

Call 2021
Final Evaluation



SQUEIS

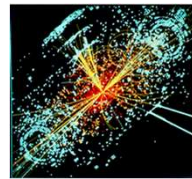
SQUeezing-Enhanced Inertial Sensing
Luca Pezzè (coordinator)

29/09/2026

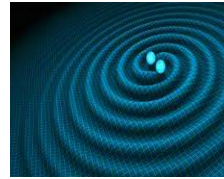


COLLABORATION

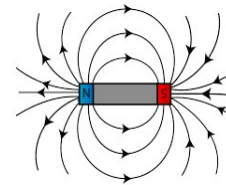
Atom interferometry is a key technology with a broad range of applications



**tests of
fundamental
physics**



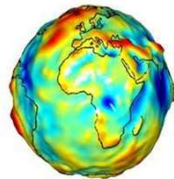
**gravitational-
wave dark-
matter search**



magnetometry



**underground
exploration**



geophysics



engineering



navigation

SQUEIS aims to enhance the sensitivity of atom-interferometric inertial sensors, including gravimeters and gradiometers, by developing protocols that exploit quantum correlations among atoms to surpass the standard quantum limit



COLLABORATION

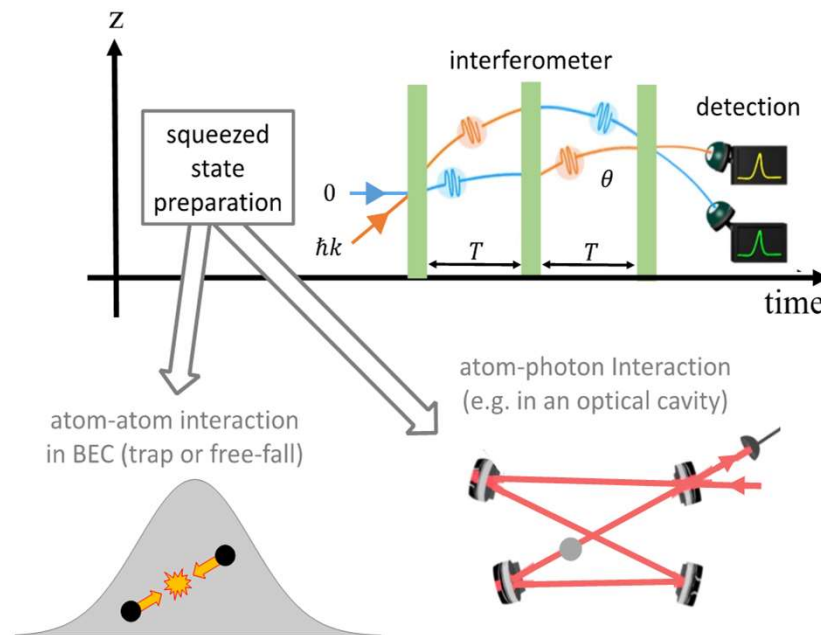
<i>Country</i>	<i>Institute</i>	<i>Local PI</i>
Italy	CNR	L. Pezzè
Italy	INFN	G. Tino
Germany	LUH	N. Gaaloul
France	SYRTE	F. Pereira dos Santos
Poland	UW	J. Chwedeńczuk



Several theory-theory and theory-experiment collaborations between different units

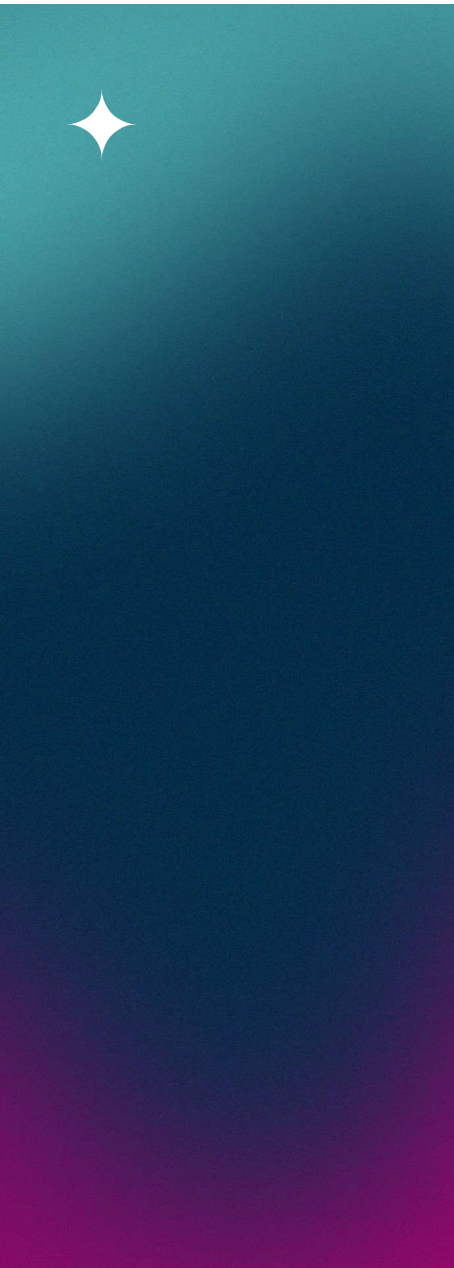
CHALLENGE

The stringent constraints required for inertial sensing pose a very strong challenge when **incorporating quantum entanglement into high precision atom interferometers**, preserving both the entanglement and the high precision of the measurement device



- 1) Squeezed states engineering
- 2) Advanced detection schemes
- 3) Optimal use of squeezed states
- 4) Squeezing-enhanced inertial sensing

GOAL: proof-of-principle demonstrations of squeezing techniques in sensing devices relevant to real-world applications



SOLUTION

**Exploration of different atomic platforms:
free-fall and compact trapped sensors**
directly relevant to applications

Innovative squeezed-state generation methods
based on tunable atom–atom interactions in quantum
gases and quantum nondemolition measurements
mediated by atom–light coupling

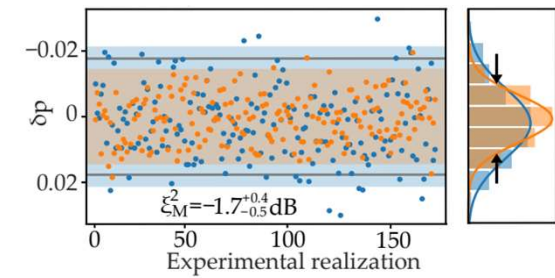
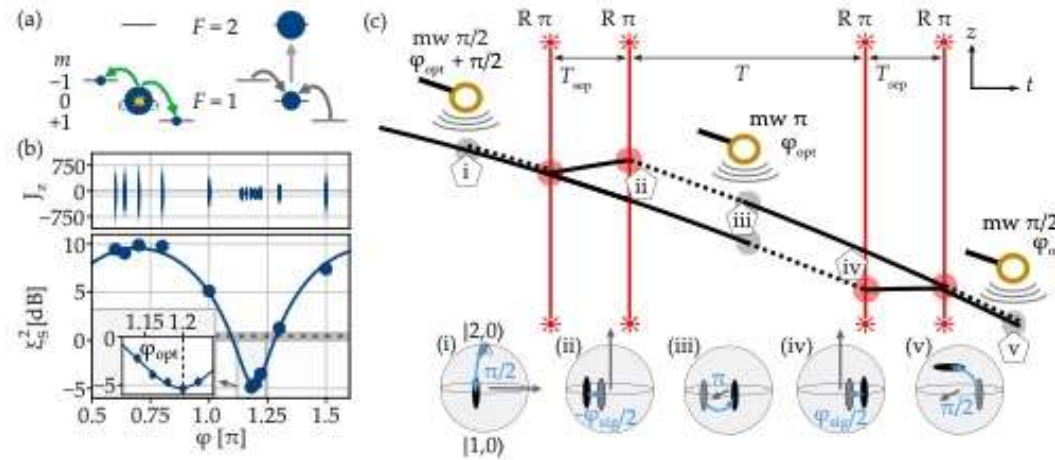
Advanced detection and control techniques:
number counting measurements, control of
interactions, manipulation of the wave packet

**synergy between experimental and theoretical experts in a consortium
characterized by well-integrated collaborations**



HIGHLIGHTS

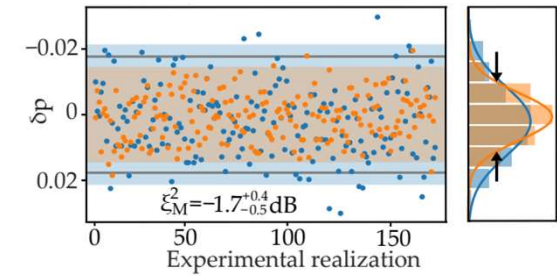
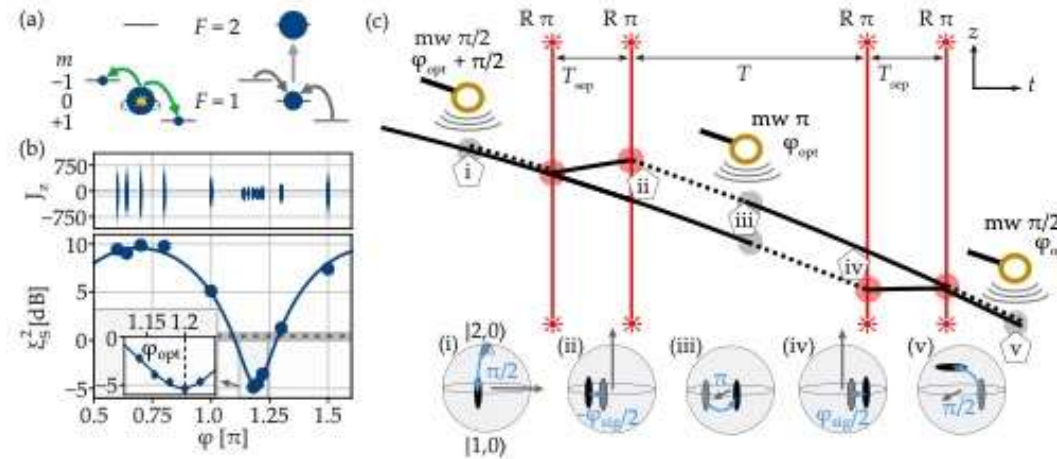
- Quantum-enhanced atom interferometry for inertial sensing (LUH)



Cassens et al., PRX 15, 011029 (2026)

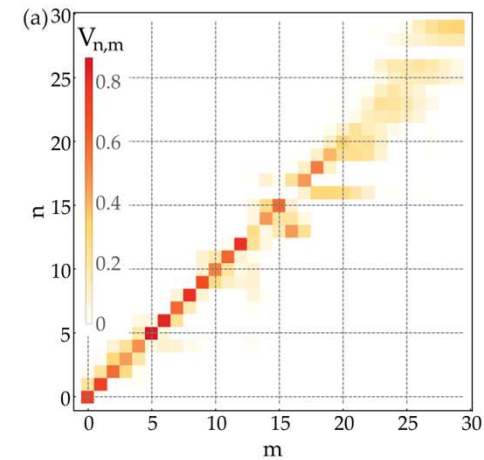
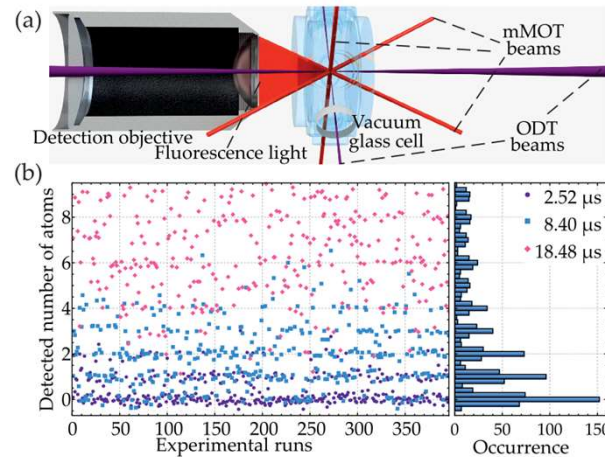
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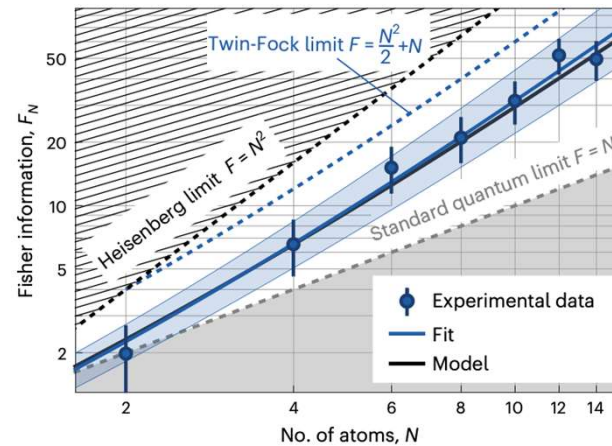
- Atomic detection with single-atom resolution (LUH-CNR)



Hetzel et al.,
Phys. Rev. Lett. 131, 260601
(2023)

HIGHLIGHTS

- Heisenberg scaling of phase sensitivity with neutral atoms (LUH-CNR)

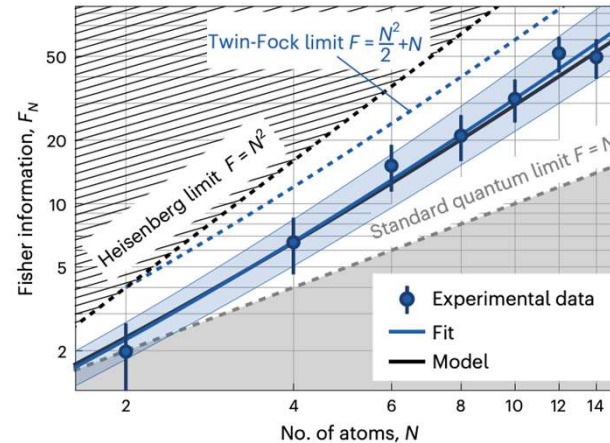


up to 8 dB of entanglement-enhanced sensitivity

Quensen et al., *Nature Physics* (2026), in press

HIGHLIGHTS

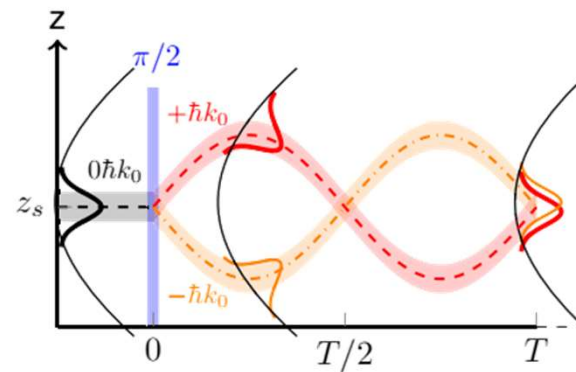
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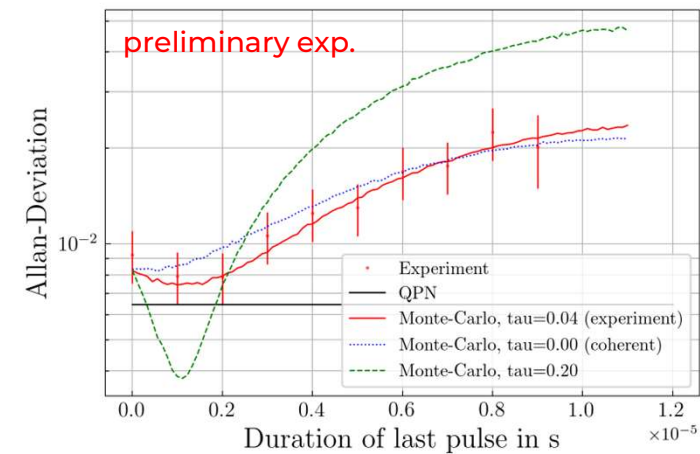
up to 8 dB of entanglement-enhanced sensitivity

Quensen et al., *Nature Physics* (2026), in press

- Validation of delta-kick squeezing (SYRTE) – very recent and not included in the final report

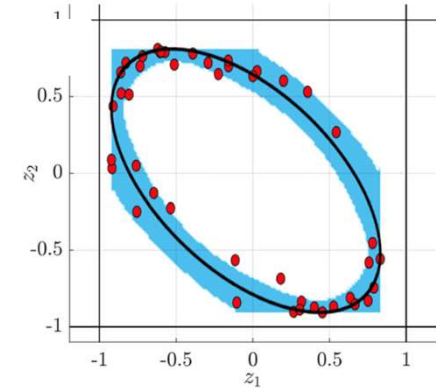
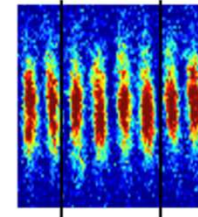
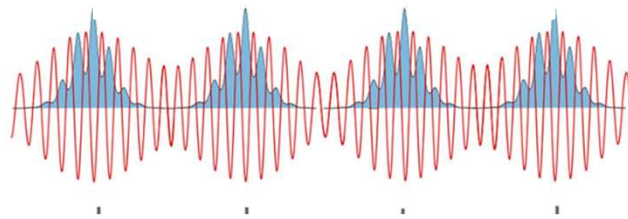


Piest et al., *in preparation*



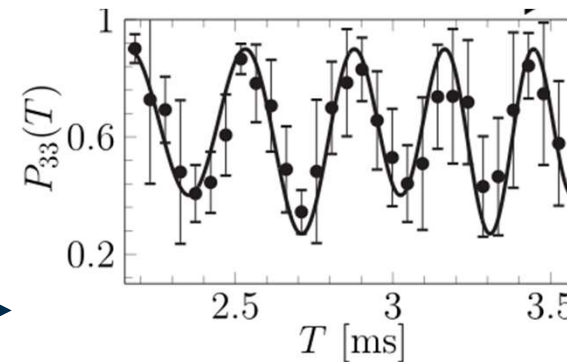
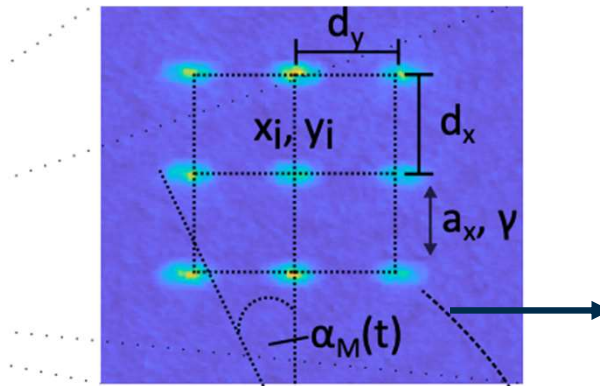
HIGHLIGHTS

- Trapped BEC gradiometer with coupled interferometers that benefits from common-mode noise rejection (CNR)



Petrucciani et al., *Nature Communications* 17, 3948 (2026)

- Multi-axis inertial sensing with a 2D array of BECs (LUH-CNR)

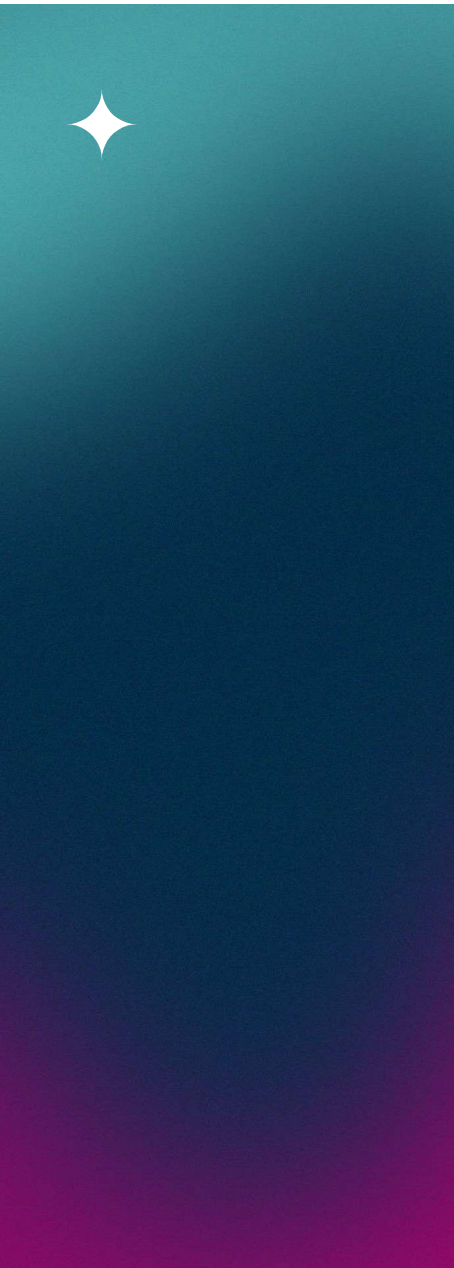


Stolzenberg et al.,
Phys. Rev. Lett. 134, 143601 (2025)

- Free-fall gradiometer with cancellation of systematic effects (INFN)

Salvi et al. *PRL* 131, 103401 (2023)

These results do not yet exploit squeezing, but establish exp. architectures for future differential and multi-axis quantum sensors, including common-mode noise rejection and long coherence times



Several theoretical studies and collaborations

- Optimal generation of spin-squeezing and Bell correlations in a double-well potential (UW)

[Płodzień et al. PRL 129, 250402 \(2022\); PRR 6, 023050 \(2024\)](#)

- Entanglement generation in an optical cavity (INFN-CNR)

[Sharma et al., PRR 7, L012038 \(2025\); Trifa et al., arXiv:2608.27132](#)

- Impact and optimization of momentum width in Bragg interferometry (LUH-CNR-SYRTE)

[Günter et al. QUANTUM 10, 2122 \(2026\);](#)

- Improved accuracy and precision in squeezing-enhanced differential measurements (SYRTE-CNR-INFN)

[Corgier et al. QUANT. SCI. TECH. 10, 45016 \(2025\);](#)

Cross-fertilization:

- Multiparameter estimation applied to inertial sensing with squeezed states (CNR-SYRTE)

[Corgier et al. QUANTUM 7, 965 \(2023\); Malitesta et al. PRA 108, 032601 \(2023\); Pezzè et al., PRL 135, 260805 \(2025\)](#)

- Josephson dynamics in novel trapped systems: supersolids and ring Fermi superfluids (CNR-SYRTE-UW)

[Biagioni et al. NATURE 629, 773 \(2024\); Pezzè et al. NAT. COMM. 15, 4831 \(2024\); Nesti et al. arXiv:2607.08345](#)

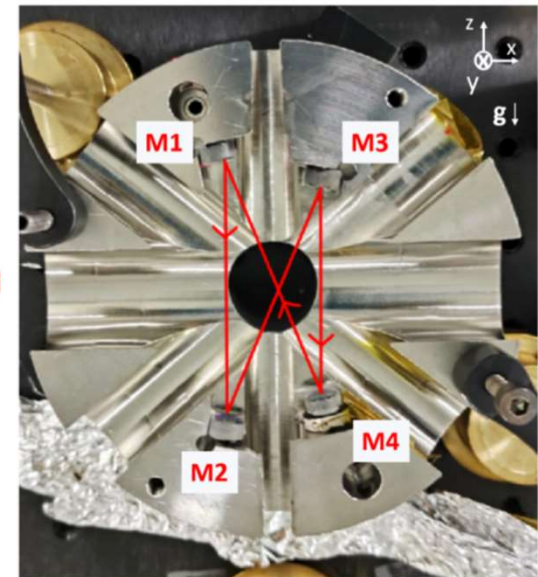
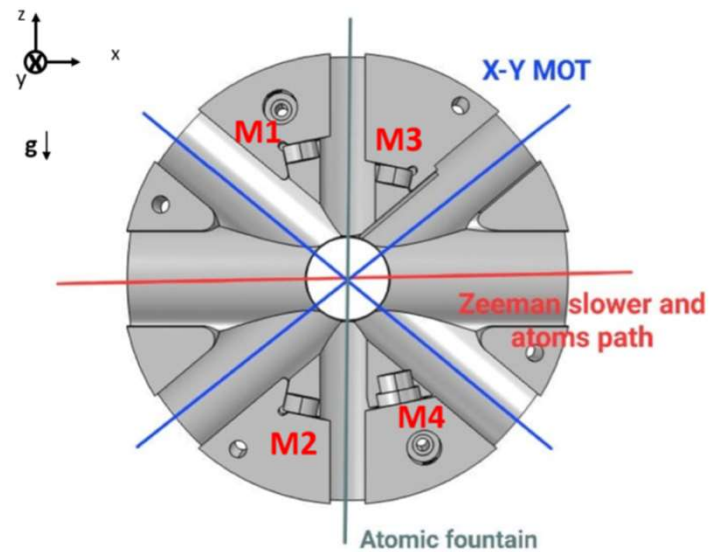


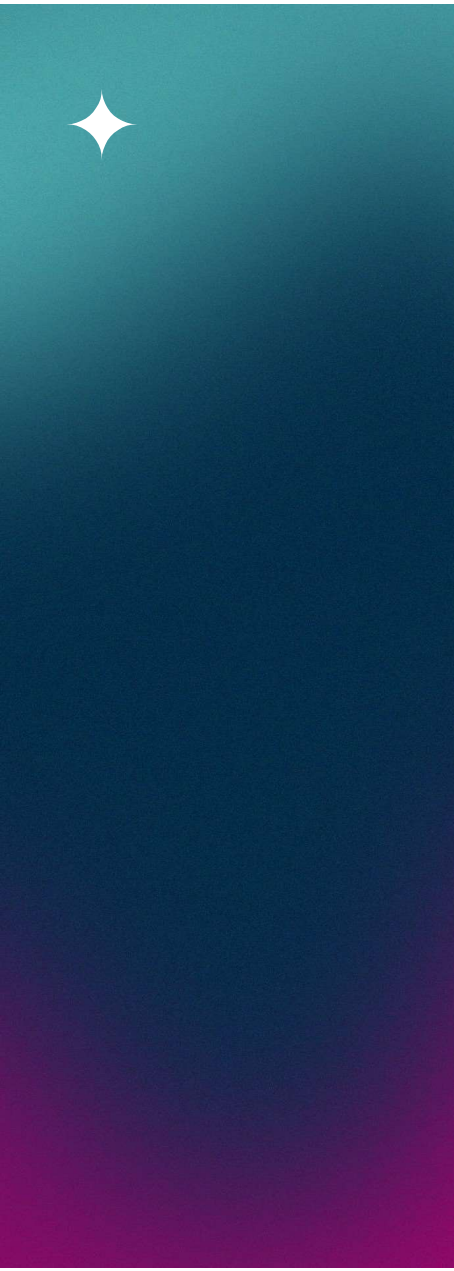
HURDLES

INFN

Problem: Vibrational noise and difficulties in stabilization prevented the realization of cavity squeezing (INFN)

Solution: A new monolithic cavity - with high rigidity, high thermal control and low thermal expansion – has been designed: it is currently implemented on the device (expect squeezing within 1 year)





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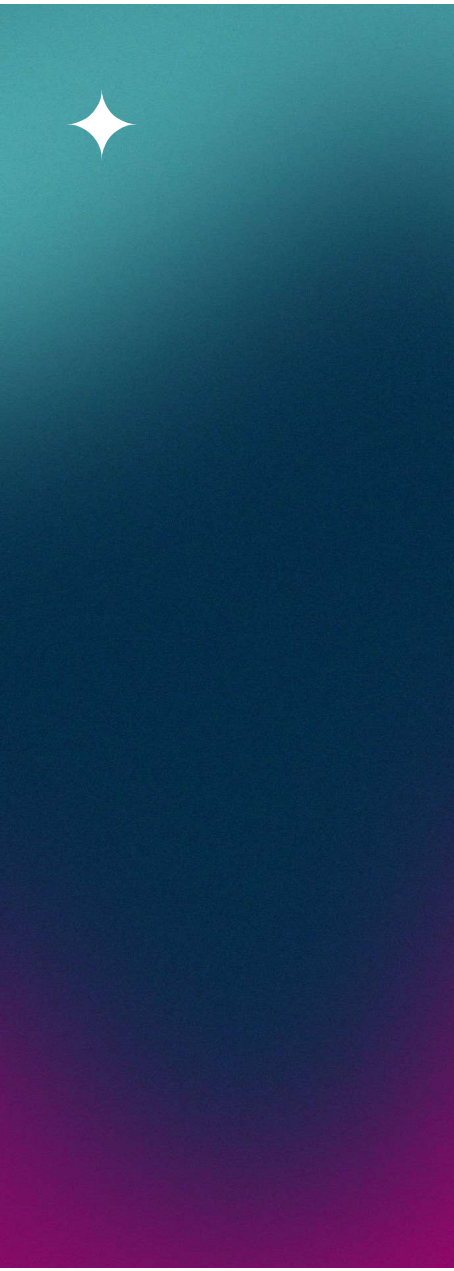
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CNR

Problem: Magnetic field noise prevents the demonstration of squeezing in the trapped BEC interferometer. General delay due to various experimental elements

Solution: use magnetically-insensitive dressed states where it is still possible to tune the interaction: under study (expect squeezing within 2-3 year)





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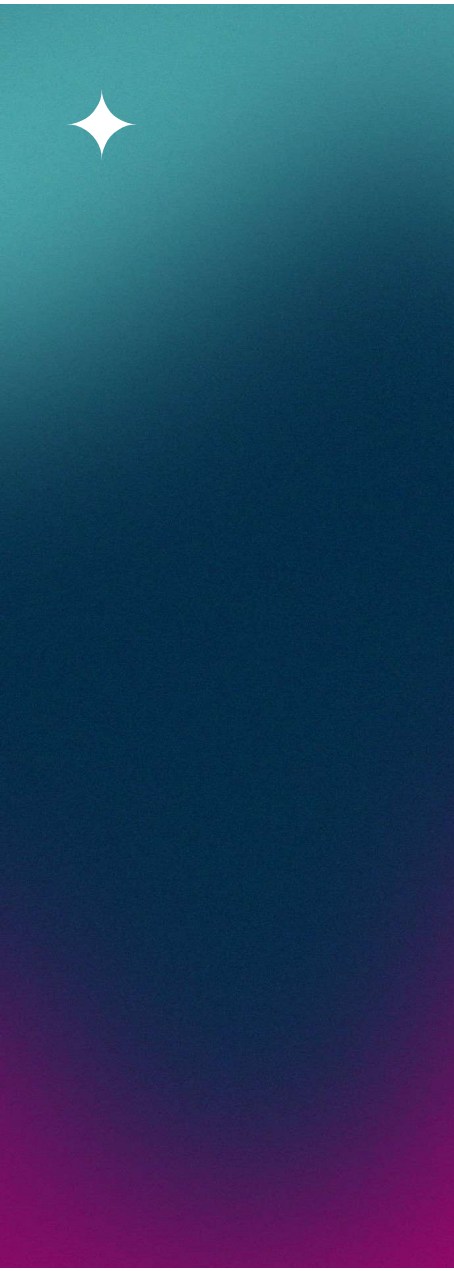
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SYRTE

Problem: Mirror vibrations, the large atom number, and atomic losses have so far prevented the demonstration of squeezing-enhanced sensitivity

Solution: The effects of delta-kick squeezing have been observed, although the sensitivity remains above the SQL. Squeezing already improves the sensitivity of the classical sensor (squeezing enhanced interferometry expected within 6 months)





HURDLES



INFN	Problem: Vibrational noise and difficulties in stabilization prevented the realization of cavity squeezing (INFN) Solution: A new monolithic cavity - with high rigidity, high thermal control and low thermal expansion – has been designed: it is currently implemented on the device (expect squeezing within 1 year)
CNR	Problem: Magnetic field noise prevents the demonstration of squeezing in the trapped BEC interferometer. General delay due to various experimental elements Solution: use magnetically-insensitive dressed states where it is still possible to tune the interaction: under study (expect squeezing within 2-3 year)
SYRTE	Problem: Mirror vibrations, the large atom number, and atomic losses have so far prevented the demonstration of squeezing-enhanced sensitivity Solution: The effects of delta-kick squeezing have been observed, although the sensitivity remains above the SQL. Squeezing already improves the sensitivity of the classical sensor (squeezing enhanced interferometry expected within 6 months)
LUH	The K-39 apparatus, including the atomic source and upgraded detection system, was delayed by technical issues with laser sources and laboratory infrastructure. As a result, validation of all-optical delta-kick squeezing could not be completed within the project duration (success of delta-kick at SYRTE will help progress: expect squeezing within 2-3 years)





IMPACT



TRAINING AND EDUCATION:

10 fellowships/contracts have been created within SQUEIS:
2 were awarded to women (20%); 2 were awarded to researchers from widening countries (Poland, Albania) (20%); 4 to extra-european researchers (40%)



OPEN SCIENCE:

about 40 research papers acknowledge SQUEIS:
1 Nature; 1 Nature Communications; 1 Nature Physics; 1 PRX; 6 PRL; 2 Quantum; 8 PRA/PRR

all publications and preprints are openly available (arXiv)
Experimental data are available upon request to the corresponding authors
For some experiments a publicly available GitHub repository has been created

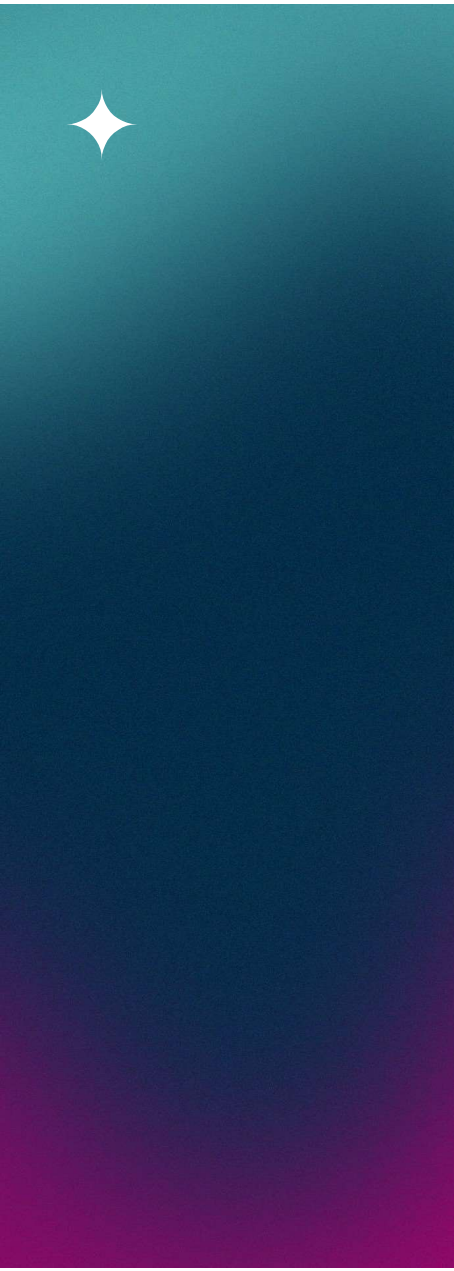


PUBLIC ENGAGEMENT:

more than 100 public presentations/posters acknowledge SQUEIS
(national/international conferences; workshops; seminars)

more than 24 hours of lectures at various PhD Schools (FOMO, Les Houches, Shanxi University, etc.)





IMPACT



COOPERATION:

- the consortium continues with QuantEra project INTEGRA: focused on trapped interferometry, with squeezing included in the work plan
- other projects submitted with an enlarged consortium: focusing on squeezing for distributed sensing with atomic quantum networks

new submissions include collaboration with industrial partners, EXAIL in particular, focusing on data analysis in noisy environments and squeezing

- cooperation with PASQuanS2.1 – quantum flagship project on quantum simulation: some of the methods developed in SQUEIS can be applied to parameter estimation and noise benchmarking in quantum simulators





Co-funded by
the European Union