ESRF

A Light for Science

Experience with AC dipole optics measurements at the old ESRF storage ring (2016-2018)

Andrea Franchi (ESRF, Grenoble)

Thanks to the Beam Dynamics & Diagnostics groups for the experimental campaign

FCC-ee meeting of Marc 22nd 2022

Outlines

- Measuring ultra-low coupling via AC dipole and turn-by-turn (TbT) BPM data
- Simulation of beta-beating measurement via AC dipole and turn-by-turn (TbT) BPM data
- AC dipole and BPM TbT spectrum
- regarding $(1-\lambda^2)$

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ultra-low coupling via (TbT) BPM data

Idea: replace pulsed excitation with continuous AC excitation close to the betatron tune, $d=Q-Q_{AC}$ (RHIC 1998 [*], Tevatron/RHIC 2008- [^], LHC 2009-[&], ….)

- thousands of TbT with no decoherence
- efficient data cleaning

} high spectral resolution

- but some precautions & corrections to interpret data (theory not completed yet)

more recent: https://www.bnl.gov/isd/documents/74582.pdf

https://accelconf.web.cern.ch/ipac2021/papers/wepab400.pdf

https://cds.cern.ch/record/2747899/files/CERN-ACC-NOTE-2020-0065.pdf

[*] S. Peggs, C. Tang, RHIC/AP/159, 1998; M. Bai *et al.* , PRL **80**, 4673 (1998)

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Very successful on hadron machines (beating, coupling, nonlinearities). Can it work in lepton rings with radiation damping & diffusion (and high chroma @ ESRF)?

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ultra-low coupling via (TbT) BPM data

Betatron coupling described by two CRDTs Fxy & Fyx (*) inferred from single-BPM x and y TBT data (i.e. without the evaluation of the momenta p_x and p_y which requires the use of pairs of BPMs thus introducing systematic errors)

$$Fxy = f_{1001} - f_{1010}^{*}$$
$$Fyx = f_{1001}^{*} - f_{1010}^{*}$$

PRSTAB **17** 074001 (2014)

ultra-low coupling via (TbT) BPM data

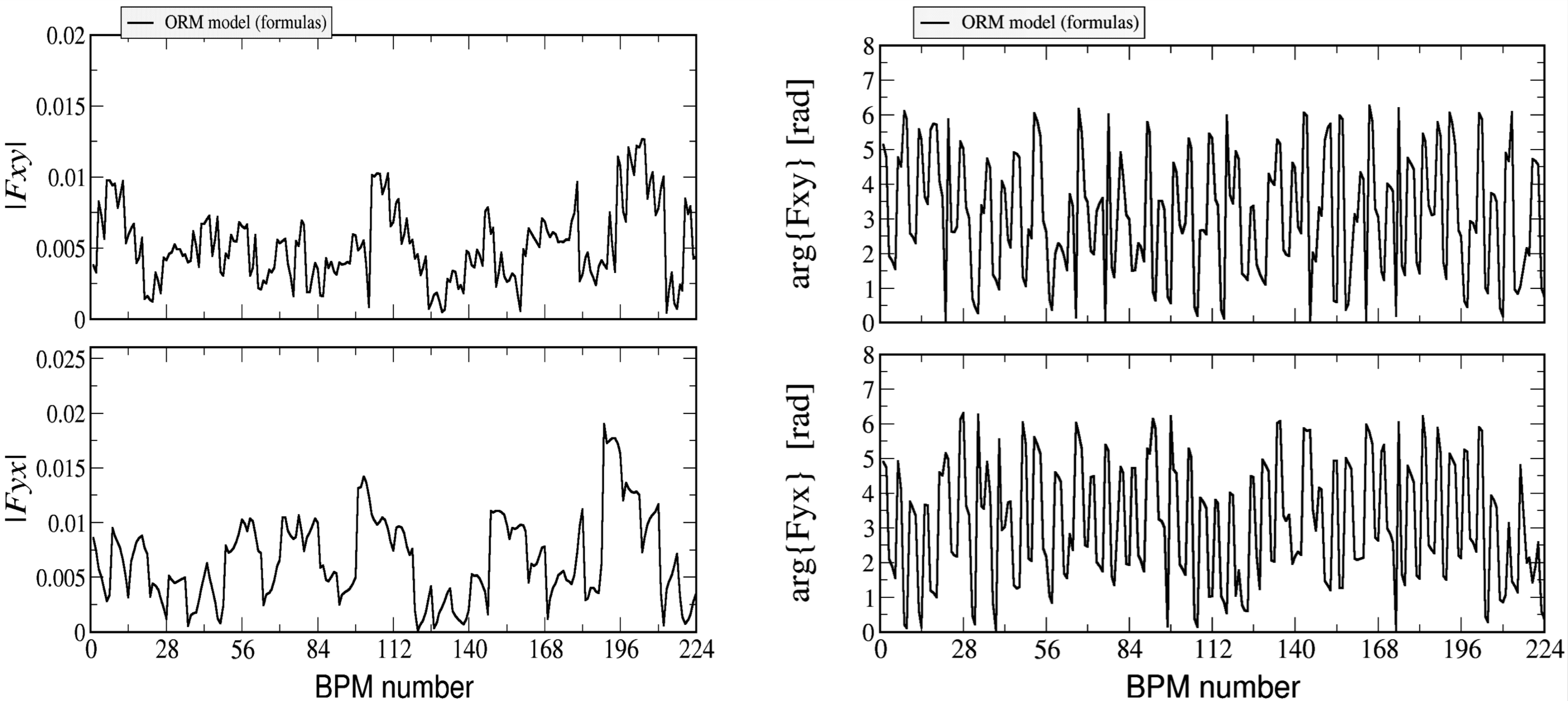
Betatron coupling described by two CRDTs F*xy* & F*yx* (*)

Measurement with **low chroma (0,0) & detuning sext. optics**

compare ($\varepsilon_y/\varepsilon_x$~1‰) ORM model with TbT harmonic analysis

AMPLITUDE

PHASE



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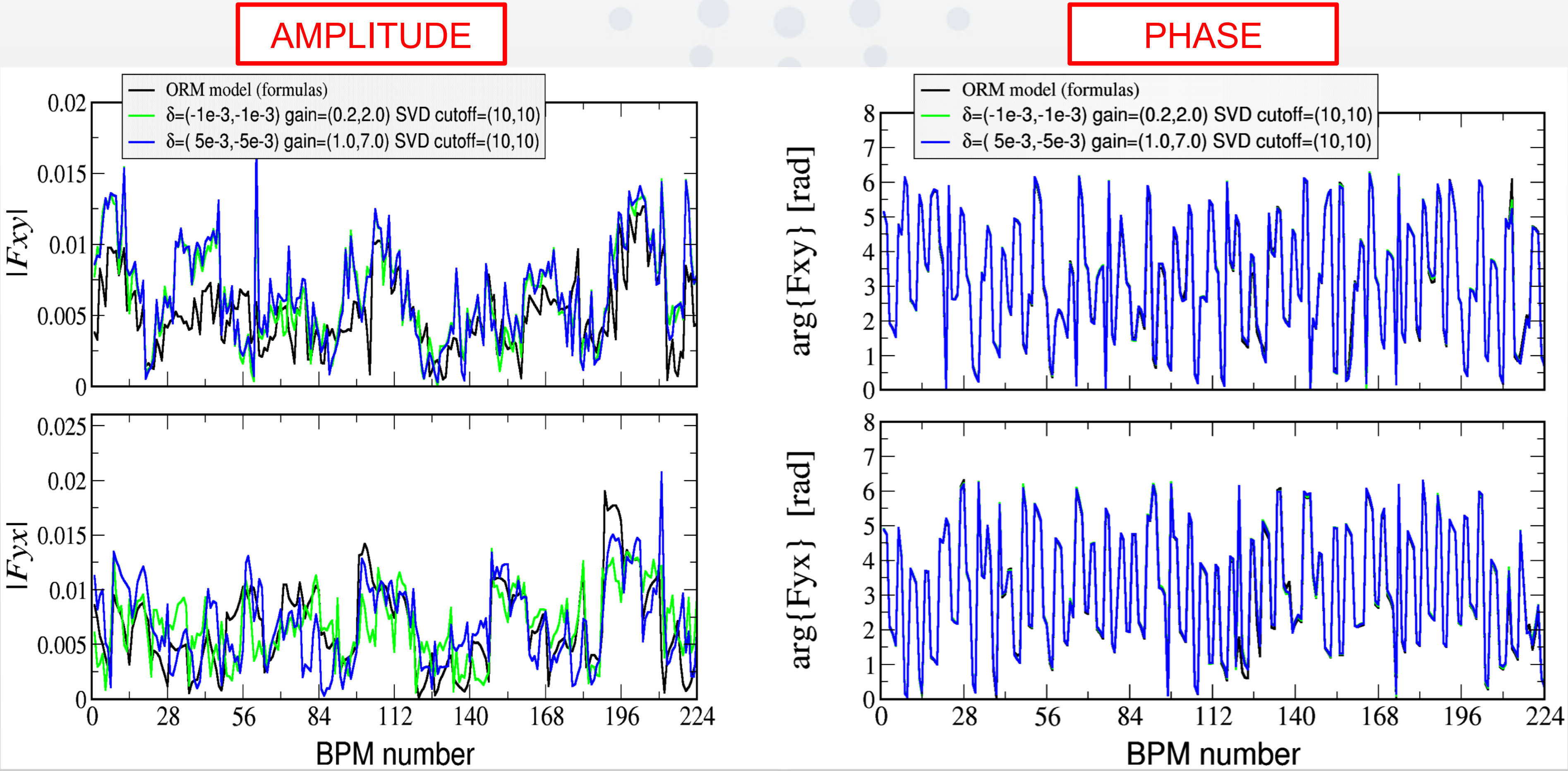

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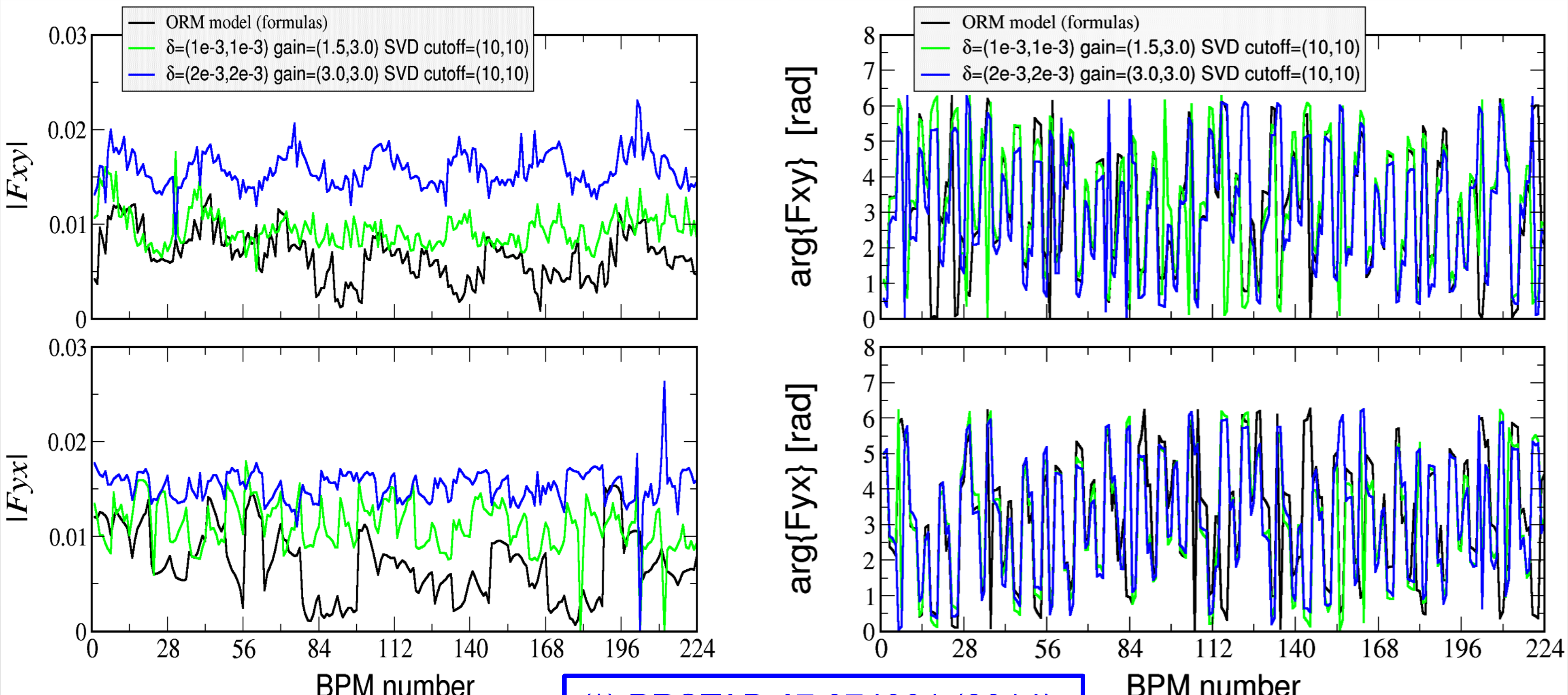

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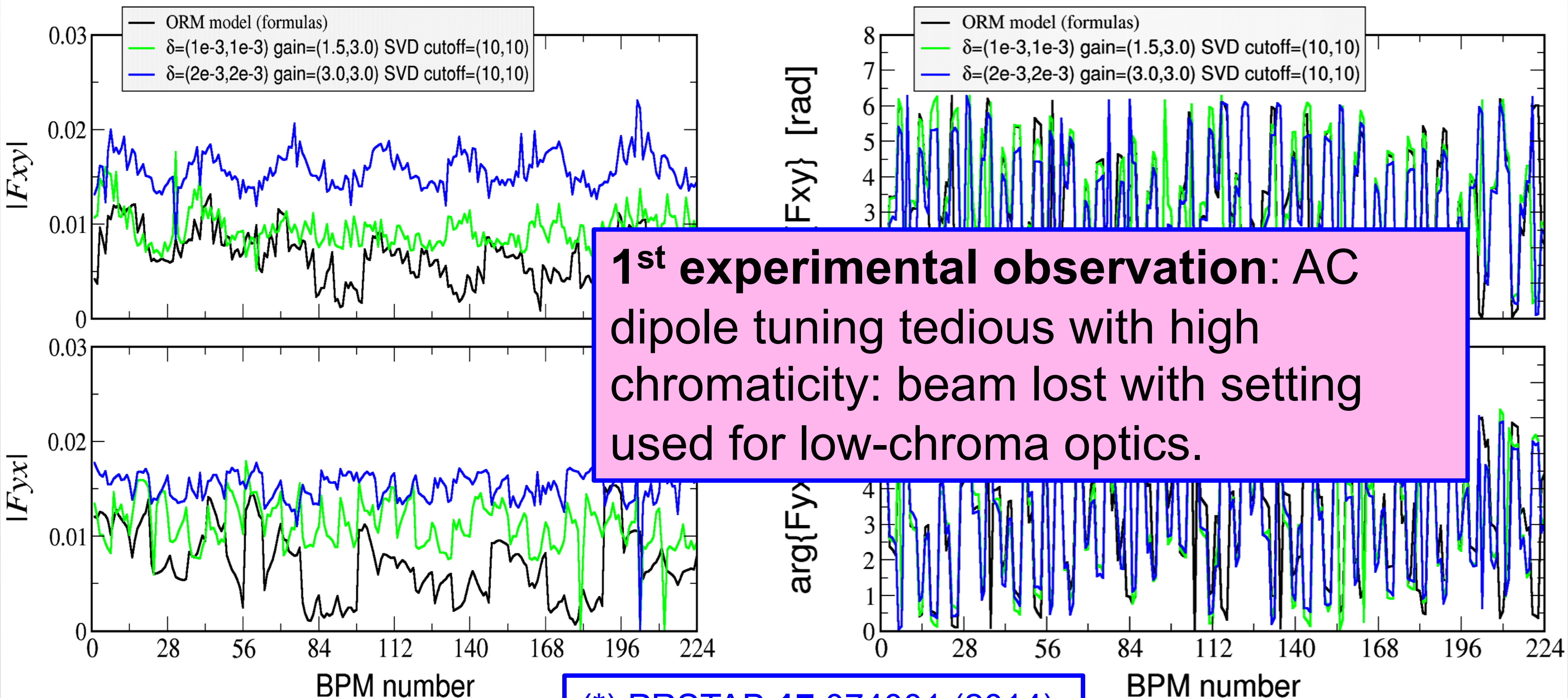

1st experimental observation: AC dipole tuning tedious with high chromaticity: beam lost with setting used for low-chroma optics.

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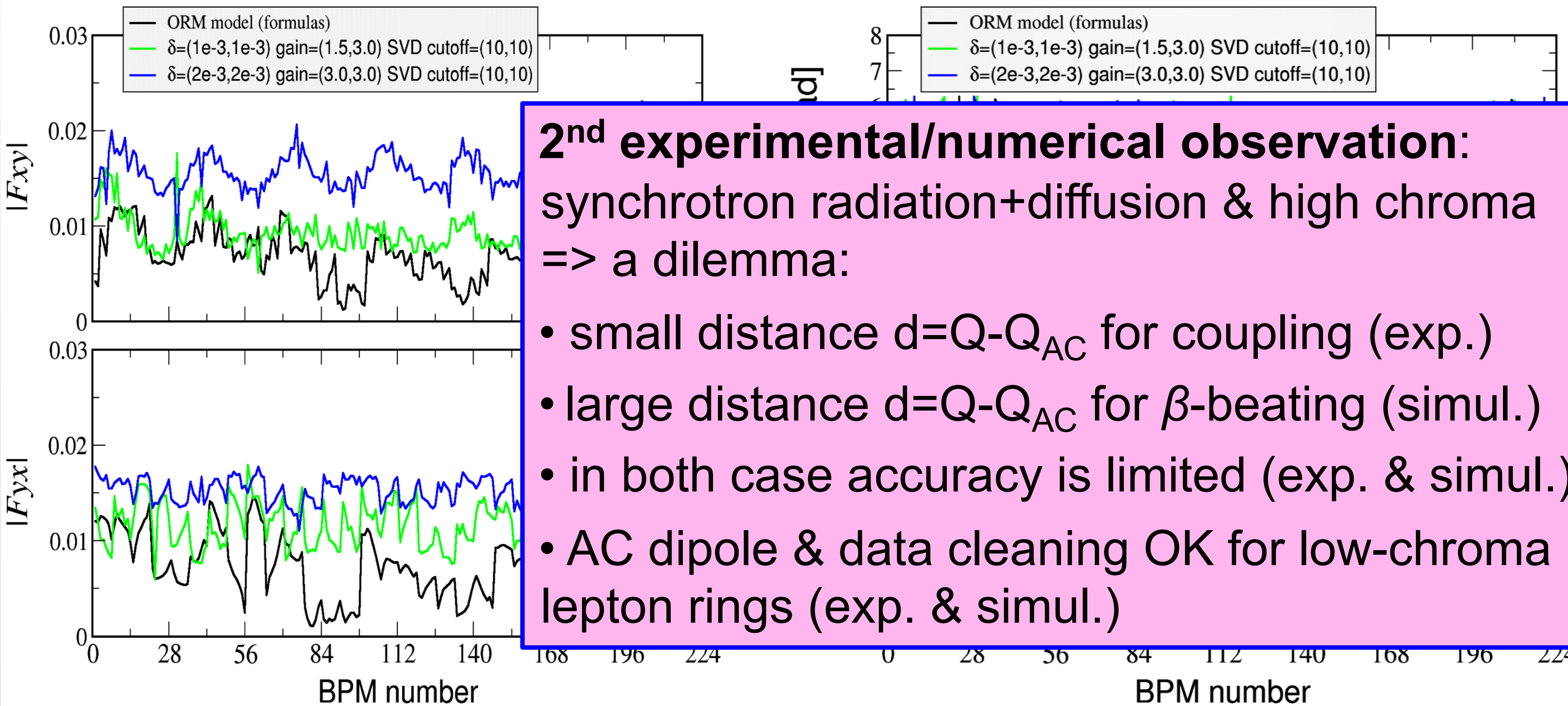

2nd experimental/numerical observation:
synchrotron radiation+diffusion & high chroma => a dilemma:

- small distance d=Q-Q_{AC} for coupling (exp.)
- large distance d=Q-Q_{AC} for β-beating (simul.)
- in both case accuracy is limited (exp. & simul.)
- AC dipole & data cleaning OK for low-chroma lepton rings (exp. & simul.)

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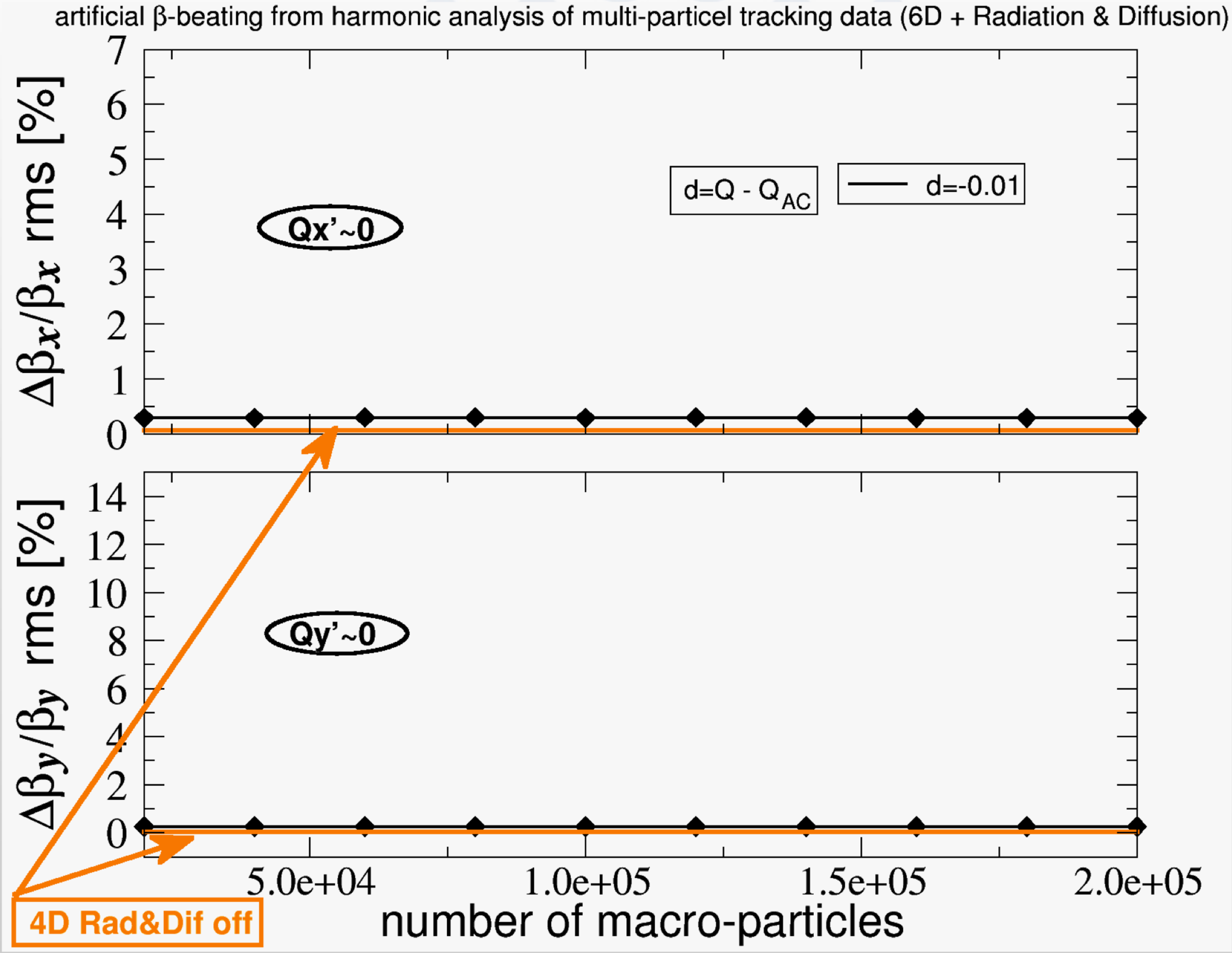
low (0,0) Vs high (8,13) chroma sextupole optics

Artificial β-beating from multiparticle & leptonic nature of the beam



Low chroma & detuning

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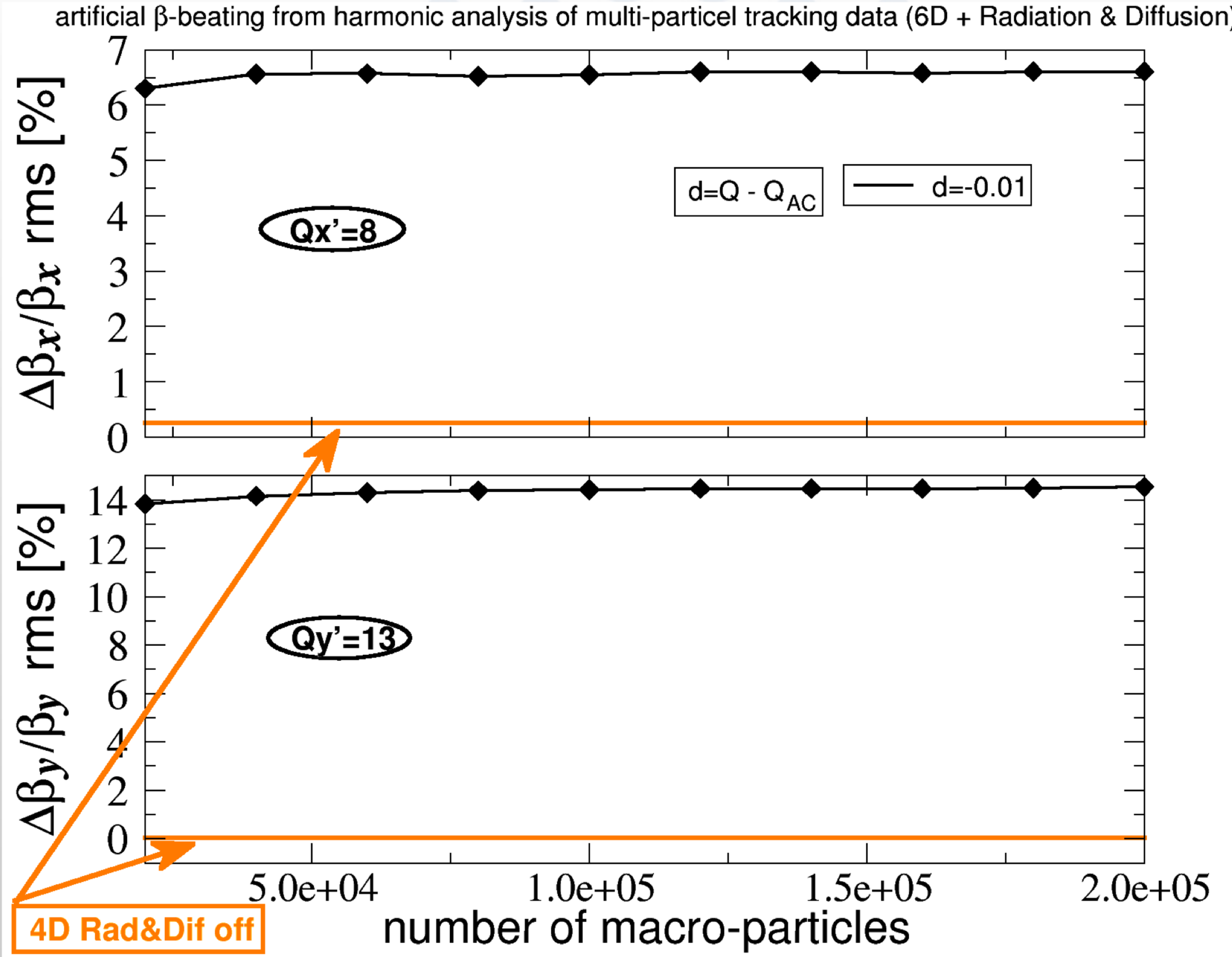

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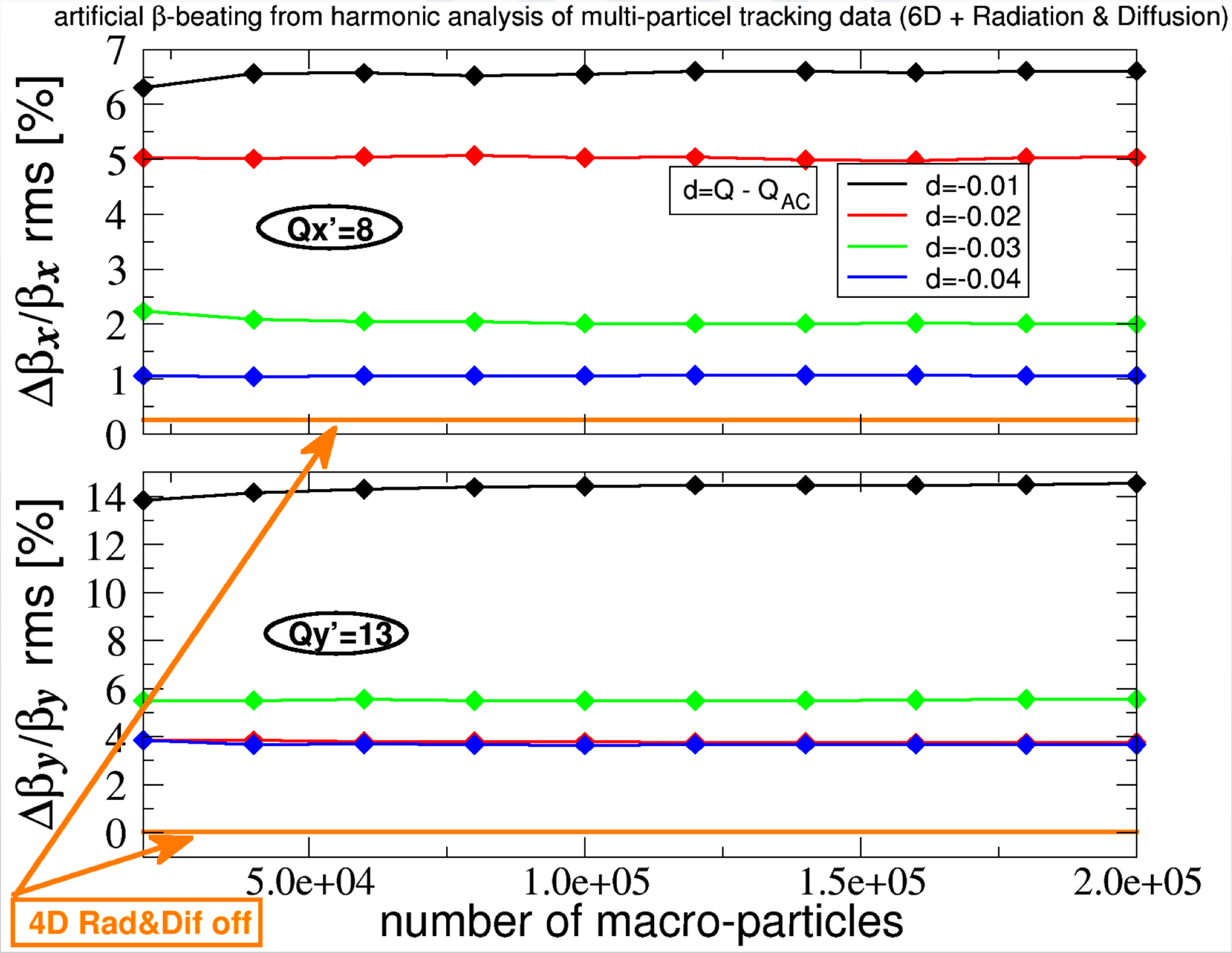

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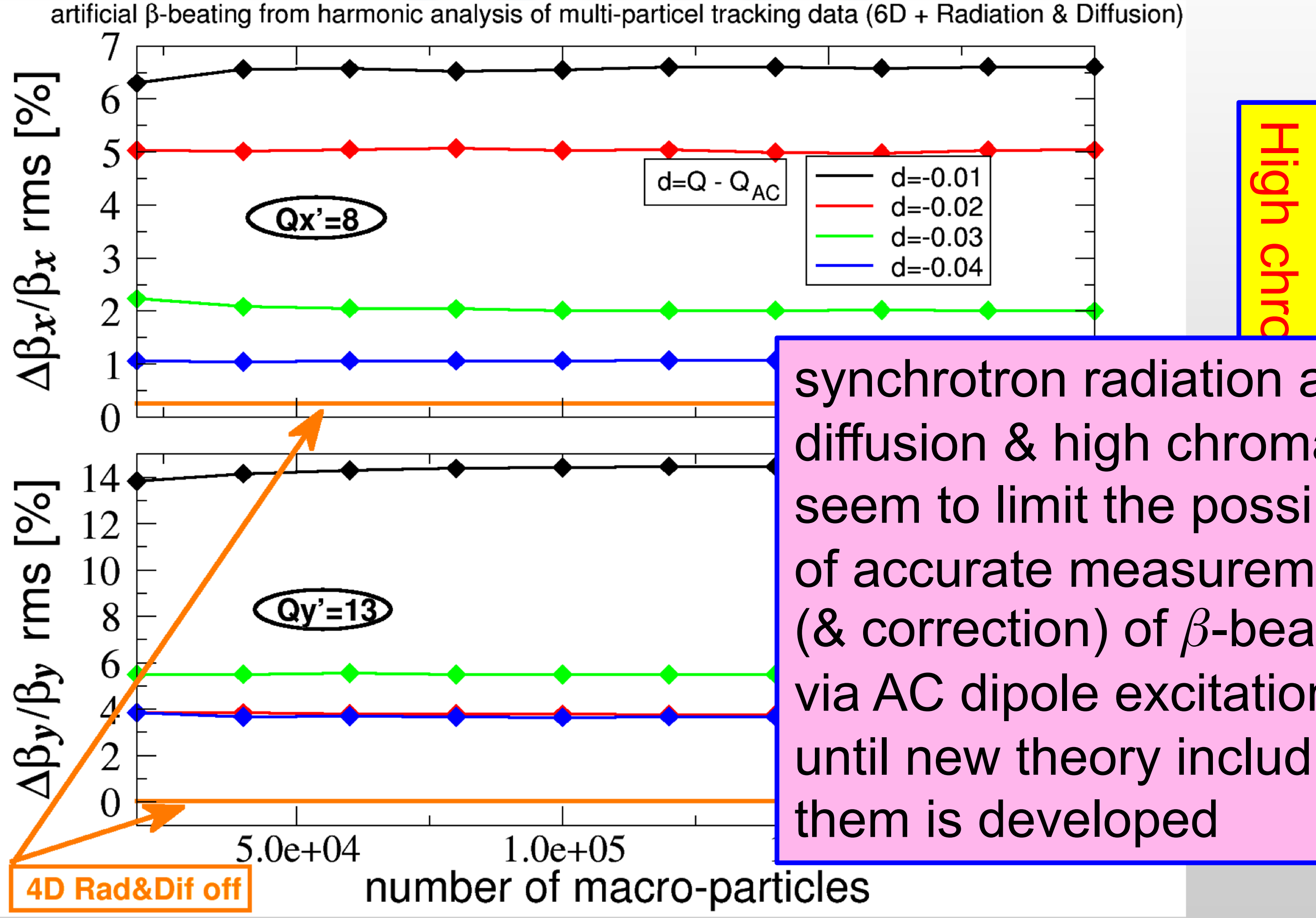

synchrotron radiation and diffusion & high chroma seem to limit the possibility of accurate measurement (& correction) of β-beating via AC dipole excitation … until new theory including them is developed

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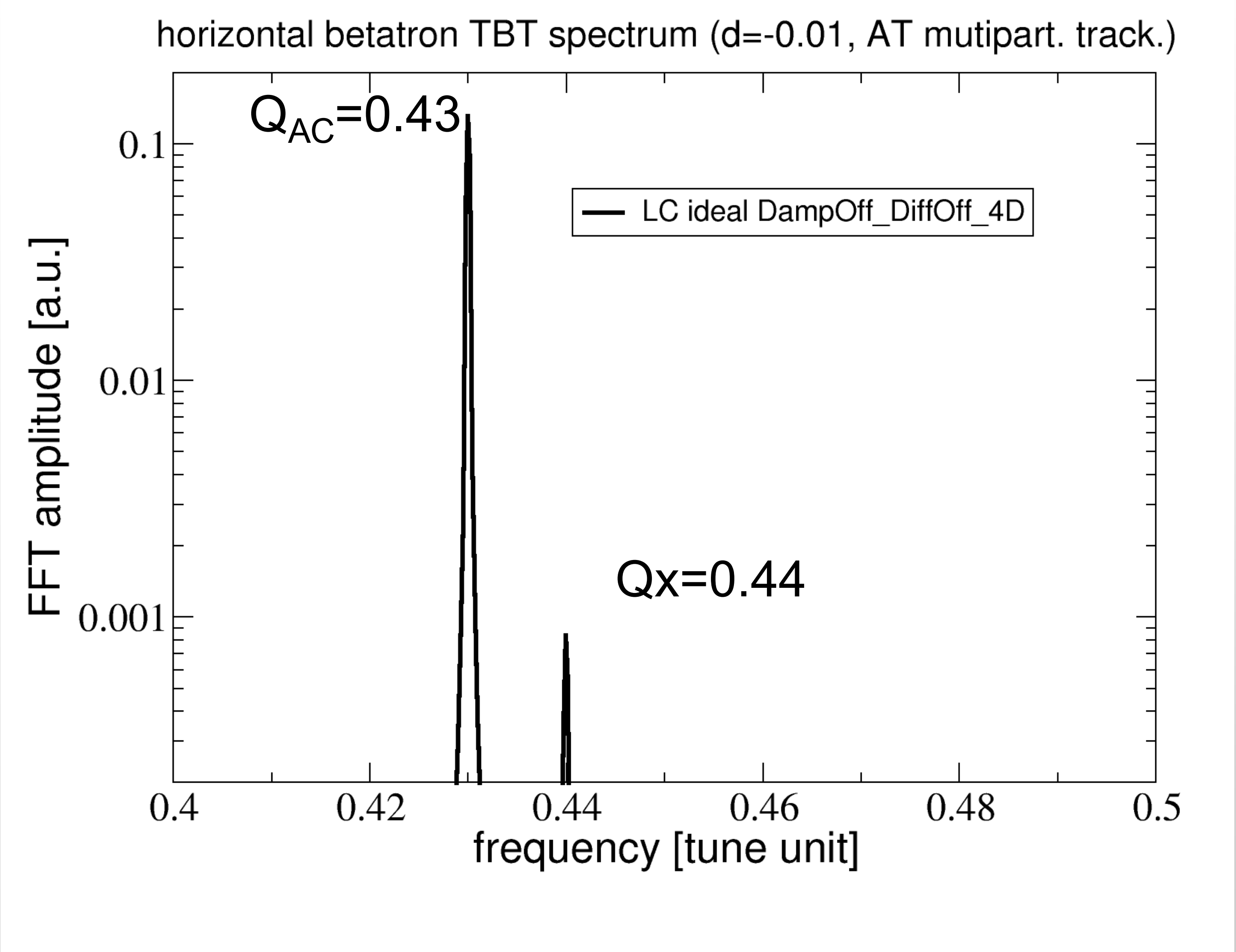

AC dipole and BPM TbT spectrum

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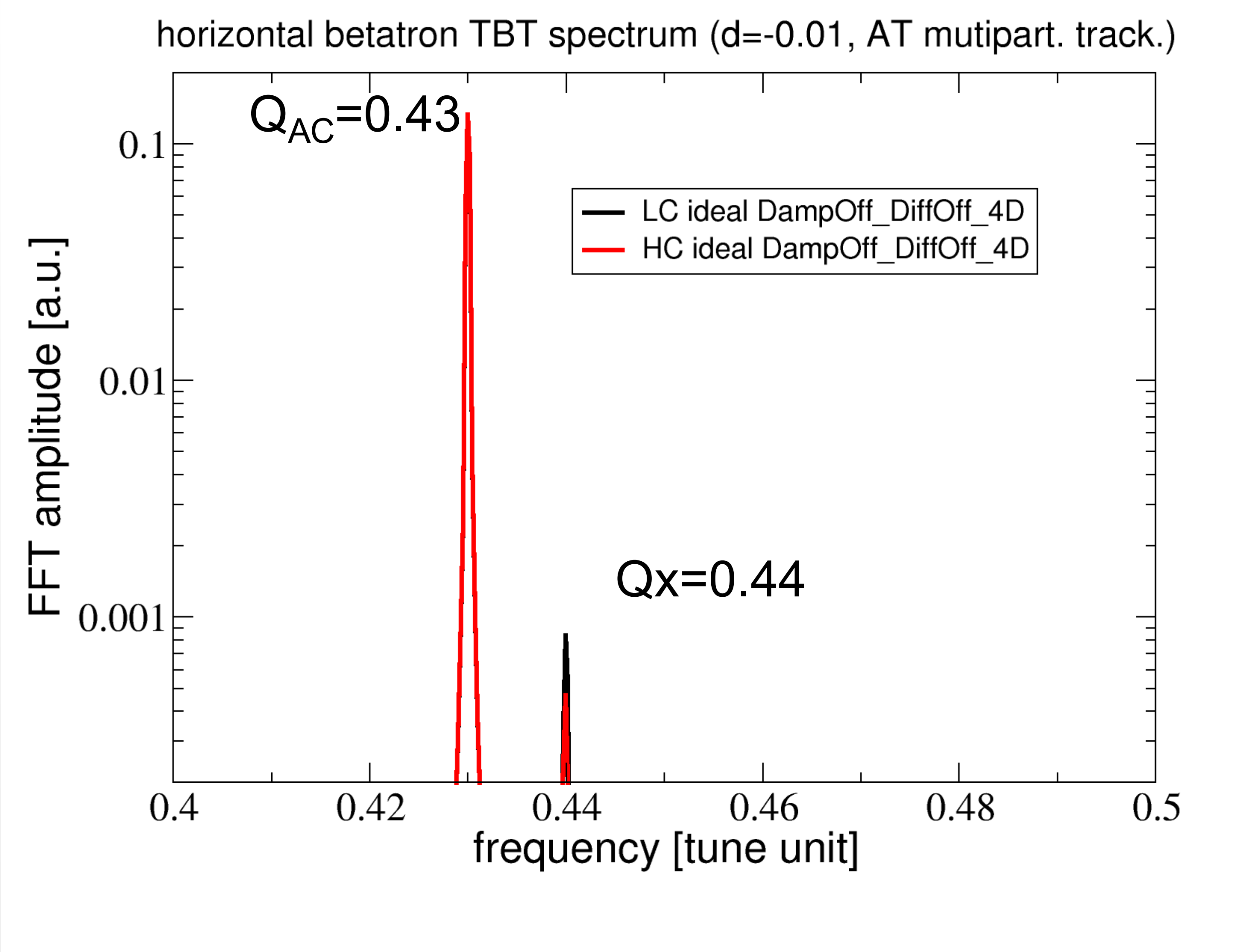

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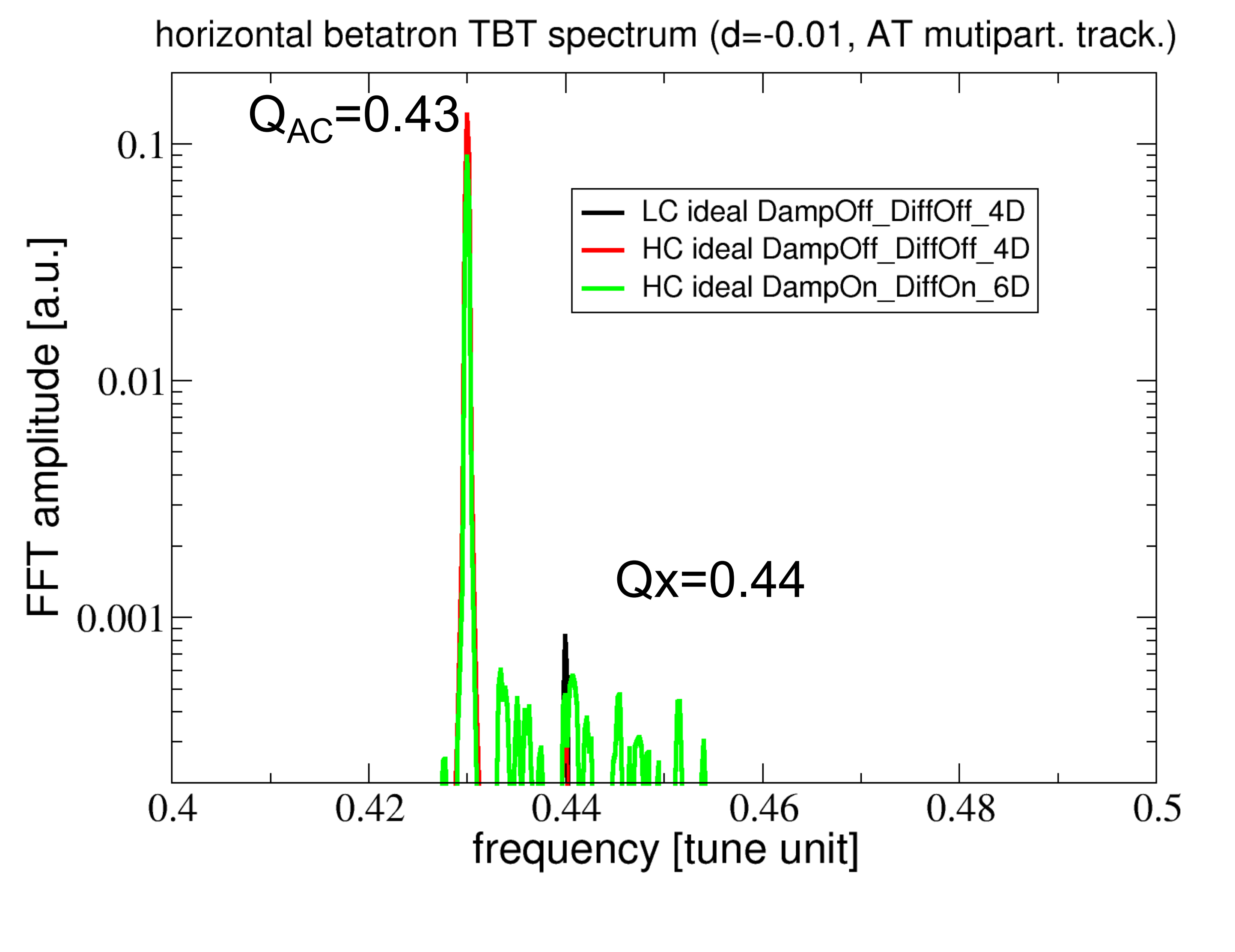

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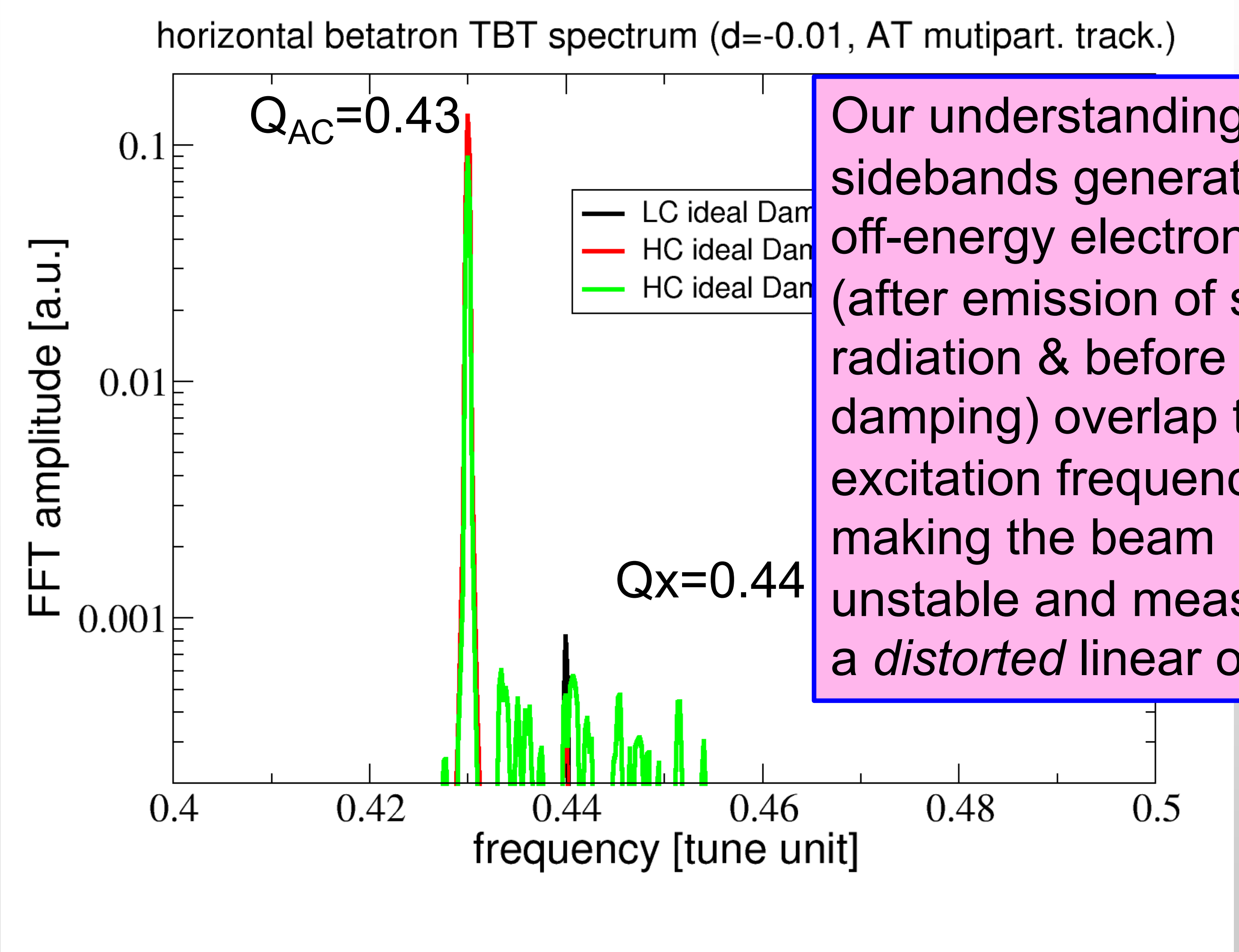
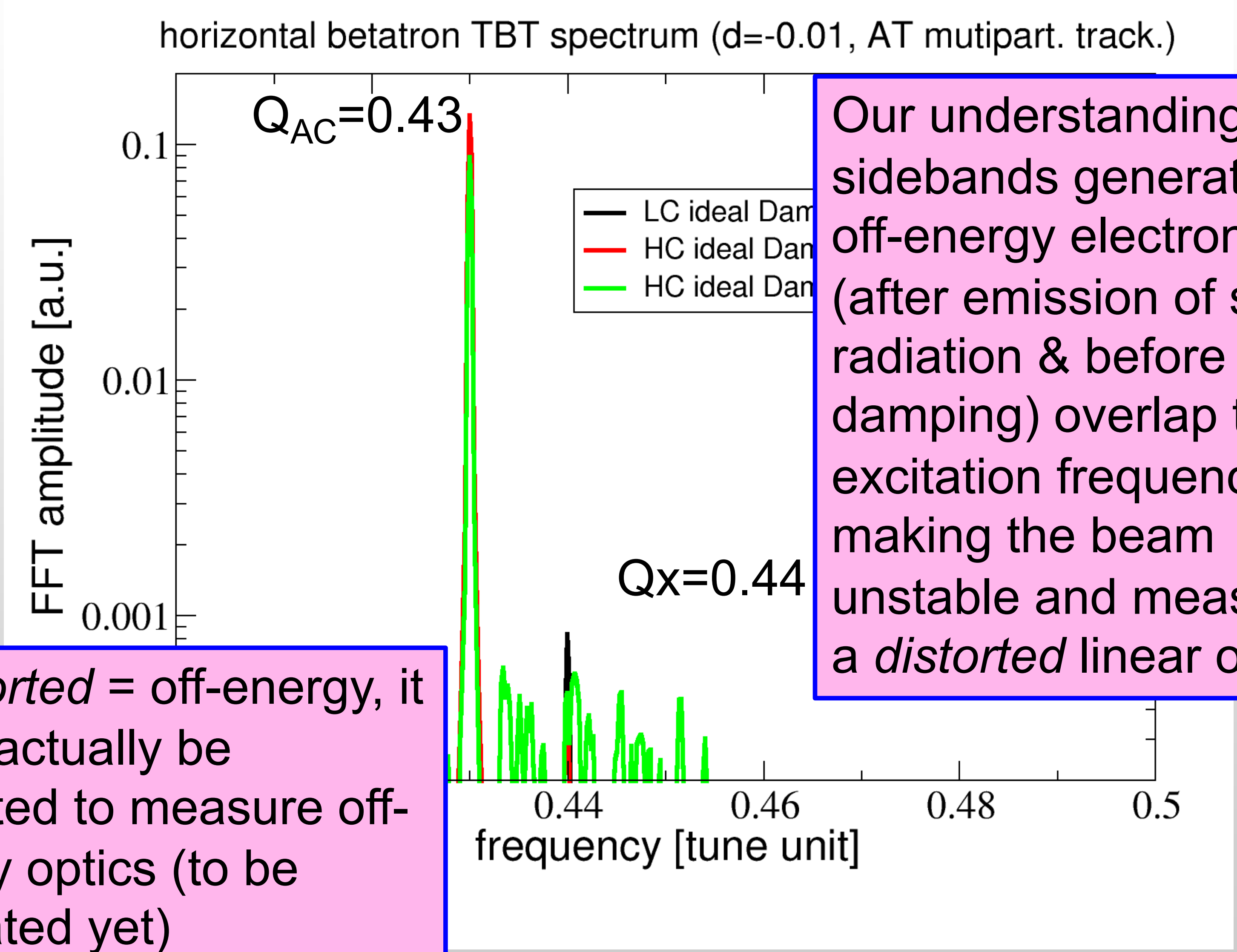


Our understanding: sidebands generated by off-energy electrons (after emission of synchr. radiation & before long. damping) overlap the AC excitation frequency, thus making the beam unstable and measuring a *distorted* linear optics

low (0,0) Vs high (8,13) chroma sextupole optics



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If distorted = off-energy, it could actually be exploited to measure off-energy optics (to be simulated yet)

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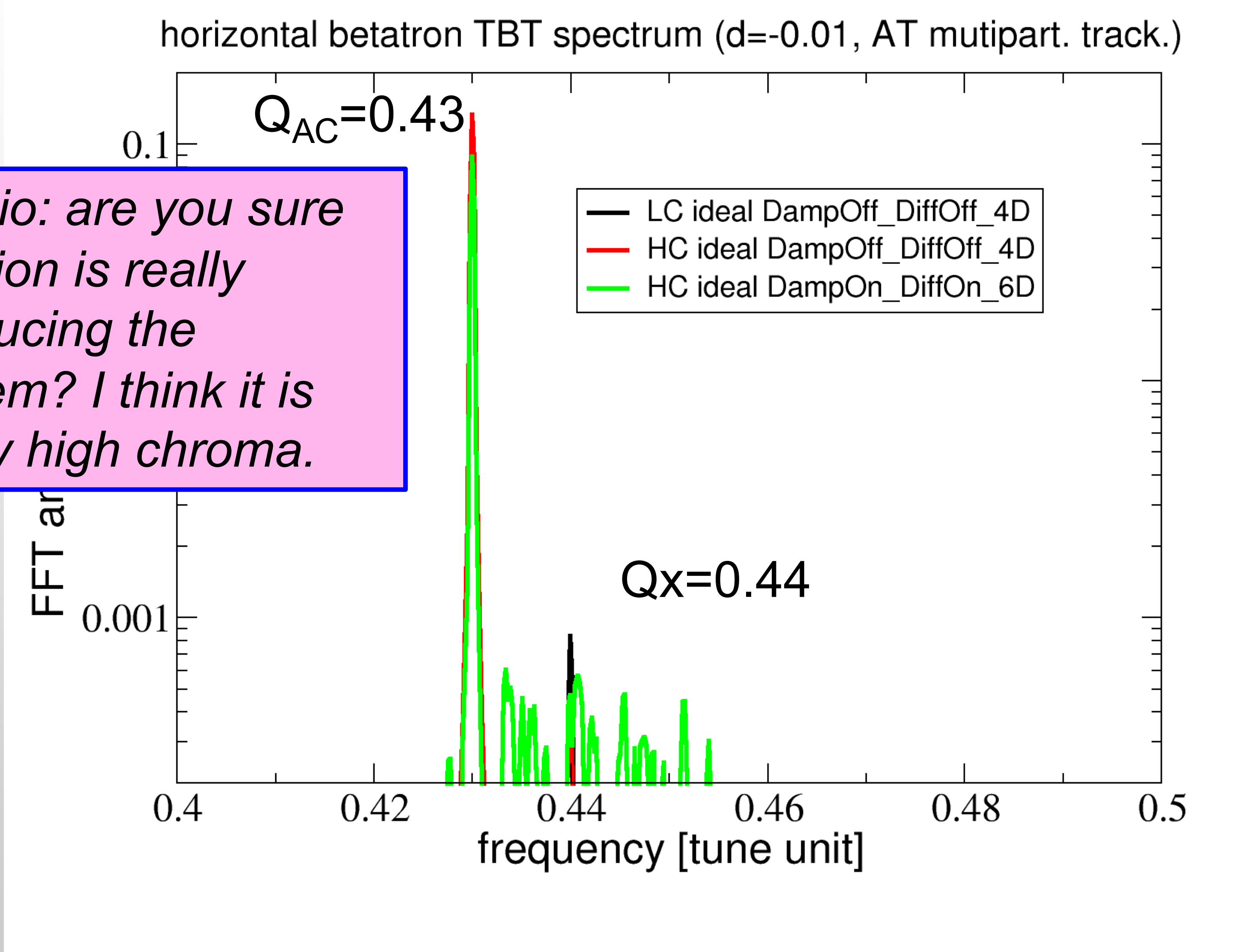

Rogelio: are you sure radiation is really introducing the problem? I think it is mostly high chroma.

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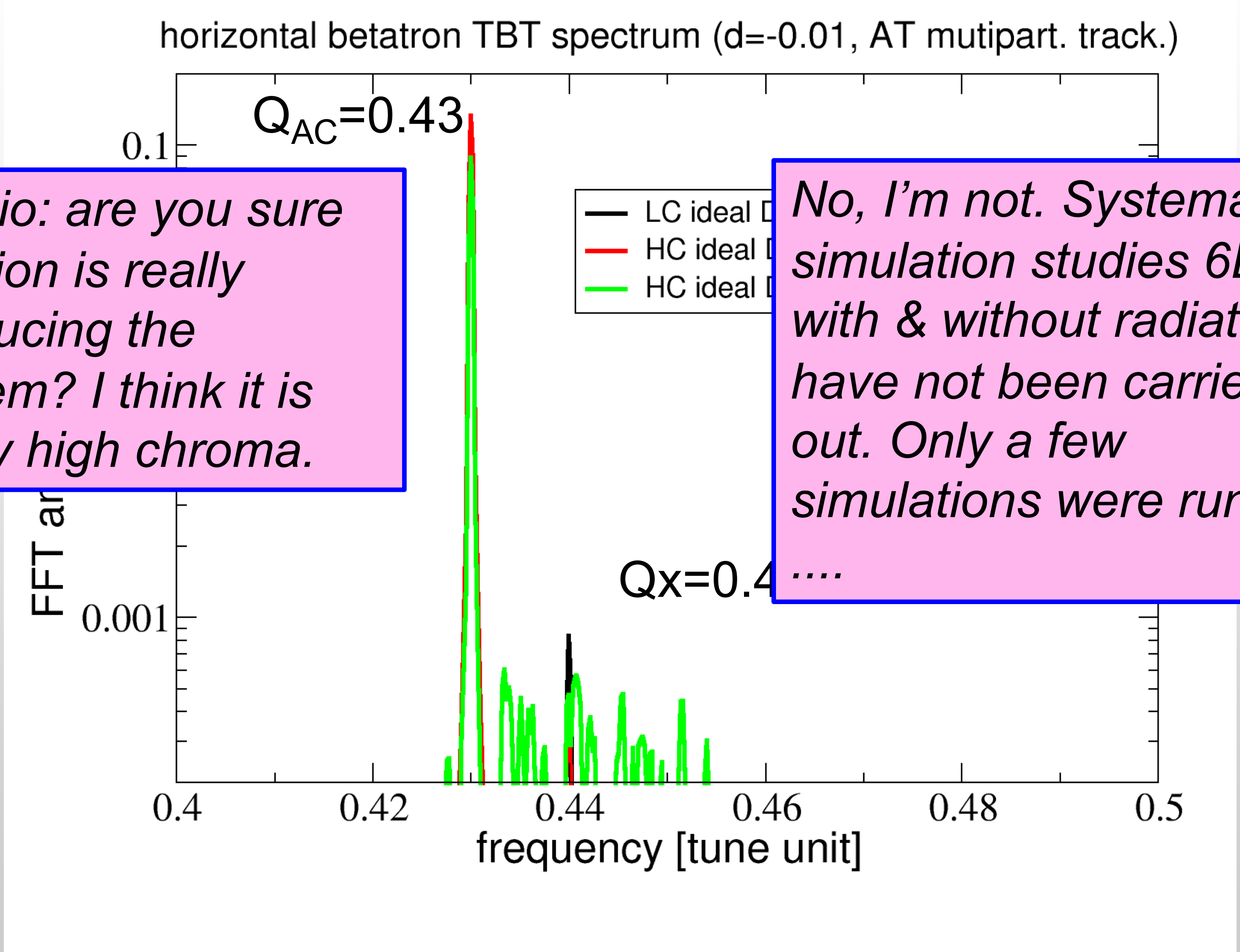
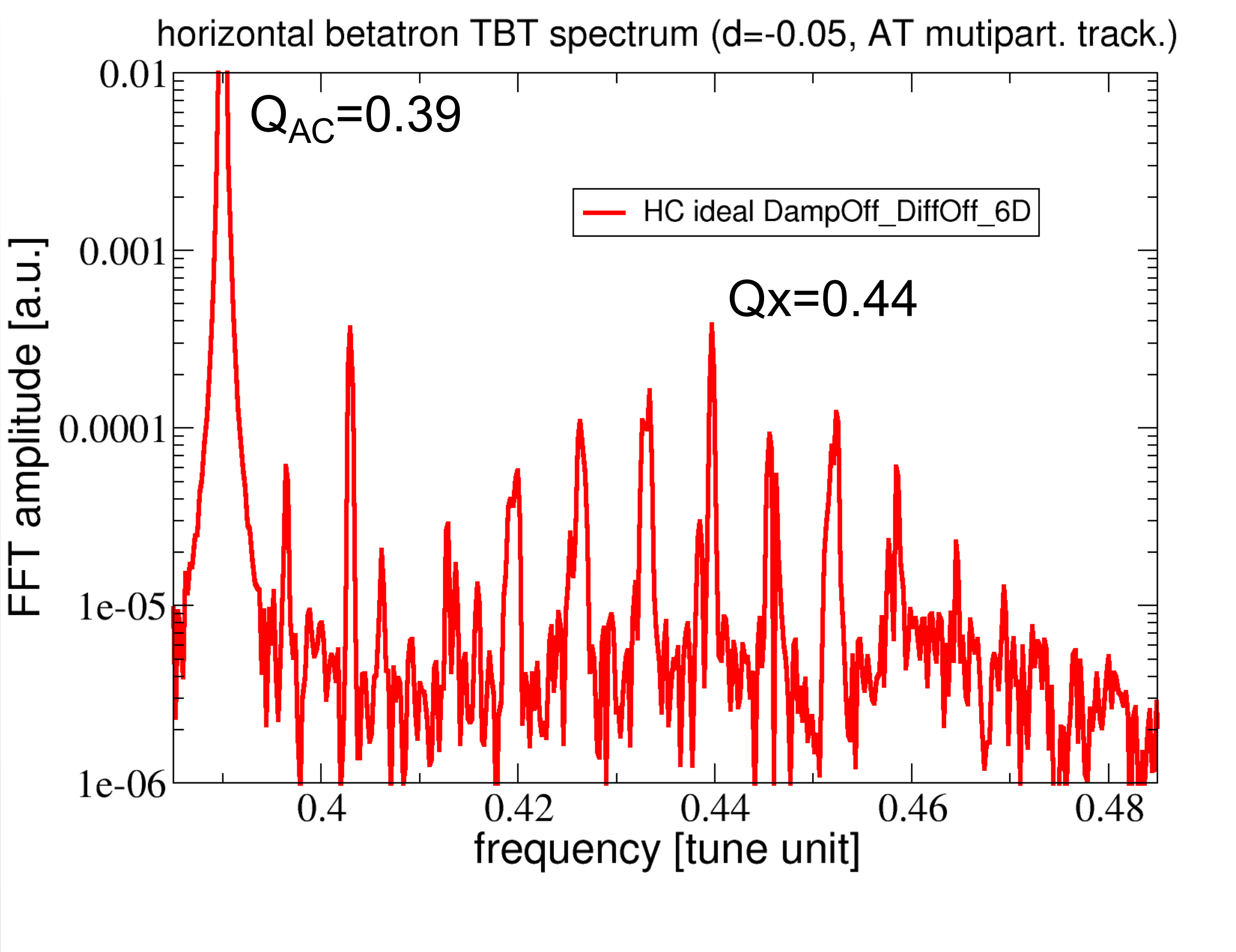


Rogelio: are you sure radiation is really introducing the problem? I think it is mostly high chroma.

No, I'm not. Systematic simulation studies 6D with & without radiation have not been carried out. Only a few simulations were run ….

high (8,13) chroma sextupole optics: RAD OFF & ON



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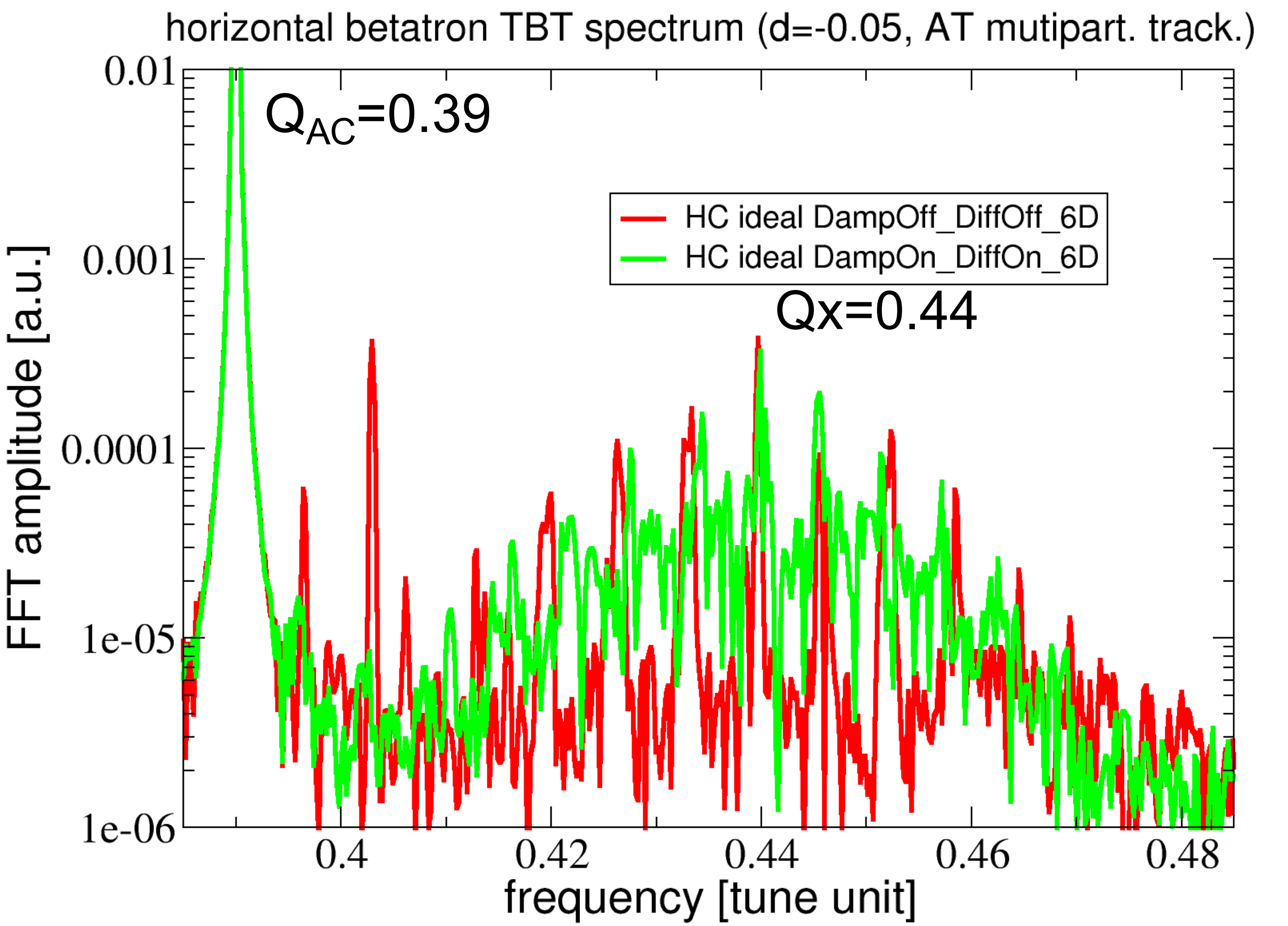
high (8,13) chroma sextupole optics: RAD OFF & ON



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regarding $(1-\lambda^2)$

The measurable *driven* optical parameters are computed from the measured phase advance & model functions via the λ parameter

$$\lambda_h = \frac{\sin[\pi(\nu_{x,h} - \nu_x)]}{\sin[\pi(\nu_{x,h} + \nu_x)]}$$

$$\Psi_x(\bar{s}_2, \bar{s}_1) = \psi_x(\bar{s}_2, \bar{s}_1) - \pi\nu_x \mathrm{sgn}(\bar{s}_2 - \bar{s}_1)$$

see Ryoichi Miyamoto’s PhD thesis, notes and papers

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$$\tan[\Psi_{x,h}(\bar{s}, \bar{s}_h)] = \frac{1+\lambda_h}{1-\lambda_h} \tan[\Psi_x(\bar{s}, \bar{s}_h)]$$

$$\beta_{x,h}(\bar{s}) = \frac{1+\lambda_h^2 - 2\lambda_h \cos[2\Psi_x(\bar{s}, \bar{s}_h)]}{1-\lambda_h^2}\beta_x(\bar{s})$$

$$A_{x,h} = \frac{\theta_h}{4\sin(\pi\delta_h)}\sqrt{\beta_x(\bar{s}_h)(1-\lambda_h^2)}$$

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regarding $(1-\lambda^2)$

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hypothesis: λ << 1

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hypothesis: λ << 1

hypothesis not really met @ESRF:
ν=(36.44,13.39)
$d=\nu_{x,h}-\nu_x=0.01 \Rightarrow \lambda_x=0.09$
$d=\nu_{x,h}-\nu_x=0.03 \Rightarrow \lambda_x=0.34$

$$\Psi_x(\bar{s}_2, \bar{s}_1) = \psi_x(\bar{s}_2, \bar{s}_1) - \pi\nu_x s$$

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regarding $(1-\lambda^2)$

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$$\lambda_h = \frac{\sin[\pi(\nu_{x,h} - \nu_x)]}{\sin[\pi(\nu_{x,h} + \nu_x)]}$$

hypothesis: λ << 1

$(1-\lambda^2)$ artificially introduced to retrieve the same C-S relations between β,α & γ, though it is not needed.

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regarding (1–λ²)

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(1-λ²) removed for all analysis @ ESRF, both in simulations & measurement to retrieve good matching with model and measured linear optics

$$\beta_{x,h}(\bar{s}) = \frac{1+\lambda_h^2 - 2\lambda_h\cos[2\Psi_x(\bar{s}, \bar{s}_h)]}{\cancel{1-\lambda_h^2}}\beta_x(\bar{s})$$

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outlook

- Simulations and measurement @ the old ESRF storage ring revealed problems in using AC dipole TbT data along with large chromaticity & synchrotron radiation.
- Sources of pollution (large chroma Vs synch. rad.) have not yet been disentangled and quantified individually. This is feasible in simulations, though not experimentally.
- A light source with robust linear modelling via ORM and TbT BPM data (with MAF filter & AC dipole) could be used as playground for an experimental campaign. PETRA looks a good candidate!!