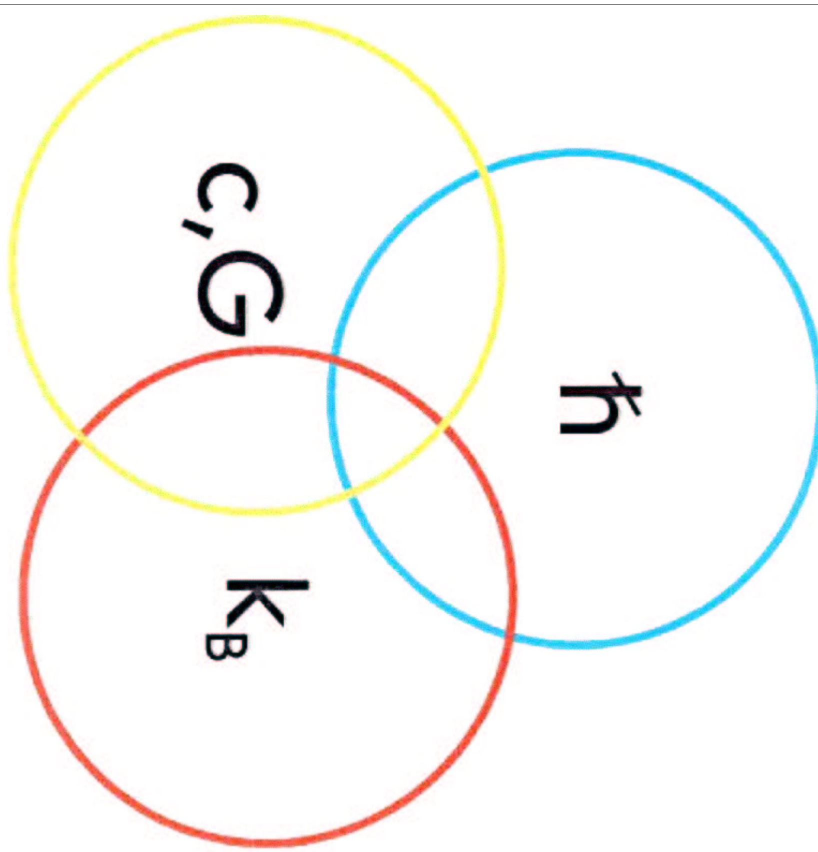
# Faster-than-light effects in quantum and classical contexts

- Introduction: Three circles of physics
- EPR faster-than-light correlations
- Faster-than-light phenomena in tunneling and in inverted atomic media
- Negative group delays in electronic circuits
- Negative group delays in transmission of atoms through atomic BECs
- Conclusions

Lecture by R. Y. Chiao at UCSB ITP workshop on fast/slow light, 7/2002




The Three Pillars of Physics
(at beginning of $21^{st}$ century)

# Introduction

- Conceptual tensions between QM, SM, and relativity
  - I. *Locality* vs. *nonlocality* of physical systems
  - II. *Objectivity* vs. *subjectivity* of probabilities
  - III. *Reversibility* vs. *irreversibility* of time

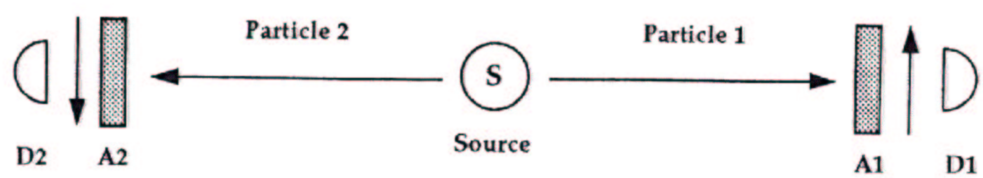



FIG. 1. Bohm's version of the EPR Gedankenexperiment

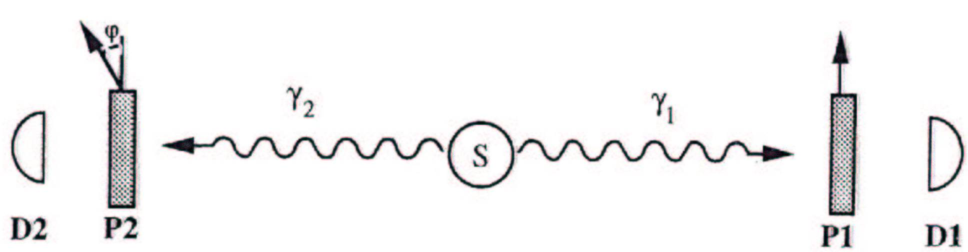
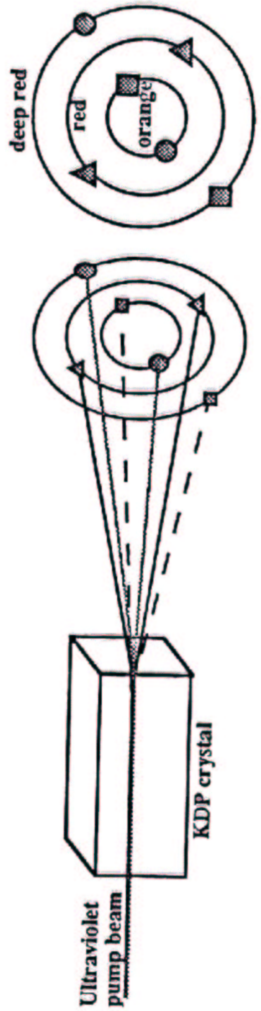



FIG. 2. Optical version of EPR experiment



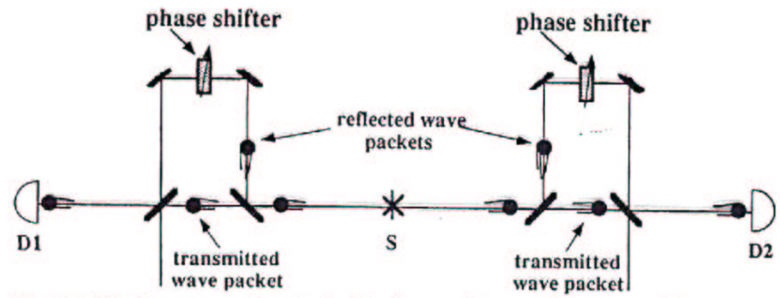




Figure 5: The Franson experiment: the interference of two spatially separated, but entangled, photons in two unbalanced Mach-Zehnder interferometers.

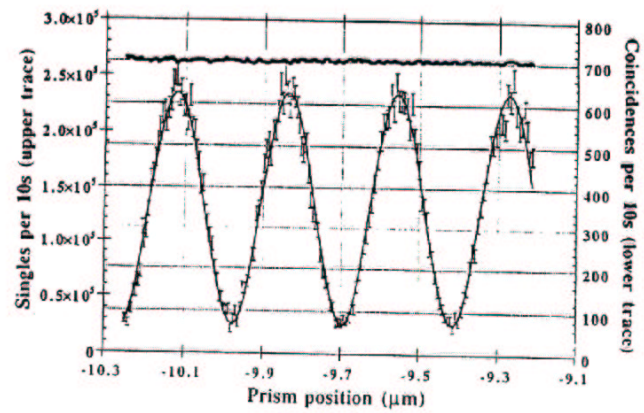
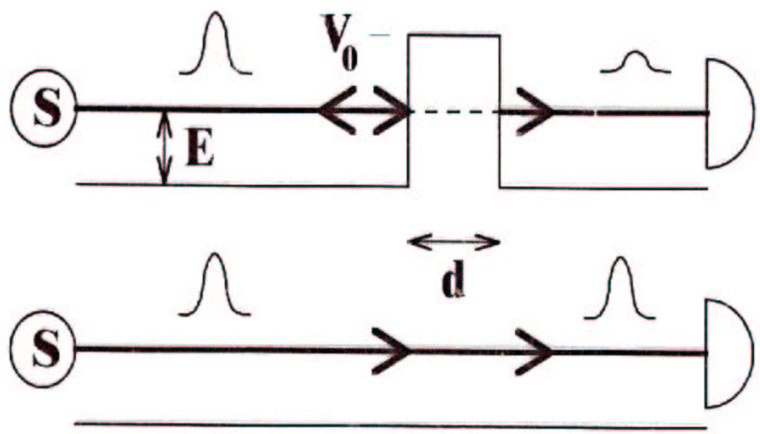
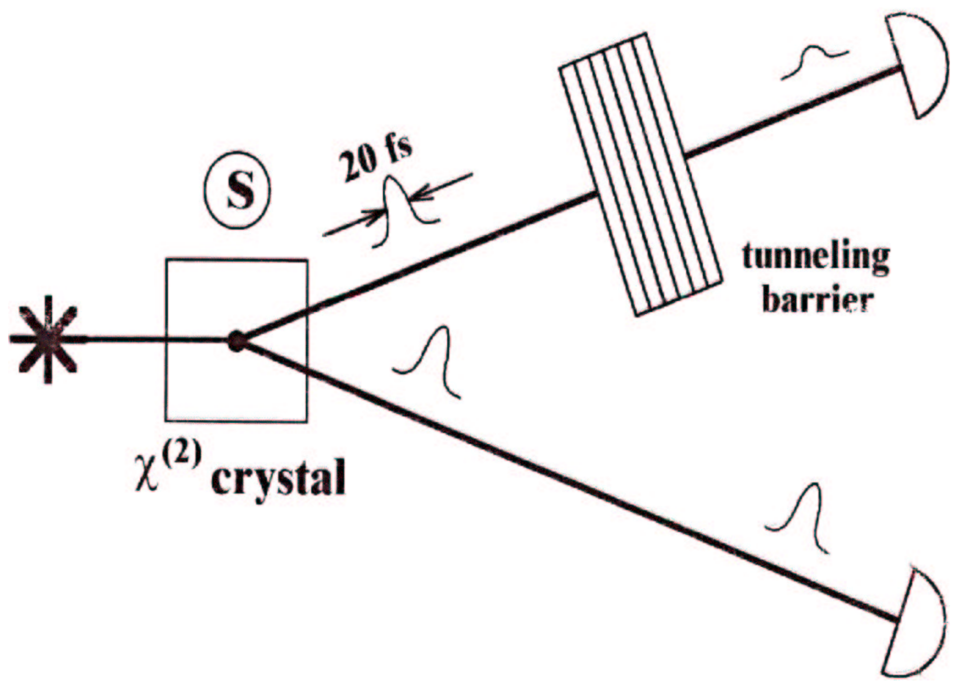
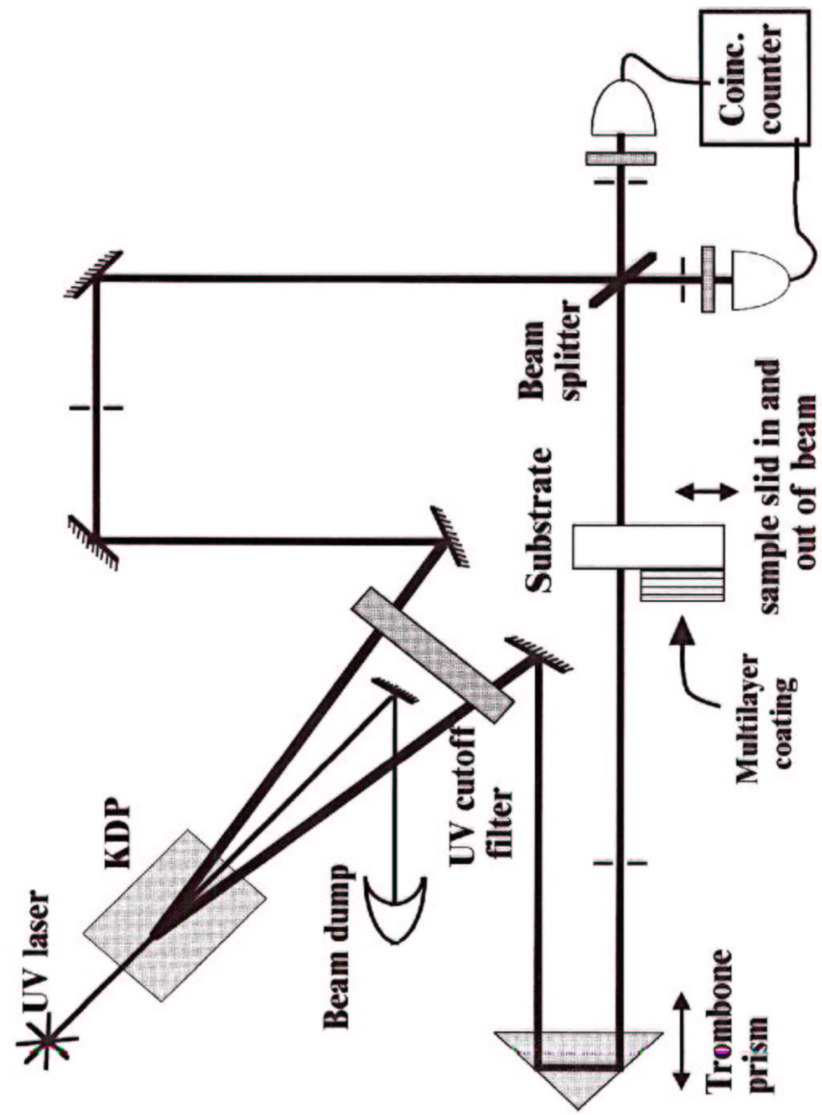
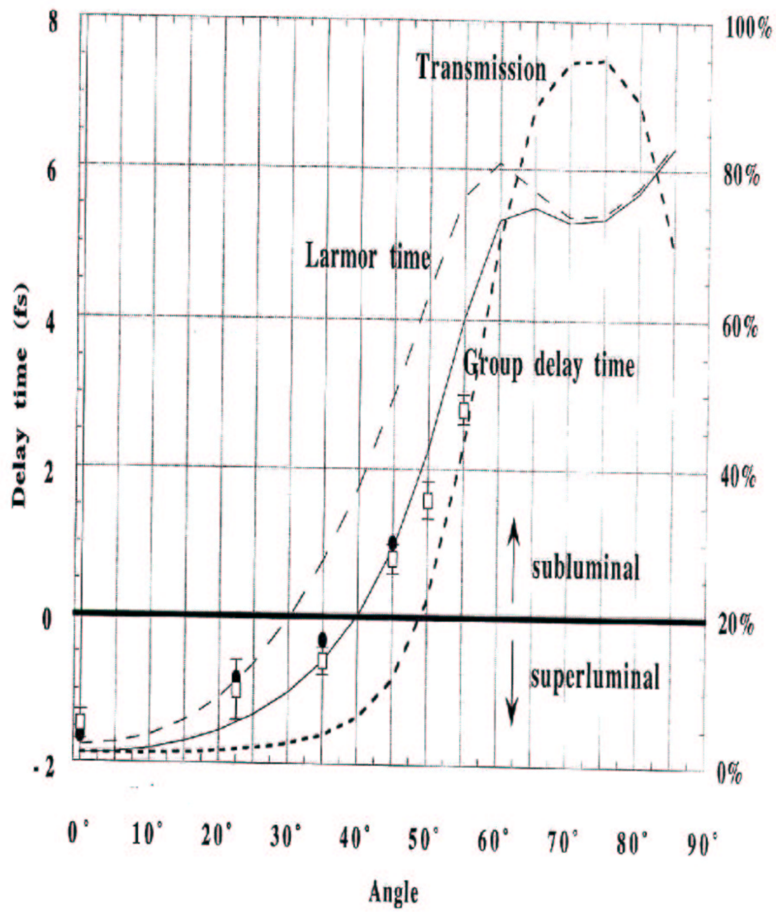



Figure 6: Interference fringes seen in the Berkeley Franson experiment in coincidence detection. Upper trace: the singles rate exhibit no interference fringes. Lower trace: The coincidence count rate between the two detectors for the two photon twins of Fig. (5), as a function of the path length difference between the long and short arms of one of the two unbalanced Mach-Zehnder interferometers, exhibit fringes with very high visibility (i.e., contrast).


S
$V_0$
E
d
S


S
20 fs
tunneling
barrier
$\chi^{(2)}$ crystal


Coinc.
counter
Beam
splitter
Substrate
sample slid in and
out of beam
Multilayer
coating
UV cutoff
filter
KDP
UV laser
Beam dump
Trombone
prism




Negative group delays in "Scattering of atoms on a BEC"

by Uffe Poulsen & Klaus Mølmer

arXiv: cond-mat/0207029

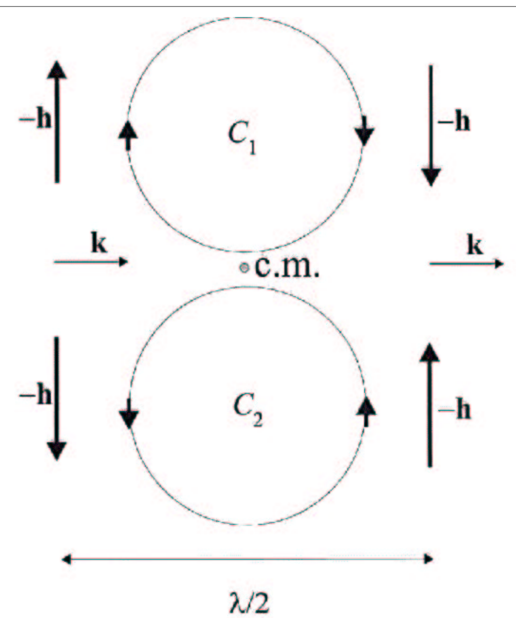

Atom leaves far side of BEC BEFORE incident atom arrives at near side.

# Three conceptual tensions between QM and GR

⇒ • (1) *Nonseparability* of entangled states in QM vs. *separability* in GR.

(skip) • (2) *Equivalence principle* of GR vs. *uncertainty principle* of QM.

(skip) • (3) *Mixed states* in GR vs. *pure states* in QM.




Side-view snapshot of a gravitational plane wave propagating to the right inside a thick slab of superconductor. Note that circulations around $C_1$ & $C_2$ are nonvanishing, violating the single-valuedness of the macroscopic wavefunction.

*A Concrete Example:*

## Weber bars vs. quantum gravitational antennas (e.g. superconductor)

$$\eta_{Weber} \equiv \frac{\Gamma_{grav}}{\Gamma_{heat}} = \frac{64\, G M v_{sound}^4}{15\, L^2 c^5 \Gamma_{heat}} \simeq 3 \times 10^{-34}$$

Entanglement ⇒ Rigidity of wavefunction

$$\therefore \quad \frac{\eta_{sc}}{\eta_{weber}} > \left(\frac{c}{v_{sound}}\right)^4 \simeq 10^{20}$$

## Meissner-like effect in superconductors for Lense-Thirring fields

DeWitt Hamiltonian implies minimal coupling

$$H = \frac{1}{2m_{2eff}}\left(\underset{\sim}{p} - e_2 \underset{\sim}{A}(t) - m_2 \underset{\sim}{h}(t)\right)^2$$


← superconductor

$H$ ⇒ CROSS TERM $\boxed{H_{int} \sim e_2 \underset{\sim}{A} \cdot \underset{\sim}{h}}$

1st order perturbation theory gives

Meissner-like energy shift

$$\boxed{\overline{\Delta E_{int}^{(1)}} = \frac{1}{16}\left(\frac{m_2}{m_{2eff}}\right) N e_2 A_+ h_+ a^2}$$

Using Q. Adiabatic Theorem

2nd quantization + RWA gives

$$H_{int} \propto a^+ b + a b^+$$

# Impedance of free space for gravity waves

Impedance of free space for EM waves

$$Z_0 = \frac{E}{H} = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\,\Omega$$

Impedance of free space for GR waves

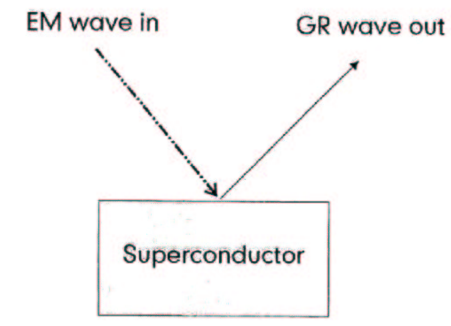
$$Z_G \simeq \frac{E_G}{H_G} = \sqrt{\frac{\mu_G}{\epsilon_G}} \simeq \frac{16\pi G}{c} = \boxed{1.12 \times 10^{-17}\,\frac{m^2}{s \cdot Kg}}$$

Speed of GR waves = speed of EM waves

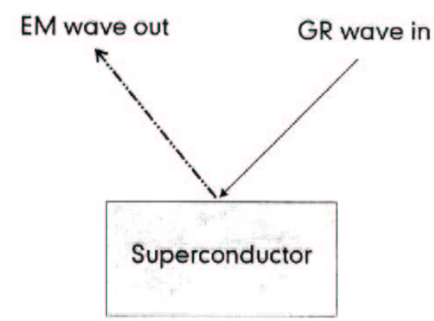
$$c = \frac{1}{\sqrt{\epsilon_G \mu_G}} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3.00 \times 10^8\,\frac{m}{s}$$

CAVEAT → (From MAXWELL-like equations for weak gravity, see Braginsky, Caves & Thorne PRD 1977).
Sign of forces...

## Superconductor as Transducer

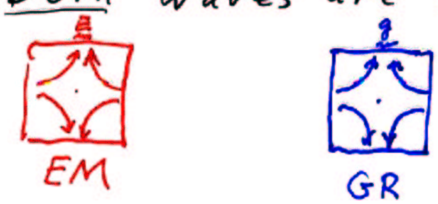



(a)



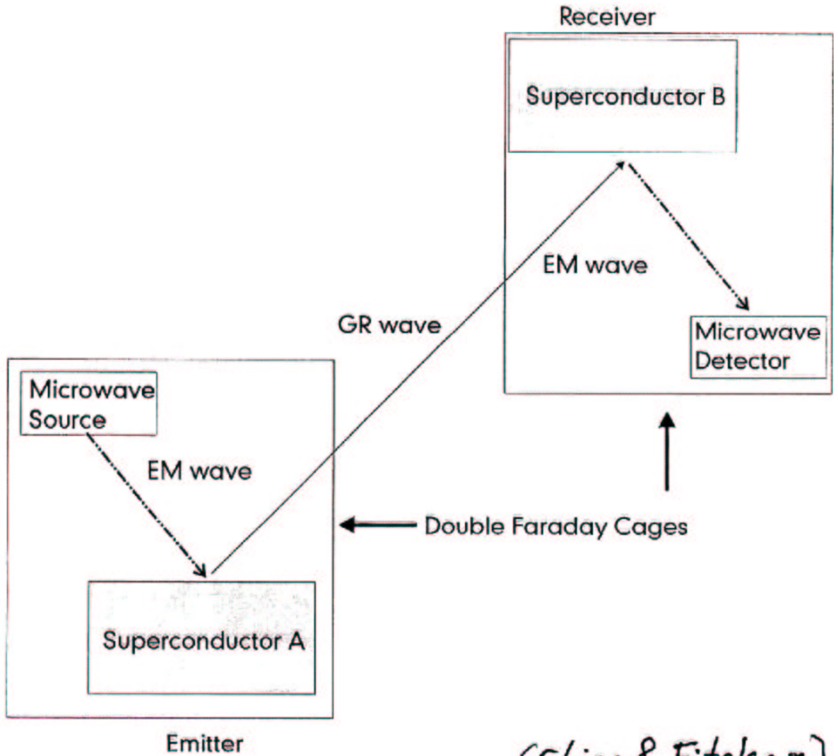

(b)

Polarizations of Both waves are QUADRUPOLAR



Hertz-like

Experiment in progress:




(Chiao & Fitelson)