

# Quantum-enhanced BEC interferometry

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*Team: Atom Interferometry & Inertial Sensors*

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Systeme de Références Temps-Espace

Observatoire de Paris - PSL

Sorbonne Université

Laboratoire National de Métrologie et d'Essais

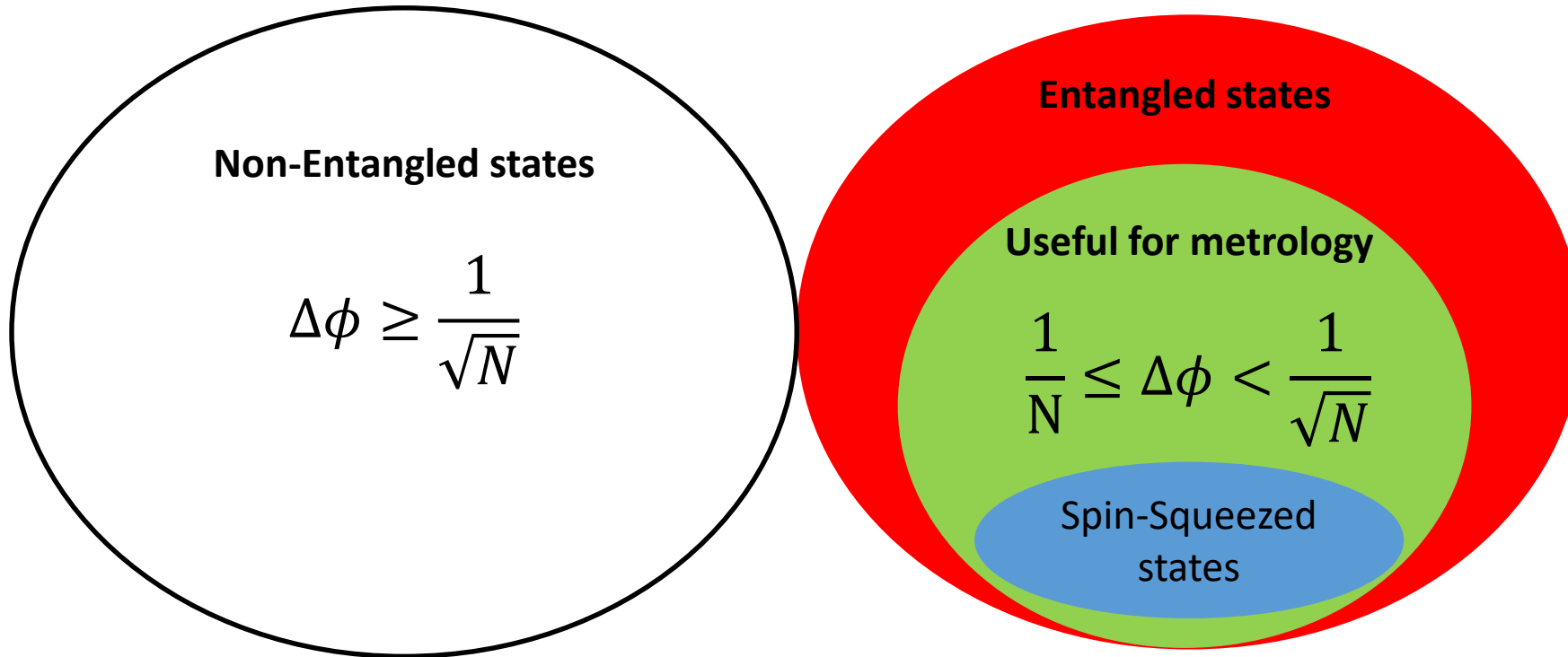
CNRS



Systèmes de Référence Temps-Espace



2nd Terrestrial Very-Long-Baseline Atom Interferometry Workshop



1) **Delta-kick Squeezing**

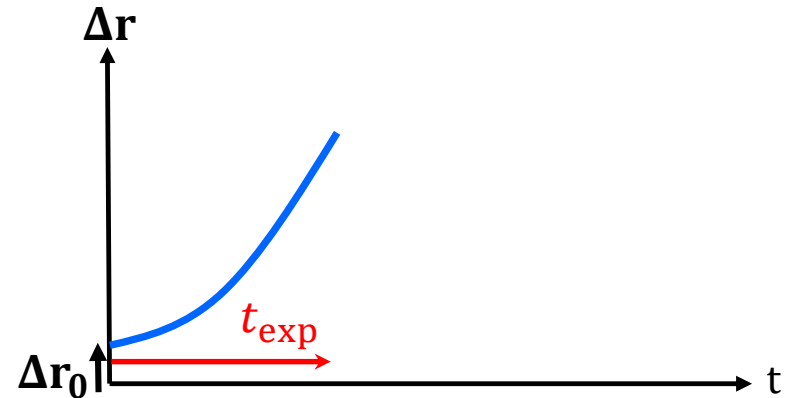
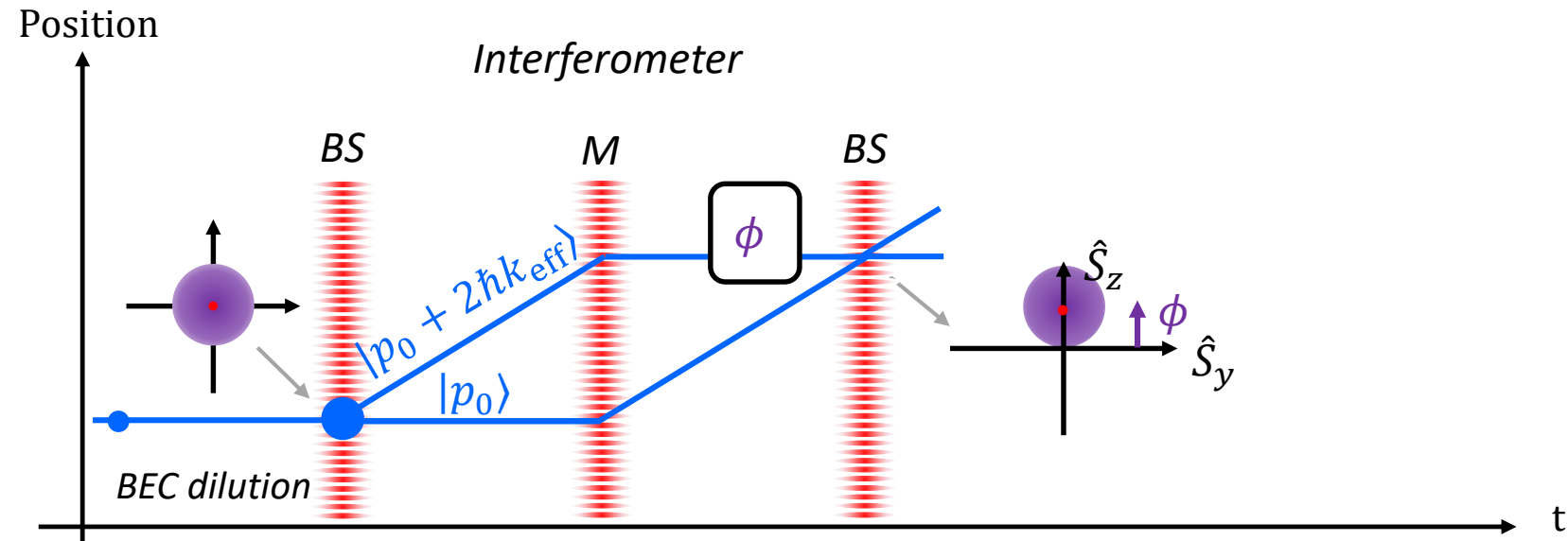
[R. Corgier, N. Gaaloul, A. Smerzi and L. Pezzè](#), PRL **127**, 183401 (2021).

2) **Quantum-enhanced differential measurements**

[R. Corgier, M. Malitesta, A. Smerzi and L. Pezzè](#), Quantum **7**, 965 (2023).

# BEC Interferometry with non-entangled state

## ➤ Typical sequence

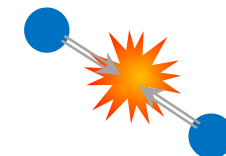


# BEC enables spin-squeezing dynamics

- Bose-Einstein Condensate

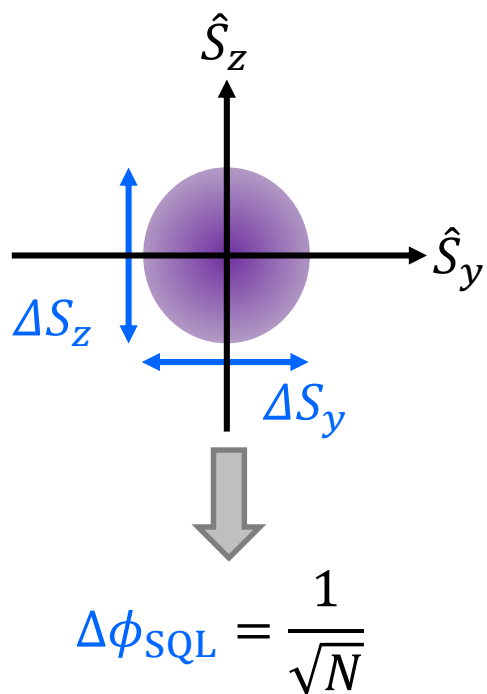
$$\hat{H}(t) = \hat{H}_0(t) + \hbar\chi(t) \hat{S}_z^2$$

Non-linear Interaction term  
 $\propto$  Density of the BEC



- One Axis Twisting Dynamic

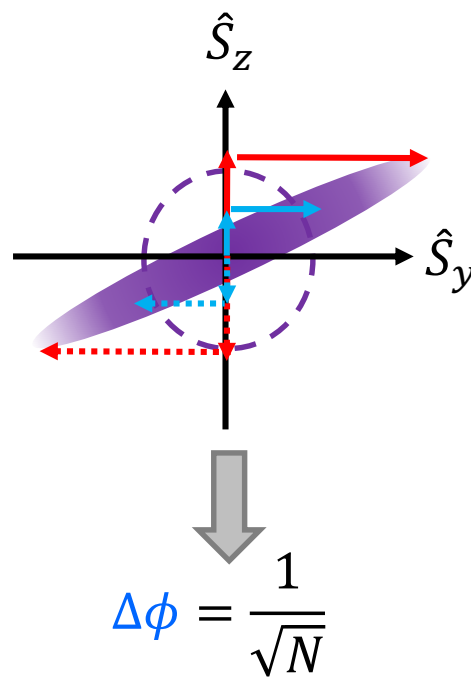
1) Coherent state



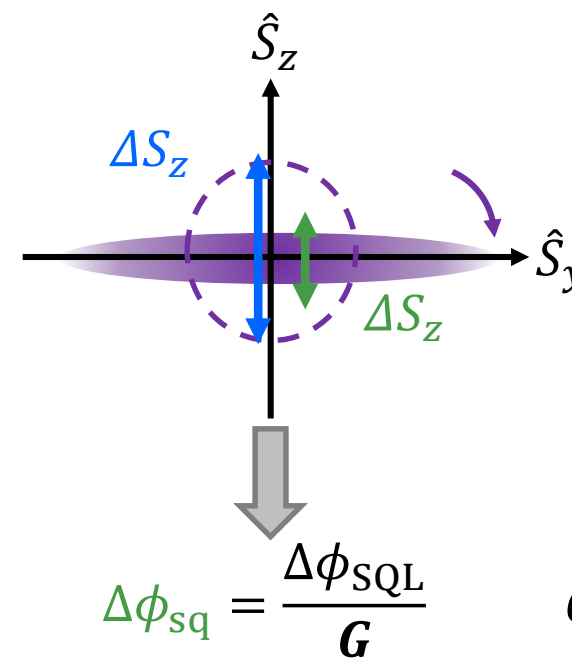
$\hat{H}_{\text{int}} \propto \hat{S}_z^2$

« Rotation around  $S_z$  with strength  $\propto S_z$  »

2) Deformation of the quadrature



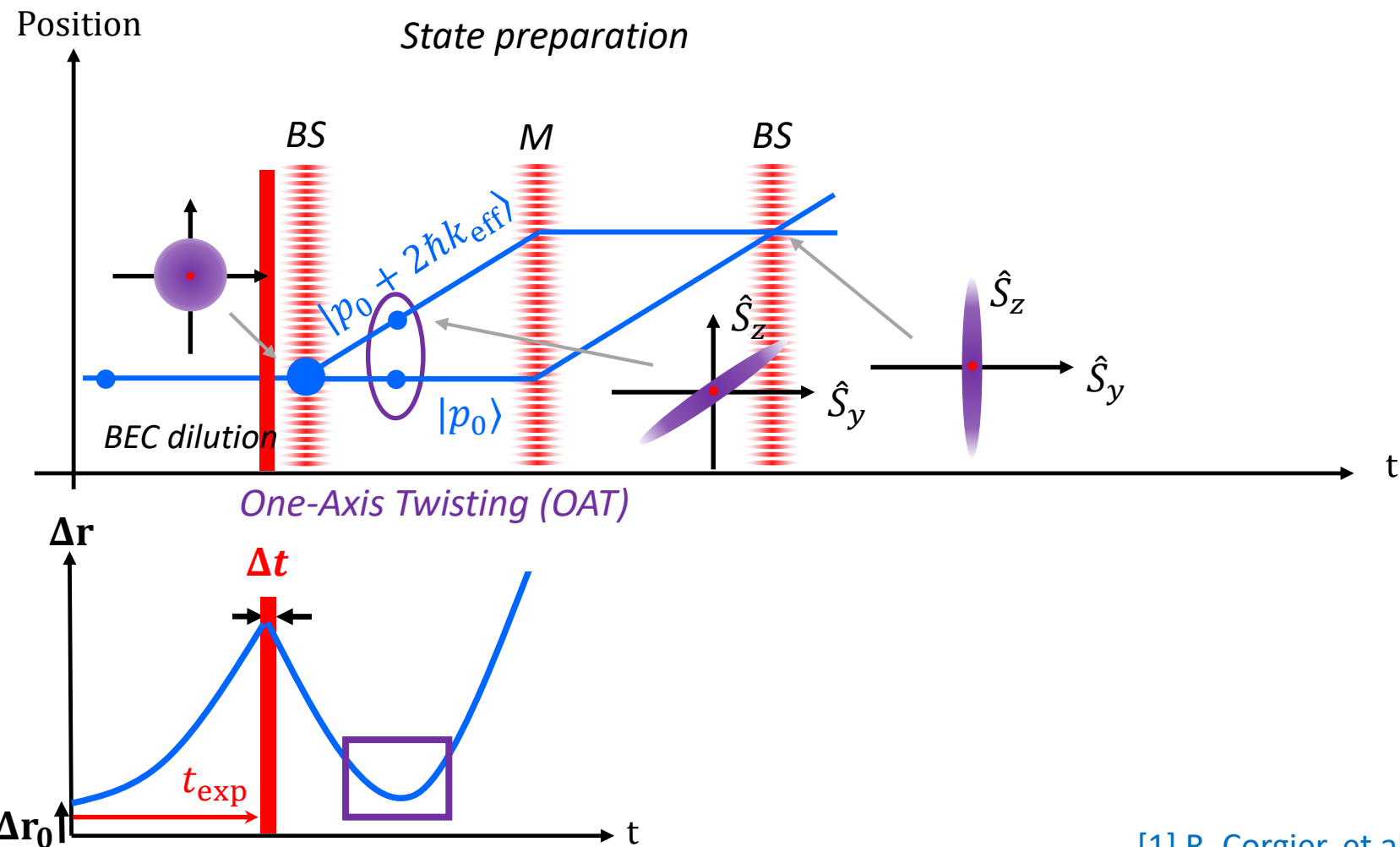
3) Squeezed state optimized for  $\hat{S}_z$



$$G \propto \frac{\Delta S_z}{\Delta S_{\text{sq}}} > 1$$

# BEC Interferometry with spin-squeezed state

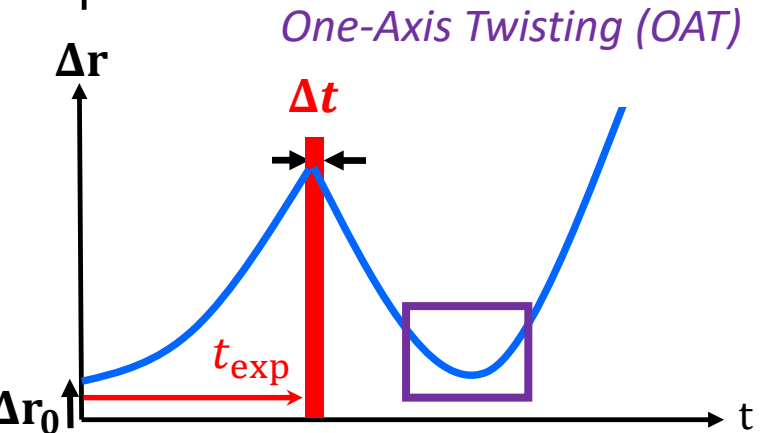
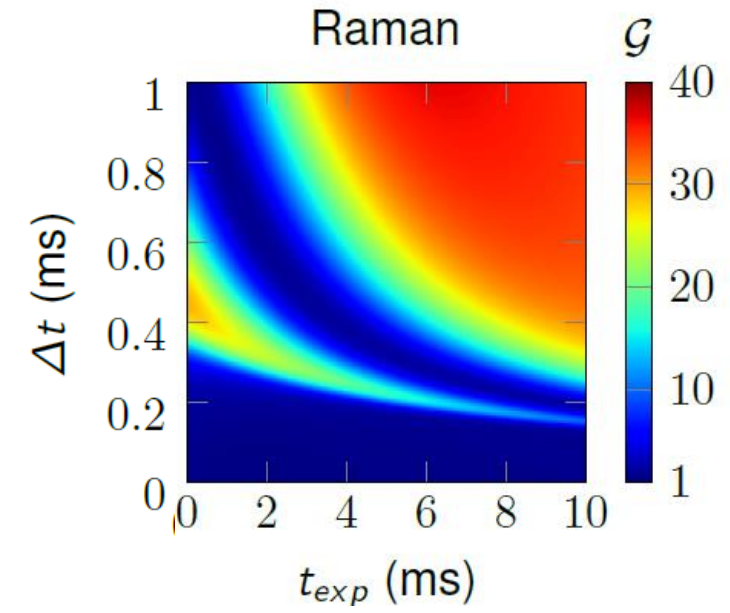
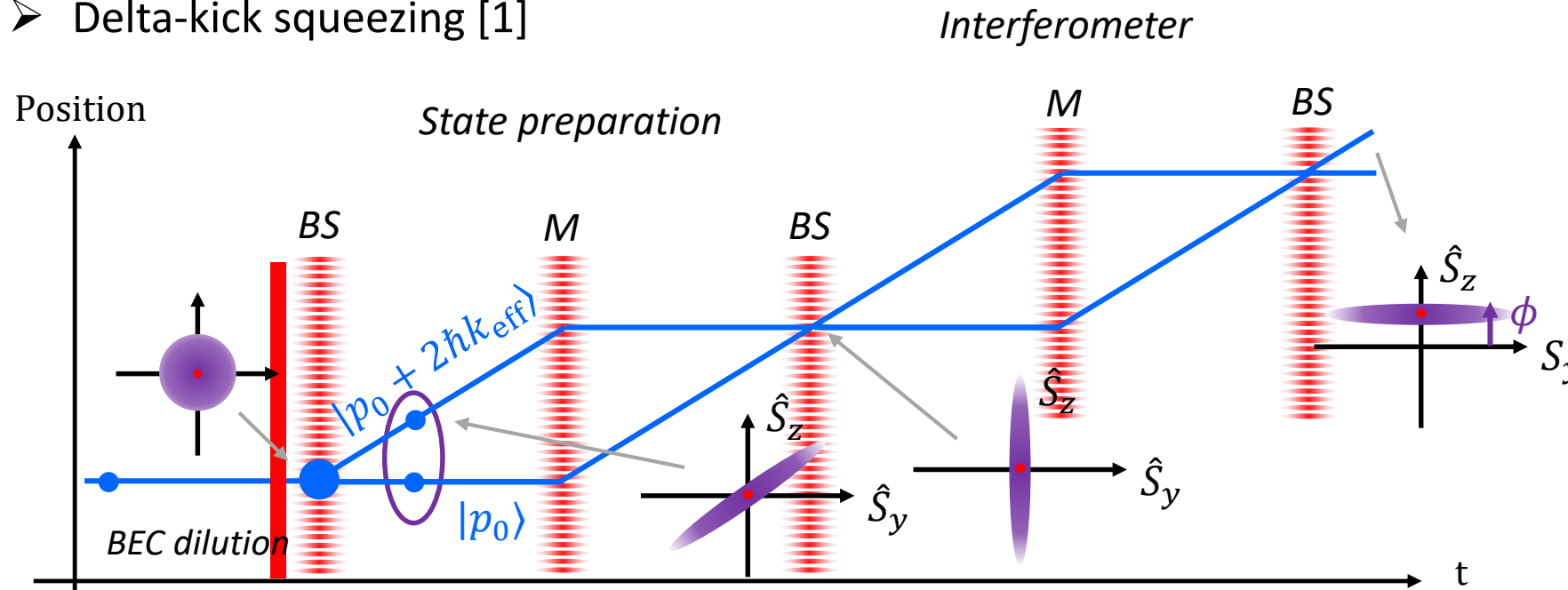
## ➤ Delta-kick squeezing [1]



[1] R. Corgier, et al., *Delta-kick Squeezing*, PRL **127**, 183401 (2021).

# BEC Interferometry with spin-squeezed state

## ➤ Delta-kick squeezing [1]



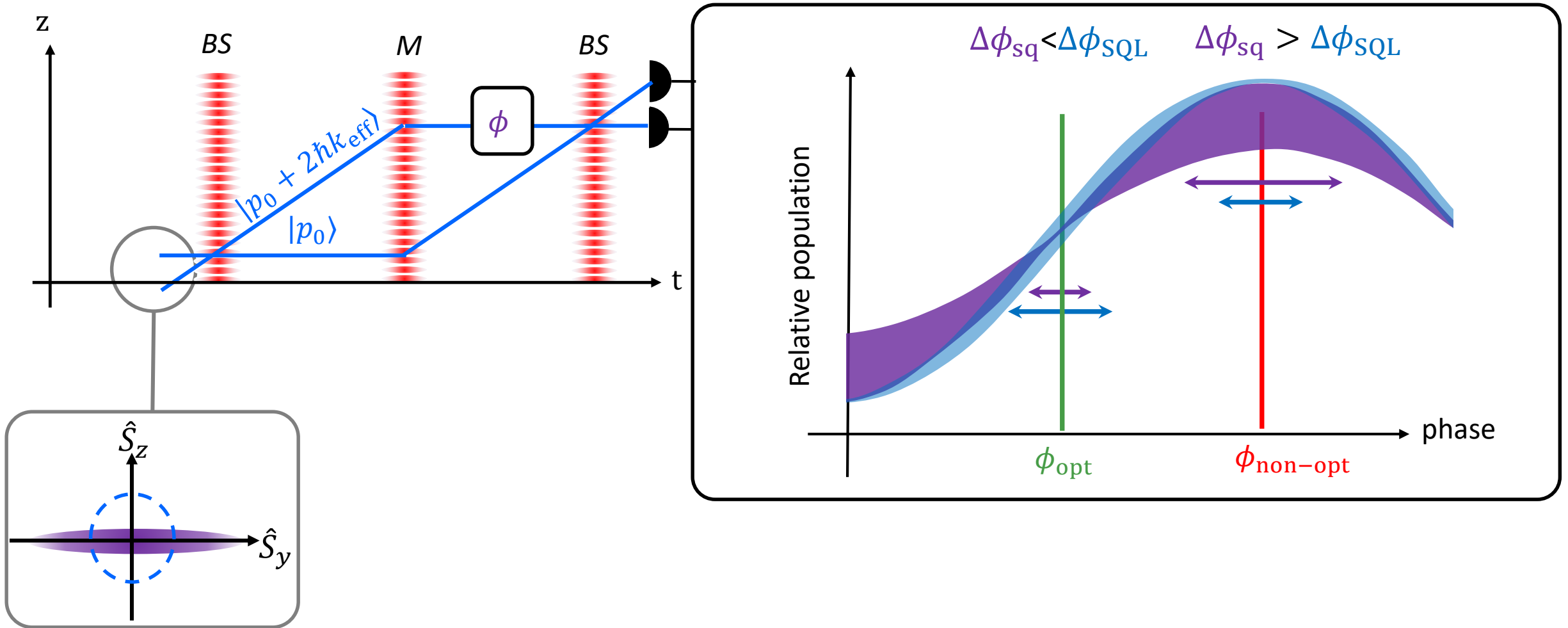
## ➤ Advantages:

- Non-Interacting ensemble during atom-light coupling
- Avoid Shape deformation

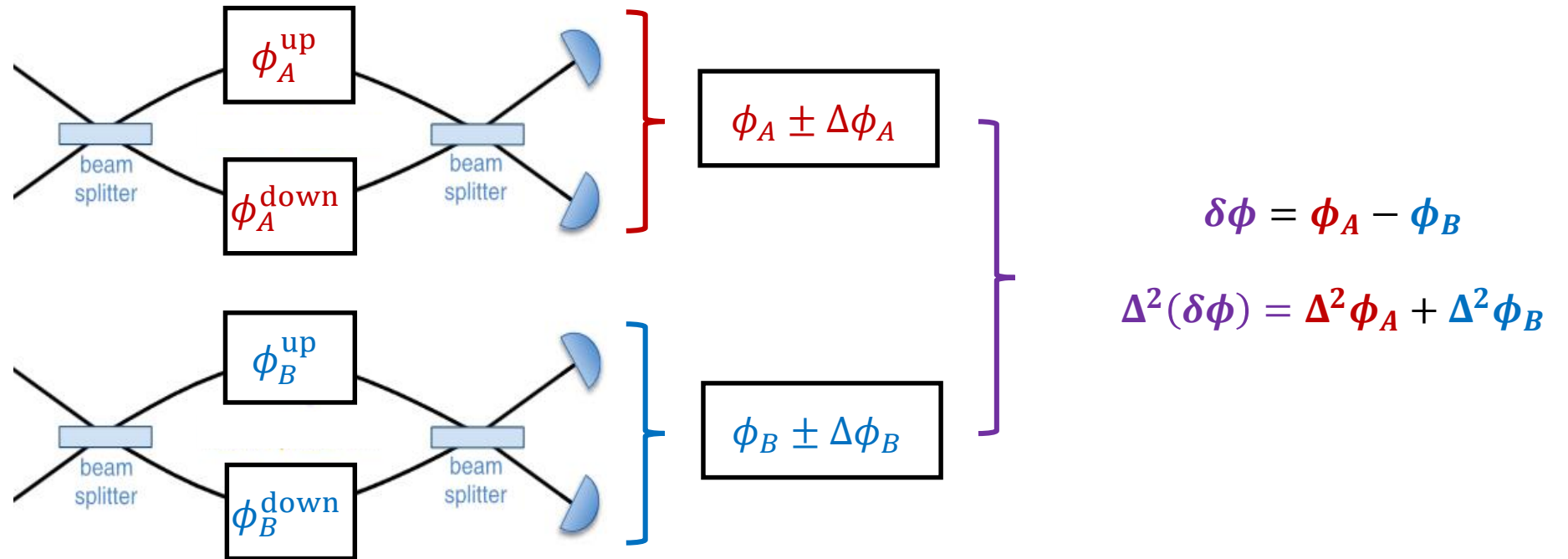
➤ Implementation to a real experiment  
@ SYRTE - Group of F. Pereira Dos Santos

[1] R. Corgier, et al., *Delta-kick Squeezing*, PRL **127**, 183401 (2021).

# Challenge of Quantum-Enhanced Inertial Sensors

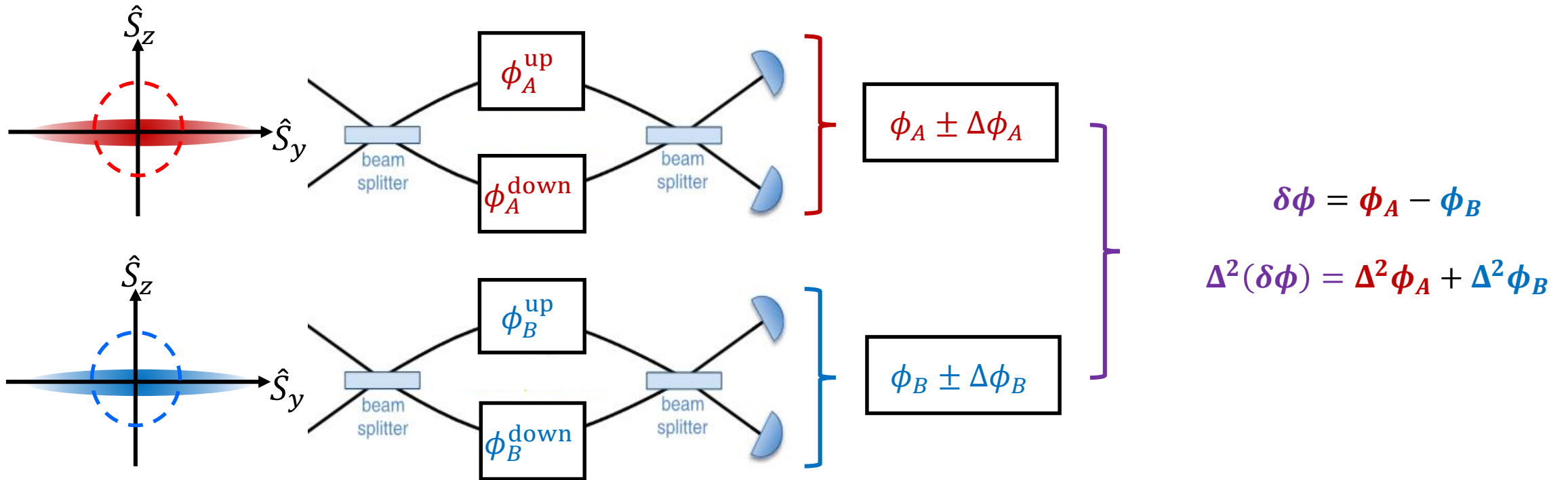


## Part 2: Quantum-enhanced differential measurements





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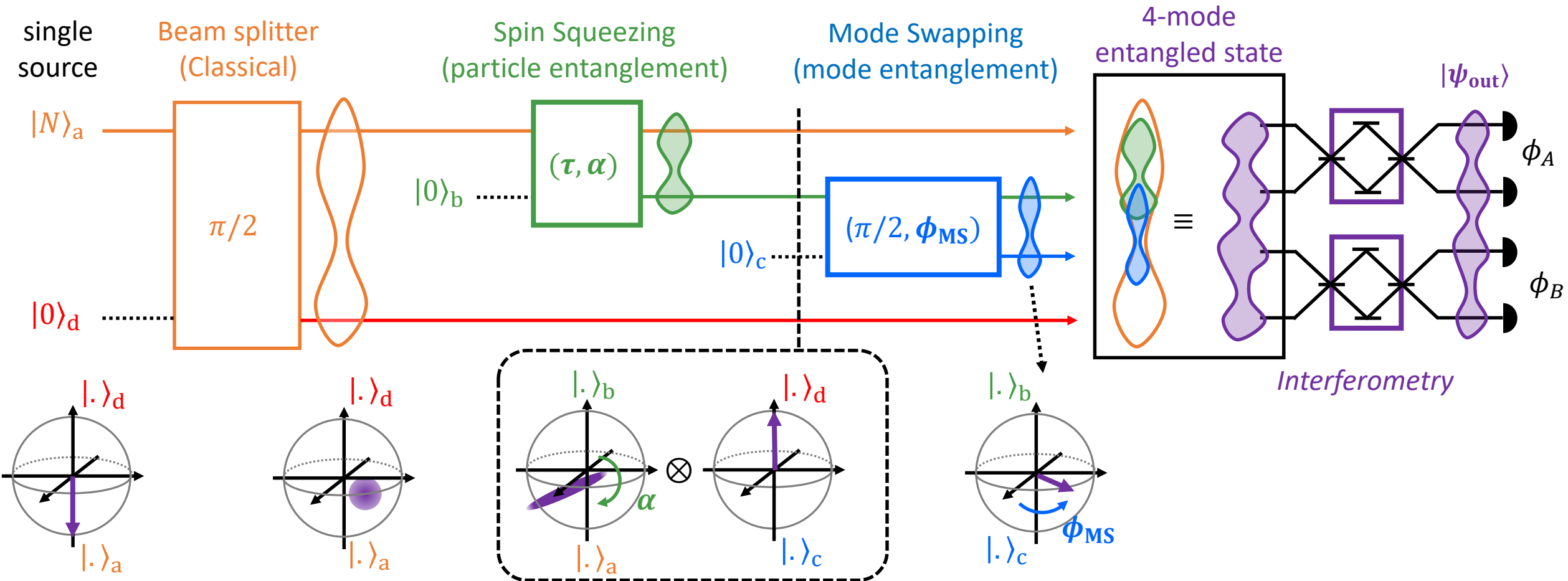


Question: Can we do the same with only 1 spin-squeezed state ?

[R. Corgier, M. Malitesta, A. Smerzi and L. Pezzè, Quantum 7, 965 \(2023\).](#)

# Spin-squeezing & Mode Swapping

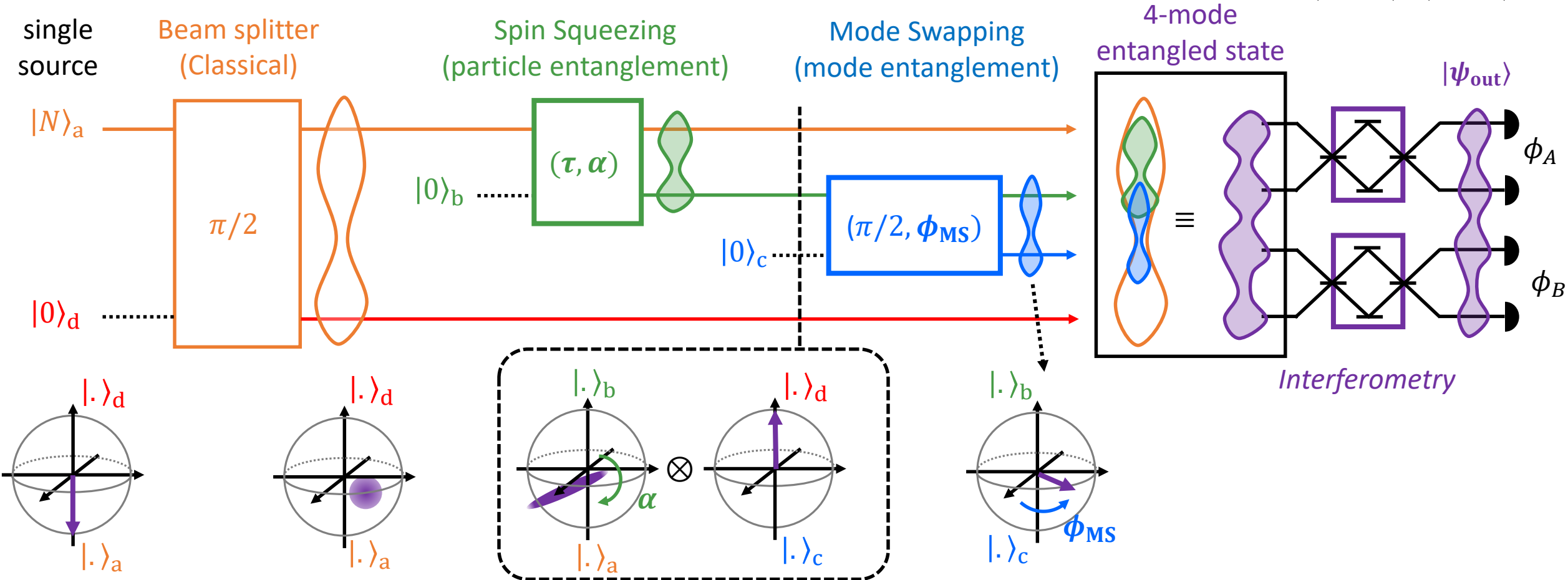
- Generating a 4-mode entangled state



# Spin-squeezing & Mode Swapping

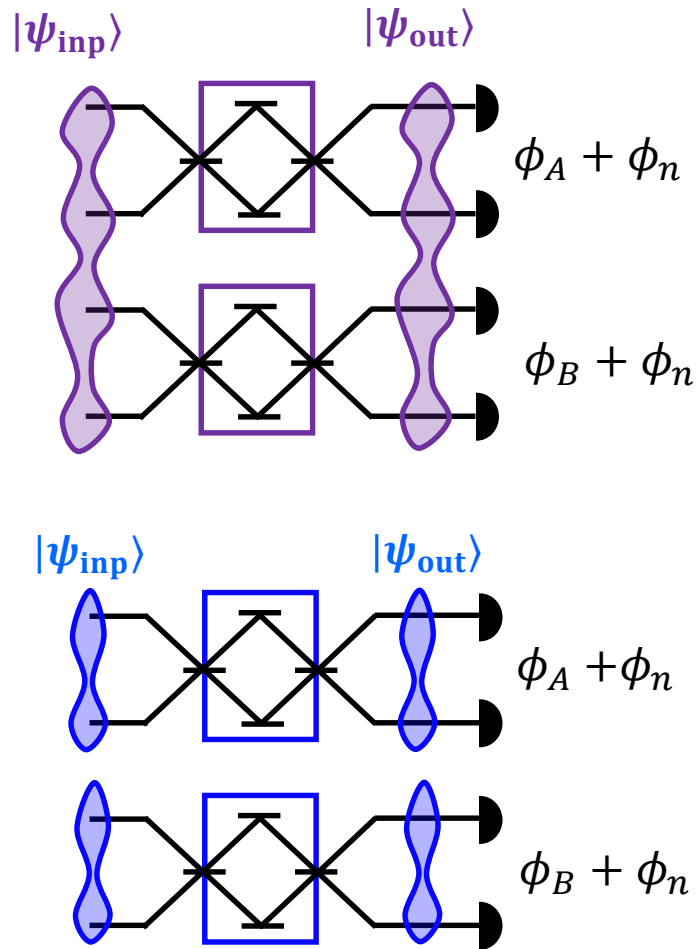
➤ Generating a 4-mode entangled state

$$\Delta^2(\phi_A - \phi_B) = \Delta^2\phi_A + \Delta^2\phi_B - \frac{2\Gamma_{AB}(\alpha, \phi_{MS})}{\left(\frac{\partial\langle\hat{S}_Z^A\rangle}{\partial\phi_A}\right)\left(\frac{\partial\langle\hat{S}_Z^B\rangle}{\partial\phi_B}\right)}$$



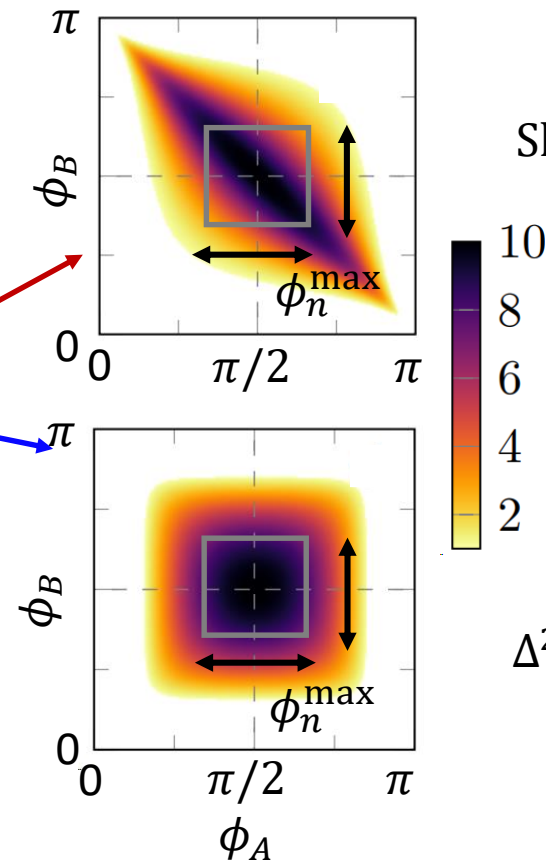
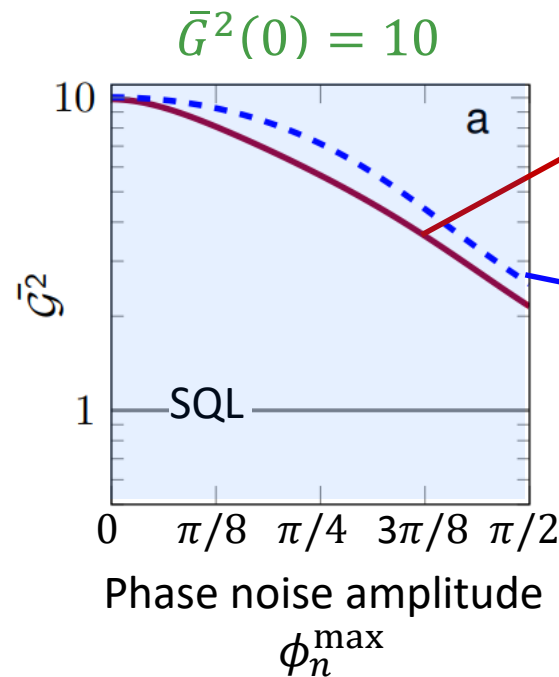
# 4-mode vs 2x2-mode entangled state

➤ Generating a 4-mode entangled state



Impact of common phase noise on average ?

$$\bar{G}^2(\phi_n^{\text{max}}) = \frac{1}{(2\phi_n^{\text{max}})^2} \int_{-\phi_n^{\text{max}}}^{+\phi_n^{\text{max}}} d\phi_p G^2(\phi_A^{\text{opt}} + \phi_p, \phi_B^{\text{opt}} + \phi_p)$$

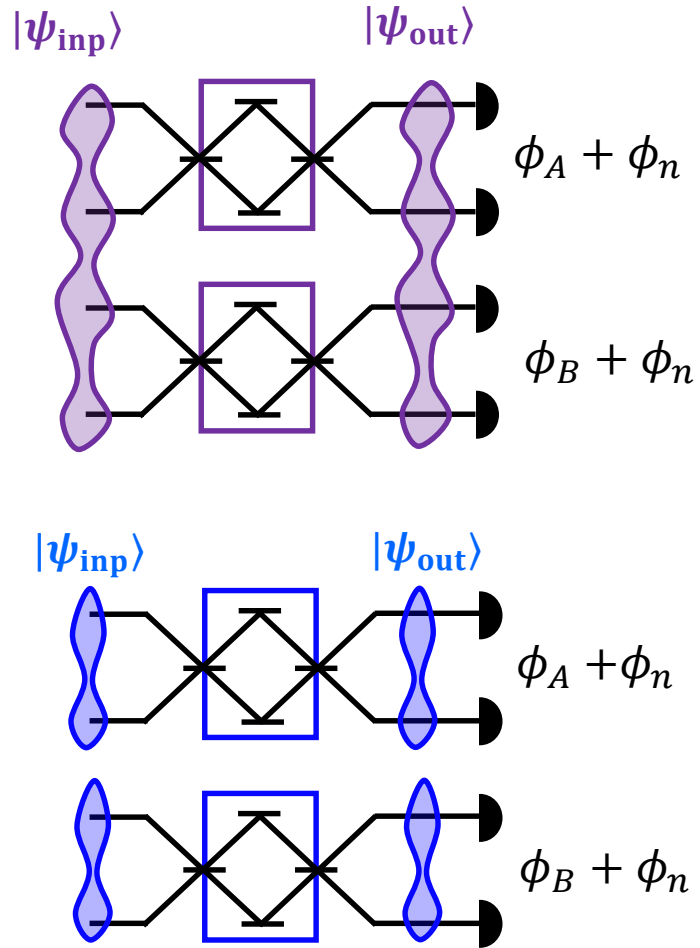


Shape control  $\propto \Gamma_{AB}(\alpha, \phi_{MS})$

$$\Delta^2(\phi_A - \phi_B) = \Delta^2\phi_A + \Delta^2\phi_B$$

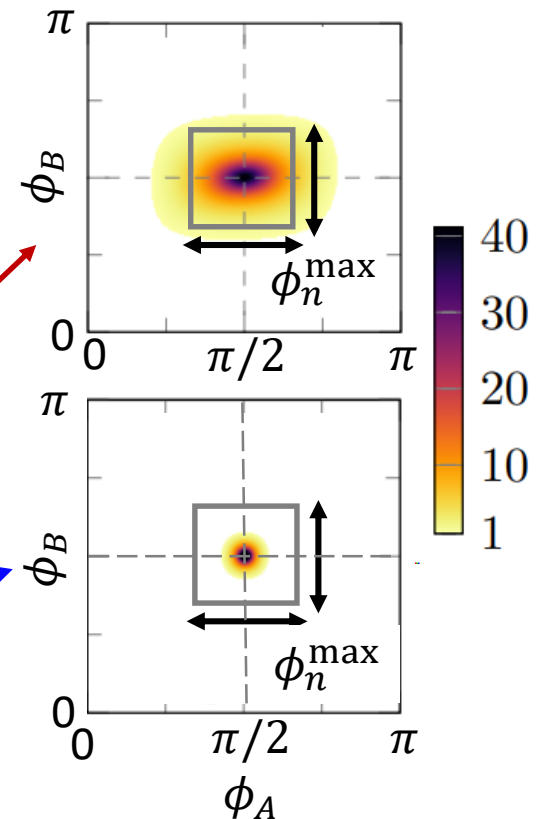
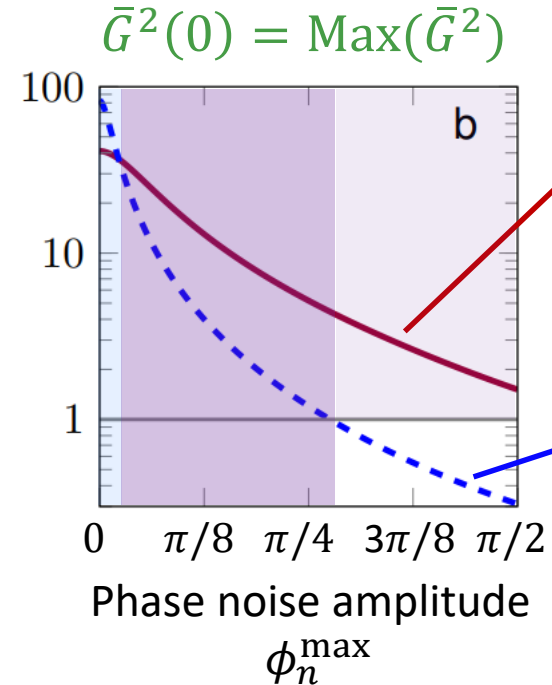
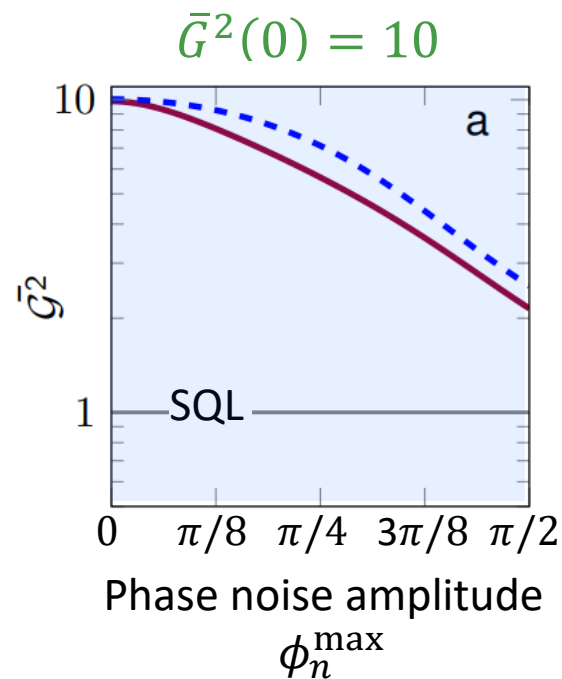
# 4-mode vs 2x2-mode entangled state

➤ Generating a 4-mode entangled state



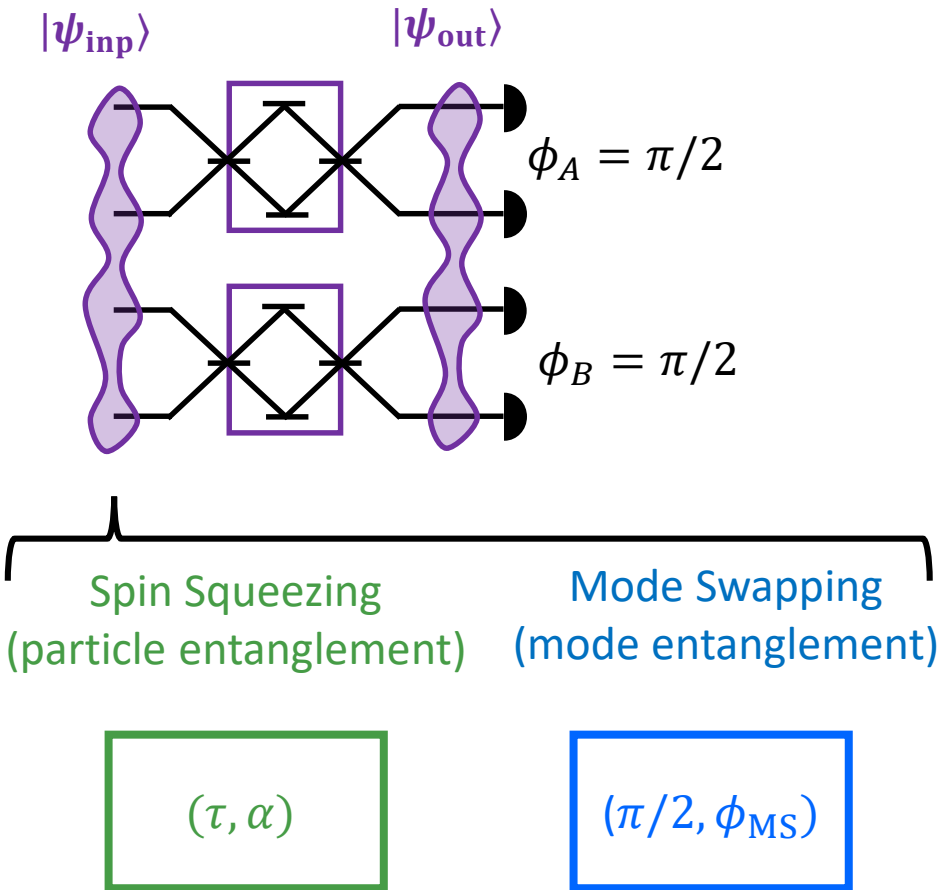
Impact of common phase noise on average ?

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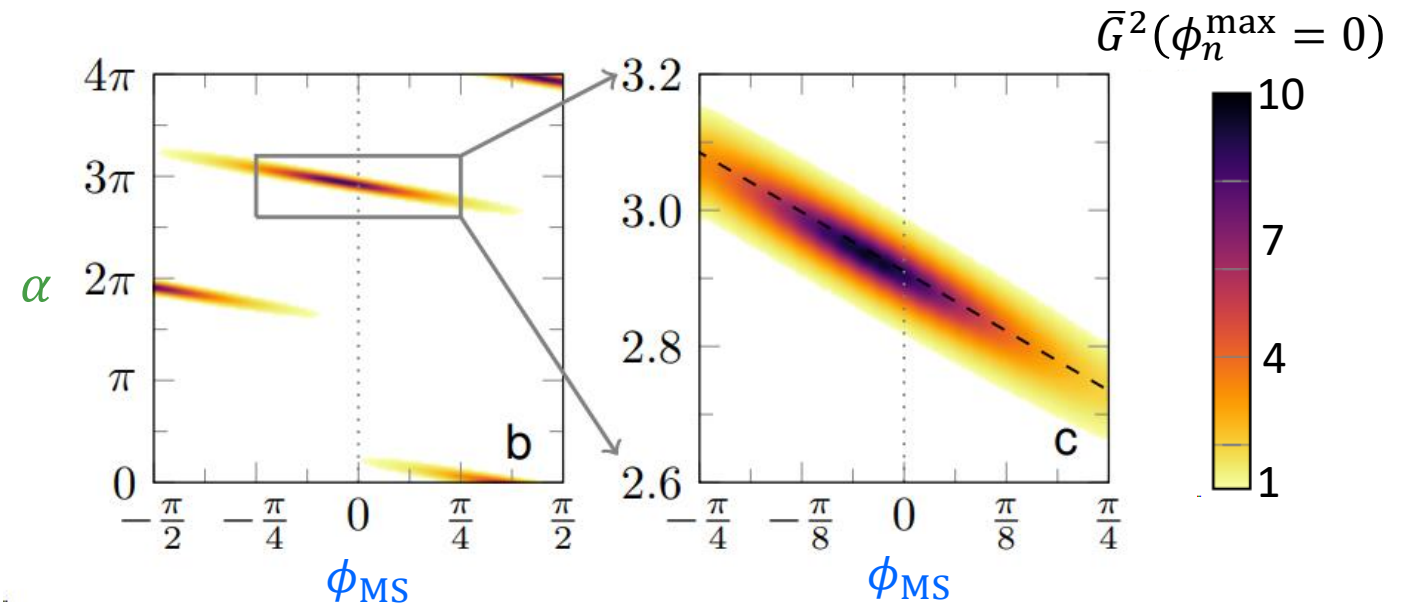


# 4-mode entangled state robustness

- Generating a 4-mode entangled state



Squeezing orientation vs Mode Swapping coupling phase



# Conclusion



- 2 groups aiming to implement the Delta-kick Squeezing
  - @ SYRTE : group of F. Pereira Dos Santos (Raman)
  - @ IQ : group of D. Schlippert (Bragg)

## ❖ Collaborators

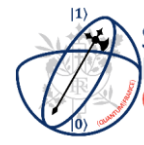
- **Institute for Quantum Optic (Hanovre, Germany)**  
E. Rasel, D. Schlippert, N. Gaaloul
- **Laboratoire Européen de Spectroscopie Non-Linéaire (Florence, Italy)**  
A. Smerzi & L. Pezzè

Thank you for  
your  
attention

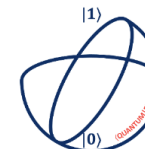
## Experimental Postdoctoral Position at SYRTE :

Contact : [franck.Pereira@obspm.fr](mailto:franck.Pereira@obspm.fr)

<https://syрте.obspm.fr/spip/science/iaci/>



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PROGRAMME ET  
EQUIPEMENTS  
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