Experimental Studies on Interactions of Atomic Ions with Single Electrons

see review: A. Müller, Adv. At. Mol. Phys. 55 (2008) 293

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GIESSEN

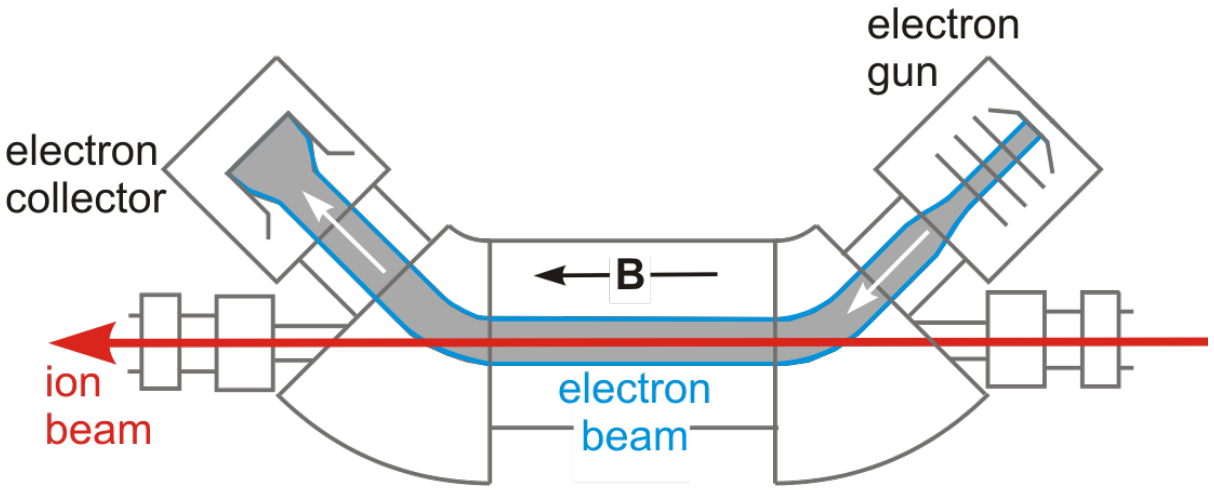
IAEA Technical Meeting on Uncertainty Assessment and Benchmark Experiments for Atomic and Molecular Data for Fusion Applications

IAEA Headquarters, Vienna, December 19 – 21, 20146

Interacting beams of electrons and ions

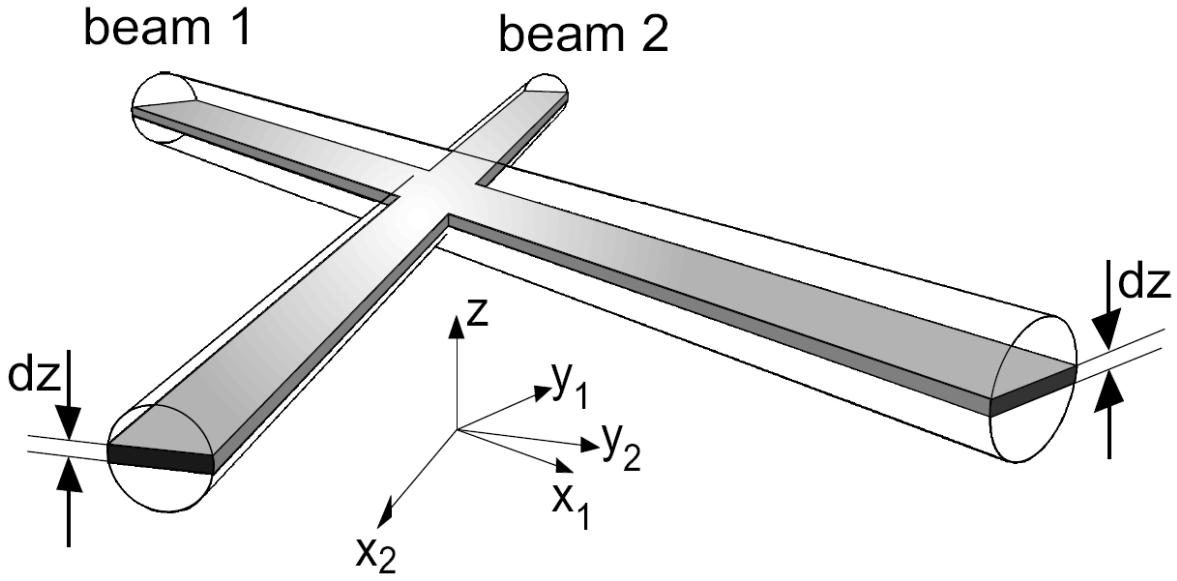
merged beams

see talk by
Andreas Wolf

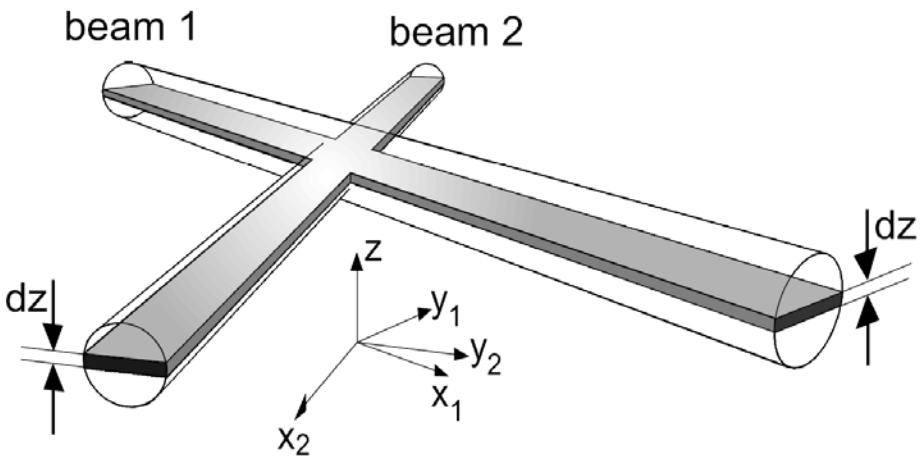


Both techniques can be used in ion storage rings

crossed beams



Cross sections from crossed-beams experiments



slices of beam 1 interact with corresponding slices of beam 2

probed by moving a narrow slit across both beams
or
by moving one beam across the other (animated beams)

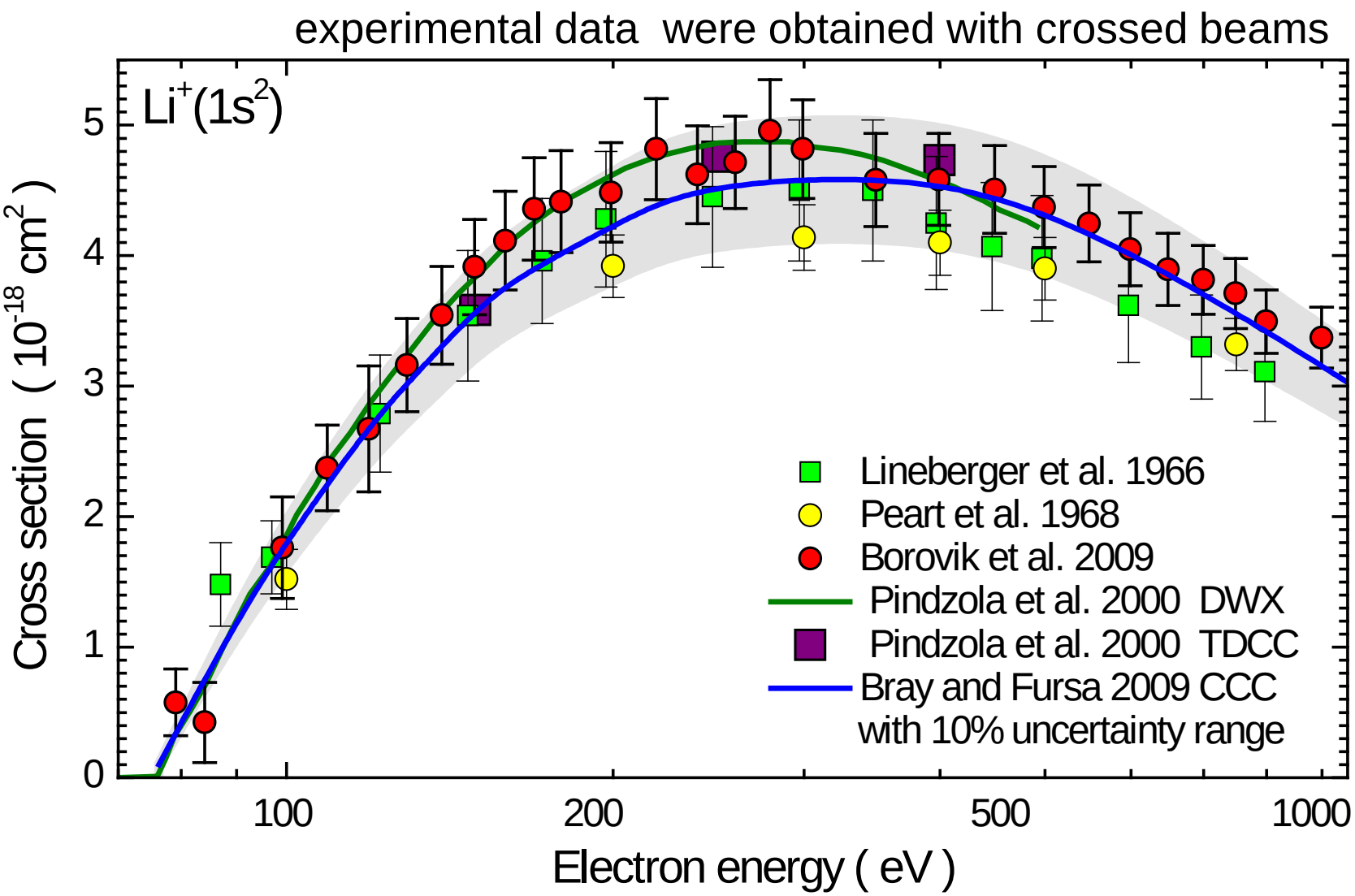
cross section $$\sigma(E) = \frac{R\, qe^2\, v_e\, v_i}{I_e\, I_i\, \left|\vec{v}_i - \vec{v}_e\right|} \frac{F}{\varepsilon}$$

beam overlap $$F = \frac{I_e\, I_i}{\int_z I_e(z)\, I_i(z)\, dz}$$

σ	cross section
R	signal count rate
q	ion charge state
e	elementary charge
v_e / v_i	electron / ion velocity
I_e / I_i	electron / ion current
ε	detection efficiency

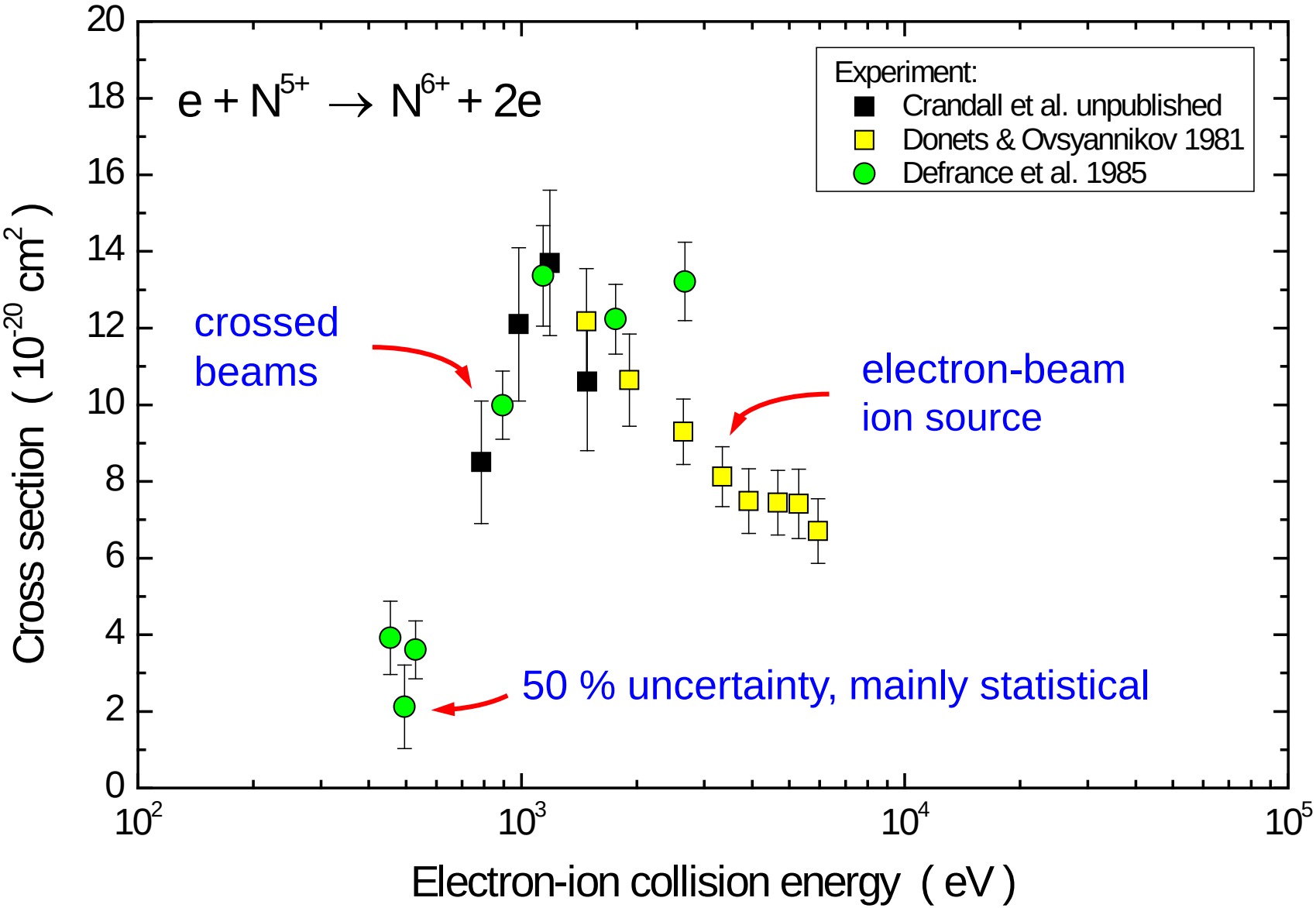
Systematic uncertainties typically (8 ± 2)%

Cross sections for ionization of $Li^+(1s^2)$



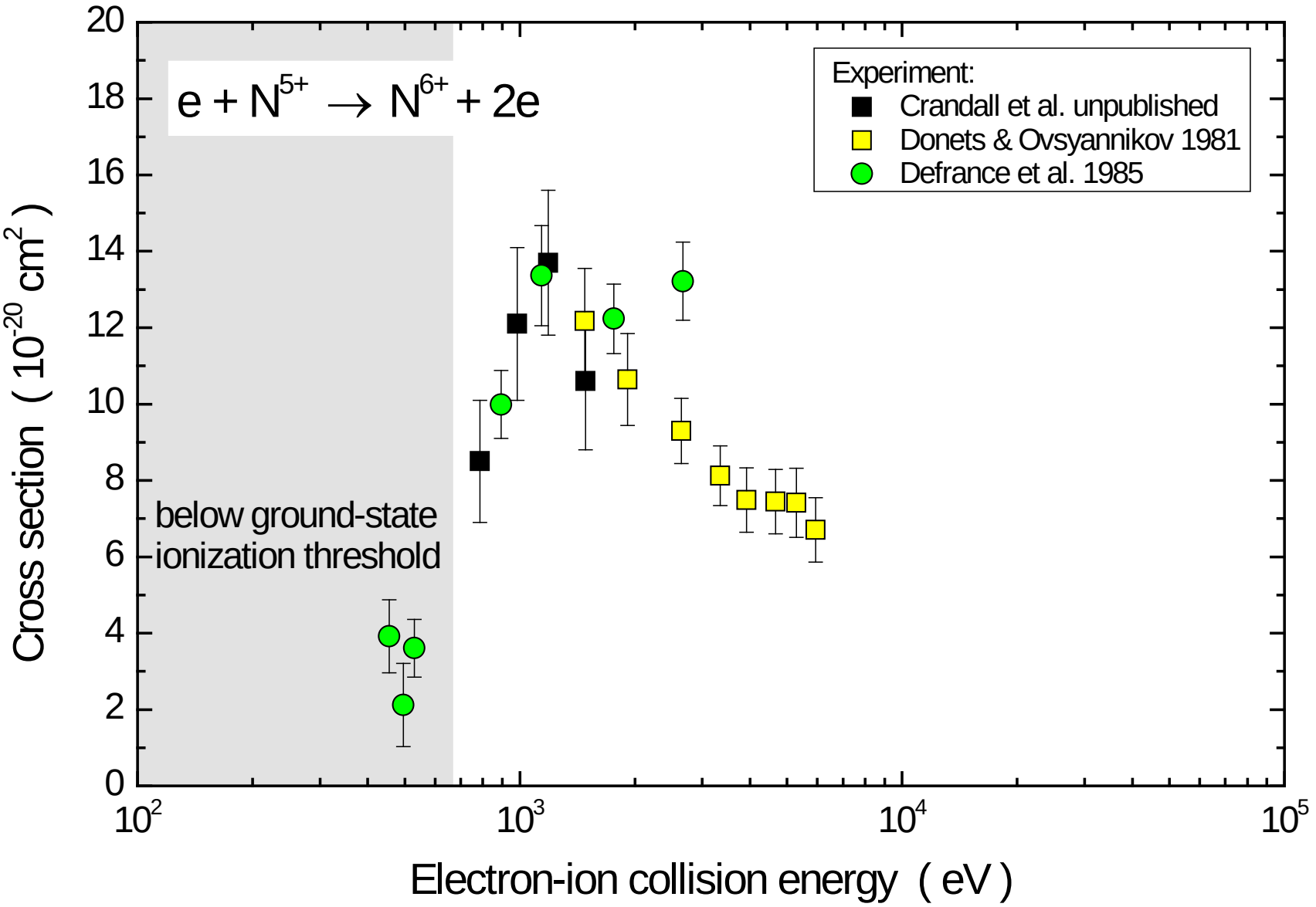
experimental data within 10% uncertainty range around CCC results

Statistical, systematical and model-related errors



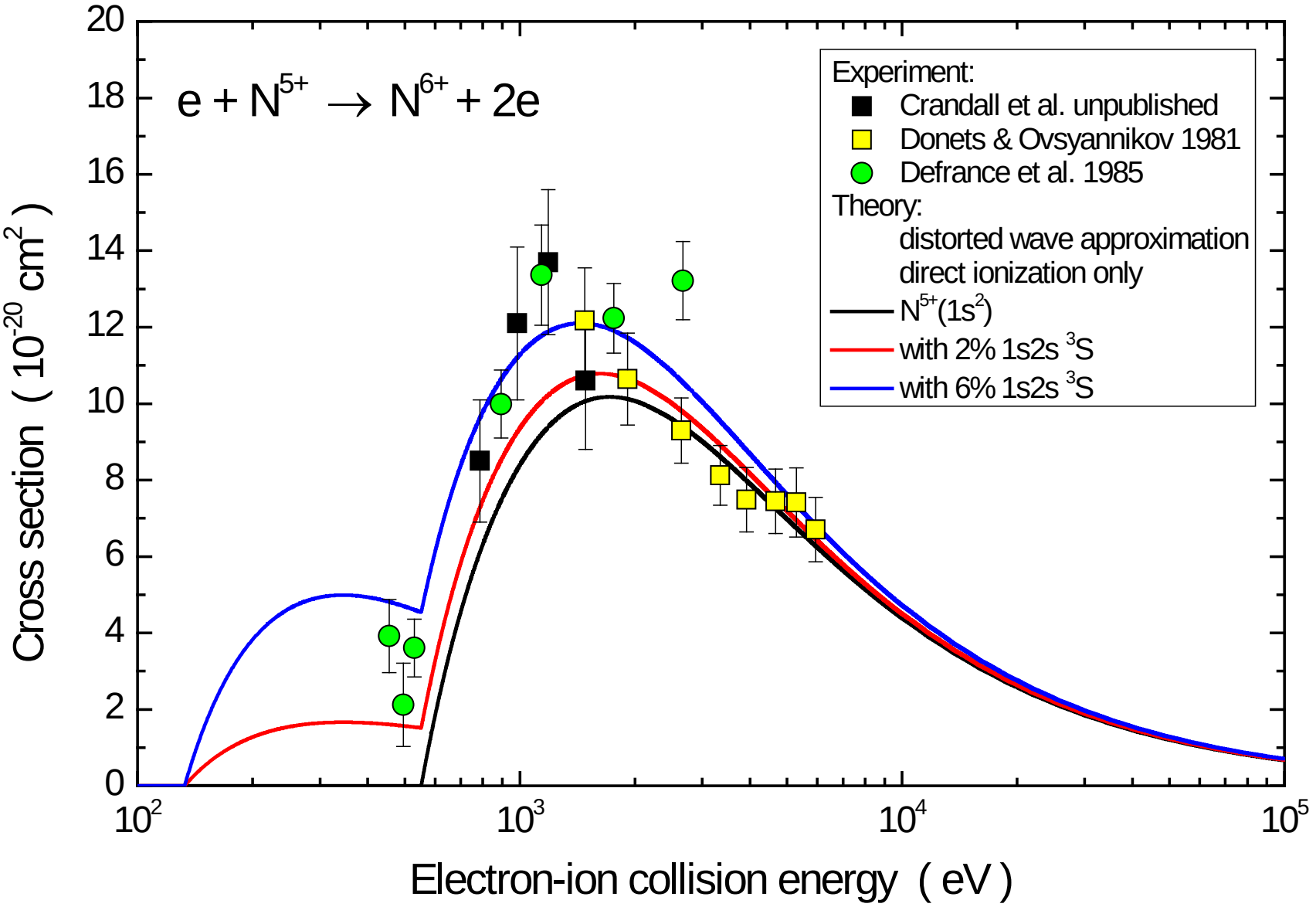
large uncertainties and discrepancies

Statistical and systematical uncertainties: N^{5+}



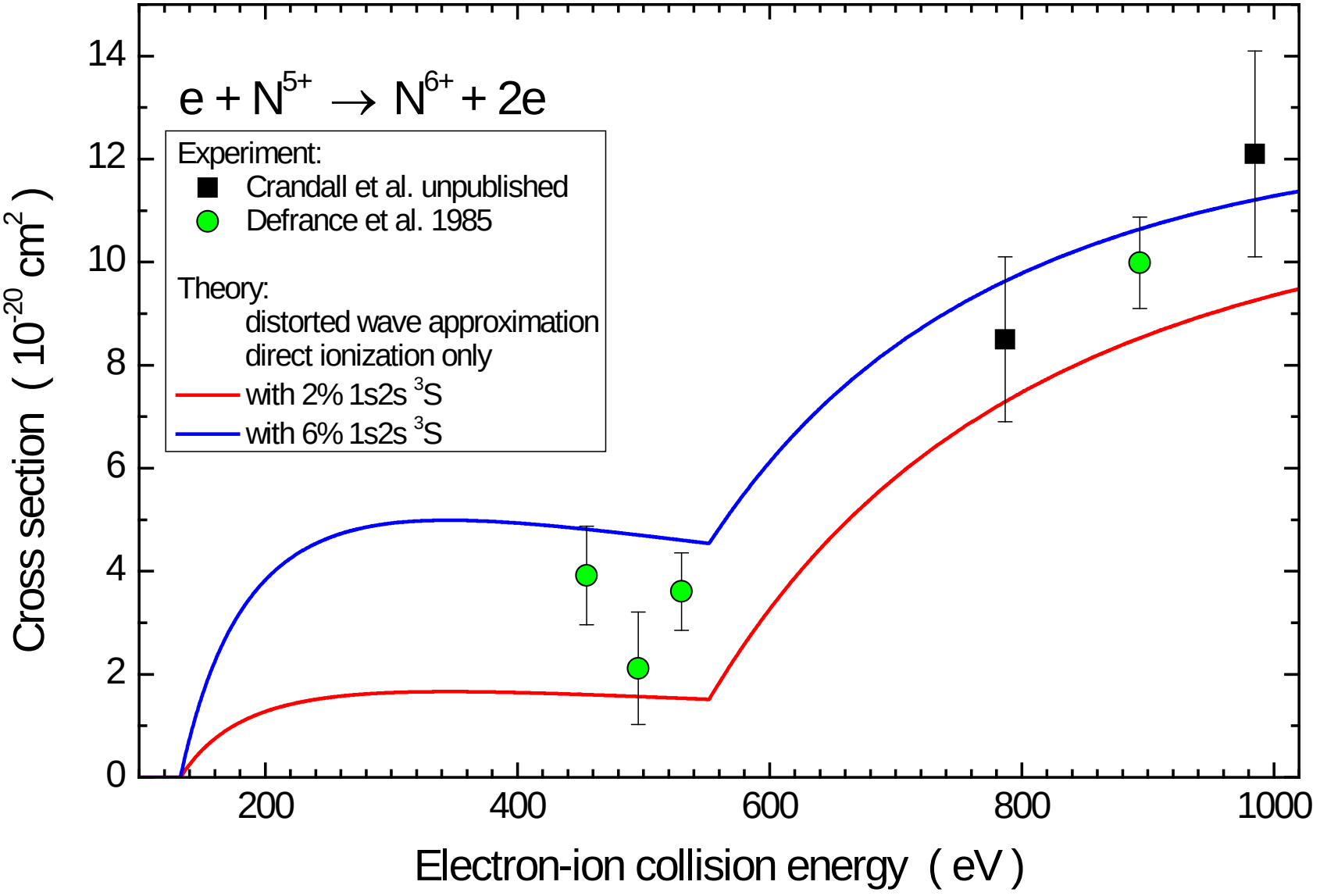
signal below the ground-state threshold: metastable excited states

Statistical and systematical uncertainties: N^{5+}



primary ion beam contained between 2 and 6% metastable ions

New data for electron-impact ionization of N^{5+} ions



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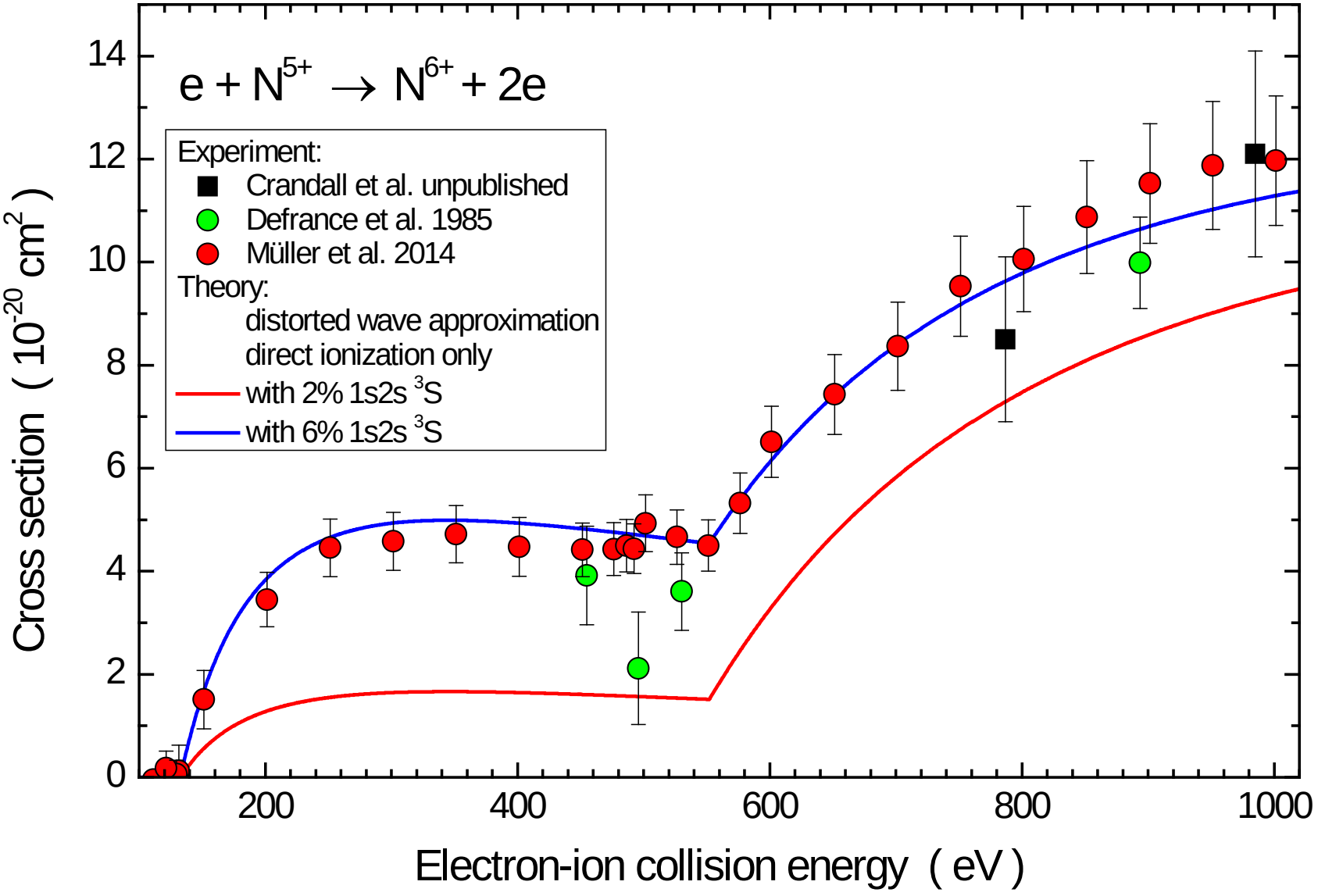

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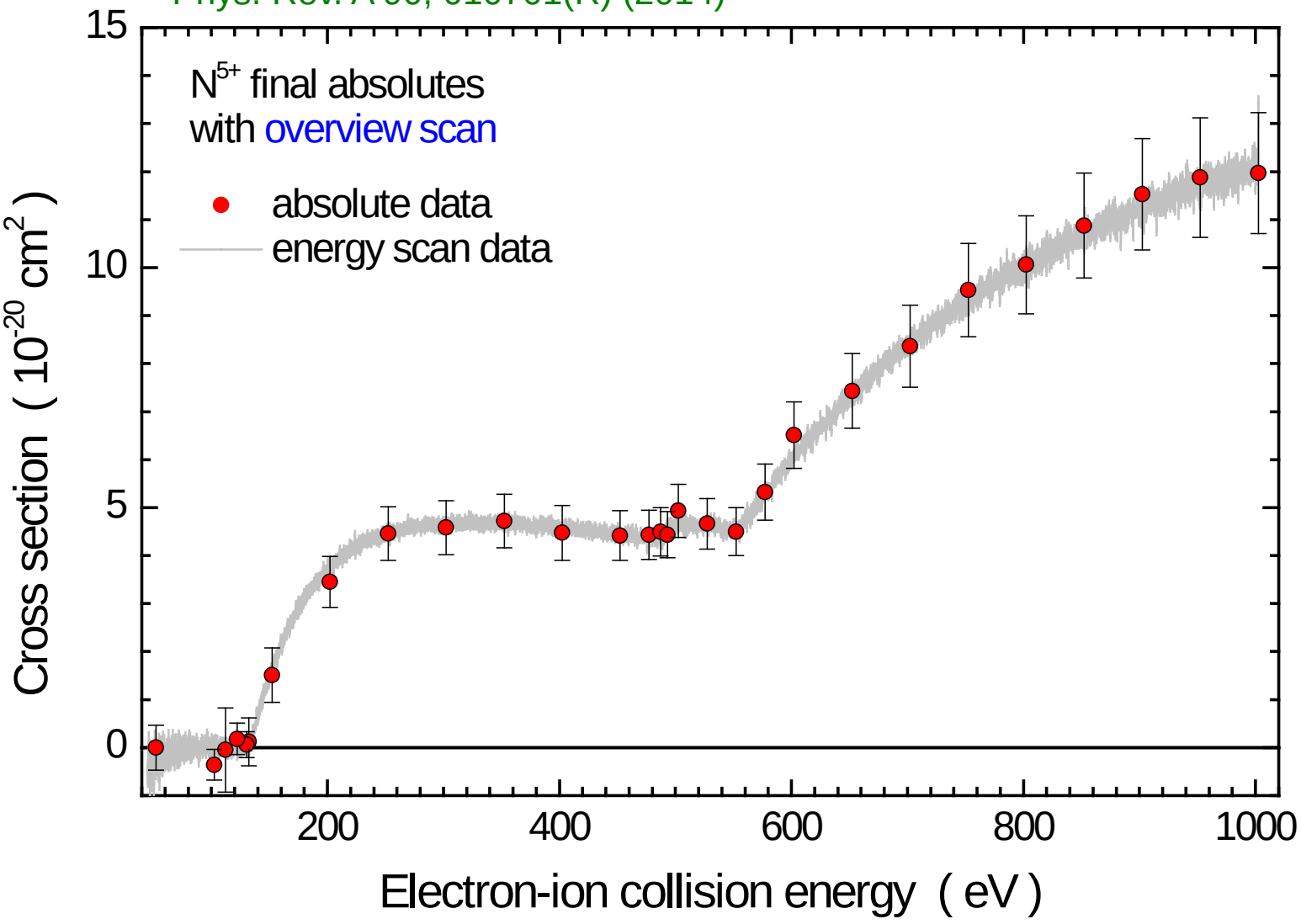
Electron-impact ionization of N^{5+} ions

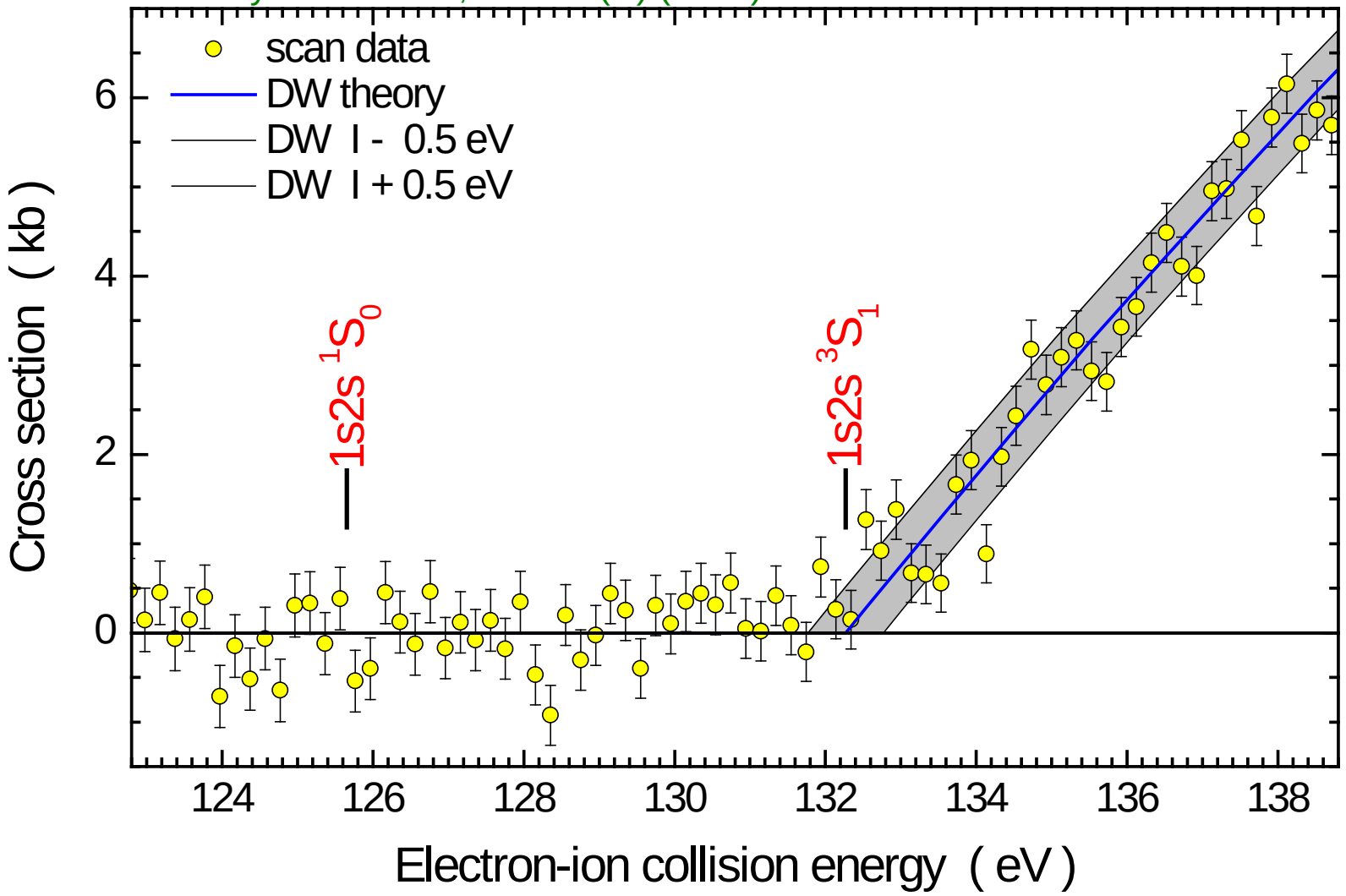
A. Müller, A. Borovik Jr., K. Huber, S. Schippers, D. V. Fursa, I. Bray, Phys. Rev. A 90, 010701(R) (2014)



Combination of absolute measurements and fine-step energy scans

Scrutinizing the threshold energy region

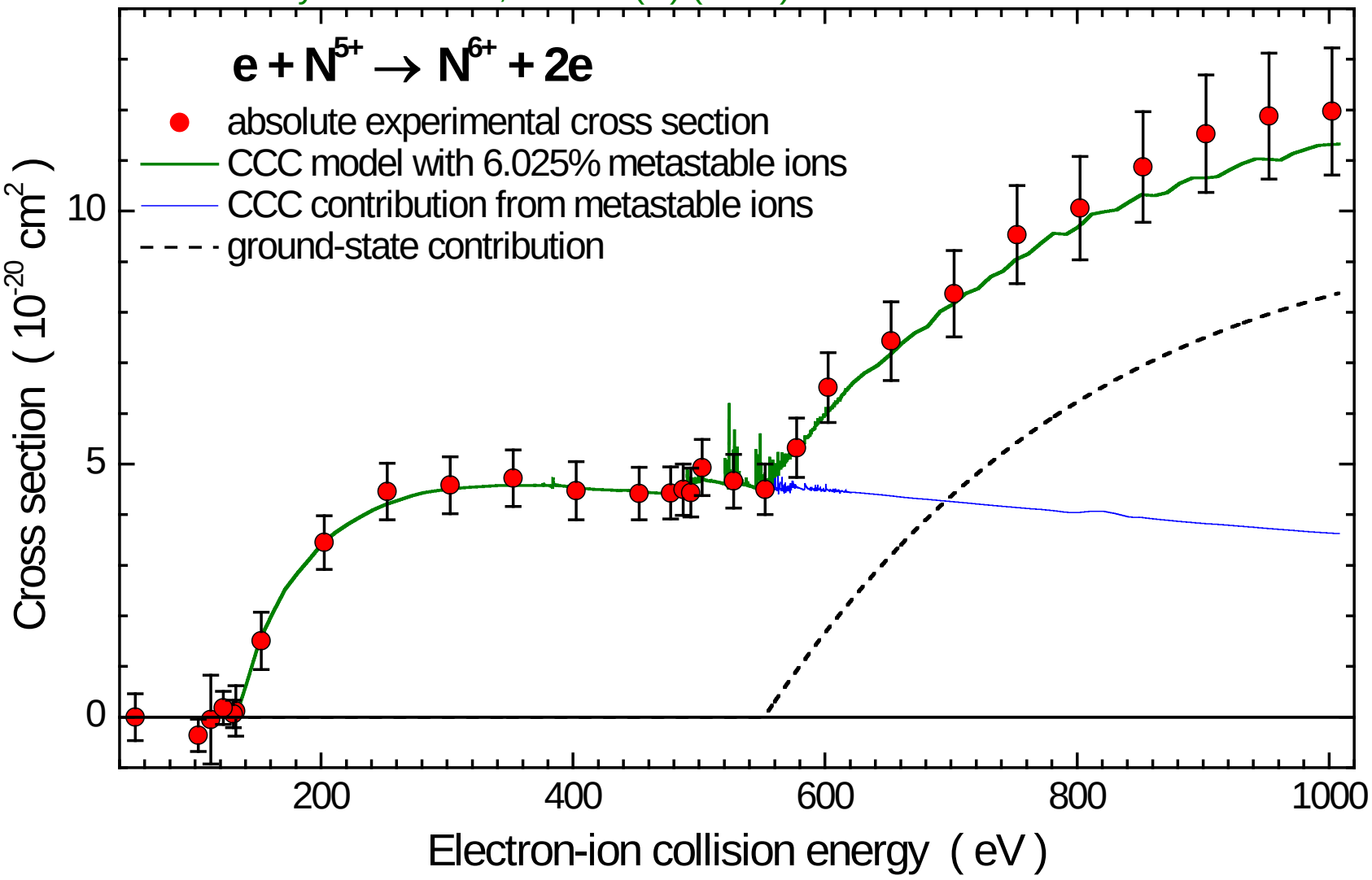
A. Müller, A. Borovik Jr., K. Huber, S. Schippers, D. V. Fursa, I. Bray,
Phys. Rev. A 90, 010701(R) (2014)



Metastable state of ions in the projectile beam identified: $1s2s\ ^3S_1$

Modeling the metastable fraction by CCC theory

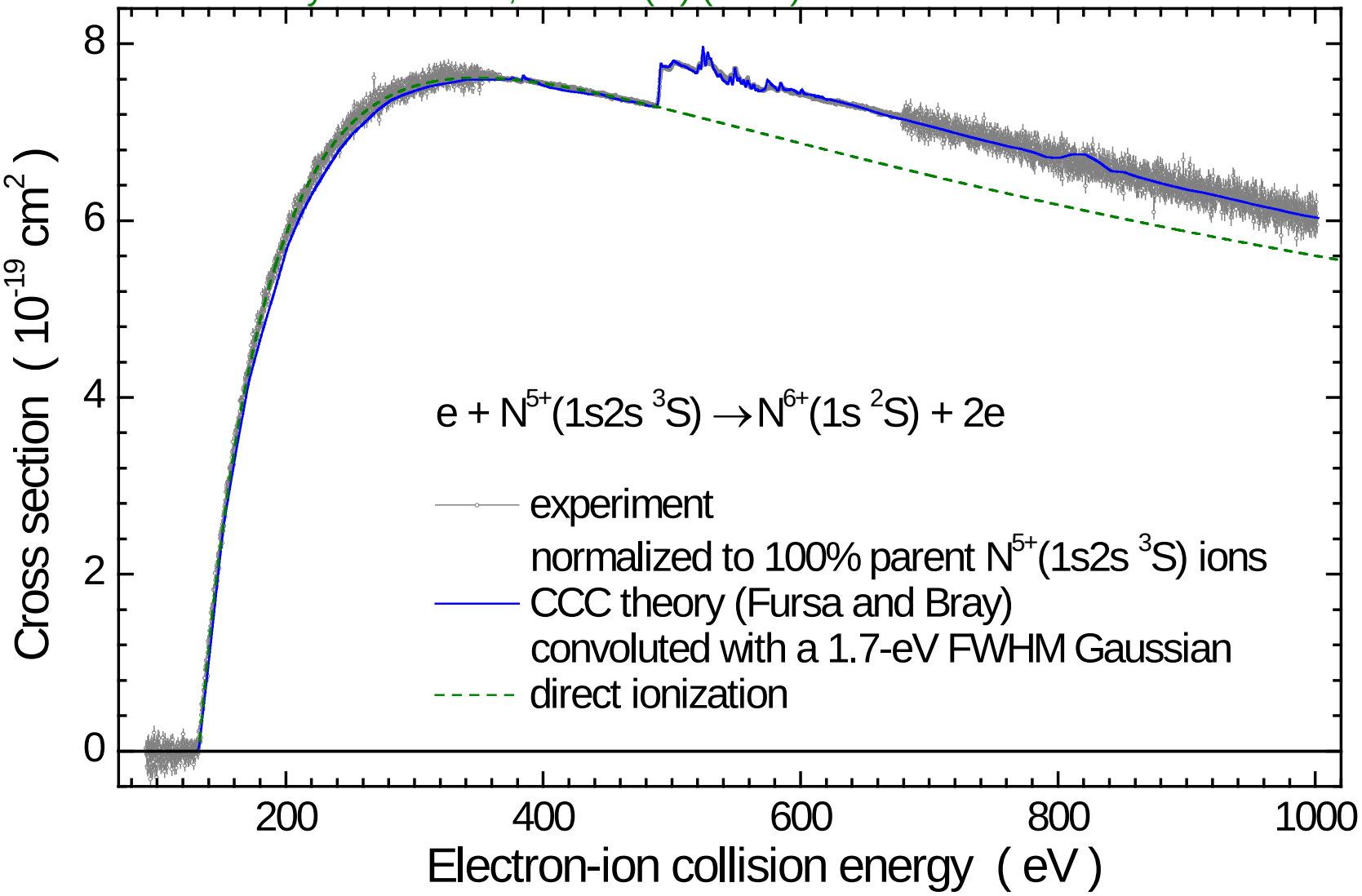
A. Müller, A. Borovik Jr., K. Huber, S. Schippers, D. V. Fursa, I. Bray,
Phys. Rev. A 90, 010701(R) (2014)



The comparison suggests 6.025% metastable ions

Ionization cross section for N^{5+} ($1s2s\ ^3S_1$)

A. Müller, A. Borovik Jr., K. Huber, S. Schippers, D. V. Fursa, I. Bray, Phys. Rev. A 90, 010701(R) (2014)

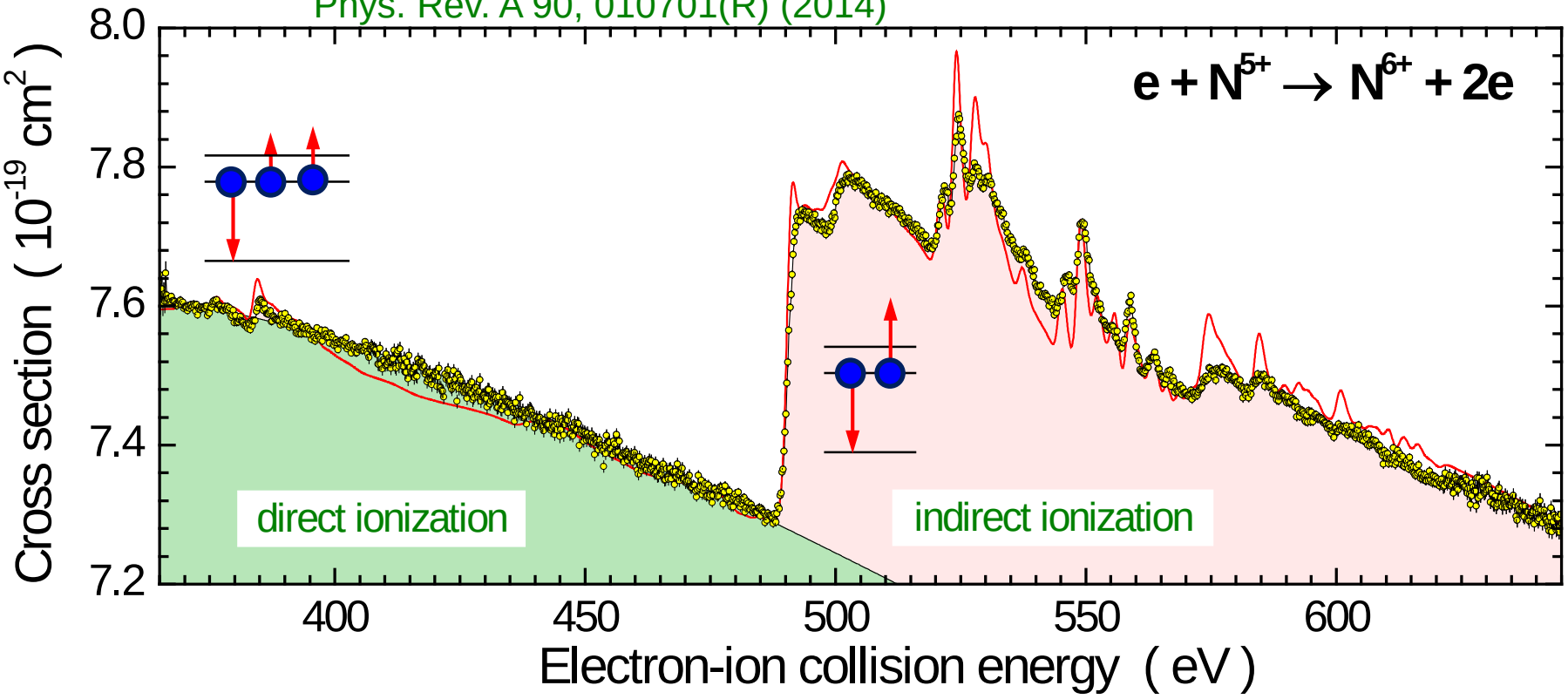


Assuming 6.025% metastable ions in the parent ion beam

Zooming in on the cross section for N^{5+} ($1s2s\ ^3S_1$)

excitation-autoionization (EA) and
resonant excitation followed by two-electron emission

A. Müller, A. Borovik Jr., K. Huber, S. Schippers, D. V. Fursa, and I. Bray, Phys. Rev. A 90, 010701(R) (2014)



Production of double-K-vacancy states

Resonant-excitation-auto-double-ionization

$$e + N^{5+}\left(1s2s\ {}^3S_1\right) \rightarrow N^{4+}\left(2s\, n\ell\, n'\ell'\right) \rightarrow N^{6+}\left(1s\ {}^2S_{1/2}\right) + 2e$$

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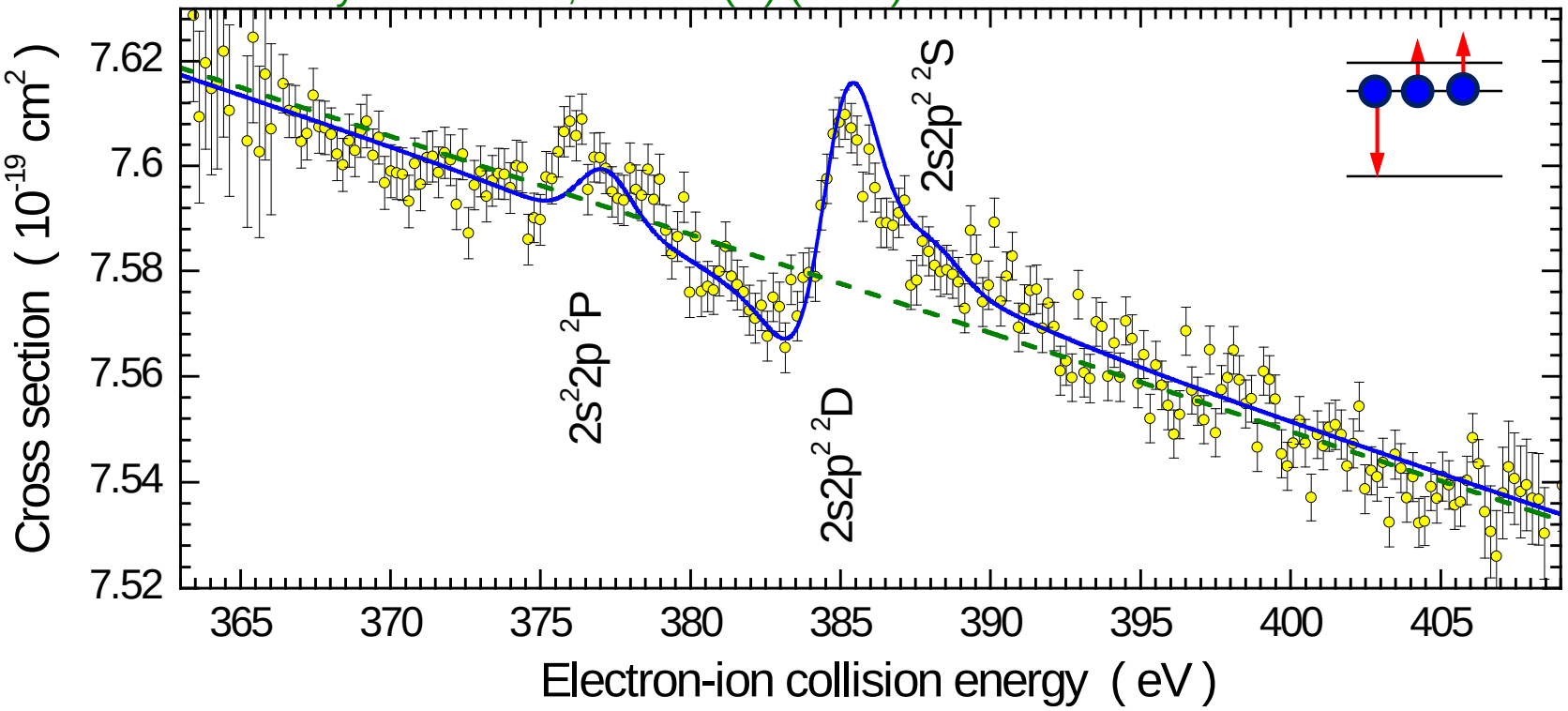

statistical uncertainties are at the 0.05% level

Interference of direct and resonant excitations

Zooming in on the cross section for $N^{5+}(1s2s\ ^3S_1)$

EA : $e + N^{5+}\left(1s2s\ ^3S_1\right) \rightarrow N^{5+}\left(2s\,n\ell\right) + e \rightarrow N^{6+}\left(1s\ ^2S_{1/2}\right) + 2e$

REDA : $e + N^{5+}\left(1s2s\ ^3S_1\right) \rightarrow N^{4+}\left(2s\,n\ell\,n'\ell'\right)$

$\rightarrow N^{5+}\left(2s\,n''\ell''\right) + e \rightarrow N^{6+}\left(1s\ ^2S_{1/2}\right) + 2e$

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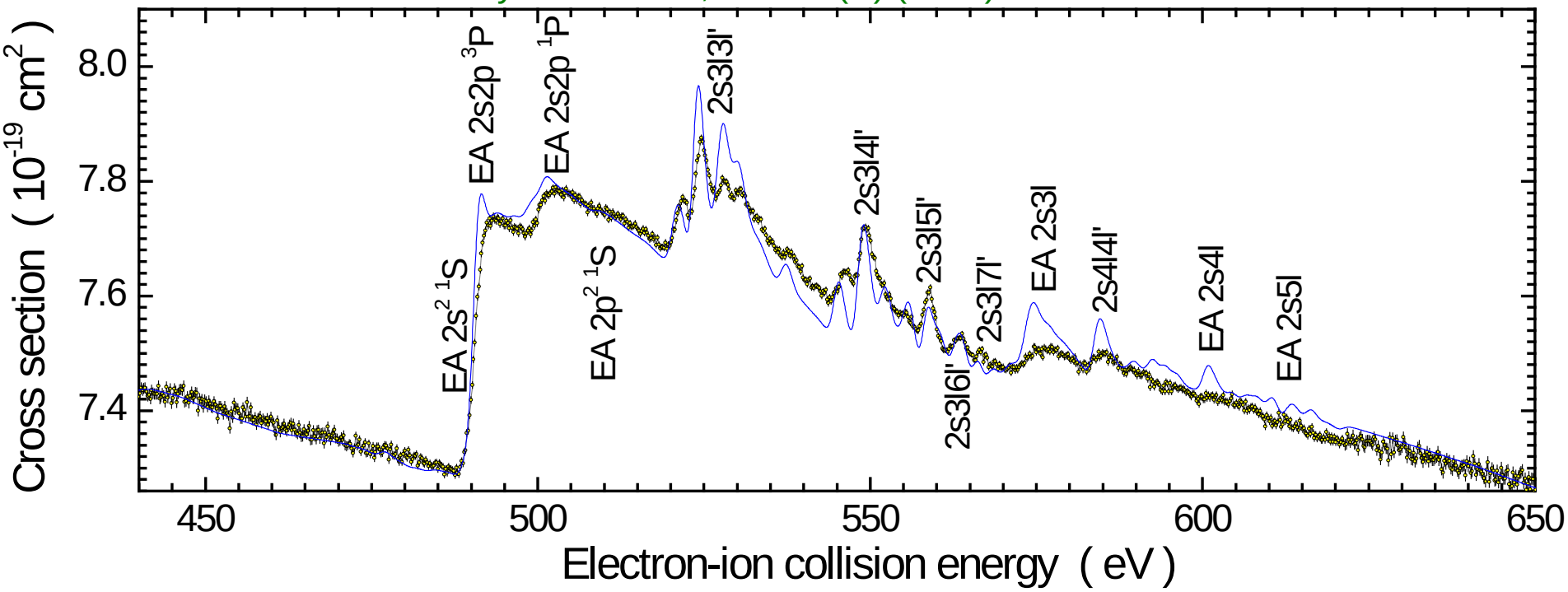

differences between theory and experiment are typically 0.2% and at most 1%

Summary

Crossed beams experiments

- Can provide data with about 10% systematic uncertainty
- Have provided high resolution data with 0.01% statistical uncertainty
- Provide possibilities for quantifying metastable beam components
- Allow for determination of cross sections for metastable levels of ions

Thank you for your attention!