Status of the ChDR Bunch Length Monitor for Run 2c

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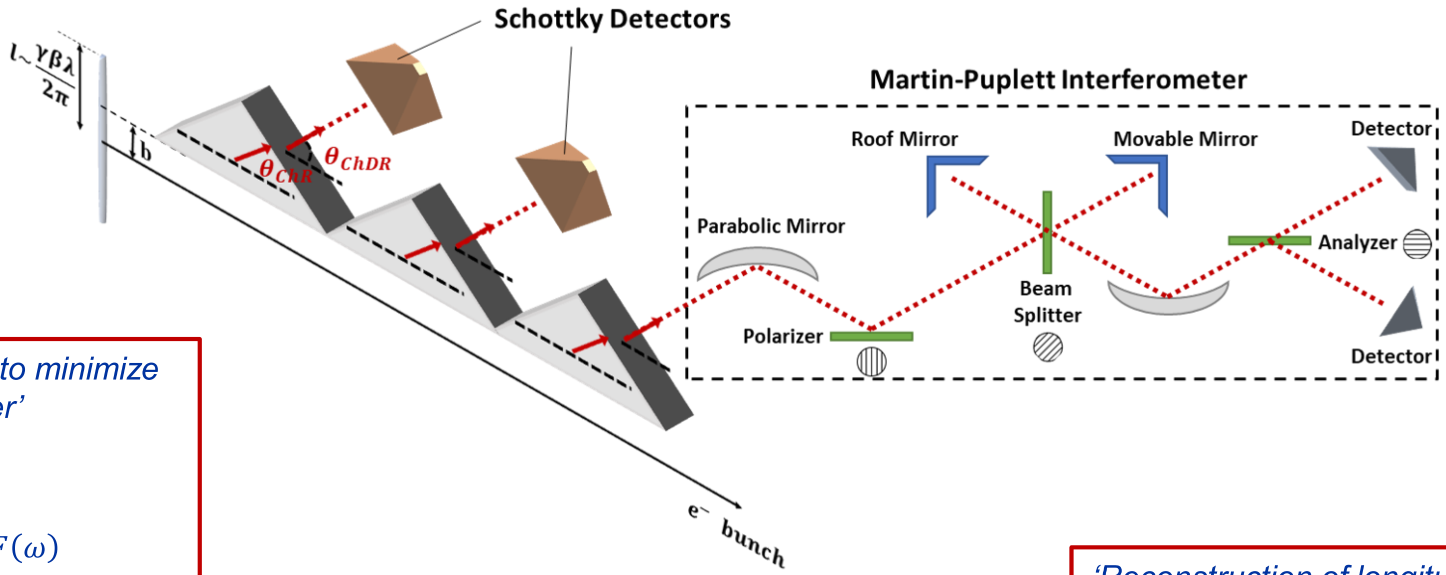
Bunch Length Monitor for AWAKE Run 2c

- Goal : Simultaneous RMS Bunch length & longitudinal profile measurement by using coherent Cherenkov diffraction radiation (ChDR)



'Suppression of bunch charge effects to minimize beam position & angular jitter'

$$\left[\frac{d^2W}{d\omega d\Omega}\right]_{rad} = N^2 \left[\frac{d^2W}{d\omega d\Omega}\right]_{single} F(\omega)$$

$$S(\omega) = N^2\, S_e(\omega)\, F(\omega)$$

$$\frac{S_1(\omega_1)}{S_2(\omega_2)} = \frac{S_{e1}(\omega_1)\cdot \exp(-k_1^2\sigma_z^2)}{S_{e2}(\omega_2)\cdot \exp(-k_2^2\sigma_z^2)}$$

$$\sigma_{z,rms} = \sqrt{\left|\frac{1}{k_2^2 - k_1^2}\cdot \ln\left(\frac{S_1(\omega_1)\cdot S_{e2}(\omega_2)}{S_2(\omega_2)\cdot S_{e1}(\omega_1)}\right)\right|}$$

Two independent methods provide a cross-check in the measurements.

'Reconstruction of longitudinal charge distribution'

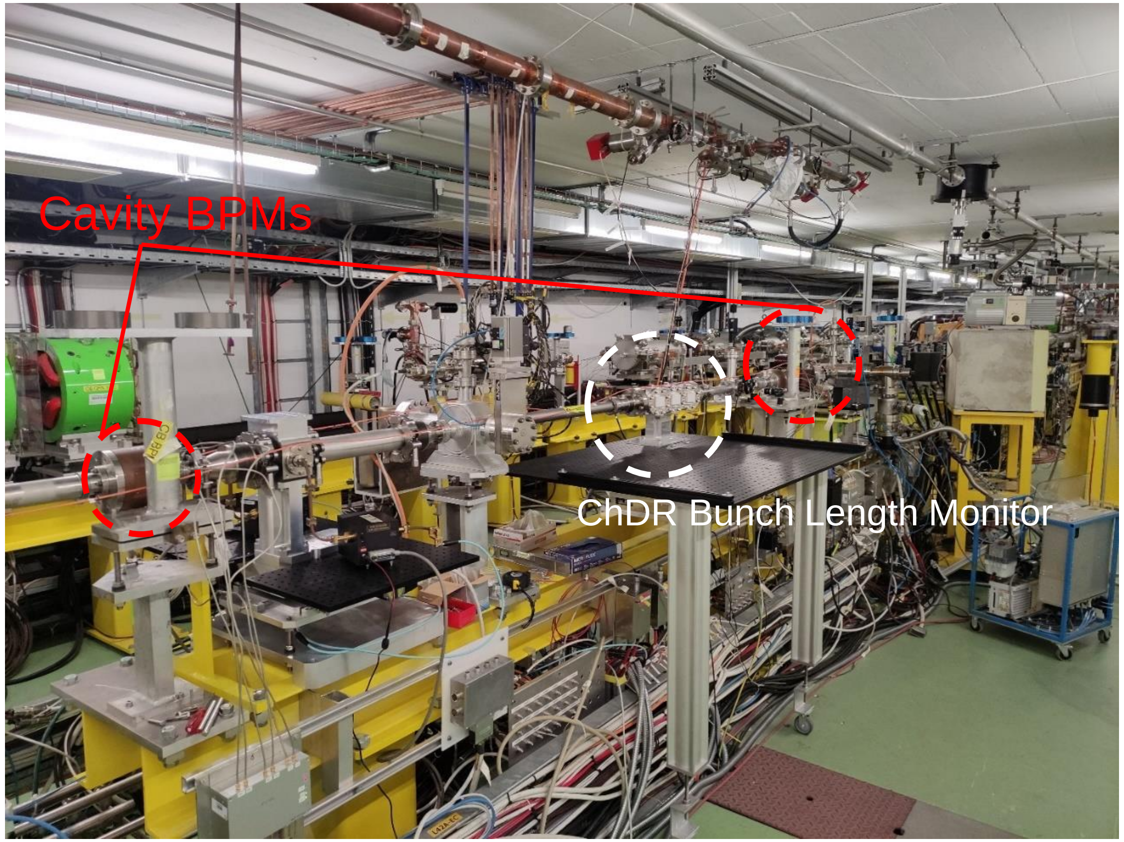
$$\left[\frac{d^2W}{d\omega d\Omega}\right]_{rad} = N^2 \left[\frac{d^2W}{d\omega d\Omega}\right]_{single} F(\omega)$$

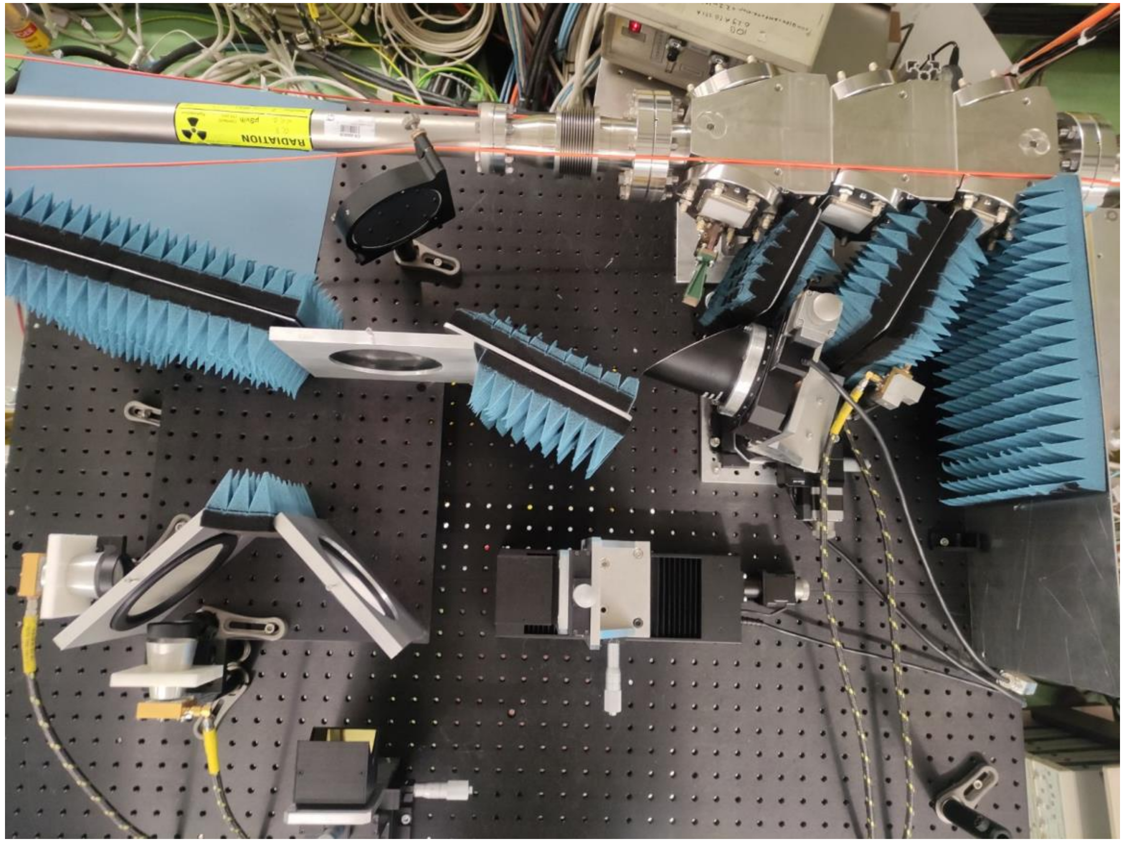
$$S(\omega) = N^2\, S_e(\omega)\, F(\omega)$$

$$\rho(z) = \frac{1}{\pi c}\int_0^\infty \sqrt{\frac{S(\omega)}{S_e(\omega)}}\,\cos\left(\Psi(w) - z\frac{\omega}{c}\right) d\omega$$

Installation for the Tests @CLEAR

- Installation of vacuum chamber, breadboard, supports and hardware has been completed in CLEAR test facility.





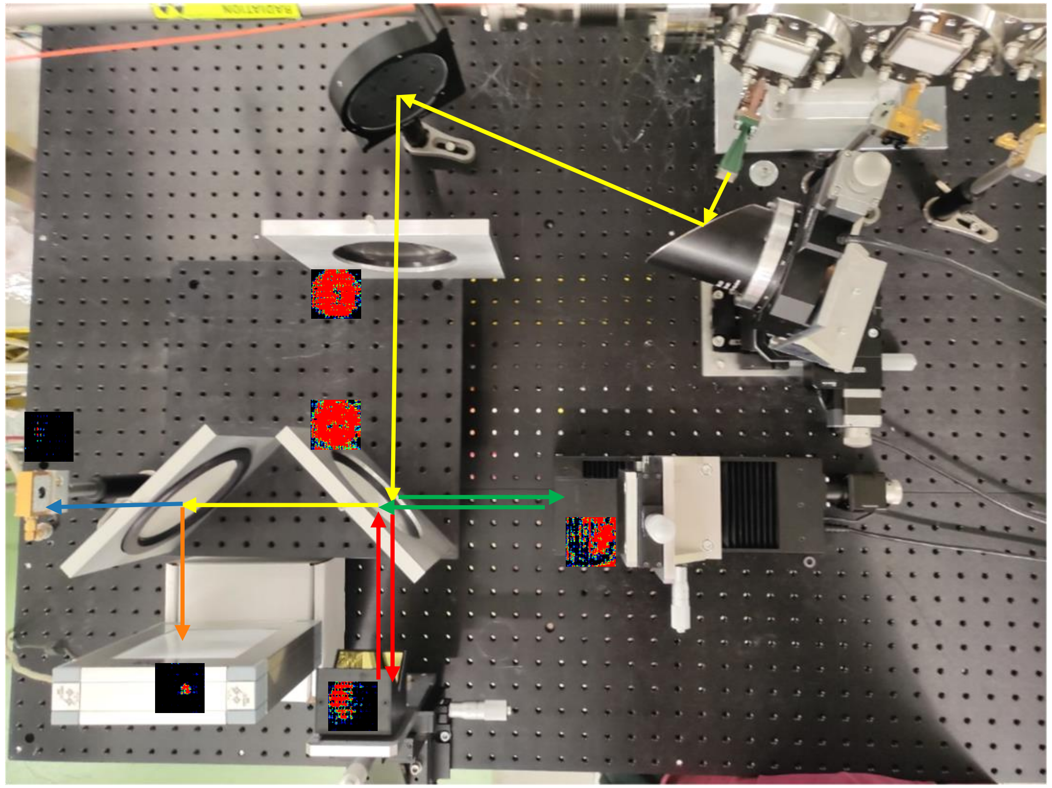
Test Schedule & Outlook

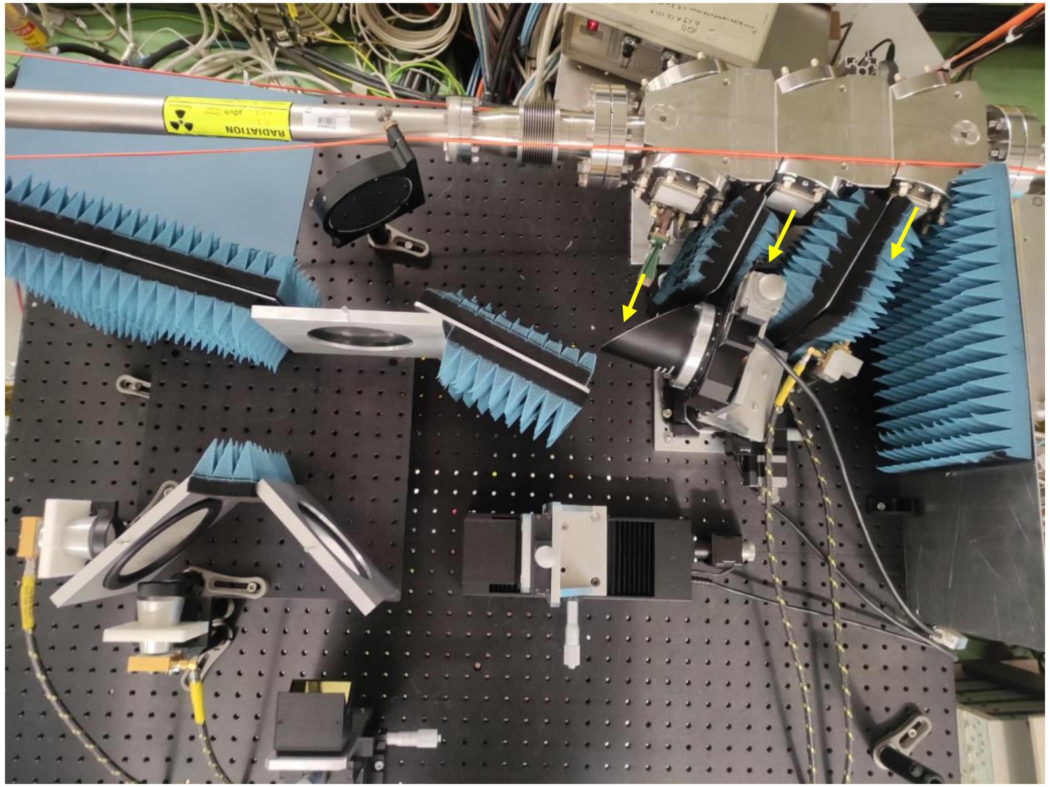
		Scheduled	Performed	Comment
	Installation of Vacuum Chamber	15th July	18th, 19th July	Leak Test completed on Tuesday evening.
	1st Test	18th – 22nd July	22nd, 23rd July (eq. 1 full day)	Poor data. 1st improvement of the system : • 20 dB attenuator between horn and Schottky diode
	2nd Test	22nd and 26th August	-	No data. RF deflector couldn't used for bunch length measurement.
	3rd Test (Night Shifts)	30th and 31st August	30th – 31st August (eq. 1 full day)	Poor data. 2nd improvement of the system. • THz lenses and metallic cone to shield the QODs
	4th Test	22nd September (parasitic measurement w/ChDR BPM)	-	No data. Klystron break down.
shared	5th Test	10th – 14th October (2.5 days)		
Dedicated beam time	6th Test	31st October – 4th November		
Dedicated beam time	7th Test	28th and 29th November		

Effective beam time usage (including parasitic measurements)	**2 / 10 days**
Dedicated beam time duration (until the end of year)	9.5 days + ? (parasitic measurements)

Tests @CLEAR – Preparation of the Setup

- Alignment of the Interferometer





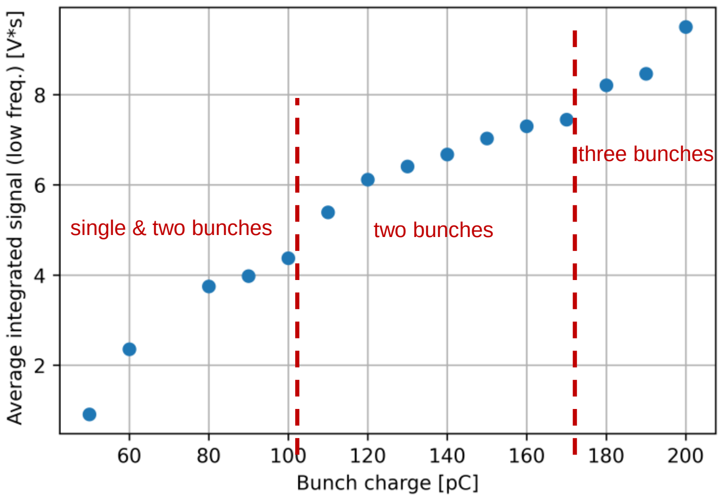
Emitter :	26.5 – 40 GHz
Wire Grid Polarizers :	10 µm thickness, 25 µm spacing
Quasi Optical Detectors :	100 GHz – 1 THz
THz camera :	4096 pixel & 0.05 – 0.7 THz

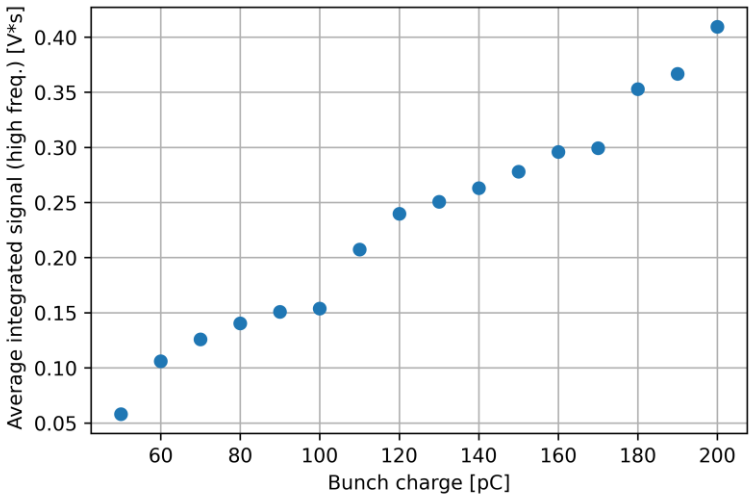
Schottky Diodes : 60 – 90 GHz (low freq.) & 140 – 220 GHz & 400 – 600 GHz (high freq.)

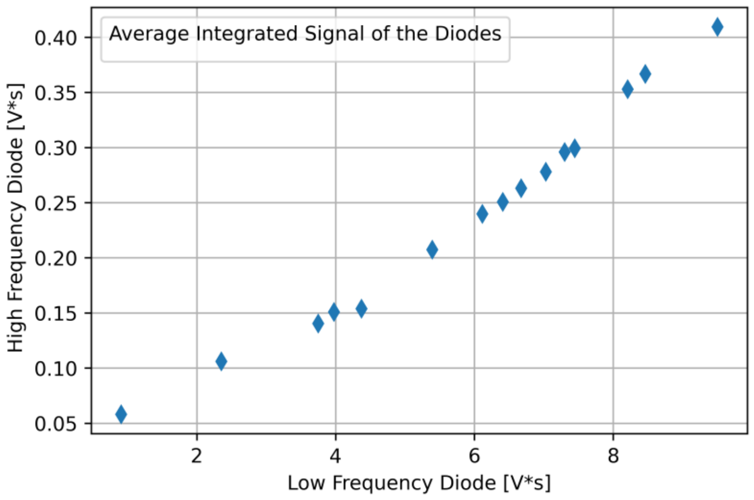
Tests @CLEAR – Charge Scan

- Short bunch lengths (<1 ps) couldn't obtained during the beam time !
- Frequency ranges of Schottky diodes : 60 – 90 GHz & 140-220 GHz (instead of 400-600 GHz)

Electron Bunch Parameter	Value
Energy, E	150 [MeV]
Charge, Q	20-200 [pC]
Length, σ_z	1 ps
Size, σ_r	0.3 mm







- The response of the diodes are in the same operation regime as it is shows linear response to the charge.

Tests @CLEAR - Impact Parameter Scan

Electron Bunch Parameter	Value
Energy, E	150 [MeV]
Charge, Q	100 [pC]
Length, σ_z	0.13-0.25 ps
Size, σ_r	0.2 mm

'Suppression of bunch charge effects to minimize beam position & angular jitter'

$$\left[\frac{d^2W}{d\omega d\Omega}\right]_{rad} = N^2 \left[\frac{d^2W}{d\omega d\Omega}\right]_{single} F(\omega)$$

$$S(\omega) = N^2\, S_e(\omega)\, F(\omega)$$

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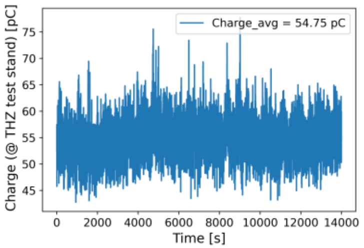
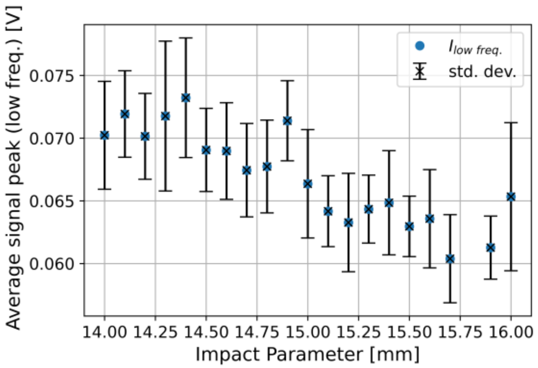
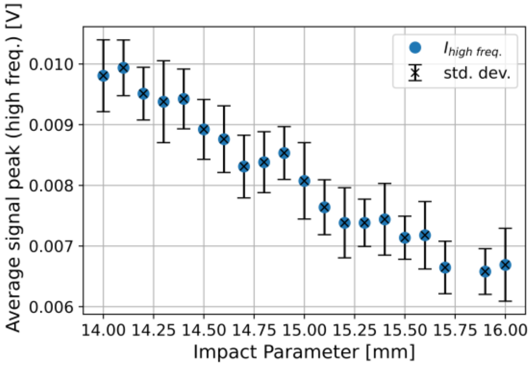
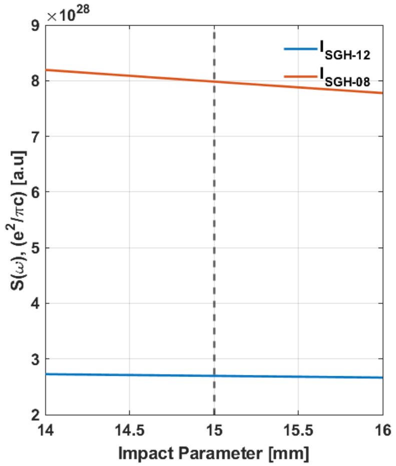
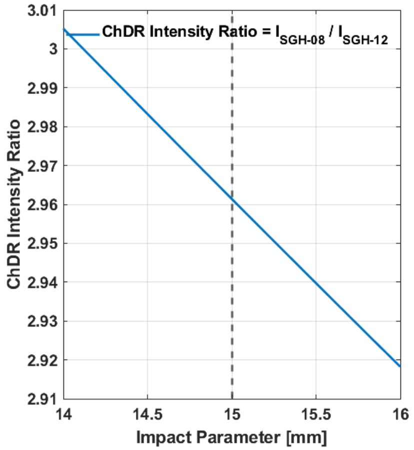
$$\sigma_{z,rms} = \sqrt{\left|\frac{1}{k_2^2 - k_1^2}\cdot \ln\left(\frac{S_1(\omega_1)\cdot S_{e2}(\omega_2)}{S_2(\omega_2)\cdot S_{e1}(\omega_1)}\right)\right|}$$

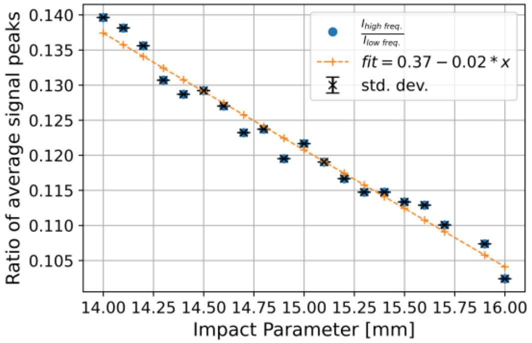












±1 mm position jitter ≈ %1.5 change in CHDR intensity ratio (PCA Theory)

±1 mm position jitter ≈ %14 change in CHDR intensity ratio (Experiment)

Tests @CLEAR – Bunch Length Sensitivity

- Reference : Transverse Deflecting Cavity measurements

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$$\left[\frac{d^2W}{d\omega d\Omega}\right]_{rad} = N^2 \left[\frac{d^2W}{d\omega d\Omega}\right]_{single} F(\omega)$$

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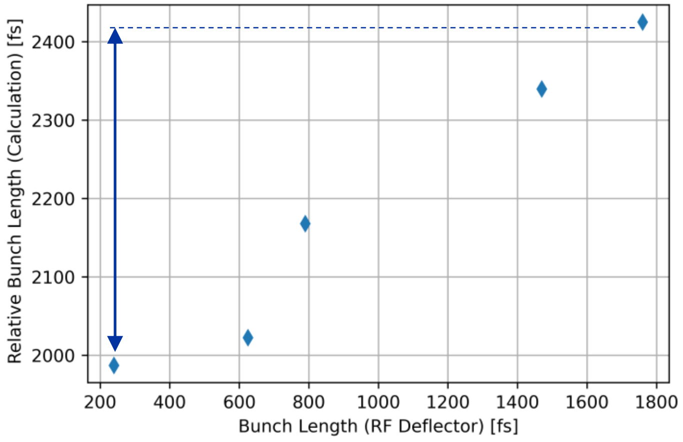
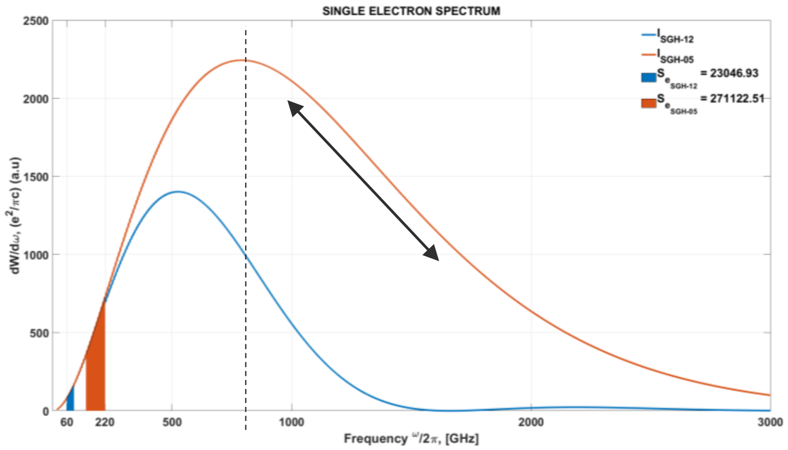
$$\sigma_{z,rms} = \sqrt{\left|\frac{1}{k_2^2 - k_1^2}\cdot \ln\left(\frac{S_1(\omega_1)\cdot S_{e2}(\omega_2)}{S_2(\omega_2)\cdot S_{e1}(\omega_1)}\right)\right|}$$

RF Deflector : 0.2 ps to 2 ps
CHDR : 2 ps to 2.4 ps



Both detectors are working in DR dominated part : no bunch length sensitivity !

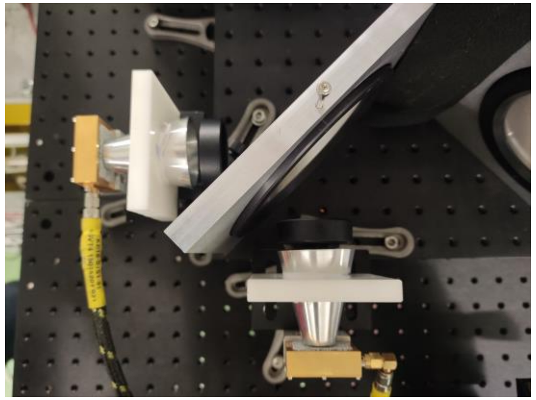
Insensitivity to bunch length leads to have compressed changes in the RMS bunch length calculation !



Simulation Parameters	Value
Energy, E	150 [MeV]
Charge, Q	100 [pC]
Length, σ_z	200 fs
Size, σ_r	0.2 mm

Tests @CLEAR - MP Interferometer

- TPX50 THz lenses is located after the analyser.
- Cylindrical metallic shield between detector and lens to avoid low frequency domination of the spectrum.
- Motor step size : 0.25 mm (100 steps)

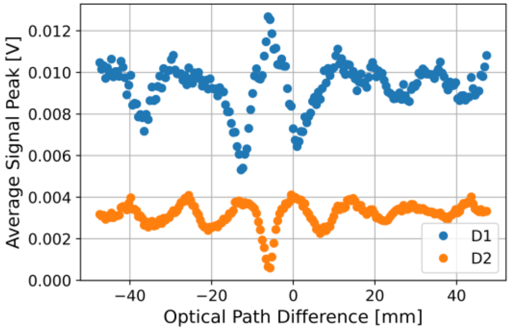


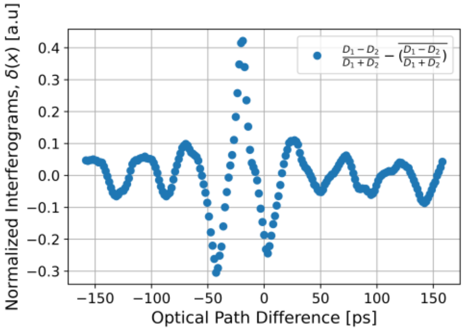
$$f_{max} = \frac{c}{2 \times (2{,}5\ \mu m\ \times 2)} = 30 \text{ THz} \quad \Rightarrow \quad f_{test} = \frac{c}{2 \times (250\ \mu m\ \times 2)} = 300 \text{ GHz}$$

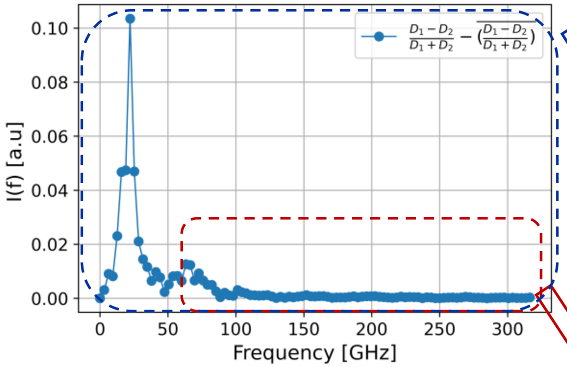
$$\Delta f_{resolution} = \frac{c}{2 \times max\ optical\ path\ difference} = 1.43 \text{ GHz} \quad \Rightarrow \quad \Delta f_{test,resolution} = \frac{c}{2 \times max\ optical\ path\ difference} = 6 \text{ GHz}$$

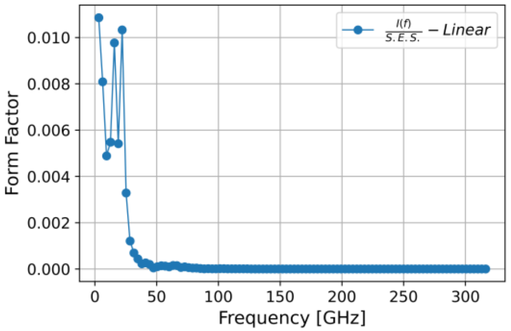
Electron Bunch Parameter	Value
Energy, E	160 [MeV]
Charge, Q	50-60 [pC]
Length, σ_z	0.5 - 0.7 ps
Size, σ_r	0.2 mm

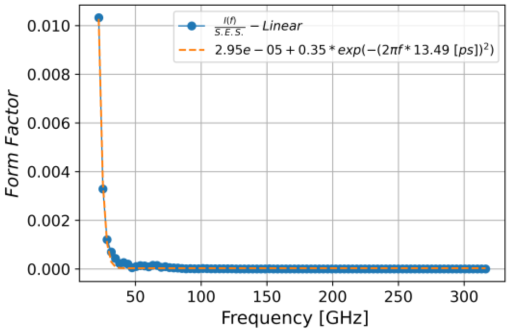
Tests @CLEAR – MP Interferometer



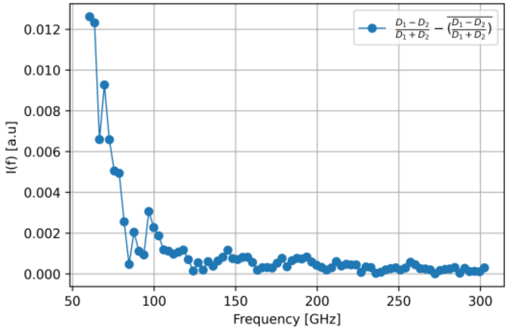


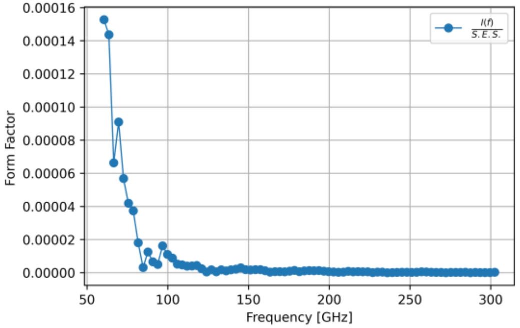


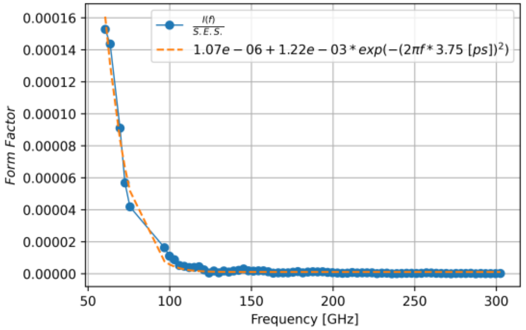




Missing the high frequency component of ChDR due to large impact parameter (b=15mm) !







Experiment Plan - (%100)

Tests (In order)	Aim of the Test	How to Proceed	Beam Parameters	Estimated time of completion of the test
Charge Scan_1	Identification of working regime of Schottky Diodes for different bunch lengths	• Charge scan for single bunch with pairs of diodes • Charge scan for single bunch by using voltage-preamplifiers with pairs of diodes	E = 150 MeV $\sigma_z = [0.2 - 0.3\ - 0.4 - 0.5\ - 0.6\ \text{ps}]$ $\sigma_r < 50\ \mu m$ b = 15 mm	• 3 access required • 1 full day
Interferometer Scan_1	To check the sufficiency of the range of the motor to observe a dumped interferogram for current impact parameter (15 mm)	Scan with the current impact parameter (b=15 mm) for full range of the motor (42215 steps =100 mm)	E = 150 MeV $\sigma_z = 1\ \text{ps}$ $\sigma_r < 50\ \mu m$ b = 15 mm Q = to be decided after charge scan	• 1 access required • For a step size (100 steps=0.25 mm) : 141 minutes • 1 full day
Interferometer Scan_2	Determination of operational impact parameter range to use MP Interferometer without low frequency dominated CHDR spectrum	Interferometer (IF) scan for different impact parameters (starting from 5mm to 15mm with 1mm increment for each IF scan)	E = 150 MeV $\sigma_z = 0.2\ \text{ps}$ $\sigma_r < 50\ \mu m$ Q = to be decided after charge scan b = [5mm:15mm:1mm]	• 1 access required. • For a step size (100 steps=0. 25 mm) : 141 minutes • For a smaller step size (20 steps=0.05 mm) to reach 1.5 THz. (The range of movable mirror will be adjusted considering where normalized interferogram dumps.) • In total 10 scans. • 5 full days
Charge Scan_2	Identification of working regime of Schottky Diodes for the new operational impact parameter that interferometer works effectively	• Charge scan for single bunch with pairs of diodes • Charge scan for single bunch by using voltage-preamplifiers with pairs of diodes	E = 150 MeV $\sigma_z = [0.2 - 0.3\ - 0.4 - 0.5\ - 0.6\ \text{ps}]$ $\sigma_r < 50\ \mu m$ b = to be decided after IF scan_2	• 3 access required • 1 full day
Impact Parameter Scan	Observation of beam position dependency of RMS bunch length calculation besides comparison the experimental data with PCA analysis and CST simulations	• ±1 mm scan with 0.02 mm step size voltage-preamplifiers with pairs of diodes • Full range scan (±10 mm) with 0.1 mm step size voltage-preamplifiers with pairs of diodes	E = 150 MeV $\sigma_z = [0.2 - 0.3\ - 0.4 - 0.5\ - 0.6\ \text{ps}]$ $\sigma_r < 50\ \mu m$ Q = to be decided after charge scan_2	• 3 access required • 2 full days
Angular Jitter Scan	Observation of beam angular jitter dependency of RMS bunch length calculation besides comparison the experimental data with PCA analysis and CST simulations	• Possibility of steering beam and reference point will be discussed with CLEAR team.		• 3 access required • 2 full days
Bunch Length Scan	Find the optimum operation frequency ranges to calculate RMS bunch length correctly with a correction factor applied.	Usage of RF Deflector as a reference for each bunch length scan	E = 150 MeV $\sigma_z = [0.2 - 0.3\ - 0.4 - 0.5\ - 0.6\ \text{ps}]$ $\sigma_r < 50\ \mu m$ Q = to be decided after charge scan_2 b = to be decided after IF scan_2	• 1 access required. • 3 full days.
Interferometer Scan_4	To compare bunch length scan and RF deflector values	In parallel with bunch length scan		
Reproducibility of Each Scan	To check the consistency of data.	Charge Scan, impact scan, bunch length scan, interferometer scan will be repeated with the optimum conditions determined beforehand.		• 2 access required • 5 full days.
NI 9751 Digitizer replacement	In order to have an online bunch length measurement GUI to analyze each CHDR signal and calculate the RMS bunch length & interferograms with a LabVIEW code	Streching the ChDR signal by using voltage-preamplifiers and calculating the data spontaneously via Labview code		• 1 access required • 3 full days
Beam Position Scan	Observation of a possible the kick due to protruded radiators	Detection of ChDR with the symmetric radiators on both sides of the beam	E = 150 MeV $\sigma_z = [0.2\ - 0.4\ - 0.6\ \text{ps}]$ $\sigma_r < 50\ \mu m$ Q = to be decided after charge scan_2	• Vacuum intervention required • 1 access required • 1 full day
-	-	-	-	• **In total 24 days required to complete the plan.**

Conclusion

- Data analysed carefully and the issues leading calculation errors were diagnosed to improve the quality of the measurements and data.

  - Voltage-preamplifiers will be used for low charge scan to identify the working regime of the all diodes.

  - Impact parameter will be decreased in order to ;
    - reduce the effect of the radiator width on the beam position sensitivity (impact parameter).
    - avoid low frequency dominance in the interferometric measurement.

  - Bunch length scan will be repeated (in a narrow span) after further PCA analysis to use the sensitivity diodes (140-220 Ghz & 400-600 GHz) in the bunch form factor dominated area of the ChDR spectrum to find an effective correction factor to be used in the RMS bunch length calculation.

  - Upcoming beam time : Next week (hopefully !)

  - Commissioning of the bunch length monitor will be completed until the end of year.

  - Further improvements – such as online monitoring, preparation of a GUI etc. - will be done in the next year.

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