XX ISIAC at Crete, Greece, Aug 1-4,2007

State-Selective Electron Capture in He^{2+}-He collisions studied by COLTRIMS

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Outline

- Motivation
- Experimental setup
- Experimental results
- Summary and Outlook

Motivation

- The symmetric He^{2+}-He collision system is one of the simplest example of the interaction of multiply charged ions with atoms, one-electron and two-electron can be studied

- The plasma diagnostics e.g. fusion product of helium nuclei in the plasma

$He^{+}(n)$ $(n=4,l)$ line emission in the visible range

He^{2+}-He collision system reaction channel

Direct one-electron ionization DI_1 : $He^{2+} + He \rightarrow He^{2+} + He^{+} + e^{-} + Q_{DI1}$

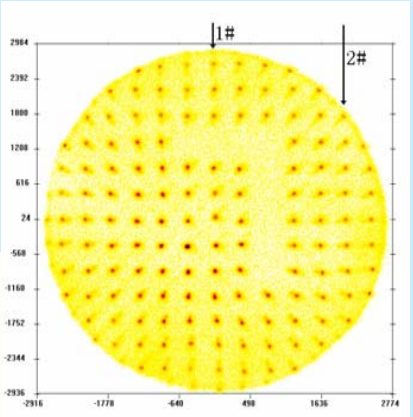
Direct two-electron ionization DI_2 : $He^{2+} + He \rightarrow He^{2+} + He^{2+} + 2e^{-} + Q_{DI2}$

Single electron capture SC : $He^{2+} + He \rightarrow He^{+} + He^{+} + Q_{SC}$

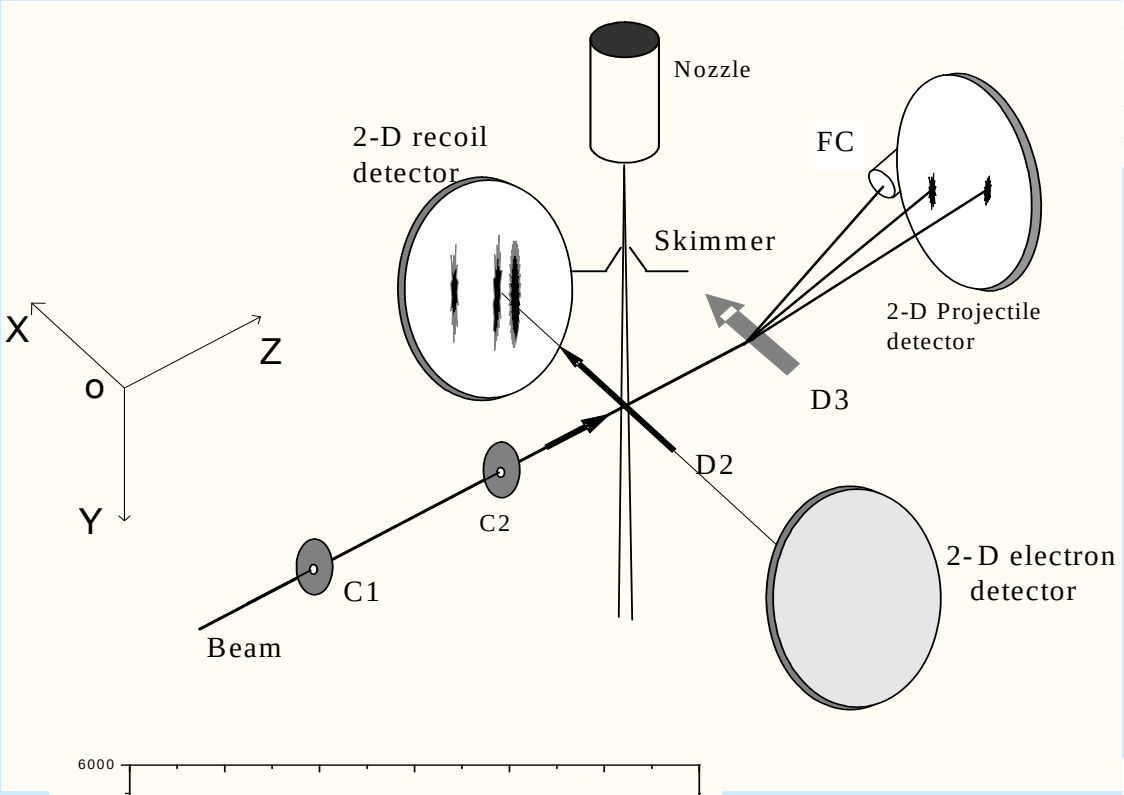
Double electron capture DC : $He^{2+} + He \rightarrow He^{0} + He^{2+} + Q_{DC}$

Transfer ionization TI : $He^{2+} + He \rightarrow He^{+} + He^{2+} + e^{-} + Q_{TI}$

Experimental setup



Position resolution <0.1mm



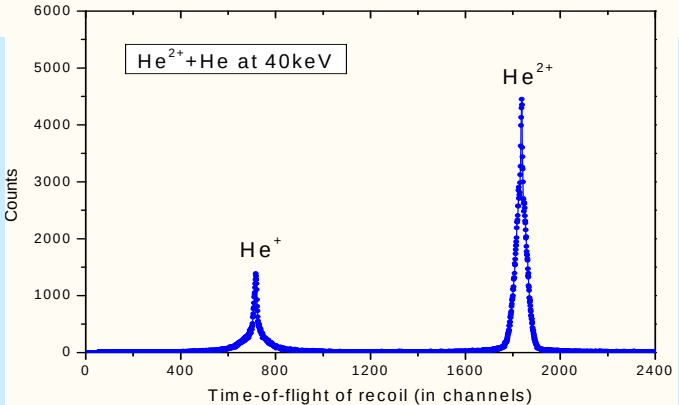
$$P_{long} = P_z$$

$$P_{trans} = \sqrt{P_X^2 + P_Y^2}$$

$$P_Z = m\frac{Z - Z_0}{T} = \alpha_Z \cdot (Z - Z_0)$$

$$P_Y = a_Y (Y - Y_0)$$

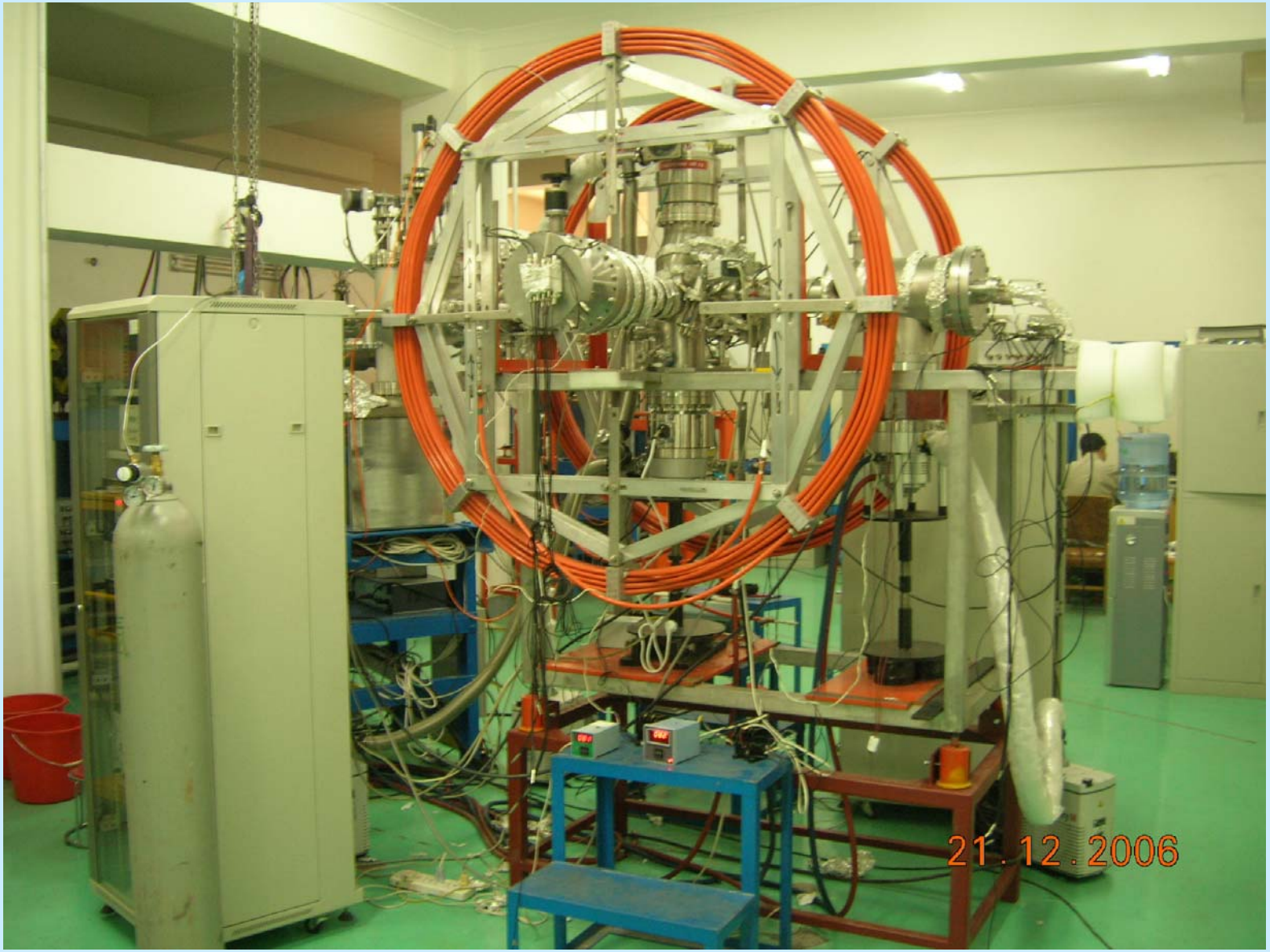
$$P_X \approx -a_X \cdot \Delta T$$



momentum and energy conservation laws

$$P_{long} = -\frac{Q}{v_p} - \frac{n_c}{2} v_p$$

$$P_{trans} = m_{p,i} v_p \tan\theta$$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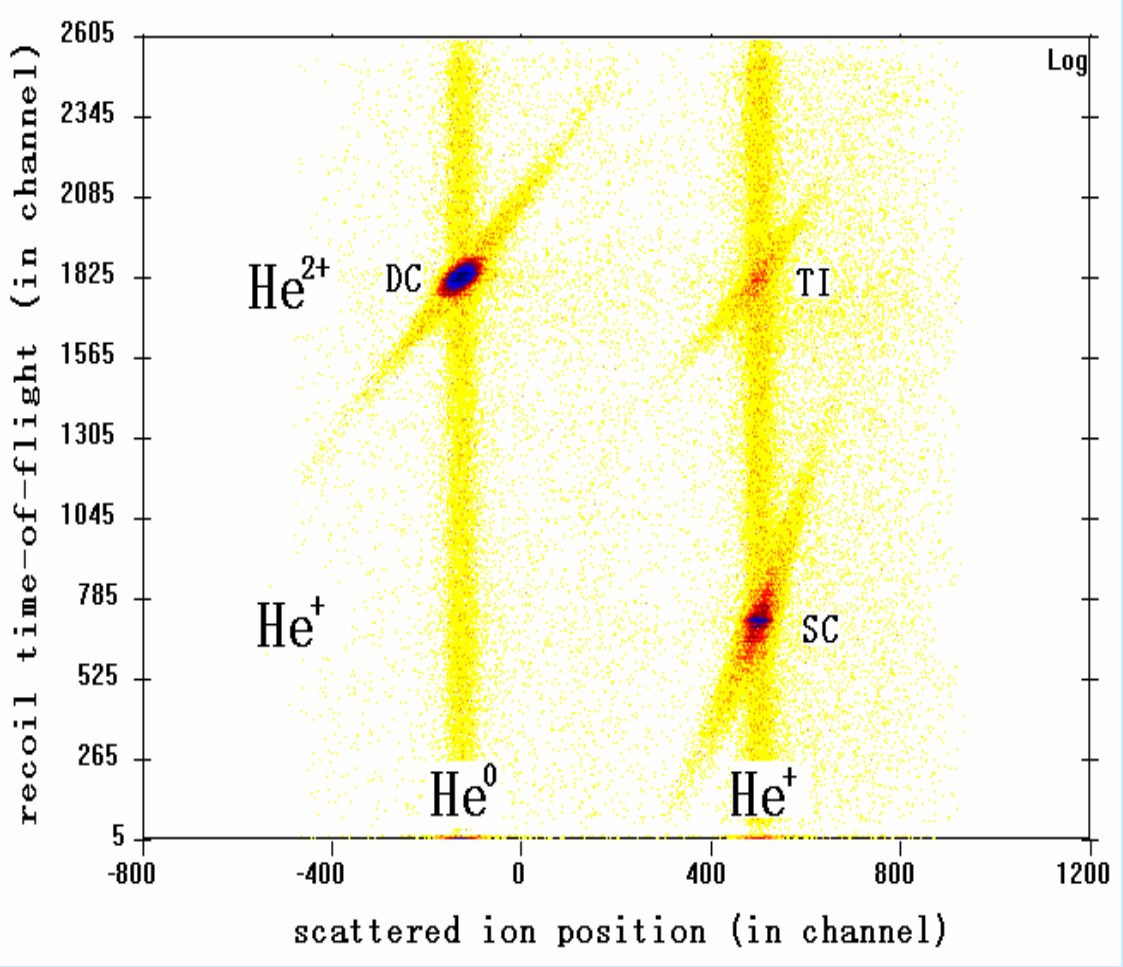
Experimental results



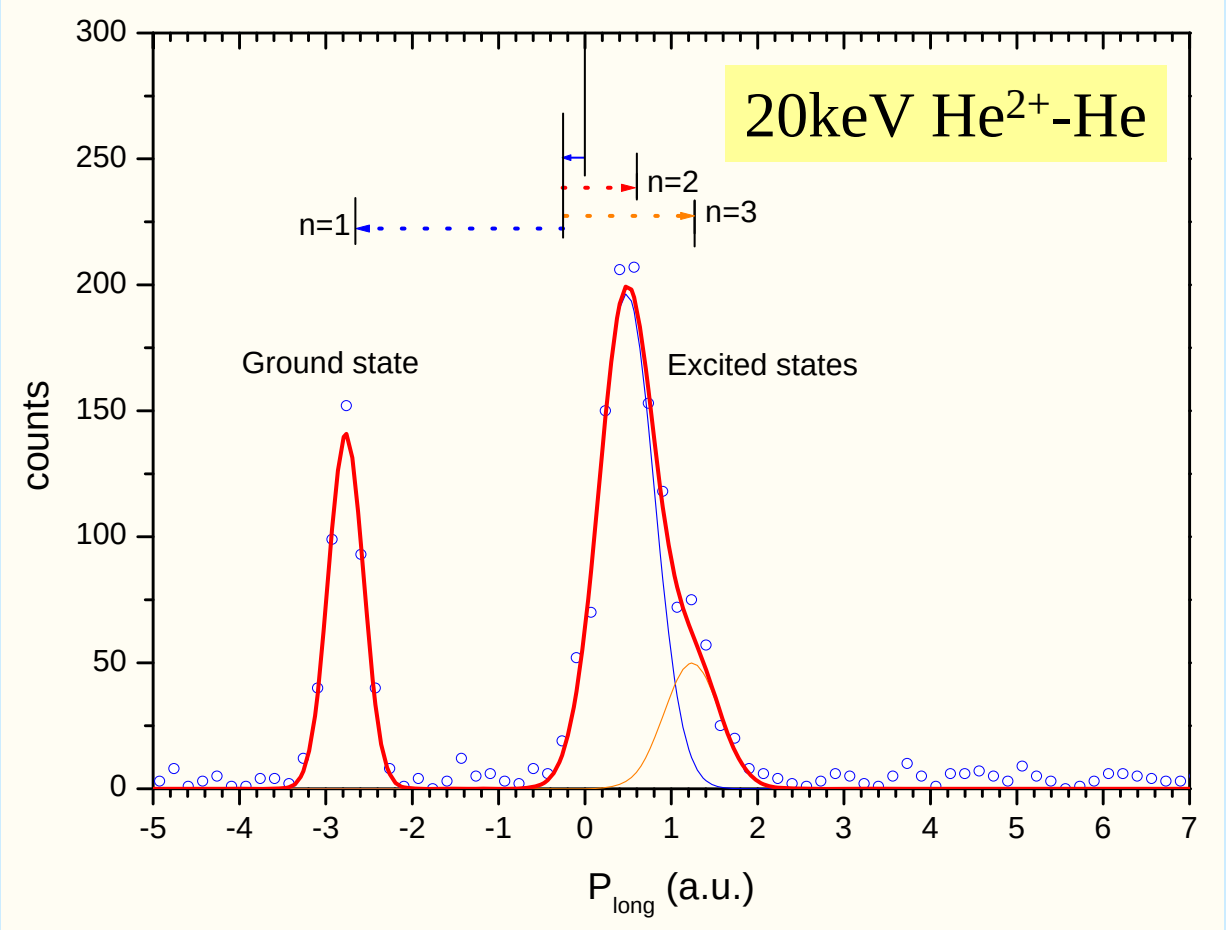
Charge conservation

Different reaction channels can be identified

2D map for scattered ions versus recoil time-of-flight

Experimental results – state-selective SC

SC $He^{2+}+He(1s^2)\rightarrow He^{+}(n)+He^{+}(n')$



K shell: (n,n')=(1,1)
L shell: (1,2)&(2,1)
M shell: (1,3)&(3,1)

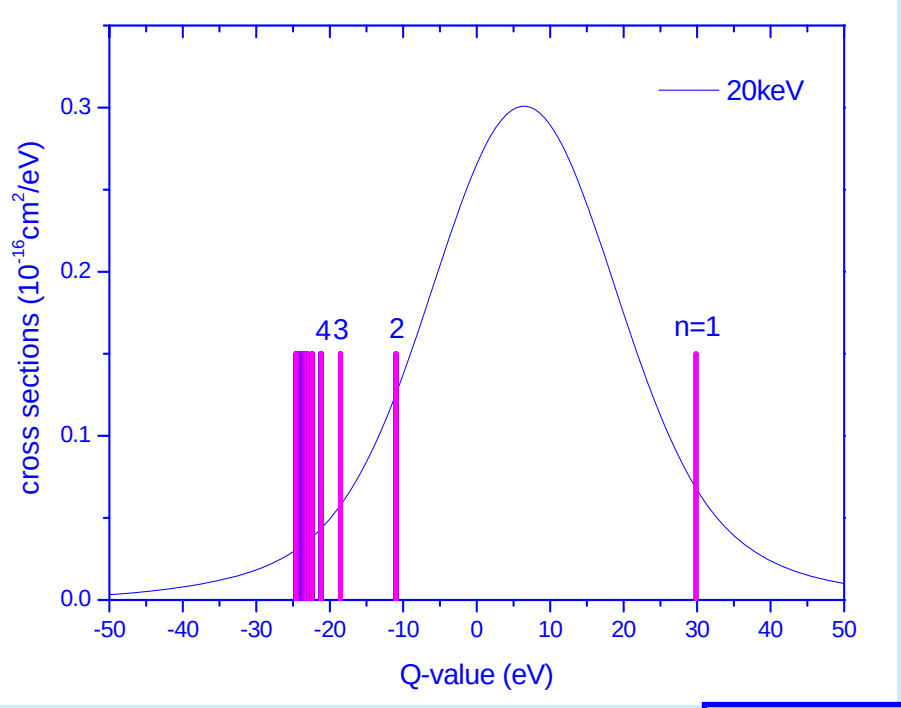
L shell capture is dominant

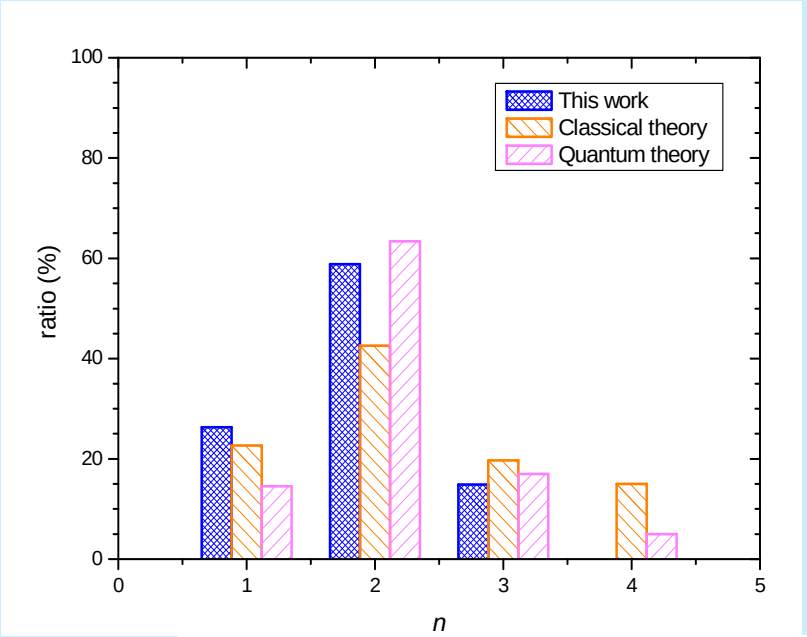
Energy Levels matching conditions

Qualitatively understood

Longitudinal momentum of recoil He^{+} ion, different contributions sre indicated by arrows , and capture into final states are identified

Experimental results – state-selective SC

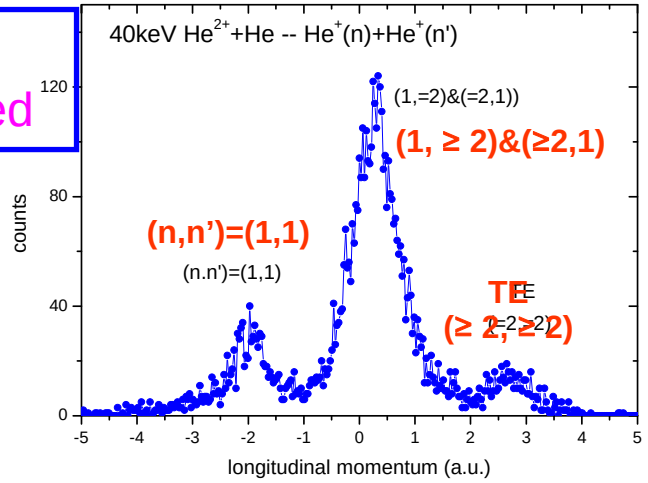




W. Fritsch, J. Phys. B:27(1994)3461

Reaction windows

Choose large Px
TE can be observed

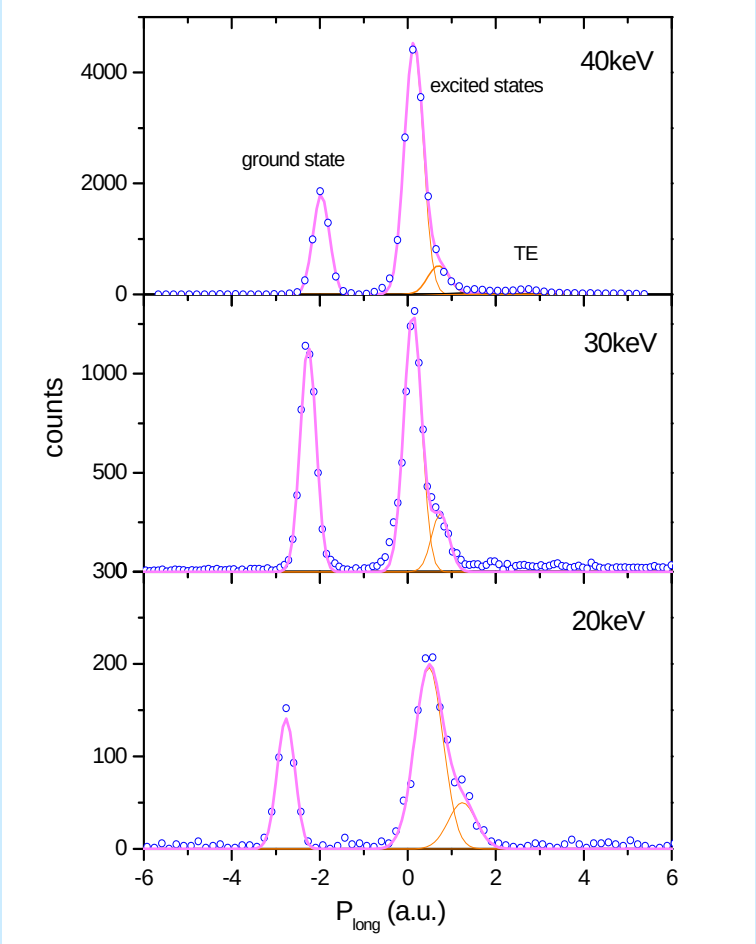


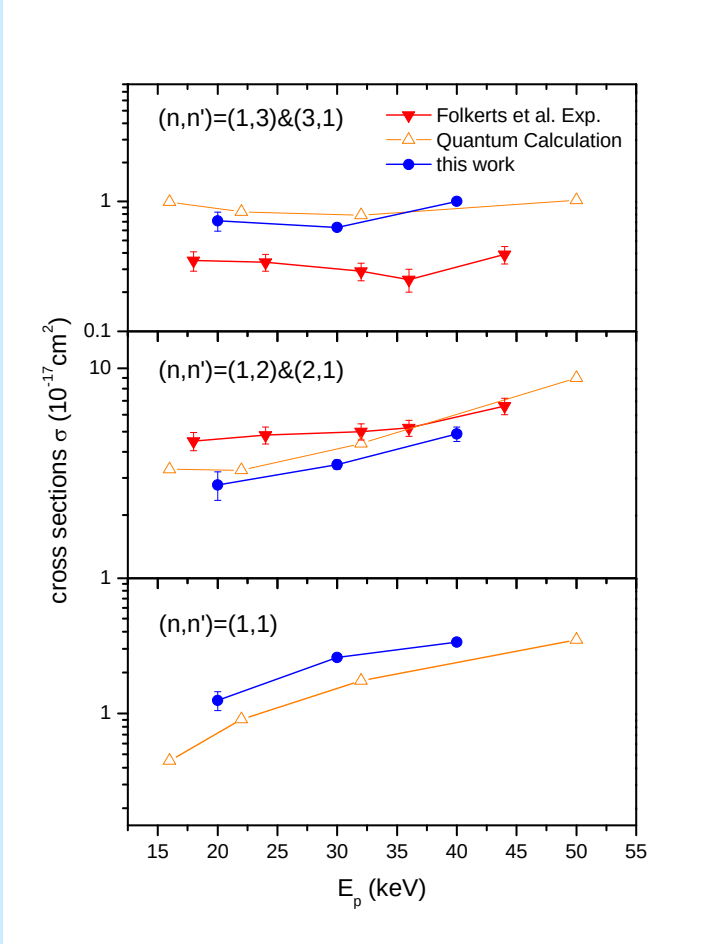
A. Niehaus, J. Phys. B, 19 (18), 2925, 1986

Chen Lanfang et al. Acta Physica Sinica 55(2006)6347

Chen Lanfang et al. Journal of Atomic and Molecular Physics 23(2006)1004

Experimental results – state-selective SC





Normalizing single electron capture cross sections to references:

M. B. Shah et al. J. Phys. B22(1989)3037

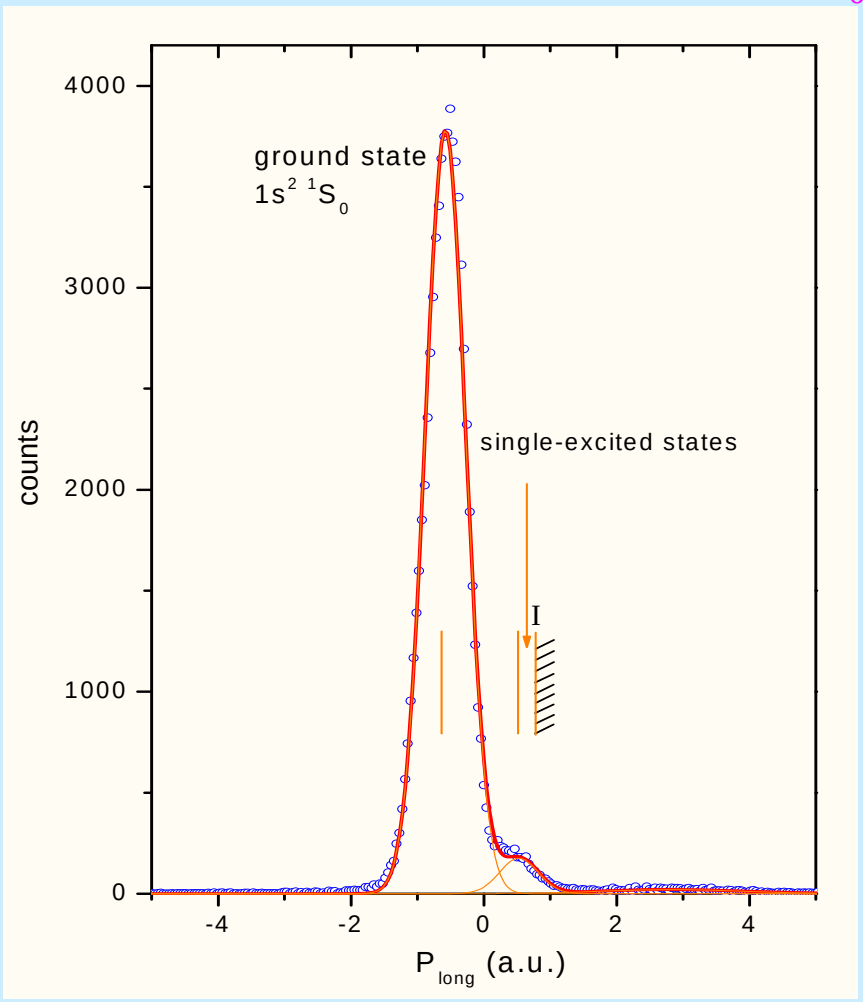
R. D. Dubois et al. Phys. Rev. A36(1987)2585

W. Fritsch, J. Phys. B:27(1994)3461

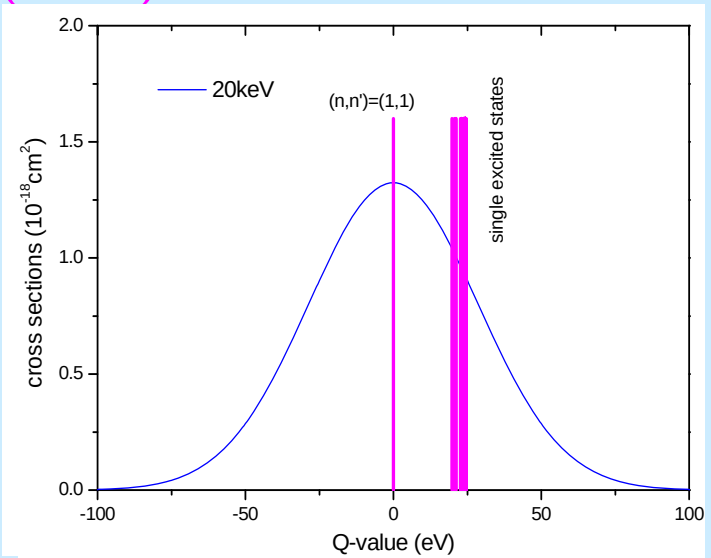
Folkerts, J. Phys. B:27(1994)347

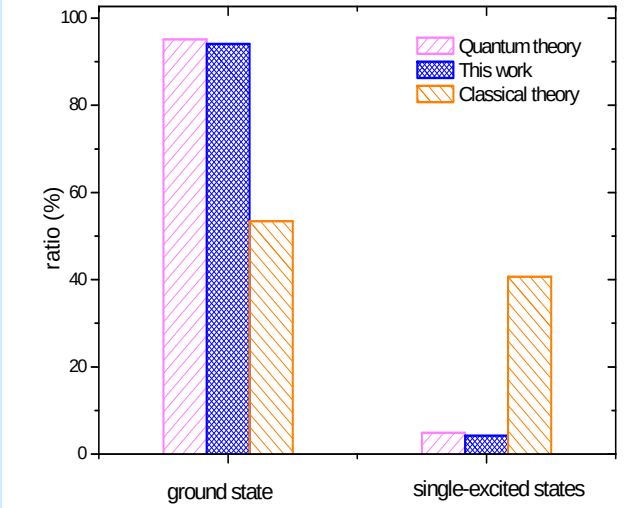
Experimental results – state-selective DC

DC $He^{2+}+He(1s^2\ ^1S_0)\rightarrow He^0(nln'l')+He^{2+}$



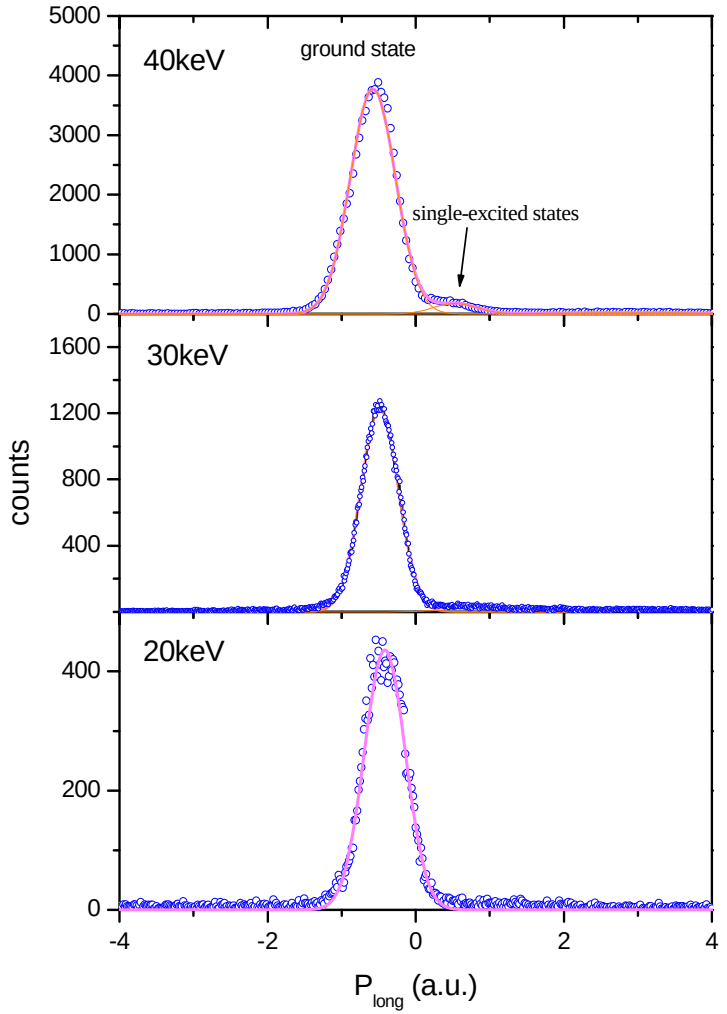
Longitudinal momentum of recoil He^{2+} ion

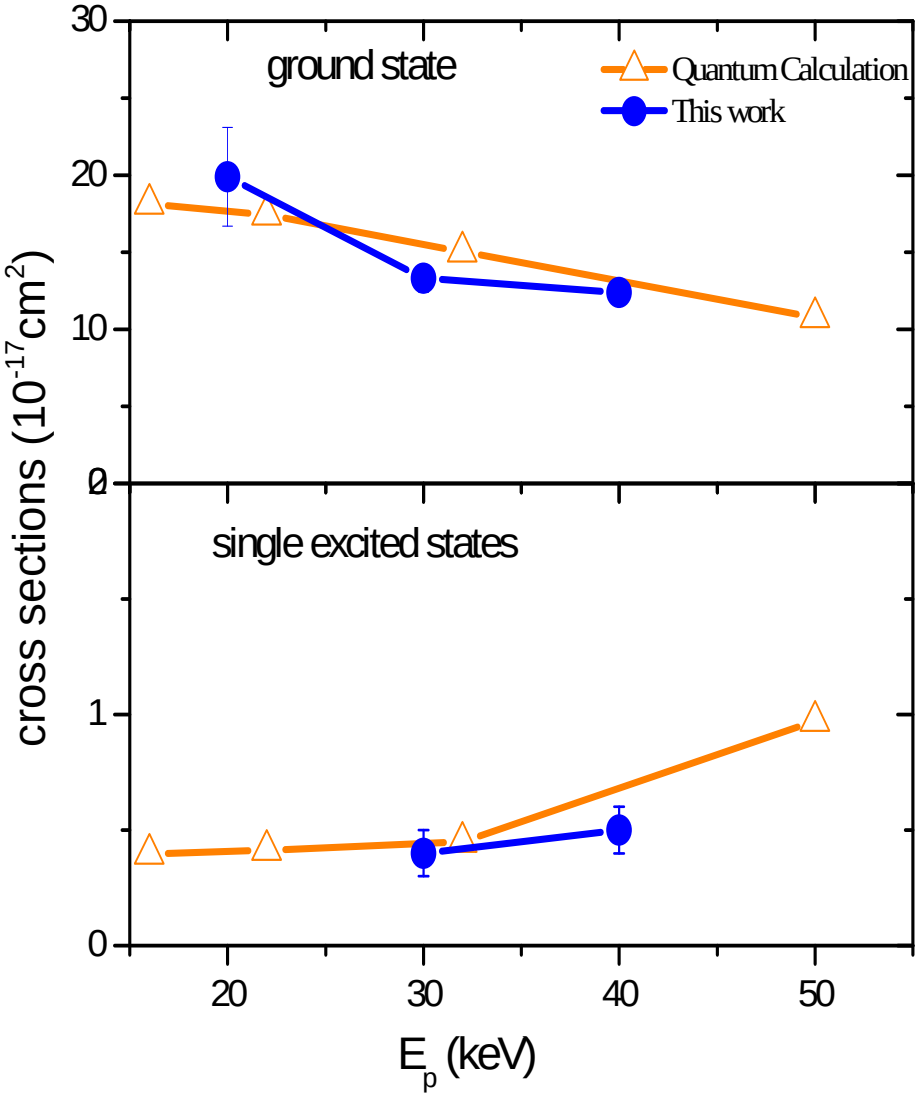




Resonant double-electron capture Q=0 energy levels

W. Fritsch, J. Phys. B:27(1994)3461


40keV
ground state
single-excited states
30keV
20keV
counts
5000
4000
3000
2000
1000
0
1600
1200
800
400
400
200
0
-4
-2
0
2
4
P_long (a.u.)


ground state
Quantum Calculation
This work
single excited states
cross sections (10^-17 cm^2)
30
20
10
0
1
0
20
30
40
50
E_p (keV)

Experimental results – state-selective TI

For He^{2+}-He collisions system, the mechanism of TI:

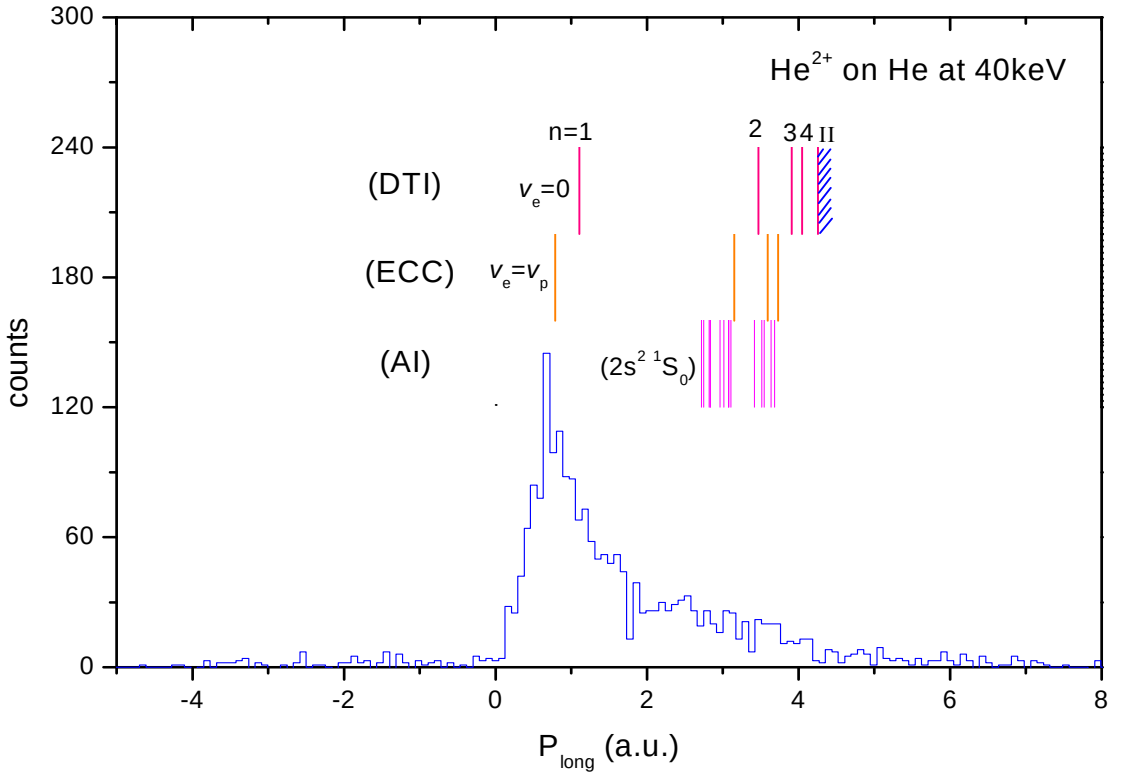
Direct transfer ionization (DTI)

Electron capture into the continue states of projectile **(ECC)**

Auger electron emission(AI)

$$He^{2+}+He\rightarrow\begin{cases} He^{+}(nl)+He^{2+}+e^{-}+Q^{DTI} \\ He^{+}(nl)+He^{2+}+e^{-}+Q^{ECC} \\ He^{**}+He^{2+}\rightarrow He^{+}(nl)+He^{2+}+e^{-}+Q^{AI} \end{cases}$$

Experiment results – state-selective TI

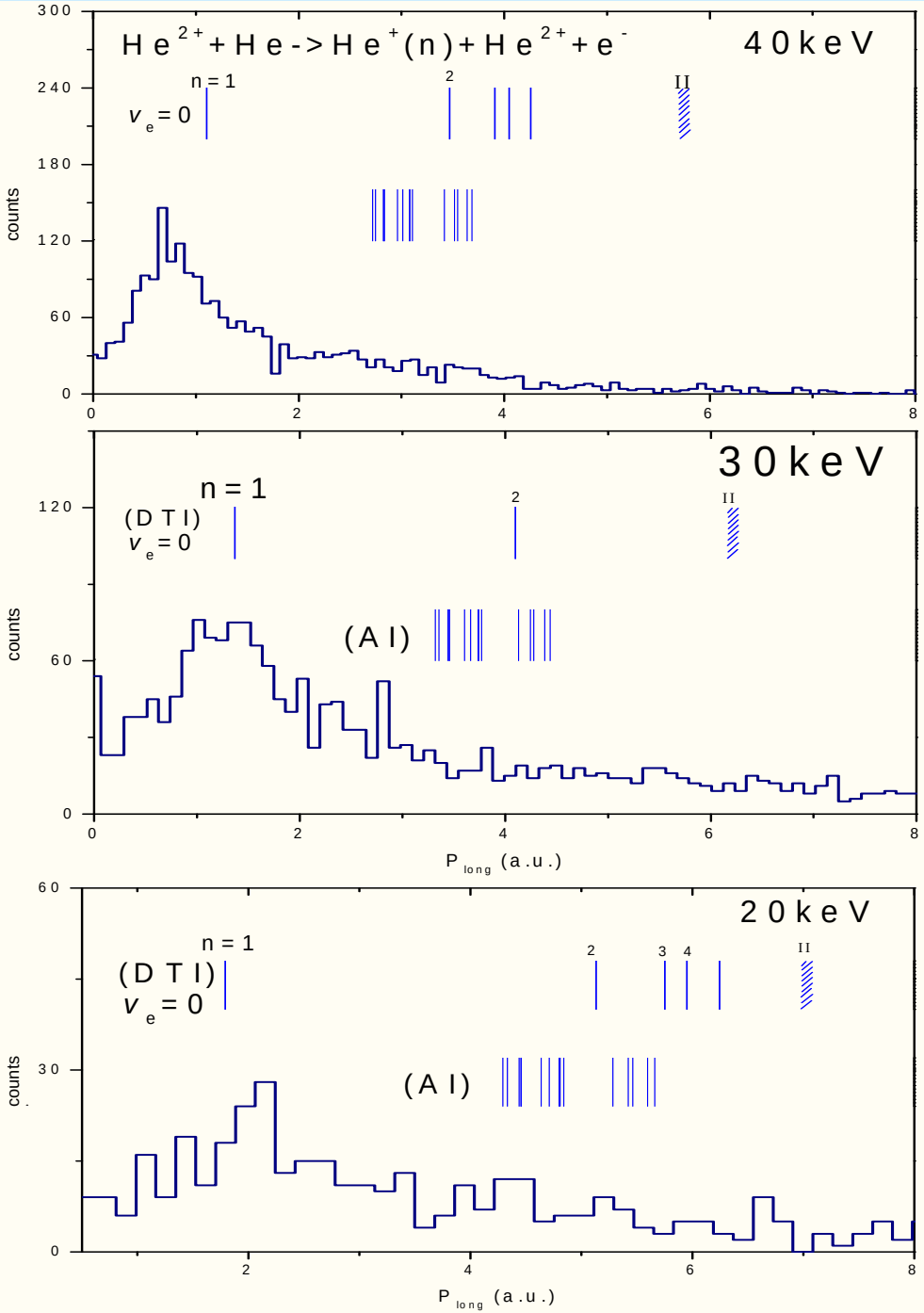


$$DTI \qquad P_{long} = -\frac{Q}{v_p} - \frac{1}{2}v_p + \frac{E_{e,f}}{v_p} - P_{long,\ e,f}$$

$$ECC \qquad AI \qquad P_{long} = -\frac{Q}{v_p} - v_p$$

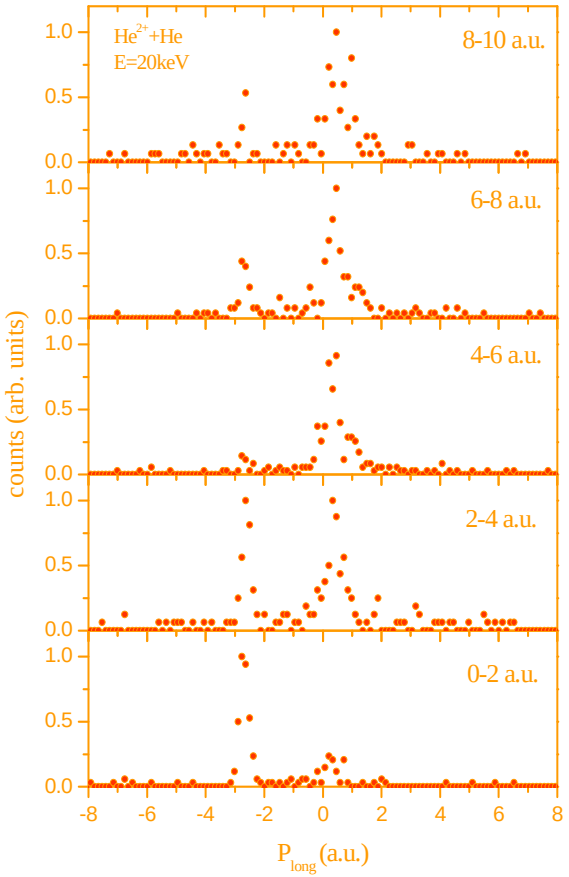
Longitudinal momentum of recoil He^{2+} ion from transfer ionization

ECC and DTI are dominant , AI has some contributions.

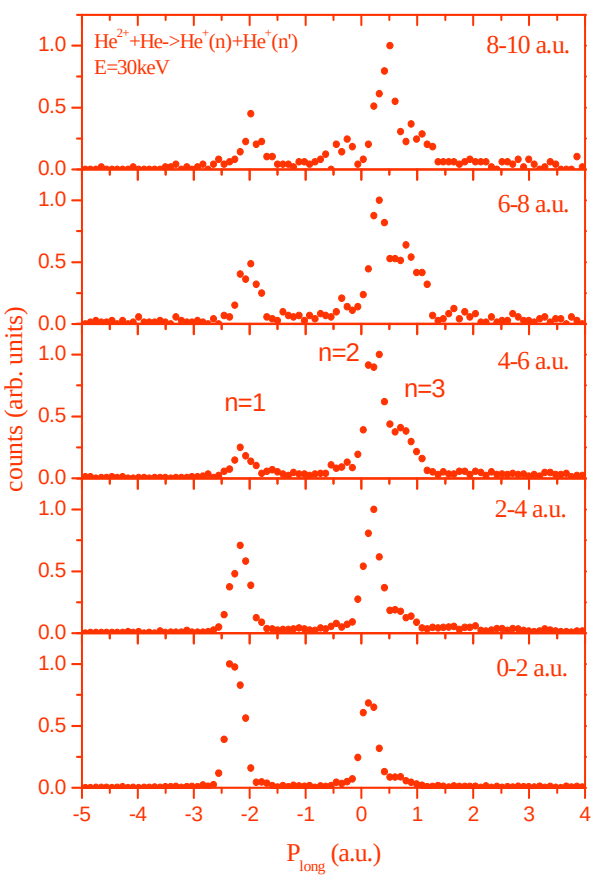

He2+ + He -> He+(n) + He2+ + e-
40 keV
n = 1
ve = 0
2
II
counts
30 keV
(D T I)
(A I)
Plong (a.u.)
20 keV

Experimental results – Angular differential cross sections

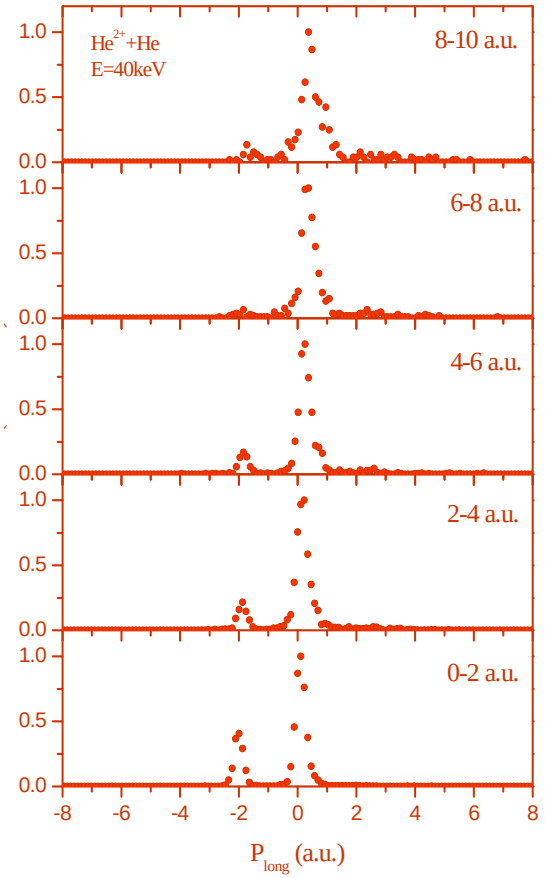
20keV



30keV



40keV



Compare to theory – *impact parameter dependence*

a complete unified theoreticaldescription where excitation, transfer and ionization are treated simultaneously on an ab initio level.

Table 1
Integral relative probability for charge transfer, transfer and ionization for the system $He^{++} \rightarrow He$ at 30 keV

Scattering system	Process	Relat. probability for the process	
		exp.	theoret.
$He^{++} + He \rightarrow$:	$He + He^{++}$	64.3%	66%
	$He^{+}(1s) + He^{+}$	12.1%	8%
	$He^{+}(n = 2) + He^{+}$	16.4%	18%
	$He^{+}(n > 2) + He^{+}$	2.9%	4%
	$He^{+} + He^{++} + e$	2.9%	4%
	$He^{++} + He^{+} + e$	1.4%	

Compare to theory – impact parameter dependence

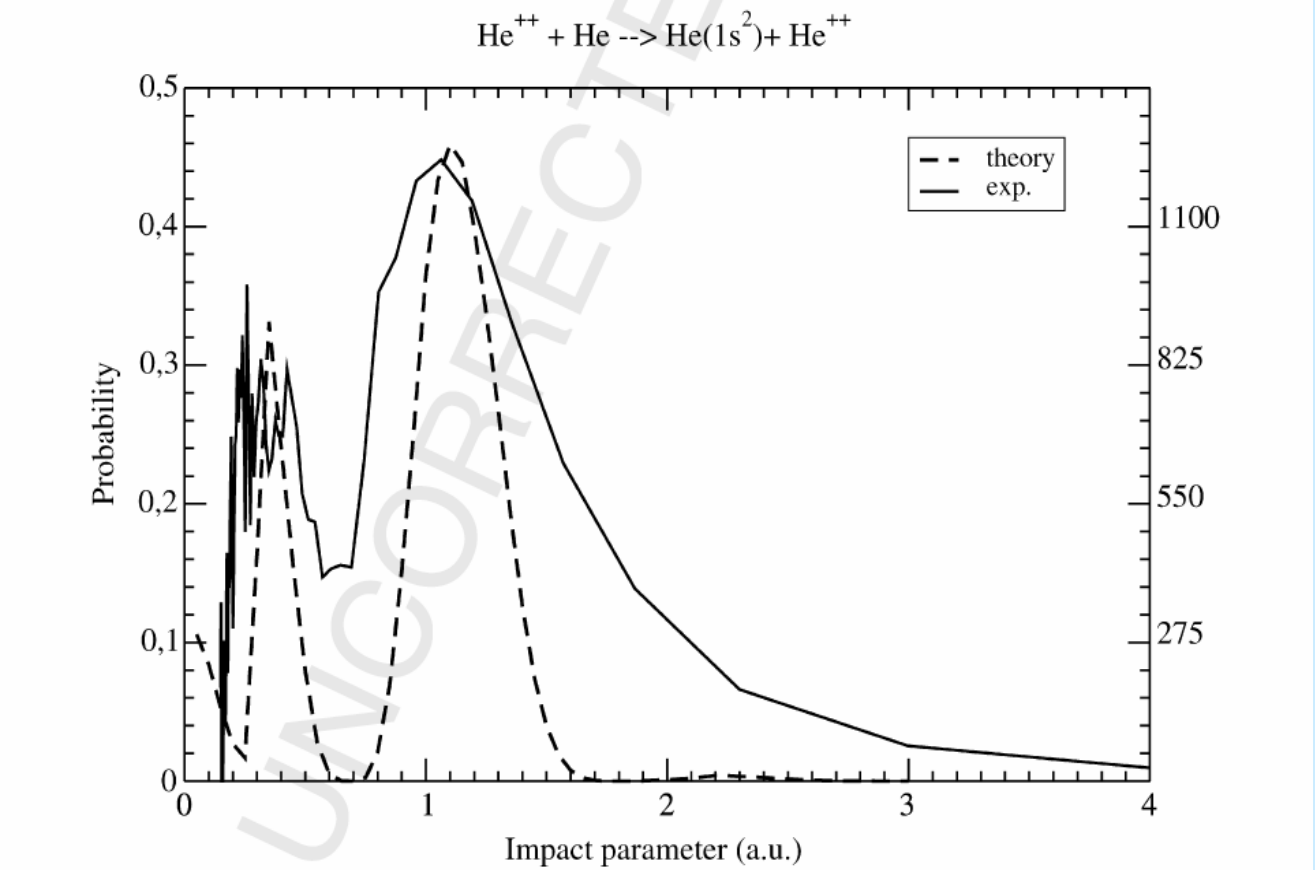
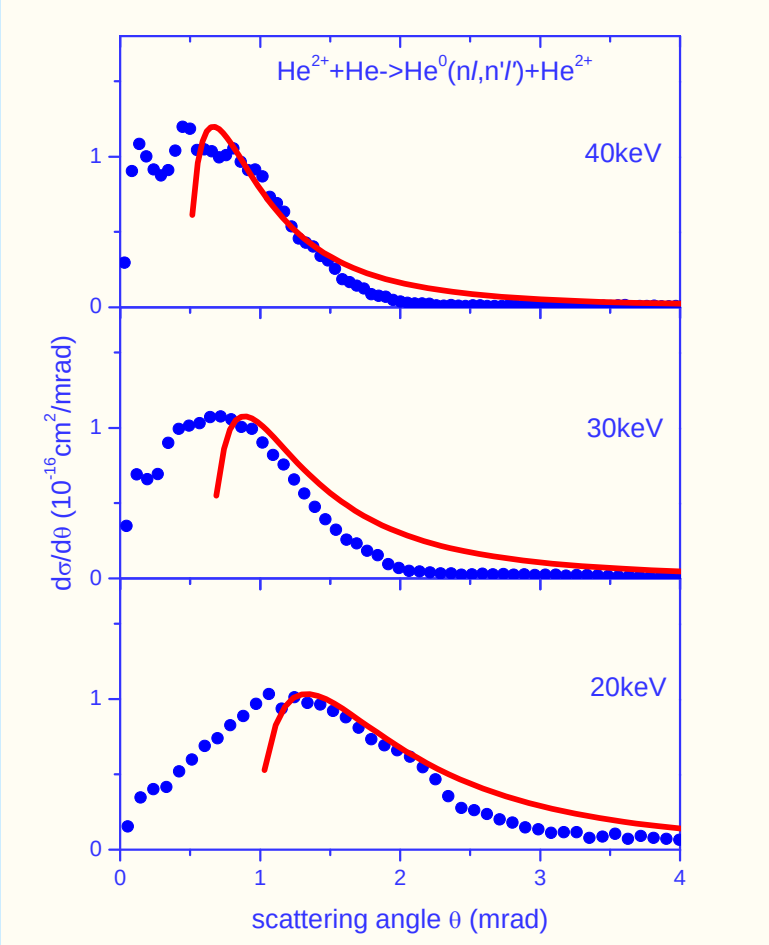


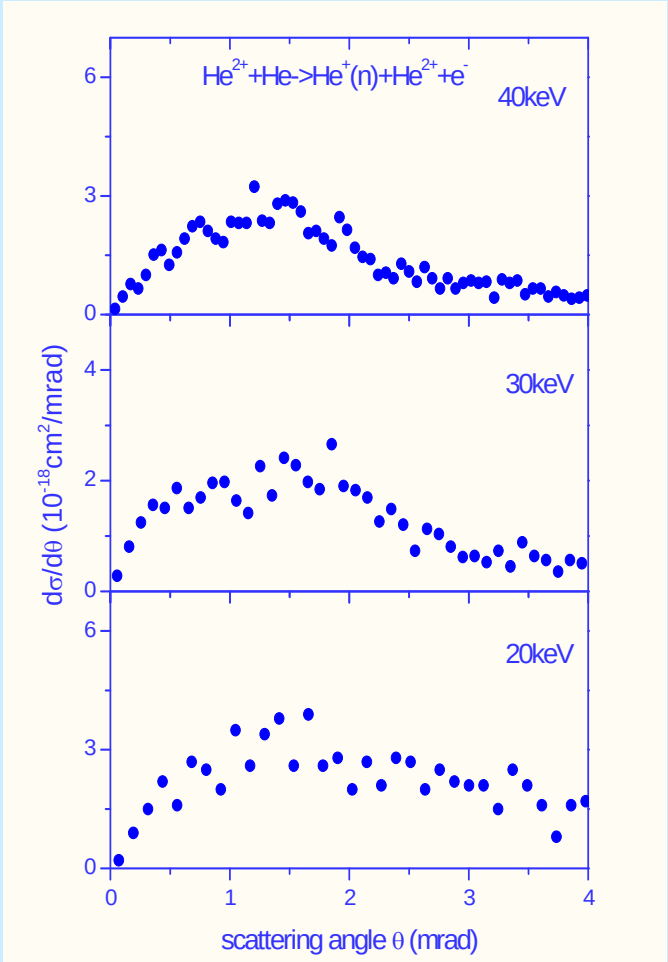
Fig. 2. Impact parameter dependent probability for the double charge transfer for the scattering system He^{++} on He at 30 keV.

J. Anton, B. Frickeet al. Phys. Lett. A(2007)
in press

Experimental results – Angular differential cross sections



Comparison of DC total angular differential cross sections with MCBM Model at different impact energy



TI total angular differential cross sections

Summary

- The absolute state-selective and angular differential cross sections for one- and two- electron capture will be reported for incident energy from 5 keV/u to 10keV/u.
- The results show that single-electron capture into L-shell is dominant while double electron capture into the ground state of projectile is by far the dominant process. The final state distributions are compared to the results of close-coupling calculations as well as classical calculations , and resonable agreement was found.
- The angular differential cross sections for state-selective electron capture were obtained for singly charged and neutral projectiles, and the results are compared with theoretical calculation in impact parameter respresentation.
- The mechanism of transfer ionization was discussed by analysing the recoil momentum.

Outlook

He^{2+} on He system

- Improve of the momentum resolution
- Improve of statistics of detected electrons
- Explore single ionization at low energy

The experimental team