An efficient Zeeman slower for the ROYMAGE transportable Ytterbium clock

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[1]LNE-SYRTE, Observatoire de Paris - Université PSL, CNRS, Sorbonne Université, LNE, Paris, France, [2]Real Instituto y Observatorio de la Armada (ROA), Cecilio Pujazón s/n, 11100 San Fernando (Cádiz), Spain, [3]Université de Paris, IPGP, CNRS, IGN, F-75005 Paris, France, [4]ENSG-Géomatique, IGN, F-77455 Marne la-Vallée, France, [5]SHOM, 13 rue du Chatellier, 29200 Brest, [6]IGN, 73 Av. de Paris, 94160 Saint-Mandé

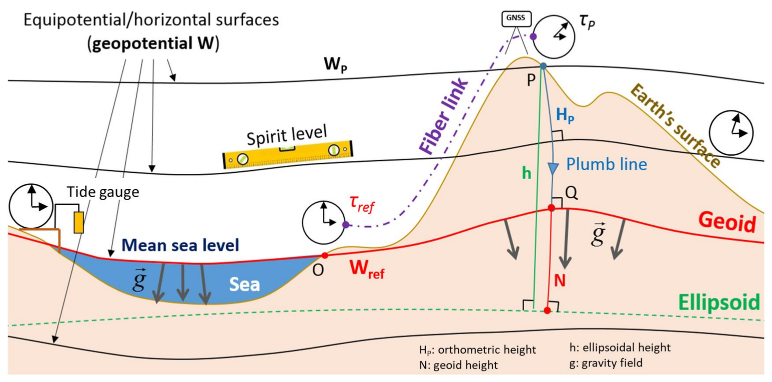
Motivation : apply quantum sensors to Earth Sciences

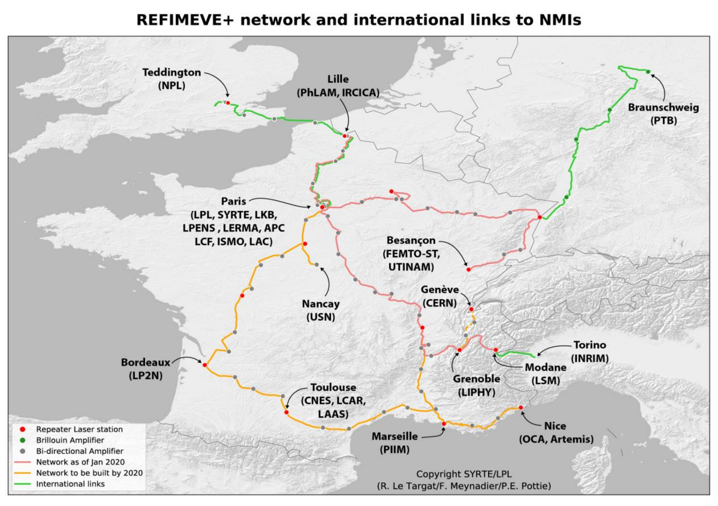
❑ Optical Lattice Clocks allow a control of **18 significant digits** (10^{-18}) of their frequency, with a statistical resolution of a few $10^{-16}/\sqrt{\tau}$, with τ the integration time.

❑ As predicted by Einstein, atomic frequencies ν are sensitive to the local gravitational potential W and therefore to the altitude .

$$\frac{\Delta\nu}{\nu} = \frac{\Delta W}{c^2} \approx \frac{g \cdot \Delta h}{c^2}$$

❑An atomic clock travelling in the field can be used to perform a **cartography of the geopotential**, by remote comparisons with ~12 existing optical clocks in Europe, connected by ultrastable fiber links.



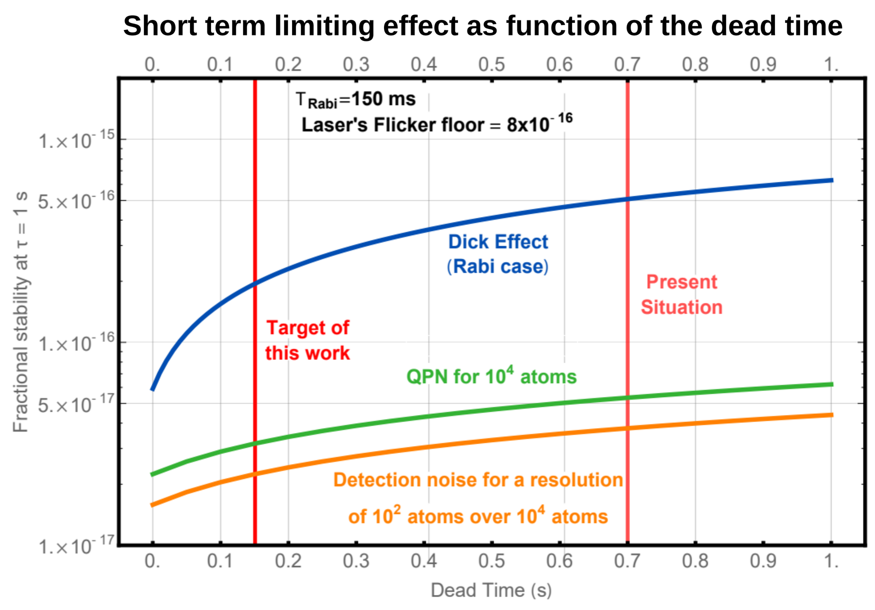


❑ The Equipex **REFIMEVE+** disseminates a **1542 nm ultrastable IR carrier** throughout France, with connections to corresponding networks in Germany, UK and Italy.

Impact of dead time on the clock short term stability

❑When interrogating the clock transition the result is judged by two criteria :

- The uncertainty, or how close we believe the corrected measured frequency is to the 'ideal' unperturbed value, and it will be reflected by how well are known the corrections made due to systematical effects shifting this frequency.
- The stability, when the values of repeated measurements are clustered close together and have minimal scatter over time.



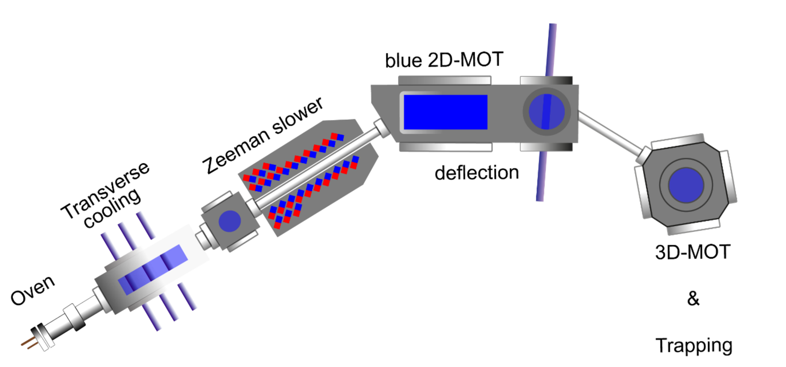
The major limitation noise on the stability

Dick effect

Loading as fast as the coherence of the laser will reduce it

The project aims at loading >10^4 atoms into the optical trap in <150 ms.

Cold Yb source design and simulation

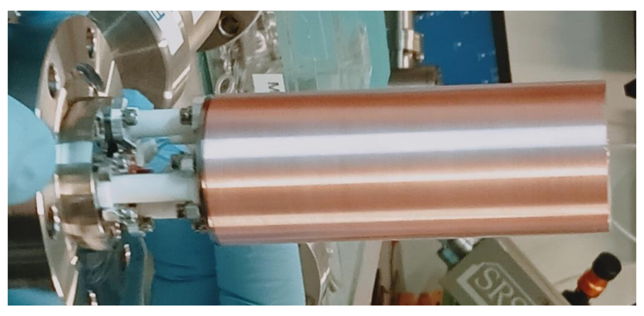


❑ Design main points [2]:

- Optical molasses for transverse velocity reduction.
- Zeeman slower for longitudinal velocity reduction.
- 2D MOT for cold atomic flux collimation.
- 3D MOT prior to loading into an optical trap.

First stages of the clock

Oven

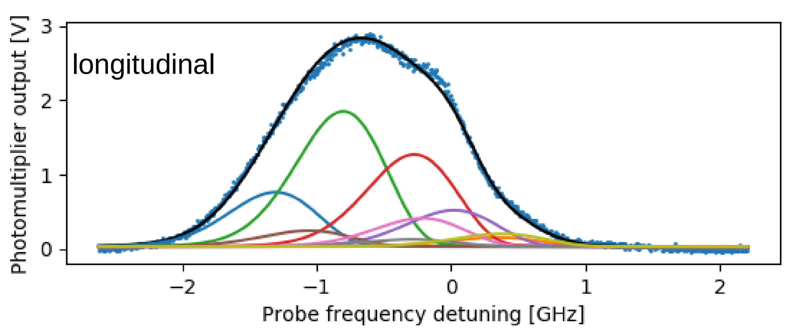


❑ Ytterbium flux source :

- Oven containing ytterbium metal.
- Collection of microtubes at the oven output.

❑ The atomic flux is defined by the dimension of the microtubes and the oven temperature.

Fluorescence spectroscopy @399nm

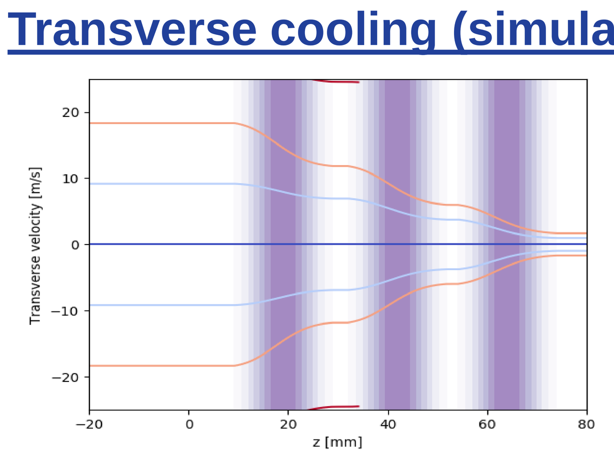


❑ Longitudinal spectroscopy at 399 nm :

- Fit model : convolution between a lorentzian and a modified gaussian profile [1].
- Quantitative fits give :
  - T_{longit}= 712 K (440 °C)
  - Most probable velocity : 322 m/s

Atomic beam divergence [2] : 5.4-6.8 ° (half angle)

Transverse cooling (simulation)



❑Proposed scheme : three atoms-light interraction zone with a gradient in detuning (spacial-distribution detuning).

Optimized results :

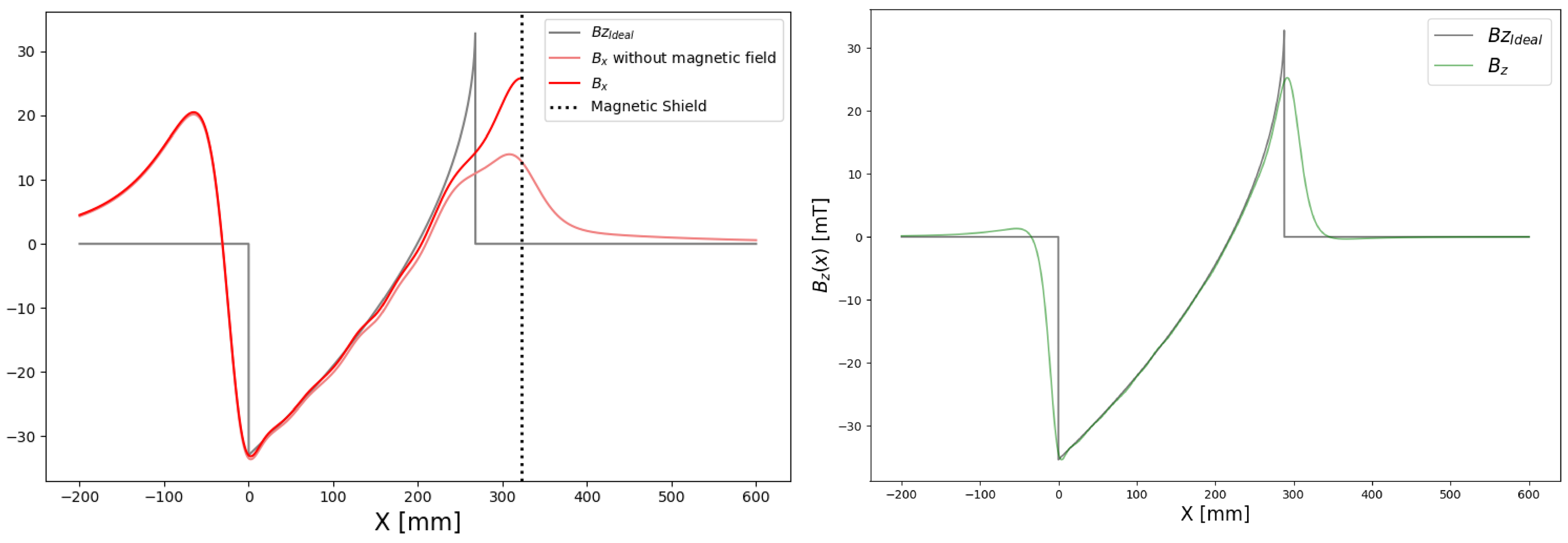
❑ In order to have a maximum radius of **8 mm**, we can reflect trajectories with initial radial velocity up to **18 m/s**.

Zeeman slower with permanent magnet (simulation)

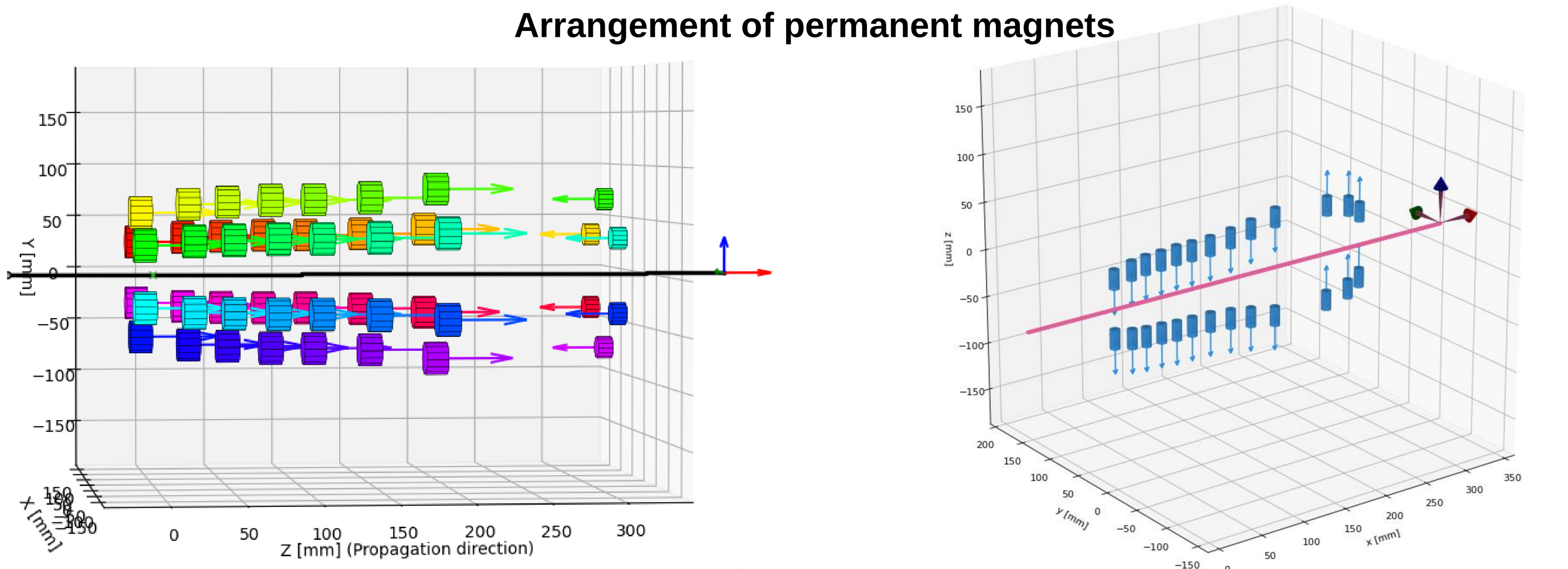
❑ Zeeman slower skeleton is based on the next three totally-related parameters:

- Velocity capture, being higher velocity the ZS is able to cool down.
- Maximum (des)acceleration, defined by the cooling laser intensity.
- Length of the ZS, defined as the minimum distance to stop atoms at v=0m/s.

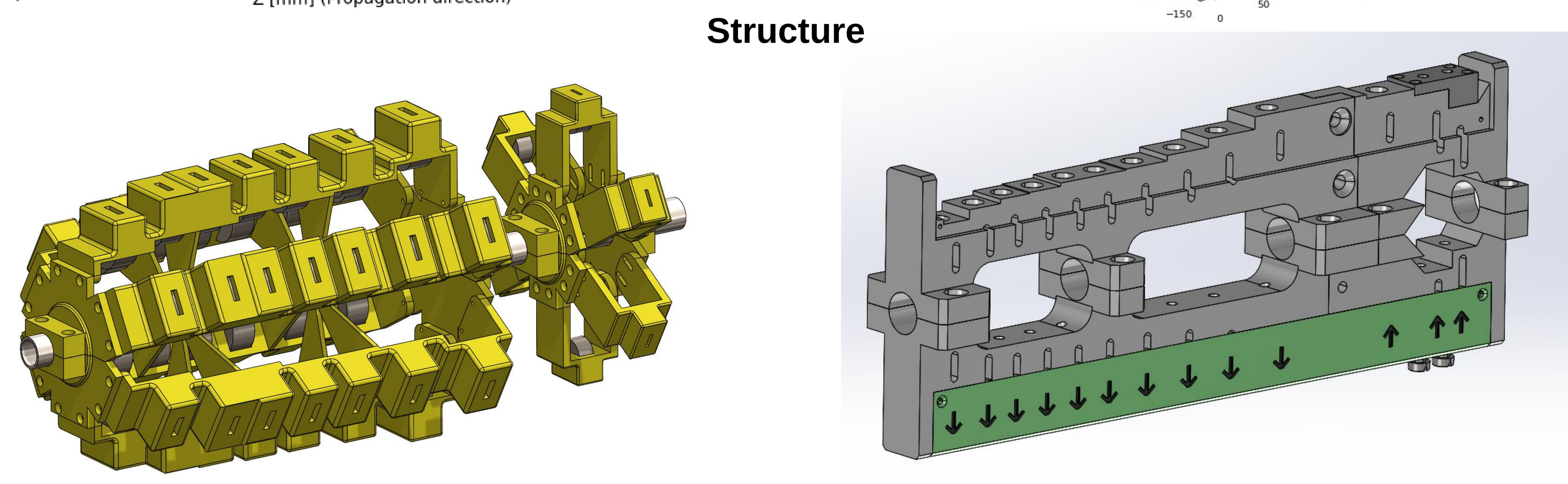
Magnetic field along Zeeman axis



Arrangement of permanent magnets



Structure



- Complex structure.
- Difficult to calculate the position of the magnets.
- Use much more magnets, it is heavier.
- Magnetic shield is 100% needed.
- Long decay of magnetic gradient along optical path.
- Use 100% of the laser power.

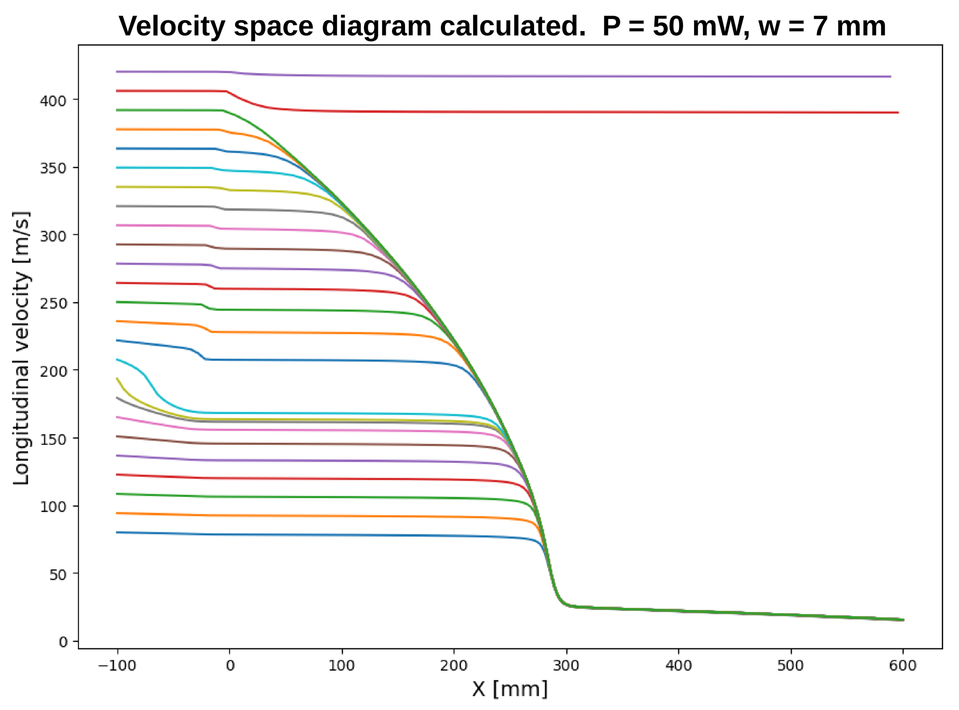
- Easy structure.
- Easy to calculate the position of the magnets.
- Less magnets are needed, it lighter.
- The magnetic shield is most likely not necessary.
- Short decay of magnetic gradient along optical path.
- Use 50% of the laser power.

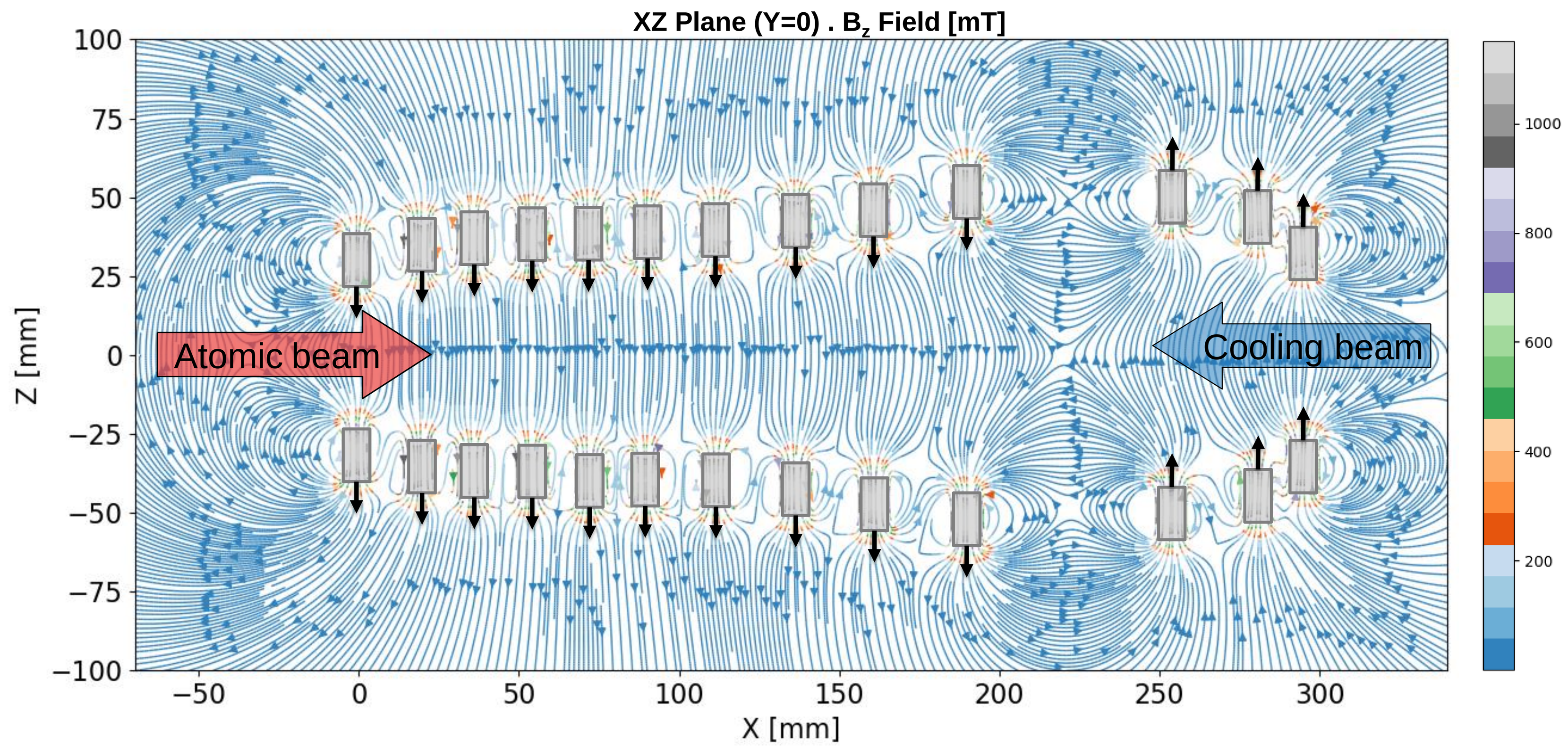
Winner Zeeman Slower ⟶ Transversal

❑ Maximum acceleration at the beginning and two screws at the end to control of the velocity output by modifying the radial distance of the last two magnets.

❑ Simulated Annealing to find the global optimum configuration of the array.

❑ Since the proposed array is symmetric, rotations will not change the shape of the magnetic field.





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Reference

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