A new method to produce laser calibration beams in gaseous detectors.

A.Lebedev
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

A new method utilizing diffraction of UV laser beams on annular diaphragms provides very narrow laser beams with full diameter 0.1-0.4 mm, divergence ~0.05mrad and effective length up to 10 meters, which exceeds existing methods with focusing optics. The characteristics of laser beams and linear ionization created with different diaphragm sizes are present. Optics scheme is proposed to create a system with multiple new beams.

1. Introduction

Narrow laser beams widely used in many experiments to simulate charge particles and align detectors[1]. For LHC or future linear collider the requirements to correct the position and to measure coordinates of particles are about 10-20μm for whole detector with the size ~ 10 meters. Different approaches were proposed to monitor and align different detectors in the scale ~10 μm [2-4]. Some of these approaches use Gaussian beams with dimensions more than 1 mm. The ability to resolve the location of beam is proportional to the beam radius and it is very attractive to use calibration beams with less diameters and smaller divergence. We propose a new approach to create laser beams with sub millimeter size, smaller divergence and capable to simulate charge particles in gaseous detectors.

2. Poisson spot beam.

Until now two main principles were used to create narrow laser beams for detector's calibration. First is a focusing telescope with Gaussian beam. There are physical limitations in this approach due to diffraction limit. Divergence of the beam is ~0.64λ /w, where λ-wavelength (nm) and w (mm)- waist of the beam. Below in estimations we are using the same units. It is obvious that it is impossible to create long beams with sub millimeter diameter. Other approach is a use of diffraction of plane wave through small aperture. It called Airy pattern and produced beam has characteristics similar to focusing telescope.

It is known the creation of bright spot, called Poisson spot, when wide wave plane illuminates an opaque sphere. Behind this sphere at some distance from ball diffraction pattern is formed and this pattern has following characteristics. There is a line of light, the Poisson line, generated behind the sphere, this line is perpendicular to incident plane wave. The intensity of line increases asymptotically to the incident intensity as distance from sphere increases. The diameter of Poisson line decreases as the diameter of sphere increased. The diameter of Poisson line increases with distance from sphere, however the diameter of line over any distance behind the sphere can always be kept much smaller than a Gaussian beam propagating over the same distance. The divergence of Poisson line is significantly smaller $\theta \sim \lambda /d$, where d is diameter of the ball and could be chosen much bigger to satisfy small divergence. The use of Poisson line first was proposed to align and monitor magnets of long free electron laser [5]. Also Poisson line was used in STAR Time Projection Chamber (TPC) laser calibration system to align and monitor wide laser beam [6].

We propose to use Poisson line to simulate straight tracks in gaseous detectors. This beam could create ionization due to two-photon ionization process. One problem exists with this approach is a presence of bright field from propagated wave. Additional diaphragm installed after the ball or annular diaphragms eliminates background ionization from bright field. Now the picture of Poisson line formation became slightly different. At start we have bright annular beam along of wave propagation and Poisson spot is created. After 2-4 meters annular beam disappeared and finally only central lobe presents Poisson beam.

3. Results.

We used experimental set-up to measure beam profile and ionization formation (see Fig.1). Microscope with screen used to measure size of Poisson spot at different distances from ball, while drift chamber with 2 cm sensitive region along the laser beam used to measure ionization produced by two-photon ionization. First we measured Poisson beam size for different ball sizes and two wavelengths- 633nm from He- Ne laser and 266 nm wavelength from quadrupled Ne-YAG laser. Direct measurements gave us divergence for Poisson beam much smaller than we have for regular Gaussian beam. For He-Ne laser we achieved divergence $\theta = 1.28\ \lambda/d$, which is close to measurements made in [5], and for UV laser we have $\theta = 1.02\ \lambda/d$. Please note that we did measurements for beam on base of spot profile, while estimations for Gaussian beam quoted for width on half of amplitude. On fig.2 we present beam size and linear electron density for Poisson line from 5mm ball. Beam energy ~20μJ was capable to produce ionization exceeding MIP in the region 6 -11 meters from ball, because ionization from Fe55 produces the same number of electrons in drift chamber.

Proposed method provides a lot of laser beam losses from opaque sphere, if a common approach with ball and diaphragm applied. In real detector a significant number of calibration laser beams is required. For example in STAR TPC and ALICE TPC there are hundreds of calibration beams. It is attractive to create a set of annular initial beams, each of annular beam will produce Poisson beam. Possible scheme to create annular beams (see Fig. 3) is a set of small laser beams with diameter ~1mm, created from bundle of micromirrors in wide laser beam and after this bundle spread out of 1mm beams is going through set of cone lenses. Output from cone lens creates annular profile. Cone lens will not be damaged, because there is no focused points exists inside lens.

4. Summary.

A new method to produce narrow laser beams could be a first step for more precise next generation laser system to calibrate gaseous detectors.

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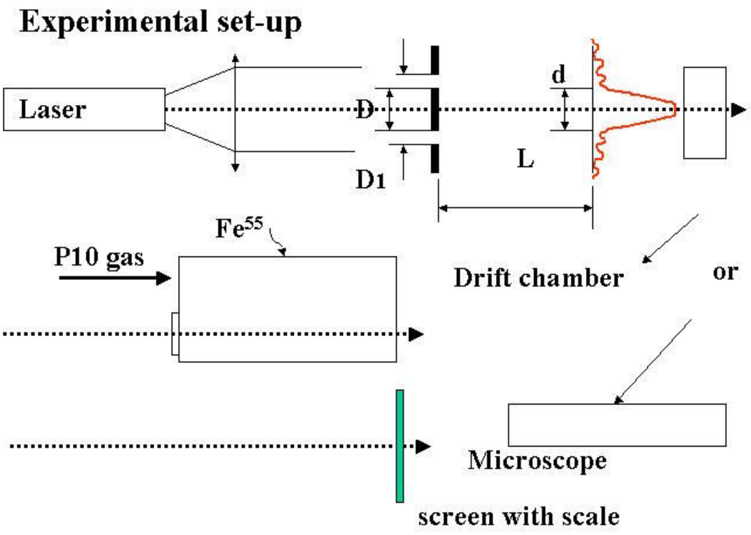

Fig. 1 Experimental setup to measure characteristics of Poisson beam.

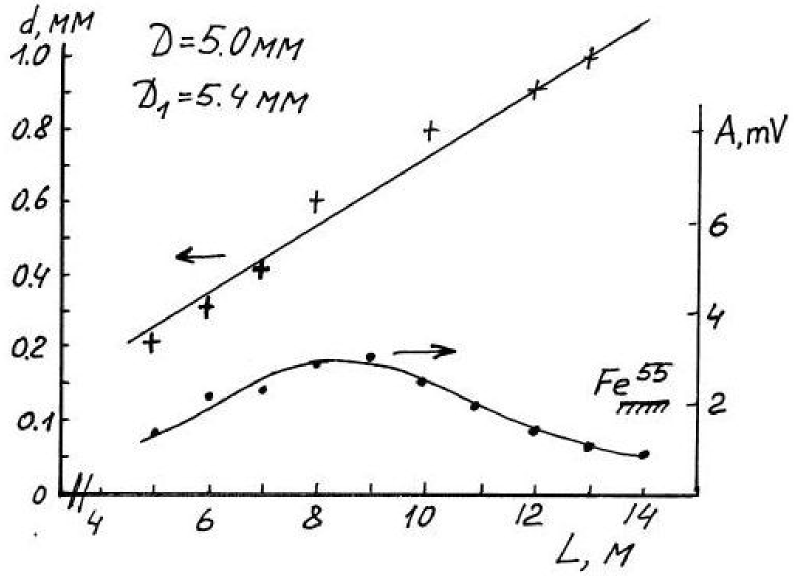

Fig. 2 Poisson beam diameter and linear electron density from 5 mm ball illuminated

by UV laser.

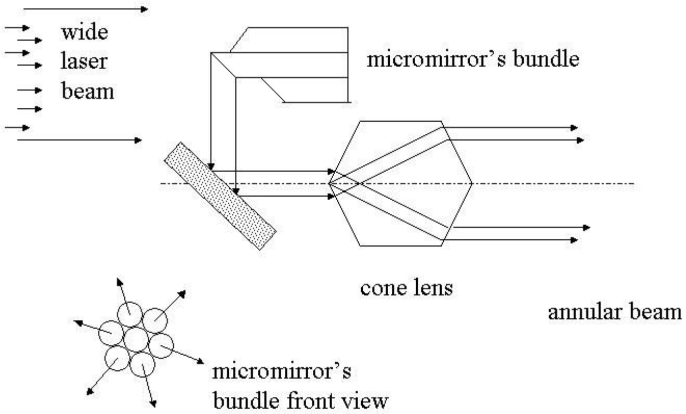

Fig. 3 Proposed optics to create multiple Poisson beams.