

FIG. 3. (Color online) Diffraction of Rb, K, and Na atoms from the same nanograting. Best-fit flow velocity  $v_0$  and velocity distribution  $\sigma_v$  with statistical errors are shown. As discussed in the text, the velocity distribution is found from contrast-loss measurements.

the contrast loss measurements. We then fix  $\sigma_v$  when fitting the diffraction patterns to find the final flow velocity  $v_0$ .

#### IV. PHASE AND CONTRAST MEASUREMENT

After recording several diffraction scans to measure the flow velocity, we center the detector on the zeroth-order diffraction peak, replace the narrow collimating slits with wider ones (35 and 45  $\mu\text{m}$ ), and insert the second and third gratings into the beamline to form the interferometer. We use a wider beam for our interferometer than Ekstrom *et al.* [5] for two reasons. First, wide collimating slits allow more flux to reach the detector. Second, wide slits minimize the velocity-selective detection of interference fringes caused by the dispersive nature of diffraction. We calculate that the flow velocity of the atoms detected from the interferometers when the detector wire is centered on the beam is about 0.25% faster than the flow velocity of the entire beam. We use the adjusted flow velocity when determining the polarizability, yielding a 0.5% correction to the polarizability. The correction to the velocity distribution parameter  $\sigma_v$  is negligible. If we had used small slits with the detector on the centerline, this correction and the uncertainty in this correction would have been three times larger.

Next, we calibrate the position of the interaction region by eclipsing the beam with the cylindrical electrode and then moving the interaction region out of the beam path as we record the average flux through the interferometer and the position of the interaction region. We use the position at which the flux is 50% of the maximum to locate the center of the beam a distance

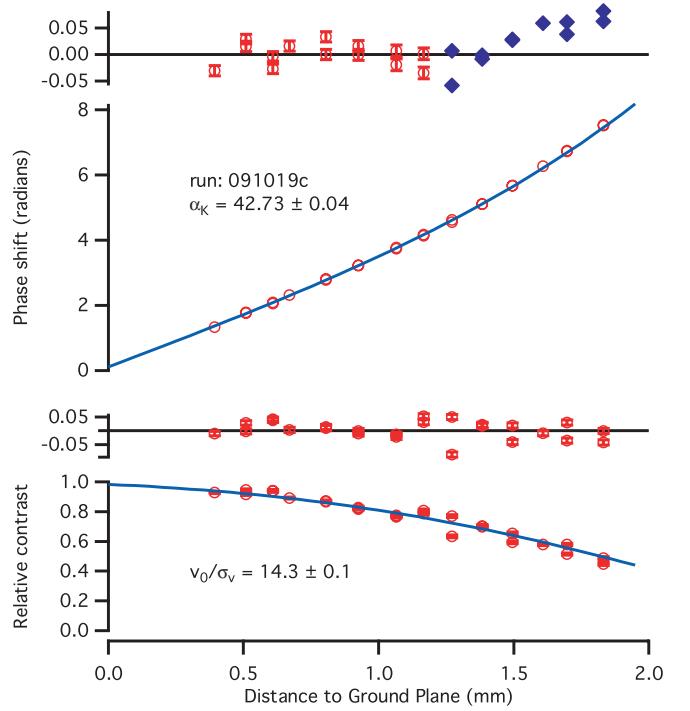


FIG. 4. (Color online) Phase shift and relative contrast vs. electrode position  $x$ . The best-fit polarizability and the statistical error for one data set are shown. We only fit the phase shift measurements with relative contrast greater than 75%. Residuals for the fit data points (circles) are shown with error bars. For reference, residuals for the unfitted data points (filled diamonds) are also shown. The contrast loss determines  $v_0/\sigma_v$ .

$a$  from the ground plane. We then move the interaction region across the beam in steps of 100  $\mu\text{m}$  and measure the phase shift [Eq. (12)] and contrast loss [Eq. (13)] at each position. Figure 4 shows the measured phase shift and contrast loss for a typical data set.

We determine the flow velocity, velocity distribution, and polarizability from the diffraction, contrast loss, and phase shift data, respectively. In Sec. III, we discussed how we find the flow velocity  $v_0$ . In Sec. II, we discussed how the contrast of the measured fringe pattern is reduced by performing an incoherent sum of the fringes formed by atoms of multiple velocities. We fit the contrast loss data to determine  $v_0/\sigma_v$  with an uncertainty of 10%. The primary source of error in this measurement of  $\sigma_v$  comes from vibration-induced fluctuations in the reference contrast. We then refit the diffraction data, holding  $\sigma_v$  fixed, to find the best-fit flow velocity  $v_0$ . This procedure yields a small correction to  $v_0$  of less than 0.2%. Finally, we use  $v_0$  and  $\sigma_v$  as inputs to the polarizability fit of the phase data. We exclude data points in which the relative contrast is less than 75% to minimize the uncertainty in the polarizability due to uncertainty in  $\sigma_v$ .

After fitting all the data, we apply small corrections to the polarizability due to beam thickness and isotope ratios. To account for beam thickness, we modify Eq. (11) to include an integral over the beam width. The correction to the polarizability due to beam thickness is +0.04(2)% for each atomic species. To account for isotope ratios we modify Eqs. (11) and (17) to include weighted sums over isotopes.