Prototype BPM measurements results

Jan. 2021

Noise Treatments

- Several treatments were applied to minimise noise level on measured signal:
  - The pipe position is hold for 3 seconds (Holding Time: HT) before moving to next position (default: 200ms).
  - Band pass filter (500kHz - 4MHz) was added on LabVIEW software.
- Applied polynomial fitting on the measured pipe position (u, v) along horizontal axis (Fig.1). The difference between the point *(v_i)* and corresponding position *$f(v_i)$* is computed by

$$dV = v_i - f(v_i)$$

and plotted as shown in Fig.2.

- The band pass filter reduced systematic noise efficiently.

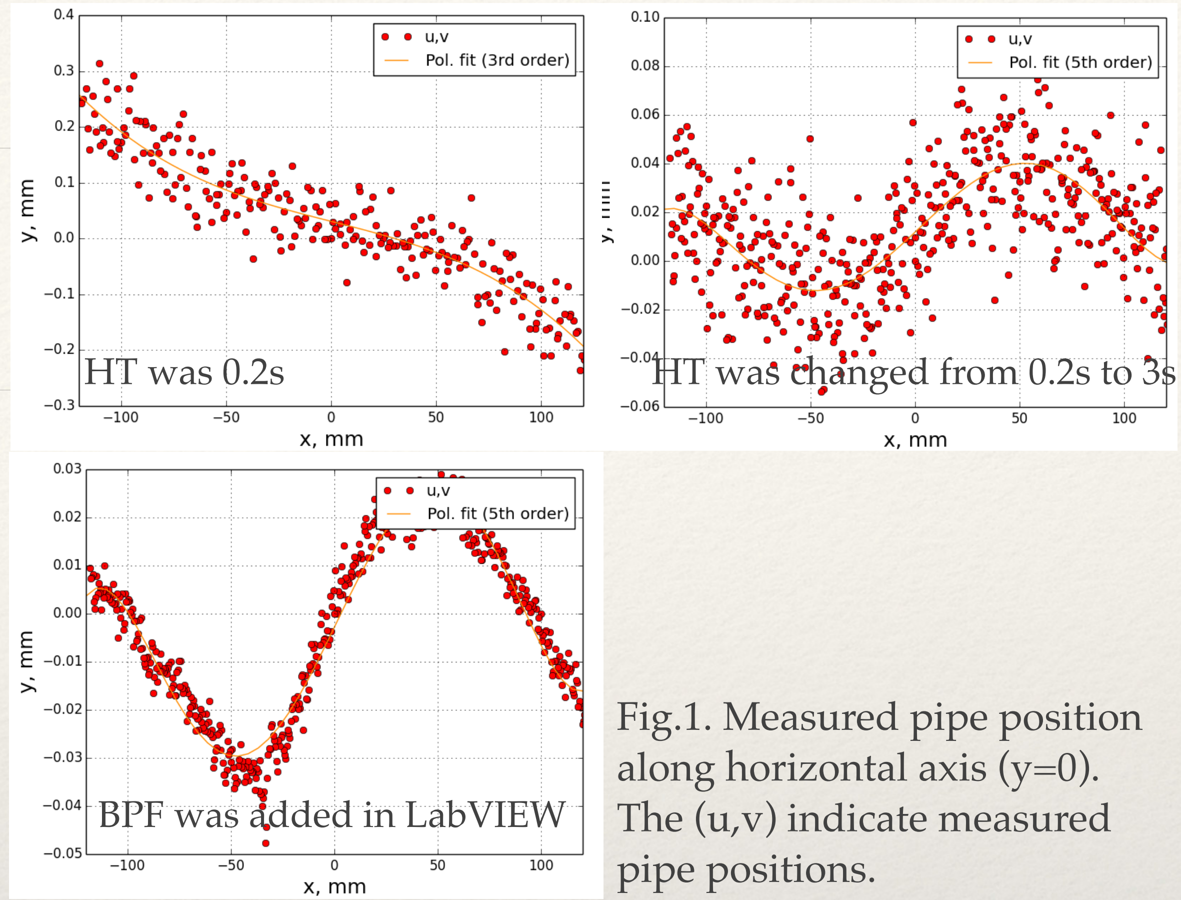


Fig.1. Measured pipe position along horizontal axis (y=0). The (u,v) indicate measured pipe positions.

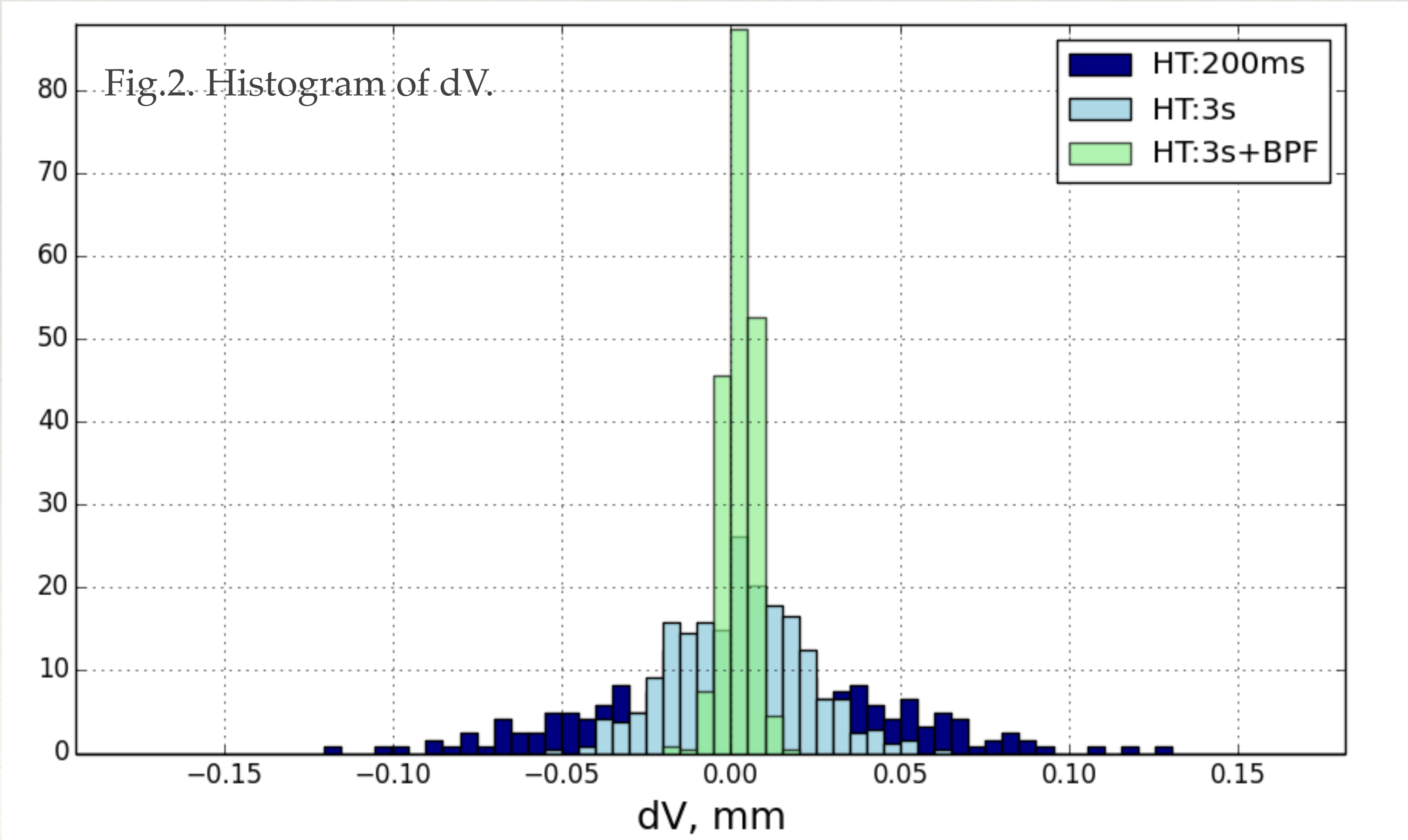
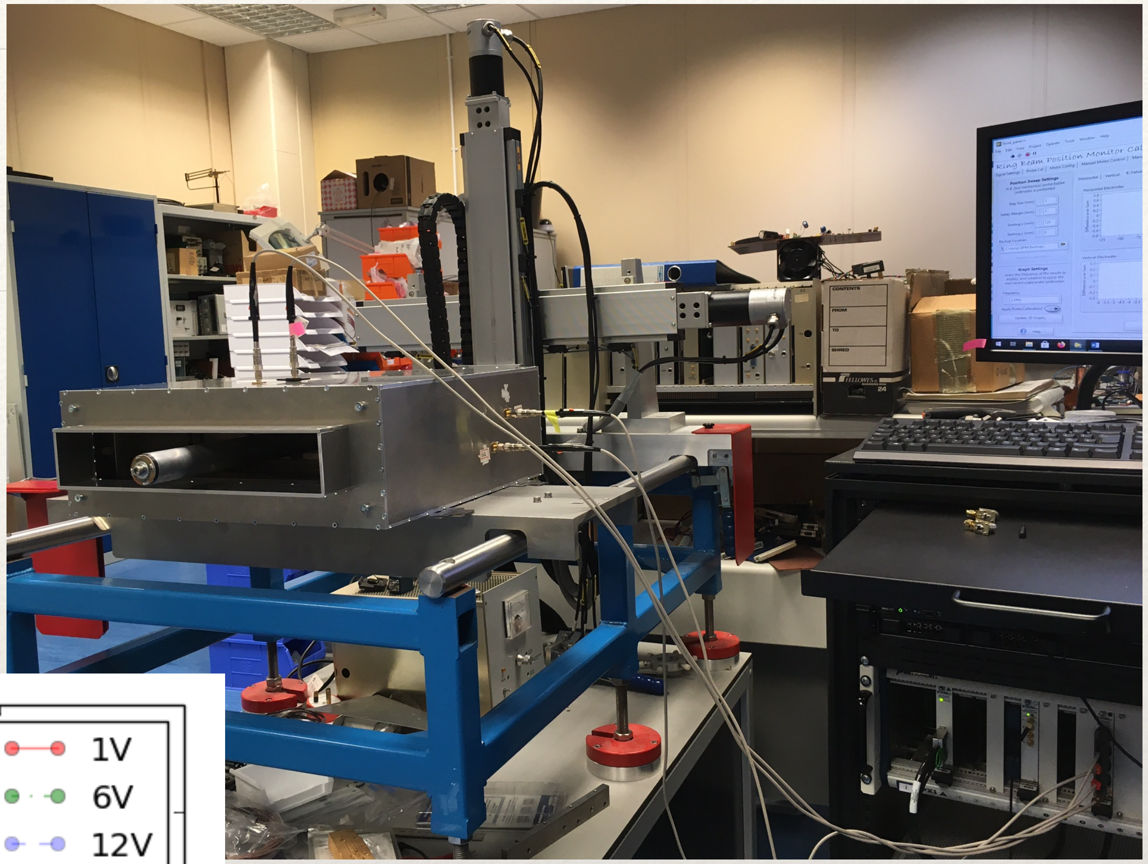
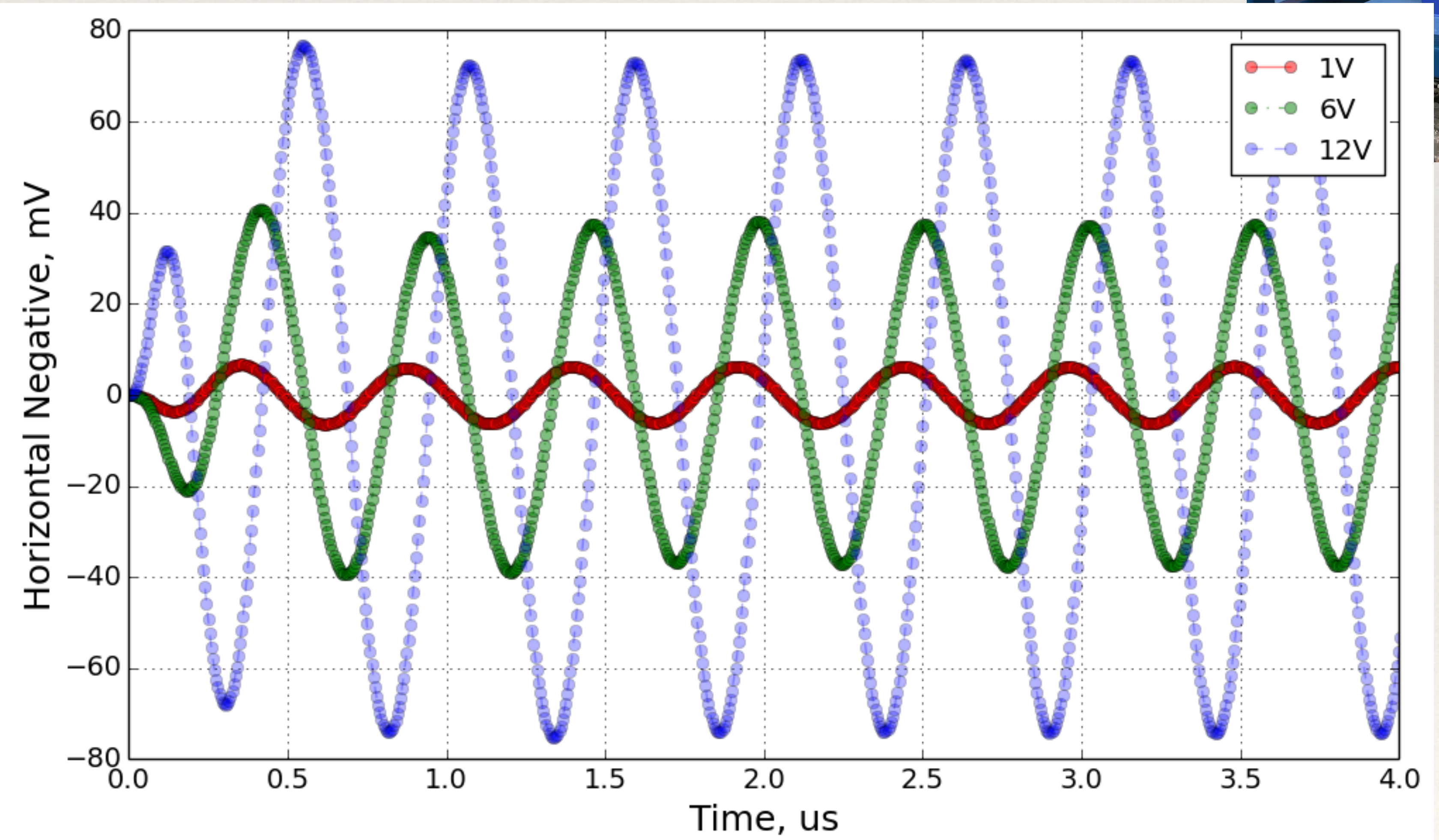


Fig.2. Histogram of dV.

Dependency of Drive Signal Amplitude

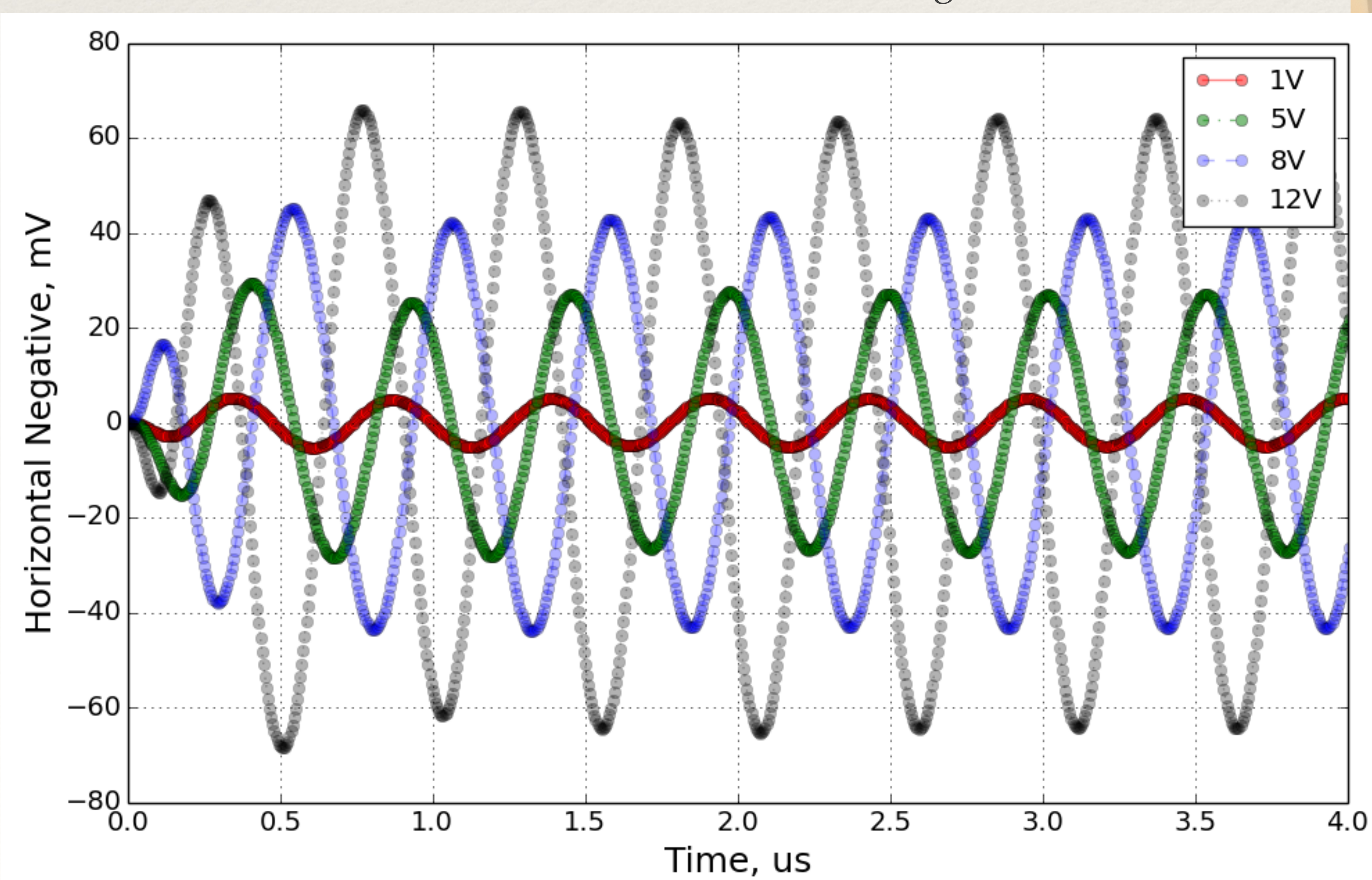


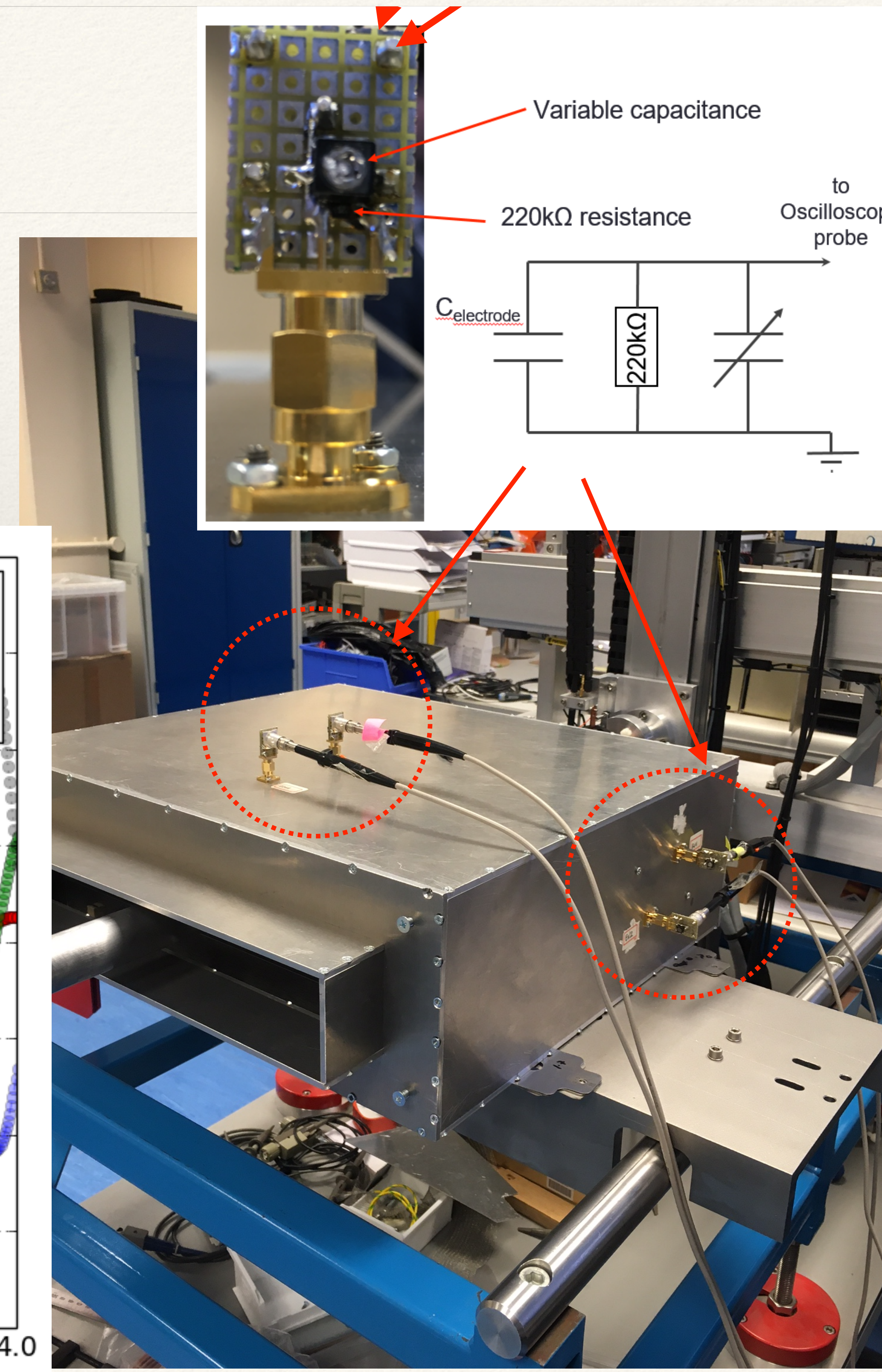
- Cable, diode and top-hat electronics are not used in this measurement.
- Drive signal on the pipe was changed by 1, 6 and 12V in LabVIEW software.
- In the software, the band pass filtering was applied between 500kHz and 4MHz.
- When the pipe was centred in the BPM, the signal from horizontal electrode were measured as shown in the bottom figure.



Dependency of Drive Signal Amplitude with Top-Hat Electronics

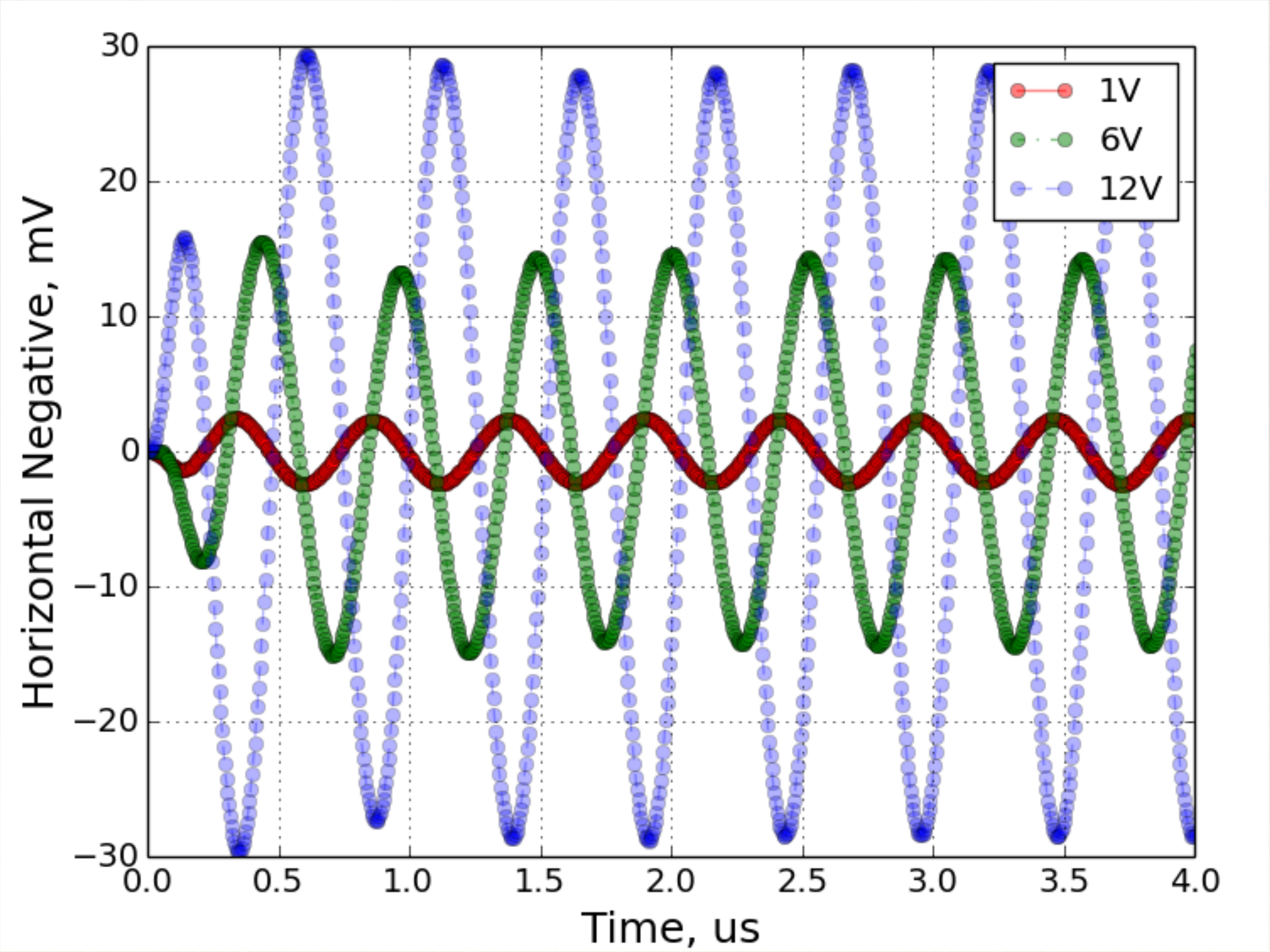
- Top-hat electronics was installed on the feedthrough directly in this measurement.
- Drive signal on the pipe was changed by 1, 5, 8 and 12V in LabVIEW software.
- In the software, band pass filtering was applied between 500kHz and 4MHz.
- When the pipe was centred in the BPM, the signal from horizontal electrode were measured as shown in the bottom figure.

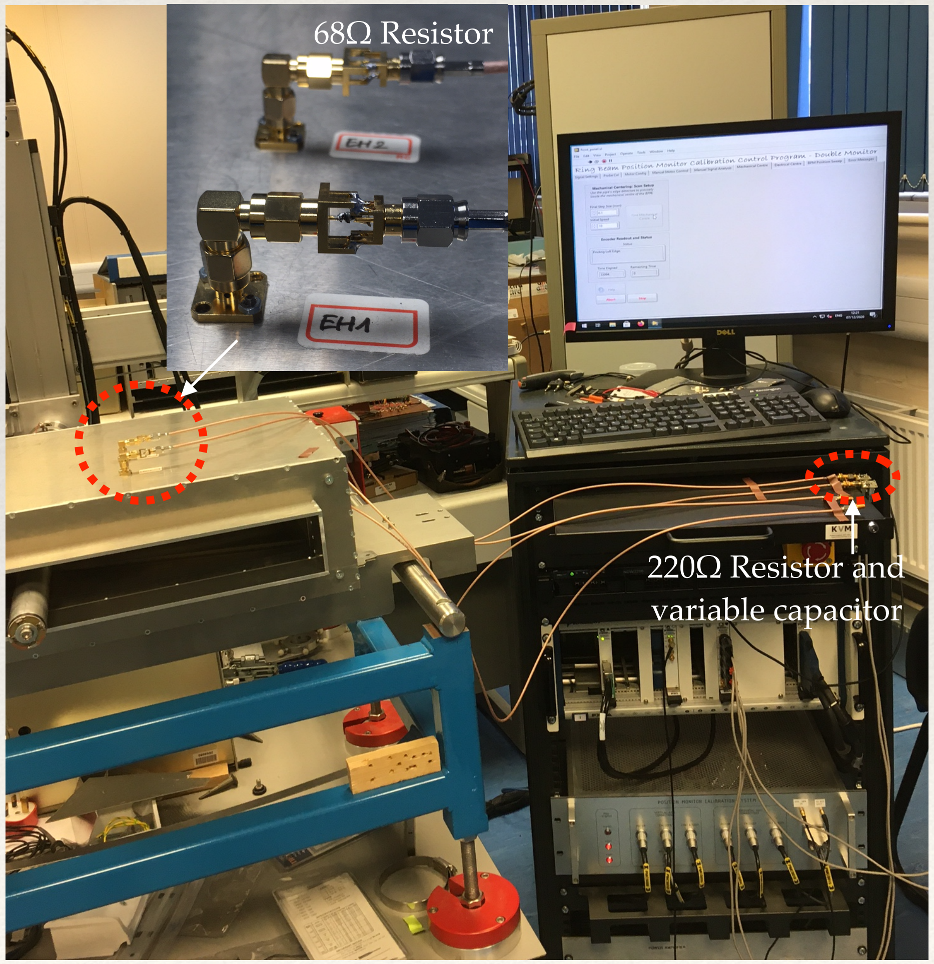




Dependency of Drive Signal Amplitude with Top-Hat Electronics and Long Cable

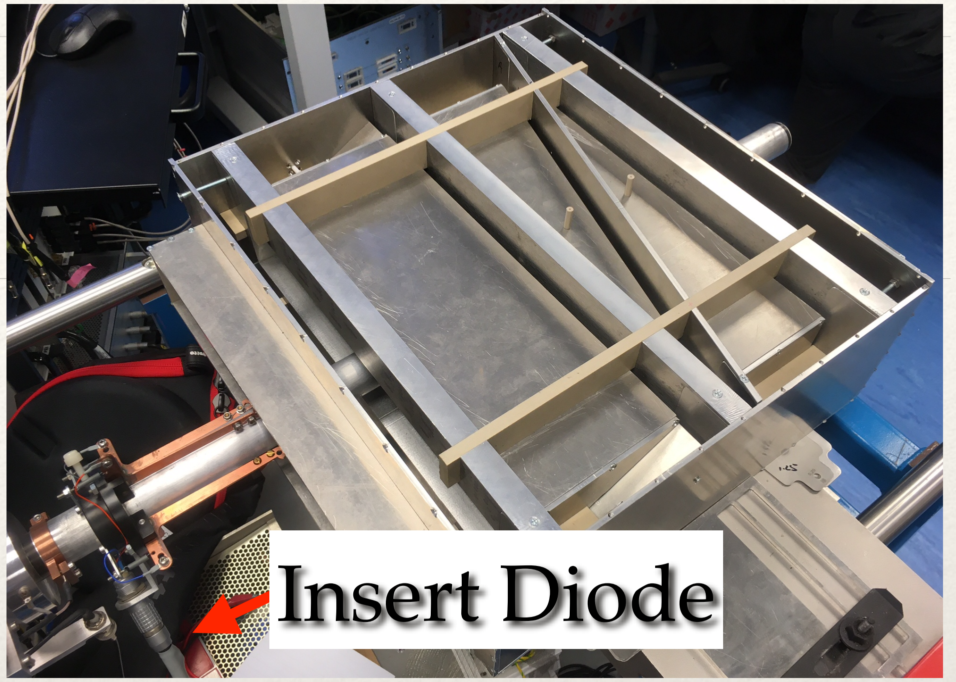
- Long cables (1m long) will be installed between feedthrough and chamber flange in the vacuum at KURNS.
- To avoid reflections in the cable, 68Ω resistor will be placed on the feedthrough.
- Top-hat electronics will be then connected outside of vacuum chamber. To reduce cut off frequency, 10 MΩ scope prove or Transformer will be used for the beam test at KURNS.
- Drive signal on the pipe was changed by 1, 6 and 12V in LabVIEW software.
- In the software, band pass filtering was applied between 500kHz and 4MHz.
- When the pipe was centred in the BPM, the signal from horizontal electrode were measured as shown in the bottom figure.

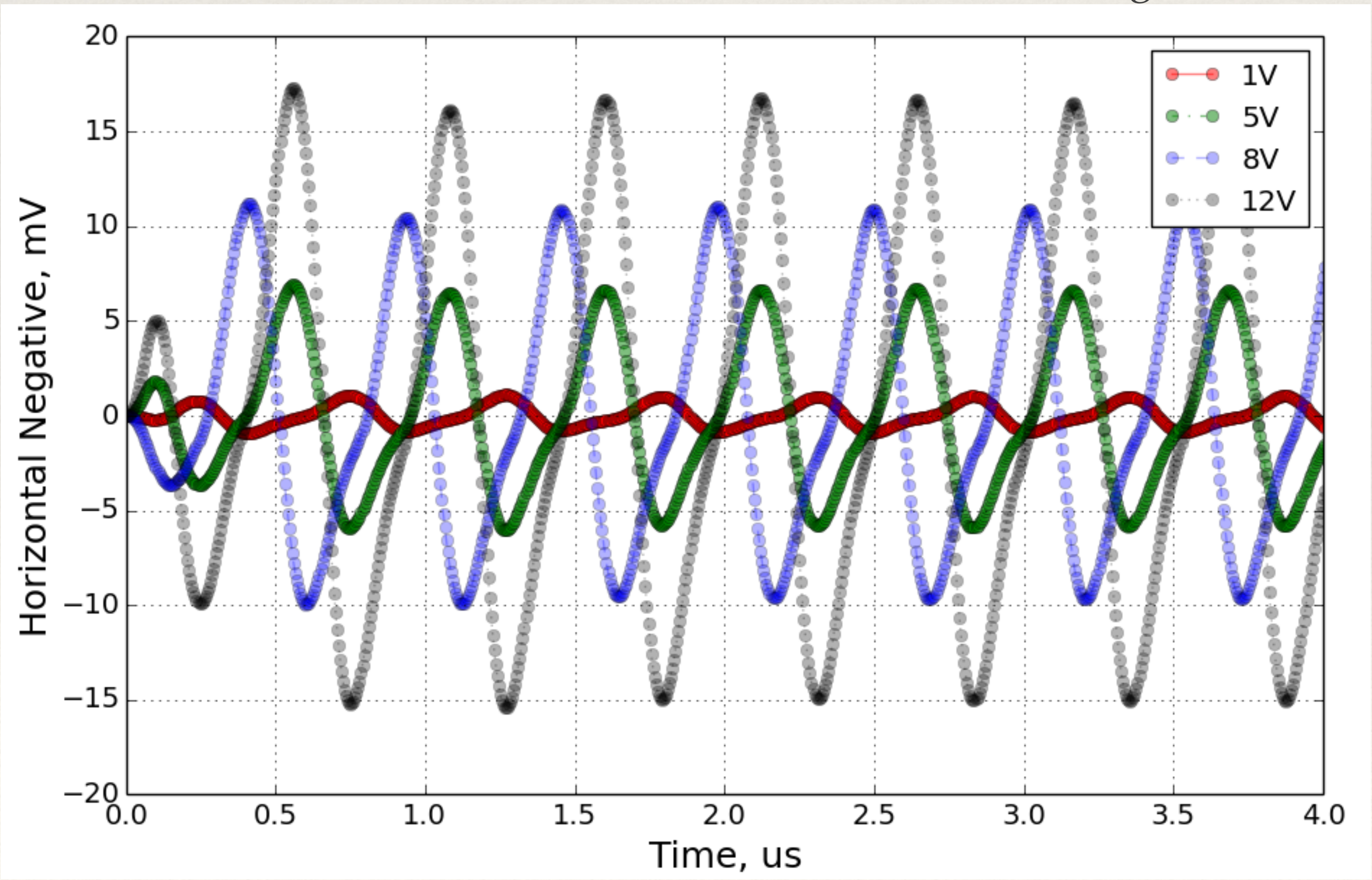


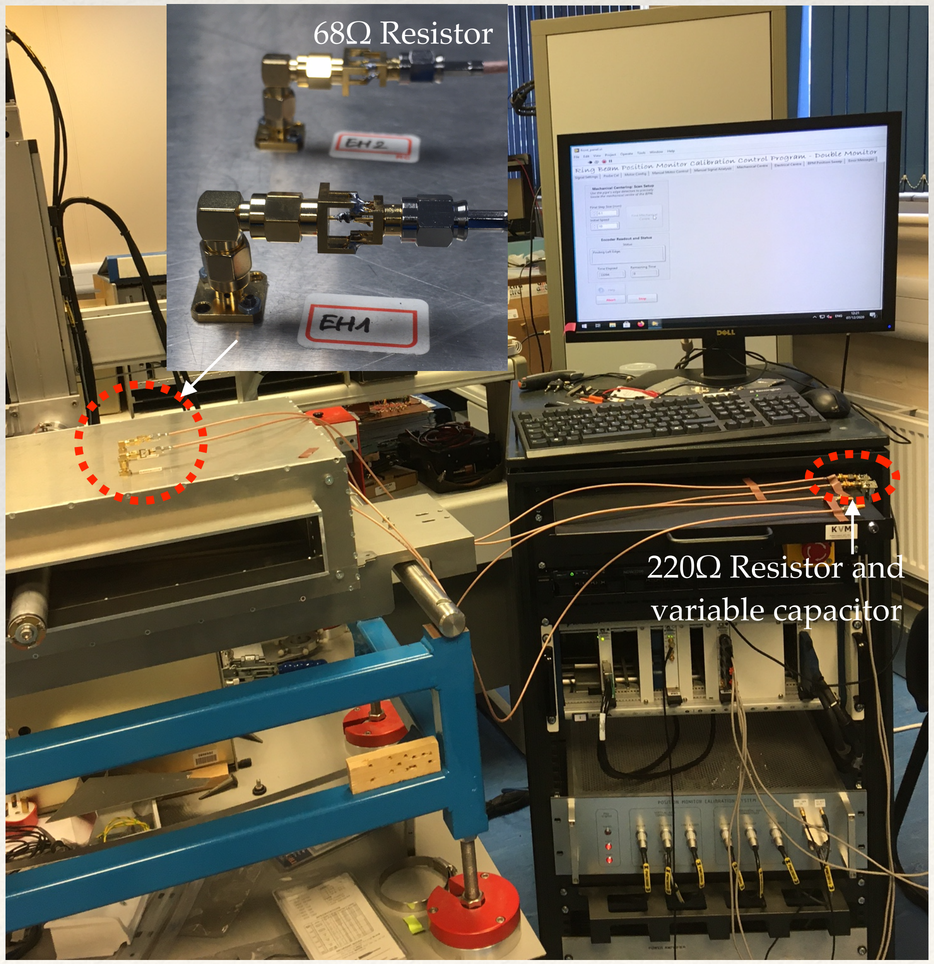


Dependency of Drive Signal Amplitude with Diode, Top-Hat Electronics and Long Cable

- Diode was installed on the pipe to imitate a beam signal.
- Drive signal on the pipe was changed by 1, 5, 8 and 12V in LabVIEW software.
- In the software, band pass filtering was applied between 500kHz and 4MHz.
- When the pipe was centred in the BPM, the signal from horizontal electrode were measured as shown in the figure.

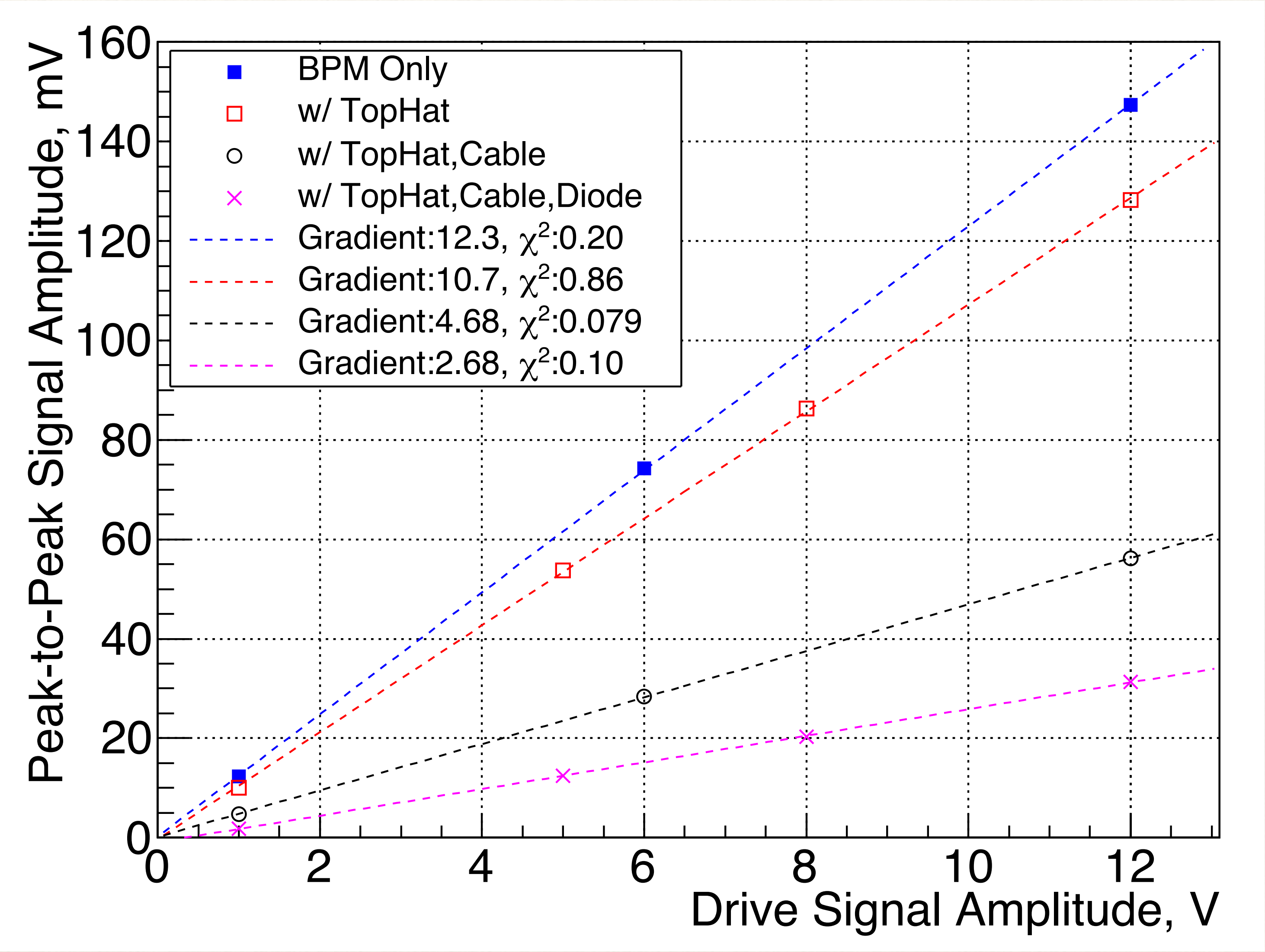






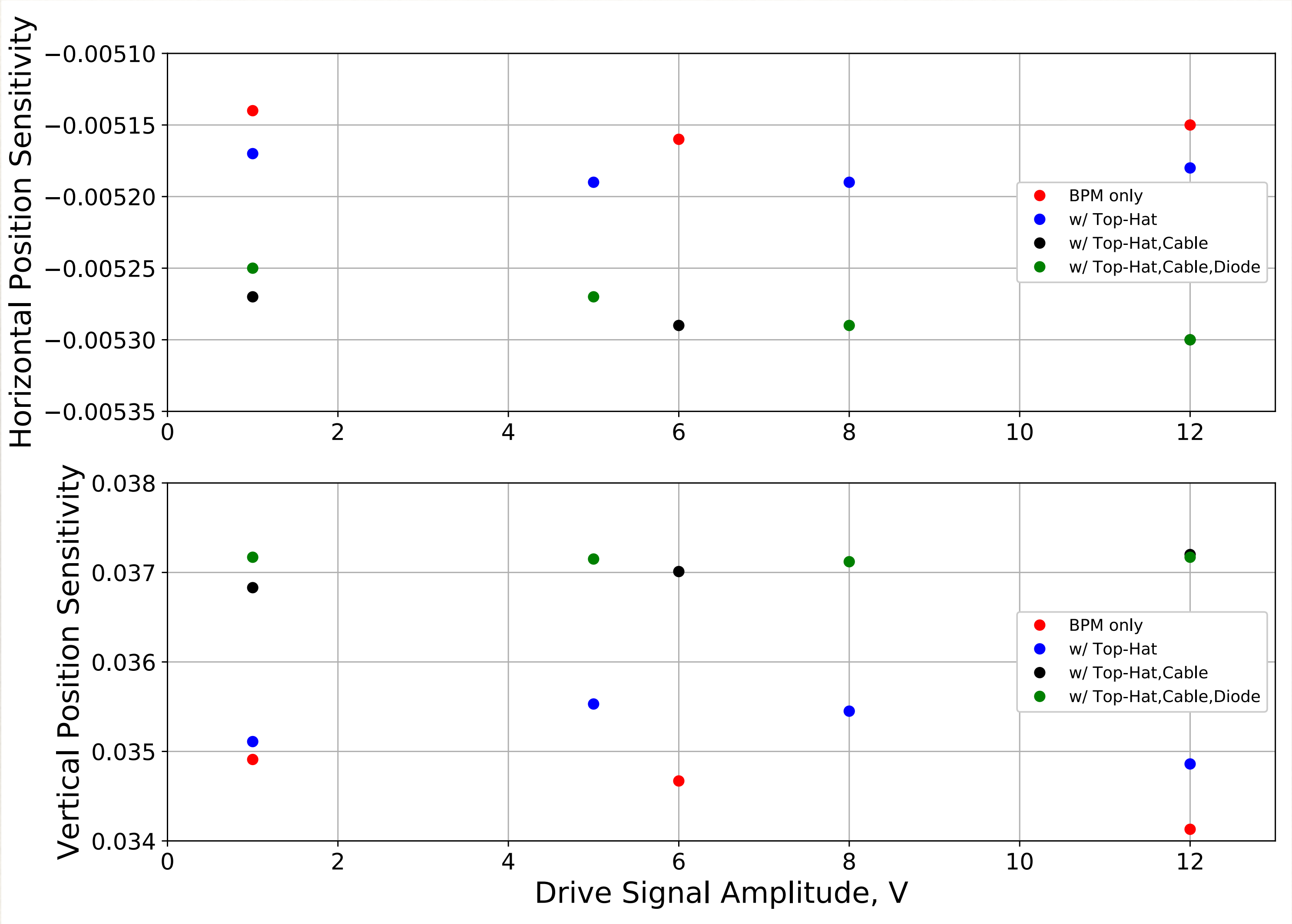
Linearity of Signal Amplitude with Drive Signal Amplitude

- When the pipe was at centre of BPM, the signal from horizontal electrode was measured.
- Averaged peak to peak signals were computed and plotted as a function of drive signal amplitude in the figure.
- <u>Measured signal amplitude shows good linearity with drive signal amplitudes for each set of measurement.</u>



Position Sensitivity with Drive Signal Amplitude

- Ideally position sensitivity should be consistent to the drive signal amplitude.
- As shown in the plot, the differences of position sensitivity with drive signal amplitudes are less than 1% in horizontal and within a few percent in vertical.



Signal Amplitude Reduction due to Long Cable Insertion

- Peak to peak signal (Fig.1) with 1m long cable is reduced by 47% comparing to the signal without cable as shown in the Fig.1. (pipe is in the centre of chamber)
- Position sensitivity changes a few percent with additional cables (Fig.2).

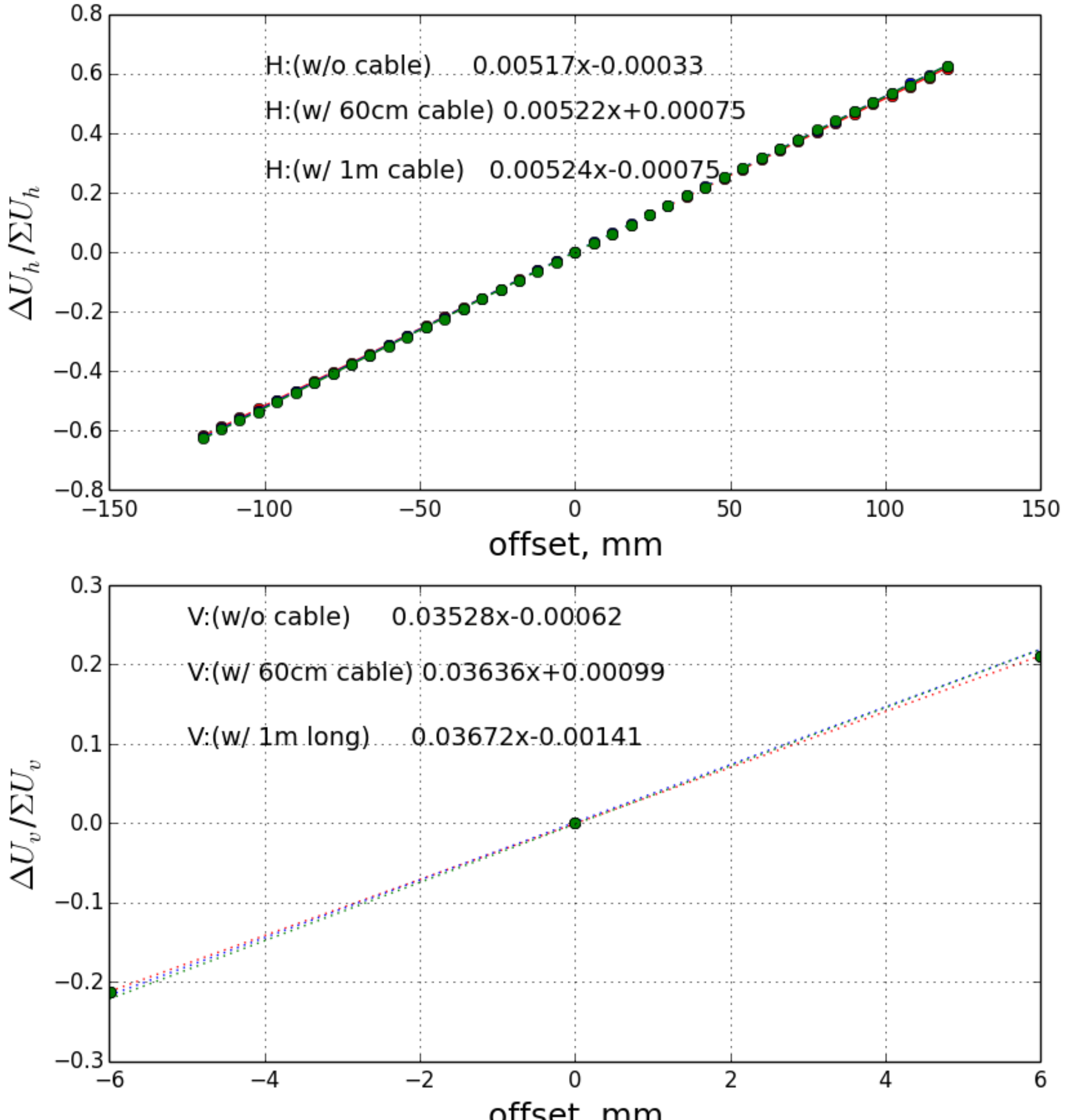
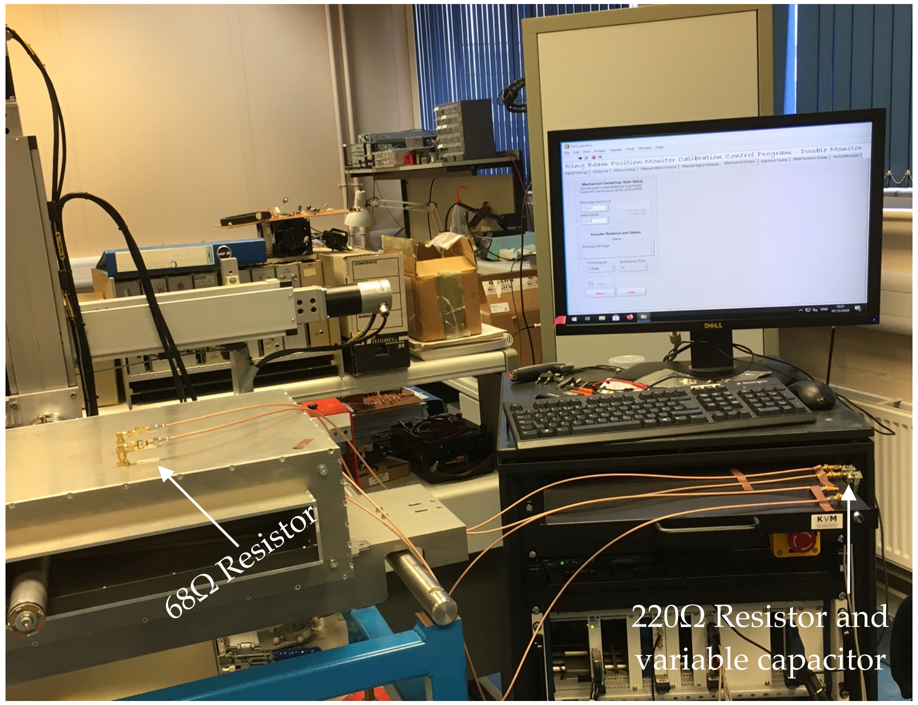


Fig.2 Position sensitivity



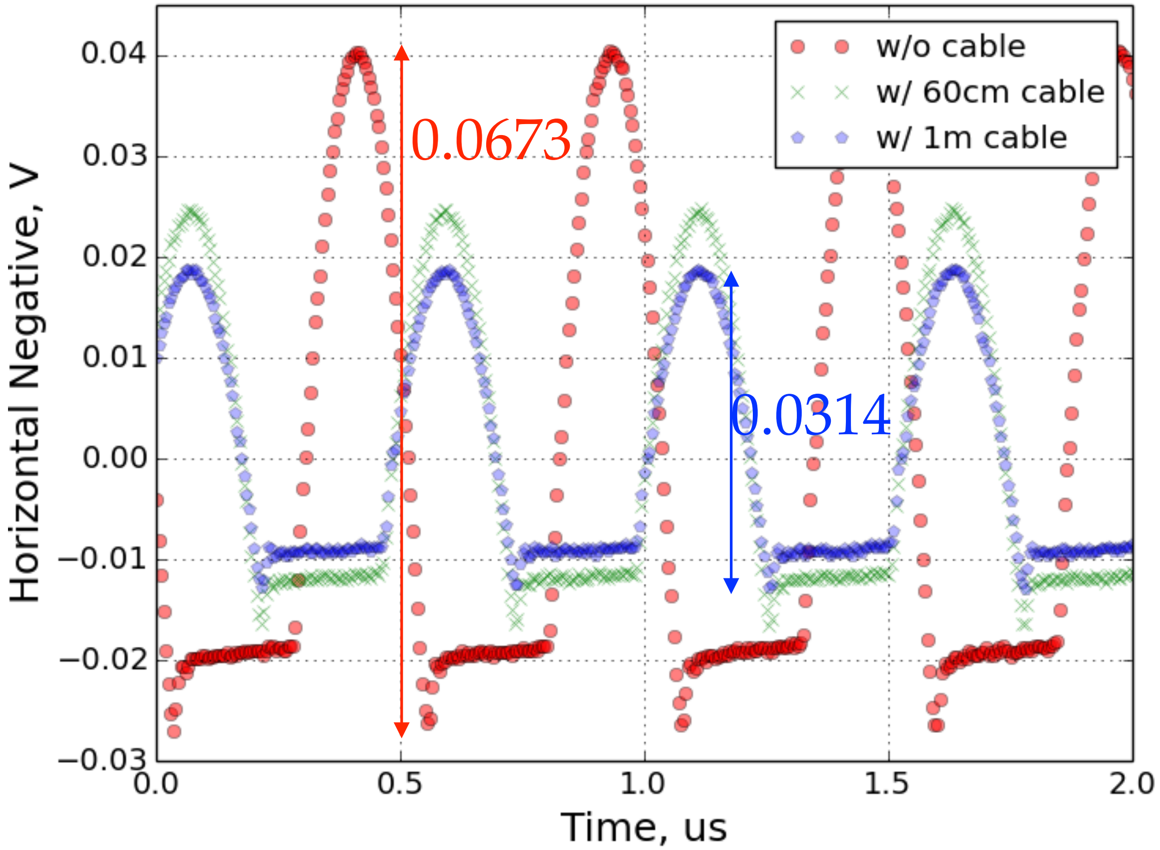
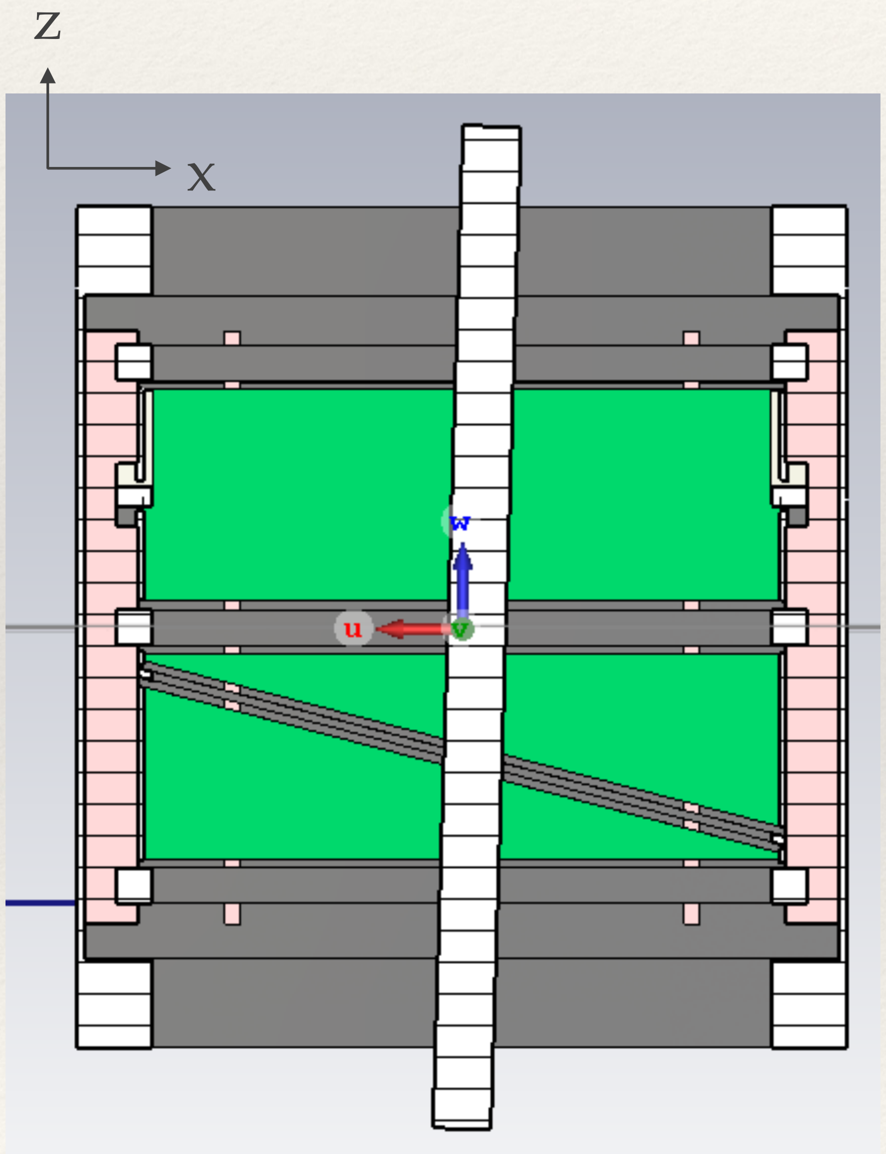
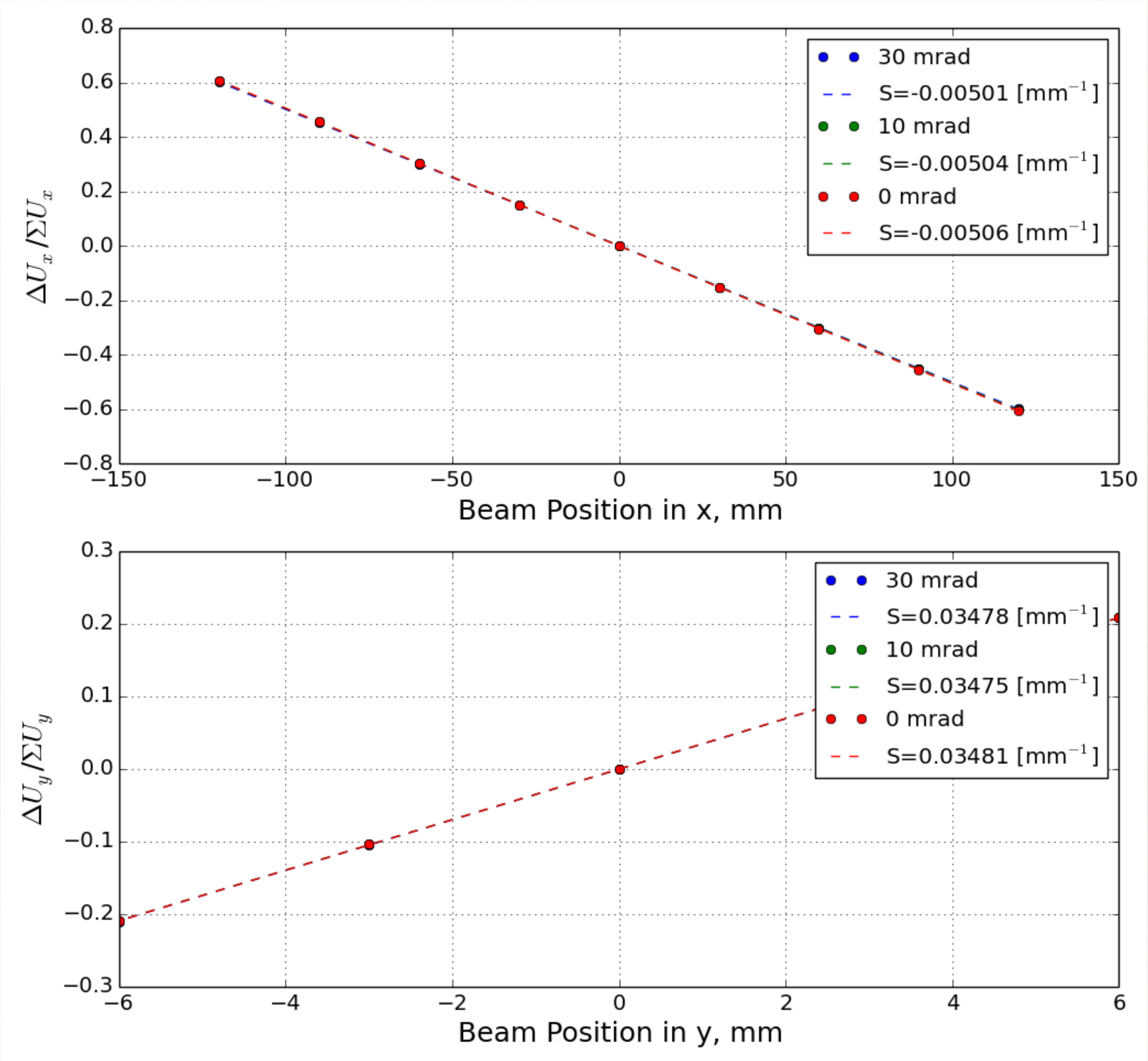


Fig.1 Signal from horizontal BPM electrode.

Position sensitivity with beam angle

- Position sensitivity is computed by CST with several beam angles: 0 mrad, 10 brad and 30 mrad in x direction.

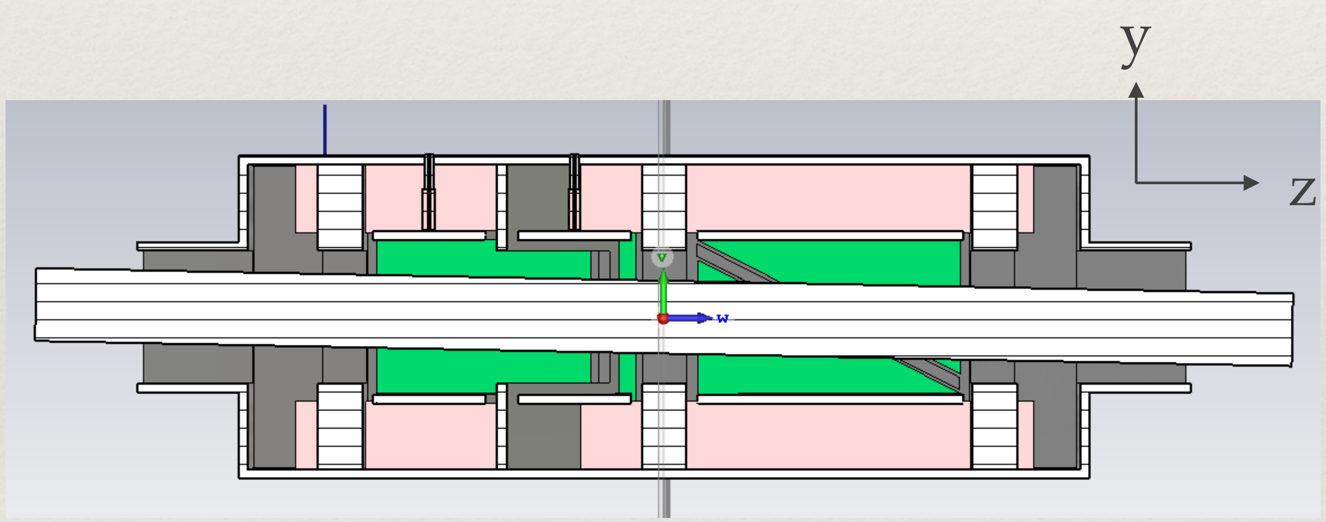


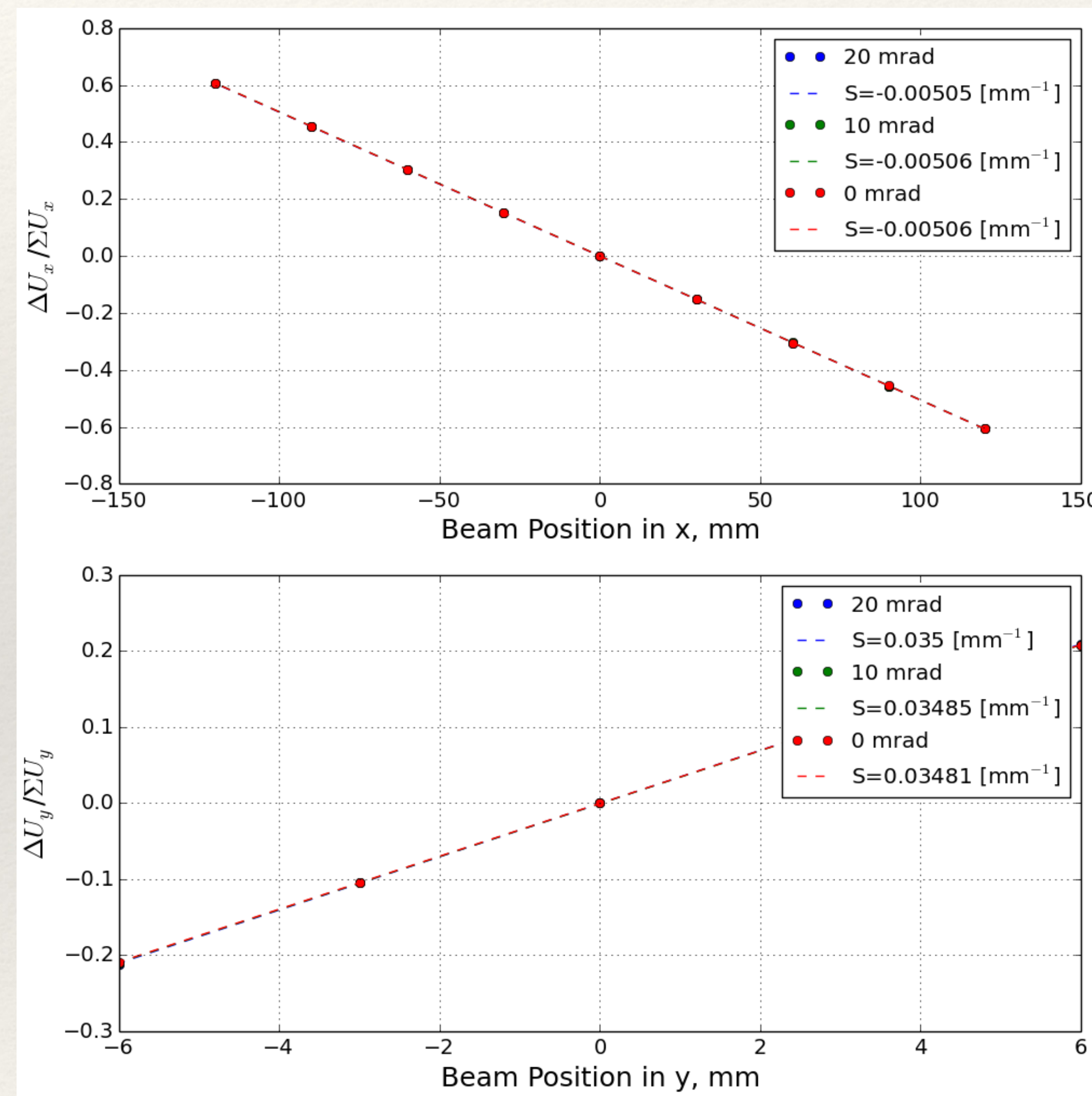


- Position sensitivity will be worse when the beam has an angle in BPM. Position difference in x direction will be a few mm when the beam has an angle of 30 mrad in BPM.

Position sensitivity with beam angle

- Position sensitivity is computed by CST with several beam angles in y direction: 0 mrad, 10 brad and 20mrad.





- Position sensitivity will be worse when the beam has an angle in BPM. Position difference in y direction will be less than 0.2 mm when the beam has 20 mrad angle in BPM.

Intrinsic Resolution Estimation

Theoretical intrinsic resolution is defined by

$$\text{resolution} = k_{\text{PU}}\frac{\sqrt{2}N}{2S} = \frac{k_{\text{PU}}}{\sqrt{2}}\left(\frac{S}{N}\right)^{-1}$$

$$v_{\text{noise}} = \sqrt{4kTR\Delta f}$$

k = 1.38 · 10−23 J/K (Bolzmann constant), T = 300 K (typical operating temperature), and R = 50 Ω (load impedance of the BPM electrode).

Ref: https://arxiv.org/pdf/2005.14081.pdf

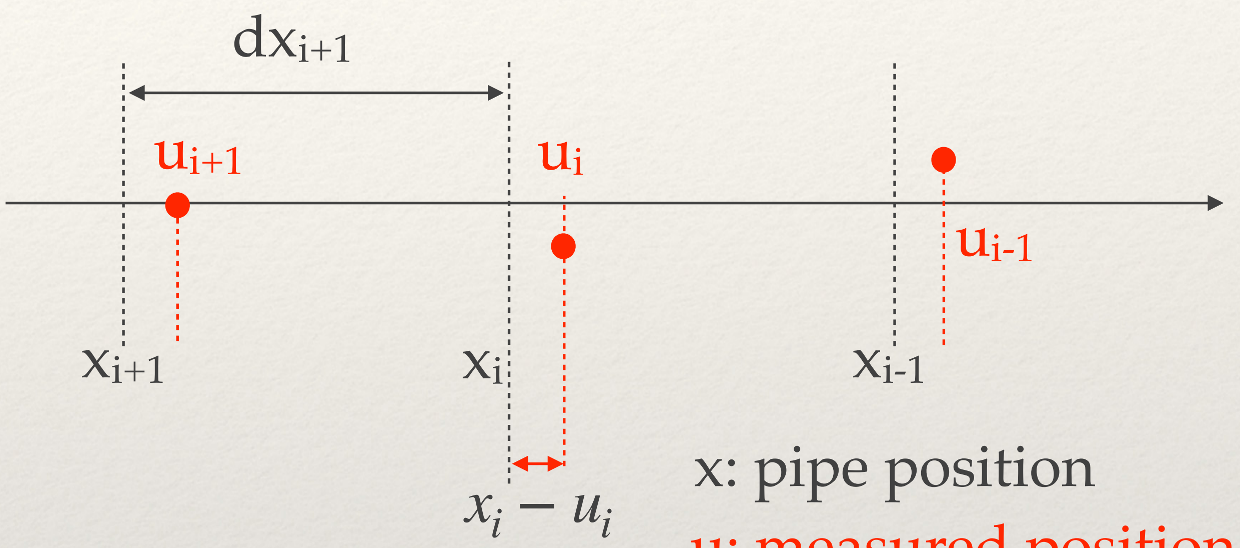
(K_{pu}^{h}, K_{pu}^{v}), mm @measured at Lab	(199, 29)
Δf	3.5 MHz (=500kHz - 4MHz)
(S_h,S_v), V @KURNS	(0.28, 0.38)
v_{noise} , uV	1.7
Resolution, um	**(0.85, 0.091)**

In reality, the resolution of whole set-up of BPM is lower than the intrinsic (best) resolution due to the noise of electronics and other accelerator components.

Measurement Accuracy and Resolution Estimation

1. Accuracy of measured position is estimated by the distance between pipe positions and measured pipe positions given by

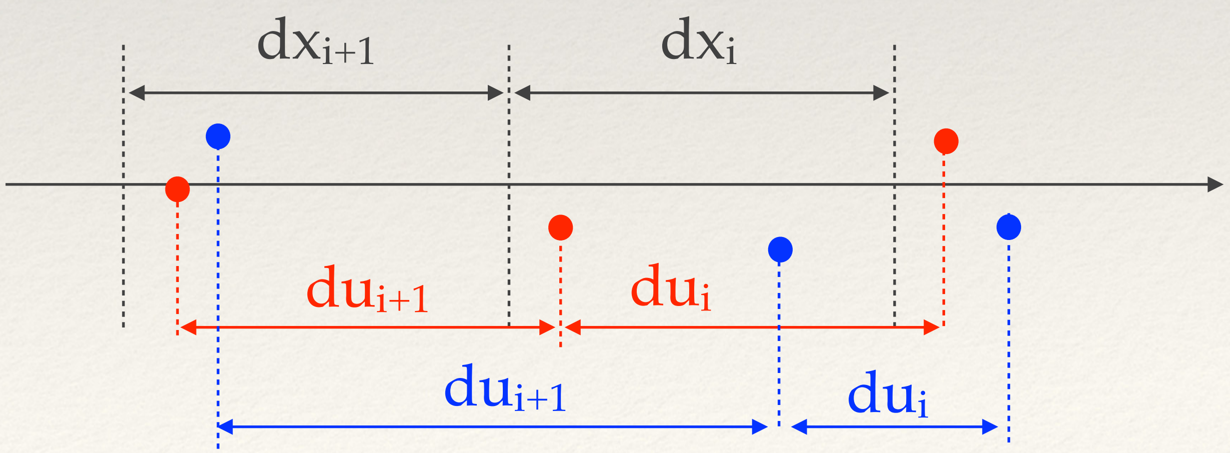
$$x_i - u_i$$



- If the accuracy is good, the mean value of distribution of $[x_i - u_i]$ will be zero and its σ (precision) will be narrow.

2. In this study, the resolution of monitor is defined by

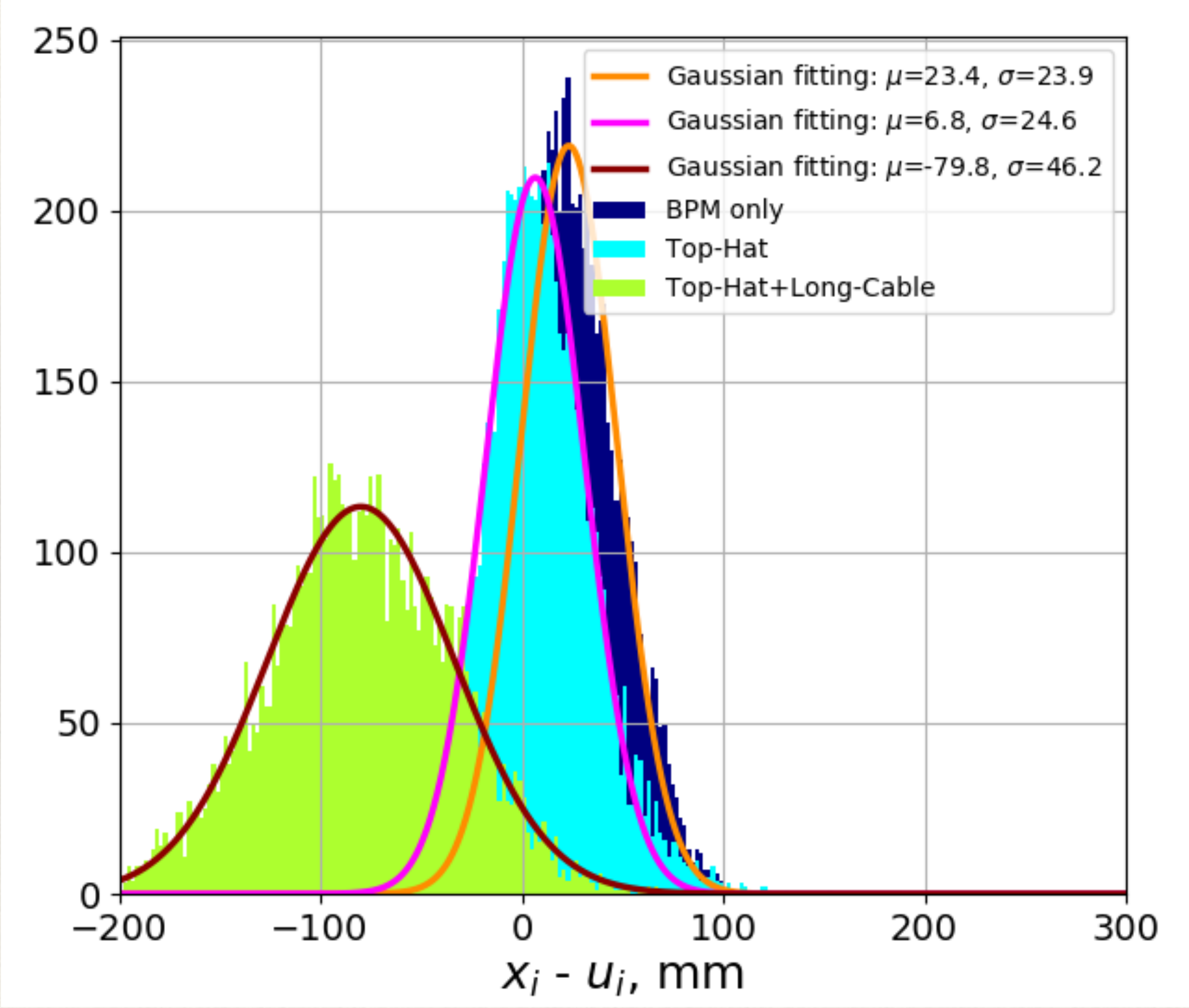
$$dx_i - du_i$$

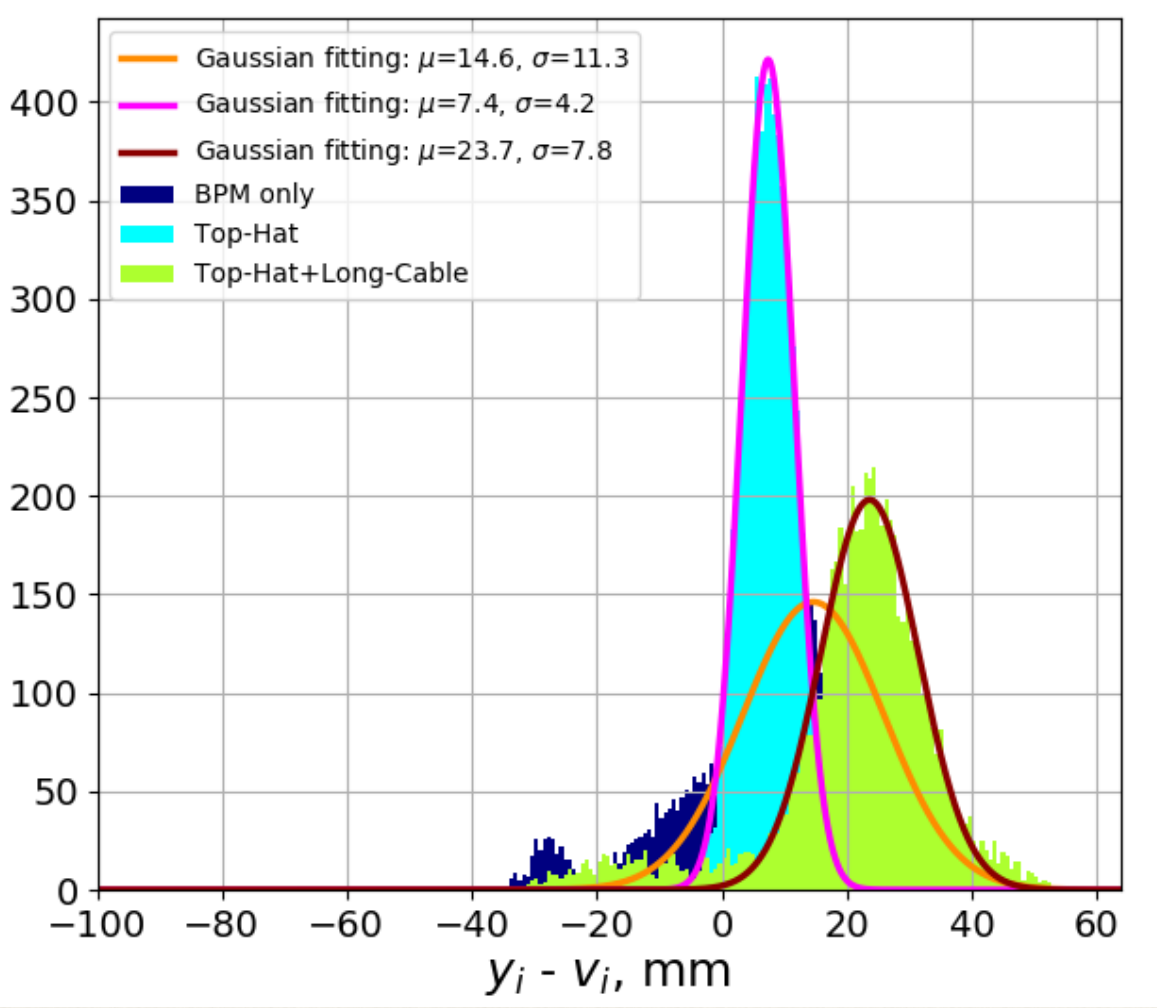


- If the resolution is good, the distribution of $[dx_i - du_i]$ will be narrow.

Accuracy and Precision Estimation of Monitor: 25um steps

Difference between pipe positions and measured pipe positions in x (left) and y (right) directions.

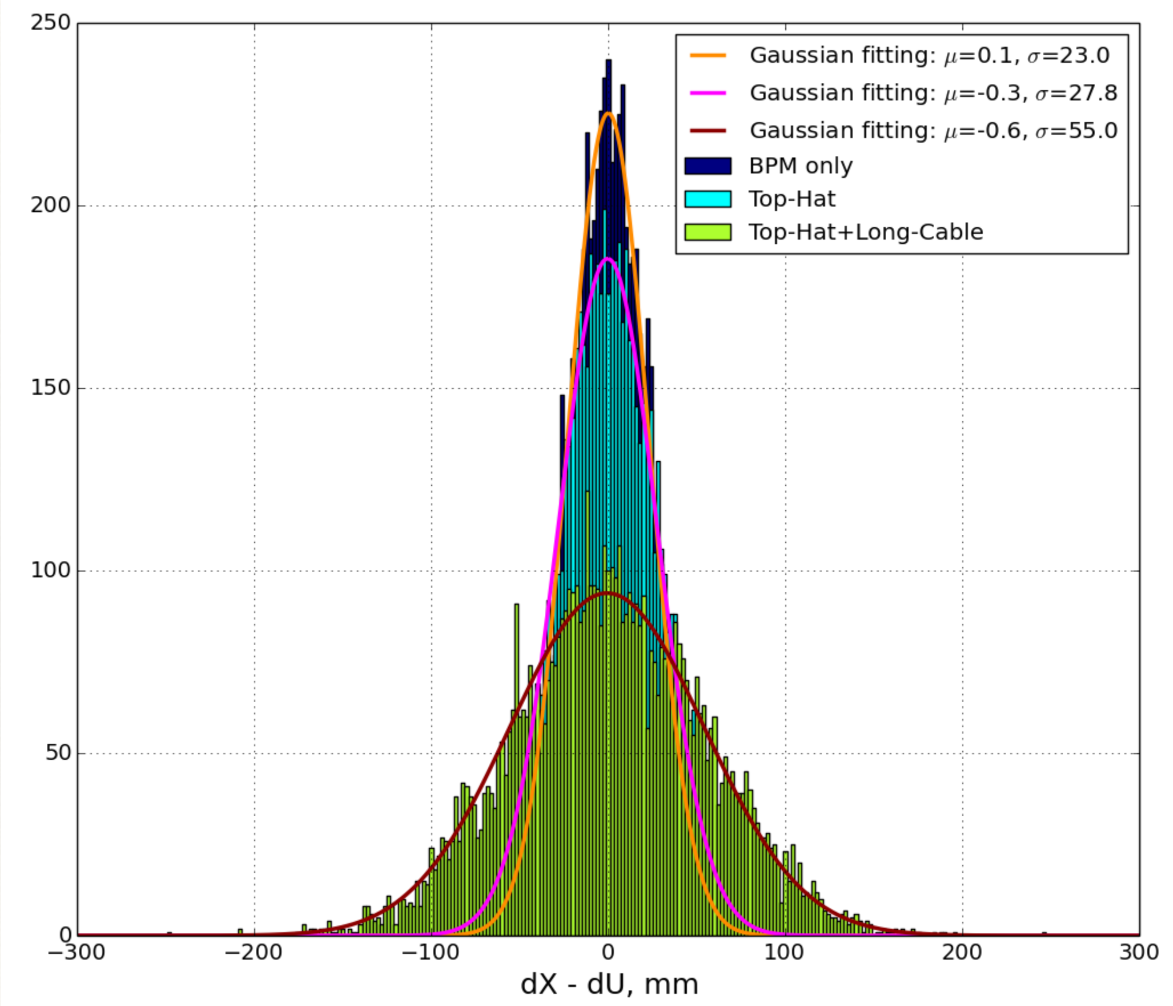


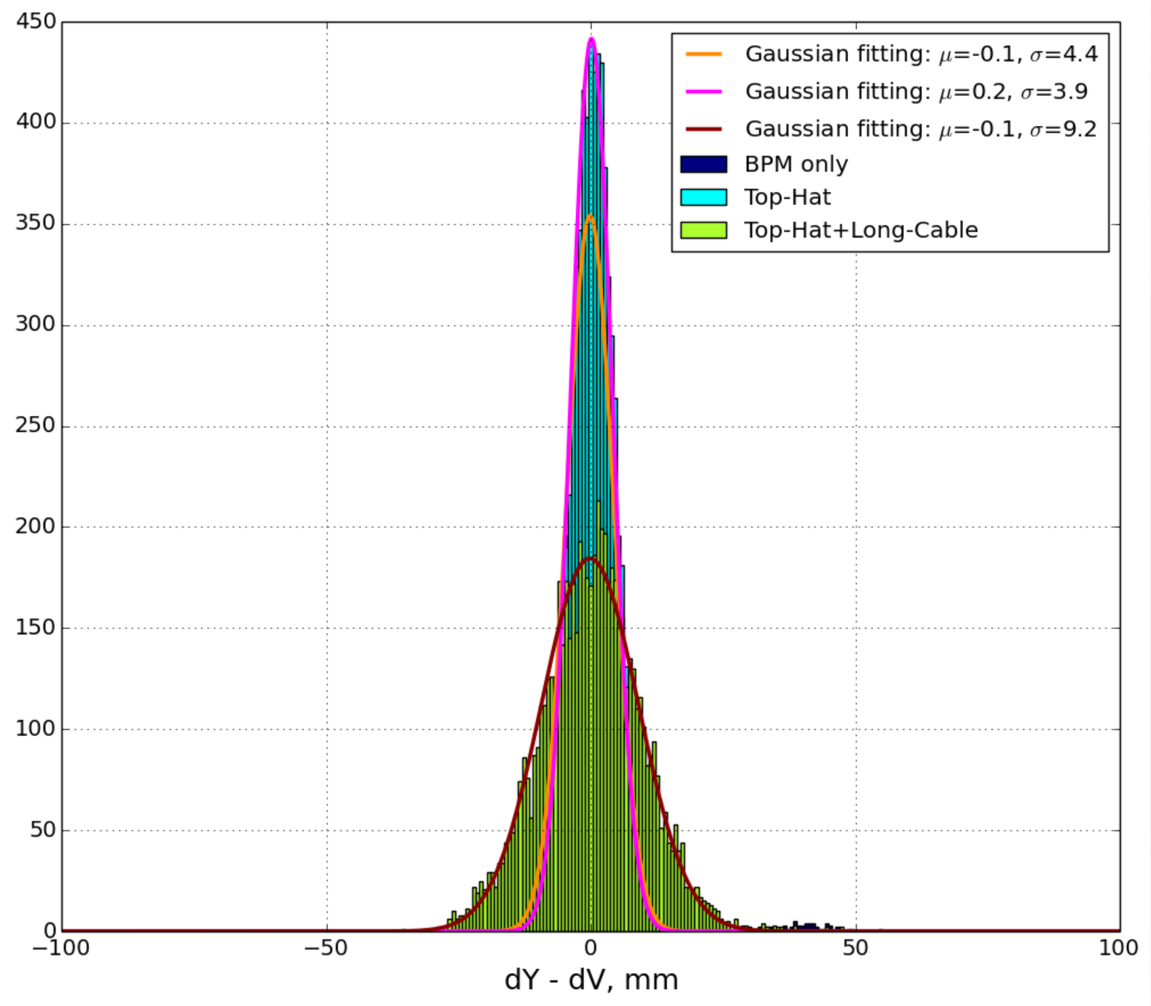


- Top-hat electronics improves measurement accuracy by adjusting unbalanced capacitances of each electrode.
- Precision becomes worse when the long cable is used, that is due to noise, lower signal etc.

Resolution Estimation : 25um steps

The $dx_i - du_i$ is plot in x (left) and y (right) directions. Distribution is wider when the cable is installed due to noise, lower signal etc.





The resolution is **25um or smaller in the best case scenario**, but it would get worse when it's installed in the real machine as the beam signal will be more noisy, likely weaker, and the electronics will get some noise from other components in the machine.

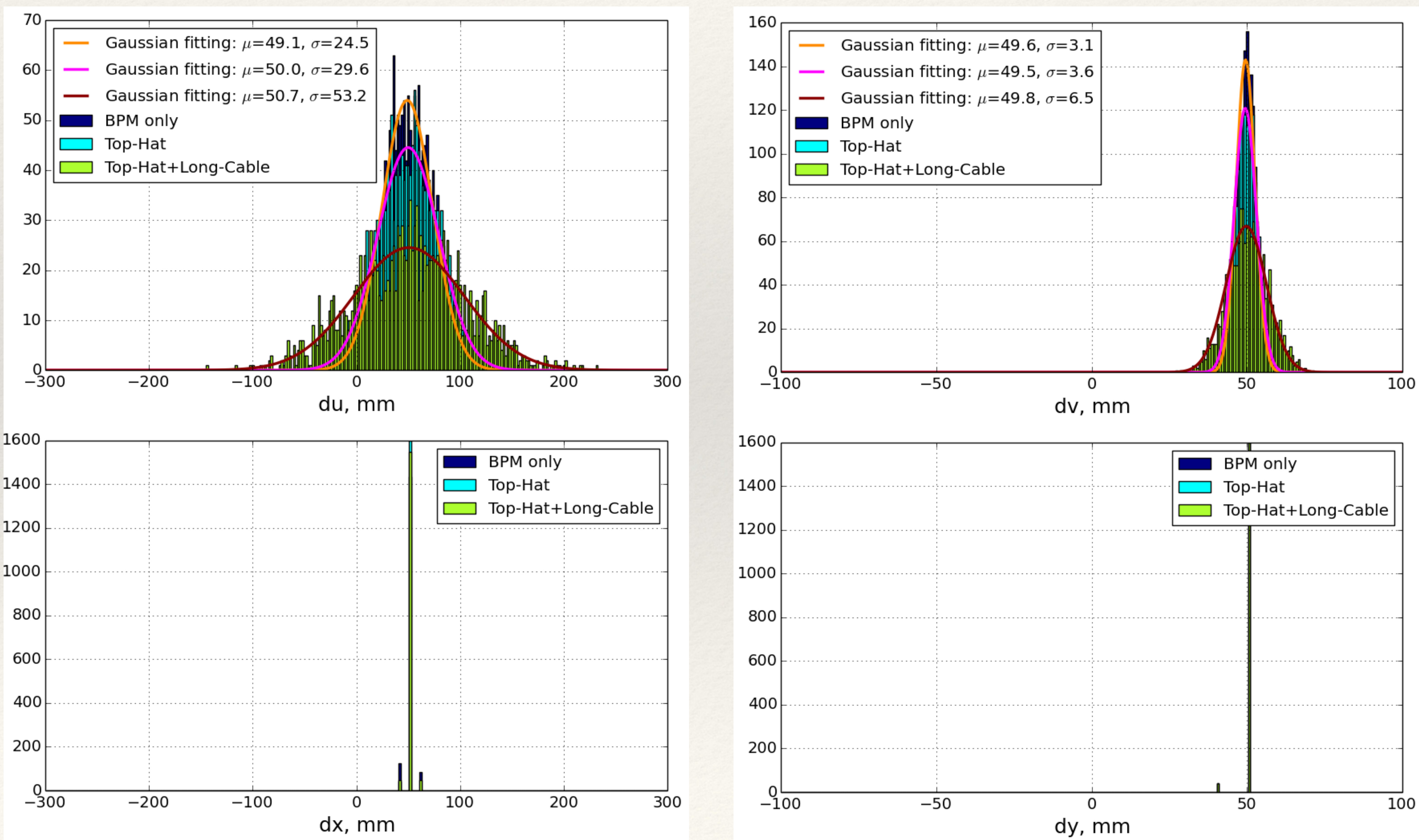
Resolution Measurements

- Once several BPMs are installed in FETS-FFA, the resolution of whole BPM system can be measured assuming the transfer matrix is known.
- Beforehand, we can test both methods in ISIS BPMs.

Backup slides

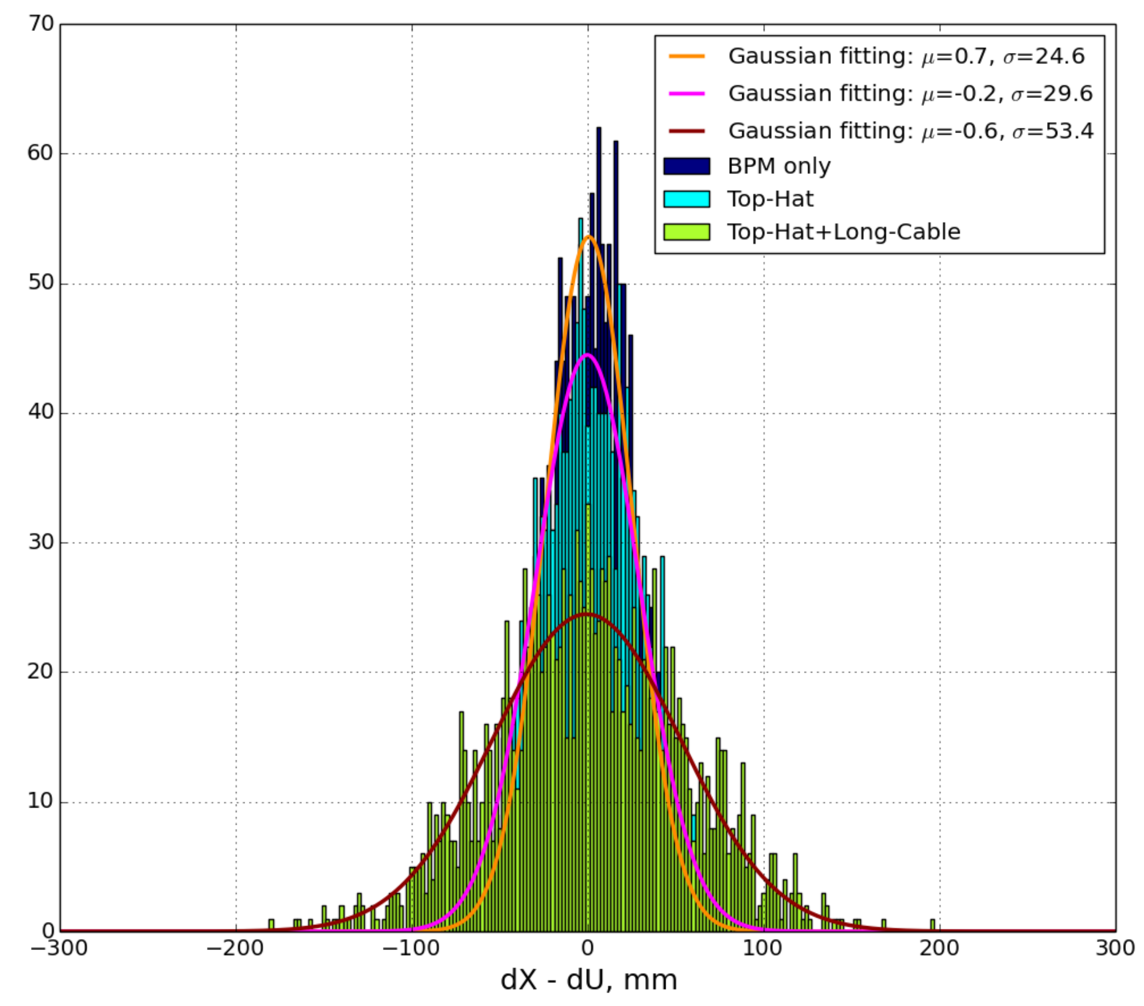
Resolution Estimation : 50um steps

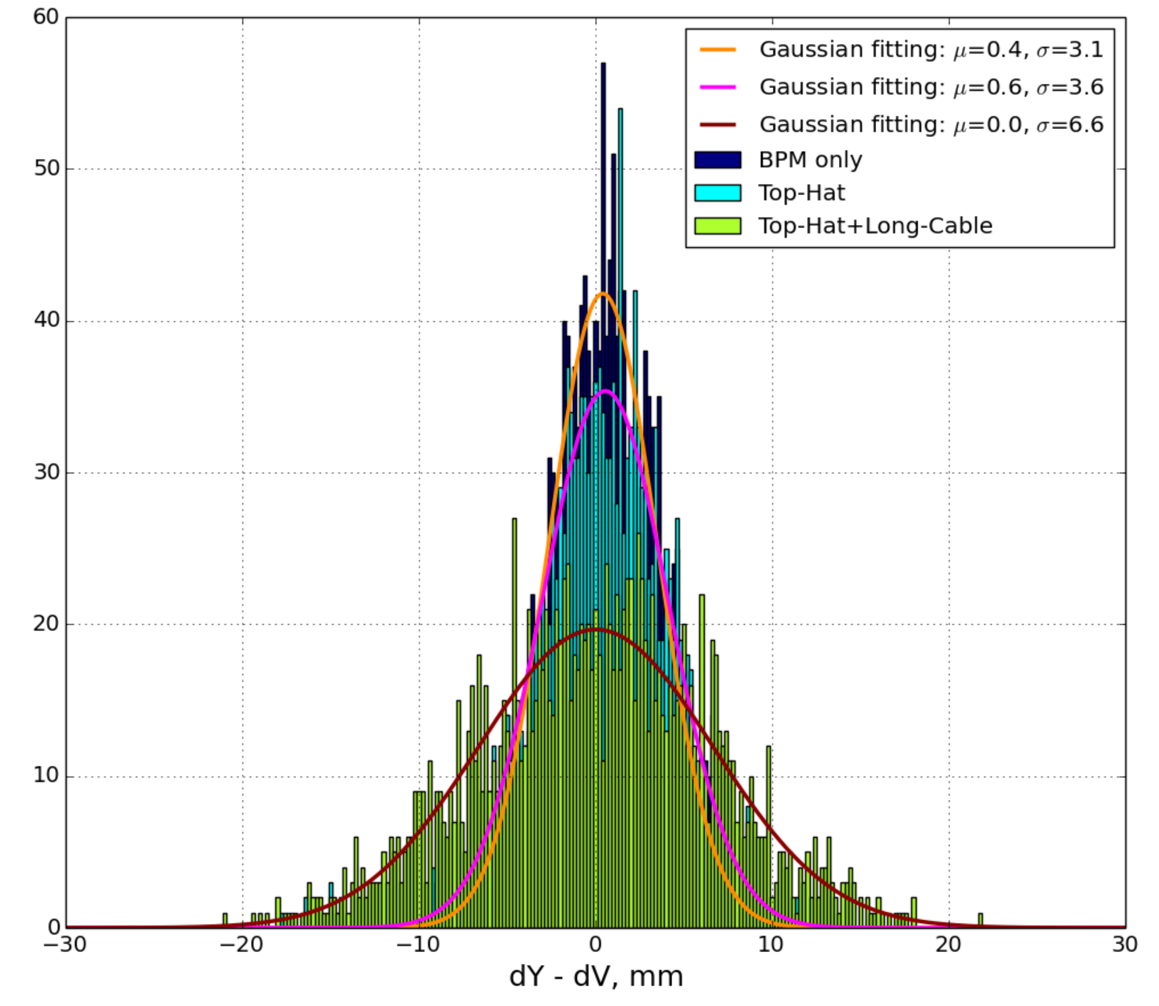
2. Distance between adjacent measured pipe position. Top: measured pipe position. Bottom: pipe position.



Resolution Estimation : 50um steps

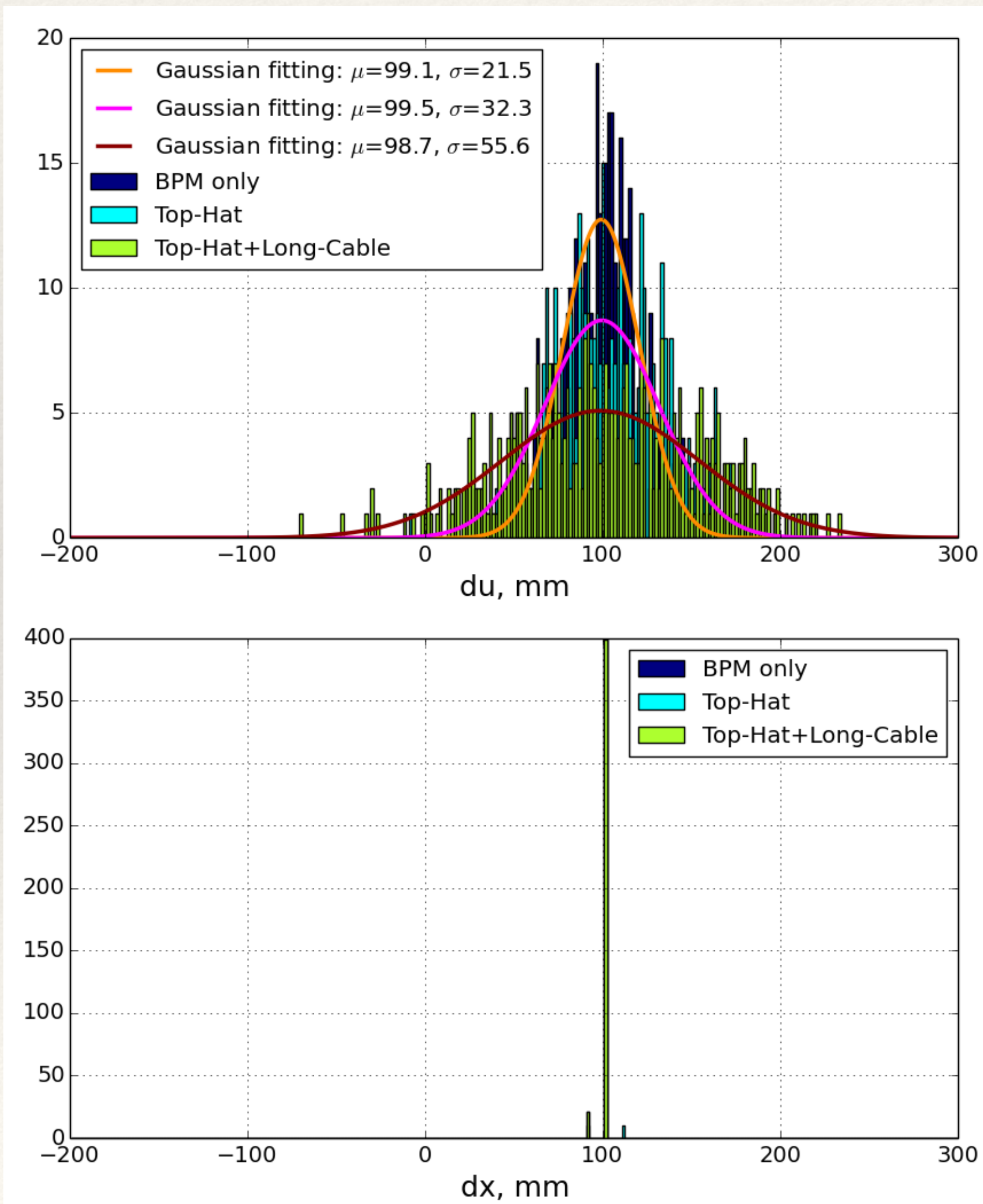
3. Resolution of measured pipe position.

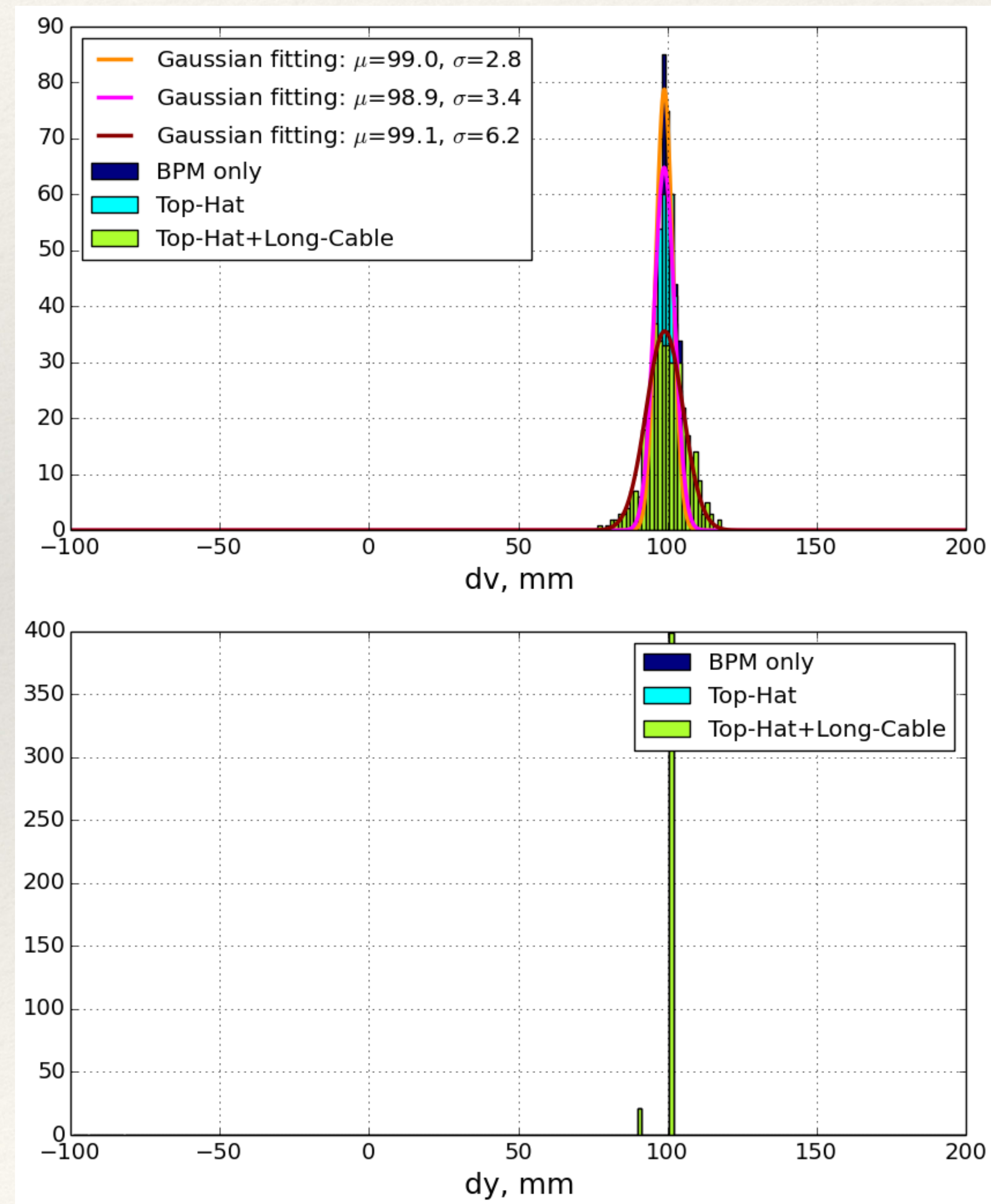




Resolution Estimation : 100um steps

2. Distance between adjacent measured pipe position. Top: measured pipe position. Bottom: pipe position.





Resolution Estimation : 100um steps

3. Resolution of measured pipe position.