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Noise Rejection using time Correlated Photons

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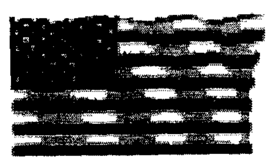
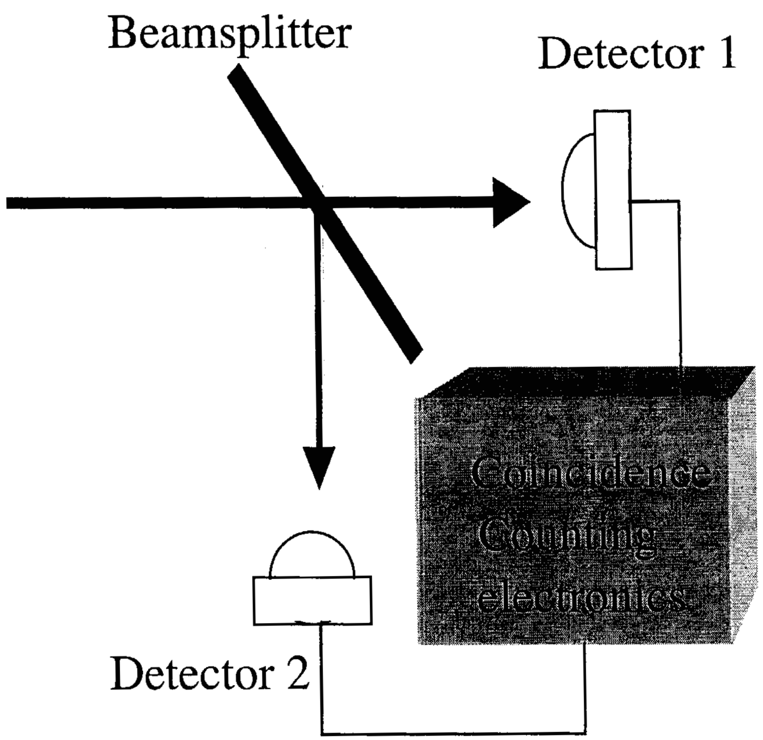


Outline

- Near Range Telecommunications Applications
- Advantage of two-photon sensitive detectors
- Applications using femtosecond pulsed sources
- Supporting Technology Development Requirements
  - Two-photon sources
  - Femtosecond pulsed sources
  - Two-photon detectors
- Conclusions

Advantages of Two-photon Sensitive Detectors

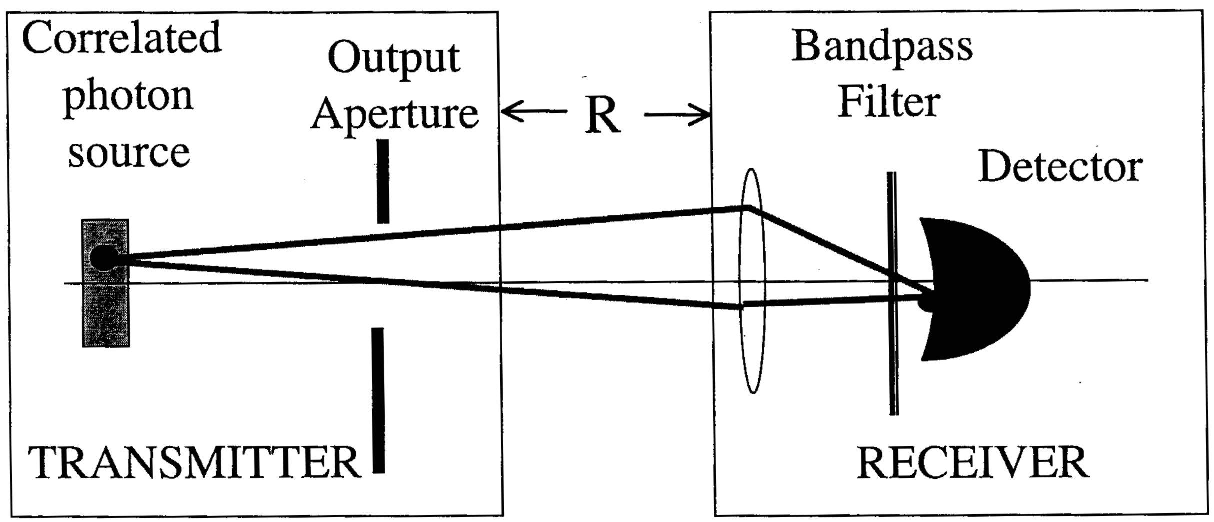


- A two-photon detector replaces
  - Detectors pair
  - Coincidence counters
  - Computer interface
- Shortens gated coincidence window by orders of magnitude
- Continuous measurement significantly increases counting rate
- More compact detection hardware
- Cost Effective

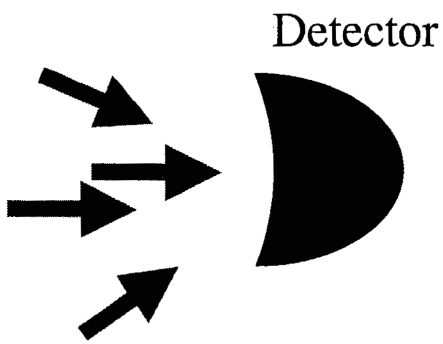
Near Range

Architectures where full output power of the transmitter is subtended and collected by the receiver collection aperture:

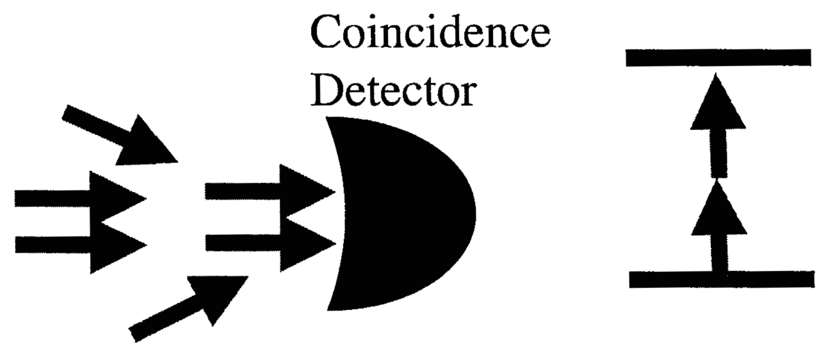
$$D_r \geq \frac{2.44\lambda}{d_t} R$$



Two-Photon Sensitive Detector



Classical



2-Photon Correlated

Near Range Classical Photon Link

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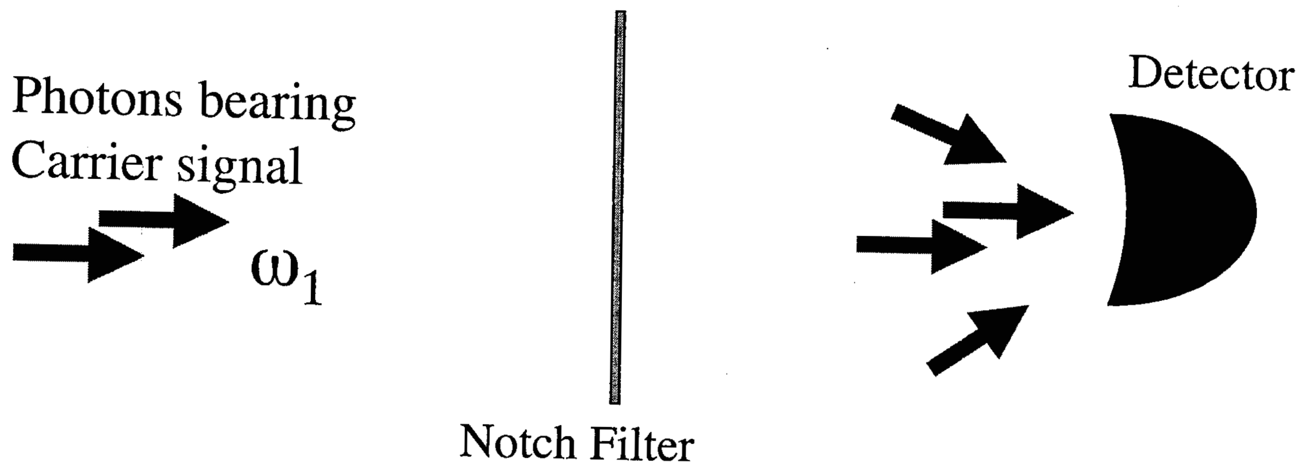
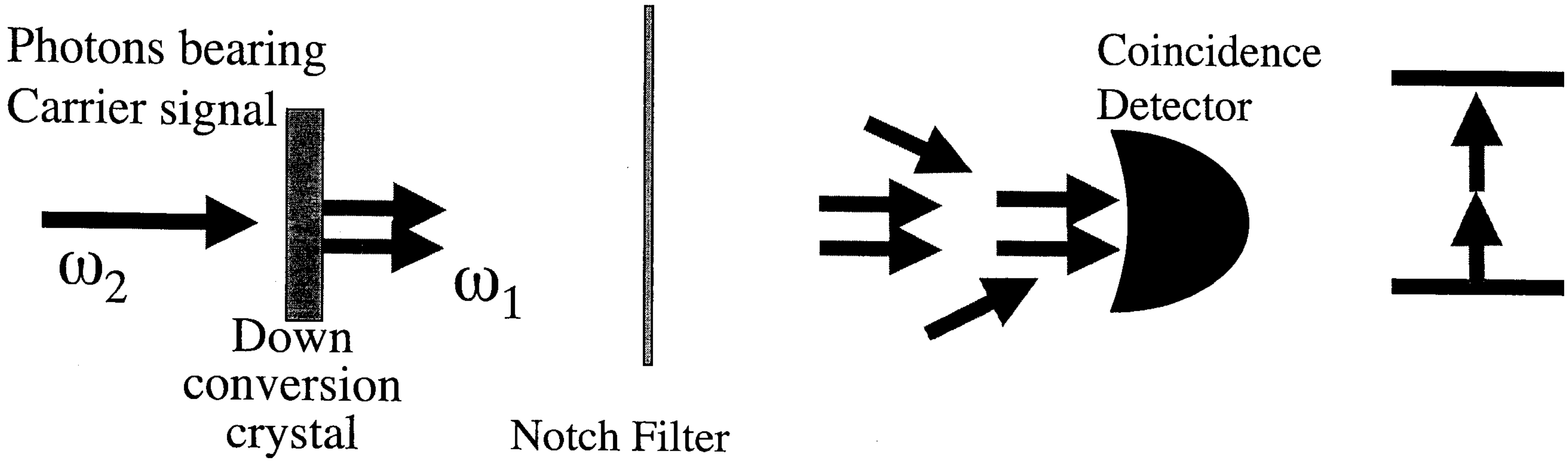


$$P_r(\omega_1, t) = \mu P_t(\omega_1, t) L; \quad \mu = 1$$

$$SNR_{classical} = \left(\frac{\eta_{\det} P_r(\omega_1, t)}{\sqrt{\sum_i \sigma_i^2}} \right) = \frac{I_0}{\sqrt{\sum_i \sigma_i^2}}$$

Near Field Correlated Photon Link



Require that:

$$P_t(\omega_1,t)\big|_{\text{classical}} = P_t\,(\omega_2,t)\big|_{\text{correlated}}$$

Correlated Properties

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- Both photons created simultaneously
- Both photons created at same spatial point.
- Energy conservation: $\omega_2 = 2\omega_1$
- Momentum conservation: $\vec{k}_2 = 2\vec{k}_1$

$$P_r'(\omega_1, t) = \mu P_t(\omega_2, t) L = \eta_{PDC} P_t(\omega_2, t) L$$

$$SNR_{correlated} = \left(\frac{\eta_{2-ph} P_r'(\omega_1, t)}{\sqrt{\sum_i \sigma_i^2}} \right) = \frac{I_0'}{\sqrt{\sum_i \sigma_i^2}}$$

Noise Sources

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$$\sum_i \sigma_i^2 = \sigma_{thermal}^2 + \sigma_{shot}^2 + \sigma_{laserRIN}^2 + \sigma_{background}^2$$

Noise source	Classical photons	Correlated photons
Thermal noise	$\frac{8kTB}{R_i}$	$\frac{8kTB}{R_i}$
Shot noise	$4eI_0B$	$4eI_0'B$
Laser RIN noise	$2BF_{RIN}I_0^2$	$2BF_{RIN}(I_0')^2$
Background noise	$\sigma_B^2 = \eta_{\det}P_{r-B}B$	$\sigma_B^2 = \eta_{1-ph}P_{r-B}B$

Comparing Link Efficiencies

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- Shot Noise Limited Link

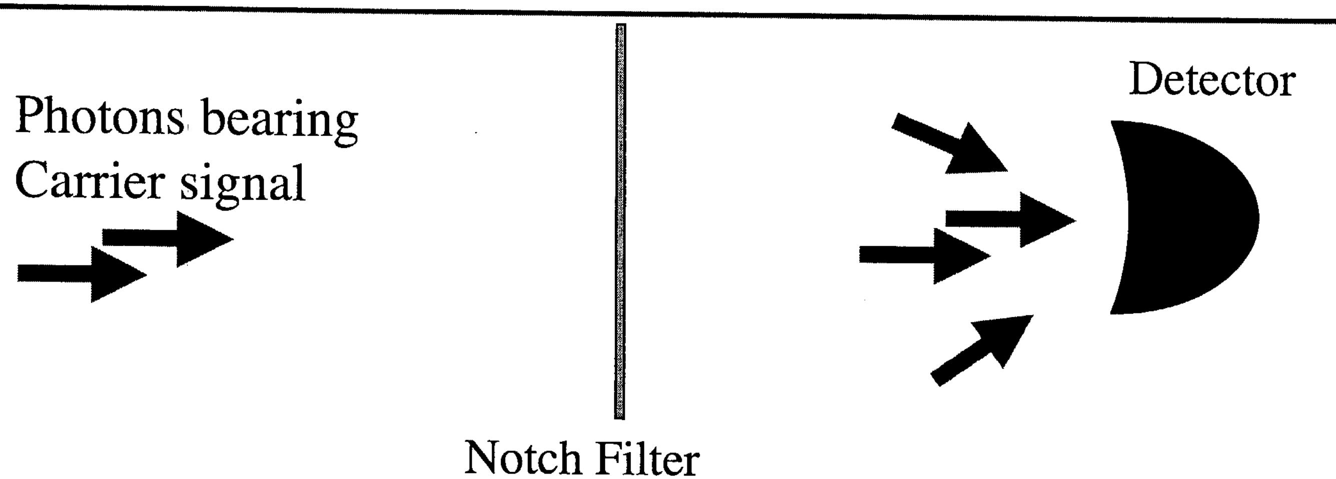
$$\frac{SNR_{correlated}}{SNR_{classical}} = \sqrt{\frac{\eta_{2-ph} P_r'(\omega_1, t) L(\omega_1)}{\eta_{\det} P_r(\omega_1, t)}} = \sqrt{\frac{\eta_{2-ph} \eta_{PDC} L(\omega_1)}{\eta_{\det}}} < 1$$

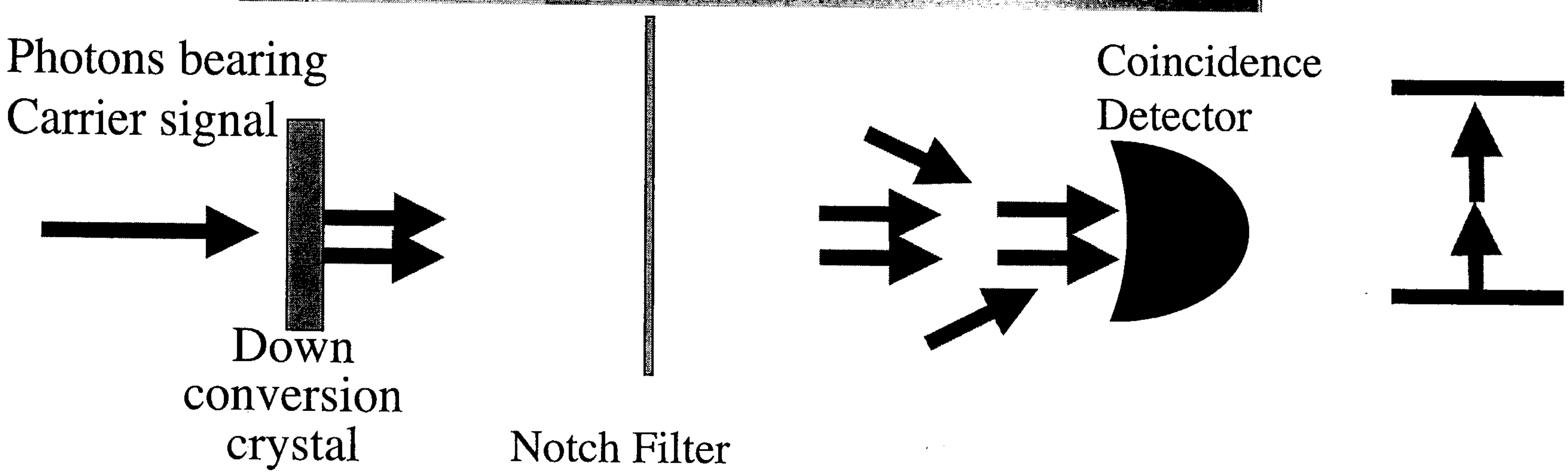
- Background Noise Limited Links

$$\frac{SNR_{correlated}}{SNR_{classical}} = \frac{\eta_{2-ph} \eta_{PDC} L(\omega_1)}{\sqrt{\eta_{\det} \eta_{1-ph}}} > 1; \quad I_0' < I_B$$

No saturation of detector on background signal

Common Mode Noise Rejection of a Large Background Noise Source





Advantages of Two-photon Sensitive Detectors

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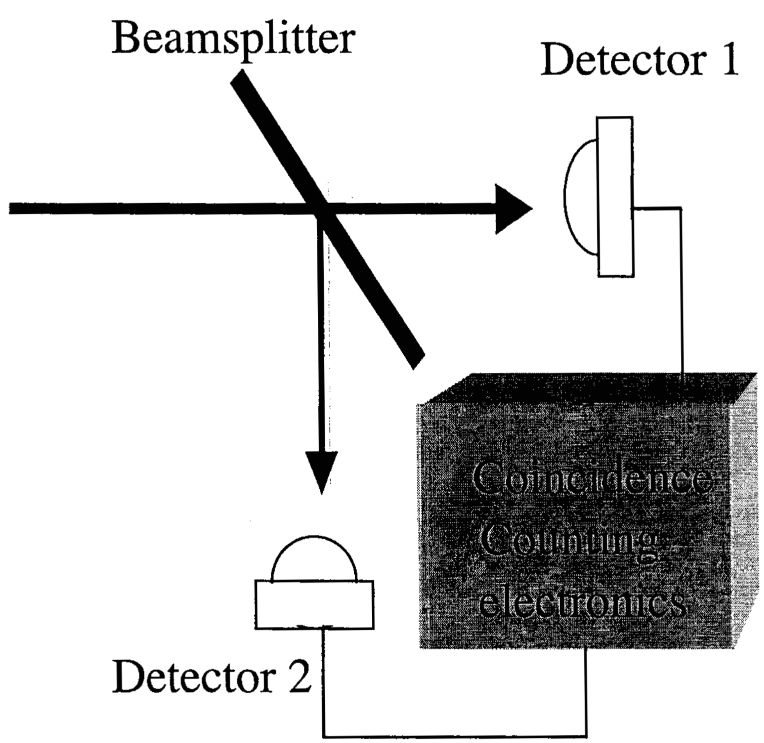

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Far Field: Received Power Law

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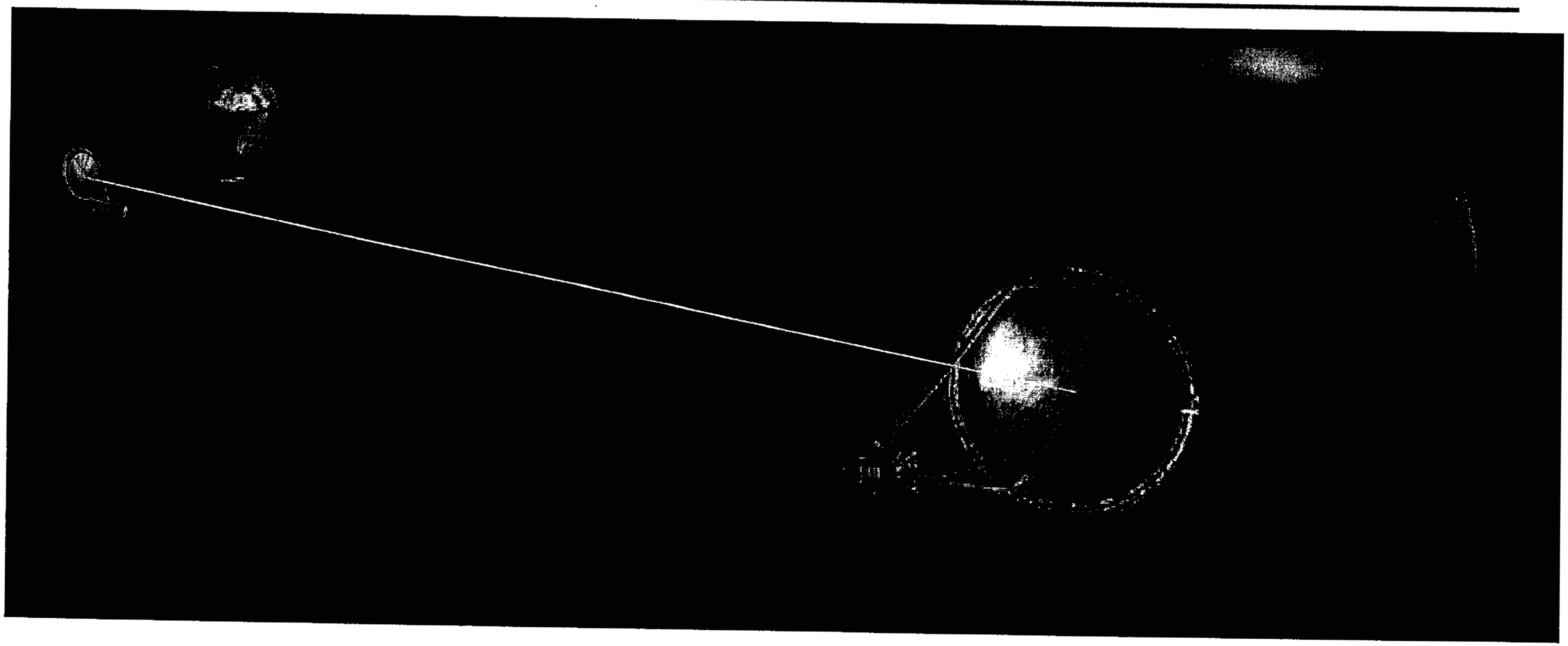

$$P_r = \mu P_t L \frac{A_t}{R^2} \frac{A_r}{\lambda^2}$$

Mode Locked Picosecond Pulse Generation from Diode Lasers

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- Picosecond pulses offer opportunity for multiple photons to arrive simultaneously at detector
- CREOL laser configuration (H. Shi et al., IEEE Photonics Technology Letters 9 (1997) 1439.) offers possibility of color tagging backscattered light.

Supporting Technology Requirements

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- Two-photon sources
  - A. Lamas-Linares et al., Nature 412, (2001) 887-890.
  - K. Sanaka et al., PRL 86 (2001) 5620-5623. (diode laser technology)
- Femtosecond pulsed fiber or diode lasers
- Two-photon detector
  - Solar Blind PMT's
  - 2-photon resonant atomic detection

Resonant Detection Scheme

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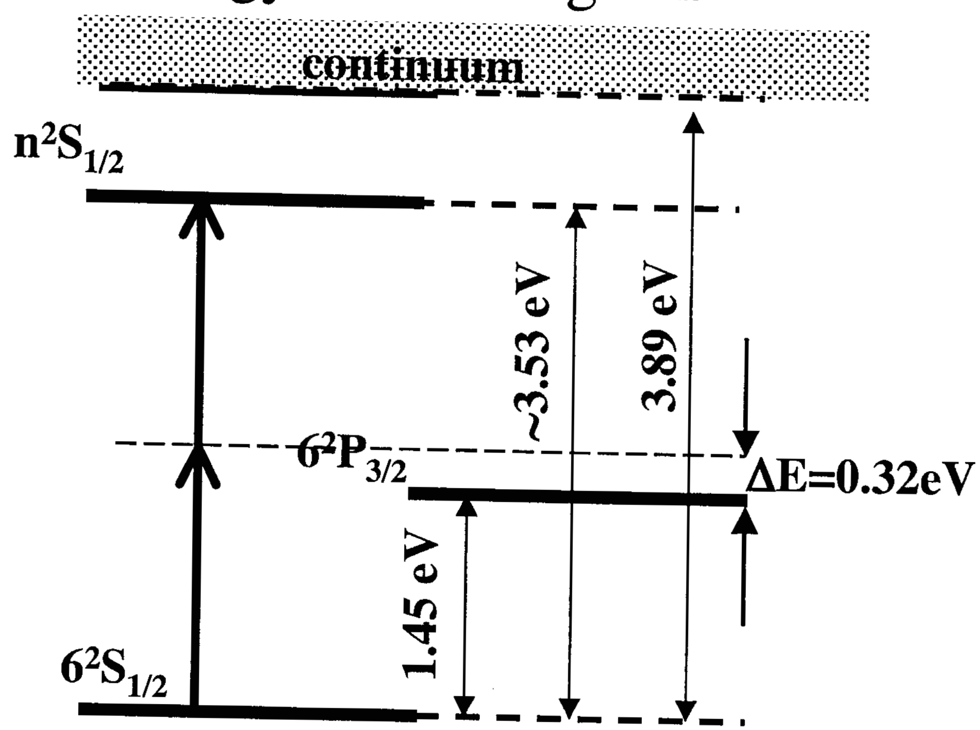
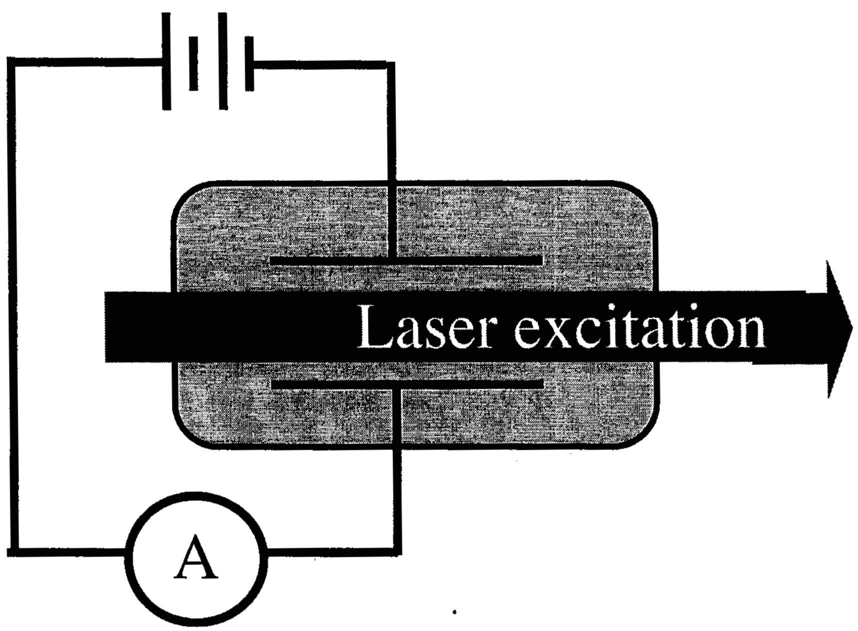
Cs Energy Level Diagram



NOT TO SCALE

Ionization Detection Mechanism



- Advantage
  - Efficient ionization permits detection of most excited atoms.
- Issue
  - Achieving good overlap of 2-photon wavefunctions within detector.
  - Ability to scale to arrays.

Whispering Gallery Mode Resonators Increase Optical Absorption path

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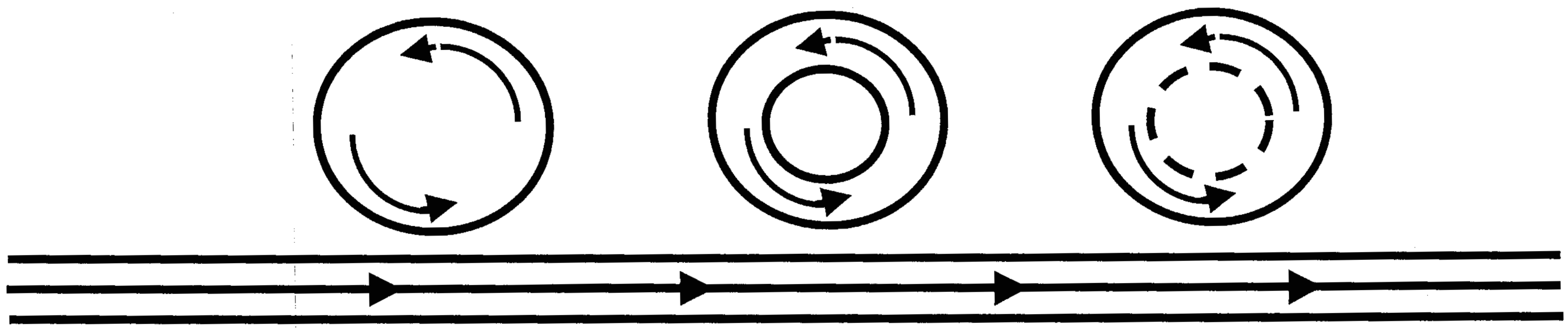
SCISSOR

Side Coupled Integrated Spaced Sequence of Resonators



S.L. McCall et al., Applied Physics Letters 60 (1992) 289.

SCISSOR Cavity Detector can be Integrated into Linear Arrays

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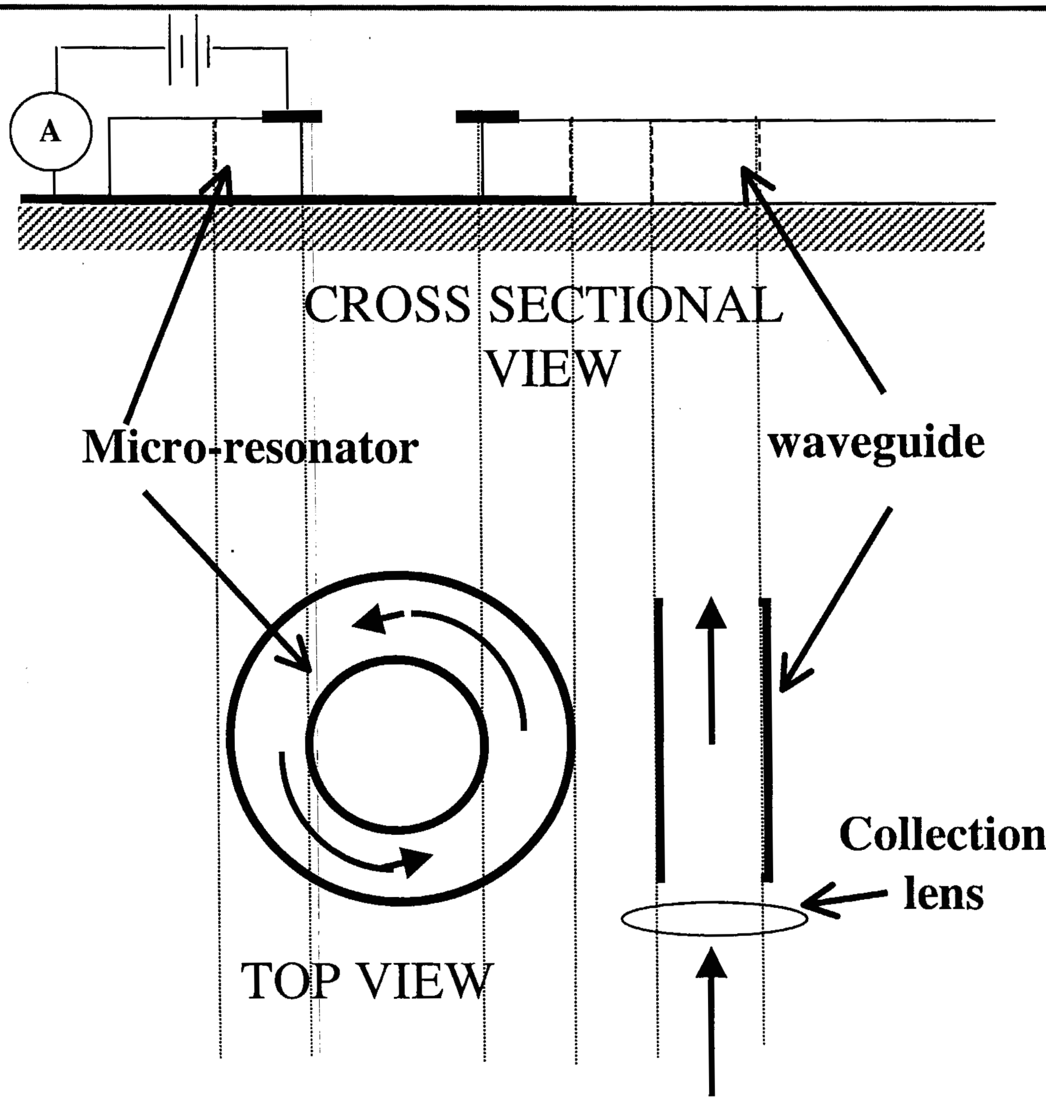

Cavity Q Allows:

- Adjustment of detection time window
- Long absorption pathlength to improve quantum efficiency

Conclusions

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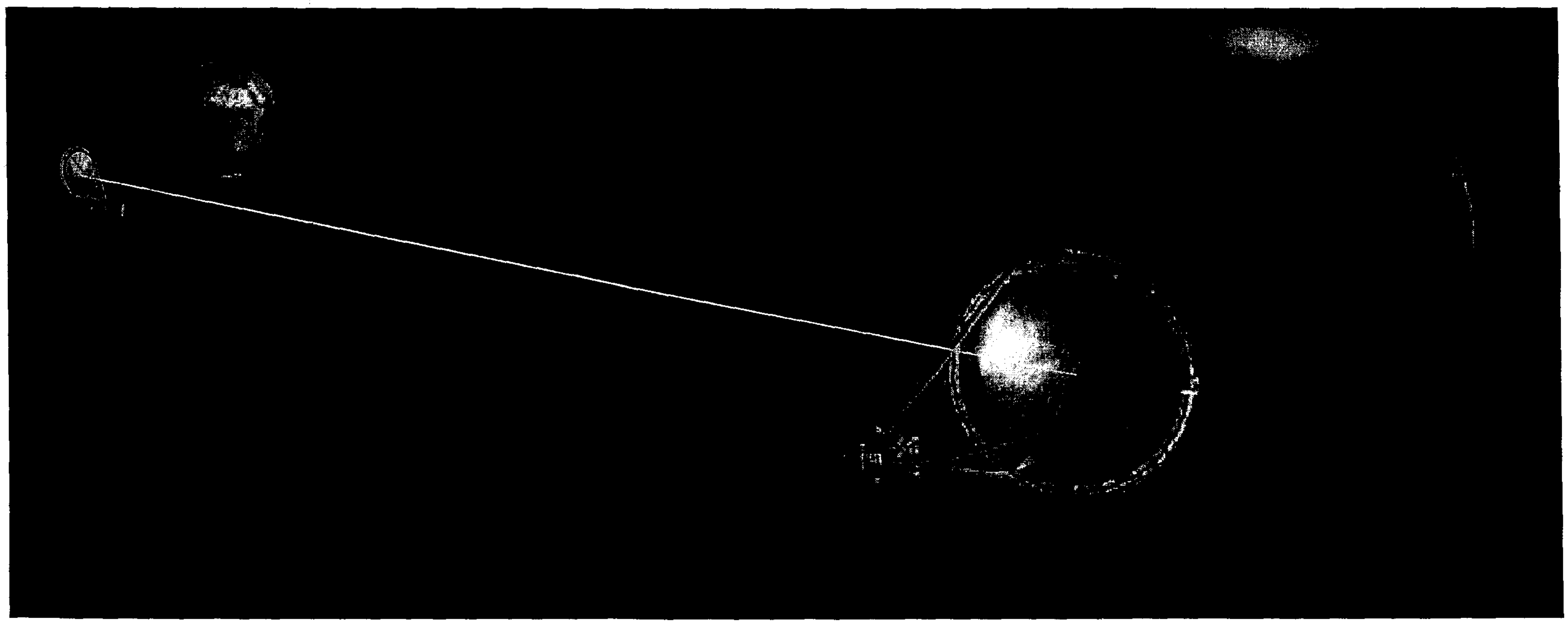
- Using correlated photons for signal carrier can help remove large background noise.
  - Benefits--
    - Eliminate detector saturation on background noise signal.
- Applications: Common mode rejection detection schemes
  - Signal recovery from large solar or other noise background
  - Secure line of sight communications
  - Noisy fiber networks

Backup Slides

Far Field: Received Power Law



$$P_r = \mu P_t L \frac{A_t}{R^2} \frac{A_r}{\lambda^2}$$

Subset of Photon Paths Form Interferrometer

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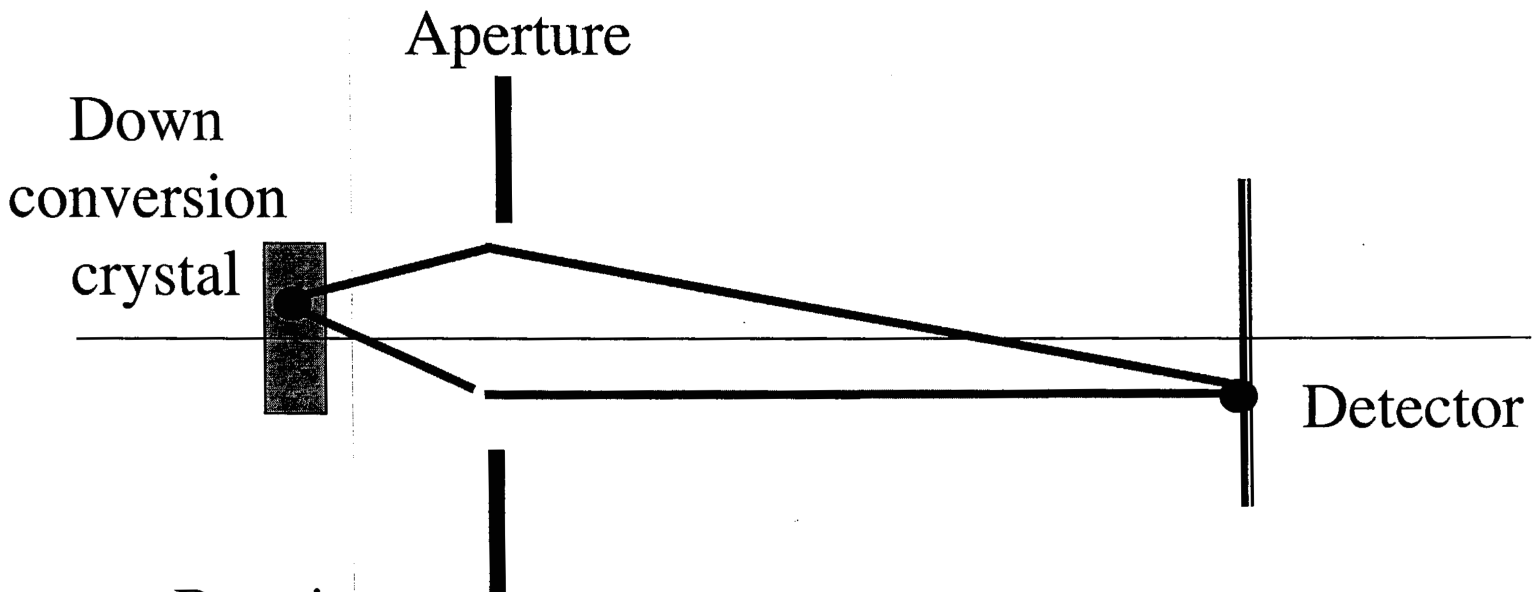
$$A\left(\vec{k}_{01},\vec{k}_{02}\right)=\int\int\left[G_{1,k_1\beta_1}G_{2,k_2\beta_2}+G_{1,k_2\beta_2}G_{2,k_1\beta_1}\right]F\left(\vec{k}_1\beta_1,\vec{k}_2\beta_2\right)d\vec{k}_1 d\vec{k}_2$$



Require:

- Degenerate photons; $\omega_1 = \omega_2 = \omega_p/2$
- Equal path lengths

Second Order Probability Amplitude

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1990, Javanainen and Gould predict startling result:

For parametrically driven photons at low intensities, two-photon transition rate is linear in I, not quadratic!

$$\left|A\left(\vec{k}_{01},\vec{k}_{02}\right)\right|^2 = \left\langle\Psi\right|E_1^{(-)}E_2^{(-)}E_1^{(+)}E_2^{(+)}\left|\Psi\right\rangle \propto I_{coinc}$$

J. Javanainen and P.L. Gould, "Linear intensity dependence of a two-photon transition rate", Phys. Rev. A 41 (1990) 5088.

Potential Applications

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- 1. Adapive optics: *A factor of 10 improvement in the signal to noise ratio by the use of correlated photon signal recovery techniques translates to a factor of 100 in cost savings.*
- 2. Improvement of SNR in optical telecommunications links in circumstances where the signal is swamped by background noise and atmospheric turbulence prevents heterodyning.
- 3. Reduce hand off time of optical navigation tracking algorithms by with faster edge detection due to improved SNR