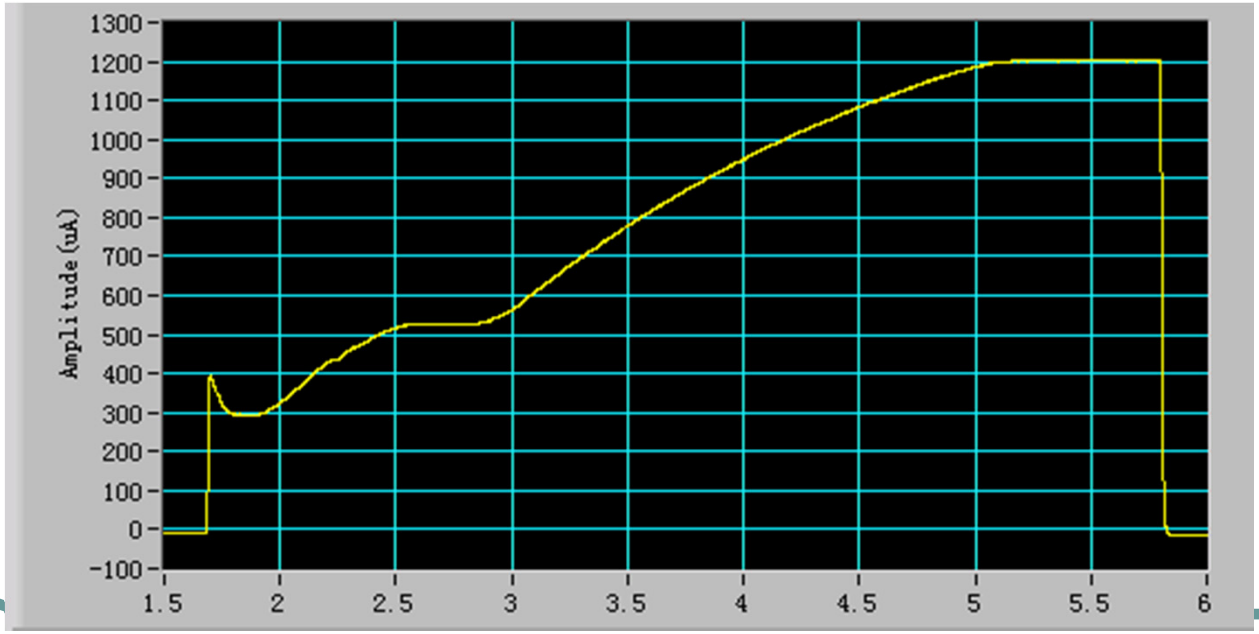


Gain and Efficiency



Carbon injection results

- MCI/10s → $1.2X10^{10}$
- MCI/1.5s → $1X10^{8}$
- RF Bucket-on single CI, no e-cooler → $1.3X10^{9}$

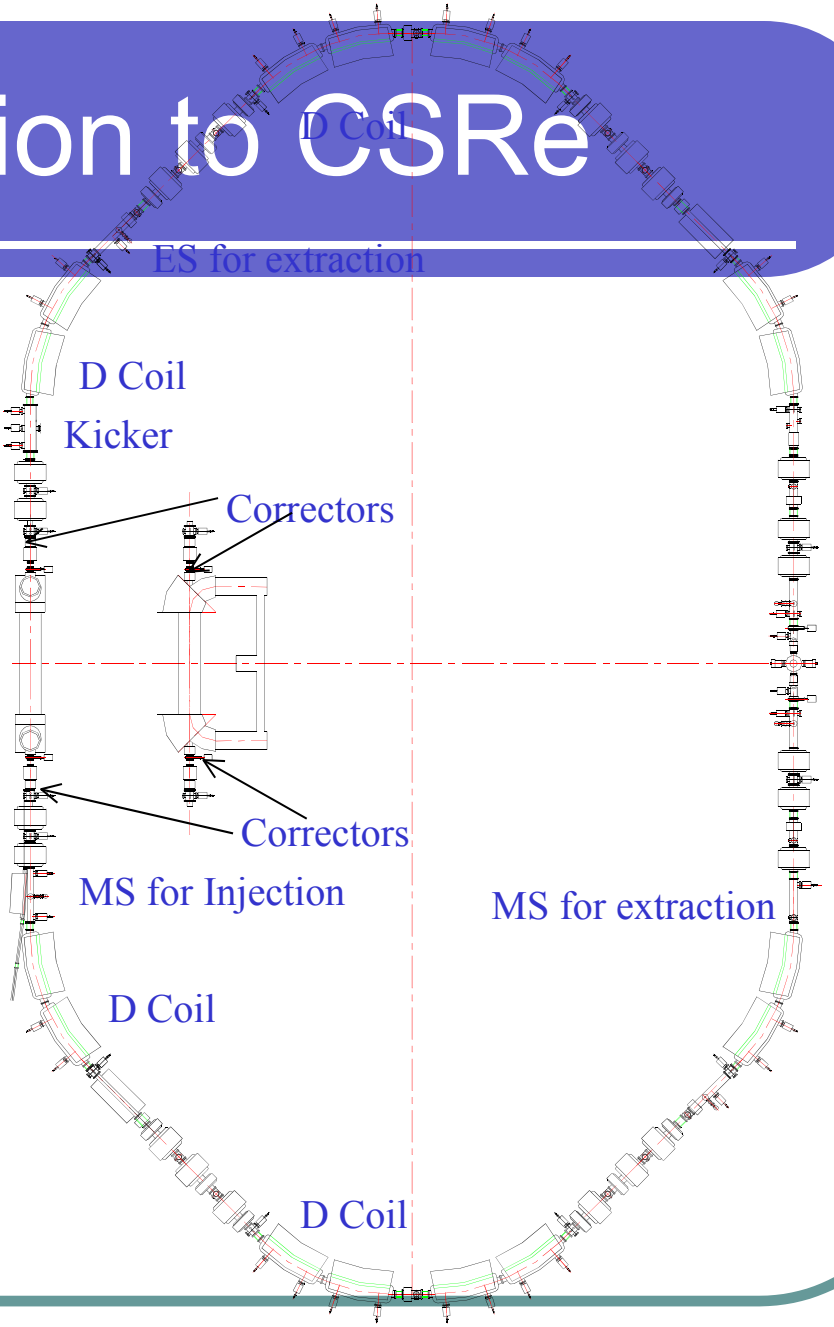


List of the provided beam from cyclotron injectors

Ion	E (MeV/u)	Injector Intensity (eμA)	Injection method	N ions stored in CSRm
H_2^{1+}	10	7	MMI+eC	4.9E+08
$^{12}C^{4+}$	8	5	CSI+eC	9.7E+09
$^{12}C^{4+}$	8	5	CSI	2.2E+09
$^{18}O^{6+}$	7	3	CSI+eC	1.59E+09
$^{22}Ne^{7+/10+}$	6.17	9	CSI+eC	7.03E+09
$^{36}Ar^{8+/18+}$	22	3	MMI+eC	2.33E+08
$^{58}Ni^{19+}$	6.3	1.8	MMI+eC	1.51E+08
$^{78}Kr^{19+/28+}$	4	7	MMI+eC	1.83E+08
$^{86}Kr^{20+/28+}$	3.63	4.5/1.1	MMI+eC	1.92E+08
$^{129}Xe^{27+}$	3	4	MMI+eC	2.19E+08
$^{209}Bi^{36+}$	2	2	MMI+eC	4.03E+07
$^{238}U^{32+}$	1.22	1	MMI+eC	1.59E+08

Single turn injection to CSRe

- 4 cells kicker with 150ns fall time and 700ns flattop
- D-coils for local orbit
- Fit all high resolution mode and isochronous operation modes
- 1 magnet septum



Injection Orbit: high resolution mode

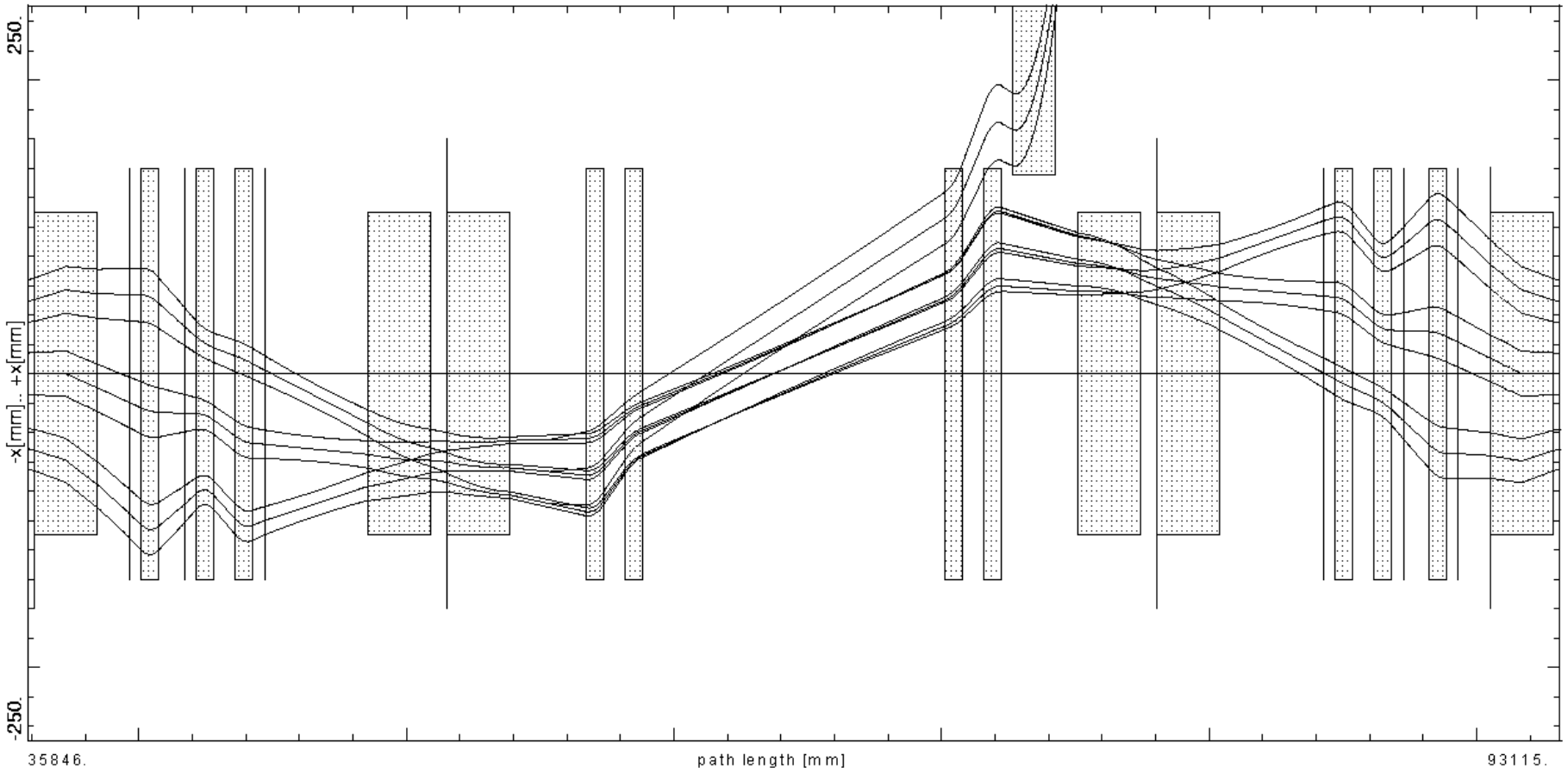


Figure 3-23 CSRe Single Turn Injection (High Resolution Mode)

Injection Orbit: Isochronous mode

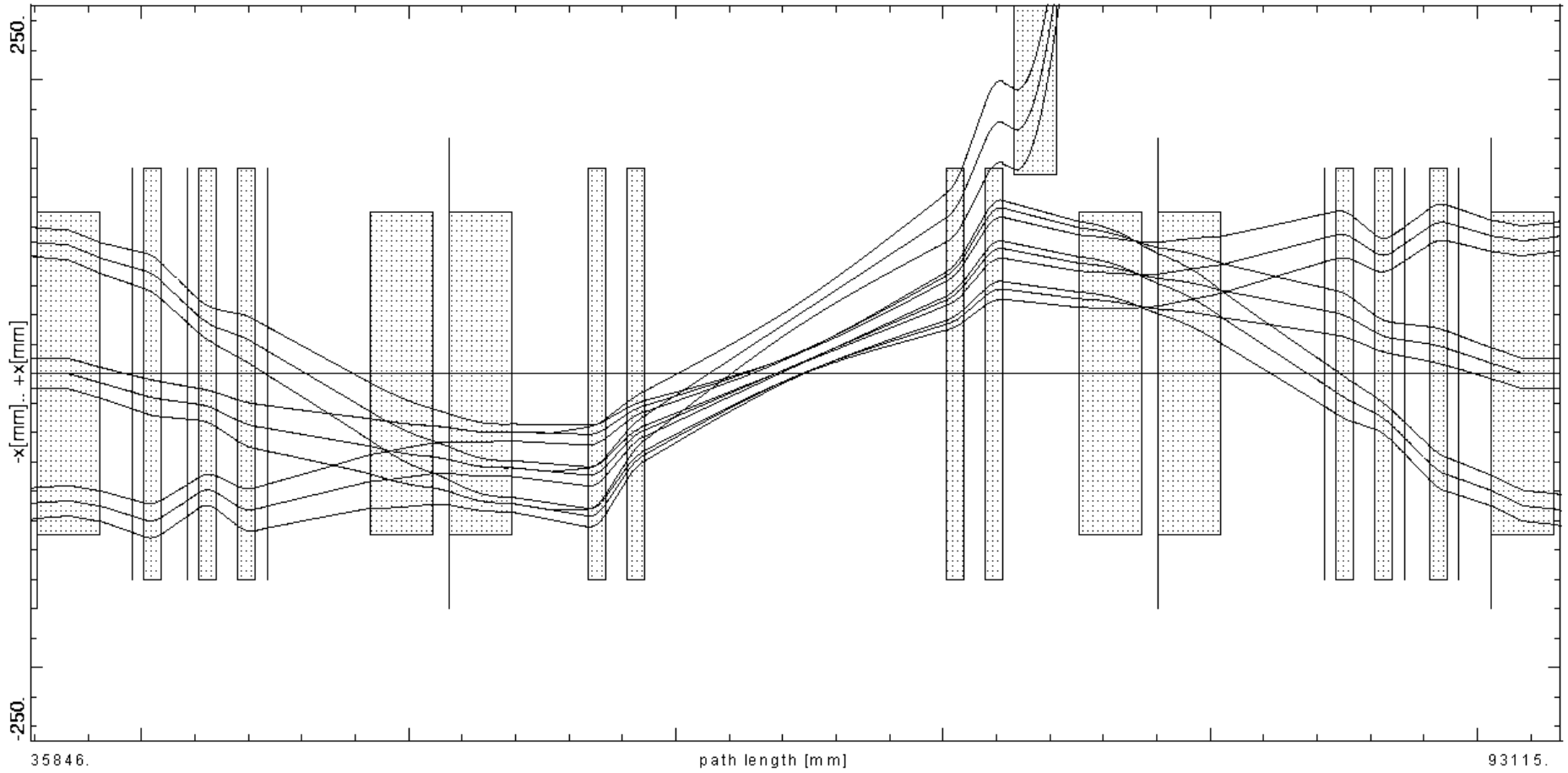


Figure 3-24 CSRe Single Turn Injection (Isochronous Mode)

Injection Orbit: high resolution mode

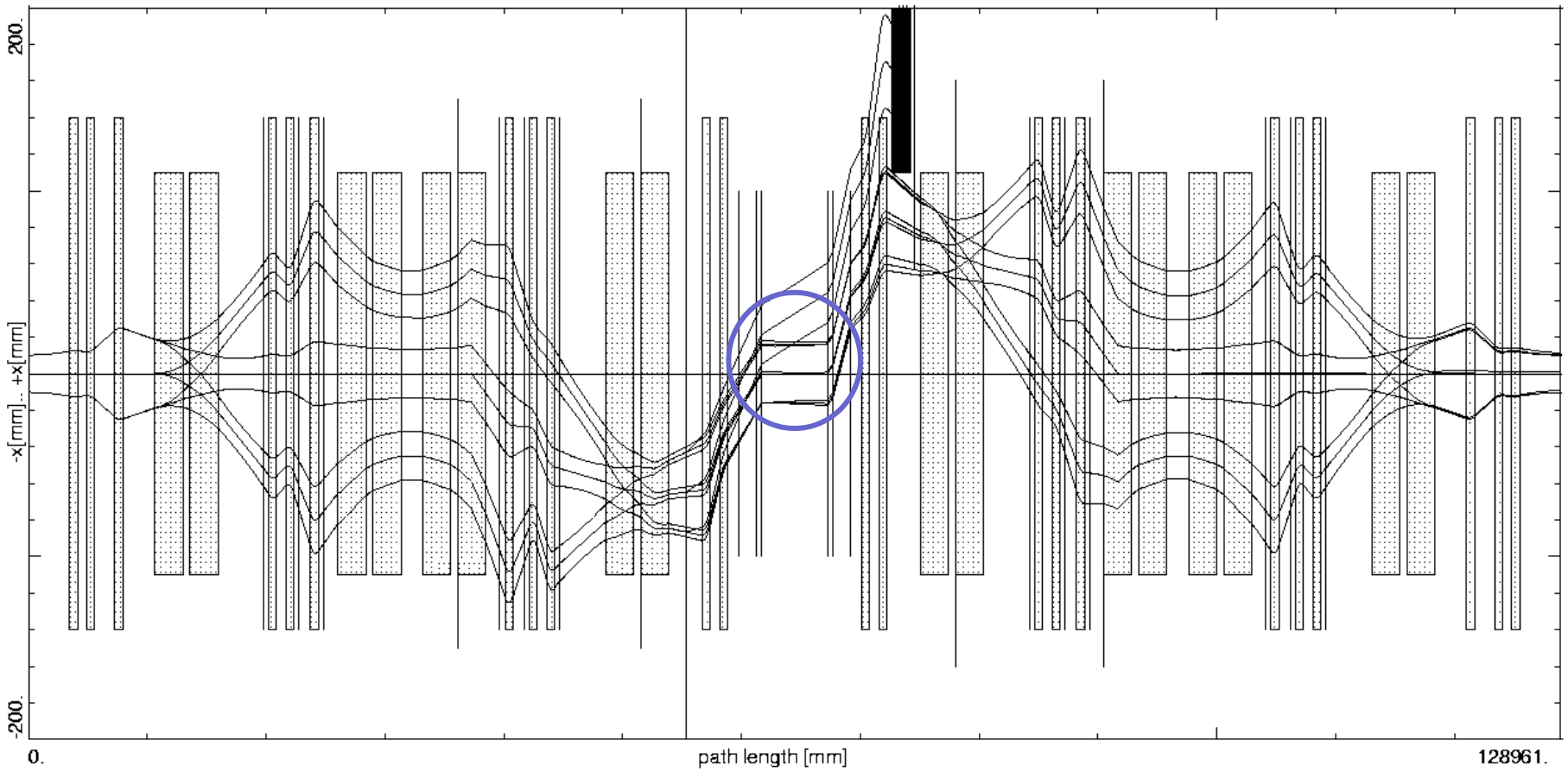


Figure 3-25 CSRe Injection Orbit with Cooling Section Correction(High Resolution Mode, 8.4T.M)

Injection Orbit: Isochronous mode

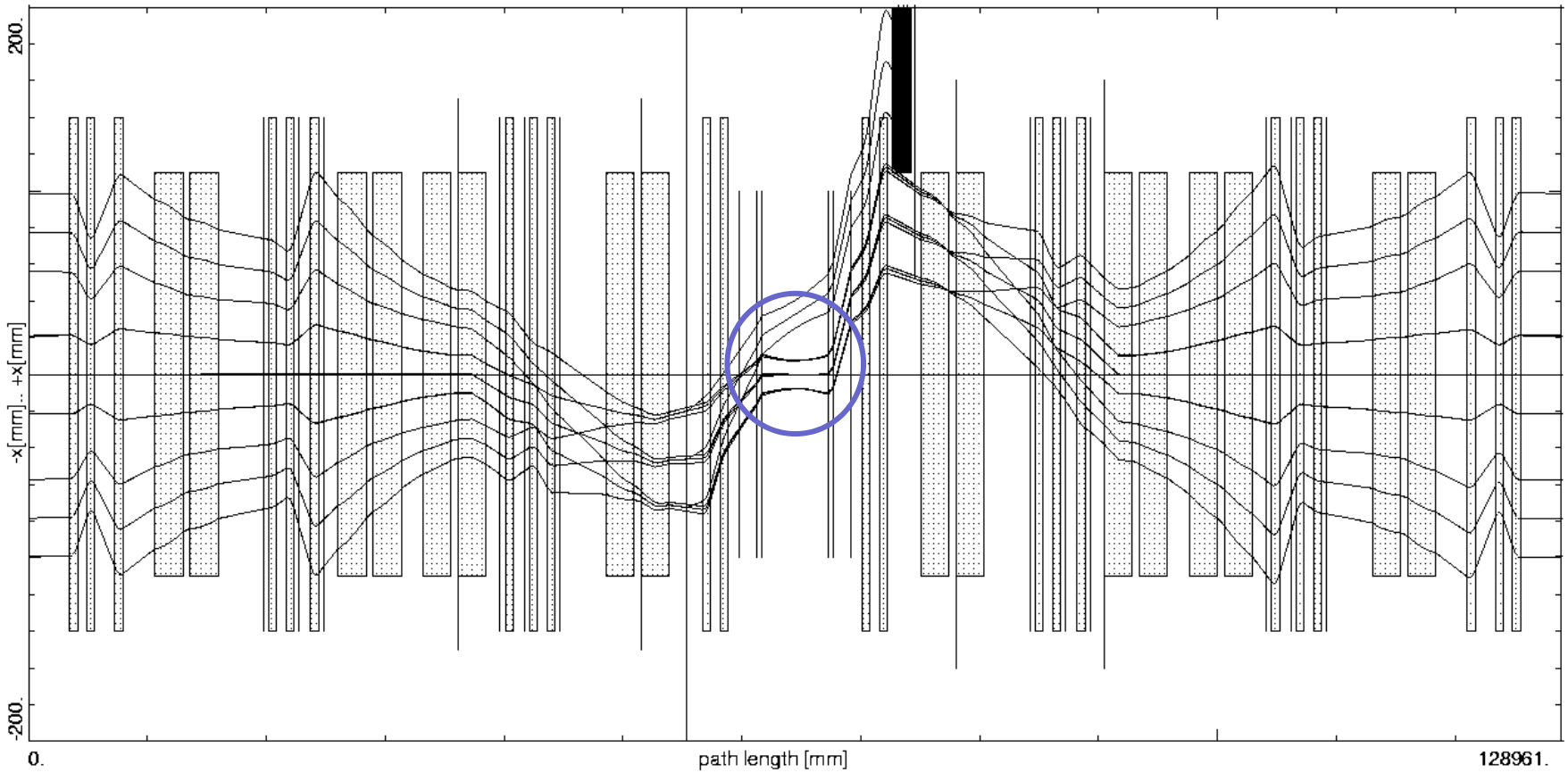
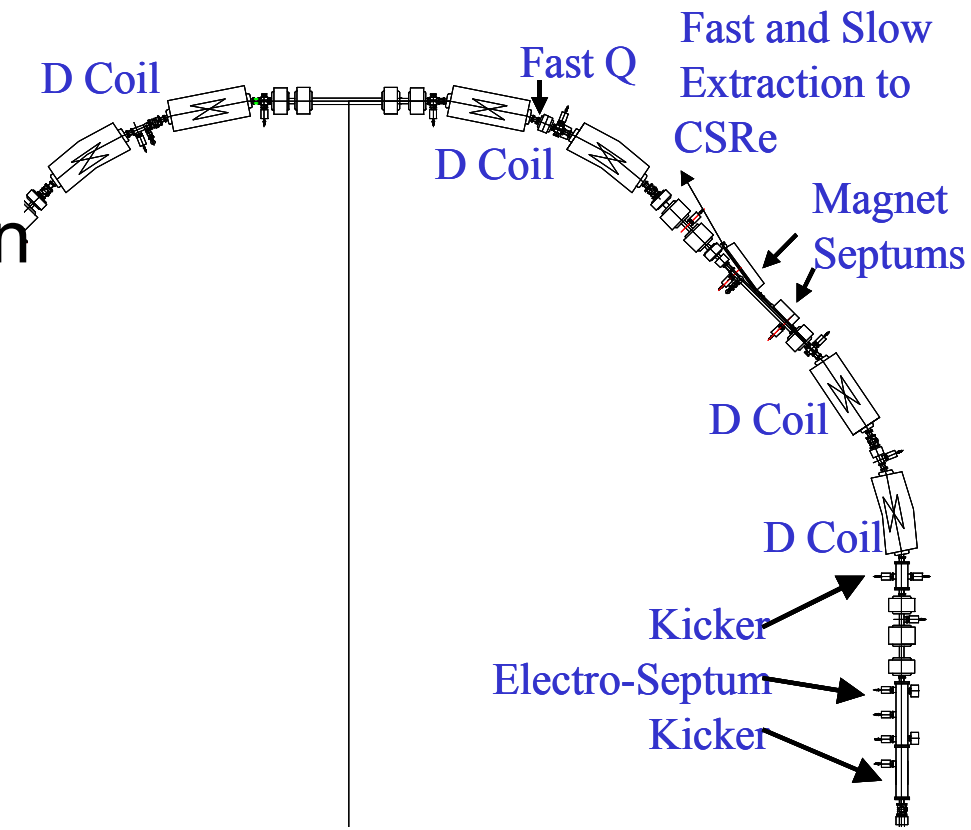


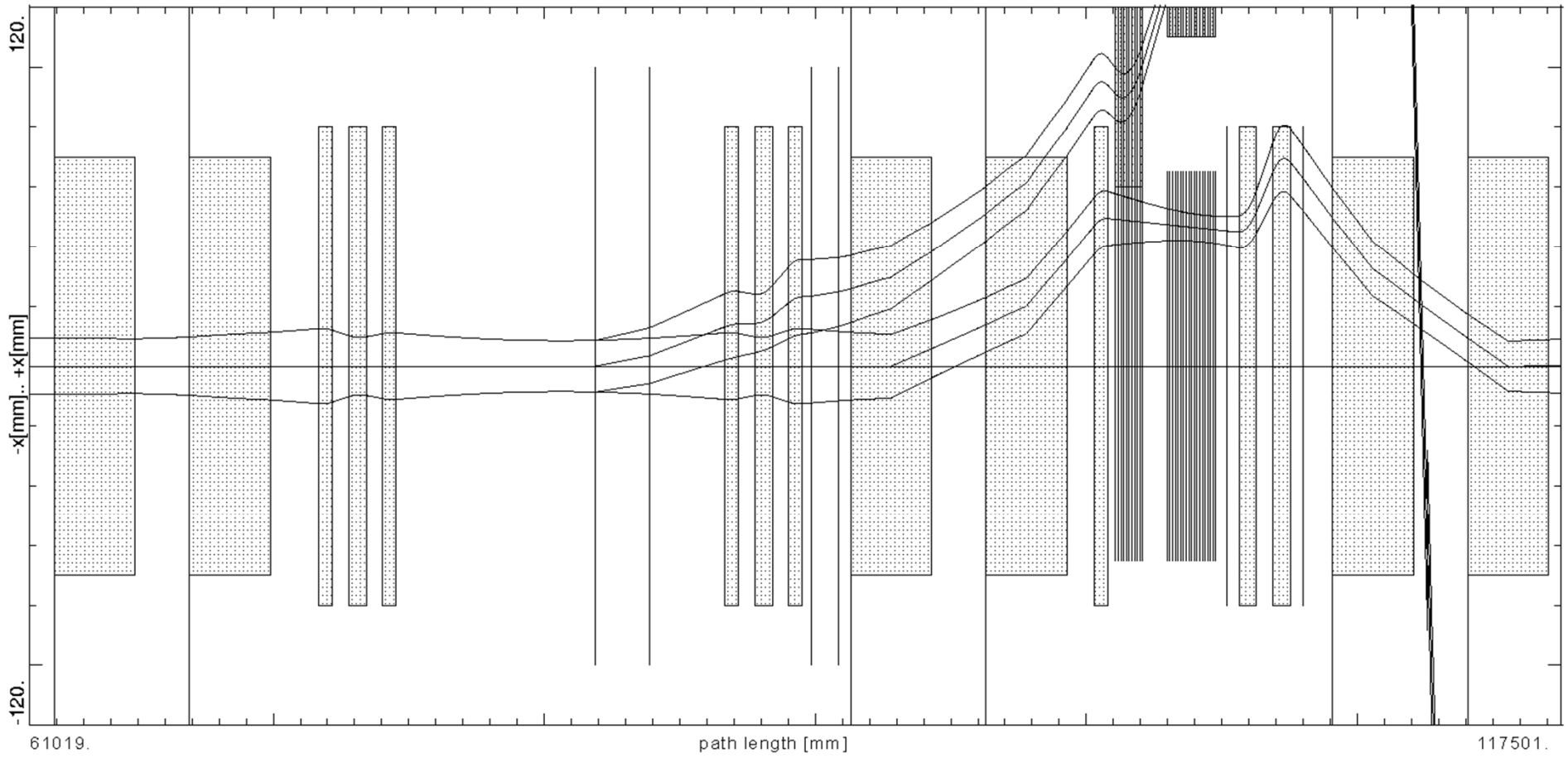
Figure 3-27 CSRe Injection Orbit with Cooling Section Correction(Isochronous Mode, 8.4T.M)

Fast extraction from CSRm

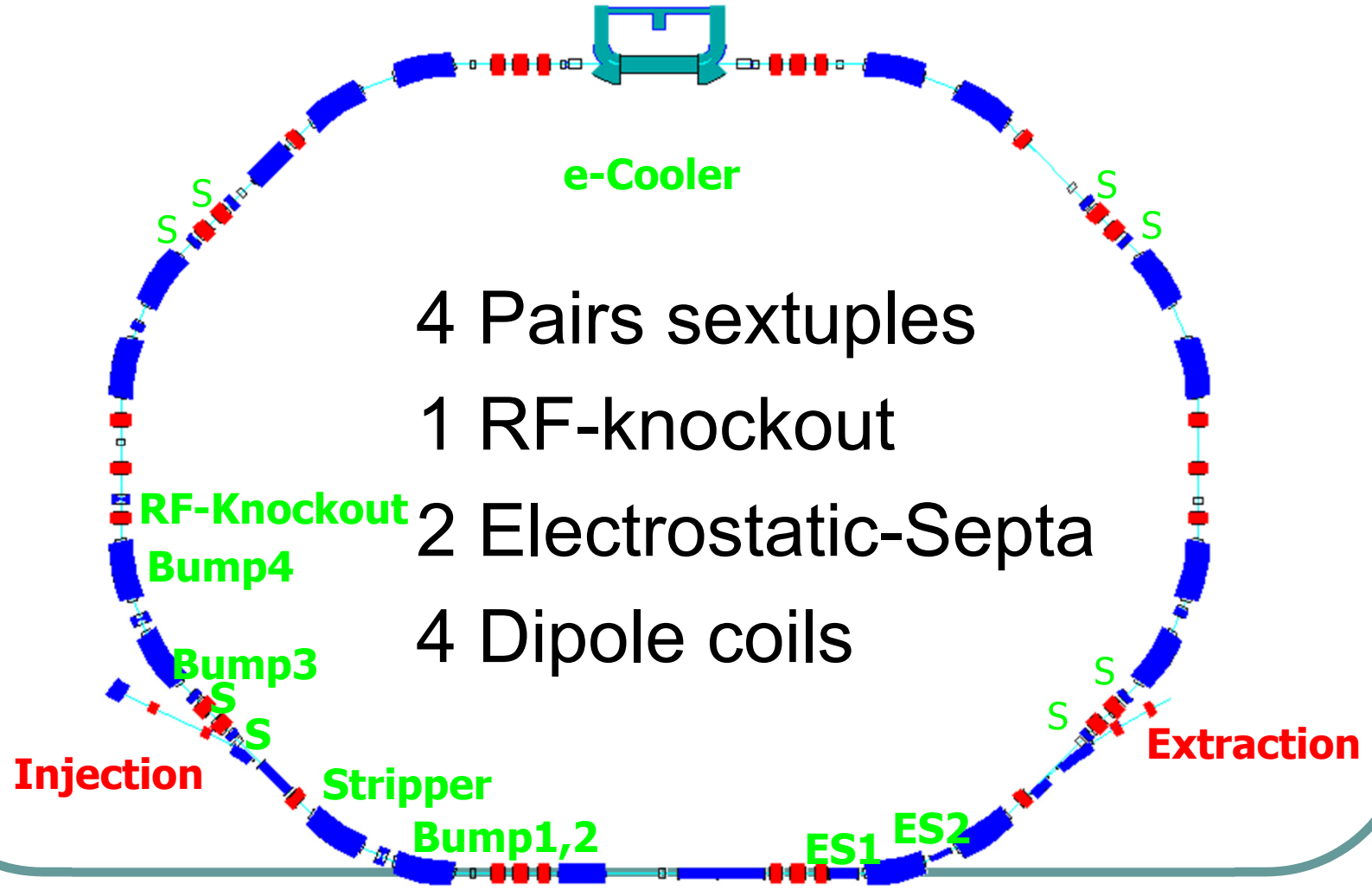
- Use the same extraction tunnel with slow extraction
- 6 cell kicker with 150ns raise time and 700ns flattop
- D-coils or global orbit shift
- 2 septum magnets



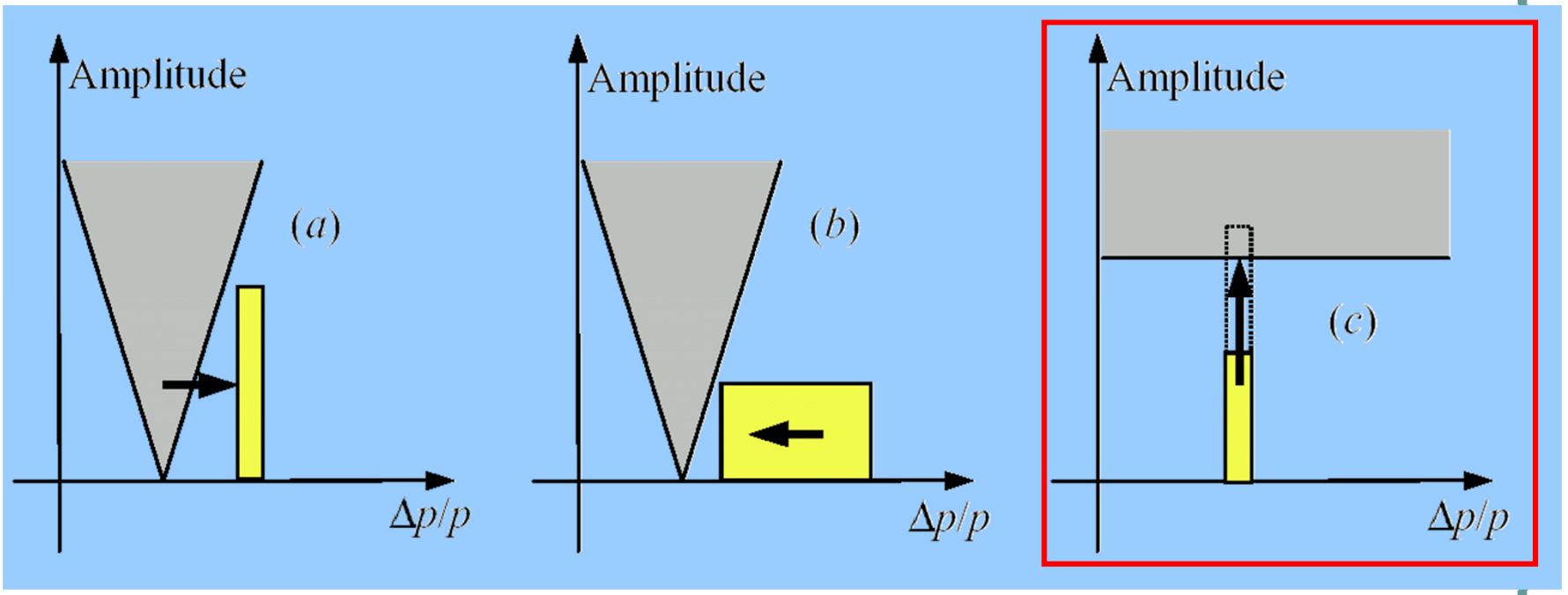
CSRm Extraction Orbit



Layout of CSRm Slow Extraction



Slow Extraction Scheme

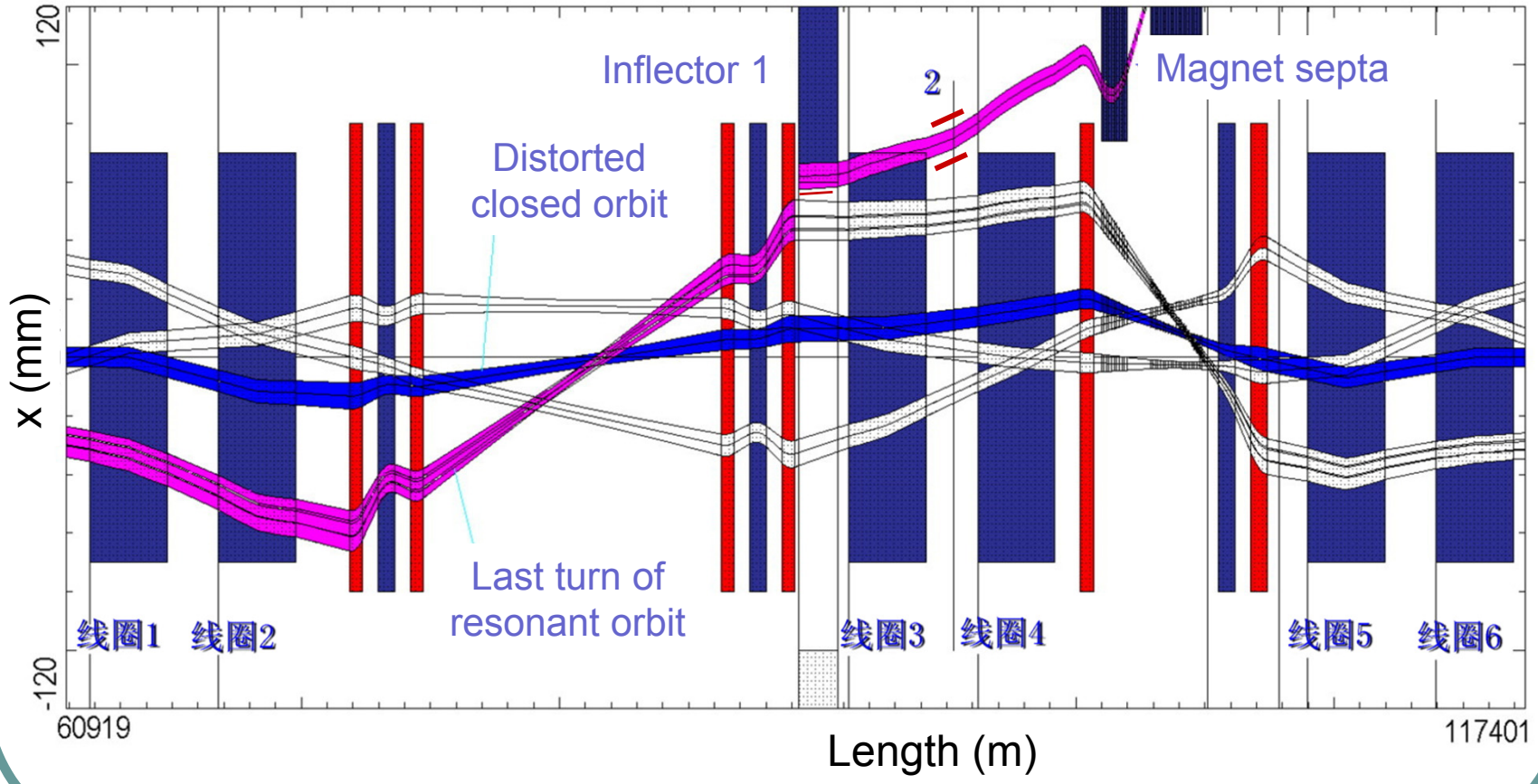


(a) Amplitude selection + tune moving $\delta p \downarrow \xi \uparrow$

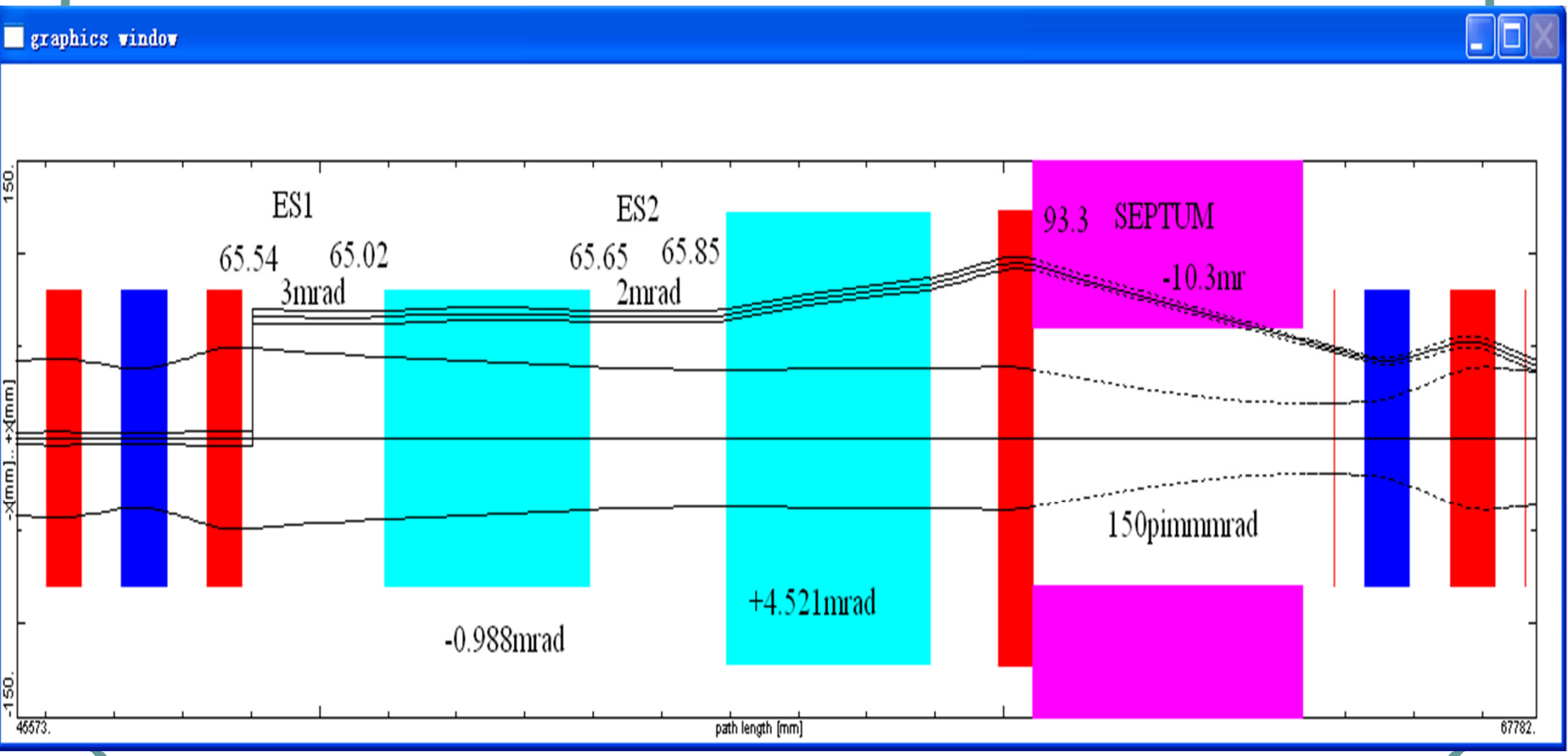
(b) Momentum + Amplitude selection $\delta p \uparrow \xi \uparrow$

(c) RF Knock-out —Zero Chromaticity $\delta p \downarrow \xi \downarrow = 0$ **(CSRm)**

The last turns of 1/3 integer resonant / RF knock-out slow extraction at CSRm

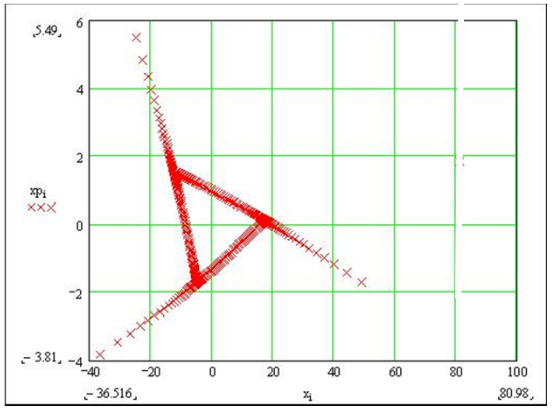


The slow extraction orbit



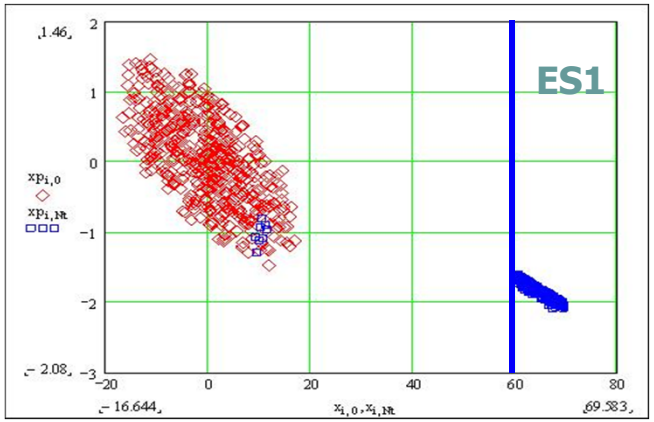
Basic Tracking Study

Stable 1/3 integer resonance phase space area



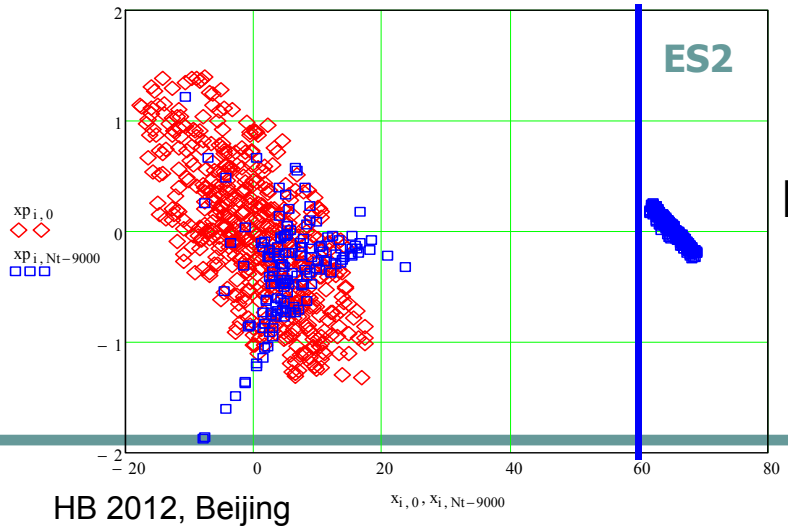
As=13π mm mrad

Extracted beam at 1st ES



k_{ES1}=3mrad

Extracted beam at 2nd ES

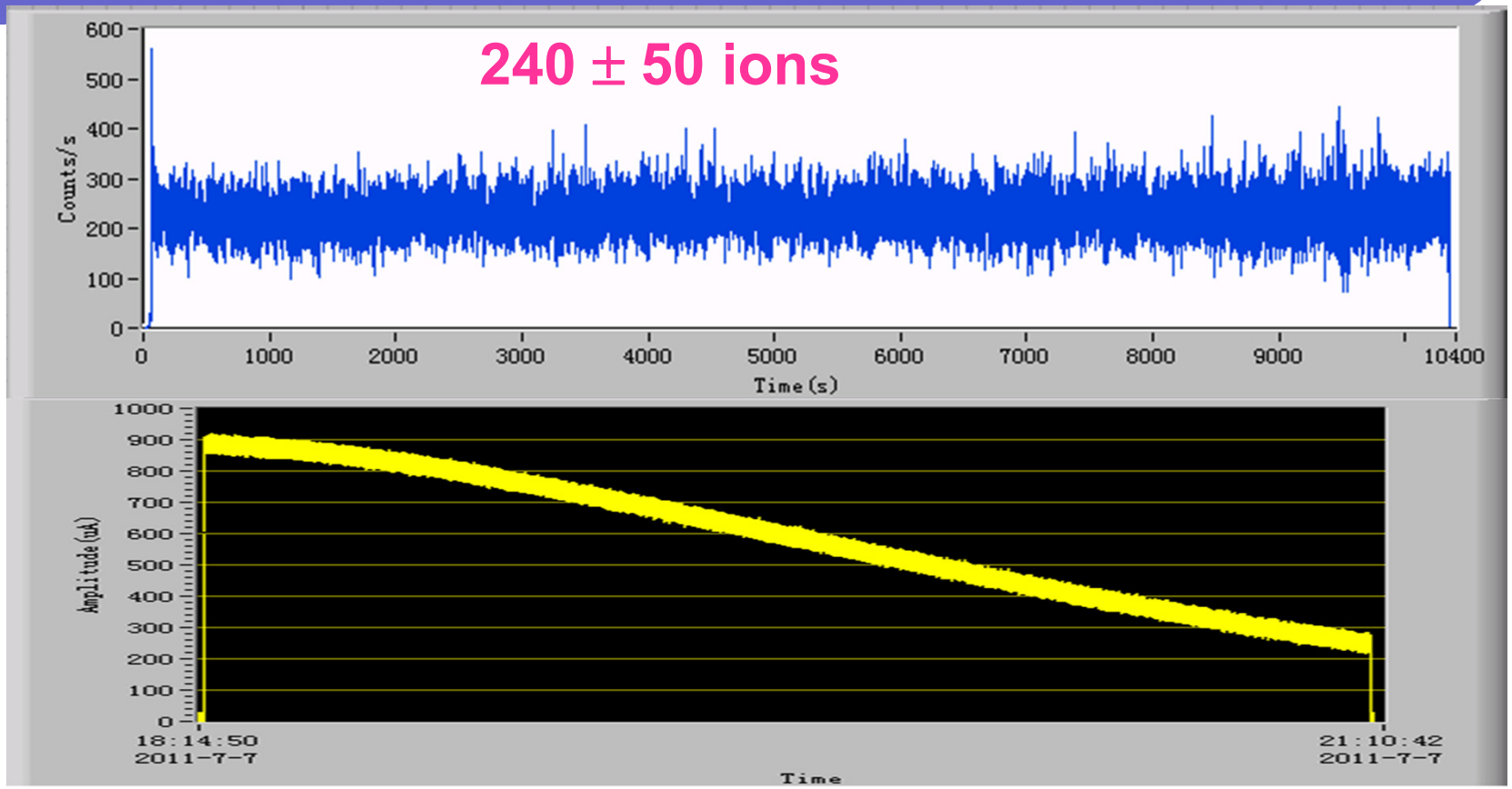


k_{ES1}=2mrad

Commissioning strategy for slow extraction

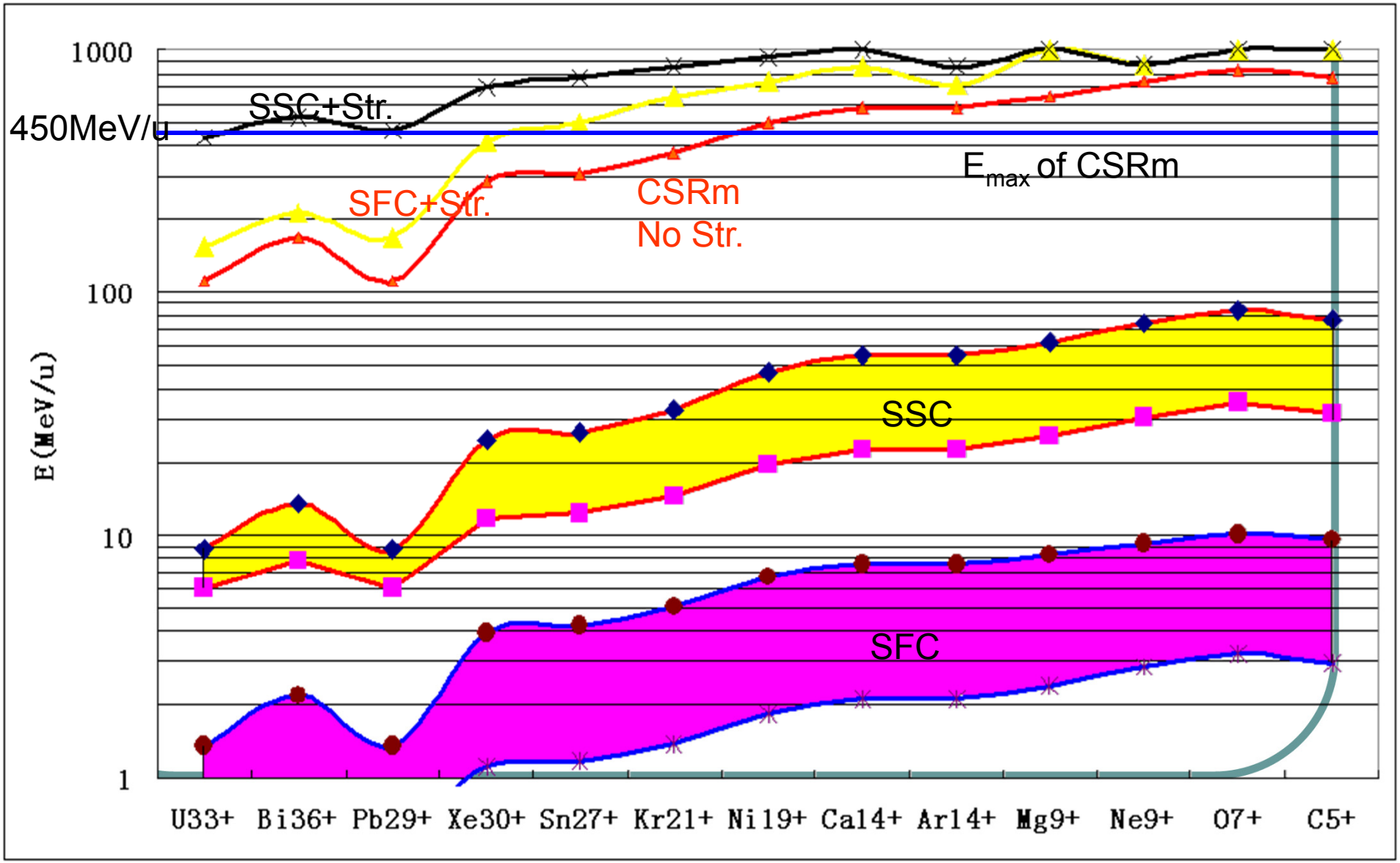
- Hardware: 8 sextuples, RF Knock-out, 2 ES, 4 orbit distortion coils
- From 2nd ramping section,
  - Starts the sextuples from 0.
  - Ramping the Qx→3.664, keep Qy
  - Keep the beam intensity
- → extraction section (top energy)
  - Resonance exciting strength S=12
  - Stable area A_s=13π mm mrad
- The parameters for k''L
  - 20S1=0.9745,21S2=-0.6700,22S2=-2.03, 23S2=-1.0527,24S2=0.2939
    - ✓ Exciting：20S2=0.240559,-1.11941,-0.142105,1.204465
    - ✓ Cancel natural chromaticity：20S2=-0.91060673033
- Orbit corrections for slow extracted beam

Time structure of long period slow extraction at CSRm

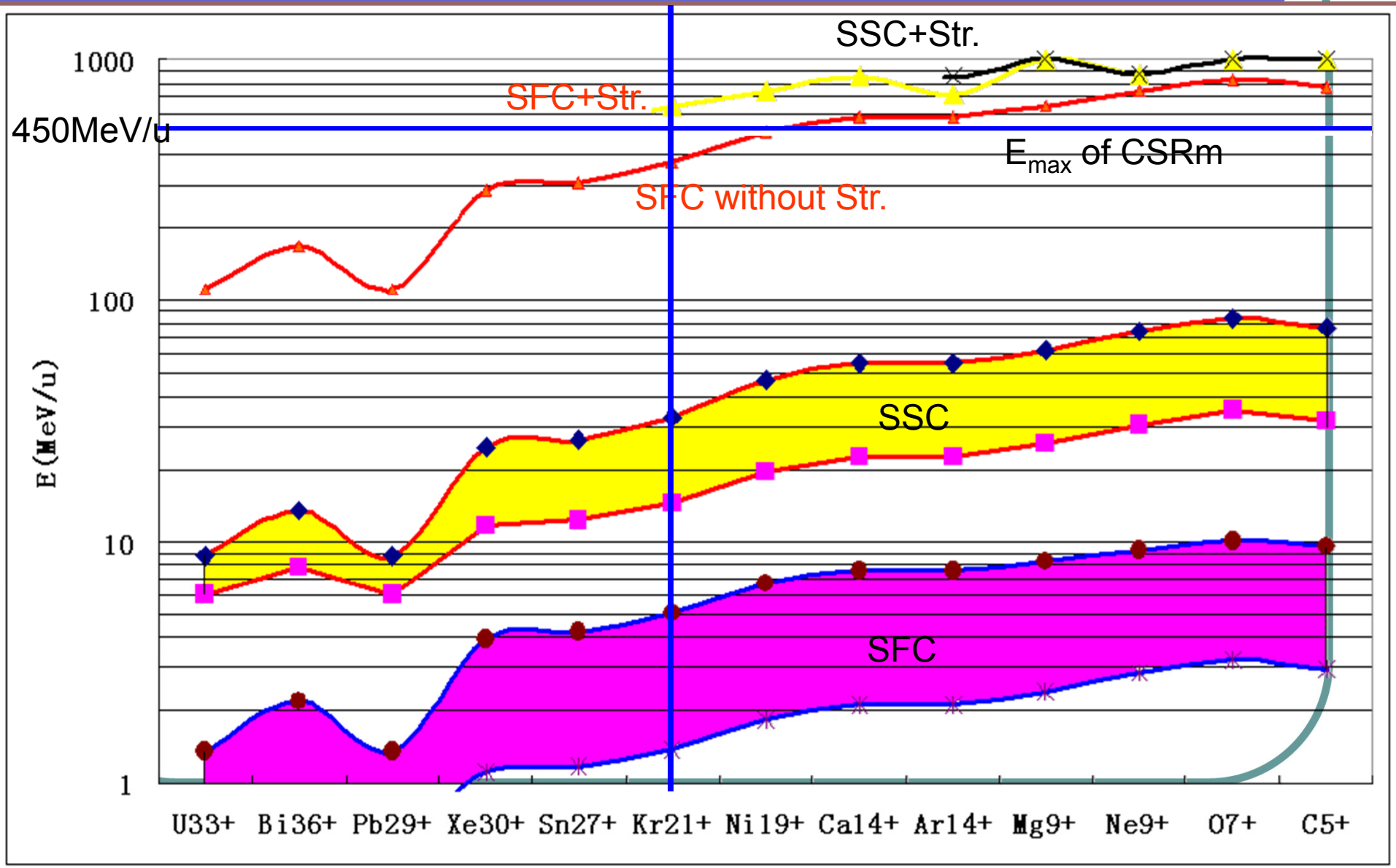


- 1/3 resonance slow extraction
- RF-Knockout exciting
- Feedback of extraction rates with fast servo Qs

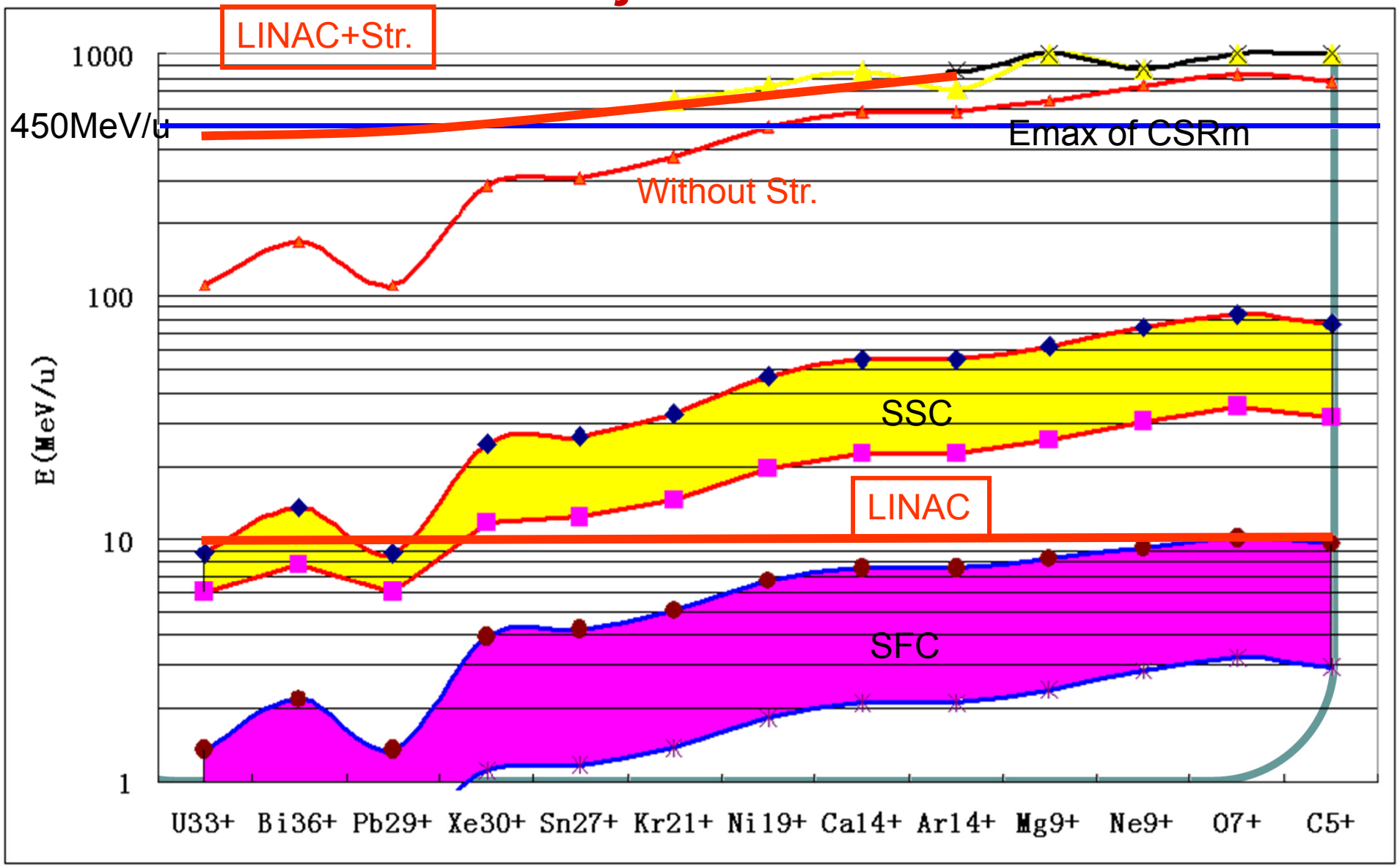
Energy range of HIRFL at design



Energy range of HIRFL if Iinj>1eμA

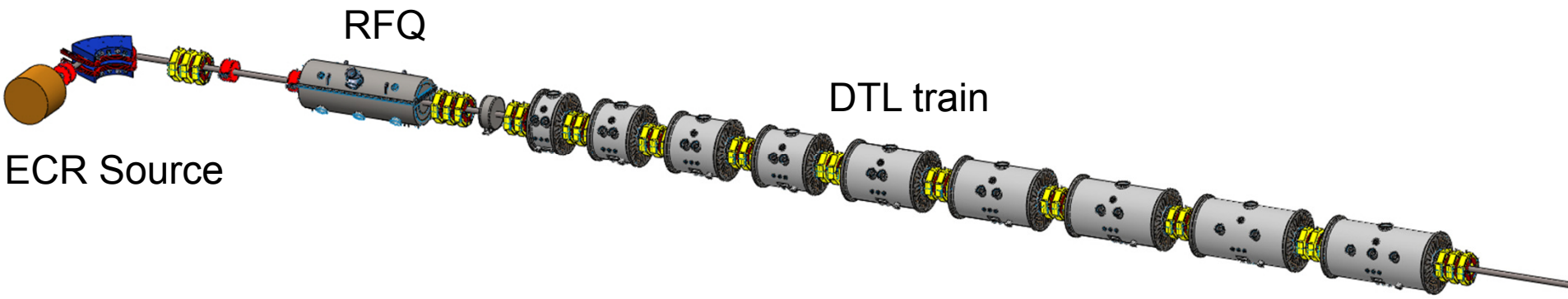


Energy range of HIRFL
with new LINAC injector



The New LINAC Injector

- Accelerate ion beam C-U with Q/A=1/3 ~1/7 up to 10MeV/u
- Pulsed operation <10Hz, <5ms duration.
- Up to 150 eμA, 10~1000 times of cyclotron injector.




Thank you very much
for your attention!