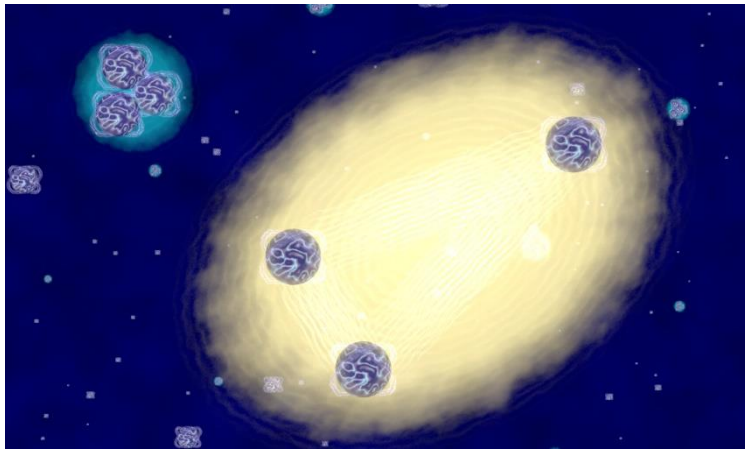
Structure and field-induced dynamics of small helium clusters



Maksim Kunitski, Jan Kruse, Qingze Guan,
Dörte Blume, and Reinhard Dörner

EFB25
Mainz 03.08.2023

Outline

1. Introduction: why small helium clusters?
2. Experimental (preparation, selection and detection)
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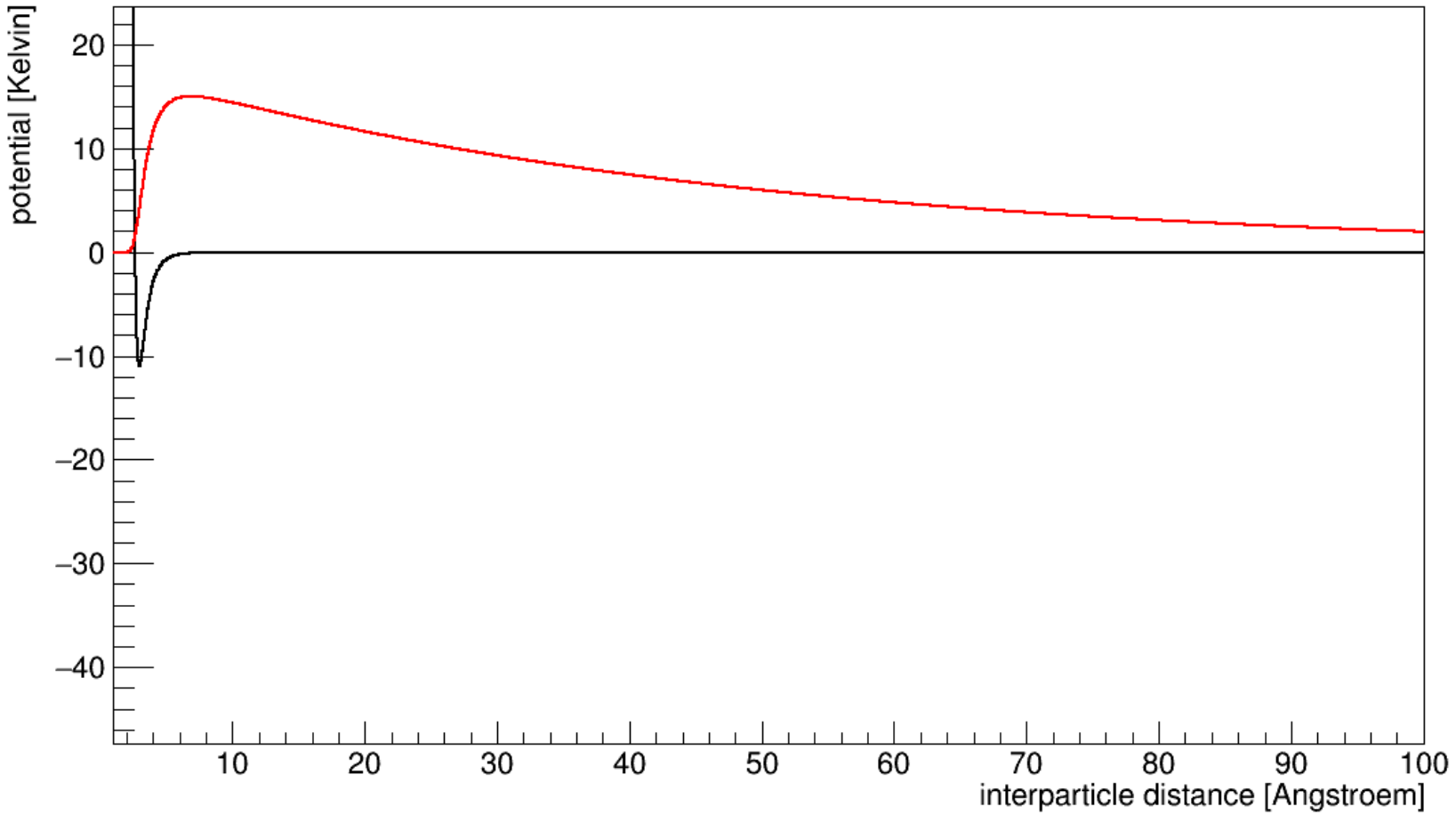

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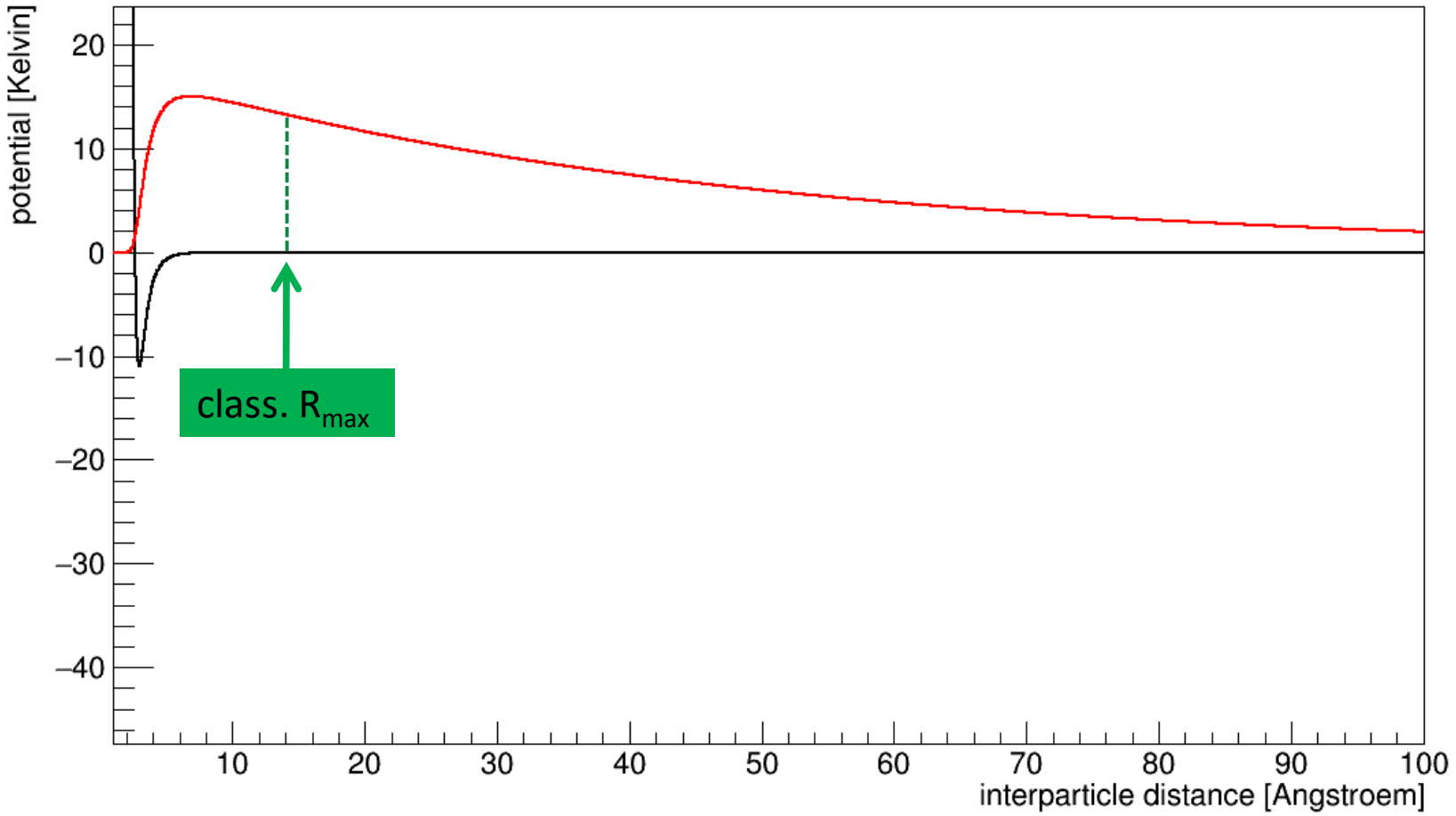

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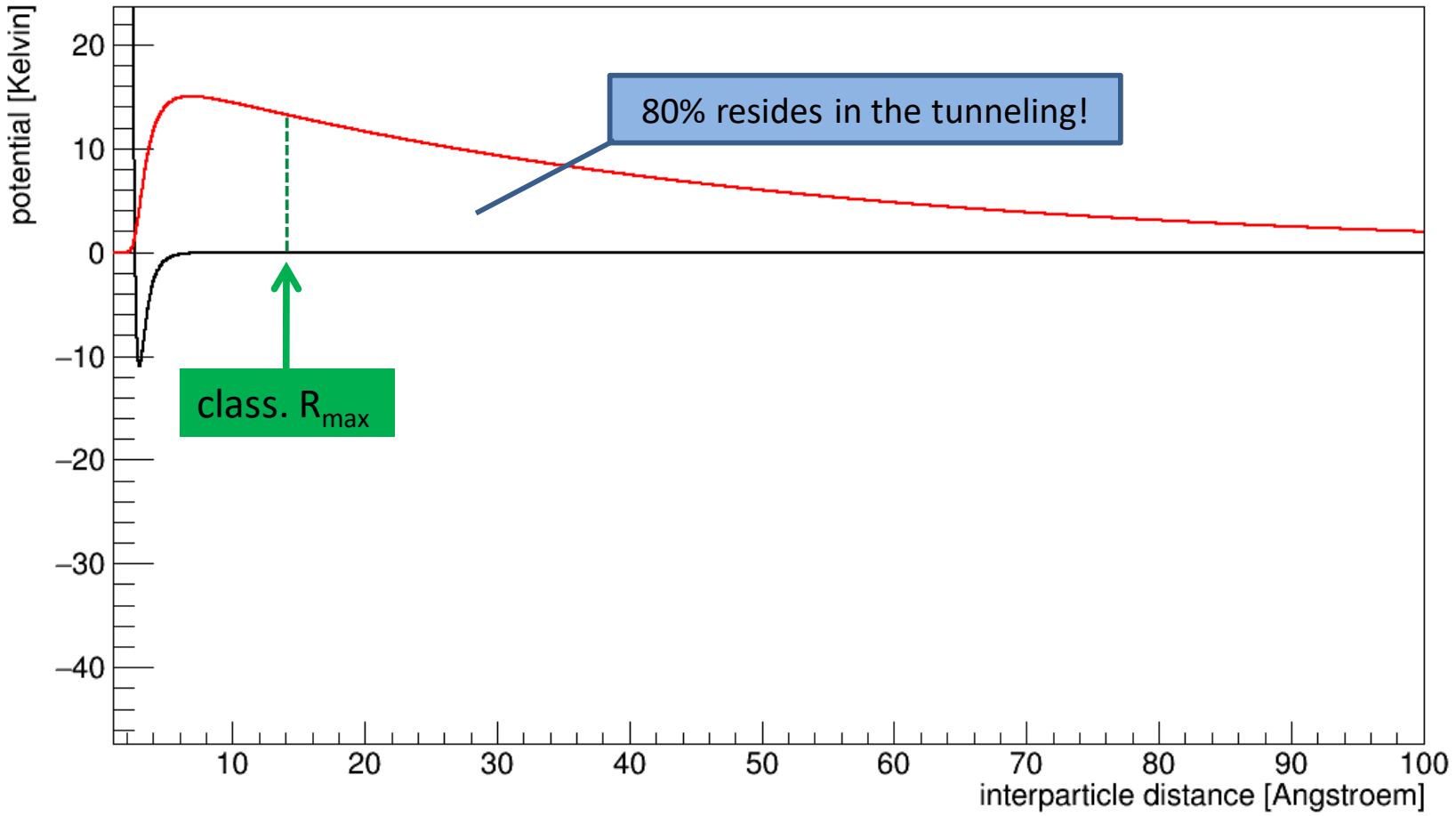

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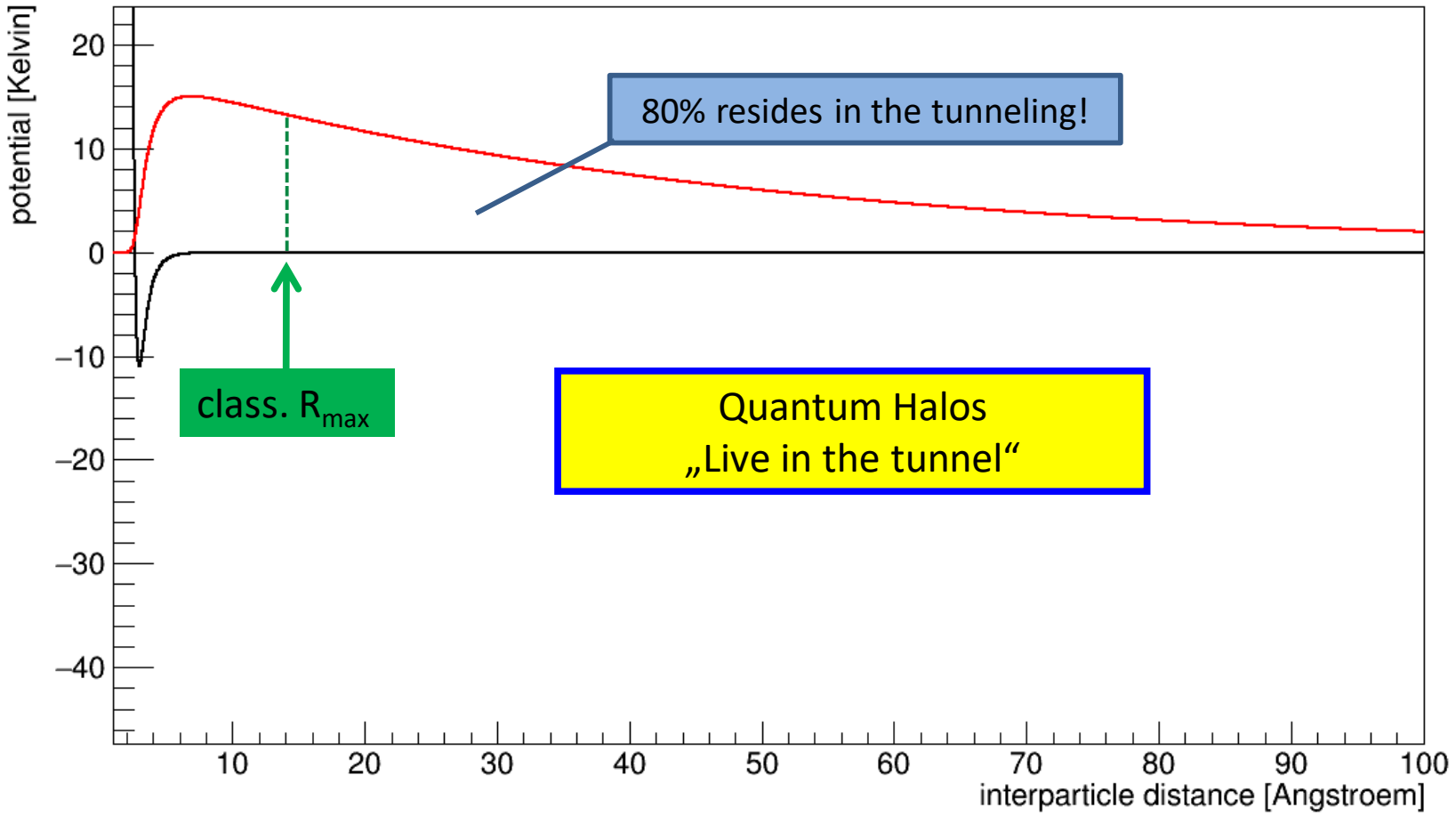

Helium clusters: Three-body system (He_3)

Vitaly Efimov in 1977

when interaction is so weak that
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There is an **infinite** number
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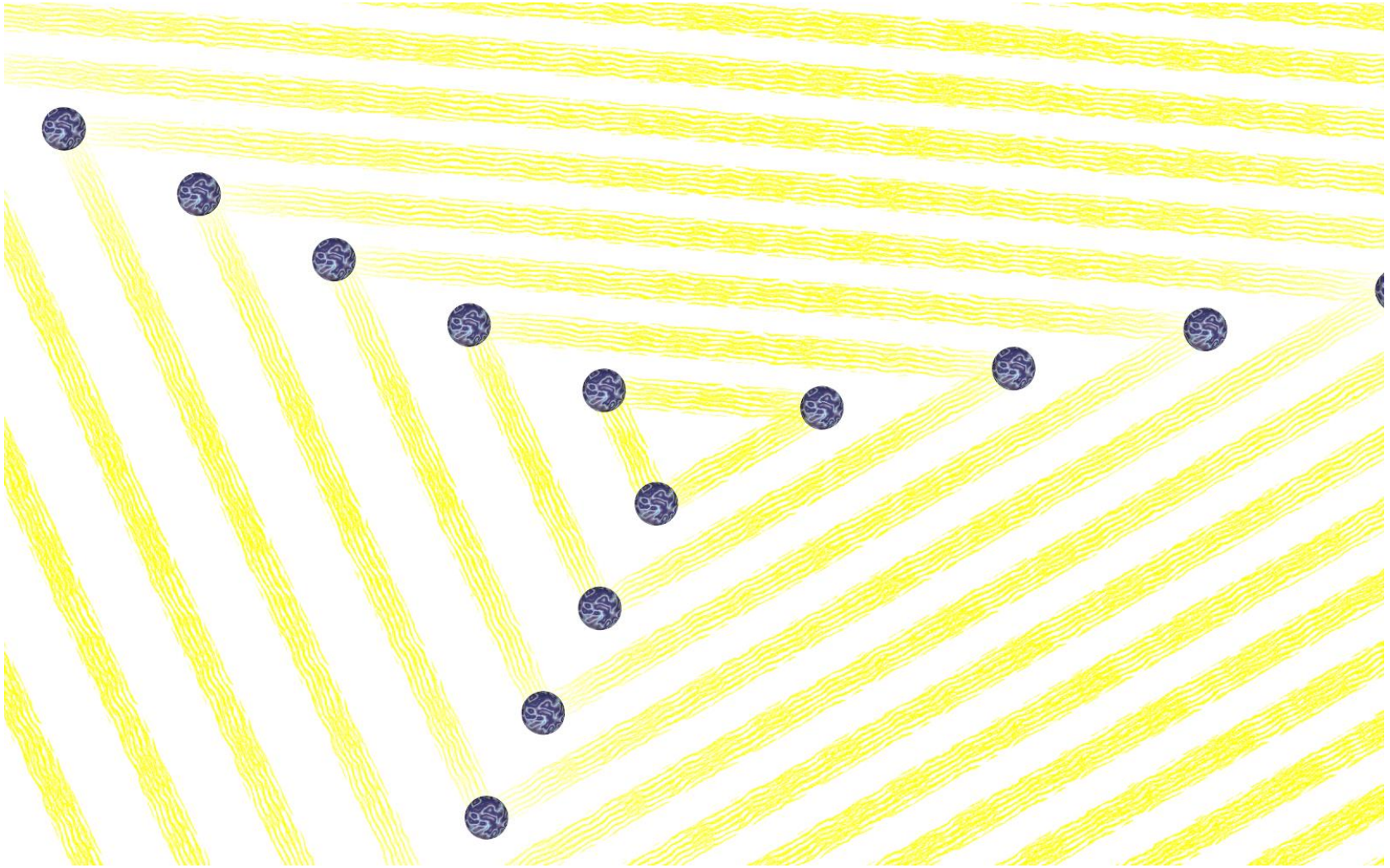

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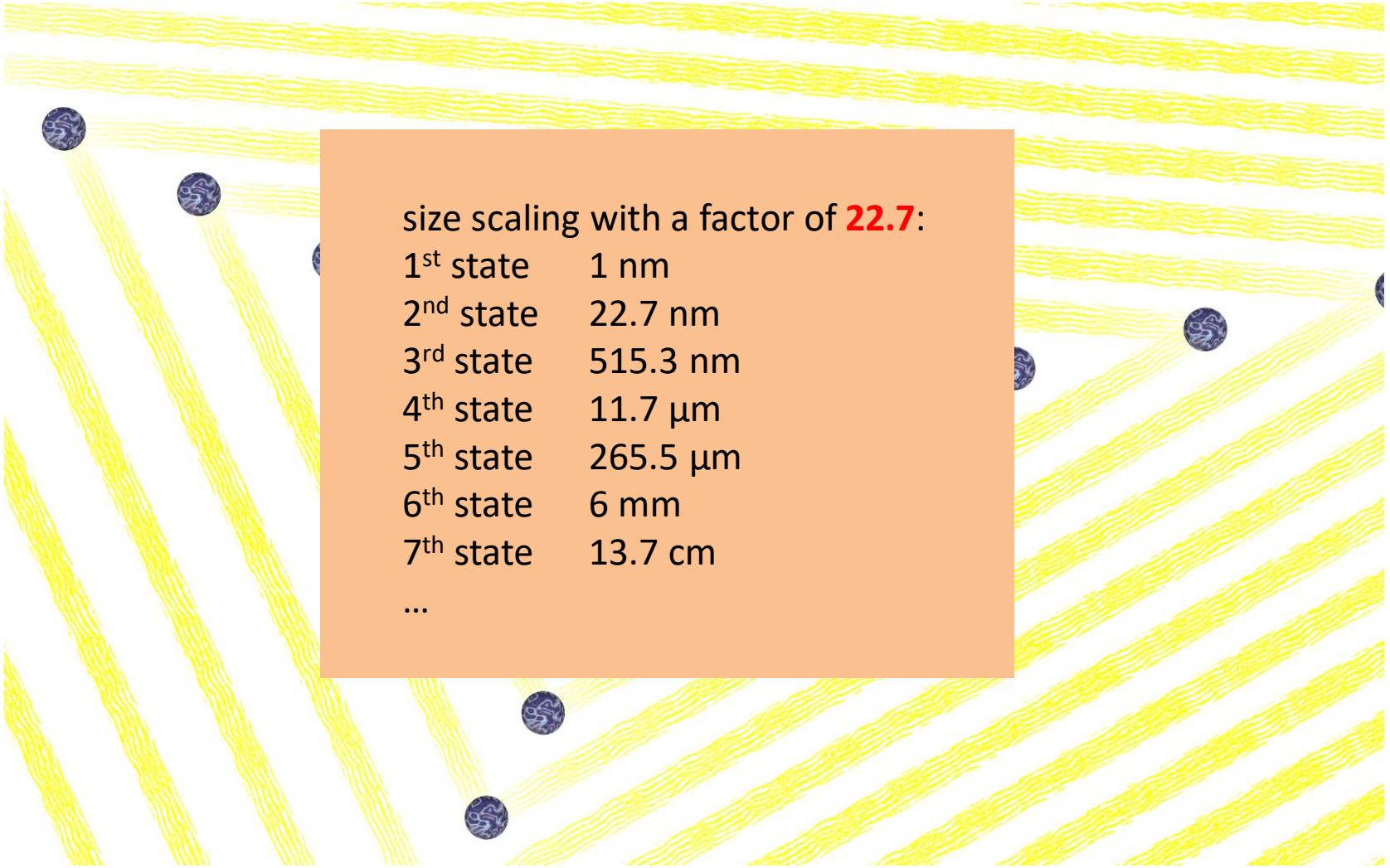

size scaling with a factor of **22.7**:

1st state	1 nm
2nd state	22.7 nm
3rd state	515.3 nm
4th state	11.7 µm
5th state	265.5 µm
6th state	6 mm
7th state	13.7 cm
…	

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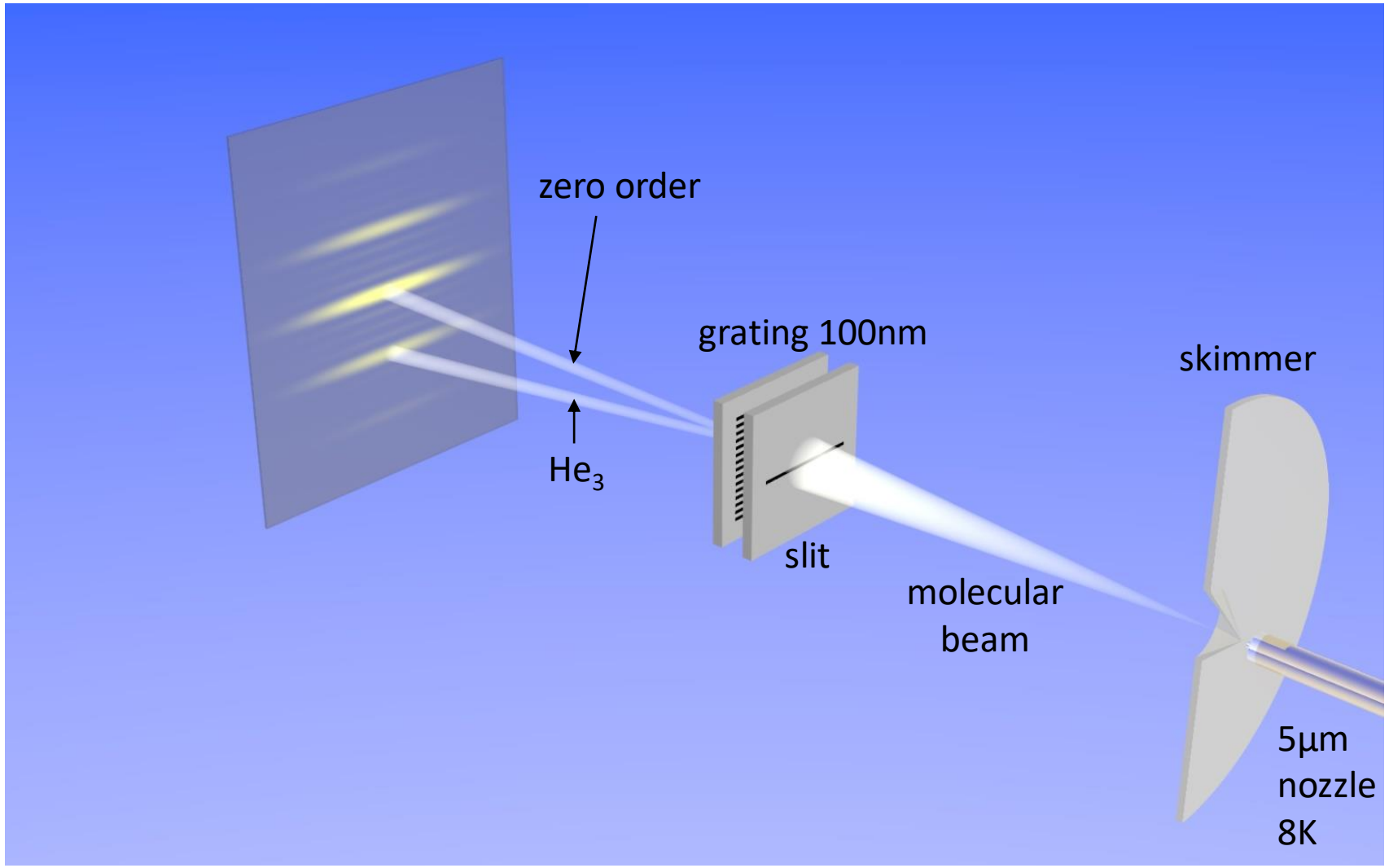

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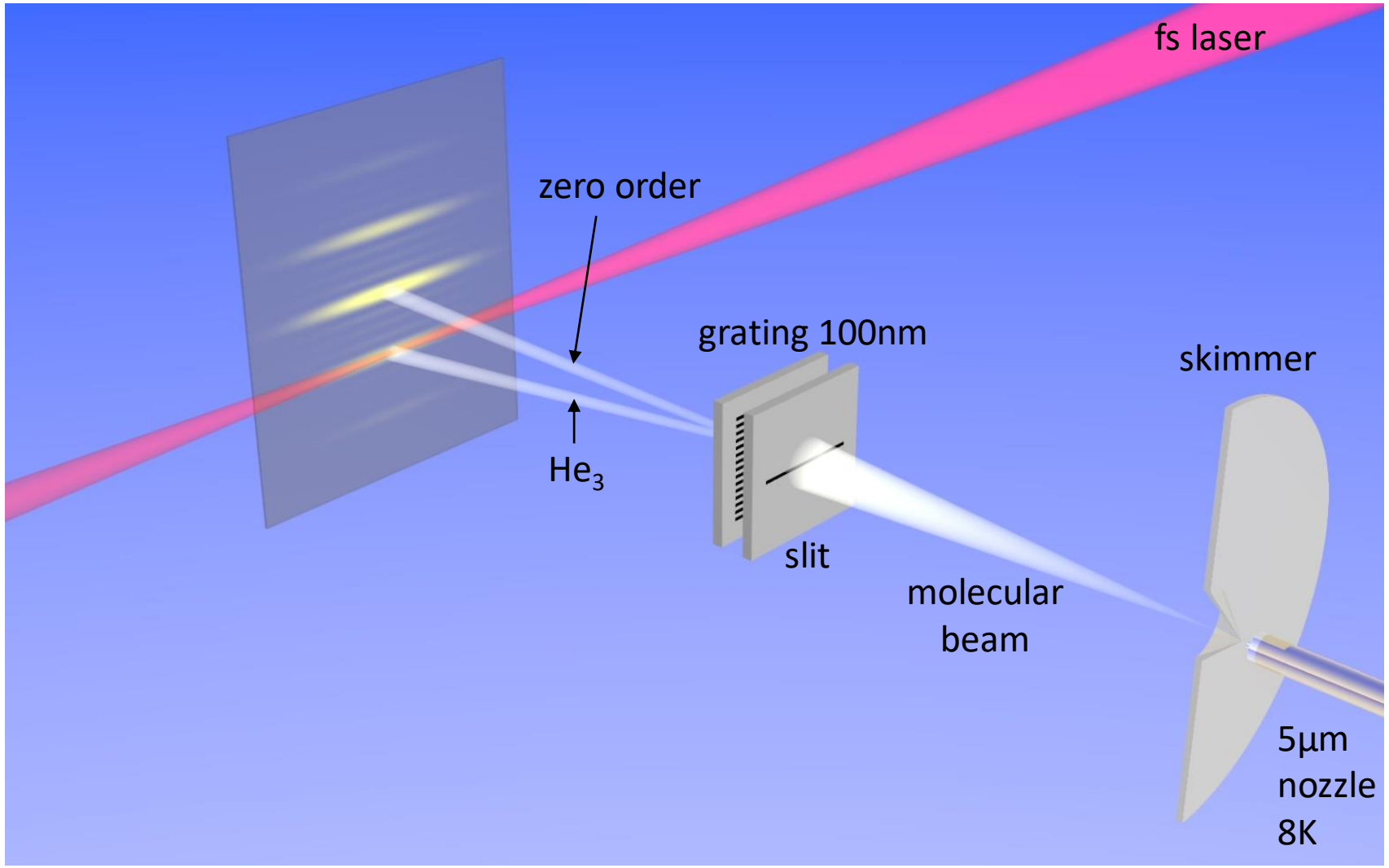

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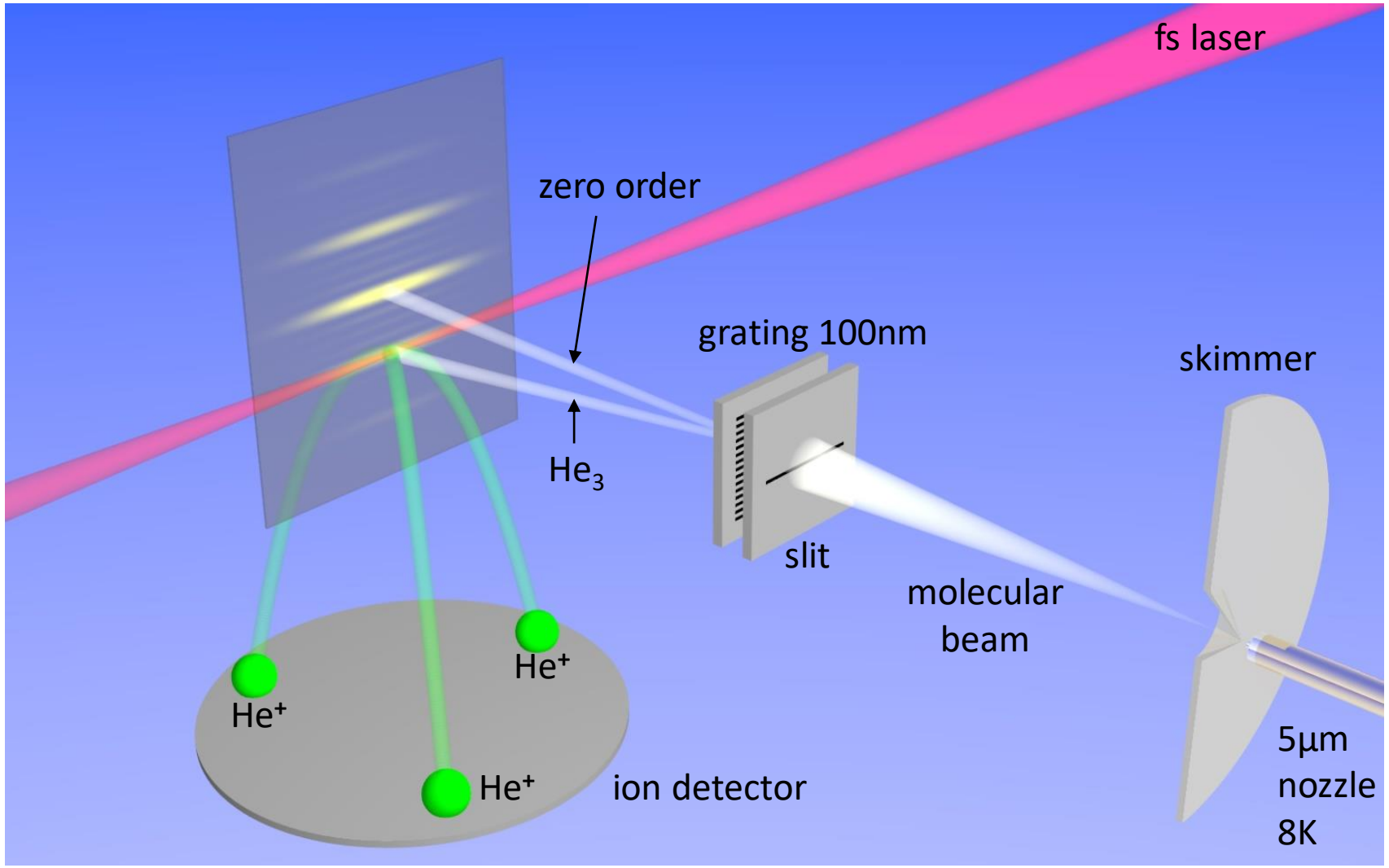

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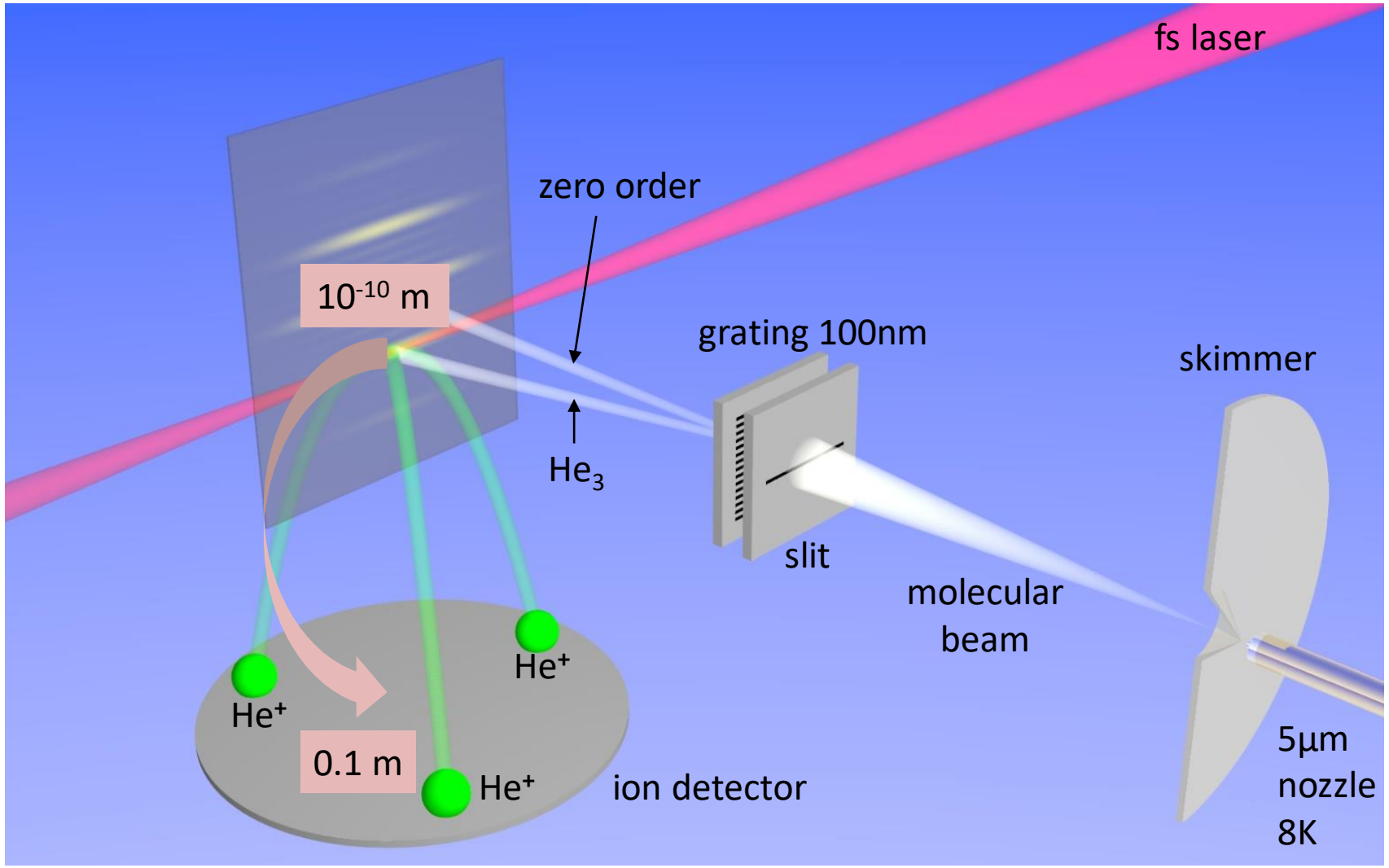

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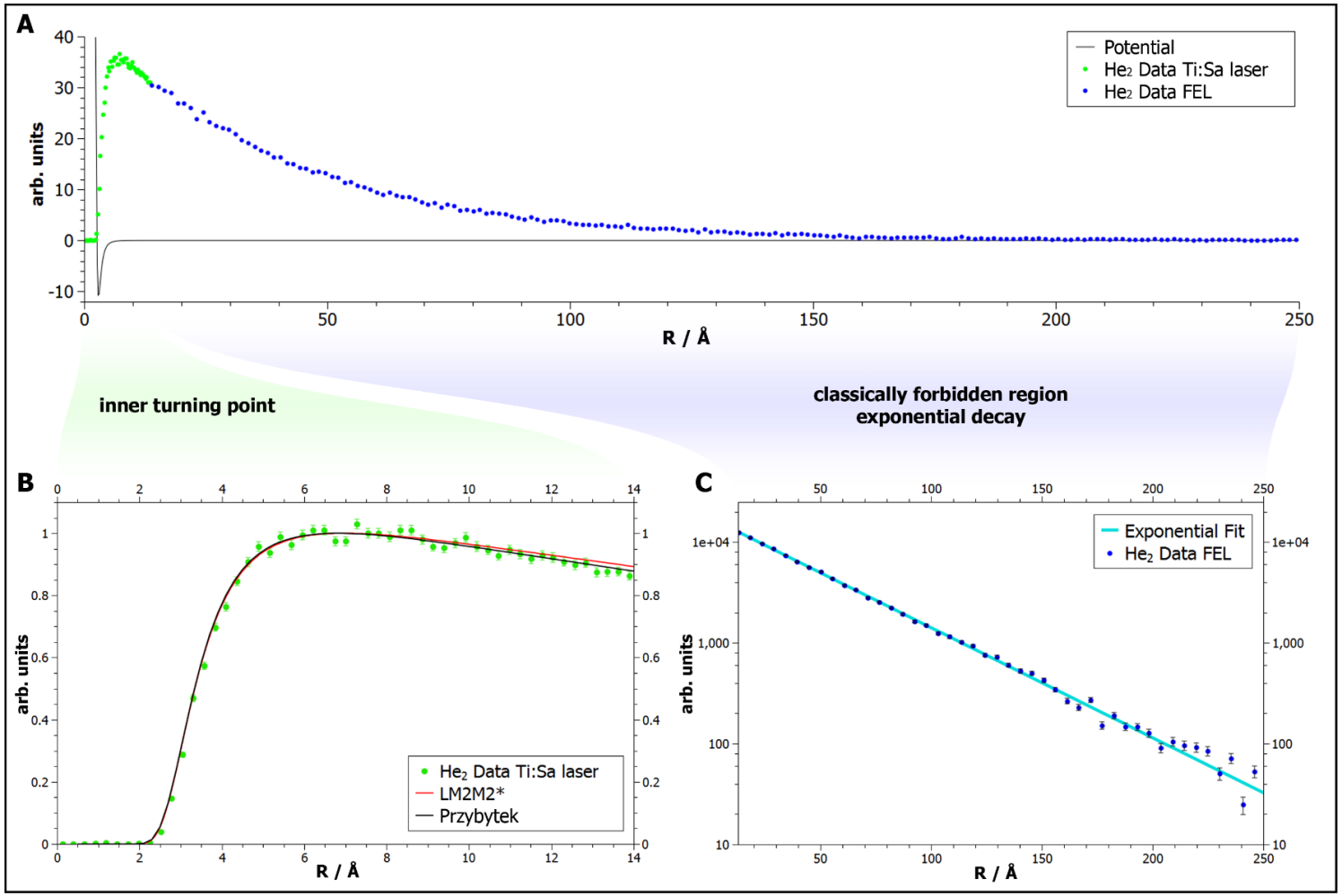
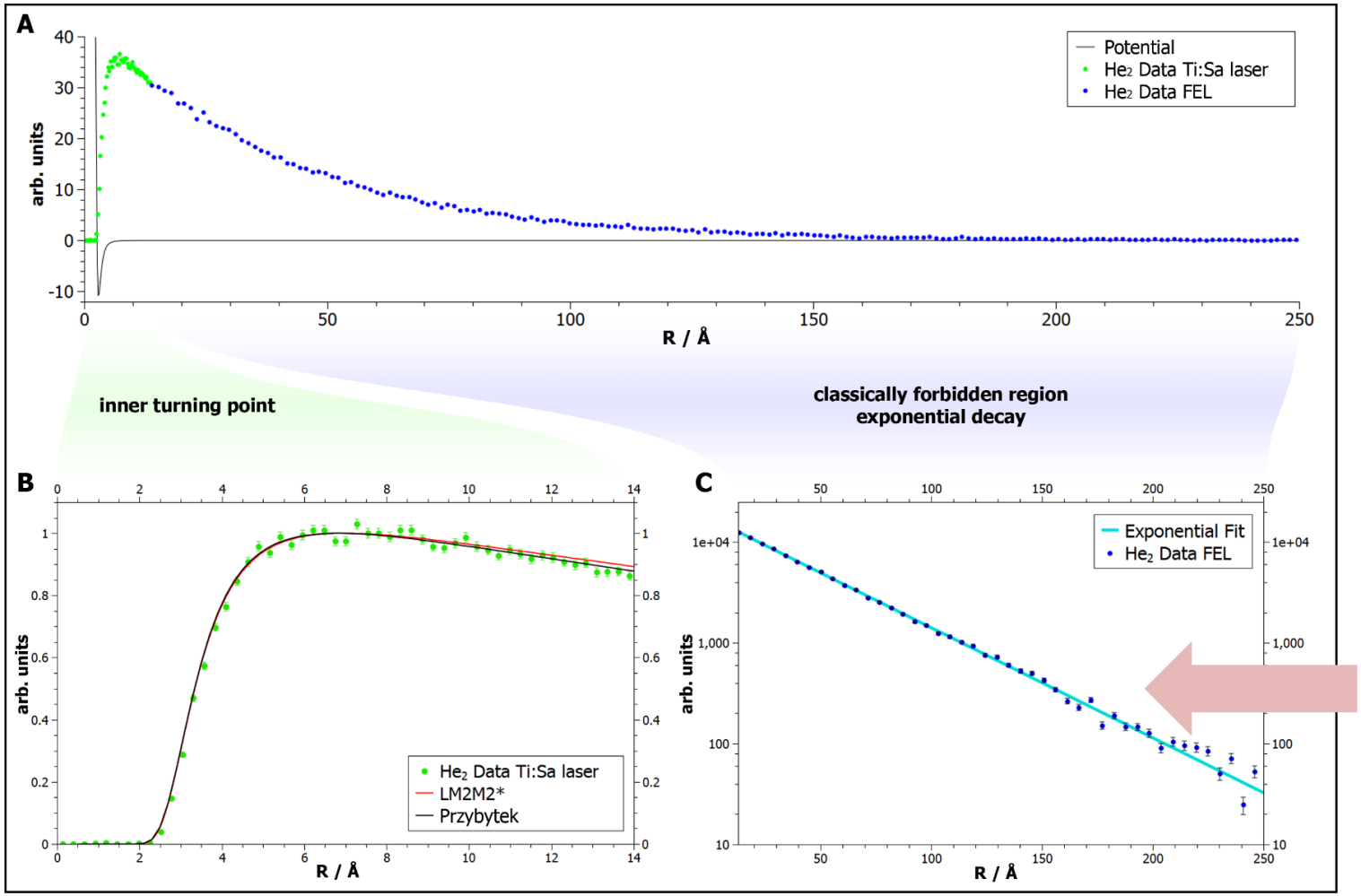
Structure: He_2



S. Zeller *et al.*, *PNAS* **113**, 14651–14655 (2016)

Structure: He_2



$$\Psi^2(R) \propto e^{-\frac{\sqrt{8mE_b}}{\hbar}R}$$

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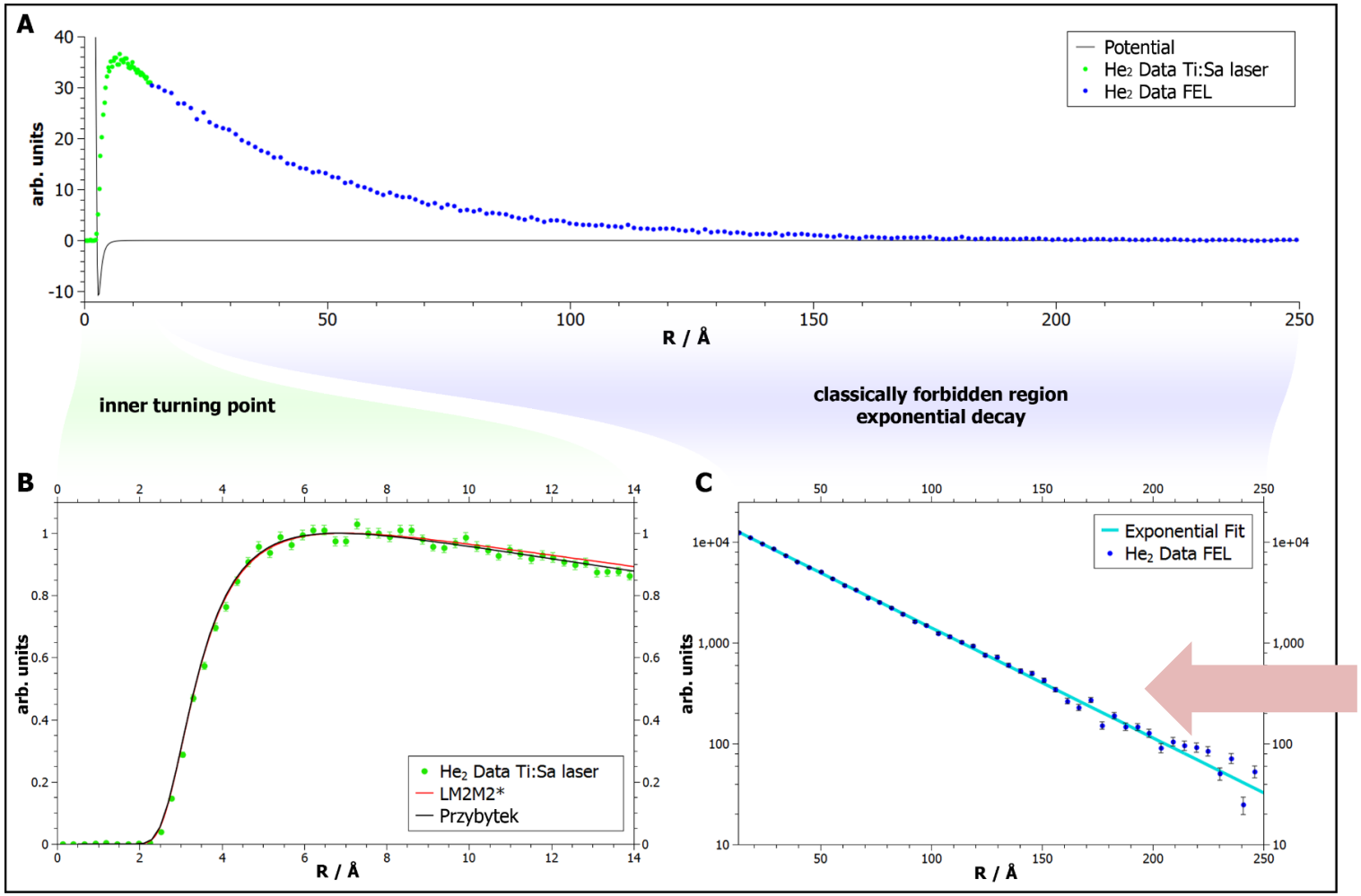

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E_b=1.77±0.15 mK

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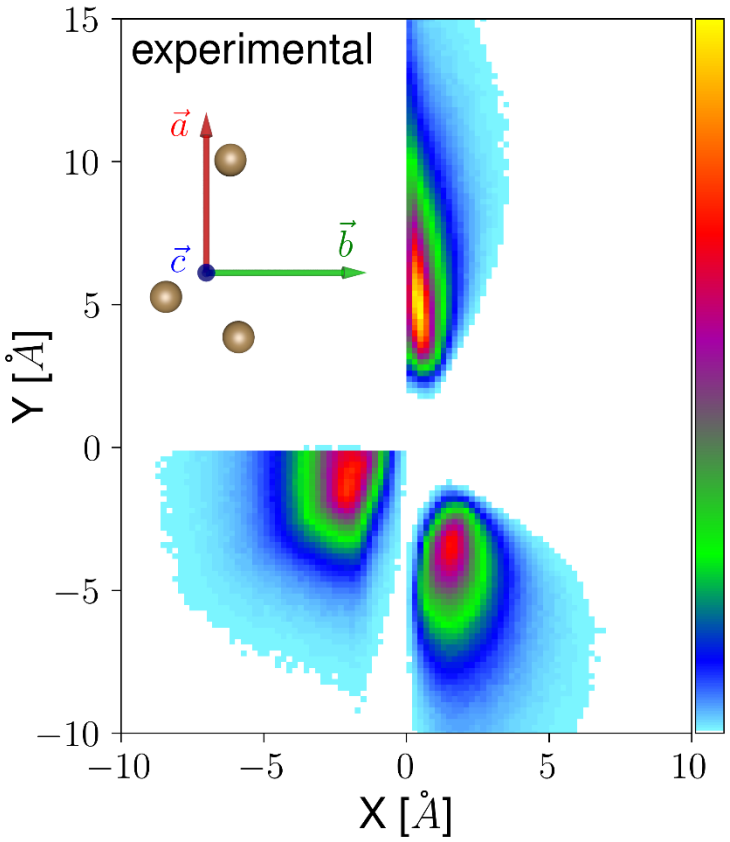

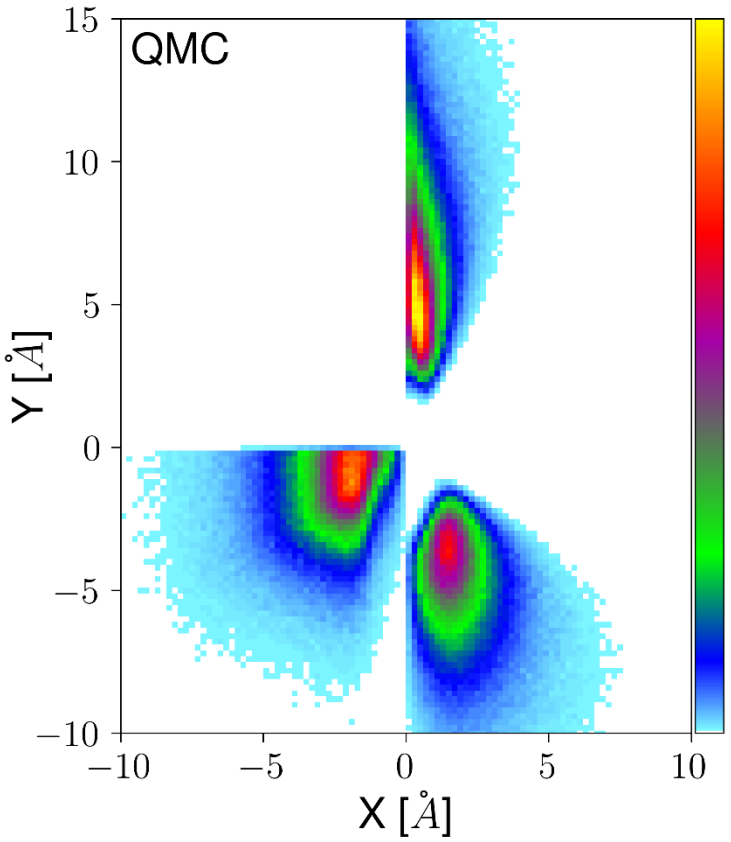

J. Voigtsberger *et al.*, Nat. Comm. 5, 5765 (2014)

theory by Dario Bressanini

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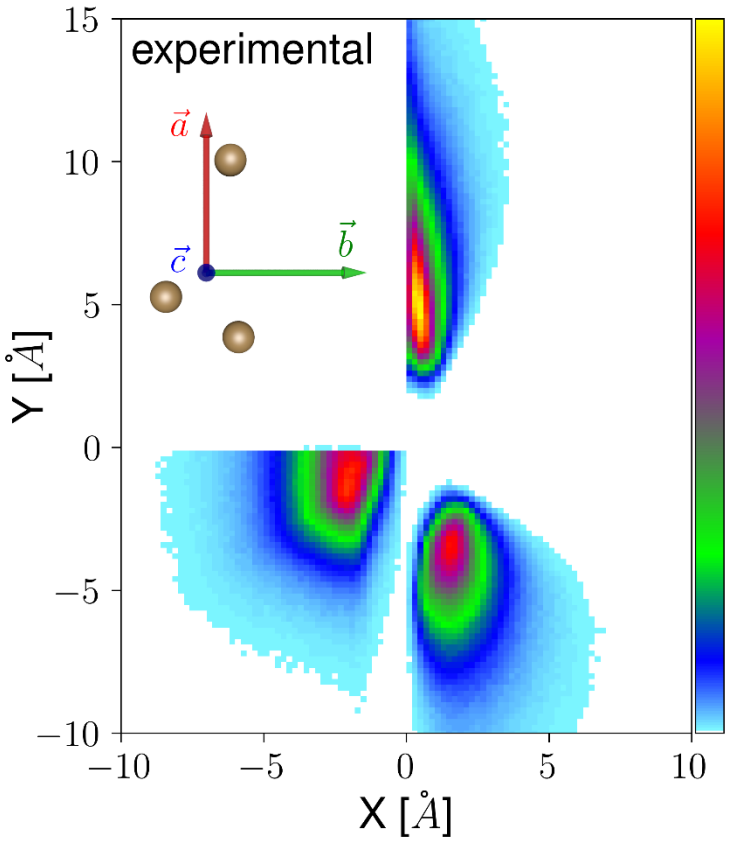

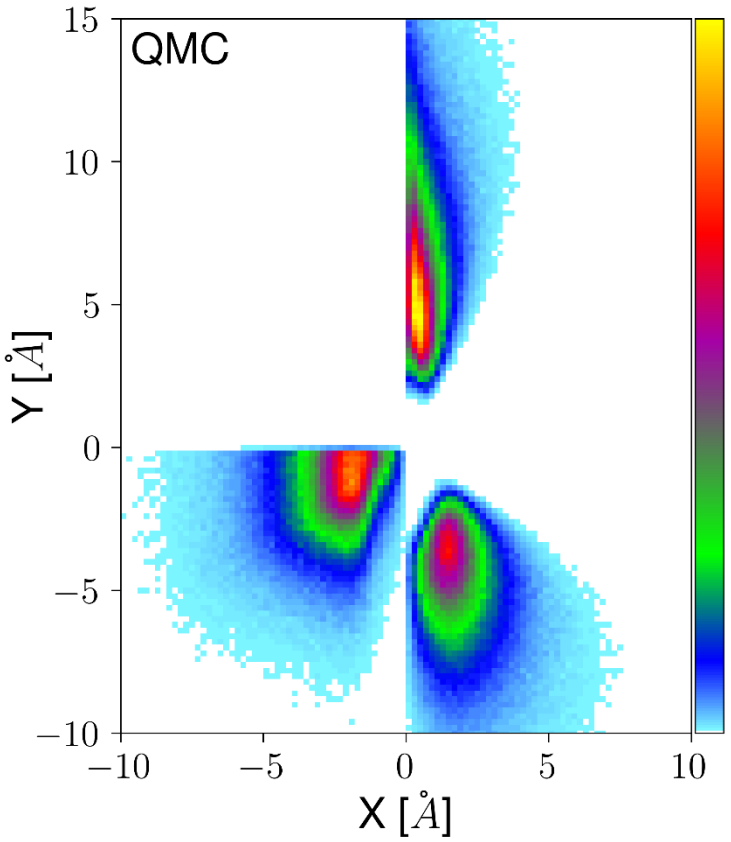

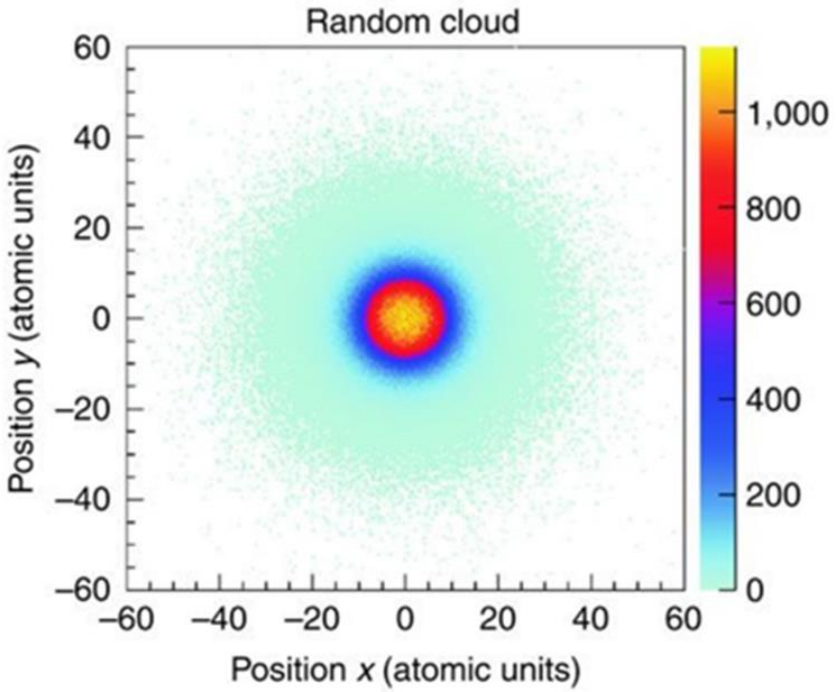

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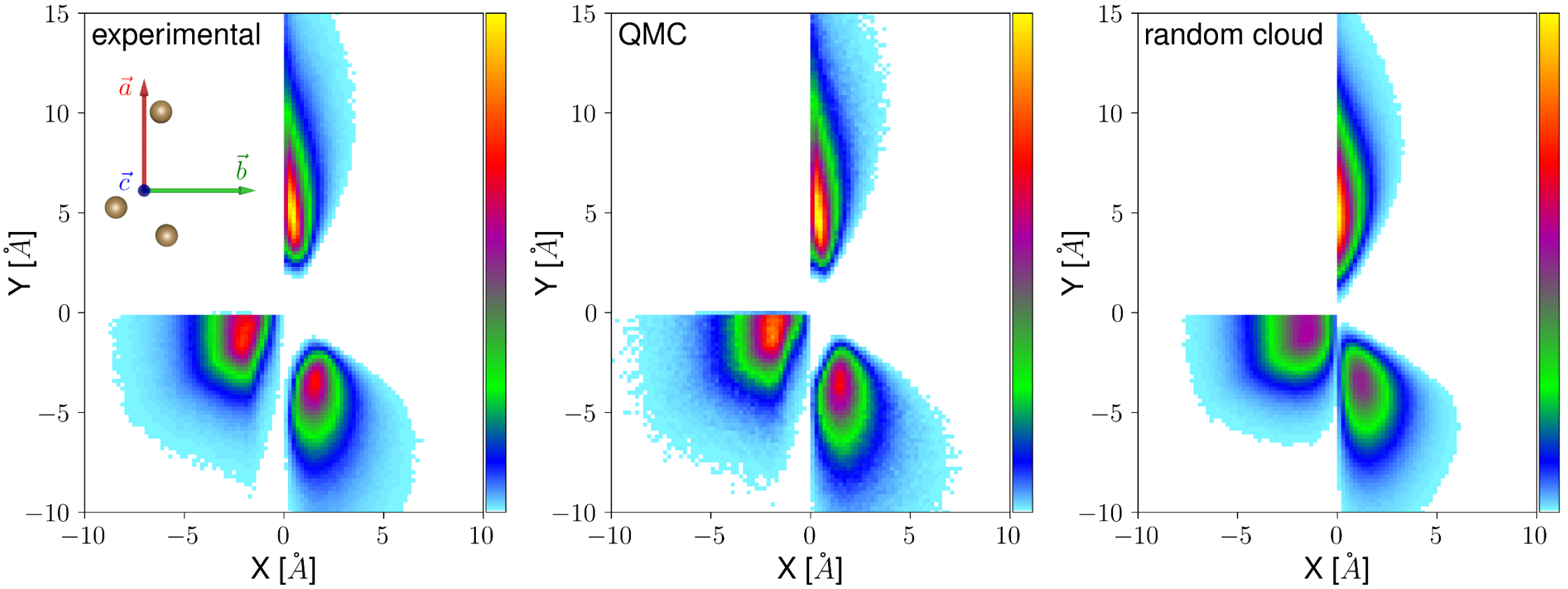

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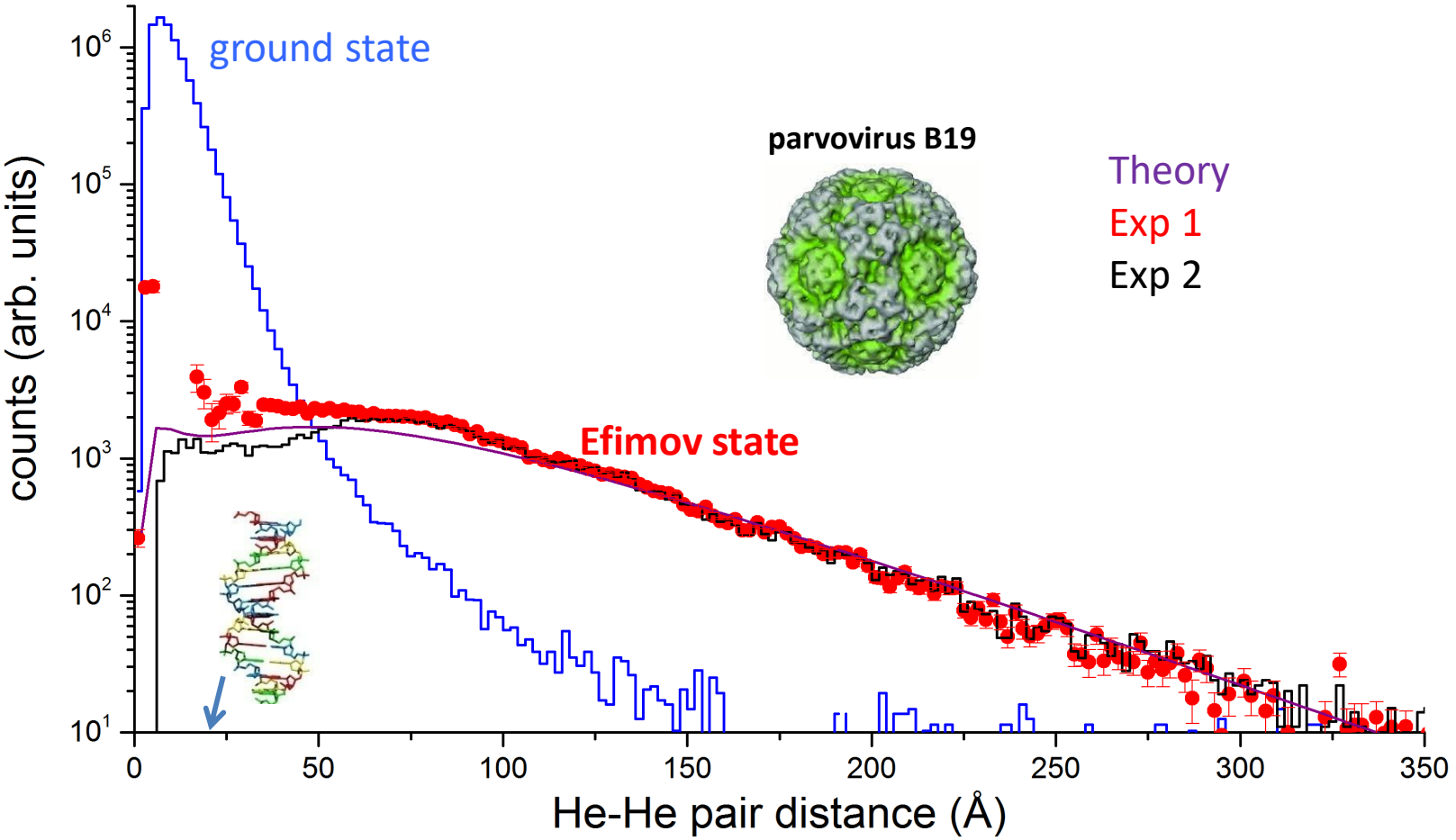

Science, **348**, p.551, 2015

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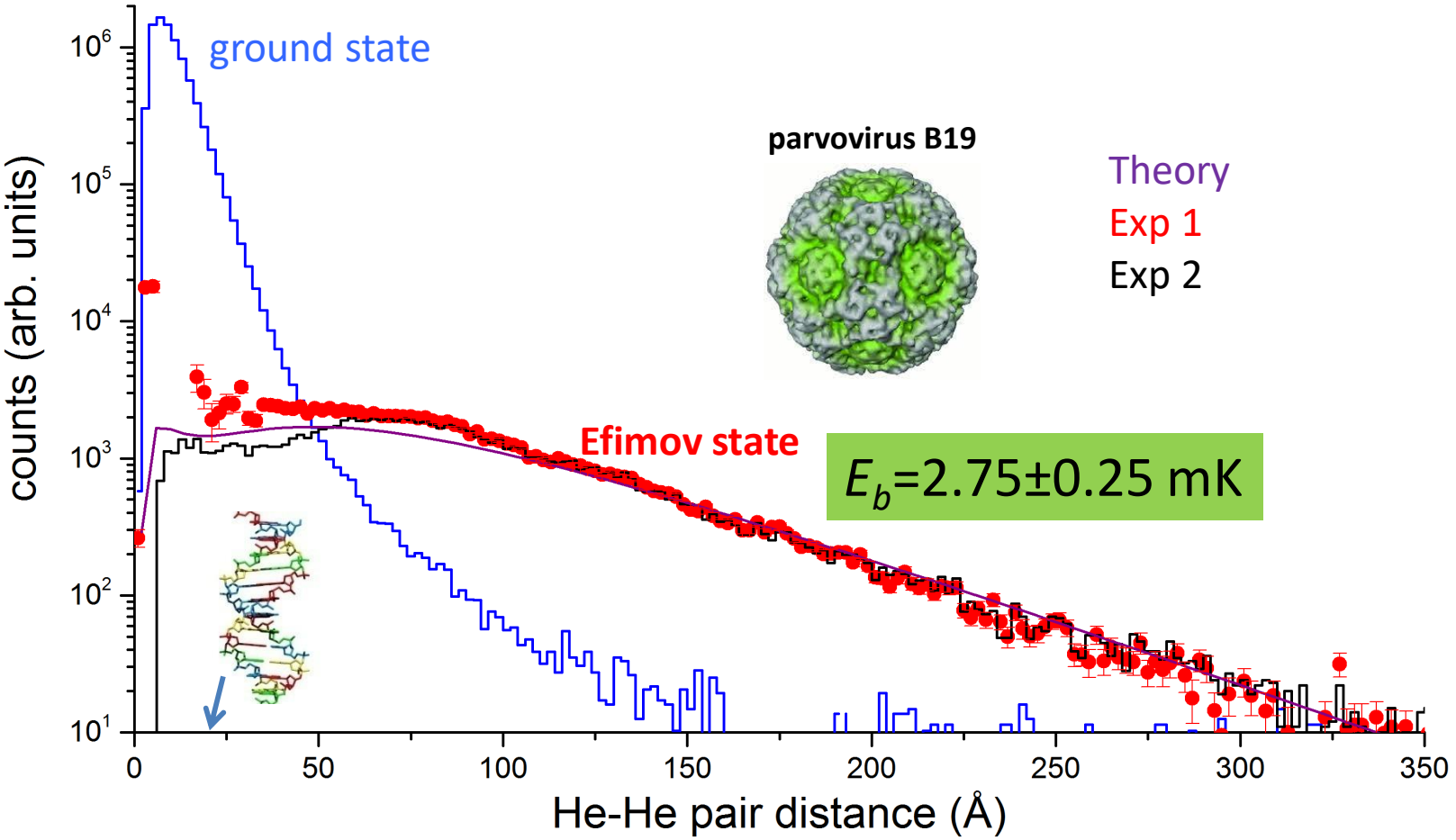

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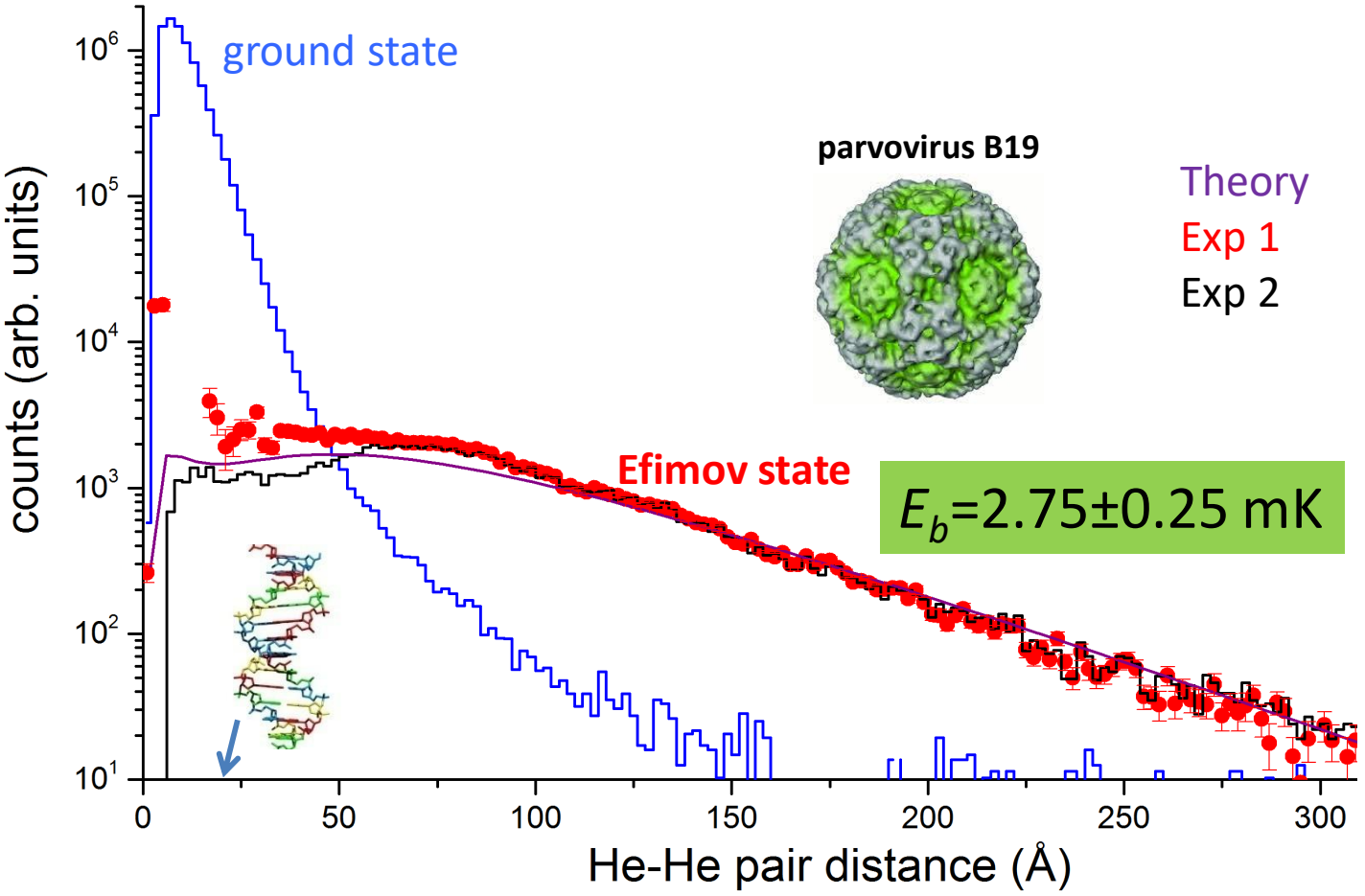
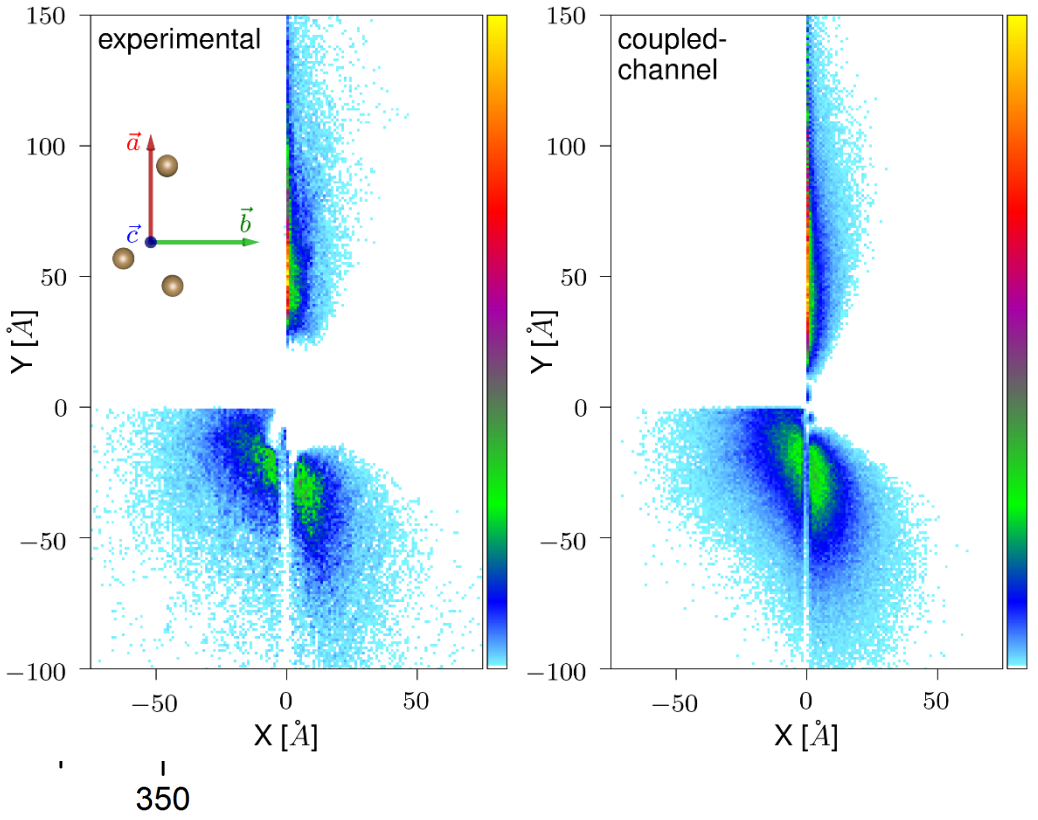
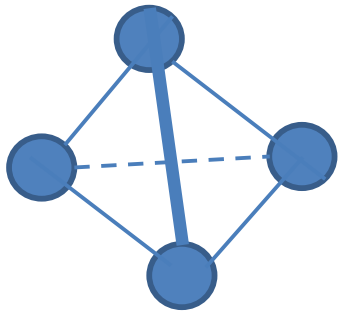


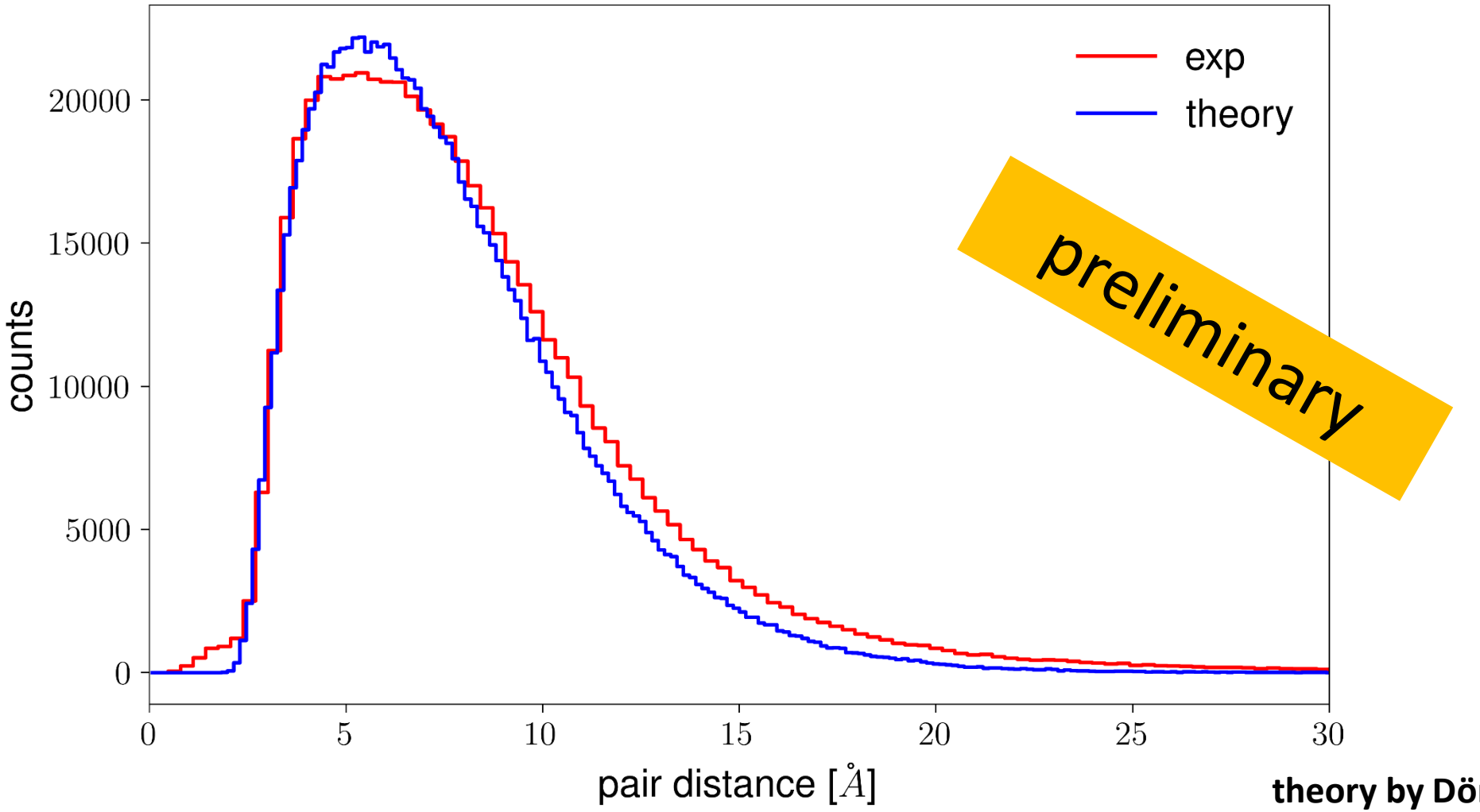


Science, **348**, p.551, 2015

theory by Dörte Blume

Structure: He_4





preliminary

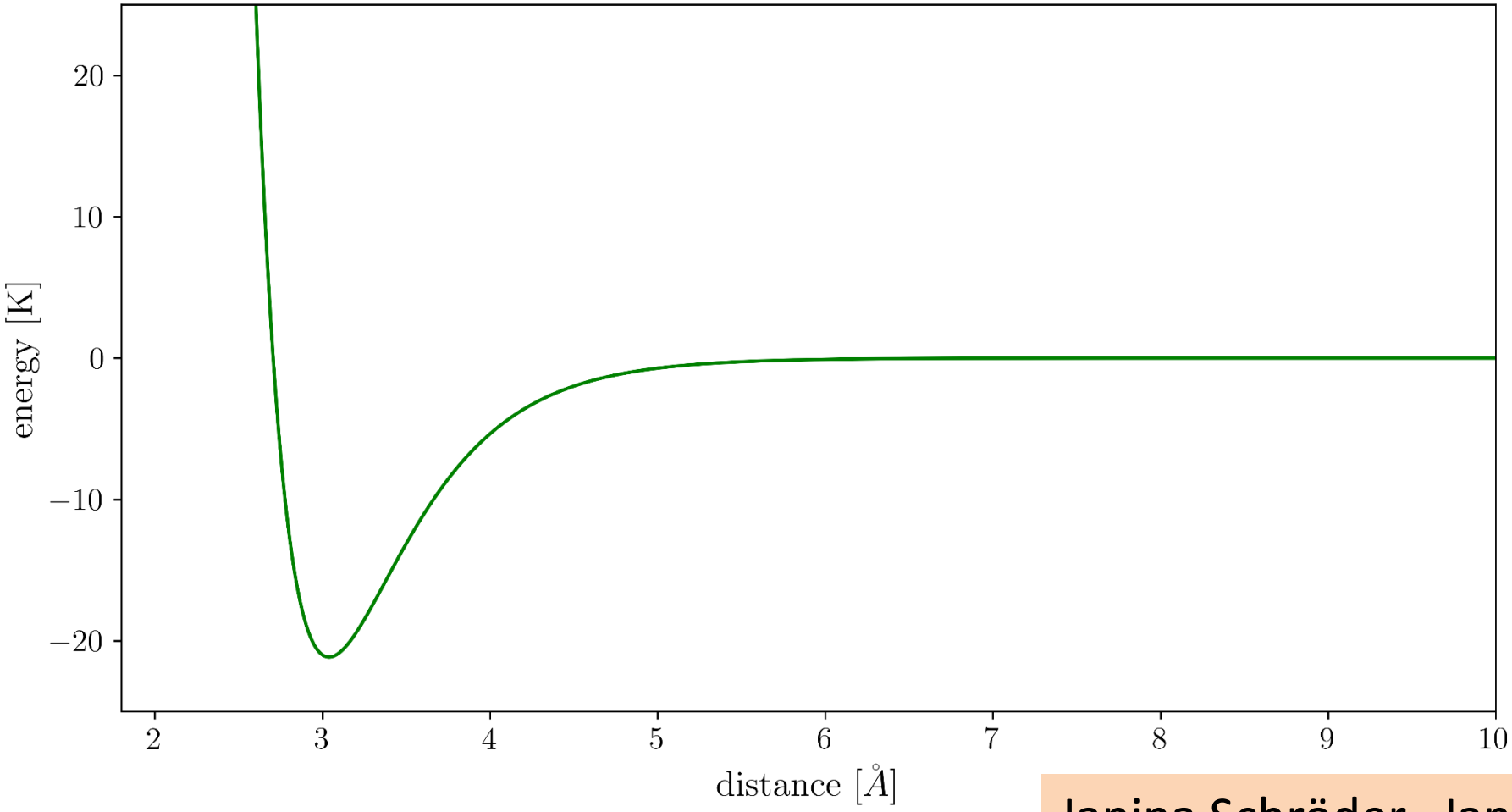
Jan Kruse

theory by Dörte Blume

Structure: He – Ne dimer

CCSDT/aug-cc-pV5Z

preliminary



Janina Schröder, Jan Kruse

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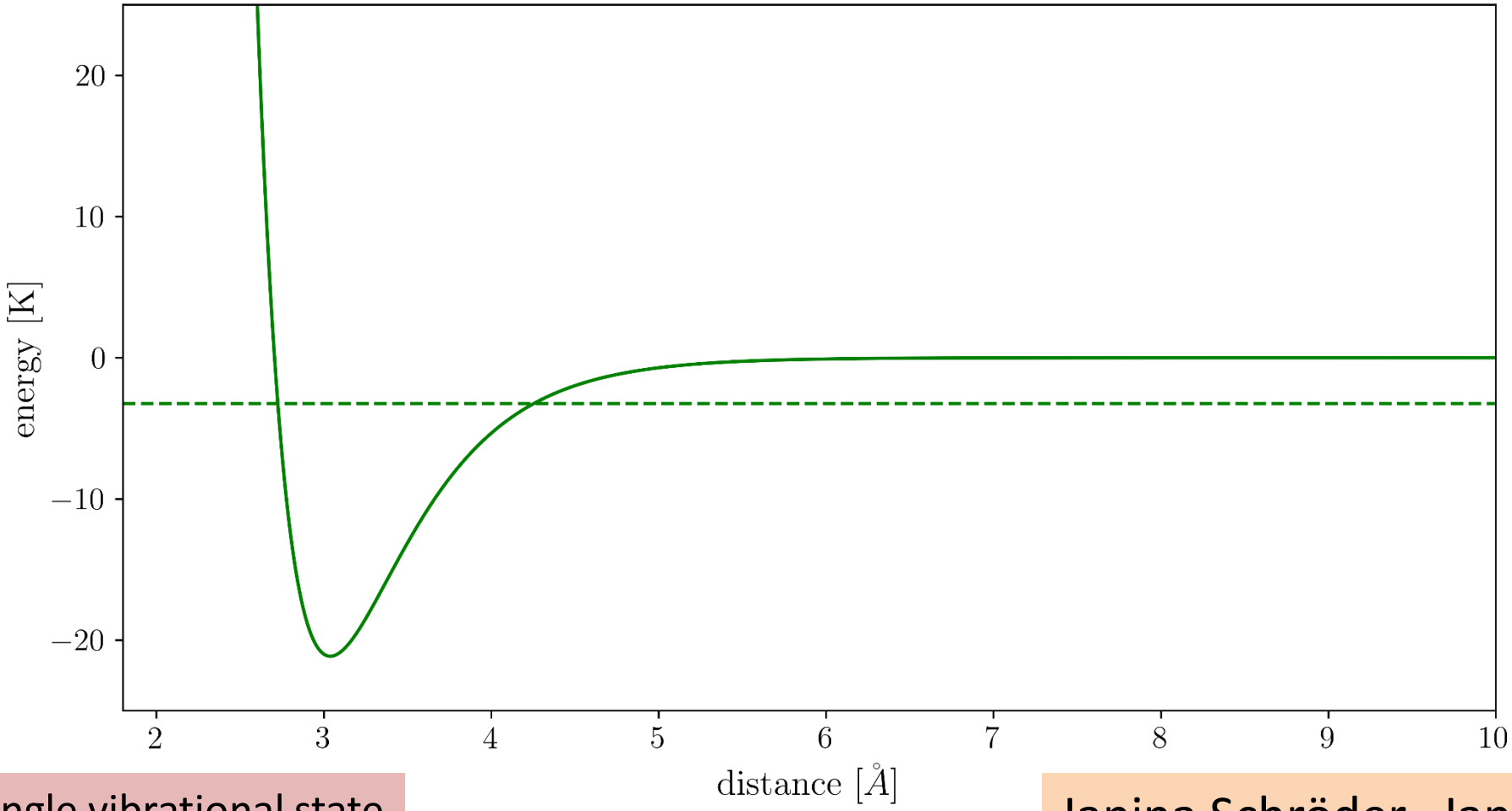

single vibrational state

Janina Schröder, Jan Kruse

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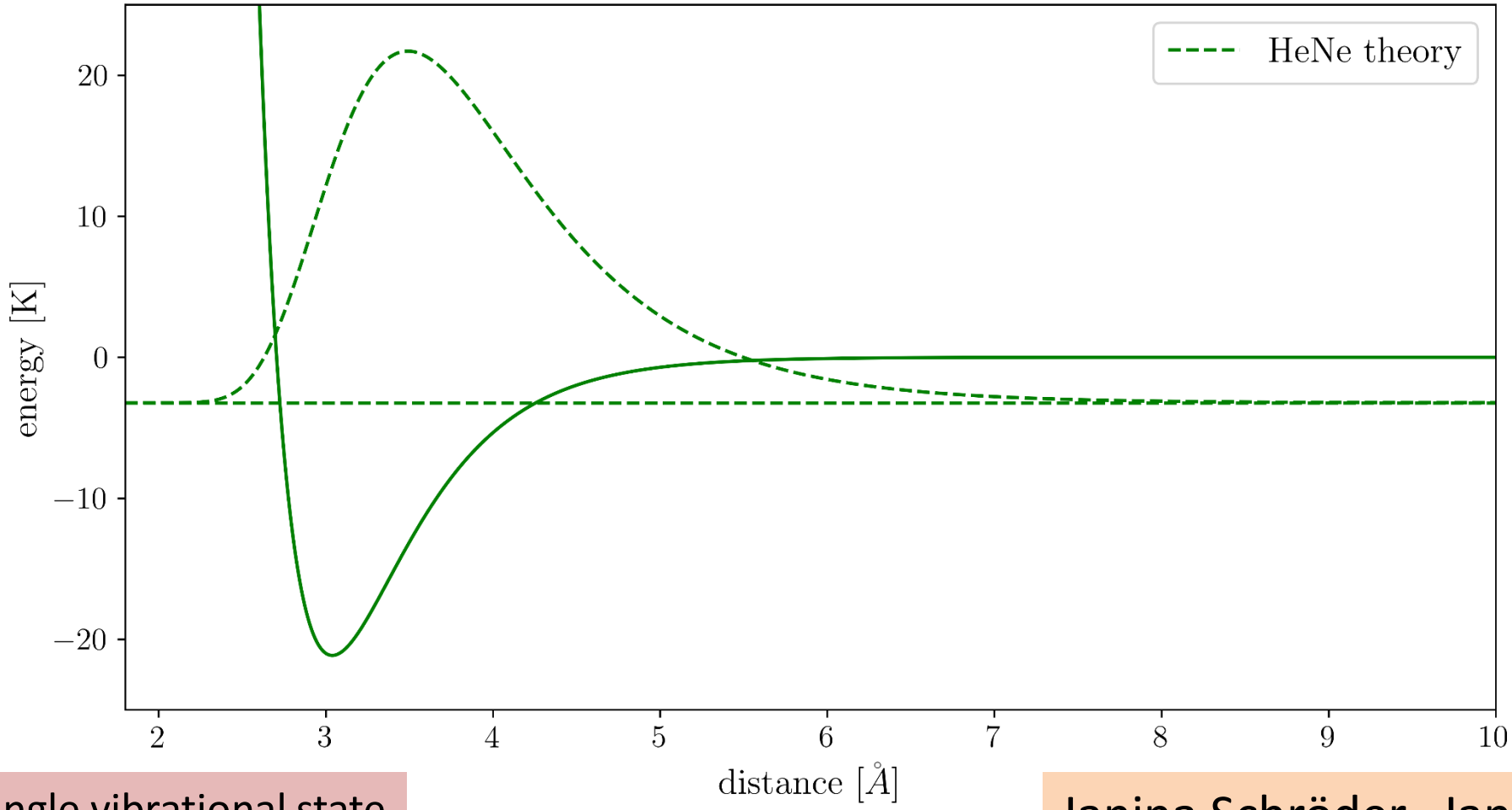

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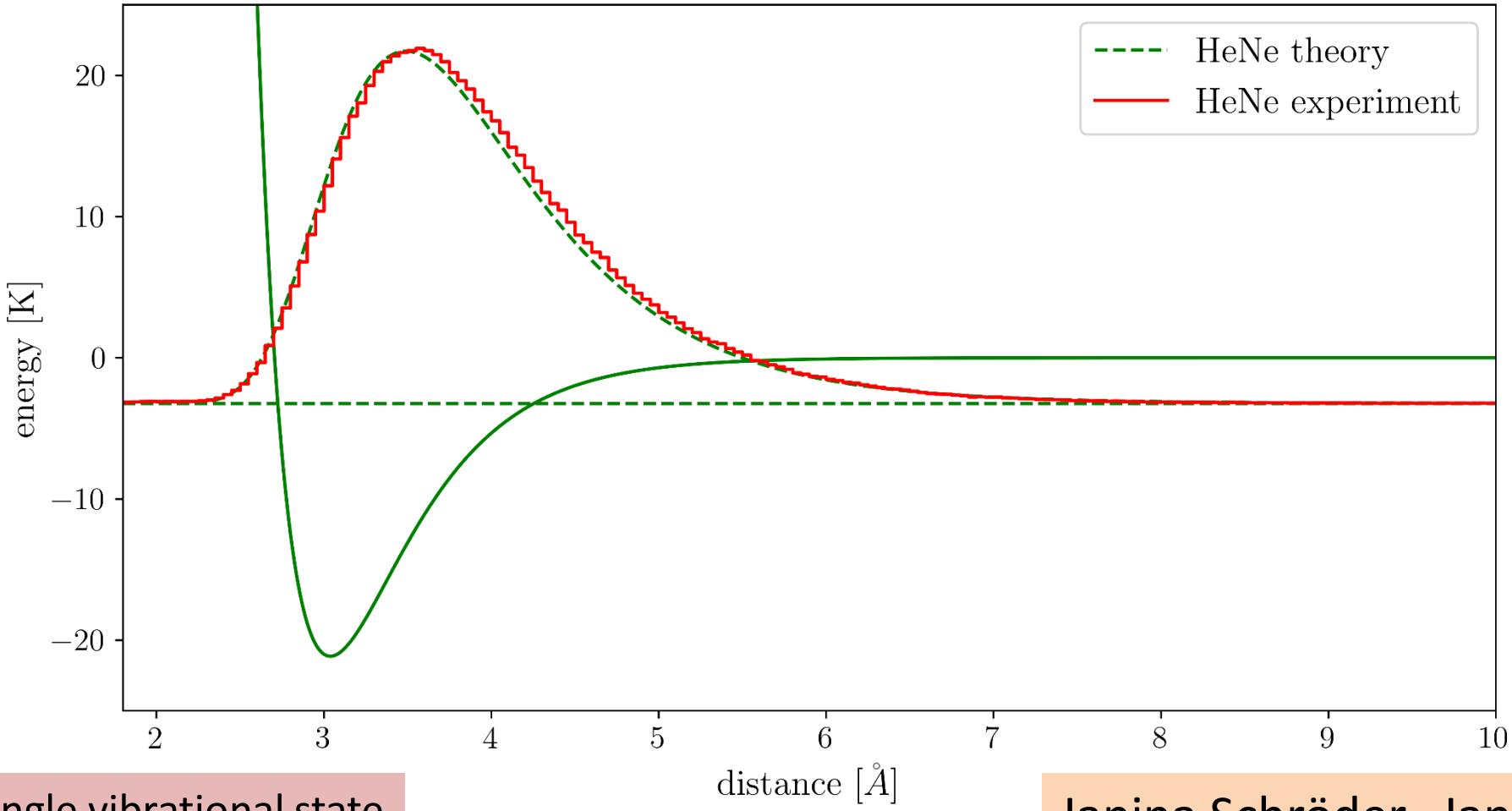

single vibrational state

Janina Schröder, Jan Kruse

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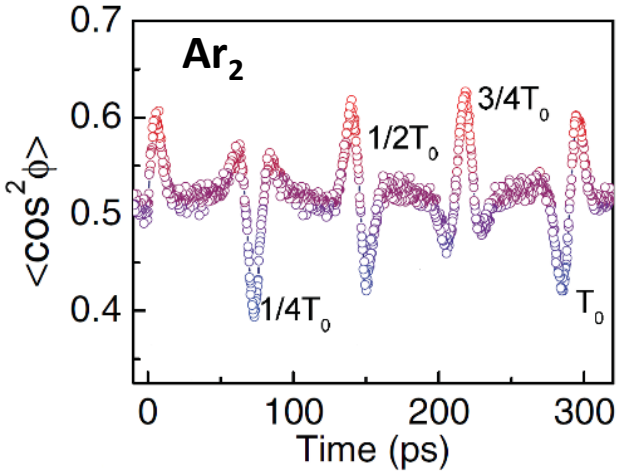
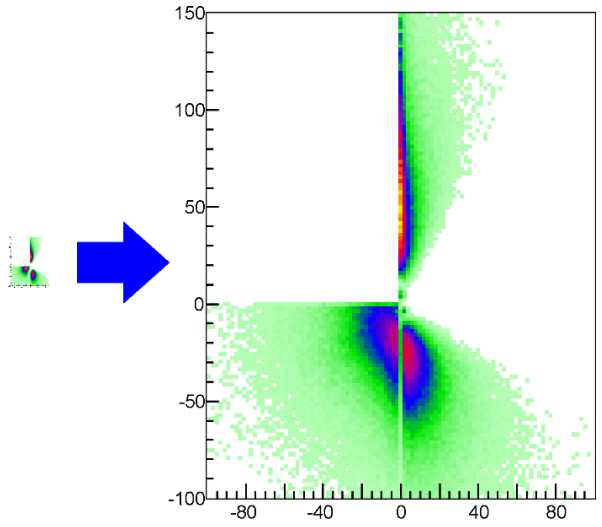
Motivation

- Can interaction between helium atoms in a cluster be changed?
- How would a quantum halo react to a laser field?
- Would one observe alignment?
- Revivals, periodicity in time?
- What happens to He_3 upon interaction with a strong laser field? Can the Efimov state of the trimer be populated by a laser “kick”?





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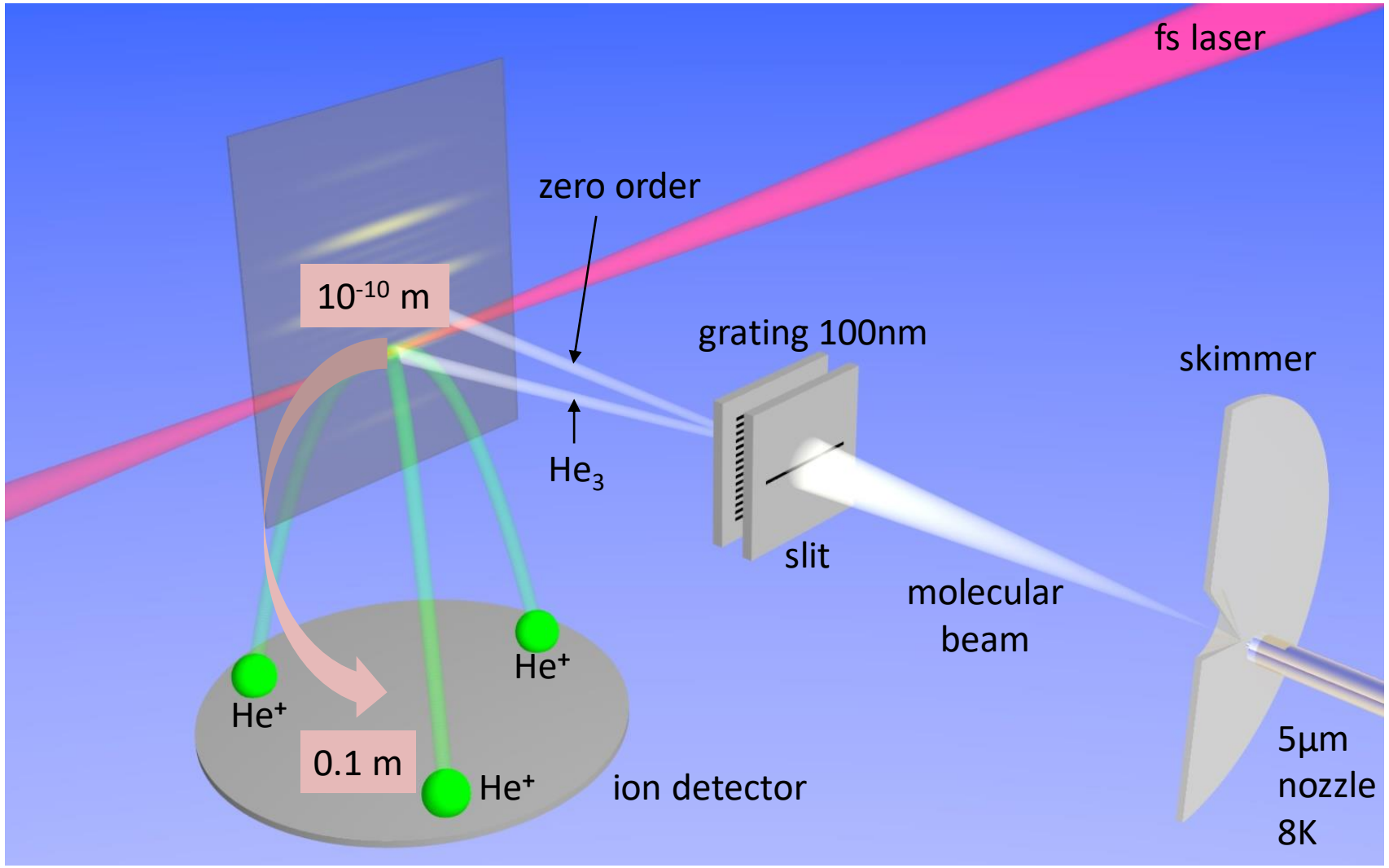

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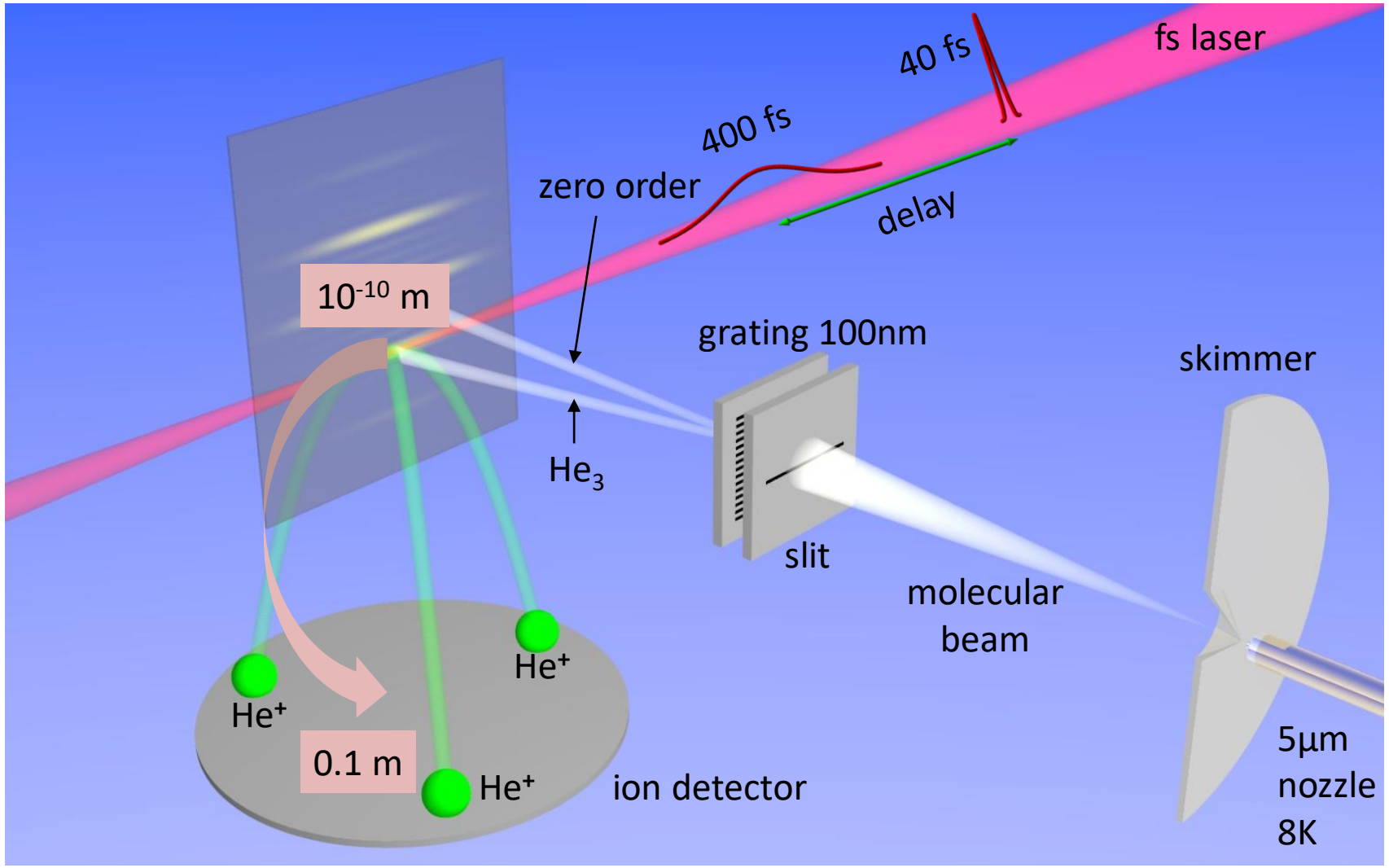
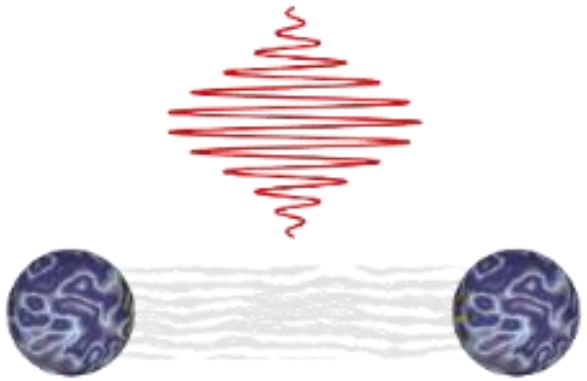
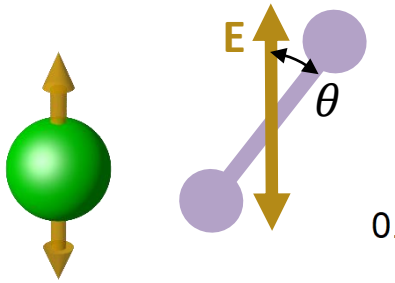


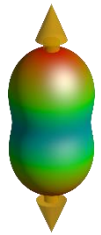
Results: Helium dimer (He_2)



He_2 alignment



$\langle \cos^2\theta \rangle = {}^1/_3$



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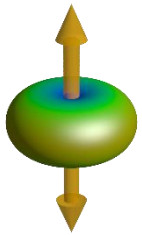

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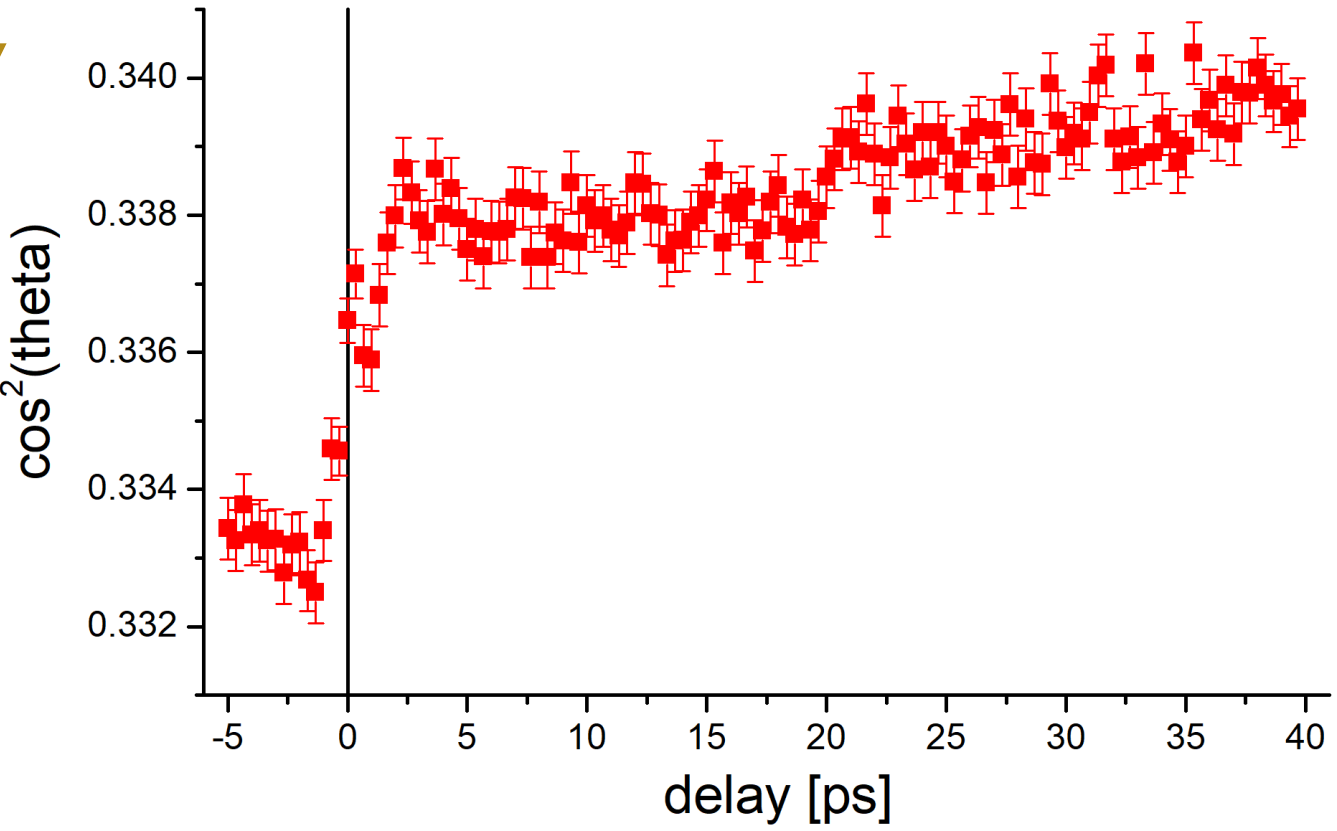

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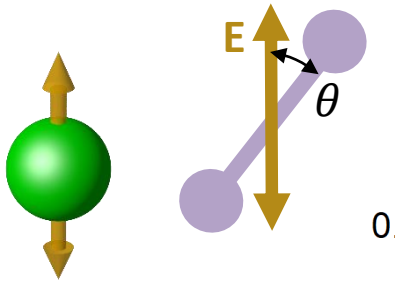

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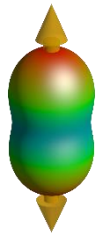

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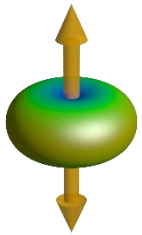

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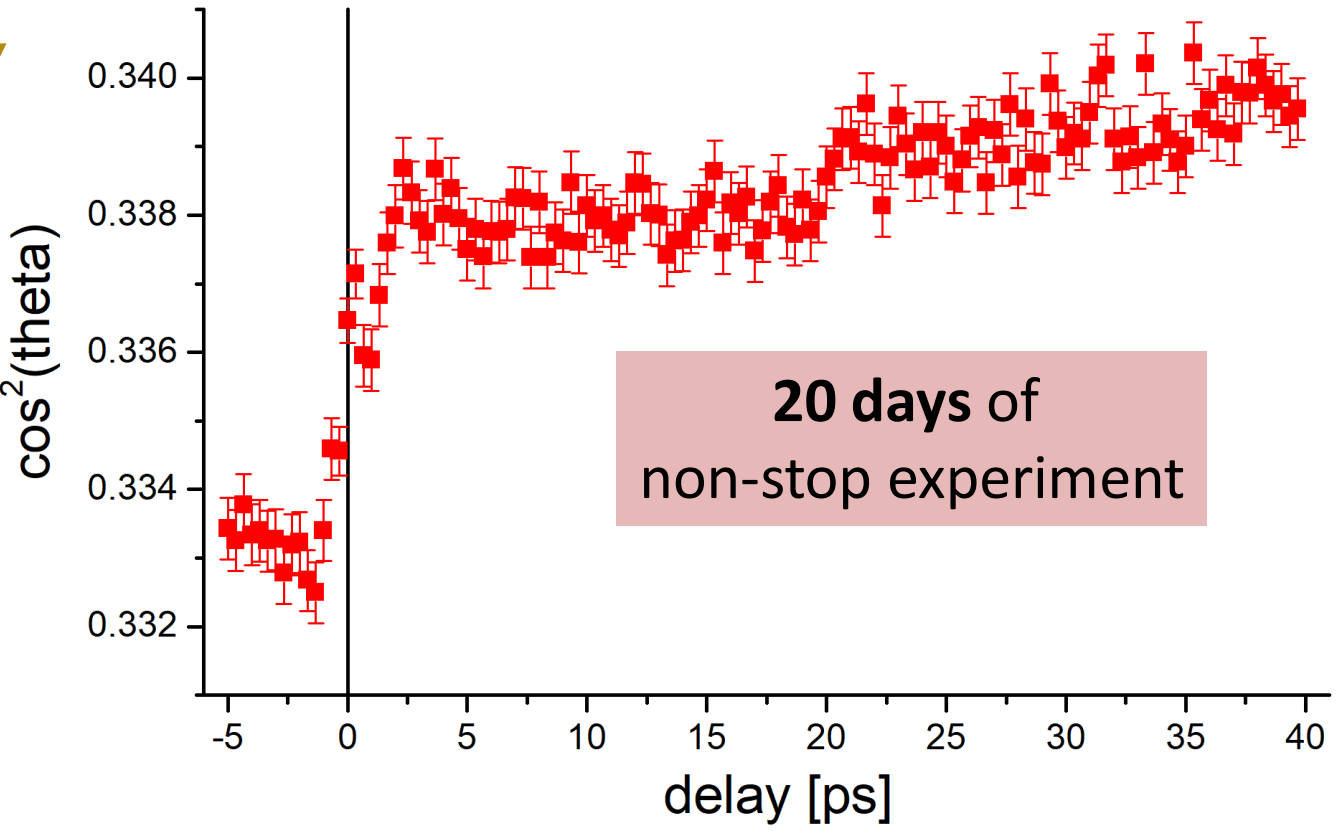
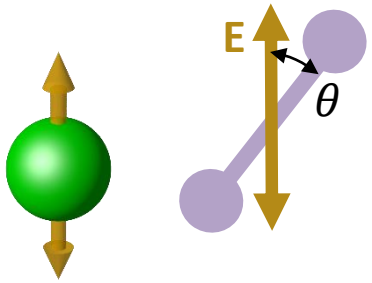


20 days of
non-stop experiment

He_2 alignment



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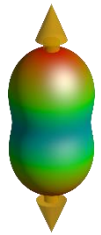

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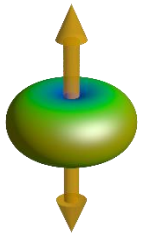

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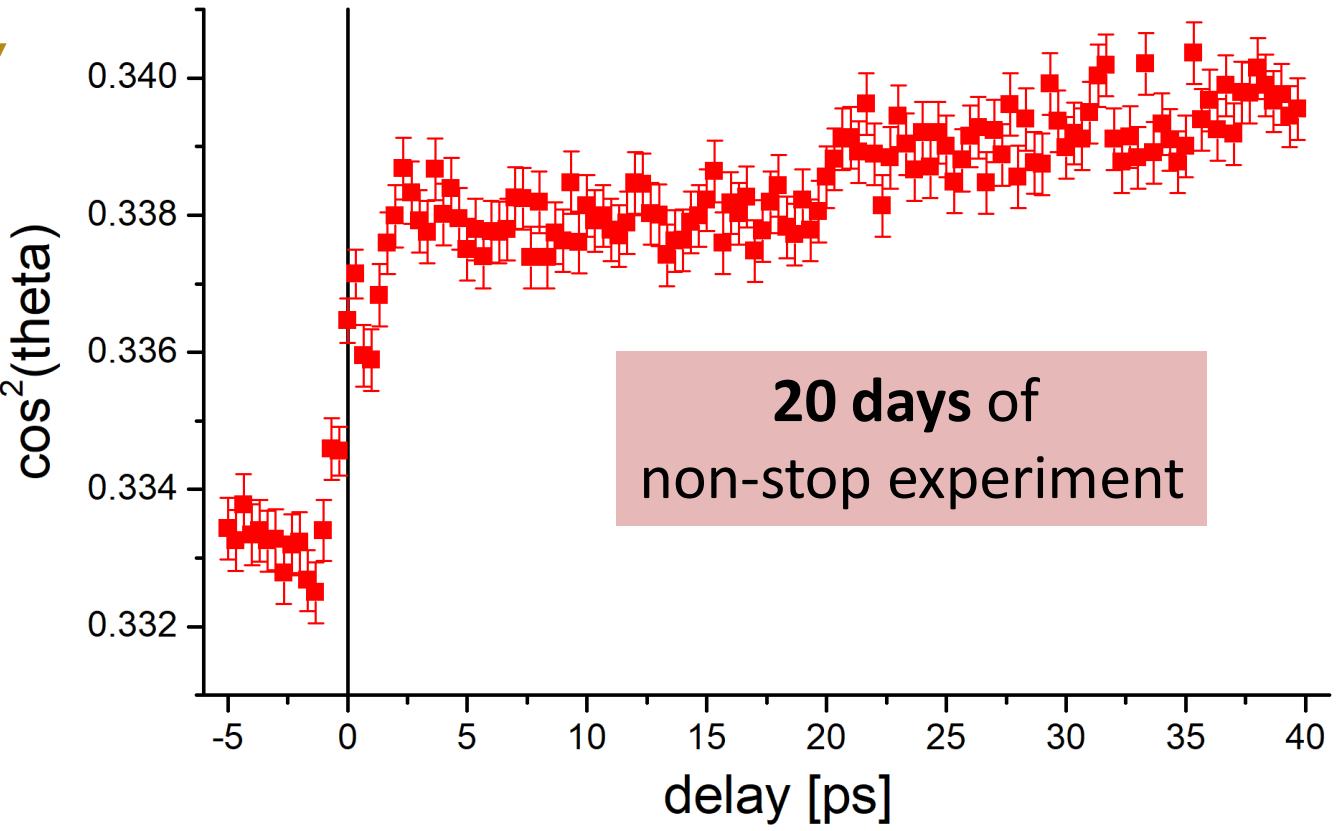

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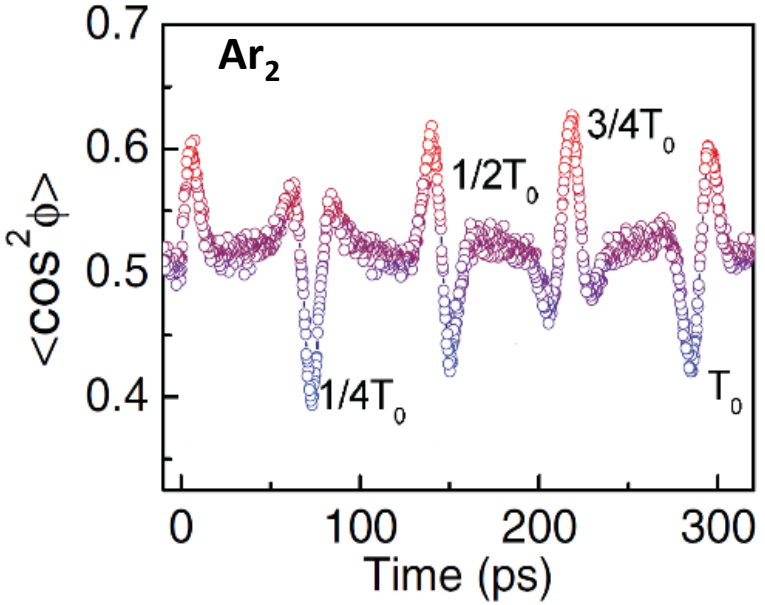
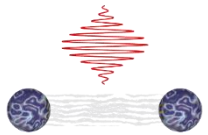


by Jian Wu

He_2: alignment wave



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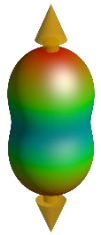
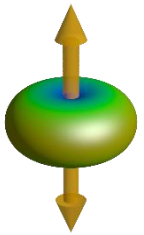
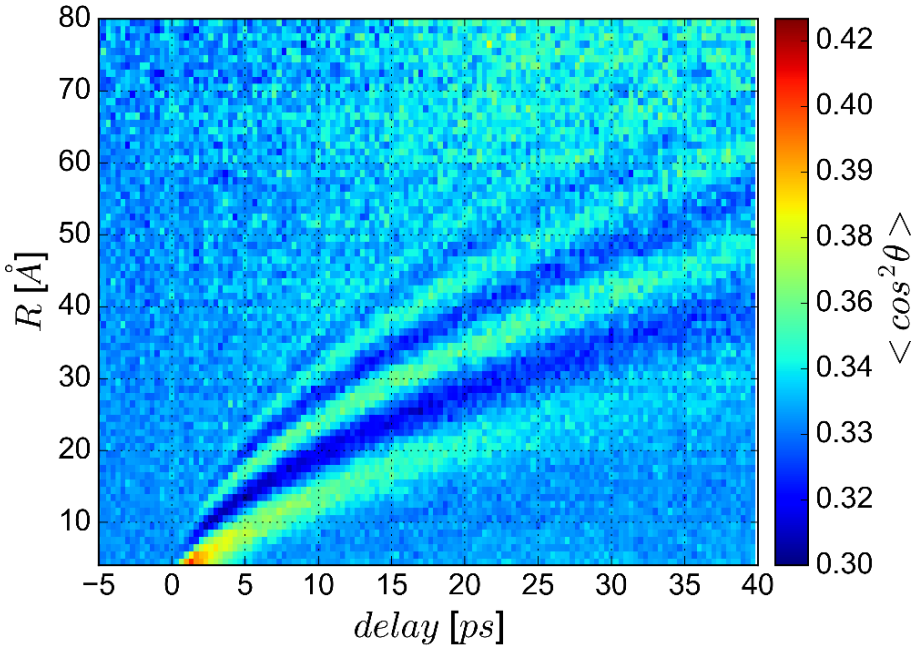


$\langle \cos^2\theta \rangle > {}^1/_3$

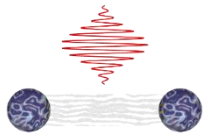


$\langle \cos^2\theta \rangle < {}^1/_3$

experiment

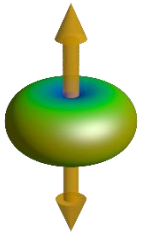


He_2: alignment wave



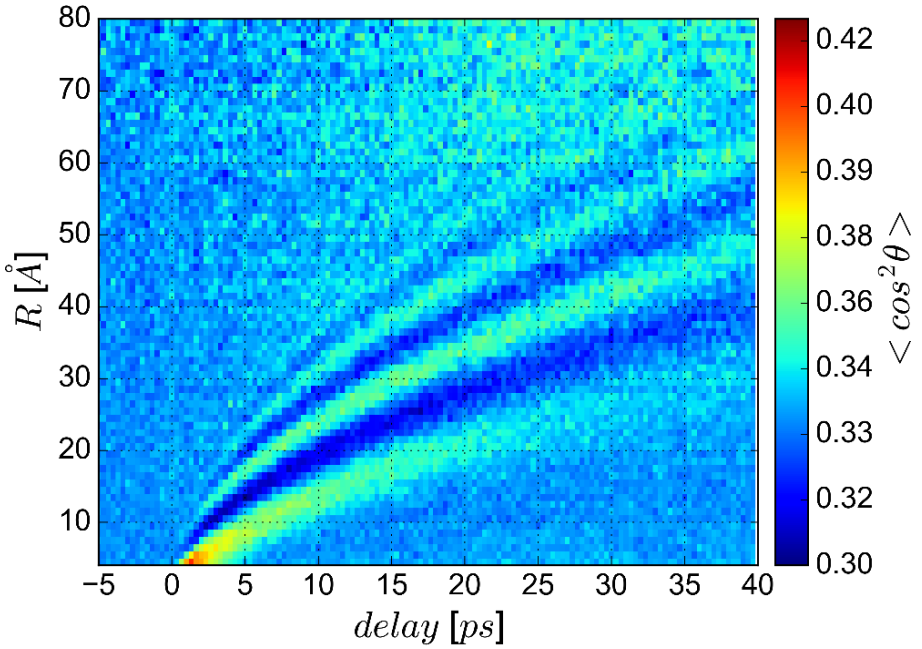
$\langle \cos^2\theta \rangle = {}^1/_3$

$\langle \cos^2\theta \rangle > {}^1/_3$

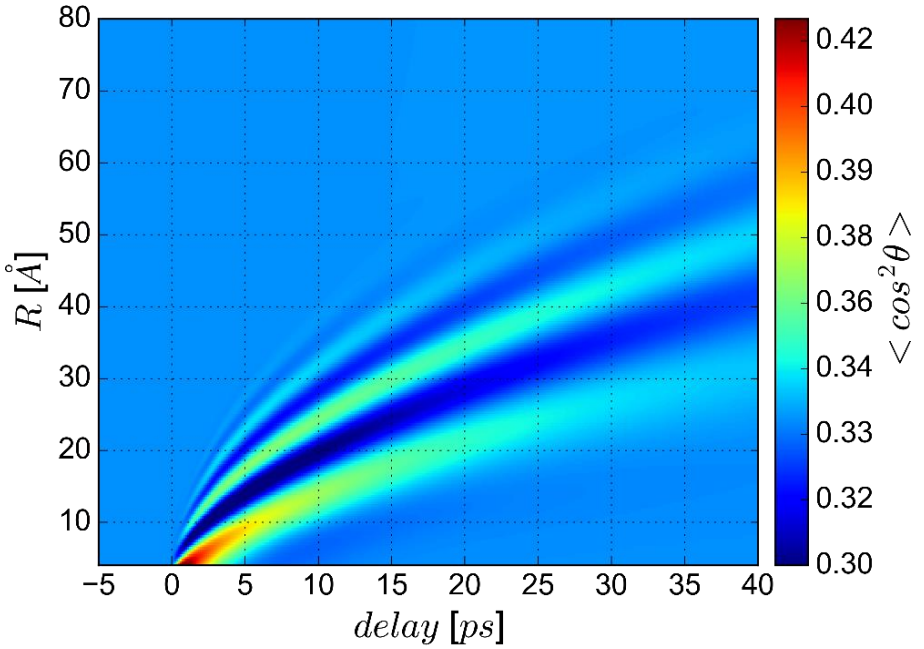


$\langle \cos^2\theta \rangle < {}^1/_3$

experiment



theory



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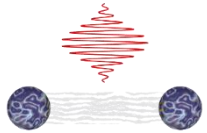
He_2: alignment wave



$\langle \cos^2\theta \rangle = {}^1/_3$

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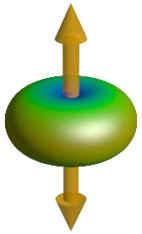
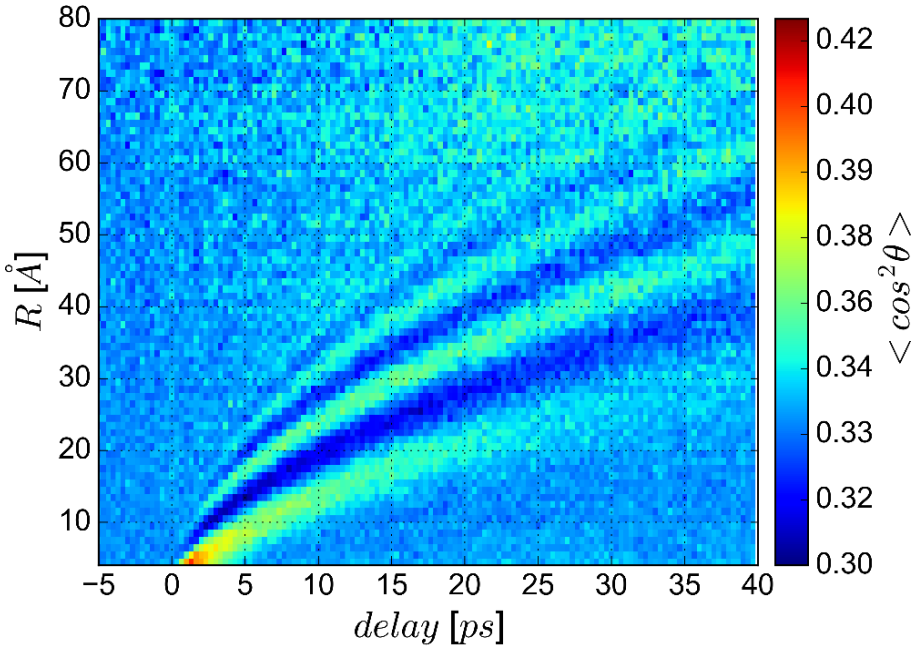
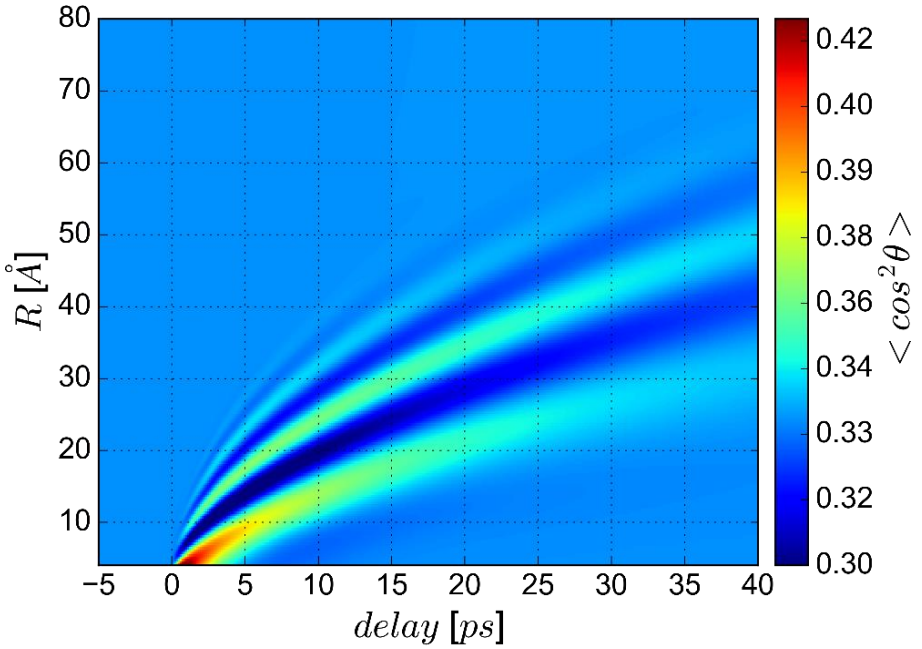


$\langle \cos^2\theta \rangle < {}^1/_3$

experiment



theory



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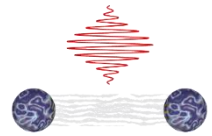
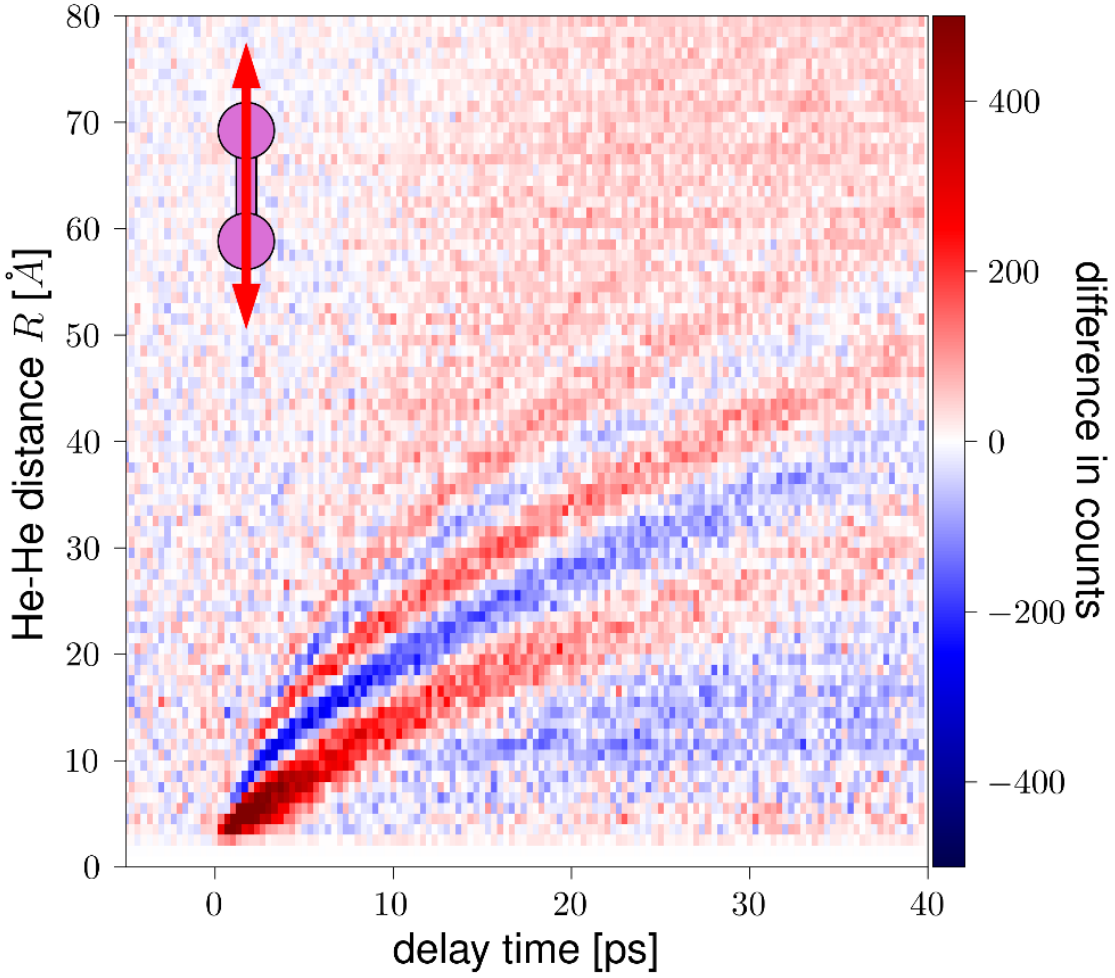
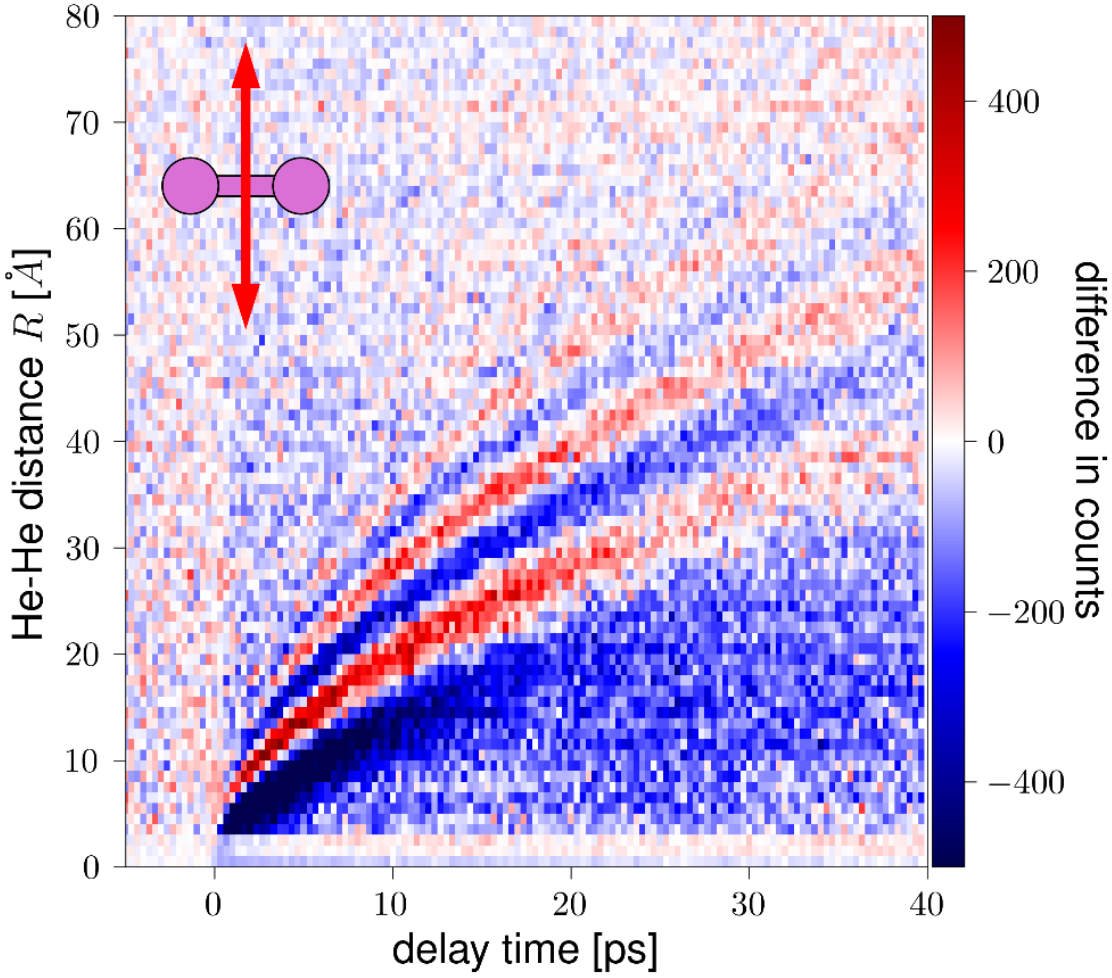
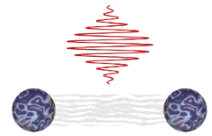
$\Psi^2(\vec{R},t) - \Psi^2_{GS}(\mathrm{R})$

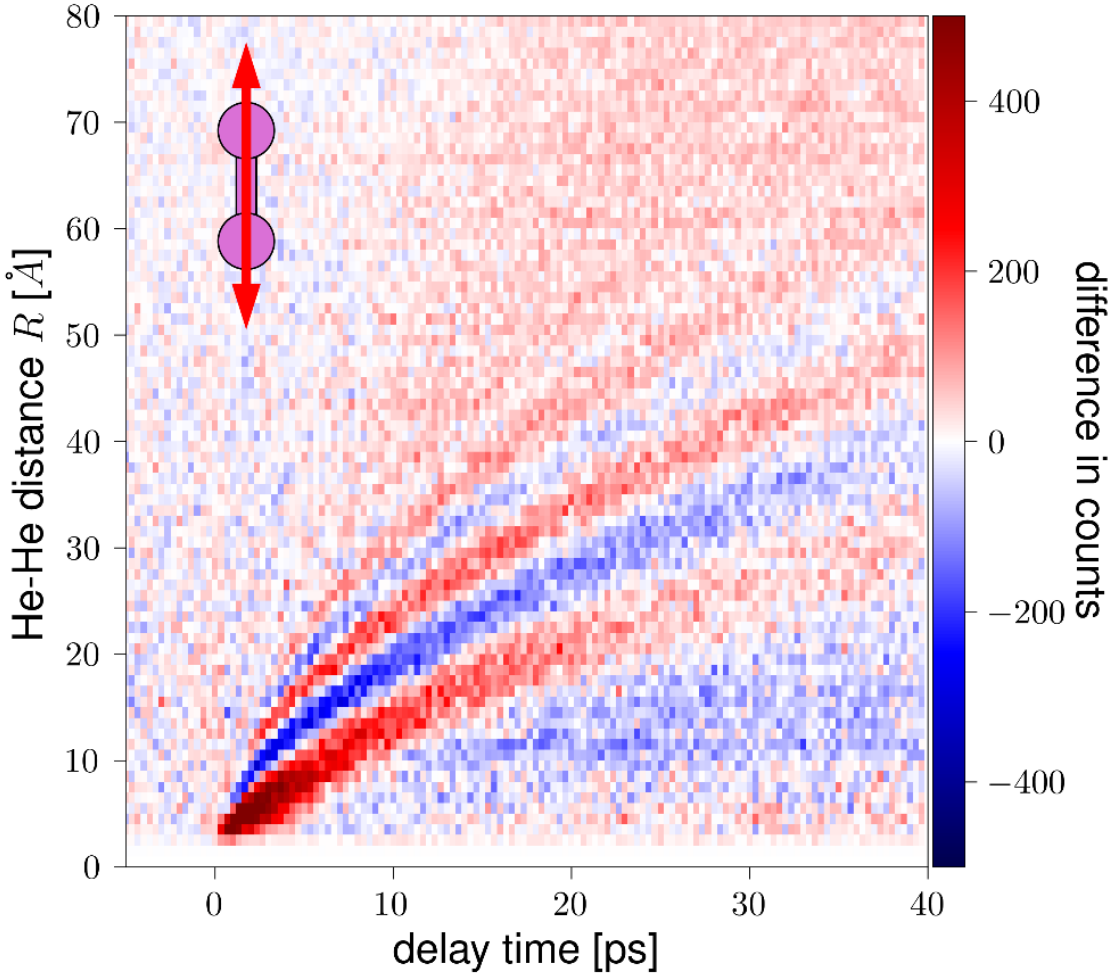


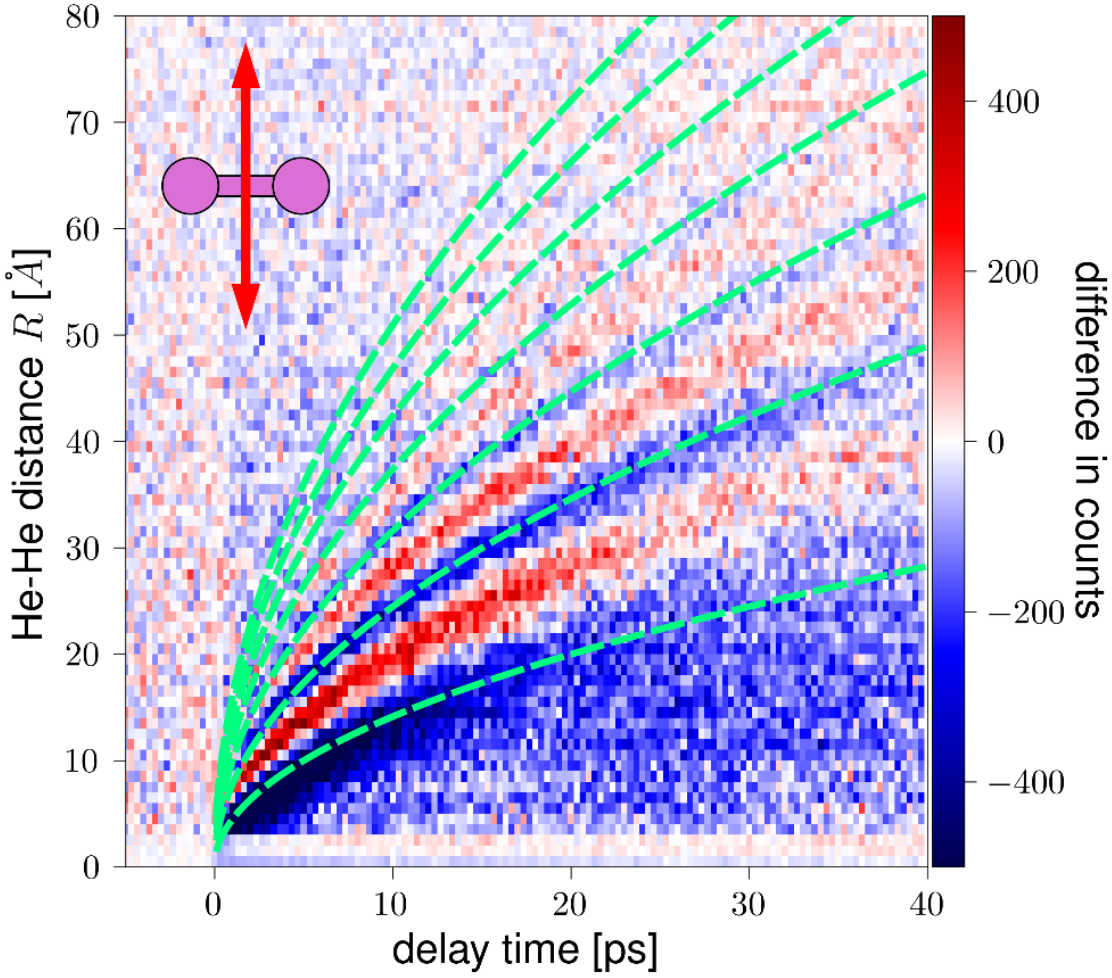




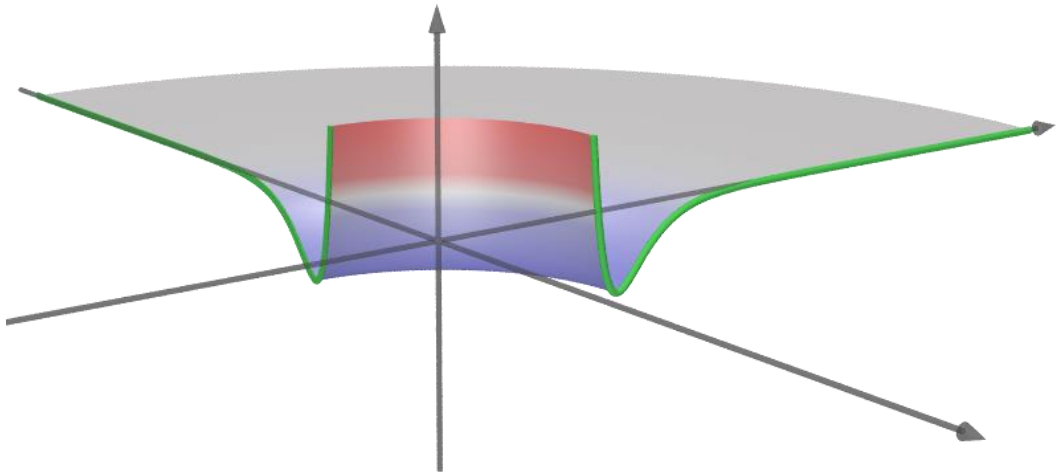
$\Psi^2(\vec{R},t) - \Psi^2_{GS}(\mathrm{R})$



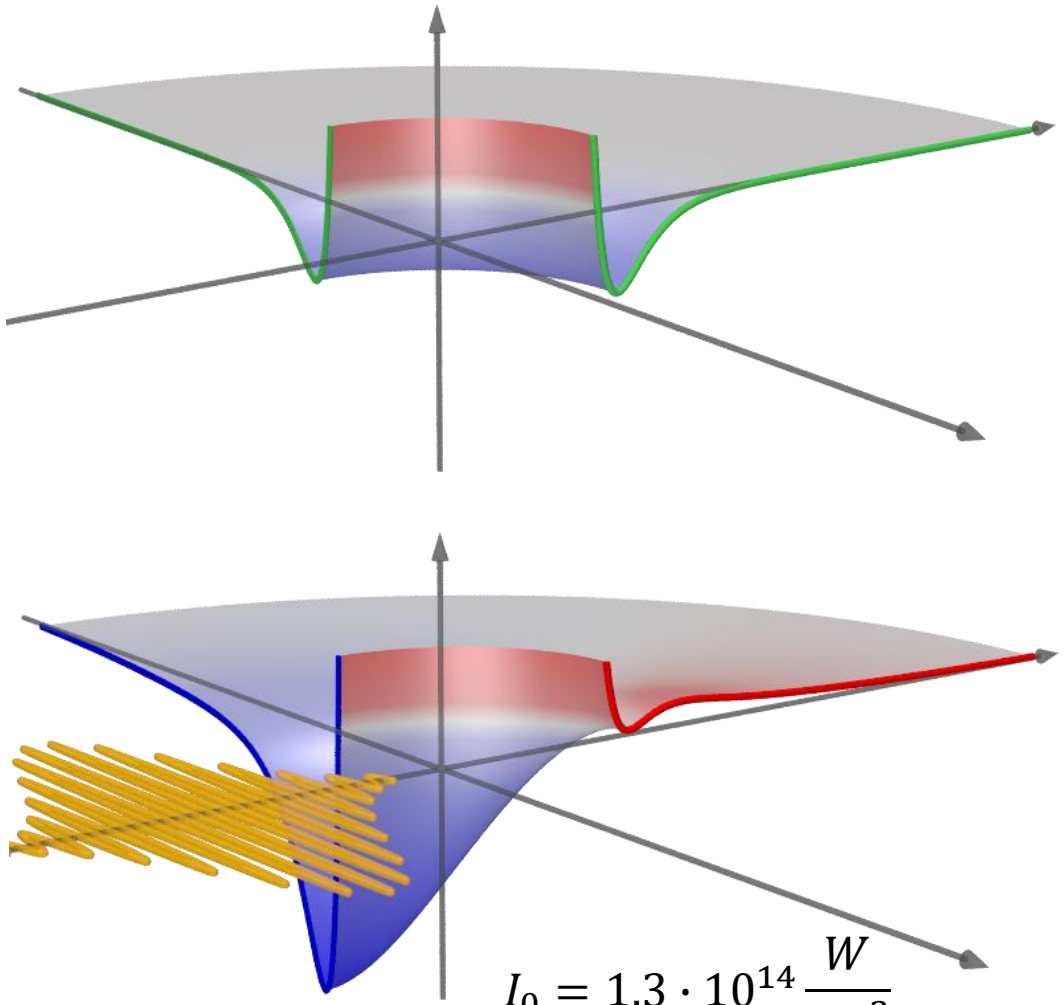




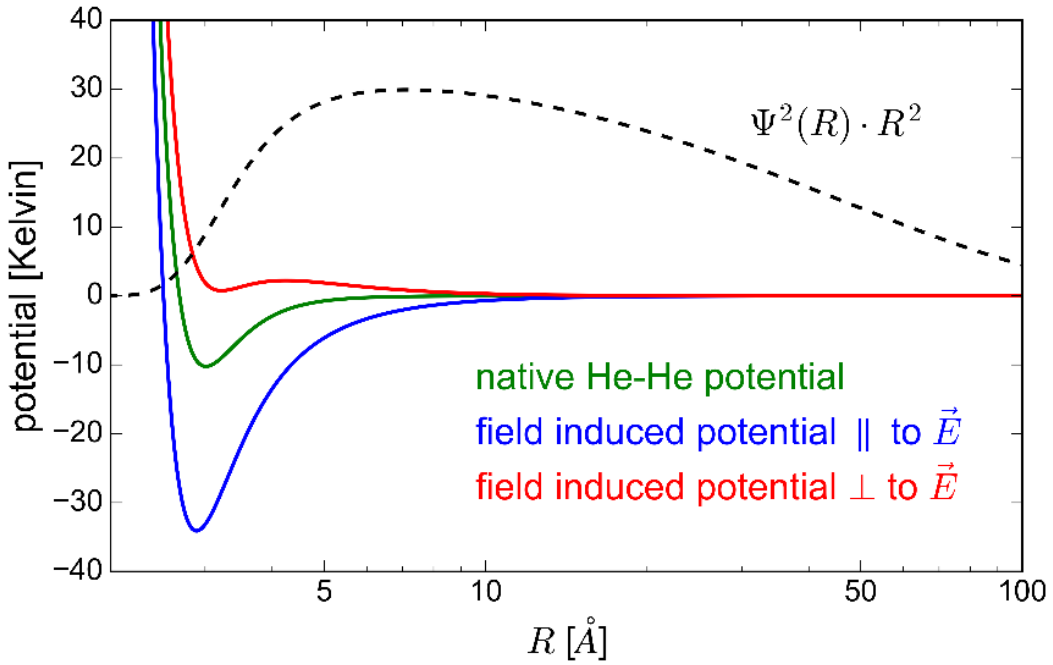
Field-induced potential in He_2



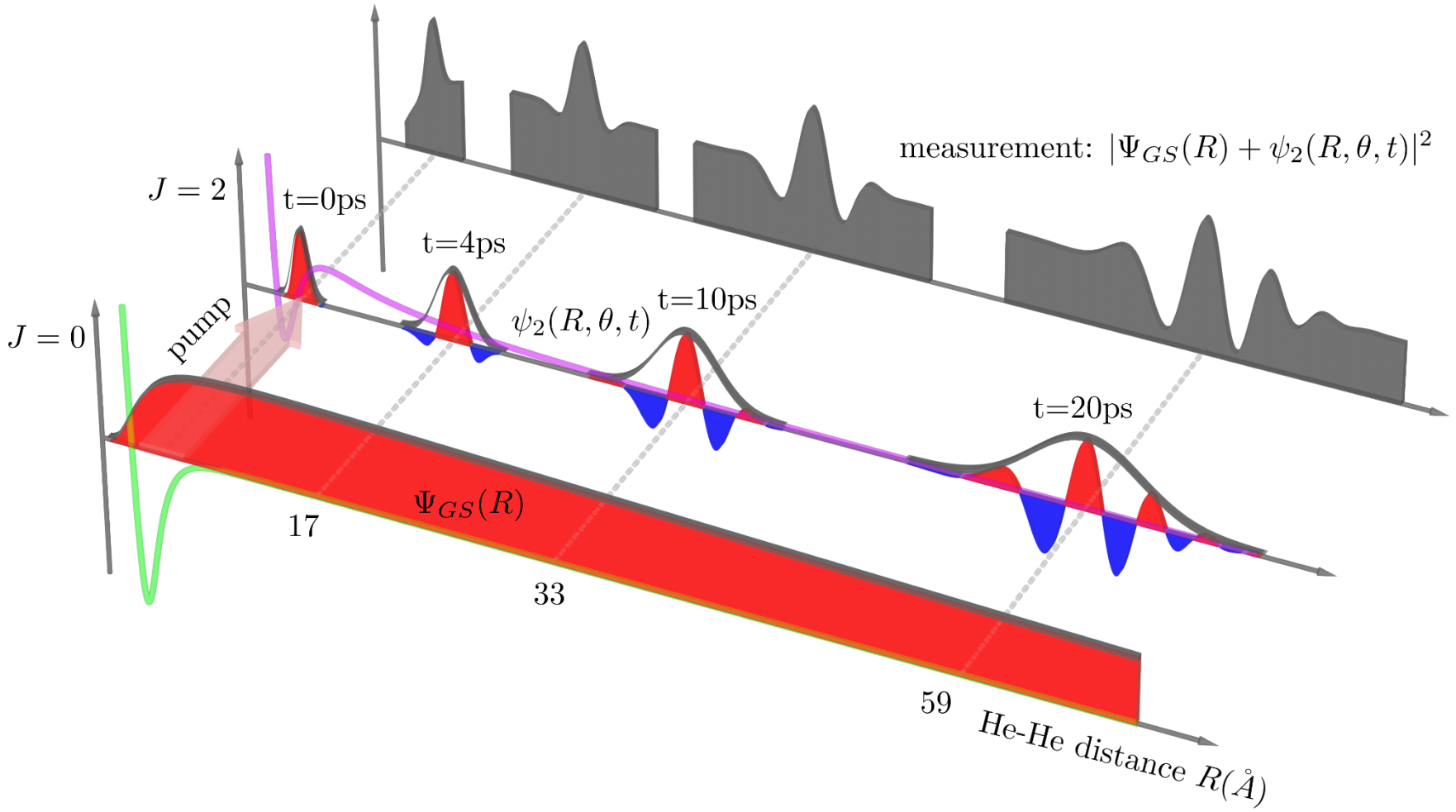
Field-induced potential in He_2



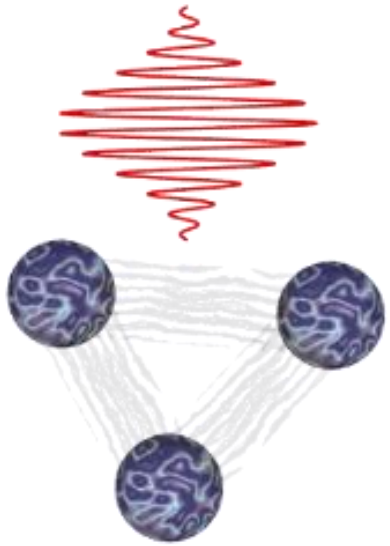
$$I_0 = 1.3 \cdot 10^{14} \frac{W}{cm^2}$$



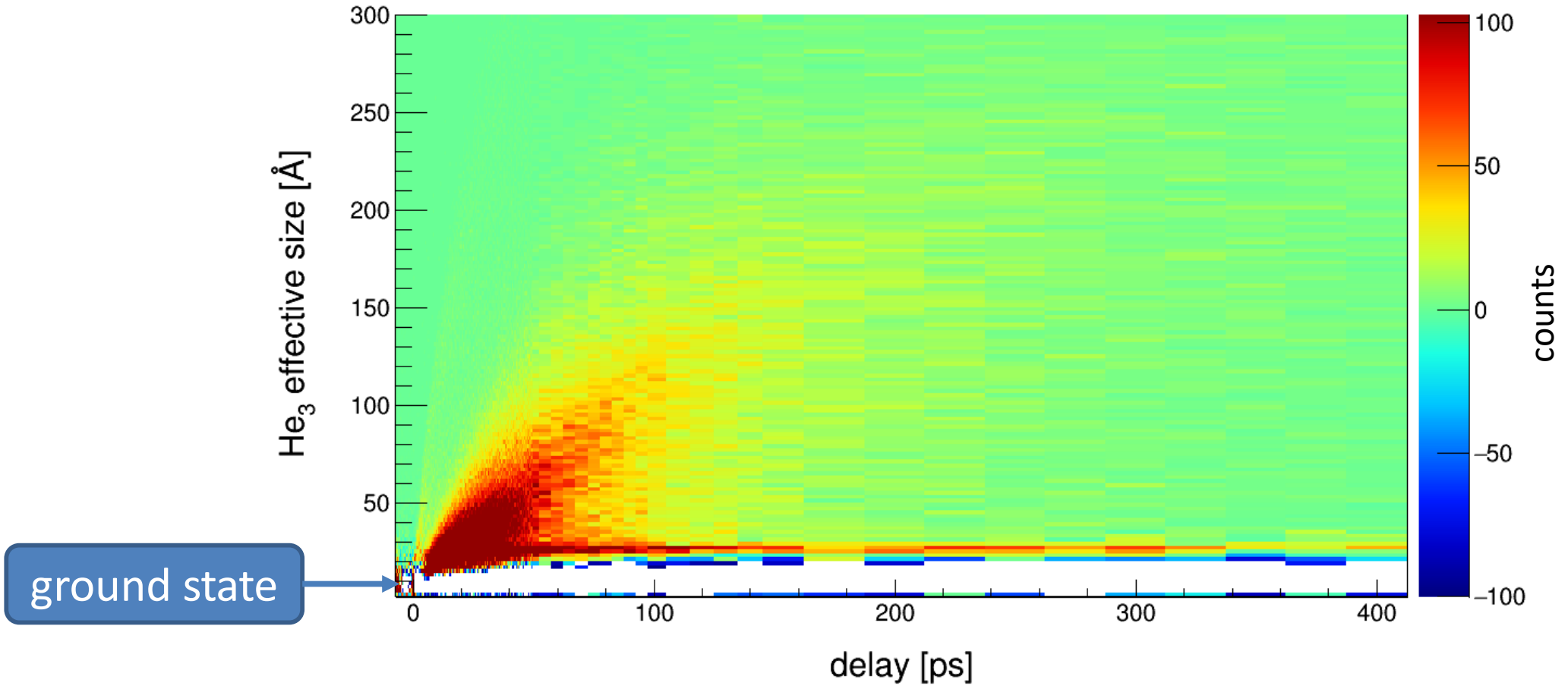
Overall picture



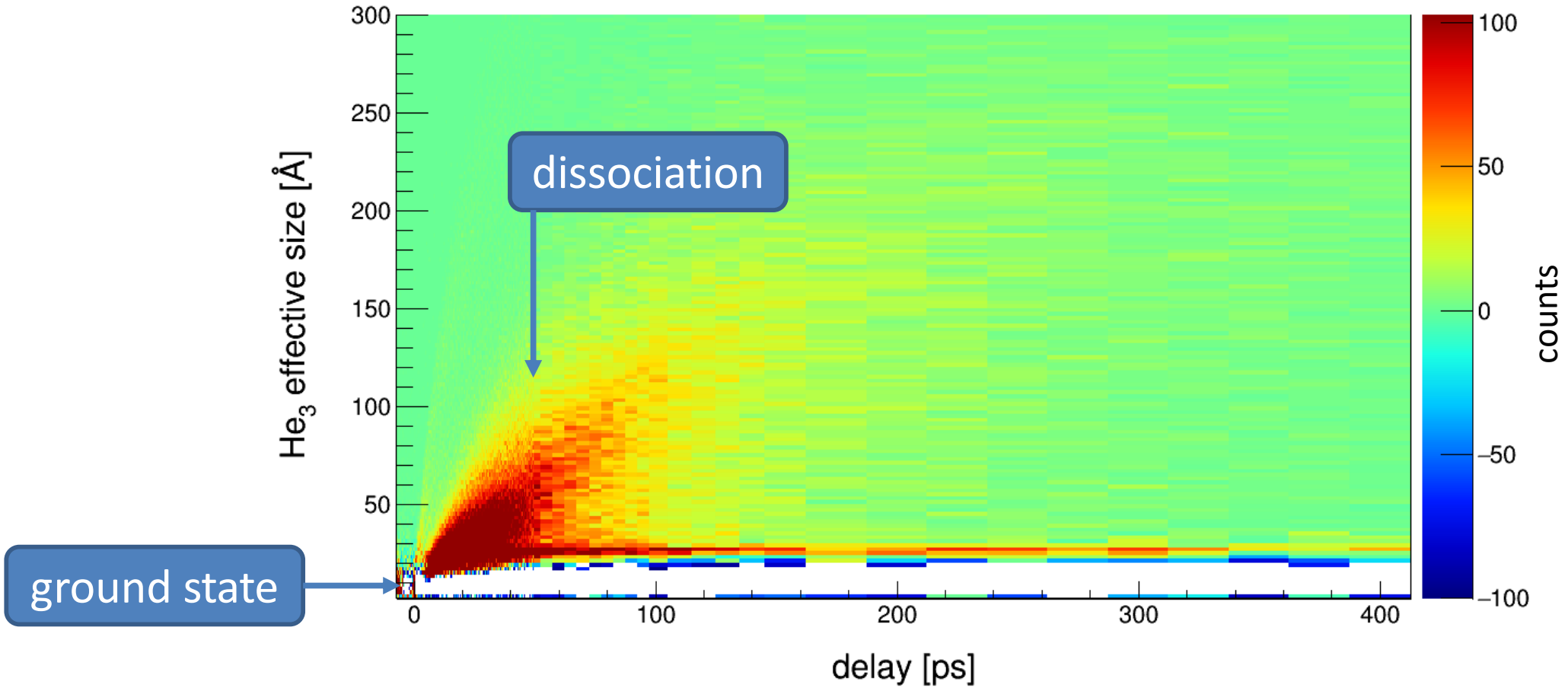
Results: Helium trimer (He_3)



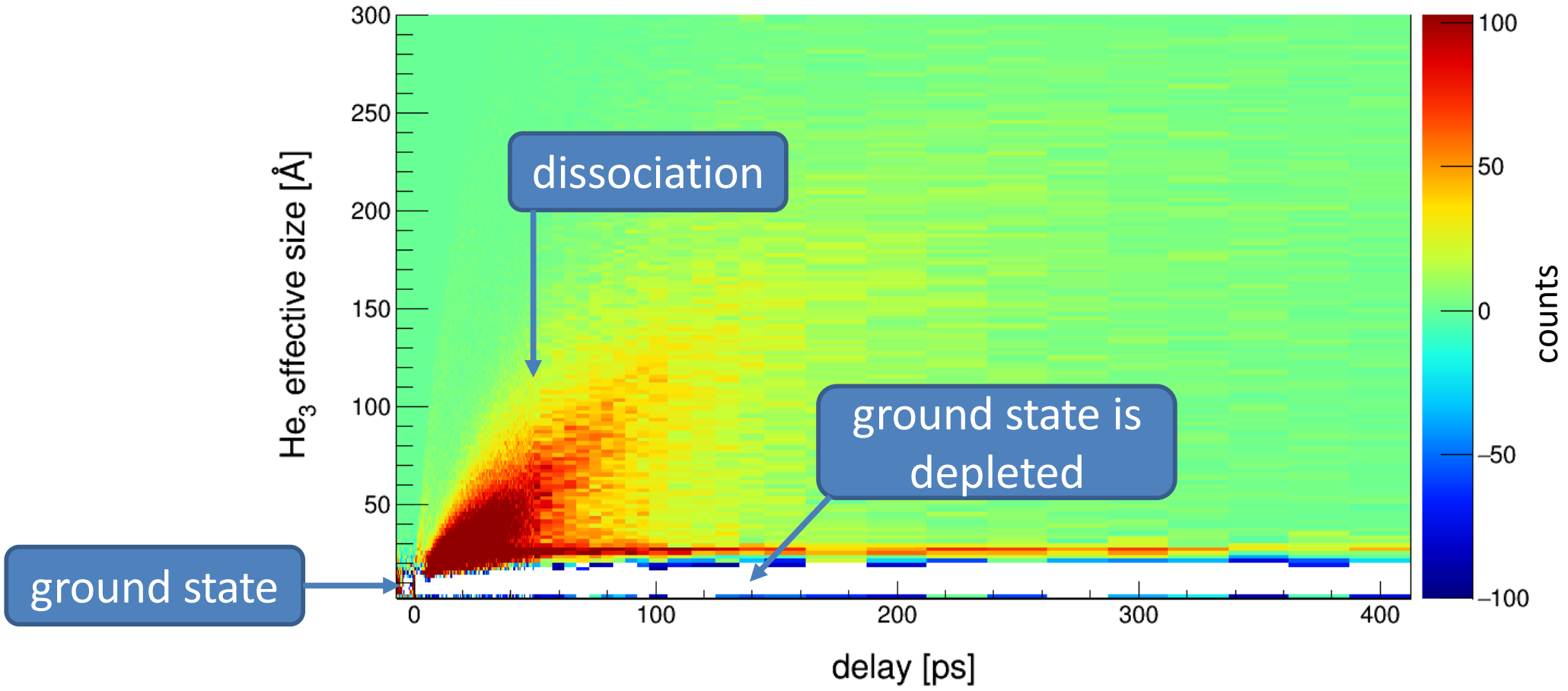
Field-induced dynamics in He_3



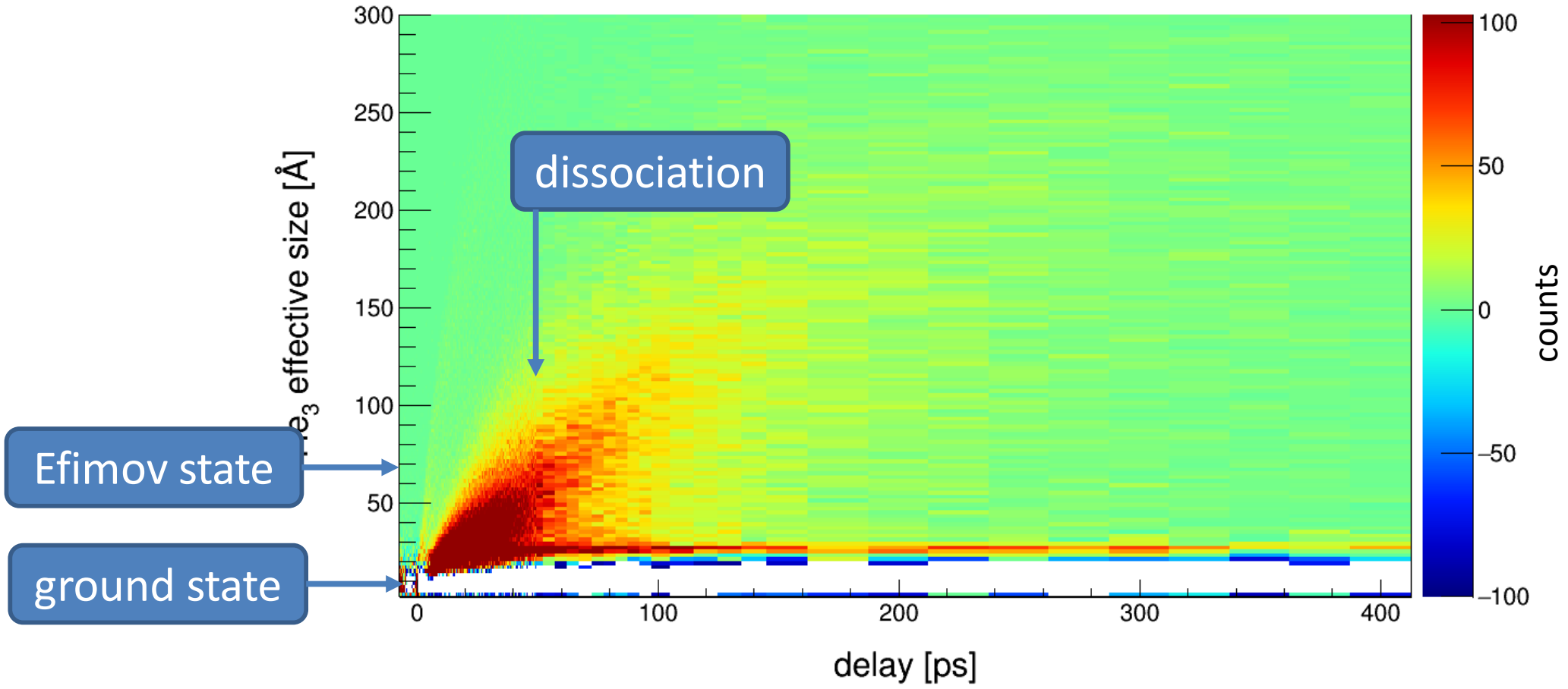
Field-induced dynamics in He_3



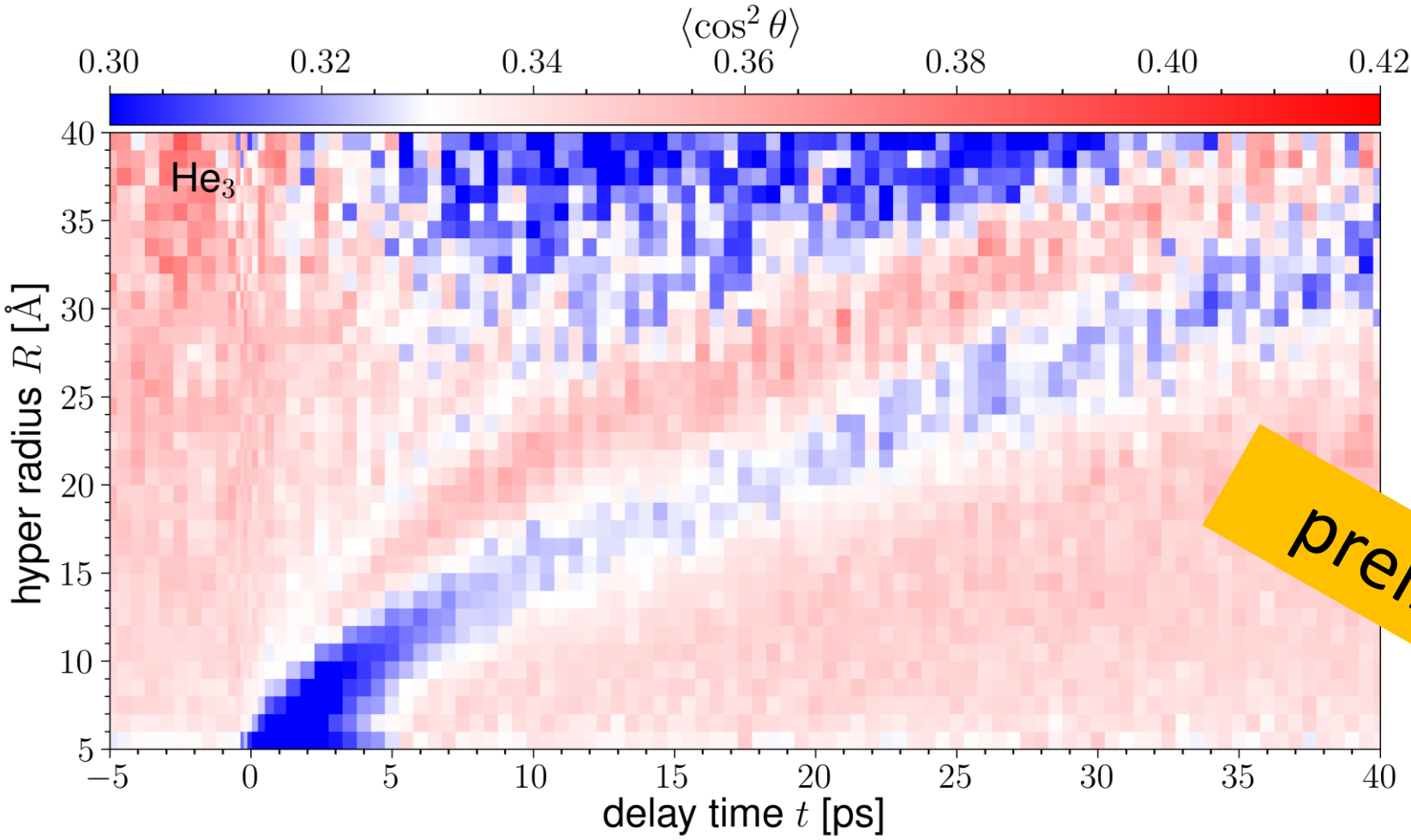
Field-induced dynamics in He_3



Field-induced dynamics in He_3



Field-induced dynamics in He_3

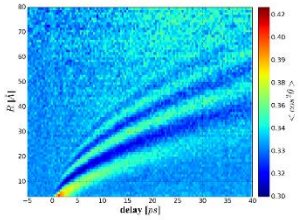


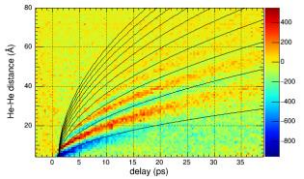
preliminary

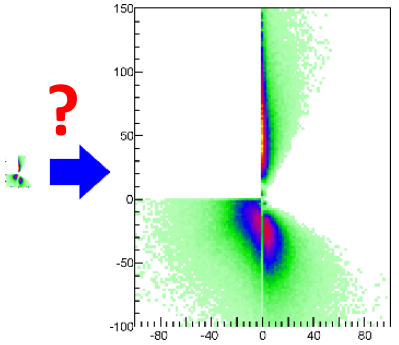
Jan Kruse

Summary

- Images of the structure of small helium clusters
- only small part of the wave function at small internuclear distances “sees” the laser field
- internuclear distance dependent alignment pattern for He_2
- this pattern has been attributed to the dissociation dynamics of the unbound J=2 state
- no rotational revivals
- a free particle wave packet evolution (with a phase!)
- no evidence for a significant population of the Efimov state of He_3
- The origin of the interferences in the alignment wave of He_3 is still unknown







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Thank you for your attention!