

# The First Ionization Potential Measurement of Lawrencium (Lr, $Z = 103$ )

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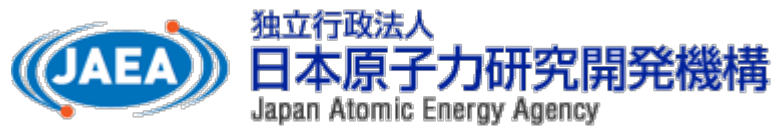
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# Collaboration

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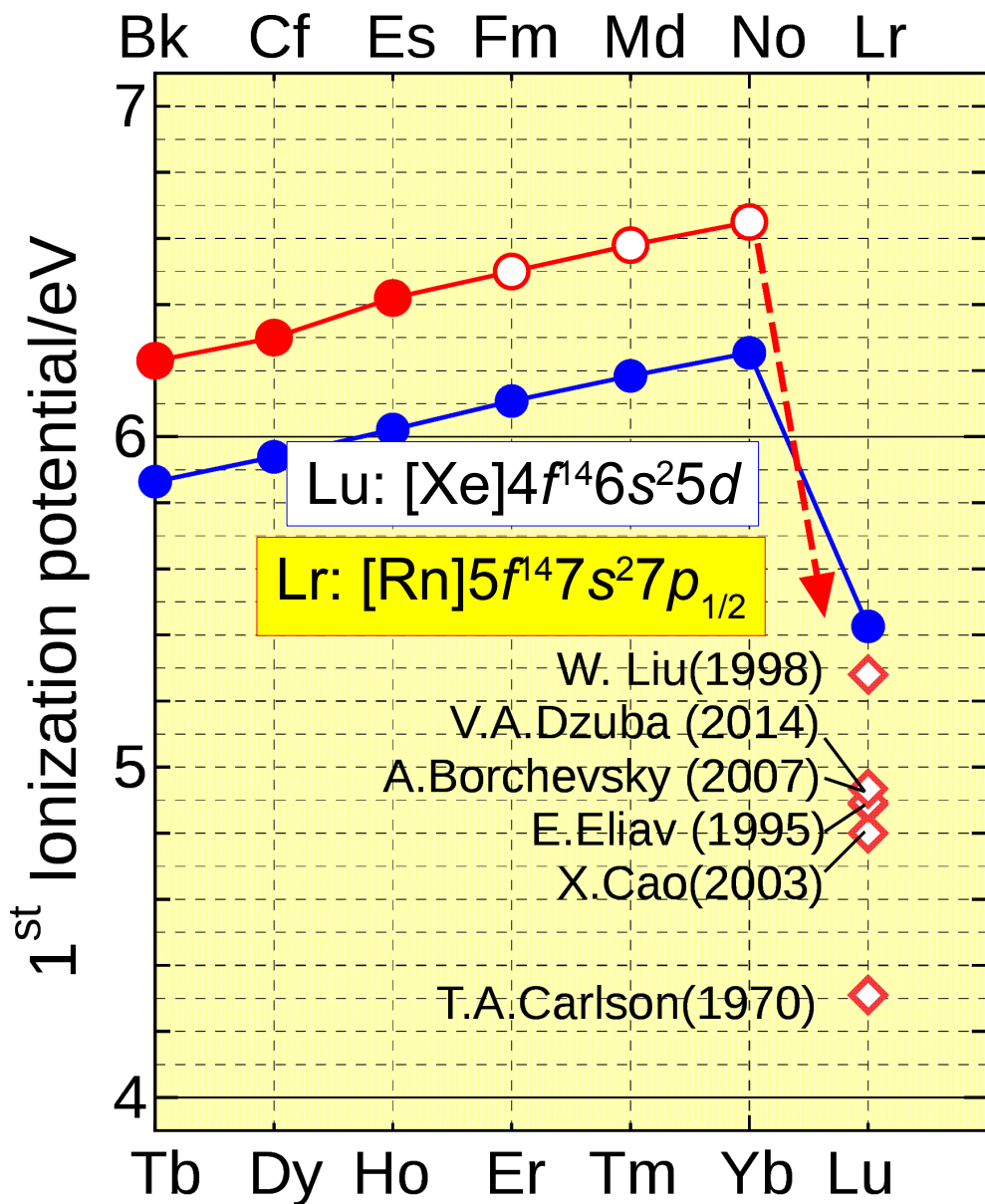
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# 1<sup>st</sup> ionization potential (IP<sub>1</sub>) of Lr



Production rate of <sup>256</sup>Lr ( $T_{1/2} = 27$  s)  
 : ~20 atoms/min

Properties of the heaviest elements must be studied on “an atom-at-a-time” scale.

**A NEW IP<sub>1</sub> measurement method is required for Lr.**

➔ **Surface ionization**

# Surface ionization

## Saha-Langmuir eq.

$$\alpha = \frac{N^+}{N^0} = \exp\left(\frac{\varphi - IP_1^*}{kT}\right)$$

Effective  $IP_1 (IP_1^*) : IP_1^* = IP_1 - kT \ln(Q_i/Q_o)$

$N^+$  and  $N^0$ : the numbers of ions and atoms

$\varphi$ : work function [eV]

$T$ : surface temperature [K]

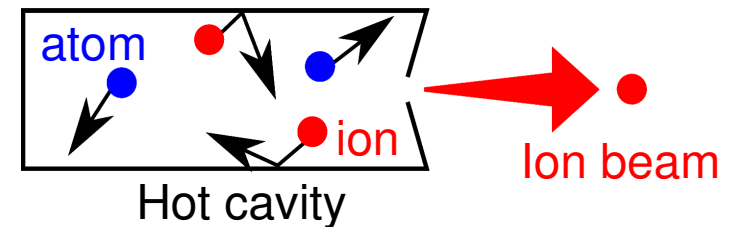
$Q_i$  and  $Q_o$ : statistical weights of ion and atom

$IP_1$ : 1<sup>st</sup> ionization potential

## Cavity effect in surface IS

$$\text{Ionization eff.} = \frac{N \alpha}{1 + N \alpha}$$

$N$ : number of collisions of an atom with a surface



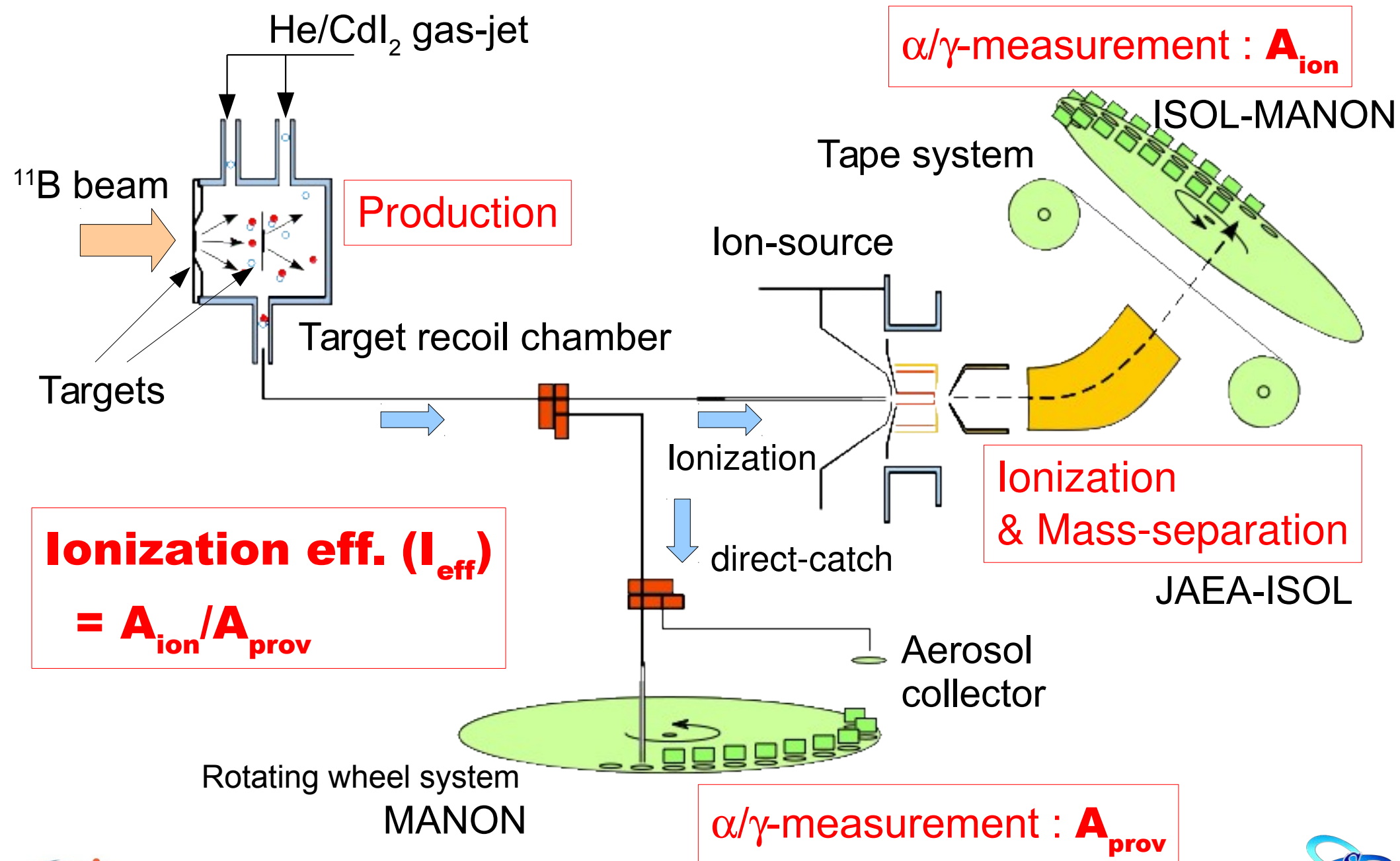
$$I_{eff} = \frac{A_{ion}}{A_{prov}} = \frac{N \exp\left(\frac{(\varphi - IP_1^*)}{kT}\right)}{1 + N \exp\left(\frac{(\varphi - IP_1^*)}{kT}\right)}$$

$A_{ion}$ : amount of ions

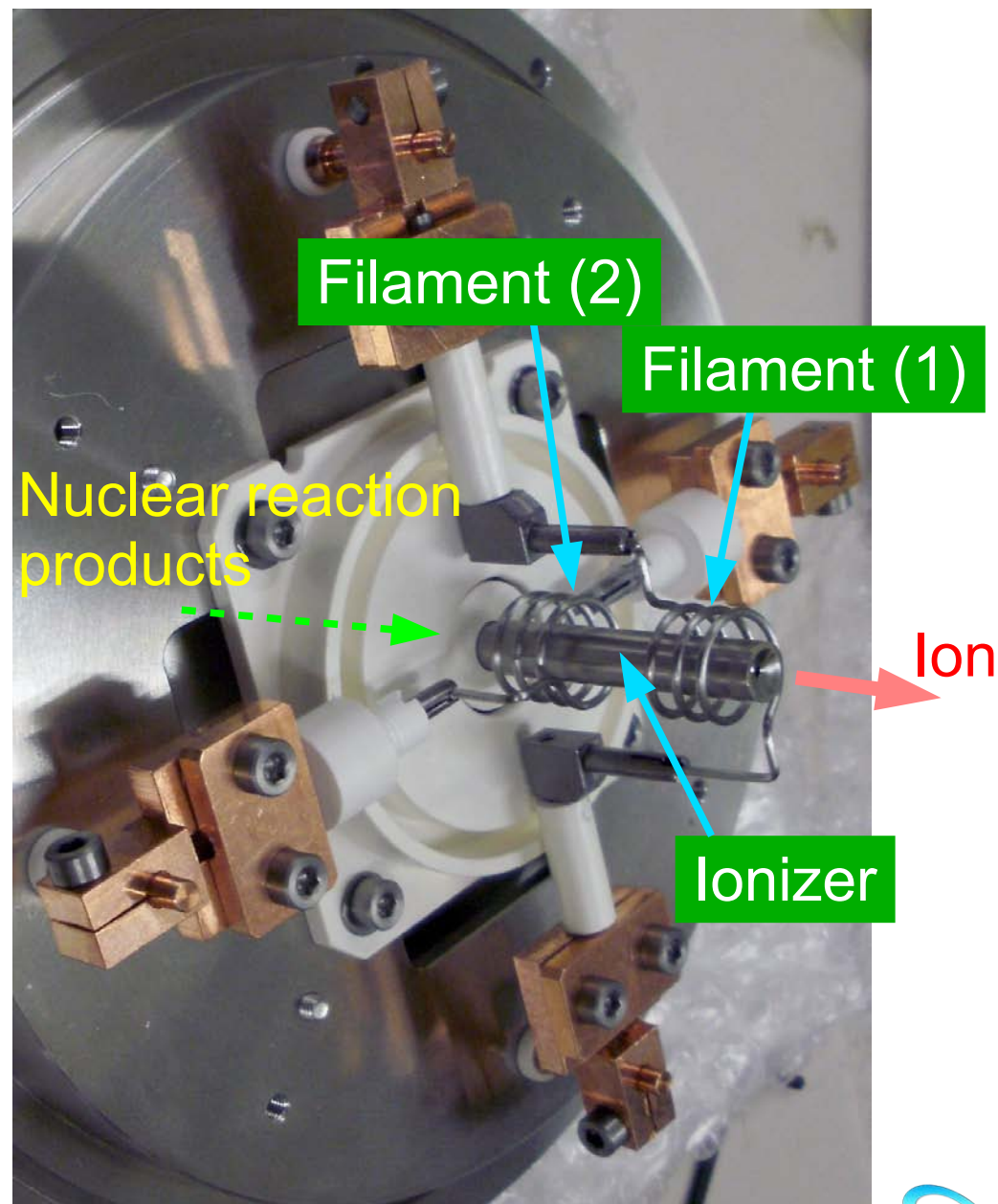
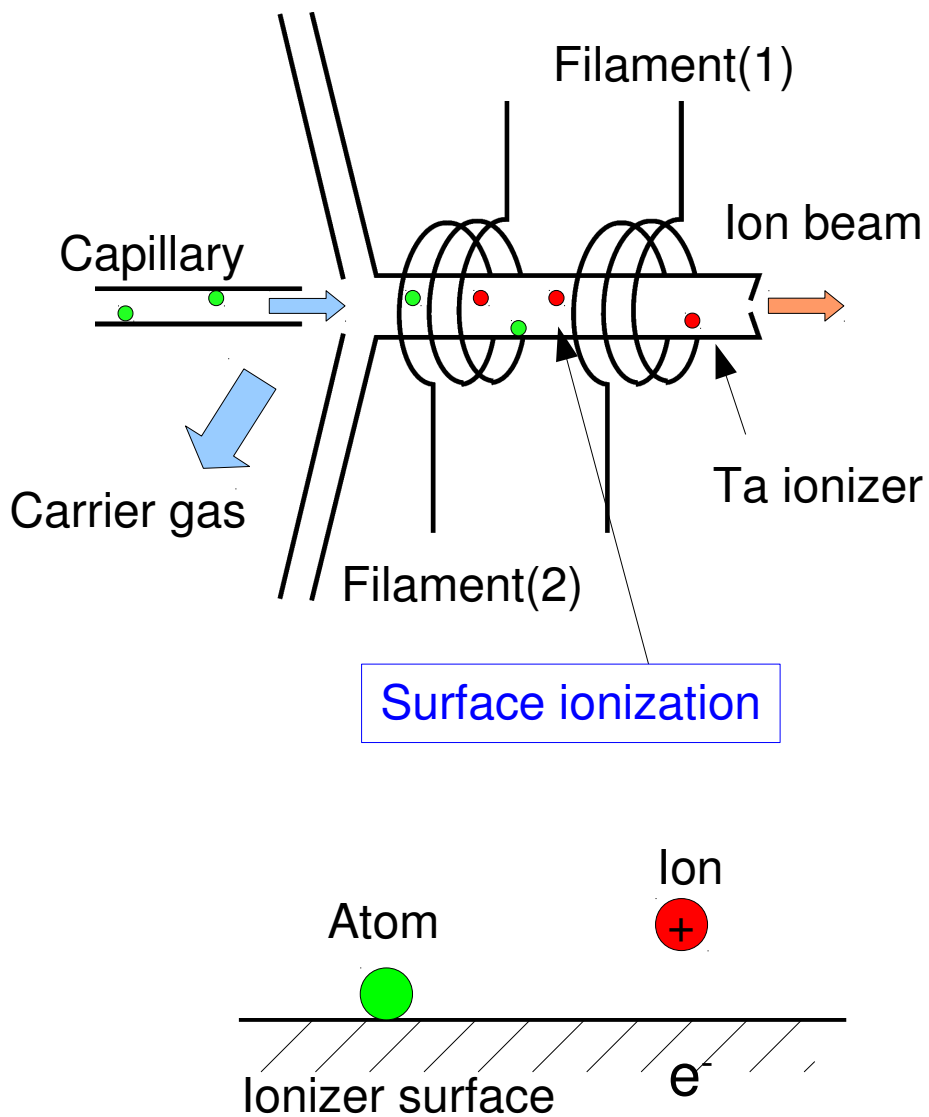
$A_{prov}$ : amount of atoms provided to ion. process

**Ionization eff. ( $I_{eff}$ )**  $\longleftrightarrow$  **Effective  $IP_1 (IP_1^*)$**   $\rightarrow$   **$IP_1$**  😊

# Experimental setup



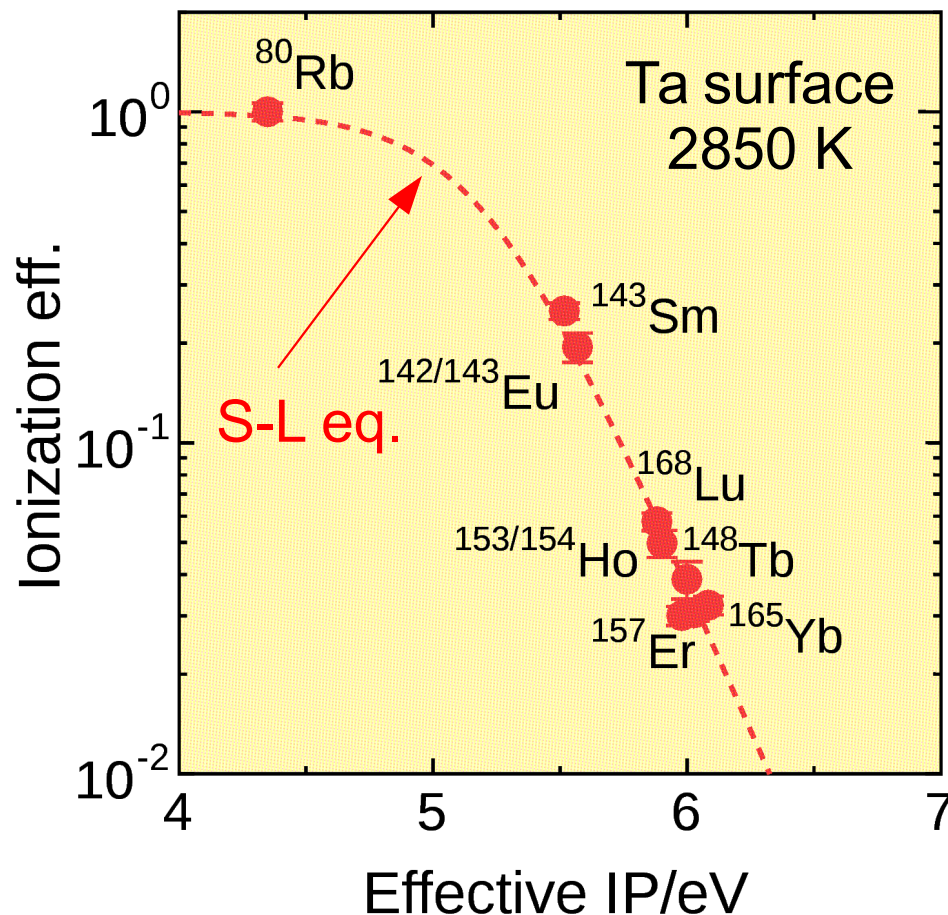
# Surface ionization ion-source



T.K.Sato et al RSI, 84, 023304 (2013).

# Ionization eff. ( $I_{eff}$ ) of Ln isotopes

Isotopes :  $^{80}\text{Rb}$ ,  $^{140}\text{Pm}$ ,  $^{142,143}\text{Eu}$ ,  $^{143}\text{Sm}$ ,  $^{148}\text{Tb}$ ,  $^{154}\text{Ho}$ ,  $^{157}\text{Er}$ ,  $^{165}\text{Yb}$ , and  $^{168}\text{Lu}$   
 Beam :  $^{11}\text{B}$ (67.9 MeV)  
 Targets :  $^{136}\text{Ce}/^{141}\text{Pr}/^{142}\text{Nd}/^{147}\text{Sm}$ ,  $^{159}\text{Tb}/^{162}\text{Dy}/^{\text{nat}}\text{Eu}$ , and  $^{\text{nat}}\text{Ge}$



S-L eq.

$$I_{eff} = \frac{N \exp\left(\frac{(\varphi - IP^*)}{kT}\right)}{1 + N \exp\left(\frac{(\varphi - IP^*)}{kT}\right)}$$

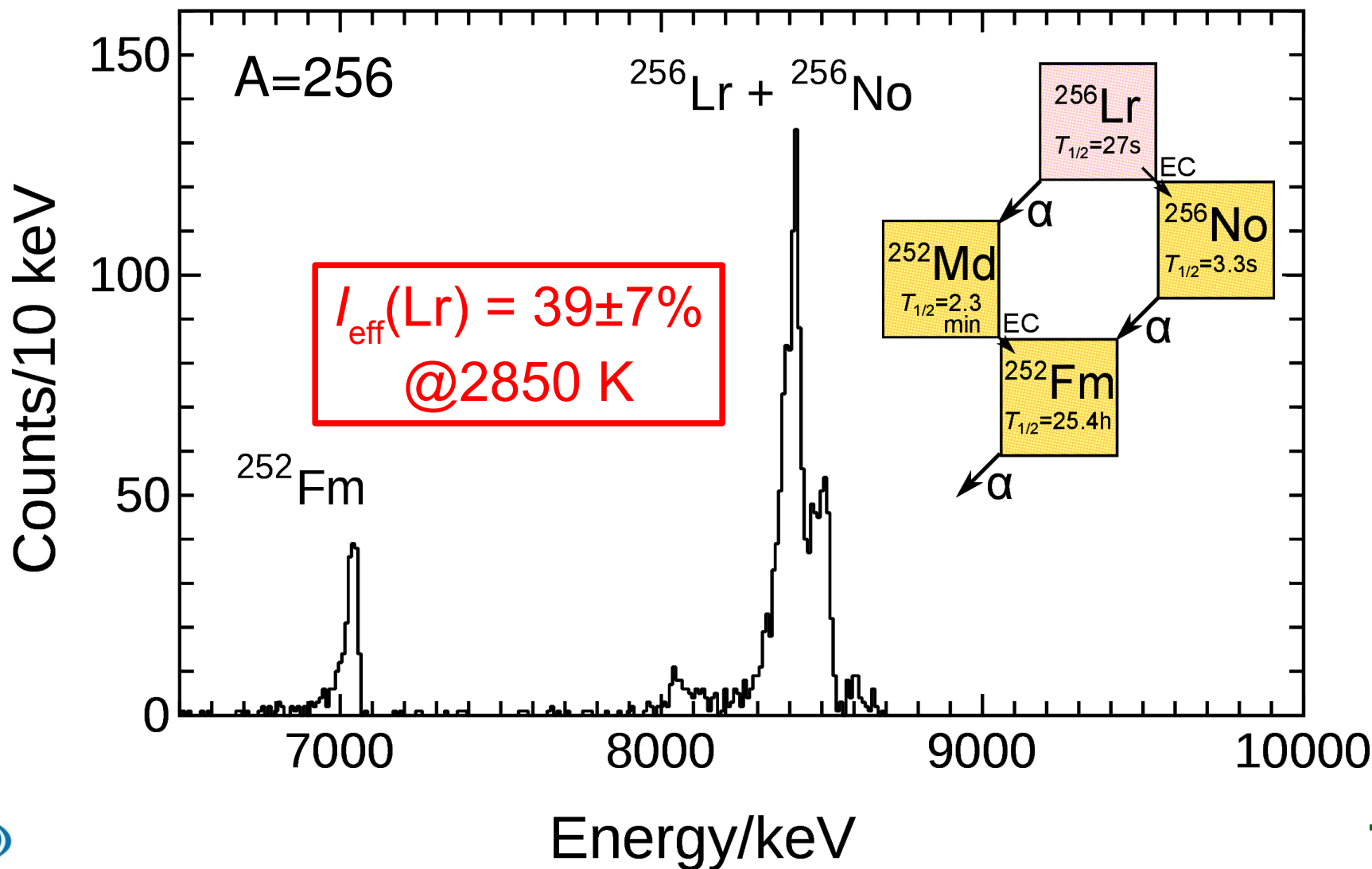


# Ionization of $^{256}\text{Lr}$

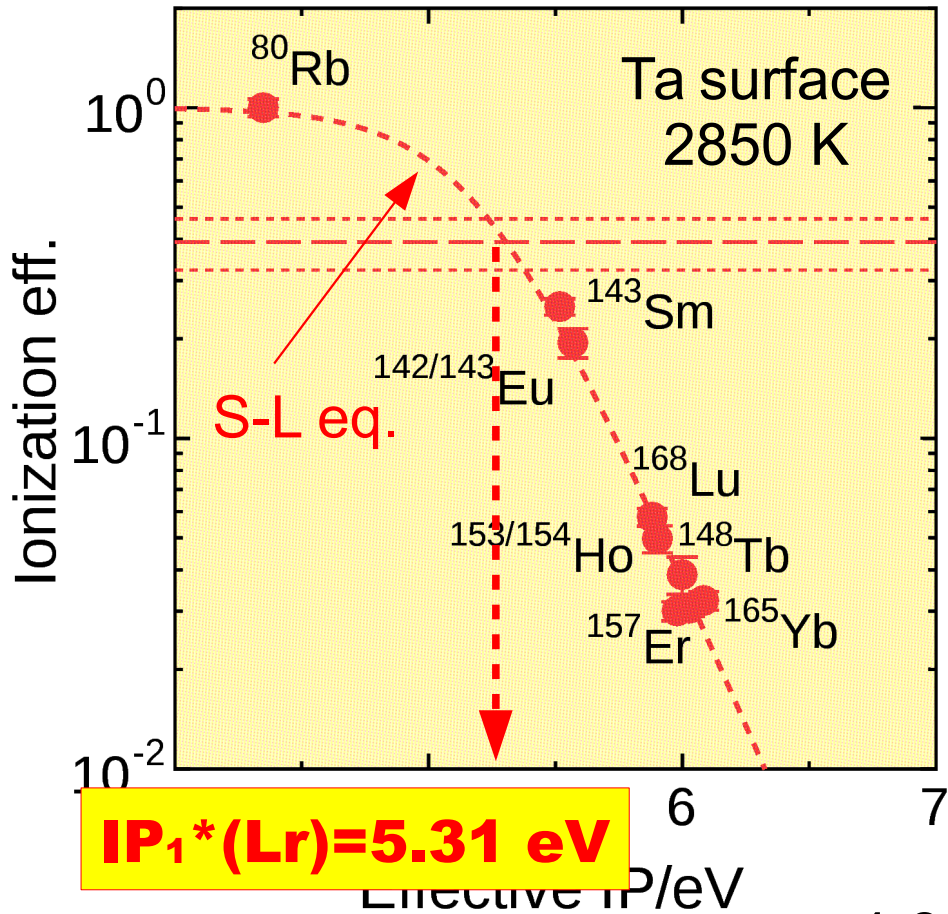
Isotope :  $^{256}\text{Lr}$  ( $T_{1/2} = 27\text{ s}$ )

Beam :  $^{11}\text{B}$  (67.9 MeV)

Target :  $^{249}\text{Cf}$  ( $260\ \mu\text{g}/\text{cm}^2$ )



# $I_{\text{eff}}(\text{Lr})$ on $IP^* - I_{\text{eff}}$ curve



$$I_{\text{eff}}(\text{Lr}) = 39 \pm 7\%$$

$$IP_1^*(\text{Lr}) = 5.31 \text{ eV}$$

$$IP_1^* = IP_1 - kT \ln(Q_i/Q_0)$$

		$Q_{i/0}$
Lr	$^2P_{1/2} + ^2D_{3/2} + ^2D_{5/2} + ^2P_{3/2}$	4.65
Lr <sup>+</sup>	$^1S_0$	1

$$-kT \ln(Q_i/Q_0) = -0.37$$

$$IP_1(\text{Lr}) = 4.94 \text{ eV}$$

4.893 eV

A. Borschevsky, EPJ 45(2007)115

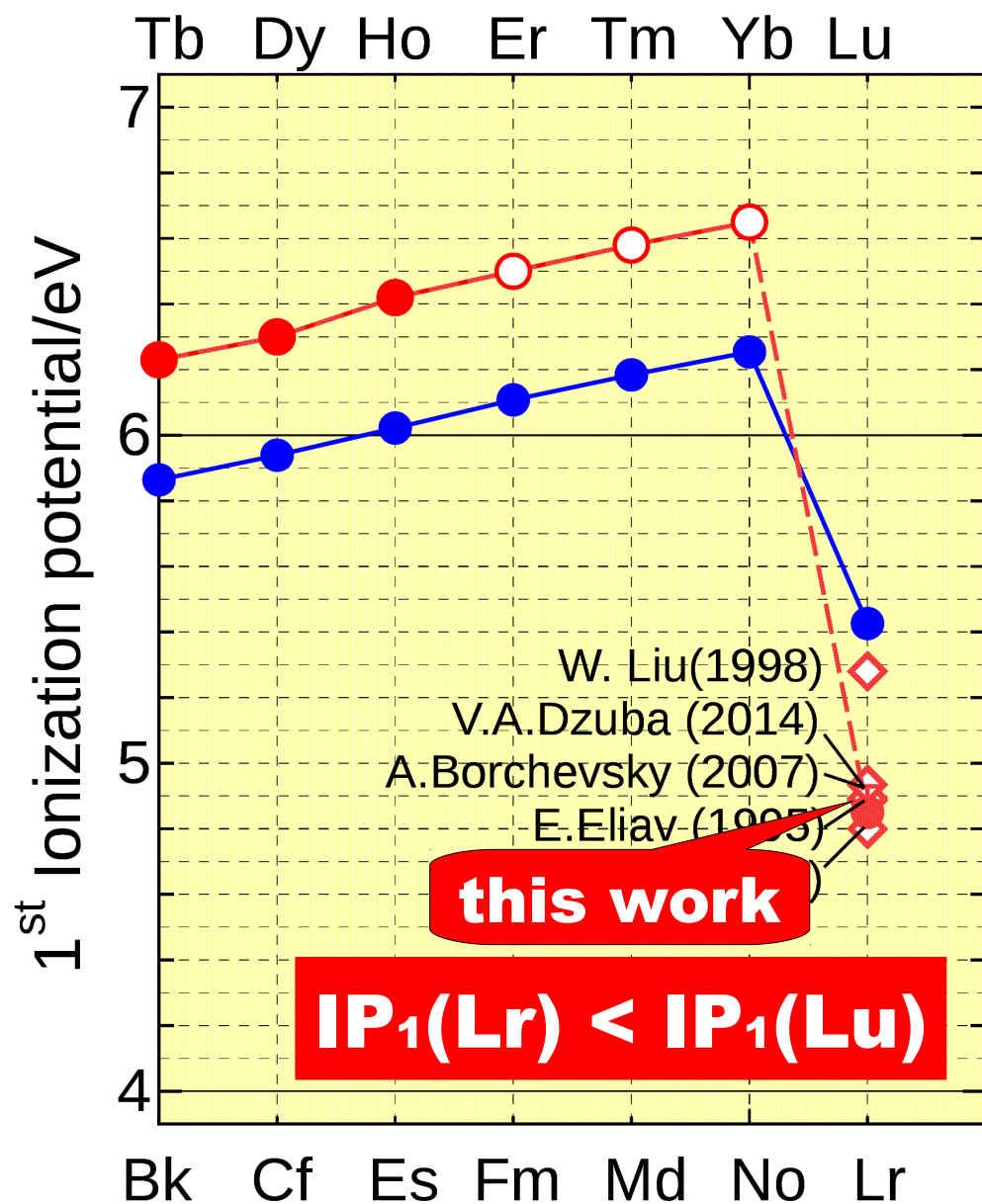
4.935 eV

V. A. Dzuba, PRA 90(2014) 012504

**The first successful measurement of  $IP_1$  in the heaviest elements region ( $Z > 100$ )!!**

# Summary

- Short-lived Lr isotope ( $^{256}\text{Lr}$ ) was successfully ionized with the present system.
- The  $\text{IP}_1$  value of Lr was experimentally evaluated for the first time.
- Obtained  $\text{IP}_1$  value of Lr is in excellent agreement with theoretical value based on  $[\text{Rn}]5f^{14}7s^27p_{1/2}$ .



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your attention!!**

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to seeing you again at  
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