Gun requirements for low rep rate FELs

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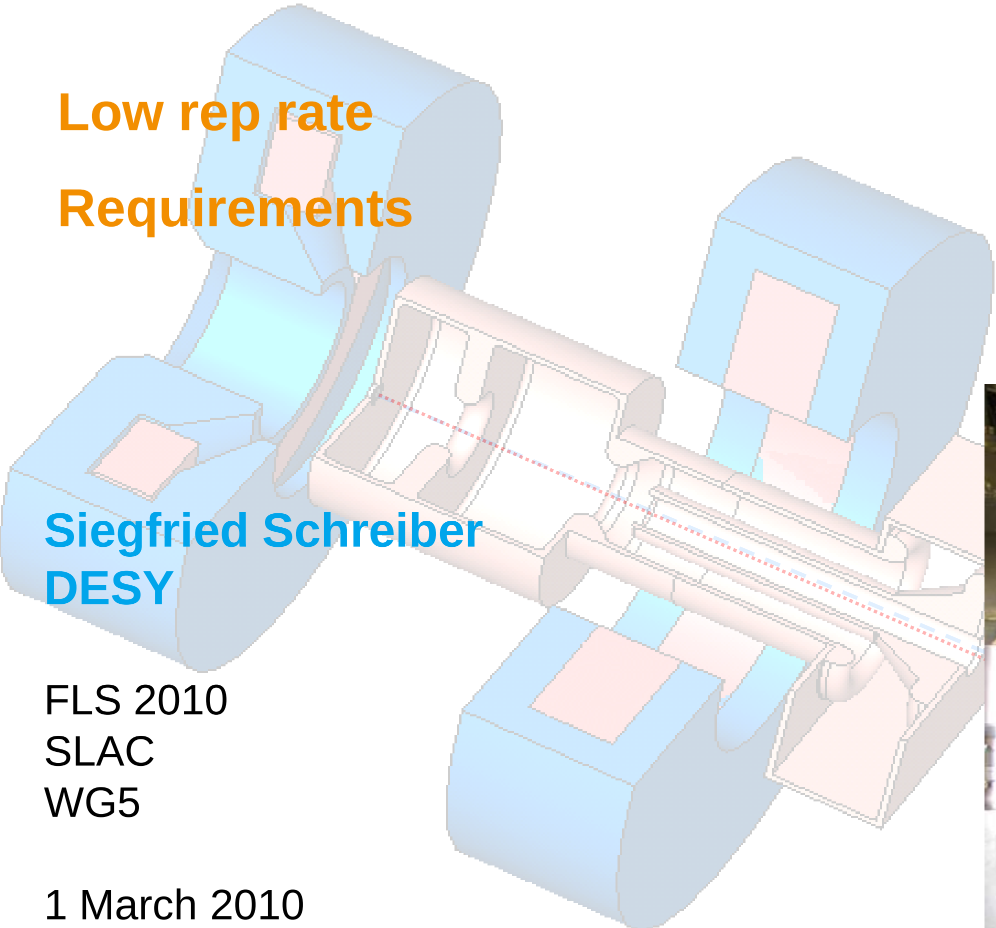
Free-Electron Laser in Hamburg



Low rep rate

Requirements

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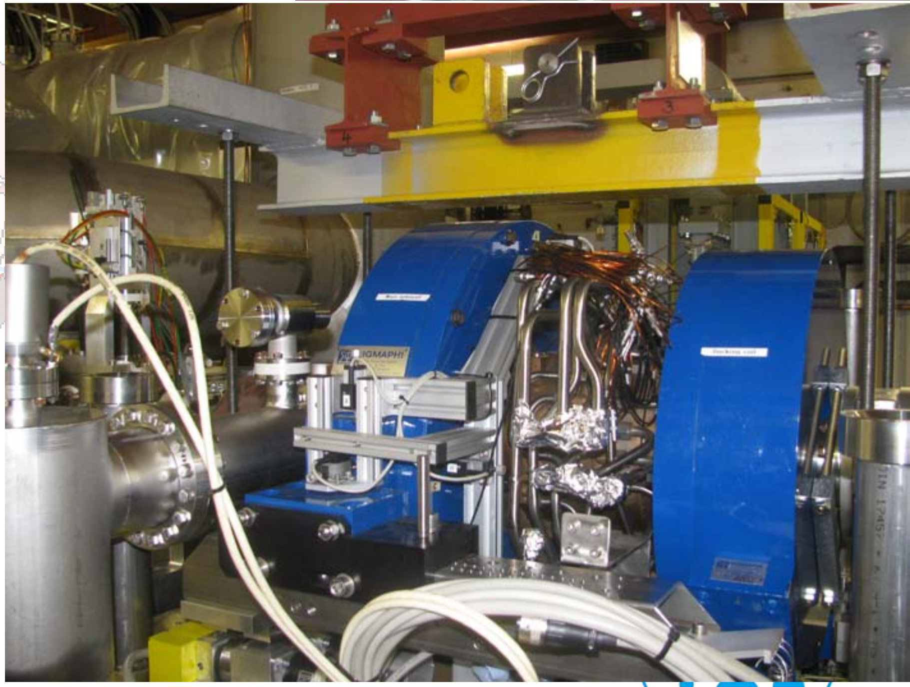

Low Repetition Rate

> What is low repetition rate?

> Examples:

- LCLS: single bunch, 30 to 120 Hz
- SwissFEL: single bunch, 100 Hz
- SCSS: 20 to 60 Hz

> don't talk about ERLs or CW machines

> For accelerators using superconducting technology, the situation is a bit different: burst mode

> Examples:

- FLASH: burst mode 800 us, 1 MHz (up to 9 MHz for 1 nC), 10 Hz
- European XFEL: burst mode 600 us, 4.5 MHz, 10 Hz

> NLS design approaches high rep rate with 1 kHz/1 MHz upgrade

Low rep rate – burst mode – high reprate

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> Besides the rep rate, the requirements on the electron beam depend on the type of FEL you want to build

→ we talk about (soft)X-ray FELs

> For these FELs, the requirements on the beam are very similar, independent of the rep rate – for example NLS

> Superconducting guns are discussed for ERLs and cw operation

- but also for low rep rate burst mode machines like FLASH , a superconducting gun would be a perfect choice
  – if it meets the requirements on beam parameters
- SCSS has shown, that also the type of gun (laser driven photoinjector ↔ heated cathode + bunching system) can be freely chosen

> The technological overhead for high rep rate options is enormous

→ low rep rate options are better suited to initiate and test new schemes to considerably improve the electron beam performance

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'Old' Canonic numbers

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> In the early days of guns for FELs, the emittance was considered to be one of the most important parameter:
- beam charge 1 nC
- transverse emittance (proj./norm.) 1 mm-mrad

> Issues with this approach:
- small transverse emittance is achieved with rather long bunches
- harmonic cavities required
- roll-over compression showed (at FLASH), that even for rather large transverse emittances, a small part with low charge but good slice emittance together with high peak current gives good SASE performance

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To drive an FEL

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- We need:
  - high peak current with a small slice emittance
    (yes we always knew that) > 2 kA, < 1 mm mrad
  - fs type bunch length (10 to 100 fs)
  - synchronization to other laser sources < FEL pulse length (< 10 fs)
- This goal can be achieved in different ways:
  - compression of a canonical 1 nC bunch with proper tailored phase space
  - strong compression of low charged bunch
    – either with the FLASH roll-over compression
    or
    – better with a suitable tailored phase space
  - fiber laser based synchronization system
- Long term goal: approach attosecond-regime with ultra low charged beams

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FELs from the users point of view

> (Soft)X-ray FEL beam users need

- The right wavelength (often as short as possible)
- Small spectral width
- Coherence
- Polarization (left and right)
- Femtosecond type pulse length (10 to 100 fs)
- High single pulse energy (50 uJ to mJ)
- Synchronized to other lasers to the fs level (pump-Probe)

(Not all experiments need all these requirements at the same time)

> You may summarize these with ‘high brightness’

> All this with the best stability the FELs can offer over long experimental runs

Specs on beams

- All this boils down to
  - fs-type bunches with kAmps peak current
  - 10 fs, >2 kA SASE
  - 100 fs, >2 kA seeding
  - perfect stability in energy (charge/orbit…) and in time
  - smallest slice emittance as possible (slice with kA peak current)
- timing jitter < 10 fs (< pulse length)
- energy jitter <10-5
- slice emittance <0.5 mm-mrad (at whatever charge has been chosen)
  - to reduces the gain length and improves coherence

Example for smaller bunch charges

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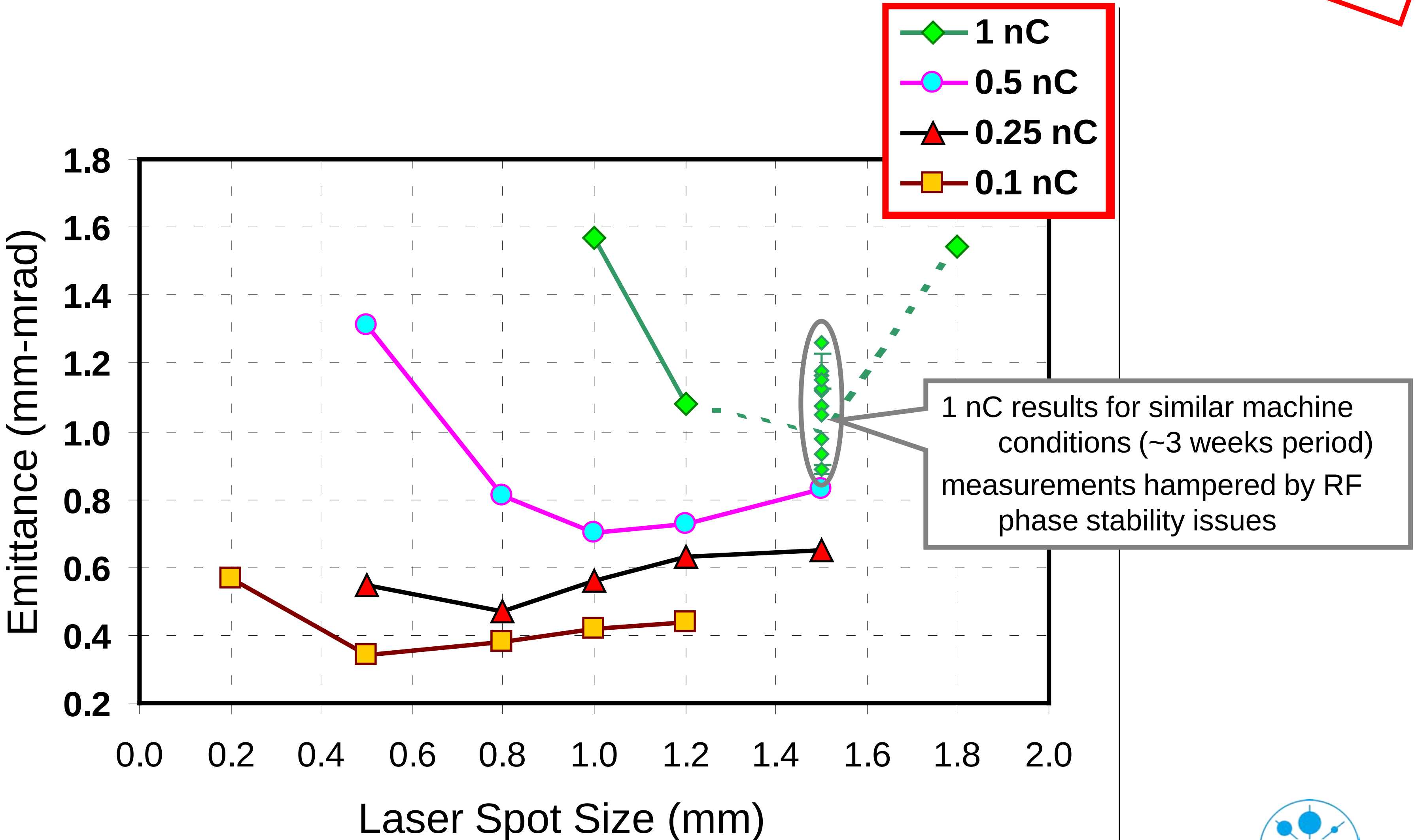
preliminary results

> Emittance approaches 0.3 mm mrad for 100 pC



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FLASH: Expected Parameters from Simulation

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> Different compression schemes with 3rd harmonic cavities

	with harmonic module					without
Bunch charge, nC	1	0.5	0.25	0.1	0.02	0.5-1
Wavelength, nm	6.5					6
Beam energy, MeV	1000					1000
Peak current, kA	**2.5**			**2.1**	**1.5**	1.3-2.2
Slice emittance, mm-mrad	**1-1.3**	**0.7-0.9**	**0.5-0.7**	**0.4-0.5**	**0.3-0.4**	1.5-3.5
Slice energy spread, MeV	0.1-0.2	0.1-0.2	0.25	0.2-0.4	0.25	0.3
Saturation length, m	**13**	**12**	**11**	**10**	**11**	22-32
Energy in the rad. pulse, µJ	1000-1400	700	500	200	30	50-150
Radiation pulse duration FWHM, fs	**70**	**30**	**17**	**7**	**2**	15-50
Averaged peak power, GW	5-7					2-4
Spectrum width, %	0.4-0.5			0.3-0.4		0.4-0.6
Coherence time, fs	4-5			-	-	-

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Examples

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- Most design look very similar – all have (more or less):
  - high QE cathodes if required, with load-lock systems
  - shaping the laser beam transverse and longitudinal or blow out
  - increase RF field as much as possible
  - solenoids
  - as r-phi-symmetric as possible
  - proper thermal management
  - working probes or precise directional couplers
  - many ways to access transverse and longitudinal phase space – slits, deflecting cavities, tomography and many more
- Seams like that most present proposals use the simple scaling law Hans Braun mentioned this morning:
  - approaching an order of magnitude better emittance by reducing the single bunch charge
- Examples of proposals not even designing the ‘1 nC’: PSI and NLC
- Crystalline beams at UCLA

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Layout of the FLASH Synchronization System

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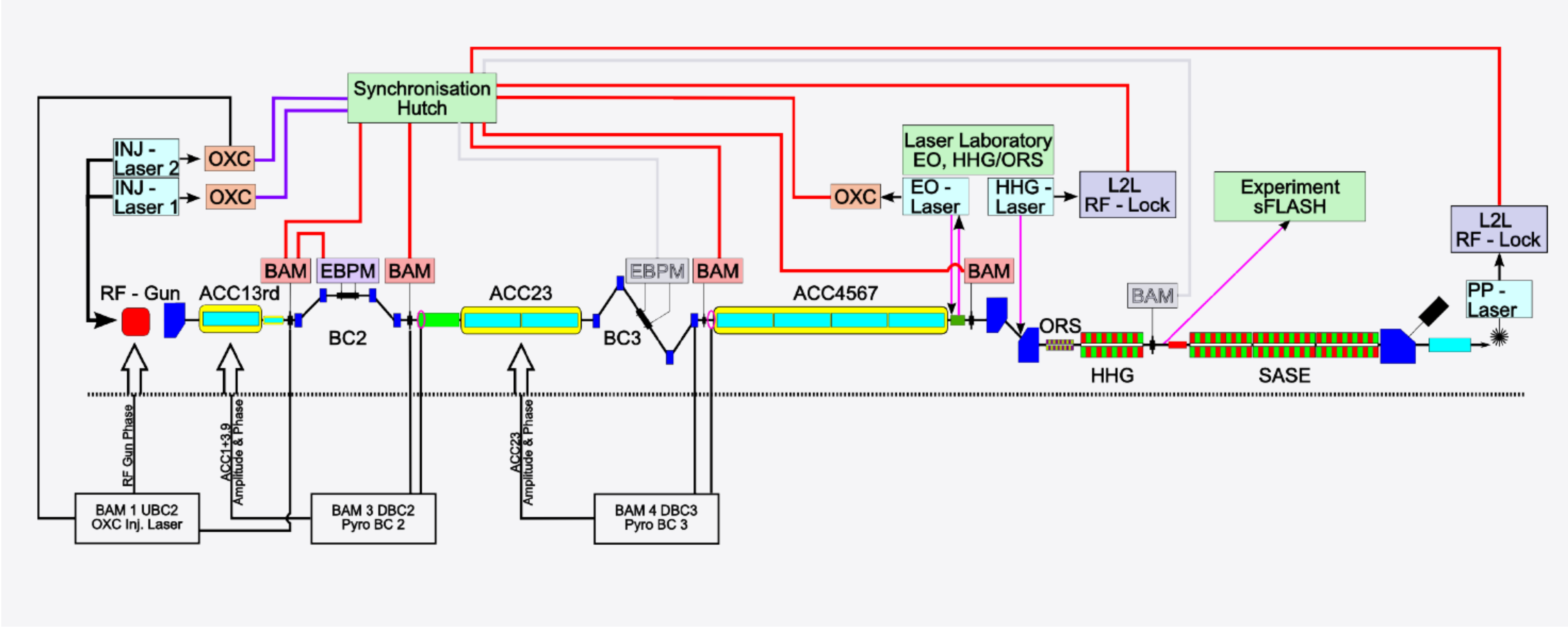

> Fiber base synchronization system

> laser pulse train phase measured and corrected with cross correlation techniques

> beam based arrival time monitors to act on rf gun phase and on amplitude and phase of booster modules

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Summary

- The requirements on electron beam parameters for low repetition rate (soft) X-ray FELs are not different from those for high rep rate FELs
- The demands on FEL radiation properties is driven by the user experiments
- Emphasis is on coherent, small spectral width, fs pulses with an excellent short and long term stability and synchronized to other sources
- This points to guns/injectors with very small slice emittances << 1 mm mrad at low bunch charges together with strong compression to achieve >> kA currents in femtosecond long bunches
- Synchronization schemes required
- Low rep rate guns might pave the way, high rep rate versions with their technological overhead typically follow