HEDP and HIF research at IMP-Lanzhou

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Cooperated with

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Outline

- Brief introduction to IMP
- Current activities in plasma physics research at IMP
- HIF/HED research plan at HIAF-IMP
- Concluding remarks

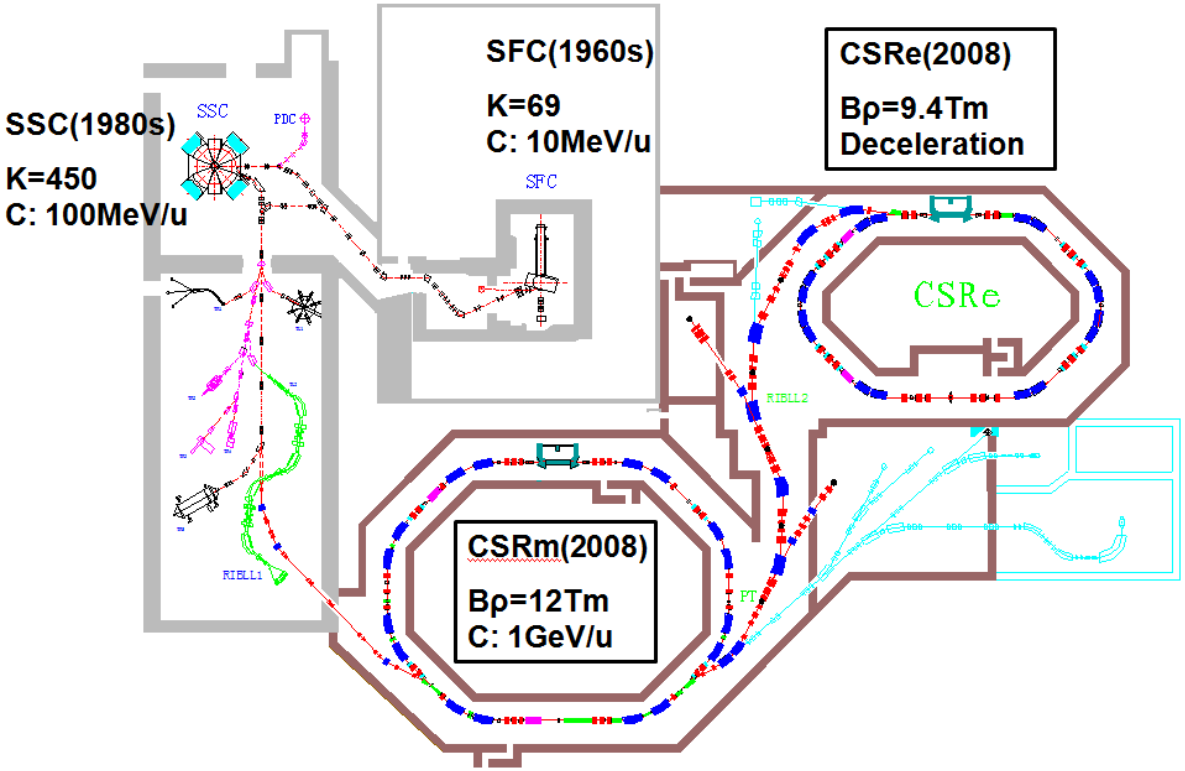
Fusion Energy Research in China

Comparing to LIF and MCF, HIF is at the starting stage!

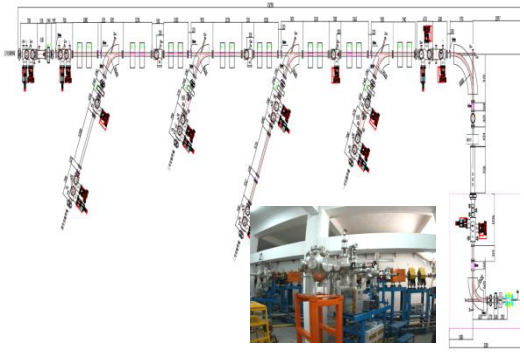
Main Facilities

➢Institute of Modern Physics (IMP,CAS), was founded in 1957. As one of the four national laboratory, the National Laboratory for the Heavy Ion Research Facility in Lanzhou (NL-HIRFL) was established at the IMP in 1991.

- Basic research in heavy ion physics
- Related interdisciplinary science
- Accelerator physics and technology
- Applications of nuclear technology

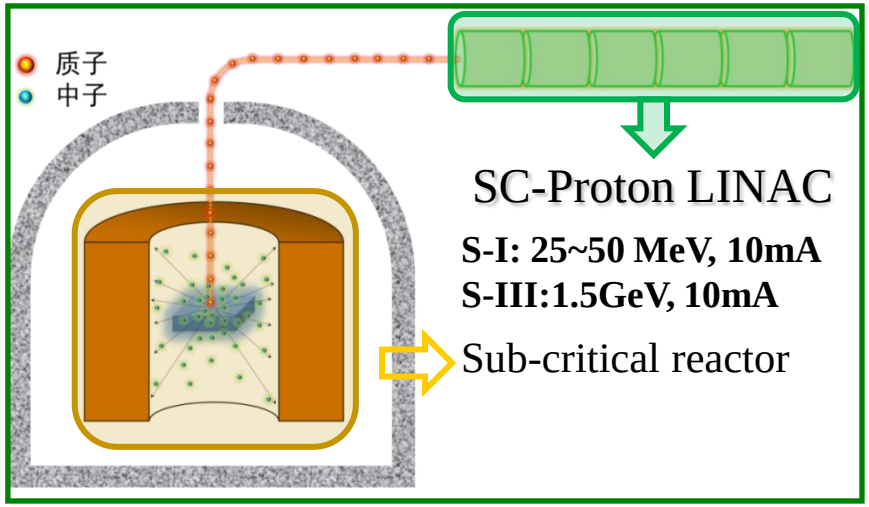


Layout of the main facilities at HIRFL

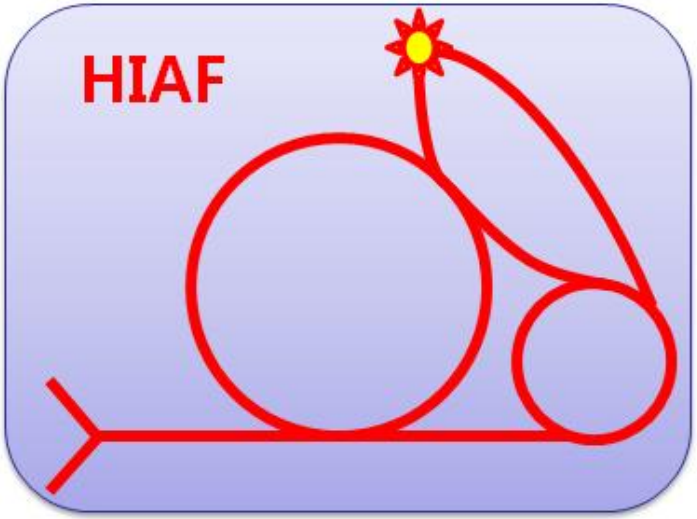


SC-ECR and 320kV ECR Platform

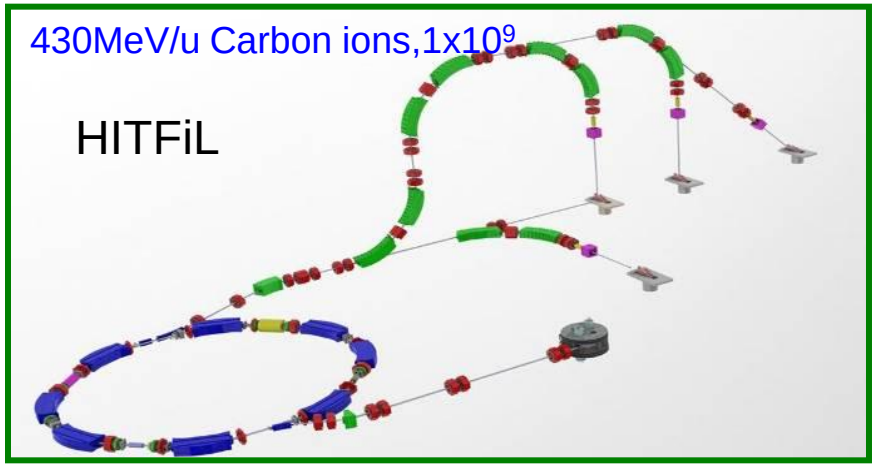
Future Facilities



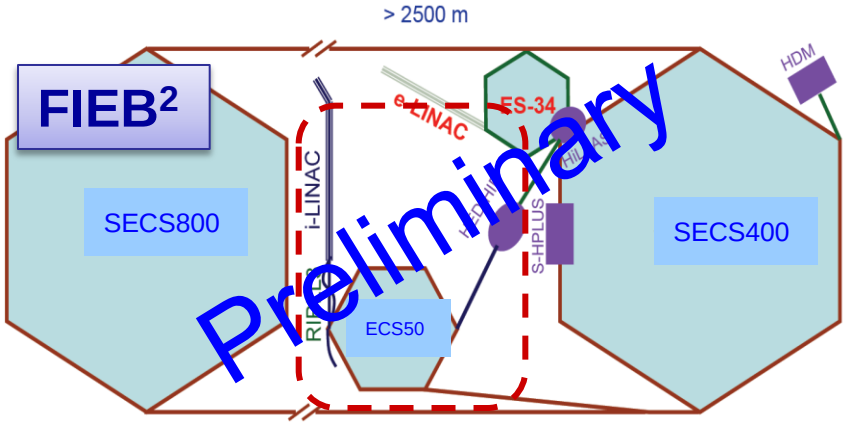
ADS Project 2011-2032
Budget approved: 1.78B RMB, 2011-2015



High Intensity heavy-ion Acc. Facility
Budget Proposed: 1.98B RMB, (2013-2017)



Heavy Ion Therapy Facility in Lanzhou
Budget approved: 0.5B RMB, 2011-2013



Facility of Ion, Electron, and Beta Beams
Budget poposed:14.7B RMB,2020-2035

Organization

Board of directors

Basic Research Division

- Exp. Phys. Center
- Material Center
- Nucl. Instr. Center
- Rad. Bio-Phys. Lab
- Medical Phys. Lab
- Rad. medicine Lab
- Space Rad-bio. Lab
- Rad. Pharm. Center
- Nucl. Theory Dept.

Accelerator Division

- Acc. Physics Lab
- RF Lab
- Vacuum Lab
- Ion Source Lab
- Magnet Lab
- Power Supply Lab
- Rad. Safety Lab
- IT/Electronics lab
- e-Acc. Center
- Tech. Support Lab

ADS Project Division

- LINAC Center
- Spall. Target Lab
- Reactor Lab
- Nucl. Data Center
- Rio. Chemistry Lab
- Project Office

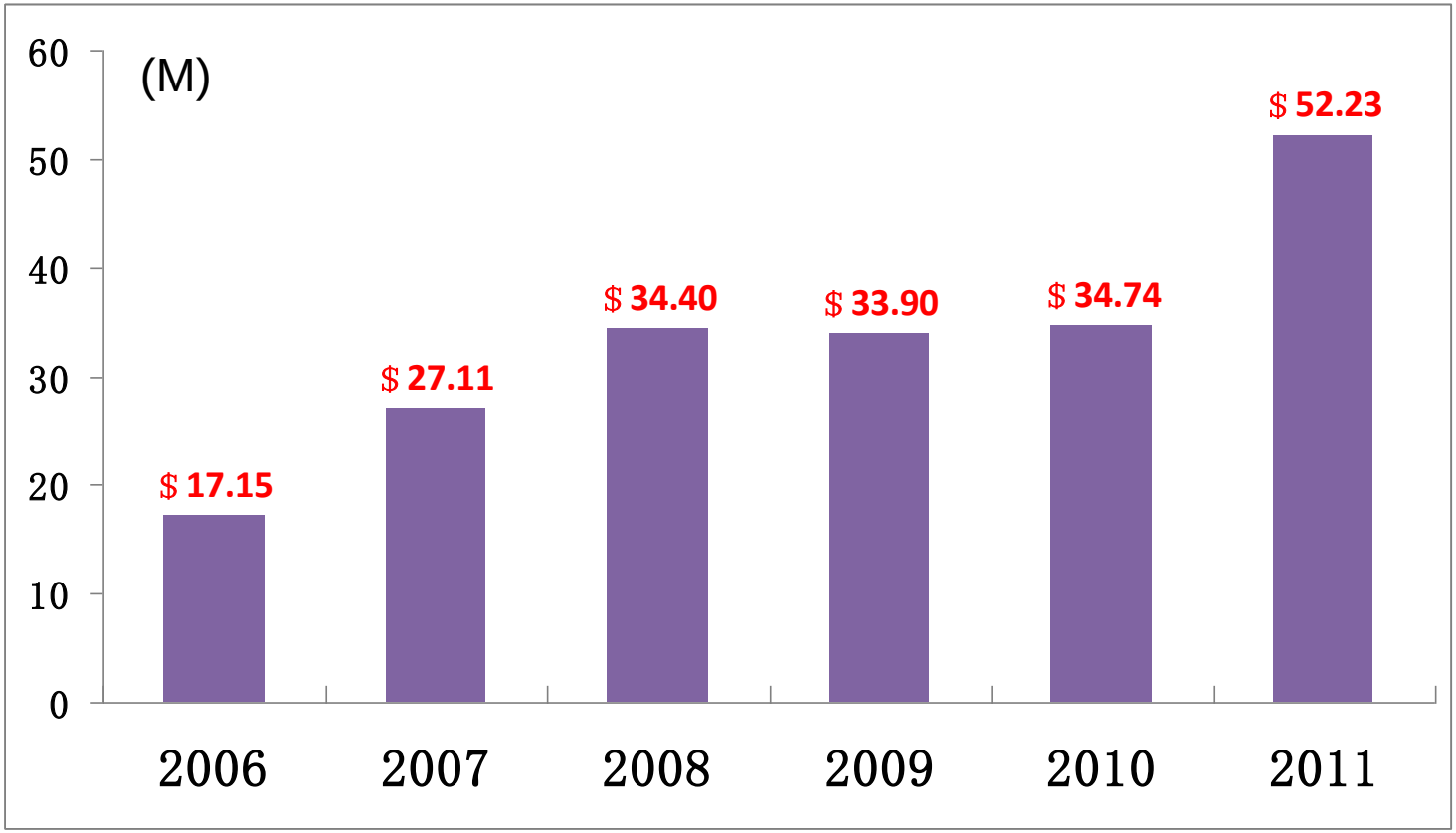
Administration Division

- Sci. and Tech. Dept.
- S-owned Assets Dept.
- Personal Res. Dept.
- Inter. Coop. Dept.
- Supervision Dept.
- Security Dept.
- Administrative Dept.
- Retired Service Dept.
- HI Therapy Dept.
- Marketing Dept.

Manpower & Budget

Total manpower now: 733 (+211) permanent staffs
+ 20 Post-docs
+ 150 temporary
+ 240 graduate students

Budget in 2012: ~70M$ (expected)



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- Current efforts in plasma physics research at IMP
- HIF/HED research plan at HIAF-IMP
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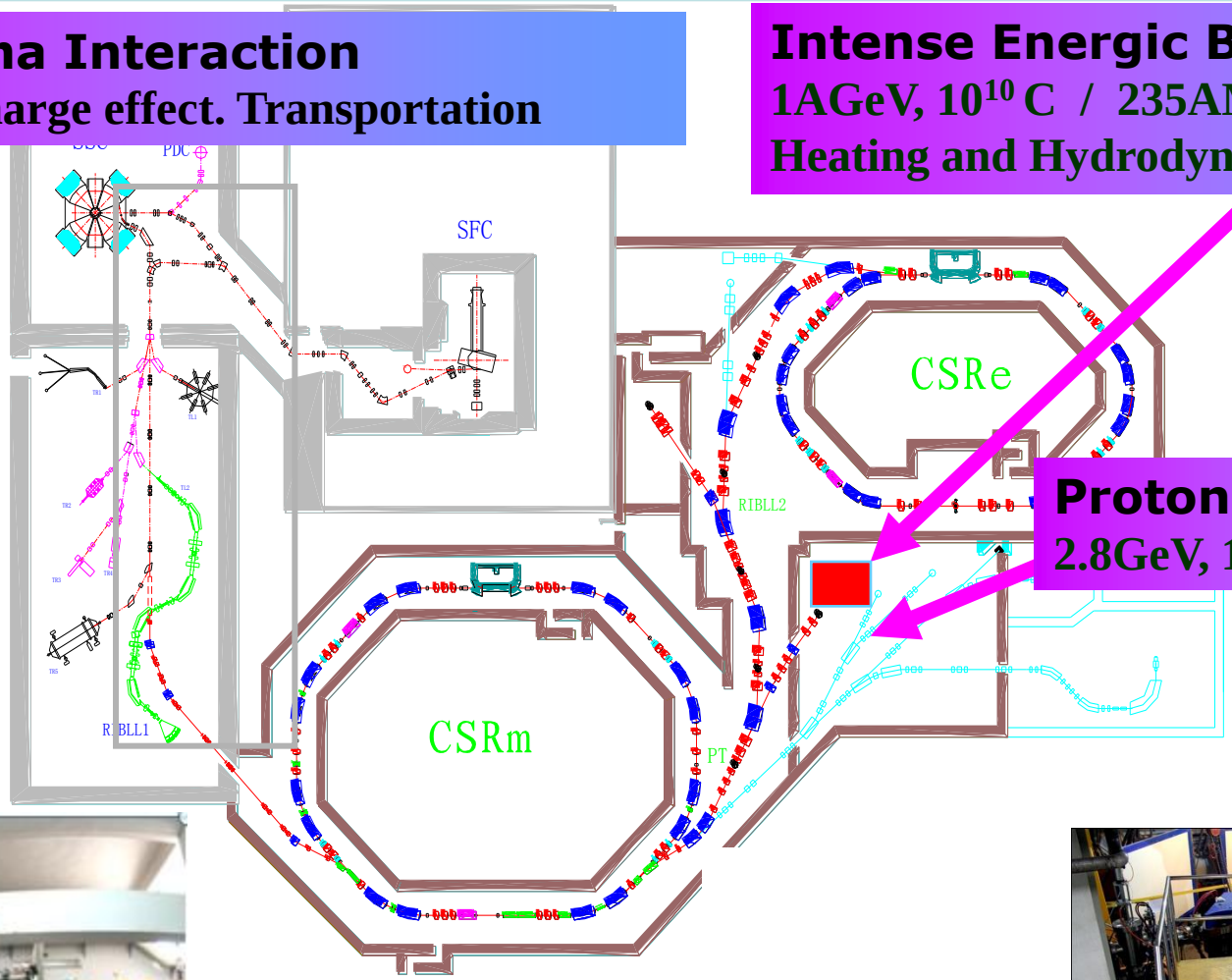
Current activities in plasma physics

- **Highly charged ion Physics(Atomic Pr. in Plasma)**
  - **Intense energy deposition**: Nano-etching effects, etc.
  - **Inner shell processes during collisions**: X ray emission
- **Beam plasma interaction**
  - **Energy loss and the charge effects**
  - **Transportation**: plasma lens and plasma stripper
- **High Energy Density(HED) matter generated by intense heavy ion beam**
  - **Heavy ion/proton radiography and other diagnostics**
  - Beam compressing, focusing and precisely controlling
  - Theories and simulations…

Experimental Platforms for PP experiments

HIB Plasma Interaction
Stopping. Charge effect. Transportation

Intense Energic Beam Heating
1AGeV, 10^{10} C / 235AMeV, 10^{8} Xe
Heating and Hydrodynamics



Proton Radiography
2.8GeV, 10^{12} ppp

HCI-Matter interaction
Spectroscopy and Charge effect

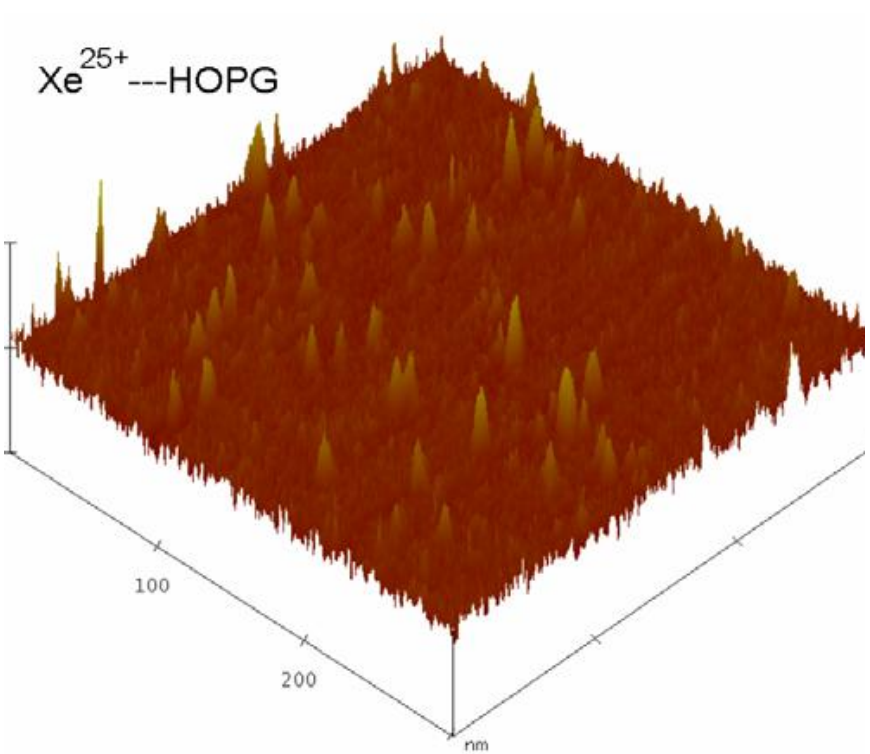
300*q keV, A^{q+}, 10^{9-12}pps

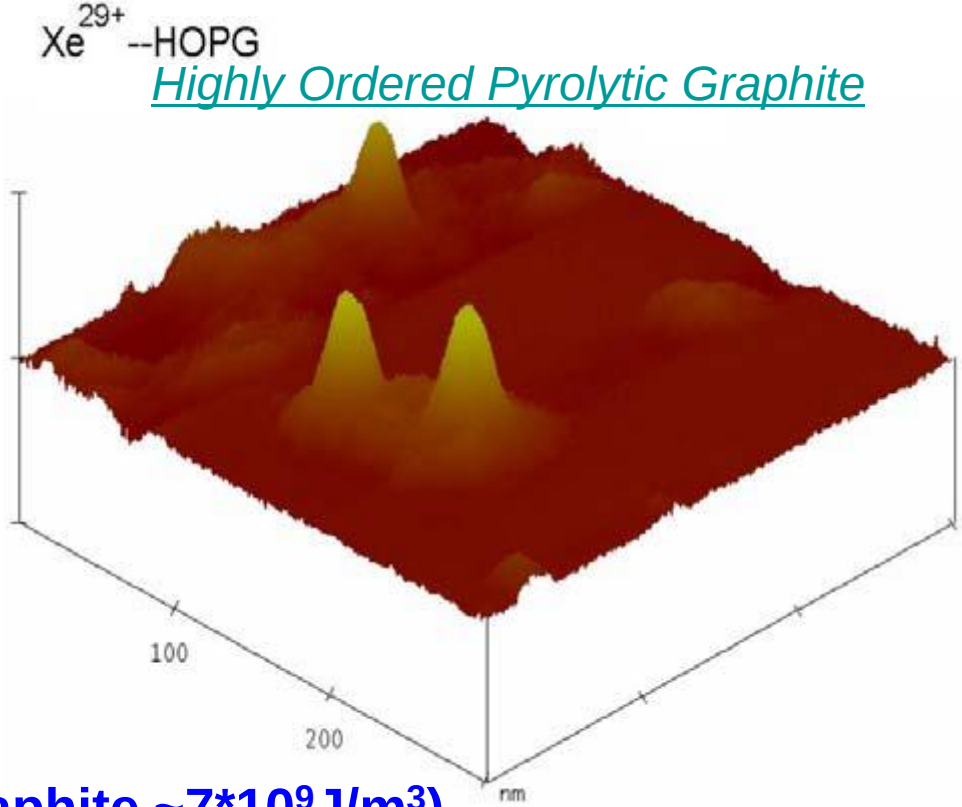
25*q keV, Ar^{18+} / Xe^{45+}

HCI: Intense energy dep.

Fast(fs) and enhensed energy diposition by HCI

---a potential way to produce HED in a small volume(nm)



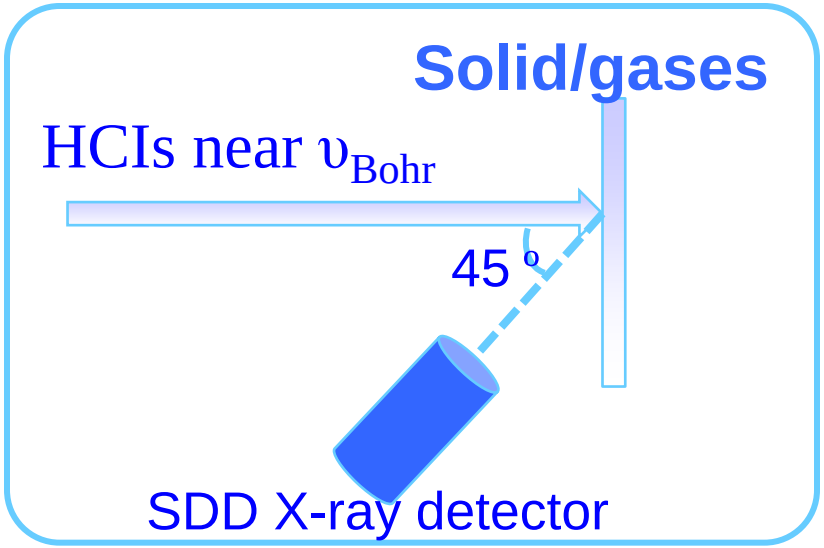


Highly Ordered Pyrolytic Graphite

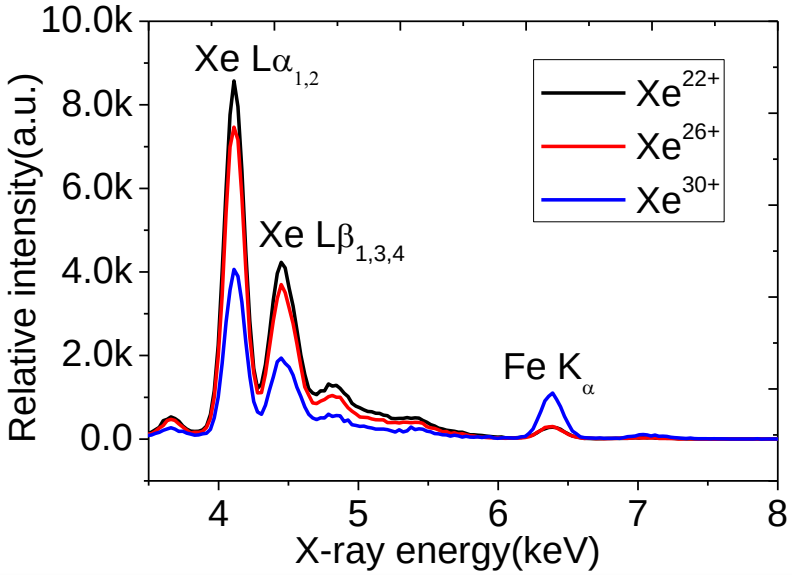
(Melting point of Graphite ~$7*10^9 J/m^3$)

- ***Xe^{29+} --- 10keV potential energy --- in $70nm^3$ --- $2*10^{10} J/m^3$***
- ***Xe^{54+} ---200keV potential energy --- in $100nm^3$ --- $>10^{11} J/m^3$ ---HED!***

HCI: Inner shell processes



Experimental Scheme



Vacacy Sharing due to level matching

For collisions near υ_{Bohr} =2.19*10^{6}m/s,

- Significant interaction length ~100A;
- Proper initial energy to approach T. atoms;
- Enough time to form a quasi-molecular ~fs;

The initial charge effects on the inner shell processes will be significant, especially inner shell electron transferring!

Transfer ratio, from Xe L to Fe K

$$P = \frac{\exp(2\lambda(1+\cos\theta)) - 1}{\exp(4\lambda) - 1}$$

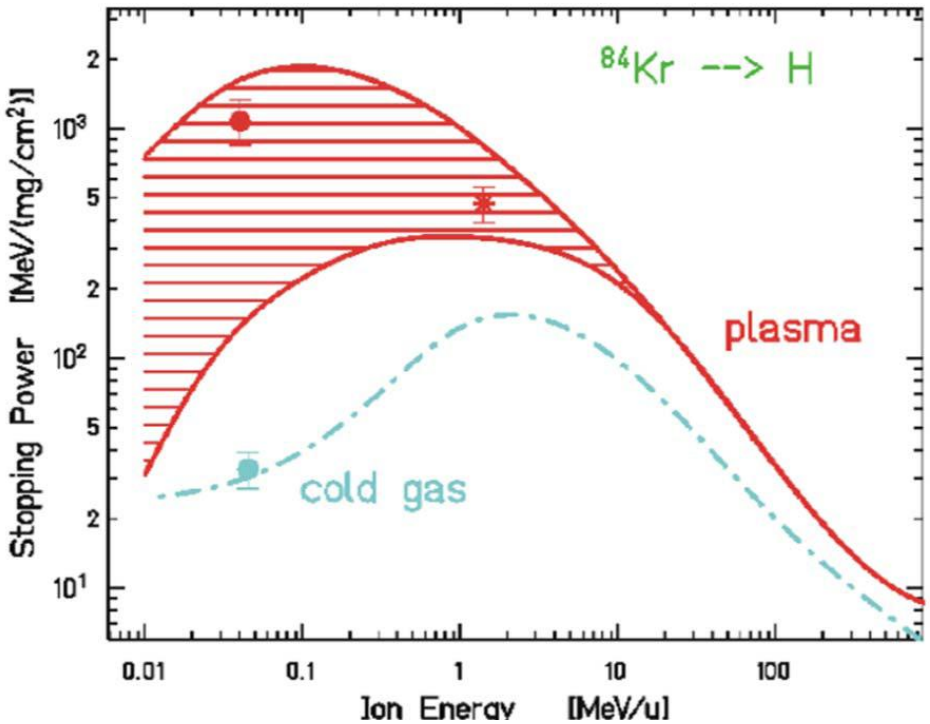
where

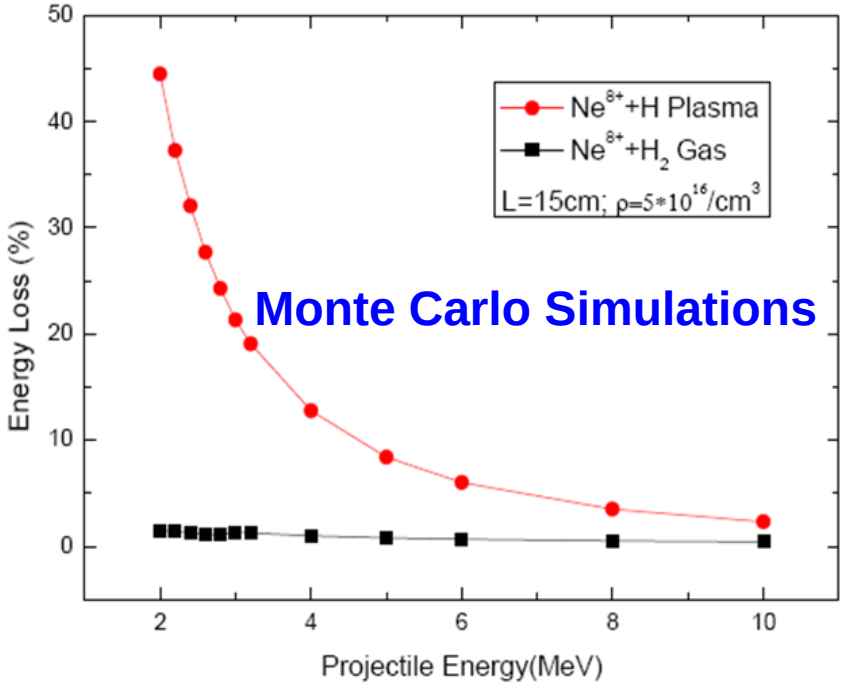
$$2\lambda = \frac{\pi\left|\sqrt{I_H} - \sqrt{I_L}\right|}{\left(\frac{1}{2} * m_e * v_p^2\right)^{1/2}},$$

Ion beam plasma interaction

Energy deposition of slow heavy ion in plasma

$$-\frac{dE}{dx}=\frac{4\pi e^4 Z_{eff}^{\ 2}}{m_e v_p^{\ 2}}\left[\sum_k G(\frac{v_p}{v_k})n_{bek}\ \ln\left(\frac{2m_e v_p^{\ 2}}{I_k}\right)+G(\frac{v_p}{v_{th}})n_{fe}\ \ln\left(\frac{2m_e v_p^{\ 2}}{\hbar\omega_P}\right)\right]$$





Limited points at low energy (J.J. et.al)

E.L. v.s. Ion Energy (D.H. et.al)

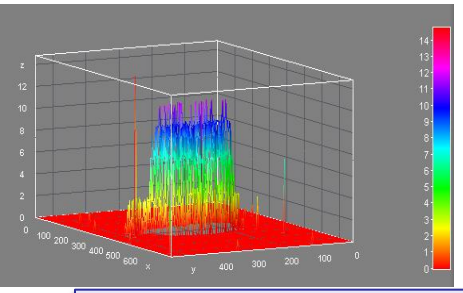
Effect of Initial Kinetic Energy, Initial Charge State, Projectile Atomic Z

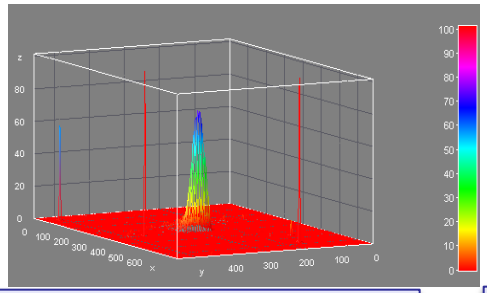
Ion beam plasma interaction

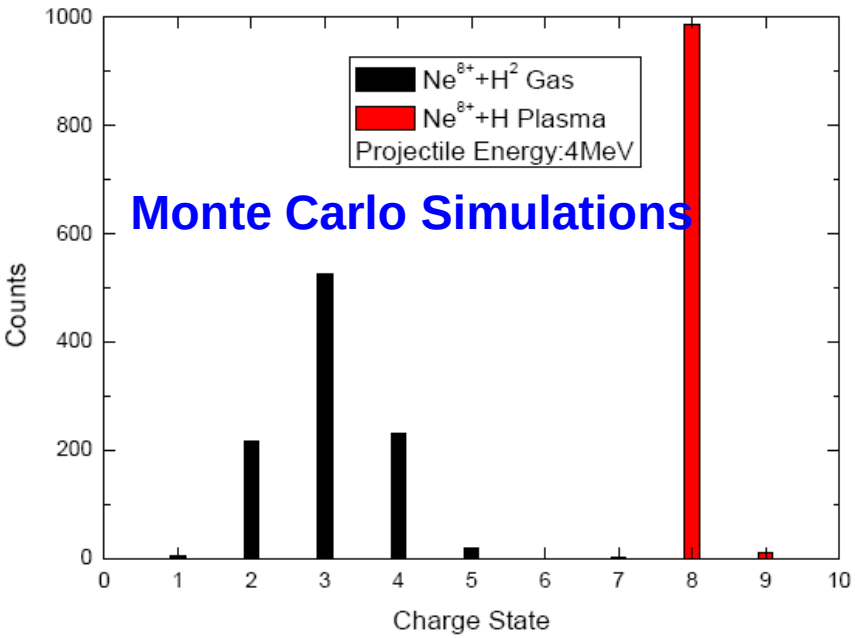
Transportation of ion beam in plasma: Pls. lens and stripper !

Before
(Max=10, D=10mm)

After
(Max=80, FWHM=2.5mm)







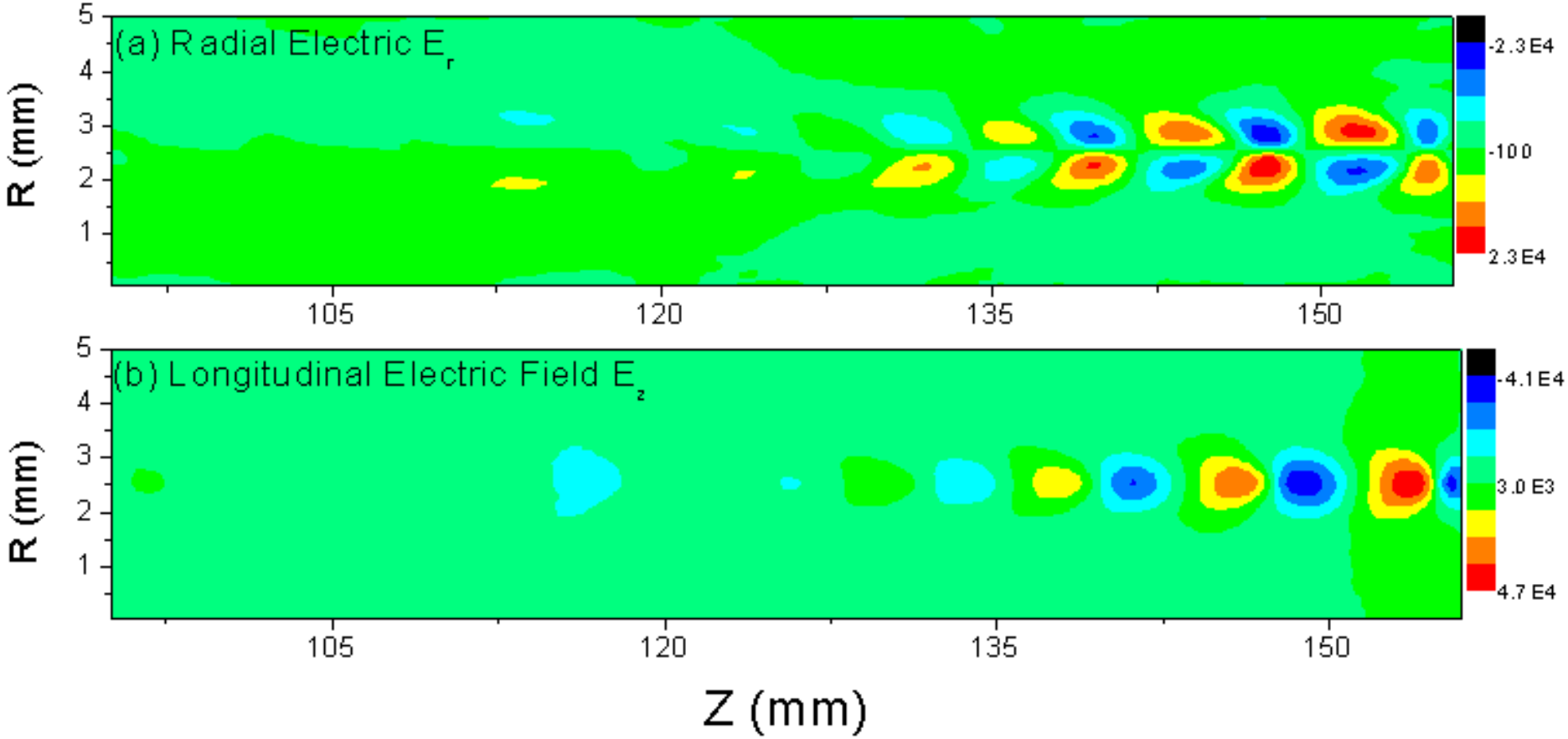
Gabor Plasma Lens by Y. Liu et.al
Excellent lens for ion beam!

Charge state revolution (D.H.)
Excellent stripper: Ac. efficiency

IMP would like to support us to develop different kinds of plasma device

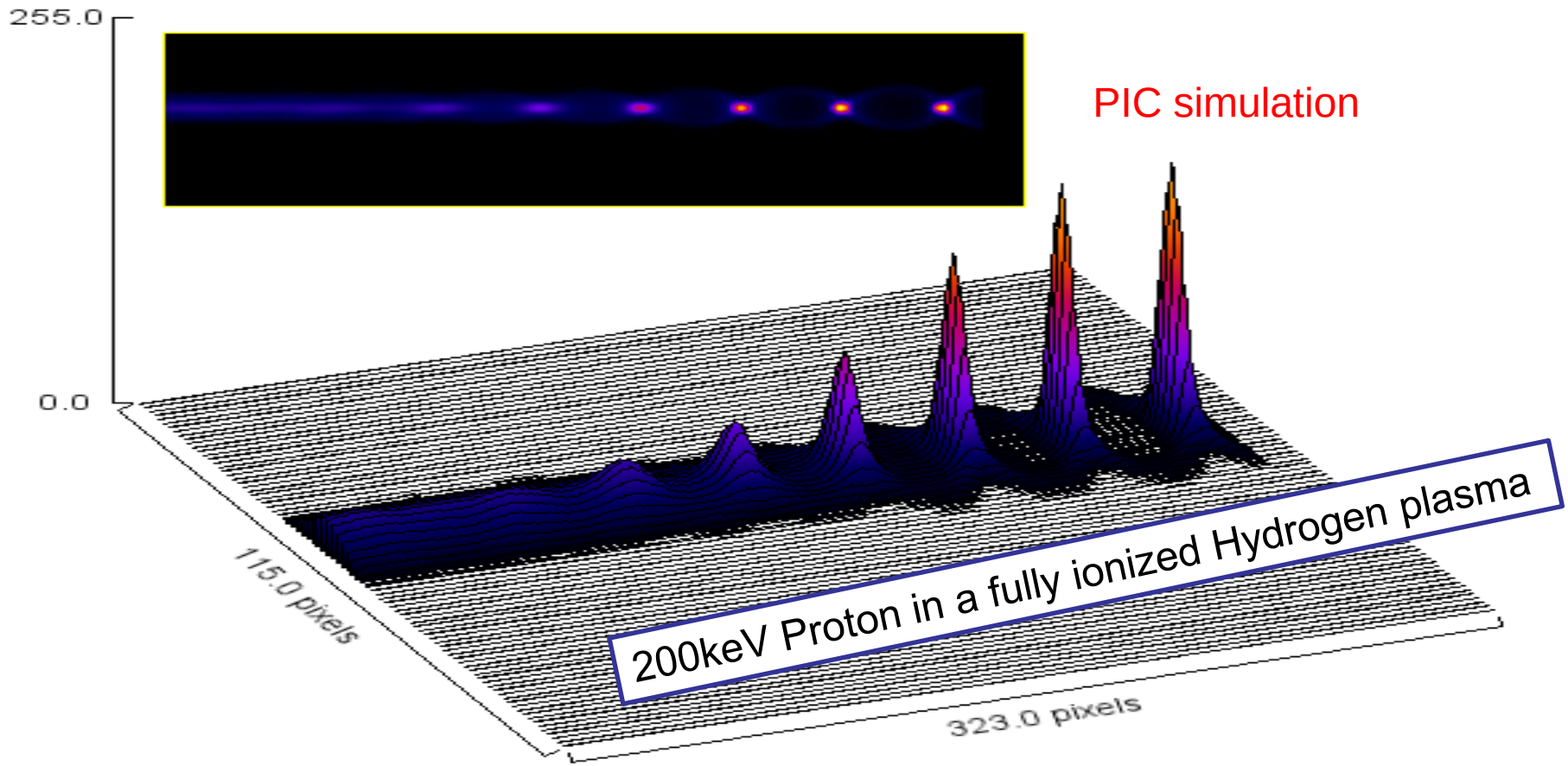
Ion beam plasma interaction

PIC simulation: Due to the weak field of the ion beam in plasma, a pulsed and strongly focused beam will be formed!



200keV Proton in a fully ionized hydrogen plasma

Ion beam plasma interaction



Typically, period: 2ns; pulse duration: 300ps; intensity: one order higher than before. Mainly depended on the ion specie and free electron density.

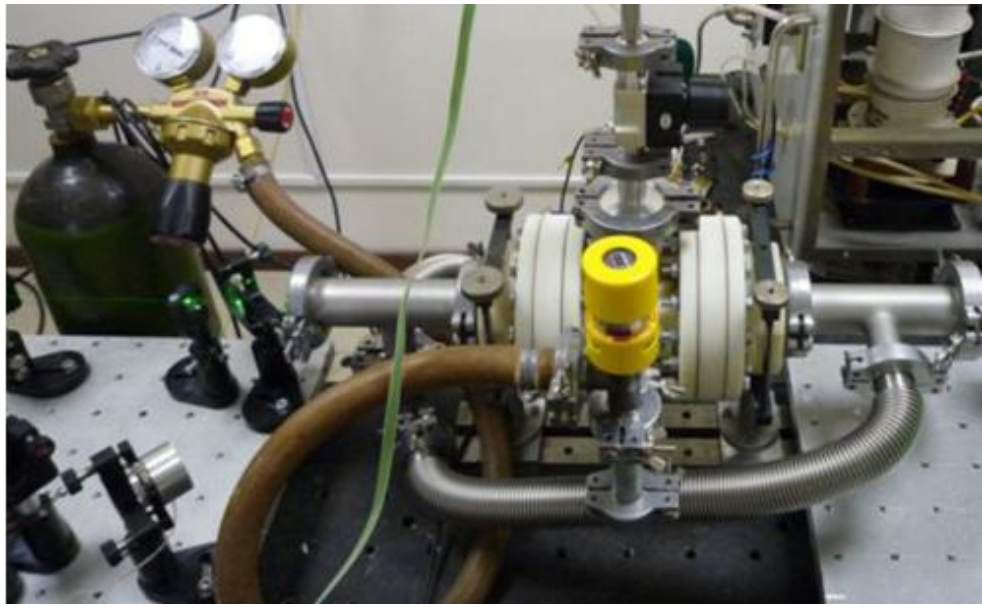
- **Only happens to the low energy ion beam or plasma long enough!**
- **Uniform distribution of plasma was assumed!**

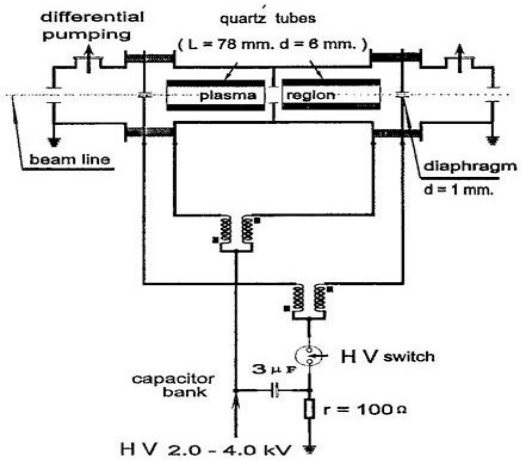
Ion beam plasma interaction

Plasma Device and Tests

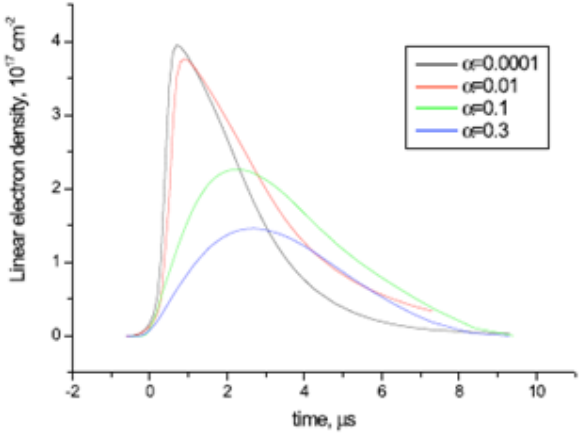
Gas Discharge Plasma (GDP):
An ideal plasma device with

- **High temperature (~2eV),**
- **Low density($10^{16}cm^{-3}$, $10^{17-19}/cm^{-2}$),**
- **Fully ionized hydrogen,**
- **Long lived(3μs),**
- **Fare homogenously,**
- **With successful experience**

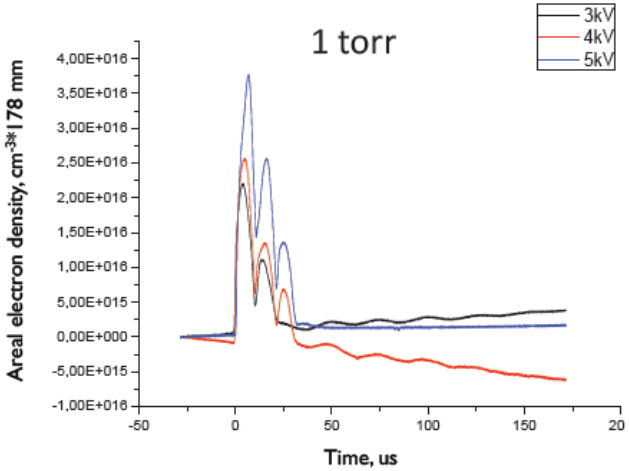




Principle scheme



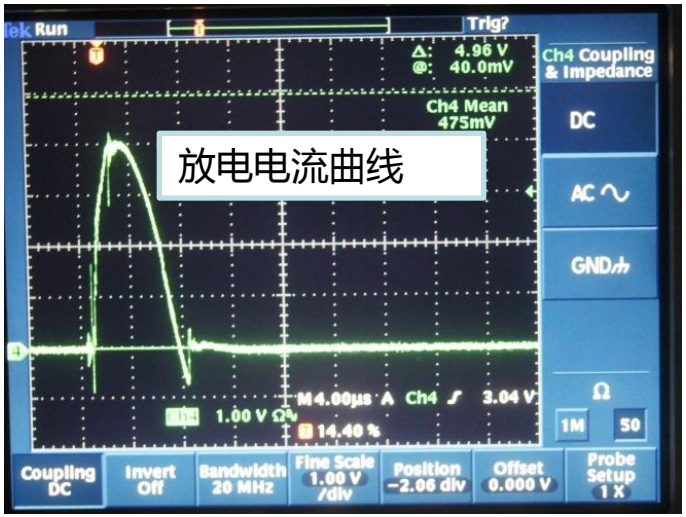
Simulation results



Measurements during test

Ion beam plasma interaction

Exp. Setup and Tests



Experiment of O^{5+} ions penetrating H_2 gas

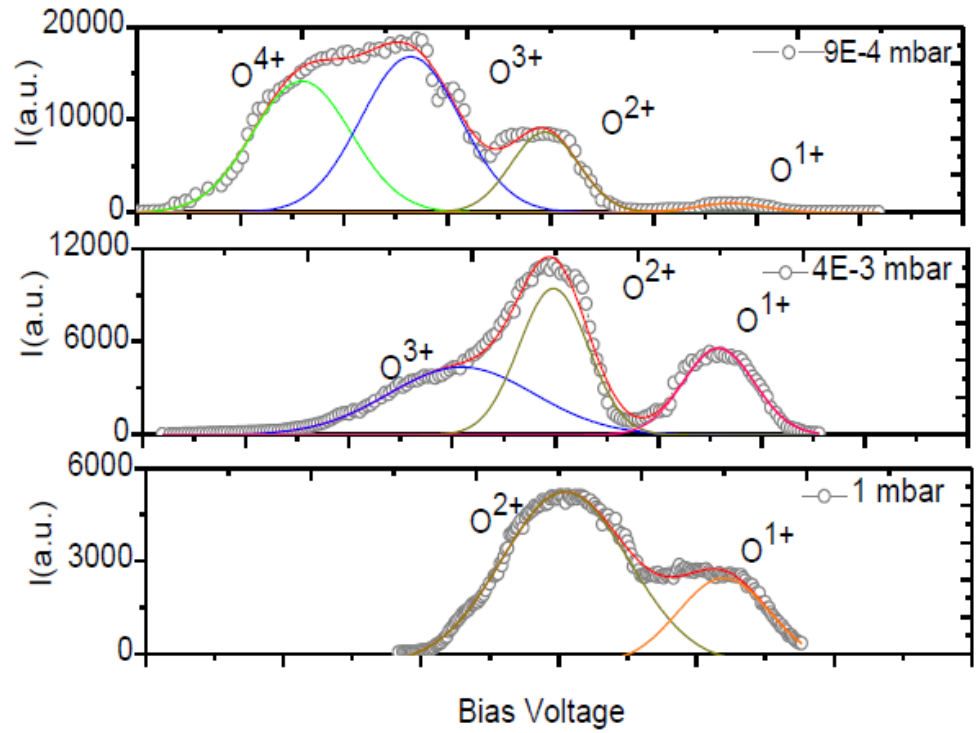
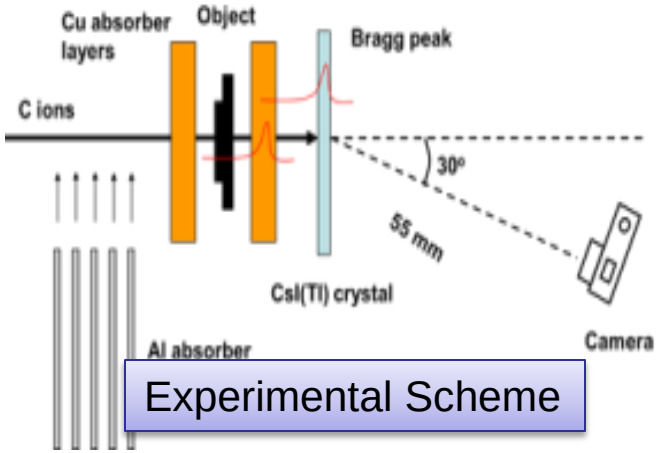


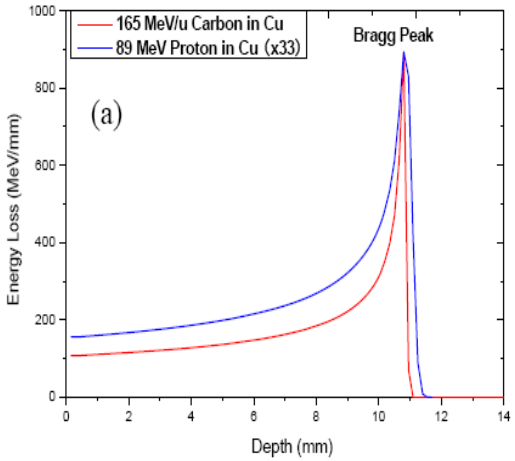
Fig.2 the charge state distribution of outgoing oxygen ions changes with different pressures when 1MeV O^{5+} ions penetrating the gas target

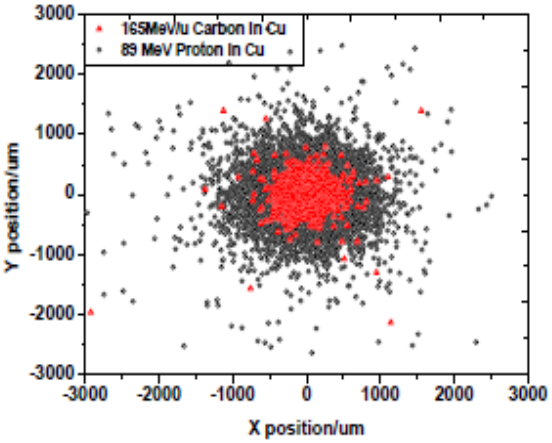
The first online experiment will be in Oct. 2012

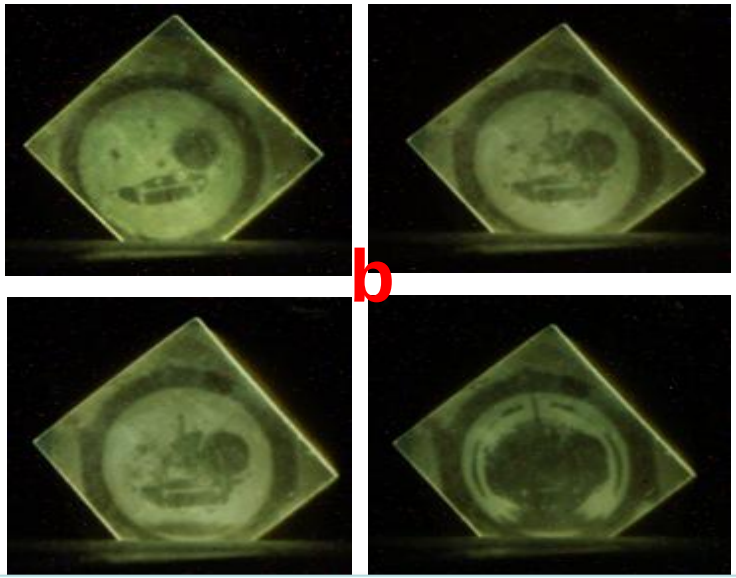
High energy heavy ion radiography (Marginal Range Radiography)

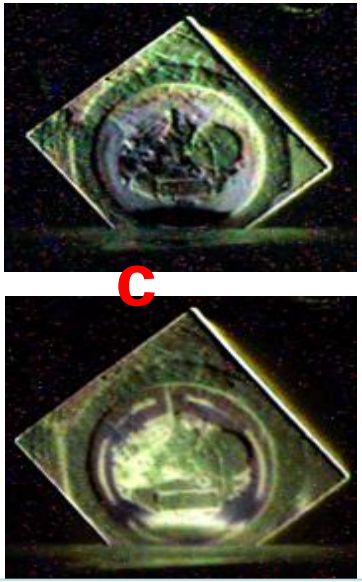


Experimental Scheme



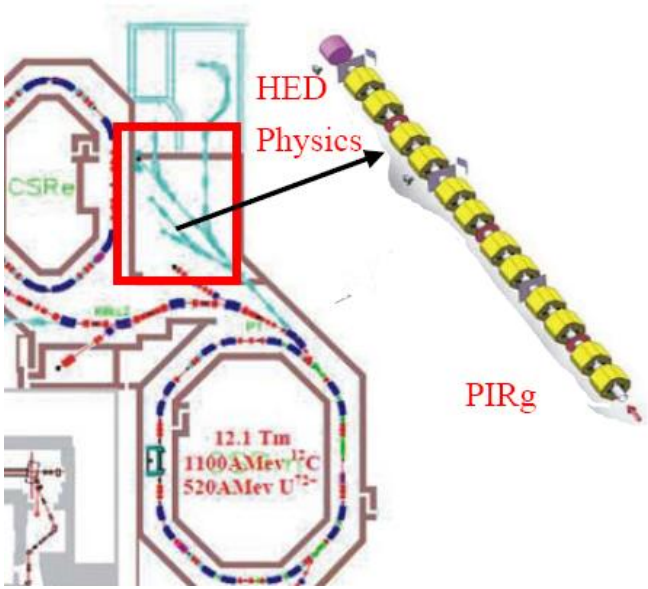


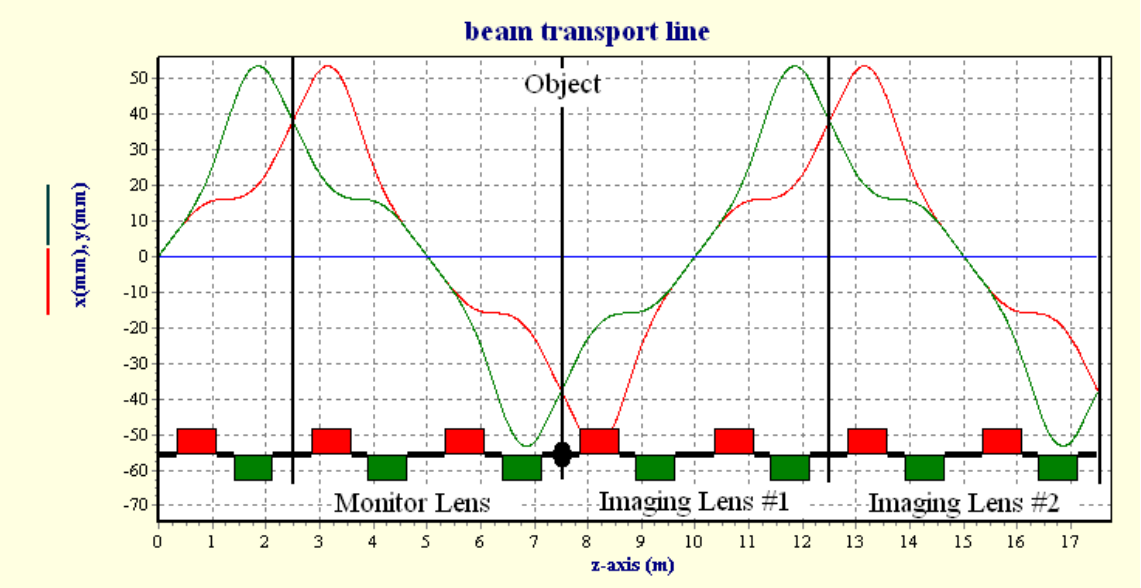




High Energy Carbon Radiography on a Watch (a:Photos, b:Rough; c:Calculated)

Proton/Ion Radiography @CSR





PIRg beam line (Proton/Ion Radiography) under construction

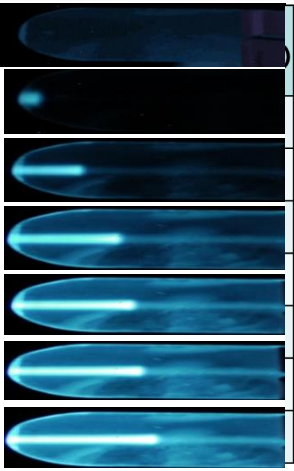
Main parameters

particle/energy（GeV/u）	p(0.8~2.2)，C(0.4~0.83)
Max. irrad. diameter（mm）	100
Intensity（proton）	1×10^{10}~1×10^{11}
Particle/pixel	10^4
pixel/frame	$10^{6\sim7}$
Q surface field（T）	1.2
Q bore radius（mm）	60

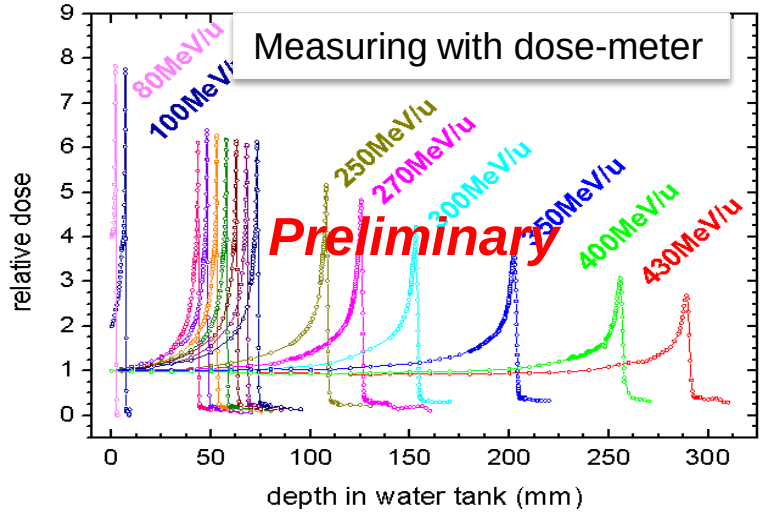
A test experiment with 2GeV proton is planned to be carried out in Sep. 2012.

Progresses on other diagnostics

Scintillator Bragg-Peak spectrometer

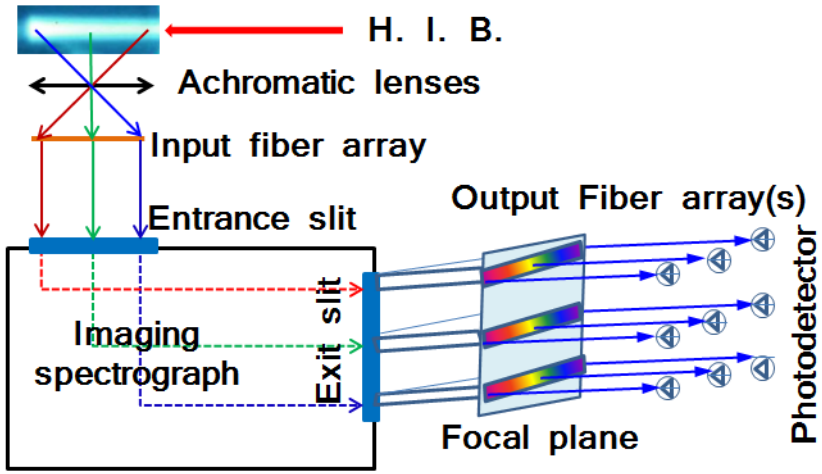


能量 (AMeV)	LISE射程 (mm)	测量射程1 (mm)	测量射程2 (mm)
154.1	21.7	21.7	21.7
152.5	21.3	------	21.3
145.9	19.8	19.7	19.8
137.3	17.9	18.0	17.5
128.3	15.9	16.1	15.6
98.1	10.0	10.4	------
38.7	2.0	2.8	------

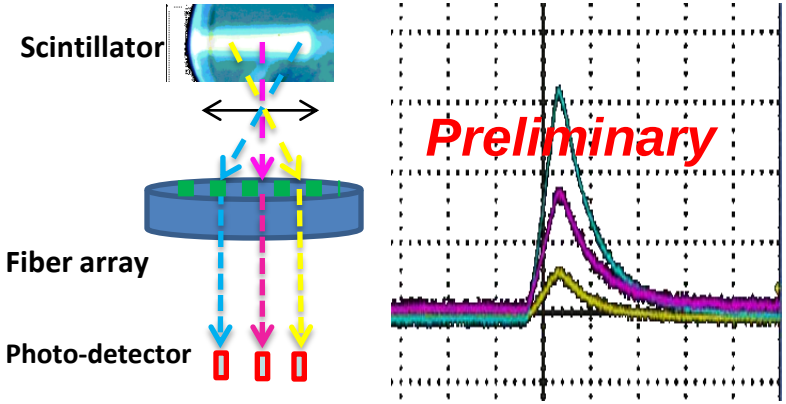


SBP spectrometer resolution ~1%@154MeV/u

Multi-Channel Pyrometer with I. Spec.

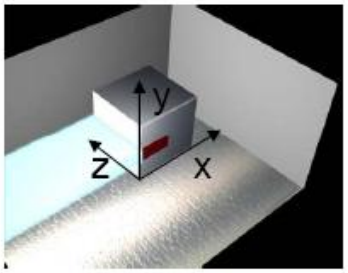


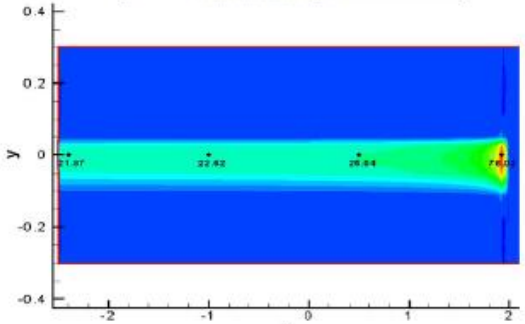
Fast and Multi-points Pyrometer



Test with fast-extracting beam from CSR

2D simulations with HIAF design by Dr. Yang





Beam:

Krypton,

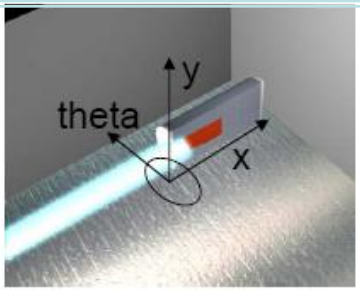
1.2GeV/u,

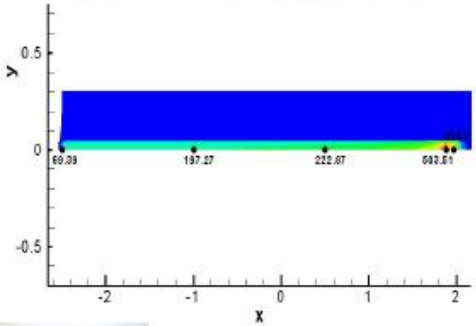
10^12 ppp,

100 ns

Target:

Lead





1. Beam Dynamics of Accelerator
2. Beam Dynamics of Plasma Lens
3. Micro-Simulation of Beam-Target interaction
4. Hydrodynamic Simulation of Beam-Target interaction
5. Mechanics of Mesoscopic Target
6. Burning Processing Simulation
7. ICF Simulation

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0086 931 4969187

Outline

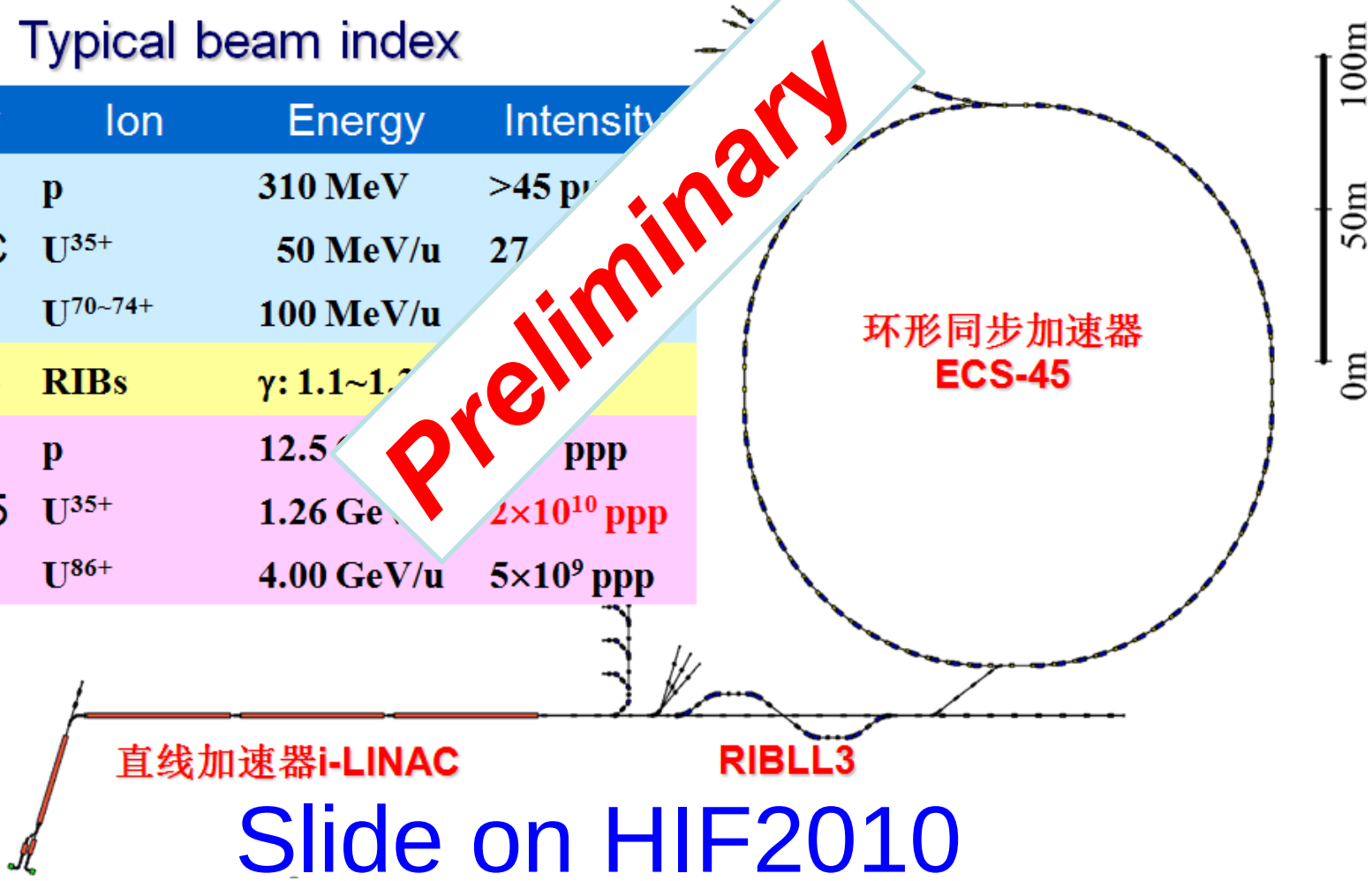
- Brief introduction to IMP
- Current activities in plasma physics research at IMP
- HIF/HED research plan at HIAF-IMP
- Concluding remarks

HIAF (Heavy Ion Application Facility) -1.2bRMB

Typical beam index

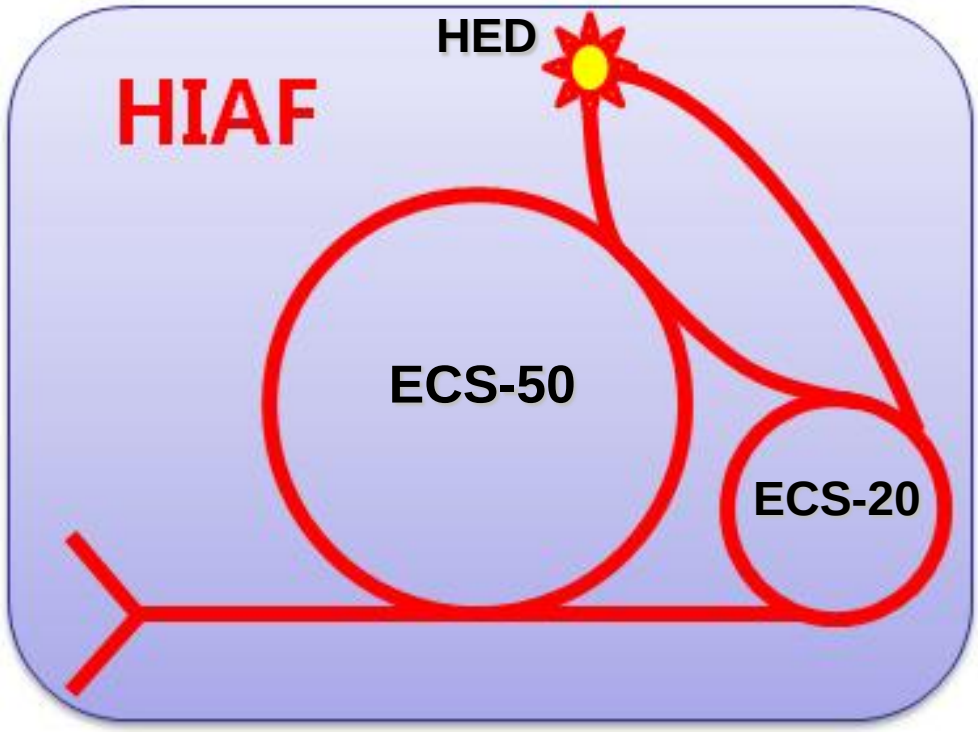
Facility	Ion	Energy	Intensity
i-LINAC	p	310 MeV	>45 p
	U^{35+}	50 MeV/u	27
	$U^{70\sim74+}$	100 MeV/u	
RIBLL3	RIBs	γ: 1.1~1.	
ECS-45	p	12.5	ppp
	U^{35+}	1.26 Ge	2×10^{10} ppp
	U^{86+}	4.00 GeV/u	5×10^{9} ppp

Preliminary



Slide on HIF2010

HEDP at HIAF: Beam parameters



High Intensity heavy-ion Acc. Facility
(Heavy Ion Advanced Facility)

HIAF: the 12th 5-year-plan of China

Budget: 1.98b RMB (1.2b)

LINAC: 150MeV/u (50MeV/u)

Main ring: ECS50 (ECS45)

Add a booster ring(ECS20)

Add a cross-beam line( )

Typical Beam Parameters for HED

Preliminary

E: 500-3000MeV/u

N: $1*10^{12}$(ECS20);2-5*10^{12}(ECS50)

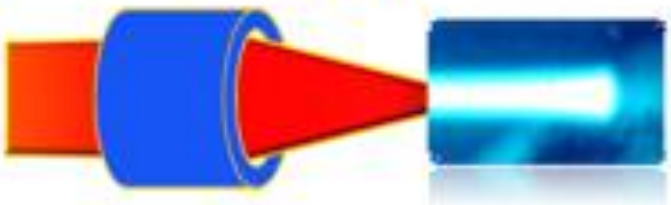
FWHM : <1mm

τ : <100ns (50ns after upgrading)

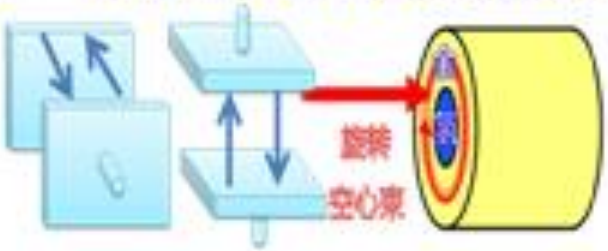
The TP for HIAF will be finalized and handed up to NDRC in Oct.2012.
After approved, constructions may be started from 2013.
NDCR: National Development and Reform Commission P.R.C.

HEDP at HIAF: Tech. Proposals

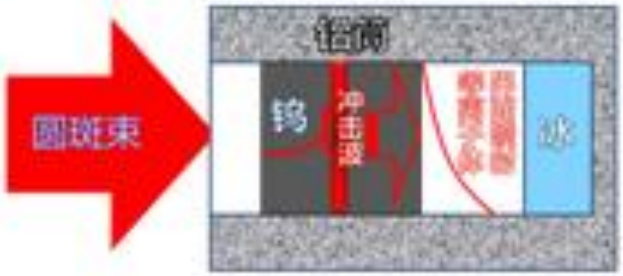
1. Direct heating



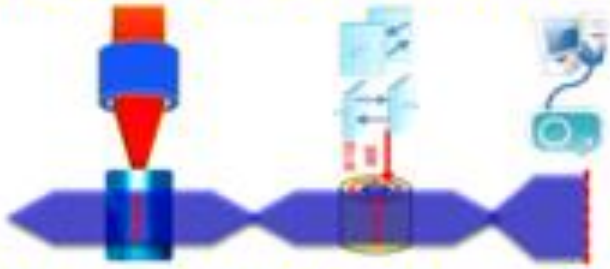
2. Ring-shaped compressing



3. Ramp Compression

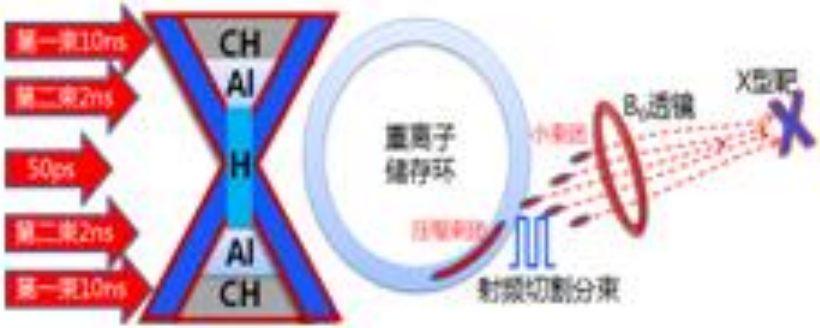


4. Double beams 1 (Radiography)



5. Double beam2 (Comp. + Heating)

6. X-Target



Your proposals are very much welcomed!

Summary and Acknowledgement

- **IMP, as the Heavy Ion Research Center in China, was briefly introduced.**
- **Current activities on plasma physics research are focusing on HCI physics, Ion-beam plasma interaction, and diagnostics of HEDM.**
- **HIF/HED research program at IMP were introduced.**
- **Many thanks for the supports from:**

- *Dieter Hoffmann (TUD)*
- *Grant Logan(HIFVNL)*
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- *Dmitry Varentsov(GSI)*
- *Naeem Tahir (GSI)*
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- *Boris Sharkov(ITEP)*
- *Roberto Piriz(UCLM)*
- *Xiaoan Zhang(XYNU)*
- *Zhongfeng XU(XJTU)*

Thank you very much for your attention!

Welcome to IMP, Lanzhou

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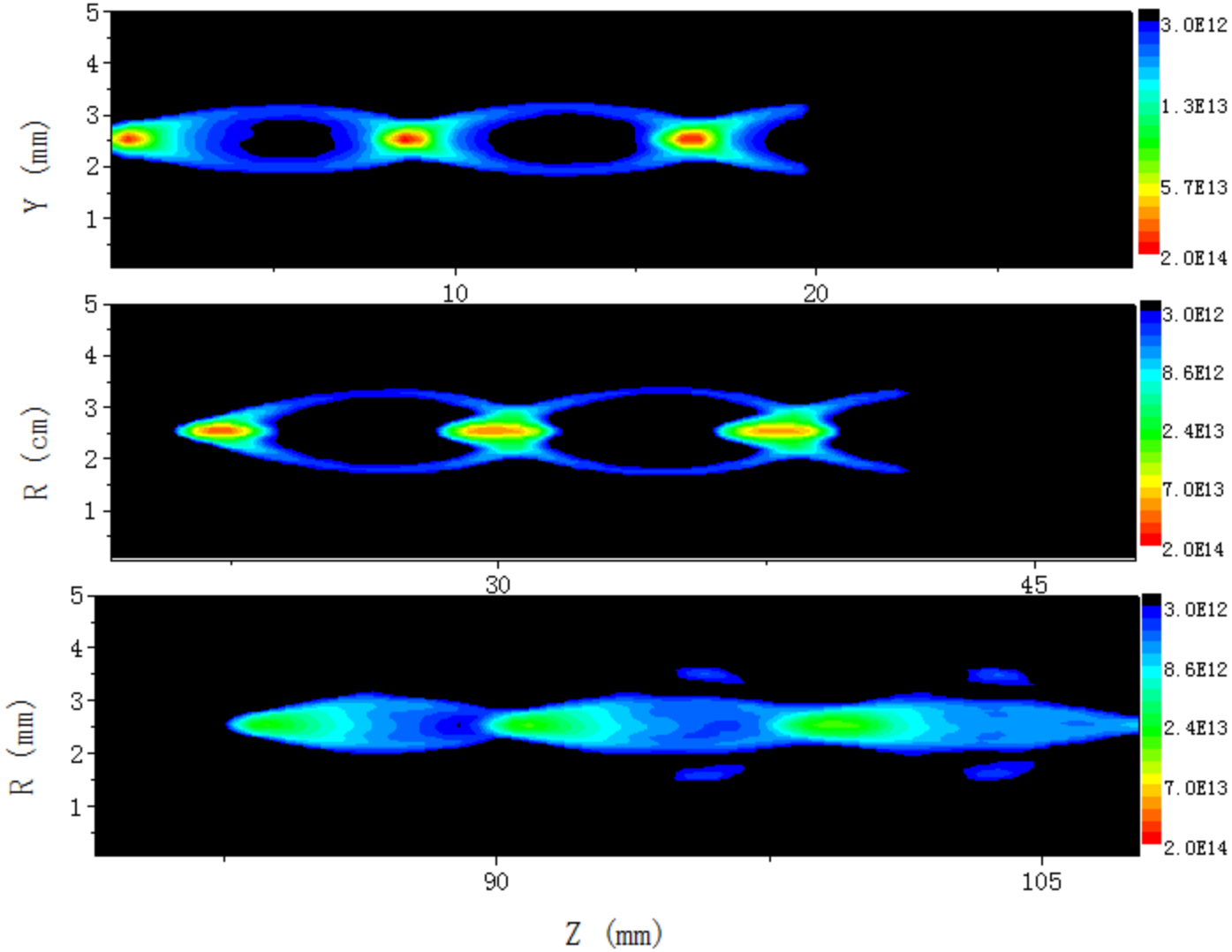
Further Transition in vaccuum



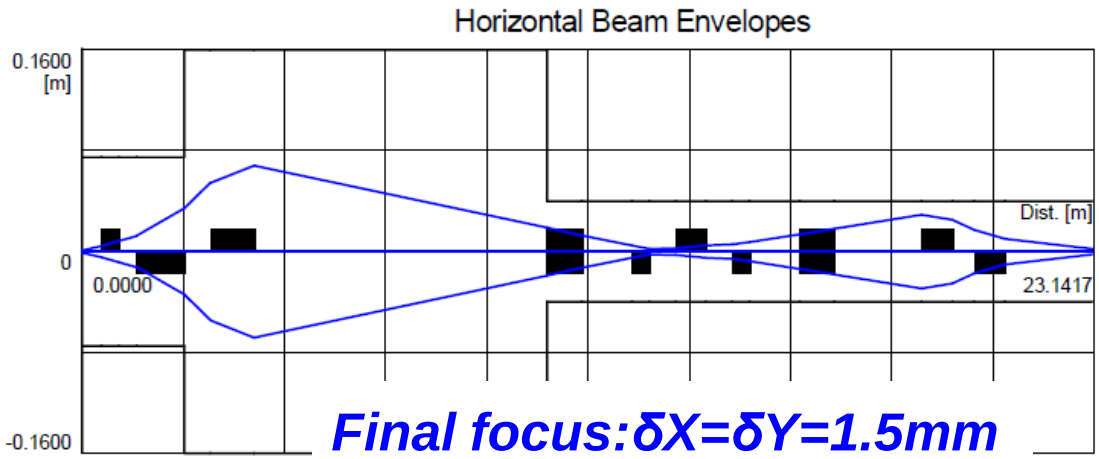
Dx=0

Dx=23 mm

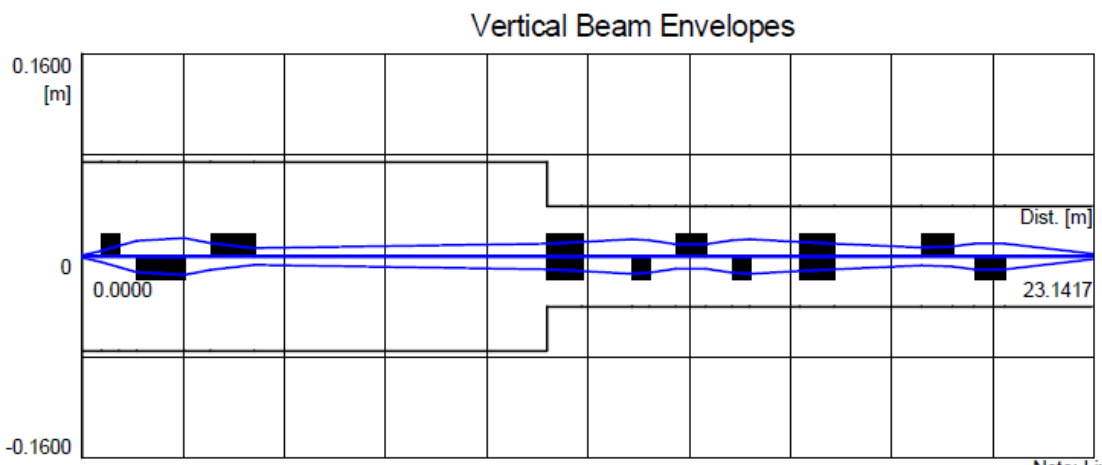
Dx=90 mm

Intense Energic Beam Heating at CSR

Beam optics CSR-HED terminal



Final focus:δX=δY=1.5mm



Note: Linear optics

Beam parameters:

Ion: Xenon

Energy: up to 235MeV/μ

Intensity: $1.5*10^9$

Pulse duration: 170-890ns

Focus: 1.5mm

Special Energy deposition:

In Ne: 120J/g

Status: Just started designing the chamber