Electron cooling before the RCS

Can the beams be cooled transversely in 0.1 s?

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ACCUMULATION

IN THE PREVIOUS MEETING WE DISCUSSED USING A RING TO ACCUMULATE IONS WITH ELECTRON COOLING AT 100 MEV/U. CALCULATIONS OF ELECTRON COOLING ARE ESSENTIAL FOR ESTIMATES OF ACCUMULATION WITH 0.1 S BETWEEN EACH INJECTION.

HOWEVER, THIS TALK IS ABOUT A SOMEWHAT DIFFERENT USE OF THE

PROBLEM

MULTITURN INJECTION IN THE RCS GIVES 80-100 π MM MRAD HORISONTAL EMITTANCE. HOWEVER, DUE TO THE PS ACCEPTANCE LIMIT THE EMITTANCES HAVE TO BE BELOW

ε_X 16.4 π MM MRAD

ε_Z 8.8 π MM MRAD

SCENARIO

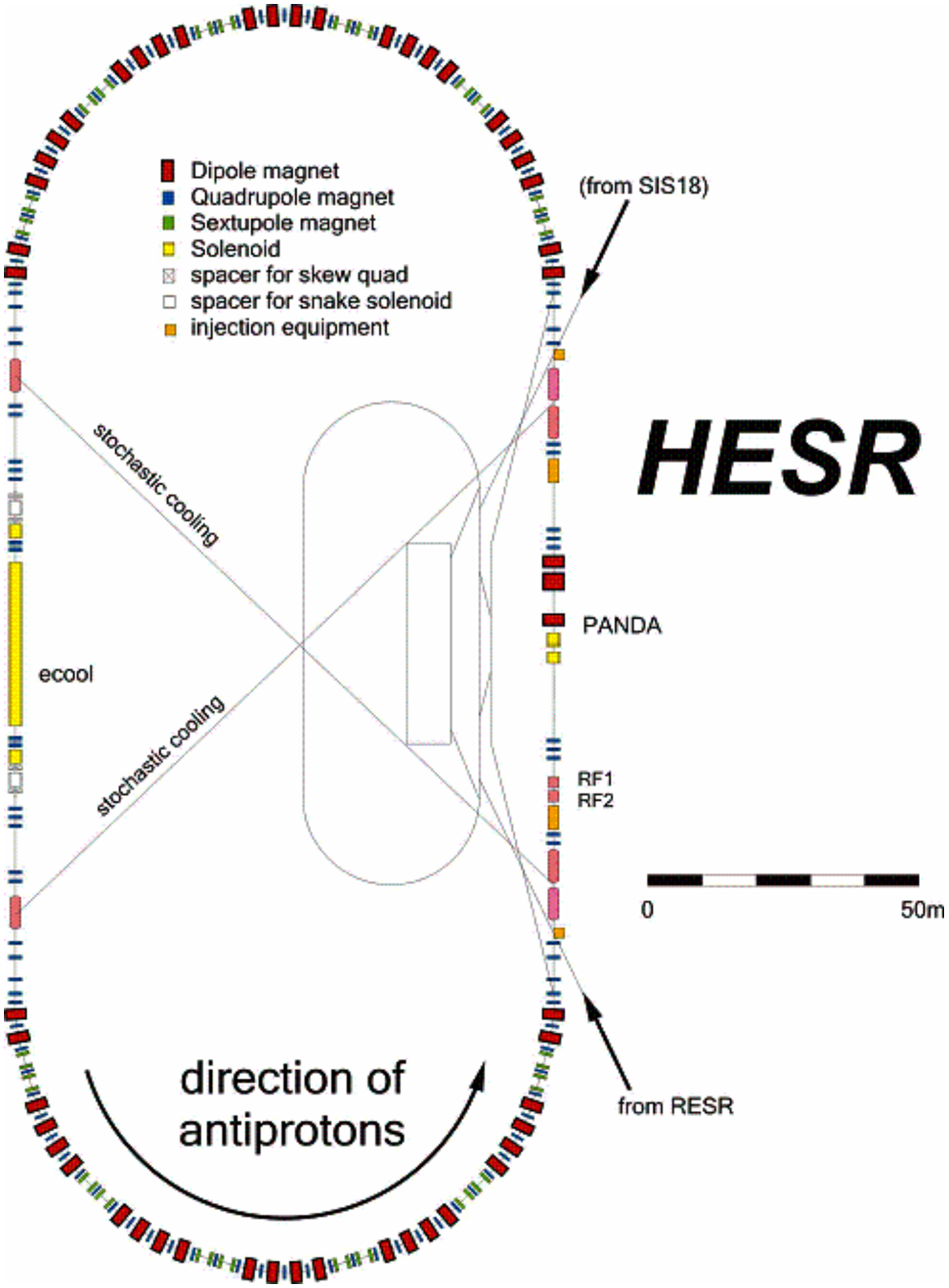
20 CYCLES DURING 2 S, THEN 5 S PAUSE

10 HZ LINAC → COOLER RING → RCS → PS

100 MEV/U 100 MEV/U 300 MEV/U

ACCUMULATION

SEVERAL LINAC BUCHES ARE MERGED IN THE COOLER RING WITH ELECTRON COOLING FOR EVERY BUNCH SENT TO THE RCS



- A 430 m cooler ring from FAIR
- one 30 m long electron cooler
- one section for injection and extraction

The RCS is 208 m, the cooler ring can be e.g. 104 m or 208 m.

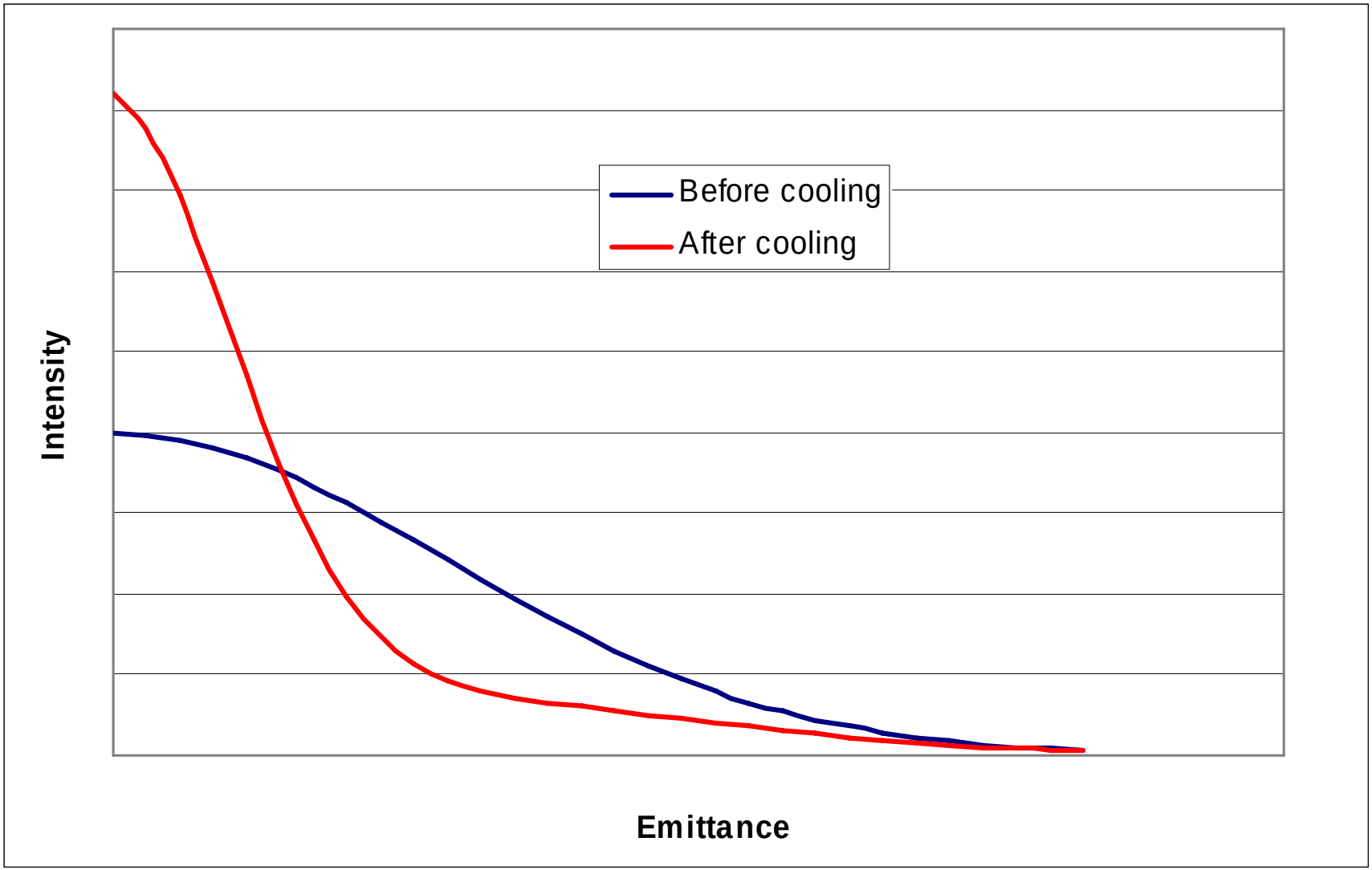
Electron Cooling

Fast for cold ions, slower when electron and ion velocities differ

Not dependent on ion current

Much faster longitudinally than transversely

$1/\text{Cooling Time} \sim Q^2/A \times I_E/\Theta^3$, where Θ is the angle between ions and electrons


Before cooling
After cooling
Intensity
Emittance

ELECTRON COOLER

THE COOLING SECTION IS ONE TO SEVERAL METERS LONG

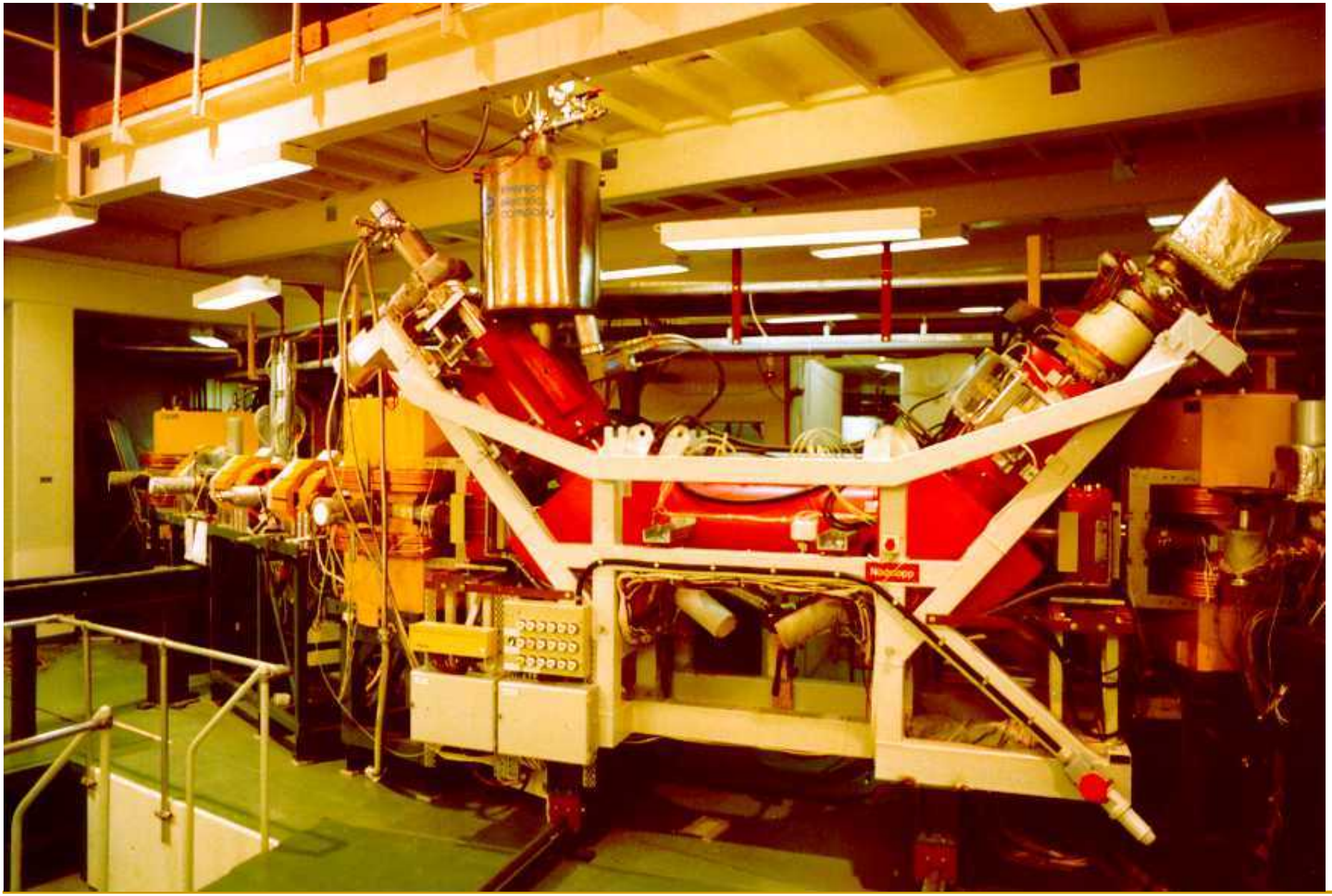
UP TO 1 A ELECTRON CURRENT

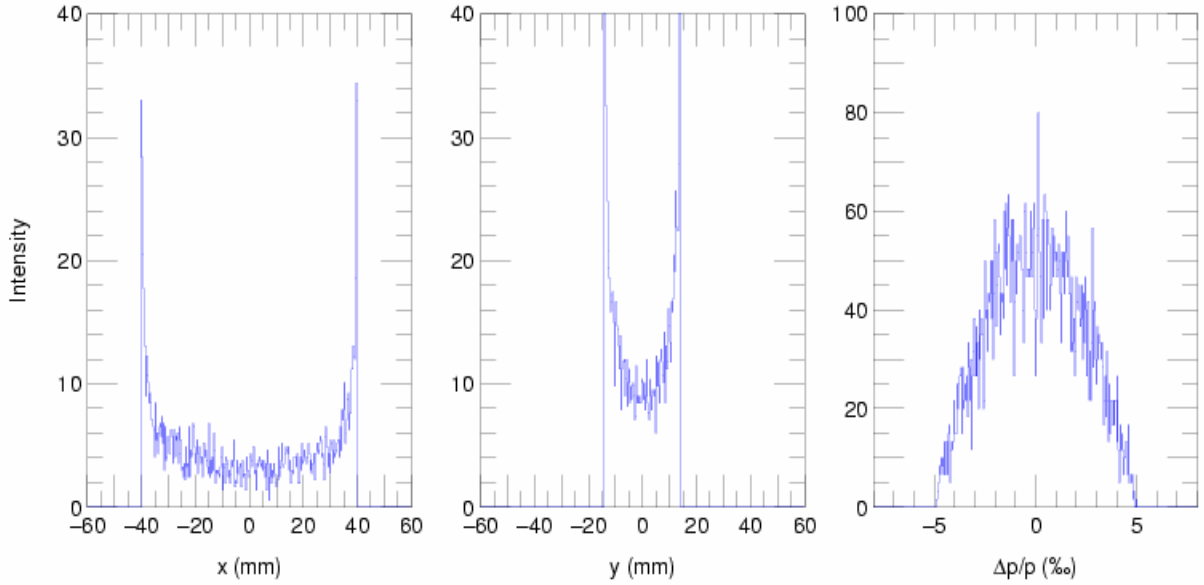
55 KV FOR 100 MEV/U

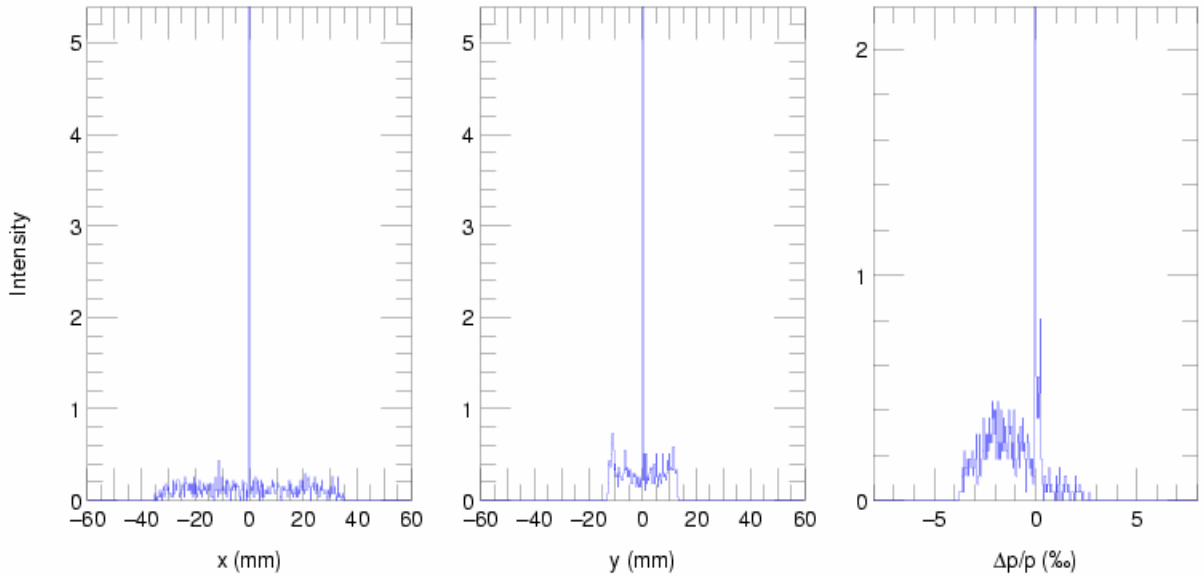
LARGE β–FUNCTIONS GIVE FAST COOLING,
1/COOLING TIME ~ $1/\Theta^3$ ~ $\beta^{1.5}$

Simulations of transverse cooling

- Input: hollow ion beams so all ions have the same transverse emittance
- Simple tracking with 3 D cooling force and electron beam space charge
- Intrabeam scattering isn't included, so the results for the coldest ions are wrong







$^{18}NE^{10+}$

0.1 S COOLING

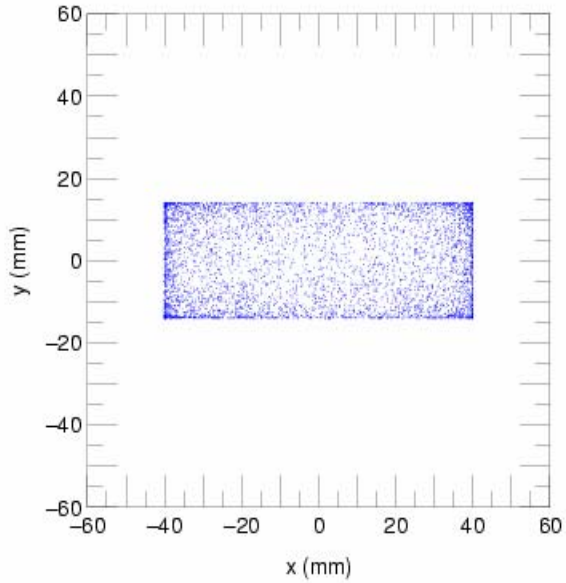
10% ELECTRON COOLER

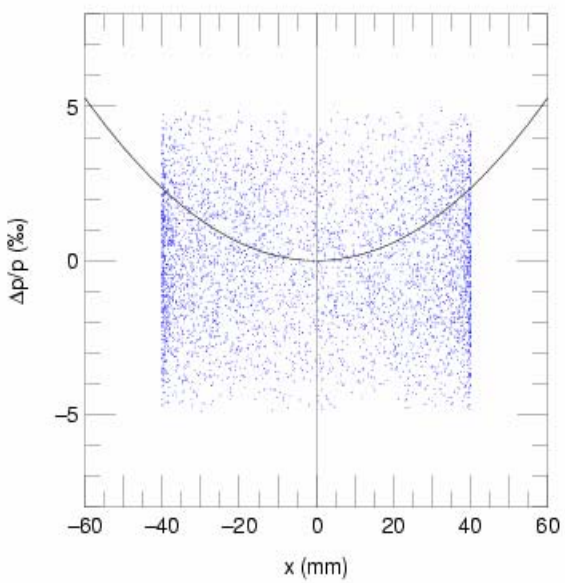
1 A ELECTRON CURRENT

$\beta X = 16$ M

$\varepsilon X = 100\ \pi$ MM MRAD

PS LIMIT 16 MM / 7 MM

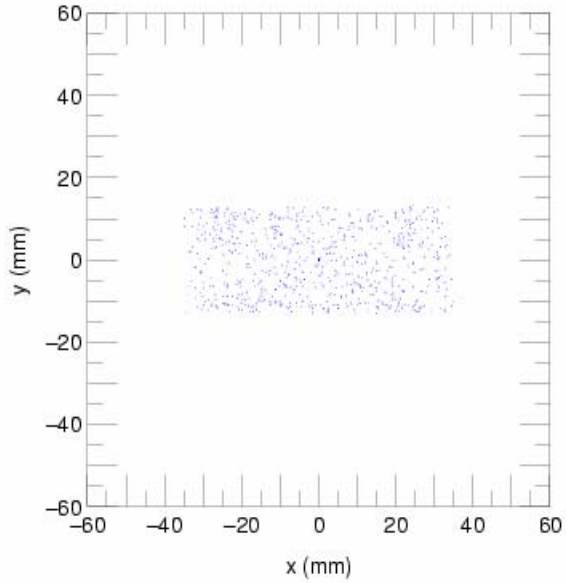


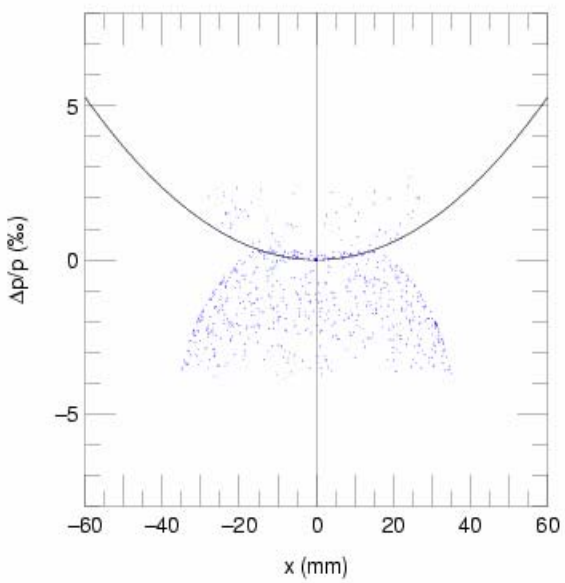


SIMCOOL 19-MAY-106 13:21:58

β_x, β_y = 16.00, 5.00 m
D = 0.00 m
Q_x, Q_y = 5.70, 5.55
l_{cool} = 208.00 m
r_{beam} = 20.0 mm
particles = 5000
turns = 62000
m_i = 18
q_i = 10
$E_{e,cool}$ = 55.000 keV
E_e = 55.000 keV
I_e = 1.000 A
θ_x, θ_y = 0.00, 0.00 mrad
B_z = 0.025 T
x_{max}, y_{max} = 40.00, 14.00 mm
$\Delta p/p_{max}$ = 5.0000 ‰
force = '1'
θ_{canc} = 0

x_{ave}, y_{ave} = -0.708, -0.098 mm
$\Delta p/p_{ave}$ = -0.0002
x_{rms}, y_{rms} = 28.317, 9.941 mm
$\varepsilon_x, \varepsilon_y$ = 49.995, 19.599 mm mrad
$\Delta p/p_{rms}$ = 2.2084 ‰





$^{18}NE^{10+}$

0.1 S COOLING

10% ELECTRON COOLER

1 A ELECTRON CURRENT

βX = 16 M

εX = 100 PI MM MRAD

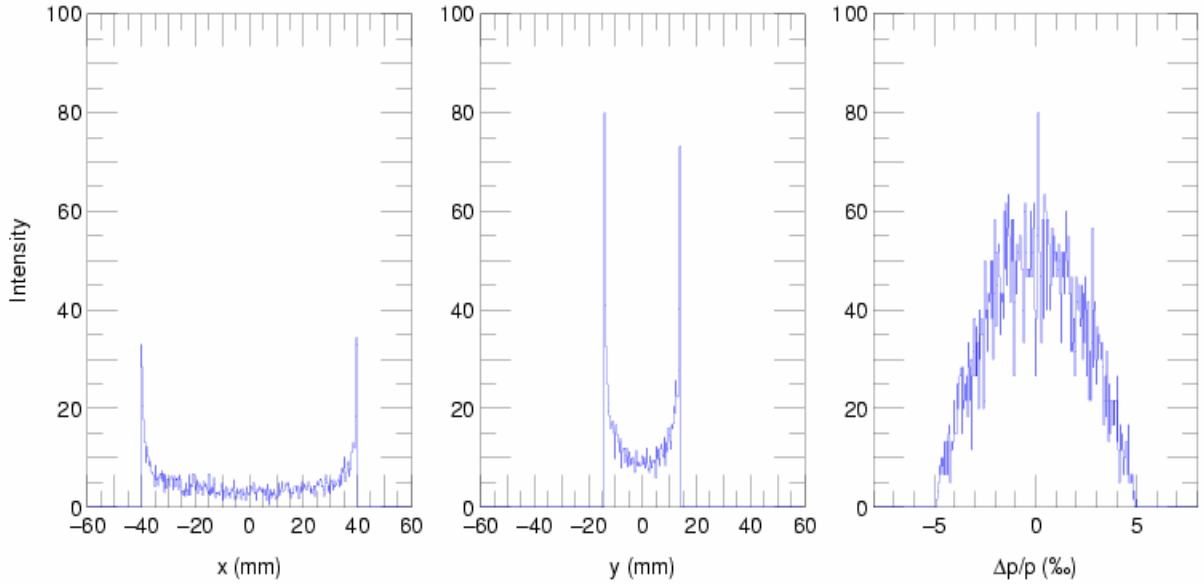
x_{ave}, y_{ave} = -0.009, -0.034 mm
$\Delta p/p_{ave}$ = -0.0178
x_{rms}, y_{rms} = 7.367, 3.059 mm
$\varepsilon_x, \varepsilon_y$ = 3.441, 1.929 mm mrad
$\Delta p/p_{rms}$ = 0.6957 ‰

$^{6}He^{2+}$ vs $^{18}Ne^{10+}$

1/cooling time ~ Q^2/A (theory)
or
1/cooling time ~ $Q^{1.7}/A$ (cryring measurements)

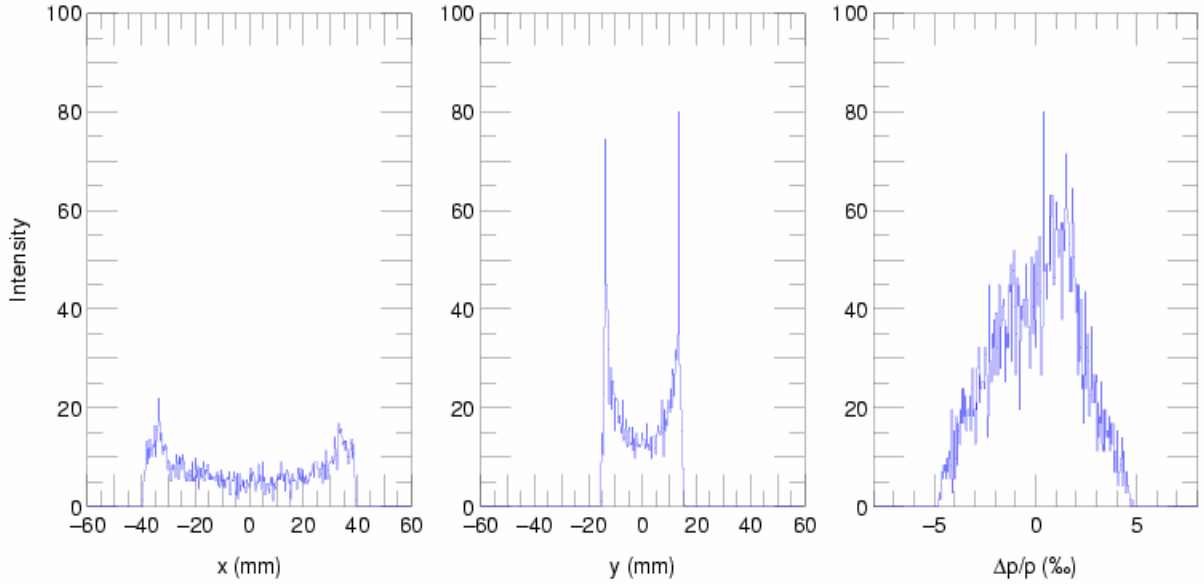
$^{18}Ne^{10+}$ / $^{6}He^{2+}$ = 5 – 8, cooling of neon is much faster

Space charge tune shift
→ dQ = −0.022 / −0.14



SIMCOOL 19-MAY-106 13:30:25

β_x, β_y = 16.00, 5.00 m
D = 0.00 m
Q_x, Q_y = 5.70, 5.55
l_{cool} = 208.00 m
$r_{e\text{-}beam}$ = 20.0 mm
particles = 5000
turns = 62000
m_i = 6
q_i = 2
$E_{i,cool}$ = 55.000 keV
E_e = 55.000 keV
I_e = 1.000 A
θ_x, θ_y = 0.00, 0.00 mrad
B_z = 0.025 T
x_{max}, y_{max} = 40.00, 14.00 mm
$\Delta p/p_{max}$ = 5.0000 ‰
force = '1'
θ_{cool} = 0

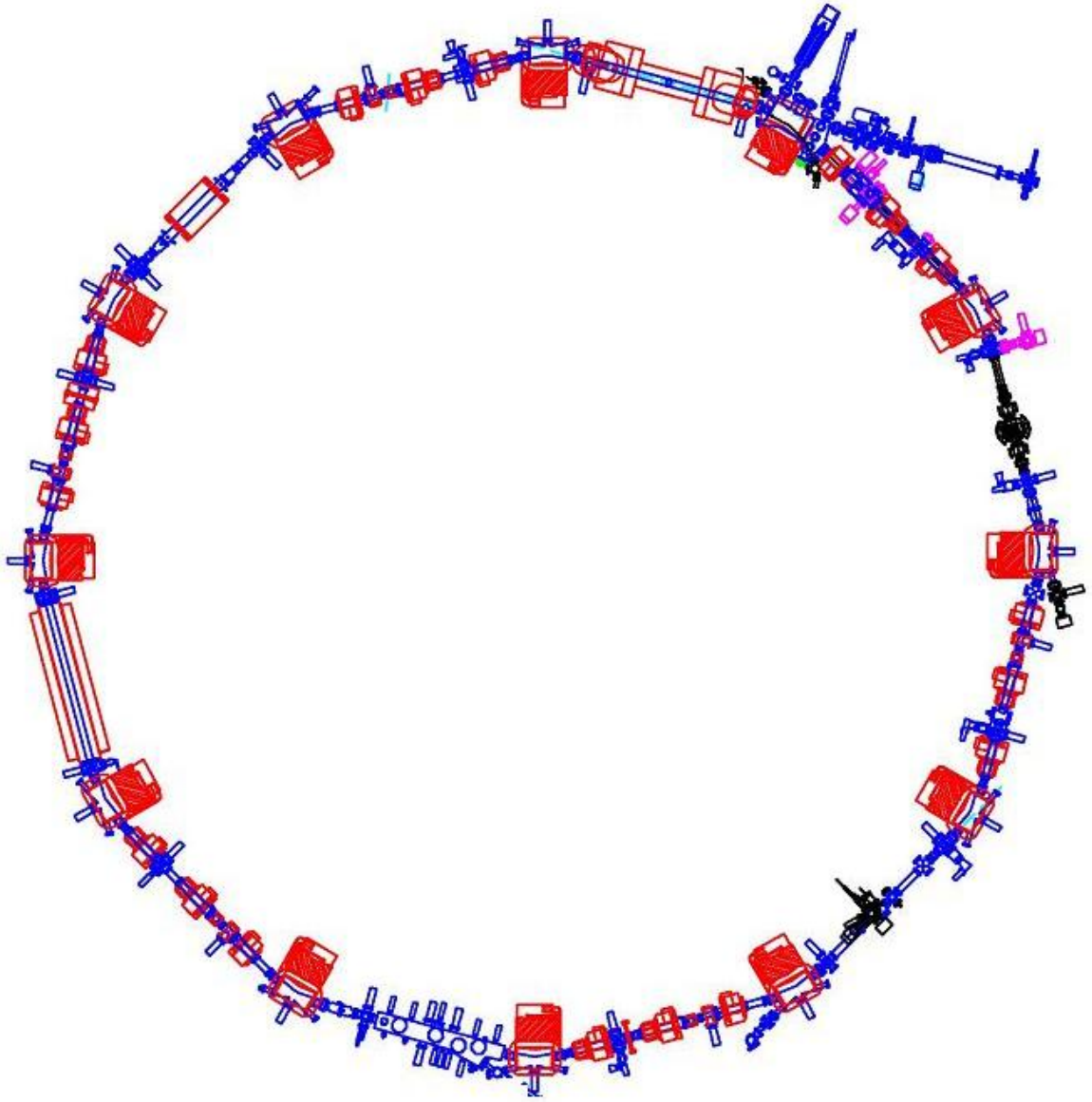


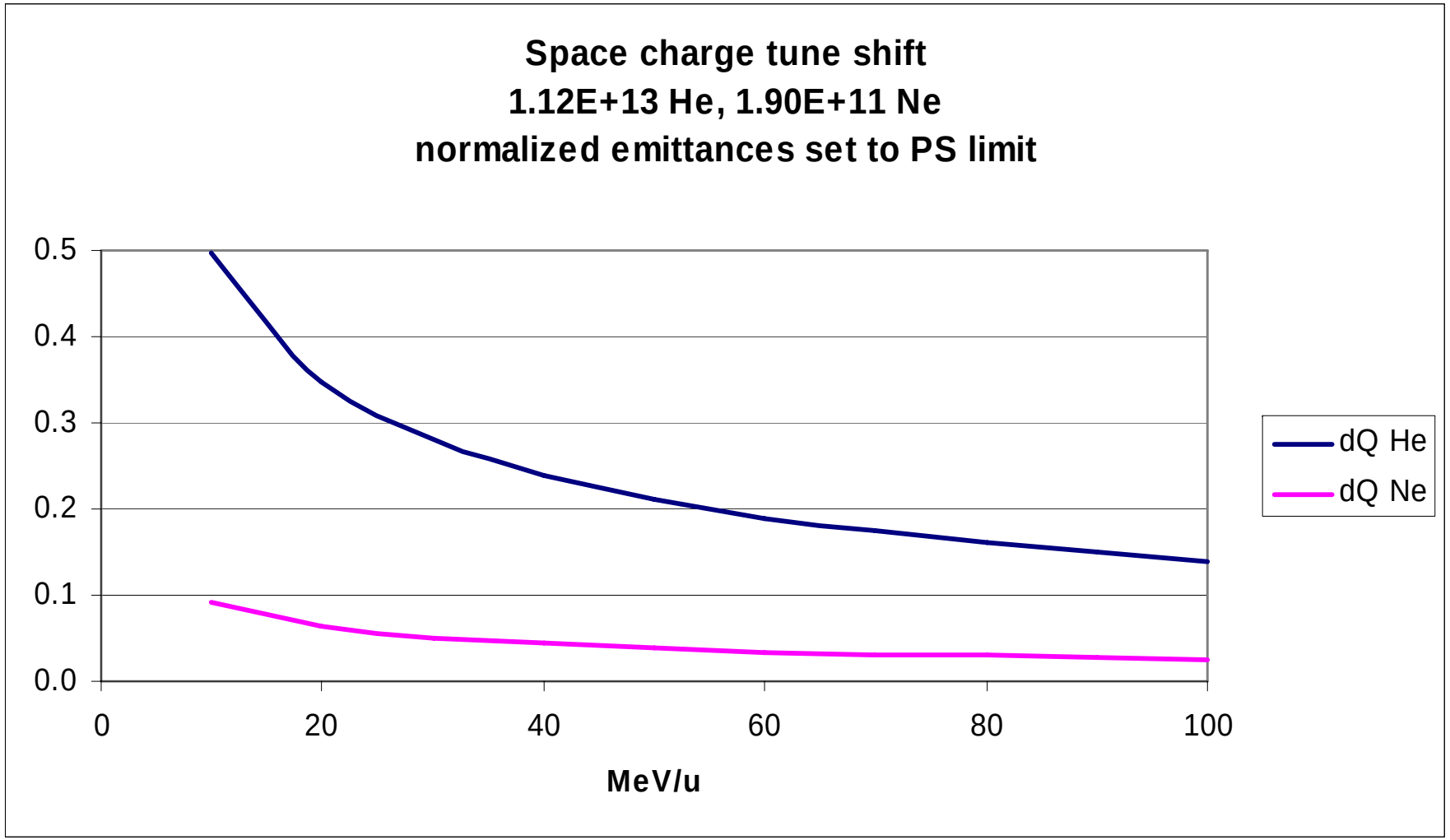
6HE2+
0.1 S COOLING
10% ELECTRON COOLER
1 A ELECTRON CURRENT
βX = 16 M
εX = 100 PI MM MRAD

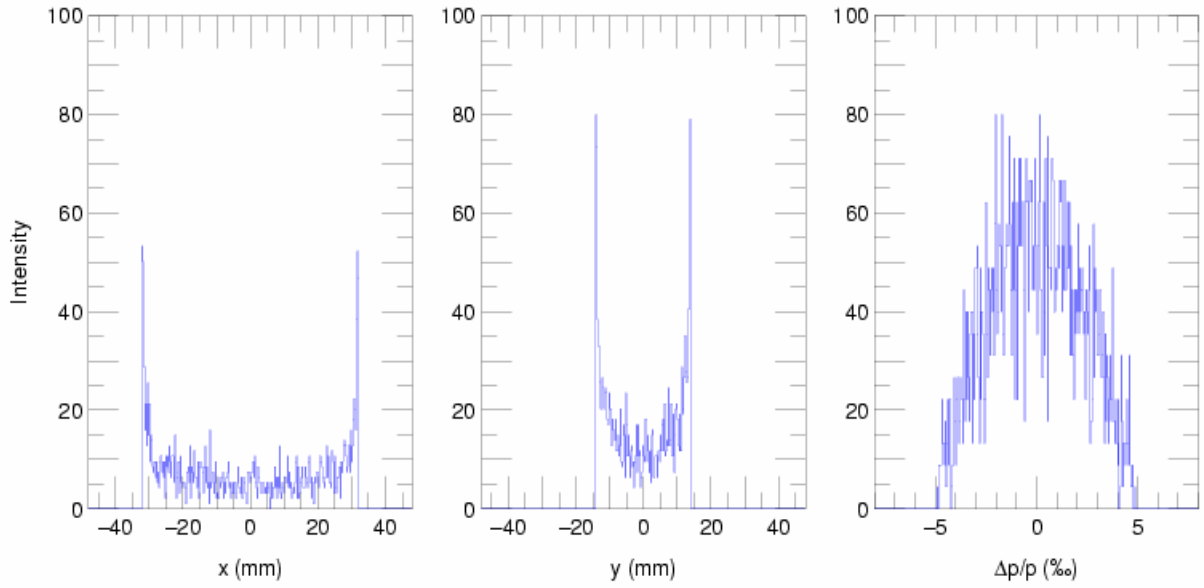
CONCLUSION

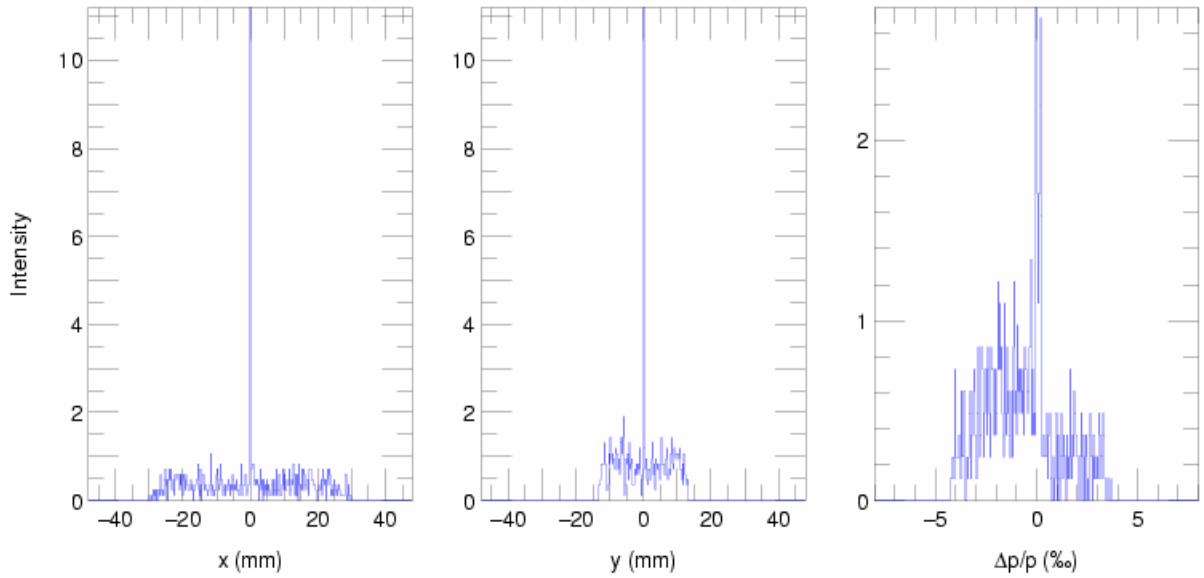
A COOLING RING WITH MULTITURN INJECTION BEFORE THE RCS CAN DRAMATICALLY REDUCE THE HORIZONTAL EMITTANCE OF $^{18}Ne^{10+}$ WITH 0.1 S COOLING.

THE $^{6}He^{2+}$ CASE IS MUCH MORE DIFFICULT, SINCE THE COOLING TIME IS LONGER AND THE SPACE CHARGE TUNE SHIFT LARGER.




Space charge tune shift
1.12E+13 He, 1.90E+11 Ne
normalized emittances set to PS limit
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
MeV/u
dQ He
dQ Ne

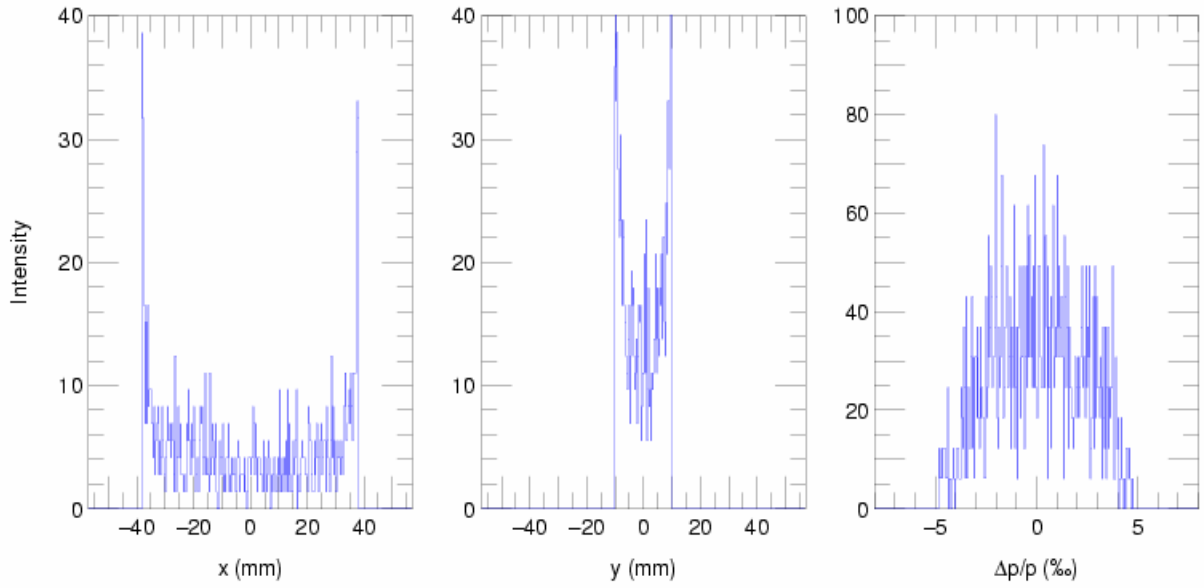


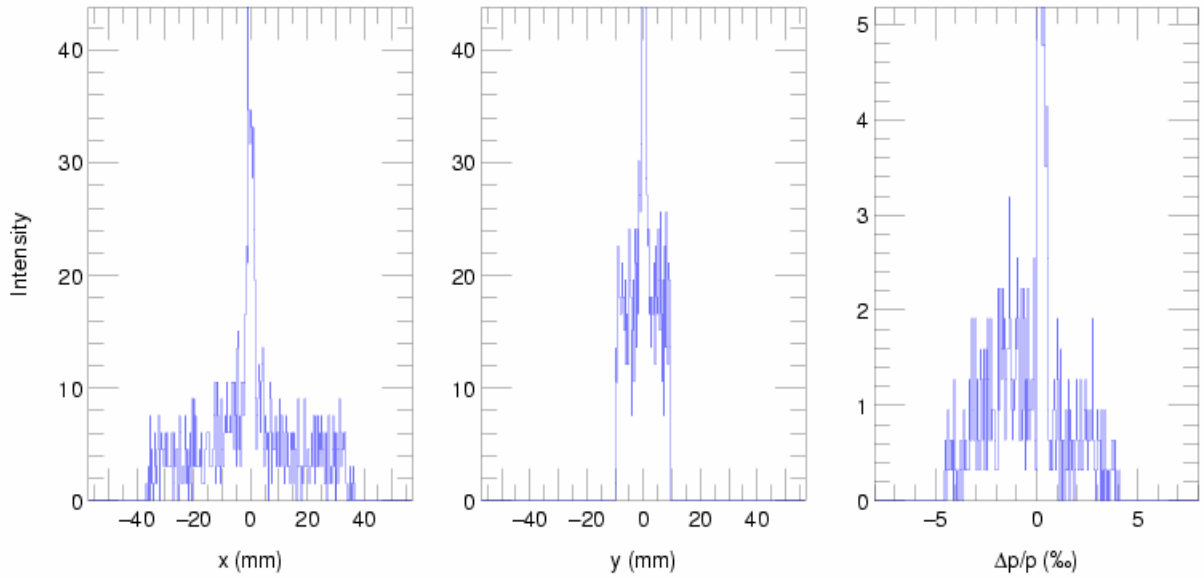


SIMCOOL 17-MAY-106 19:43:40

β_x, β_y = 13.00, 5.00 m
D = 0.00 m
Q_x, Q_y = 5.70, 5.55
l_{cool} = 10.00 m
$r_{e\text{-}beam}$ = 20.0 mm
particles = 2000
turns = 620000
m_i = 18
q_i = 10
$E_{e,cool}$ = 55.000 keV
E_e = 55.000 keV
I_e = 1.000 A
θ_x, θ_y = 0.00, 0.00 mrad
B_z = 0.070 T
x_{max}, y_{max} = 32.00, 14.00 mm
$\Delta p/p_{max}$ = 5.0000 ‰
force = '1'
θ_{orbit} = 0

18Ne10+
0.1 s cooling
10 m long electron cooler
1 A electron current
betax = 13 m
epsx = 80 pi mm mrad

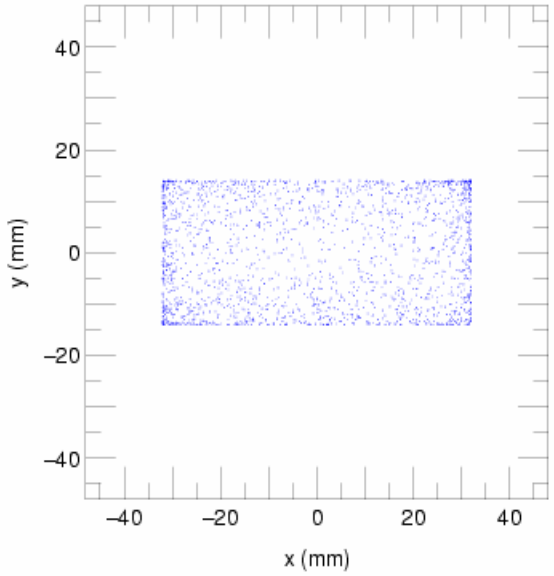


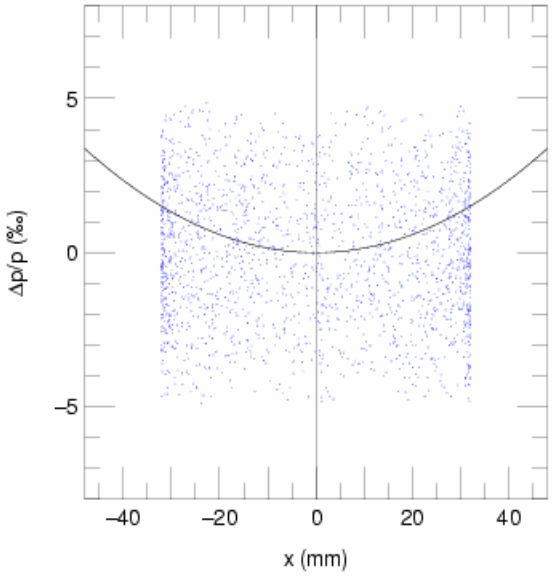


SIMCOOL 18-MAY-106 22:00:11

β_x, β_y = 16.00, 5.00 m
D = 0.00 m
Q_x, Q_y = 5.70, 5.55
l_{cool} = 50.00 m
$x_{e\text{-}beam}$ = 20.0 mm
particles = 1000
turns = 62000
m_i = 18
q_i = 10
$E_{e,cool}$ = 55.000 keV
E_e = 55.000 keV
I_e = 1.000 A
θ_x, θ_y = 0.00, 0.00 mrad
B_z = 0.050 T
x_{max}, y_{max} = 38.00, 10.00 mm
$\Delta p/p_{max}$ = 5.0000 ‰
force = '10'
θ_{orbit} = 0

18Ne10+
0.1 s cooling
5 m long electron cooler
1 A electron current
betax = 16 m
epsx = 90 pi mm mrad

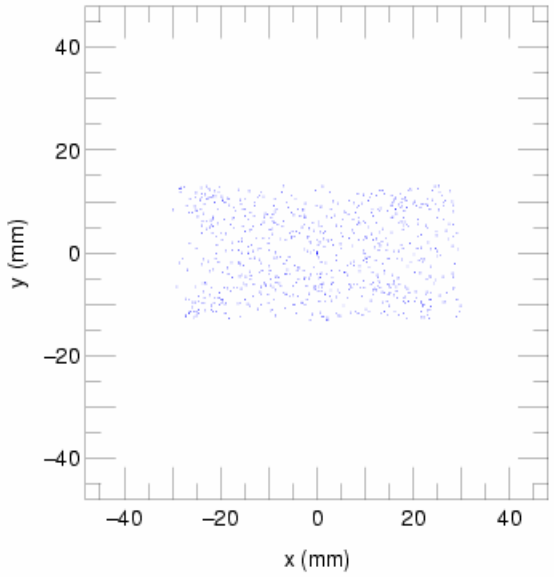


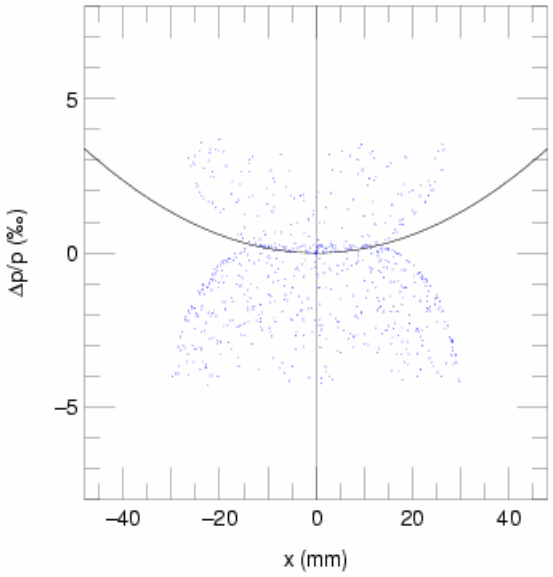


SIMCOOL 17-MAY-106 19:43:40

β_x, β_y = 13.00, 5.00 m
D = 0.00 m
Q_x, Q_y = 5.70, 5.55
l_{cool} = 10.00 m
r_{beam} = 20.0 mm
particles = 2000
turns = 620000
m_i = 18
q_i = 10
$E_{e,cool}$ = 55.000 keV
E_e = 55.000 keV
I_e = 1.000 A
θ_x, θ_y = 0.00, 0.00 mrad
B_z = 0.070 T
x_{max}, y_{max} = 32.00, 14.00 mm
$\Delta p/p_{max}$ = 5.0000 ‰
force = '1'
θ_{rest} = 0

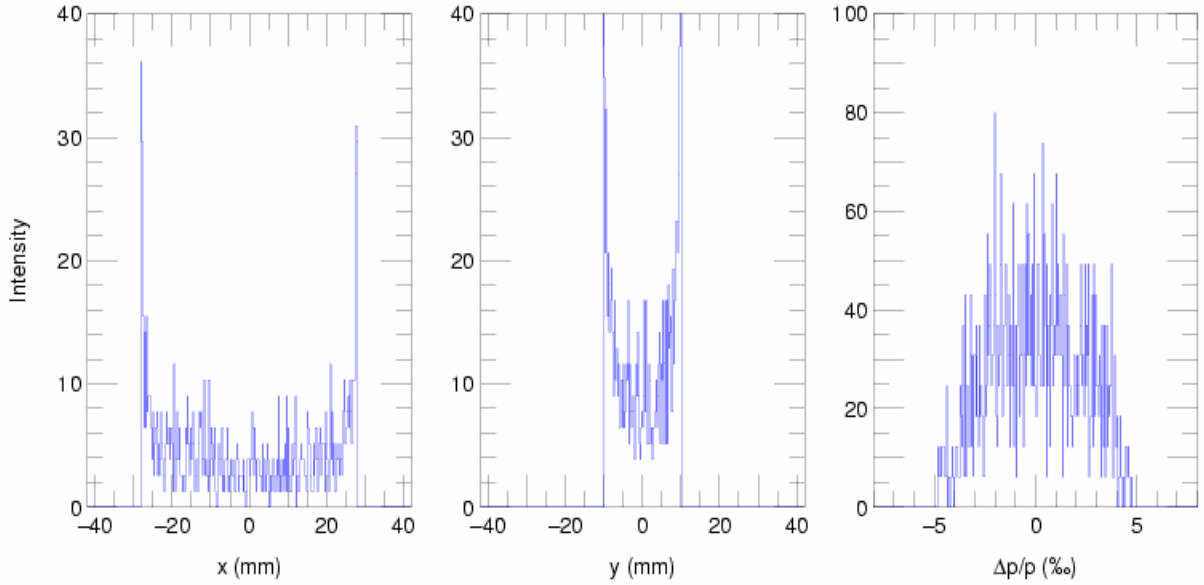
x_{ave}, y_{ave} = -0.739, 0.022 mm
$\Delta p/p_{ave}$ = -0.0035
x_{rms}, y_{rms} = 22.498, 9.958 mm
$\varepsilon_x, \varepsilon_y$ = 39.377, 19.594 mm mrad
$\Delta p/p_{rms}$ = 2.2374 ‰





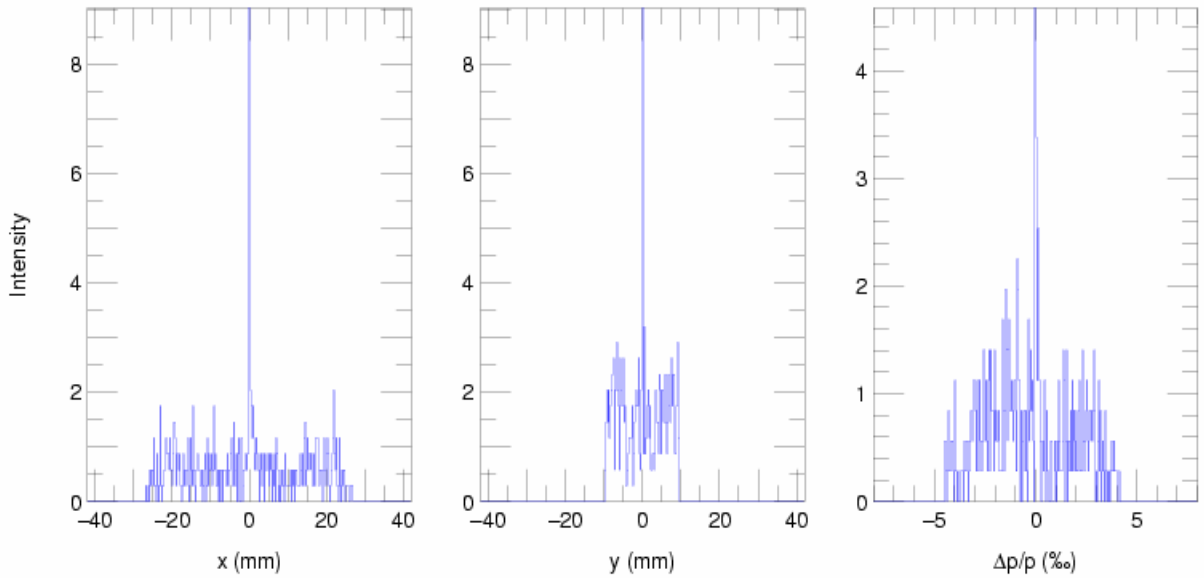
18Ne10+
0.1 s cooling
10 m long electron cooler
1 A electron current
betax = 13 m
epsx = 80 pi mm mrad

x_{ave}, y_{ave} = 0.080, -0.031 mm
$\Delta p/p_{ave}$ = -0.0258
x_{rms}, y_{rms} = 9.839, 4.583 mm
$\varepsilon_x, \varepsilon_y$ = 7.730, 4.195 mm mrad
$\Delta p/p_{rms}$ = 1.1930 ‰



SIMCOOL 18-MAY-106 21:53:31

β_x, β_y = 16.00, 5.00 m
D = 0.00 m
Q_x, Q_y = 5.70, 5.55
l_{cool} = 50.00 m
$r_{e\text{-}beam}$ = 20.0 mm
particles = 1000
turns = 62000
m_i = 18
q_i = 10
$E_{e,cool}$ = 55.000 keV
E_e = 55.000 keV
I_e = 1.000 A
θ_x, θ_y = 0.00, 0.00 mrad
B_z = 0.050 T
x_{max}, y_{max} = 28.00, 10.00 mm
$\Delta p/p_{max}$ = 5.0000 ‰
force = '10'
θ_{cusp} = 0



18Ne10+
0.1 s cooling
5 m long electron cooler
1 A electron current
betax = 16 m
epsx = 50 pi mm mrad