Storage Ring Measurements of the Dissociative Recombination of H_3^+

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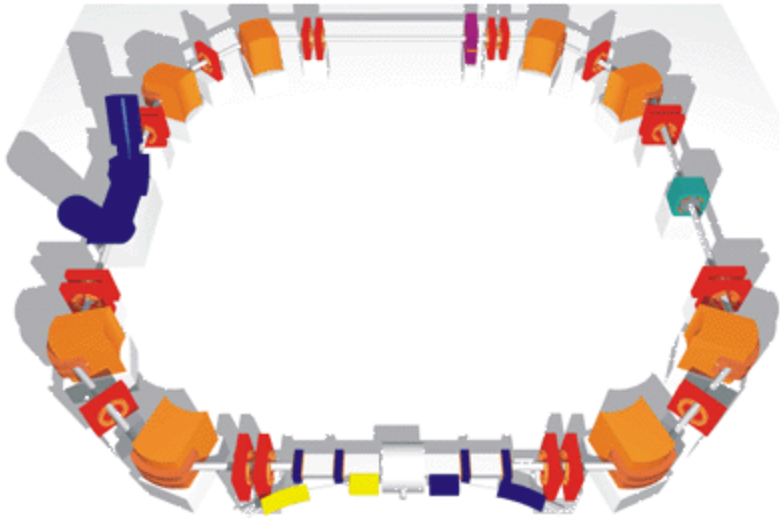


QUANTUM DYNAMICS

Dissociative Recombination (DR) of Molecular Ions

Molecular ion

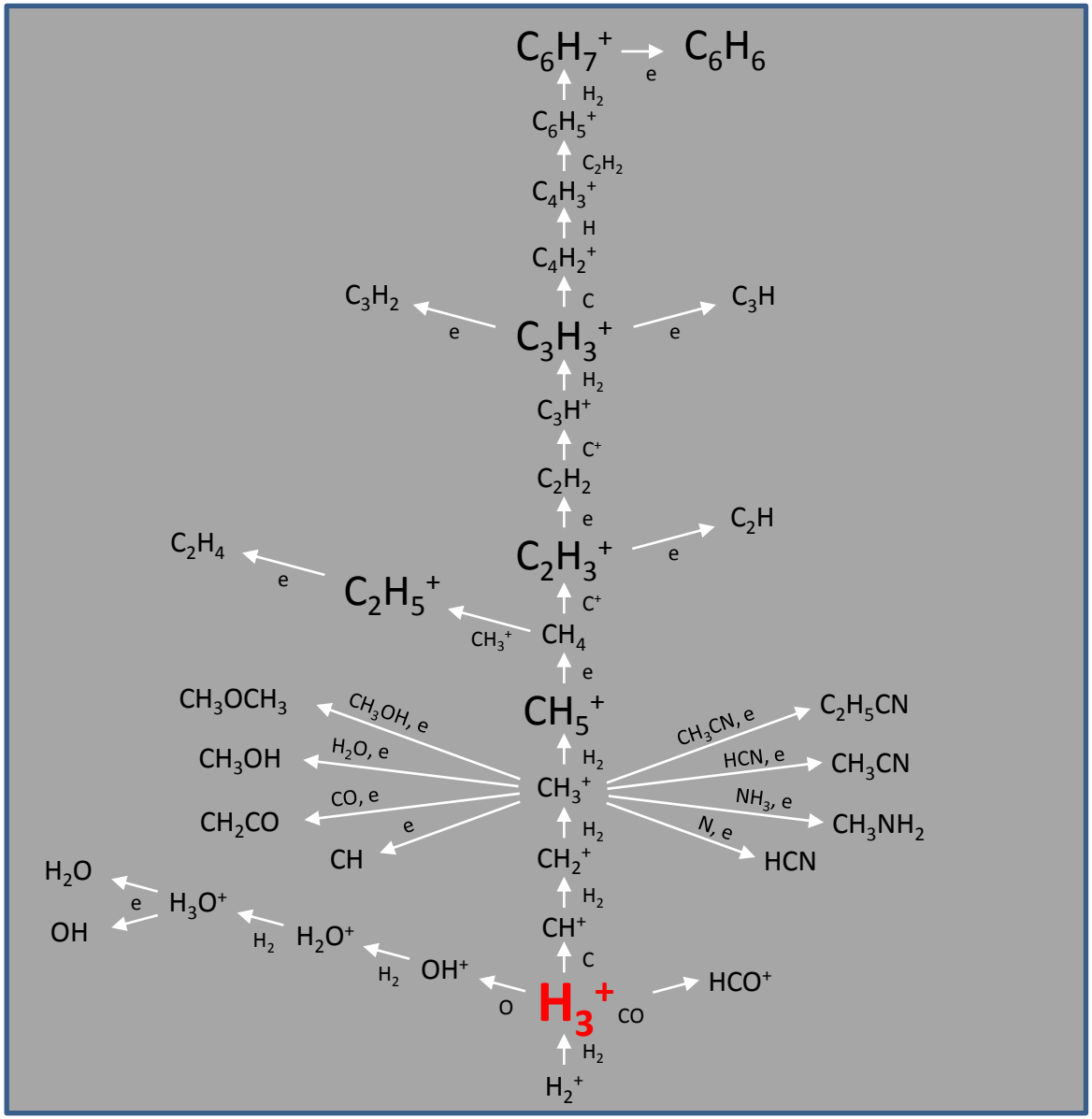
Free electron

Neutral fragments

$$AB^+ + e^- \longrightarrow A + B$$

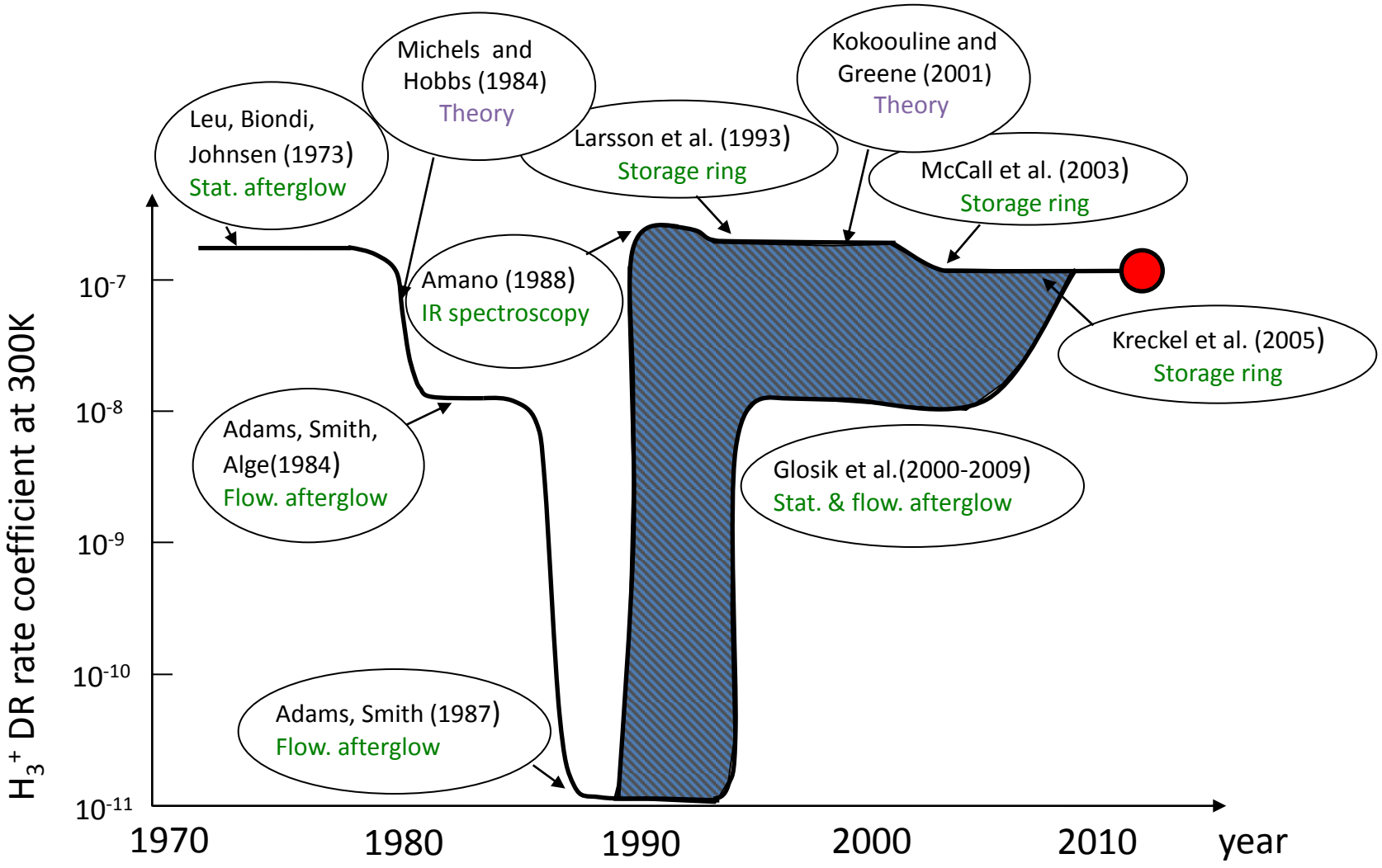
$$H_3^+ + e^- \longrightarrow \begin{matrix} H + H + H \\ H_2 + H \end{matrix}$$

Importance of DR in the interstellar medium



McCall, 2001

"Perceived" H_3^+ DR rate coefficient



Storage Ring DR Measurements

Advantages

- radiative relaxation (rotations, vibrations)

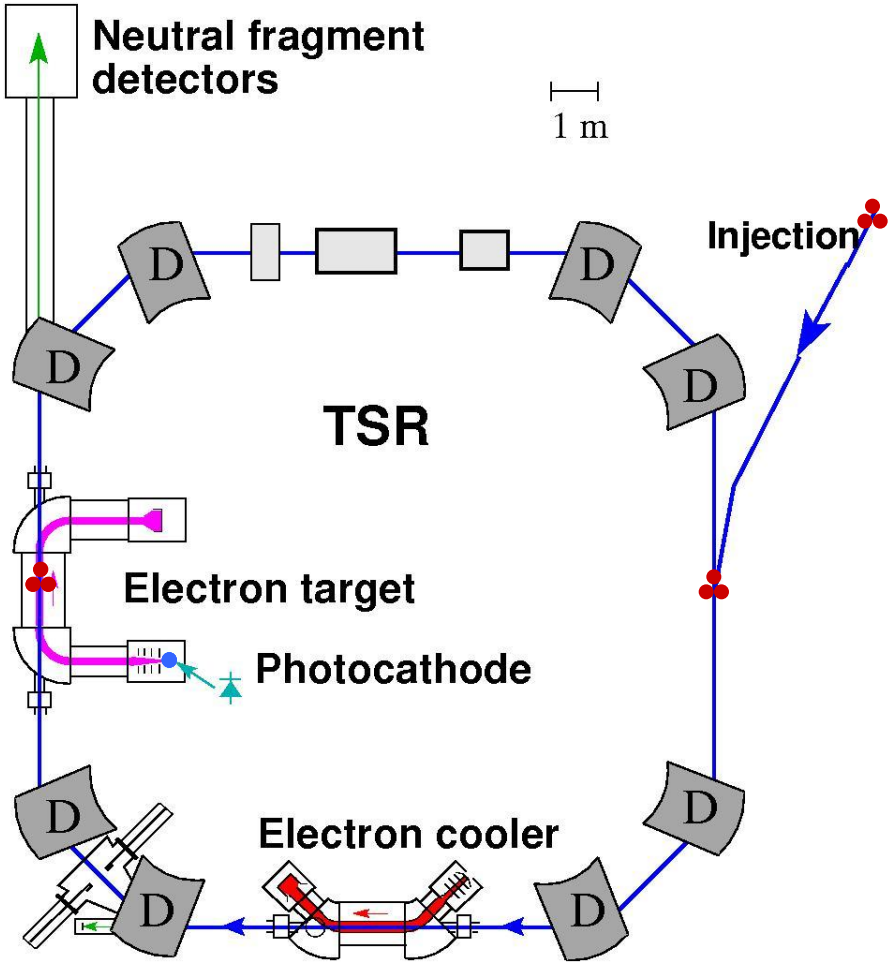
- direct measurement
- 100% detection efficiency
- high resolution

Problem

H_3^+

Vibrations?

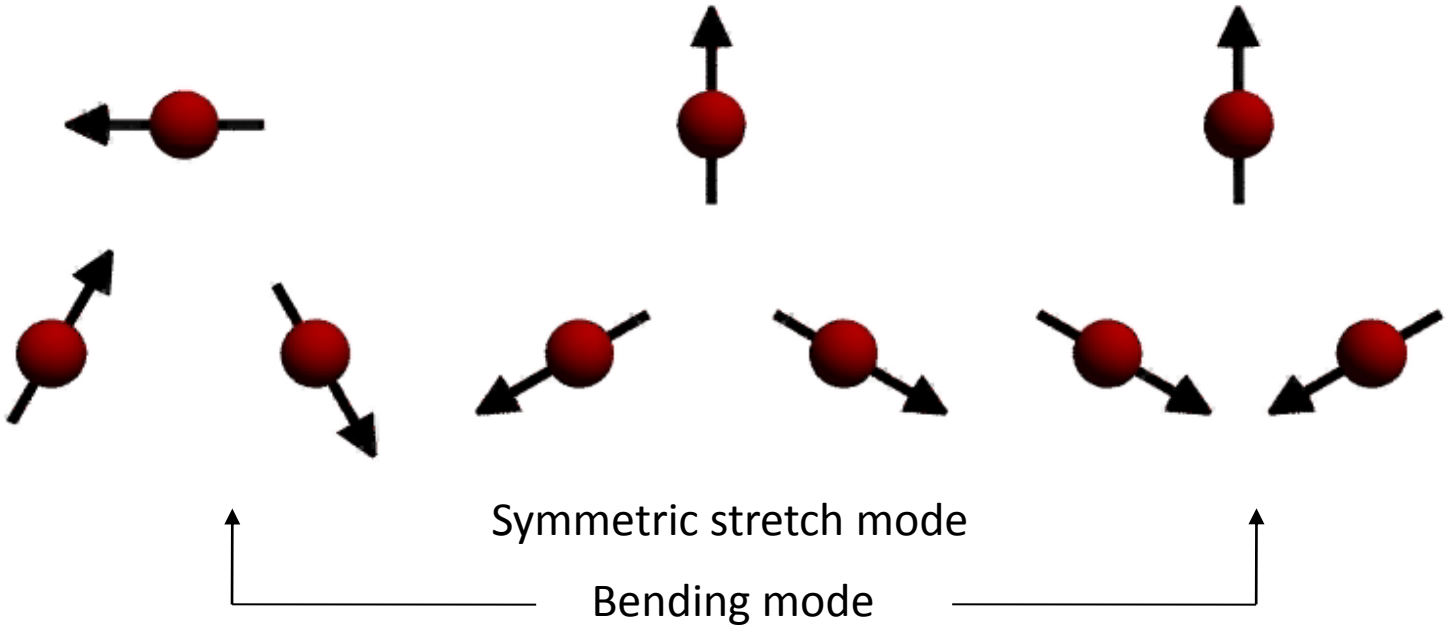
Rotations?



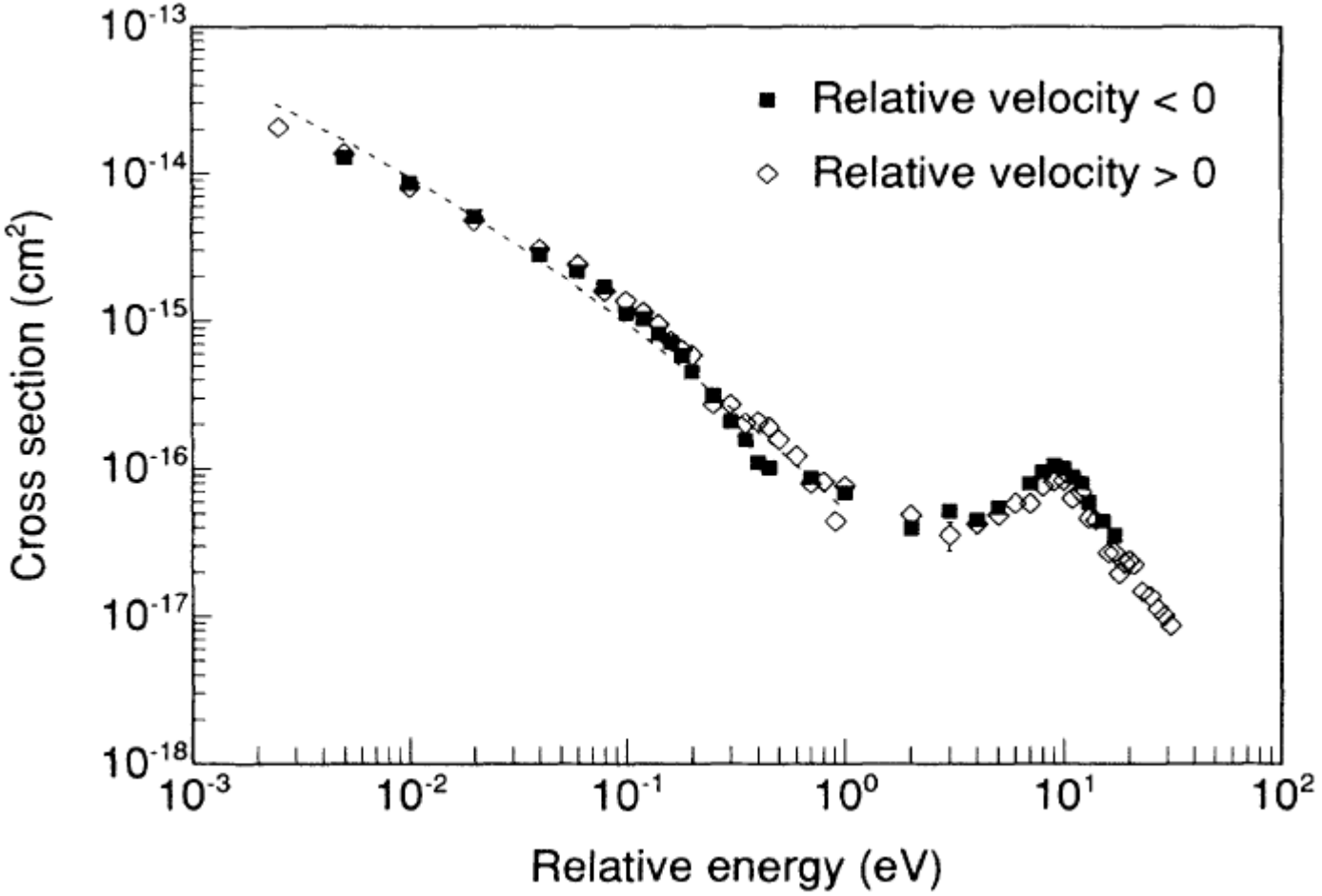
H_3^+: A Special Molecule

- no electronic excited states
- no permanent dipole moment
- very efficient formation:

$$H_2^+ + H_2 \rightarrow H_3^+ + H \quad (+ 1.7eV)$$

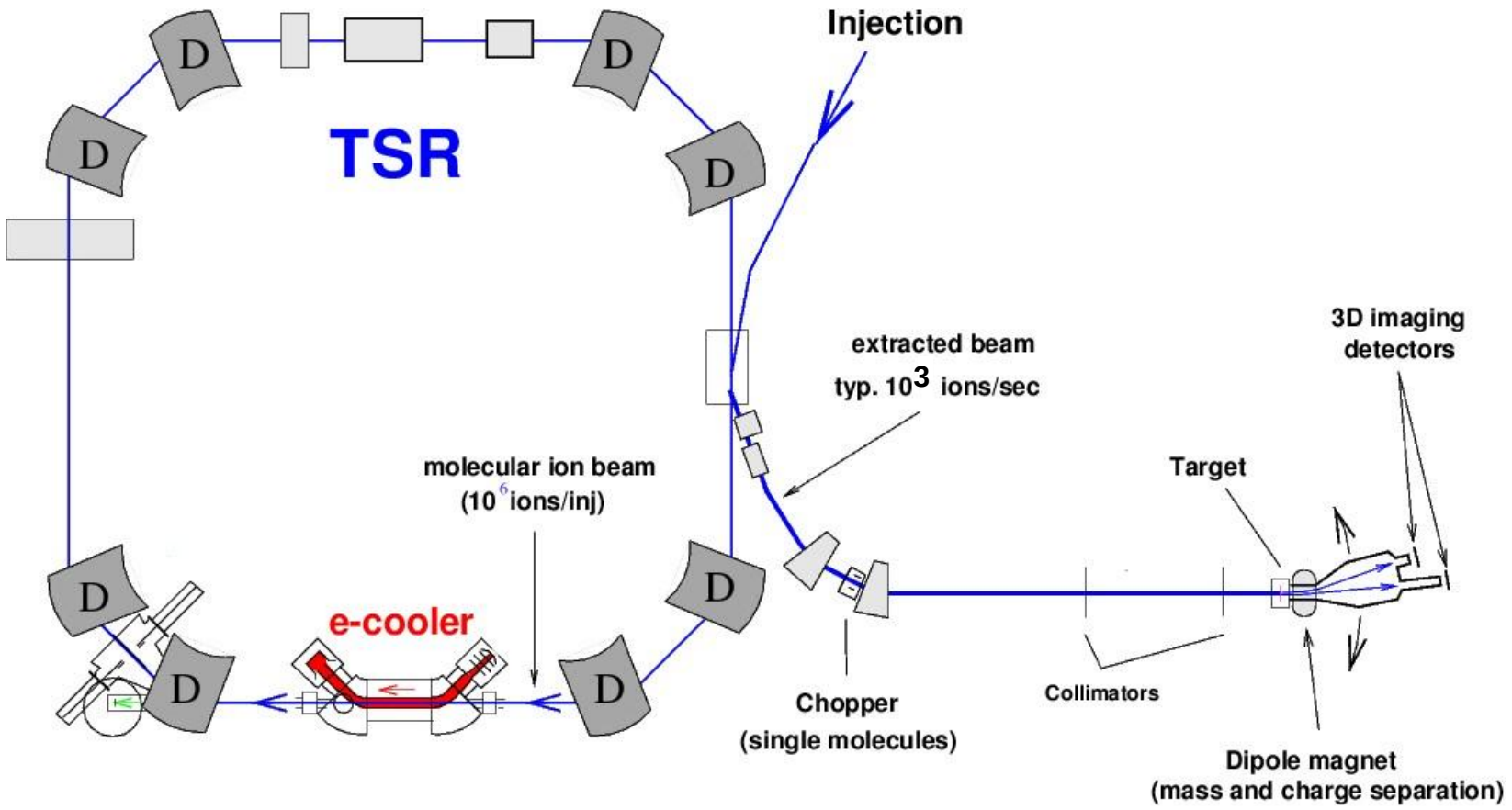


First H_3^+ Storage Ring Experiment

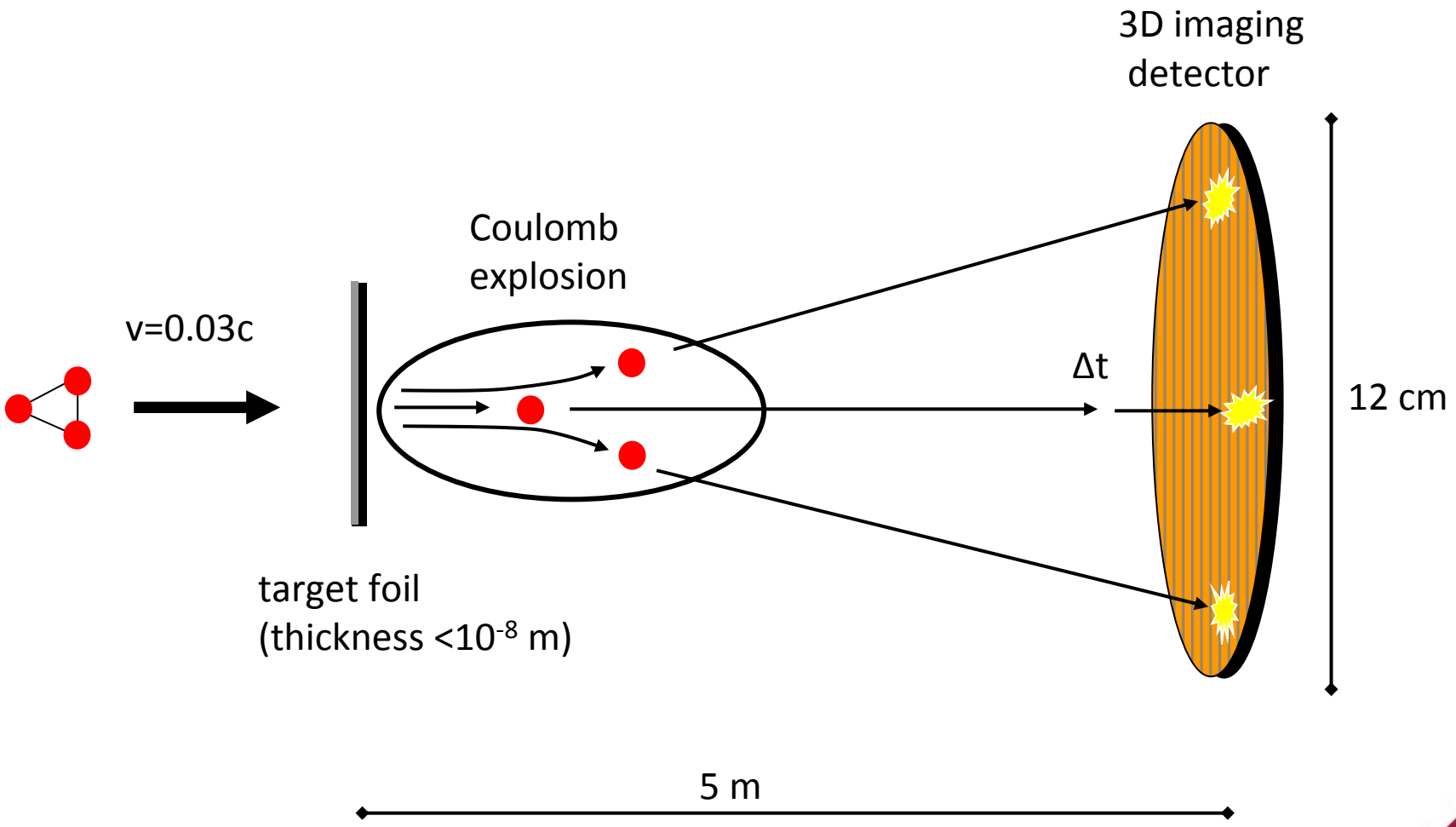


Larsson et al., PRL 70, 430 (1993)

Coulomb Explosion Setup: Slow extraction

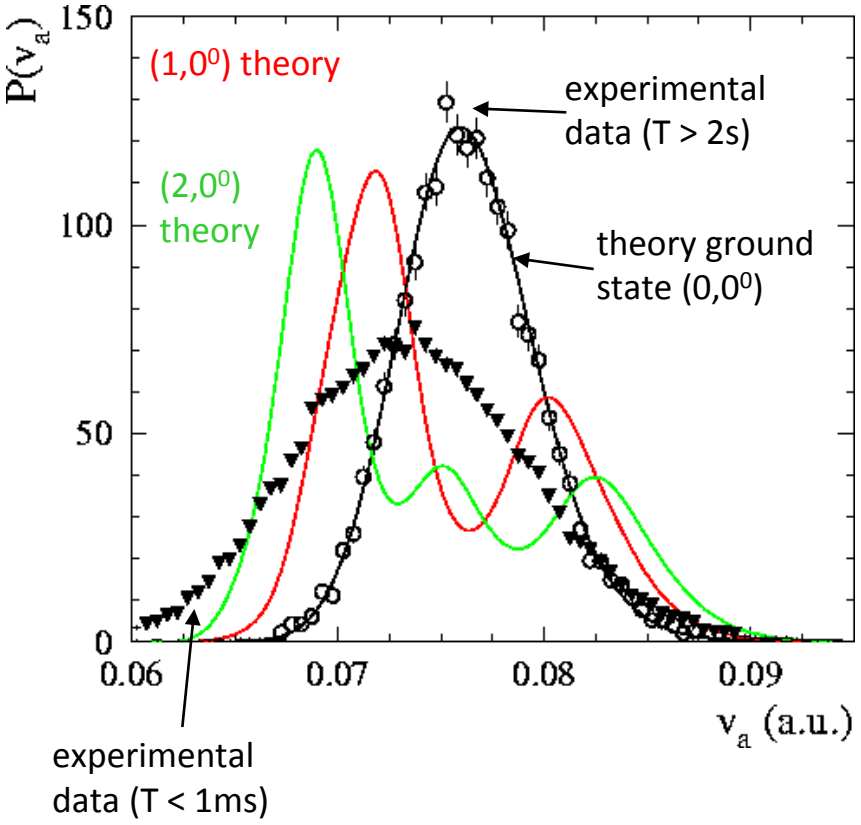


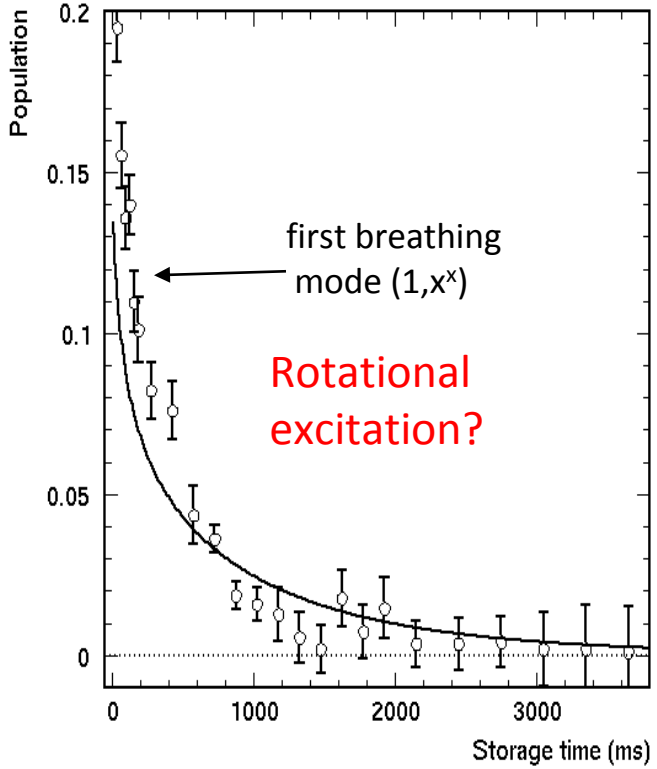
Coulomb Explosion Imaging (CEI)



H_3^+ Vibrational Cooling

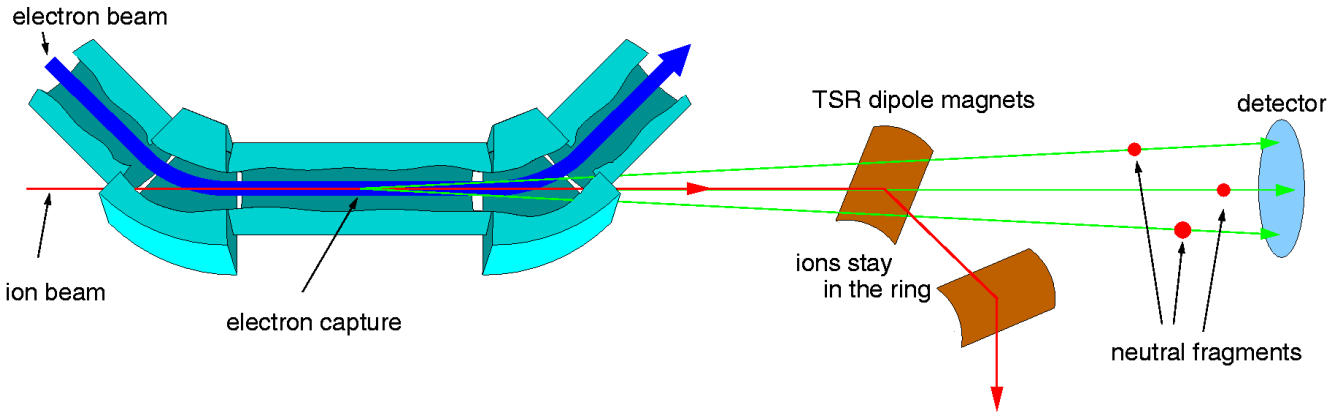
Coulomb Explosion Results



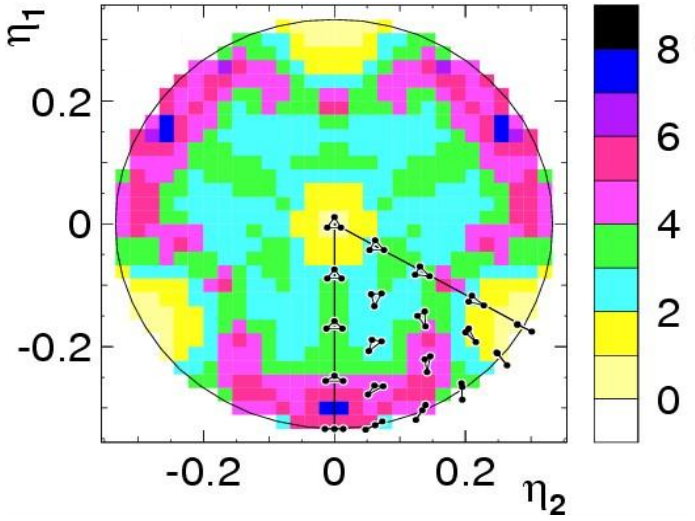


Kreckel et al., PRA 66, 052509 (2002)

DR Fragment Imaging



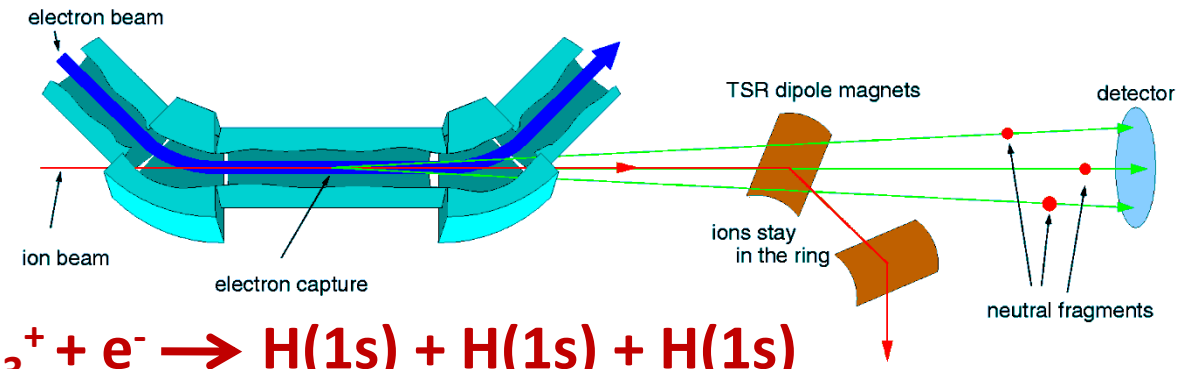
Dissociative Recombination



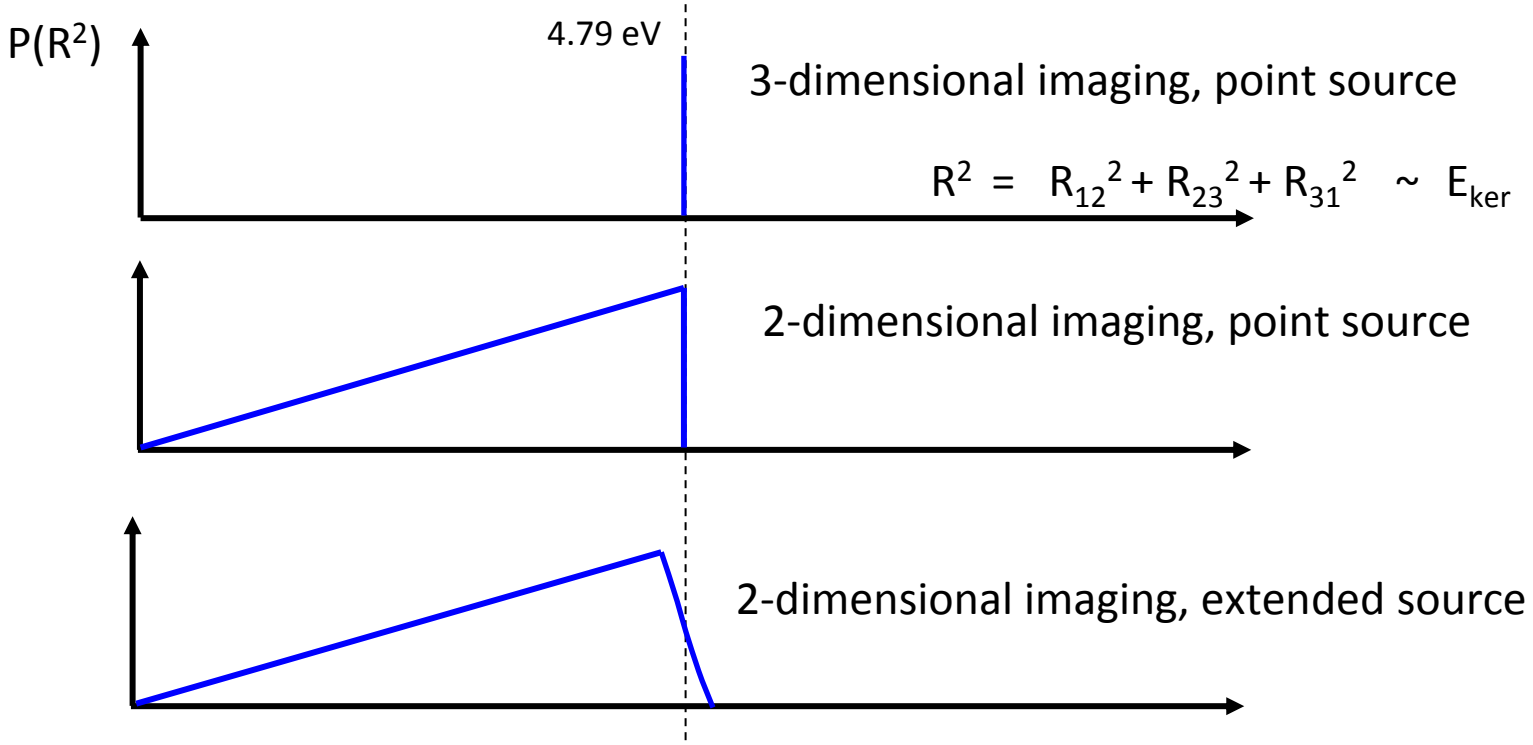
$H_3^+ + e^- \longrightarrow H + H + H$

D. Strasser et al., PRL 86, 779 (2001)

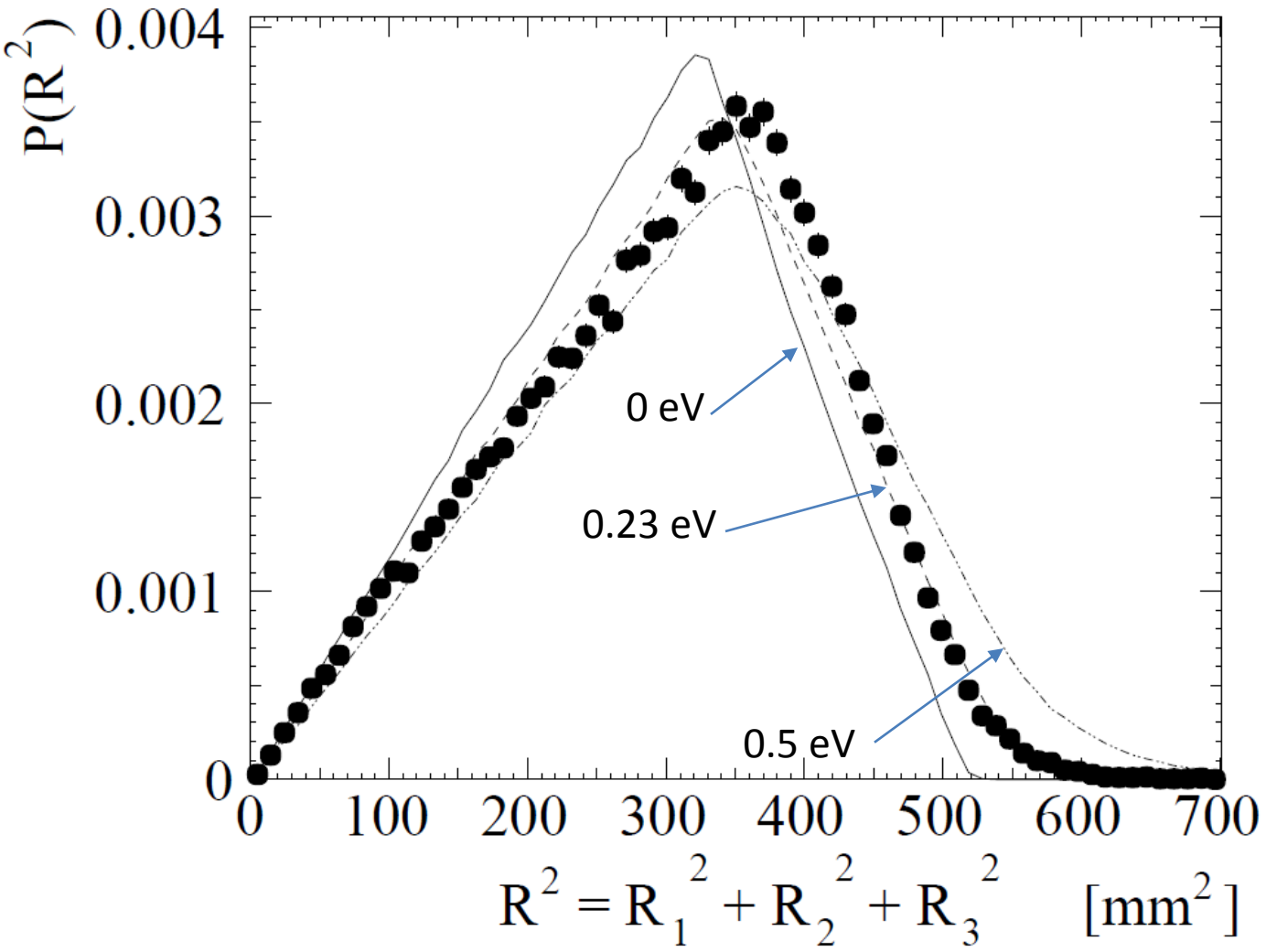
DR Imaging of the Kinetic Energy Release



$H_3^+ + e^- \rightarrow H(1s) + H(1s) + H(1s)$

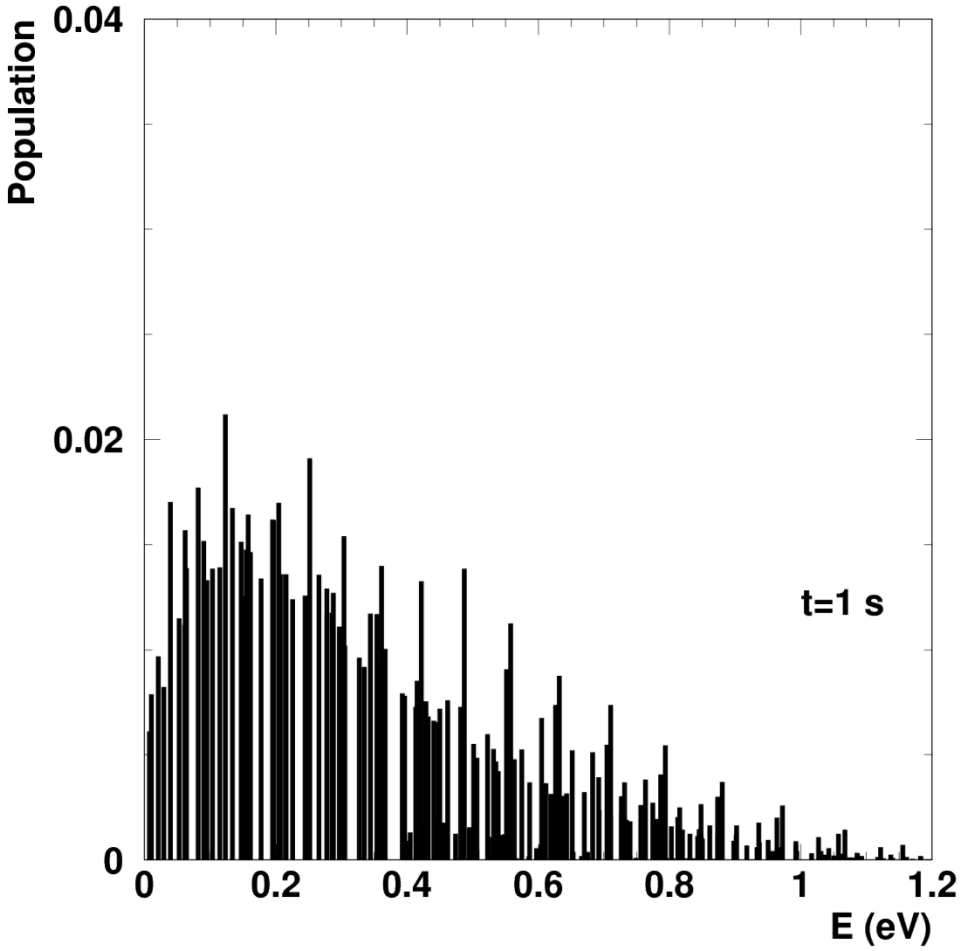


DR Imaging of the three-body breakup



H_3^+ Rovibrational Relaxation Model

$T_{initial}$ = 2700 K



Kreckel et al., New J. Phys. 6, 151 (2004)

H_3^+ Rovibrational Relaxation Model

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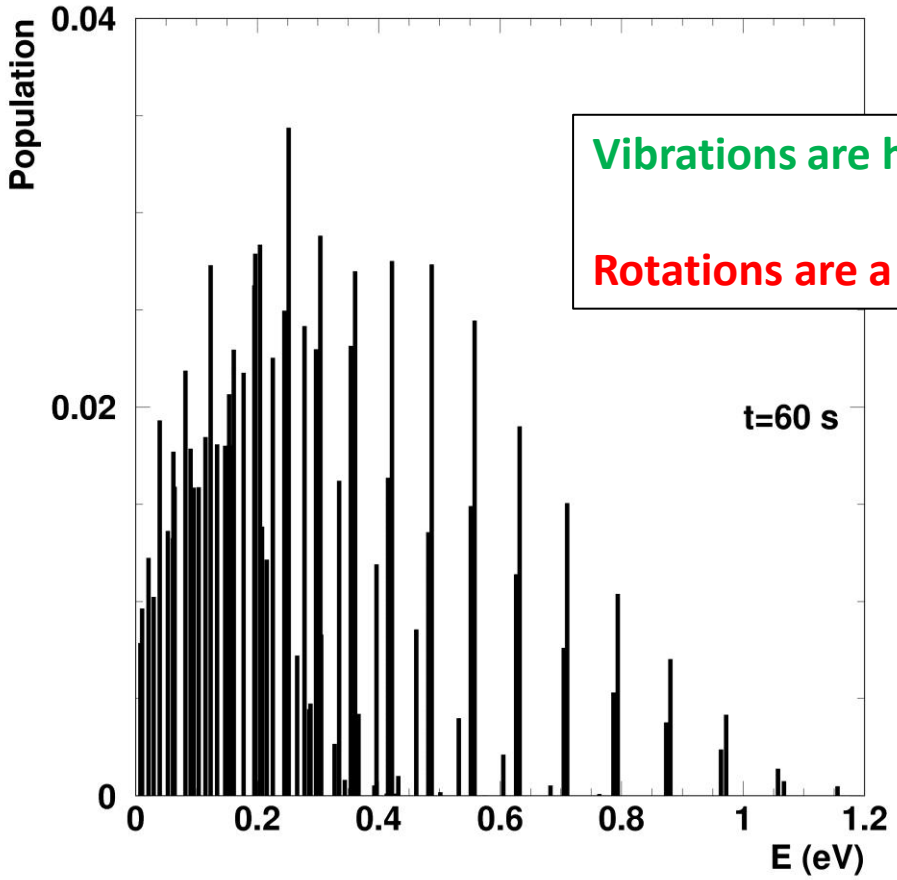
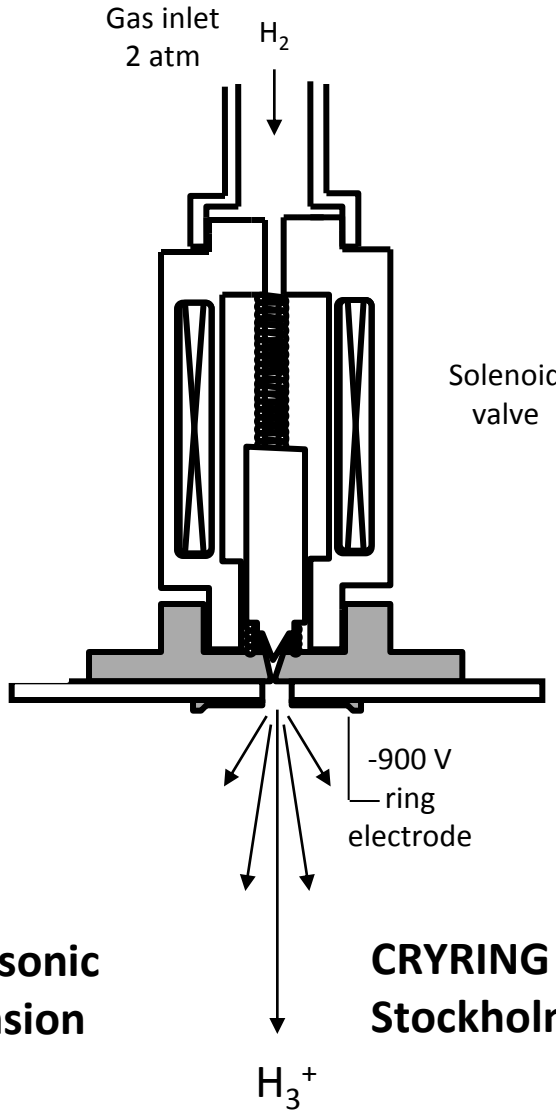


Vibrations are harmless.

Rotations are a problem!

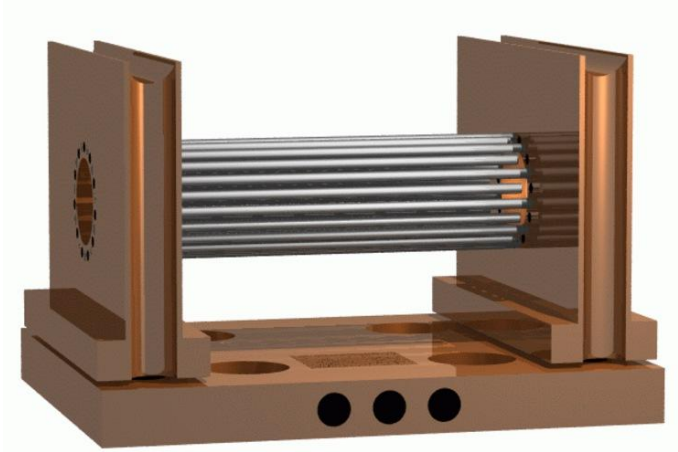
Kreckel et al., New J. Phys. 6, 151 (2004)

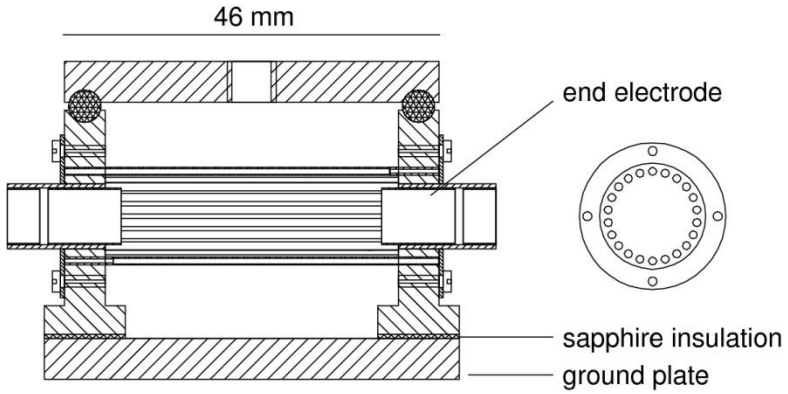
Rotationally “cold” Ion Sources



Supersonic expansion

CRYRING Stockholm



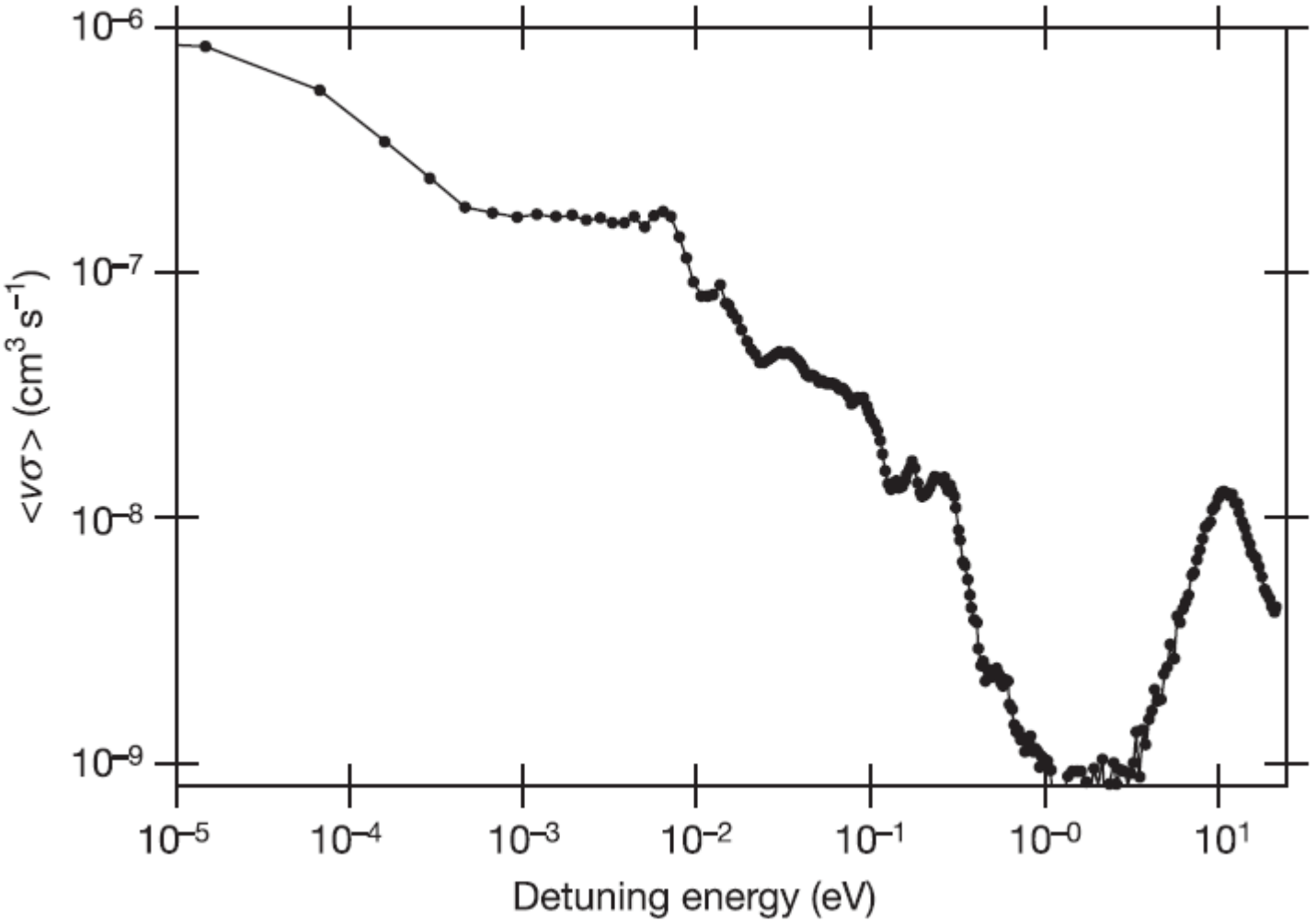


Cryogenic 22-pole ion trap

TSR Heidelberg

Gerlich, Physica Scripta T59, 256 (1995)

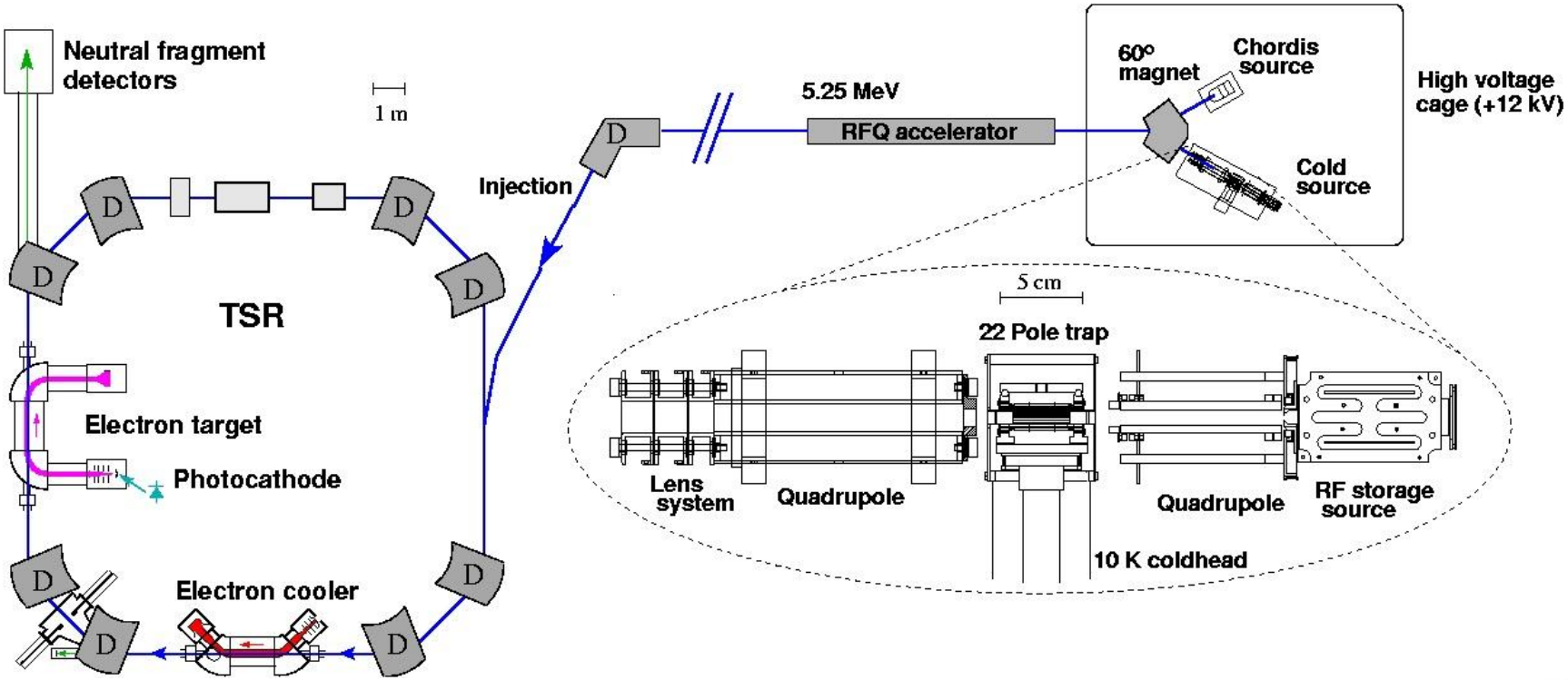
Expansion Source Results / CRYRING 2003



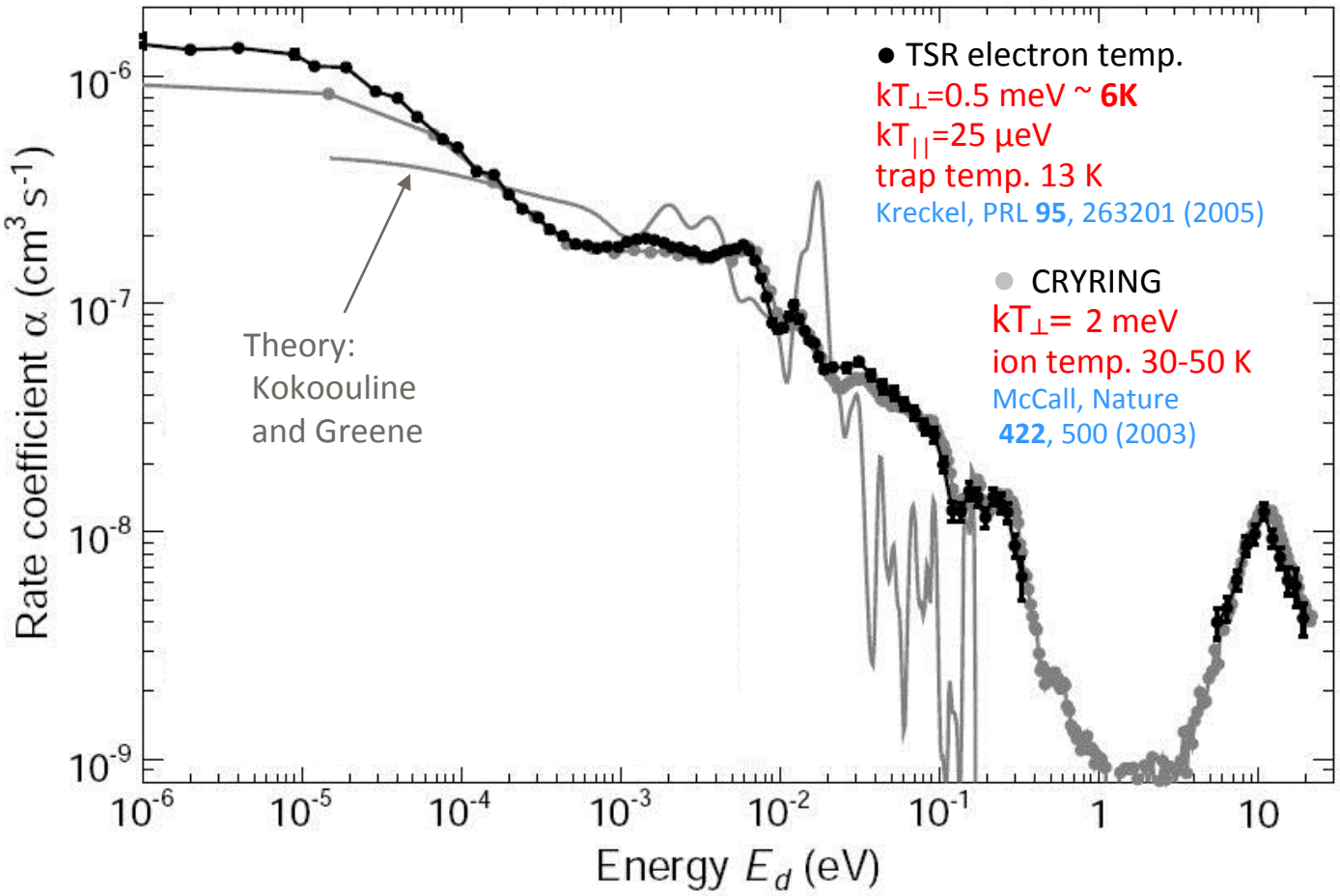
McCall et al., Nature **422**, 500 (2003)

High Resolution DR Measurement at TSR

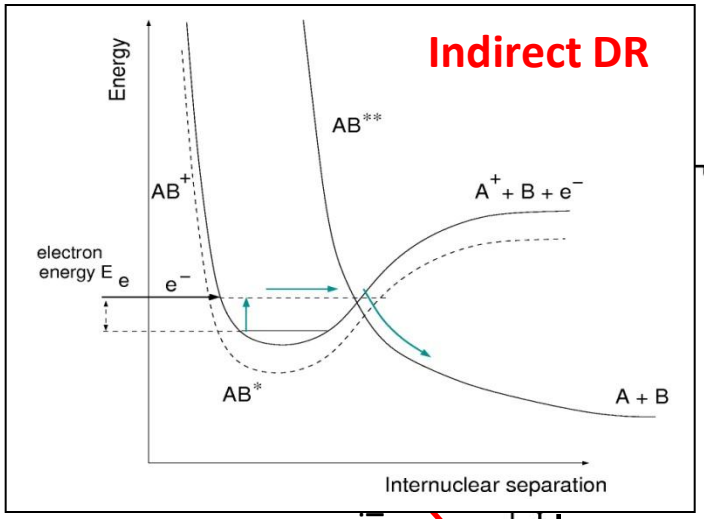
- 2.5 x 10^6 H_3^+ ions inside the ion trap
- up to 40% transmission to the TSR
- helium buffer gas inside the trap (6 x 10^{14} cm^{-3})
- trap storage times ranging from 1-130 ms

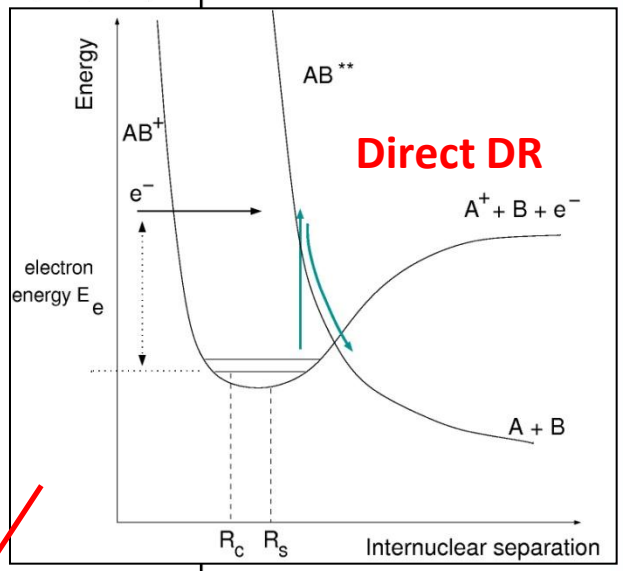


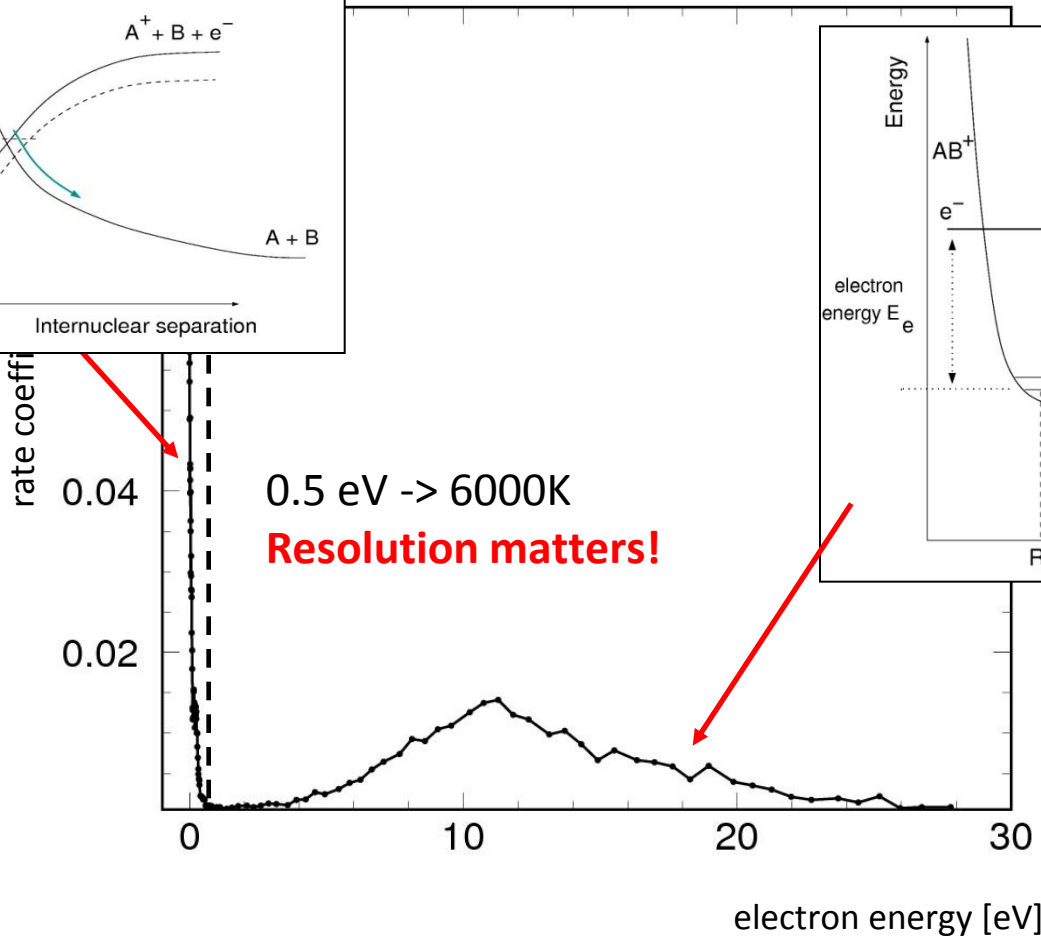
H_3^+ DR Spectrum High Resolution



What do we really see?





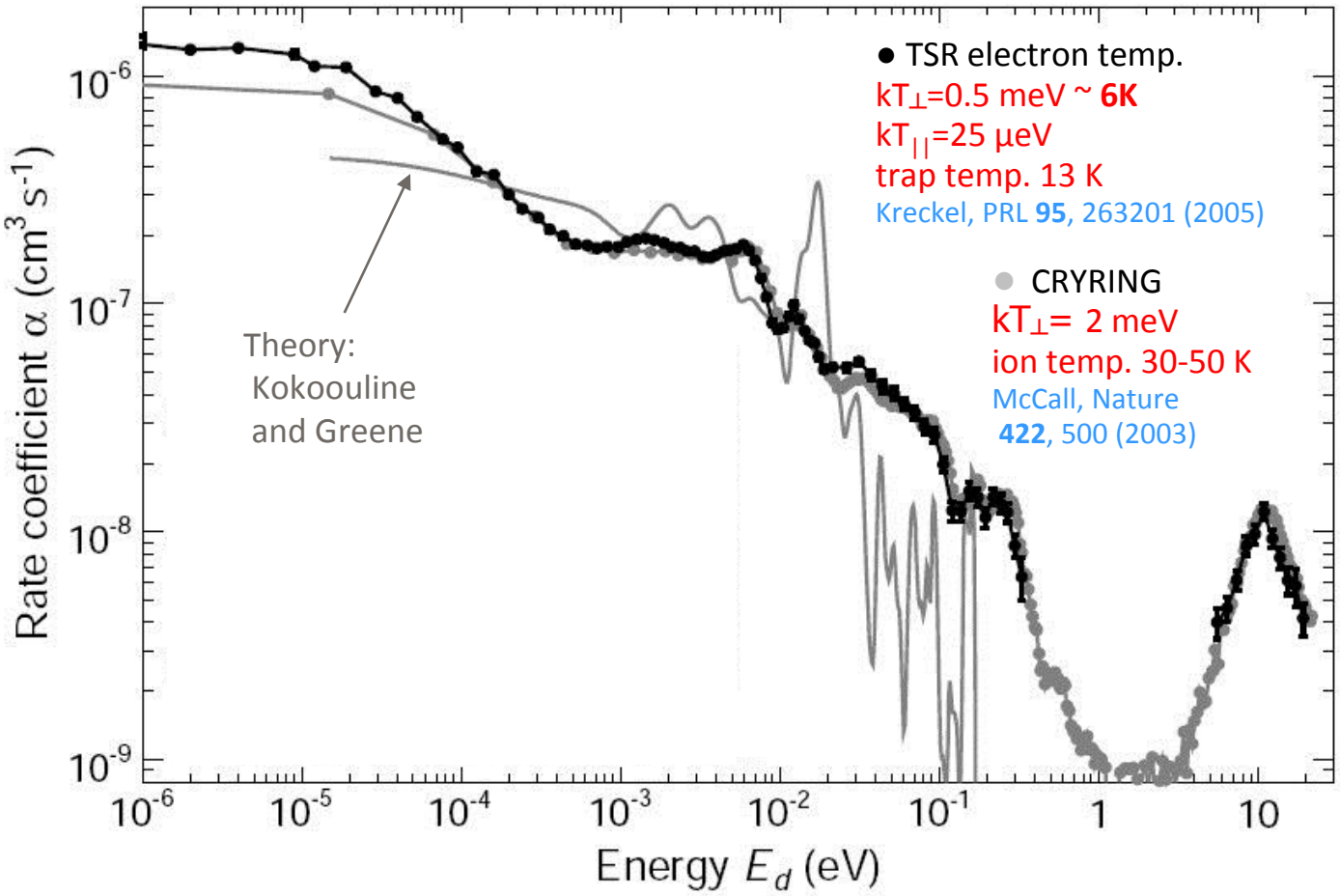


0.5 eV -> 6000K

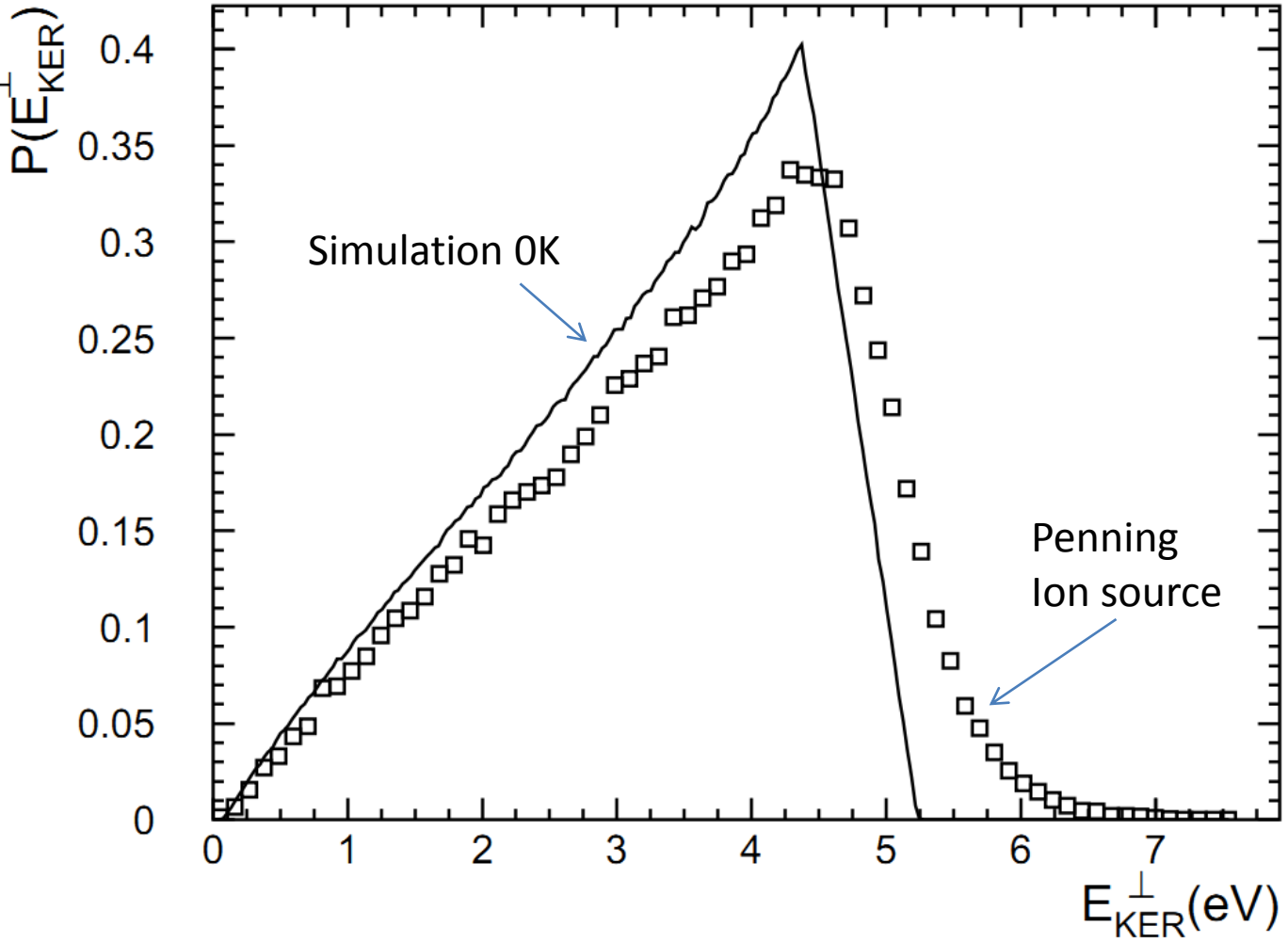
Resolution matters!

QUANTUM DYNAMICS

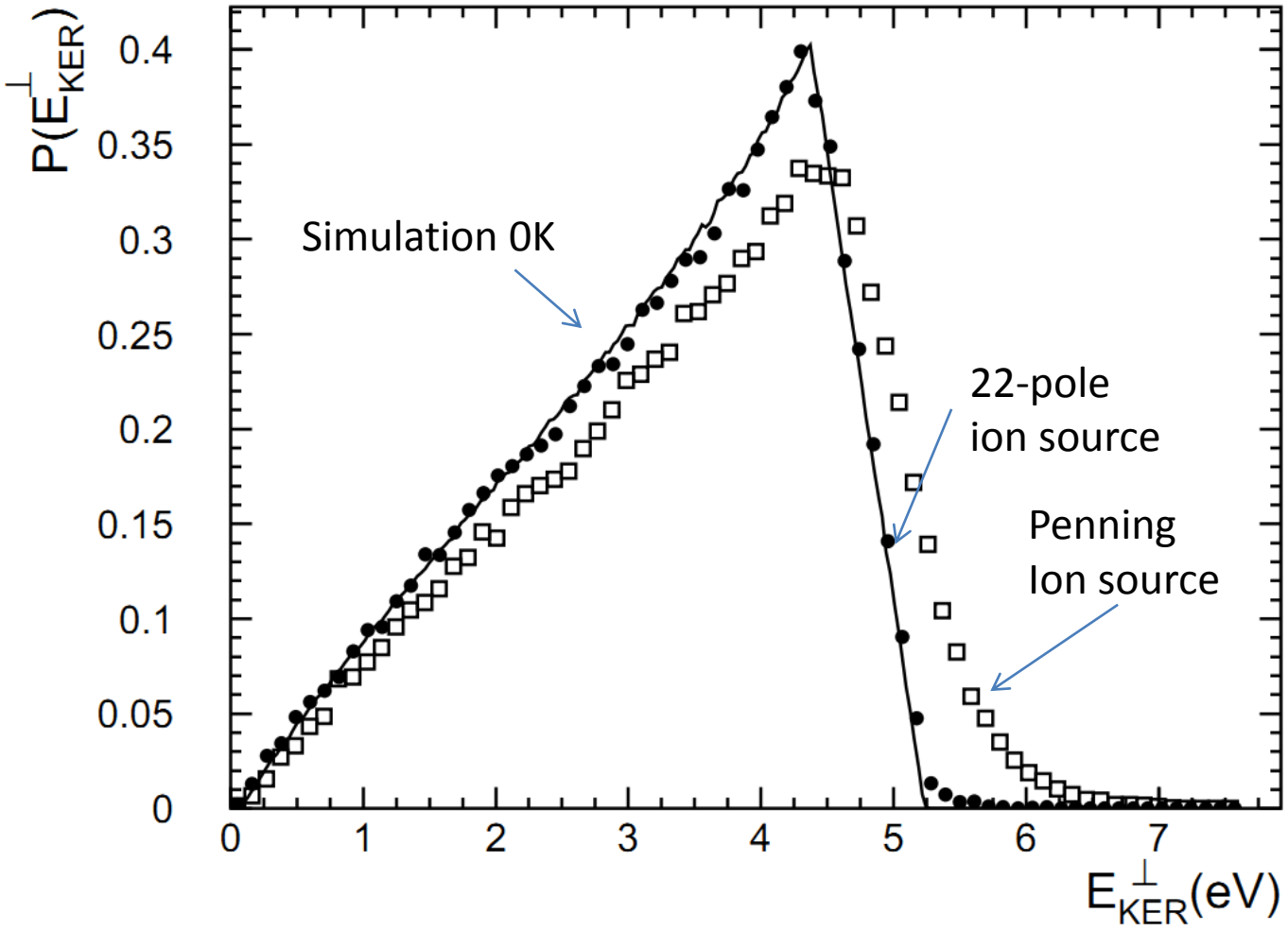
H_3^+ DR Spectrum High Resolution



DR Imaging Results

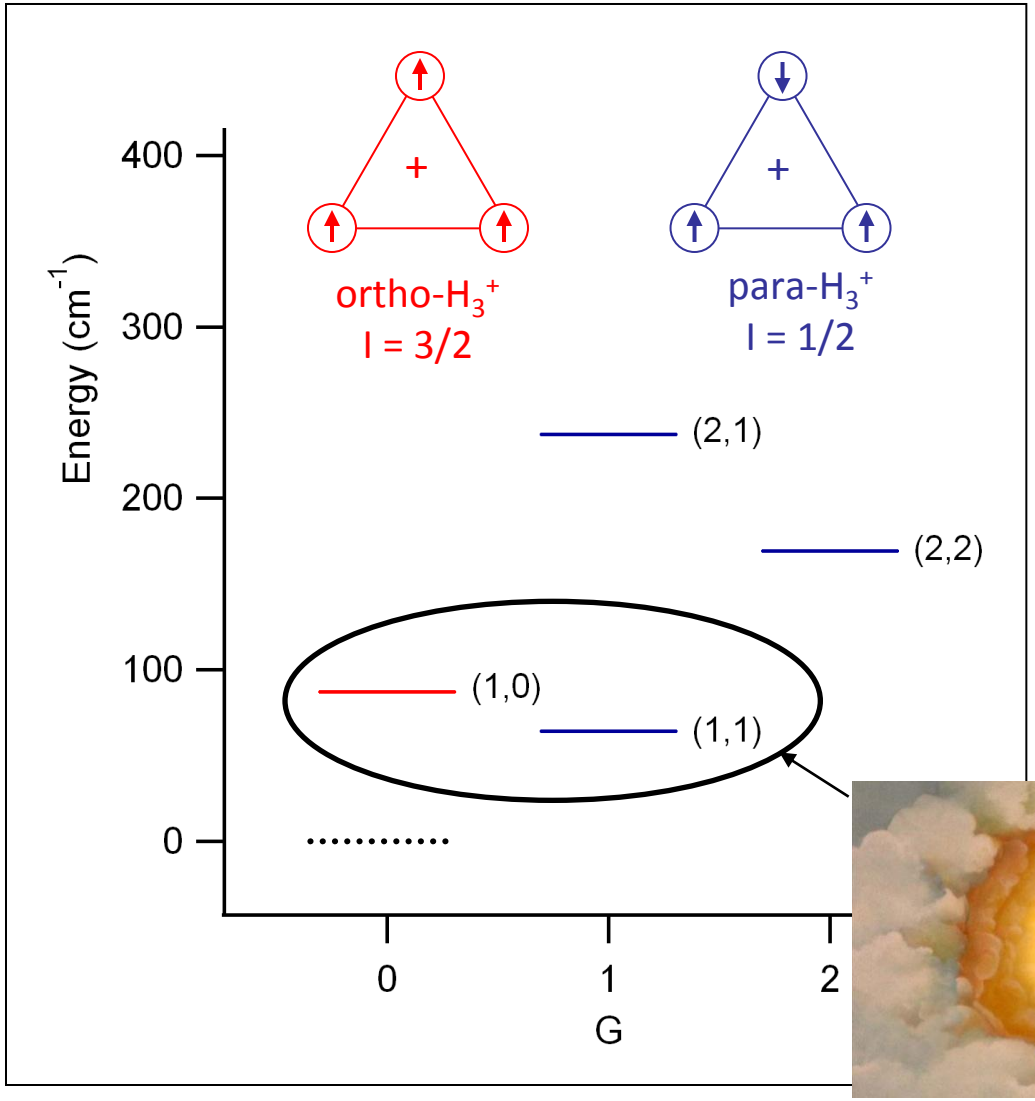


DR Imaging Results



The Holy Grail: State-Specific Measurements

H_3^+ rotational levels



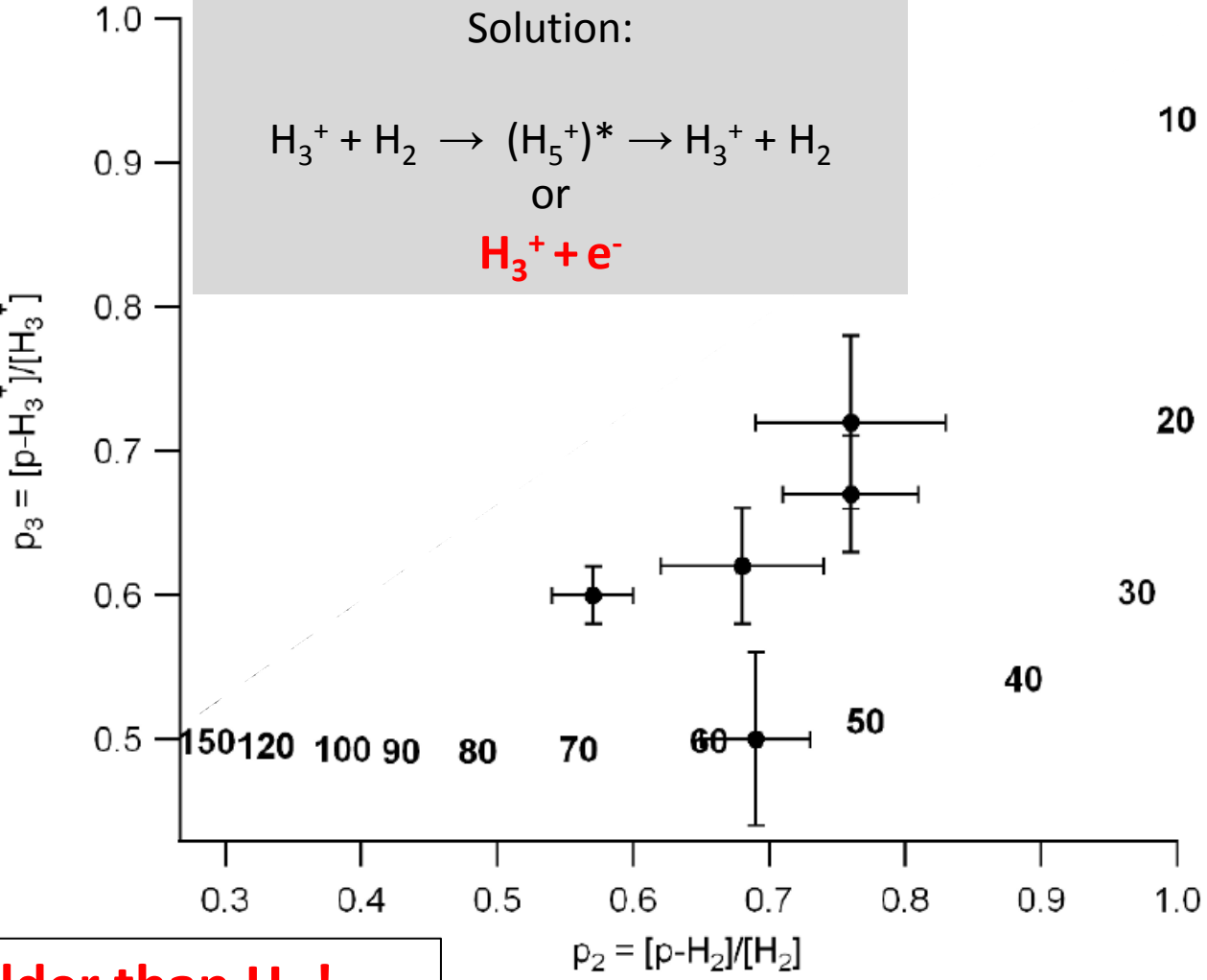
The Case to Continue the Quest

Solution:

$H_3^+ + H_2 \rightarrow (H_5^+)^* \rightarrow H_3^+ + H_2$

or

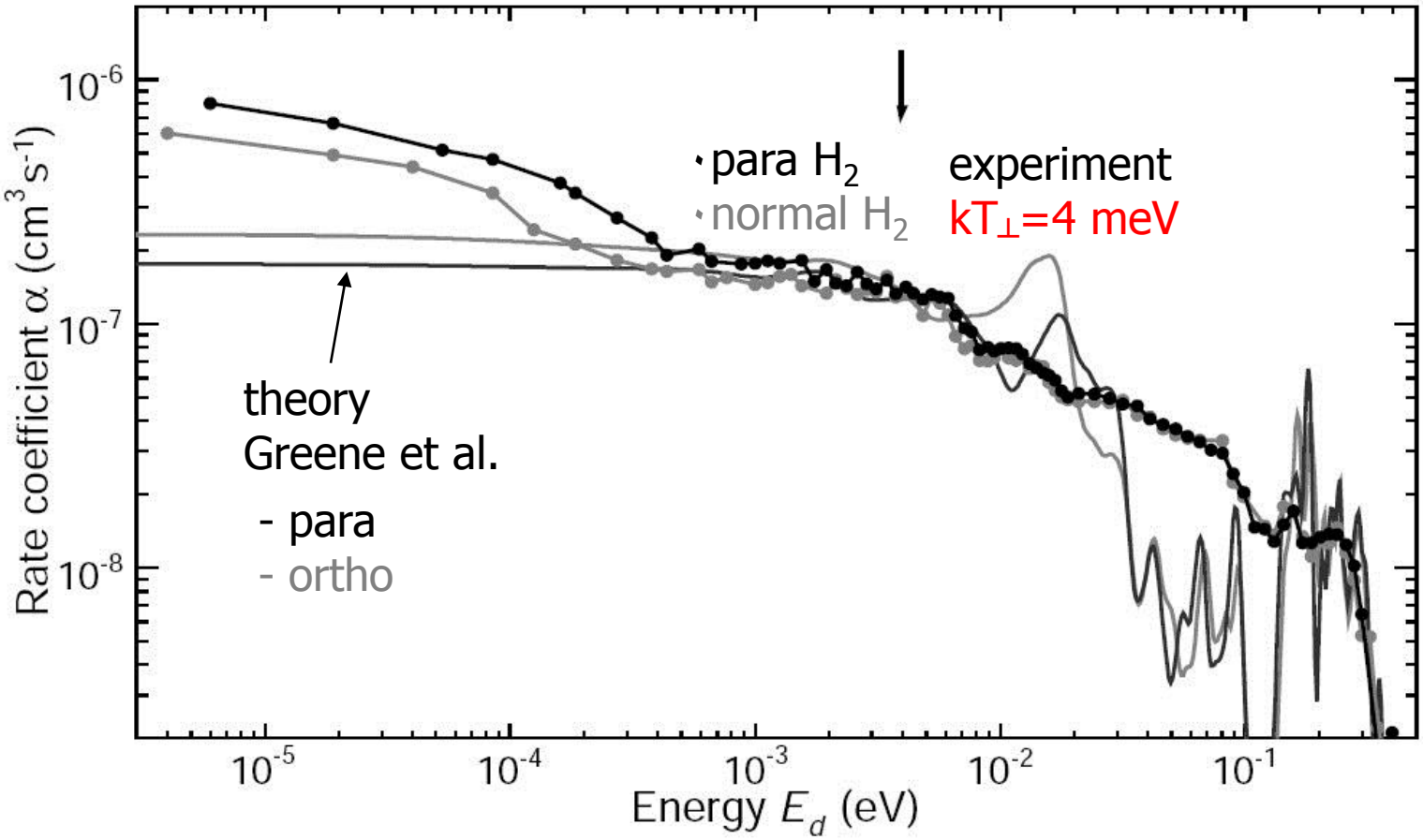
$H_3^+ + e^-$



H_3^+ colder than H_2 !
Too much para-H_3^+

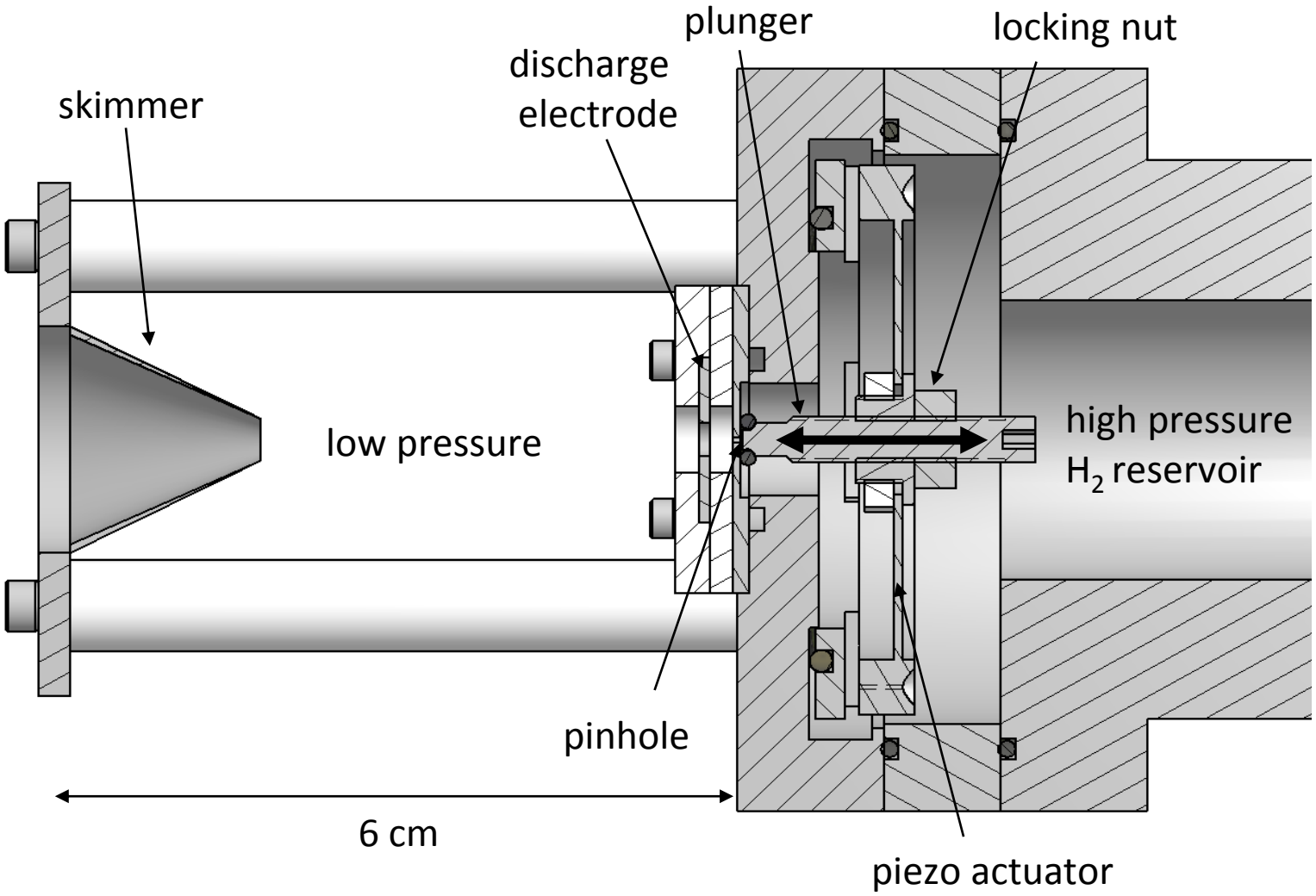
Crabtree et al., ApJ 729, 15(2011)

Nuclear Spin Effect: Exp. and Theory 2005

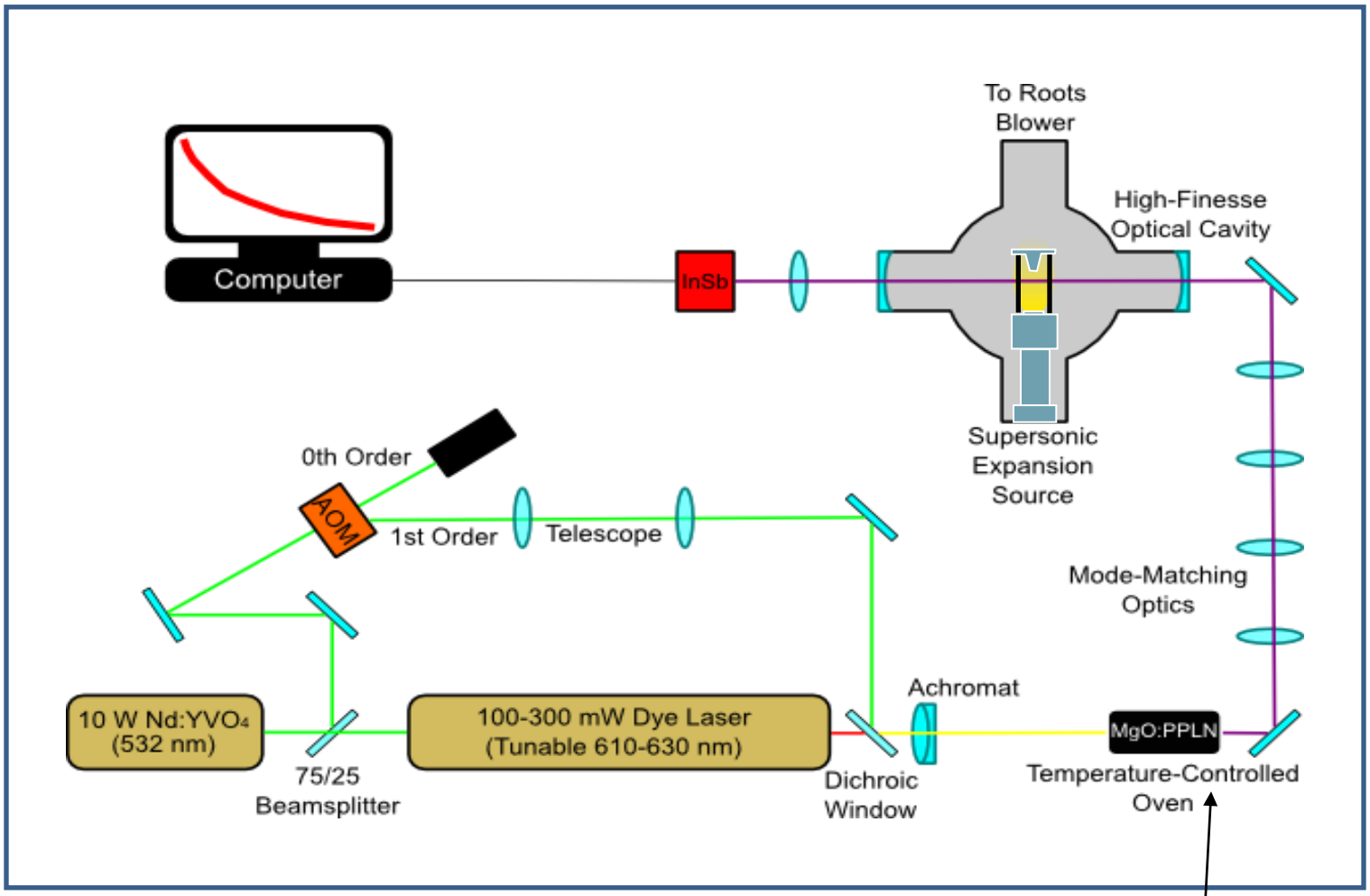


Kreckel et. al, PRL 95, 263201 (2005)

Piezo Expansion Source



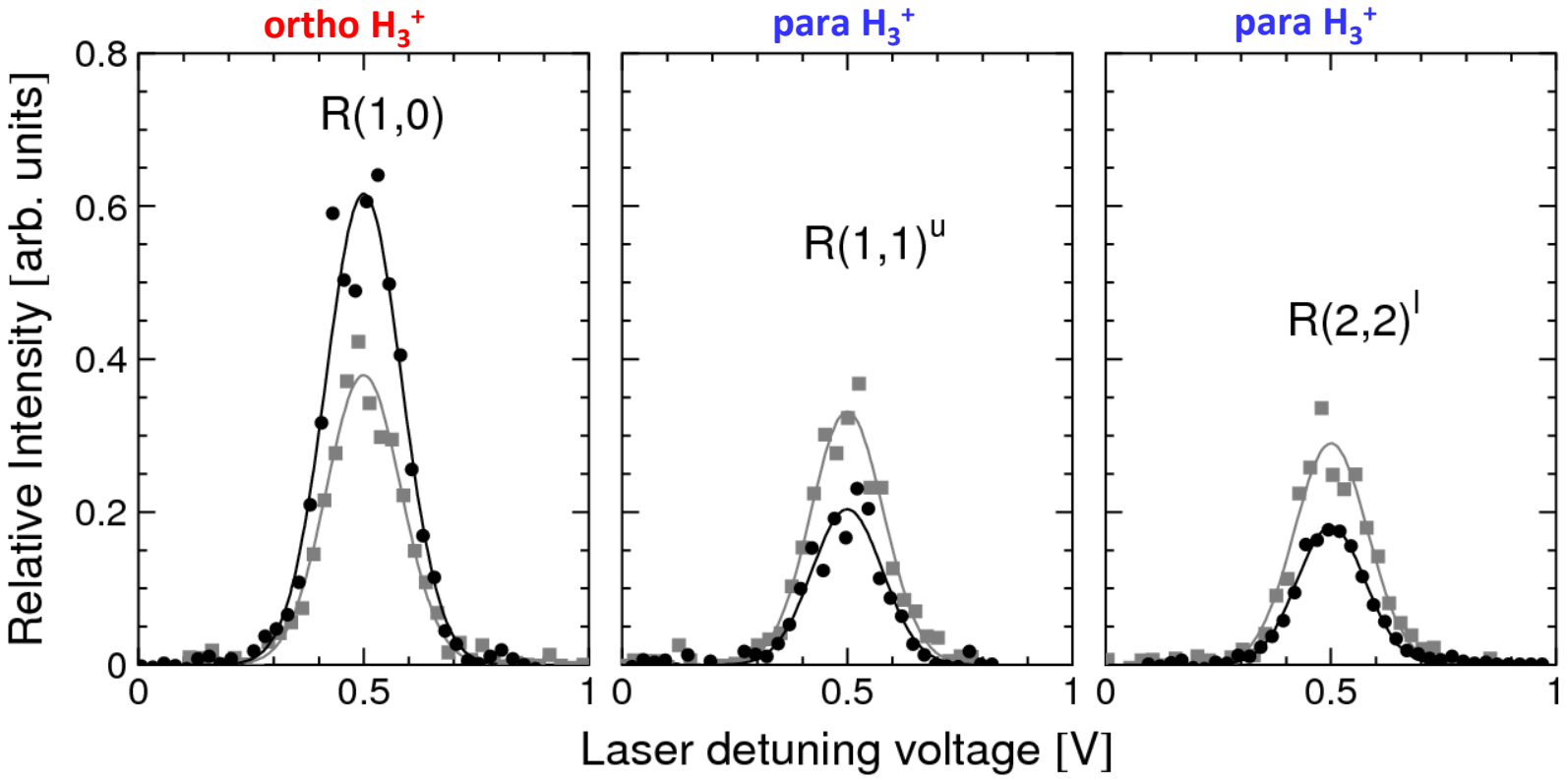
Cavity Ring Down Measurements at UIUC



Difference frequency generation: 3.67 µm

Nuclear Spin Manipulation

Rotational temperature ~ 180K



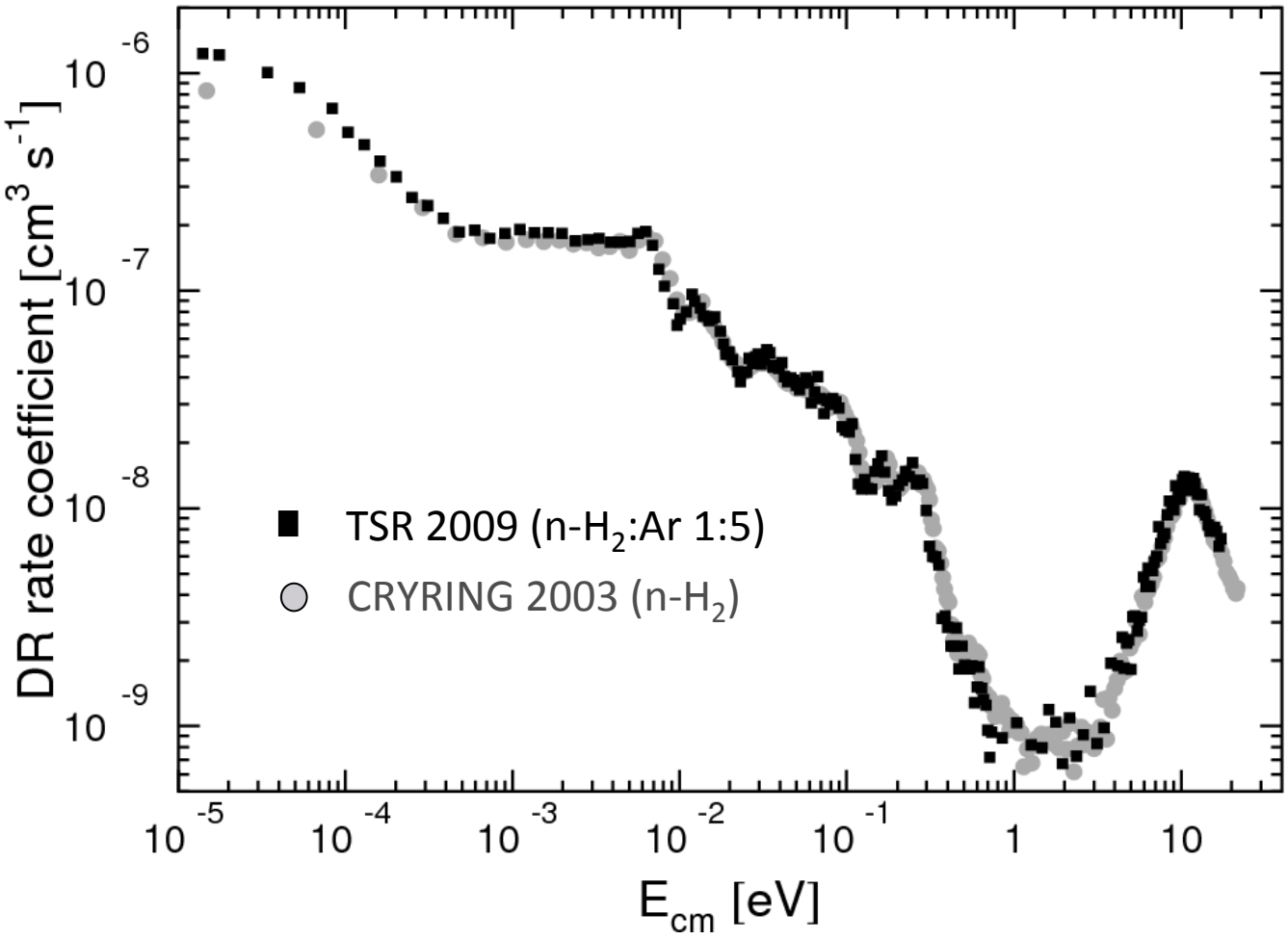
- 1:5 n-H_2 : Argon mixture
- 1:5 p-H_2 : Argon mixture

p-H_3^+ fraction p_3= (47.9 ± 2) %

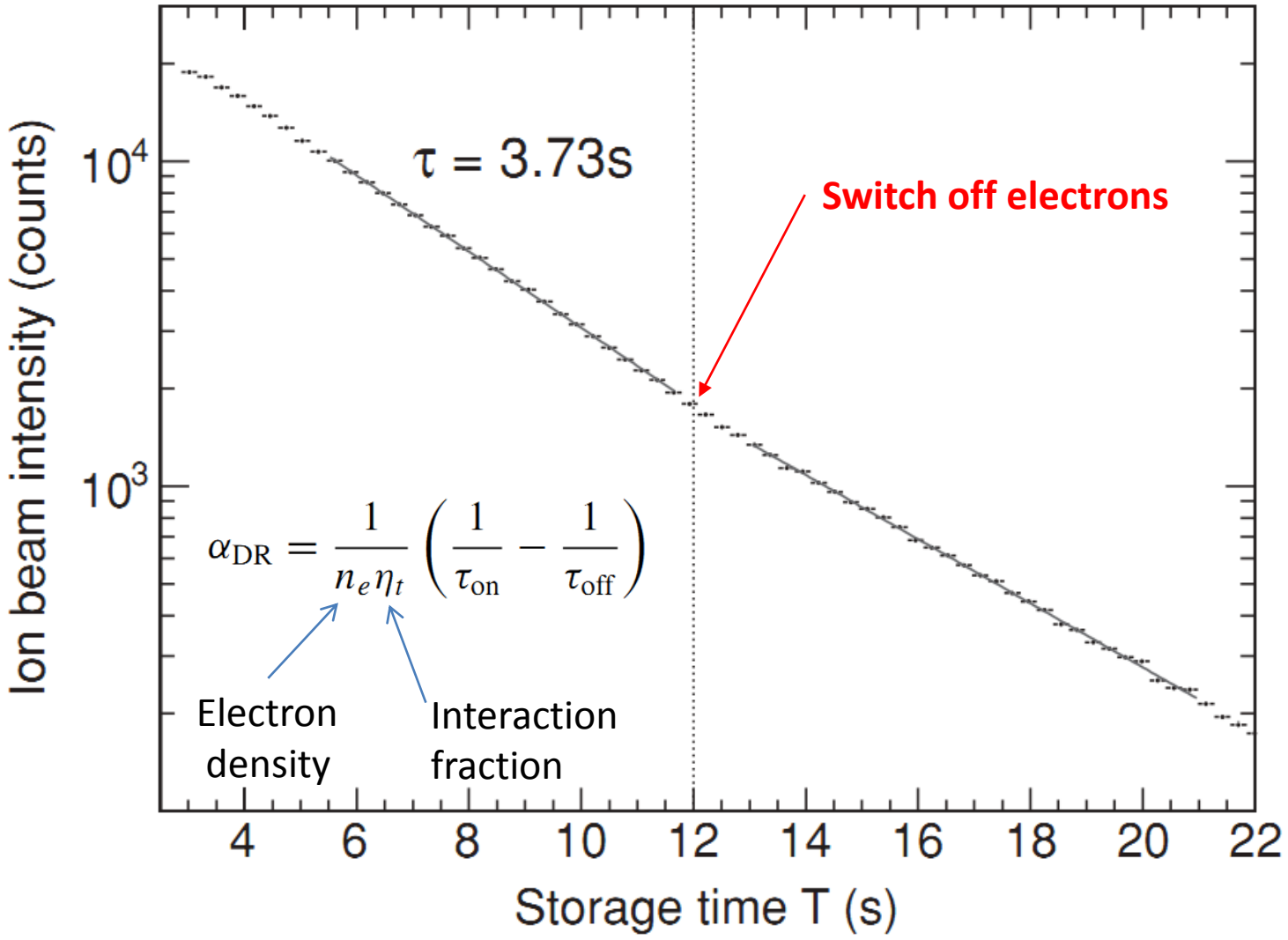
p-H_3^+ fraction p_3= (70.8 ± 2) %

QUANTUM DYNAMICS

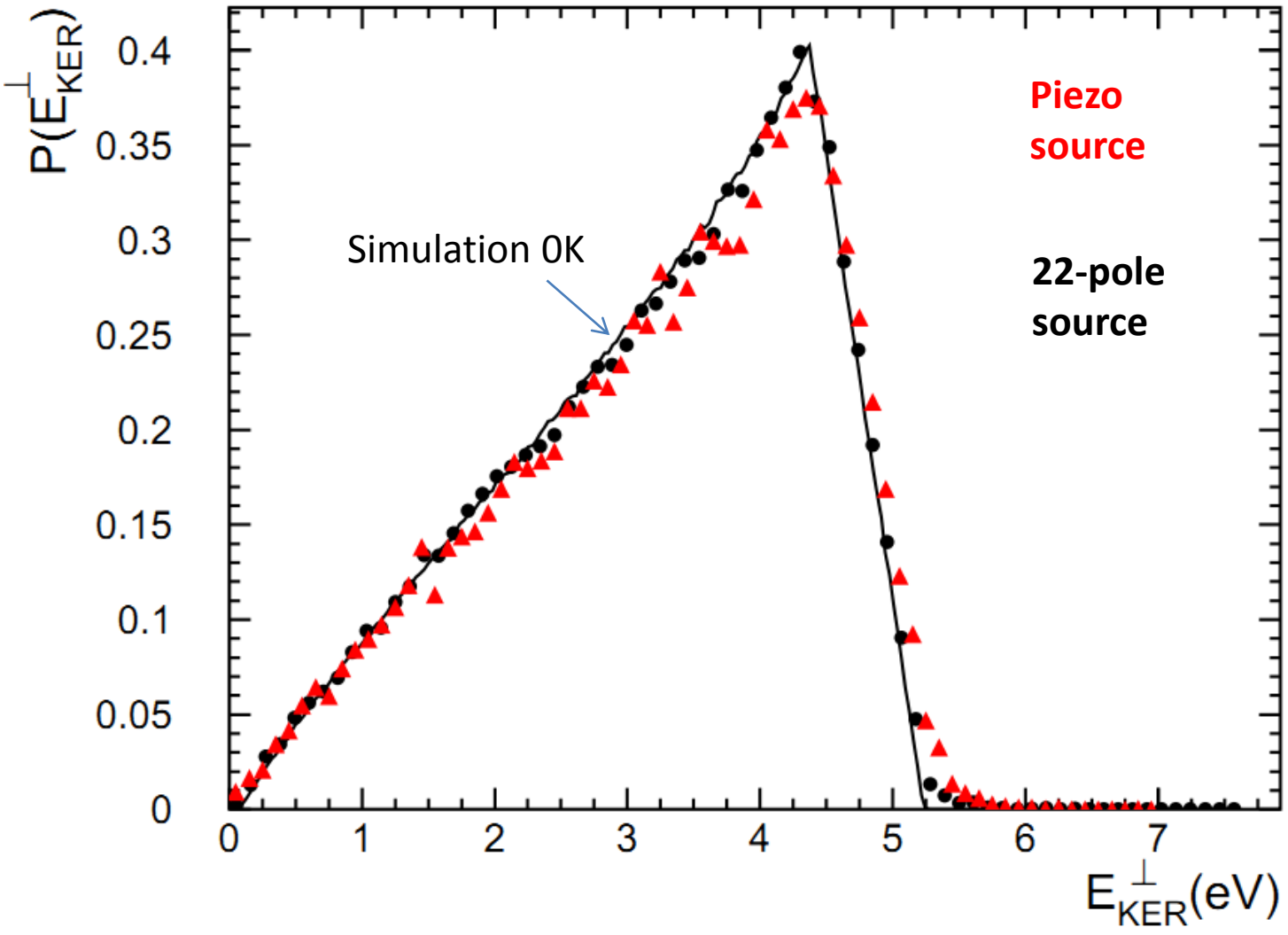
Comparison to CRYRING 2003



Absolute Calibration through Lifetime Measurements



DR Imaging Results



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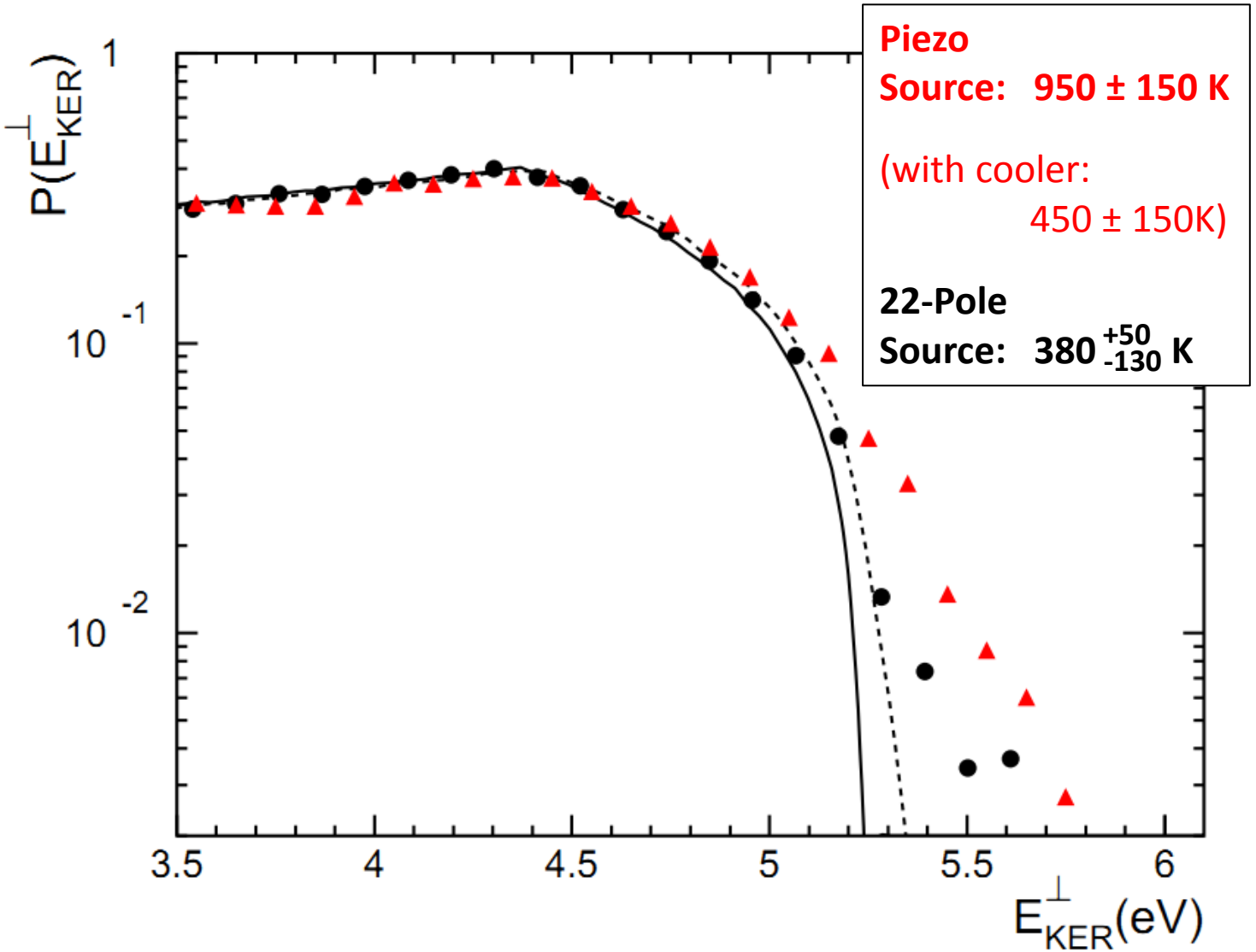
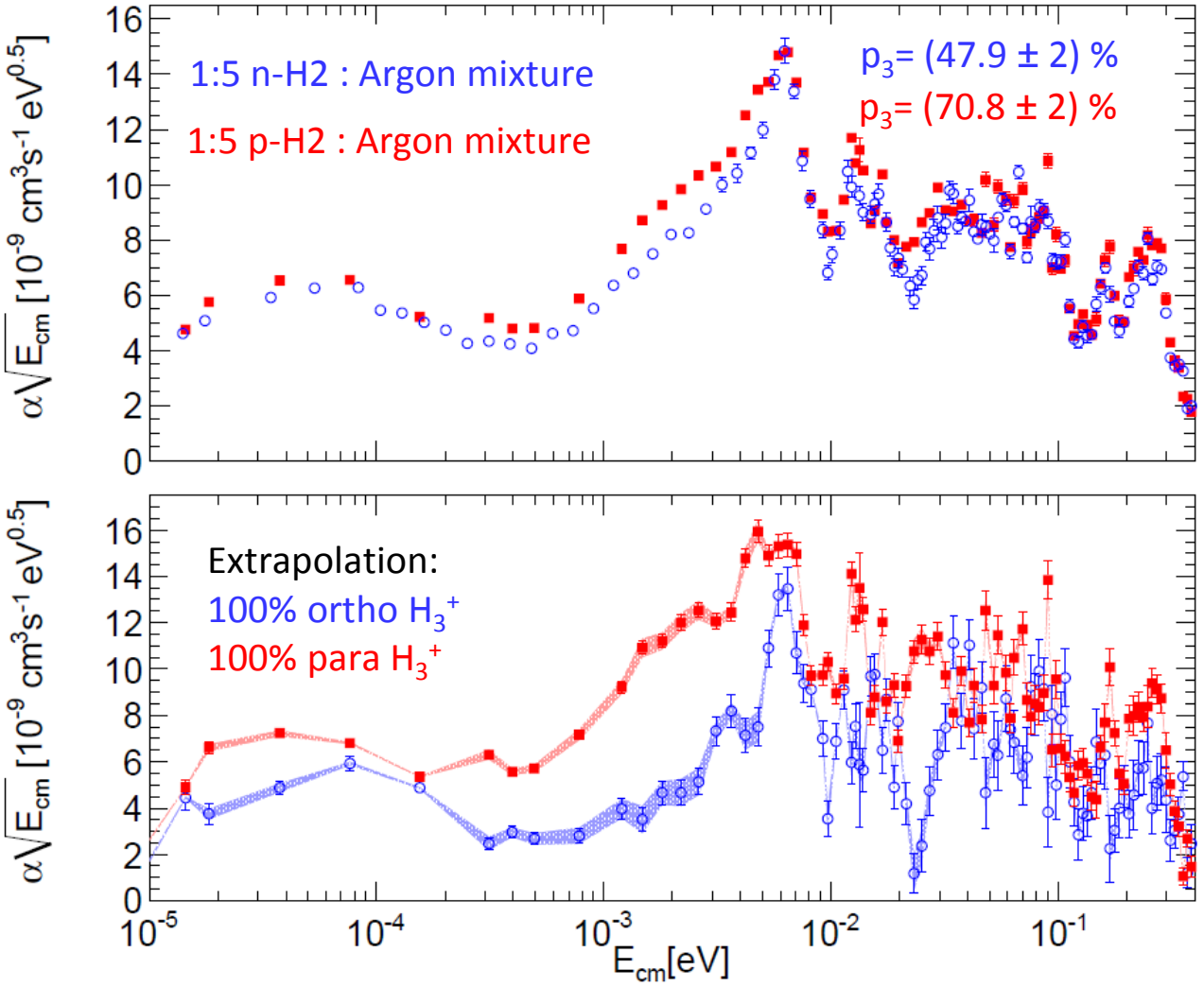
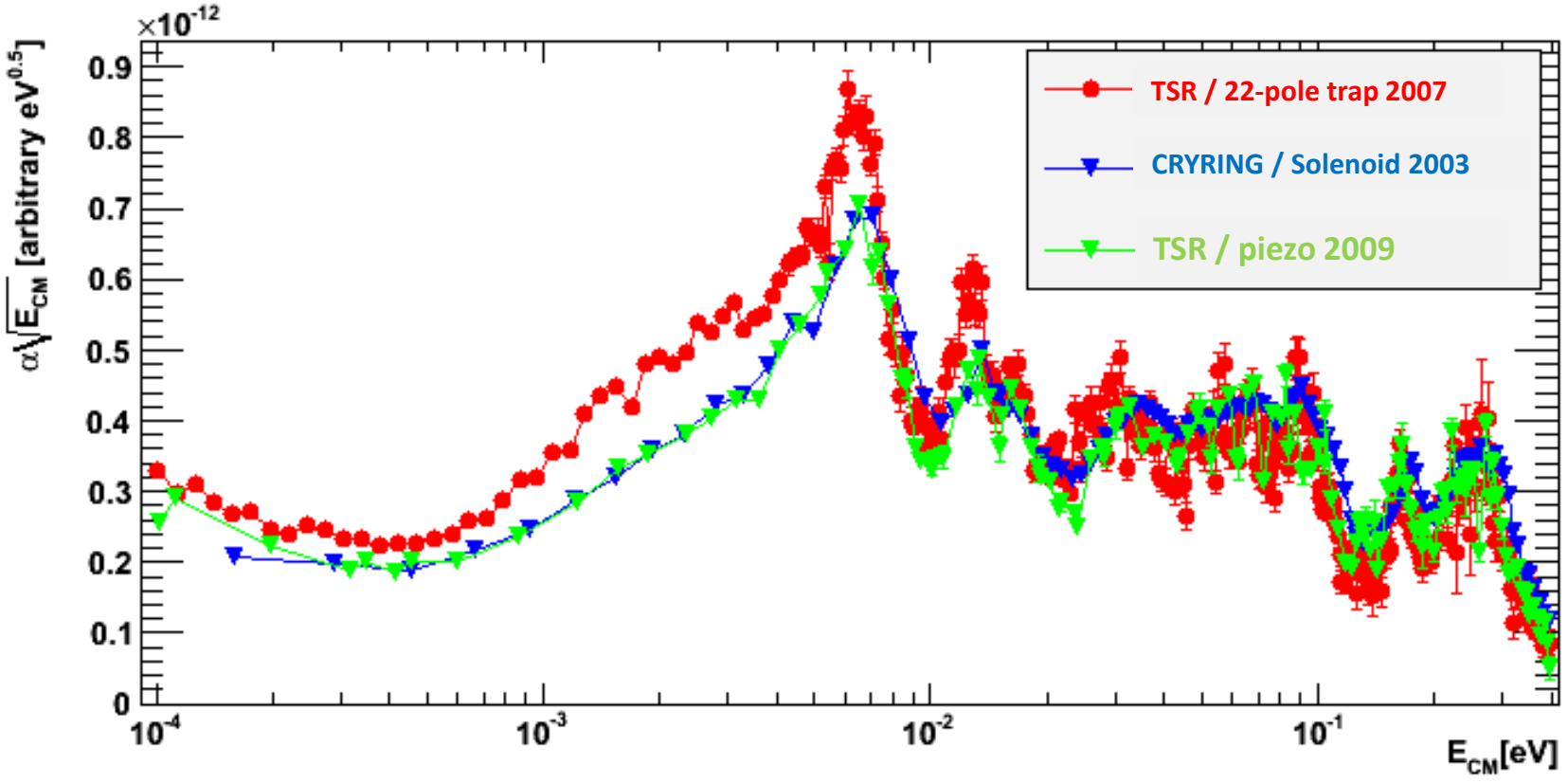


Nuclear Spin Dependence: H_3^+ DR

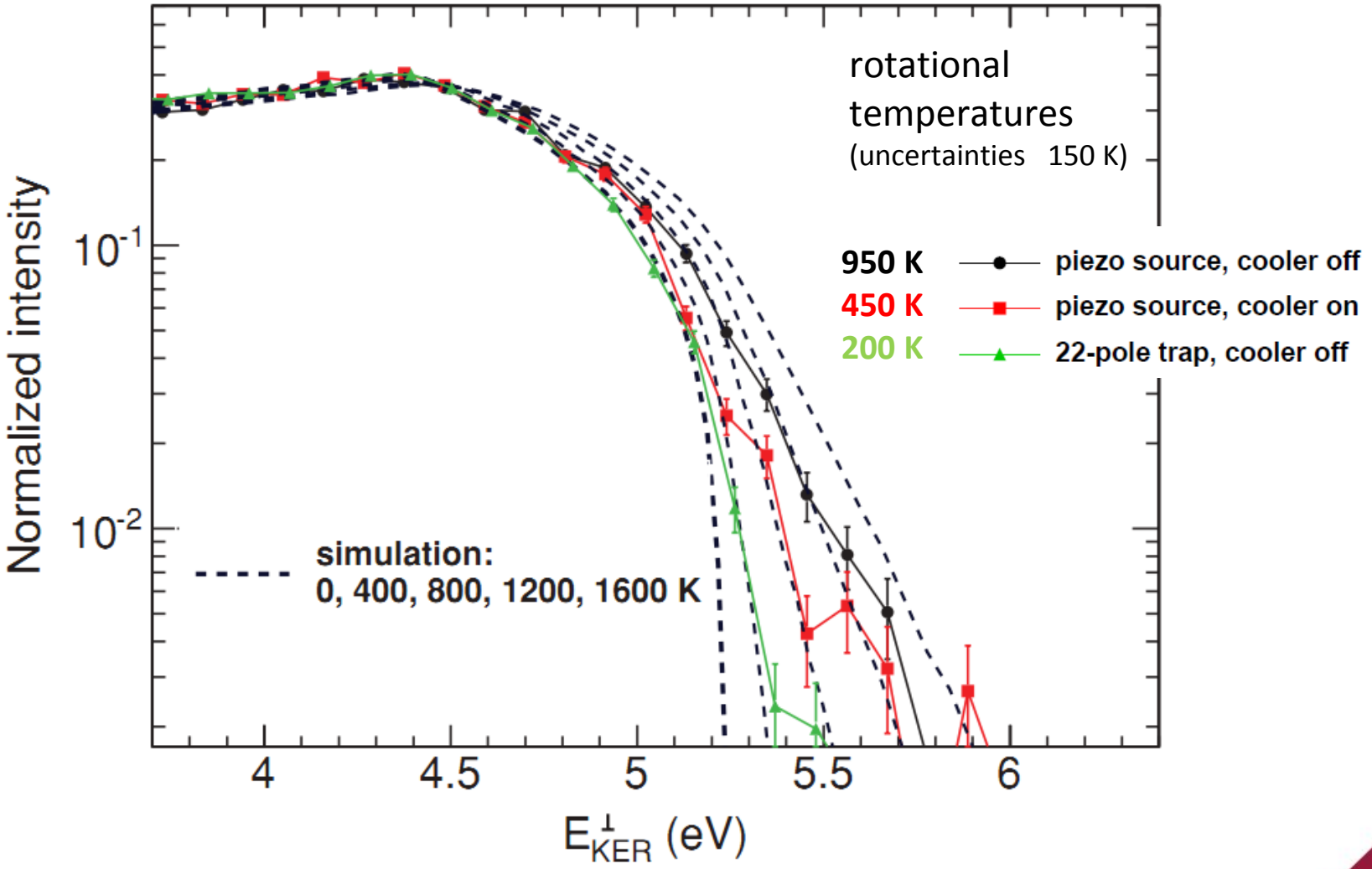


Kreckel et al., PRA 82, 042715 (2010)

Detailed rate coefficient comparison



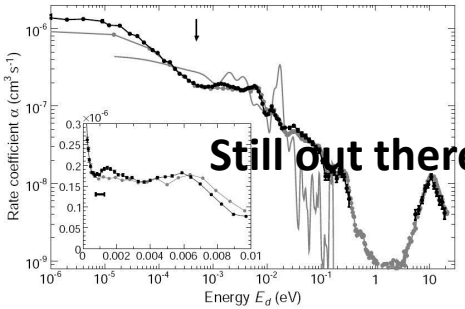
DR Imaging Results



Kreckel et al., PRA 82, 042715 (2010)

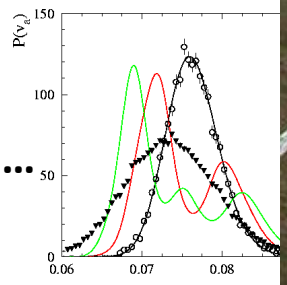
Summary

- H_3^+ recombines efficiently with electrons
- good agreement between storage rings
- good agreement between storage rings and theory concerning the absolute scale
- vibrations cool fast, rotations don't
- coldest measurement on record: 380K
- para-H_3^+ recombines faster than ortho-H_3^+ at low energies

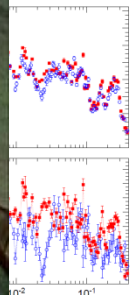


Rate coefficient

Still out there …



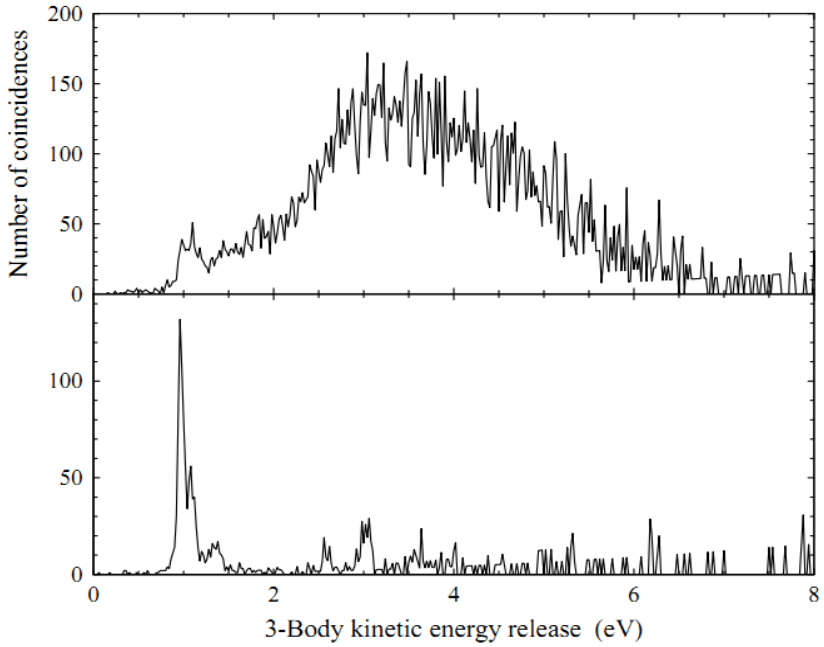
Coulomb Explo

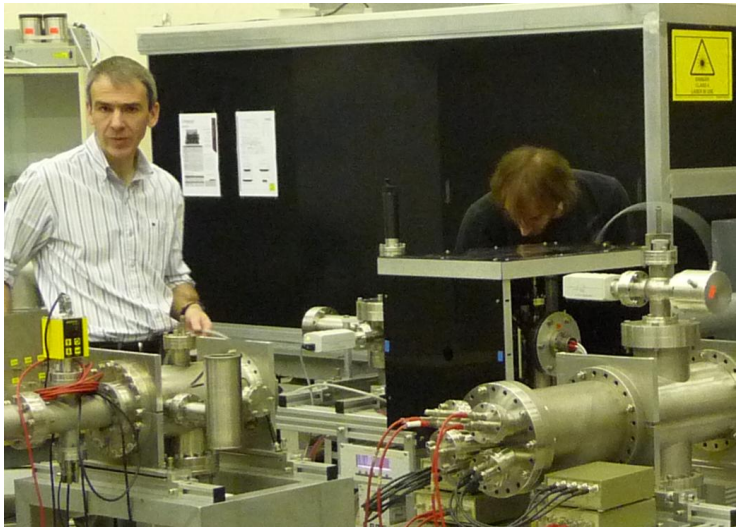


pin

Perspectives

Supersonic expansion

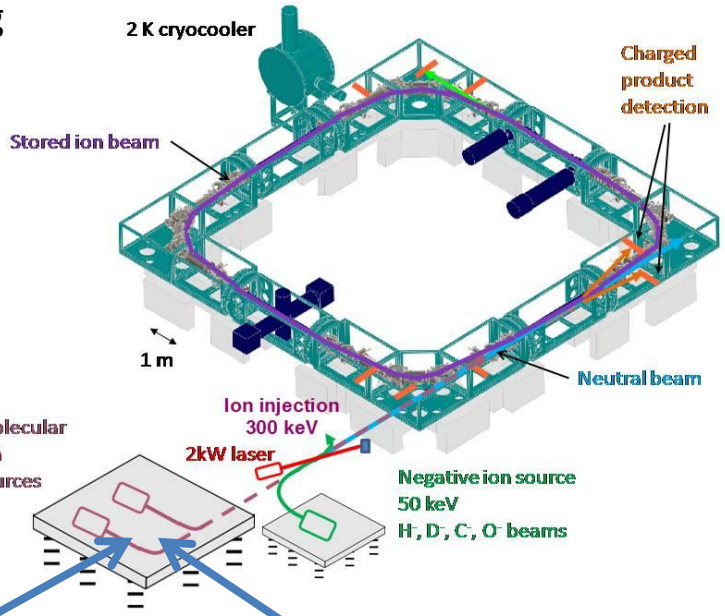


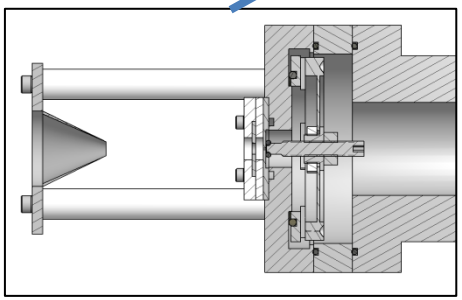


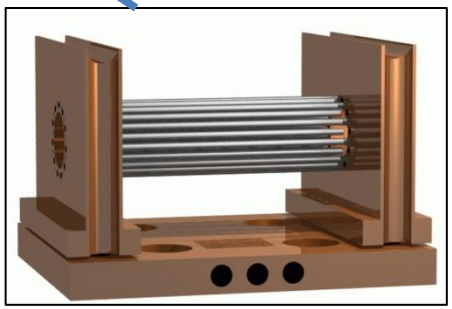
Xavier Urbain / UC Louvain la Neuve

Perspectives

Cryogenic **S**torage **R**ing
@ MPIK







$$H_3^+ + e \longrightarrow \begin{matrix} H + H + H \\ H_2 + H \end{matrix}$$

$$H_3^+ + C \longrightarrow CH^+ + H_2$$

$$H_3^+ + O \longrightarrow OH^+ + H_2$$

Collaboration / TSR DR Experiments

TSR Group

Oldřich Novotny
Annemieke Petrignani
Max H. Berg
Dennis Bing
Manfred Grieser
Claude Krantz
Michael Lestinsky
Mario B. Mendes
Christian Nordhorn
Roland Repnow
Julia Stützel
Andreas Wolf

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University of Illinois

Kyle N. Crabtree
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Benjamin J. McCall

Weizmann Institute

Henrik Buhr

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