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<td>8:30 – 9:00 AM</td>
<td>Gennady Stupakov (SLAC)</td>
<td>Theoretical approaches to microbunching instability.</td>
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<td>9:00 – 9:30 AM</td>
<td>Alexander Zholents (ANL)</td>
<td>Collective effects in the double emittance exchange bunch compressor.</td>
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<td>Bruce Carlsten (LANL)</td>
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<td>10:20 – 10:50 AM</td>
<td>Enrico Allaria (Sincrotrone Trieste)</td>
<td>Observations of microbunching in the FERMI FEL.</td>
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<td>10:50 – 11:20 AM</td>
<td>Bolko Beutner (PSI)</td>
<td>Operation Modes and Longitudinal Dynamics of the SwissFEL Hard X-Ray Facility</td>
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<td>11:20 AM – 12:30 PM</td>
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G. Stupakov: “Theoretical approaches to microbunching instability”

Outline of the talk

- Introduction
- Microbunching in rings
- Wakefields causing microbunching
- Microbunching in a bunch compressor
- Correlation functions technique
- Noise suppression—an example of “anti-microbunching”
Correlations of particle positions in the beam

Coherent effects can amplify the radiation (up to a factor of \( \sim N \)), but they can also suppress it. The beam with distribution on the left graph radiates incoherently, and the beam with the distribution on the right does not radiate at all at the wavelength \( \lambda \).
Correlations of particle positions in the beam

The blue particles are distributed randomly but positions of each red one is shifted by $\eta \lambda/2$ relative to the blue one with $\eta$ being an odd number.

This is used for a quiet start in FEL simulation codes. The idea of noise suppression in a beam was studied by Gover and Dyunin (2009) and Litivinenko (2009).
Conclusions

- A well developed standard theory explains the mechanism behind the microbunching instability caused by CSR and SC wakefields in the system. Based on this theory, a laser heater was proposed and is currently employed at LCLS to suppress the instability. However, remaining MBI makes the OTR diagnostics at LCLS useless.
- To properly address the instability starting from random noise, a more sophisticated theoretical technique of correlation functions is required. The traditional method of Vlasov equation is not sufficient.
- Noise suppression in relativistic beams is a new exciting direction in the MBI studies.
Manipulate the longitudinal phase space with ease of manipulation of the transverse phase space.

Concern: electron bunch is too short in the telescope area (middle part) because transverse emittance of the electron beam is very small.

Longitudinal space charge effects seem to be OK, emittance degradation is less than 0.3%. However, CSR effects is a serious problem requiring additional deflecting cavities producing electron bunch lengthening in the vicinity of the central part.
Deflecting cavities (tcav) deflect the electron bunch in the vertical plane and produce a large vertical chirp in the chicane’s bending magnets.

CSR is suppressed by a factor

$$\approx \frac{\Sigma_y}{\sigma_{dif}}$$
Overview

Partitioning the eigen-emittances to decrease the transverse emittances by increasing longitudinal energy spread, may be an alternative to laser heating.

“There is enough “spare” area in the longitudinal phase space to move excess area from the transverse phase spaces.”

- Low emittance requirements for the MaRIE 42-keV XFEL motivate this research (and also the use of a double EEX for compression).
- Flat-beam transforms (FBTs) and other eigen-emittance concepts.
- Description of some nominal eigen-emittance schemes with the potential to achieve very low emittances.
Concept of eigen-emittance partitioning

This longitudinal emittance is for a 250-keV energy spread and LCLS emittance scaling.

There is enough "spare" area in the longitudinal phase space to move excess area from the transverse phase spaces.

Nothing special with 1 nC – optimum may be with higher charge.
Summary

- Future XFEL designs will require higher brightness electron beams

- Exploiting eigen-emittances may lead to a new way of achieving very low transverse emittances by moving excess transverse phase space into the longitudinal dimension (which may help with the MBI)

- There are several ways to implement eigen-emittance concept

- Two-stage generation of beam correlations (using a non-symplectic beamline element) may be a practical application of eigen-emittances
SINCROTRONE TRIESTE is a nonprofit shareholder company of national interest, established in 1987 to construct and manage synchrotron light sources as international facilities.

**ELETTRA Synchrotron Light Source:** up to 2.4 GeV, top-up mode.

**FERMI@Elettra FEL:**
100 – 4 nm HGHG,

Sponsors:
- Italian Minister of University and Research (MIUR)
- Regione Auton. Friuli Venezia Giulia
- European Investment Bank (EIB)
- European Research Council (ERC)
- European Commission (EC)

E. Allaria: “Observation of microbunching in the FERMI FEL”
FERMI’s two FELs will cover different spectral regions.

FEL-1, based on a single stage high gain harmonic generations scheme initialized by a UV laser will cover the spectral range from ~100 nm down to 20 nm.

FEL-2, in order to be able to reach the wavelength range from 20 to ~4 nm starting from a seed laser in the UV, will be based on a double cascade of high gain harmonic generation. The nominal layout uses a magnetic electron delay line in order to improve the FEL performance by using the fresh bunch technique. Other FEL configurations are also possible in the future (e.g. EEHG).
HGHG with quadratic e-beam chirp

Energy modulation on the quadratic chirp

Due to the nonlinear chirp different part of the beam suffer from different compression and wavelength shift. Spectrum broadening.

Density modulation and compression vary along the bunch
Experimental evidence of microbunching instabilities at FERMI?

When FEL is optimized to maximize the power on the on axis mode the typical FEL spectrum has a single spike. When working with a single compressor scheme this is well reproducible and robust.

After several shifts on FEL with BC1&BC2 it has been possible to have tens of μJ from the FEL using the beam compressed with both BC1 and BC2. While the produced power was of the same order than what produced with the single compressor scheme, the measured spectrum showed a structure. Due to the limited time dedicated to the optimization, results can not be considered conclusive.

FEL results seems to suggest that the microbunching is stronger for the beam compressed with BC1 and BC2 than with only BC1. More studies are needed.
Bolko Beutner: “Operation Modes and Longitudinal Dynamics of the SwissFEL Hard X-Ray Facility”
SwissFEL Overview

- Aramis Hard X-Ray Undulator – SASE
- Athos Soft X-Ray Undulator – Self-seeding and SASE

- Two bunch operation is foreseen with 28ns spacing
- Photon energy of Athos and Aramis are decoupled by a c-band module (1 klystron for 4 cavities) after the switchyard
- Laser based THz pump source in Athos line
SwissFEL Injector Test Facility

HF Status

FINSS
- Interlock: Interlock OK
- Power: 20.92 MW, Modulator: Ok, Phase: -17.22deg

FINSSB01
- Interlock: Interlock OK
- Power: 15.06 MW, Modulator: Ok, Phase: 2.33deg

FINSSB02
- Interlock: Interlock OK
- Power: 34.42 MW, Modulator: Ok, Phase: 66.46deg

FINSSB03
- Interlock: Interlock OK
- Power: 22.29 MW, Modulator: Ok, Phase: -12.29deg

FINXB
- Interlock: Interlock OK
- Power: 0.36 MW, Modulator: Ok, Phase: 4.31deg

F10D1
- Interlock: Modulator HV
- Power: 0.00 MW, Modulator: Ok, Phase: -51.00deg

Laser
- Power: 10.4 mW
- Shutter: Open

Last 1h

PSA
- Radpegei Low
- Doors
- Rundgang OK
- Tunnel closed
- NO Alarm
- North CLOSE
- West CLOSE
- South CLOSE

11.04.2012
Injector Recent Results

Beam parameters 4/5 April:
• 100 pC beam charge
• Ti:Sa laser (pulse stacked mode)
• 100% transmission
• 223.5 MeV
  – First S-band cavity only at half power (requires more conditioning)

• SwissFEL Injector Test Facility is ready to study Beam Dynamics and Microbunching effects experimentally

• Microbunching Issues in the Lattice design:
  – Laser Heater is mandatory in this design
Discussion topics

• What are the origins of microbunching instability, shot noise, laser intensity fluctuations, other?
• Energy spread is capable to dilute microbunching, but where does the uncorrelated energy spread come from? “Hot” electrons right out of the gun, is this feasible?
• How to increase the uncorrelated energy spread?
• IF one trusts CSR and LSC impedance models, is this sufficient to predict microbunching instability and calculate the gain?
• Where we are with code benchmarking between codes and with experiments? How to deal with a granularity of the numerical models?
• Electron beam “heating”, is it helpful and what is the best way to do it?
• Role of 3D effects, is transverse microbunching possible?
• What are the other means to mitigate microbunching besides increasing energy spread, i.e., exotic noise suppressors (silencers), targeted linac designs, etc.
• Reversible “heaters”, pros and cons.
• What is the microbunching gain in the velocity compression technique?
• Can we make a “good” use of microbunching instability for THz or other light sources?
Thank you for your attention