PHASE SUPERSENSITIVITY IN AN UNBALANCED SU(1,1) INTERFEROMETER

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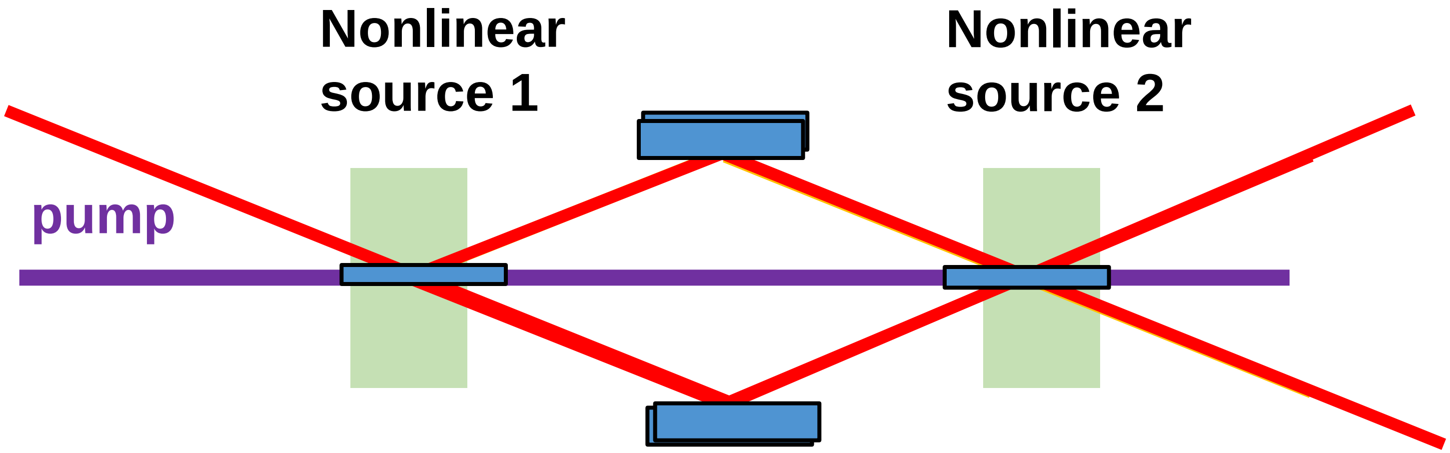
OUTLINE

1. Nonlinear SU(1,1) interferometer
2. Phase sensitivity
3. Gain unbalancing and loss tolerance
4. Experiment
5. Conclusions

NONLINEAR INTERFEROMETER

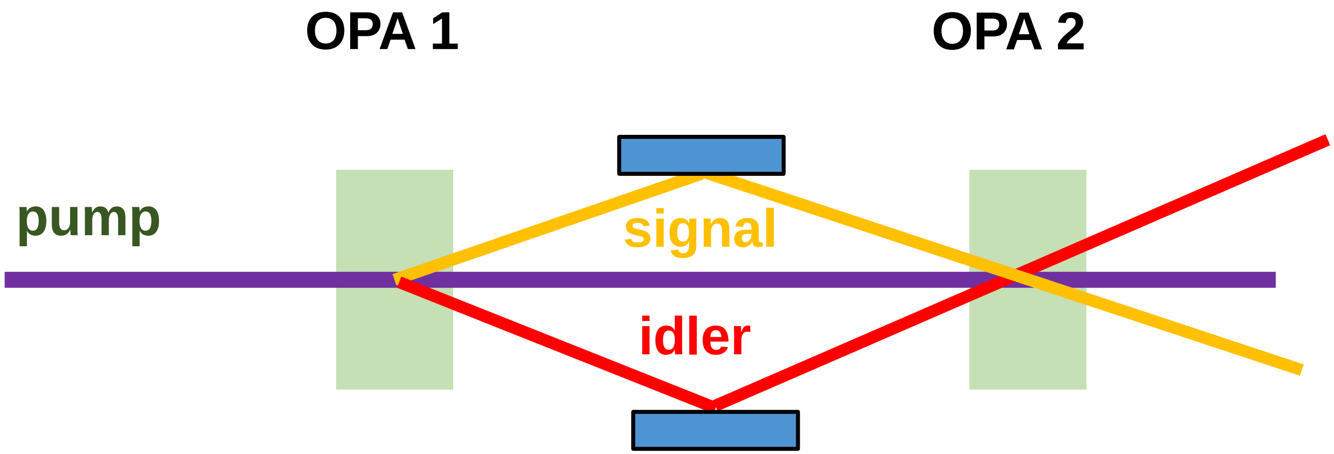


Linear Mach-Zehnder interferometer

Nonlinear Mach-Zehnder interferometer

SU(1,1) INTERFEROMETER

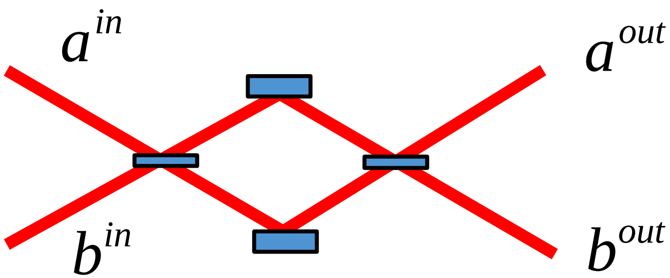
Parametric down-conversion or four-wave mixing



B. Yurke, S.L. McCall, and J.R. Klauder, PRA 33, 4033 (1986)

SU(2) AND SU(1,1) INTERFEROMETERS

SU(2) interferometer



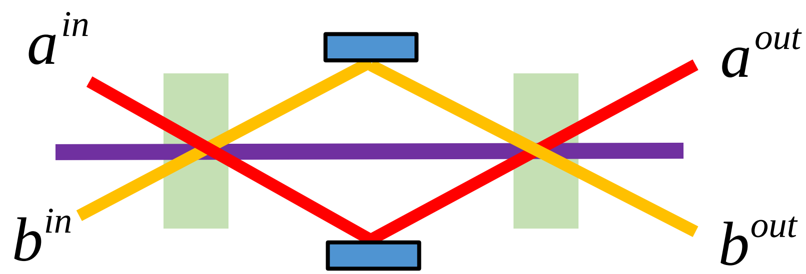
$$\begin{pmatrix} a^{out} \\ b^{out} \end{pmatrix} = \mathbf{U} \begin{pmatrix} a^{in} \\ b^{in} \end{pmatrix},$$

$$|U_{11}|^2 + |U_{12}|^2 = 1,$$

$$U_{21} = -U_{12}^*, U_{22} = U_{11}^*$$

'beamsplitter', SU(2) group

SU(1,1) interferometer



$$\begin{pmatrix} a^{out} \\ [b^{out}]^+ \end{pmatrix} = \mathbf{S} \begin{pmatrix} a^{in} \\ [b^{in}]^+ \end{pmatrix},$$

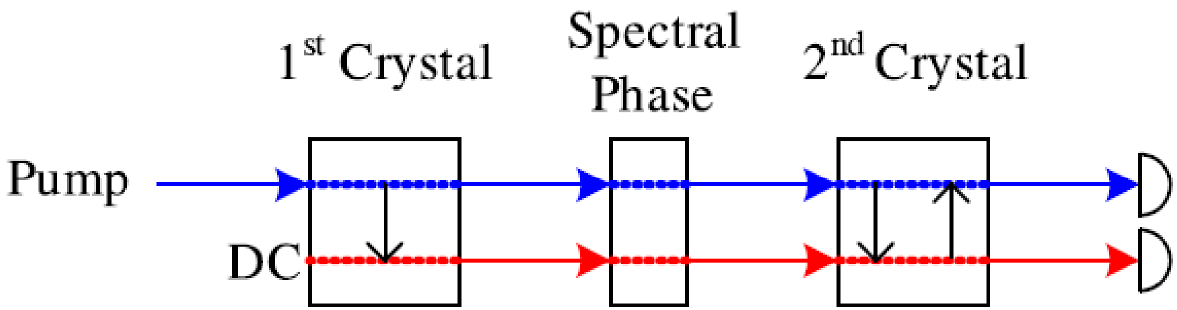
$$|S_{11}|^2 - |S_{12}|^2 = 1, |S_{22}|^2 - |S_{21}|^2 = 1,$$

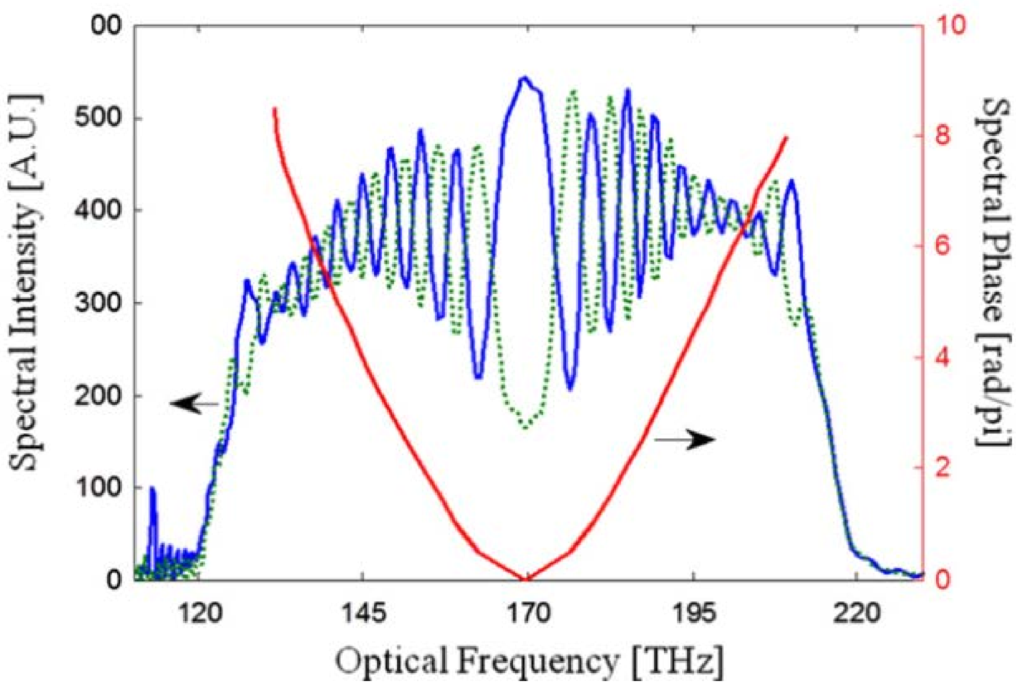
$$S_{11}S_{21}^* = S_{12}S_{22}^*$$

'Bogolyubov', SU(1,1) group

B. Yurke, S.L. McCall, and J.R. Klauder, PRA 33, 4033 (1986)

SU(1,1) INTERFEROMETER: BIPHOTON PHASE CHARACTERIZATION

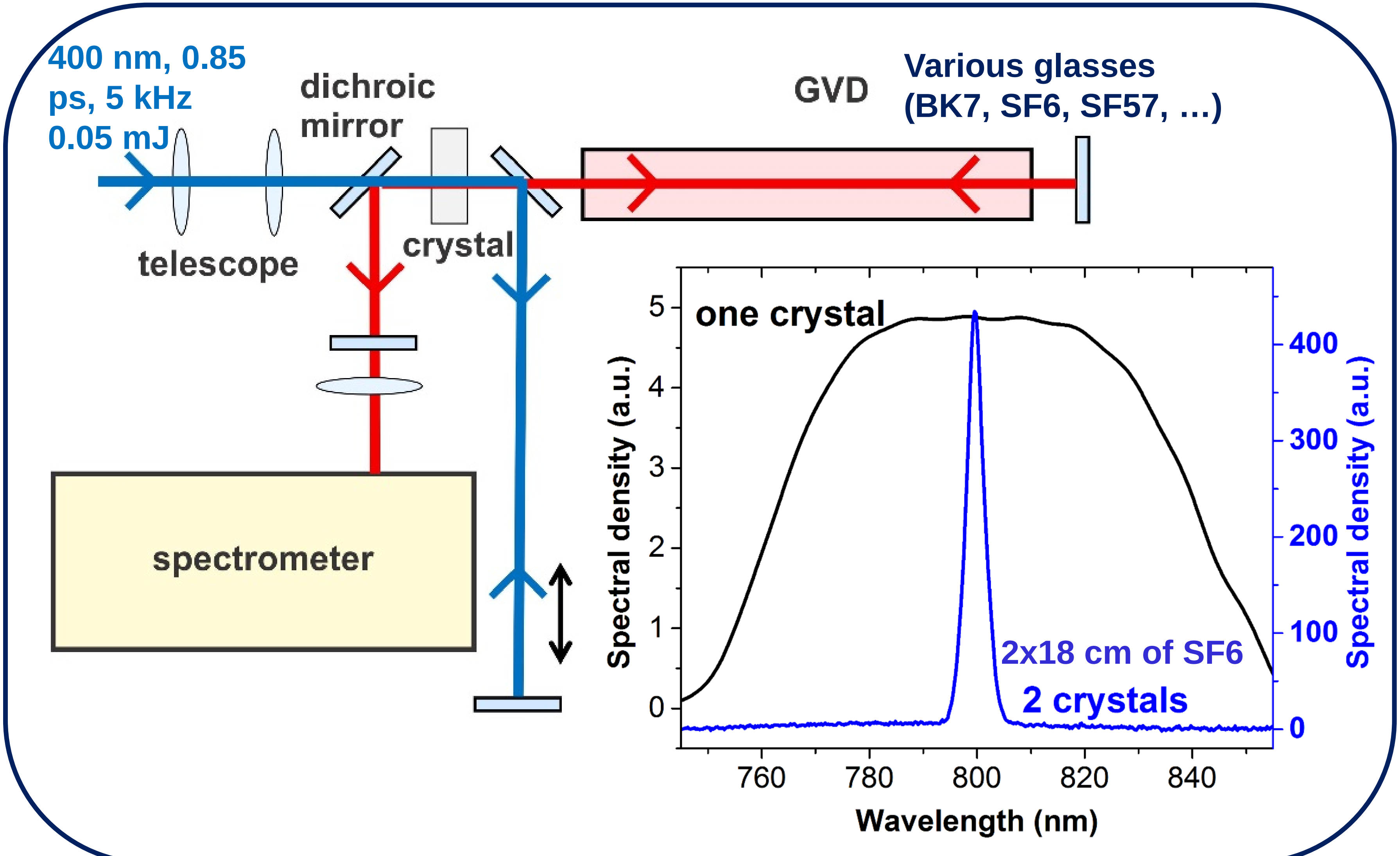




Amplification or deamplification in the second crystal, depending on the phase: enables the phase retrieval

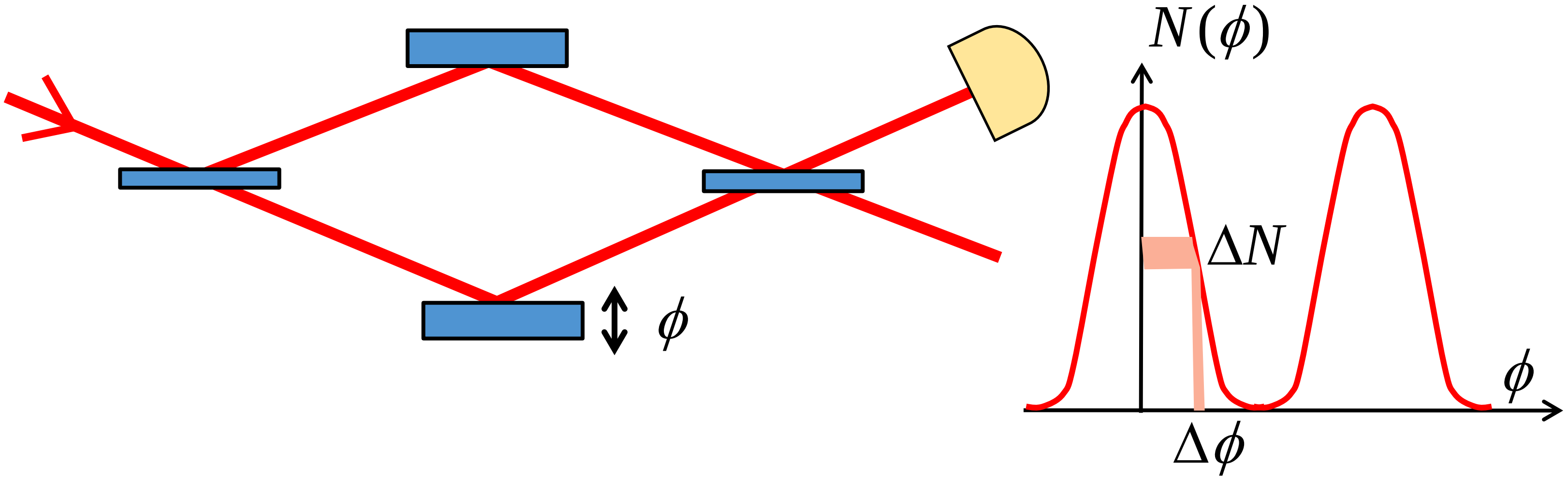
Y. Shaked, R. Pomerantz, R. Z. Vered, and A. Pe'er, NJP 16, 053012 (2014)

HIGH-GAIN SU(1,1) INTERFEROMETER: SPECTRUM SHAPING



S. Lemieux, M. Manceau, P. R. Sharapova, O. V. Tikhonova, R. W. Boyd, G. Leuchs, and M. V. Chekhova, Phys. Rev. Lett. 117, 183601 (2016).

PHASE SENSITIVITY



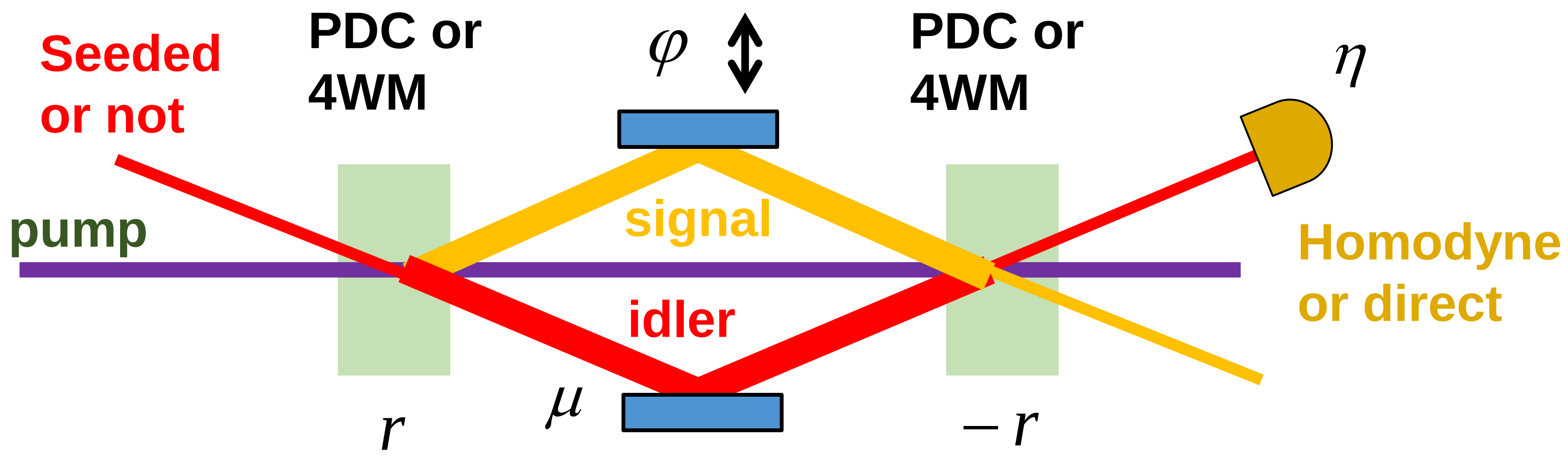
$$\Delta\phi = \frac{\Delta N}{\left| dN / d\phi \right|}$$

Shot-noise limit (coherent state) $$\Delta\phi_{SNL} = \frac{1}{\sqrt{\langle N \rangle}}$$

Phase supersensitive measurement: $\Delta\phi < \Delta\phi_{SNL}$

Heisenberg limit (exotic states like NOON): $$\Delta\phi_H \sim \frac{1}{\langle N \rangle}$$

HIGH-GAIN SU(1,1) INTERFEROMETER: PHASE SUPERSENSITIVITY



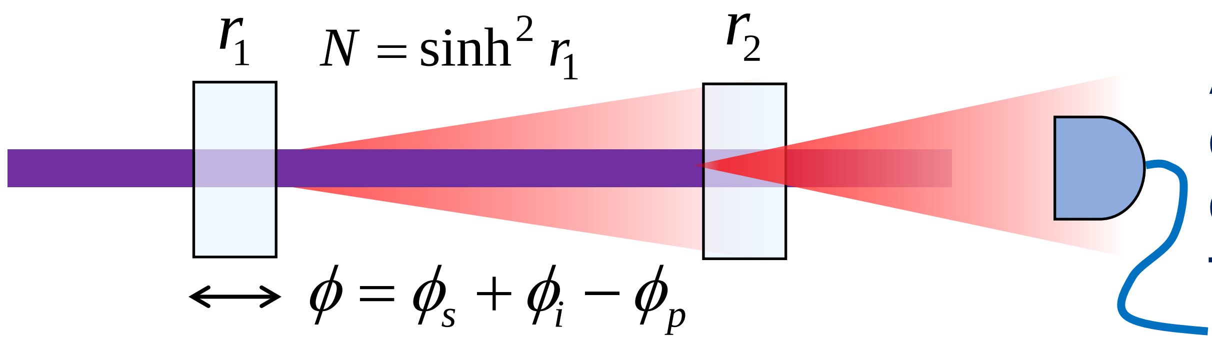
No losses: Heisenberg limit $\Delta\varphi \sim \dfrac{1}{\langle N \rangle}$

Internal transmission μ**, external** η**:** $\Delta\varphi = \dfrac{1}{\sqrt{\langle N \rangle}} \sqrt{\dfrac{1-\eta+\mu\eta}{\mu\eta} e^{-2r} + \dfrac{1-\mu}{\mu}}$

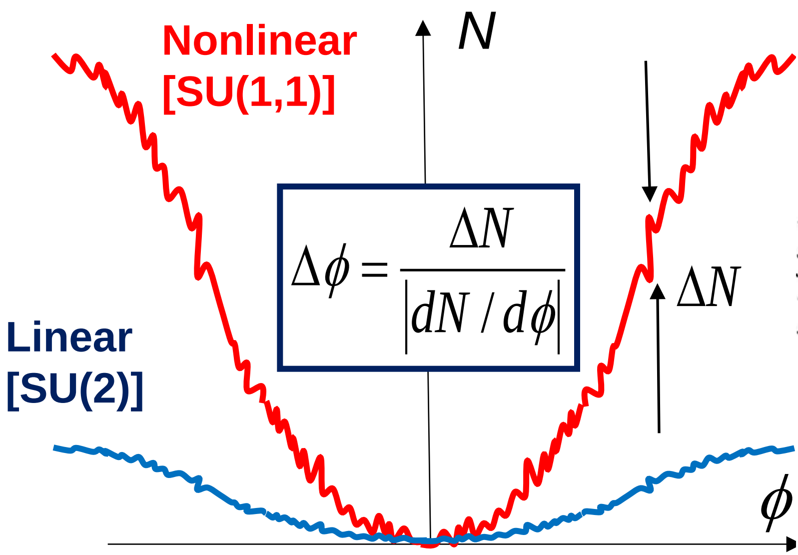
External (detection) losses can be completely overcome! $\sim \dfrac{1}{\langle N \rangle}$

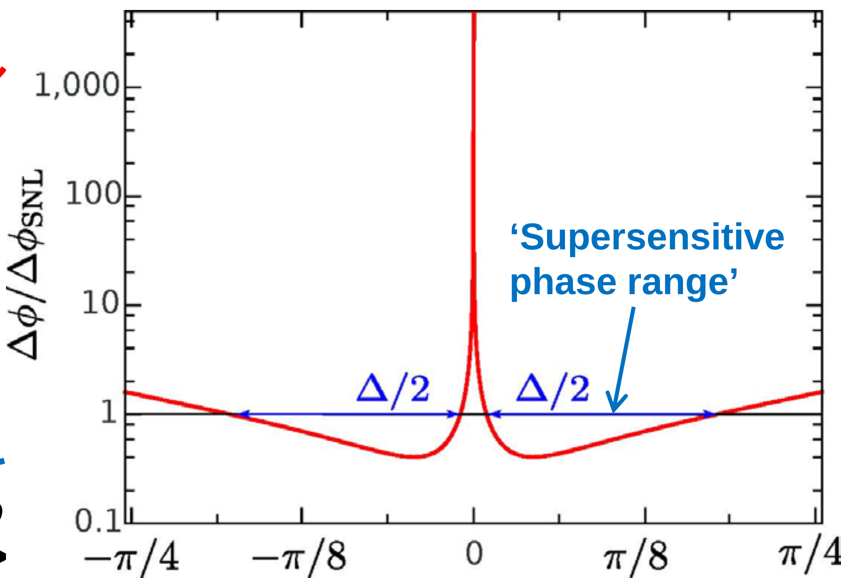
A.M. Marino, N. V. Corzo Trejo, and P. D. Lett, PRA 86, 023844 (2012);
F. Hudelist, J. Kong, C. Liu, J. Jing, Z.Y. Ou, and W. Zhang, Nature Comm. 5:3049 (2014)

OUR SCHEME: NO SEEDING, DIRECT DETECTION



Amplification or deamplification depending on the phase

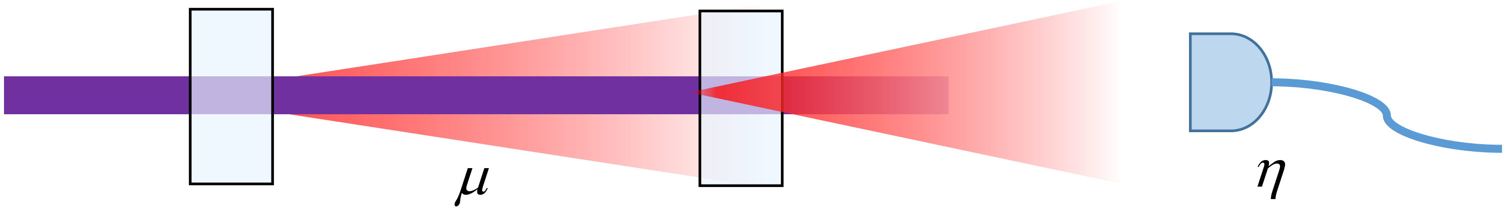




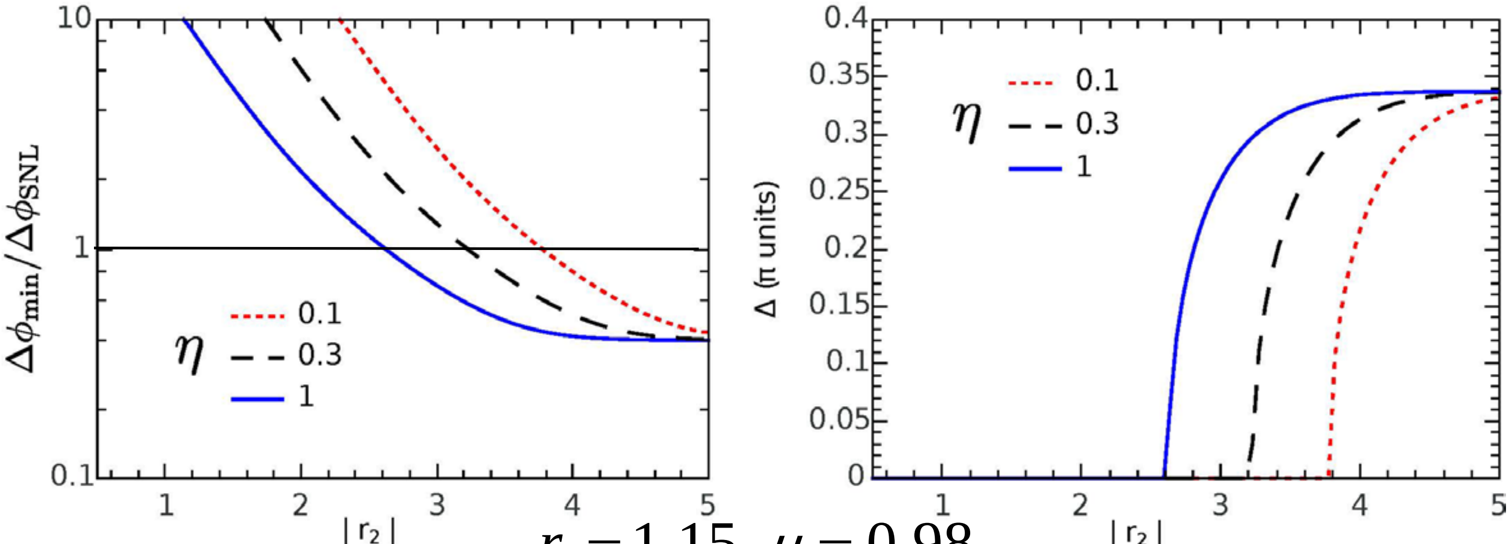
F. Hudelist et al., Nature Comm. 5:3049 (2014).

M. Manceau, F. Khalili, and M. V. Chekhova, NJP 19, 013014 (2017).

MAIN IDEA: GAIN UNBALANCING



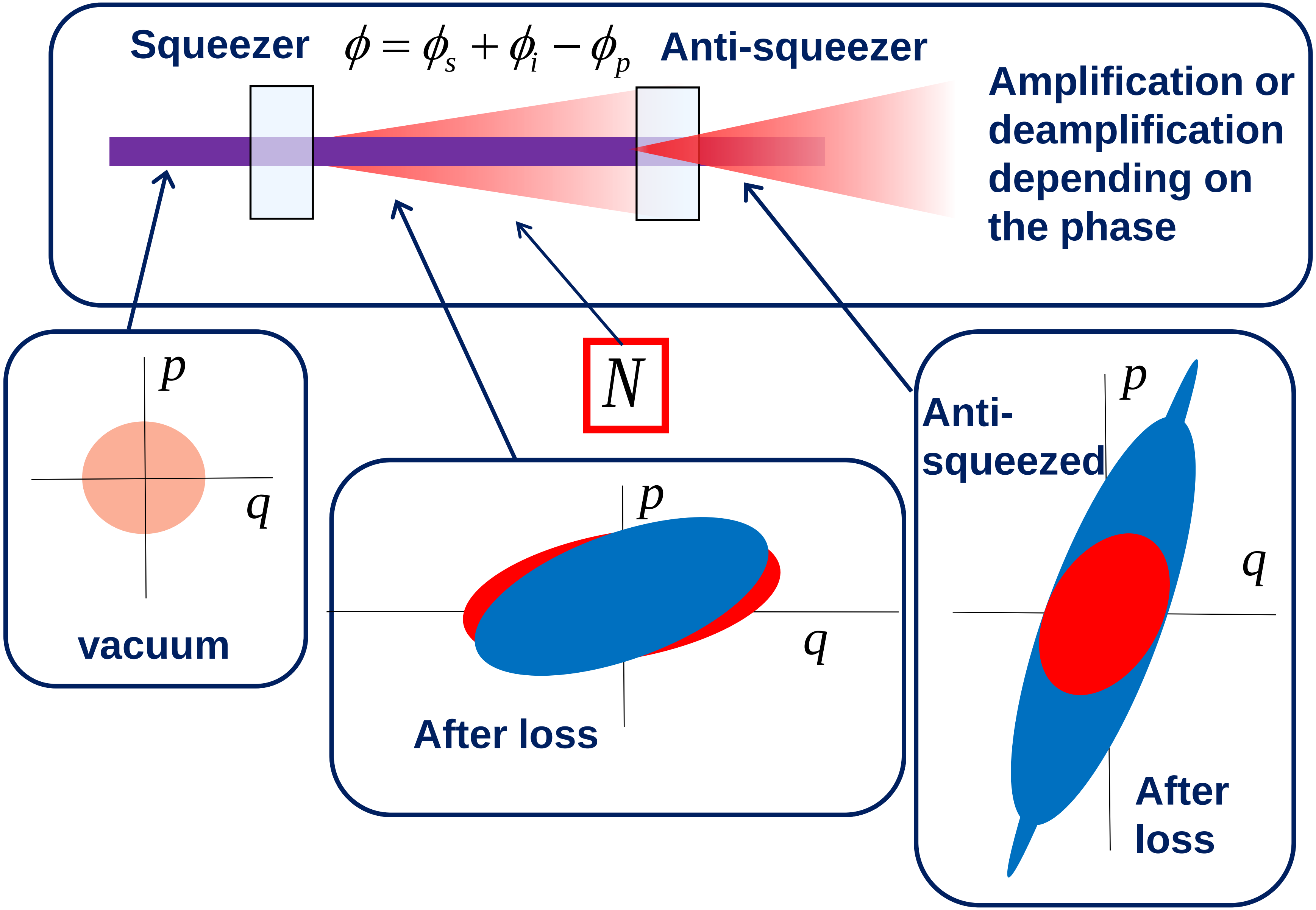
Different gain values! $|r_2|>|r_1|$



$r_1 = 1.15,\ \mu = 0.98$

M. Manceau, F. Khalili, and M. V. Chekhova, NJP 19, 013014 (2017).

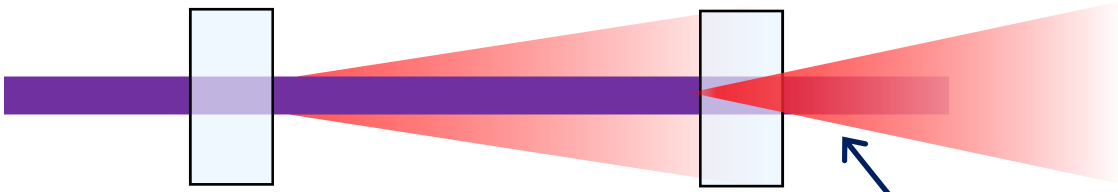
HOW IT WORKS



Squeezer
$\phi = \phi_s + \phi_i - \phi_p$
Anti-squeezer
Amplification or deamplification depending on the phase
p
q
vacuum
N
p
q
After loss
Anti-squeezed
p
q
After loss

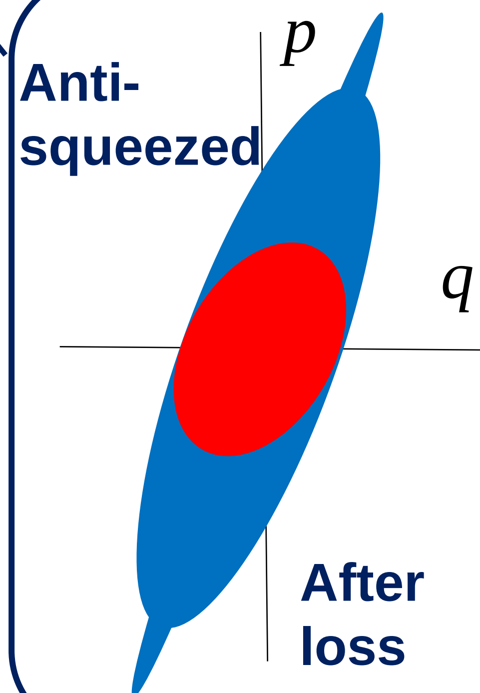
HOW IT WORKS

Squeezer $\phi = \phi_s + \phi_i - \phi_p$ **Anti-squeezer**

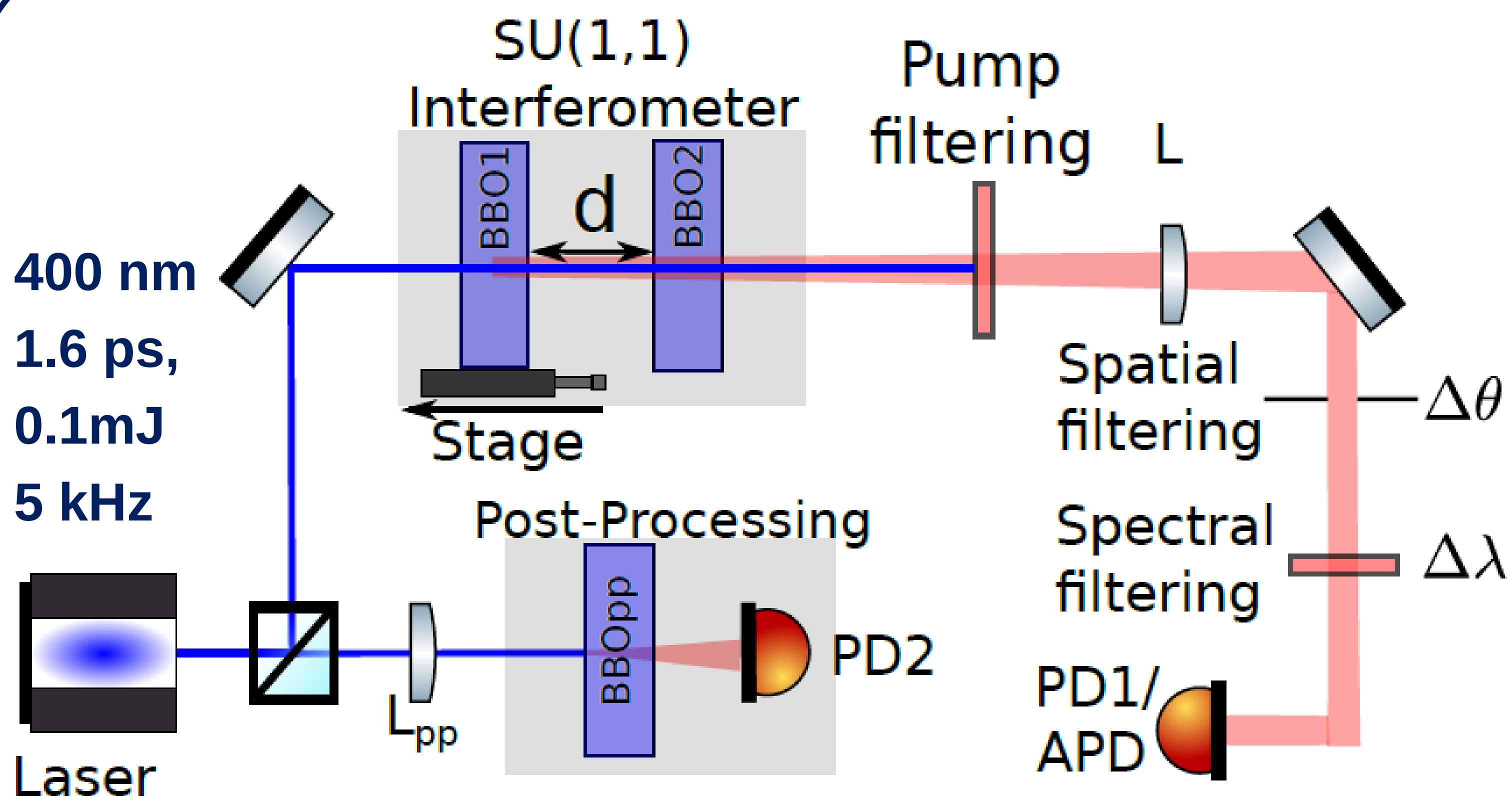


Amplification or deamplification depending on the phase

The quadrature responsible for the phase information is amplified before loss and therefore 'protected'

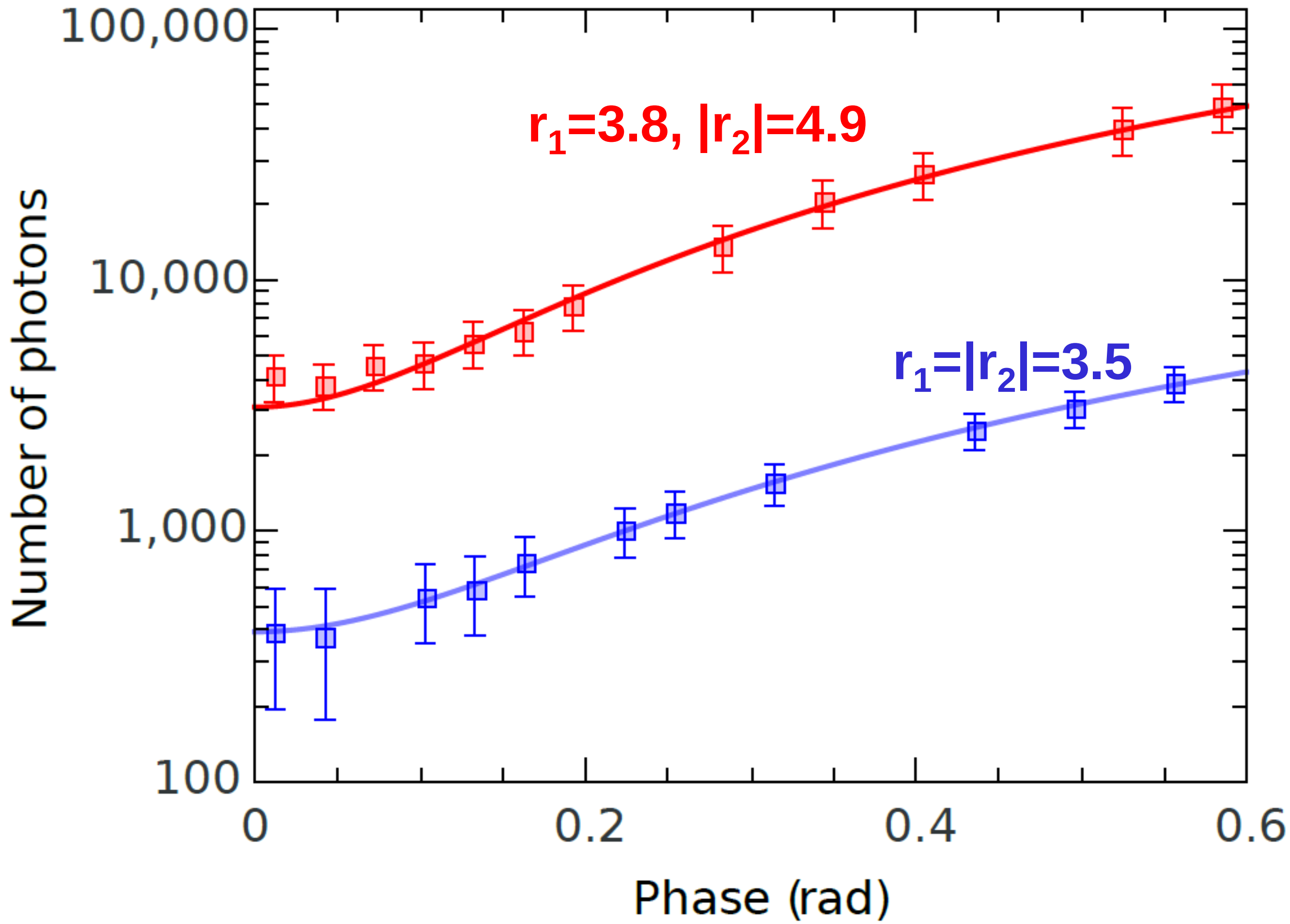


EXPERIMENTAL SETUP

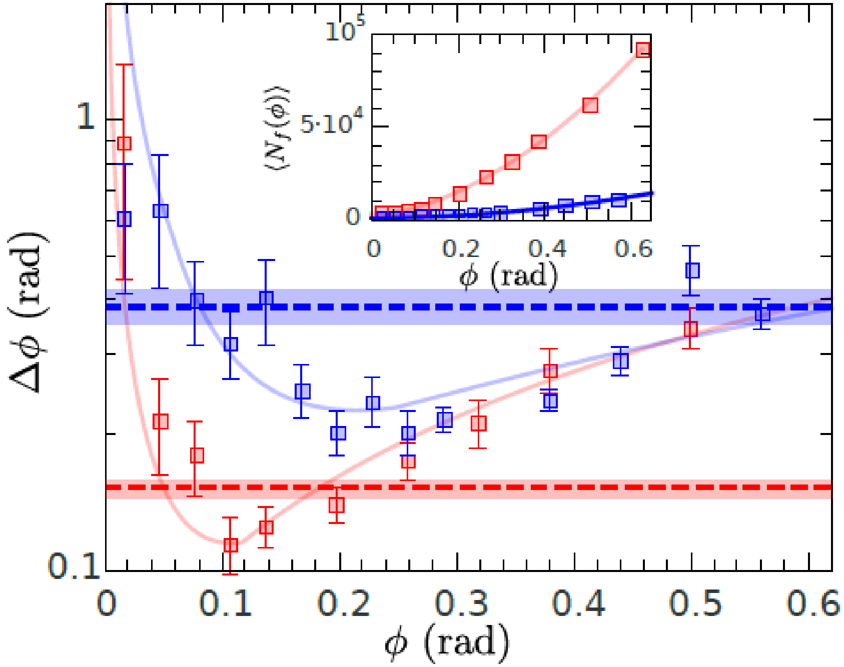


$$\Delta\phi_{SNL} = 1/\sqrt{\langle N(\Delta\theta, \Delta\lambda)\rangle}$$

INTERFERENCE FRINGES



SUPER-SENSITIVE PHASE MEASUREMENTS

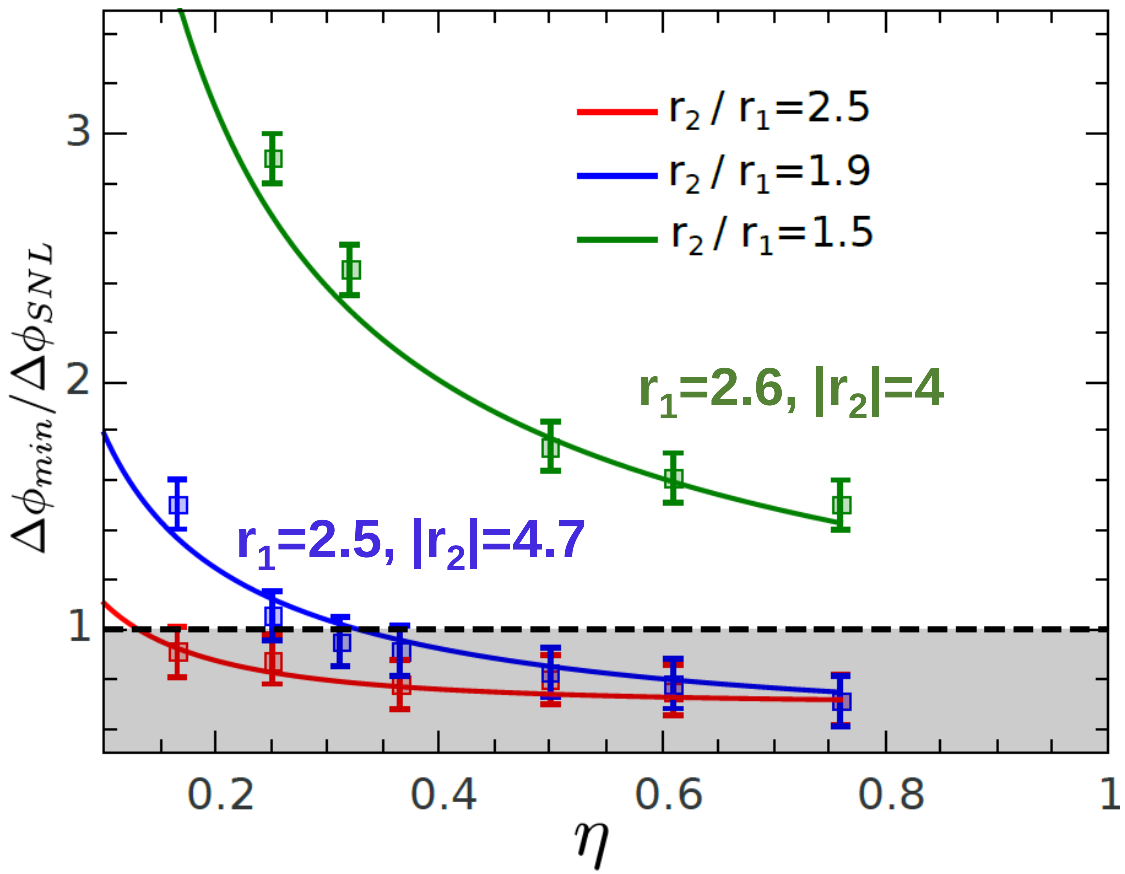


r_1=1.5, N=1.7, $|r_2|$=5

r_1=2.7, N=11, $|r_2|$=5

M. Manceau, F. Khalili, G.Leuchs, and M. V. Chekhova, arXiv:1705.02662

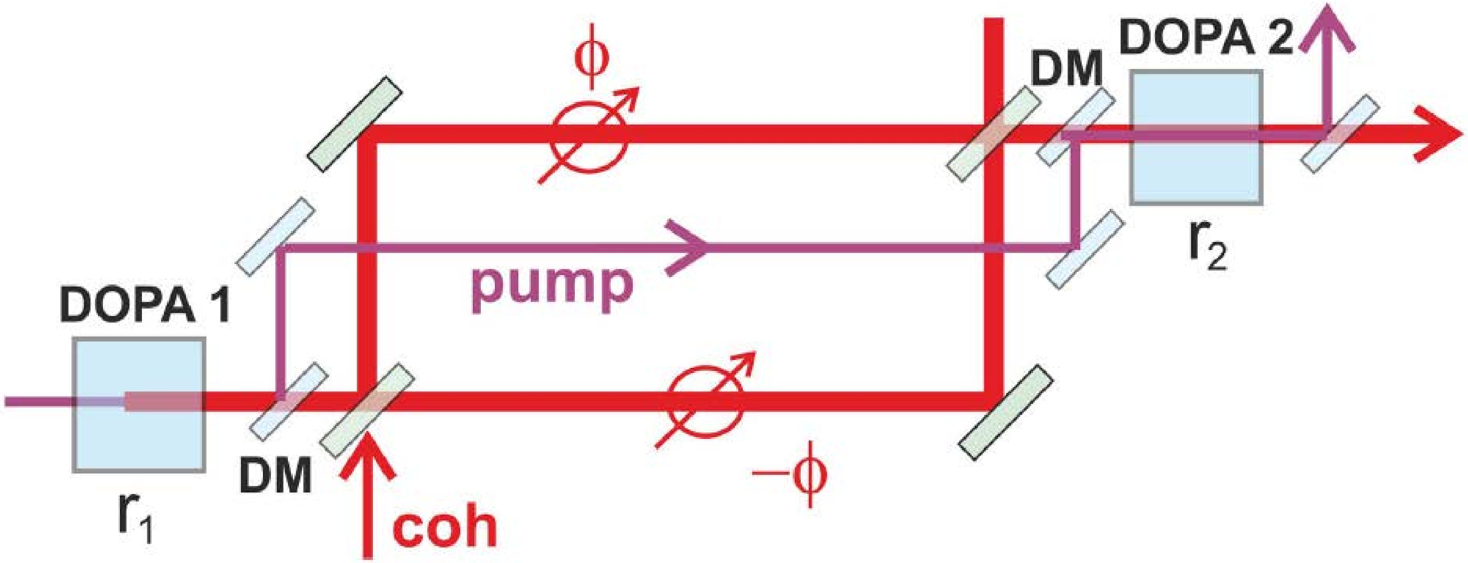
THE EFFECT OF LOSS



r_1=2.1, $|r_2|$=5.2

M. Manceau, F. Khalili, G.Leuchs, and M. V. Chekhova, arXiv:1705.02662

A MORE PRACTICAL SETUP

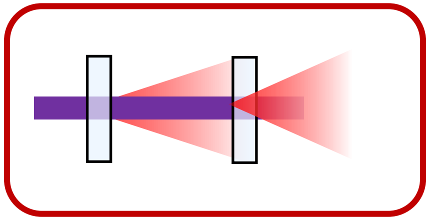


SU(2) interferometer preceded by a squeezer and followed by an anti-squeezer: unbalanced configuration leads to the same advantages

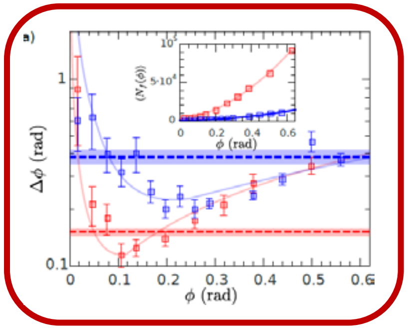
M. Manceau, F. Khalili, and M. V. Chekhova, NJP 19, 013014 (2017).

CONCLUSIONS

- **SU(1,1) interferometer with no seeding and direct detection; the effect of gain unbalancing.**

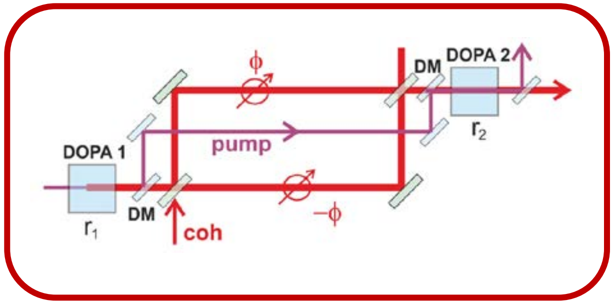


- **Phase sensitivity 2.3 dB below SNL**



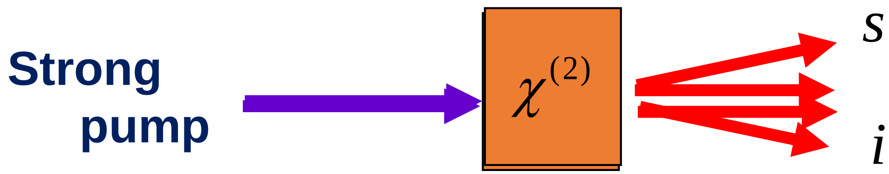
- **Phase supersensitivity for up to 11 photons, tolerant to losses (QE as low as 17%)**

- **The same “unbalancing” strategy for SU(2) with OPAs placed before and after it**



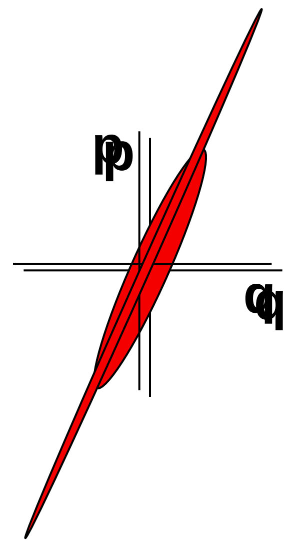
THANK YOU FOR YOUR ATTENTION!

BRIGHT SQUEEZED VACUUM



Quadrature-squeezed BSV

Twin-beam BSV



$$\langle \hat{N} \rangle = \langle a^{+} a \rangle = \sinh^{2}(G) >> 1$$

Up to $G \sim 20, \langle \hat{N} \rangle \sim 10^{18}$

Nonclassicality: 7.8 dB photon-number squeezing (observed in the non-degenerate regime)

T. Sh. Iskhakov et al., OL 41, 2149 (2016).