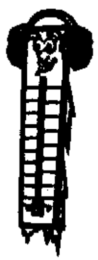
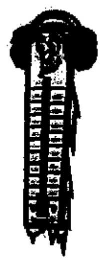
Summary from the Hadron Beam Cooling session



Sergei Nagaitsev,FNAL

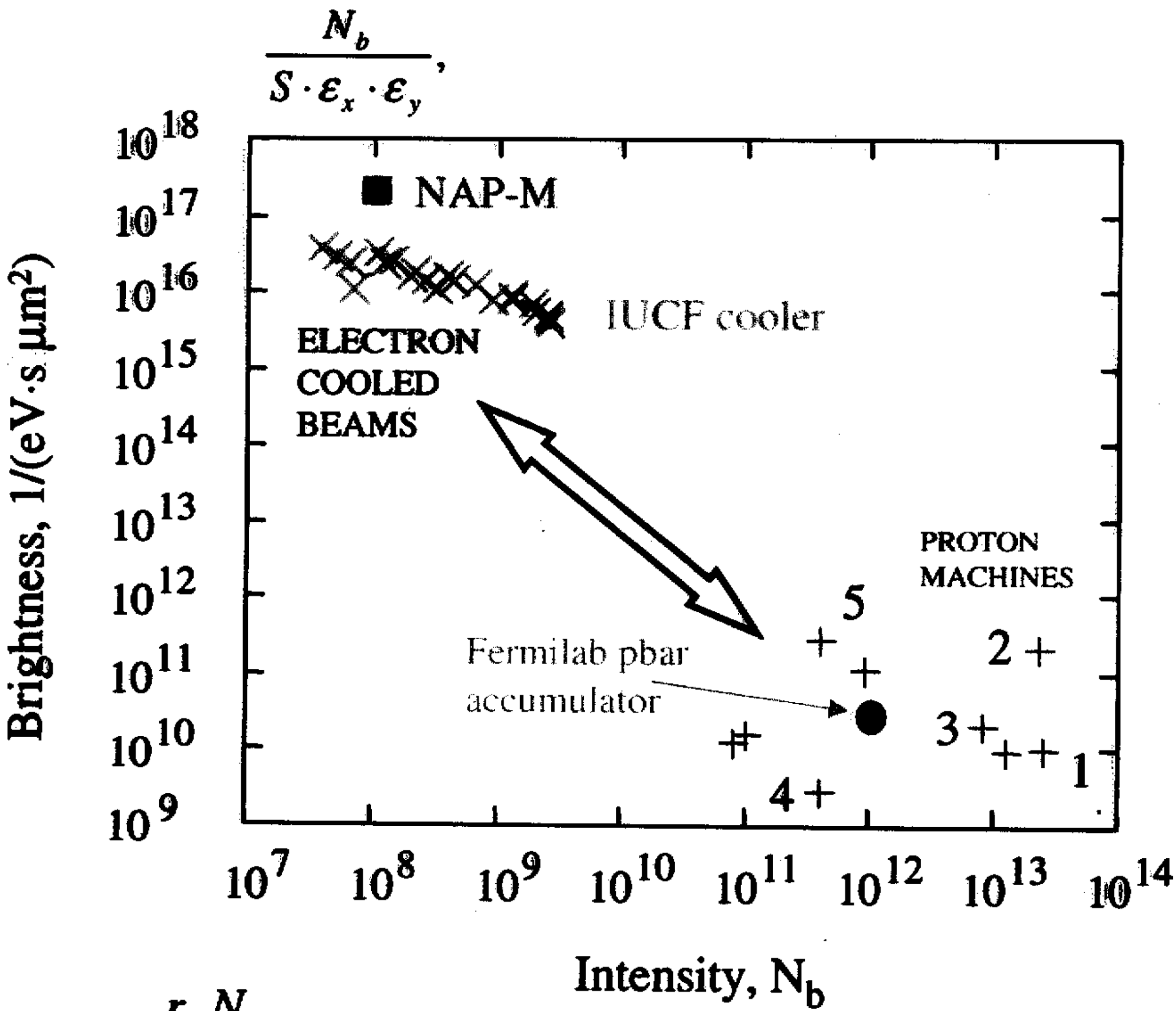
April 12, 2002



Types of cooling

- Longitudinal cooling due to acceleration
- Stochastic cooling
- Synchrotron radiation
- Electron cooling
- Laser cooling (of certain ion beams)
- dE/dx (ionization) cooling (not yet tested)
- Technique for rapid transverse cooling in a straight transport line is yet to be found.

High Intensity ~~and~~ or High Brightness



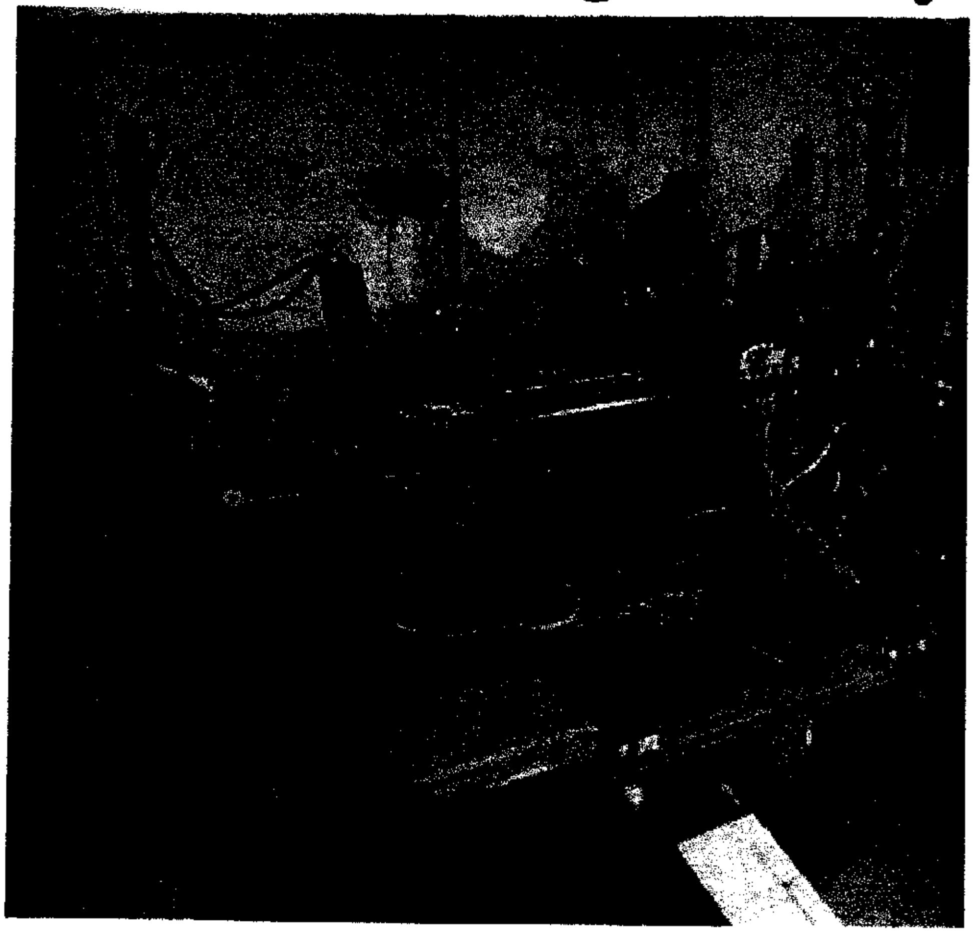
$$\varepsilon_{x,y} = \frac{r_p N_b}{4\pi\beta\gamma^2 \Delta Q} \propto N_b$$

$$S = \Delta E \cdot \tau \propto N_b$$

$$\frac{N_b}{S\varepsilon_x \varepsilon_y} \propto \frac{1}{N_b^{3/2}}$$

1 – μμ driver,
2 – PSR,
3 – ISIS,
4 – KEK PS,
5 – FNAL Main Inj.

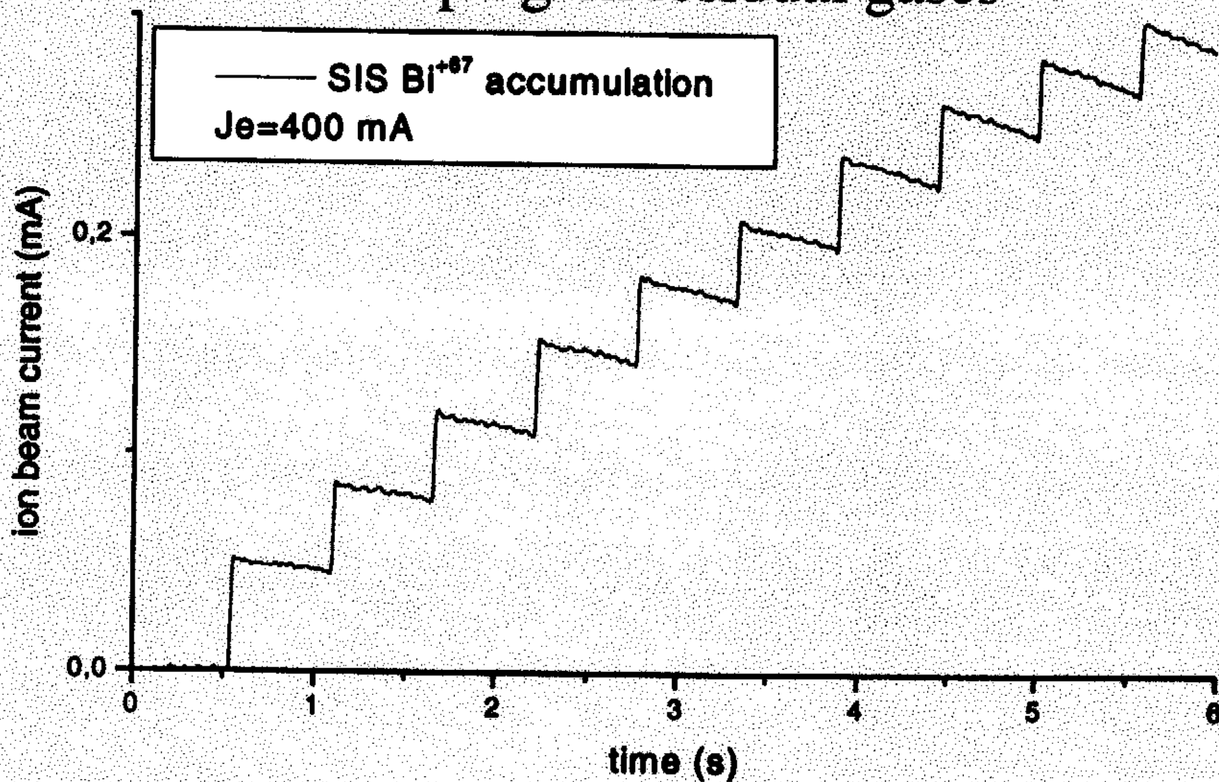
Electron cooling (30+ years)



- Was first tested in 1974 with 68 MeV protons at NAP-M storage ring at INP.

Beam accumulation

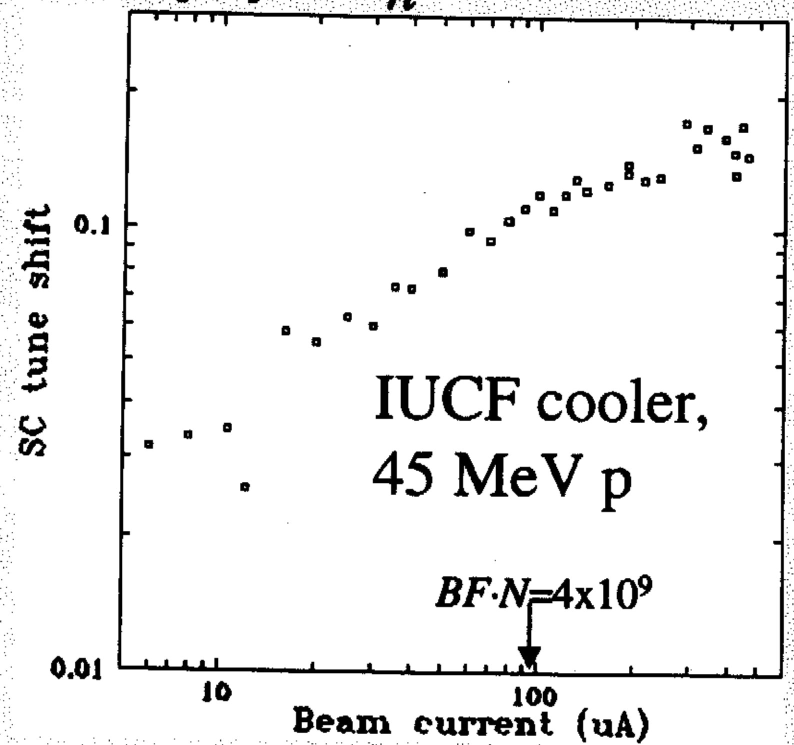
cooling and new multiturns injection ion beam.
Decay between injection is result of recombination and striping on residual gases



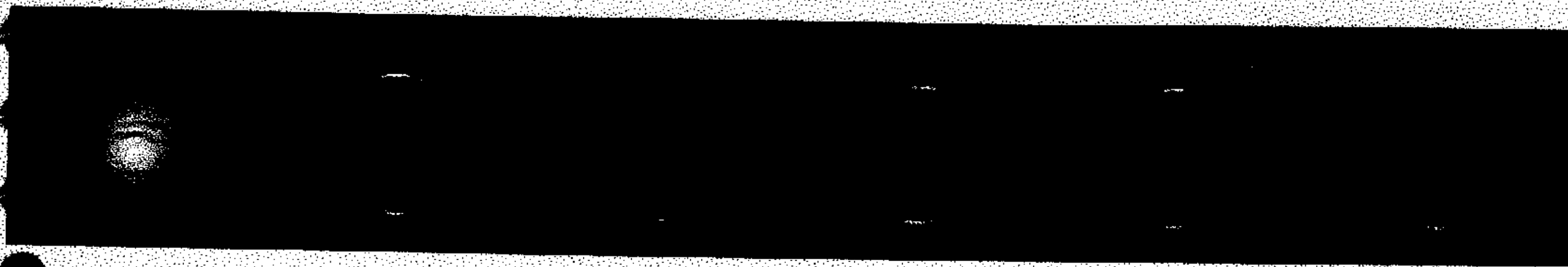
Laslett tune shift

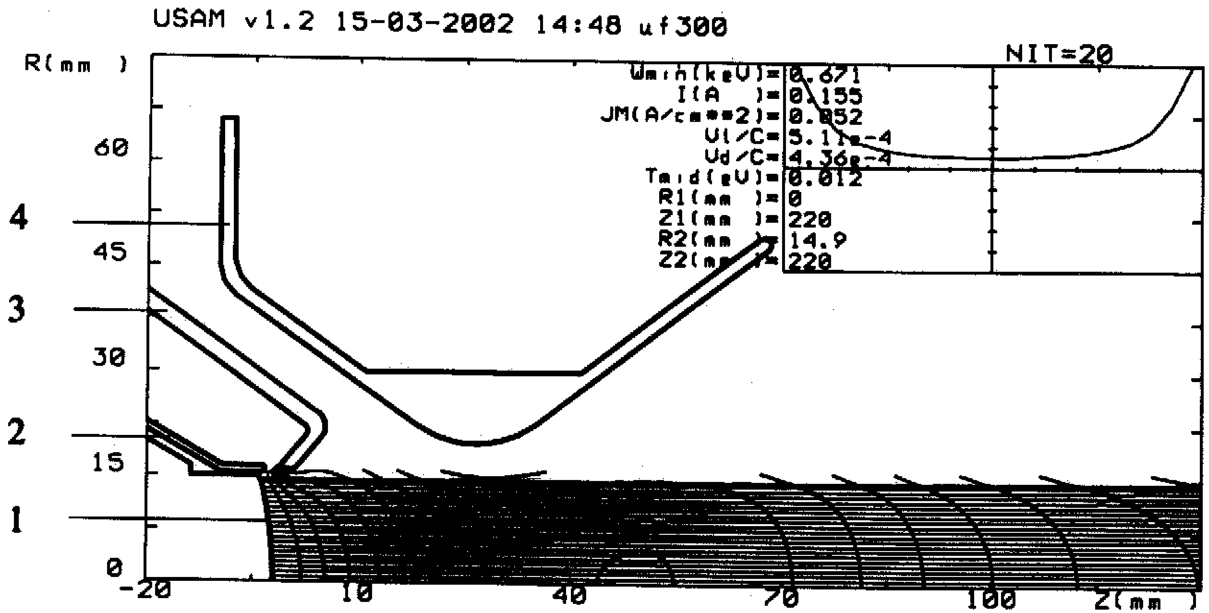
$$\Delta Q_L = -\frac{r_i BF \cdot N}{4\pi\beta\gamma^2\varepsilon_n}$$

ε_n - r.m.s. norm. emittance
N - number of ions per bunch
BF – bunching factor



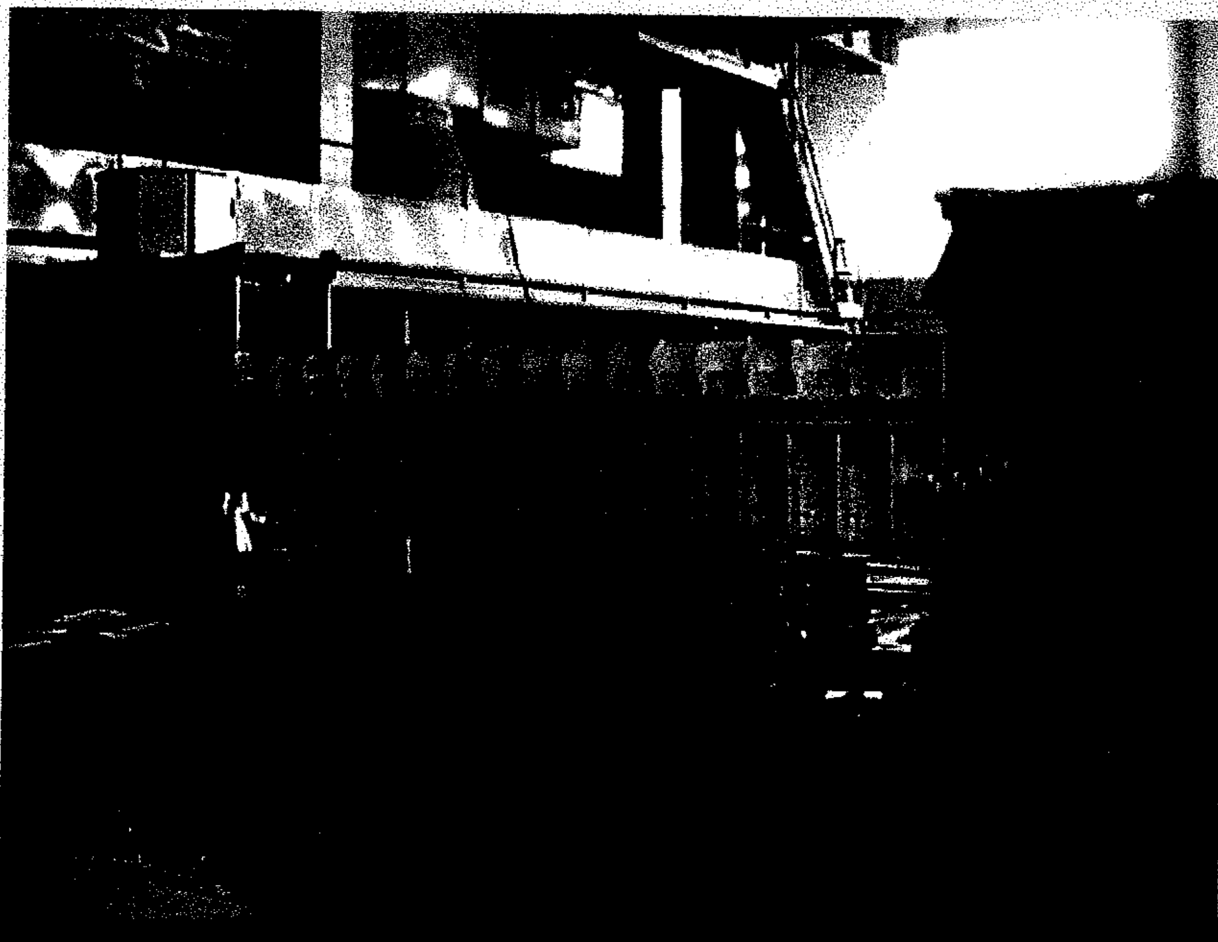
Variation electron beam profile with different voltage on electrodes





The new tools for control cooling intensive ion beams

-cooler for CSR project at IMP Lanzhow (China)



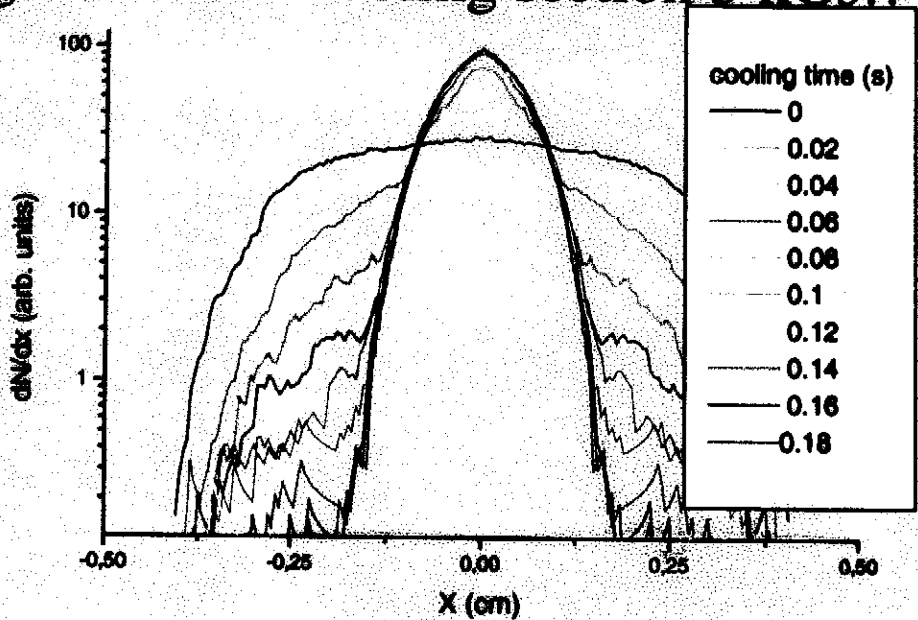
Draft estimation fast cooling p-beam energy 400 MeV, emittance 1 μm, Np=10^{12}

Proton beam current 0.2A

Electron beam current 5 A!!

Electron beam energy 200 kV

Magnet field at cooling section 5 kGs!!



High Energy Electron Cooling

- I define a "high energy" as the energy where the conventional technology to produce and transport electrons becomes difficult to use. These technologies are:
  - Power supply (or energy source);
  - Continuous magnetic field of 1 kG or more;
  - Short cooling section (about 2 m).
- This probably corresponds to $\gamma > 1.5$
- Well understood fundamentals but much R&D is needed.
- At present, only Fermilab has committed funds to do a full-scale R&D for a system to cool 8.9 GeV/c antiprotons.

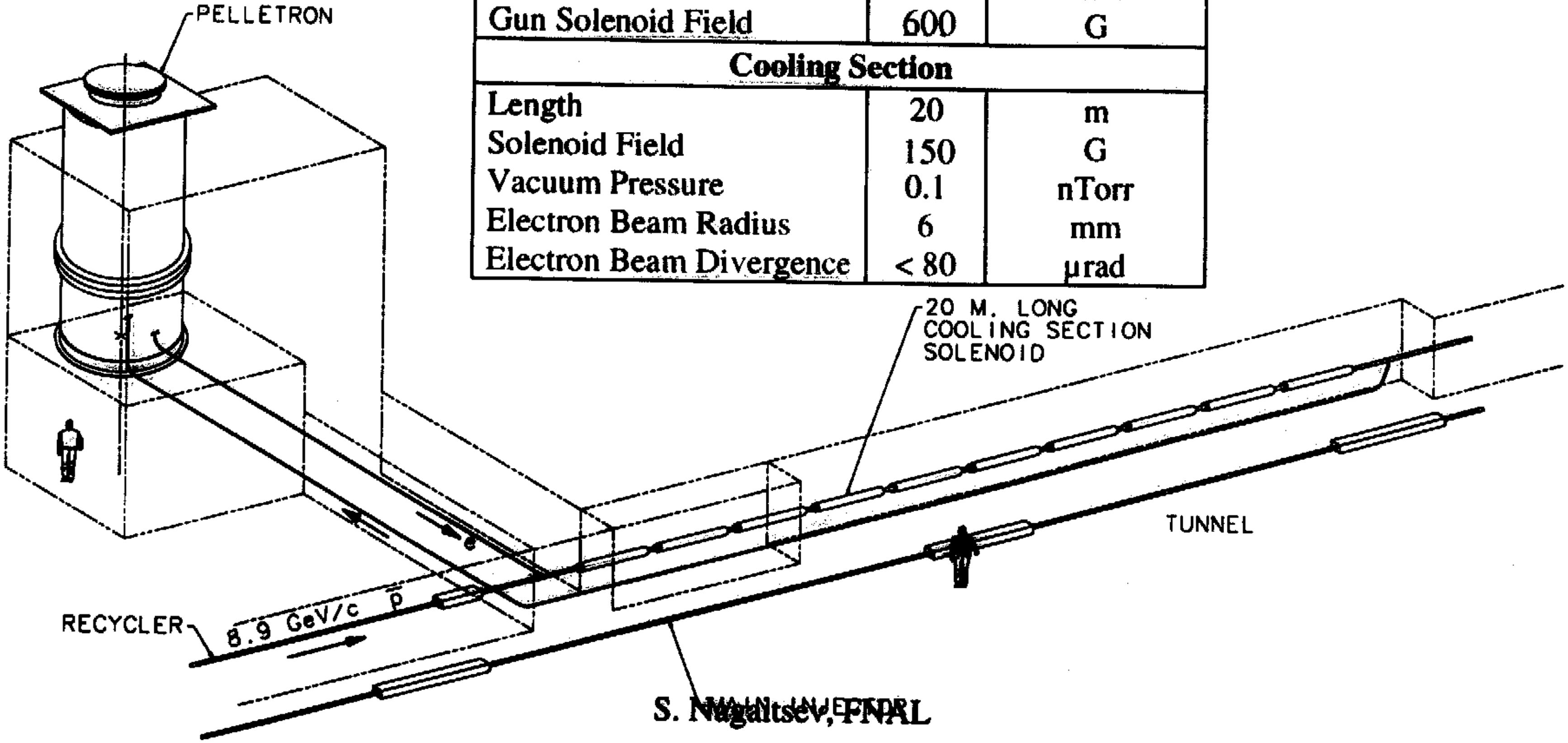
Why sudden new interest in high energy cooling?

- The existing stochastic cooling technology is band-width limited (10 GHz or so).
- The lack of progress in bunched-beam stochastic cooling
- The advance in electron gun and collector technology (experience of low energy e-cooling), and in recirculation of DC beams.
- The advance in recirculating linac technologies.
- The advance in linear optics on beams with a large angular momentum.

Schematic Layout of the Fermilab's Recycler Electron Cooling

Electron Cooling System Parameters

Parameter	Value	Units
Electrostatic Accelerator		
Terminal Voltage	4.3	MV
Electron Beam Current	0.5	A
Terminal Voltage Ripple	500	V (FWHM)
Cathode Radius	2.5	mm
Gun Solenoid Field	600	G
Cooling Section		
Length	20	m
Solenoid Field	150	G
Vacuum Pressure	0.1	nTorr
Electron Beam Radius	6	mm
Electron Beam Divergence	< 80	μrad



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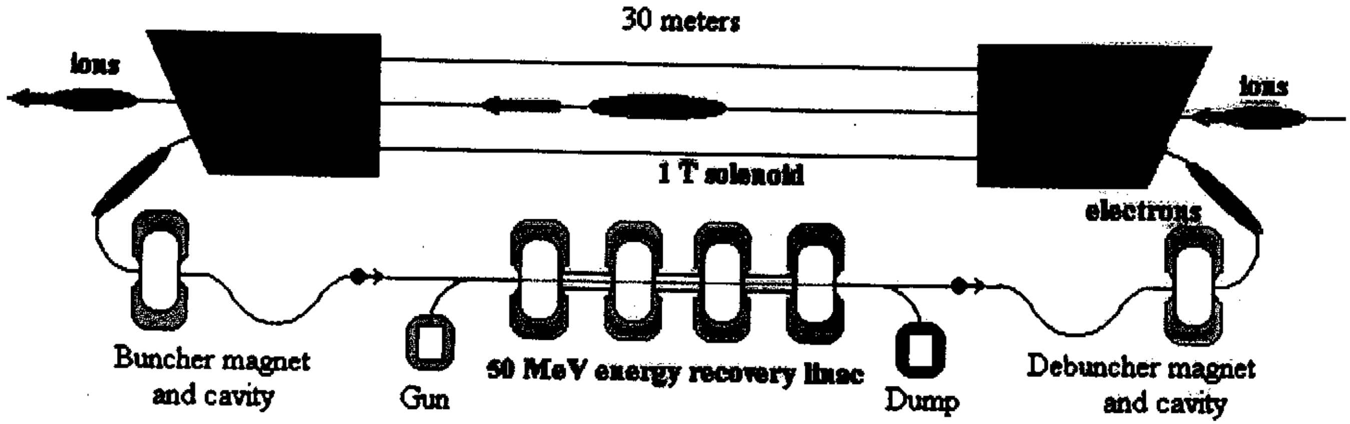
Schematic of the RHIC Cooler

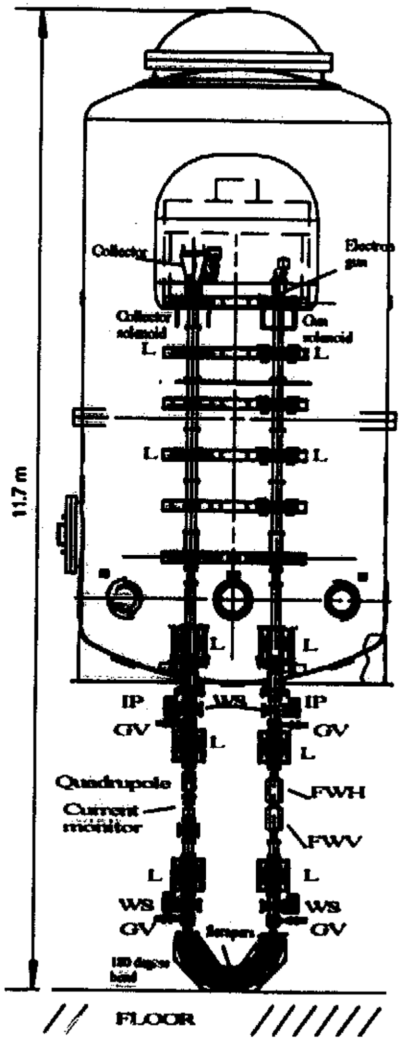
(from I. Ben-Zvi's talk 06/18/01)

- Energy Recovery Linac
- Buncher - debuncher



> x10 increase in the integrated luminosity of RHIC, as well as better accumulation of rare species.

Electron Cooling R&D Facility at WideBand
(Recirculation experiment)



GOAL

- To demonstrate a 0.5 A recirculation for 1 hr. at 4.3 MV

HISTORY

Feb 99: 5 MV Pelletron ordered.

Jun 00: Pressure tank installed at WideBand.

Dec 00: Tank at 80 psig, 5 MV tests without vacuum tubes.

Feb 01: Gun-side vacuum tubes installed and tested.

Mar 01: Collector-side tubes installed. Operations began.

Apr 01: Beam permit issued. All components in place.

May 01: First beam of 30 μA in the collector at 4.3 MV.

July 01: Reached 10 mA, HV conditioning is very unstable, tubes do not behave properly.

Aug 01: Switched to operations with 3.5 MV. Routine conditioning to 4.3 MV.

Jan 02: Reached stable 500 - 600 mA beam at 3.5 MeV

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