2nd European Advanced Accelerator Concepts Workshop

Energetic negative ion and neutral atom beams from intense laser-plasma interaction

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Isola d'Elba

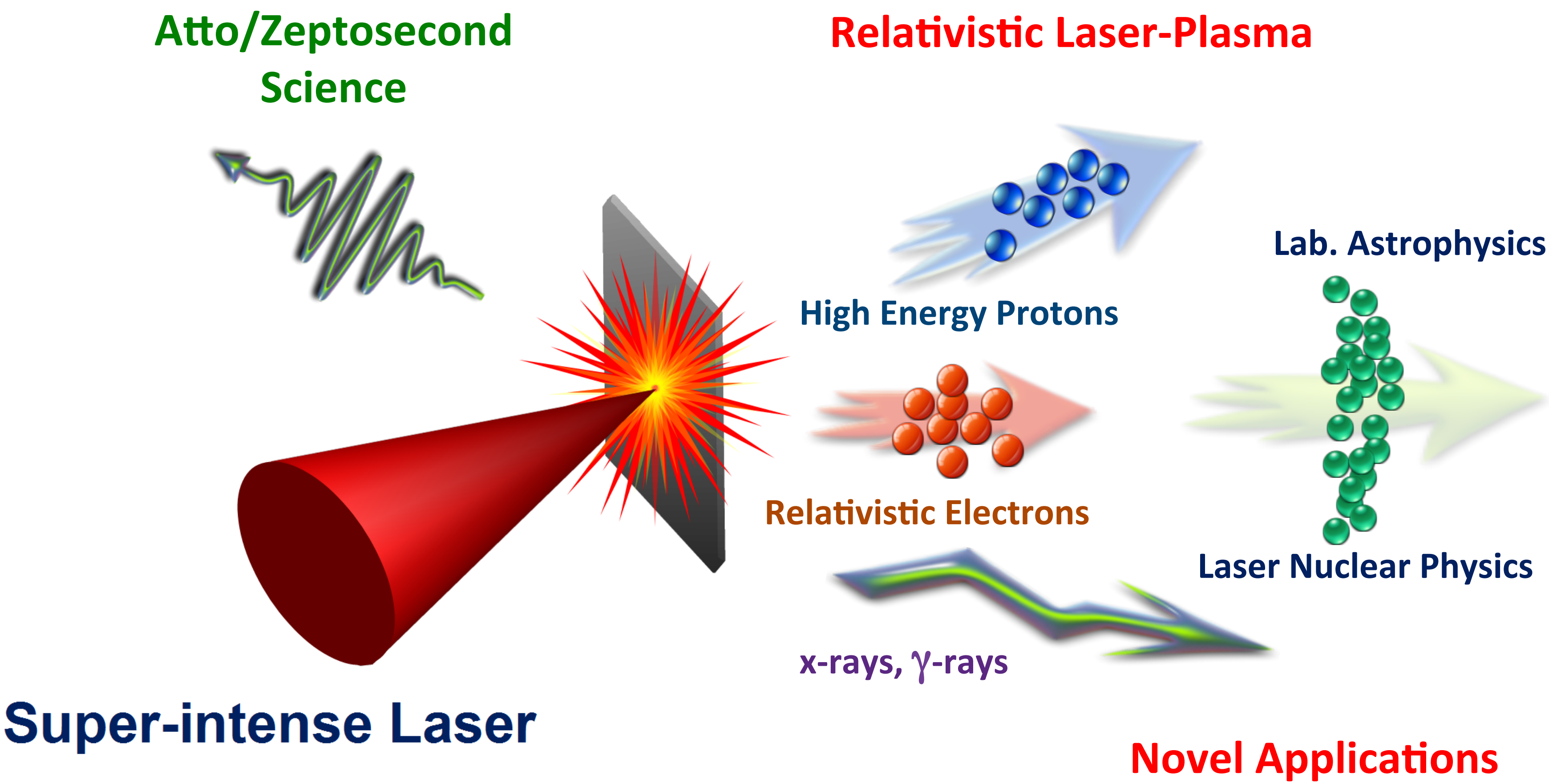
Gwangju Institute of Science and Technology

Institute for Basic Science

IBS Center for Relativistic Laser Science

GIST Ultrashort Quantum Beam Facility

exploration of Relativistic Laser-Matter Interactions



New Plasma Regimes - highly relativistic plasma

This work highlights another important aspect of ion acceleration study:

namely the capability of generation **high energy**

Negative ion and Neutral atom beams

S. Ter-Avetisyan et al., Appl. Phys. Lett. 99, 051501 (2011)   M. Schnuerer et al., Phys. Plasmas 20, 113105 (2013)

Why the negative ions are interesting?

there is a strong fundamental interest in negative ions

- in screening of nucleus the inter–electronic interactions become relatively more important than the electron–nuclear interactions

- electron correlation plays an important role.

The interplay of these attractive and repulsive interactions allows better understanding of atomic physics.

Why the negative ions are interesting?

- High brightness beams of heavy negative ions are required for

  - high current tandem accelerators
  - for ion beam microscopy and
  - lithography

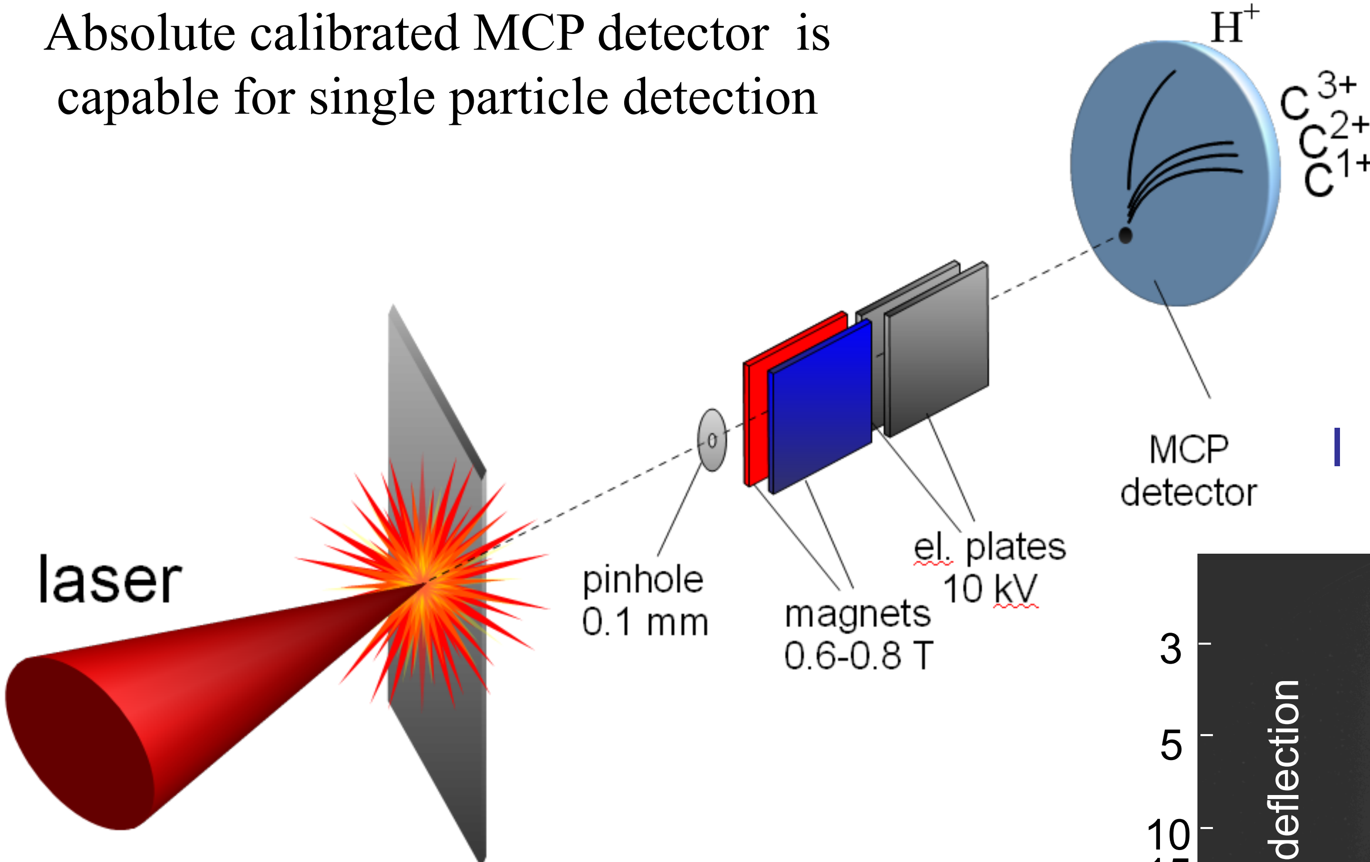
- negative ions as an alternative to positive ions for heavy ion fusion drivers in inertial confinement fusion:

  - electron accumulation would be prevented and,
  - if desired, the beams could be photo detached to neutrals.

if sources of positive ions are widely available now, the negative ion source development has lagged behind due to different kind of technological complications.

laser acceleration of ions

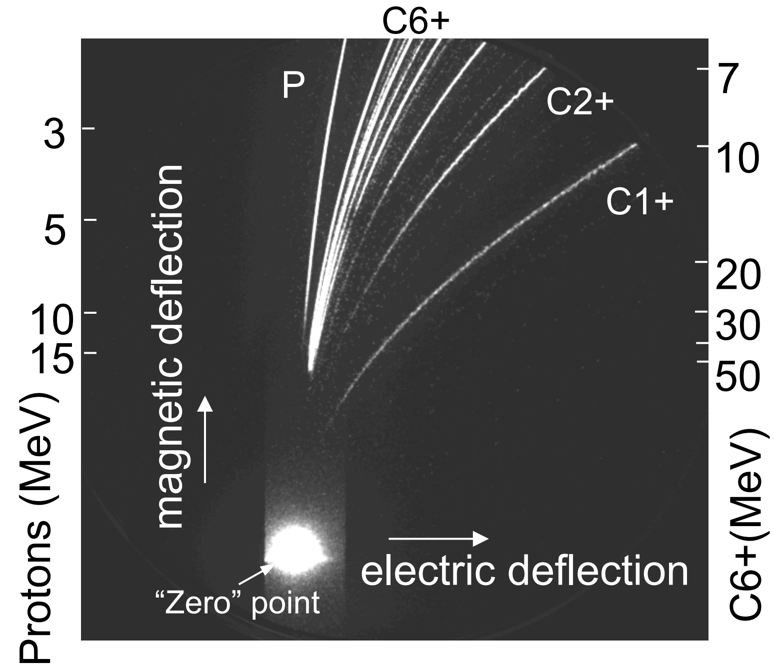
Absolute calibrated MCP detector is capable for single particle detection



I > 10^{18} W/cm^2

10 nm C, 10 J

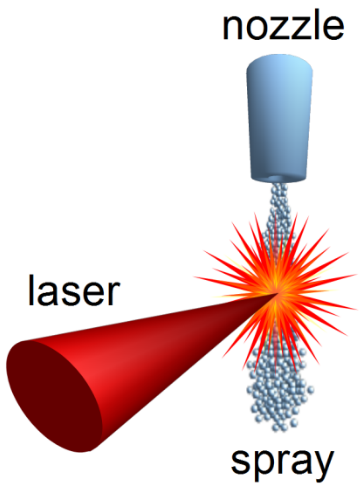
I ~ 5×10^{20} W/cm^2



Ion spectra (Thomson parabola)

negative ion acceleration in water spray

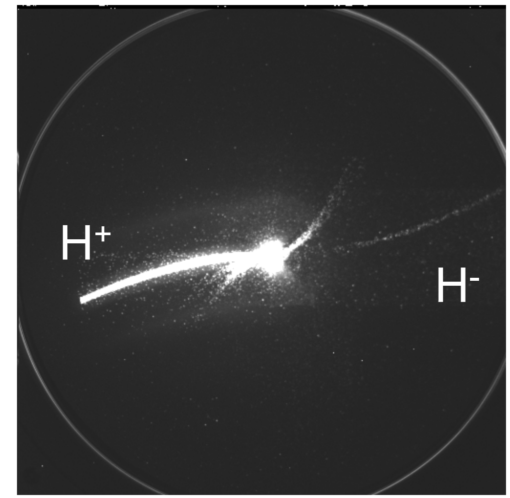
I ~ 5×10^{19} W/cm^2, contrast <10^{-8} at 10 ps prior the peak

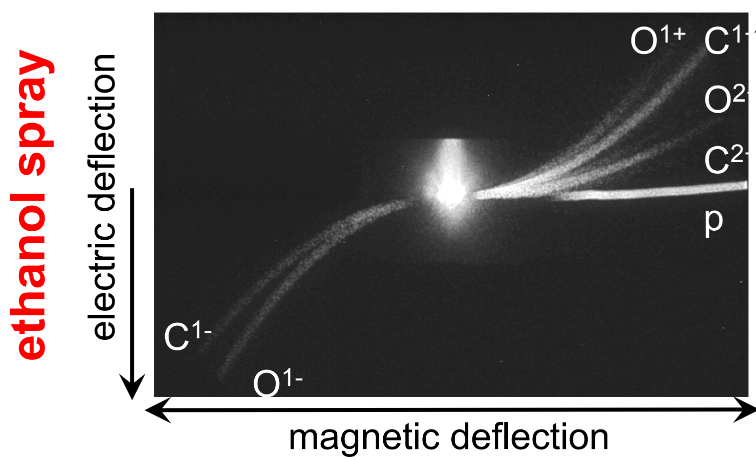


$d_{droplet}$ ~150 -180 nm

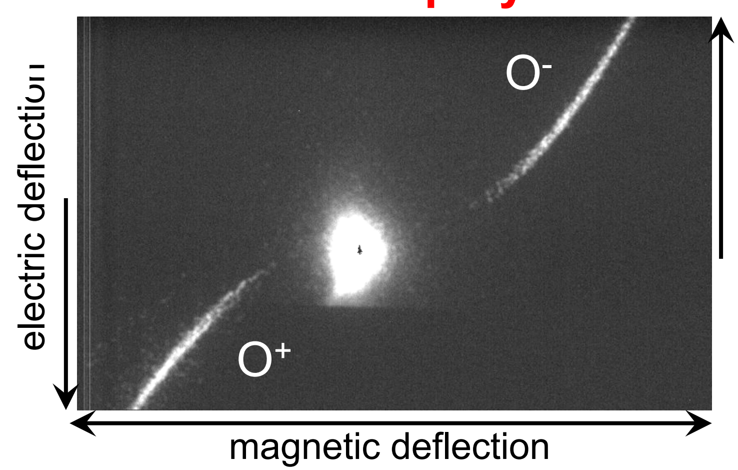
density 10^{18} - 10^{19} cm^{-3}

H^- ~ 150 keV

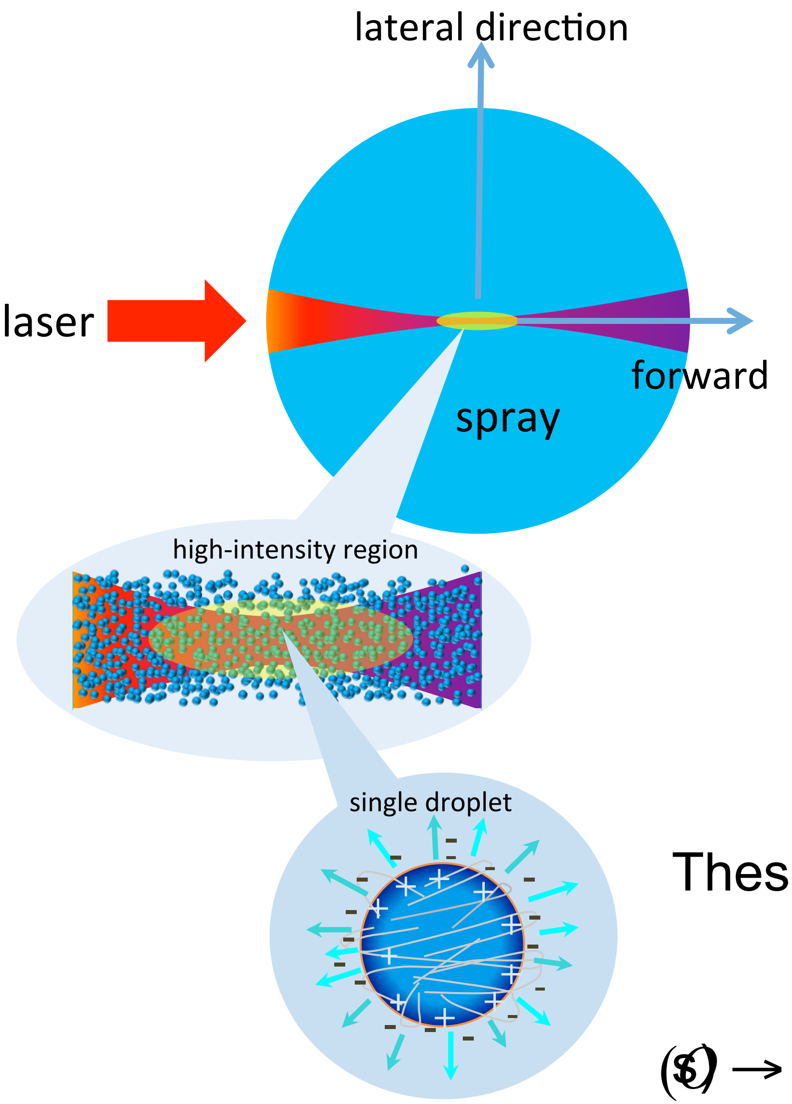




water spray



negative ion formation in charge-exchange



- positive ions are accelerated

- propagation through the spray is collisional

  mean free path for oxygen: $L \sim 50\ \mu m$,
  for protons: $L \geq d_{spray}$

- charge-exchange in a spray can explain the formation of negative ions:

$$O^{n+} \leftrightarrow O^{(n-1)+}$$

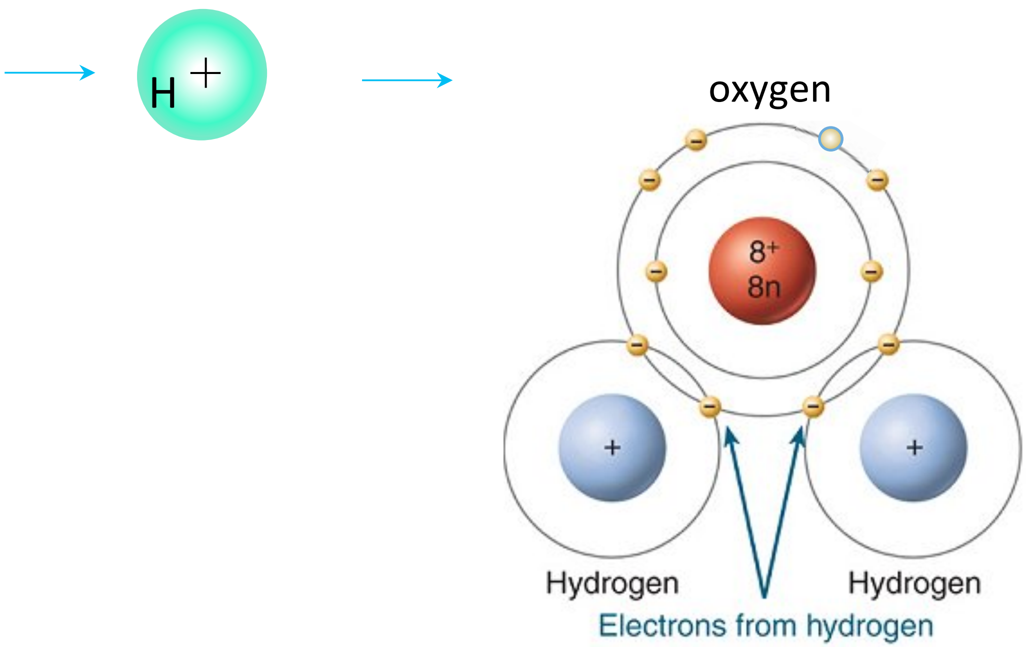
electron capture and loss

These are resonant processes:
probability is max. if fast ion $v_{ion} \sim v_{bound\ el.}$
($1 MeV\ O^{1+} = 3.4\times10^{6}$ m/

$(s) \rightarrow O^{-})$ $\sigma_{0\text{-}1} \sim 1\times10^{-16}\ cm^{2}$ (for 0.1–1 MeV),

- spray density distribution is modified by the laser

Artist's conception of electron capture by proton



$$A^+ \rightarrow A^0 \begin{cases} \nearrow A^- \\ \searrow A^+ \end{cases}$$

- the angular spread is very narrow, of the order of 1°

- the interaction proceeds almost elastically, without energy exchange

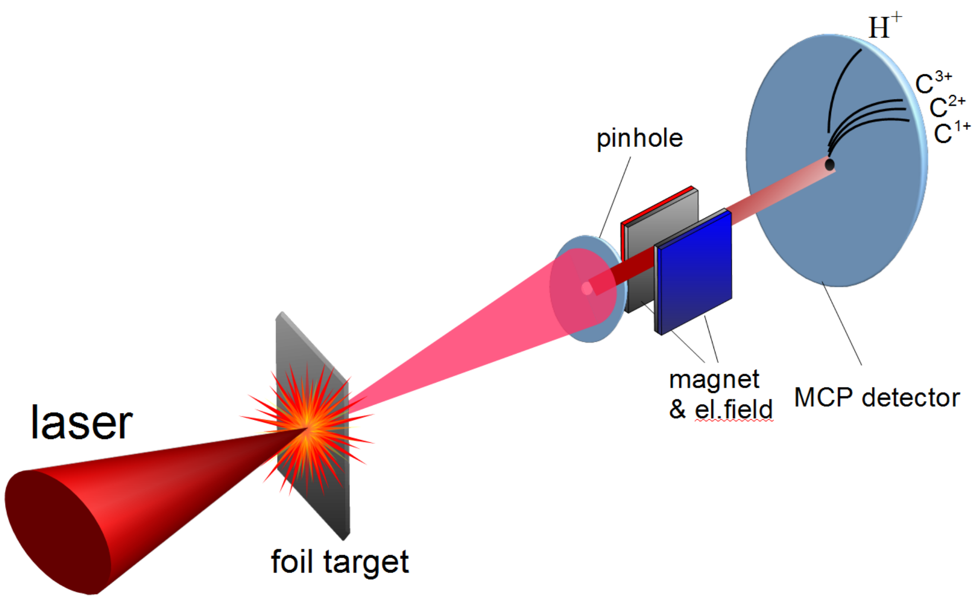
The ion that captures or loses an electron propagates essentially in the same direction and with the same energy as before the collision.

- to use the spray as a secondary target:

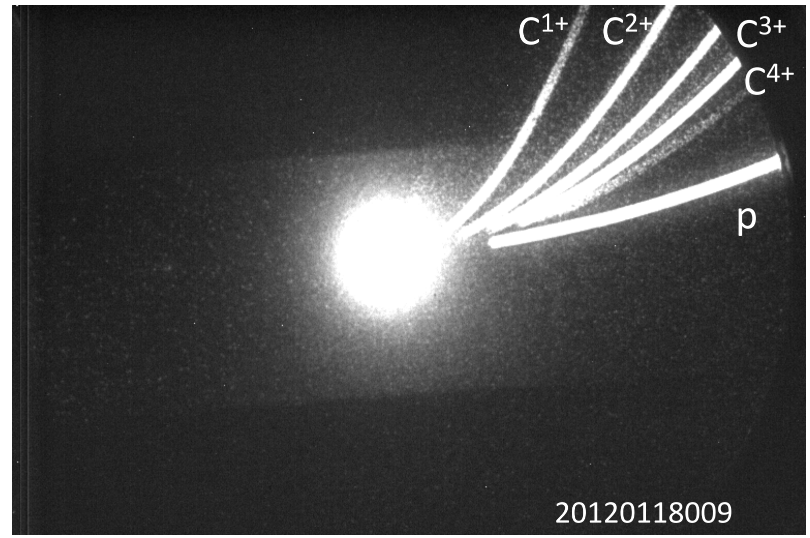
ions accelerated from the foil are propagating through the spray

spray as secondary target

$$A^{+} \rightarrow A^{0} \begin{cases} \nearrow A^{-} \\ \searrow A^{+} \end{cases}$$

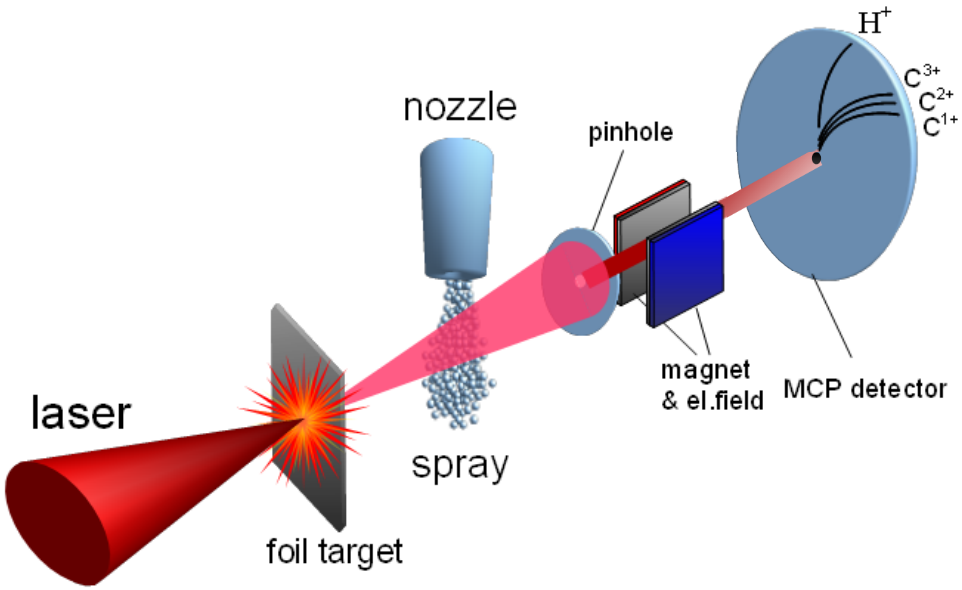


ions from Ti target

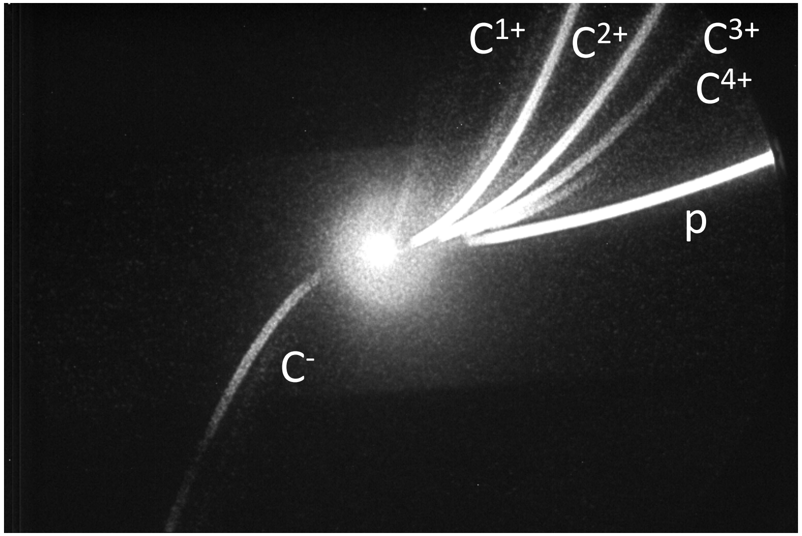


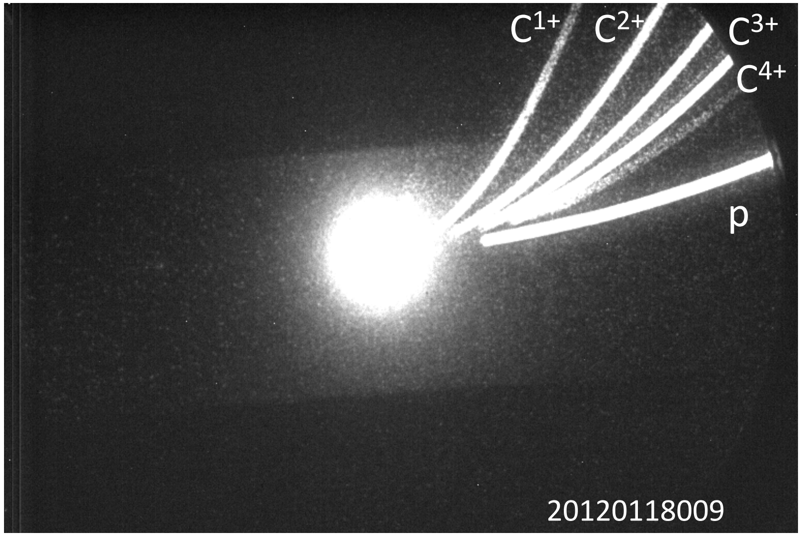
chase for neutrals

$$A^+ \rightarrow A^0 \begin{array}{l} \nearrow A^- \\ \searrow A^+ \end{array}$$



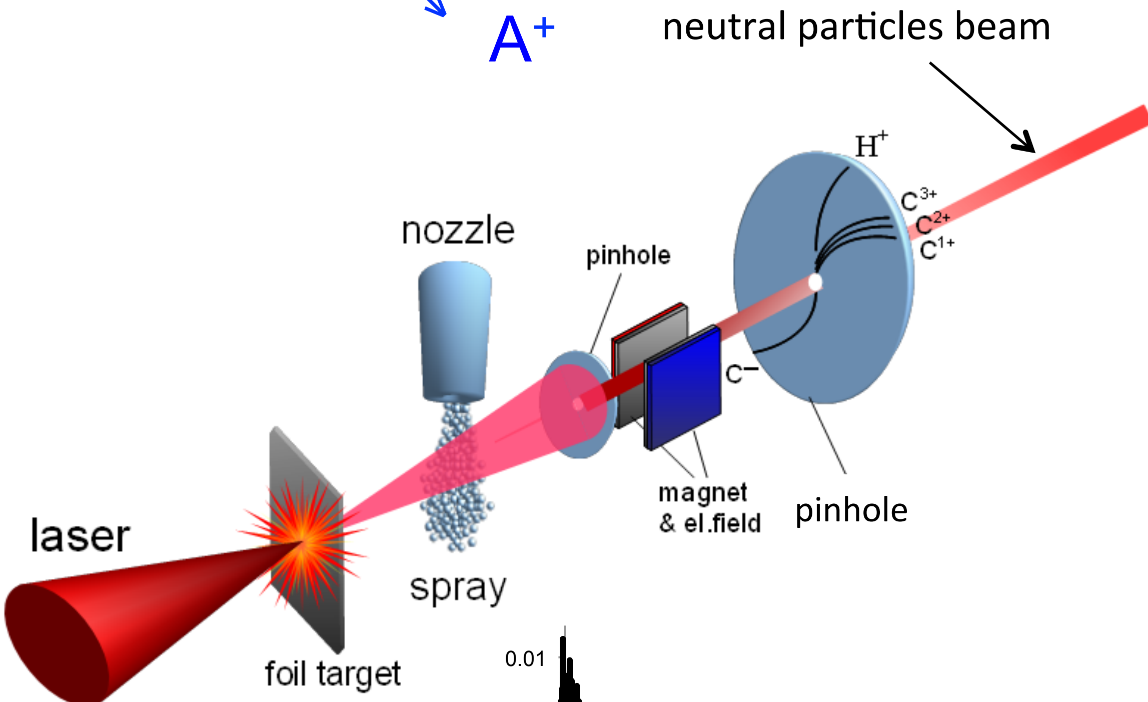
ions through H_2O spray



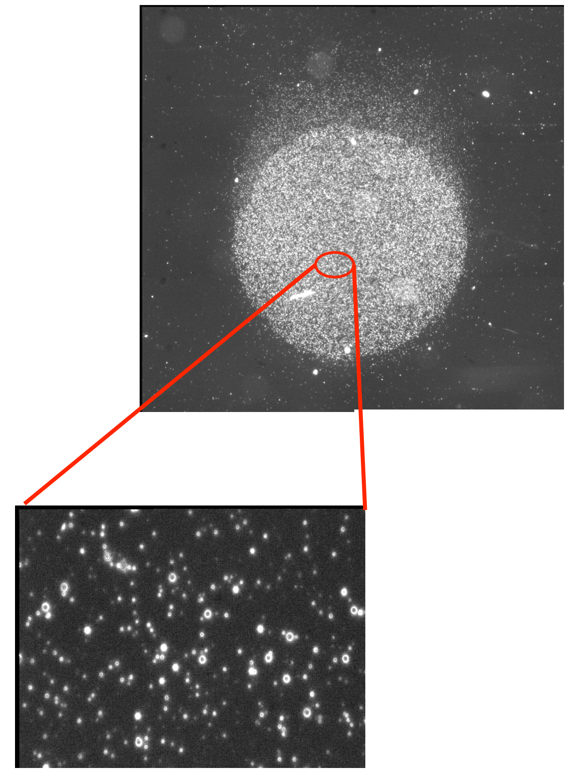


chase for neutrals

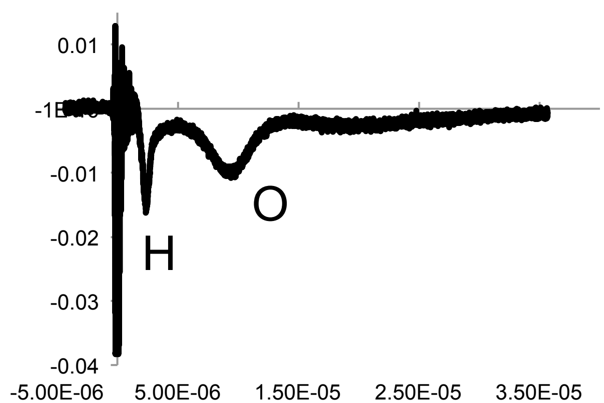
$A^+ \rightarrow A^0$ ↗ A^- ↘ A^+



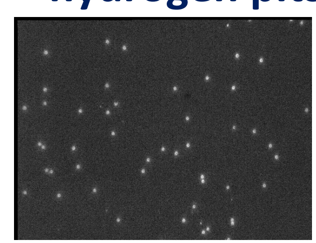
"zero" point on CR39 (1mm pinhole)



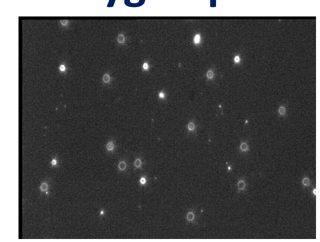
TOF of neutrals: H and O



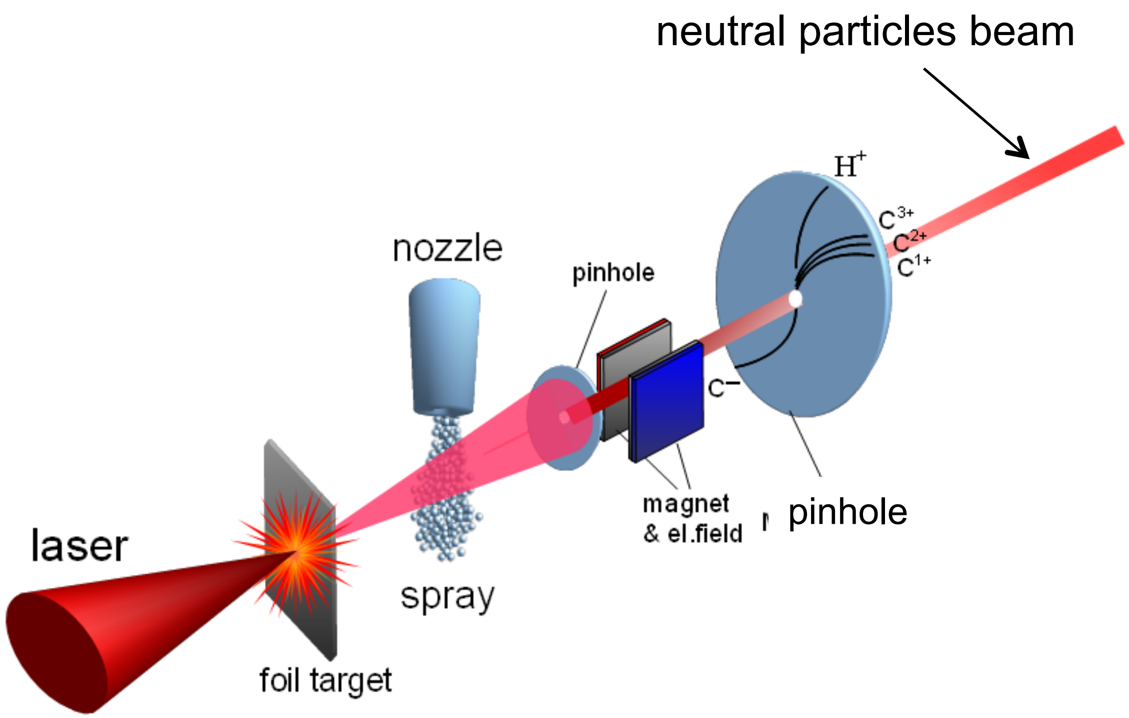
hydrogen pits



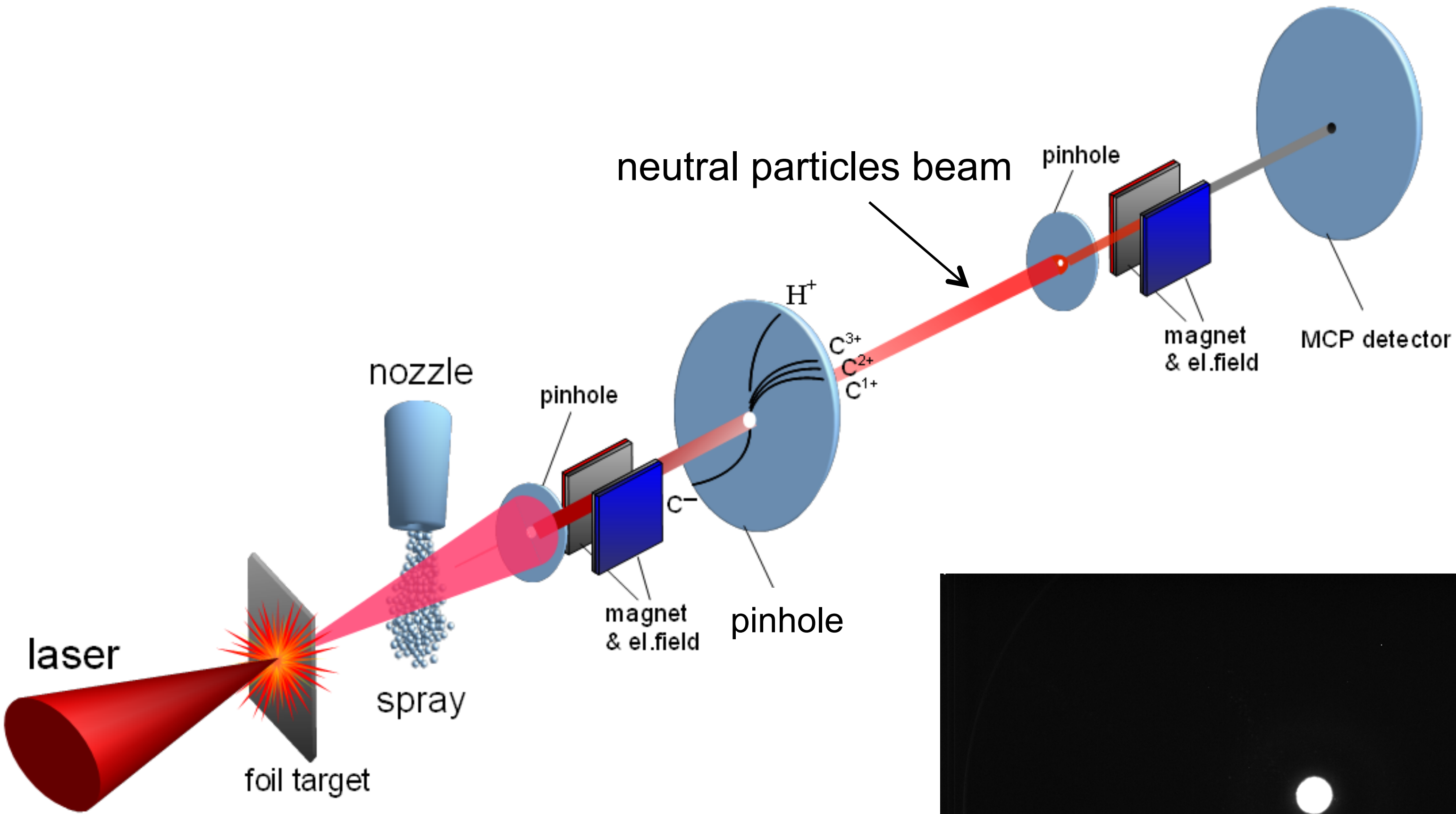
oxygen pits



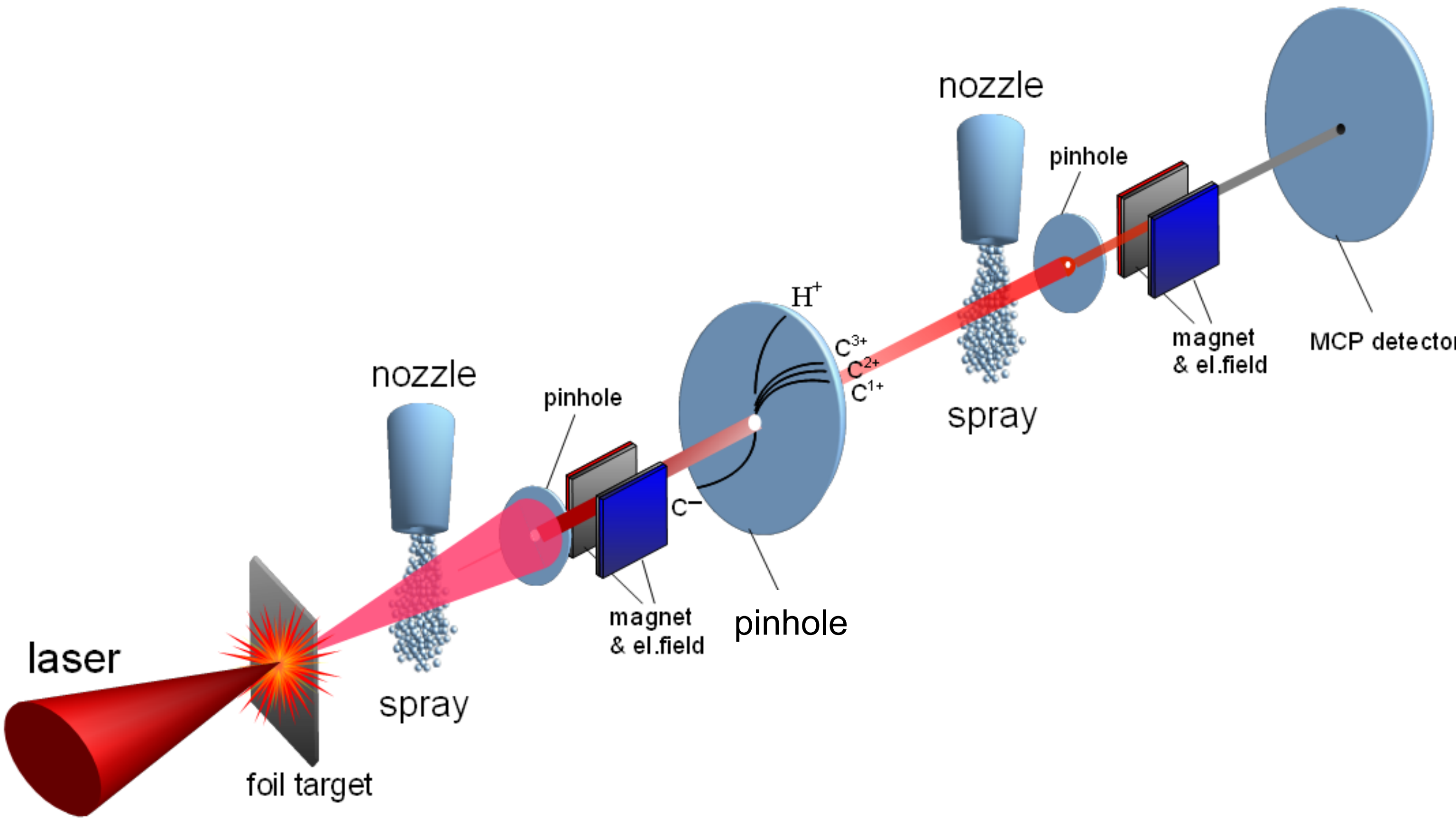
chase for neutrals



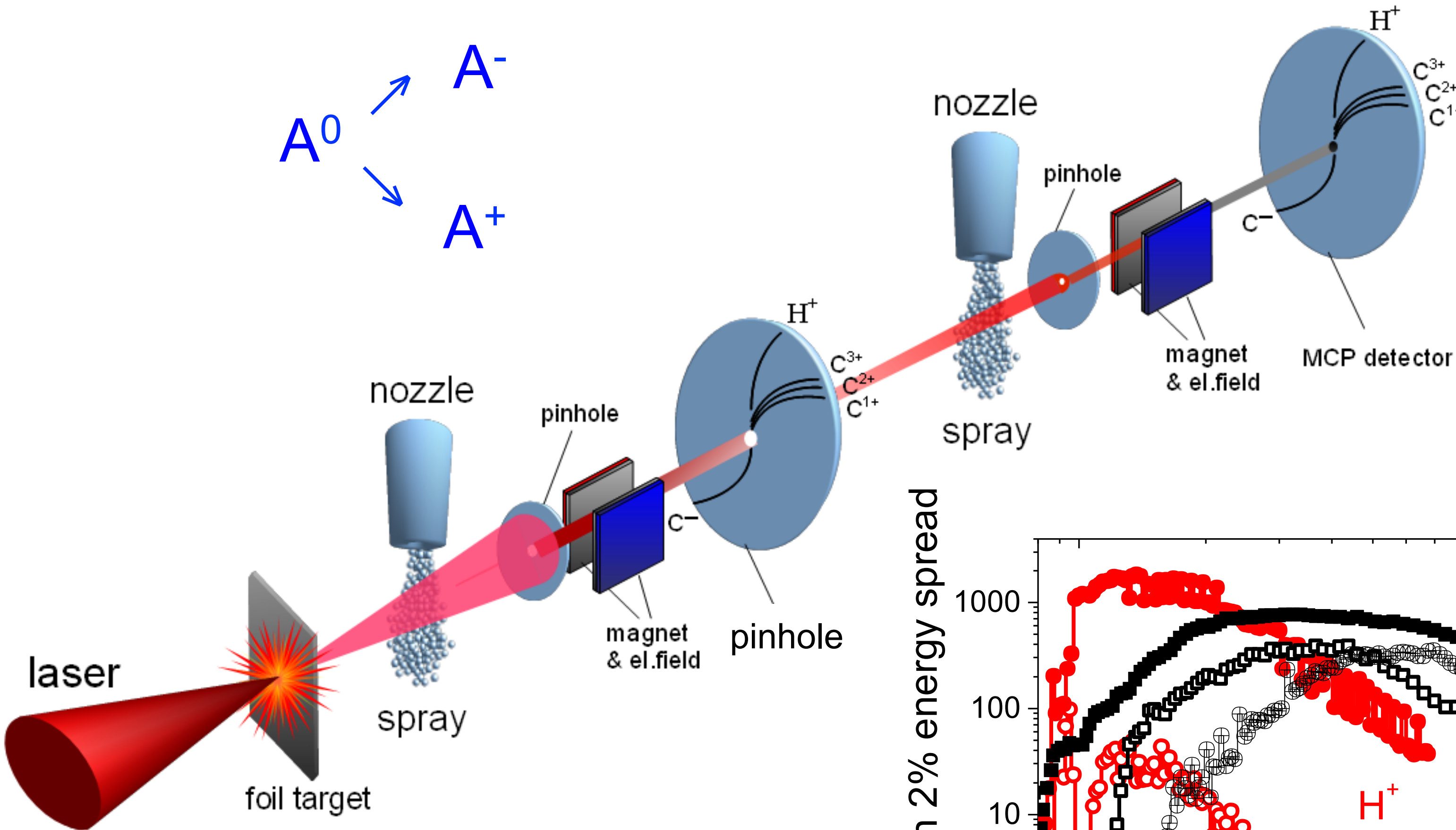
chase for neutrals



chase for neutrals

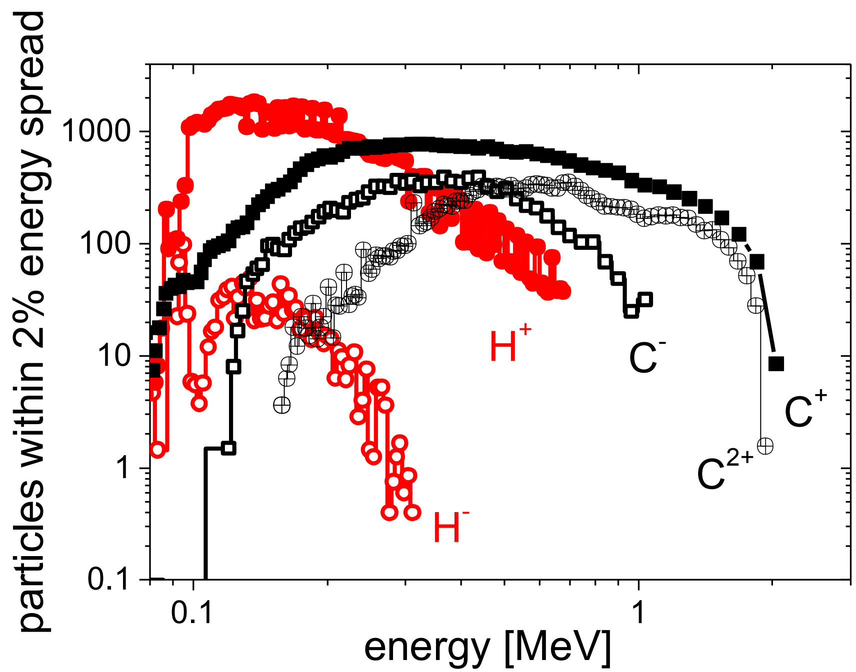


chase for neutrals



$C^{-}_{max} \sim 1$ MeV

$H^{-}_{max} \sim 300$ keV



summary

- negative ions are generated in electron–capture and –loss processes:

$$A^{+} \rightarrow A^{0} \begin{cases} \nearrow A^{-} \\ \searrow A^{+} \end{cases}$$

- different positive ions species can be converted to negative in the spray

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- the brightness of negative ion source is extremely high:

$$B > 10^{8}\ A \cdot cm^{-2} sr^{-1}$$

(mainly due to the ultrashort duration of the emission)

open problems

- what is the role of droplet in the processes responsible for negative ion creation

- H^- needs additional detailed investigations on:

  - spatial distribution
  - energy dependence on propagation length

- create other negative heavy ion species

  - to use other liquids