C IV Line Intensity Studies using SH-HtscEBIT for Assisting Tokamak Plasma Diagnostics

Xiao Jun

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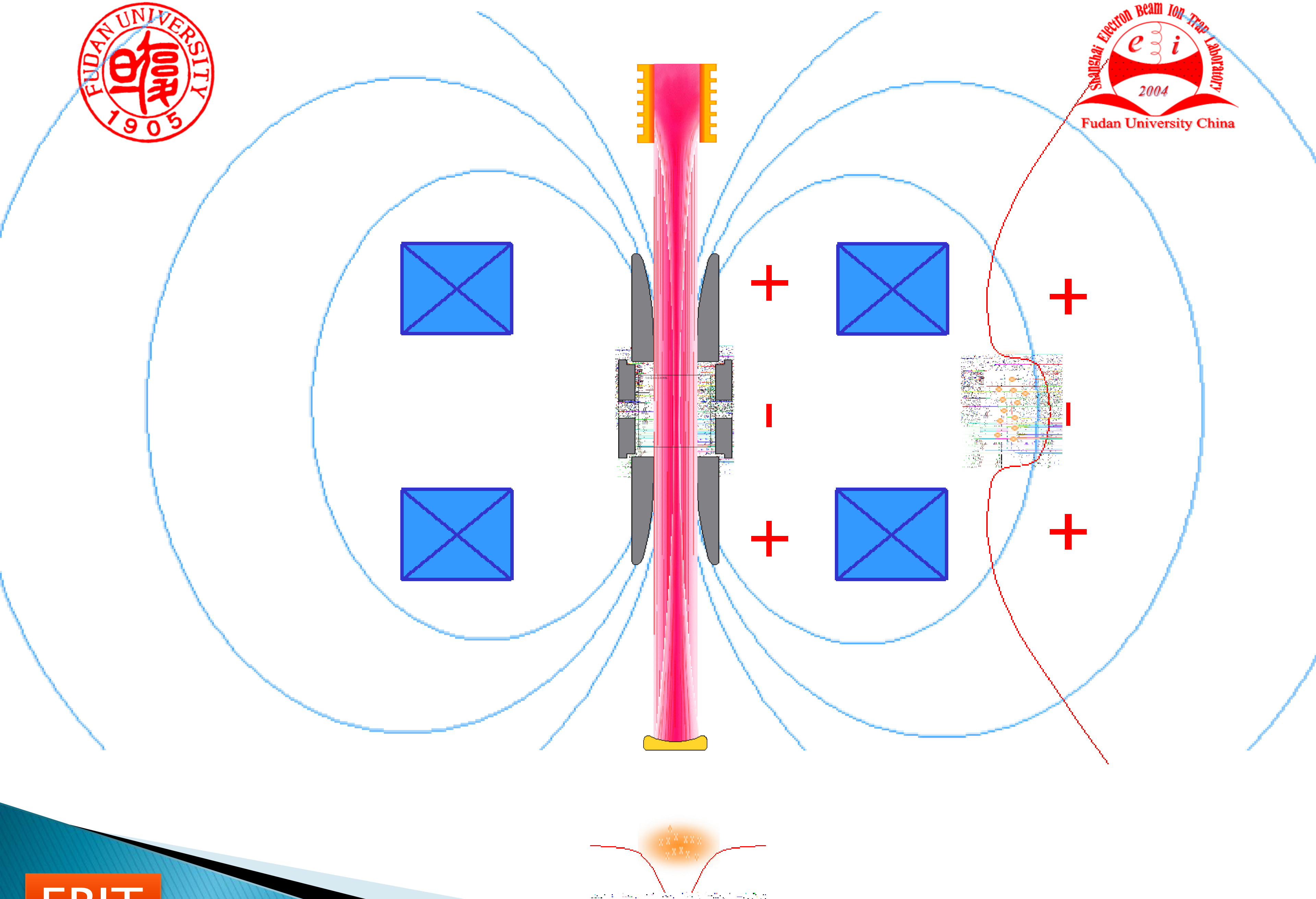
ADAS2016@Gunsan

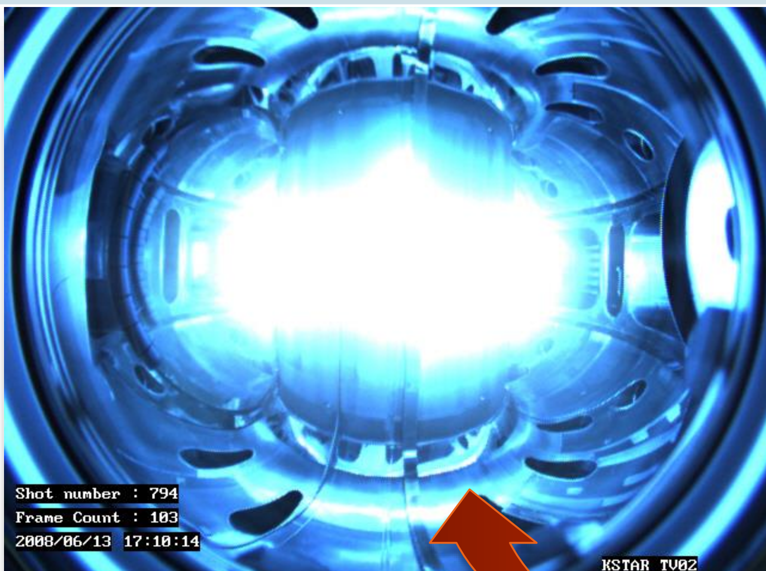
Shanghai EBIT Lab

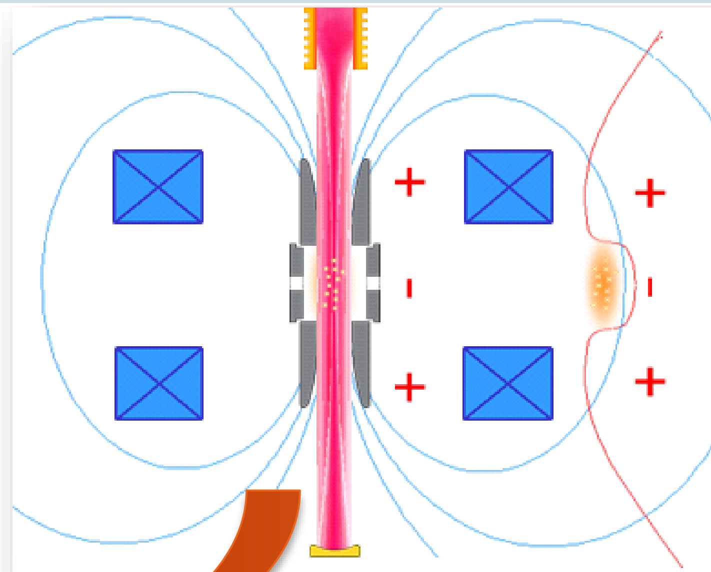


EBIT

Tokamak vs EBIT Plasmas

Tokamak Plasmas	EBIT Plasmas
often have several ion species	have one or a few
numerous atomic processes	can isolate
have bulk motions & hot	cold and stationary





Electron Density:

EBIT: ~10^{16} m^{-3}

Tokamak: ~10^{19} m^{-3}

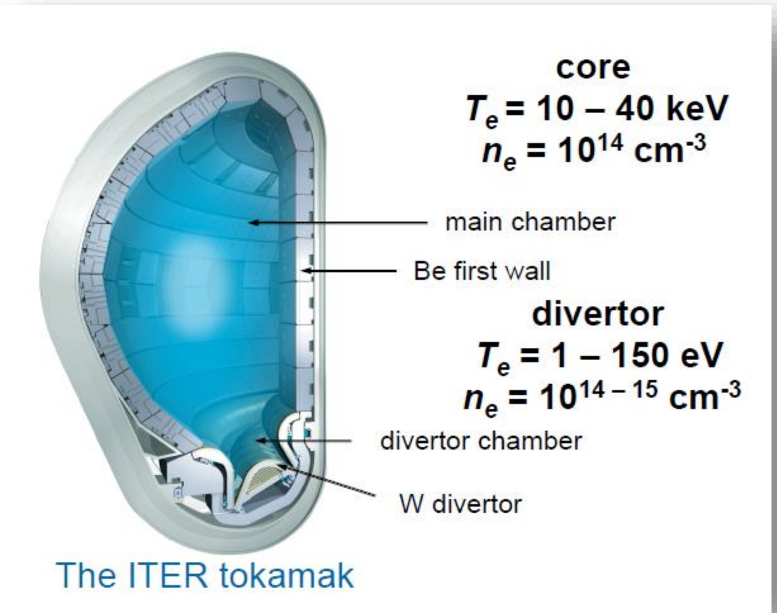
What can EBITs do?

1. Survey and Identification of Unreported Lines

   Benchmark Spectra for disentangling plasma spectra

2. Plasma Diagnostics: Density, Temperature, Magnetic Field

… DR

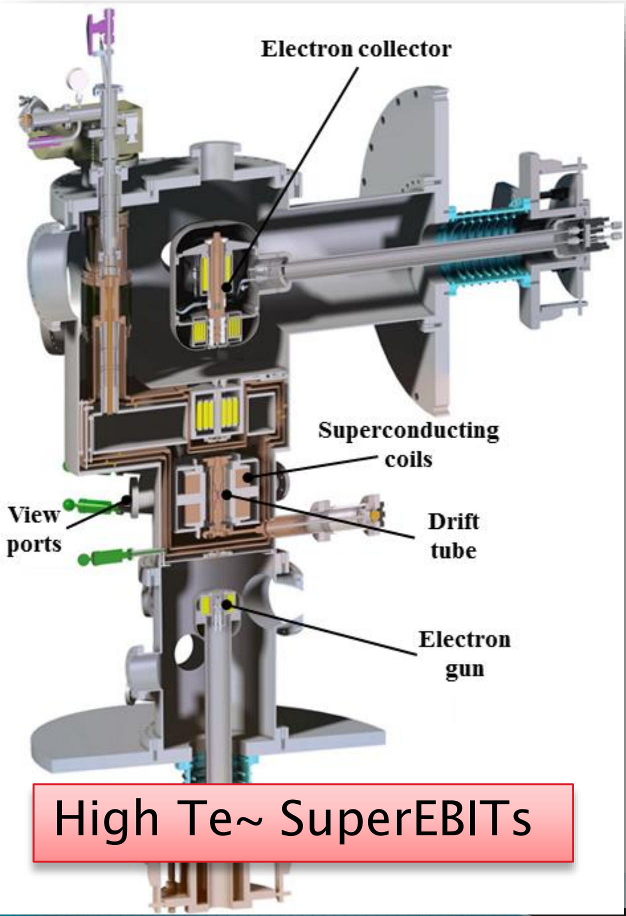


High Te~ SuperEBITs

Low Te~ MiniEBITs

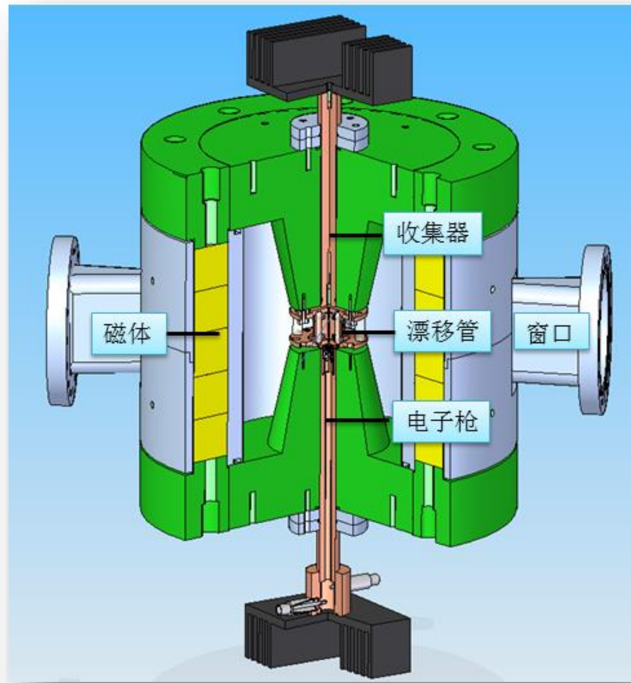
ShanghaiEBITs

Shanghai EBIT
1~150 keV

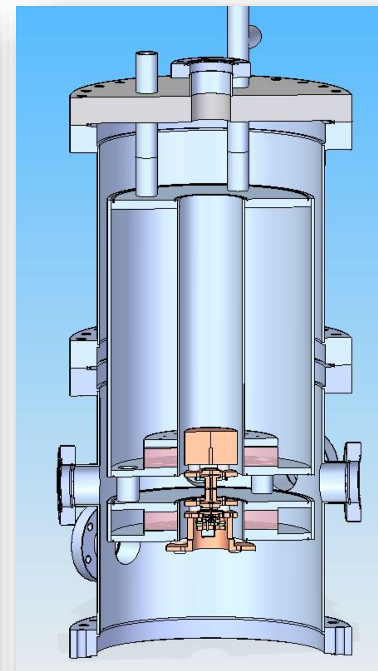


High Te~ SuperEBITs

SH-PermEBIT
60~5000 eV

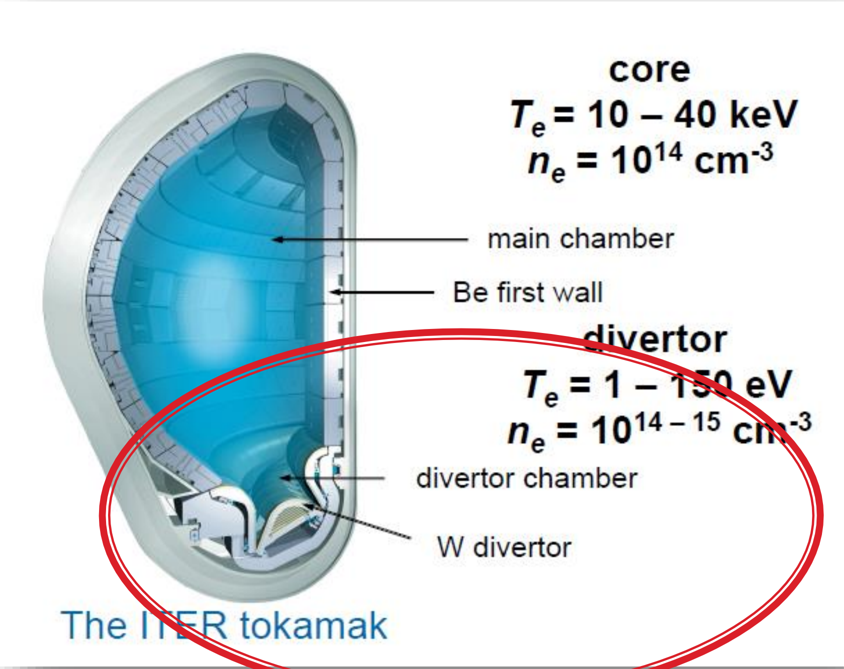


SH-HtscEBIT
30~4000 eV

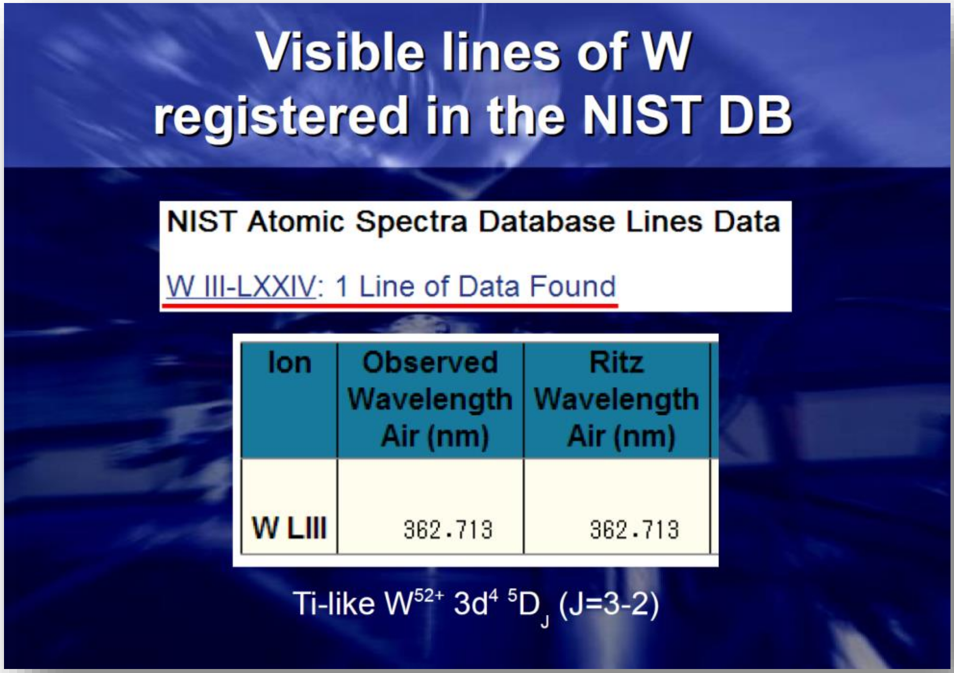


Low Te~ MiniEBITs

1.Tungsten Spectroscopy



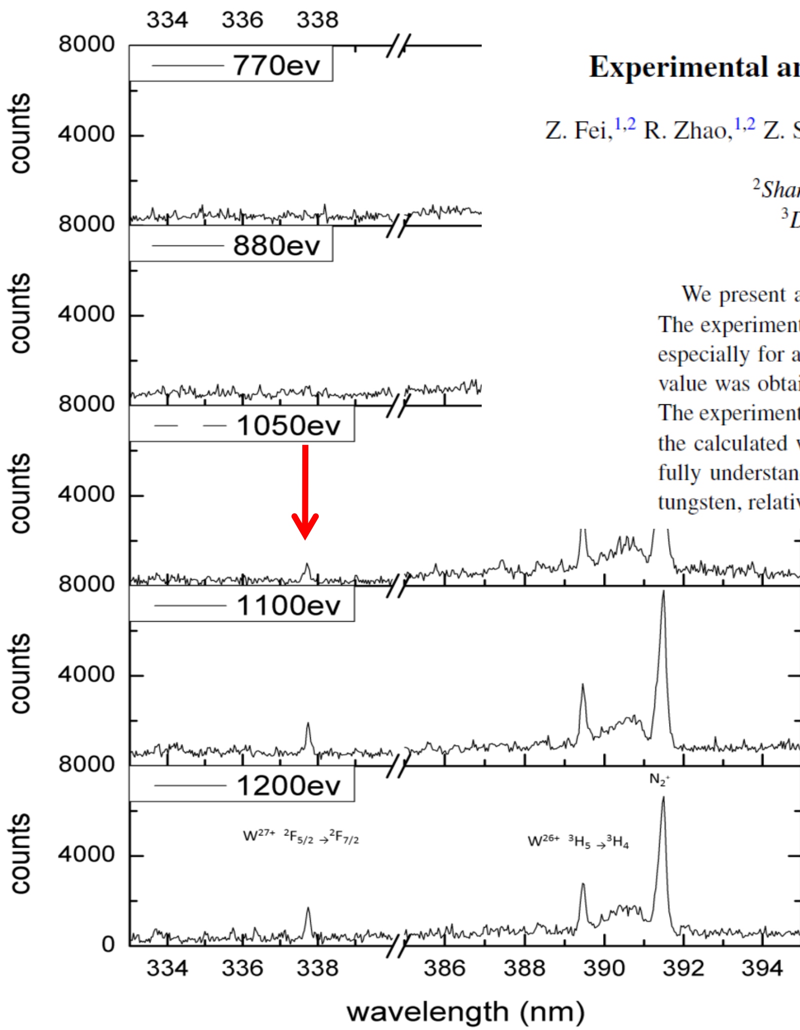
Tungsten and the NIST data tables



Ion	Observed Wavelength Air (nm)	Ritz Wavelength Air (nm)
W LIII	362.713	362.713

Very Few is Known about Tungsten Spectroscopy !

1.Tungsten Spectroscopy



PHYSICAL REVIEW A **86**, 062501 (2012)

Experimental and theoretical study of the ground-state *M*1 transition in Ag-like tungsten

Z. Fei,[1,2] R. Zhao,[1,2] Z. Shi,[1,2] J. Xiao,[1,2] M. Qiu,[1,2] J. Grumer,[3] M. Andersson,[1,2] T. Brage,[3] R. Hutton,[1,2,*] and Y. Zou[1,2,†]
[1]*The Key Lab of Applied Ion Beam Physics, Ministry of Education, China*
[2]*Shanghai EBIT Laboratory, Modern Physics Institute, Fudan University, Shanghai, China*
[3]*Division of Mathematical Physics, Department of Physics, Lund University, Sweden*
(Received 13 August 2012; published 3 December 2012)

We present an experimental and theoretical study of the $^2F_{5/2} \rightarrow {}^2F_{7/2}$ $M1$ transition in Ag-like W (W^{27+}). The experiments employed the Shanghai permanent magnet electron beam ion trap, which has been developed especially for assisting spectroscopic diagnostics of edge plasmas for magnetic fusion devices. The theoretical value was obtained using the GRASP2K set of computer codes and included a comprehensive correlation study. The experimental $M1$ wavelength was measured as 3377.43 ± 0.26 Å (3378.43 Å vacuum wavelength), whereas the calculated wavelength is in good agreement at 3381.80 Å. This good agreement shows the importance of fully understanding the electron correlation effects to predict the energy of the fine structure even in this, for tungsten, relatively simple case.

Z Z Fei et. al, **Phys. Rev. A 86**, 062501 (2012)
R F Zhao et.al **J. Phys. B. 47**, 185004(2014)
M L Qiu et.al, **J. Phys. B. 47**, 175002 (2014)
Z Z Zhao et.al, **J. Phys. B. 47**, 175002 (2014)
W X Li et.al, **Phys.Rev. A 91**.062501(2015)

27+, 26+,25+,28+,13+,…

2. Line Intensity Studies

JET divertor

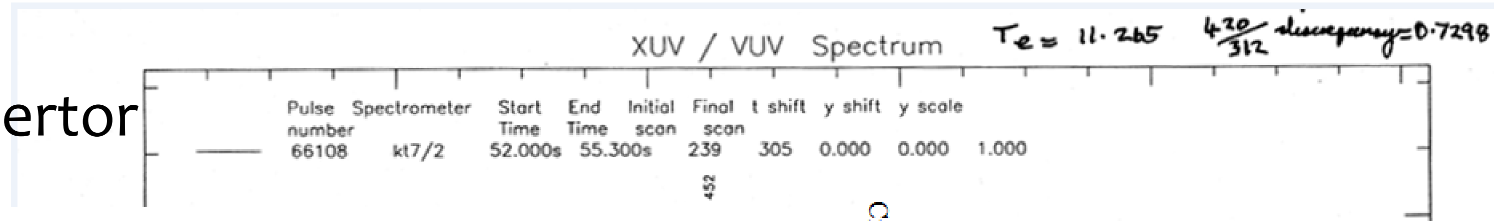
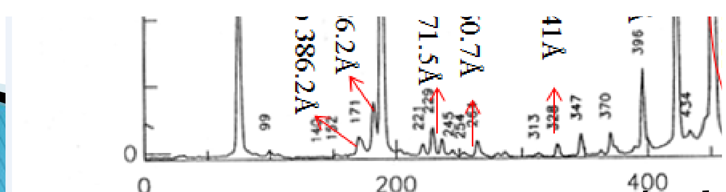
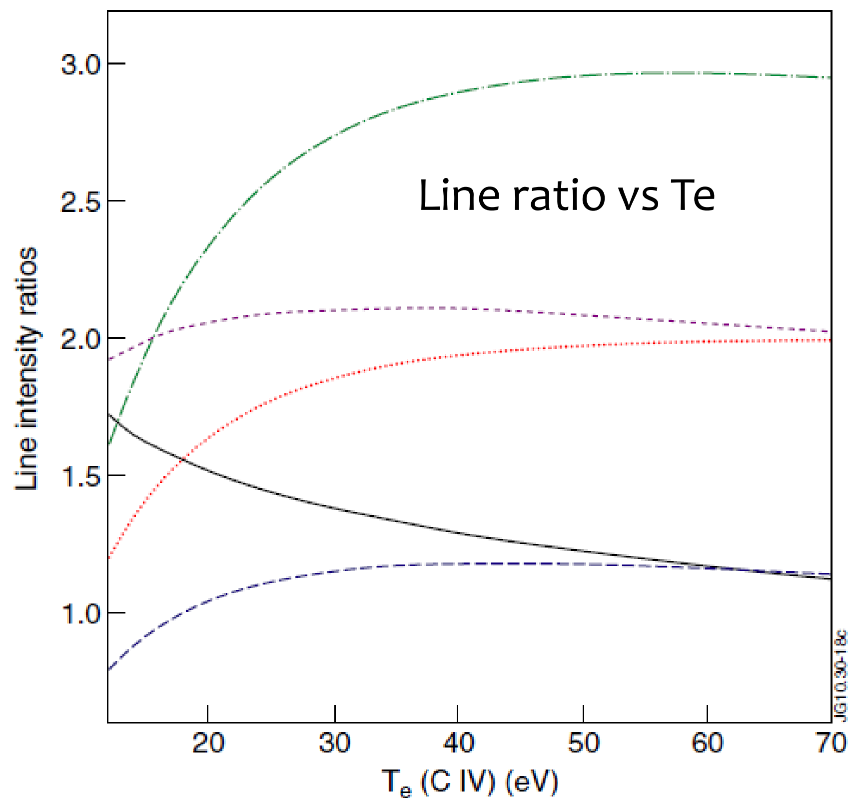


Table 1. C IV lines used in the analysis.

Wavelength (Å)	Transition
244.9	$1s^2 2s\ ^2S_{1/2}–1s^2 4p\ ^2P_{1/2,3/2}$
289.2	$1s^2 2p\ ^2P_{1/2,3/2}–1s^2 4d\ ^2D_{3/2,5/2}$
296.9	$1s^2 2p\ ^2P_{1/2,3/2}–1s^2 4s\ ^2S_{1/2}$
312.4	$1s^2 2s\ ^2S_{1/2}–1s^2 3p\ ^2P_{1/2,3/2}$
384.1	$1s^2 2p\ ^2P_{1/2,3/2}–1s^2 3d\ ^2D_{3/2,5/2}$
419.6	$1s^2 2p\ ^2P_{1/2,3/2}–1s^2 3s\ ^2S_{1/2}$





K D Lawson et. al, **Phasma Phys. Control. Fusion 53,** 015002 (2011)

Uncertainty & Discrepancy in Te Diagnostics

- Divertor~±10%
- SOL~Significant Discrepancies

Need more Cal or Exp

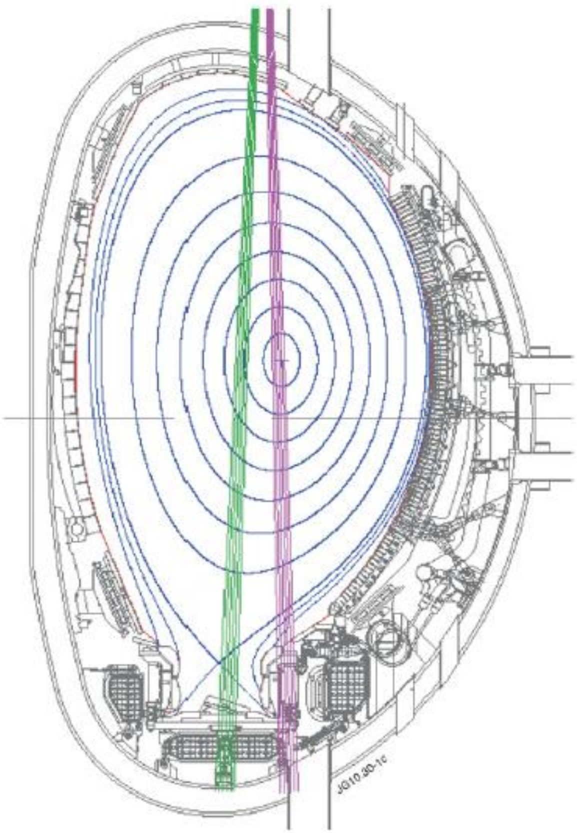


Figure 1. Lines-of-sight of the JET divertor-viewing spectrometer. — (left) divertor view, — (right) view to the SOL above outer divertor throat and — magnetic configuration of pulse 69957 at 10 s. (Colour online.)

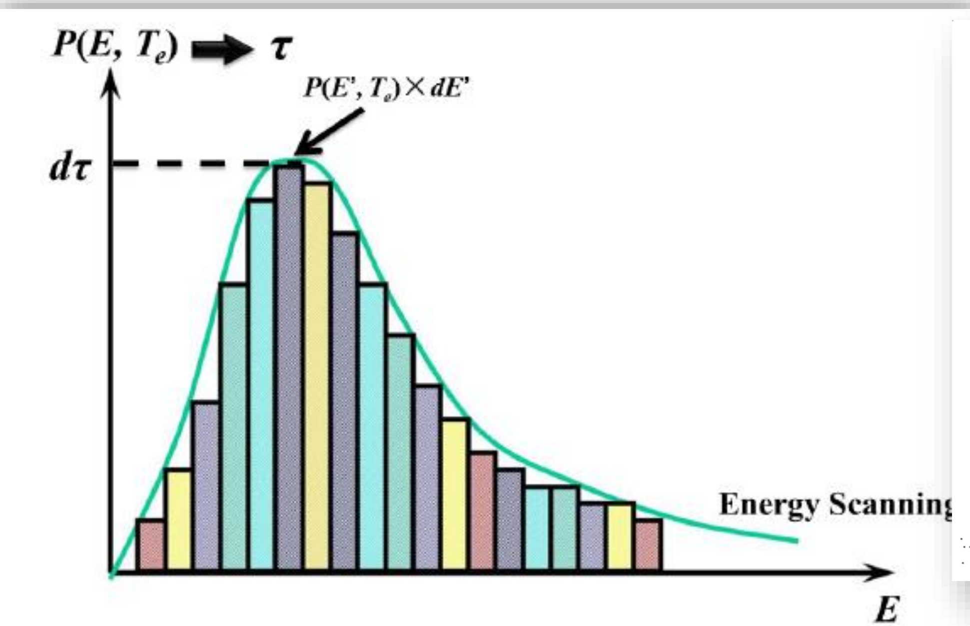
EBIT Simulation Principle

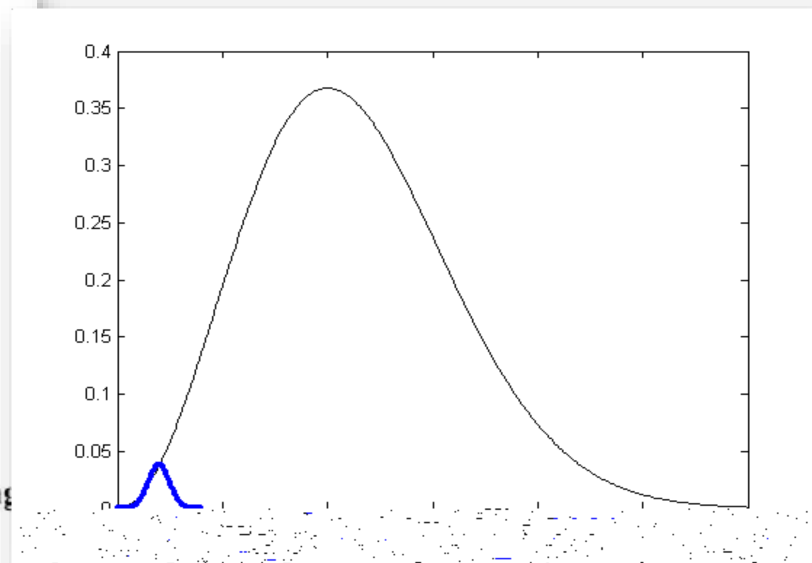
Maxwell-Boltzmann Distribution

$$P(E,T_e)dE = \frac{2E^{1/2}}{\pi^{1/2}(k_B T_e)^{3/2}} \exp\left(\frac{-E}{k_B T_e}\right) dE,$$

Time Distribution

$$\frac{d\tau}{\tau_0} = P(E',T_e)dE', \quad \tau(E) = \tau_0\left[\mathrm{erf}(x) - \frac{2xe^{-x^2}}{\sqrt{\pi}}\right]$$





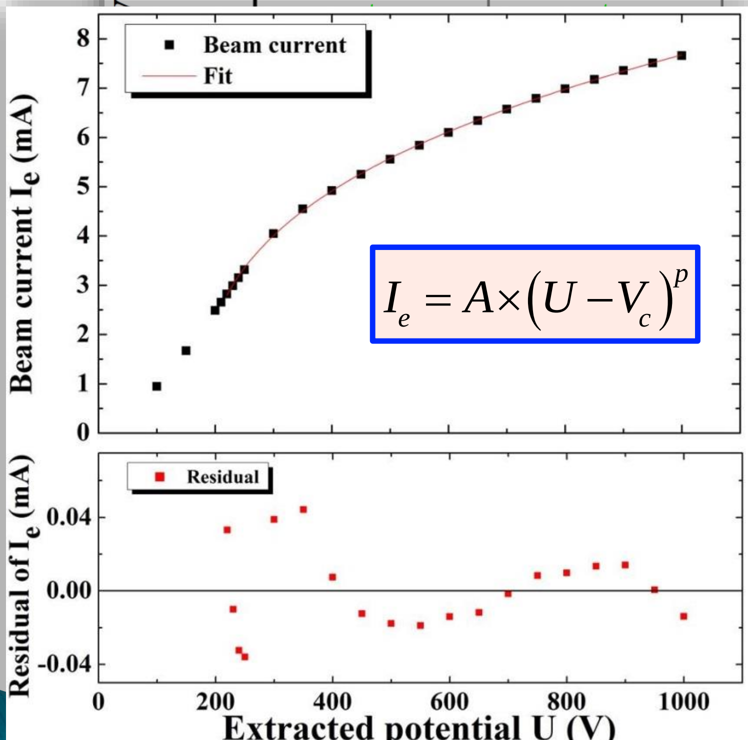
D.Savin et. al Rev. Sci. Instrum. 71, 3362(2000)

Scan Sequence of Electrodes

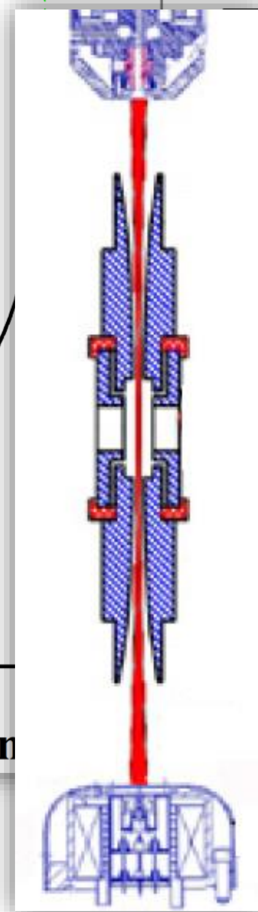
★ Keep the electron density const.

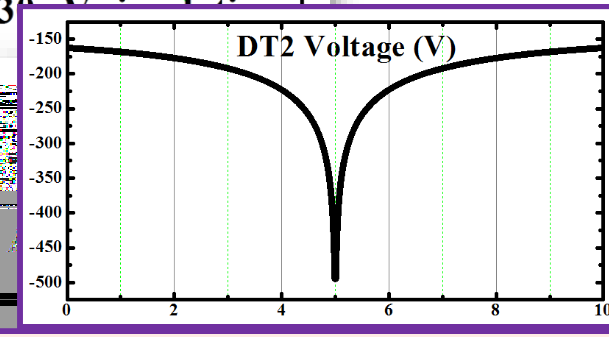
$$n_e \propto I_e \times E^{-1/2}$$

E_{max}~8T_e

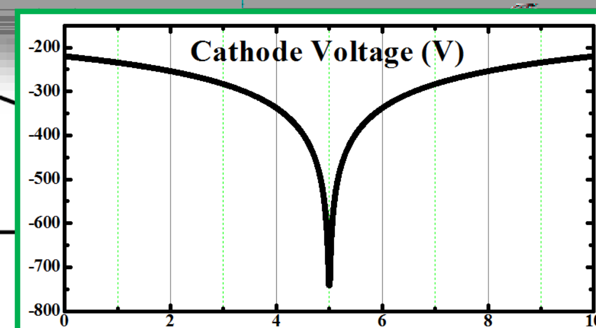


$$I_e = A\times\left(U - V_c\right)^p$$



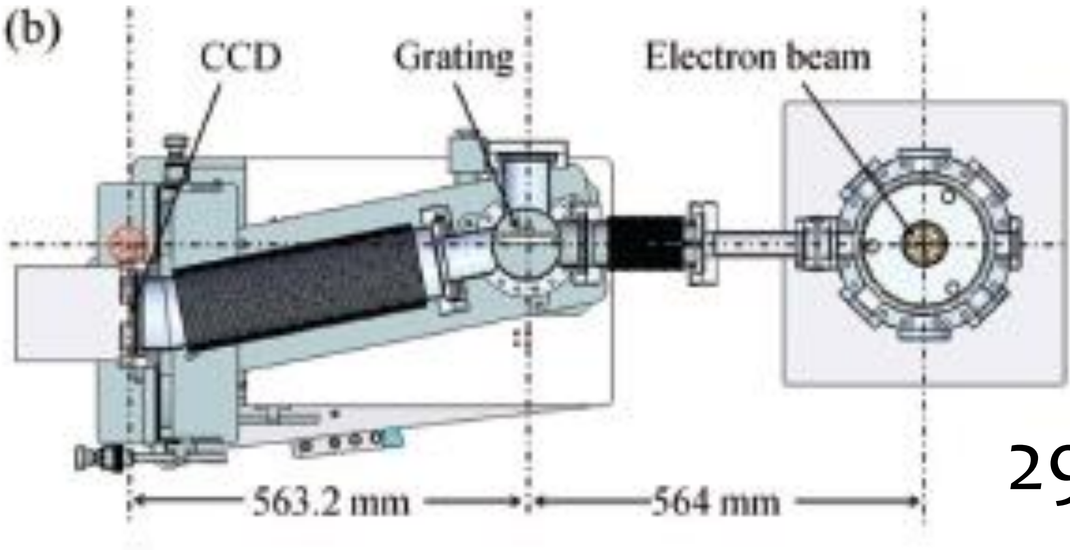


$$V_{DT2}(\tau) = E(\tau) + V_{cathode}(\tau) - V_{sp}$$



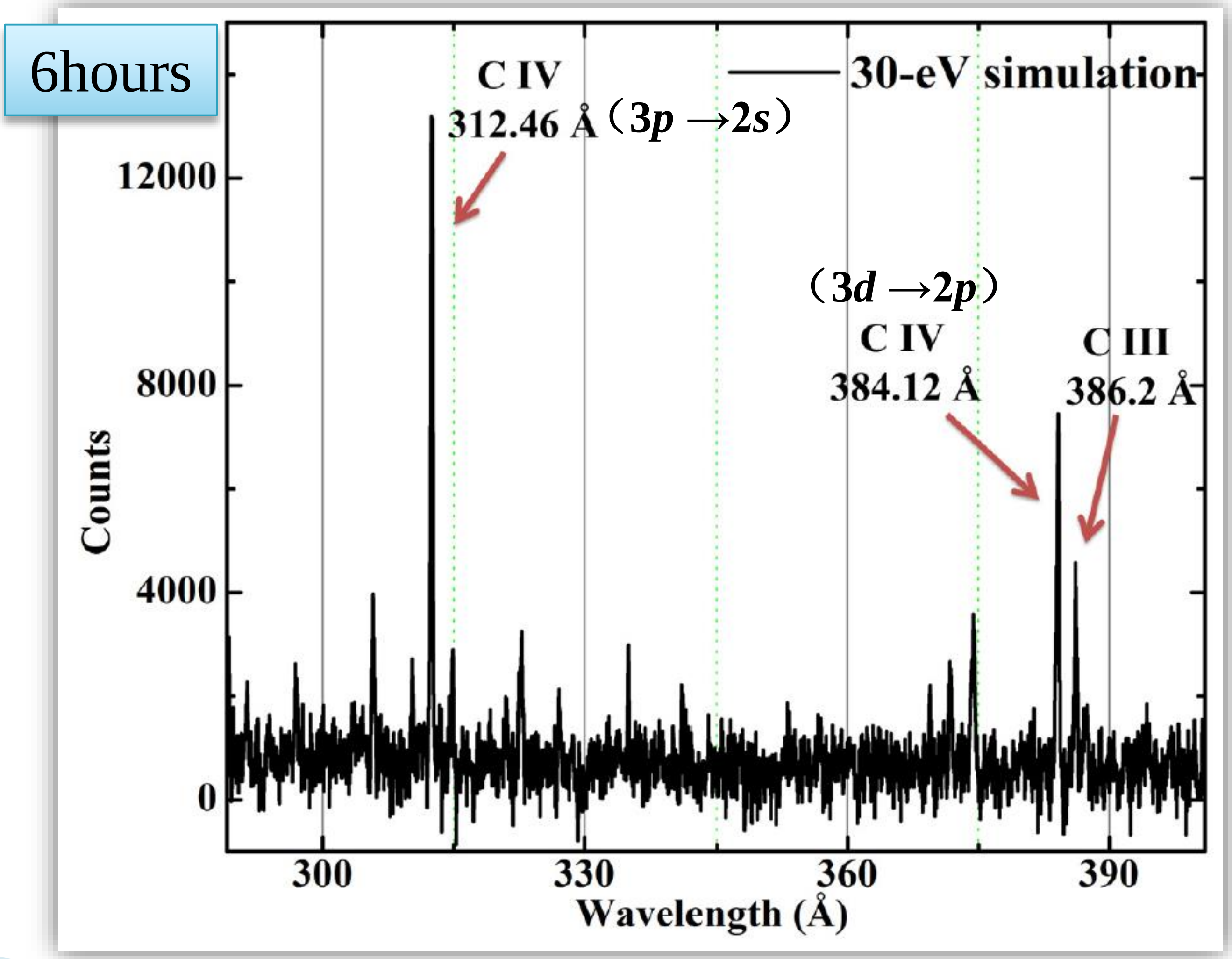
$$V_{cathode}(\tau) = \left(\frac{E(\tau)}{E_i}\right)^{\left(1/2p\right)}\left(V_c + V_i\right) - V_c$$

Experiment setup



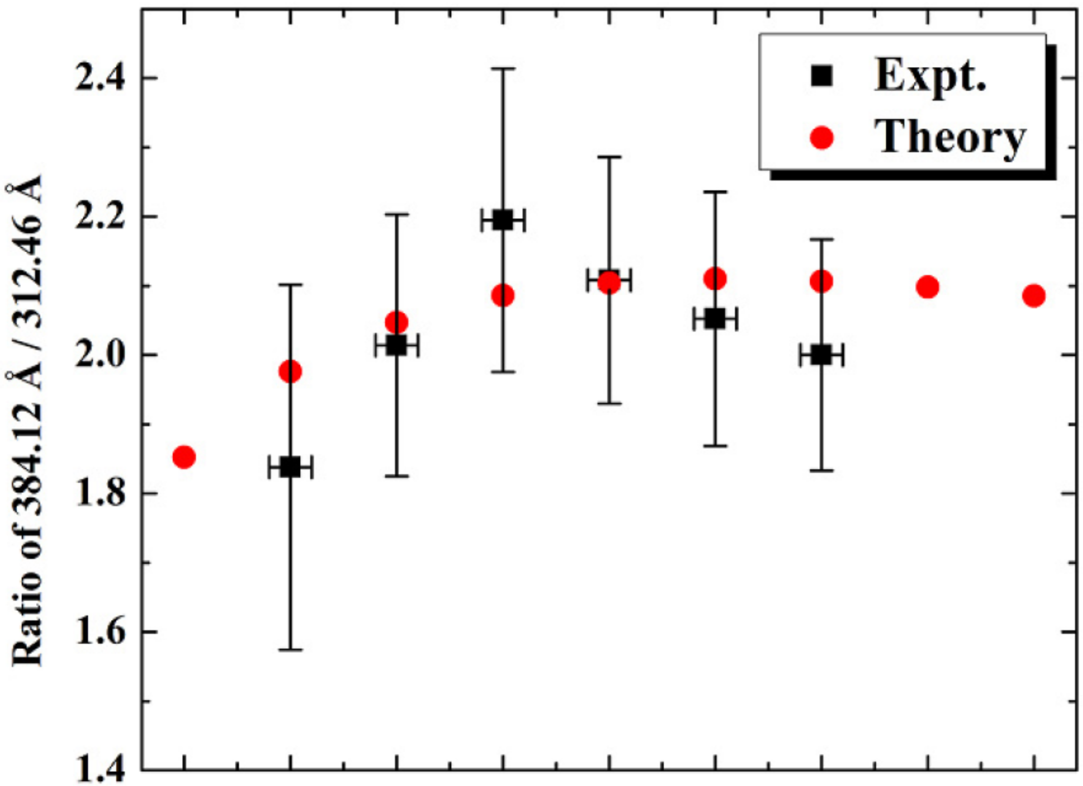
290-410 A

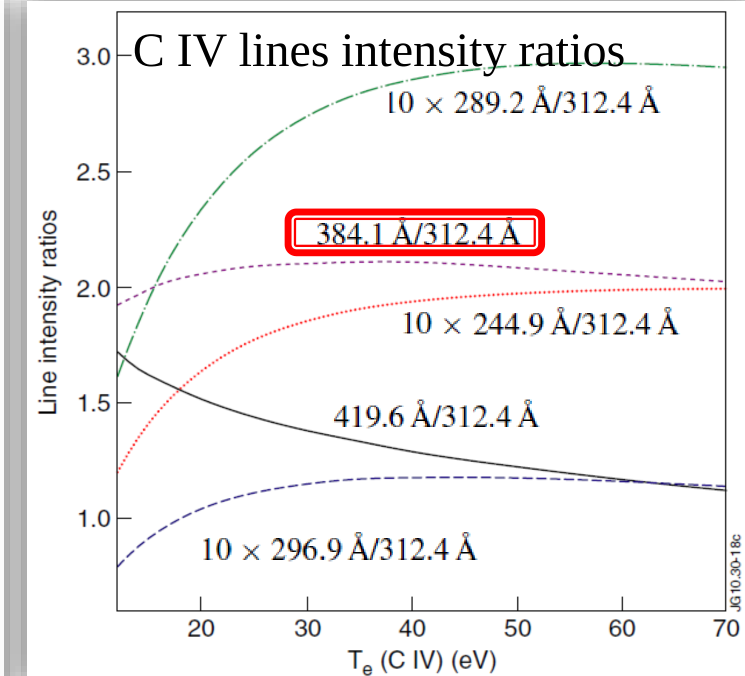
C IV spectra



6hours
C IV
312.46 Å（3*p* →2*s*）
30-eV simulation
（3*d* →2*p*）
C IV
384.12 Å
C III
386.2 Å
12000
8000
4000
0
Counts
300
330
360
390
Wavelength (Å)

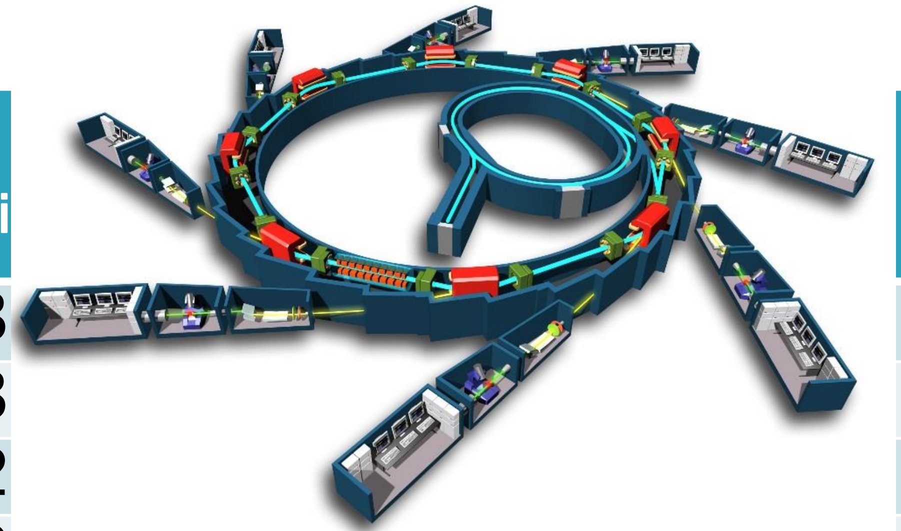
C IV line ratio
384.12 Å / 312.46 Å vs Te





Does this result mean something?

Relative Intensity Calibration Of the Spectrometer



Electron energy (eV)	Measured intensity rati		
80	0.75±0.03		
100	0.73±0.03		
120	0.72±0.02		
140	0.70±0.029	2.01	2.86
160	0.63±0.026	1.93	3.04
180	0.61±0.041	1.85	3.06

This calibration is not OK!
We need other way to calibrate the spectrometer…

EBIT and Tokamak?

Tokamak Plasma

CRM

Exp

EBIT Plasma

CRM-1

Exp-1

Conclusion

What can EBITs do?

1. Survey and Identification of Previously Unreported Lines

Benchmark Spectra for di... angling plasm...

2. Plasma Diag... ...sity, Tem... ...agnetic Field

… DR cross section

…

Wavelength

Line Intensity

- Thank you for your attention!
- 谢谢!