Laboratoire Kastler Brossel
Physique quantique et applications

Sympathetic cooling using laser cooled Be^+ ions : precision measurements using light ions

L. Hilico, LKB

The team

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Nicolas Sillitoe PhD
Johannes Heinrich PhD

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- The objectives

  H_2^+ spectroscopy

  The Gbar project

  Highly charged ions

- The First TF contribution

Ion sympathetic cooling

How to cool ions when

- buffer gas cooling is not cold enough
- laser cooling is not possible ?

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Several ion species
Trap Force + Coulomb repulsion
Laser cooling of one specie

→ cooling of the other species

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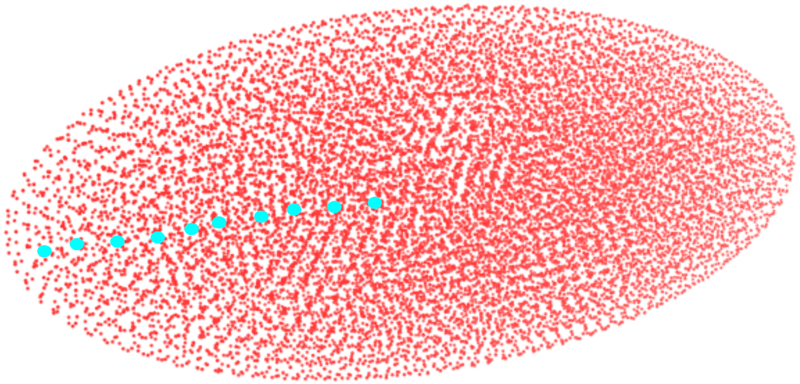
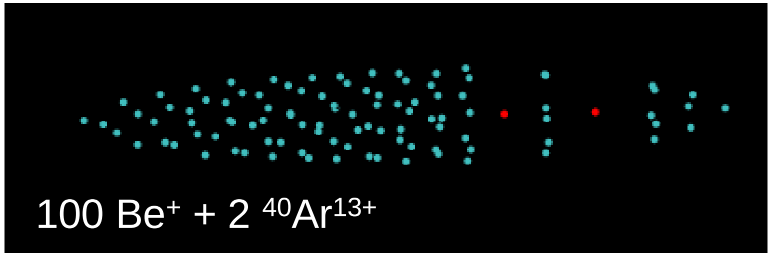


15350 Be^+ + 10 H_2^+



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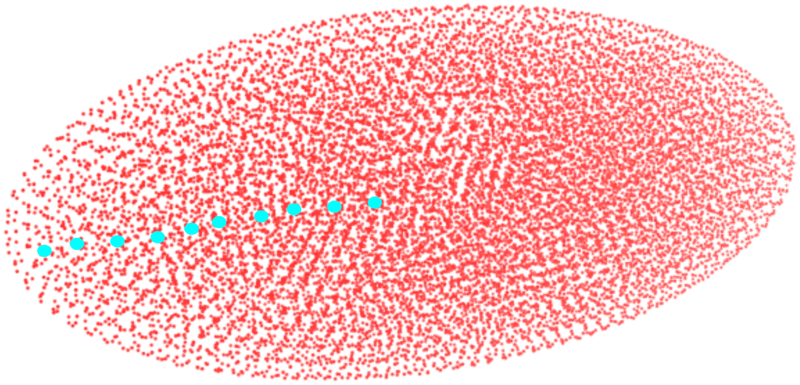

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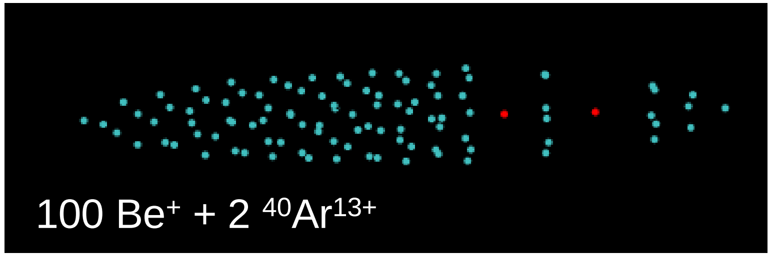


Examples

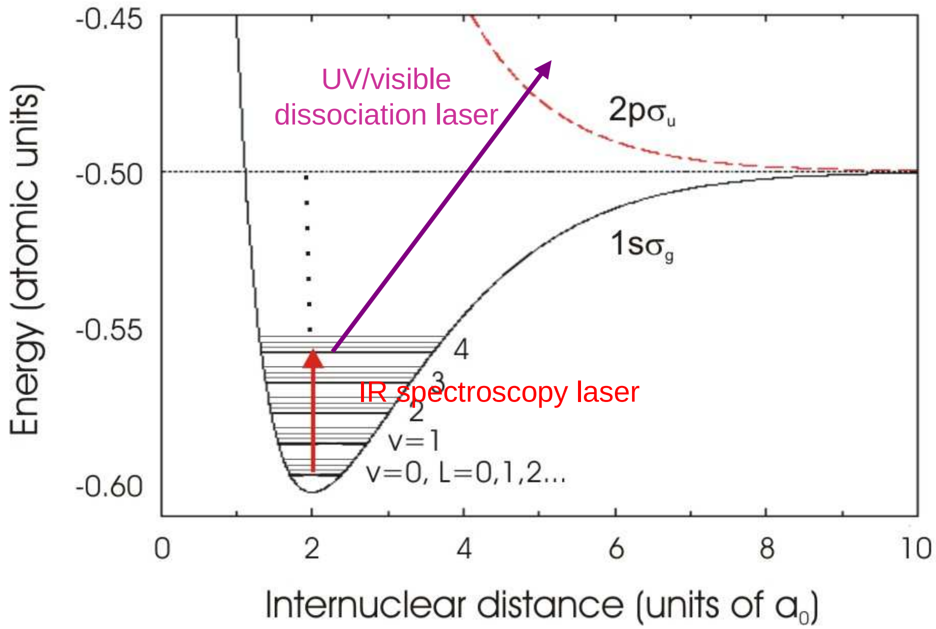
- Cold molecular ions MgH^+, $Biomolec^+$ for spectroscopy
- Ultra cold chemistry
- NIST, PTB Al^+/Mg^+ and Al^+/Be^+ optical clocks

Hydrogen ion spectroscopy

- Molecular bound level QED
- Direct optical determination of

$$m_p / m_e$$

Hydrogen ion spectroscopy



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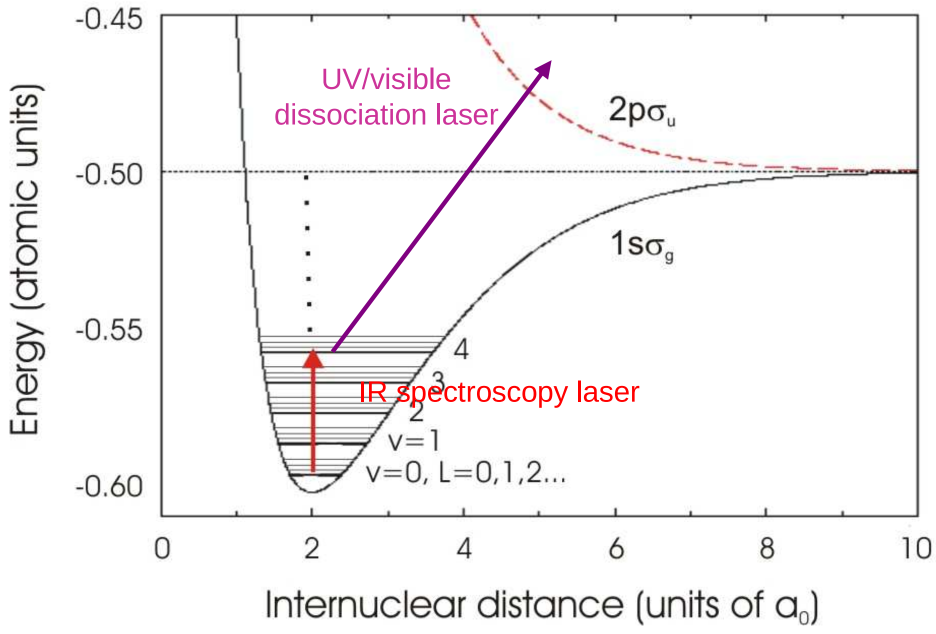
Idea: quasi harmonic vibrational levels

$$\frac{\Delta \nu}{\nu} = \frac{1}{2} \frac{\Delta(m_p / m_e)}{m_p / m_e}$$

Hydrogen ion spectroscopy



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Idea: quasi harmonic vibrational levels $\frac{\Delta\nu}{\nu} = \frac{1}{2}\frac{\Delta(m_p/m_e)}{m_p/m_e}$

Codata: $\frac{\Delta(m_p/m_e)}{m_p/m_e} = 4.1 10^{-10}$

$m_e / m_{^{12}C}$ Mainz, Werth/Blaum

$m_p / m_{^{12}C}$ Van Dyck

Accurate relativistic and QED corrections in H_2^+ and HD^+ Karr, Korobov, Hilico

$$\frac{\Delta(m_p/m_e)}{m_p/m_e} = 6.10^{-11} \ldots 1.5 10^{-11}$$

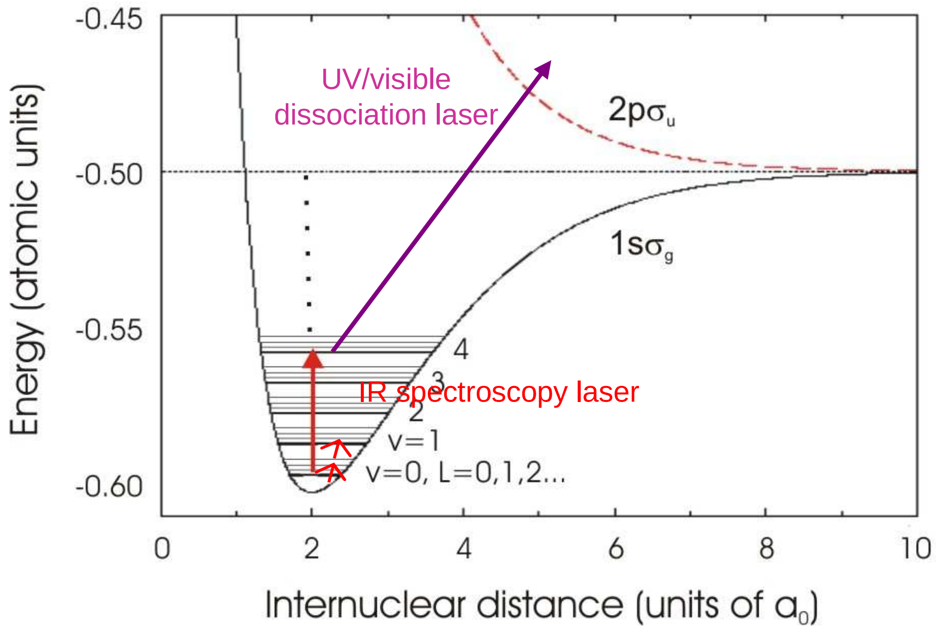
better than new Mainz $m_e / m_{^{12}C}$

Hydrogen ion spectroscopy

Experimental method

REMPD resonance enhanced multiphoton dissociation

on trapped ions



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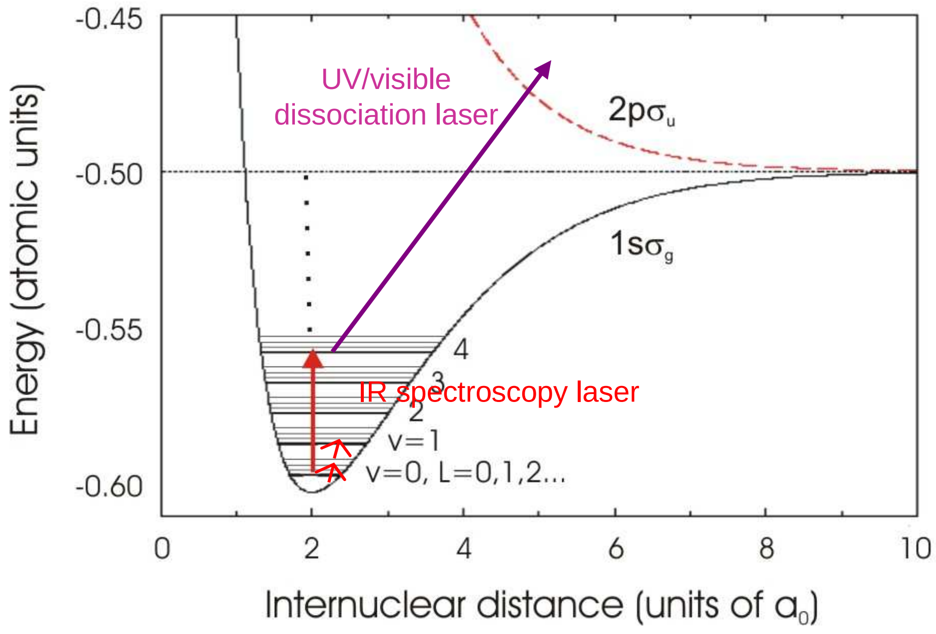


- Düsseldorf, S. Schiller HD^+ dipole transition $\delta v=4$, $\Delta\nu/\nu \sim 2.\ 10^{-9}$

Limited by Doppler effect

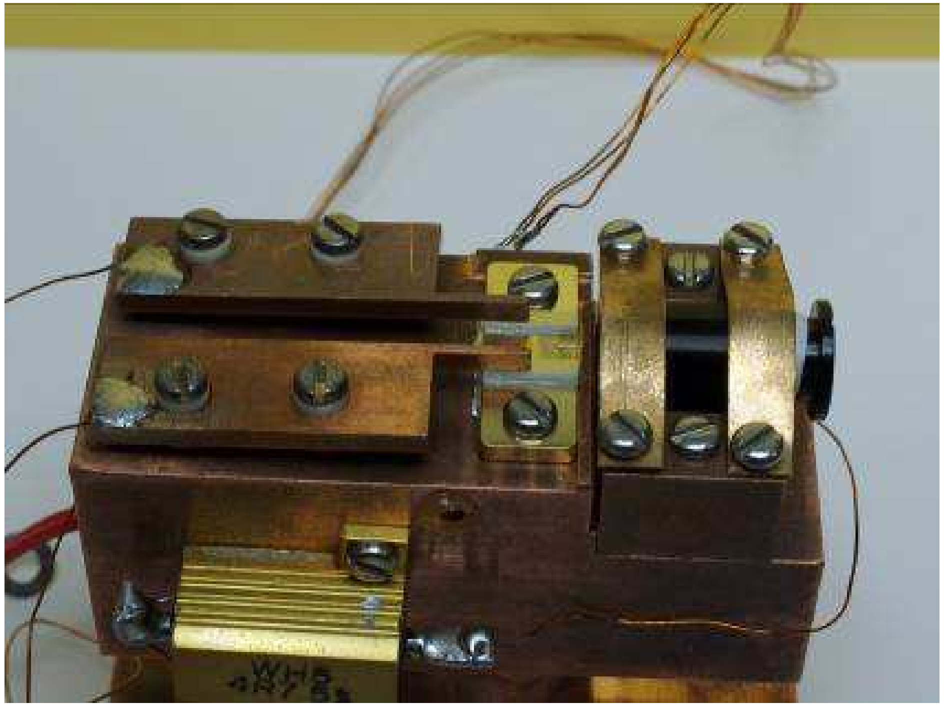
- Amsterdam, J. Koelemeij HD^+ dipole transition $\delta v=8$, $\Delta\nu/\nu \sim 2.\ 10^{-9}$

- Paris, LKB H_2^+ Doppler-free two photon transition at 9.166 µm

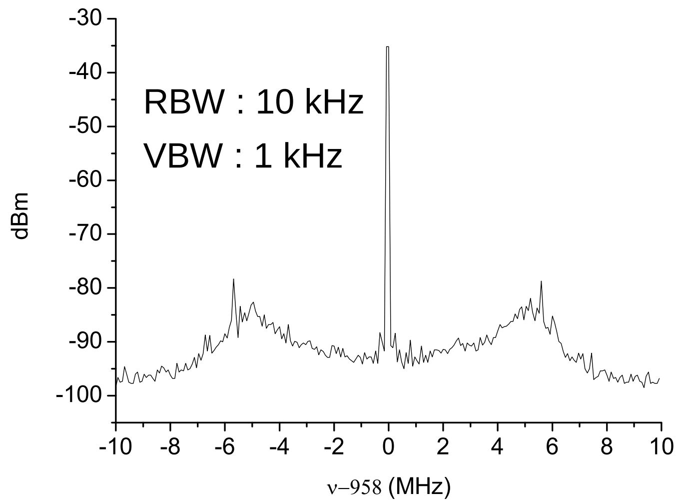
$1.5\ 10^{-11} \leftrightarrow 500$ Hz

Hydrogen ion spectroscopy

• Two photon excitation source

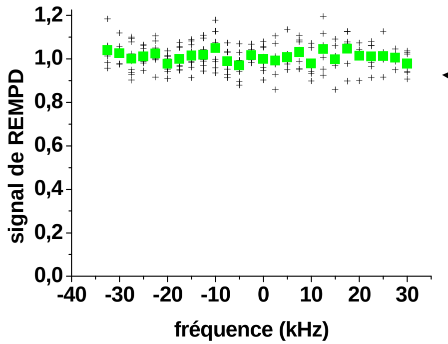


Ultrastable
9.17 µm quantum cascade laser
phase-locked to a CO_2 laser



F. Bielsa, A. Douillet, T. Valenzuela,
J.-Ph. Karr, L. Hilico,
Optics Letters 32, 1641-1643 (2007)

• Hyperbolic ion trap + electron impact ionisation + photodissociation, no cooling

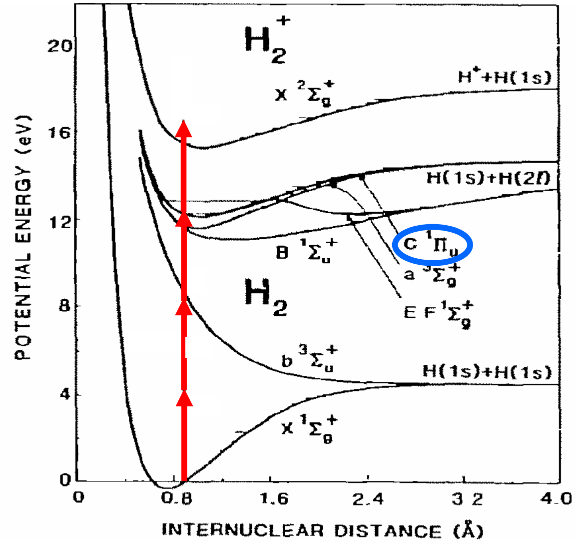


Too low signal to noise ratio

New ionisation scheme
New ion trap and sympathetic cooling

Hydrogen ion spectroscopy

A new 3+1 REMPI ion source



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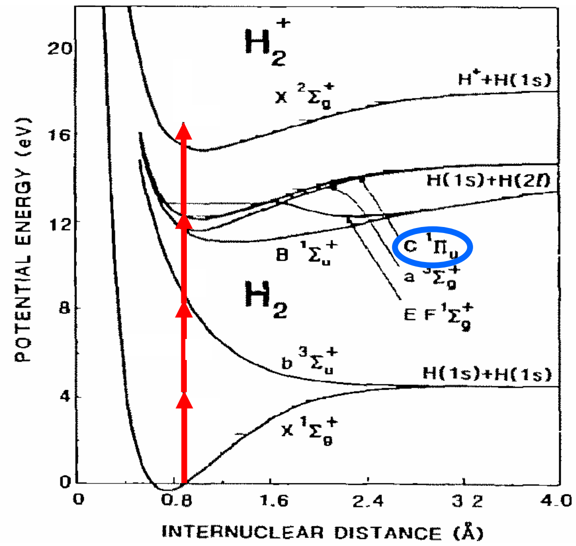
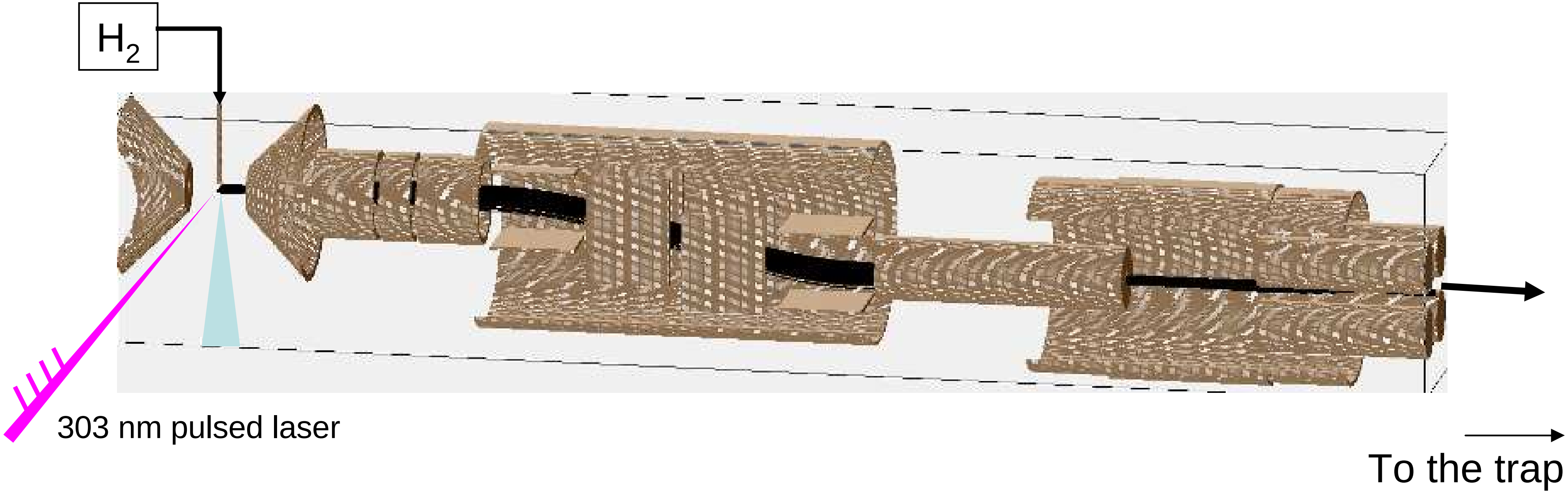




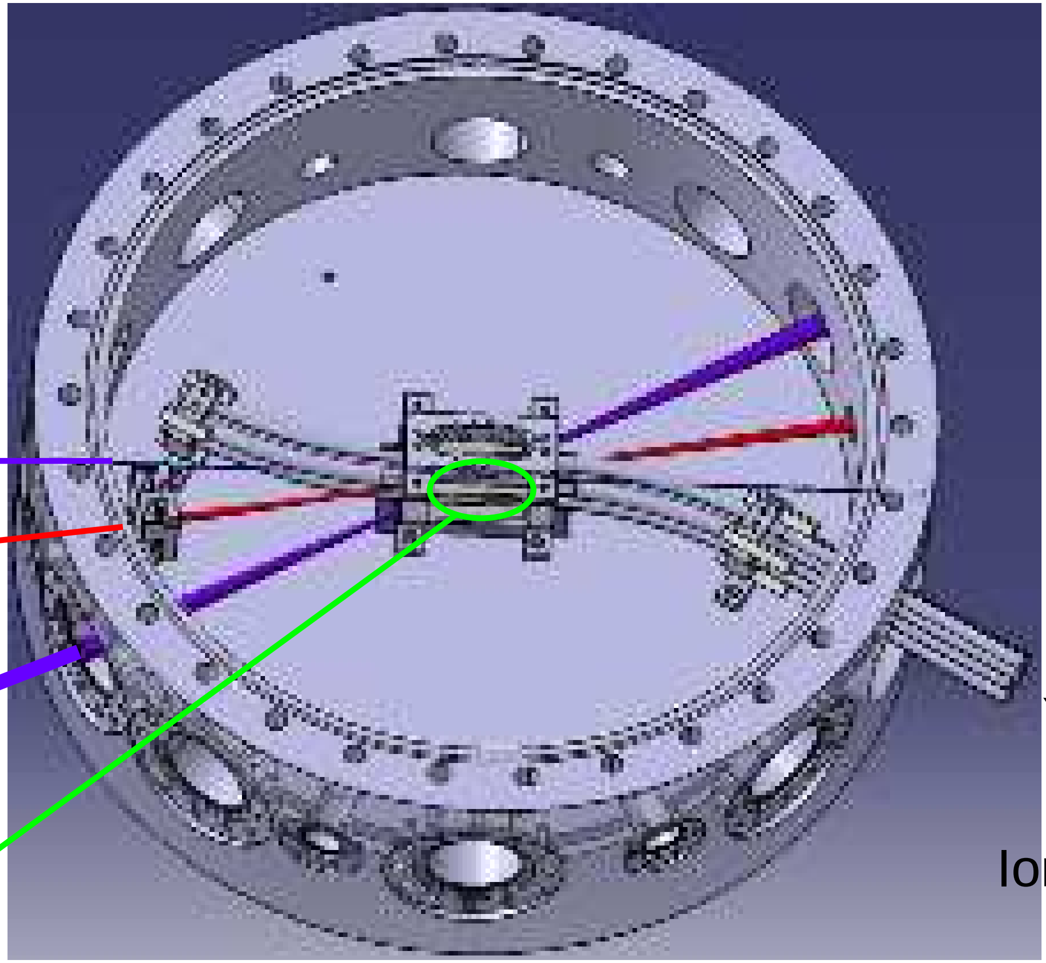
Hydrogen ion spectroscopy

A new ion trap

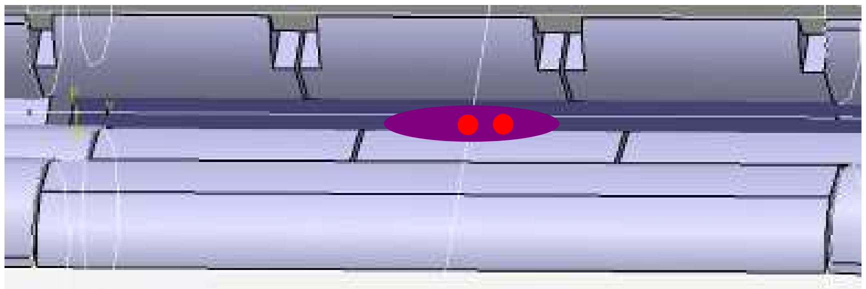
Be^+ ion cooling 313 nm

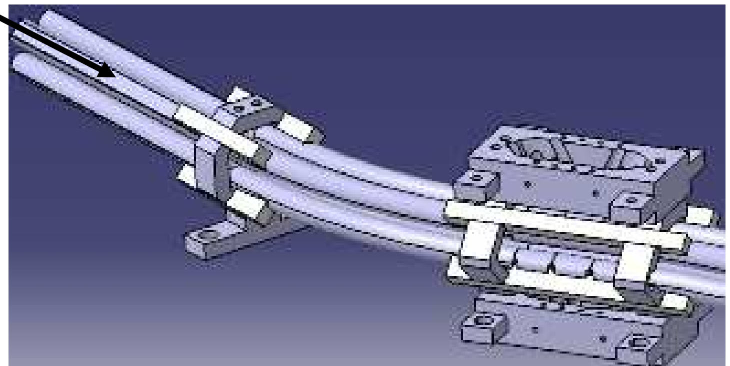
H_2^+ excitation 9.166 µm

Photodissociation 213 nm



Ion injection





The Gbar project

International collaboration
to mesure gravity $\bar{g}$
on antimatter neutral atoms $\bar{H}$

State of the art : $-110\ g \leq \bar{g} \leq 110\ g$

Nature comm. 2013

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Requirements for 1% accuracy on $\bar{g}$

- 30 cm free fall
- initial velocity ≤ 1 m/s

impossible with $\bar{H}$ direct laser cooling

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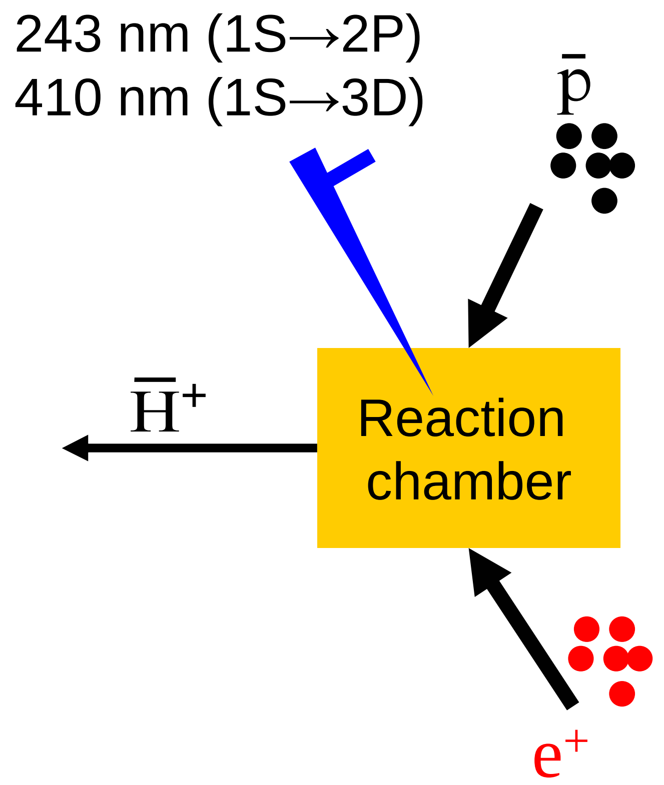
The Walz & Hänsch idea General relativity and gravitation, 36, 561 (2004)

1- Produce $\bar{H}^+$ ions
2- Sympathetically cool $\bar{H}^+$ ions
3- Photodetach the excess positron
4- Mesure the $\bar{H}$ free fall

The Gbar project



$$\begin{cases} e^+ + \text{porous silica} \rightarrow e^+e^- \\ \bar{p} + e^+e^- \rightarrow \bar{H} + e^- \\ \bar{H} + e^+e^- + h\nu \rightarrow \bar{H}^+ + e^- \end{cases}$$

a few per bunch

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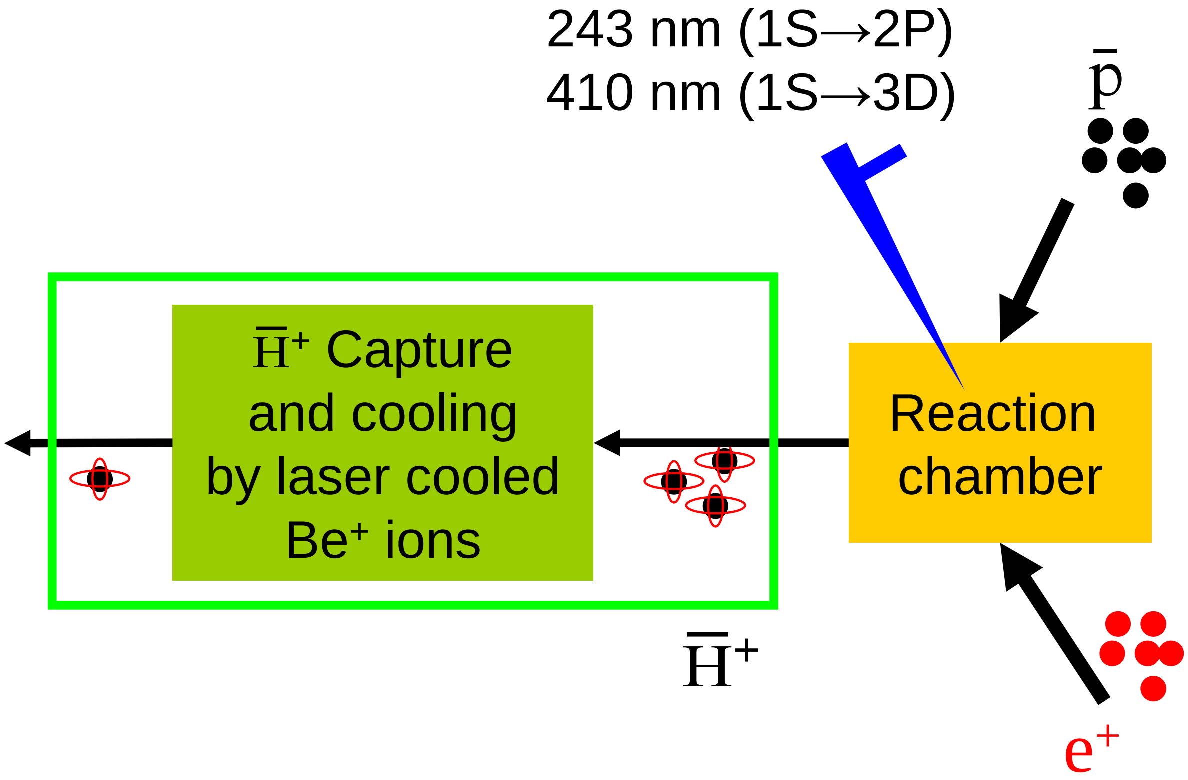

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Cooling challenge 20 µK / 3 neV ← 1 .. 6 keV / Temp ~ 60 .. 300 eV

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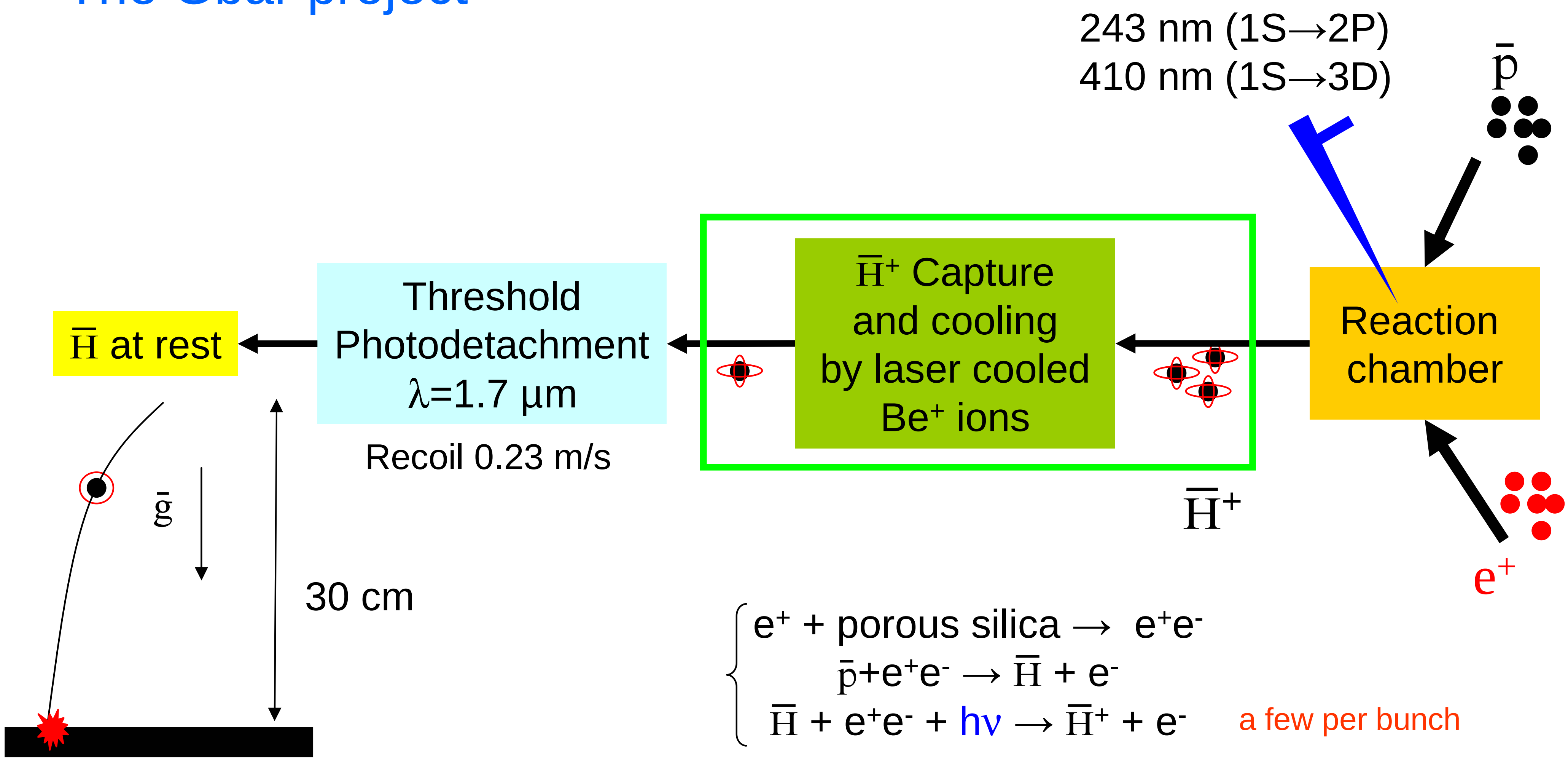

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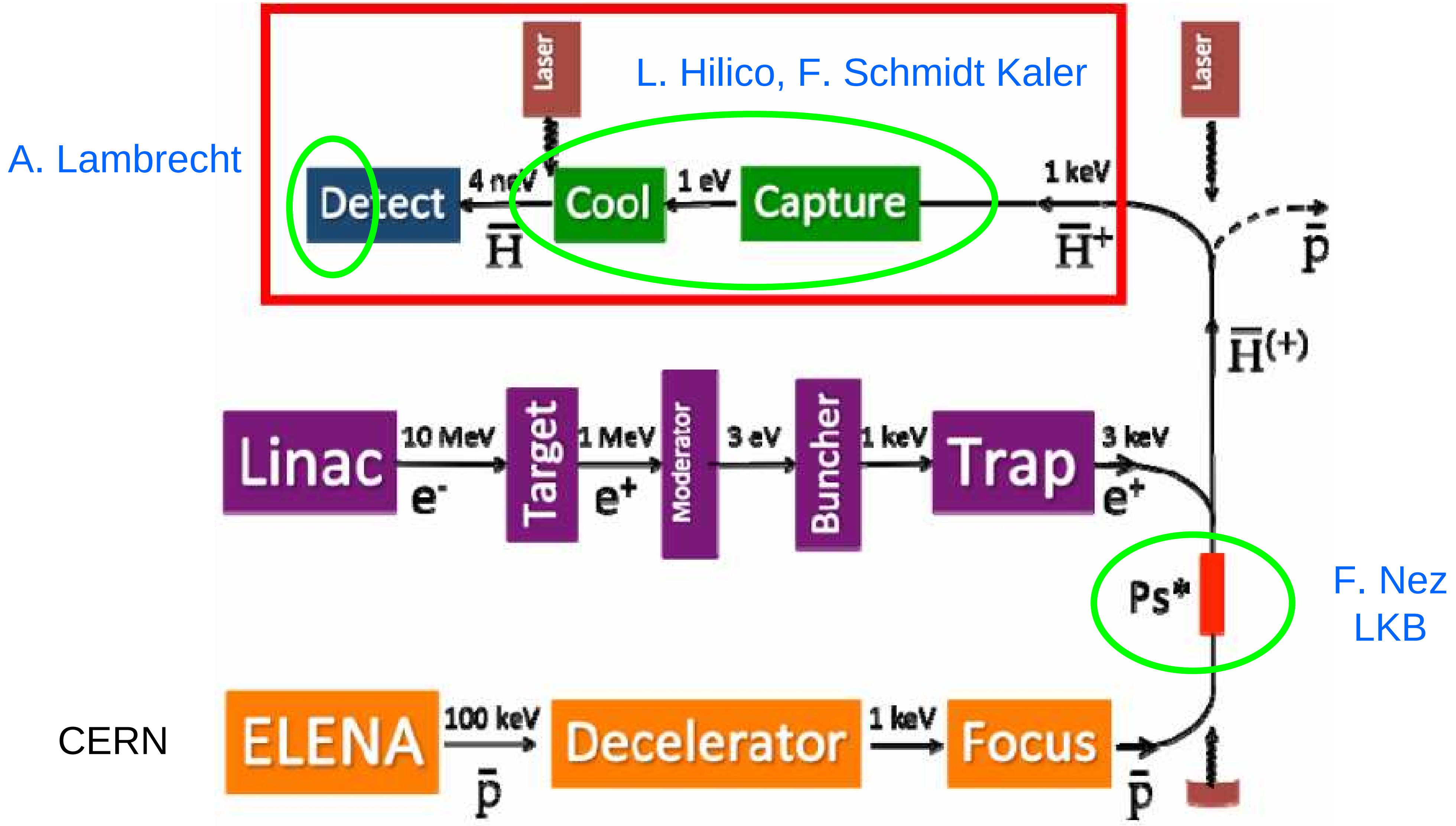

Highly charged ion $^{40}Ar^{13+}$, $^{208}Pb^{28+}$, ...

- Relativistic and QED tests at high Z

- Candidates for atomic clocks ?

Derevianko, Dzuba, Flambaum, PRL 109, 180801 (2012)

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Paul Indelicato, LKB

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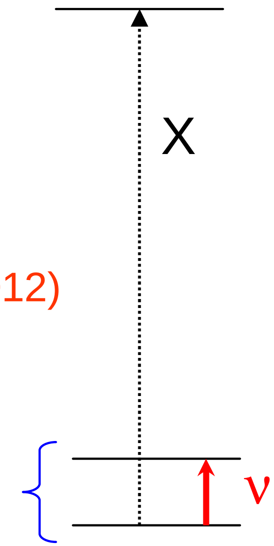

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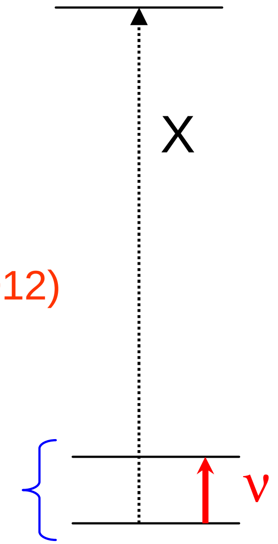

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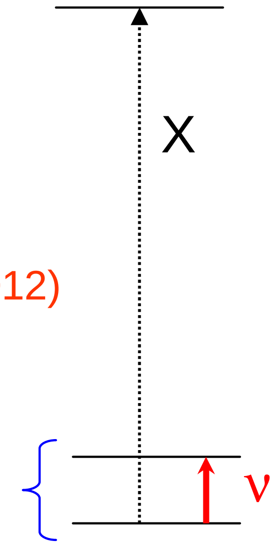

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$$\frac{\Delta\nu}{\nu} = \frac{3k_B T}{mc^2}$$

Sympathetically cooled heavy ions → small second order Doppler effect

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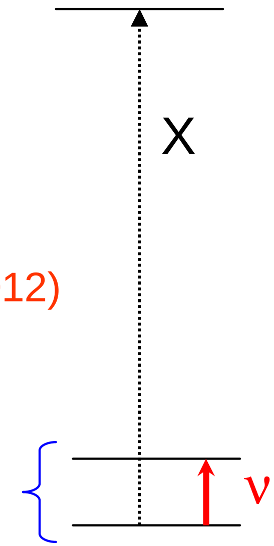

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NIST $^{27}Al^{+}/Mg^{+}$ systematic uncertainty ~ 7.8 10^{-18}
$^{208}Pb^{28+}/Be^{+}$ ~ 1. 10^{-18}

The First-TF contribution

A HIGHFINESSE WS7 wavemeter
cofinancing

Be^+ cooling fiber lasers 1550 + 1051 → 626 nm 626 x 2 → 313 nm
DBR 626 nm laser diodes (project)

H_2^+ creation pulsed 303 nm

H_2^+ dissociation pulsed 213 nm

Gbar Ps excitation pulsed 410 or 243 nm
Gbar $\bar{H}^+$ photodetachment 1.7 µm

H_2^+ two-photon excitation 9.166 µm = 91660 nm

Collaboration with
Tübingen university
WS6 / WS7 for mid-IR/fIR