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

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Purpose:

Non-invasive characterization of the electron bunch length

Approach:

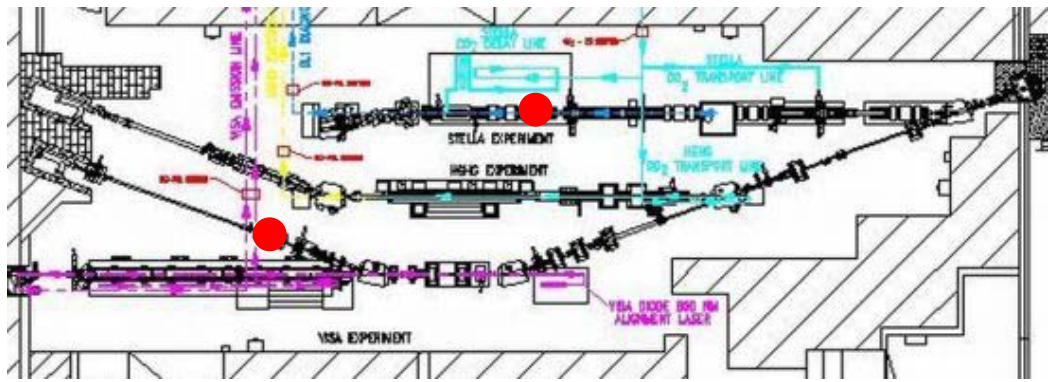
- Using the Coulomb field of the electron beam to modulate an electro-optical crystal
- Free space Mach-Zehnder interferometer to convert phase modulation to intensity

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

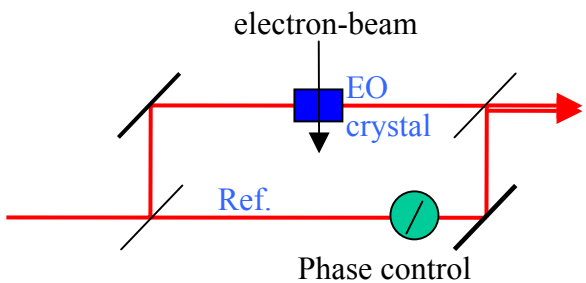
Funding: no current funding
part-time scientists
borrowed equipments



Free-space Mach-Zehnder arrangement

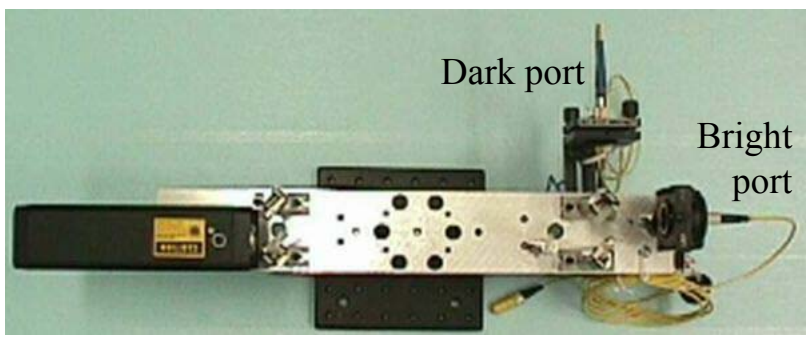
E-beam: 45 MeV, 0.5 nC, ~10 ps

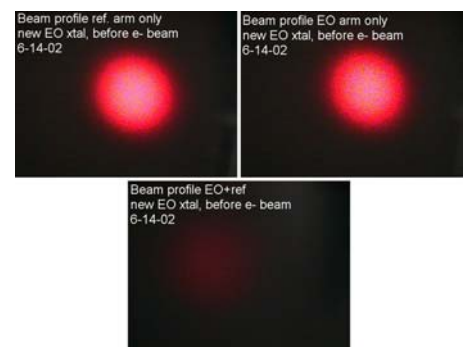
$$E_z = \frac{1}{4\pi\varepsilon_o}\frac{\gamma N_e q\, T(t)}{\varepsilon r^2} \sim 10^5\text{-}10^6 \text{ V/m}$$



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

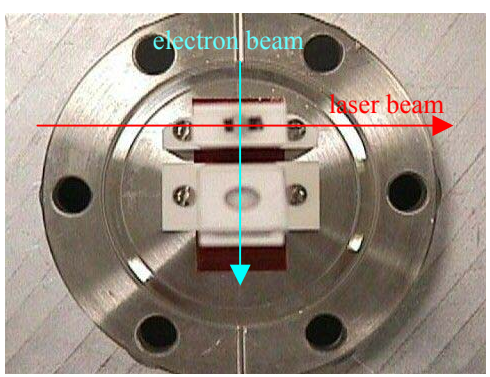
$$\frac{I}{I_o} \approx I_{dc} + \frac{r^3_{eo} N_e q\, T(t)}{4\pi\varepsilon_o \varepsilon r}$$

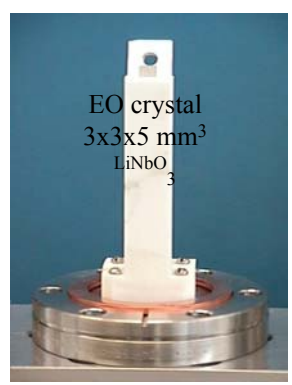


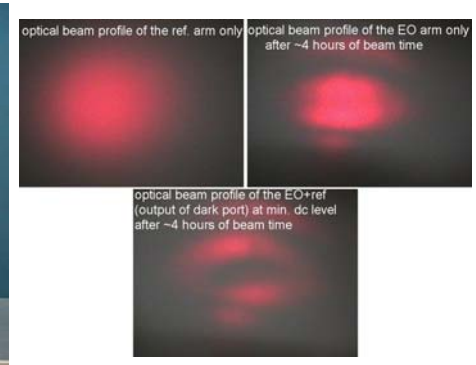


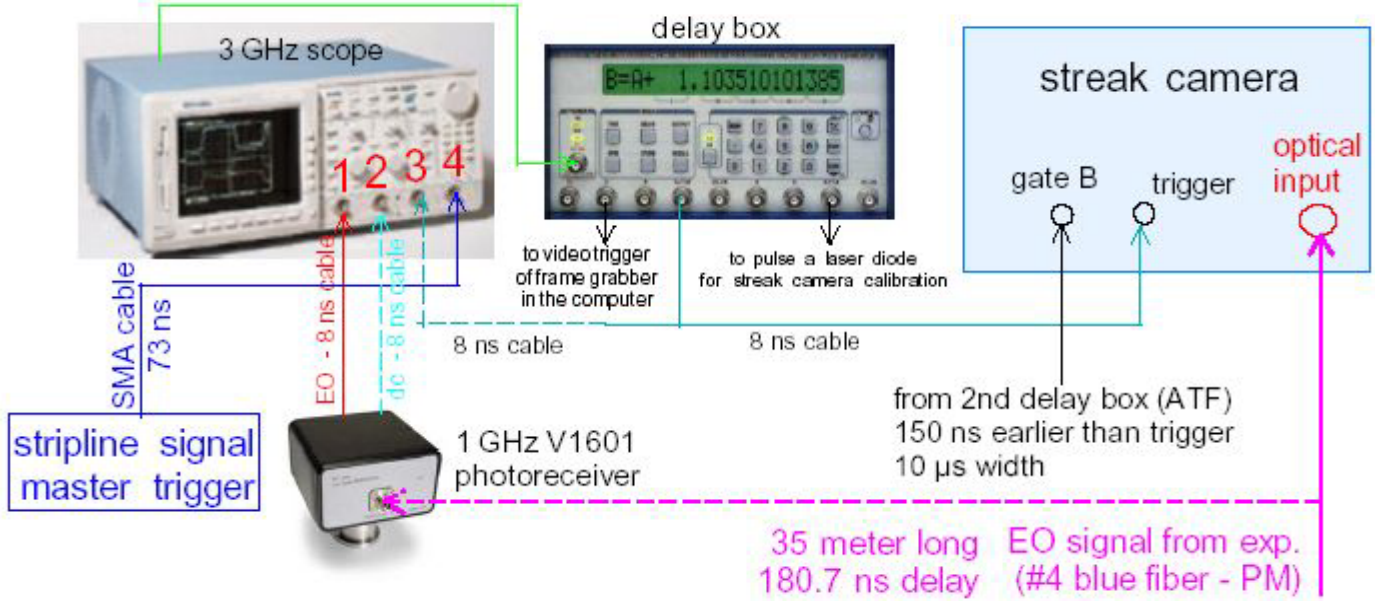
~1 mW cw

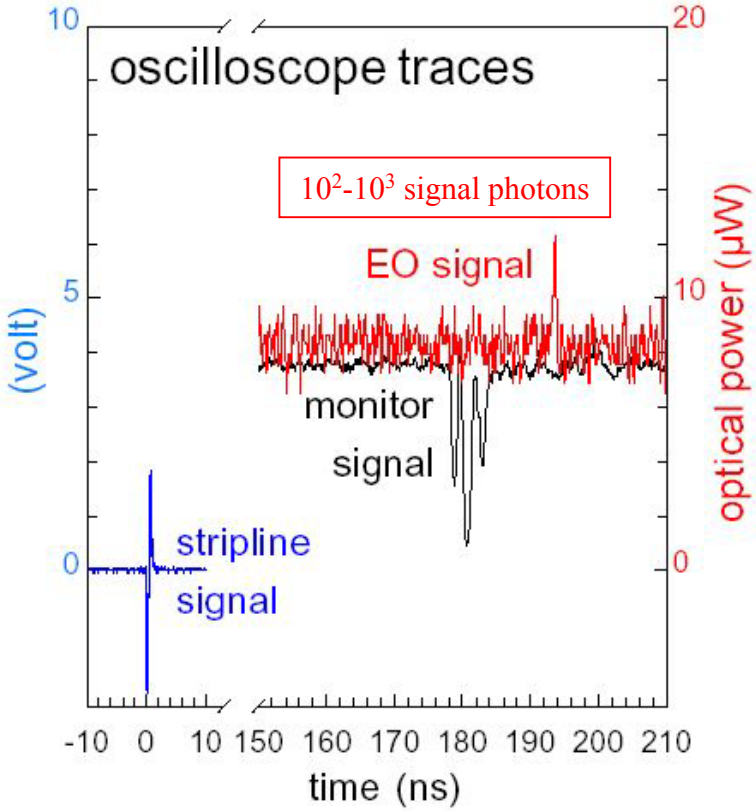
~10 μW cw background

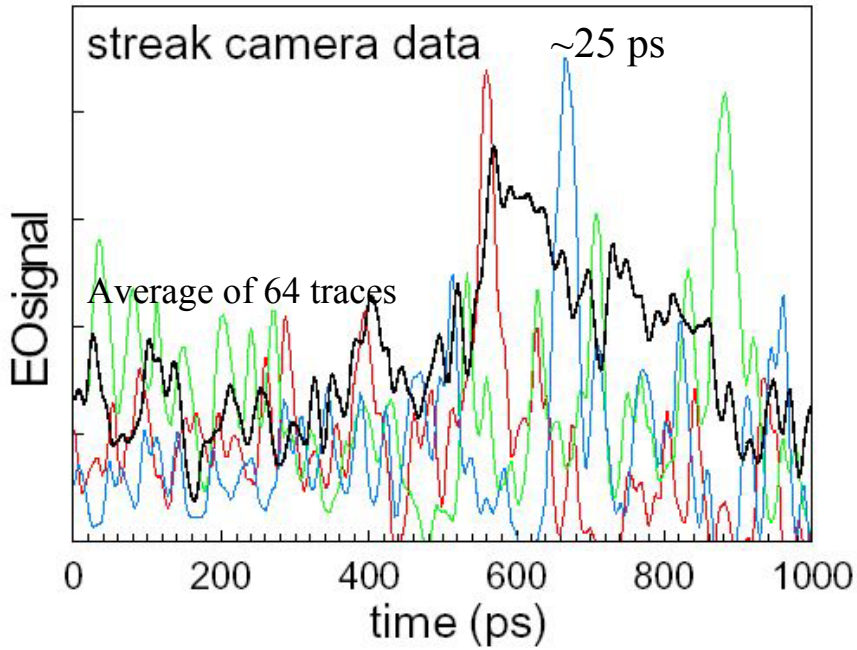


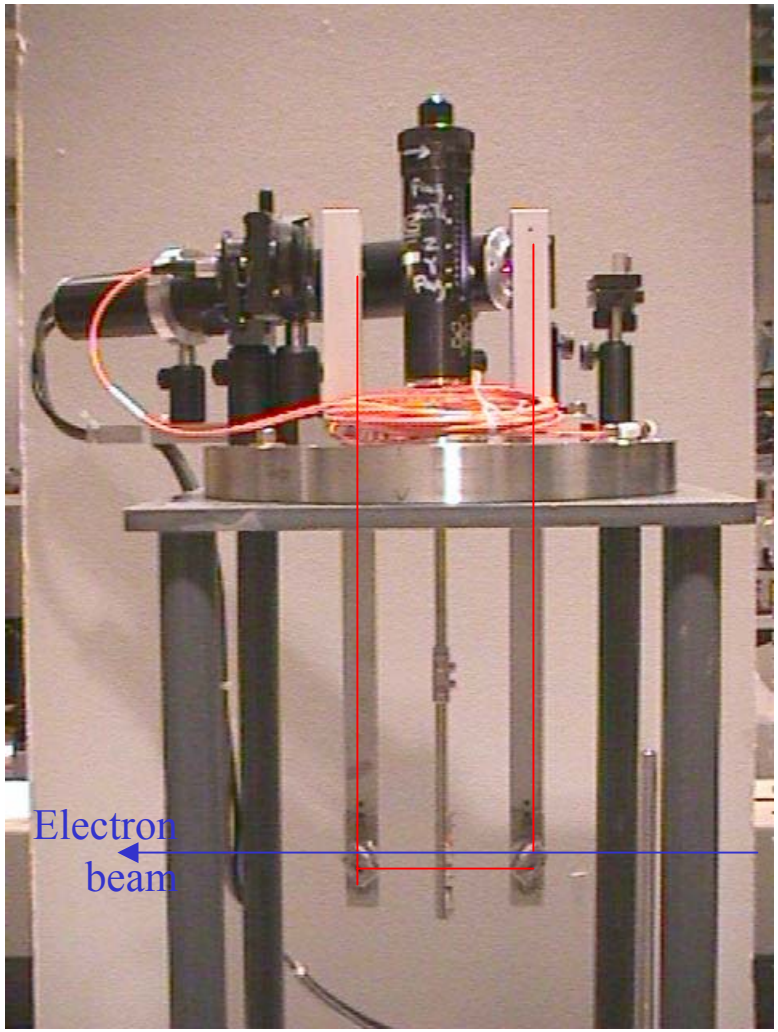




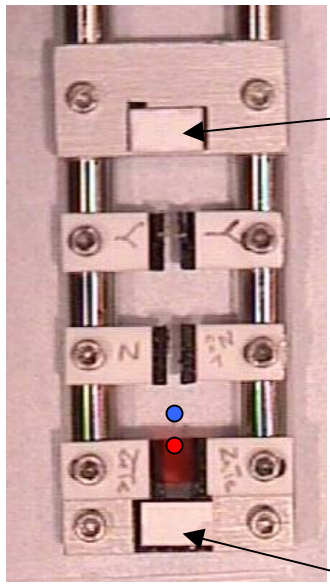

3 GHz scope
1 2 3 4
delay box
B=A+ 1.103510101385
streak camera
gate B
trigger
optical input
to video trigger of frame grabber in the computer
to pulse a laser diode for streak camera calibration
SMA cable 73 ns
EO - 8 ns cable
dc - 8 ns cable
8 ns cable
8 ns cable
from 2nd delay box (ATF)
150 ns earlier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

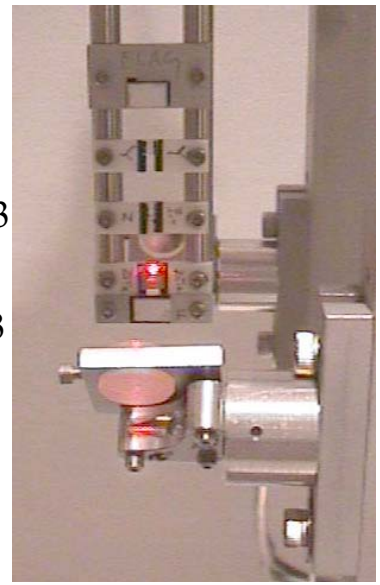

oscilloscope traces
10^2-10^3 signal photons
EO signal
monitor
signal
stripline
signal
(volt)
optical power (μW)
10
5
0
20
10
0
-10 0 10 150 160 170 180 190 200 210
time (ns)


streak camera data
~25 ps
Average of 64 traces
EOsignal
0 200 400 600 800 1000
time (ps)

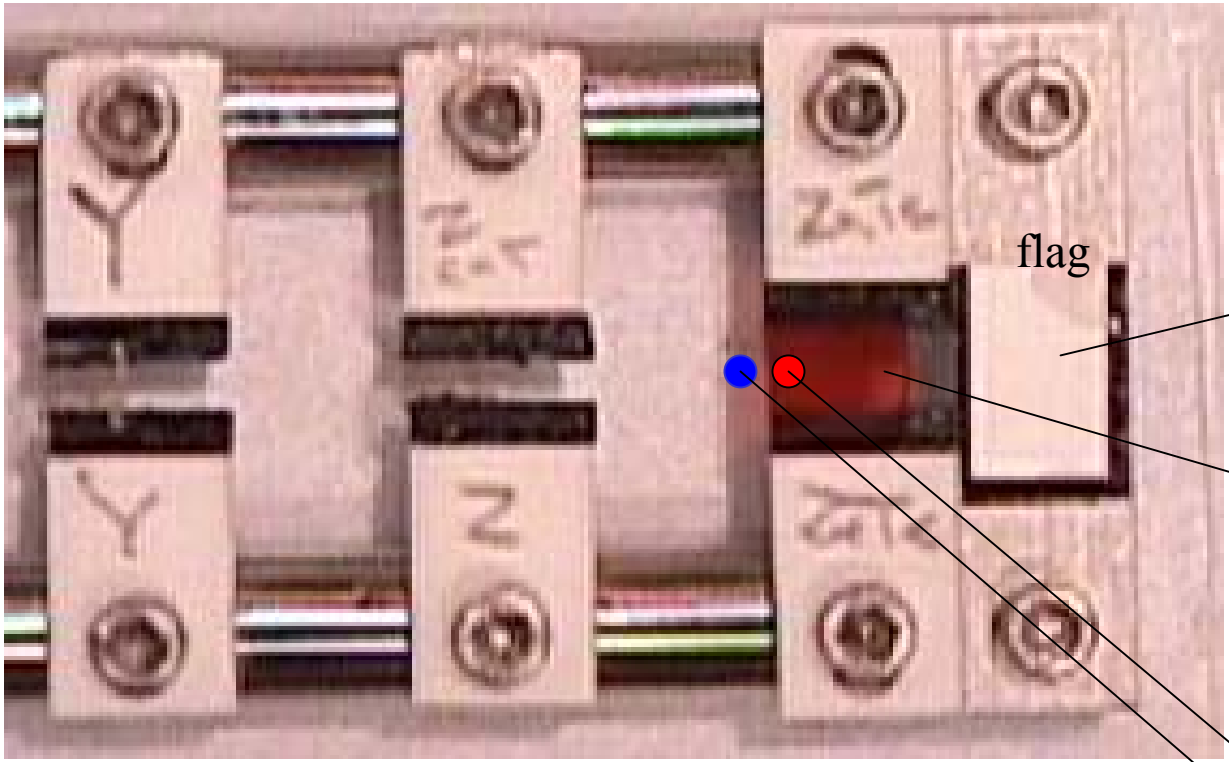


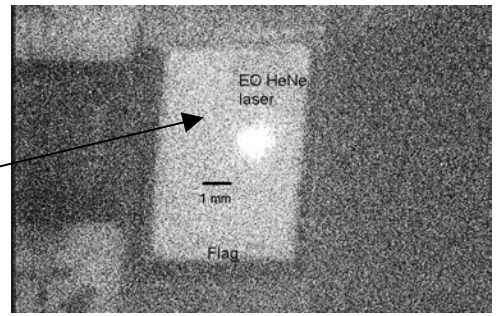
- E-beam co-propagate with cw probe laser beam
- Various EO crystals are loaded on one holder

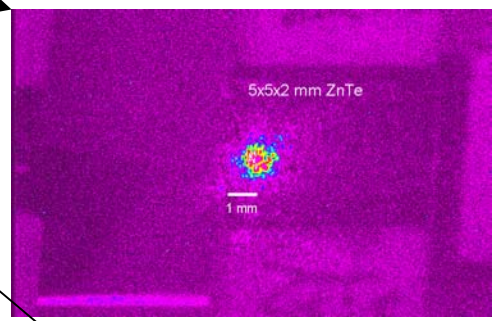


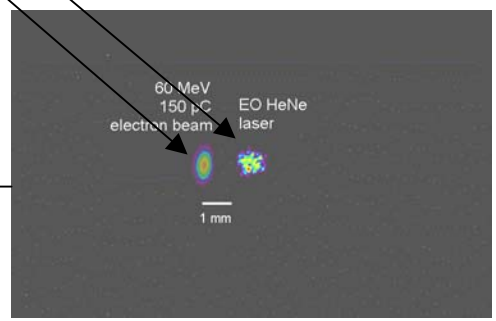


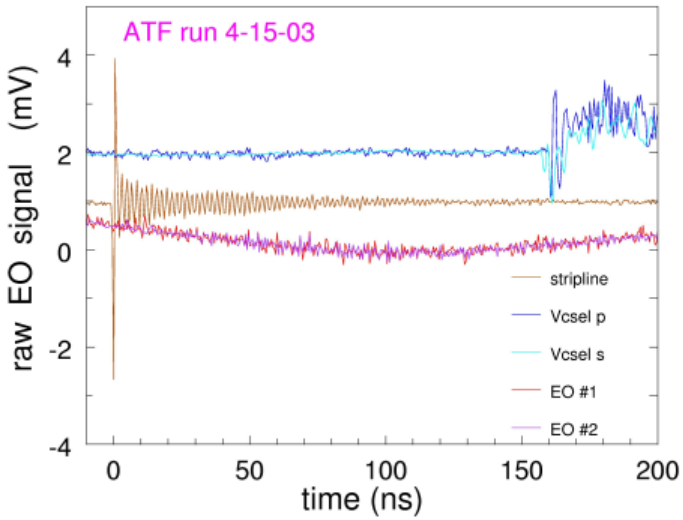
Electron beam profiles



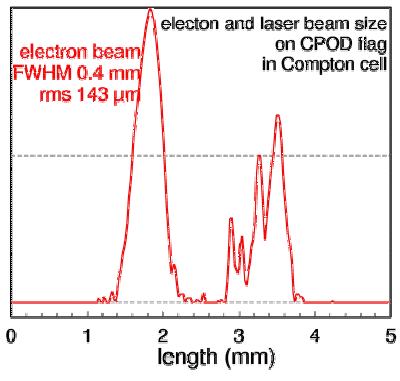








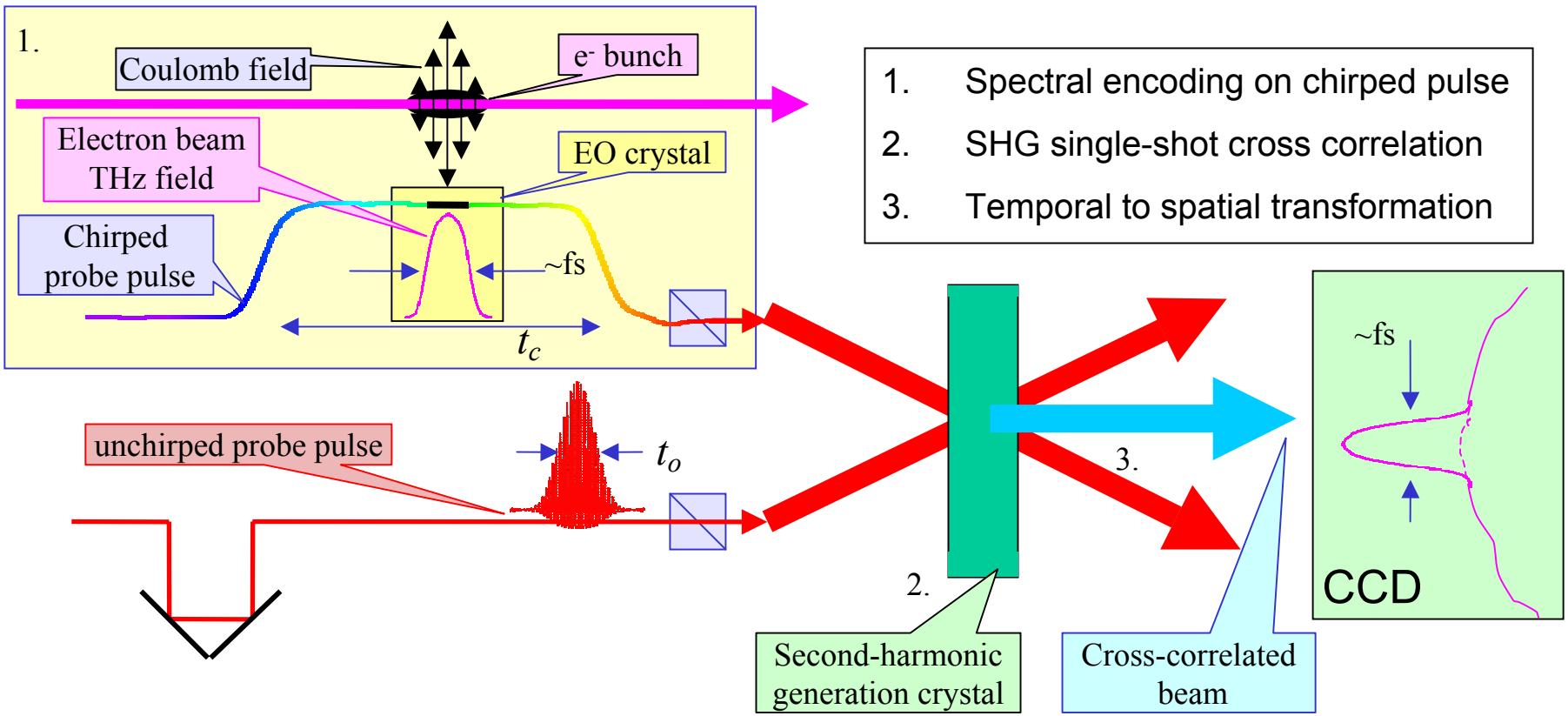
Line scan beam profile



Electron beam size
FWHM ~0.4 mm

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