FCC ee Instrumentation

T. Lefevre

Outline

- Bunch length by Streak camera

- Bunch length by electo-optical sampling

- the ‘to do’ list

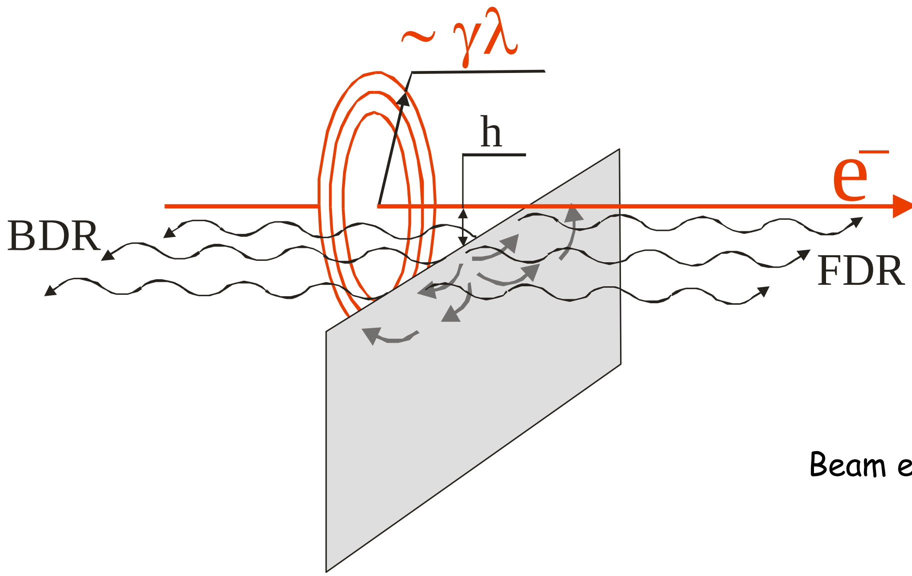
Light source to Streak Camera

- Synchrotron radiation: Should work well but photons spectrum should be calculated (for different beam energies)

- Other option
  - Optical diffraction radiation
  - Optical Diffraction cherenkov radiation

Optical diffraction radiation

'DR is generated when a charged particle passes through an aperture or near an edge of dielectric materials, if the distance to the target h (impact parameter) satisfies the condition :



Beam energy

Radiation wavelength

$$h \leq \frac{\gamma\lambda}{2\pi}$$

<u>Limitations :</u>

- Not enough photons in the visible for low energy particles : E < 1 GeV for a decent impact parameter (100μm)

T. Muto et al, ***Physical Review Letters 90 (2003) 104801***

Optical diffraction Cherenkov radiation

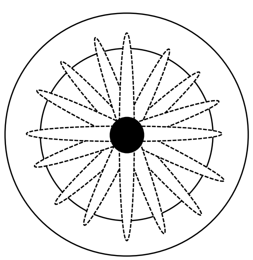
- Studying non-interceptive beam diagnostic using Diffraction Radiation for Linear Collider
  - ODR as transverse beam size monitor at CESR (Synchrotron ring - 2GeV e^-) and ATF2@KEK (extraction line- 1.2GeV e^-)

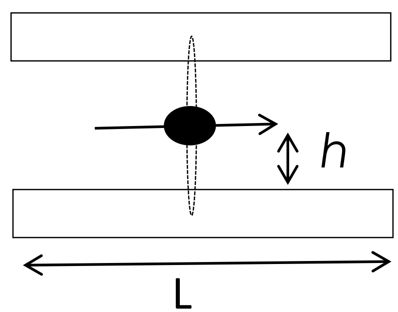
- From incoherent DR to incoherent Cherenkov DR
  - Investigation for possible use of such radiation processes for high energy hadrons and rings
  - Looking for highest possible light yield intensity using longer dielectric material rather than slit.
    - For $\gamma \gg 1$, $N_{oTR} \approx N_{oChR}$ for 1micron long radiator
    - In Visible, IR, and THZ depending on material Fused silica (SiO2), Silicon (Si) or Diamond
  - Motivated by the work of many groups present today
    - A. Potylitsyn *et al*, Journal of Physics: Conference Series 236 (2010) 012025
    - T. Takahashi *et al*, Physical Review E 62 (2000) 8606
    - M.V. Shevelev and A.S. Konkov, JETP 118 (2014) 501

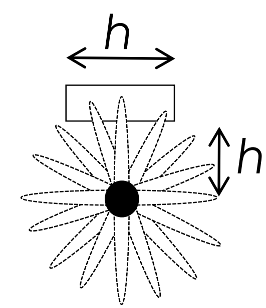
Optical diffraction Cherenkov radiation

- A simple model to estimate the radiation power spectrum and photon flux
- Combining Cherenkov angular spectrum as predicted by Tamm's theory by a weighting factor which accounts for the transverse exponential decay of the particle field

$$\frac{d^2 P}{dq\,dl} = \frac{an}{l}\left(\frac{L}{l}\right)^2 e^{\frac{-4p\cdot h}{gbl}} \left(\frac{\sin\left(\frac{pL}{bl}\left(1 - bn\cos(q)\right)\right)}{\frac{pL}{bl}\left(1 - bn\cos(q)\right)} \right)^2 \sin^2(q)$$



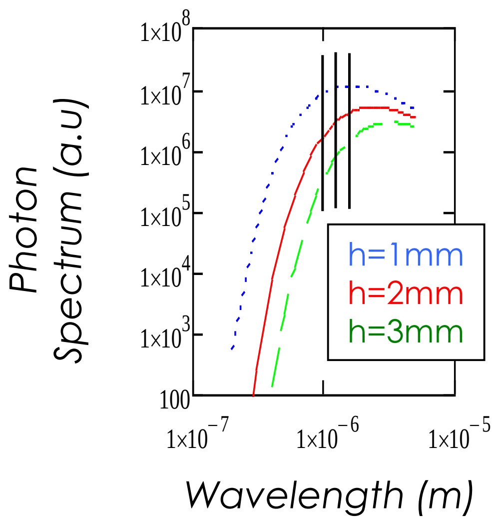




Additional reduction factor(x0.2) to take into account the smaller angular polarization field

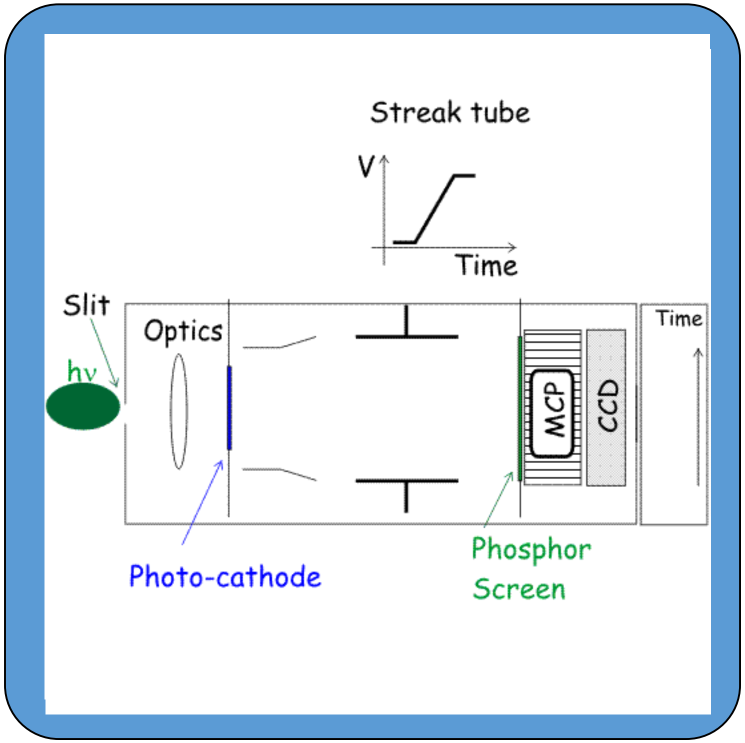
Optical diffraction Cherenkov radiation

- **Measure the Cherenkov DR photon spectrum and intensity** as function of beam position
    - 1000nm, 40nm and 10nm bandwidth
    - 1300nm, 10nm bandwidth
    - 1550nm, 10nm Bandwidth



- **Test with positron and check the light directivity**
- **Measure any possible effects on the beam**
    - CESR lifetime is around 30minutes (limited by Touschek scattering)
    - Typical SR damping time of 50ms and emittance 20pm (vert) and 3nm (hor)
        - To be compared with 2 minutes damping time for 2mm slit aperture 1cm long radiator

Streak Camera



'Streak cameras uses a time dependent deflecting electric field to convert time information in spatial information on a CCD'

Mitsuru Uesaka et al, ***NIMA 406 (1998) 371***

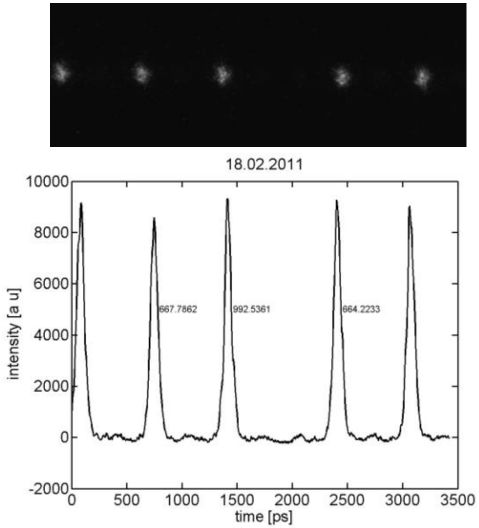
200fs time resolution obtained using reflective optics and 12.5nm bandwidth optical filter (800nm) and the Hamamatsu FESCA 200

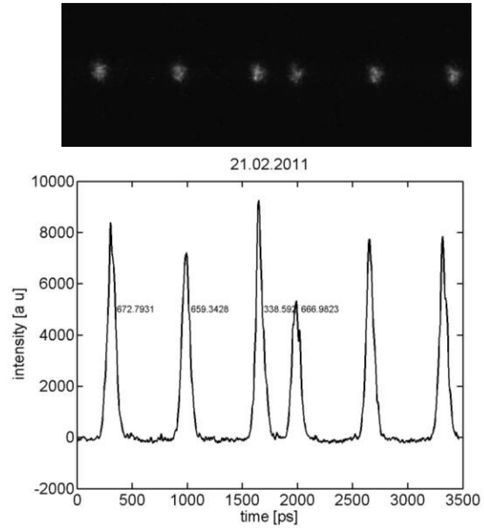
Limitations : Time resolution of the streak camera :

(i) Initial velocity distribution of photoelectrons : *narrow bandwidth optical filter*
(ii) Spatial spread of the slit image: *small slit width*
(iii) Dispersion in the optics

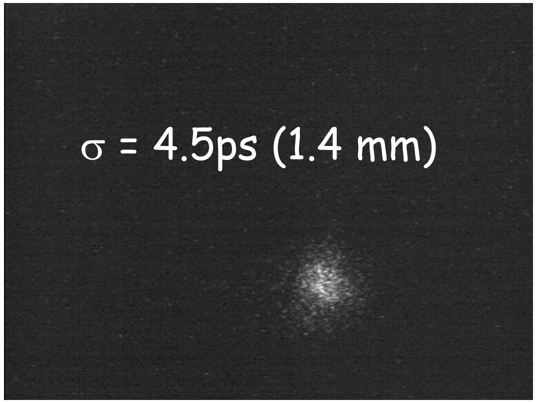
Streak Camera

Observation of 5MeV electron bunch train using cherenkov
Sweep speed of 250ps/mm

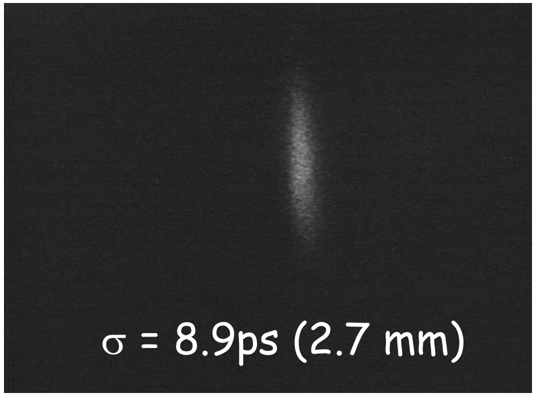




Measure of bunch length using OTR and OSR

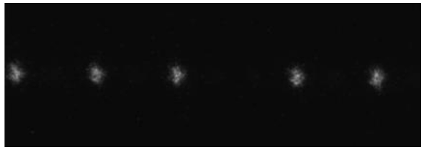


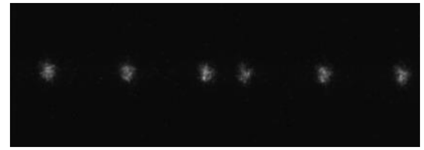
Sweep speed of 10ps/mm

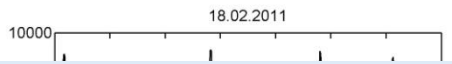


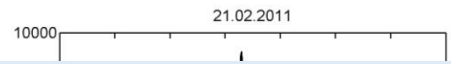
Streak Camera

Observation of 5MeV electron bunch train using cherenkov
Sweep speed of 250ps/mm

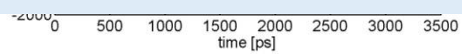


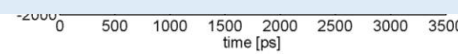




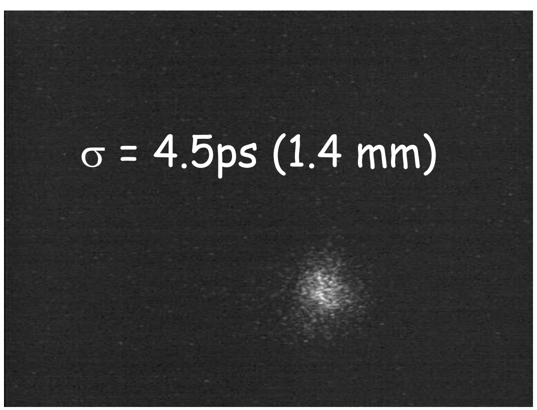


For FCC:
- Need to average to get to the required resolution
- Additional difficulty: to measure long bunch with best resolution due to the finite size of the camera

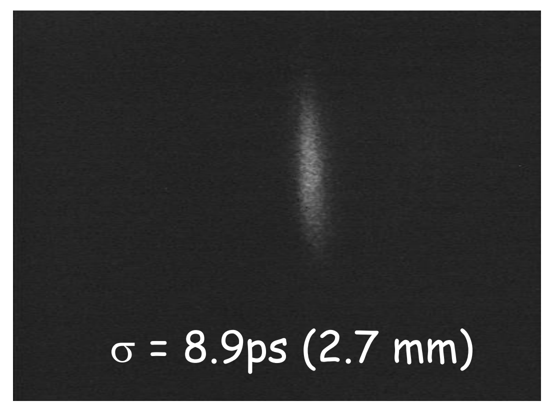




Measure of bunch length using OTR and OSR



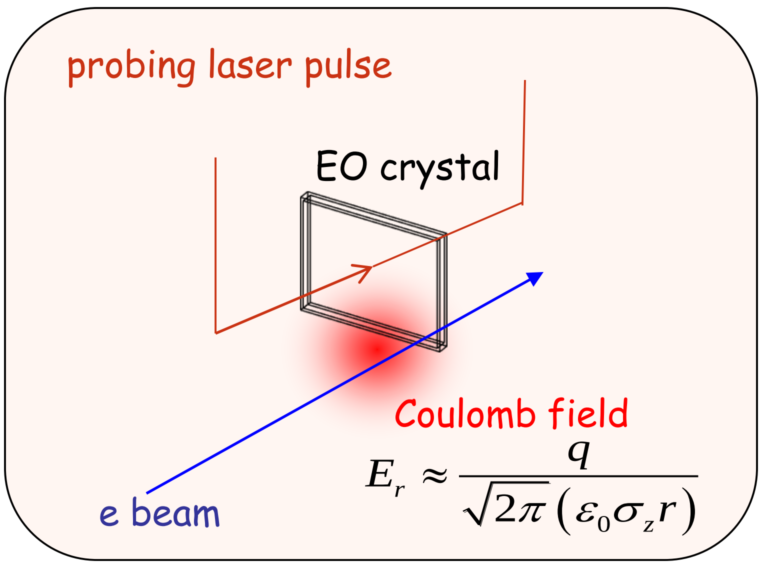
Sweep speed of 10ps/mm



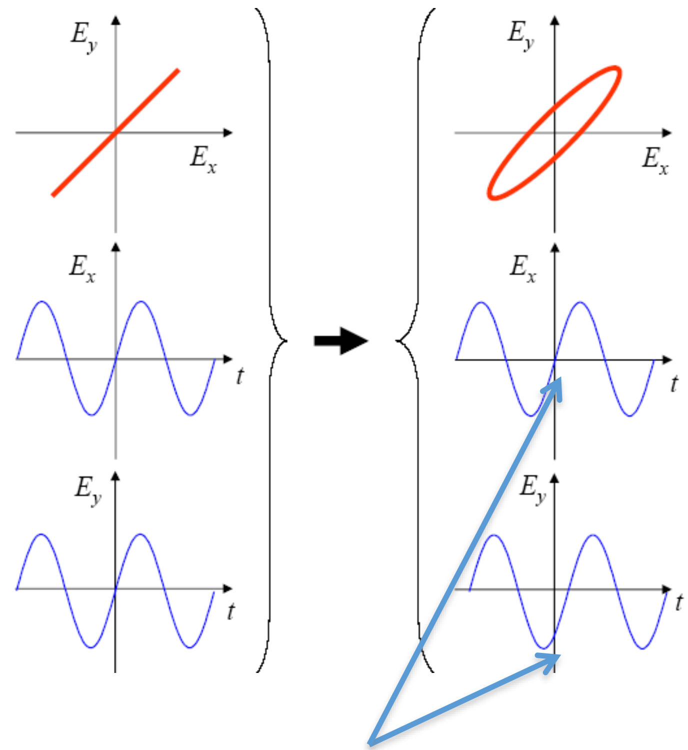
Electro optical detection

'This method is based on the polarization change of a laser beam which passes through a crystal itself polarized by the electrons electric field'

E-field induced birefringence in EO-crystal : Pockels effect



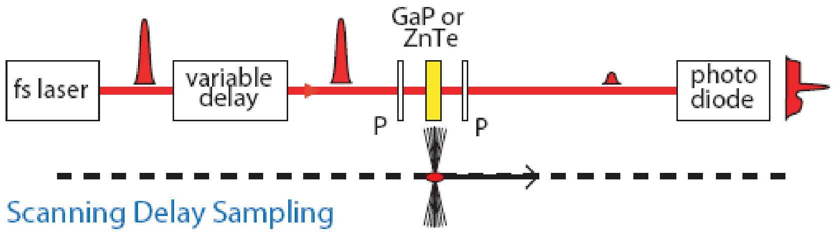
- Polarization diagram
- electric field of the horizontal polarization
- electric field of the vertical polarization



$$G = \frac{2pd}{l_0}\left(n_x - n_y\right) = \frac{2pd}{l_0} n_0^3 r_{41} E_r$$

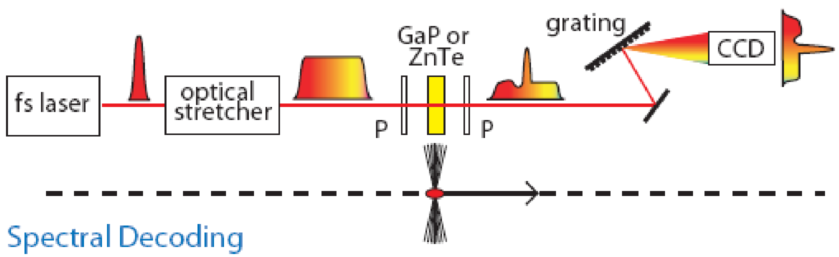
Relative phase shift between polarizations increases with the beam electric field

Electro optical detection



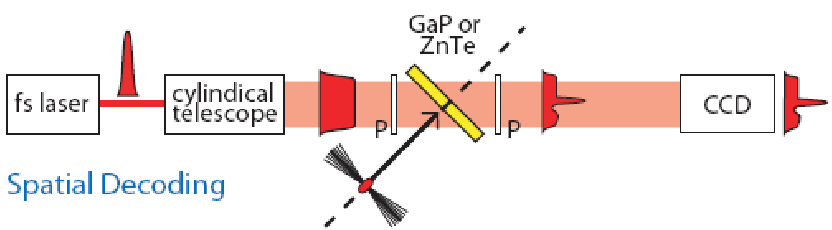
1. Sampling:
- multi-shot method
- arbitrary time window possible

1



2. Chirp laser method, spectral encoding
- laser bandwidth limited~ 250fs

Wilke *et.al.*, PRL 88 (2002) 124801

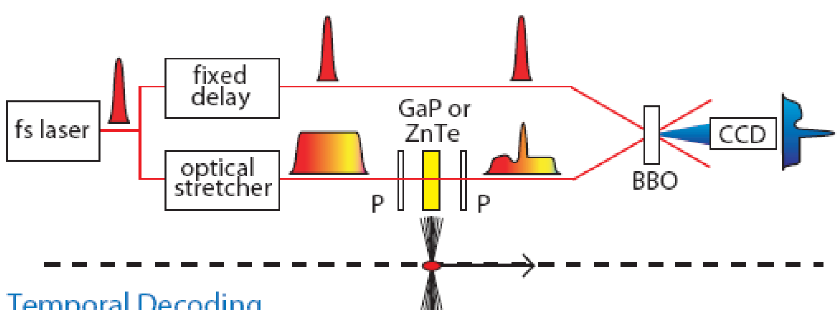


3. Spatial encoding:
- imaging limitation ~ 30-50 fs

Cavalieri *et. al*, PRL 94 (2005) 114801

Jamison *et. al*, Opt. Lett. 28 (2003) 1710

Van Tilborg *et. al*, Opt. Lett. 32 (2007) 313

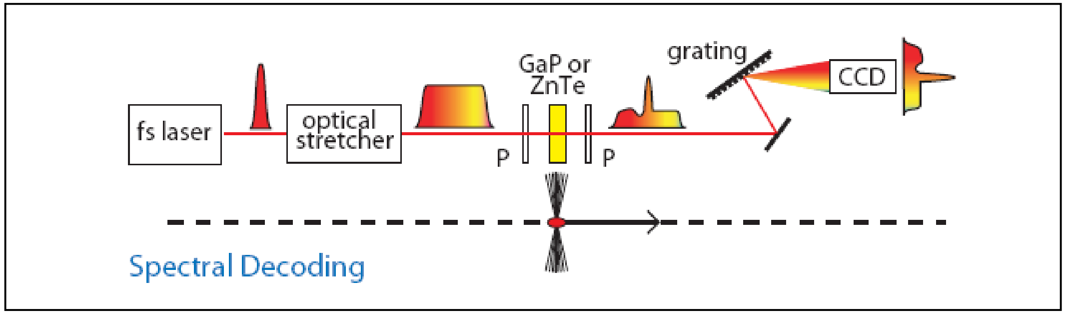


4. Temporal decoding:
- laser pulse length limited ~ 30fs

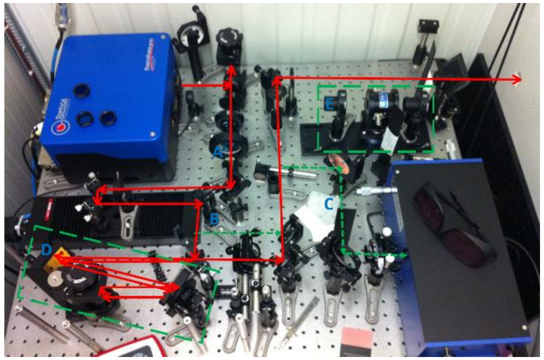
Berden *et.al*, PRL 93 (2004) 114802

Electro optical detection

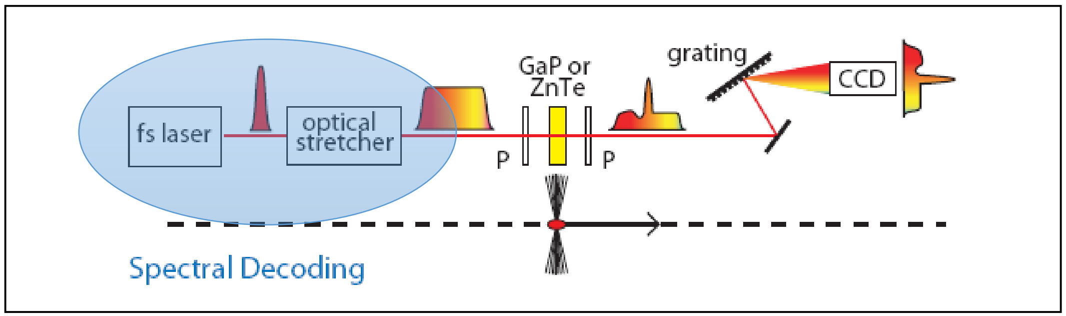
Electro- **O**ptical **S**pectral **D**ecoding Technique
Single shot bunch length measurement



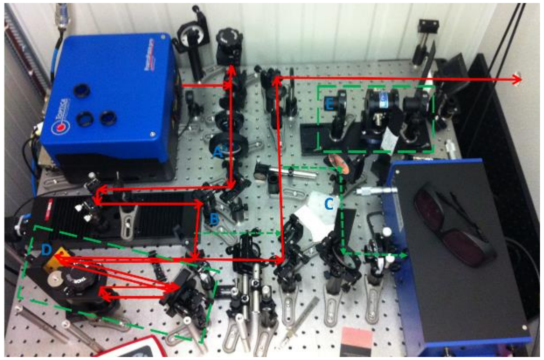
Electro optical detection



Er laser
780nm
150fs – 12ps



Electro optical detection



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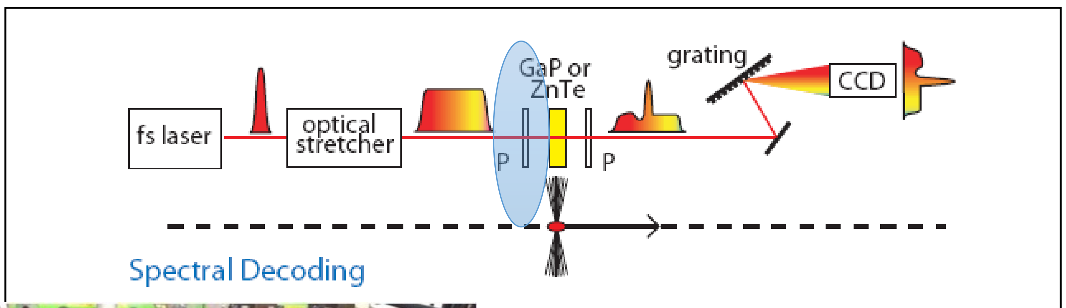
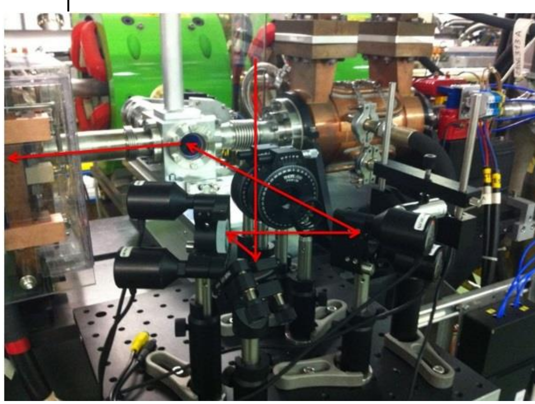
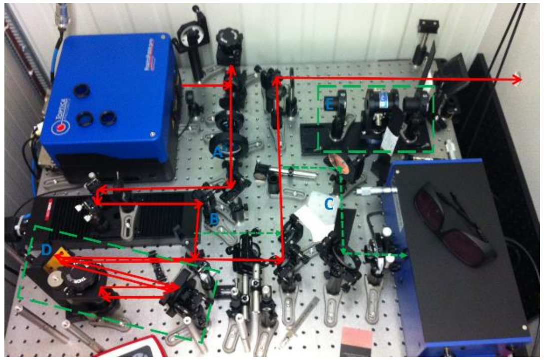




First polariser and Laser injection Chamber

Electro optical detection



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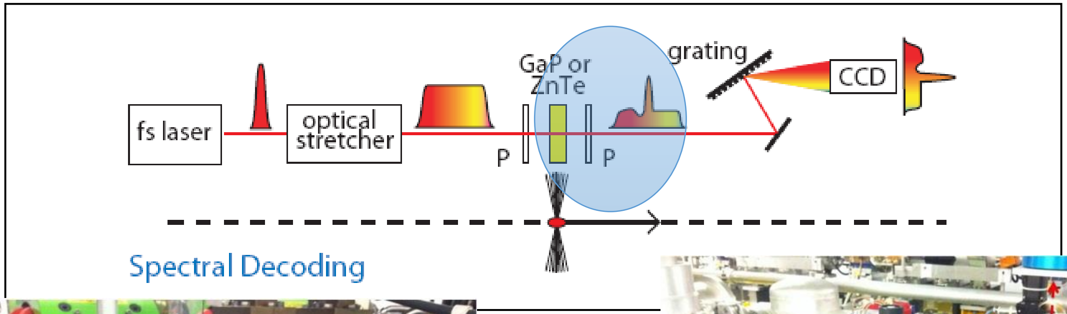
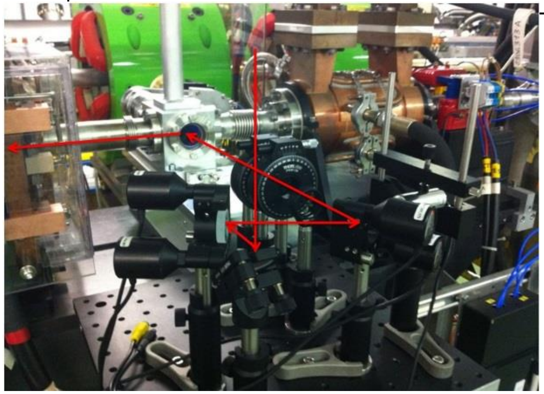
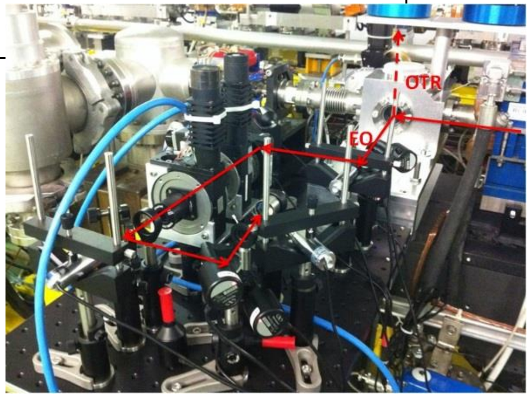


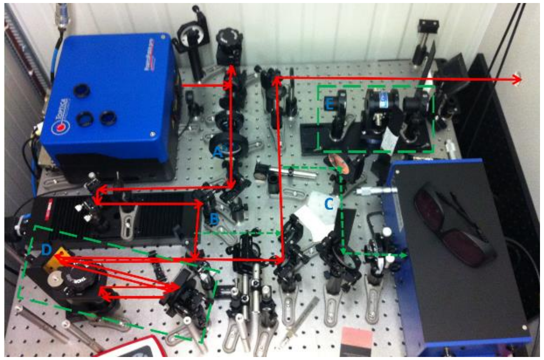


First polariser and Laser injection Chamber

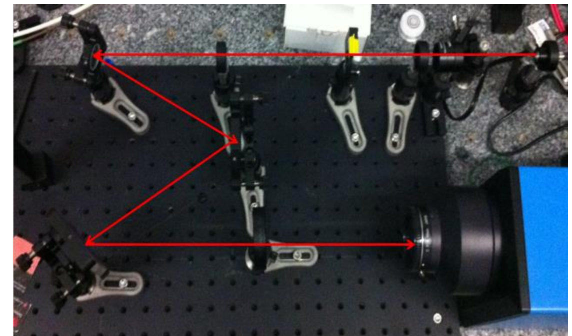


Crystal chamber (4mm ZnTe), crossed polariser and fiber coupling

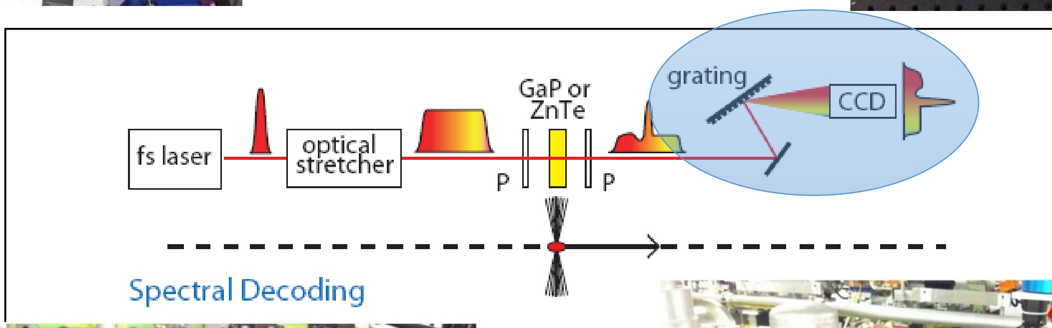
Electro optical detection

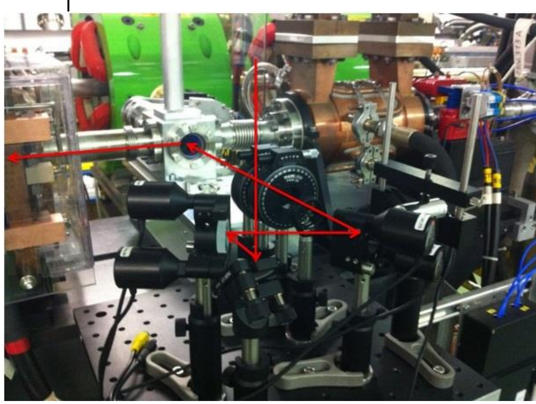


Er laser
780nm
150fs – 12ps

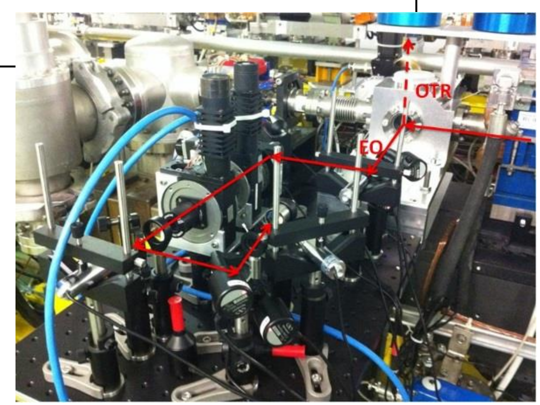


Spectrometer with grating and intensiifed gated CCD camera





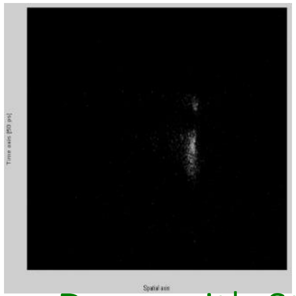
First polariser and Laser injection Chamber

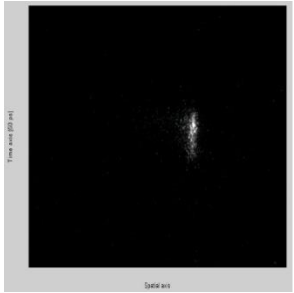


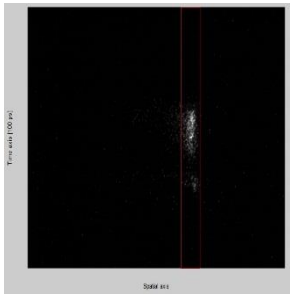
Crystal chamber (4mm ZnTe), crossed polariser and fiber coupling

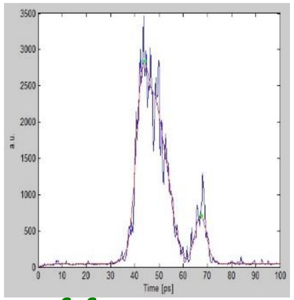
Electro optical detection

1 – Laser-electron beam synchronization





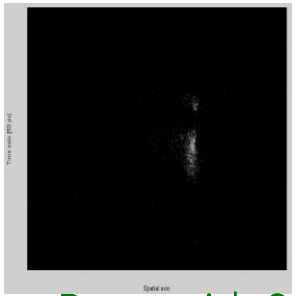


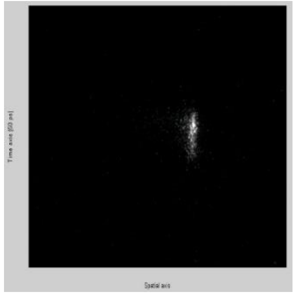


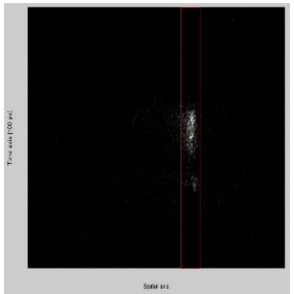
Done with Streak camera measurements with an accuracy of few ps

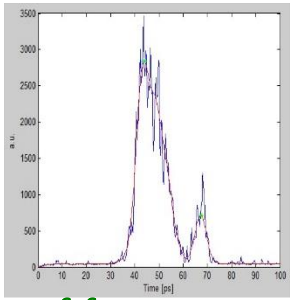
Electro optical detection

<u>1 – Laser-electron beam synchronization</u>







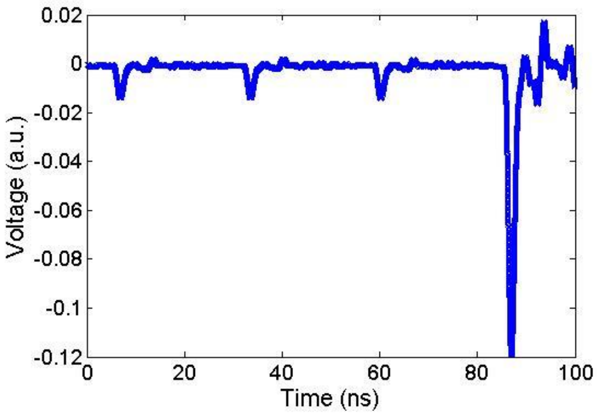


Done with Streak camera measurements with an accuracy of few ps

<u>2 – EO measurements</u>

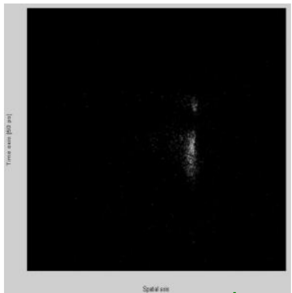
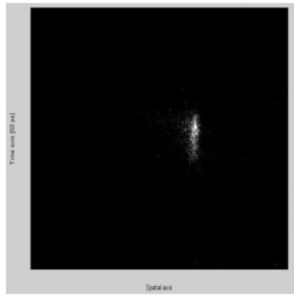
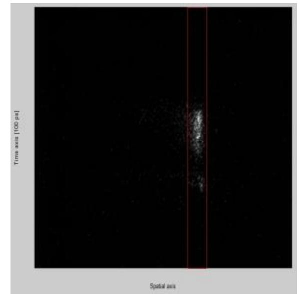
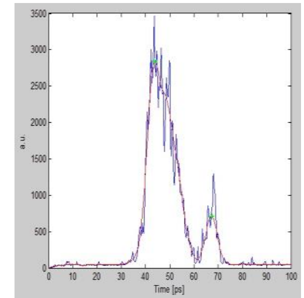
- First optimizing the EO signal intensity using a PMT and scope

  The laser is pulsed every 26ns



Electro optical detection

1 – Laser-electron beam synchronization

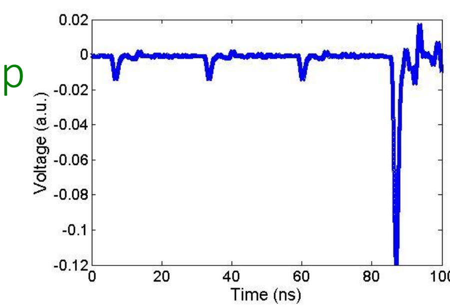





Done with Streak camera measurements with an accuracy of few ps

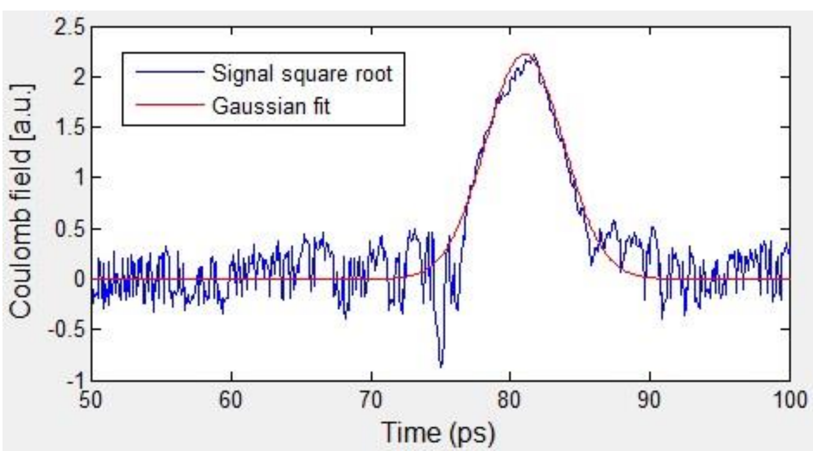
2 – EO measurements

- First optimizing the EO signal intensity using a PMT and scop

  The laser is pulsed every 26ns



- Then measuring bunch length with spectrometer



- 6.6ps FWHM, 0.35nC bunch charge
- Measured down to 0.1nC per bunch
- S/N ratio was 2-3 times better than streak camera measurements

THE 'TO DO' LIST

- INVESTIGATE SOURCE OF LIGHT OPTION
  - OSR, ODR, OCHDR

- TEST STREAK CAMERA (200fs) with 10ps bunch or laser pulse
  - Investigate the interplay between the noise/integration time and resolution

- EOS :
  - Conceptual design of a light spectrometer to provide high resolution for long bunches
  - Possibly test on CLEAR @ CERN
  - Synergy with the current R&D from CLIC and AWAKE