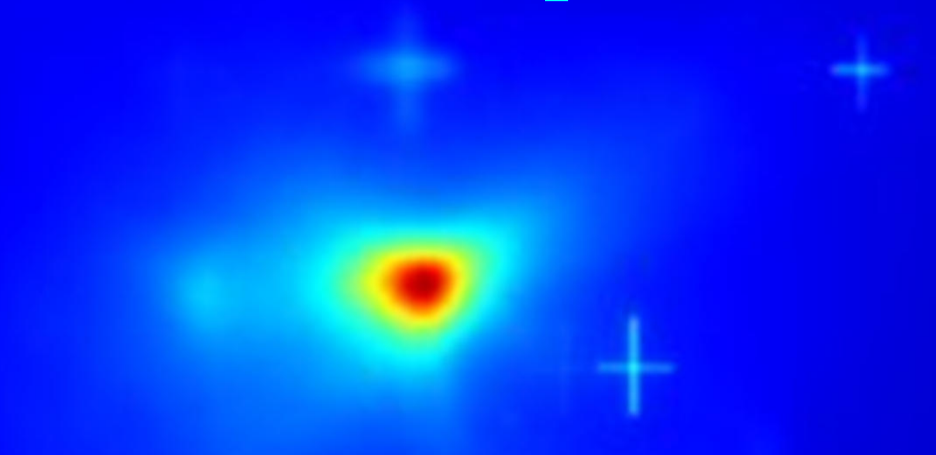
REGAE: The Relativistic Electron Gun for Atomic Exploration



K. Floettmann

1st ARD Workshop ST3

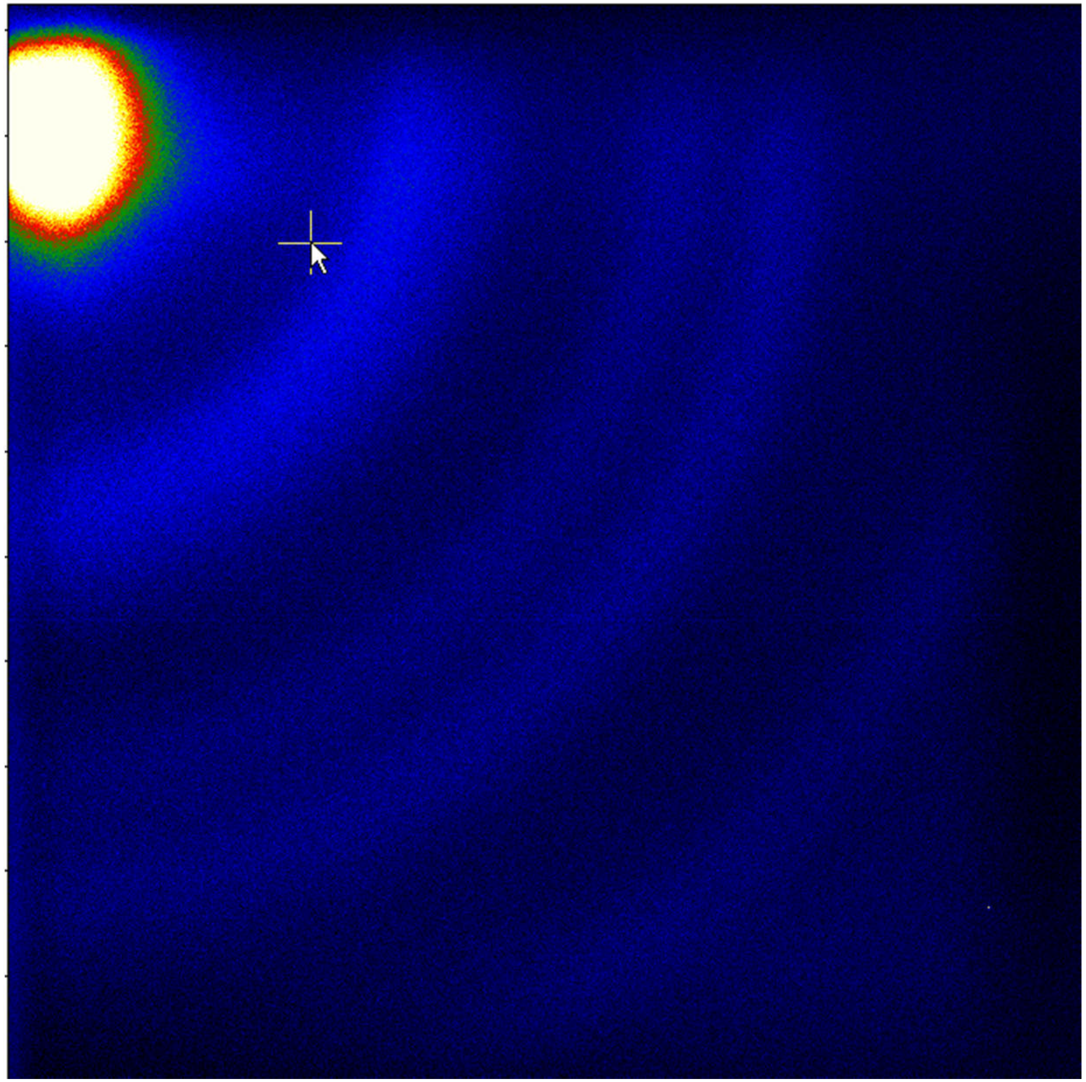
ps-fs Electron and Photon Beams

21 August 2012

REGAE

REGAE is an electron source for time resolved electron diffraction experiments, which is build on initiative of Prof. Dwayne Miller (formerly University Toronto) in the framework of the **C**enter for **F**ree **E**lectron **L**aser Science **CFEL**

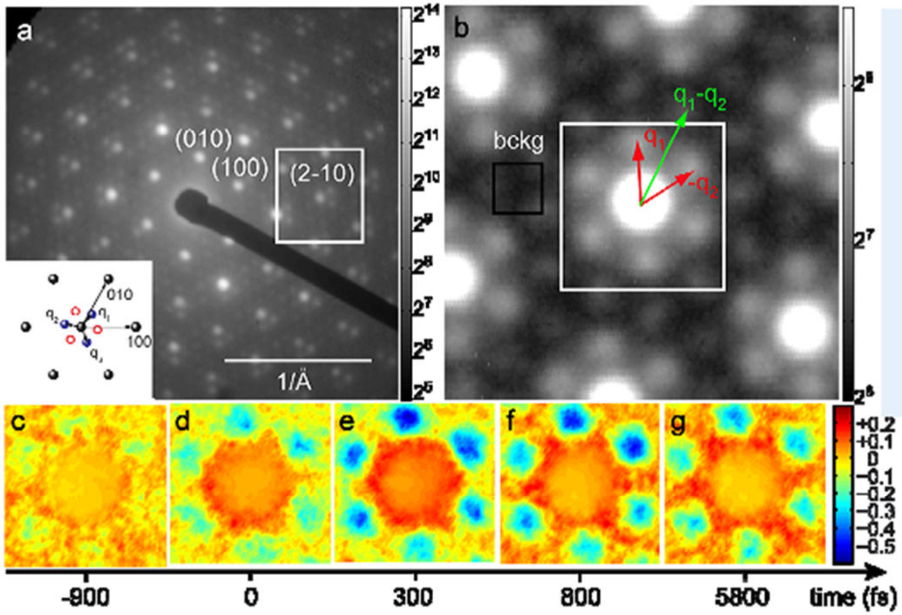
Electron Diffraction @ REGAE

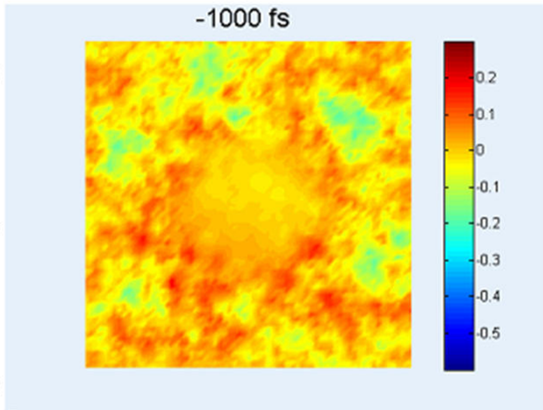


polycrystalline
gold sample

Example for a time resolved measurement

Direct Observation of the Structural Order Parameter





Fluence: 2.4mJ/cm^2

T=200 K

ΔT(pump) ~90 K

τ_{pump}= 140 fs

τ_{probe} = 200 fs

Dwayne Miller et al. Nature 468, Nov. 2010

Pros & Cons

- The advantage of electrons, as compared to photons, is the 4 to 6 orders of magnitude higher scattering cross section. This allows non-destructive measurements at low intensities.

- The disadvantage is that the intensity is limited due to space charge effects

- Advantages of higher energies:
  - reduced space charge effects
  - longer penetration depth, i.e. thicker targets

Coherence length

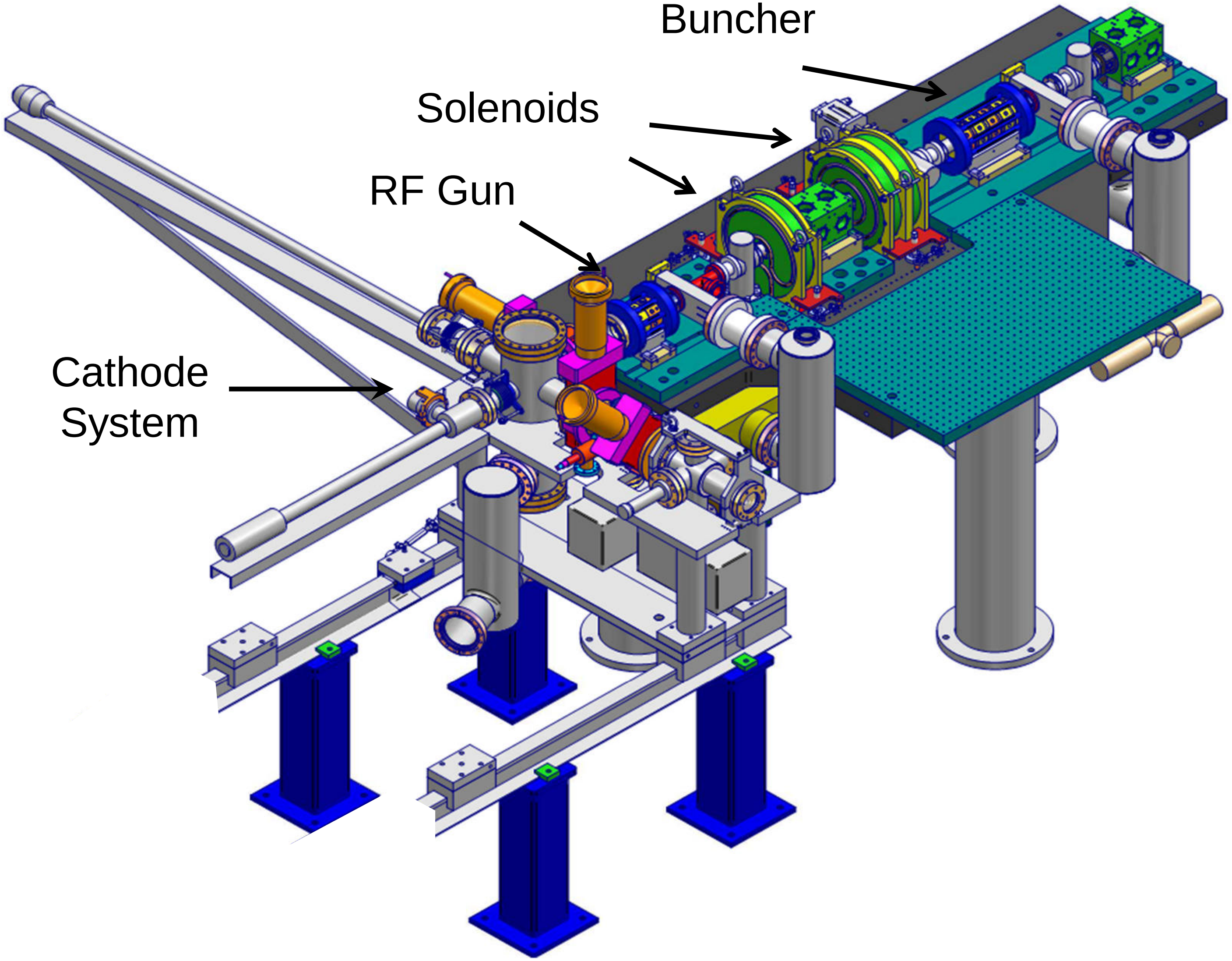
The coherence length of an electron beam is proportional to the uncorrelated beam divergence:

$$L_c = \lambdabar_e \frac{\sigma_x}{\varepsilon_n}$$

$$\lambdabar_e = \hbar / mc = 3.8 \cdot 10^{-13} m$$

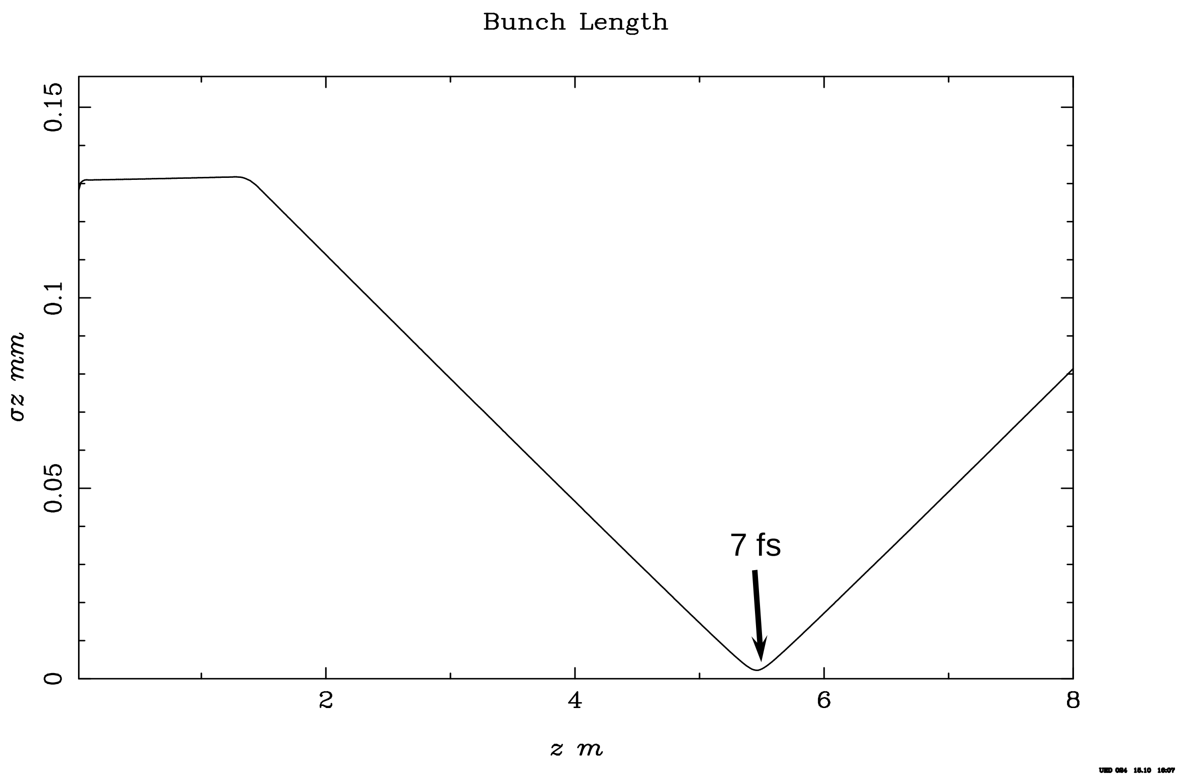
Requirements: 10 nm coherence length for solid states
30 nm coherence length for proteins

The first section of REGAE



Simulation Example: 80 fC, 5 MeV

(opt. assump. for bunch shape and thermal emittance to explore the limits)



Bunch length vs. longitudinal position

Simulation parameters:

Q = 80 fC

σ_x^{cath} = 7 µm

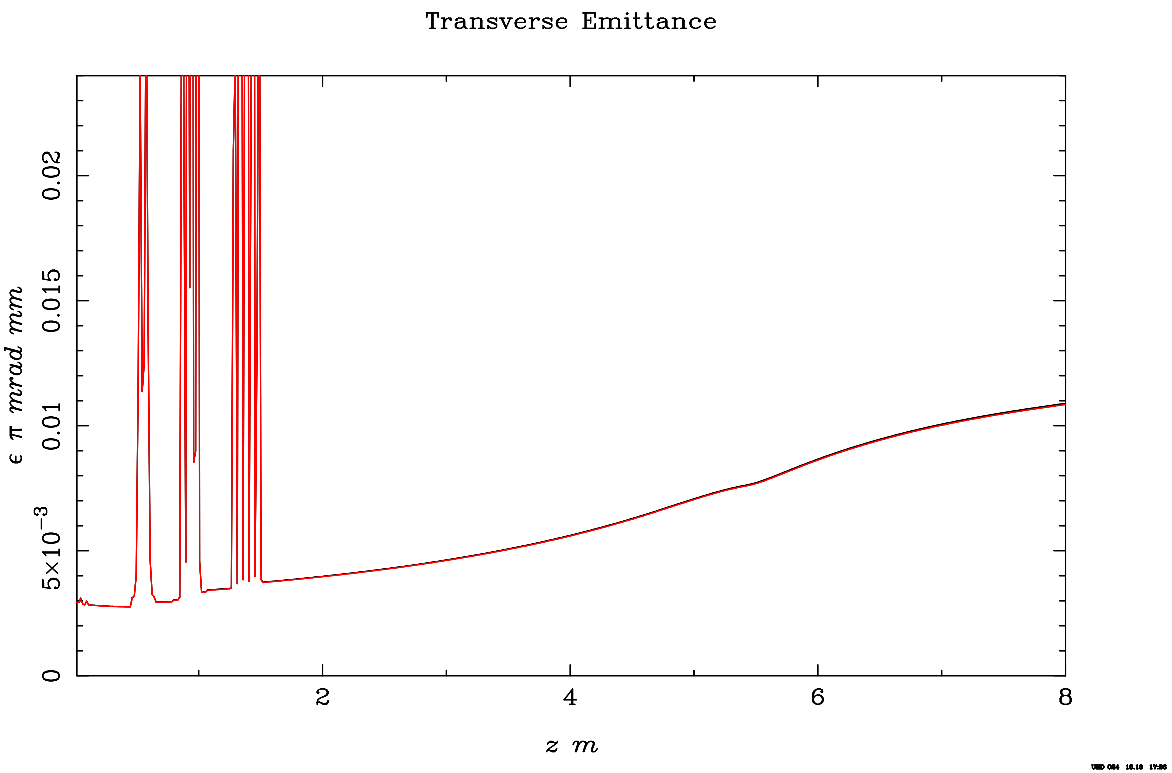
σ_t^{cath} = 500 fs

perfect cylindrical bunch

E_{kin} = 0.1 eV

Simulation Example: 80 fC, 5 MeV

(opt. assump. for bunch shape and thermal emittance to explore the limits)



Transverse emittance vs. longitudinal position

Simulation parameters:

Q = 80 fC

σ_x^{cath} = 7 μm

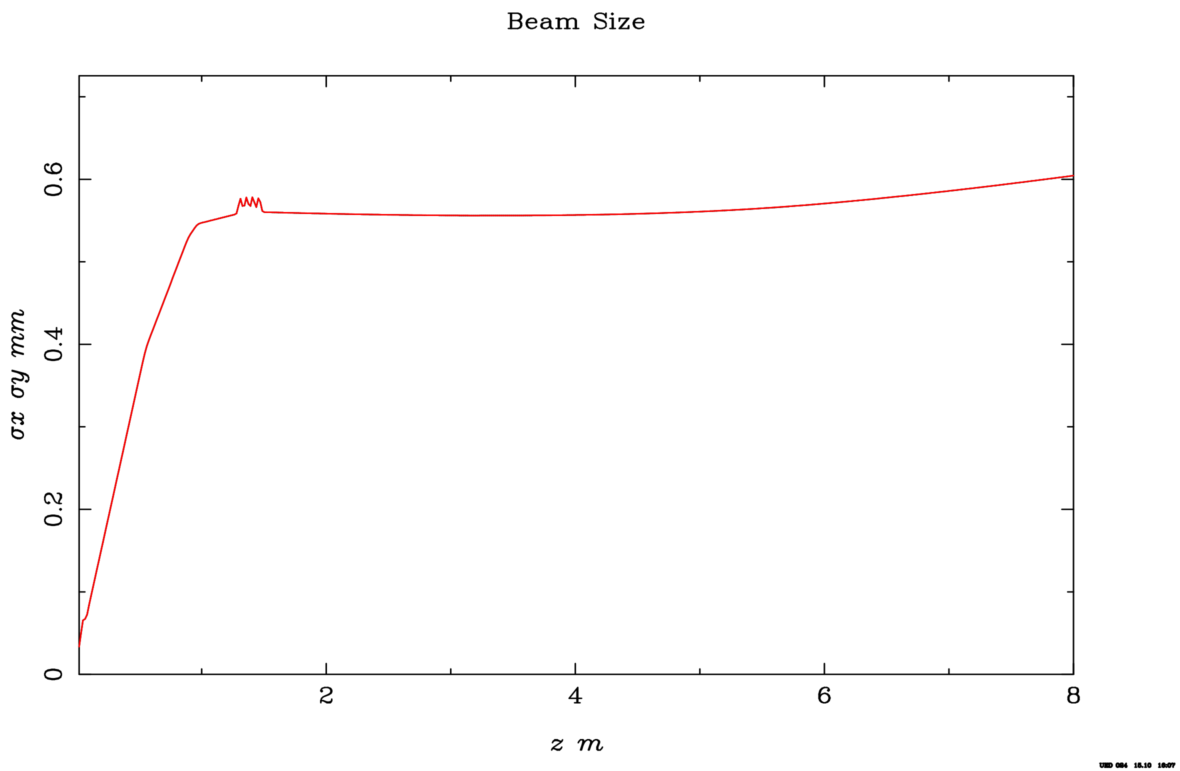
σ_t^{cath} = 500 fs

perfect cylindrical bunch

E_{kin} = 0.1 eV

Simulation Example: 80 fC, 5 MeV

(opt. assump. for bunch shape and thermal emittance to explore the limits)



Transverse beam size vs. longitudinal position

Simulation parameters:

Q = 80 fC

σ_x^{cath} = 7 μm

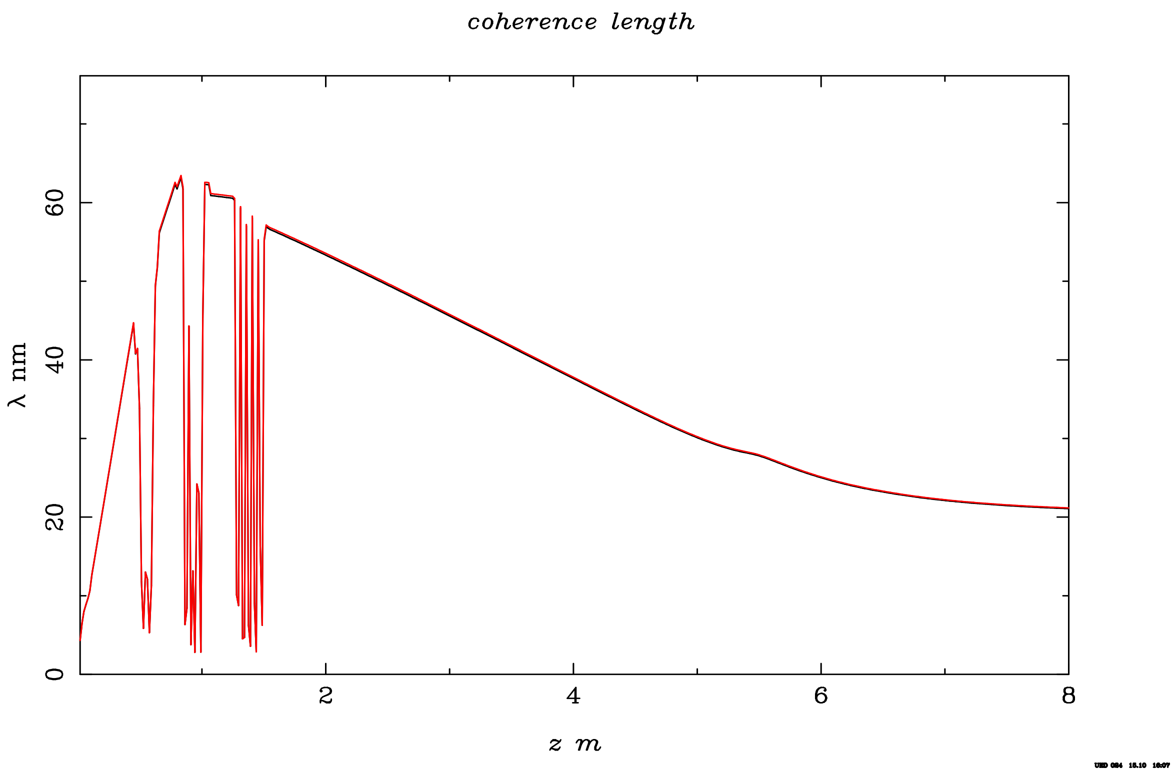
σ_t^{cath} = 500 fs

perfect cylindrical bunch

E_{kin} = 0.1 eV

Simulation Example: 80 fC, 5 MeV

(opt. assump. for bunch shape and thermal emittance to explore the limits)



Coherence length vs. longitudinal position

Simulation parameters:

Q = 80 fC

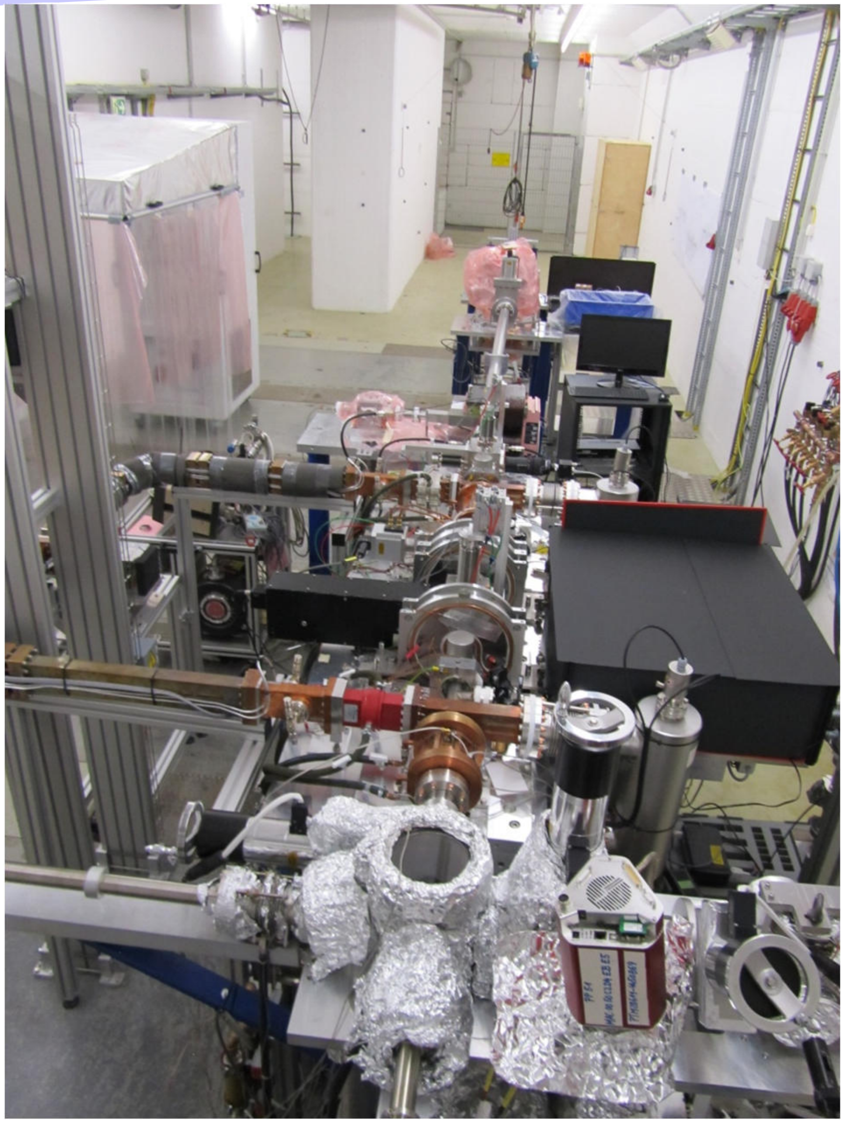
σ_x^{cath} = 7 μm

σ_t^{cath} = 500 fs

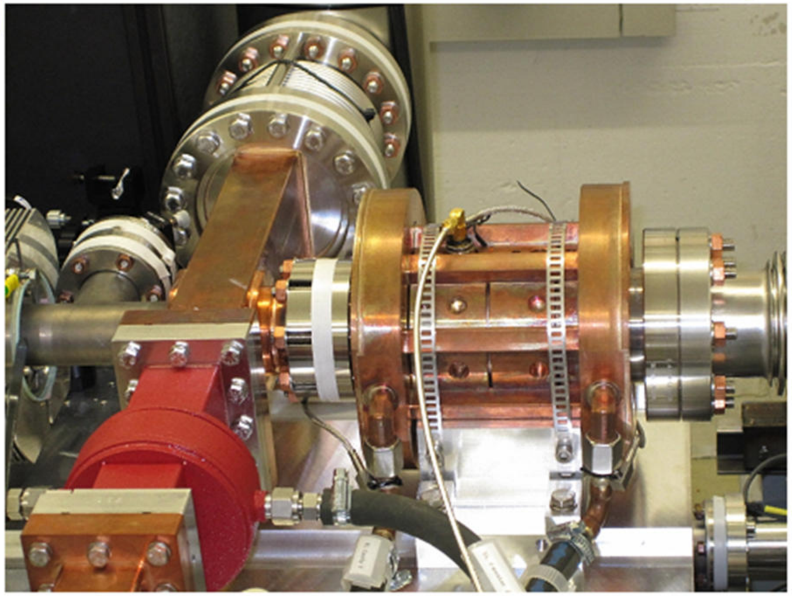
perfect cylindrical bunch

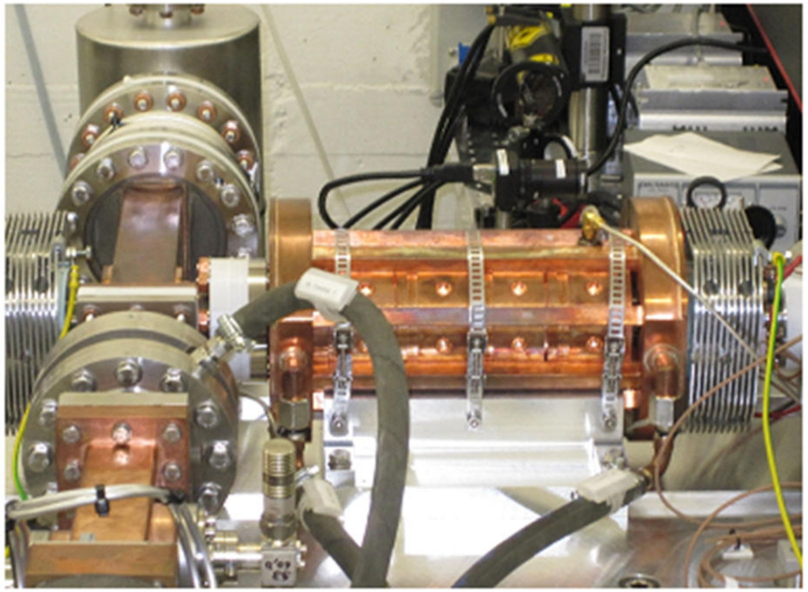
E_{kin} = 0.1 eV

REGAE beam line



Cavities and Coupler





RF-Gun Cavity

3 GHz S-Band

Gradient on cathode

≥ 110MV/m

50 Hz rep Rate

~5 µs pulse length

Buncher Cavity

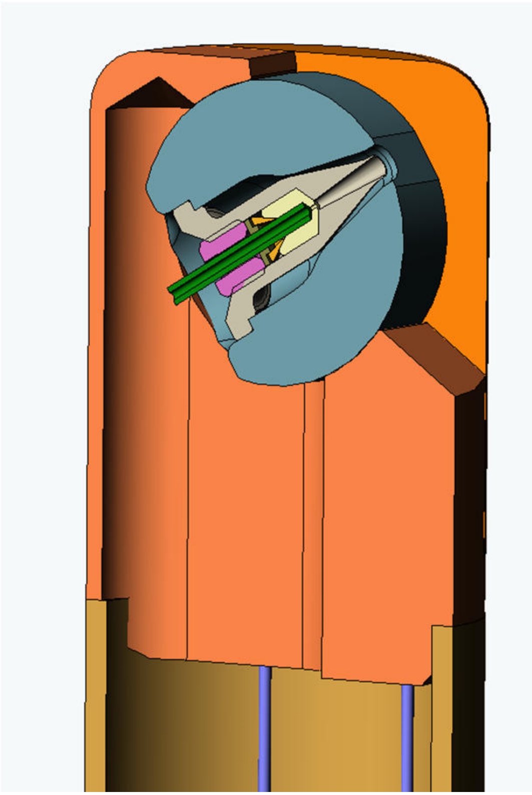
3 GHz S-Band

4-cells

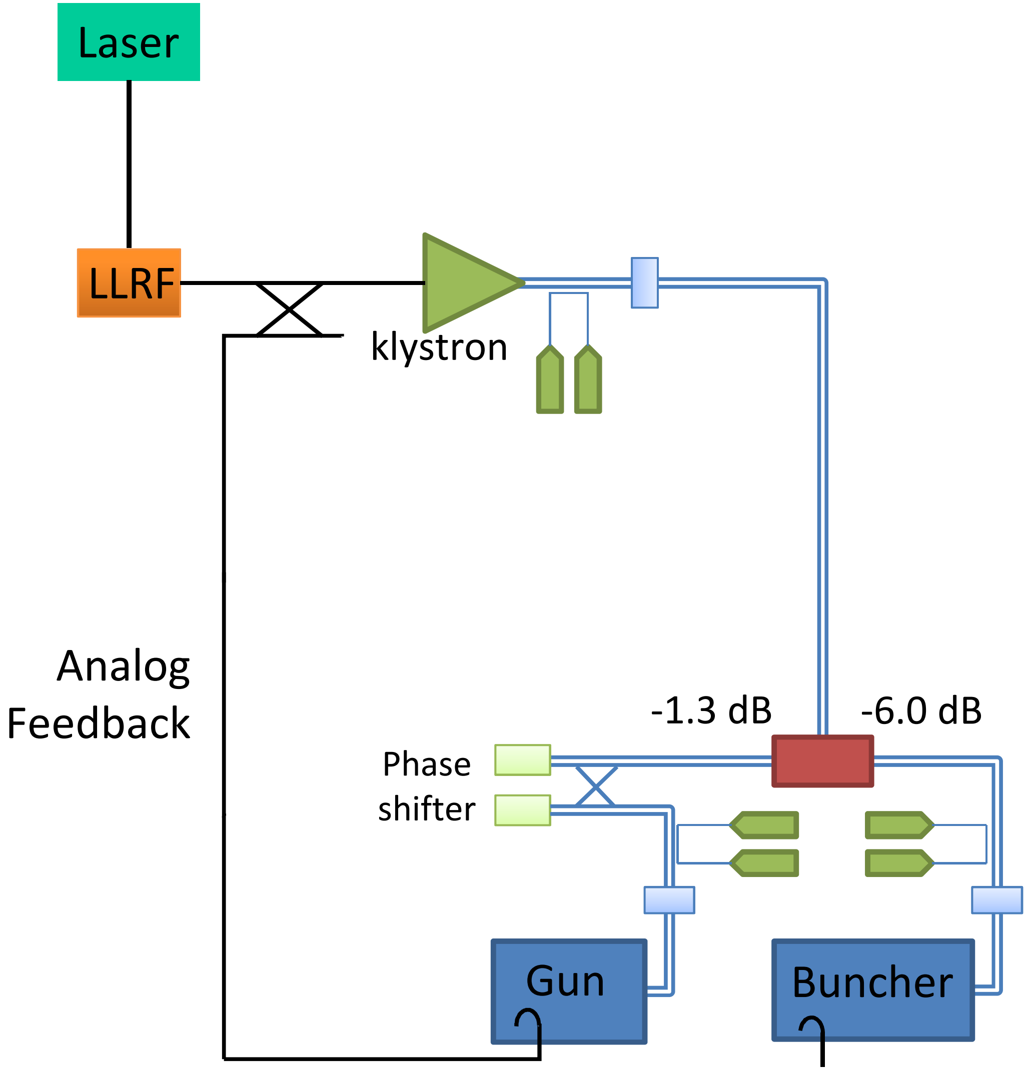
average gradient

~15-20 MV/m

Reduction of dark current: Dry Ice Cleaning



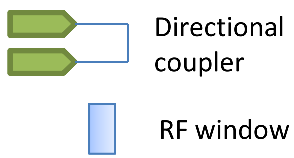
REGAE RF-System



Fundamental Frequency:
3 GHz, S-Band
max. power:

- Klystron: 24 MW
- Gun: 17 MW
- Buncher: 6 MW

50 Hz, max. 6 µs



Tolerances

Gun phase	Δt = 100 fs/deg ΔE = -14 keV/deg
Gun gradient	Δt = -938 fs·m/MV ΔE = 22 keV·m/MV
Buncher phase	Δt = -1286 fs/deg ΔE = 5.3 keV/deg
Buncher gradient	Δt = 25 fs·m/MV ΔE = 1.5 keV·m/MV

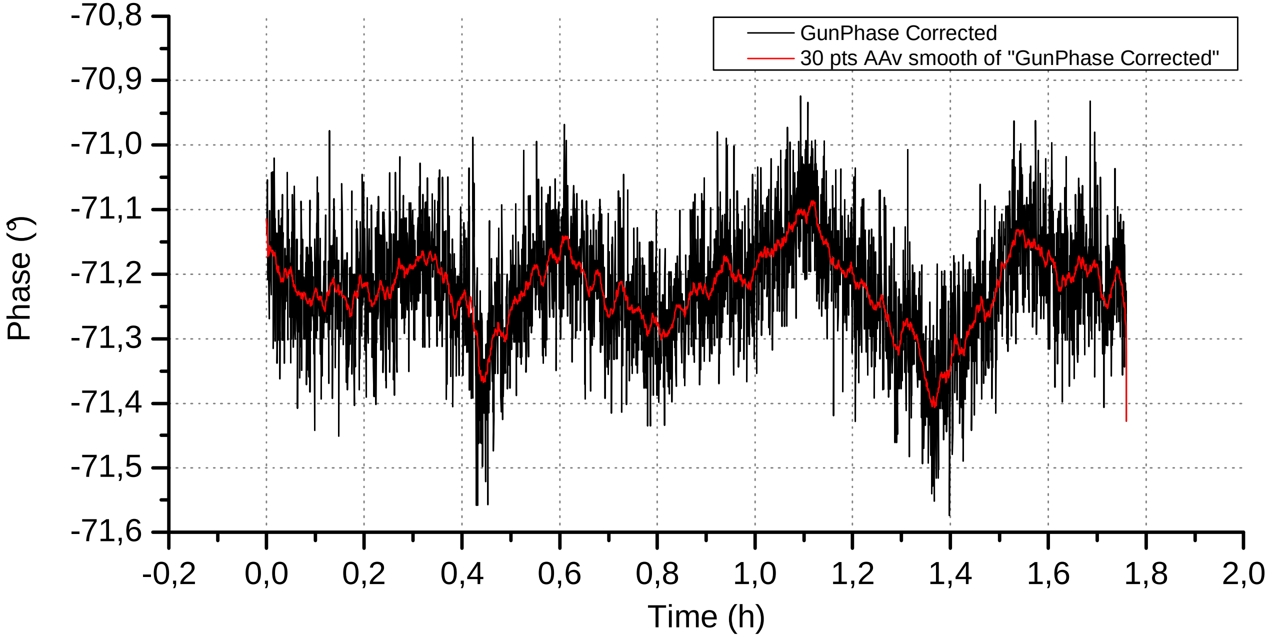
dominated by the phase of the buncher cavity and the gradient of the gun cavity
typical requirements to achieve 10 fs stabilization:
phase stability 0.01 deg
gradient stability: 10^{-4}

Solid state modulator:

$$\frac{\Delta V}{V} \leq 10^{-4}$$

Phase stability without LLRF

REGAE Gun Phase

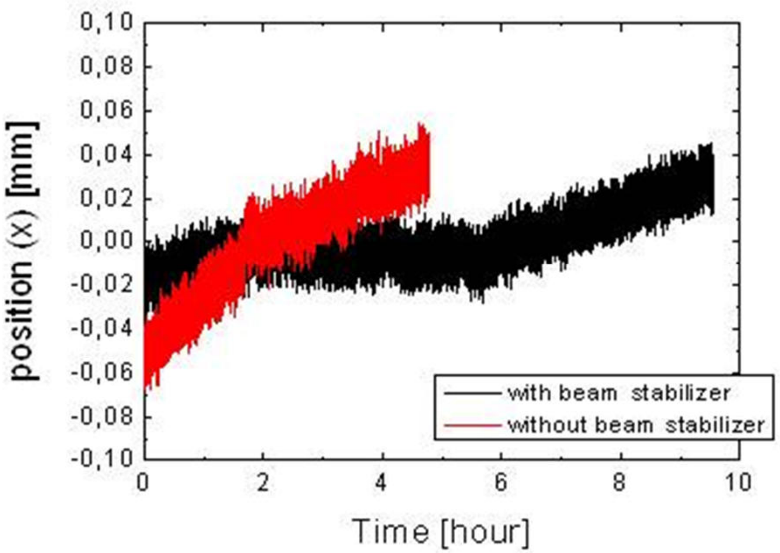


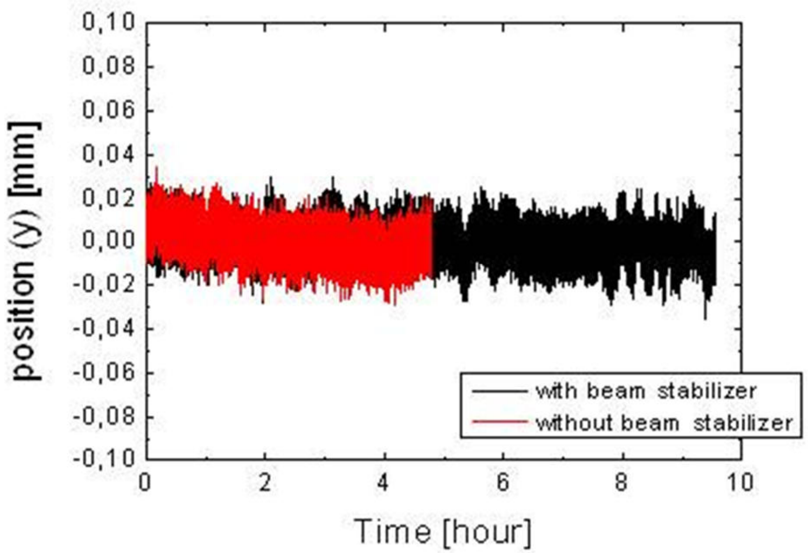
corresponds to a temperature stability of $7 \cdot 10^{-3}$ °C

Standard Deviation: **0.0927°**
0.0563°

Stability measurements

Long term measurement of laser pointing





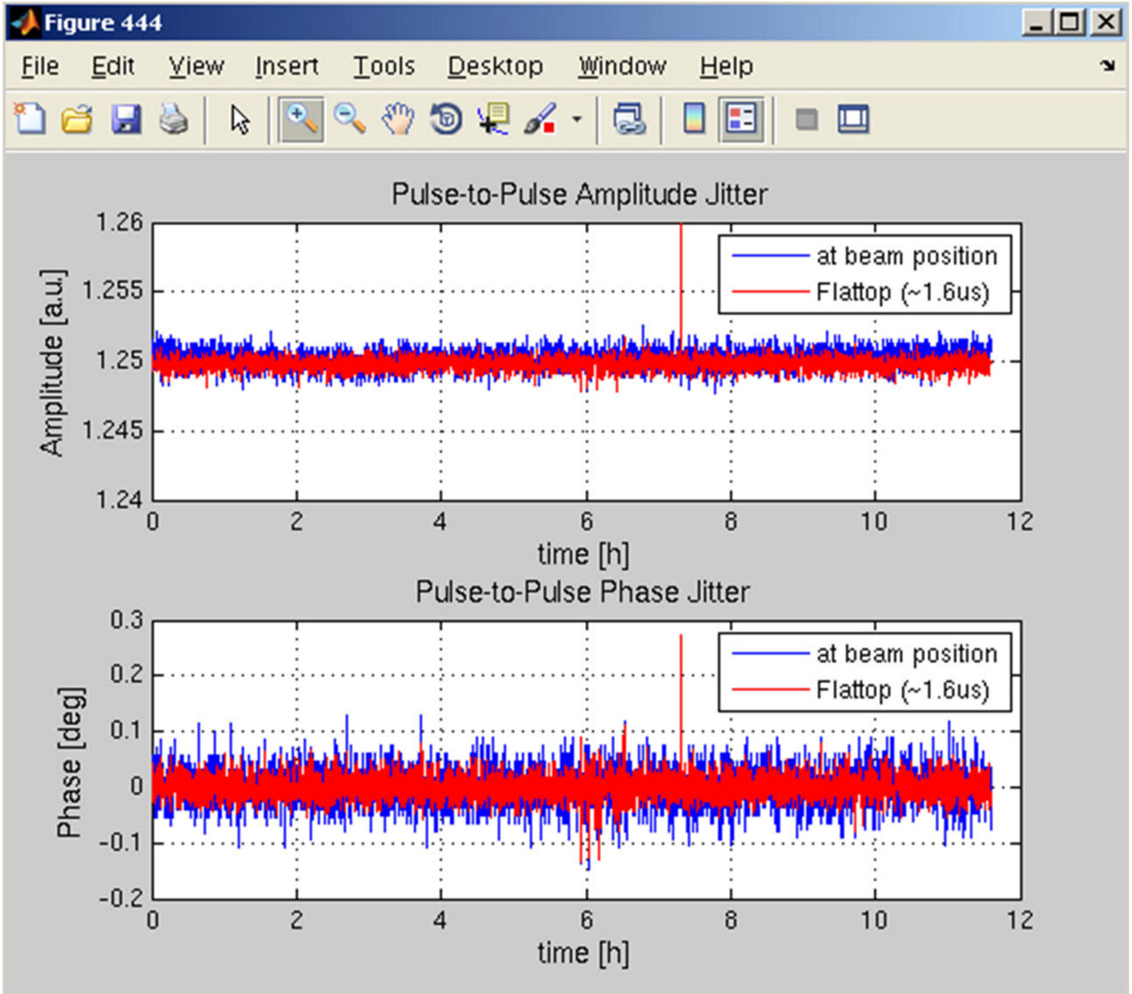
- laser intensity and pointing stability 10^{-3} (rel.)
- temperature stability at various places as racks, cable trays etc. <0.05 deg
- mechanical vibrations ok

Synchronization and LLRF

Preliminary results from LLRF operation

- new 3 GHz LLRF system based on µTCA
- 10 channel RF processing (Kly/Gun/Buncher/Laser)
- ultra-low noise down-converters to intermediate frequency 25MHz
- 125MHz sampling rate
- resolution LLRF system: dA/A ~ 0.035% rms / φ ~ 0.02 deg @ 80MHz bandwidth
- results in dA/A ~ 0.007% rms / φ ~ 0.004 deg at the cavity bandwidth
- Laser to RF synchronization: ≤ 14 fs

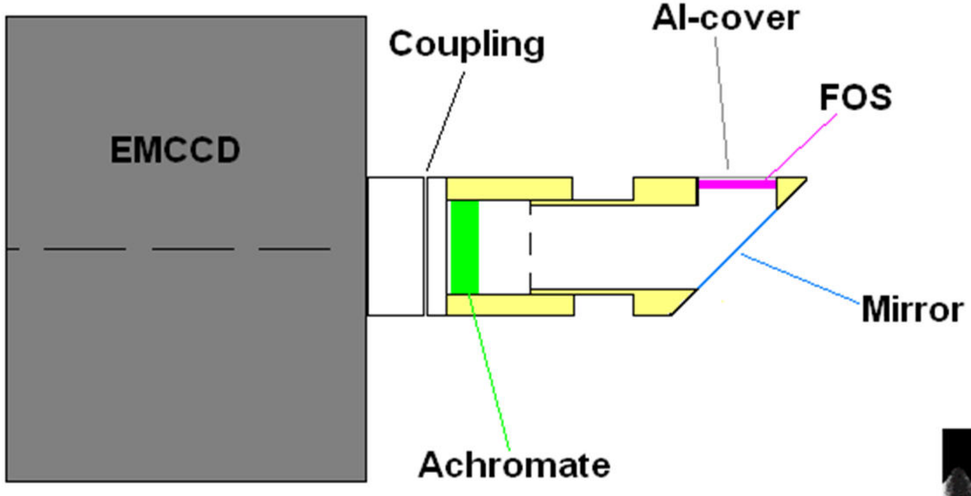
First operation with LFF and analogue Feedback



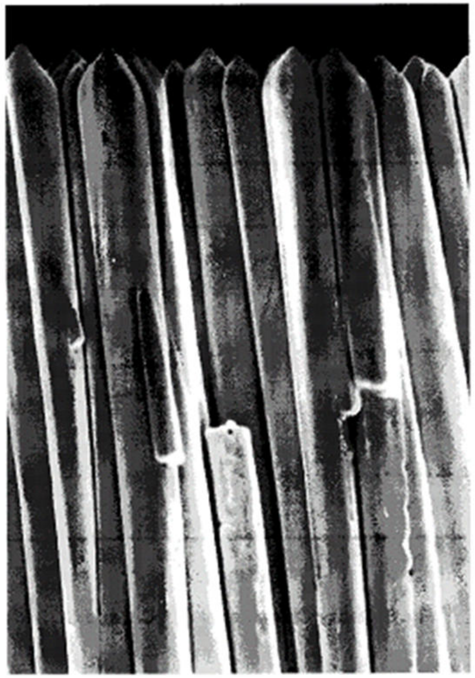
12h operation – in loop measurement:

- average over flat-top (1.6 μs): 20 fs
- average at beam position: 31 fs

Electron Detector

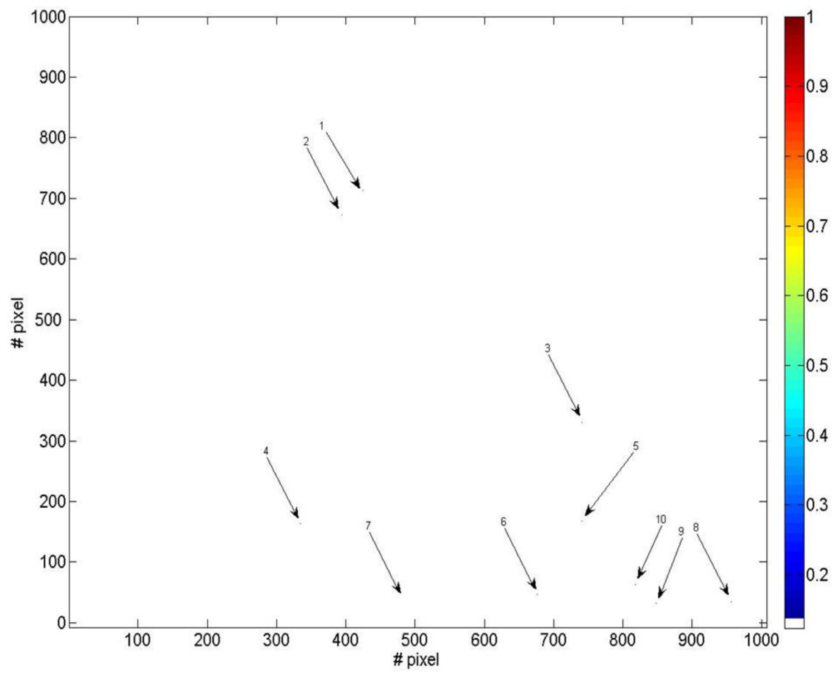


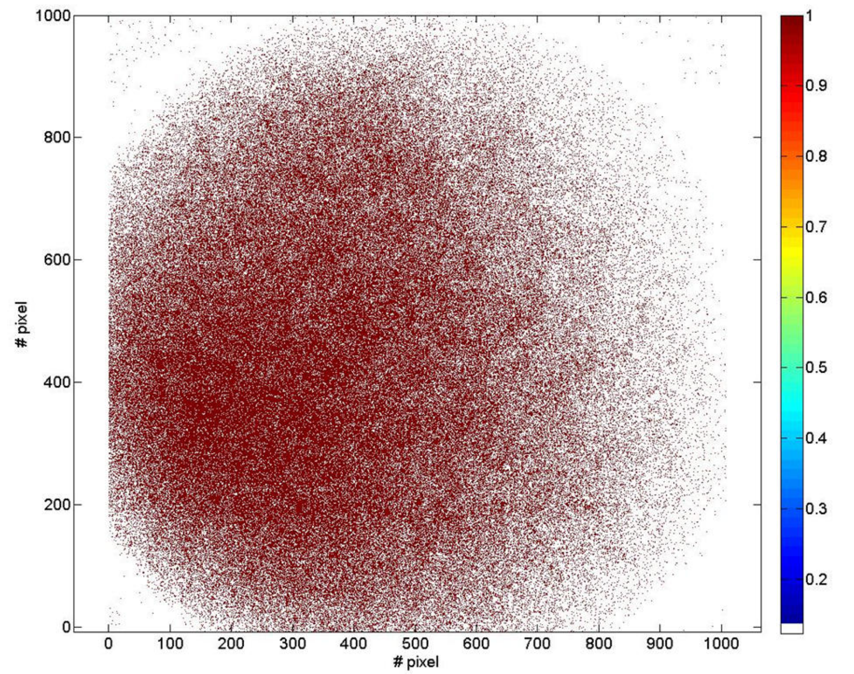
Fiber **O**ptical **S**cintillator
- CsI needle crystals on fiber optical plate
- high light output
- high resolution



Electron Multiplying CCD
- 'on chip multiplication'
- thermo electric cooled
- 95% QE
- 16-Bit, 1024 x 1024 Pixel

Images with 5 Seconds integration time

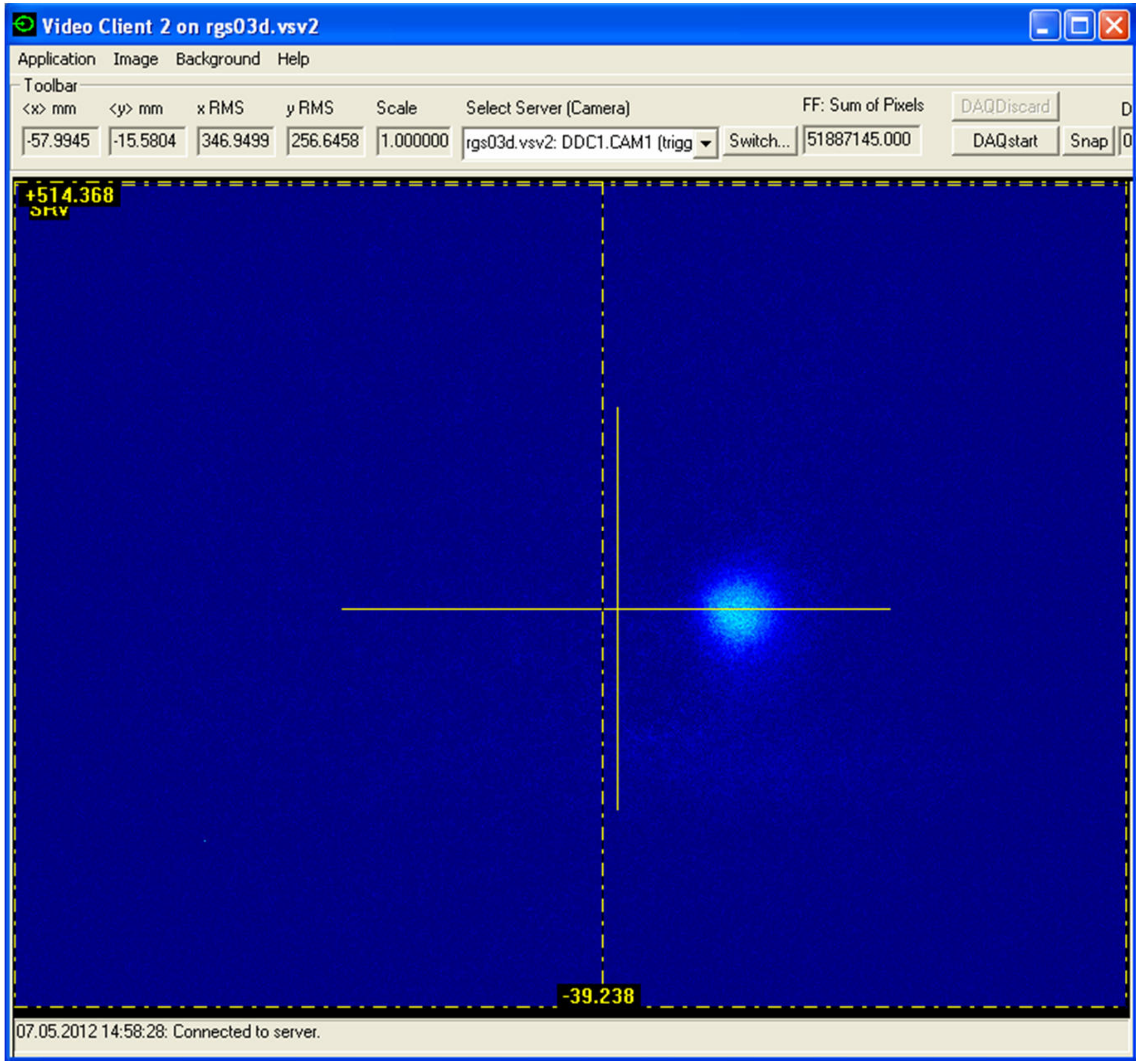




without source: only 10 pixels show a signal

with Cs^{137} source: all Signals have the same value, i.e. single photon detection

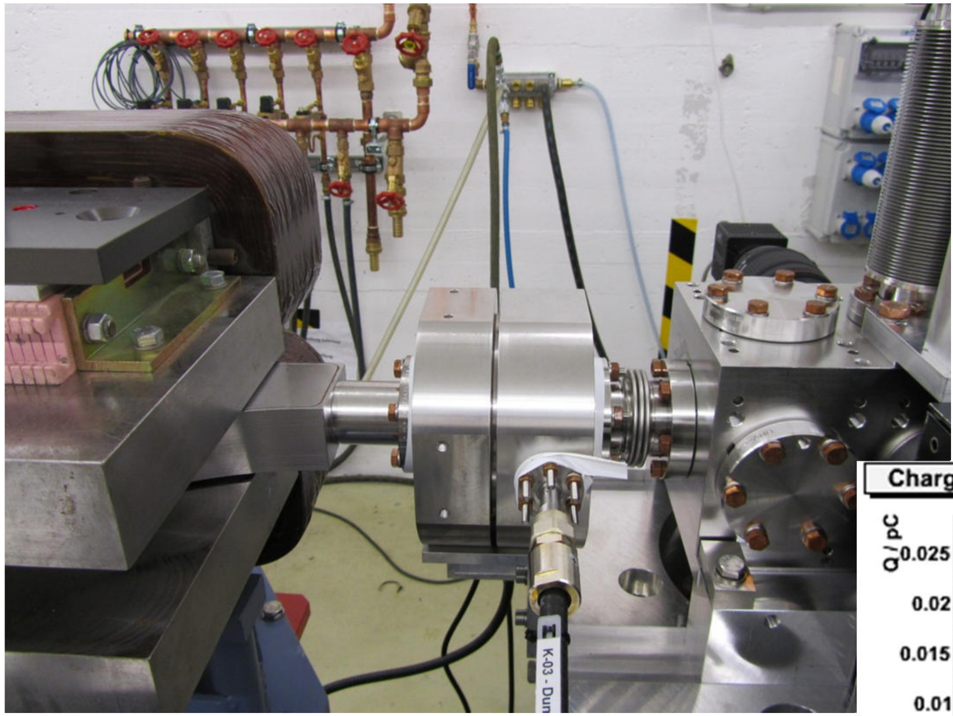
Imaging low Intensity Beams

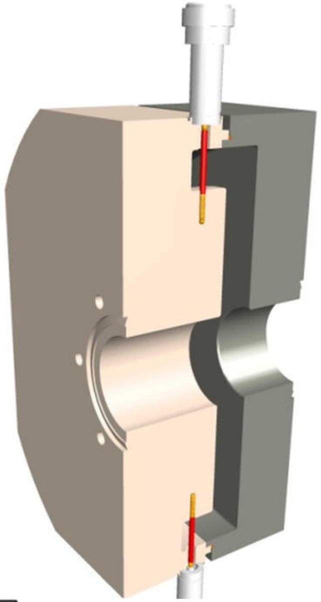


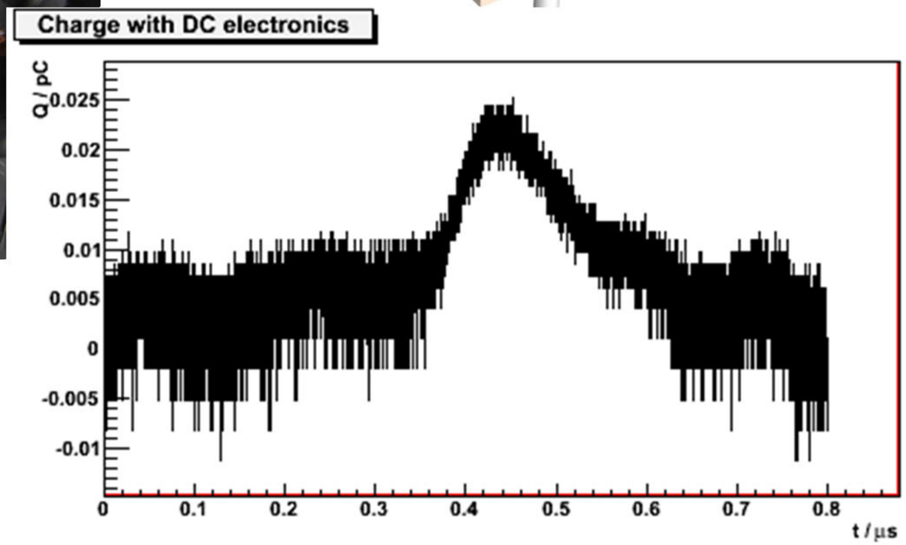
First test of image intensifier:

- position just behind the gun, i.e. highest dark current level of a few pC
- beam charge 50 - 100 fC
- 50 ns gating + background subtraction

Diagnostics: Cavity Monitor for Charge measurements



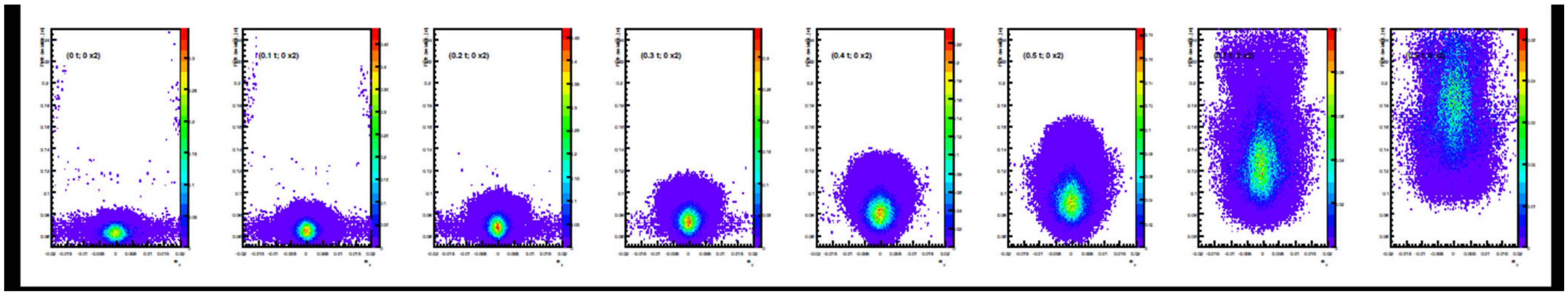




Sensitivity of 10 fC demonstrated

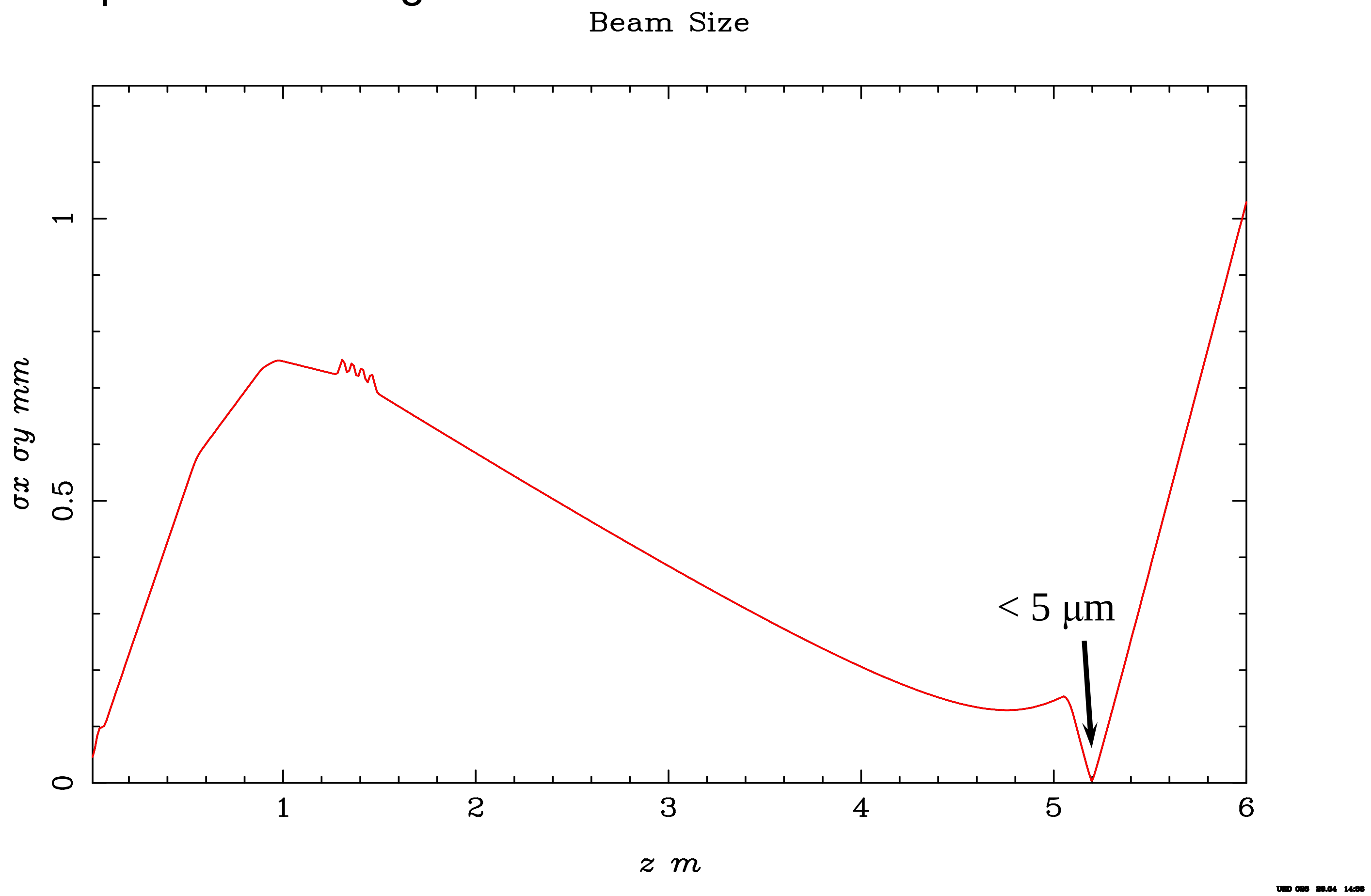
Plasma Acceleration at REGAE

Inject a REGAE bunch into a laser driven plasma to probe the wake field as function of injection phase and transverse off set.



Simulation Example: 0.5 pC
(not fully optimized)

transverse beam size with additional permanent magnet solenoids:



Simulation Example: 0.5 pC
(not fully optimized)

bunch length: