ESRF | The European Synchrotron

Collective Effects at the ESRF

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16/12/2022

OVERVIEW

- Introduction
- EBS Machine and the Short Range Wake Potential Model
- Single bunch collective effects:
  Measurement vs Simulations
- Conclusions

INTRODUCTION

- **The ESRF has recently installed and commissioned the EBS, a new 4th generation light source with reduced horizontal emittance.**

- **Small vacuum chamber apertures were required in order to allow the magnetic poles to be closer to the beam.**
    - Strong impedance effects expected (true for all 4th gen. light sources following the HMBA design).
    - A challenge to design the vacuum chambers and a lot of work to properly develop and characterise the impedance model

- **Here we present the comparison of simulations and measurements for single bunch collective effects.**

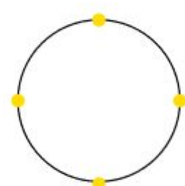
EBS

Uniform:
992 bunches
200mA total

7/8+1:
868+1 bunches
200mA total
8mA single

16 bunches:
90mA total
~6mA per bunch

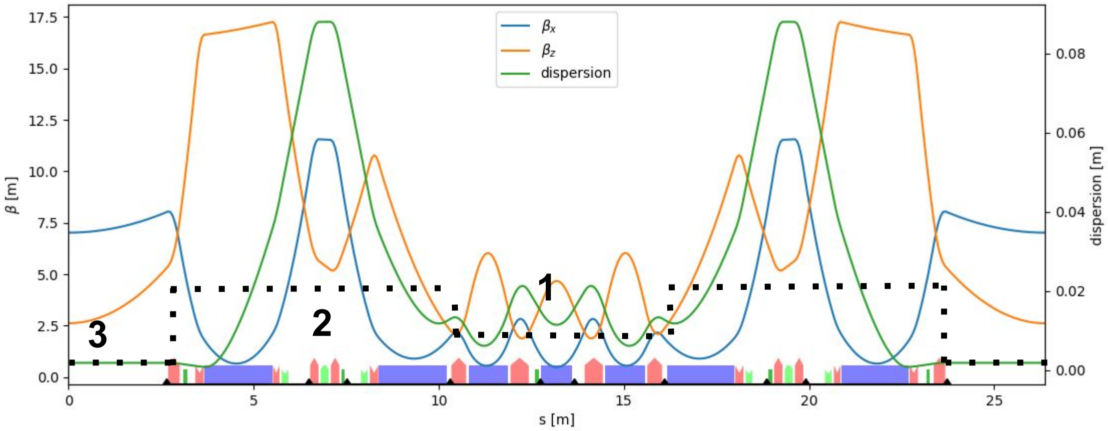
4 bunches:
40mA total
10mA per bunch



The EBS is not sensitive to coupled bunch instabilities!

	units	DBA	HMBA
Energy	GeV	6.04	6
Circumference	m	844.391	843.877
Max. total current	mA	200	200
Max. Single bunch current	mA	10	10
Max number of bunches		992	992
Average Hor. beta	**m**	**21.41**	**4.16**
Average Ver. beta	**m**	**23.28**	**7.66**
Hor. emittance	pm.rad	3993	133
Momentum compaction factor	**10^{-5}**	**17.795**	**8.512**
Zero current momentum spread	10^(-3)	1.062	0.9356
Zero current bunch length	**mm**	**4.67**	**3.06**
Energy loss per turn	MeV/turn	4.879	2.533
RF Voltage	MV	8	6
Synchrotron Tune	**10^{-3}**	**5.429**	**3.490**

HMBA

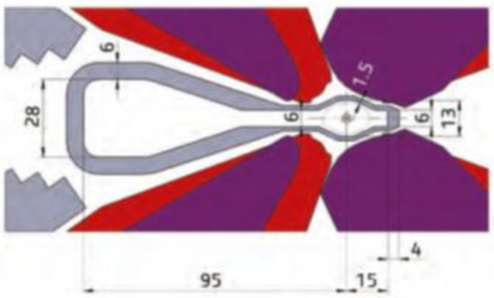


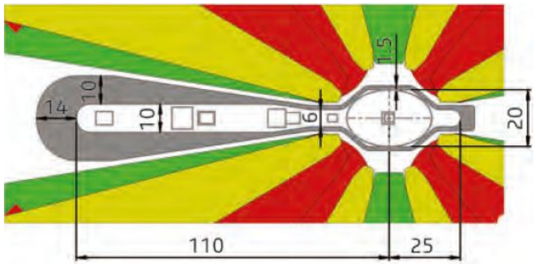
- Three different apertures (generally speaking).
- -I transformation across the two dispersion bumps to minimize sextupole resonances.
- Chambers are made out of either aluminium or stainless steel.
- DBA vertical aperture was ±32mm.

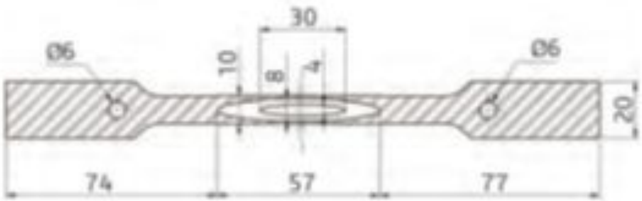
1. Small aperture for strong focussing region. H aperture is ± 15mm. V aperture is ± 6mm.

2. Large aperture for weaker focussing region. H aperture is ± 25mm. V aperture is ± 10mm.

3. ID chamber. Aluminium with NEG coating. H aperture is ± 25mm. V aperture is ± 4mm.



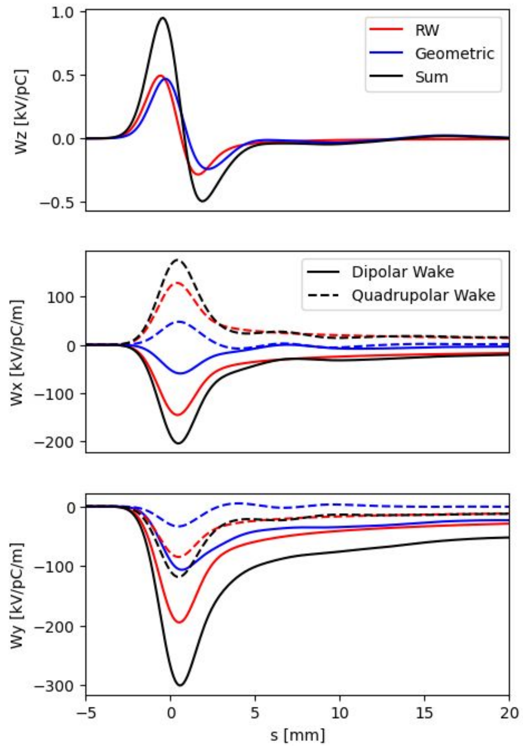




SHORT RANGE WAKE POTENTIAL MODEL

	Number
BPM (Large + Small)	192 + 128
RF Cavity (Cavity + Short Damper + Tapers)	13 + 13 + 3
Collimator	2
Current Transformer	2
RF Fingers (Large + Small)	288 + 64
Flange (Large + Small)	480 + 64
ID Taper	32
Low Beta Taper	32
Horizontal Stripline	2
Vertical Stripline	3
Vacuum Valve	64
Ceramic Chamber	8
Invacuum Undulator (Open)	12
Absorber RF	15
Septum	1

- **Resistive Wall model was generated using IW2D (N. Mounet).**
- **The short range wake model was computed for each combination of chamber material and aperture.**
- **The average beta was computed across each chamber, and all of the contributions summed with appropriate weighting.**



- **For the geometric model, each of the elements in the table was simulated in GdfidL with an excitation pulse of σ_z=1mm (lowest that could be achieved for all elements with ESRF cluster).**

- **Geometric wake total length is 165m. Therefore RW wake is over estimated by 20% which means total wake is overestimated by 10%.**

COMMISSIONING

- Not going to discuss the beam commissioning.
- For those interested (links below):

ESLS 2020 EBS commissioning - Presentation by Pantaleo Raimondi

EBS Lessons Learned - LEL 2022 - Presentation by Nicola Carmignani

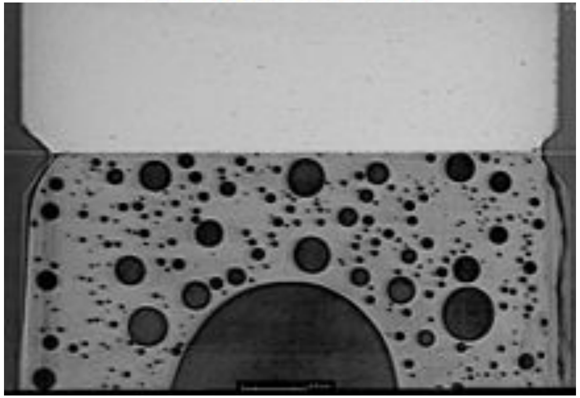
P. Raimondi, N. Carmignani, L. R. Carver, J. Chavanne, L. Farvacque, G. Le Bec, D. Martin, S. M. Liuzzo, T. Perron, and S. White, "Commissioning of the hybrid multibend achromat lattice at the European Synchrotron Radiation Facility", Phys. Rev. Accel. Beams 24, 110701, (2021)

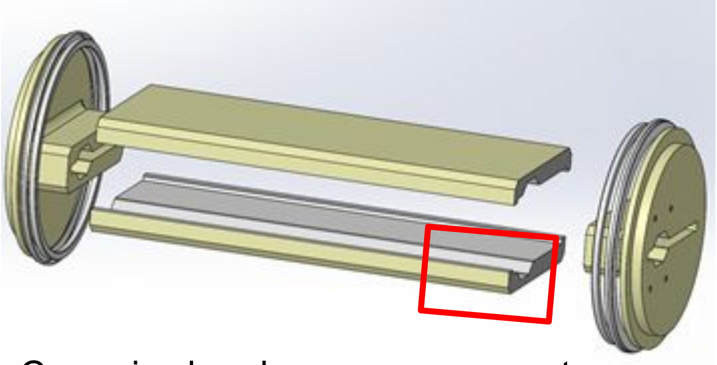
…but it was a success!

COMMISSIONING PROBLEMS - KICKER LEAK

- **We are able to deliver design currents in all filling modes except two:**
  - 16 bunch mode (highest heating, current now limited to 75mA)
  - Hybrid mode (24*8+1 is design, now running 28*12+1 to reduce heating).
- **While filling in 16 bunch mode (the filling mode with the highest power deposition), an air leak occurred on one of the 4 injection kickers.**
- **The leak is coming from the glazing joint between the two ceramics, and probably occurred due to thermal stress. Formation of air bubbles in he glazing during thermal cycle!**
- **Full kicker chamber redesign has occurred. Kickers have been recoated while new chambers are fabricated.**
- **Total current in 16 bunch mode has been kept to 75mA (instead of 92mA) until the spares are ready.**

broken kicker

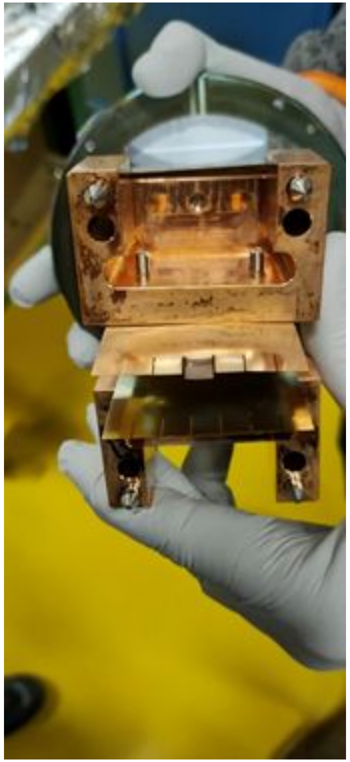




Ceramic chambers measurements performed at BM05 beam line (courtesy of P. Tafforeau)

COMMISSIONING PROBLEMS- CPMU RF FINGERS

- **Two problems observed with RF fingers on the CPMU.**
- **The first was a deformed finger, repaired quickly.**
- **The second was excessive heating while trying to reach design current in 16b mode.**
  - Caused by poor thermal contact. Redesign of RF fingers needed.
- **Total current in 16b remained limited to 65mA while all RF fingers for the CPMUs were replaced with the new design.**
- **Now we are only limited in total current because we are waiting for the spare kicker chambers. We hope to reach 92mA in 2023.**

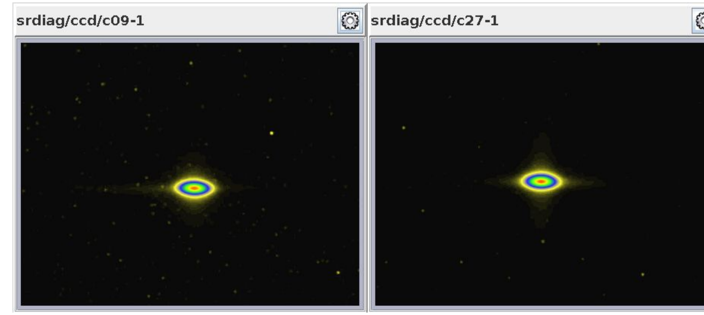


Dec 2020

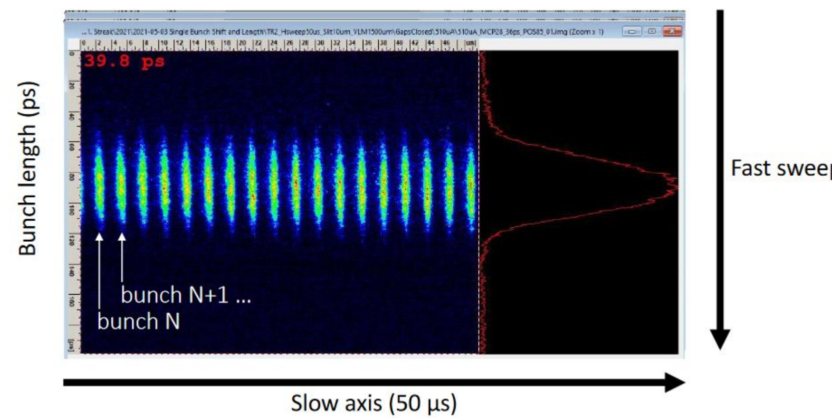
May 2022

EBS LONGITUDINAL IMPEDANCE DIAGNOSTICS

- **5 pinhole cameras that collect x-rays from either a DL or DQ magnet.**
- **Situated at one of two different locations in the standard cell, with different betas and dispersions.**
- **Through numerically fitting the spot sizes, the horizontal and vertical emittance and the energy spread can be computed.**

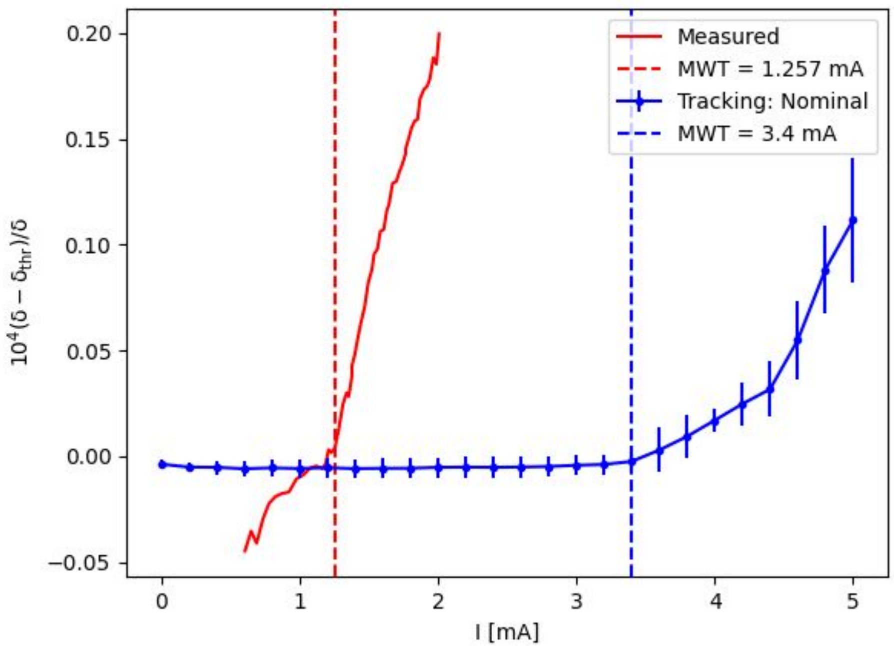


- **A Hamamatsu C10910 streak camera is installed in the visible light diagnostics beam line.**
- **Measures the bunch distribution, and also the relative bunch centroid position.**



MICROWAVE THRESHOLD

- Measurement of energy spread versus single bunch current.
- Tracking simulations performed in PyAT.
- MWT observed at 1.257mA, compared to the simulated value of 3.4mA.
- We will come back to this.



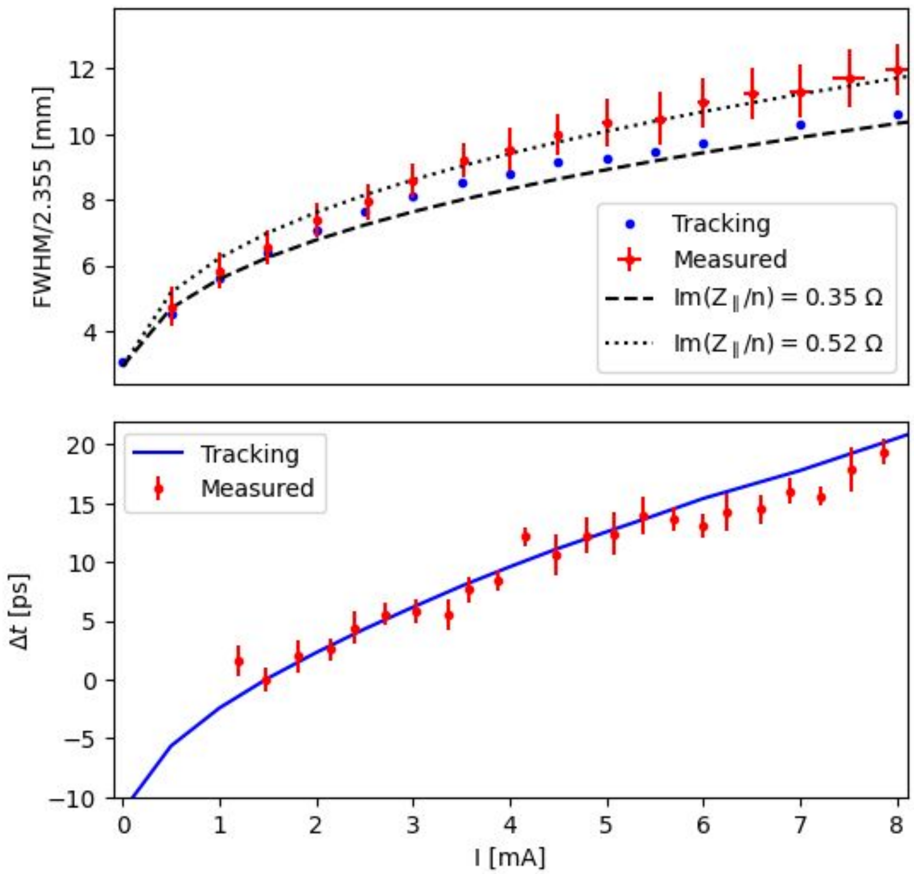
BUNCH LENGTH AND SYNCHRONOUS PHASE

- **Single bunch measurements made, streak camera profiles extracted.**

- **Relative synchronous phase shift agrees well with tracking simulations.**

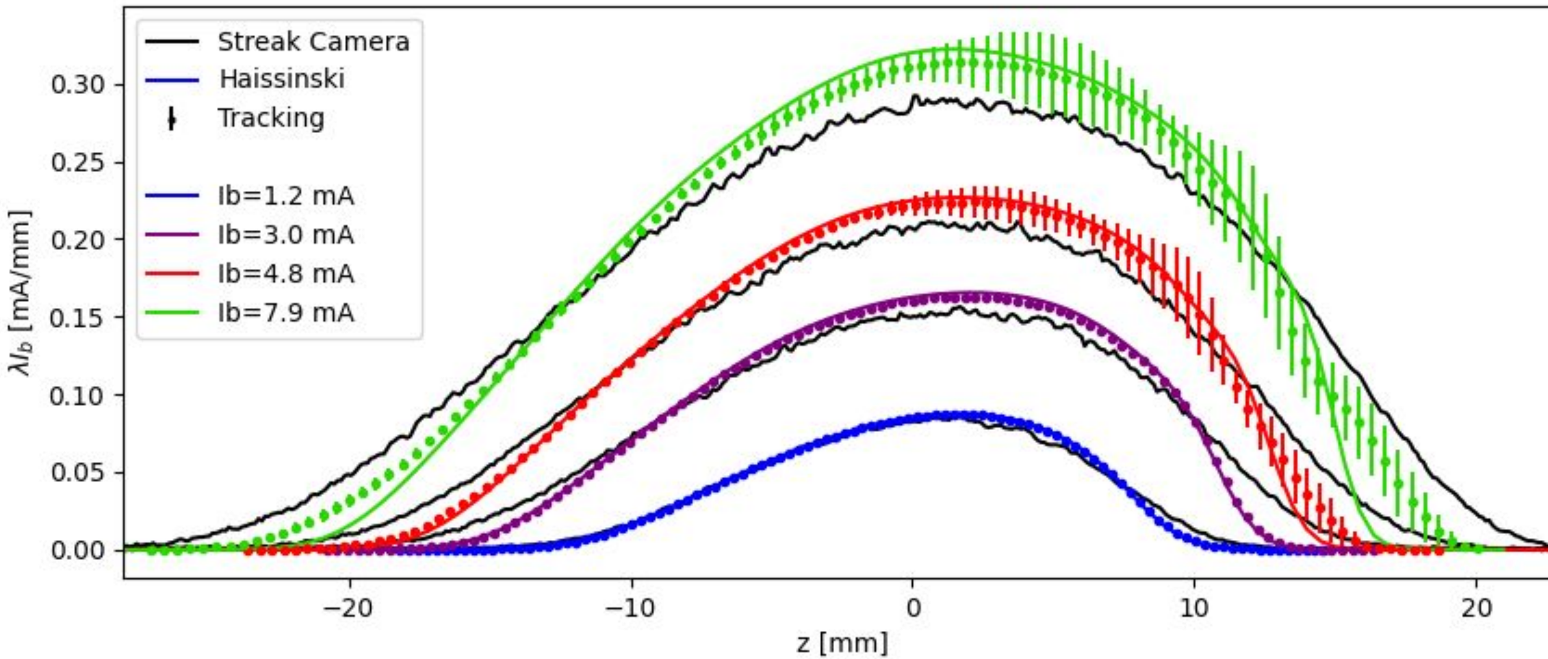
- **The bunch length measurements over estimate the bunch length by approximately 10-15%.**
  - Similar disagreement is also seen at zero current (10mA/992 bunches).
  - Streak camera over-estimation is routinely seen at other light sources (BESSY, old ESRF, SLS).

- **We believe the real bunch length is closer to the tracking than shown here.**



BUNCH DISTRIBUTIONS

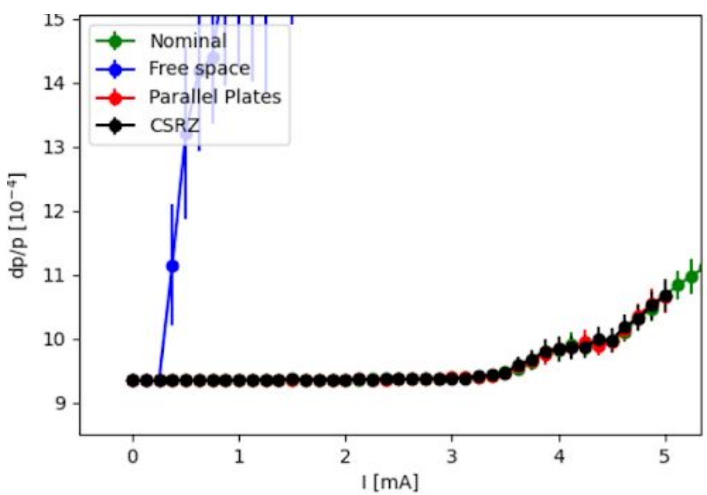
- **Comparison of measured distributions (black), with tracking simulations (coloured points) and solution to Haissinski equation (solid coloured).**



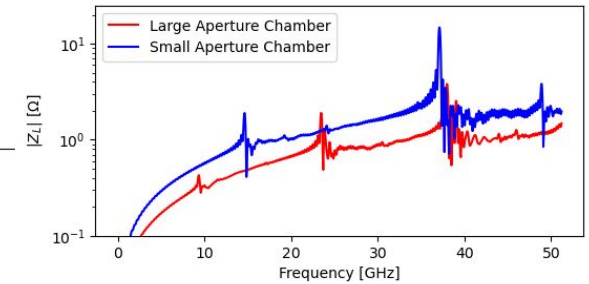
MICROWAVE THRESHOLD - POSSIBLE CAUSES FOR DISCREPANCY

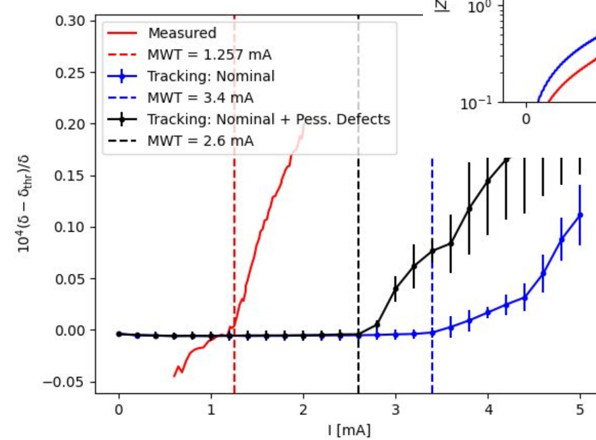
- **Bunch length and synchronous phase shift approximately agree with prediction, MWT threshold is out by a factor 2.7 -> implies a missing impedance at high frequency.**
  - Two additional contributions have been explored. CSR and welding defects.

- CSR wake developed using CSRZ (D. Zhou).
- Free space wake enormously strong, but when shielding included the impact becomes negligible due to the small vacuum apertures.



- Welding defects create small high frequency cavities at every weld location (~2000 combined for small and large aperture).
- Max height of 300um. Length of 2.5mm.
- Assume all defects have these parameters.

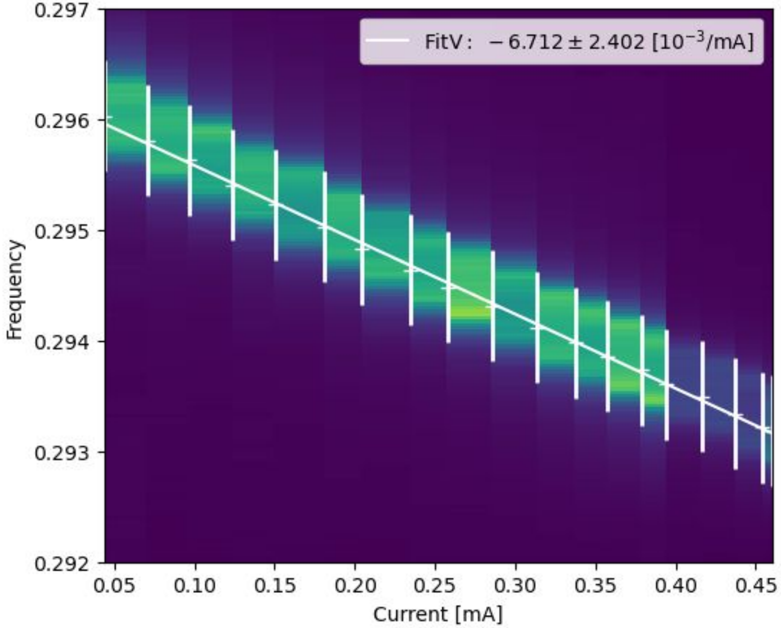




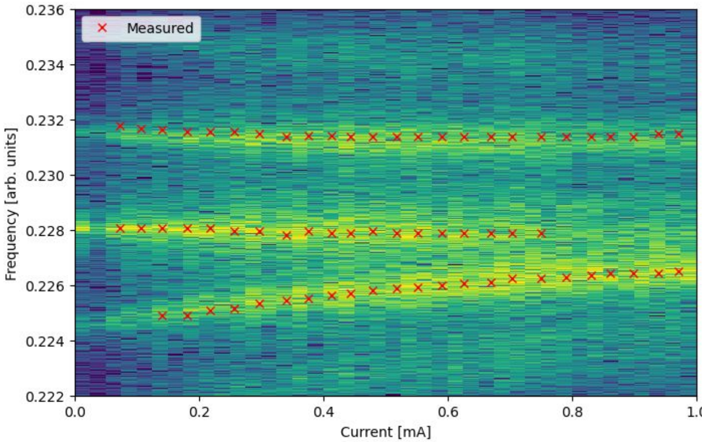
TMCI AND TUNE SHIFT MEASUREMENTS

- **Left: vertical tune shift and TMCI measurement for Q'=0. Comparison with simulation in the table.**
- **Right: measured (red crosses) modes -1,0,1 compared to simulation (background spectrum) for Q'H=1.5**

Q'V=0



Q'H=1.5

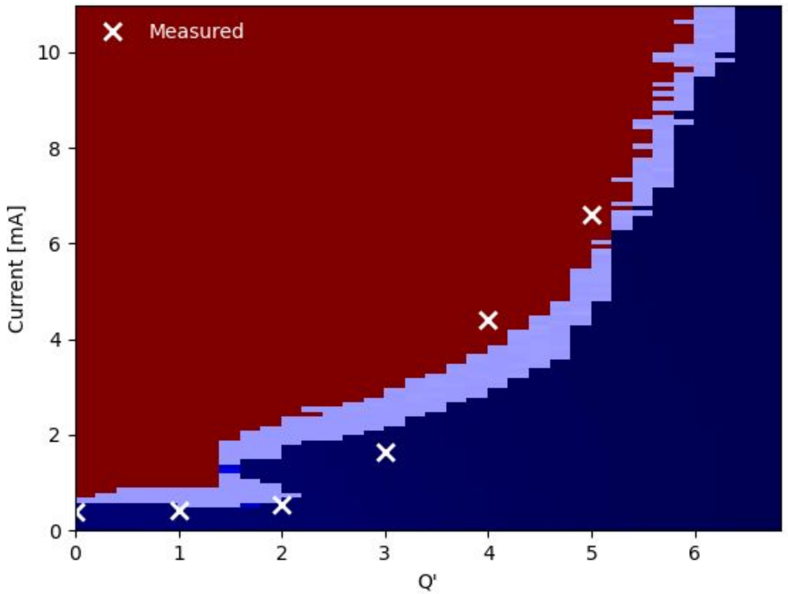


	Simulated	Measured	Units
TMCI	0.53	0.44	mA
Tune Shift V	-4.988	-6.712 ± 2.4	1e-3/mA
Tune Shift H	-0.501	-1.082 ± 2.3	1e-3/mA

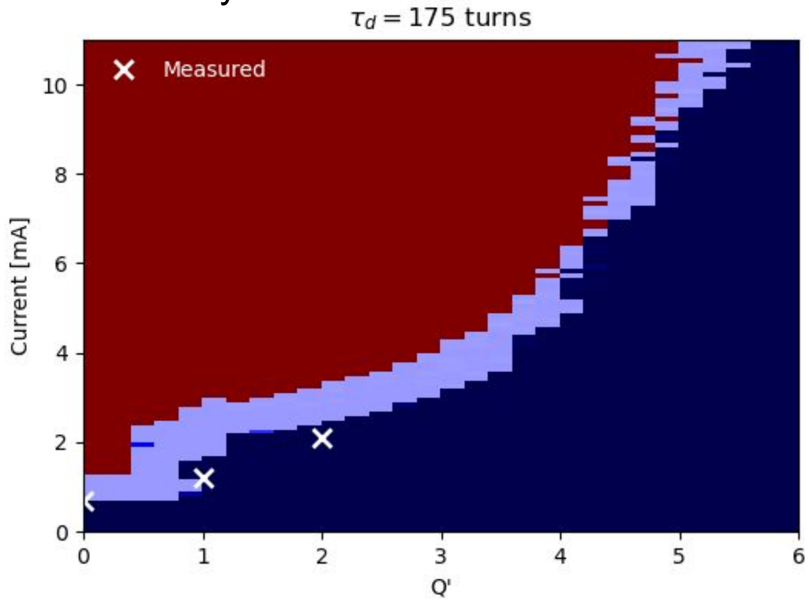
INSTABILITY THRESHOLD

- As a function of the chromaticity (Q'H=Q'V=Q'), the vertical instability threshold was measured (left). Dark blue is stability, red is unstable, the light blue is stable over 10,000 turns but not small amplitude.
- Vertical instability first, then we switched the BBB feedback on and measured the next threshold (right, horizontal or vertical).
- Good qualitative agreement as a function of chromaticity.

Vertical instability threshold: Q'H=Q'V



Instability threshold with feedback: Q'H=Q'V

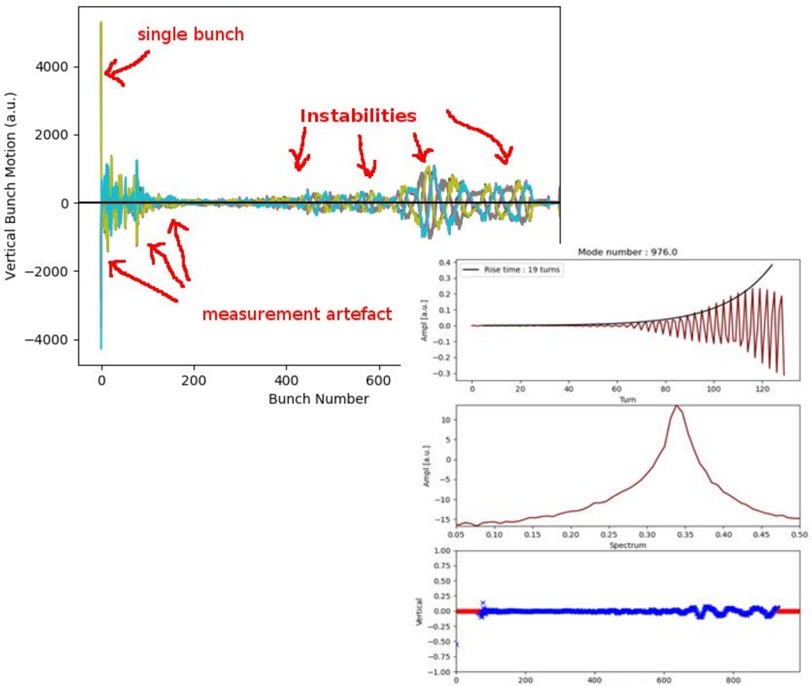


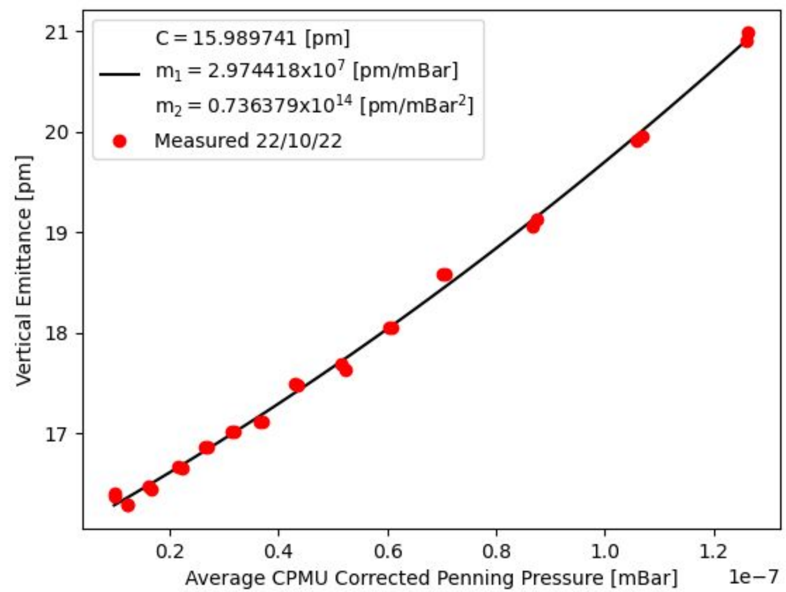
ION OBSERVATIONS

- Left: during commissioning, strong outgassing occurred from the K3 kicker. Large coupled bunch beam instability observed with fast rise times. Filling mode 7/8+1.

- Right: Measurement of vertical emittance growth as a function of a local increase of pressure. Measurement made while intentionally heating one cryogenic undulator which caused outgassing.

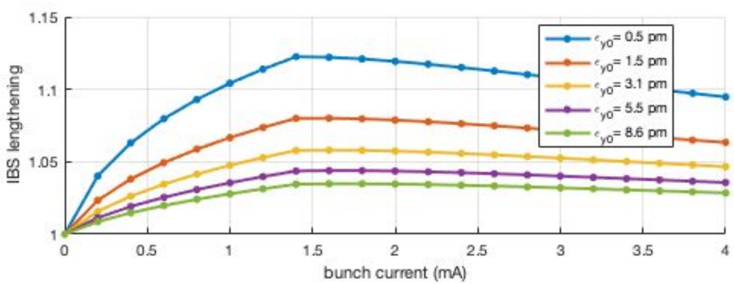
- These are interesting observations to try and simulate, but in terms of operation we are not limited by ion effects and are not sensitive to ion trapping.

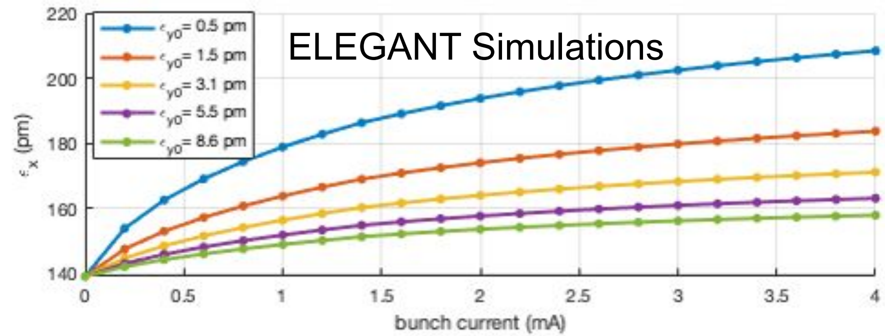


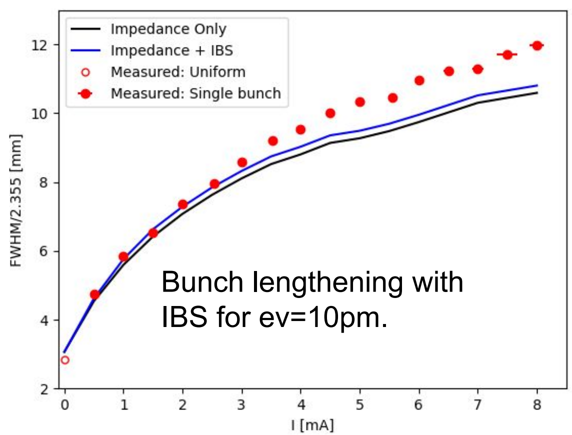


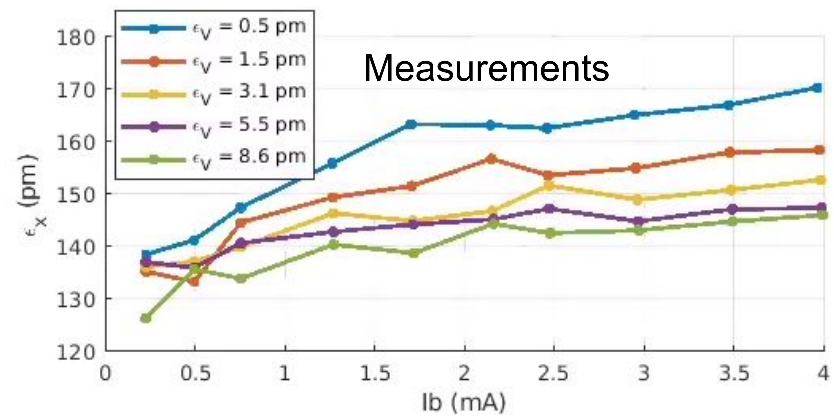
INTRA BEAM SCATTERING

- Some IBS effects are expected: horizontal emittance blowup and bunch lengthening.
- Performed a 2D scan of single bunch current and vertical emittance.
- For low vertical emittance, agreement not so good due to difficulty to maintain constant vertical emittance. Agreement better for higher vertical emittance
- Expected bunch lengthening at 10pm is small, was not able to be measured. Does not contribute to discrepancy.









CONCLUSIONS

- **EBS has been successfully commissioned and is running at the design current in (almost) all modes.**
- **The bunch lengthening and synchronous phase shift approximately agree with the simulations.**
- **The simulated MWT is larger by a factor of 2.7 compared to measurements.**
    - Investigations have shown some possible causes, but no clear indication yet. Likely caused by missing high frequency impedance.
    - A 4th harmonic cavity project is ongoing, the MWT will be reduced when this is in place.
- **The TMCI threshold agrees within approximately 20%. Tune shift measurements fell within the (large) error bars of the measurement.**
- **Instability threshold measurements vs chromaticity follow the simulations well.**

MANY THANKS FOR YOUR ATTENTION