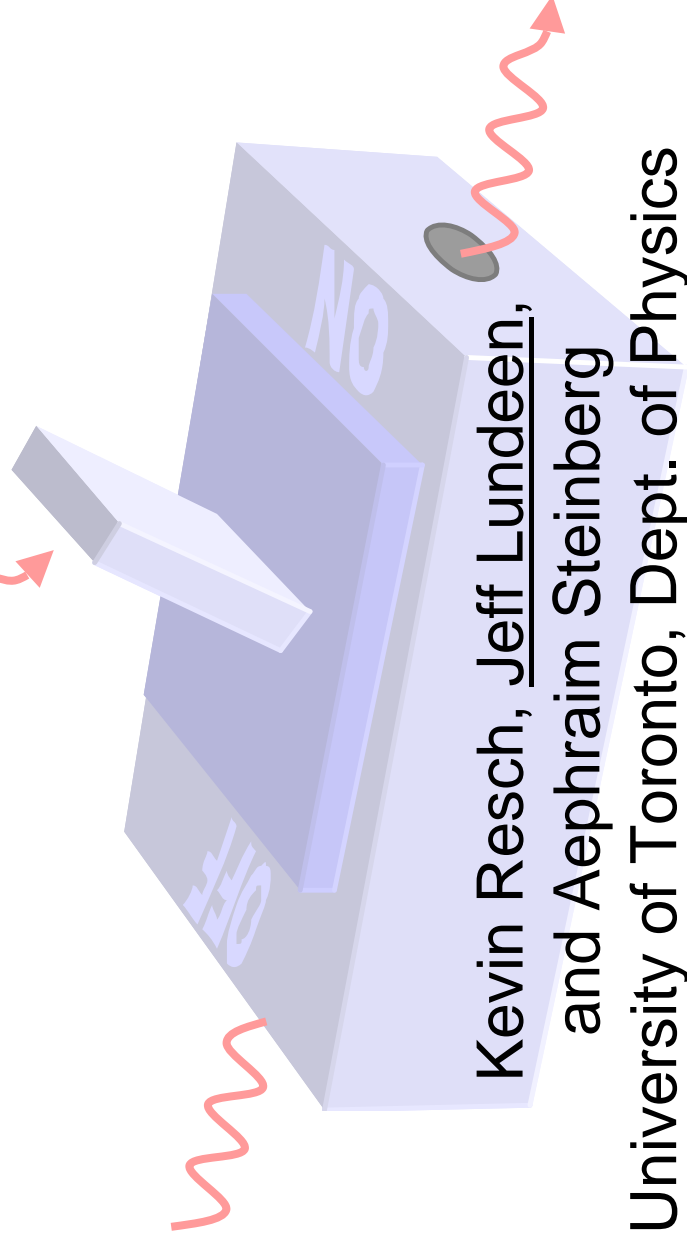


# Nonlinear Optics With Less Than One Photon



PQE XXXI

Financial Support from NSERC, CFI, Photonics  
Research Ontario and the Walter C. Sumner Found.



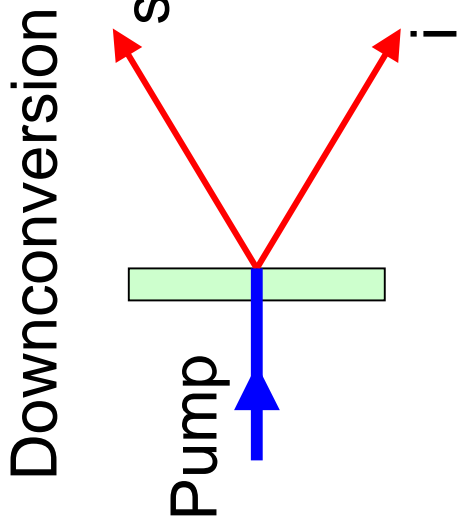
PQE XXXI

# Outline

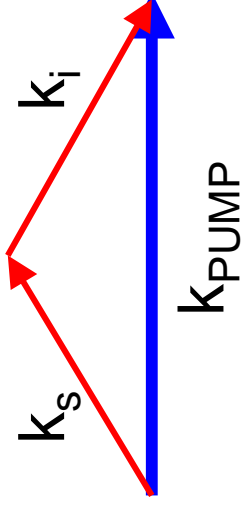
- Can a nonlinear effect be observed between two photons?
- Is 100% efficient upconversion possible at the quantum level?
- Can we make a two-photon optical switch?
- Suppression and enhancement of spontaneous down-conversion by quantum interference.
- Experimental setup and Results.



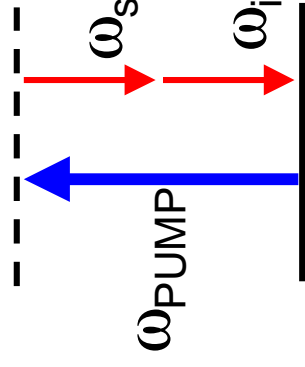
# Spontaneous Parametric Downconversion



Momentum is conserved..



..as well as energy



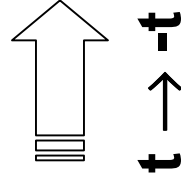
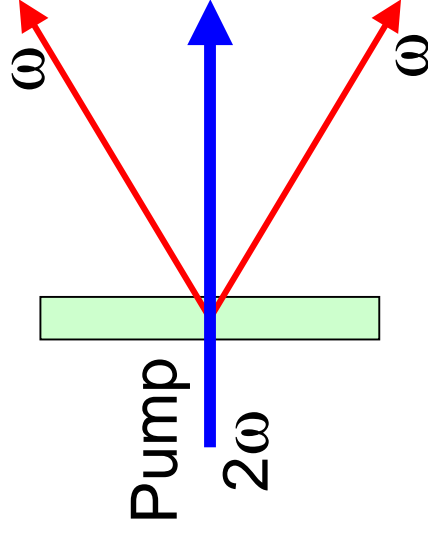
$$\varphi_{\text{PUMP}} = \varphi_s + \varphi_i$$

- A pump photon is spontaneously converted into two lower frequency photons in a material with a nonzero  $\chi^{(2)}$

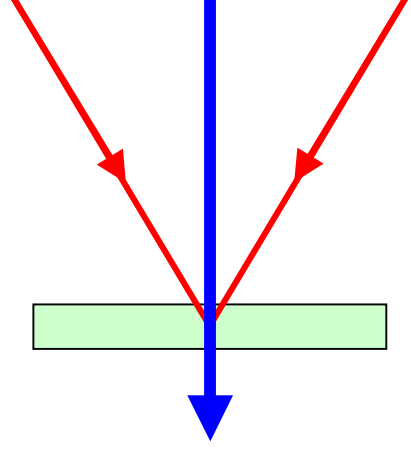


# Consider...

Spontaneous  
Parametric Down-  
conversion



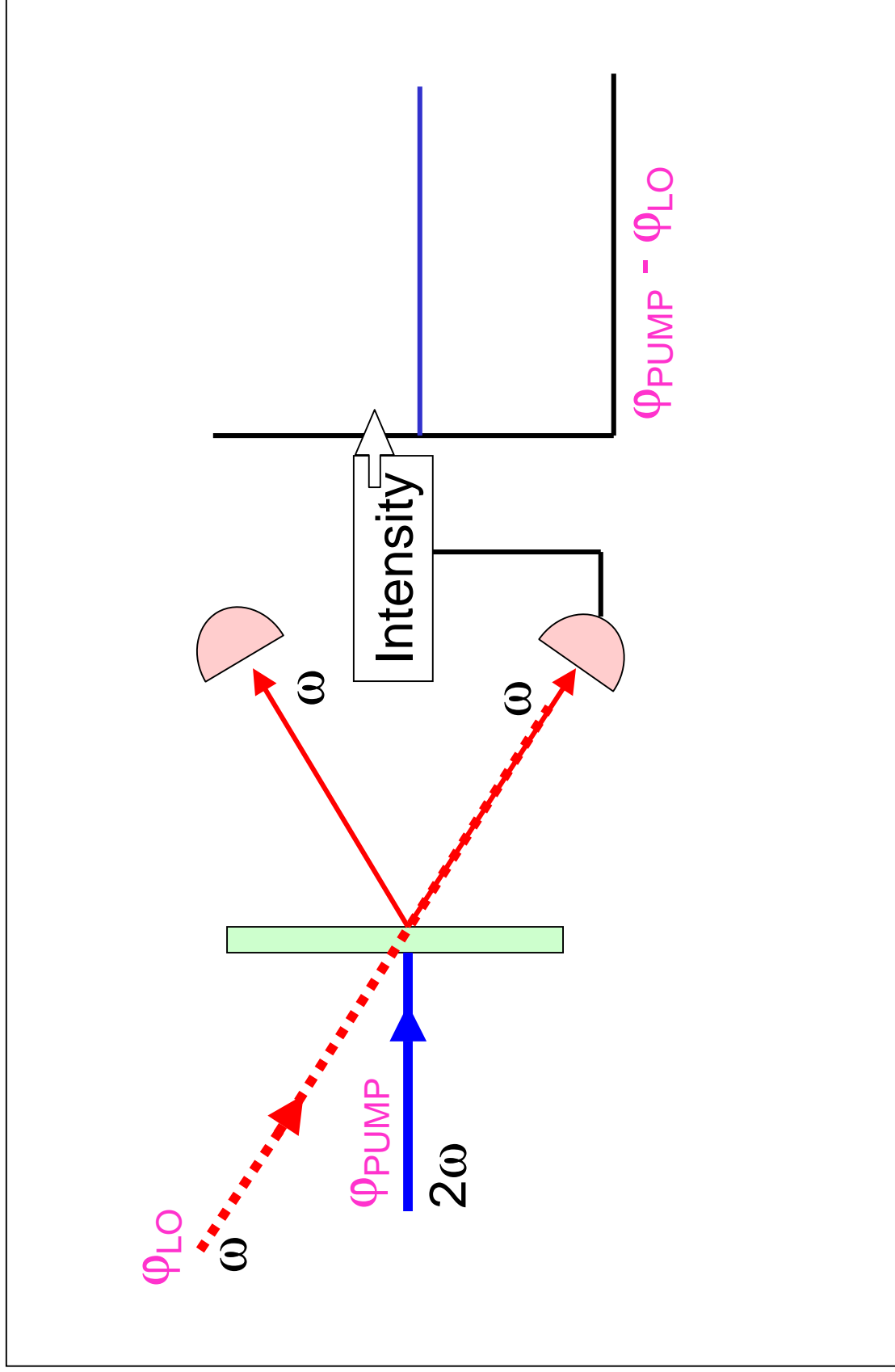
Time-Reversed



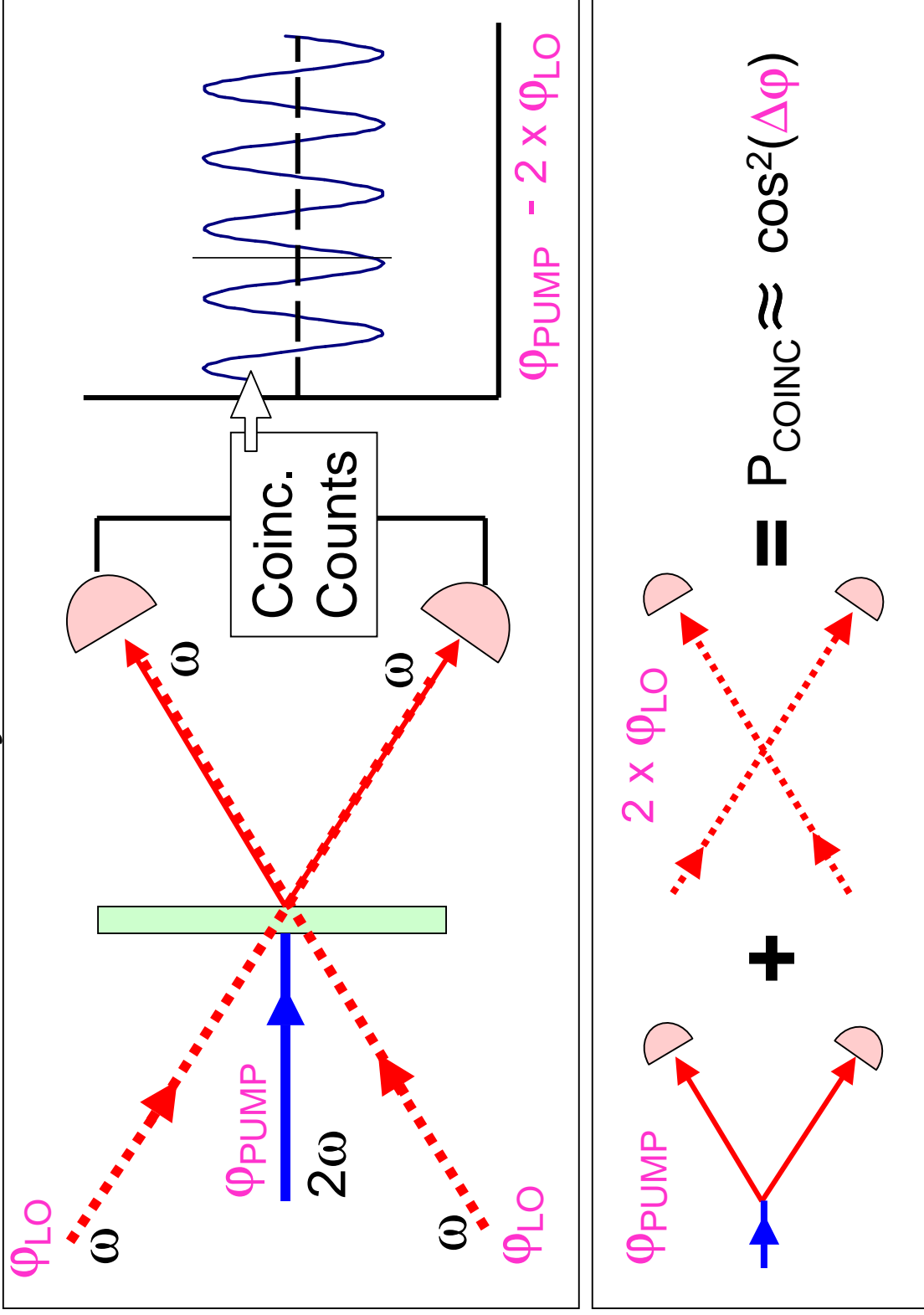
- 100% efficient upconversion



# Which-Path Information

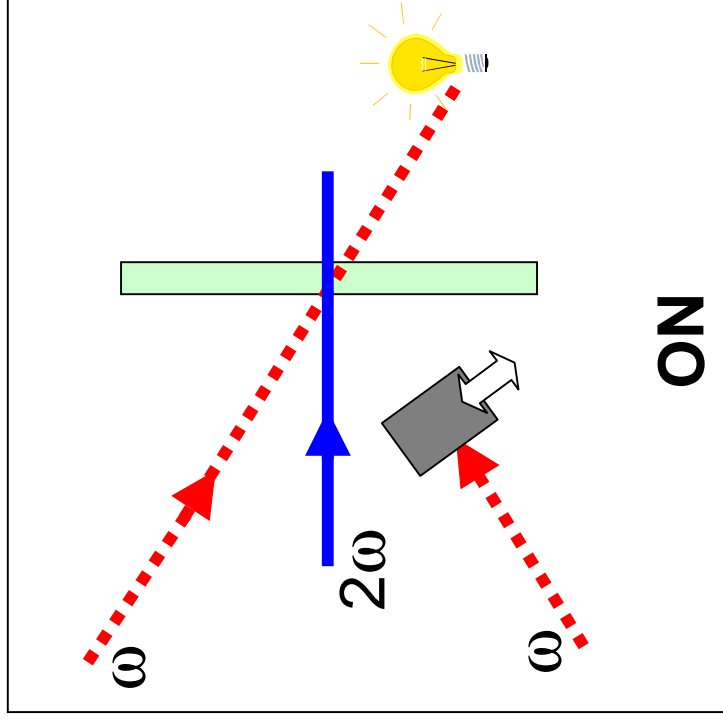
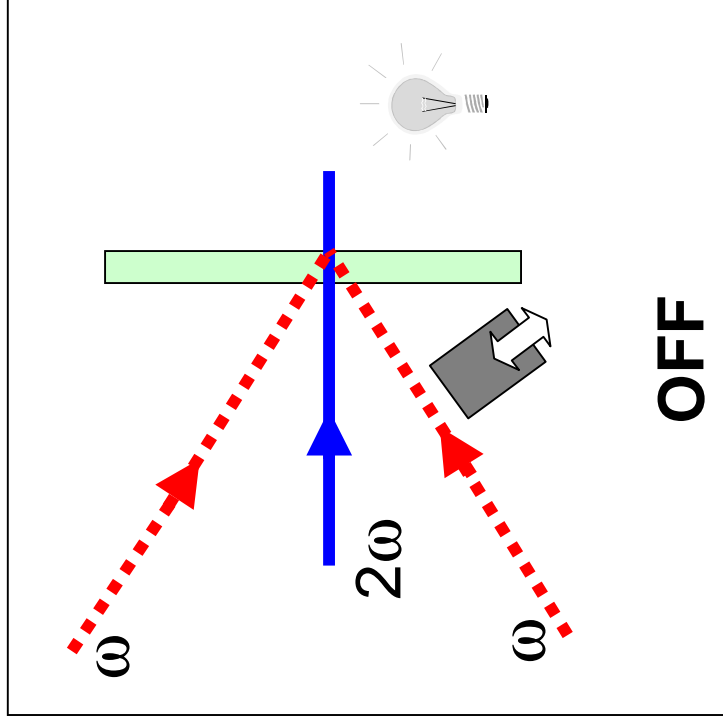


# The Feynman Paths

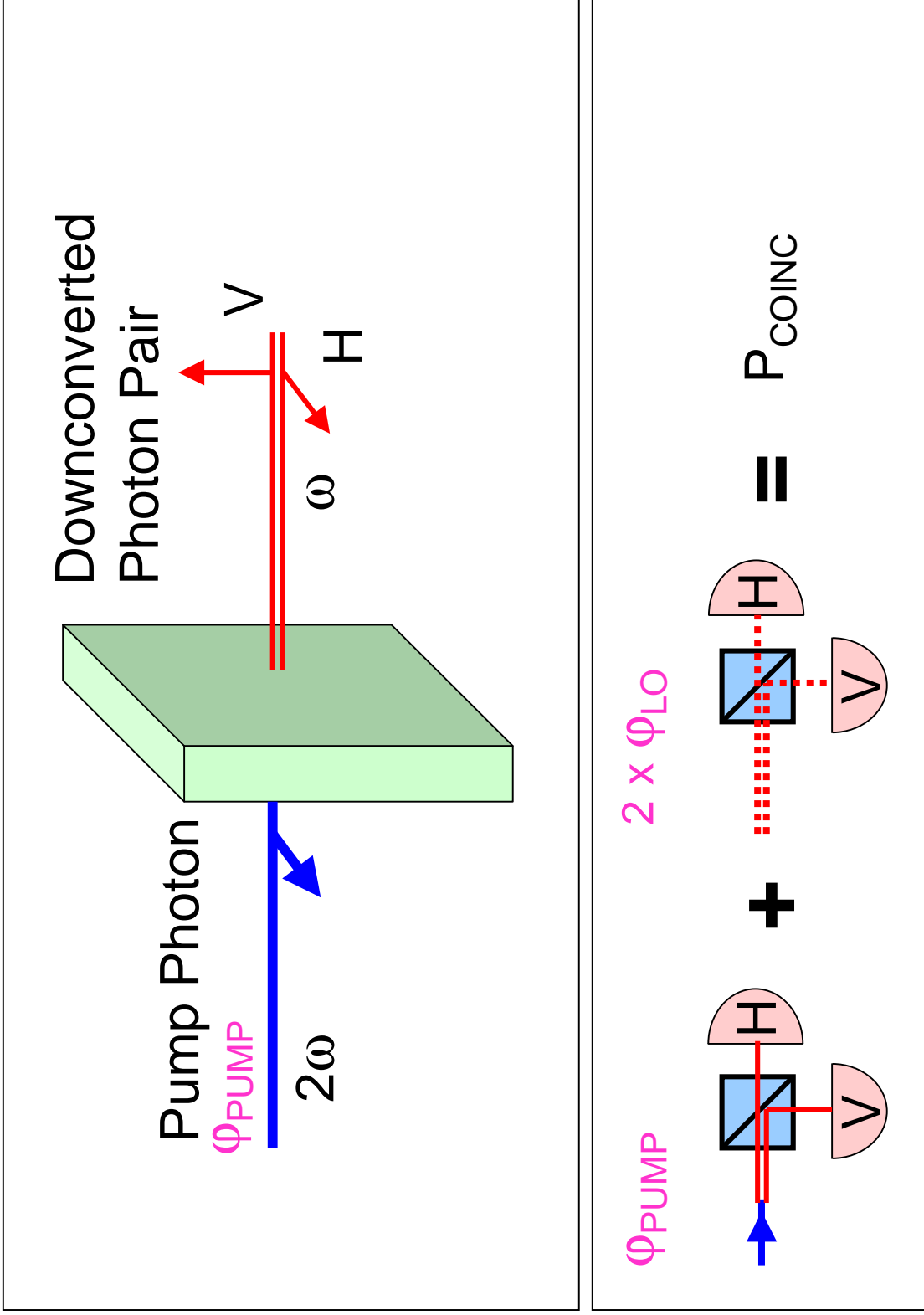


# The Switch

- Phase chosen so that coincidences are eliminated

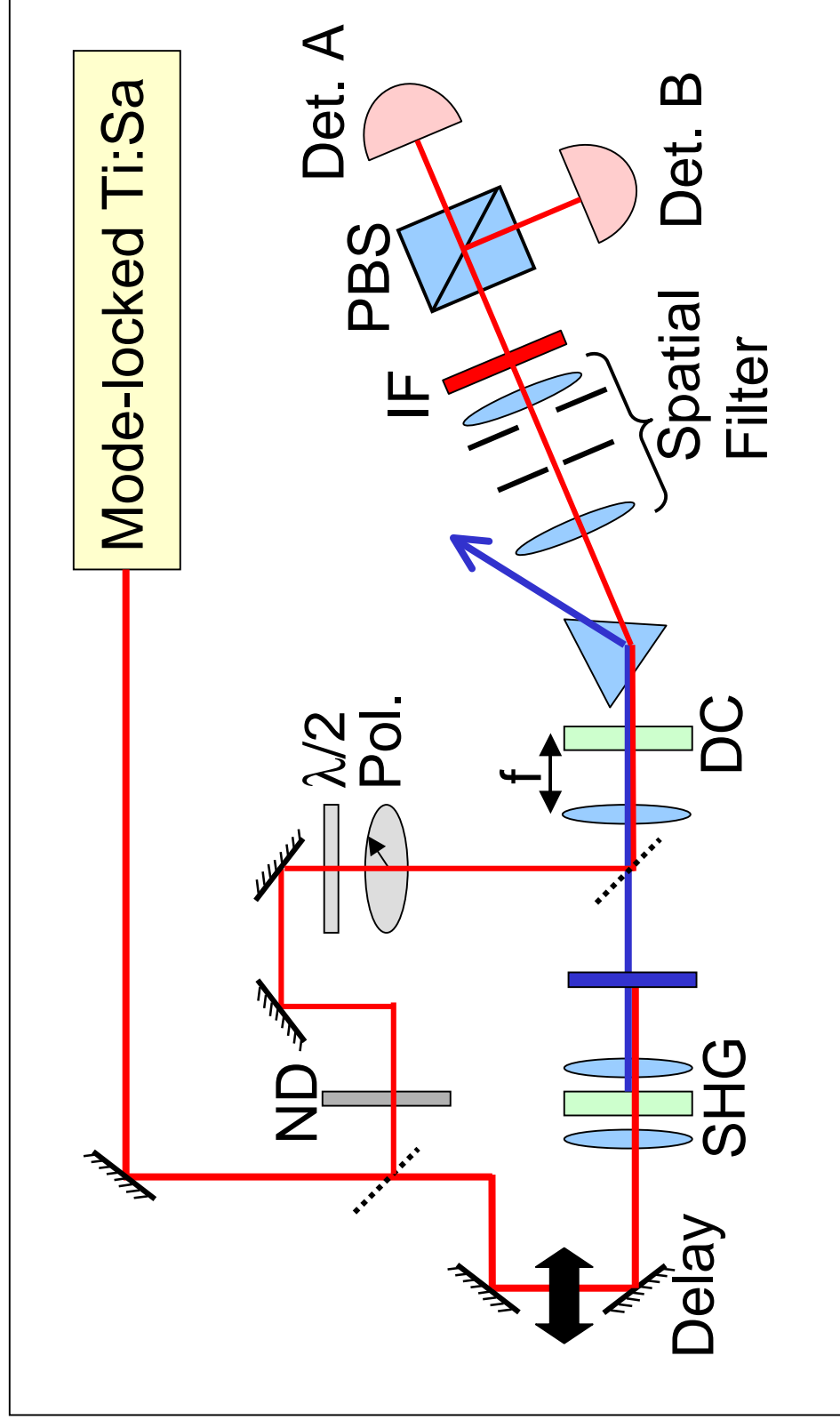


# Type II Downconversion

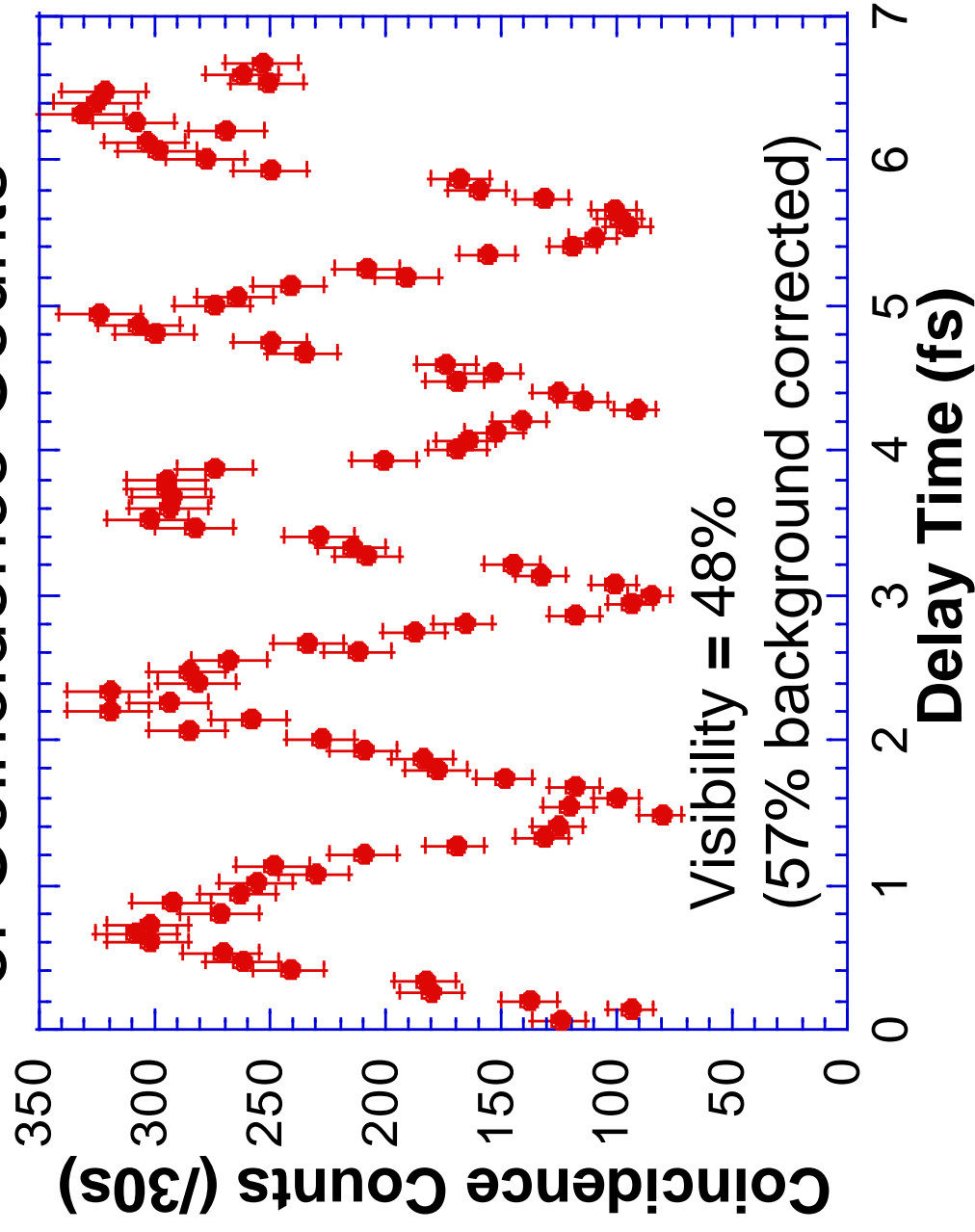




# Experimental Setup

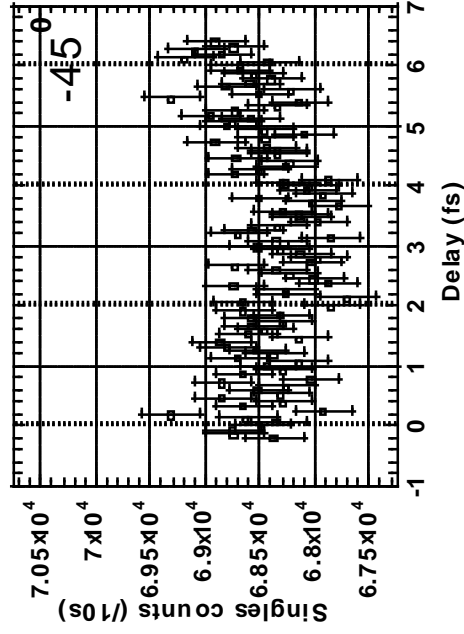


# Suppression and Enhancement of Coincidence Counts

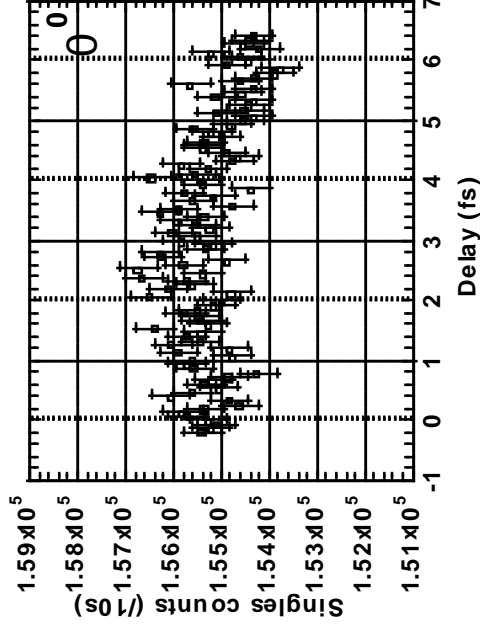


# Intensity Modulations: The Switch

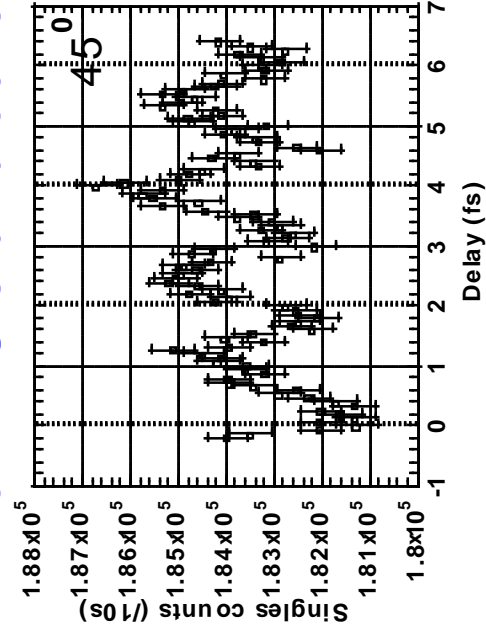
Both LO's blocked



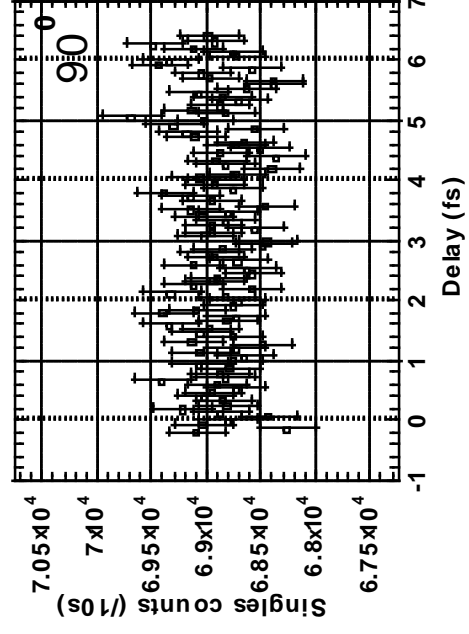
Vertical LO blocked



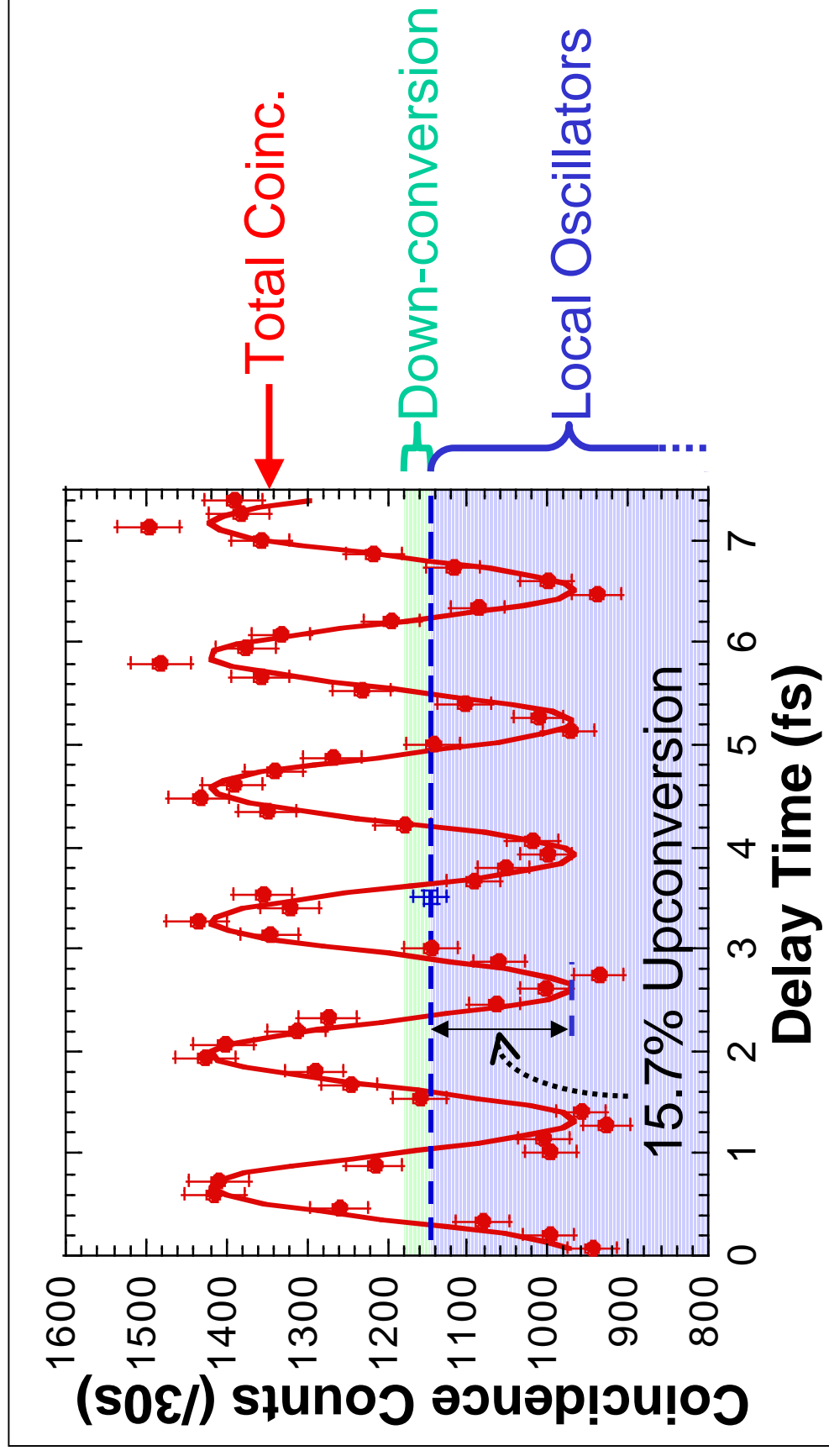
Both LO's unblocked



Horizontal LO blocked



# Upconversion of Photon-Pairs



# Summary

- We have demonstrated a quantum interference effect which is an effective nonlinearity at the single-photon level.
- Pairs of photons can be removed from independent laser beams.
- A single-photon switch was demonstrated by observing a change in the intensity of the beams.
- **A conditional phase-shift may be possible:  
Controlled phase gate?**

