Electro-Optical Sampling

C.Y. Tan

MAJOR QUESTION: How do I measure something so short?

- How do we measure a rms ~1 ps long bunch?
  - Wait for Tektronix to produce a THz scope.
    - Probably have to wait for a long time ...
  - The trick: Transform time sampling into a space sampling
    - This is the key!
    - Electro Optical Sampling done correctly can do this.
  - There are at least 4 EOS methods for doing this, but I will only talk about spectral decoding.

An Example

- At SASE FEL, total bunch length is about 2ps and using EOS, the time structure resolution of the bunches is better than 200 fs rms and has a rep. Rate of 60Hz
  - RMS Length of ILC bunches ~6mm (20ps) before compression, and ~0.3mm (1 ps) after compression
  - Bunch Compressor Design Study http://www-project.slac.stanford.edu/ilc/acceldev/LET/BC/
- Everything from this talk is from
  - Spectral Decoding Electro-Optic Measurements For Longitudinal Bunch Diagnostics At the DESY VUV-FEL, B. Steffen et al, Proc. 27th International Free Electron Laser Conference.

What is EOS?

- Electro-optical Sampling (EOS)
  - Use a material which has the property which changes its optical characteristics when an E-field is applied to it.
- Electro-optical Sampling
  - Use an optical trick that transforms a temporal domain measurement to a spacial domain measurement.

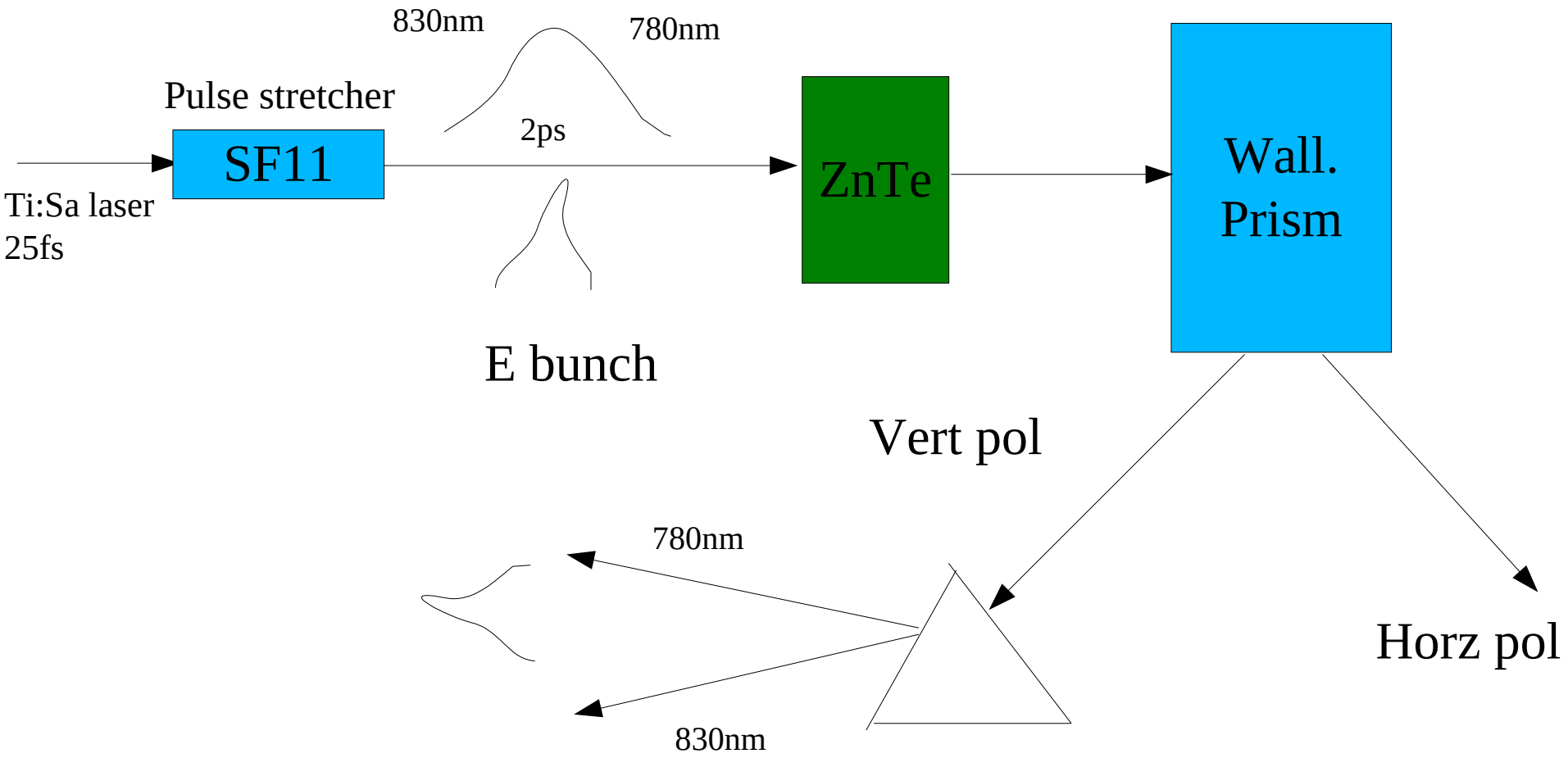
The Magic Material

- ZnTe is optically isotropic at vanishing fields (or GaP)
- In presence of strong E-field, it ZnTe becomes birefringent
  - Vertical and horizontally polarized light do not propagate with the same refractive index through the crystal.
- The laser's polarization components acquire a phase shift difference of $\Gamma \propto r_{41} E_e$ where r_{41} is the electro-optical coefficient of ZnTe, and E_e is the E field of the bunch.
  - Therefore, we just need to measure the amount of elliptic polarization of the laser light after the crystal which will then give us the bunch distribution.

What We Need To Do

- Cut the crystal in such a manner that a horizontally polarized laser pulse will be elliptically polarized if there is an electric field.
  - The ellipse becomes more tilted as the E-field increases.
  - This means that the size of the vertical component gives the size of the bunch E-field.
  - A Wolloston prism can separate out the horz and vert laser component after the crystal.

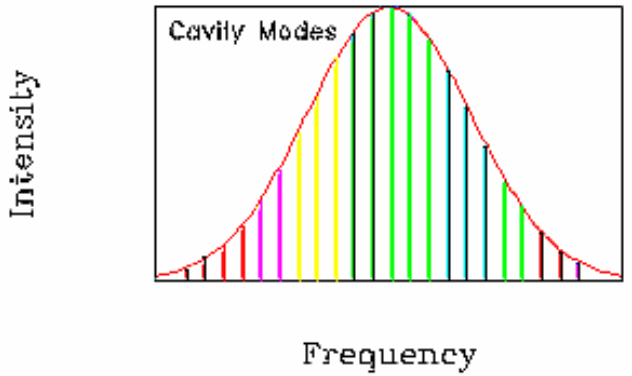
The Picture

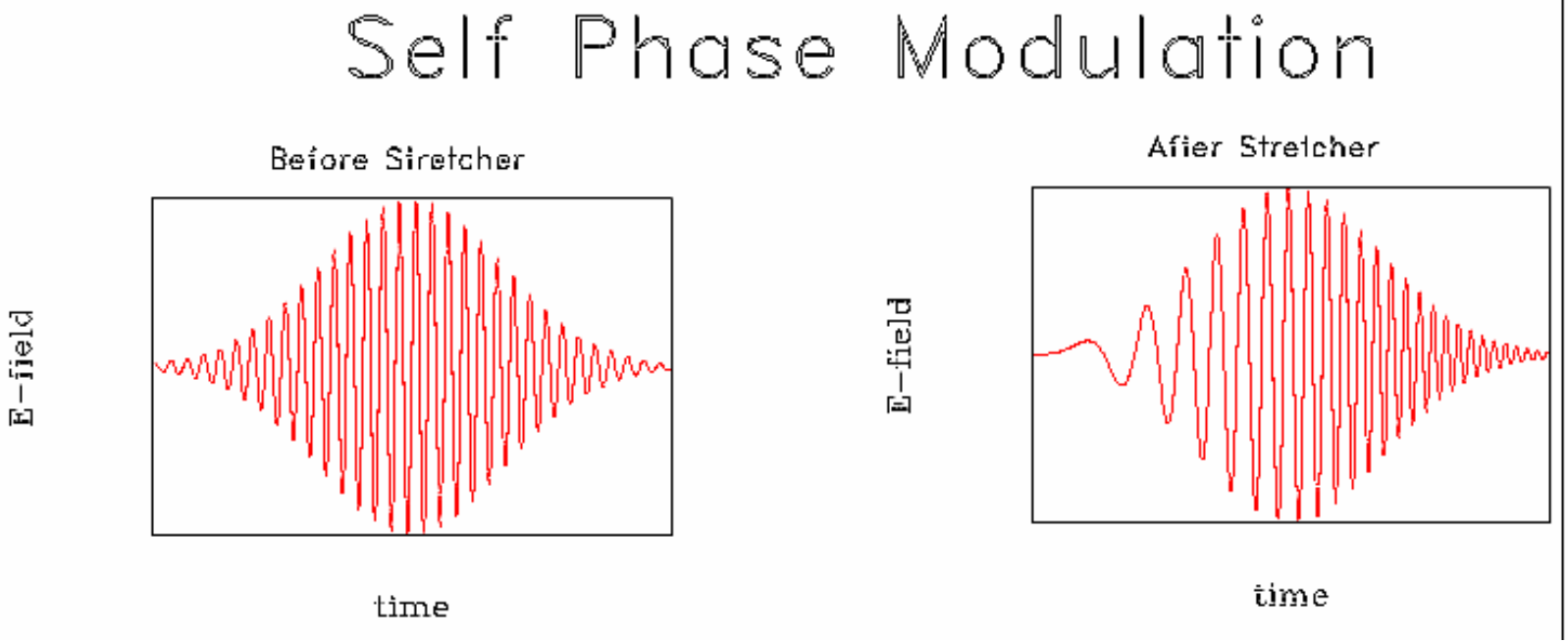

830nm
780nm
Pulse stretcher
SF11
2ps
Ti:Sa laser
25fs
ZnTe
Wall.
Prism
E bunch
Vert pol
780nm
Horz pol
830nm

The Magic continues ...

- Now comes the clever part:
  - Put an SF11 block to “stretch” the laser beam before the crystal.
    - Kerr effect (refractive index $\propto$ to intensity) to rearrange the frequencies so that the shorter wavelength light ~780nm will be out first and longer wavelength ~830nm will be out last. (Kerr effect also increases bw)
    - Before dispersion effect, laser pulse is 25fs (FWHM), λ = 805nm, bw=50nm. After block, stretched to 2ps because of the refractive index. Note that too much dispersion will smear out the phase coherence of the pulse.

Self Phase Modulation





The Magic continues ...

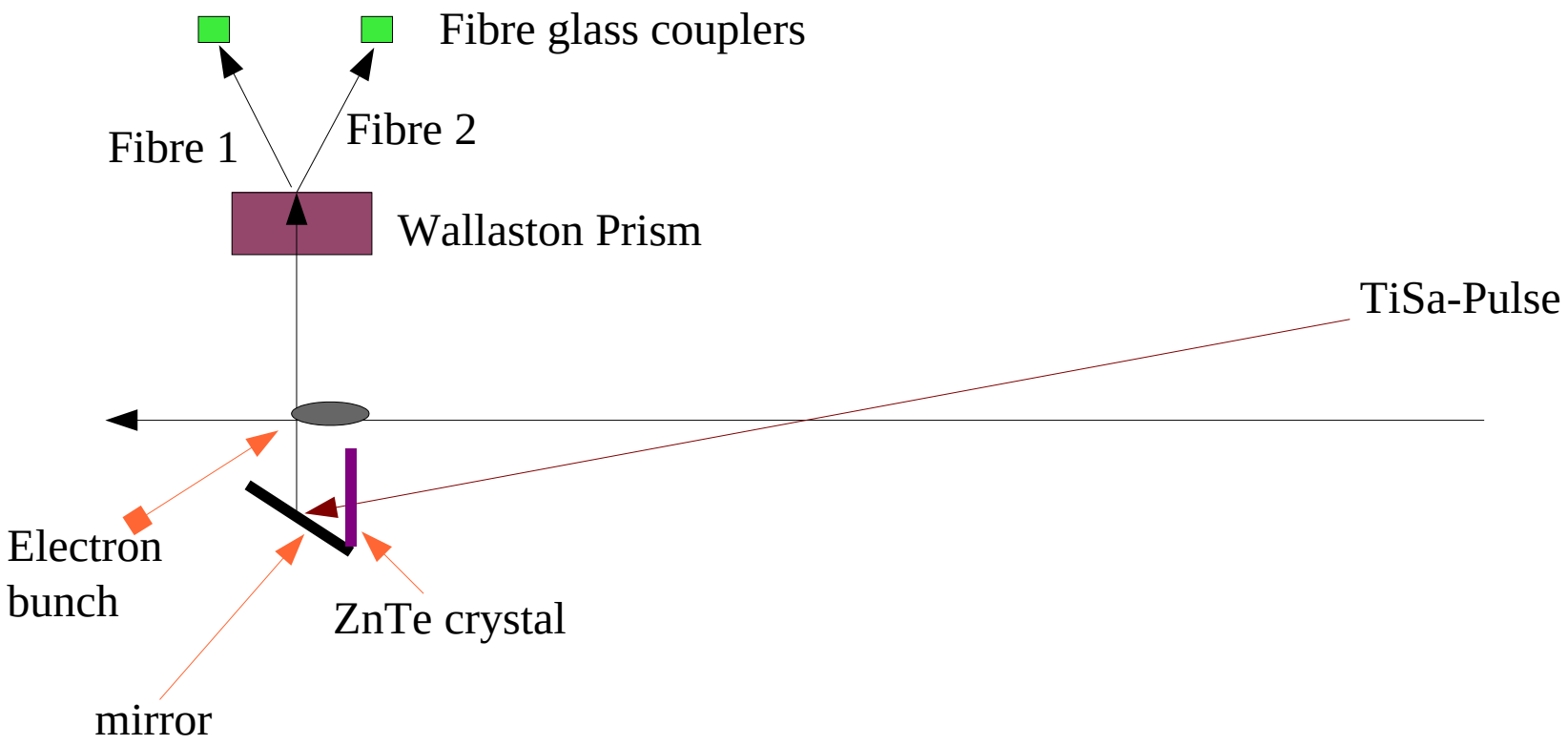
- Now the start of the laser pulse (780nm) will sample the start of the bunch while the end of the laser pulse (830nm) will sample the end of the bunch.

- After the Wollaston prism, we spread out the laser vert polarized laser pulse using a spectrometer, so that the intensity of each wavelength can be seen.
  - Voila, we have transformed a temporal distribution into a spatial distribution that can be intensified and measured with a CCD camera.

Advantages

- Non destructive.
- Single shot measurement. 60Hz rep rate
  - No multiple bunch “averaging”.
- Better resolution than streak camera.
  - Current limit is 370 fs (FWHM)
  - Streak camera is destructive. (OTR)

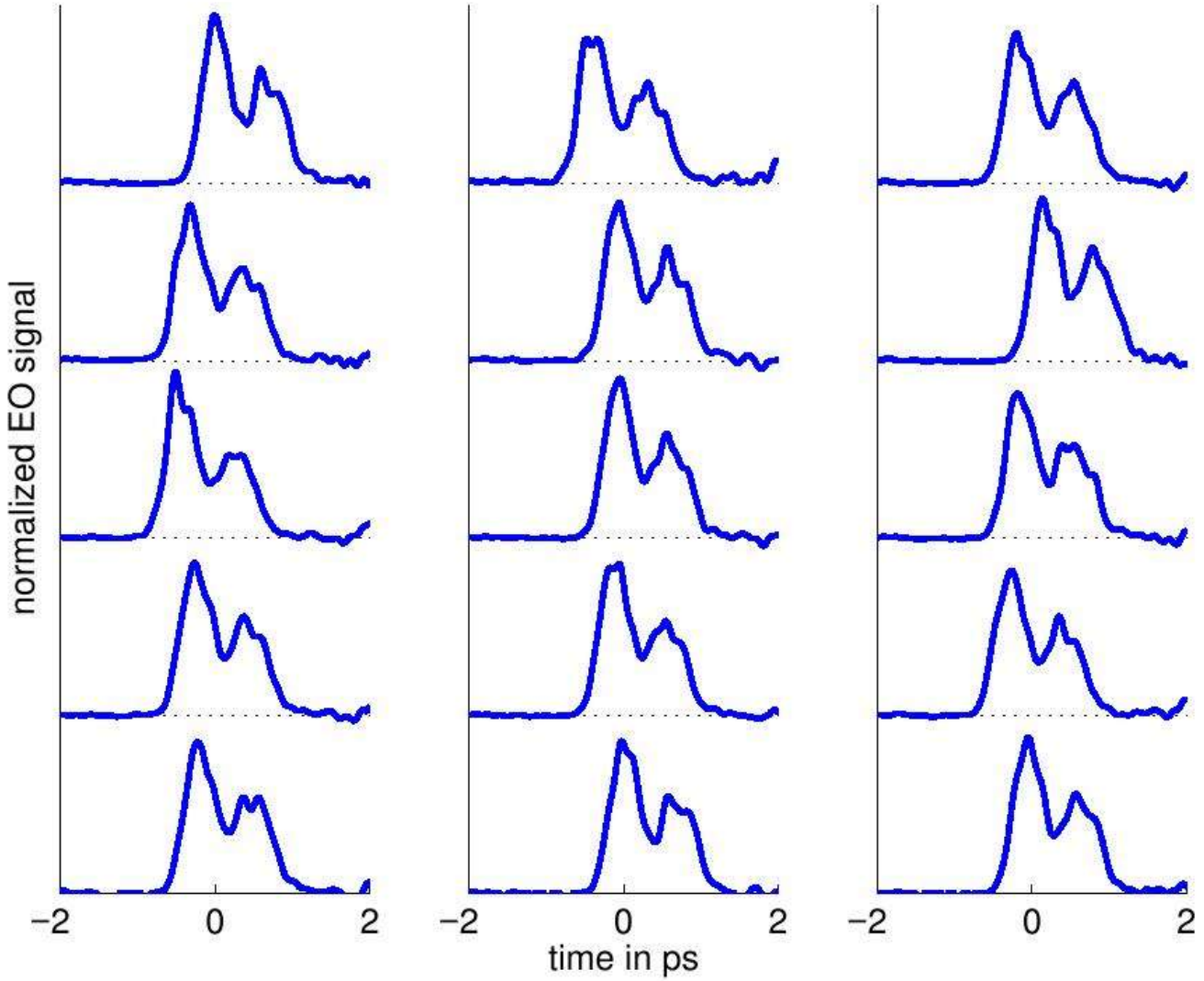
EOS Setup at DESY



Temporal Resolution

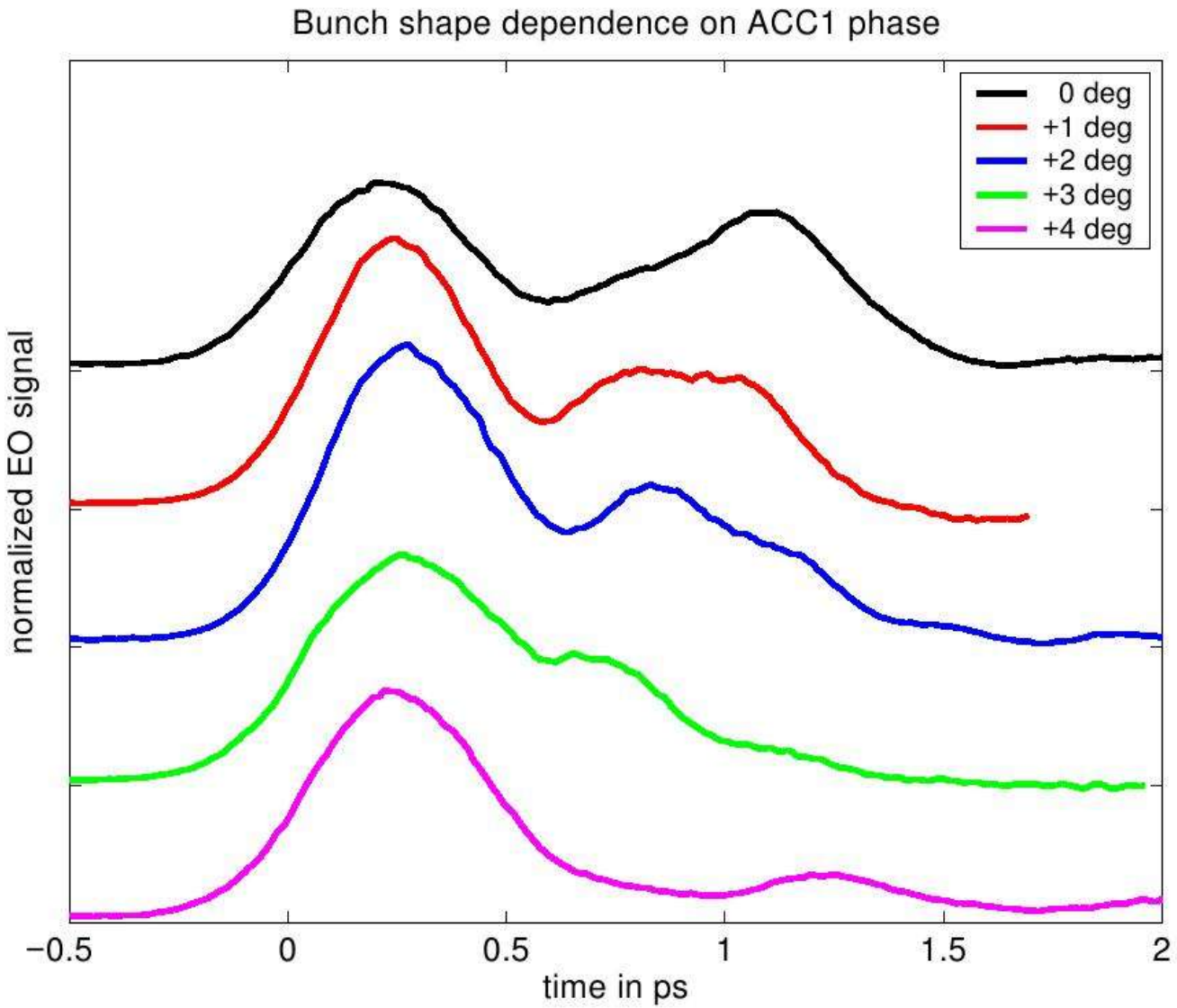
- Material and thickness of the electro-optical crystal.
  - For 300 μm thick ZnTe, lower limit is 250fs (FWHM).
- BW limited length of laser pulse.
  - For the laser that is used, bunch lengths shorter than 245 fs (FWHM) the measured profile will be distorted.
- The distance from crystal to e beam.
  - For 12mm resolution is 90 fs (rms)
- The resolution of the spectrometer and camera = 40 fs.
- Total resolution is approx 400 fs (0.12mm FWHM) or 175 fs (0.05mm rms).

Results



Single shot meausurement of 15 consecutive bunches

Results



Measurement of the bunch • field for different settings of the phase in the first accelerating module. Each line represents the average of 100 normalized and time jitter corrected single shot measurements. The leading edge of the bunch is on the left.

Conclusion

- This will be done in collaboration with the
  - A0 laser person: Jinhao Ruan.
  - Instrumentation group: Vic Scarpine and Randy Thurman-Keup.
  - ANL: Yuelin Li.
- There's lots of work to be done!!!!
  - Going to ANL to get experience with their system.
  - Calculations, simulations etc.