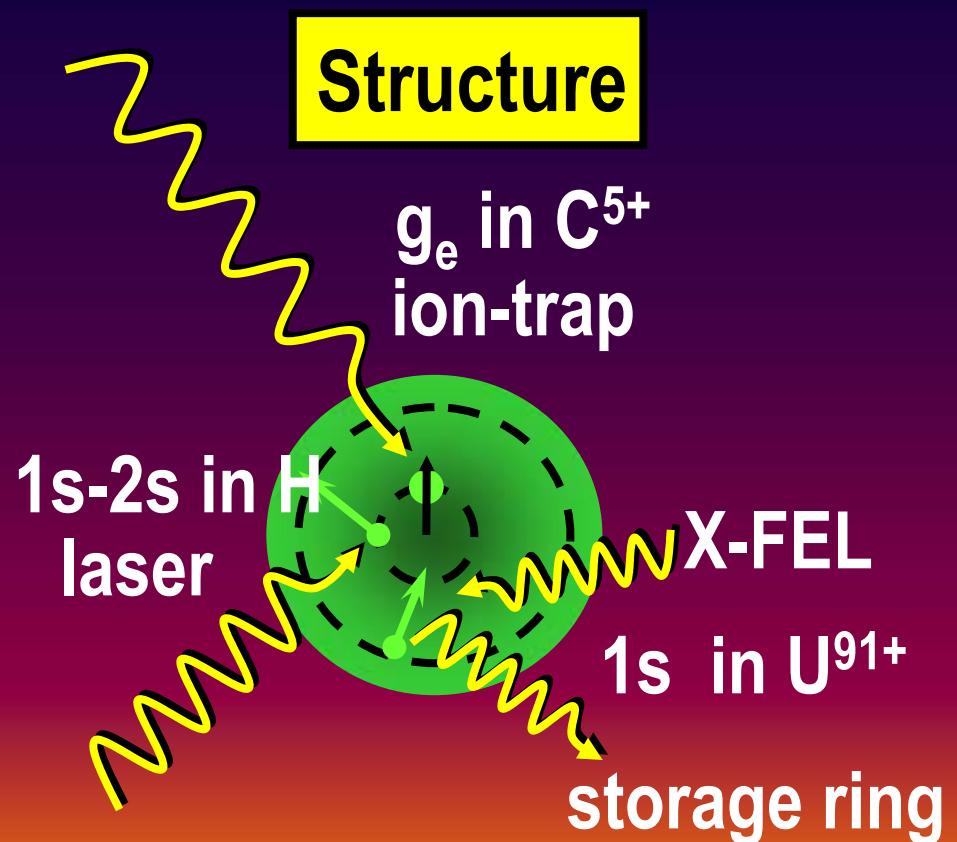
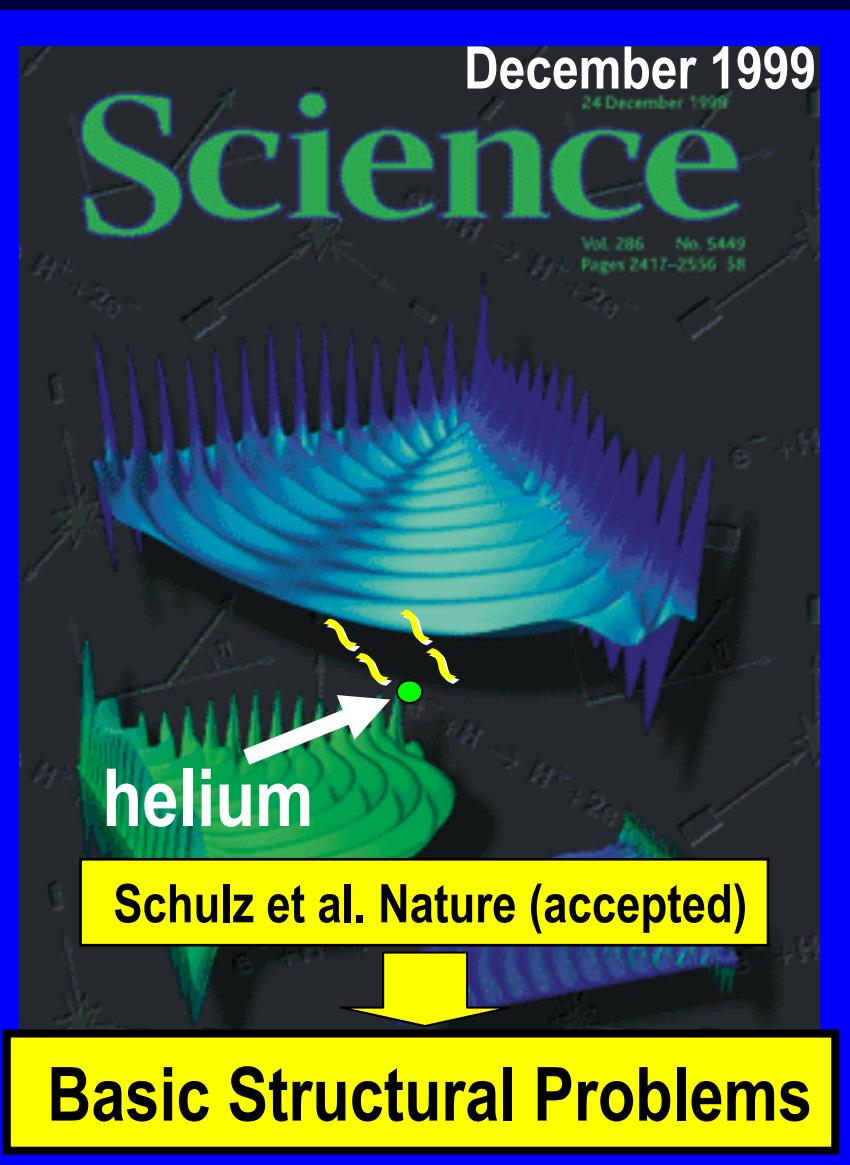


GSI Future Facility: Unique Tool for Fundamental Collision Studies



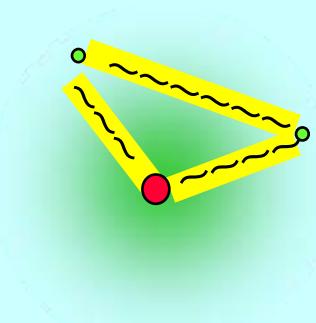
Tremendous Precision



Basic Structural Problems

At Least Three Problems:

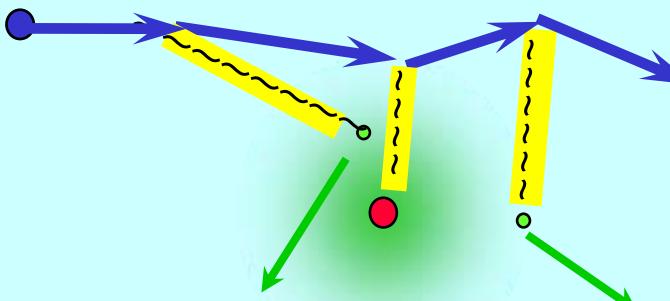
initial state



correlated initial
state wave function

- no analytic solution
- good for scattering ?
- can we map the w.f. ?

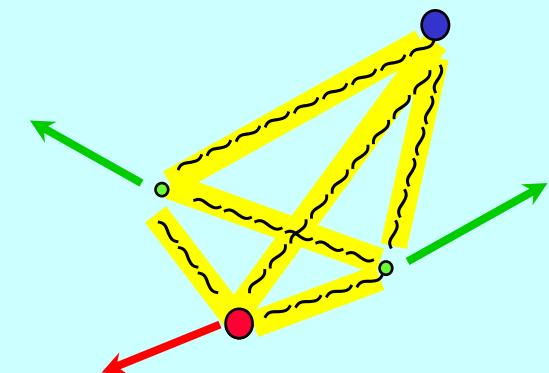
transition



dynamic mechanisms
matrix-elements

- which ones are important ?
- are they of physical reality ?
- observable in experiment ?

final state

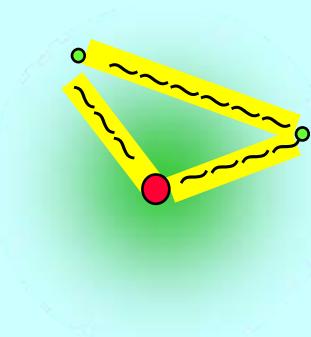


structure of n-particle
Coulomb continuum

- $n = 3$: solution for $r_{ij} \rightarrow \infty$
- $n = 3$: no solution $r_{ij} < \infty$
- $n > 3$: no solution

At Least Three Problems:

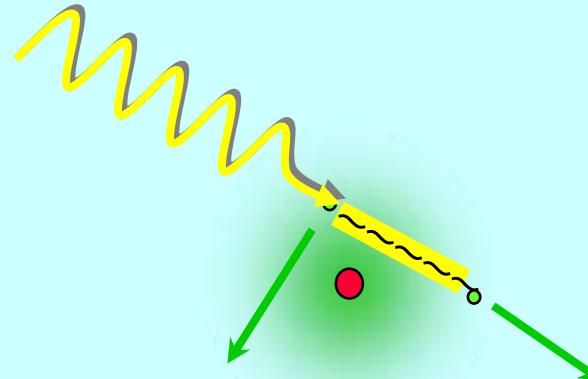
initial state



correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

transition

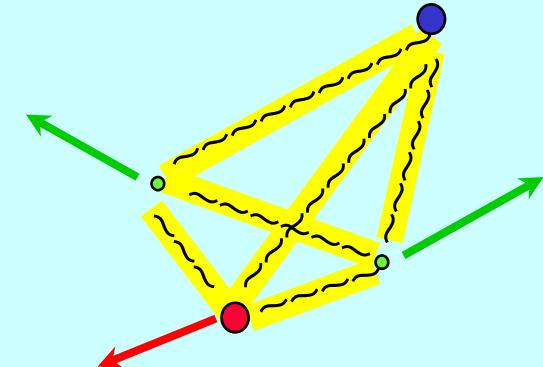


!! make it simple !!

1. understood



final state

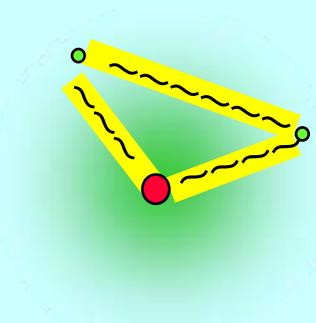


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- $n = 3$: no solution $r_{ij} < \infty$
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At Least Three Problems:

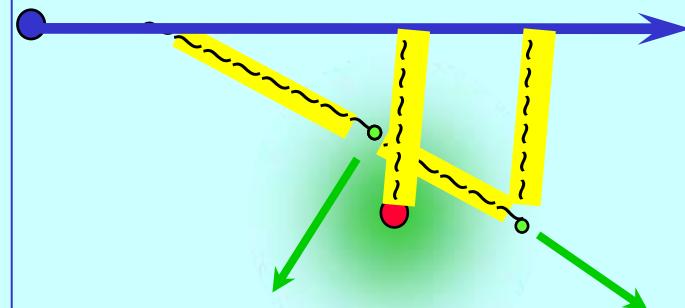
initial state



correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

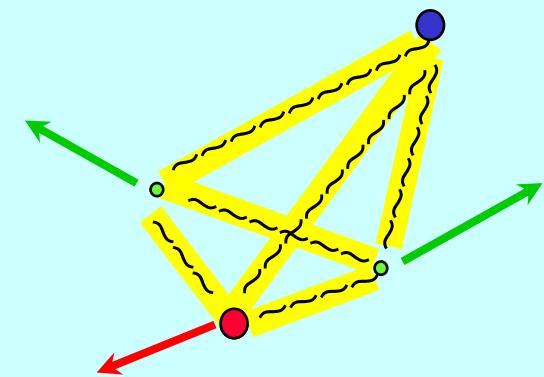
transition



!! make it simple !!

1. understood ☺
2. understood ☺
 - at large velocity
 - at large distance
 - for small charge

final state

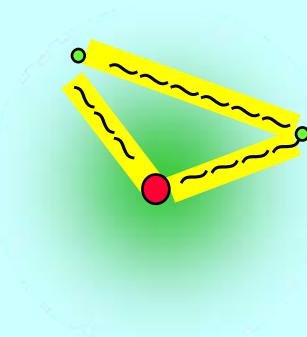


structure of n-particle
Coulomb continuum

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- $n > 3$: no solution

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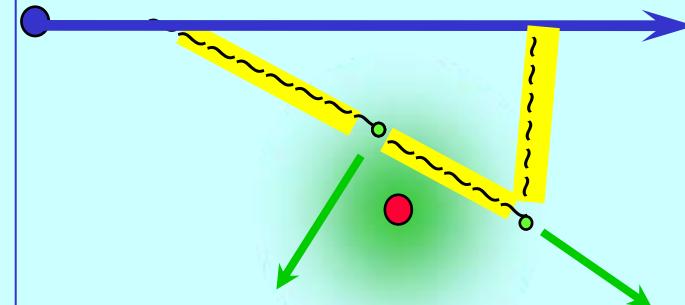
initial state



correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

transition



!! make it simple !!

1. understood

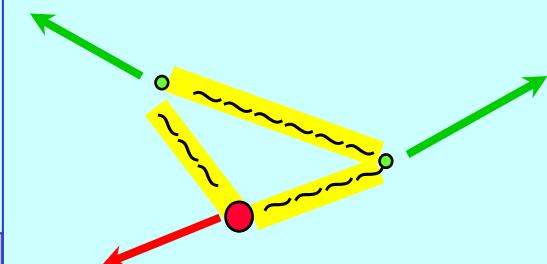


2. understood ?



- at large velocity
- at large distance
- for small charge

final state

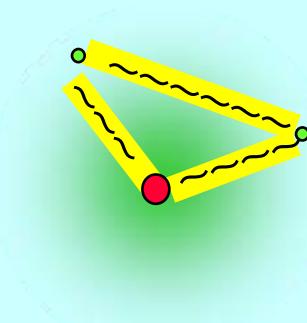


structure of n-particle
Coulomb continuum

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- $n = 3$: no solution $r_{ij} < \infty$
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At Least Three Problems:

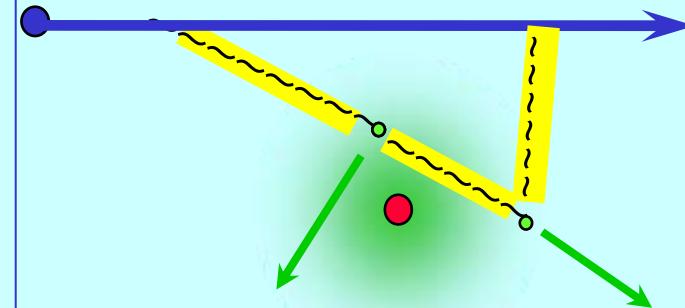
initial state



correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

transition



!! make it simple !!

1. understood



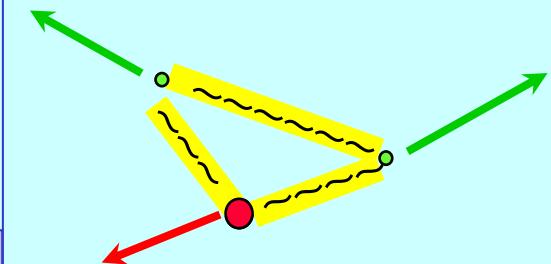
2. understood ?



Moshammer et al., PRL 2002

Schulz et al., Nature, accepted

final state

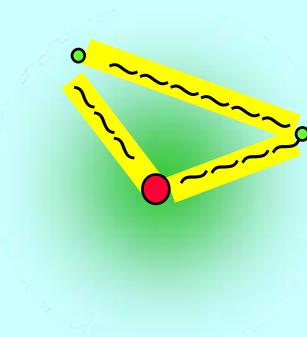


structure of n-particle
Coulomb continuum

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At Least Three Problems:

initial state

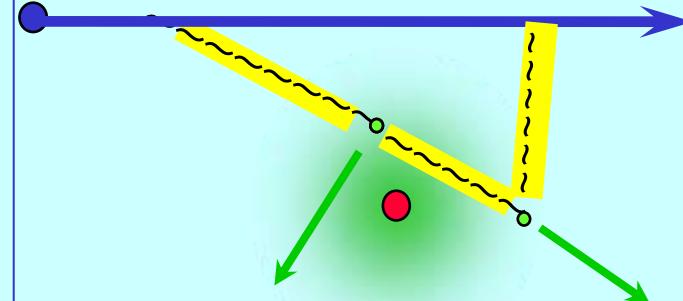


correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

transition

$p^{(+)} / \bar{p}^{(-)}$ at 3–20 MeV



!! make it simple !!

1. understood

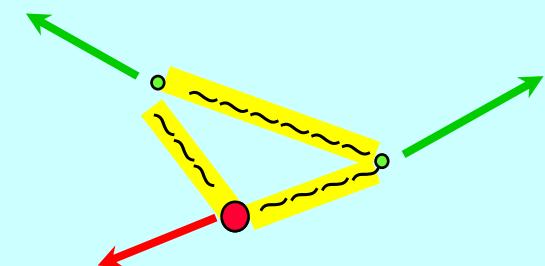


2. understood ?



- at large velocity
- at large distance
- for p/ \bar{p} - @ GSI

final state

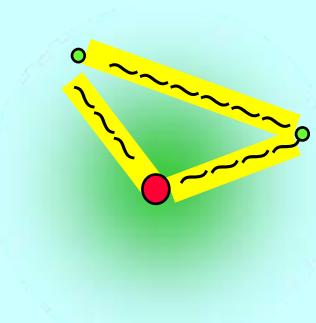


structure of n-particle
Coulomb continuum

- n = 3: solution for $r_{ij} \rightarrow \infty$
- n = 3: no solution $r_{ij} < \infty$
- n > 3: no solution

At Least Three Problems:

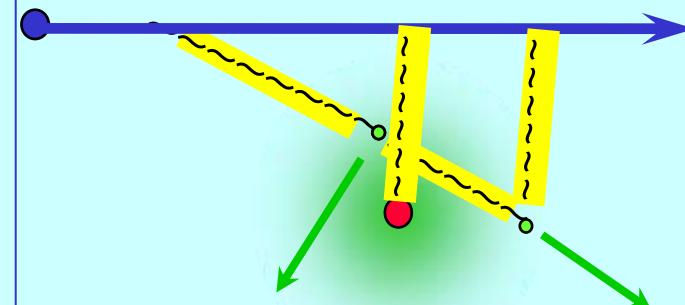
initial state



correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

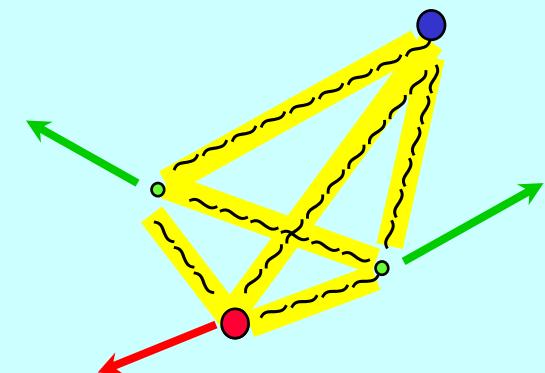
transition



!! make it simple !!

1. understood
2. charged particles
 - at large velocity
 - at large distance
 - for large charge

final state

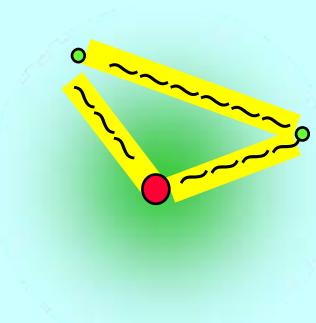


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initial state

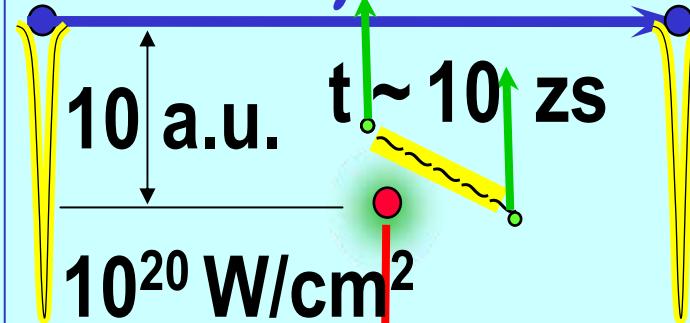


correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

transition

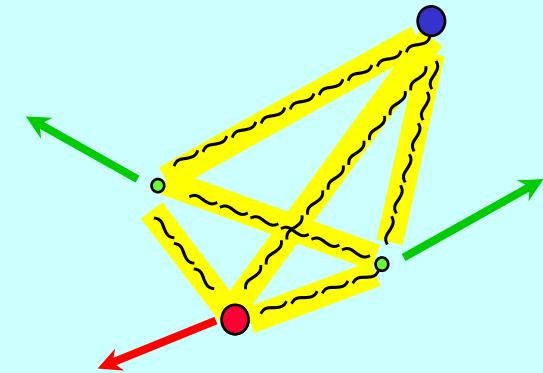
U^{92+} at $\gamma=20$



!! make it simple !!

1. understood
2. charged particles
 - relativistic vel.
 - at large distance
 - U^{92+} at GSI

final state

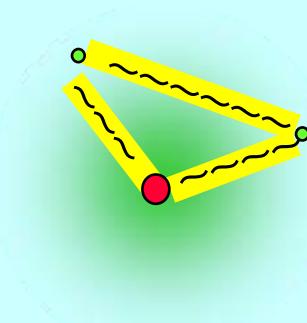


structure of n-particle
Coulomb continuum

- $n = 3$: solution for $r_{ij} \rightarrow \infty$
- $n = 3$: no solution $r_{ij} < \infty$
- $n > 3$: no solution

At Least Three Problems:

initial state

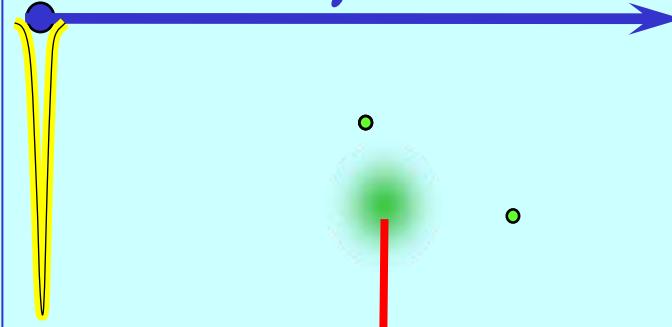


correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

transition

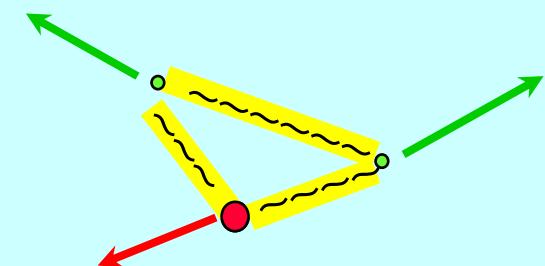
U^{92+} at $\gamma=20$



!! make it simple !!

1. understood
2. charged particles
 - relativistic vel.
 - at large distance
 - U^{92+} at GSI

final state

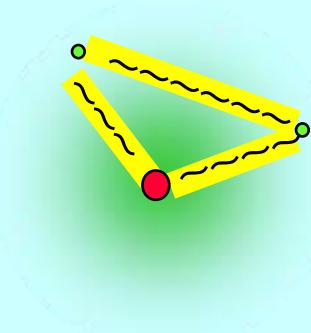


structure of n-particle
Coulomb continuum

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initial state

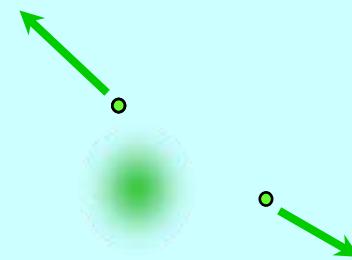


correlated initial
state wave function

- no analytic solution
- good for scattering ?
- observable?

realisation of
(Heisenberg Microscope)

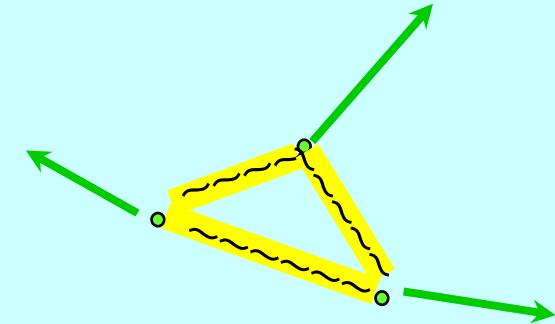
transition



!! make it simple !!

1. understood
2. charged particles
 - relativistic vel.
 - at large distance
 - U^{92+} at GSI

final state



structure of n-particle
Coulomb continuum

- $n = 3$: solution for $r_{ij} \rightarrow \infty$
- $n = 3$: no solution $r_{ij} < \infty$
- $n > 3$: no solution

Moshammer et al., PRL 1999
Perumal et al., PRA 2002

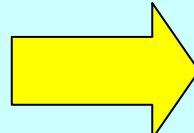
Three Fundamental Experiments

- 1. From First to Second Born:
Double Ionization by Protons and Antiprotons**

- 2. Exawatt/cm², Zeptosecond Fields:
The Heisenberg (Attosecond) Microscope?**

- 3. Electron Impact Ionization of Ions:
Differential Experiments in Inverse Kinematics**

Kollmus et al., PRL 2002

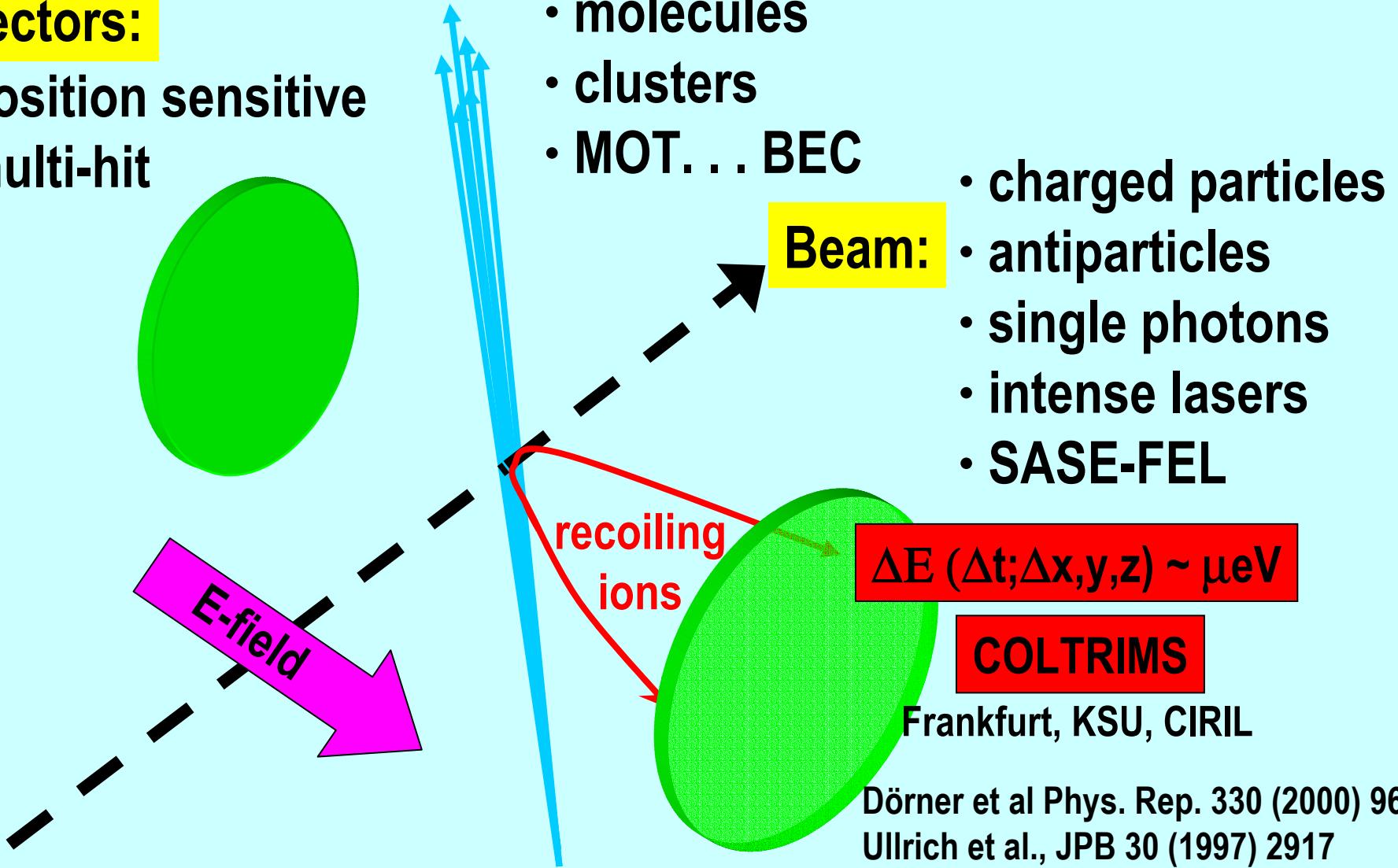


Poster: S. Hagmann

Experiment: Reaction Microscope

Detectors:

- position sensitive
- multi-hit



Dörner et al Phys. Rep. 330 (2000) 96

Ullrich et al., JPB 30 (1997) 2917

Experiment: Reaction Microscope

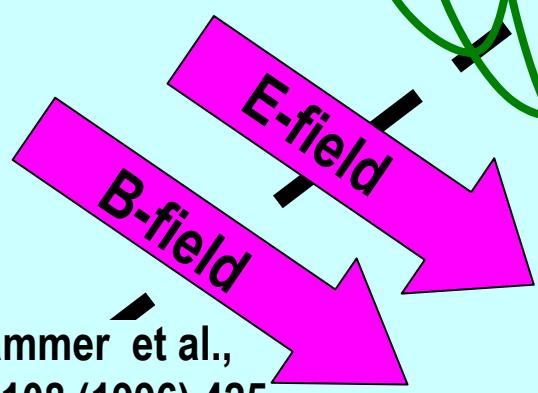
Detectors:

- position sensitive
- multi-hit

10 electrons

$\Delta E \sim \text{meV}$

GSI, Freiburg,
Heidelberg



Target:

- supersonic atomic jet
- molecules
- clusters
- MOT... BEC

Beam:

- charged particles
- antiparticles
- single photons
- intense lasers
- SASE-FEL

$\Delta E (\Delta t; \Delta x, y, z) \sim \mu\text{eV}$

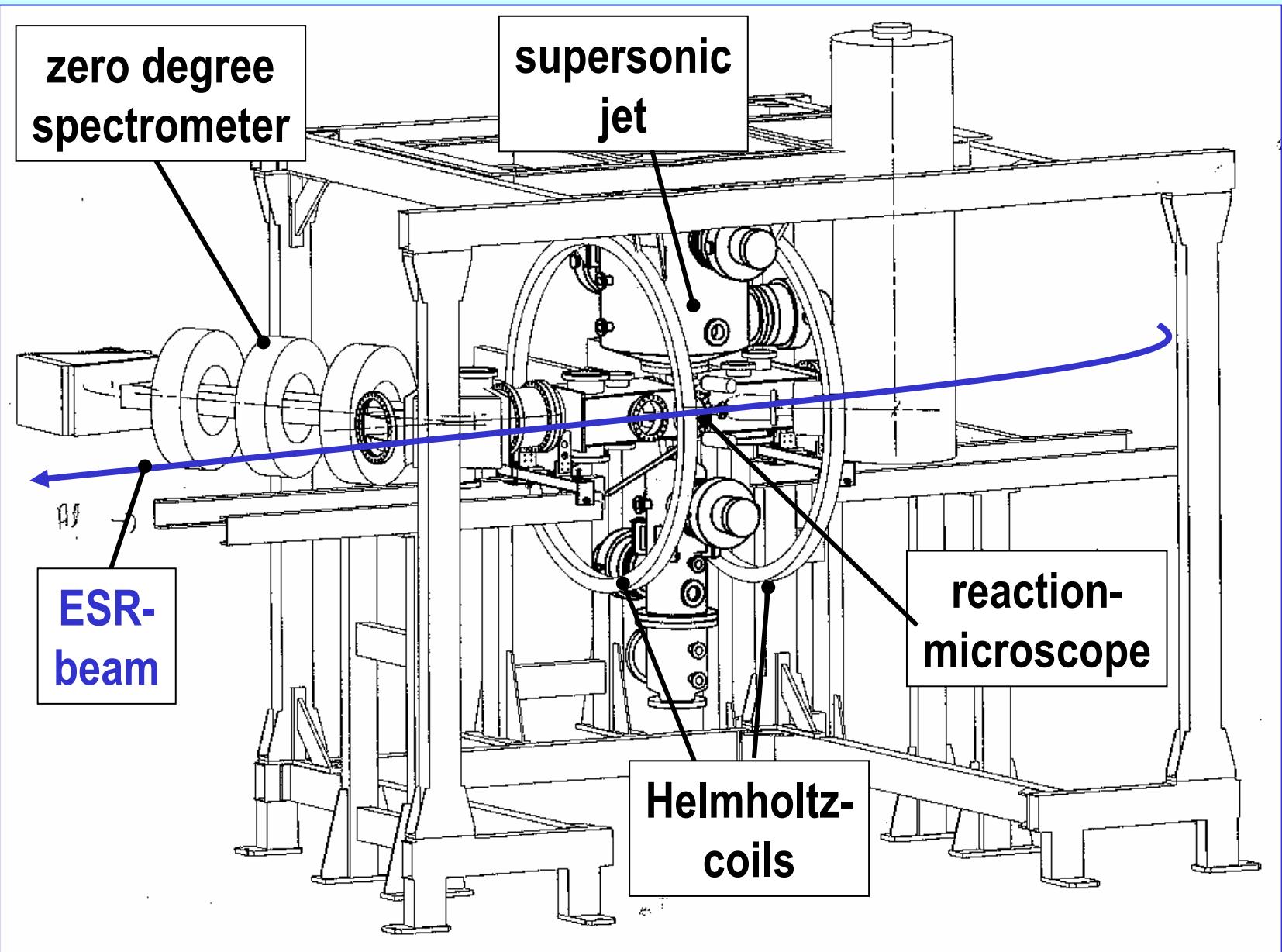
COLTRIMS

Frankfurt, KSU, CIRIL

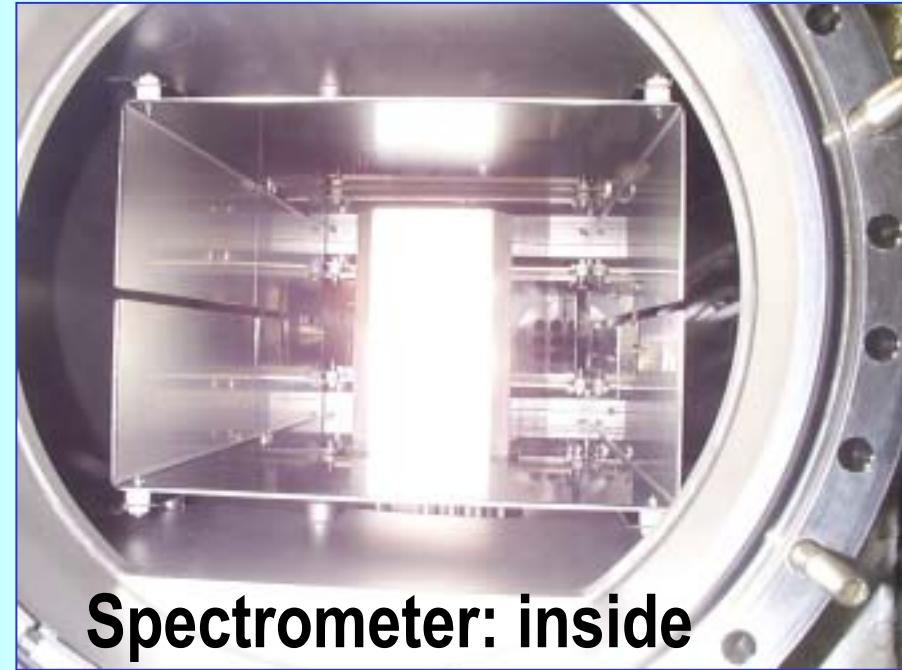
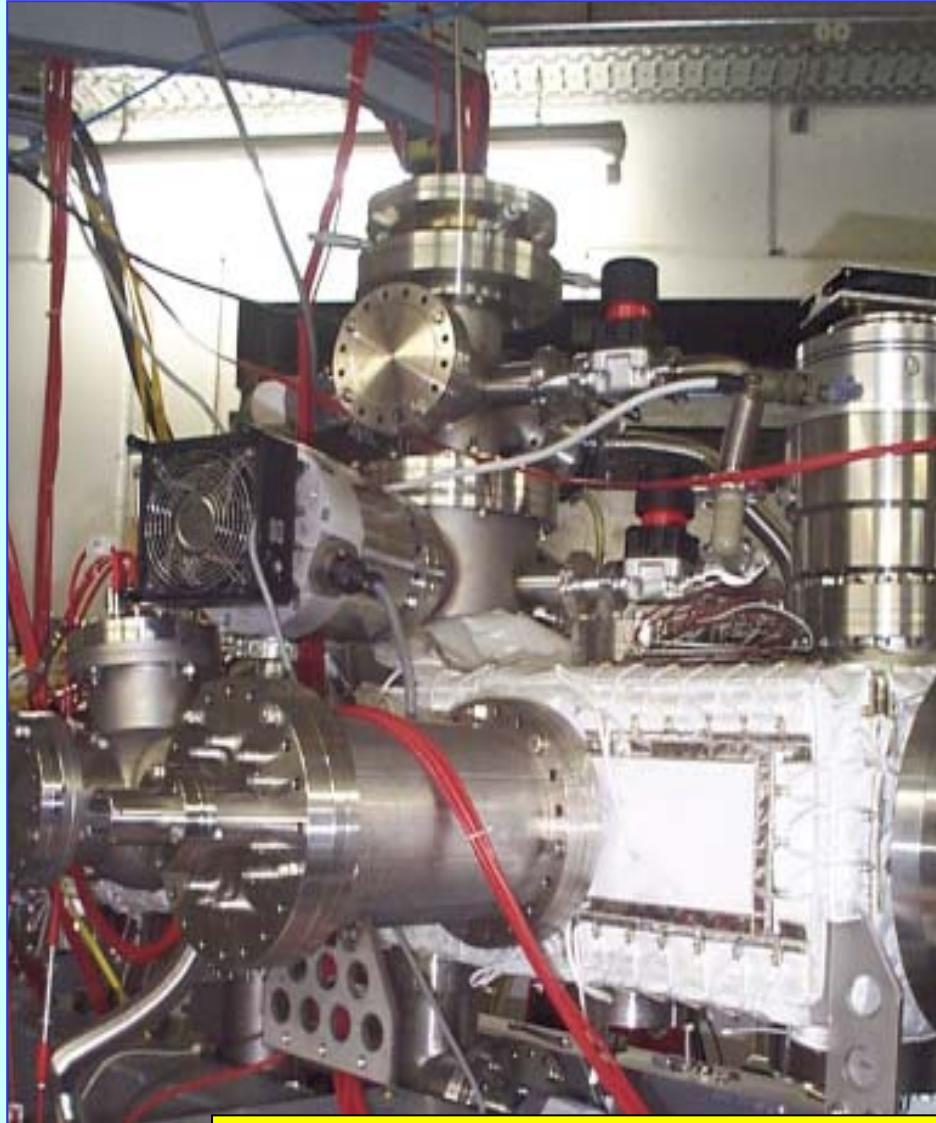
Moshammer et al.,
NIM B 108 (1996) 425

Dörner et al Phys. Rep. 330 (2000) 96
Ullrich et al., JPB 30 (1997) 2917

ESR - Reaction Microscope



ESR - Reaction Microscope



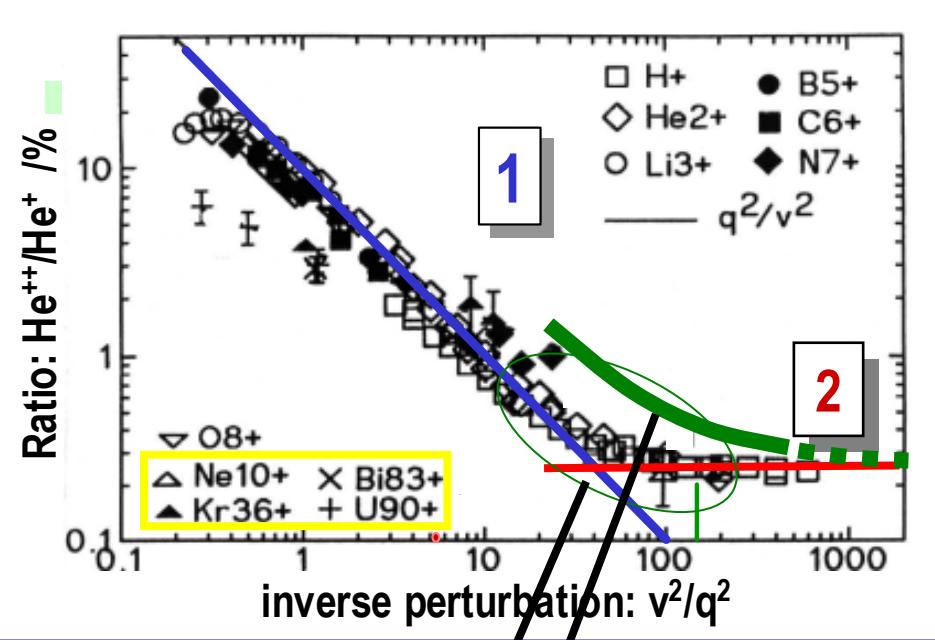
Spectrometer: inside



MCP detector

Supported by BMBF: indispensable for realization!

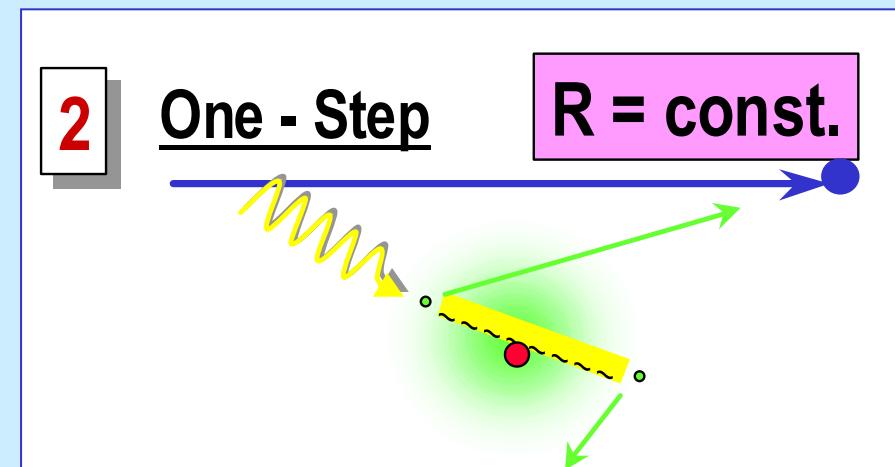
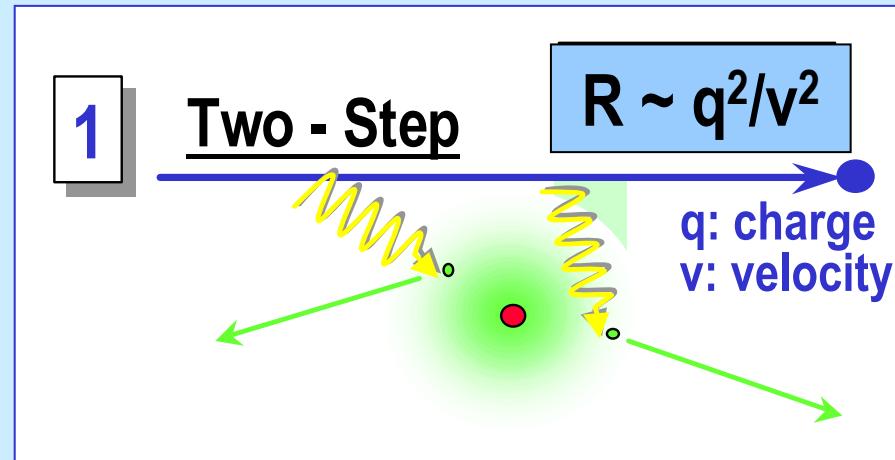
1. From 1st to 2nd Born: $p \leftrightarrow \bar{p}$



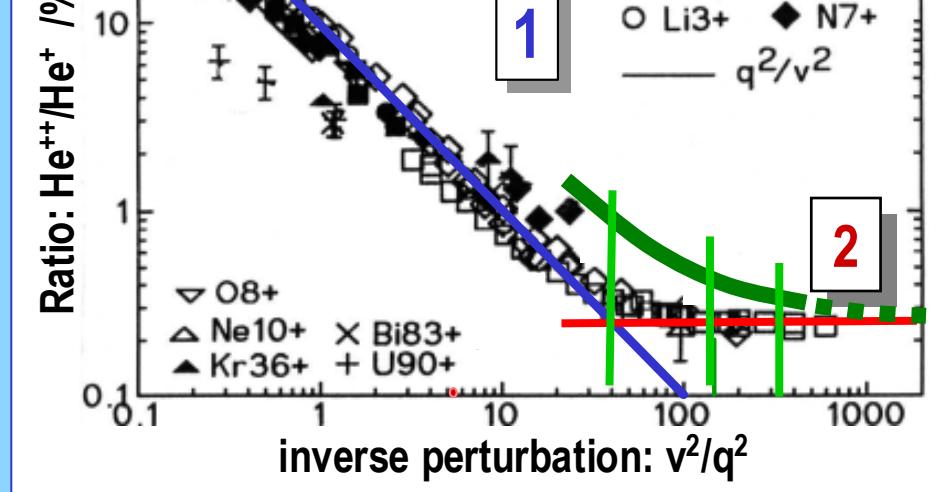
Ullrich et al. PRL (1994); NIMB (1994)

Interpretation at 2nd order:

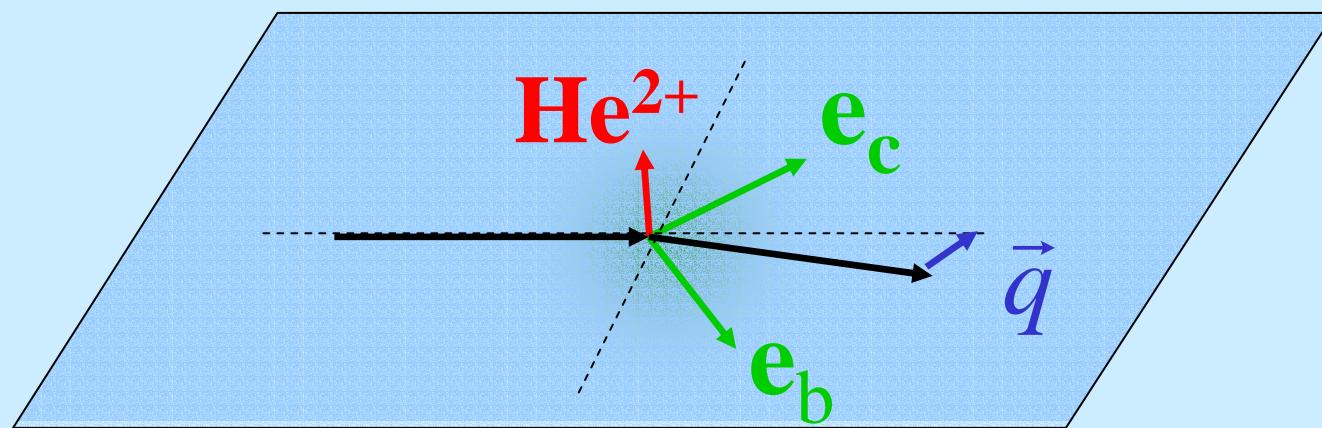
$\sigma \sim E^4 R \alpha^3$ CERN ..



The $p \leftrightarrow \bar{p}$ difference



fully differential cross sections:



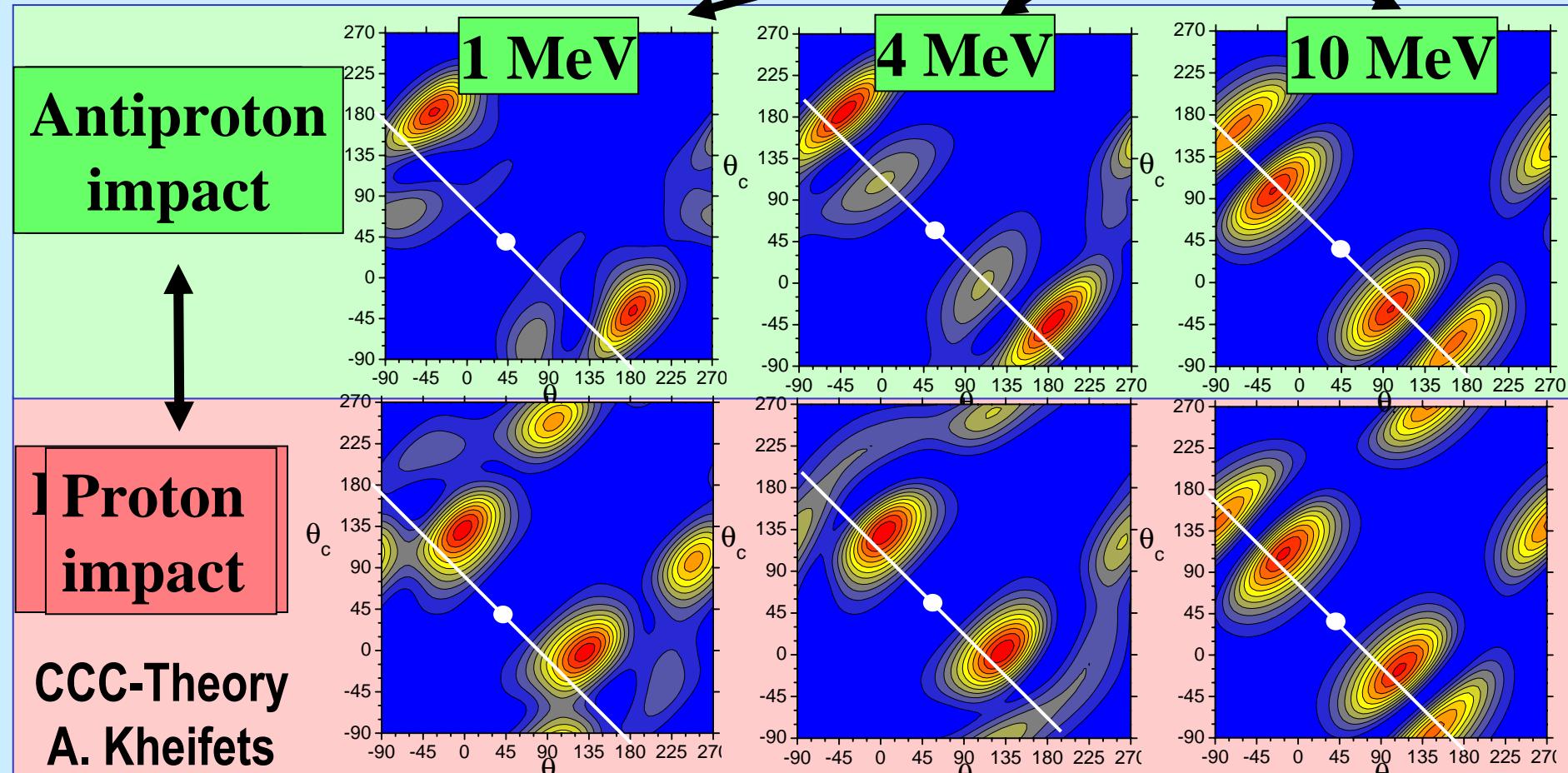
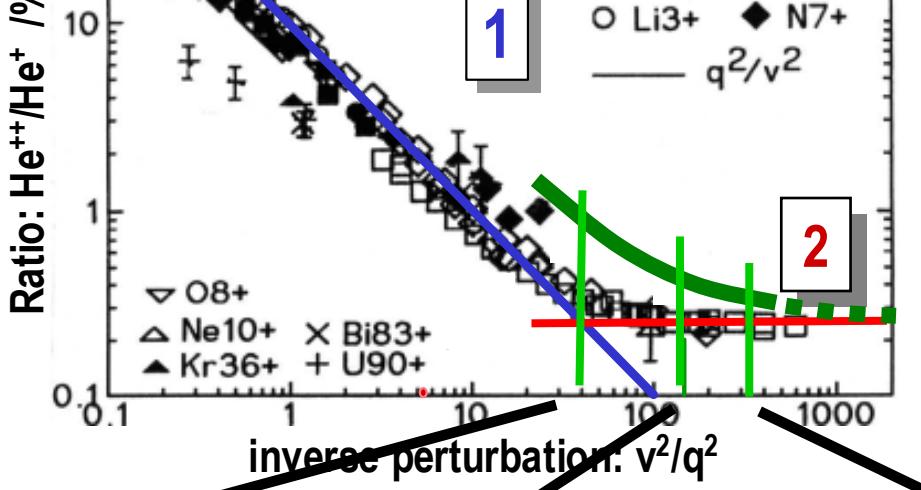
Dorn et al.,

PRL 2000

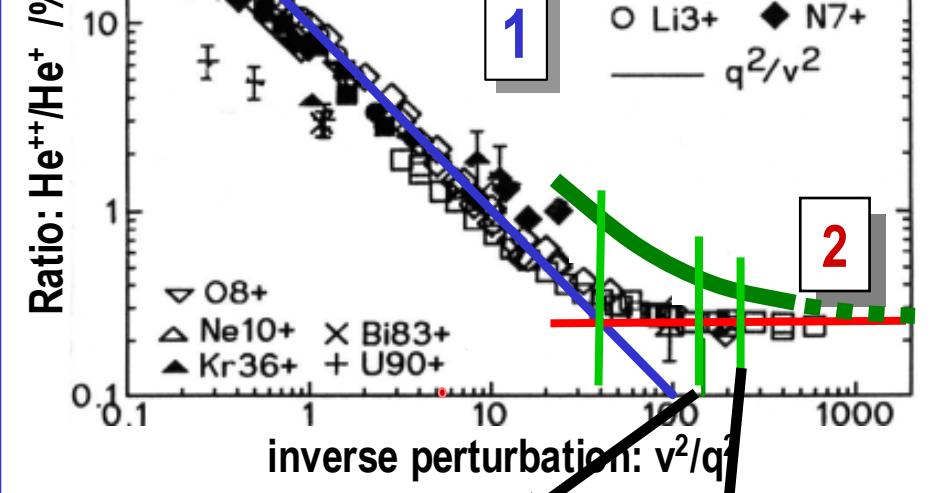
PRL 2002

PRL submitted

The $p \leftrightarrow \bar{p}$ difference



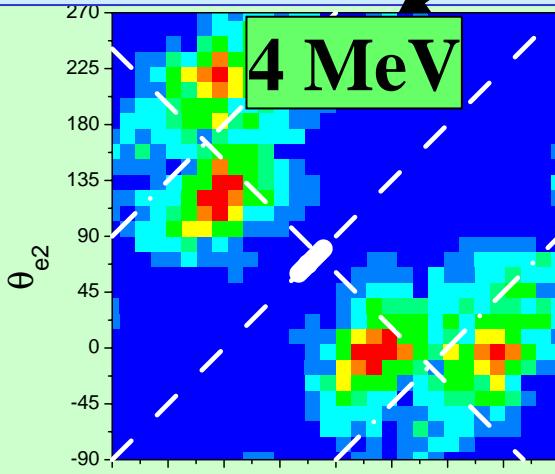
The $p \leftrightarrow \bar{p}$ difference



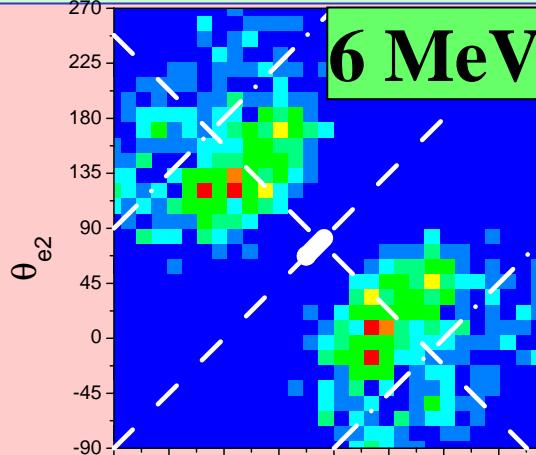
Electron
impact



Proton
impact

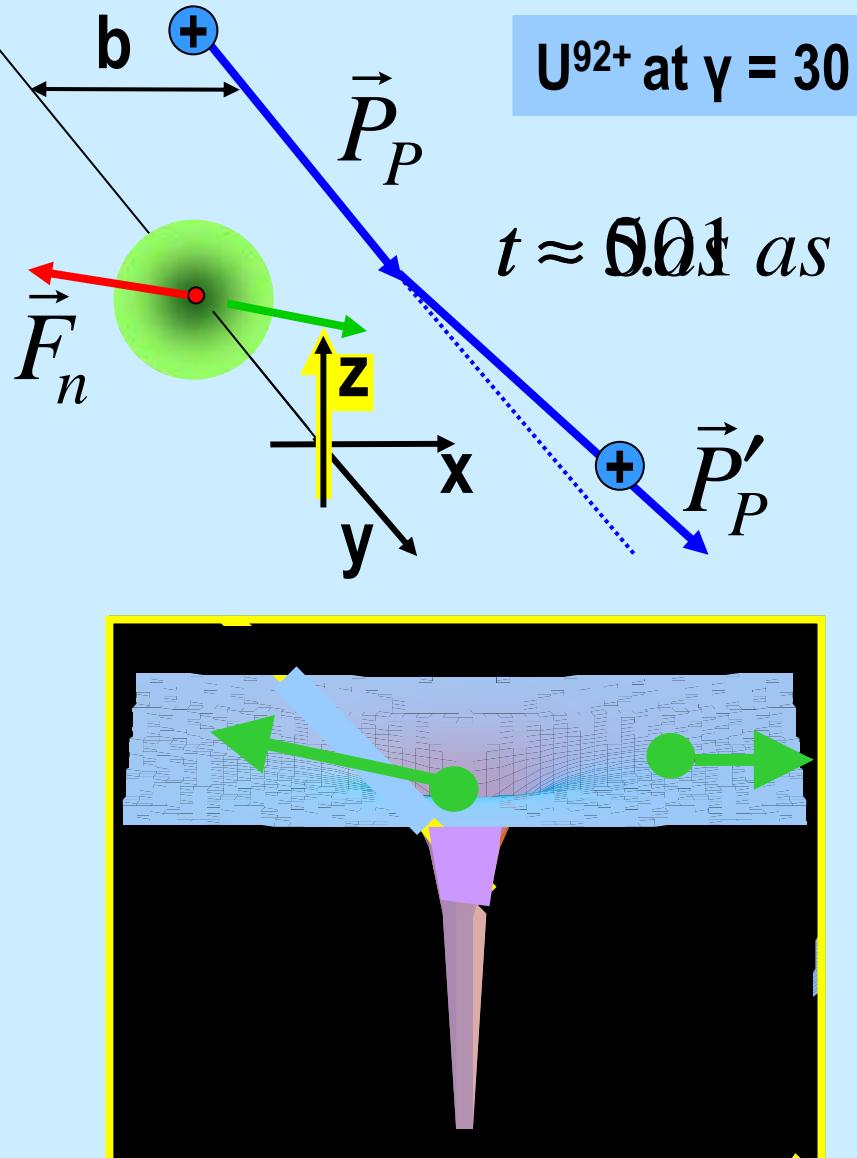


Dorn et al.,
PRL, submitted



Fischer: Thesis
Heidelberg

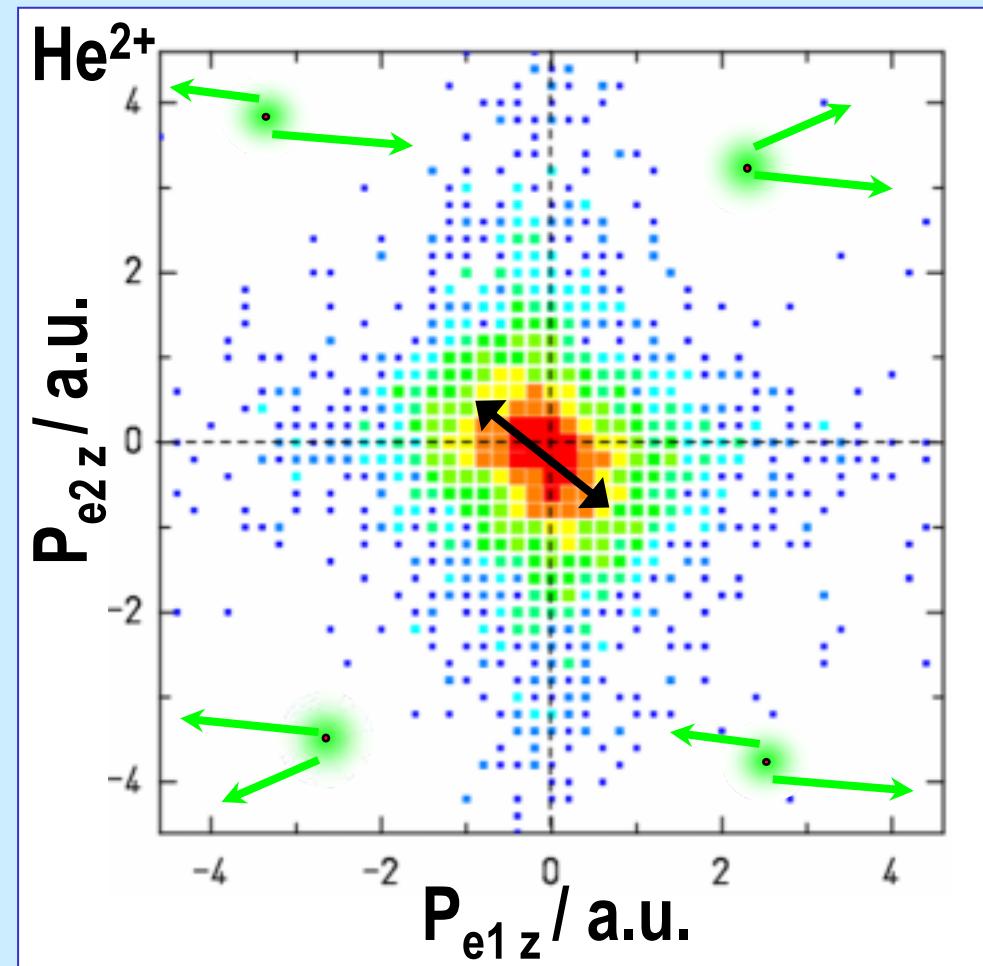
2. The Heisenberg Microscope



$t \approx 6.01 \text{ as}$

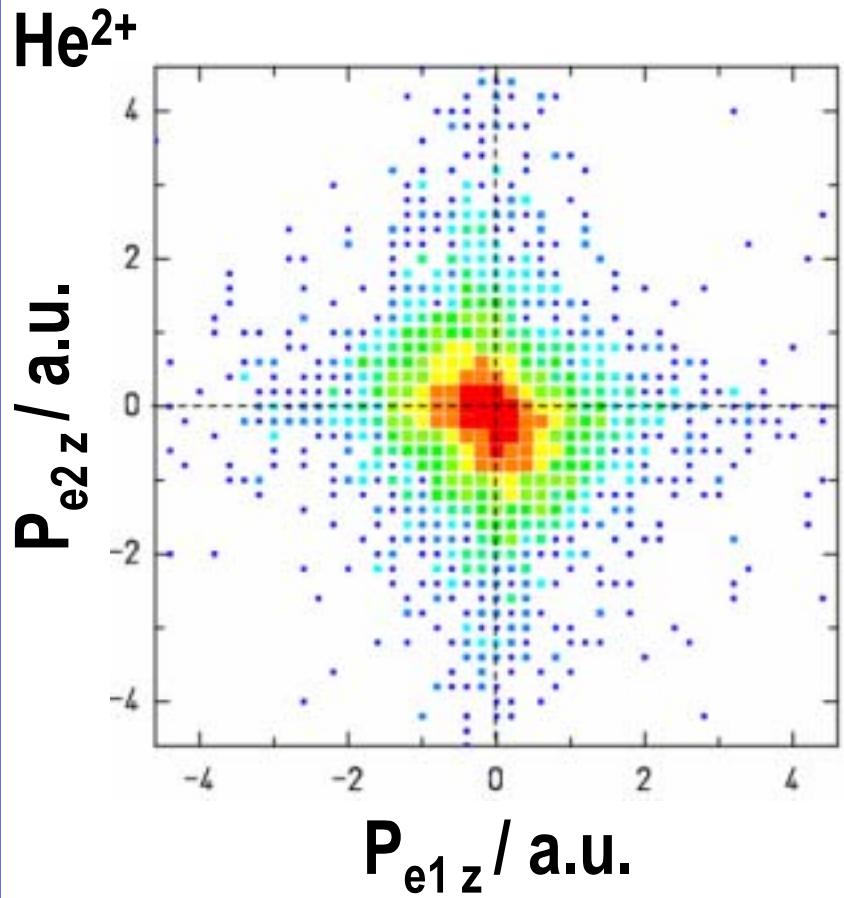
projection onto z-direction:

„no“ force !?

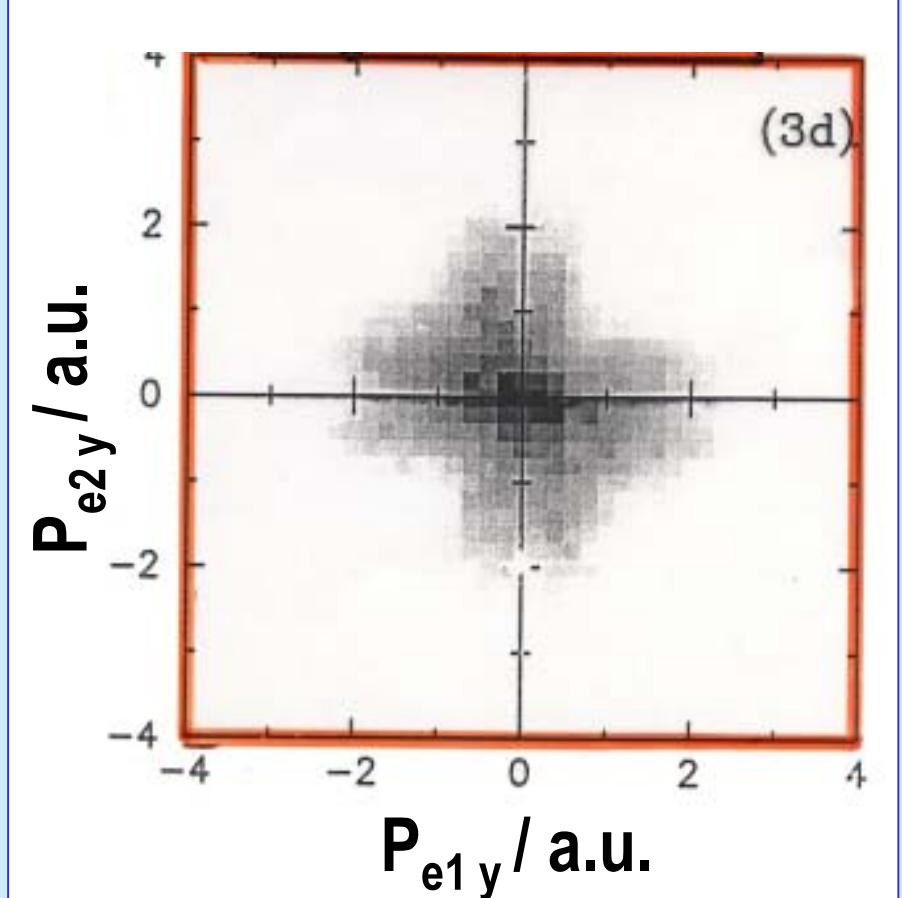


2. The Heisenberg Microscope

Experiment: 5.9 MeV/u Au⁵³⁺

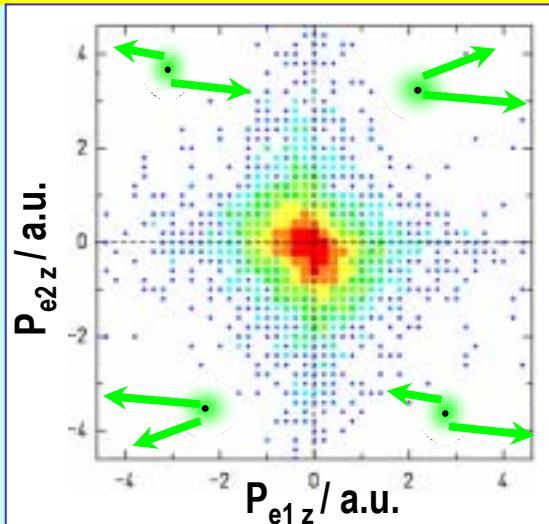


Theory: 2 GeV/u U⁹²⁺

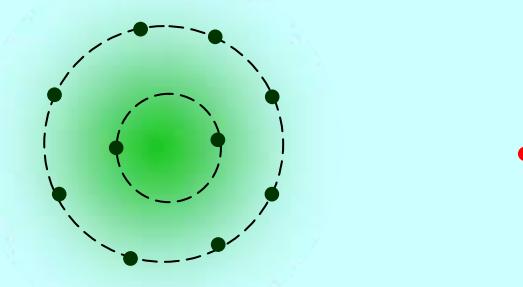


2. The Heisenberg Microscope

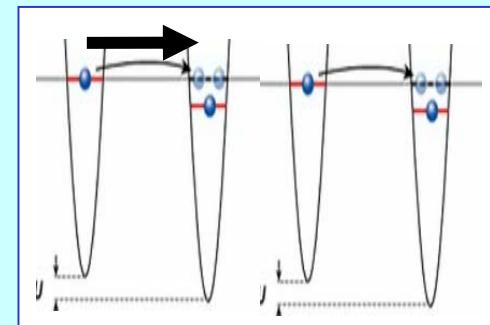
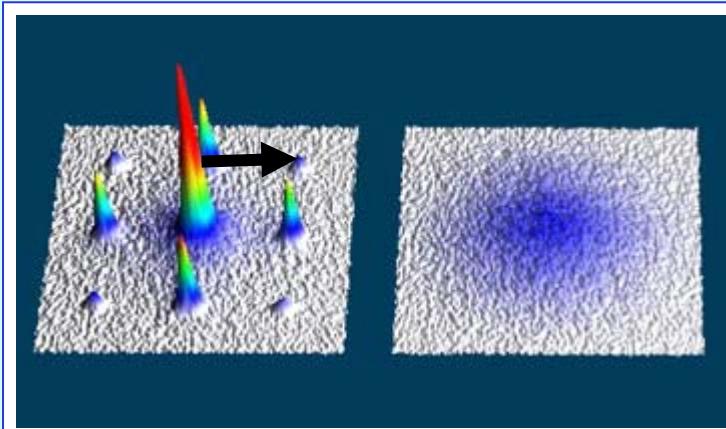
correlated momenta: degenerate Fermi gas



- projectiles not fast enough
- only in one dimension
- true n-particle systems



momentum distribution: degenerate Bose crystal



Max-Planck Institut, Heidelberg

- *R. Moshammer, H. Kollmus, D. Fischer, B. Feuerstein, W. Schmitt,*
- *A. Dorn, C.D. Schröter, C. Höhr, G. Saghelashvili, J. Deipenwisch,*
- *K. Zrost, B. Jesus, J. R. Crespo Lopez-Urrutia,*
- *A. Voitkiv, B. Najjari, T. Kirchner, J. Ullrich*

GSI, Darmstadt

S. Hagmann, R. Mann

Bariloche, Argentina

P. Fainstein

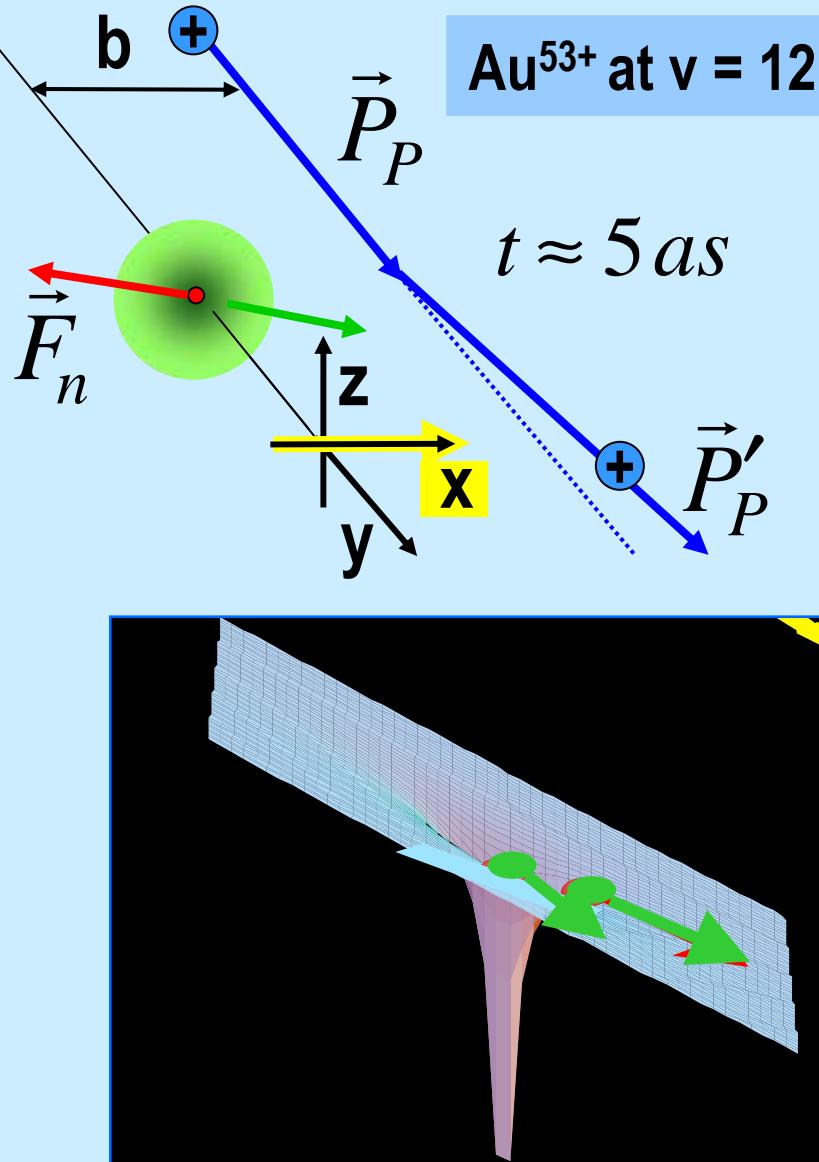
Canberra, Australia

A. Kheifets, J. Lower

UMR, Rolla

*M. Schulz, R.E. Olson, D. Madison,
B. DuBois*

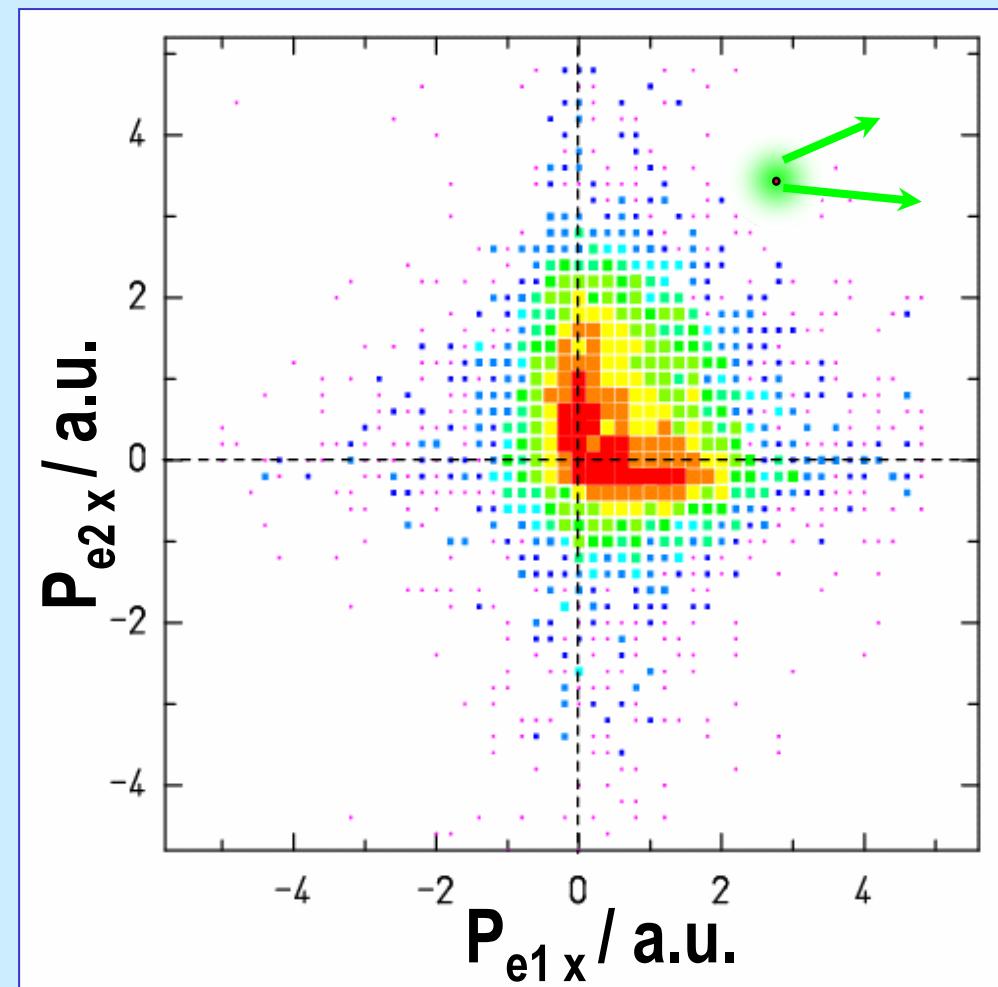
2. The Heisenberg Microscope



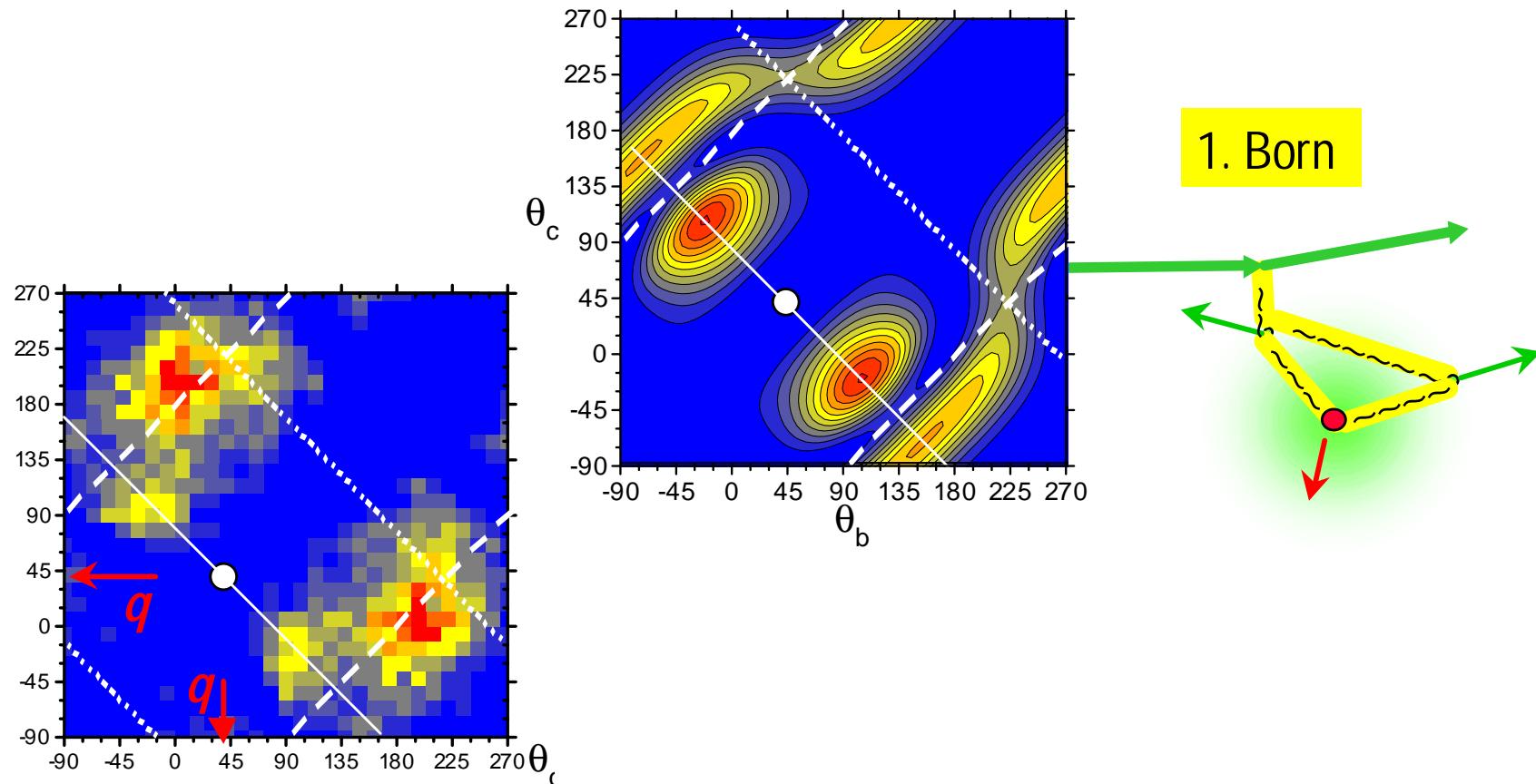
Au⁵³⁺ at $v = 12 \text{ a.u.}$

projection onto x-direction:

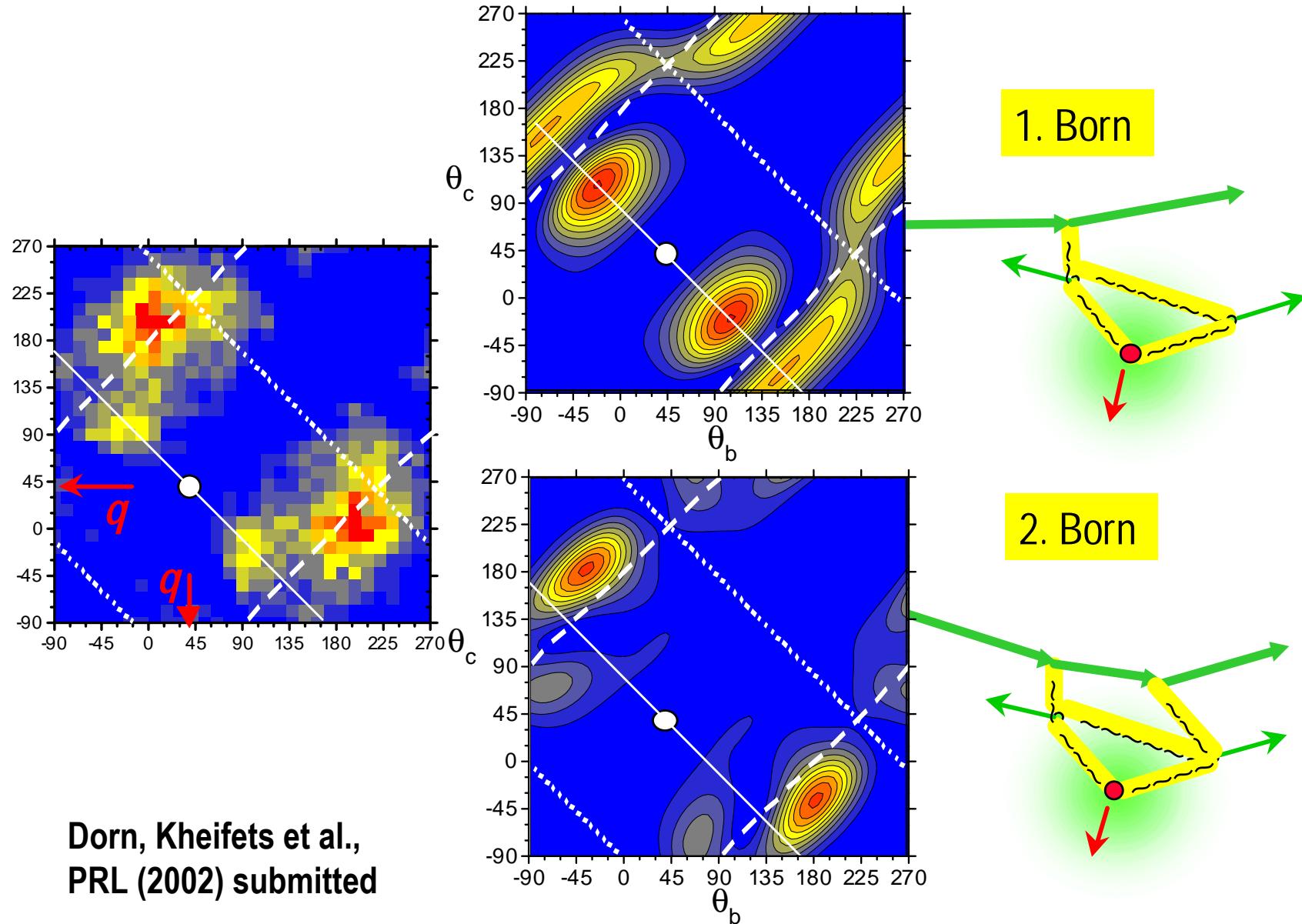
„maximum“ force



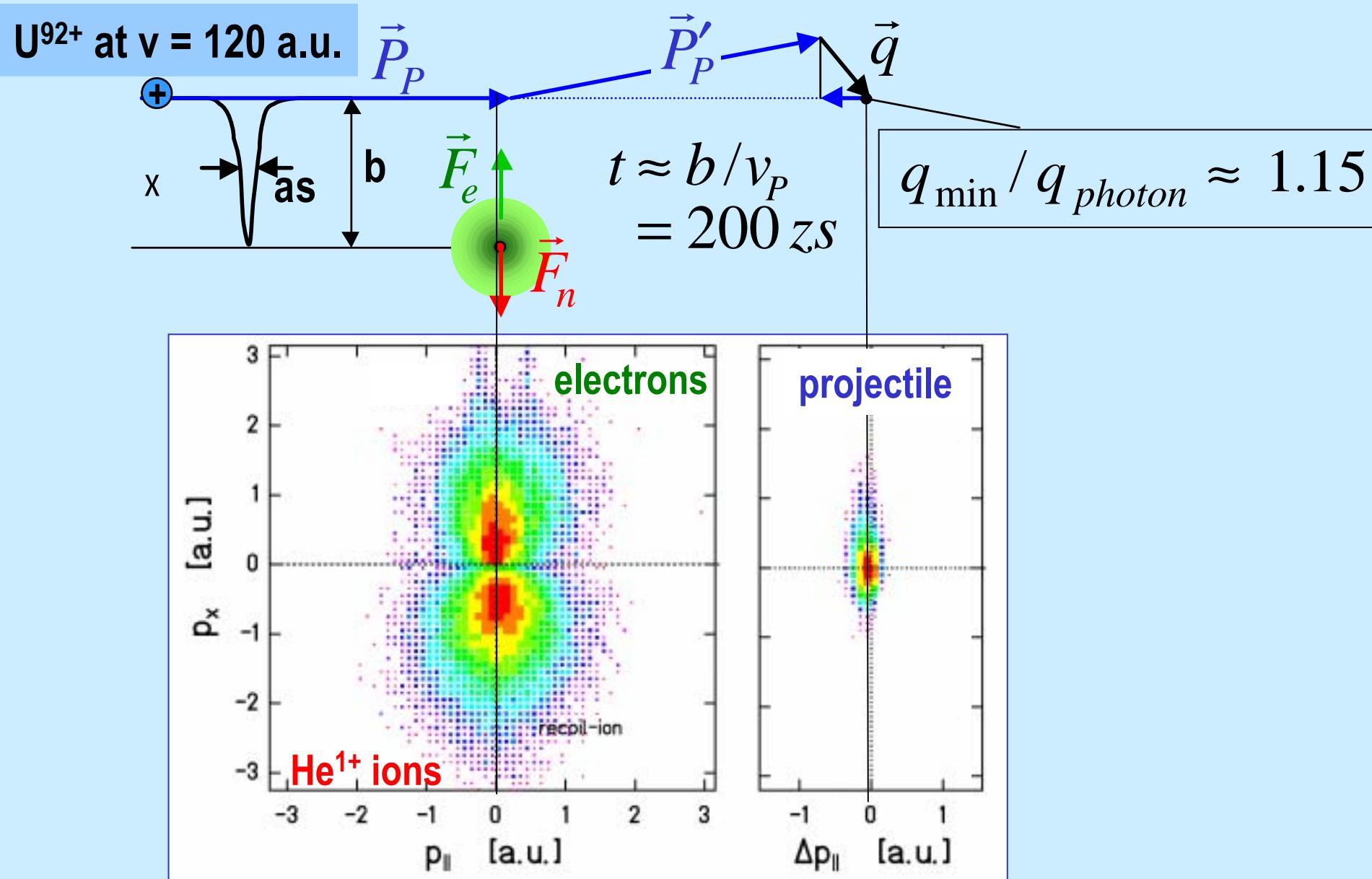
1. From 1st to 2nd Born: $p \leftrightarrow \bar{p}$



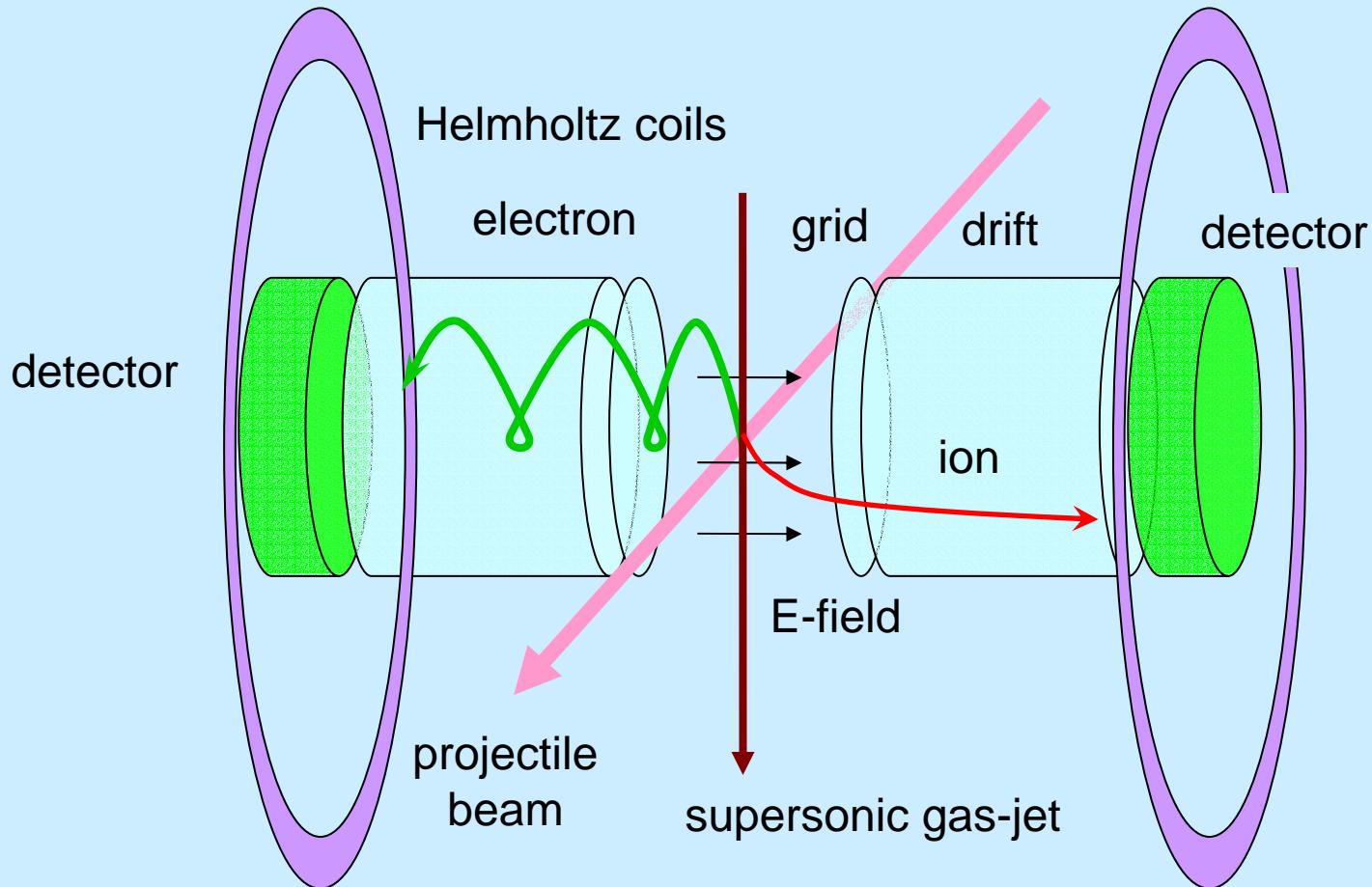
1. From 1st to 2nd Born: $p \leftrightarrow \bar{p}$



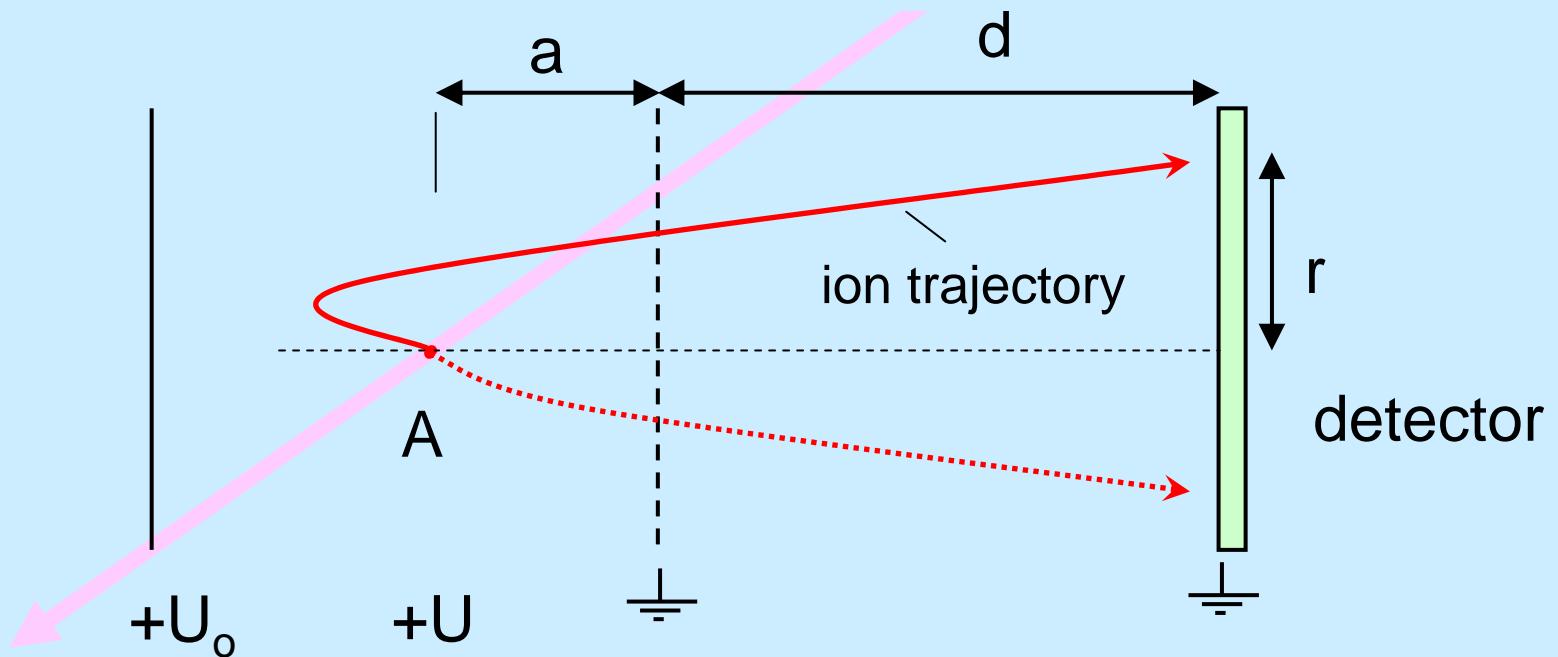
2. The Heisenberg Microscope



Reaction Microscopes



Reaction Microscopes

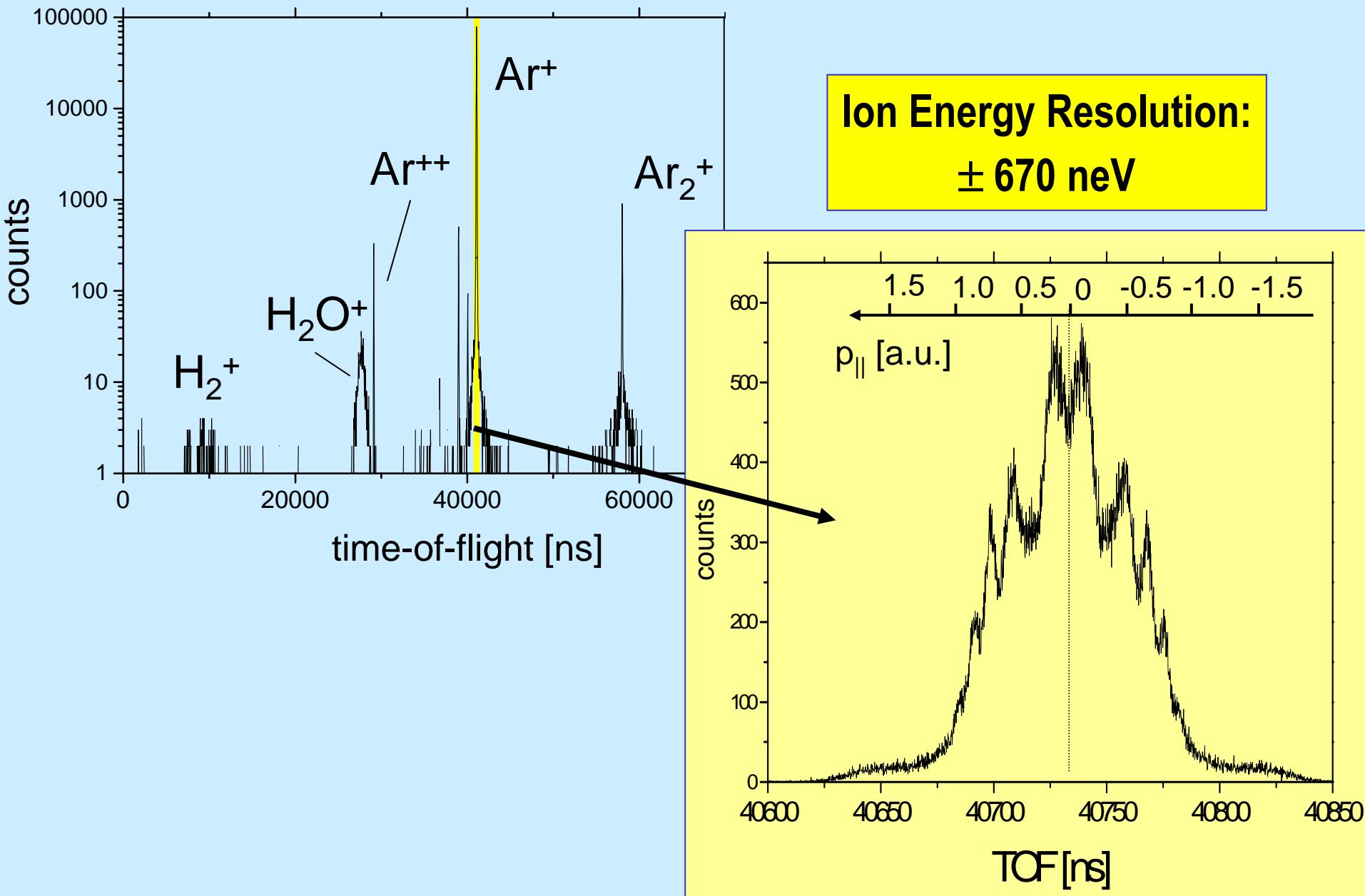


ion time-of-flight:

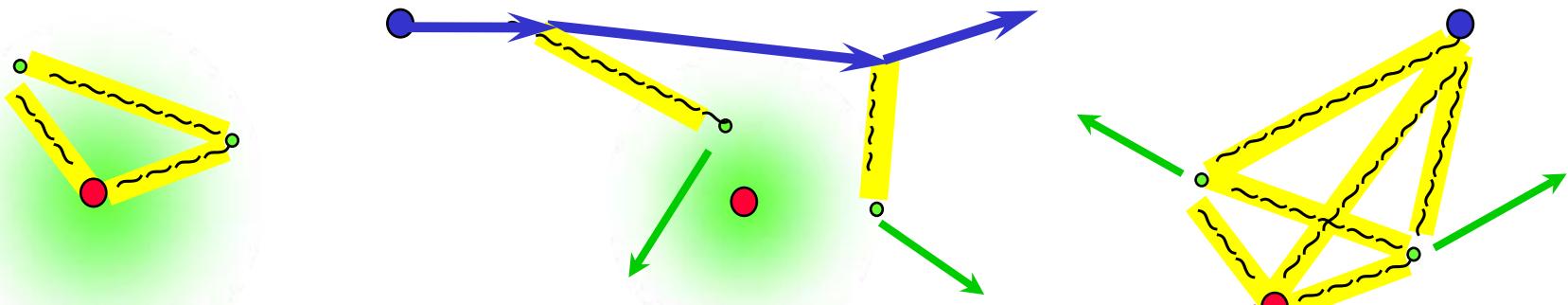
$$t_{+/-}(E) = 720 \cdot \sqrt{m} \cdot \left[\frac{2a}{\sqrt{E + qU}} \pm \sqrt{E} + \frac{d}{\sqrt{E + qU}} \right]$$

[t] = ns, [m] = amu, [E] = [qU] = eV, [a] = [d] = cm

Reaction Microscopes



Doppel- und Mehrfachionisation



Impulskorrelation
im Anfangszustand

Dynamische Mechanismen:
Matrixelemente

Struktur des
Vielteilchenkontinuums

- „Zu kompliziert“ (...1000 Par.)
Li, Ne, Xe,...Cluster, Moleküle
- Kleine Anteile entscheidend?:
Photoionis. bei hohen E_γ
Transfer-Ionisation (Ffm)
katalyt. chemische Reaktion
- Keine direkte Messung
Einfacher Mechanismus ?

- MBPT: „beliebig“ viele
Photonen : 3 (1. Ord.)
Multi-Photon: 6 (1. Ord.)
- Welche sind wichtig?
abhängig von Eichung?
abhängig vom Prozeß?
- Keine direkte Messung
isolierbar, phys. Realität ?

- Schrödinger- Gln. nicht lösbar
(e,2e) bei kleinen Energien
(p,pe) bei kleinen Energien
- Güte: Klassik, Semiklassik
- Dichtefunktionaltheorie
- keine direkte Messung: $n > 3$
Zentralfeld \leftrightarrow Korrelation
Symmetrien \rightarrow neue Symm