Elettra Sincrotrone Trieste

Non-standard use of laser heater for FEL control and THz generation

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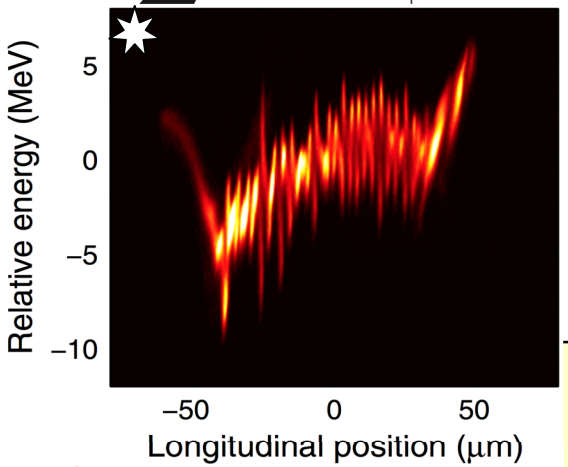
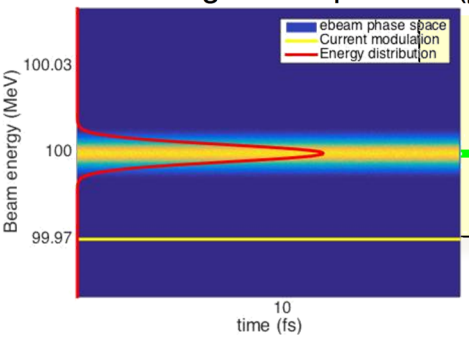
Outline

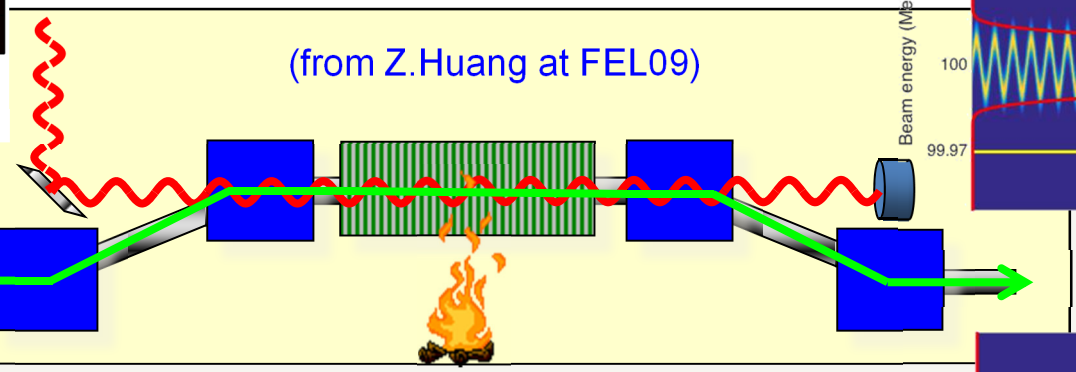
- **Laser heater in free electron lasers**
- **The FERMI setup**
- **Non-standard electron-beam tuning with LH**
  - Non Gaussian energy distribution
  - Temporal shaping
  - Seeding the linac micro-bunching instability
- **Conclusions**

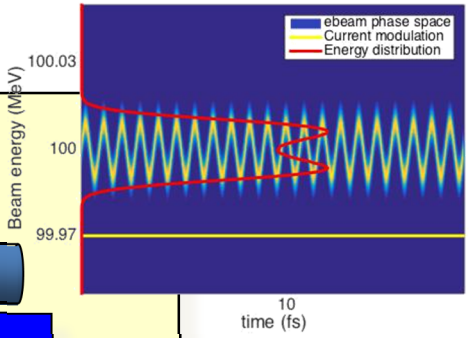
The need of a laser heater

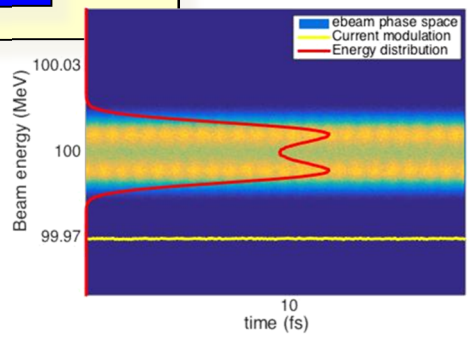


High brightness electron-beams used in **high gain FELs** can develop **micro-bunching instabilities** (μBI) in the **linac** and **compressors** that are detrimental for FEL.

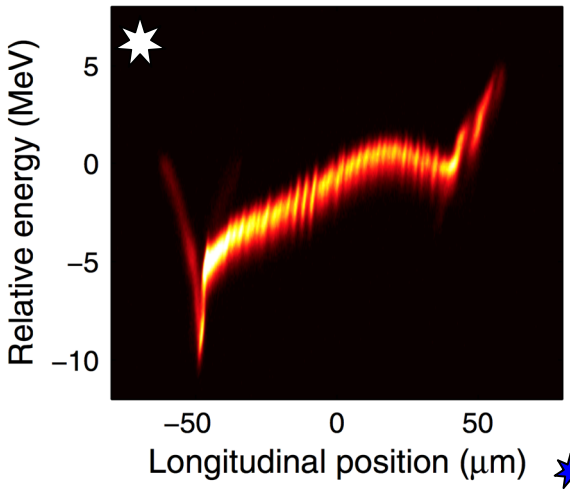








The LH induces a uniform increase of the uncorrelated energy spread of the e-beam that damps the μBI.



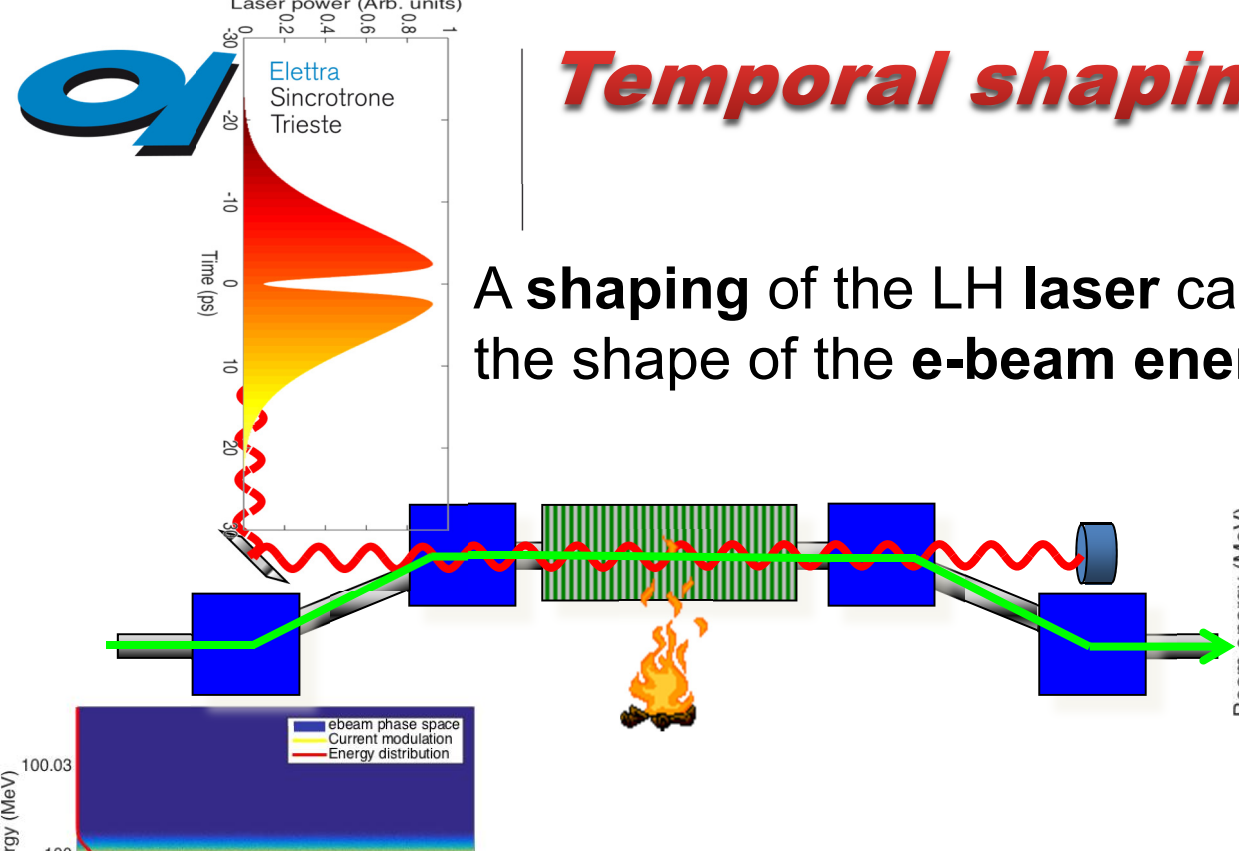
Depending on e-beam and laser parameter the energy spread distribution can be highly non-Gaussian[1]

[1] Z. Huang, PRSTAB 7, 074401 (2004)

D. Ratner et al. PhysRevSTAB 18 30704 (2015)

Temporal shaping

A **shaping** of the LH **laser** can be used for **controlling** the shape of the **e-beam energy spread**.

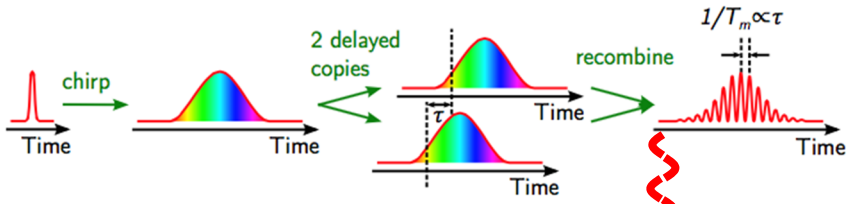


Energy spread is a **critical** parameter for **FEL** gain. **Optical shaping** of e-beam[1] with the LH can be an alternative method for a localized **spoiling of e-beam** for **FEL emission control**.

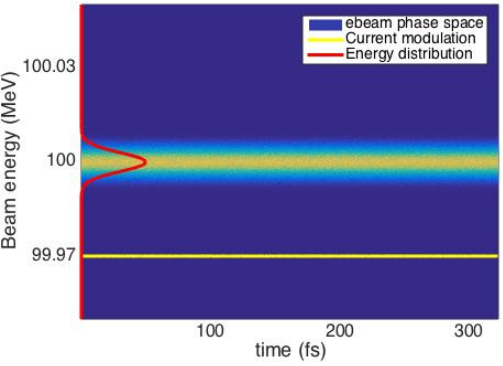
Shaping is performed before compression. The lasing region is compressed by the beam compression factor.

[1] A. Marinelli et al. PRL **116**, 254801 (2016)

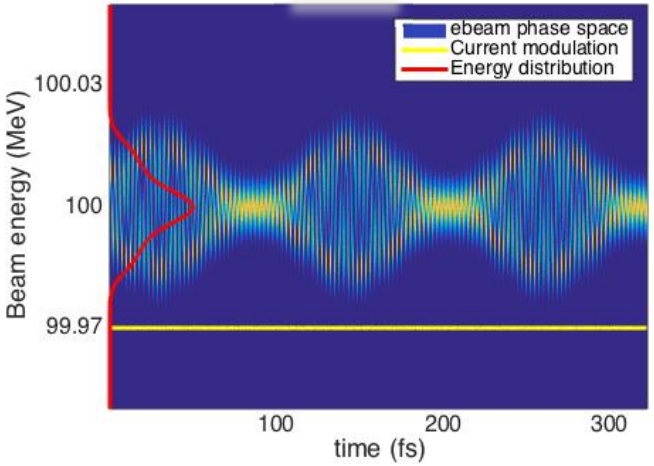
Amplitude modulated LH



LH laser usually generated from 100***fs*** laser **stretched** to few 10**ps** length.

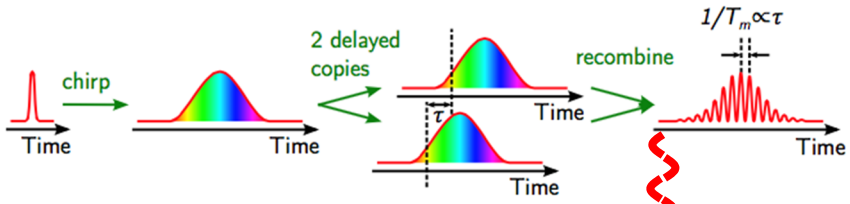


2 slightly **delayed pulses** produce a pulse carrying an **amplitude modulation** that can be **controlled** in **frequency** and **amplitude**.



Such an amplitude modulation can be **imprinted** into the **e-beam** energy spread and does survive to the smearing occurring into the LH chicane.

Amplitude modulated LH



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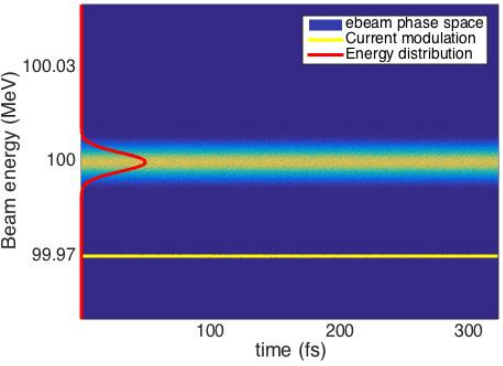

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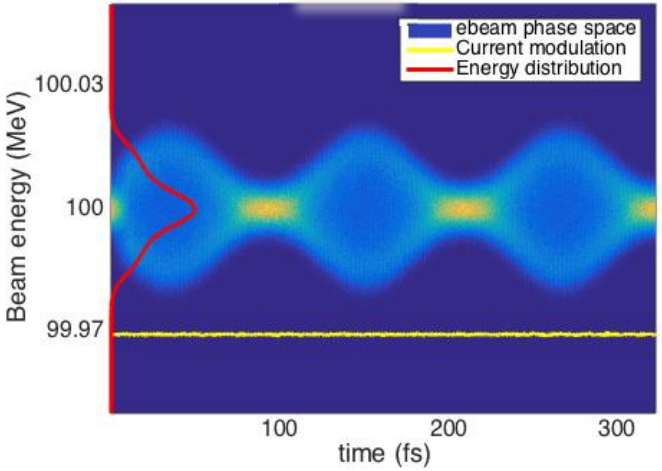

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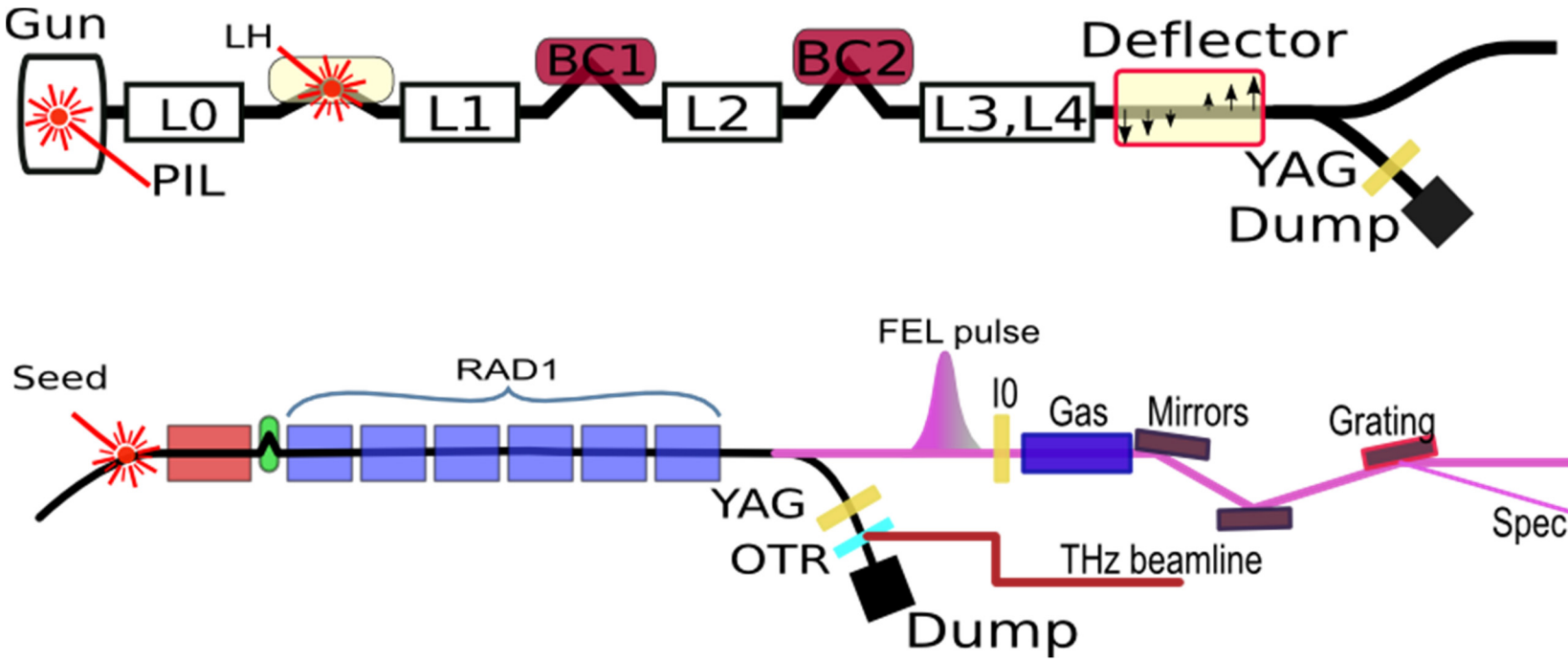
FERMI layout



Linear accelerator:

- Rep rate 50Hz
- Beam charge 700pC
- Beam energy 1.5GeV
- Peak current ~700A
- Phase space diagnostic

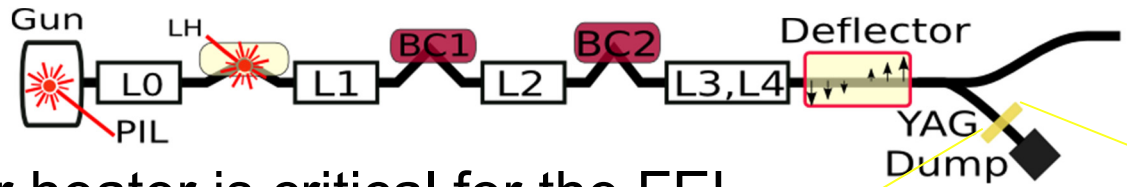
FEL:

- Two Seeded FELs
- Variable gap and polarization undulators
- Online diagnostic for FEL properties

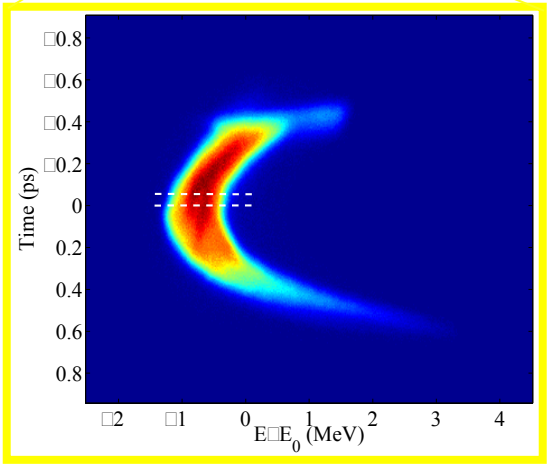
TeraFERMI:

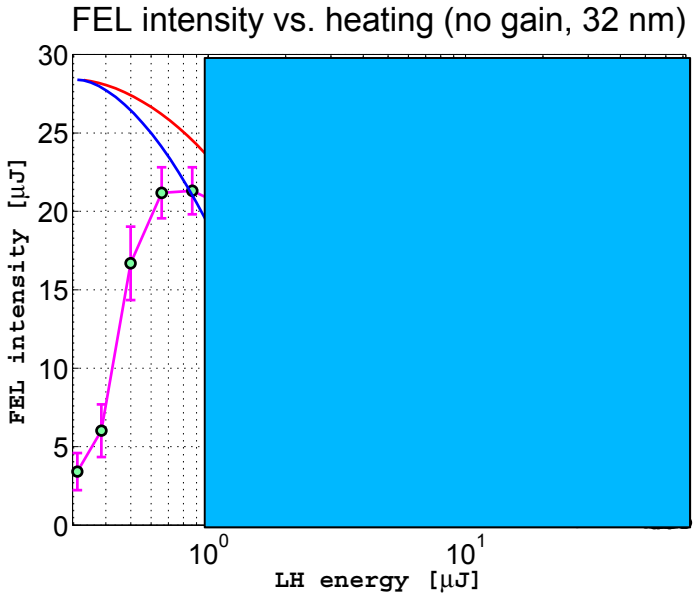
- THz beamline optimized for 1-10THz
- THz transport in vacuum
- THz diagnostic

Non-Gaussian energy spread



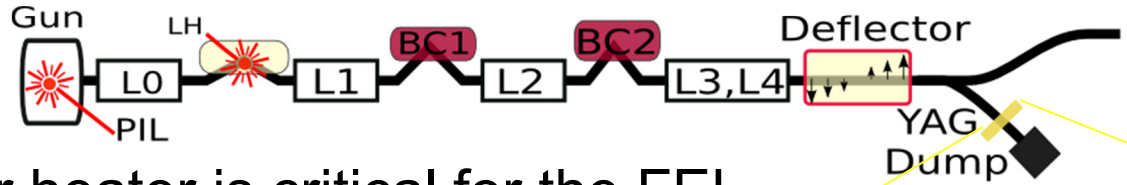
The use of the laser heater is critical for the FEL optimization.





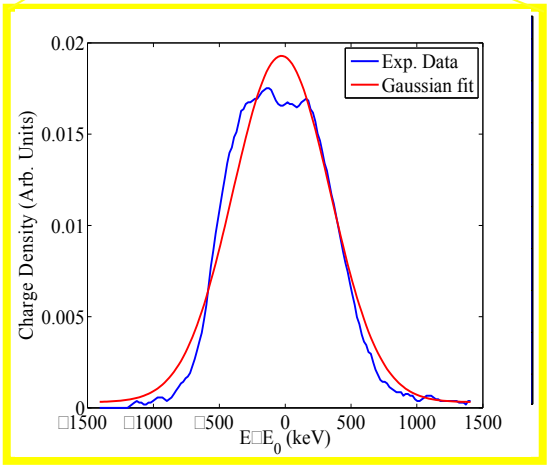
[1] E. Ferrari et al., PRL 112 114802 (2014)

Non-Gaussian energy spread

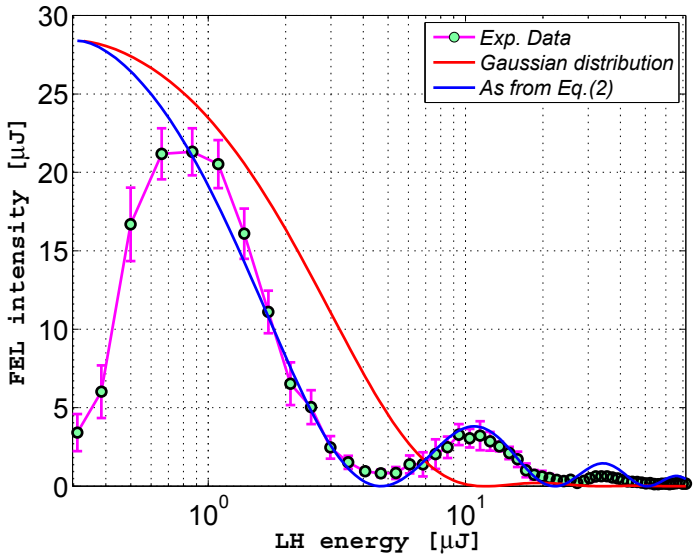


The use of the laser heater is critical for the FEL optimization.

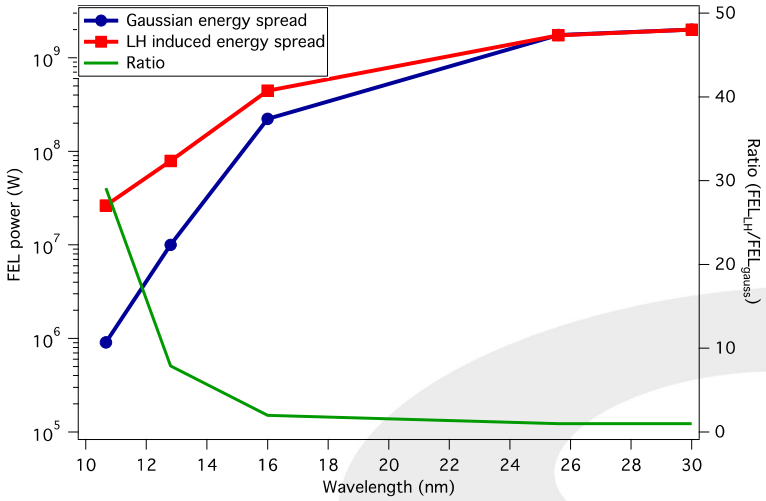
For large energy spread the effect of the non-Gaussian distribution become visible on FEL.



FEL intensity vs. heating (no gain, 32 nm)

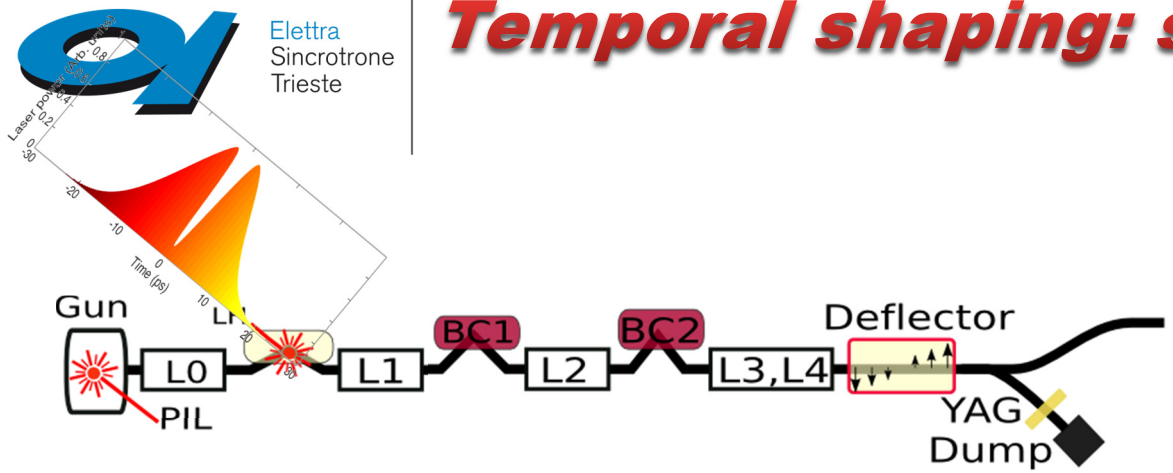


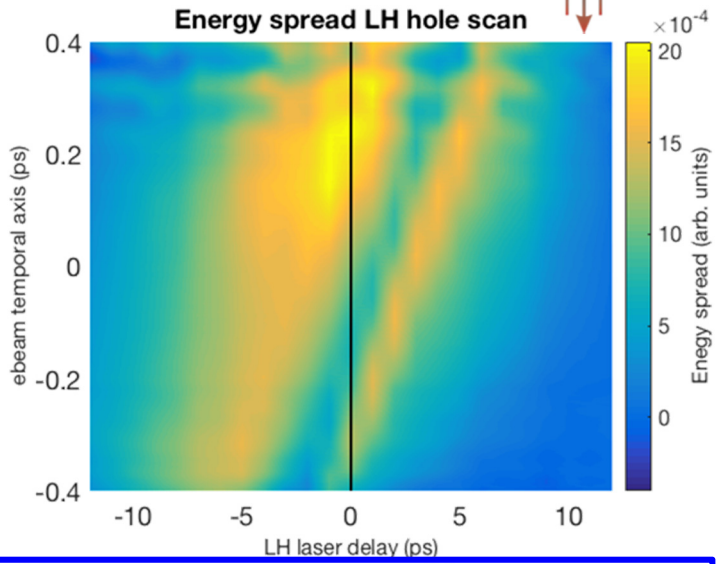
The specific energy distribution can be exploited for improving FEL performances.



[1] E. Ferrari et al., PRL 112 114802 (2014)

Temporal shaping: short pulses

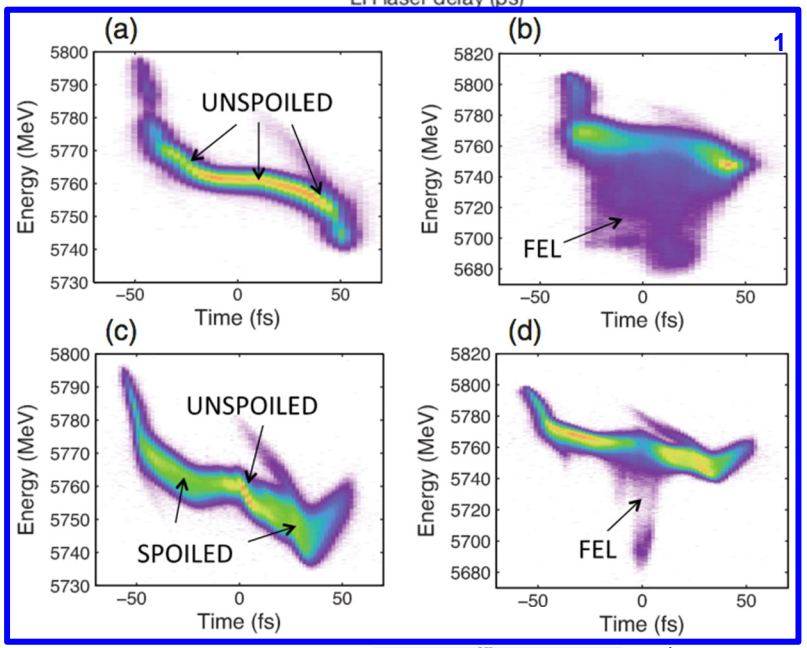




Shaping of the energy **distribution** induced in LH is **preserved** by the beam and **measured** at the linac end.

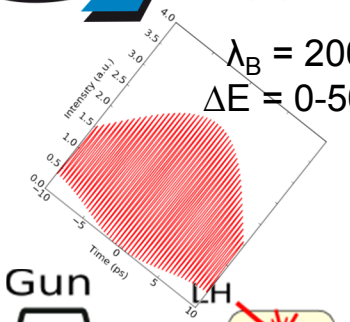
Accurate **control** of the **energy spread** profile would **allow** to **control** and shorten the FEL **pulse length** at FERMI.

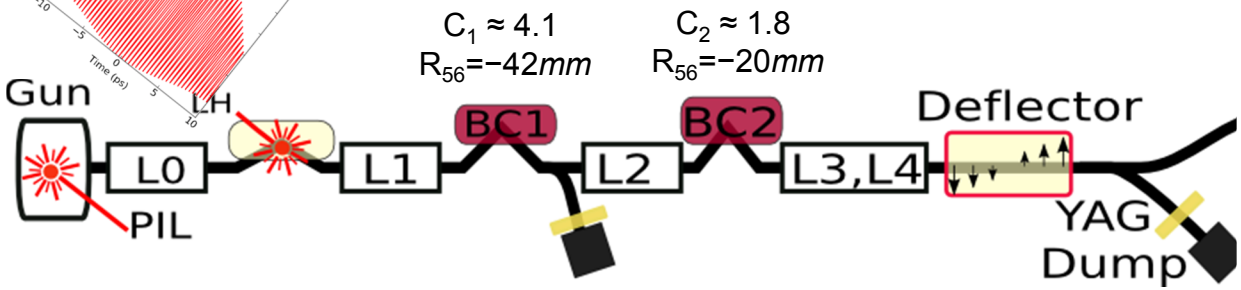
A similar setup has been successfully used at LCLS for generating 10 fs pulses.

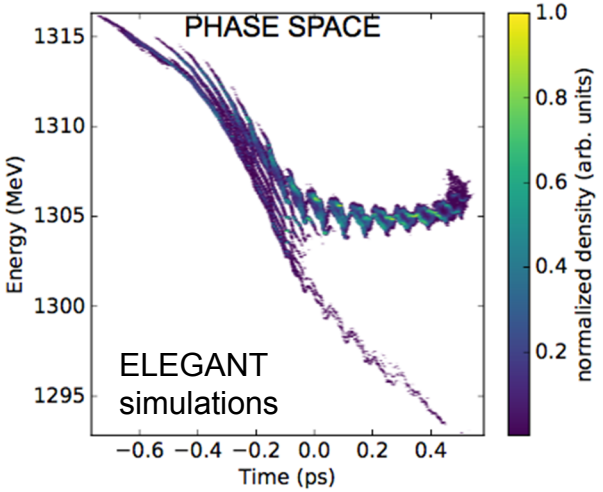


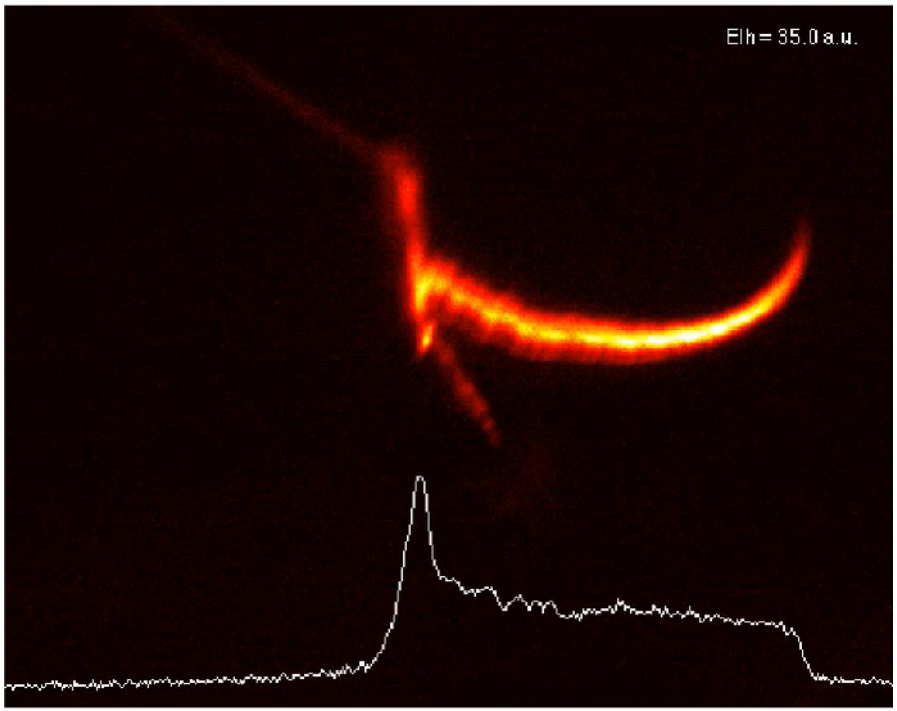
[1] A. Marinelli et al. PRL **116**, 254801 (2016)

LH beating for seeded μBI





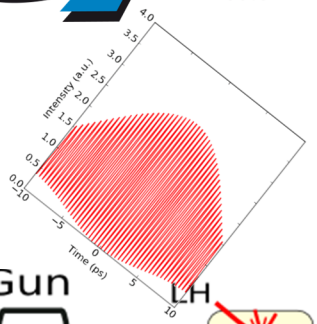




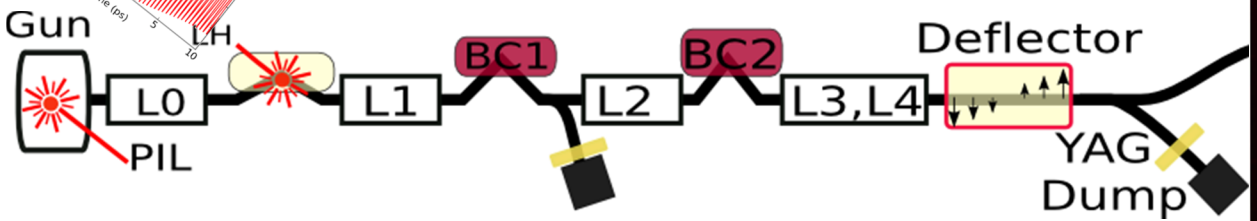
With the linac in double compression scheme, LH induced structures are easily detected in the e-beam phase space. **Density** and **energy modulation** at the end of the linac become stronger with higher LH laser power.

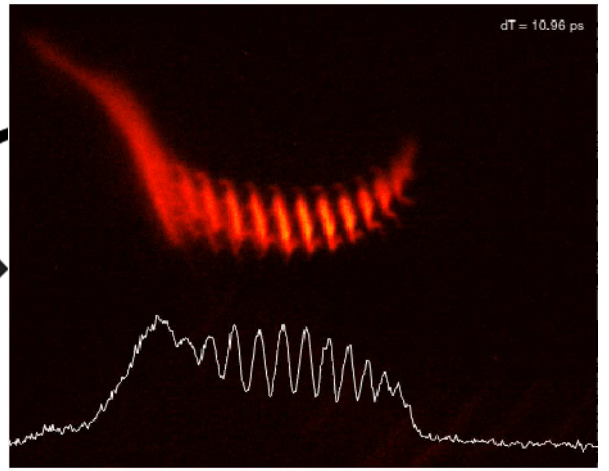
Measured phase space is well reproduced by simulation with elegant.

e-beam phase space modulation



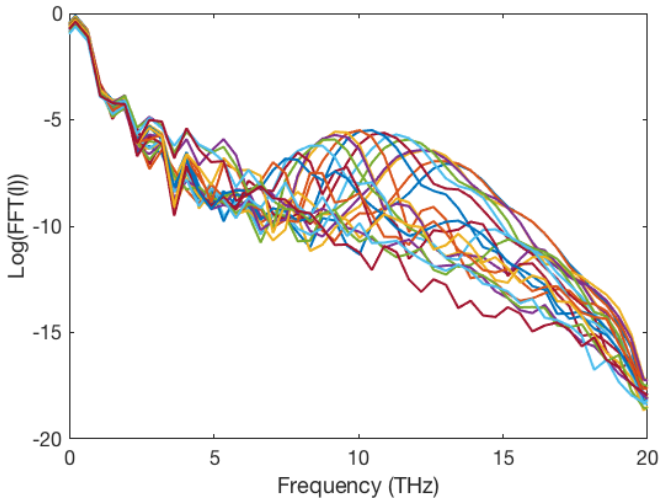
Amplitude of energy modulations varies with the beating frequencies.

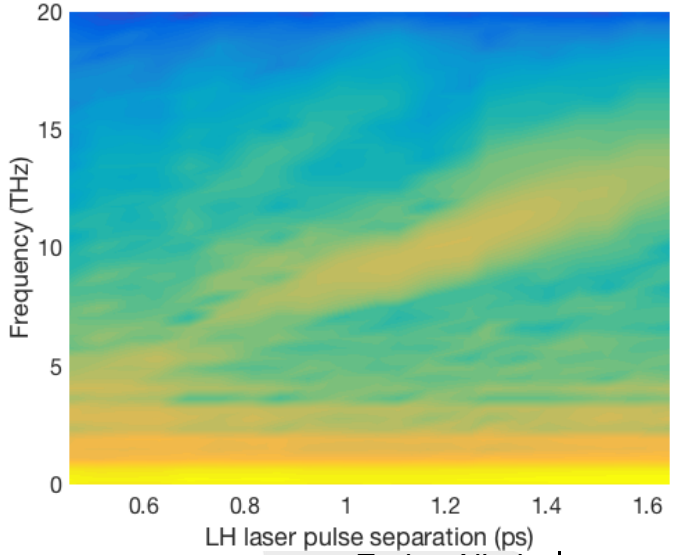




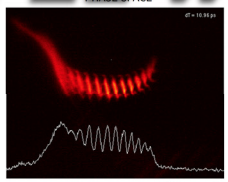
The LH modulations are amplified by μBI gain in the linac.

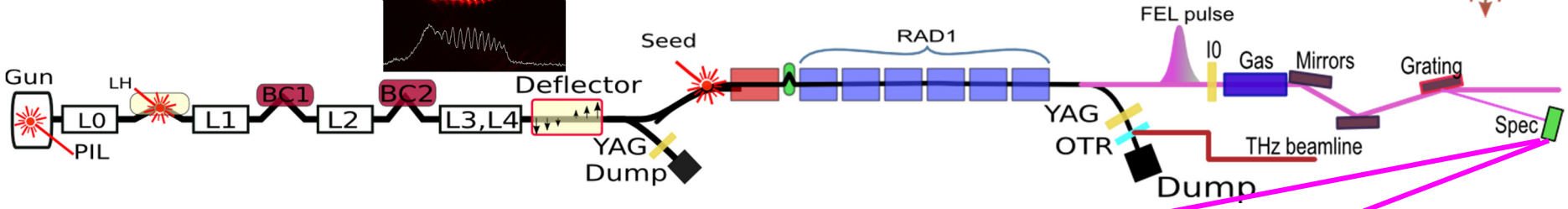
Non negligible modulation also for longer wavelengths.





FEL with periodic μB

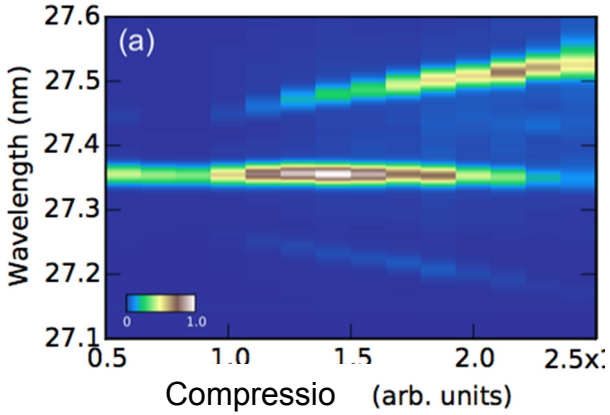




The e-beam modulation leads to phase modulation of the field responsible to sidebands in the FEL spectrum.

Seeded FEL

Combined with seeding the periodic modulations produce controlled sidebands that varies with the beating frequency .



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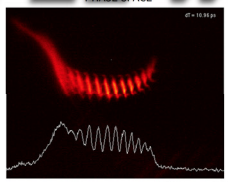

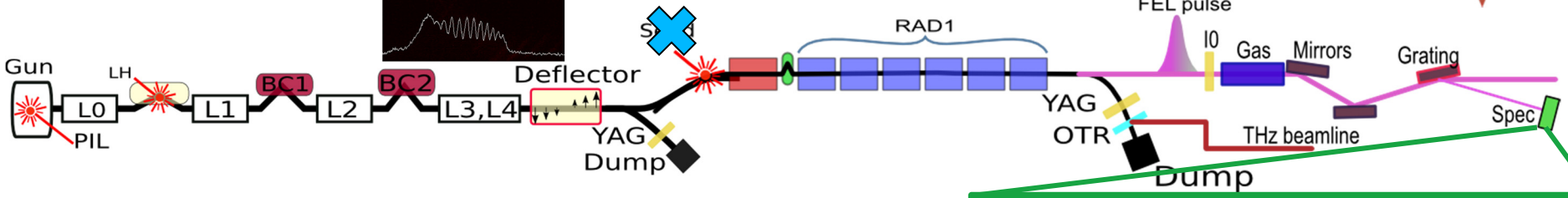

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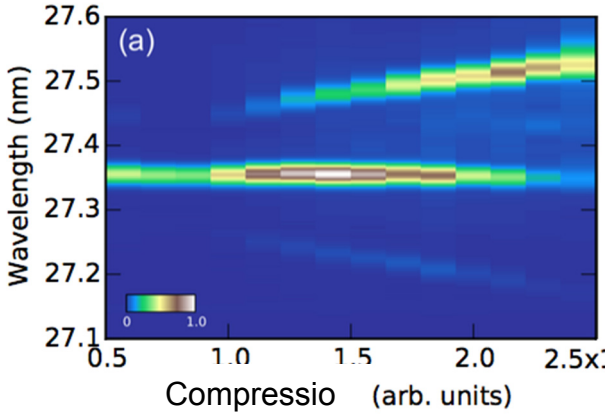
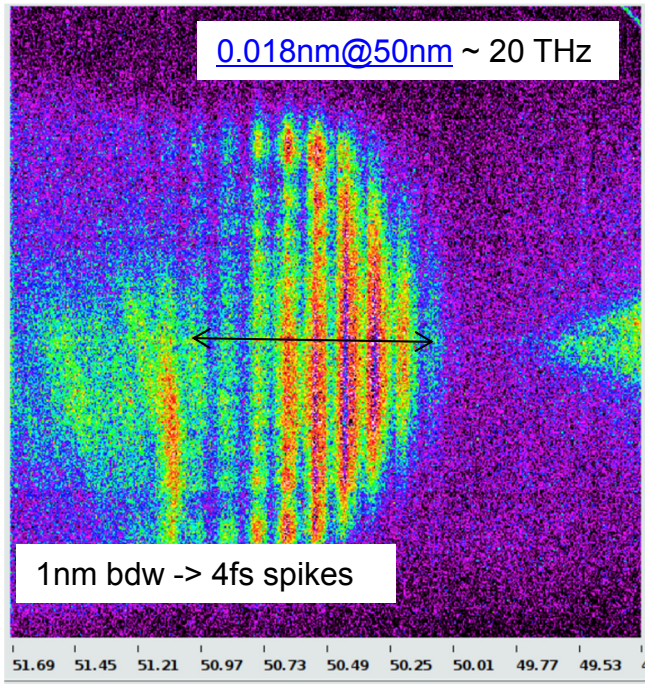
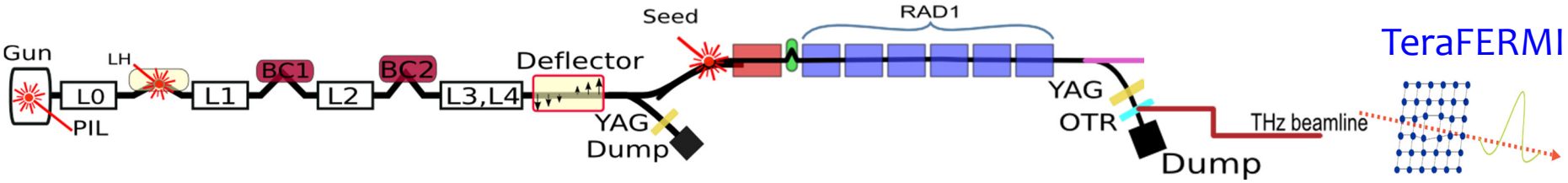




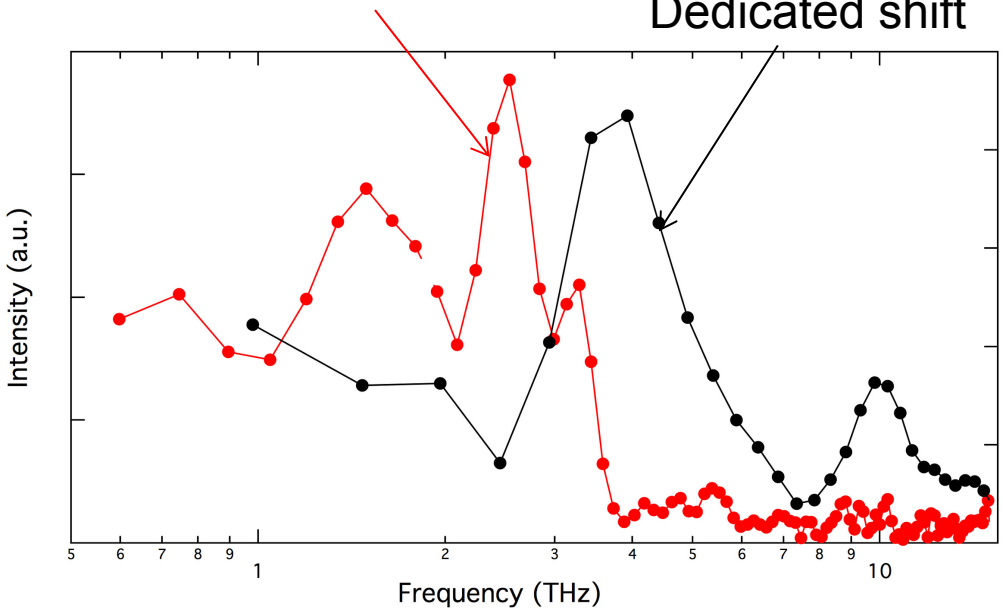
For SASE the strong current modulations leads to a regular spike train.

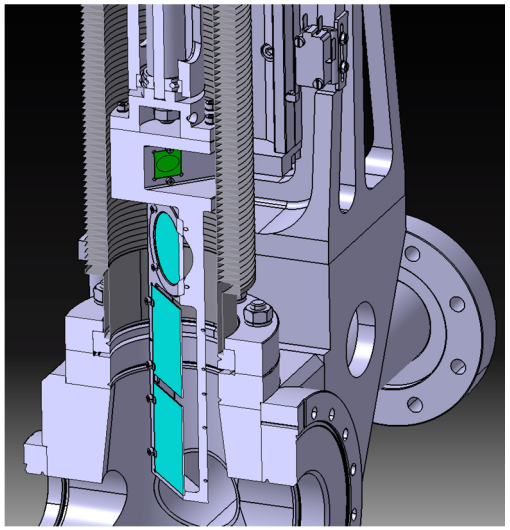
Seeded μB for coherent THz



Seeded micro-bunching are promising for narrow bandwidth and tunable THz radiation.

Planning for an experiment in collaboration with the TeraFERMI team.





TeraFERMI designed for non-linear THz optics at MV/cm fields

Ultra-short, high-power THz pulses between 1 mm - 20 μm (0.3 -15 THz)

TeraFERMI performances:

- Pulse energy up to 60 μJ/pulse at source → up to 100 μJ recorded during machine shifts
- Pulse energy up to 20 μJ on the optical table (in air!)
- Spectral content up to 4 THz → up to 15 THz during machine shifts
- THz spot size at focus ~ 1 mm FWHM
- > MV/cm electric fields in the lab

Conclusions

- ✓ Laser heater is a indispensable tool for x-ray FELs
- ✓ LH gives an additional knob for controlling the electron beam properties.
- ✓ E-beam can be tailored for special FEL modes.
- ✓ E-beam can be tailored for enhance and control THz radiation.

Thank you!