A Moving Trap Zeeman Decelerator

A. Mizouri, U. M. Krohn, and D. Carty

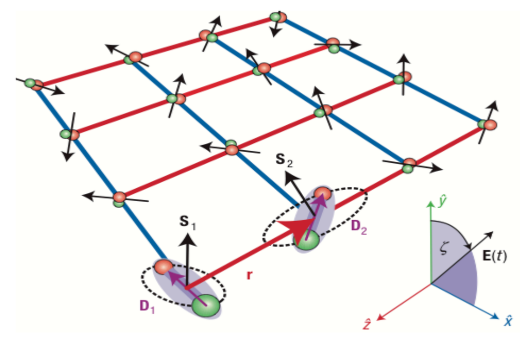
Joint Quantum Centre, Department of Physics, Durham University, Durham, DH1 3LE, UK

Vision: Our research is part of an experimental program to build a quantum simulator using polar molecules. The aim of this program, entitled "MicroKelvin Molecules in a Quantum Array (MMQA)", is to cool high densities of molecules to µK temperatures and trap them in an optical lattice to create an ideal, tunable and highly versatile tool for modeling strongly-interacting quantum systems and understanding the remarkable quantum phenomena they exhibit. The moving trap Zeeman decelerator is a new innovation in molecule cooling that promises to produce a diverse range of cold (tens of mK) paramagnetic molecules and atoms in large quantities and high densities. The molecules will then be loaded into a microwave trap in their absolute ground state and be sympathetically cooled with ultracold atoms down into the µK regime.

Motivation

Richard Feynman (1918-1988)

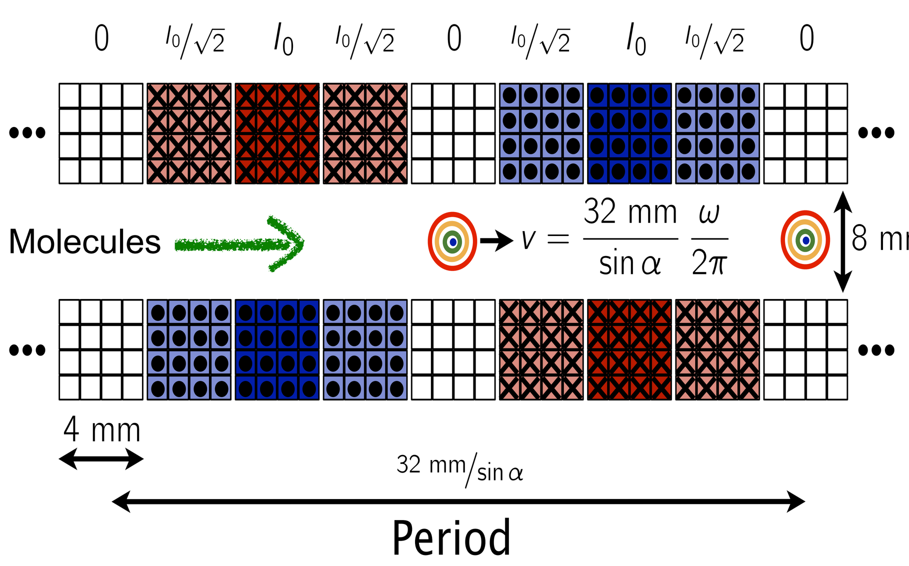
"I believe it's true that with a suitable class of quantum machines you could imitate any quantum system, including the physical world." [1]



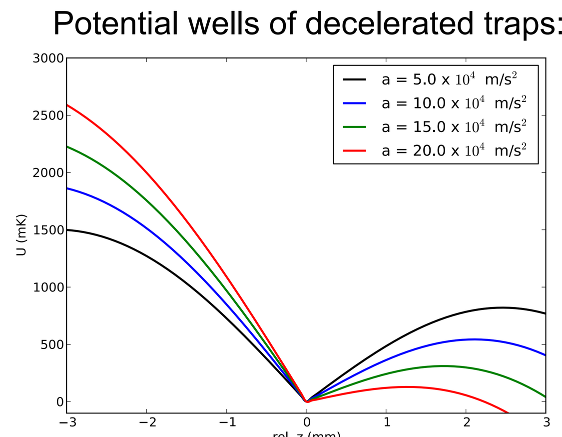
The complex behaviour of many-body quantum systems is one of the greatest challenges which still remain in modern physics. A quantum simulator will allow us to investigate the many-body quantum phenomena that arise when dipolar molecules organize themselves in a trap or on a lattice. [2]

Decelerating a moving trap

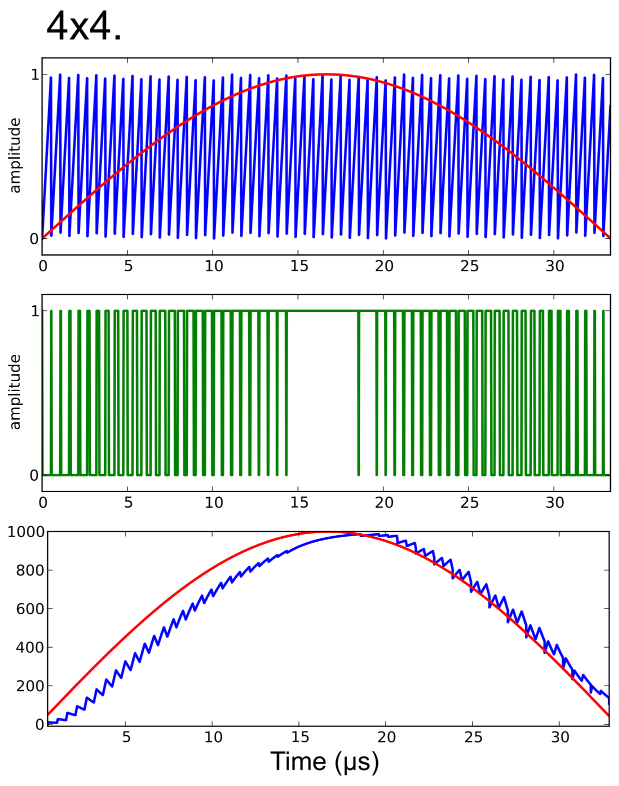
Zeeman deceleration is a general method of cooling molecules down into the mK regime and can be used, in principle, on any paramagnetic atomic or molecular species e.g. Ne($^3P_2$), CN($^2\Sigma^+$), SO($^3\Sigma^-$), F($^3P_2$), SH($^2\Pi_{3/2}$), OH($^2\Pi_{3/2}$), and CaF($^2\Sigma^+$). [3]

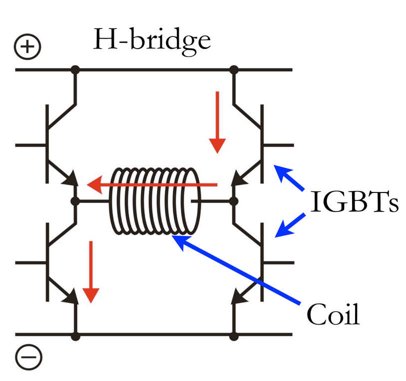


Potential wells of decelerated traps:



A moving magnetic trap is formed by modulating current sinusoidally in the set of wires in blocks of 4x4.





A **sine wave** is sampled with a **sawtooth function**. If the **sawtooth function** is bigger than the **sine wave**, the power supply is **off (=0)**, if its value is lower the power supply is **on (=1)**.

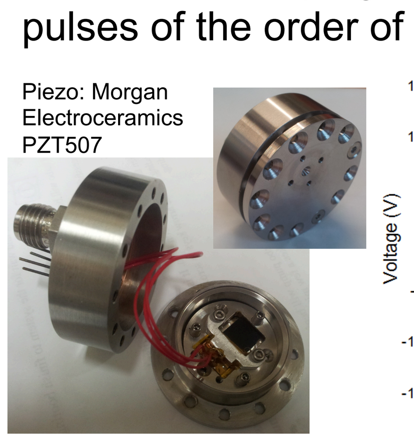
Decelerator Electronics

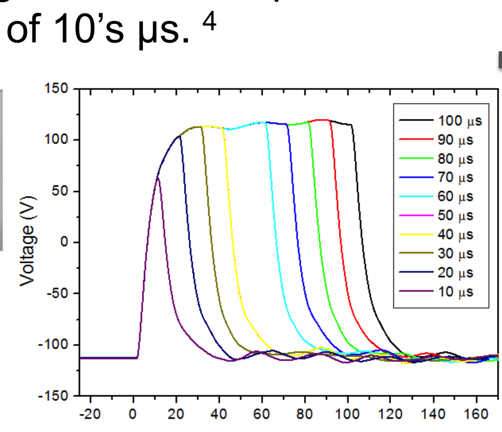
We need to deliver sinusoidal currents up to 1000 A (peak-to-peak) in each wire at frequencies from ω=2π×36 kHz to DC for durations of a few ms.

We will control the current in the flat coils using a series of high current generators based on a full H-bridge circuit and using pulse width modulation. The prototype circuit delivers a single pulse of I_0 = 2000 A with a risetime < 10 µs.

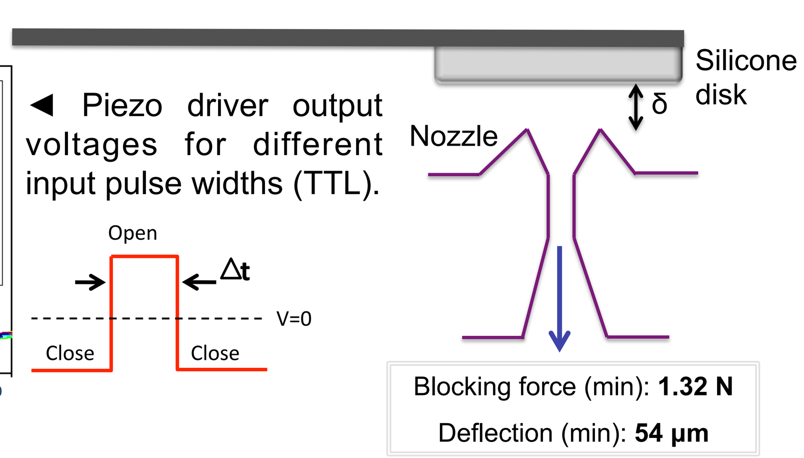
Decelerator source

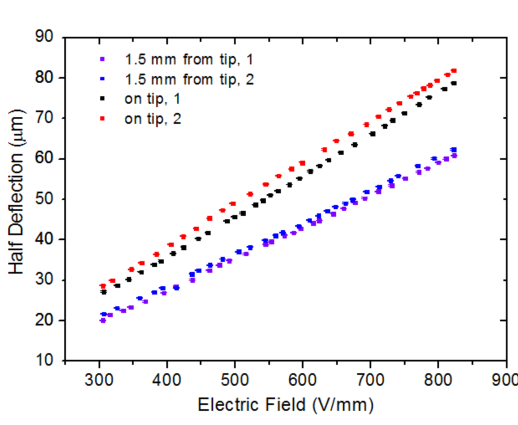
We are developing a cantilever piezo valve that is capable of producing short gas pulses of the order of 10's µs. [4]





◄ Piezo driver output voltages for different input pulse widths (TTL).

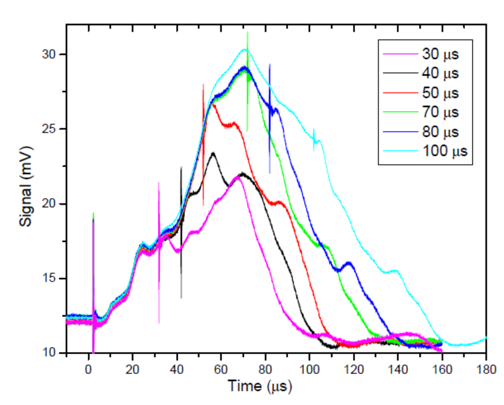


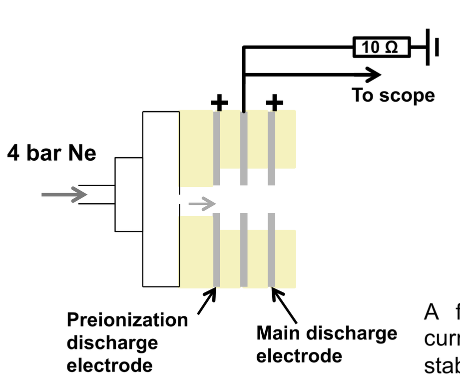


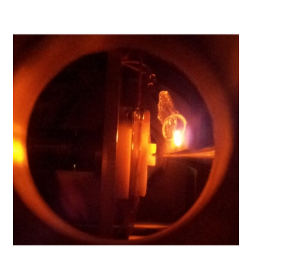
$$\delta \propto d_{31}\frac{l^2}{t} \qquad v_1 \propto \frac{t}{l^2} \qquad F_{bl} \propto \frac{wt^2}{l}$$

► Photodiode signal from reflected light on the piezo tip showing the piezo time response.

◄ Piezo displacements for static voltages, measured with a confocal probe.

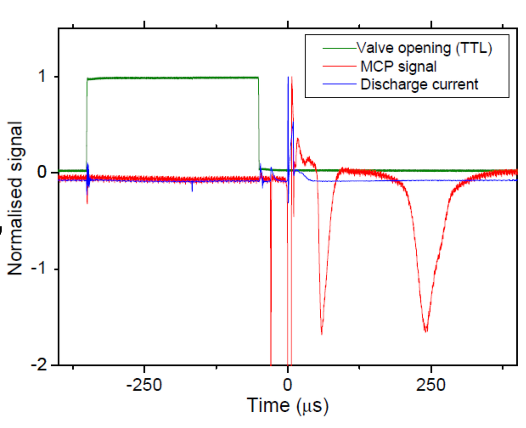




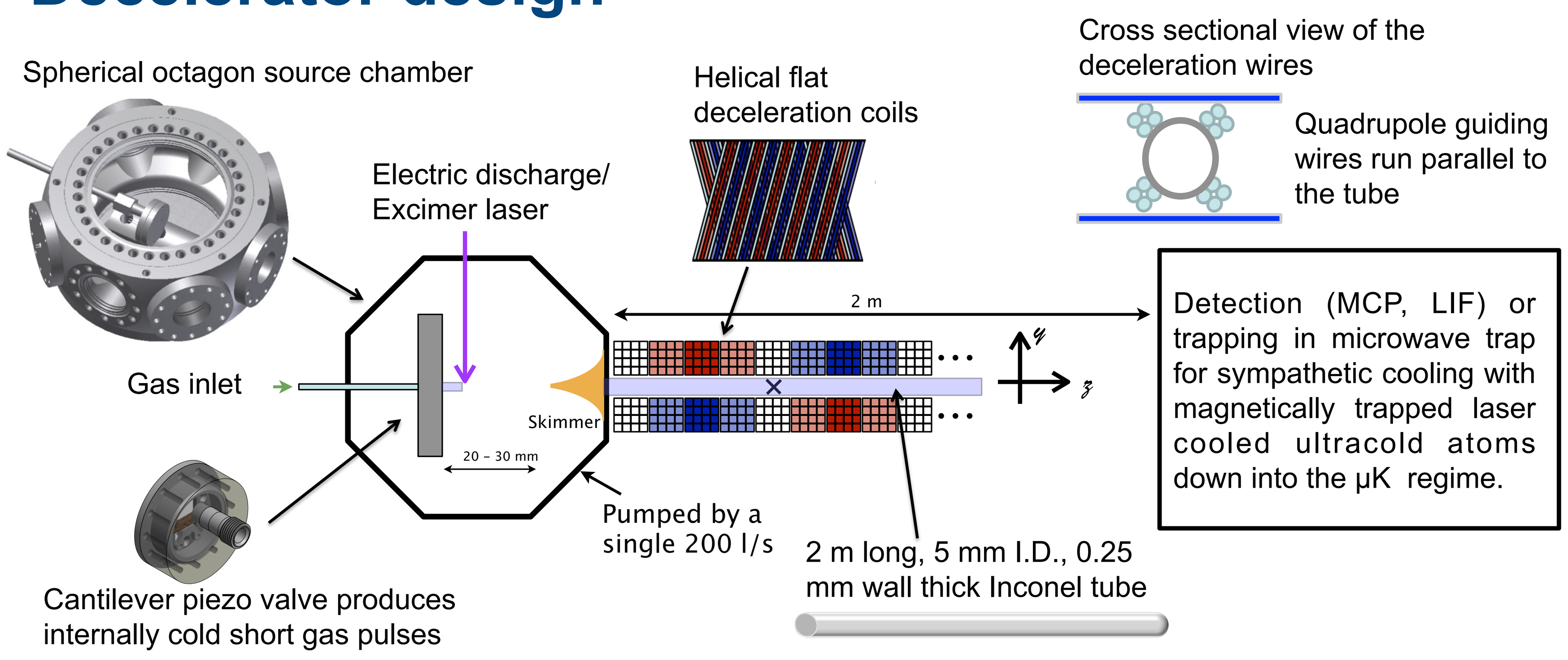


A filament with variable DC current (0.3-3.0 A) is used to stabilise the discharge.

We will test the decelerator with neon atoms in the $^3P_2$ metastable paramagnetic state, produced using a pulsed electric discharge.



Decelerator design

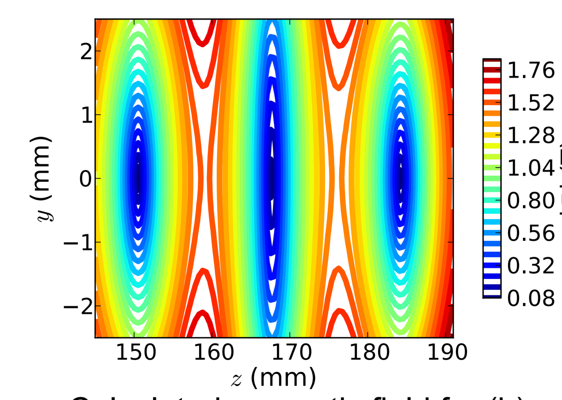


Monte Carlo trajectory simulations

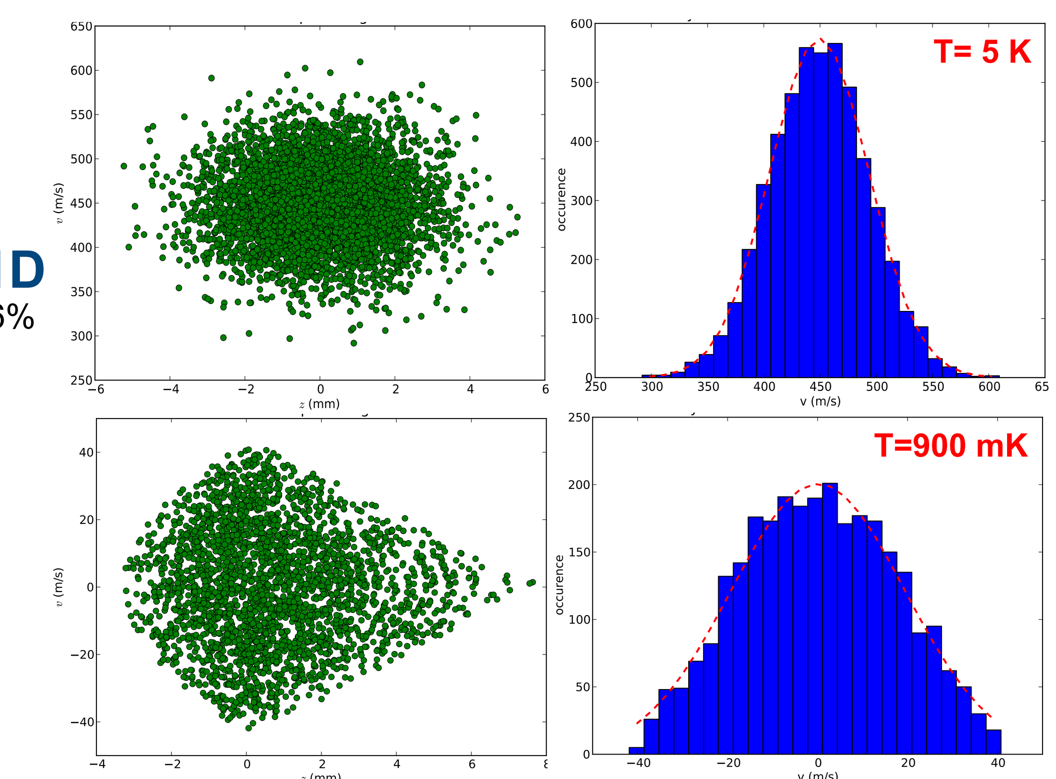
All simulations were carried out for Ne($^3P_2$) atoms using a 2 m long decelerator, from 450±45 m/s to rest at a deceleration of 5×10⁴ m/s². Calculation results in 1D and 3D are depicted in phase-space diagrams with their efficiencies (η) .

In 1D

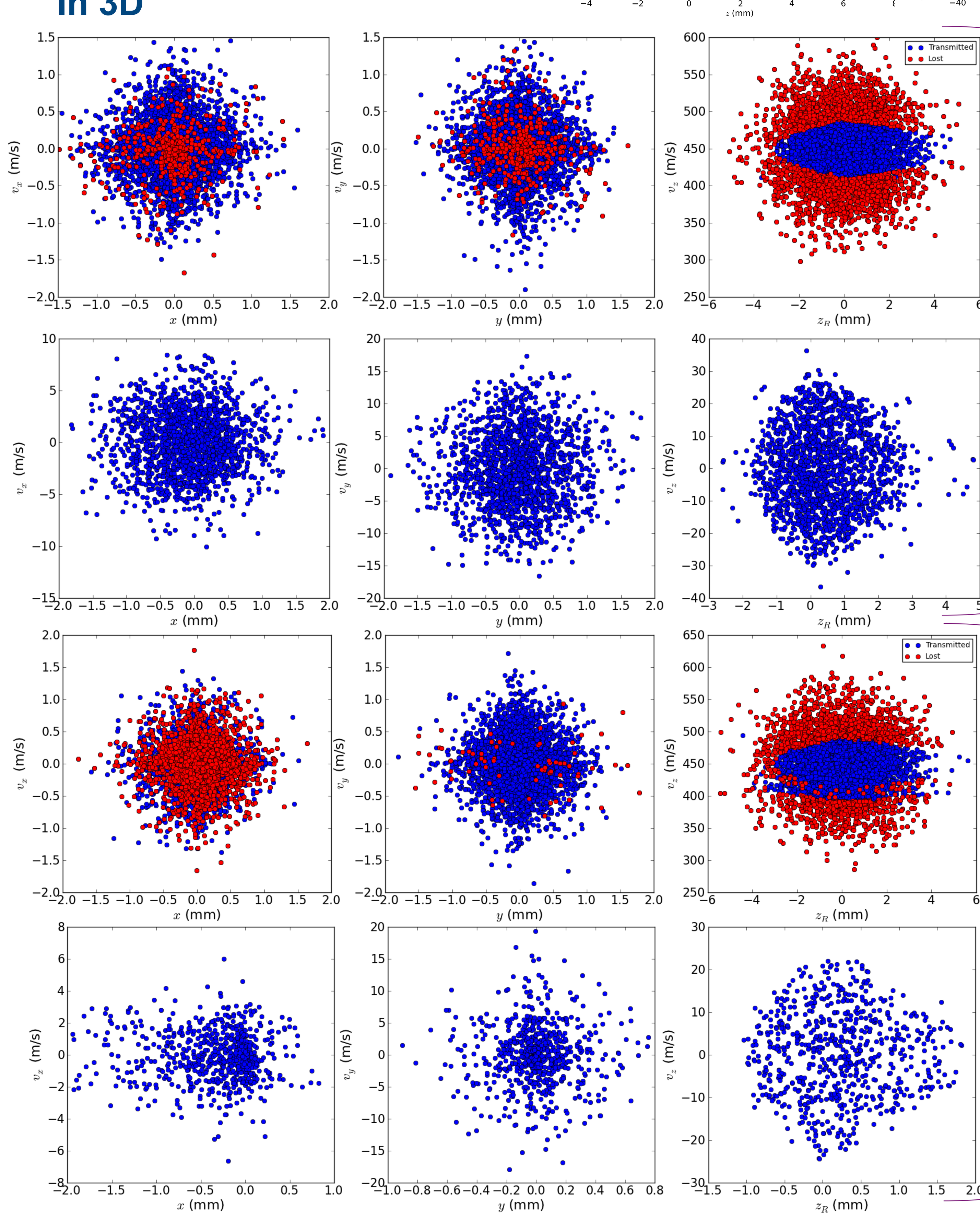
η=56%



Calculated magnetic field for (b).

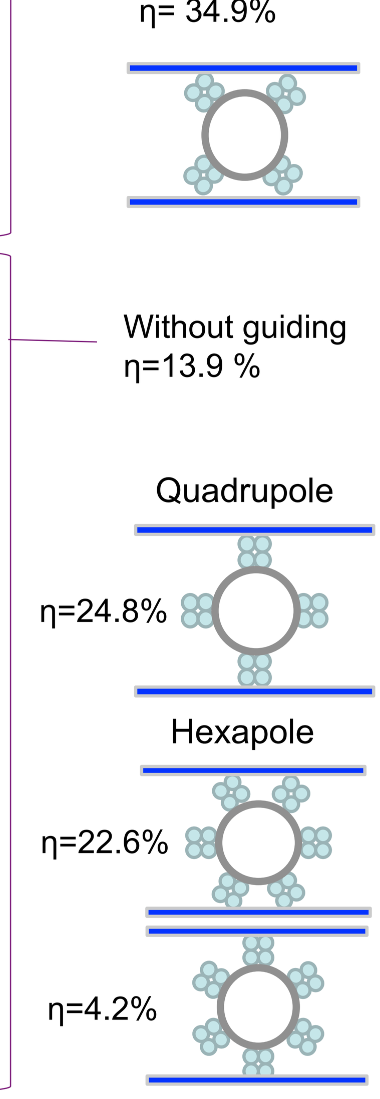


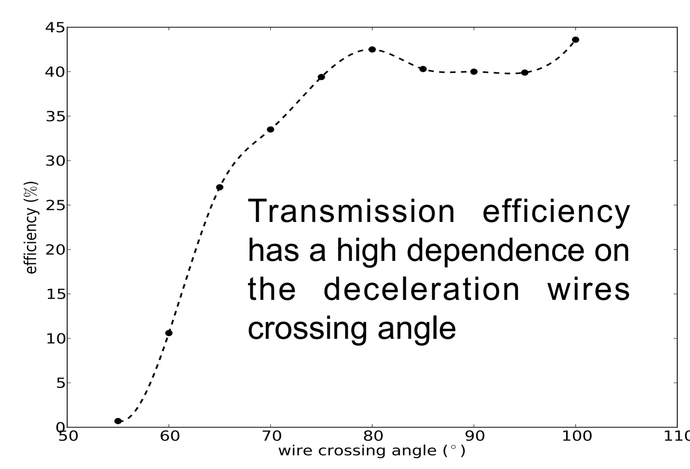
In 3D



Top row of each panel: molecular beam emittance showing the origins of atoms that are transmitted, defined as the decelerator acceptance.

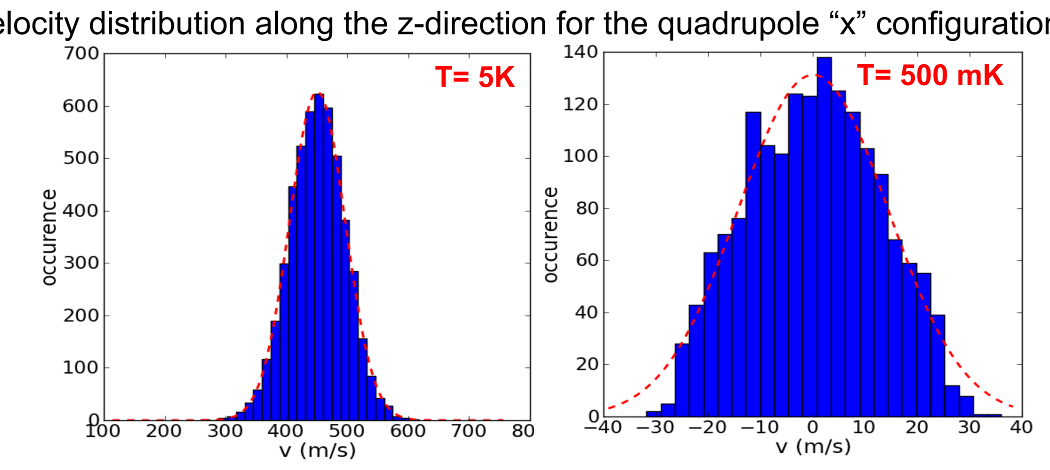
Wire crossing angle α=70°.





Transmission efficiency has a high dependence on the deceleration wires crossing angle

Velocity distribution along the z-direction for the quadrupole "x" configuration



References

1. R. P. Feynman, *International Journal of Theoretical Physics*, **21**, 467, 1982.
2. A. Micheli, G. K. Brennen, and P. Zoller, *Nature Phys.*, **2**, 341, 2006.
3. A. Trimeche, M.N. Bera, J.P. Cromières, J. Robert, and N. Vanhaecke· *Eur. Phys. J. D.*, **65**, 263, 2011.
4. D. Irimia et al., *Rev. Sci. Instrum.*, **80**, 113303, 2009.

Acknowledgements

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