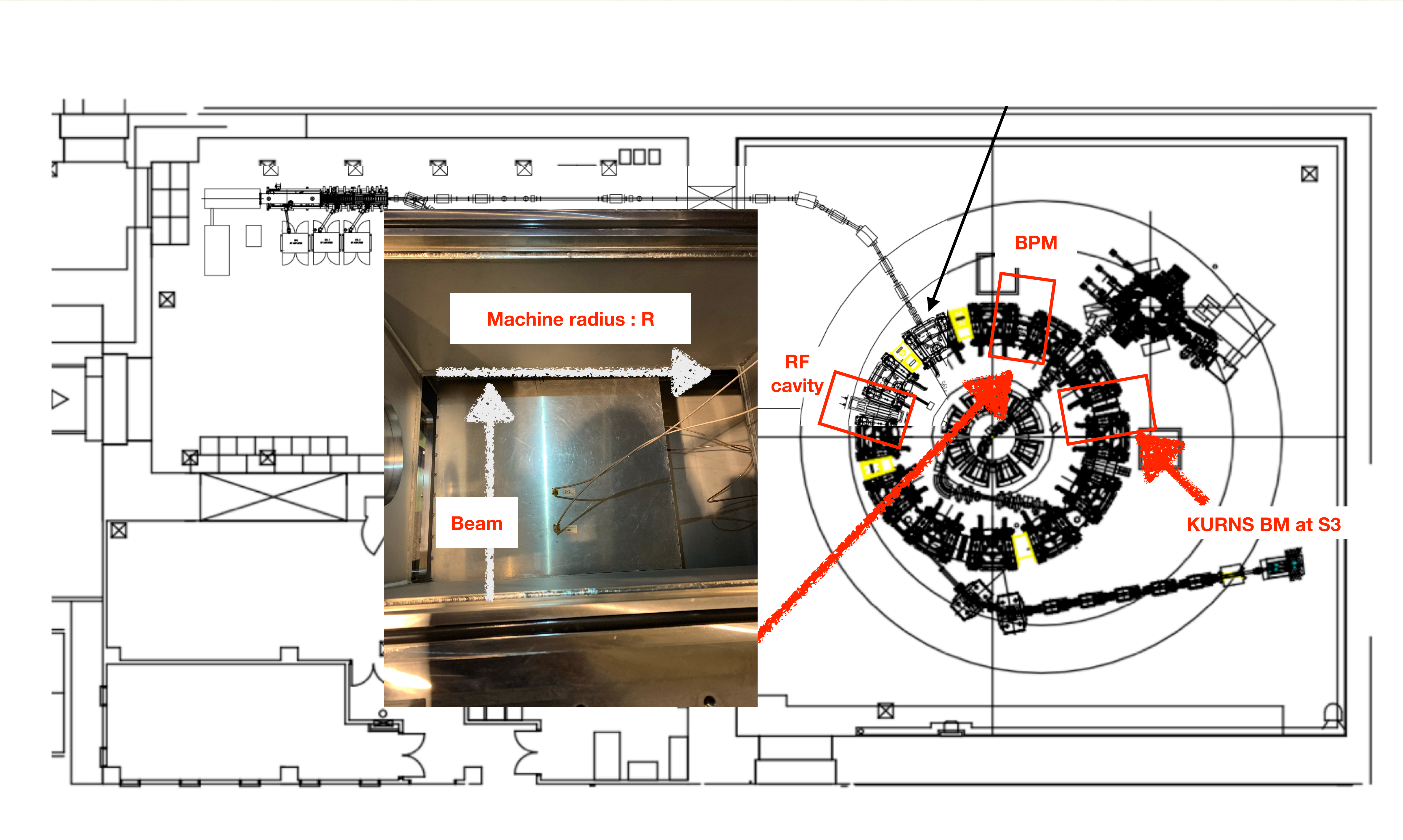
16 December 2021

BPM tests at KURNS and WSM HV test at ISIS Lab.

E. Yamakawa

BPM installation in KURNS vacuum chamber

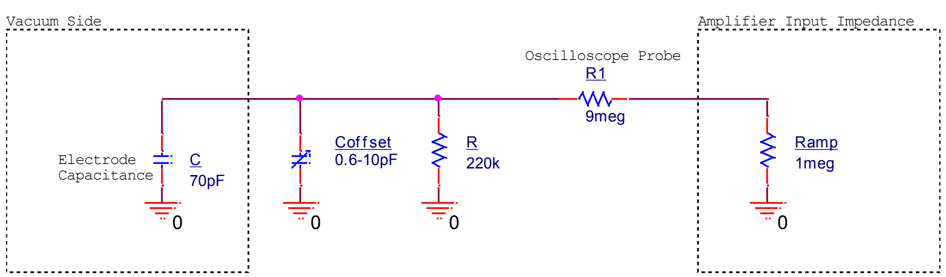


BPM Impedance transformer

- Impedance transformer was installed on each electrode to reduce cutoff frequency. Impedance transformer on EV2 was damaged and not in use in this measurement.

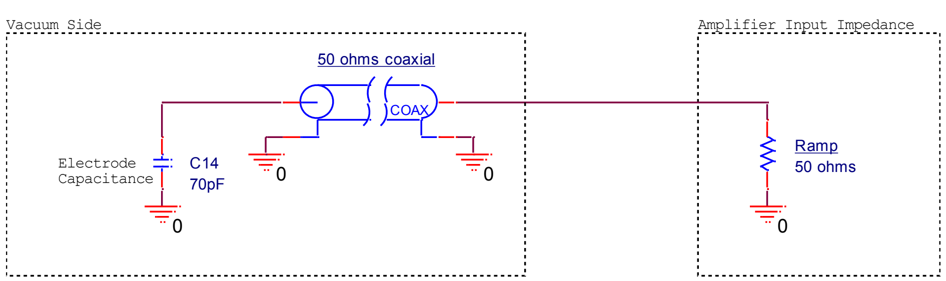
FFA BPM - Measuring Setups

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



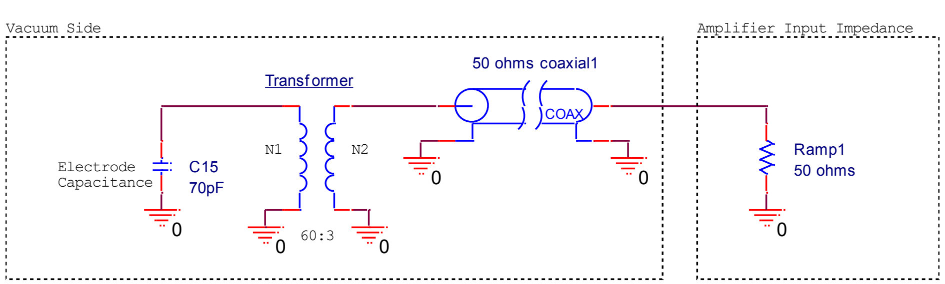
$f_c \approx$ 10 kHz (dominated by RC as measuring circuit impedance >> RC)

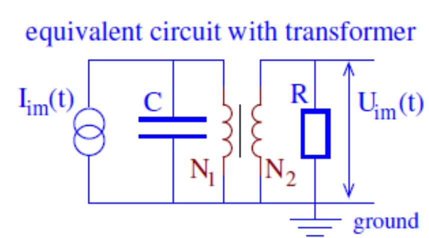
KURNS FFA BPM (C + 50 ohms coaxial + 50 ohms input impedance amplifier):



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

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





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

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

Background (beam-off) signals

- Background signal on each electrode were recorded and applied FFT.
  - Even when a beam was not in the ring, the RF noise was seen on the signal of each electrode.

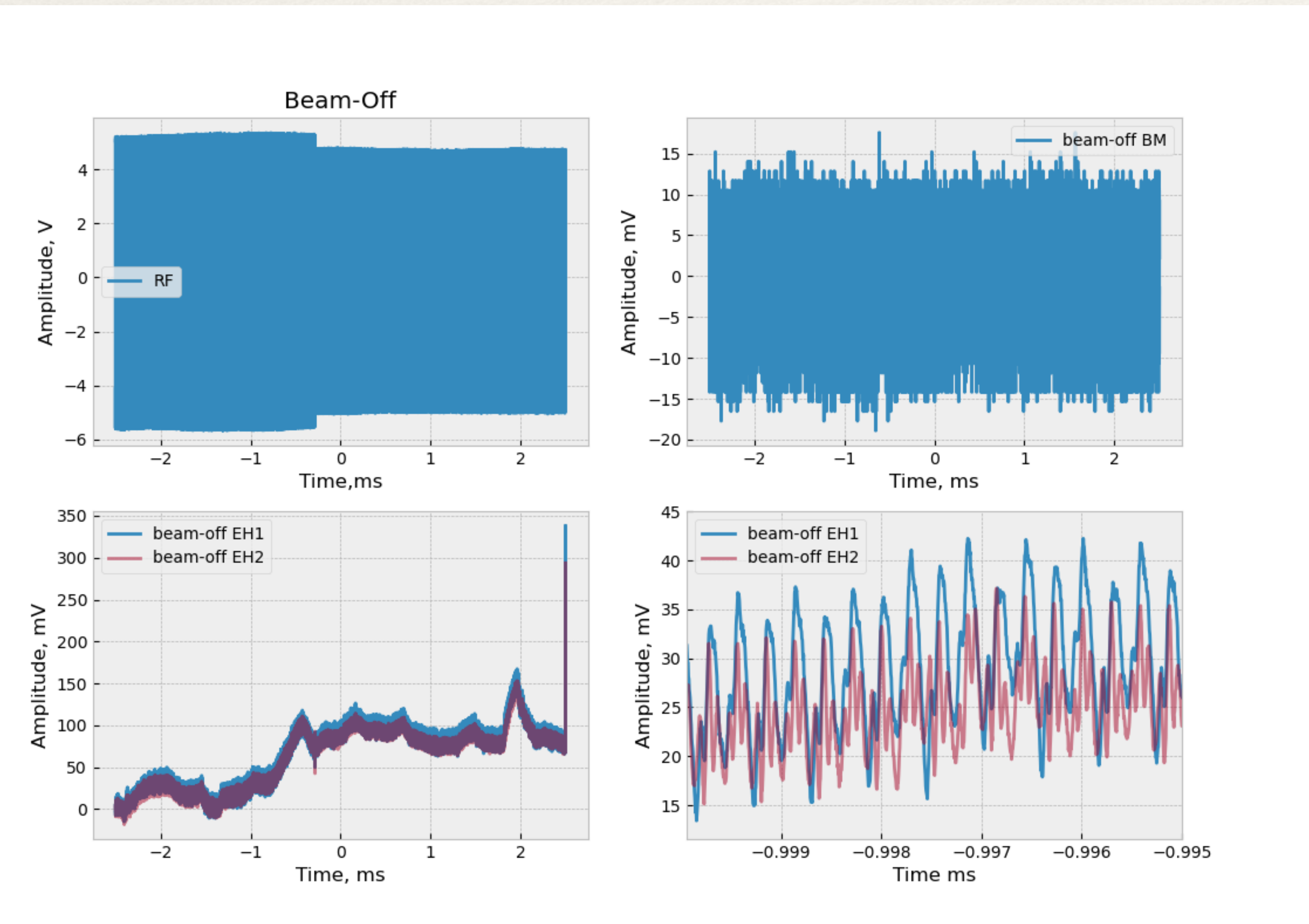


Fig.1. Top left: RF waveform (18MeV-10msFT), Top right: KURNS Bunch monitor (BM), Bottom left: horizontal electrodes (EH1&EH2), Bottom right: zoom up on horizontal electrodes.

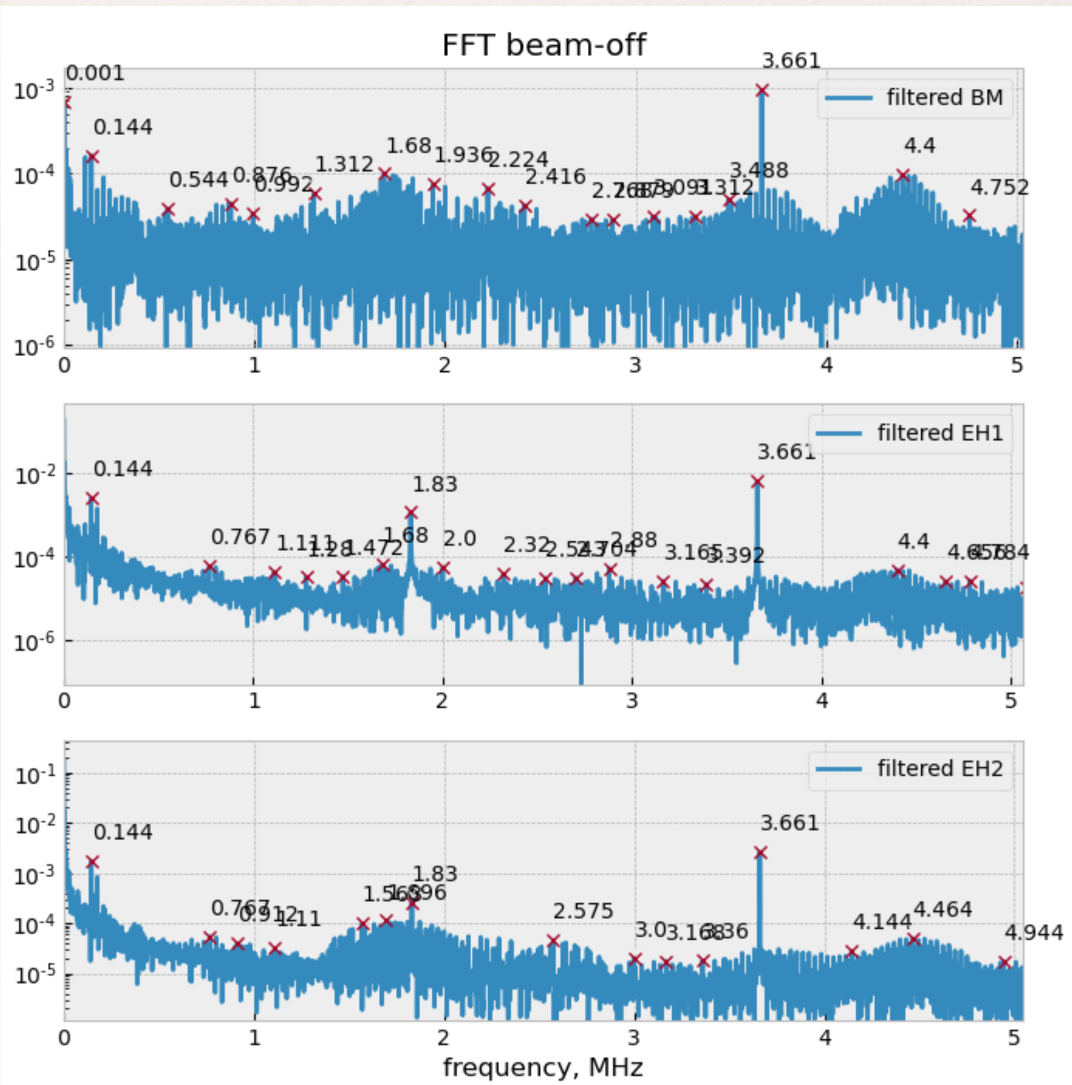


Fig.2. FFT on raw BM (Top), EH1 (Middle) and EH2 (Bottom).

Beam intensity vs signal amplitude w/ Imp-Trans+FETS_FFA-Amp

- Background signal (beam-off) was subtracted from electrode signals.
- BPF (500kHz-2.0MHz) was applied on KURNS BM and BPM signals over FT region (Fig.1).
- Peak-to-peak amplitude (V_{pp}) over FT region was computed with different beam intensities (Fig.2).
- The **dependency of BPM sum signals on beam intensity agreed with the one of existing Bunch Monitor (BM).**

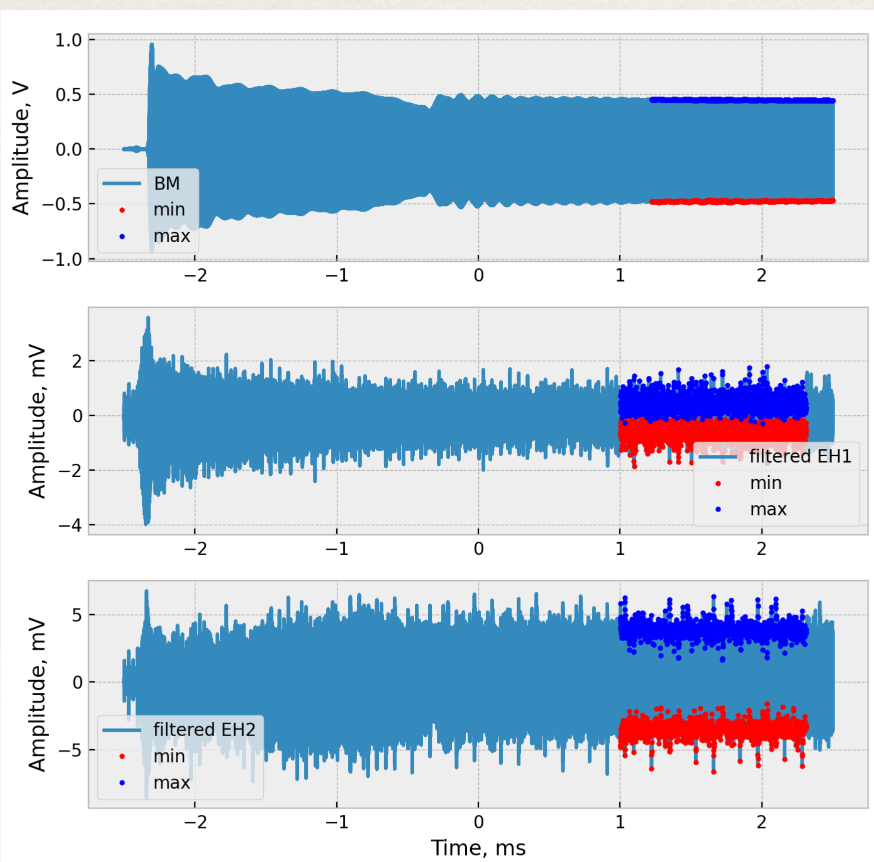


Fig.1. Signals with Minimum (red) and maximum (blue) peaks. Top: BM (16MeV-10msFT), Middle: EH1 waveform, Bottom: EH2 waveform when full beam intensity.

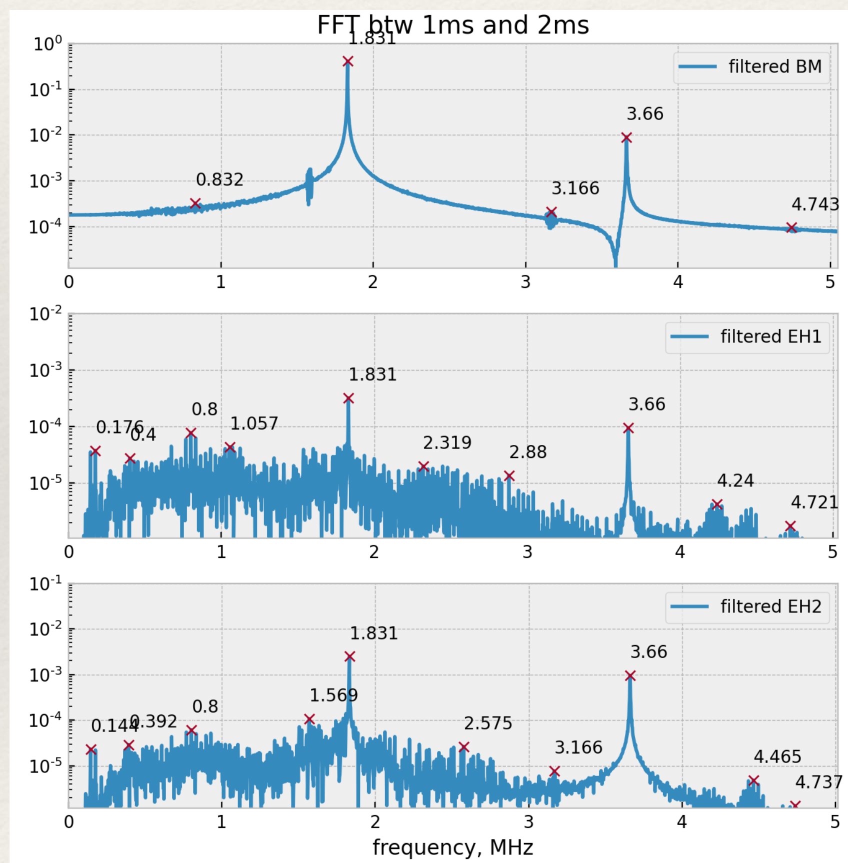


Fig.2. FFT on each signal. Top: KURNS BM, Middle: EH1 and Bottom: EH2.

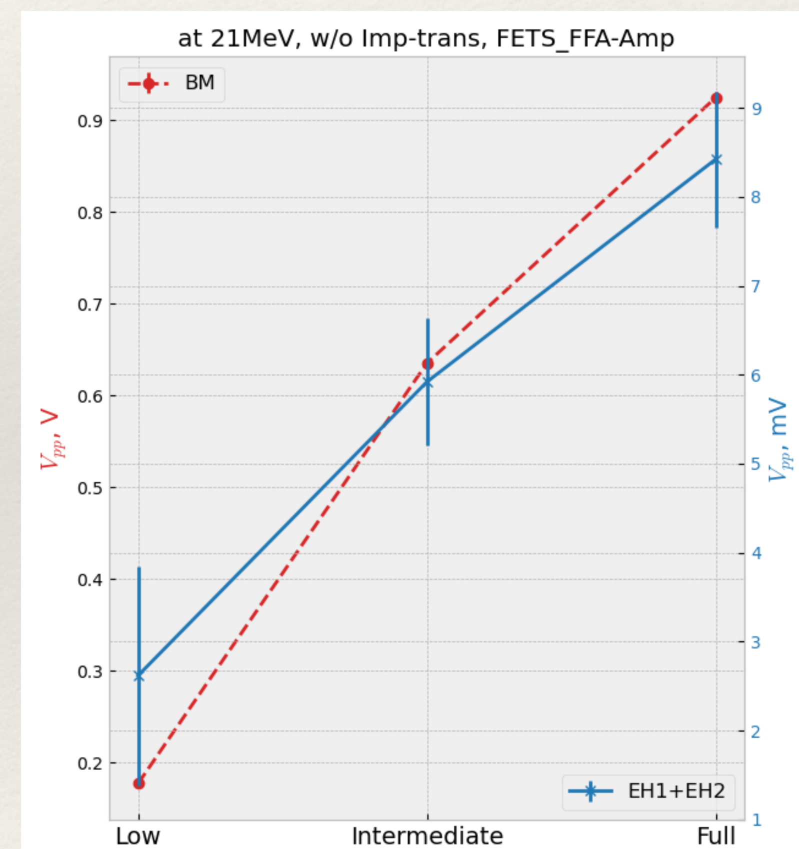


Fig.3. Amplitude dependency of electrode signals on beam intensity. Red marker indicates peak to peak voltage (V_{pp}) of KURNS BM. Blue markers indicates the V_{pp} of sum signal of horizontal electrodes.

Beam positions w/ Imp-Trans +FETS_FFA-Amp

- Horizontal beam position is computed at **full/Intermediate/Low beam intensity** using pre-measured position sensitivity (K) and offsets (δ): $\frac{dU}{\Sigma U} = Kx + \delta$: *K=-0.00512, δ=0.00236.*

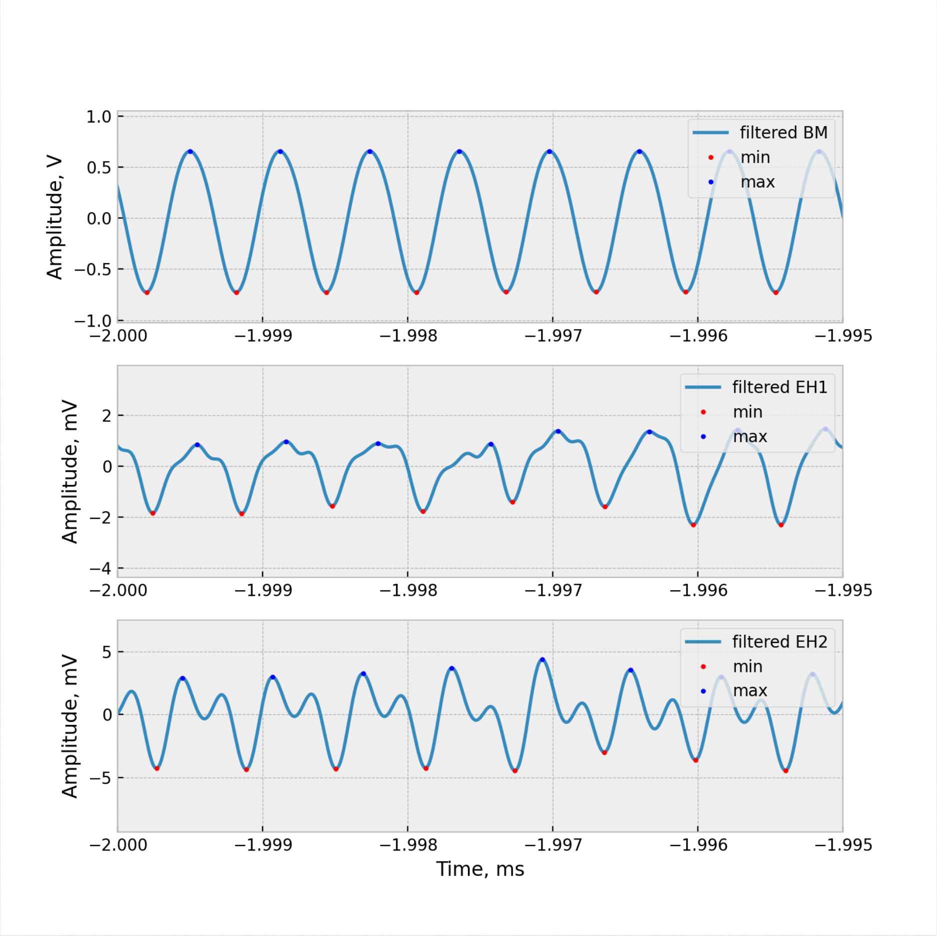


Fig.1. Filtered signal of KURNS BM (top), EH1 (middle) and EH2 (bottom) with minimum and maximum data points.

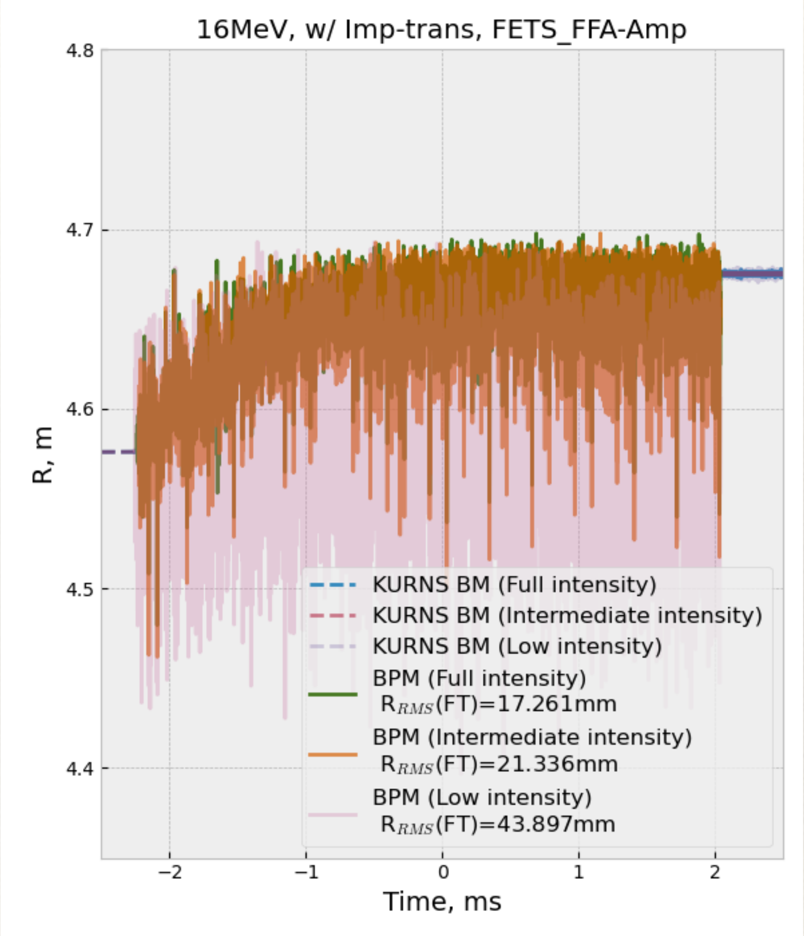


Fig.2. Horizontal beam positions predicted by KURNS BM (dashed lines) and calculated by BPM (solid lines) with different beam intensities.

When **full and intermediate beam intensities, beam positions are following the beam positions predicted by KURNS BM**. But it is very noisy due to RF noise (2nd harmonics).

Beam signal vs beam intensity w/o Imp-Trans + FETS_FFA amp

- Background signal (beam-off) was subtracted from each electrode signal.
- BPF (500kHz-2.0MHz) was applied on each data.
- Peak-to-peak amplitude (V_{pp}) at FT were computed with different beam intensities

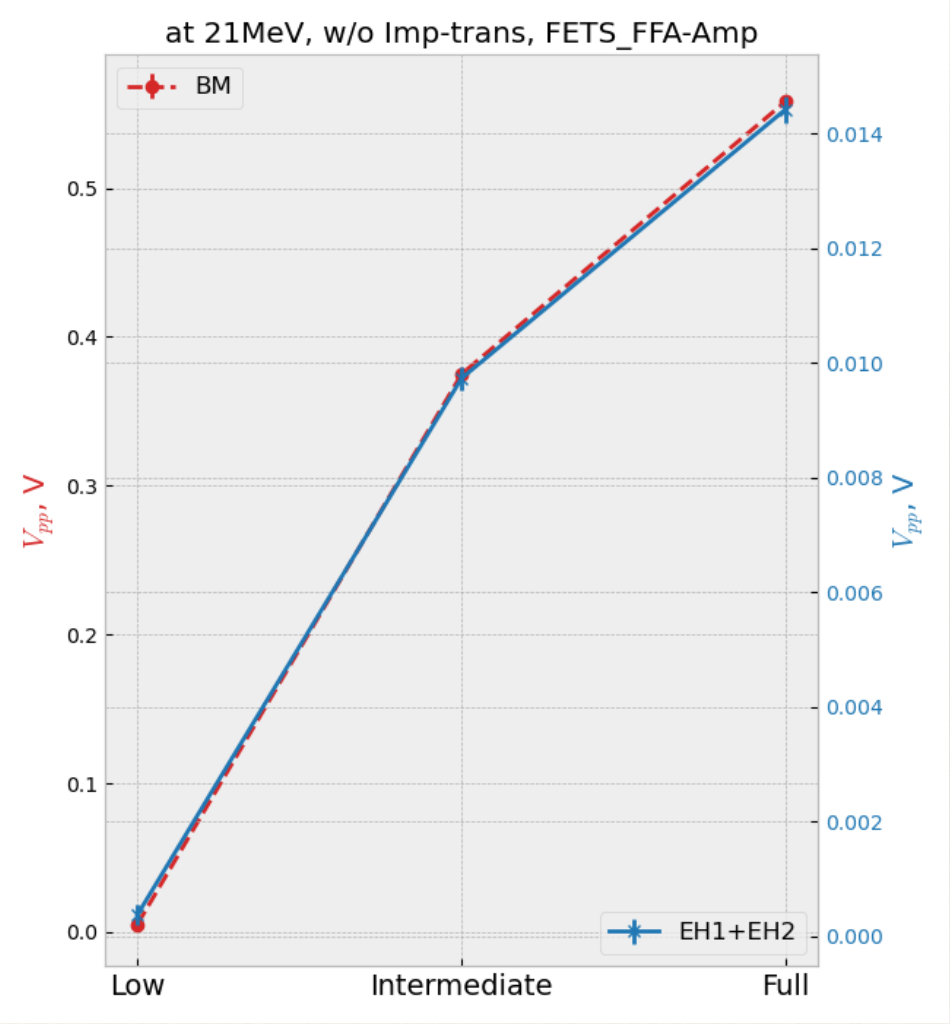


Fig.1.Amplitude dependency of sum signal of horizontal BPM on beam intensity (blue) and KURNS BM (red).

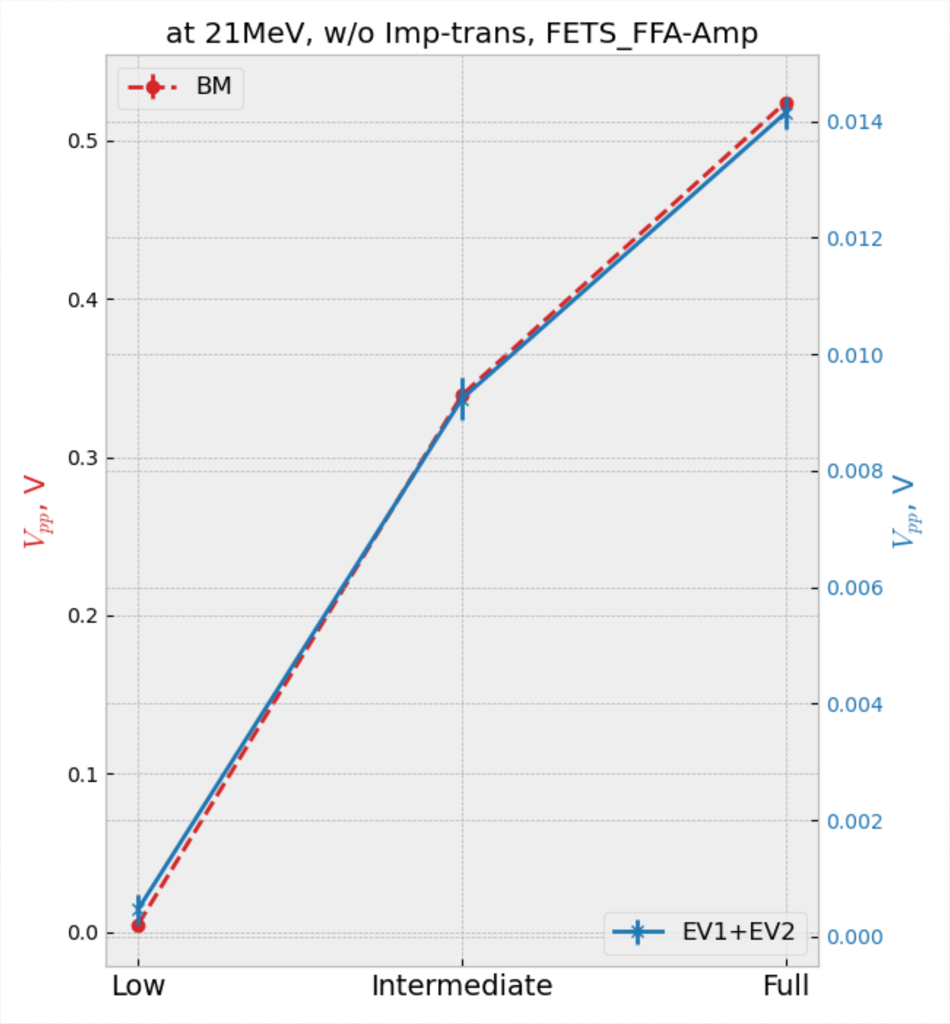


Fig.2. Amplitude dependency of sum signal of vertical BPM on beam intensity (blue) and KURNS BM (red).

- **Amplitude dependency on beam intensity agreed with KURNS BM when FETS_FFA-amp is used.**

Beam signal vs beam intensity w/o Imp-Trans + NF amp

- Background signal (beam-off) was subtracted from each electrode signal.
- BPF (500kHz-2.0MHz) was applied on each data.
- Peak-to-peak amplitude (V_{pp}) at FT were computed with different beam intensities

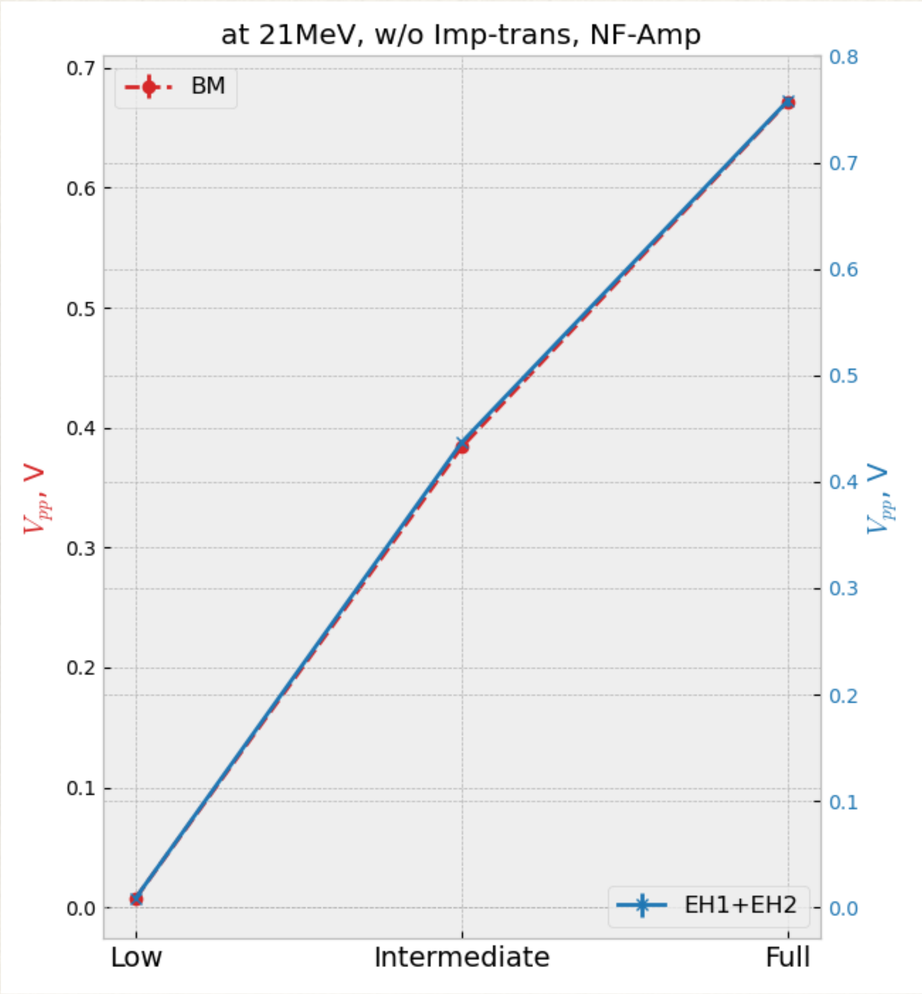


Fig.1.Amplitude dependency of sum signal of horizontal BPM on beam intensity (blue) and KURNS BM (red).

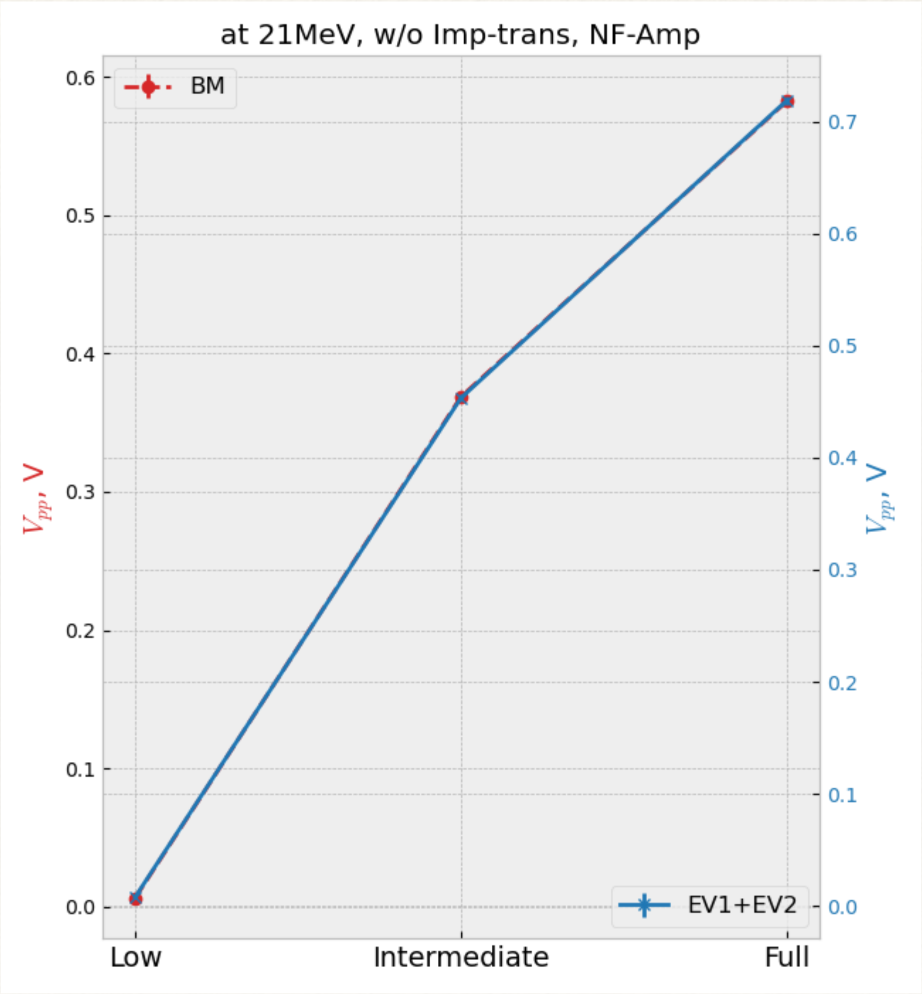


Fig.2. Amplitude dependency of sum signal of vertical BPM on beam intensity (blue) and KURNS BM (red).

- **Amplitude dependency on beam intensity agreed with KURNS BM when NF-amp is used.**

Horizontal beam positions w/o Imp-Trans + NF/FETS_FFA-Amp

- Horizontal beam position is computed at **full/Intermediate/Low beam intensity** using pre-measured position sensitivity (K) and offsets (δ): $\frac{dU}{\Sigma U} = Kx + \delta$: *K=-0.00512, δ=0.00236.*
- BPF between 500kHz and 2MHz was applied on background subtracted signals.

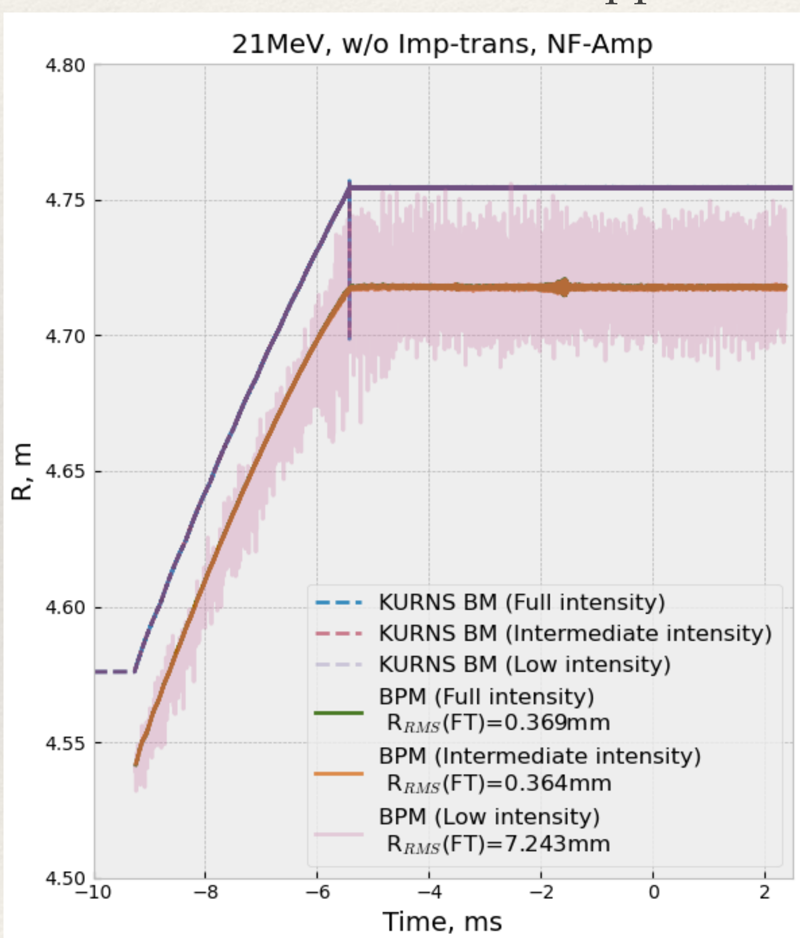


Fig.1. Measured beam position by BPM (line) and KURNS BM (dashed) with NF-Amp in different beam intensity.

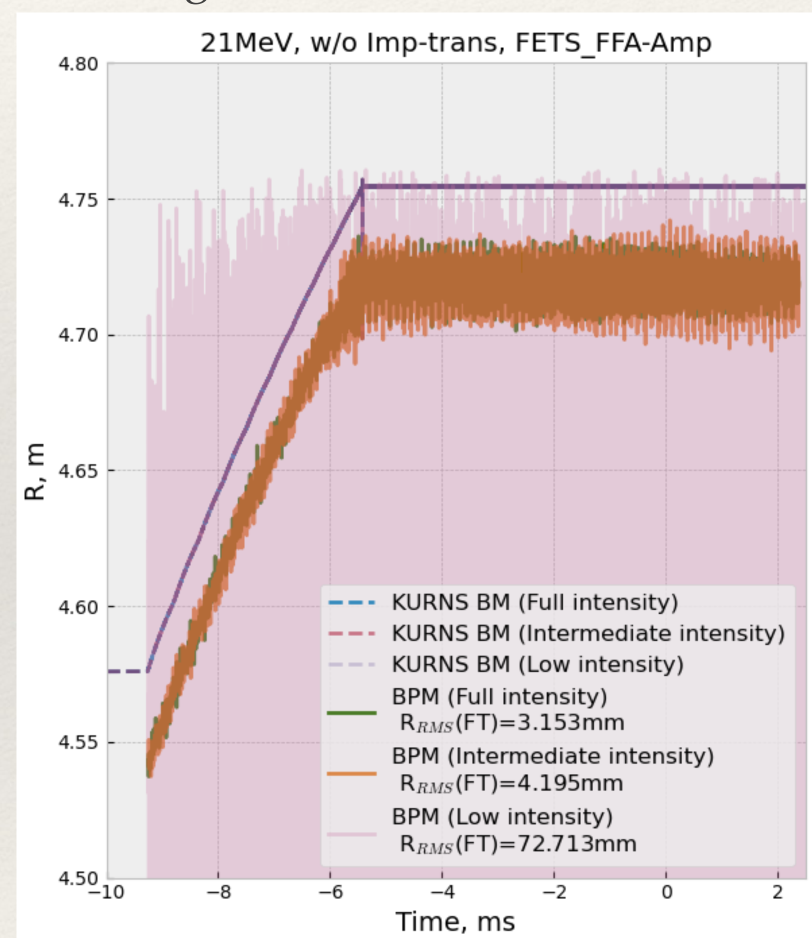


Fig.2. Measured beam position by BPM (line) and KURNS BM (dashed) with FETS_FFA-Amp in different beam intensity.

BPM beam positions are following the pattern of position change predicted by KURNS BM. As signal to noise ratio is lower when FETS_FFA-Amp is used, position jitter is large, hence lower position resolution.

Vertical beam positions w/o Imp-Trans + NF/FETS_FFA-Amp

- Vertical beam position is computed at **full/Intermediate/Low beam intensity** using pre-measured position sensitivity (K) and offsets (δ): $\frac{dU}{\Sigma U} = Kx + \delta$: K=-0.0342, δ=0.0005.
- BPF between 500kHz and 2MHz was applied.

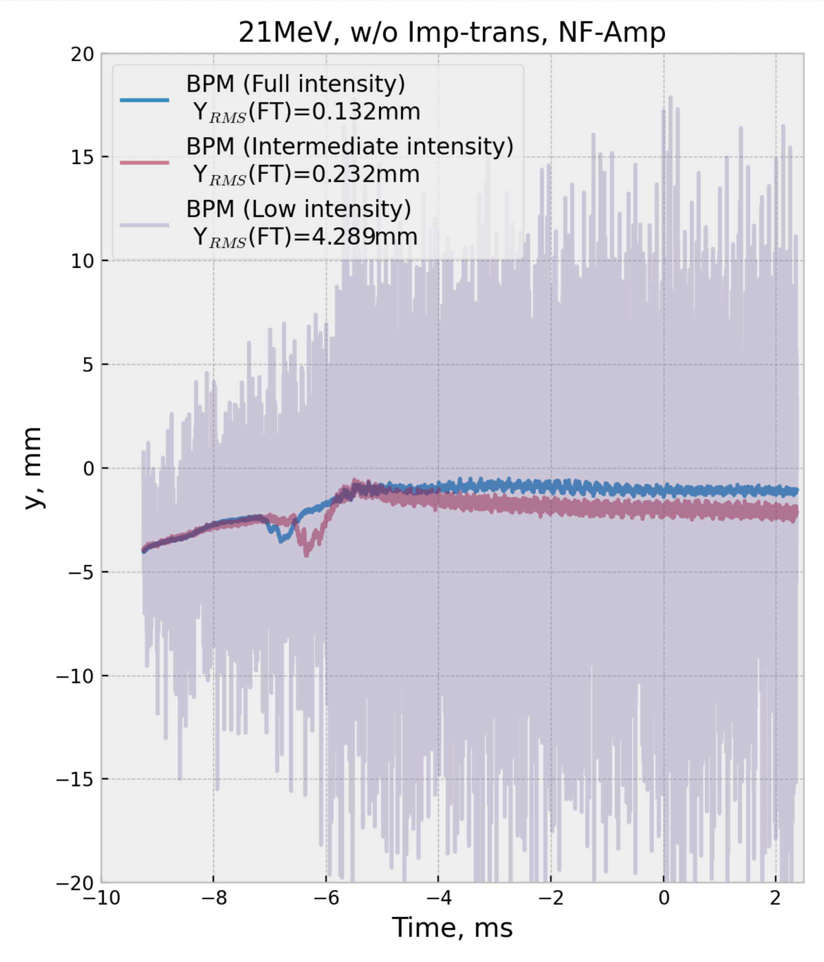


Fig.1. Measured beam position with different beam intensities when NF-amp was used.

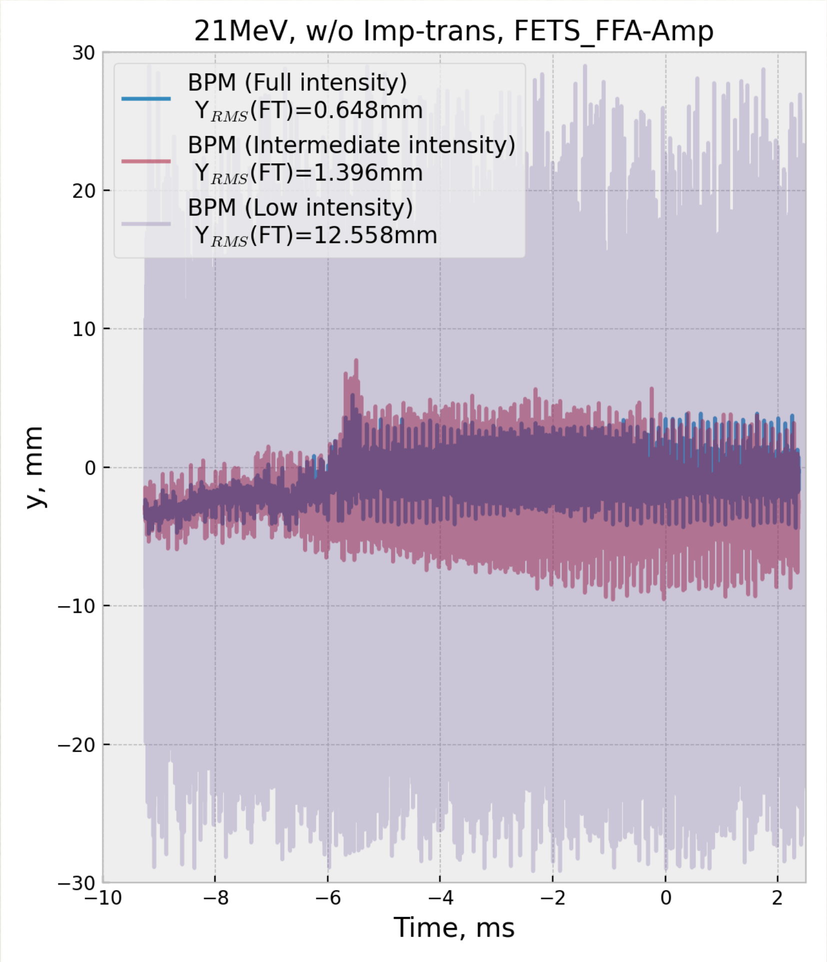


Fig.2. Measured beam position with different beam intensities when FETS_FFA-amp was used.

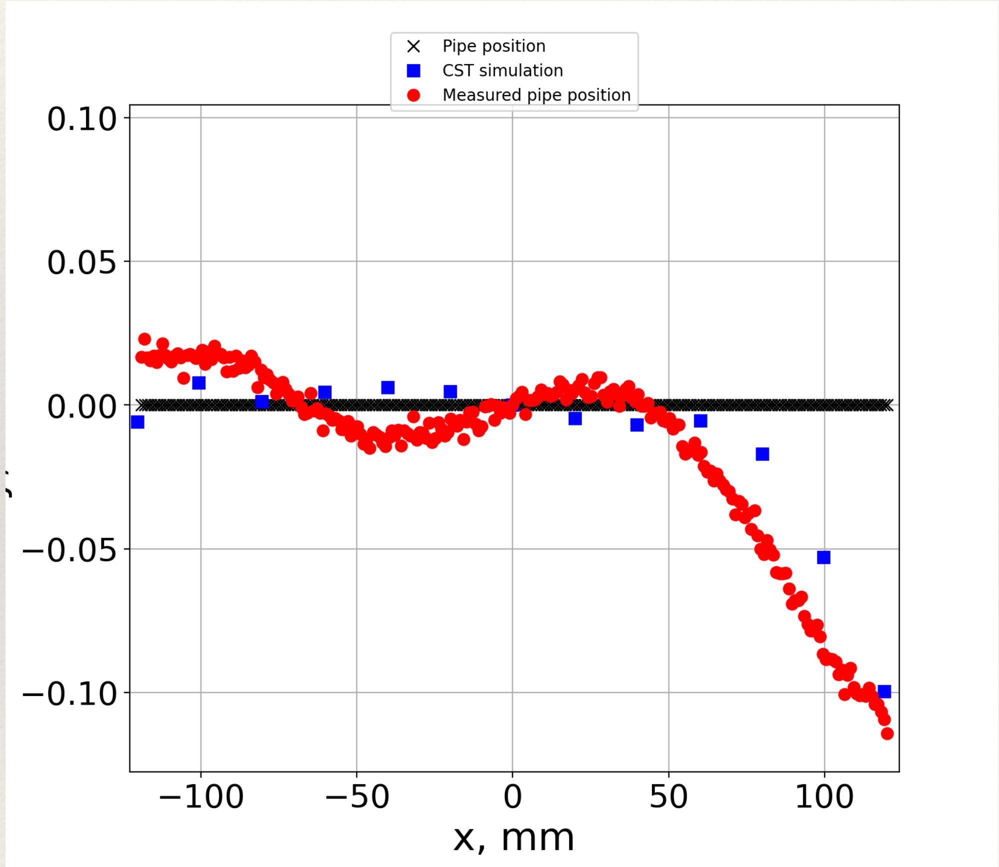


Fig.3. Estimated (CST) and measured probe positions at test bench at Diag. Lab in ISIS.

- ***Vertical beam position is moving over the energy range and displaced from the centre of BPM. The centre position of BPM might not be adjusted to the beam mid-plane, non-linearity around the edge or real?***

Bunch shape w/o Imp-Trans + FETS_FFA-Amp

- Impedance transformers (Imp-Trans) were removed from feedthroughs and FETS_FFA-Amp (50Ω) used.
- Background signal (beam-off) was subtracted from electrode signals, but no filtering.
- Electrode signal was integrated when full beam intensity.

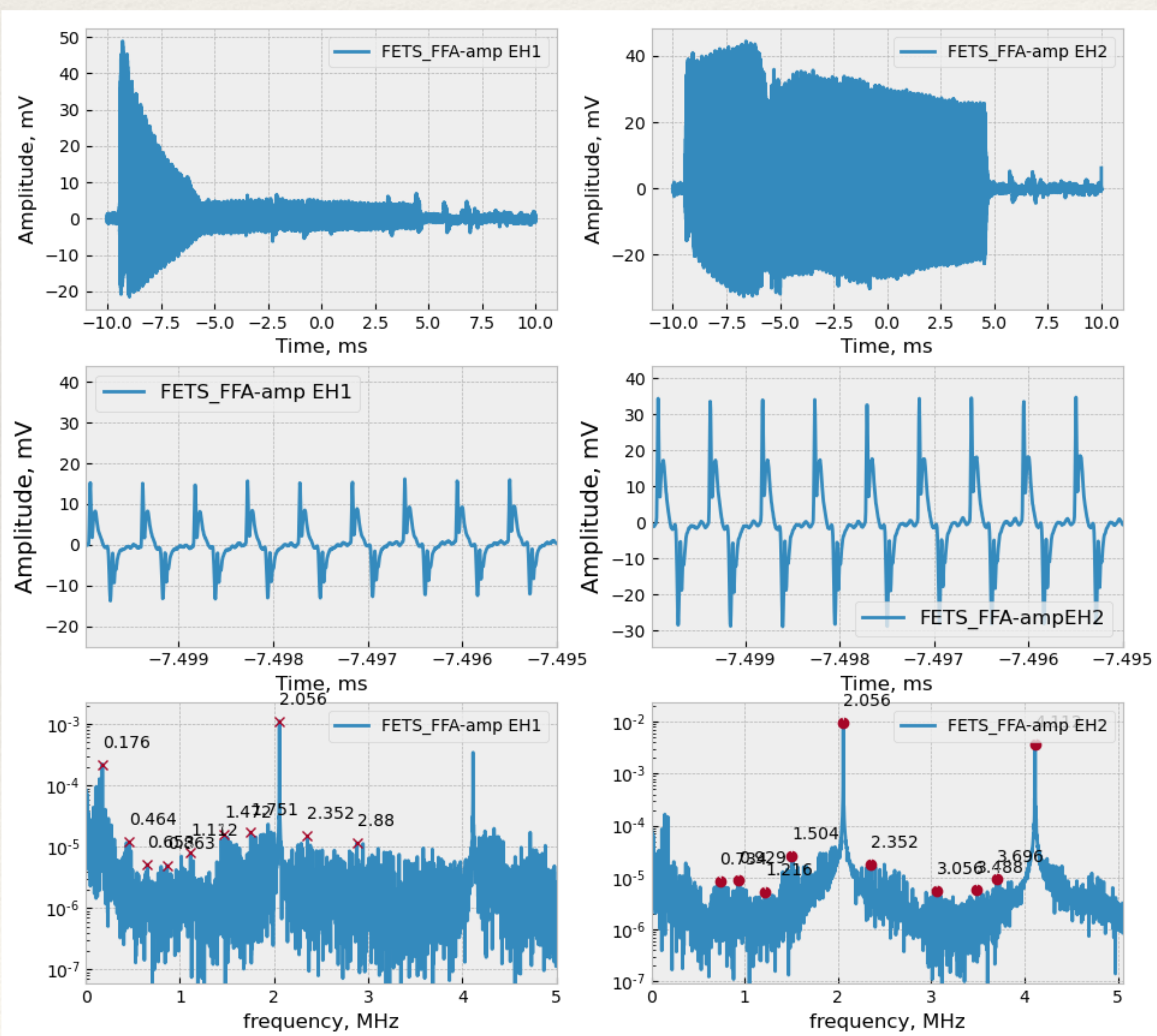


Fig.1. Raw signals of horizontal electrodes with FETS_FFA-amp (top four figures) and its FFT (bottom two figures).

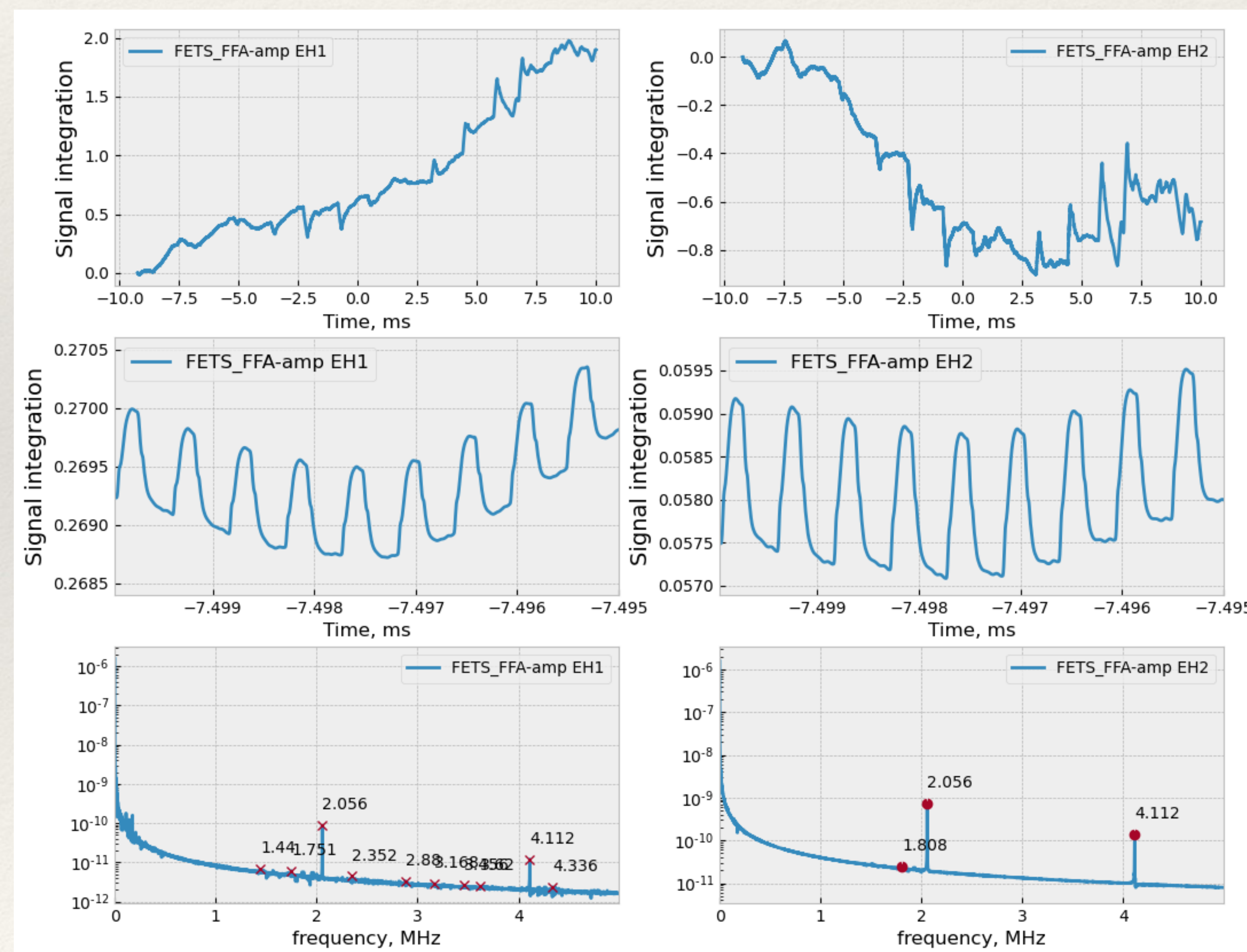


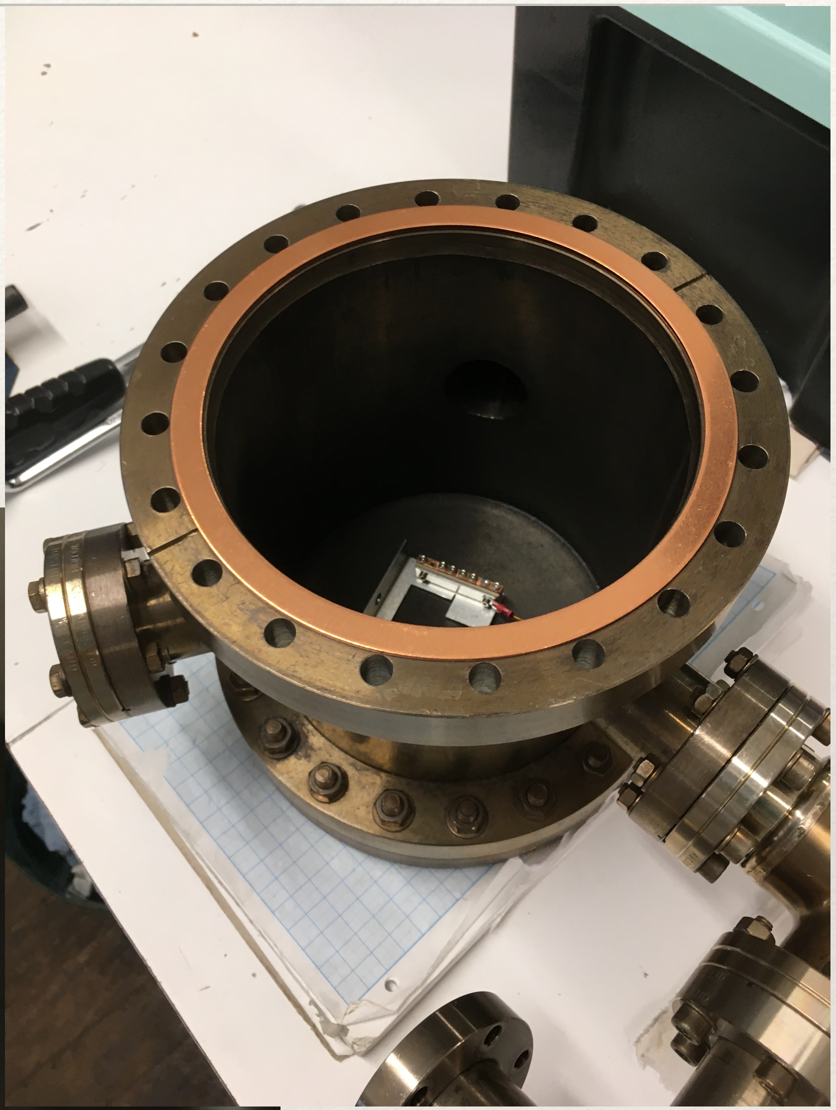
Fig.2. Signals integration of EH1 (left side) and EH2 (right side) with FETS_FFA-amp. Bottom plots show FFT analysis of each signal.

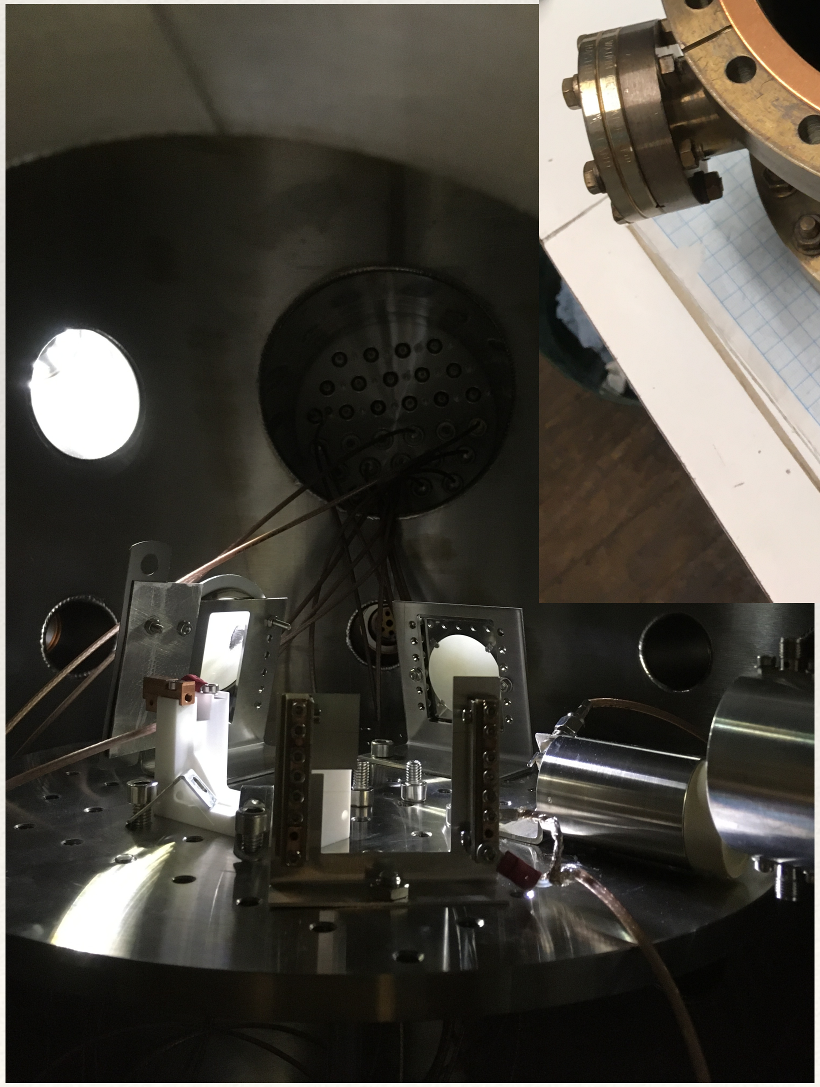
Summary and future plan

- Turn by turn position measurements can be achieved by capacitive pickup type of BPM (FETS-FFA BPM) in FFA ring.
- To improve signal to noise ratio, impedance transformer will be modified:
  - small number of winding number.
  - damping resistor will be installed in series before impedance transformer.
  - top side of BPM box will be electrically grounded to the KURNS vacuum chamber.
- For the next beam test (whenever possible),
  - Check the electronics/ground connection effects on measurements.
  - Push BPM box outward to measure beam position in full aperture of BPM.
  - Resolution analysis by PCA method.

WSM Baking

- CNT wires and frame were baked out in baking chamber:
  - 250C for 3 days (1e-7 Pa)
  - 100C for 4 days (1e-7 Pa)
  - 150C for 7 days (1e-7 Pa)
- Applying DC current on 40um wire to heat up.
  - 50mA for 4.5m
  - 50mA for 4.5h + 55mA for 2.5h
  - 55mA for 3.7h





Bake SWCNT by Baking chamber

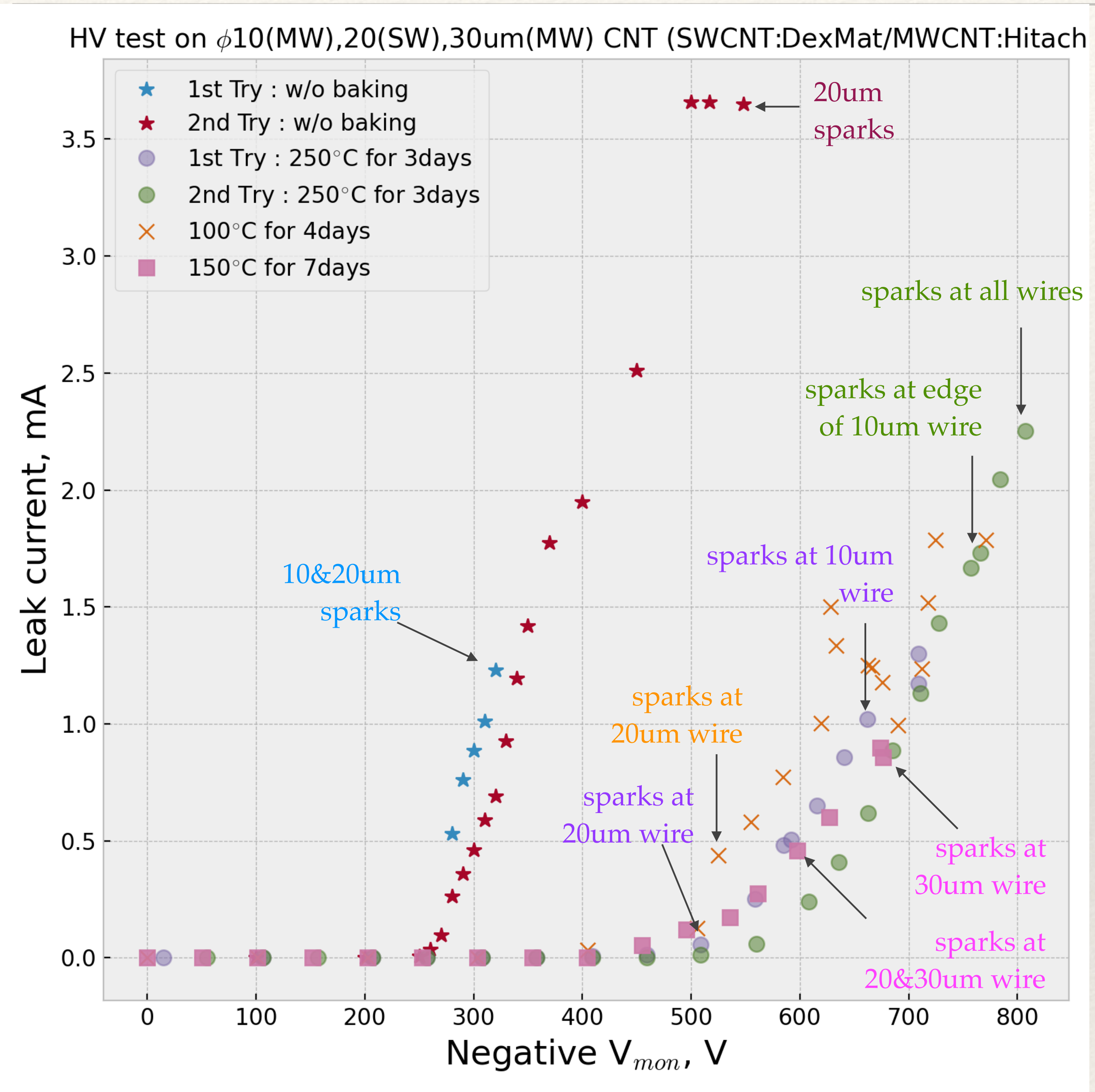


Fig.1. Leak current with a function of negative voltages.

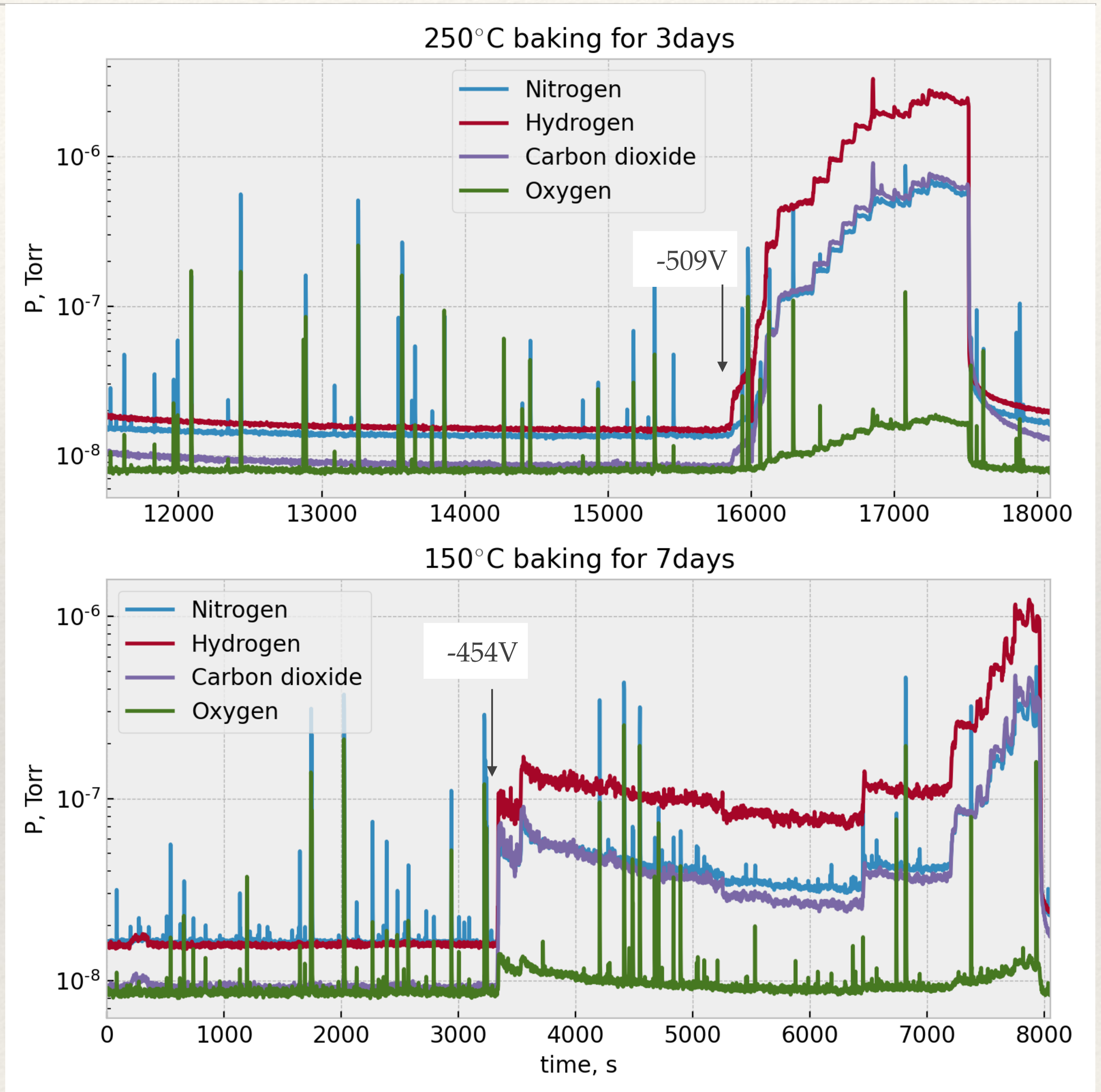
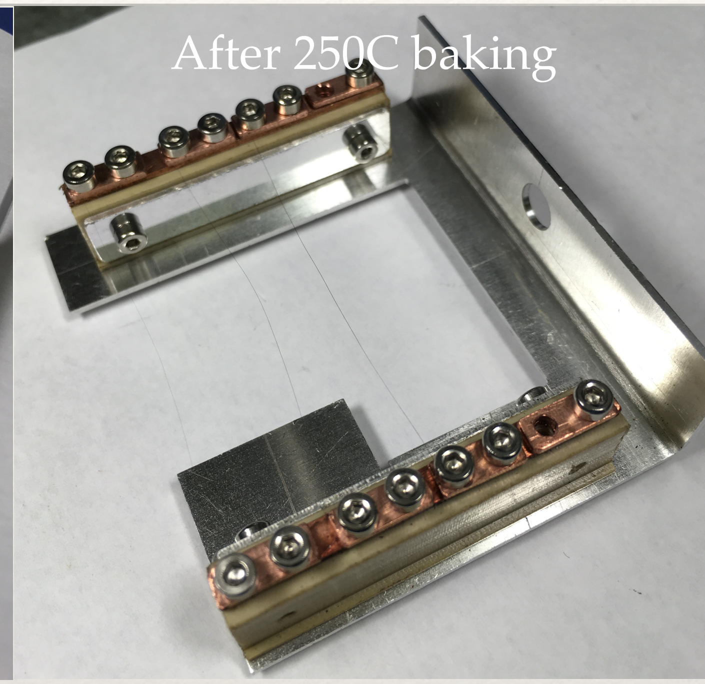
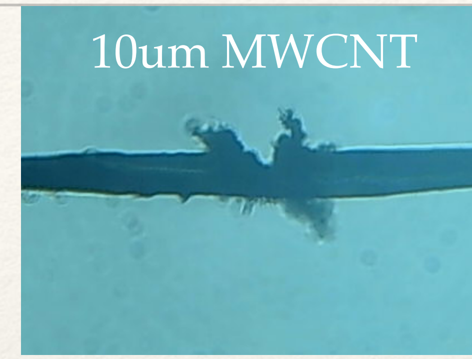


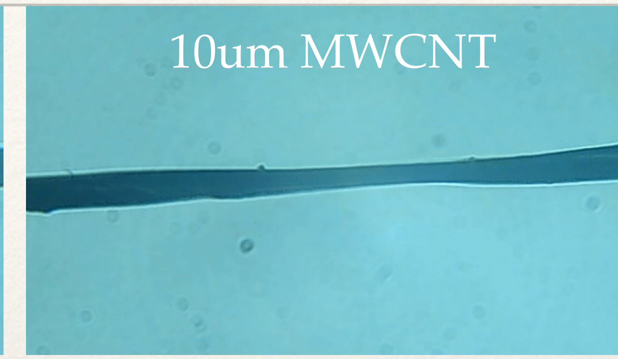
Fig.2. Residual gas during HV tests on multi wires baked out at 250C (Top) and 150C (bottom)

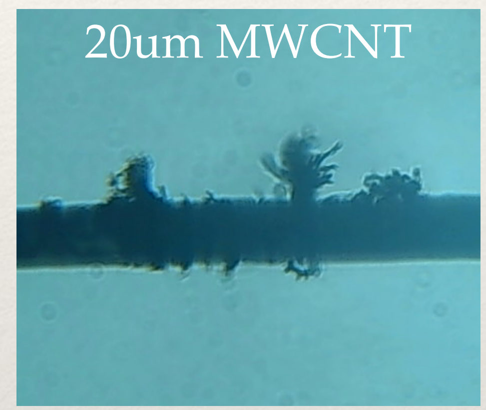
Baking with 150°C shows a good performance. Baking at 150C or 200C for a few days would be a beneficial to apply voltage higher.

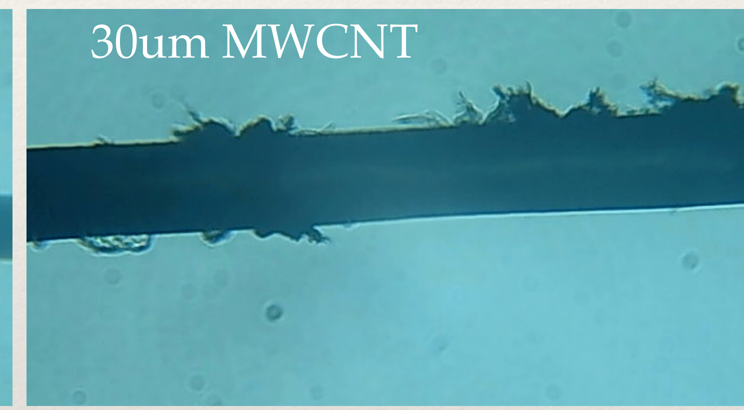
Bake SWCNT by Baking chamber

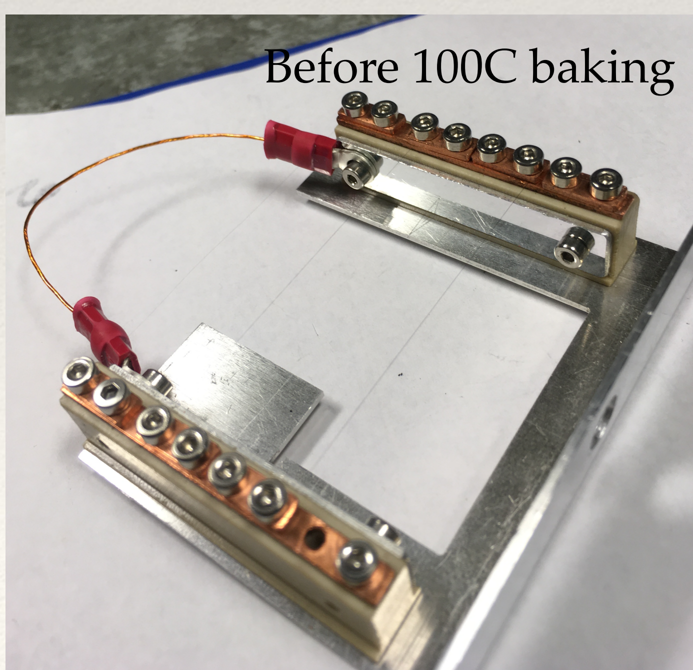


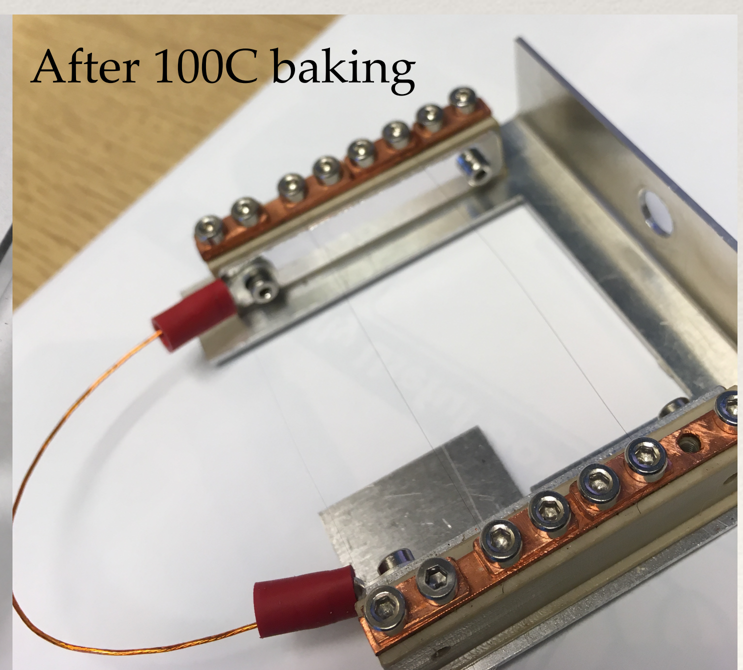


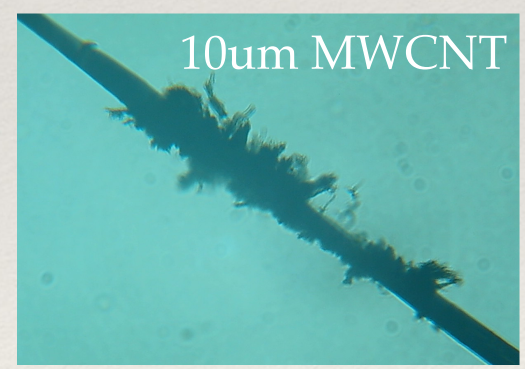


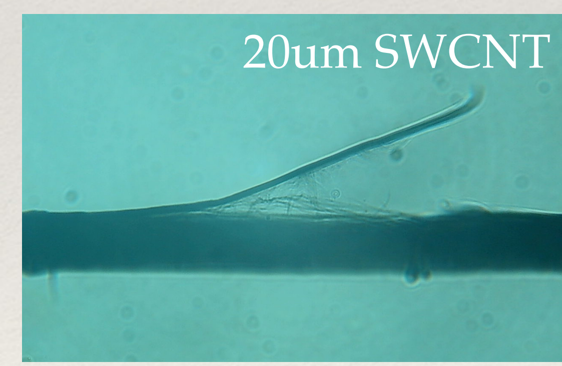


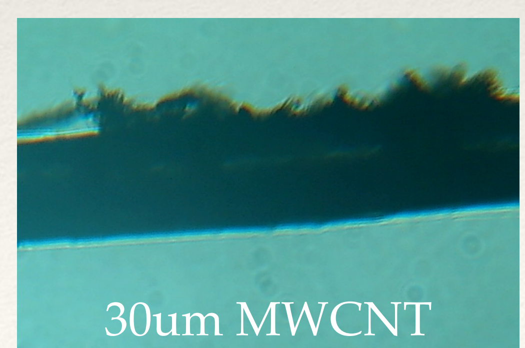


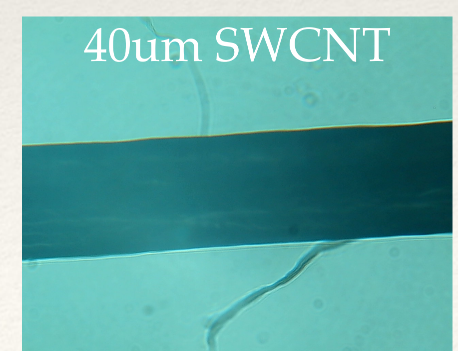












Bake SWCNT by DC currents

- Applying DC current on 40um wire to heat up.
  - New wire with 50mA for 4.5m (1. Dec.)
  - Old wire with 55mA for 2.5h (7. Dec.), including 50mA for 4.5h (1. Dec.)
  - New wire with 55mA for 3.6h (14. Dec.)
- When drive current was higher than 50mA, the difference in residual gas was observed.

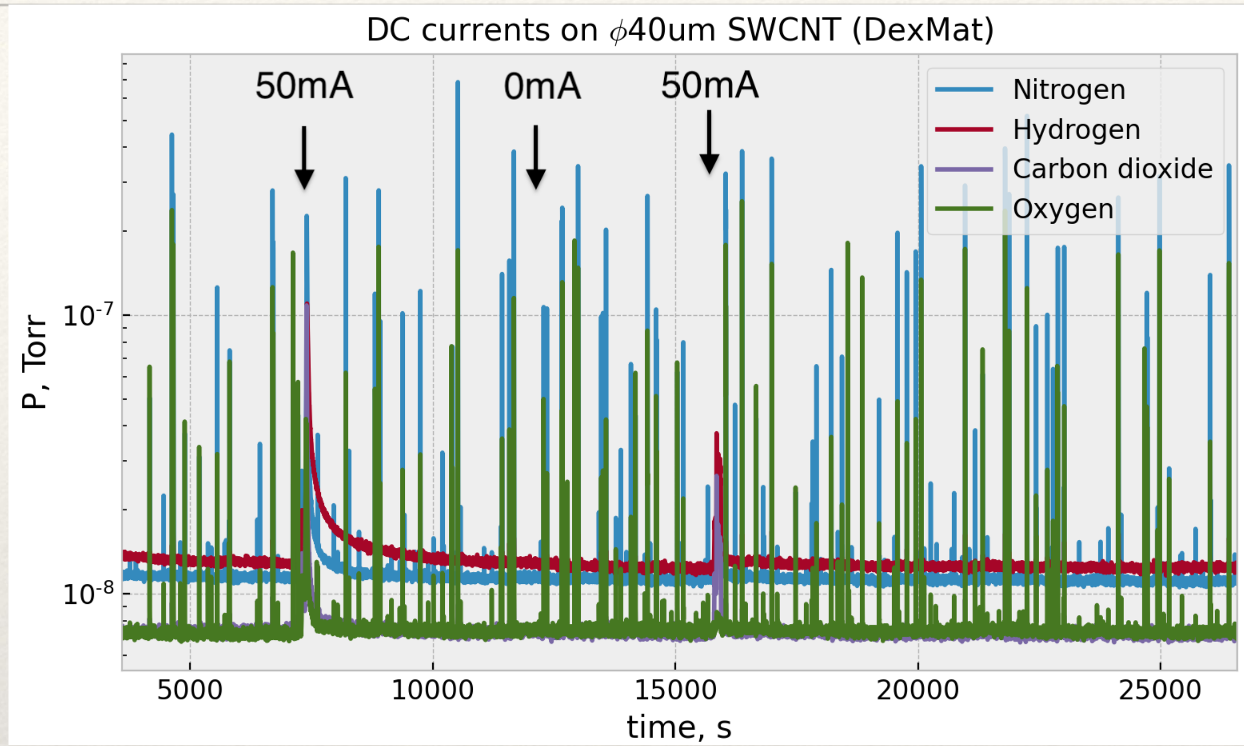
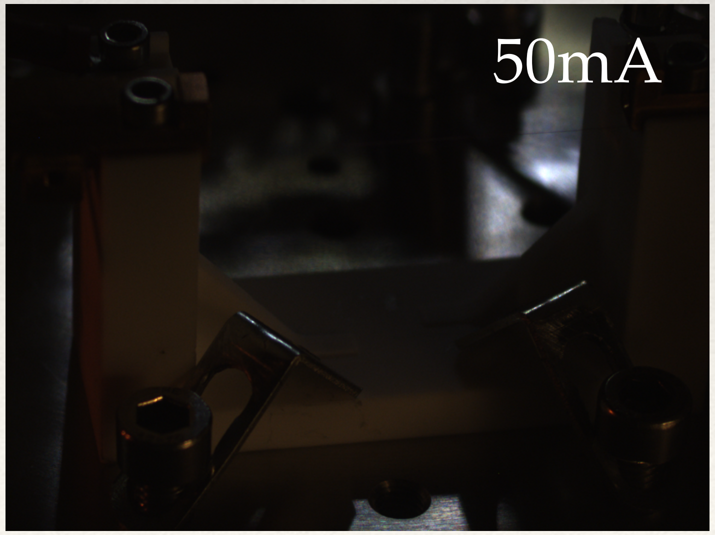


Fig.1. Residual gas monitor while DC current was applied on wire.

- Joule heat of 40um CNT = RI^2t, (assuming R=50Ω and 50mA for 3.6h = 1.296kJ)
- Spec heat (Cp) of CNT wire at room temperature ~ 750 J/kg/K.
- Assuming density of CNT is 1400 kg/m3, length of CNT is 50mm, Mass = 87.96e-9 kg
- Expected temperature = $RI^2t/C_p/V_{CNT}$ ~ 25e6 K!!



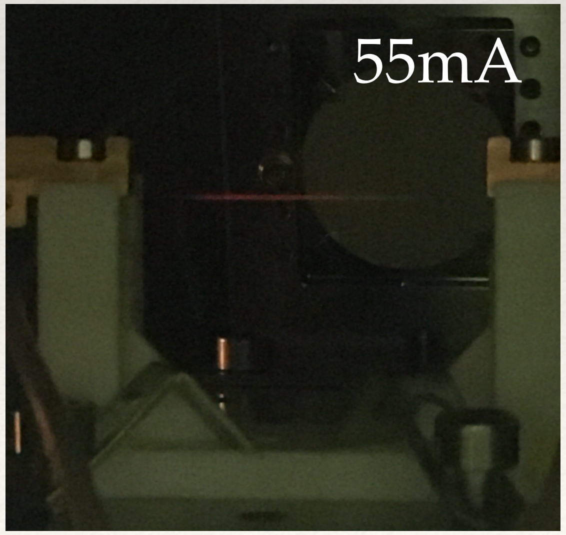
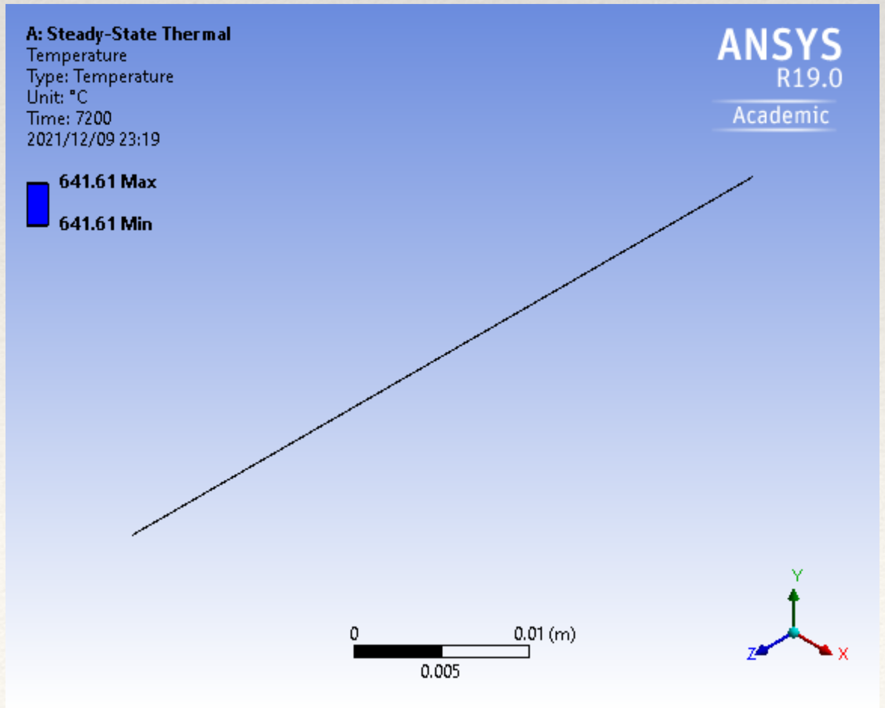


Fig.1. Pictures of Φ40um CNT wire applied DC current at 50mA and 55mA.

Bake SWCNT by DC currents

- Applying DC current on 40um wire to heat up.
  - New wire with 50mA for 4.5m (1. Dec.)
  - Old wire with 55mA for 2.5h (7. Dec.), including 50mA for 4.5h (1. Dec.)
  - New wire with 55mA for 3.6h (14. Dec.)
- When drive current was higher than 50mA, the difference in residual gas was observed.



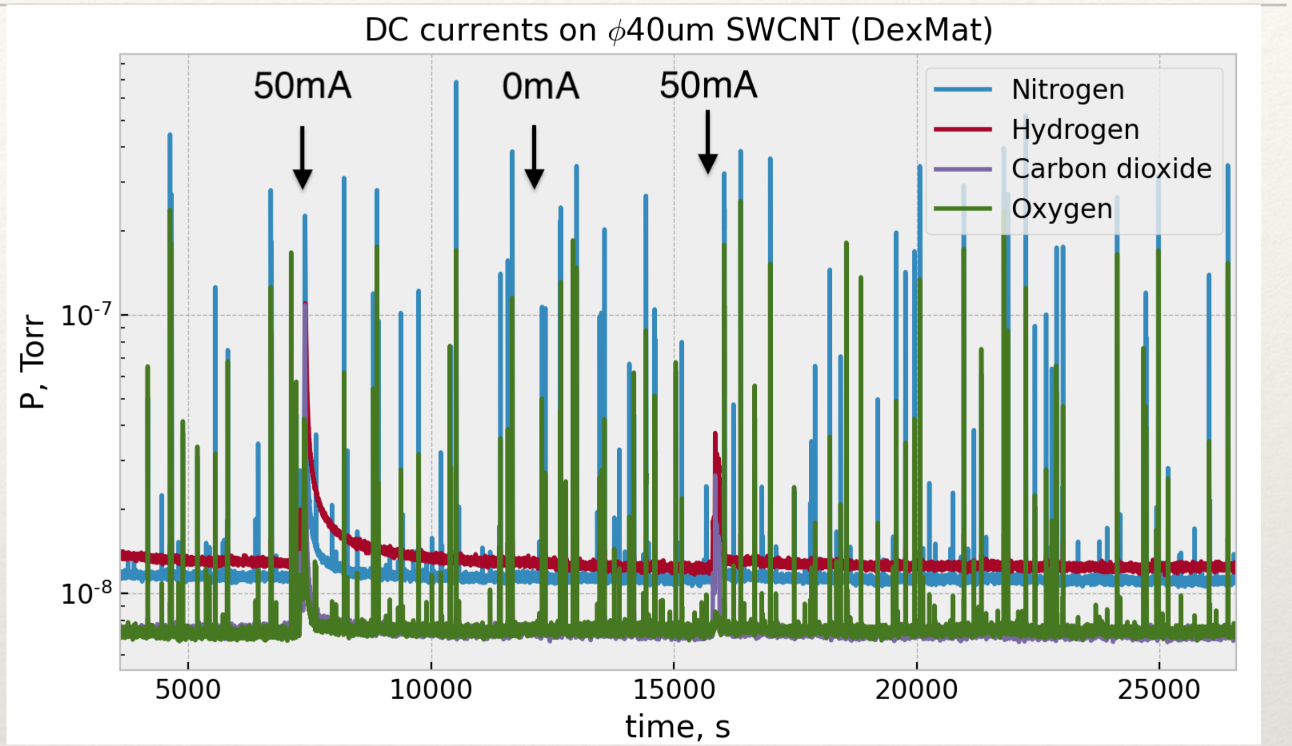


Fig.1. Residual gas monitor while DC current was applied on wire.

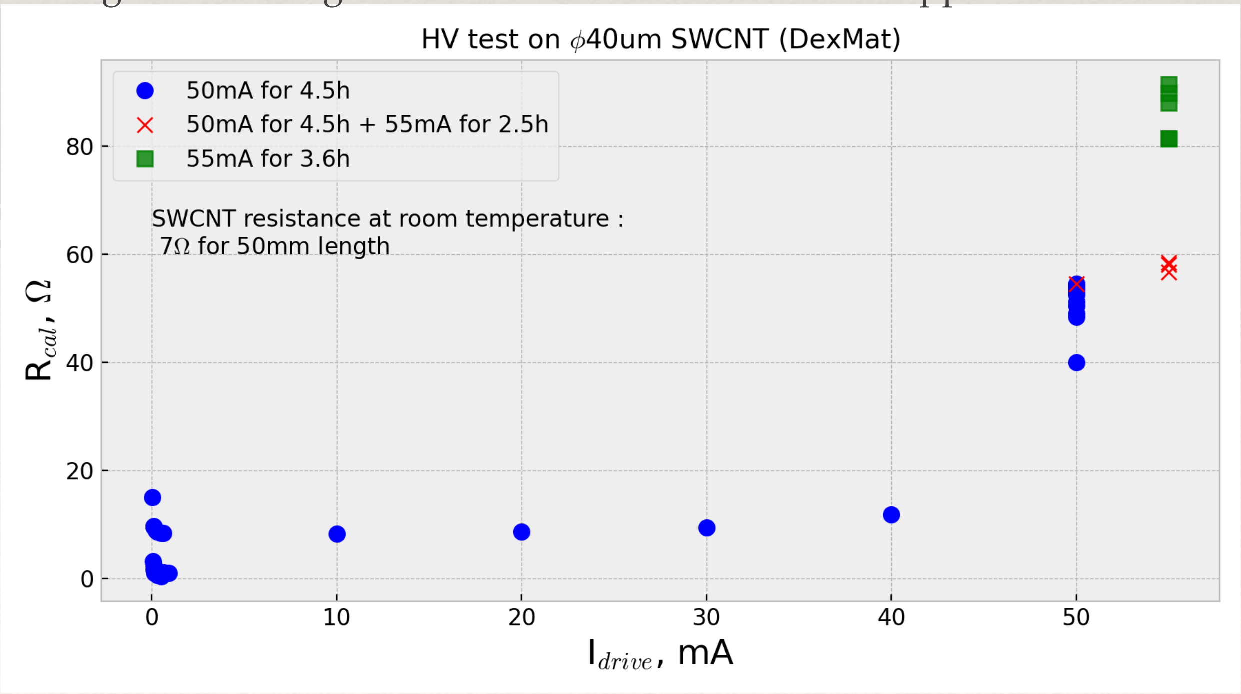


Fig.2. Calculated wire resistance with a function of drive DC currents.

Bake SWCNT by DC currents

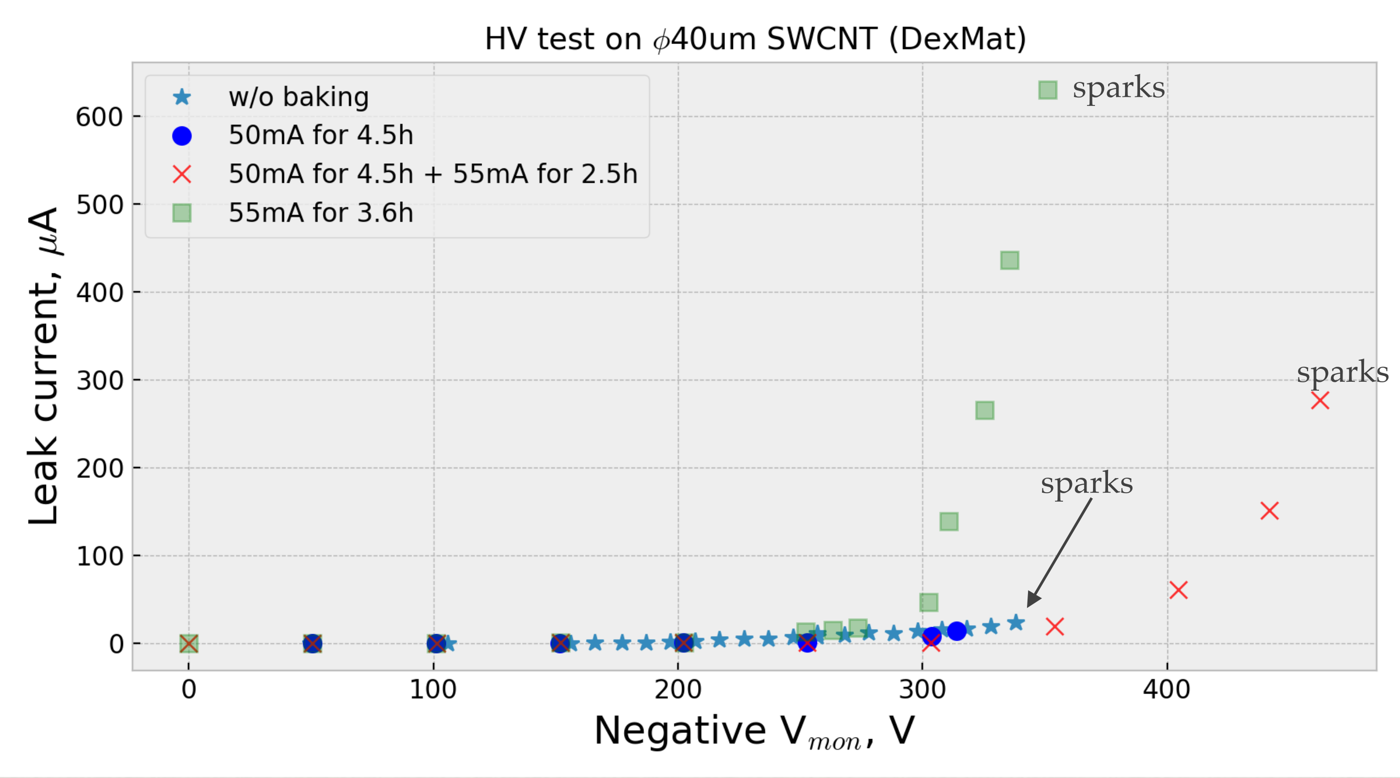


Fig.1. Leak current with a function of negative voltages.

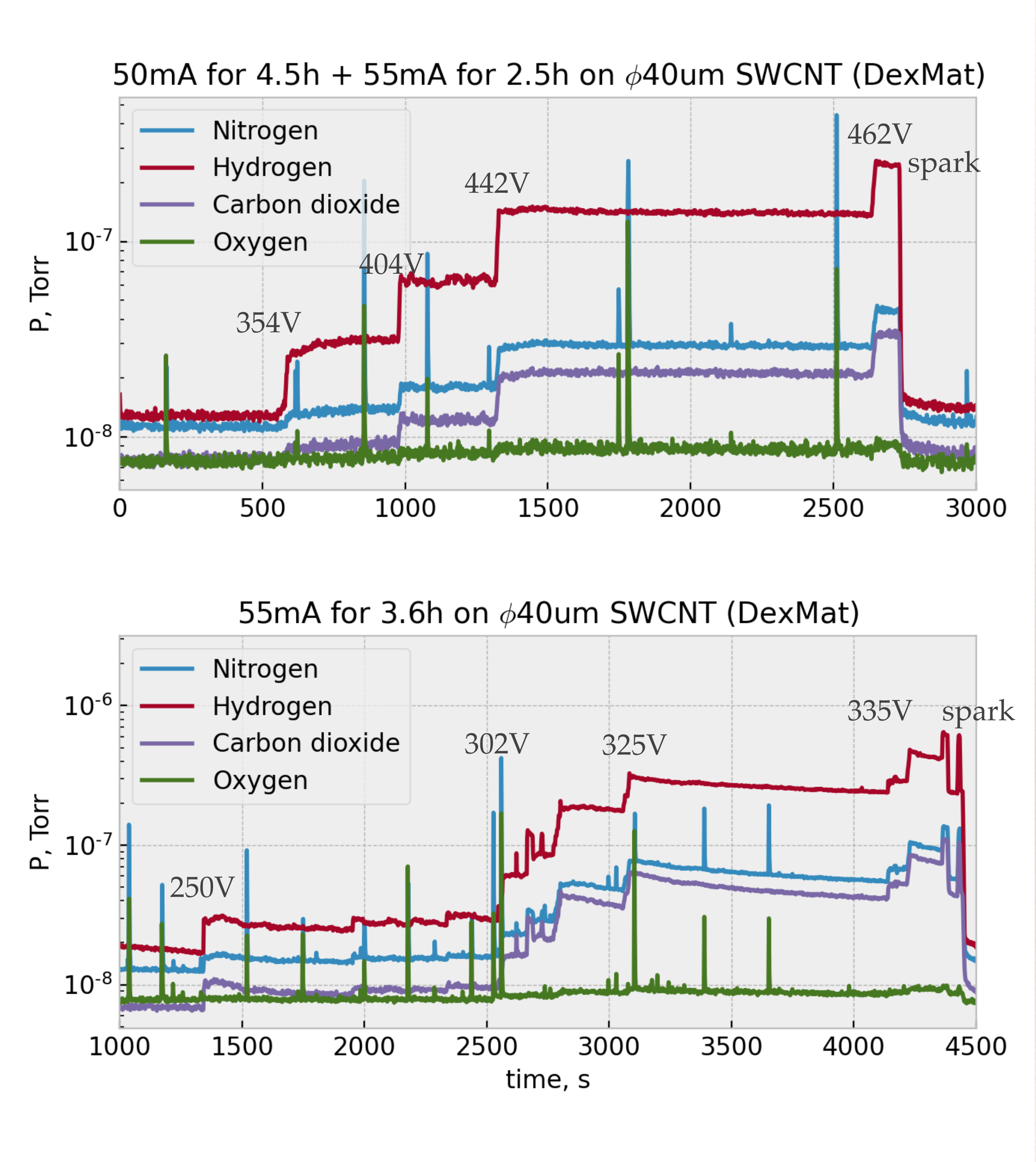
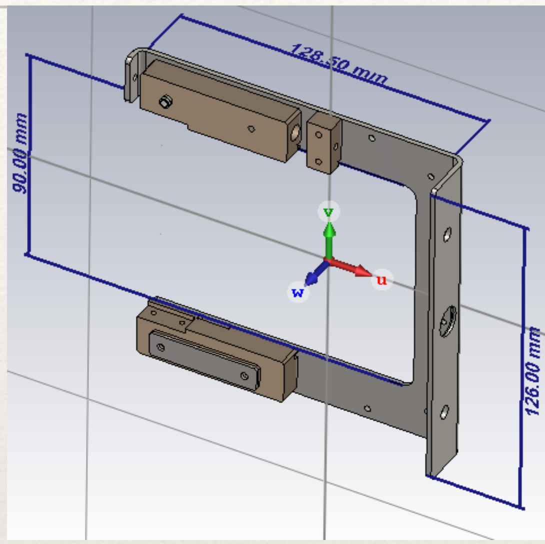


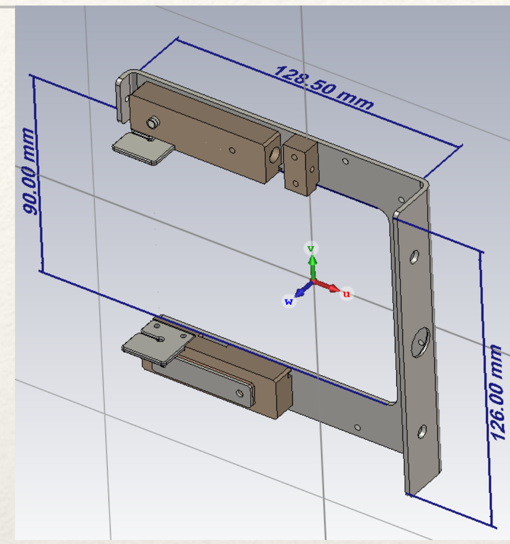
Fig.2. Residual gas in time during HV tests.

- Baking wire with DC drive currents mitigates electrical sparks on wire.
- But the voltage gain is about 1.4 comparing to the case for combination of baking with 50mA and 55mA.
- Baking with 55mA was too high for the wire, changing resistance and heating wire with HV easier.
- ***Baking at 50mA for many hours would be best solution.***

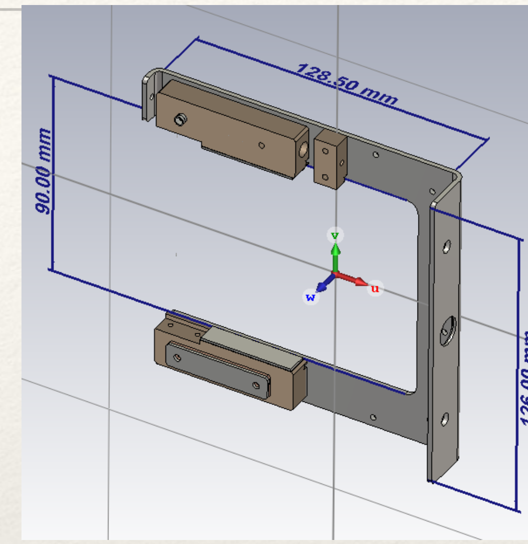
WSM required HV at KURNS tests



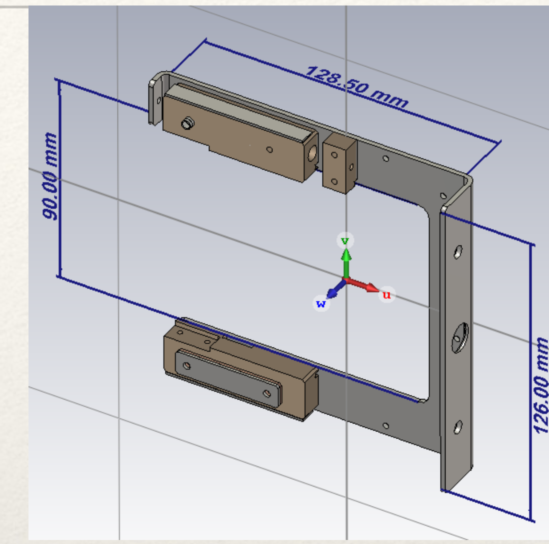
w/o shield plates



w/ slot plates



w/ short shield plates



w/ long shield plates

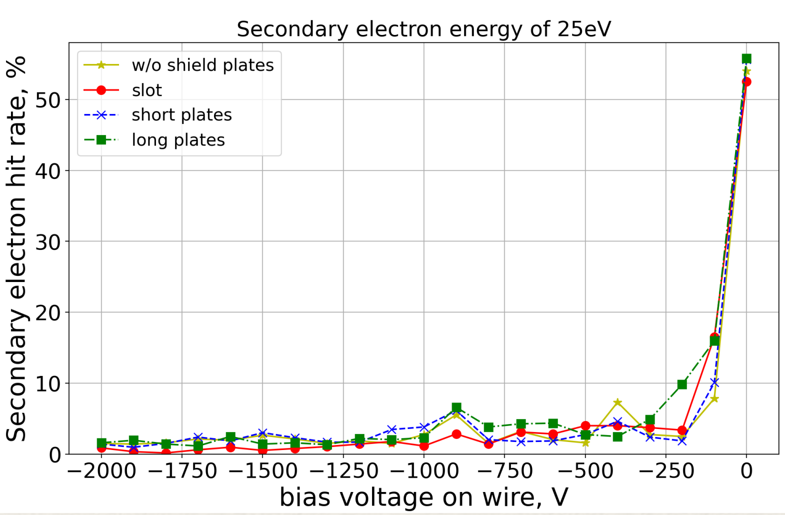


Fig.1. Bias voltage is applied only at wire.

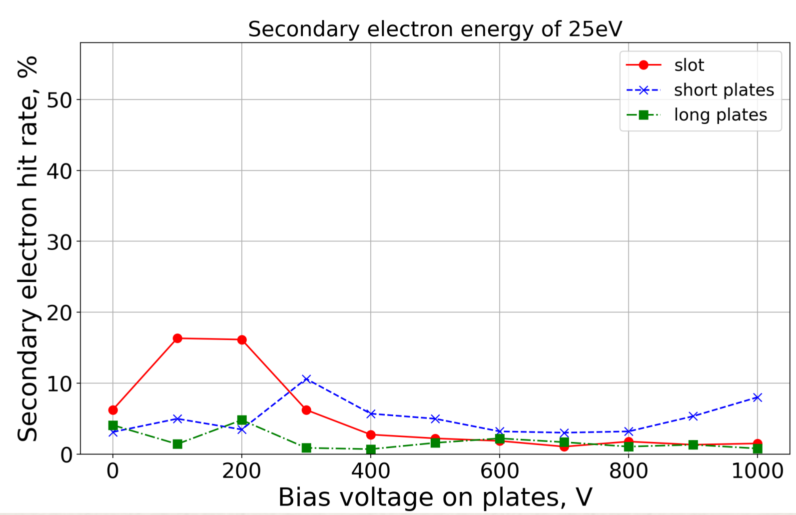


Fig.2. Bias voltage of -200V is applied at wire and positive bias voltage is applied on shield plates .

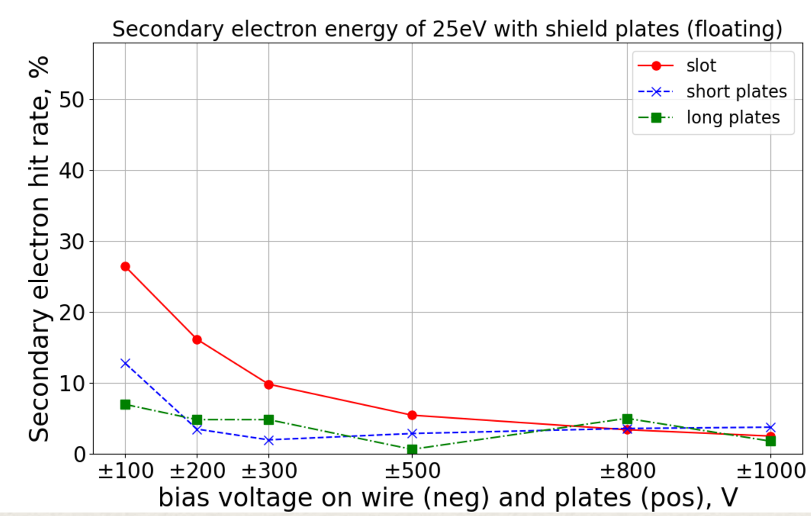


Fig.3. Bias voltages are applied at wire and shield plates with same amount but different polarity.

To mitigate an effect of stray fields of 0.05T at KURNS, -200V bias voltage will prevent more than 95% of secondary electrons (25eV) returning to the wire.

Summary and future plan

- Assemble the prototype FETS-FFA WSM
  - fixing a thin wire on spring is challenging!
- HV tests in Diag. Lab with 10 and 30um wire to be sure we can apply -200V without sparks.
- We will have a meeting with IMDEA in Madrid if they can provide better CNTs…
- KURNS beam tests next year…!!

Pre-measured position sensitivites

- Position sensitivities were measured with function of drive signal amplitudes at test bench in ISIS Diag. Lab.
    - Frequency of drive signal is 2 MHz.
    - Impedance transformer is used
    - FETS_FFA-Amp is used.