# Session 4: Instability Theory and Modeling

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ICFA Mini-workshop on Impedances and Beam Instabilities in Particle Accelerators

# Overview

- Transverse Mode Coupling (TMCI):

  $\longrightarrow$ Analytical Solutions and Theory
    - Models of TMCI with SC and impedances
    - impact of different longitudinal distribution functions
    - influence of chromaticity on TMCI

  $\longrightarrow$ Simulations
    - Should use exact analytic models for benchmarking
- Micro-bunching instability in LINACs
- Circulant matrix formalism $\longleftrightarrow$ 2-particle model
- Electron cloud and beam–ion instabilities

# Mike Blaskiewicz: Space Charge in Coherent Instabilities

## Simulations and checking

- For estimates that are sufficiently realistic to design an accelerator it appears that simulations are necessary.
- How do you know your code is right?
- For SC with linear RF and a parabolic line density we have Neuffer's exact longitudinal solutions [5].
- For boxcar bunches in linear RF with SC we have Sacherer's exact transverse solutions [6].
- For hollow bunches in a square well we have numerically exact transverse solutions with SC and wake potentials that are sums of (complex) exponentials. [7,8]
- A new basis expansion technique generalizing [6] appears to give *convergent solutions with wakefields* [9]

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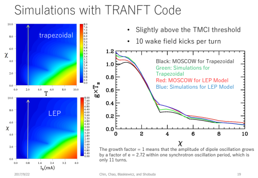
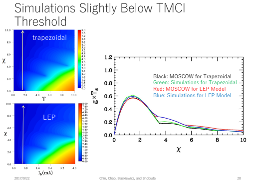
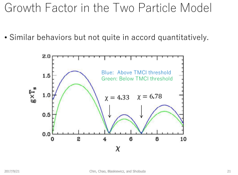
- analytic models proposed which should be reproduced by any simulation as benchmark




- finite chromaticity does not improve TMCI threshold for reasonably low chromaticities
- 2-particle model can reproduce critical chromaticity behaviour
- trapezoidal model for Vlasov analysis and macro-particle simulations can well replace realistic wake models (e.g. LEP)

### 2.1 Spectra for const-wake (ABS)

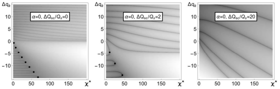



Figure: Spectra for the ABS model and const-wake ($\Delta Q_{sc}/Q_s = 0, 2, 20$).

Tim Zolkin, Alexey Burov TMCI at strong space charge

### 2.2 TMCI threshold as a function of SC (ABS)

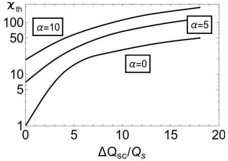
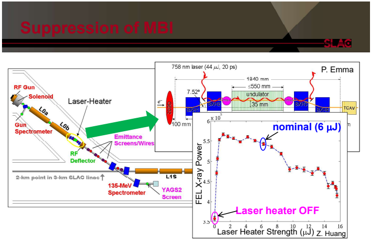


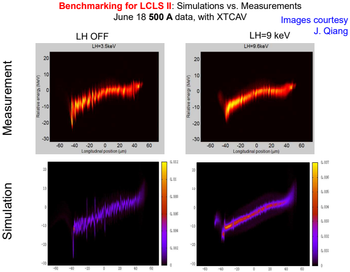

Figure: TMCI threshold as a function of space charge for the ABS model with the constant and exponential wakes (after M. Blaskiewicz).

Tim Zolkin, Alexey Burov TMCI at strong space charge

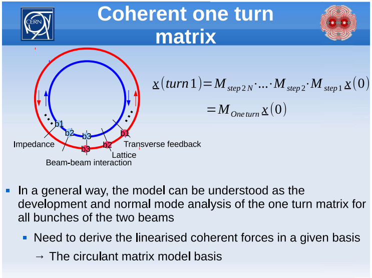
- monotonic increase of threshold for mode 0 and -1 coupling instability with space charge is true e.g. for negative constant wakes
- oscillating wakes (e.g. sin and cos) can lead to very different, not necessarily monotonically increasing behaviour
- universal plots apply to different longitudinal distribution functions

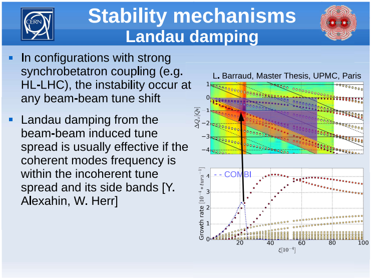



$$G(k) \approx \frac{I_0 k}{\gamma I_A}\left|R_{56}\int_0^\ell ds \frac{4\pi Z(k/C,s)}{Z_0}\right| \boxed{\exp\left(\frac{-k^2 R_{56}^2 \delta^2}{2}\right)}$$

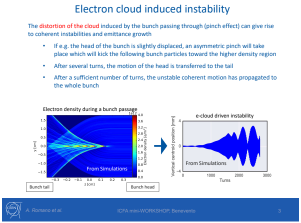


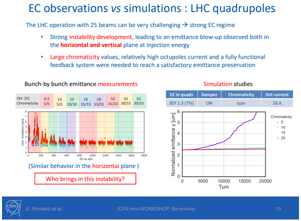

- increase of momentum spread by laser heating in dispersive region mitigates microbunching instability



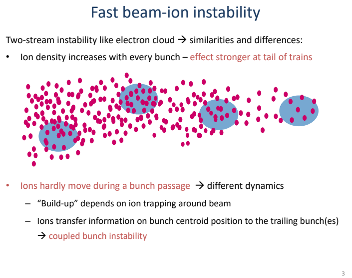

- circulant matrix formalism equivalent to Vlasov solving via eigenmodes
- conceptually an extension of 2-particle model
- benchmarked with many other codes
- predictions vs. measurements at LHC



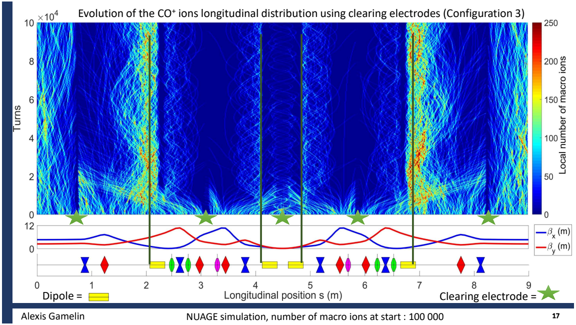

- electron cloud (EC) instabilities simulated with strong–strong macro-particle model
- EC in dipole magnets at high bunch intensities non-detrimental
- EC in dipole magnets at low bunch intensities at flat-top energy $\Longrightarrow$ vertical instability
- EC in quadrupolar magnets at injection plateau $\Longrightarrow$ horizontal and vertical instability

# Lotta Mether: Fast Beam-ion Instabilities




- electron beams can suffer from fast instabilities with ions
- simulations with PyECLOUD-PyHEADTAIL
- gas leak in LHC (16L2) causes serious problems for LHC operation, suggested mechanisms:
  1. proton beam – ion instability possible but extremely high gas density needed
  2. EC from gas ionisation requires very high electron densities (→ strong ion space charge)
  3. possibly three-beam instability mechanism needed

$\Longrightarrow$ on-going efforts




- weak-strong model for electron beam (weak) – ion (strong) motion
- investigate mitigation of beam – ion instabilities by clearing electrodes
- longitudinal motion of ions important for mitigation scenarios

Thank you for your attention!