Phase Center Measurement for the 'Gibson' Horn in the CHAI receiver

Fore-optics is designed to converge the Gaussian beam of each mixer piexl and modify the ratio of pixel spacing (s) and beam waist (ω) for the CHAI receiver. To preserve the designed s/ω raito and avoid defocus problems, the position of the virtual Gaussian BW of the horn must be precisely known. For the Gibson horns used in CHAI, we plan to measure the BW position.

Method and Experimental setup

One approach is to measure the optimal focus of the fore-optics for a near-field point by adjusting the position of the horn along optical axis untill the maximum power in the near point is achieved. In the measurement, the distance (***z***) between the horn's aperture and the mirror must be precisely recorded. The optimal focus position also can be accurately calculated based on Gaussian optics theory. Comparing the measured aperture position ***z*** with the theoretical focal point, we can get the BW position relative to the horn's aperture.

The experimental setup is shown in Figure 1. Here,we utilize a **1:3 scale-up** model to measure the BW position at frequency of **158.33GHz (1.89mm)**. The Gibson horn connected with a VDI transmitter is mounted in the optical plane as the source. A pyro-detector is mounted in xy-stage located 0.93m, 1.47m, 1.95m and 2.49m to measure the power of the collimated beam respectively.

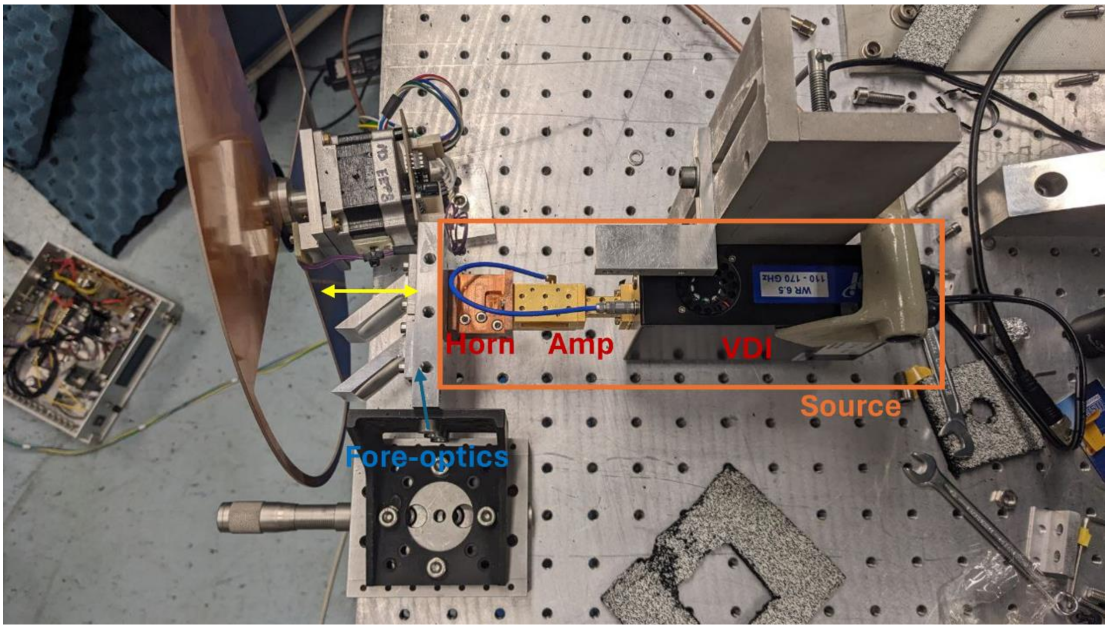


Figure 1.Setup of the fore-optics best focus measurement

The separation distacne (***z***) between horn's aperture and the mirrors is chagned by moving the mirrors back and forth with a precision stage. The initial separation distance is **18mm**. In the measurement, we change the distance from 18mm to 30mm with step size of 0.1mm (or 0.05mm). The diagram in Figure 2 illustrates the measurement.

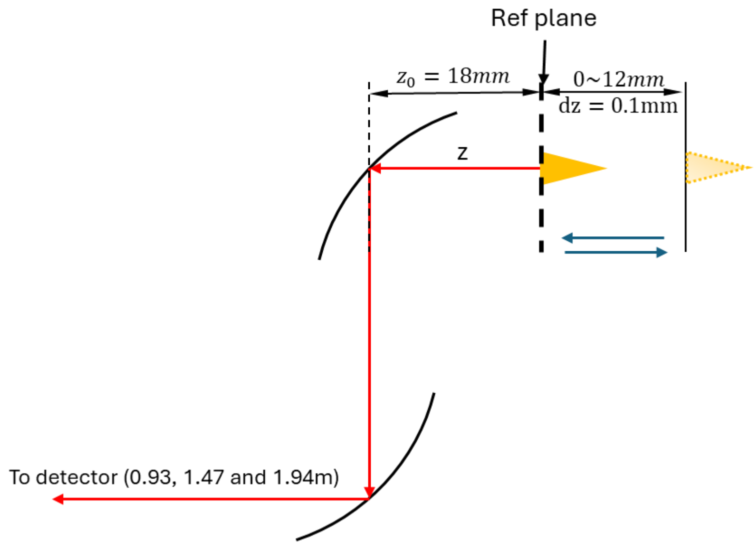


Figure 2. Experimental diagram. The horn moves from 18mm to 30mm

If assuming the BW is located at the center of the horn's aperture, the optimal focus position for the detector at different points, where the maximum power is measured by the detector, can be predicted theoretically, see Figure 3. Taking the difference between measured and calculated focus positions can give the position offsets of the BW from the horn's aperture plane.

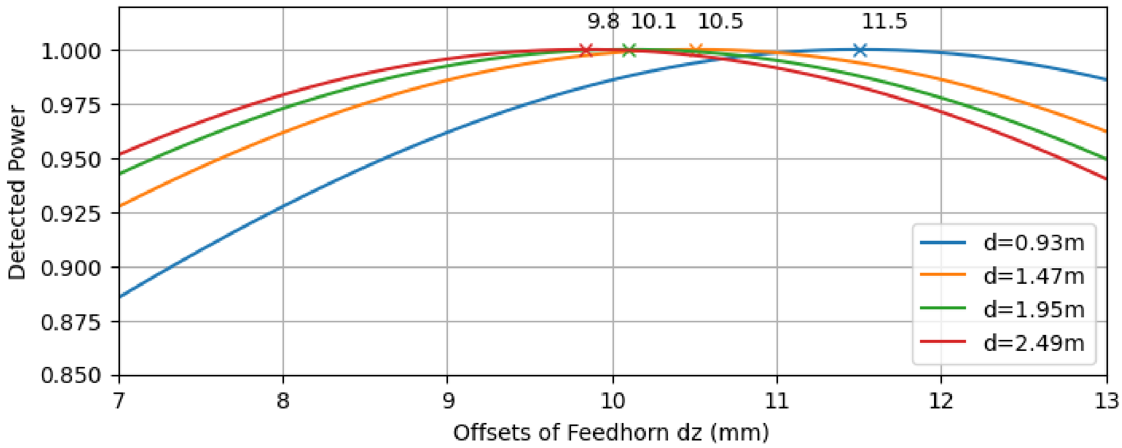
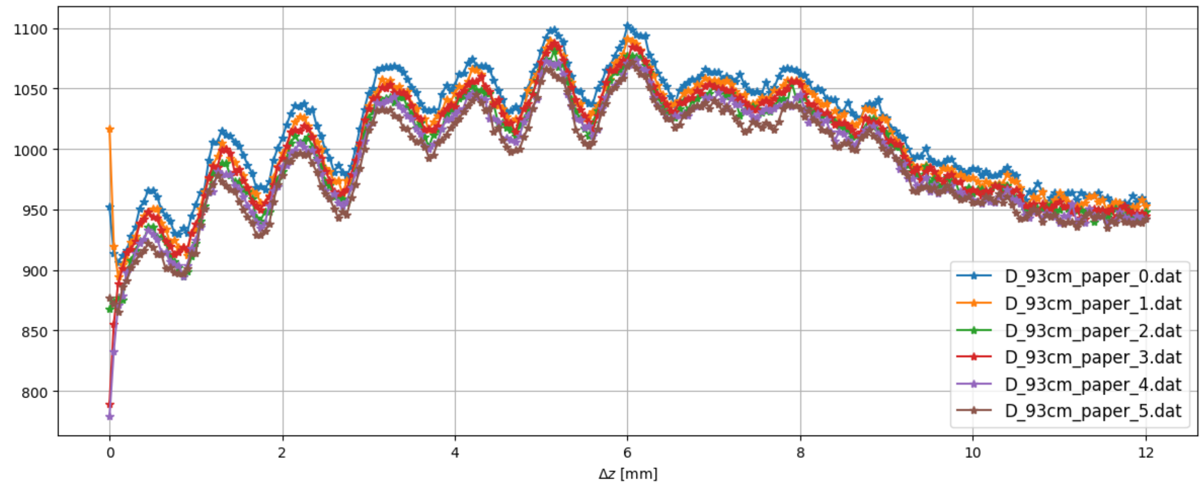


Figure 3. The theroetrical position of the optimal focus relative to the reference plane for the detector at 0.93m, 1.47m, 1.95m and 2.49m away from the Fore-optics, if the beam waist is located at the center of the horn's aperture plane.

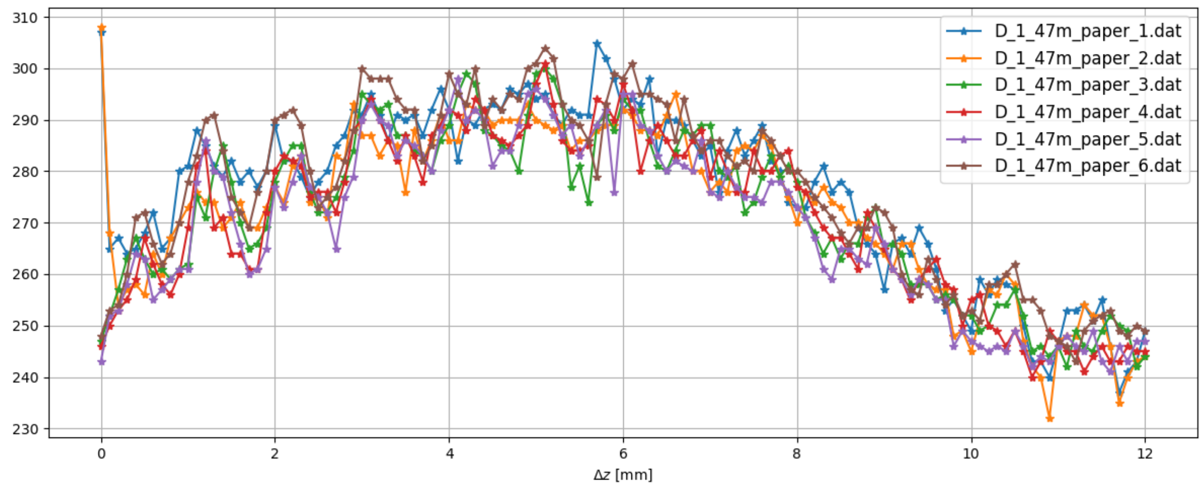
Data

Before the measurement, a cross beam scan is carried out first to align the detector and the optics. Then the distance between the optics and the detector is recorded. Following is the measured data for different separation distance.

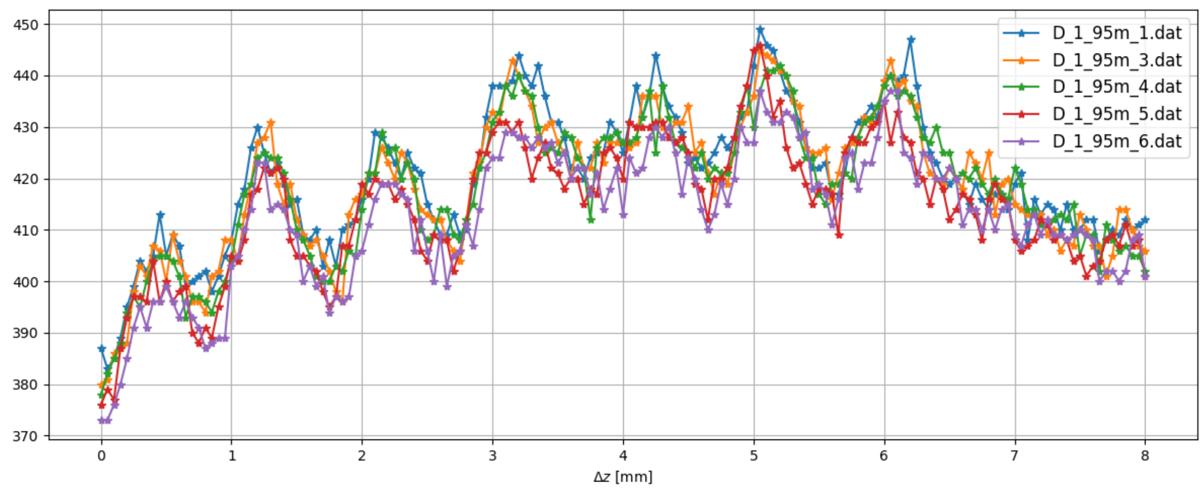
- Detector is 93cm away from the mirror



- Detector is 1.47m away from the mirror



- Detector is 1.95m away from the mirror



- Detector is 2.49m away from the mirror

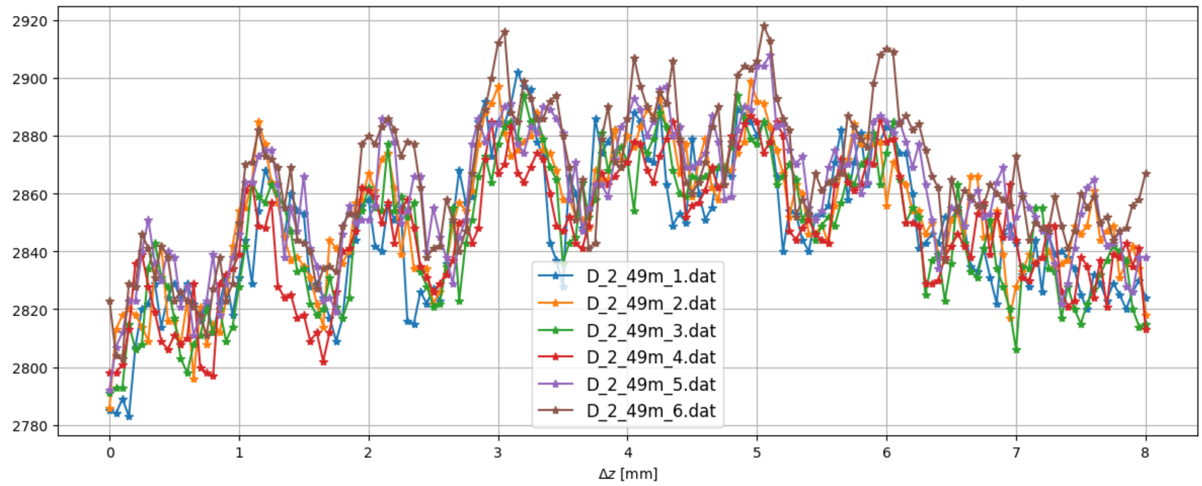


Figure 4. Measured data.

Data analysis

The power detected by the pyro-detector relative to the horn offsets can be approximately modeled by a parabolic equation (eq. 1). The parameters, a, b, and c, are gotten by using fitting algorithm. The fitted parameter **b** represents the best focal point.

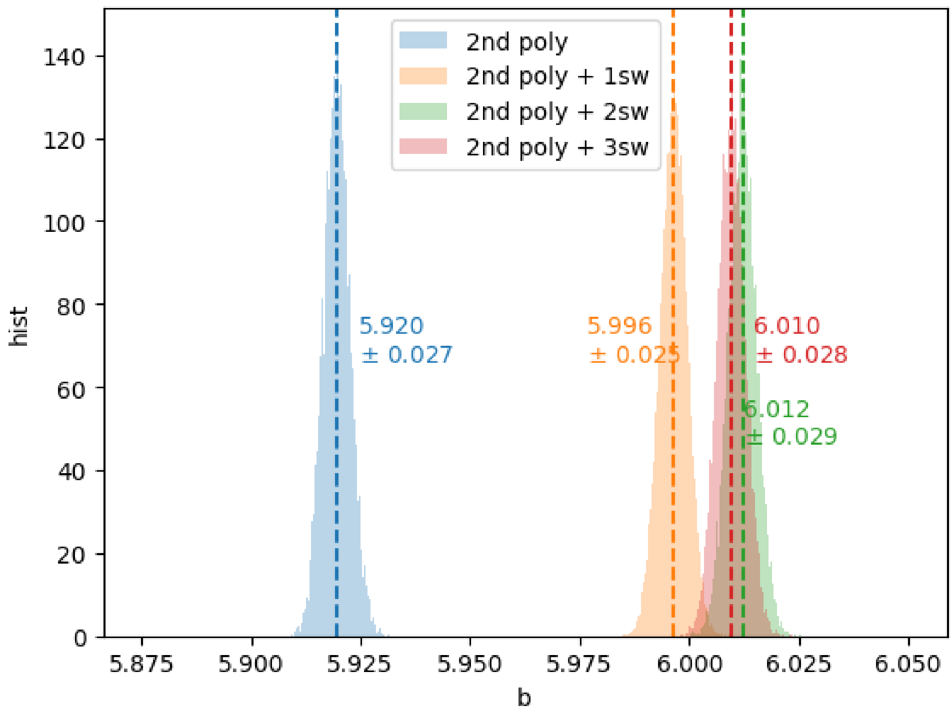
$$P(z) = a \cdot (z - b)^2 + c \tag{1}$$

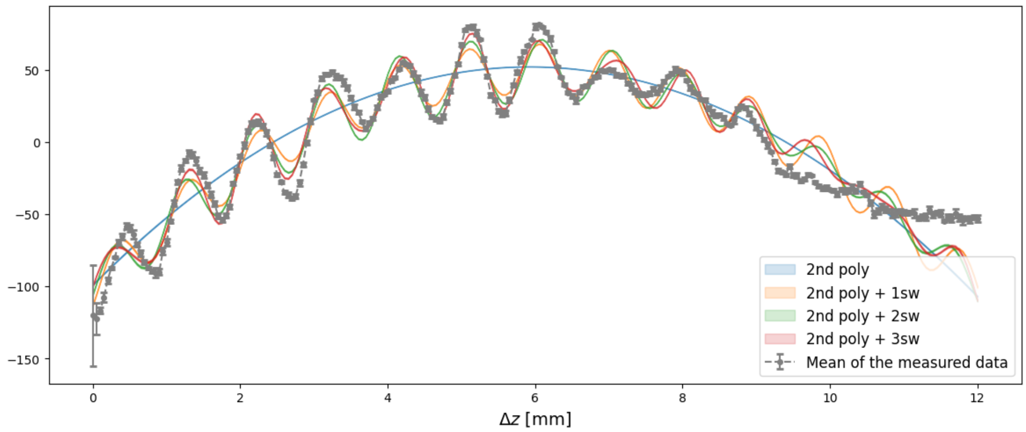
It is evident from the measured data that a standing wave with a period of approximately 1mm exists, which is half of the operating wavelength. To avoid the effect of reflections in the lab, that creats systematic bias, the standing wave is modeled by one or more sine functions (eq. 2).

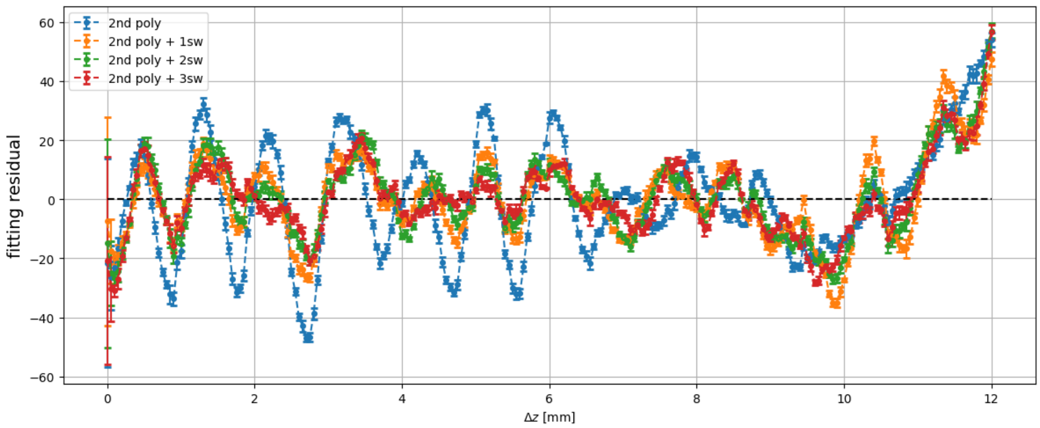
$$P(z) = a \cdot (z - b)^2 + c + \ A_0 \cdot \sin\left(\frac{2\pi}{\lambda_0} \cdot z + \phi_0\right) + A_0 \cdot \sin\left(\frac{2\pi}{\lambda_1} \cdot z + \phi_1\right) + \cdots \tag{2}$$

The three new parameters are also fitted together with the parabolic function. The values of the fitted b using different model and the fitted curve compared with the original data are shown in Figure 5.

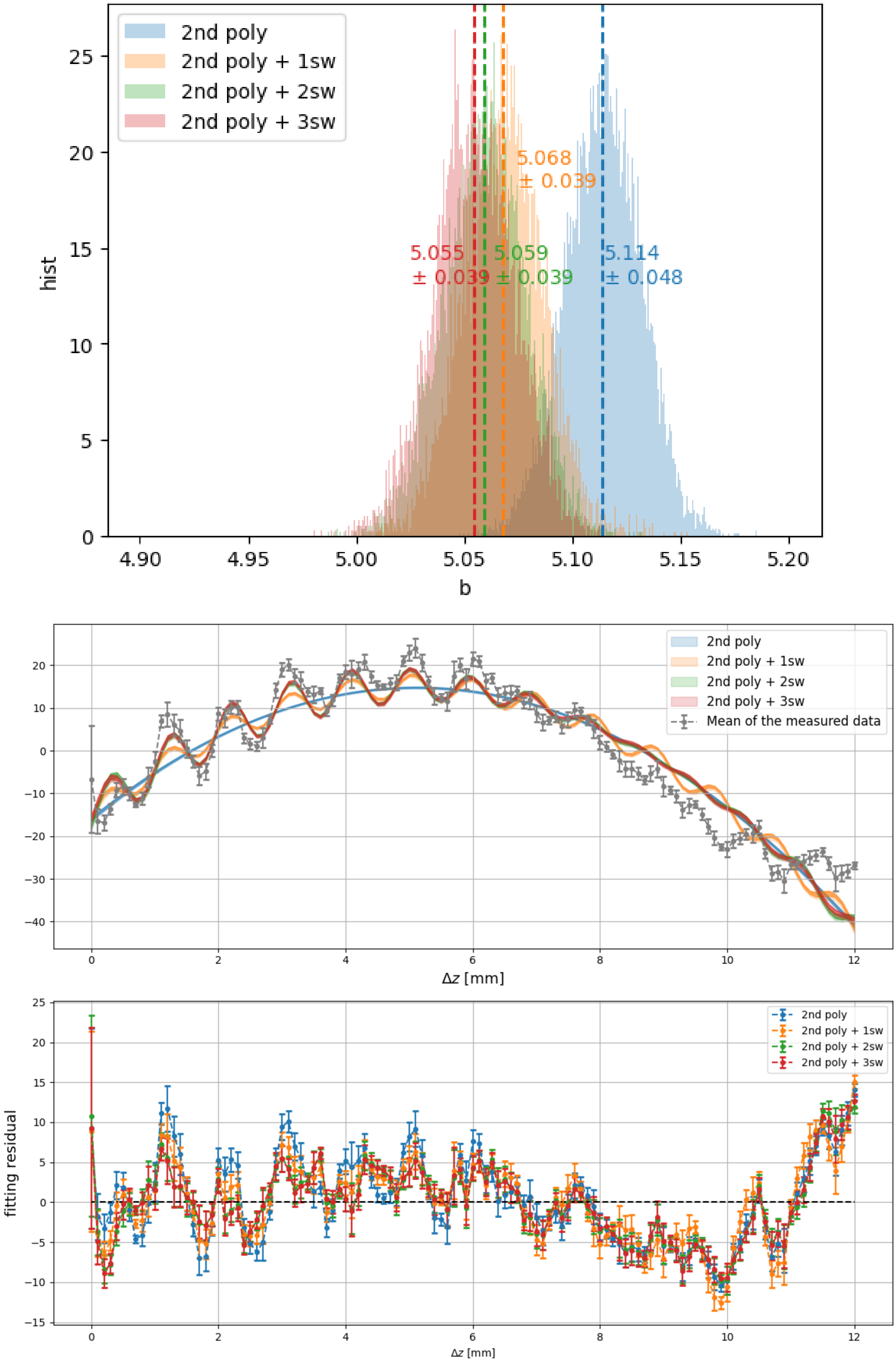
- 93cm


2nd poly
2nd poly + 1sw
2nd poly + 2sw
2nd poly + 3sw
5.920
± 0.027
5.996
± 0.025
6.010
± 0.028
6.012
± 0.029
hist
b


2nd poly
2nd poly + 1sw
2nd poly + 2sw
2nd poly + 3sw
Mean of the measured data
Δz [mm]

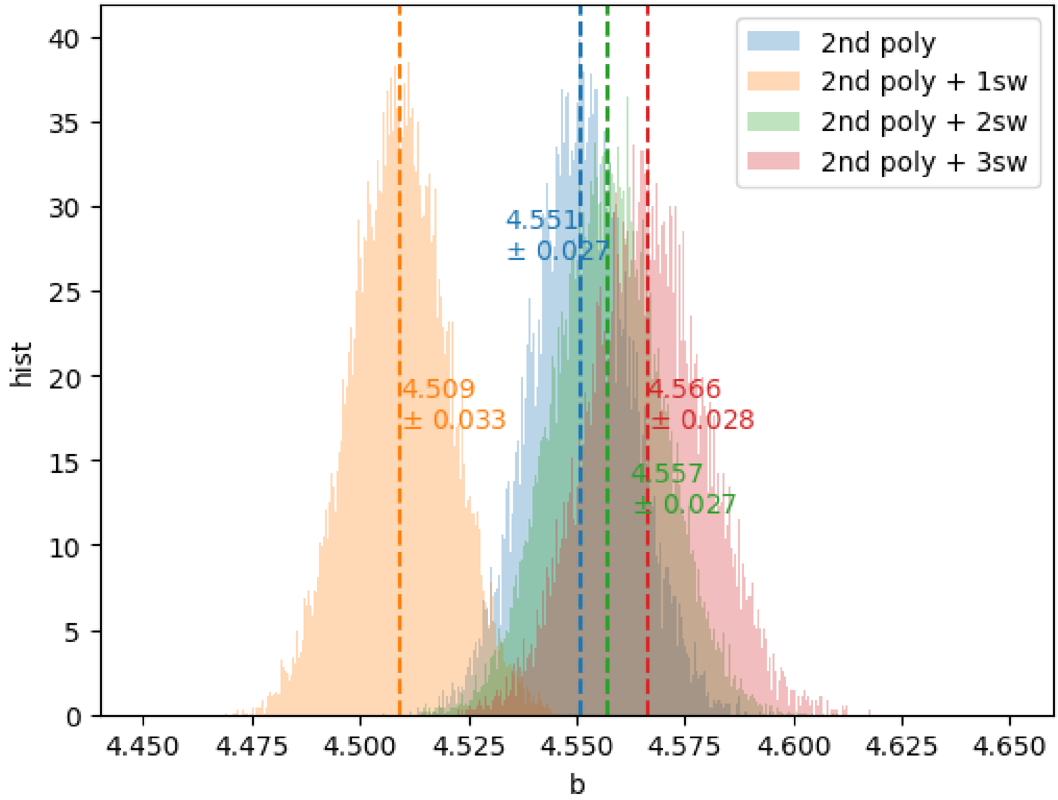

2nd poly
2nd poly + 1sw
2nd poly + 2sw
2nd poly + 3sw
fitting residual
Δz [mm]

- 1.47m

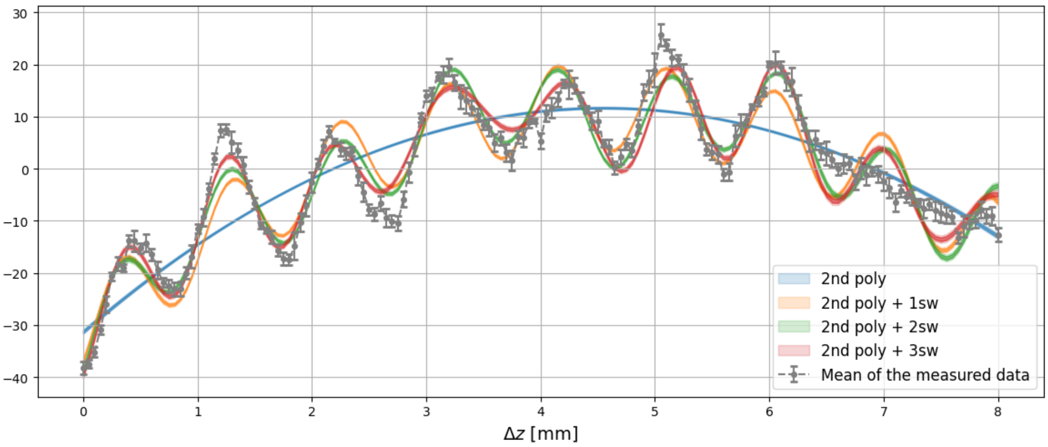


2nd poly
2nd poly + 1sw
2nd poly + 2sw
2nd poly + 3sw
5.068
± 0.039
5.055
± 0.039
5.059
± 0.039
5.114
± 0.048
hist
b
Mean of the measured data
Δz [mm]
fitting residual

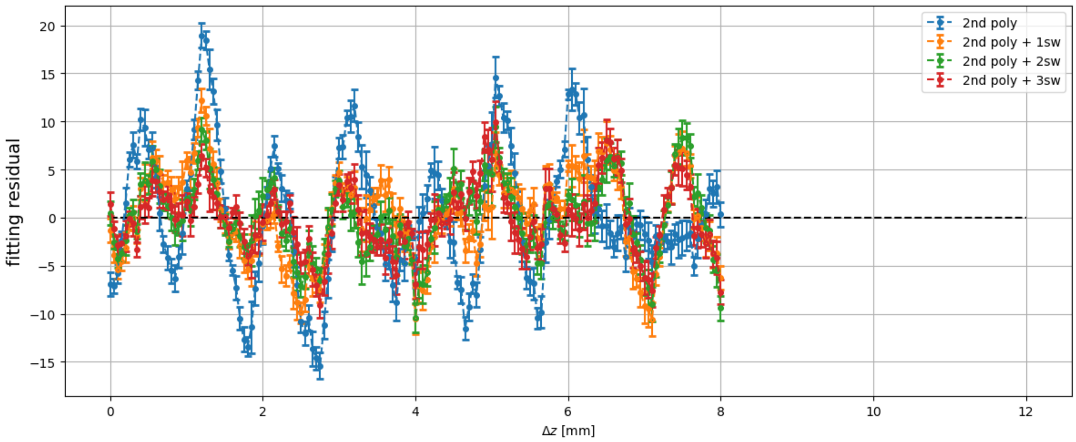
- 1.95m



2nd poly
2nd poly + 1sw
2nd poly + 2sw
2nd poly + 3sw
4.551
± 0.027
4.509
± 0.033
4.566
± 0.028
4.557
± 0.027
hist
b

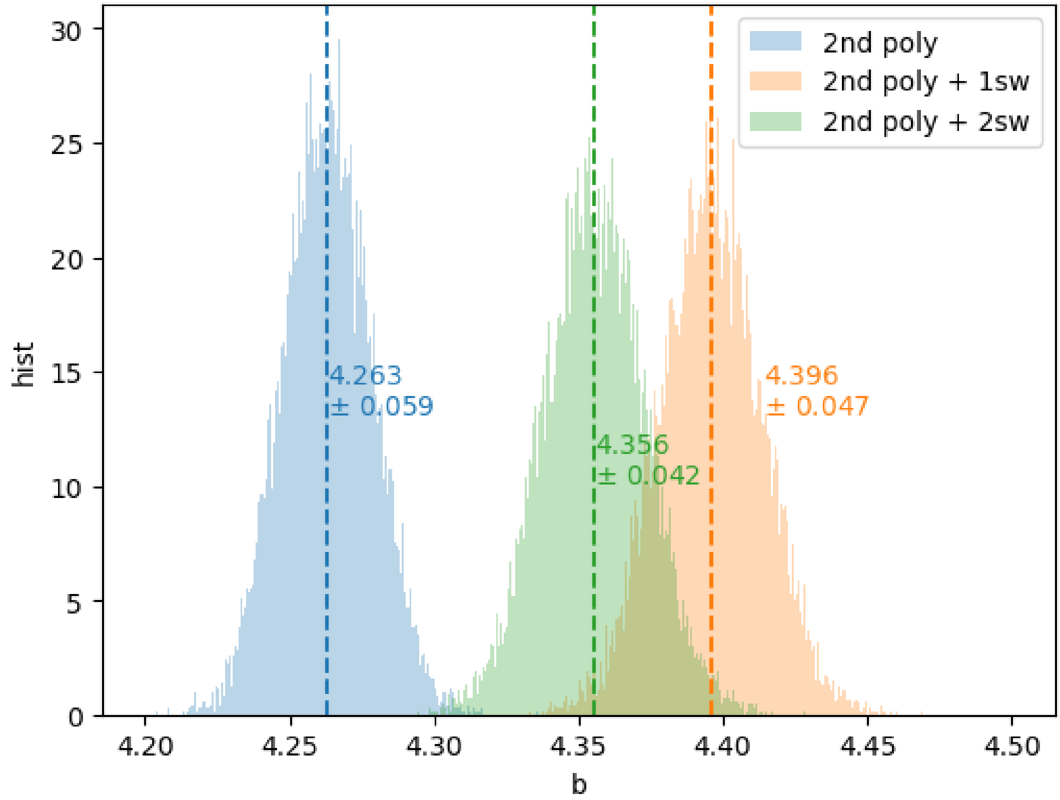


2nd poly
2nd poly + 1sw
2nd poly + 2sw
2nd poly + 3sw
Mean of the measured data
Δz [mm]

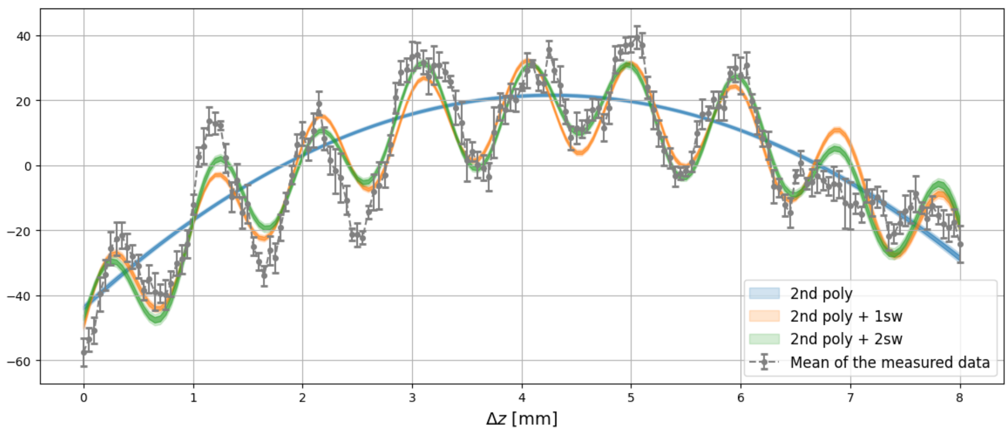


2nd poly
2nd poly + 1sw
2nd poly + 2sw
2nd poly + 3sw
fitting residual
Δz [mm]

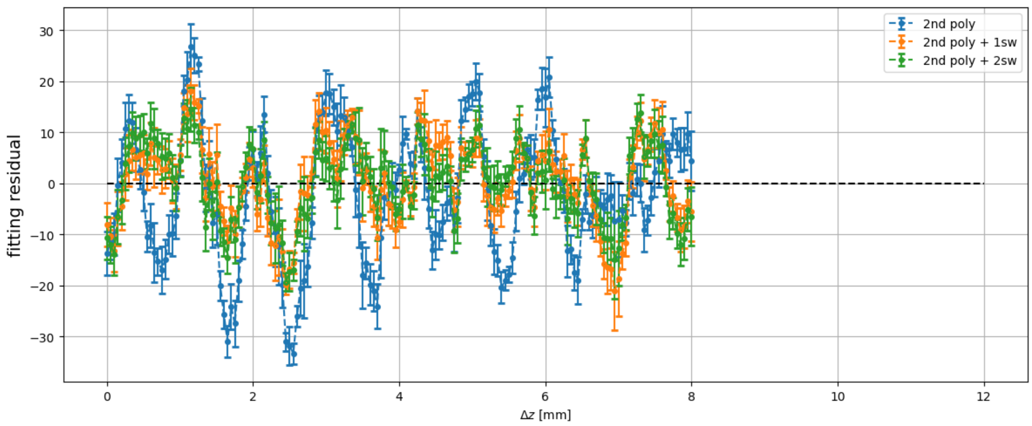
- 2.49m



2nd poly
2nd poly + 1sw
2nd poly + 2sw
4.263
± 0.059
4.356
± 0.042
4.396
± 0.047
hist
b



2nd poly
2nd poly + 1sw
2nd poly + 2sw
Mean of the measured data
Δz [mm]



2nd poly
2nd poly + 1sw
2nd poly + 2sw
fitting residual
Δz [mm]

Calculate BW position

Comparing the measured best focus positions with the theoretical focal points, see below figure, the position of the virtual beam waist of the Gibson horn is **5.49mm behind** the horn's aperture.

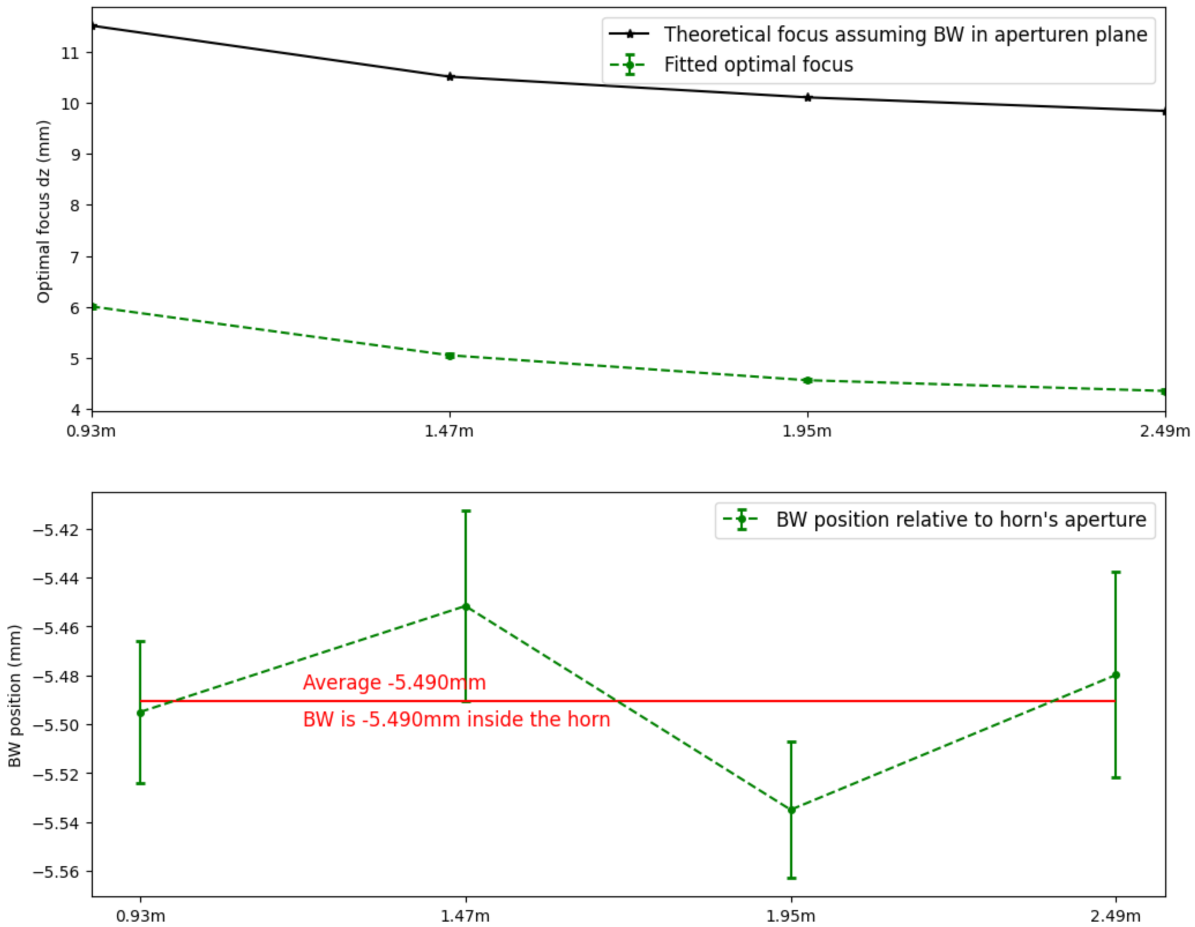


Figure 5. The measured optimal focal points for the 4 different detector distances. Comparing the measured focus to the theoretical values, we can get the offsets of the BW of the Gibson horn which is about 5.49mm behind the horn's aperture.