Kavan Modi

Centre for
Quantum
Technologies

NUS
National University
of Singapore

Enhancement in Quantum Metrology

Hugo Cable

Mark Williamson

Vlatko Vedral

Metrology

science of (precision) measurement.

Quantum

anything we do not call classical.

Quantum

anything we do not call classical.

superposition?

Quantum

anything we do not call classical.

superposition?
entanglement?

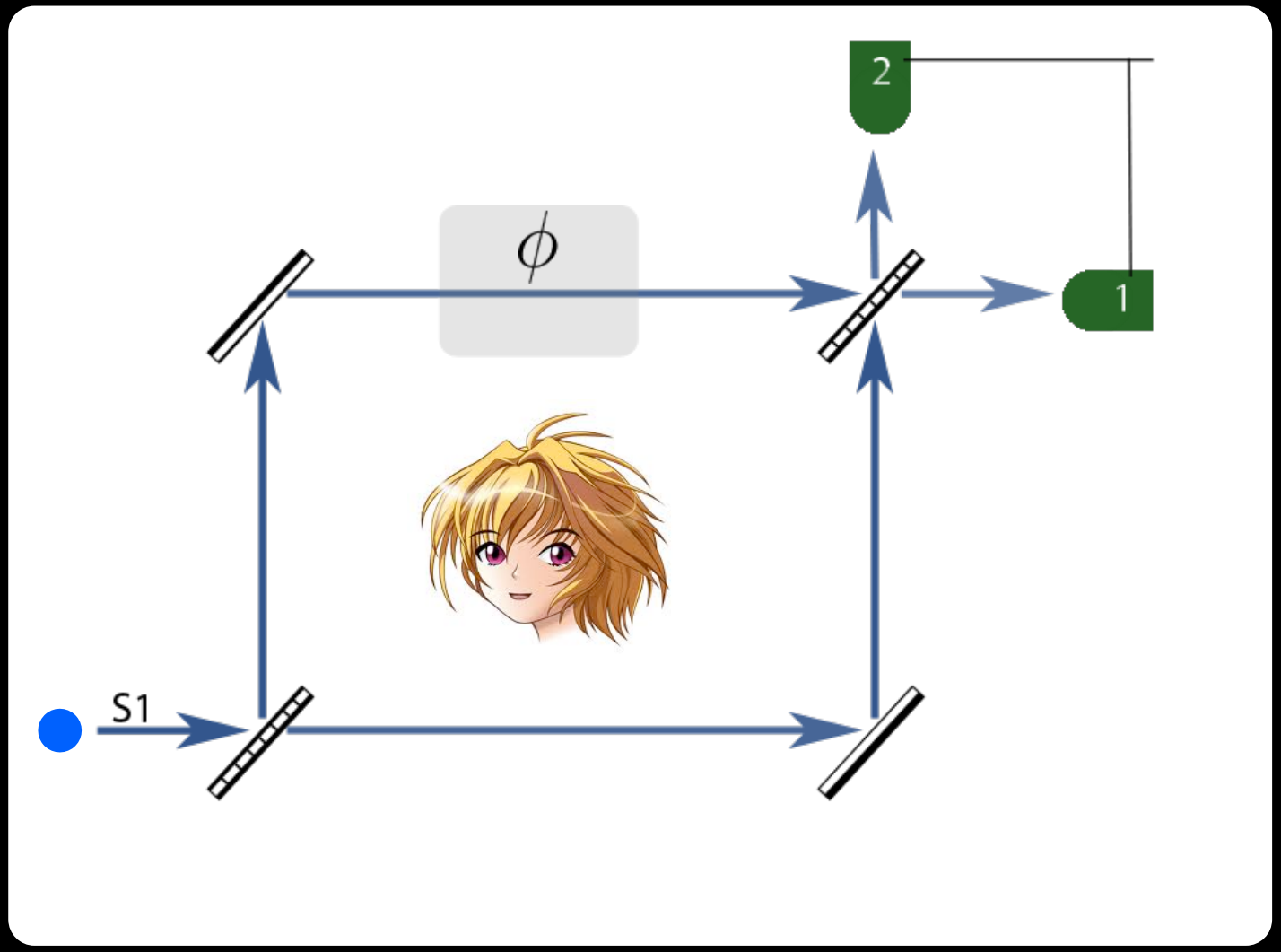
Quantum

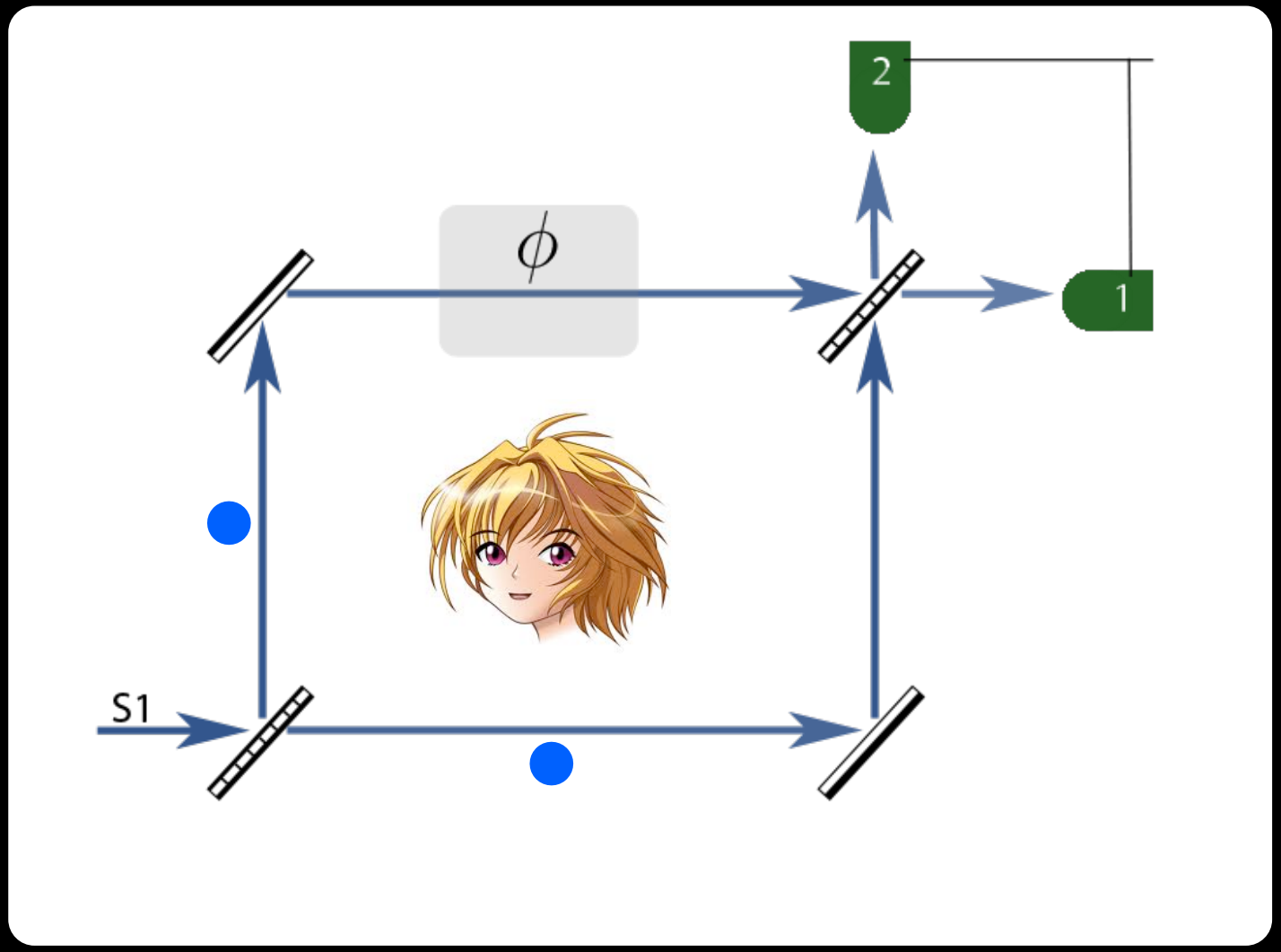
anything we do not call classical.

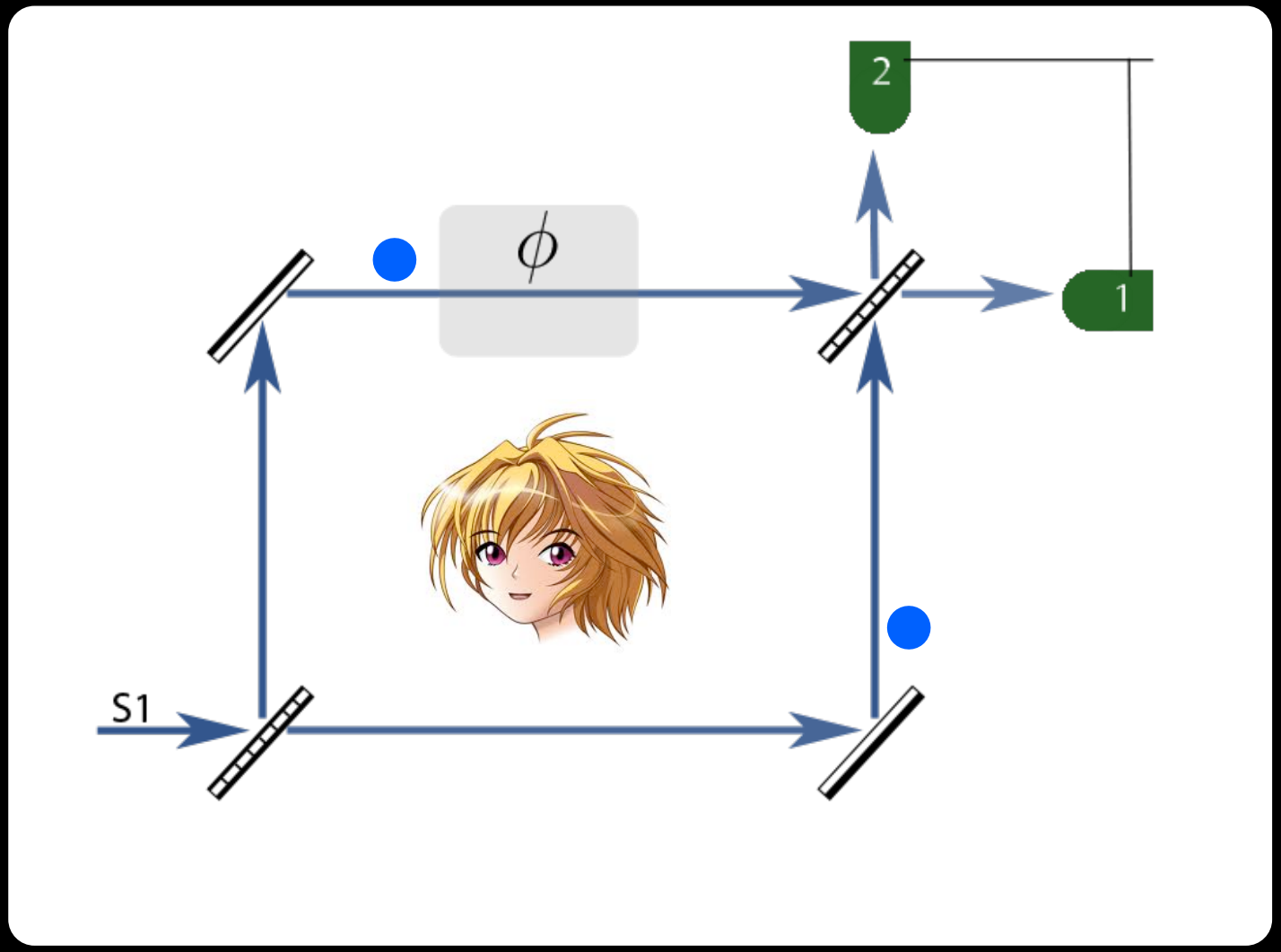
superposition?
entanglement?
discordant?

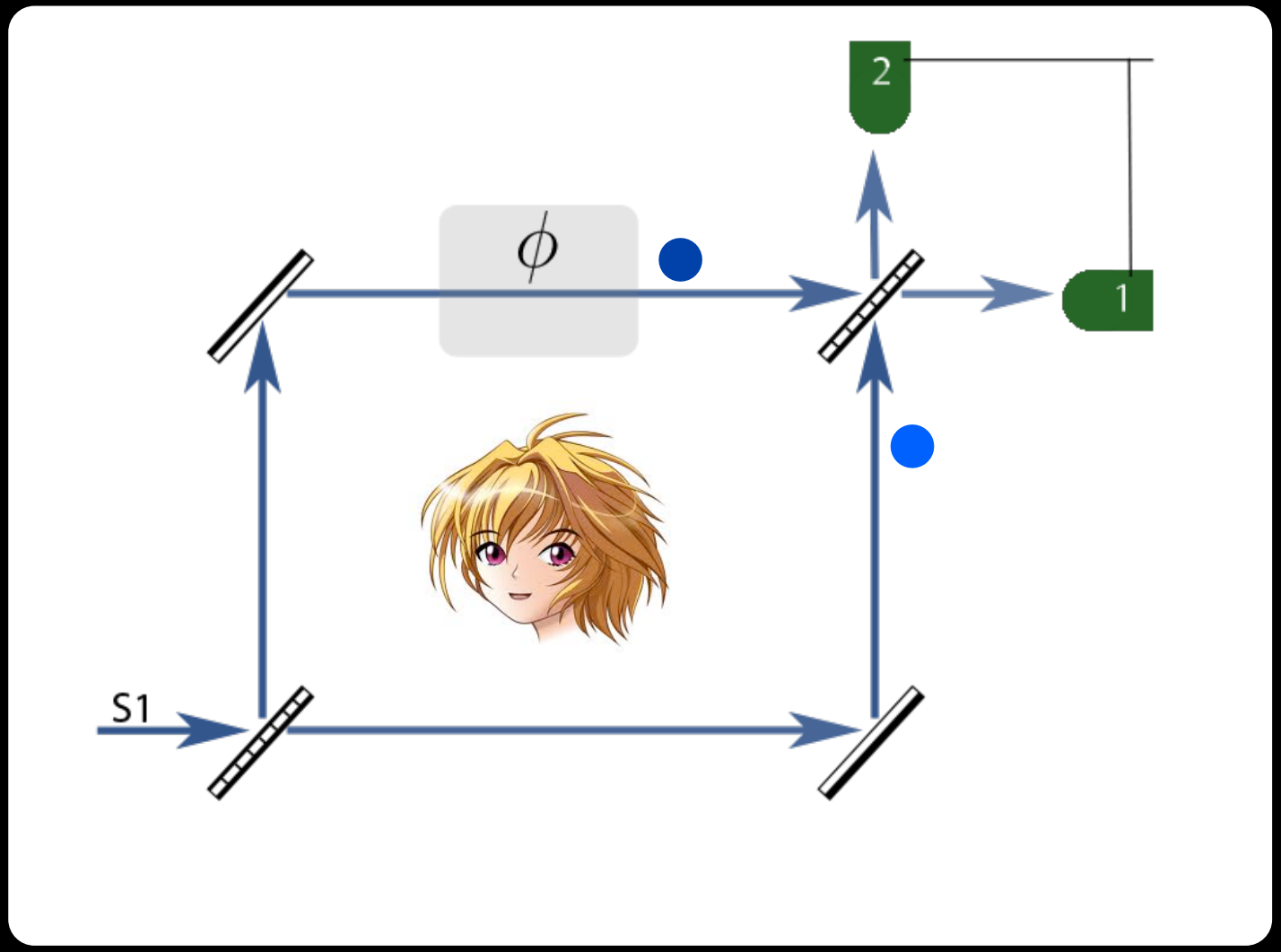
What do we mean by quantum discord?

Metrology

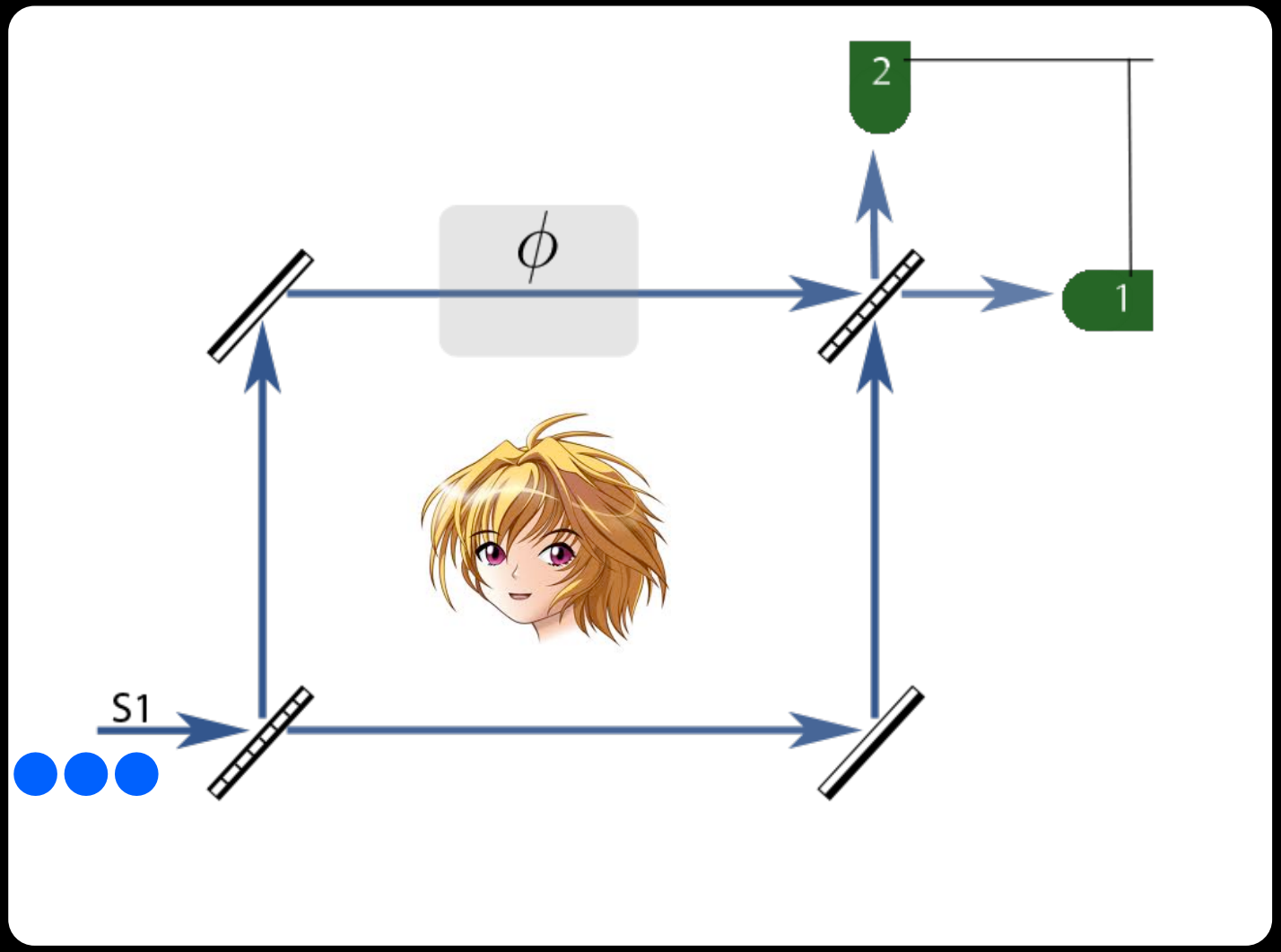

2
ϕ
1
S1

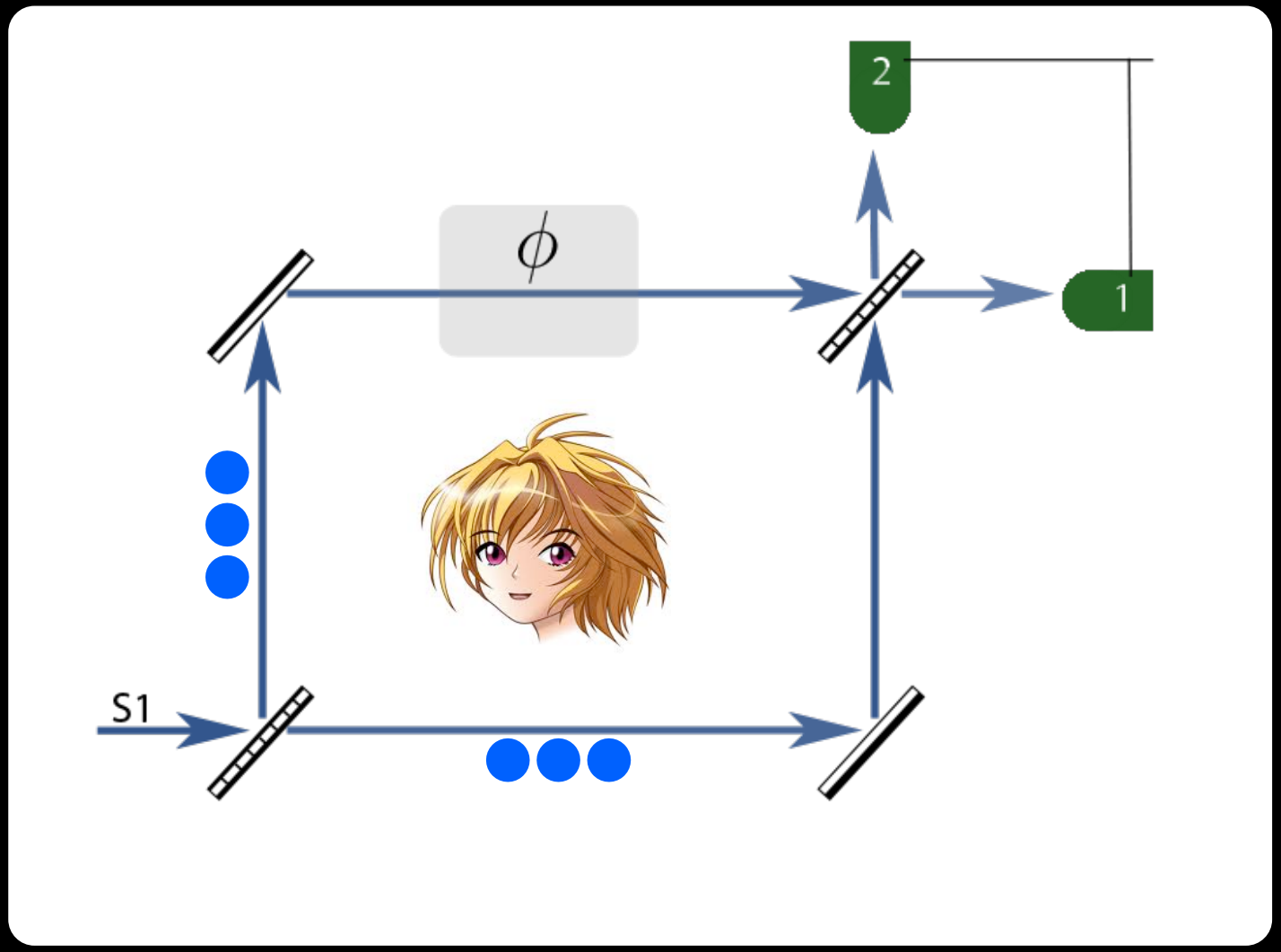

2
ϕ
1
S1

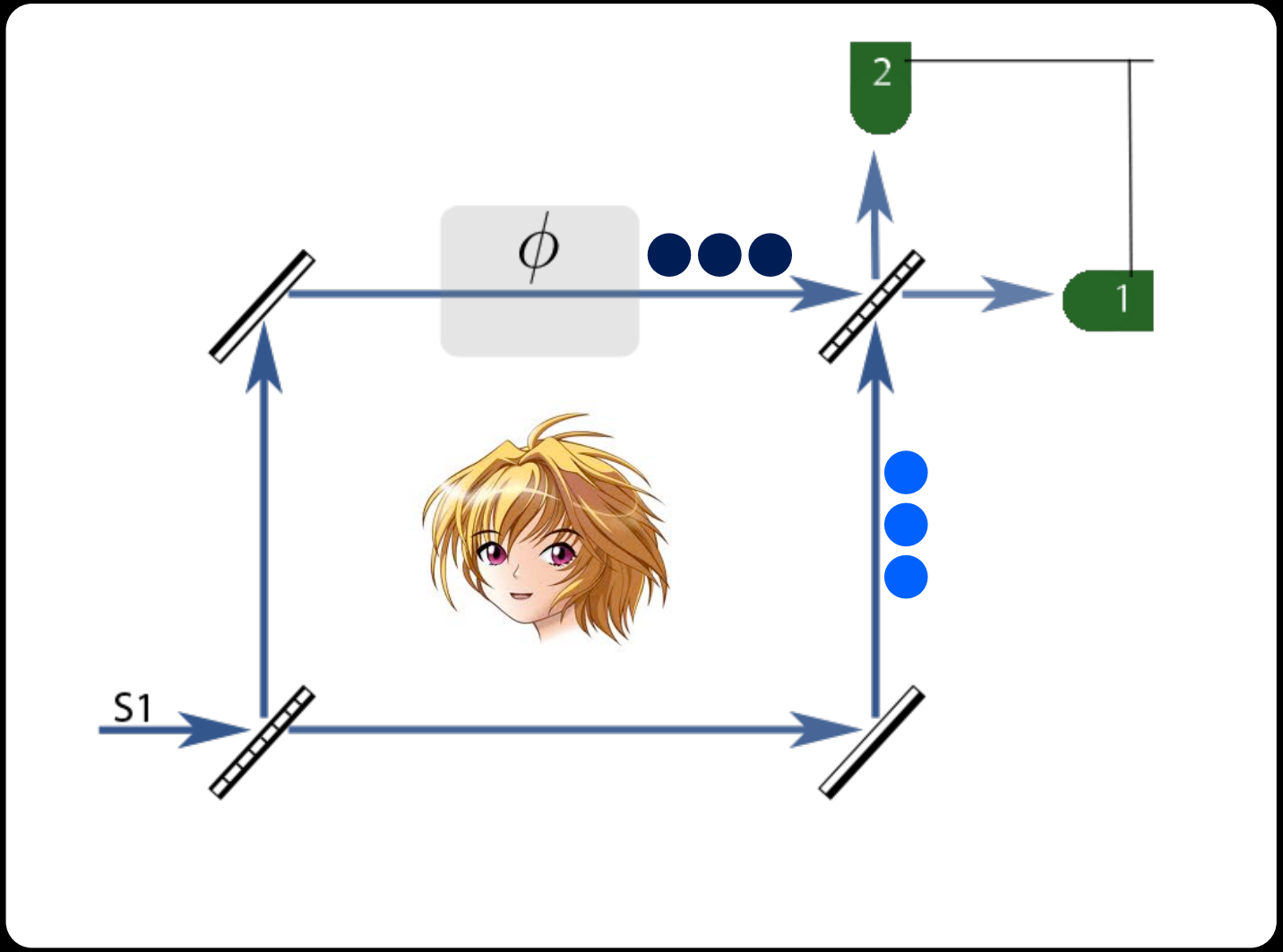

2
ϕ
1
S1


2
ϕ
1
S1

$$\Delta\phi \quad \text{is} \quad \frac{1}{\sqrt{N}}$$

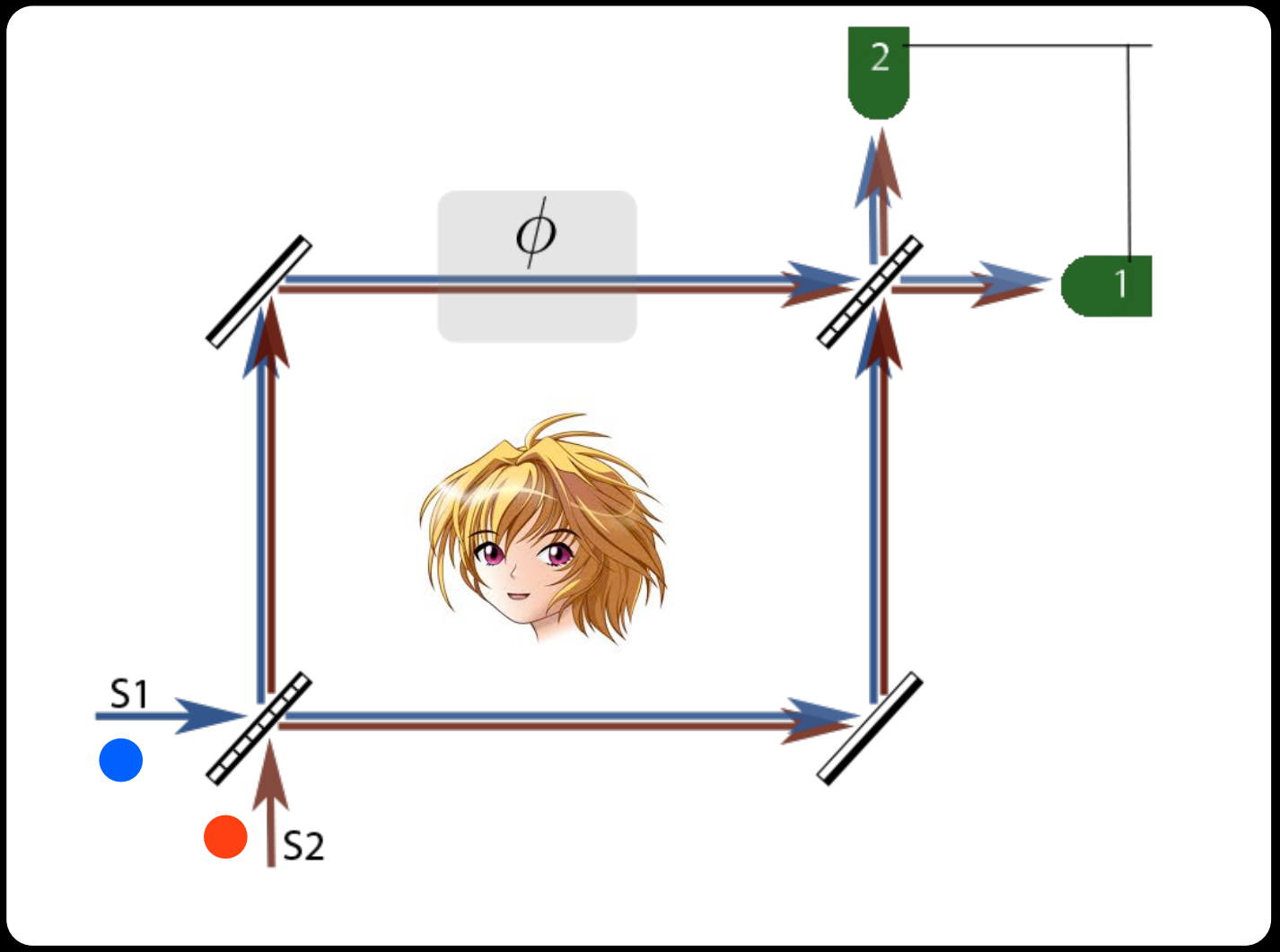

2
ϕ
1
S1

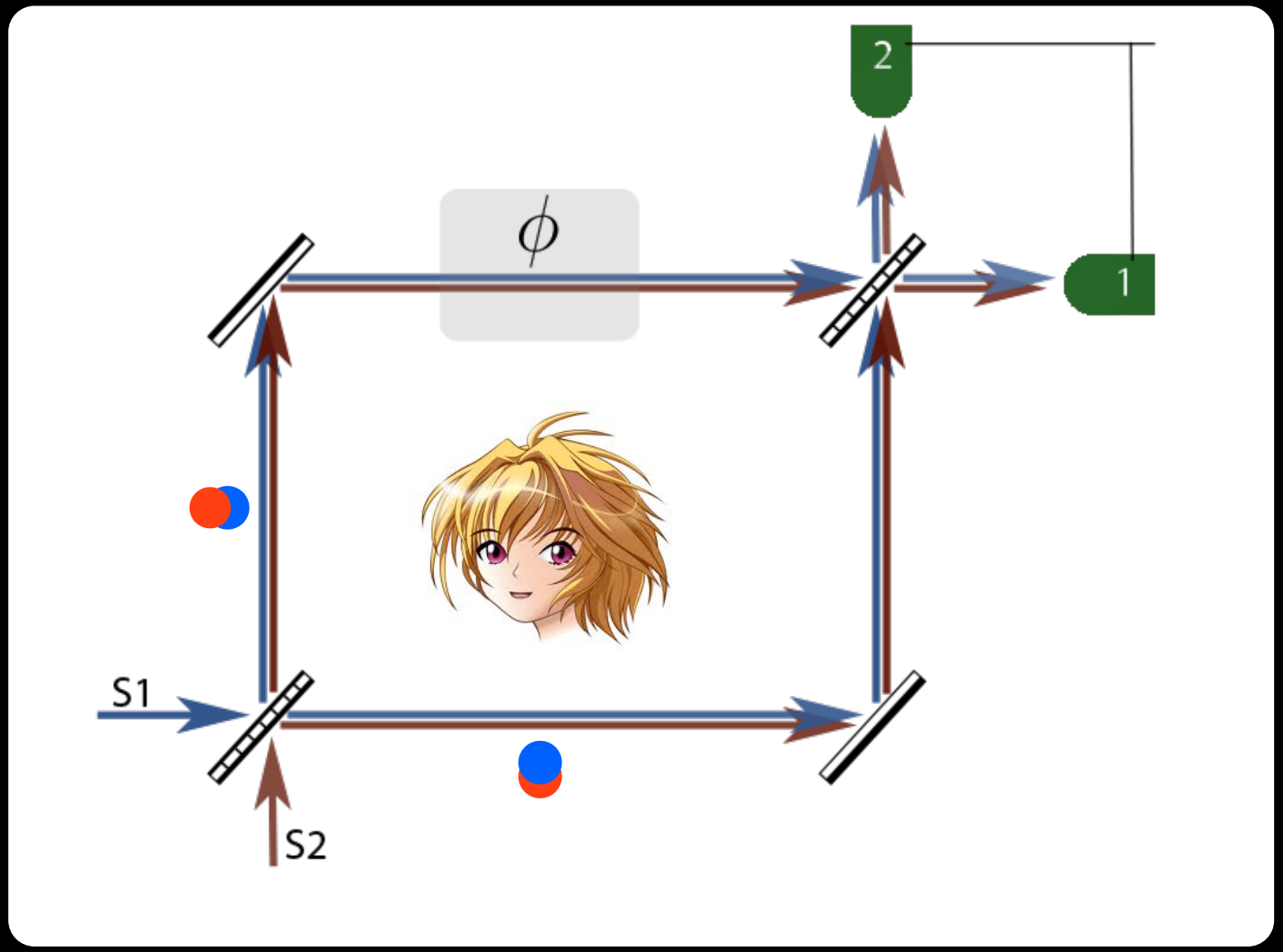

2
ϕ
1
S1

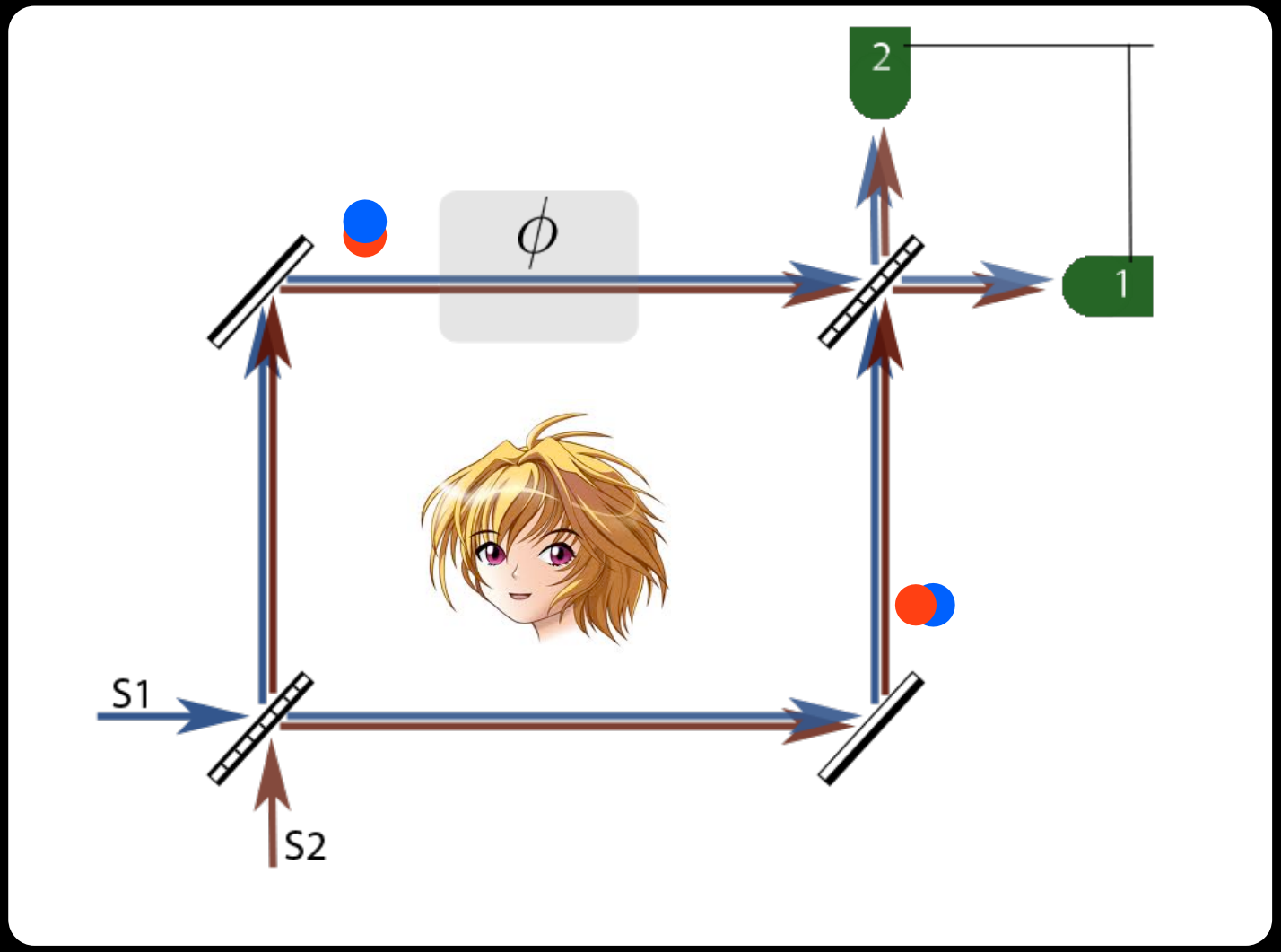

2
ϕ
1
S1

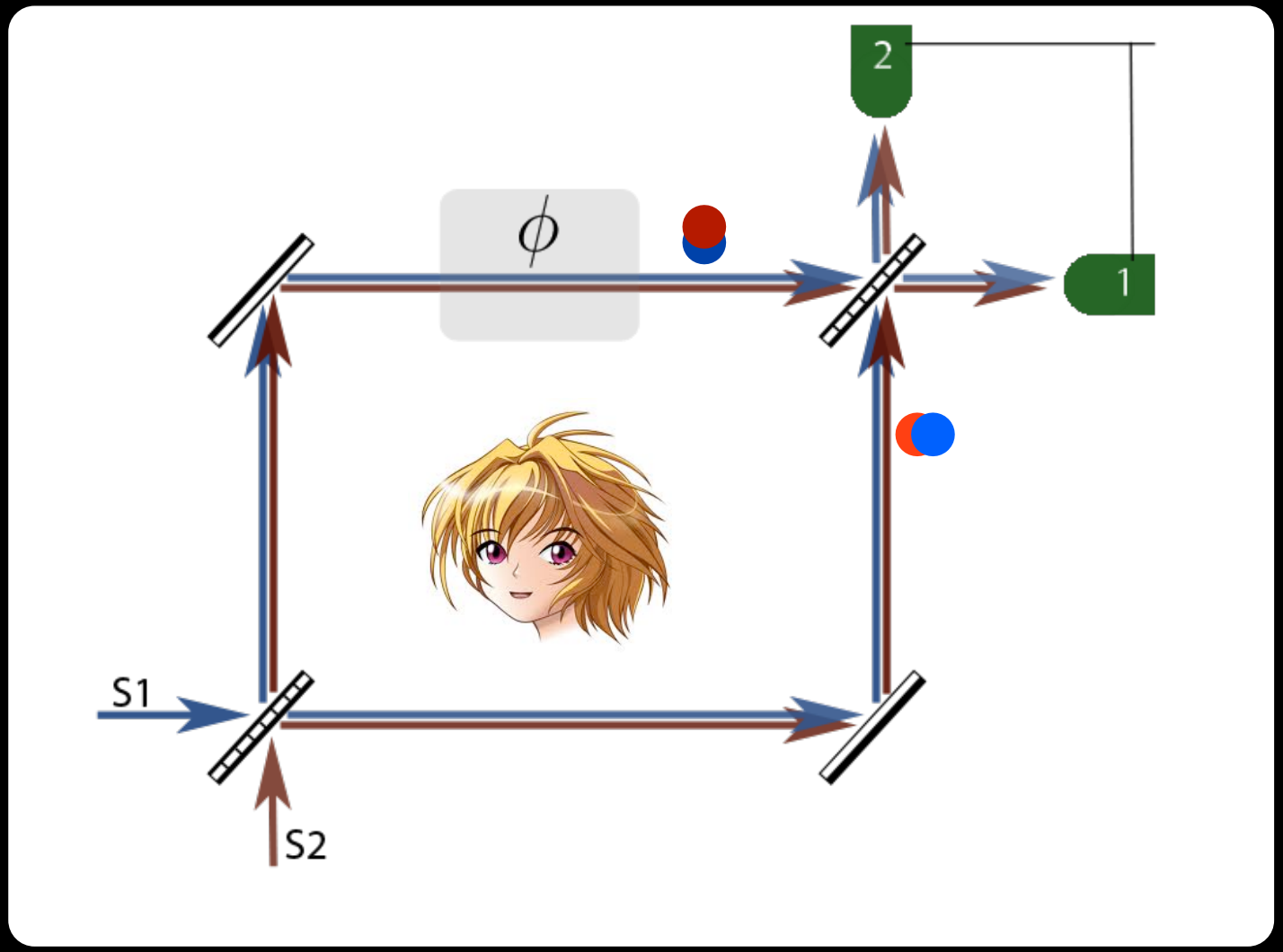
$$\Delta\phi \quad \text{is} \quad \frac{1}{N}$$

Mixed states


2
ϕ
1
S1
S2


2
ϕ
1
S1
S2


2
1
ϕ
S1
S2

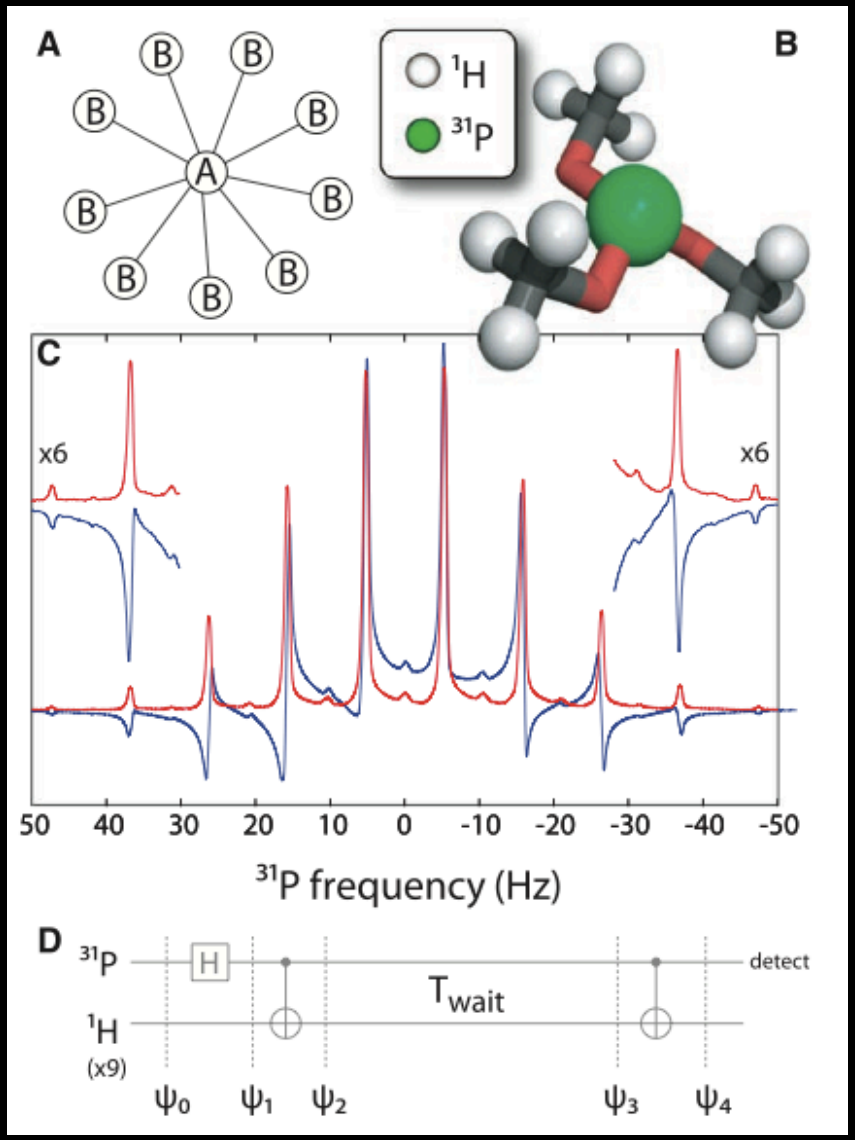

2
1
ϕ
S1
S2

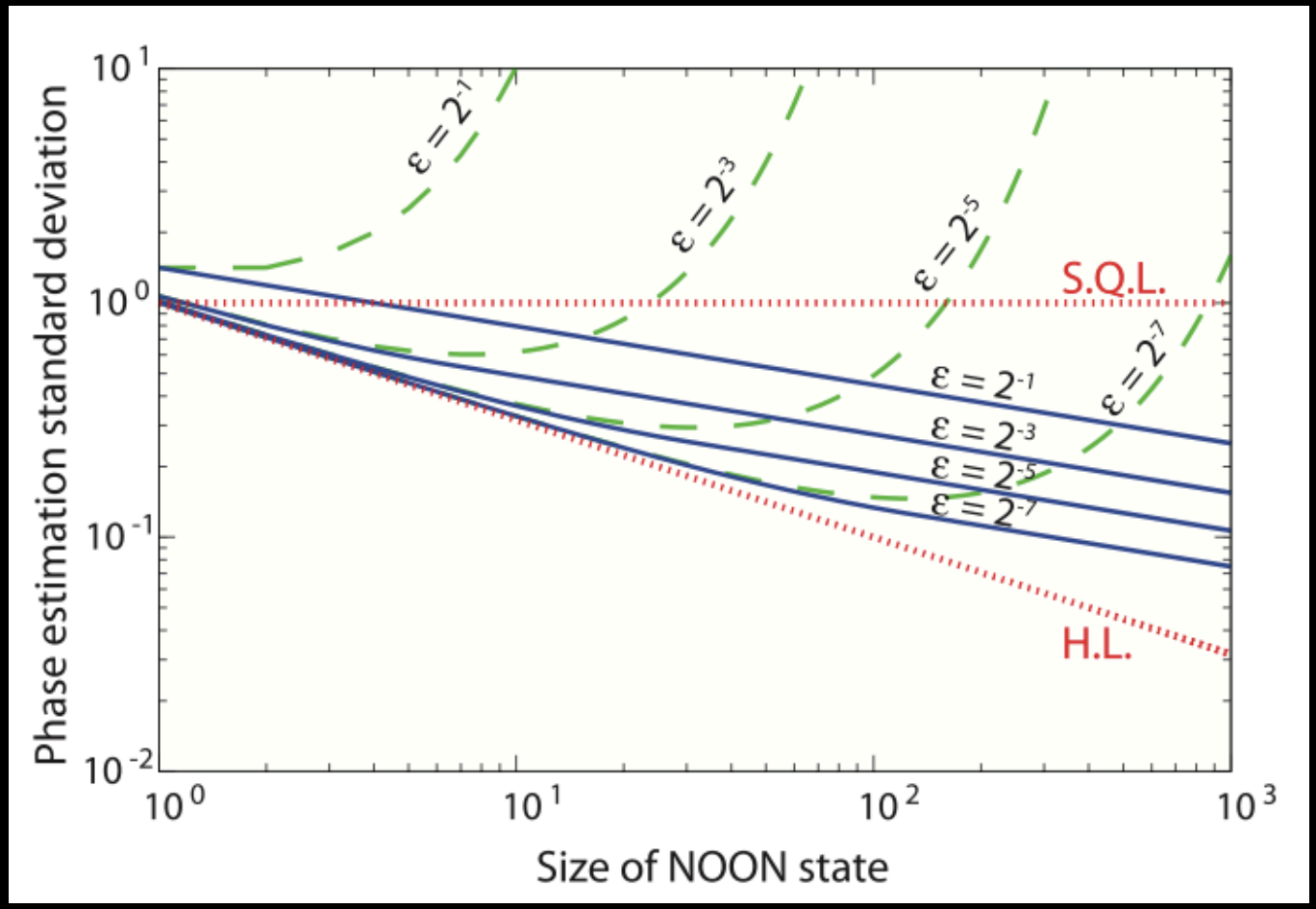
$$\Delta\phi \quad \text{is} \quad \frac{1}{p\sqrt{N}}$$

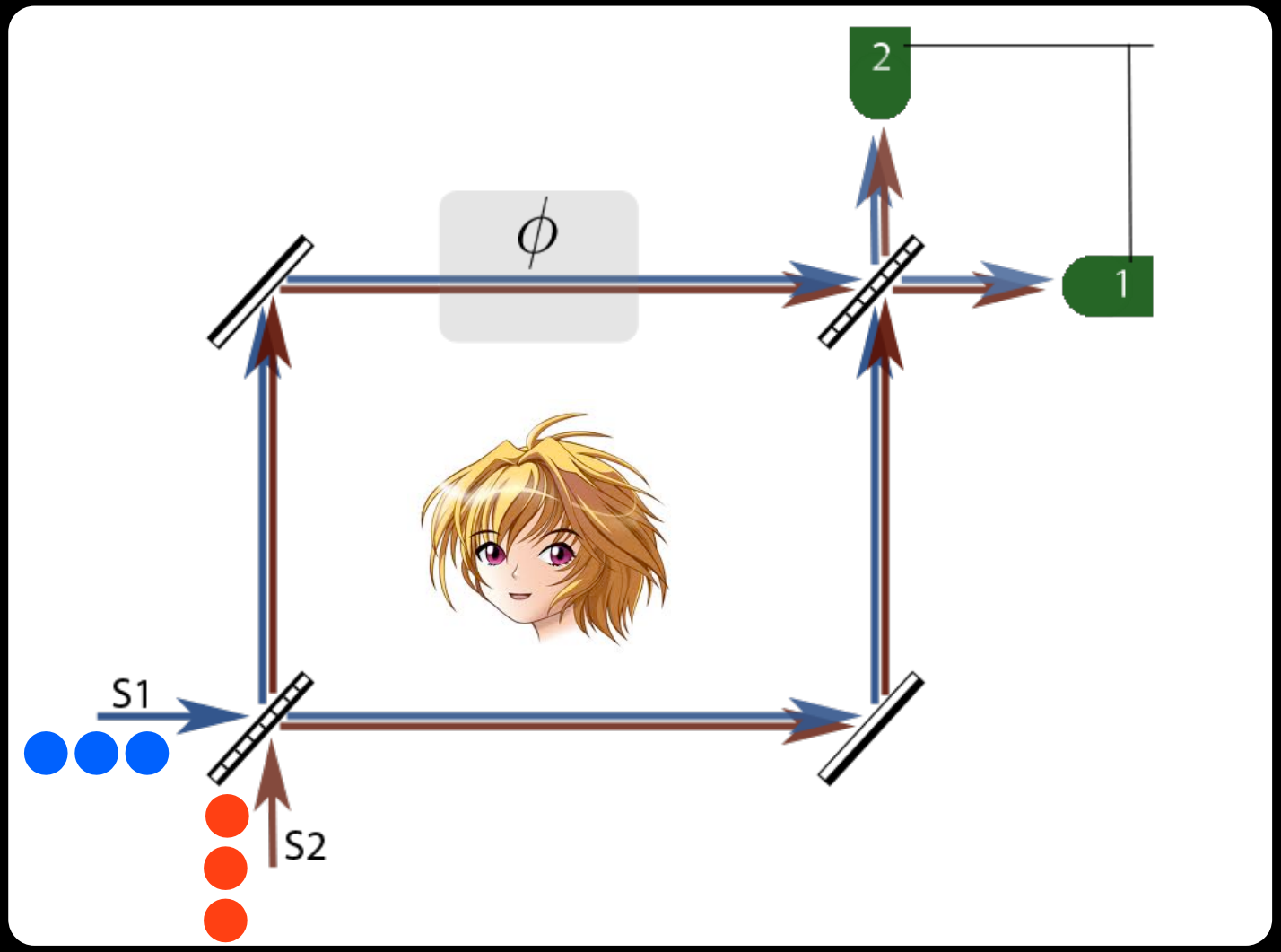
Magnetic Field Sensing Beyond the Standard Quantum Limit Using 10-Spin NOON States

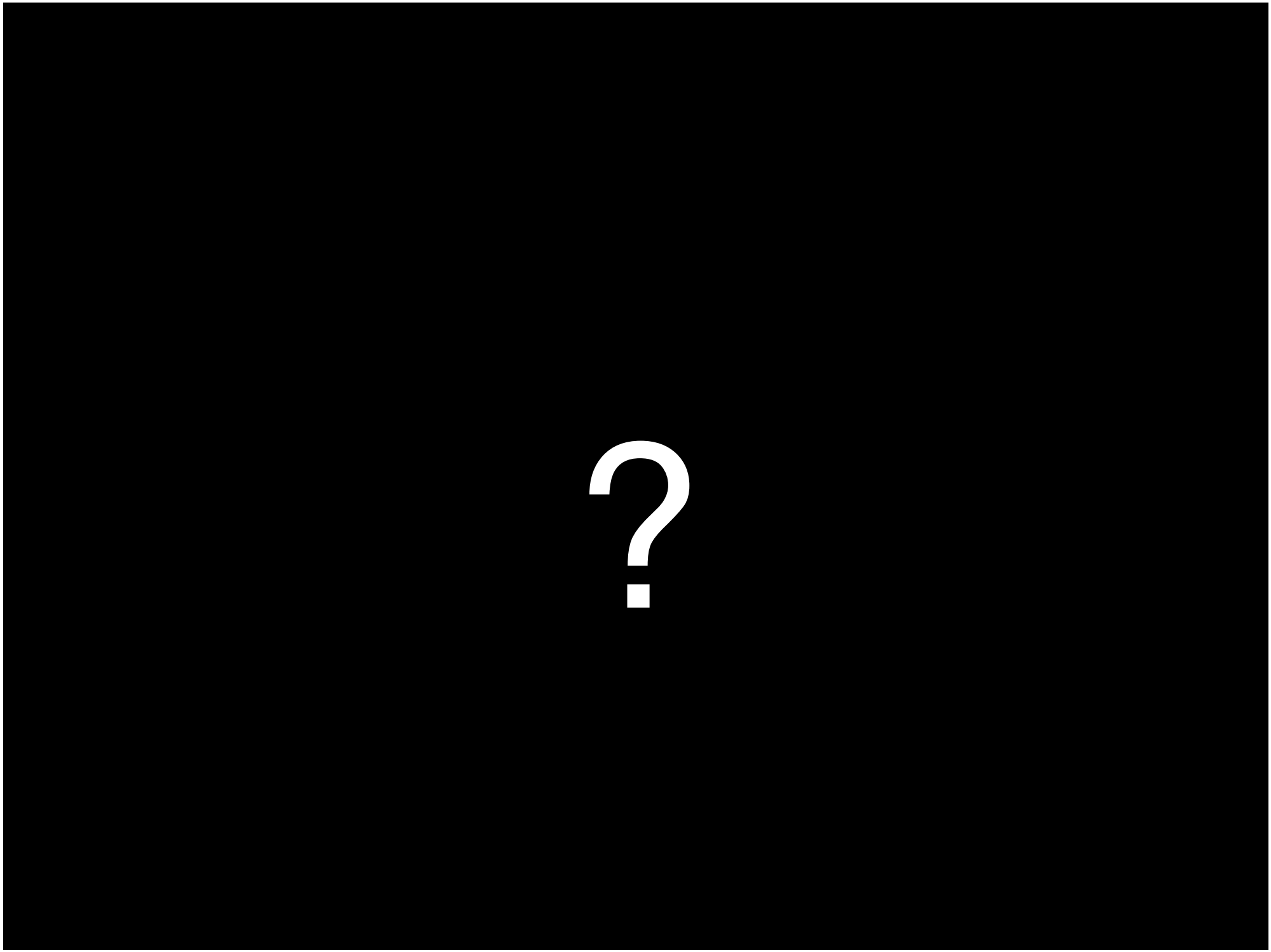
Jonathan A. Jones,[1] Steven D. Karlen,[2] Joseph Fitzsimons,[2,3] Arzhang Ardavan,[1] Simon C. Benjamin,[2,4] G. Andrew D. Briggs,[2] John J. L. Morton[1,2*]

Science

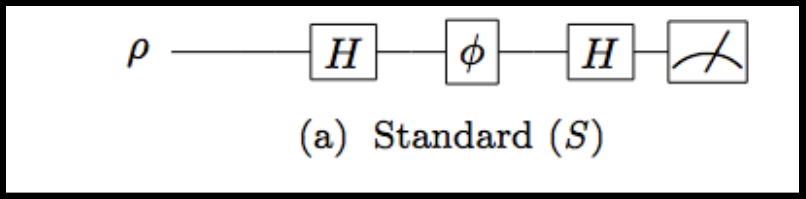

A
B
B
B
B
B
B
B
B
B
A
B
^{1}H
^{31}P
C
x6
x6
50
40
30
20
10
0
-10
-20
-30
-40
-50
^{31}P frequency (Hz)
D
^{31}P
H
detect
T_{wait}
^{1}H
(x9)
ψ_0
ψ_1
ψ_2
ψ_3
ψ_4


Phase estimation standard deviation
Size of NOON state
S.Q.L.
H.L.
ε = 2^-1
ε = 2^-3
ε = 2^-5
ε = 2^-7

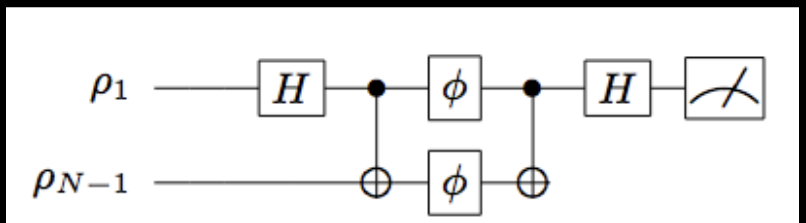

2
ϕ
1
S1
S2



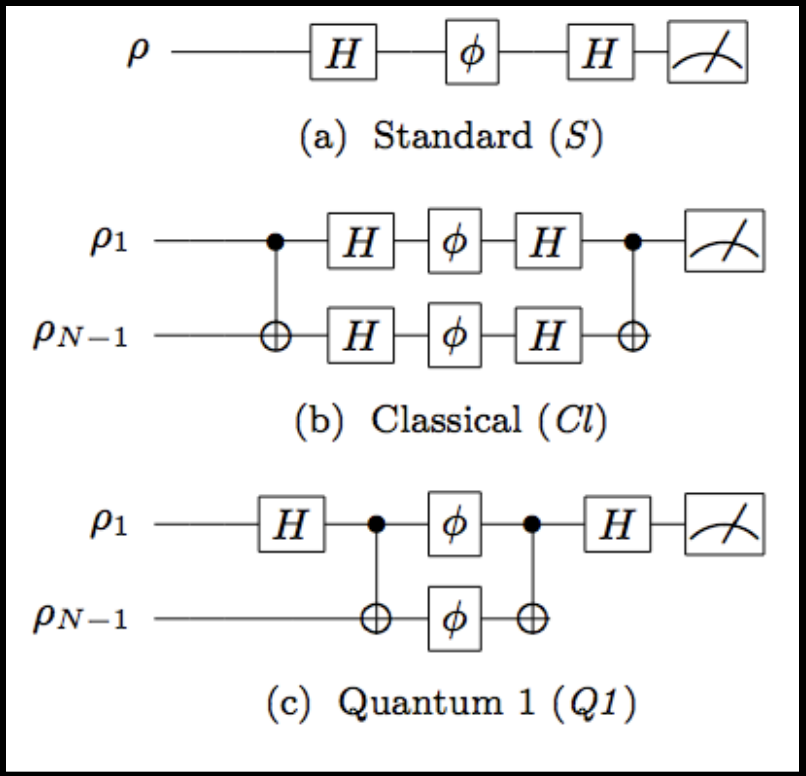
(a) Standard (S)

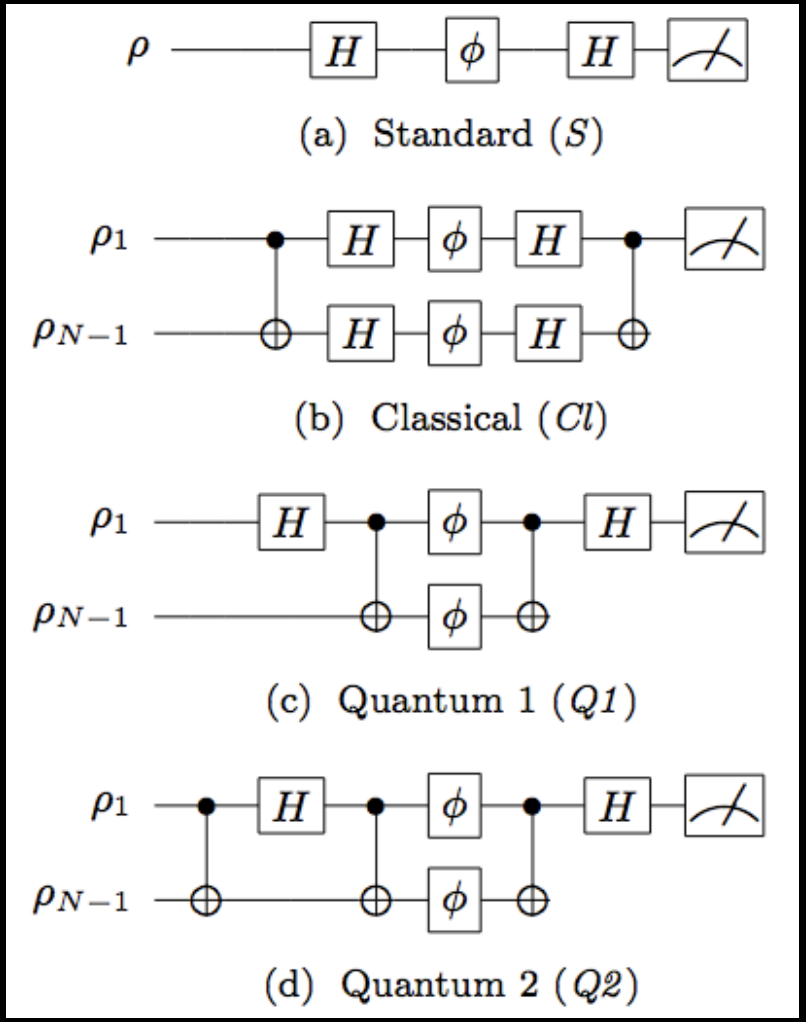


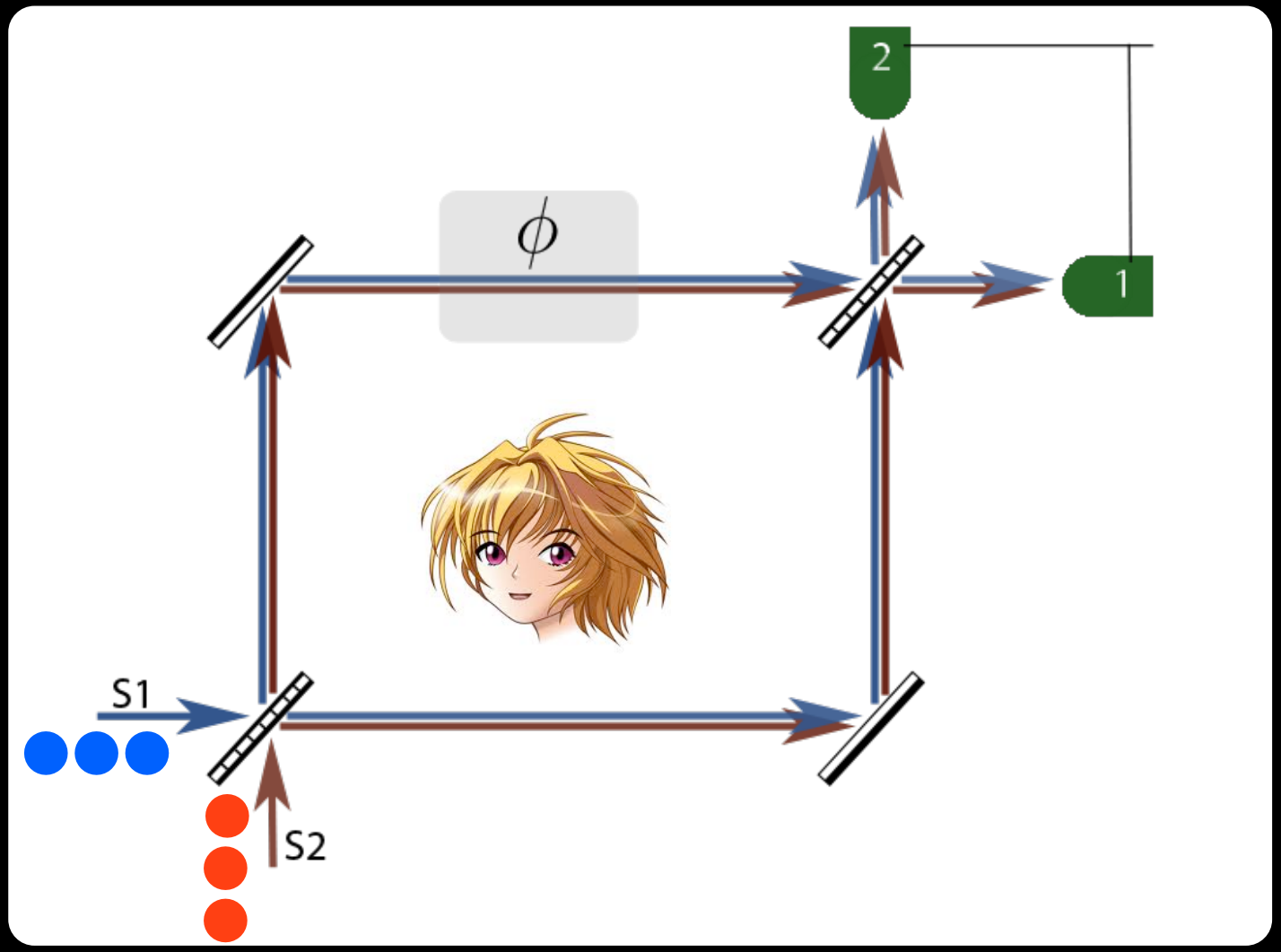
(a) Standard (S)

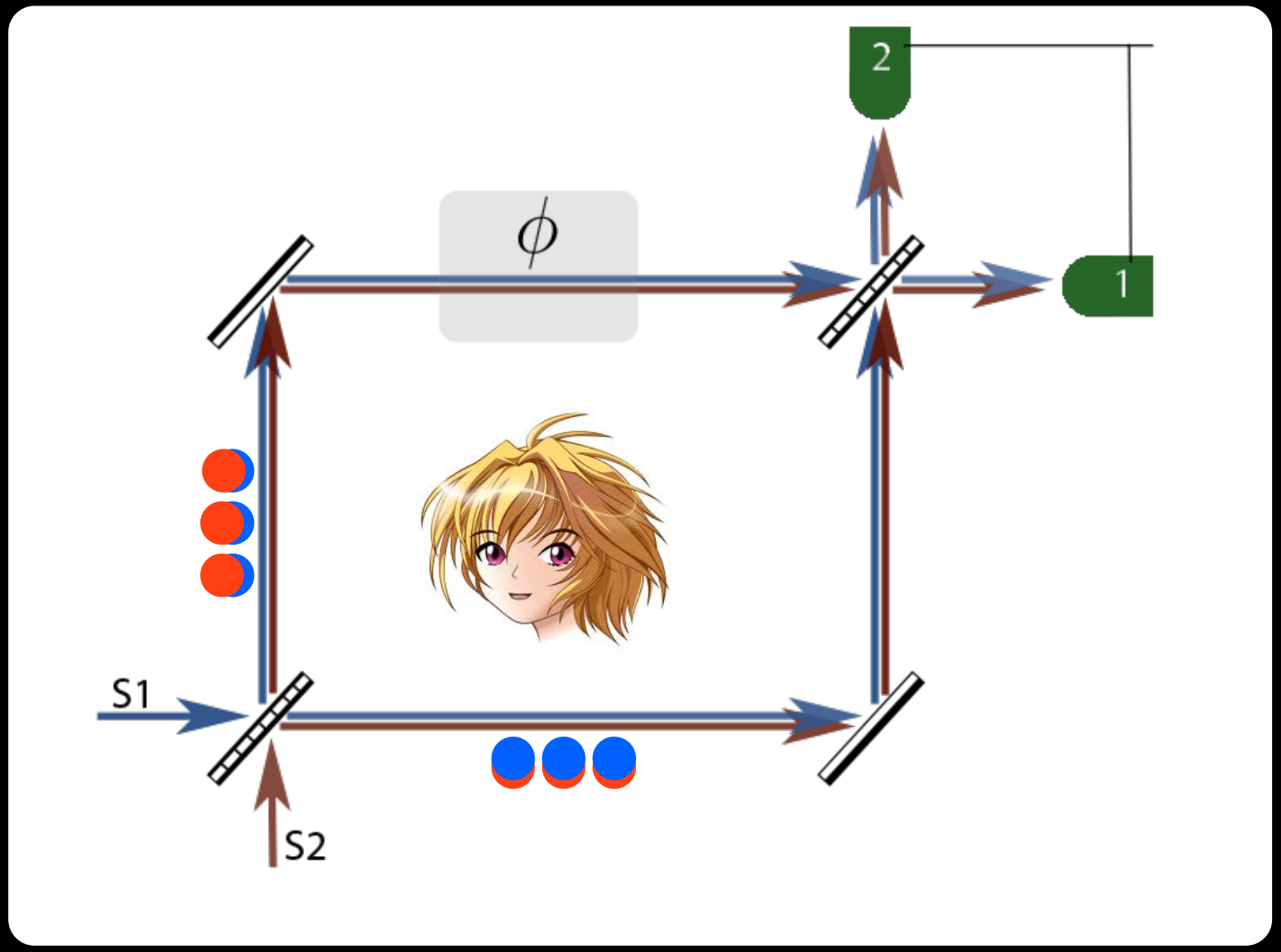


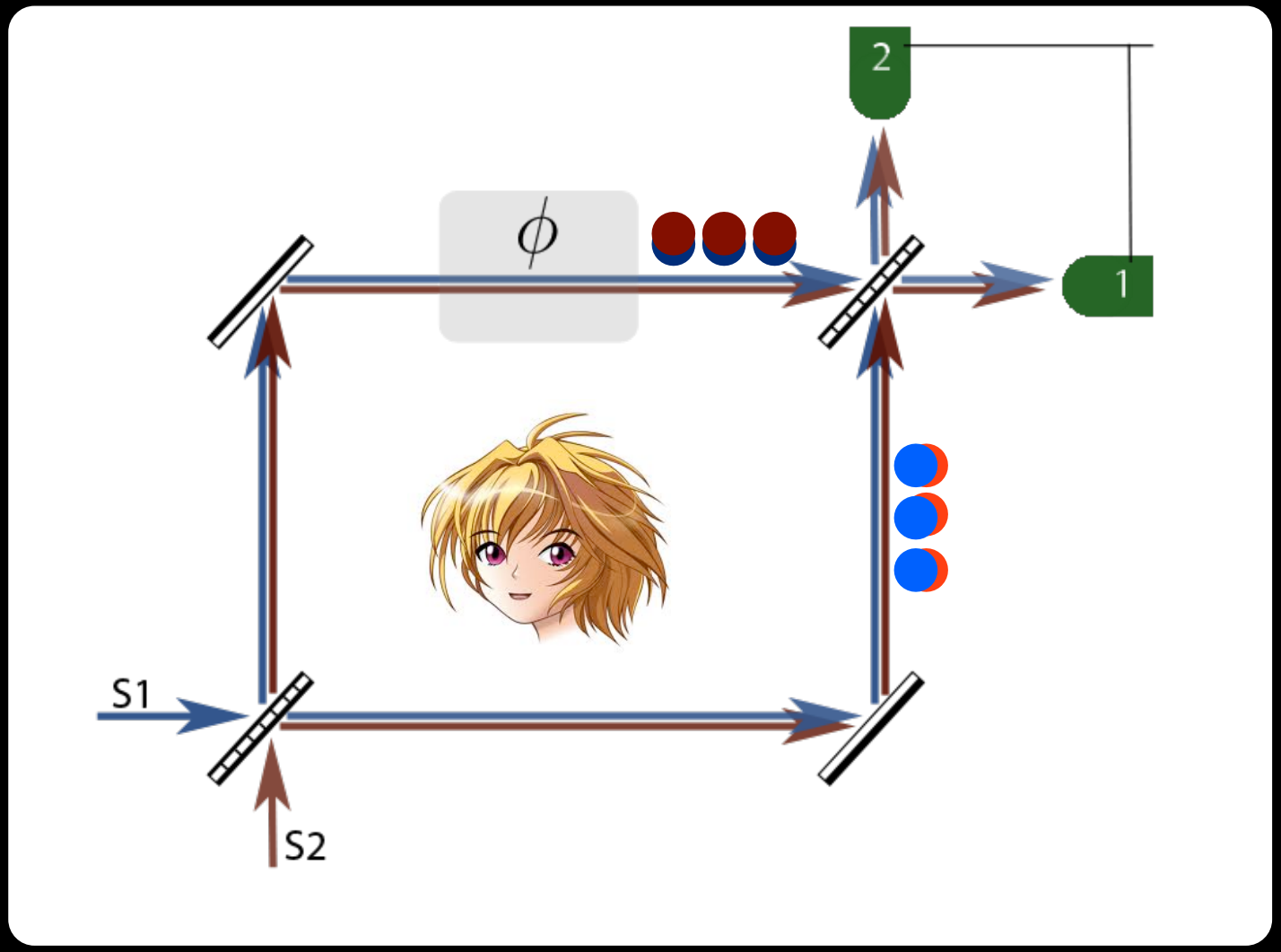
(c) Quantum 1 ($Q1$)


ρ
H
ϕ
H
(a) Standard (S)
ρ1
ρN−1
H
ϕ
H
H
ϕ
H
(b) Classical (Cl)
ρ1
ρN−1
H
ϕ
H
ϕ
(c) Quantum 1 (Q1)


ρ
H
ϕ
H
(a) Standard (S)
ρ1
ρN−1
H
ϕ
H
H
ϕ
H
(b) Classical (Cl)
ρ1
ρN−1
H
ϕ
ϕ
H
(c) Quantum 1 (Q1)
ρ1
ρN−1
H
ϕ
ϕ
H
(d) Quantum 2 (Q2)

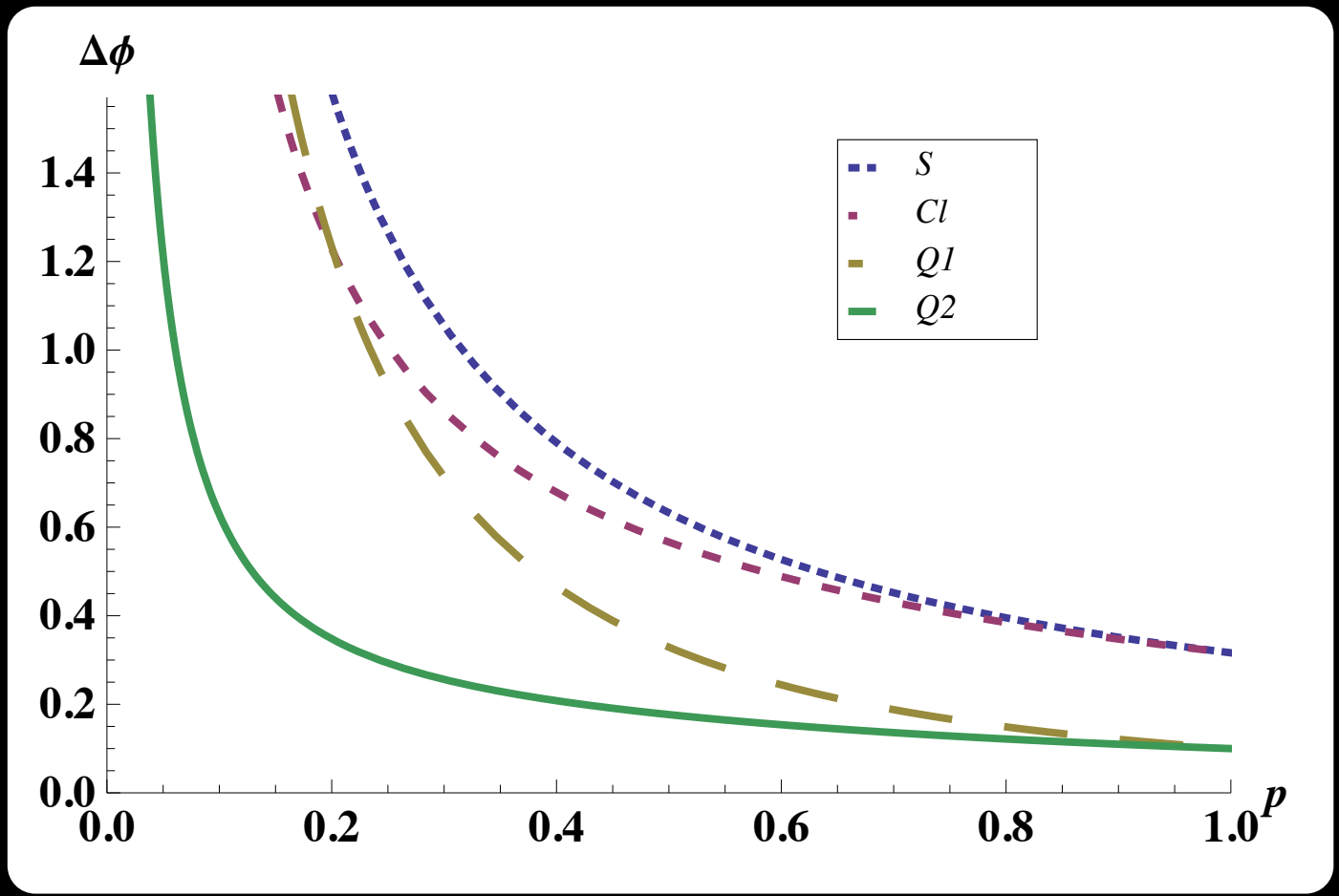

2
ϕ
1
S1
S2

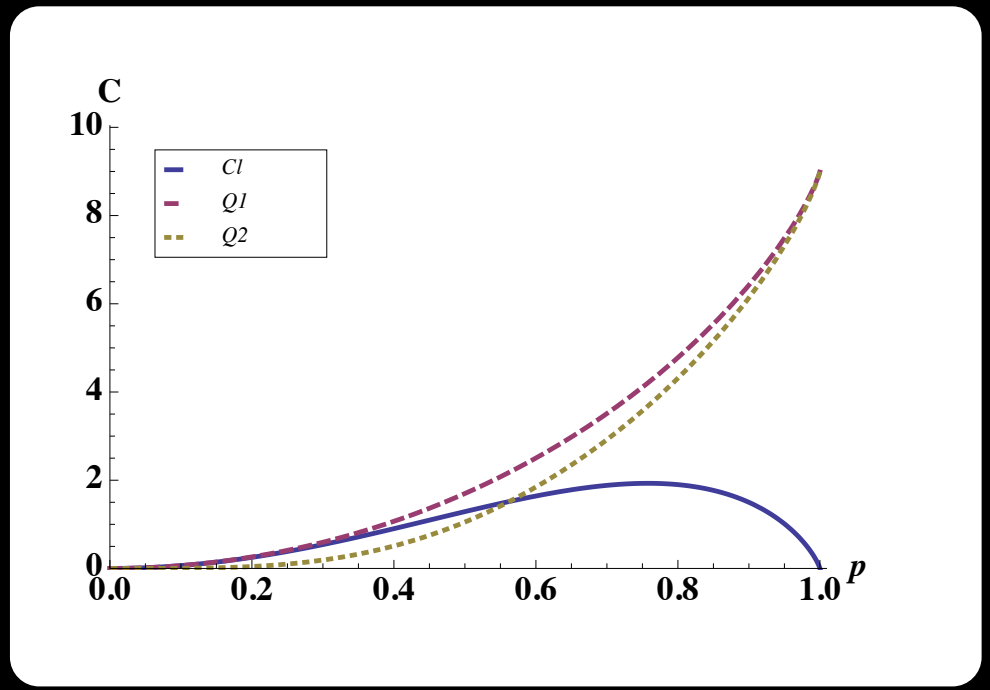

2
ϕ
1
S1
S2

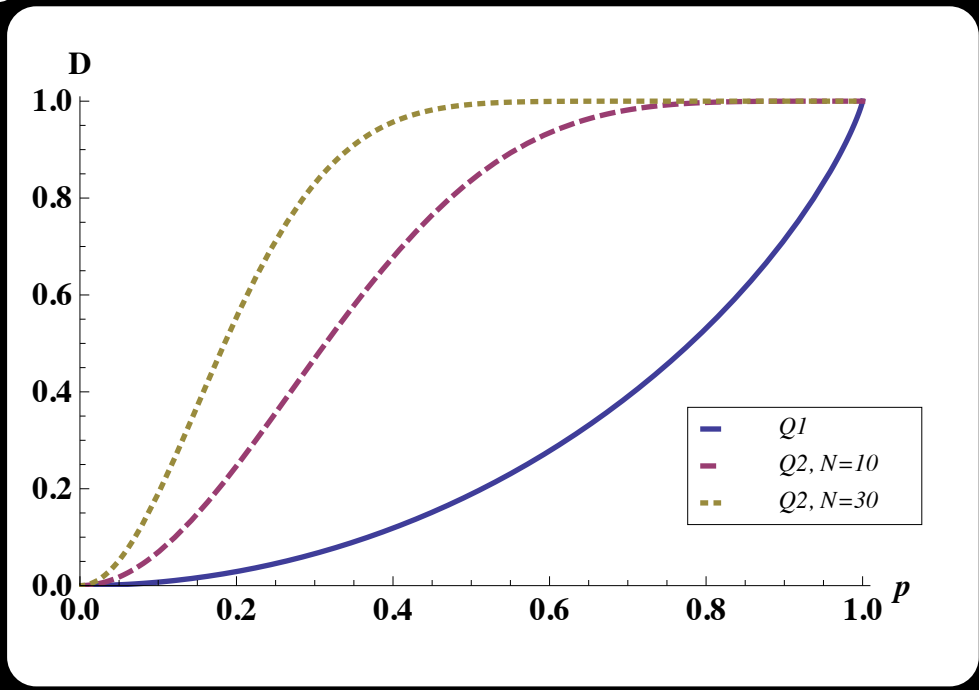

2
ϕ
1
S1
S2

$$\Delta\phi \quad \text{is} \quad \frac{1}{pN}$$

$$F(\varrho) = 4 \sum_{j>k} \frac{(\eta_j - \eta_k)^2}{\eta_j + \eta_k} \left| \langle \Psi_j | \, G \, | \Psi_k \rangle \right|^2$$


Δϕ
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
p
S
Cl
Q1
Q2


C
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
p
Cl
Q1
Q2


D
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
p
Q1
Q2, N=10
Q2, N=30

Quantum enhancement does not suffer from classical noise

It is independent of entanglement

Quantum correlations should be present

Optimality is still unresolved

To appear in PRX (next week).
arXiv:1003.1174