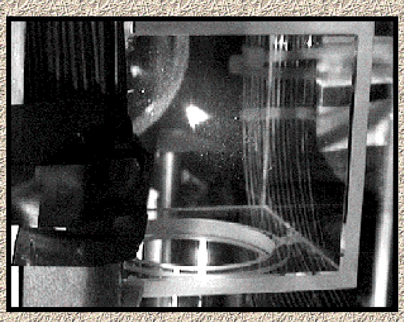
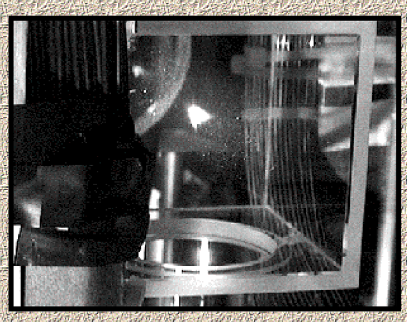


MESOSCOPIC PHYSICS WITH LIGHT IN COLD ATOMS



Institut Non Linéaire de Nice (France)

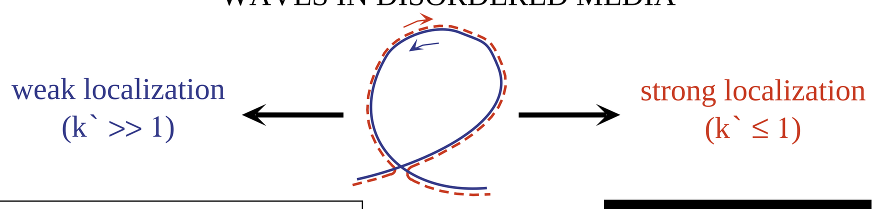
http://www-lod.inln.cnrs.fr

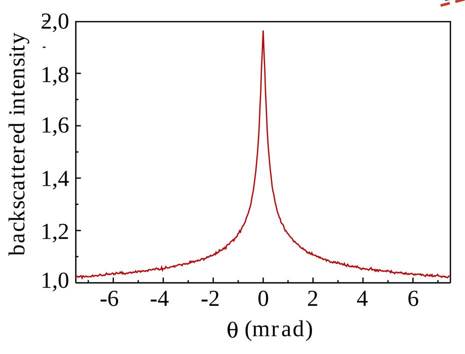
INLN (Nice) : R. Kaiser, G. Labeyrie, C. Miniatura, D. Wilkowski, Y. Bidel, T. Chanelière, C. Müller, T. Wellens

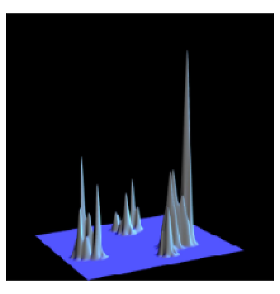
LKB (Paris) : D. Delande, B. Grémaud, T. Jonckheere, O. Sigwarth

MESOSCOPIC PHYSICS

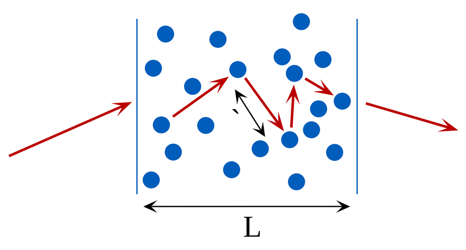
INTERFERENCE CORRECTIONS TO TRANSPORT OF WAVES IN DISORDERED MEDIA







COHERENCE LENGTH



spatial scales :
- sample size L
- wavelength λ
- mean free path ` = $(\sigma n)^{-1}$
- coherence length L_Φ

"mesoscopic criterion" : ` < L < L_Φ

multiple scattering — coherent transport

WHY COLD ATOMS ?

- "clean" & controllable system :
  - ⇒ well-known and well-controlled scatterers
  - ⇒ no absorption
  - ⇒ tunable ` (δ)
- new physics & new regimes :
  - ⇒ higly resonant and monodisperse samples
  - ⇒ internal structure
  - ⇒ feedback : mechanical effects, optical pumping, entanglement
  - ⇒ non-linearities

ATOMS ARE COOL BUT ...

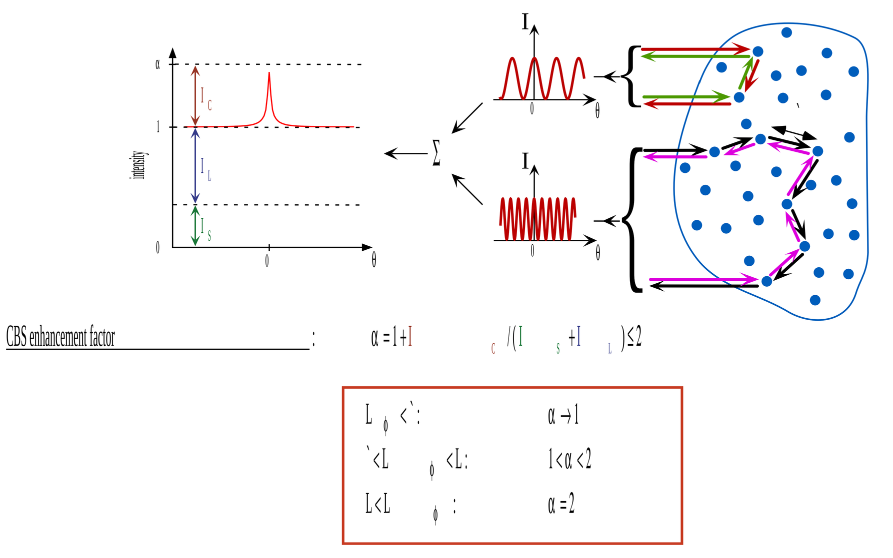
SEVERAL MECHANISMS LIMIT L_Φ

internal structure of ground state

atomic motion

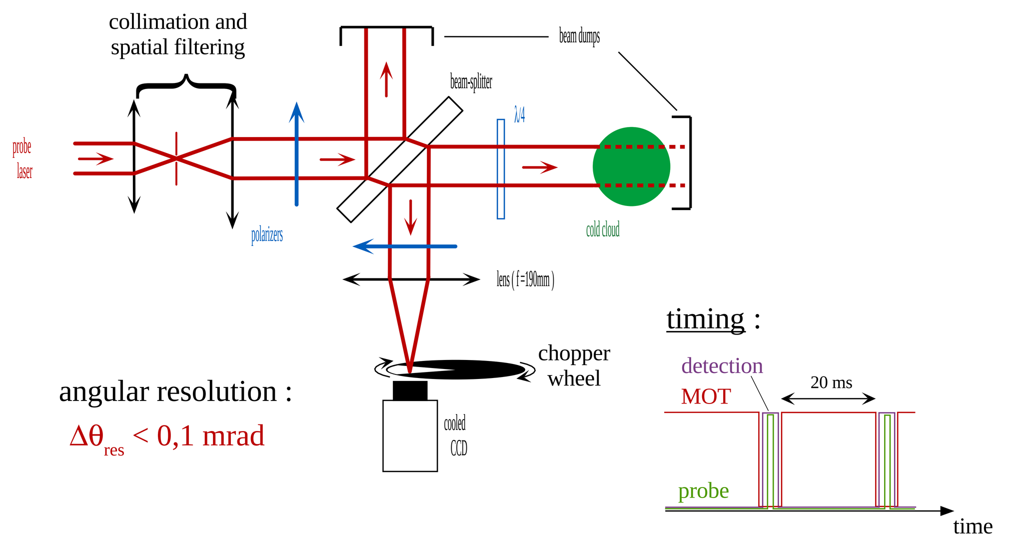
saturation of atomic transition (inelastic scattering)

COHERENT BACKSCATTERING : A TOOL TO PROBE L_Φ



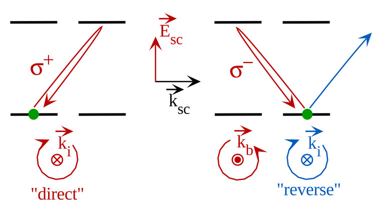
CBS SETUP

setup :

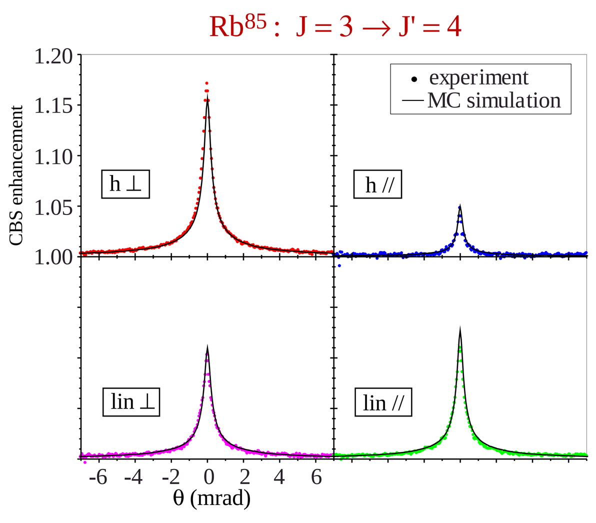


angular resolution : $\Delta\theta_{res}$ < 0,1 mrad

INTERNAL STRUCTURE OF GROUND STATE



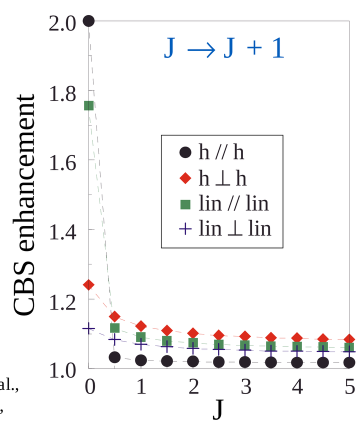
internal structure ⇒ amplitude imbalance : $\alpha < 2$ in all channels



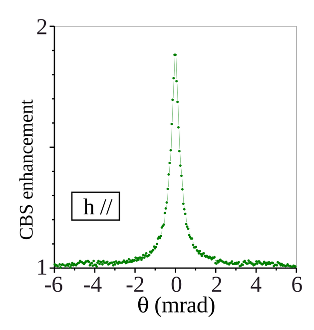
- Labeyrie et al., Phys. Rev. Lett. 83, 5266 (1999).
- Labeyrie et al., Europhys. Lett. 61, 327 (2003).

INTERNAL STRUCTURE

internal structure ⇒ drastic reduction of L_Φ



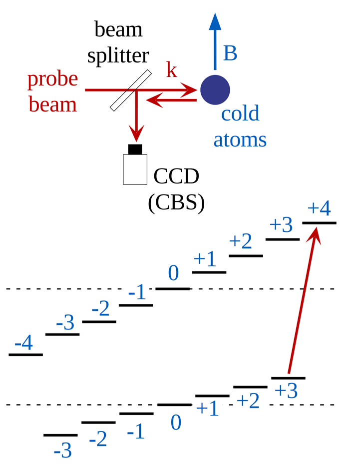
- C. A. Müller et al., Phys. Rev. A 64, 053804 (2001).

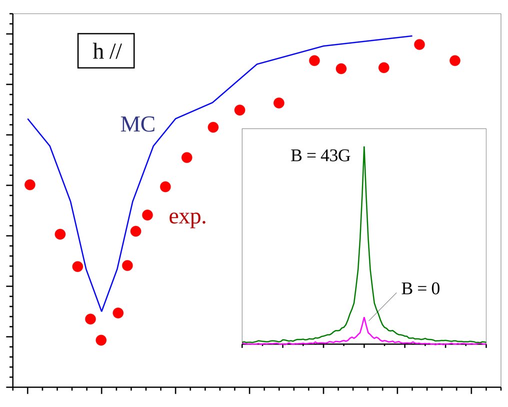


- Bidel et al., Phys. Rev. Lett. 88, 203902 (2002).

J = 3 → J' = 4 ⇒ L_Φ = ` / 3

RESTORING L_Φ WITH A MAGNETIC FIELD





Zeeman lifting of degeneracy ⇒ quasi-2 level system

RESTORING L_Φ WITH A MAGNETIC FIELD

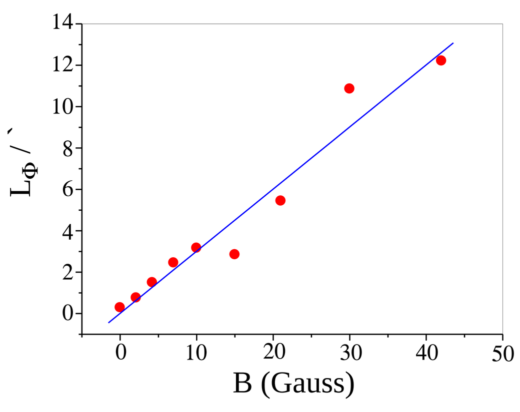
"usual" situations :

B breaks time-reversal symmetry ⇒ L_Φ decreases

our case :

L_Φ increases ∝ B !!!

- Sigwarth et al., Phys. Rev. Lett. 93, 143906 (2004).



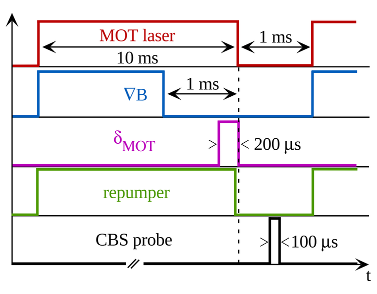
Zeeman lifting of degeneracy ⇒ quasi-2 level system

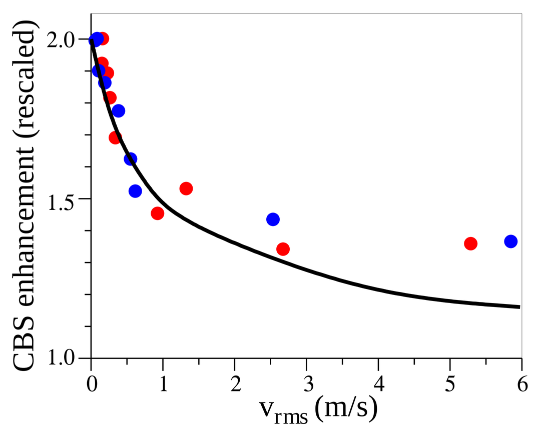
ATOMIC MOTION

motion of scatterers ⇒ random phase

- A. A. Golubentsev, Sov. JETP 59, 26 (1984).

experimental observation of "dynamical breakdown" : heating by intense near-resonant optical molasse



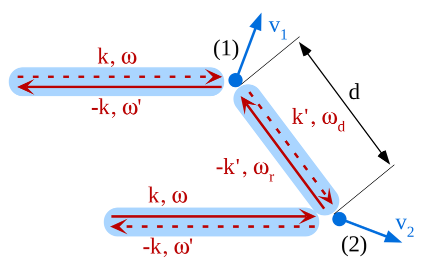


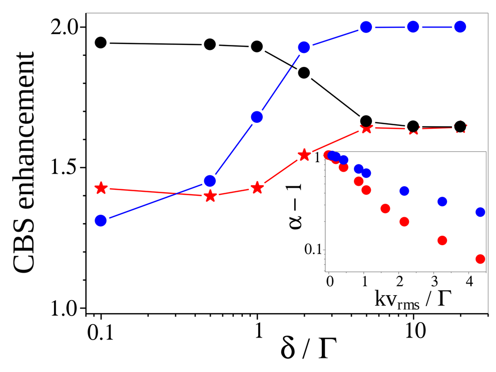
DYNAMICAL BREAKDOWN OF CBS

Doppler effect ⇒ ≠ frequencies

scattering phase : $\langle\Delta\varphi_s\rangle = 4\,\frac{kv_{rms}}{\Gamma}\,\frac{1}{1+4(\delta/\Gamma)^2}$

propagation phase : $\langle\Delta\varphi_p\rangle = -2\,\frac{kv_{rms}}{\Gamma}\,\frac{1-4(\delta/\Gamma)^2}{1+4(\delta/\Gamma)^2}$





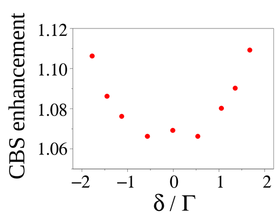
DYNAMICAL BREAKDOWN : PRELIMINARY CONCLUSIONS

- sharp decrease of L_Φ when v_{rms} increases : $L_\Phi / ` \approx \left(\frac{kv_{rms}}{\Gamma}\right)^{-2/3}$

⇒ mesoscopic criterion for optical thickness b :

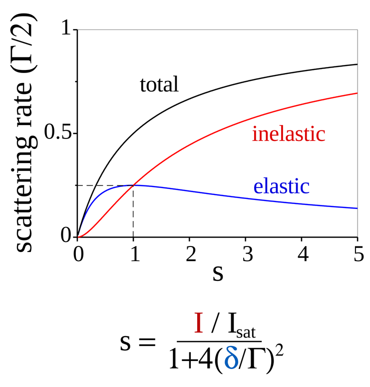
$\frac{kv_{rms}}{\Gamma} < 1/b^3$ — difficult to fulfill for b >> 1

- partial restoration of CBS when δ increases

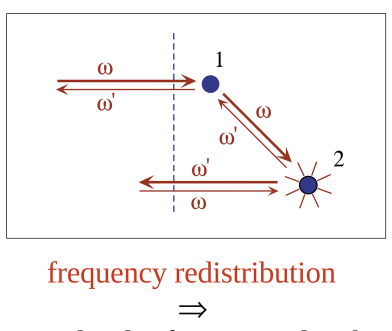


SATURATION OF THE ATOMIC TRANSITION

saturation ⇒ inelastic scattering



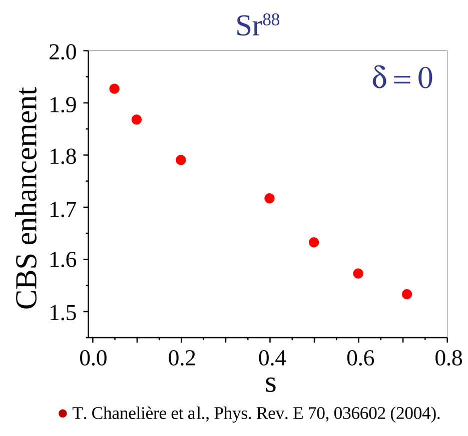
$s = \frac{I/I_{sat}}{1+4(\delta/\Gamma)^2}$



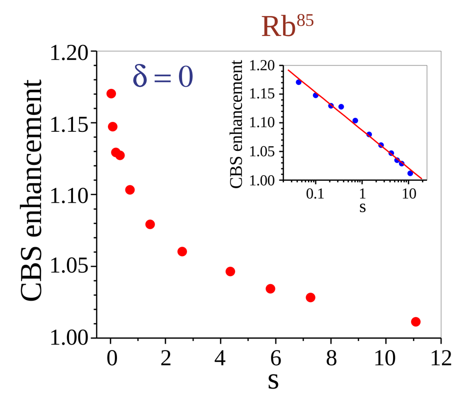
frequency redistribution ⇒ ≠ amplitudes for reversed paths

- T. Wellens et al., Phys. Rev. A 70, 023817 (2004).

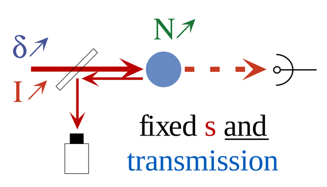
CBS AND SATURATION



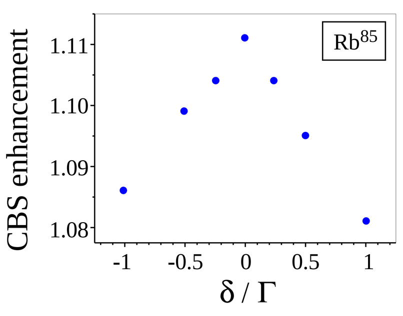
- T. Chanelière et al., Phys. Rev. E 70, 036602 (2004).

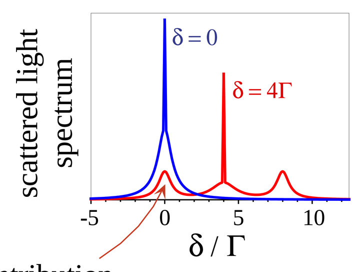


ROLE OF SCATTERED LIGHT SPECTRUM



fixed s and transmission





enhanced contribution of inelastic scattering when $\delta \neq 0$

CONCLUSION

- identification and demonstration of several coherence-reducing mechanisms :
  - ⇒ internal structure
  - ⇒ temperature
  - ⇒ saturation
- solutions :
  - ⇒ internal structure : apply B field (or use J = 0 → J' = 1)
  - ⇒ temperature : cool down ... but severe limitation for long scattering paths !
  - ⇒ saturation : use s<<1; possible problems in random laser and strong localization