The Few-Body Problem in Simple Atomic Systems

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Relevance of few-body problem to controlled fusion?

Controlled fusion: Reliable rate coefficients for various processes in ion-atom collisions needed

Experimental data: tedious and costly to obtain, afflicted with experimental uncertainties

difficult to account for e.g. thermal energy distribution of ions and density effects in plasma

Alternative: **theoretical calculations**

Major challenge: Schrödinger equation not analytically solvable for more than 2 mutually interacting particles even when underlying forces are precisely known $\Rightarrow$ **few-body problem**

⇒Theory has to resort to heavy numerical modelling efforts.

Assumptions entering in models have to be tested by detailed experimental data

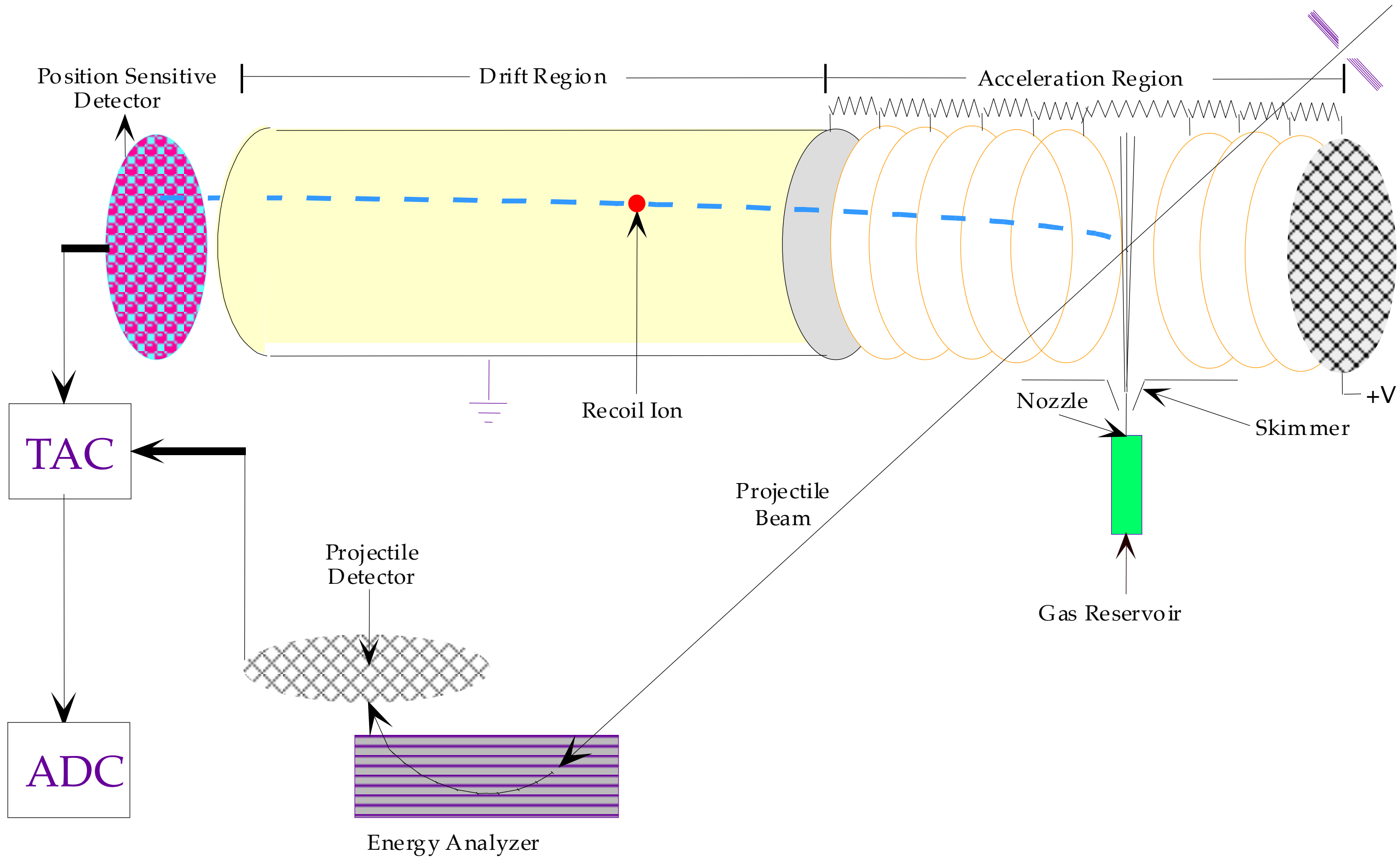
Kinematically complete experiments particularly important as they offer most sensitive test of theory

Kinematically complete experiment on ionization

$$P^{Z+} + T \rightarrow P^{Z+}(\Theta) + T^{+} + e^{-}$$

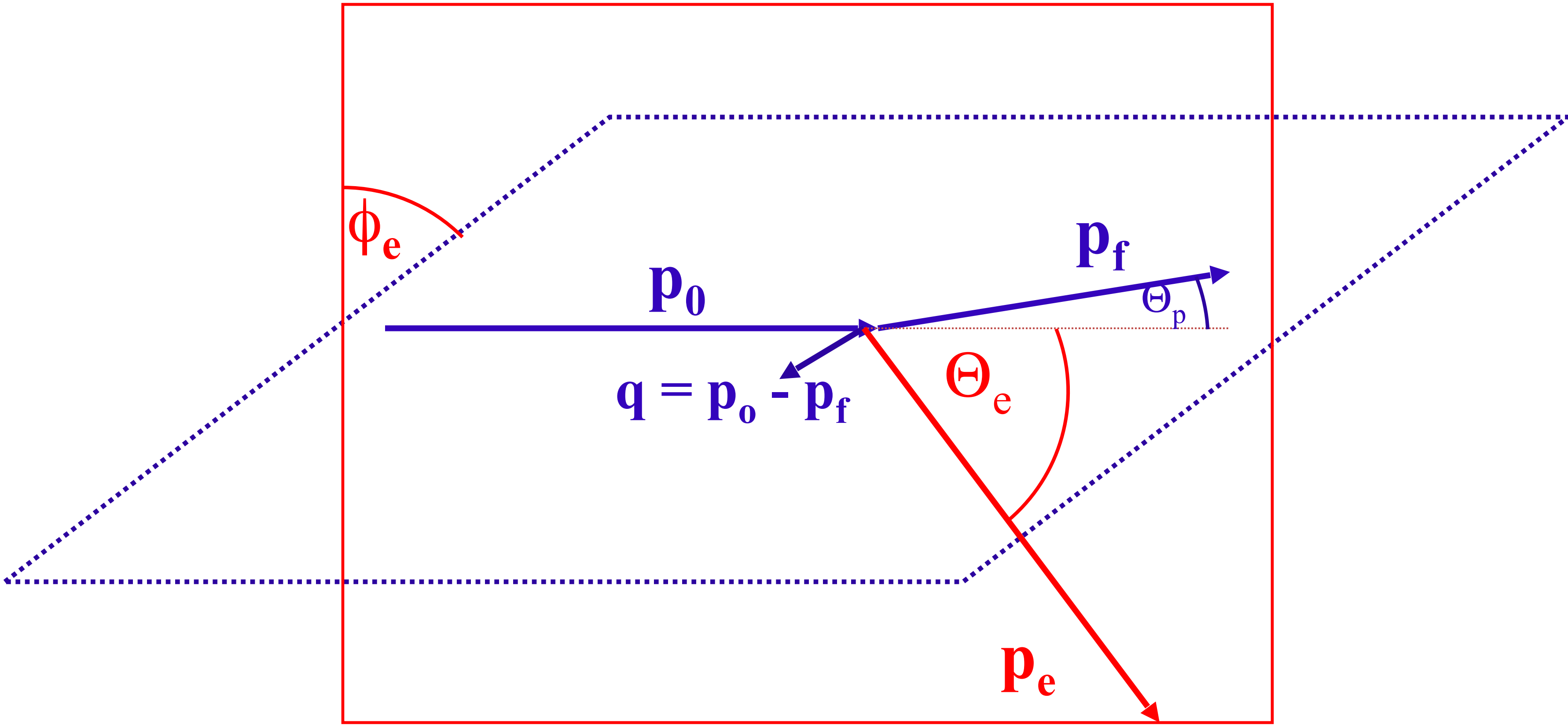
Measure 2 momentum vectors, third determined by momentum conservation

Experimental Setup, 75 keV p + H_2, He



Complete projectile and recoil-ion momenta measured. Electron momentum from conservation laws ⇒ kinematically complete ⇒ FDCS

Three-Dimensional Fully Differential Single Ionization Data

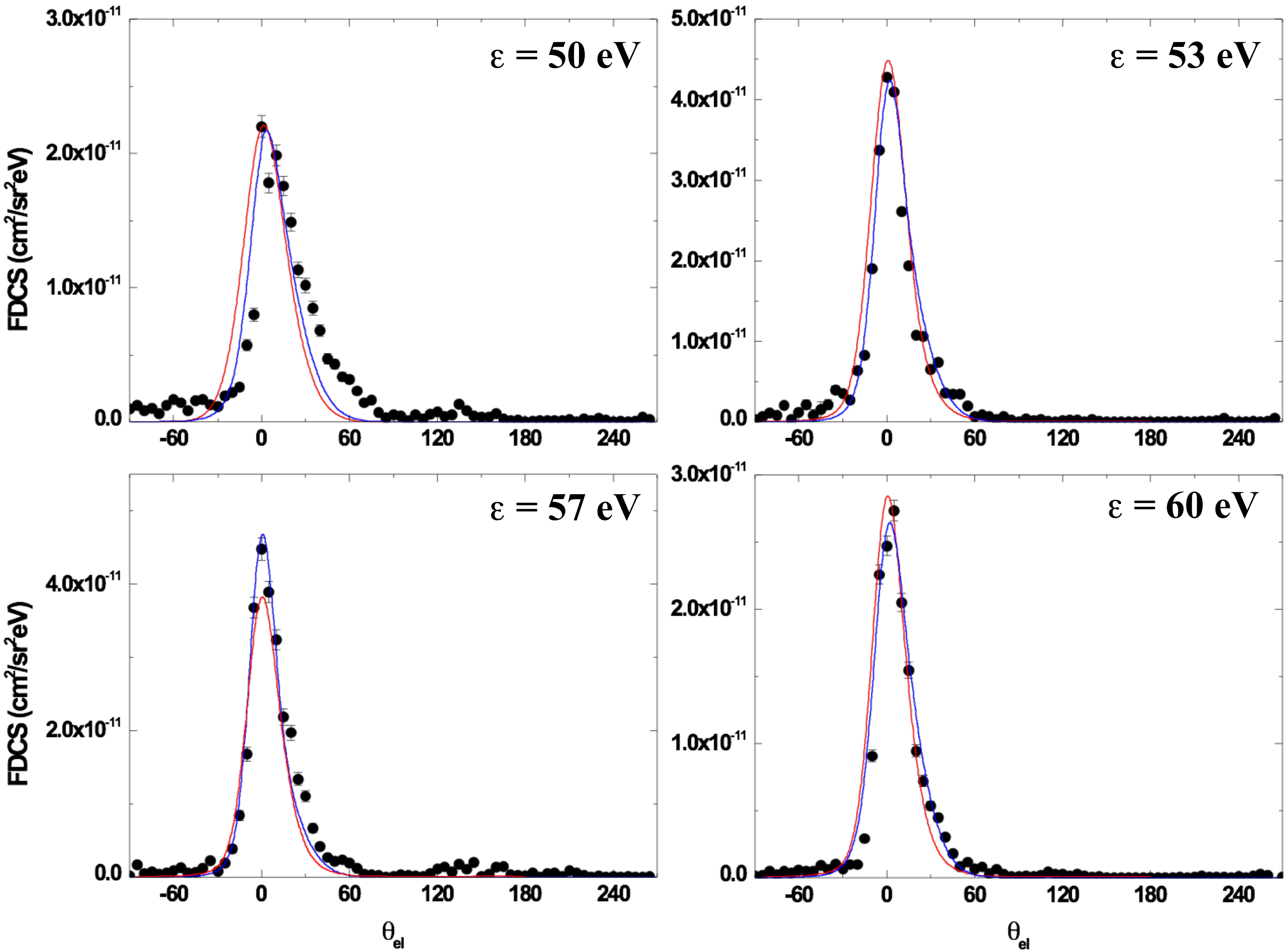


Blue: Scattering plane defined by p_o and p_f

Red: electron emission plane defined by p_o and p_e

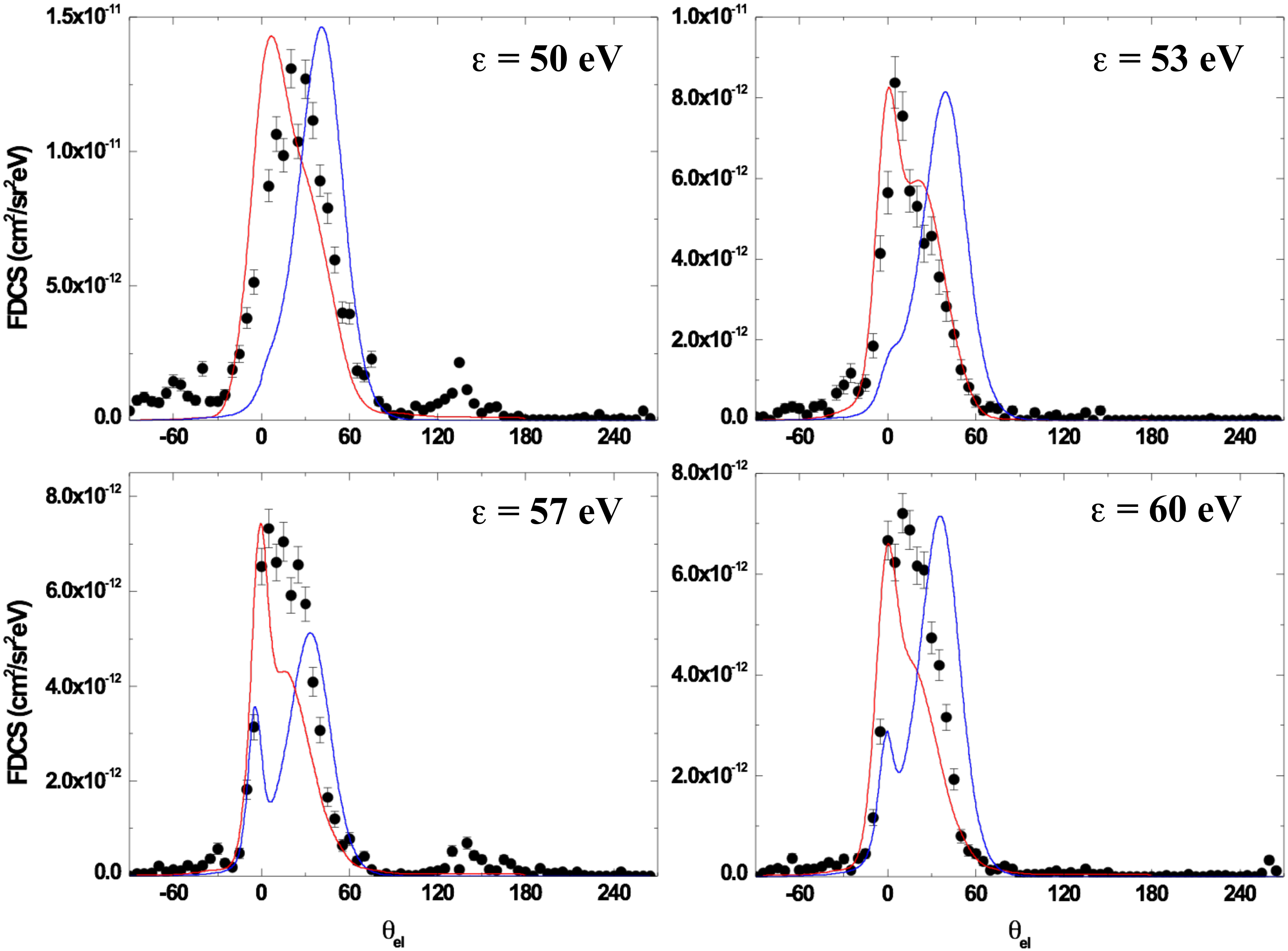
Quantities fixed: ϕ_p, q, and E_e, spectra plotted as a fct. of ϕ_e and θ_e

Electrons ejected into scattering plane, $\theta_p = 0.1$ mrad



Red lines: 3DW model   blue lines: CDW-EIS model

Electrons ejected into scattering plane, $\theta_p = 0.325$ mrad



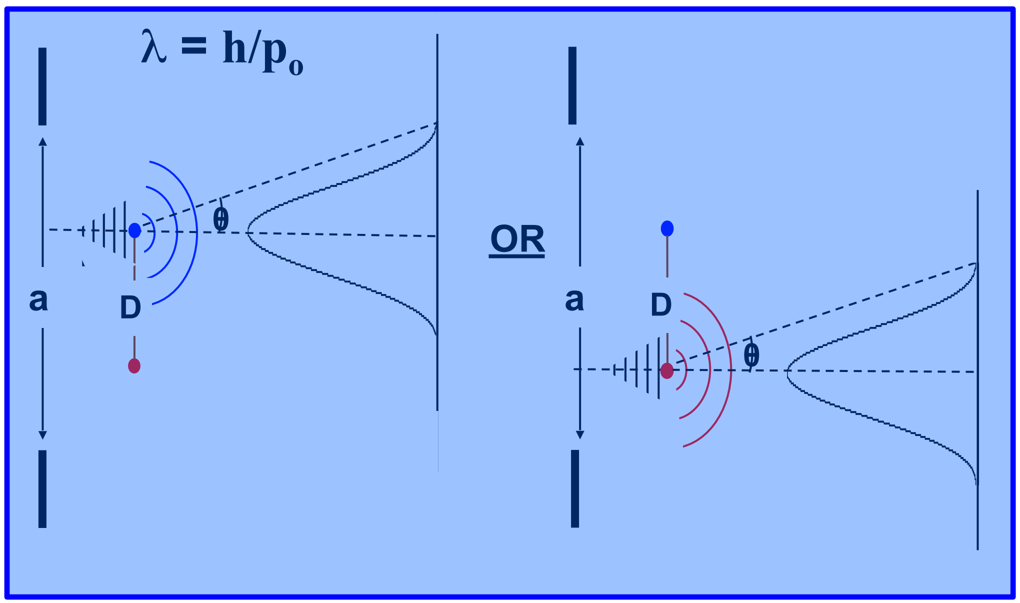
⇒ **Ball is in the theorists court now**

Interference in atomic scattering well established. E.g.: two-center interference in projectile diffraction from diatomic molecules

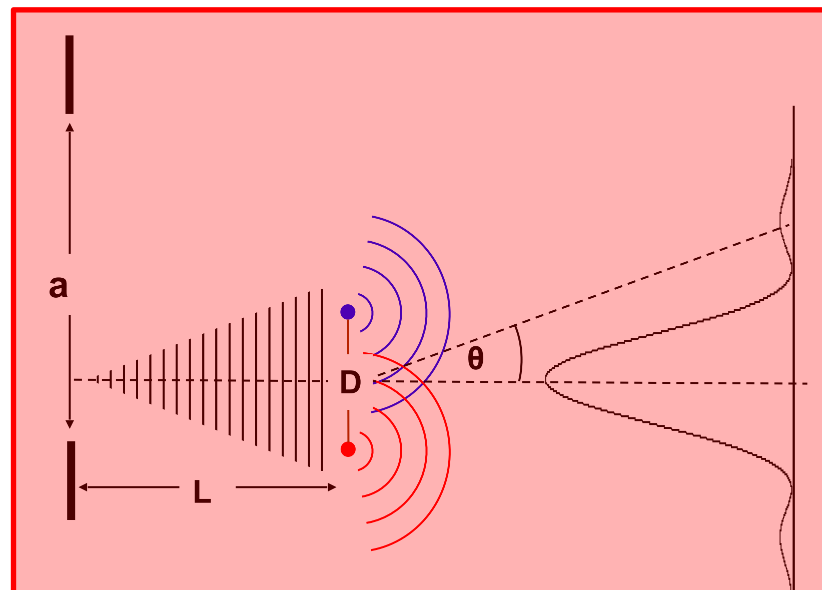
BUT: transverse coherence length Δx must be large enough to coherently illuminate both centers simultaneously: Δx > D

Δx given by geometry of collimating slit and DeBroglie wavelength:

$$\Delta x = {}_{1/2}\,\lambda\, L/a$$



Small L ⇒ Δx < D ⇒ no interference



Large L ⇒ Δx > D ⇒ interference

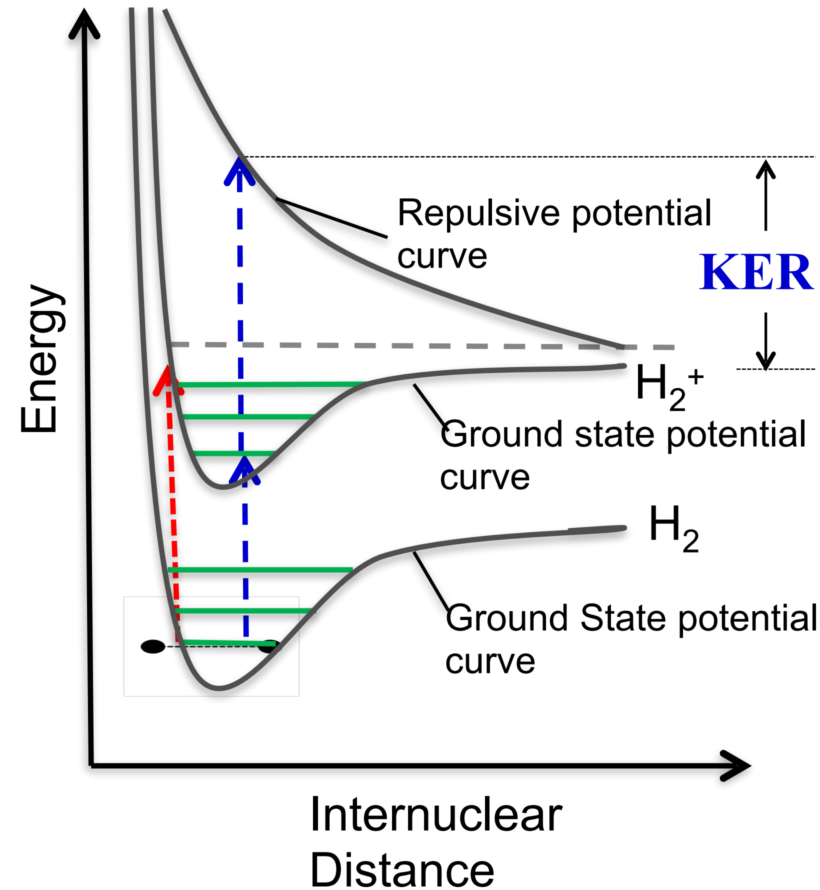
Completely overlooked by theory for decades!

Dissociation of Hydrogen molecule

$H^+ + H_2$ → $H^0 + H_2^+$ → $H^0 + (H_2^+)^*$ → $H^0 + H^+ + H^0$

- Electronic transition to a repulsive state
- large KER

- Vibrational excitation of the nuclear motion
- small KER

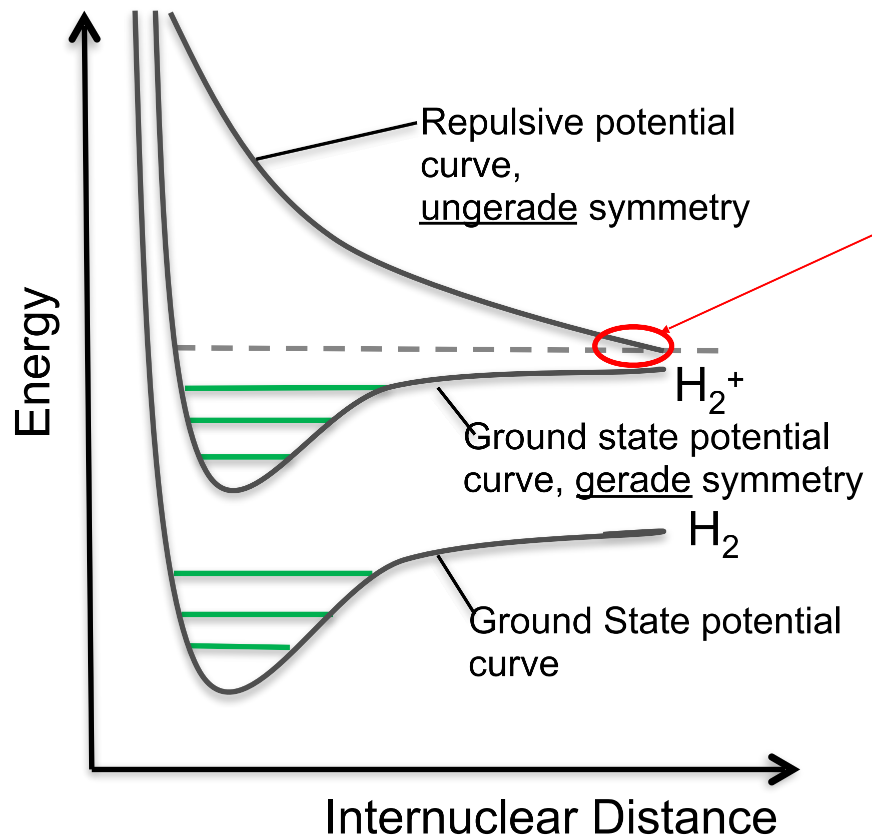


$d\sigma_{coh} = d\sigma_{inc} I \Rightarrow$ ratio $R = d\sigma_{coh}/d\sigma_{inc}$ is interference term I

$$I = 1 + \alpha \cos(p_o \sin\theta_p D + \pi)$$

what leads to this π-phase shift?

Shaofeng Zhang (IMP Lanzhou):



curve crossing
transition to ungerade state?

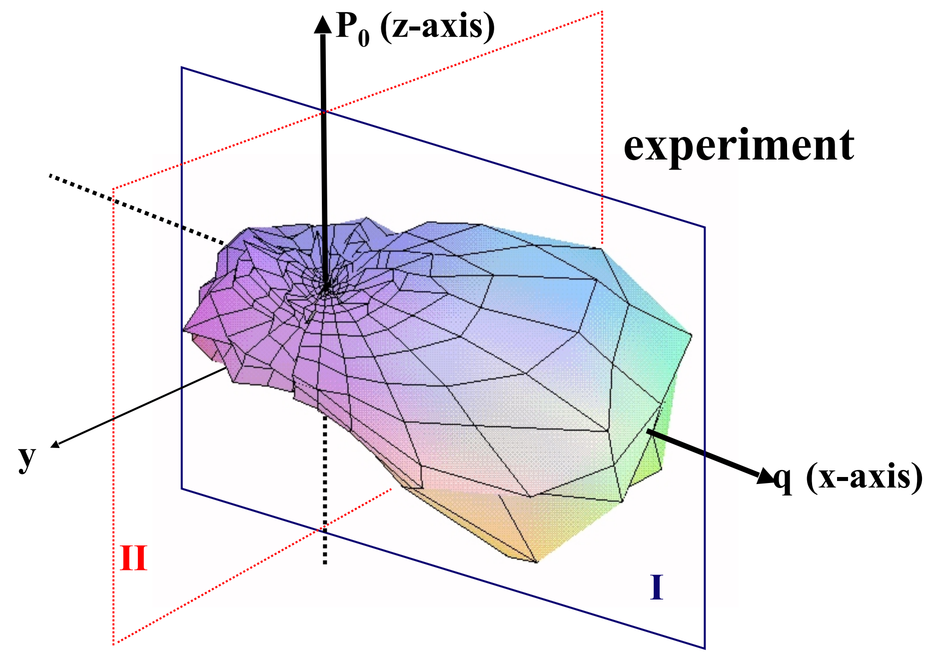
parity conservation:
projectile needs to compensate for symmetry switch in electronic wavefunction
π phase shift

Problems: **a) coupling probability needs to be close to 1! Realistic?**
b) when fragments reach coupling region projectile is long gone!
how does it "know" about switch in symmetry?
entanglement?

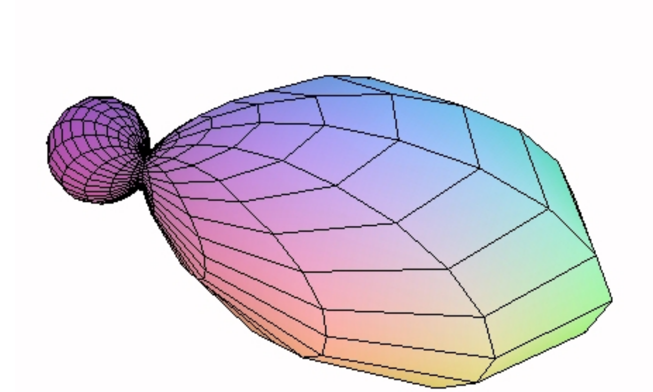
Collaborations

<u>I. IMP Lanzhou</u>, Xinwen Ma, Shaofeng Zhang, …
various projects

a) very fast collisions: discrepancies observed earlier



1.2 GeV C^{6+} + He



3DW, quantum-mechanical NN

Due to unrealistic projectile coherence properties in theory?

Need to repeat experiment. Facilities available at IMP

b) Fully differential cross sections for highly charged ions (e.g. Ne^{10+}) at very small projectile energies (≈ 10 to 20 keV)

very non-perturbative regime ($\eta = Q_p/v_p \approx 30$ to 50)
important regime for plasmas
no fully differential data available!

II. Theory

a) **Don Madison at S&T, pioneer on 3DW model**
b) **Marcelo Ciappina, Czech Republic, CDW-EIS model**
c) **Raul Barrachina, Argentina, and Ladislau Nagy, Romania, projectile coherence effects**

III. Desired future collaborations:

Theory groups using non-perturbative and time-dependent models to describe slow HCI collisions and coherence effects

funding??

<u>Funding situation in US:</u>

two agencies fund collision physics: NSF and DOE
both under increasing financial pressure
policy seems to be (at least at NSF) to reduce funding level before reducing number of funded projects

⇒ All AMO research activities at S&T currently still funded, but budget puts us in increasingly difficult situation.