BI Day----Convention Centre of Archamps
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Electro-Optic Bunch Profile Monitor for the CERN-CTF3 probe beam

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DITANET

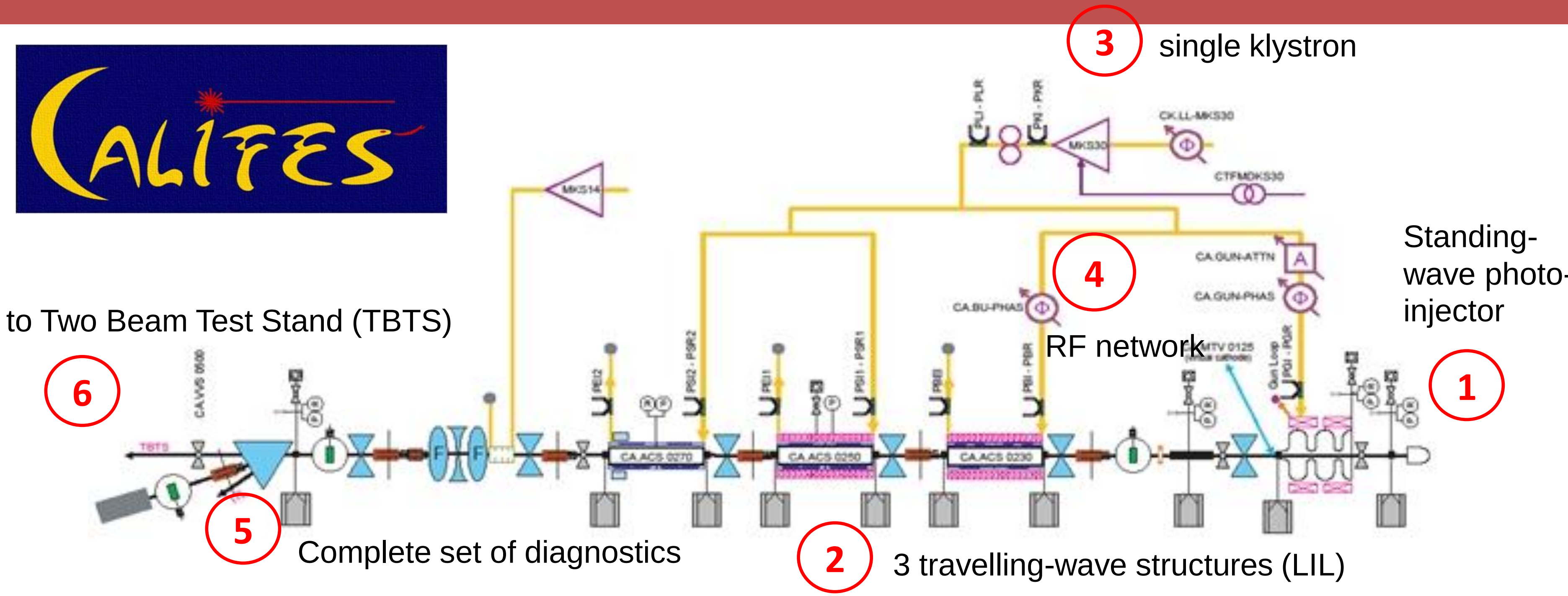
MARIE CURIE ACTIONS

PEOPLE

Outline

- Introduction for CALIFES
- EOSD principle and Simulation
- EO bunch profile monitor system
- Resolution
- Summary

Introduction ---- CALIFES



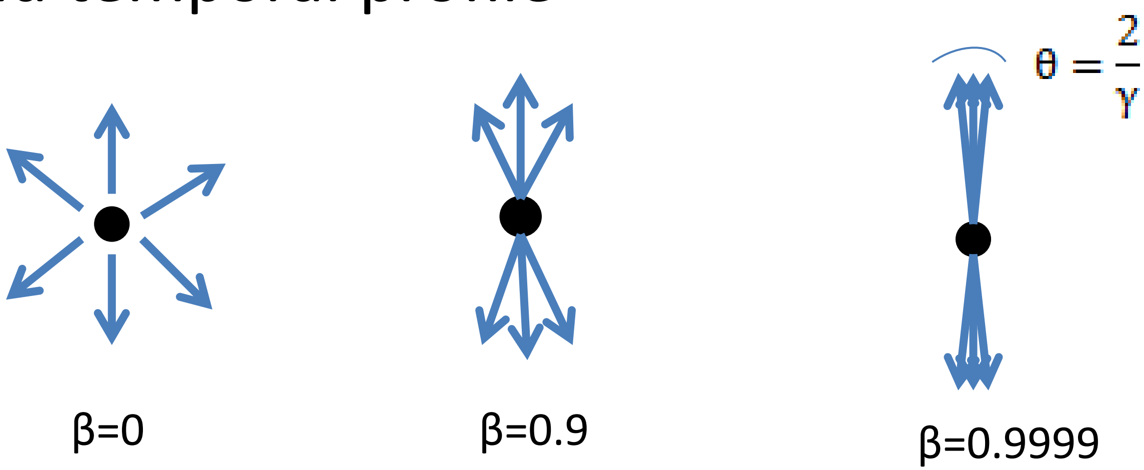
Energy	**200 MeV**
Train duration max.	140ns
Train rep. rate	5 Hz
Bunch length	8-10 ps (1.4 ps)
Bunch rep. rate	1.5 GHz
Bunch charge	0.1–0.05nC (0.6 nC)

Existing bunch profile monitor:

1. Deflecting cavity (bunch head downward, tail upward)
2. Bunch length measurement with an acceleration structure (bunch head decelerated, tail accelerated)

Coulomb field of e-bunch

Coulomb field temporal profile



$$E_{e0}(r_0,t)=\frac{e_0\gamma}{4\pi\varepsilon_0}\cdot\frac{r_0}{(r_0^2+\gamma^2 v_e^2(t-t_0)^2)^{3/2}}$$

Coulomb field of one electron

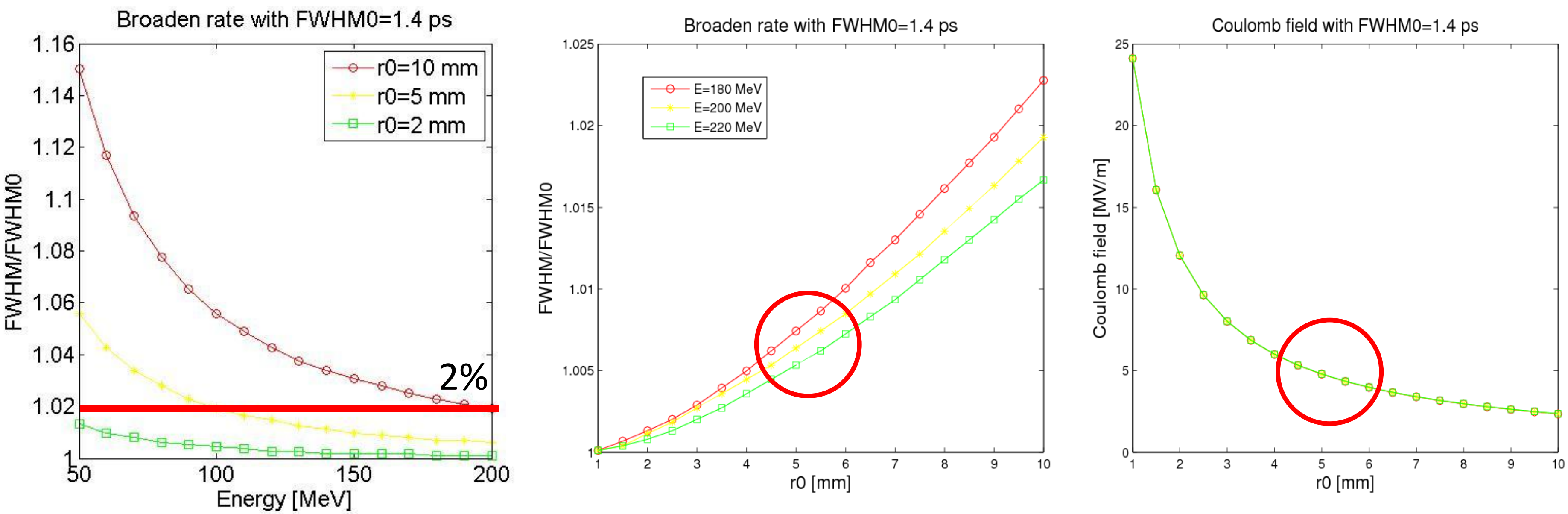
- High energy , Coulomb field temporal profile is approximately the bunch temporal profile
- Broadening of profile: $\Delta t \sim \frac{2r}{\gamma}$

Simulation: Coulomb field of e-bunch

Coulomb field temporal profile and broadening

$$E_{Colm} = E_{e0} * \rho$$

- Radial offset from single electron E_{e0}
- Electrons' density distribution within one bunch ρ
- Convolution



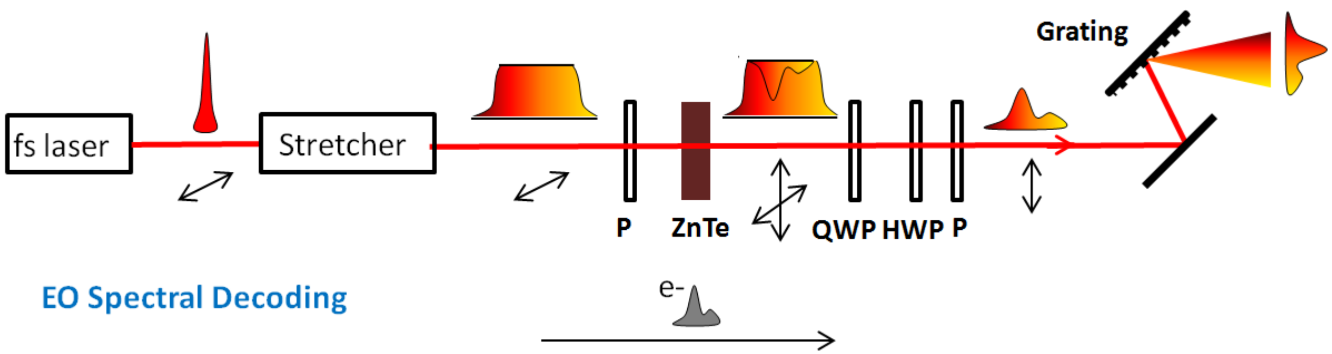
For high energy beam (200 MeV):
Broadening rate < 2% @ 10 mm

r0: the distance far away from e-bunch

Damage to crystal ← Closer — Further → Crystal survives, low Coulomb field

Simulation: EOSD

Electro-Optical Spectral Decoding:



EO bunch profile measurements:

--EO spectral decoding

--EO temporal decoding

--EO spatial encoding

--EO up conversion

- Linear chirped optical pulse
- Polarization variation caused by Coulomb field—laser nonlinear effect
- Polarization → Intensity, by two crossed polarizers
- I(λ) ←→ I(t)

$$E_{out} = (0 \quad 1) R(\varphi) M_{hw} R(-\varphi)\, R(\alpha) M_{qw} R(-\alpha)\, R(\theta) M_{EO} R(-\theta) \begin{pmatrix} E_{opt}^{chirp}(f) \\ 0 \end{pmatrix}$$

$R(\theta)$---- rotation matrix

M_{qw}----Jones matrix for quarter waveplate

M_{hw} ----Jones matrix for half waveplate

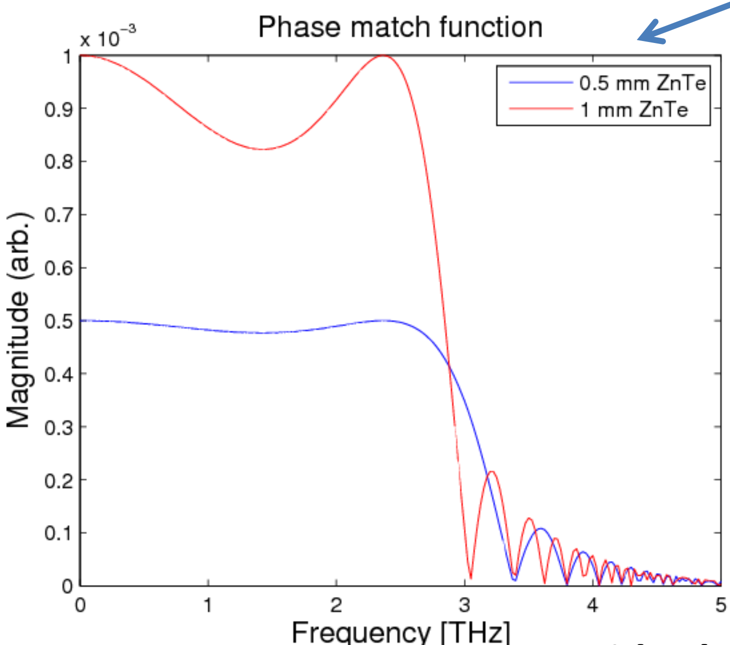
Simulation: EO phase mismatching

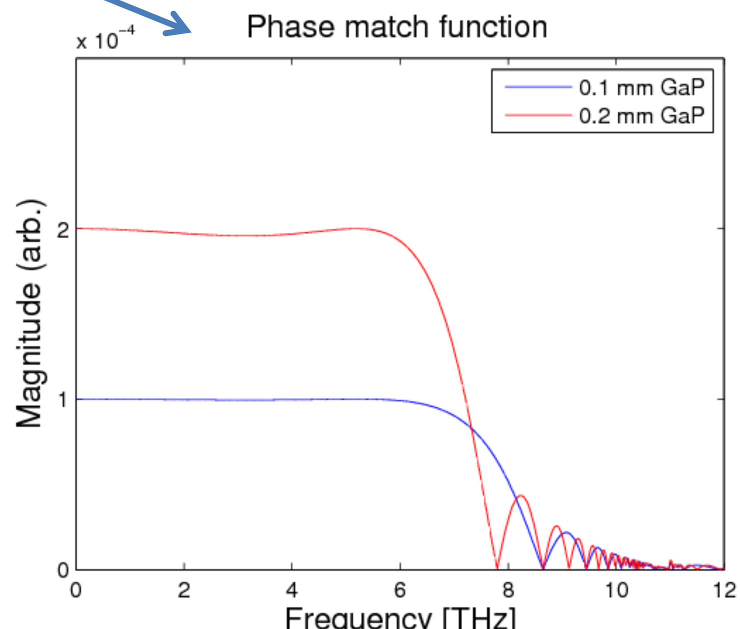
EO effect: **Frequency mixing** —induce→ **Polarization variation**

$$\tilde{E}_{sum}(z,\omega) = \frac{i\omega^2}{2c^2 k^R_{opt}(\omega)} \exp\left[ik_{opt}(\omega)z\right]$$

$$\times \int_{-\infty}^{+\infty} d\Omega \left\{ \chi^{(2)}_{eff}(\omega,\Omega) \left[\frac{\exp(i\Delta k(\omega,\Omega)z)-1}{i\Delta k(\omega,\Omega)}\right] \times \tilde{E}_{THz}(0,\Omega)\tilde{E}_{opt}(0,\omega-\Omega) \right\}$$

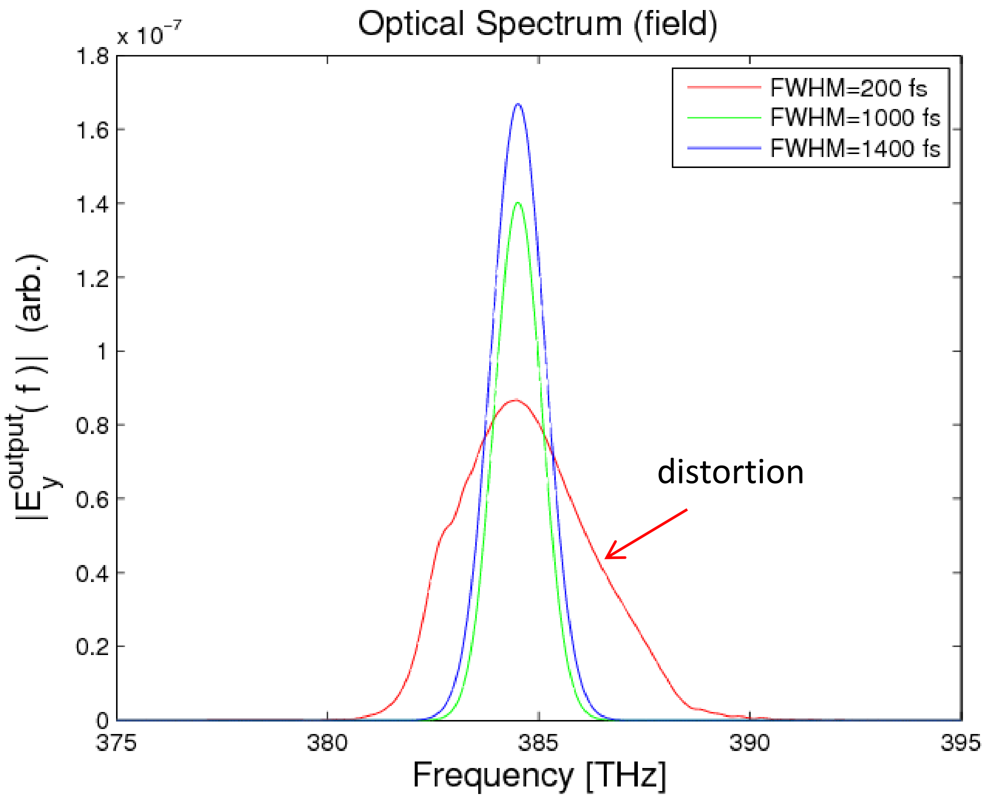
Coulomb field Laser





Wider bandwidth, better resolution !

Simulation: EOSD results and limitation

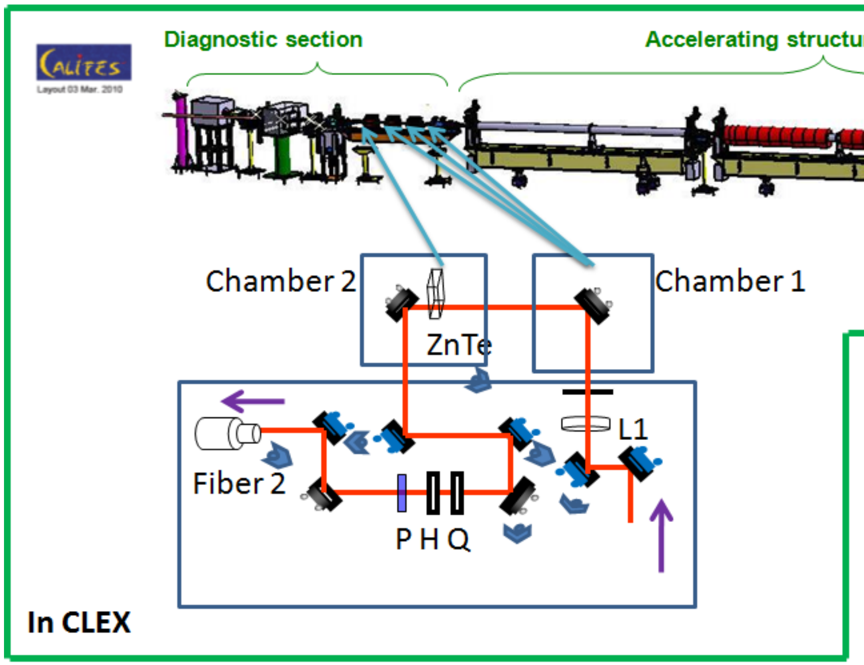


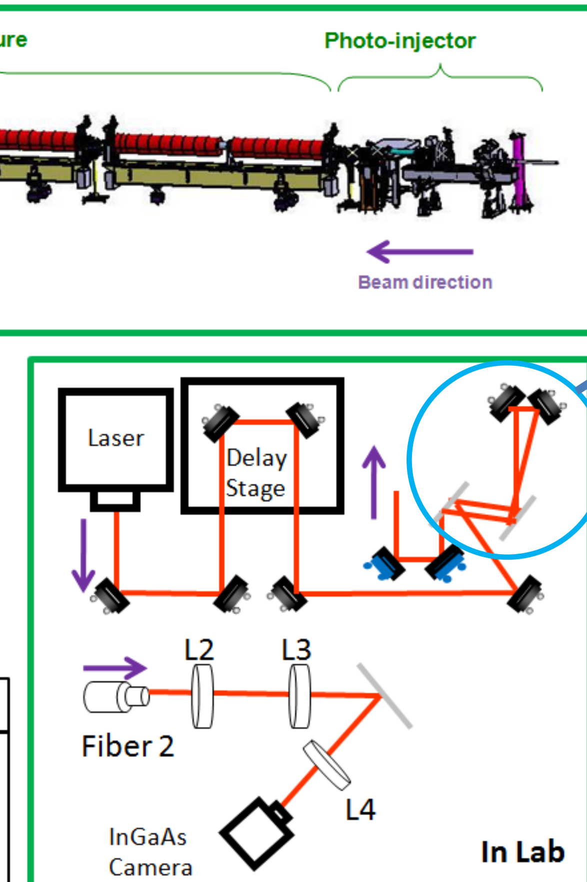
Other parameters:
Laser wavelength: 780nm
Laser pulse energy: 1.5nJ
Pulse duration: 150fs

Crystal thickness: 1mm
Distance: 5mm

Short bunch----fast temporal modulation---- spectral content ---- t~λ mapping

EO monitor Design for CALIFES





In CLEX		In Lab	
10 Motors 3 Rotate motors 6 Pinhole cameras	7 plane mirrors 2 polarizers 3 wave plates 1 lens 1 fiber head 2 photodiodes	1 Laser 1 InGaAs Camera 1 motor stage 4 Motors	10 plane mirrors 3 gratings 3 lens 1 fiber head

Scheme

Stretcher:
- SF11 glass
- 100fs----3.24ps

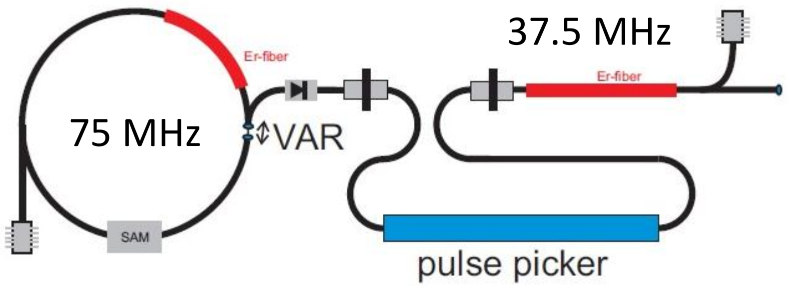

Actuator


Cameras


Rotation stage

Laser system

Laser system

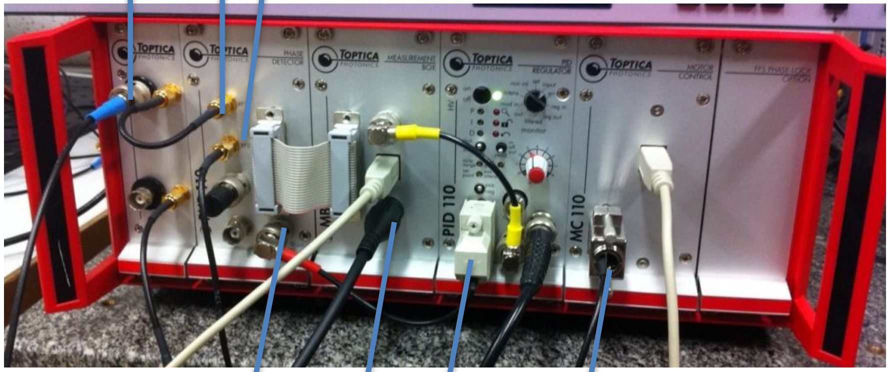


Custom Erbium fiber laser with pulse picker

Laser head and controller

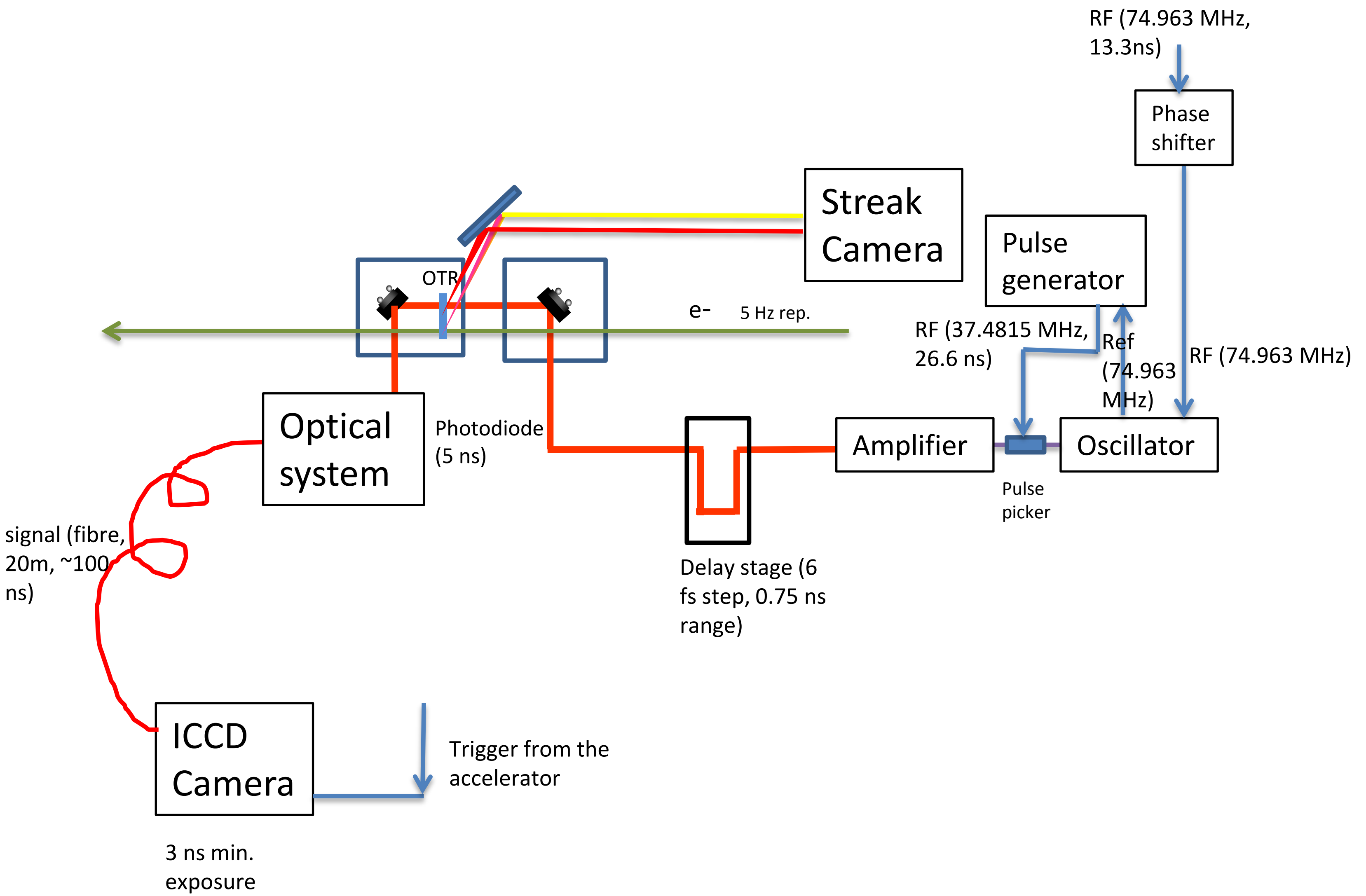
Fundamental wavelength	**1560 nm**
Laser output power	> 350 mW
Pulse width	< 120 fs
Repetition rate	37.482 MHz
Second-harmonic wavelength	780 nm
Laser output power	> 120 mW
Pulse width	< 120 fs
Beam size (1/e²)	Typ. Ø 1.2 mm (780 nm) Typ. Ø 3.5 mm (1560 nm
Beam divergence	< 1 mrad (780 nm) < 2 mrad (1560 nm)

PID: Proportional Integral Differential



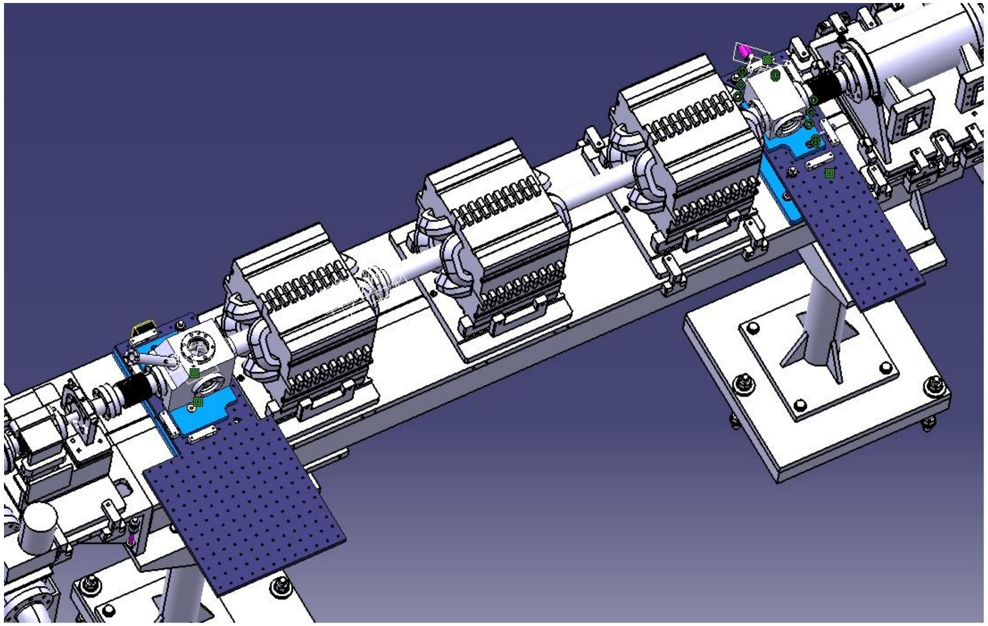
Synchronization box

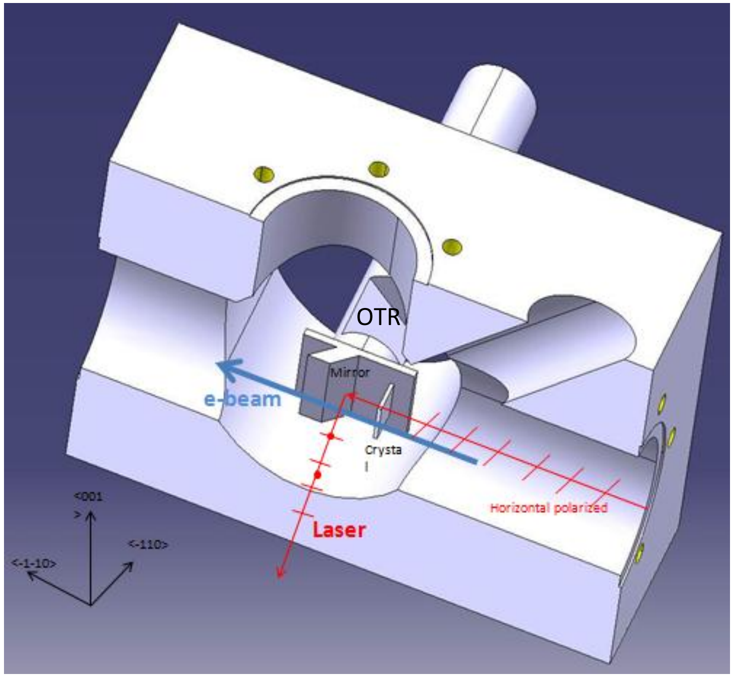
Timing and synchronization scheme



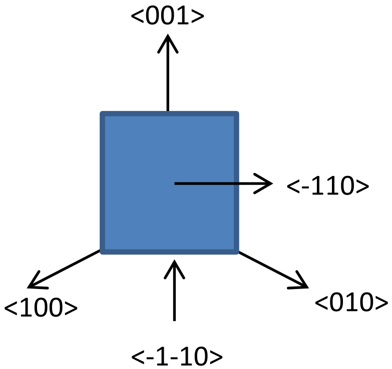
EO monitor Design for CALIFES

Chamber design



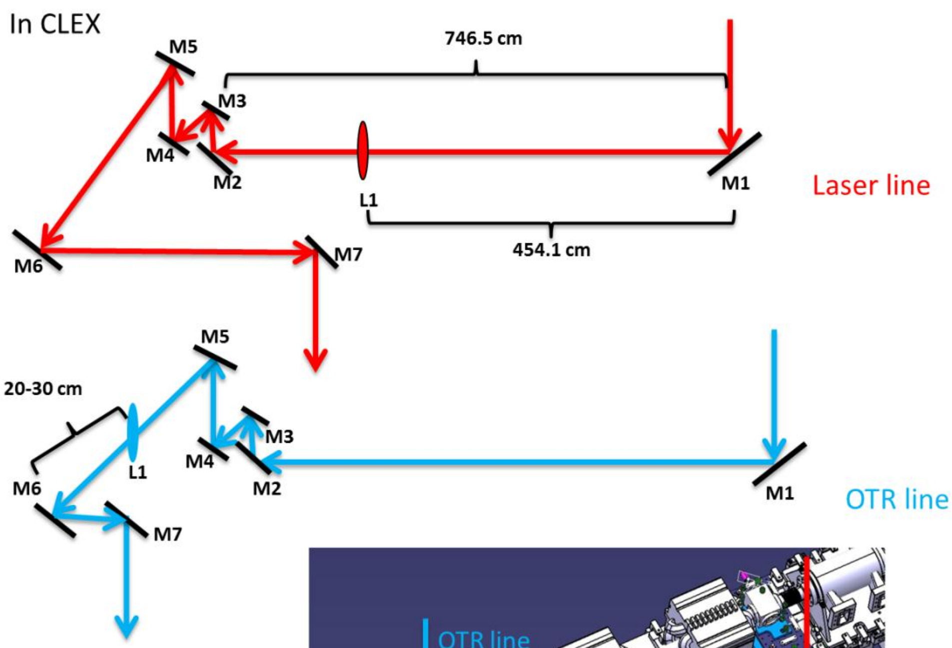


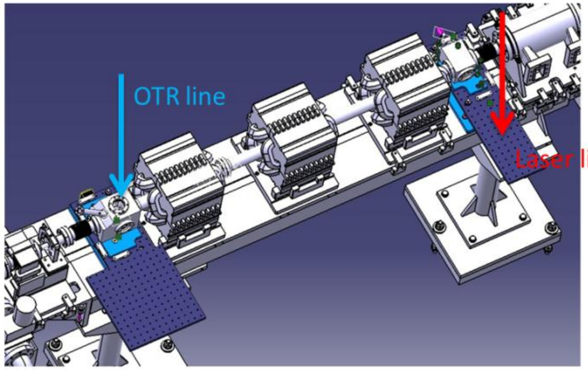
First chamber includes a mirror
The second chamber includes a mirror, a crystal and a OTR screen

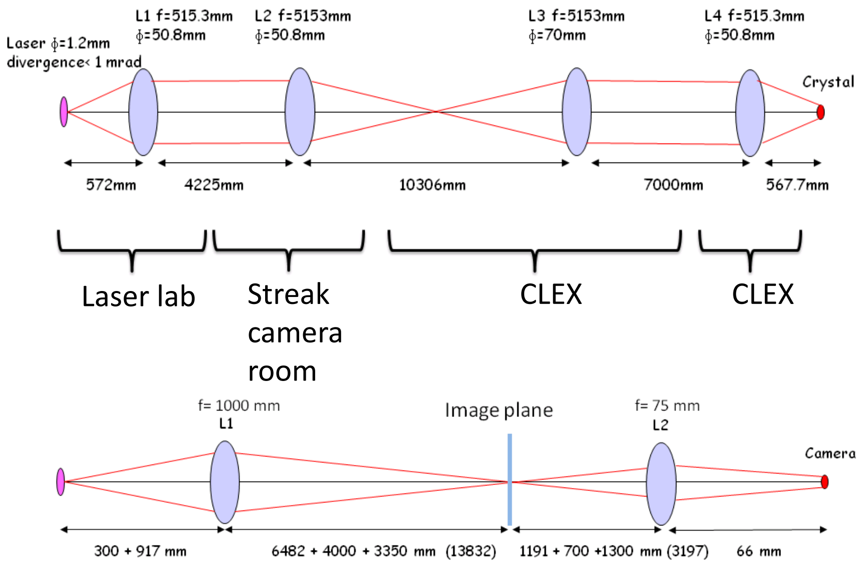


Crystal orientation

Laser/OTR Transfer Line







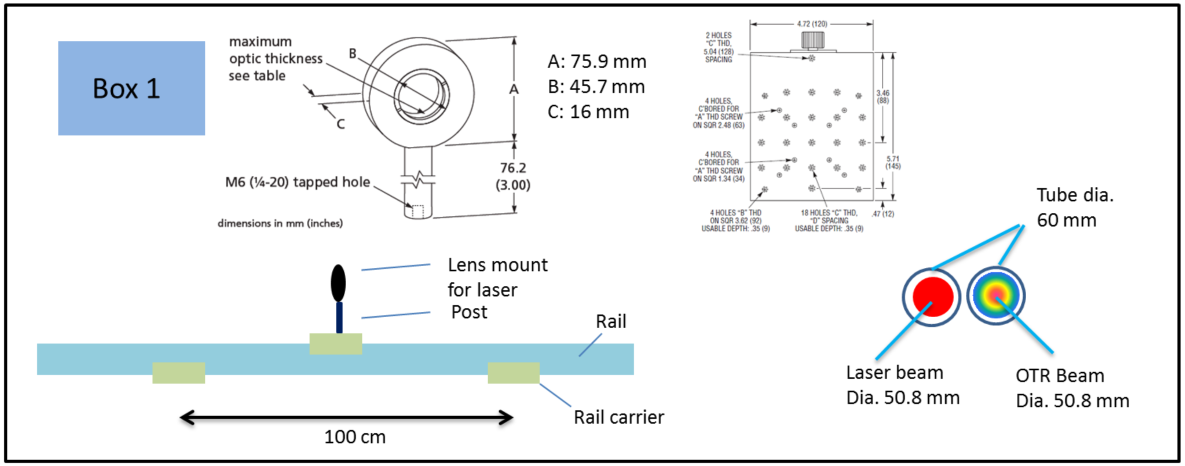
We transfer the 780nm fs laser from our laser lab (building 2010-1-002) to CLEX, and transfer the OTR photons from CLEX to our lab.

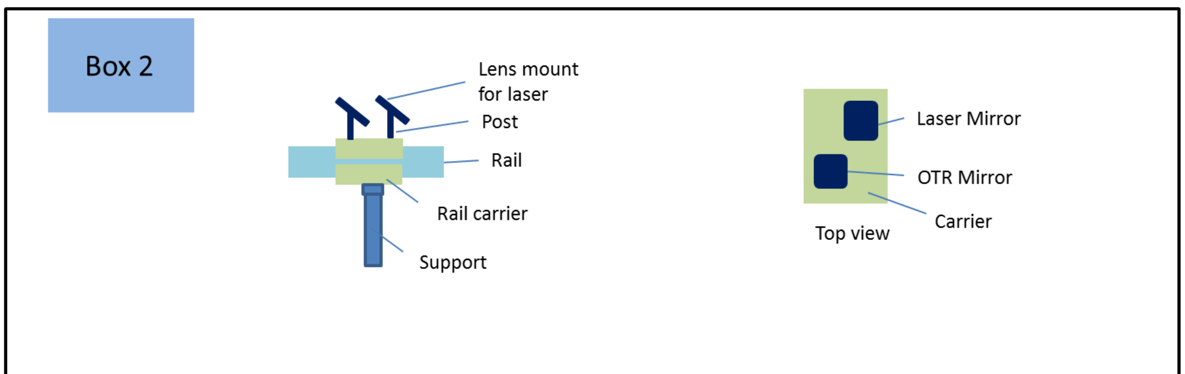
Laser/OTR Transfer Line 2

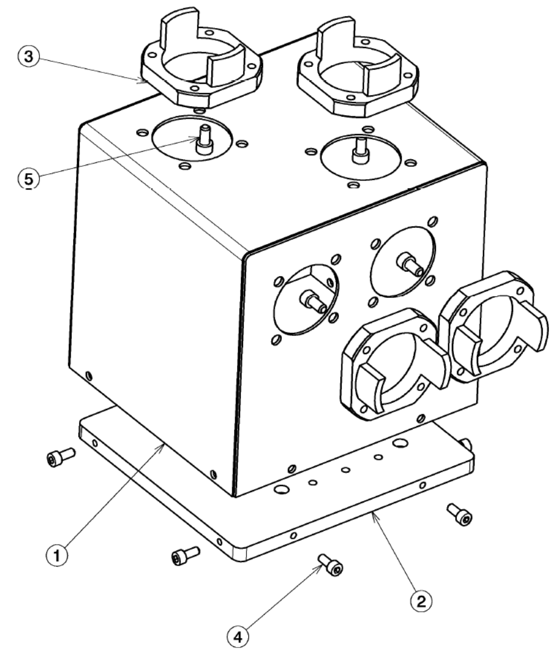
Installation:

Take the box1 and box2 for example

Box details:

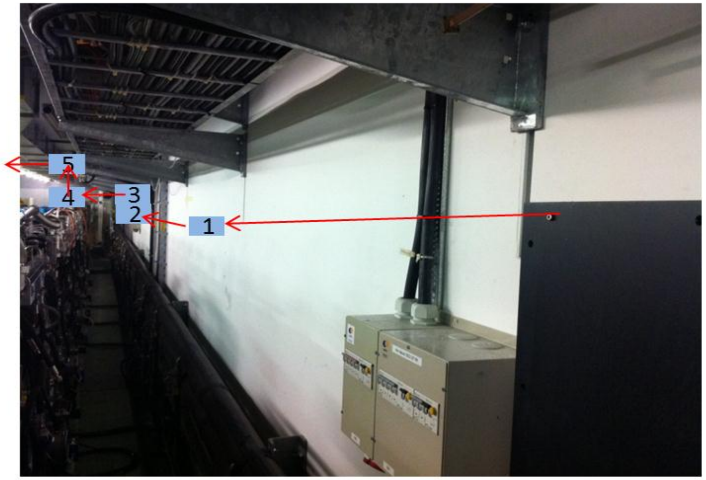


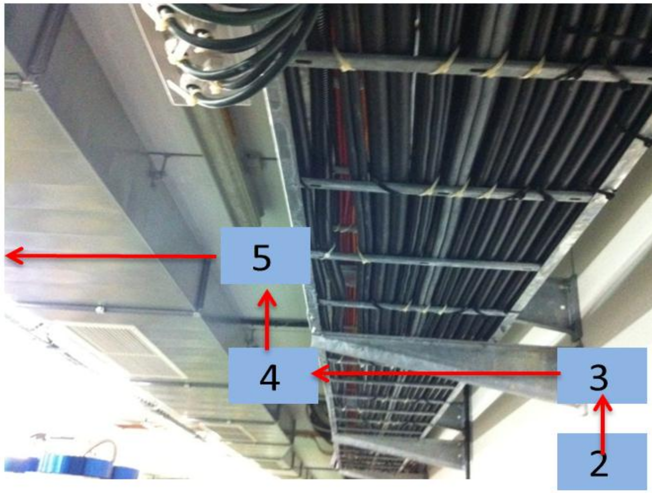


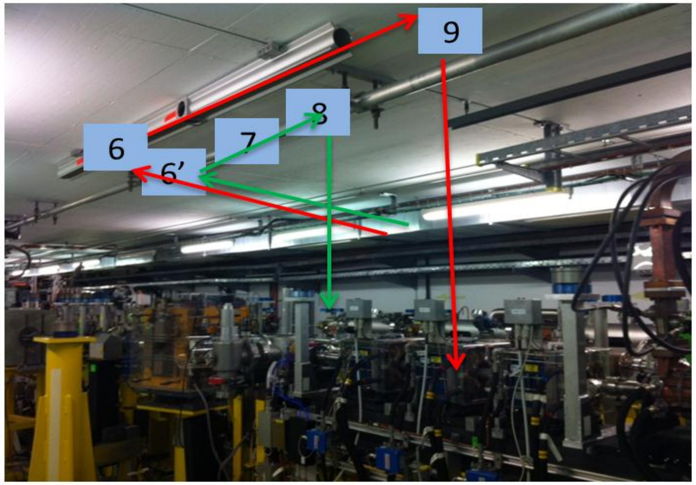


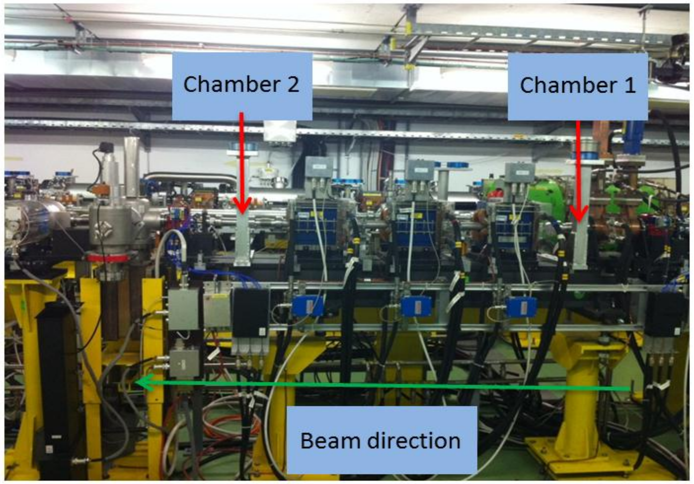
Mirror/lens cover box

Laser/OTR Transfer Line 3

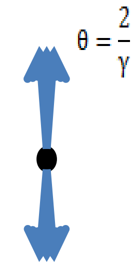








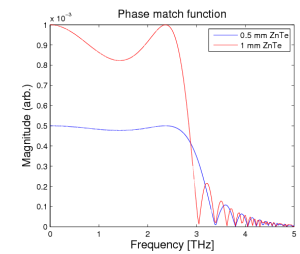
Expected Resolution



1. Distance between crystal and e-beam

$$\Delta t \sim \frac{2r}{\gamma}$$ ~10 fs at r=5 mm

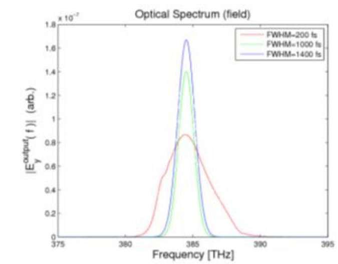
2. The frequency response of crystal (material and thickness)



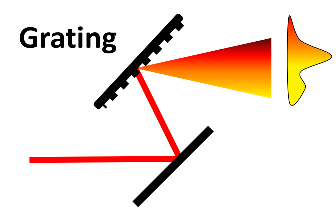
for 1 mm ZnTe: ~333 fs ~1/(3THz)

3. EOSD limitation (Laser pulse duration and chirped duration)

$$\tau_{\lim} = \sqrt{\tau_0^{FWHM} \tau_c^{FWHM}}$$ ~550 fs (100 fs→3 ps)



4. Resolution of spectrometer and CCD ~40 fs (512 pixels)



Summary & Outlook

Summary:

- EO technique is a non-destructive testing technique, and has the feasibility in fs resolution.
- System simulation, designs of laser system, transfer line, chambers, detection system and timing and synchronization have done.
- Based on numerical simulation, the resolution of this system is expected to be sub-picosecond.

Outlook:

- The system waiting for being installed during the winter shut down. First measurement in the beginning of next year.
- Resolution improvement study

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Thank You !

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