3 June 2021, KURNS meeting

Progress of BPM and WSM

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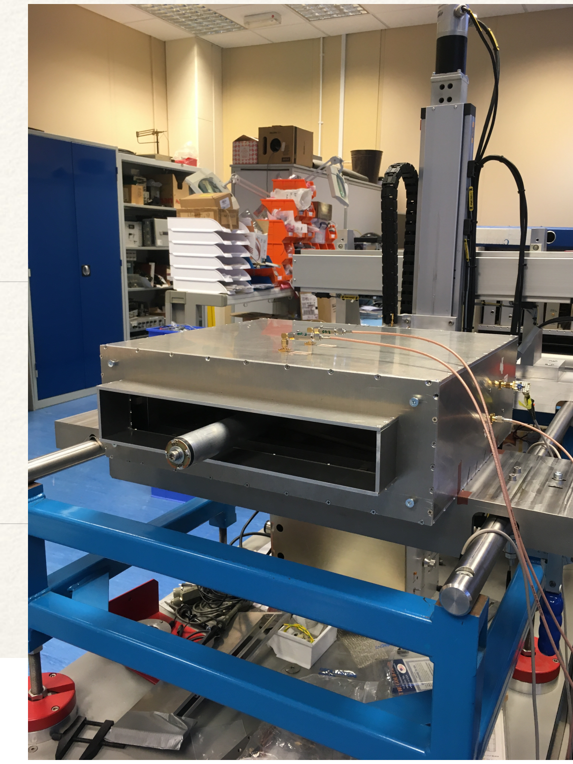
prototype FFA BPM



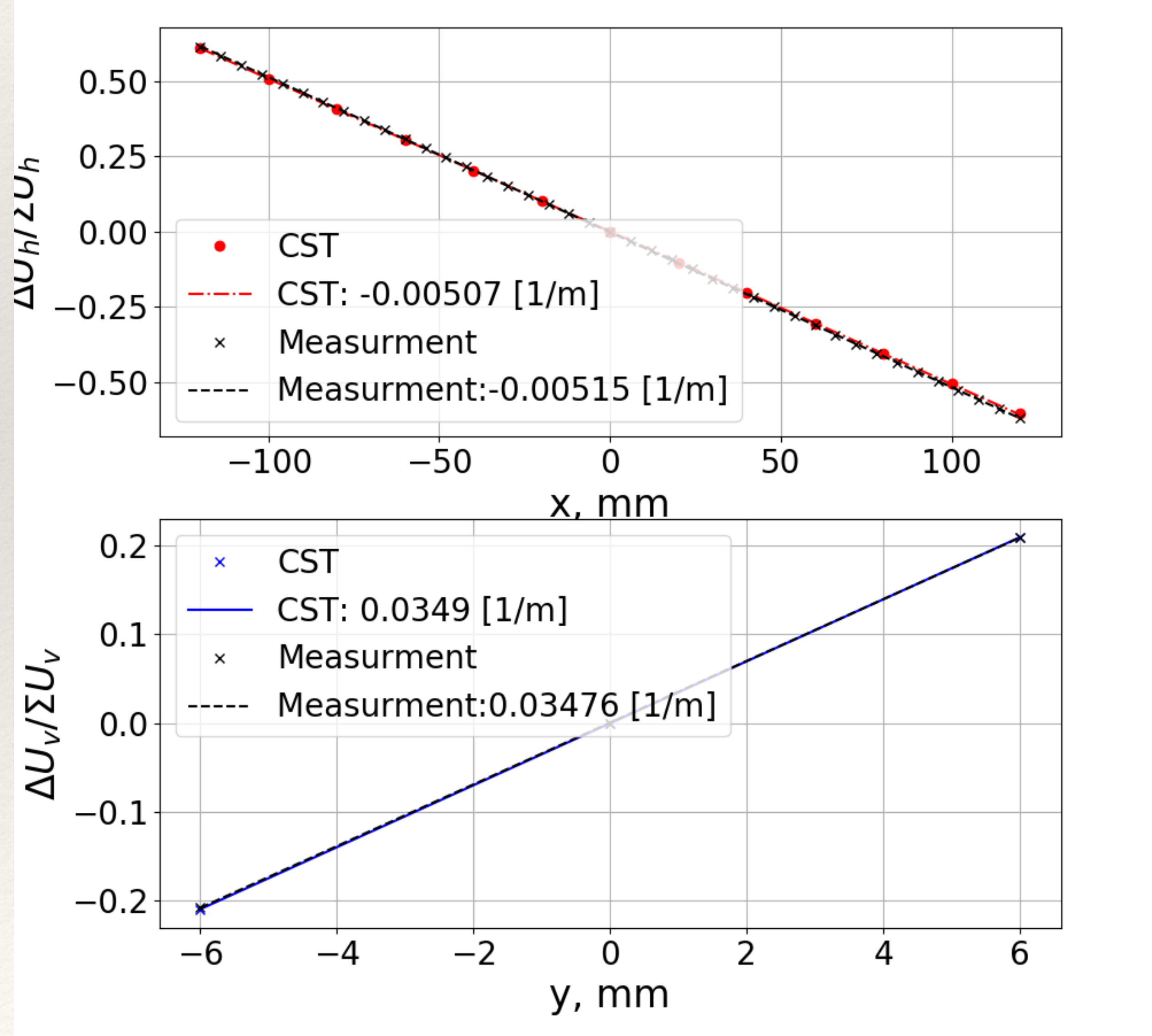
- Measured and predicted (CST) capacitances of each electrodes are good agreement each other:

	EH1	EH2	EV1	EV2
Meas	71.6	69.7	64.4	64.0
CST	71.6	70.0	63.5	62.4

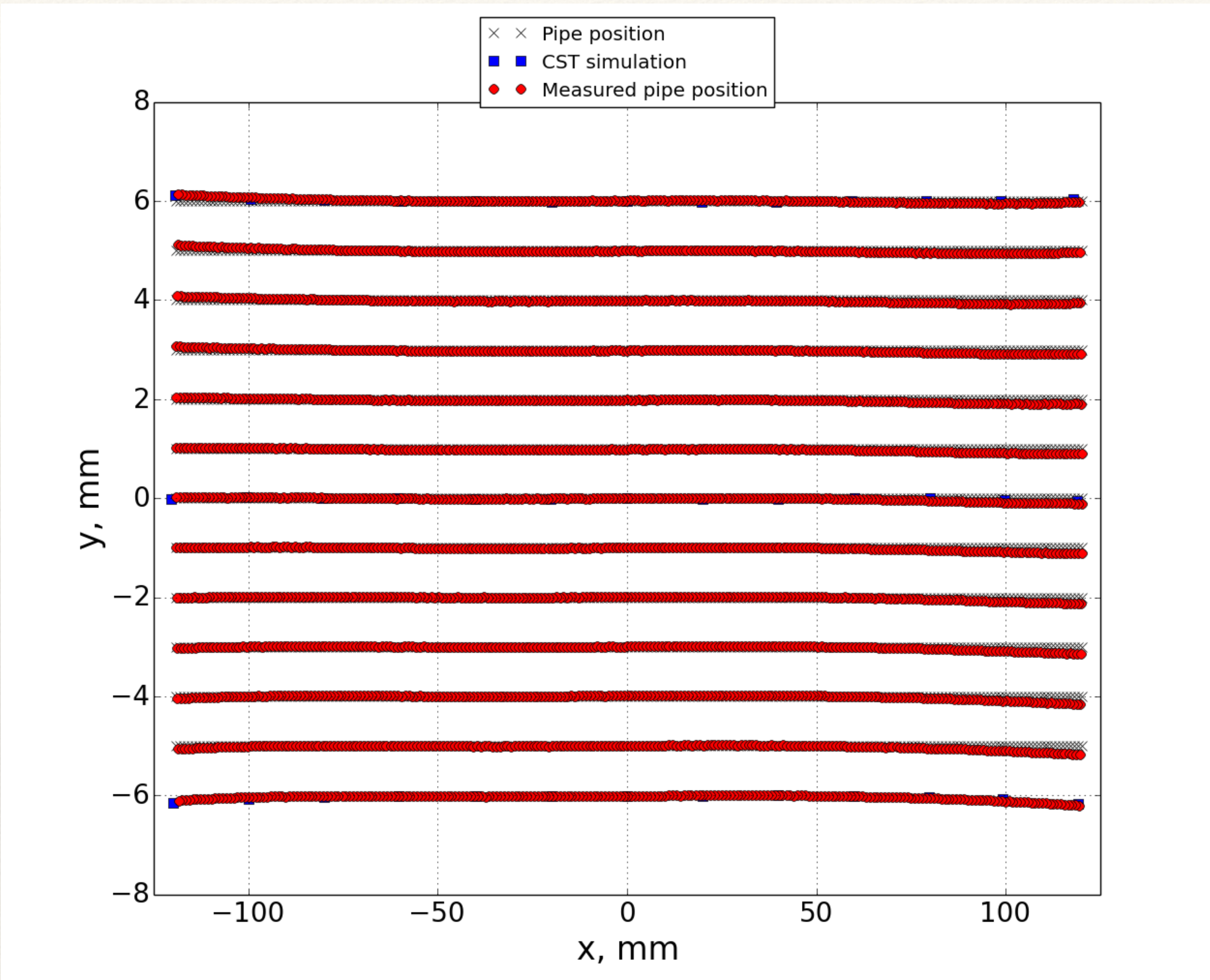
- Position sensitivity (K) is computed by the data along horizontal and vertical axis:

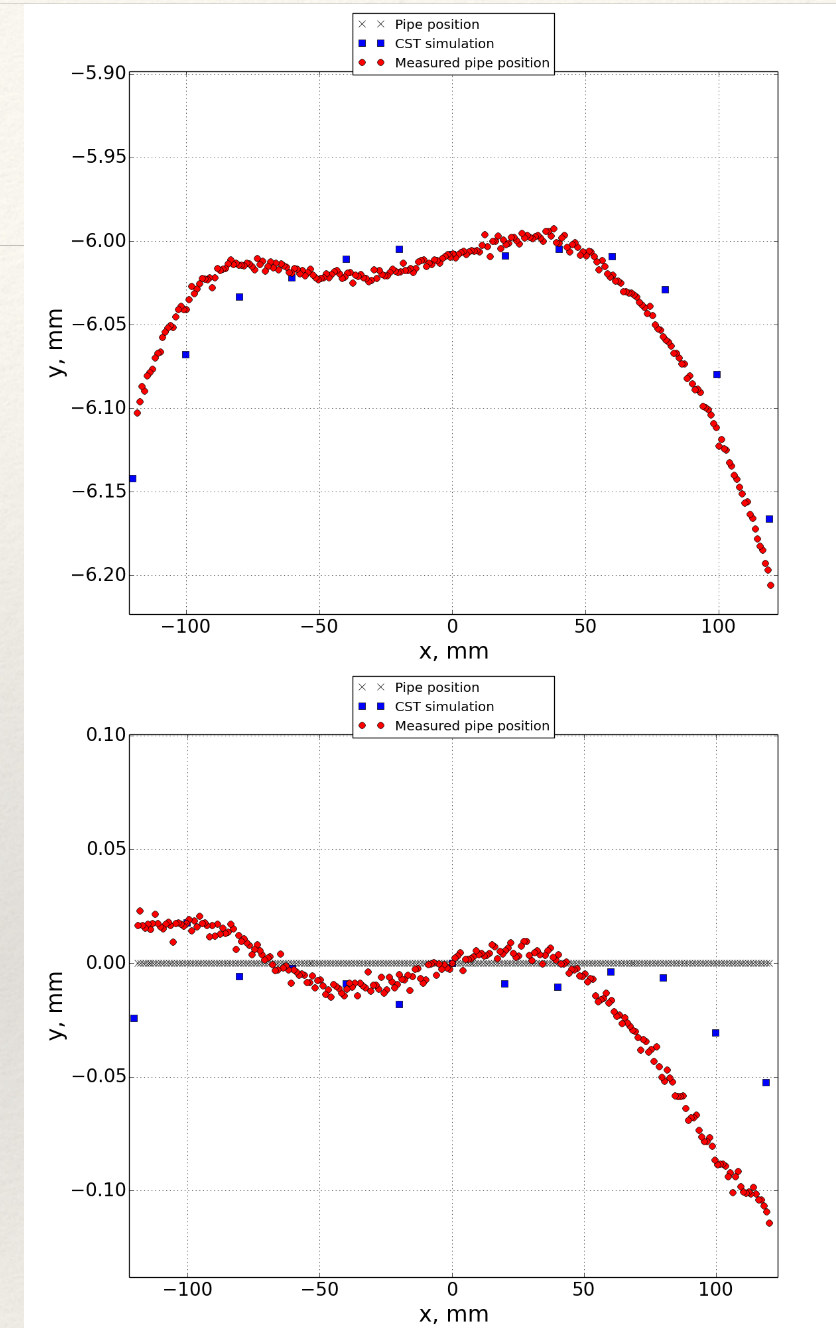
$$\frac{\Delta U}{\Sigma U} = Kx + \delta$$

Position sensitivities in both direction are well matched to the CST simulations.



Comparisons of measured and predicted (CST) probe positions

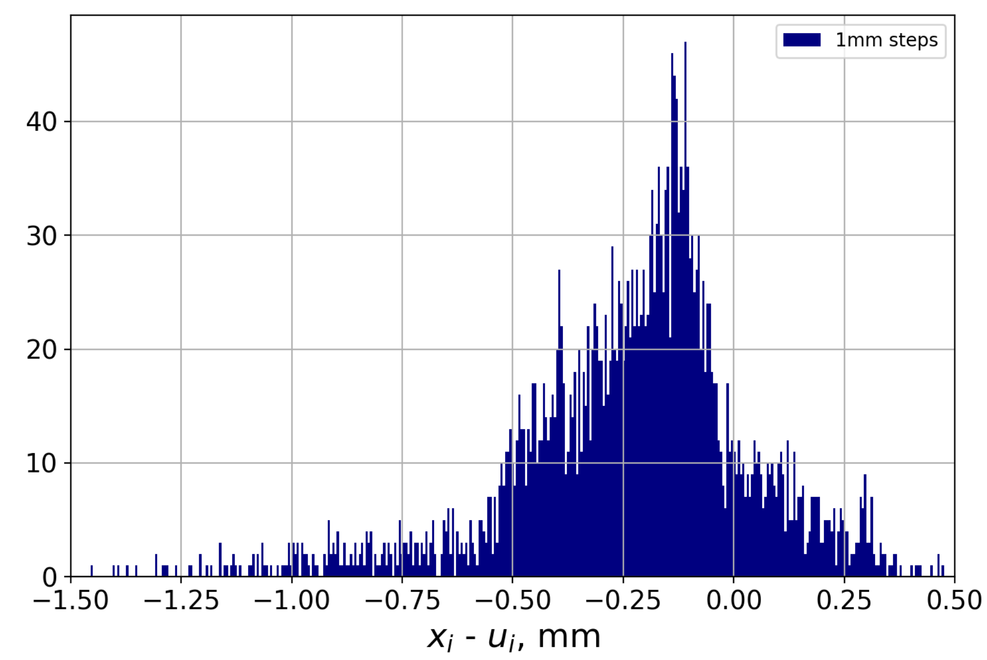


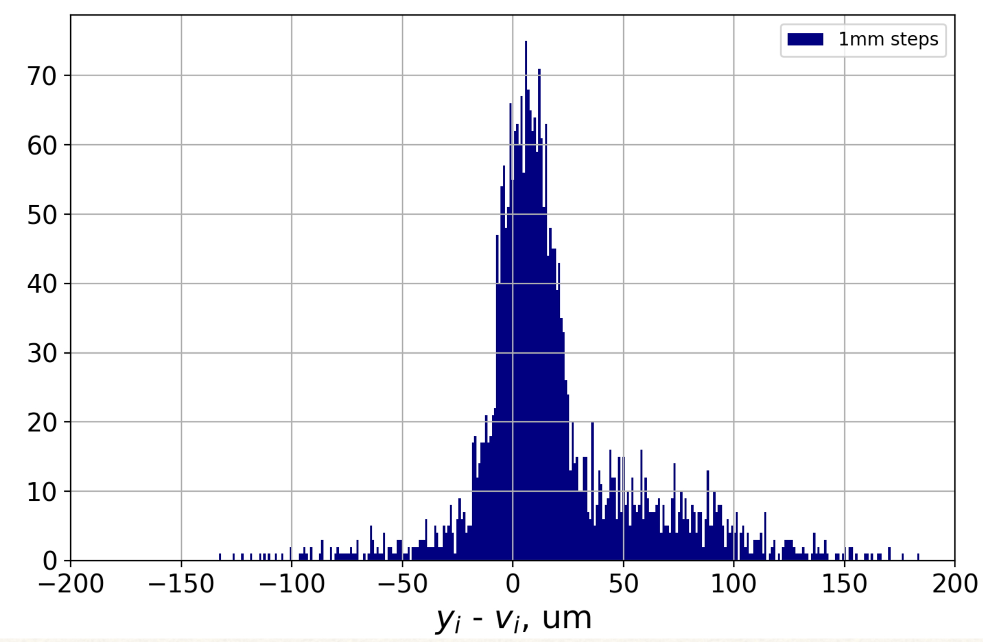


CST model predicts the measured probe position around the edge of BPM, but not so well in the mid-plane of BPM.

Position precision at test rig in the Lab

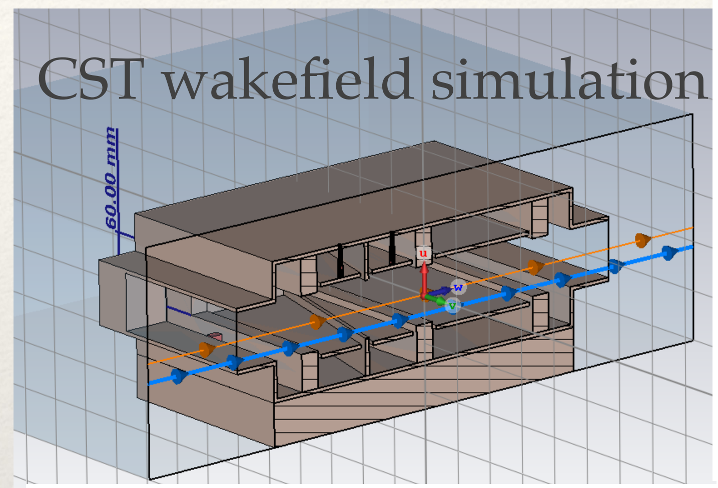
- Difference between probe position (±120mm/±6mm movements in hori/vert with 1mm steps) and measured position are plotted in hori (top figure)/vert (bottom figure).
- Top-hat (220kΩ) + 10MΩ scope probe is used in circuit, so cut-off frequency is about 10kHz.
- <u>RMS values of difference signal are 0.35mm/42um in hori/vert</u>, that is a position precision of single measurement at Lab.
- There is a systematic error (degrades position accuracy) in hori/vert difference signal. This could be a mix of errors from the BPM tilting, linear stages mechanical distortion and monitor electrodes distortion. To be investigated with final setup of BPM.

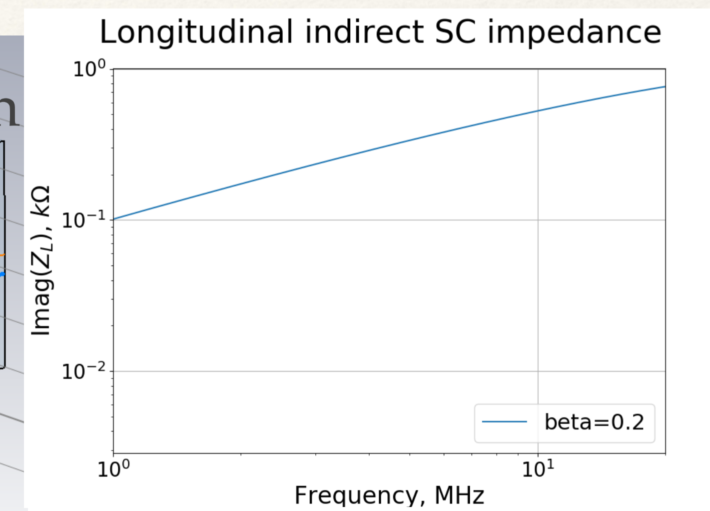


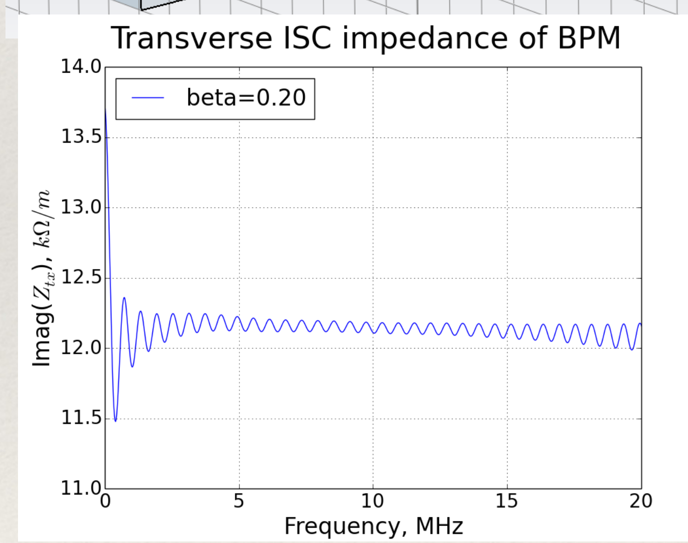


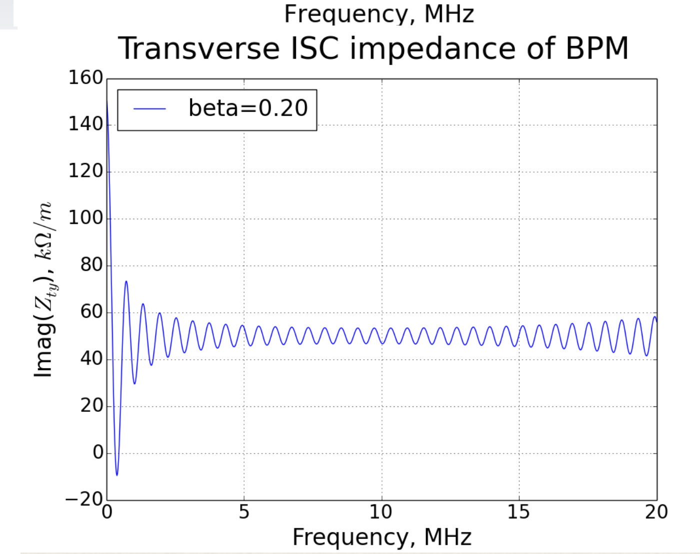
Beam coupling impedance and tune shift

- Longitudinal and transverse indirect space charge (ISC) impedance of prototype BPM is computed by combination of CST and analytical model. (BPM and beam are at centre of KURNS vacuum chamber in CST.)
- Synchrotron/Betatron tune shift due to ISC impedance of BPM are computed analytically with KURNS nominal beam parameters:
    - Bunch length=200ns
    - Bunch intensity=10^{10}
    - Sync. tune=0.0348
    - Beta. cell tune=(0.319, 0.0917)
- Installation of BPM in KURNS ring does not affect tune shift (β=0.2).





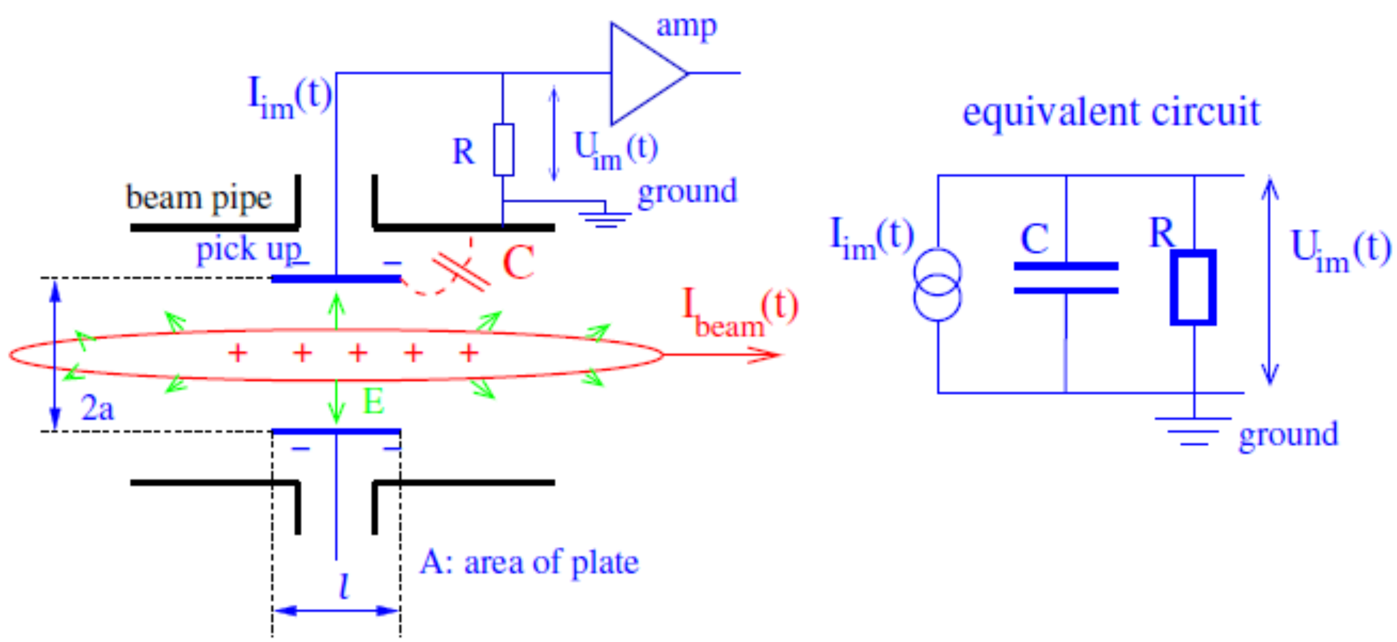




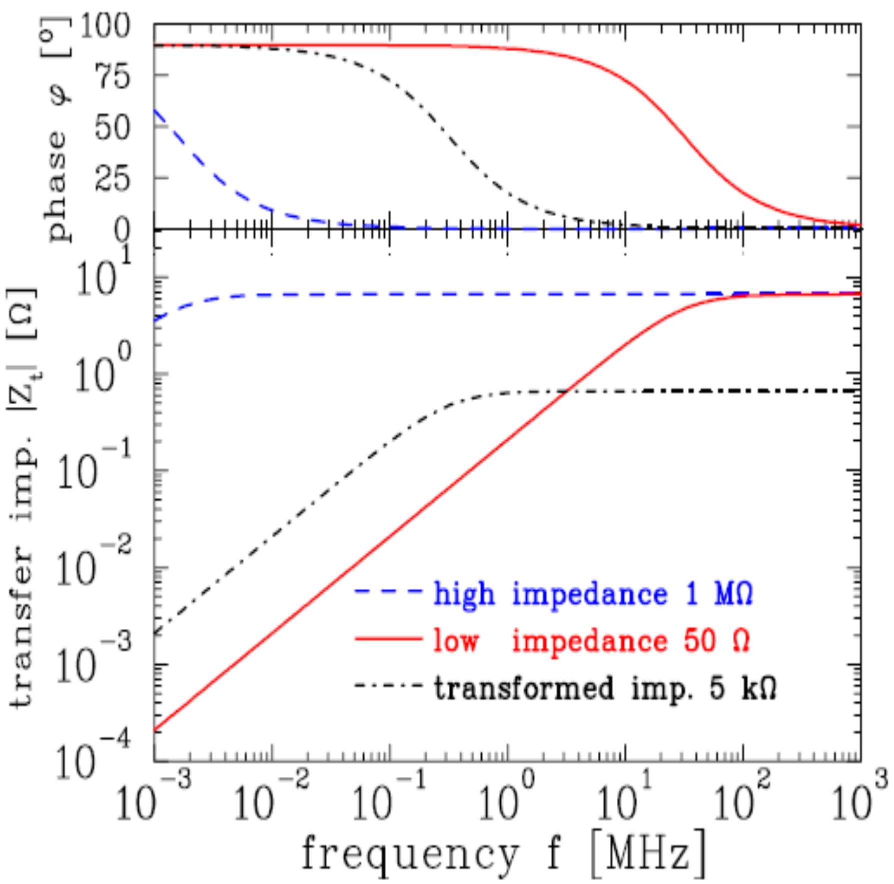
Sync. Tune shift	Cell tune shift: $\Delta\nu_x$	Cell tuen shift: $\Delta\nu_y$
-1.56E-06	-1.7E-07	-1.9E-06

Split-Electrode BPM

Equivalent circuit of a capacitive pickup BPM



Frequency response of a capacitive pickup BPM



Equivalent impedance: $\frac{1}{Z} = \frac{1}{R} + i\omega C \iff Z = \frac{R}{1 + i\omega RC}$

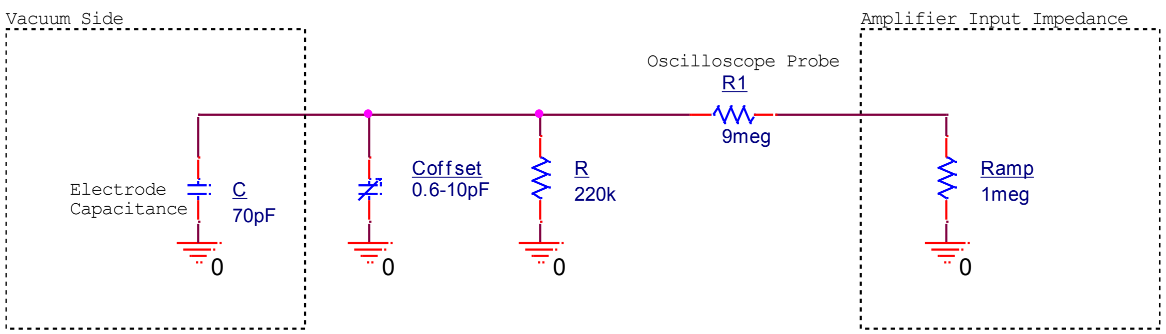
Voltage induced on the plate: $U_{\text{im}} = \frac{R}{1 + i\omega RC} \cdot I_{\text{im}}$

The lower cut-off frequency (f_c) is dictated by the electrode capacitance and the measuring resistor:

- We want C as low as possible to increase sensitivity.
- We want R as high as possible to lower f_c below beam spectrum, in order to obtain good bunch longitudinal information.

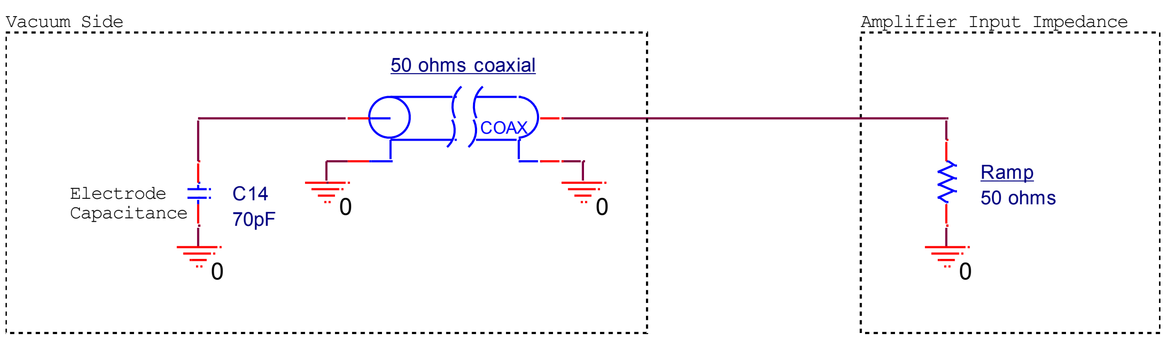
FFA BPM – Measuring Setups

ISIS FFA BPM (RC + Oscilloscope Probe + 1 Mohms input impedance amplifier):



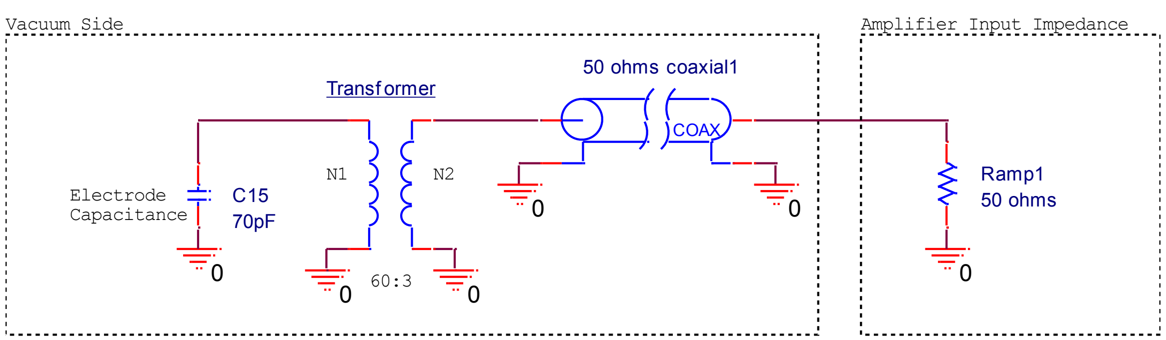
$f_c \approx$ 10 kHz (dominated by RC as measuring circuit impedance >> RC)

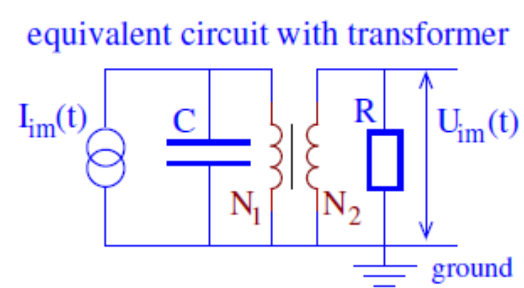
KURNS FFA BPM (C + 50 ohms coaxial + 50 ohms input impedance amplifier):



$f_c \approx$ 45 MHz (dominated by C and coaxial impedance)

KURNS FFA BPM (C + Impedance Transformer + 50 ohms coaxial + 50 ohms input impedance amplifier):

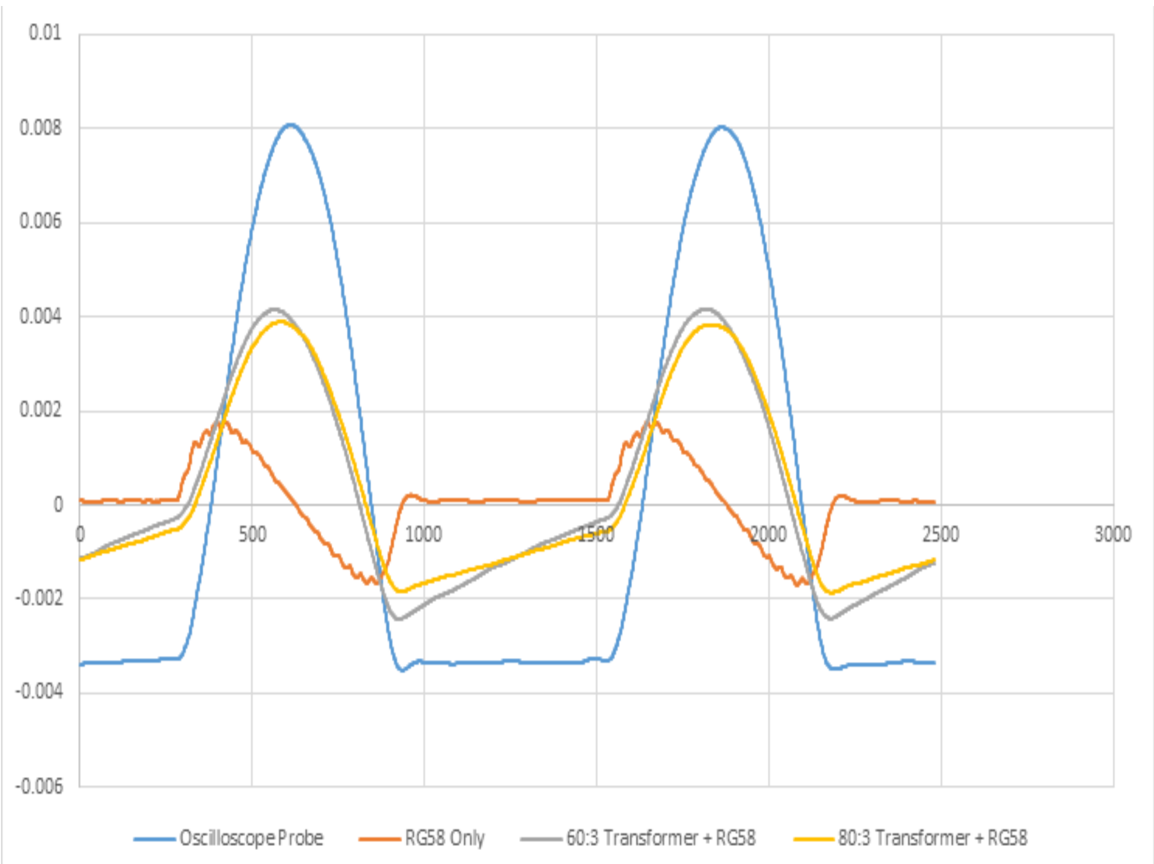




$$Requiv = \left(\frac{N1}{N2}\right)^2 \times 50ohms = \left(\frac{60}{3}\right)^2 \times 50 = 20kohms$$

$f_c \approx$ 110 kHz (dominated by C and equivalent impedance)

FFA BPM – Measuring Results Comparison



Acquired signals with different measuring circuits. The excitation signal is a half-wave rectified 1 MHz sinewave. The vertical axis is in volts and the horizontal in number of samples.

- The oscilloscope probe setup provides the closest representation for the excitation signal (apologies for not including it on the results).
- By using only a 50 ohms coaxial, due to the high cut-off frequency, the measured signal is a differentiation of the excitation signal.
- The use of an impedance transformer lowers the cut-off frequency, improving significantly the representation of the signal, but not correcting the errors completely.
- By increasing the transformer ratio, it's possible to improve slightly the measured signal.

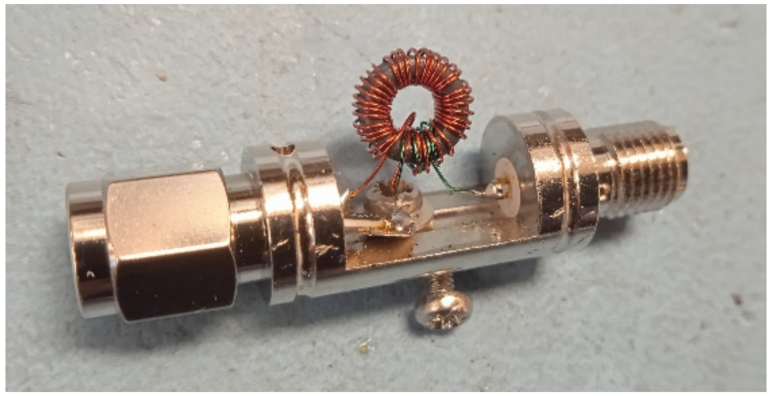
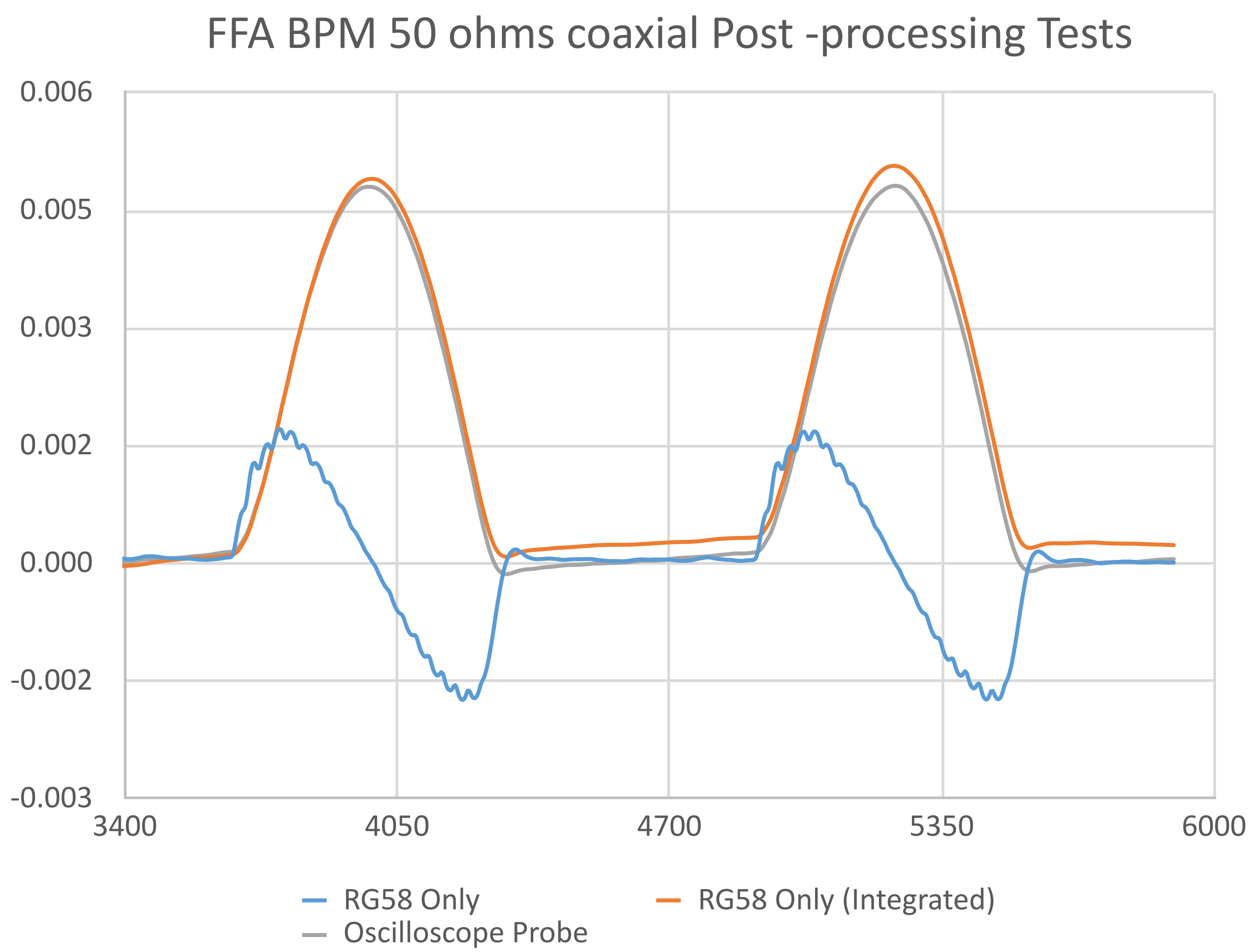


Photo of one of the impedance transformers tested, built into a SMA case.

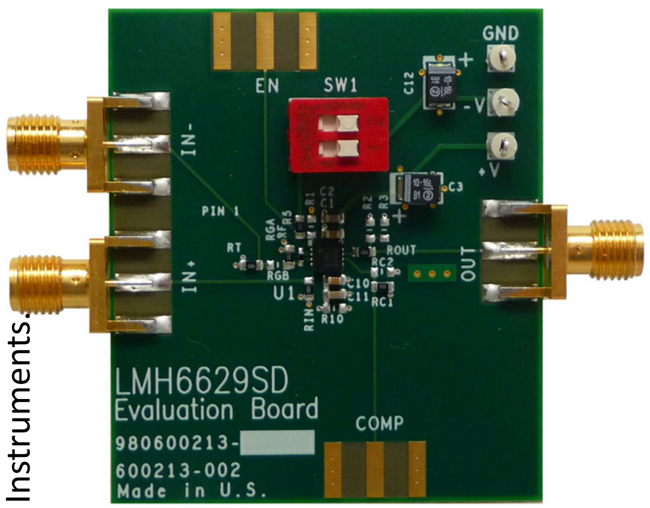
FFA BPM – Post-processing



Comparison between the waveforms obtained from the use of an oscilloscope probe, a single 50 ohms coaxial and the post processed signal form the 50 ohms coaxial measuring circuit.

- By using only a 50 ohms coaxial cable for connecting the BPM electrode to the DAQ system, it is possible to post-process the resulting signal in order to reconstruct the excitation waveform.
- On the example on the left, any offset from the signal was removed and then integrated in software.
- By using this method, the resulting signal provides a better representation of the excitation waveform than the obtained with the impedance transformers.
- Further/better post processing might reduce the measuring errors.
- This setup simplifies the installation but increases the complexity of the measuring device (a DAQ system instead of just an oscilloscope).

FFA BPM – BPM Amplifiers



Due to limited amount of available electronics designers and time, a modified High Speed LMH6629 Low Noise Operational Amplifier evaluation board from Texas Instruments will be used.

The modified amplifier has the following characteristics:

- Input/output impedance: 50 ohms
- Voltage gain: 30 V/V
- Bandwidth: DC - 70 MHz
- Input equivalent noise: 170 uVrms

The required power supply will be provided:

- Input: 90-240Vac
- Output: +/-15Vdc

Would the gain/bandwidth combination be suitable?

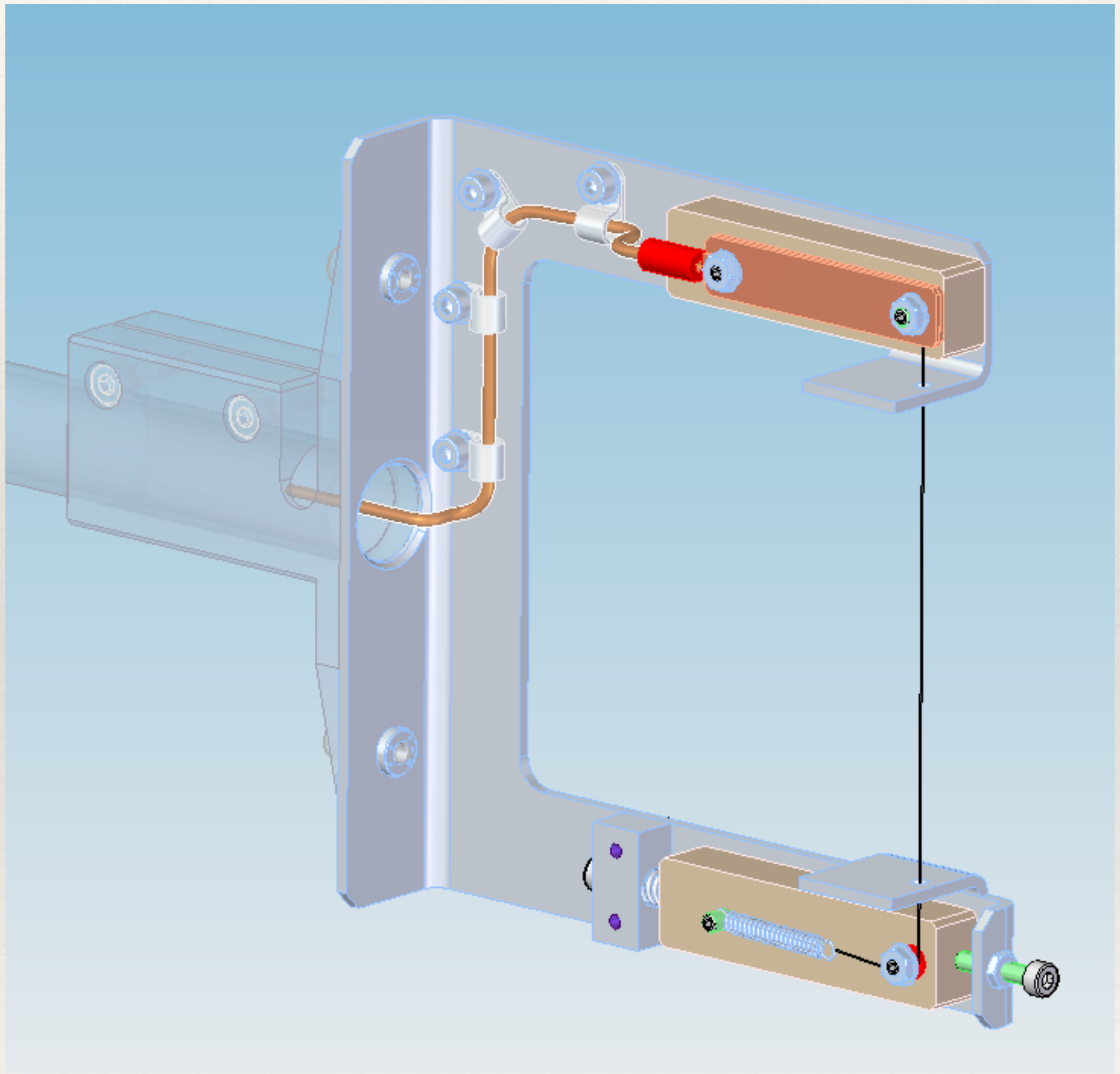
Would it be desirable more gain and less bandwidth?

FFA BPM – Comments

- The oscilloscope probe setup (used for more than 30 years on the ISIS BPMs) provides the closest representation for the excitation signal without the need of complex DAQ systems. Direct observation of beam motion and longitudinal profiles can be obtained by the use of an oscilloscope.
- For the FFA BPM prototype, as the connection between the prototype and the vacuum vessel feedthroughs has to be done within vacuum, the use of oscilloscope probes might not be practical/suitable.
- The use of only a 50 ohms coaxial cable is the simplest of all the setups, but requires a more complex DAQ system and some post-processing in order to obtain a good representation of the bunch longitudinal profile.
- The use of an impedance transformer allows a better representation of the bunch longitudinal profile with only the use of an oscilloscope, but doesn't correct the errors completely.
- No error analysis have been done for any of the measured signals. How accurate information of the longitudinal profile is required?
- Can we use trimmer capacitors in vacuum? The offset calibration/compensation might be affected by different cables lengths (different capacitances in parallel with the electrodes).
- Should we reduce the bandwidth on the amplifiers in order to obtain a larger signal gain?

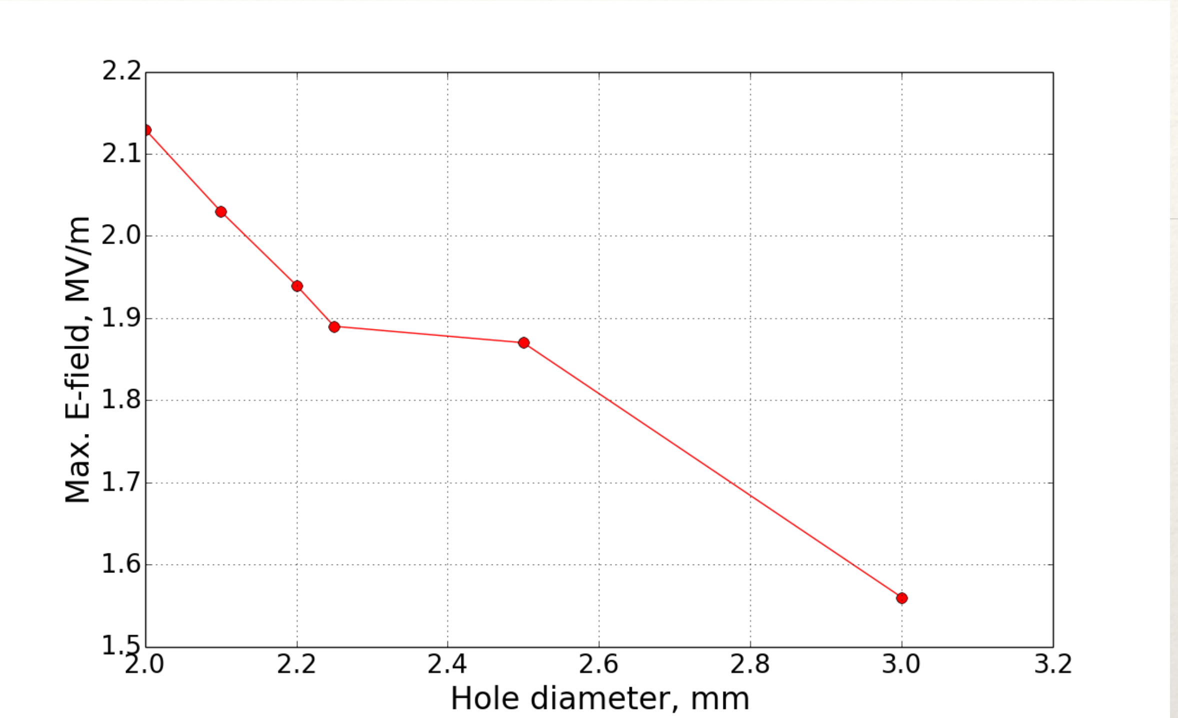
Prototype FFA WSM design

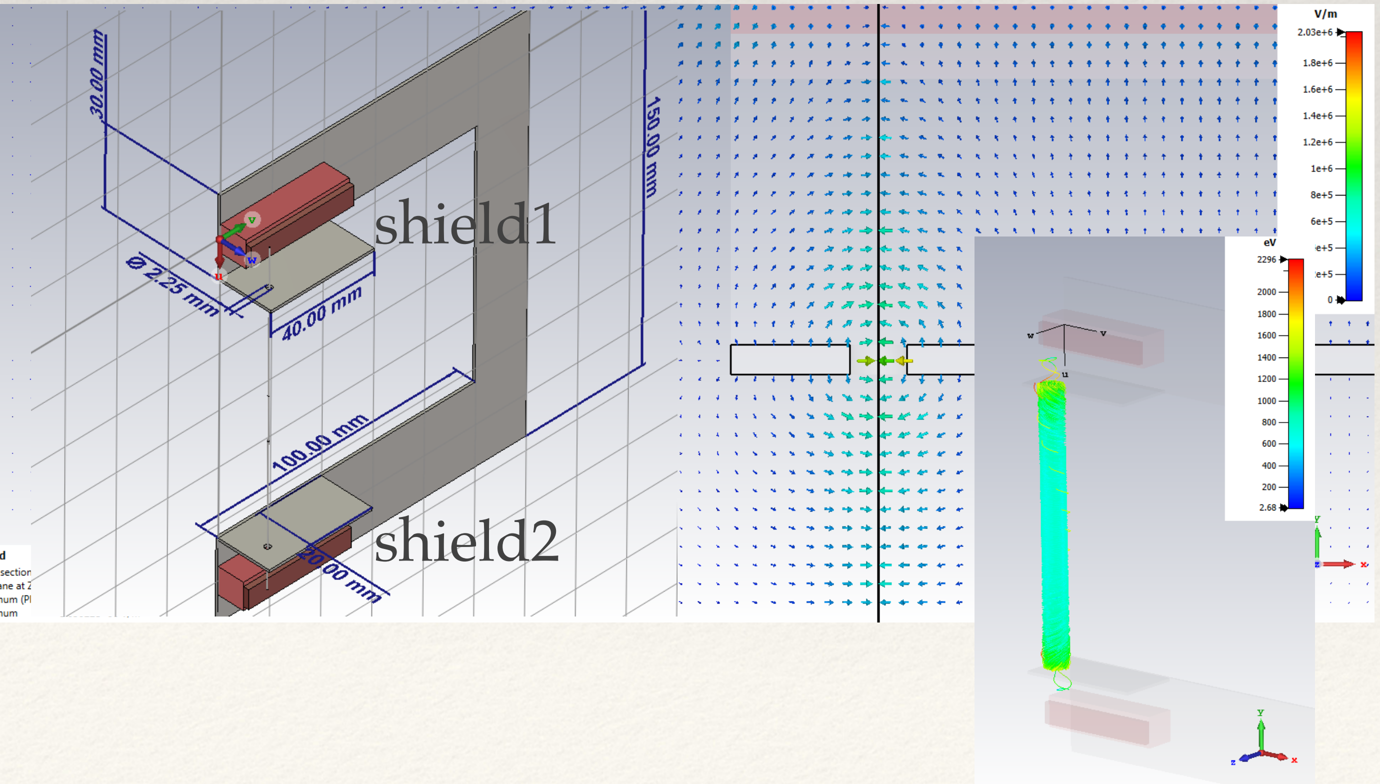
- Prototype WSM will be built and tested in hFFA at KURNS (Japan) in Winter (Nov.-Dec.) 2021.
- ϕ10um CNT wire will be delivered at ISIS in mid-June.
- Design work of wire frame has been started.

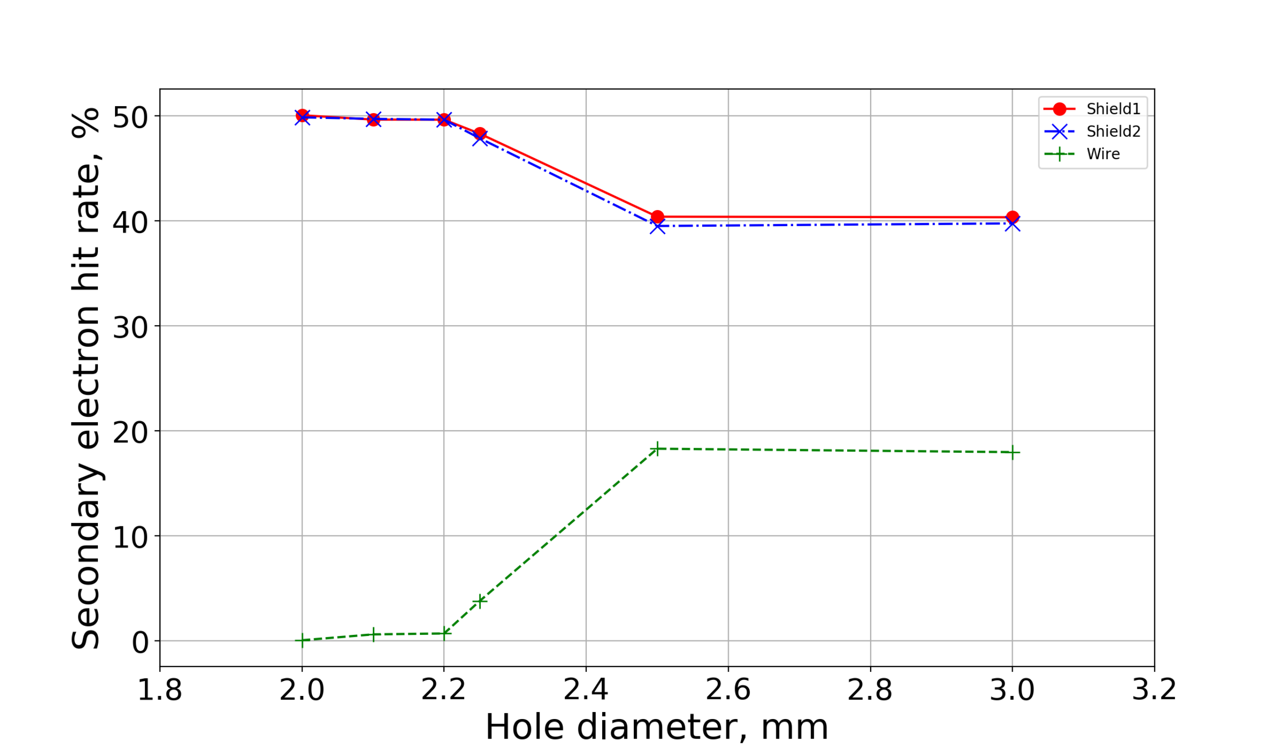


Hole dimension

- 25eV electrons (as a secondary electron) are generated on surface of ϕ10um CNT wire.
- Stray field of 0.05T is applied around the frame.
- Bias voltage of -1.5kV is applied on the wire.
- Maximum E-field in the hole is measured (Top right figure) in CST.
- The number of secondary electrons hit each component is counted (Bottom right figure).
- Endurance test of CNT wire will be done with bias voltage (-1.5kV) in vacuum tank at Diag Lab in this month.





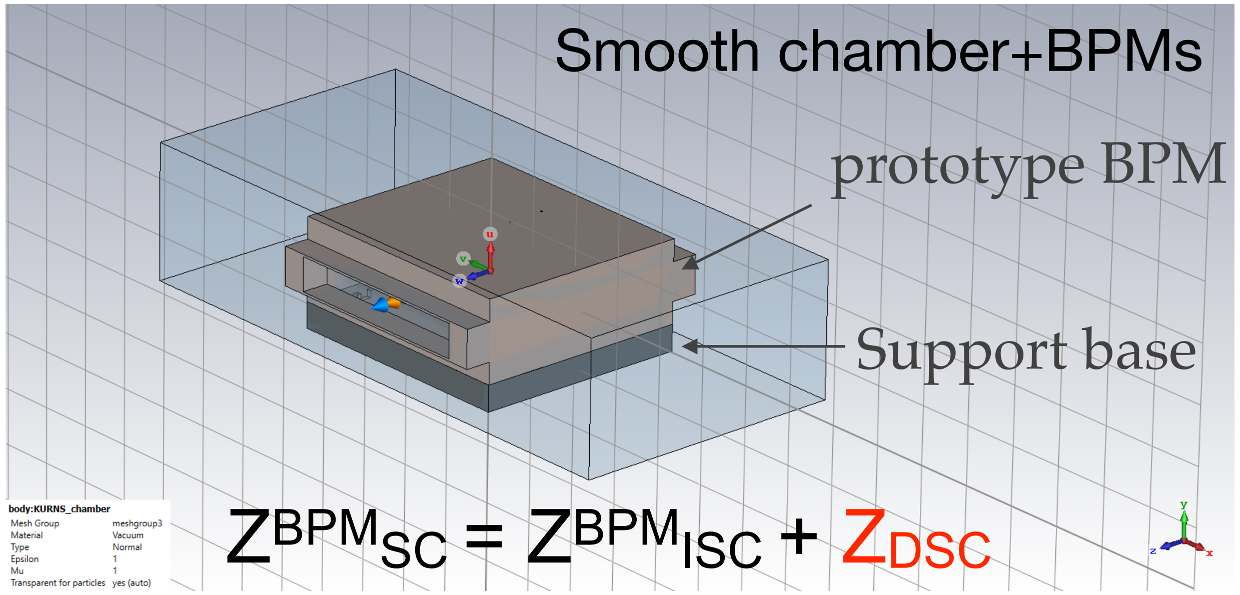


Next thing to do…

- BPM
    - BPM base to adjust its hight will be ready in next week.
    - Electronics (Amplifier and impedance transformer) will be prepared in hit month.
    - Remeasure position sensitivity and BPM features (precision with different setups etc) with final measurement setup.
- WSM
    - The high voltage is applied on CNT wires in vacuum tank at Lab in June. This is also to confirm the diameter of wire hole (ϕ2mm).

Spare slides

Indirect space charge impedance of prototype BPM chamber



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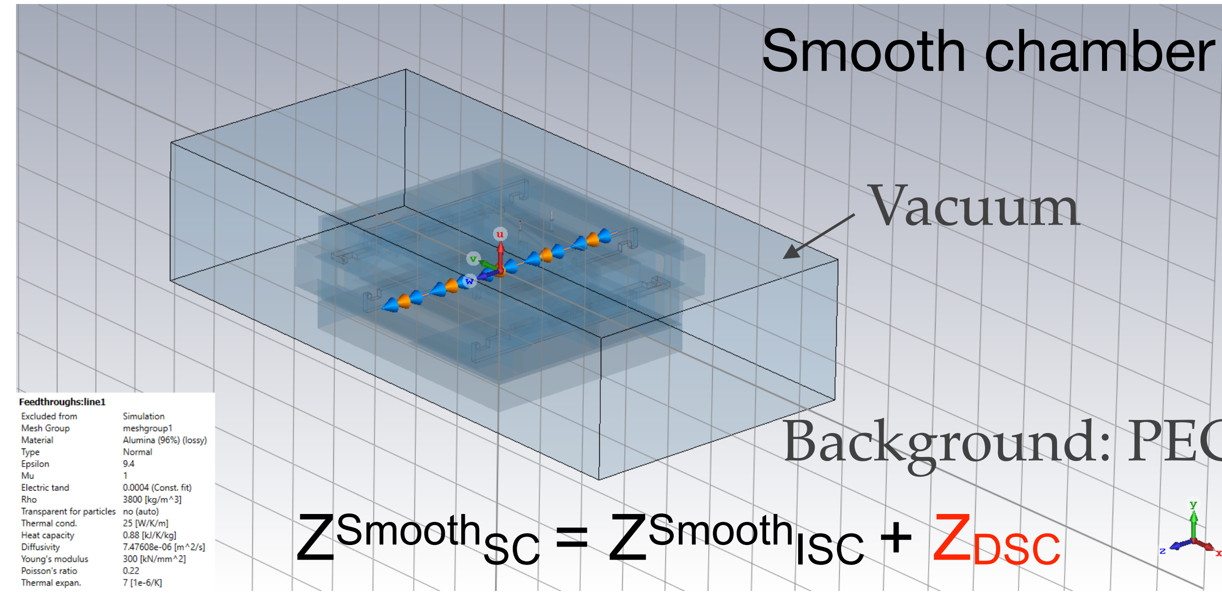

- Substitute Z^{Smooth}_{SC} from Z^{BPM}_{SC} to cancel Z_{DSC}. Meshsizes of two simulations are frozen, so that beam size for both simulations are the same and therefore Z_{DSC} is for both cases are the same.

$$Zsim = Z^{BPM}_{SC} - Z^{Smooth}_{SC} = (Z^{BPM}_{ISC} + Z_{DSC}) - (Z^{Smooth}_{ISC} + Z_{DSC})$$

$$= Z^{BPM}_{ISC} - Z^{Smooth}_{ISC}$$

- Indirect SC impedance of prototype BPM chamber is given by

$$Z^{BPM}_{ISC} = Zsim + Z^{Smooth}_{ISC}$$

here Z^{Smooth}_{ISC} is calculated analytically.

Longitudinal indirect space charge impedance

Longitudinal

$Z^{BPM}{}_{ISC} = Zsim + \underline{Z^{Smooth}{}_{ISC}}$

$$Z_{||}(\omega) = -j\frac{\omega Z_0 L}{2\pi c\beta^2\gamma^2} I_0^2(s)\left[\frac{K_0(s)}{I_0(s)} - \frac{K_0(x)}{I_0(x)}\right] * F(h/w)$$

$$F_0(\lambda) = \pi\left[\Sigma_{n=1,odd}\frac{1}{cosh^2(n\pi/2\lambda)} + \lambda\Sigma_{n=1,odd}\frac{1}{cosh^2(n\pi\lambda/2)}\right]$$

$$s = \frac{\omega a}{\beta c\gamma}, x = \frac{\omega b}{\beta c\gamma} : a = \text{beam size}, b = \text{ pipe radius},$$

I_0 and K_0 the Bessel functions of imaginary argument [1], h the half hight of rectangular beam pipe and w the half width of rectangular beam pipe [2].

[1] R. L. Gluckstern, "Analytic methods for calculating coupling impedances", CERN 2000-011, (2000)

[2] R. L. Gluckstern, J. van Zeijts and B. Zotter, "Coupling impedance of beam pipes of general cross section", Pays. Rev. E4 7. 656, (1993)

Transverse

$Z^{BPM}{}_{ISC} = Zsim + \underline{Z^{Smooth}{}_{ISC}}$

$$Z_{\perp}(\omega) = -j\frac{Z_0 L}{\pi\beta\gamma^2}\left[\frac{1}{a_{x,y}^2} - \frac{\xi_{1x,y} - \epsilon_{1x,y}}{h^2}\right]$$

h the half hight of rectangular beam pipe and a the beam radius [3].

$$\epsilon_{1y} = \frac{K^2(k)}{12}(1 - 6k + k^2)$$

$$\epsilon_{1x} = -\frac{K^2(k)}{12}(1 - 6k + k^2)$$

$$\xi_{1y} = \frac{K^2(k)}{4}(1 - k)^2$$

$$\xi_{1x} = K^2(k)k$$

[3]K.Y. Ng, "Physics of intensity dependent beam instabilities".

Tune shift

- Synchrotron tune shift [4]:

$$\Delta\nu_s = \frac{eI_b\eta c^3}{8\sqrt{\pi}\beta^2\sigma_z^3\omega_0^2 Q_s E_0} Im\left(\frac{Z_{//}}{\omega}\right)_{eff}$$

where I_b the bunch intensity, η the slippage factor, σ_z the bunch length,Q_s the synchrotron tune , ω_0 the angular frequency of beam energy E_0.

[4] A. W. Chao, "Physics of collective beam instabilities in high energy accelerators"

- Betatron tune shift [4]:

$$\Delta\nu = -\frac{e\beta I_b c^2}{4\sqrt{\pi}\sigma_z\omega_0^2 Q_\beta E_0} Im(Z_\perp)_{eff}$$

where I_b the bunch intensity, σ_z the bunch length,Q_β the betatron tune , ω_0 the angular frequency of beam energy E_0.