Dielectronic Recombination of Be-like $^{40}Ar^{14+}$ at the CSRm

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tline

I. Introduction and Motivation

II. Experimental setup and Method

DR experimental setup @ CSRm, detuning scheme, data analysis

III. Results and Disscussion

Li-like $^{36}Ar^{15+}$, Be-like $^{40}Ar^{14+}$

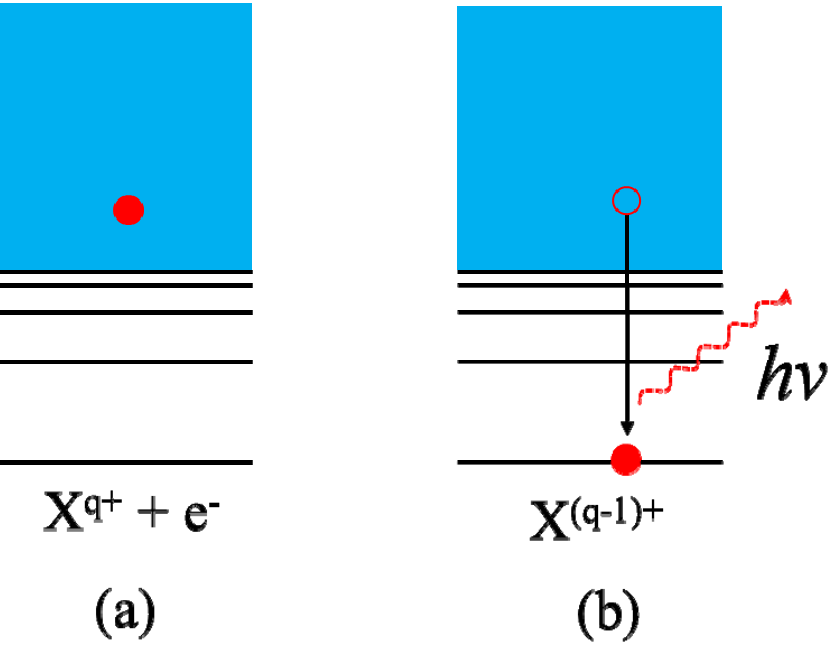
IV. Summary and Outlook

Upcoming DR experiments at the CSRe

DR precision spectroscopy at the future HIAF facility

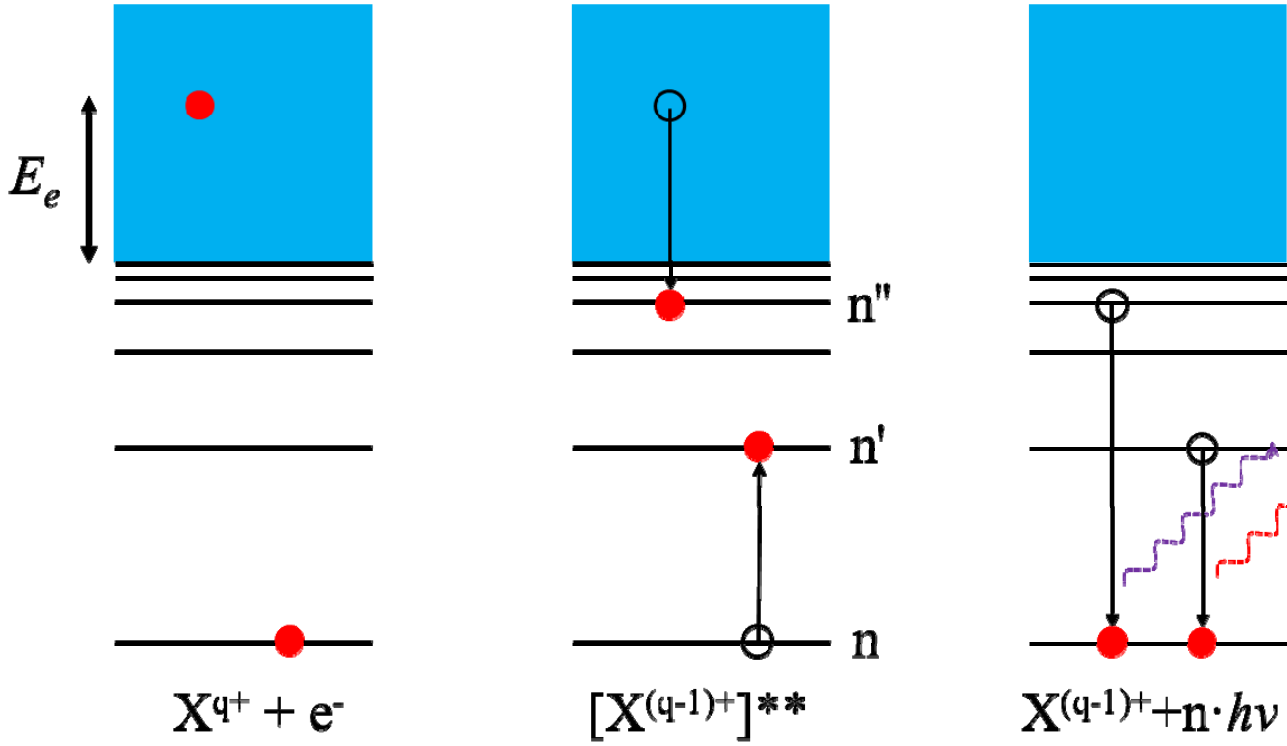
roduction-RR and DR

adiative recombination(RR)



$$e^- + X^{q+} \rightarrow X^{(q-1)+} + n \cdot h\nu$$

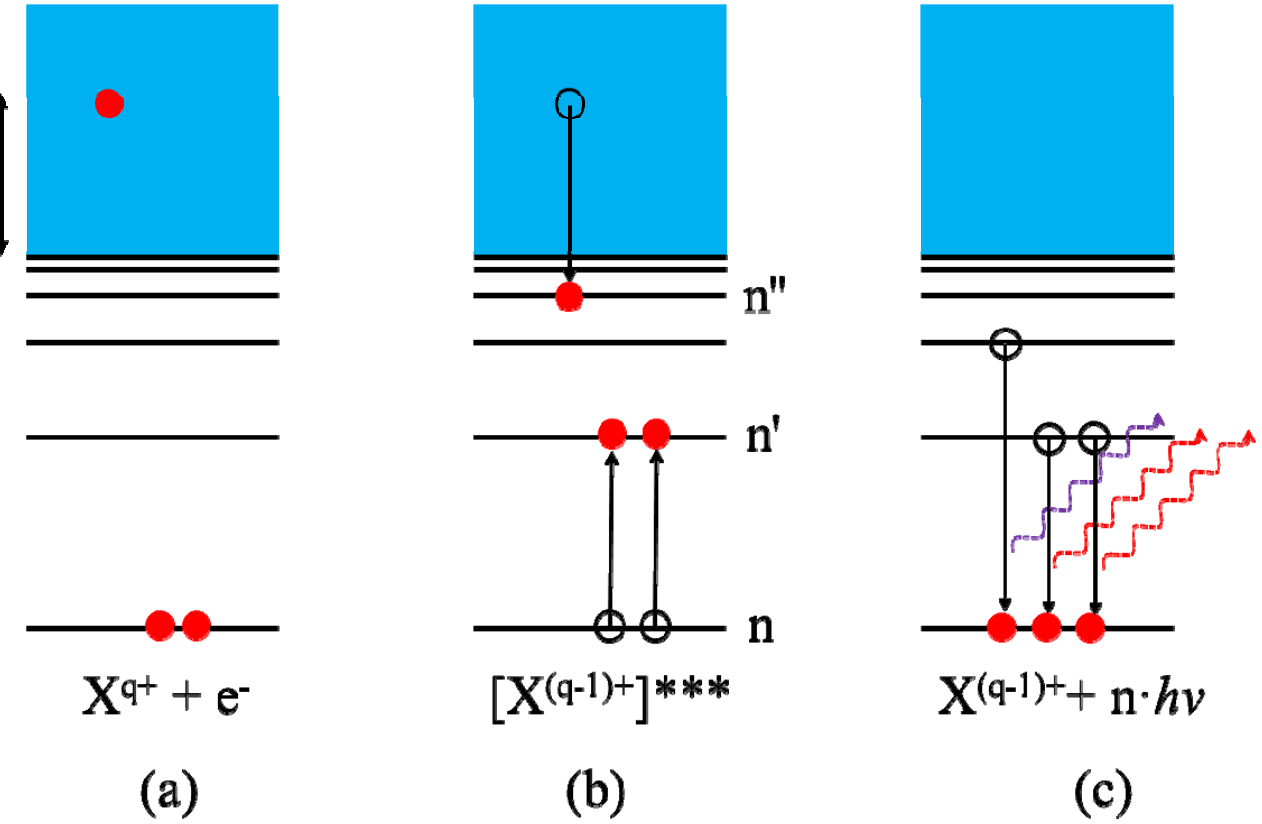
dielectronic recombination(DR)



$$e^- + X^{q+} \rightarrow [X^{(q-1)+}]^{**} \rightarrow X^{(q-1)+} + n \cdot h\nu$$

roduction- TR

trielectronic recombination(TR)



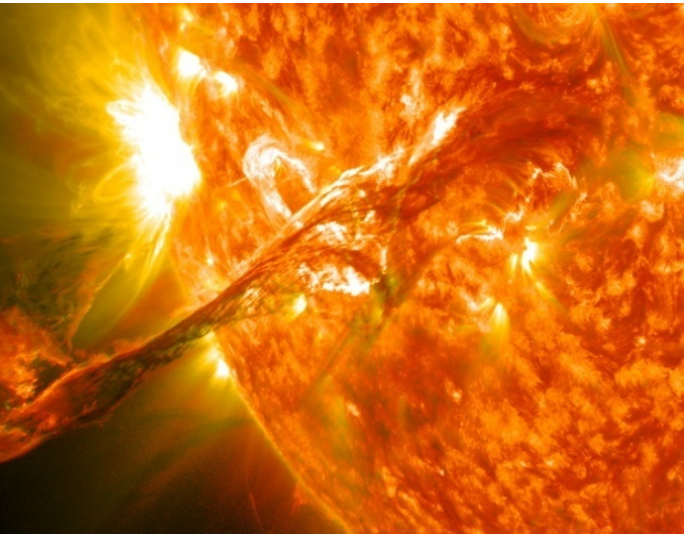
- a free electron is captured;
- Two bound electrons are excite resonantly;
- The whole resonant recombinat process through a triply excited state;

$$e^- + X^{q+} \rightarrow [X^{(q-1)+}]^{***} \rightarrow X^{(q-1)+} + n \cdot h\nu$$

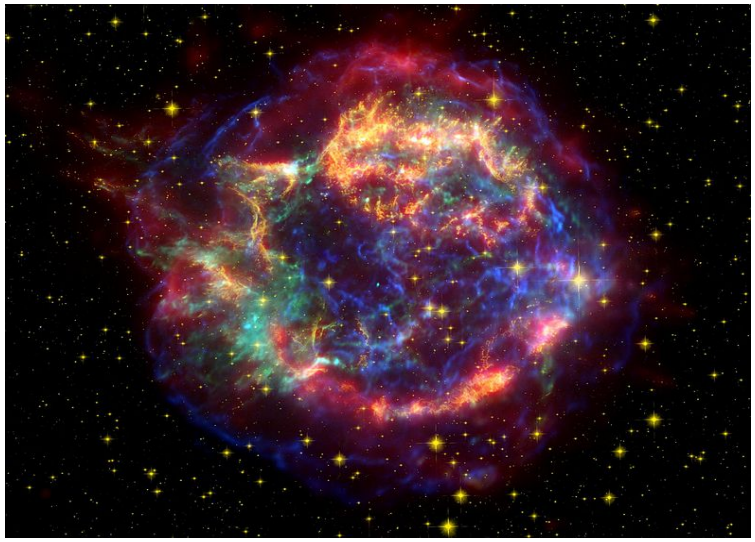
otivation 1: Astrophysics

R experimental data can be used to:

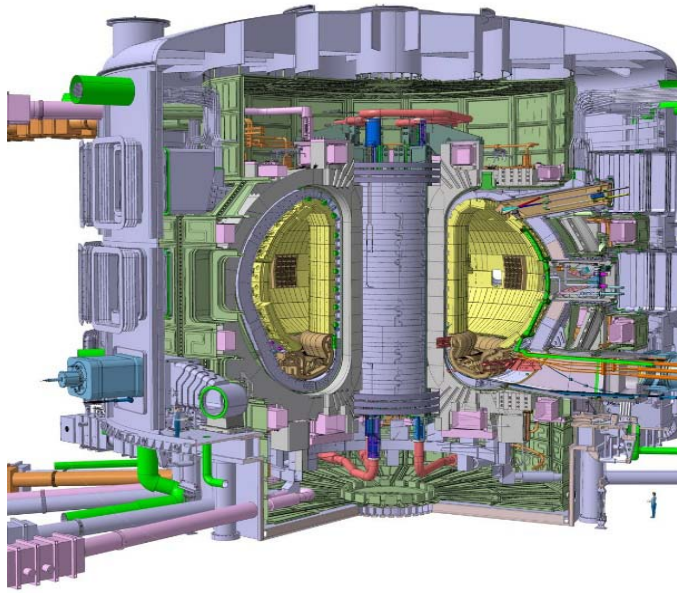
- Diagnose status (T_e and n_e) of natural and man-made plasmas;
- Benchmark the astrophysics theory and model, interpret the spectra f cosmic sources;



corona



supernova explosion



ITER project

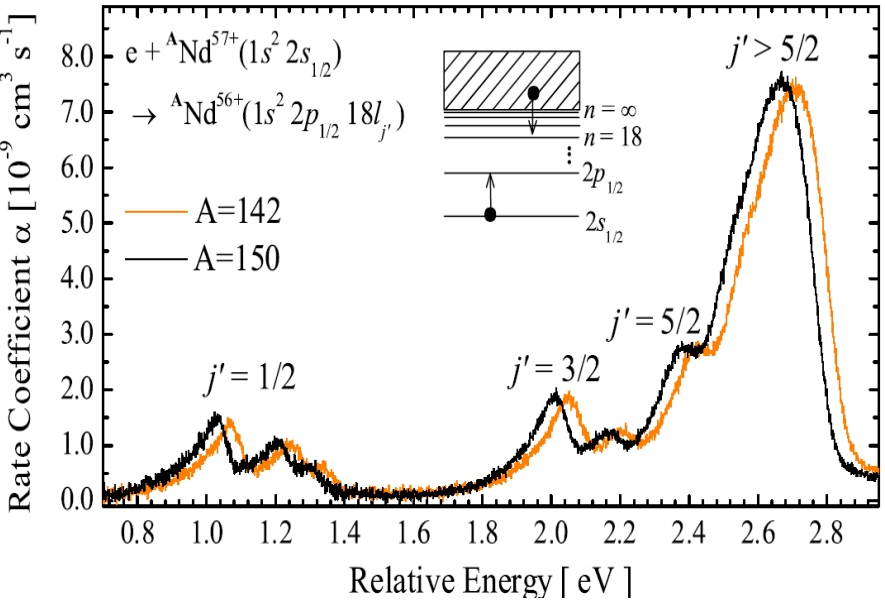
otivation 2: Atomic structure

R technique as a precision spectroscopy tool;

Test QED in strong field (Au^{76+}, Pb^{79+}, U^{89+}) ;

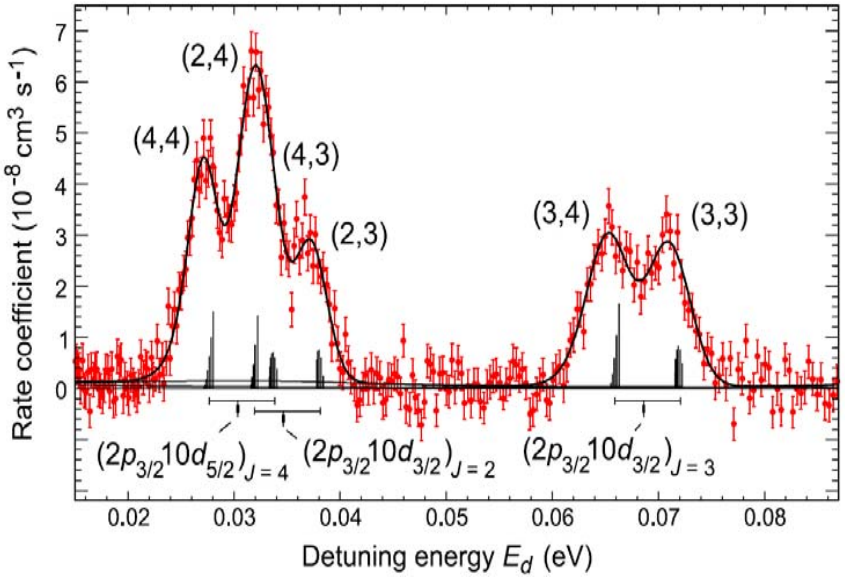
Measure Isotope shift ($^{142,150}Nd^{57+}$, $^{207,208}Pb^{53+}$) and hyperfine splitting (Sc^{18}

Isotope shift of DR resonances in $^{142,150}Nd^{57+}$



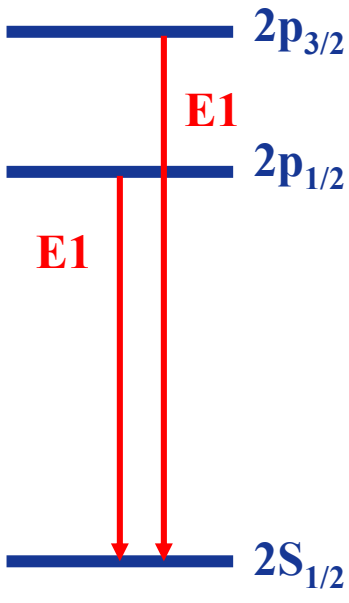
C. Brandau et al., PRL ***100****, 073201(2008)*

Hyperfine splitting of DR resonances in Sc^{18}

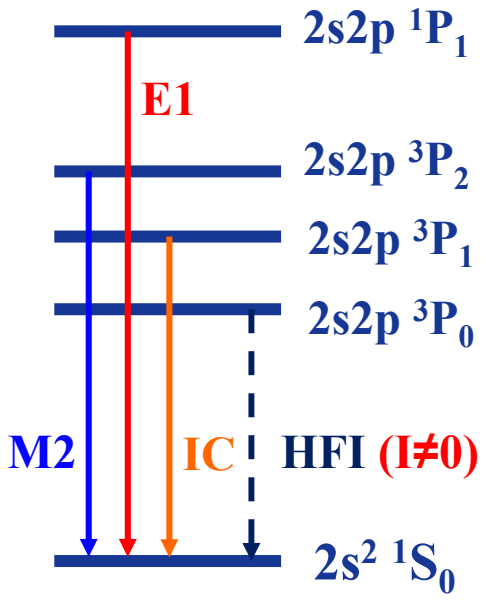


M. Lestinsky et al., PRL ***100****, 033001(2*

ptical transitions of Li-like and Be-like ionsc



Li-like

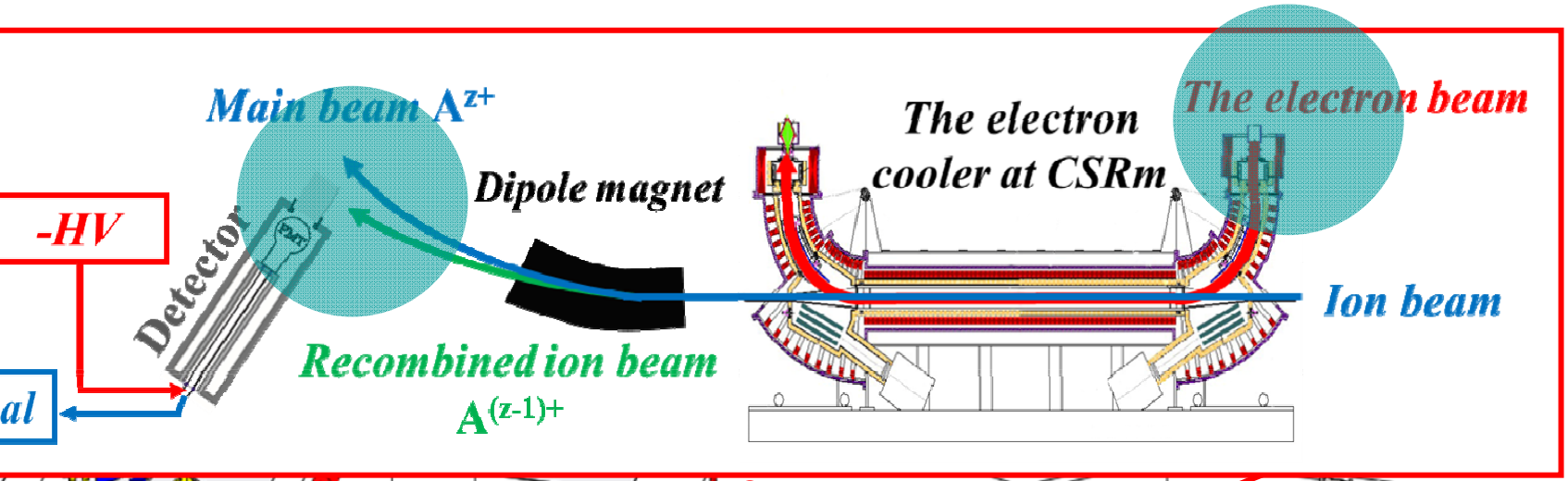


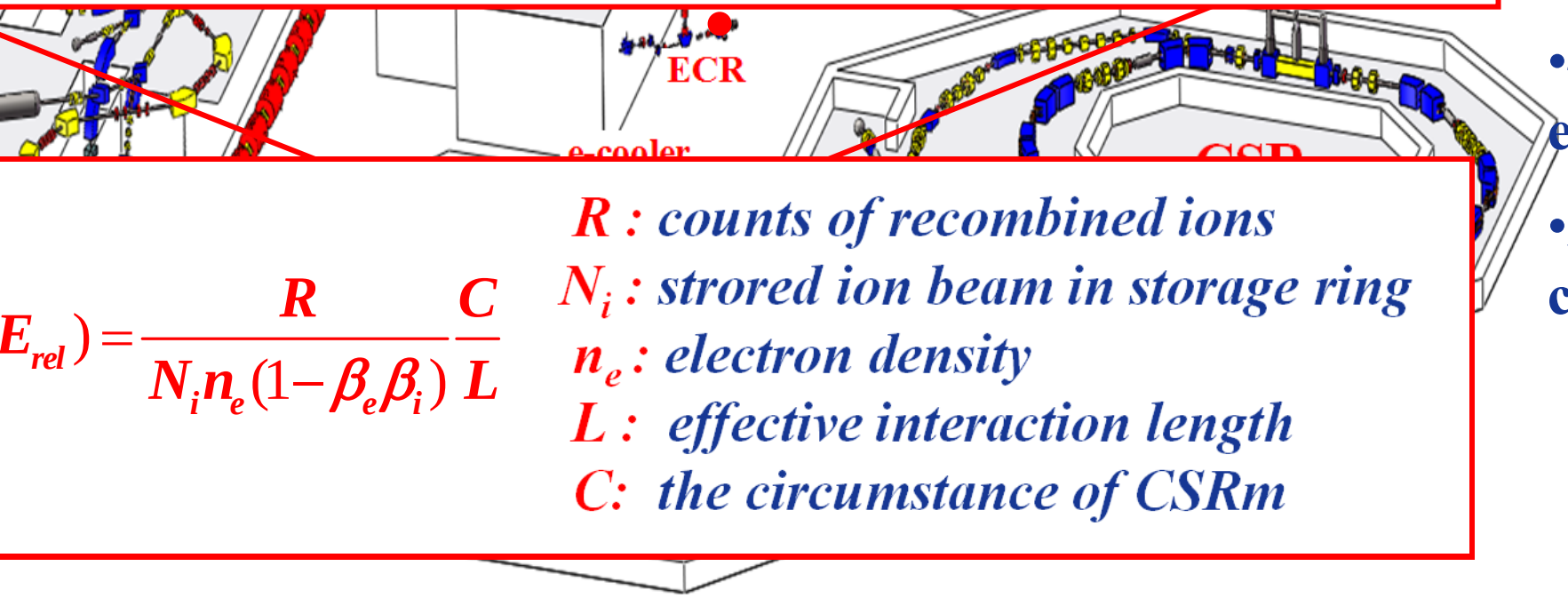
Be-like(low Z)

- Observe and investigate TR process
- Lifetime study of $^3P_0$ level [I≠0];

Test QED in strong fields and benchmark relativistic atomic theories;

R experimental setup at the HIRFL-CSRm





$$\sigma(E_{rel}) = \frac{R}{N_i n_e (1-\beta_e\beta_i)} \frac{C}{L}$$

R : counts of recombined ions

N_i : strored ion beam in storage ring

n_e : electron density

L : effective interaction length

C: the circumstance of CSRm

-----Advangtages----

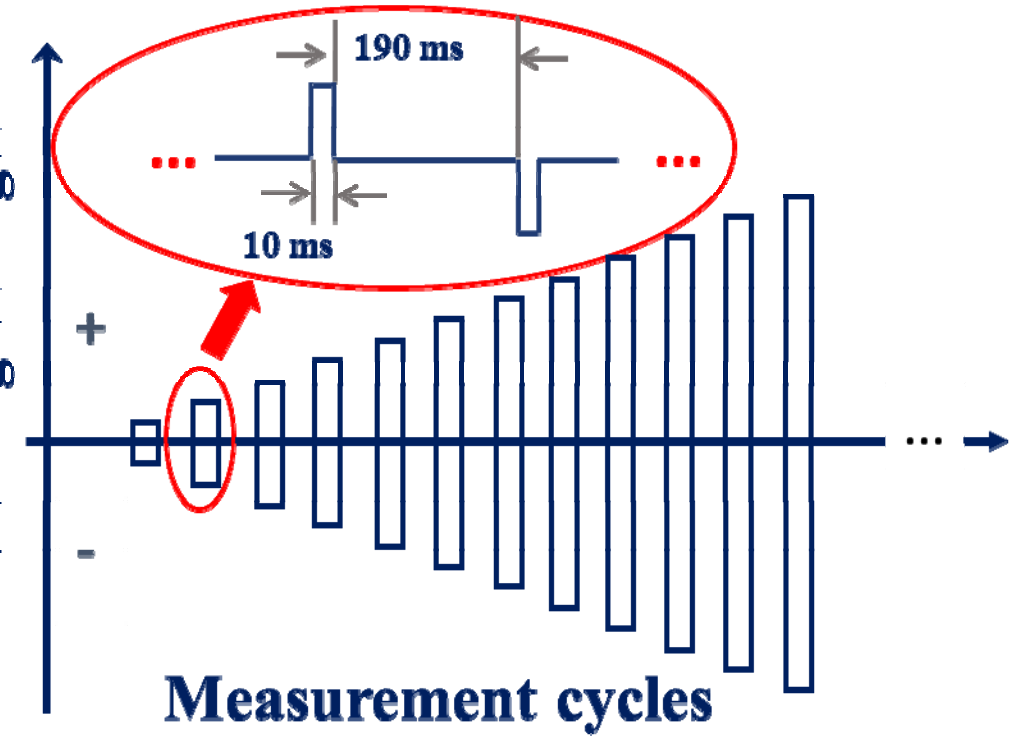
- Low background
- Broad energy ran
- Ultra-high precisi
- ~100% detection efficientcy
- Absolute rate coefficients

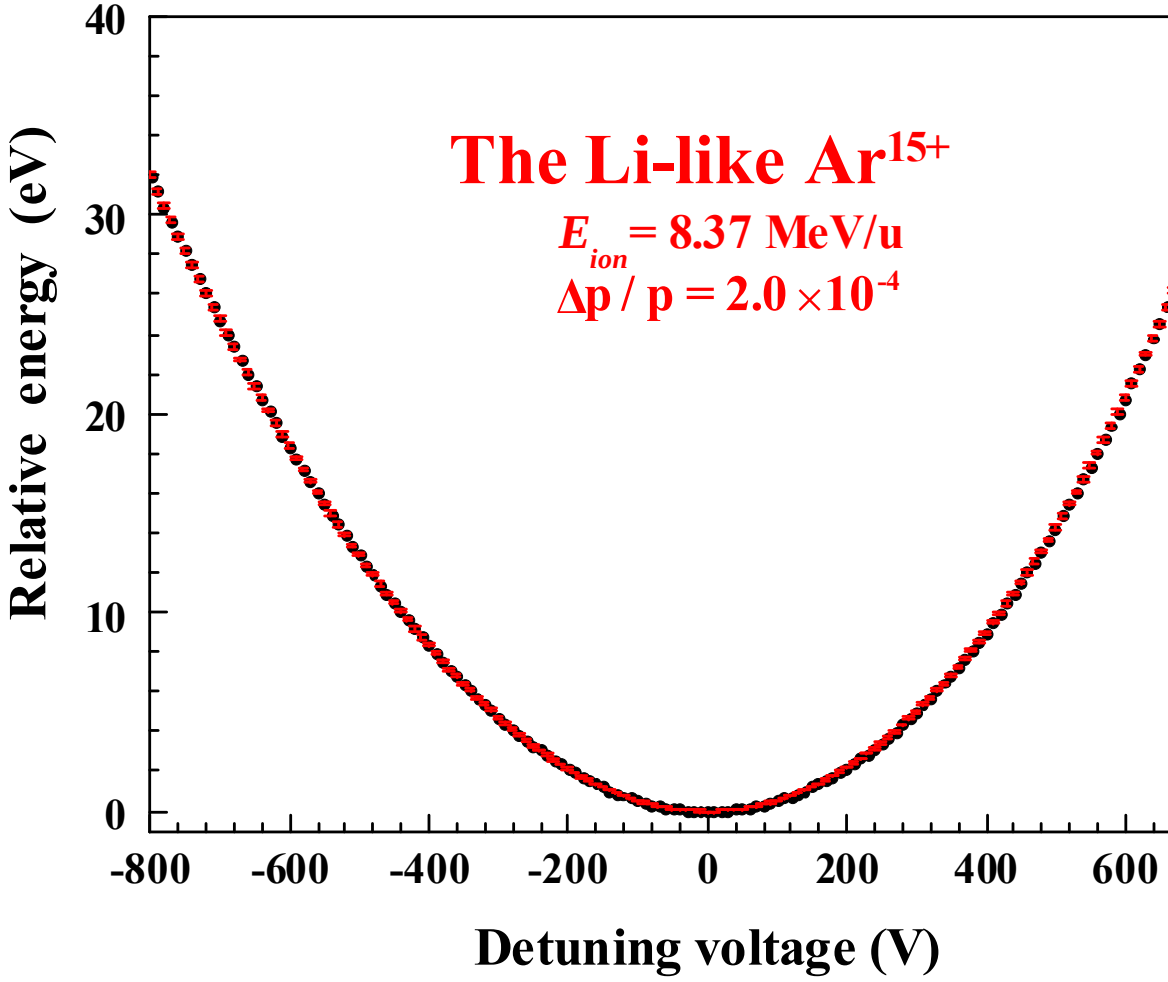
perimental parameters

Parameters（units）	Li-like $^{36}Ar^{15+}$	Be-like $^{40}Ar^{14+}$
Circumstance of CSRm（m）	161.0	161.00
Interaction length（m）	4.0	4.0
The radii of beam tube（cm）	25	25
Beam energy（MeV/u）	**8.37**	**6.82**
The max beam current（μA）	**200**	**50**
Beam momentum spread（δp/p）	**2.0×10^{-4}**	**2.2×10^{-4}**
Beam life time（s）	**120**	**50**
Cooling point（kV）	**-4.5810**	**-3.7597**
Electron beam current（mA）	**112.90**	**118.40**
The radii of electron beam（cm）	2.60	2.60
Magenet field at cooling section（GS）	390	390
Magenet field at gun section（GS）	1250	1250

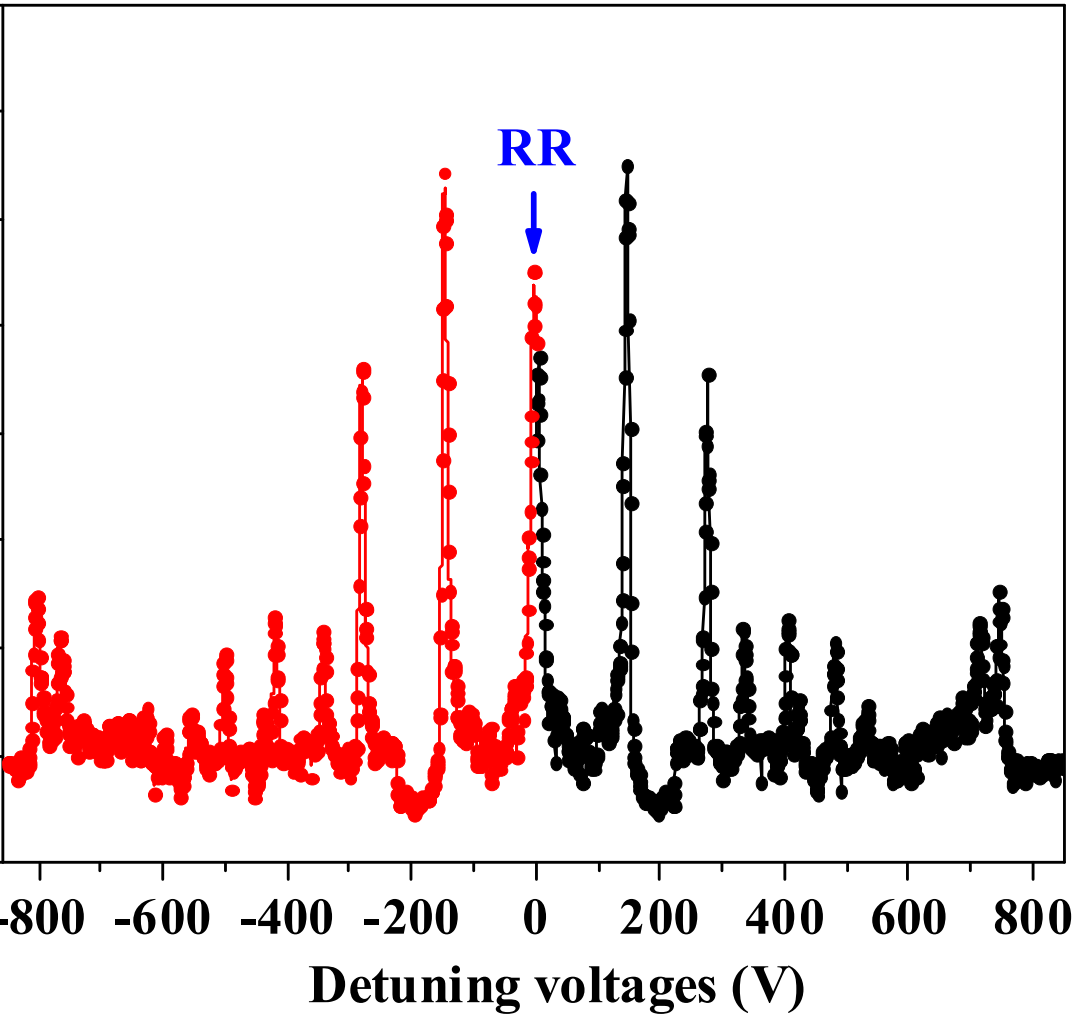
perimental results: Li-like $^{36}Ar^{15+}$

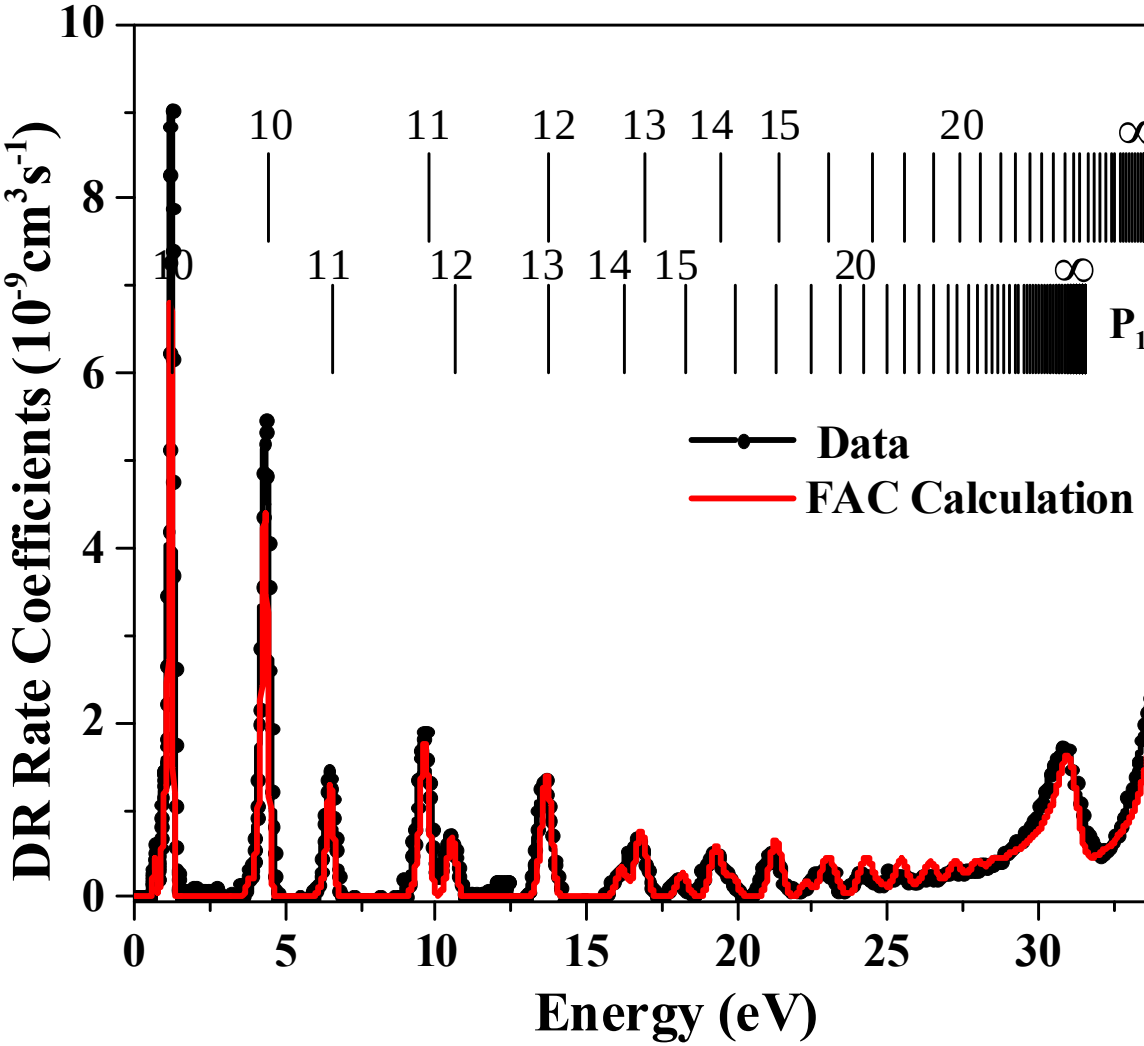
uning timing scheme for DR experiments
ne CSRm





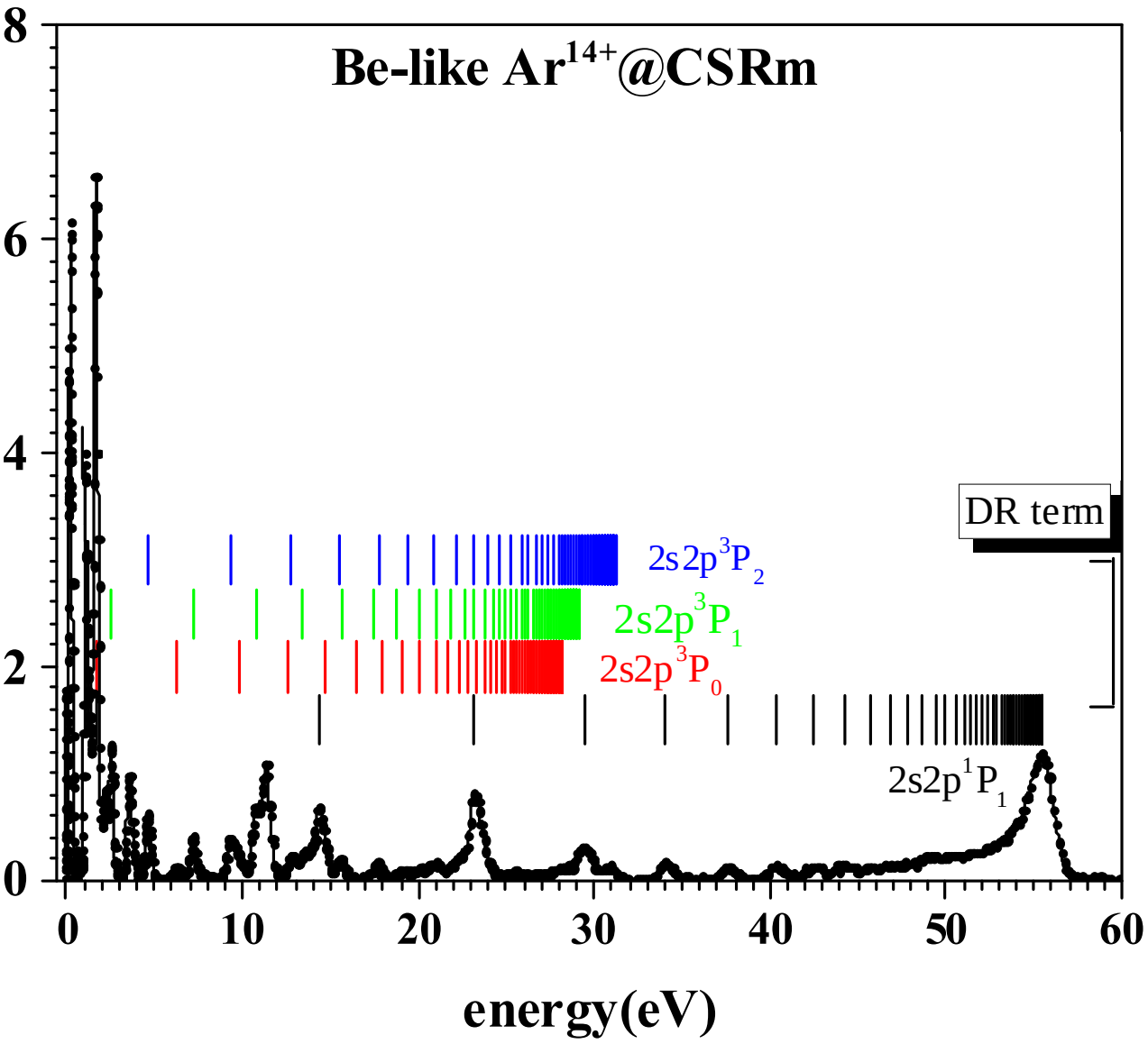
perimental results: Li-like $^{36}Ar^{15+}$





Zhongkui Huang et al. Phys. Scr. T166 (2015) 014023

perimental results: Be-like $^{40}Ar^{14+}$



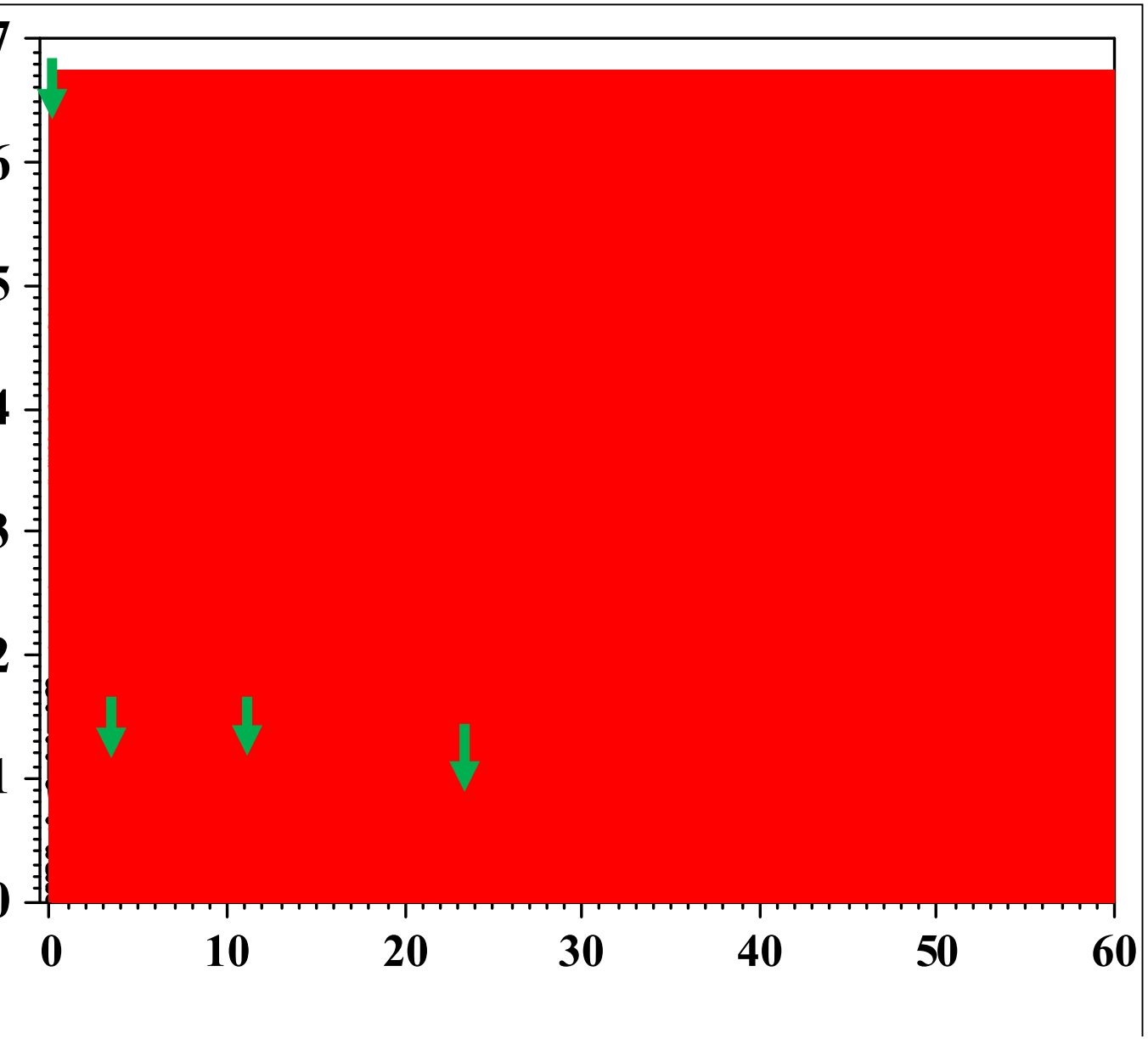
- DR ($2s^2 \rightarrow 2s2p$) $^1P_1$, ^3P_J (J =0,1
- TR ($2s^2 \rightarrow 2p^2$) $^1S_0$, $^1D_2$, $^3P_2$, $^3P_1$

The vertical bar indicated in the fig is estimated by Redberg formula:

$$E_{res} = E_{exc} - \frac{RZ_{eff}}{n^2}$$

E_{exc} is the core excitation energy
R is the Rydberg constant
$Z_{eff} = Z-4$ is the charge of the target ic

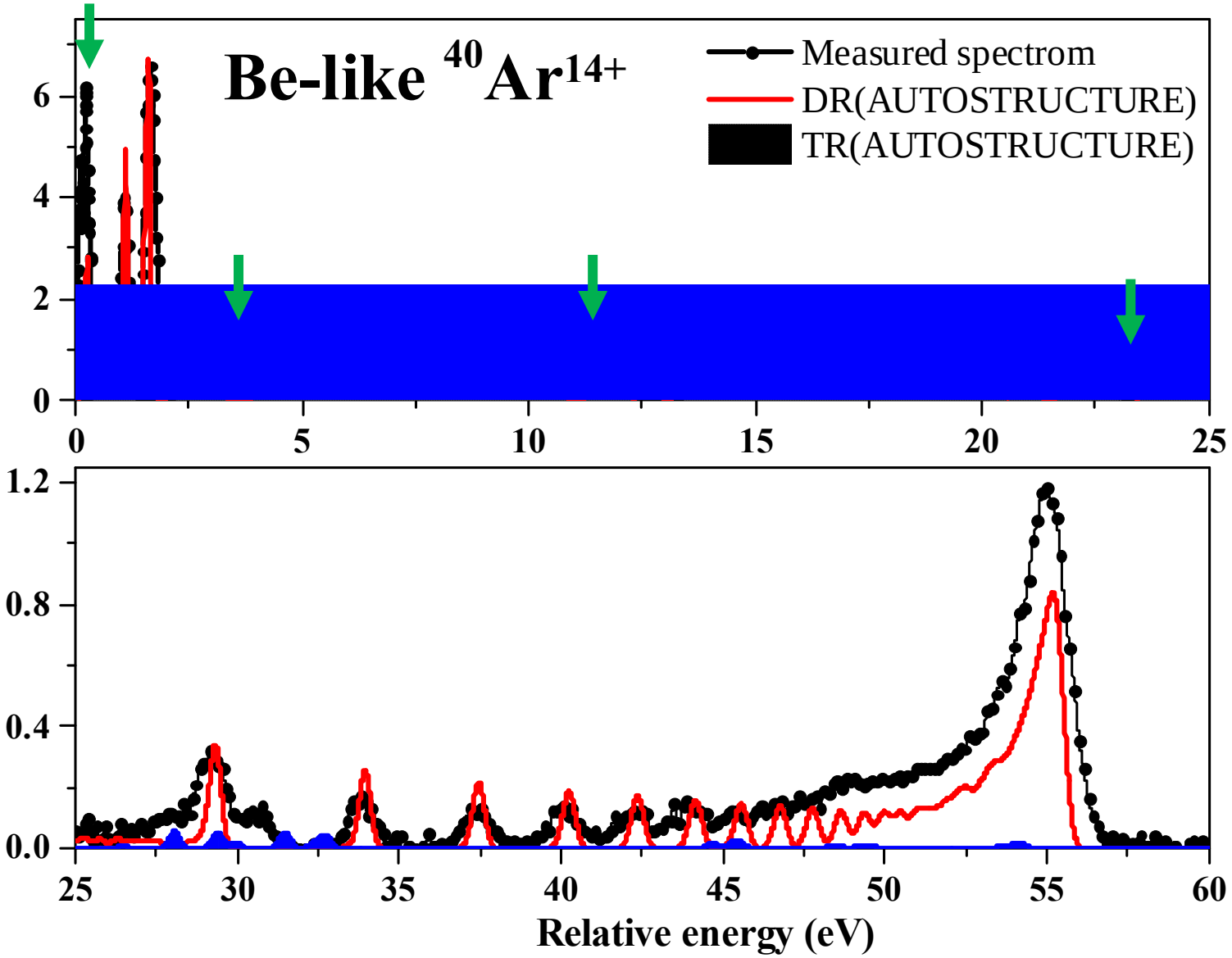
perimental results: Be-like $^{40}Ar^{14+}$



- Only consider the DR process
- Several peaks indicated by gr
  arrows cannot be fully identif
  within DR profile;

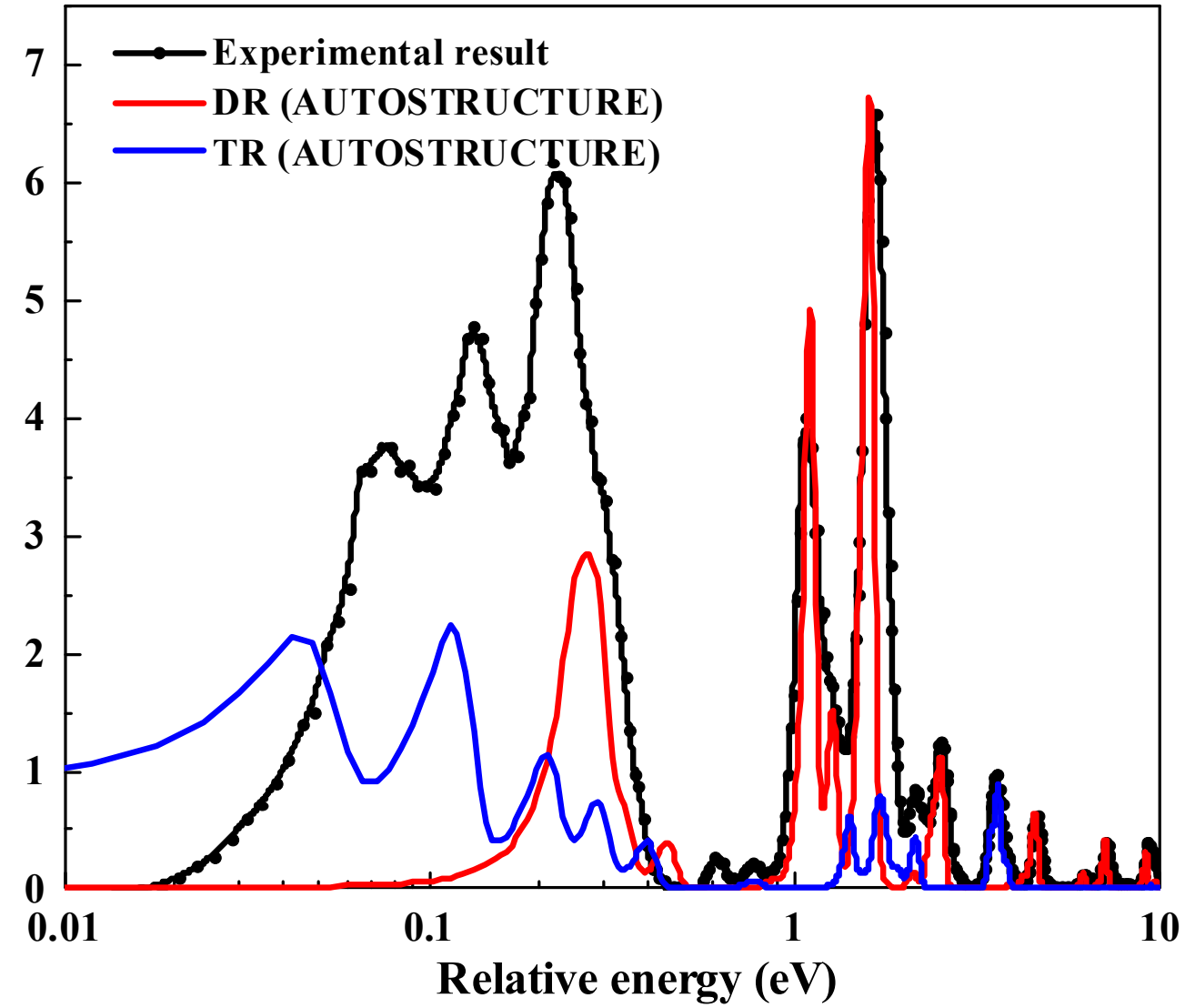
Theoretical calculation is supported b
Prof. N.R. Badnell and Dr. Simon Pr

perimental results: Be-like $^{40}Ar^{14+}$



- consider both DR and T processes in this energy region;
- The agreement between experimental result and calculation becomes much better;
- N_{cut}=75

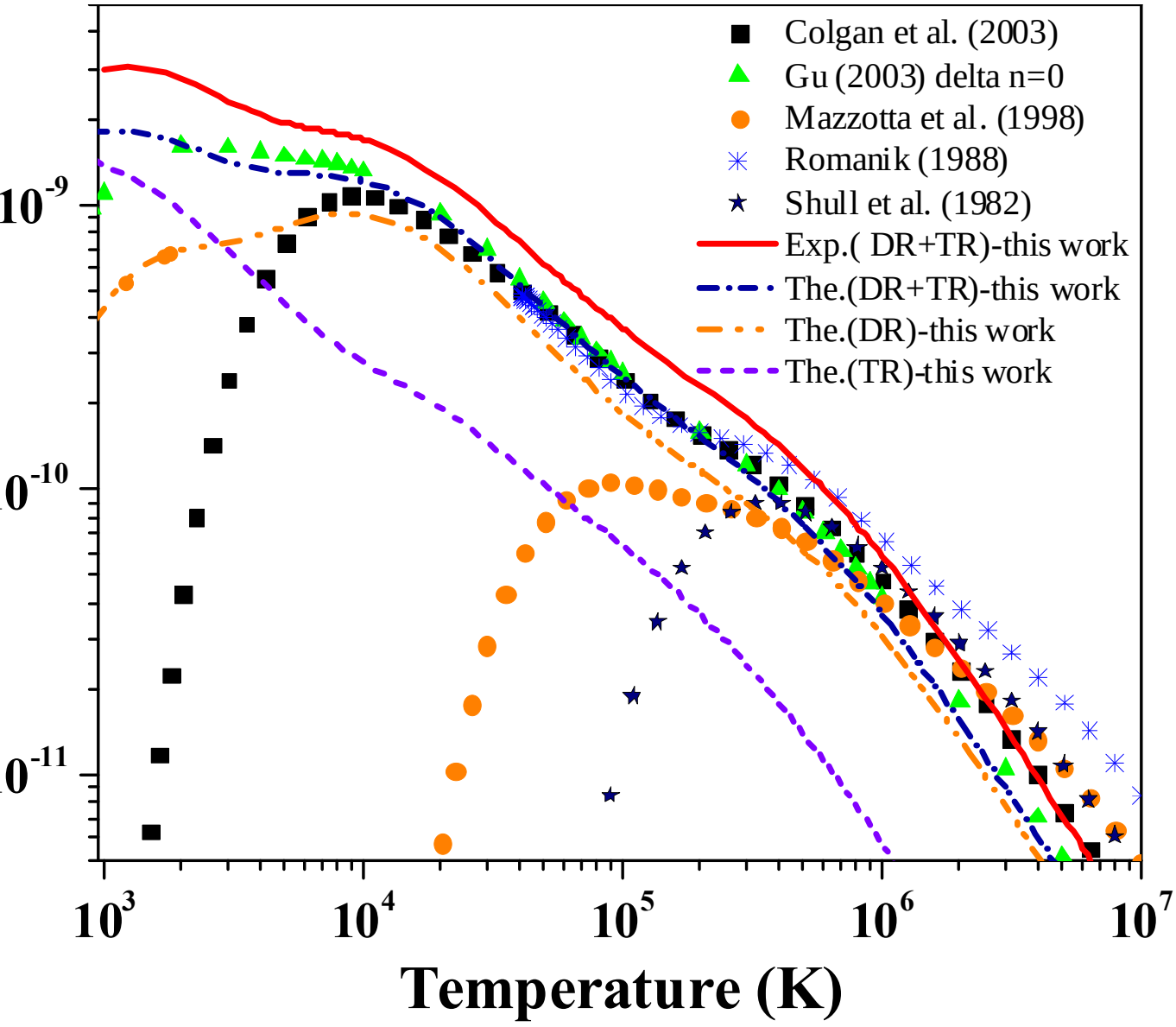
perimental results: Be-like $^{40}Ar^{14+}$



- [1-10 eV]
  experimental results and calcula
  are in good agreement;

- [around 0 eV]
  experimental results and calcula
  are are in obvious discrepancy

sma rate coefficients



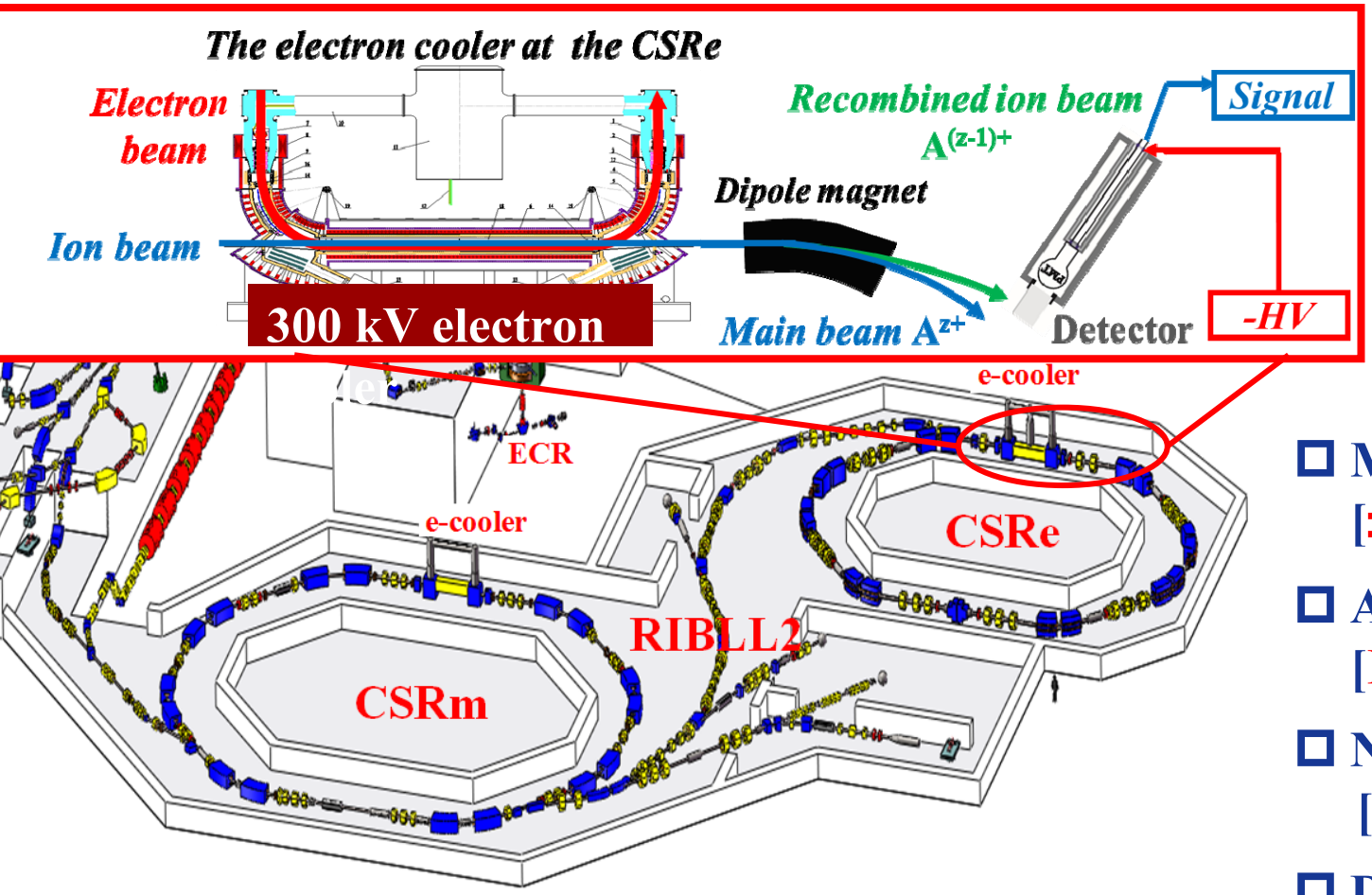
- The AUTOSTRUCTURE calculation in this work is in good agreement with Gu(200

- surprisingly strong trielectro recombination resonances at low energy

perimental results: brief summary

- DR spectrum of Be-like argon was measured first time;
- TR resonances were observed in the measured spectrum;
- The plasma rate coefficients was derived and compared with the existe theoretical calculation;
- The difference of plasma rate coefficient at low energy can be explaine with the surprisingly strong trielectronic recombination resonances;
- The DR experiments at the CSRm pave the way for our upcoming DR experiments at the CSRe and also on the future facility HIAF;

tlook-upcoming DR experiment at the CSRe



Sketch wiew of DR experiment at the CSRe

- Much broader detuning energy rang
  [±30 kV~1500 eV (U^{89+}@200MeV/u)
- Astrophysics relevant DR spectrosc
  [H-like, He-like, Li-like, Be-like]
- Nuclear excitation by electron captu
  [NEEC]
- DR research on radioactive ion bear
  [CSRm + RIBLL2 + CSRe]

tlook-future DR experiment at the HIAF-SRing

SRing: Spectrometer ring

Circumference:290m

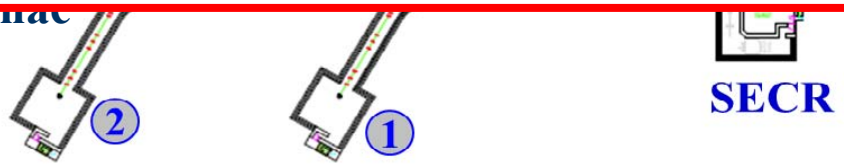
The highlight of DR experiments at HIAF

electron-cooler & an ultra-cold electron-target

a unique research platform

electron-ion recombination spectroscopy!

POSTER: Mon-6



h:100 m

y: 17MeV/u(U^{34+})

Z.K. Huang, et al. Nucl. Instr. Meth. B

international cooperation group

IMPCAS, Lanzhou	X. Ma, Z. K. Huang, W. Q. Wen, H. B. Wang, S. Mahmood, N. Khan, X Y. Chai, L. J. Dou， X. L. Zhu, D. M. Zhao, L. J. Mao, Y. J. Yuan, J. Li, X. M, Ma, J. C. Yang ;
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NWNU， Lanzhou	C. Z. Dong, L. Y. Xie;
Uni. Strathclyde	N. R. Badnell, Simon Preval;

Thank You!

Thanks for your kind attention!

ata analysis

Detuning Voltages → The relative energy between electron and ion in c.m. frame ;

$$= \sqrt{m_e^2c^4 + m_{ion}^2c^4 + 2m_e m_{ion}\gamma_e\gamma_{ion}c^4(1-\beta_e\beta_{ion}cos\theta)} - m_ec^2 - m_{ion}c^2$$

Cooling Point $\gamma_{e-0} = \gamma_{i-0}$

Detuning + Correction

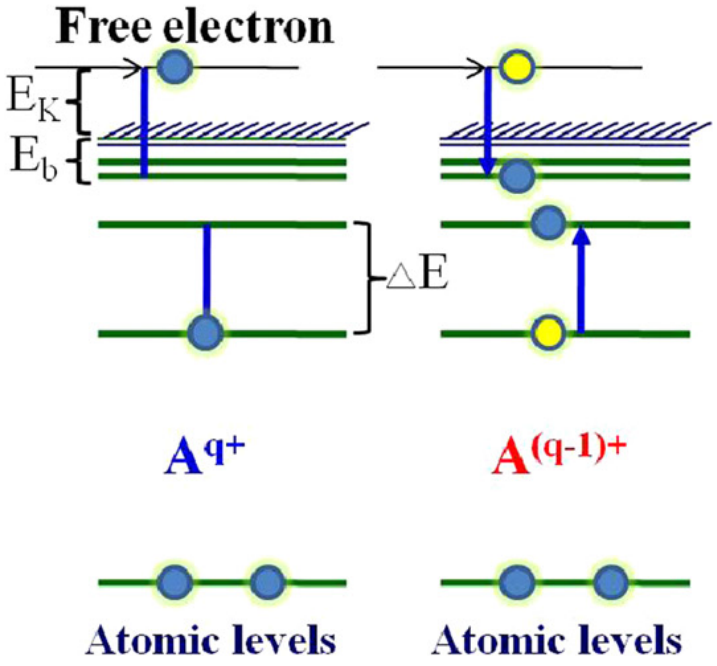
Energy detuning $\gamma_e = 1 + \frac{E_{e-0} + \Delta E_e}{m_ec^2} = \gamma_i + \frac{\Delta E_e}{m_ec^2}$

Count of recombined ion →Rate coefficients ;

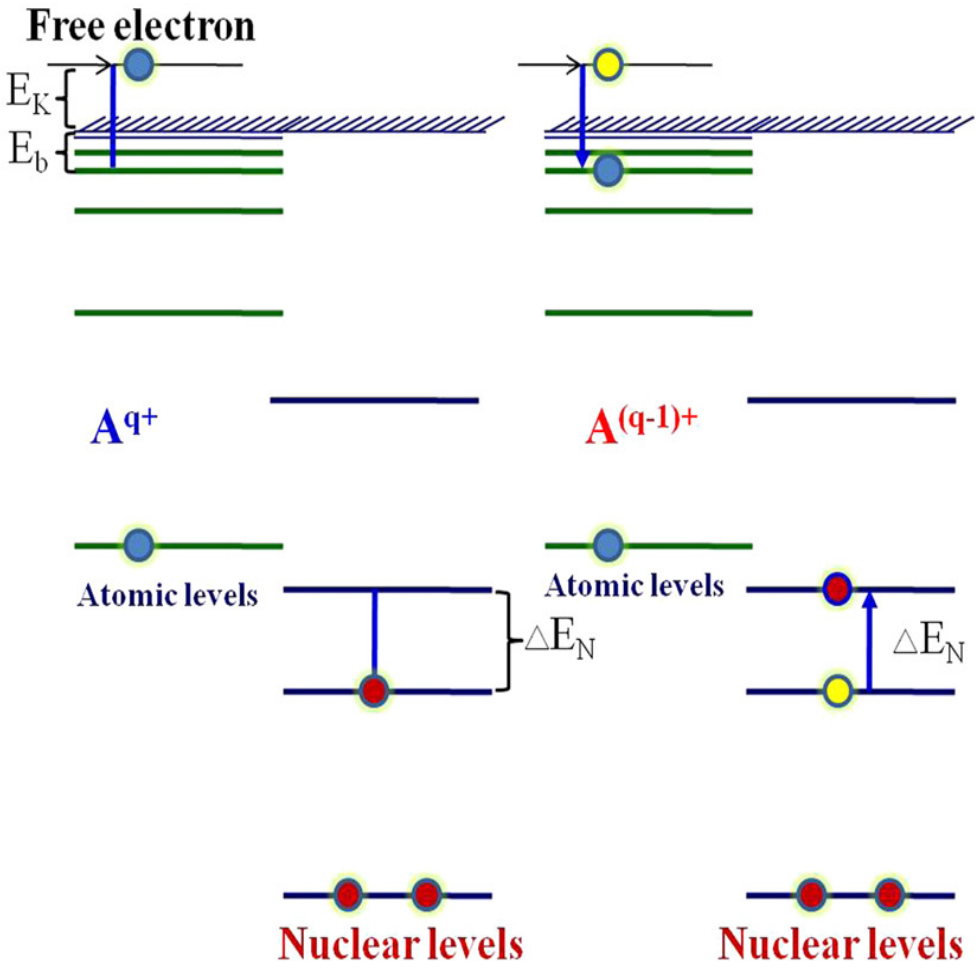
$$E_{rel}) = \frac{R}{N_i n_e (1-\beta_e\beta_i)} \frac{C}{L} = qe^2c^2\pi r_e^2 \cdot \frac{\beta_e\beta_i}{1-\beta_e\beta_i} \cdot \frac{RL}{I_{ion}I_e}$$

→ **The recombined spectrom**

EEC (nuclear excitation by electron capture)



Dielectronic Recombination



Nuclear Excitation by Electron Capture

Adriana Pálffy et al. *Phys. Lett. B* **661** (2008) 330–334; X ma et al. *Phys. Scr.* **T166** (2015) 014012 (4p