KURNS meeting

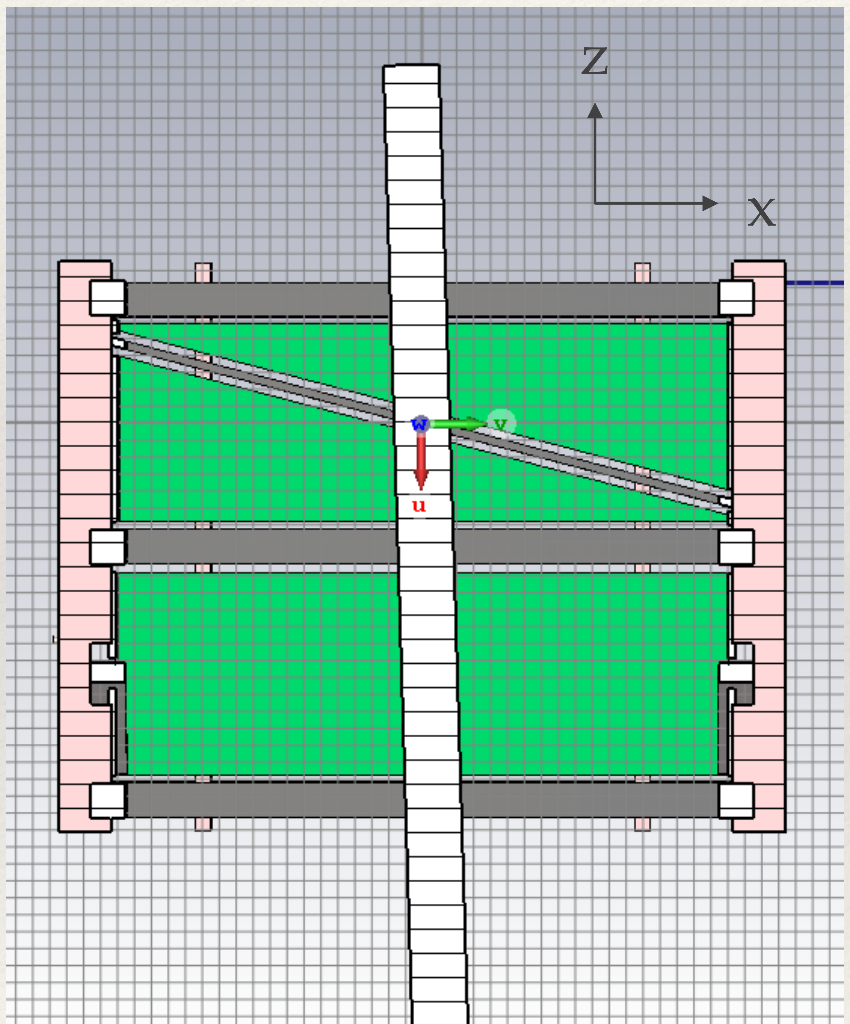
Prototype BPM & WSM

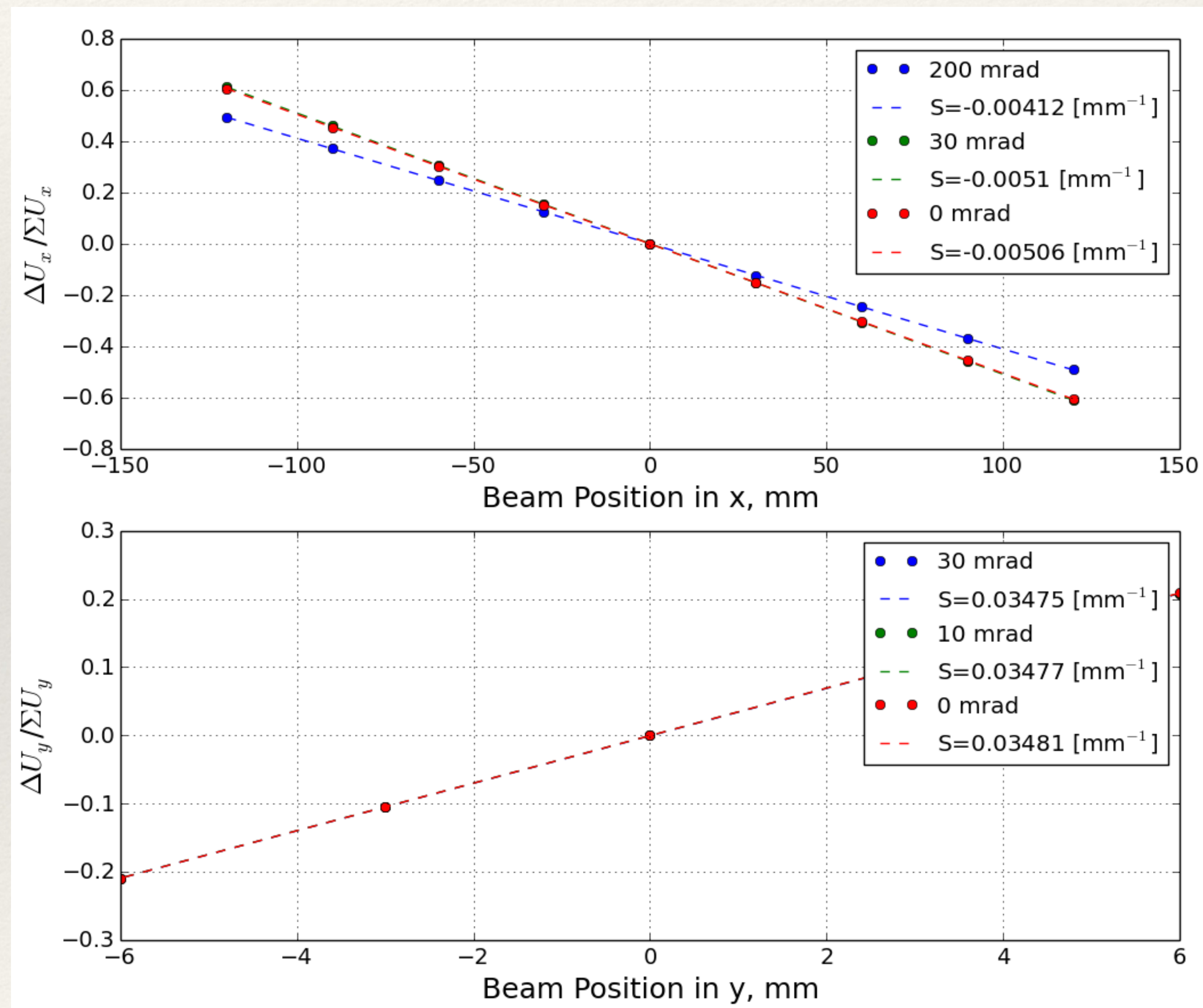
4. March. 2021

E. Yamakawa, A. Pertica, D. W. Posthuma de Boer

Position Sensitivity with Beam Angle

- Position sensitivity is computed by CST with several beam angles: 0 mrad, 30 mrad and 200 mrad in x direction.

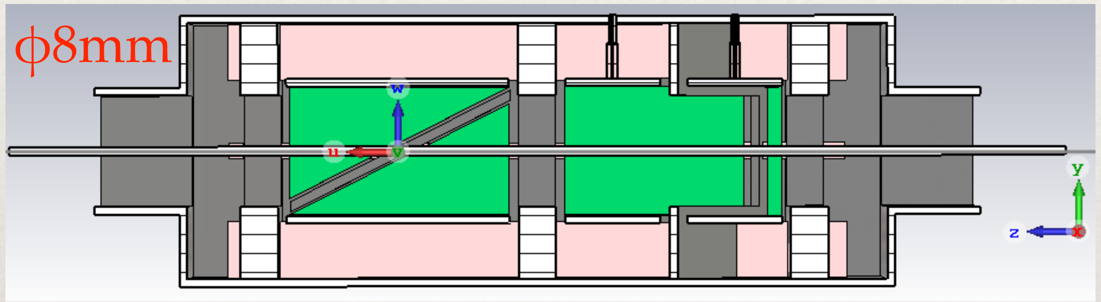


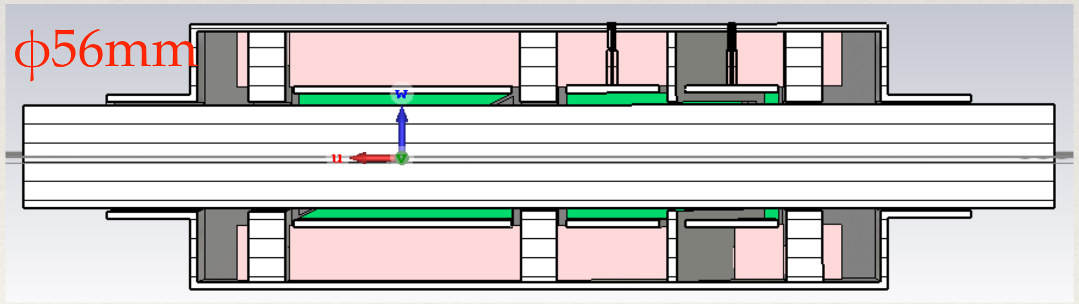


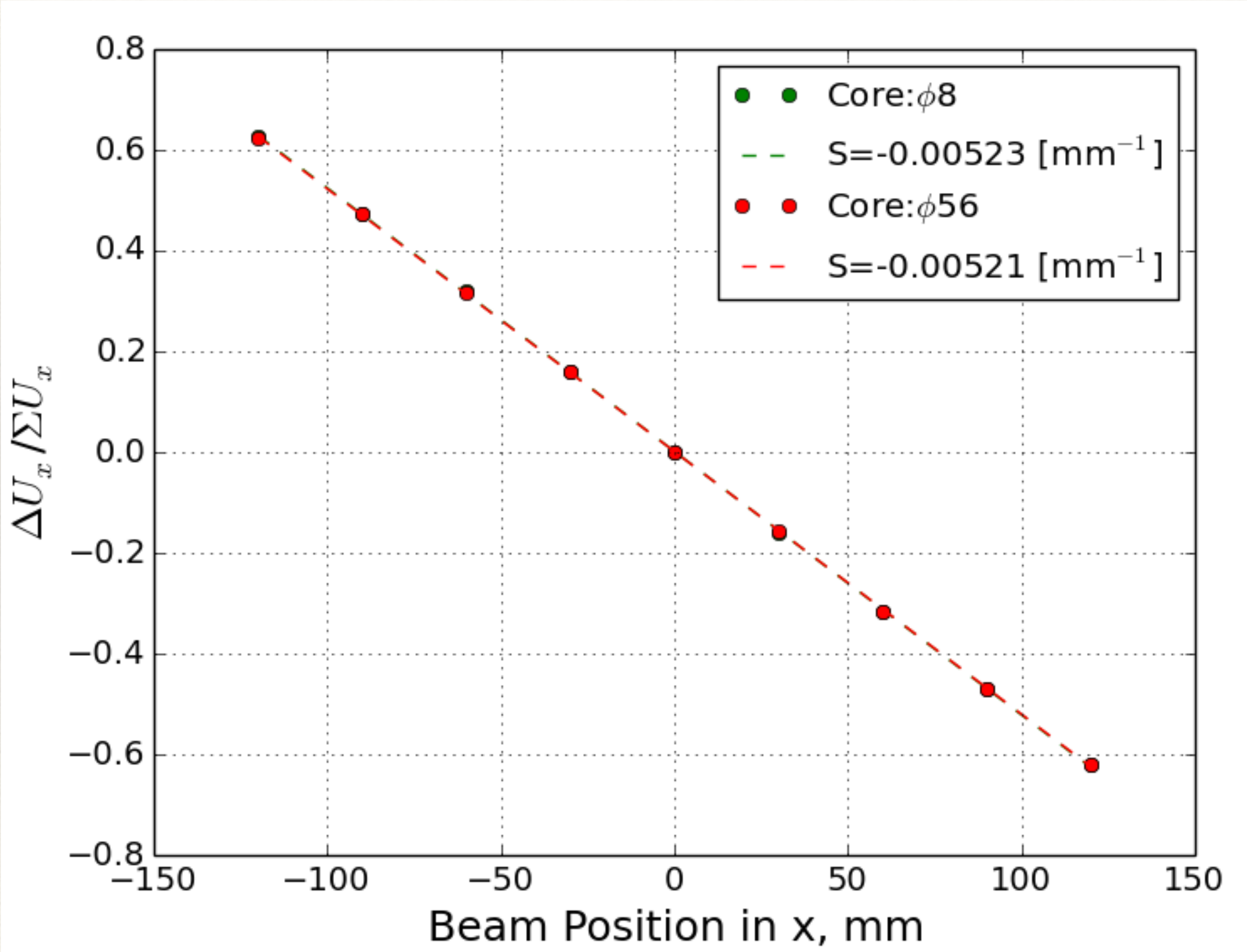
- Position sensitivities in x direction is decreased by 18.6 % when the beam is twisted by 200 mrad.

Position Sensitivity with Beam Size

- Position sensitivity is computed by CST Electro-Static Solver with several beam (probe) size: ϕ8mm and ϕ56mm. Electric charge (1.6e-19[C]x10[10][ppb]) is applied in the volume of the pipe.



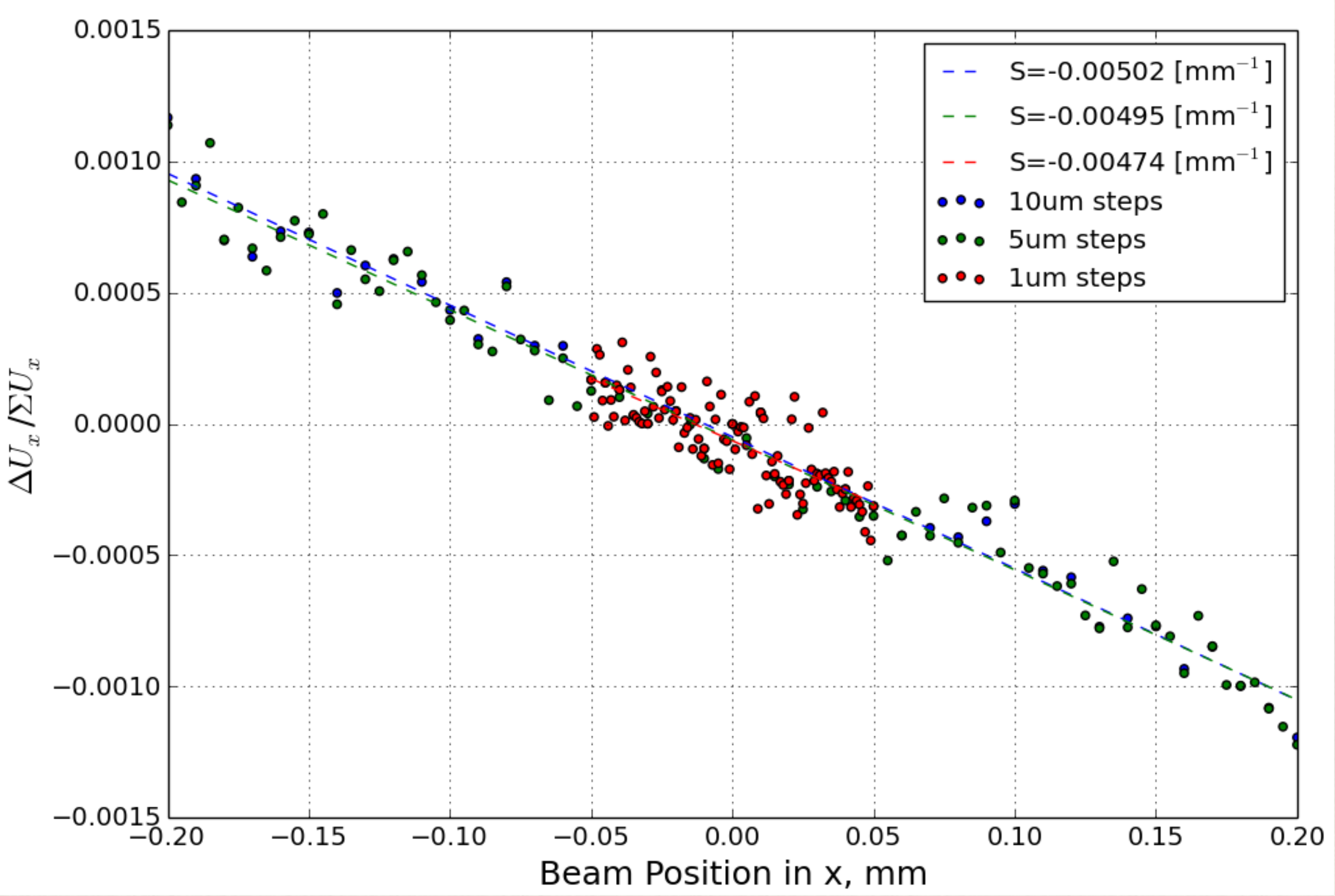




- Position sensitivity has not changed by beam size if the bunch charge is the same.

Position Resolution of Prototype BPM in CST

- Definition of resolution is "smallest possible difference in successive measurements".
- In CST, the probe position moves in x direction by 10 um, 5 um and 1 um steps and position sensitivity is computed.
- Position sensitivity is degraded by smaller pipe position steps, that is also depending on the mesh size in simulation. This degradation affects position 'accuracy'.
- We can still measure signal differences in position change of 1 um. <u>This means the prototype BPM has at least 1 um position resolution in CST.</u>



Intrinsic Resolution of Prototype BPM

Theoretical intrinsic resolution of BPM 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 = 220 kΩ (load impedance of the prototype BPM electrode).

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

(K_{pu}^{h}, K_{pu}^{v}), mm @measured at Lab with top-hat	(199, 29)
Δf	3.5 MHz (=500kHz - 4MHz)
(S_h,S_v), V @KURNS 30MeV	(0.28, 0.38)
v_{noise} , uV	123
Resolution of BPM, um	**(57, 6.0)**

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.

Ideal Resolution of prototype BPM at test rig in ISIS

- Measurement resolution of prototype BPM at test rig in the Lab can be estimated by theoretical ADC resolution and other source of errors. **<u>This is based on a single point measurement.</u>**

- Theoretical resolution of ADC is defined by

$$\text{Resolution } (\sigma_U) = V_{max}/2^N$$

N: number of ADC bit, V_{max}: maximum scale of ADC.

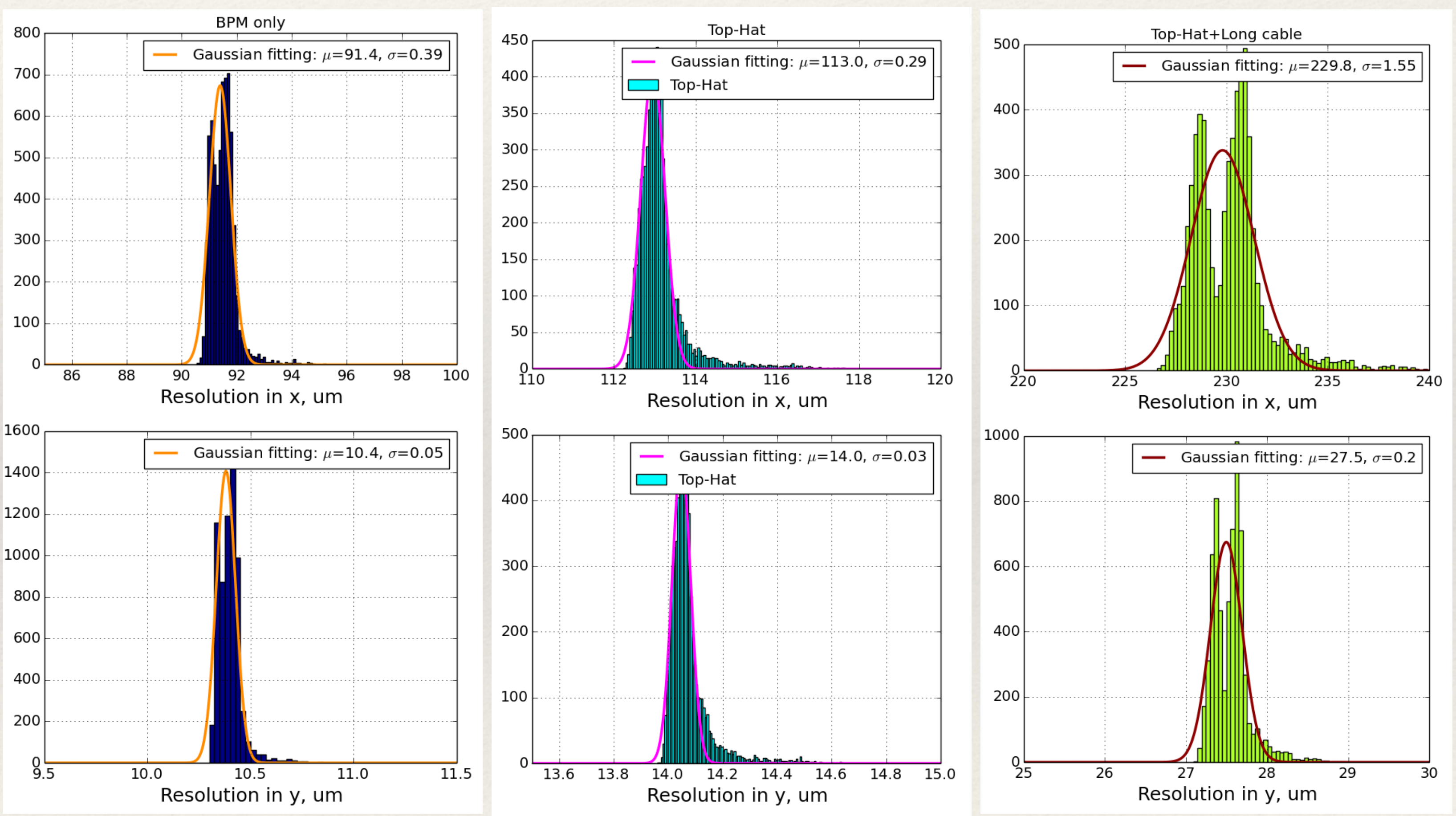
- In the case of test rig, theoretical resolution of ADC (σ_U) is <u>97.65 uV</u> with $N = 10$ and $V_{max} = 100$ mV.

- Theoretical resolution (σ_R) of prototype BPM at test rig is computed by error propagation as

$$f(U_1, U_2) = K\frac{U_1 - U_2}{U_1 + U_2} + \delta,$$

$$\sigma_R = |K|\sqrt{\left(\frac{\partial f}{\partial U_1}\right)^2 \sigma_{U_1}^2 + \left(\frac{\partial f}{\partial U_2}\right)^2 \sigma_{U_2}^2}$$

σ_{U1}: ADC resolution of one electrode, σ_{U2}: ADC resolution of the other electrode, assuming $\sigma_{U1} = \sigma_{U2} = 97.65$ uV.



<u>Theoretical resolution of prototype BPM is about 230 um in x direction (large aperture) and about 28 um in y direction (small aperture) at Lab test rig.</u>

WSM

- The test samples of ϕ10um and ϕ30um CNT wires as well as 3um thickness of CNT foil are provided by Hitachi Zosen and delivered at KURNS for beam test.

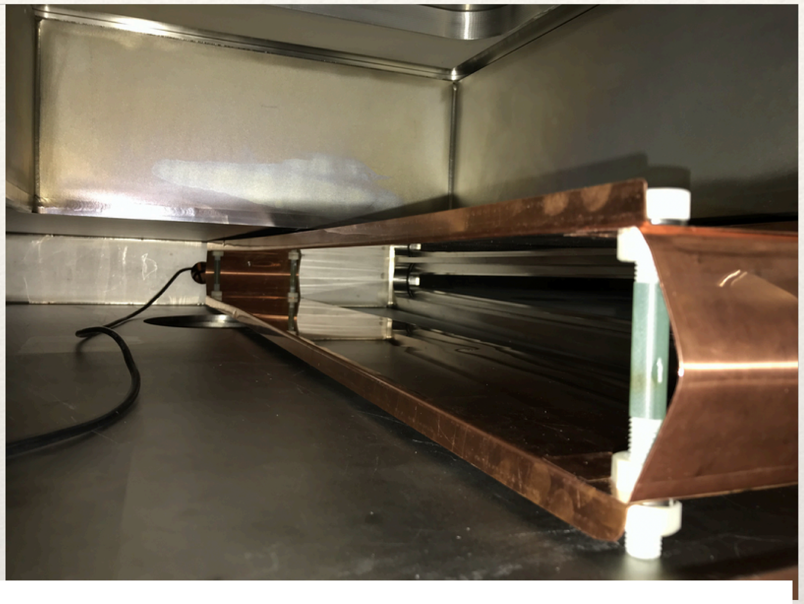
- The aim of this test is to decide which CNT wires we should purchase from the company. For this purpose, ϕ10um and ϕ30um CNT wires are installed in the KURNS main ring and see if
  - significant beam loss happens,
  - the wire is broken by beam induced heat-up.

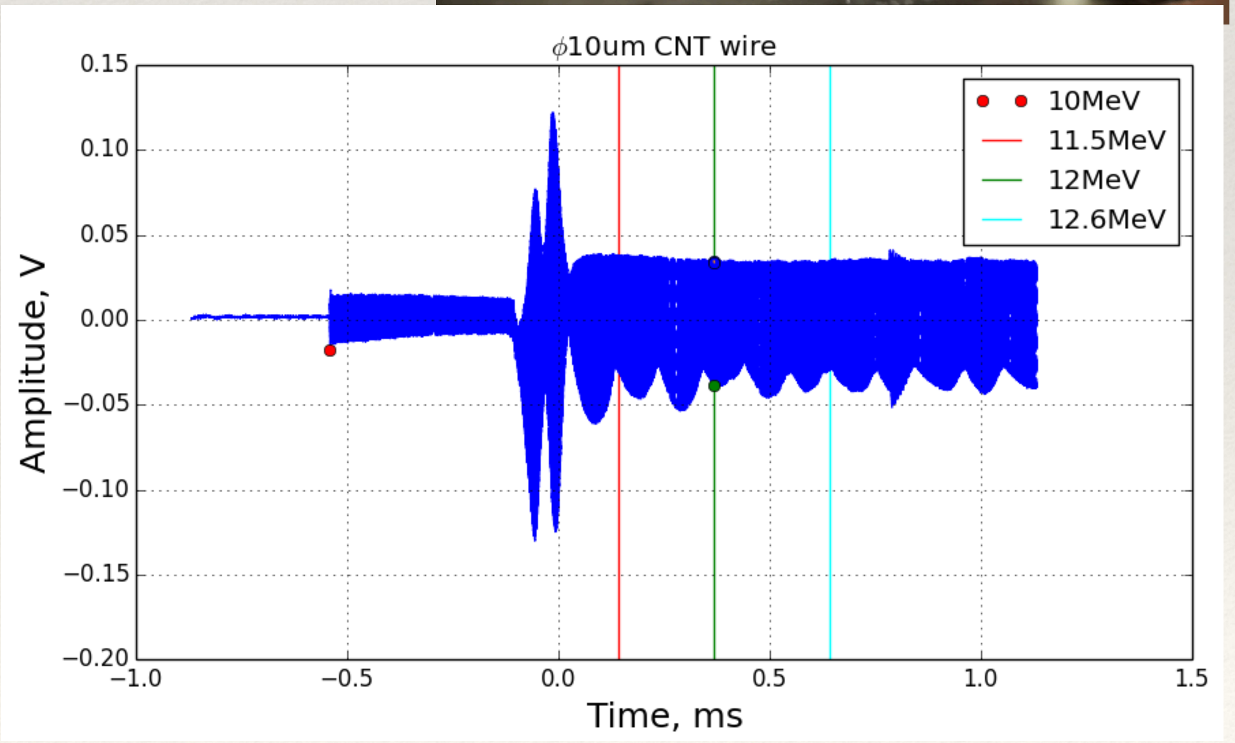
CNT Wire Test

- Samples of ϕ10um and ϕ30um of Carbon Nano Tube (CNT) wires are at KURNS from Hitachi Zosen Cooperations.
- ϕ10um CNT wire was installed at 12 MeV orbit in KURNS Main Ring on 26th February.
- The wire is attached on the foil frame (right picture) by aluminium tape.
- Proton beam was irradiated at the wire for 10 minutes.

BPM signal with ϕ10um CNT wire

- Bunch signal was measured by Full aperture BPM (FAB) as shown in the right picture.
- Average beam current can be estimated by calibration coefficient [1] over the range of acceleration.
  - I_{ave}=245pA @11.5MeV
  - I_{ave}=236pA @12MeV
  - I_{ave}=239pA @12.6MeV
- **Significant beam loss is not visible even when the wire is installed.**





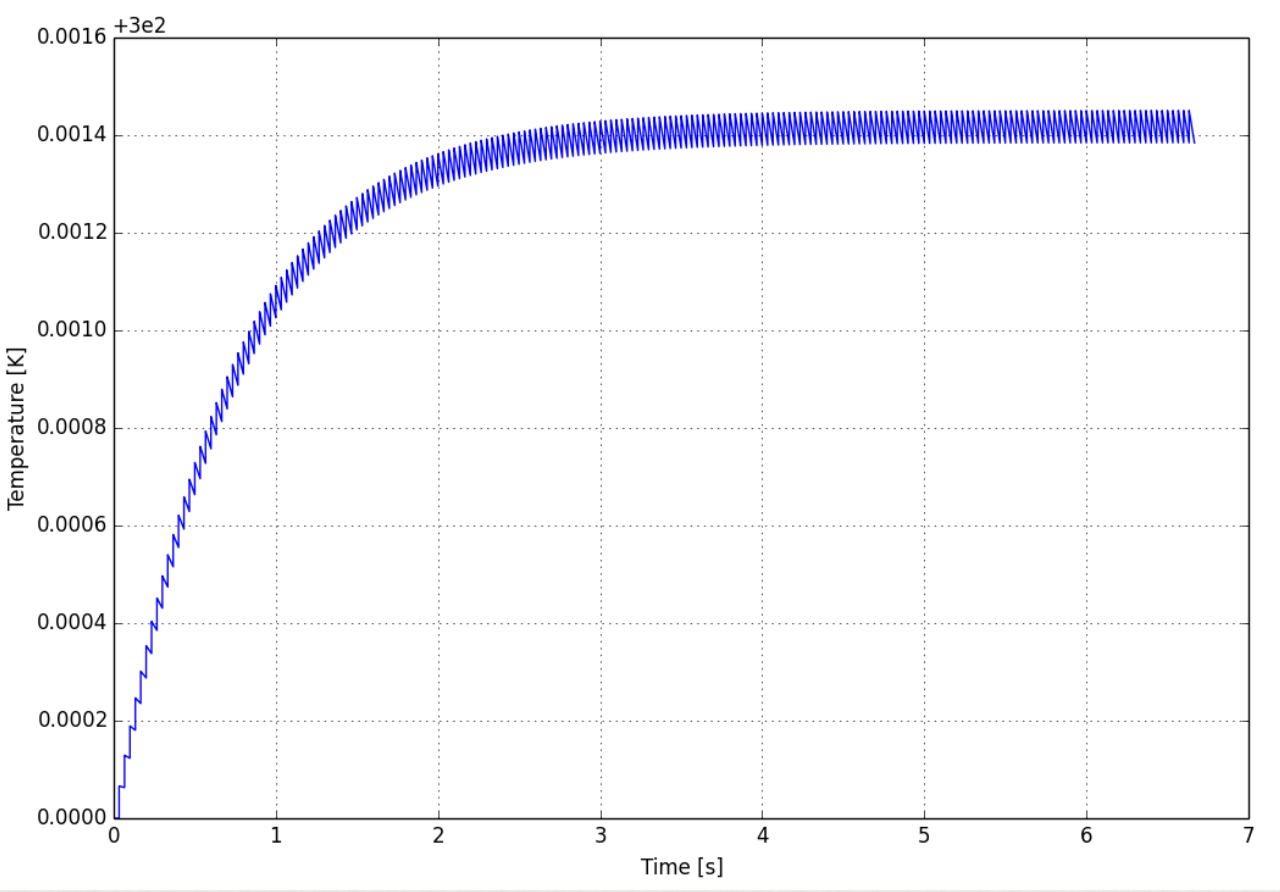
[1] doi:10.18429/JACoW-IPAC2019-WEPGW040

Ib = Iave / 30 / 300ns

Thermal analysis

Parameters used in this simulation

Wire diameter [um]	10
Emissivity ε	0.6
Spec heat capacity C_p [J.kg/K]	750
Density ϱ [g/cm³]	1.4
Wire length where the beam hits l [mm]	10
dE/dx (computed by SRIM) @12MeV	0.4967 (ϕ10um)
Number of bunches interacting the wire (N)	219 turns
Bunch length (Tb)	300 ns
Pulse period Tp = Tb x N	65.7 us
Peak bunch current (from I_{ave})	26.2 nA
Repetition rate	30 Hz



- The temperature on the wire is negligible as beam current is very small at the test.
- The wire was not broken and it seemed that any damages have not seen on the wire.

Summary

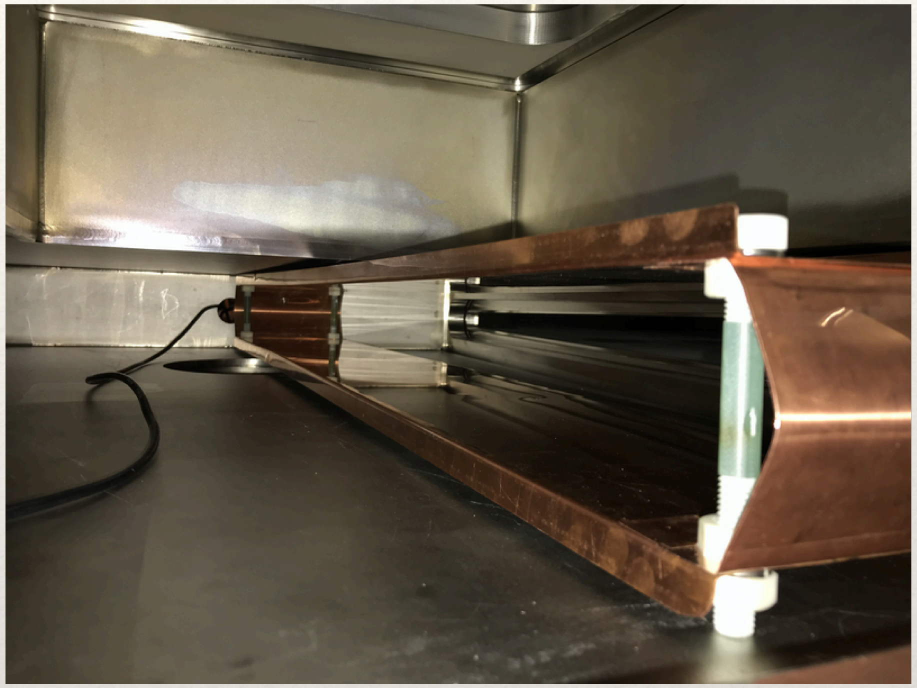
- If the beam is twisted by a few tenth of mrad, the position sensitivity will be the same. However, when the beam angle is 200 mrad (maximum expected at FETS-FFA) in x direction, the position sensitivity will be degraded by 18.6% at prototype BPM.
- When the beam size is close to the chamber acceptance, the position sensitivity will drop from CST Electro-Static Solver simulation.
- The intrinsic resolution of prototype BPM is estimated by **60 um in x direction and 6 um in y direction in the best case scenario at current prototype BPM system in the lab test** (220 kΩ loaded resistance on prototype BPM).
- The resolution of prototype BPM is also estimated by theoretical ADC resolutions, and **it is 230 um in x direction (large aperture) and 28 um in y direction (small aperture)**. This is based on a single point measurement in the lab test. We have to think about the resolution measurement of prototype BPM when it is installed at KURNS machine. As for FETS-FFA BPM, the resolution of whole system will be measured by nominal resolution measurement techniques (three BPM methods, PCA etc).
- ϕ10um CNT wire was installed at 12 MeV orbit in KURNS main ring. The beam was accelerated over the cycle with ϕ10um CNT wire and there was no critical damage on the wire.

BPM (FAB) monitor

- Capacitive electrostatic pickup (BPM) is used to estimate beam current over whole acceleration cycle.
- Average beam current is estimated by

$$\tilde{I} = f_{\rm rep} \times \int I_p \, {\rm d}t$$

$$= 50.32(nA/Vs) \times \frac{v}{c} \times \int_{\rm rf-cycle} V \, {\rm d}t$$



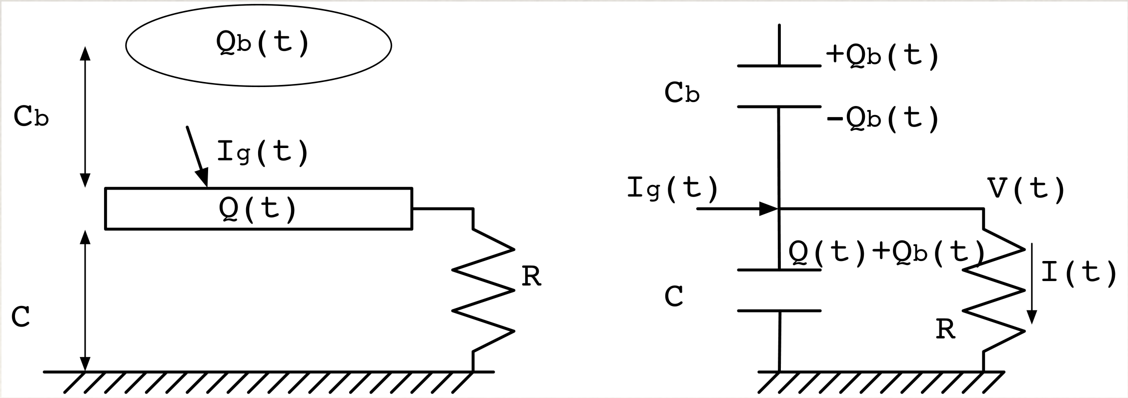


Figure 3: Equivalent circuit.

Thermal analysis

Orbit energy of wire location	12 MeV
Beam size (σ)	5 mm
Orbit excursion to move off the wire	10 mm
Energy range to move off the wire	11.784 - 12.22 MeV
Turn separation	46 um
Number of bunches interacting the wire (N)	219 turns
Bunch length (Tb)	300 ns
Pulse period $T_p = T_b \times N$	65.7 us
Peak bunch current (from I_{ave})	26.2 nA
Repetition rate	30 Hz