Hanbury Brown Twiss Effect for Metastable Helium Experimental Features

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He* Experiment in the Atomic Optics group in Orsay:

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- Denis Boiron

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What bothers an experimentalist:

Signal to Noise Ratio

We need sufficient SNR for just measuring:

\[ g^{(2)}(\Delta R) \]

We would eventually like to measure:

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The Signal to Noise Ratio

**Estimation:**

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

which simplifies to:

\[ SNR \propto h\sqrt{N_{\text{runs}}} N_{\text{atoms}} \prod \sqrt{l_\alpha/s_\alpha} \]

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 dependence, that is in \( T^{-3/2} \).
- the dependence on the atoms number.
The Signal to Noise Ratio

Bunching height:

Depends on the Size/Resolution:

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

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 dependence:**
  Can potentially add another \( T \) dependence to SNR.
- **Time dependence:**
  The longer the time of flight, the longer the correlation length.
Outline

1 Experimental Setup

2 Experimental Results

3 Detection Limitations and Perspectives
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The metastable Helium experiment:

**Experimental setup:**

- Creation of a cold He* cloud (in $\sim 1'$)
- Cut off the trap at $t = 0$
- $308\text{ms}$ 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 diameter
- 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)
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Basic idea:

 Detection

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

Micro-channel plates (MCPs)

- 8 cm diametre
- 1 He* detected ρ ∼ 10^8 electrons
- Detection efficiency ∼ 25%

MCP + delay-lines + electronics

- pixel size = 200μm
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3D Reconstruction of the Detected Cloud:

- Real 3D detector for each atom detected.
- Only detector that does real 3D on a BEC (50 cents AU$ coin!)
- Use:
  - Detection of a small condensate
  - Local measurements, etc...
- **Macroscopique** detection of a BEC (50 cents AU$ coin!)
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SNR considerations at 1µK:

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

**Bunching height:**

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

- $\text{SNR} \propto t$
- $\text{SNR} \propto T^{-2}$
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Thermal clouds raw results:

Procedure:

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

Mean Flow

Correlation of the Flow
Thermal clouds raw results:

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

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

Results comply to perfect gas theory:

Detector of limited resolution (500 \( \mu \text{m} \) and 1 ns)
\[ \rightarrow \text{bunching height} \sim 1.06 \text{ instead of 2.} \]

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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)
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Some Limitations:

**Saturation of the TDC**
The TDC saturates at 700k particles/second (this corresponds to 14M bytes/second).

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

**Inhomogenous Detection Efficiency**

Detection Efficiency vs x and y:

![Graph](image.png)

**Solution: Doesn’t matter for HBT**
Normalisation procedure:
\[
\frac{\Sigma \text{Corr}(T_{of})}{\text{Corr}(\Sigma T_{of})}
\]
Saturation of MCP:

The MCP saturates at high local flows:

BEC = very high local Flow
Saturation of MCP:

**Cold Gas**

Local saturation rate: 
\(~ 300 \text{kparticles/s/cm}^2\)
Could be solved with some more Euros.
Resolution: 250 µm ≫ 100 µm 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!