CERN

PS Integer Experiment & Simulation

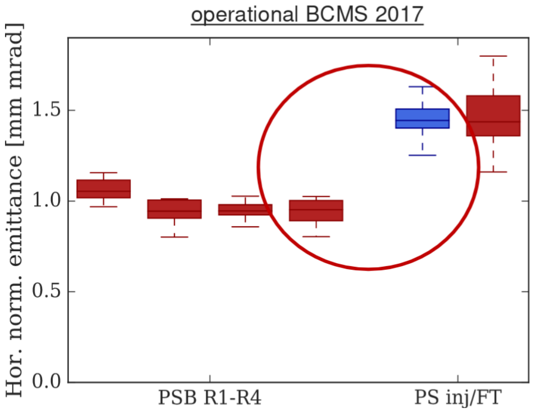
Foteini Asvesta, Hannes Bartosik, Alex Huschauer, Myrsini Kaitatzi, Haroon Rafique (BE-ABP)

haroon.rafique@cern.ch

27.02.20

Motivation

What do we want to achieve?

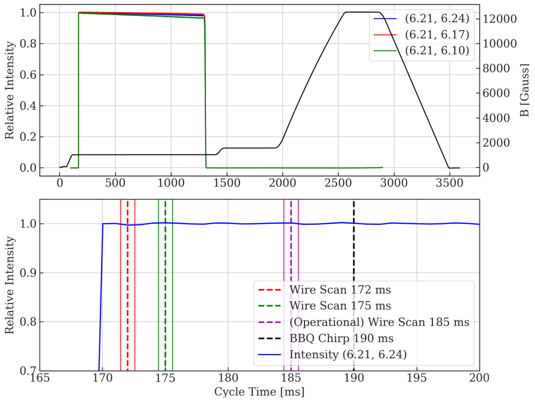


Goal: Assess space charge contribution to observed PS injection blowup.

Figure: A. Huschauer et. al., Chamonix 2018

Approach

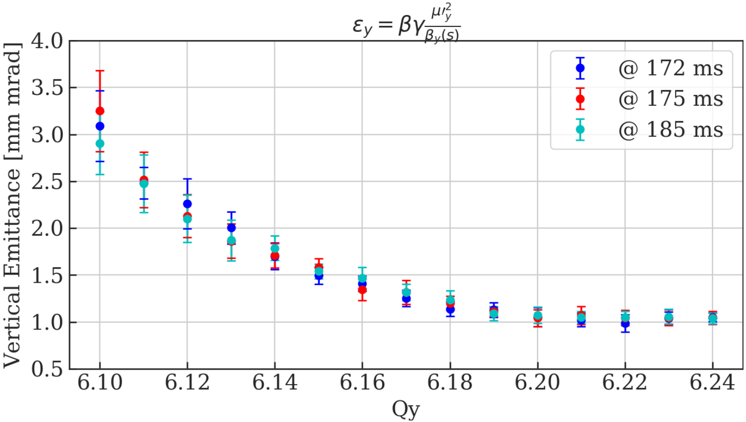
How do we observe effect of space charge?



- Use a space charge dominated beam (BCMS low chroma).
- Move the working point (WP) to the integer using Low Energy Quadrupoles (LEQs).
- Use wirescanner to measure beam profile at 2, 5, 15 ms post injection to observe blow-up.
- For parameters see here.

Observation

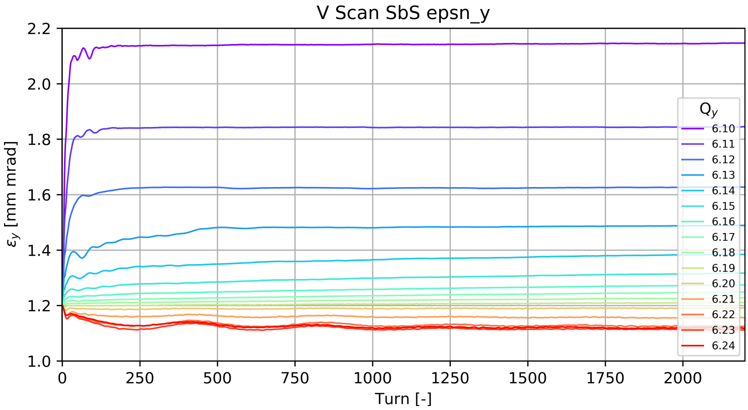
What did we measure?



- Beam blow-up as WP approaches the integer.
- No dependence on measurement time - implies very fast < 2ms.

Simulations

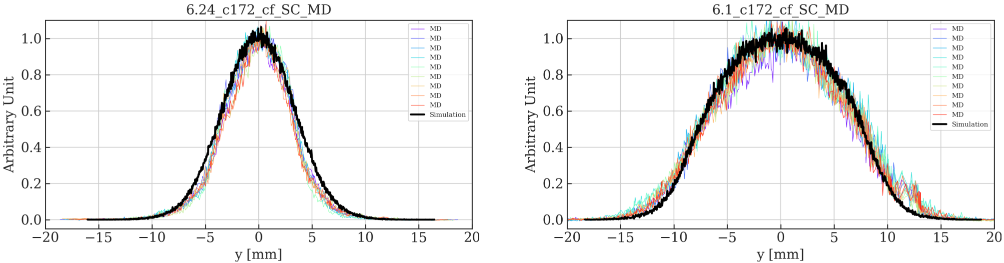
What do we observe?



- Vertical emittance growth (V scan) in first few hundred turns.
- Wire-scanner too slow to see blow-up (takes 500 turns to measure).

Vertical Bunch Profiles

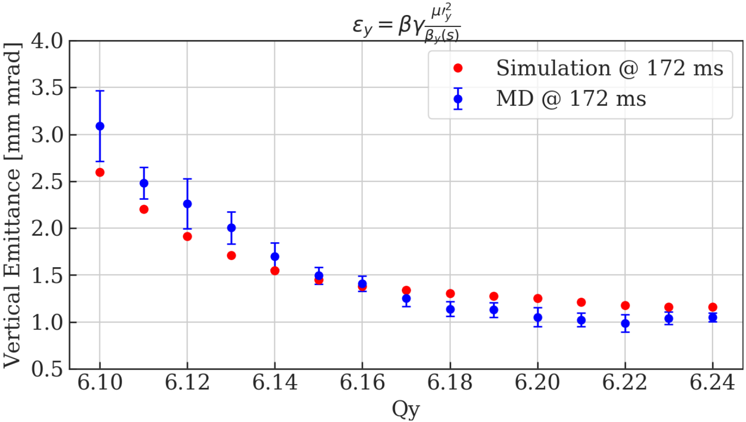
Compare simulations to measurement, Q_y = 6.24 (left), Q_y = 6.10 (right)



Growth due to lower WP, simulations and measurements agree well.

Benchmarking

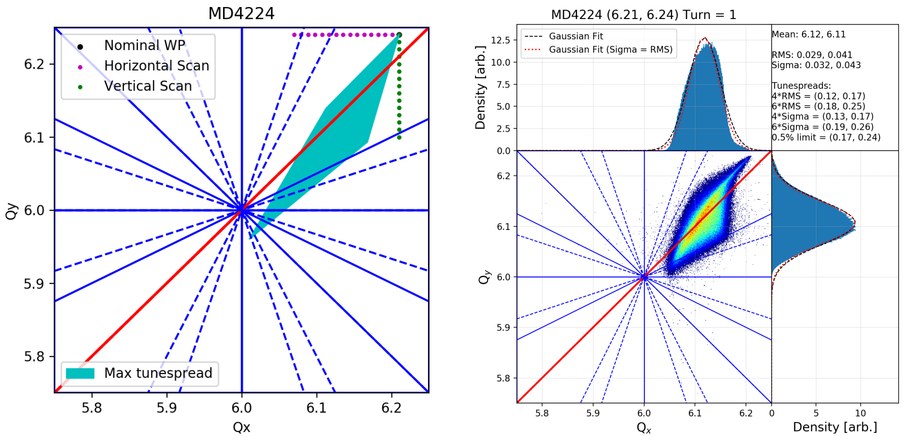
Simulations agree with measurements



- Beam blow-up as WP approaches the integer.
- **No blow-up observed around operational WP (6.24).**

What causes the blow-up?

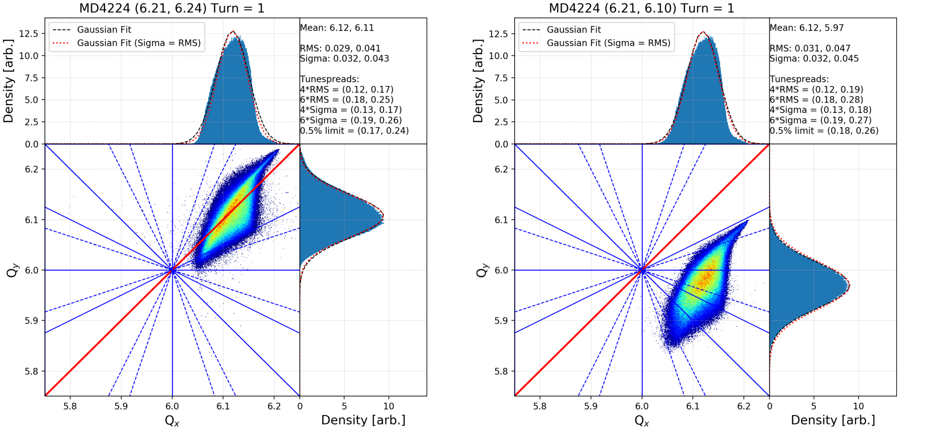
Look at tune footprints, measurement scan (left), Q_y = 6.24 PyORBIT simulation (right)



Tune footprint at nominal working point - no blow-up observed.

What causes the blow-up?

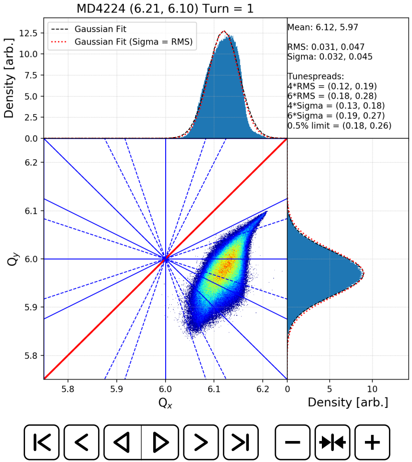
Look at tune footprints, Q_y = 6.24 (left), Q_y = 6.10 (right)

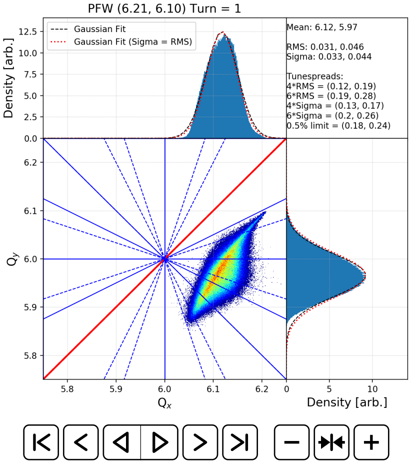


Tune footprint covers integer at lowest WP. See here and here for more animations.

What causes the blow-up?

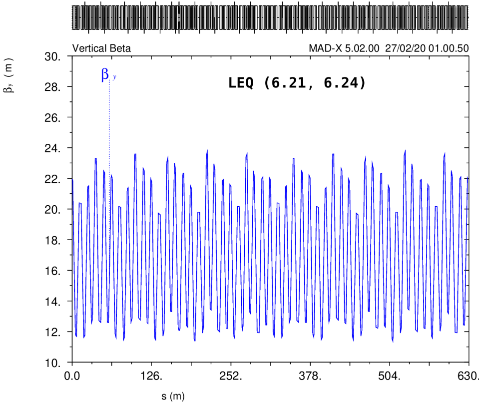
Compare tune behaviour when modulating tune with LEQ (left) or PFW (right)

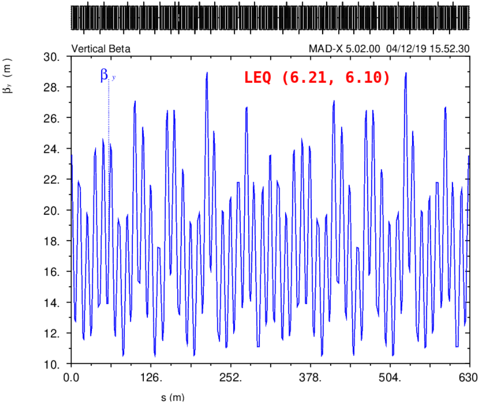




What causes the blow-up?

Compare optics at Q_y=6.24 (left) with Q_y=6.10 (right)

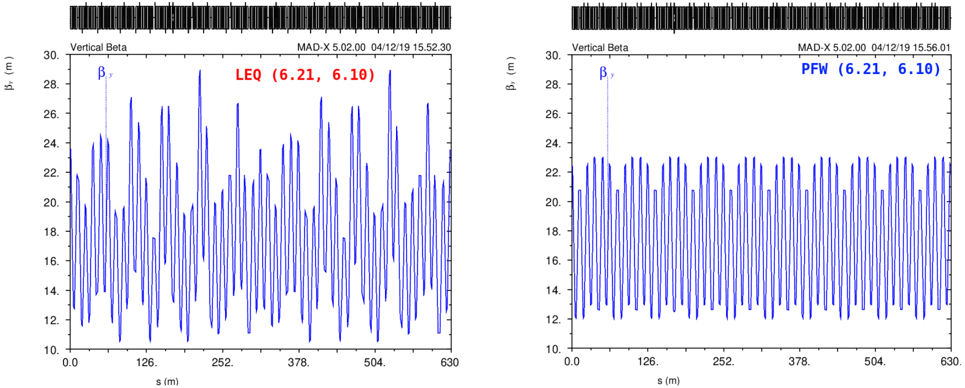




Optics are distorted at low tune as LEQs are not periodically positioned in the PS.

Can we modify tune another way?

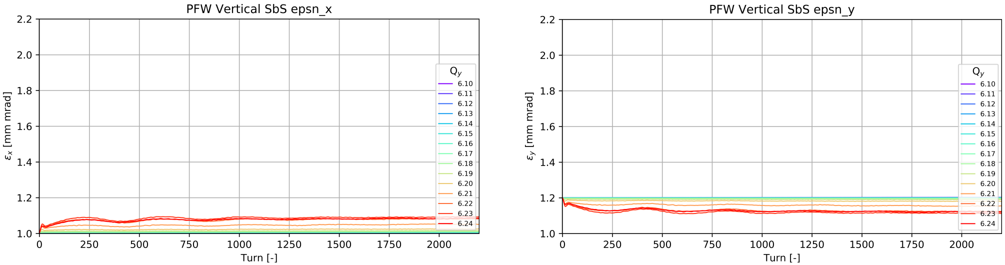
Yes - use Pole Face Windings (PFWs): compare LEQ (left) with PFW (right) optics



Optics comparison shows beta-beating is due to LEQs violating periodicity of the lattice. **Postulate beam interacts with half-integer resonance due to use of LEQs.**

Can we prove our postulate?

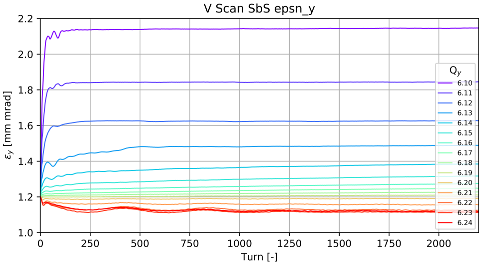
Is blow-up due to use of LEQs?

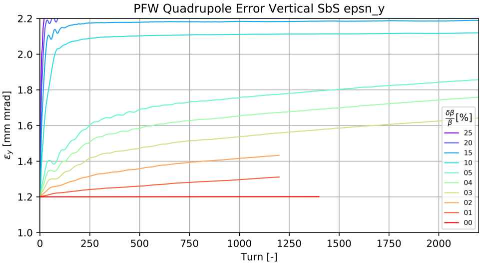


Using PFWs to change the tune we see no blow-up, only emittance exchange via the Montague coupling resonance.

Are we sure it's a quadrupolar error?

Add single quad error to PFW simulations to confirm postulate: compare LEQ (left) result with PFW with quad error (right)

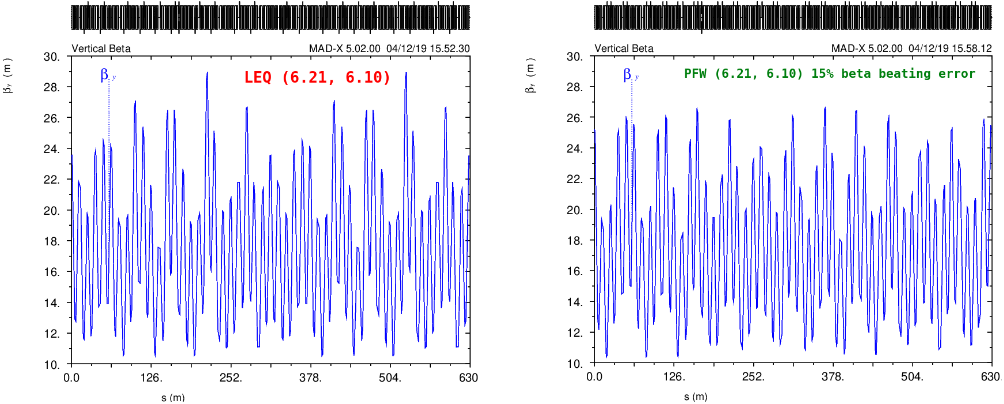




Quadrupolar error expressed as 15% beta-beating shows similar behaviour. PFW scan Q_y fixed to 6.10.

Effect of Quadrupolar error

Compare optics for LEQ Q_y=6.10 and PFW Q_y=6.10 with quadrupole error generating 15% beta-beating



Similar beta-beating from PFW + single quad error as compared to using all LEQs to modify the tune.

Conclusion

What have we learnt?

- Space charge effect on PS BCMS beam gauged by: using LEQs to bring working point close to integer tune, and measuring effect on bunch profile.
- Measurements and simulations agree: the beam blows up in < 1 ms as the working point approaches the integer. **No blow-up is observed around the operational working point**.
- Although tune footprint overlaps with the integer at low WPs, using PFWs in simulation shows blow-up due to use of LEQs to modify tune.
- **Operation: At nominal WP (6.21, 6.24) we do not expect space charge alone to cause beam blow-up at injection.**
- **Tools: PyORBIT benchmarked with measured MD data, currently used for LIU predictions.**
- For more details see https://indico.cern.ch/event/828559/contributions/3528372/attachments/1937687/3212811/4th_ICFA_SC_Workshop_HR.pdf

M.A. Fraser, *Transverse effects with twice brighter beams in the PS*, presentation at LIU Workshop 2019, 13 – 15 Feb 2019, Montreux, Switzerland

Expected emittance growth sources today (1)*

*For input emittance of 1 mm mrad (rms, norm) at 1.4 GeV and 75e10 p

<table>
<tr><th>Source</th><th>Expected $\Delta\varepsilon/\varepsilon$
BCMS OP [%]</th><th colspan="2">Comment</th></tr>
<tr><td>Dispersion mismatch</td><td>12 (in H)
1 (in V)</td><td colspan="2">Estimates taken empirically from turn-by-turn SEM and BPM data in the first turns after injection</td></tr>
<tr><td>Betatronic mistmatch</td><td>~ 1 - 3 (in H and V)</td><td colspan="2">Turn-by-turn SEM data indicate negligible betatronic mismatch (uncertainties in MADX model from PSB extraction parameters)</td></tr>
<tr><td>Injection mis-steering</td><td>Negligible with TFB ON (<%)</td><td colspan="2">For 0.5 mm (max.) oscillation with TFB OFF: one computes ~ 2%</td></tr>
<tr><td>Injection bump</td><td>Negligible (<%)</td><td colspan="2">No blow-up observed (measurements on second instance)
Studies have specified BSW synchronization to avoid blow-up</td></tr>
<tr><td>Injection energy error</td><td>Negligible after correction (< %)</td><td colspan="2">Potentially a strong source of blow-up, $\Delta p/p$ ~ few 10^{-4} is important and needs operational attention!</td></tr>
<tr><td>KFA14 ripple</td><td>< 1 (in H only)</td><td>Synchronisation with beam will be an important commissioning</td><td rowspan="3">TFB should be effective to compensate ripple (< 30 MHz), effectiveness of damping to be computed: need to check damping time in light of space-charge simulations</td></tr>
<tr><td>KFA10/20 ripple</td><td>2 – 3 (in V only)</td><td>Depends on ring and PS injection energy</td></tr>
<tr><td>KFA45 ripple + post-pulse</td><td>0 – 3.5 (in H only)</td><td>Depends on ring and PS injection energy</td></tr>
</table>

LIU Workshop, 20-22 January 2020 M.A. Fraser

Expected emittance growth sources today (2)*

*For input emittance of 1 mm mrad (rms, norm) at 1.4 GeV and 75e10 p

Source	Expected $\Delta\varepsilon/\varepsilon$ BCMS OP [%]	Comment
PS optics mismatch induced by space-charge	Negligible (< %)	PS closed solution with considering KV (rms) tune spread
Space-charge blow-up in TL	Expected to be negligible (< %)	Unlikely in view of turn-by-turn PyORBIT simulation results: to be checked
Space-charge blow-up in PS	Negligible (< %)	Studies of sensitive of blow-up to WP at injection show a range of Q_x,Q_y ~ 0.02 where no blow-up is observed from 2 to 15 ms after injection

Acknowledgements

“If I have seen further it is by standing on the shoulders of Giants” - Newton

- H. Bartosik & A. Huschauer: Leadership & guidance.
- F. Asvesta, M. Kaitatzi: MD/simulation assistance & discussions.
- PSB & PS Operators: MD setup & assistance.
- S. Albright, A. Santamaria Garcia, E. K. Platia: Assistance with tomoscope to PyORBIT tomo distribution.
- A. Oeftiger: Tunespread tool, low brightness MDs, general assistance.
- CERN HPC: HPC-Batch support.
- CERN IT: AFS & LXPlus support.
- G. Sterbini: MD Analysis SWAN Toolbox.

Thank you for your attention!

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