The first electron bunch measurement by means of DAST organic EO crystals

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JASRI / SPring-8

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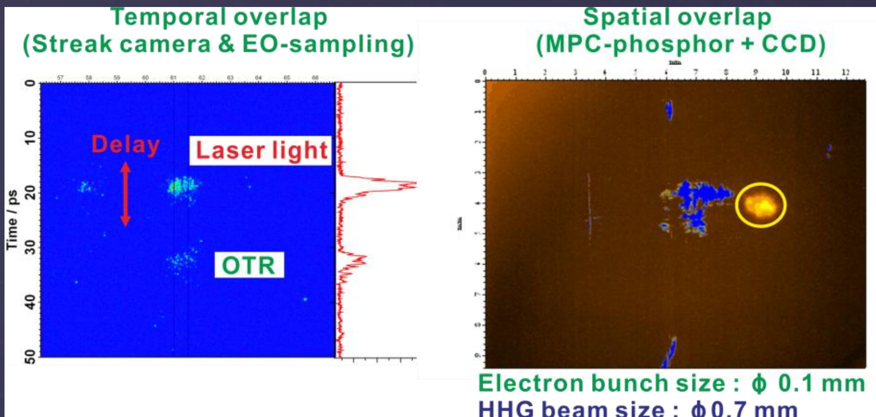
Contents

Introduction / motivation

Keys to success the experiment
w/ HHG-seeded FEL amplification :

1) Full coherent light source
   → both temporal & spatial



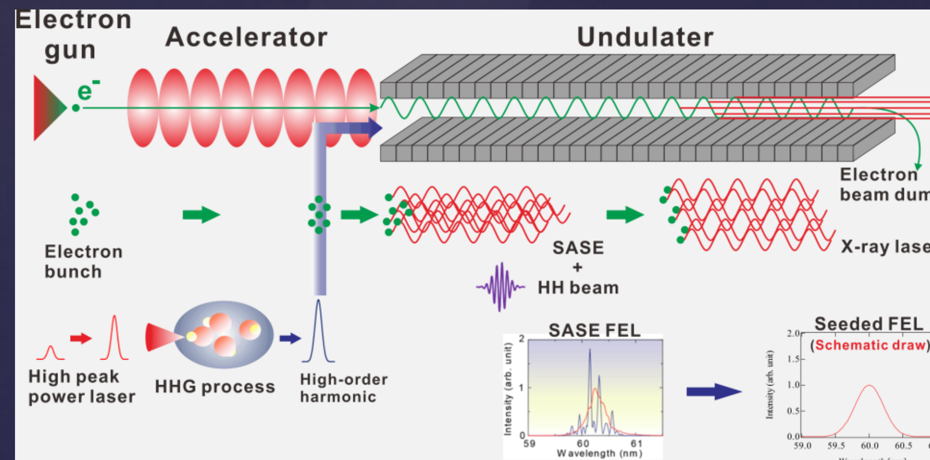
2) Monochromatic amplification
   → specific harmonic order
   selected by undulator tuning

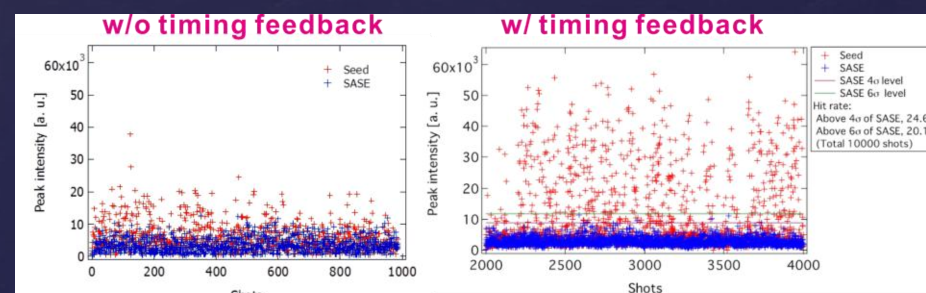
3) Jitter-free (probe laser – HHG laser)
   synchronization w/ ultra-short laser pulse

4) Compact undulator (in-vacuum) design
   for short wavelength generation

R&D for Feedback system
→ HHG laser pulse, EO probe laser pulse
& electron bunch temporally & spatially overlapped.

Test experiment successfully carried out
on July 2012 @ SCSS, SPring-8





Details; S. Matsubara's poster (MOPA49)

Our history

In the past :

FY 2006 : 3D-BCD concept proposed by H. Tomizawa

FY 2009 : 3D-BCD feasibility test w/ ZnTe succeeded (A. Maekawa)

FY 2011 : The first observation of EO signal
w/ organic Pockels EO crystal (Y. Okayasu)

FY 2012 (first half) : User exp. w/ HHG-seeded FEL laser.
Keep optimum overlap only for temporal direction
between electron bunch and EO probe laser.
HHG-seeded FEL hit rate increased by x100
comparing to previous experiment on 2008.

Principle of the 3D-BCD monitor

We introduce…

3 Dimensional Bunch Charge Distribution (3D-BCD) monitor.

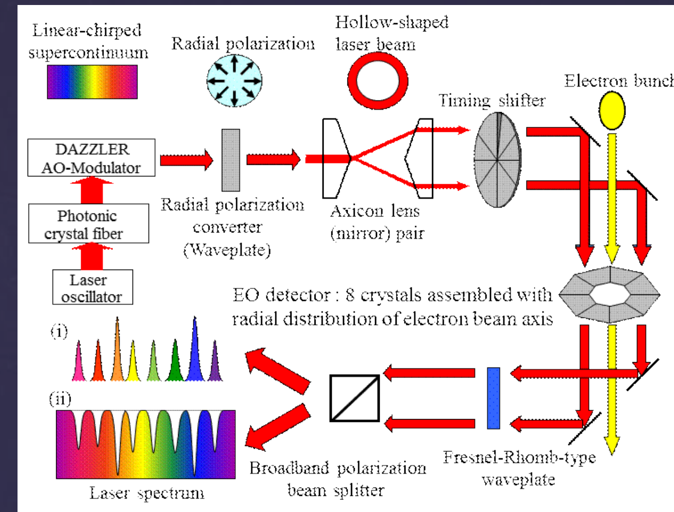
1) Non-destructive measurement
 → Merit of EO-sampling

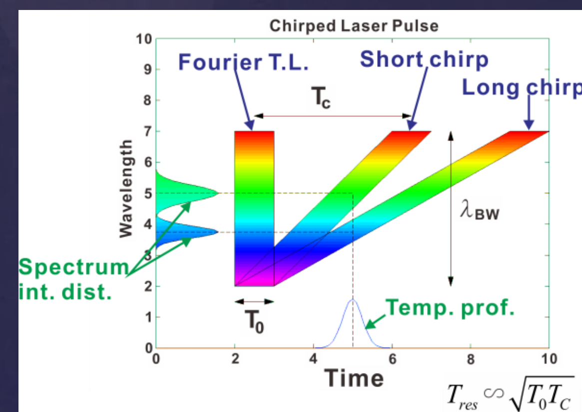
2) Single-shot measurement
 → w/ multi-channel spectrometer

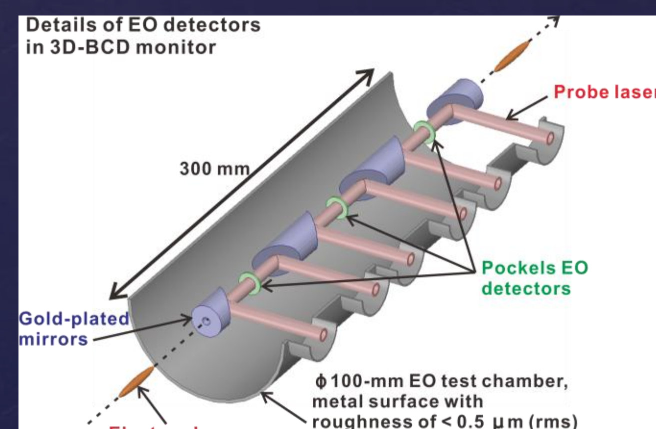
3) Real-time reconstruction
 → Linear-chirped probe laser
 w/ square-shaped spectrum

4) High temporal resolution : ≈30 fs [FWHM]
 ($\tau 0$ = 3 fs in FWHM, τc = 300 – 400 fs in FWHM)
 → Broadband (300 – 400 nm [FWHM]) probe laser
 w/ organic Pockels EO crystals

5) 3D-BCD measurement
 → radially polarized & hollow-shaped probe laser
 w/ Pockels EO crystals radially surrounding
 electron beam axis



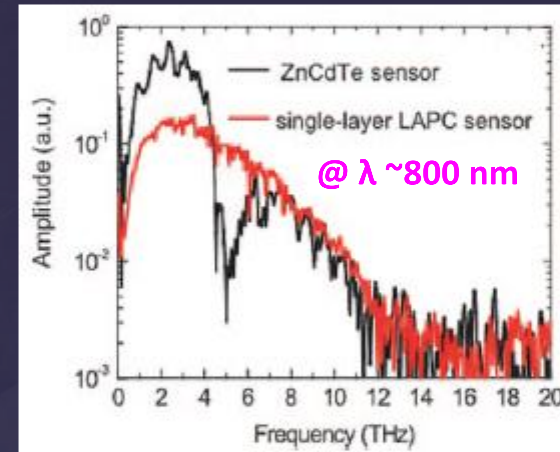


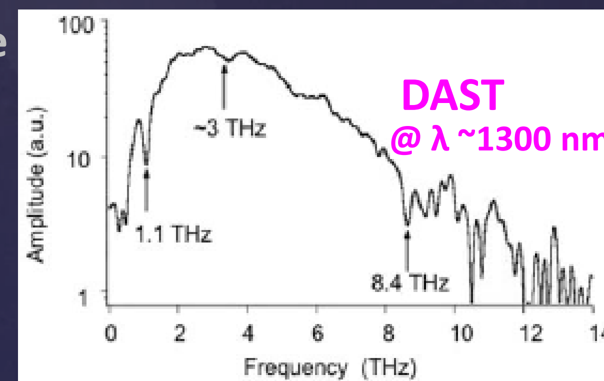


Longitudinal (temporal) detection

Temporal resolution is crucial issue.

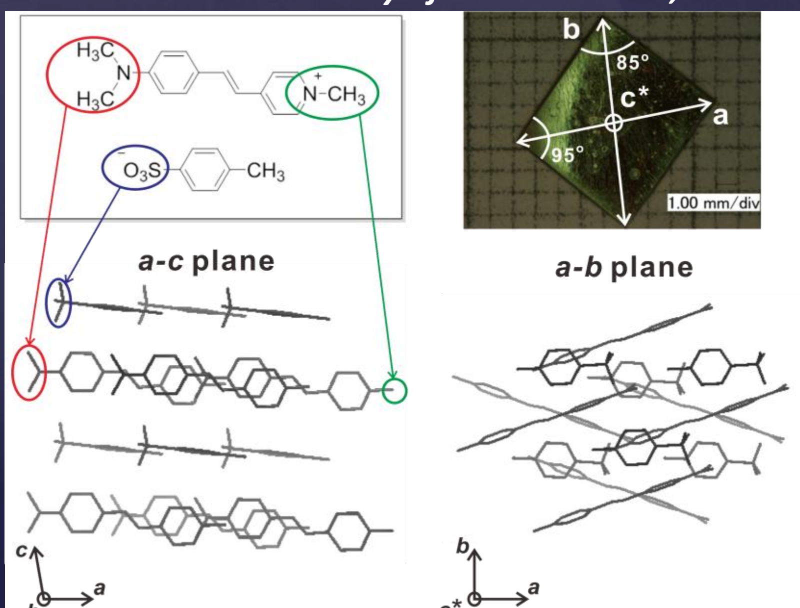
So far, inorganic Pockels EO crystals;
ZnTe and GaP have been used for EO samplings.
→ Significant absorption @ 5 THz (ZnTe), 11 THz (GaP) [1]
(equivalent to electric field from electron bunch)
→ temporal resolution limited by 110 – 130 fs (FWHM)
even w/ 300 – 400 nm (FWHM) of broadband probe laser pulse





X. Zheng et al., Jour. Nanoel. Optel. 2 1 (2007)

Courtesy of K. Matsukawa, RIKEN



Organic Pockels EO crystals, such as DAST
(DAST : 4-*N*, *N*-dimethylamino-4'-*N*'-methyl stilbazolium tosylate)
→ transparent in 600 – 2000 nm
→ Absorption free in broadband frequency domain
→ ~30 fs (FWHM) of temporal resolution expected [2].

[1] G. Berden et al., Phys. Rev. Lett. 99 164801 (2007)
[2] X. C. Zhang et al., Appl. Phys. Lett. 61 3080 (1992)

Transverse (spatial) detection

Electric field from electron bunch :

$$E(r) = \frac{Q}{(2\pi)^{3/2}\varepsilon_0 c r \sigma}$$

Refractive index change (Δn) of isotropic EO media :

$$|\Delta n| = \frac{n_0^3}{2}\left\{\xi_P E(r) + \xi_K E(r)^2\right\}$$

Assuming that Pockels EO effect is dominant, then signal intensity at EO crystal (detection point) :

$$I = I_0 \sin^2\left(\frac{\pi}{2\lambda}\Delta n L\right) = I_0 \sin^2\left(\frac{\pi n_0^3 \xi_P E(r) L}{4\lambda}\right)$$

Phase retardation

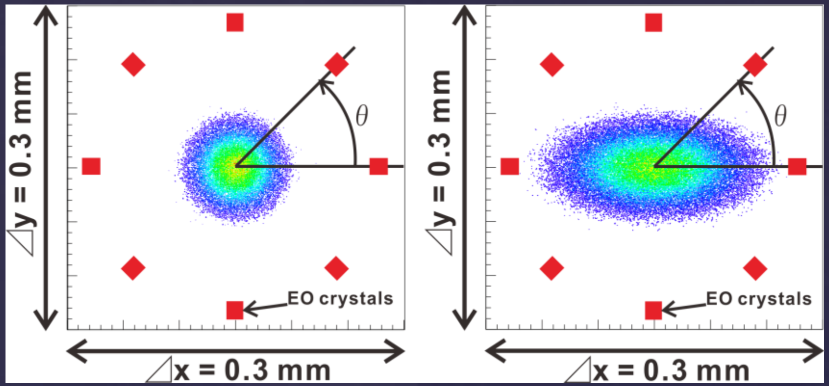
Signal intensity modulation :

$$\Delta I = \frac{I_{ell} - I_{org}}{I_{org}}$$

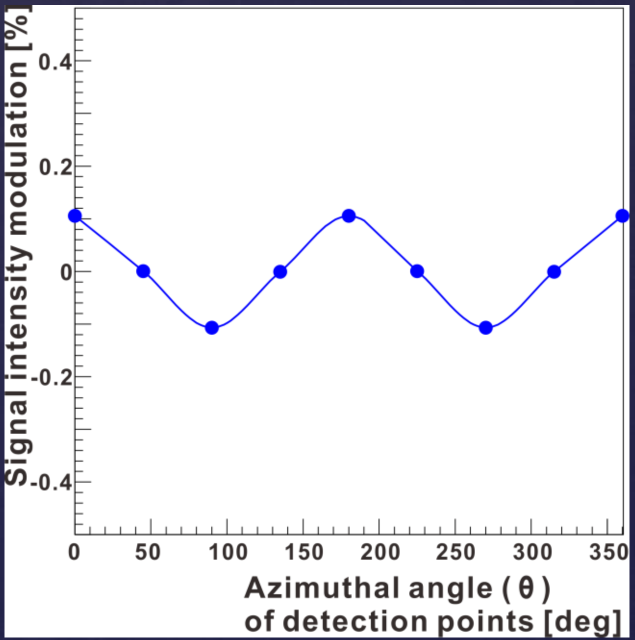
Bunch charge : Q	100 pC
Bunch duration : σ	30 fs (FWHM), Gaussian
Pockels EO crystal	ZnTe
Crystal position from beam axis : r	2 mm
Crystal thickness : L	1 mm
Refractive index : n_0	2.85
Pockels EO coefficient : ξ_P	3.97 x 10^{-12} m/V
Sliced bunch size (rms)	r_{hol} : 80 µm, r_{ver} : 40 µm → 60 µm

Sliced bunch profiles in transverse :

original (*org*) ellipse (*ell*)



Note, EO crystals indicate just azimuthal positions, not real scale in radial direction!

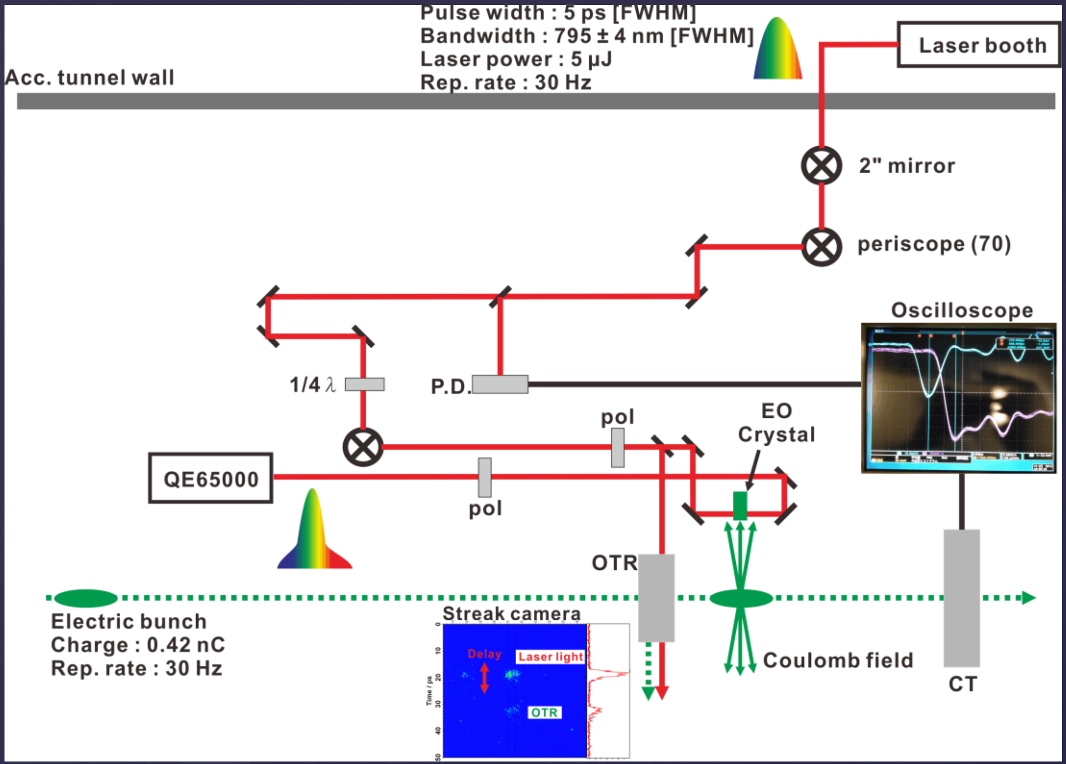


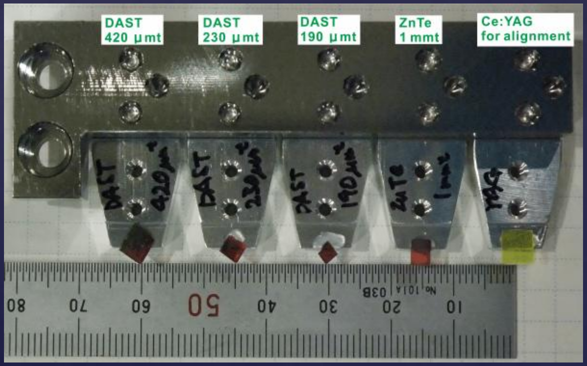
Max. 0.2 % of sig. int. modulation evaluated w/ 60 µm beam size.

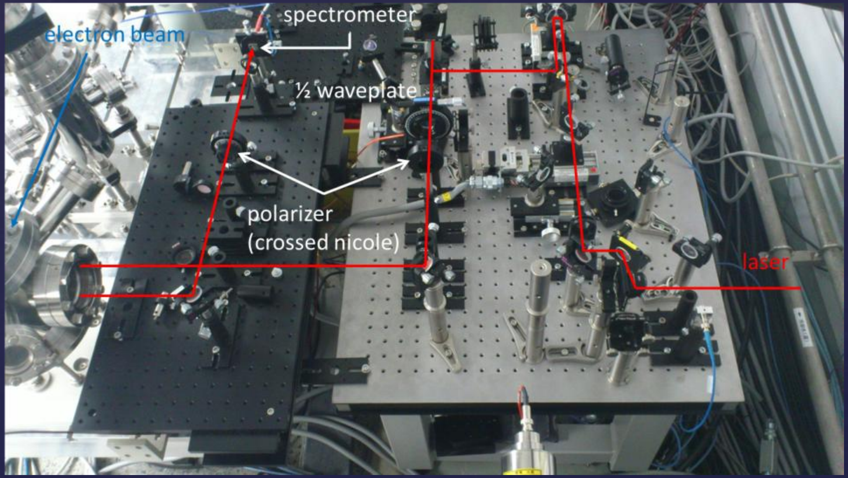
→ For 40 µm beam size (SACLA), *s*-wave spectrum must be measured instead of *p*-wave for higher S/N ratio.

Feasibility experiment @ Prototype Test Accelerator, SPring-8

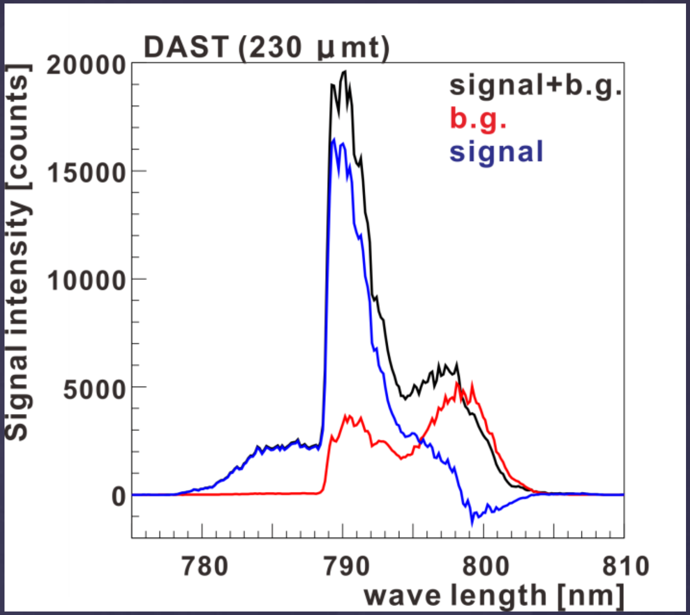
Electron beam	
Energy	250 MeV
Bunch charge	30 – 420 pC
Bunch duration	300 fs (FWHM)
Reputation rate	30 Hz
Peak current	> 300 A
Probe laser	
Bandwidth	5 nm (FWHM) @ 795 nm
Pulse energy	5 μJ (40 μJ/cm²)
Pulse duration	5 ps (FWHM)
Linear chirp rate	0.6 ps /nm
Reputation rate	30 Hz
EO crystal (in case of ZnTe)	
Size	$3^W \times 4^H \times 1^T$ mm³
Distance from electron beam axis	2 mm
Phase retardation	~50 degree





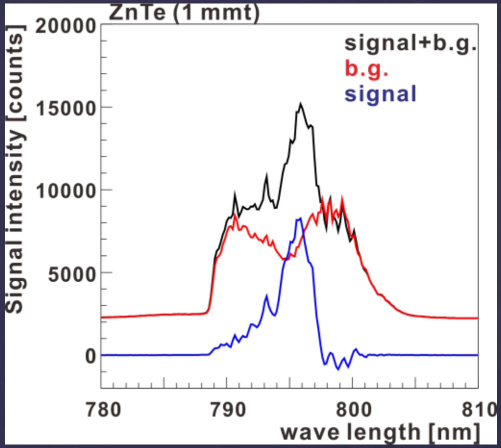


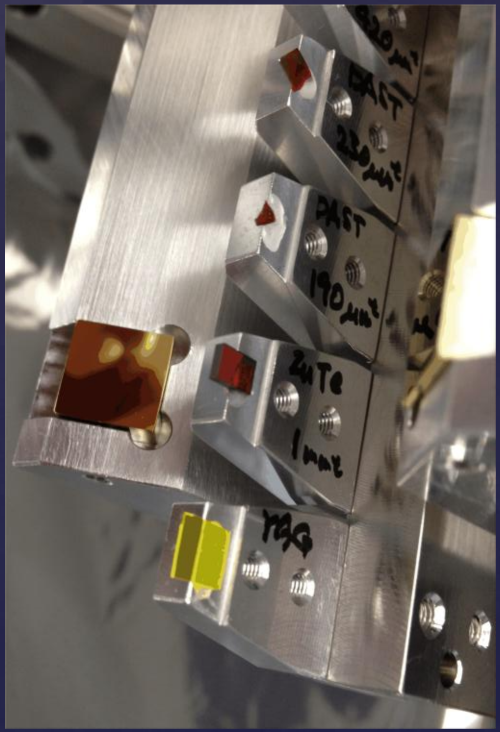
EO signal intensity spectrum w/ organic Pockels EO crystal; DAST



Signal : single shot

Background : average of 40 shots w/o electron bunch





The first observation w/ DAST.

* Background double peaks

→ Diffusion at an EO chamber window (somehow, sapphire)

* FAST temporal response

→ Phase retardation of DAST : ~200 deg (cf. ZnTe : ~50 deg)

→ DAST is much sensitive for electric field than ZnTe

* Spectrum structure around 794 – 798 nm

→ Bandwidth enhancement effect ? [3] or Bunch structure ?

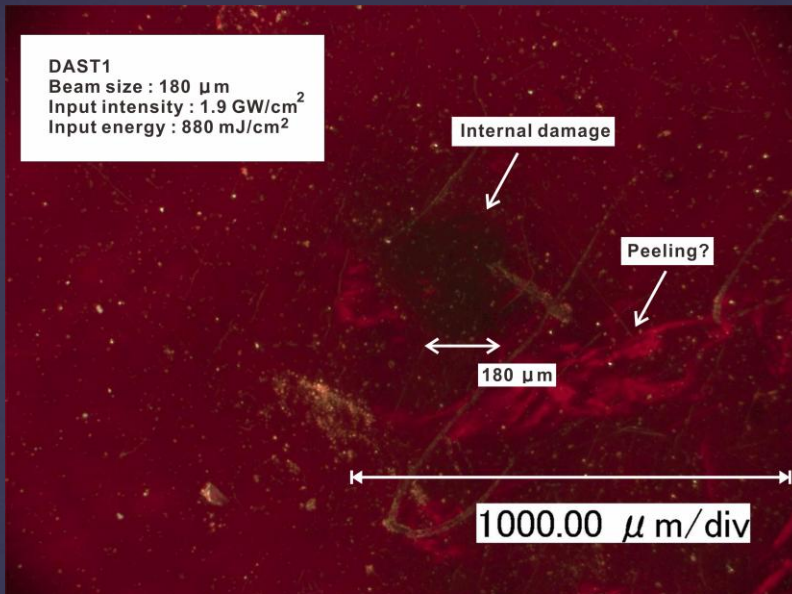
After 30 min. data taking, EO signal was disappeared.

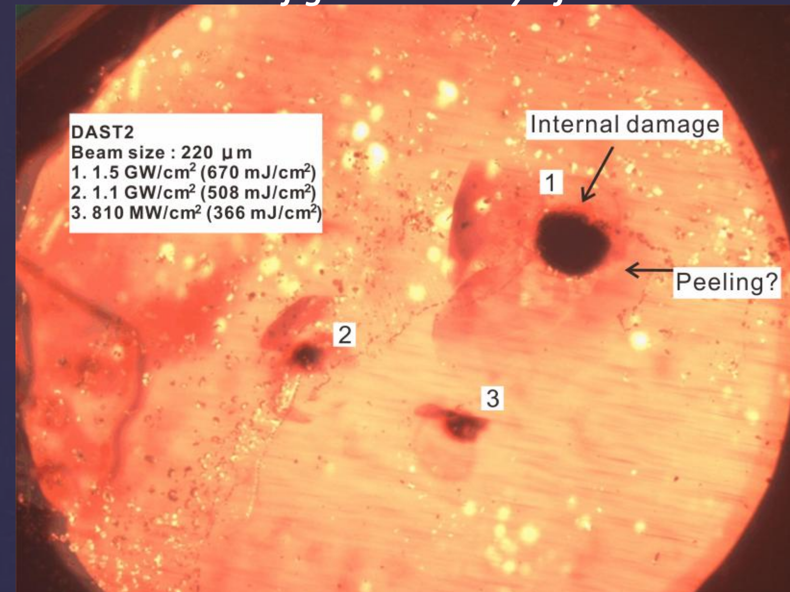
What happened…?

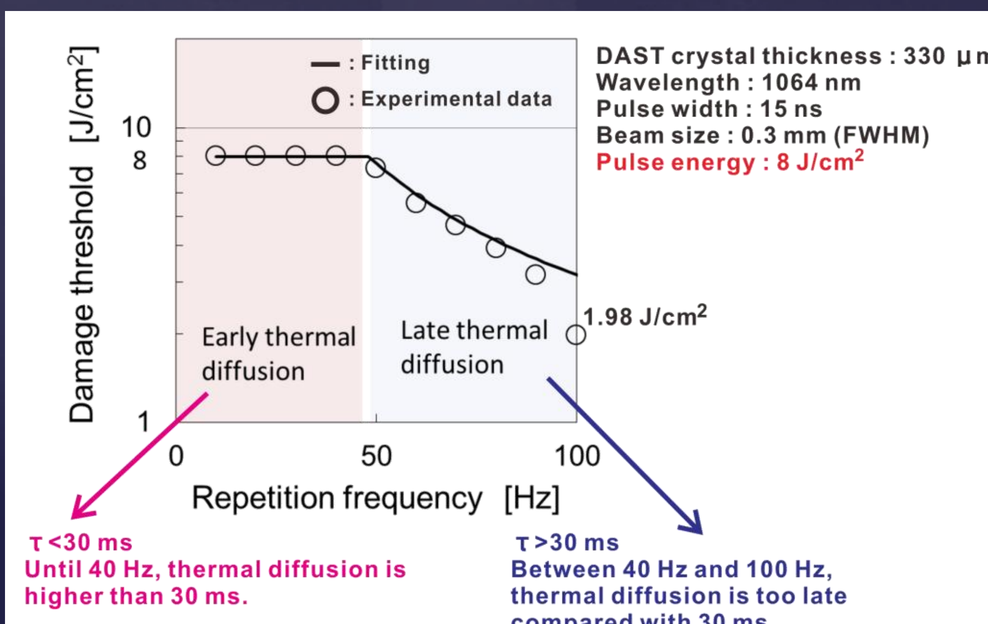
[3] P. Bolton, private communication.

DAST damage investigation @ RIKEN; illumination damage

All figures courtesy of K. Matsukawa, RIKEN







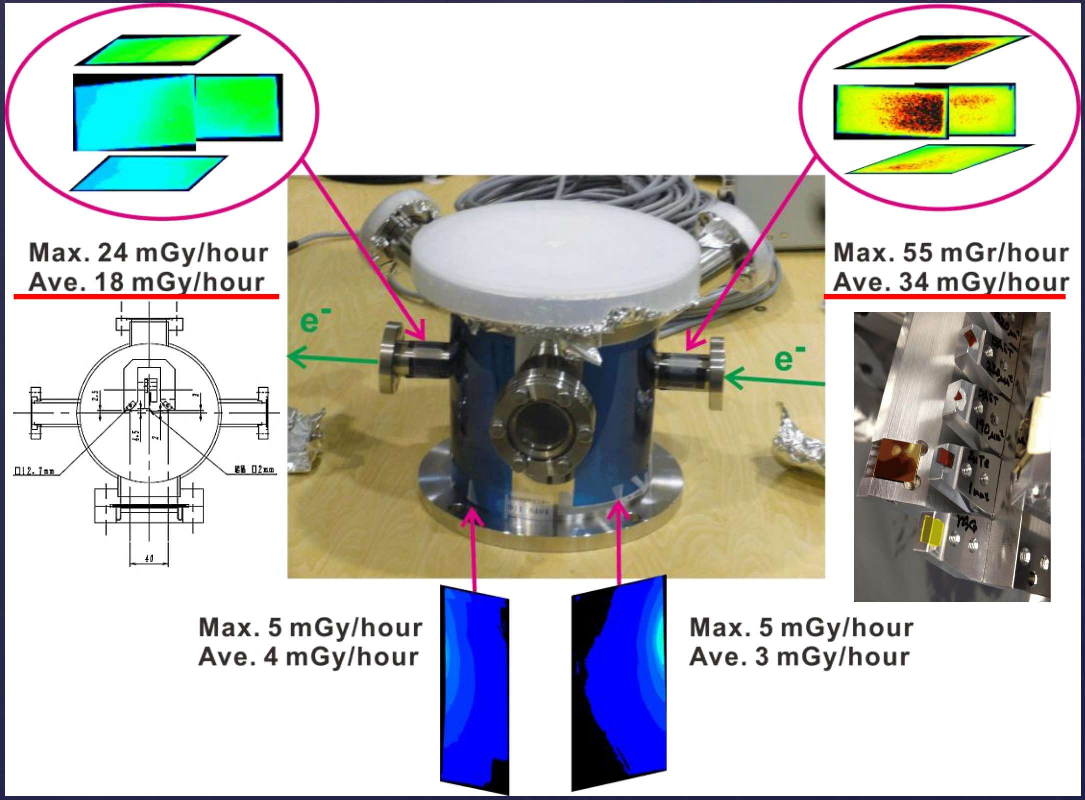
In our experiment;
Ave. laser pulse energy : 40 μJ/cm^2
Rep. rate : 30 Hz
→ Laser illumination damage won't be possible origin?
→ But our pulse width is 2 - 5 ps (FWHM)!
→ Further goal : ~500 fs (FWHM)
Damage test w/ our experimental condition is now in process.

DAST damage investigation @ SPring-8; radiation damage

Dose measurement
w/ Gafcromic films on EO chamber.
Higher dose on beam ducts (I.D. ϕ23 mm) @ both ends.
Electron halo ? Cascades?

Dose on DSAT crystal is evaluated to be…
(18 + 34)/2 = 26 mGy/hr,
Effective life time (signal obtained) : 0.5 hrs
→ 13 mGy .

None of superficial changes recognized thru visual / microscopic checks.



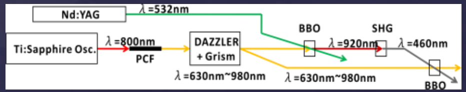
Summary

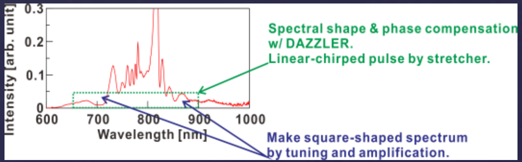
User experiment w/ HHG-seeded FEL laser started
on July 2012 @ Test Accelerator Facility, SPring-8.

The first EO signal w/ organic Pockels EO crystal successfully observed.

Investigations of both laser illumination & radiation damage
for the organic crystal now in process.

Further light source upgrades also in process
→ K. Ogawa's poster (MOPA20) for details





In the past and future :

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FY 2009 : 3D-BCD feasibility test w/ ZnTe succeeded (A. Maekawa)

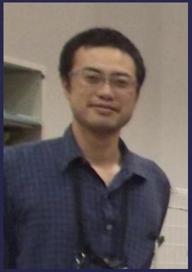
FY 2011 : The first observation of EO signal w/ organic Pockels EO crystal (Y. Okayasu)

FY 2012 (first half) : User exp. w/ HHG-seeded FEL laser.
Keep optimum overlap only for temporal direction
between electron bunch and EO probe laser.
HHG-seeded FEL hit rate increased by x100.

FY 2012 (second half) : Realize 3D overlap and increase the hit rate by limit.

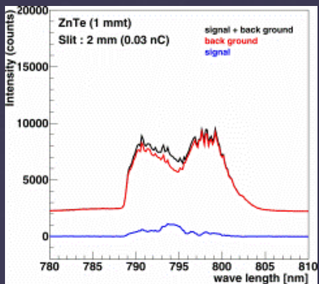
FY 2013 : Feasibility test of ultimate high resolution 3D-BCD monitor.

Thank you !

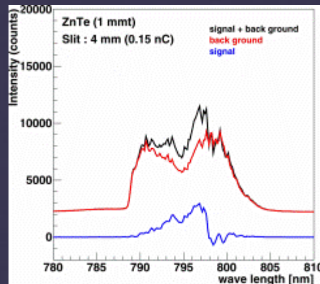


EO intensity spectra (ZnTe) VS. bunch charge

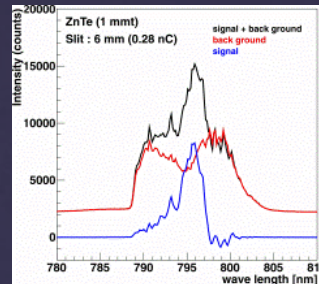
0.03 nC



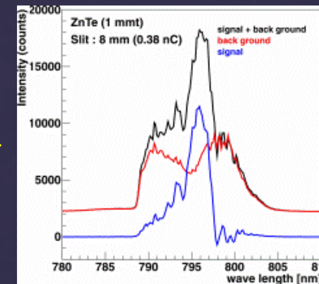
0.14 nC



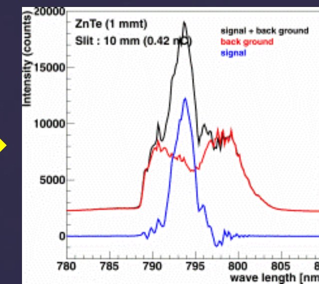
0.28 nC

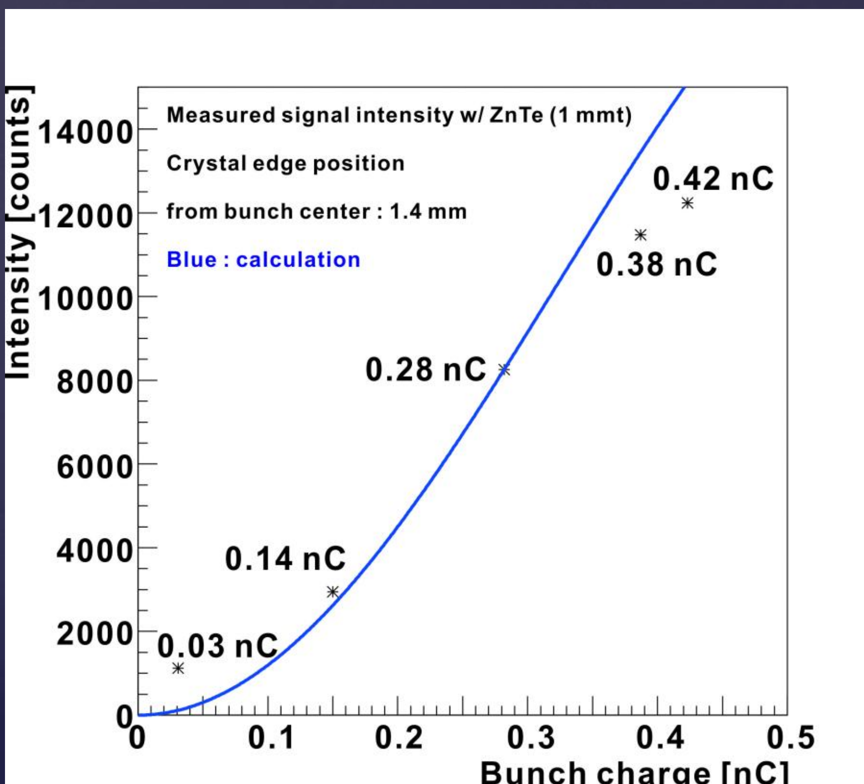


0.38 nC



0.42 nC





Electric field from electron bunch :

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Refractive index change (Δn) of isotropic EO media :

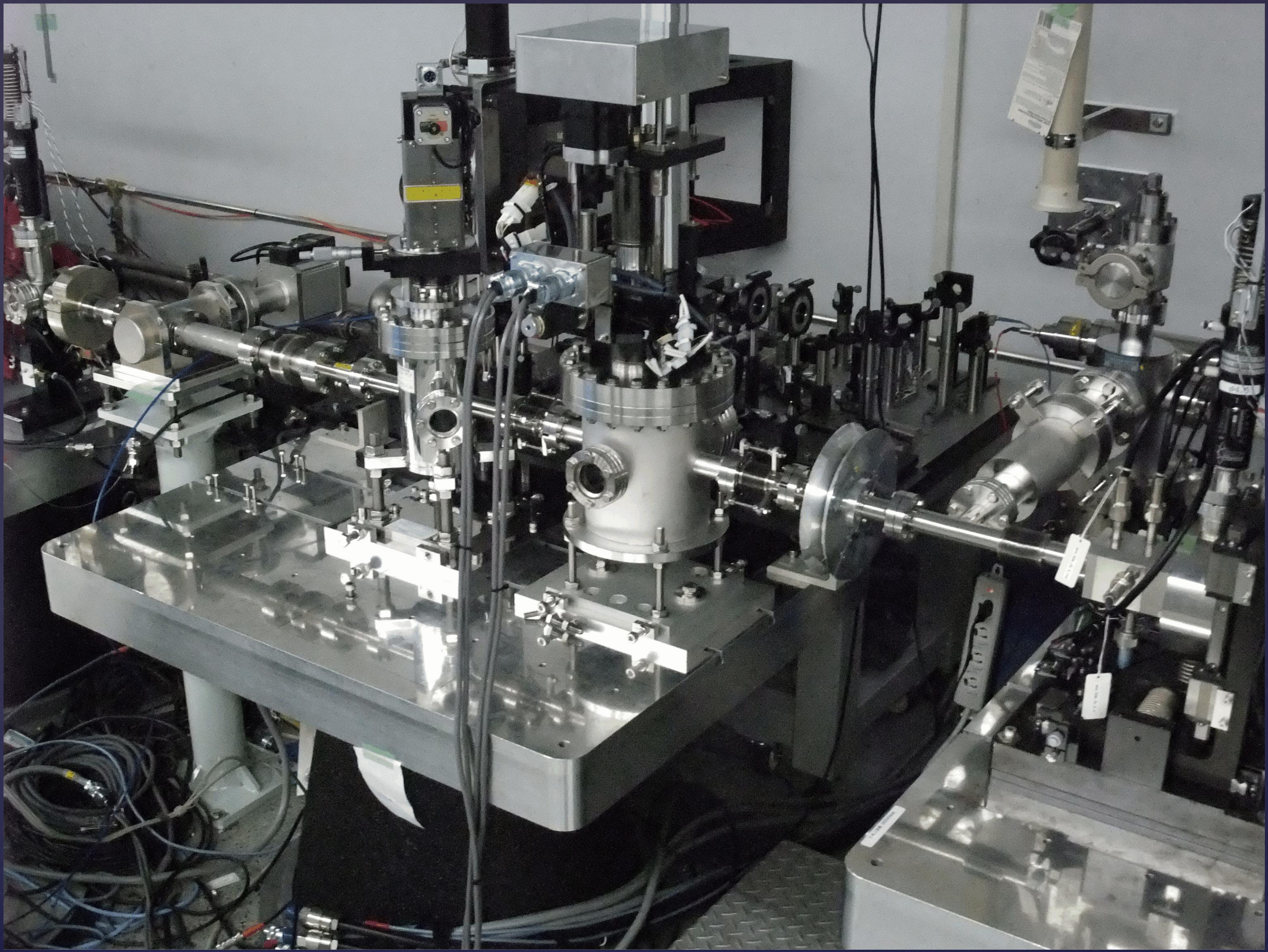
$$|\Delta n| = \frac{n_0^3}{2}\left\{\xi_P E(r) + \xi_K E(r)^2\right\}$$

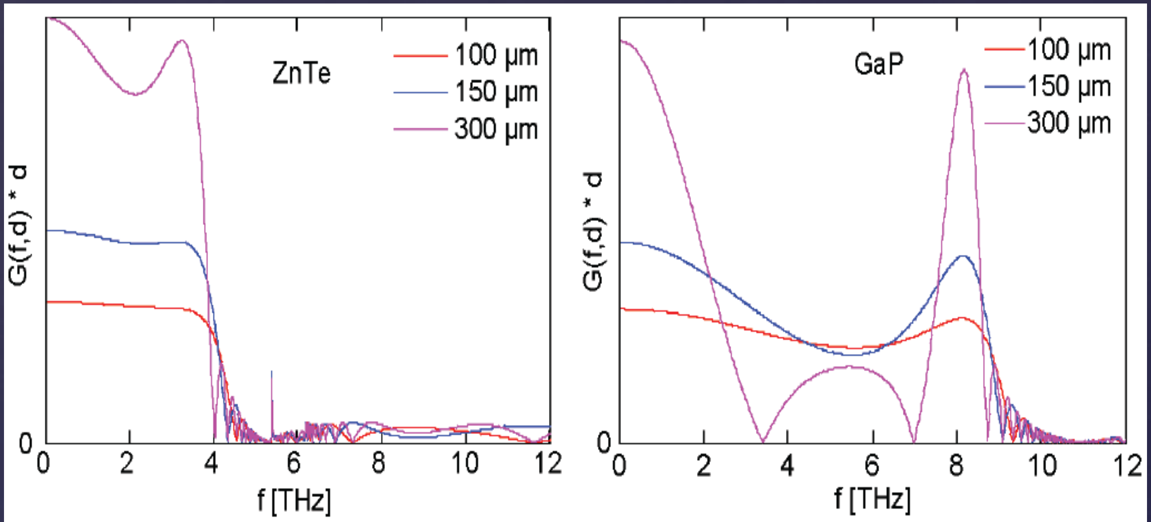
Signal intensity at EO crystal (detection point) :

$$I = I_0 \sin^2\left(\frac{\pi}{2\lambda}\Delta n L\right) = I_0 \sin^2\left(\frac{\pi n_0^3 \xi_P E(r) L}{4\lambda}\right)$$

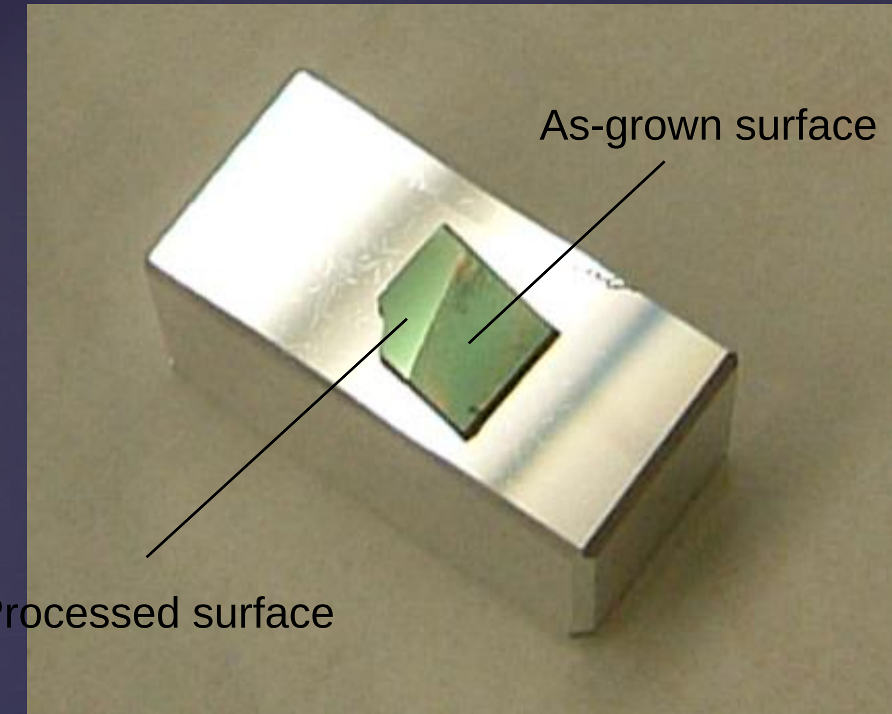
Phase retardation

In calculation, I_0 is normalized by data w/ 0.28 nC.
Intensity seems to be saturated beyond 0.28 nC.
Below 0.14 nC, S/N of intensity spectrum degenerated.





B. Steffen, FLS workshop, Hamburg (2006)



DAST characteristics :

Crystal structure	Monoclinic
Melting Point	256 deg
Transparency region	720 – 3000 nm
EO coefficient	r111 = 82 pm/V @ 780 nm
Nonlinear optical coefficient	d111 = 230 pm /V @ 1550 um
Refractive indices	n1 = 2.40, n2 = 1.69, n3 = 1.62 @ 780 nm
Dielectric constants	e1 = 5.2, e2 = 4.1, e3 = 3.0
Hardness	Vickers 65