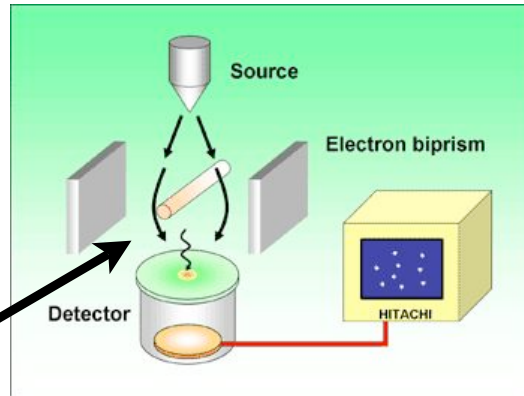


# Luce, materia: onde, particelle, altro?

# Elettroni

## Interferenza di elettroni: un esperimento moderno

Elettroni emessi singolarmente dalla sorgente, e registrati singolarmente sullo schermo.



Doppia  
fenditura

<http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm>

Tonomura et al., American Journal of Physics 57, 117 (1989)

## Elettroni: onde o particelle? Formazione delle frange di interferenza

Si veda il filmato scaricabile da:

<http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm>

## Che percorso segue la particella?

Gli elettroni *arrivano individualmente*: corpuscoli!

Al passar del tempo,  
*l'arrivo di numerosi elettroni produce frange di interferenza.*

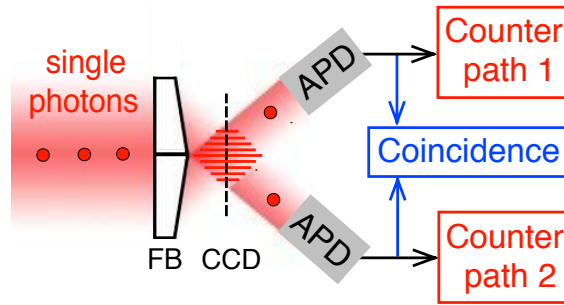
Non ha significato chiedersi *dove* sono passati i singoli elettroni che hanno dato luogo alla figura di interferenza: finché si tratta di enti in transito, non misurati, non ha senso descriverli in termini di onde o corpuscoli.

La *statistica* è correlata intimamente al comportamento quantistico.

## Fotoni

# Onde o particelle?

## Interferenza di fotoni singoli

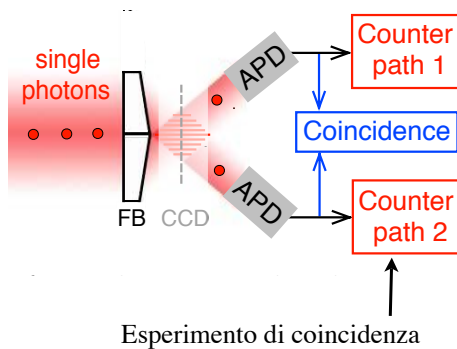


**Fig. 1.** Wavefront-splitting set-up based on a Fresnel's biprism (FB). APDs are avalanche silicon photodiodes operating in photon counting regime. An intensified CCD camera (dash line) records interference fringes in the overlapping region of the two deviated wavefronts. When the CCD is removed, it is then possible to demonstrate the single photon behaviour by recording the time coincidences events between the two output channels of the interferometer.

Single-photon wavefront-splitting interference. An illustration of the light quantum in action, V. Jacques, E. Wu, T. Toury, F. Treussart, A. Aspect, P. Grangier and J.-F. Roch, Eur. Phys. J. D **35**, 561-565 (2005)

<http://epjd.edpsciences.org/content/view/232/283/lang,en/>

# Onde o particelle?



anticoincidenza  
(ideale:  $\alpha=0$ , onde:  $\alpha=1$ ).  
Risultato: particelle

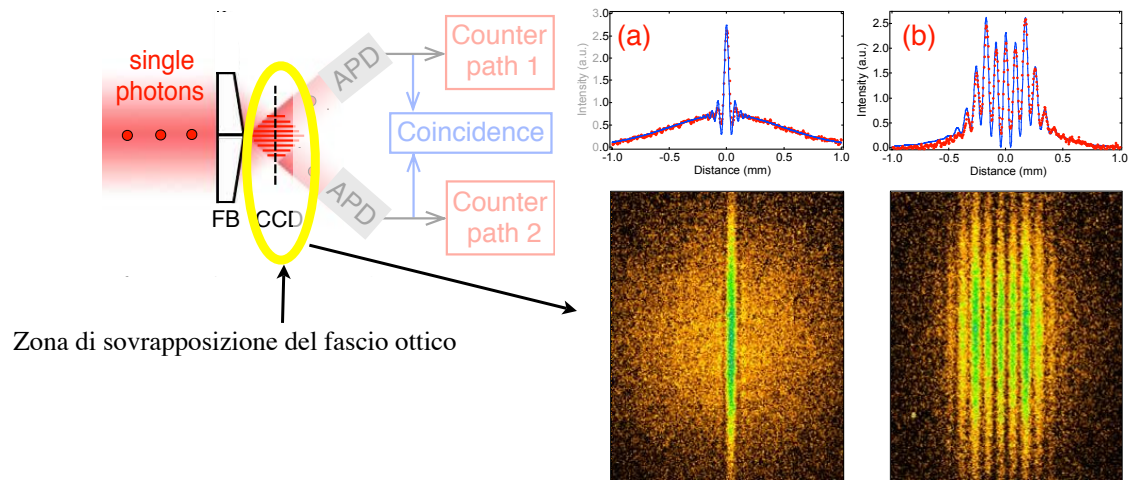
(b) Single-photon pulses

Counting time (s)	$N_1$	$N_2$	$N_C$	$\alpha$
5.138	49135	50865	28	0.132
5.190	49041	50959	23	0.109
5.166	49097	50903	23	0.109
5.173	49007	50996	28	0.133
5.166	48783	51217	29	0.137
5.167	48951	51049	31	0.147
5.169	49156	50844	30	0.142
5.204	49149	50851	32	0.152
5.179	49023	50977	26	0.124
5.170	48783	51217	26	0.123

Single-photon wavefront-splitting interference. An illustration of the light quantum in action, V. Jacques, E. Wu, T. Toury, F. Treussart, A. Aspect, P. Grangier and J.-F. Roch, Eur. Phys. J. D **35**, 561-565 (2005)

<http://epjd.edpsciences.org/content/view/232/283/lang,en/>

## Onde o particelle?



Risultato: frange di interferenza

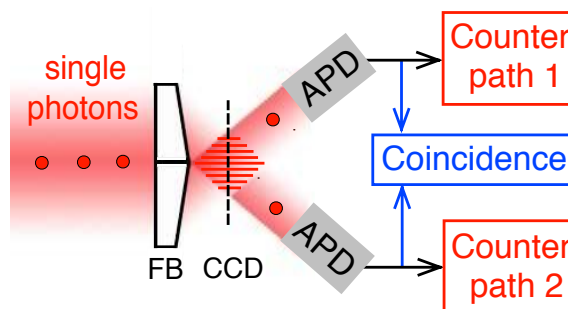
Fig. 5. Examples of interference patterns observed in the overlapping region of the two transmitted beams through the Fresnel's biprism, for (a)  $z = 11$  mm and (b)  $z = 98$  mm. Overlaid blue curves are fits evaluated from a model taking into account Fresnel diffraction and temporal coherence effects.

Single-photon wavefront-splitting interference. An illustration of the light quantum in action, V. Jacques, E. Wu, T. Toury, F. Treussart, A. Aspect, P. Grangier and J.-F. Roch, Eur. Phys. J. D **35**, 561-565 (2005)

<http://epjd.edpsciences.org/content/view/232/283/lang,en/>

## Onde o particelle.

Usando il medesimo apparato sperimentale:



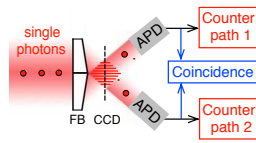
onde o particelle a seconda dell'esperimento (!)

Il fotone (o l'onda) "sa" in anticipo come deve comportarsi?

Single-photon wavefront-splitting interference. An illustration of the light quantum in action, V. Jacques, E. Wu, T. Toury, F. Treussart, A. Aspect, P. Grangier and J.-F. Roch, Eur. Phys. J. D **35**, 561-565 (2005)

<http://epjd.edpsciences.org/content/view/232/283/lang,en/>

## Interferenza e fotoni

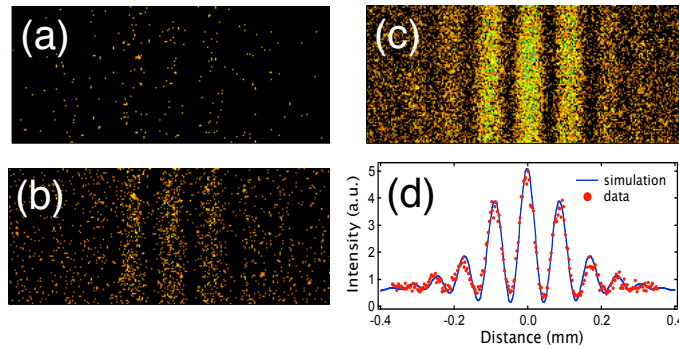


**Single-photon wavefront-splitting interference. An illustration of the light quantum in action.** V. Jacques, E. Wu, T. Toury, F. Treussart, A. Aspect, P. Grangier and J.-F. Roch, Eur. Phys. J. D **35**, 561-565 (2005)

<http://epjd.edpsciences.org/content/view/232/283/lang,en/>

Come viene  
costruito il pattern  
di interferenza?

I fotoni “sanno”  
che interferiranno  
con fotoni  
successivi???



**Fig. 4.** Observation of the interference pattern expanded by the eyepiece and recorded by the intensified CCD camera. Image (a) (resp. (b) and (c)) is made of 272 photocounts (resp. 2240 and 19773) corresponding to an exposure duration of 20 s (resp. 200 s and 2000 s). Graph (d) displays the resulting interference fringes obtained by binning columns of CCD image (c) and fit of this interference pattern using coherent beam propagation in the Fresnel diffraction regime, and taking into account the finite temporal coherence due to the broad spectral emission of the NV colour centre. A visibility of 94% can be associated to the central fringe.

filmato su:

<http://epjd.edpsciences.org/index.php?option=article&access=standard&Itemid=129&url=/articles/epjd/olm/2005/10/d05194/d05194.html>

## Che percorso segue la luce?

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Non ha significato chiedersi *dove* sono passati i singoli fotoni che hanno dato luogo alla figura di interferenza: finché si tratta di enti in transito, non misurati, non ha senso descriverli in termini di onde o corpuscoli.

La *statistica* è correlata intimamente al comportamento quantistico.

# Riassunto

Gli esperimenti indicano che una teoria quantistica dovrà contenere:

- Natura ondulatoria e corpuscolare.
- Probabilità.