POSSIBLE PHYSICS INTERESTS FOR THE TRAPPING OF RADIOACTIVE Rb ATOMS

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ATOMIC PHYSICS MOTIVATIONS

Recoil Ion Momentum Spectroscopy

4π detection solid angle

Collision Dynamics

Internal Energy

Kansas State University, Manhattan, Kansas

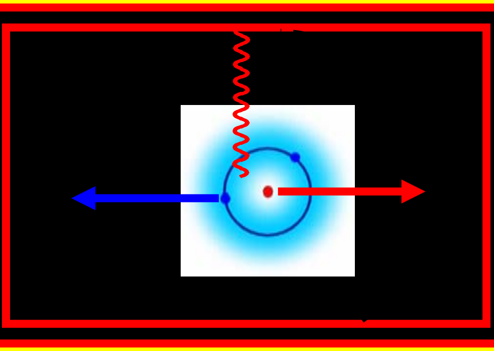
IKF, Frankfurt, Germany

CIRIL, Caen, France

ATOMIC PHYSICS MOTIVATIONS

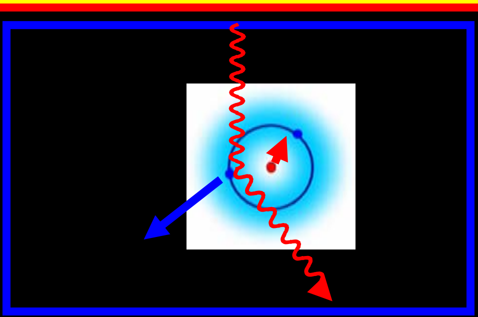
Photoelectric Effect

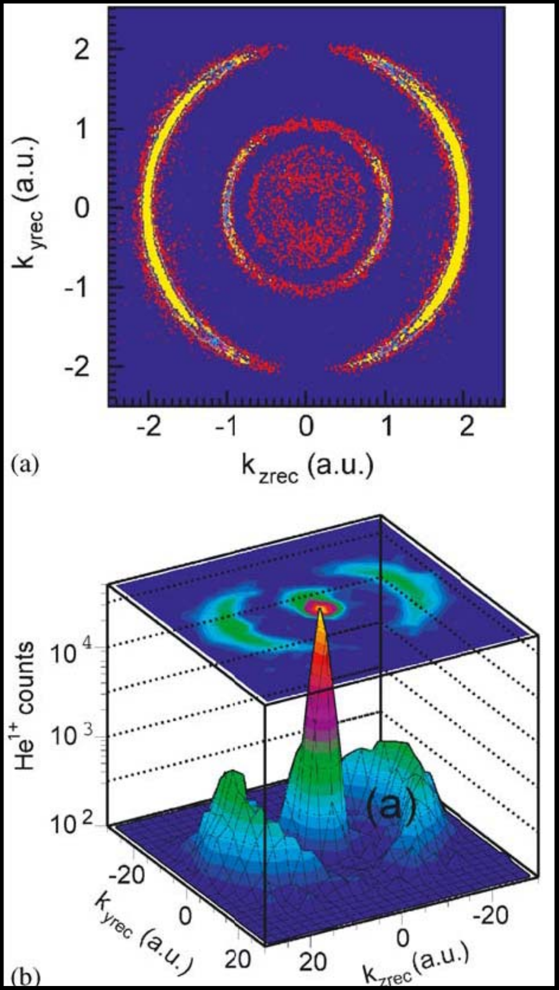
$h\nu$ (80 eV) + He → $He^+ + e^-$



$h\nu$ (7 keV) + He → $He^+ + e^-$

→ $He^+ + e^- + h\nu'$





R.Dörner et al, IKF Frankfurt

ATOMIC PHYSICS MOTIVATIONS

Ion-Atom Collisions
Electron capture = inelastic 2-body collision + mass transfert

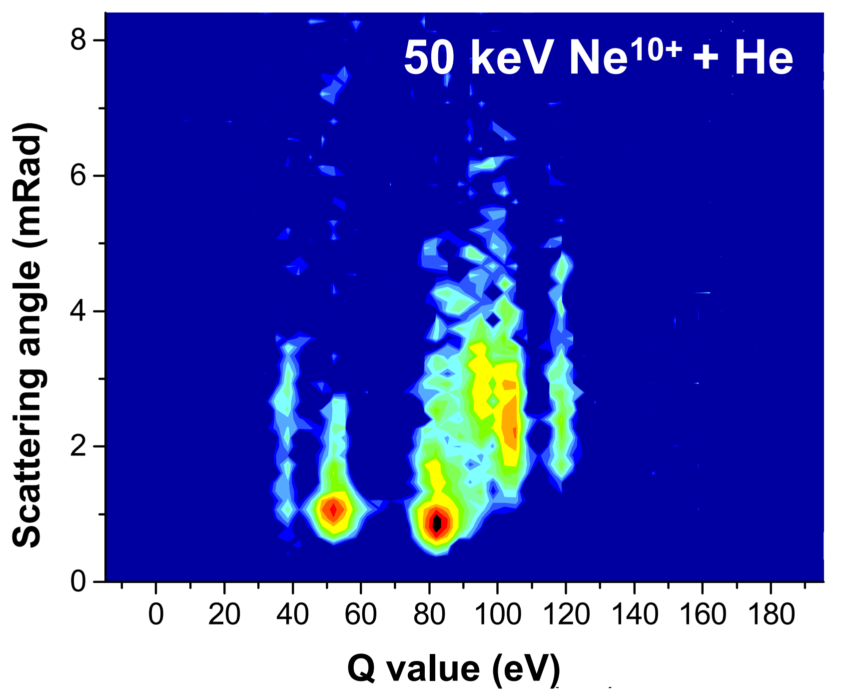
Energy and Momentum conservation

Inelasticity Q

$$Q = v_P P'_{R//} + v^2_P N_C/2$$

Scattering angle θ

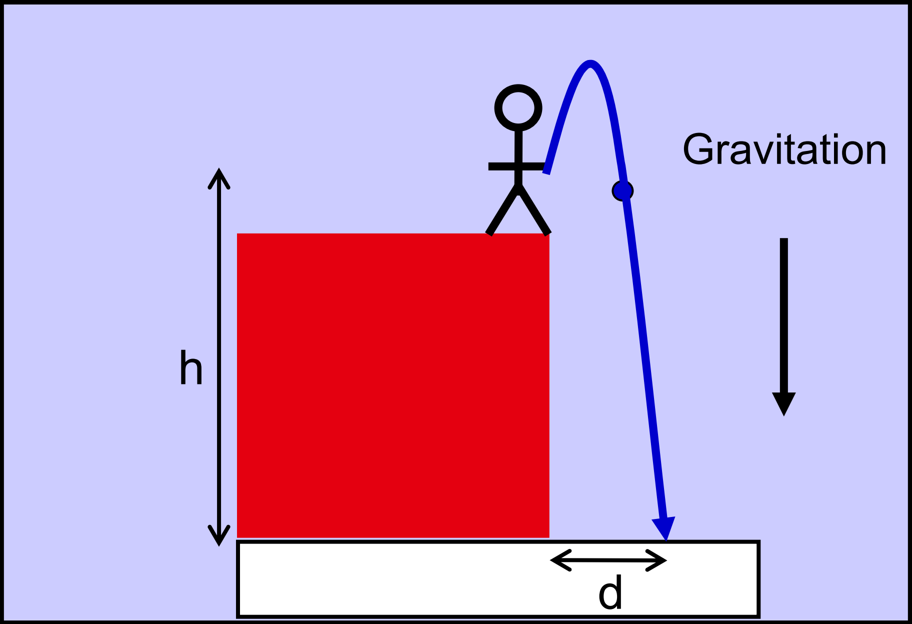
$$\theta = P'_{R\perp} / P_{P//}$$



X.Fléchard et al, CIRIL, Caen

ATOMIC PHYSICS MOTIVATIONS

Recoil Ion Momentum Spectroscopy: Principle



→ **<u>COLD</u> and <u>LOCALIZED</u> Target**

NUCLEAR PHYSICS MOTIVATIONS

β– ν angular correlation measurements using a Paul Trap

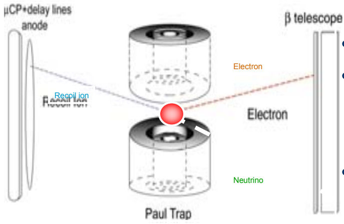
LPCTrap

② RFQ buncher + Pulse Cavity 1

Ion bunch →

③ Pulse Cavity 2 + Paul trap + Detection system

3.2) Recoil-ion detector 3.1) Transparent Paul trap 3.3) β-Telescope



- Low cost.
- Any ion produced by the source can be practicable.
- Easy-to-use device.

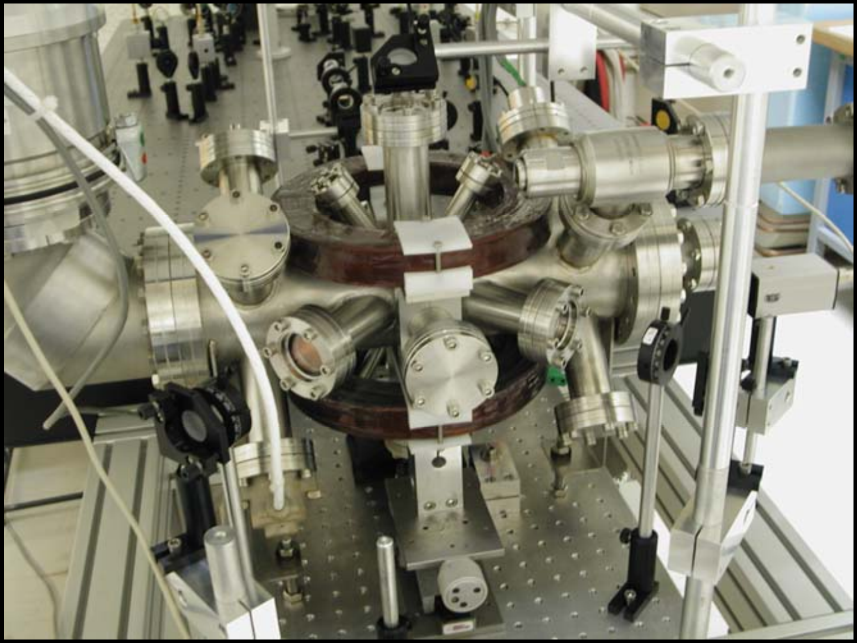
Ions at rest inside the trap

NUCLEAR PHYSICS MOTIVATIONS

**The main contributions to systematic uncertainties
are coming from TEMPERATURE
and
SIZE of the ion cloud,**

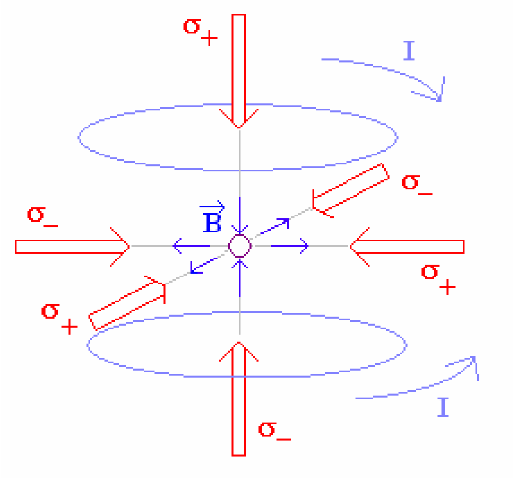
→ <u>COLD</u> and <u>LOCALIZED</u> Target

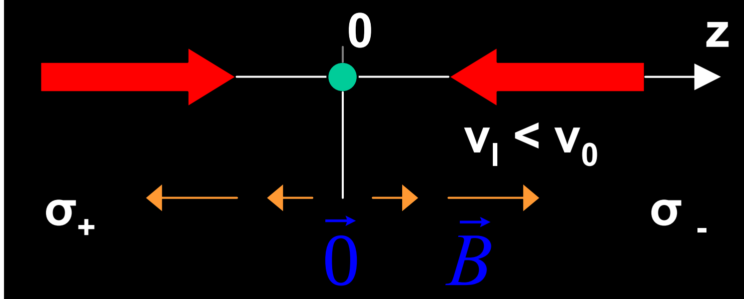
^{87}Rb Magneto Optical Trap



^{87}Rb D_2 line

$5^2S_{1/2}$ (F=2) → $5^2P_{3/2}$ (F'=3)
780nm





Velocity dependent force

Position dependent force

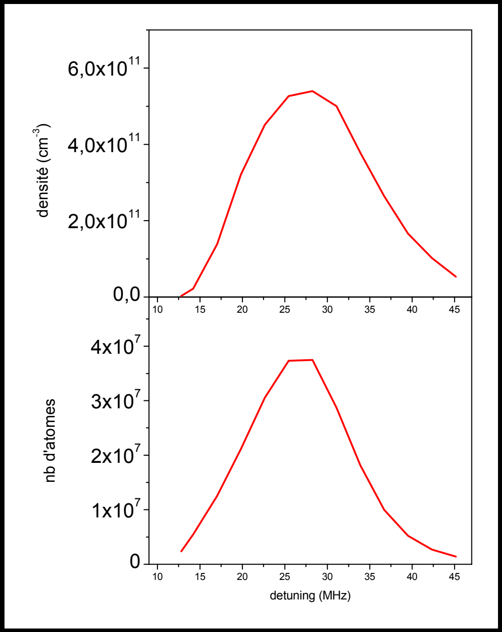
^{87}Rb Magneto Optical Trap: caracteristics

Number of atoms

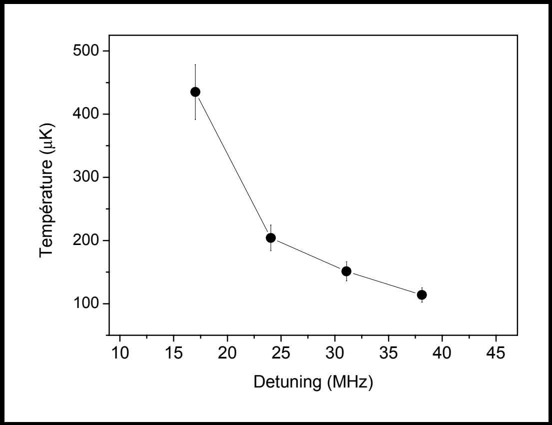
4 10^7 atoms

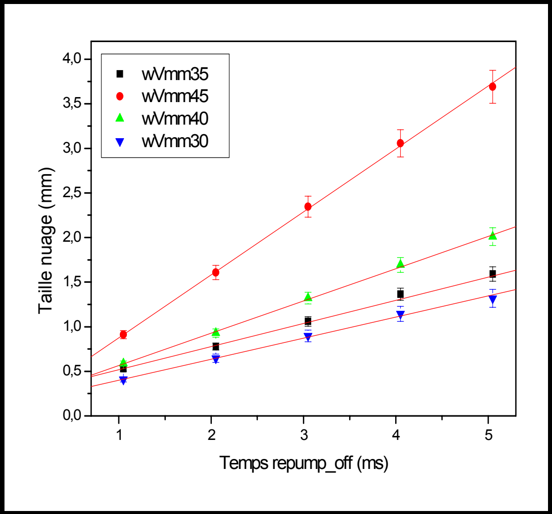
Density

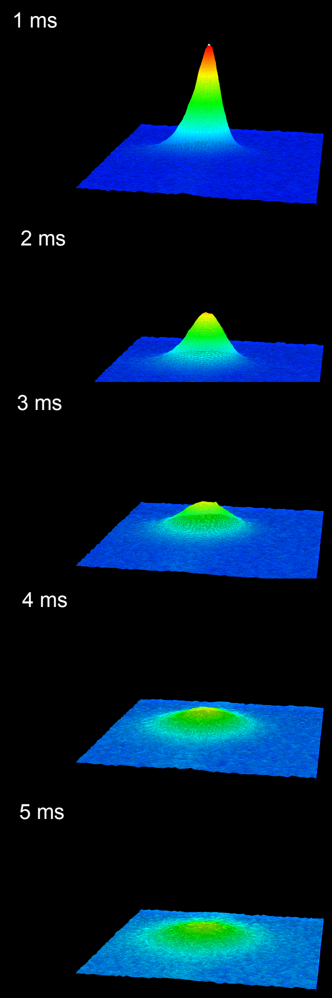
> 5 10^{11} at/cm^3



Temperature < 200µK







Cloud size 500µm

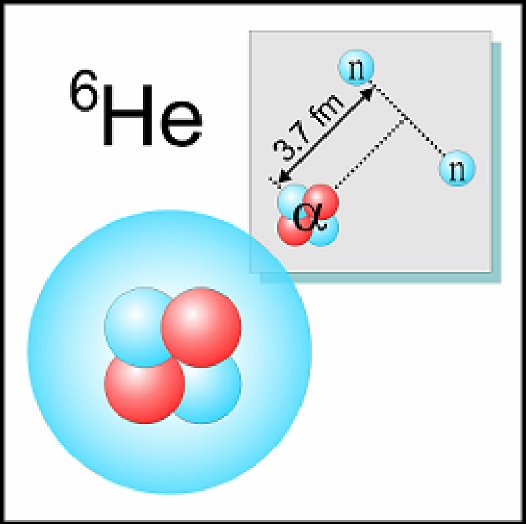
^{87}Rb Magneto Optical Trap: caracteristics

	Paul Trap	MOT
Temperature	1000 K	200 µK
Size	1.2*0.6 mm	Ø 500 µm

Trapping radioactive Rb atoms?

The Magnetic Optical Trap: a powerful tool for

- **Laser Spectroscopy!**



L.-B. Wang et al.,
*PRL **93**, 142501 (2004)*

Isotope shift

(2^3S_1 - 3^3P_2, ^{6}He – ^{4}He)

43 194.772(56) MHz

⬇

^{6}He rms charge radius

2.054(14) fm (0.7%)

Courtesy of Peter Müller,
Argonne Nat. Lab

Isotope shifts and hyperfine structure

Rb: almost all measurements have been done with collinear laser spectroscopy

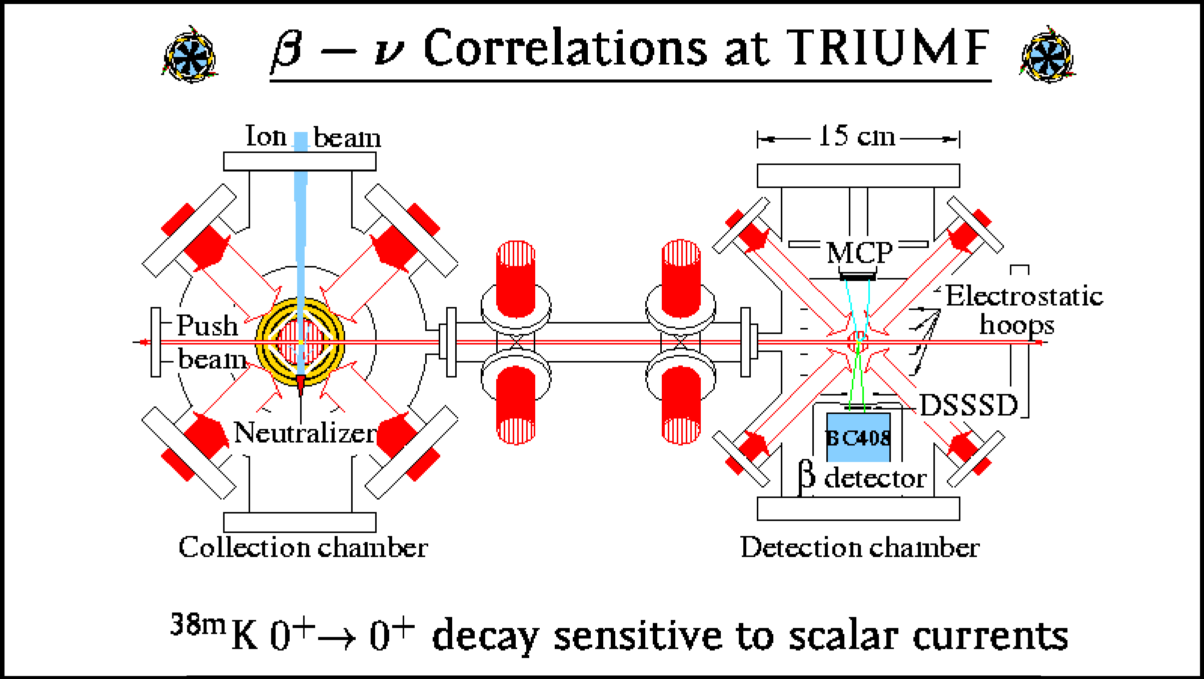
$\delta\langle r^2\rangle$, μ, Q, J → ***C. Thibaut et al., Phys. Rev. C 23(1981)2720***

Bohr Weisskopf effect or “hyperfine anomaly”?

Trapping radioactive Rb atoms?

The Magnetic Optical Trap: a powerful tool for

- **$\beta - \nu$ angular correlation measurements**



$\beta - \nu$ Correlations at TRIUMF

^{38m}K $0^+ \rightarrow 0^+$ decay sensitive to scalar currents

TRIUMF: ^{38m}K

J. Behr et al,
Phys. Rev.
Lett. ***79****, 375*

Berkeley: ^{21}Na

N. D. Scielzo et al,
Phys. Rev. Lett. ***93****,*
102501 (2004)

From Dan Melconian, PhD, Triumf

A. Gorelov et al,
Phys. Rev. Lett. ***94****, 142501*

$$\tilde{a} = 0.9981 \pm 0.0030 \, {}^{+0.0032}_{-0.0037}$$

e- shakeoff

^{74}Rb: a possible candidate!

Trapping radioactive Rb atoms?

The Magnetic Optical Trap: strong potentialities for

✹ The tests of fundamental symmetries!

Physics with polarized nuclides

An additional trap for polarization is needed!

- **Test of the parity violation in the nuclear beta decay of ^{82}Rb**

  LANL, S. Crane et al., PRL 86, 2967, (2001)

- **Probing the T-reversal symmetry by the search for an atomic EDM in ^{225}Ra**

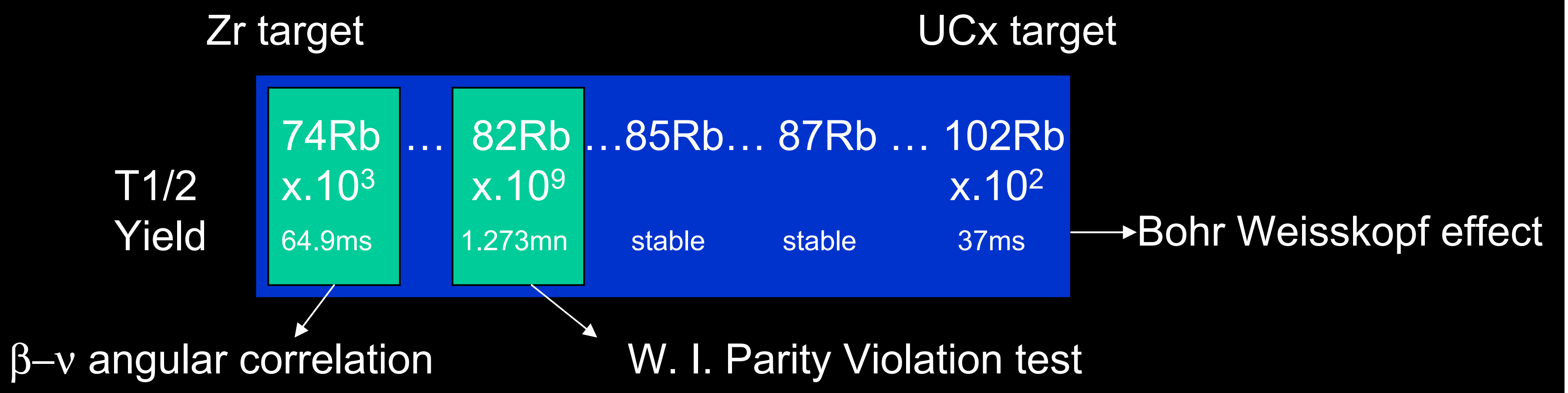
  Argonne National Laboratory

- **Atomic Parity Non Conservation in Francium**

  INFN Ferrara/Legnaro and Stony Brook

Trapping radioactive atoms?

- Some preliminary ideas



Zr target

UCx target

	74Rb	…	82Rb	…	85Rb	…	87Rb	…	102Rb
T1/2	$x.10^3$		$x.10^9$						$x.10^2$
Yield	64.9ms		1.273mn		stable		stable		37ms

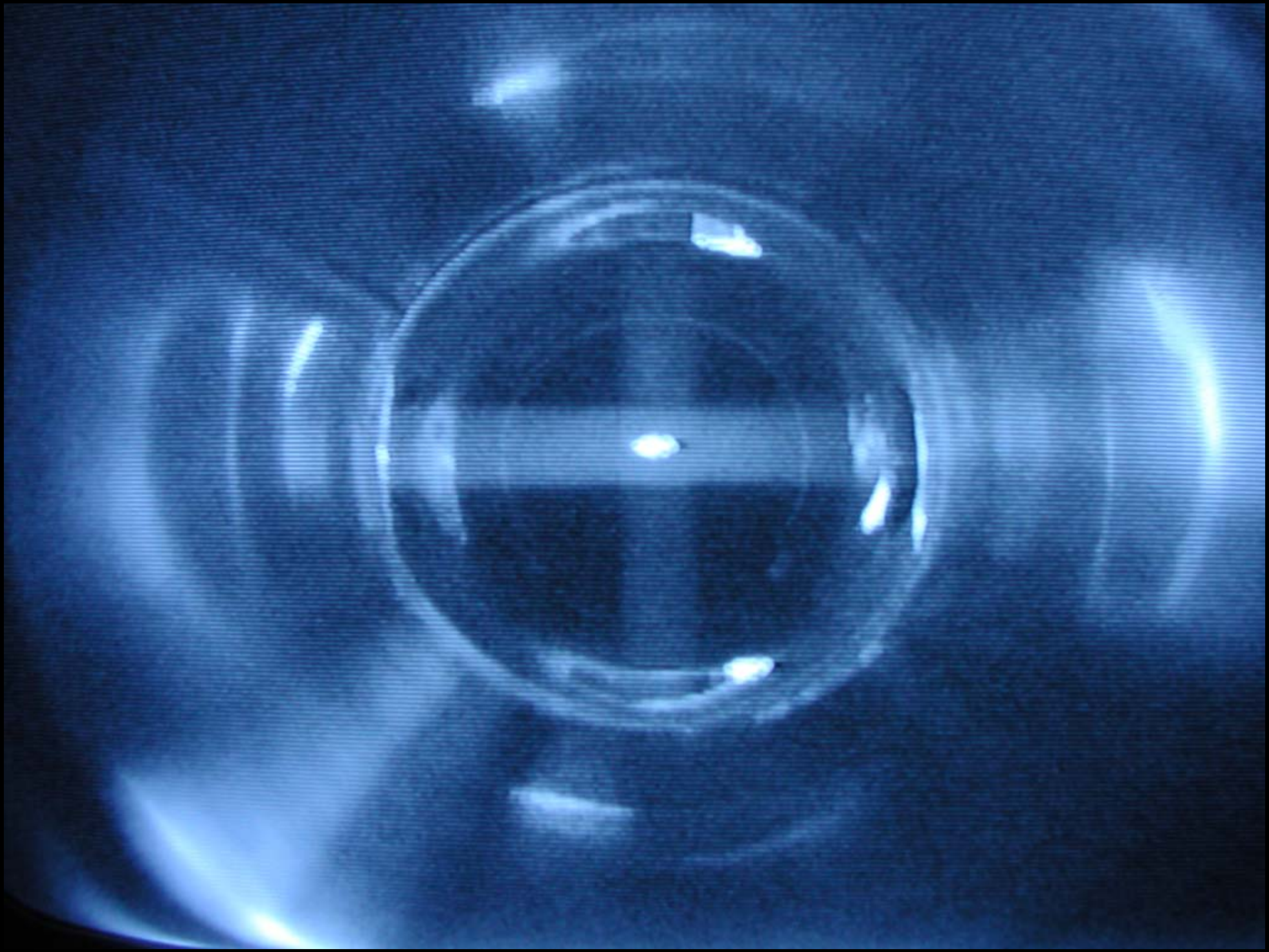
→Bohr Weisskopf effect

β–ν angular correlation

W. I. Parity Violation test

- Trapping capabilities can be extended to K and Li isotopes
- Any proposition is welcome!!
- Set up can be moved to any facility
- Schedule

THANK YOU FOR YOUR ATTENTION

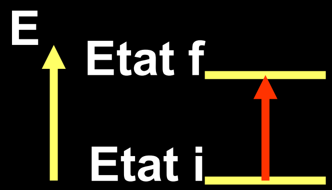


Principe du MOT

Refroidissement laser

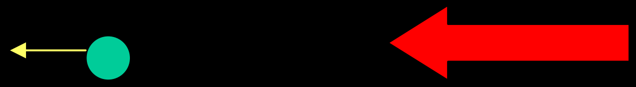
Idée 1 : force exercée par une lumière résonnante sur un atome.

Absorption:

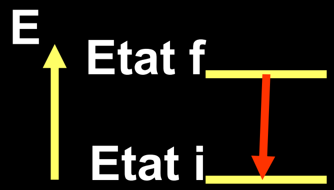


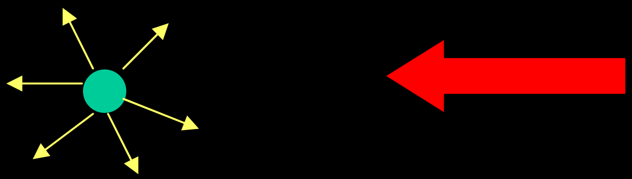
Impulsion vers l'avant

Laser de fréquence v_0



Émission spontanée:





ISOTROPE

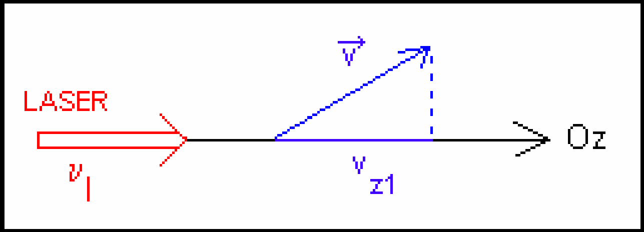
BILAN : Force exercée sur l'atome dans la direction et le sens du faisceau.

Principe du MOT

Refroidissement laser

Idée 2: Utilisation de 2 faisceaux contrapropagatifs de fréquence $\nu_l < \nu_0$

Effet DOPPLER:

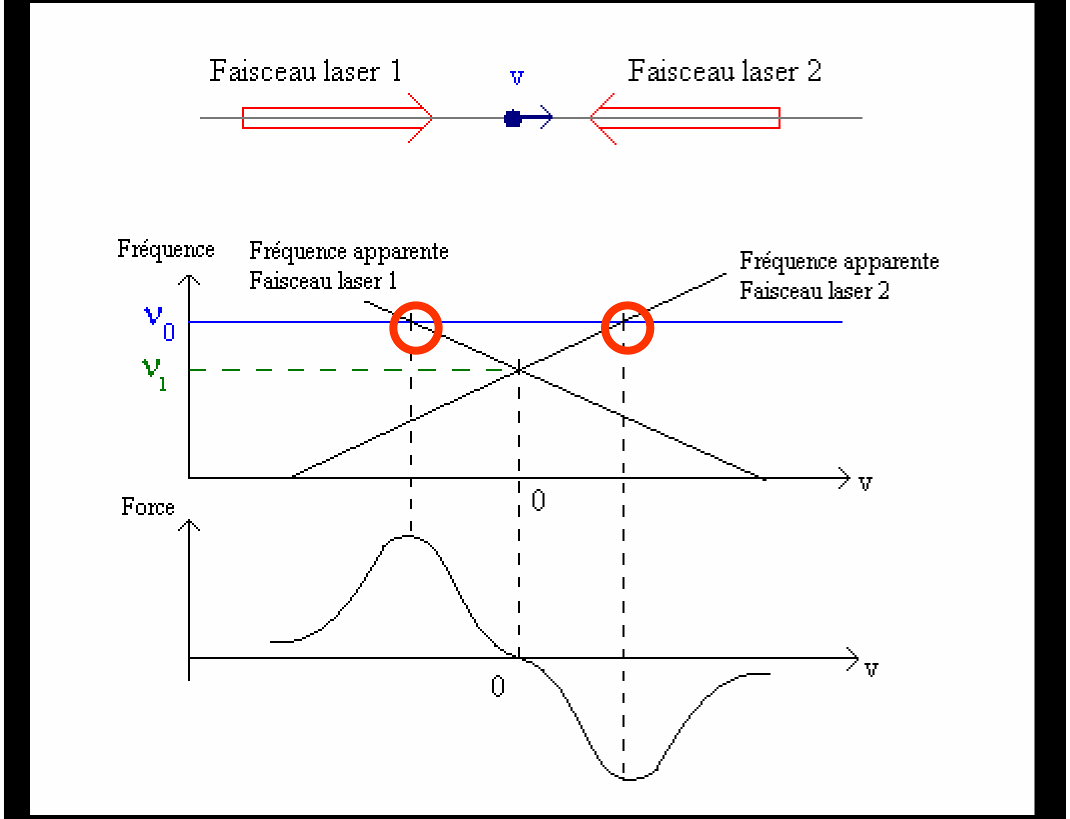


Atome de vitesse v perçoit une fréquence lumineuse:

$$\nu_{atome} = \nu_l \frac{1}{1+\frac{v_{z1}}{c}}$$

Atome et laser en situation:	Fréquence laser apparente:
Parallèle	$< \nu_l$
Antiparallèle	$> \nu_l$

REFROIDISSEMENT:



« MELASSE OPTIQUE »

Principe du MOT

Piégeage des atomes

Confinement des atomes ? => Utilisation d'un gradient de champ magnétique.

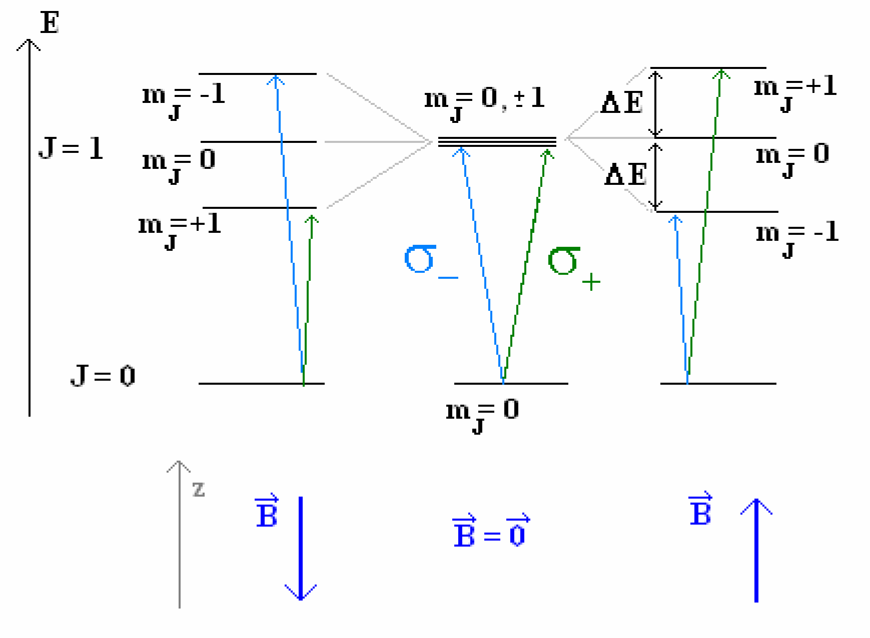
Modèle simplifié : atome effectuant une transition J = 0 → J = 1

Effet ZEEMAN:

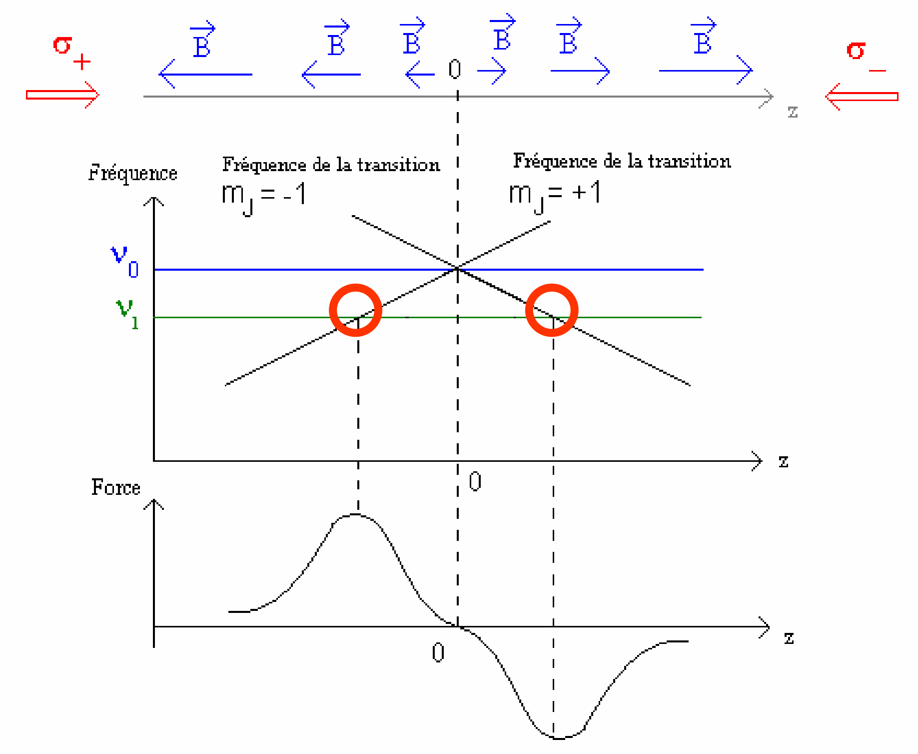
Levée de dégénérescence des sous niveaux m_J en présence d'un champ magnétique:

$$\Delta E = g\mu_B m_J B$$

g facteur de Landé, μ_B magnéton de Bohr



Utilisation de 2 faisceaux contrapropagatifs de polarisations opposées, en présence d'un gradient de champ porté par l'axe des faisceaux:



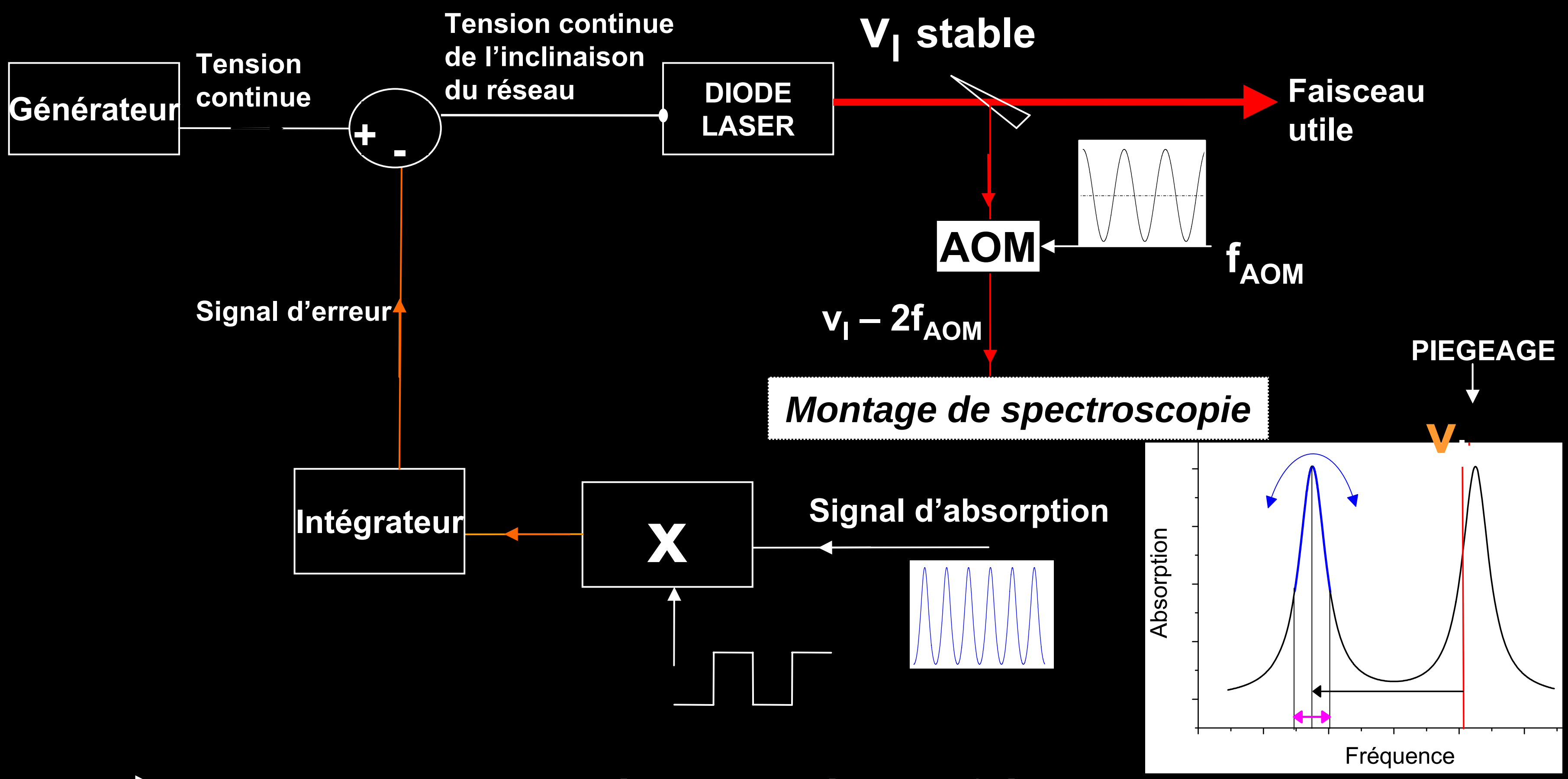
→ **FORCE DE RAPPEL**

Principe du MOT

Asservissement de la fréquence d’émission laser

Principe de la boucle d’asservissement pour le laser de piégeage:

Utilisation d’un modulateur acousto-optique (AOM) placé en entrée du montage de spectroscopie :
- Décalage de la fréquence lumineuse
- Modulation sur une raie voisine de la transition de piégeage



Générateur

Tension continue

Tension continue de l’inclinaison du réseau

DIODE LASER

ν_l stable

Faisceau utile

AOM

f_{AOM}

$\nu_l - 2f_{AOM}$

Signal d’erreur

Montage de spectroscopie

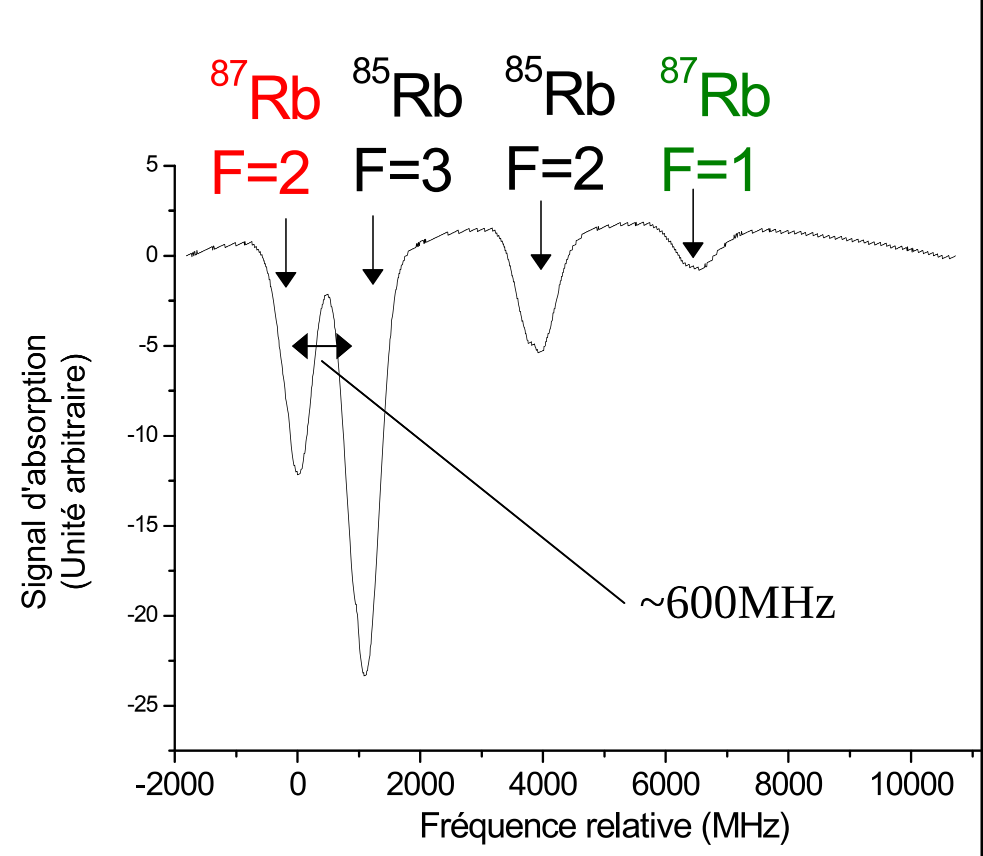
PIEGEAGE

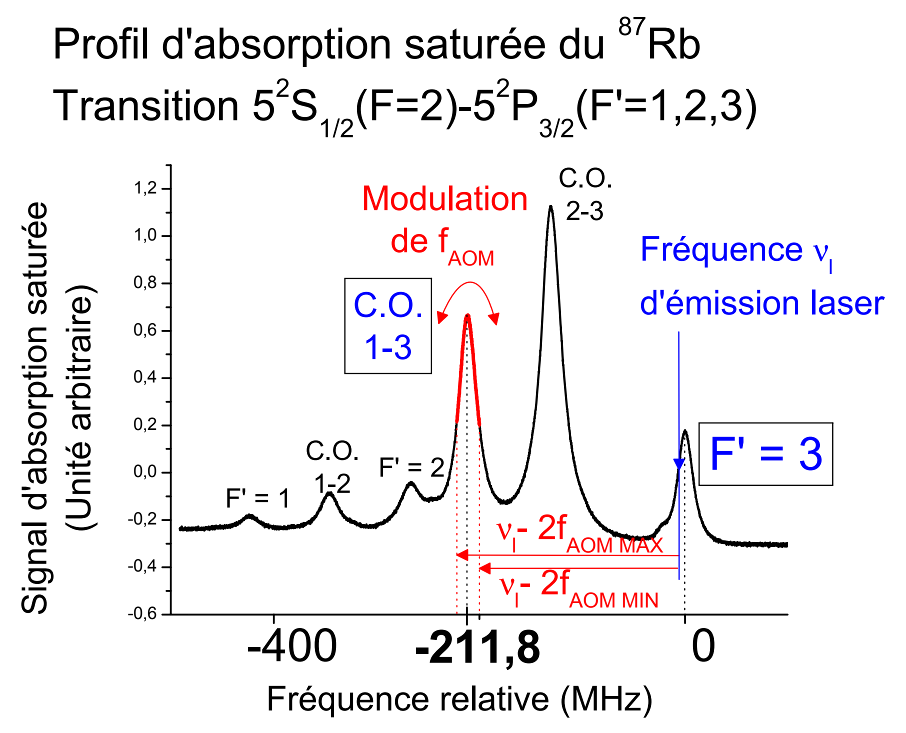
Intégrateur

x

Signal d’absorption

→ Faisceau utile envoyé vers le piège de fréquence stable

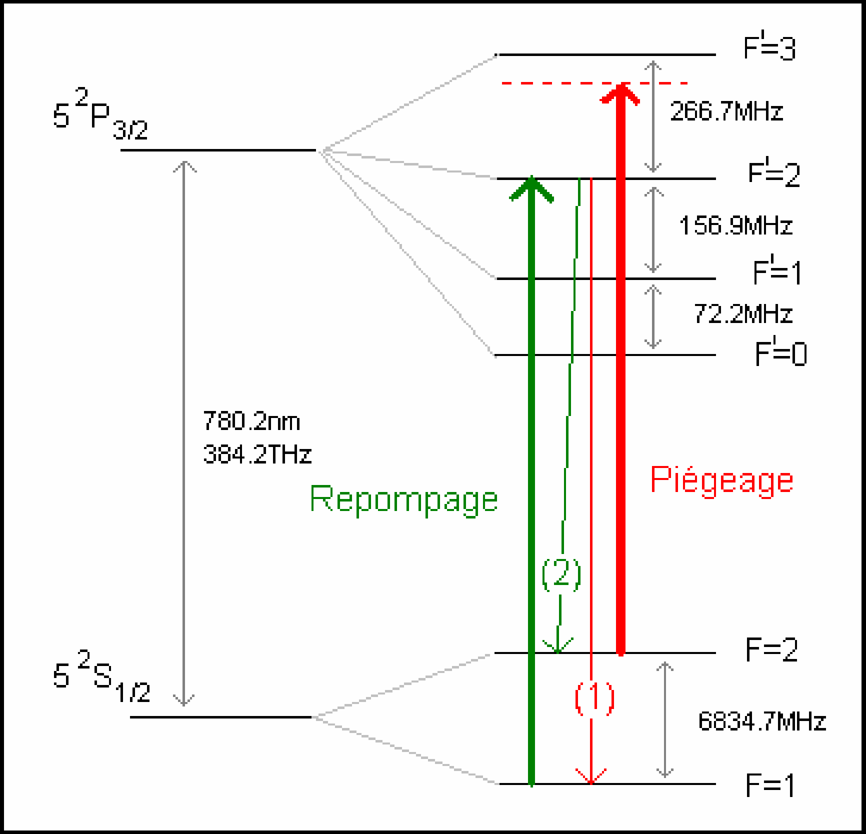


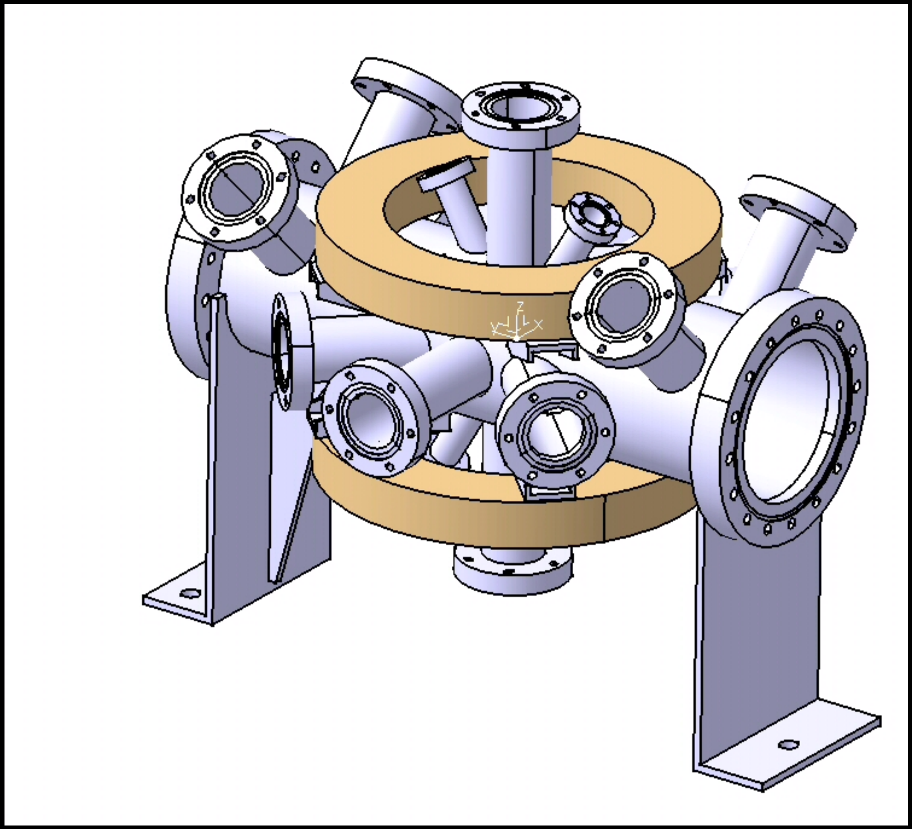


Profil d'absorption saturée du ^{87}Rb

Transition $5^2S_{1/2}(F=2)-5^2P_{3/2}(F'=1,2,3)$

Laser frequency : +/- 50 kHz over 384.2 THz


$5\,^2P_{3/2}$
F'=3
266.7MHz
F'=2
156.9MHz
F'=1
72.2MHz
F'=0
780.2nm
384.2THz
Repompage
Piégeage
(2)
(1)
$5\,^2S_{1/2}$
F=2
6834.7MHz
F=1



^{87}Rb D_2 line

Number of atoms in the MOT

$$\boxed{f = \frac{n_{excited}}{n_{total}}}$$

$$f = \frac{s_0}{1 + 2s_0 + 4\left(\frac{\Delta}{\Gamma}\right)^2}$$

$\Delta = Laser\ \ Detuning$

$\Gamma = Linewidth\ \ of\ \ Excited\ \ State$

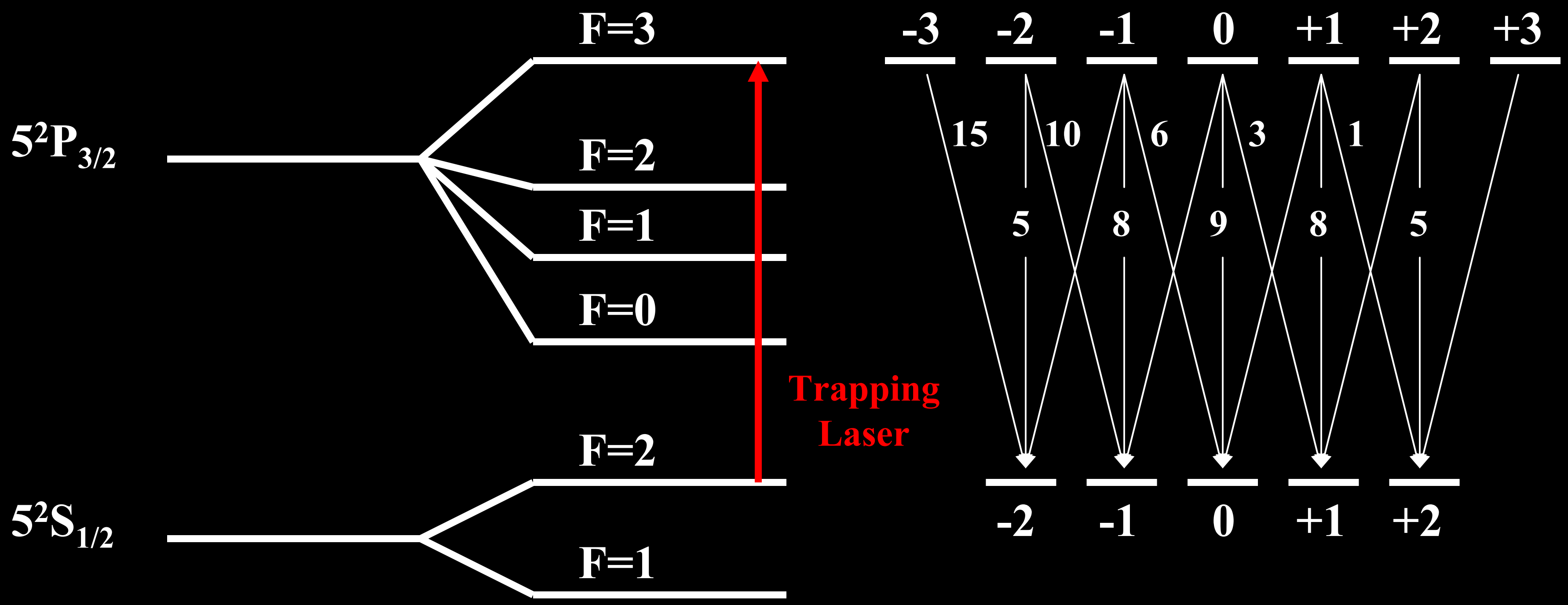
$$s_0 = \frac{I_{total}}{I_{saturation}}$$

$$I_{saturation} = \frac{2\pi hc}{3\lambda^3}\gamma$$

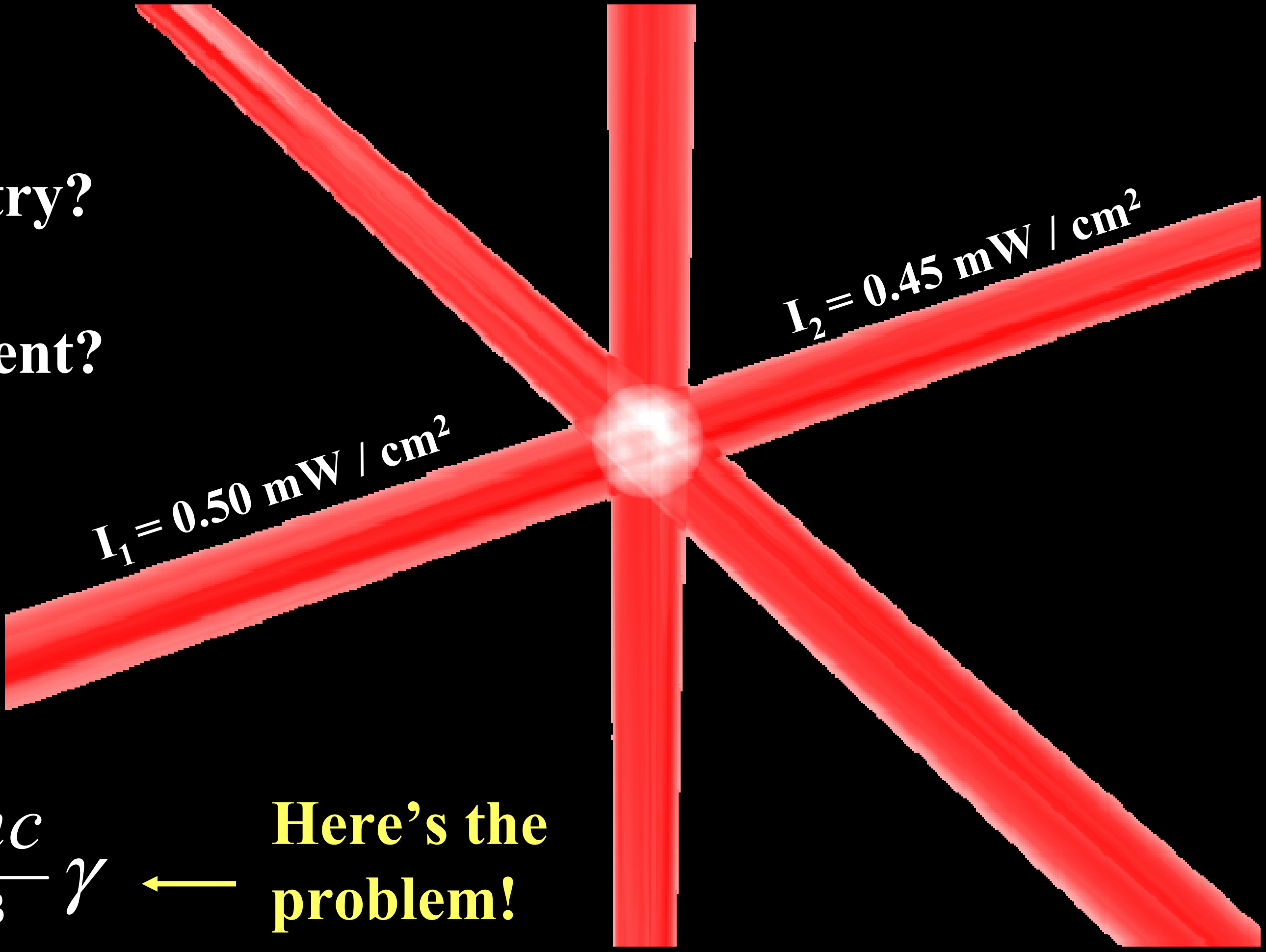
$$\boxed{\gamma = Spontaneous\ \ Emission\ \ Rate\ \ of\ \ System}$$

So, What’s the Problem!?

Specific Example: ^{87}Rb



So, What's the Problem!?



Beam Symmetry?

B-Field Gradient?

$$I_{saturation} = \frac{2\pi hc}{3\lambda^3}\gamma \longleftarrow$$

Here's the problem!