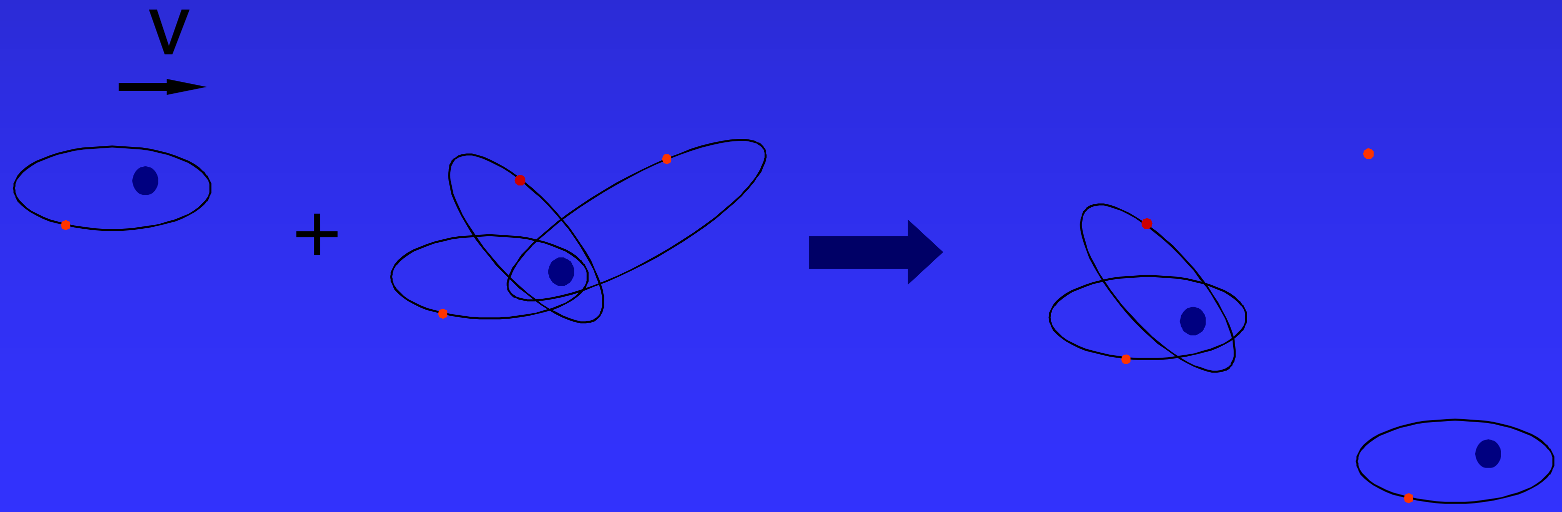
# Atomic collisions using slow antiprotons in ASACUSA at CERN

**Károly Tőkési**

**Institute of Nuclear Research of the Hungarian Academy of Sciences, (ATOMKI)**
**H--4001 Debrecen, P.O.Box 51, Hungary**



# Co-workers

Experiment

**H. Knudsen**[a], H.-P.E. Kristiansen[a], H.D. Thomsen[a], U.I. Uggerhřj[a], T. Ichioka[a],1, S.P. Mřller[b], C.A. Hunniford[c], R.W. McCullough[c], M. Charlton[d], N. Kuroda[e], Y. Nagata[e], H.A. Torii[e], Y. Yamazaki[e,f], H. Imao[f], H.H. Andersen[g]

[a] Department of Physics and Astronomy, University of Aarhus, Ny Munkegade Building 1520, 8000 Aarhus C, Denmark
[b] Institute for Storage Ring Facilities, University of Aarhus, Denmark
[c] Department of Physics and Astronomy, Queens University, Belfast, UK
[d] Department of Physics, University of Swansea, UK
[e] Institute of Physics, Komaba, University of Tokyo, Japan
[f] Atomic Physics Laboratory, RIKEN, Saitama, Japan
[g] Niels Bohr Institute, University of Copenhagen, Denmark

**Theory**

J. Wang
Department of Physics, University of Massachusetts Dartmouth, North Dartm outh, MA 02747, USA
L. Gulyás
Institute of Nuclear Research of the Hungarian Academy of Science (ATOMKI), Debrecen, Hungary
S. Borbély
Faculty of Physics, Babes-Bolyai University,str. Kogalniceanu nr. 1, 400084 Cluj-Napoca, Romania
S. Nagele, J. Feist, J. S. Nagele, J. Feist, Burgdörfer
Institute for Theoretical Physics, Vienna University of Technology, A1040 Vienna Austria, EU

# Outlook

- Why? – antimatter factory-> new energy source
  – test of various theories

Experiment – Theory
time-of-flight CC, CDW, CTMC

- Past

Single ionization of He
Single and double ionization of Ar

- Present

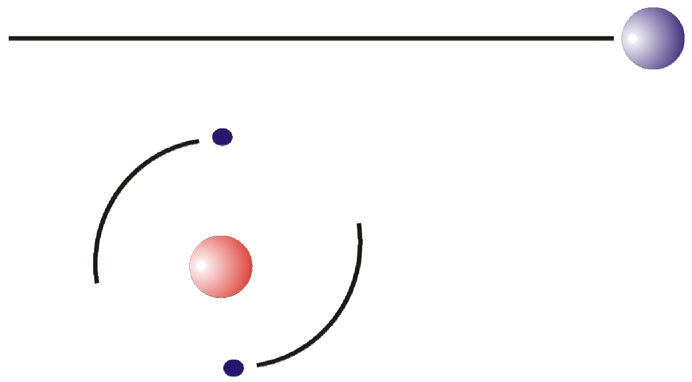
Ionization of H and $H_2$

- Future

Differential cross sections – anti-cusp

Summary, Conclusions

# Dynamic systems with more than one electron



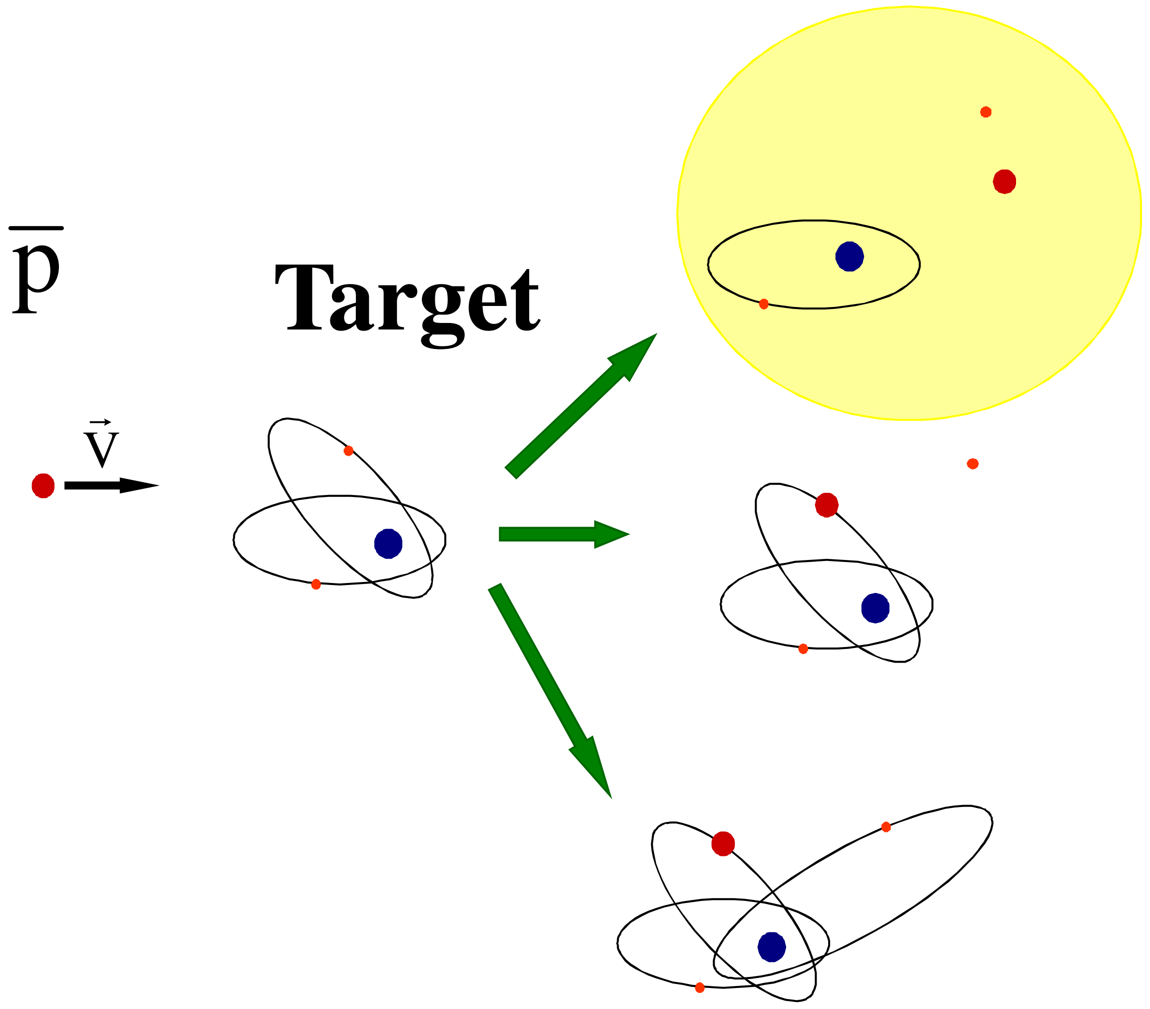
Advantages with antiprotons:

Antiprotons do not capture electrons (one center problem, essentially)
Antiprotons follow a classical path (classical orbital approximation)
Very slow antiprotons can still ionize ( ”adiabatic” collisions can be investigated)

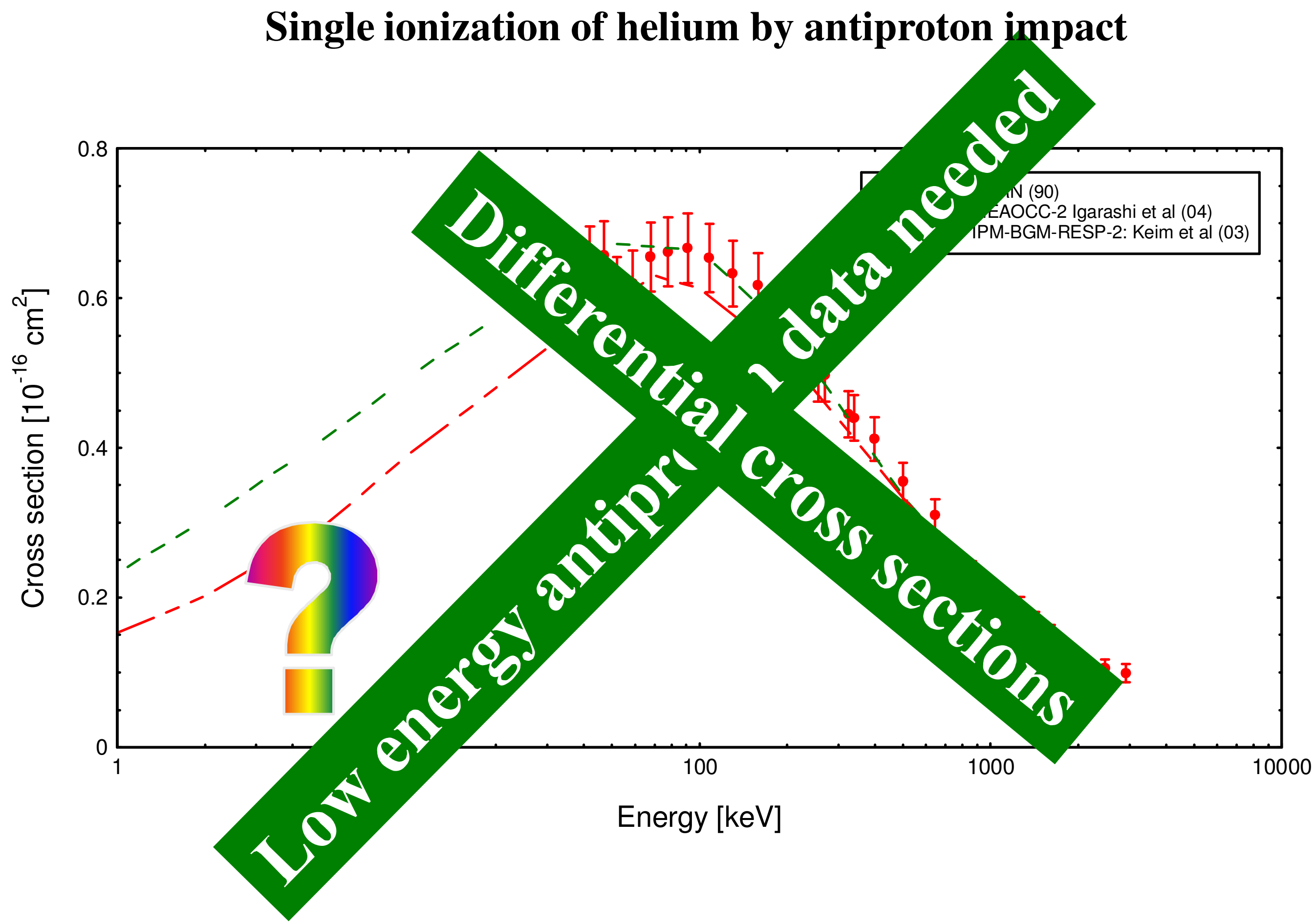
- Antiprotons can give benchmark data

# Antiproton Radiotherapy – application of antiprotons??

# Reaction Channels



# Ionization of noble gas atoms in slow antiproton collisions

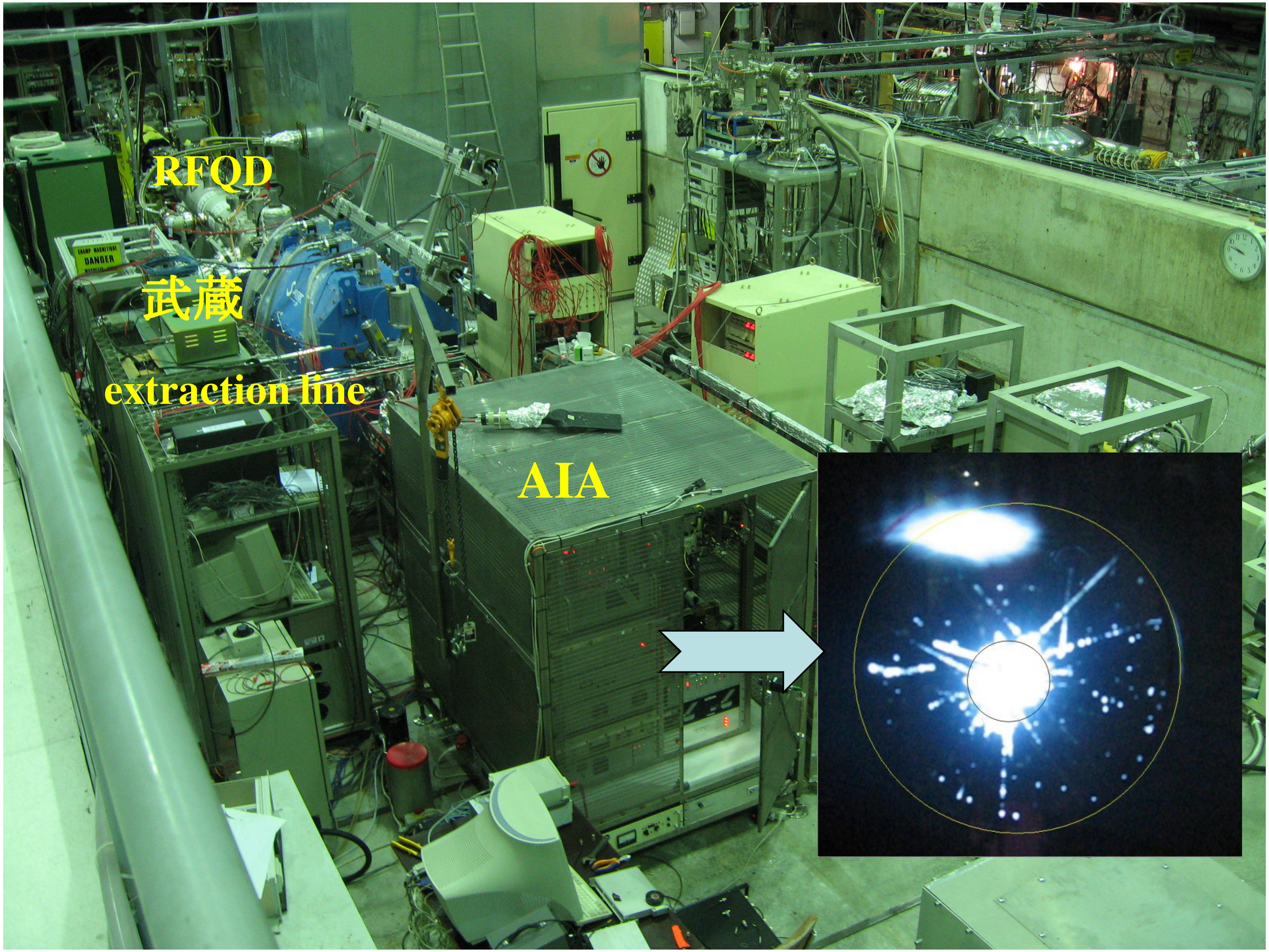


# Past

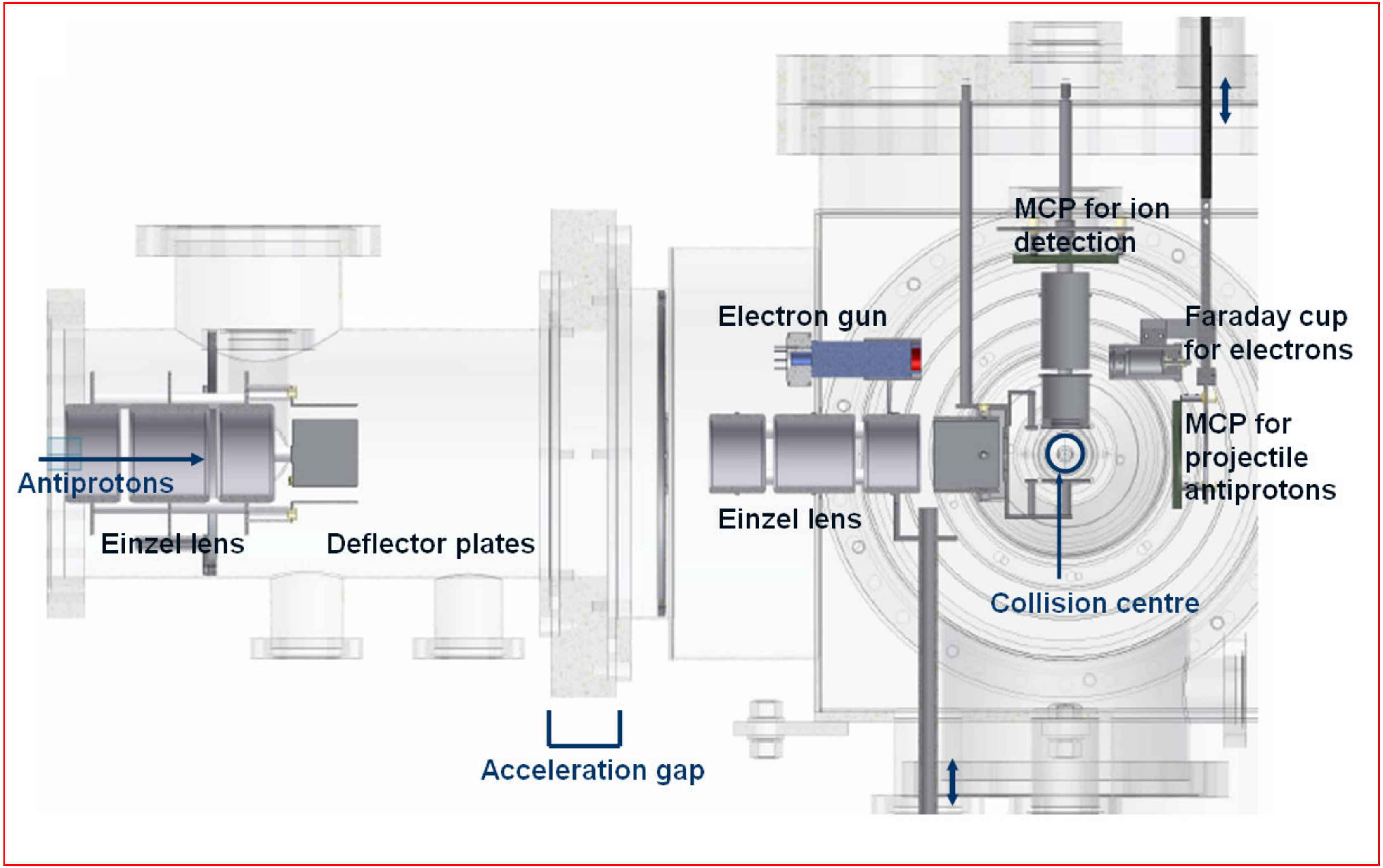
"Ionization of Helium and Argon by Very Slow Antiproton Impact"
Knudsen et al Phys. Rev. Letters 101 (2008)

"On the double ionization of helium by very slow antiproton impact"
Knudsen et al NIMB 267 244 (2009)

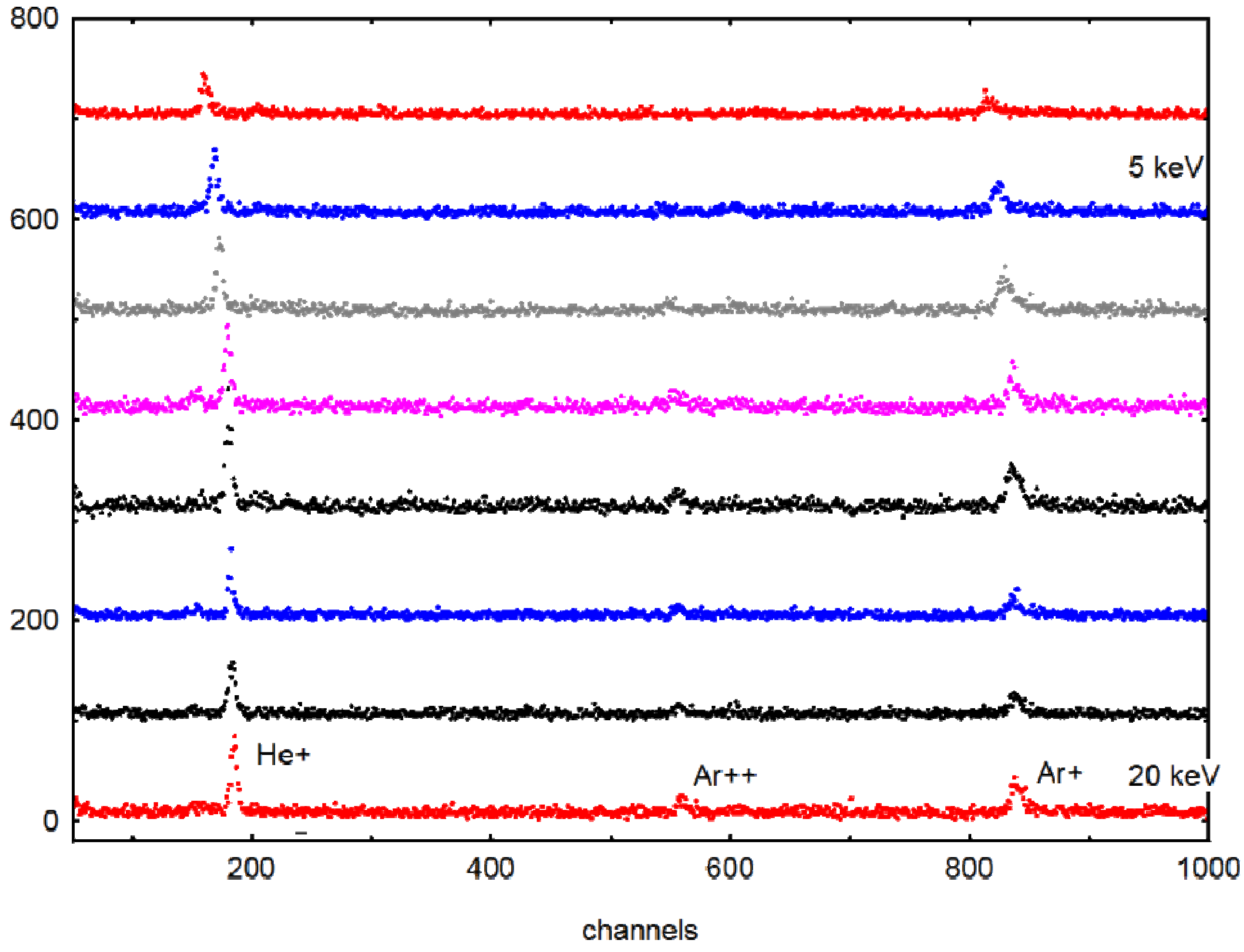
# Experimental setup



# AIA

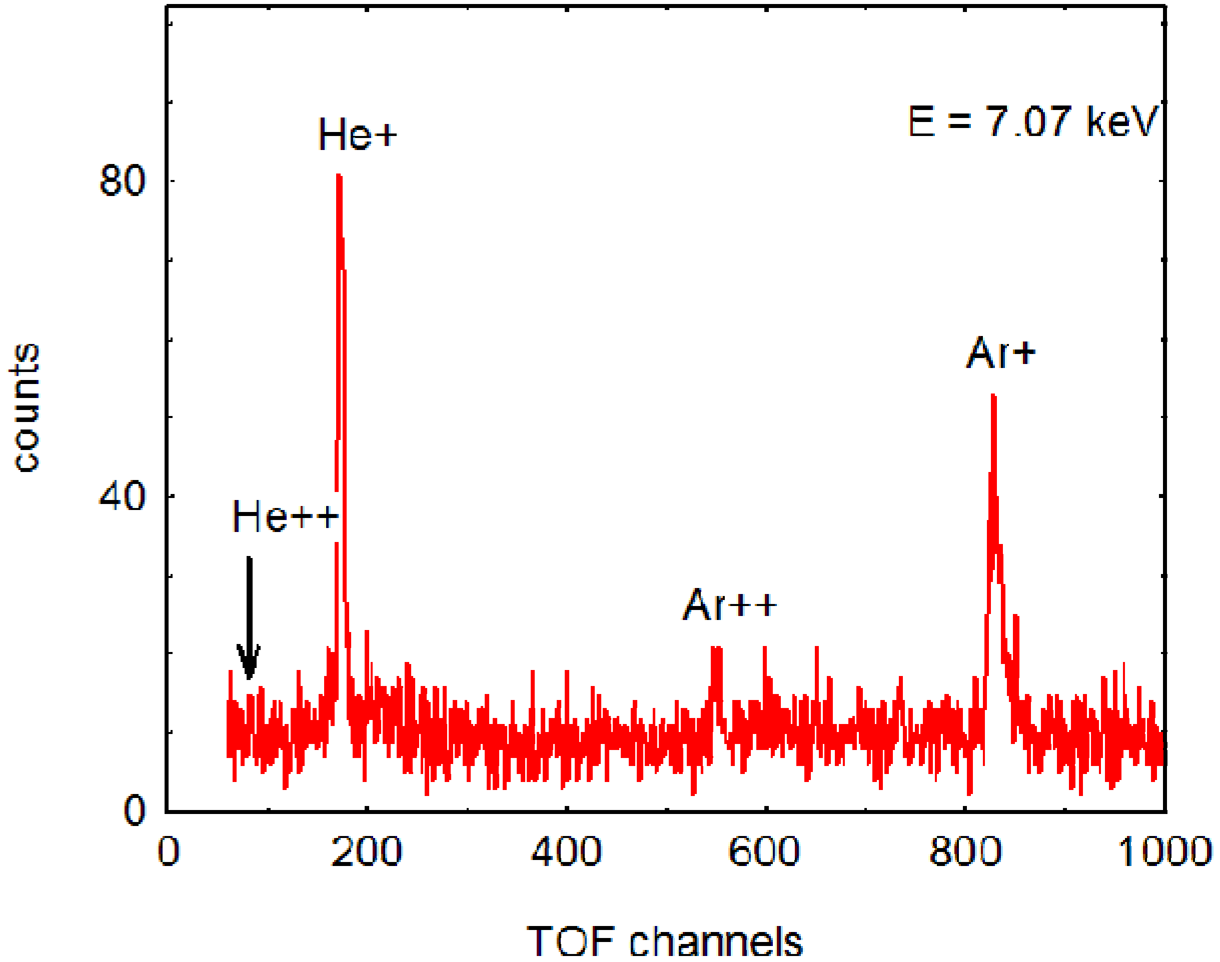

MCP for ion
detection
Electron gun
Faraday cup
for electrons
MCP for
projectile
antiprotons
Antiprotons
Einzel lens
Deflector plates
Einzel lens
Collision centre
Acceleration gap

# TOF SPECTRA

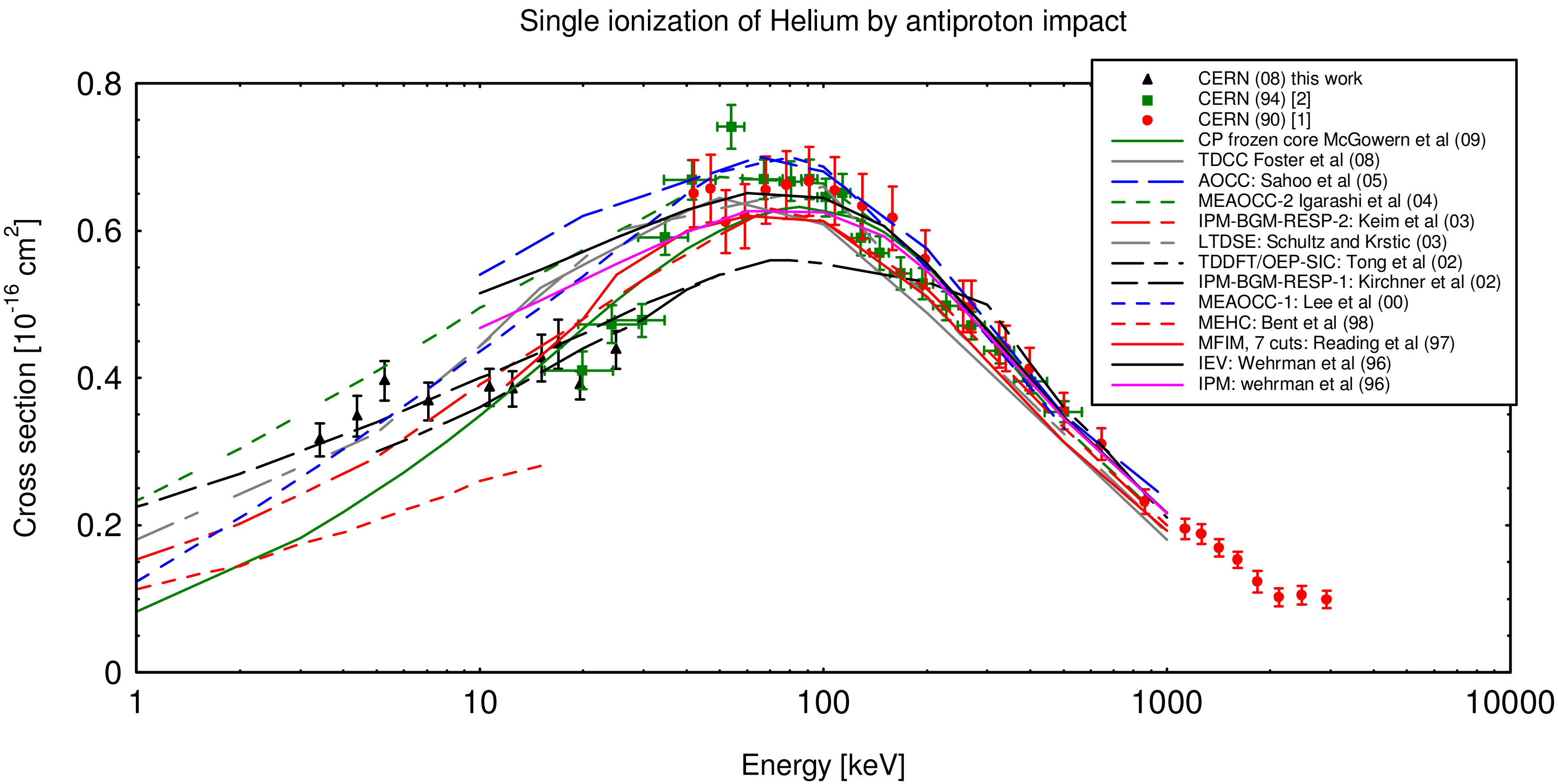


800
600
400
200
0
5 keV
He+
Ar++
Ar+
20 keV
200
400
600
800
1000
channels

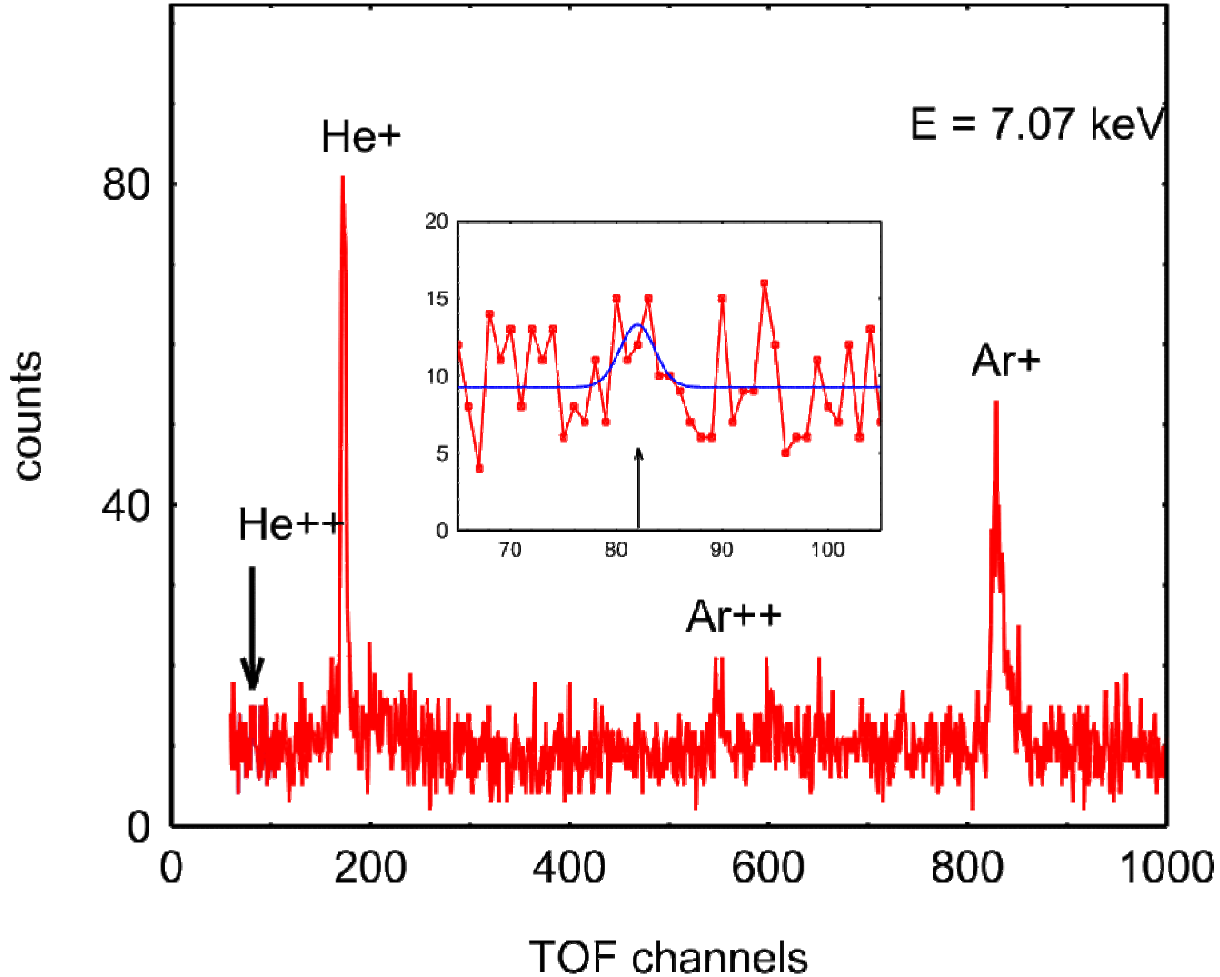
# Ionization of helium atoms in slow antiproton collisions



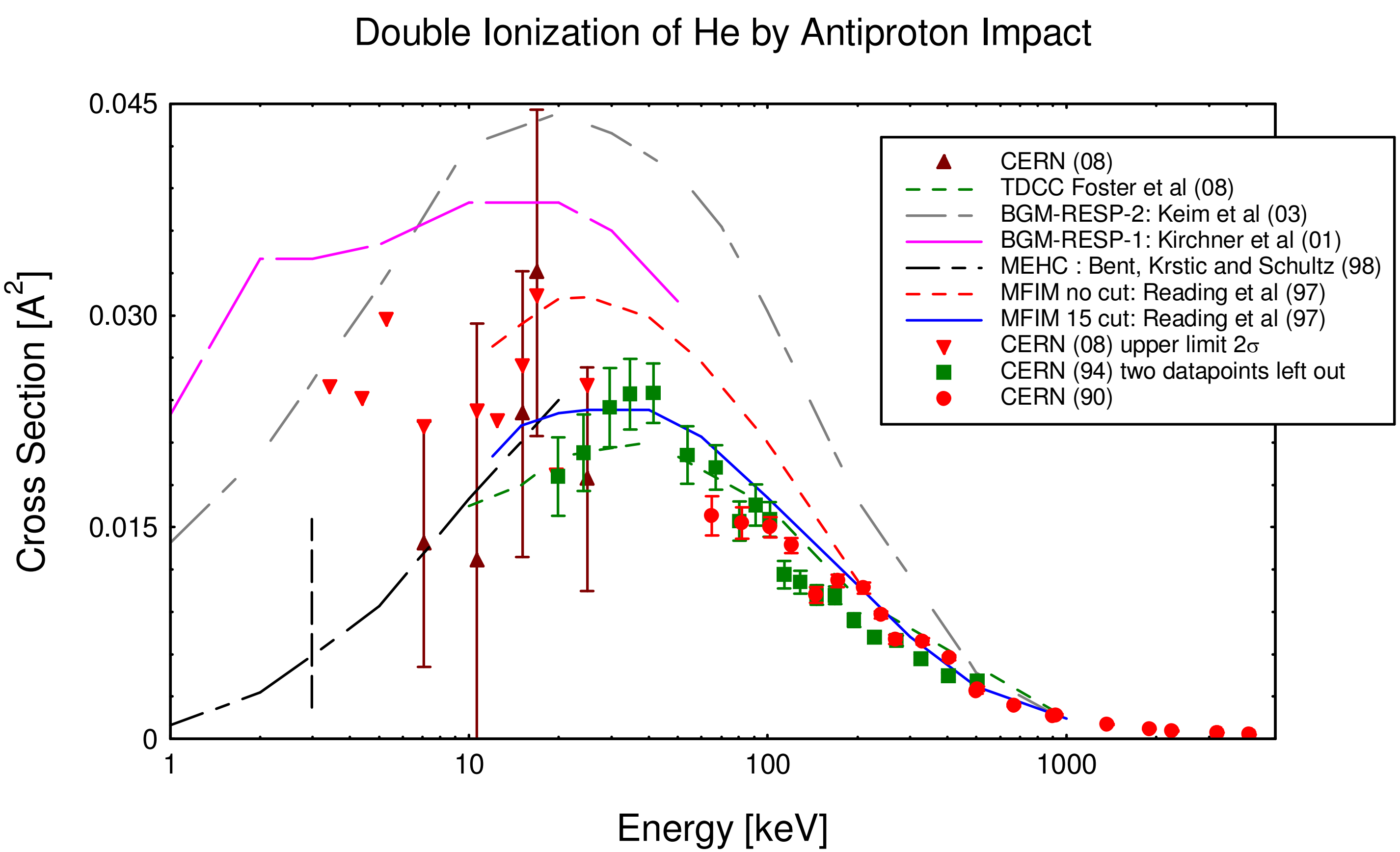
# Single Ionization of helium atoms in slow antiproton collisions
# THEORY in the year 2009



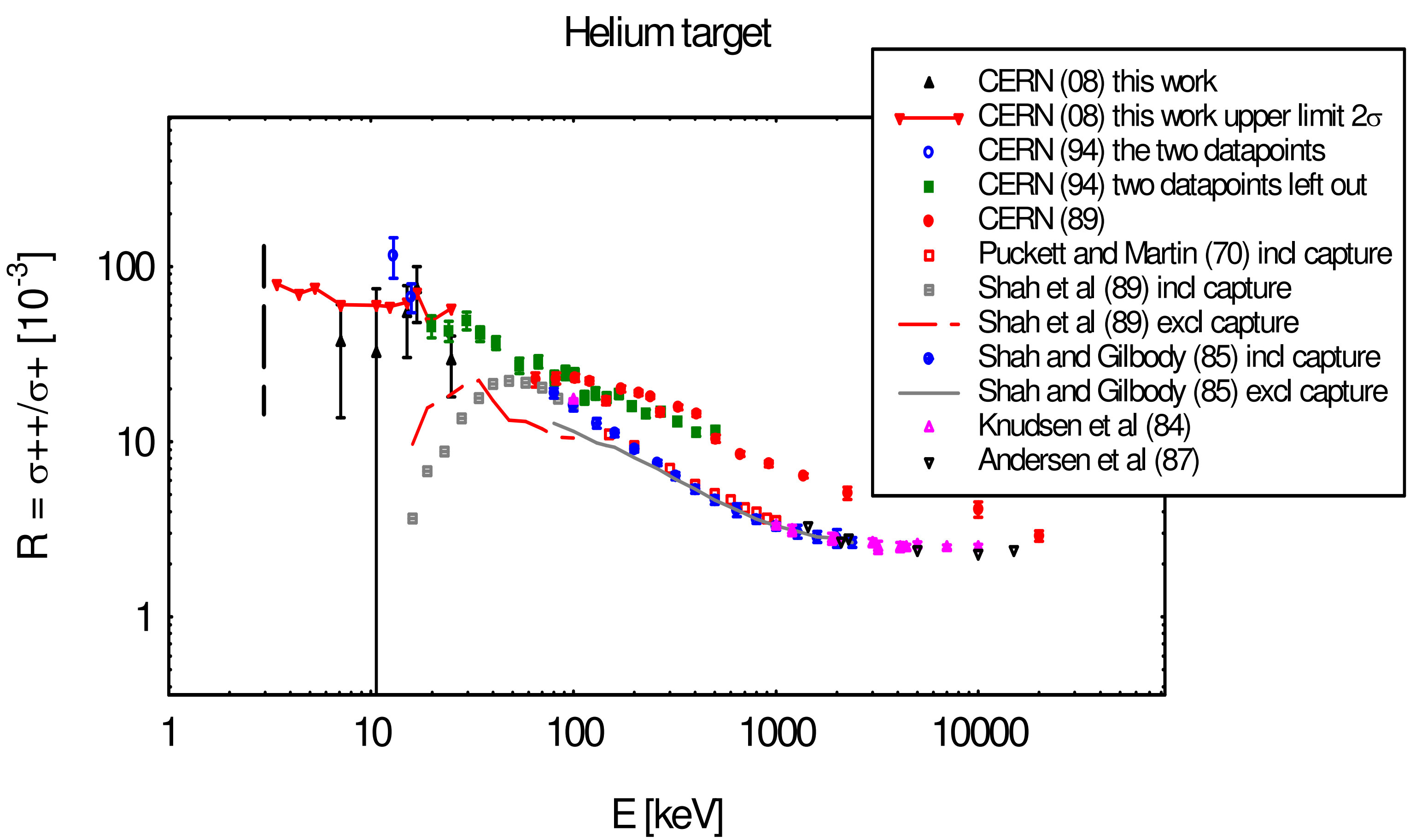
# Double Ionization of helium atoms in slow antiproton collisions



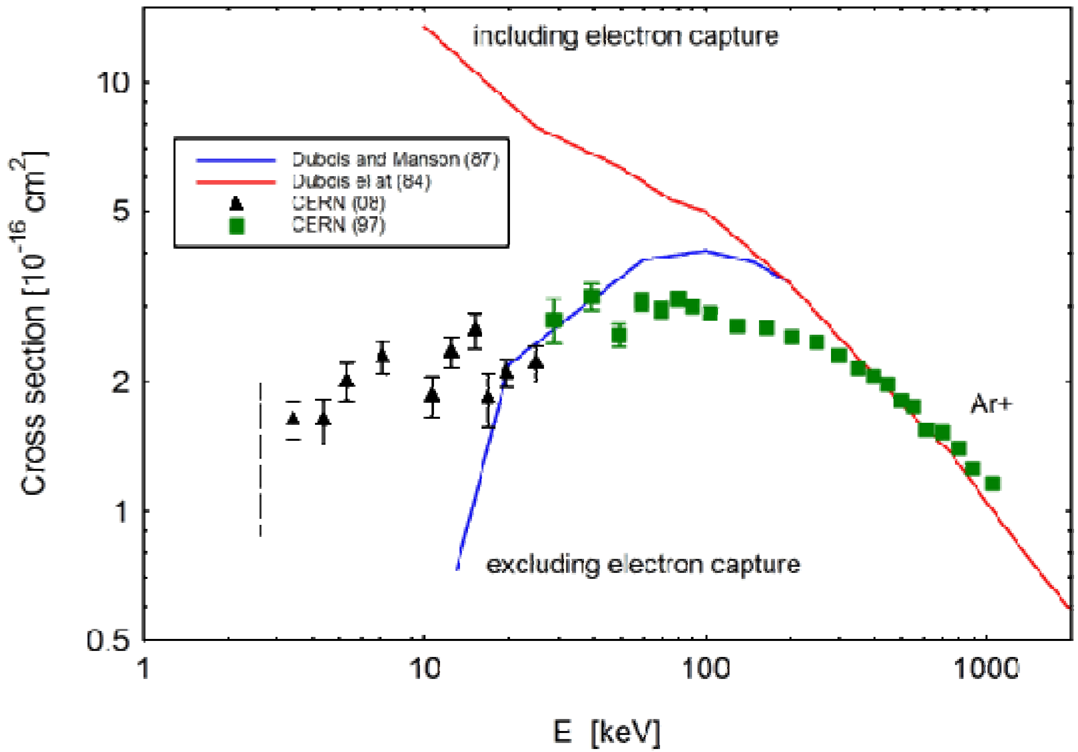
# Double Ionization of helium atoms in slow antiproton collisions



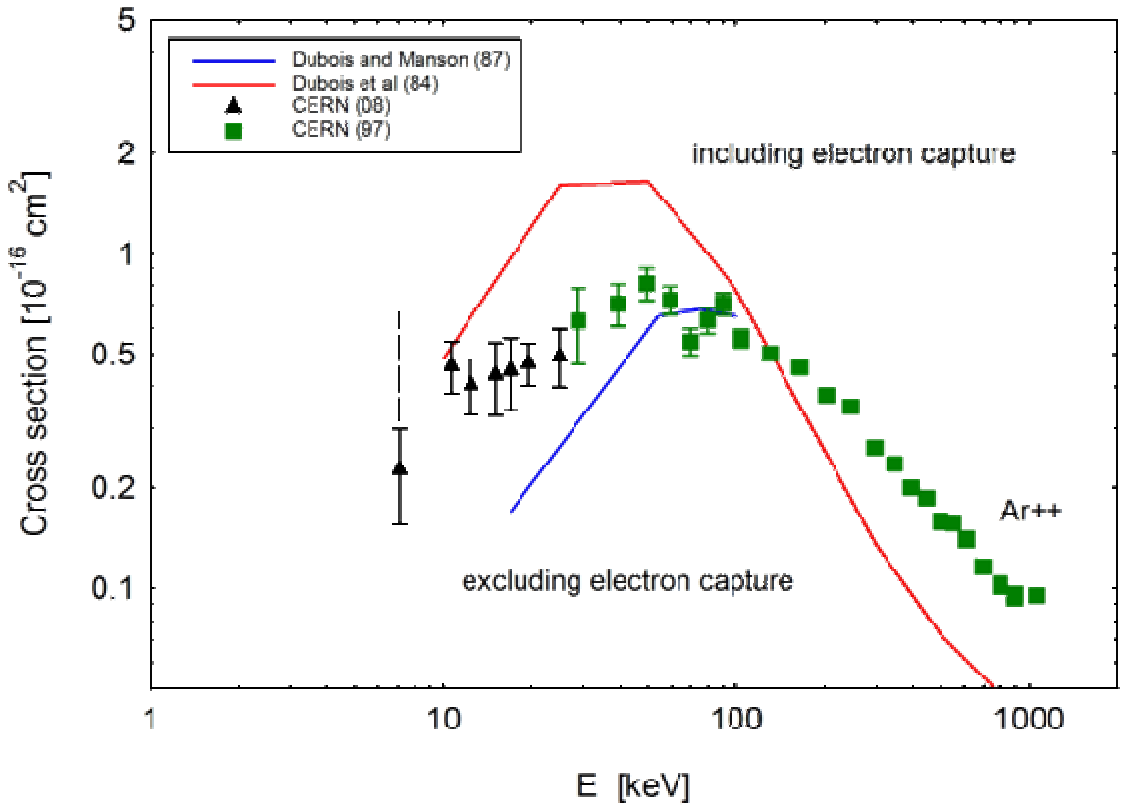
# Double Ionization of helium atoms in slow antiproton collisions



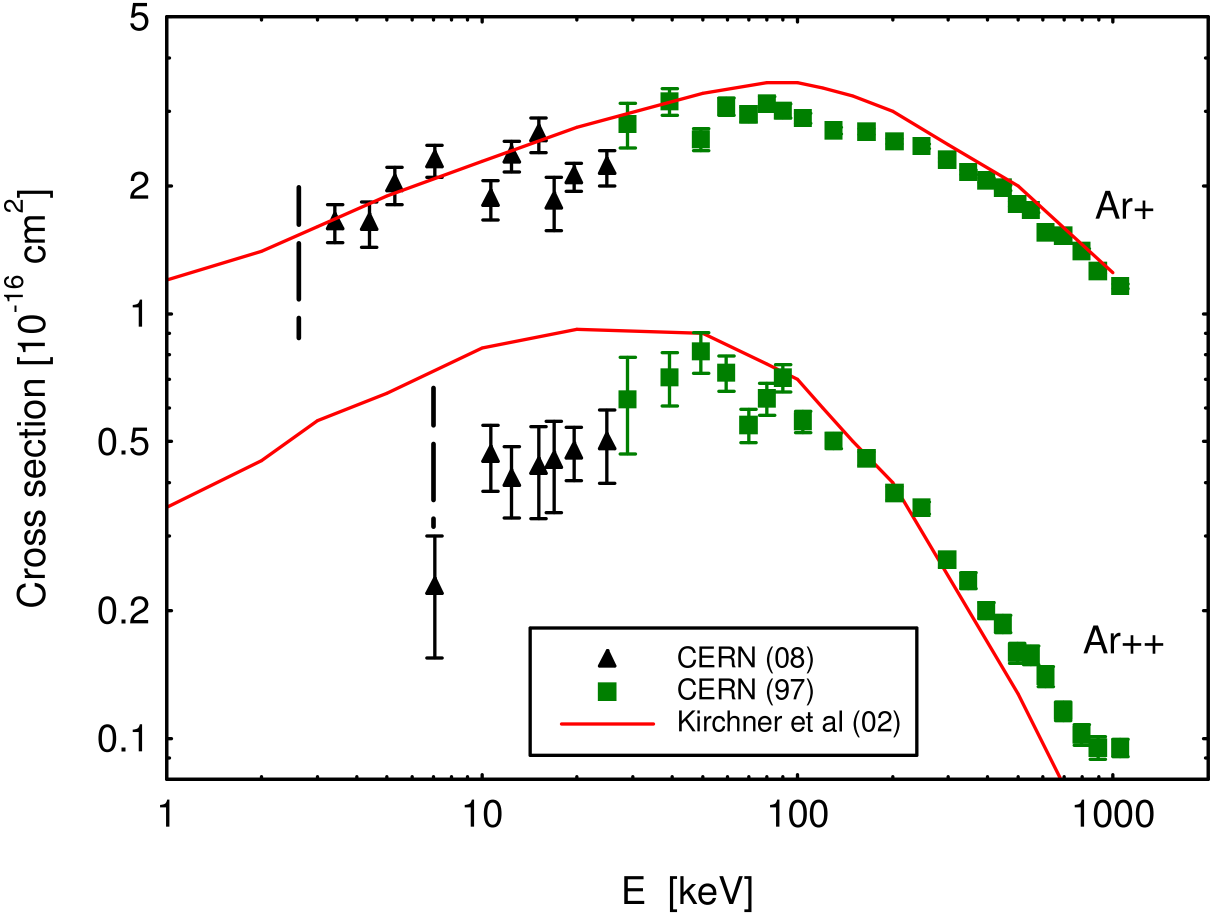
# Single ionization of argon atoms in slow antiproton collisions



# Double ionization of argon atoms in slow antiproton collisions

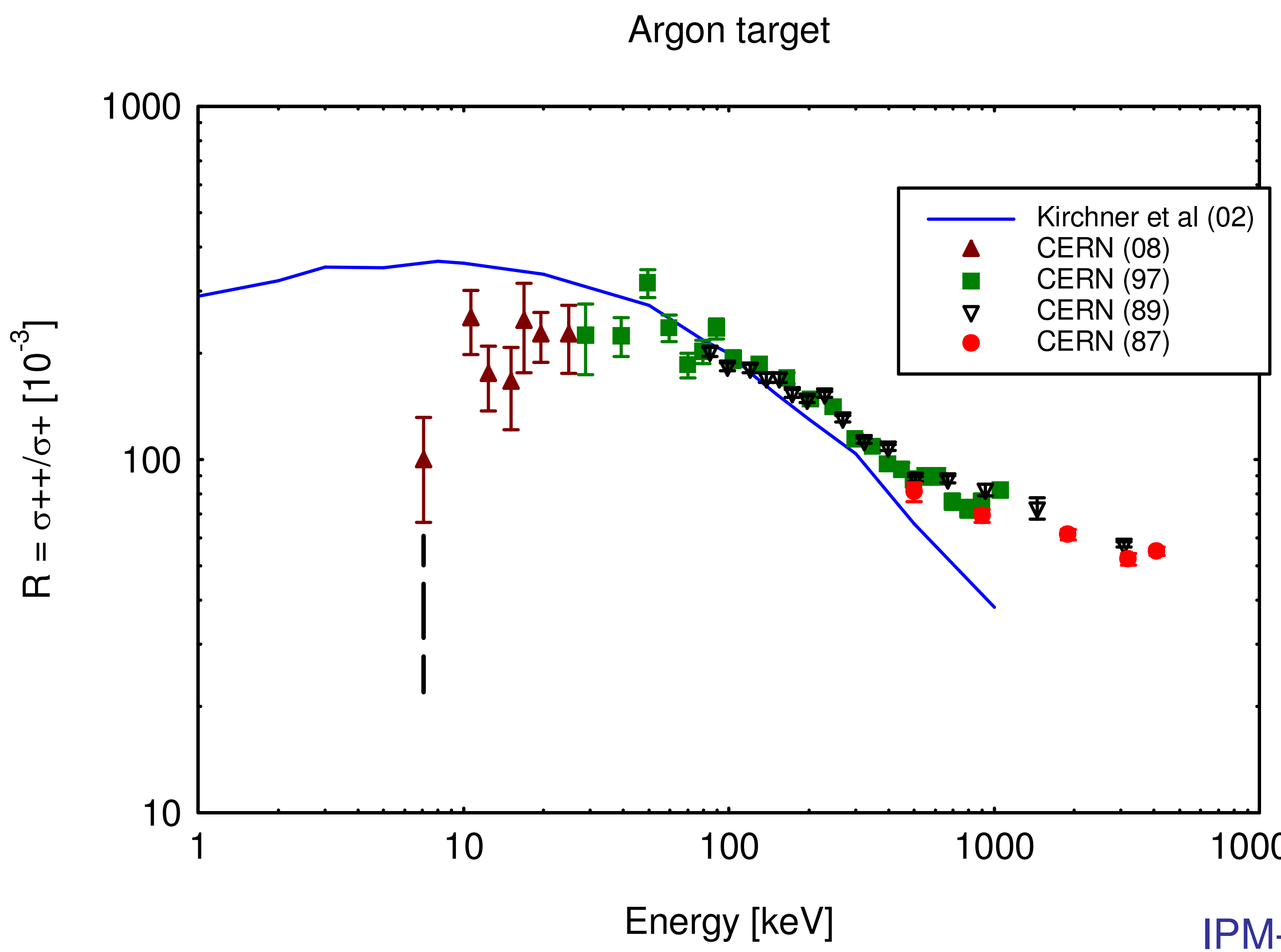


# Ionization of argon atoms in slow antiproton collisions




Theory:
IPM-BGM-RESP

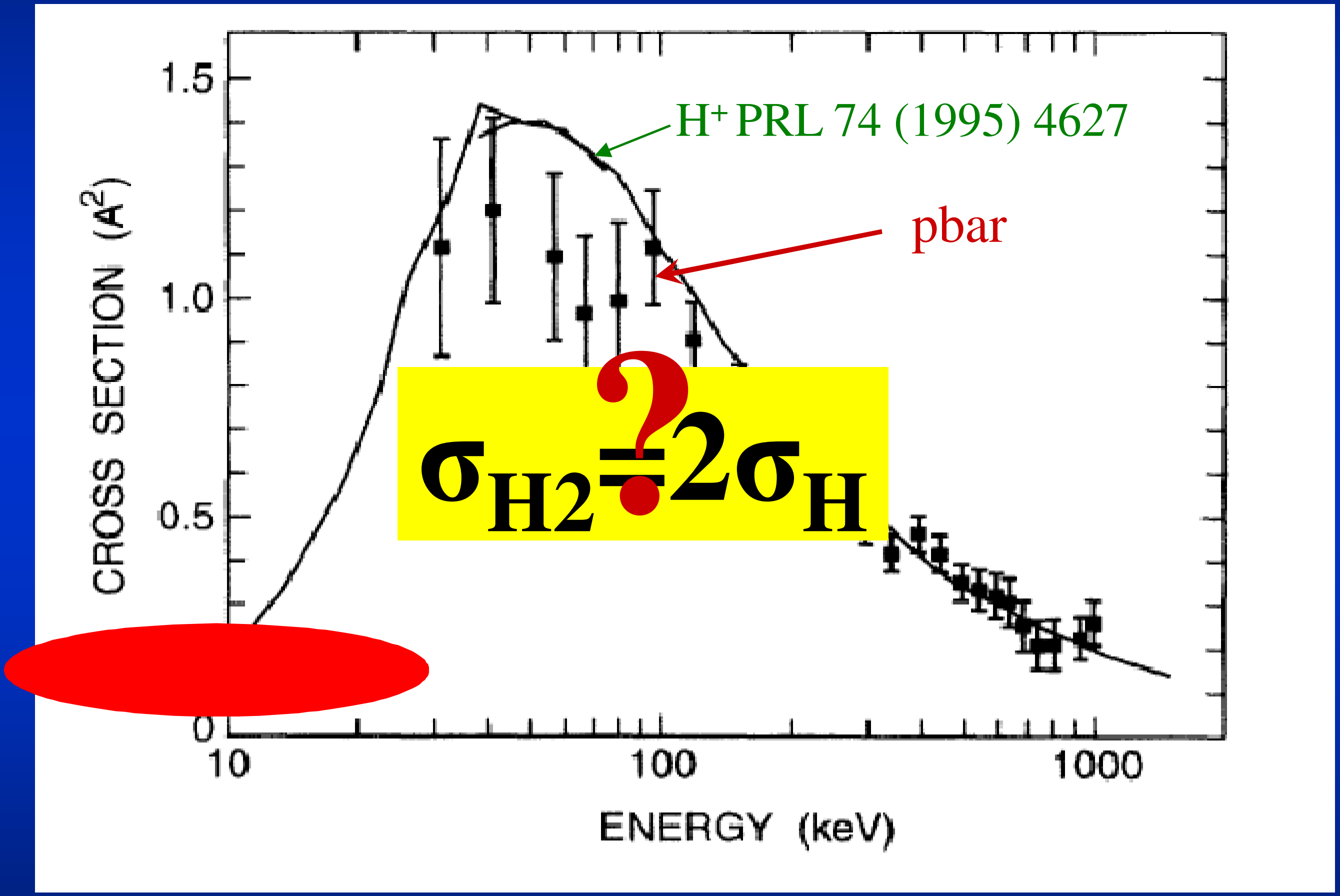
# Ionization of argon atoms in slow antiproton collisions




Theory:
IPM-BGM-RESP

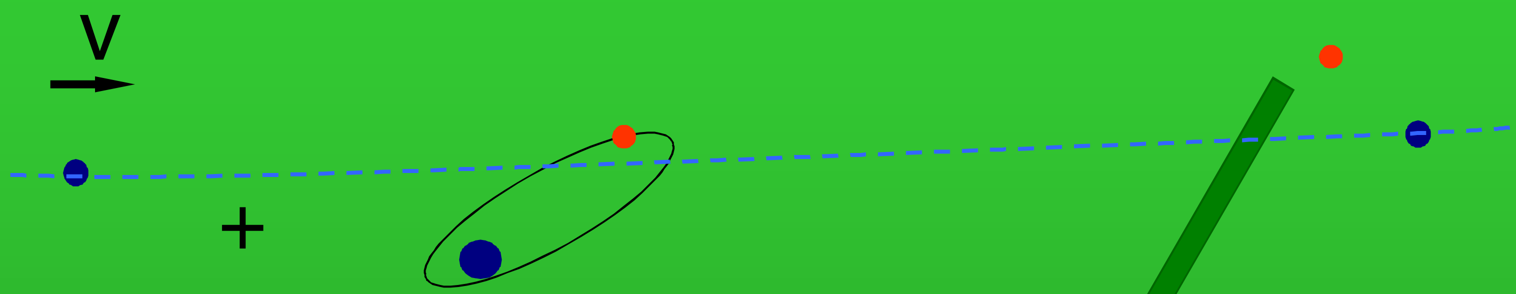
# Present

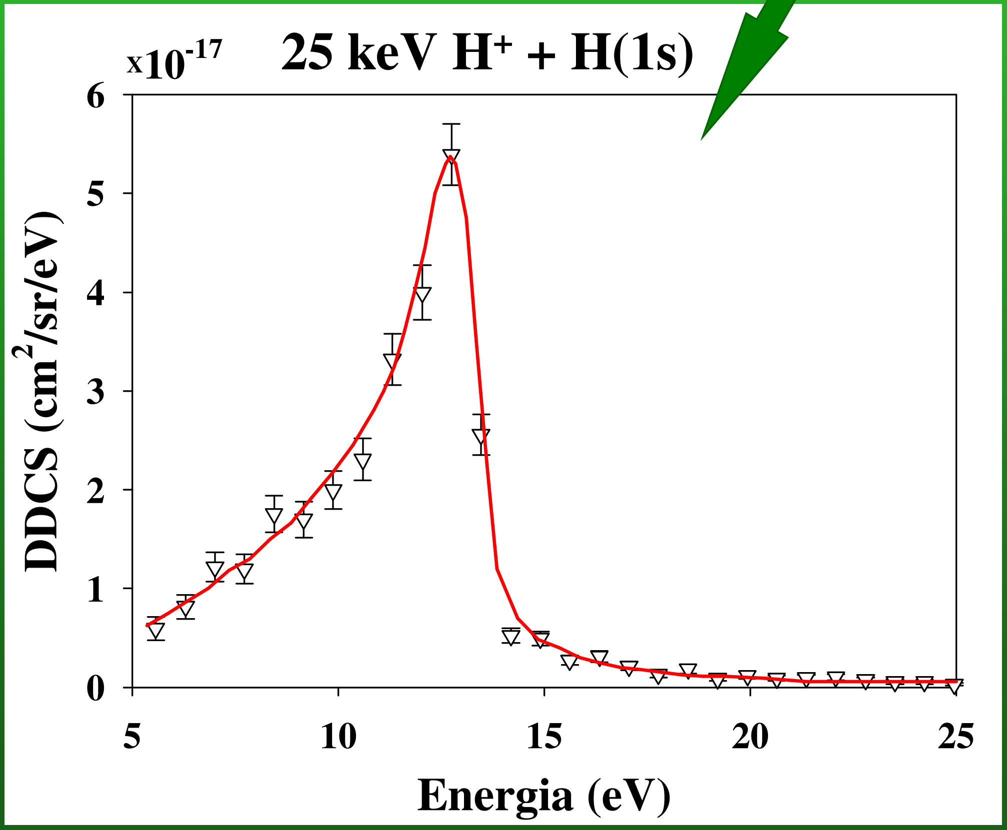
# Ionization of H and $H_2$



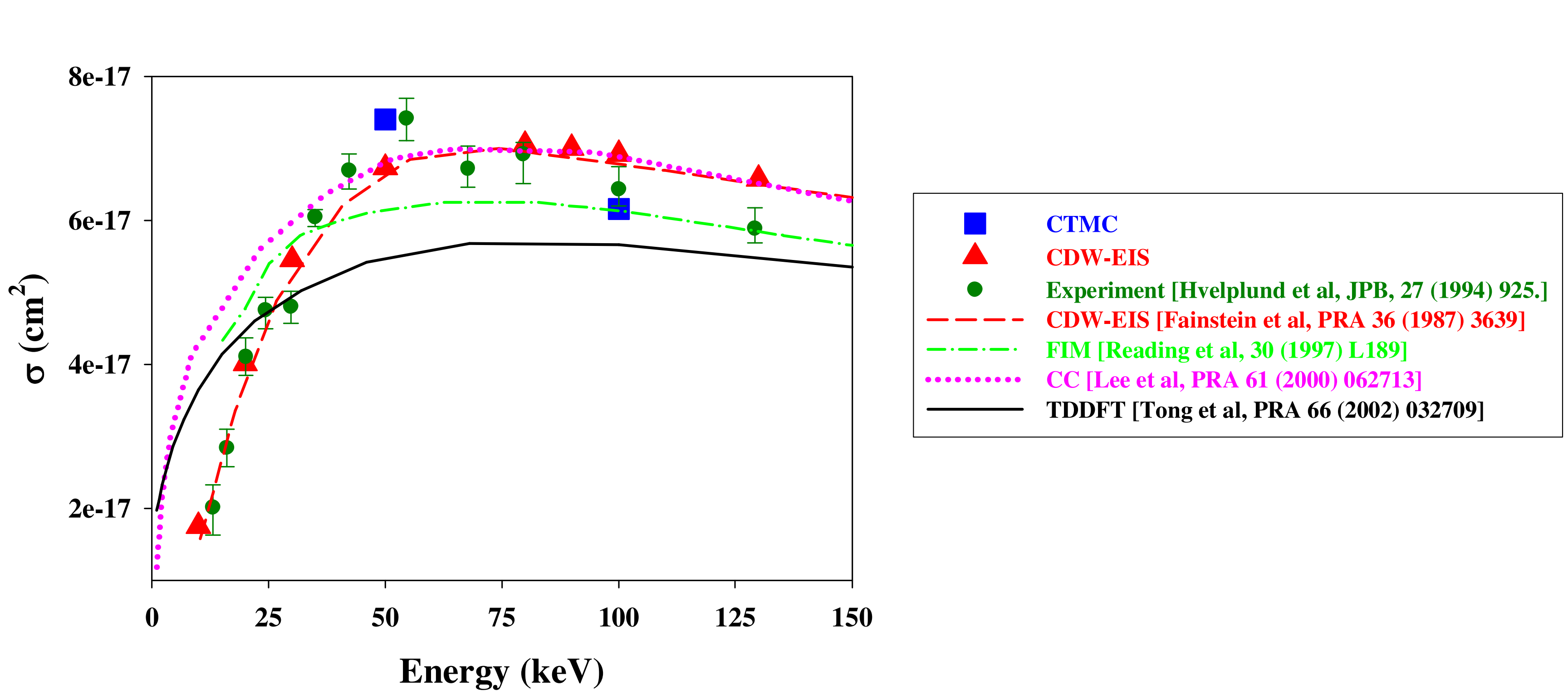
# Future/Theory

# The special case of target ionization

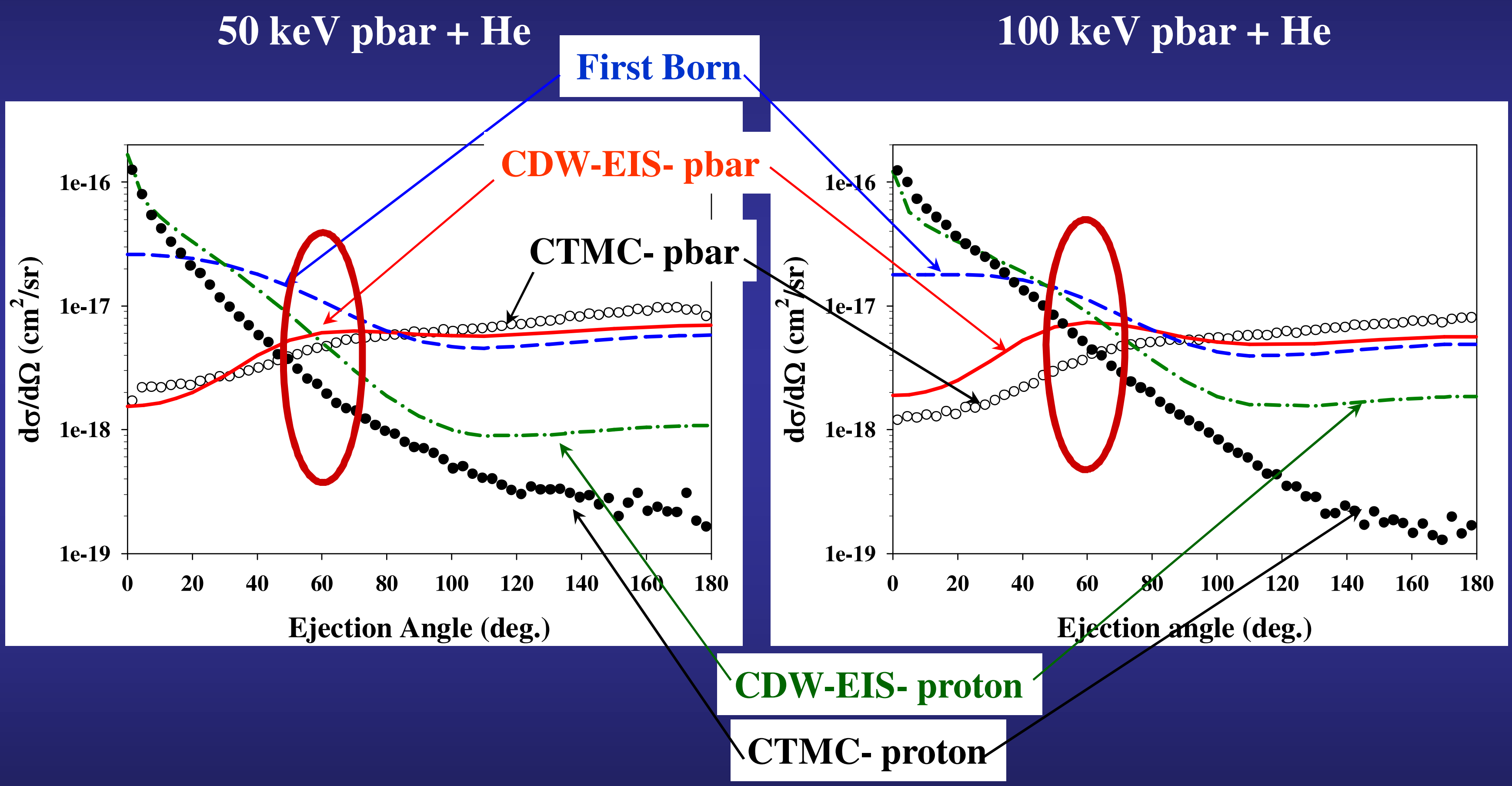


# Total cross sections



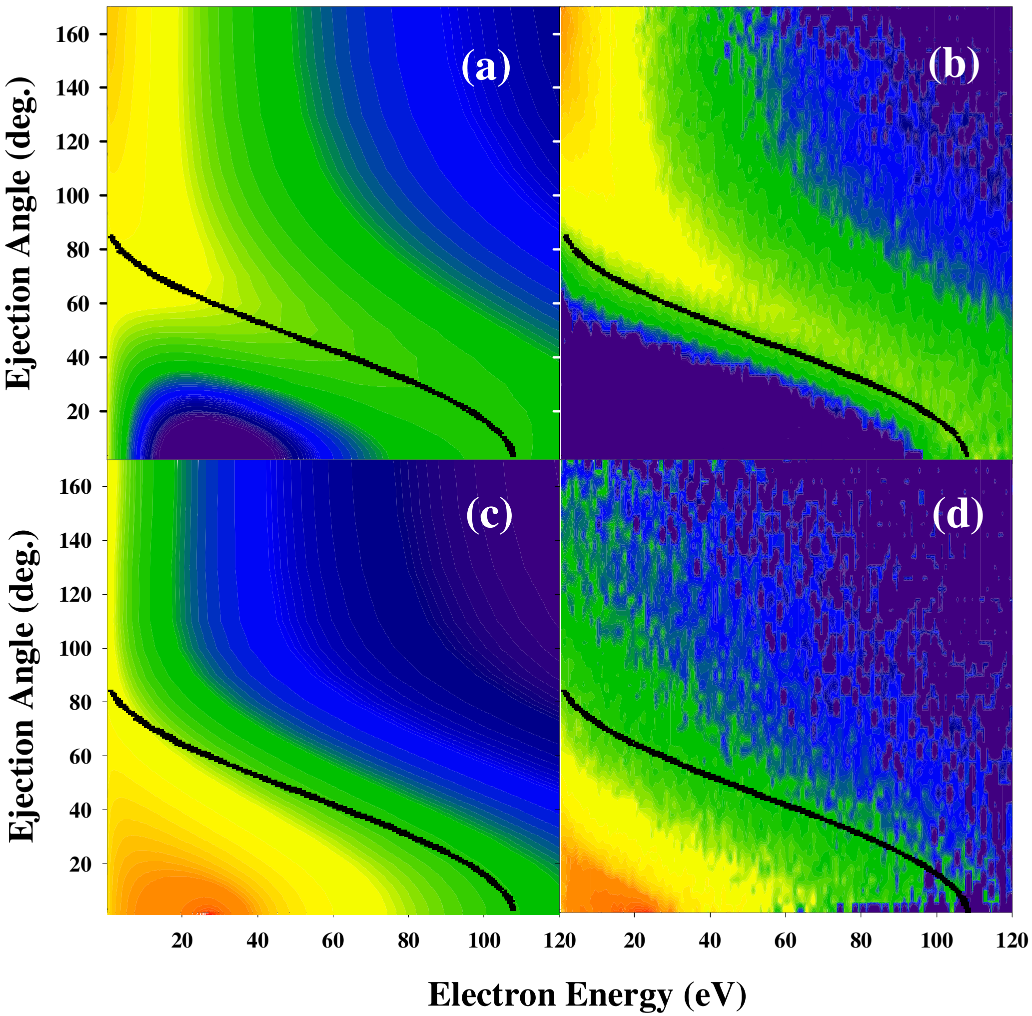
# Angular differential electron emission cross sections



# Double differential electron emission cross sections

## E=50 keV

**CDW-EIS** **CTMC**



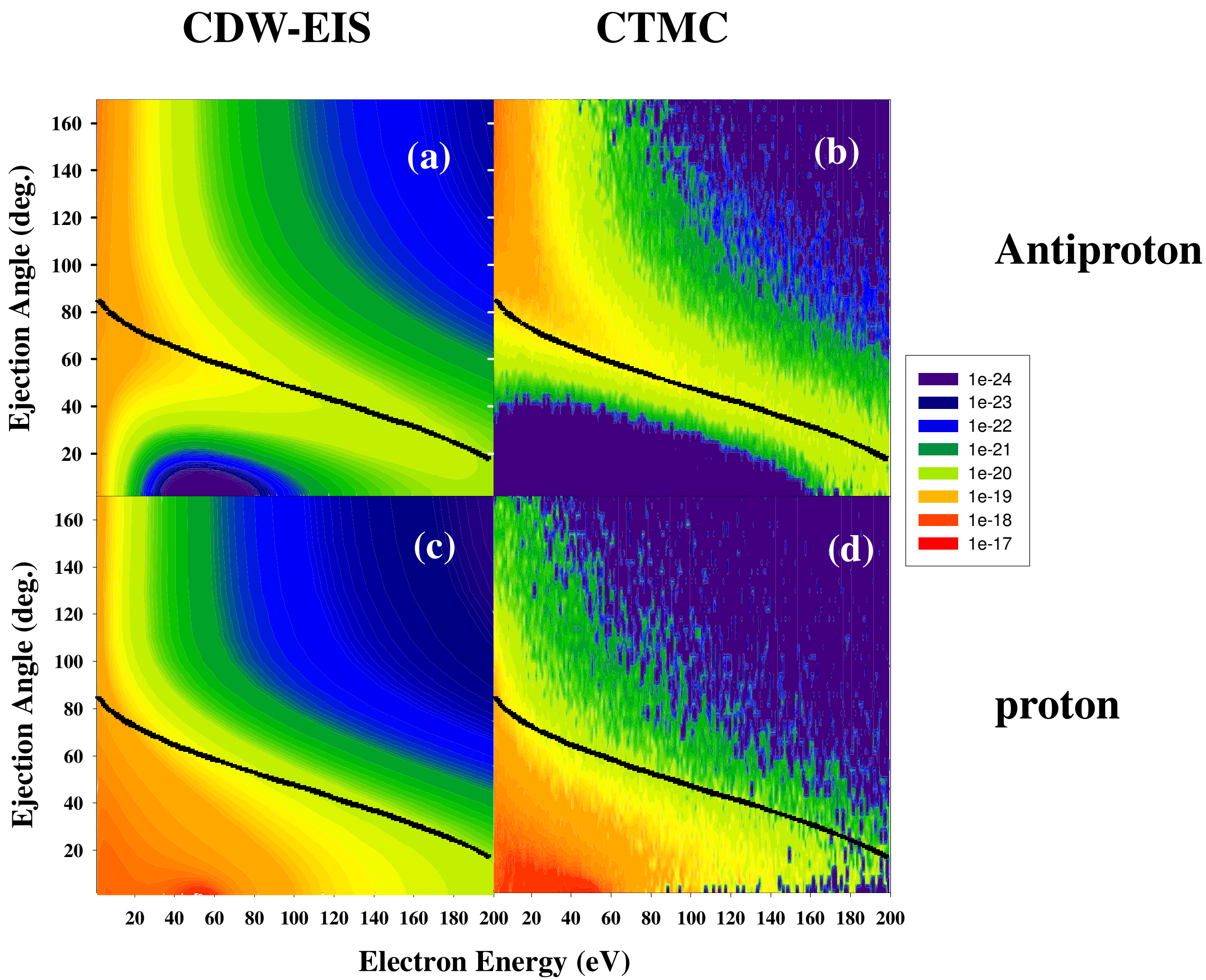

**Antiproton**

$$E = 4\frac{m}{M}E_p \cos^2\theta$$

**proton**

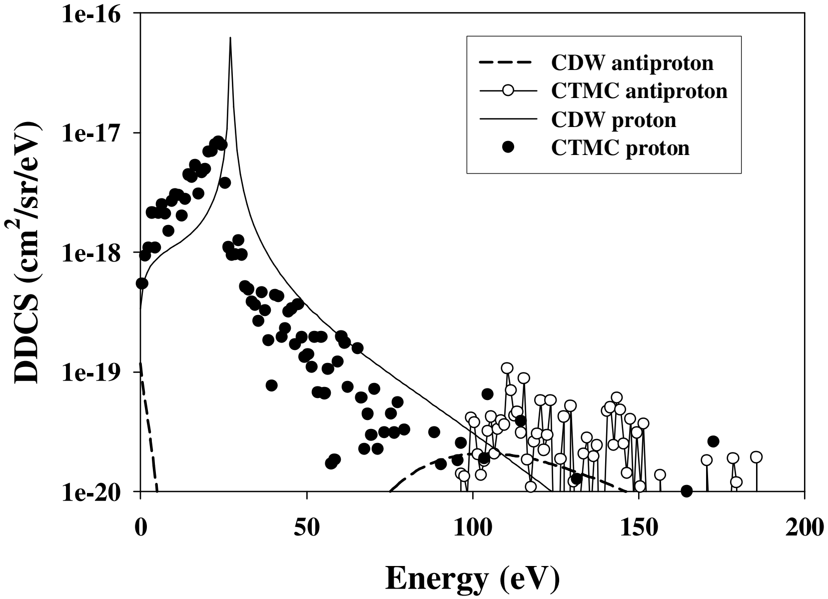
# Double differential electron emission cross sections

## 100 keV

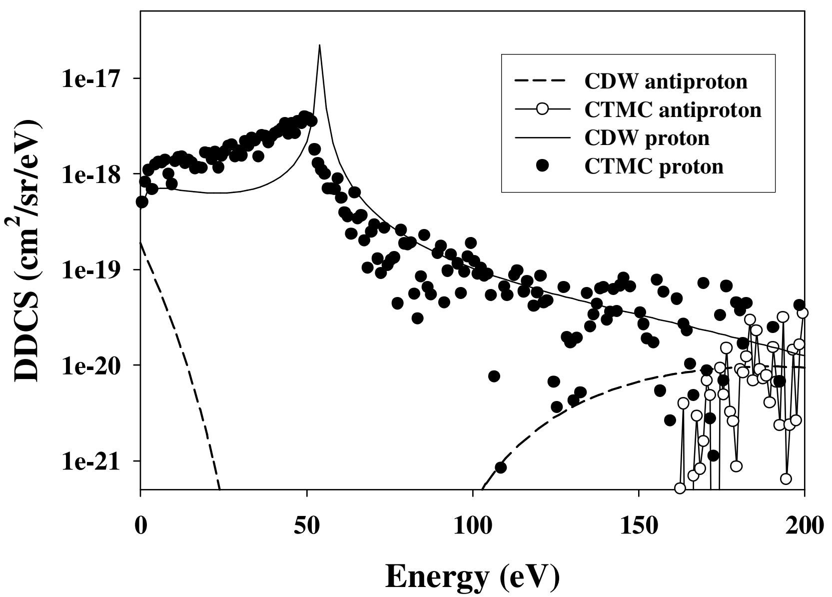


# Energy distributions at 0 degree

**50 keV pbar + He**



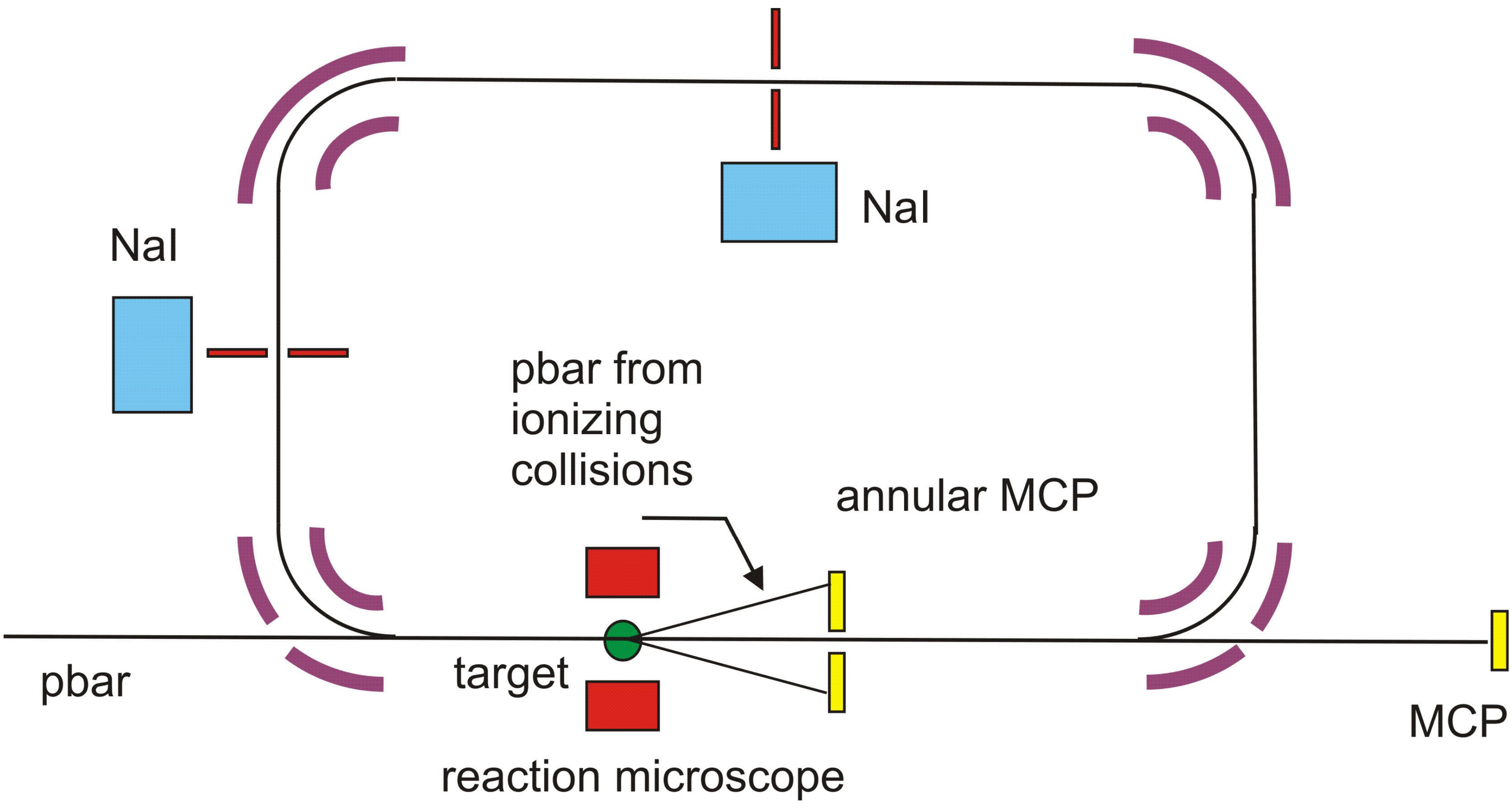

**100 keV pbar + He**



# Future/Experiment

# PBAR RECYCLER

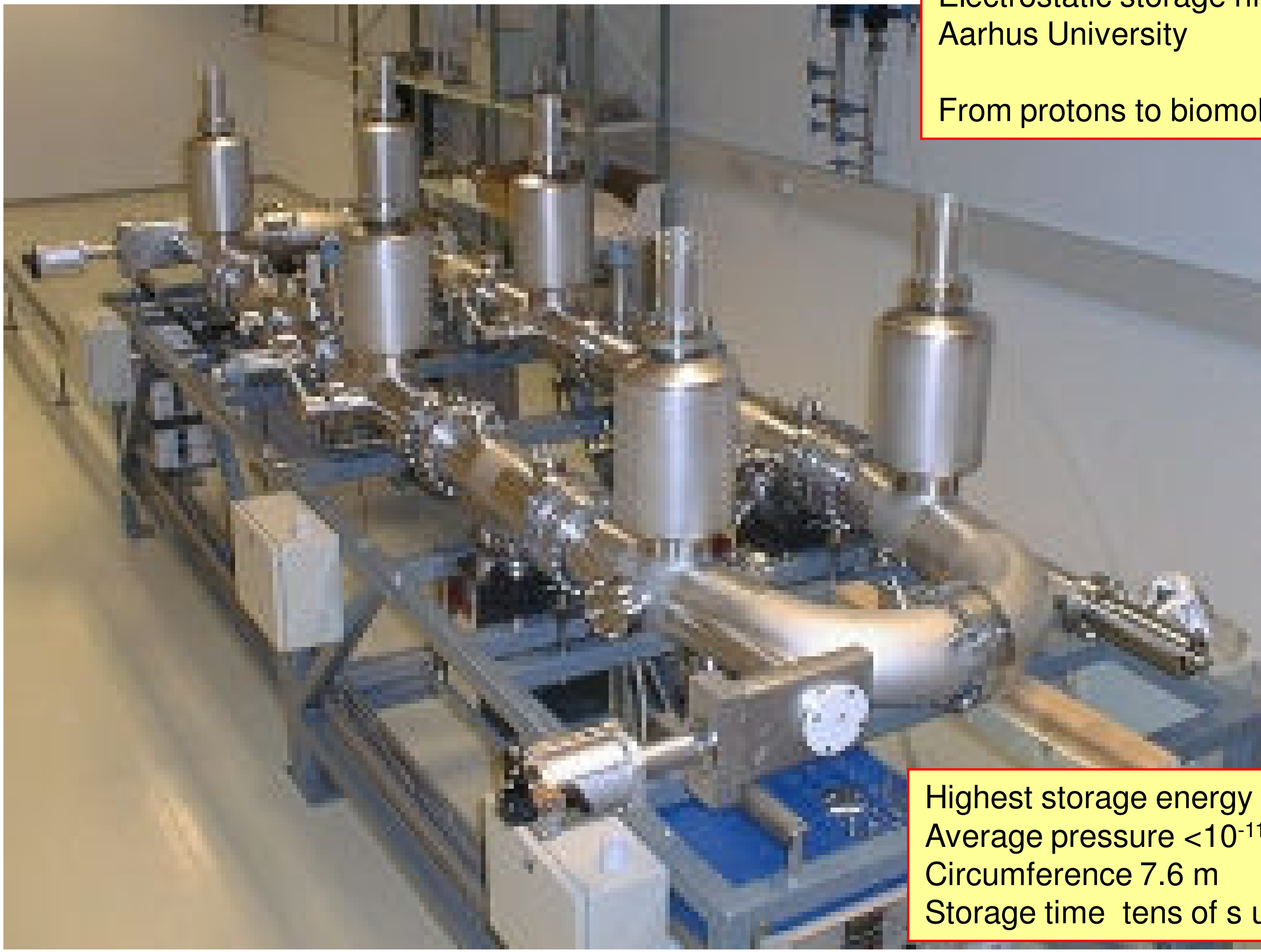
# PBAR COLLIMATION


NaI
NaI
pbar from
ionizing
collisions
annular MCP
target
pbar
MCP
reaction microscope

ELISA

Electrostatic storage ring
Aarhus University

From protons to biomolecules

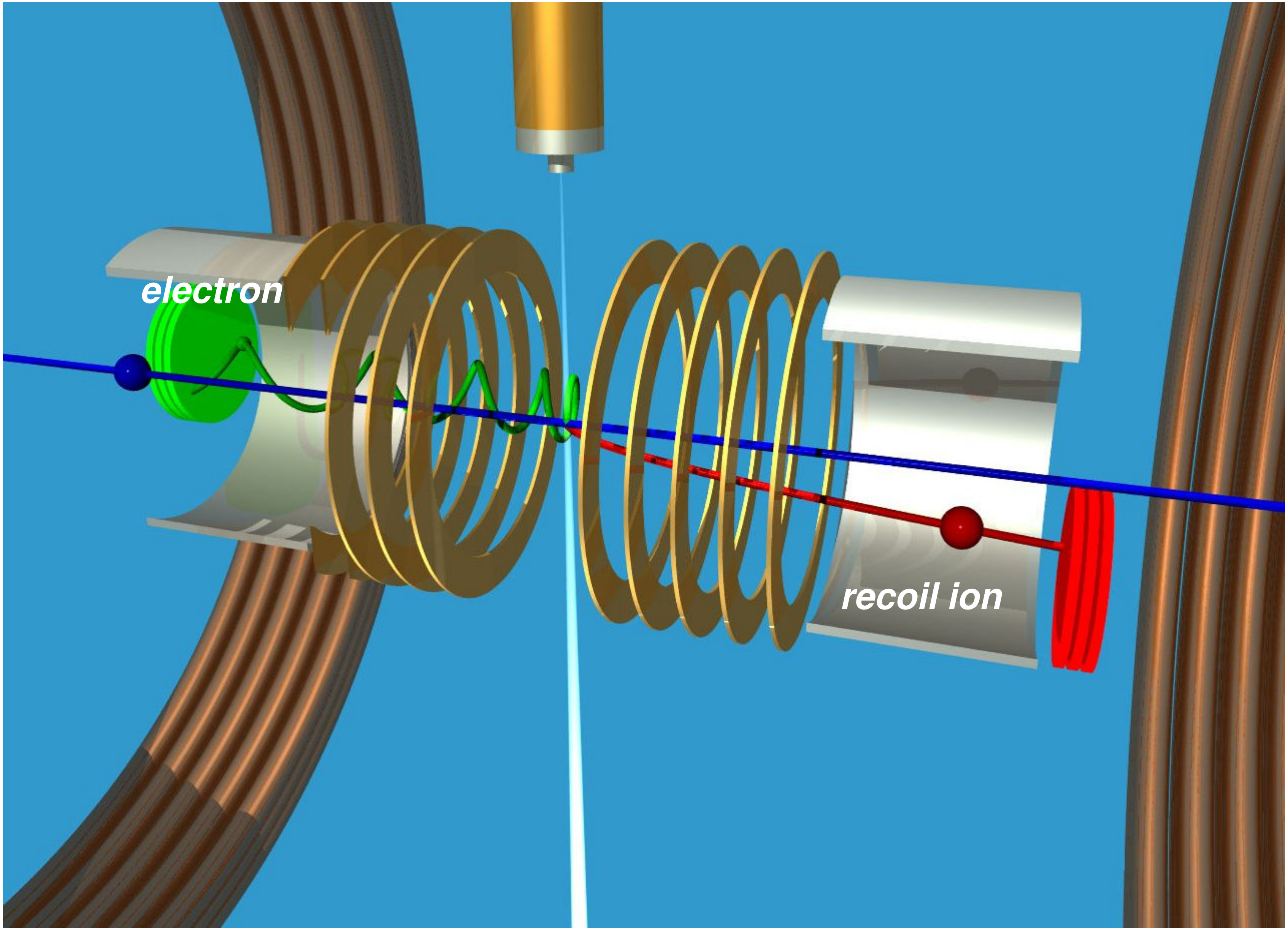


Highest storage energy 22 keV
Average pressure $<10^{-11}$ mBar
Circumference 7.6 m
Storage time tens of s up to minutes

## Is it necessary to detect the antiprotons?

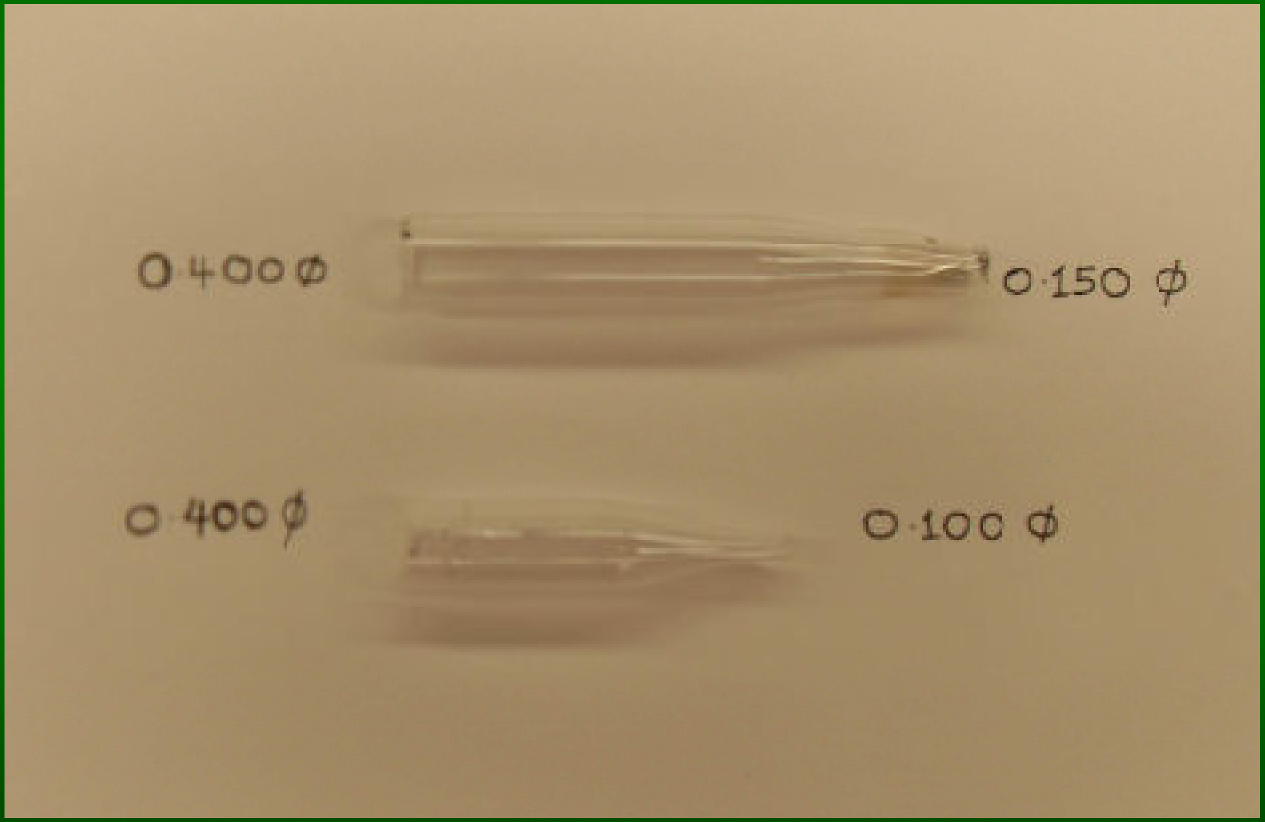
It should be possible to get *some* information about the triple differential cross section by detecting the emitted electron and the emitted ion.

Also, remember that the pbar, deflected after ionization can be detected by their emitted pions


electron
recoil ion

# Pbar beam focusing

## Capillary with conical shape



# Conclusions

- we have obtained experimental benchmark data for the development of advanced models and calculations of atomic collisions in general and for ionization

- we found upper limits to the low energy double ionization cross section and to the ratio between double and single ionization cross sections.

**TO BE CONTINUED ……..**

Thank you!