Heavy Ion Therapy System

Electron Cooling Application for Cancer Therapy Accelerator Facility

E.Levichev, V.Parkhomchuk, A.Skrinsky, V.Vostrikov
BINP, Novosibirsk, Russia

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HITS

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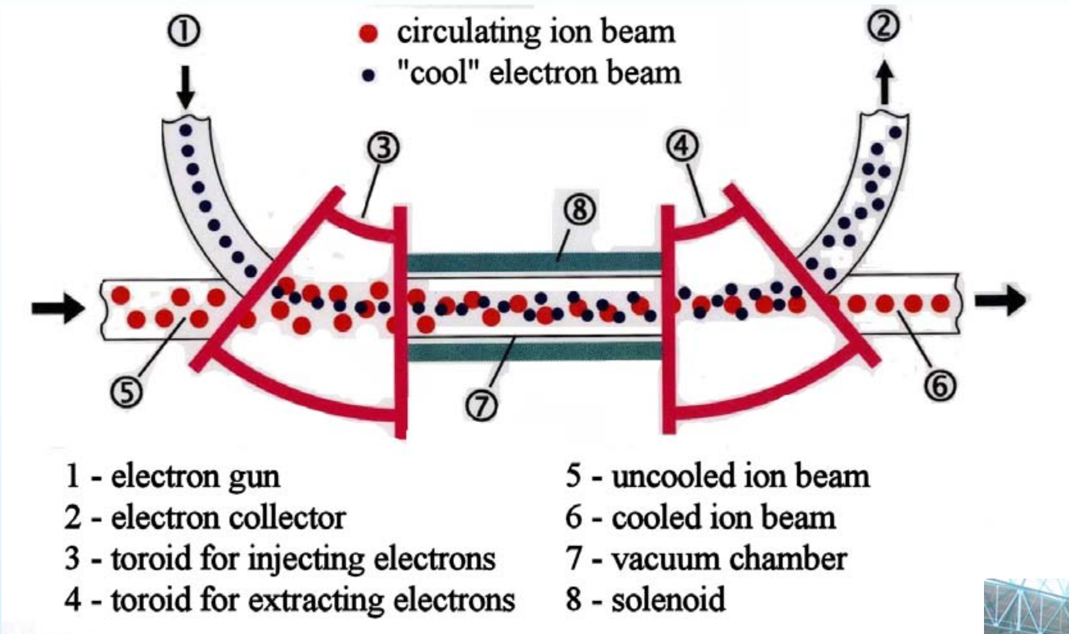
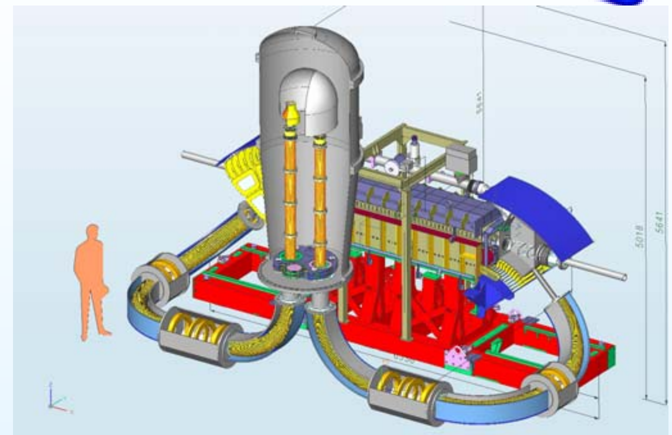
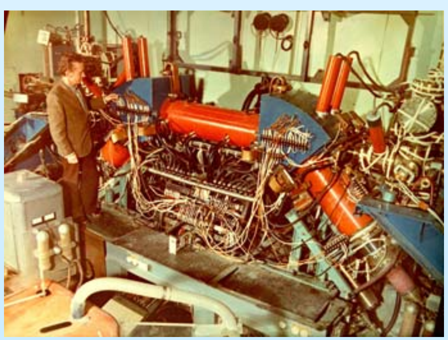
Electron cooling basis. BINP progress.



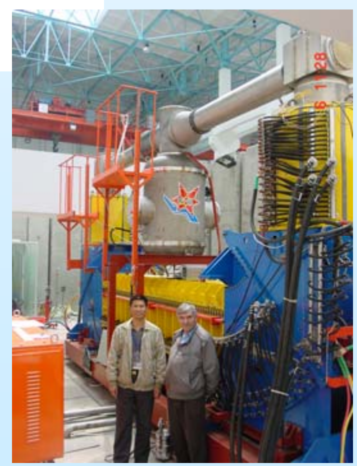


Future 2 MeV cooler for COSY, production start in 2009



NAP-M, BINP, 1975

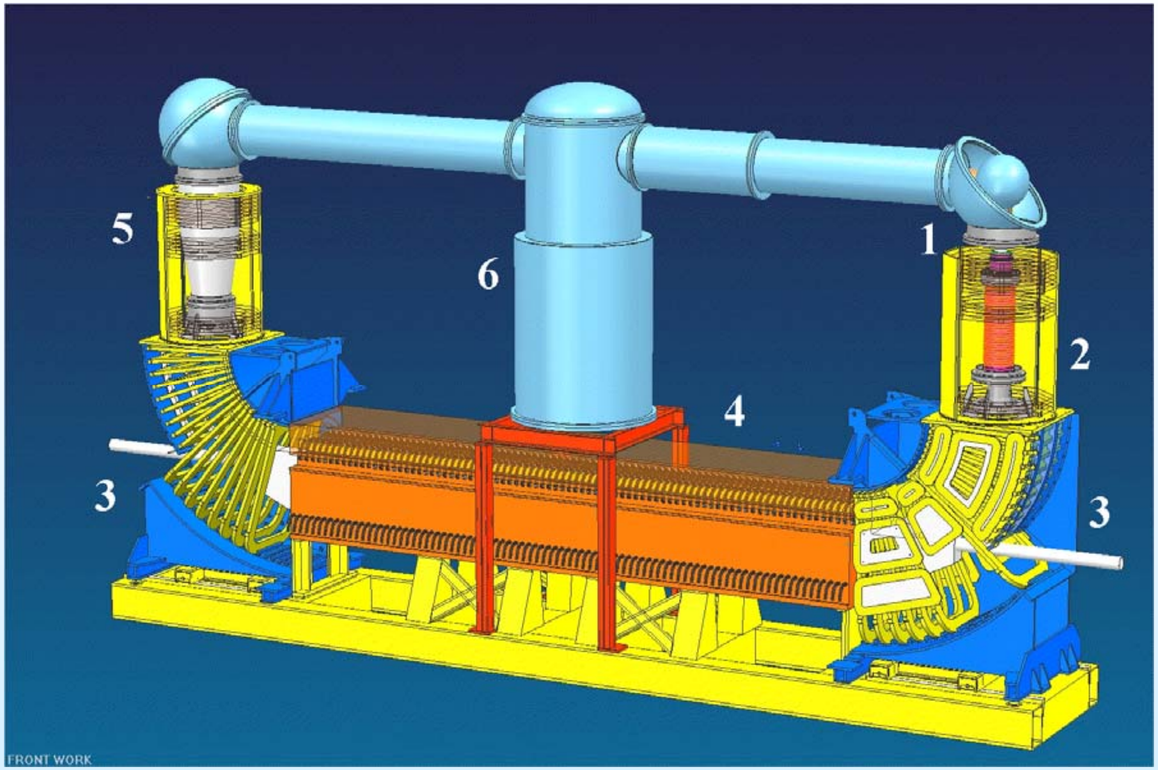
SIS-18, GSI, 1998



HIRFL-CSR, EC-35, EC-300, 2004

LEIR, CERN, 2006

Electron cooler 300 keV



1- electron gun,
2-acceleration tube,
3-ion beam chamber,
4- cooling section,
5-collector,
6- high voltage generator.

Electron beam energy	up to 300 keV
Total length	8 m
Cooling length	4.8 m
Magnetic field	0.1-0.15 T
Magnetic field quality	10^{-4}

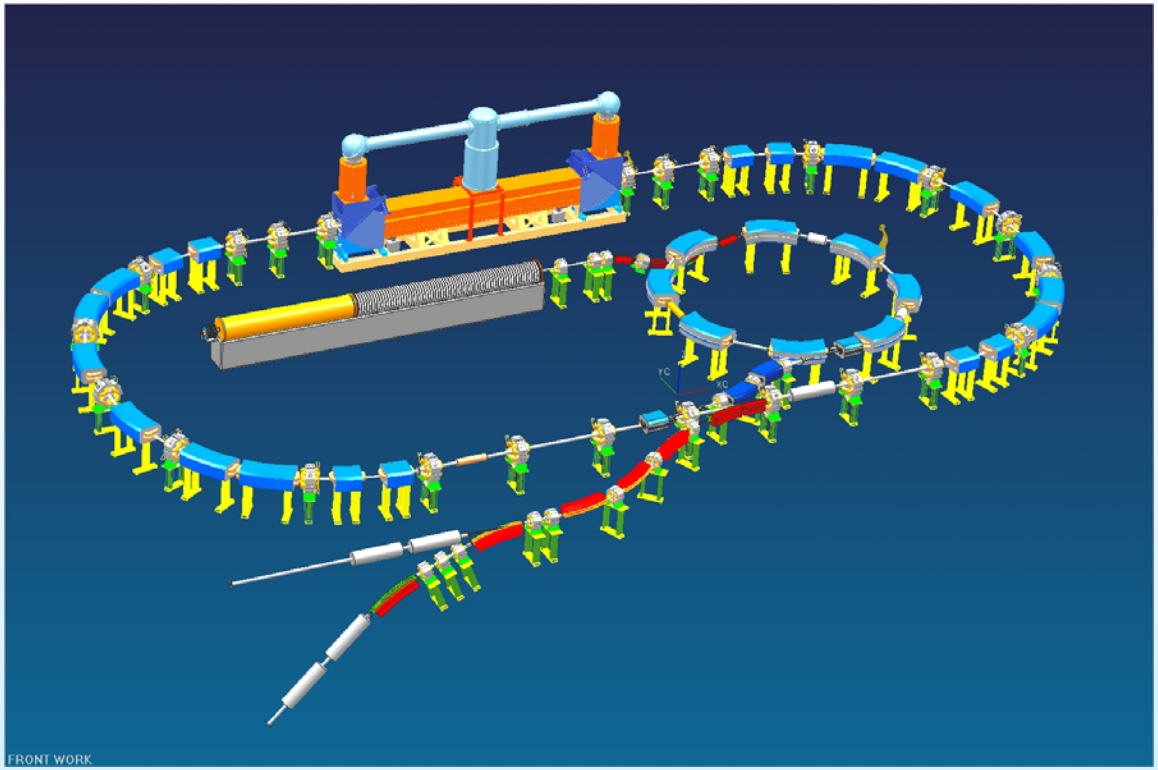
Electron cooling application in therapy facility

- High intensity of ion beam
- High quality ion beam

  (extreme small transverse emittance and narrow energy spread)
- Decrease of elements aperture

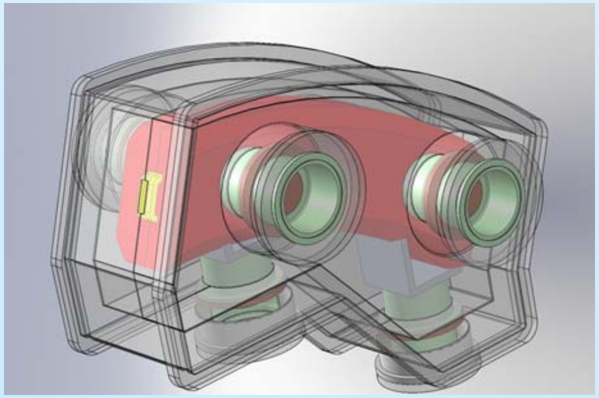
  (synchrotron & HEBT magnets, gantry, scanners and etc.)
- Precise ion beam energy variation
- Slow extraction on recombination for raster scanning
- Slow small bunches (“pellet”) extraction for spot scanning
- Specific (short-lived PET) isotopes can be accumulated and used for irradiation

HITS project of ion therapy facility

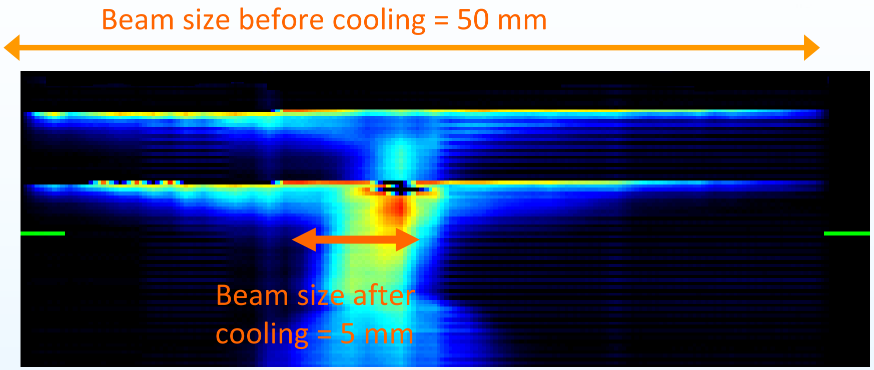


- clinical spec: p: fixed ports/gantry, C: fixed ports/ SC gantry
- particle energy: p: 50 – 250 MeV, C: 100 – 430 MeV/u
- average dose rate: 5 Gy/min
- field size: 20 cm × 20 cm
- dose uniformity: ± 4 %
- delivered dose accuracy: ± 2 %
- irradiation method: spot scanning with synchronization of respiration
- beam accuracy in the iso-center: ± 0.5 mm
- Intensity: p: 10^{8} - 10^{11} part/cycle, C: 10^{7} - 10^{10} part/cycle

- Racetrack synchrotron with electron cooling
- Booster as source of 250 MeV proton beam for treatment and carbon ion beam 30 MeV/u for injection at main ring
- Accumulation of ion beam at main ring and control emittance for energy range 100-400 MeV/u
- Extraction with recombination and small bunches (pellets)
- Superconducting carbon ion gantry



Electron cooling in action



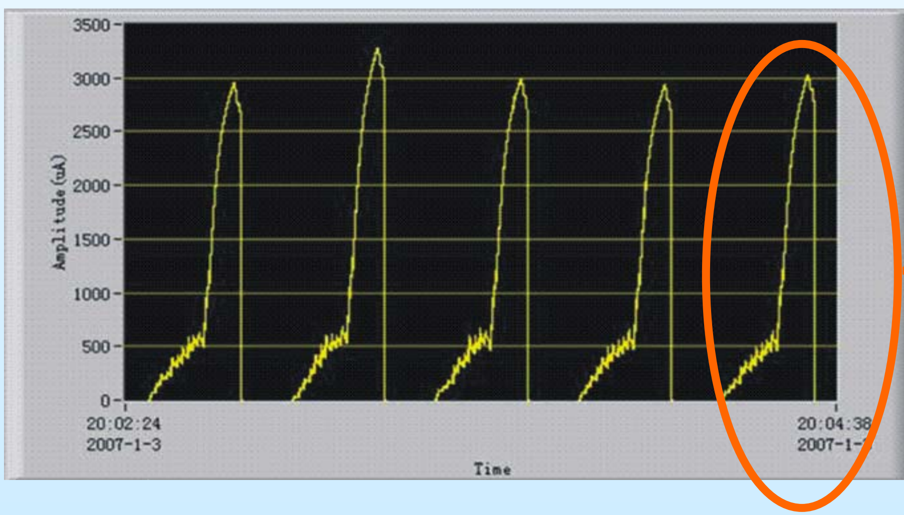
1st injection at 5 MeV/u

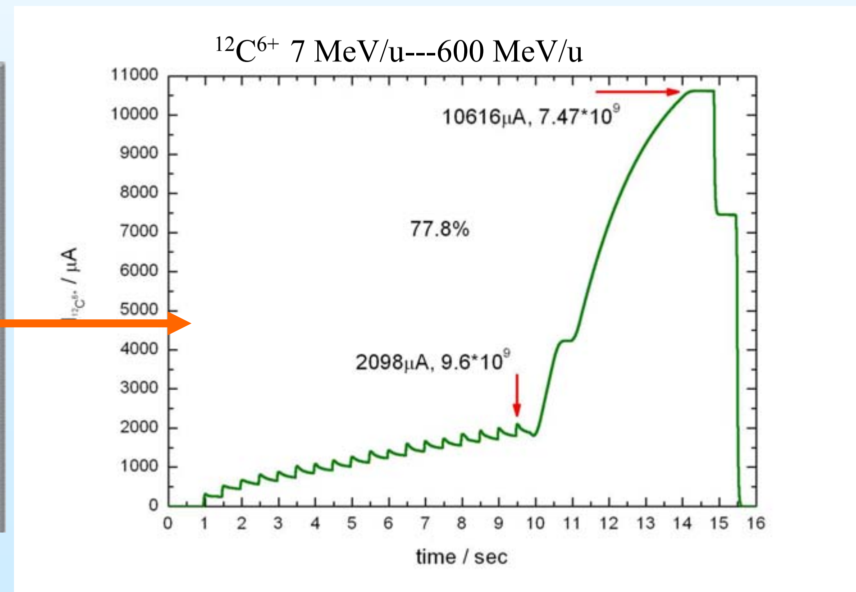
2nd injection at 5 MeV/u

Cooling

Accelerating to 70 MeV/u

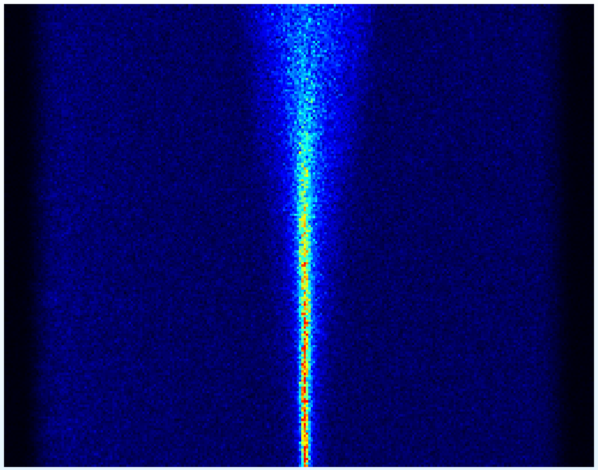
Pb ions beam cooling and accelerating at LEIR, CERN

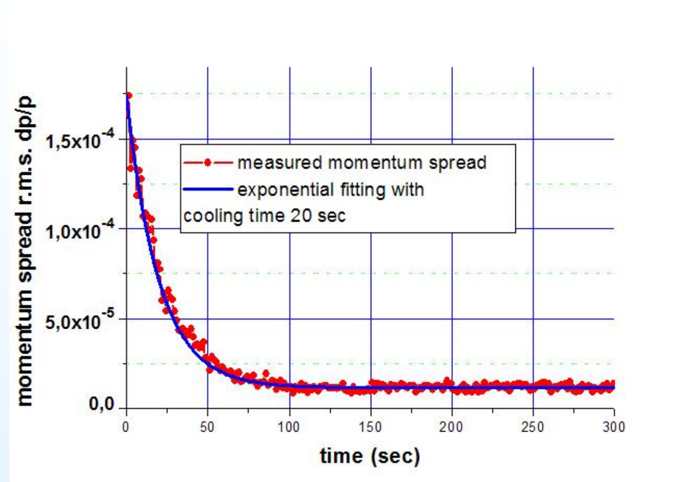




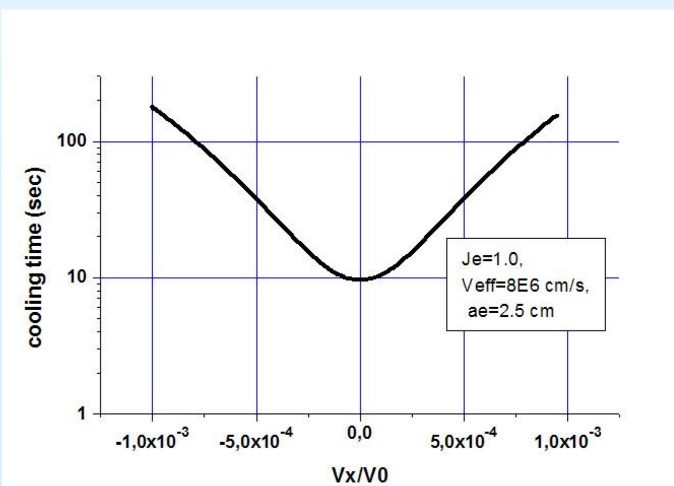
Storage and acceleration of C-ions in CSRm, China.
Using of the electron cooling provides required intensity.

Cooling of 400 MeV/u carbon ion beam



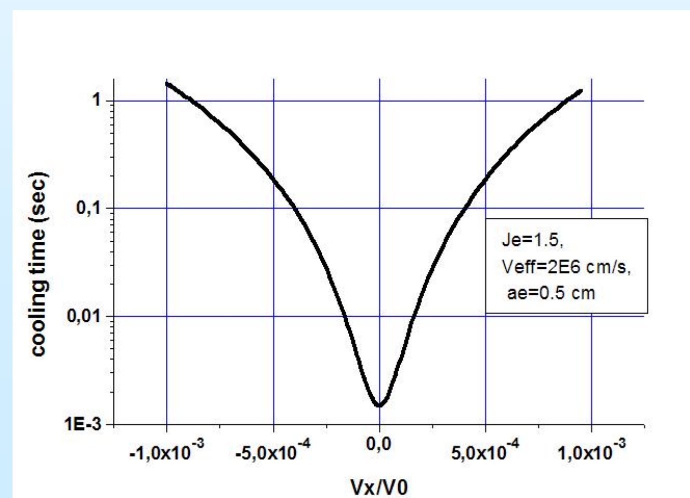


First experiments of in cooling 400 MeV/u C^{+6} in CSRm. The electron current is 0.75 A.



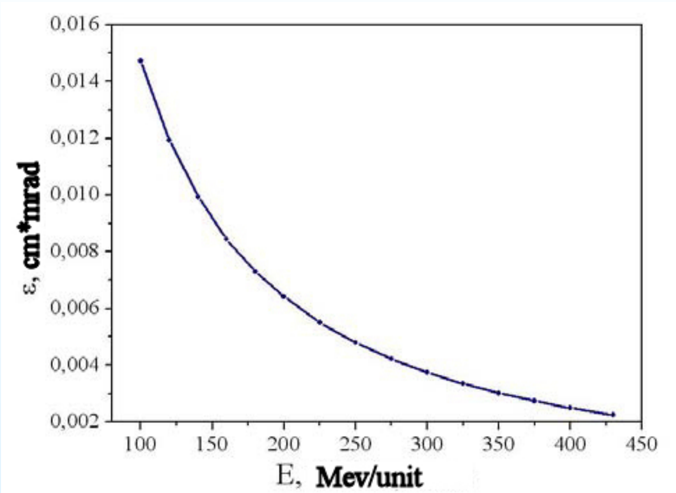
Cooling time measured at May 2009

Fine tuning and increasing of e-beam density



Cooling time required for HITS

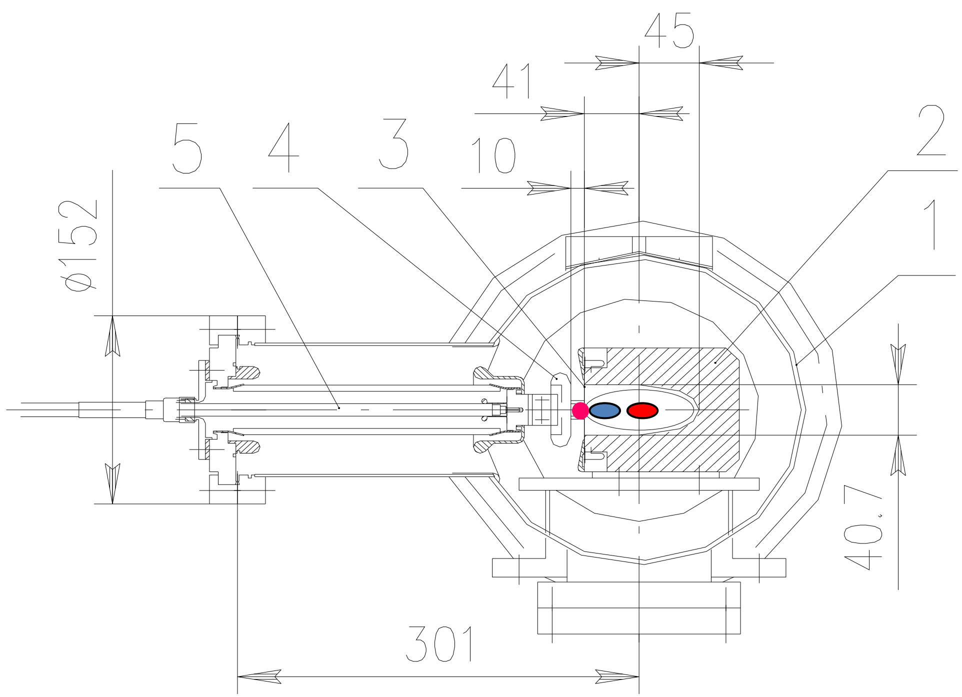
HITS elements aperture



Transverse emittance of cooled carbon ion beam with intensity 10^{10} depends on beam energy

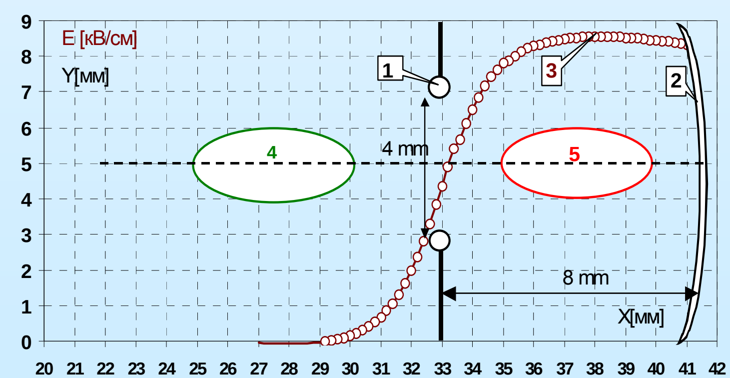
	HITS	**PIMMS**
Intensity	Up to 10^{10} ions per cycle	10^9 pps
Injection energy	30 MeV/u	6-8 MeV/u
Injector type	Pre-injector and 10 Hz booster	Linac
Circumference	83 m	75 m
Main dipole gap	36 mm	72 mm
Main quad aperture diameter	70 mm	170 mm
HEBT dipole gap	20 mm	62 mm
HEBT quad aperture diameter	38 mm	80 mm

“Pellet” extraction



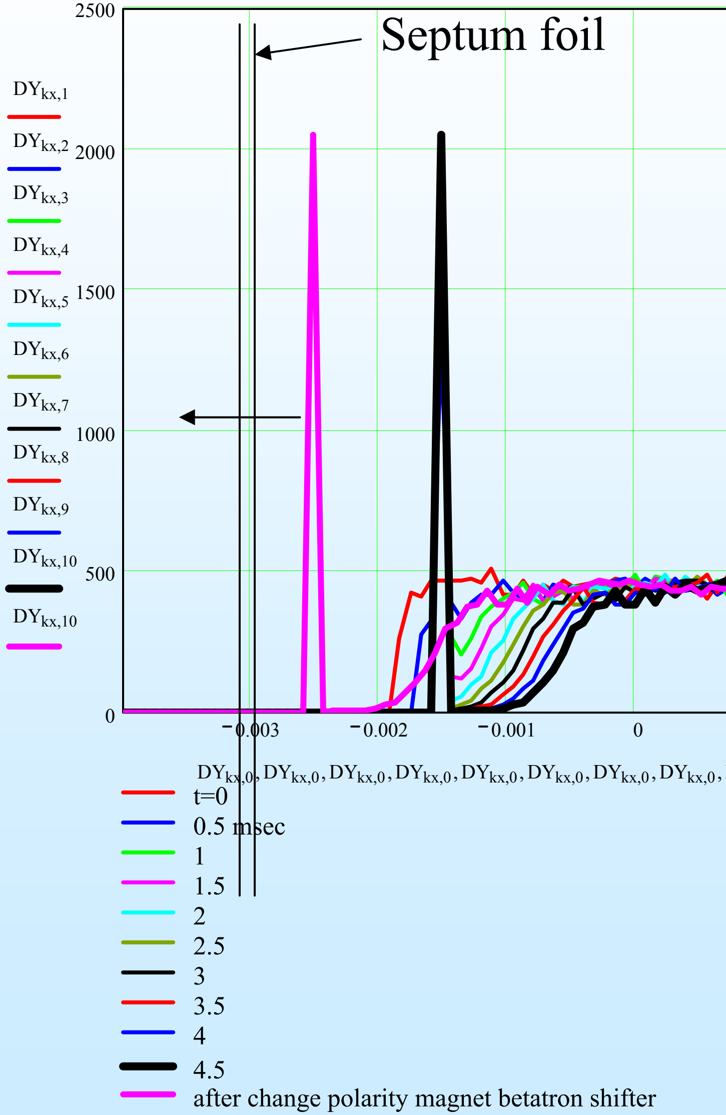
Ion beam is split to portions (“pellets”) with controllable intensity.
Number of portions - up to 10^4
Minimal intensity of portion - 10^6 ions
Portion prepared by electron cooling gymnastics is shifted to small aperture kicker (Dx≠0) by betatron core and extracted through electrostatic septum
Repetition rate - 200 Hz

Electrostatic septum
1- vacuum chamber, 2- foil unit,
3- Ti foil 0.1 mm, 4- Electrode
5- HV input

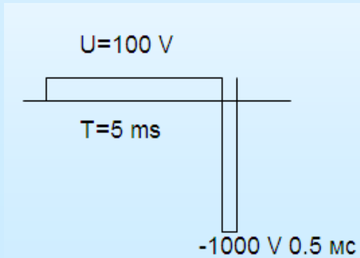


Ion beam in the kicker azimuth

Ion beam splitting to portions

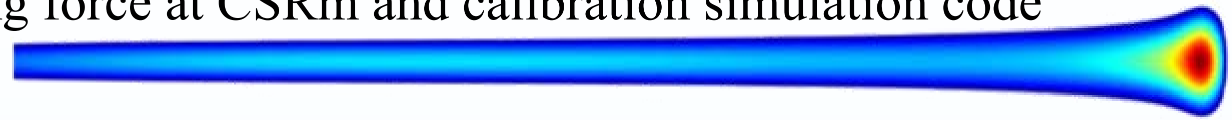


1) Preparation of flat ions momentum distribution by fast scanning of electron energy.
2) Electron cooler energy optimized for cooling to $dp/p=-1.5*10^{-3}$. Forming of portions.
3) Betatron core fast shift energy of whole beam close to septum.
4) After kick out of extraction portion the betatron core slowly moved ions back
5) Forming of next portion of extracted ions at $-1.5*10^{-3}$



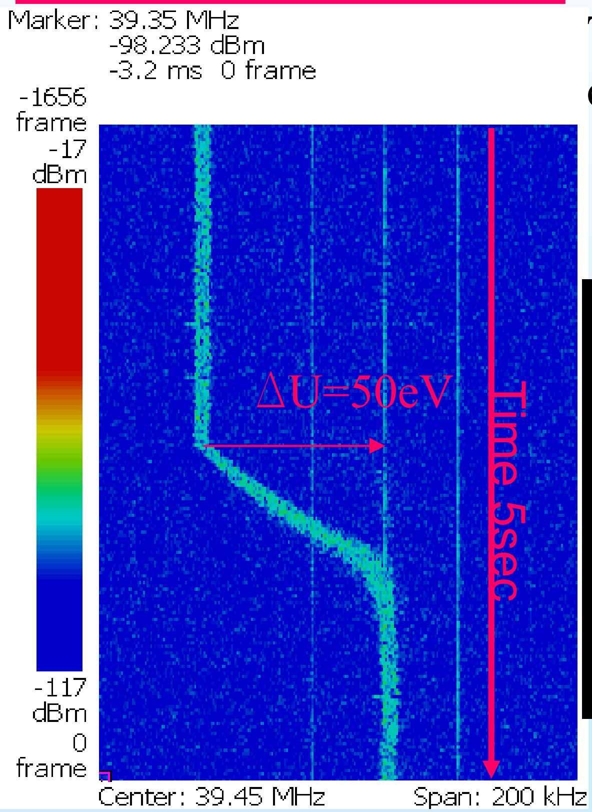
Betatron core cycle

Extraction with electron cooling: testing cooling force at CSRm and calibration simulation code

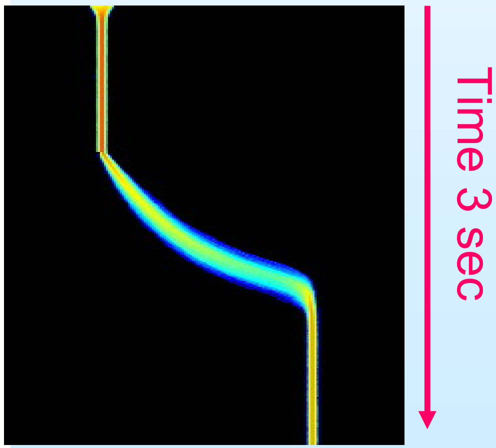


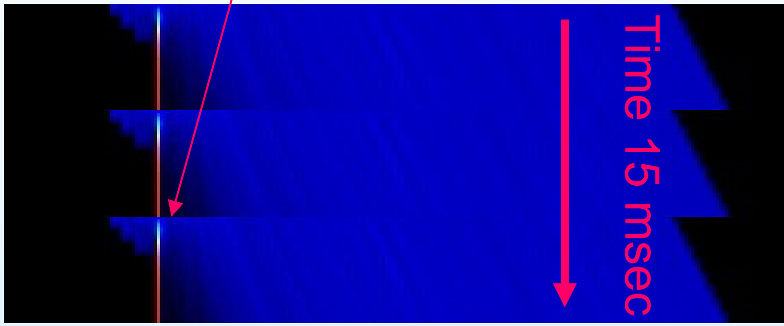
Computer simulation with the same code portion extraction from HITS
Fraction of ion beam prepared for 200 Hz extraction

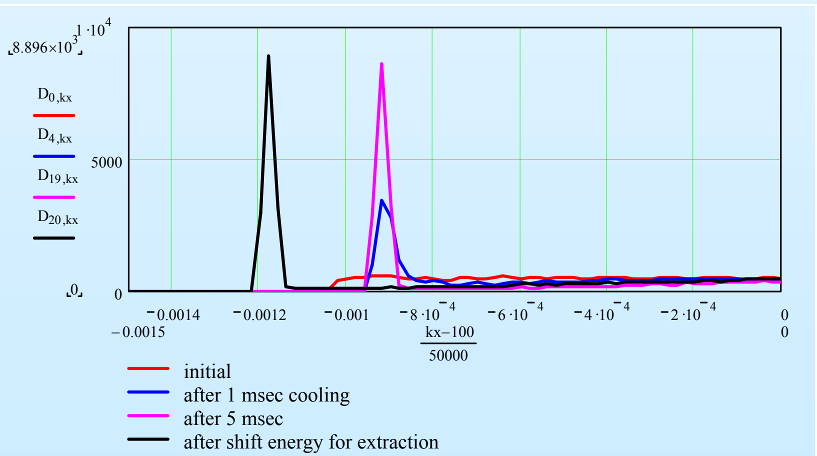
CSRm experiment with change energy of $^{36}Ar^{+18}$



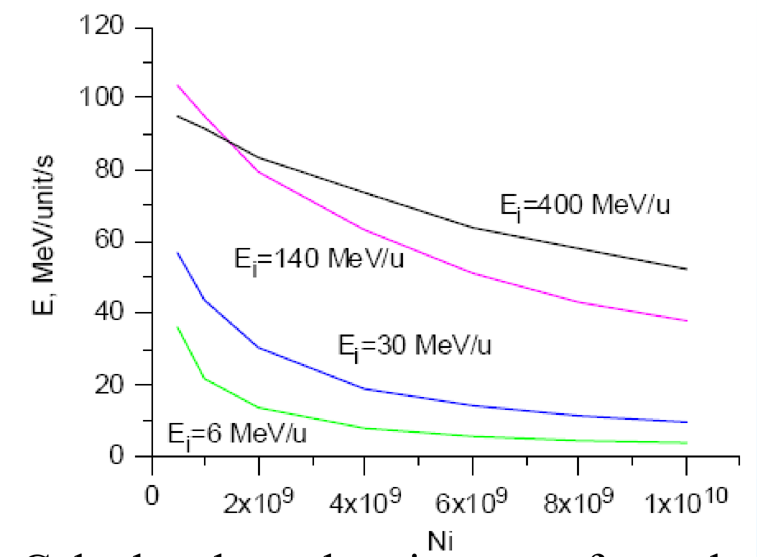
The verification of computer simulation code for CSRm experiment



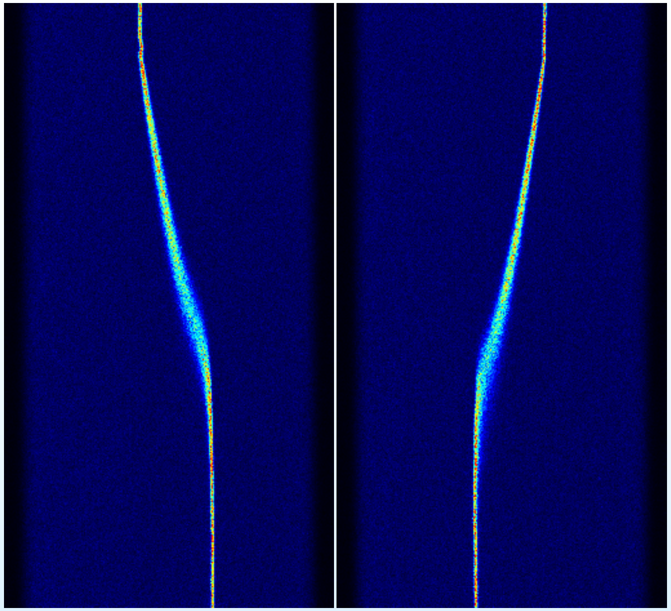




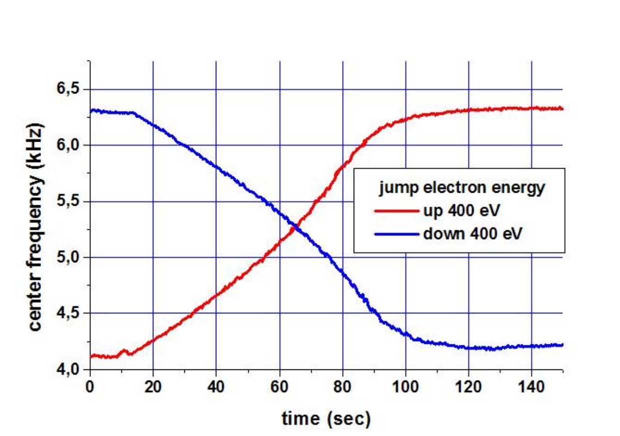
Ion beam energy variation by electron cooling



Calculated accelerating rates for carbon ion beam with optimal operating of EC parameters and synchrotron magnet field



Shift energy of 400 MeV/u carbon ion in CSR during first experiments. Schotky spectra of ion beam versus time after jump energy change



Average position frequency vs. time

Production of short lived isotopes for “online” PET

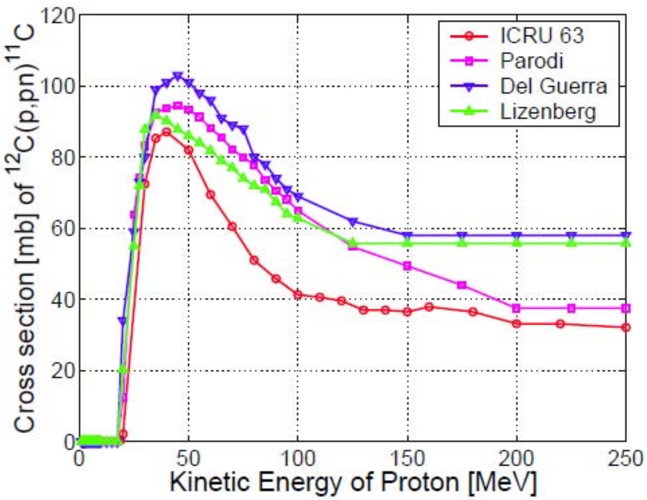
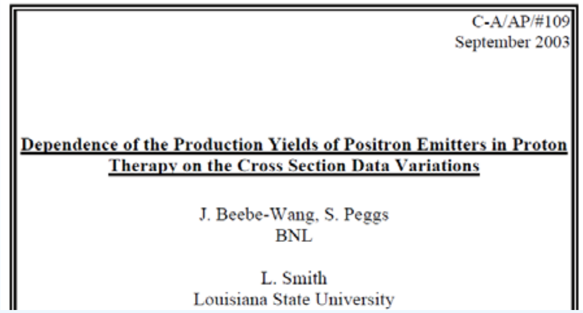


Figure 3. Nuclear reaction cross sections of $^{12}C(p,pn)^{11}C$. The data from four different resources are presented for comparison.



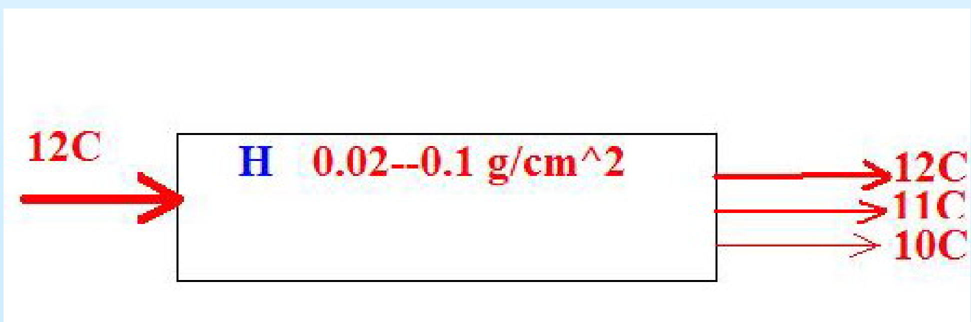
C-A/AP/#109
September 2003

Dependence of the Production Yields of Positron Emitters in Proton Therapy on the Cross Section Data Variations

J. Beebe-Wang, S. Peggs
BNL

L. Smith
Louisiana State University

^{11}C life time ~20 min
Yield efficiency ~0.5%
Time of accumulation of ^{11}C beam with intensity 10^{10} is ~200 s.



10 Hz carbon beam 30 MeV/u from booster

Accumulation and cooling of isotopes in MR

Conclusion

- Electron cooling technology can be applied in cancer therapy facility
- High intensity and high quality beam
- Low requirements for injection chain by accumulation.
- Extraction and distribution beams with low aperture line and low power capacity scanning system (more effective and safely)
- 200 Hz spot scanning (irradiation of moving targets)
- Recombination extraction for precise control doses for small tumor
- Specific isotopes can be used (online PET visualization for solve of moving targets problem)
- Using superconducting gantry with low aperture and low mass (<100 t)