High intensity MDs and operational experience

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HL-LHC Collaboration meeting 09.10.2024

Content

- Some important milestones
- Beam induced heating
- Injection losses
- Beam stability and losses at top energy
- Beam-beam impact on the collimation hierarchy
- Conclusion

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  → Next milestones : Physics with $1.8 \cdot 10^{11}$ p/b, collisions of 12b trains with $2.3 \cdot 10^{11}$ p/b
- Injection of trains of 2x48b (tot 348b) with **$2.3 \cdot 10^{11}$ p/b** in MD, but not fully ready for operation See B. Karlsen-Baeck
  → Next milestone : Beam quality preservation with $2.3 \cdot 10^{11}$ p/b (losses at start of the ramp). Injection of longer trains (HL-LHC baseline : 4x72b per injection) in MDs ($2.3 \cdot 10^{11}$ p/b) and potentially in operation ($1.8 \cdot 10^{11}$ p/b)

Beam induced heating : operational experience

- Main consequences of large electromagnetic fields in surrounding components:
  - Vacuum spikes (TCLD, TDI, vacuum modules, LHCb VeLO)
  - Vacuum degradation (BGI, TDIS, TOTEM)
  - Damage (BSRT, TDI, BGI, vacuum modules, ALFA)
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- Towards HL-LHC parameters
  - Increase of at least a factor 2 of beam-induced heat deposition (at constant bunch length)
  - Several unexpected issues may come up on the way to HL-LHC parameters (many new equipments)
  - Improved control of bunch length put in place this year will help

Beam induced heating status

equipment	Problem	2011	2012	2015	2016	2017 and 2018	2022	2023	2024	2025
Vacuum modules	Damage	VMTSA spring gone, RF fingers melting	VMTSA removed		Spring on VMSI gone	Spring on VMSI gone again	vacuum spikes in 5R4	ID212 Spring gone, RF fingers melting	Intensity limited to 1.6E11 p/b	Elliptical bellows still there
TDIS	Damage	Beam screen bent	Beam screen bent	non-conformity with hBN material	vacuum behavior with 55mm gap, could be e-cloud related			Abnormal temperature signals	Signals more normal on spare TDIS	
MKI	Wait for injection or reduce intensity			Beam screen upgrade and non conformity solved			Temperature interlocks increased with experience	Temperature interlocks increased with experience	Temperature interlocks increased with experience	
Collimators	Few dumps			Non conformity solved. TCTVB removed			TCLD vacuum spikes		TCLD vacuum spikes	
TOTEM	Beam screen regulation at the limit	Q6R5 affected by TOTEM	Q6R5 affected by TOTEM	Upgrade of the valves + TOTEM check						
Roman pots (ALFA and AFP)	Risk of damage and outgassing	ATLAS-ALFA close to limit	ATLAS-ALFA close to limit	New design for ATLAS-ALFA + cooling			AFP pots are getting close to 50 C	Cooling improved		
BSRT	Deformation suspected		Mirror damage	New design + cooling						
BGI	Vacuum increase			To be followed up	BGI heats up and damaged	BGIs removed				
LHCb Velo	Vacuum spikes						vacuum spikes			

→ Main worry is vacuum modules for 2025, all ID212 modules removed

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New intensity limit at $2.2 \cdot 10^{11}$ p/b with remaining smaller modules. They will be exchanged during LS3.

→ Main worry is vacuum modules for 2025, all ID212 modules removed

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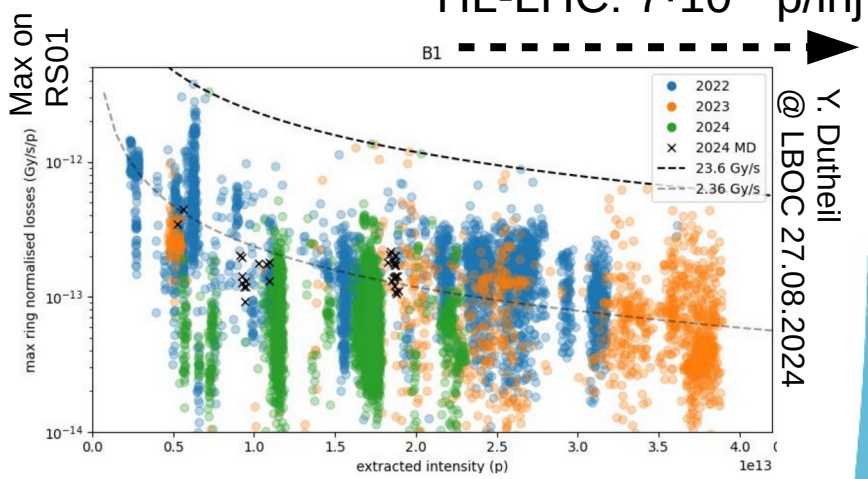
Injection losses

Suffered from injection losses in 2022/23 (hybrid, 236b / inj) See. S. Morales

→ Cause(s) not clearly identified (strong year-to-year and fill-to-fill fluctuations, beam-to-beam differences)



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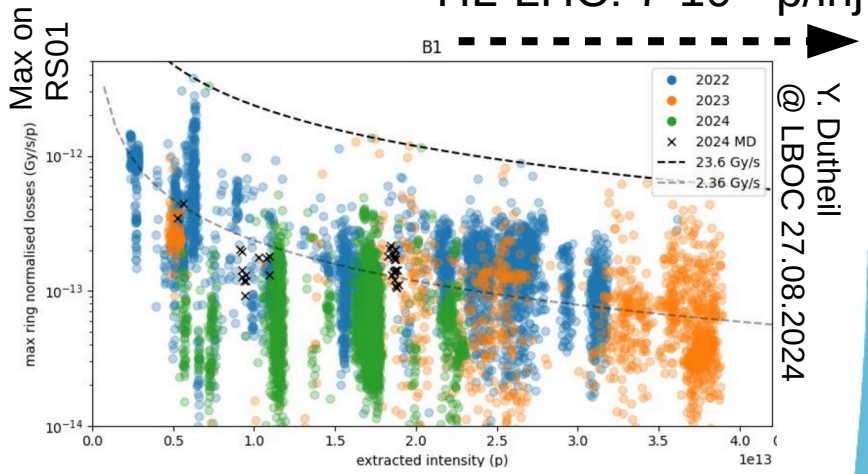

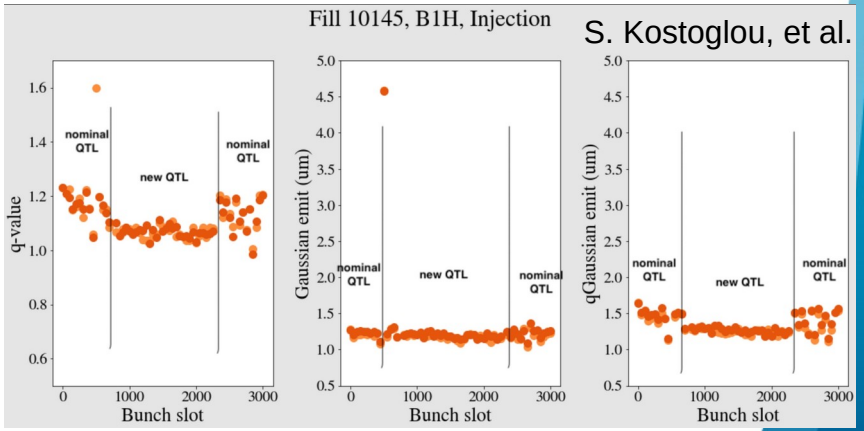

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- Current operation with short trains (108b / inj) offers large operational margin
  → Need tests in MD and in operation with longer trains at injection : Consider few weeks with hybrid scheme in 2025 ?

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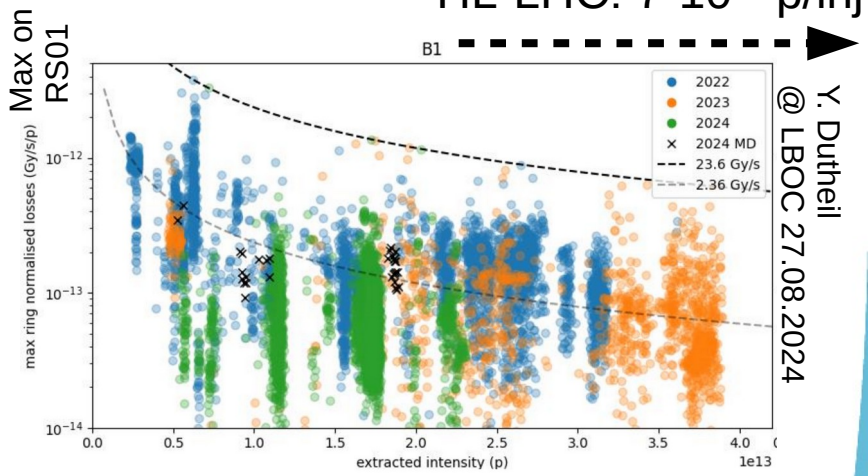

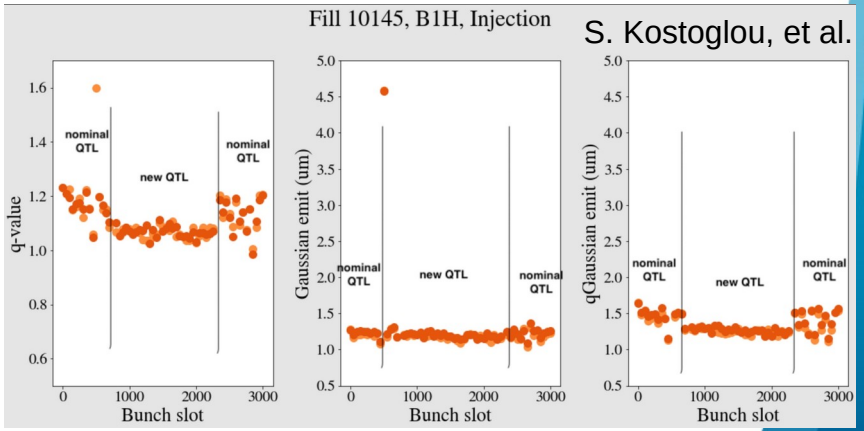

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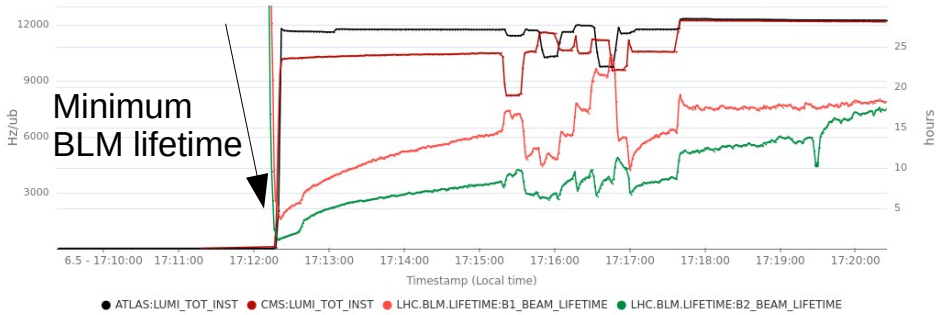
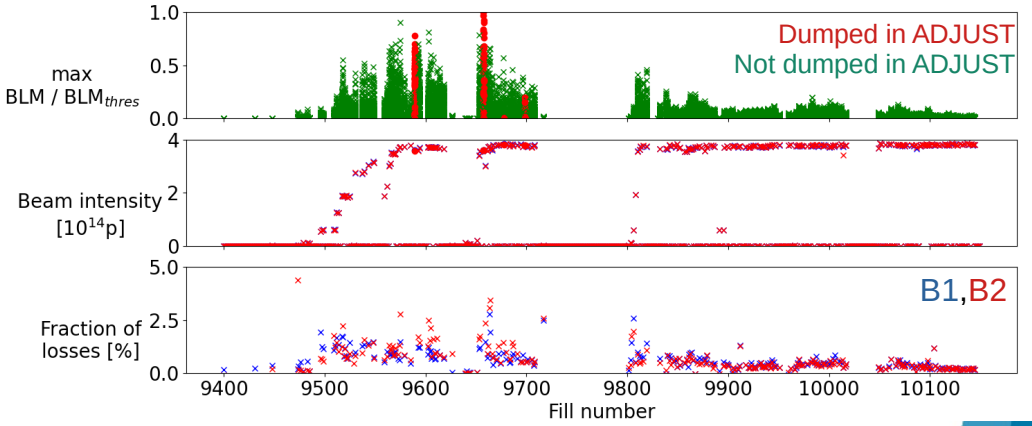
- Beam losses in ADJUST were close to dump levels See S. Morales





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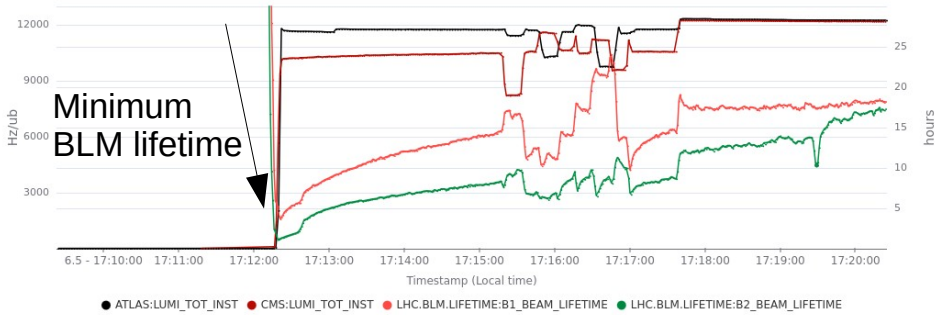

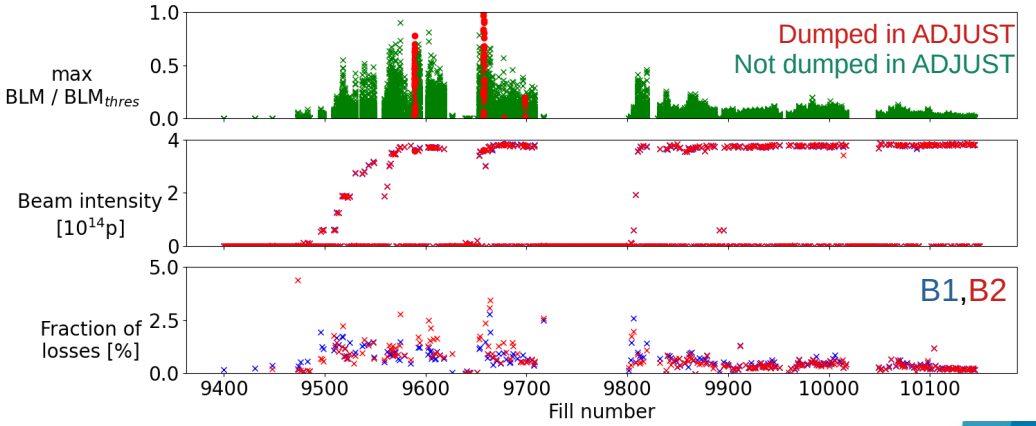

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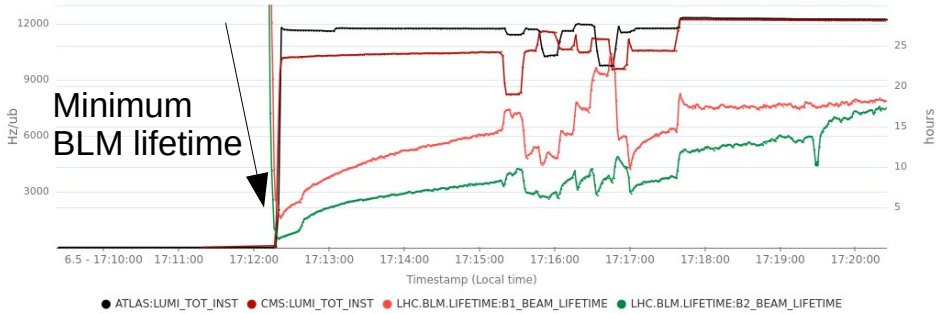
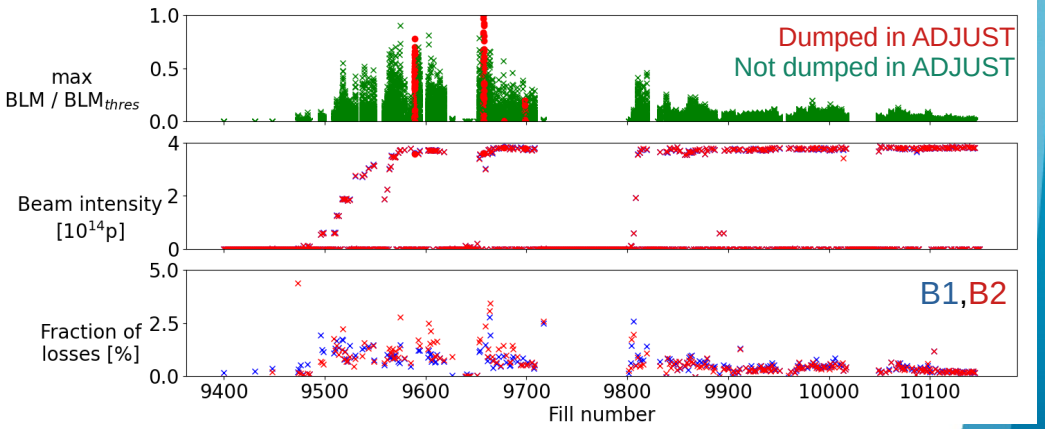
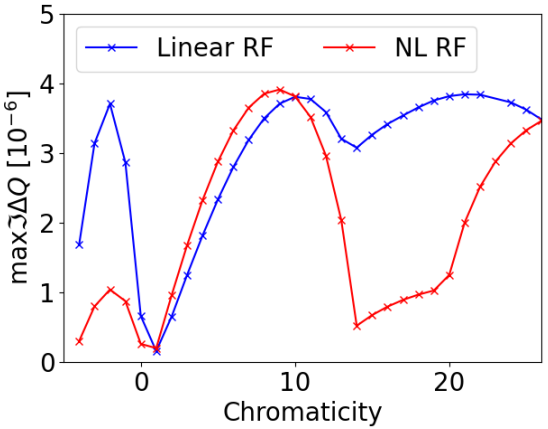
- Beam losses in ADJUST were close to dump levels See S. Morales
  → Clear correlation with tail population See. S. Kostoglou
- Chromaticity and octupole requirement are set by flat-top (w/o head-on) and the DA is limited only once in collision.
  → Need to quantify experimentally the link between the DA drop and the losses in ADJUST

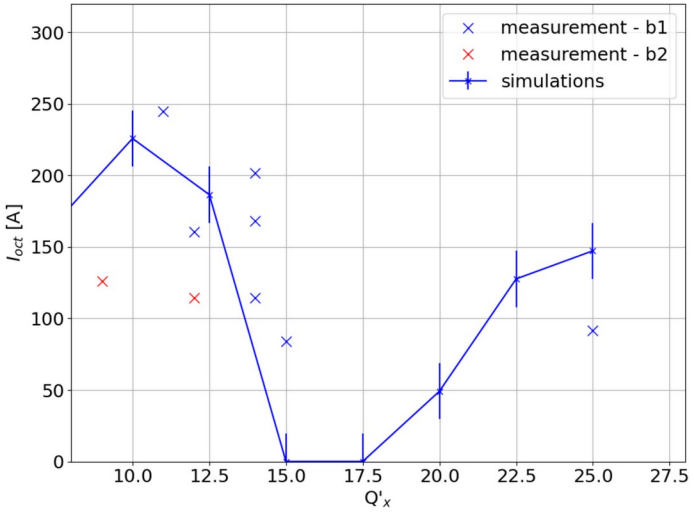




Stability requirement at flat top

- The existence of a ‘sweet spot’ for chromaticities between 15 and 20 units was demonstrated experimentally





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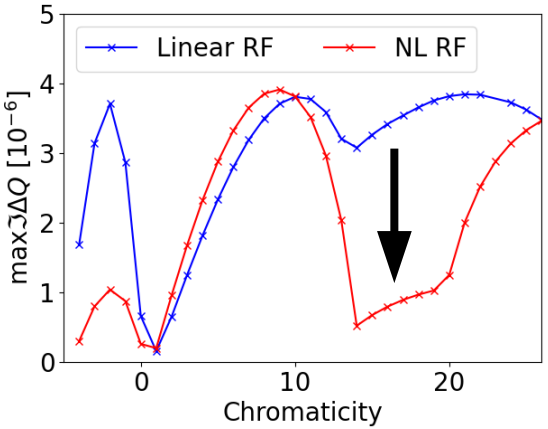

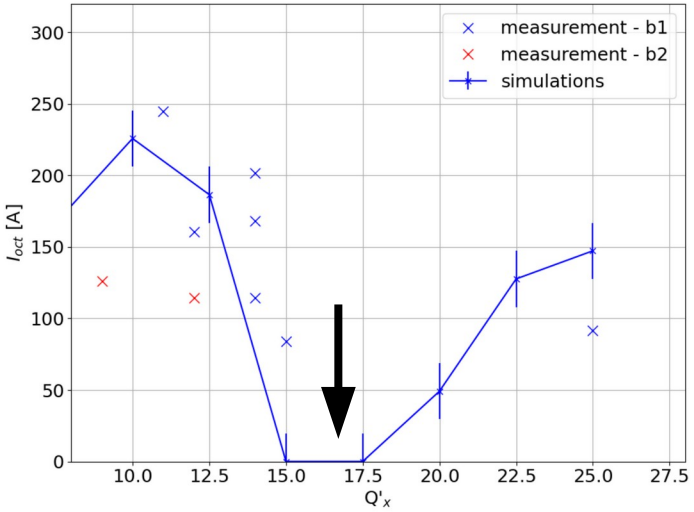

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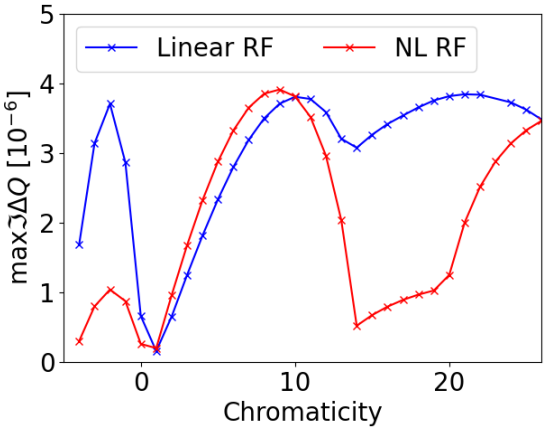

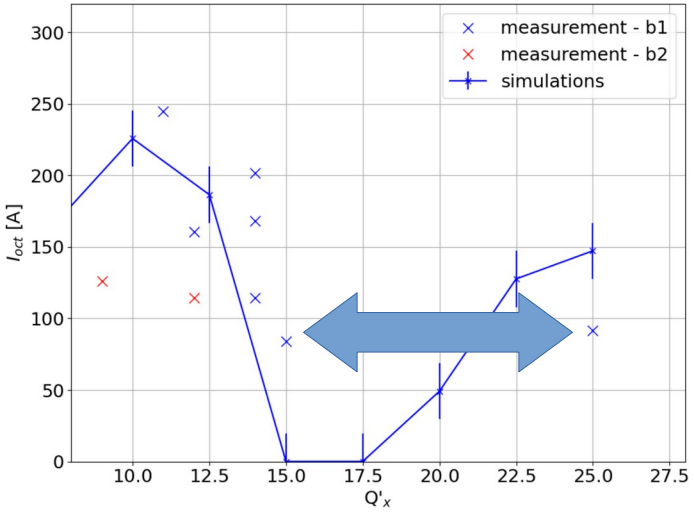

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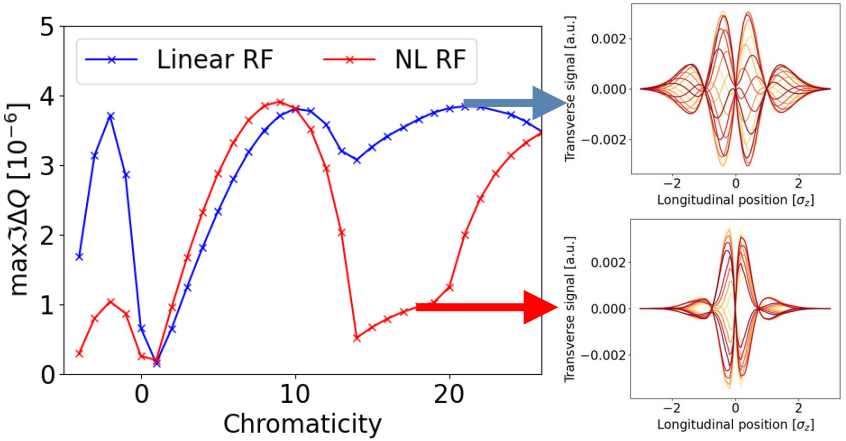

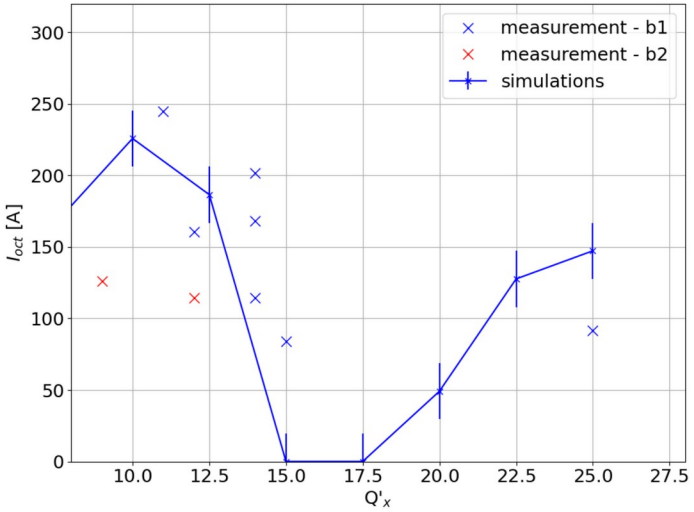

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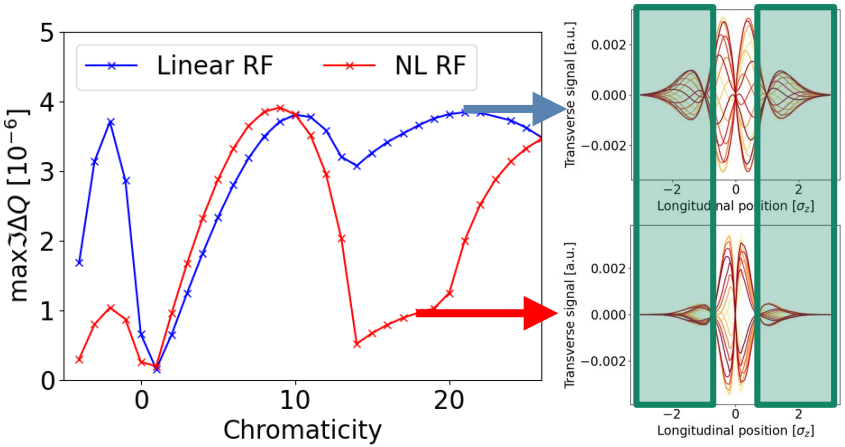

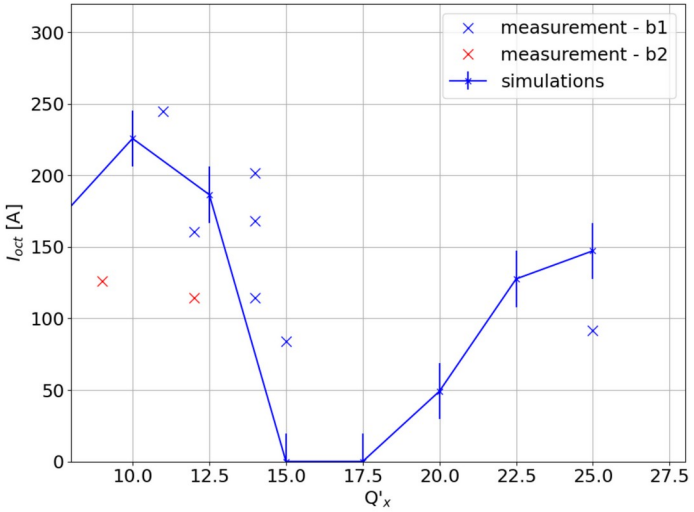

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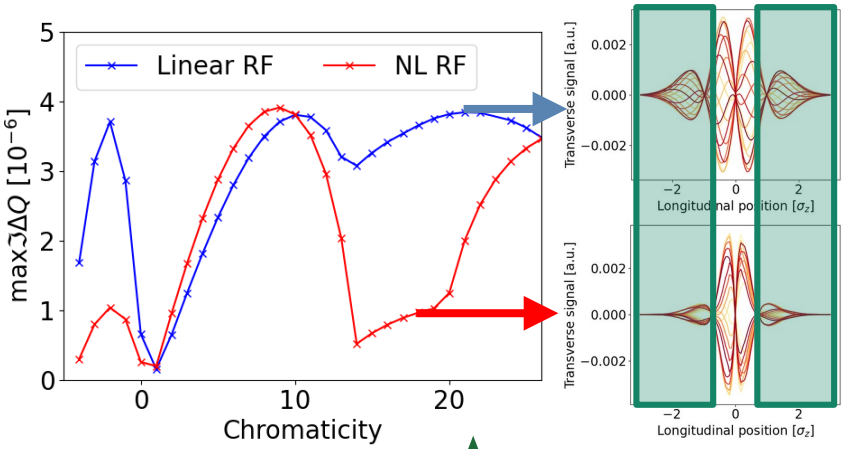

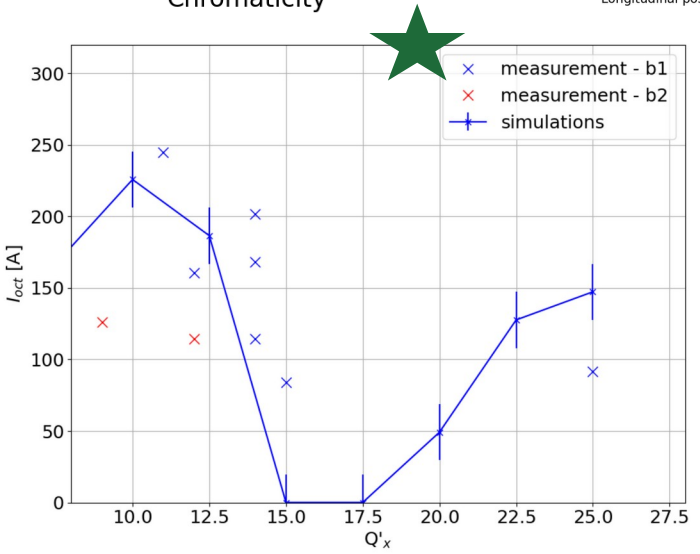

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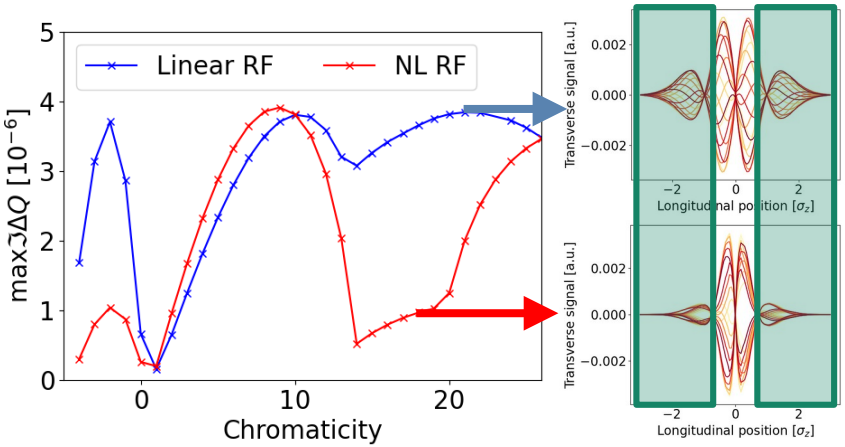
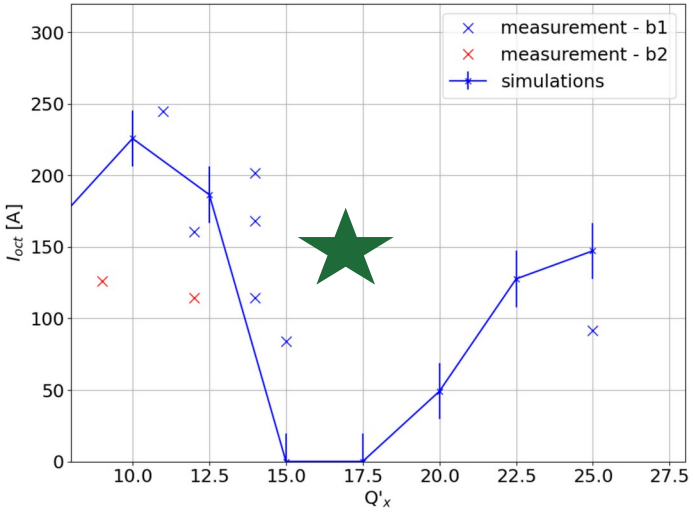
  - → 17 units / 150A could be tested operationally in 2025/2026





Experience with BTF, AC-KFC and Schottky

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  - No losses or emittance growth
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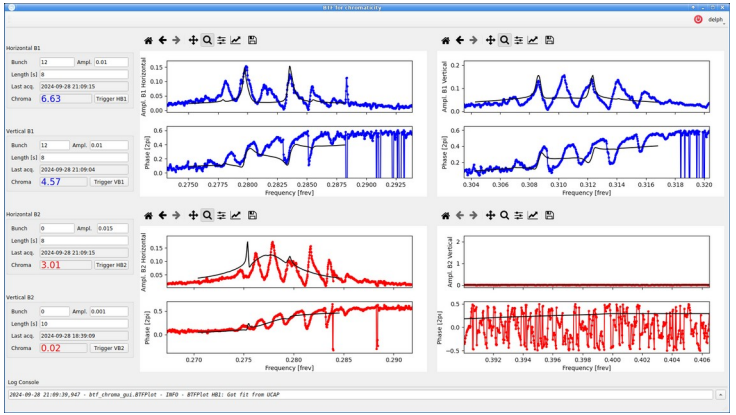

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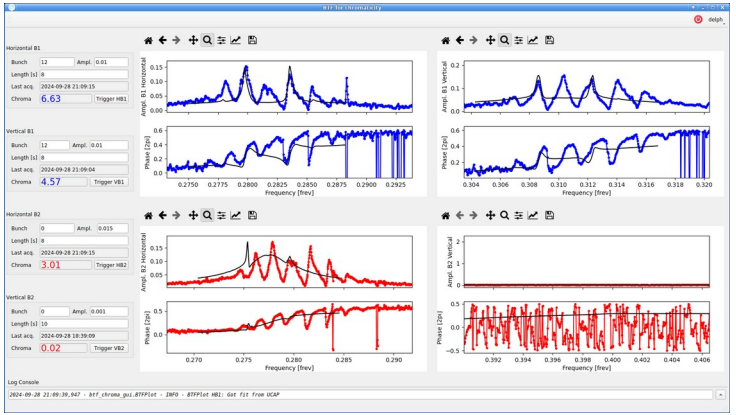

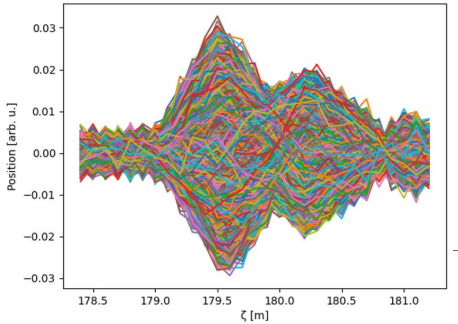

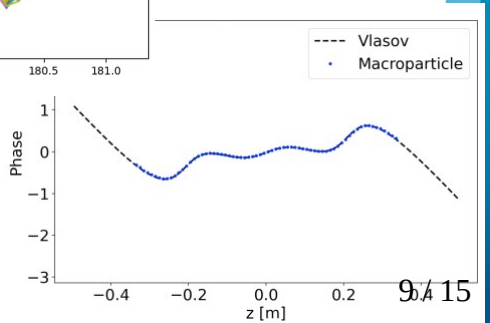

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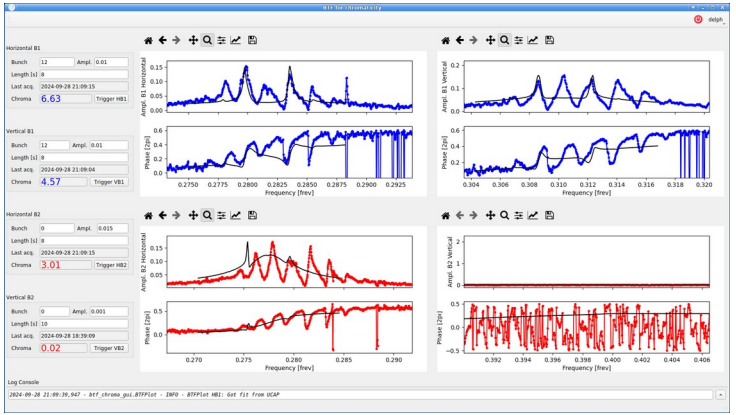

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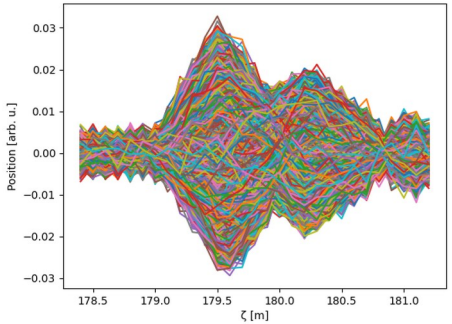
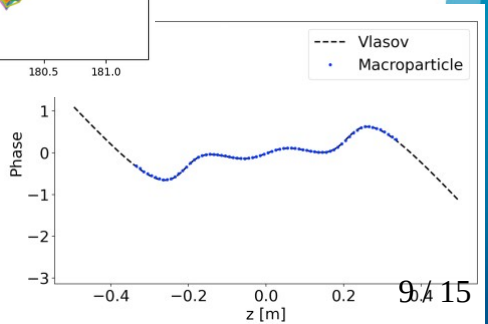


- Chromaticity measurement based on Schottky signal are promising but remains challenging at flat top see K. Lasocha @ LBOC 22.10.2024



Chromaticity and octupole requirement in collision

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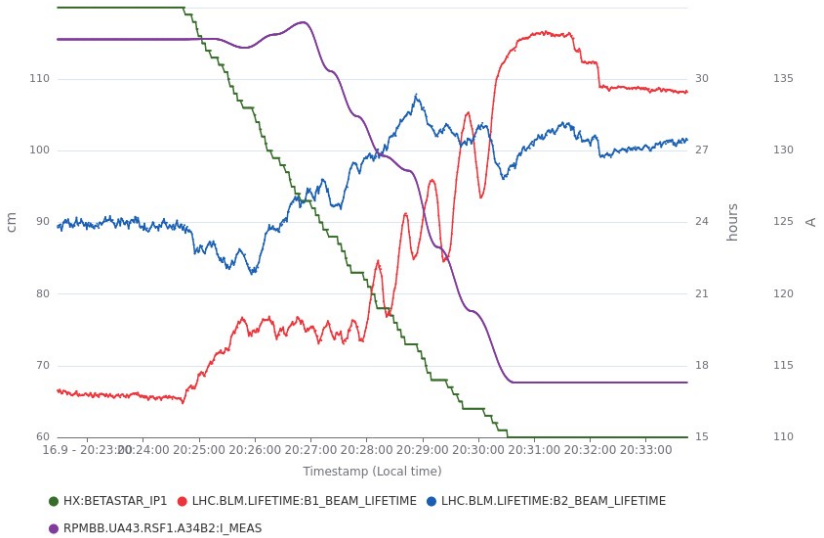

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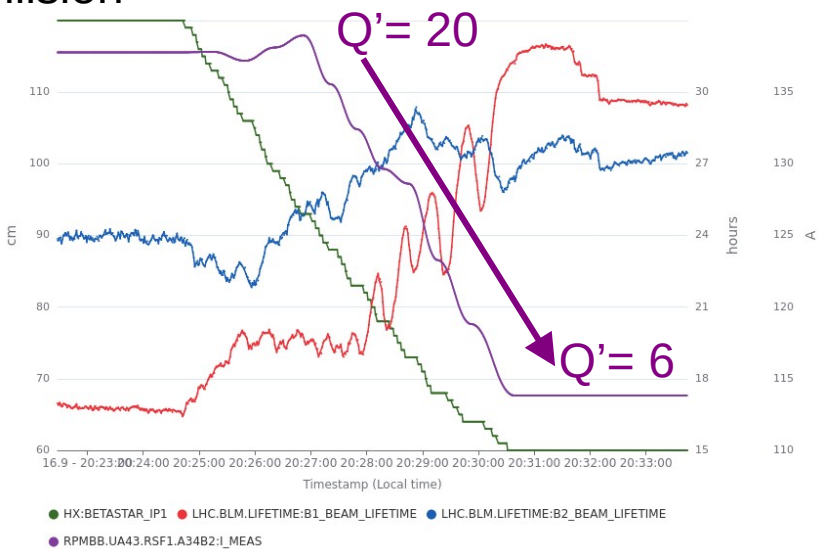

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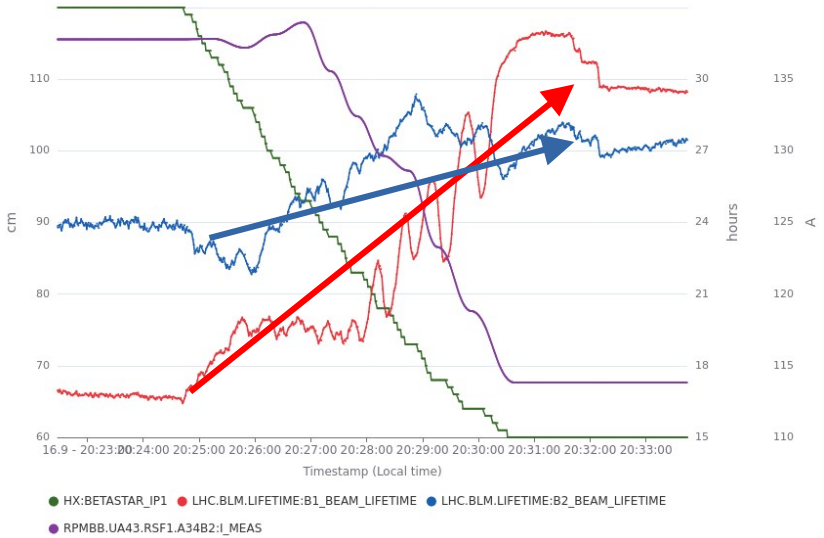

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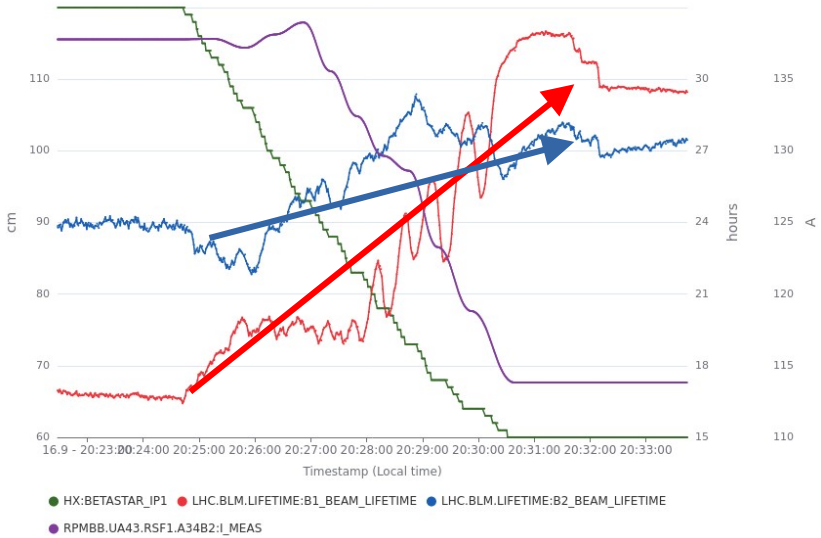
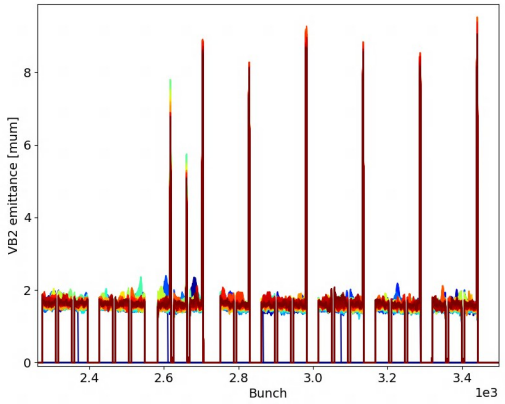
  → Few vertical instabilities with offset beams in either IP1 and 5. No Showstopper, yet it shows that the e-cloud instability threshold is not far





- Fill 10138
- 1.6·10^{11}p/b
- 45cm
- Offset in CMS

Experience with negative polarity of the octupoles

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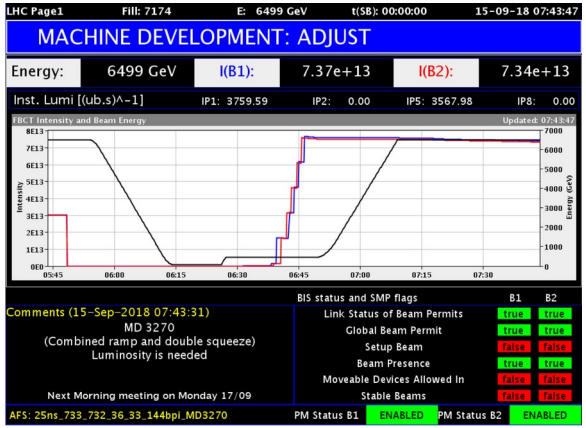

Full cycle with negative polarity of the octupoles, 733b

S. Fartoukh, et al., CERN-ACC-2020-0028

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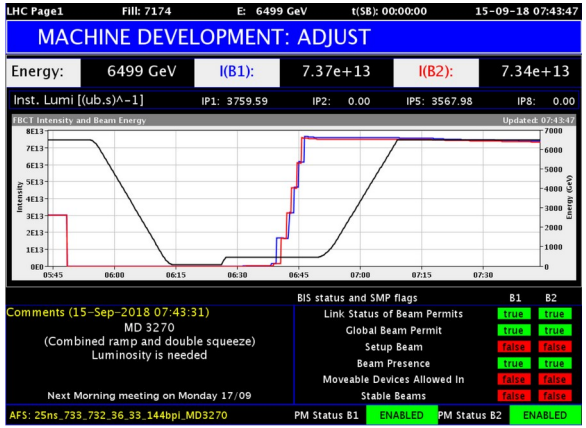
  - Next MD block: lifetime optimisation with e-cloud at injection and negative octupole polarity

→ Operating the LHC in 2025/26 with the negative polarity would provide valuable experience though the gain in performance might remain marginal



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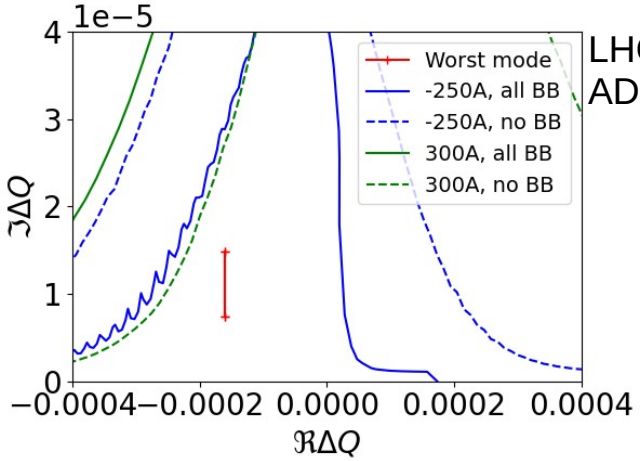

LHC 2025 ADJUST

Beam-beam and collimation hierarchy : Linear

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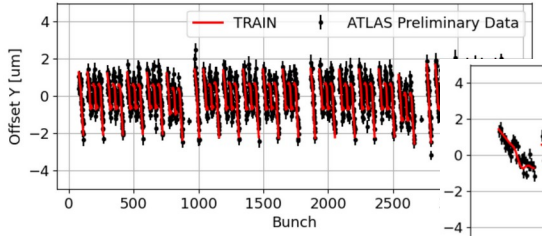
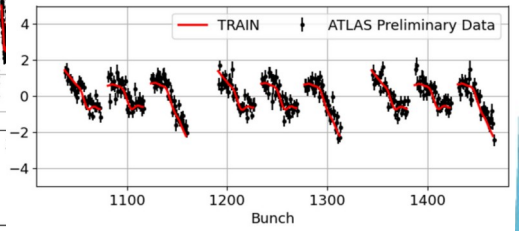
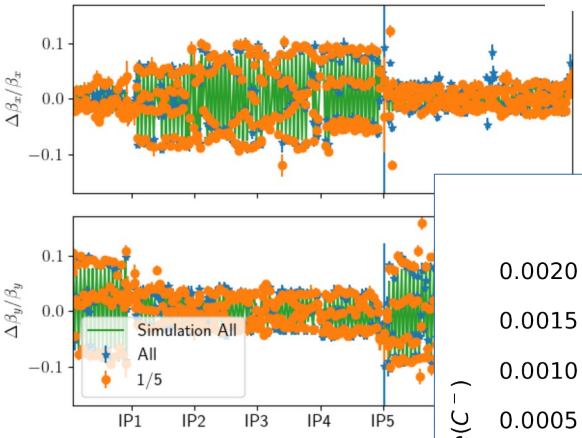


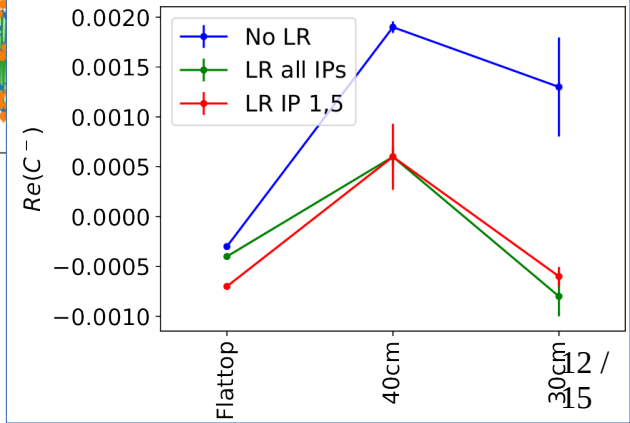
M. Hostettler @ BB24



T. Persson @ BB24



J. Wennigner, et al.,
CERN-ACC-NOTE-2018-0026



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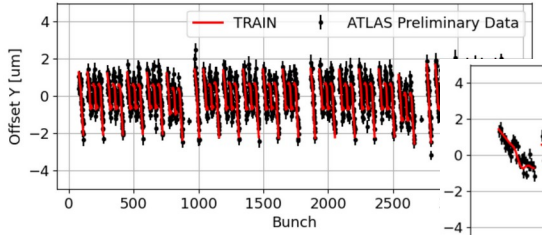

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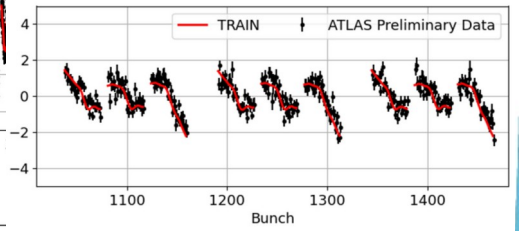

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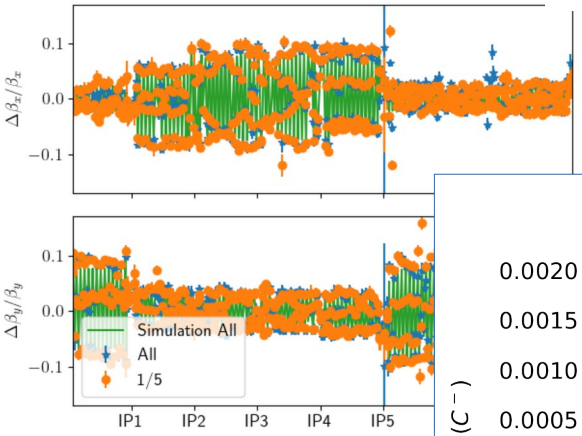

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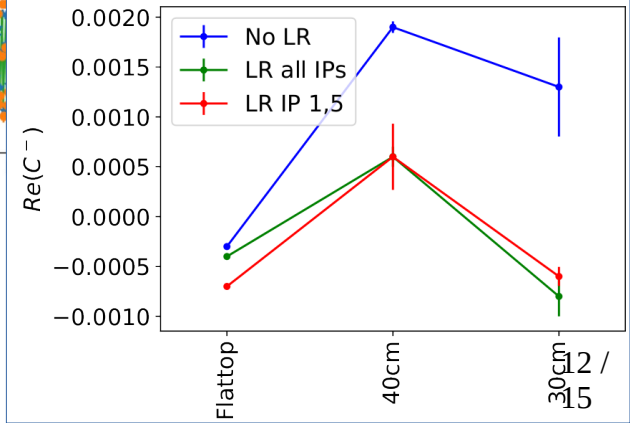

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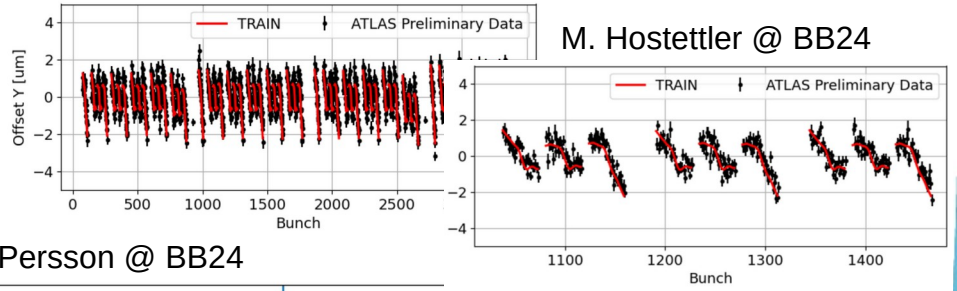

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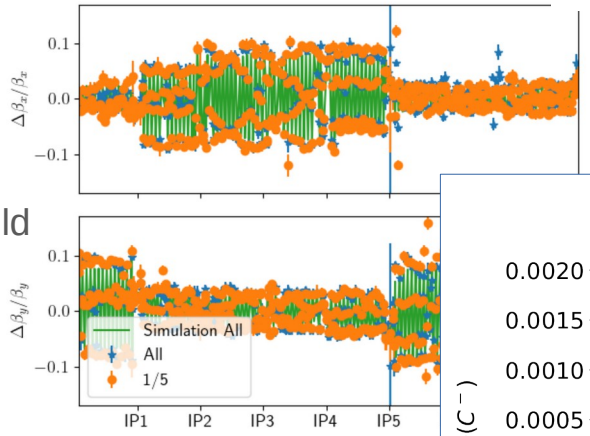

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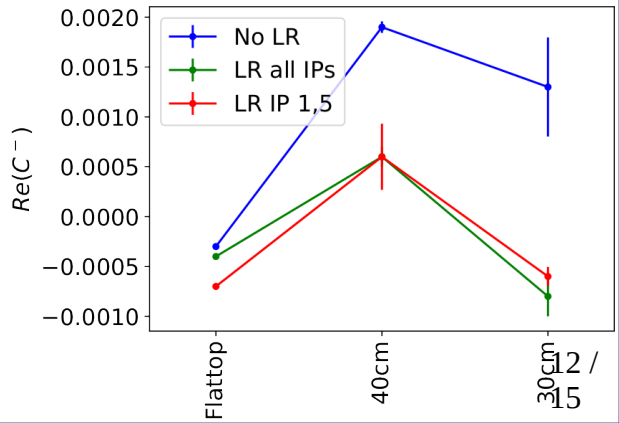

*X. Buffat, et al., CERN-ACC-NOTE-2018-0036
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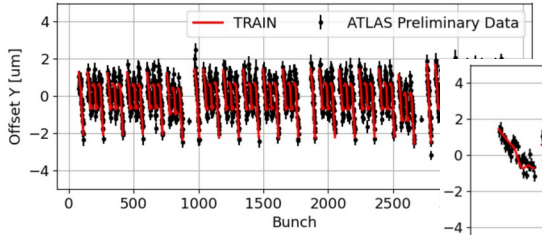
→ Compatible with baseline 1.5σ retraction



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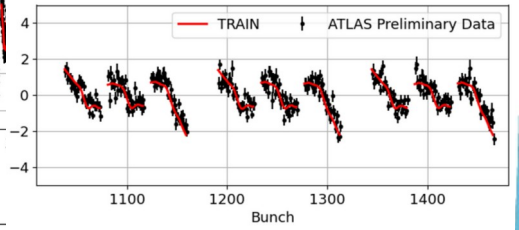

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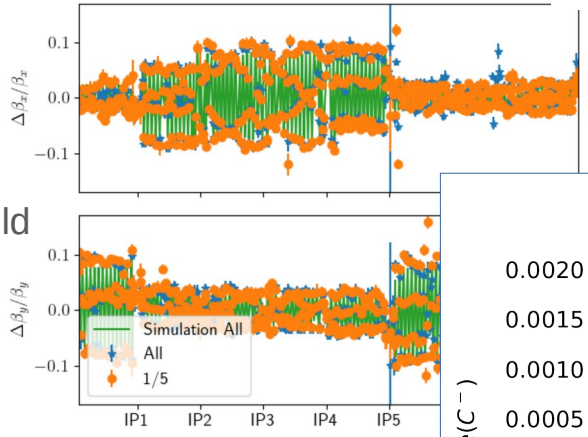

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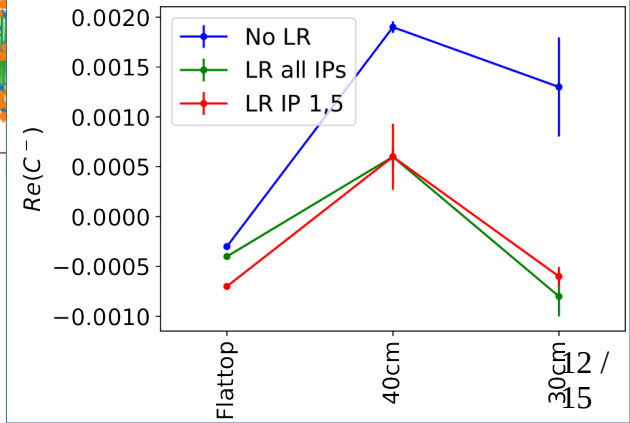

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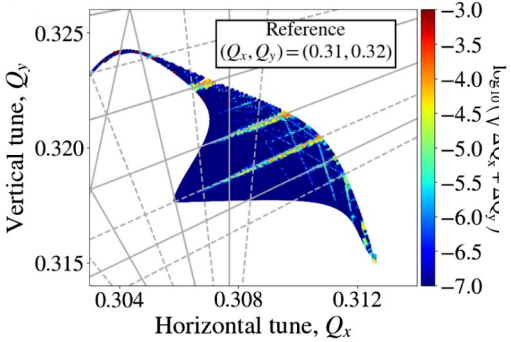
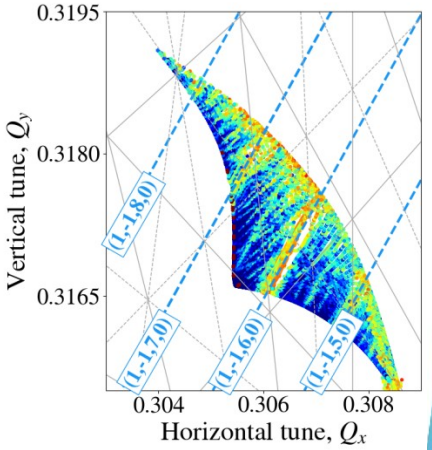


S. Kostoglou, Phys. Rev. Accel. Beams 23, 121001 (2020)



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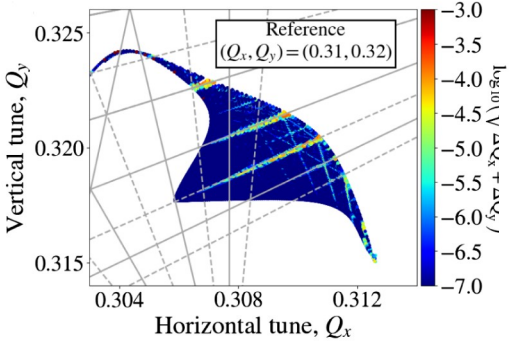

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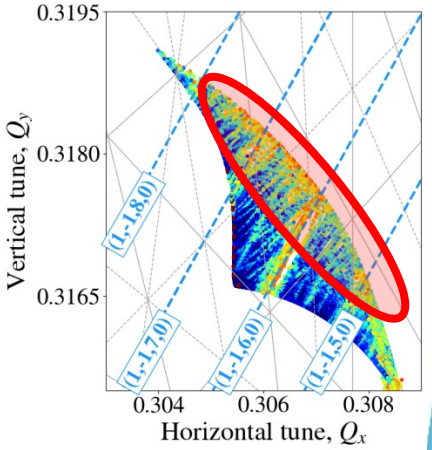

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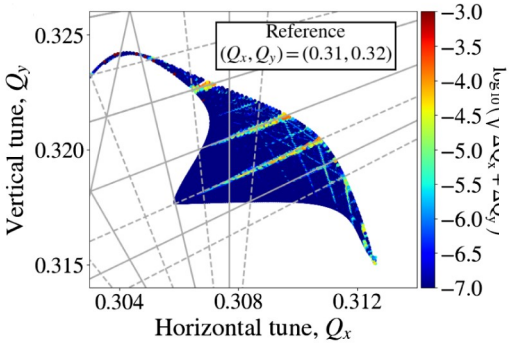

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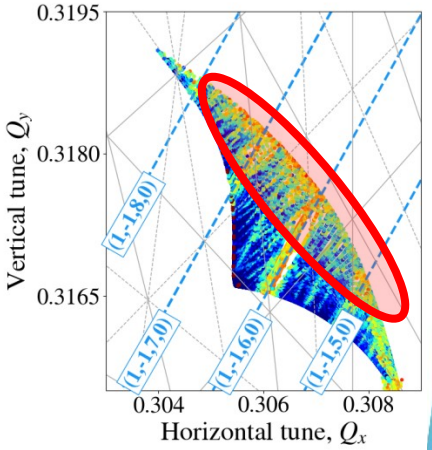

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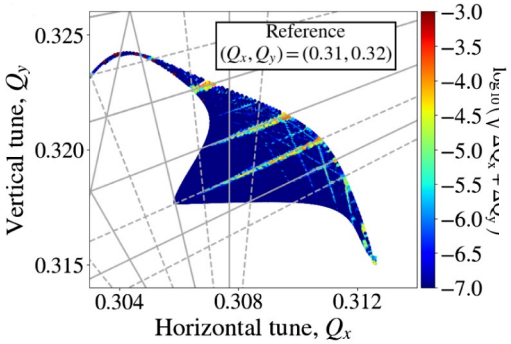

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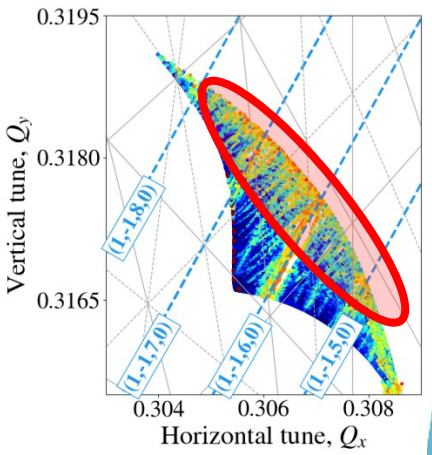
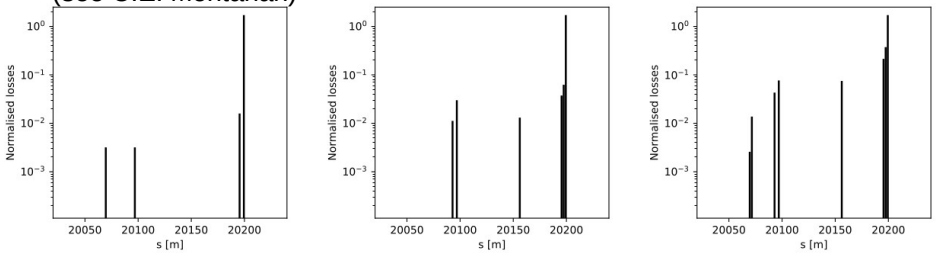


F. Van der Veken @ BB24
(see C.E. Montanari)



no beam-beam
chroma 7
octupoles 400

beam-beam
chroma 7
octupoles 400

beam-beam
chroma 20
octupoles 200

Summary

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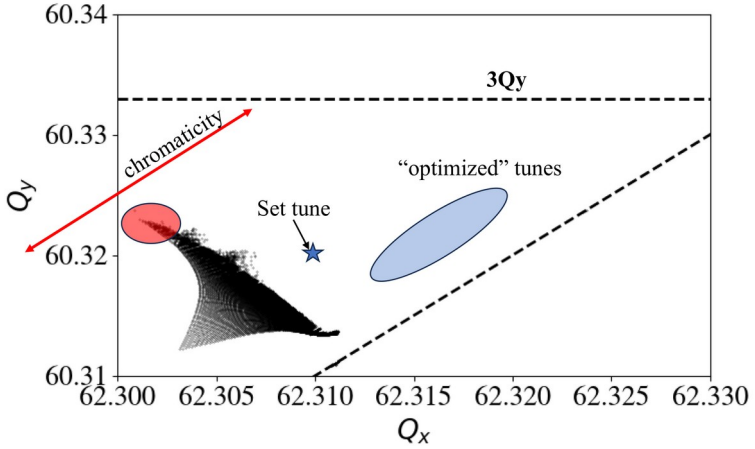
  → Impedance reduction (see L. Giacomel, B. Lindstrom), tune, chromaticity and detuning control, negative polarity of the octupoles
- Loss mechanisms breaking the collimator hierarchy and linked to beam-beam effects were observed
  - Linear effects are under control, but can eat part of the margin. Other effects can be shadowed when validating the machine at low intensity.
  - Transverse losses of off-momentum particles are not covered by present betatron+off-momentum loss maps scheme.

Distorted trajectories (K. Paraschou, et al., @ LBOC 04.06.2024)

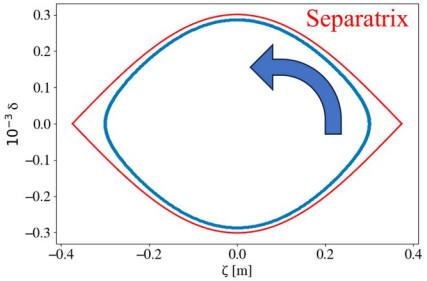
Tune diagram

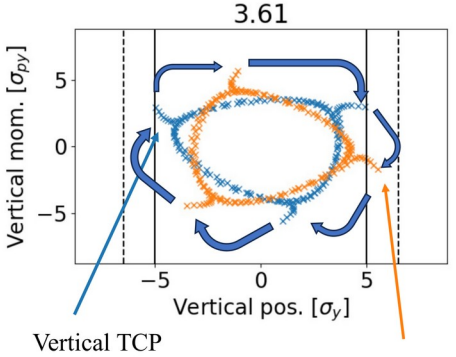


Phase space distortion happens when you get **close to resonances**.

* Footprint was not simulated with the exact 2024 configuration, but remains qualitatively similar.

Trajectory of the single particle





Initialize particles with
- Small horizontal amplitude: $x = 0.5\sigma$, $p_x = 0$
- Large vertical amplitude: $y = \sim 4\sigma$, $p_y = 0$
- Large longitudinal amplitude: $\zeta = 0.3$m, $\delta = 0$

Synchrotron oscillations + chromaticity brings particles to the 3Qy resonance which heavily distorts the phase space.

Before reaching 5σ at the TCP, particle reaches a larger maximum position in TCSG.