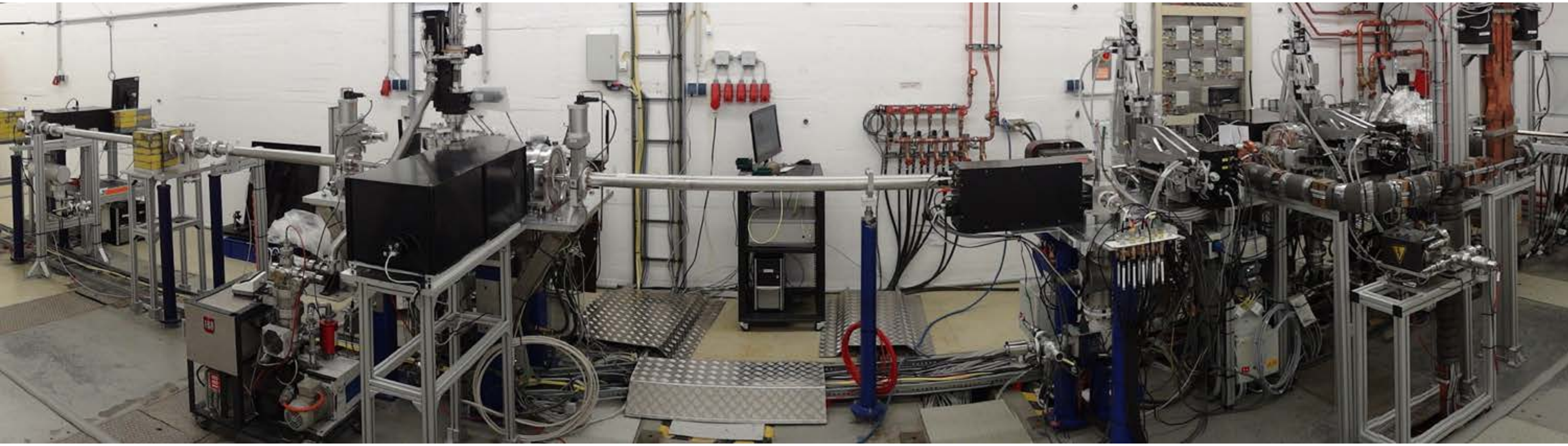
REGAE: The Relativistic Electron Gun for Atomic Exploration

Ultrafast Beams and Applications

Klaus Floettmann

July 4, 2017

REGAE: The Relativistic Electron Gun for Atomic Exploration



start: 2010
first beam: Nov. 2011
shared responsibilities
DESY: build and maintain
MPG: operate and experiment

Average Energy	5.6 MeV
Energy Spread	10 keV
Bunch Charge	100 fC
Bunch Length	<10 fs (rms)
Beam Size	600 μm (rms)
Transv. Emittance	0.03 π mm mrad

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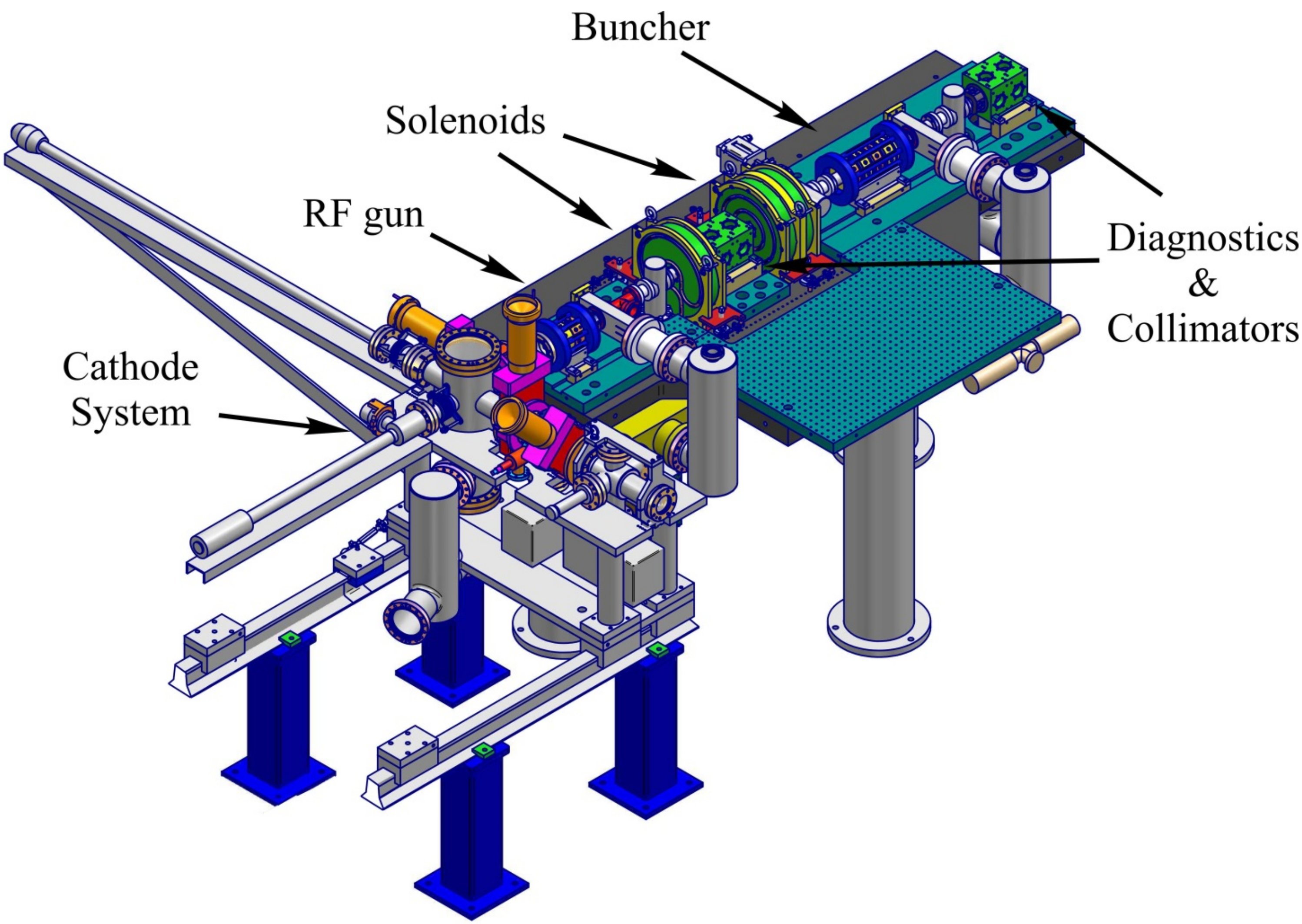
REGAE: The Relativistic Electron Gun for Atomic Exploration

- electron diffraction experiments (MPG)
- time-resolved microscopy (in preparation, MPG)
- accelerator physics & machine development (DESY):
  - ultra-short, ultra-low emittance beams
  - diagnostics for low charge beams
  - synchronization and stabilization
  - laser-driven plasma experiment (in preparation)
  - …

REGAE: The Relativistic Electron Gun for Atomic Exploration



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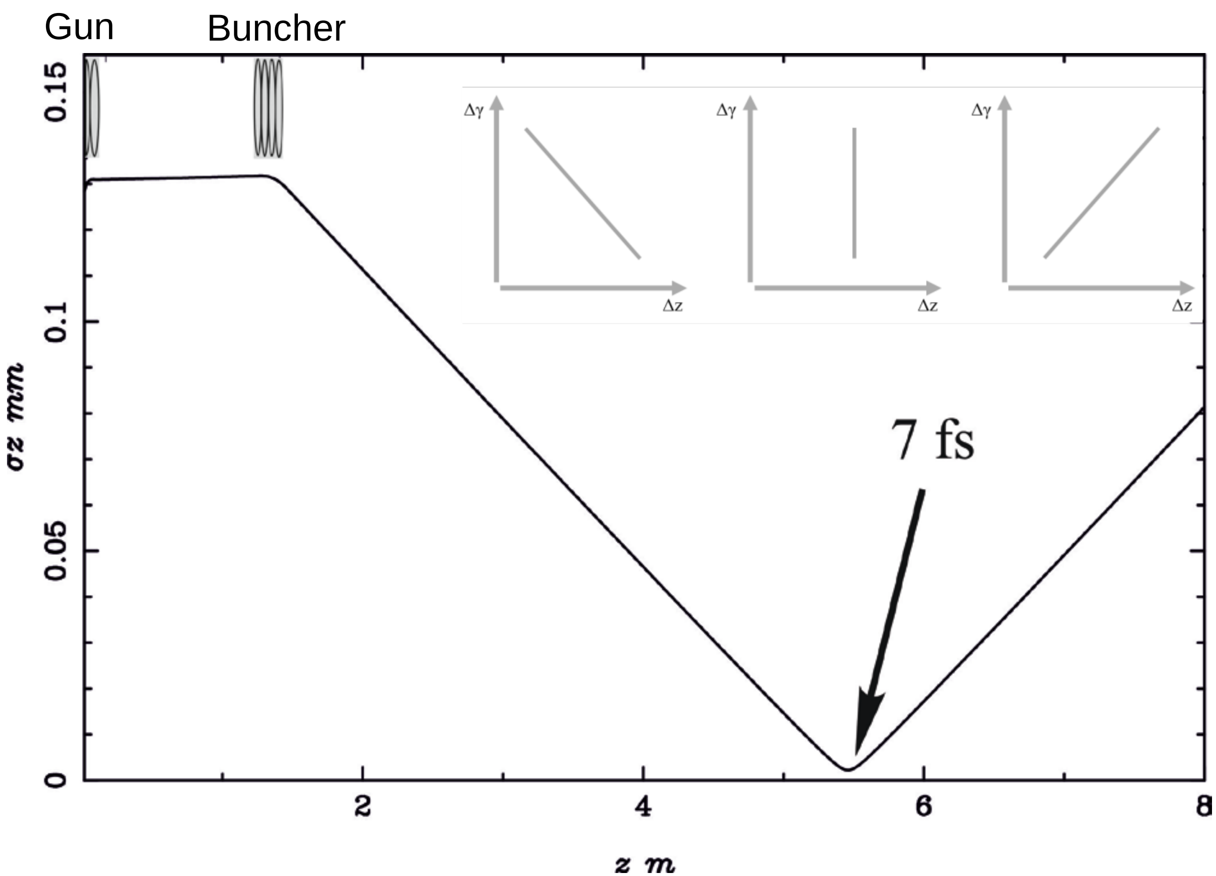
Ballistic Bunching at REGAE



Bunch length vs. position

Simulation parameters:

Q = 80 fC

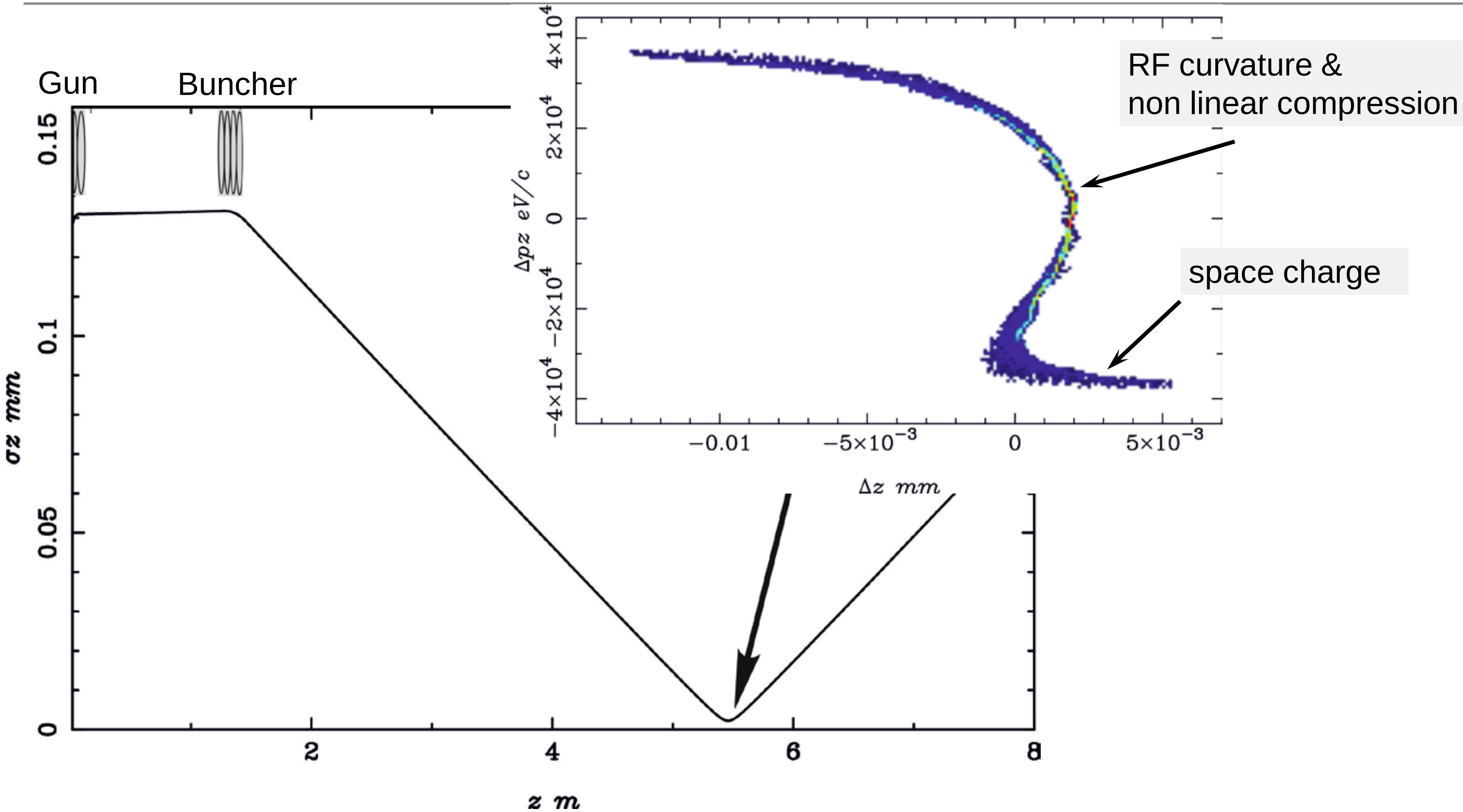
σ_x^{cath} = 7 µm

σ_t^{cath} = 500 fs

perfect cylindrical bunch

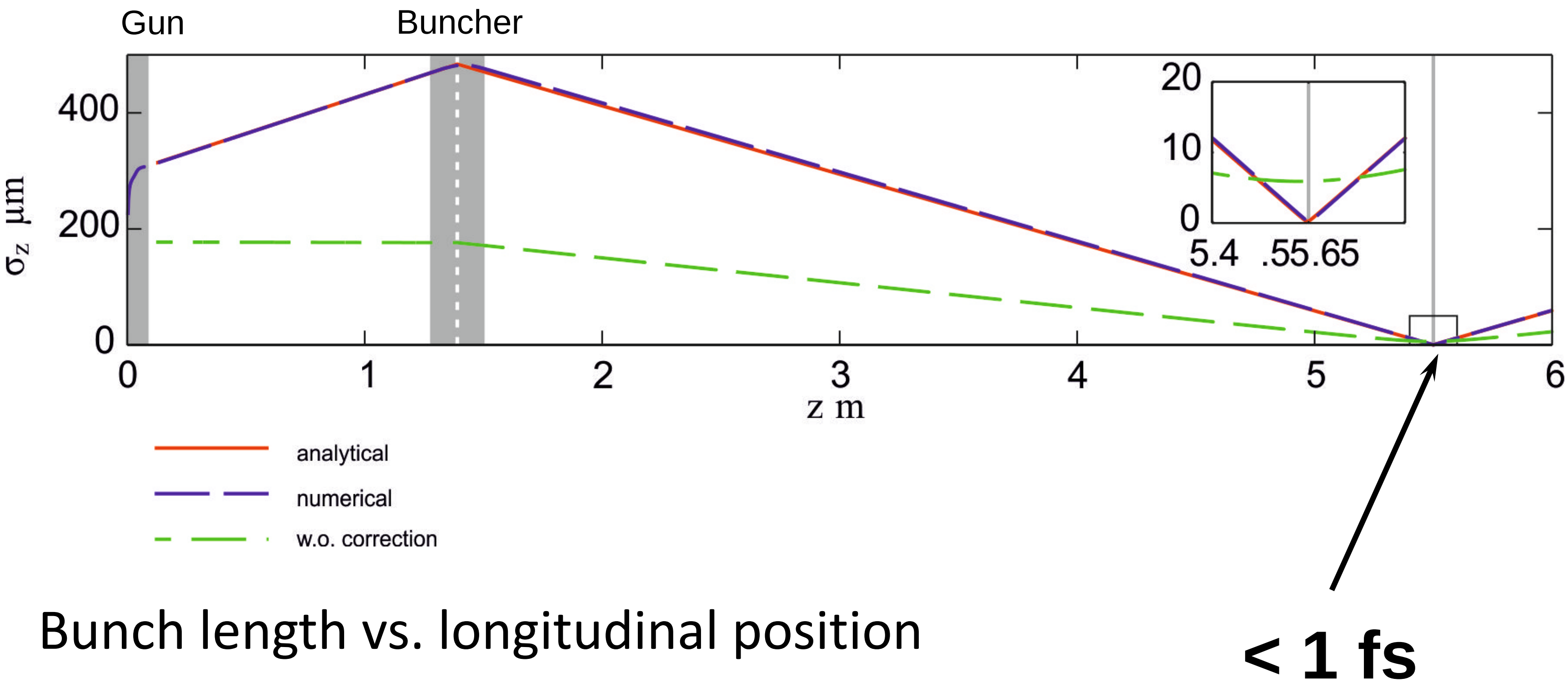
E_{kin} = 0.1 eV

Simulation Example: 80 fC, 5 MeV



Bunch length vs. position

Correction of the curvature in the stretcher mode

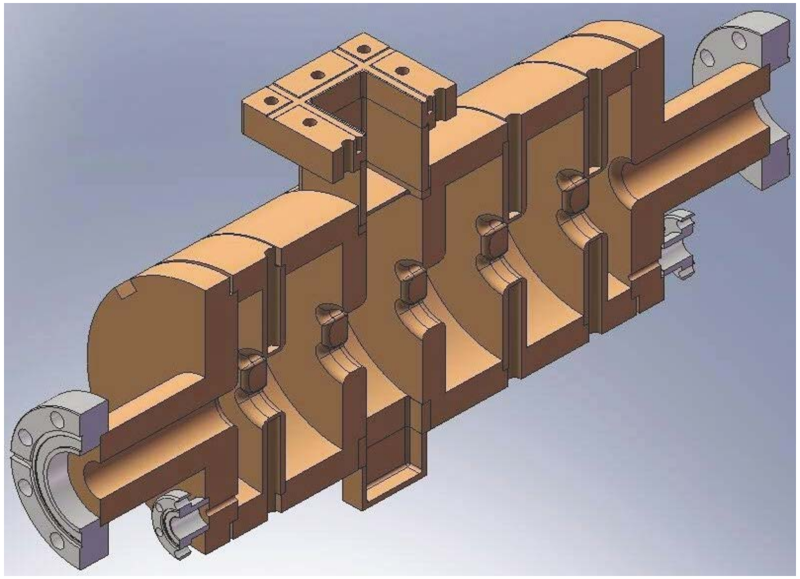


Bunch length vs. longitudinal position

Talk by B. Zeitler on Wednesday

B. Zeitler et al., 'Linearization of the longitudinal phase space without higher harmonic field', PRST-AB 18, 120102, 2015.

Transverse deflecting structure for REGAE



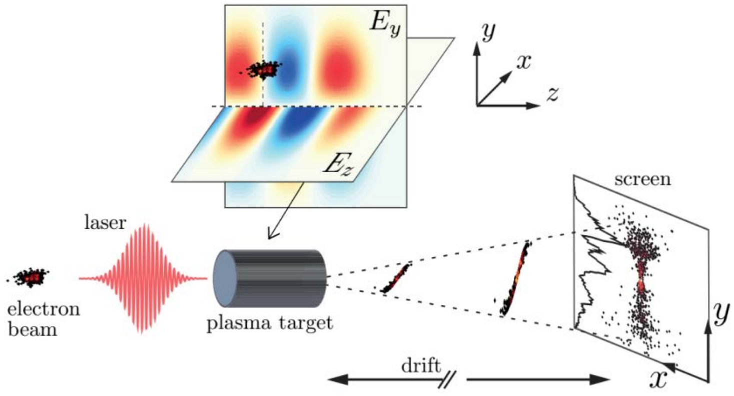
Innovative design

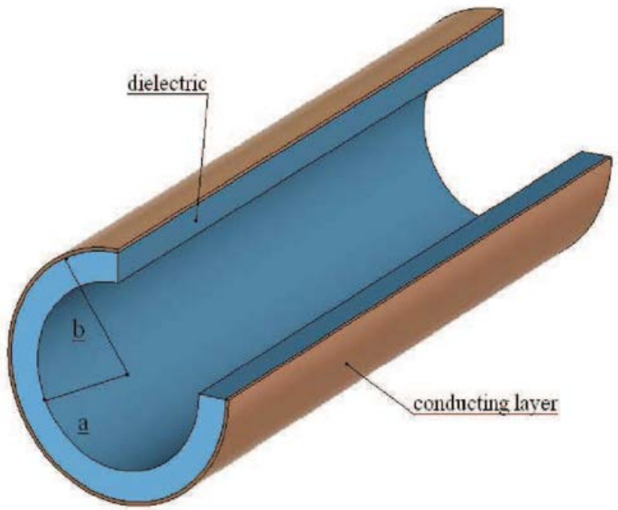
- special beam dynamics requirements for MeV - energies
- high efficiency - powered by a solid state amplifier
- under construction at CANDLE SRI
- expected resolution <10 fs

Talk by H. Delsim on Friday
Lab Tour on Thursday

K. Floettmann, V. Paramonov, 'Beam dynamics in transverse deflecting rf structures', PRST-AB 17, 024001, 2014.

Can we resolve < 1fs bunch length?





Plasma-driven transverse deflecting 'structure'

Transverse deflecting mode in a dielectric-lined waveguide

Talk by F. Lemery on Friday

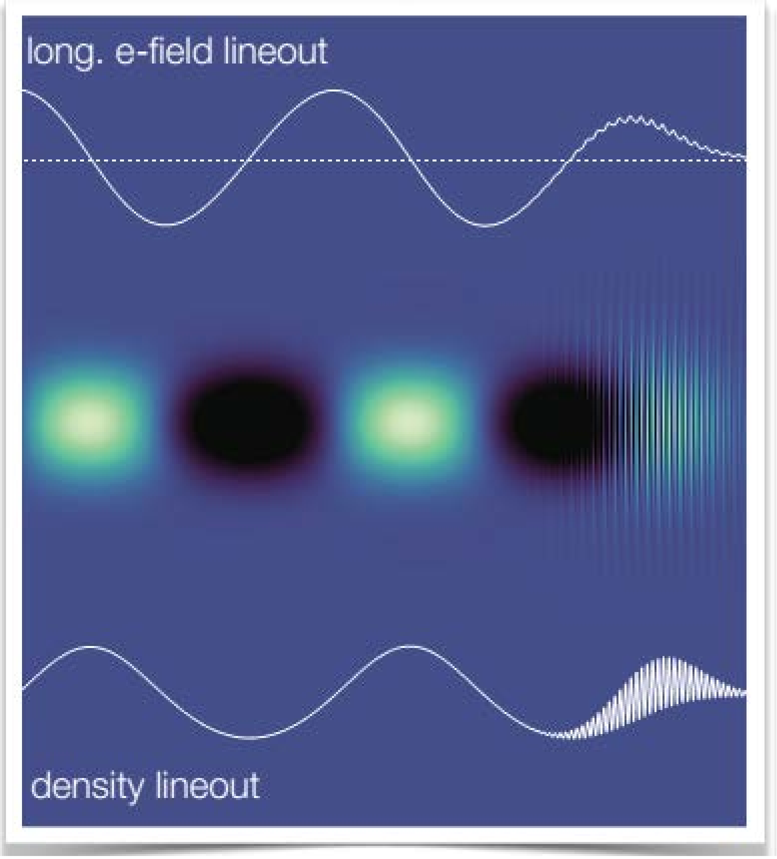
I. Dornmair et al., 'Plasma-driven ultra short bunch diagnostic', PRST-AB 19, 062801, 2016.
F. Lemery, K. Floetttmann, 'A Transverse Deflection Structure with Dielectric-lined waveguides in the Sub-THz Regime', Proc. of IPAC 2017.

Plasma Experiment: The Basics

When a high power laser (TW) travels through a gas, the atoms are ionized and the electrons are separated from the ions.

A plasma wave is induced with very high field gradients (up to GV/m) which can be used to accelerate electrons.

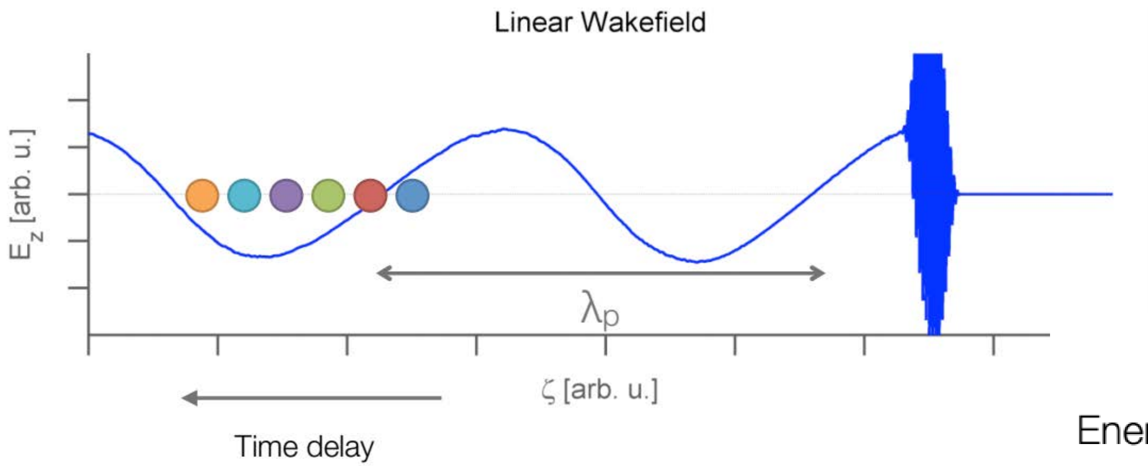
But are the simulations correct?



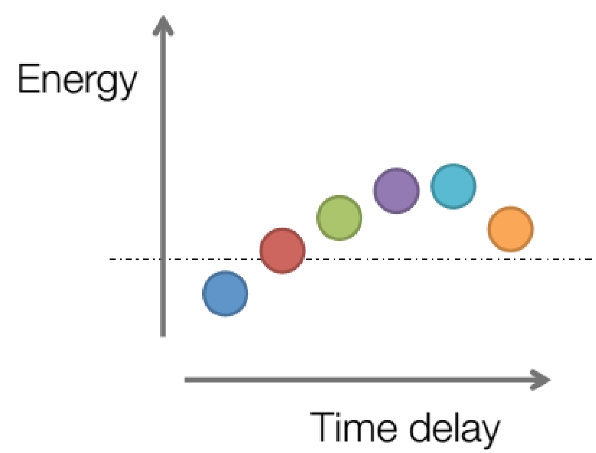
B. Zeitler, 'Phase Space Linearization and External Injection of Electron Bunches into Laser-Driven Plasma Wakefields at REGAE', PhD Thesis, 2016.

Plasma Experiment: The Plan

Generate a linear wakefield by means of a TW-Laser in a plasma, inject a bunch from REGAE …

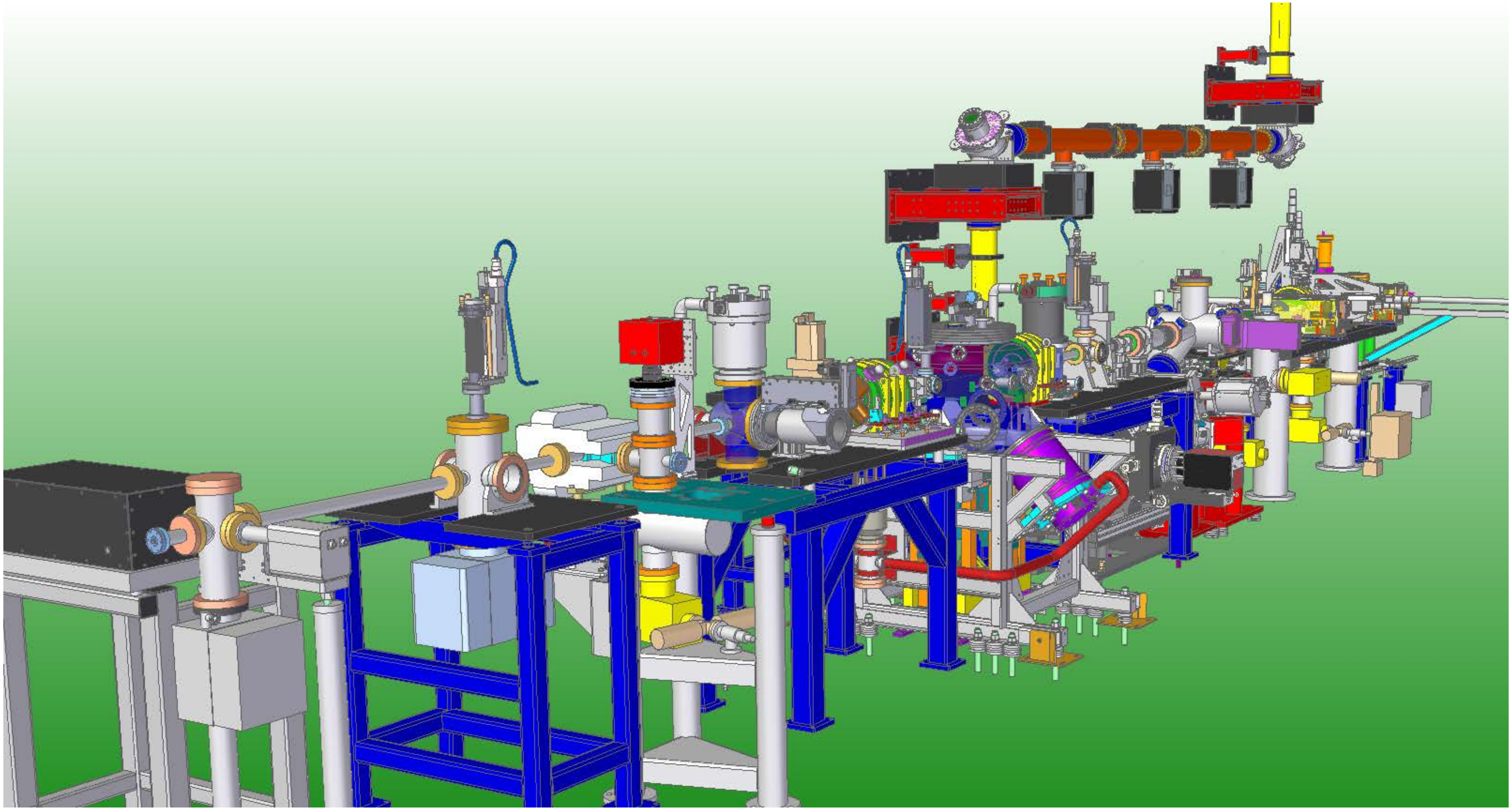


… and measure the bunch properties at the exit as function of Phase and position



B. Zeitler, 'Phase Space Linearization and External Injection of Electron Bunches into Laser-Driven Plasma Wakefields at REGAE', PhD Thesis, 2016.

Plasma Experiment: Upgrade of the beamline



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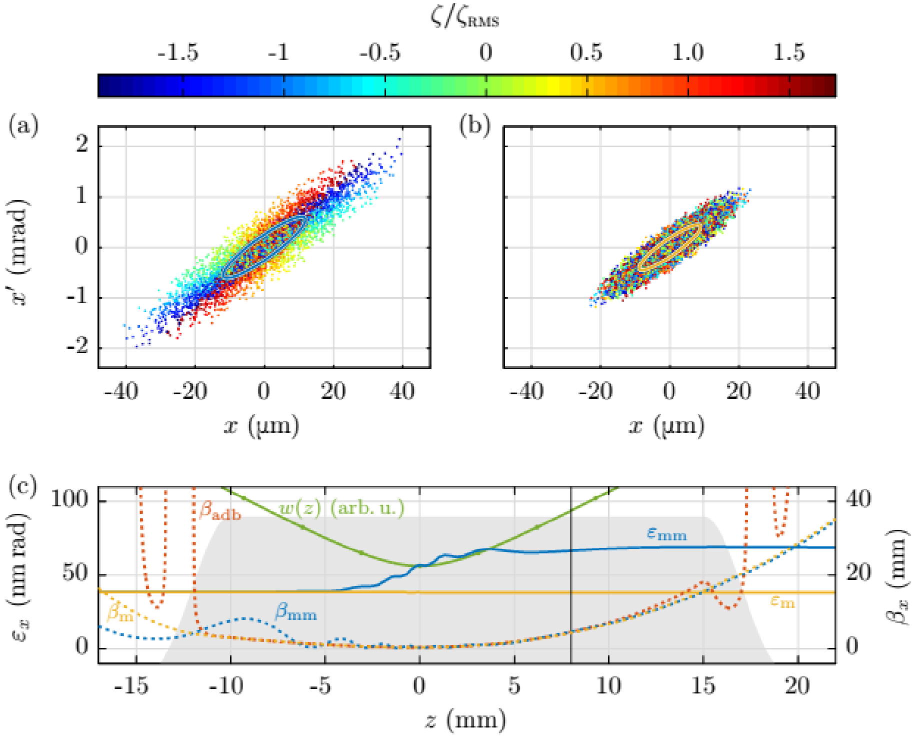
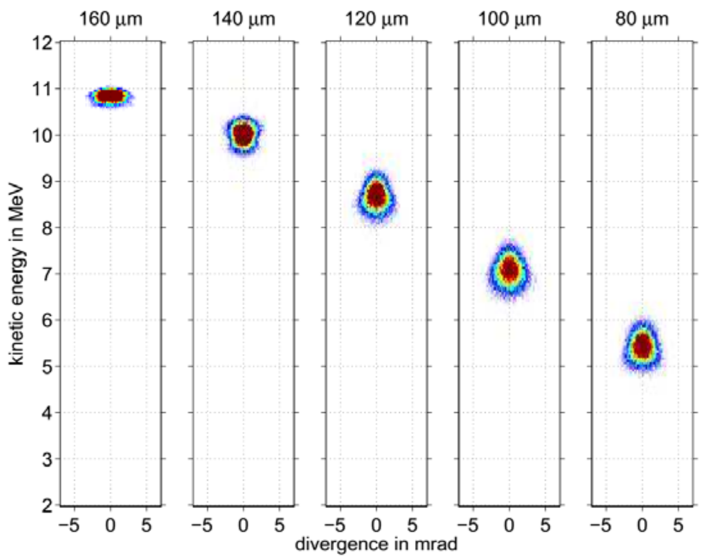
Plasma Experiment: Simulations

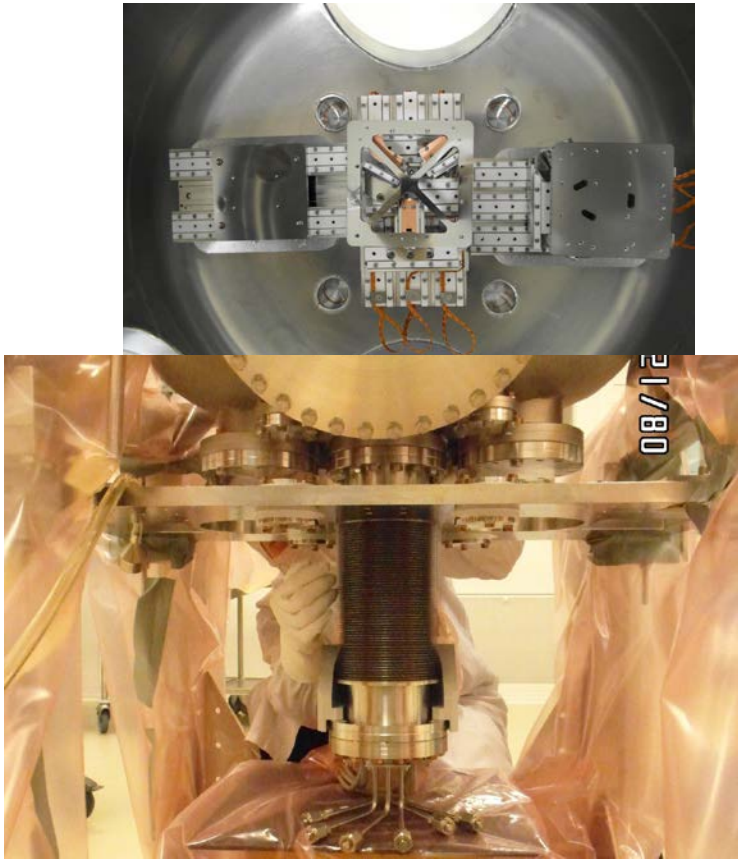




Matched injection and …

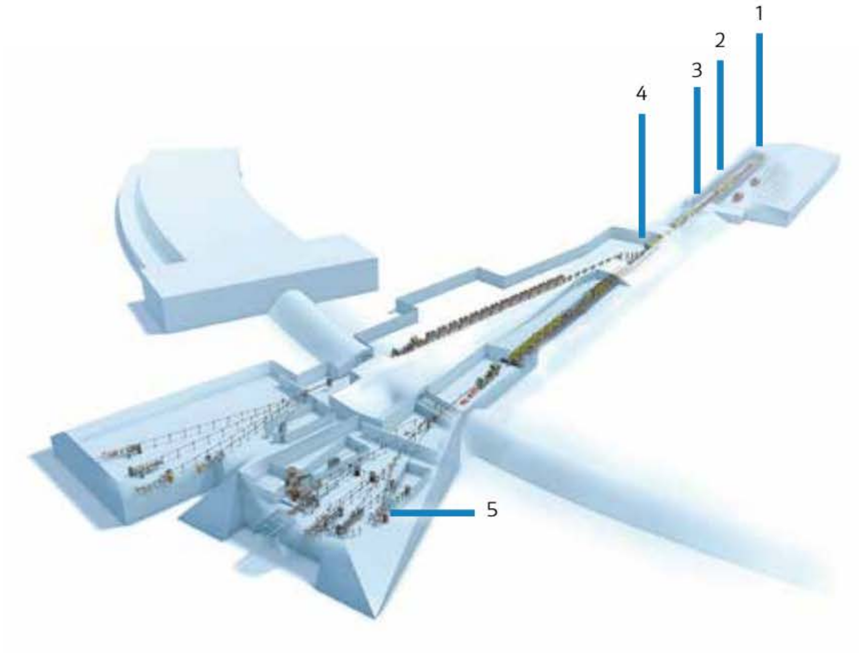
… delay scan

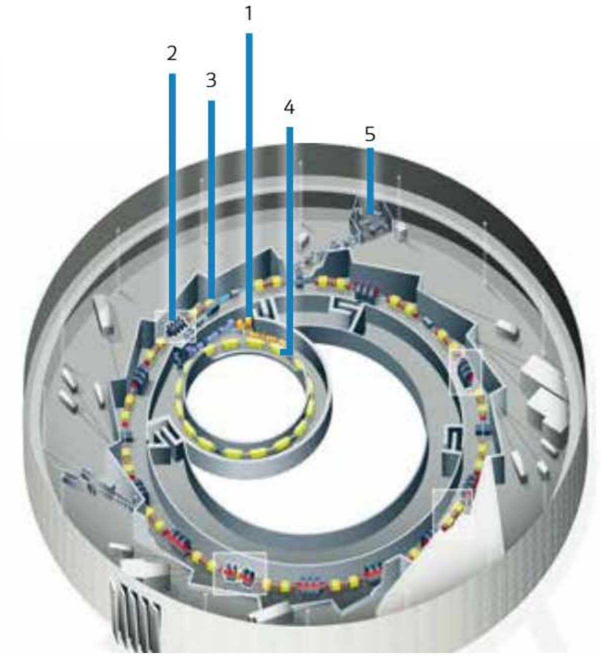
Status



Many (not all) components in house
Pre-installation has started

X-ray Diffraction, the workhorse of life and material science





Generate a high quality electron beam, accelerate it to several GeV, produce photons and use them…

Why not using the Electrons directly?

Advantages:

- compact facilities
- 4 - 6 orders of magnitude higher scattering cross-section
- less damage to the sample
- mean free path matches to the penetration depth of pump lasers
- easy to manipulate

Disadvantages:

- space charge limits the particle density!

Challenging parameters:

The coherence length is given as:

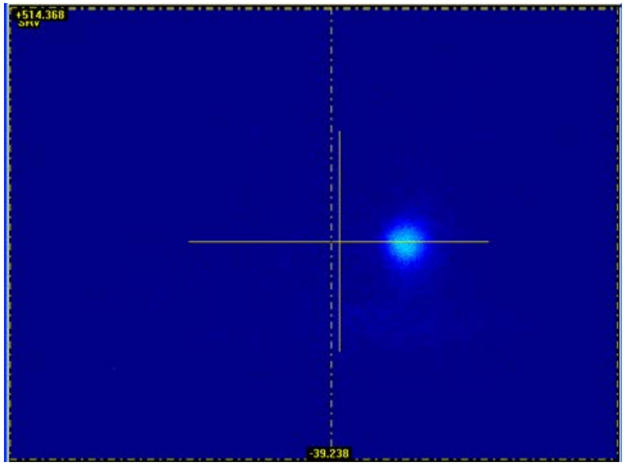
$$L_C = \lambdabar_e \frac{\sigma_x}{\varepsilon_{n,rms}}$$

$\lambdabar_e = 3.8 \cdot 10^{-4}$ nm reduced Compton wavelength

$L_C = 10$ nm for $\sigma_x = 260$ µm and $\varepsilon_n = 10$ nm

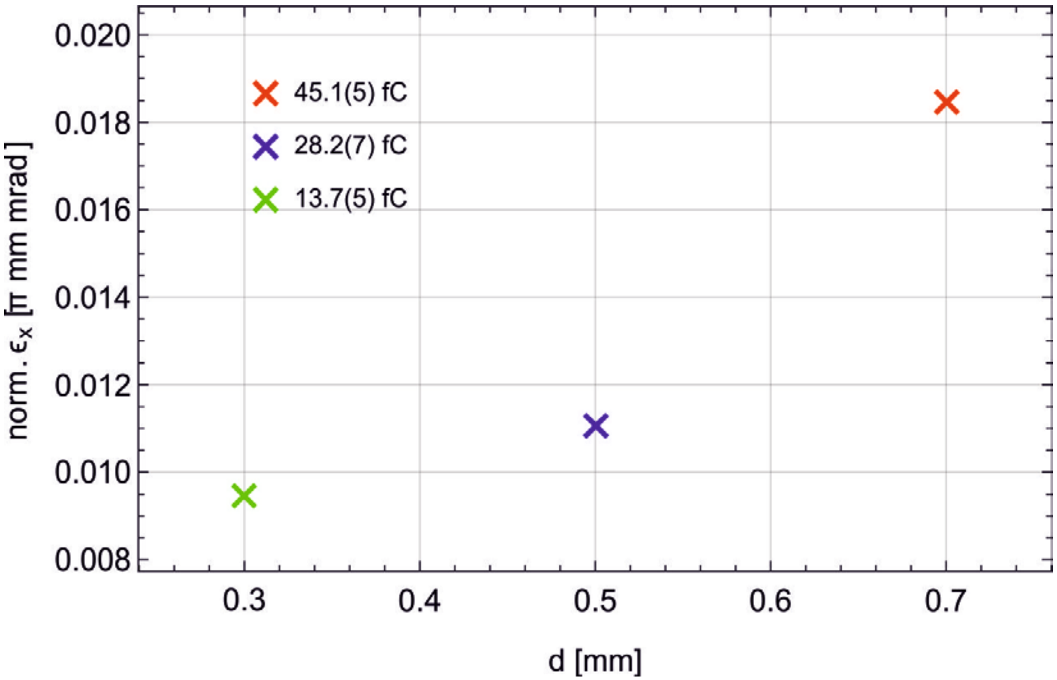
XFEL, FLASH	REGAE
Q = 0.1 – 1 nC ε_n = 0.2 – 1 µm	Q ≈ 100 fC ε_n ≈ 10 nm

Transverse beam diagnostics:



Beam size measurements work well below 100 fC…

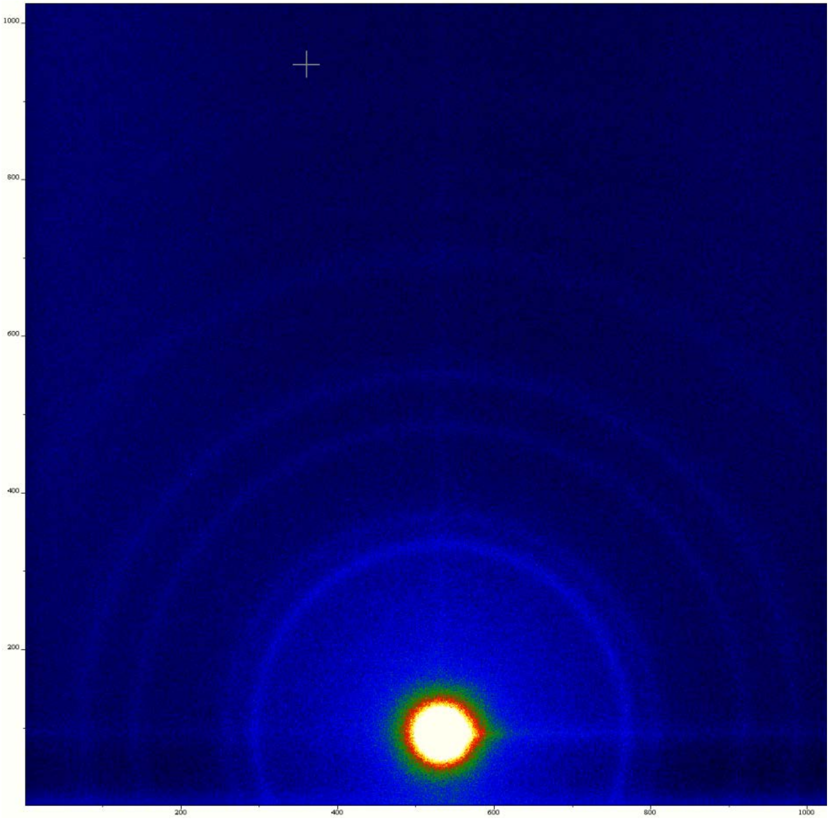
Talk by H. Delsim on Friday



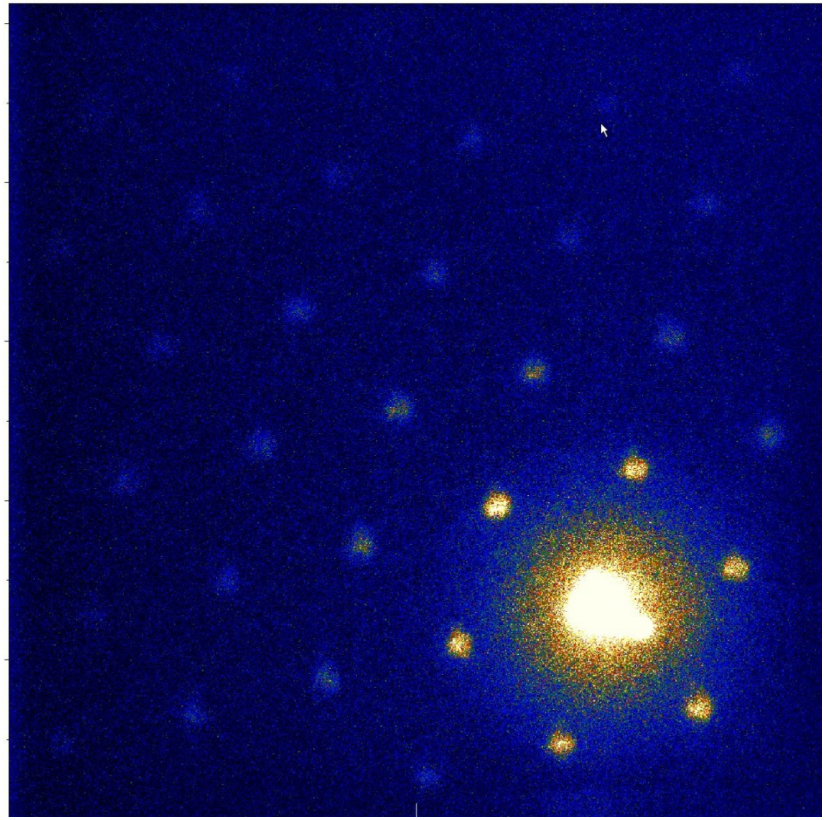
Measured emittance vs. aperture diameter

M. Hachmann, 'Measurement of Ultra Low Transverse Emittance at REGAE', Proc. of EAAC 2015.

Single Shot Examples from REGAE



Au polycrystalline



MoS_2

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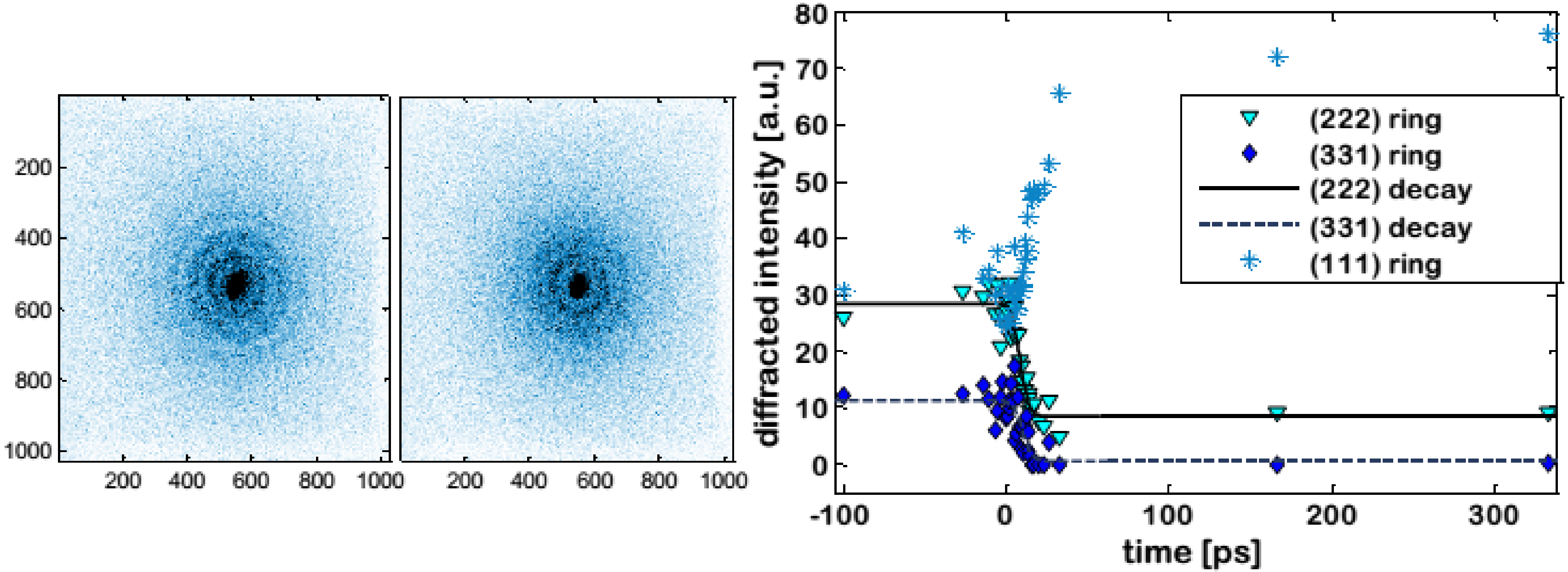
Single Shot Examples from REGAE



Time resolved observation of melting, single shot on Au

S. Manz et al., 'Mapping atomic motions with ultrabright electrons: towards fundamental limits in space-time resolution', Faraday Discussion, Volume 117, 2015.

Stability requirements

Ideally the temporal jitter is lower than the pulse length
On which time scale?

Repetition rate of REGAE: 50 Hz

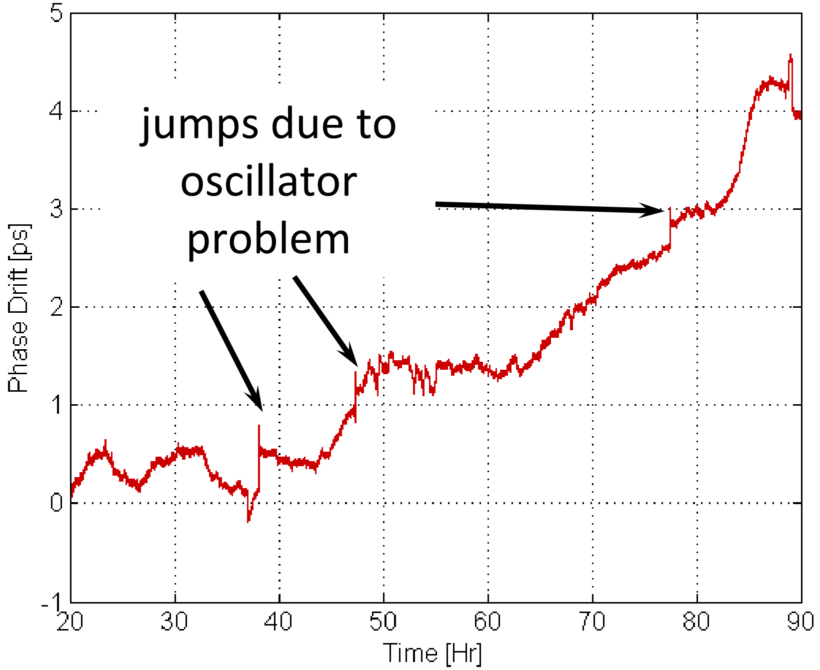
- presently limited to 12.5 Hz to avoid influence of DESY synchrotron
- limited to ~1 Hz due to readout of the (old) detector
- the new detector (being commissioned) should allow 50 Hz operation
- principle limit of normal conducting S-band technology: ~1 kHz

Synchronization and Stabilization

Timing jitter in the order of 20 - 30 fs rms.

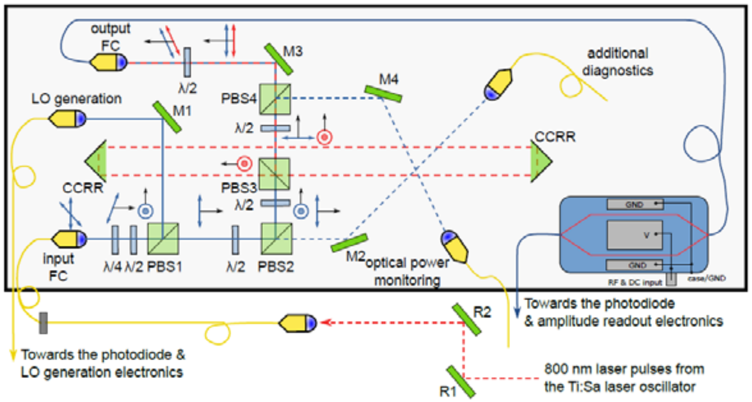
Problems:

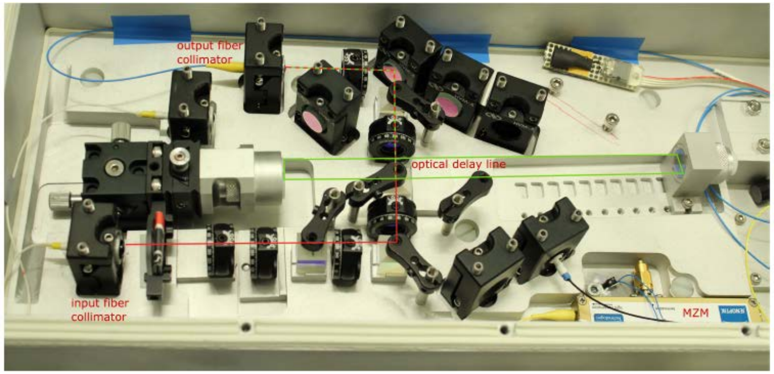
Long term timing drifts several ps due to AM/PM conversion in a photodiode & environmental dependencies.



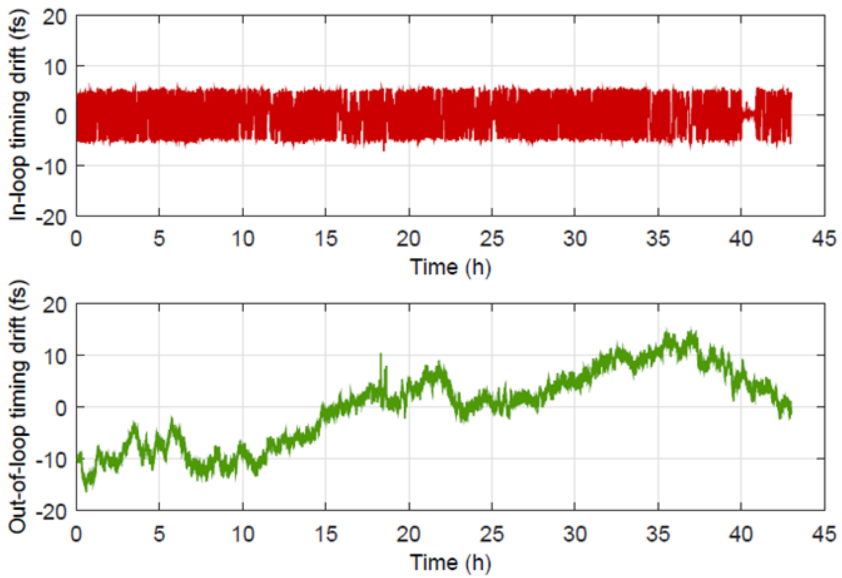
New oscillator to get rid of the jumps

New Mach-Zehnder based Laser-to-RF synchronization





> Timing drift (out of loop):
>
> $T_{\text{pk-pk}}$ = 31 fs over 43 h

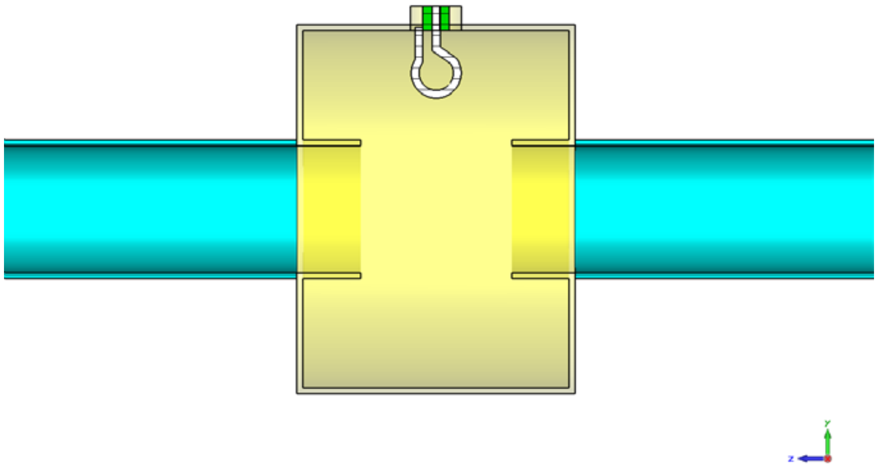


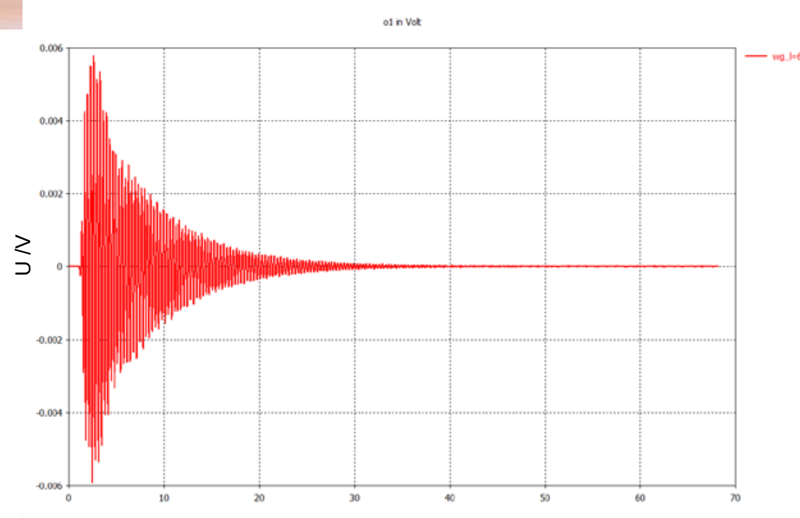
M. Tidberitze et al. 'Present and Future Optical-to-Microwave Synchronization Systems at REGAE Facility for Electron Diffraction and Plasma Acceleration Experiments', Proc. of IPAC 2015.

Beam Arrival Cavity for a slow feedback

Beam Arrival Cavity

- design finished, production is going to start





- we hope to achieve a resolution of ~ 10 fs with 1pC charge

M. Hansli et al., 'A Beam Arrival Time Cavity for REGAE at DESY', Proc. of IPAC 2014.

Upgrade Plans for 2017 (starting in August)

- second modulator to improve tuning capability
- Transverse Deflecting Structure
- new Laser-2RF synchronization
- Drift Calibration Modules
- Beam Arrival Cavity
- modify beamline for linearization and plasma experiments

Thank You!