Cooling of Ion Beam by a Bunched Electron Beam in Storage Ring

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on behalf of IMP-JLab collaboration team

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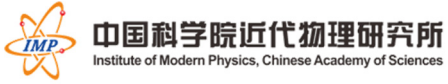


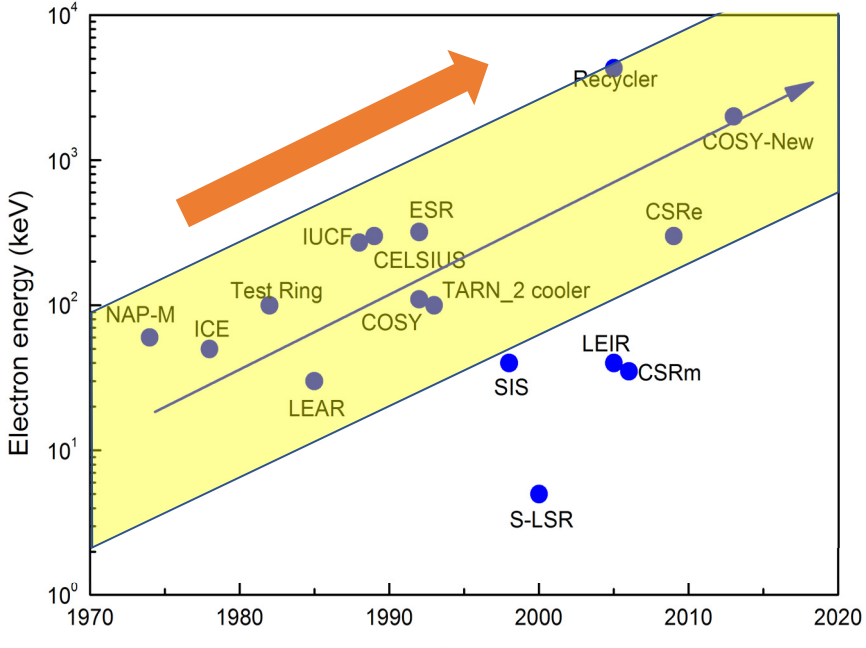
✳ This work was supported by Chinese Academy of Sciences & U.S. Department of Energy

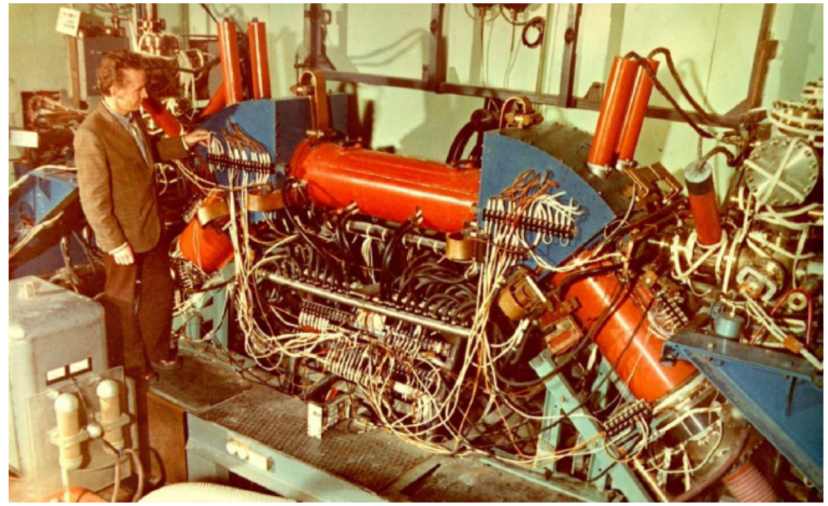
Outline

I. Scientific motivation
II. Experimental setup and conditions
III. Experimental & simulation results
IV. Summary

➢ Scientific motivation

all electron coolers are operated base on the DC electrostatic accelerators energy up to 4.3 MeV electron beam (Recycler, Fermilab)



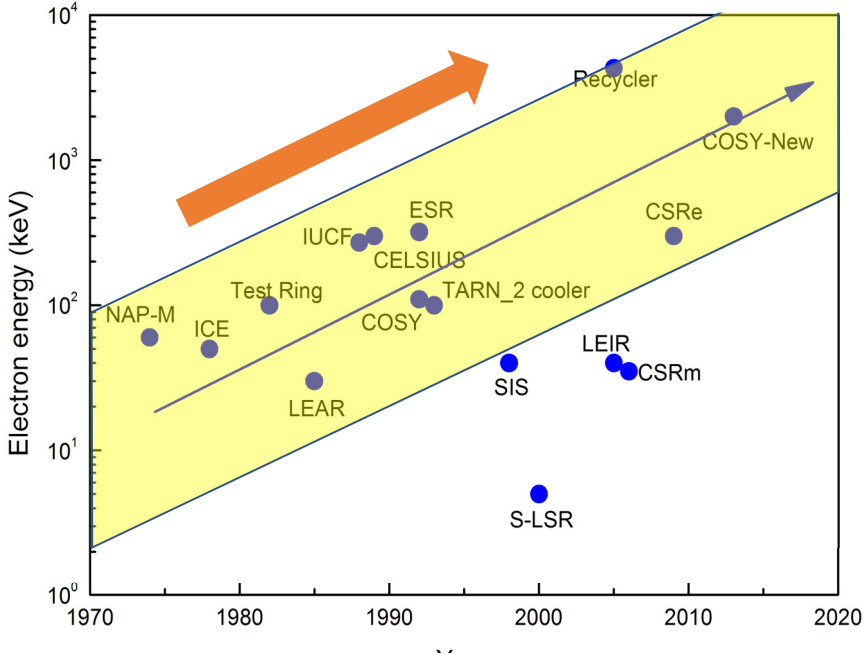


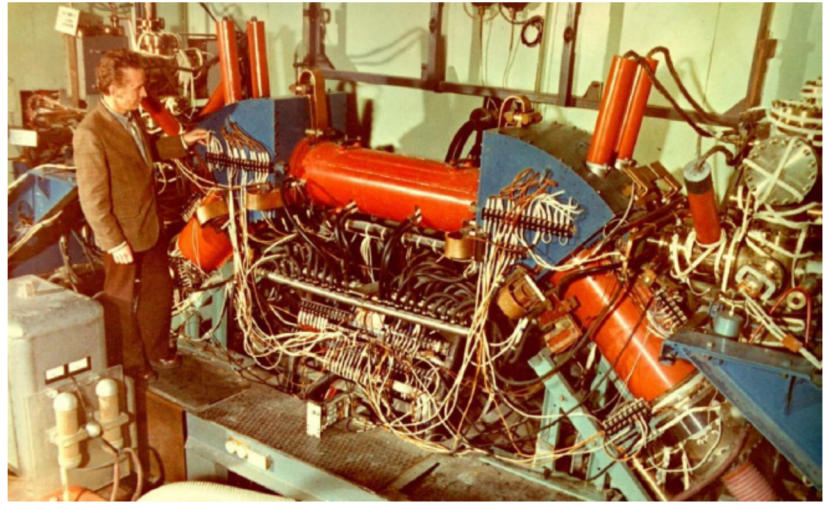
First electron cooler @ BINP Russia

◆ **Powerful high energy electron cooling method is required for EICs.**

Scientific motivation

all electron coolers are operated base on the DC electrostatic accelerators energy up to 4.3 MeV electron beam (Recycler, Fermilab)



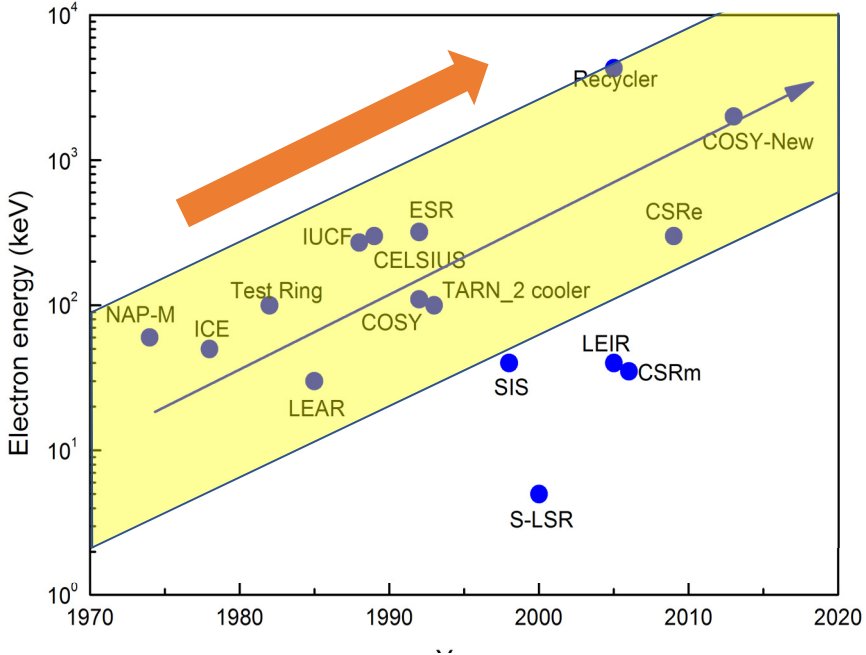


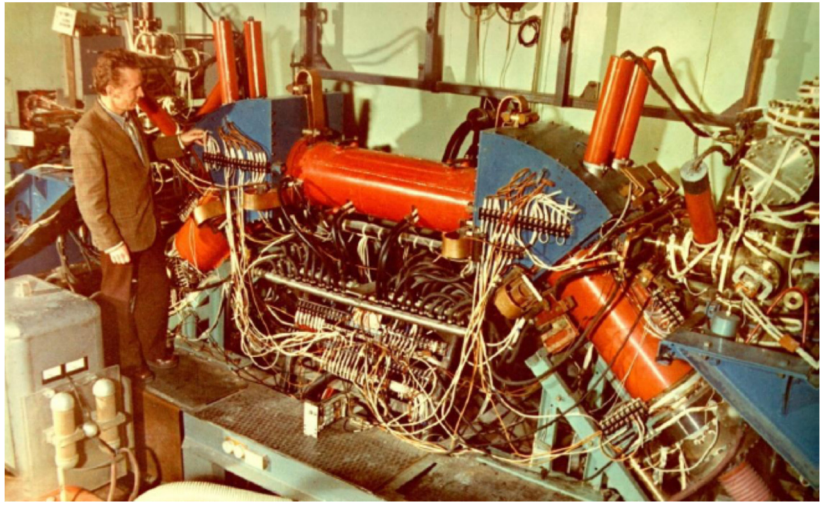
First electron cooler @ BINP Russia

◆ **Electrostatic accelerators are NOT available and RF accelerator is needed**

Scientific motivation

all electron coolers are operated base on the DC electrostatic accelerators energy up to 4.3 MeV electron beam (Recycler, Fermilab)



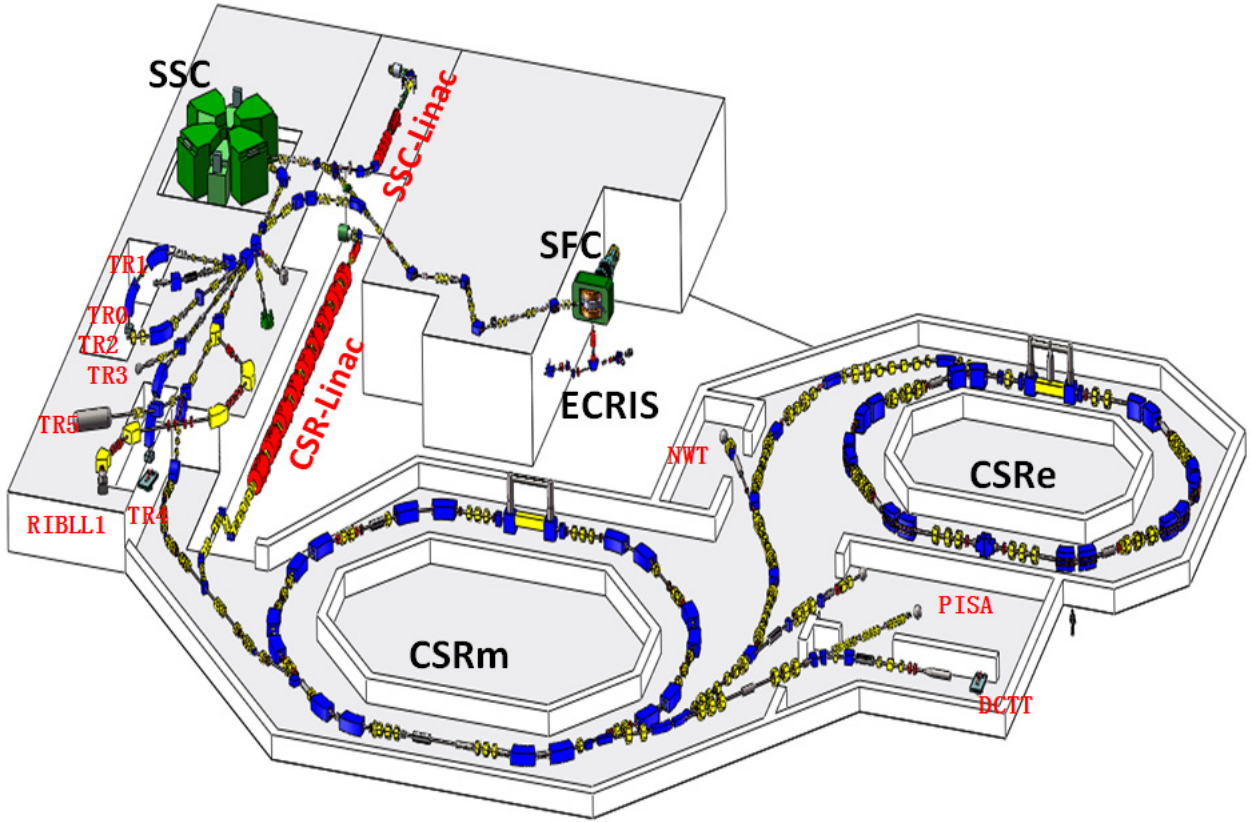


First electron cooler @ BINP Russia

◆ **Electron beam is bunched**

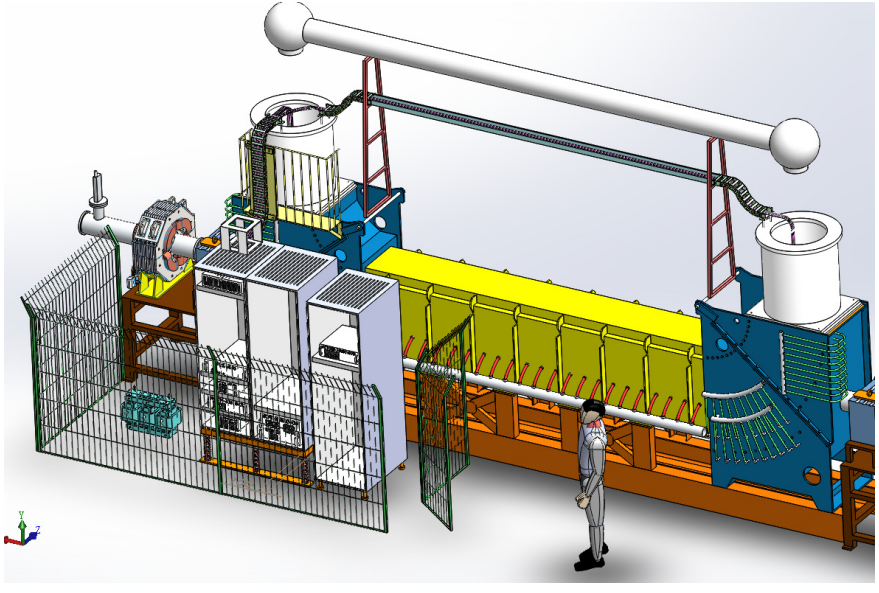
➢ Scientific motivation

To investigate the bunched electron beam cooling process on the classical electron cooler @ CSRm, IMP Lanzhou

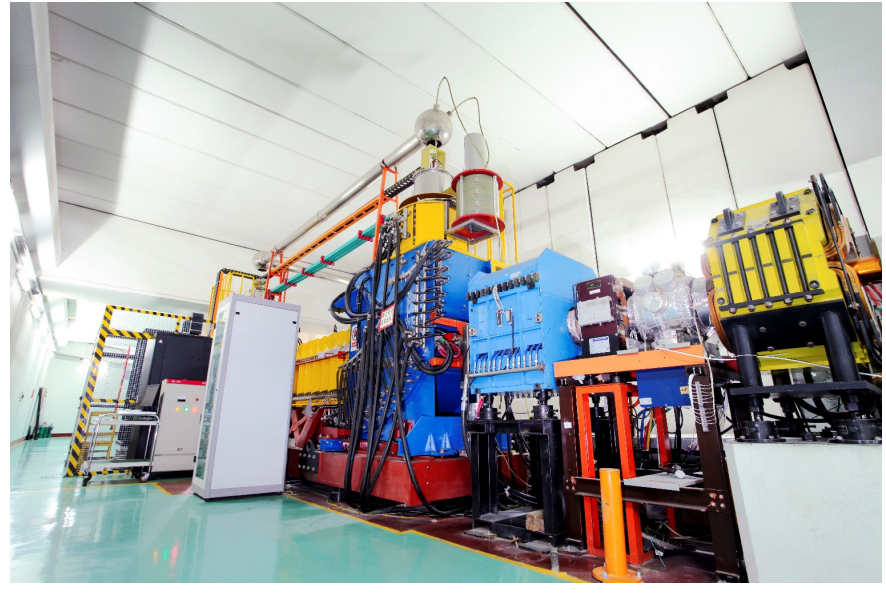


➢ Experimental setup and conditions

New high voltage system is used to produce pulsed electron beam



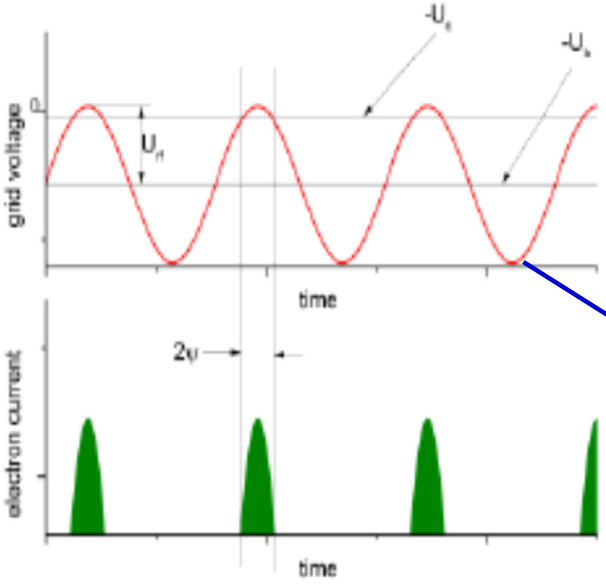
High voltage platform closed to the gun

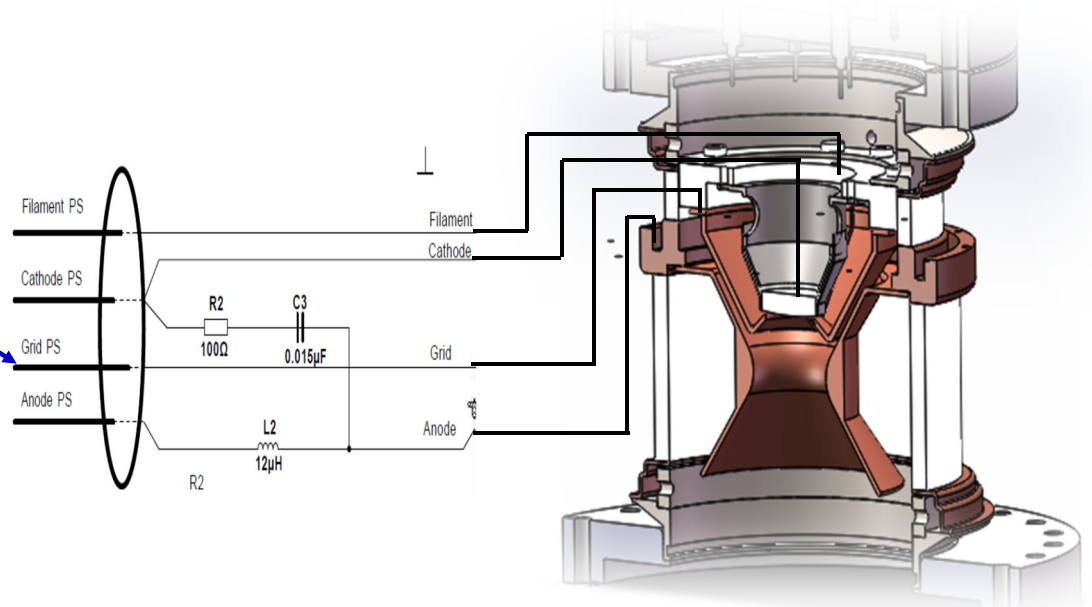


35 kV electron cooler @ CSRm

➢ Experimental setup and conditions

Basic idea: Switch on/off electron beam by the grid electrode





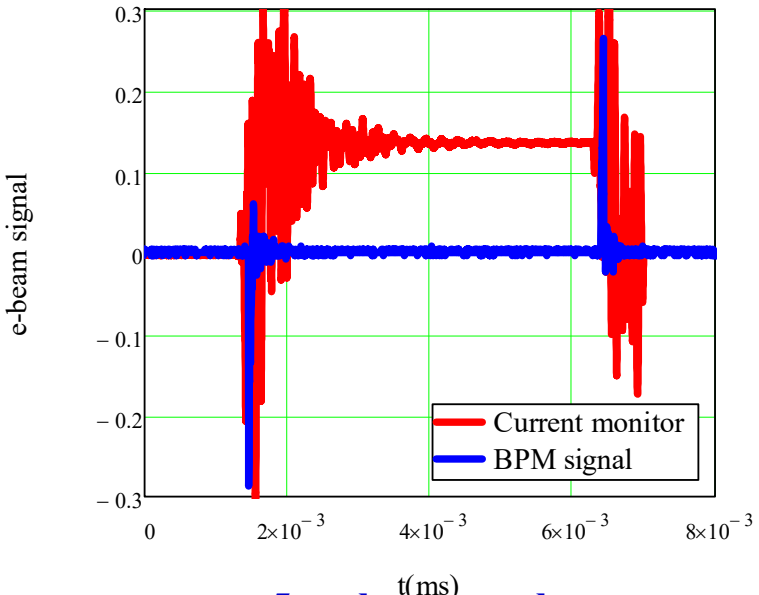
Grid voltage from a pulse generator

Grid electrode is used to control the electric field at the cathode

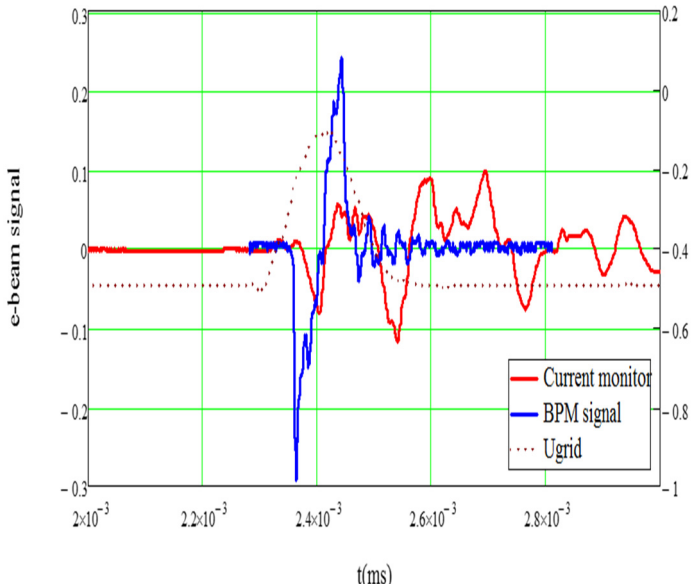
Experimental setup and conditions

Pulsed electron beam is obtained with:

- The pulse width from 70 ns to DC
- The peak current up to 70 mA
- The repetition frequency up to 450 kHz



5us electron pulse



70ns electron pulse

➢ Experimental setup and conditions

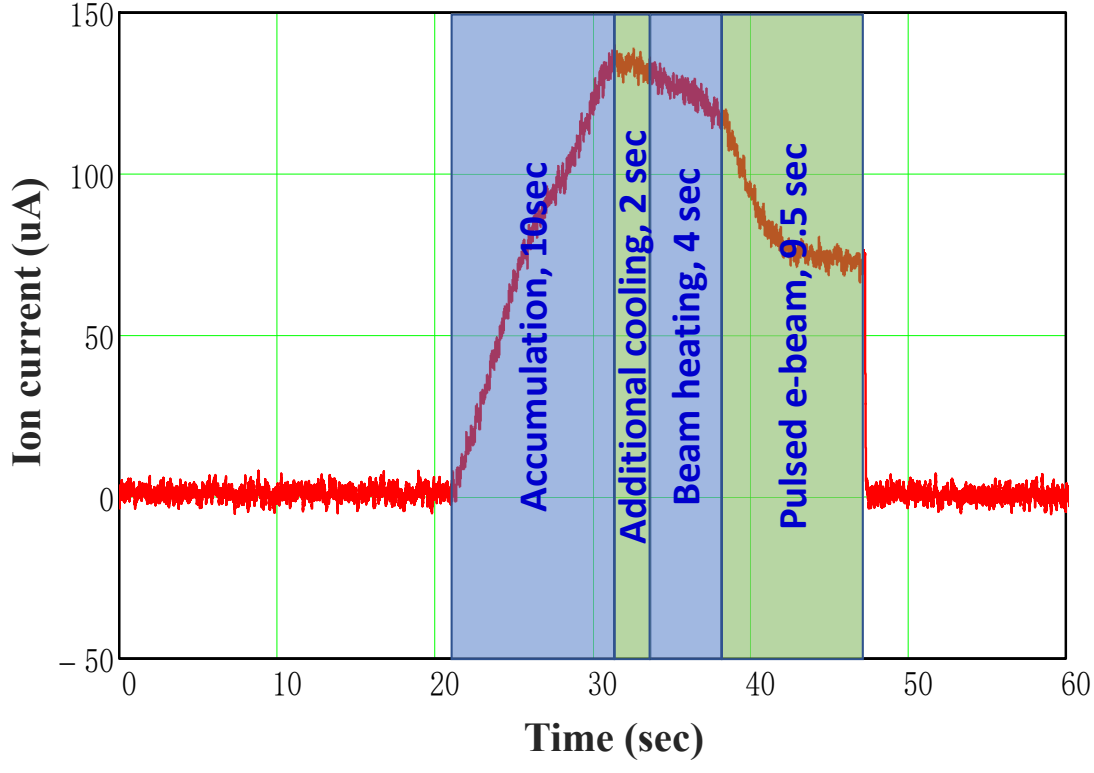
The main parameters of the experiments

Item	value
Ion	$^{86}Kr^{25+}$
Energy	4.98 MeV/u
Revolution frequency	191.4 kHz
Harmonic number	2
RF voltage	600 V
Stored particle number	~10^8
Electron energy	2734.5 V
Electron current (DC)	~30 mA or even less
Ion bunch width	~1000 ns (RMS value)
Pulse width	300 ns to 1200 ns for bunched ion beam 500 ns to 4000 ns for coasting ion beam

➢ Experimental setup and conditions

The total measurement cycle is 50 seconds in the experiment

1. Beam stacking with DC cooling, around 10 seconds
2. Continuously DC cooling, to improve the beam quality, around 2 seconds
3. Switch off the DC electron beam (without cooling), beam blows up, around 4 seconds
4. Switch on the detectors, including BPM, Schottky and IPM
5. Switch on RF system, after 500 ms, switch on the pulsed electron beam.

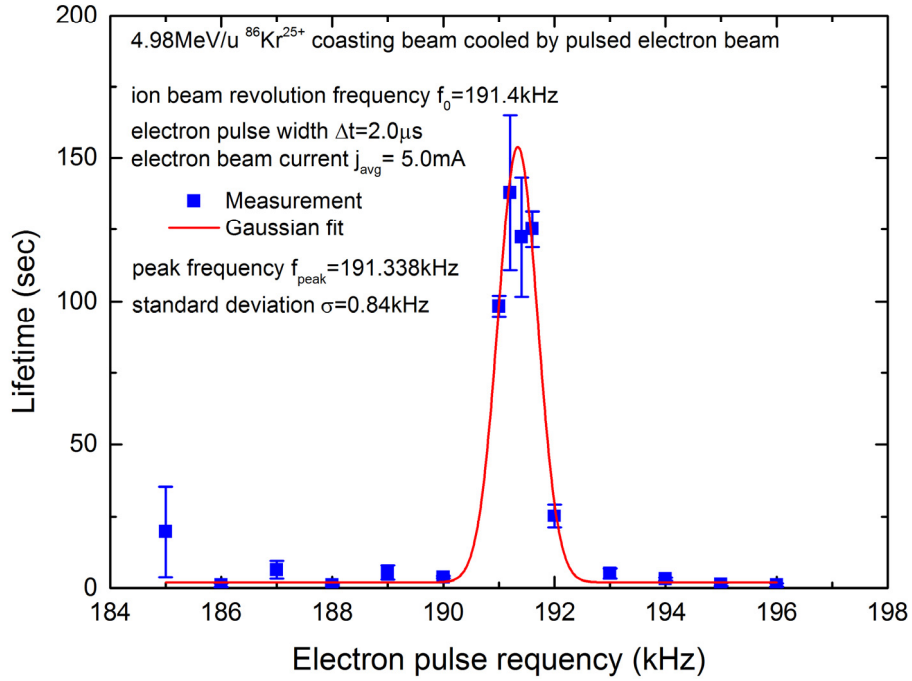


The ion beam current in the experiment

Experiment and simulation results

Synchronization

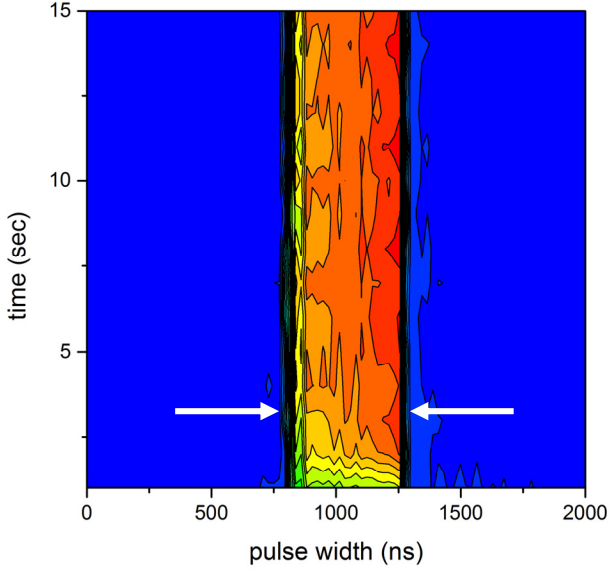
The repetition frequency of electron pulse **must be matched to** the ion beam revolution frequency



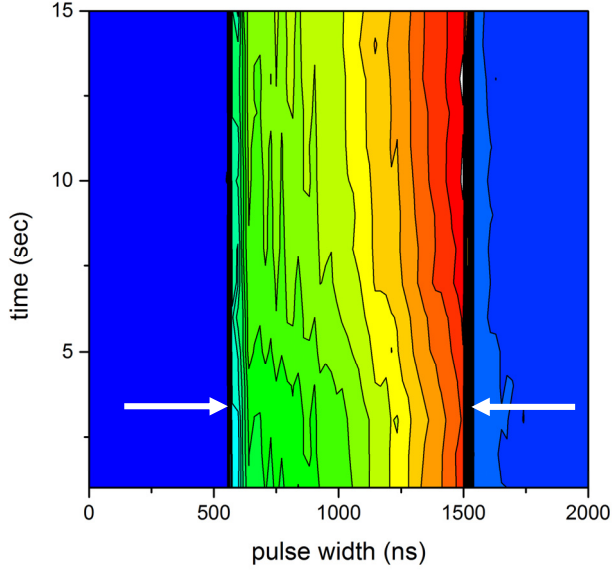
Experiment and simulation results

Grouping effects

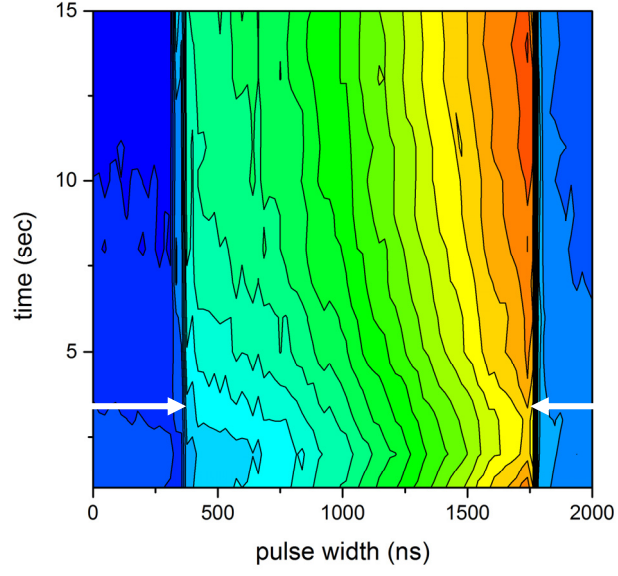
- The coasting ion beam (no RF in the ring) can be cooled and captured in the electron pulse.
- Finally the ion pulse length **is equal to** the electron pulse length



500ns electron pulse



1000ns electron pulse

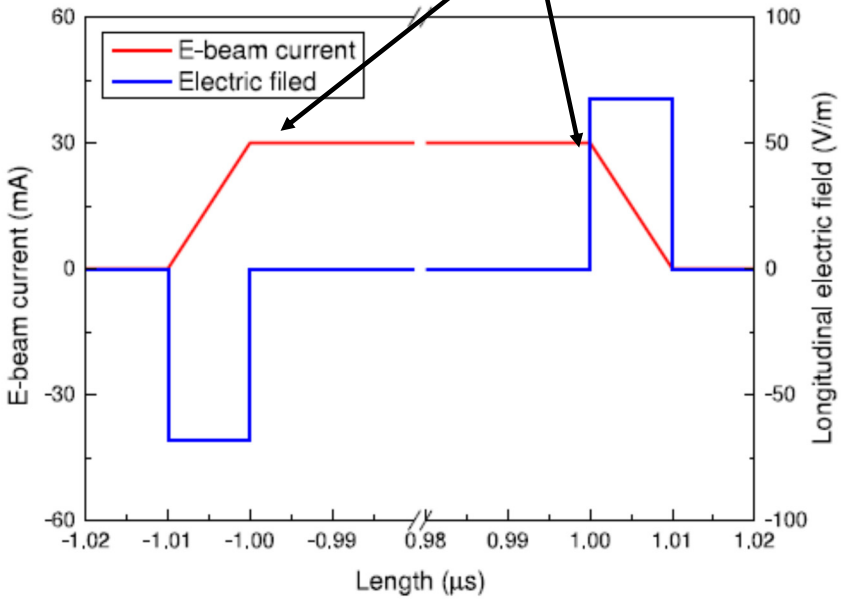


1500ns electron pulse

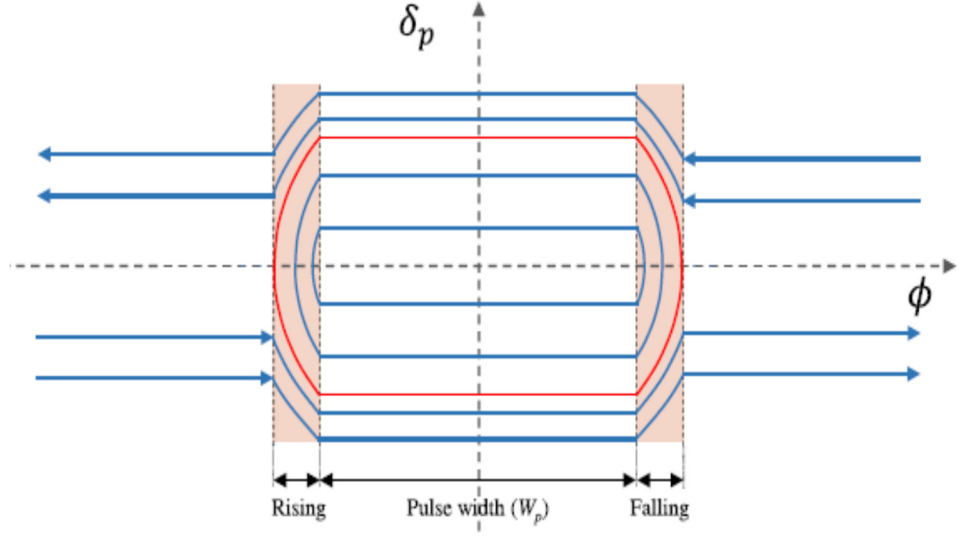
➢ Experiment and simulation results

A "**barrier bucket**" is produced by the space charge field of the pulsed electron beam

$$E_z(z) = -\frac{g}{4\pi\varepsilon_0\beta c\gamma^2}\frac{dI_e(z)}{dz}.$$

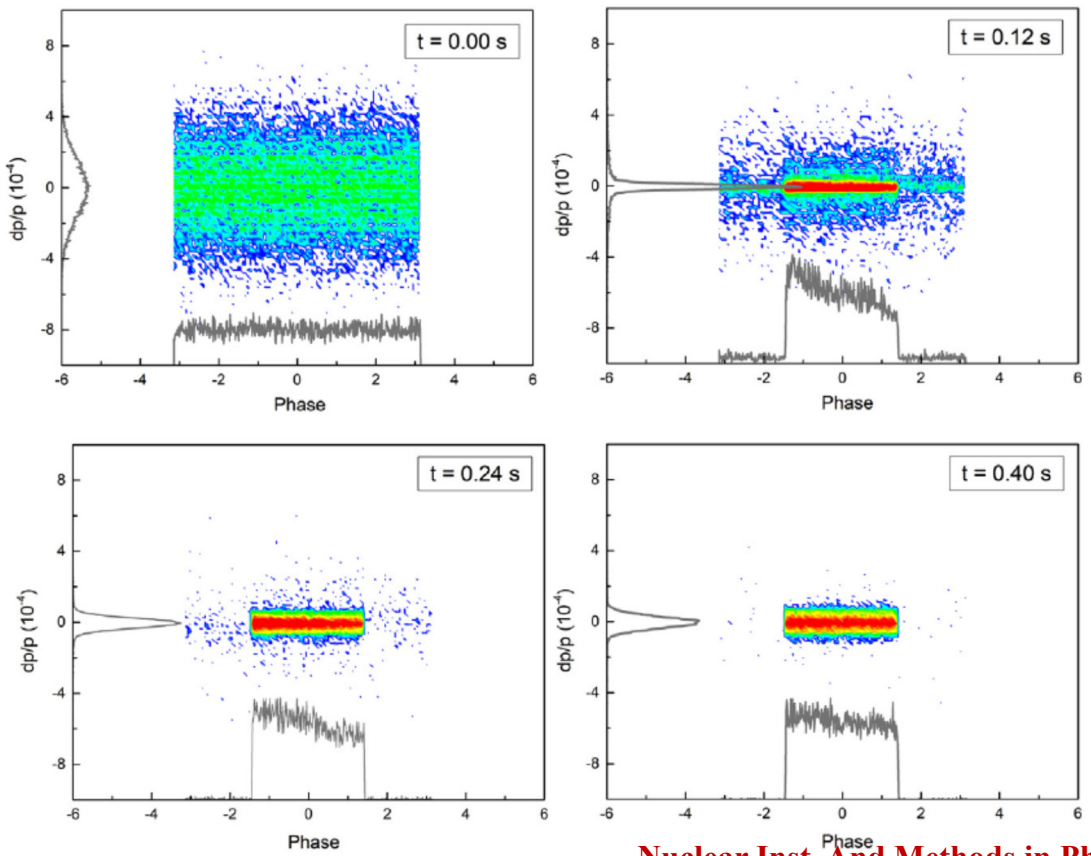


The ions (with the energy spread smaller than the bucket height) will be captured in the bucket



➢ Experiment and simulation results

A simulation show the cooling process of coasting ion beam by a pulsed e-beam

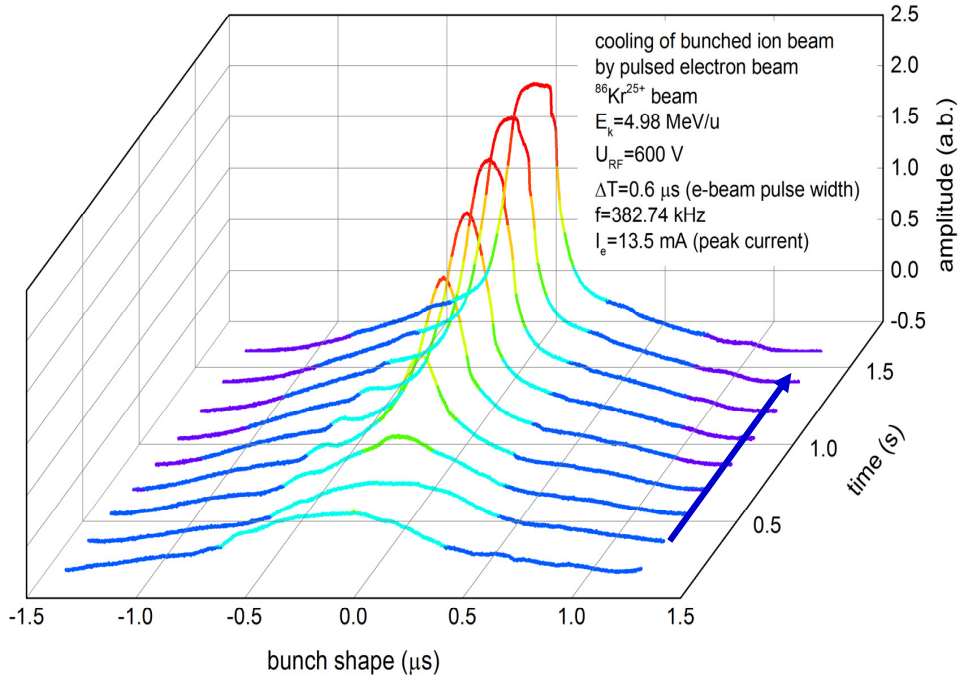


Nuclear Inst. And Methods in Phys. Research, A 902 (2018) 219-227

➢ Experiment and simulation results

■ Bunched ion beam cooling by pulsed electron beam

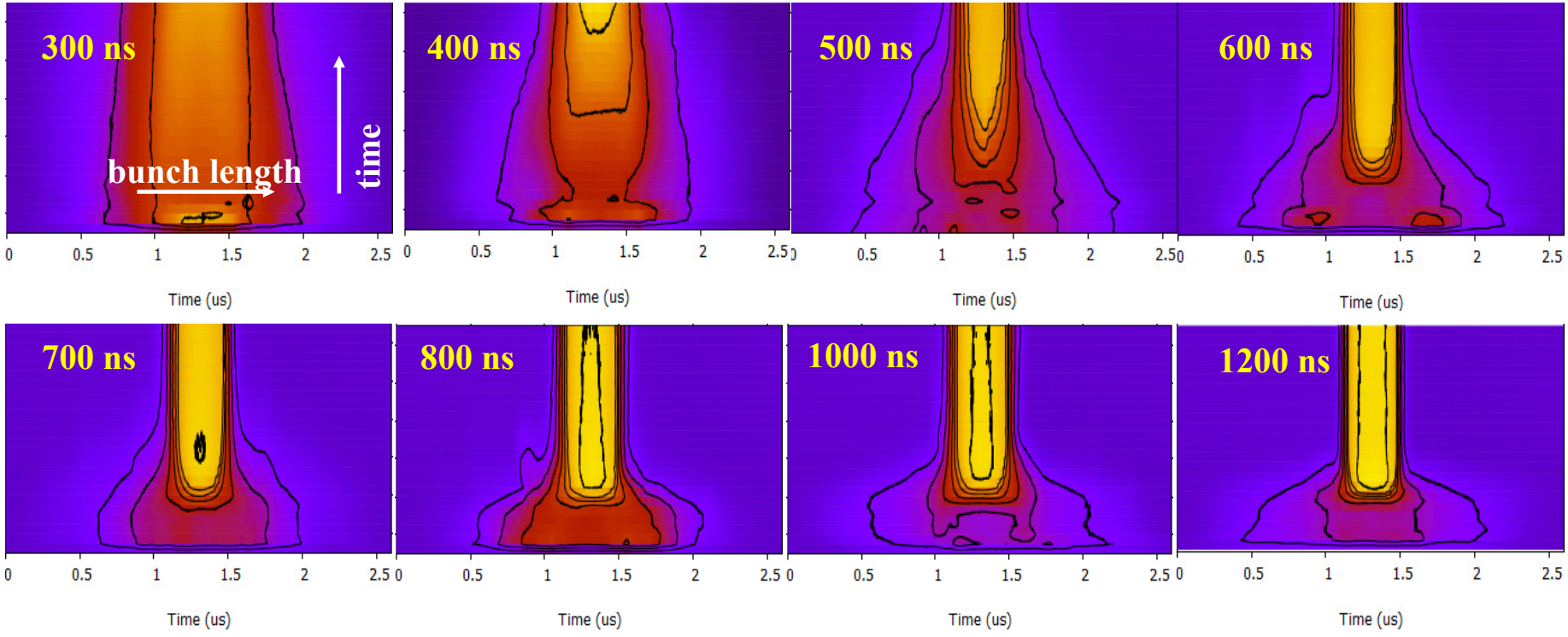
- ➢ The ion bunches **can be cooled** by pulsed electron beam
- ➢ Even the electron pulse width **is shorter than** the initial ion beam bunch length



➢ Experiment and simulation results

The cooling process with different electron pulse length

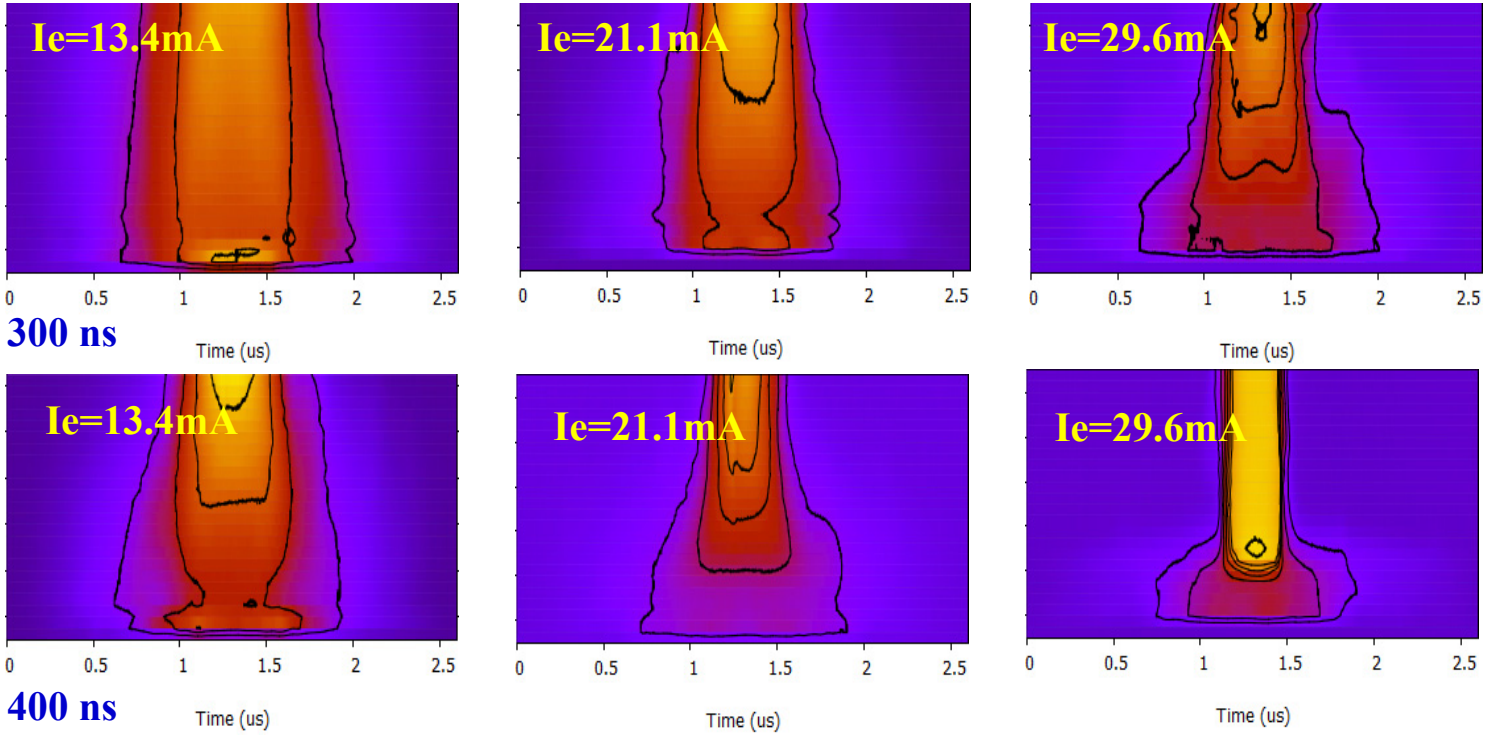
- It is observed that the cooling is **faster with larger e-beam pulse length** (the electron peak current is a constant)



➢ Experiment and simulation results

The cooling process with different electron peak current

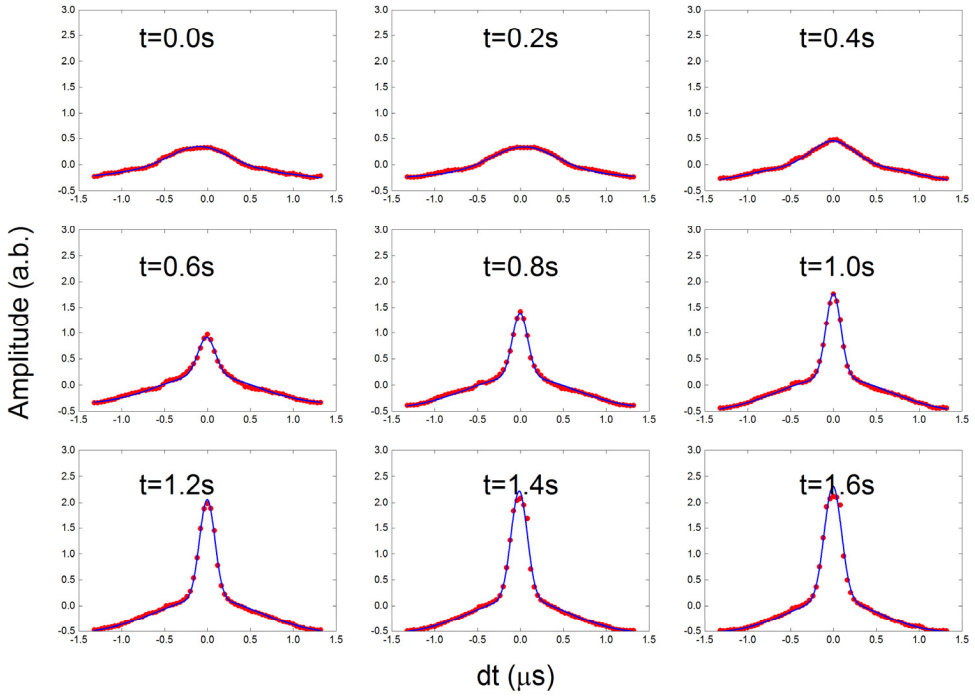
- It is also observed that the cooling is **faster with high e-beam peak current** (the electron pulse length is a constant)



Experiment and simulation results

The measured longitudinal beam shape can be fitted by Bi-Gaussian distribution

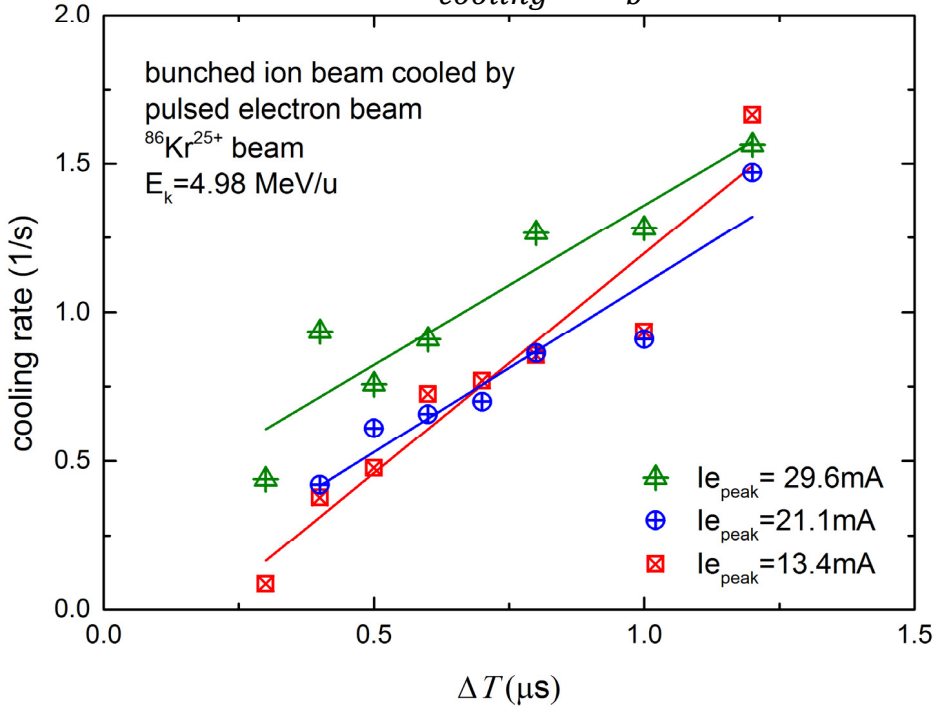
$$y = \frac{\Gamma_c}{\sqrt{2\pi}}\frac{1}{\sigma_c}\exp\left(\frac{(t-t_0)^2}{2\sigma_c^2}\right) + \frac{\Gamma_t}{\sqrt{2\pi}}\frac{1}{\sigma_t}\exp\left(\frac{(t-t_0)^2}{2\sigma_t^2}\right) + \delta \quad \Rightarrow \quad \sigma = \frac{S_c\sigma_c + S_t\sigma_t}{S_c + S_t}$$



Experiment and simulation results

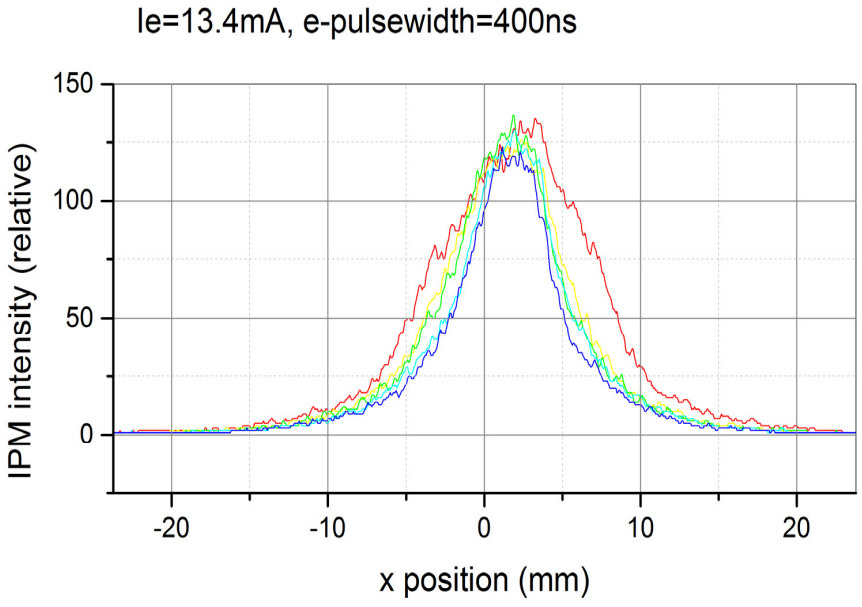
- The cooling rate **increases** with increasing of **the electron pulse length** and **the e-beam peak current**.

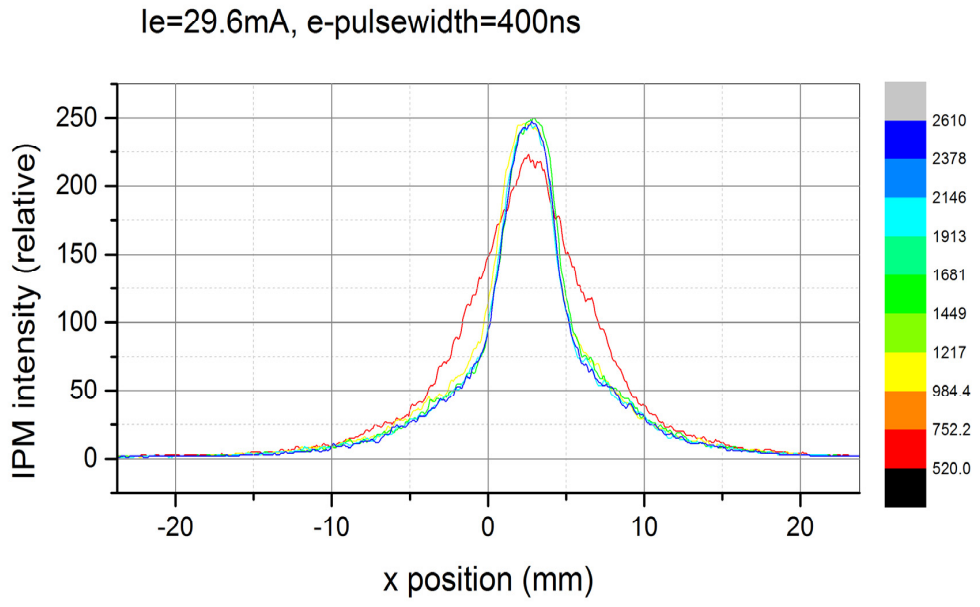
$$\lambda_{cooling} = \frac{1}{\tau_{cooling}} = \frac{1}{\sigma_b}\frac{d}{dt}\sigma_b$$



Experiment and simulation results

- The transverse beam cooling effect was observed by IPM detector.





Summary

- Both coasting and bunched ion beam can be cooled by pulsed electron beam in transverse and longitudinal phase space;
- The electron pulse and ions should be synchronized;
- A group effect is observed while the coasting ion beam cooled by pulsed electron beam.
- A dependence of cooling rate on different pulse electron beam parameters is summarized preliminary;
- A cooling effect was observed while the electron bunch length is shorter than the ion bunches.

Yuhong Zhang, Stephen Vincent Benson, Andrew Hutton, Kevin Jordan, Tom Powers, Robert Rimmer, Michael Spata, Amy Sy, Haipeng Wang, Shaoheng Wang, He Zhang (JLab, Newport News, Virginia)
Jie Li, Xiaoming Ma, Lijun Mao, Meitang Tang, Jiancheng Yang, Xiaodong Yang, He Zhao, Hongwei Zhao (IMP/CAS, Lanzhou)

Thanks very much for your attention!