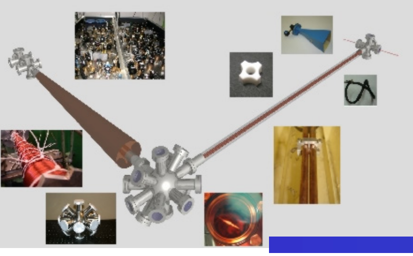
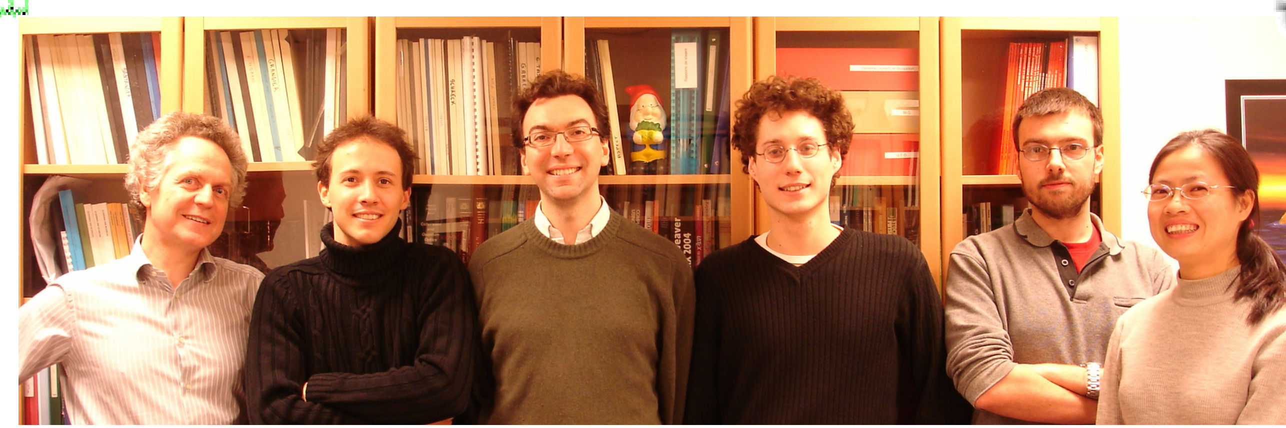


Evaporative cooling of a magnetically guided beam

David Guéry-Odelin

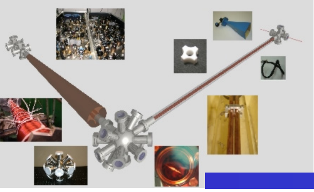
Recherche sur les Atomes Froids
Institut Francilien de
IFRAF

Kastler Brossel Laboratory



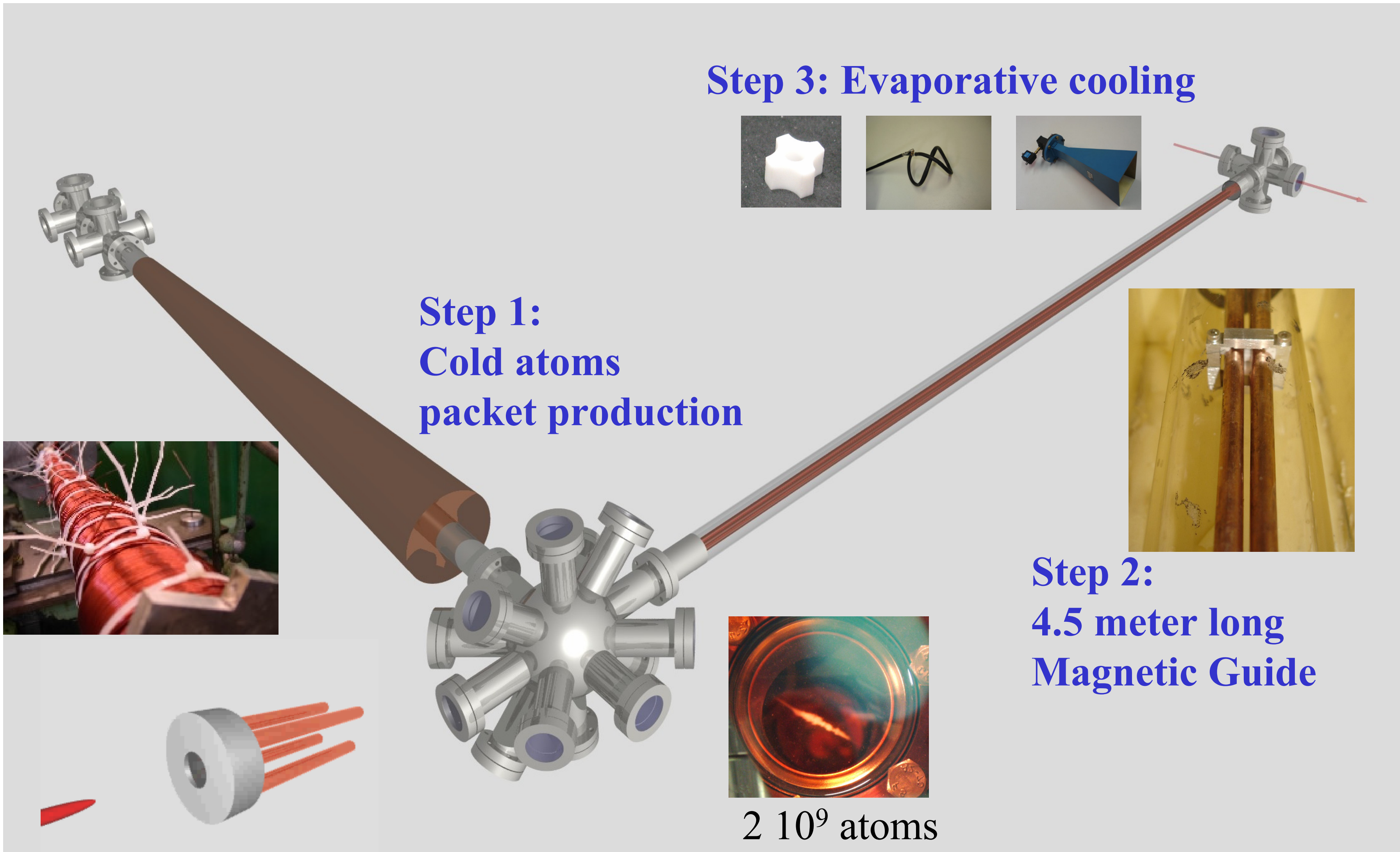
Thierry Lahaye

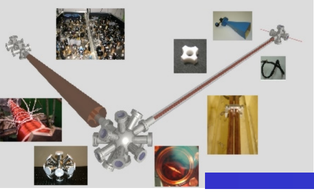
Jean Dalibard **Gaël Reinaudi (poster session)** DGO Antoine Couvert Zhaoying Wang



Overview of the experimental setup

$7 \, . \, 10^{9}$ atoms/s at 1 m/s

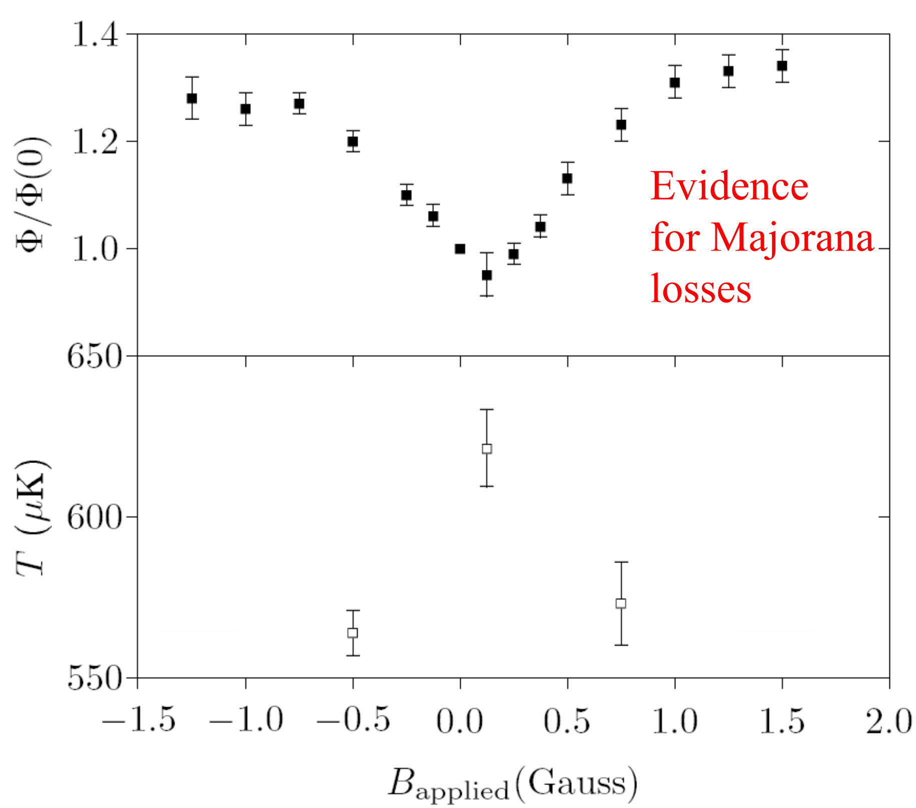




The potential experienced by the atoms

4 copper tubes in quadrupolar configuration

+ Longitudinal Bias field



$$U_{\perp}(r) = \mu\sqrt{B_0^2 + b'^2 r^2}$$

Harmonic

$$k_B T \ll \mu B_0$$

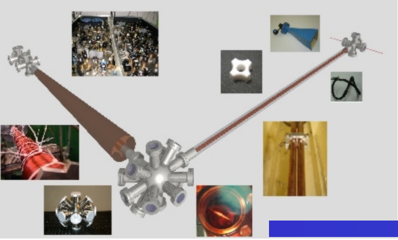
$$U(r) \simeq \mu B_0 + \frac{\mu b'^2 r^2}{2B_0}$$

Linear

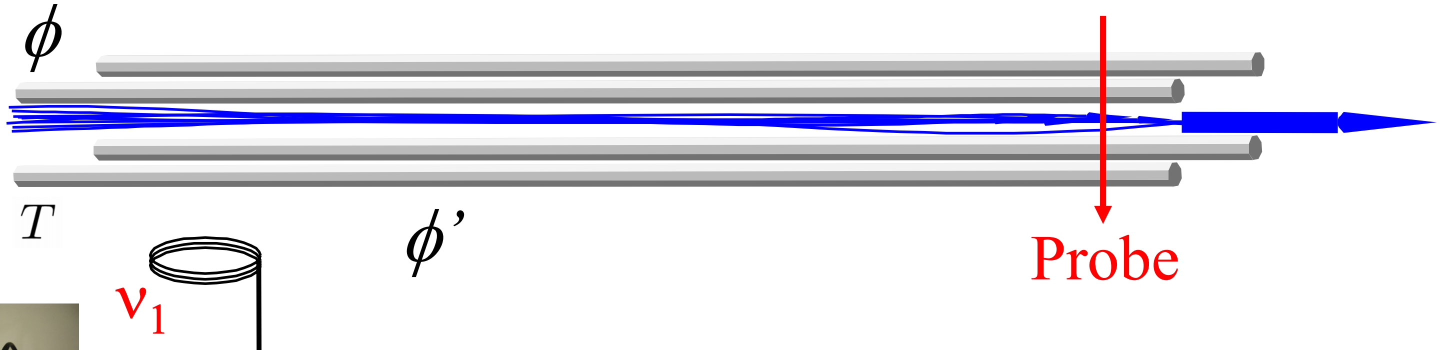
$$k_B T \gg \mu B_0$$

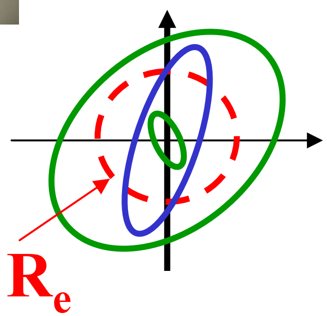
$$U_{\perp}(r) \simeq \mu b' r$$

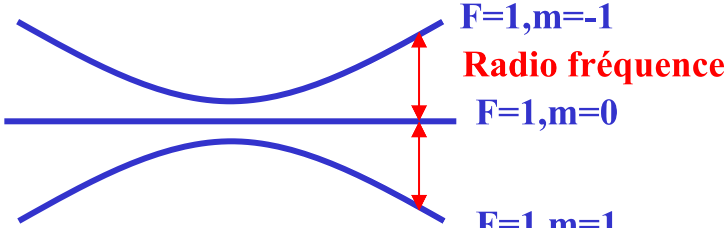
1 Gauss “ = ” 33 μK



Radio-frequency filtering = temperature measurement

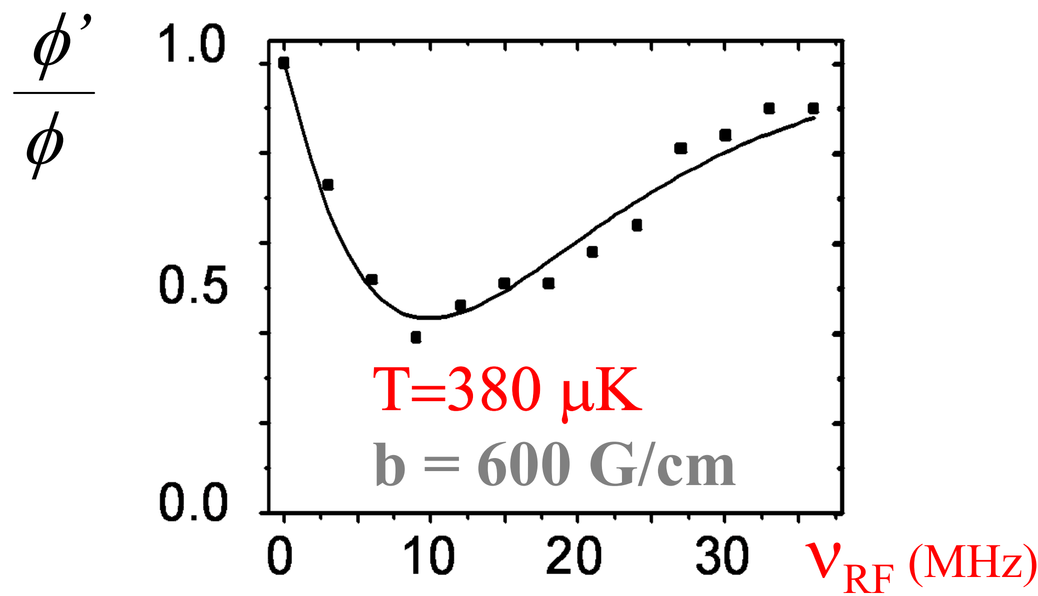


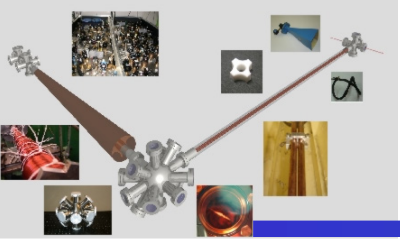




$$h\nu_{\mathrm{RF}} = U_{\perp}(R)$$

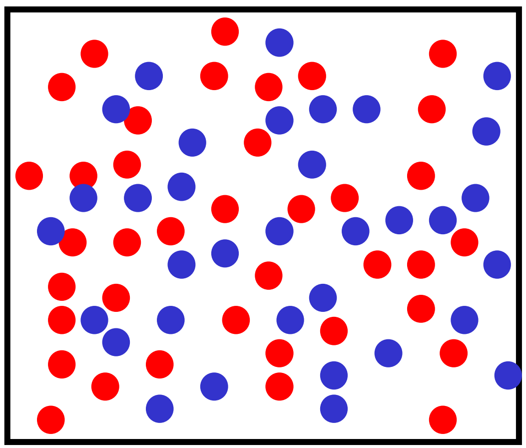
Fraction of remaining atoms

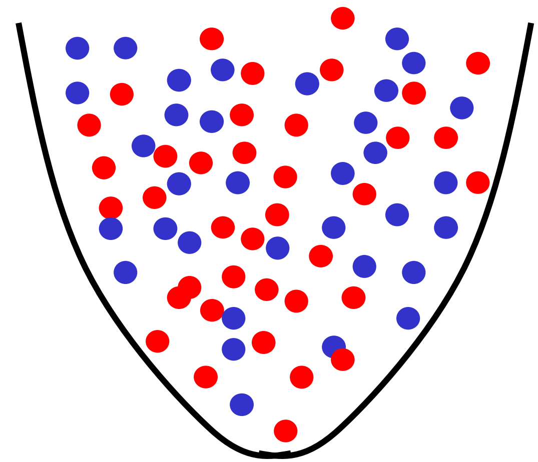




Influence of the shape of the confining potential on the thermalization time

Thermalization in a box versus thermalization in a trap



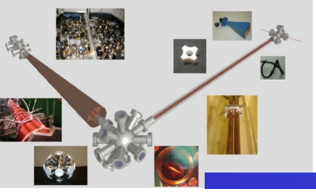


$$\frac{dT_i}{dt} = -\frac{T_i - T_j}{N_i \tau}, \quad i \neq j \qquad \tau = \frac{n_c}{\gamma}$$

$$n_c = \frac{3}{2}$$

$$n_c = 3$$

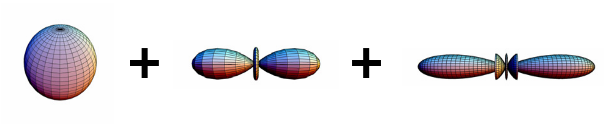
harmonic potential



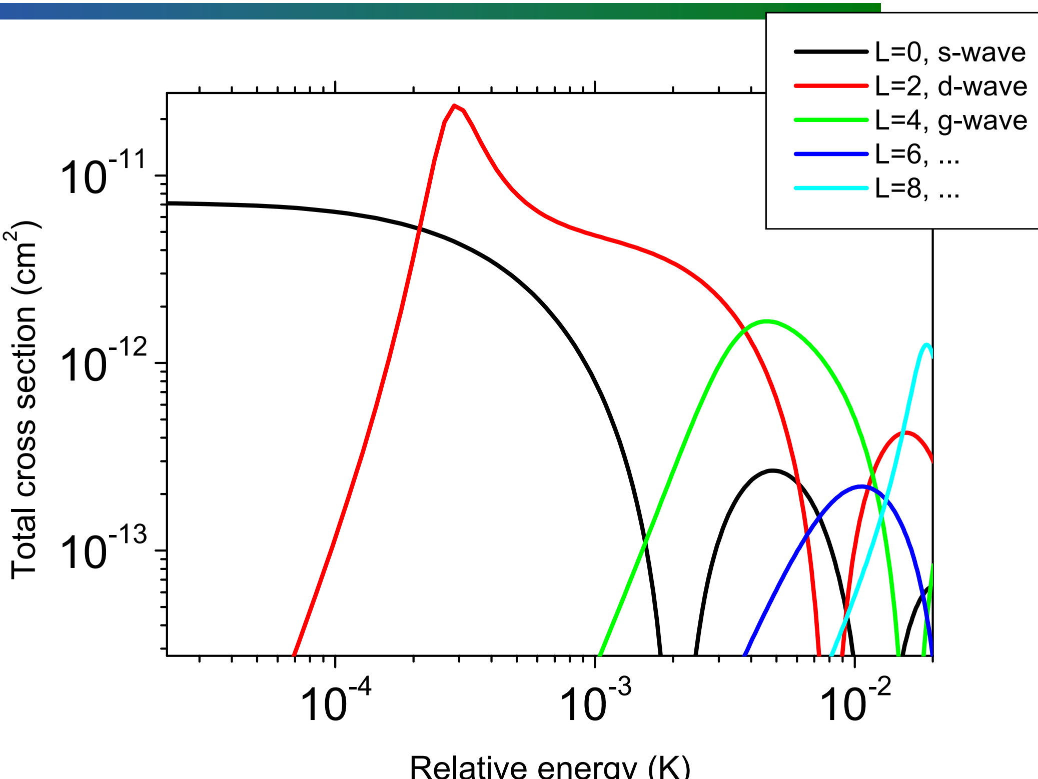
Thermalization in the multiple partial wave regime

Total cross section

$$\sigma = \sigma_s + \sigma_d + \sigma_g + \ldots$$



Collision rate $\propto \sigma$

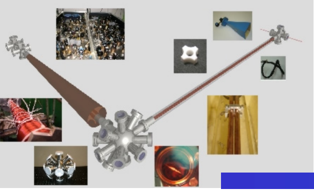


$$\frac{1}{\tau} \propto \frac{1}{T^4} \sum_{l \le l' \in \{0,2,4,\ldots\}} \alpha_{ll'} \int_0^\infty \sin\delta_l \sin\delta_{l'} \cos(\delta_l - \delta_{l'}) v^3 e^{-mv^2/2k_B T} dv$$

Interference terms

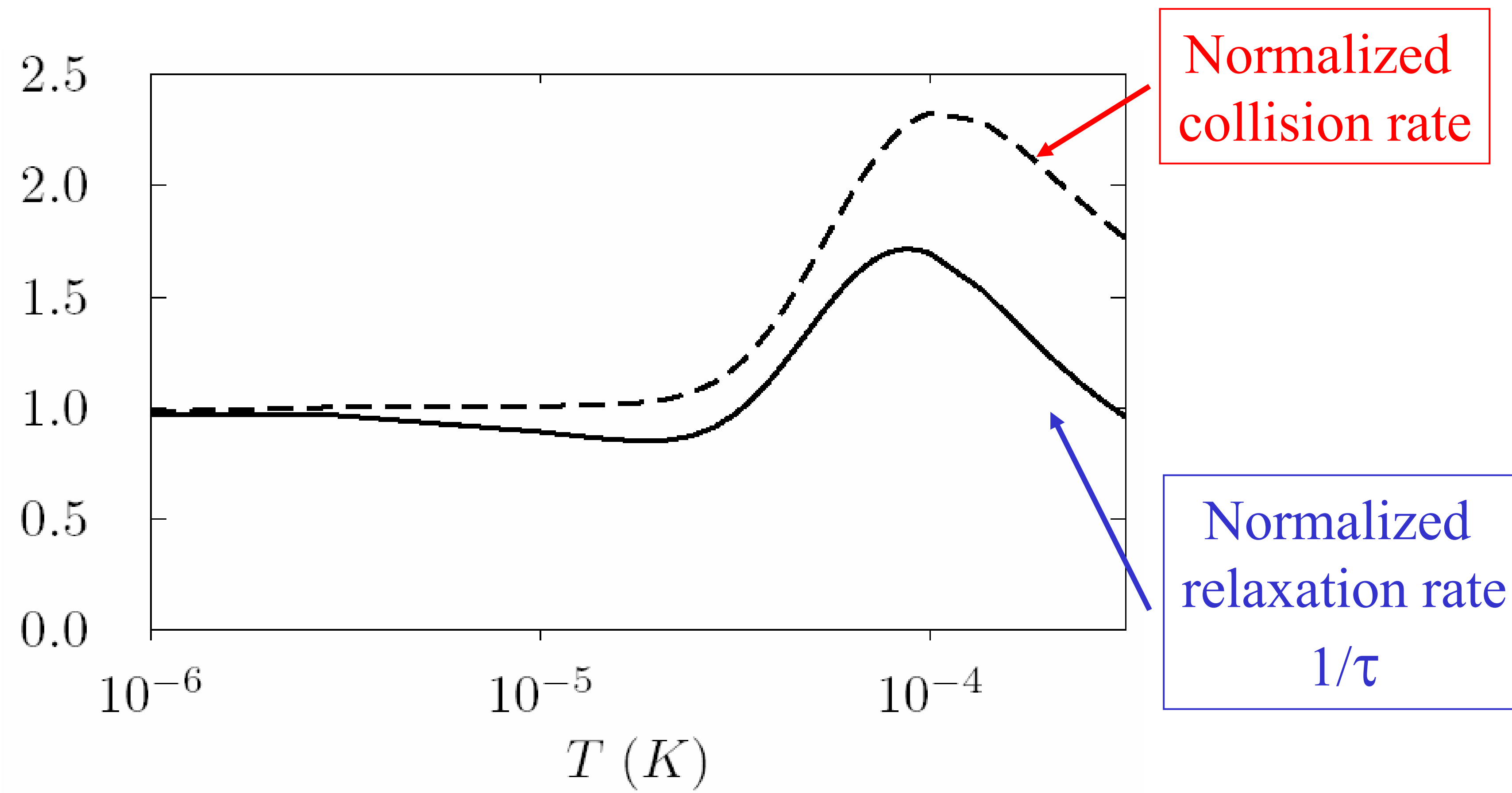
Thermalisation time is not proportional to the collision rate because of partial wave interferences

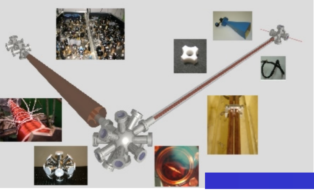
M. Anderlini and DGO, cond-mat 0507681, to appear in PRA



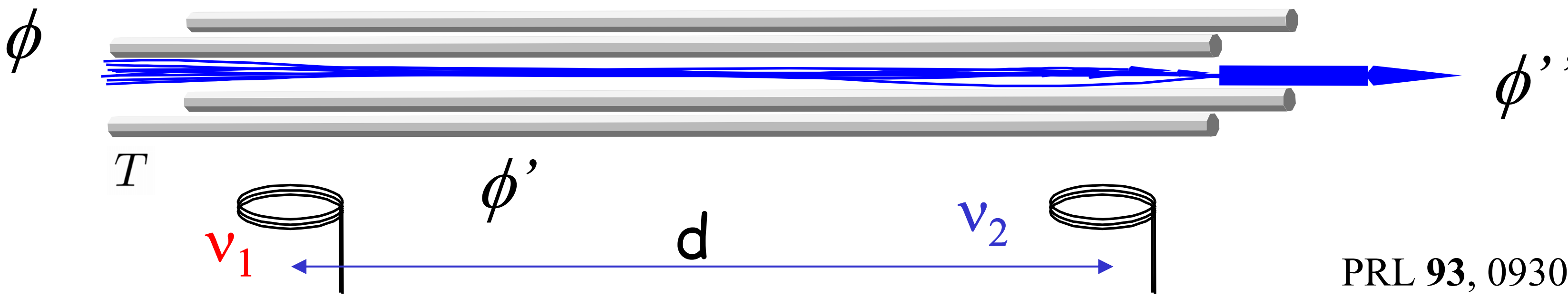
A concrete example

^{87}Rb $|F=1, m_F=-1\rangle$ and $|F=2, m_F=1\rangle$

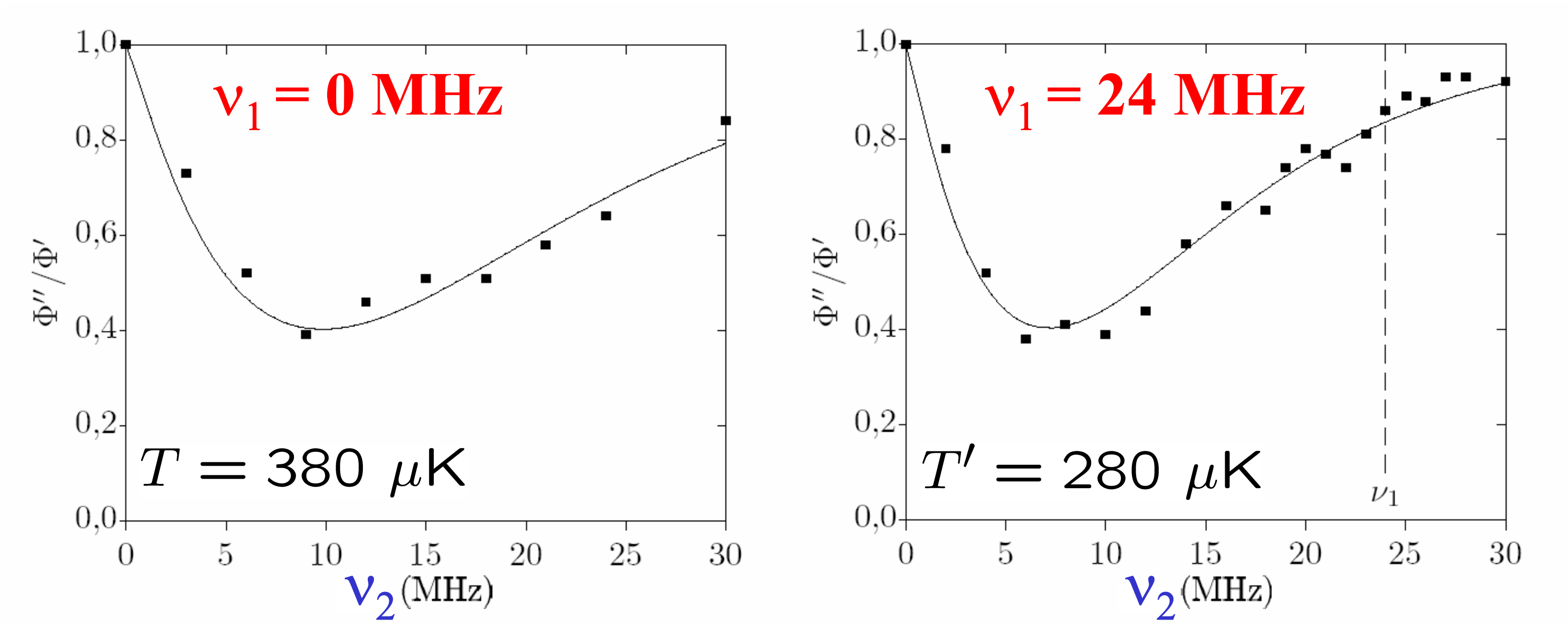




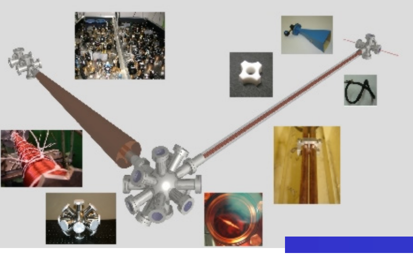
Thermalization experiments in a guide



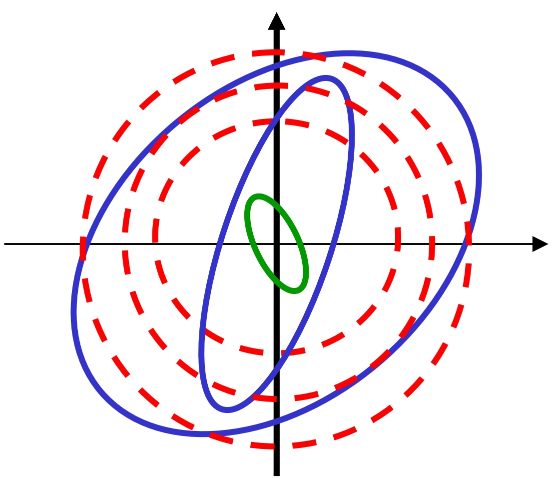
PRL **93**, 093003 (2004)

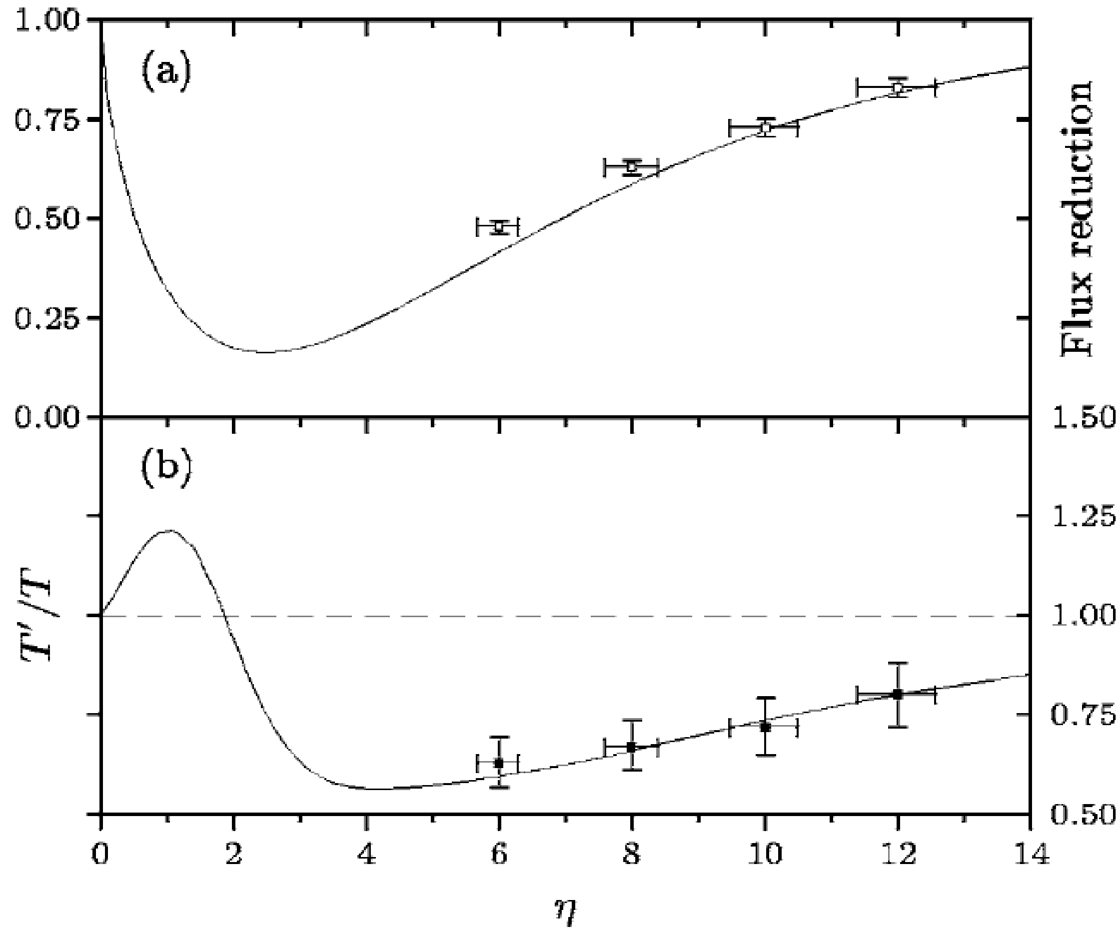


Maximum gain in phase space density with one antenna = 1.9



Thermalization experiments after a microwave evaporation

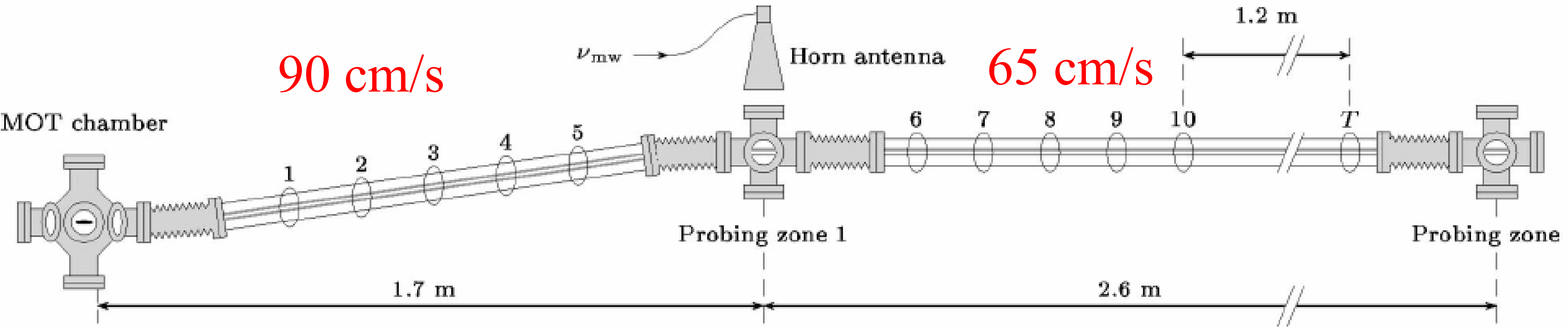


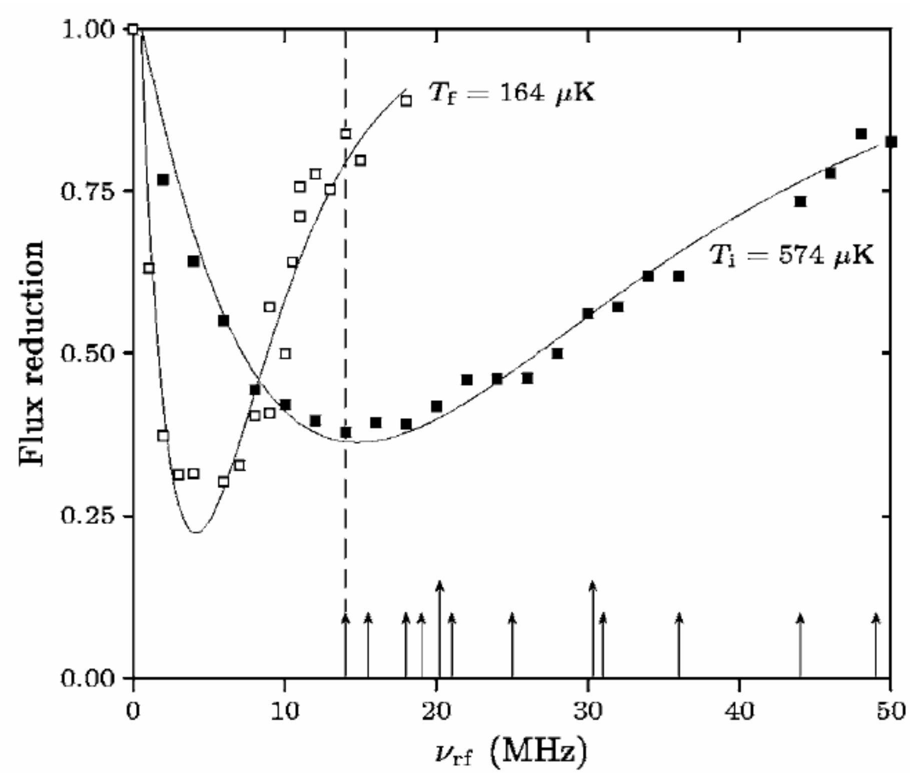


Maximum gain in phase space density = 2.6

PRA **72,** 033411 (2005)

Increasing the phase space density of the beam





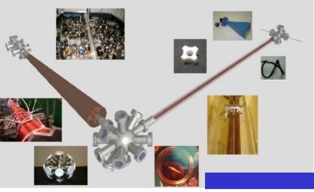
$$T_i = 574 \pm 10\ \mu K$$

$$T_f = 164 \pm 6\ \mu K$$

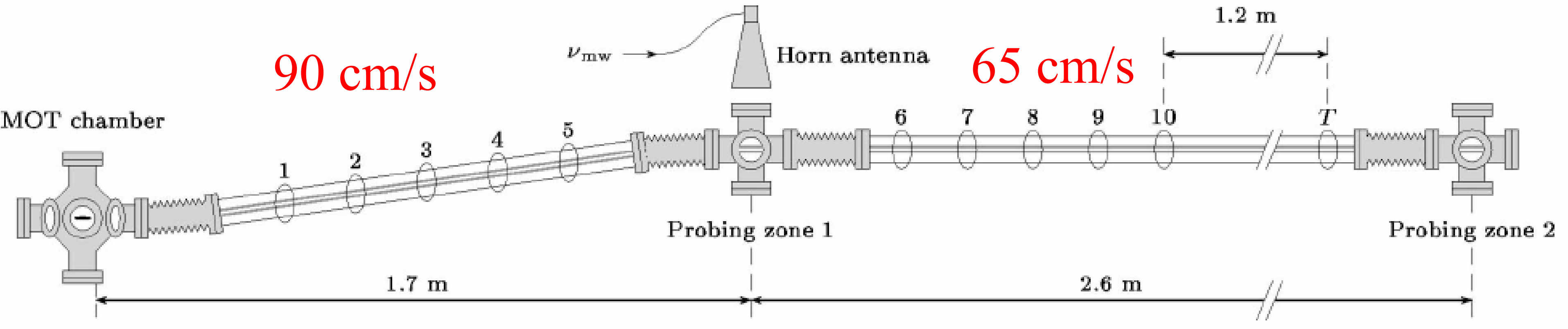
$$\Phi_f/\Phi_i = 0.13 \pm 0.02$$

$$\rho_f/\rho_i = 10.4^{+4.1}_{-3.0}$$

PRA **72**, 033411 (2005)



Increasing the phase space density of the beam

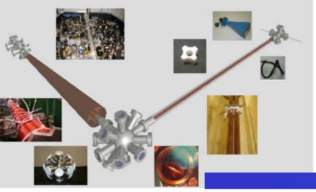


Measured range of a RF antenna = 20 cm

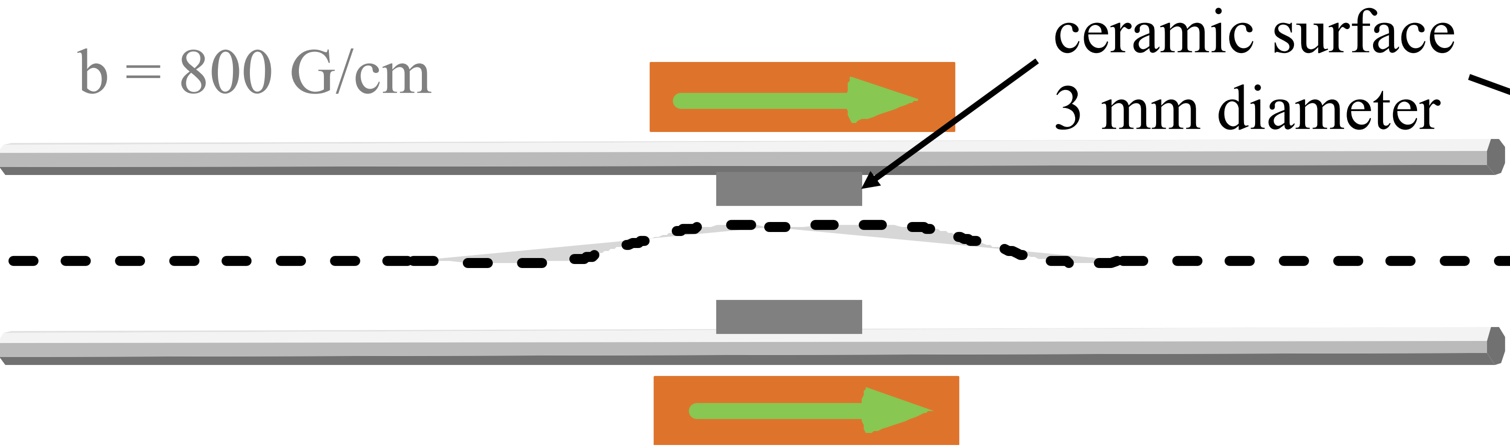
Measured range of a MW horn = 20 cm

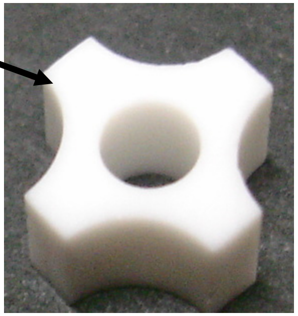
The performance in terms of gain on phase space density and collision rate of a RF antenna or of a MW horn strongly depends on their efficiency

Experimentally if is very difficult to ensure a perfect efficiency



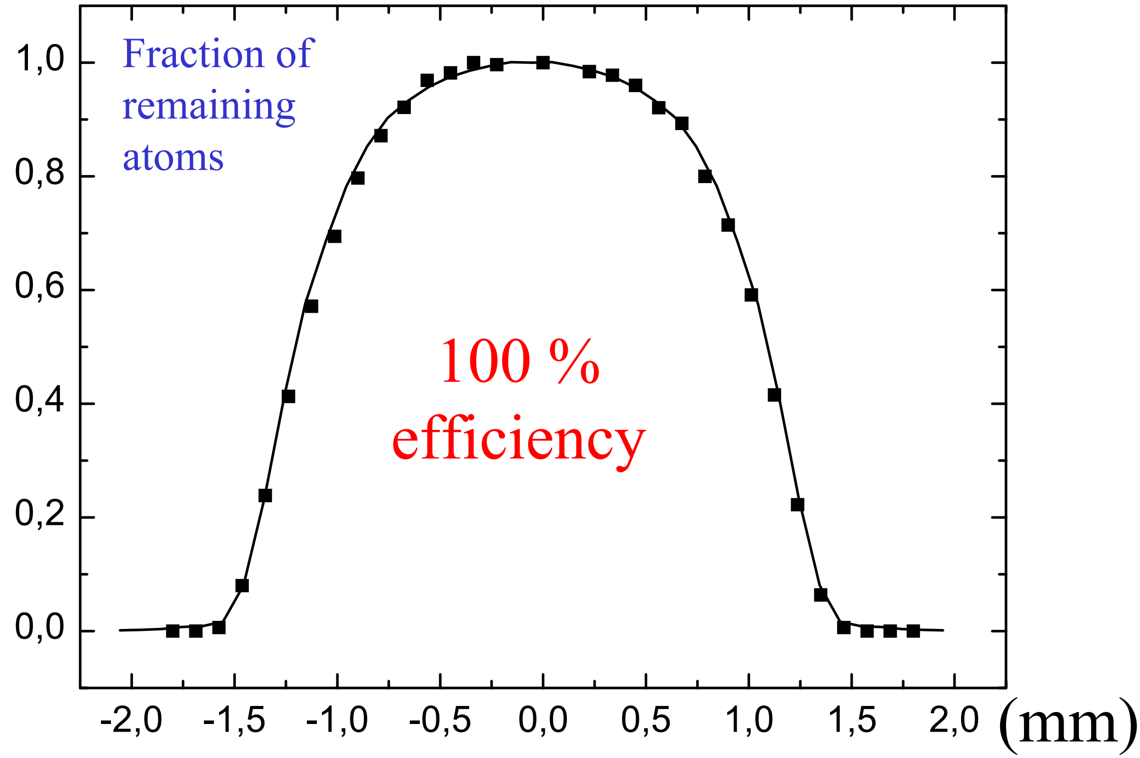
Local evaporation on dielectric surface



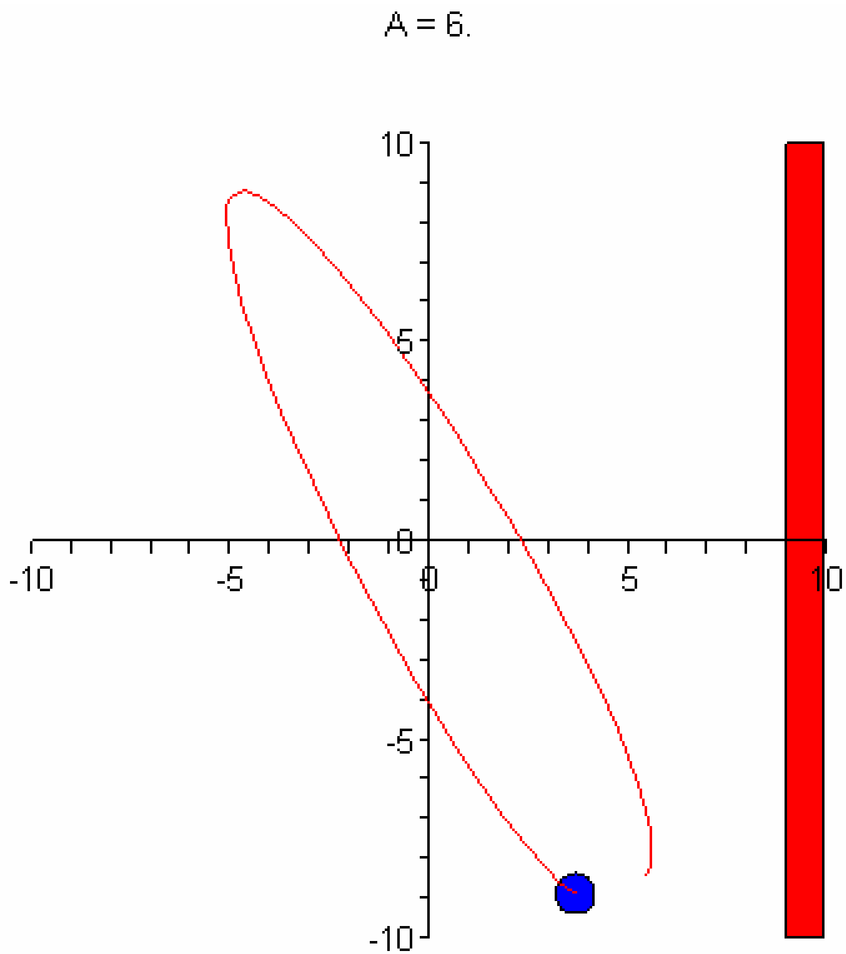


Thickness = 5 mm

The shift of the beam trajectory by a transverse magnetic field does not lead to any detectable heating of the beam downstream



Dimensionality of the evaporation

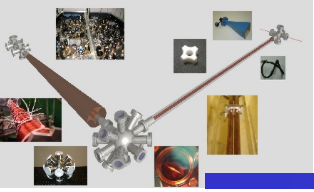


The dimensionality of evaporation depends on the time spent close to the surface

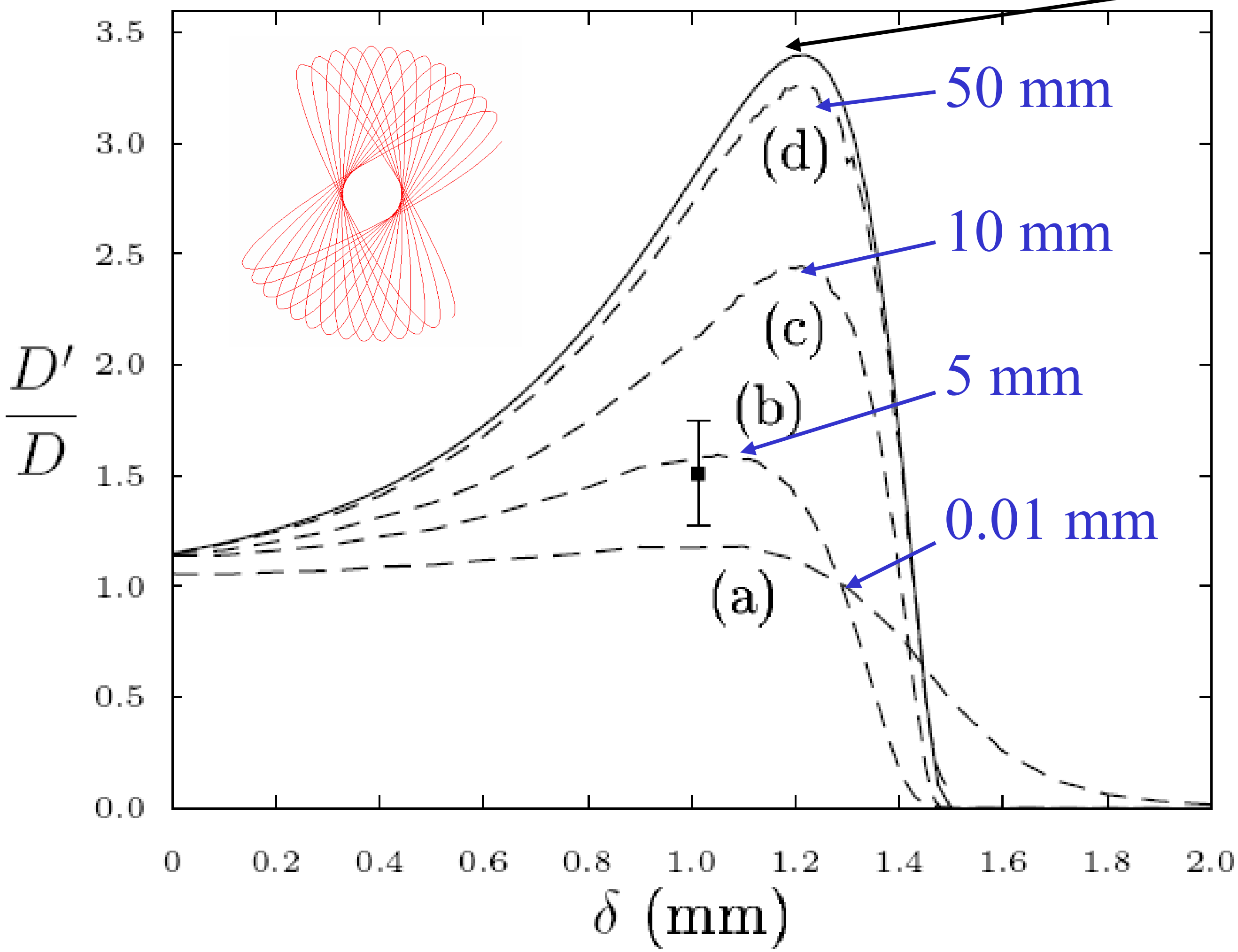
1) Low velocity

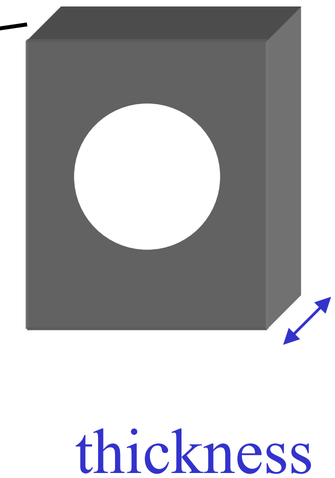
2) Large thickness of the ceramic

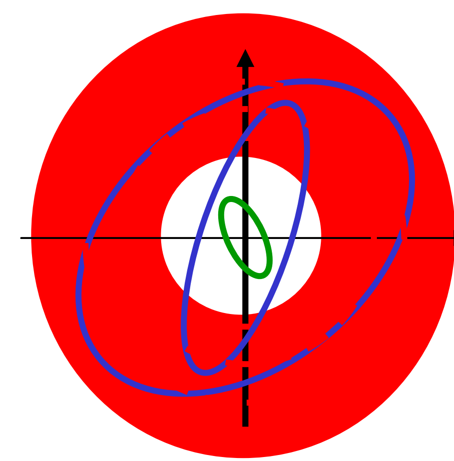
Trajectory in a **linear** confinement



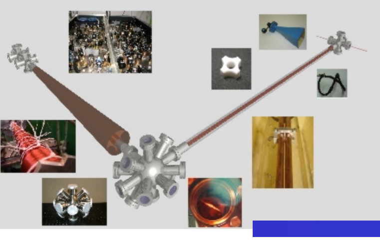
Dimensionality of the evaporation







Gaël Reinaudi *et al.*, submitted to Phys. Rev. A



What is the best parameter to evaluate the distance to quantum degeneracy ?

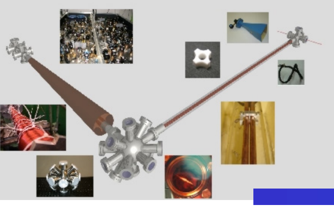
The gain in space density is dictated by the number Nc of collisions that a given atom will undergo in average

For our best parameters Nc ~ 25

Evaporation dynamics

→ Rethermalization kinetics depends on the shape of the confining potential

→ Runaway on the collision rate only possible in a linear confinement, because of the 2D character of the evaporation



Set of hydrodynamic equations

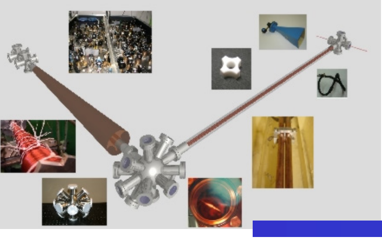
Generalize in 2D with semi-linear potential the HD equations of Mandonnet *et al.* EPJD **10**, 9 (2000).

$$\begin{cases} \partial_z(nv) = -\Gamma_1 n \,, \\ \partial_z(nv^2 + nv_{\rm th}^2) = -\Gamma_1 nv \,, \\ \partial_z\left[nv\left(\frac{5}{2}v_{\rm th}^2 + \frac{v^2}{2} + \frac{\langle U \rangle}{m}\right)\right] = -n\left(\Gamma_1\frac{v^2}{2} + \Gamma_2 v_{\rm th}^2\right) \end{cases}$$

$$v_{\rm th} = \sqrt{k_{\rm B}T/m}$$

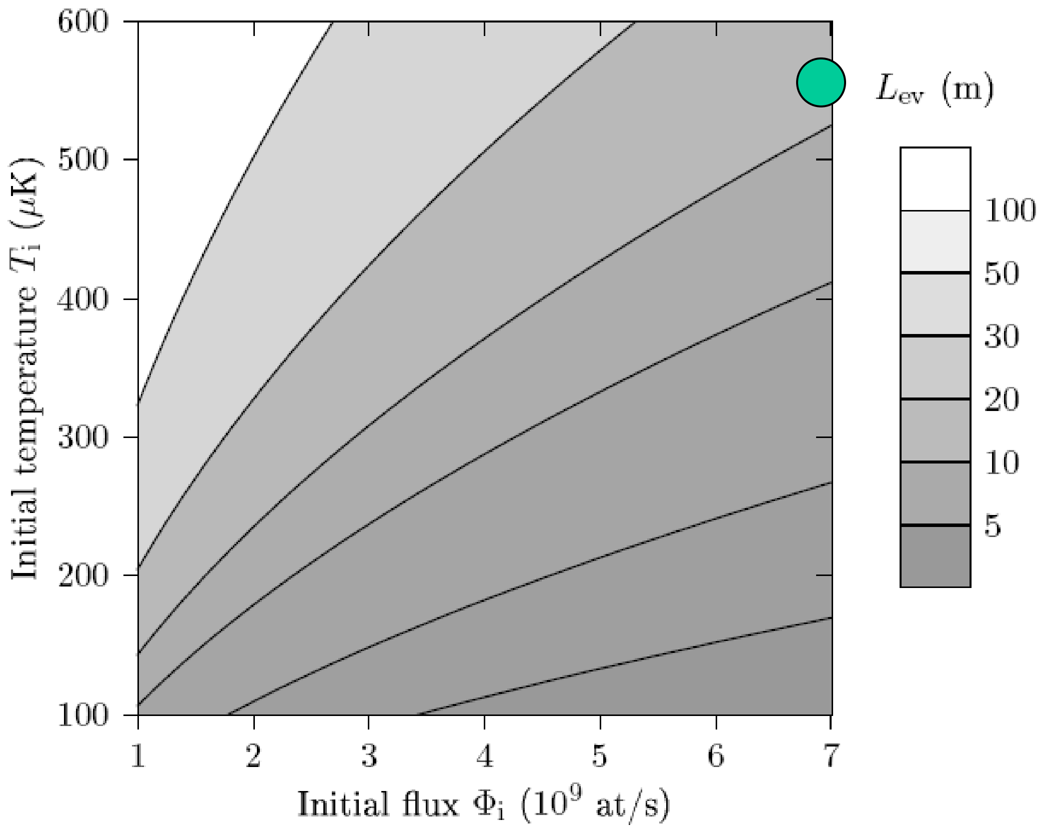
This set of equations is valid in the supersonic regime $v > 3v_{th}$

T. Lahaye and DGO, submitted to PRA



Results deduced from the HD equations

Trade off between the runaway and the kinetics

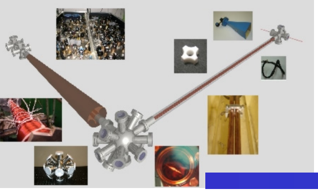


$$L_{\text{ev}} \simeq L_0 \frac{T_{\text{i}}^{3/2}}{\Phi_{\text{i}}}$$

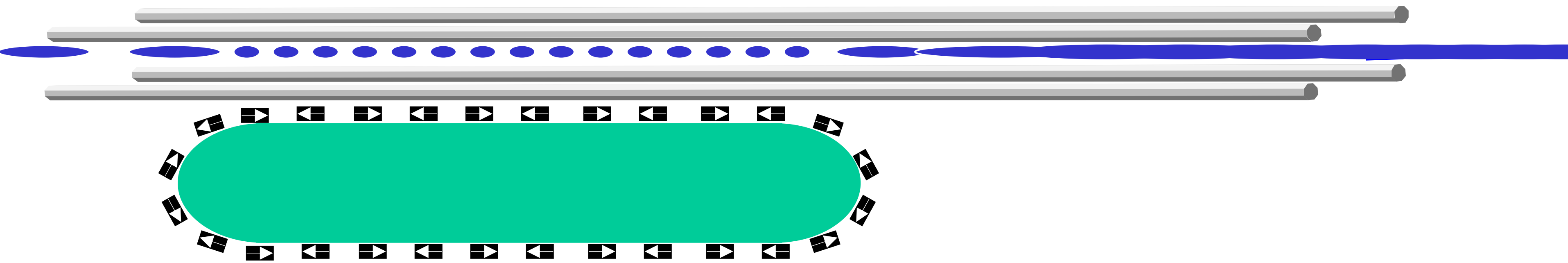
Nc ~ 200

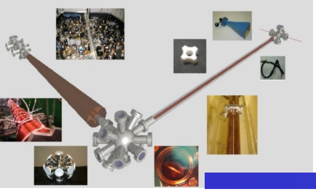
needed to reach degeneracy on 4 m

These predictions can be decreased if one reduces the mean velocity while keeping the supersonic condition

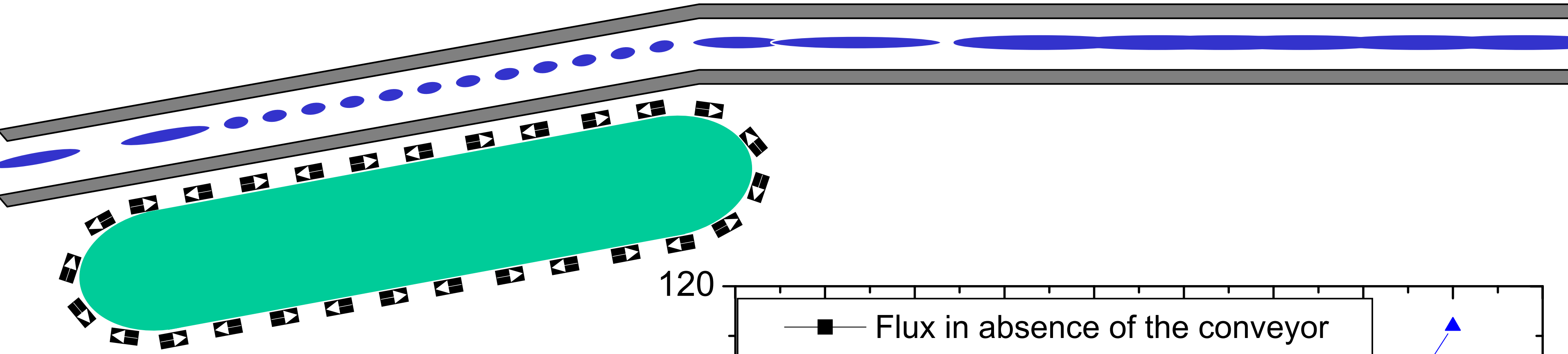


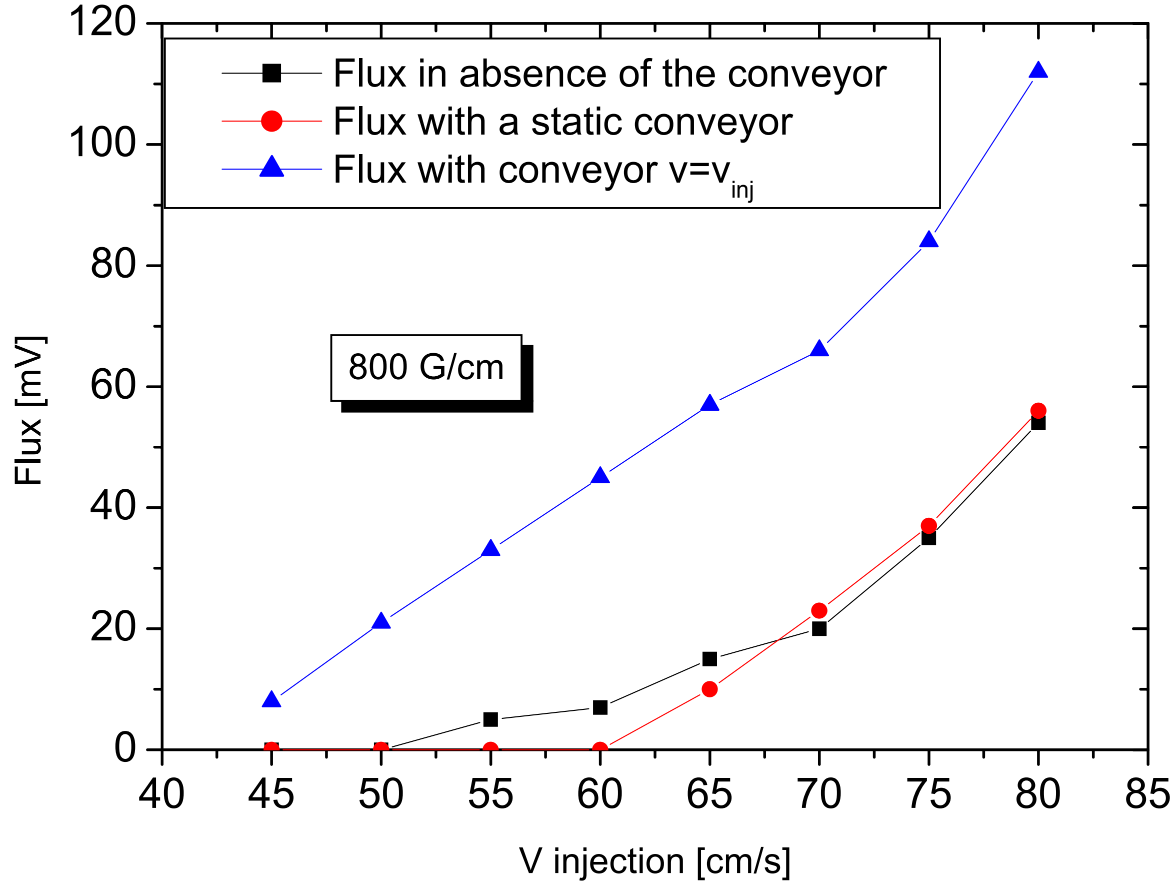
How to implement a 3D evaporation ?



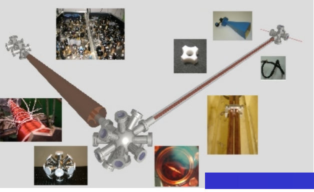


Coupling atoms into the « magnet train »





No detectable heating occurs in the coupling on the whole range of injection velocity



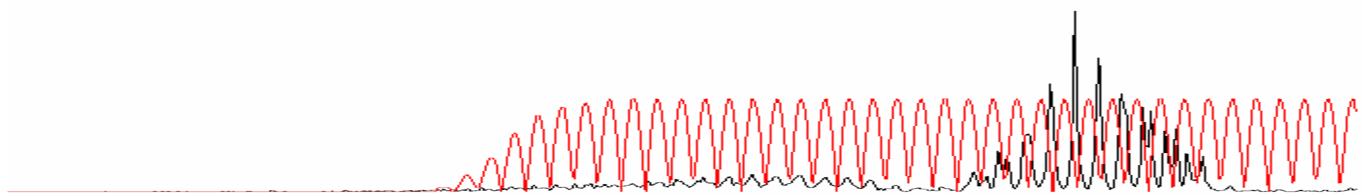
Conclusion

We have implemented evaporation on an atomic beam in 3 different manners: Radio-frequency, Microwave, Adsorption on a surface

We have gained one order of magnitude on the phase space density

To increase the number of collisions undergone by an atom during its propagation

Conveyor belt



Coupling compressed magneto-optical trap

http://www.lkb.ens.fr/recherche/atfroids/welcome.html

€ : CNRS, Ministère de la Recherche, UPMC, ENS, DGA