M1- ICFP

Evolution and measurements of quantum states

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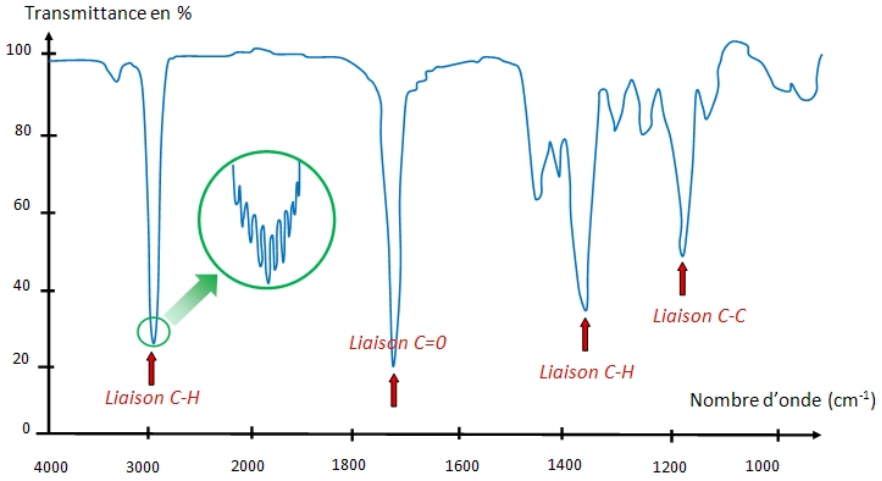
chapter I: experimental introduction

Ensemble measurement on microscopic objects

example : **energy levels of a molecule (spectroscopy)**

macroscopic sample of molecules (10^{23})

measurement device



result : absorption spectrum of molecule, and therefore the energy levels of the molecule

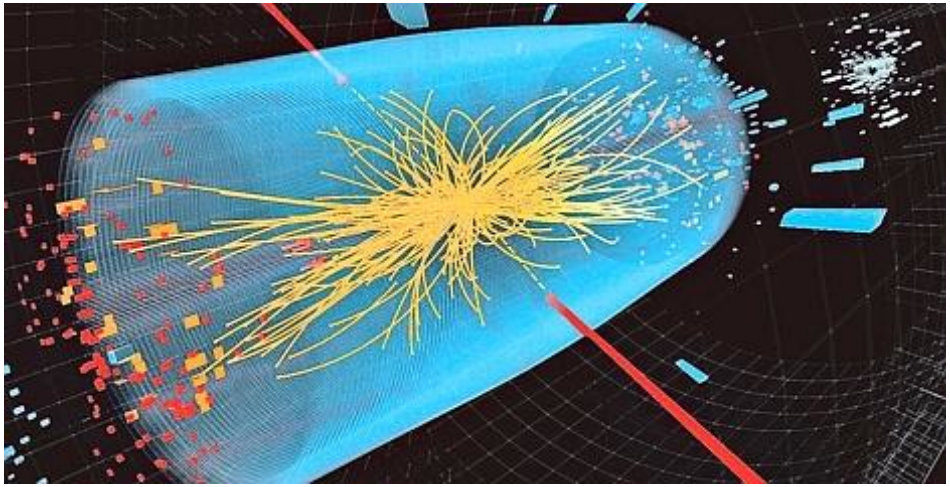
all molecules of the sample have the same spectrum

detection of **single quantum events**

High energy physics

individual particles are detectable,
because of their high energy

existence of strong fluctuations:
all collisons do not give the same result:
impossible to accumulate



example of a single p-p collision :
with signature of Higgs boson

"success rate" : roughly 10^{-10} !

detection of single ions and photons

The Nobel Prize in Physics 2012

Photo: U. Montan

Serge Haroche

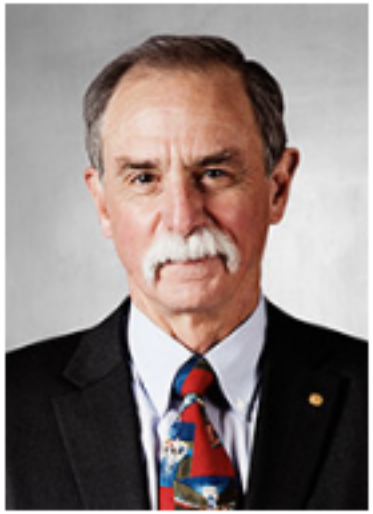
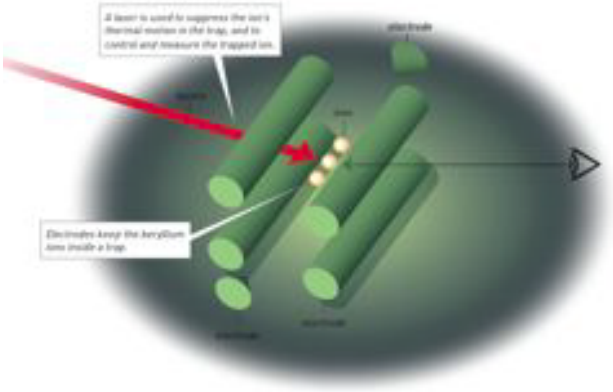


Photo: U. Montan

David J. Wineland

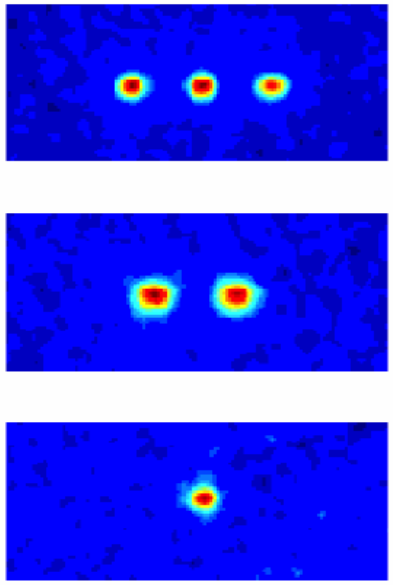
The Nobel Prize in Physics 2012 was awarded jointly to Serge Haroche and David J. Wineland ***"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"***

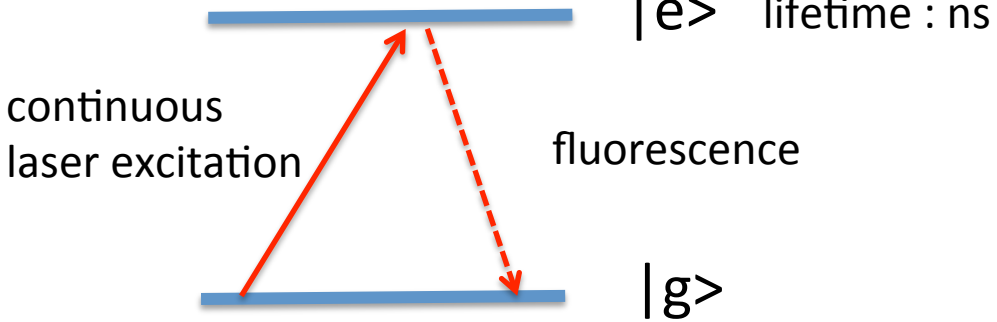
Wineland: detection of low energy trapped single ions



ion trap (in vacuum chamber)

microscope image of trap
when illuminated by a resonant laser:





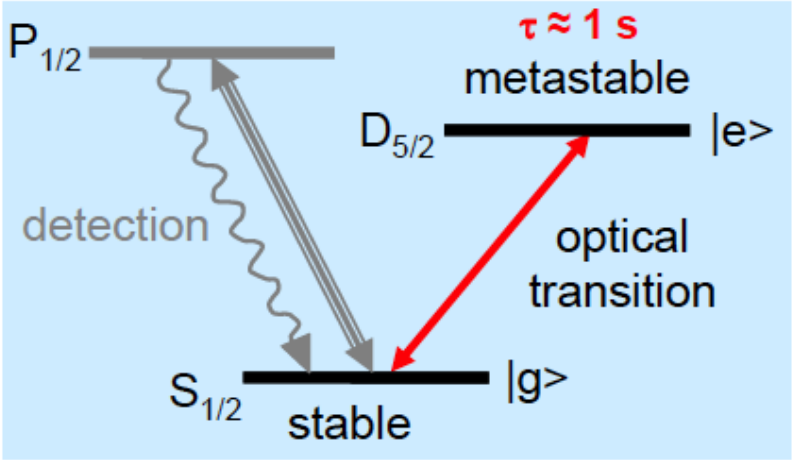
a single ion produces
10^9 fluorescence
photons per second:

easily detectable !

(size of spot is not the size of ion !)

Dehmelt: detection of the energy state of a single ion

illumination laser is resonant on the S-P transition
P level lifetime: ns



if ion is in |g>

strong fluorescence (10^9 photons per second)

if ion is in |e>

no fluorescence

Detection of quantum jumps

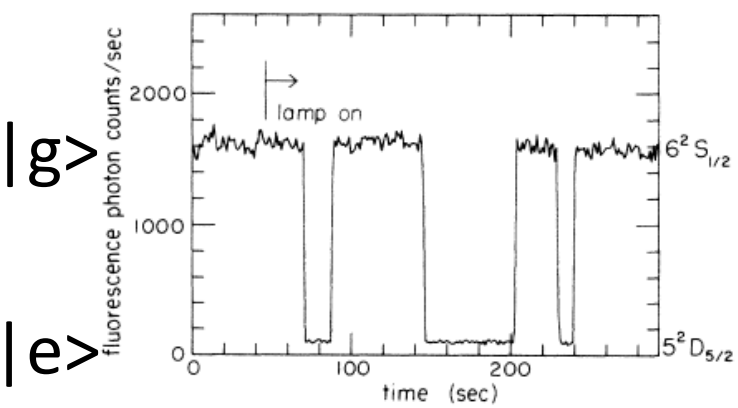


FIG. 2. A typical trace of the 493-nm fluorescence from the $6^2P_{1/2}$ level showing the quantum jumps after the hollow cathode lamp is turned on. The atom is definitely known to be in the shelf level during the low fluorescence periods.

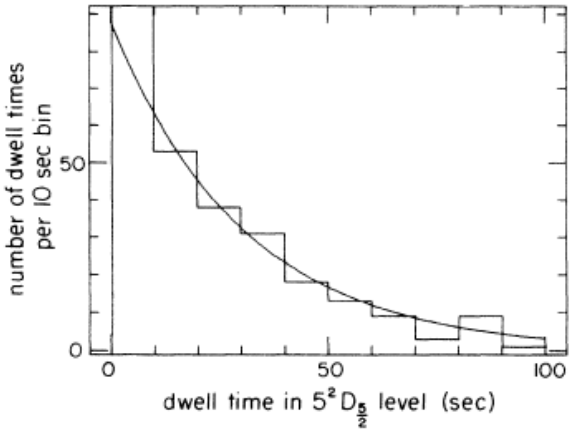


FIG. 3. Histogram of distribution of dwell times in the shelf level for 203 "off" times. A fitted theoretical (exponential) distribution for a metastable lifetime of 30 sec is superposed on the experimental histogram.

random and instantaneous character of excitation and de-excitation

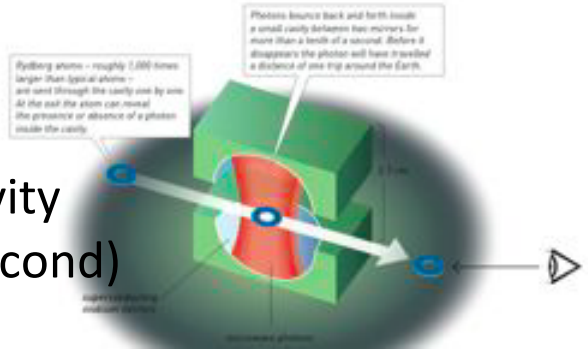
"quantum jumps"

histogram of dwell times in the excited state give the well known exponential decay behaviour

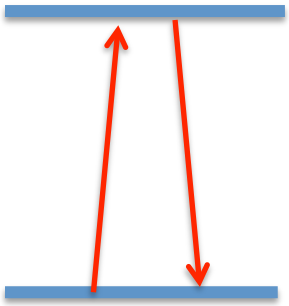
strong difference between individual and average events

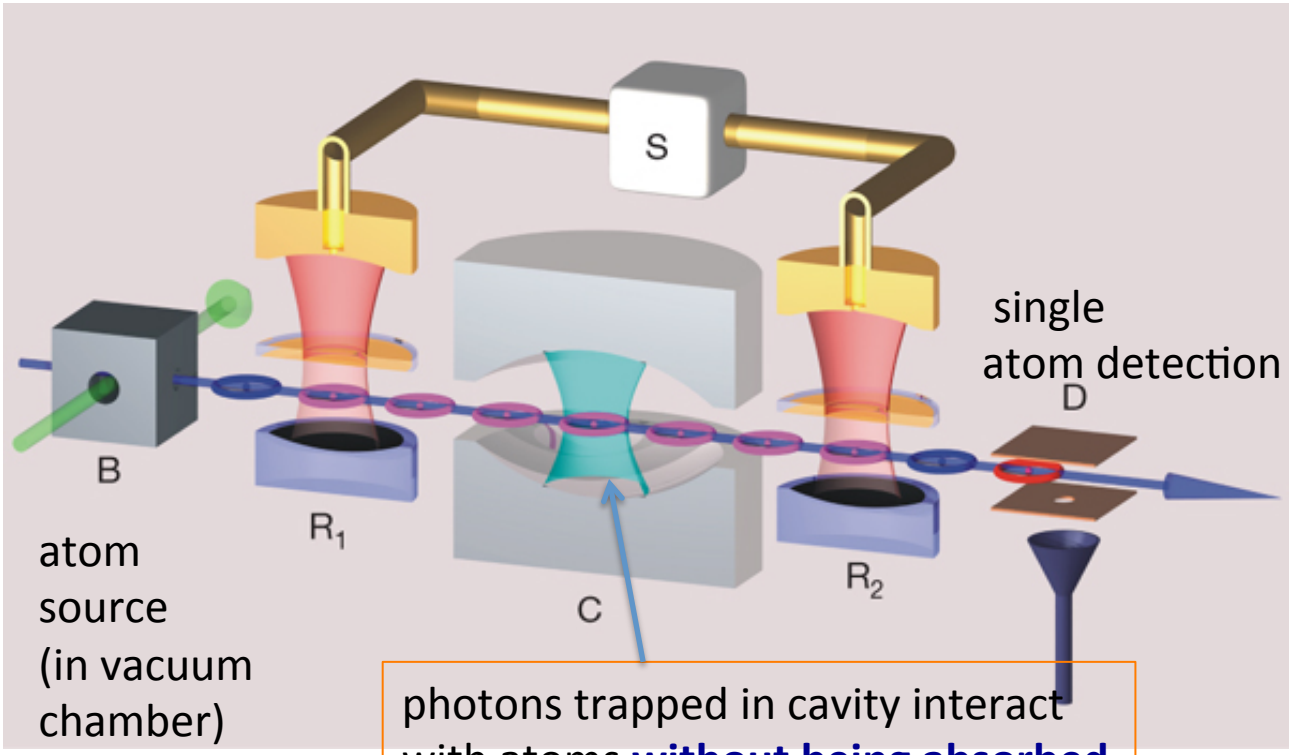
Haroche : trapped photons for Cavity Quantum ElectroDynamics"

photons
trapped in cavity
(fraction of second)



non-resonant highly excited atoms
"observe" cavity photons





single
atom detection

atom
source
(in vacuum
chamber)

photons trapped in cavity interact
with atoms **without being absorbed**

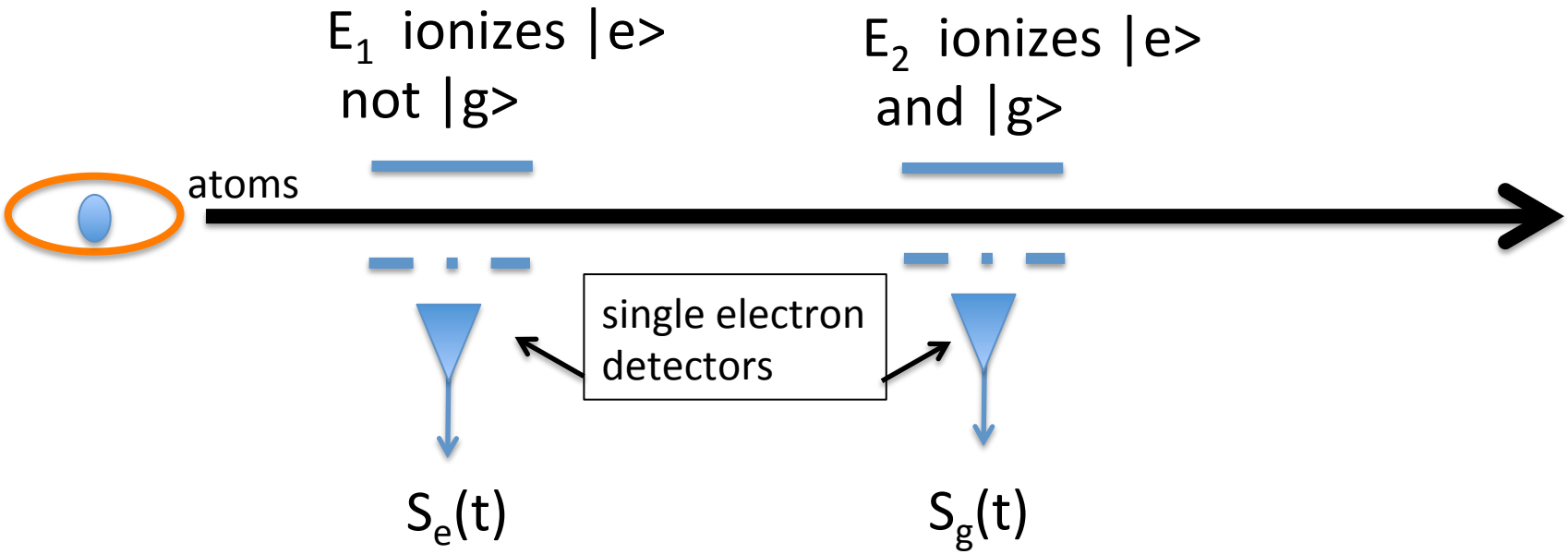
atom
in state |g>:
no photons
in cavity

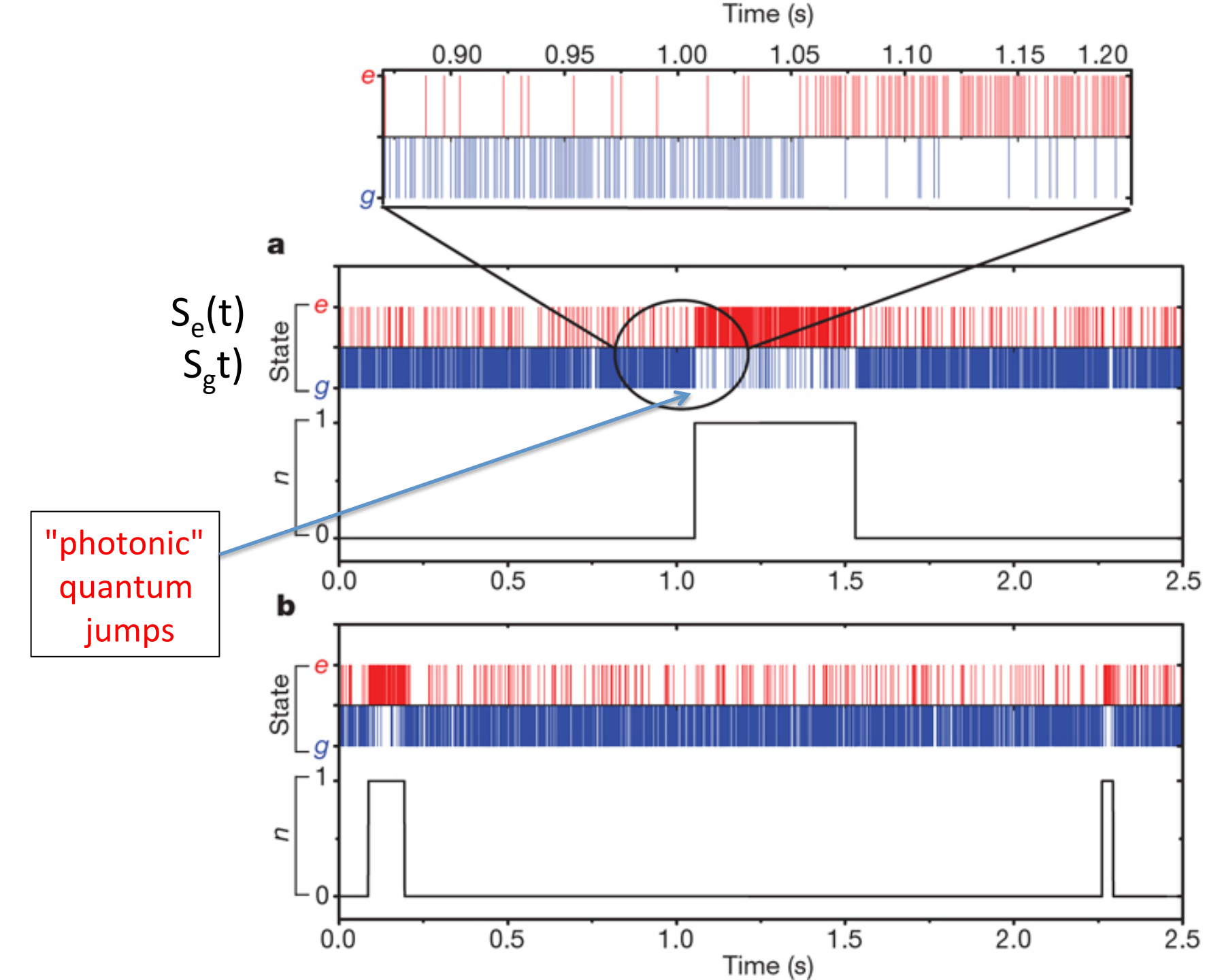
atom
in state |e>
a single photon
in cavity

|e> and |g> are highly excited hydrogen-like atoms p, circular orbits
(principal number n=50 for |e>, n=51 for |g>)

they are detected by selective electrostatic field ionization

|e> is ionized by a smaller electrostatic field E than for |g>





$S_e(t)$

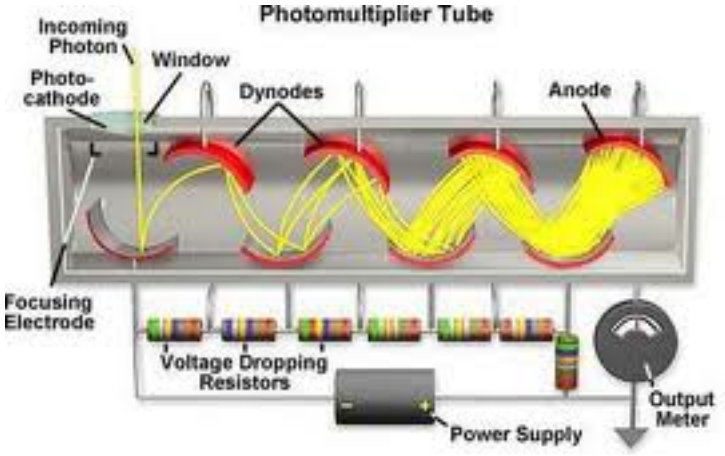
$S_g t)$

"photonic" quantum jumps

single photon detectors

photomultipliers,
and avalanche detectors

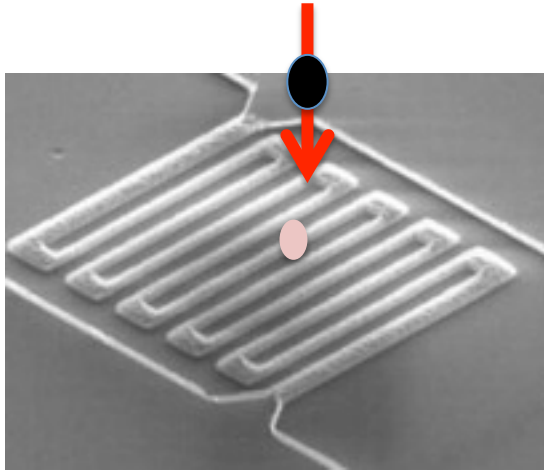
photon



use cascade effect as an amplifier

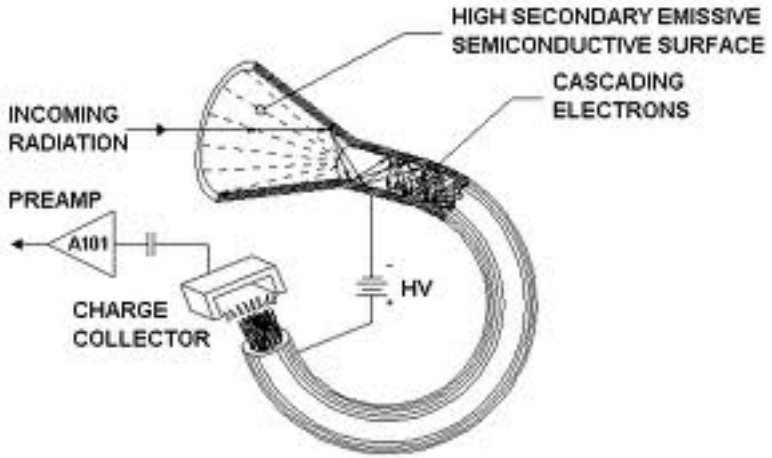
superconducting nanowires
(few nm)

thermal effect of a single photon
on one nanowire induces
transition supra -> normal,
which gives rise to a macroscopic signal



single electron detectors:

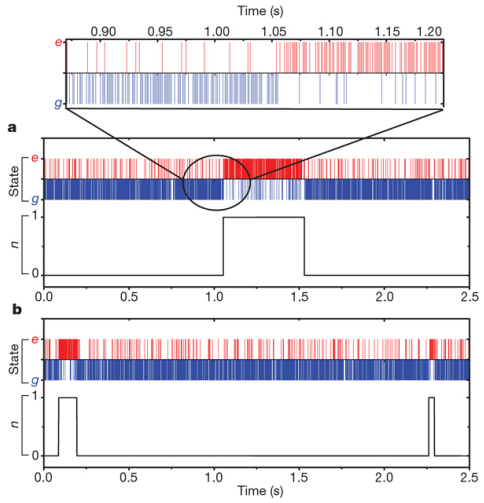
same kind of avalanche process:
a single impinging electron produces a
macroscopic bunch of electrons at the output



single event detectors

-can be **destructive** (photon and electron counters)

-can be **non-destructive** (Wineland and Haroche set-ups)



They inevitably have **defects**:

- they can miss events: not perfect quantum efficiency

-tey can make mistakes: error probability

-can give result even when there is nothing to measure: background or dark noise