Space Charge Compensation of Low Energy High Intensity Ion Beam

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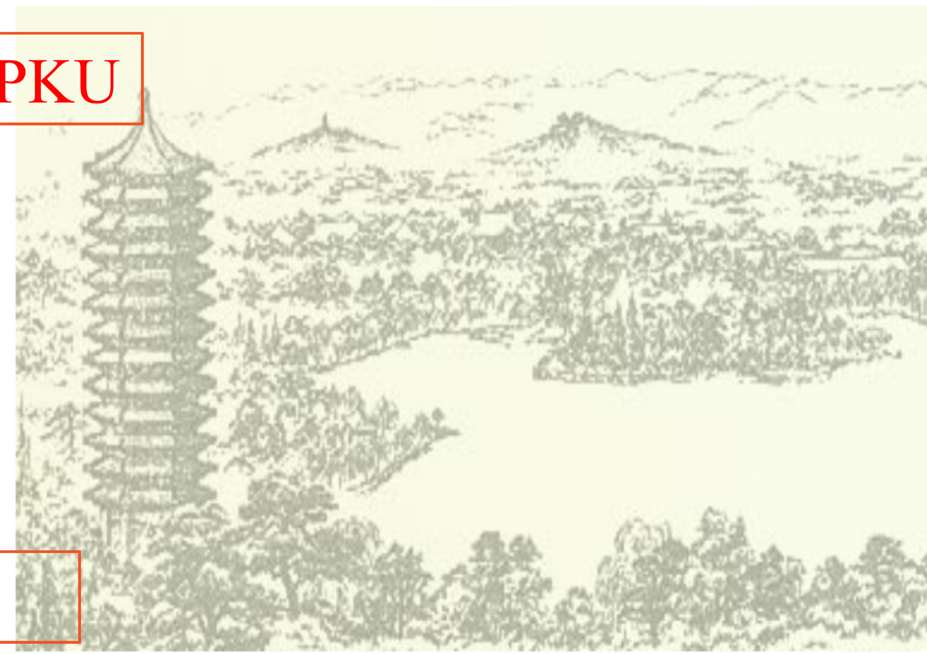
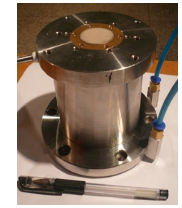
Outline



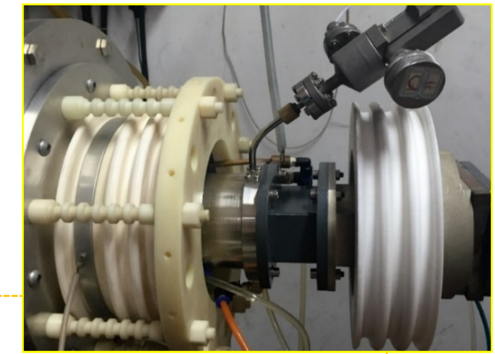
1. High Intensity Ion Source at PKU

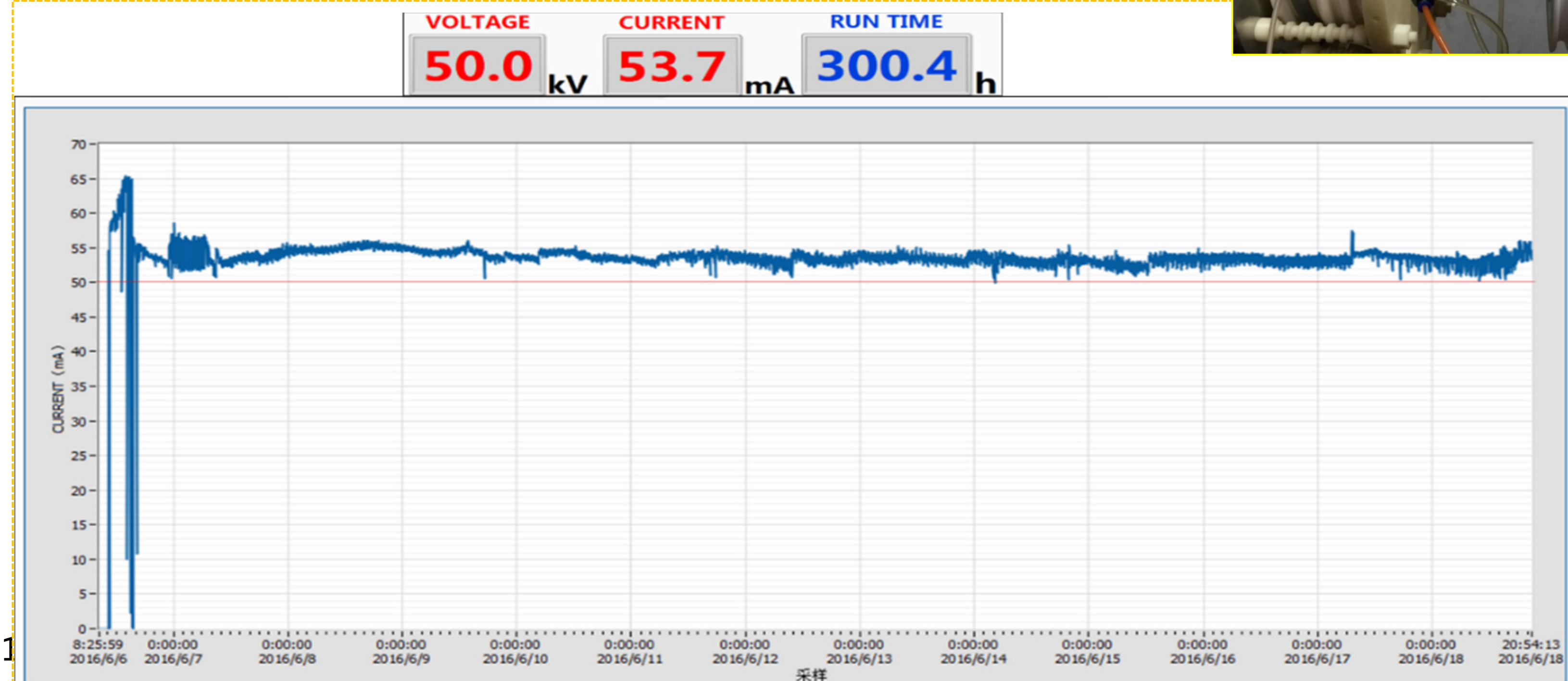
- Single-Charged 2.45GHz PMECR Ion Source



ϕ_{out}: 10 cm
H: 10 cm
ϕ_{in}: 40 mm
L: 50 mm

Labs	CEA/Saclay			PKU					
Ion type	H^+	D^+	He^+	H^+	D^+	He^+	O^+	Ar^+	N^+
Current(mA)	150	175	104	130	83	65	70	70	84
Density(mA/cm^2)	247	156	163	460	290	227	174	244	220
Projects	IPHI / FAIR / IFMIF/ MAHHAR / SPIRAL 2…			DWA	PKUNIFTY	Coupled RFQ	SFRFQ	Applications	

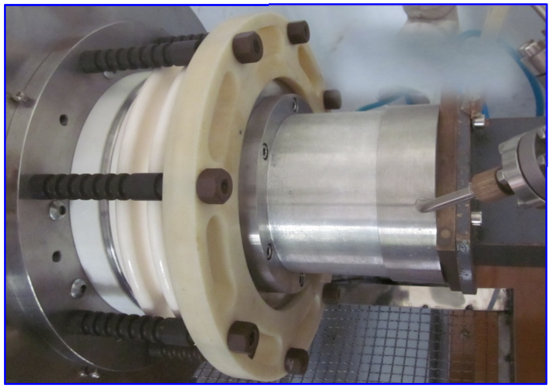


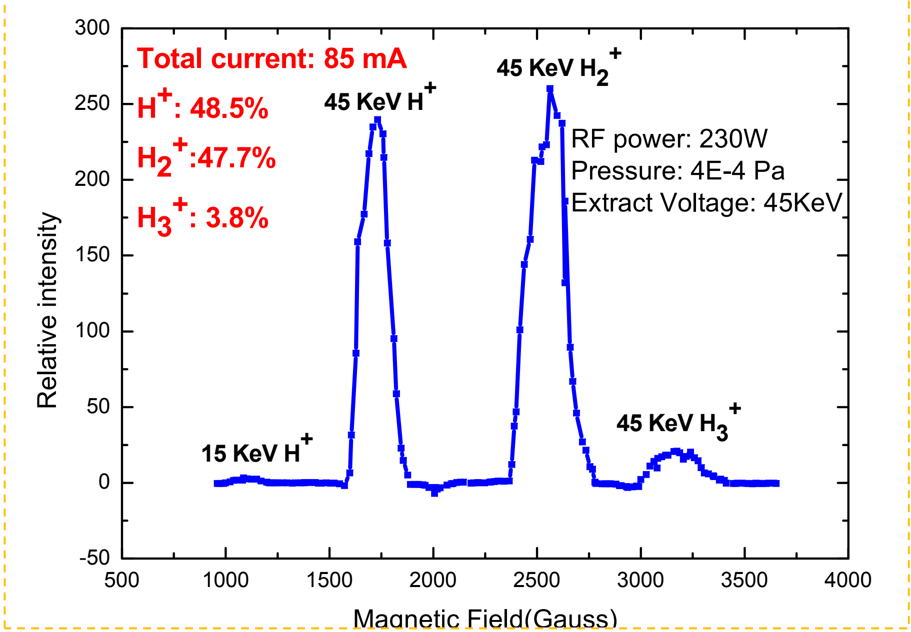


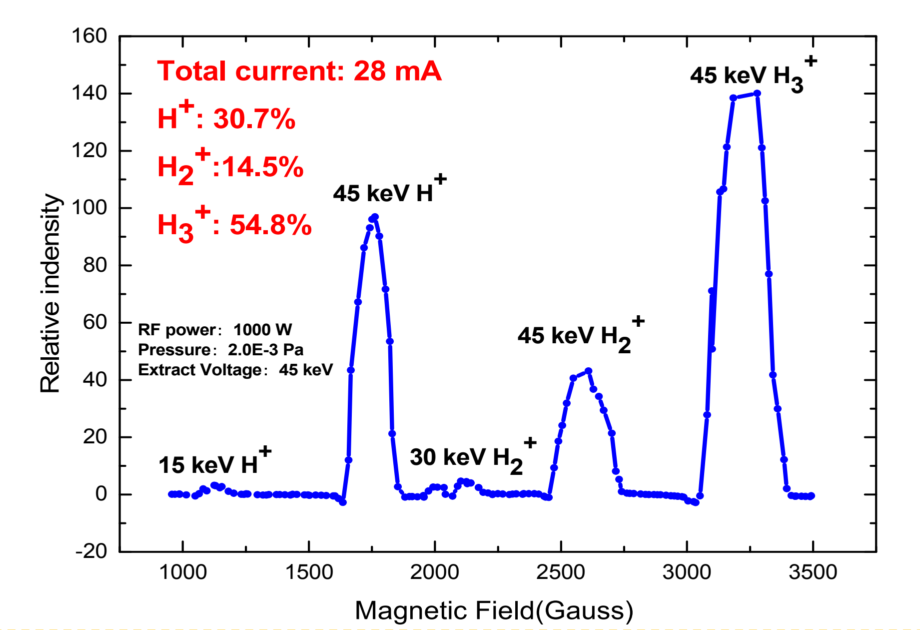
1. High Intensity Ion Source at PKU

➢ **2.45GHz PMECR Cluster Ion Source**

- H_2^+ 42mA(20mA)
- H_3^+ 20mA(2.9mA)
- O_2^+ 1mA







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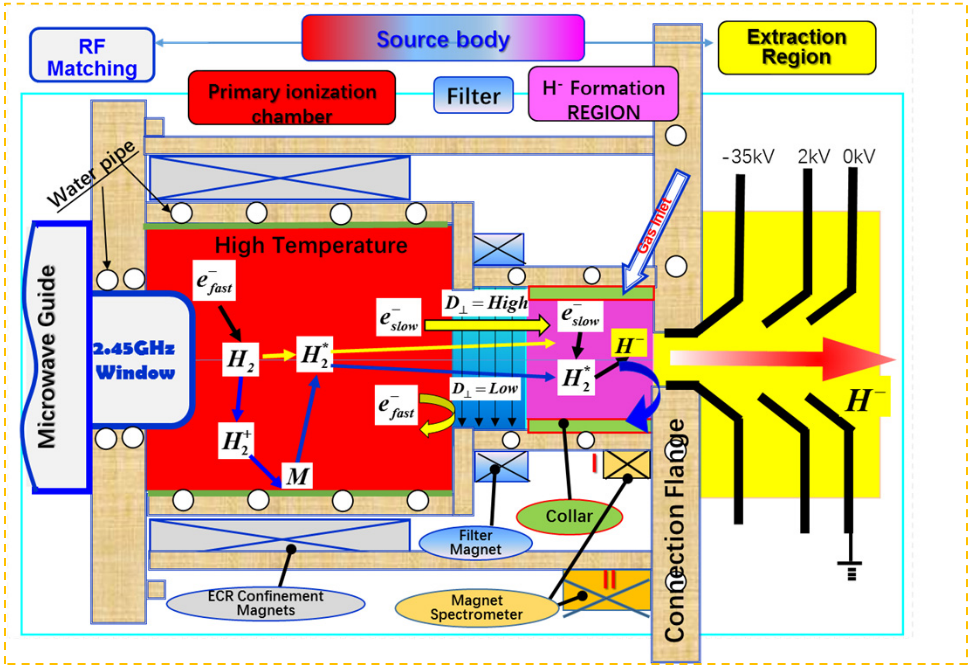
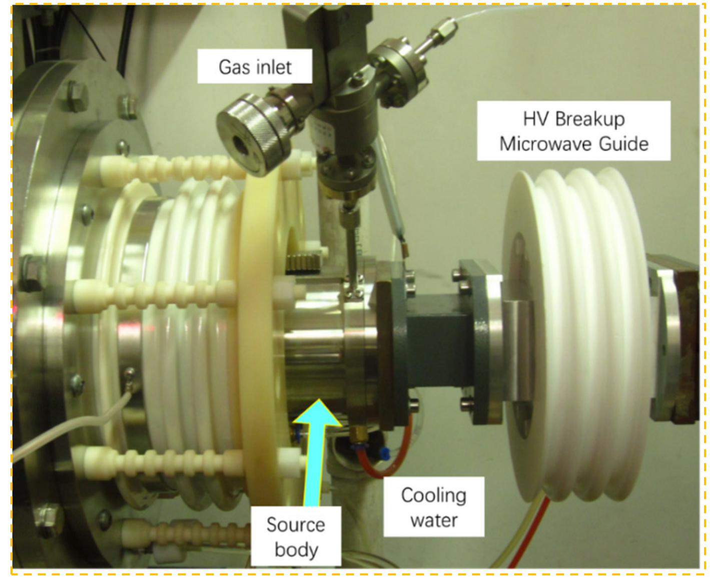
1. High Intensity Ion Source at PKU

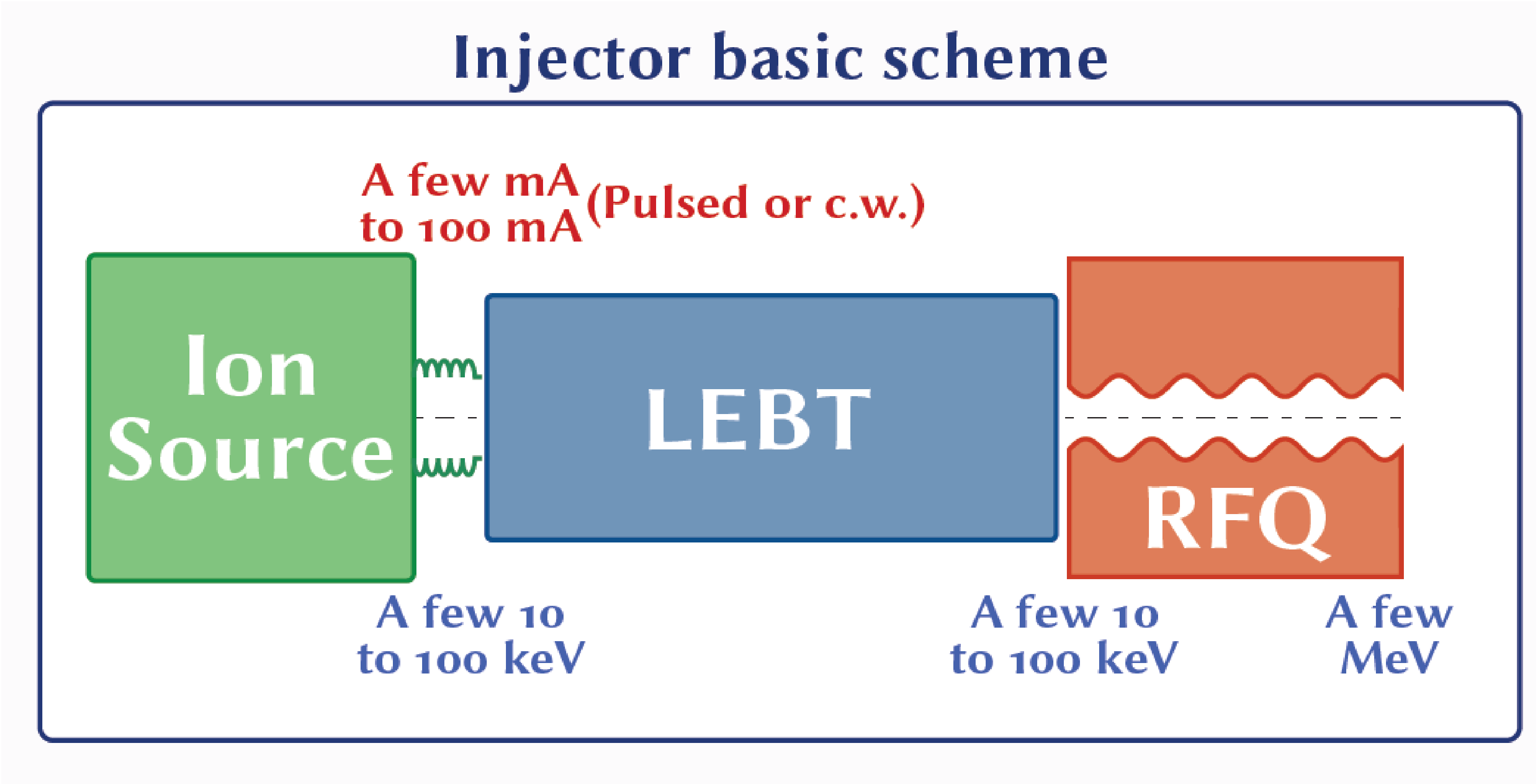
- 2.45 GHz Microwave Driven Cs-free H^- Source





Source Number		No.1	No.2	No.3	No.4
Water Cooling	RF Window	No	Yes	Yes	Yes
	Plasma Chamber	Poor	Yes	Yes	Yes
	Connection Flange	No	No	Yes	Yes
	Extraction	No	Poor	Yes	Yes
E-Dump Position		I	II	II	I
Current (mA)	CW	8	10.8	25	29
	Pulsed(100Hz/1ms)	16	20	35	45

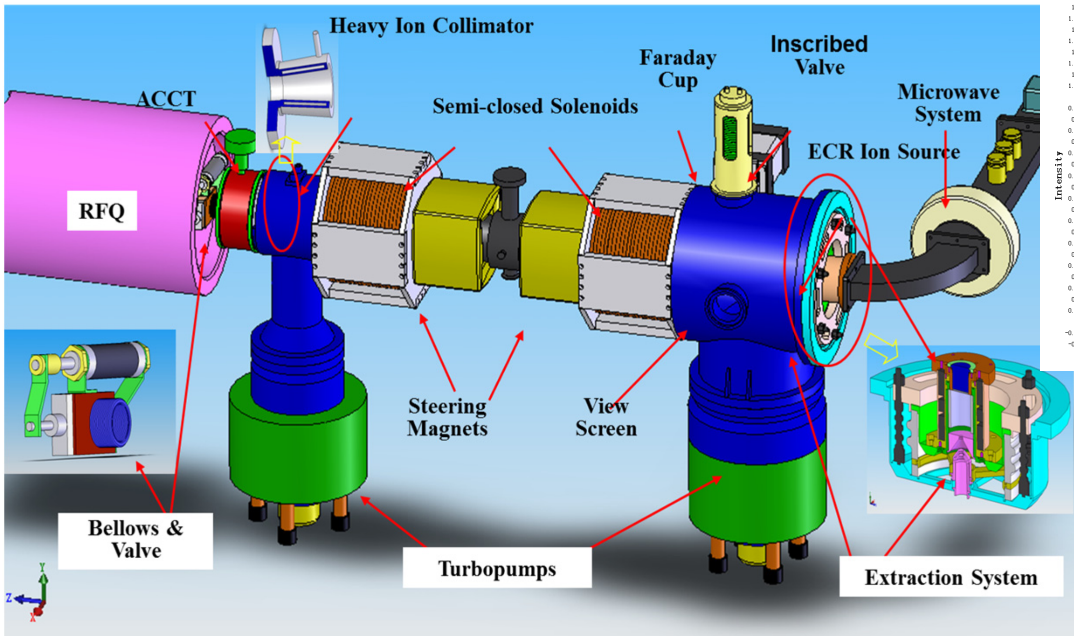
2. SCC Experiment Study

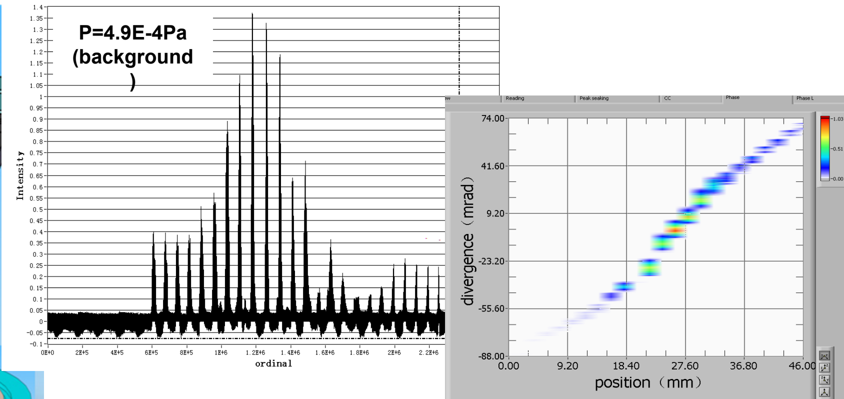


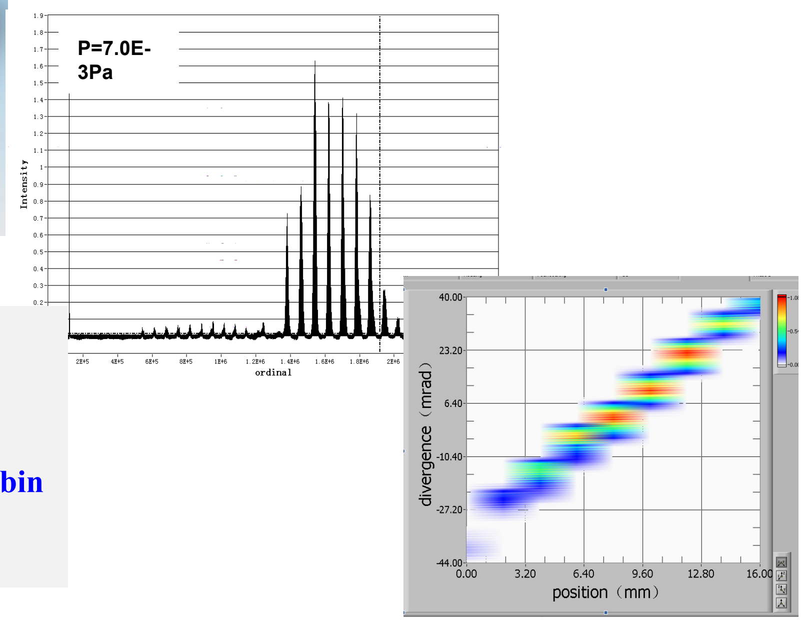
Chauvin N, Delferrière O, Duperrier R, et al. Source and Injector Design for Intense Light Ion Beams Including Space Charge Neutralisation[C]//Proc. of LINAC. 2010.

SCC on D⁺ injector for PKUNIFTY

- 70mA/50keV D^+ with 1ms/100Hz

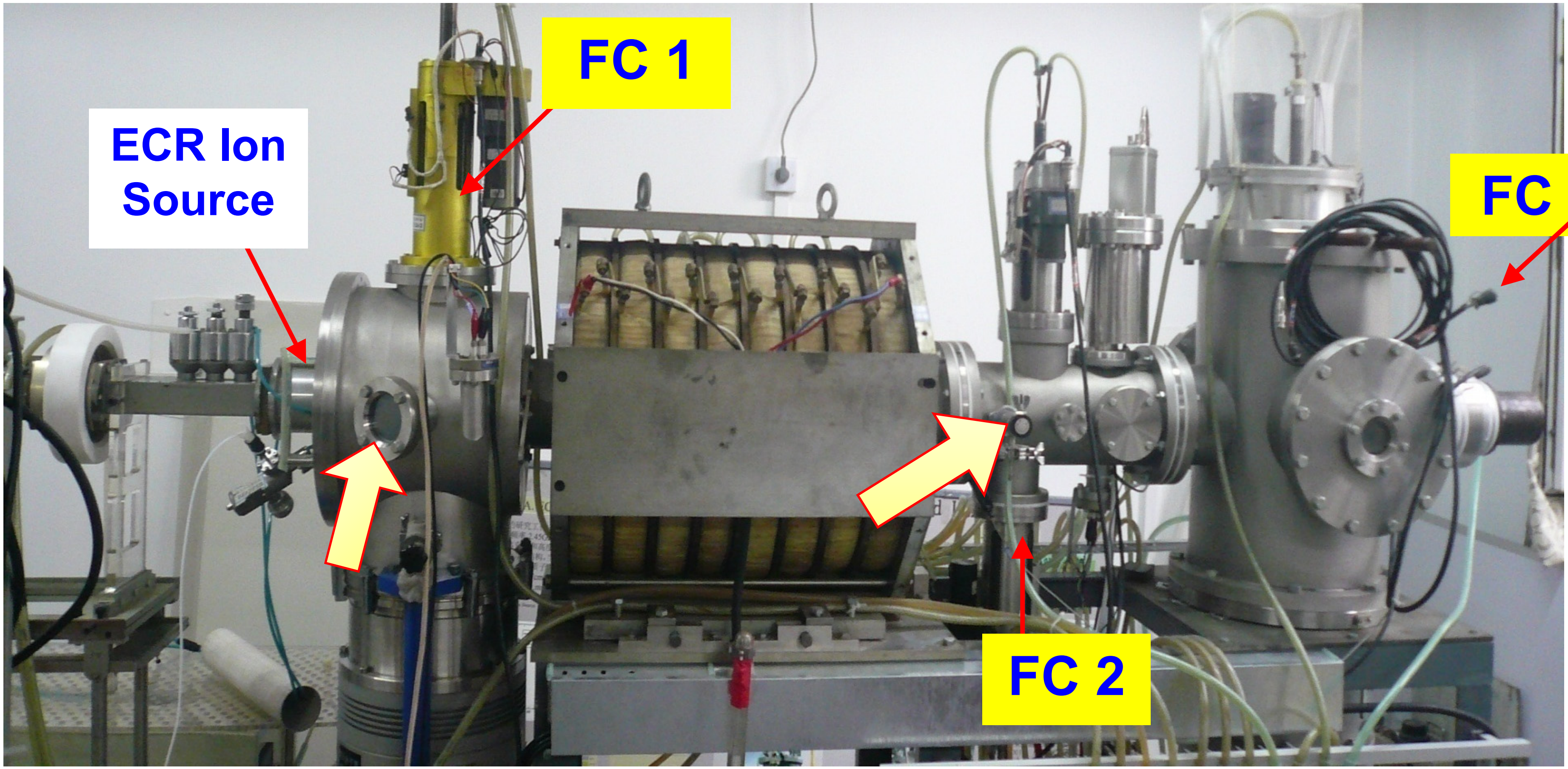






- **With/without 0.076/0.14 π.mm.mrad** **PKU**
- **With/without 0.11/0.33 π.mm.mrad.** **From R. Gobin /CEA** Rev. Sci. Instrum. **71**, 1413 (2000)

PKU LEBT Bench



S. X. Peng*, P. N. Lu, H. T. Ren, J. Zhao, J. Chen, Y. Xu, Z. Y. Guo, J. E. Chen, H. W. Zhao and L. T. Sun, Key Elements of Space Charge Compensation on a Low Energy High Intensity Beam Injector. *Rev. Sci. Instrum.* **84**, 033304 (2013)

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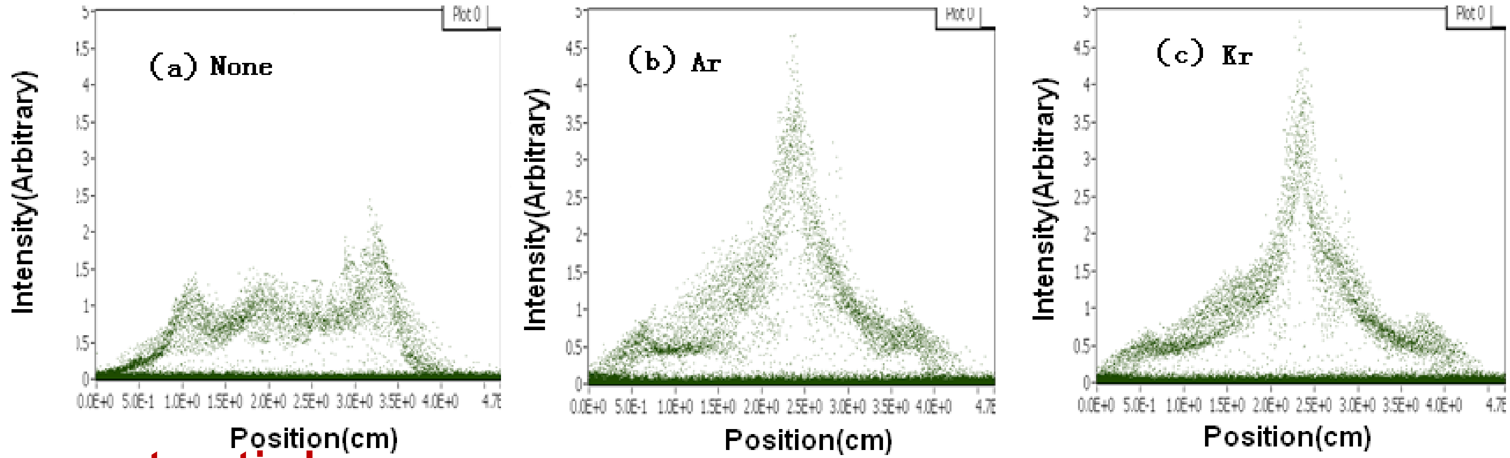
40mA@45keV H^+ Beam SCC

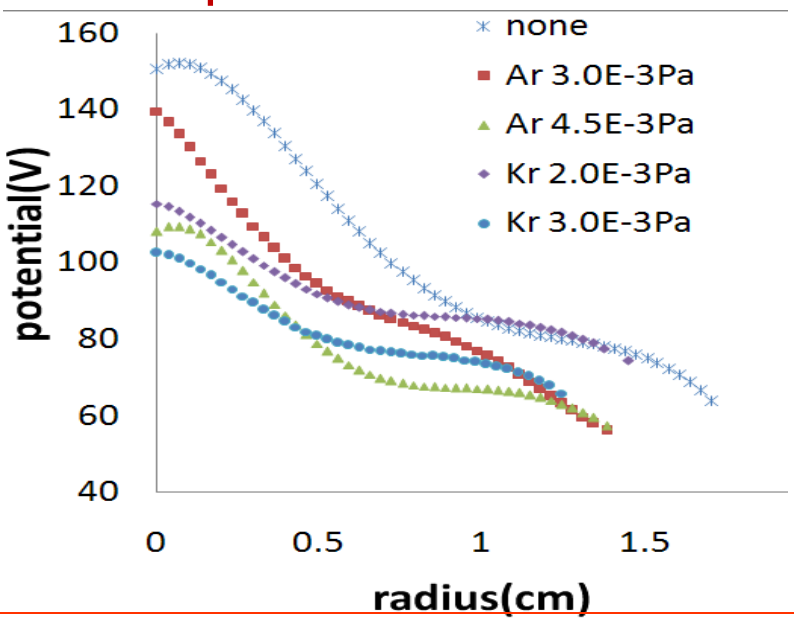
Beam distribution

2.9×10^{-3} Pa

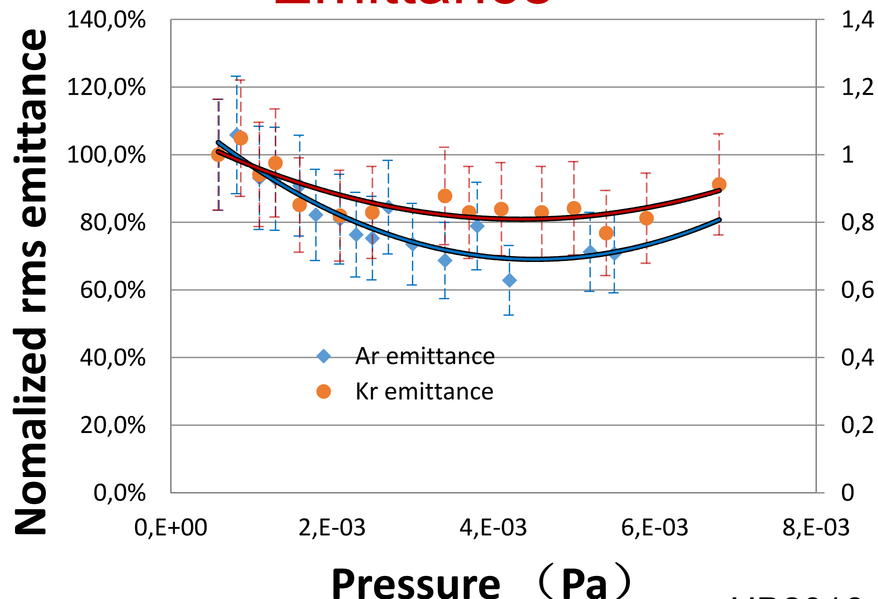
2.1×10^{-3} Pa



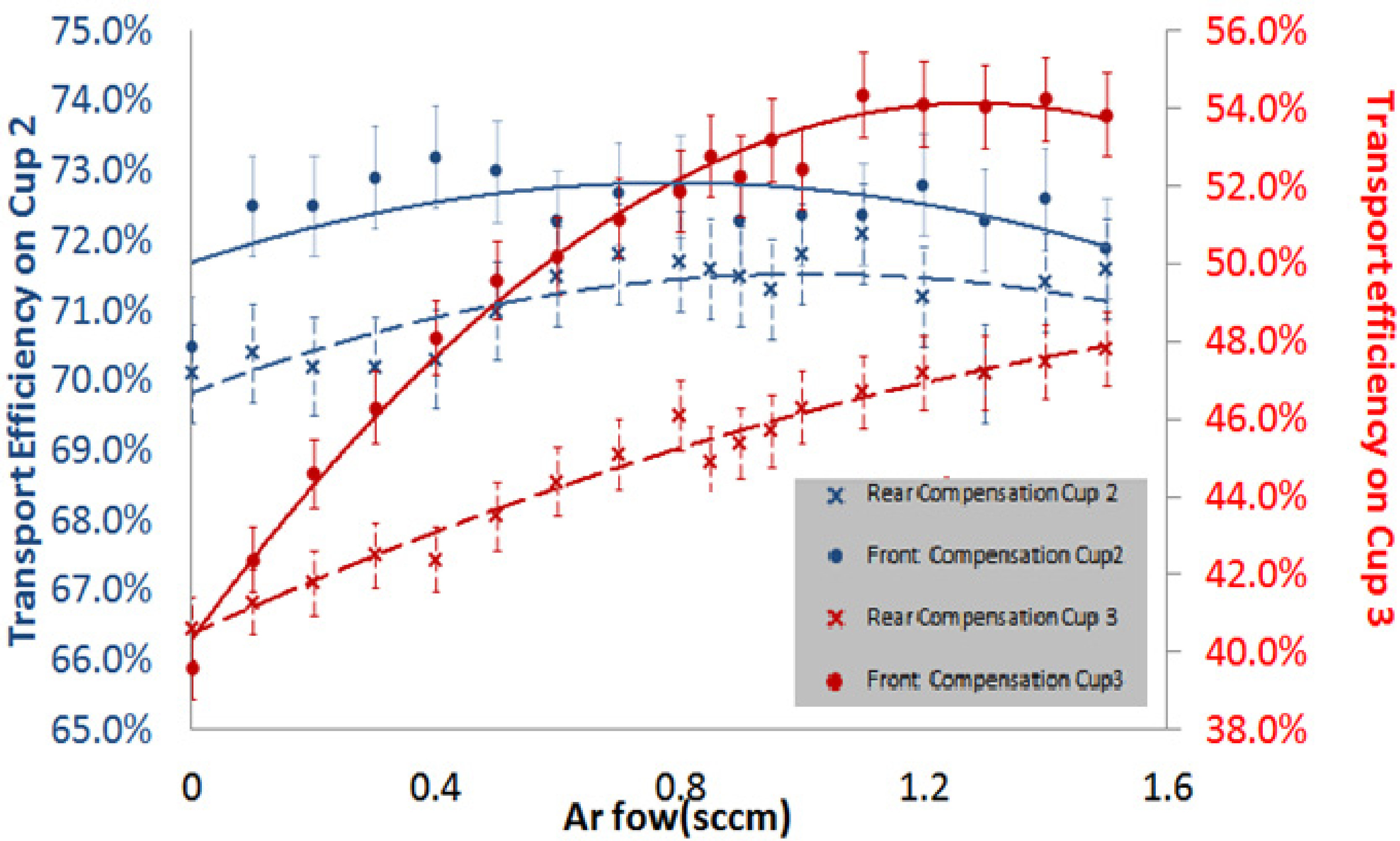
Beam potential



Emittance



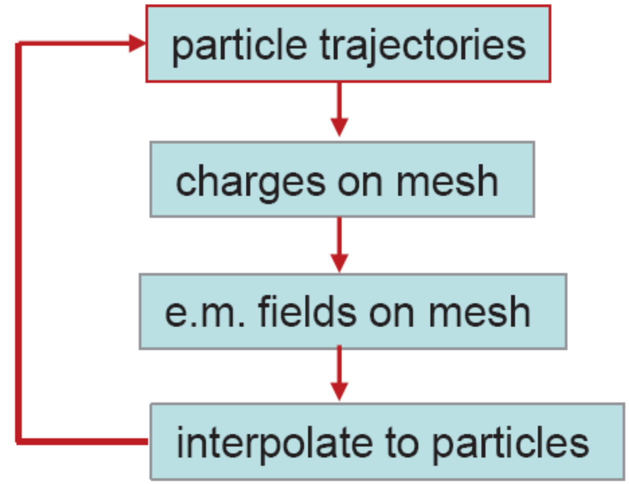
SCC of 40keV/10mA CW He^+ Beam



3. PIC – MCC Simulation

Particle-in-Cell (PIC) Development

- > 1960's developed for **fluid dynamics, plasma physics, magneto-hydrodynamics** (Buneman, Dawson, Hockney, Birdsall, Morse and others)
- > 1970's common in **fusion laboratories**
- **challenges have been short-wavelength fluctuations in density and e.m. fields - <u>scale lengths >> Debye screening length</u>**
- today largest PIC 10^{10} particles 10^{5} processors



PIC in Accelerators – 15-20 years delay

- > 1970's single particle dynamics
- binary Coulomb interaction starting
- ~1980 first PIC started in some labs
- in 1990's transition to PIC nearly everywhere
- **Challenges quite different from fluid or plasma PIC – bunch size: a < or ~ <u>Debye screening length ($\lambda_D/a \sim k/k_0$ for $k/k_0 \ll 1$)</u>**
- other methods disappearing or only for very special situations
  - binary interaction – crystalline beams (some linac codes like DYNAMION)
  - direct Vlasov solvers (1D or 2D)
  - ...
- Benchmarking challenge started late 1990's with SNS ...

PIC advantage:
→ calculation time ~ N logN instead of N^2 (for binary interactions)

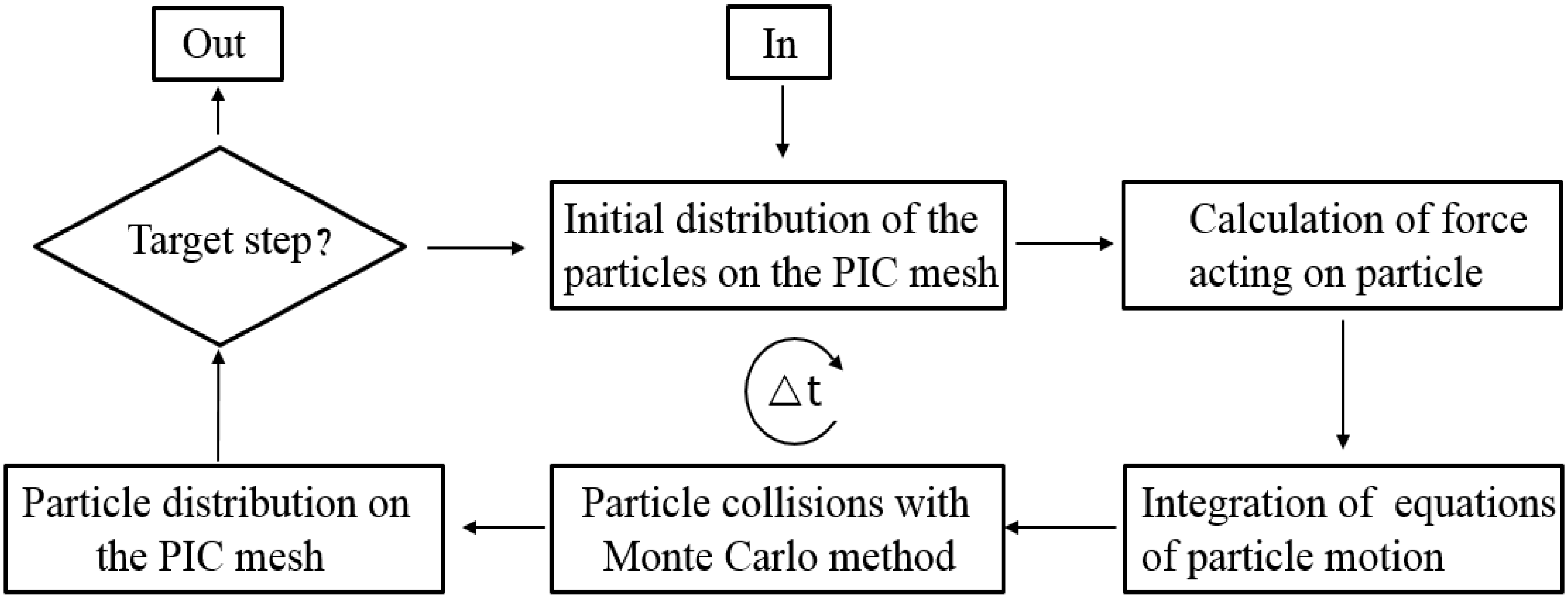
While deal with collisions
Monte Carlo method is needed

↓

PIC-MCC

Ingo Hofmann,HB2012,Beijing, September 17-21, 2012

PIC –MCC in Peking University



Flow diagram of the PIC-MCC model at PKU

ZHANG AiLin, PENG ShiXiang, etc., CPAC'14，Huazhong University of Science and Technology

2D PIC –MCC done with MATLAB

Beam： H^+ beam

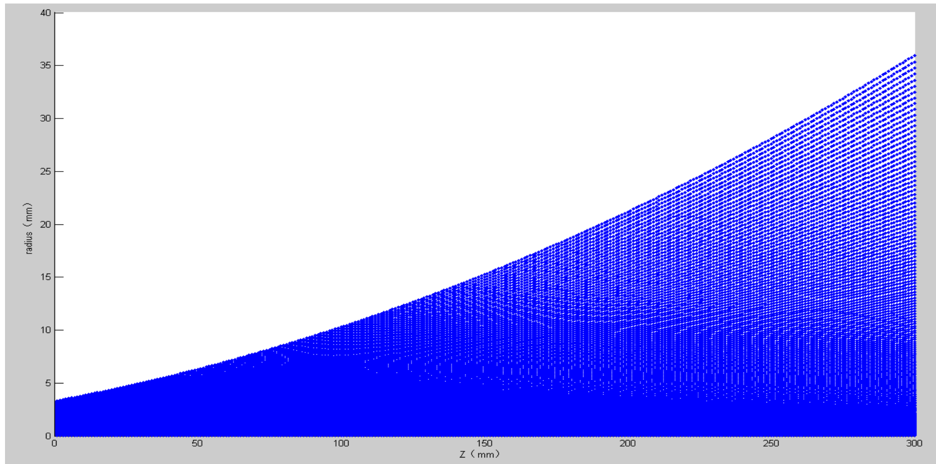
Initial radius： 3 mm

Energy： 40 keV

Current： 30 mA

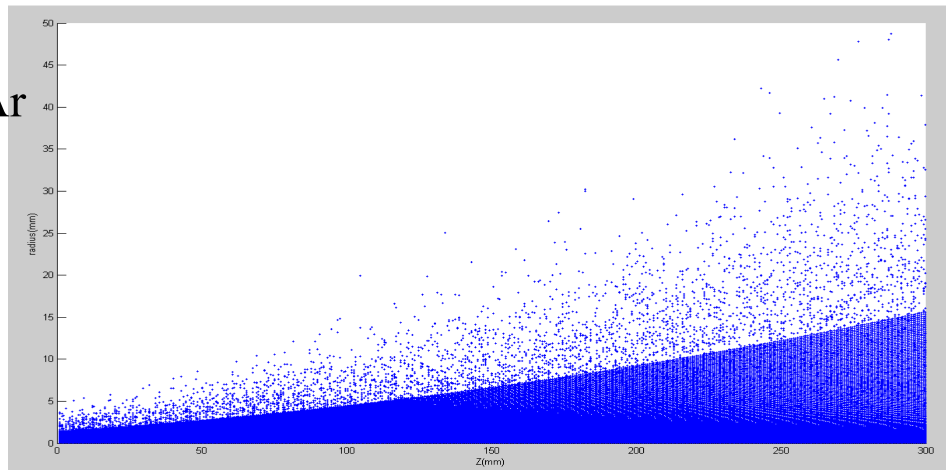
Distance： 300 mm

Compensation gas： Ar



Space charge without gas compensation

No scattering！



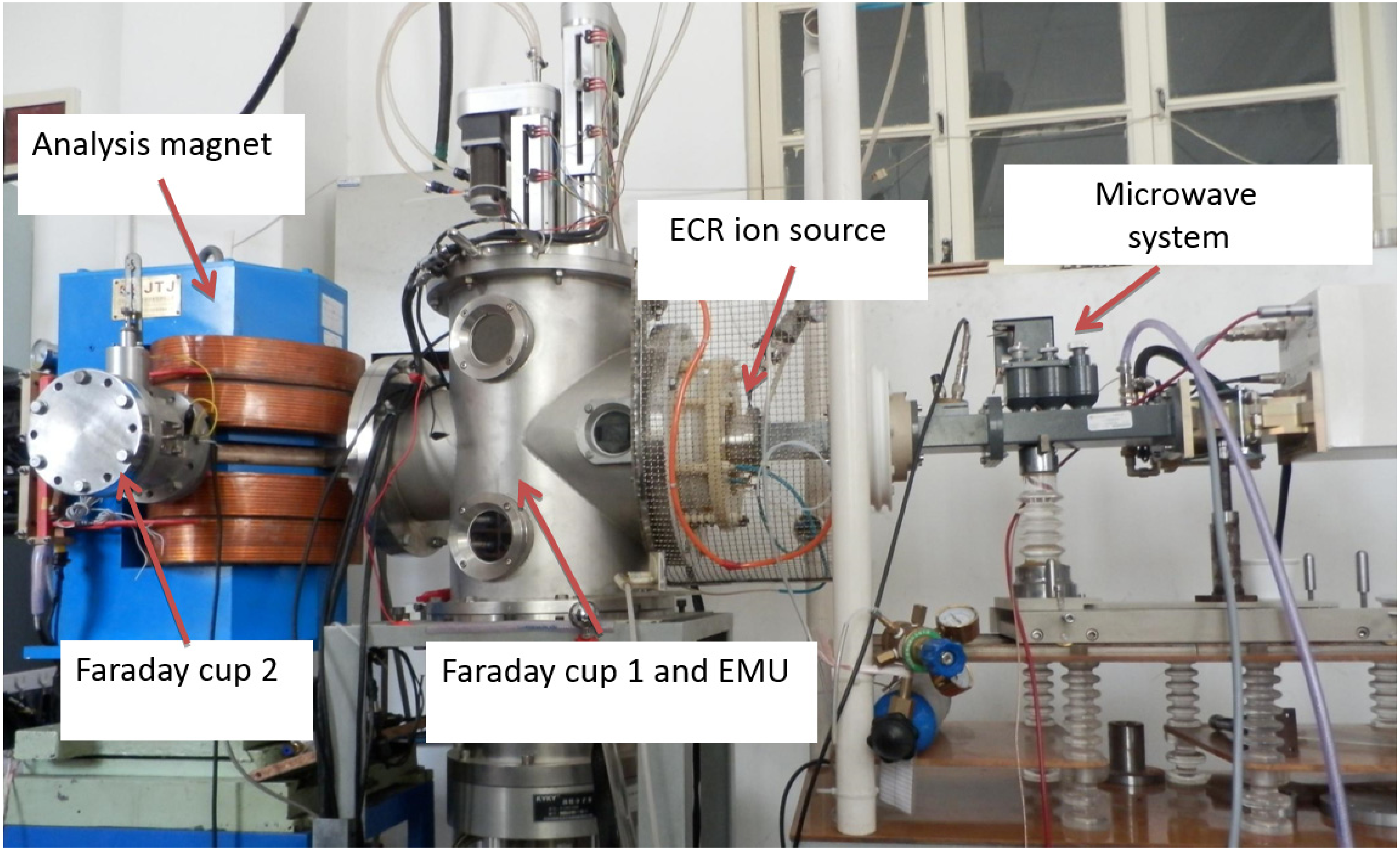
Space charge with 0.05 sccm Ar gas compensation

Strong scattering！

ZHANG AiLin, PENG ShiXiang, etc.,. CPAC’14，Huazhong University of Science and Technology

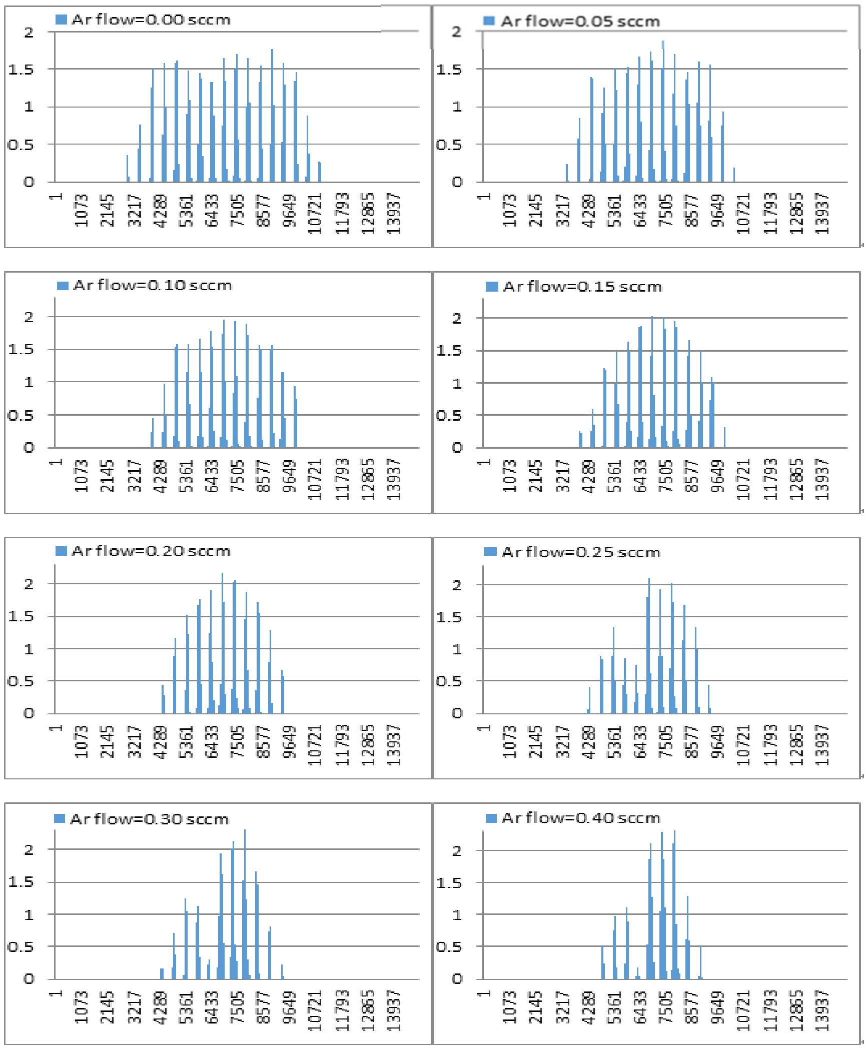
PKU ion source test bench

PKU ion source test bench

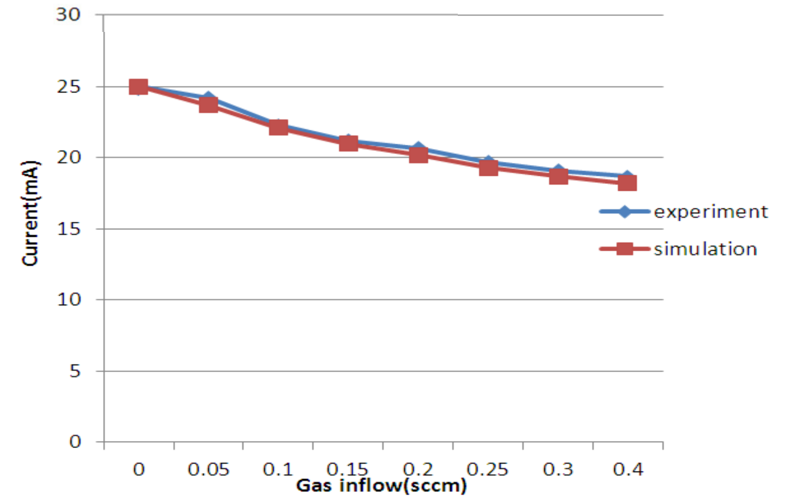


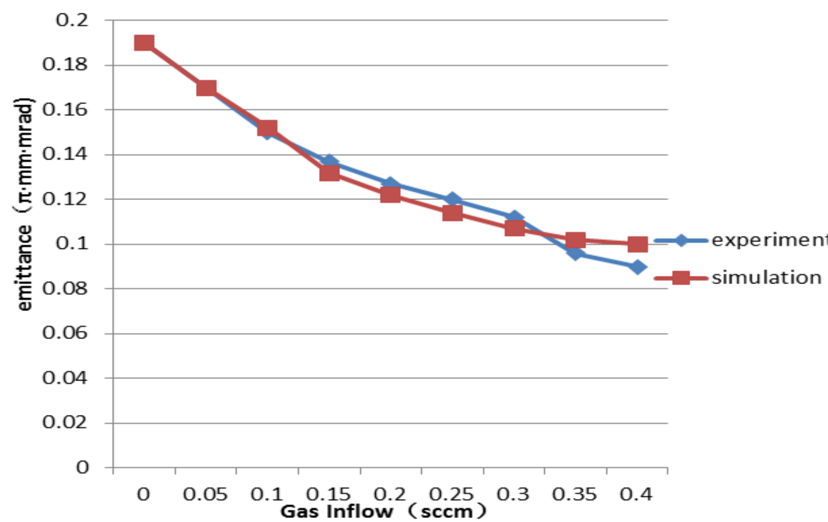
Ren H T, Peng S X, Xu Y, et al. Milliampere He2+ beam generator using a compact GHz ECRIS [J]. Science China Physics, Mechanics and Astronomy, 2013, 56(10): 2016-2018.

Ar SCC results of H^+ beam



H^+ beam compensate with different Ar gas inflow





Simulation and experiment comparison

Simulation for H^- beam

Processes in H^- beam compensated with He and Ar are:

$$H^- + He \rightarrow H^- + He^* \quad (1)$$
$$H^- + He \rightarrow H^- + He^+ + e \quad (2)$$
$$H^- + He \rightarrow H^+ + He^+ + 3e \quad (3)$$
$$H^- + He \rightarrow H^+ + He + 2e \quad (4)$$
$$H^- + He^+ \rightarrow H^+ + He^+ + 2e \quad (5)$$
$$H^- + H_2 \rightarrow H^- + H_2^* \quad (6)$$
$$H^- + H_2 \rightarrow H^- + H_2^+ + e \quad (7)$$
$$H^- + e \rightarrow H^+ + 3e \quad (8)$$

- The main computing framework of the simulations was improved to a 3D MATLAB PIC code.
- Collisions (1), (4), (6) are handled via the null-collision method.
- Cross sections for electron ionizations are calculated from the Binary-Encounter-Bethe mode.
- The residual gas H_2 is assumed as an ideal gas at constant temperature and pressure.

Zhang AiLin, Peng S X, Ren H T, et al. Study on space charge compensation in negative hydrogen ion beam [J]. Review of Scientific Instruments, 2016, 87(2): 02B915

Simulation for H^- beam

Beam： H^- beam

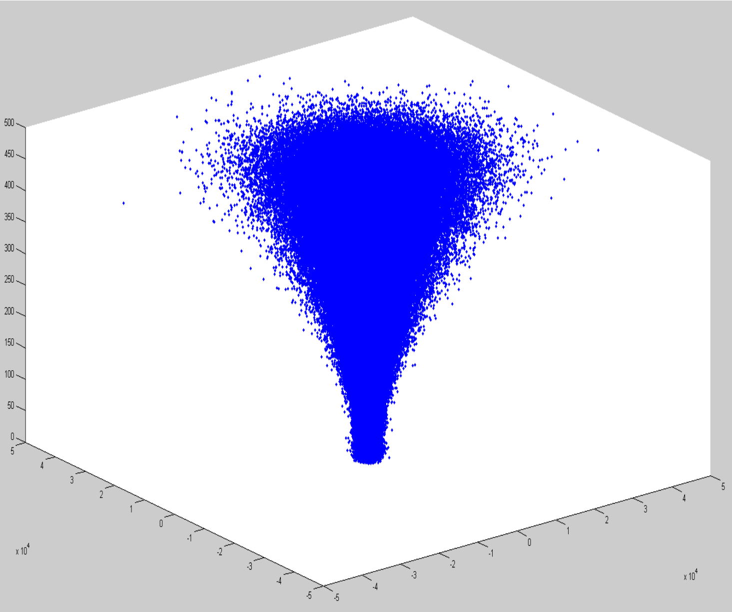
Initial radius： 3mm

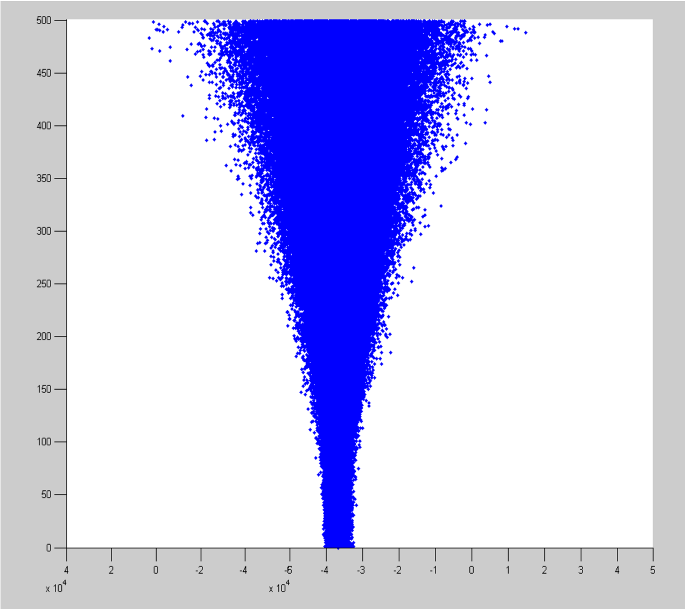
Energy： 35 keV

Current： 17 mA

Distance： 300 mm

Compensation gas： He





(x, y label represent the PIC meshgrid, z is the time step).

10^9 Particles!

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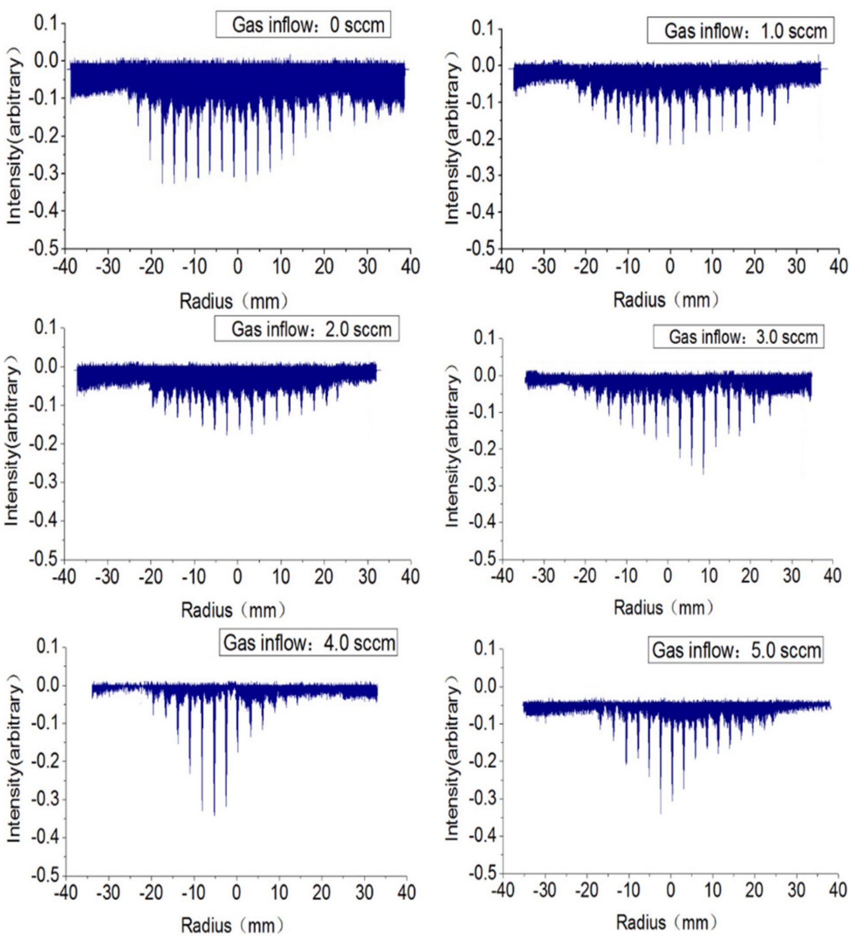
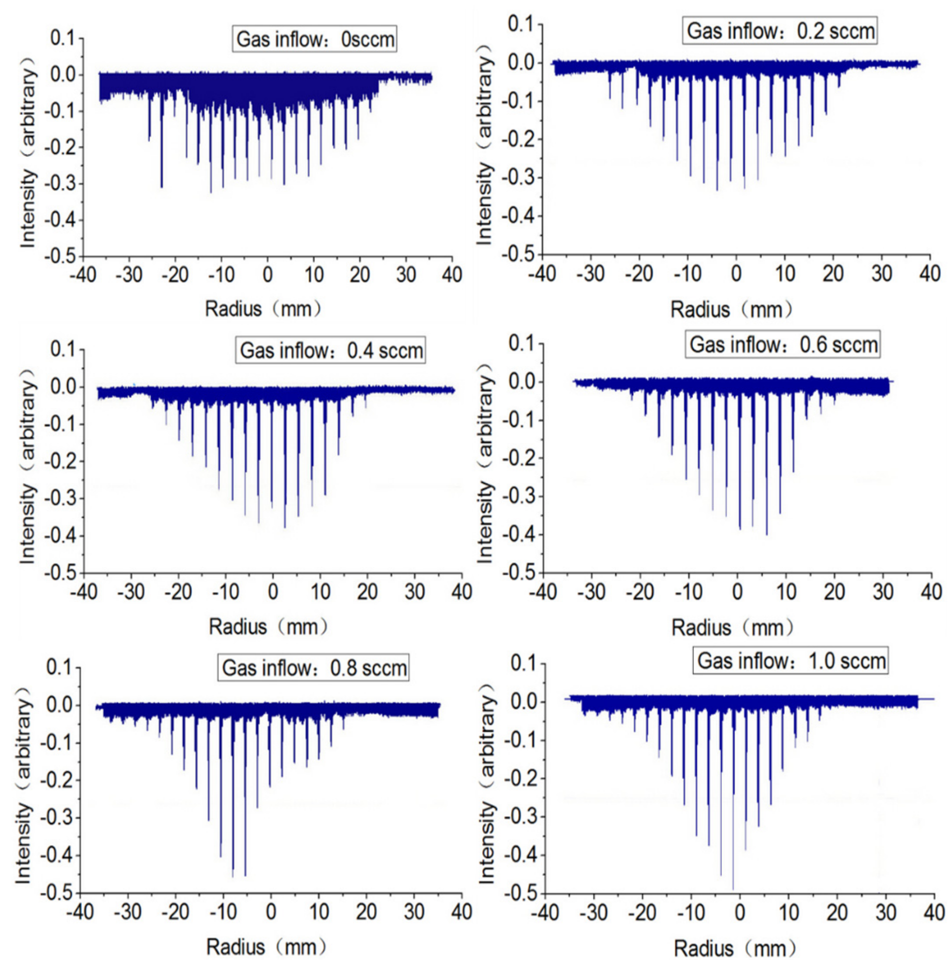
Experimental results of H^- beam



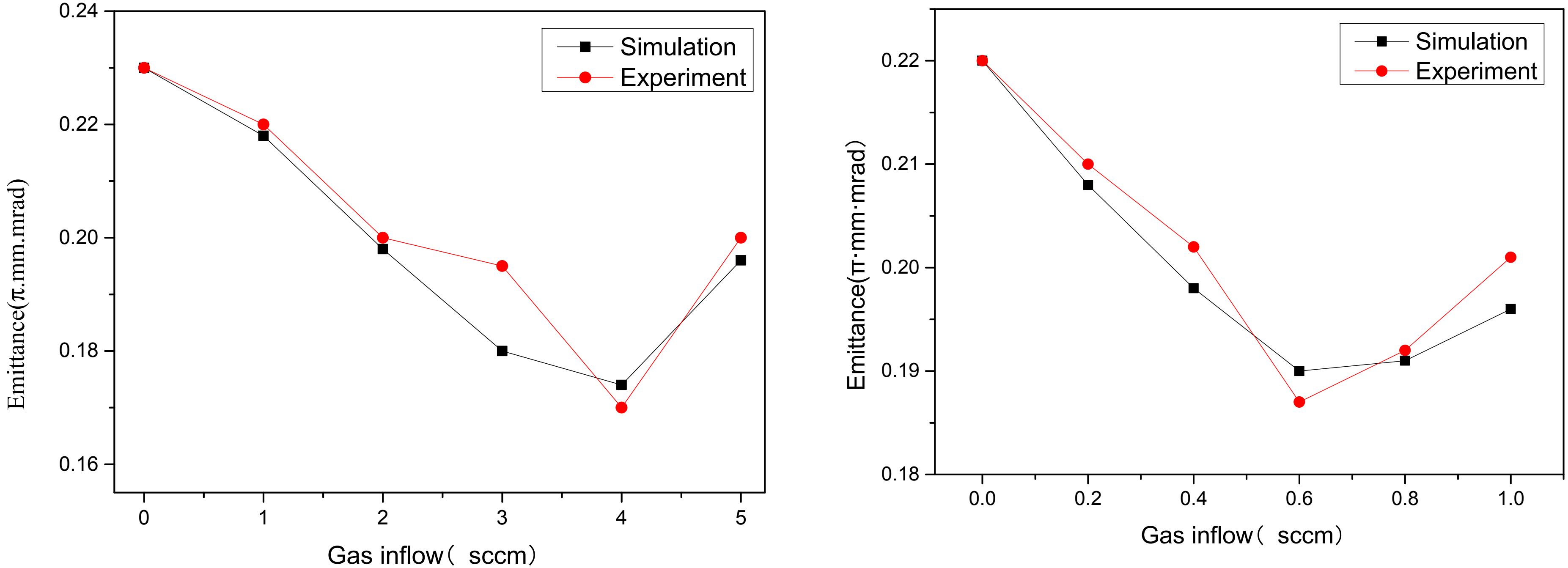
H^- beam compensate with different **He** gas inflow



H^- beam compensate with different **Ar** gas inflow

Zhang AiLin, Peng S X, Ren H T, et al. Study on space charge compensation in negative hydrogen ion beam [J]. Review of Scientific Instruments, 2016, 87(2): 02B915

Comparison results of H^- beam



- The first point of the experiment result is used to rectify the proportions of the processes;
- The minimum emittance is the location where it is believed the space charge compensation is optimum. For He 4 sccm, while for Ar is 0.6 sccm.

4. Conclusion

- High Intensity Ion Beams have been generated with PKU PMECR ion sources. Some of them have been used on several facilities.

- To better understood the SCC processes, a PIC-MCC simulations code done with MATLAB have been developed. Simulation results are agree well with the experiment ones for both H^+ beam and H^- beam . It will help us to find a best compensation circumstance easily.

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Thank you for your attention!
感谢您的聆听！