Intense Beam Generation with 2.45GHz Ion Sources for High Current Linacs

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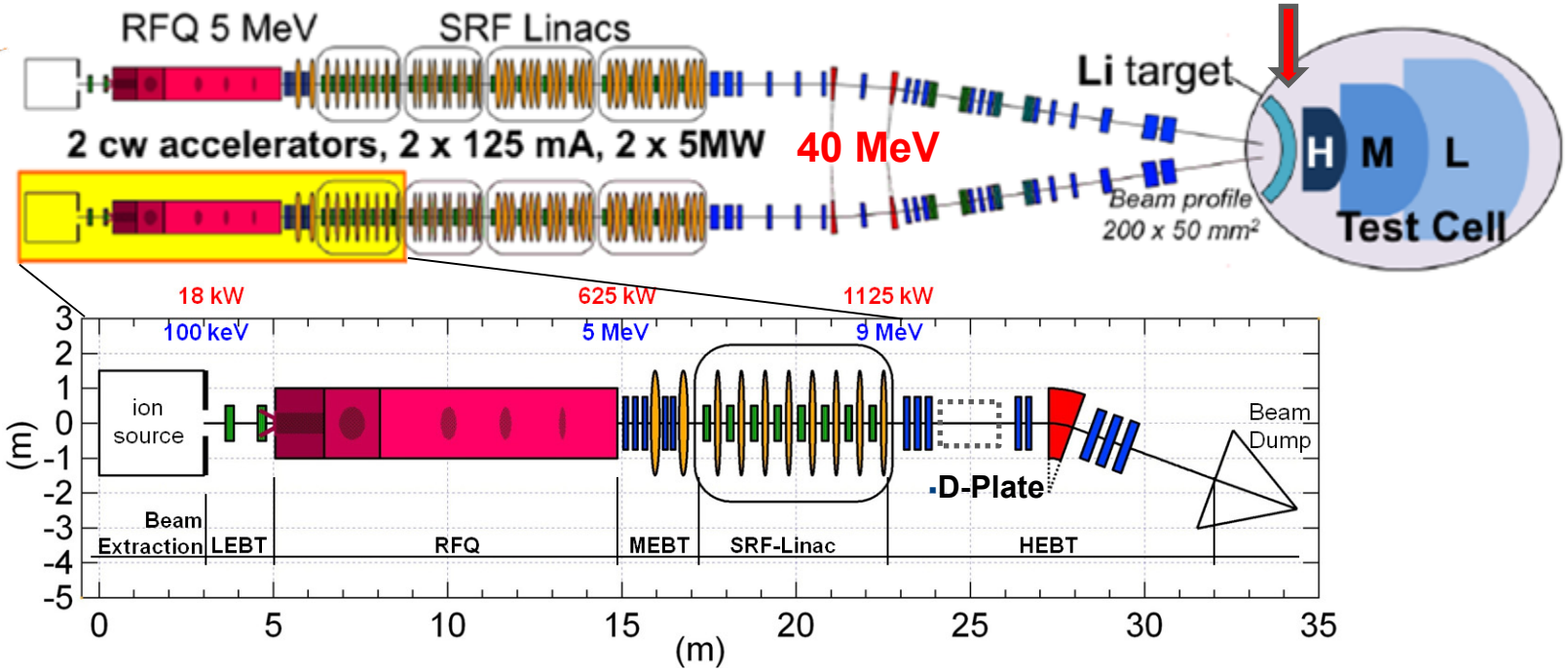
Peking University

11:40 Thursday, 20 September, Juying Ballroom

Outline

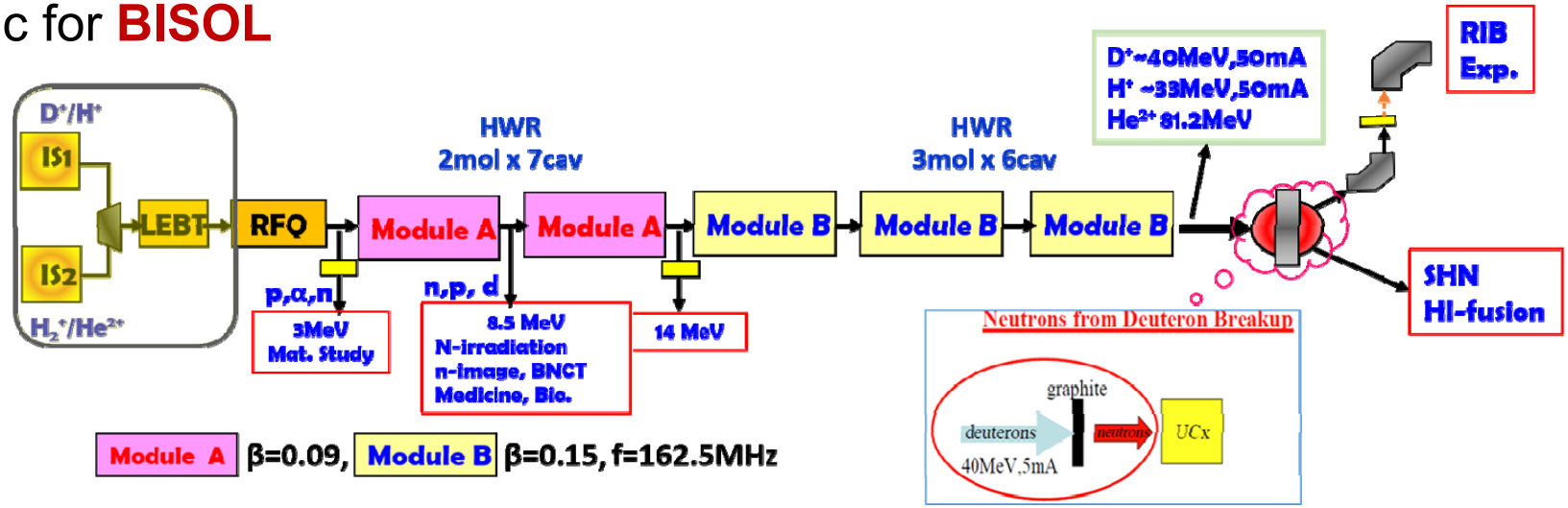
1. Driven Force of High Intense Ion Source
2. Status of Single Charged 2.45GHz ECRIS Performance
3. Other Relevant Ions Beam Results of PKU 2.45GHz Ion Source
4. Summary

Driven Force of High Intense Ion Source



▪TU2A04, M. Sugimoto

▪D^+ Linac for **BISOL**



Numerous High Intensity Linacs

Project	Particles	Intensity	Duration	Repetition	Emittance	Source Lab
	p/d/H_2/O/He/Li	mA	ms	Hz	ε(π mm.mad)	
LEDA	H^+	100	CW	-	0.25	LANL
SARAF	H^+, D^+	2	CW	-	0.2	ACCEL
IPHI	H^+	100	CW	-	0.25	CEA /Saclay
IFMIF	D^+	140	CW	-	0.25	
Spiral2	H^+, D^+	5	CW	-	0.25	
FAIR	H^+	100	1	4	0.3	
I						FN
						CAS
PKUNIFTY	D^+	40	1	100	0.2	PKU
C- RFQ	He^+	10	1-CW	166	0.2	
DWA	H^+	40	1	100	0.2	
CIFNEF	H^+, H_2^+, Li^{3+}	20	CW	-	0.2	
BISOL	H^+, H_2^+, D^+, He^{2+}	50	CW	-	0.16	

- The beam generation ability, its stability, reliability, reproducibility, lifetime, operation convenience and cost of an **ION SOURCE** is extremely important!

The Opulent Ion Source Buffet*

*Ion source list from SNS M.Stockli's report

56 different ion sources !

- *Electron Bombardment ion source*
- *Hollow Cathode ion source*
- *Reflex Discharge Multicusp source*
- *Cold- & Hot-Cathode PIG*
- *Electron C… source (EC…*
- *Electron B…*
- *Surface Co…*
- *Cryogenic …*
- *Metal Vapo… (MEVVA)*
- *Sputtering-type negative ion source*
- *Plasma Surface Conversion negative ion sour…*
- *Electro… source*
- *Hollow Cathode von Ardenne ion source*
- *Forrester Porus Plate ion source*
- *Multipole Confinement ion…*
- *EHD-driven Liquid ion sou…*
- *Microwave ion source*
- *XUV-driven ion source*
- *Arc Plasma ion source*
- *Surface Ionization ion source*
- *Field Emission ion source*
- *Atomic Beam ion source*
- *Field Ionization ion source*
- *Freeman ion source*
- *Liquid Metal ion source*
- *Beam Plasma ion source*
- *Magnetron ion source*
- *Bayard-Alpert type ion source*
- *Inverse Magnetron ion source*
- *EERIAD ion source*
- *Plasmatron*
- *Duoplasmatron*
- *Monocusp ion source*
- *Bucket ion source*
- *Metal ion source*
- *Multicusp ion source*

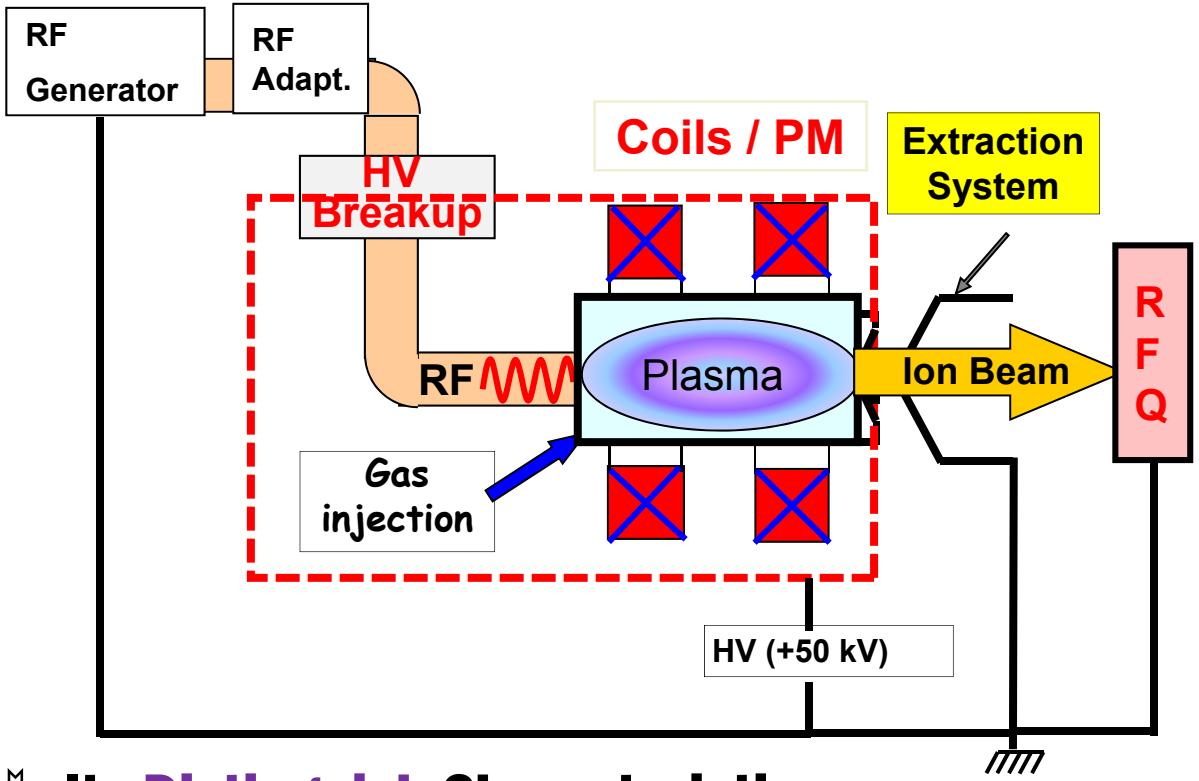
2.45GHz ECR Ion Source may be the best choice for High Intensity Linac!

Tens to hundred mA single-charged ion beam with emittance ~0.2π.mm.mrad!

- Compact-PIG-Ion Source (Dual Hollow Cathode Discharge)
- Hybrid 2.45 GHz Microwave Driven Ion Source (Li^{3+} Source)

Today's selection features the most important ion sources!

Principle of a 2.45GHz ECR Ion source



ECR Source ➔

Resonance zone :

$$\omega = e\,B / m$$

ω, pulsation

e, electron charge

B, magnetic field

m, electron mass.

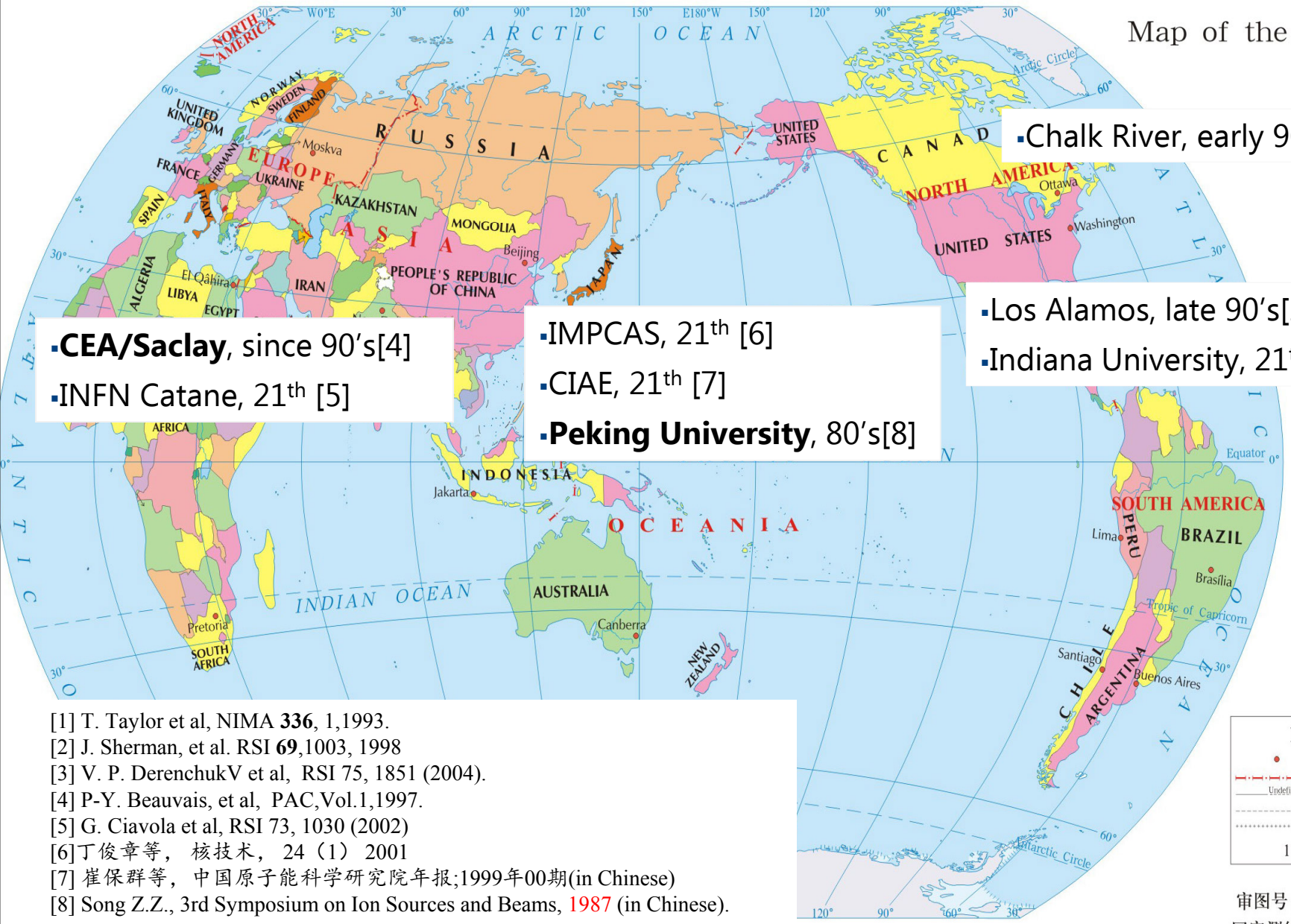
2.45 GHz ➔ 875 Gauss

Its Distinguish Characteristic:

- It can produce high intensity H^+ / H_2^+ /O^{3+}, etc. in DC/Pulsed mode;
- H^+/D^+ current can goes to Hundred mA with emittance of ~0.2π.mm.mrad;
- High stability & reliability & reproducibility, long lifetime,...

The Unique Characteristic of a 2.45 GHz ECR, is limitless life time because of no consumption units (no filament, no antenna)!

Worldwide Intense 2.45GHz Source Activity



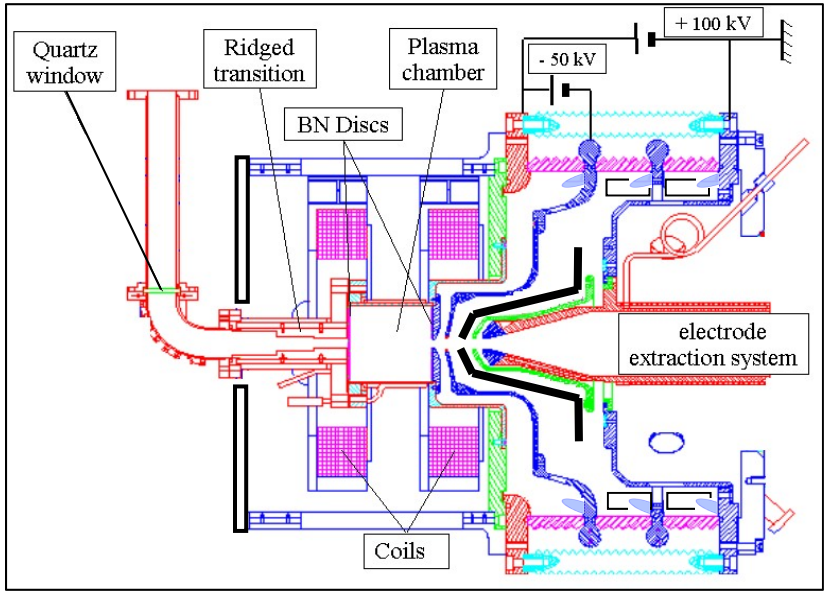
- Chalk River, early 90's[1]
- Los Alamos, late 90's[2]
- Indiana University, 21th [3]
- **CEA/Saclay**, since 90's[4]
- INFN Catane, 21th [5]
- IMPCAS, 21th [6]
- CIAE, 21th [7]
- **Peking University**, 80's[8]

[1] T. Taylor et al, NIMA **336**, 1,1993.
[2] J. Sherman, et al. RSI **69**,1003, 1998
[3] V. P. DerenchukV et al, RSI 75, 1851 (2004).
[4] P-Y. Beauvais, et al, PAC,Vol.1,1997.
[5] G. Ciavola et al, RSI 73, 1030 (2002)
[6]丁俊章等， 核技术， 24（1） 2001
[7] 崔保群等，中国原子能科学研究院年报;1999年00期(in Chinese)
[8] Song Z.Z., 3rd Symposium on Ion Sources and Beams, 1987 (in Chinese).

High Intensity Light Ion Sources(*SILHI*), CEA/Saclay

- Large Body with Coils **IPHI/IFMIF/FAIR**

Courtesy R. Gobin



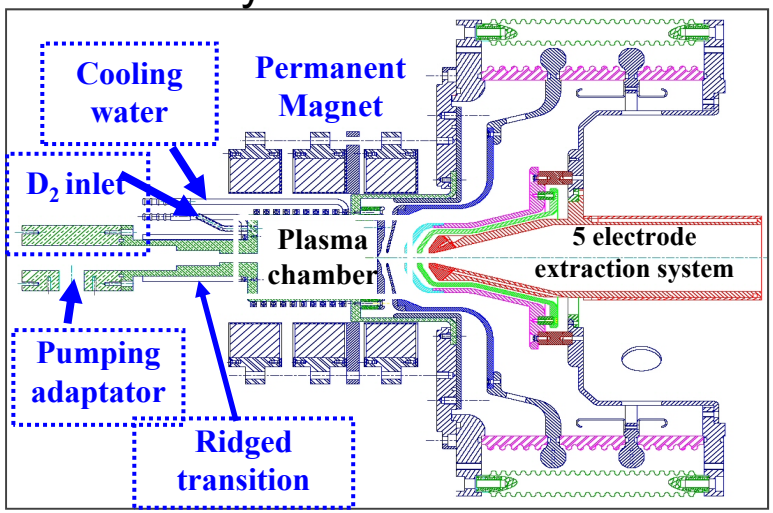
Ion type	H^+	D^+	He^+
Current(mA)	157	175	104
Density(mA/cm^2)	247	275	163

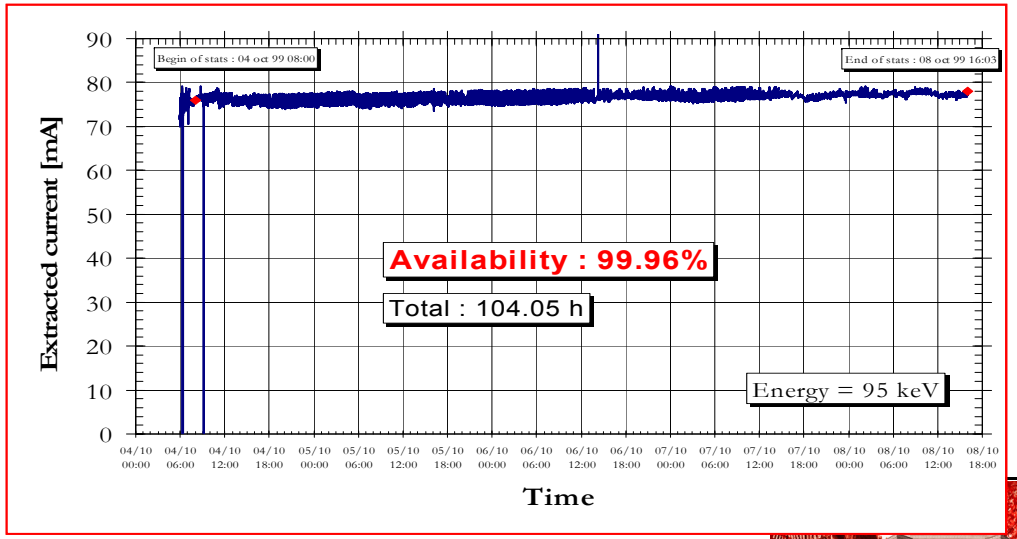
RMS emittance < 0.2π.mm.mrad

Table 1: Reliability tests

Parameters	Déc. 97	Mai 99	Oct. 99	March 01	June 01
Energy (keV)	80	95	95	95	95
Intensity (mA)	100	75	75	118	114
Duration (h)	103	106	104	336	162
Beam off number	53	24	1	53	7
MTBF (h)	1.75	4	n. appl.	≈ 6	23.1
MTTR (mn)	6	5.3	2.5	≈ 18	2.5
Uninterrupted beam (h)	17	27.5	103	25	36
Availability (%)	94.5	97.9	99.96	95.2	99.8

- Small Body with PM **SPIRAL 2**

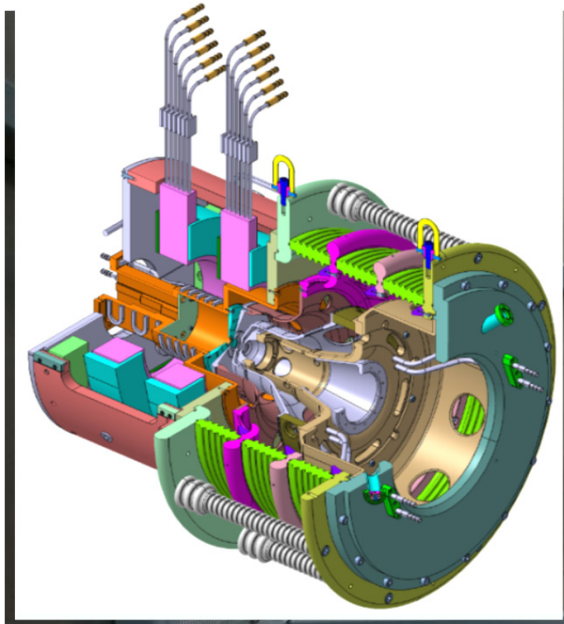


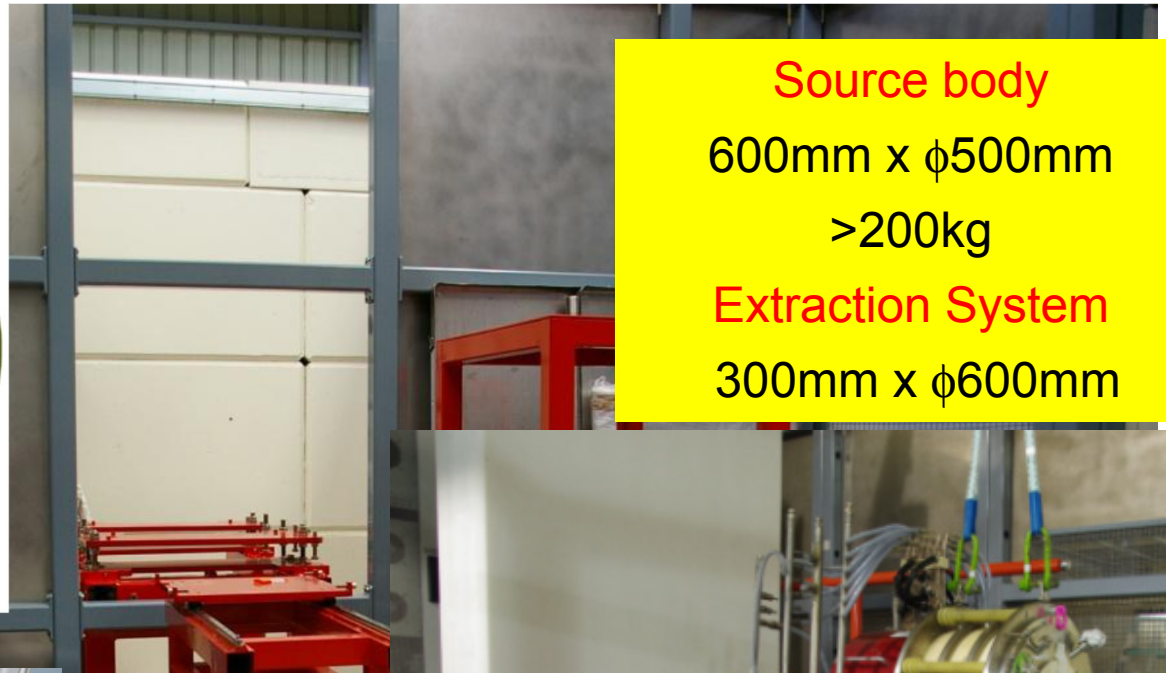


O. Delferrière, RSI **79**, 02B723 (2008)

R. Gobin, etc., EPAC 2002, Paris, France, 1712-1714(2002)

IFMIF, *SILHI source(Coil)*, CEA/Saclay





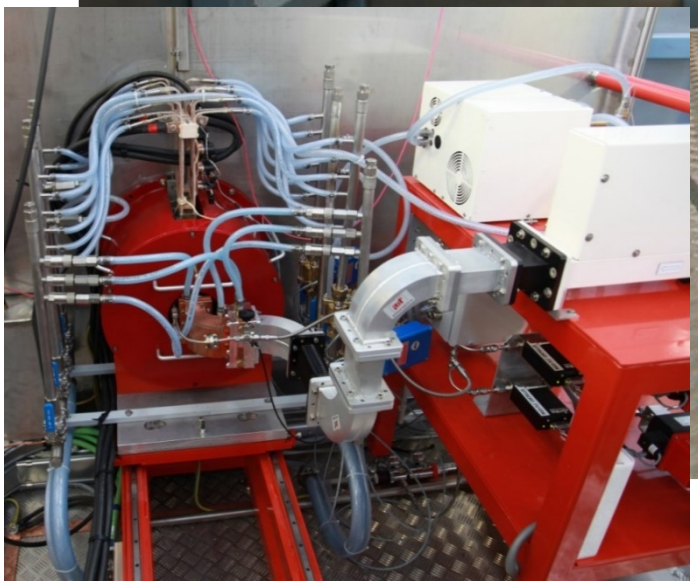
Source body

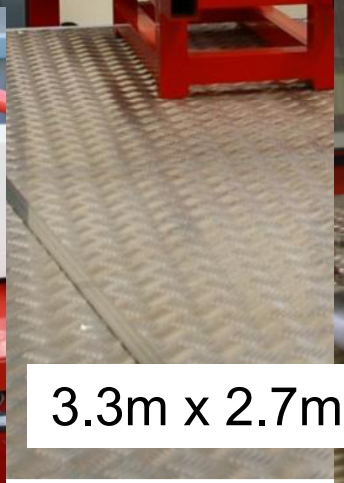
600mm x ϕ500mm

>200kg

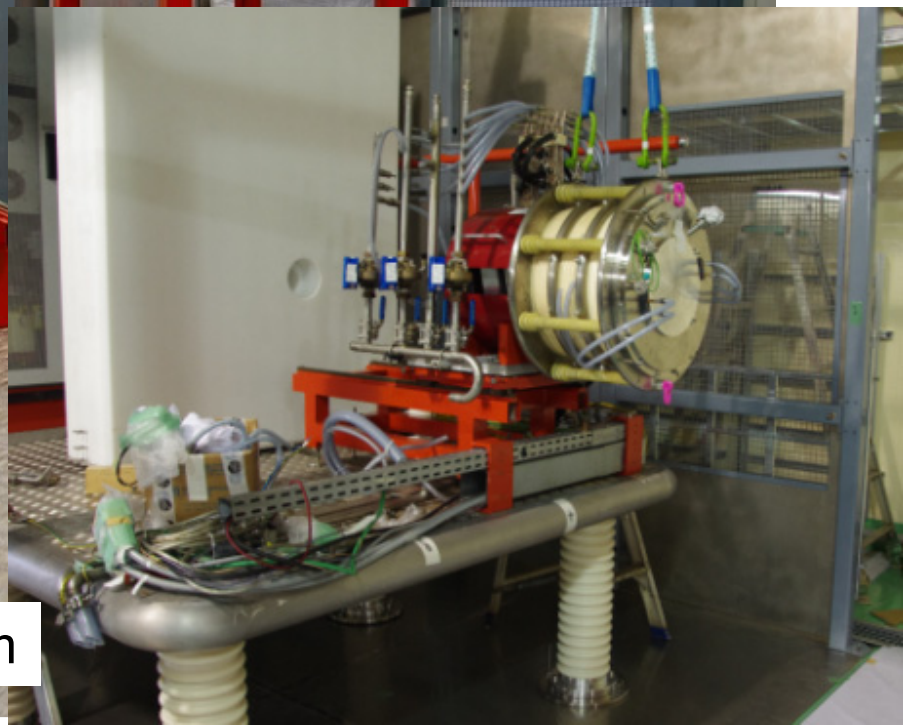
Extraction System

300mm x ϕ600mm



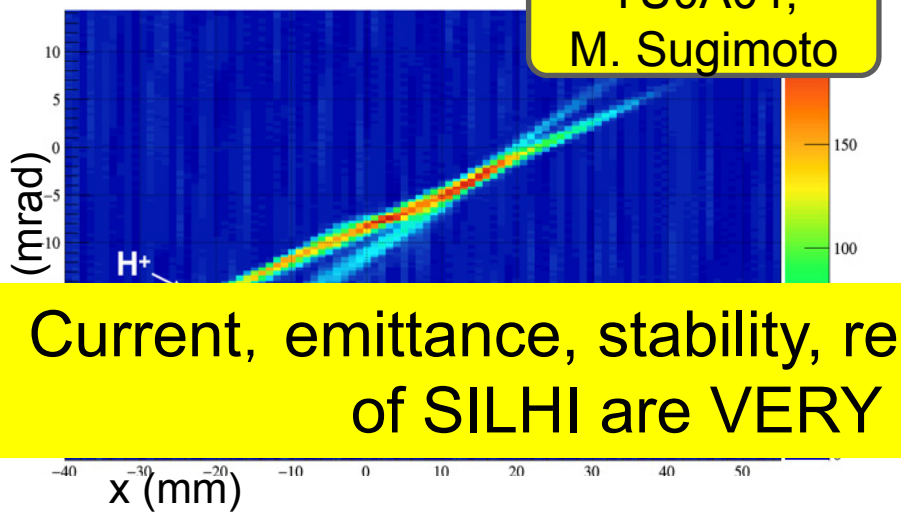


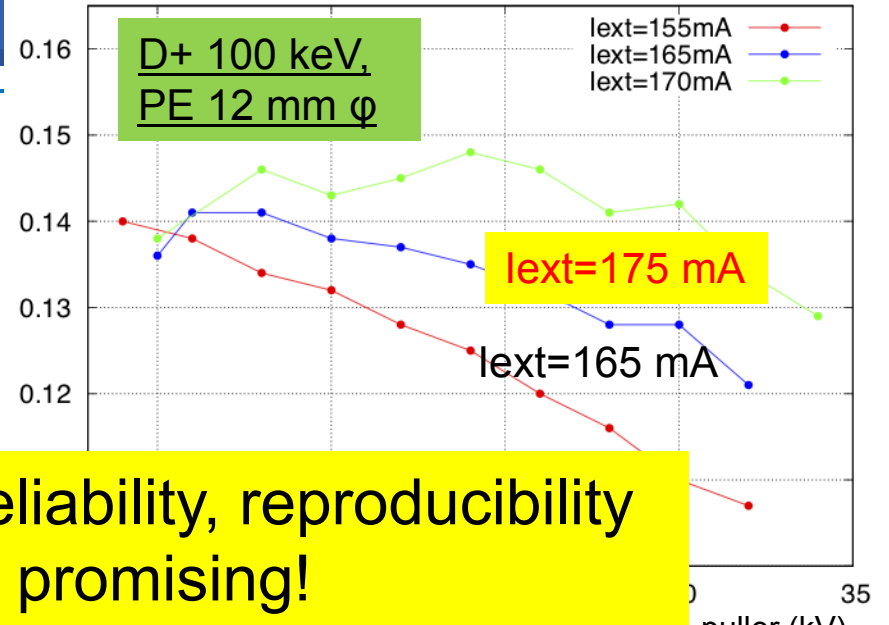
3.3m x 2.7m



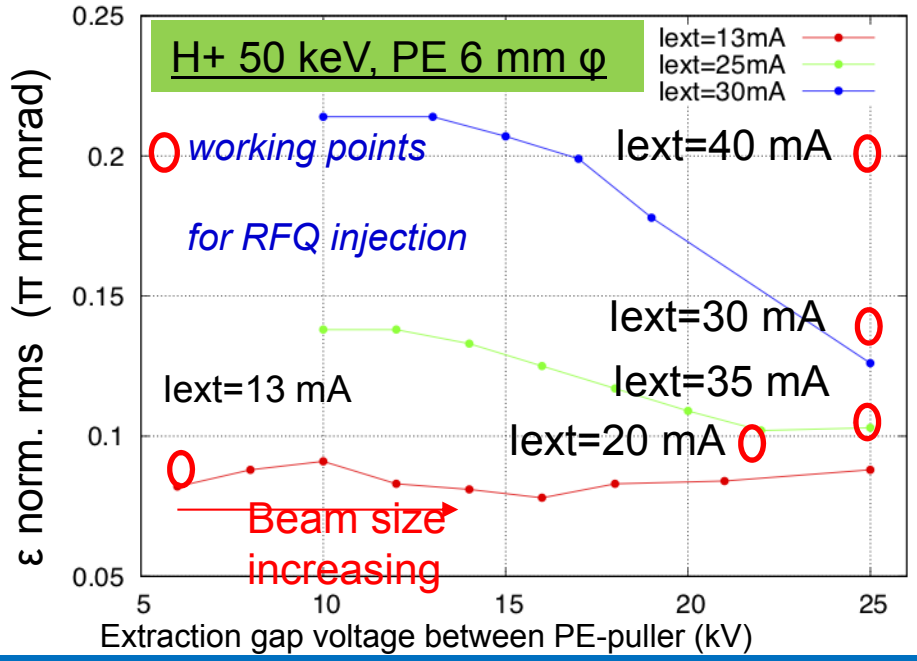
Courtesy R. Gobin

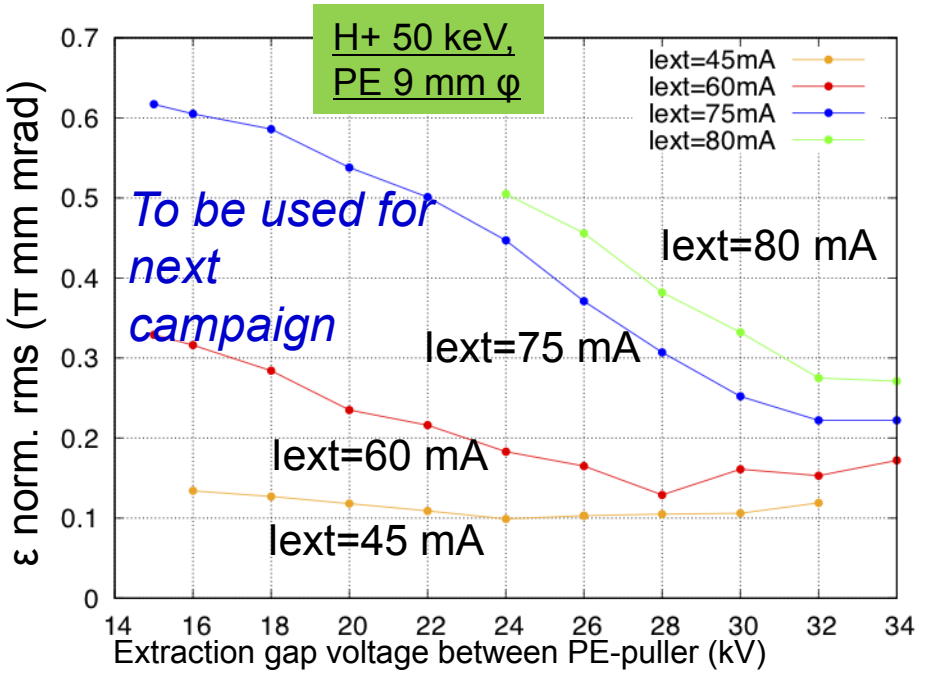
Typical EMU data (I_{ext}=20 mA)





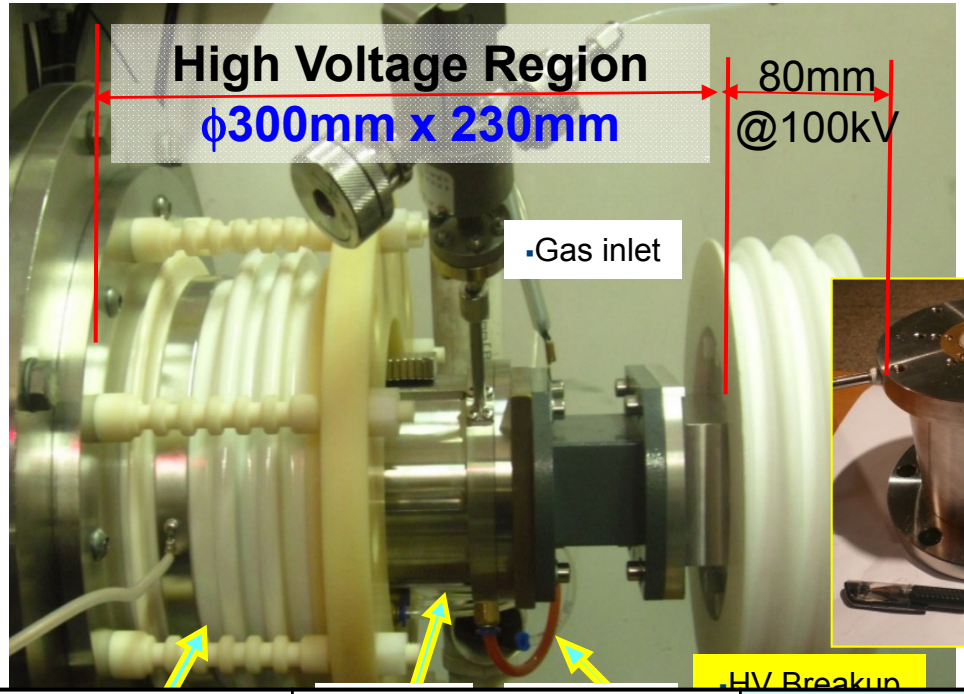
Current, emittance, stability, reliability, reproducibility of SILHI are VERY promising!





PKU PMECR Ion Source

- **Standard ones** Permanent Magnet, Dielectric Window, Limited HV region



Source Body

Out: ϕ10cm x 10 cm(H)

Inner: ϕ40mm x 50mm(H)

Wet: < 5 kg

Extraction System

100mm x ϕ 230mm

ϕ6mm hole

HV platform

ϕ300mm x 230mm

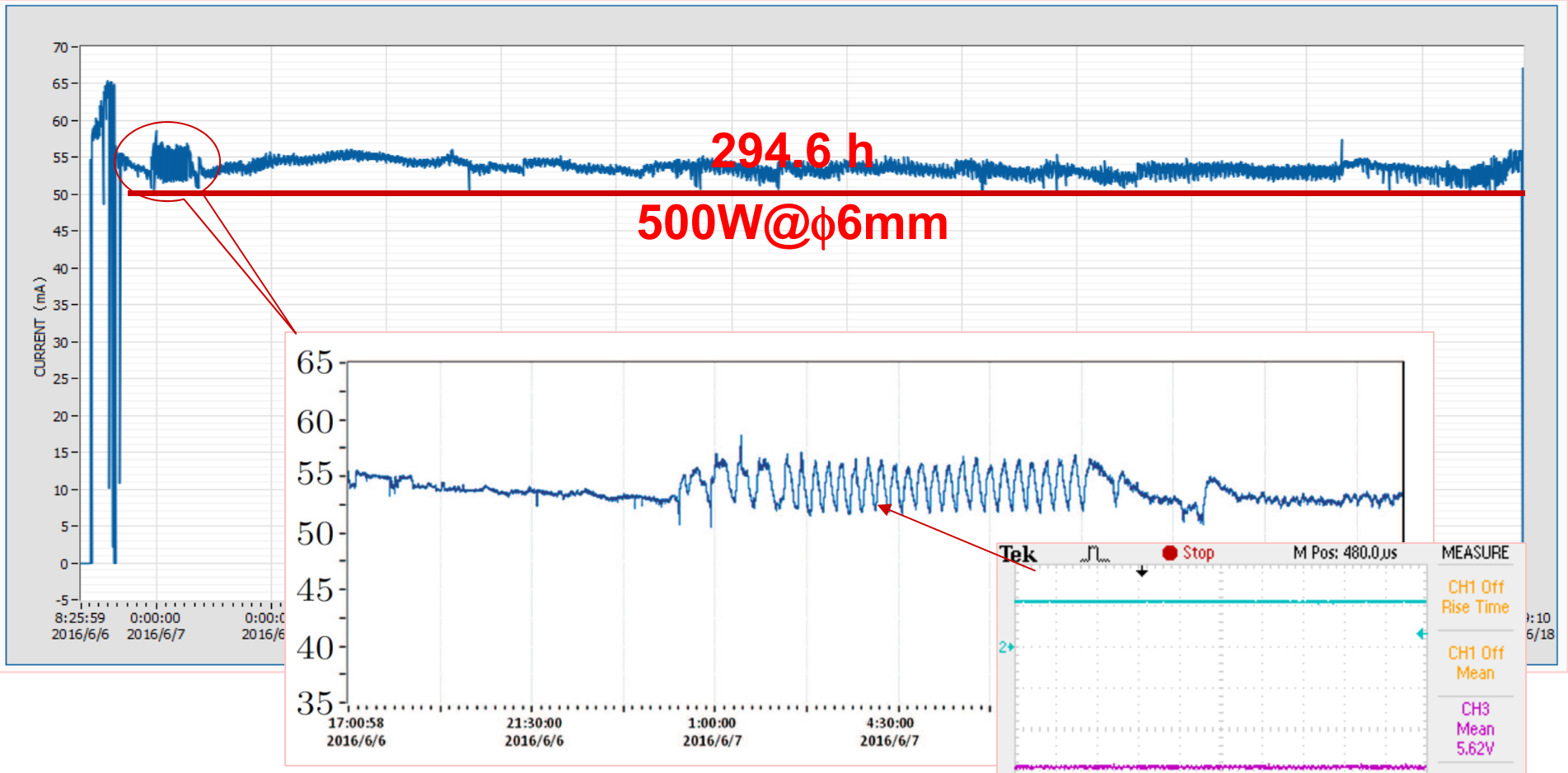
Labs	CEA/Saclay [1]			PKU[2]					
Ion type	H^+	D^+	He^+	H^+	D^+	He^+	O^+	Ar^+	N^+
Current(mA)	157	175	104	130					
Density(mA/cm^2)	247	275	163	460	294	230	247	247	297
Facility	IPHI/IFMIF/FAIR SPIRAL2, etc.			DWA/Proton Therapy	PKUNIFTY	Coupled RFQ	SFRFQ	Ion Implantation	

- emittance < 0.2π.mm.mrad

[1]O. Delferrière, RSI **79**, 02B723 (2008)

[2]S. X. Peng, A. L. Zhang, H. T. Ren, etc. *Chin. Phys. B*, 26(2): 025206(2017).

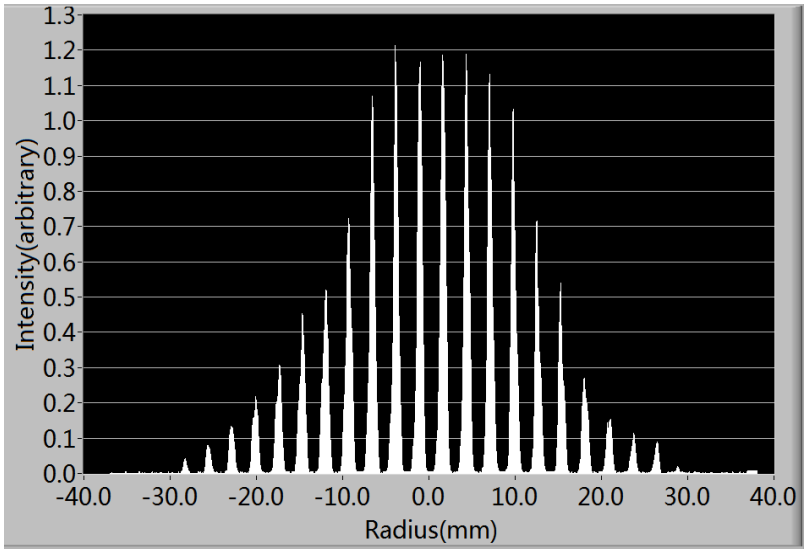
Stability of PKU CW 2.45GHz ECR Proton



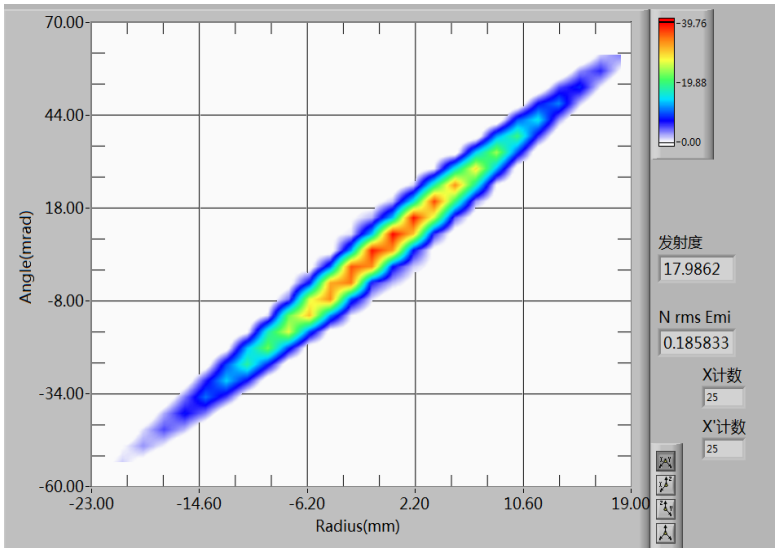
[1] **S. X. Peng**, A. L. Zhang, H. T. Ren, etc. *Chin. Phys. B*, **26(2):** 025206(2017).
[2] **S. X. Peng***, A. L. Zhang, H. T. Ren, etc., *Rev. Sci. Instrum.*, **87:** 02A706(2016).
[3] **S. X. Peng***, A. L. Zhang, H. T. Ren, etc., *Chin. Phys. B* **24(7)** :075203(2015).
[4] 张艾霖博士论文，强**流直流质子源若干物理与技**术问题**的研究**，2017年6月，中
[5] 直流质子源现场验收报告，2016年6月30日.

☞ Details of the 50mA@50keV CW H^+ Beam

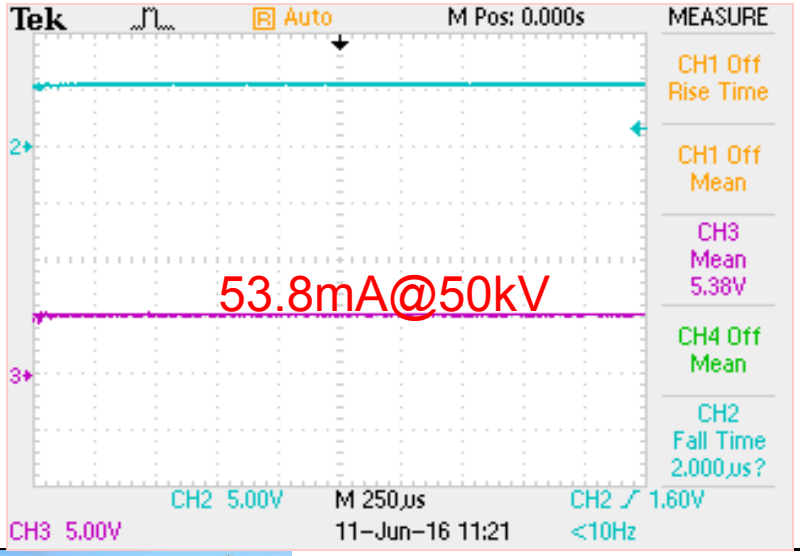
➢ Beam Transverse Distribution



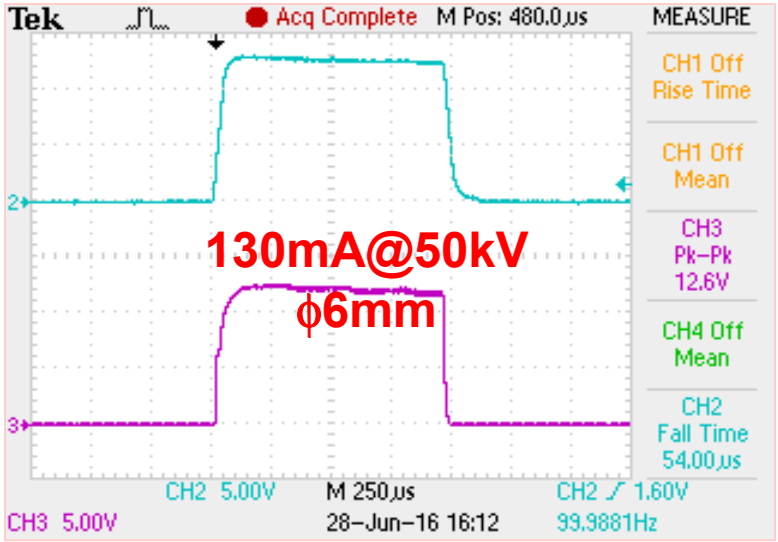
➢ Its rms emittance 0.186



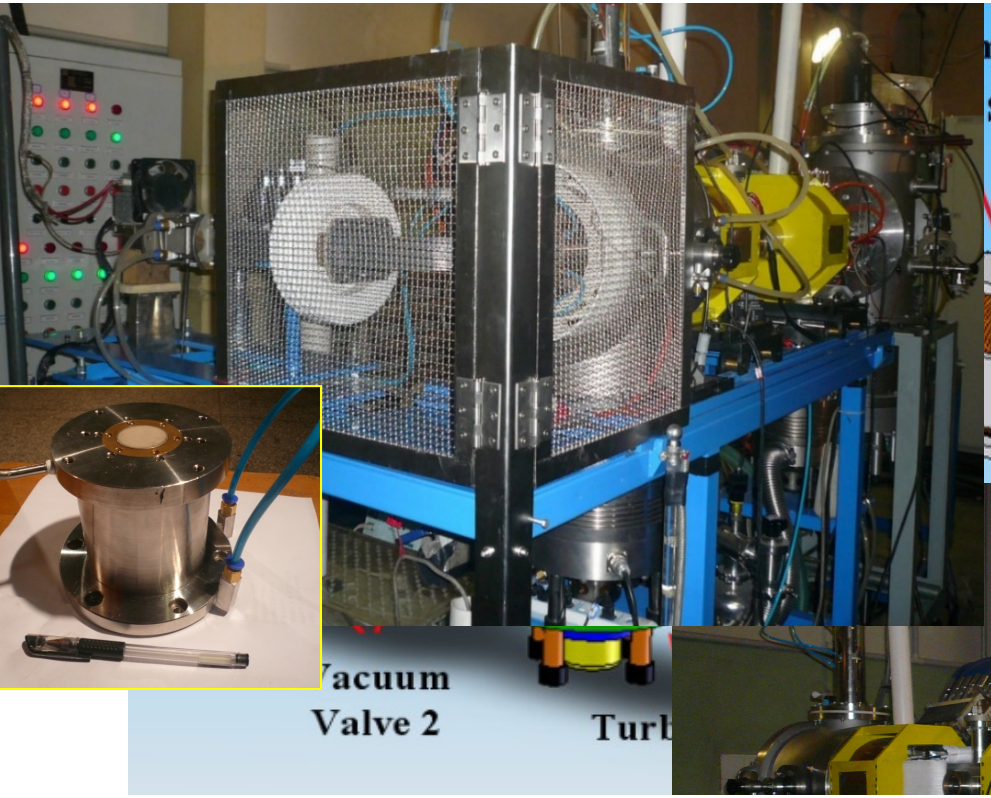
➢ Moment beam record

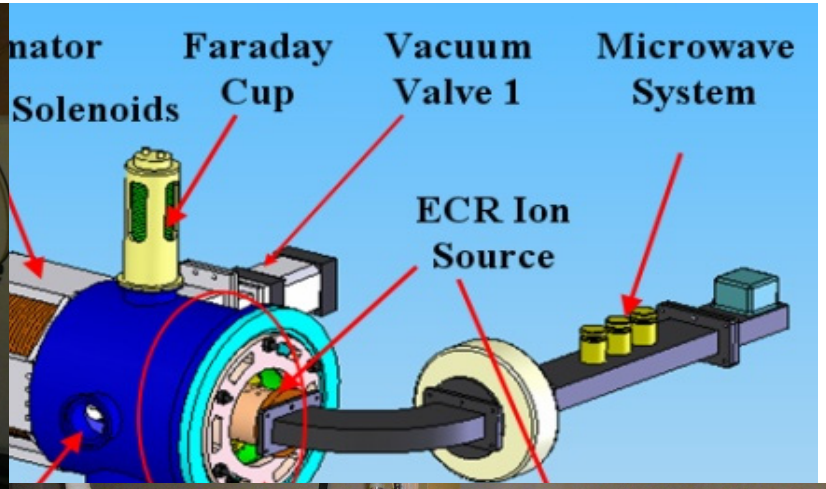


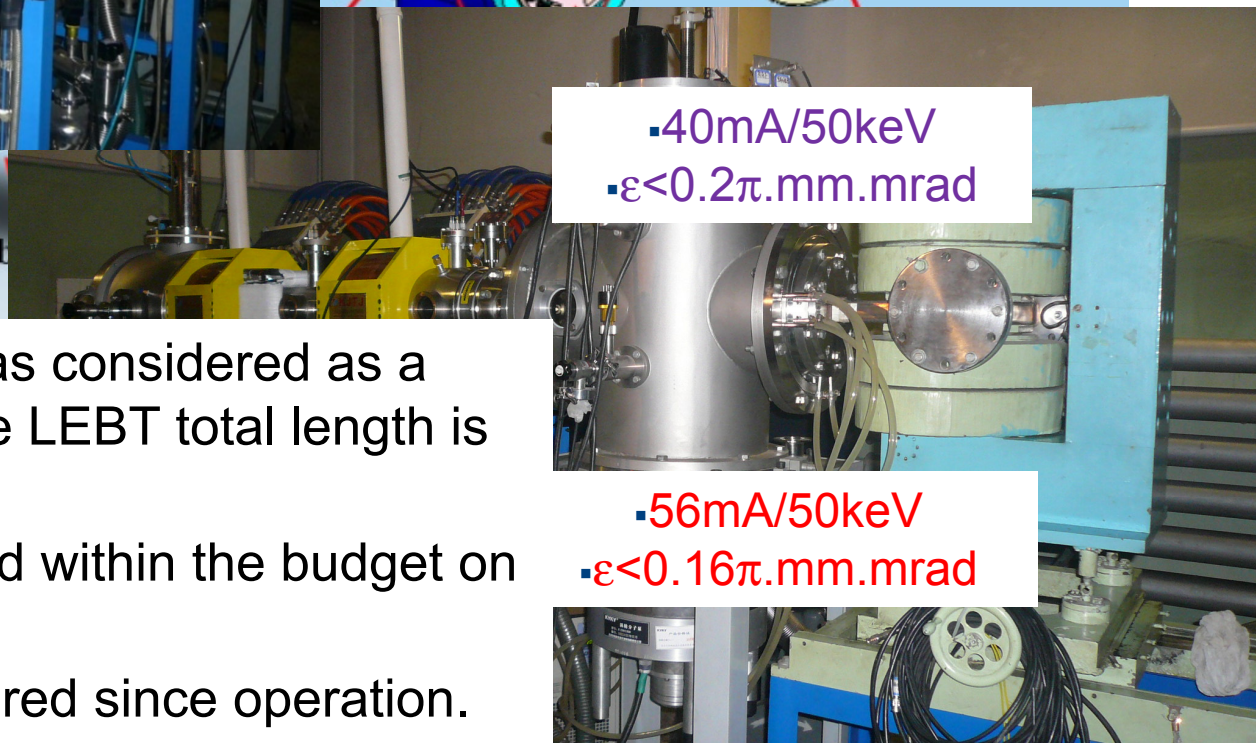
➢ Pulsed Beam



D^+ Injector for PKUNIFTY, 2010/5







- 40mA/50keV
- ε<0.2π.mm.mrad

- 56mA/50keV
- ε<0.16π.mm.mrad

- Ion source and LEBT was considered as a whole in this design. The LEBT total length is 1.36m.
- This Injector was finished within the budget on time schedule.
- No maintenance is required since operation.

▪**S. X. Peng***, etc. *Rev. Sci. Instrum.* **83**, 02B711 (2012).

DWA, H+ Online (2013/10/15， Mianyang, SiChuan）

关于北京大学研制的质子注入器应用证明

项目名称	介质壁质子直线加速器关键技术研究
应用单位	中国工程物理研究院流体物理研究所
通讯地址	四川省绵阳市绵山路 64 号
联系方式	电话：0816-2484105　传真：0816-2485139
应用时间	2014—2018 年

兹有北京大学研制的质子注入器，自 2014 年起应用于中国工程物理研究院流体物理所承担的国防科工局核能开发项目“介质壁质子直线加速器关键技术研究”中。自运行以来，该注入器一直保持稳定的工作状态，为介质壁质子直线加速器的正常运行和各项实验的开展提供了重要的技术保障。

注入器自 2013 年 10 月交付以来，截至 2018 年 4 月累计运行时间 1498 小时，40KV 高压引出下输出的质子束流强稳定于 40mA 附近，其余指标均满足使用要求，运行期间未发生技术故障，稳定性和重复性

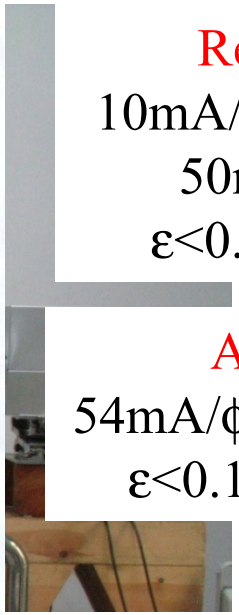
特此证明。

领域负责人签字：

应用人签

应用单位

2018 年 4 月



Requirement

10mA/ϕ10mm@40kV

50mA/ϕ40mm

ε<0.1π.mm.mrad

Achieved

54mA/ϕ10mm@40kV

ε<0.1π.mm.mrad

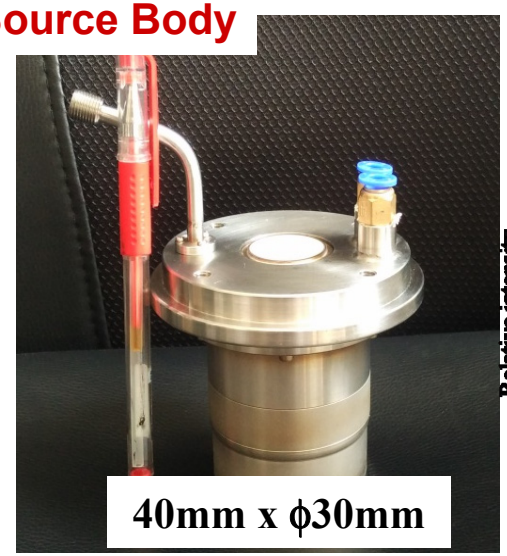
- Up to April 2018
- Count operation time: 1498h
- No beam-off
- No sparks
- High Stability
- High reproducibility
- No maintenance is required up to now.

S.X. Peng*, etc., NIM A**763** (2014) 120-123.

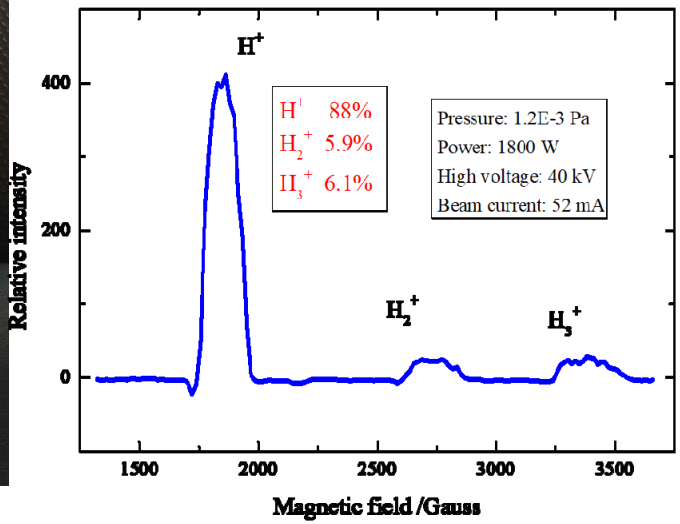
Some other relevant progress at PKU

1)New Miniaturized 2.45GHz ECR Ion Source

- **Source Body**



- Pulsed mode with 100Hz@1ms



CW@40kV

RF **180W@ 21.7mA** H^+

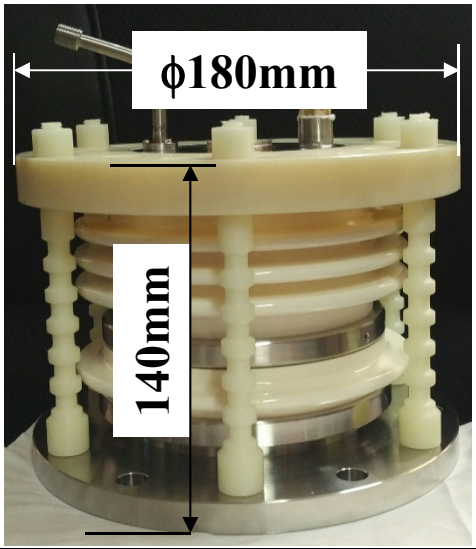
RF **10W@3mA** H^+

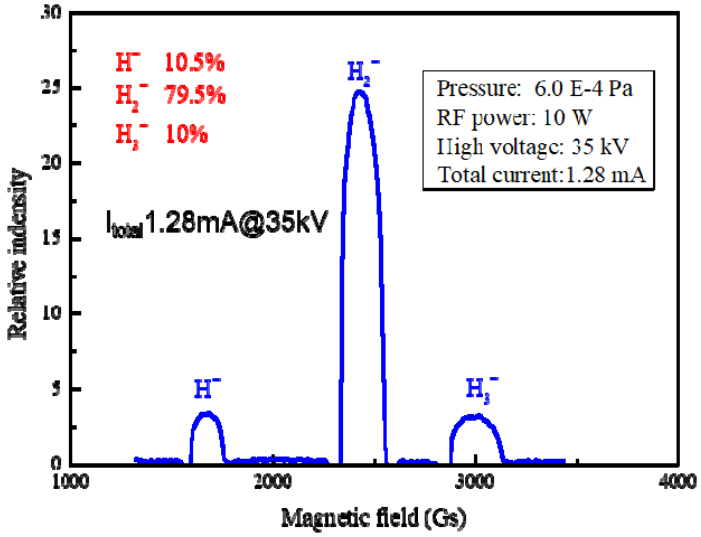
1.7mA He^+

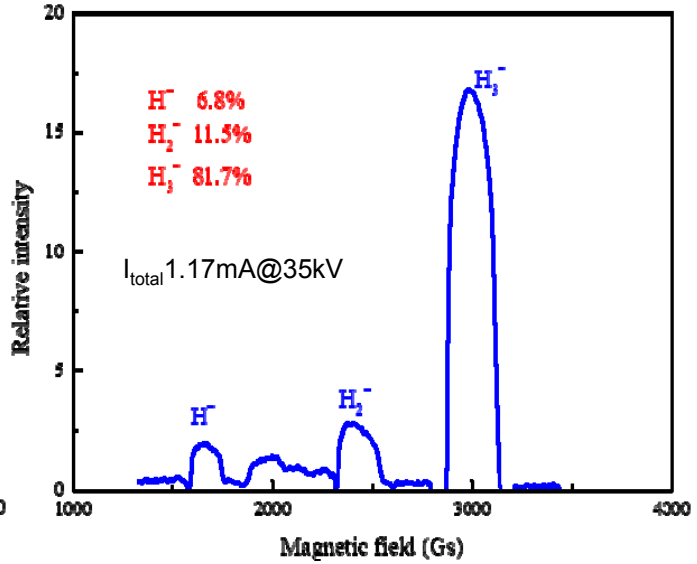
CW@5kV

He^+ **1.7mA@10W**

- **Integrated one**



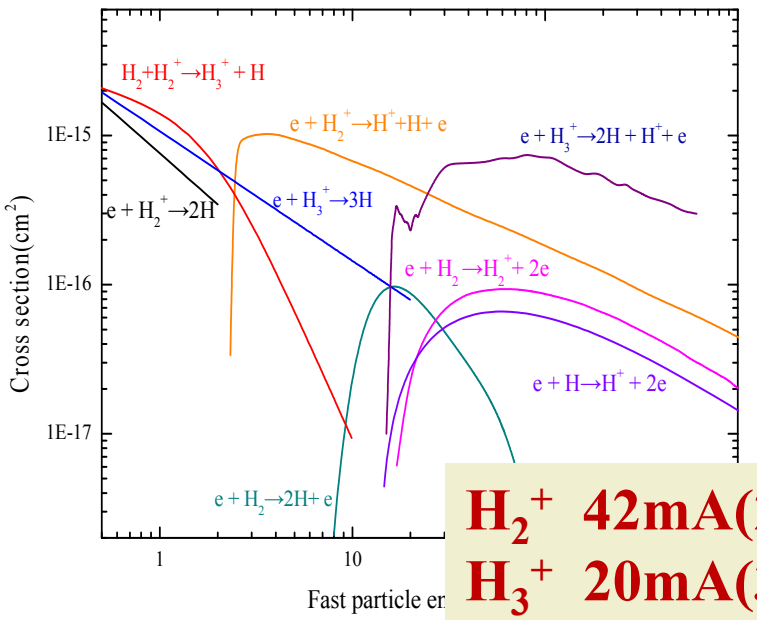




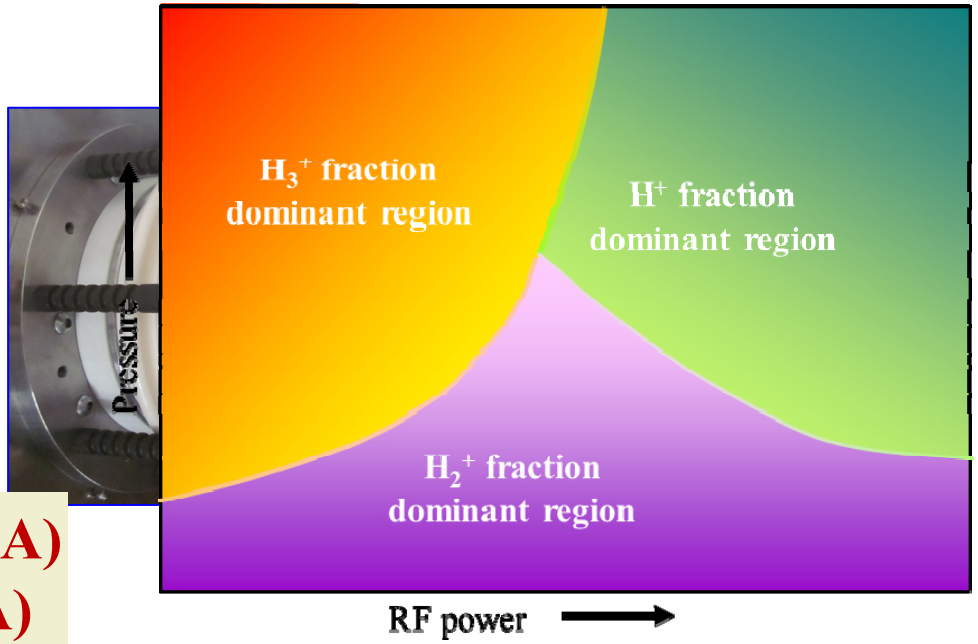
[1] Jia-Mei Wen, Shi-Xiang Peng, etc., Chin. Phys. B, 27(5) (2018): 055204.

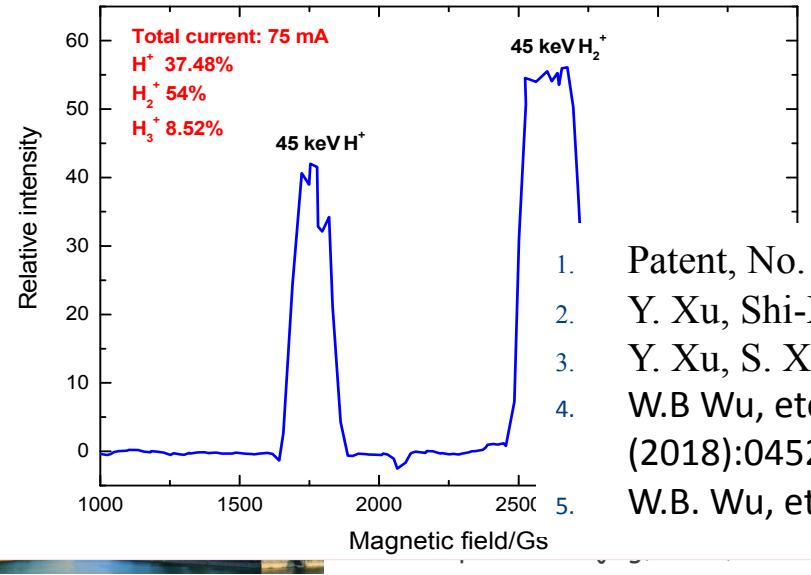
Some relevant progress at PKU

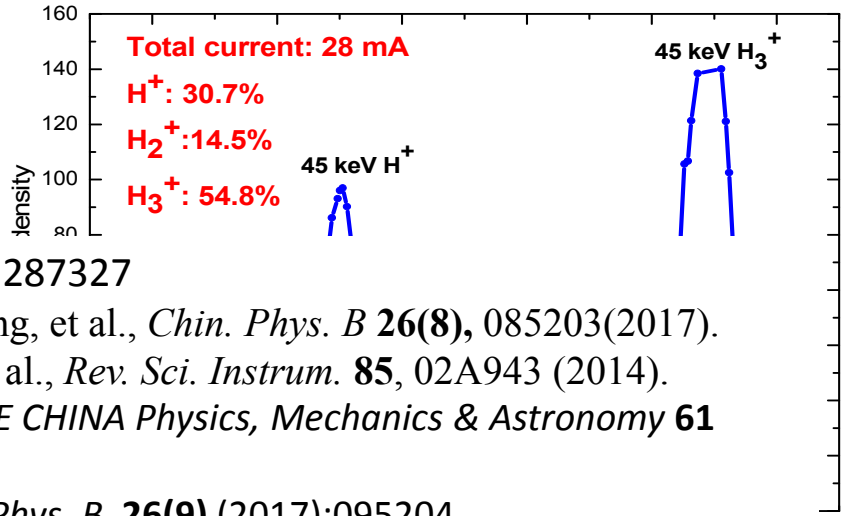
2) H_2^+/H_3^+ PMECR Source – D^+ linac, limited space charge efficiency



H_2^+ 42mA(20mA)
H_3^+ 20mA(3mA)







1. Patent, No. 2017103287327
2. Y. Xu, Shi-Xiang Peng, et al., *Chin. Phys. B* **26(8),** 085203(2017).
3. Y. Xu, S. X. Peng, et al., *Rev. Sci. Instrum.* **85**, 02A943 (2014).
4. W.B Wu, etc, *SCIENCE CHINA Physics, Mechanics & Astronomy* **61** (2018):045211.
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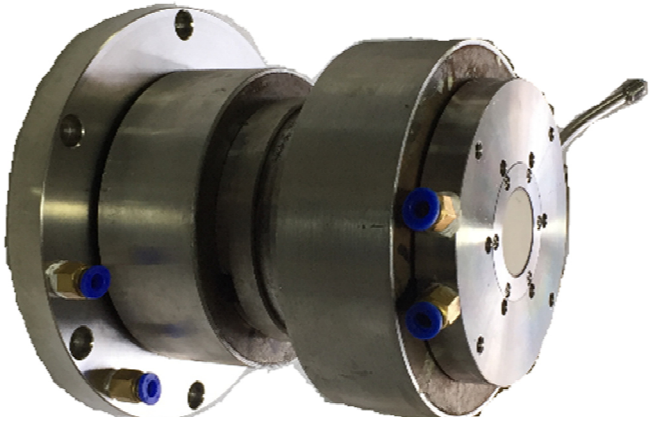
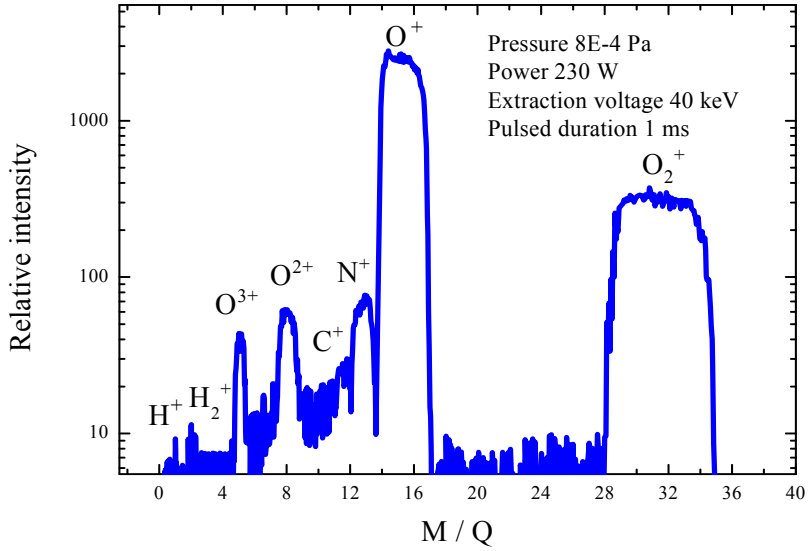
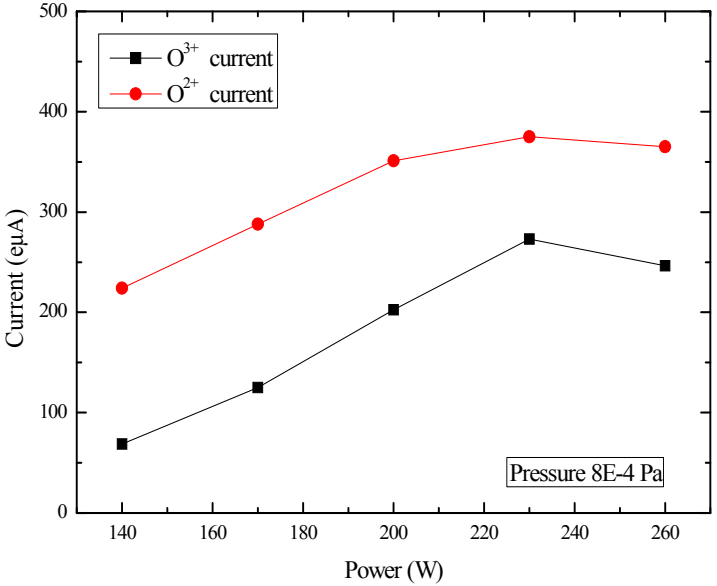
Some relevant progress at PKU

3) 2.45 GHz Microwave Driven Multi-charged Ion Source





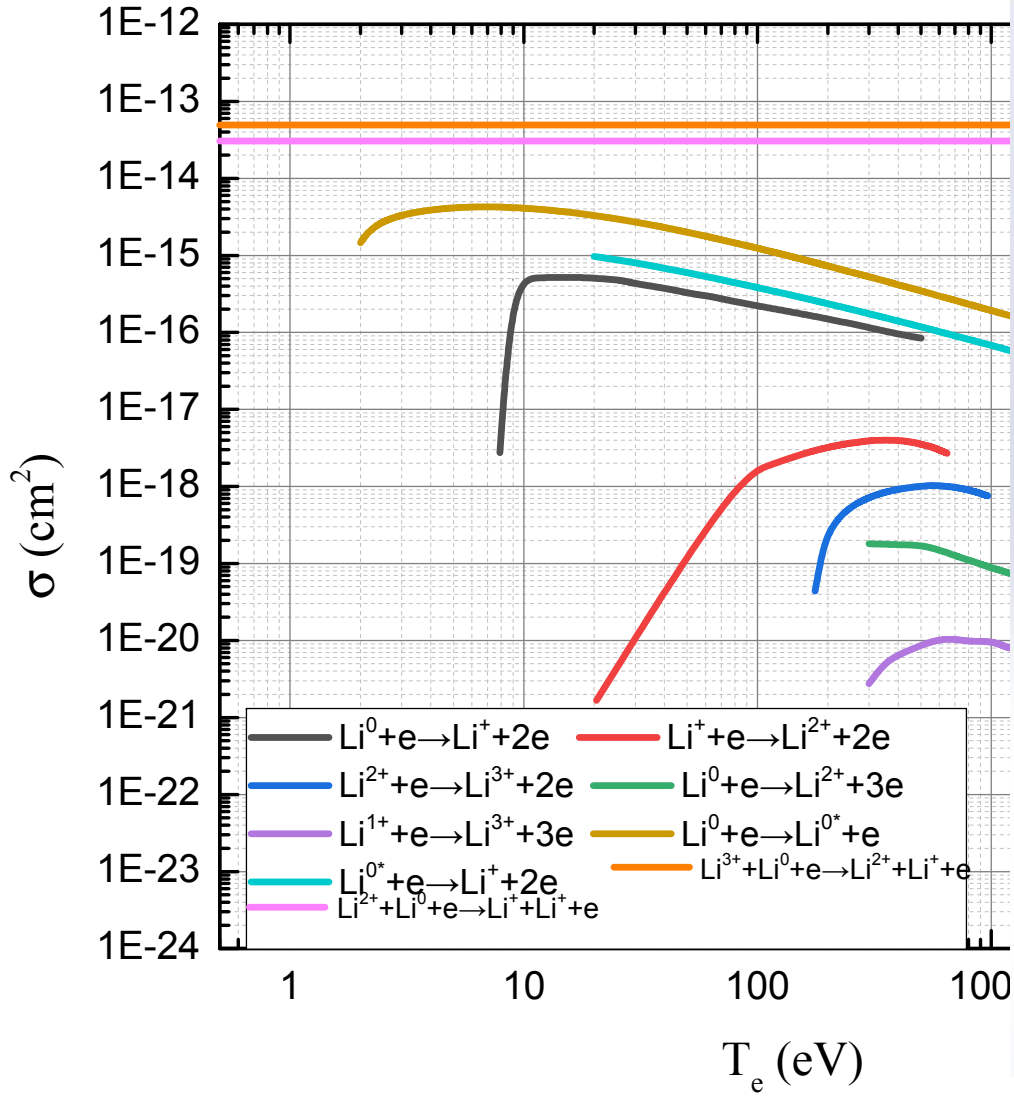


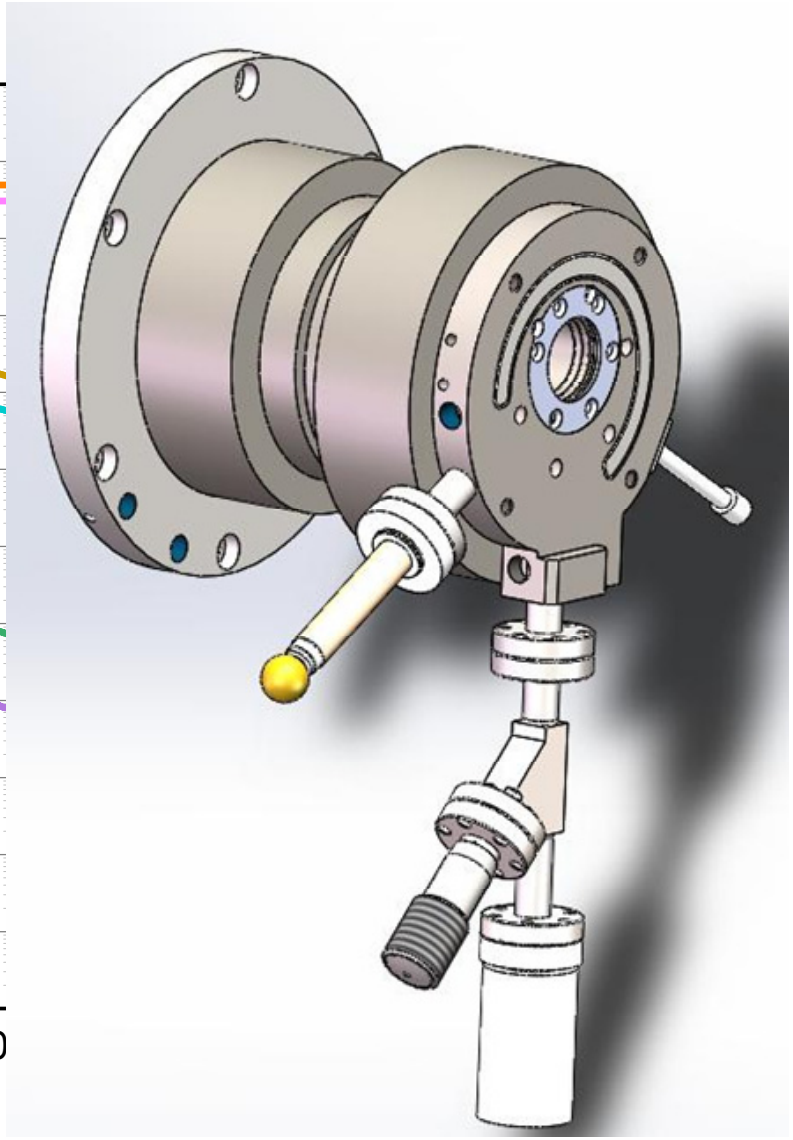
- O^{3+} 273 eμA
- O^{2+} 446eμA
- He^{2+} 4.4mA

1. Y. Xu, Shixiang Peng, et al., *SCIENCE CHINA Physics, Mechanics & Astronomy* **60**(6), 060021(2017).

Some relevant progress at PKU

4) Li^{3+} source is on the way





Summary

- High Intensity Single Charged ion beams are more and more requested by High Intensity Accelerators.
- Results of CEA/Saclay and PKU 2.45GHz ECR cases prove that the requirements of High Intensity Linacs on **beam intensity**, **reliability**, **emittance**, and so on**, can be met by this type source.**

  Source(source body, extraction system, HV region…) can be a little bit **larger** or **smaller.**

  Current can be up to **100 mA** or down to **1 mA**.
- A 2.45GHz ECR ion source can be explored to produce **tens mA H_2^+/H_3^+** and **hundred μA O^{2+}, O^{3+}** etc. with some **specific design** according to the **element** characteristic.
- **For a high intensity LINAC, a better way is to consider the Ion source and the LEBT as a whole.**

Thank you for your attention!

感谢您的关注！