Beam-splitting tricks

Antonín Černoch

Joint Laboratory of Optics of Palacký University and Institute of Physics of AS ČR

Content

Quantum information processing

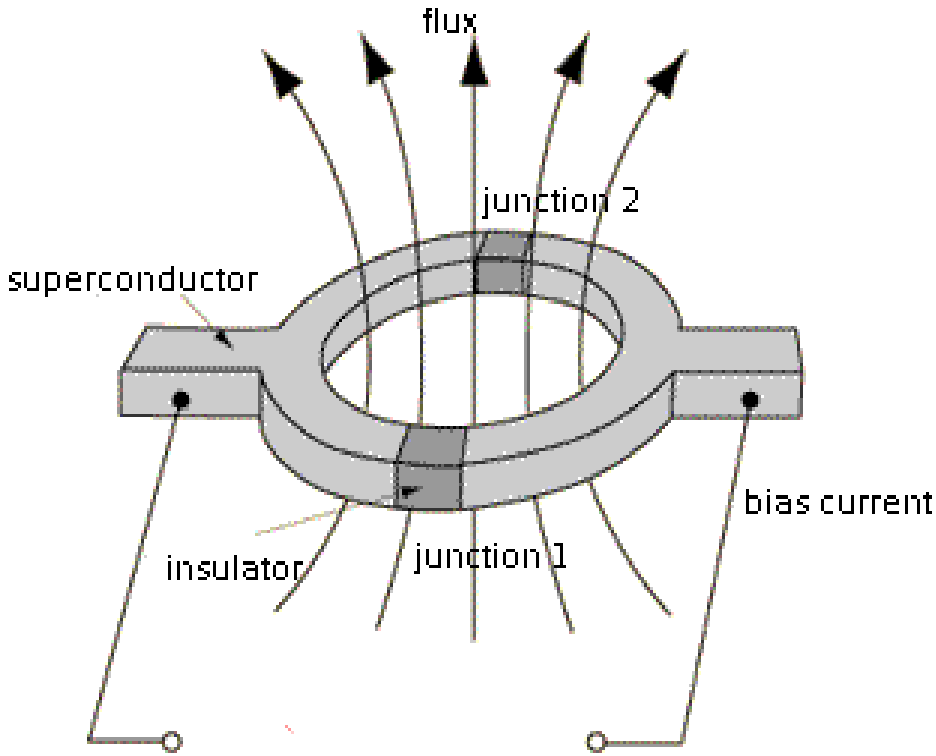
- faster computation
- secret information transfer

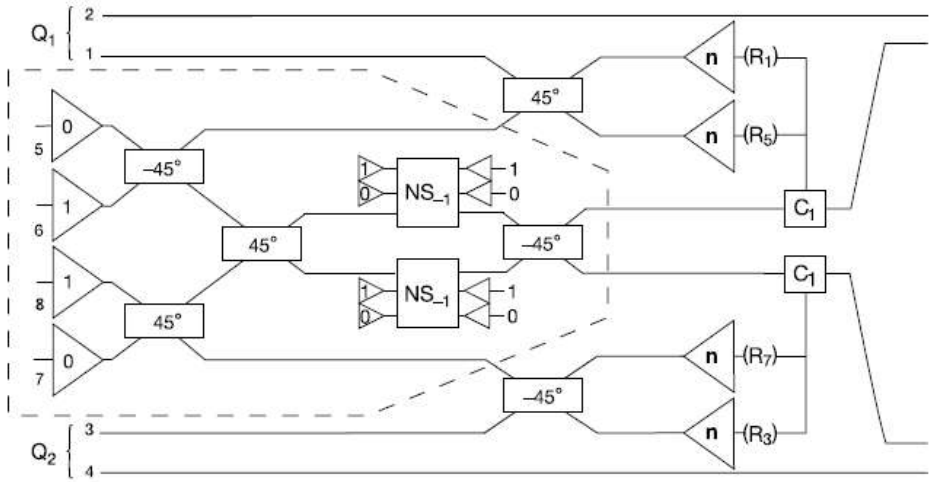
Possible platforms

- ionts in Pauli trap
- Josephsons junction
- light – cw or single photons

Linear optics

- E. Knill, R. Laflamme & G. J. Milburn, Nature (London) 409, 46 (2001)
- BS and phase shifts





BS description

t amplitude transmissivity

r amplitude reflectivity

T intensity transmittance, $T = |t|^2$

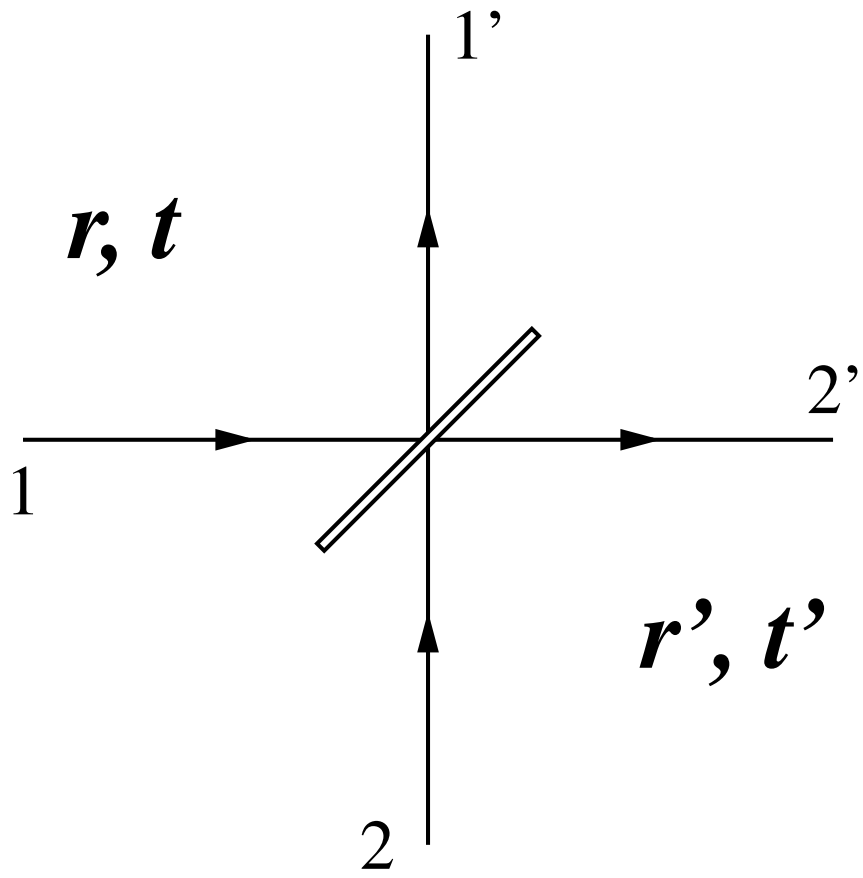
R intensity reflectance, $R = |r|^2$

Transformation on spatial modes

$$\begin{pmatrix} \hat{a}'_1 \\ \hat{a}'_2 \end{pmatrix} = \begin{pmatrix} r & t' \\ t & r' \end{pmatrix} \begin{pmatrix} \hat{a}_1 \\ \hat{a}_2 \end{pmatrix}$$

Ideal BS

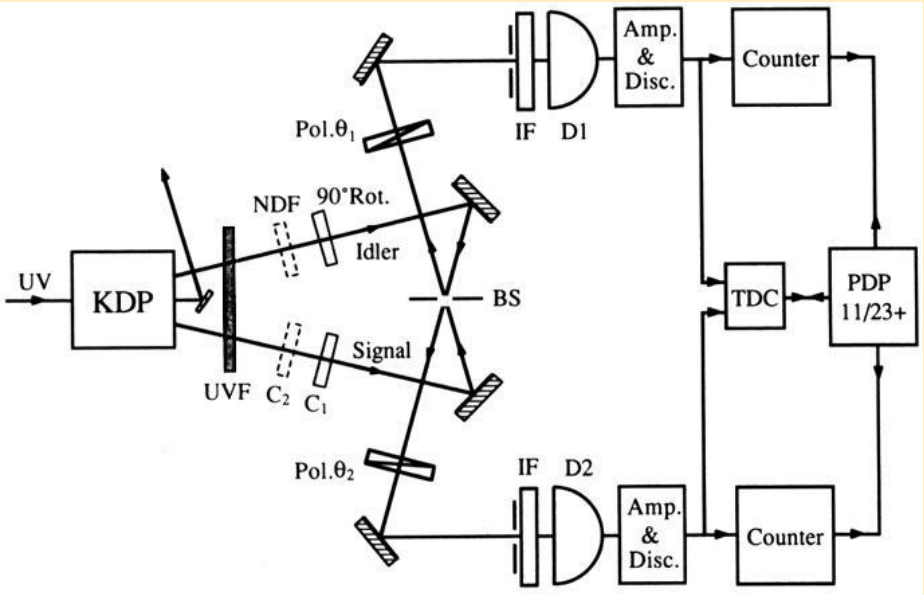
$$|r'| = |r|, \; |t'| = |t|, \; |r|^2 + |t|^2 = 1$$
$$r^* t' + r' t^* = 0 \qquad r^* t + r' t'^* = 0$$



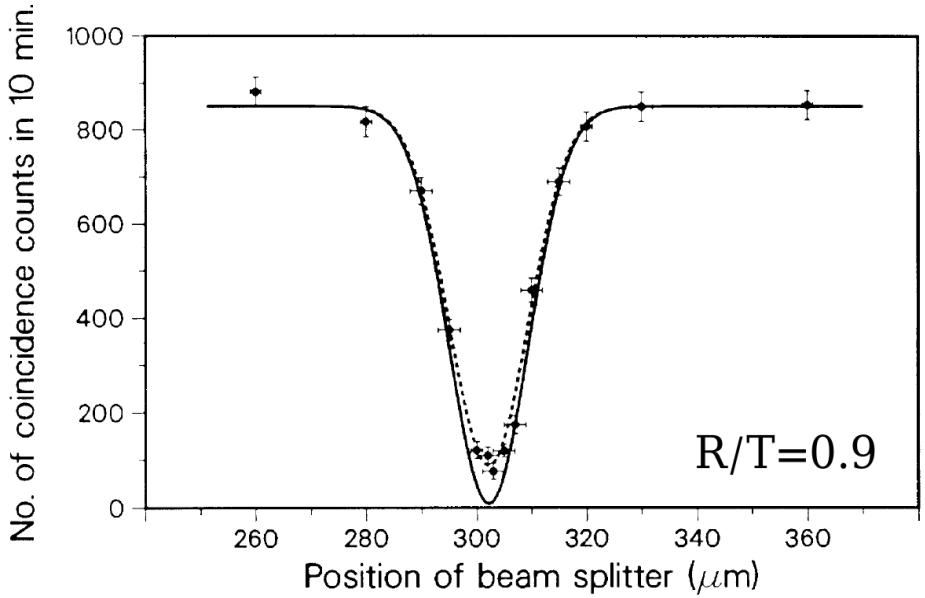
Fifty-to-fifty beam-splitter

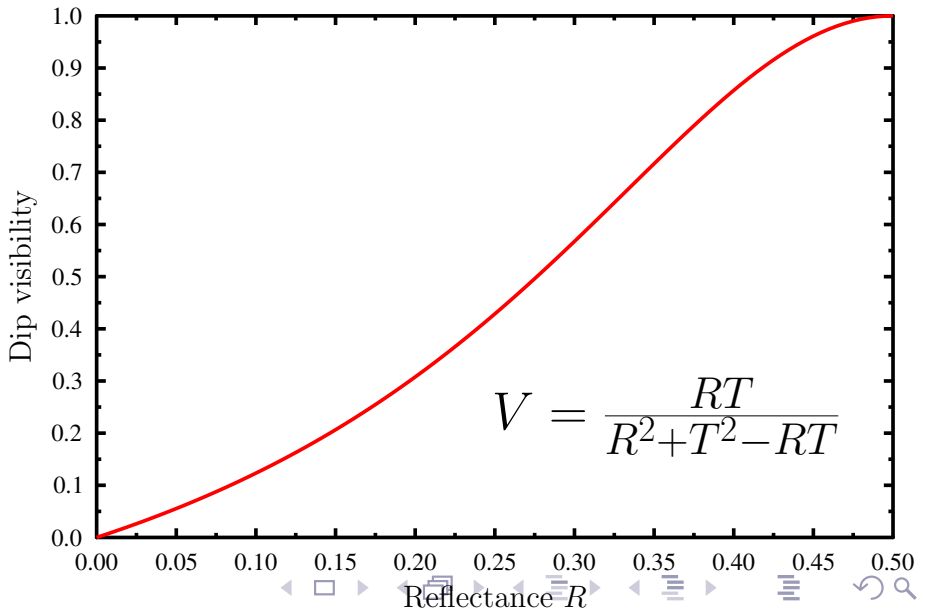
HOM cloning

C. K. Hong, Z. Y. Ou & L. Mandel, Phys. Rev. Lett. 59, 2044 (1987)



counts in minima $\sim (T-R)^2$

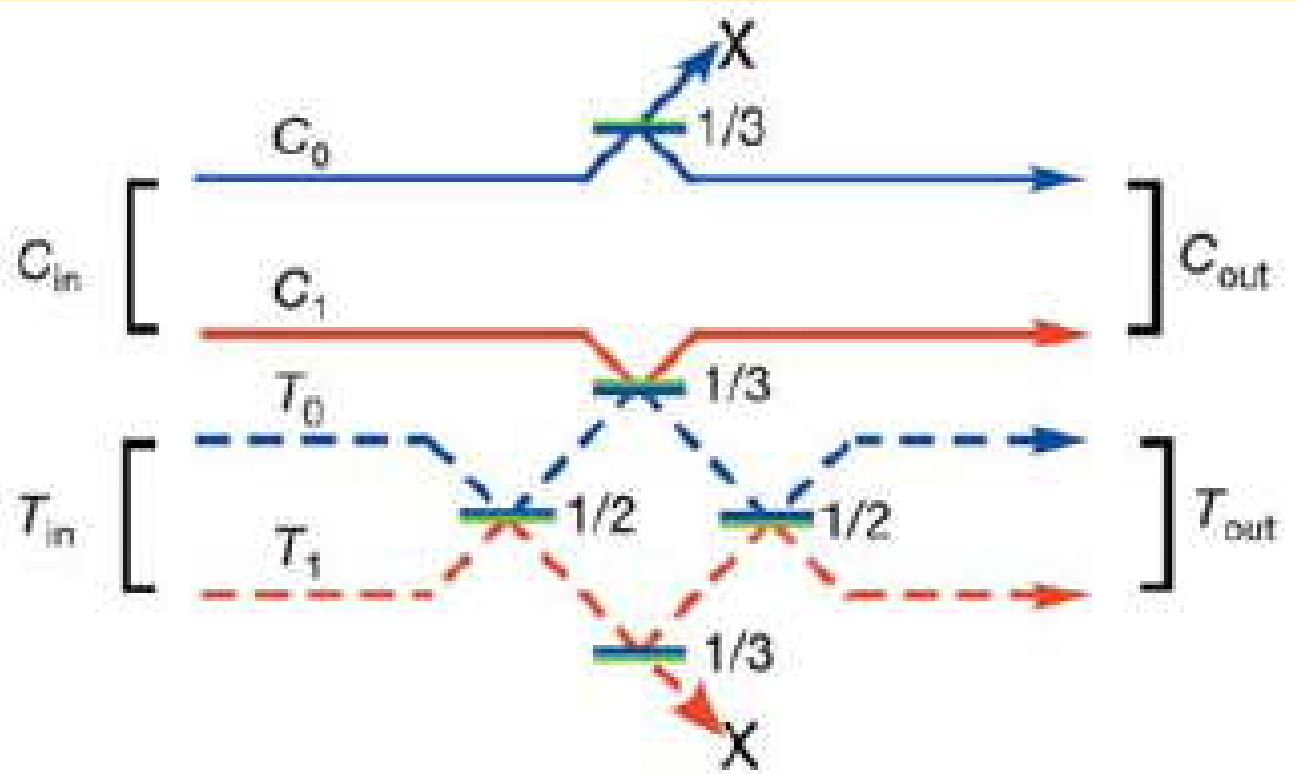


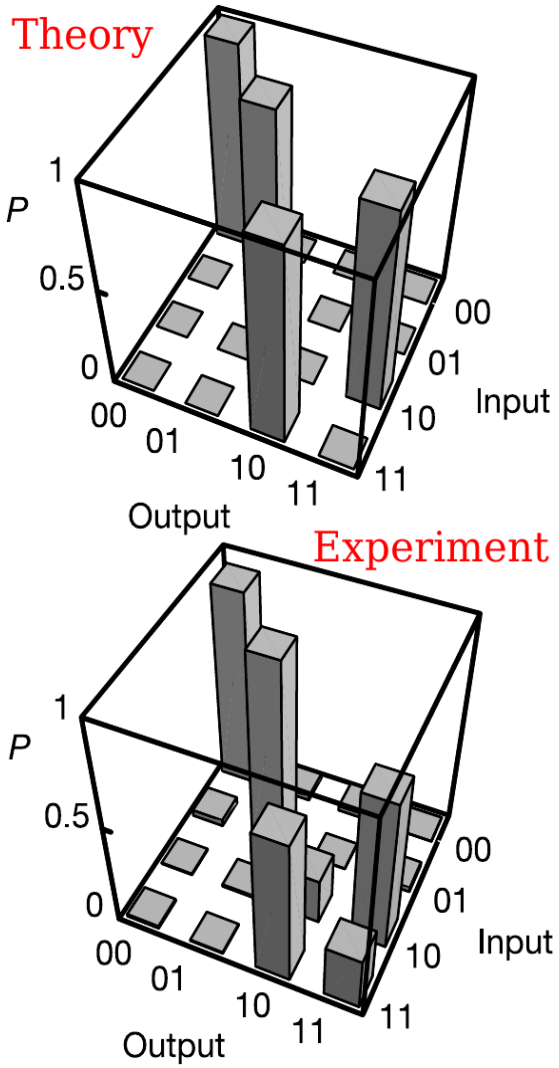


One-to-two beam-splitter

C-NOT operation

J. L. O'Brien et al., Nature 426, 264 (2003)

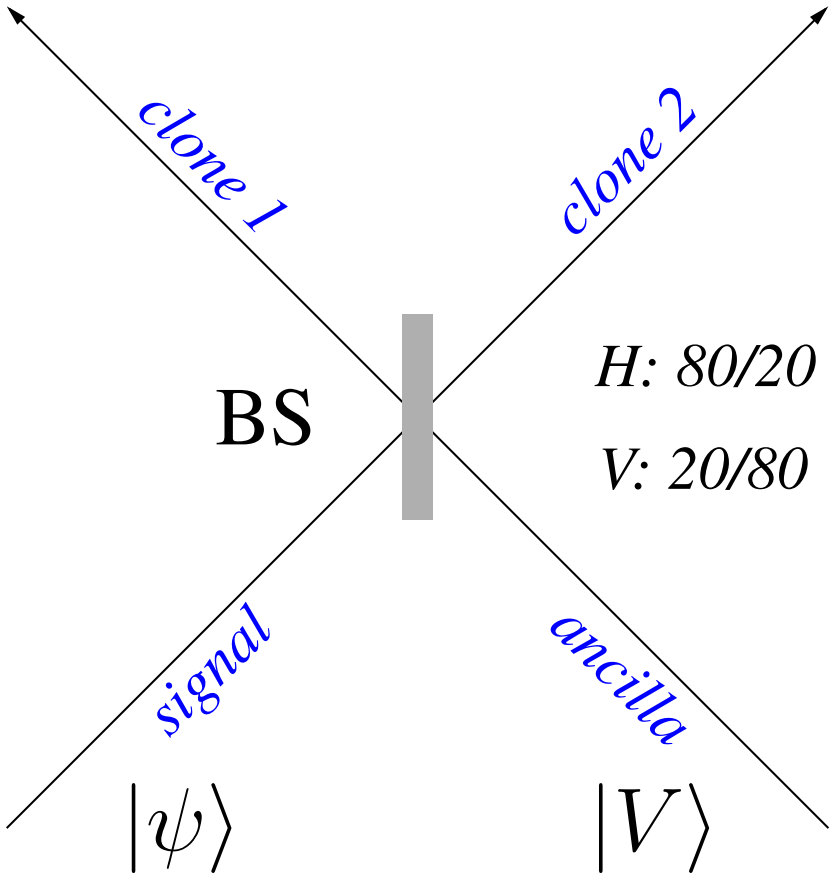




Are you kidding?

Phase-covariant clonning

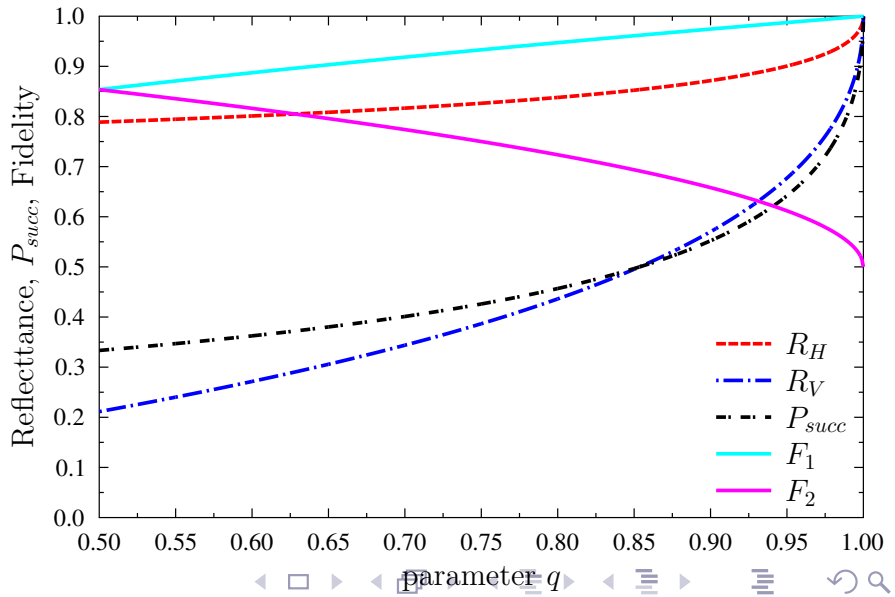
J. Fiurášek, Phys. Rev. A 67, 052314 (2003)



Asymmetric clonning

coefficient of asymmetry - q

$$F_1 = (1 + \sqrt{q})/2$$
$$F_2 = (1 + \sqrt{1-q})/2$$
$$q = R_H R_V / P_{succ}$$
$$P_{succ} = (2R_H - 1)^2$$

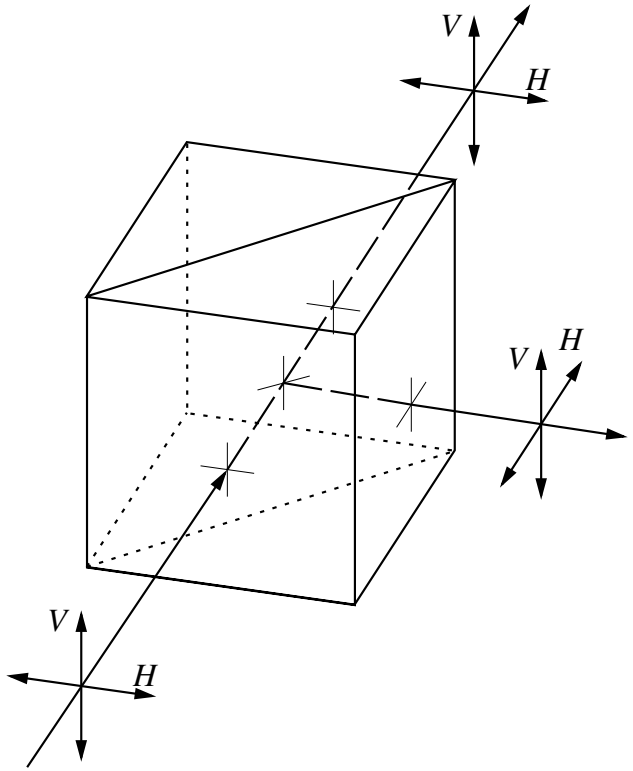


Content

What we want and what we have

Cube 50/50 BS (05BC16NP.7)

input	1	2	1'	2'
R_H [%]	42	43	42	43
R_V [%]	56	56	54	55



Broadband plate 50/50 BS (BSW08)

input	1	2
R_H [%]	39	38
R_V [%]	65	65

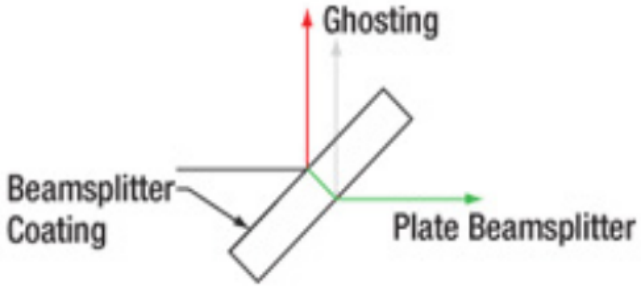
Plate BS for CNOT

specifications:

$R_s = 66\% \pm 5\%$

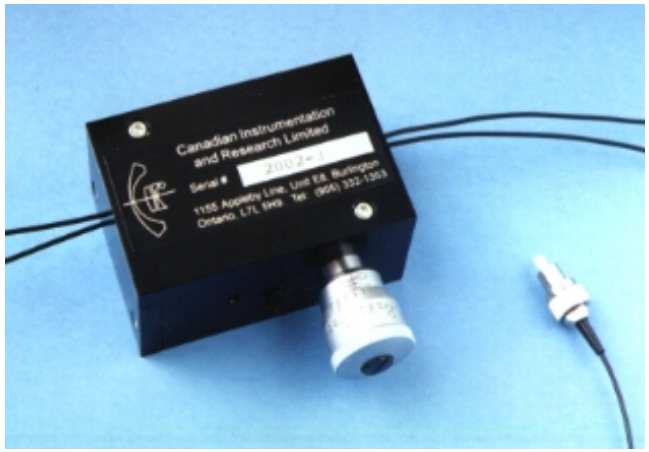
$T_p = 97\%$

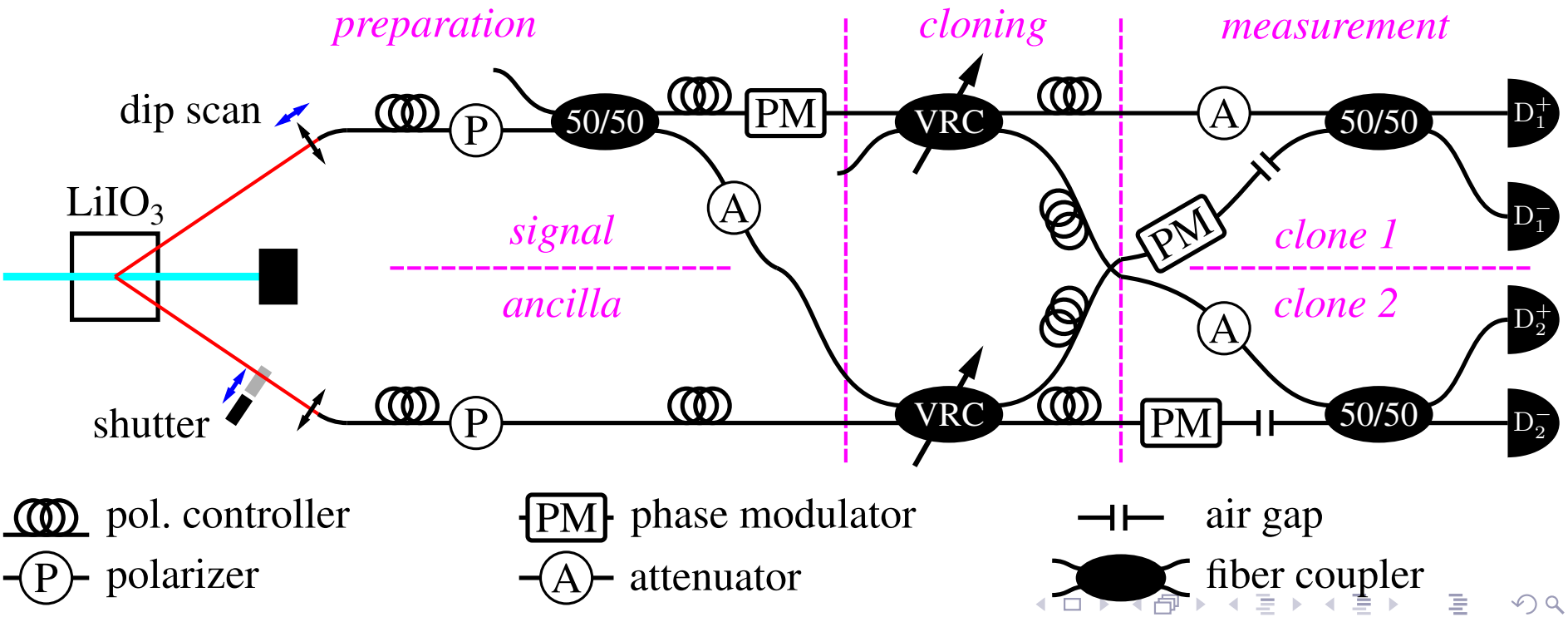
input	1	2
R_H [%]	28	26
R_V [%]	74	72



Fiber optics - feasible but unstable

- variable ratio coupler
- polarization insensitive
- spatial encoding recommended



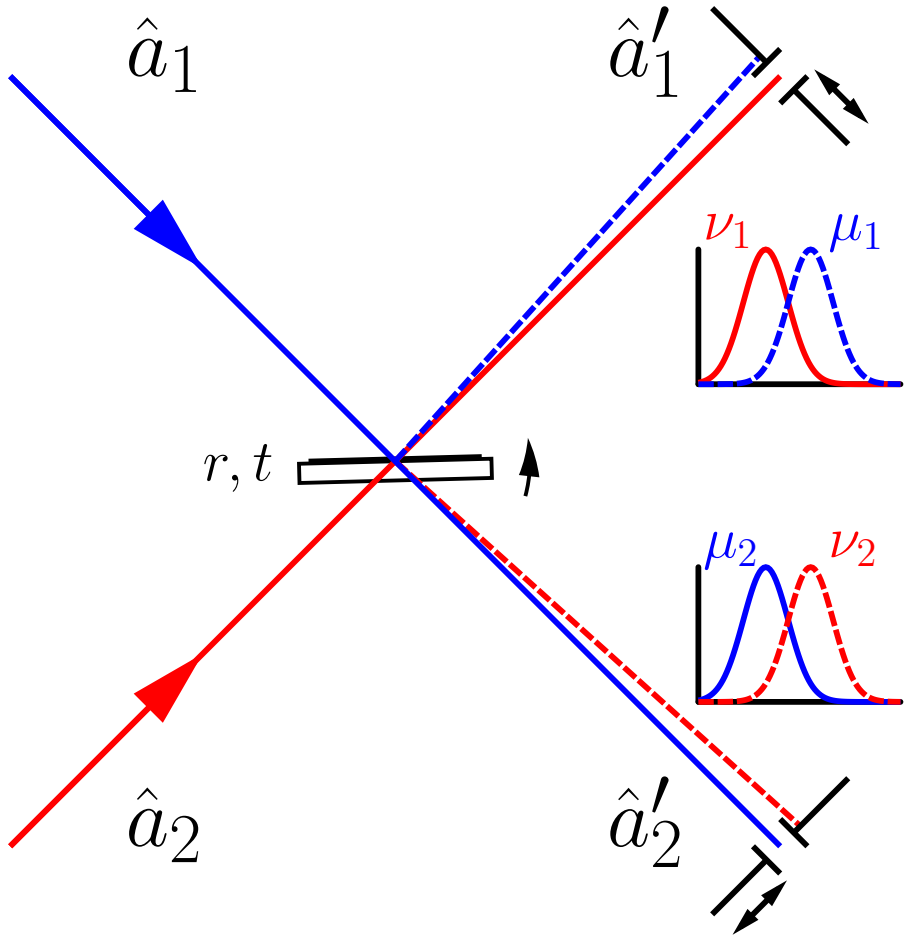


Content

Coupling losses

Losses due to different coupling

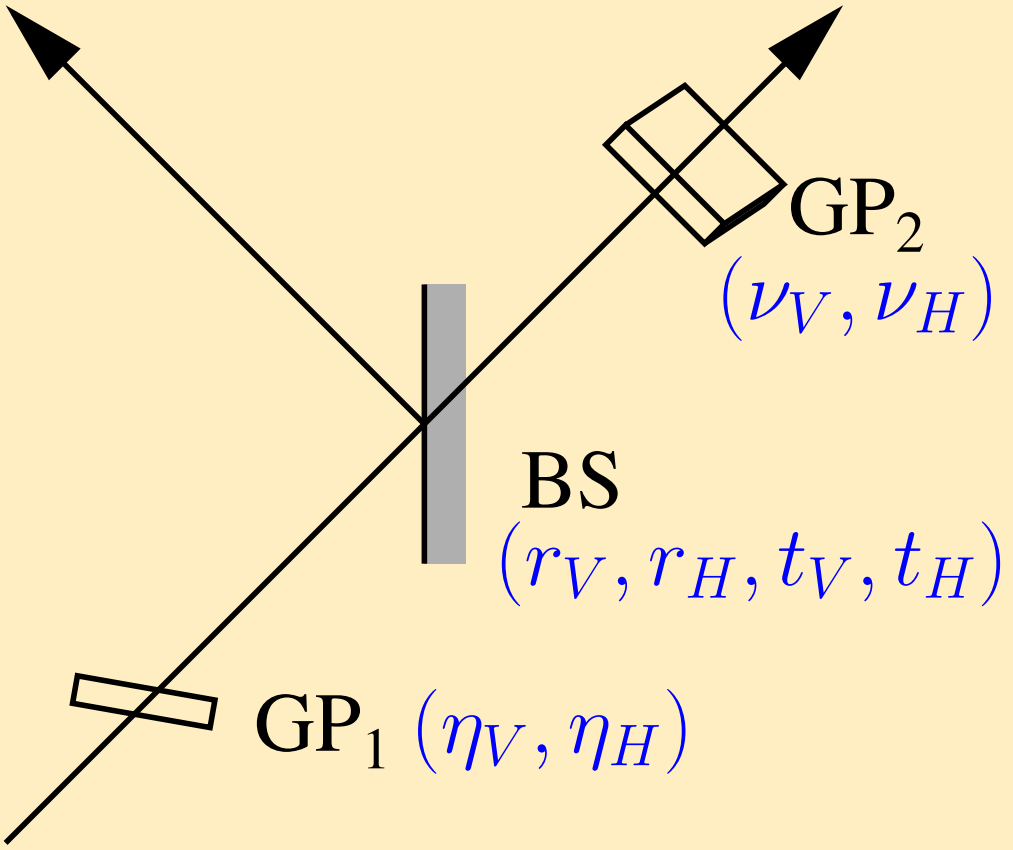
$$\begin{pmatrix} \hat{a}'_1 \\ \hat{a}'_2 \end{pmatrix} = \begin{pmatrix} r\mu_1 & t\nu_1 \\ t\mu_2 & -r\nu_2 \end{pmatrix} \begin{pmatrix} \hat{a}_1 \\ \hat{a}_2 \end{pmatrix}$$



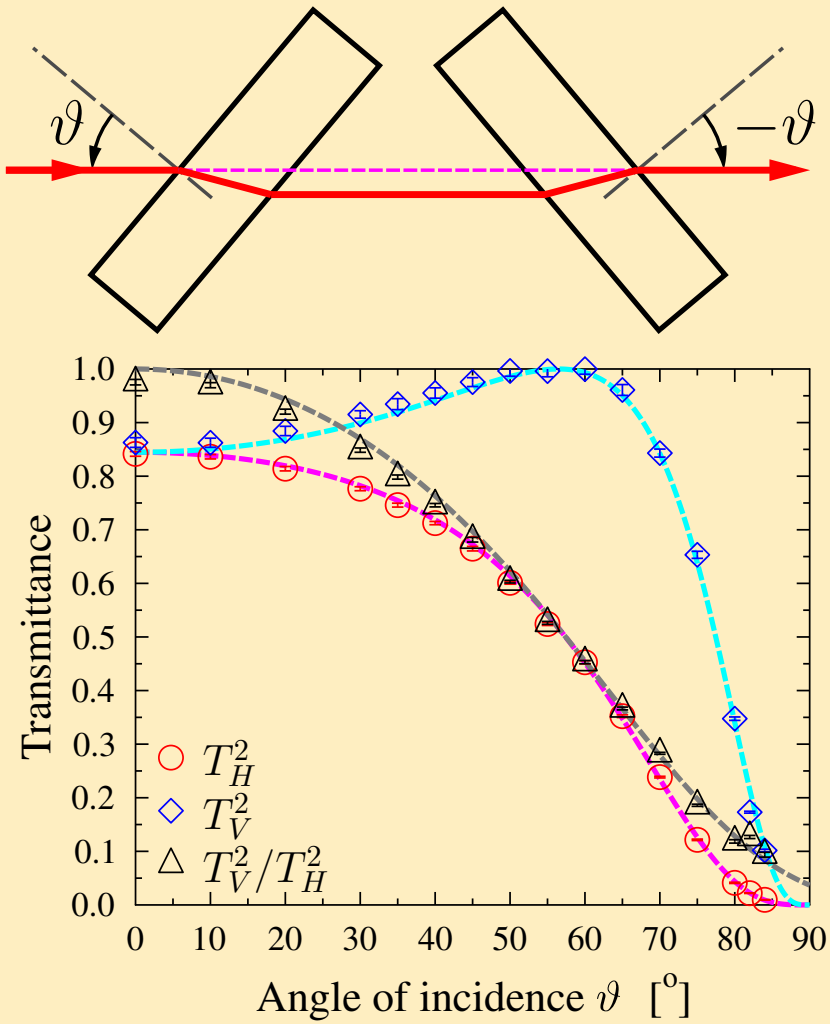
$$\left.\begin{array}{ll} R = 0.4 & T = 0.6 \\ |\mu|^2 = 1 & |\nu|^2 = 4/6 \end{array}\right\} \textbf{efective splitting ratio } 50/50$$

Polarization dependent losses

Polarization dependence of BS

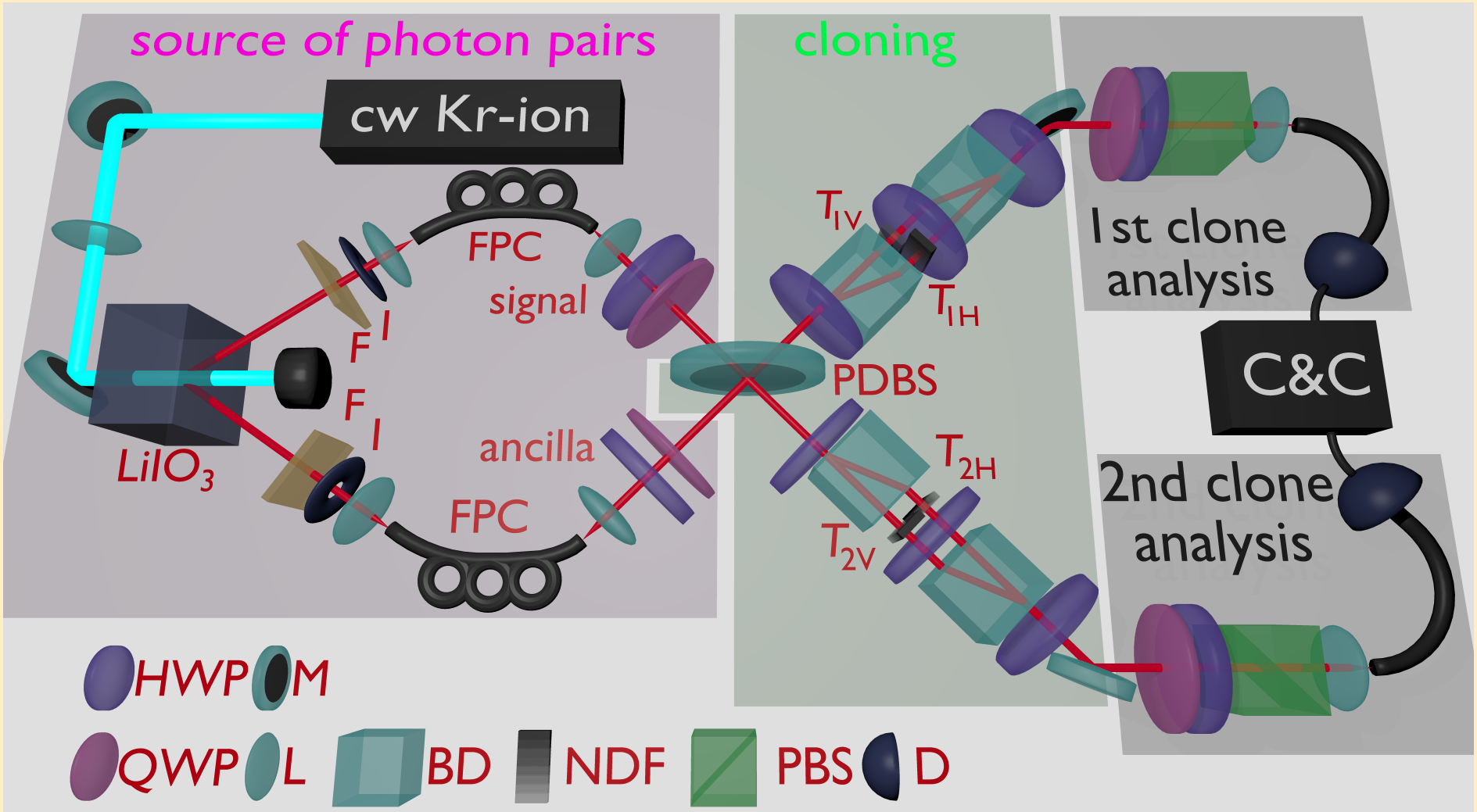


Glass plate pair



Polarization dependent losses

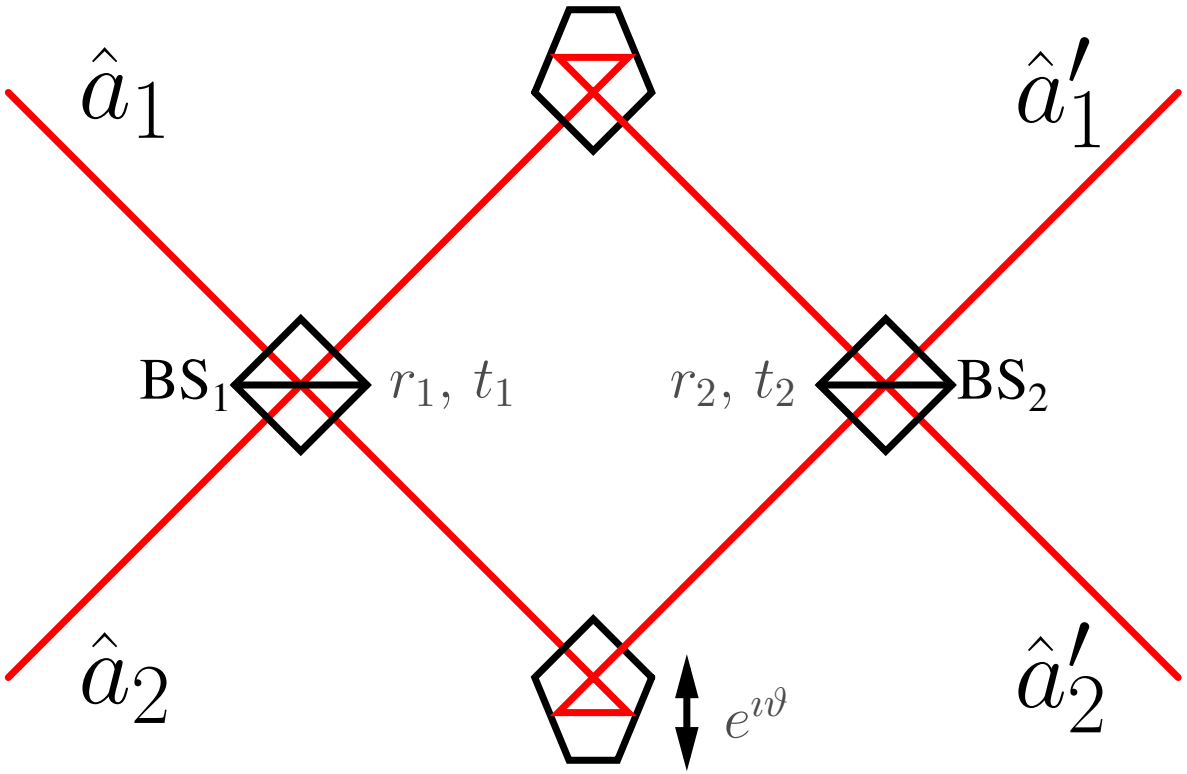
Beam Divider Assembly in work

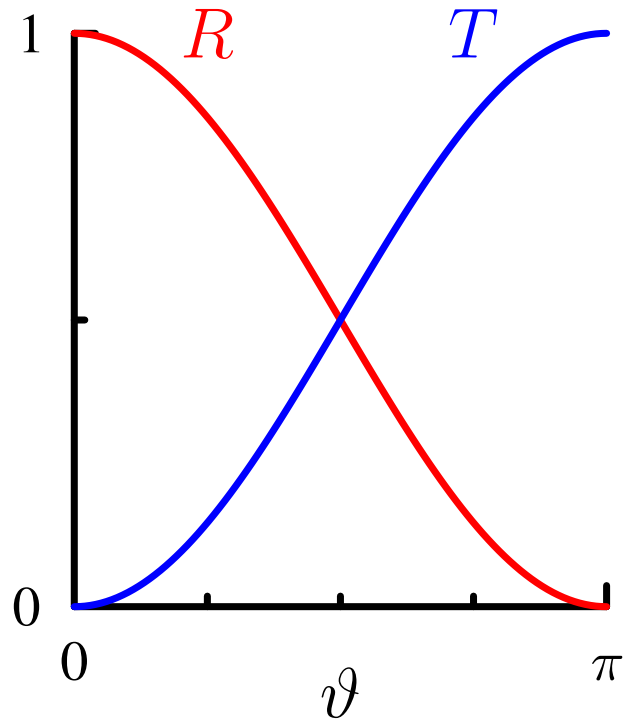


Content

Interferometer as a tunable beam-splitter

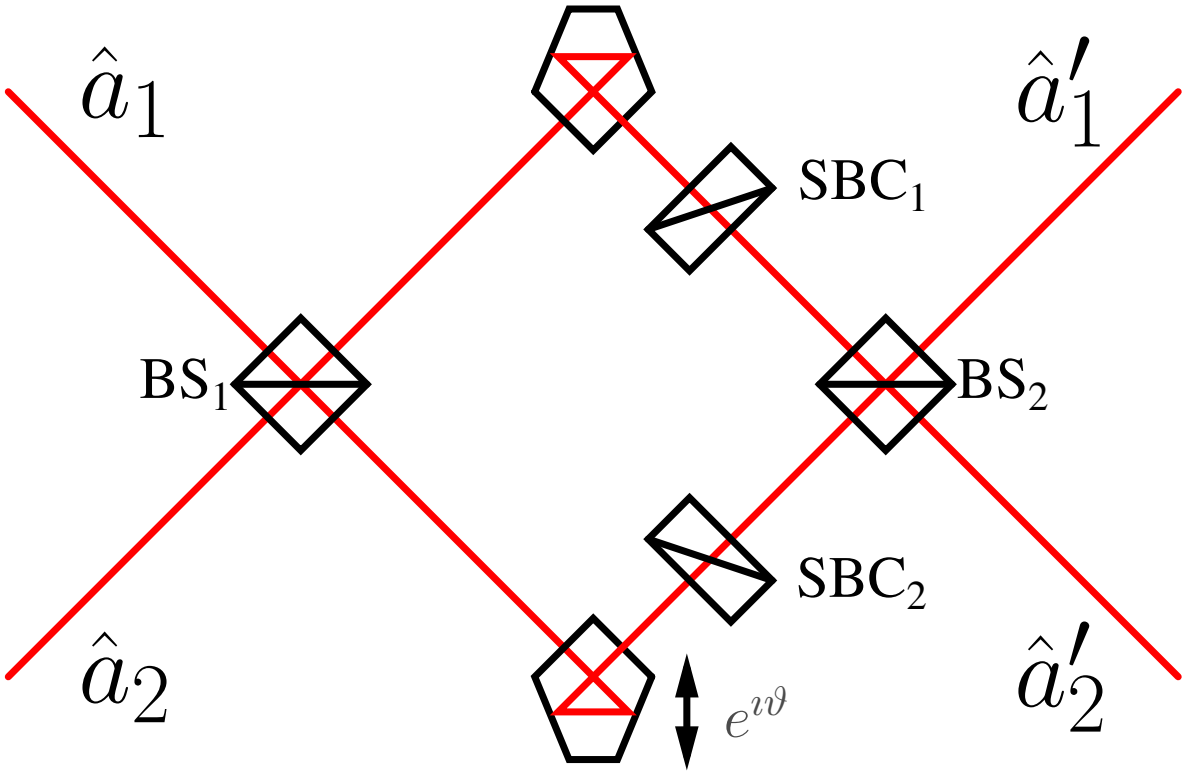
$$\begin{pmatrix} \hat{a}'_1 \\ \hat{a}'_2 \end{pmatrix} = \begin{pmatrix} r_2 & t_2 \\ t_2 & -r_2 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & e^{i\vartheta} \end{pmatrix} \begin{pmatrix} r_1 & t_1 \\ t_1 & -r_1 \end{pmatrix} \begin{pmatrix} \hat{a}_1 \\ \hat{a}_2 \end{pmatrix}$$

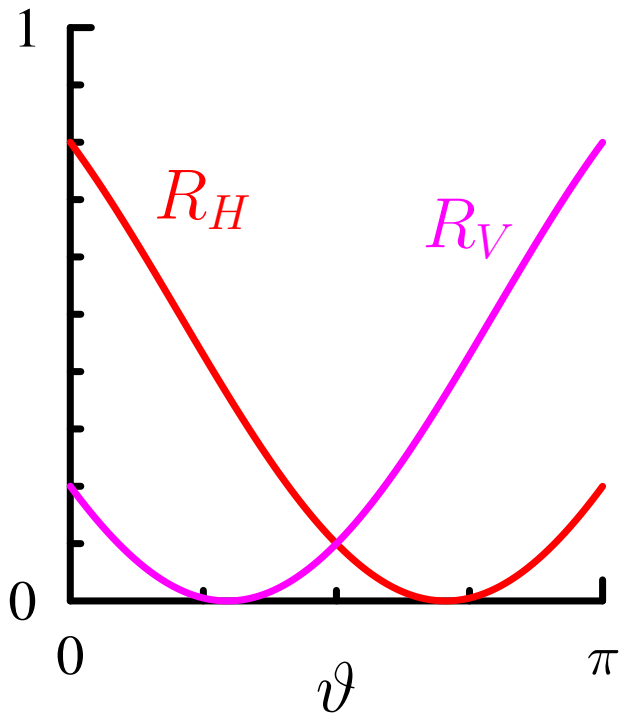




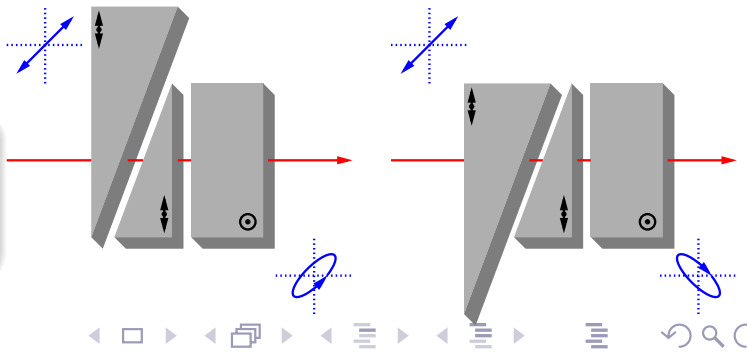
$$r_{1,2} = t_{1,2} = \frac{1}{\sqrt{2}} \quad \rightarrow \quad R = \frac{1+\cos\vartheta}{2} \qquad T = \frac{1-\cos\vartheta}{2}$$

Polarization dependent splitting by interferometer

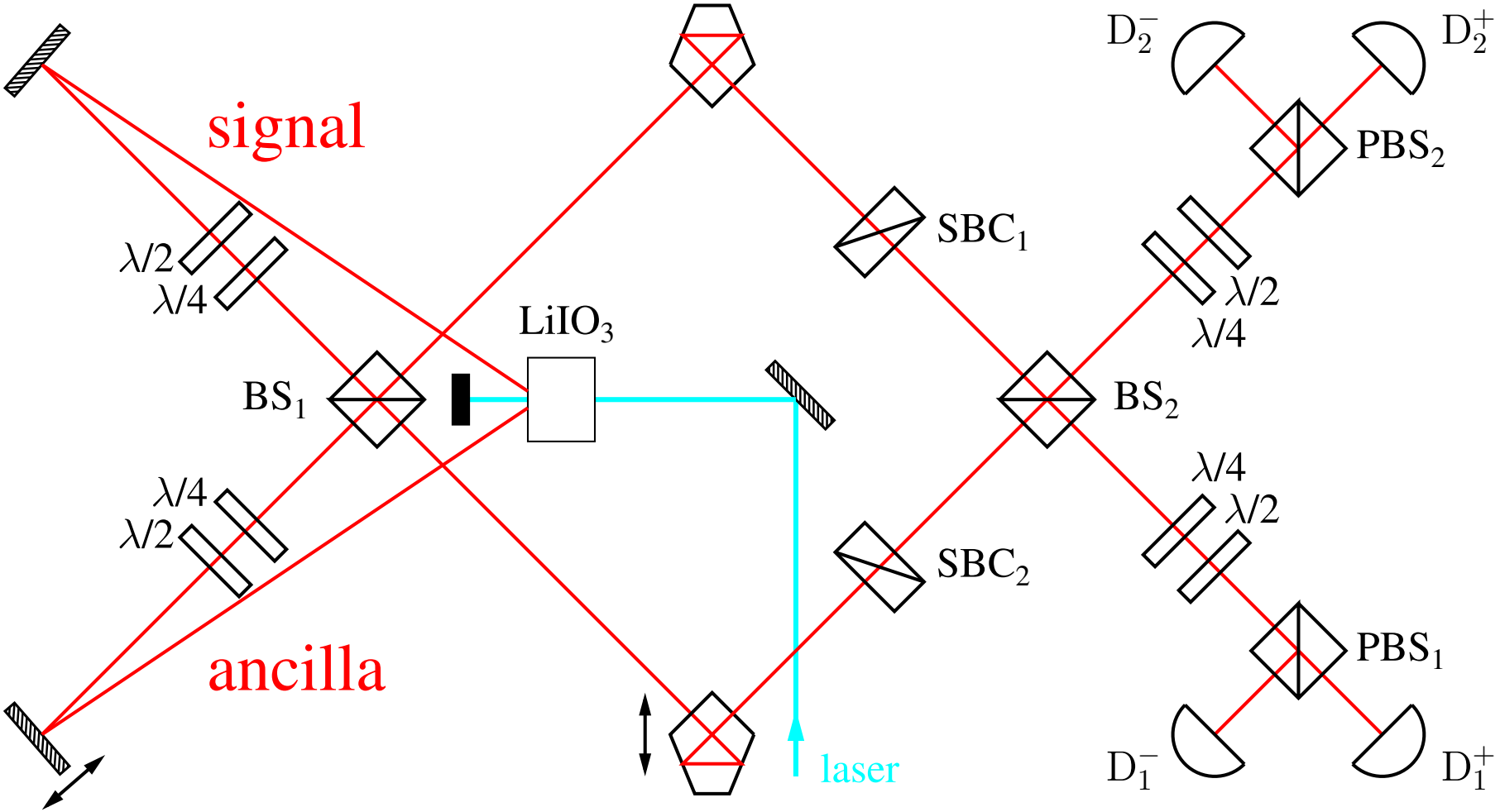




plus	minus
fully variable ratio	phase stability



First steps in 2005

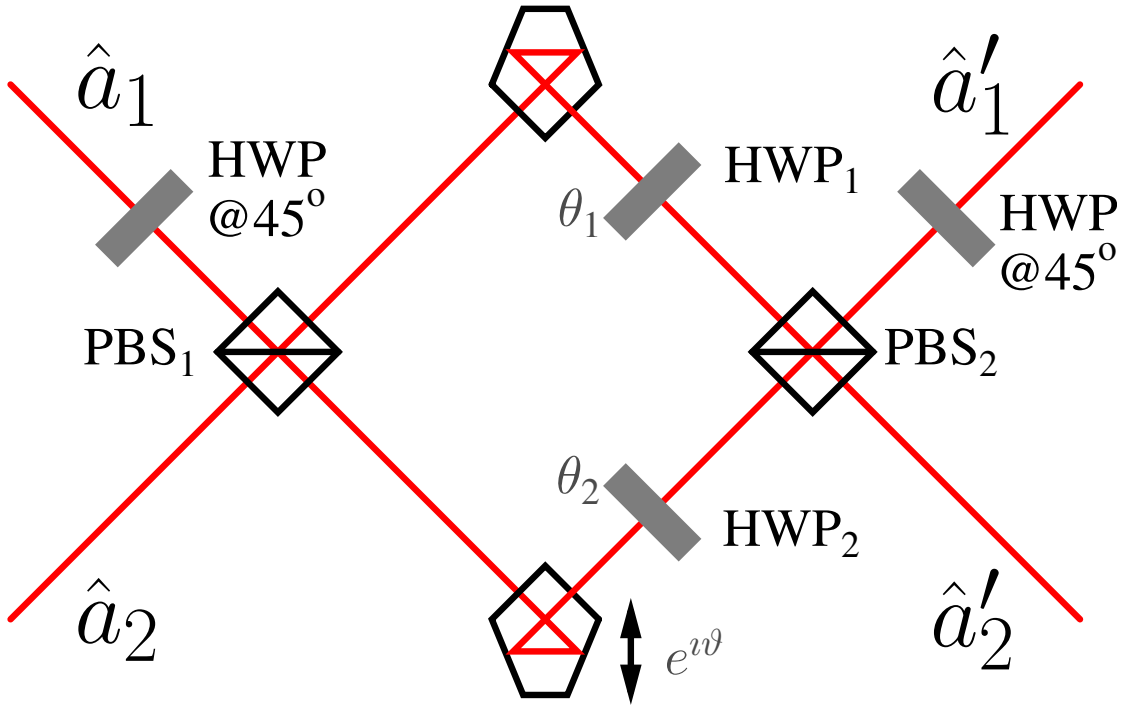


big and unstable, bad visibility because SM not used

New hope

Jan Jašek diploma thesis on Machine learned cloning

- $R_H \sim \cos^2 2\theta_1$
- $R_V \sim \cos^2 2\theta_2$
- ϑ control phase between H and V

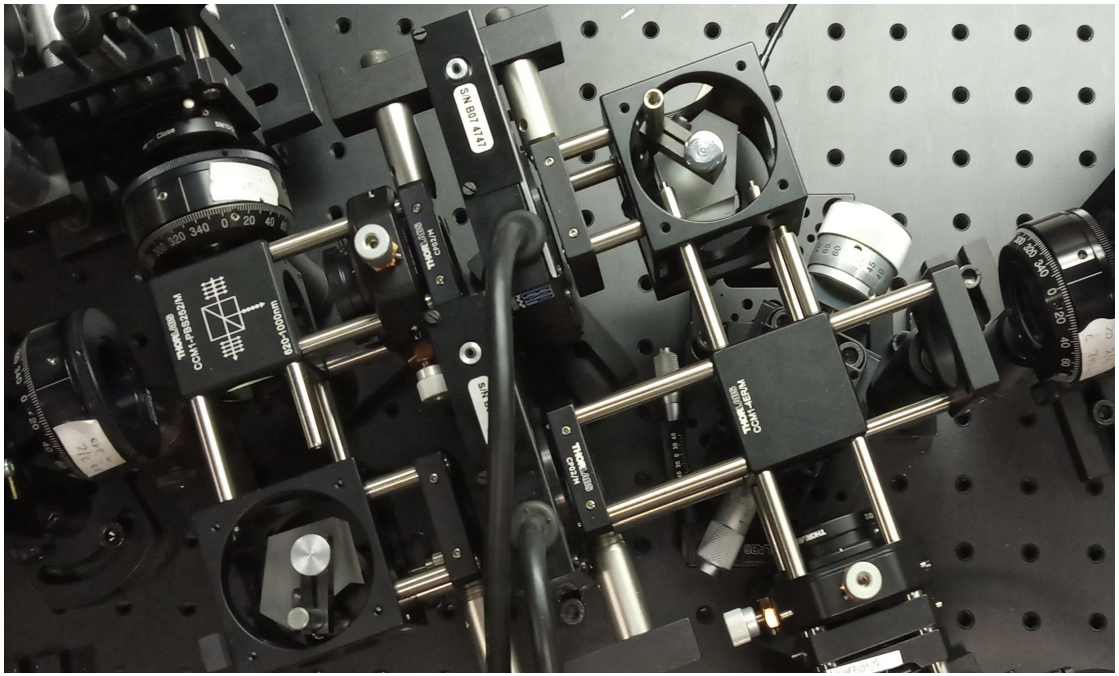


Improvements

- manufactured PBS are better than BS ($R_V > 99.5\%$, $T_H > 90\%$)
- HWP – only two surfaces with anti-reflections

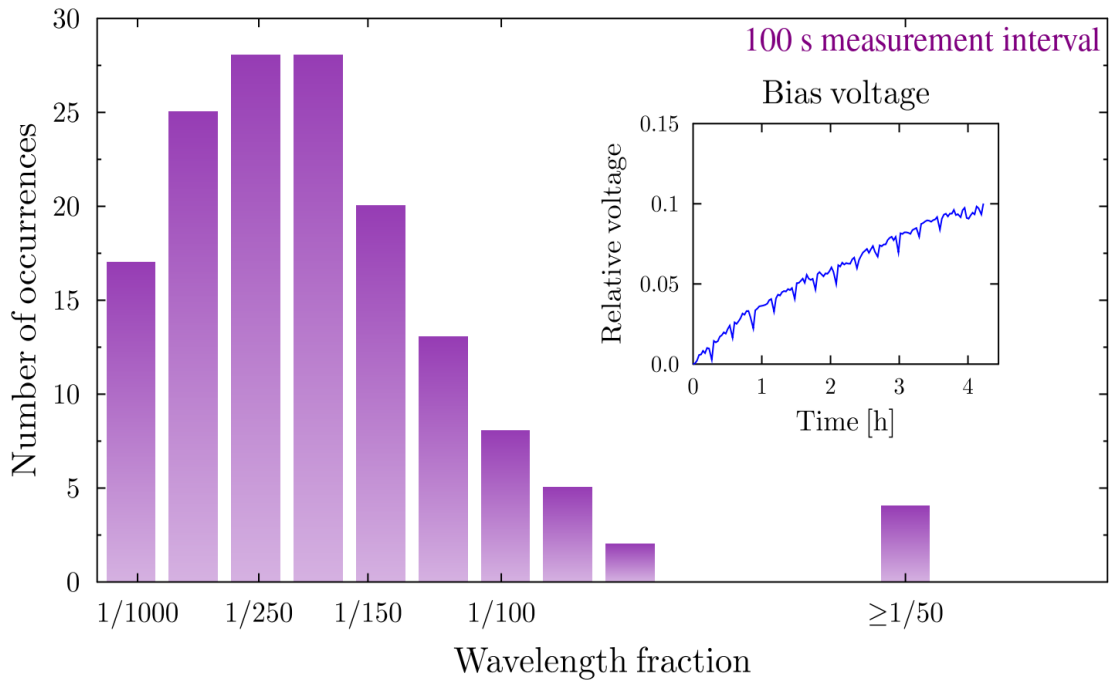
Construction

- compact cage system
- air-condition
- covering box



Preliminary measurements:
phase stability per 100 s

WORKING



This is the END – thanks for attention