Some considerations and speculations on LHC-single-atom-targets for Fwd-physics in the light of recent results in laser optics.

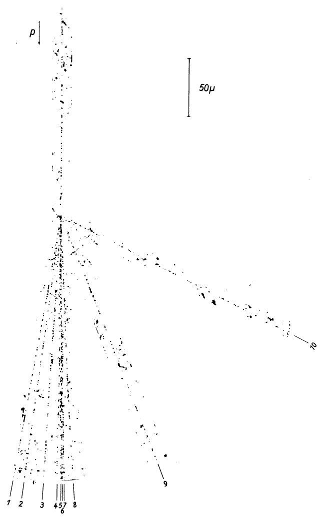
Luebbo von Lindern

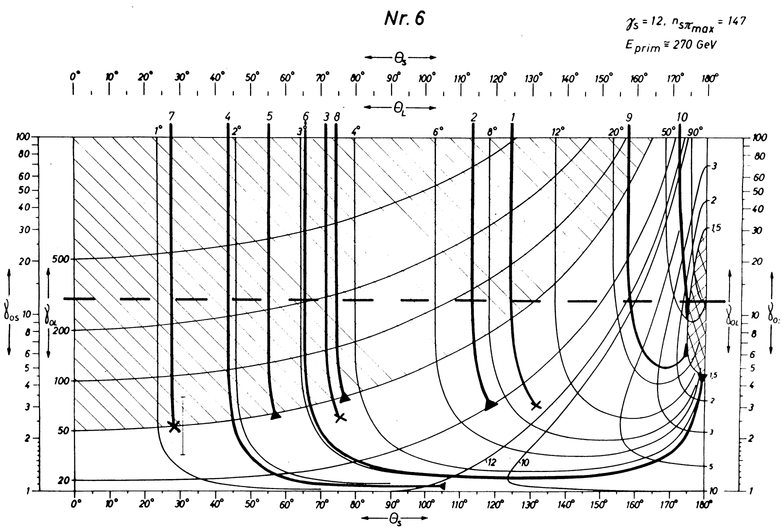
LHC Working Group on Forward Physics and Diffraction CERN June 5th 2014

figure 1: Asymptotic kinematics in common CMS at about 300 GeV lab.

nucl. emulsion track numbers indicated **CMS** variables see fig. 2

10p – 0 - 0





Thick lines in plot correspond to observed tracks:

X : energy from multiple scattering

^ : lower limit of energy from multiple scatt.

cross hatched : area, where tracks would appear with higher than minimum ionisation

hatched : noise limit for multiple scattering

Running parameters of CMS curves are:

(for broken line is $\gamma_{oS} = \gamma_S$)

$$\cos\Theta_S = \frac{\gamma_{oL} - \gamma_{oS}\gamma_S}{\sqrt{\left(\gamma_{oS}^2 - 1\right)\left(\gamma_S^2 - 1\right)}}$$

$$\beta_{oS} = \frac{\sqrt{\gamma_S^2 - 1}}{\sin\Theta_S \ \cot\Theta_L \ - \gamma_S \cos\Theta_S}$$

PHYSIKALISCHES KOLLOQUIUM

EINLADUNG

Am Montag, 02.06.2014, 16.15 Uhr in W2-1-148

spricht

Prof. Gerd Leuchs
Max Planck Institute for the Science of Light, Erlangen, Germany
Institut für Optik, Information und Photonik, University of Erlangen-Nuremberg,
Department of Physics, University of Ottawa

über

"Inverse spontaneous emission of an atom in free space – an example of time reversal symmetry in optics"

The coupling between light and a single atom is probably the most fundamental process in quantum optics. The best strategy for efficiently coupling light to a single atom in free space depends on the goal. If the goal is to maximally attenuate a laser beam, narrow-band on-resonance laser radiation is required as well as a wave front approaching the atom from a 2_ solid angle. If, on the other hand, the goal is to fully absorb the light bringing the atom to the excited state with unit success probability one will have to provide a single photon designed to represent the time reversed wave packet which the atom would emit in a spontaneous emission process. Among other conditions this requires the single photon wave packet impinging from the full 4_ solid angle and having the correct temporal shape. The state of the art is reviewed and the experimental progress is discussed. If the interaction is strong enough it will allow for building a few photon quantum gate without a cavity, with possible applications in quantum information processing.

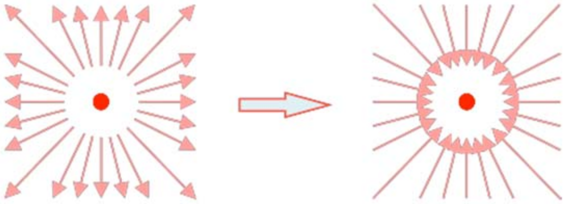


Fig.: Full absorption corresponds to time reversed emission

Latest reference:

G. Leuchs and M. Sondermann, J. Mod. Opt. 60, 36 (2013)

Einladender: Prof. Christoph Lienau

Leuchs: Inverse spontaneous emission of an atom in free space – an example of time reversal symmetry in optics

Wednesday, March 5, 2014 - 2:00 pm to 3:00 pm

Gerd Leuchs, Max Planck Institute for the Science of Light

The coupling between light and a single atom is probably the most fundamental process in quantum optics. The best strategy for efficiently coupling light to a single atom in free space depends on the goal. If the goal is to maximally attenuate a laser beam, narrow-band on-resonance laser radiation is required as well as a wave front approaching the atom from a 2_ solid angle. If, on the other hand, the goal is to fully absorb the light bringing the atom to the excited state with unit success probability one will have to provide a single photon designed to represent the time reversed wave packet which the atom would emit in a spontaneous emission process. Among other conditions this requires the single photon wave packet impinging from the full 4_ solid angle and having the correct temporal shape. The state of the art is reviewed and the experimental progress is discussed. If the interaction is strong enough it will allow for building a few photon quantum gate without a cavity, with possible applications in quantum information processing.

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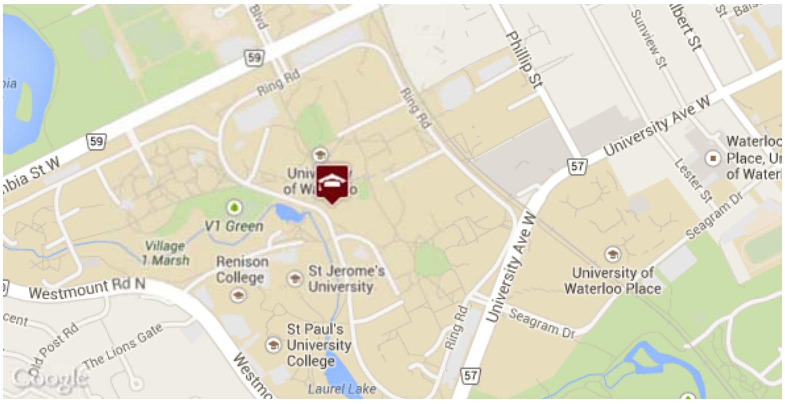

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arXiv:1311.1982v1 [quant-ph] 8 Nov 2013

Efficient saturation of an ion in free space

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We report on the demonstration of a light-matter interface coupling light to a single $^{174}Yb^{+}$ ion in free space. The interface is realized through a parabolic mirror partially surrounding the ion. It transforms a Laguerre-Gaussian beam into a linear dipole wave converging at the mirror's focus. By measuring the non-linear response of the atomic transition we deduce the power required for reaching an upper-level population of $1/4$ to be 692 ± 20 pW at half linewidth detuning from the atomic resonance. Performing this measurement while scanning the ion through the focus provides a map of the focal intensity distribution. From the measured power we infer a coupling efficiency of 7.2 ± 0.2 % on the linear dipole transition when illuminating from half solid angle, being among the best coupling efficiencies reported for a single atom in free space.

I. INTRODUCTION

Coupling light and matter is an essential part in many quantum information protocols [1]. For many of these protocols to be implemented successfully this coupling should be as high as possible. The scheme used most frequently for achieving high coupling efficiencies is to place the matter system into a high-quality resonator. Here we will rather focus on light-matter coupling in free space and the measurement and characterization of the coupling efficiency. When investigating this efficiency typically three distinct effects are measured:

Firstly, efficient coupling increases the probability of a photon being absorbed by a matter system. This provides an opportunity to use matter as a quantum memory in which one can store the state of a photon. Here, a measure for the coupling efficiency could be the probability with which one can store a single photon in a matter system [2]. As for all other types of experiments described below, spatially mode matching the light field to the transition is essential. In addition, depending on the inner structure of the matter system involved, it is necessary to create an optimal temporal shape of the incident field [3–5]. Thus the absorption probability is affected by two different effects that have to be distinguished by additional measurements.

A second effect occurring in light-matter interaction is the phase shift that a light field acquires when interacting dispersively with a medium. Here, the phase a field accumulates in comparison to a non-interacting field provides a good measure for the strength of the interaction [6–9], given the light is scattered coherently. This, however, is only the case if no upper-level population is induced and hence there is no incoherent scattering. This is only the case if the driving field is zero. To account for the amount of incoherently scattered light the upper-level population has to be determined. Additionally, investigating the phase of a field requires some way of stabilizing the phase of the non-interacting field.

A further effect that is often investigated in the context of high coupling efficiencies is the extinction of a light field traveling past a matter system. This effect is related to the previous one, because both effects originate from the interference between the impinging light and the light scattered by the emitter [7, 8, 10]. In contrast to the phase shift, which is maximized by illumination from full solid angle [6, 11], optimal results are obtained when focusing light from half the solid angle [10]. The depth of the dip in the transmission through the system provides a good measure for the amount of light that was interacting [12–15]. Like in the case of the phase shift the effect is reduced by incoherently scattered light [13].

Here, we will establish saturation measurements as a tool for characterizing the coupling efficiency in free space in an unambiguous way, utilizing the very effect that is detrimental in the types of measurements discussed above. The next section discusses the advantages of saturation measurements in more detail and reviews the relation between coupling efficiency and the necessary power to reach a given upper-level population. The experimental set-up is described in Sec. III, whereas the experimental results are presented in Sec. IV and discussed in Sec. V.

II. SATURATION MEASUREMENTS

In what follows we present an approach that provides a measure for the spatial overlap of the light field with the driven transition while neglecting temporal effects. A two-level-system (TLS) responds to the power of the driving field in a non-linear way. The amount of light scattered by a TLS is directly proportional to its upper-level population ρ. Solving the Bloch equations one finds that for strong driving fields the upper-level population in the steady state solution asymptotically reaches $\rho = 1/2$ where the TLS scatters at a rate of $\Gamma/2$, where Γ is the spontaneous emission rate of the TLS. Thus, one can directly relate the upper-level population to the amount of scattered photons. For example, at an upper-level population of $\rho = 1/4$ the TLS scatters at a rate of $\Gamma/4$. This value is commonly associated with a saturation parameter $S = 1$ in the literature

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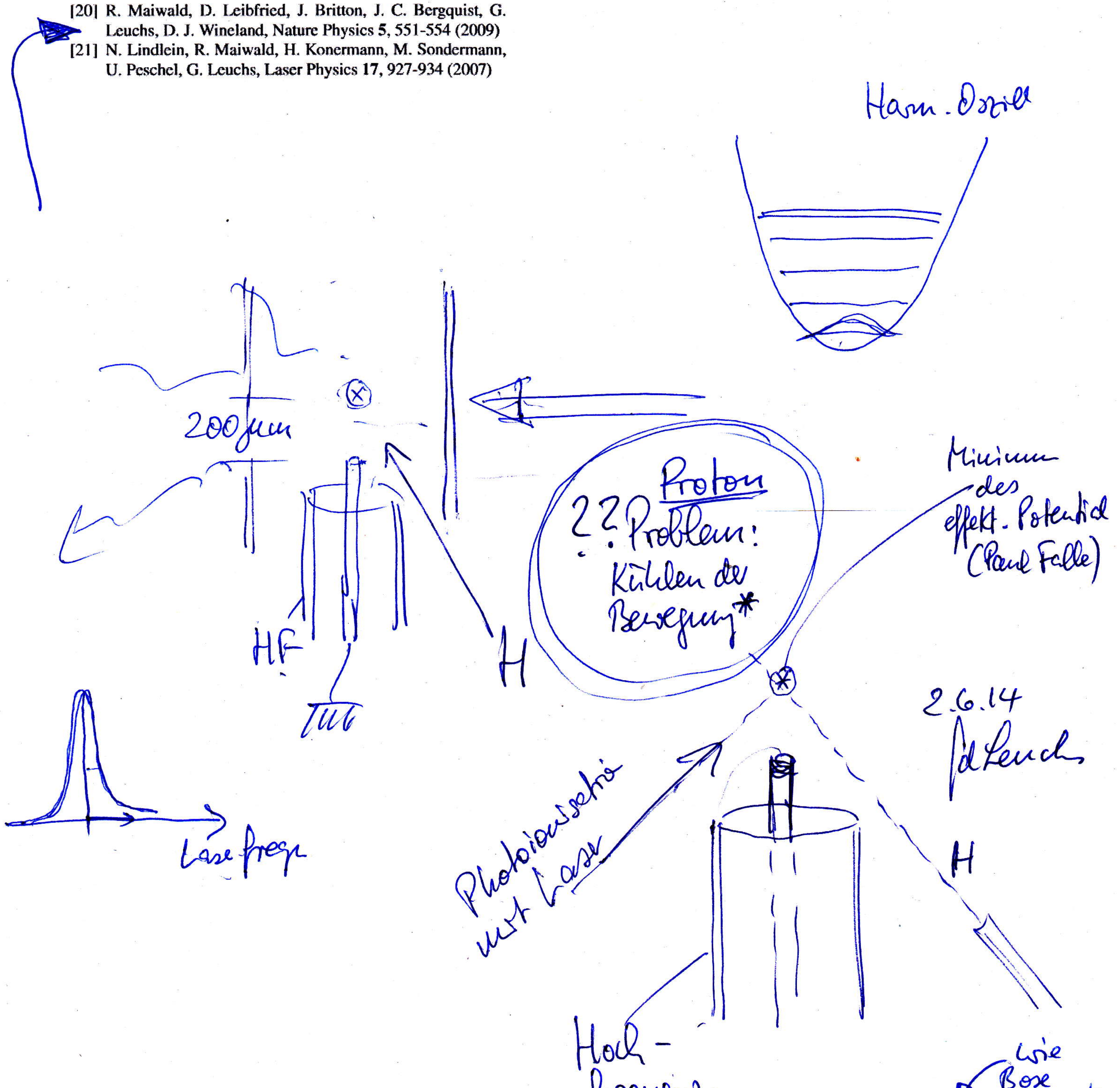

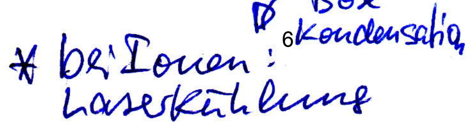

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