Hanbury Brown Twiss Effect for Metastable Helium

Experimental Features

Martijn Schellekens

Kioloa, 11 February 2006

Institut d'Optique

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

Institut francilien de Recherche sur les Atomes Froids IFRAF

He* Experiment in the Atomic Optics group in Orsay:

Permanents Members:

- Alain Aspect
- Christoph Westbrook
- Denis Boiron

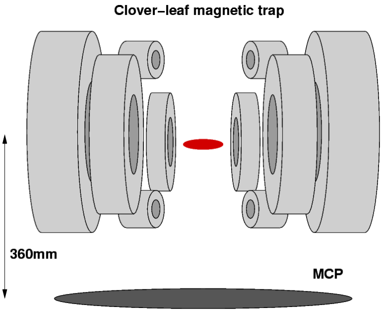
Co-PhD Students:

- Valentina Krachmalnicoff
- Aurélien Perrin
- Rodolphe Hoppeler
- Jose Viana Gomes

Post-Docs:

- Hong Chang

What bothers an experimentalist:



Signal to Noise Ratio

We need sufficient SNR for just measuring:

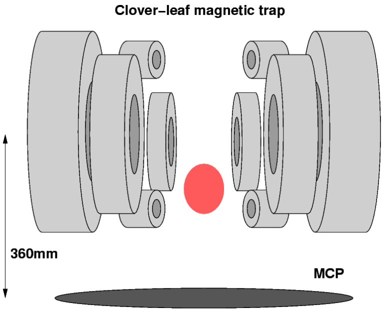
$$g^{(2)}(\Delta \mathbf{R})$$

We would eventually like to measure:

$$g^{(2)}(\mathbf{R}, \Delta \mathbf{R})$$

Indeed, bunching is non-gaussian close to condensation threshold, yet means out by integrating.

What bothers an experimentalist:



Signal to Noise Ratio

We need sufficient SNR for just measuring:

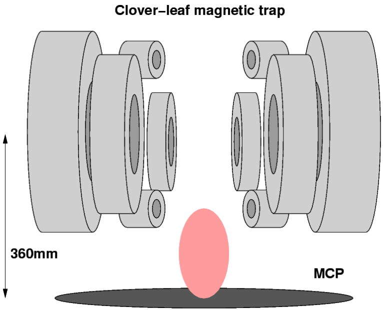
$$g^{(2)}(\Delta\mathbf{R})$$

We would eventually like to measure:

$$g^{(2)}(\mathbf{R}, \Delta\mathbf{R})$$

Indeed, bunching is non-gaussian close to condensation threshold, yet means out by integrating.

What bothers an experimentalist:



Signal to Noise Ratio

We need sufficient SNR for just measuring:

$$g^{(2)}(\Delta\mathbf{R})$$

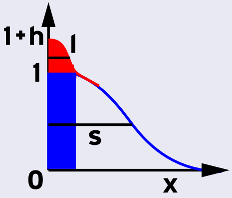
We would eventually like to measure:

$$g^{(2)}(\mathbf{R}, \Delta\mathbf{R})$$

Indeed, bunching is non-gaussian close to condensation threshold, yet means out by integrating.

The Signal to Noise Ratio

Estimation:



$$SNR \propto \sqrt{N_{runs}} \frac{h N_{atoms}^2 \prod l_\alpha / s_\alpha}{\sqrt{(1+h) N_{atoms}^2 \prod l_\alpha / s_\alpha}}$$

which simplifies to:

$$SNR \propto h \sqrt{N_{runs}} N_{atoms} \prod \sqrt{l_\alpha / s_\alpha}$$

with $l_\alpha = \frac{\hbar t}{m s_\alpha} = \lambda_{dB} \omega_\alpha t$ and $s_\alpha = t\sqrt{k_B T / m}$ in case of **harmonic trap**

Note:

- the temperature dependance, that is in $T^{-3/2}$.
- the dependance on the atoms number.

The Signal to Noise Ratio

Bunching height:

Depends on the Size/Resolution:

$$g^{(2)} - 1 = \prod_{\alpha} \frac{1}{\sqrt{1 + 4d_\alpha^2/(l_\alpha^{(corr)})^2}}$$

with $l_\alpha^{(corr)} = \frac{\hbar t}{m s_\alpha} = \lambda_{dB} \omega_\alpha t$

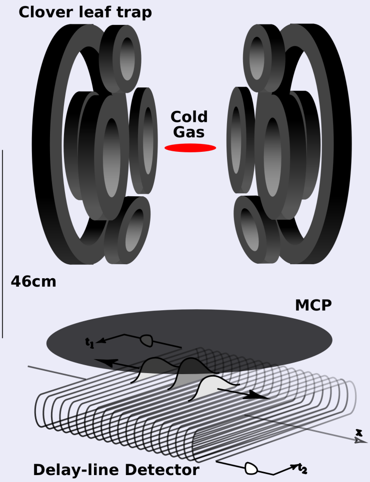
- Worse case: $d \gg l_\alpha^{(corr)}$ then $g^{(2)} - 1 \propto \prod_\alpha l_\alpha^{(corr)}/2d_\alpha$
- Best case: $d \ll l_\alpha^{(corr)}$ then $g^{(2)} - 1 = 1$
- Temperature dependance:
  Can potentially add another T dependance to SNR.
- Time dependance:
  The longer the time of flight, the longer the correlation length.

Outline

Outline

The metastable Helium experiment:

Experimental setup:



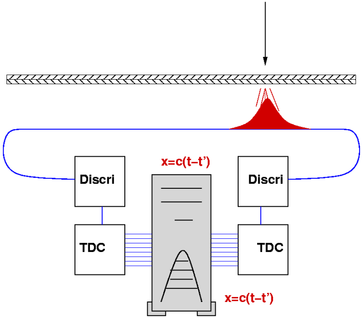
- Creation of a cold He* cloud (in $\sim 1'$)
- Cut off the trap at $t = 0$

$$\Downarrow$$

- 308ms of free fall
- 3D Detection (x, y and t) of individual atoms.

The detector : MCPs + delay-lines:

Basic idea:



Micro-channel plates (MCPs)

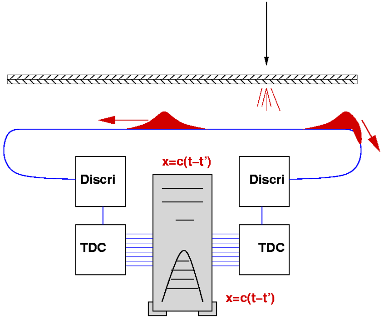
- 8 cm diametre
- 1 He^* detected $\rho \sim 10^8$ electrons
- Detection efficiency $\sim 25\%$

MCP + delay-lines + electronics

- pixel size $= 200\mu m$
- spatial resolution $= 250\mu m$ RMS
- time resolution $=$ 1ns RMS
- electronical limitations: CFD + TDC (400 ps of resolution)

The detector : MCPs + delay-lines:

Basic idea:



Micro-channel plates (MCPs)

- 8 cm diametre
- 1 He^* detected $\rho \sim 10^8$ electrons
- Detection efficiency $\sim 25\%$

MCP + delay-lines + electronics

- pixel size $= 200\mu m$
- spatial resolution $= 250\mu m$ RMS
- time resolution $=$ 1ns RMS
- electronical limitations: CFD + TDC (400 ps of resolution)

The detector : MCPs + delay-lines:

Basic idea:

Detection

- TDC = CTNM4 (R. Sellem, DTPI platform CNRS/Paris-Sud)
- Detection system $\Leftrightarrow$ camera of 400×400 pixels at 1 GHz
- $\Rightarrow$ no optical equivalent

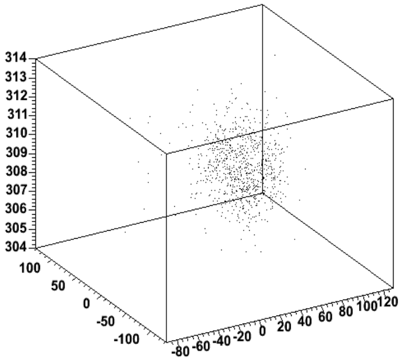
Micro-channel plates (MCPs)

- 8 cm diametre
- 1 He^* detected $\rho \sim 10^8$ electrons
- Detection efficiency $\sim 25\%$

MCP + delay-lines + electronics

- pixel size = $200\mu m$
- spatial resolution = $250\mu m$ RMS
- time resolution = 1ns RMS
- electronical limitations: CFD + TDC (400 ps of resolution)

3D Reconstruction of the Detected Cloud:



Real 3D detecteur

- $\longrightarrow x, y$ and t for each atom detected.
- Only detector that does real 3D on a BEC
- Use :
  - Detection of a small condensate
  - Local measurements, etc…
- Macroscopique detection of a BEC (50 cents AU$ coin !)

3D Reconstruction of the Detected Cloud:

Real 3D detecteur

- $\longrightarrow x, y$ and t for each atom detected.
- Only detector that does real 3D on a BEC
- Use :
  - Detection of a small condensate
  - Local measurements, etc...
- Macroscopique detection of a BEC (50 cents AU$ coin !)

SNR considerations at 1μK:

- axis x: $\omega_x = 50Hz$
  $\sqrt{2} * d_x (= 250\mu m) \gg l_x (= 30\mu m)$
- axis y: $\omega_y = 1.2kHz$
  $\sqrt{2} * d_y (= 250\mu m) \ll l_y (= 600\mu m)$
- axis z: $\omega_z = 1.2kHz$
  $\sqrt{2} * d_z (= 4nm) \lll l_z (= 600\mu m)$

Bunching height:

$g^{(2)}(0) - 1$ becomes a function of $l_x^{(corr)}/2d_x$

- $SNR \propto t$
- $SNR \propto T^{-2}$

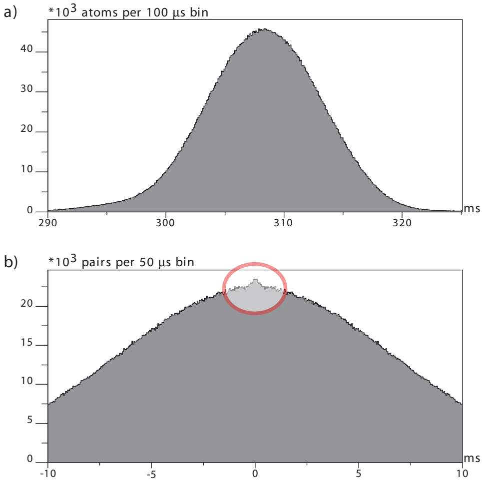
Outline

Thermal clouds raw results:

Mean Flow

Procedure:

- Save Time of Flights (ToF)
- Histogram in 3D all the differences between 2 atoms
- We average the histogram over all ToFs
- typ. 6000 atomes detected/ToF and 1500 ToFs/Temperature

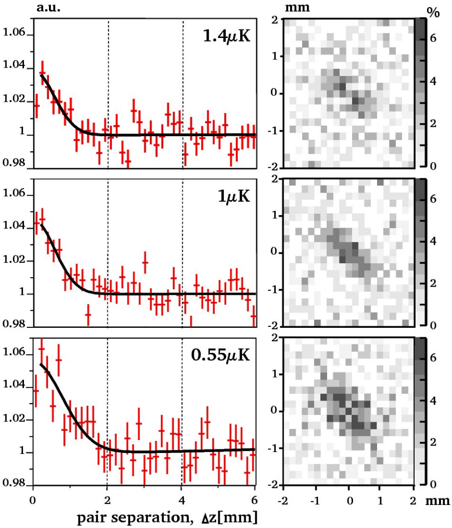


Correlation of the Flow

Thermal clouds raw results:

- Left Colomn:
  $g^{(2)}$ function of z (time)
- Right Colomn:
  bunching amplitude in the detector plane xy

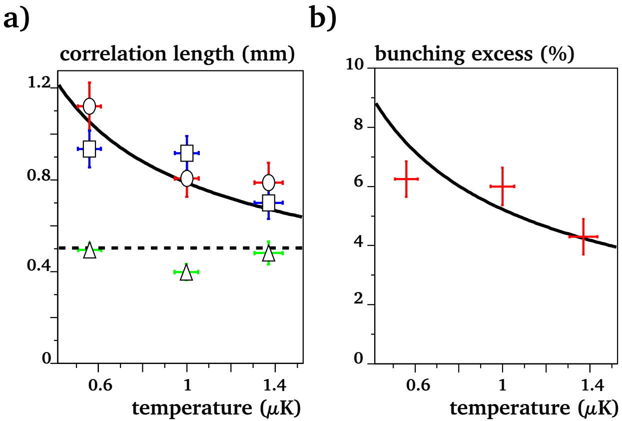
- Bunching !!
- Observe the anisotropy
- Correlation length changes with Temperature (source size)



M. Schellekens & al, Science **310**, 648 (2005)

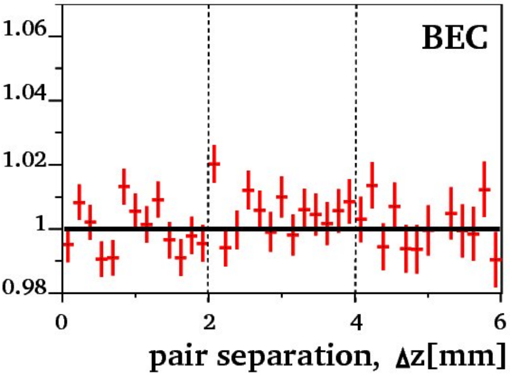
Results comply to perfect gas theory:

Detector of limited resolution (500 μm and 1 ns)
$\rightarrow$ bunching height $\sim$ 1.06 instead of 2.



Temperature $\Leftrightarrow$ Source Size

Case of the Bose-Einstein Condensate:



- Flat correlation function !
- Like a laser
- Similar results in the team of T. Esslinger : PRL **95**, 090404 (2005)

Outline

Some Limitations:

Saturation of the TDC

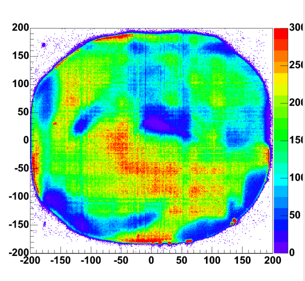
The TDC saturates at 700k particules/second (this corresponds to 14Mbytes/second).

Solution: new TDC

We have had made a new TDC by ISITech: 10M particules/second. Received last week.

Inhomogenous Detection Efficiency

Detection Efficiency vs x and y:



Solution: Doesn't matter for HBT

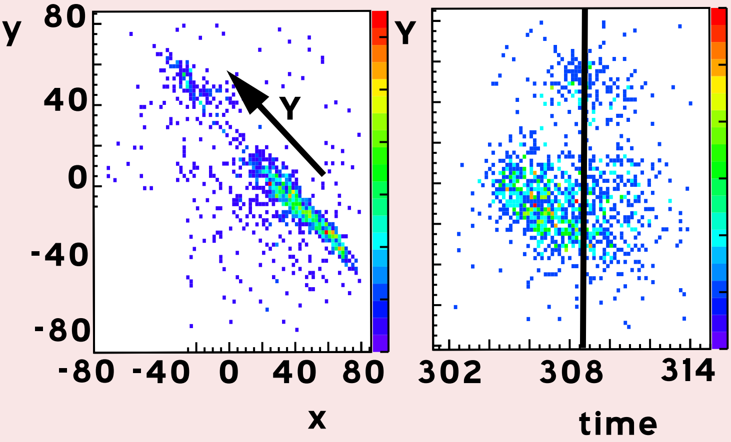
Normalisation procedure:

$$\frac{\Sigma Corr(Tof)}{Corr(\Sigma Tof)}$$

Saturation of MCP:

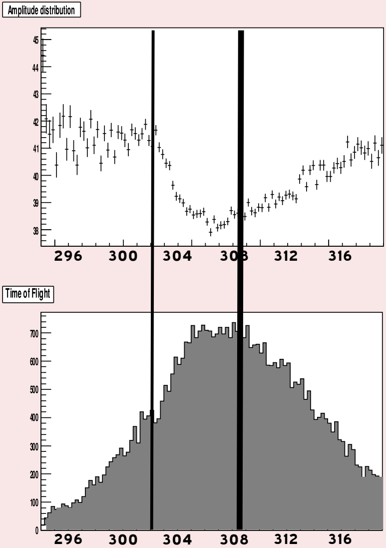
The MCP saturates at high local flows:

BEC = very high local Flow



Saturation of MCP:

Cold Gas



Local saturation rate:
$\sim 300 kparticules/s/cm^2$
Could be solved with some more Euros.

Resolution:

Resolution $= 250\mu m \gg 100\mu m$ at 400ps TDC resolution.

- We can get better TDC resolution: new has 275ps.
- Better understand the CFD: minimize jitter issues

Currently in the process of estimating the "ultimate" resolution.

Conclusion:

We managed to resolve the HBT effect in nearly 3 dimensions:

- We measured the bunching height.
- We measured the bunching width.
- We saw no bunching for a BEC.

The HBT experiment was at the limit of the detector possibilities:

- Improvements can be made on flow detection.
- Improvement could be made on resolution.
- Detection inhomogeneity is still to be understood.

What we are working towards:

- Detector improvements:
  ⇒ could allow local $g^{(2)}$ measurement.
- HBT for fermions in cooperation with W. Vassen's team:
  ⇒ experiment to be realized with the bosonic-fermionic mixture of W. Vassen (VU Amsterdam).
- Detection of correlated atom pairs through collisions:
  ⇒ 4 Wave Mixing.

Thank you for your time!