Sympathetic cooling of antiprotons using laser-cooled anionic molecules

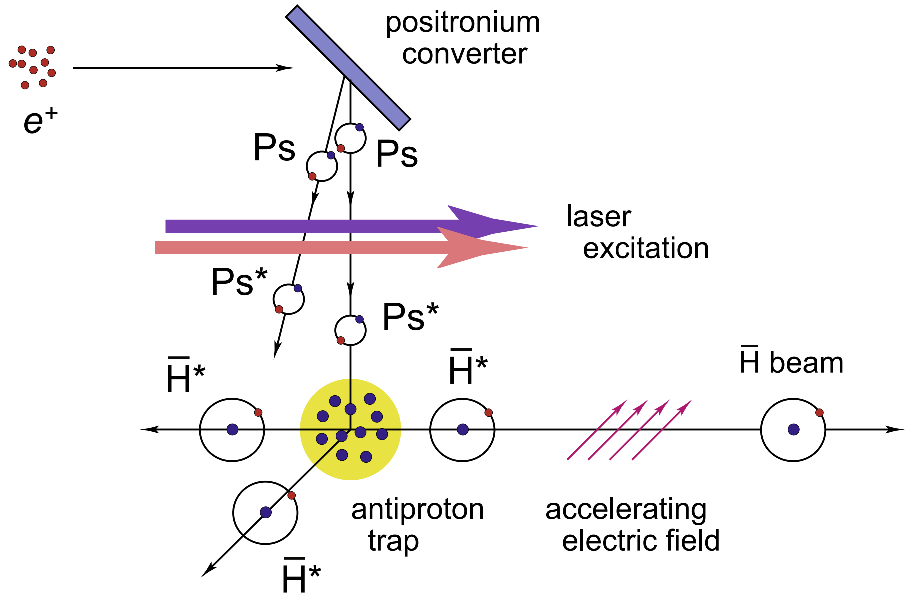
Hbar production by resonant charge exchange (RCE)

- Hbar production by resonant charge exchange:

$$\bar{\mathrm{p}} + \mathrm{Ps}^* \rightarrow \bar{\mathrm{H}}^* + \mathrm{e}^-$$
$$\sigma \propto T_{\bar{\mathrm{p}}}^{-1}$$
$$T_{\bar{\mathrm{H}}} \propto T_{\bar{\mathrm{p}}}$$

- pbar currently prepared at ~10-100 K
No direct cooling method available
->Use sympathetic cooling

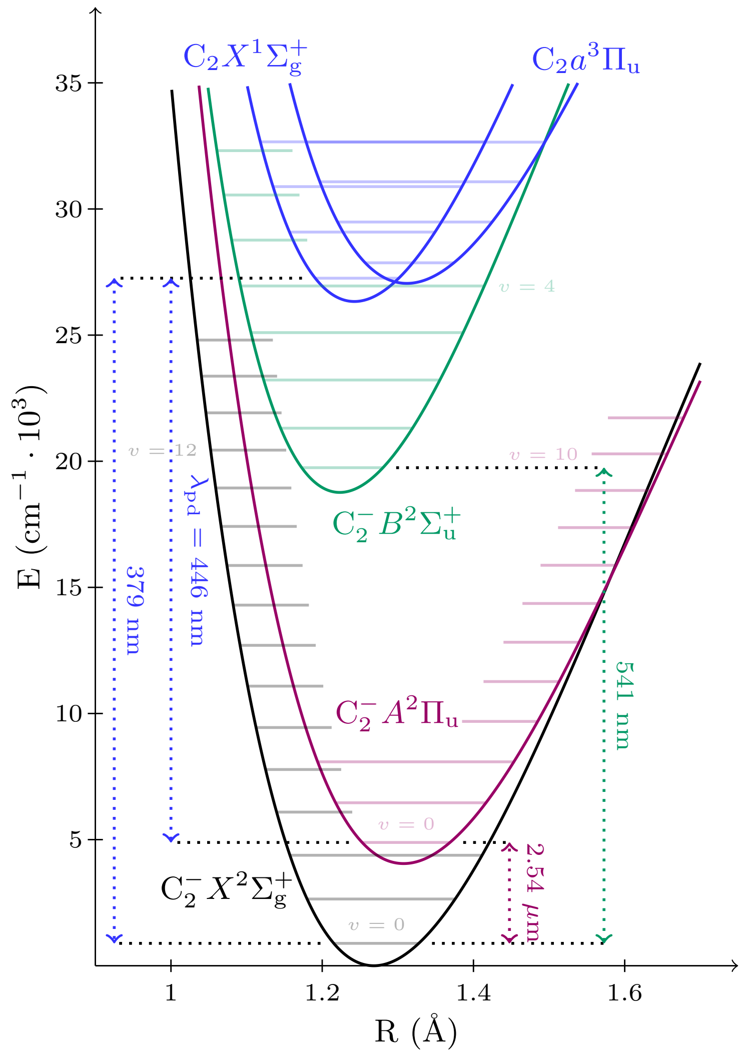
- Needs anions to avoid annihilation



A. Kellerbauer et al., Nucl. Instr. Meth. Phys. Res. B, 266, 351–356 (2008)

Anions and laser cooling

- Laser cooling of negatively charged particles has never been done.
- Only three atomic anions with electric dipole transitions known:
  La^-, Os^-, Ce^- (Alban Kellerbauers talk on Wednesday)
- Many more molecular anions known
- C_2^- level structure well known; homonuclear; no hyperfine structure



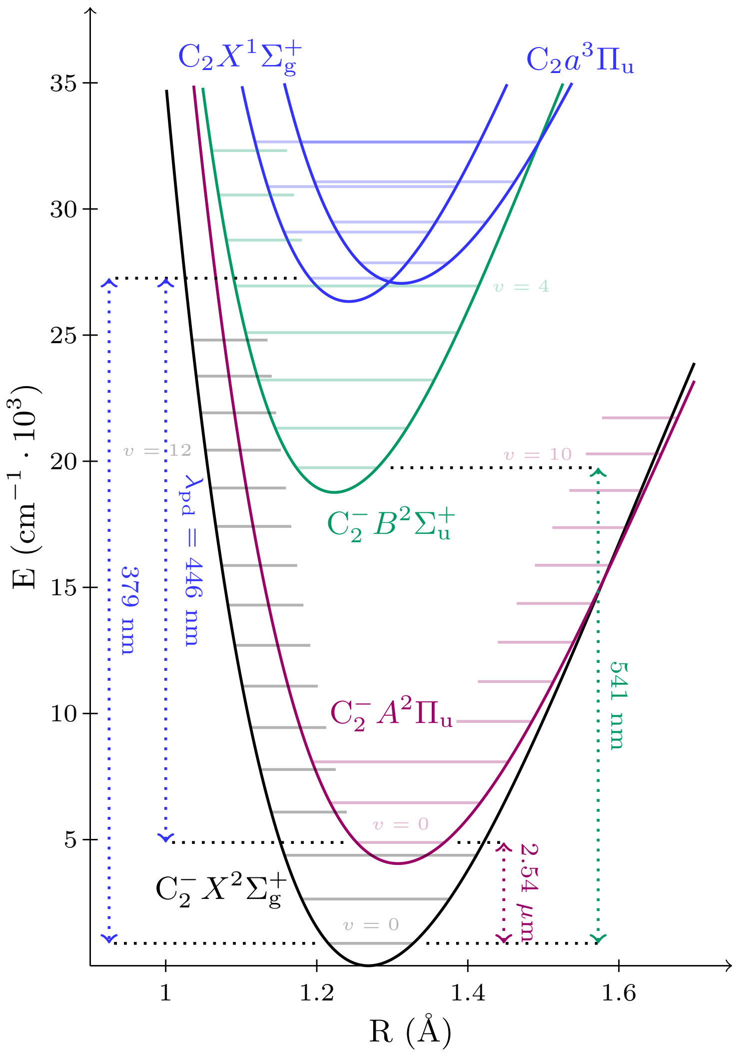
P. Yzombard et al., Phys. Rev. Lett. 114, 213001 (2015)

Level structure of C2-

- Strong X <-> B transition at 541 nm
  Lifetime: 20 ns
  12 lower vibrational levels

- Weak X <-> A transition at 2.54 um
  Lifetime: 50 us
  2 lower vibrational levels

- Photodetachment threshold:
  X -> .... 379 nm
  A -> .... 446 nm



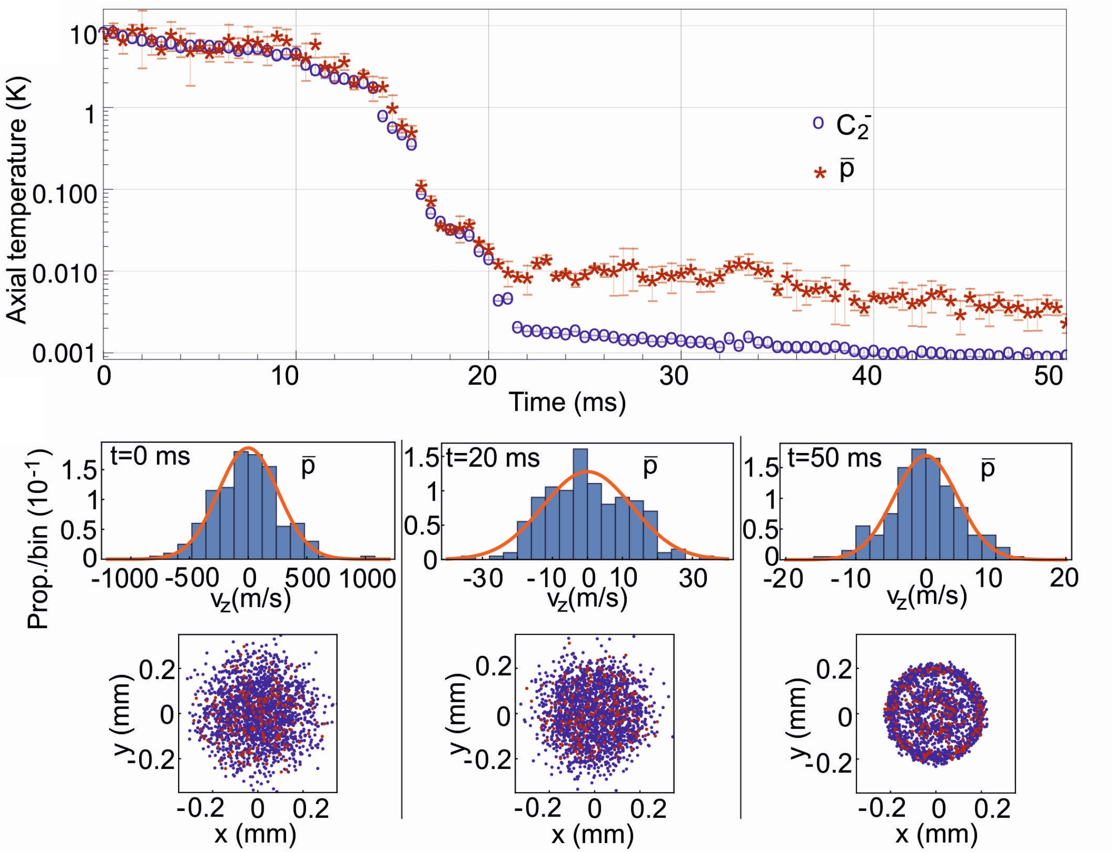
M. K. Ervin et al., J. Phys. Chem., 95, 1167 (1991)

Doppler cooling

- Simulation of 1848 C_2^- and 200 pbars

- Cooling artificially amplified by a factor of 1e4
  ->Cooling time >100 s for sub Kelvin regime

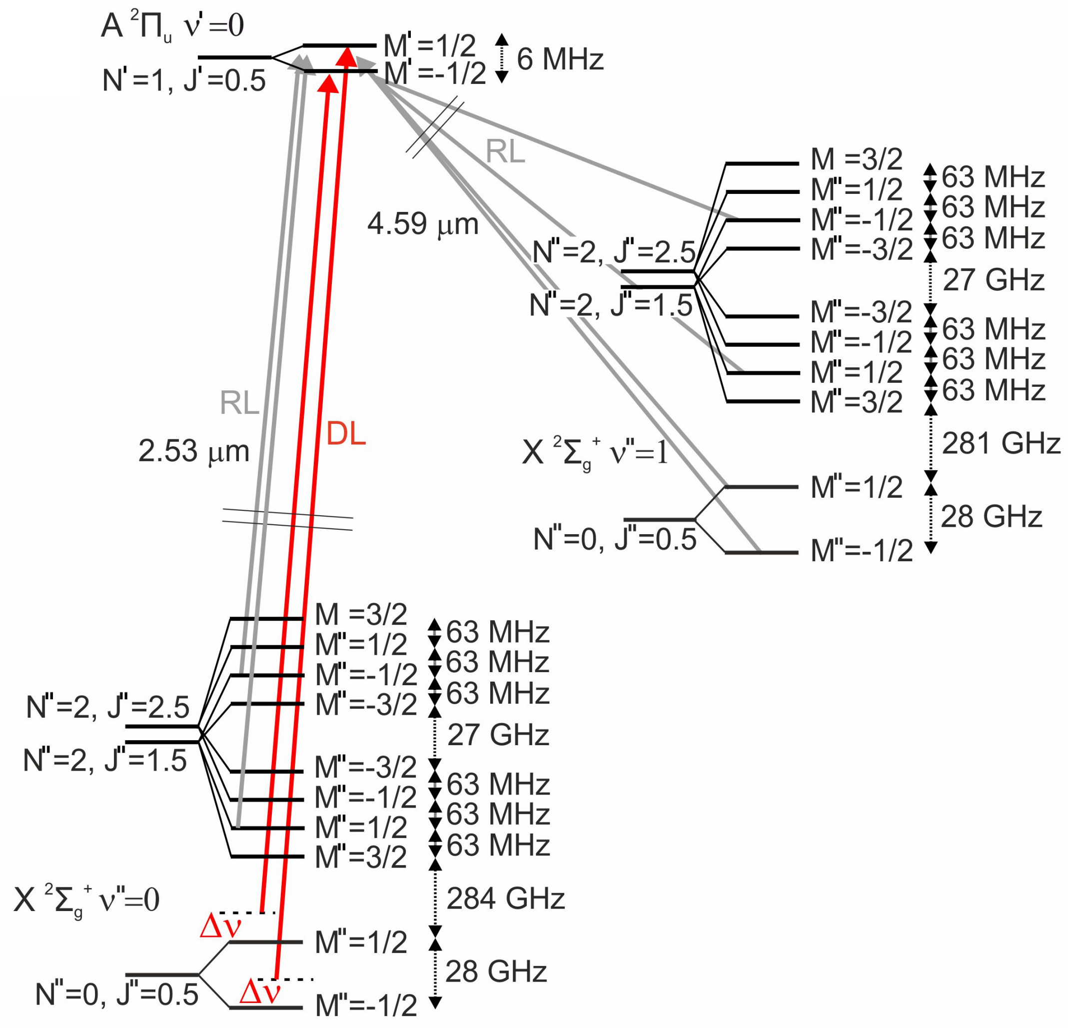
- Competing with heating mechanisms in Penning trap



S. Gerber et al., New J. Phys., 20, 23024 (2018)
S. Van Gorp et al., Nucl. Instrum. Methods Phys. Res. Sect. A, 638, 192 (2011)

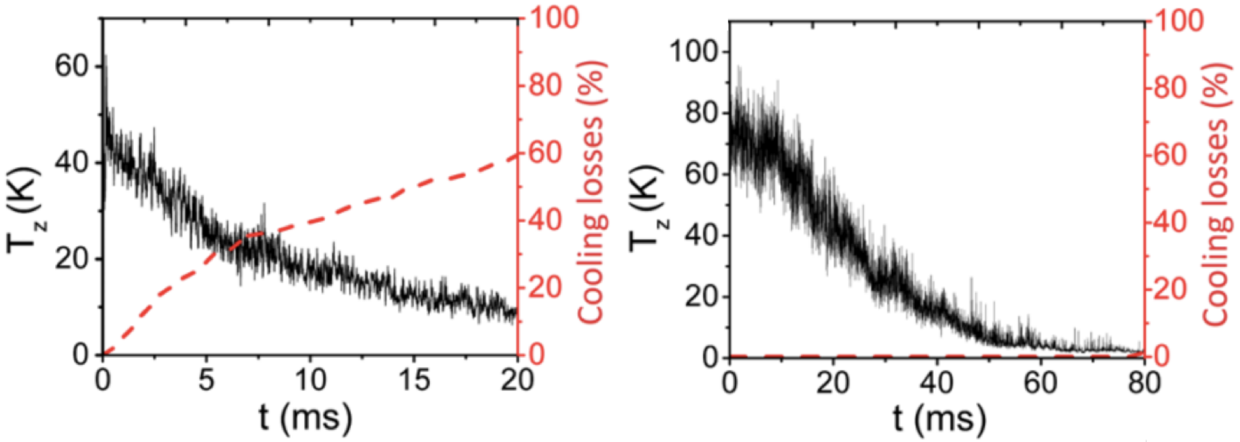
Repumping needed for Doppler cooling

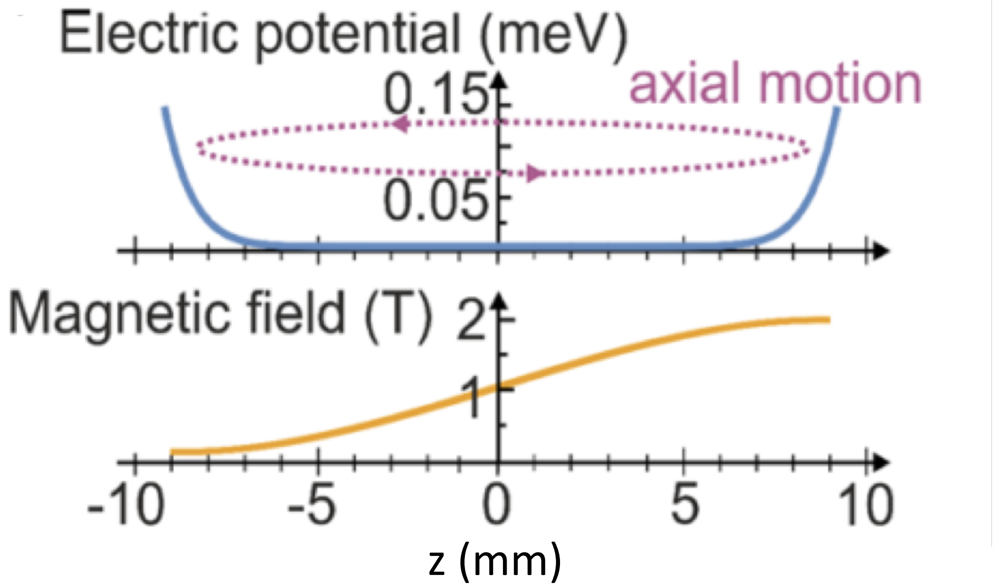
- Continuous repumping of 19 levels required
- v=1 branch repumped by single broad diode
- v=0, N=2 branch repumped by two sideband modulated lasers
- -> Total of five lasers needed



Magnetic field gradient Sisyphus cooling

- Strong cooling on a weak transition possible
- Sub Kelvin reachable in ~100 ms
- Requires axial magnetic field gradient
- Might lead to unwanted plasma dynamics due to magnetic mirror

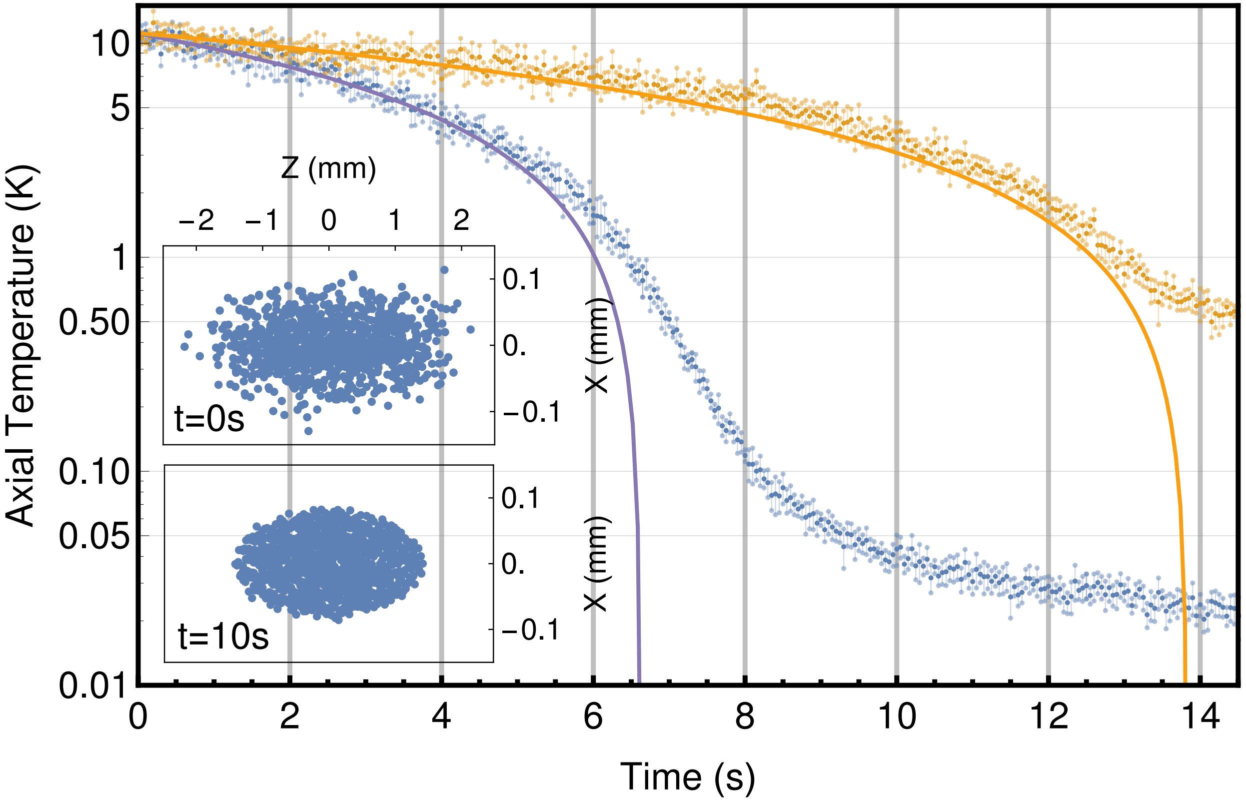




P. Yzombard et al., Phys. Rev. Lett. 114, 213001 (2015)

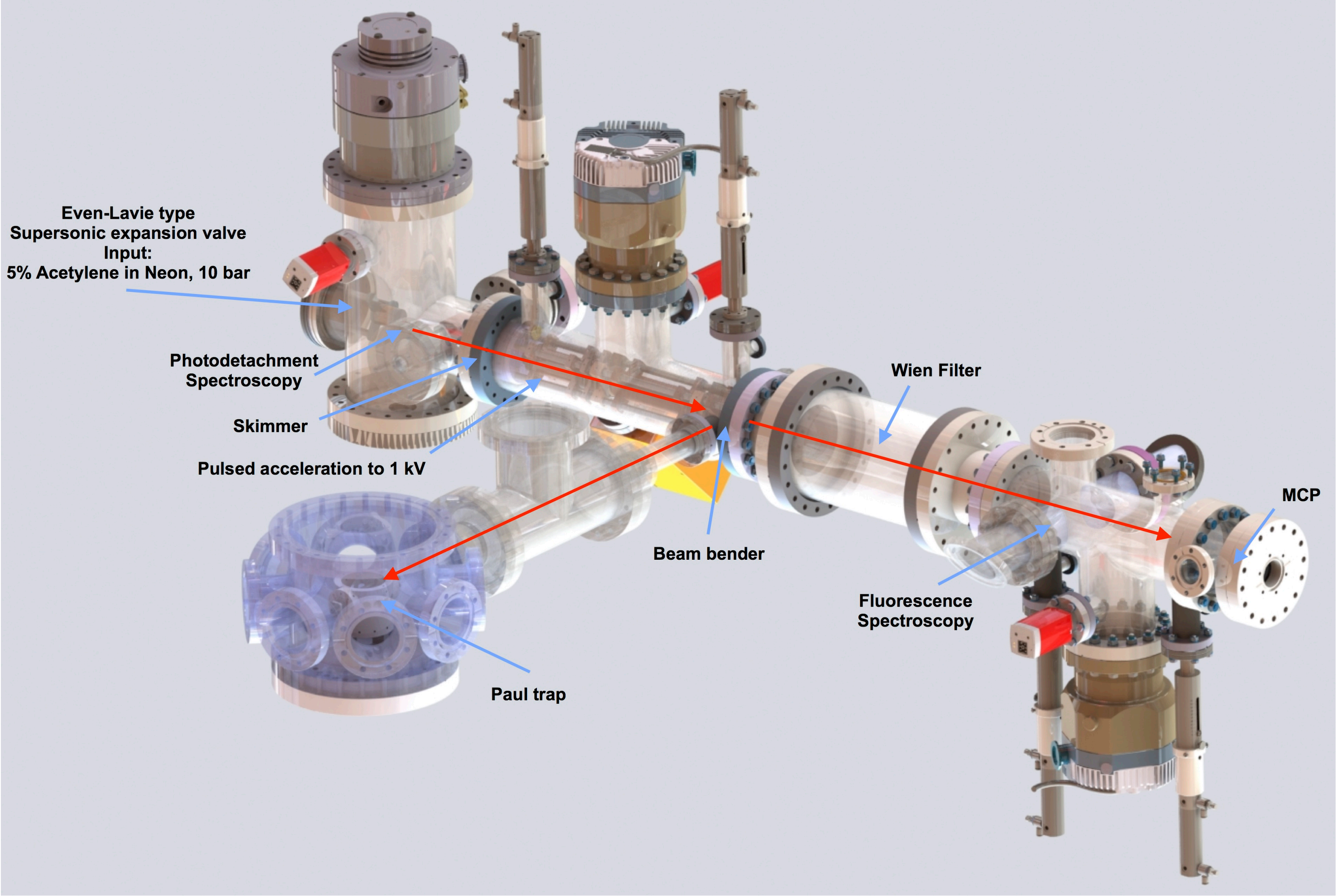
Dipole force sisyphus cooling

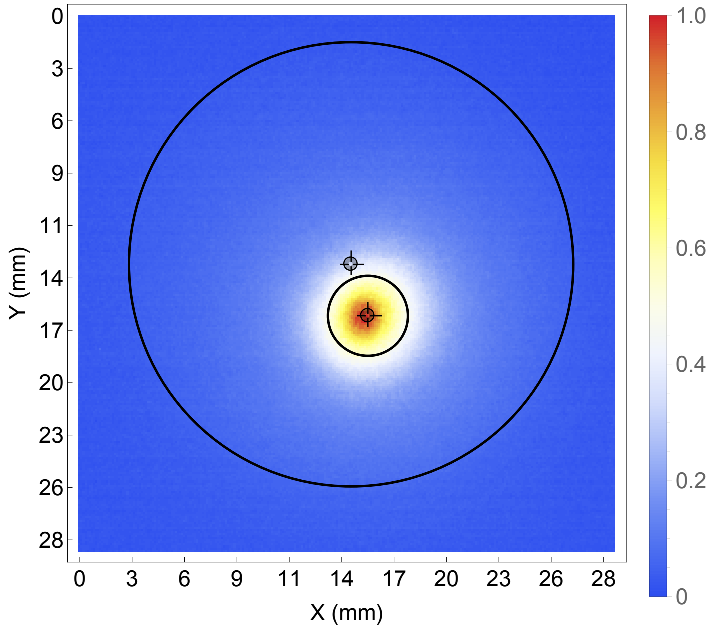
- Create modulation of potential using a strong, detuned laser on X(v=0) <-> A
- Weaker than a gradient in the magnetic field
- Better than Doppler cooling
- Requires a very intense lightfield, radially covering the whole plasma (6 W, w_0=140 um)



J. Fesel et al., Phys. Rev. A, 96, 31401 (2017)

Overview of our experimental setup





- Stable dielectric barrier discharge
- ~1e9 anions produced
- Acceleration to 1 kV
- 20 us pulse

Outlook

Next months:

- Determine abundance of C_2^- in anion pulse
- Characterise internal population of the produced C_2^- via spectroscopy
- Trap C_2^- in Paul trap

After that:

- Show proof of concept laser cooling in Paul trap
  -> Doppler selective photodetachment cooling

Thank you for the attention.

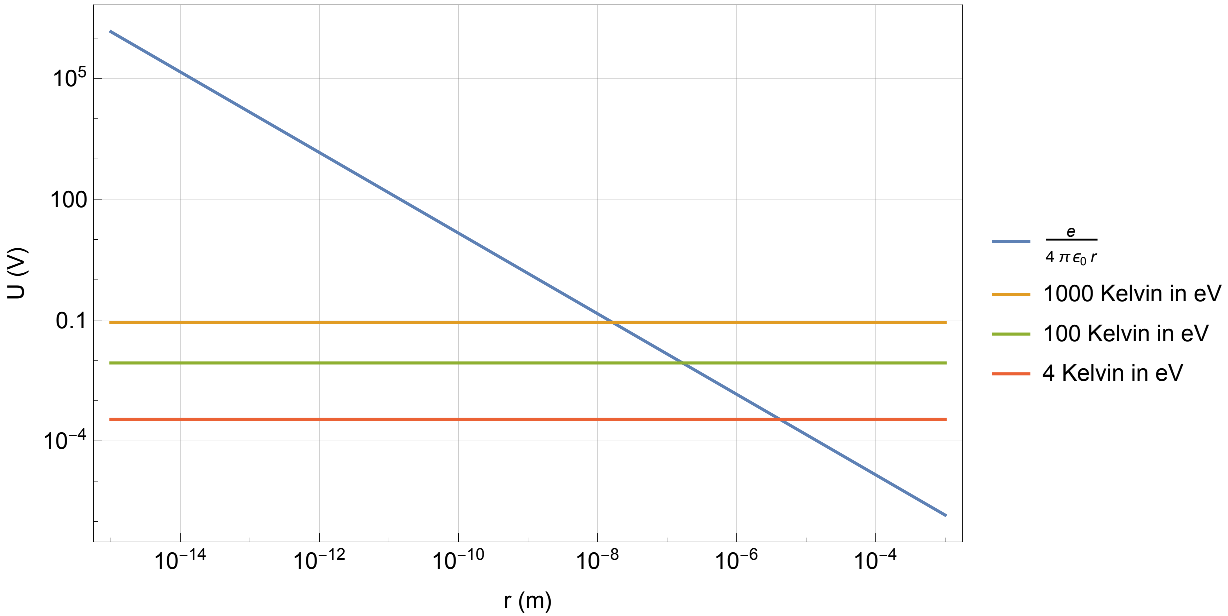
Michael Doser

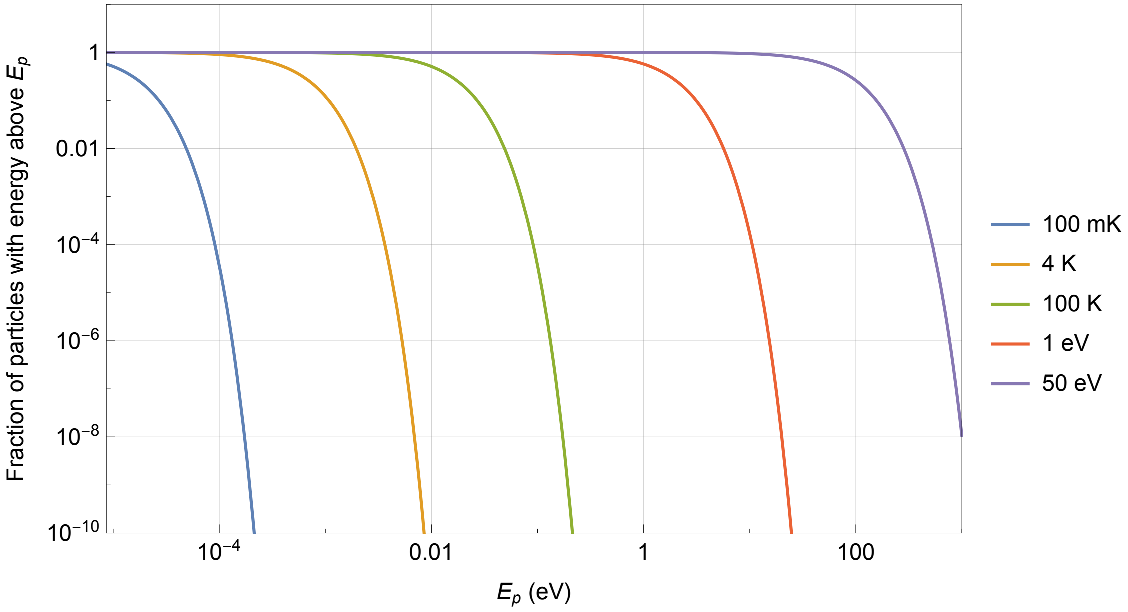
Daniel Comparat

Stefan Haider

Spares

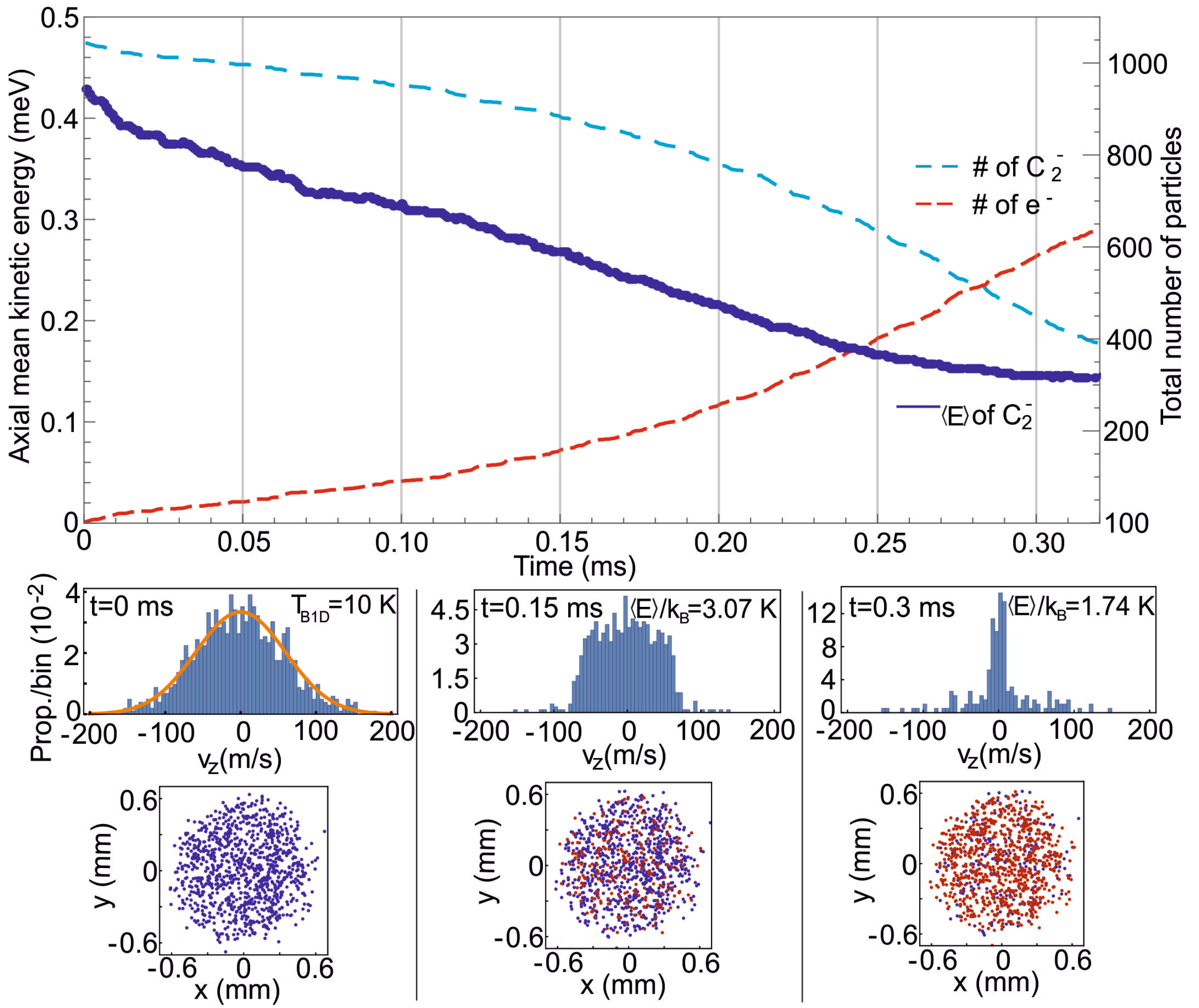
Concerning annihilation of pbars with C2-





Doppler selective evaporative cooling

- Simulation using GPU accelerated Simbuca code for 1100 C_2^-
- Initial temperature ~10 K
- Mean E_{kin} reduced by factor of ~5.5 during ~300 us.
- # of C_2^- reduced by factor of ~2.5



S. Gerber et al., New J. Phys., 20, 23024 (2018)

Repumping needed for Sisyphus cooling

- Could be used at 5 T
- Only one upper level addressed-> Need to repump 15 levels
- v=1 branch can be covered by a single diode
- Sidebands can be used for v=0, N=2 triplets
- -> 4 repumping lasers needed