Inverse Compton Source (ICS) for LUXE

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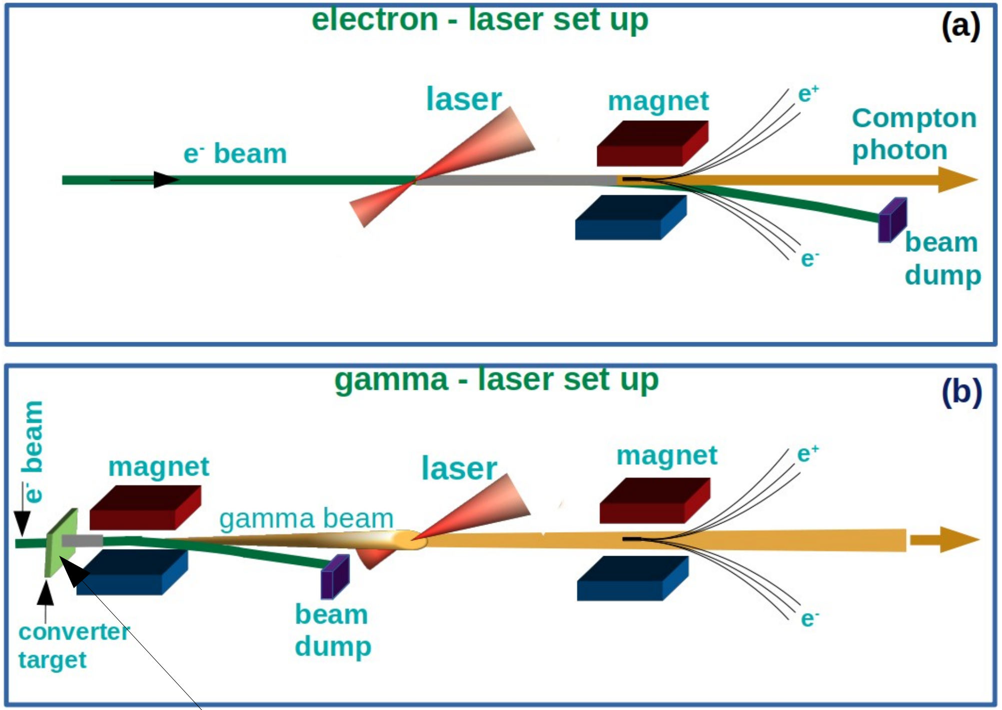
Outline:

- Brief introduction and motivation
- Methods for HHG
- Intended setup in 28m
- Prelim simulations
- Summary

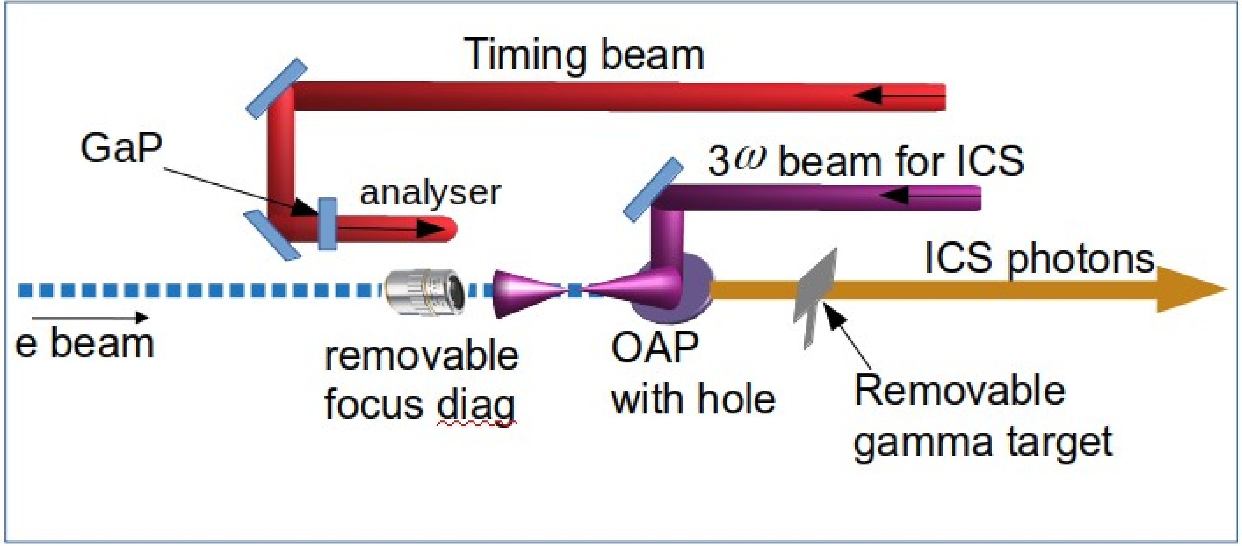
Two experimental configurations at LUXE

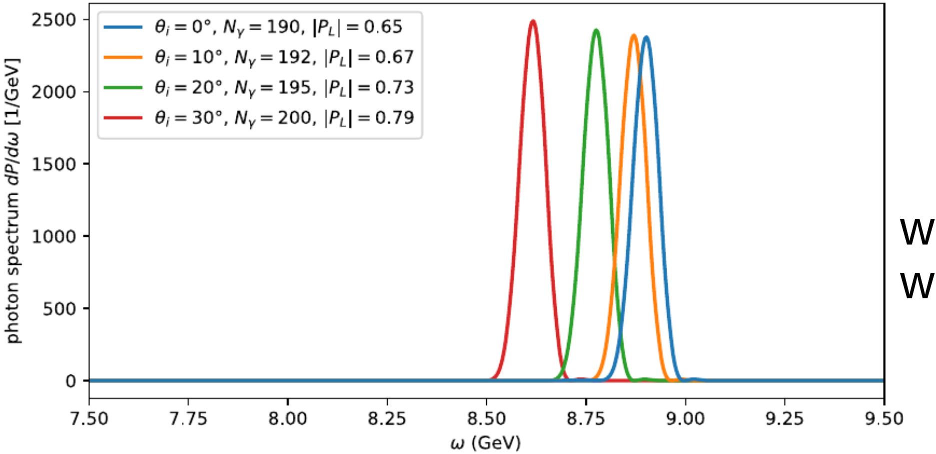


Replace this target with ICS source

LUXE CDR in Eur. Phys. J. Spec. Top.
https://doi.org/10.1140/epjs/s11734-021-00249-z

ICS setup envisaged for LUXE





$$\omega' = \frac{2(1+\cos\theta_i)\gamma^2\omega_0}{1+2\eta_{\rm ICS}+\gamma^2\theta^2+\xi_{\rm ICS}^2/2},$$

$\xi_{\rm ICS} \ll 1$

$\eta_{\rm ICS} = 0.2$

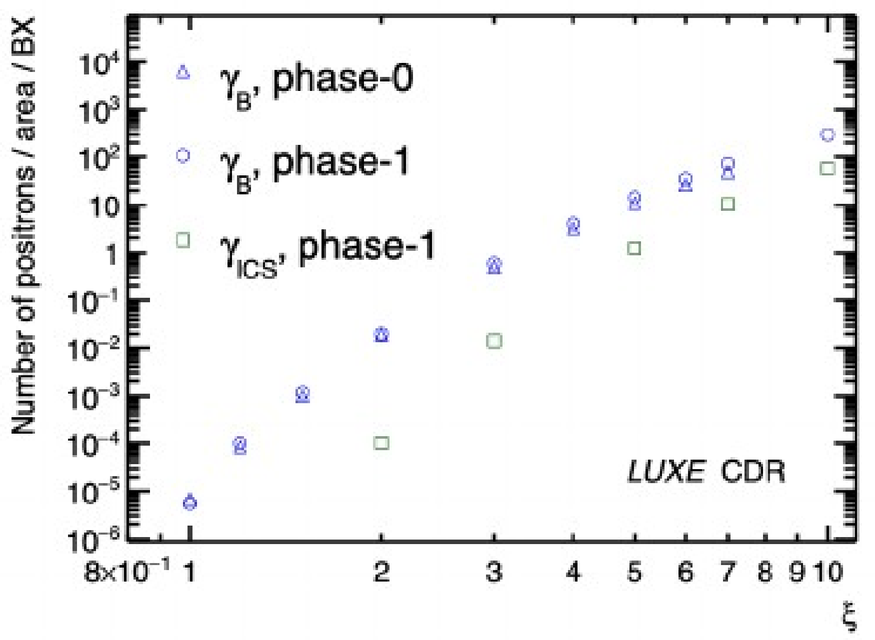
w0=1.55 eV @ 800nm, photon energy = 4.5 GeV

w=4.65 eV (3w0), photon energy ~ 9 GeV $\eta_{\rm ICS} = 0.59$

@16.5GeV e-beam energy
@head-on collision

Advantages:

- Well defined in-state of the collision between electron and photon beams → increases the precision of SFQED measurements
- Narrow energy spectra help determining n-photons channel in nonlinear Breit-Wheeler (NBW) dependence on energy similar to Compton edge shift by tuning ICS source energy



Interaction of electron beam with the harmonics of w at the IP

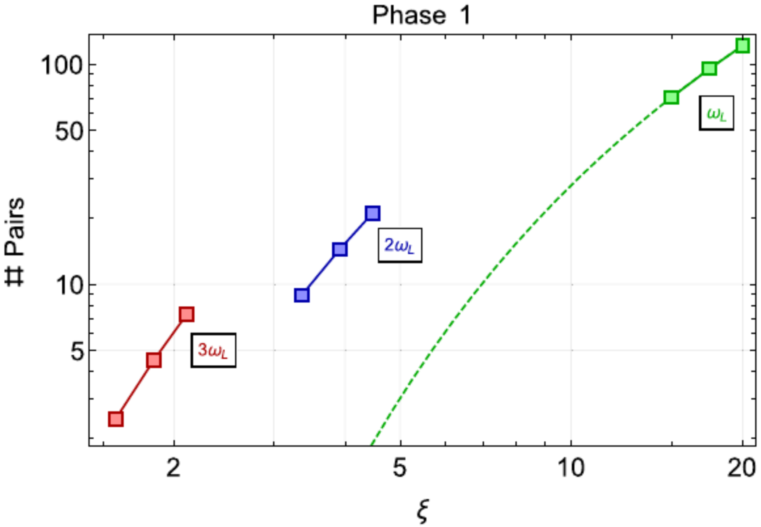


Fig. 19 Approximate yield of pairs for different harmonics of the IP laser, assuming the simulation result of ~ 8 pairs produced by a $\xi = 6.5$ laser pulse in phase 1 and a scaling of the yield given by the LCFA for a 16.5 GeV photon. The data points on each curve are for equivalent values. (Assumed transmission of laser intensity: 0.2 into $2\omega_L$ and 0.1 into $3\omega_L$)

- Different harmonics produce different pair rates

- Polarisation dependence of NBW as ICS will be highly polarised source (in case of linear polarisation of laser beam)

- Highly polarised photon source might be also useful for ALPS

Required 3w beam parameters of ICS:

- a0=0.2, in 25fs, waist=5mu needs E_3w= 5mJ
- a0=0.1, in 100fs, waist=10mu needs E_3w=16mJ
- Electron beam at ICS is more likely ~10 mu

- Beam diameter in the laser room about 2.5-5cm?
- Conversion in laser room and transport with 3w optics to ICS chamber
- Focusing by an OAP with a hole in the center

- Big question is how much energy in w we need to get the required energy
- Assuming 10% conversion efficiency we need to start with 50-150mJ in w

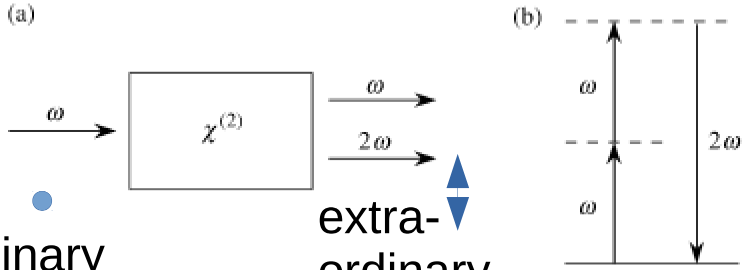
- **Main aim is to test what is the best efficiency we could achieve!!**

What are the methods?

High harmonics by nonlinear optical processes

$$\begin{aligned}\tilde{P}(t) &= \epsilon_0\left[\chi^{(1)}\tilde{E}(t) + \chi^{(2)}\tilde{E}^2(t) + \chi^{(3)}\tilde{E}^3(t) + \cdots\right] \\ &\equiv \tilde{P}^{(1)}(t) + \tilde{P}^{(2)}(t) + \tilde{P}^{(3)}(t) + \cdots .\end{aligned}$$

Second Harmonic generation (SHG)

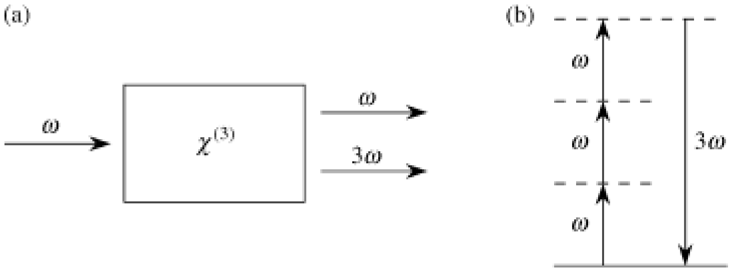


ordinary

extra-ordinary

2^{nd} order susceptibility

Third Harmonic generation (THG)

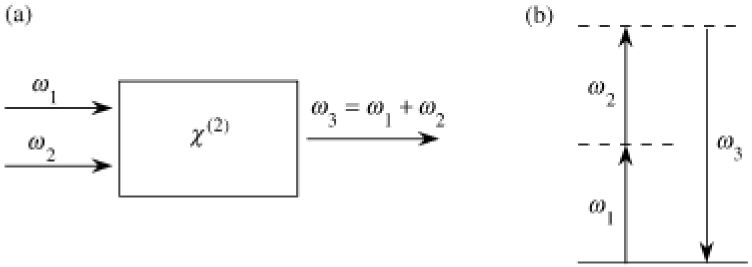


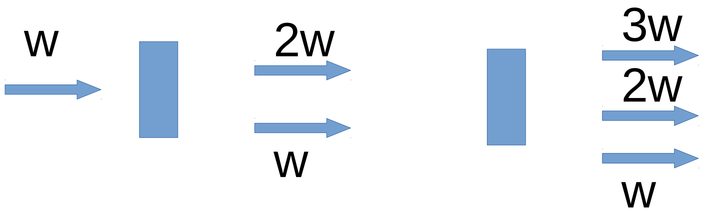
3^{rd} order susceptibility

Very low conversion efficiency

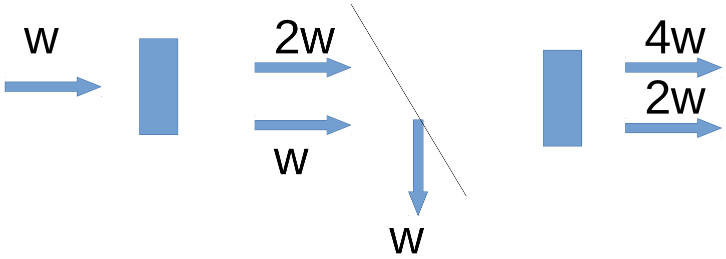
Figures from R Boyd book

Sum frequency generation



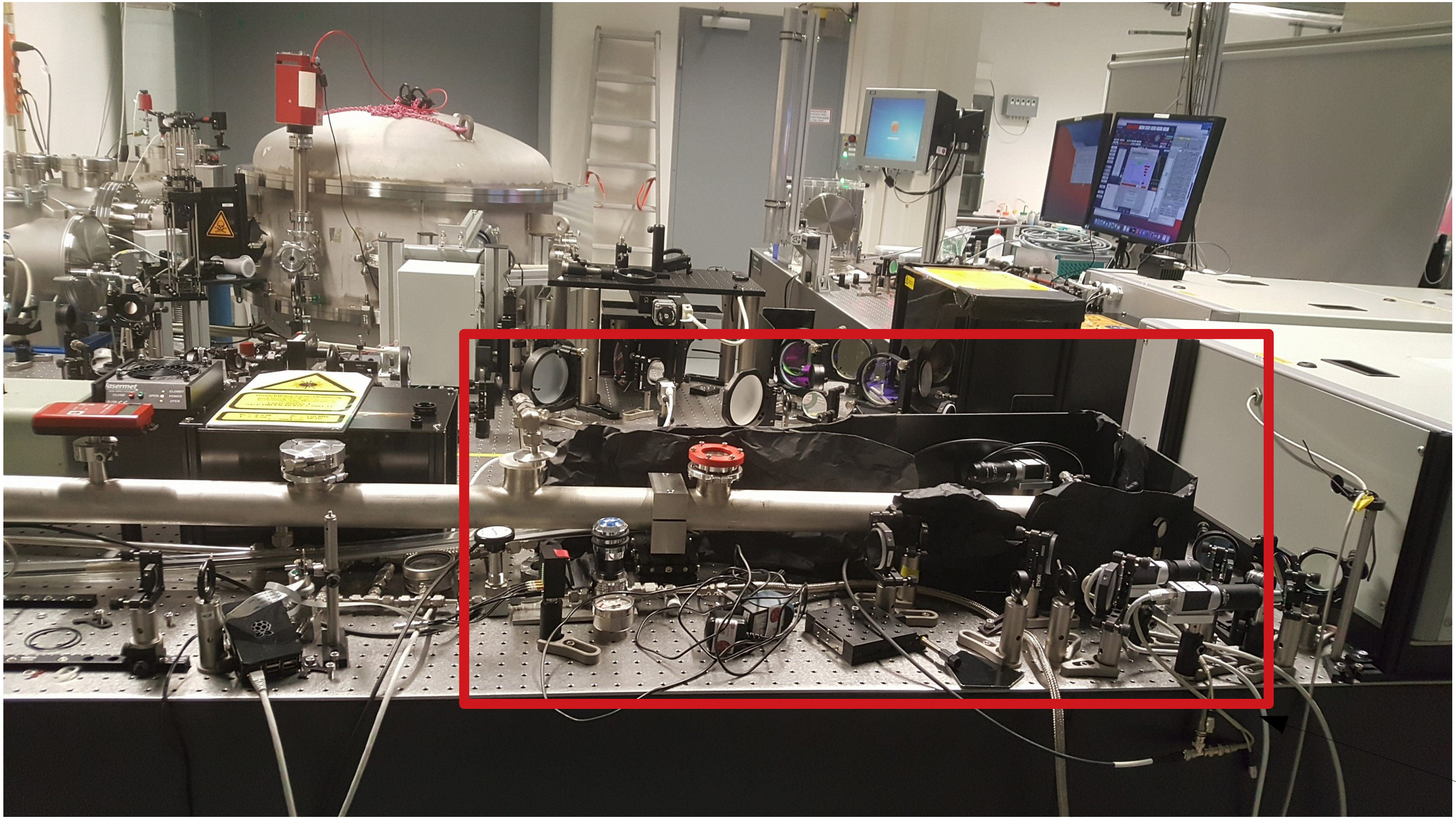


- ICS source for LUXE



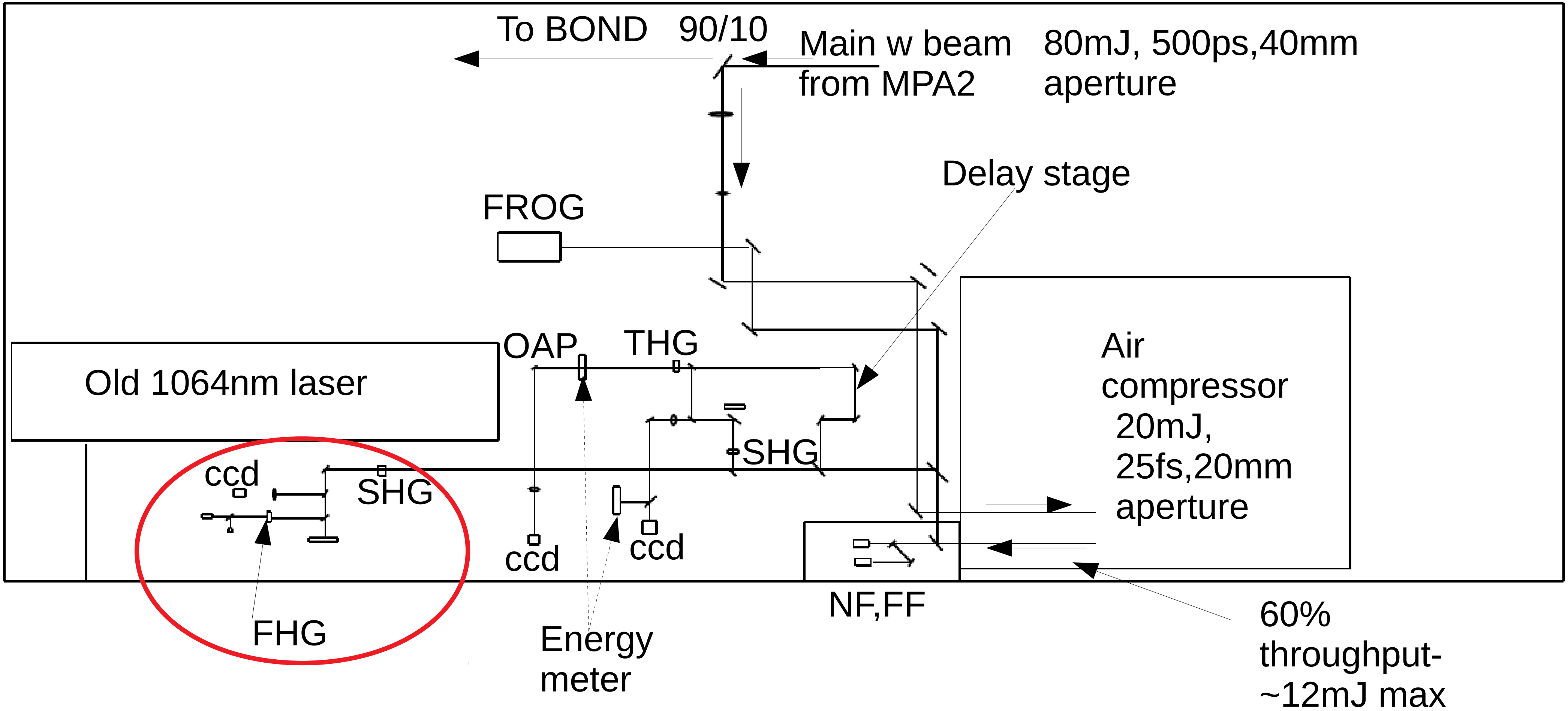
- Polarised e-beam for LEAP- a remarkable leap in laser-driven polarised source

Test in 28m lab

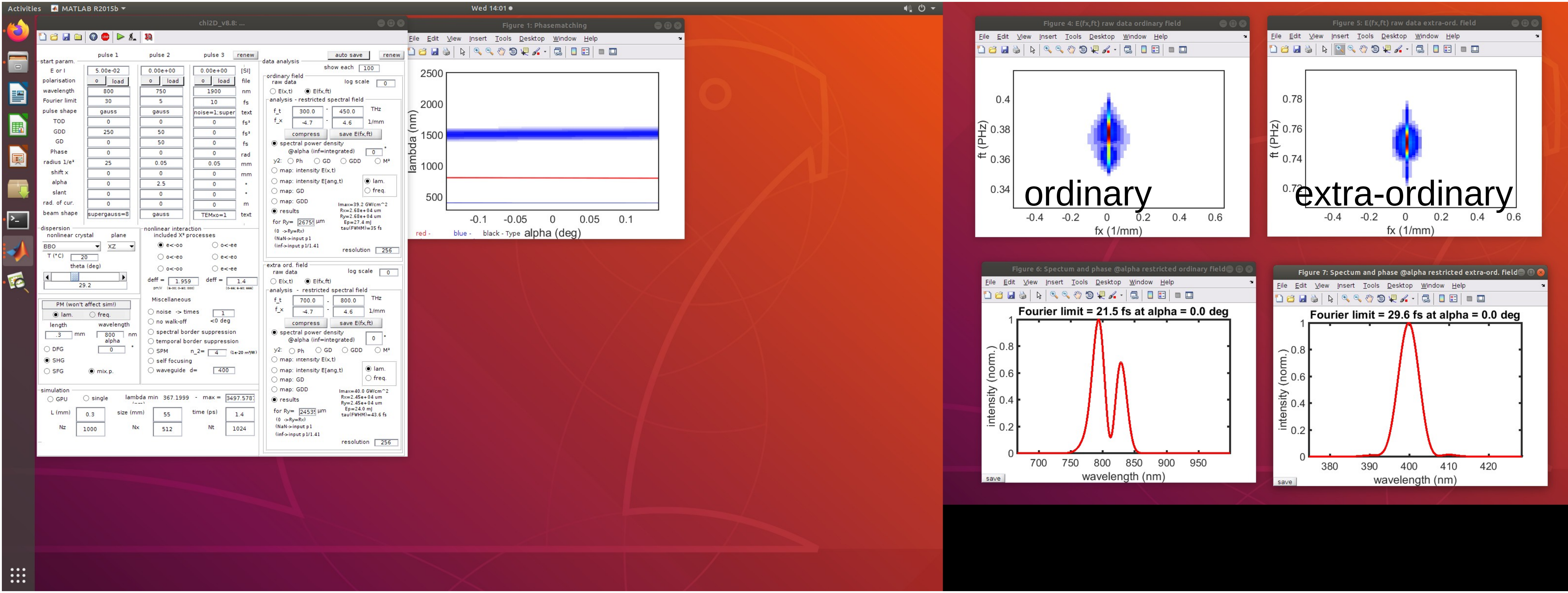


Space for
HHG

For both 3w/4w we need to prepare the input beam (w)



Simulations using Chi2d from Tino Lang



start param.

	pulse 1	pulse 2	pulse 3	
E or I	5.00e-02	0.00e+00	0.00e+00	[SI]
polarisation	o load	o load	o load	file
wavelength	800	750	1900	nm
Fourier limit	30	5	10	fs
pulse shape	gauss	gauss	noise=1;super	text
TOD	0	0	0	fs³
GDD	250	50	0	fs²
GD	0	50	0	fs
Phase	0	0	0	rad
radius 1/e²	25	0.05	0.05	mm
shift x	0	0	0	mm
alpha	0	2.5	0	°
slant	0	0	0	°
rad. of cur.	0	0	0	m
beam shape	supergauss=8	gauss	TEMxo=1	text

dispersion
nonlinear crystal: BBO
plane: XZ
T (°C): 20
theta (deg): 29.2

PM (won't affect sim!)
● lam. ○ freq.
length: .3 mm
wavelength: 800 nm
alpha: 0 °
○ DFG
● SHG
○ SFG
● mix.p.

nonlinear interaction
included X² processes
● e<-oo ○ o<-ee
○ o<-eo ○ e<-eo
○ o<-oo ○ e<-ee
deff = 1.959 pm/V (e-oo; o-eo; ooo)
deff = 1.4 (o-ee; e-eo; eee)

Miscellaneous
○ noise -> times 1
○ no walk-off <0 deg
○ spectral border suppression
○ temporal border suppression
○ SPM n_2= 4 (1e-20 m²/W)
○ self focusing
○ waveguide d= 400

simulation
○ GPU ○ single
lambda min 367.1999 - max = 3497.578
L (mm): 0.3
size (mm): 55
time (ps): 1.4
Nz: 1000
Nx: 512
Nt: 1024

data analysis
show each: 100

ordinary field
raw data
log scale: 0
○ E(x,t) ● E(fx,ft)
analysis - restricted spectral field
f_t: 300.0 - 450.0 THz
f_x: -4.7 - 4.6 1/mm
● spectral power density
@alpha (inf=integrated): 0 °
y2: ○ Ph ○ GD ○ GDD ○ M²
○ map: intensity E(x,t)
○ map: intensity E[ang,t)
○ map: GD
○ map: GDD
● results
● lam. ○ freq.
for Ry= 26755 µm
(0 ->Ry=Rx)
(NaN->input p1
(inf->input p1/1.41
Imax=39.2 GW/cm^2
Rx=2.68e+04 um
Ry=2.68e+04 um
Ep=27.4 mJ
tau(FWHM)=35 fs
resolution: 256

extra ord. field
raw data
log scale: 0
○ E(x,t) ● E(fx,ft)
analysis - restricted spectral field
f_t: 700.0 - 800.0 THz
f_x: -4.7 - 4.6 1/mm
● spectral power density
@alpha (inf=integrated): 0 °
y2: ○ Ph ○ GD ○ GDD ○ M²
○ map: intensity E(x,t)
○ map: intensity E[ang,t)
○ map: GD
○ map: GDD
● results
● lam. ○ freq.
for Ry= 24535 µm
(0 ->Ry=Rx)
(NaN->input p1
(inf->input p1/1.41
Imax=40.0 GW/cm^2
Rx=2.45e+04 um
Ry=2.45e+04 um
Ep=24.0 mJ
tau(FWHM)=43.6 fs
resolution: 256

Input parameters:

Bierfringence crystal properties:

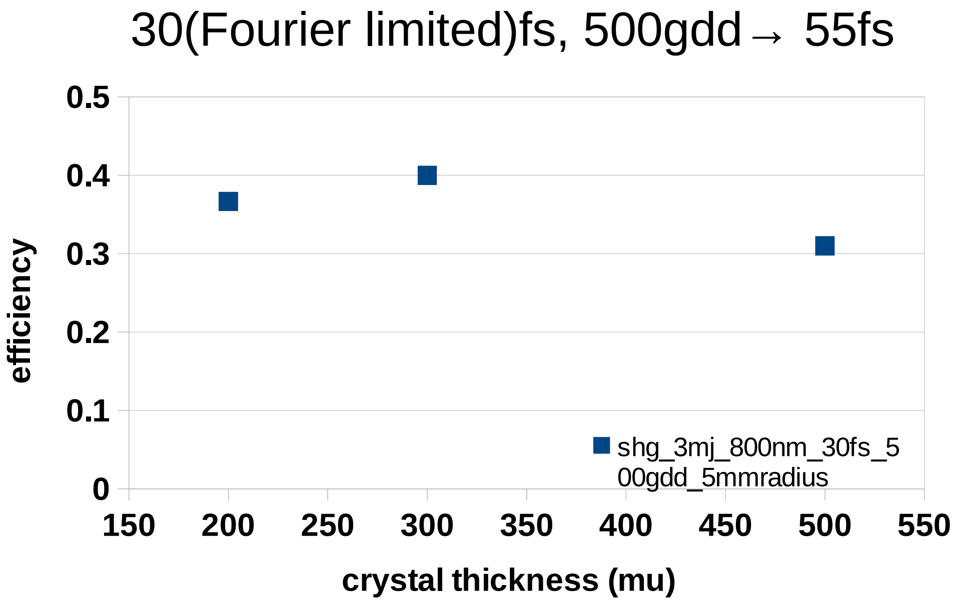
- Crystal: BBO
- Size: 10x10x [?] mm
- Type: I, e ← oo
- Phase matching angle: SHG-29.2, THG- 44.3
- Damage threshold for TEM00 1064nm:>0.5GW/cm2 at 10ns
  ~50GW/cm2 at 1 ps

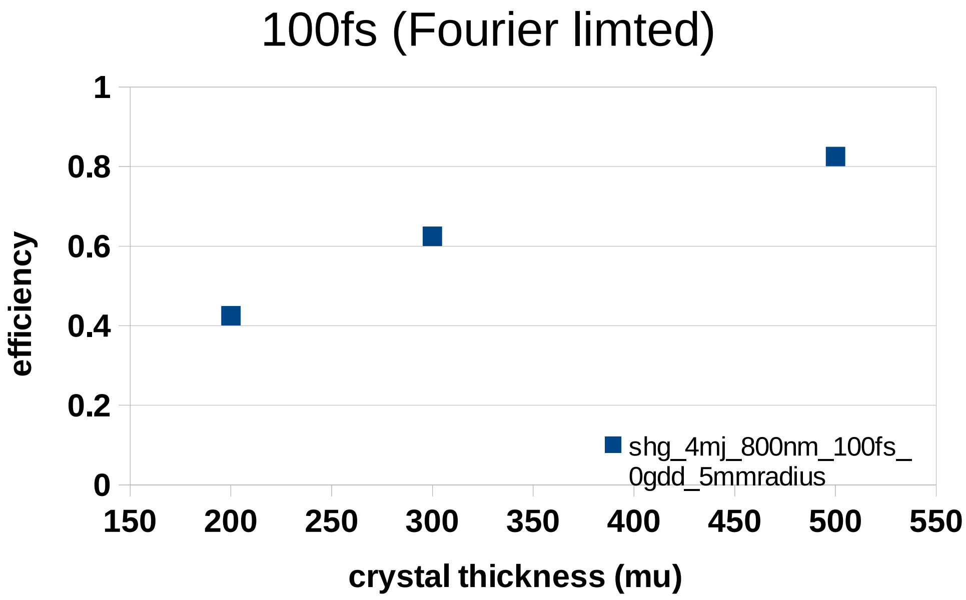
Laser Beam parameter- SHG:

- Energy: 5mJ
- Pulse length:25fs, Gauss
- Beam radius (1/e2): 5mm
- Beam spatial profile: Gauss/Supergauss

Crystal thickness optimisation for SHG case:

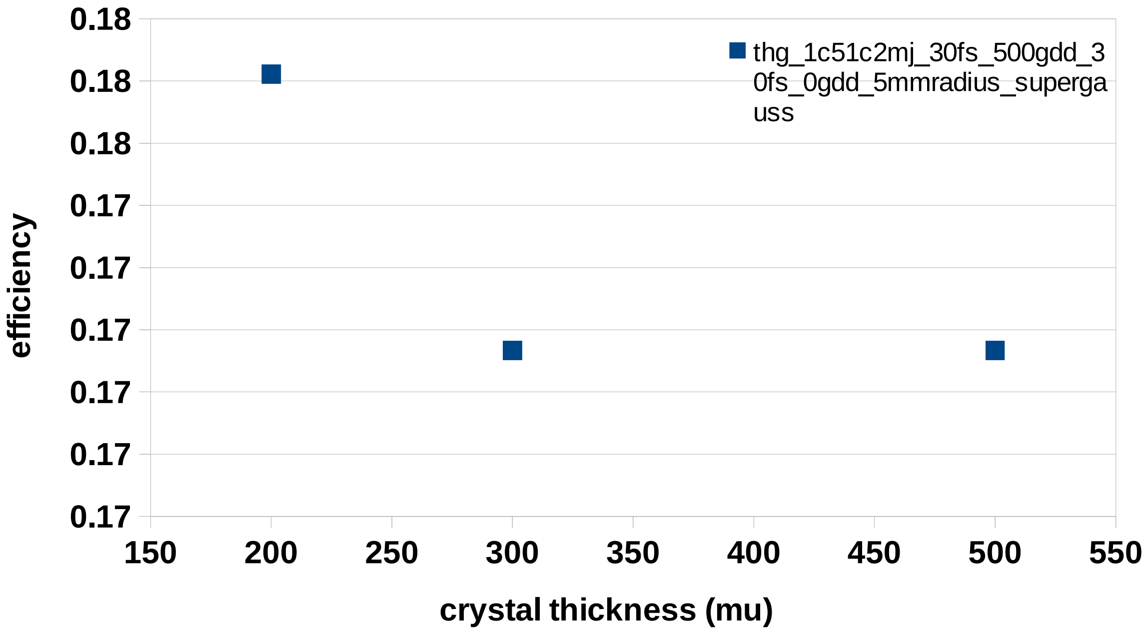
- Optimising thickness by keeping an eye on damage threshold~100GW/cm2





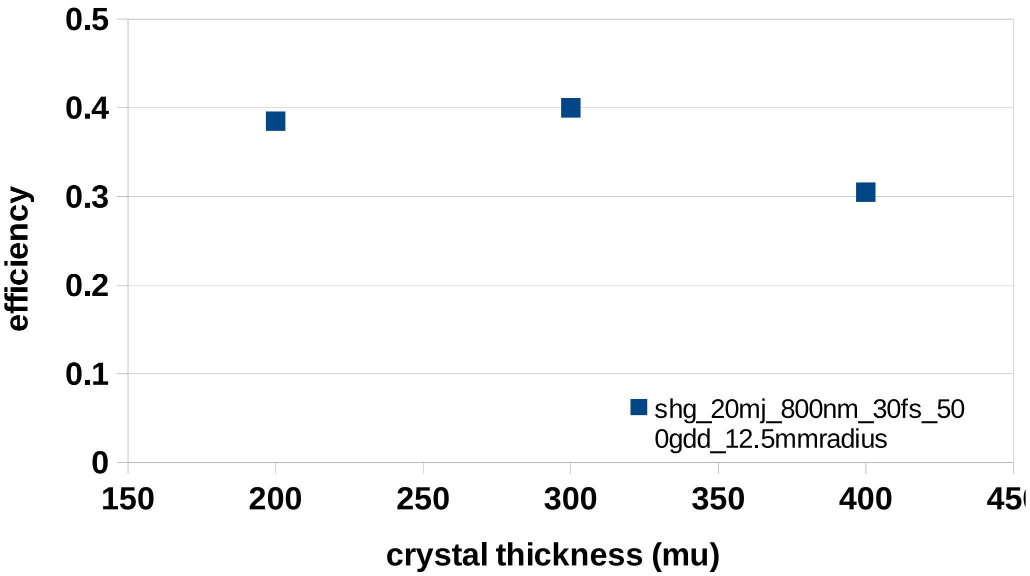
- Longer the pulse, narrow is the bandwidth- higher is the efficiency

THG case:
1.5mJ, 800nm,30fs_500gdd;1.2mJ,400nm,30fs_0gdd,5mmradius_supergauss

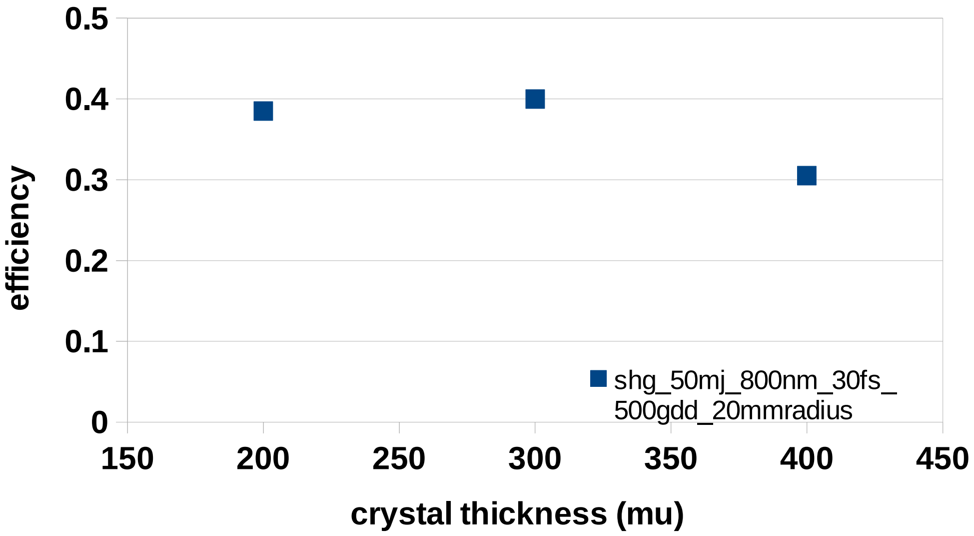


ICS case study

SHG: 20mJ(w), 25mm size beam

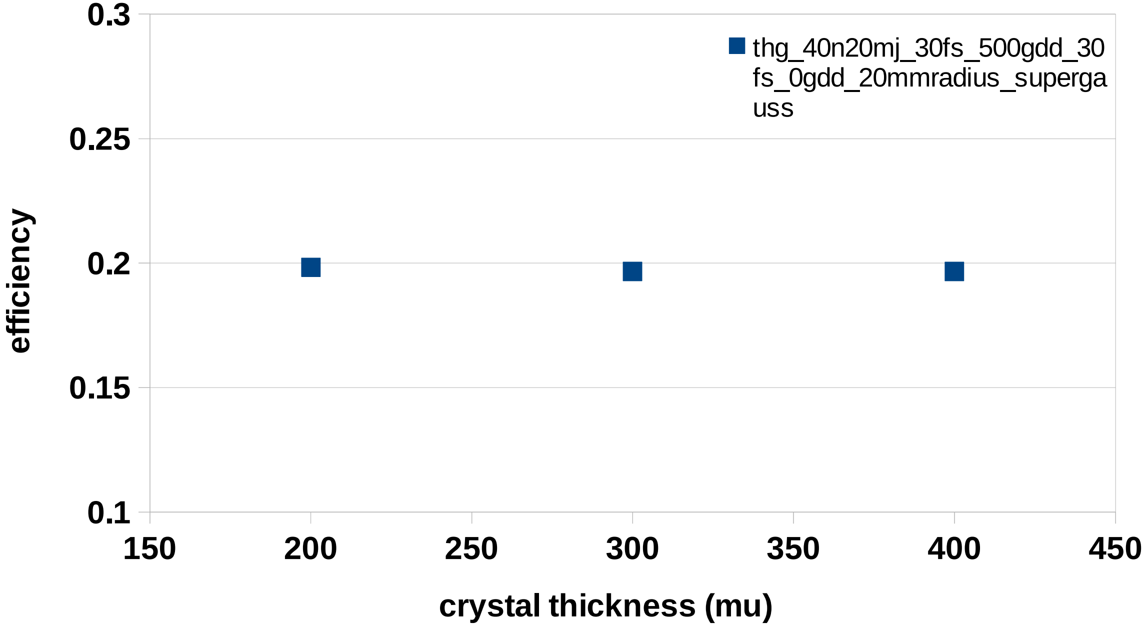


SHG: 50mJ(w), 40mm size beam



ICS case study

THG: 40+20mJ(w+2w), 40mm size beam



- Energy in 3w is roughly 12mJ
- Focus quality is also need to be checked!

Summary:

- A preliminary study of 3w generation relevant for ICS for LUXE
- Possible to get required parameters of ICS by suitable combination of energy, beam size and crystal thickness
- Common setup serves also purpose of 4w generation

$$\Delta k = k_1 + k_2 - k_3$$

$$I_3 = I_3^{(\max)} \left[\frac{\sin(\Delta k L/2)}{(\Delta k L/2)} \right]^2 .$$

$$\frac{n_1 \omega_1}{c} + \frac{n_2 \omega_2}{c} = \frac{n_3 \omega_3}{c},$$

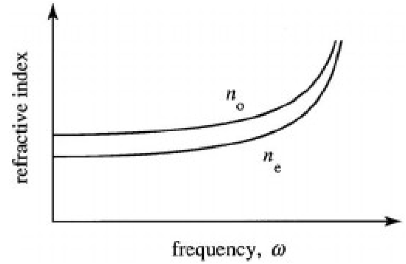


FIGURE 2.3.2 Dispersion of the refractive indices of a negative uniaxial crystal. For the opposite case of a positive uniaxial crystal, the extraordinary index n_e is greater than the ordinary index n_o.

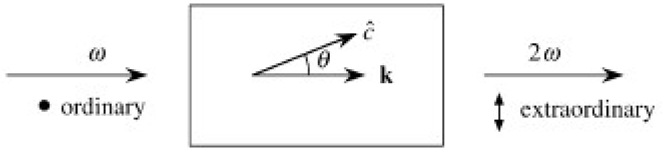


FIGURE 2.3.3 Geometry of angle-tuned phase matching of second-harmonic generation for the case of a negative uniaxial crystal.

$$\frac{1}{n_e(\theta)^2} = \frac{\sin^2\theta}{\bar{n}_e^2} + \frac{\cos^2\theta}{n_o^2}.$$