Update on strong-strong beam-beam effects

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Reminder on strategy

To date, coherent beam-beam effects were not a limiting factor for hadron collider performance (Y.Alexahin, PAC'05).

Hence, the strategy of beam-beam task is to

1. Address incoherent effects (losses, emittance growth, pacman bunches). This is done with weak-strong methods.
2. Evaluate effects of noise (may be done with both w-s and s-s).
3. Look for 'unexpected' coherent effects (instabilities).

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Noise

Noise sources: ground motion, power converter ripple, transverse feedback, RF, crab cavity

- Slow effects result in time varying beam-beam offset – may induce resonances not otherwise present in the beam-beam system.
- Fast emittance growth may occur if noise spectrum overlaps with eigen-modes (betatron and synchrobetatron) of the beam system.

Noise – selected previous work

- V.Lebedev, et al., Particle Accelerators, v. 44, pp. 147-164 (1994)
- G. Stupakov, SSC-560 (1991)
- T. Sen and J. Ellison, PRL 77, 1051 (1996)
- Y. Alexahin, NIM A391,73 (1996)
- V.Lebedev, V.Shiltsev, Accelerator Physics at the Tevatron Collider, Springer 2014

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Noise – studies for HL-LHC (K.Ohmi)

- 4th Joint HiLumi Mtg. (KEK) and http://arxiv.org/pdf/1410.4092.pdf

Weak-strong model, obtained tolerance on CC noise:

"The tolerance of the noise amplitude is $\Delta x/\sigma r$ = 0.002 and the corresponding phase error is $\Delta\phi = 4 \times 10^{-3}$ … The crab cavity noise was measured at KEKB, 1.7×10^{-4} rad for frequencies above 1 kHz"

"For CC voltage, tolerance is 10^{-5}-10^{-4} for white noise"

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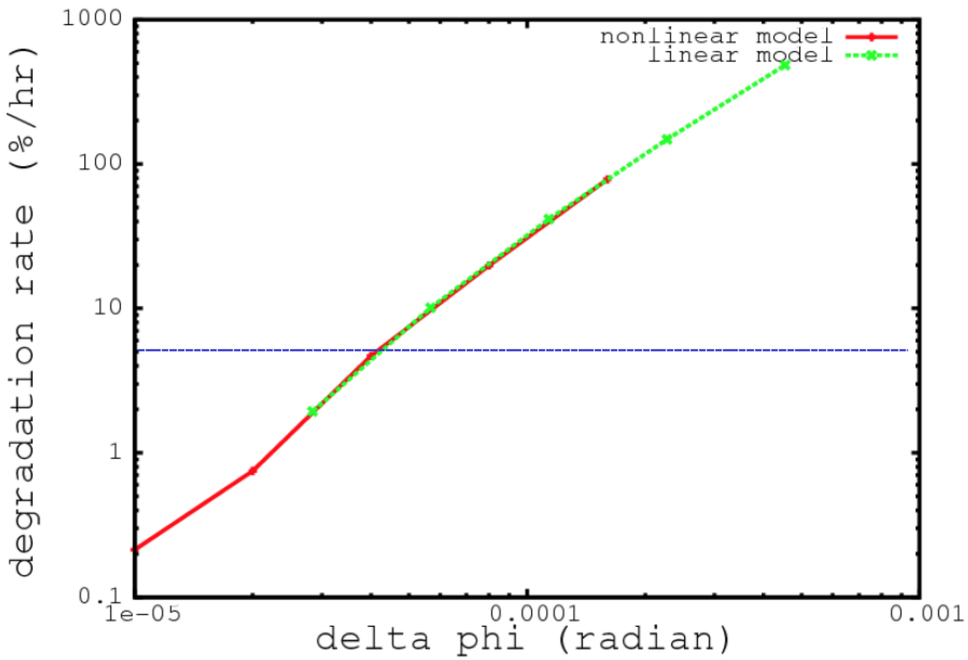
Noise – studies for HL-LHC (J.Qiang)

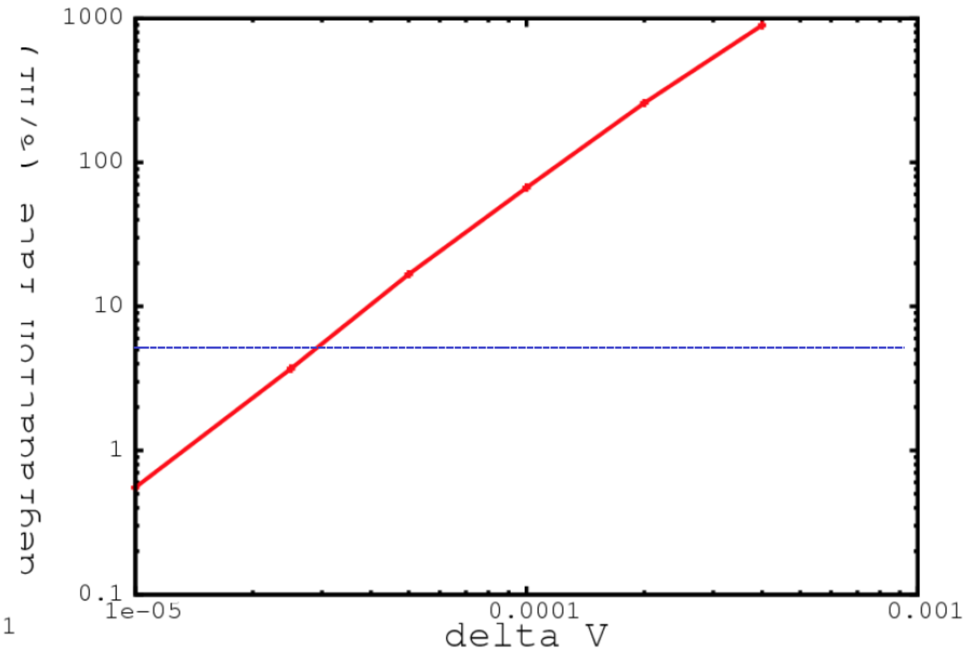
- 24th LARP / HiLumi Mtg. (Fermilab) and https://indico.cern.ch/event/402415/

Strong-strong model, also effect of damper

degradation rate vs. phase noise amp.



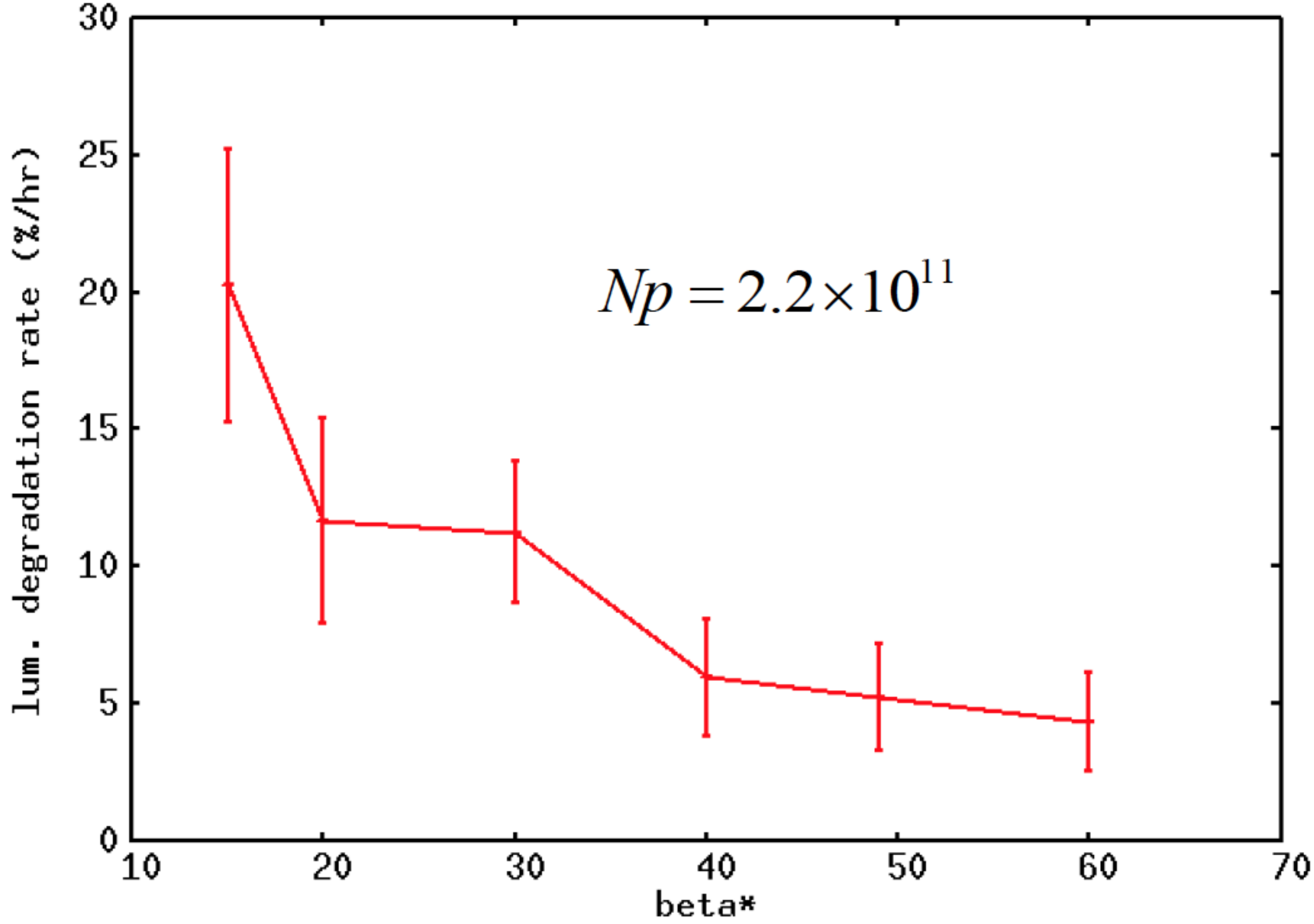
degradation rate vs. voltage noise amp.



In order to have a good luminosity lifetime ~ 20 hours,
the noise amplitude needs to be kept below the level of a few 10^{-5}.

Noise – studies for HL-LHC (J.Qiang)

effect of beta-function



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Noise – studies for HL-LHC (J.Qiang)

- Cross-checking with other modeling (P.Baudrenghien) is in progress.
- Cross-checking with operational data is necessary to establish trustworthiness of quantitative conclusions.

Noise – relevant studies for LHC (J.Barranco et al.)

- COMBI with full multi-bunch self-consistent model and feedback
- General conclusions in line with Alexahin's model predictions
- More data to be gained in MDs

Coherent instabilities

- Coherent beam-beam modes in a conservative system are stable.
- Interaction of multi-bunch beam-beam synchrobetatron modes with non-conservative force (impedance) can lead to an instability.
- Landau damping is the main stabilizing mechanism but other options exist:
  - Nonlinearity of beam-beam.
  - Octupoles.
  - Symmetry breaking (splitting the tunes of two beams).

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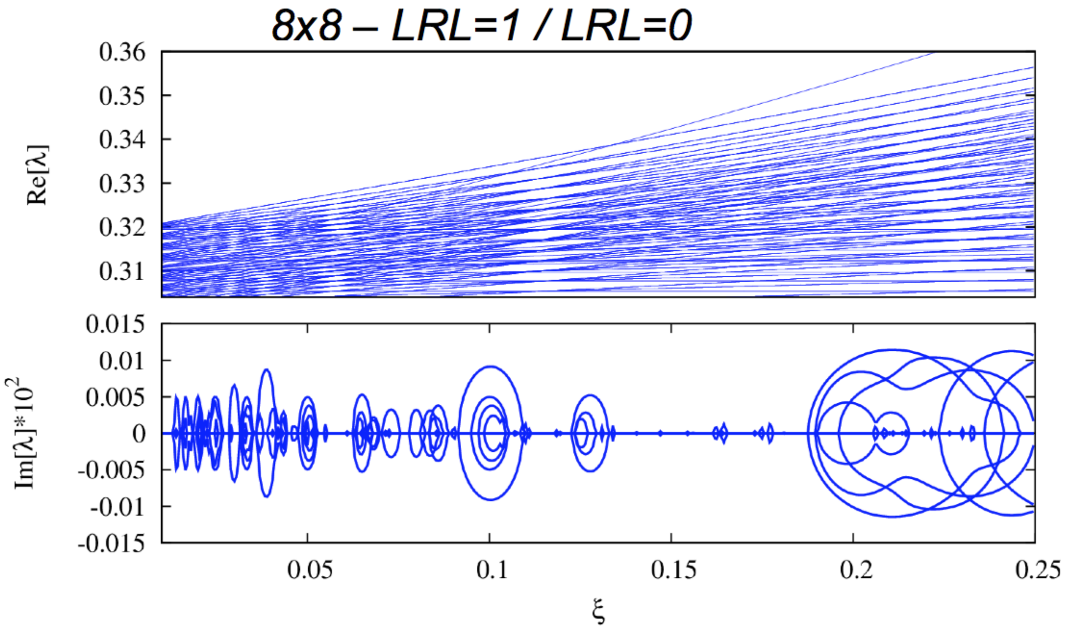
Coherent instabilities – selected works

- Y.Alexahin, NIM A480 (2002)
- A.Chao, R.Ruth, Part. Accel. 16 (1985)
- E.Perevedentsev, A.Valishev, Phys. Rev. ST Accel. Beams 4, 024403 (2001)
- S.White, X.Buffat, N.Mounet, and T.Pieloni, Phys. Rev. ST Accel. Beams 17, 041002 (2012)
- A.Burov, Phys. Rev. ST Accel. Beams 17, 021007

Coherent instabilities – studies for HL-LHC

- S.White et al.
- mode coupling instabilities occur for many tune shifts depending on which bunch/mode is involved.
- High chromaticity helps but cannot cure all the instabilities, consistent with single bunch results



Coherent instabilities – studies for HL-LHC

- T.Pieloni et al.
- Stability diagrams with beam-beam before collisions:

negative polarity preferred with small/ partial telescopic part compensating LR effects before β^* = 70 cm collisions

Summary

- Studies of noise effects (both crab cavity and damper) are relatively mature. Refining of quantitative conclusions is desired:
  - COMBI and BEAMBEAM3D codes seem to give similar results as compared also to the formula of Y.Alexahin. There is a difference in the way the two codes randomize the kick (uniform or Gaussian noise) and the impact of this on the amplitude factor of Alexahin's formula. A further difference may come from the fact that the random displacements in the IP are given in one versus both planes. It would be also good to do a similar study with BEAMBEAM3D as the one done by Xavier for COMBI regarding the impact of numerical noise. Finally, the measurements done in the actual LHC, can also be used as a guideline for the code benchmarking.

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Summary - 2

- There is almost an order of magnitude difference in the tolerance of the rms amplitude and phase variation obtained between the simulations with “white noise” and the one with the “realistic” crab cavity (CC) noise. It seems though that what is important for emittance growth is the power spectral density of the noise around the betatron tunes. In the case of the “white noise” this is constant over all frequencies but in the case of the CC noise this drops by orders of magnitudes from the low frequencies to the higher ones. What would be interesting to compare is the spectral content of the “white noise” and the CC noise, in order to make this difference completely transparent.

Summary - 3

- It is also important to include the model by Themis and Philippe in the strong-strong simulations. It should be reminded that the formalism has been already benchmarked with a 1-beam multi-particle code (HEADTAIL). What is missing is the interaction of the CC noise model with the real beam-beam effect and the modes it excites. It would be also desirable at some point to simulate the realistic crab cavity amplitude voltage noise which excites head-tail motion but does not necessarily imply offsets in the IP and the transverse damper cannot mitigate this effect. It should be finally stressed that the present simulations are "idealised", as they do not include the effect of trains (multiple modes), long-ranges, non-linearities, etc, and any tolerance should be taken with sufficient margins.

Summary - 4

- The investigation of coherent beam stability is a significant work that should be pursued in parallel theoretically and in experiment in order to indicate the important effects and benchmark models.