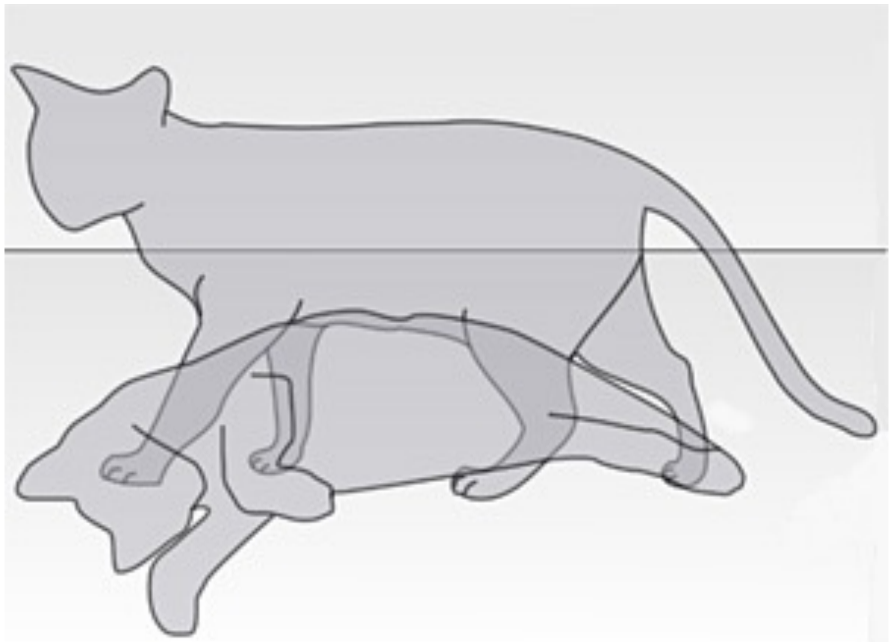
Towards the Quantum Mechanical approach

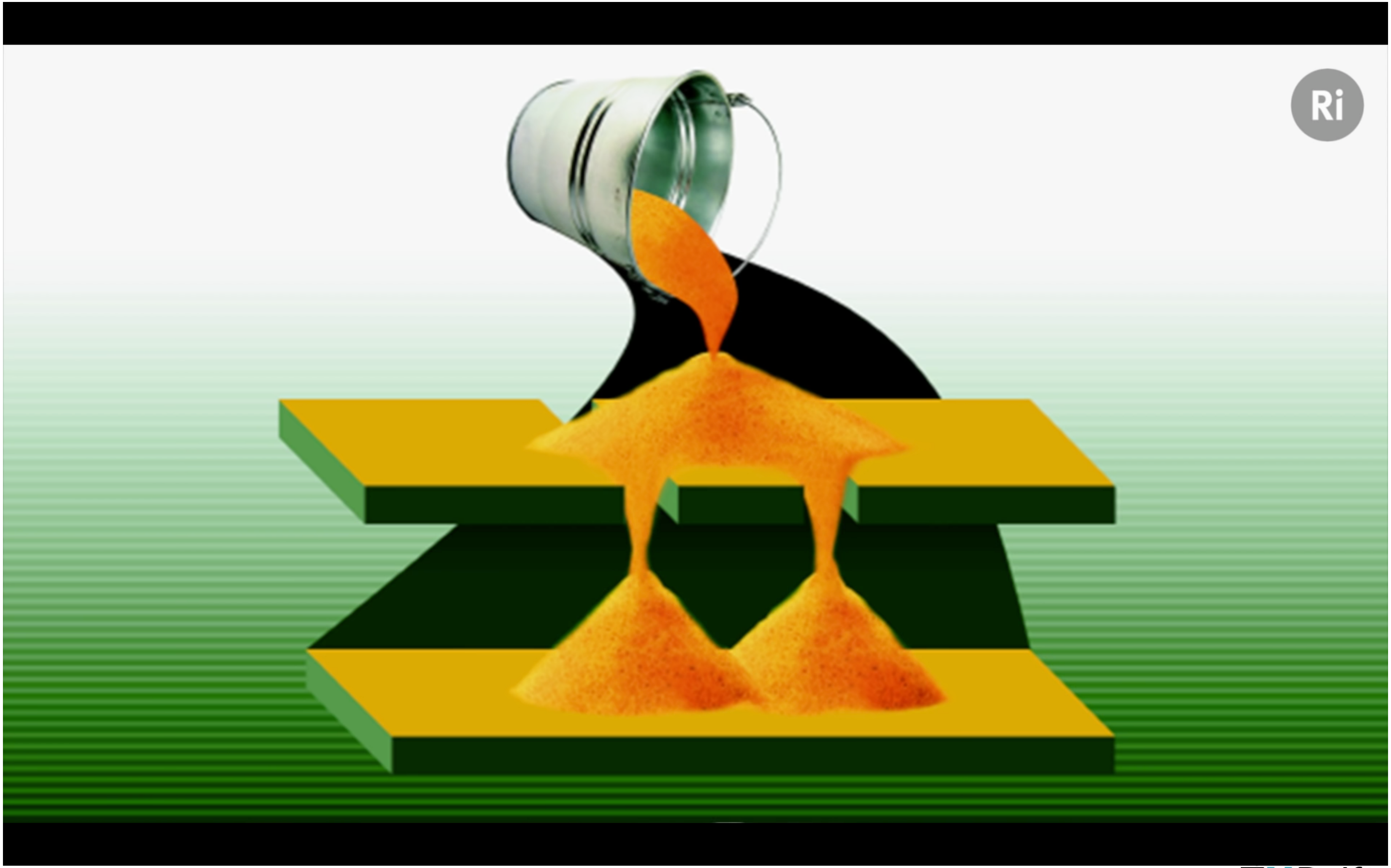


Katia Pappas

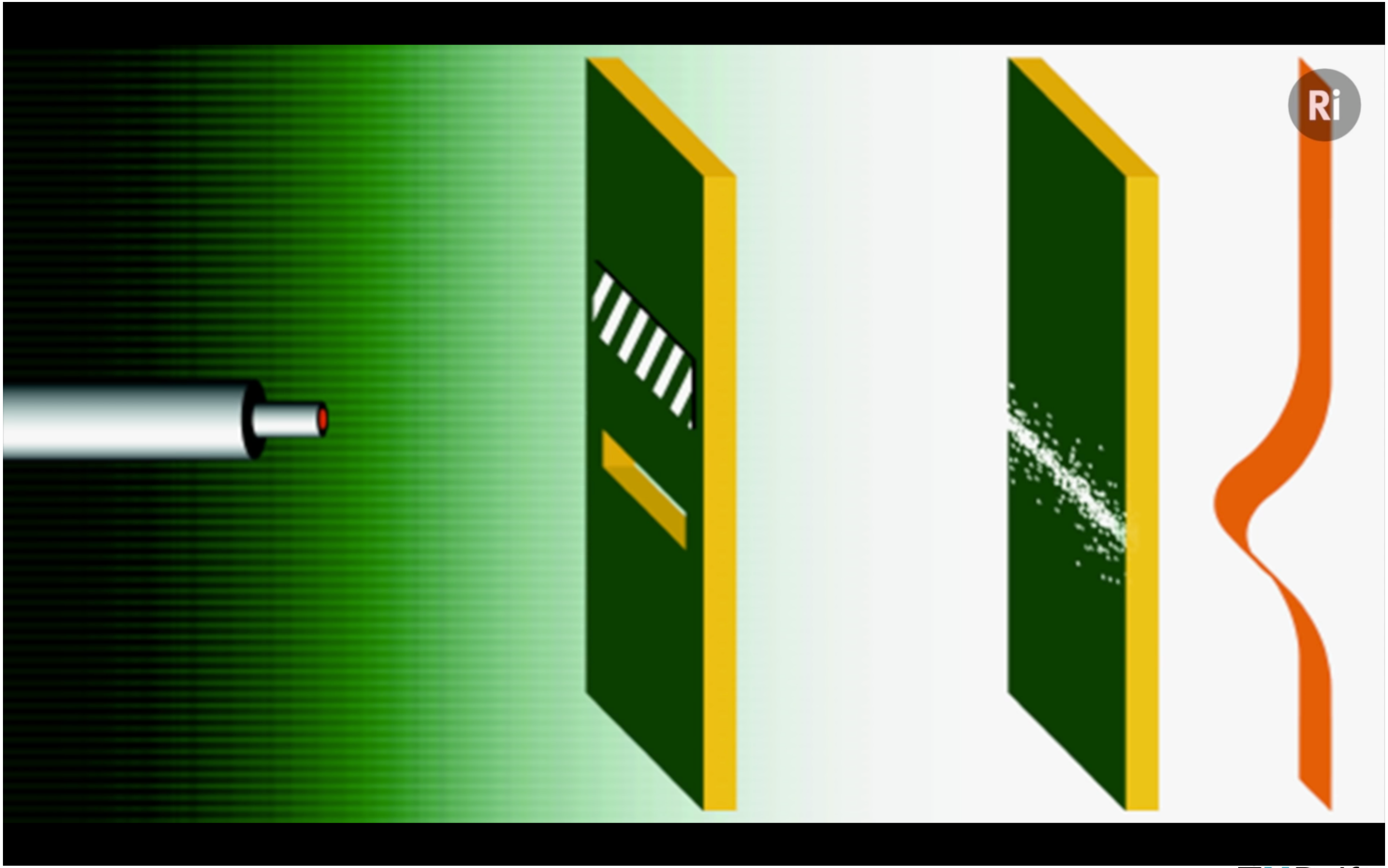
TU Delft

Classical Mechanics	Quantum Mechanics
Newton’s law of motion	Schrödinger equation
well defined particles and trajectories	wave functions
deterministic	probabilistic
local realism	quantum nonlocality

Classical Particles

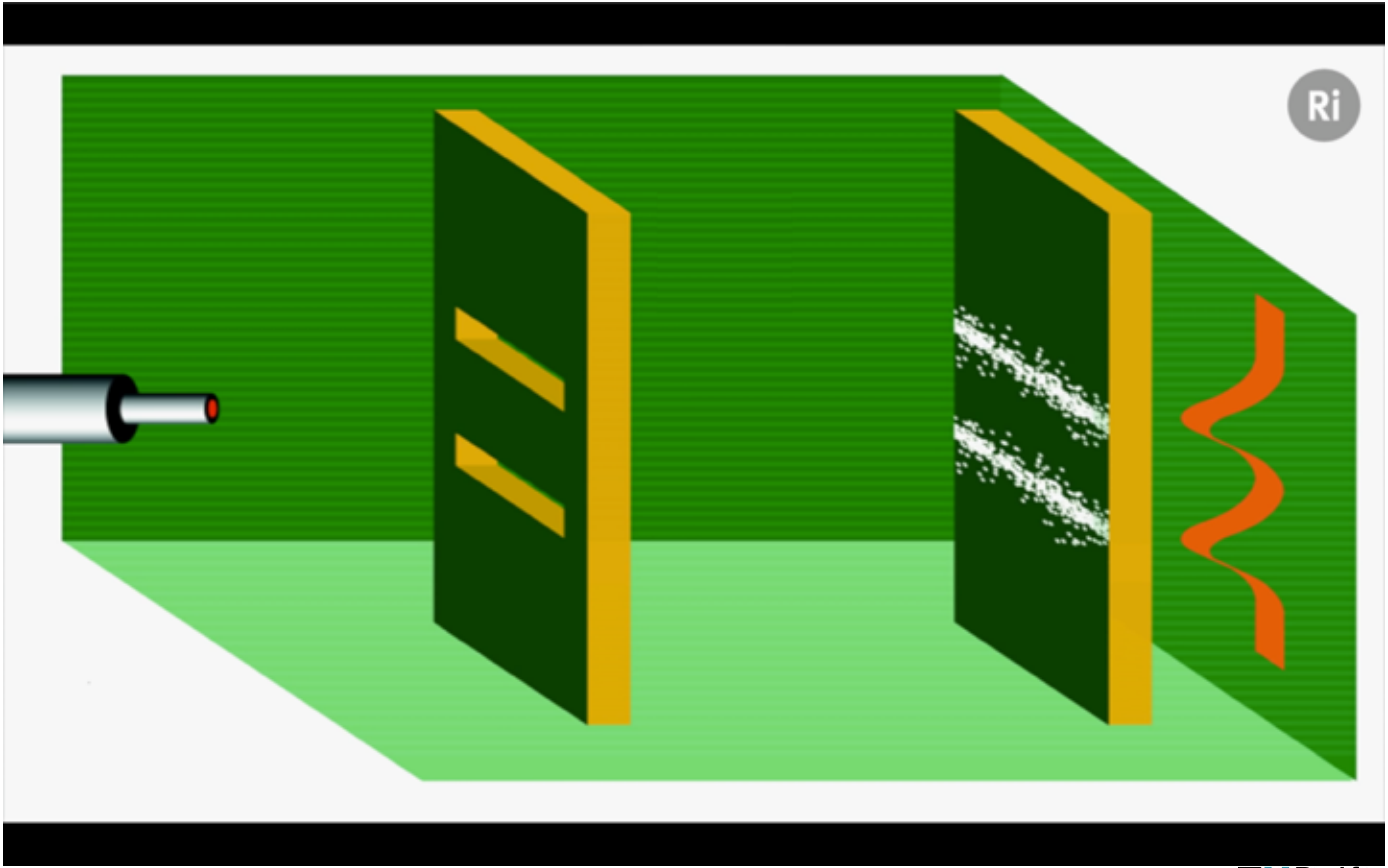


Double-slit experiment explained by Jim Al-Khalili



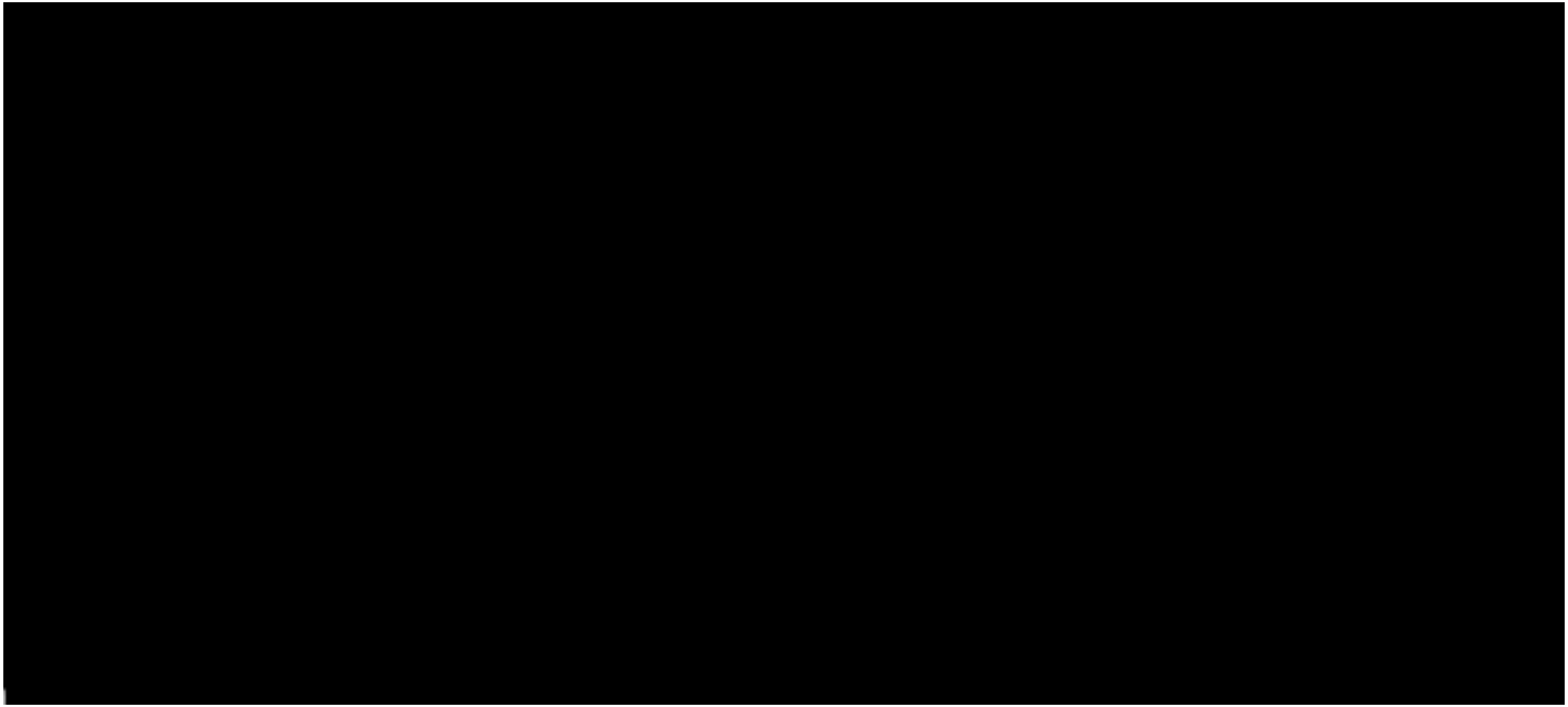
Double-slit experiment explained by Jim Al-Khalili

Classical Particles



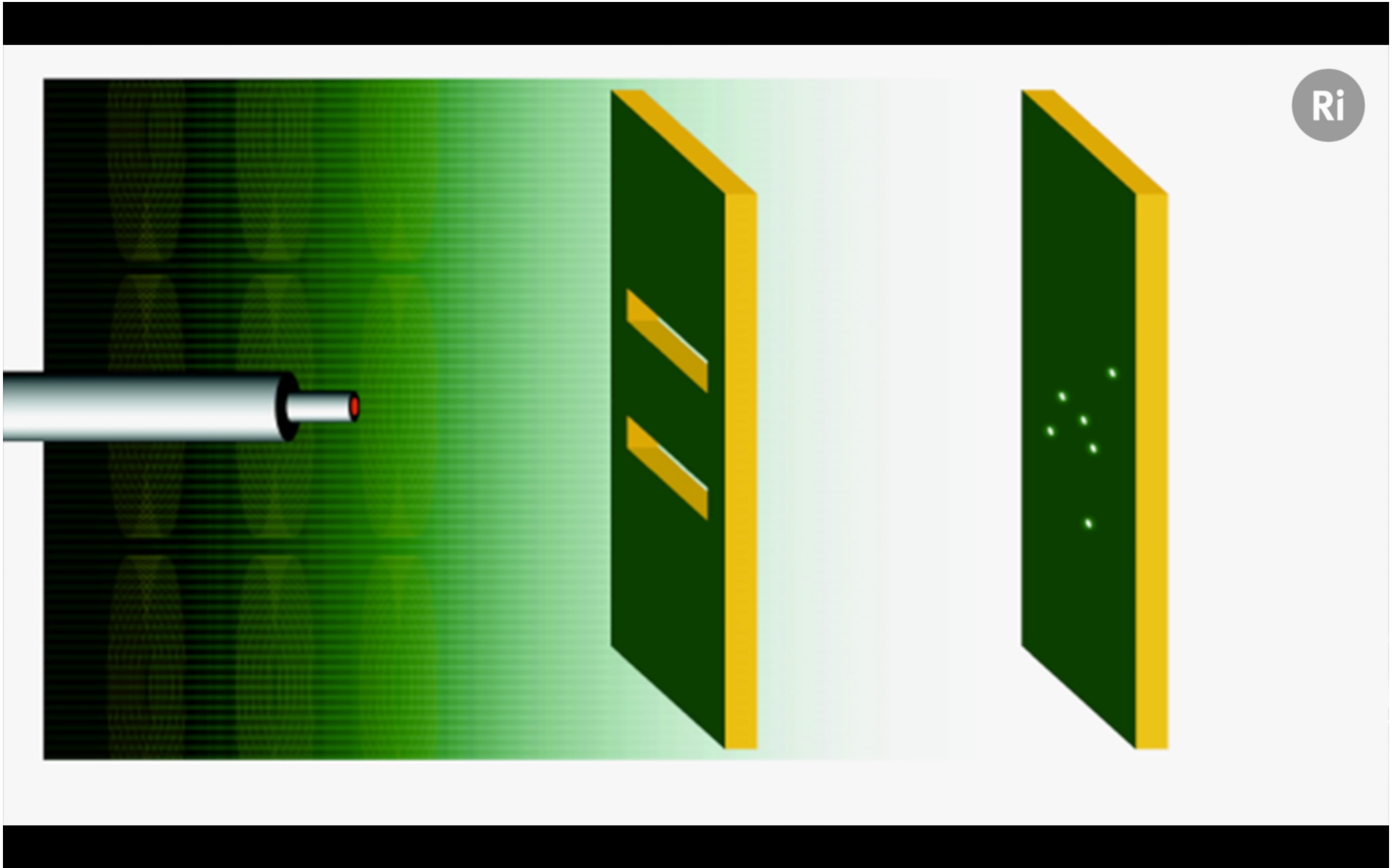
Double-slit experiment explained by Jim Al-Khalili

Double-slit experiment with electrons



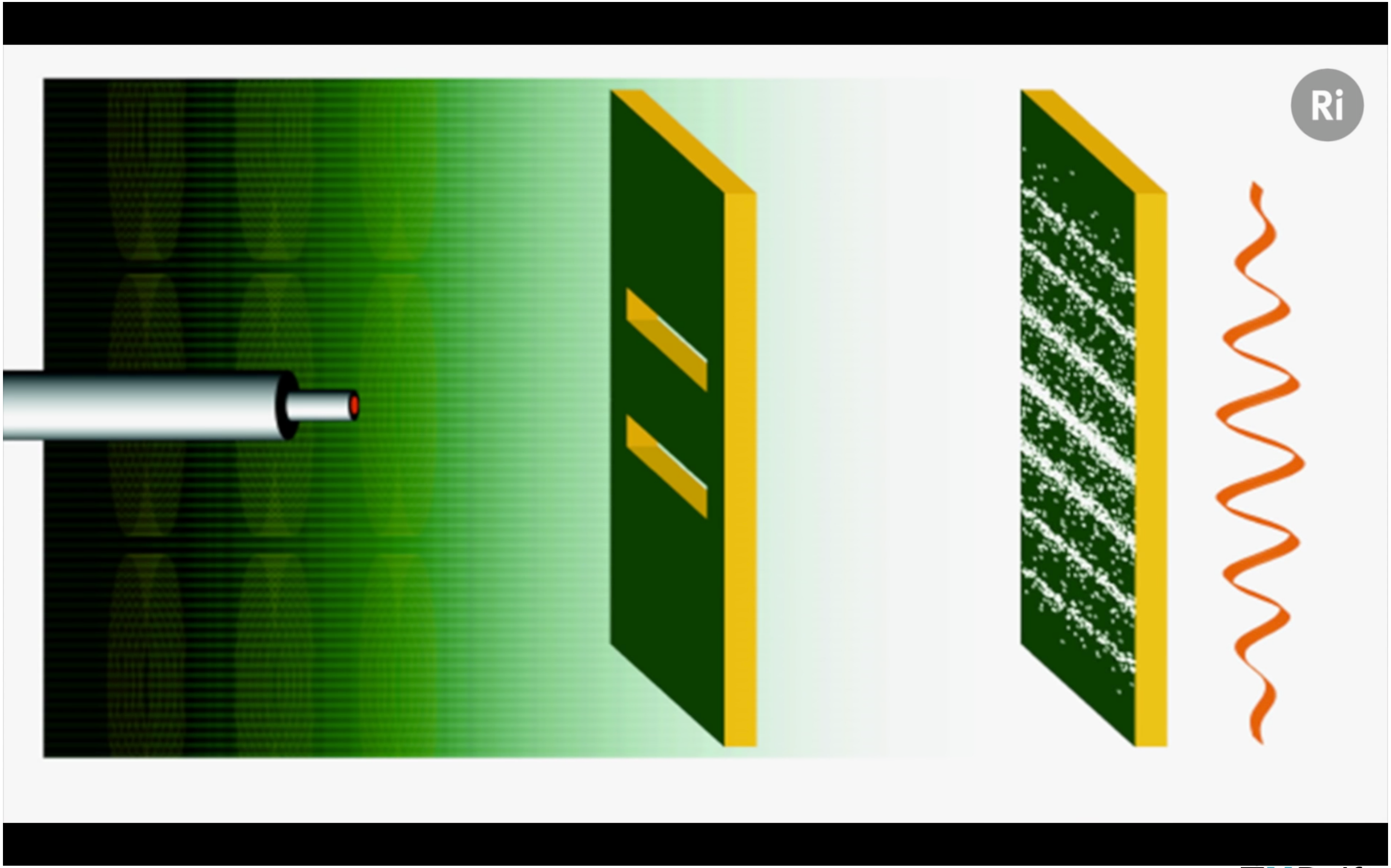
http://iopscience.iop.org/article/10.1088/1367-2630/15/3/033018/meta

Quantum System



Double-slit experiment explained by Jim Al-Khalili

Quantum System



Double-slit experiment explained by Jim Al-Khalili

QUANTUM MECHANICS: Probabilistic

information from one particle is zero !!!

There is no such thing as

polarisation or wave function of one particle

The measurement is at the heart of the interpretation of QM

- probabilistic
- wave function collapses to its eigenstates
- => observables e.g. the polarisation of a beam

Ehrenfest Theorem:

The observables of a QM system follow Newtons’ law

QUANTUM MECHANICS: non local

a particle can be everywhere in the universe !!!

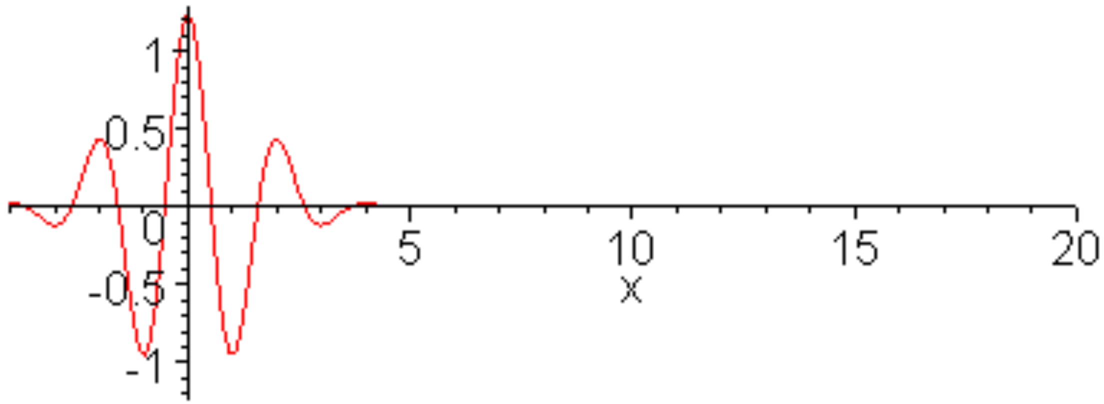
Richard Feynman, Douglas Robb Lectures Auckland 1979

available on Youtube, don't miss it !

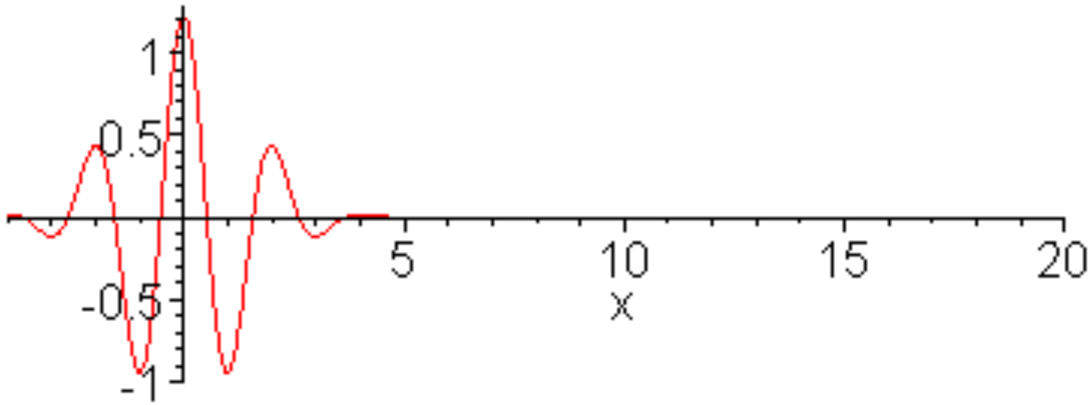
A way out: the wave packet

satisfies our classical thinking but not fundamental

because dispersive



absence of dispersion is a solitonic solution



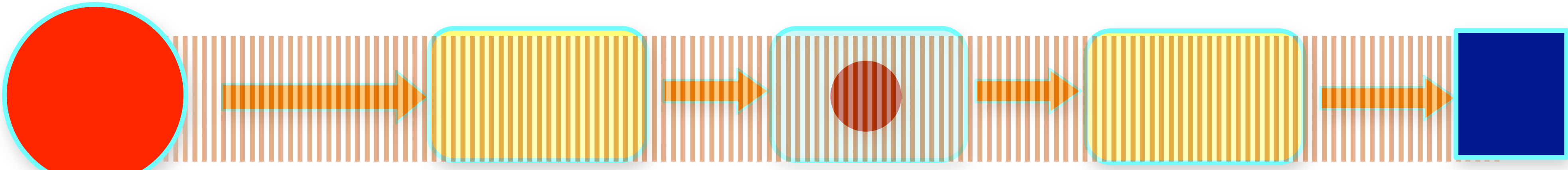
Neutron scattering : the beam defines a QM system leading to observables that can be understood by CM

Between probabilistic scattering and absorption events one can consider that neutrons propagate deterministically as point like classical particles with “infinitely” well-defined trajectories r(t), each carrying a classical magnetic moment with perfectly well-defined direction at any instance of time.

we can optimise our instruments with ray tracing Monte Carlo simulation software e.g. McSTAS

at the origin of some confusion between CM and QM

Neutron scattering : the beam defines a QM system leading to observables that can be understood by CM



observables defining a neutron beam :
Energy, polarisation, wave vector, position of the beam etc

but interference phenomena, like scattering or the doubt slit experiment, are purely QM and cannot be understood by CM.

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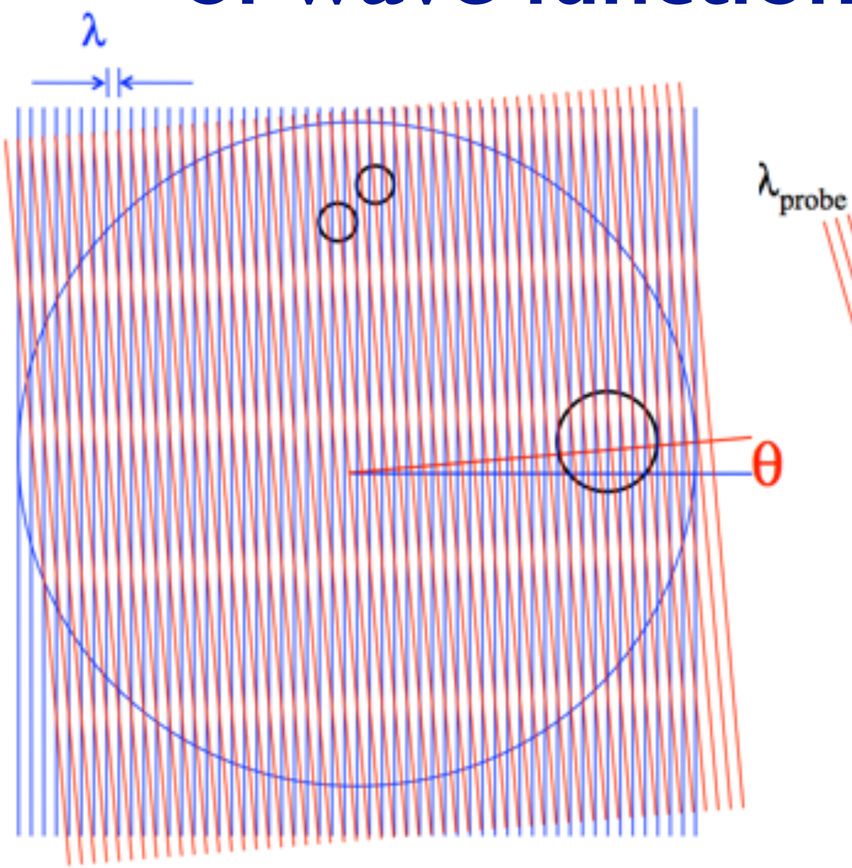
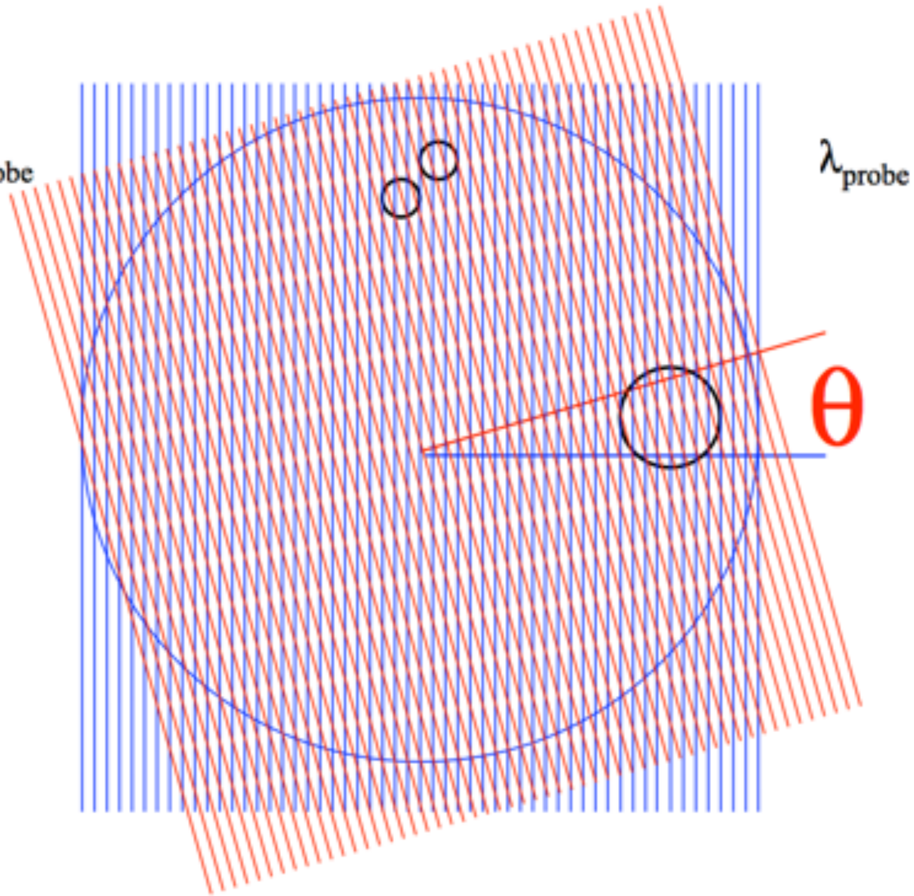
but interference phenomena, like scattering or the doubt slit experiment, are purely QM and cannot be understood by CM.

their understanding require the concepts **of wave function and non-locality**





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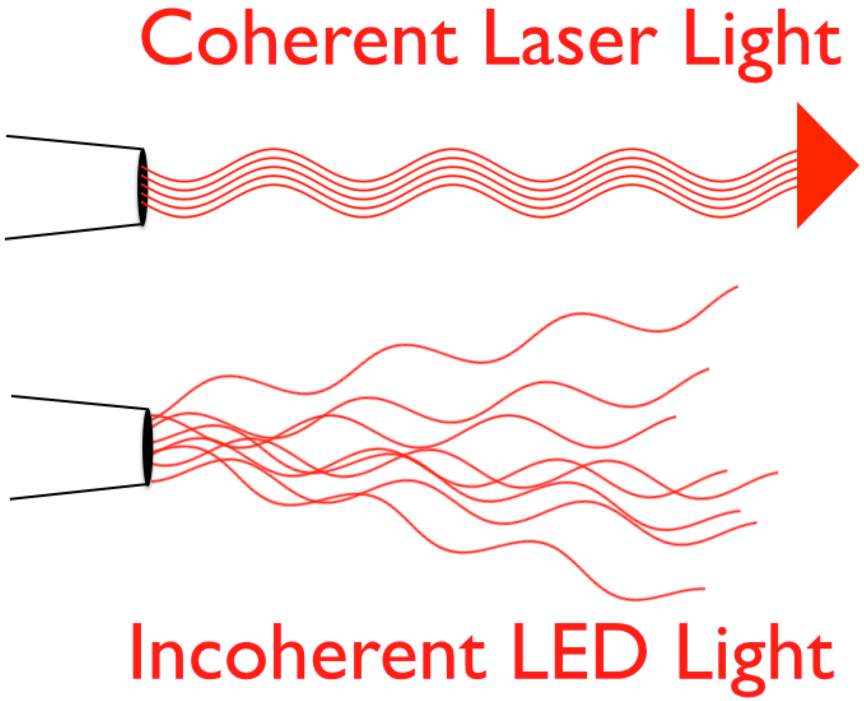

Miridia Technology Inc

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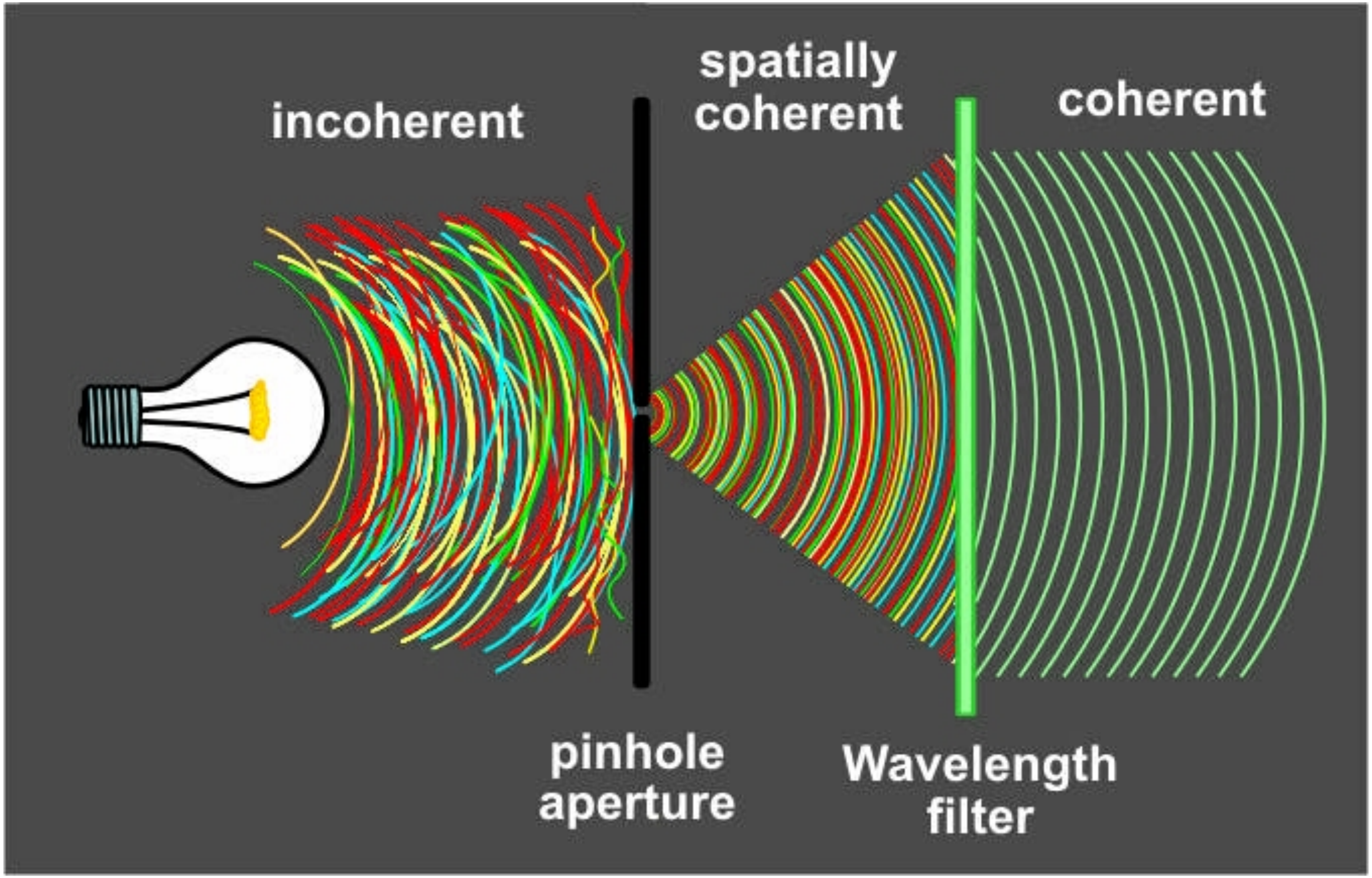
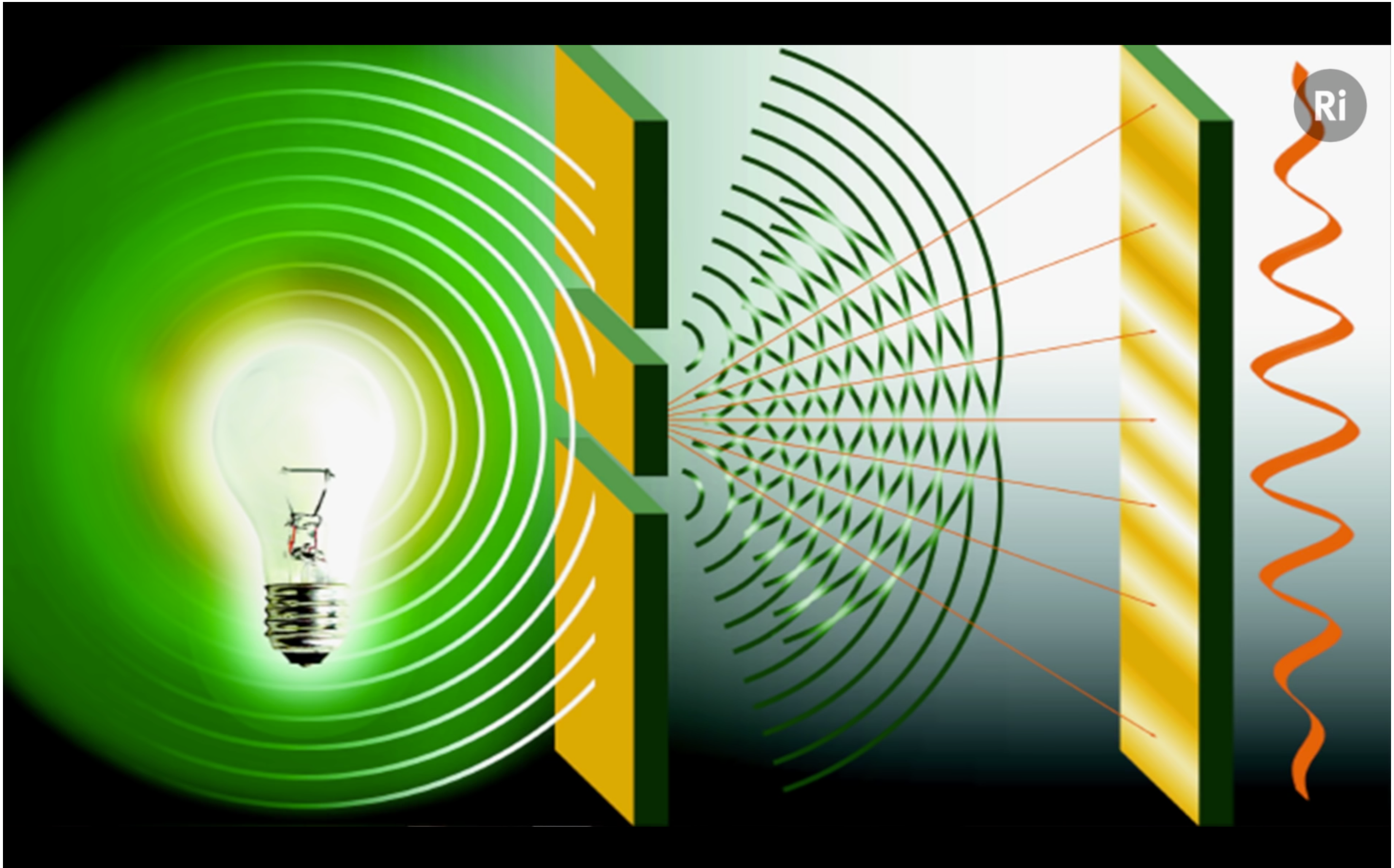
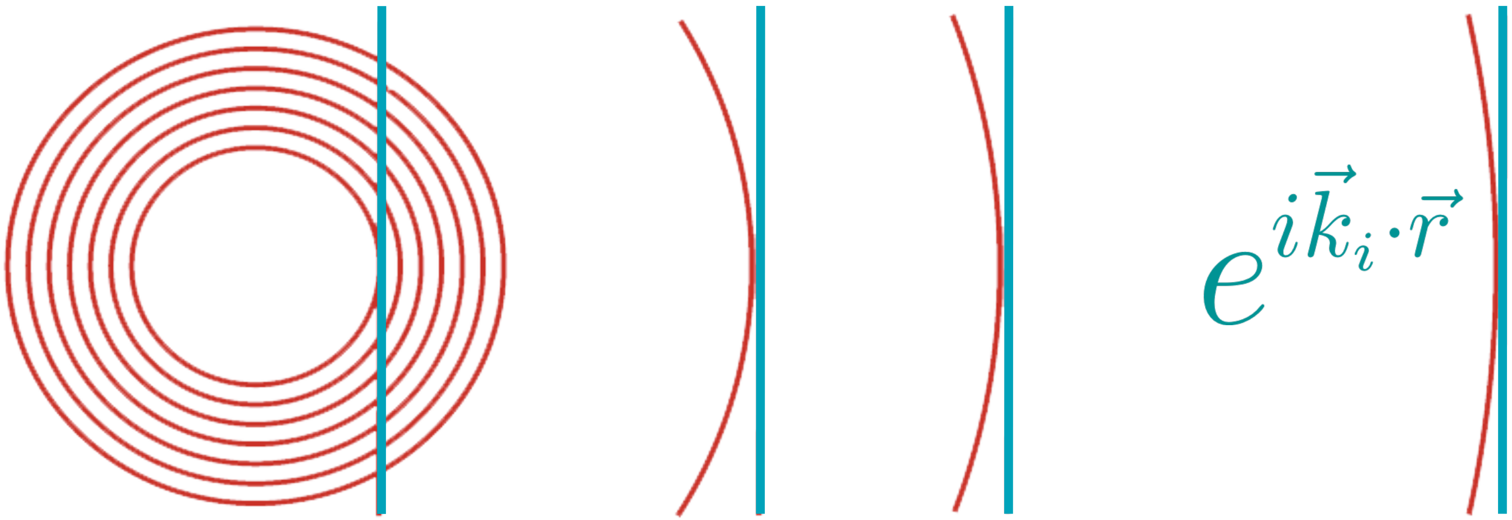


http://amasci.com

Double-slit experiment explained by Jim Al-Khalili



Neutron scattering : waves and particles



$$e^{i\vec{k}_i\cdot\vec{r}}$$

at sufficiently large distances from the source the neutron beam may be approximated by a plane wave

Everything ever observed can be explained by identifying "one neutron" with an infinite plane wave and classically (incoherently) averaging over the beam

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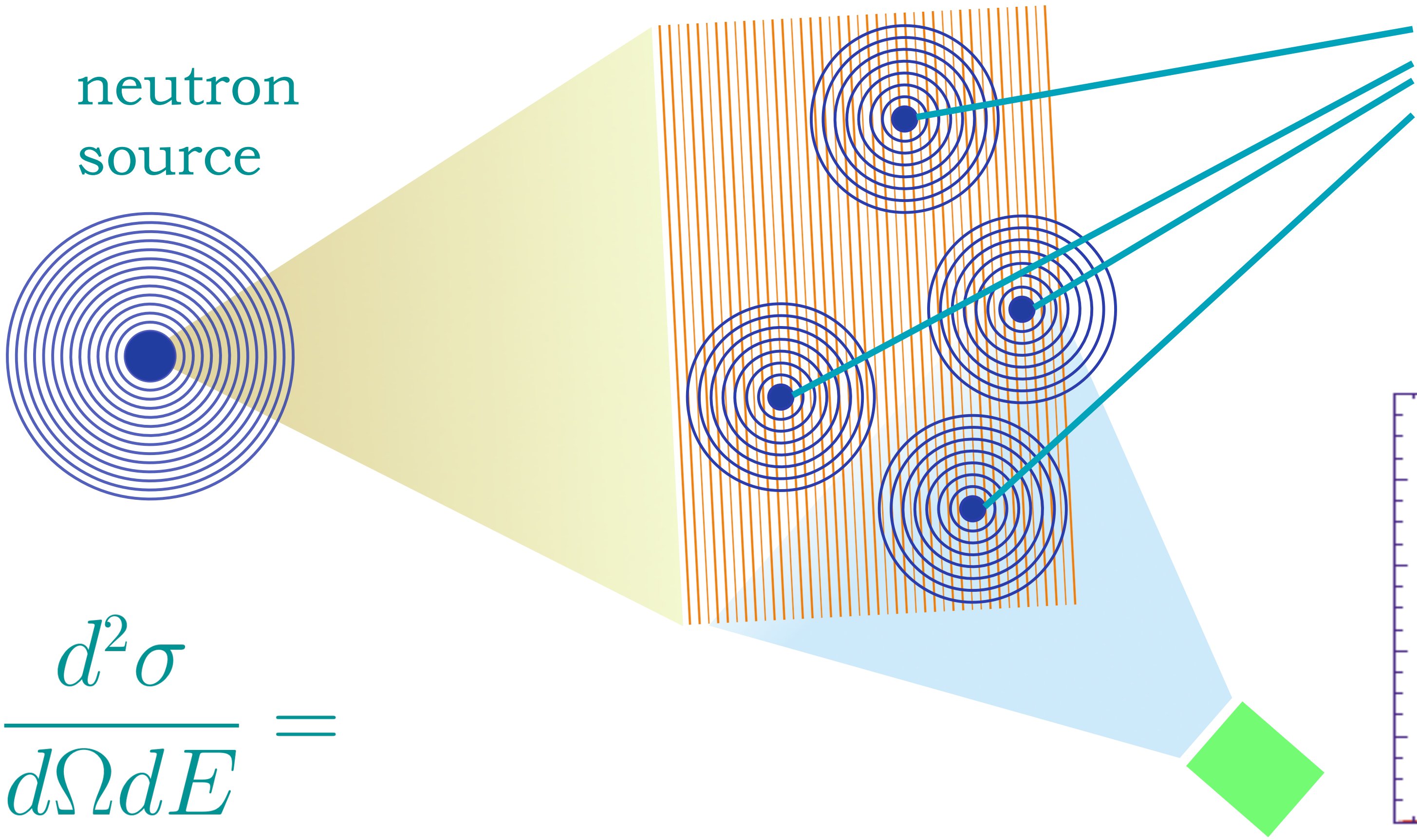
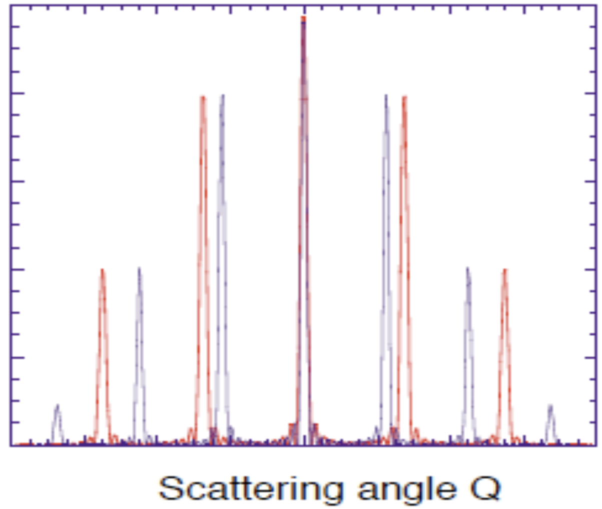
Neutron scattering : waves and particles

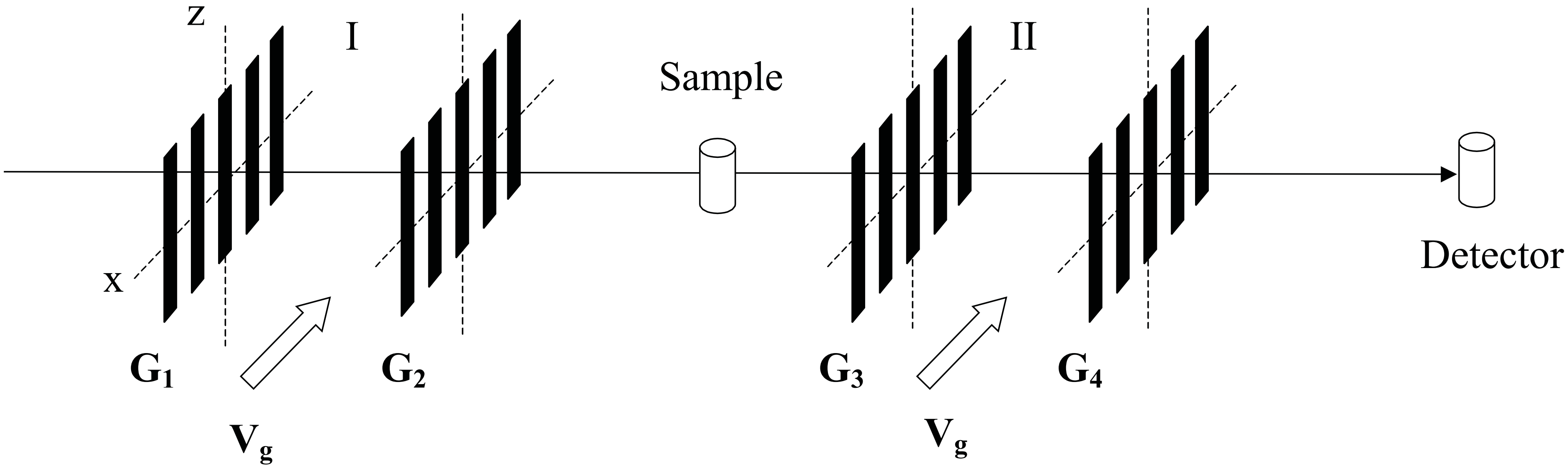


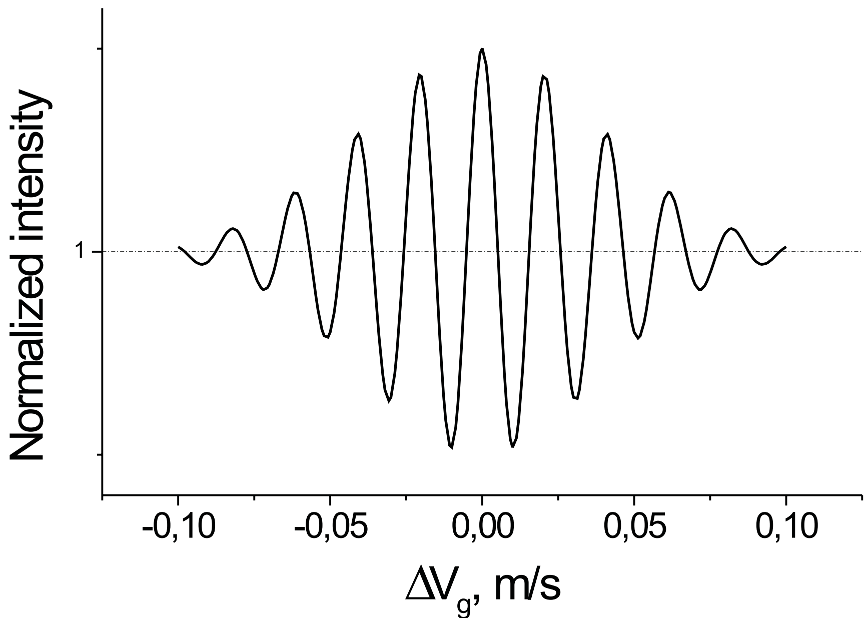
interference pattern at
the detector



$$\frac{d^2\sigma}{d\Omega dE} = \frac{k_f}{k_i} \sum_{\lambda_i,\lambda_f} p_{\lambda_i} |\langle \vec{k}_f \sigma_f; \lambda_f | V | \vec{k}_i \sigma_i; \lambda_i \rangle^2 \delta(\hbar\omega + E_{\lambda_i} - E_{\lambda_f})$$

Neutron Speed Echo (A. Ioffe 2003) ~ NSE





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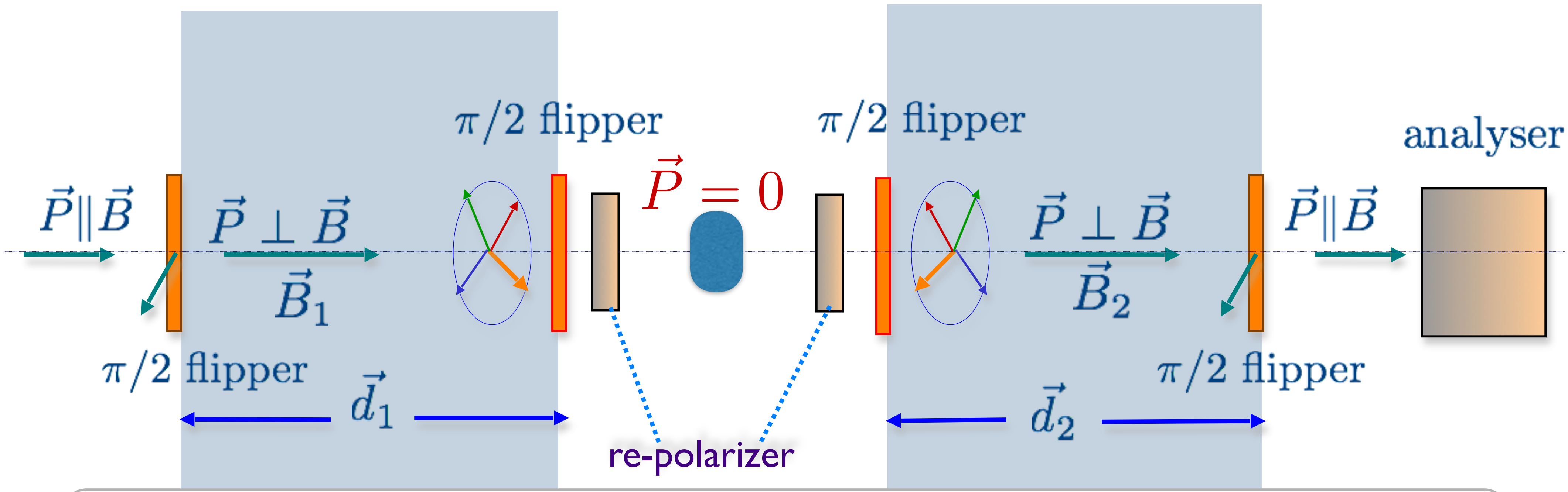
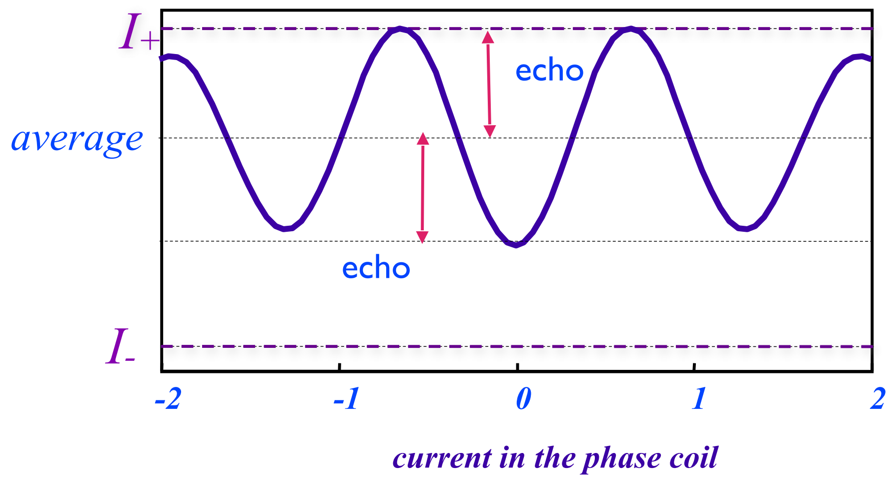
intensity modulated neutron spin echo



ideally

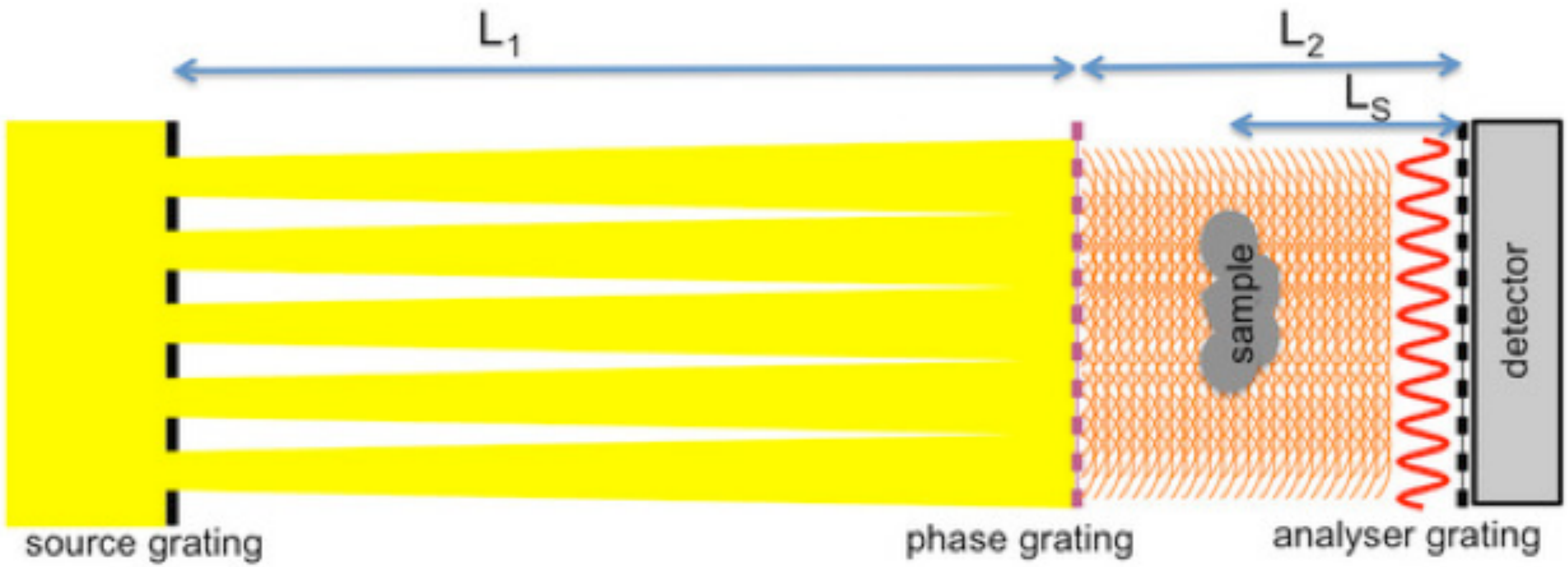
echo modulation = $(I_+ - I_-) / 3$

for $|\vec{P}| = 1$

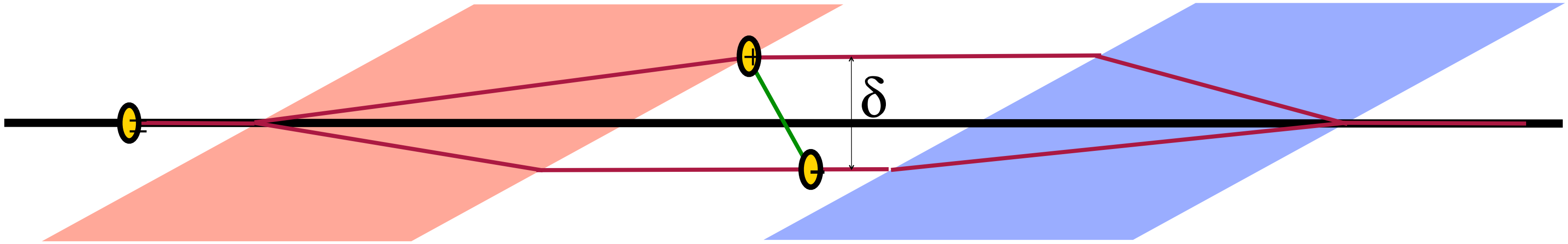


Talbot Lau grating interferometer for dark-field contrast imaging(M. Scrobl 2014)

~ SESANS

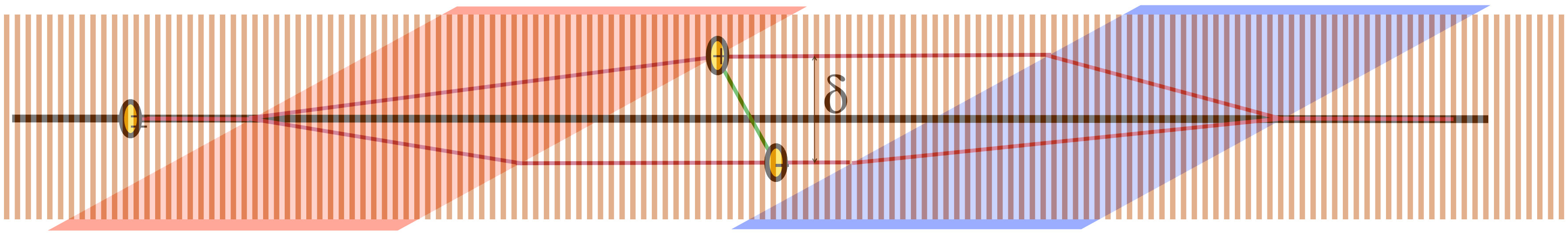


semi-classical illustration of the phase difference of the components of the wave function in SESANS



IT IS WRONG TO ASSOCIATE THIS PHASE SHIFT TO THE WAVEFUNCTION OF A SINGLE NEUTRON !

The correct QM Approach must respect quantum nonlocality within the neutron beam



beam dimensions/splitting ~ 10^{-4} mm => effect negligible

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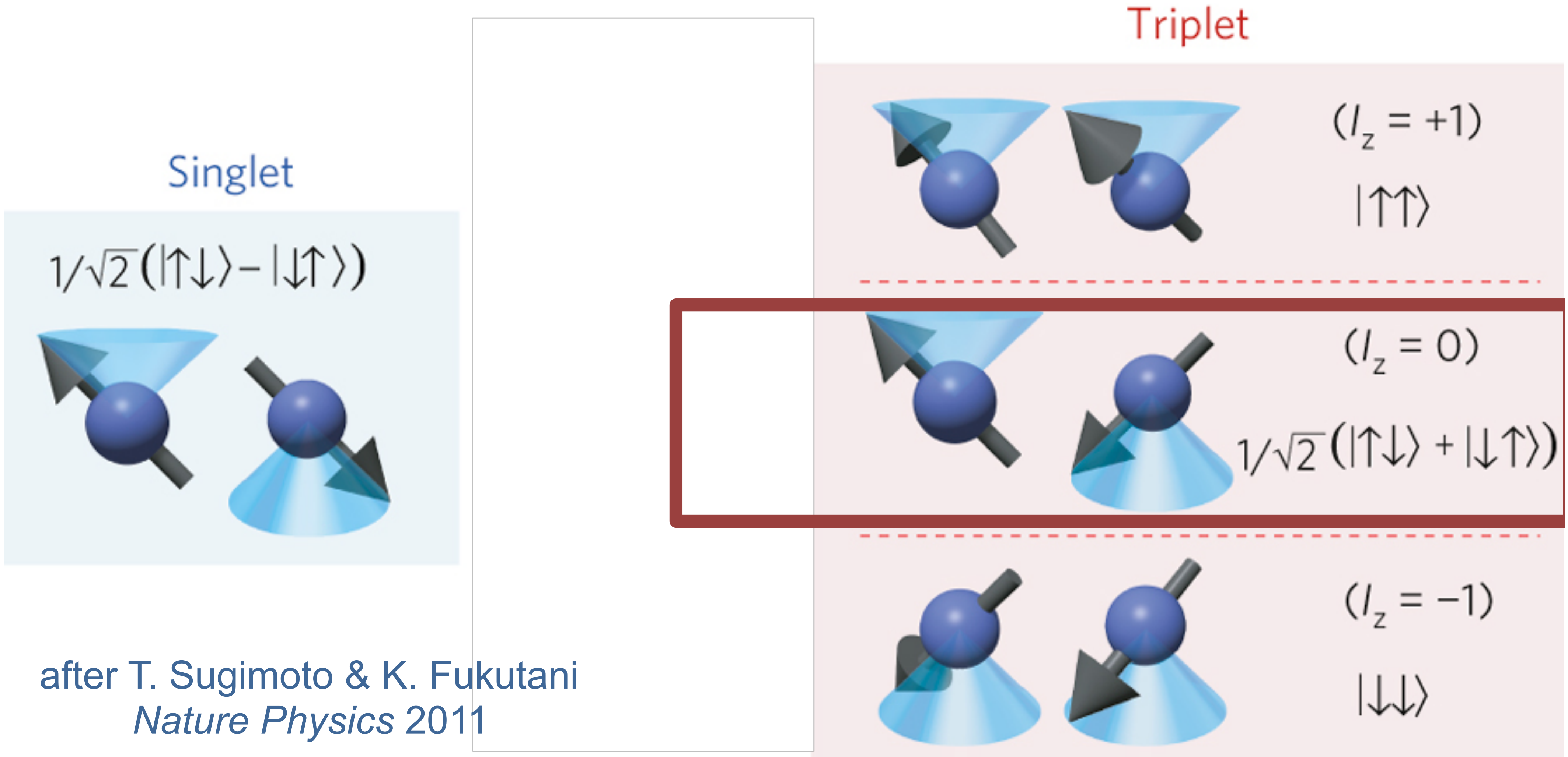
how can we understand the coherent superposition of eigenstates for a spin 1/2 ?

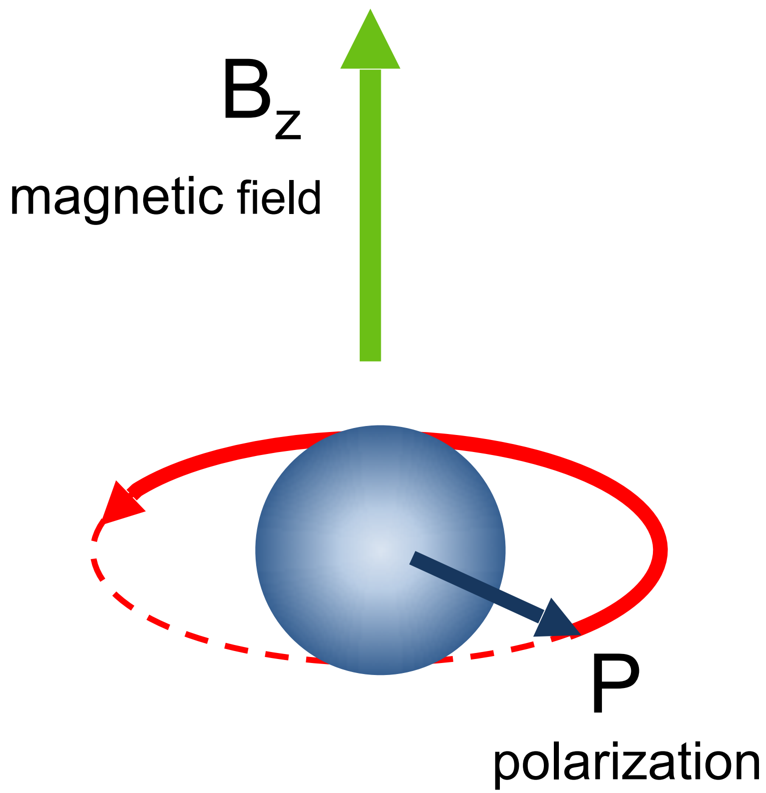
we consider the situation of spin 1



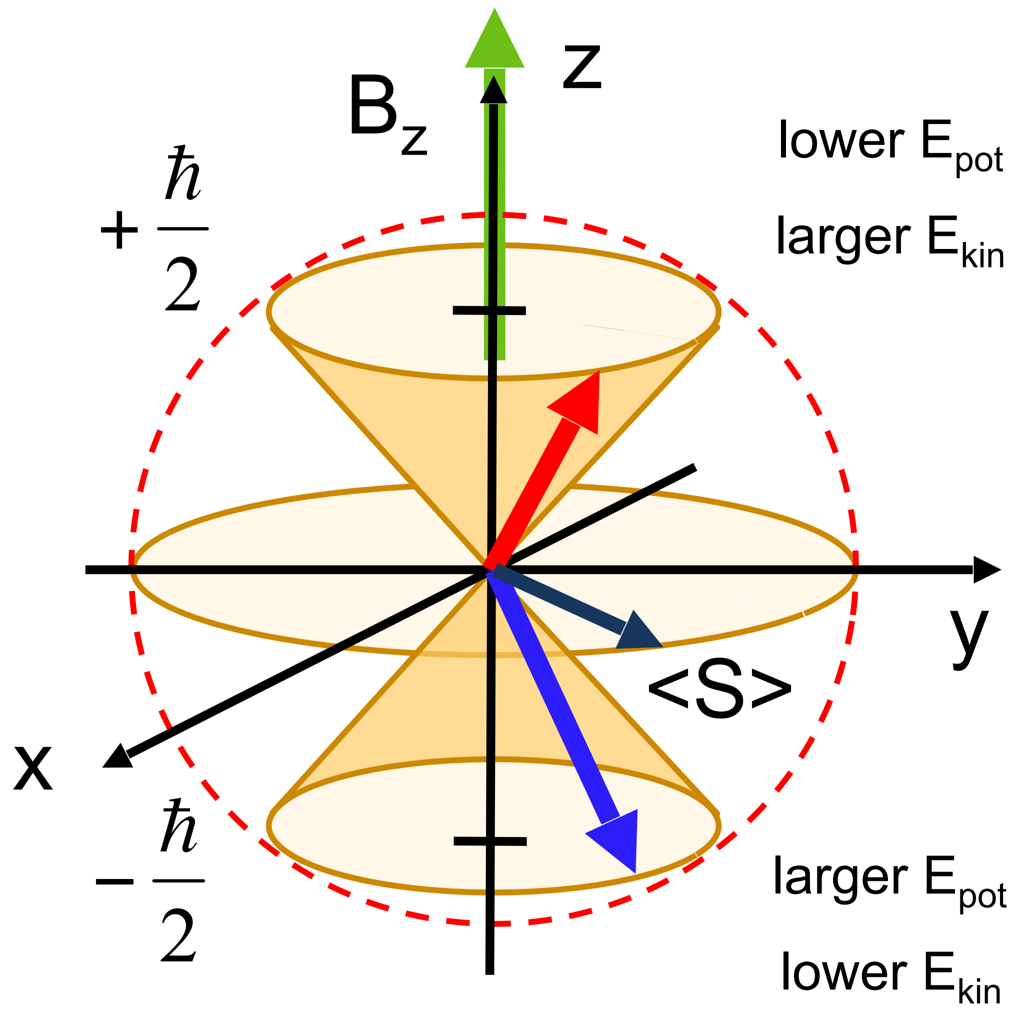
after T. Sugimoto & K. Fukutani
Nature Physics 2011

Spin Precession of Neutrons

classical mechanics

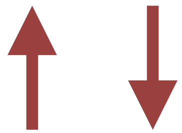
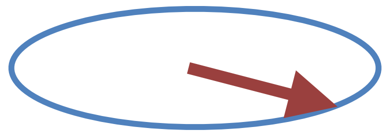


quantum mechanics

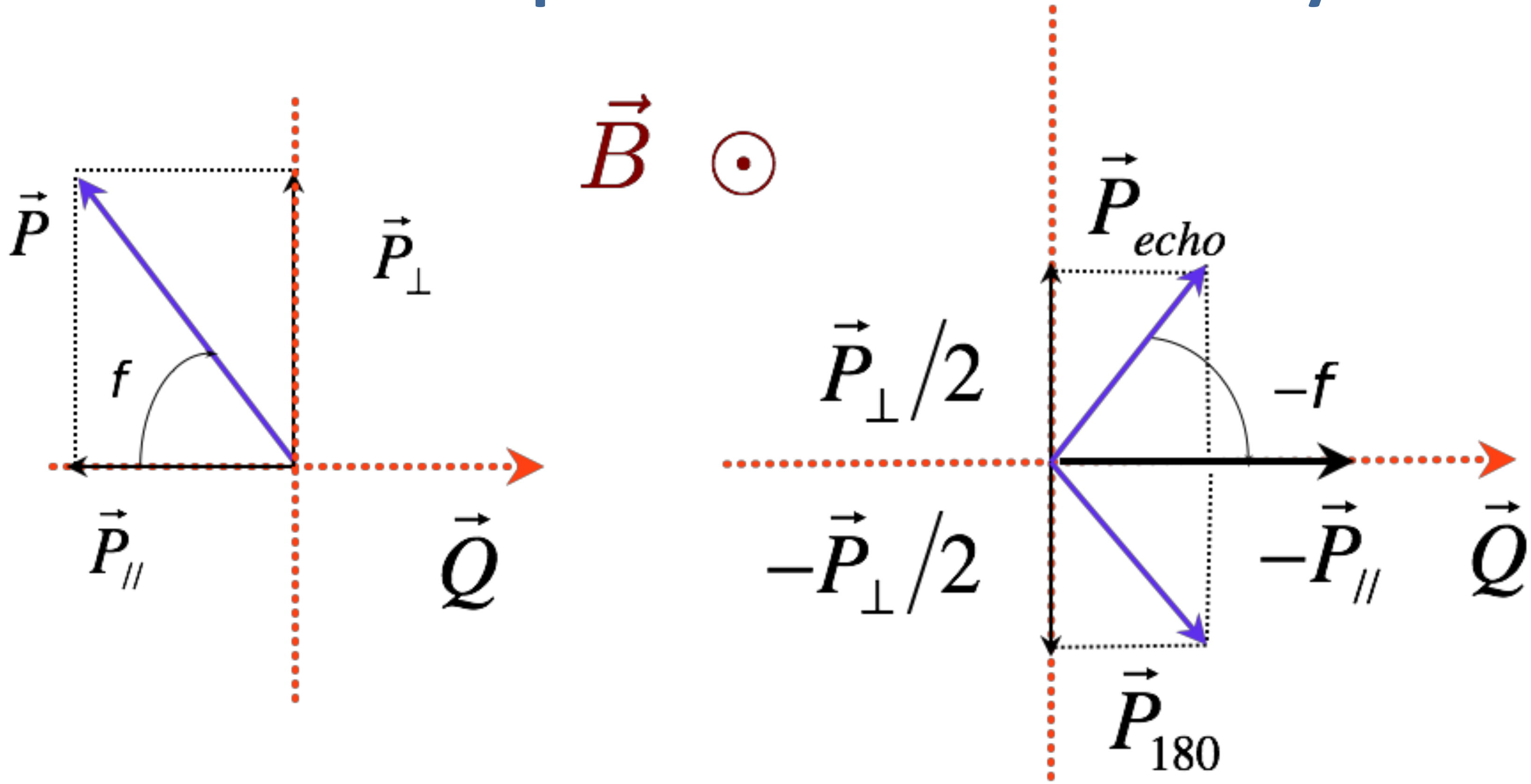


In B-field: spin up state speeds up; spin down state slows down

Anton Zeilinger plenary talk at ECNS 2013, Prague :

CM  QM 

confirmed by the selection rules for magnetic scattering at the sample discussed on Monday



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BE AWARE !

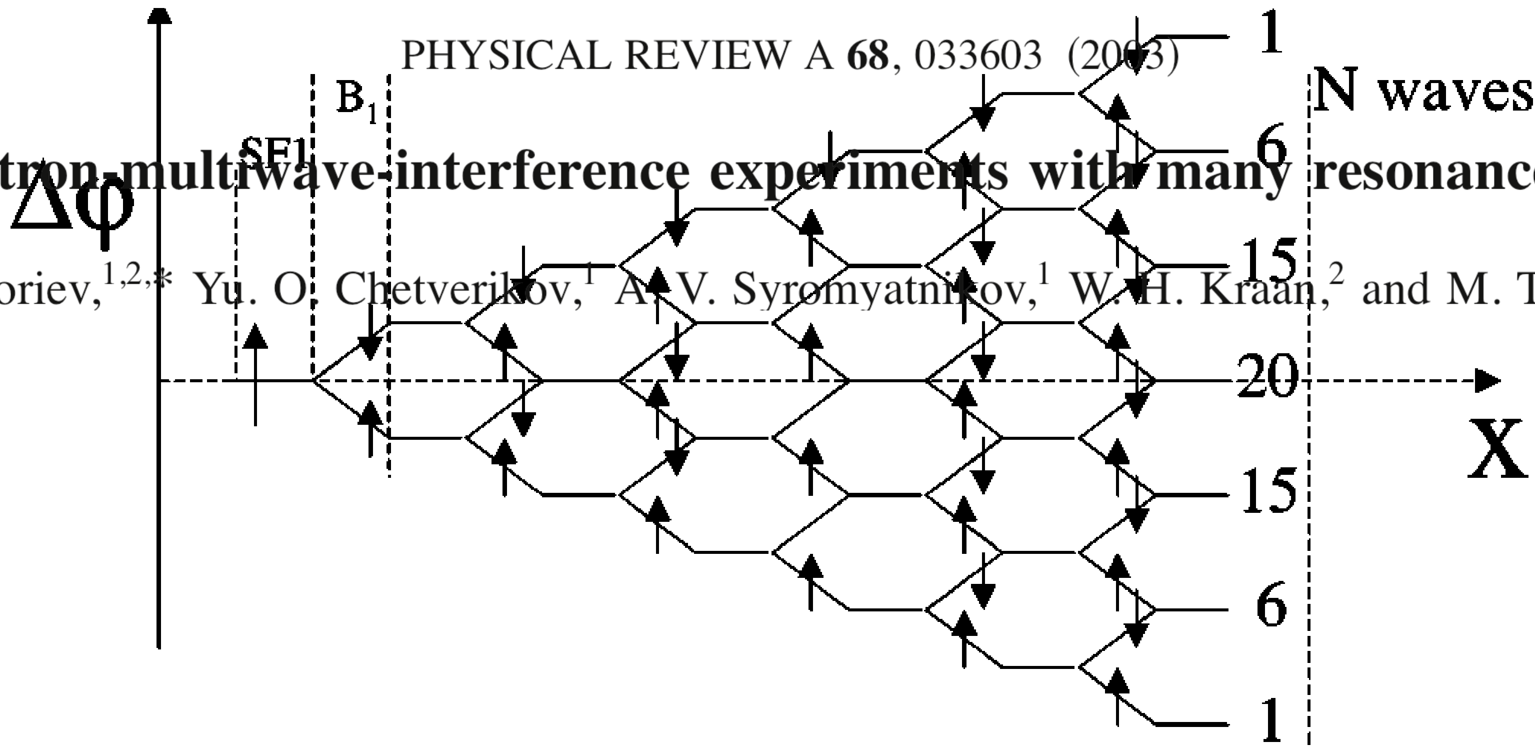
Mixing up CM and QM can lead to wrong conclusions

It has been suggested that it is possible to change the scattering process by adding an RF flipper in the beam

PHYSICAL REVIEW A **68**, 033603 (2003)

Neutron multiwave-interference experiments with many resonance coils

S. V. Grigoriev,[1,2,*] Yu. O. Chetverikov,[1] A. V. Syromyatnikov,[1] W. H. Kraan,[2] and M. Th. Rekveldt[2]



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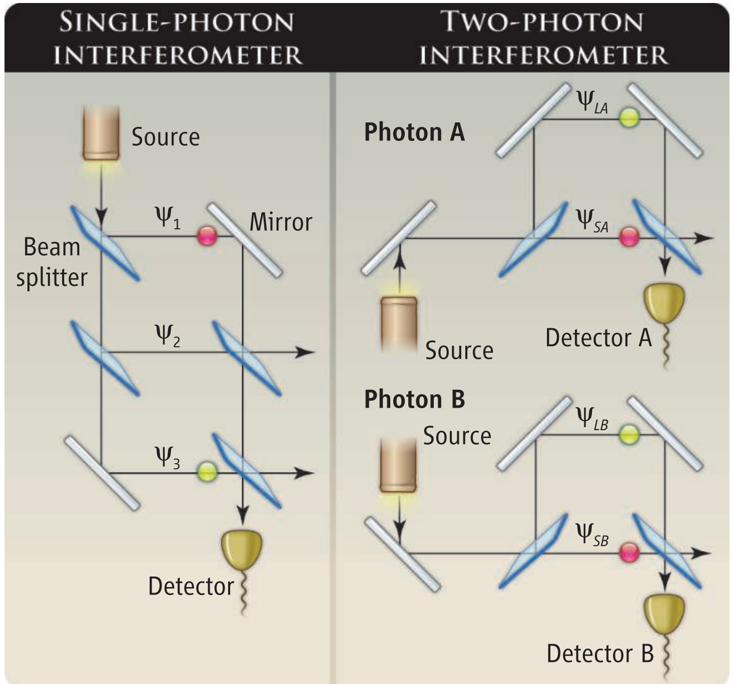
BE AWARE !
Mixing up CM and QM can lead to wrong conclusions

scattering probes pair correlation functions because quantum interference is ruled by pair correlation functions



J. D. Franson Science 2010

10.1126/science.1192624

Quantum interference between many different pathways is simply the sum of the effects from all pairs of pathways.

Sinha et al. Science 329, 418 (2010)

any other assumption would violate Bell’s theorem

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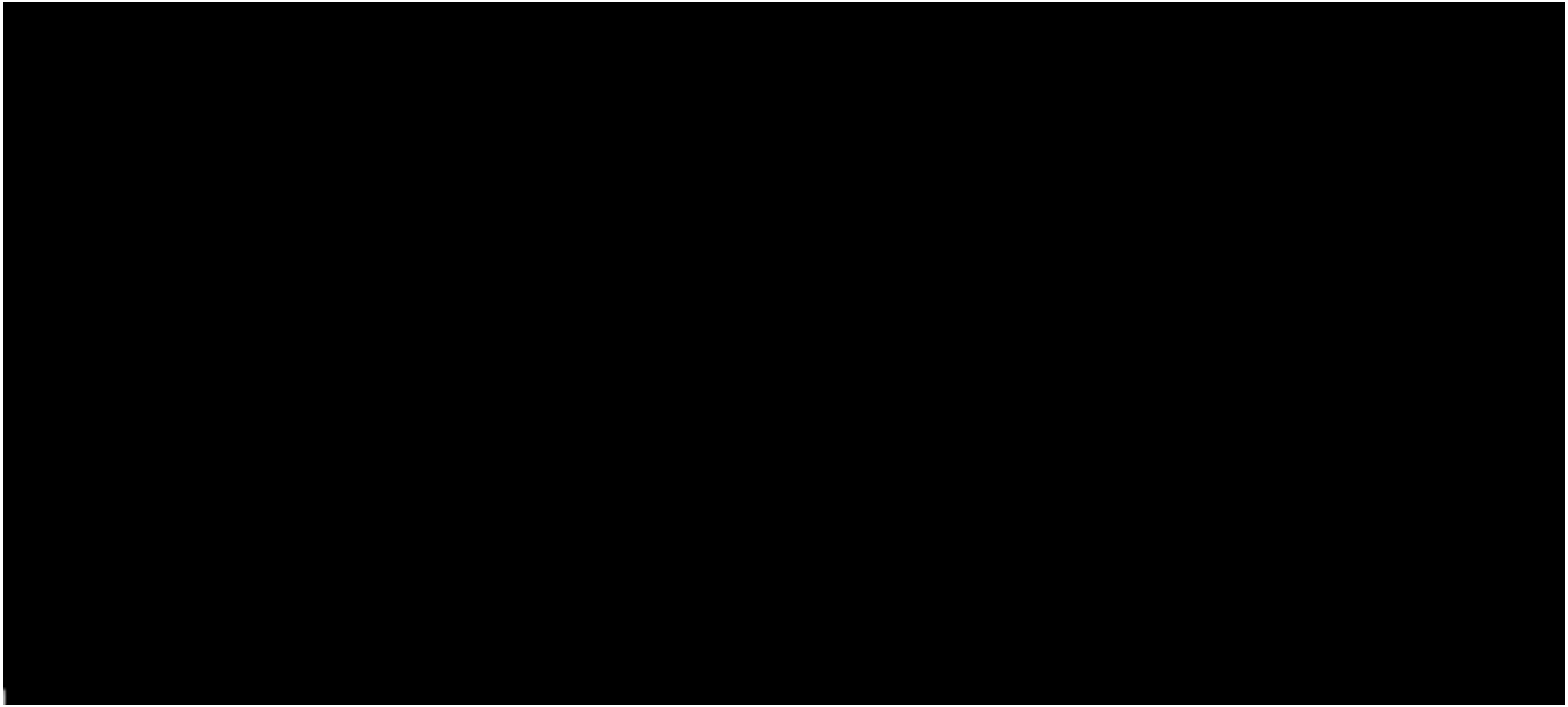
be suspicious of deterministic approaches to Quantum Mechanics

it is a strange theory of light and matter (Feynman)



http://iopscience.iop.org/article/10.1088/1367-2630/15/3/033018/meta