Ultrafast detection of relativistic Charged Particles by Optical Techniques (CPOD)

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Purpose:

Non-invasive characterization of the electron bunch length

Approach:

• Using the Coulomb field of the electron beam to modulate an electro-optical crystal

• Free space Mach-Zehnder interferometer to convert phase modulation to intensity

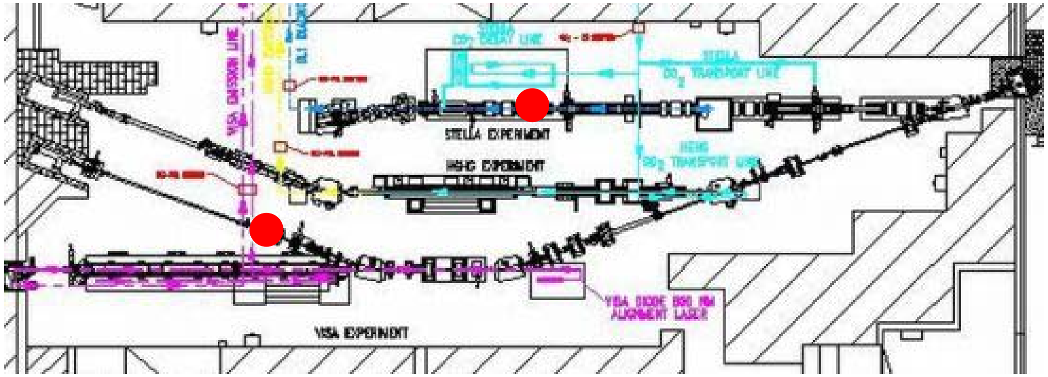
Benefit:

• Simple arrangement

• Electron bunch can be measured with unprecedented temporal resolution ps-fs

Beam time: 2003 – 4 days – beamline #1
2002 – 9 days – beamline #3b

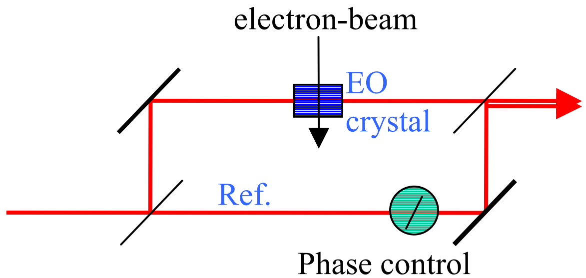
Funding: no current funding
part-time scientists
borrowed equipments



E-beam: 45 MeV, 0.5 nC, ~10 ps

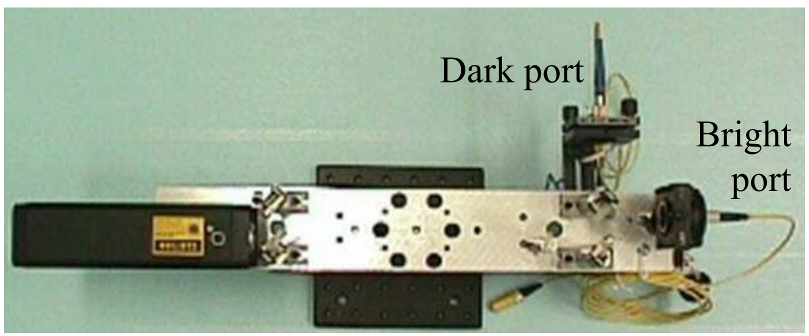
Free-space Mach-Zehnder arrangement

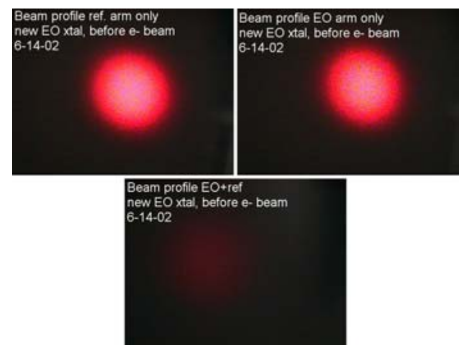
$$E_z = \frac{1}{4\pi\varepsilon_o}\frac{\gamma N_e q\, T(t)}{\varepsilon r^2} \sim 10^5\text{-}10^6\ \text{V/m}$$



$$I = I_o \cos^2[\Gamma_o + \Gamma(t)]$$

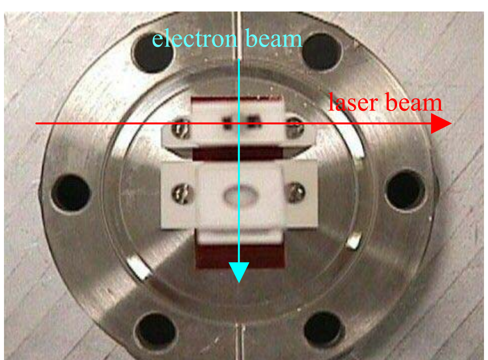
$$\frac{I}{I_o} \approx I_{dc} + \frac{r^3_{eo} N_e q\, T(t)}{4\pi\varepsilon_o \varepsilon r}$$

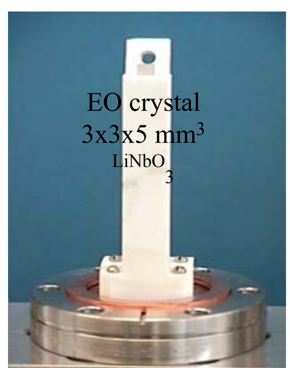


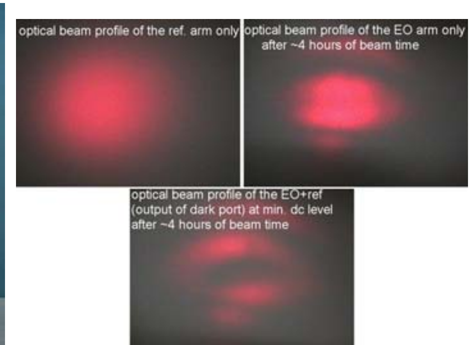


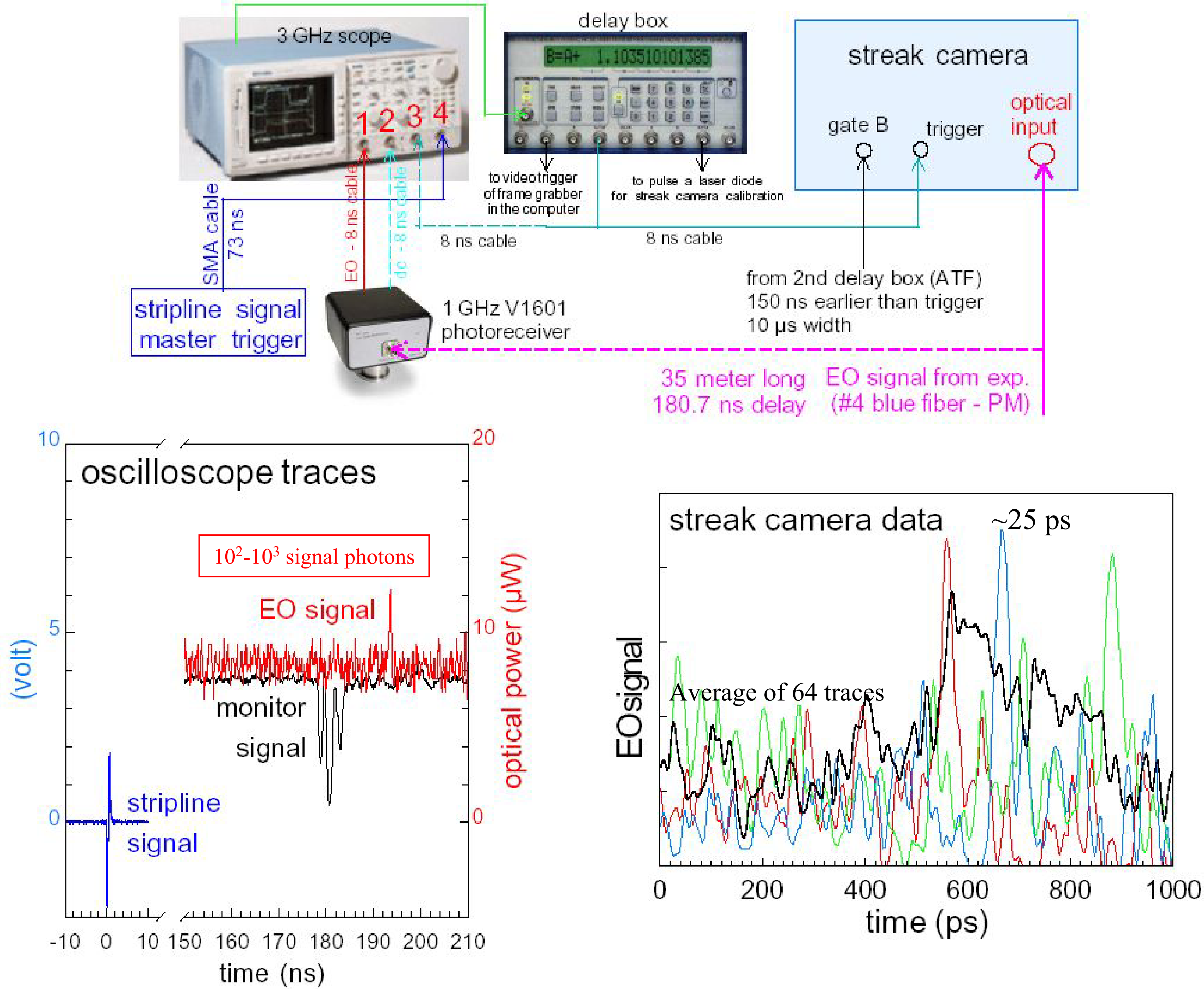
~1 mW cw

~10 μW cw background

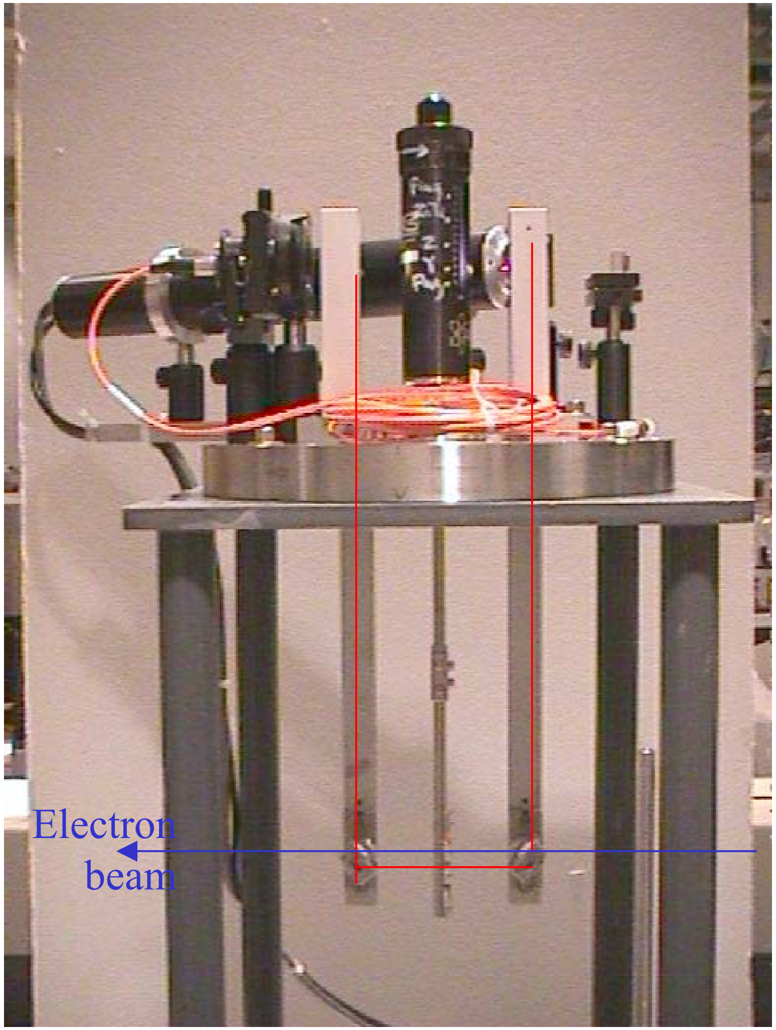


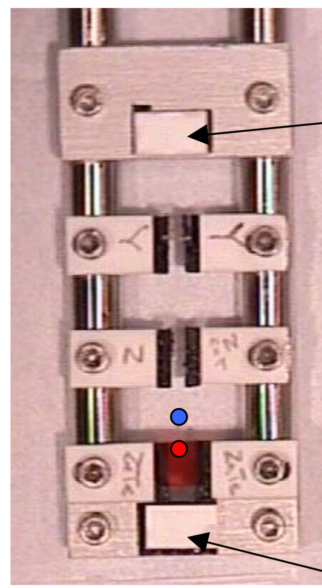


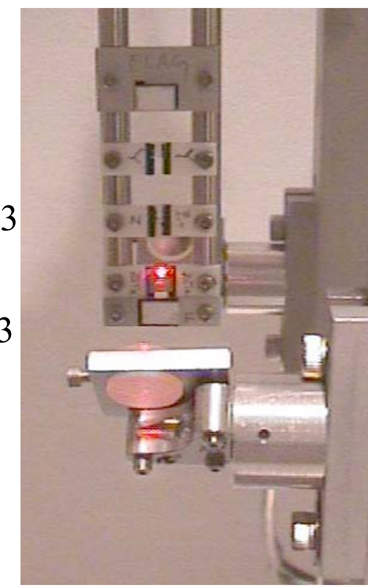



3 GHz scope
1 2 3 4
delay box
B=A+ 1.103510101385
streak camera
gate B
trigger
optical input
to video trigger of frame grabber in the computer
to pulse a laser diode for streak camera calibration
8 ns cable
8 ns cable
SMA cable 73 ns
EO - 8 ns cable
dc - 8 ns cable
stripline signal master trigger
1 GHz V1601 photoreceiver
from 2nd delay box (ATF) 150 ns earlier than trigger 10 µs width
35 meter long 180.7 ns delay
EO signal from exp. (#4 blue fiber - PM)
oscilloscope traces
10^2-10^3 signal photons
EO signal
monitor signal
stripline signal
(volt)
optical power (µW)
time (ns)
streak camera data
~25 ps
Average of 64 traces
EOsignal
time (ps)

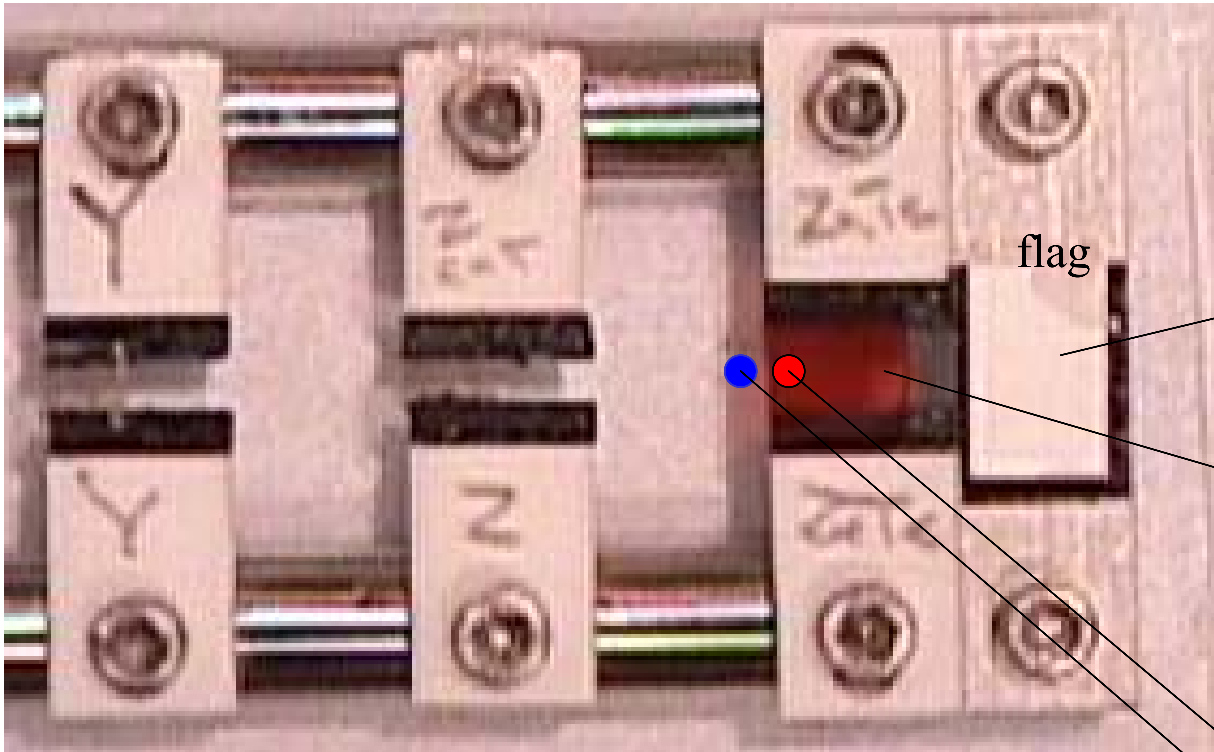
- E-beam co-propagate with cw probe laser beam
- Various EO crystals are loaded on one holder

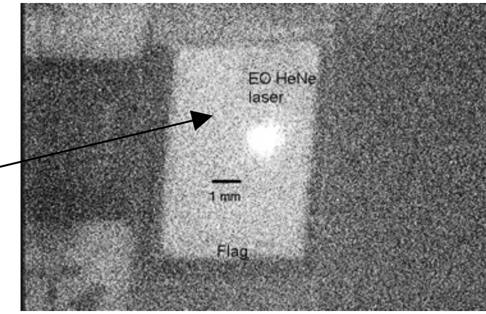


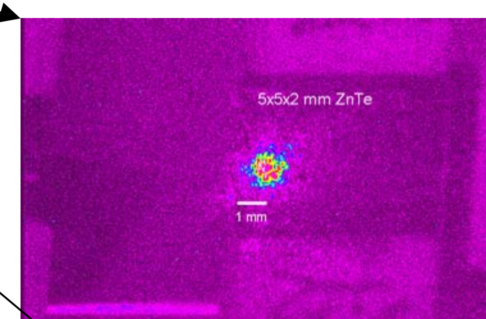


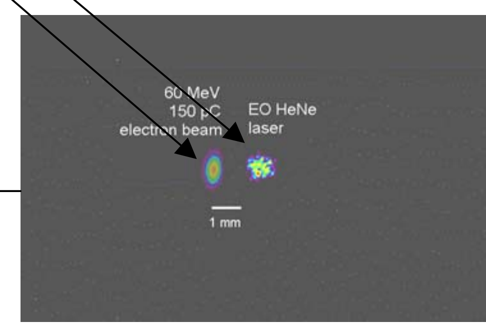


Electron beam profiles

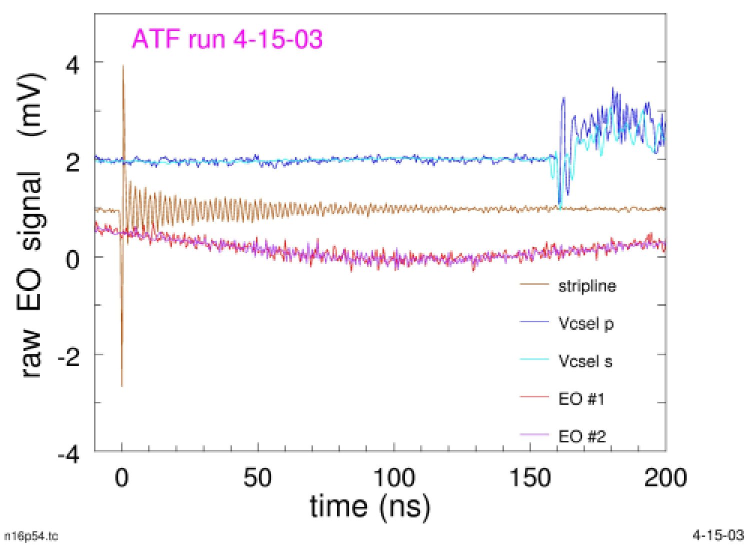




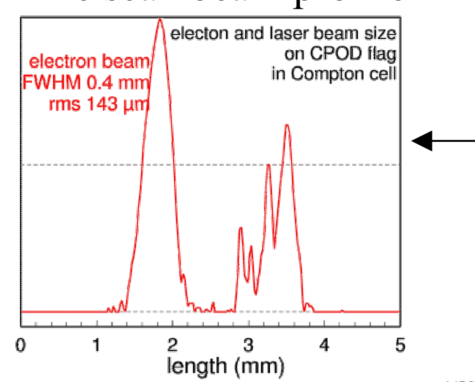




Electron beam size
FWHM ~0.4 mm

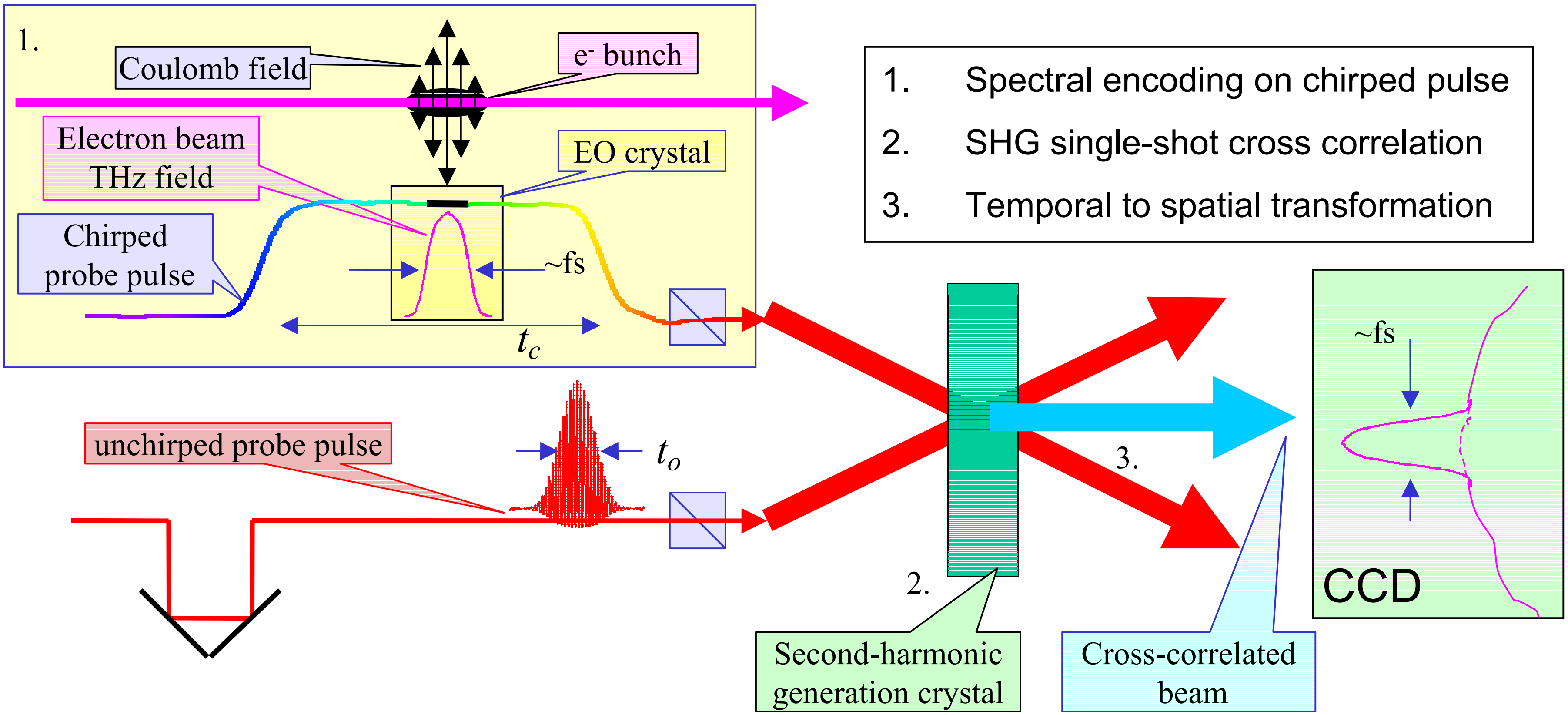


Line scan beam profile



Ultrashort electron beam bunch length – cross correlation technique

- $\Delta t_{electron} \rightarrow$100-10 fs, noninvasive bunch length measurement is needed – electro-optical technique
- spectral encoding technique has a fundamental time resolution limit, $t = \sqrt{t_o\, t_c}$
- bunch length is distorted: THz field ↔ optical carrier spectrum → additional spectral modifications
- cross correlation technique can unambiguously recover the spectral encoded EO modulation



- single-shot, noninvasive, femtosecond resolution
- no timing ambiguity

Wilke, et. al. PRL 88, 124801 (2002).
Sun, et. al., APL 71, 2233, (1998).
Fletcher, Optics Express 10, 1425, (2002).
Jamison, et. al., Optics Letters 28, 1710 (2003).

Conclusions

- a class II cw laser can be used to measure the electron bunch length
- limited # of EO modulated photons gives low SNR
- timing jitter on the trigger restricted the scan range of the streak camera

- to proceed to sub-picoseconds temporal characterization,
  optical pulses shorter than the electron bunch are needed – spectral encoding

- to fully characterize a femtosecond electron bunch w/o a timing ambiguity,
  it is necessary to cross-correlate the spectral encoded EO signal pulse
  with an unchirped pulse (almost like a FROG measurement) to recover the
  envelope information