Optics studies in the PS

E.H.Maclean <u>on behalf of W. Van Goethem</u>

Special thanks to OMCteam, PS-OP, A.Huschauer, G.Franchetti, H.Rafique, F.Asvesta

Wietse recently finished his Doct. contract at CERN

→ currently post-doc at Upsaala working on ESSnuSB project (couldn't attend today)

→ Made various PS MDs in 2024

- **ML-based prediction/control of Q/Q' with PFW**
- **Measurement and correction of RDT with ADT-AC-dipole**
- **Zero dispersion optics**

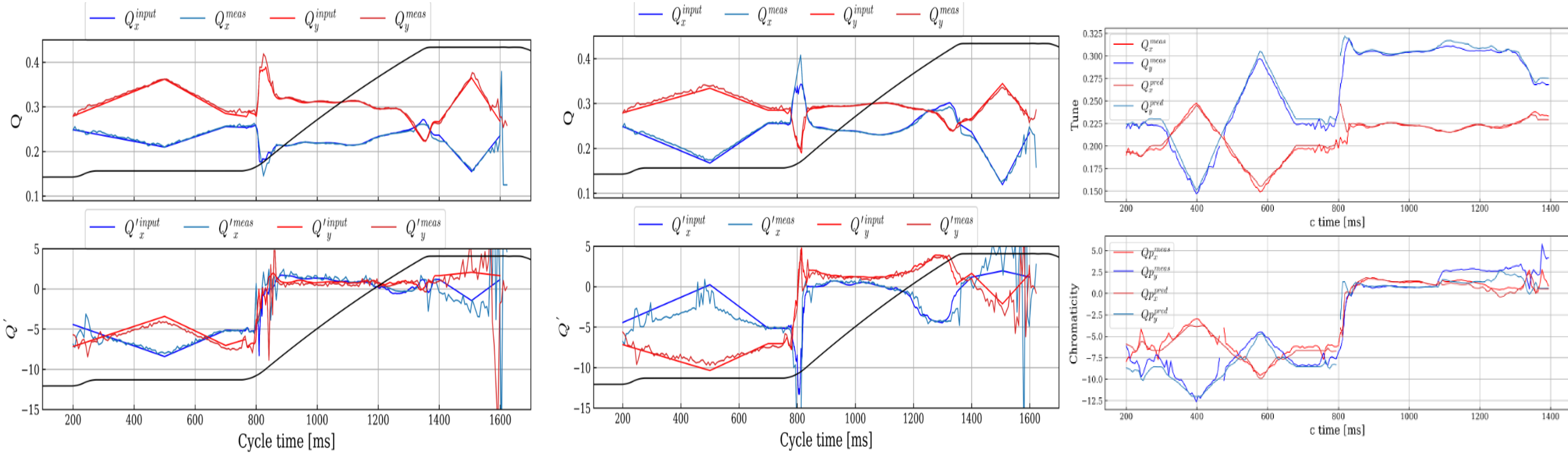
PFW control with beam-trained neural network

$$\mathbf{F}\begin{pmatrix} B \\ I_{DN} \\ I_{FN} \\ I_{DW} \\ I_{FW} \\ I_{8L} \end{pmatrix} = \begin{pmatrix} Q_x \\ Q_y \\ Q'_x \\ Q'_y \\ Q''_x \\ Q''_y \end{pmatrix}$$

Train network to predict tune/chroma throughout cycle based on applied PFW settings

Initial attempts challenging, improved training, post-processing, handling of coupling…

Predictive network working rather well, various MD tests in 2024



PFW control with beam-trained neural network

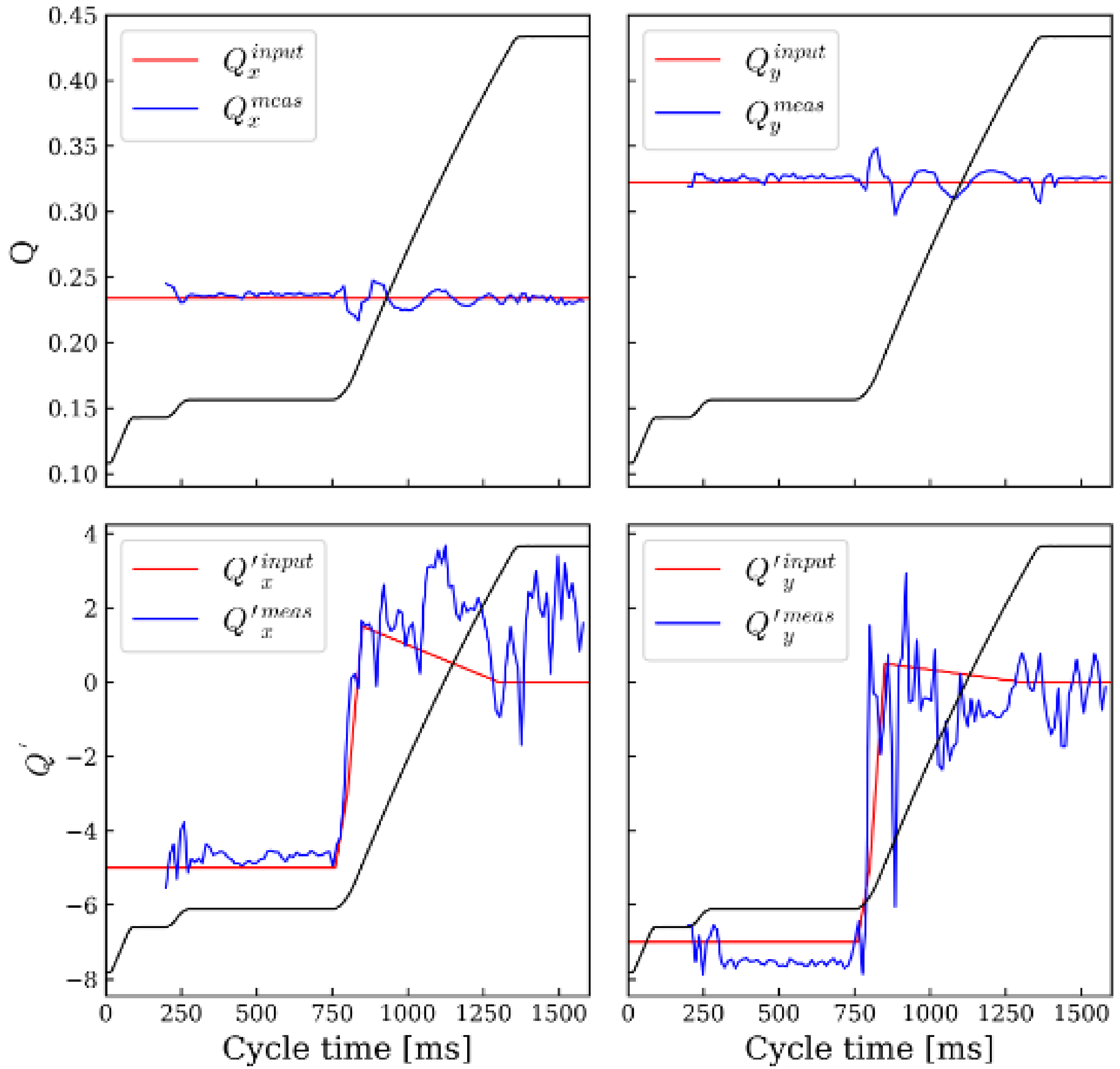
$$F^{control}\begin{pmatrix} B \\ Q_x \\ Q_y \\ Q'_x \\ Q'_y \end{pmatrix} = \begin{pmatrix} I_{DN} \\ I_{FN} \\ I_{DW} \\ I_{FW} \\ I_{8L} \end{pmatrix}$$

Aimed to use predictive network to back-train control network, to see if it can define settings of PFW. Tested in 2024 MDs & working particularly well for Q at high/low energy

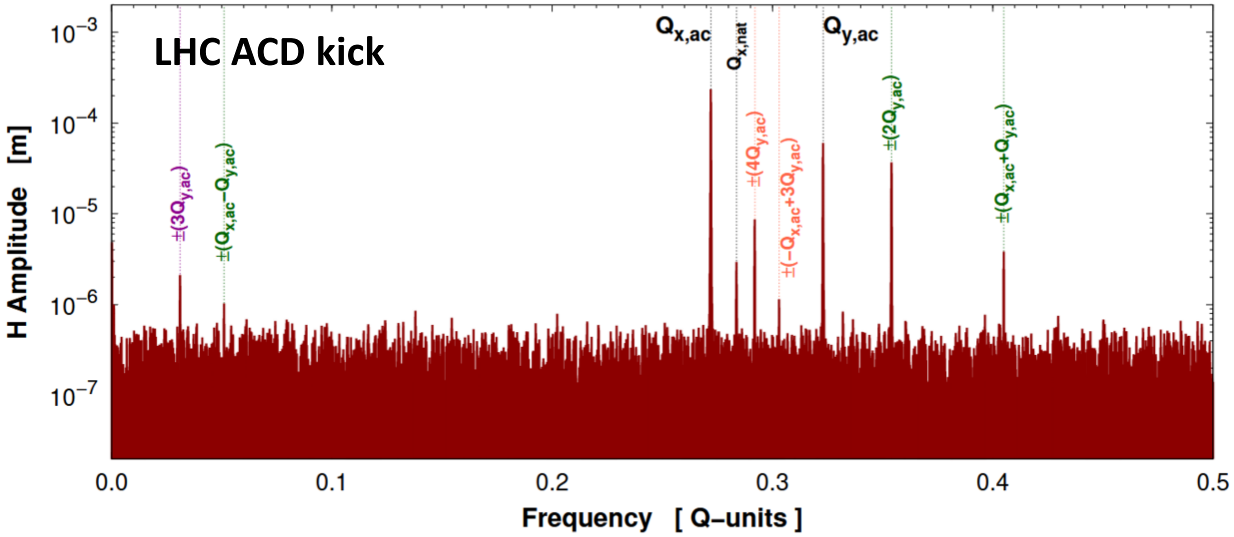
Challenging around transition – very dynamic, also where predictive model struggles most

Trained on LHC cycles – NN doesn't extrapolate well outside of trained current ranges

Interesting to combine also with parallel improvements in the MU modelling



Resonance Driving Term (RDT) correction via ADT-ACD



With RDT aim to quantify resonance strengths by how much they perturb turn-by-turn motion of excited beam

Different resonances show up as characteristic peaks at different frequencies in the Q-spectrum

RDT provides very quantitative picture of resonance strength & phase

Measurement with single kicks / injection oscillations possible, but often challenging

→ decoherence limits turns available for analysis & alters RDT amplitude, complicates measurement & benchmarking

→ Lots of success in LHC by measuring forced oscillations, but with dedicated AC-dipole HW not available in other machines

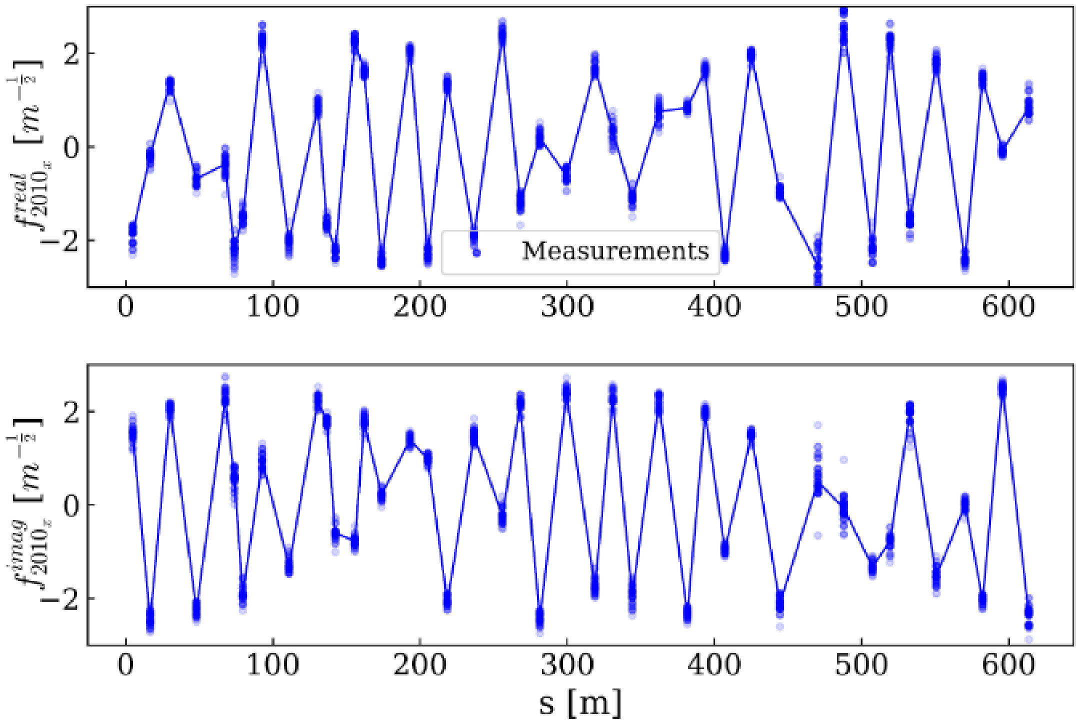
Aim of MD has been to show can use long-term low-amplitude forced oscillations from ADT to also study driven Resonance Driving Terms in the PS to benchmark models & find resonance corrections

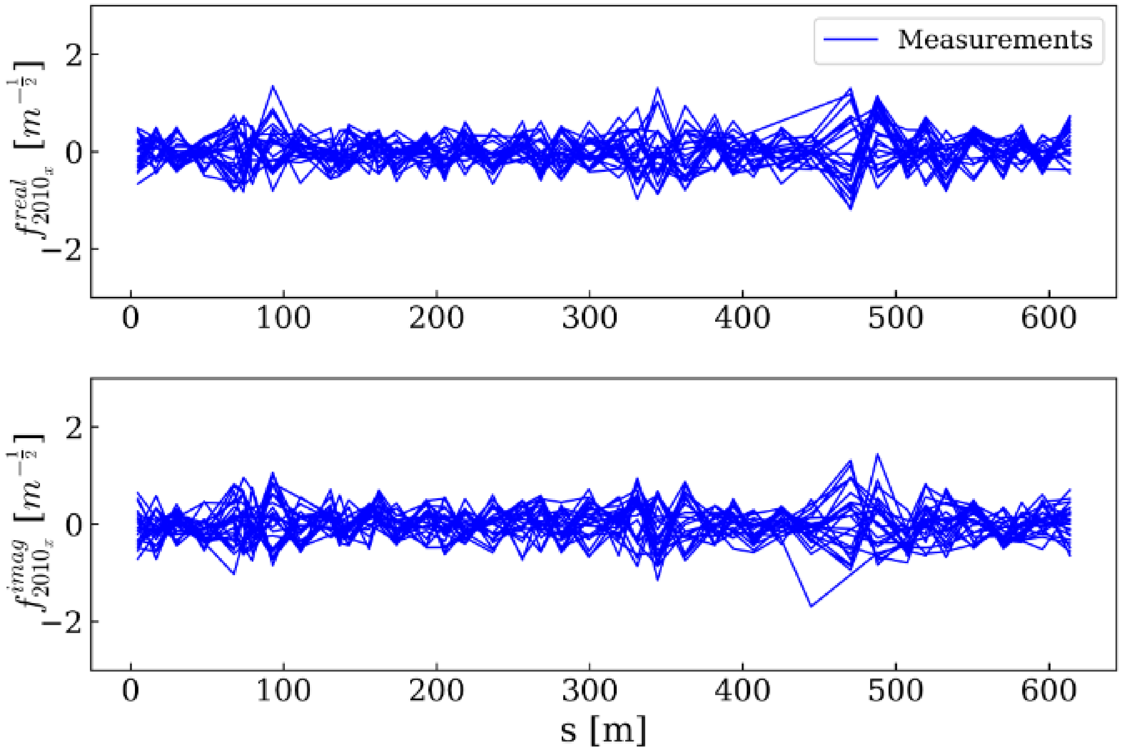
Resonance Driving Term (RDT) correction via ADT-ACD

In 2023 Wietse made various MDs using RDT to benchmark PS model of skew-sextupole correctors (large errors in I/K)

→ In 2024 MD tested correction e.g. 2Qx+Qy skew-sextupole resonance

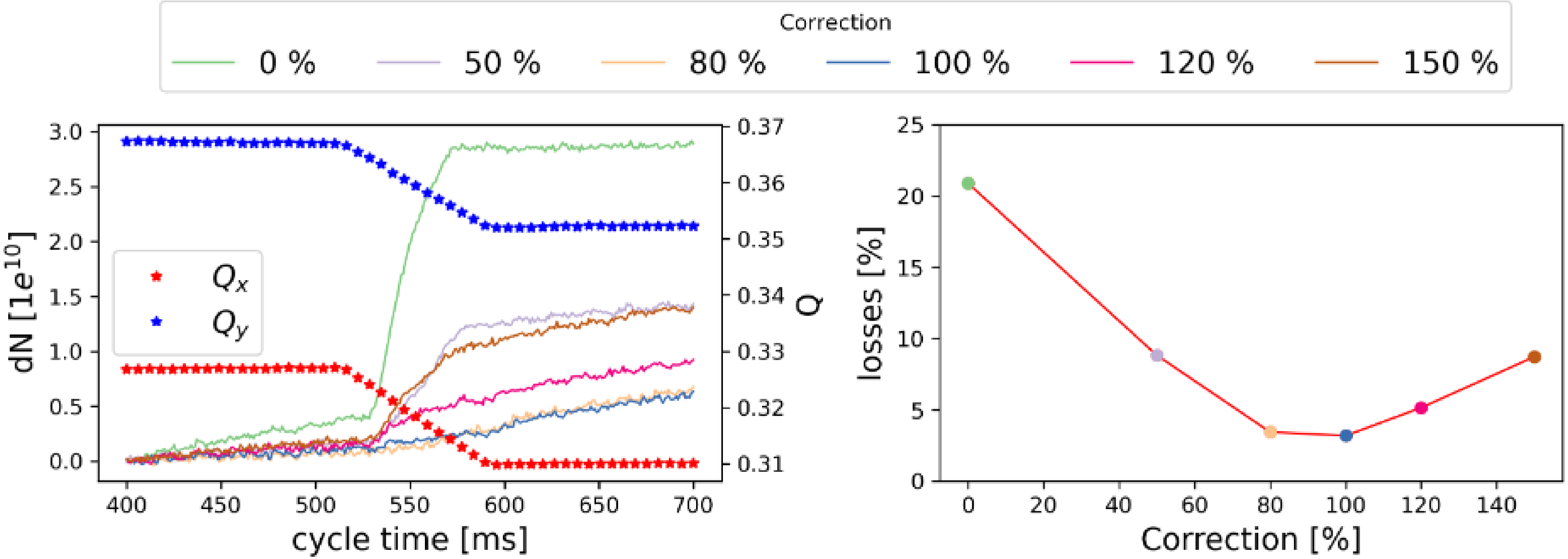
Fixed XSK MAD model used to define correction for measured RDT





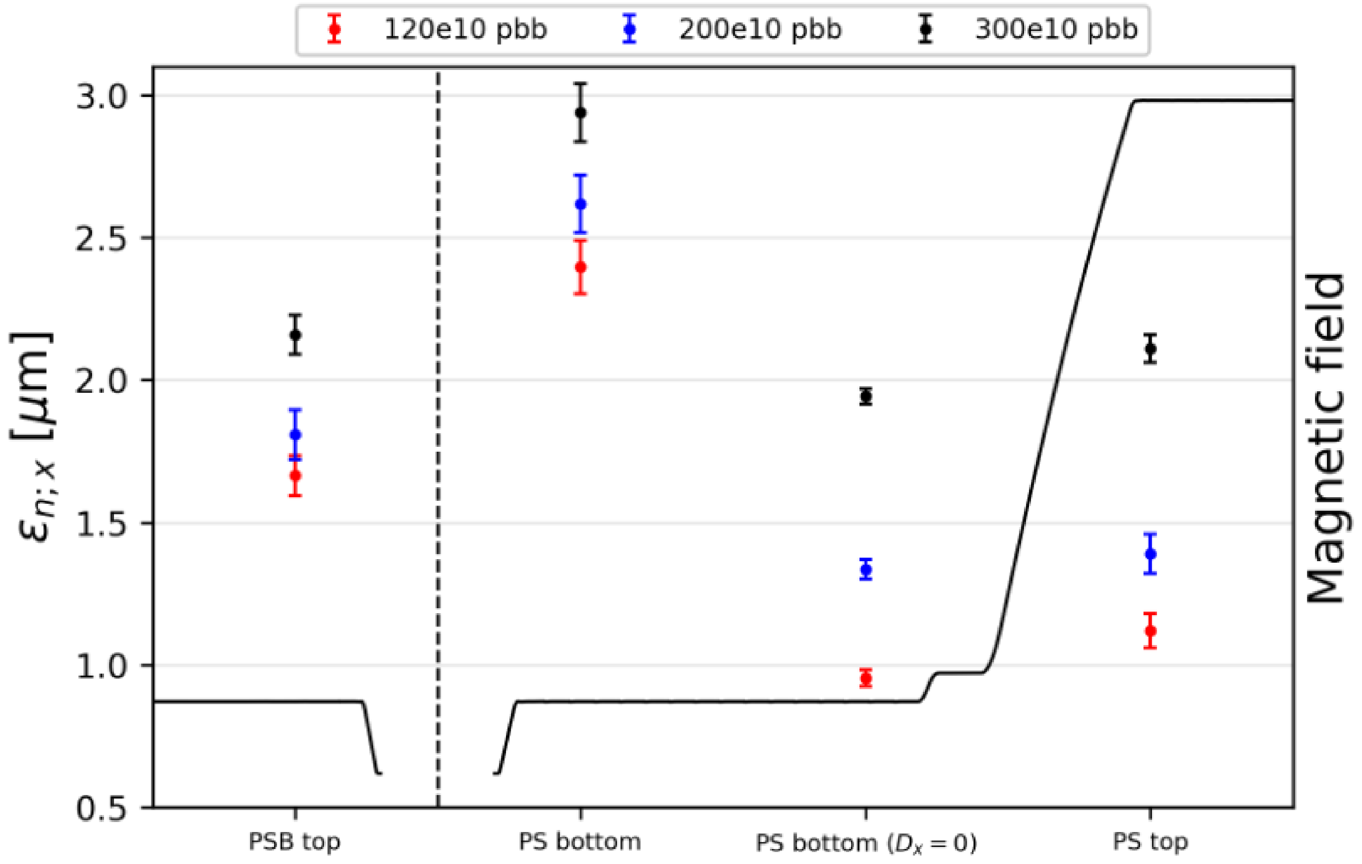
Resonance Driving Term (RDT) correction via ADT-ACD

RDT correction via PS model response matrix reduced beam losses crossing 2Qx+Qy resonance from 21% to 3% → confirms resonance suppressed by minimizing RDT



Zero Dispersion (ZDx) studies

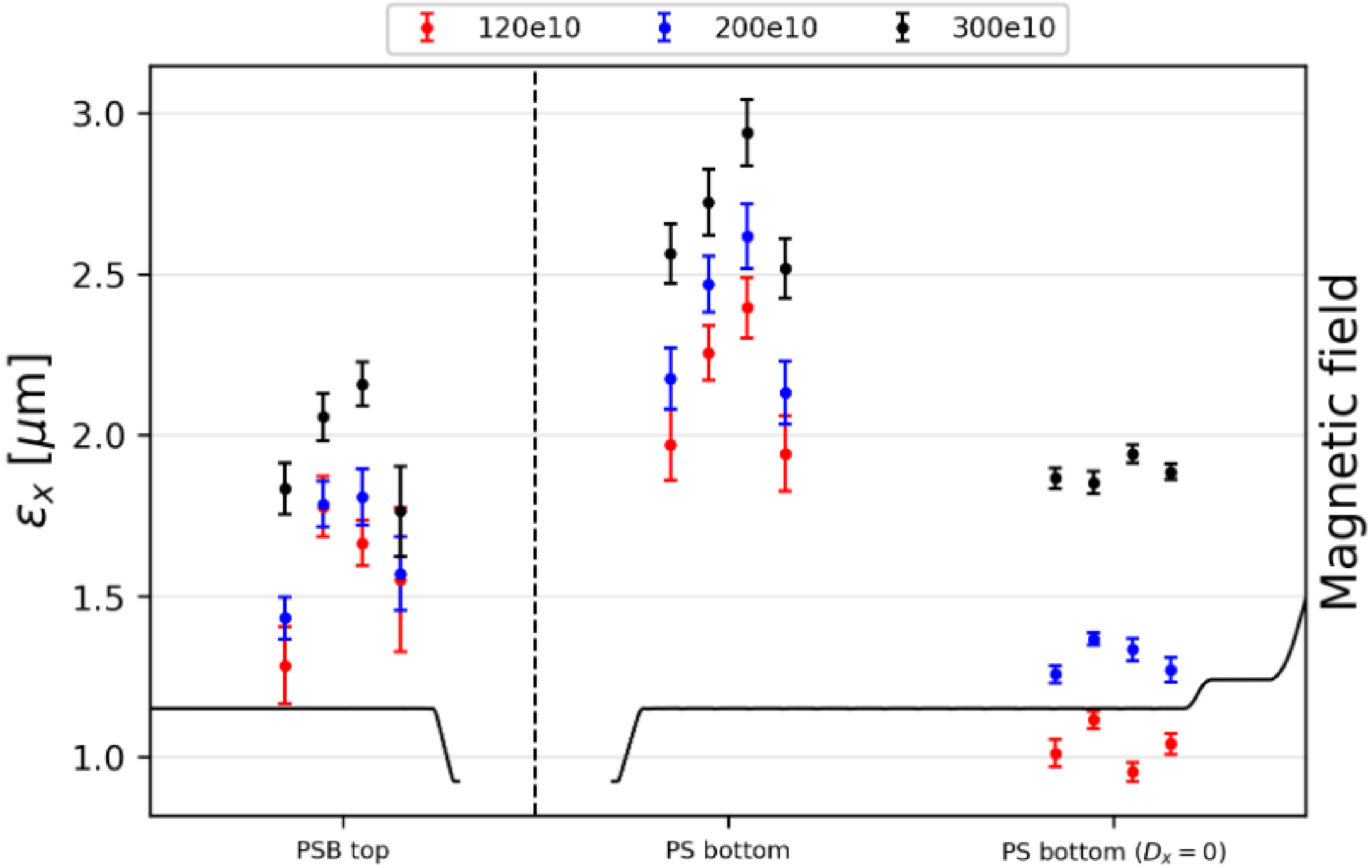
ZDx studies aim to improve PS emittance measurements by using an optics knob with LEQ to reduce Dx at BWS/BGI to zero → various MDs to exploit this in 2024



Zero Dispersion (ZDx) studies

Apparent PSB ring-to-ring H-emittance differences not real (vanish at ZDx)

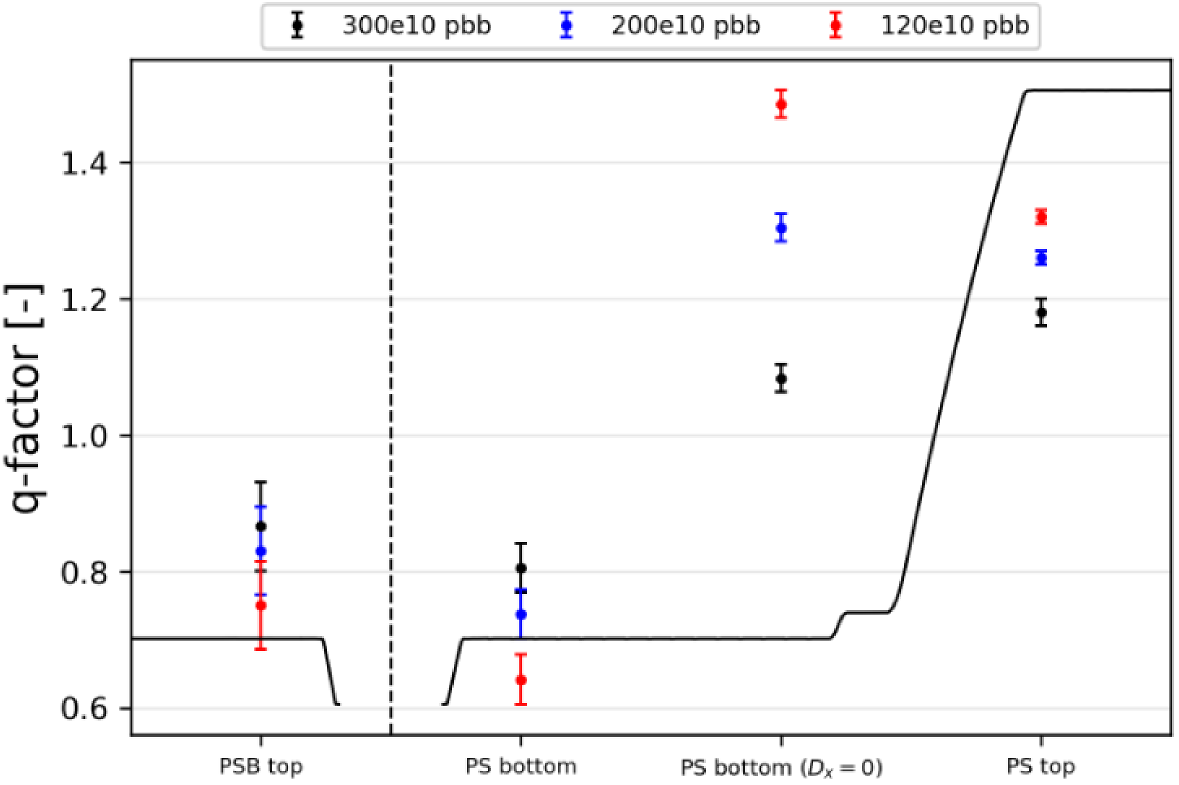
Ring-to-ring difference in longitudinal rather than transverse plane

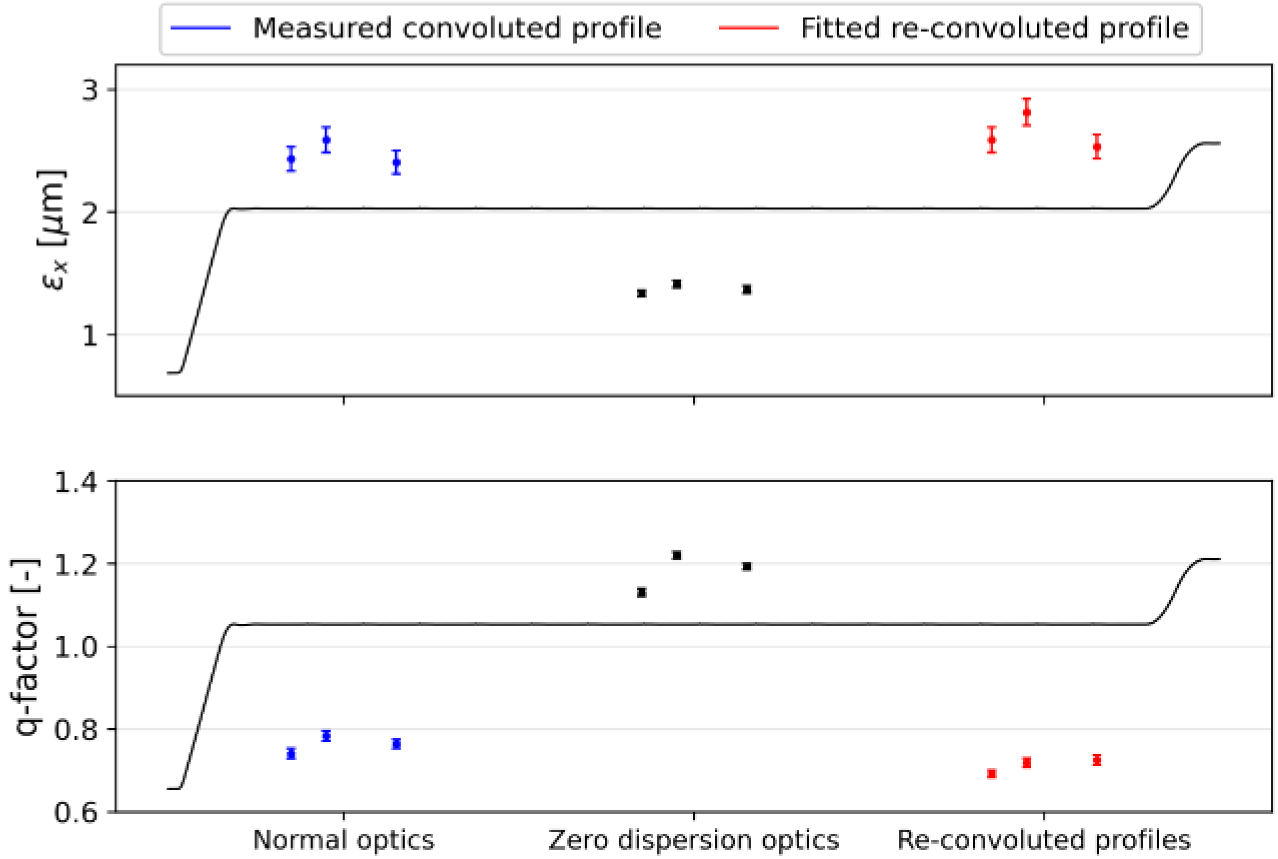


Zero Dispersion (ZDx) studies → ZDx also used to look at horizontal tails

At nominal optics measure underpopulated horizontal tails at PS injection → ZDx optics shows overpopulated

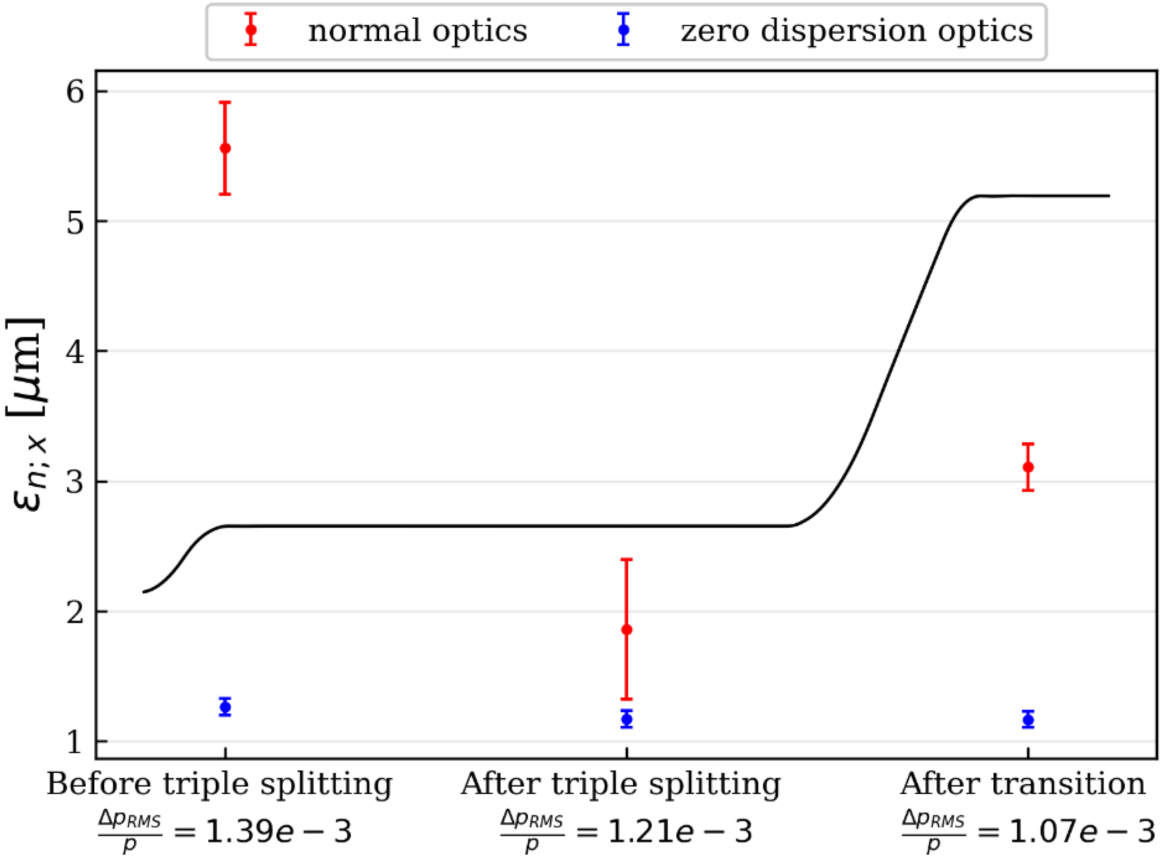
Once concern was in case apply ZDx knob caused blow up of tails → checked via numerical re-convolution

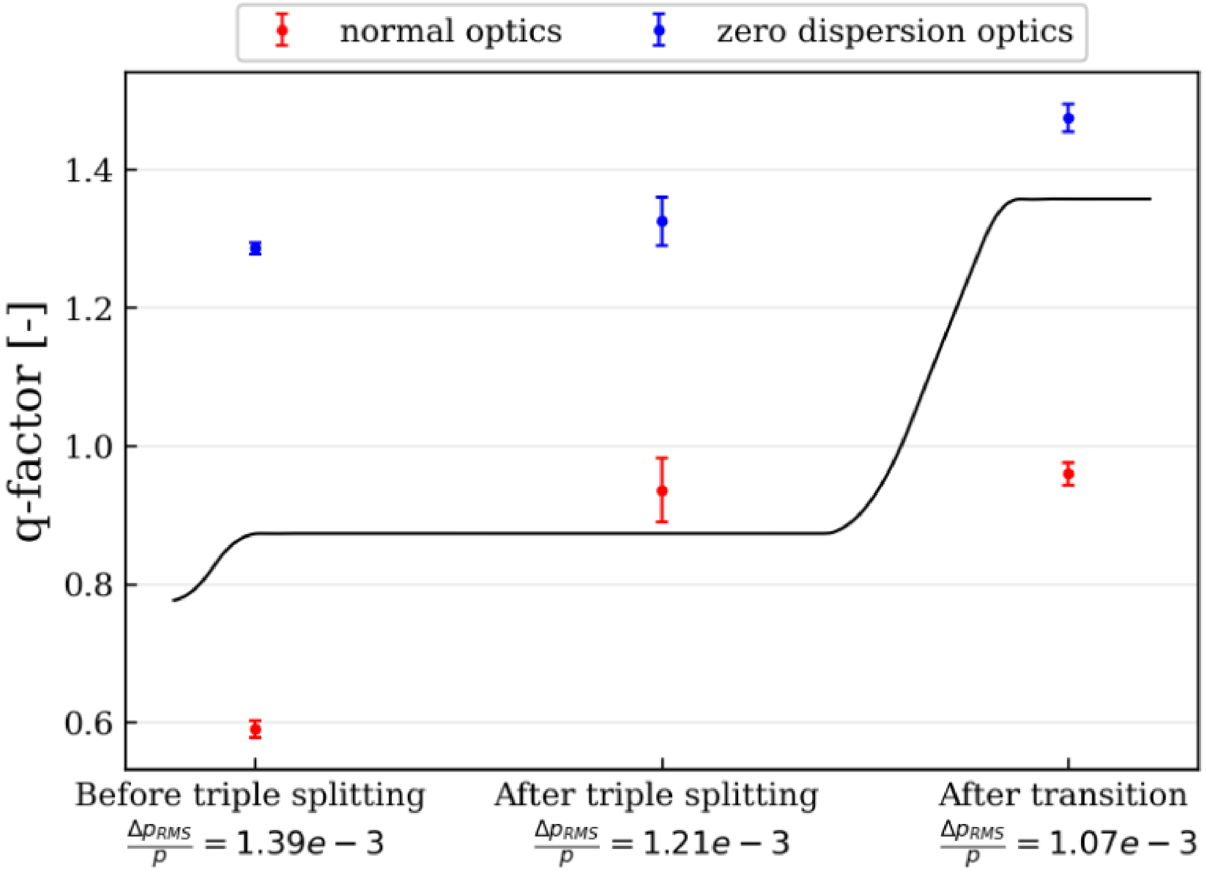




Zero Dispersion (ZDx) studies → New ZDx knobs extended to higher energy

Allowed measurements above/below transition:

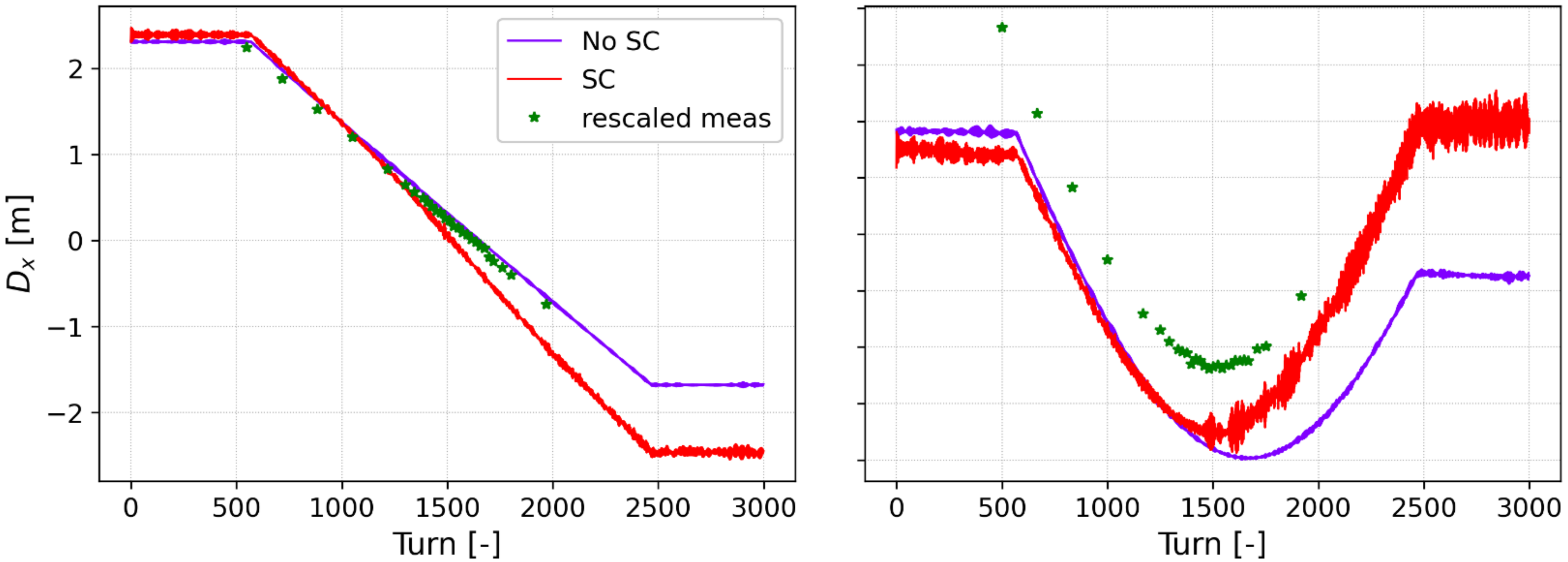




Zero Dispersion (ZDx) studies

→ **ZDx also interesting indirectly for other studies**

Interesting feature of ZDx studies is that consistently see minimum beam width reached slightly in advance of measured zero dispersion → no explanation from optics, but same effect is seen in multi-particle simulations with space-charge



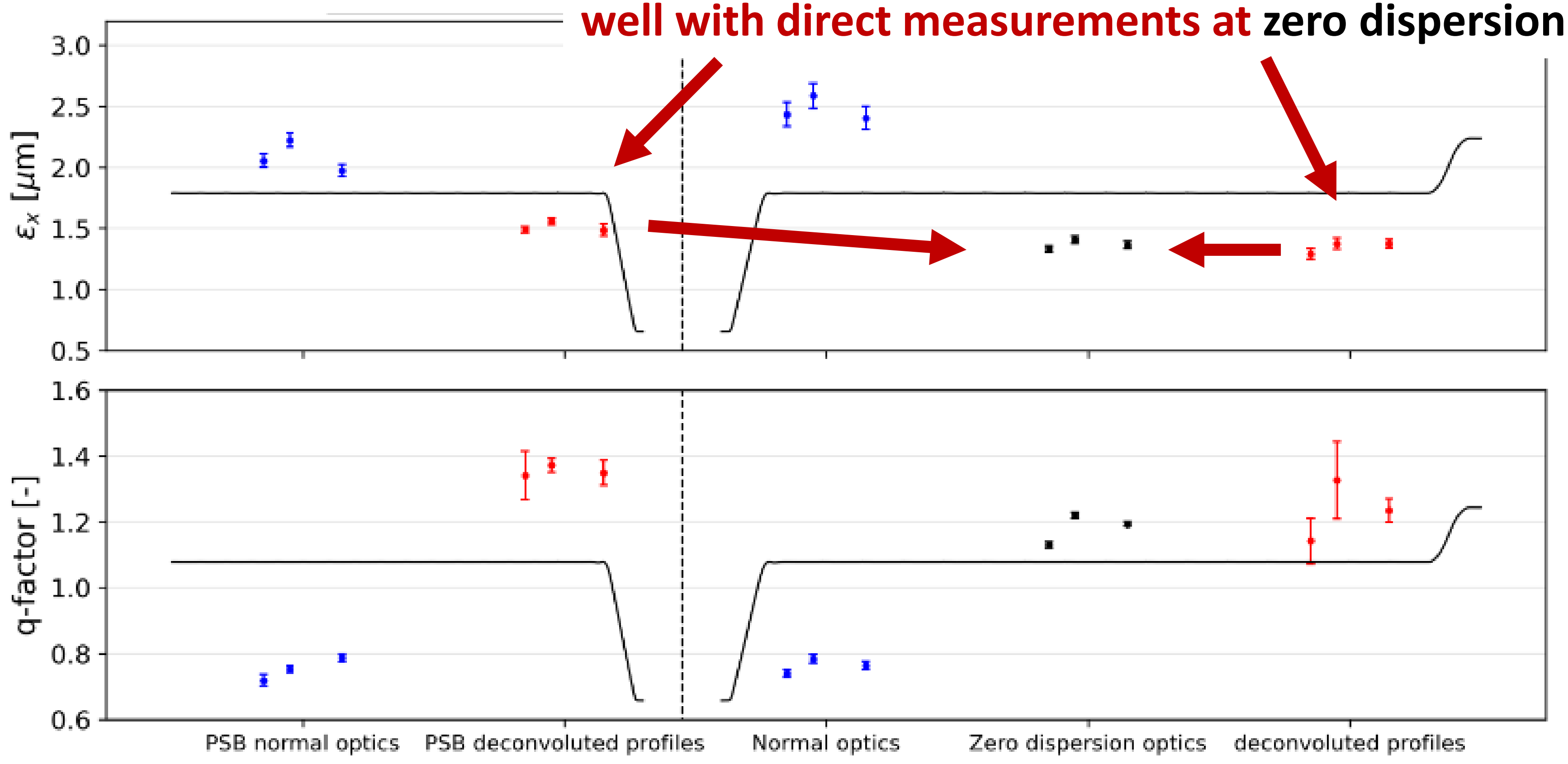
Zero Dispersion (ZDx) studies

→ ZDx also interesting indirectly for other studies

ZDx useful for dedicated tests → may not be practical for regular measurements or other machines

Tested numerical deconvolution of H-emittance measurement via zero-dispersion optics

Numerically deconvoluted profiles in PSB and PS agree well with direct measurements at zero dispersion



Conclusion

ML based prediction/control networks tested on LHC cycles
→ Good performance at low/high-energy, but challenging w.r.t. extrapolation, and around transition

RDT correction demonstrated for skew-sextupole 2Qx+Qy resonance, with corresponding reduction in beam losses

Zero Dispersion studies extended to higher-energy, used to test numerical deconvolution with broader application

W. Van Goethem, *Zero dispersion optics in the PS*, **IPP - 20 October 2023**
https://indico.cern.ch/event/1331338/

W. Van Goethem, *Emittance and tails evolution using zero dispersion optics in the PS*, **Space Charge Cooling & IBS meeting - 17 July 2024**
https://indico.cern.ch/event/1435897/

W. Van Goethem, *PS optics control*, **IPP - 16 August 2024**
https://indico.cern.ch/event/1443943/

W. Van Goethem, *Zero dispersion optics in the PS*, **ABP Group Information Meeting - 29 August 2024**
https://indico.cern.ch/event/1425640/

W. Van Goethem, *Testing emittance deconvolution with zero dispersion optics*, **PS MPC - 4 November 2024**
https://indico.cern.ch/event/1474445/