M. Heuer and W. Witt

Sympatec GmbH, System-Partikel-Technik, Burgstätterstraße 6,
D-38678 Clausthal-Zellerfeld, Germany

Extension of Laser Diffraction into the cm Region

1 Introduction

The measurement of very coarse particles is normally the standard domain of sieving. The extension of laser diffraction (LD) to a measuring range up to 8750µm was aimed to use its advantages of short analysis time and extremely high reproducibility, making it suitable for the automation of particle size analysis.

Out of different options, e.g. the application of large wavelengths [1], the use of standard He-Ne-lasers was chosen opening the potential of combination with standard instruments [2].

The development of an optical set-up of 5m focal length, which is normally an astronomic dimension, included an intensive optimisation. The desire to fit the system into a housing of only 0.5m length formed a strong restriction. In comprehensive investigations a solution was found, offering now the unique possibility to measure from 0.1µm up to nearly 1cm by the same method and keeping all advantages of LD at the same time.

Although dispersing is not so critical in the size range under discussion, a dispersing device [3] must be provided. Dropping the particles through a special shaft with built in impact walls is sufficient. It is also important that the particles must not re-enter the measuring zone, so the best is to let them fall directly through it. A new developed measuring zone with an open bottom is able to meet these requirements.

2 Technological steps to the solution

The development concerned nearly all parts of the light and the particle path through the instrument [1].

2.1 Optics

2.1.1 Laser beam shape

The standard LD system was taken as basis of the invention. This automatically includes a HeNe-laser as light source, which is the best choice for many reasons [1]. Specifically the highly stable output power, the long lifetime and the wide operational temperature range make it most useful for industrial use.

The set-up used in nearly every LD instrument is shown in Fig. 1.

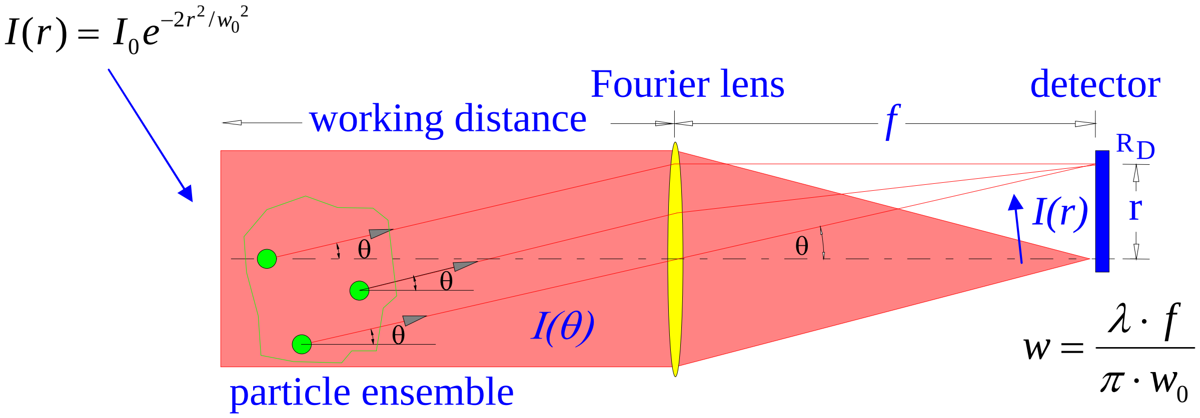

Fig. 1 The focus size depends *f* and w_0:

The beam shape had to be optimised to the desired function, i.e. the reproducible measuring of very coarse particles. The diameter of the laser beam is fixed by two main points:

The focus diameter *w*, see Fig. 1, should be as small as possible to get a good signal to noise ratio on the detector.

The focus diameter *w* can be calculated (see [1]) from $2w_0$, the full width of the laser beam at $I / I_0 = 1/e^2$, the wavelength λ and the focal length *f*:

$$w = \frac{\lambda \cdot f}{\pi \cdot w_0} \quad (1)$$

This gives a large diameter for large focal distances. Because in standard LD instruments different measuring ranges are used in a very wide range of focal lengths the beam diameter must be adapted. In Table 1 the used beam diameters and the calculated spot diameters are listed.

beam diameter w_o/mm	2,2	13	35
measuring range/µm	0,1/0.18 - 87,5	0.5/0,9 - 875	0,5/45-8.750
focal distance f/mm	50	500	5000
spot diameter w/µm	9,2	15,5	57,6

Table 1 Spot diameter vs. beam diameter

The Laser diameter must be big enough to gather a reasonable amount of particles to

- produce a remarkable signal and
- to avoid statistical errors caused by the position of the particles inside the beam.

Using a chain model the minimum number of maximum sized particles in the laser beam can easily be calculated: Table 2.

Range	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**
f/mm	**20**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**
x_{max}/µm	**35**	**87.5**	**175**	**350**	**875**	**1,750**	**3,500**	**8,750**
w_o/mm								
2.2	62.9	25.1	12.6	6.3				
13			74.3	37.1	14.9			
35				100.0	40.0	20.0	10.0	4.0

Table 2: Minimum number of particles being illuminated

This beam diameters are provides by the adaptable beam expander (ABE). Both points mentioned above tend to large beam diameters, which of course are limited by

- costs
- space in the instrument.

From many experiments it was found that the now chosen diameter of 35mm is a reasonable compromise. The collimator for this new beam was built into the standard adaptable beam expander. The principle of this is shown Fig. 2.

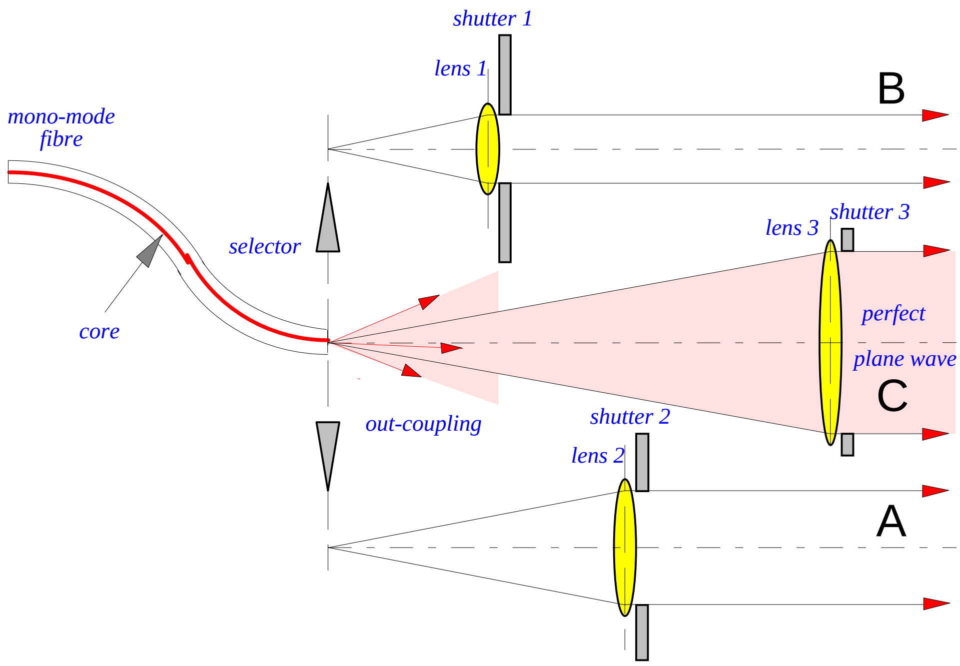

Fig. 2 Principle of adaptable beam expansion

The correct beam diameter as listed in Table 2 is automatically chosen by the instrument reading the focal length of the inserted optics.

2.1.2 Objective

The development of an optics of 5m focal length, which is normally an astronomic dimension, included an intensive optimisation of all components with respect to the main variable parameters:

- aperture of the optics
- number and shape of optical pieces

When the fixed parameters were:

- 5m focal length
- fit the complete system into a housing of only 0.5m length!

In comprehensive investigations a solution was found, see Fig. 3 and Fig. 4. Offering now the unique possibility to measure from 0.1µm up to nearly 1cm by the same method and keeping all advantages of LD at the same time. This opened up a complete new field of coarse applications in the field of particle technology: 0.5/45µm to 8750µm.

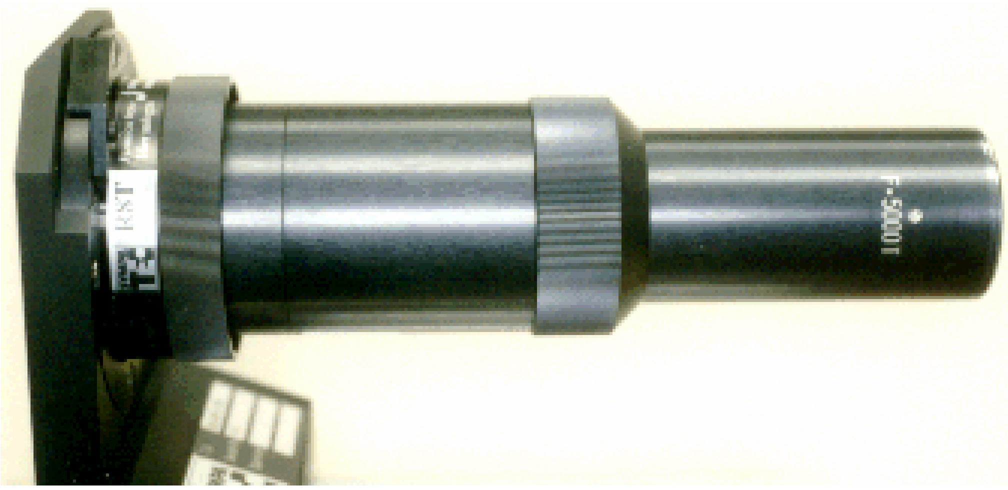

Fig. 3 Optic with f =5000mm

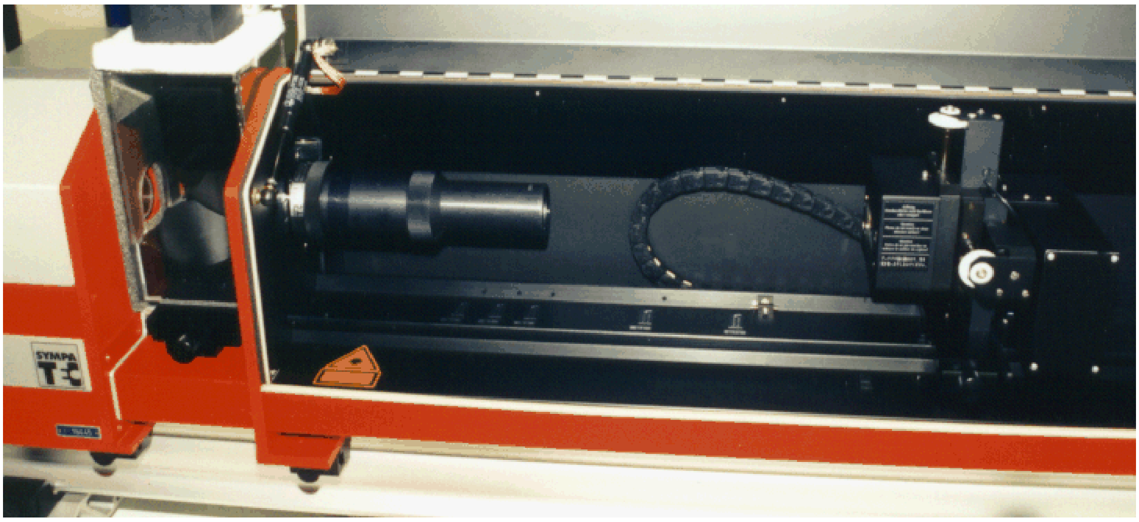

Fig. 4 New Optic module in short instrument

2.2 Particle handling

Although dispersing is not so critical in the size range under discussion, a dispersing device must be provided. Dropping the particles through a special shaft with built in impact walls is sufficient. It is also important that the particles do not miss the laser and must not re-enter the measuring zone, so the best is to let them fall directly through it. A newly developed measuring zone with an open bottom is able to meet these requirements.

The dispersing system shown in Fig. 5 also provides an encapsulation of the measuring zone against environmental influences.

Fig. 5 Feeding and dispersing system together with shield for the measuring zone called MEGAGRADIS

The housing shields the measuring zone against environmental influences and also guides the dispersed particles through the measuring zone by a quasi-laminar air flow, avoiding zones of turbulence. This is realised by holes in the housing which are covered by a filter and a special vacuum unit which also removes finest dust particles.

The whole system as shown in Fig. 6 is completely automated i.e. vibratory feeder and vacuum extraction unit are controlled by the PC belonging to the instrument.

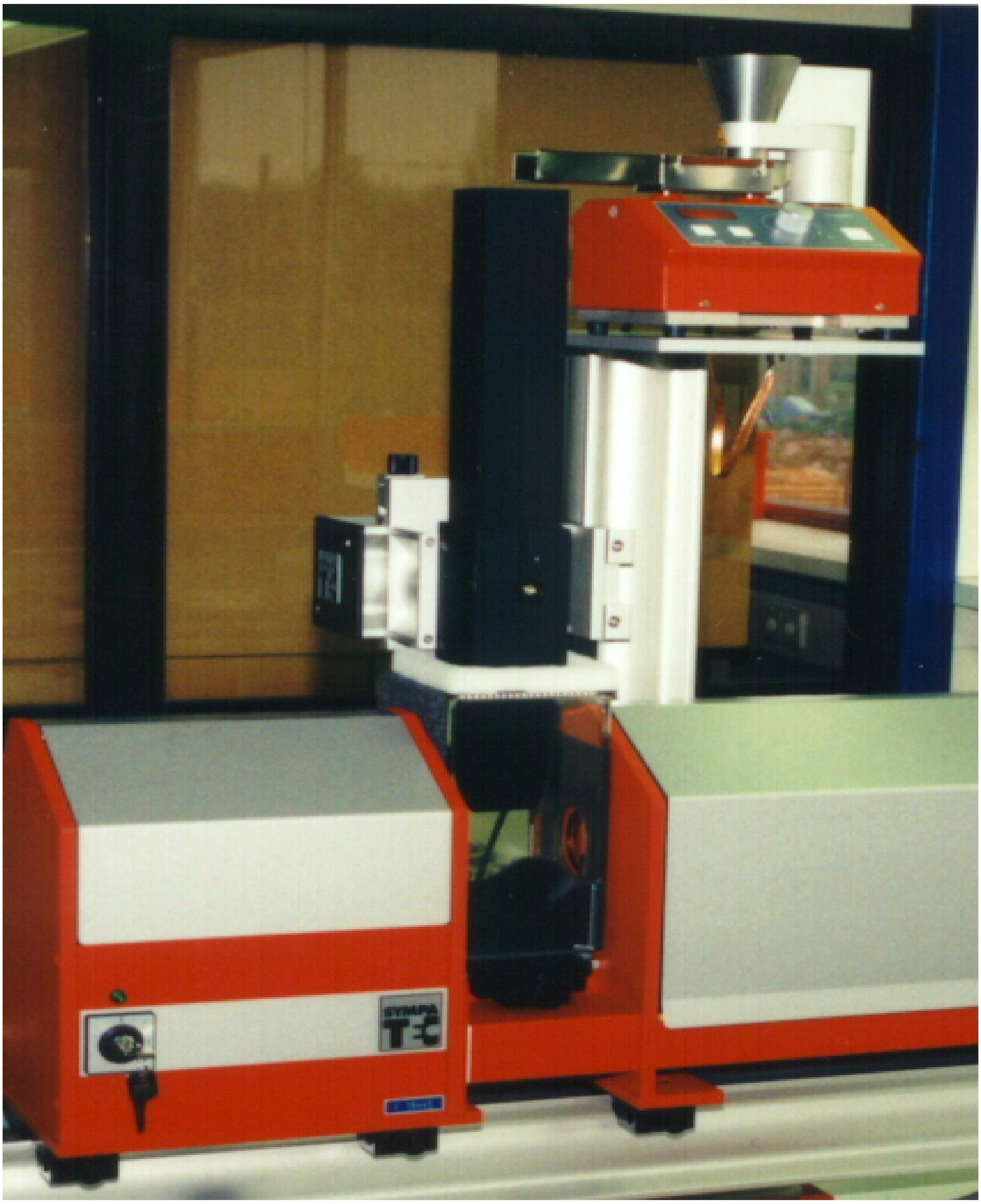

Fig. 6 The complete system with mounted disperser unit.

3 Results

3.1 Visualisation

The pictures Fig. 7 gives a good impression of coarse particle during measurement passing the laser beam.

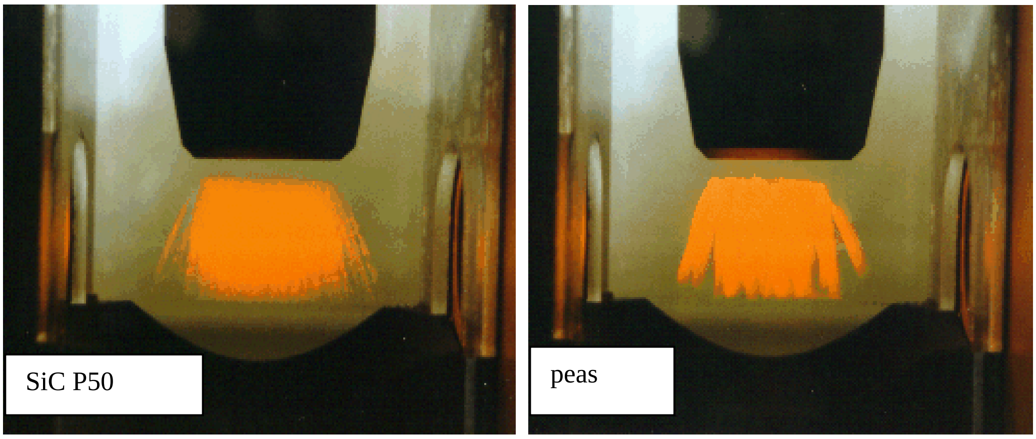

Fig. 7 Visualisation of measurement; different particles in the laser beam.

In Fig. 8 some typical products are shown to give another impression about the particles under discussion.

- fertilisers
- glass foam
- glass beads
- peas
- rice
- peeled barley
- sugar
- SiC

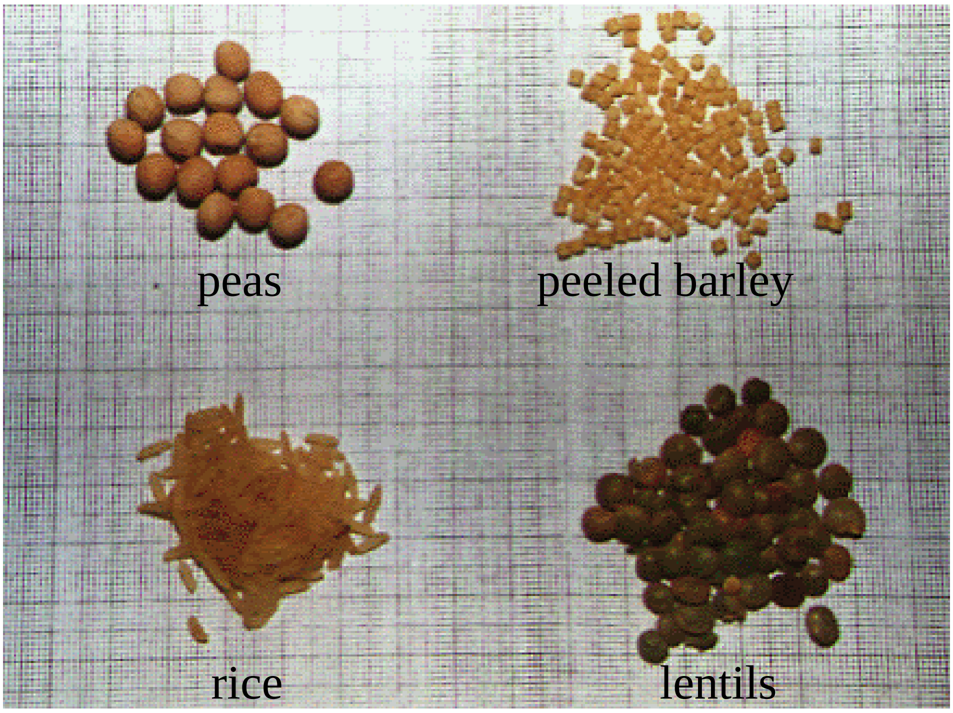

Fig. 8 Typical products for f = 5000mm measurements

3.2 Results with coarse samples

Only a small number of results can be presented here to show the strong performance of the developed system. First the results of measured SiC P50, 3mm glass beads and peas of about 7mm size are presented in Fig. 9. The measured x_{50} value only differs ca. 1% from the nominal one.

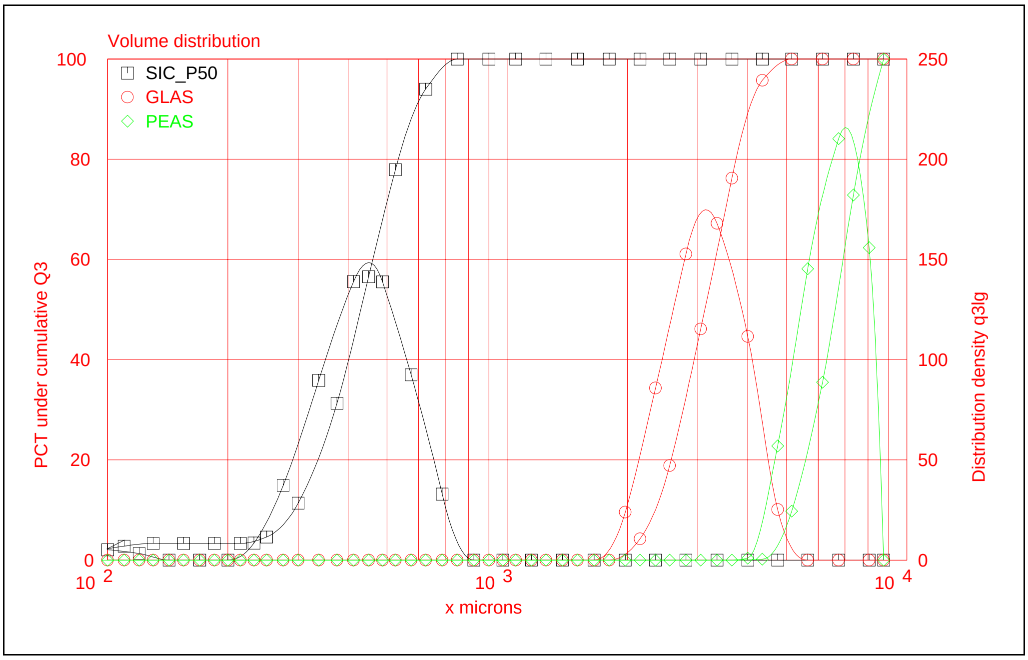

Fig. 9 Results of different products: SiC, glass beads and peas

The comparison of results measured with different measuring ranges presented in Fig. 10 shows also the high performance of the system.

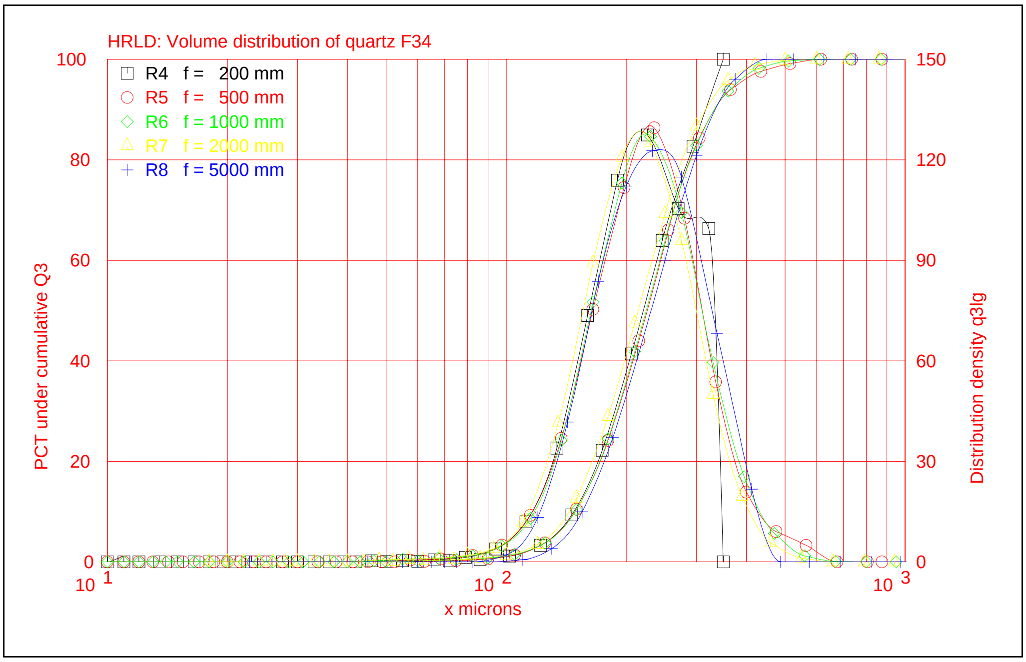

Fig. 10 Comparison with results of quartz with other measuring ranges

The comparison of results measured glass beads of 1.5mm and 3mm together with the measured 50:50 mixture shown in Fig. 11 proves also the high performance of the system.

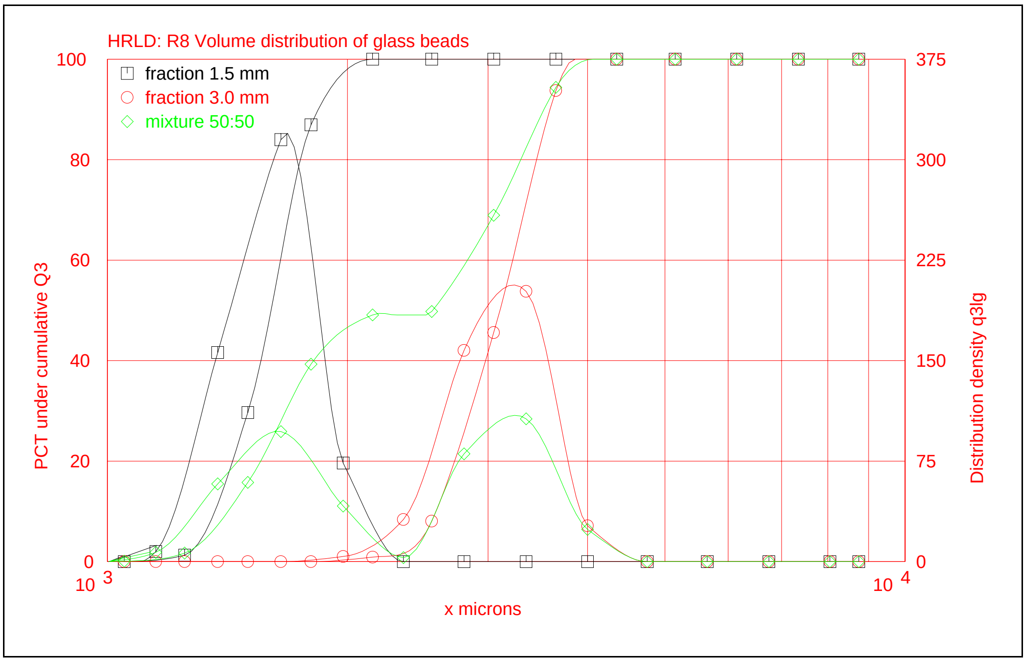

Fig. 11 Results of glass bead fraction mixture

Really interesting is the result found with long grain rice pointed out in Fig. 12. A separated bimodal distribution is reproducibly pointed out representing the main diameters of the grains.

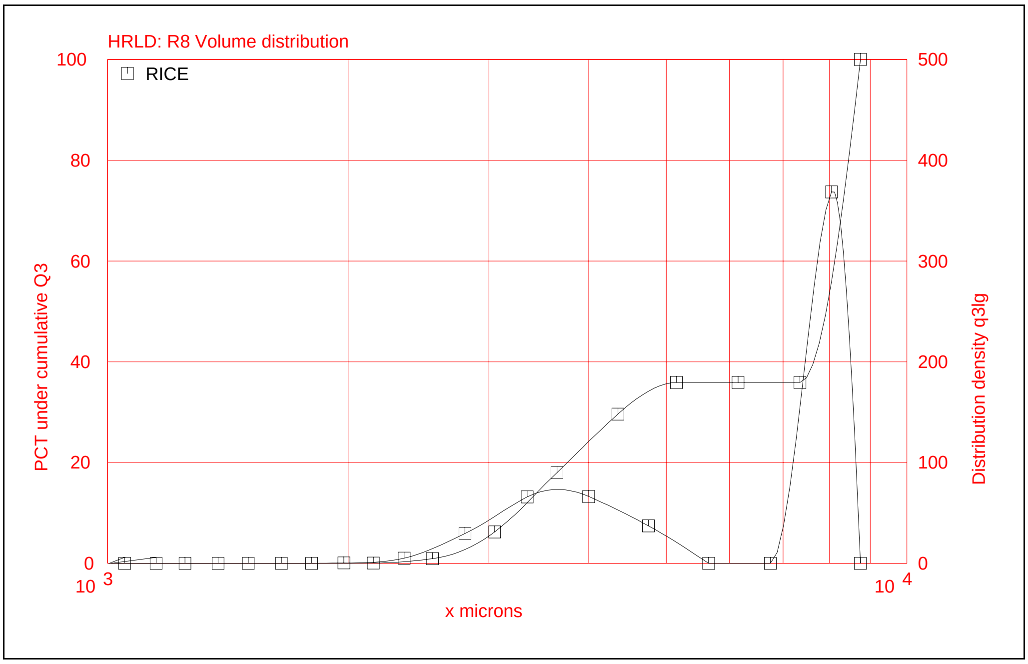

Fig. 12 Result of rice

4 Conclusions

The system is still unique world-wide. The field of laser diffraction has now been opened into the cm region. In this size range, which up to now was nearly occupied by sieving, fast reproducible LD particle sizing is available. It offers the unique possibility of using the same measuring method from 0.1µm to 8750µm.

The specially developed beam collimator and objective allow the system to fit into a 0.5m housing. This short distances between objective and detector yield high system stability, which is the basis for reproducible results.

The presented results show good accordance with standard measuring ranges. Although measurements with less than 100 particles of about ∅ 8mm are now possible, great care must be taken with sampling.

A new dispersing device was developed and tested. It disperses the particles using gravitational forces dropping them through a special shaft with built in impact walls. It guarantees that all particles pass the laser beam. Included is a shield which protects the system against environmental influences.

5 References

[1] W. Witt, S. Röthele — Laser Diffraction – unlimited? 6. Europ. Symposium Particle Charact.; (1995), 227-290

[2] M. Heuer, K. Leschonski — Erfahrungen mit einem neuen Gerät zur Messung von Partikelgrößenverteilungen aus Beugungsspektren, 3. Europ. Symp. Partikelmeßtechnik in Nürnberg, 1984

[3] K. Leschonski, S. Röthele, U. Menzel — A Special Feeder for Diffraction Pattern Analysis of Dry Powders, Part. Charact. 1 (1984) 7-13

Nomenclature

f	focal length
I	light intensity distribution
I_o	light intensity in the centre
r	radius in plane of detector
R_D	radius of detector
w	spot diameter
w_o	beam diameter
x	particle diameter
x_{10}	particle diameter to which 10 % of the cumulated undersize $Q_3(x)$ corresponds
x_{50}	particle diameter to which 50 % of the cumulated undersize $Q_3(x)$ corresponds
x_{90}	particle diameter to which 90 % of the cumulated undersize $Q_3(x)$ corresponds
λ	wavelength of light
Θ	scattering angle