THE ADVANCE TECHNOLOGY EXTRACTION FOR THERAPY IONS BEAM FROM CARBON STORAGE RING WITH ELECTRON COOLING

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Alushta, Ukraine

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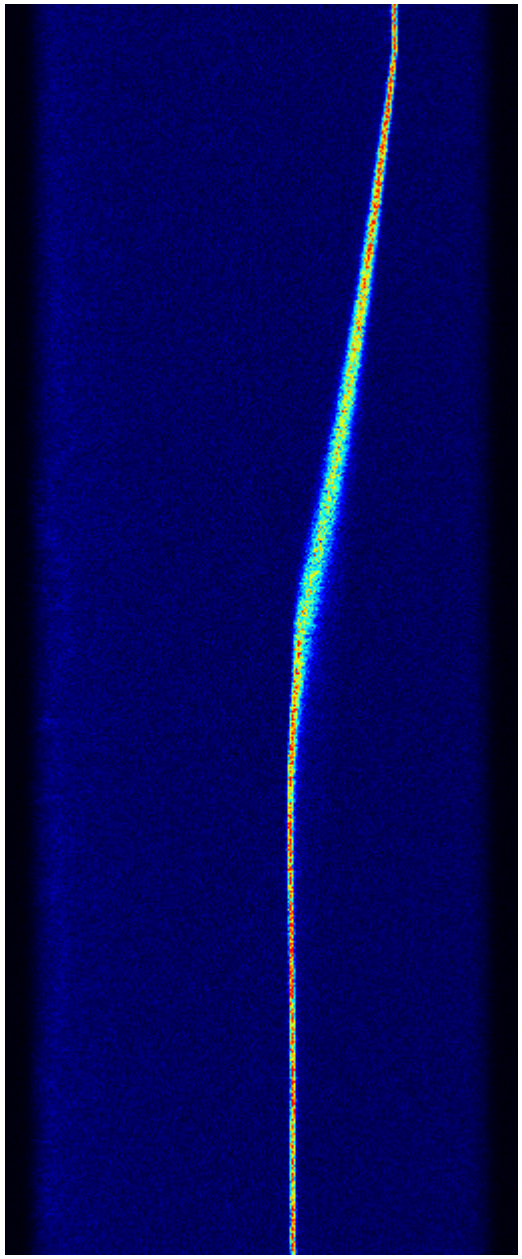
Abstract

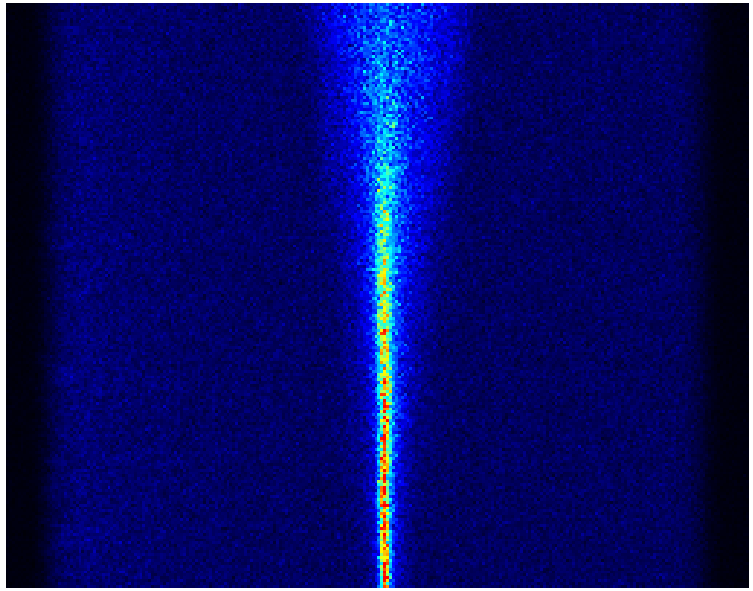
The electron cooling because of increasing the 6D phase space density of ion beams is the path for development compact accelerator ions beam therapy. The aperture magnets for the main synchrotron, the transport lines and the moveable ion gantry can be decreased very fundamentally. The systems for the extraction ions will operate with the smaller aperture and the low fields that improves reliability of dose control. The first experiments made at Landzow Institute of Modern Physics with cooling carbon beam on the energy 200 and 400 MeV/u increased enthusiasm of authors this report at these sort of the therapy systems.

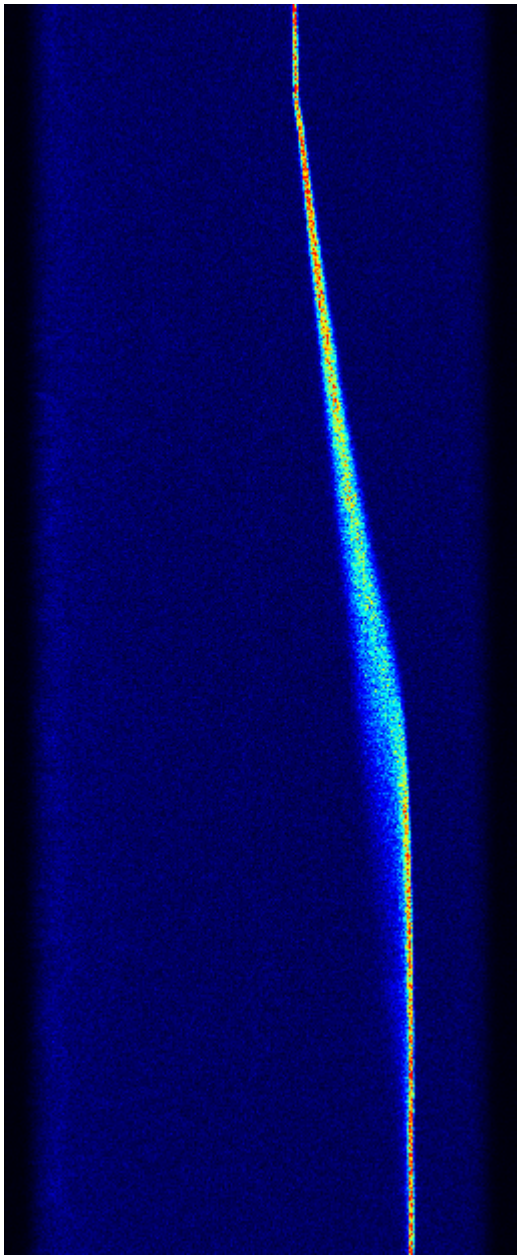

WARM WELCOME TO THE PARTICIPANTS OF COOL'09
August 31 - September 4, 2009 Lanzhou, China
兰州重离子加速器
国家实验室
重点实验室
临床研究基地

CSRe cooler in IMP

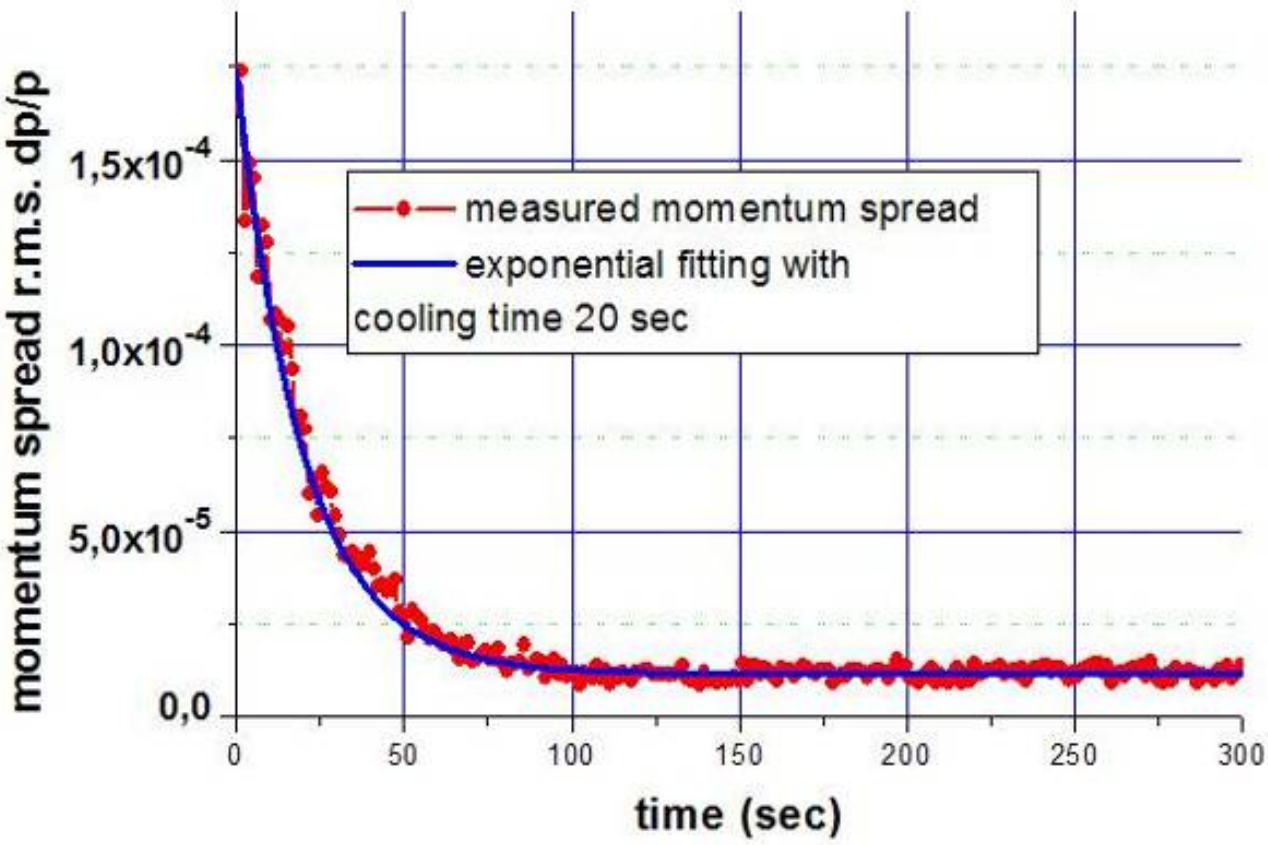


Initial momentum spread



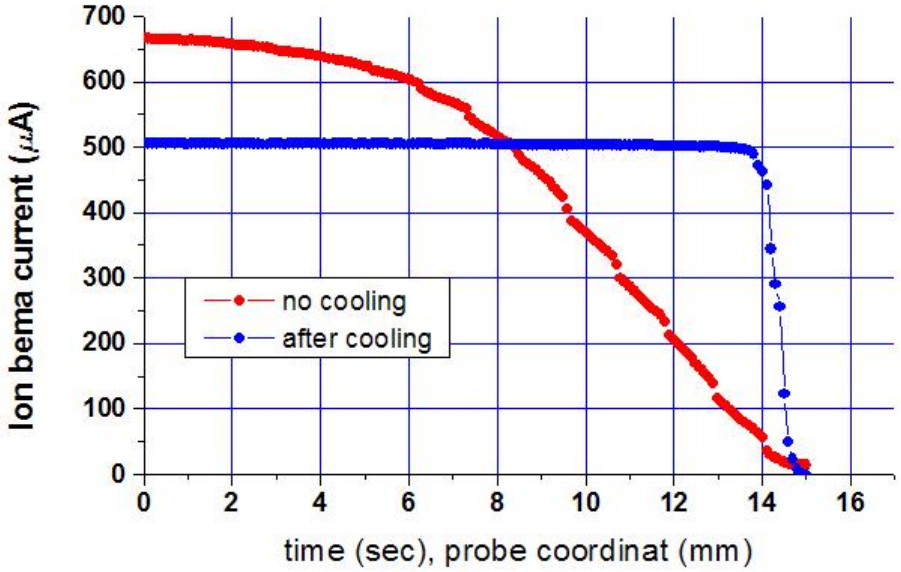


CSRe cooling carbon beam
with energy 400 MeV/u, Je=1 A
Center initial injection
Left and right evaluation
Schottky spectra after change
Electron beam energy

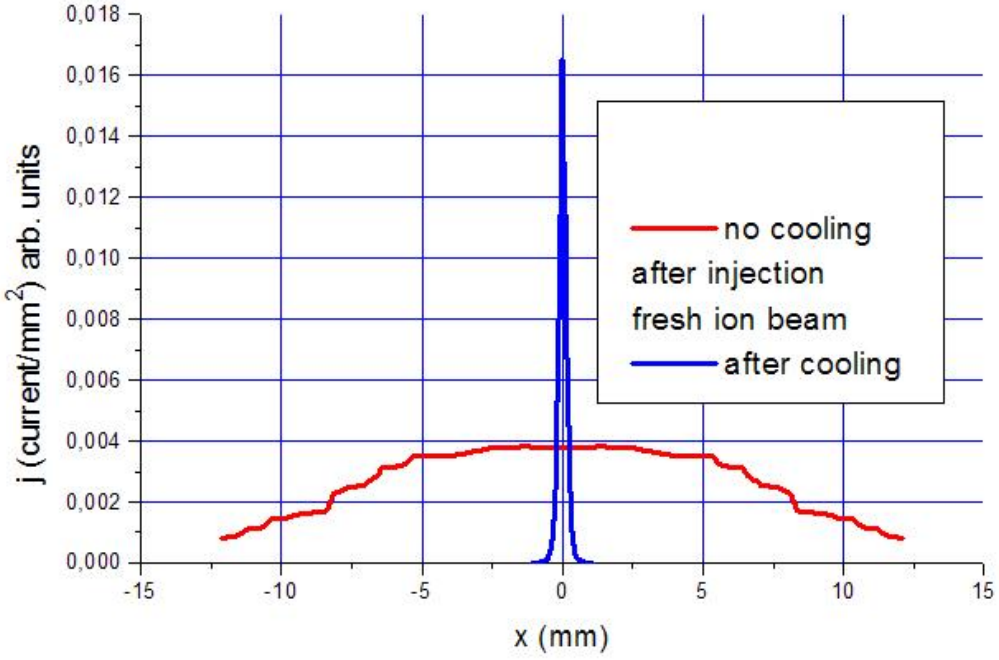


$$ne := \frac{Je}{1.6 \cdot 10^{-19} \cdot \pi \cdot ae^2 \cdot c \cdot \beta \cdot \gamma} \qquad ne = 7.244 \times 10^6$$

$$\lambda cool := \frac{4 \cdot re \cdot ri \cdot ne \cdot c^4}{V0i^3} \cdot 3 \cdot \frac{3}{120} \qquad \tau cool := \frac{\gamma}{\lambda cool} \qquad \tau cool = 22.472$$



The ion beam current versus time when probe moved inside beam with velocity 1 mm/s
Without cooling slow drop down ion beam Current
With cooling al changing inside last mm.



Transverse profiles ion beam calculated from scanning results

$$\varepsilon_{\perp} = \frac{r_i N_i g}{2\pi\delta\nu\beta^2\gamma^3}$$

$$\delta\nu \leq 0.1 - 0.2$$

The carbon beam emittance strongly function energy

$$N_i = 10^{10}$$

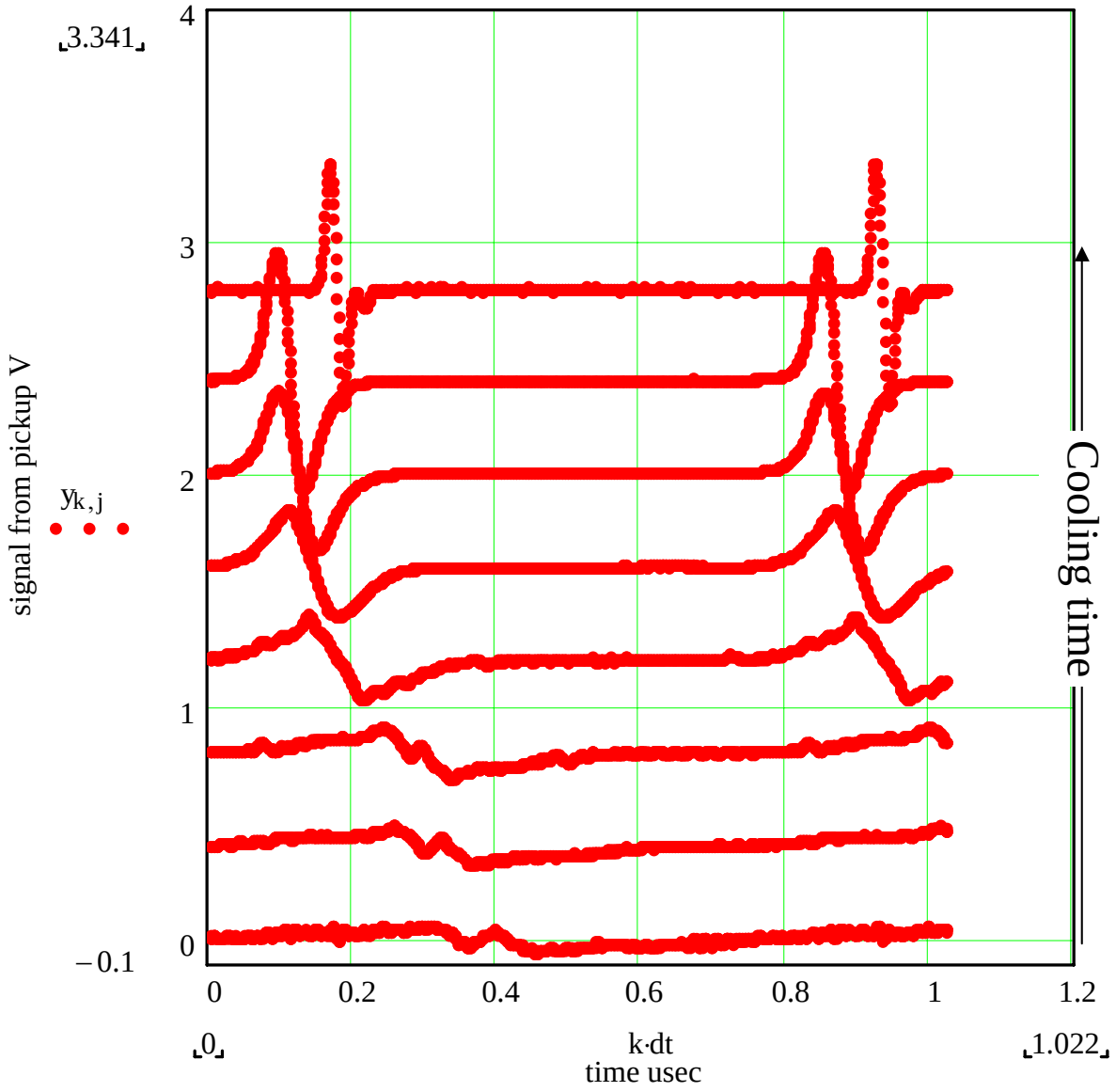
$$\delta\nu = 0.1$$

for 7 Mev/u diameter 2 cm

but for the ion beam energy

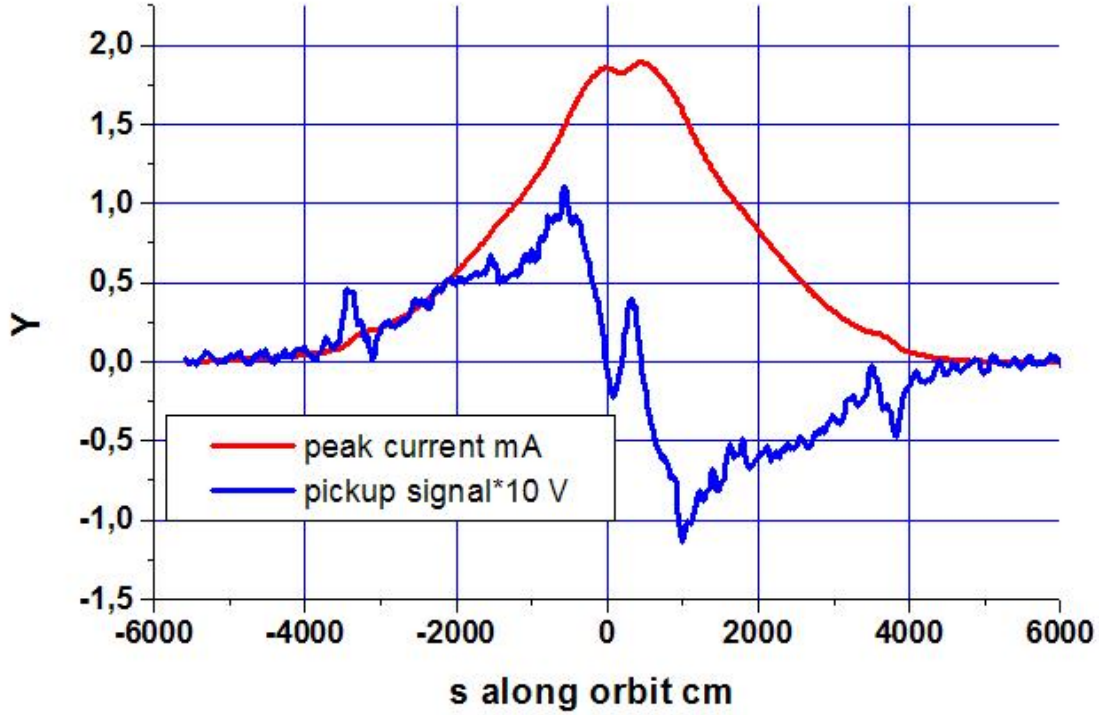
400 MeV/u diameter only 2 mm

Bunch beam cooling



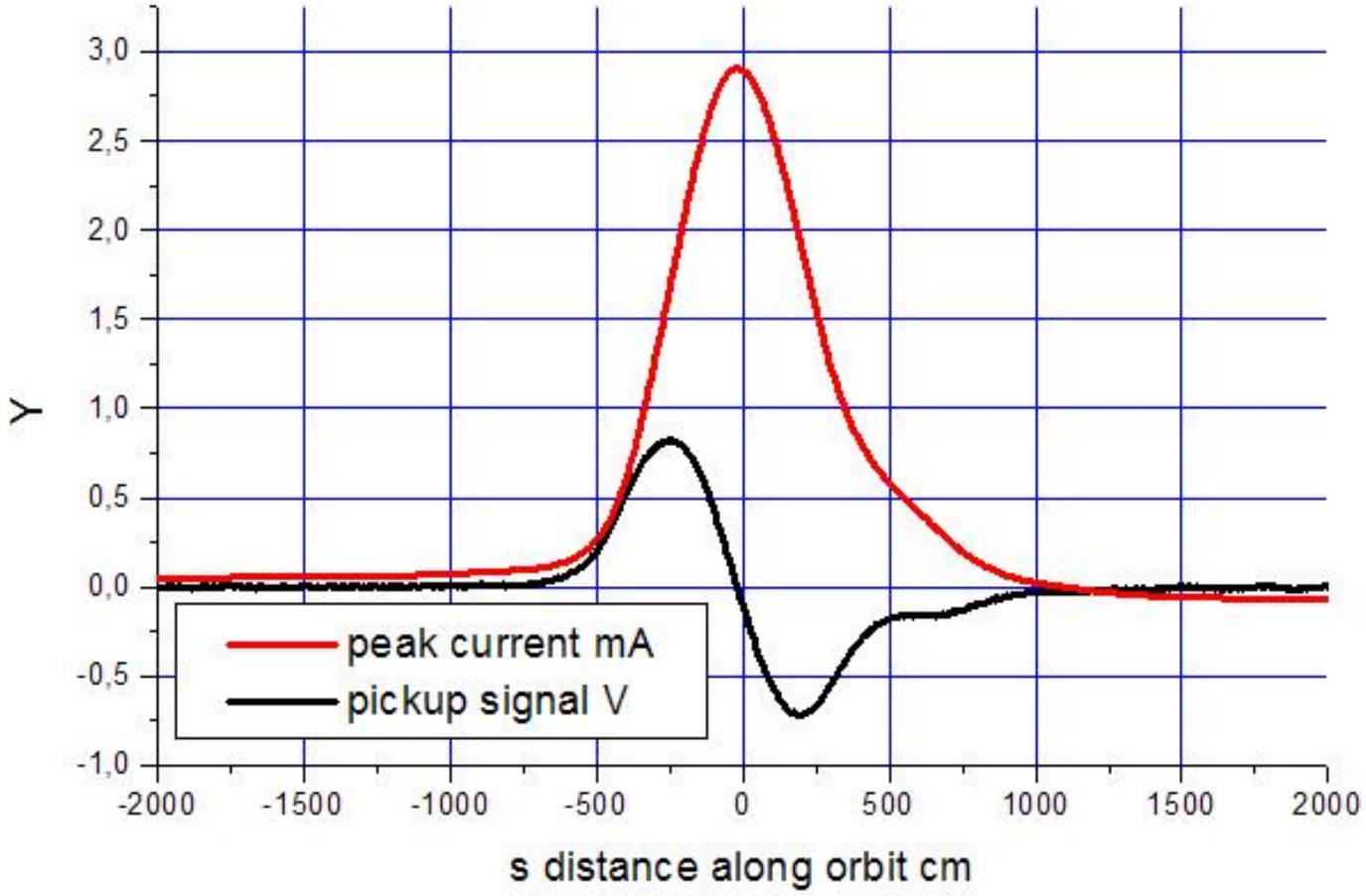
ION C(12)+6
E=200 MeV/u
Je=

Initial moment bunch profile

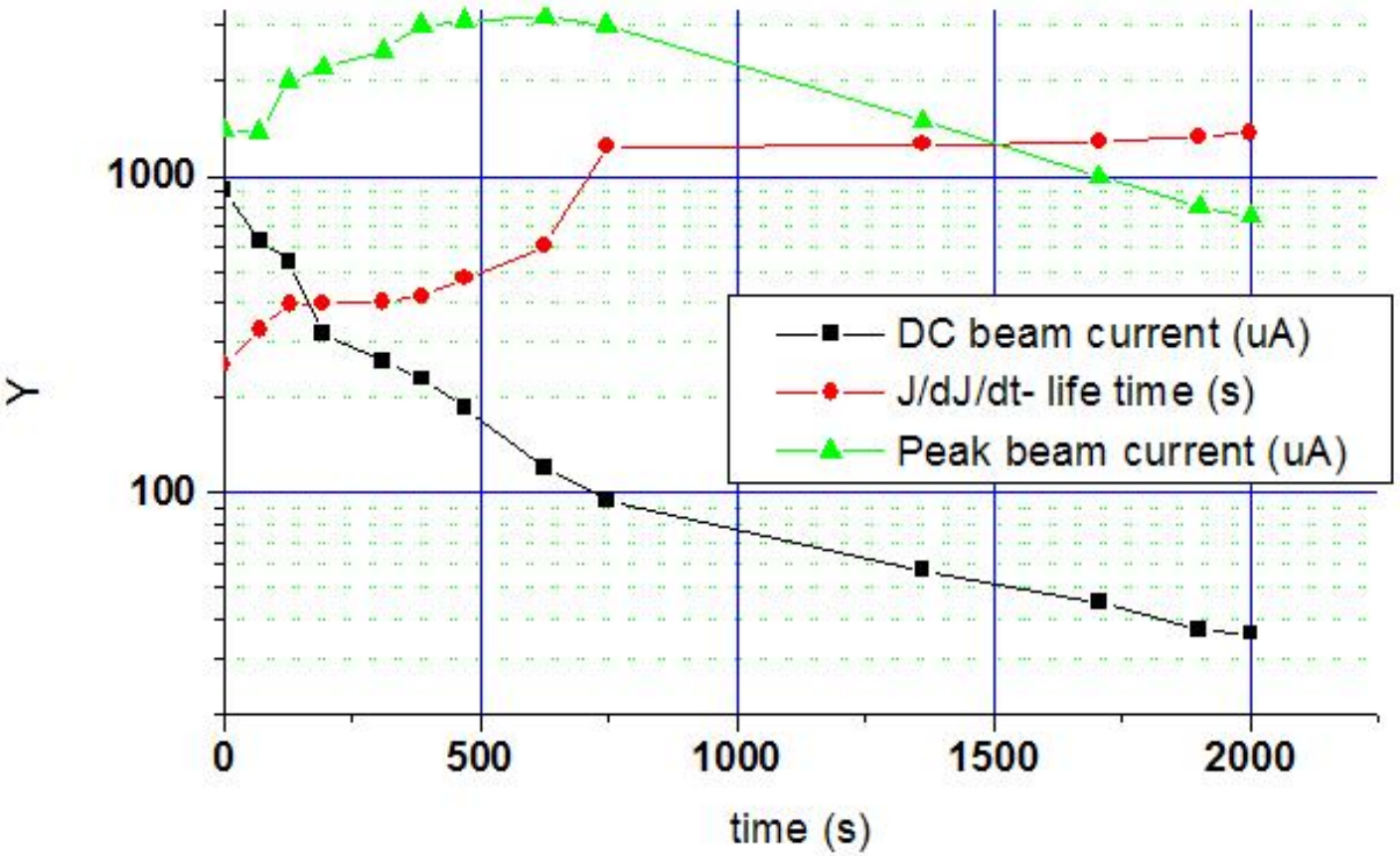


Space charge waves at electron beam?

At moment of maximal peak current

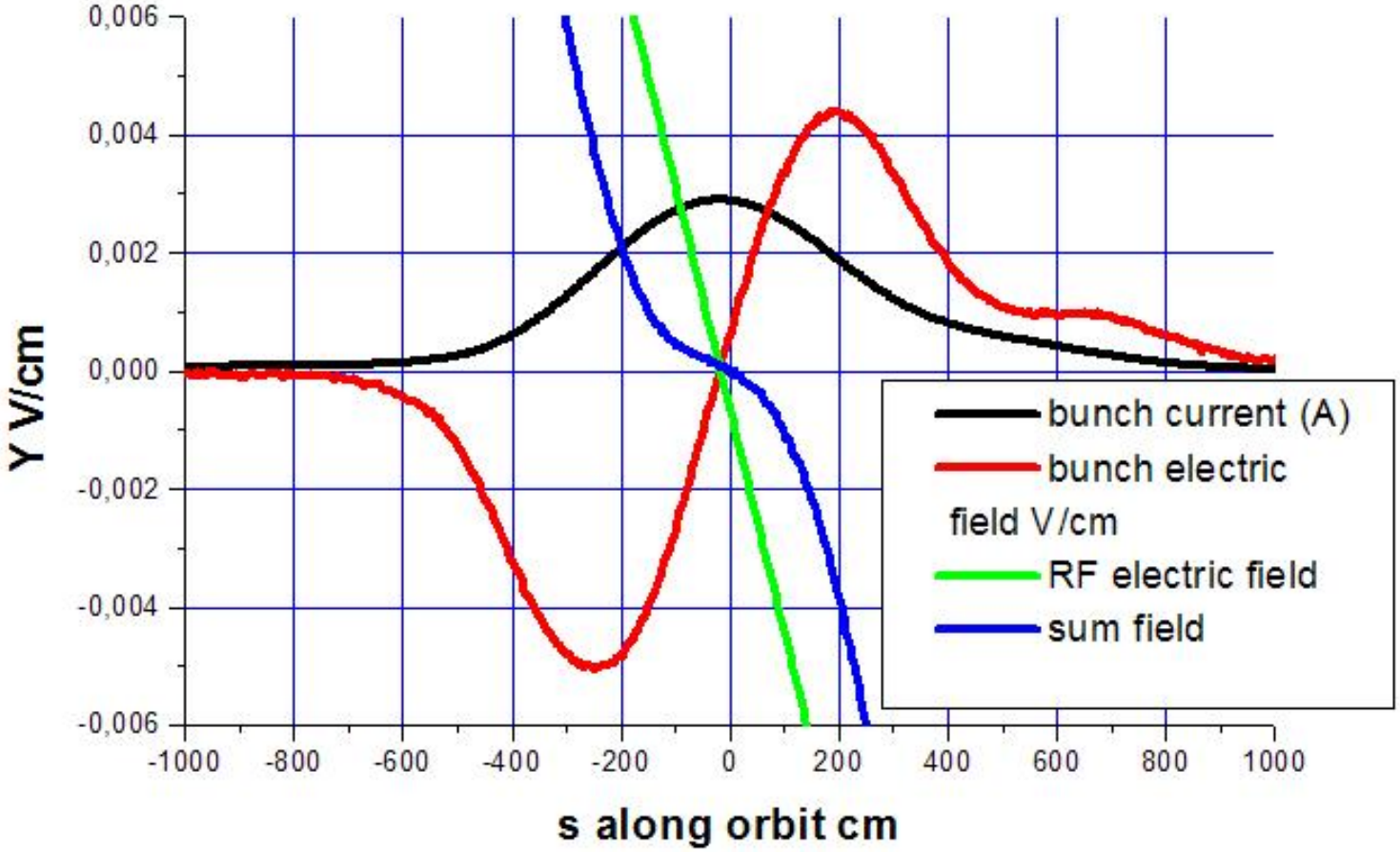


History of cooling bunch beam



Initially very pure life time about 200 s and then the life time up to 1000 s

Electric fields inside bunch



The deformation of electric field gradient very significant

Ion beam cooled up to space charge limitation

- Transverse up to $\Delta Q_{\perp} \approx 0.1$
- Longitudinal up to $\Delta Q_s / Q_s \approx 1$

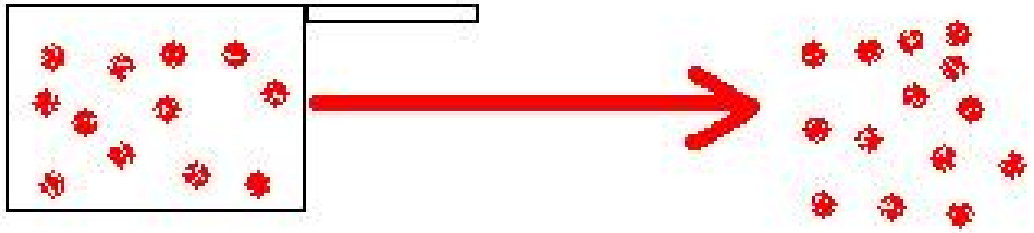
$$T_i = T_e \ldots\ldots \theta_i = \sqrt{\frac{m_e}{M_i}} * \theta_e$$

For good design cooler Te->0

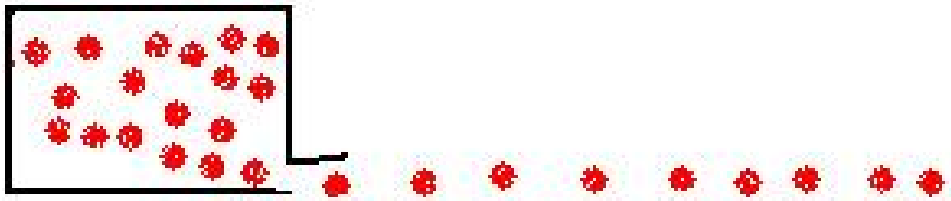
Slow extraction of this dense beam with saving low emitance are interesting scientific task.

Especially for using at medicine application

Slow extraction with transformation high transverse emittance of beam at beam with high longitudinal emittance but low transverse

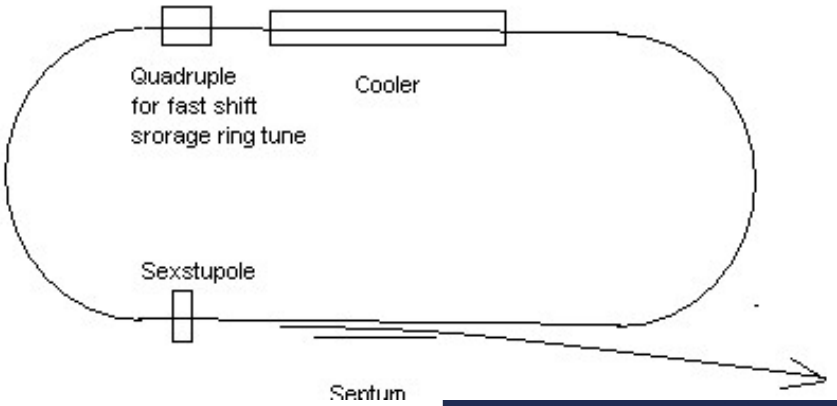


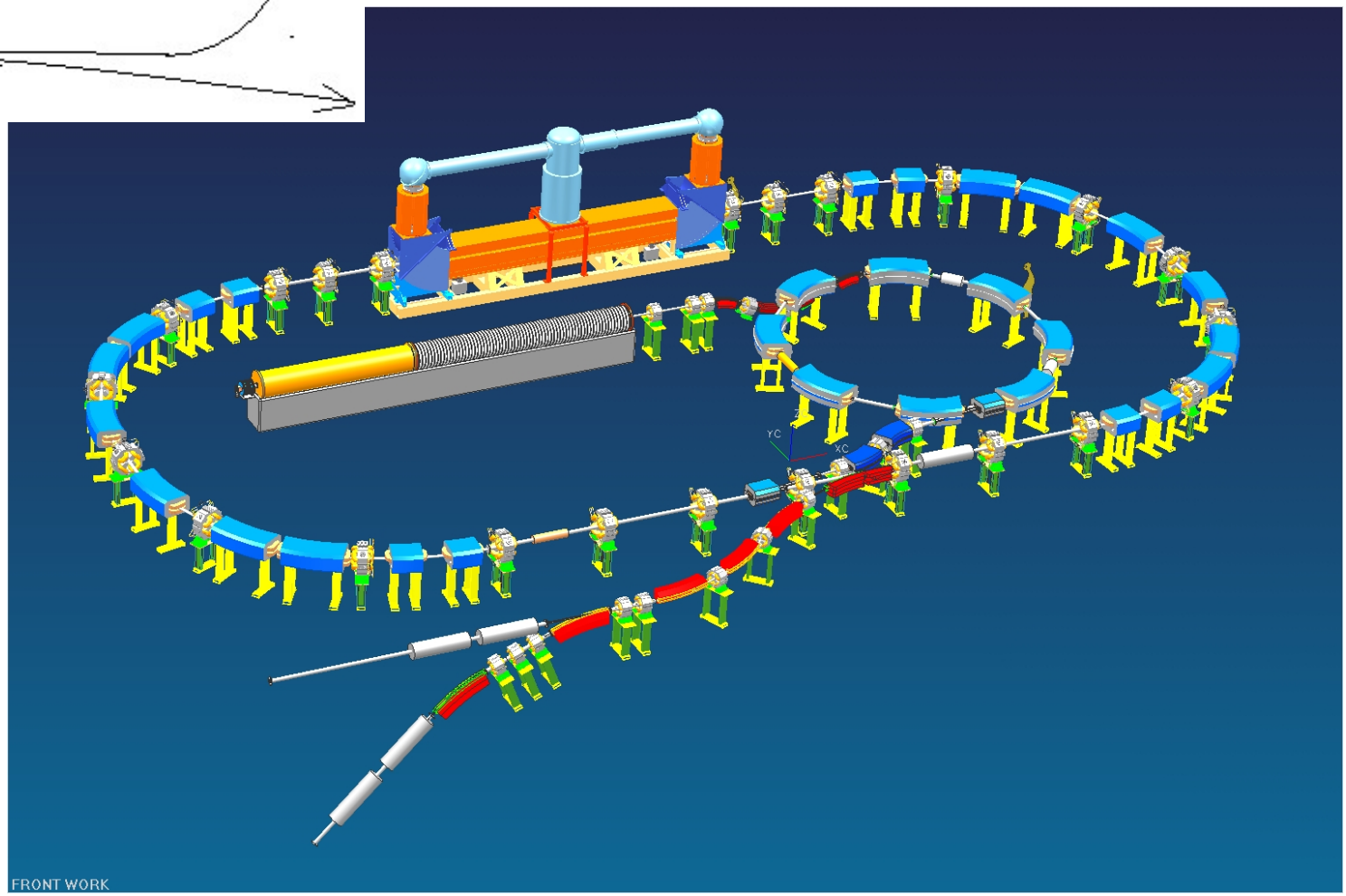
Fast extraction



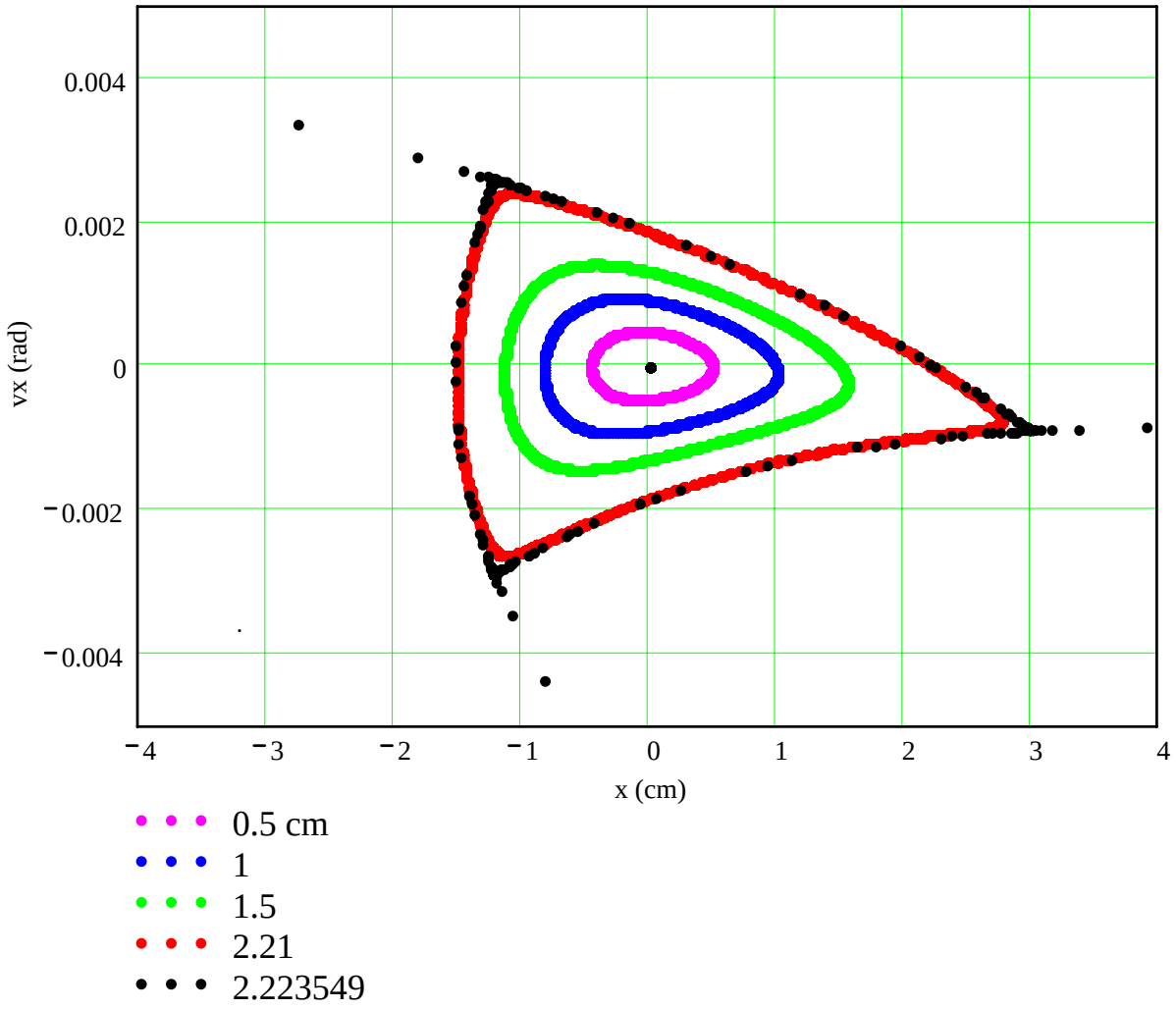
Slow extraction

3-ORDER RESONANCE EXTRACTION WITH COOLING



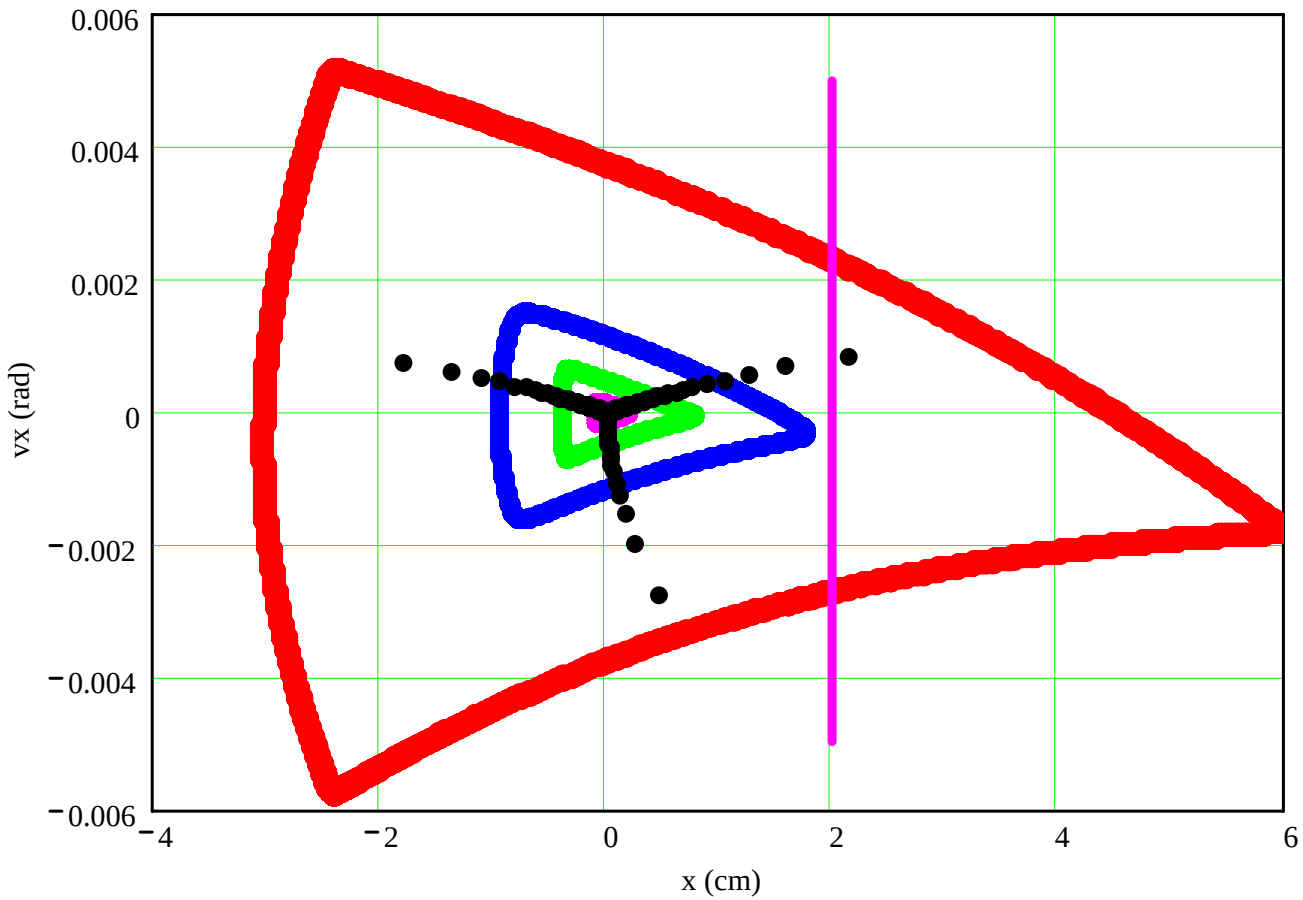


3-ORDER RESONANCE EXTRACTION WITH COOLING

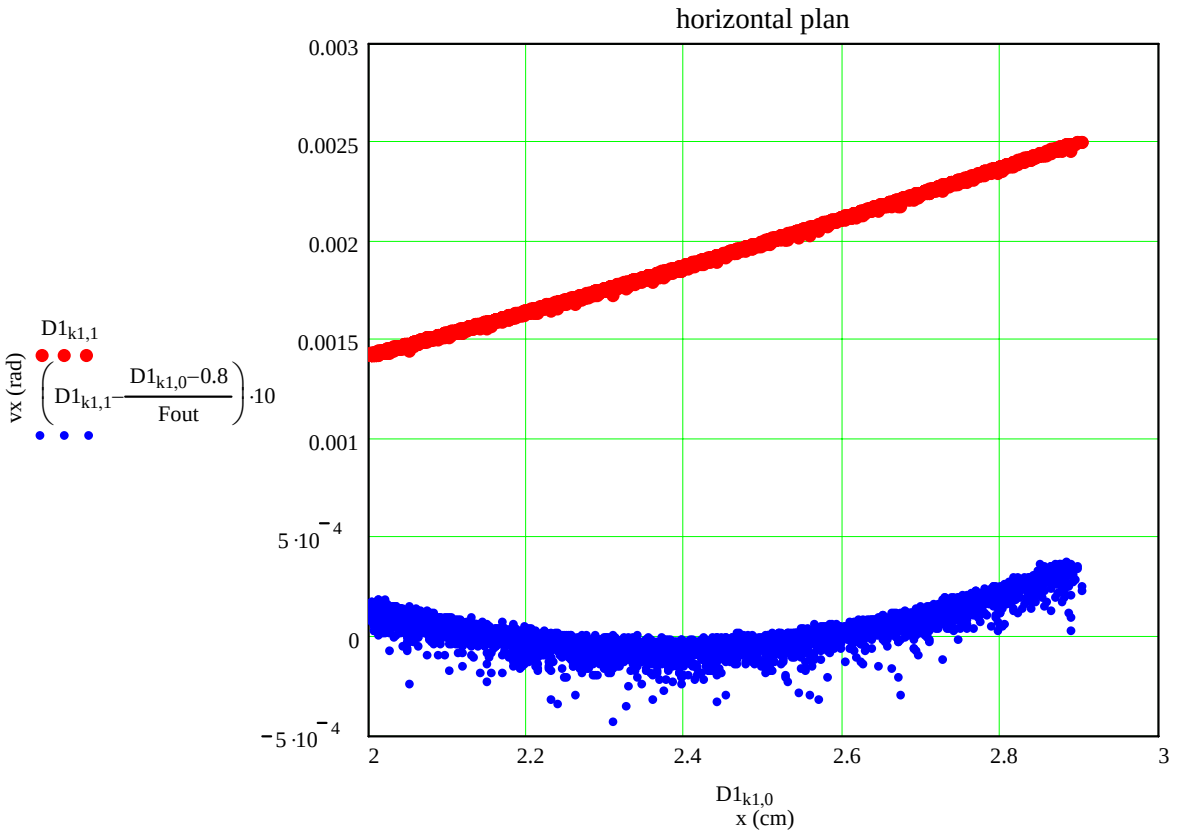


Single sextuple in the storage ring divided the phase plane space on stable-oscillation zone and unstable-extraction zone

$\nu_x = 0.36$

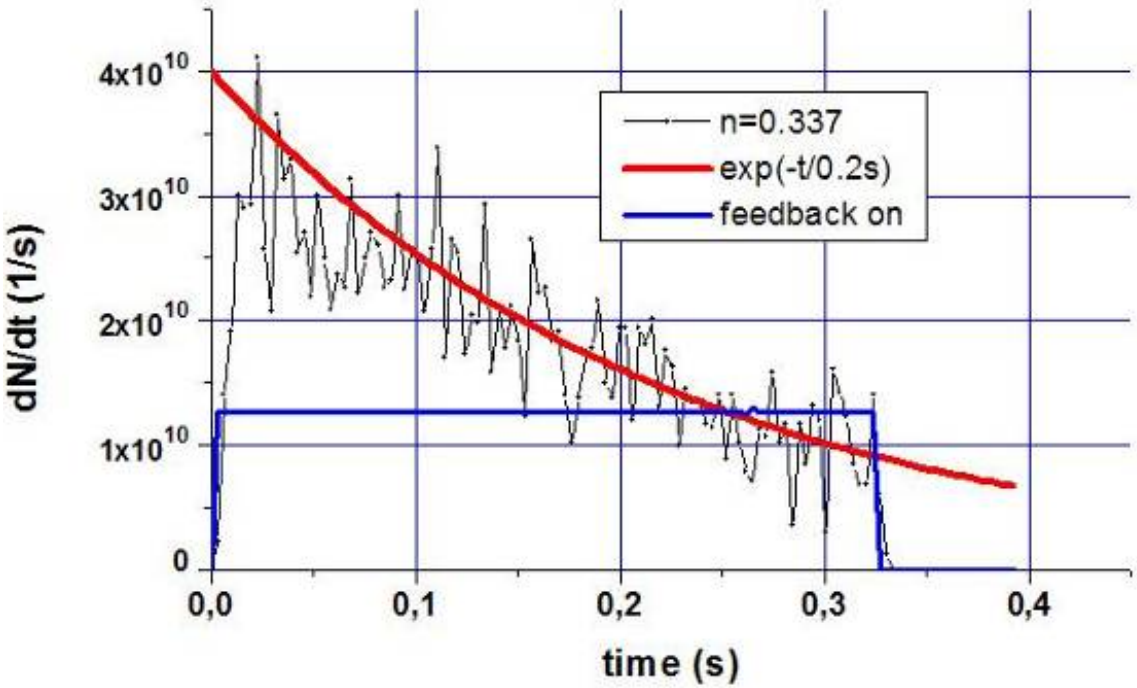


Modification separatrix when tune moved to 1/3 resonance



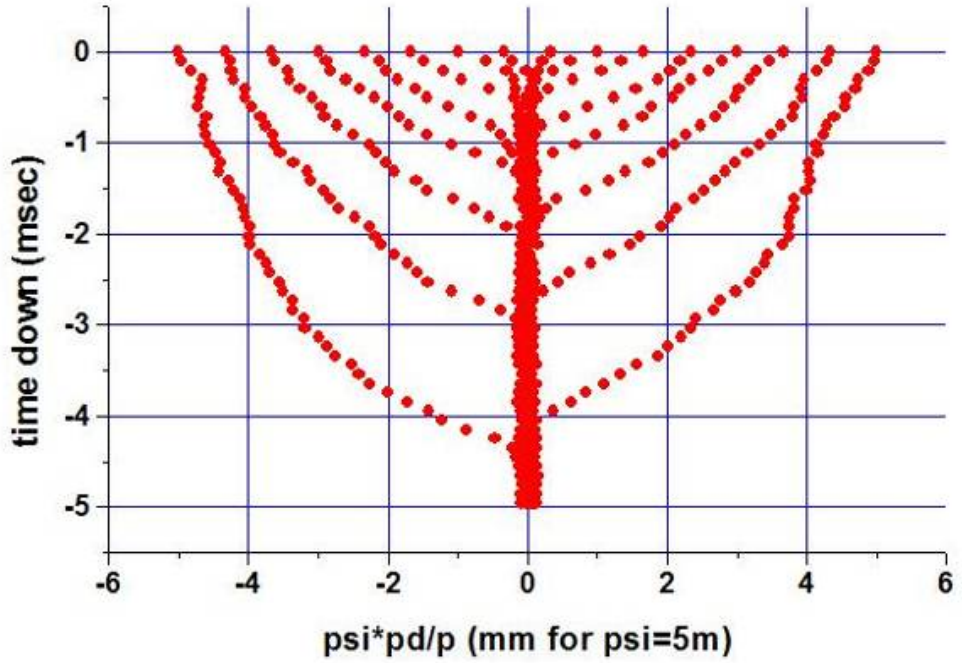
Extracted ion beam
x*vx phase plane
blue points the same but
after pass lens
(vy scale expanded 10 times

x*x’=2.0E-5 cm*rad

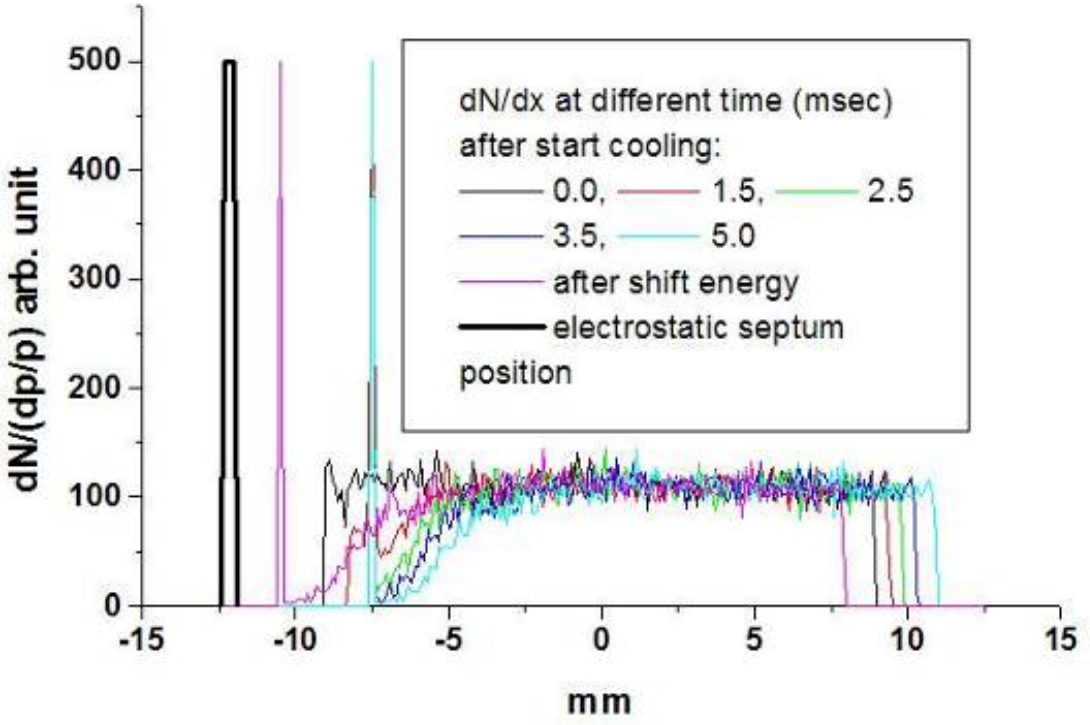


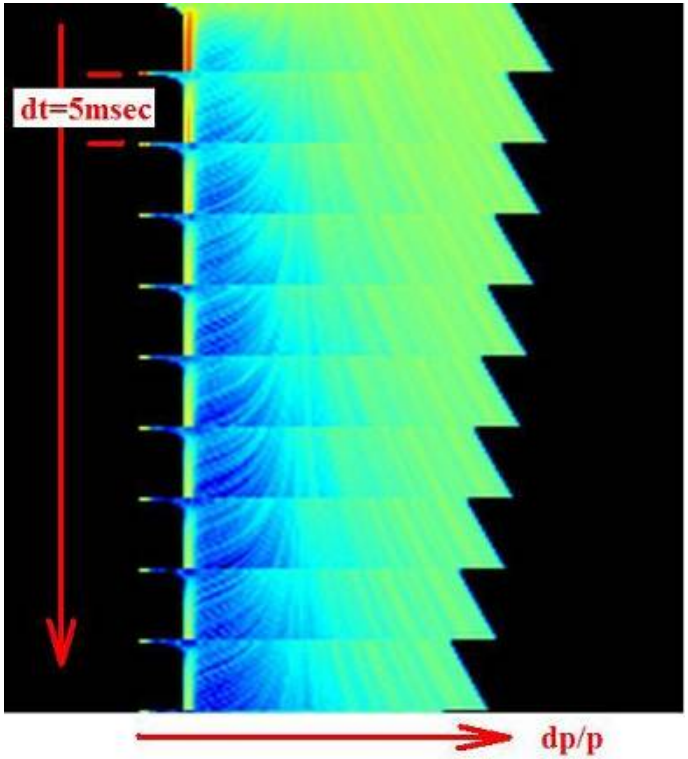
The intensity extraction versus time:
red- with constant tune tune
blue- with modulated tune feedback the extracted number

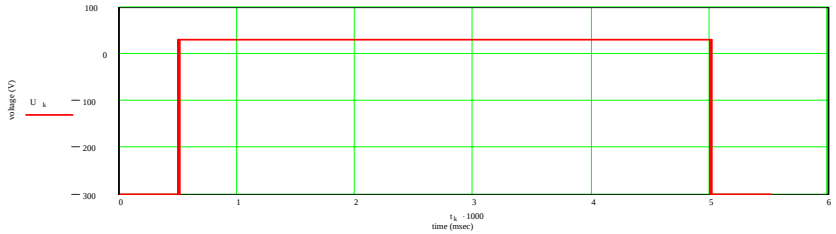
The high cooling rate of the carbon beam can be obtain with the perfect straightness magnet line at cooling section ion Cooling time few msec!

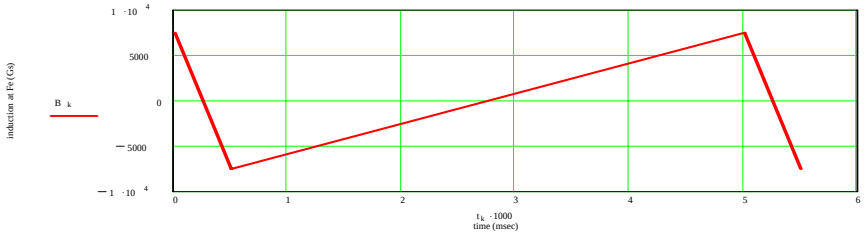


SPLITING THE ION BEAM AT MOMENTUM SPACE



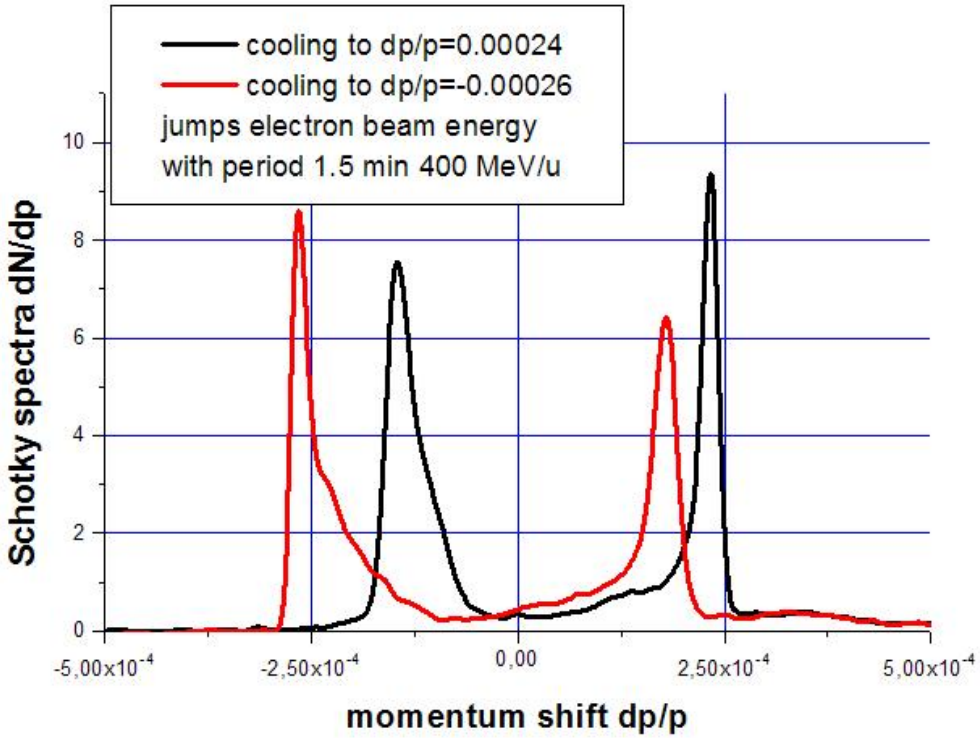


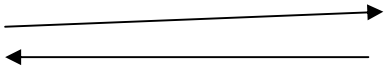




Using fast magnet for inductive shift ion beam energy

Splitting the 400 MeV/u carbon beam at CSRe by hand manipulation the electron beam energy





Jump electron beam energy

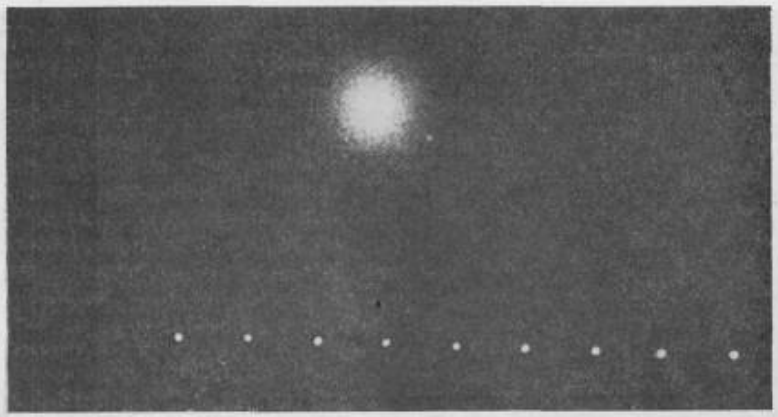


Рис. 4. Фотография ядерной фотоэмульсии, экспонированной пучком быстрых атомов водорода ($v/c = 0{,}35$), возникающих при рекомбинации протонного и электронного пучков на участке охлаждения

Фотоэмульсия расположена на расстоянии 10 м от участка взаимодействия. Метки нанесены через 1 мм. Размер изображения соответствует диаметру протонного пучка 0,5 мм и угловой расходимости $3 \cdot 10^{-5}$ рад

The experiment with extraction
H0 atoms with energy 65 MeV
on the nuclear emulsion detector
distance from cooler to film 10 m
mark points space 1mm

Example of heavy ions extraction demonstrated at GSI:

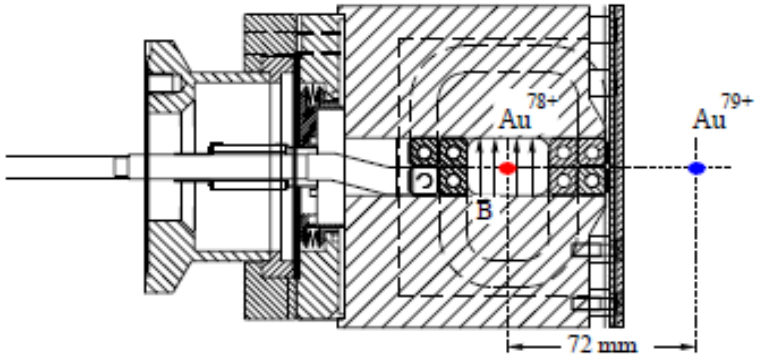


Figure 3: Side view of the movable magnetic septum. Also shown are the primary Au^{79+} and the down-charged Au^{78+} beam which are separated about 72 mm at the septum.

CHARGE EXCHANGE EXTRACTION AT THE EXPERIMENTAL STORAGE RING ESR AT GSI

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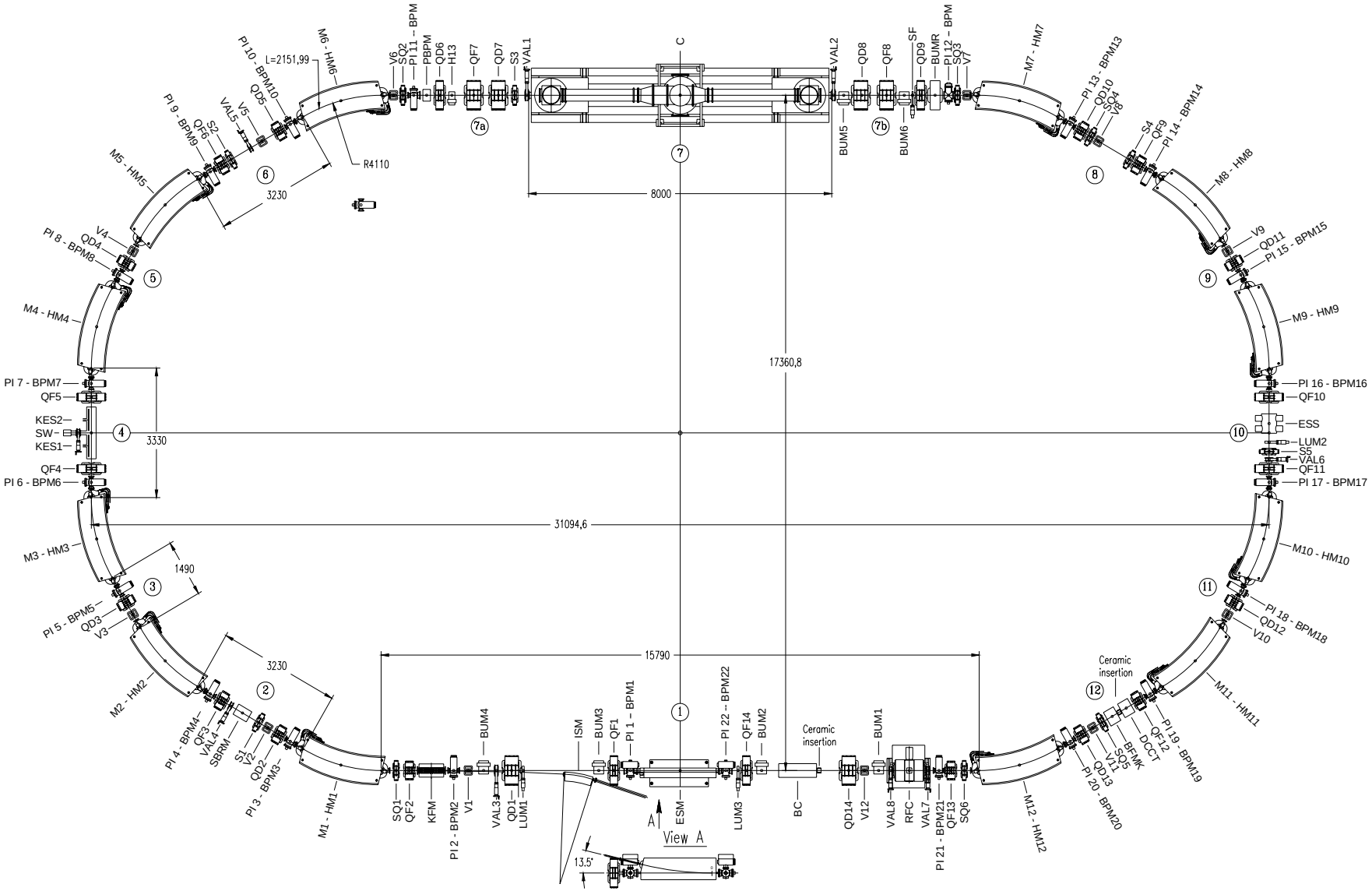
Main Ring


C
VAL2
QD8
QF8
SF
QD9
BUMR
PI 12 - BPM
SQ3
V7
M7 - HM7
PI 13 - BPM13
QD10
S4
V8
S4
QF9
PI 14 - BPM14
M8 - HM8
V9
QD11
PI 15 - BPM15
M9 - HM9
PI 16 - BPM16
QF10
ESS
LUM2
S5
VAL6
QF11
PI 17 - BPM17
M10 - HM10
PI 18 - BPM18
QD12
V10
M11 - HM11
Ceramic insertion
PI 19 - BPM19
DCCT
BFMK
SQ5
V11
QD13
PI 20 - BPM20
M12 - HM12
PI 21 - BPM21
QF13
SQ6
VAL7
RFC
VAL8
BUM1
QD14
V12
Ceramic insertion
BC
LUM3
ESM
A
View A
13.5°
PI 22 - BPM22
QF14
BUM2
ISM
BUM3
QF1
PI 1 - BPM1
BUM4
SQ1
QF2
KFM
PI 2 - BPM2
V1
VAL3
QD1
LUM1
M1 - HM1
PI 3 - BPM3
QD2
S1
V2
SBRM
VAL4
QF3
PI 4 - BPM4
M2 - HM2
PI 5 - BPM5
QD3
V3
M3 - HM3
PI 6 - BPM6
QF4
KES1
SW
KES2
M4 - HM4
PI 7 - BPM7
QF5
PI 8 - BPM8
QD4
V4
M5 - HM5
PI 9 - BPM9
QF6
S2
VAL5
V5
QD5
PI 10 - BPM10
L=2151,99
M6 - HM6
V6
SQ2
PI 11 - BPM
PBPM
QD6
H13
QF7
QD7
S3
VAL1
7a
7b
BUM5
BUM6
R4110
3230
3230
1490
3330
8000
15790
17360,8
31094,6

CONCLUSION

The carbon ion beam system is based on a few approved key innovations historically came from BINP (Novosibirsk) such as: electron cooling, using negative ions for stripping injection, storage rings. Electron cooling helps to make operation of the system easier by decreasing the beam emittance which results in stable ions energy and easy extraction. Example of CSRm operation shows that electron cooler can stable operates many months without any problems.

Thank you for attention