



# ECT\*



EUROPEAN CENTRE FOR THEORETICAL STUDIES  
IN NUCLEAR PHYSICS AND RELATED AREAS  
TRENTO, ITALY  
Institutional Member of the INF Expert Committee NuPECC

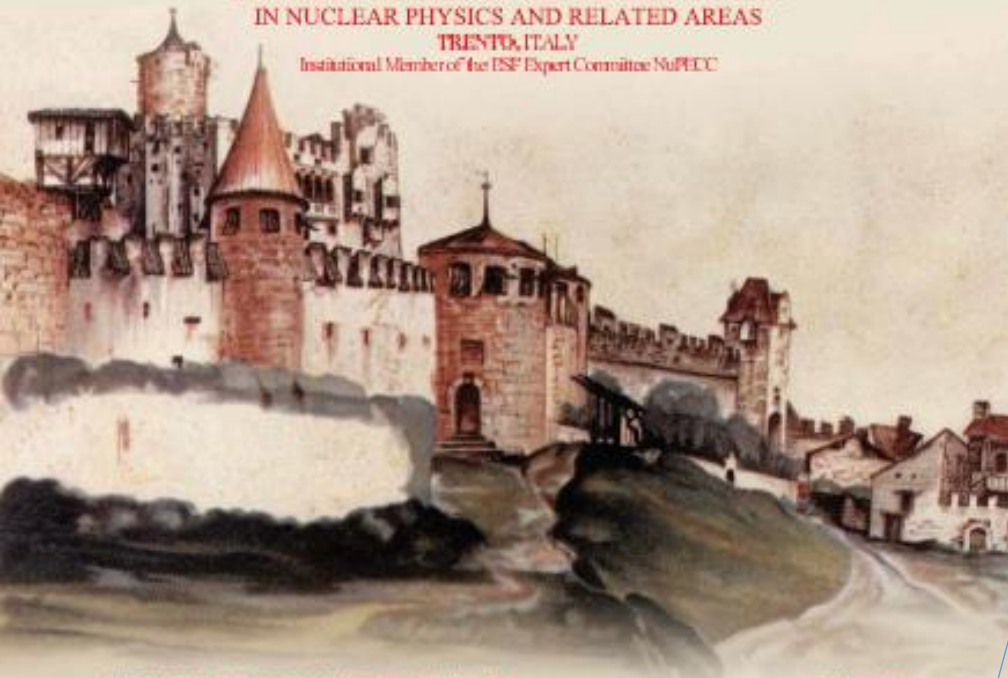


Illustration: T. Dal'oz, 1977. Original: G. De Dominicis, 1977. (www.ict.it)

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## COLD ATOMS MEET HIGH ENERGY PHYSICS

Trento, June 22-25, 2015

### Main Topics

Spontaneously broken symmetries, abelian and non abelian gauge fields, supersymmetries, Fulde-Ferrel-Larchin-Ochinokov phase, Superfluidity in strongly interacting Fermi systems, High density QCD and bosonic superfluidity, quantum hydrodynamics, Kibble-Zurek mechanism, SU(N) configurations, quantum simulation of quark confinement, magnetic monopoles, Majorana Fermions, role of extra dimensions, lattice QCD, Black holes, Hawking radiation, Higgs excitations in cold atoms, AdS/CFT correspondence, Efimov states, instantons

### Key Participants

Roberto Ballarín (Bologna), Michael Banerjee (Bonn), Andrea Cappelli (Firenze), Jacopo Caronni (Trento), Roberto Casalbanzi (Firenze), Leonardo De Luca (Pisa), Francesca Ferioli (Bonn), Gabriela Ferrari (Trento), Margueta Garcia Parra (Madrid), Jason Ho (Columbia, Ohio), Kazuhiko Konishi (Pisa), Manuel Lado (Trento), Simone Montagna (Trento), Mizuo Nitta (Ecole Normale Supérieure), Giorgio Parisi (Roma), Steven Papanicolaou (Paris), Christophe Sabot (CEA Saclay), Augusto Soreti (Firenze), Luca Tagliacozzo (ICTP Trieste), Andrea Tomasetti (SISSA Trieste), Simone Vignani (Pisa), Ezra Zoller (Munich), Peter Zoller (Bonn), Will Zwarg (Trento), Maria Zvereva (MIT)

### Organizers

Maurizio Ingrosso (INFN Trieste and INM Trento), Guido Martinelli (SISSA Trieste), Sandro Strogatz (Trento)

Director of the ECT\*: Professor Wilfried von Eke (ICTP)



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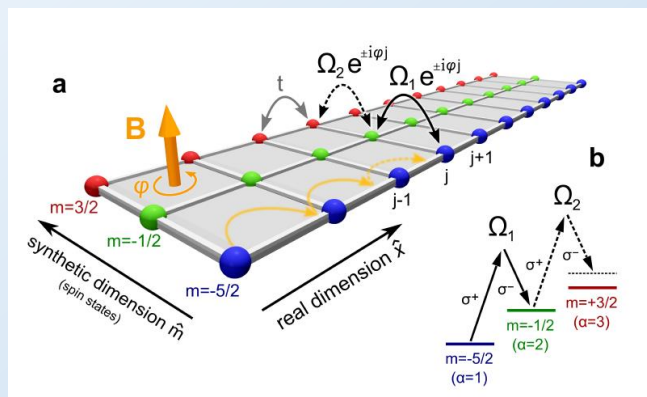
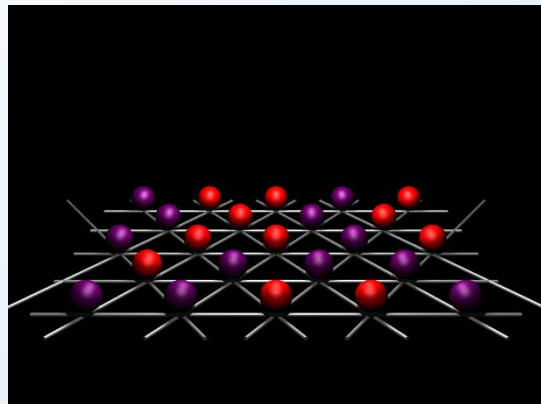
# Main Topics

Spontaneously broken symmetries, abelian and non abelian gauge fields, supersymmetries, Fulde-Ferrel-Larchin-Ochinokov phase, Superfluidity in strongly interacting Fermi systems, High density QCD and bosonic superfluidity, quantum hydrodynamics, Kibble-Zurek mechanism, SU(N) configurations, quantum simulation of quark confinement, magnetic monopoles, Majorana Fermions, role of extra dimensions, lattice QCD, Black holes, Hawking radiation, Higgs excitations in cold atoms, AdS/CFT correspondence, Efimov states, instantons

# Ultracold atoms KEY ABILITY : Controlled manipulation of Quantum Matter

- Atoms of different statistics
- Controlled dimensionality
- Controlled interactions
- Control of Disorder

Various Condensed Matter Models: Hubbard/Heisenberg Hamiltonians, Quantum Spin Liquids, Quantum Magnetism

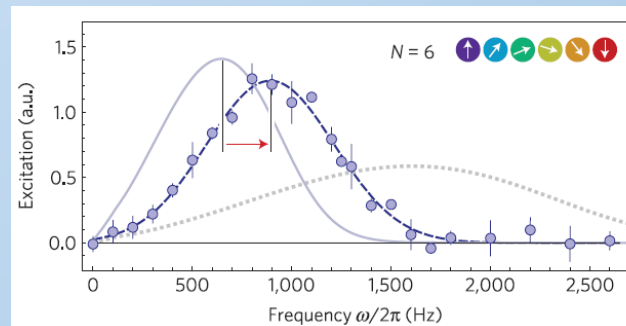


## NOVEL DEVELOPMENT!

EXTRA «synthetic» DIMENSIONS and ARTIFICIAL GAUGE FIELDS on atoms



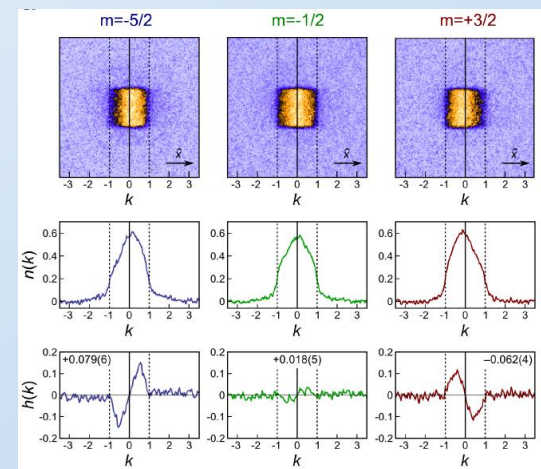
Massimo Inguscio  
Leonardo Fallani  
Giovanni Modugno  
Francesco Minardi  
Giacomo Roati  
Carlo Sias  
Matteo Zaccanti



Luttinger Liquids with Spin >1/2  
Nature Physics 10, 198 (2014)

Observation of  
**CHIRAL EDGE STATES** in atomic  
Hall ribbons

arXiv:1502.02495  
(Submitted to  
Science)



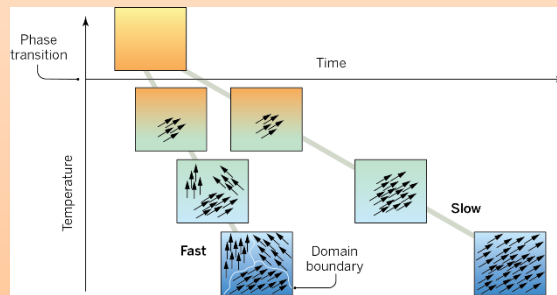
## New Experiments Starting

- 1 & 2D Fermions
- Ions+BEC
- Mass Imbalanced Fermi Mixtures



# Creation and dynamics of Topological defects in BECs

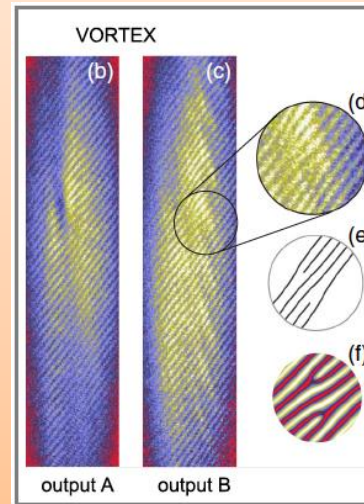
## Production of defects in elongated BECs via the Kibble-Zurek mechanism



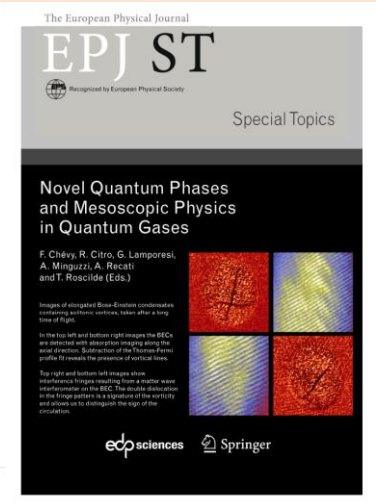
G. Lamporesi *et al.*,  
Nat. Phys. **9**, 656 (2013)

G. Ferrari,  
Science **347**, 6218 (2015)

## Observation of Solitonic Vortices in elongated BECs



S. Donadello *et al.*,  
PRL **113**, 065302 (2014)

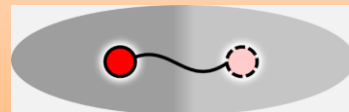


M. Tylutki *et al.*,  
EPJ-ST **224**, 575 (2015)

## Study of defects in spinorial BECs with coherent coupling

Formation of bound *vortex molecules*

Simulation of bound *quark/antiquark pairs*



D. T. Son & M. A. Stephanov,  
PRA **65**, 063621 (2002).



Trento

INO-CNR & Dept. Physics

Exp. Team

Theory Team

G. Ferrari

S. Stringari

G. Lamporesi

F. Dalfovo

S. Donadello

A. Recati

S. Serafini

M. Tylutki

E. Fava

A. Sartori

G. Colzi

F. Larcher

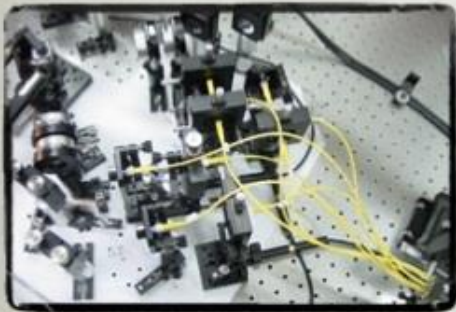




# QUANTUM OPTICS GROUP - SAPIENZA

## QUANTUM SIMULATIONS THROUGH INTEGRATED PHOTONICS

- Test on the foundations of quantum mechanics
- Quantum cryptography and communication
- Quantum interferometry, metrology and sensing
- Quantum simulation

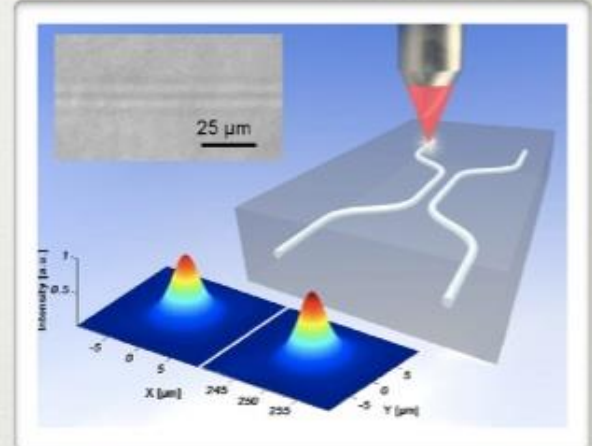


### *Limitations of experiments with bulk optics:*

- Scalability
- Large physical size
- Low stability
- Costs...



**Solution: Integrated  
waveguide technology**



### **Integrated photonic circuits: Laser writing technique**

- Femtosecond pulse tightly focused in a glass
- Waveguides writing by translation of the sample

### ***Simulation and boson sampling***

*Nat. Phot.* 7, 545 (2013)

*Nat. Phot.* 8, 614 (2014)

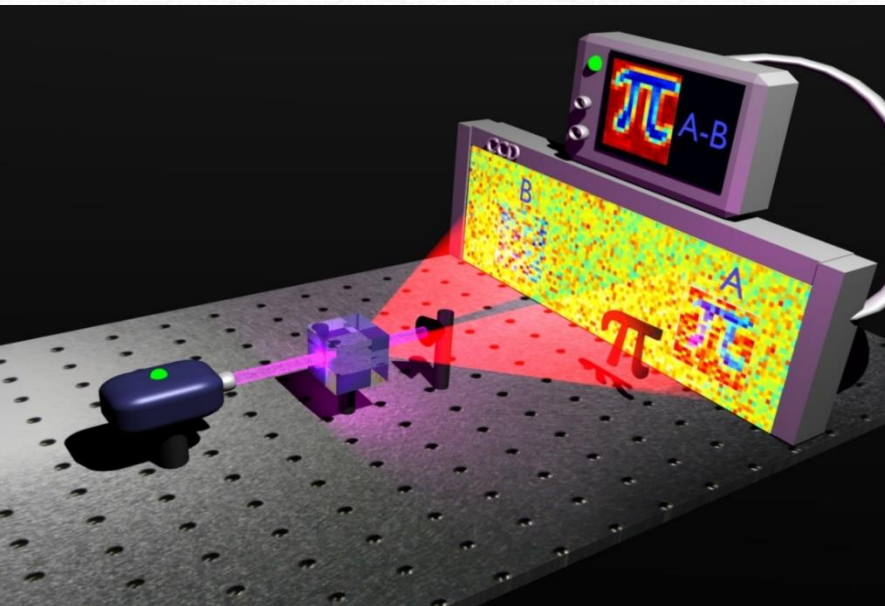
*Nat. Phot.* 7, 322 (2013)

*Nat. Com.* 5, 2549 (2014)





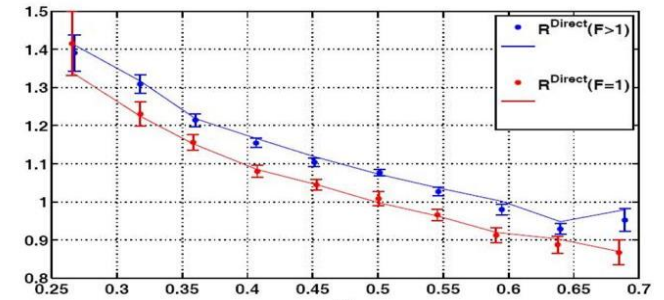
# Quantum sensing with twin beams



## Sub shot noise imaging: imaging an object in a preponderant noise

[G.Brida, M.G., I.Ruo Berchera, Nature Photonics 4 (10) 227

G.Brida, M.G., A.Meda, I.Ruo Berchera. PRA 83 (2011) 033811]

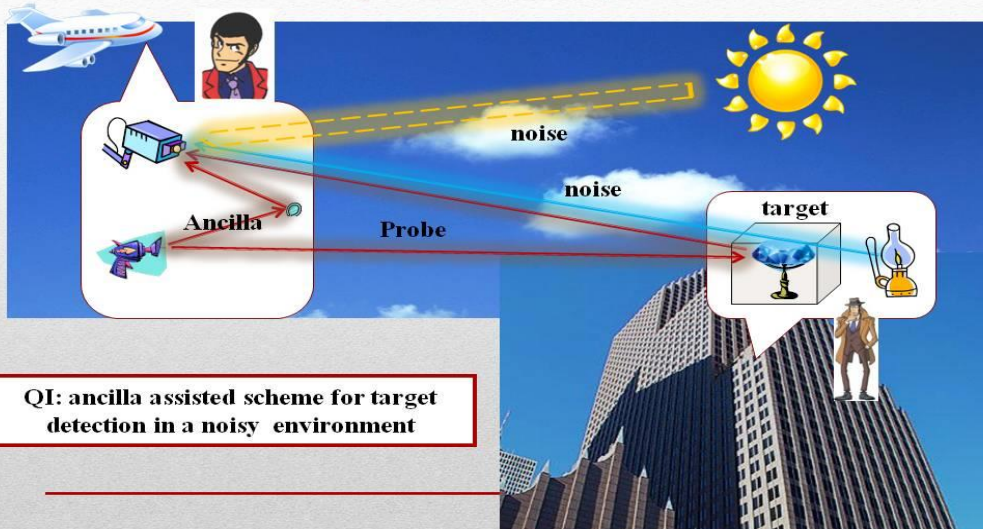


Advantage respect to the classical protocols in terms of

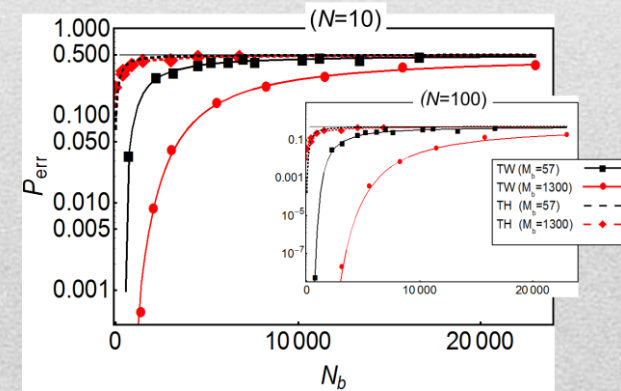


## Quantum Illumination

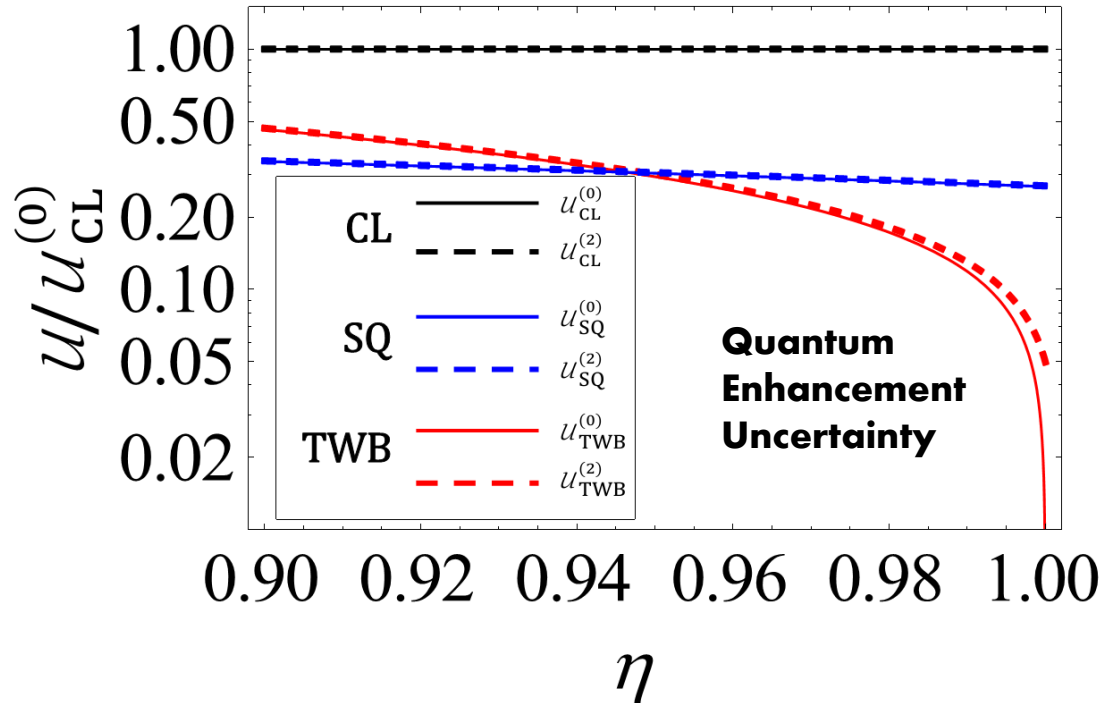
E.Lopaeva, I.Ruo Berchera, I.Degiovanni, S.Olivares, G.Brida, M.Genovese  
Phys. Rev. Lett. 110, 153603 (2013)



QI: ancilla assisted scheme for target detection in a noisy environment



## Ratio of uncertainty for quantum light over classical light



$$\lambda = 0.5$$

$$\mu = 10^{23}$$

$$\text{Meas. time} = 10^{-3} \text{ s}$$

$$\text{Wavelength} = 600 \text{ nm}$$

$$\text{Mirror mass} = 10^2 \text{ Kg}$$

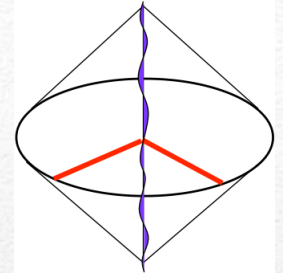
$$> 10^7 \text{ W}$$

- Advantage of quantum light:
- CL: classical light (coherent states)
  - SQ: Squeezed light
  - TWB: Twin Beams

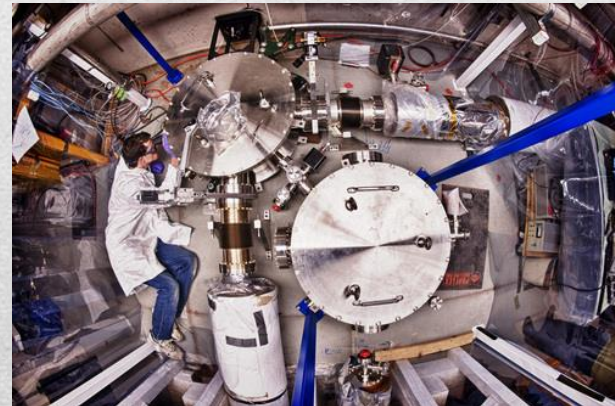




**Holometer** to measure the possible presence of a very slight random wandering of transverse position (the "holographic noise" due to quantum gravity effects) over an extended volume of space-time is currently under construction @ **Fermilab**

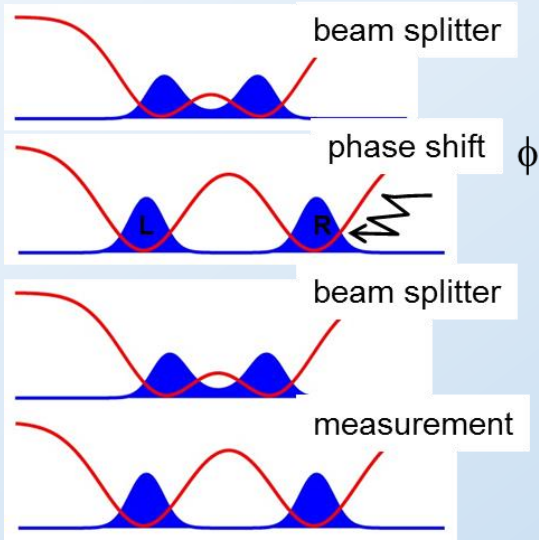


**Holometer @Fermilab:** two coupled ultra-sensitive Michelson interferometers (40 m arms)

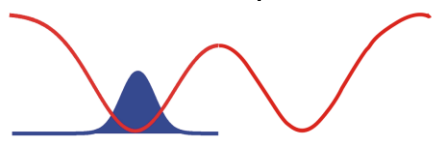


<http://holometer.fnal.gov/>

## Spatial Mach Zender Interferometer

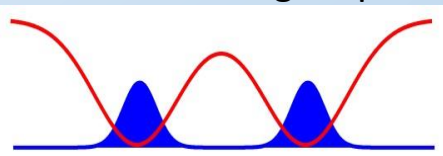


### Uncorrelated particles



$\Delta\phi \sim 1/\sqrt{N}$   
(Shot noise limit)

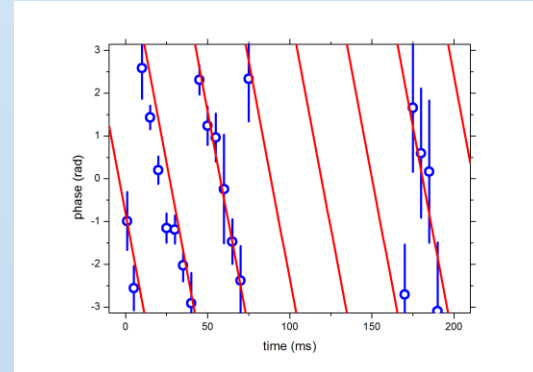
### Quantum entangled particles



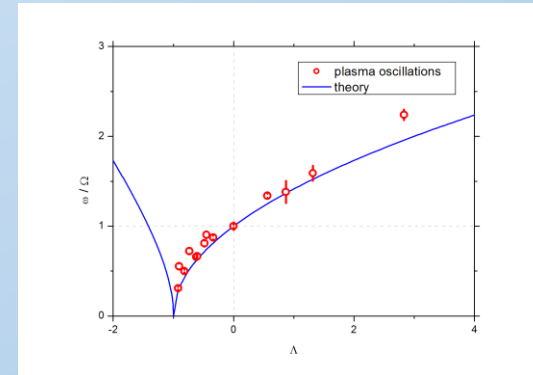
$\Delta\phi \sim 1/N$   
(Heisenberg limit)

## Tunable interatomic scattering length

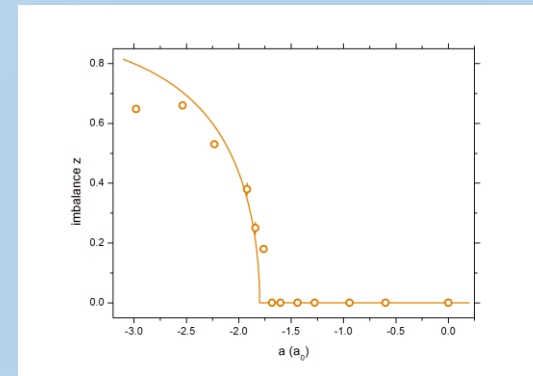
- $a_s = 0$   
Atom interferometry (MICRA)



- $a_s > 0$   
Simulation of a Bosonic Josephson Junction



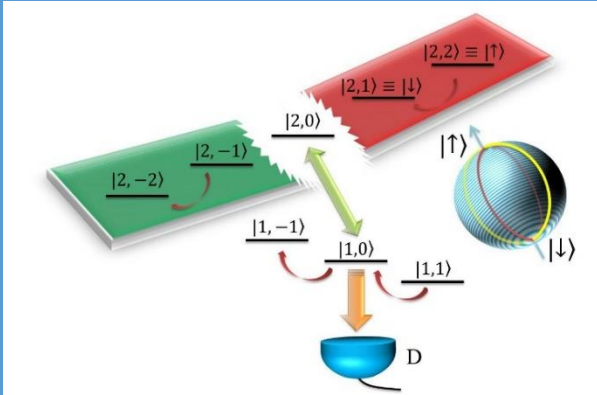
- $a_s < 0$   
Parity Symmetry Breaking QPT (Lipkin Meshkov Glick model)



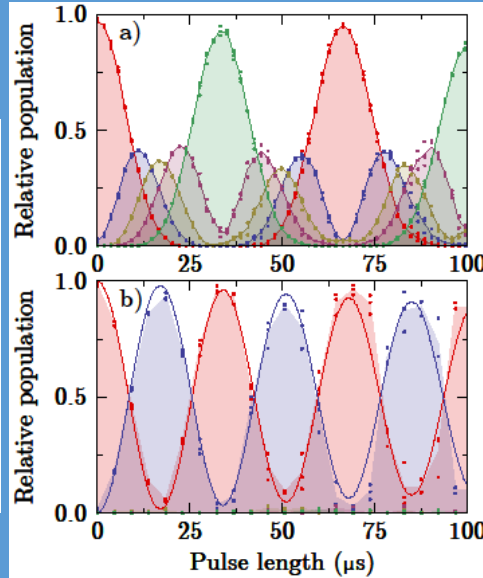


# Further directions

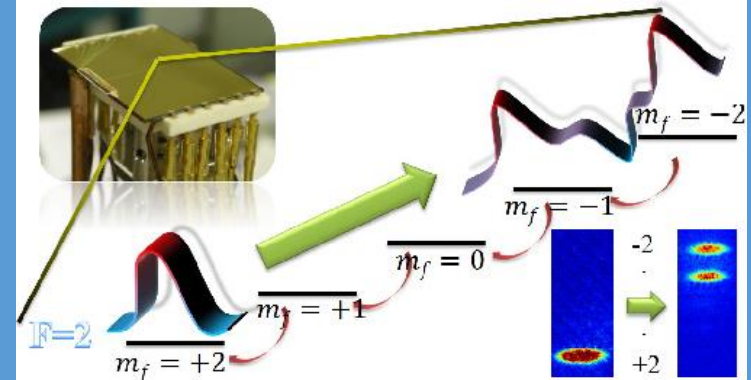
## Quantum Zeno Dynamics



Nat. Commun. 5, 3194 (2014)

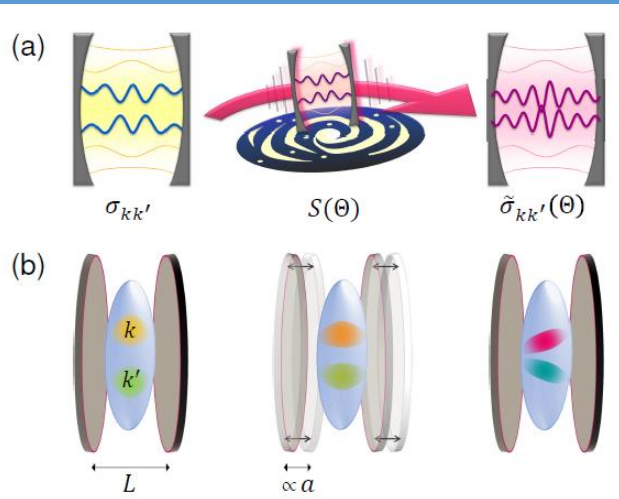


## Quantum Control



arXiv:1405.6918

## Relativistic Quantum Metrology



Sci. Rep. 4, 4996 (2014)

## Dynamical Casimir and Tailored Short Range forces



Rev. Mod. Phys. 84, 1 (2012)

