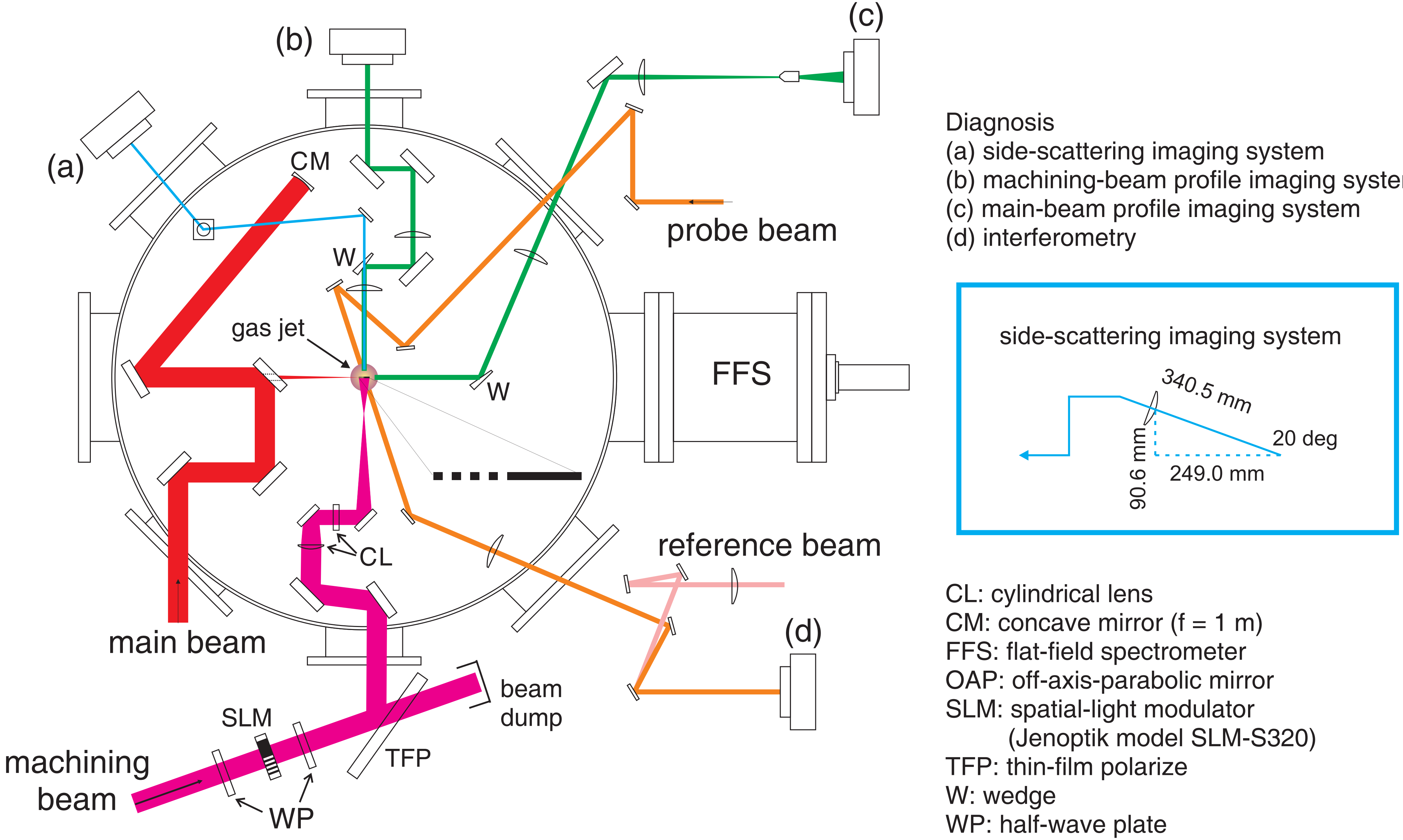
The results of last experiment

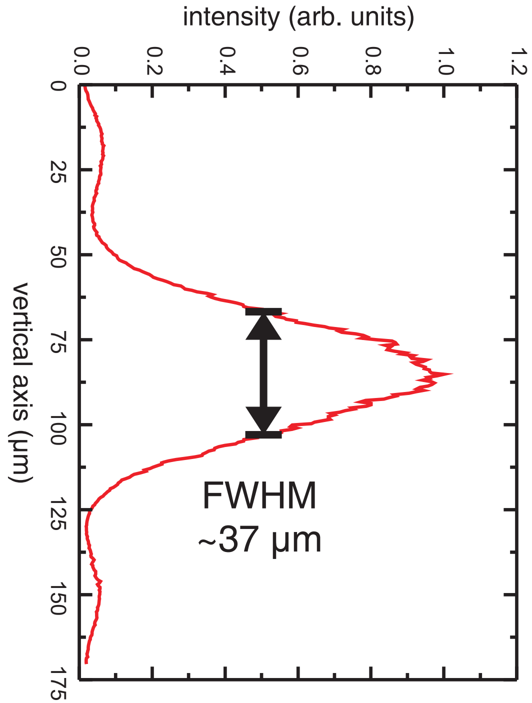
Experimental setup

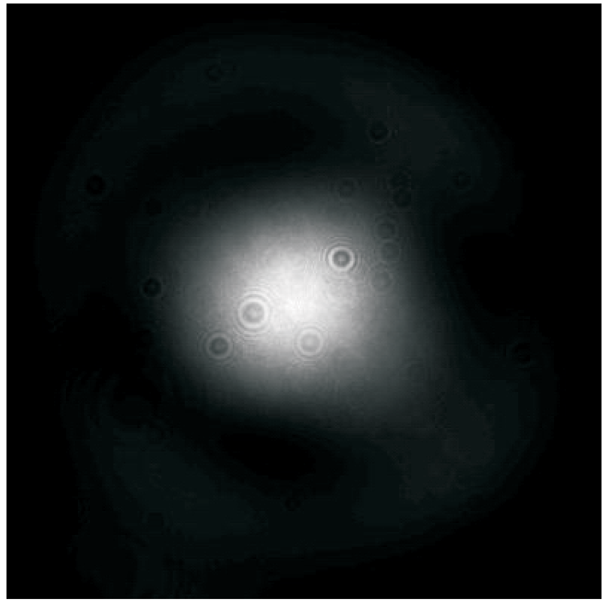


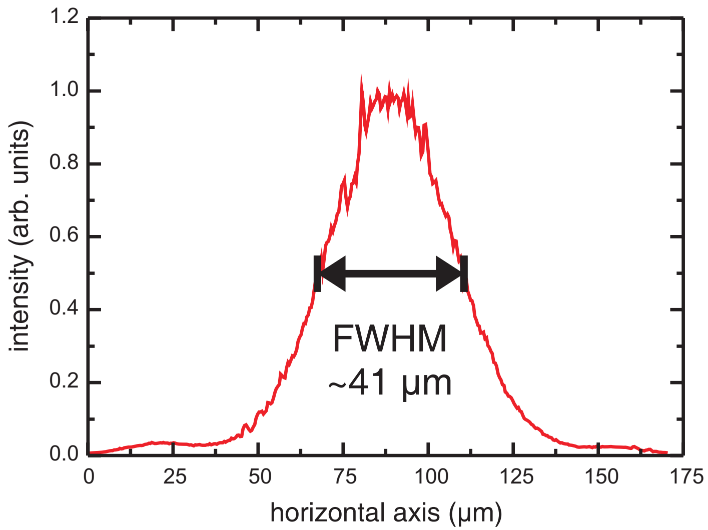
Diagnosis
(a) side-scattering imaging system
(b) machining-beam profile imaging system
(c) main-beam profile imaging system
(d) interferometry

CL: cylindrical lens
CM: concave mirror (f = 1 m)
FFS: flat-field spectrometer
OAP: off-axis-parabolic mirror
SLM: spatial-light modulator
(Jenoptik model SLM-S320)
TFP: thin-film polarize
W: wedge
WP: half-wave plate

Main-beam focusing

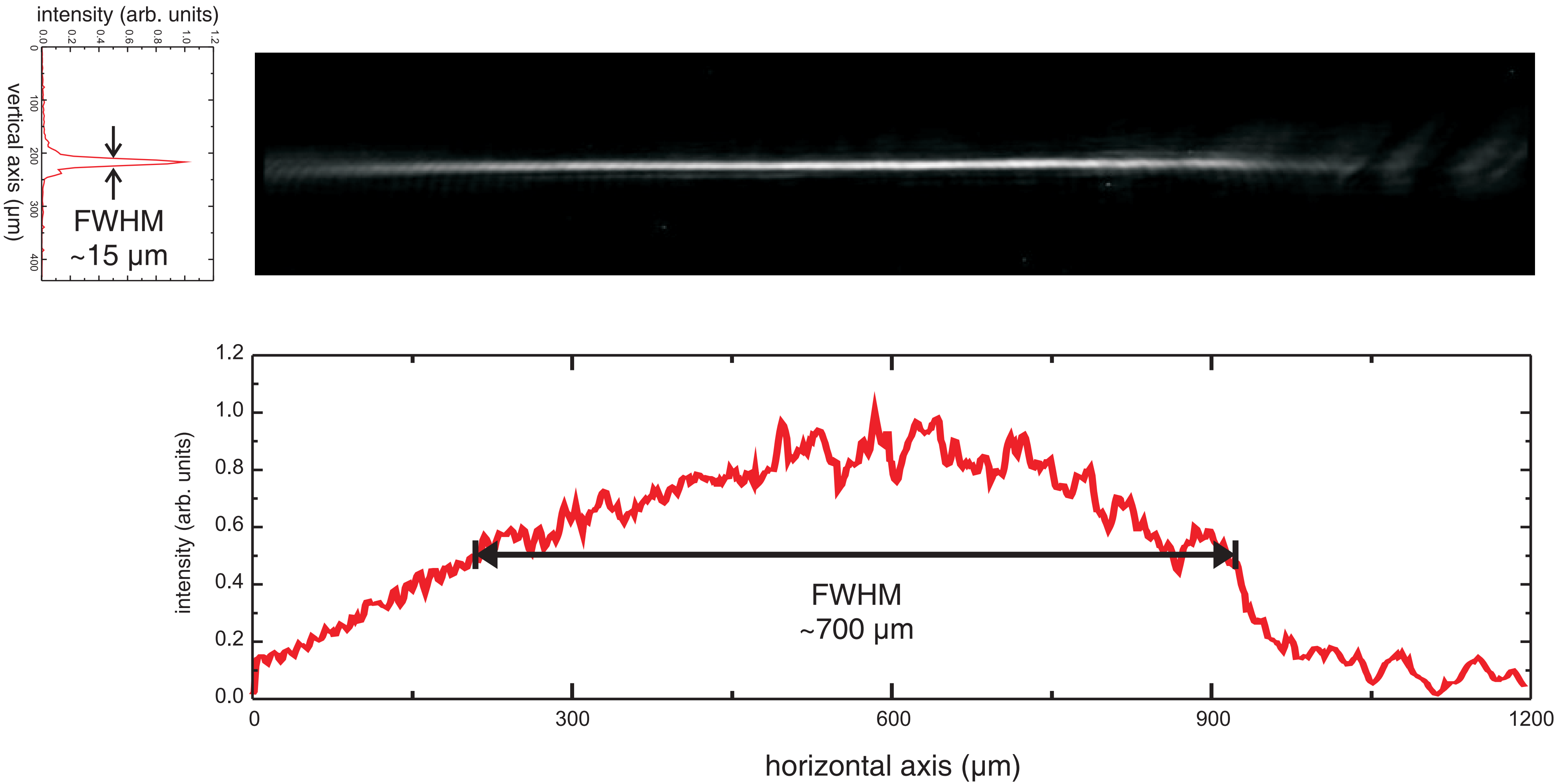






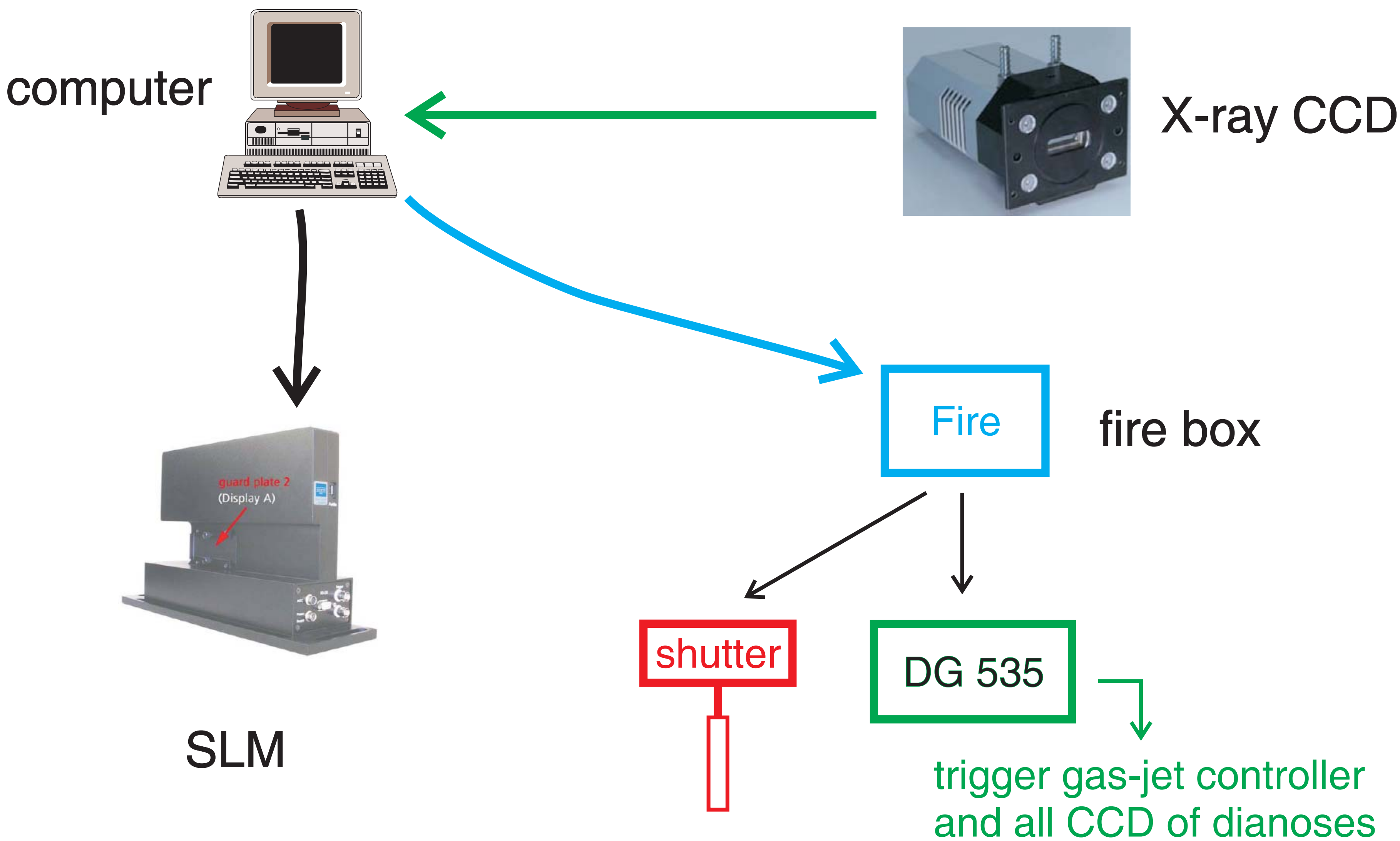
energy: 3.8 mJ
enclosed energy: 85 %
shortest pulse duration: 45 fs
peak intensity: 4.0×10^{15} W/cm^2
diffraction limit: ~1.7

Machining-beam line focusing



energy: 20 mJ
enclosed energy: 50 %
shortest pulse duration: 45 fs
peak intensity: 1.6×10^{15} W/cm^2

Adaptive-feedback-control system

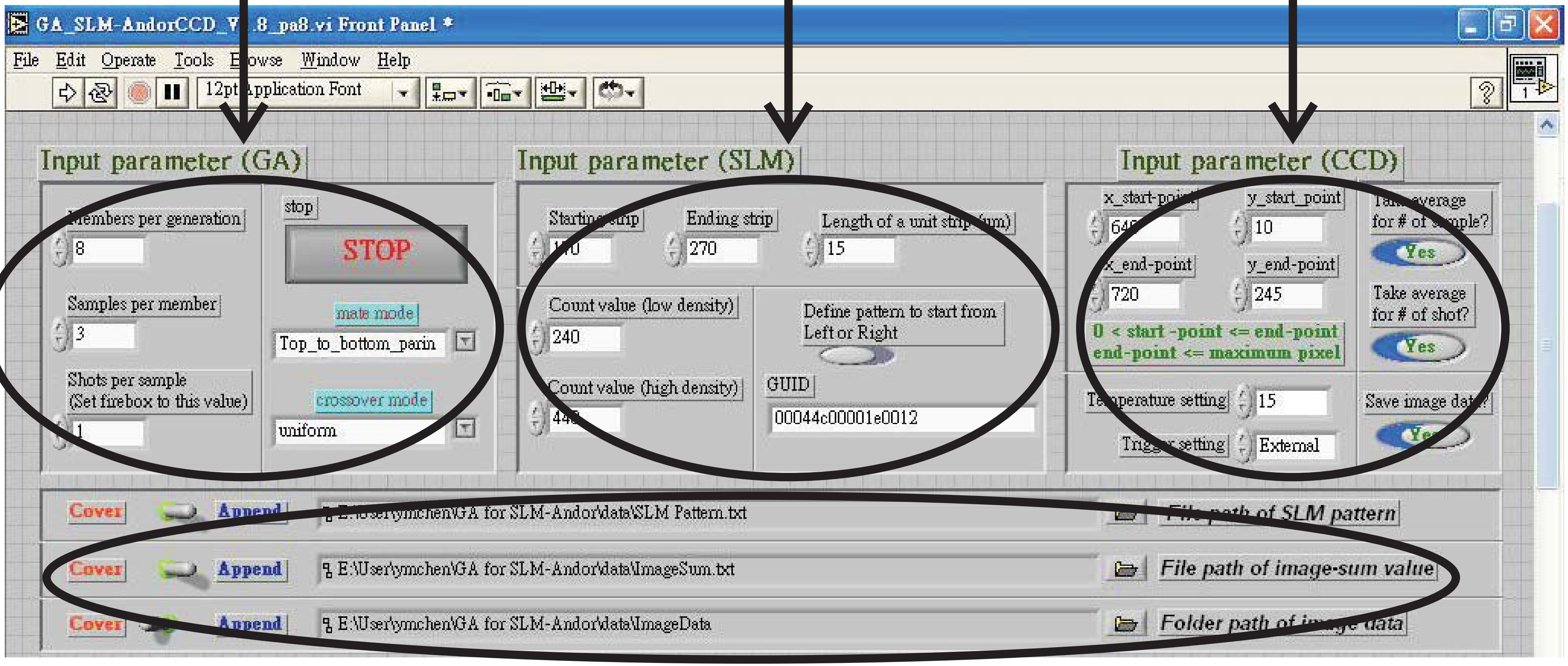


Genetic algorithm program - 1

input parameters of GA

input parameters of SLM

input parameters of CCD



save-file paths

Input parameters of GA1-program

Input parameters of GA

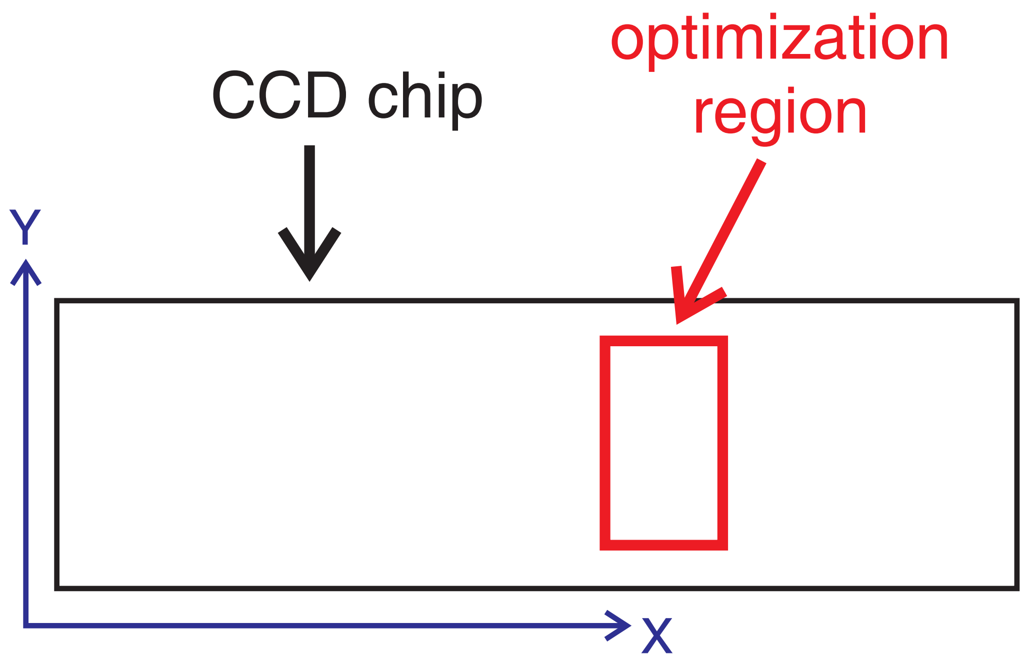
members per generation: 8
samples per member: 3
shots per sample: 1 (set fire box to this value)

Input parameters of SLM

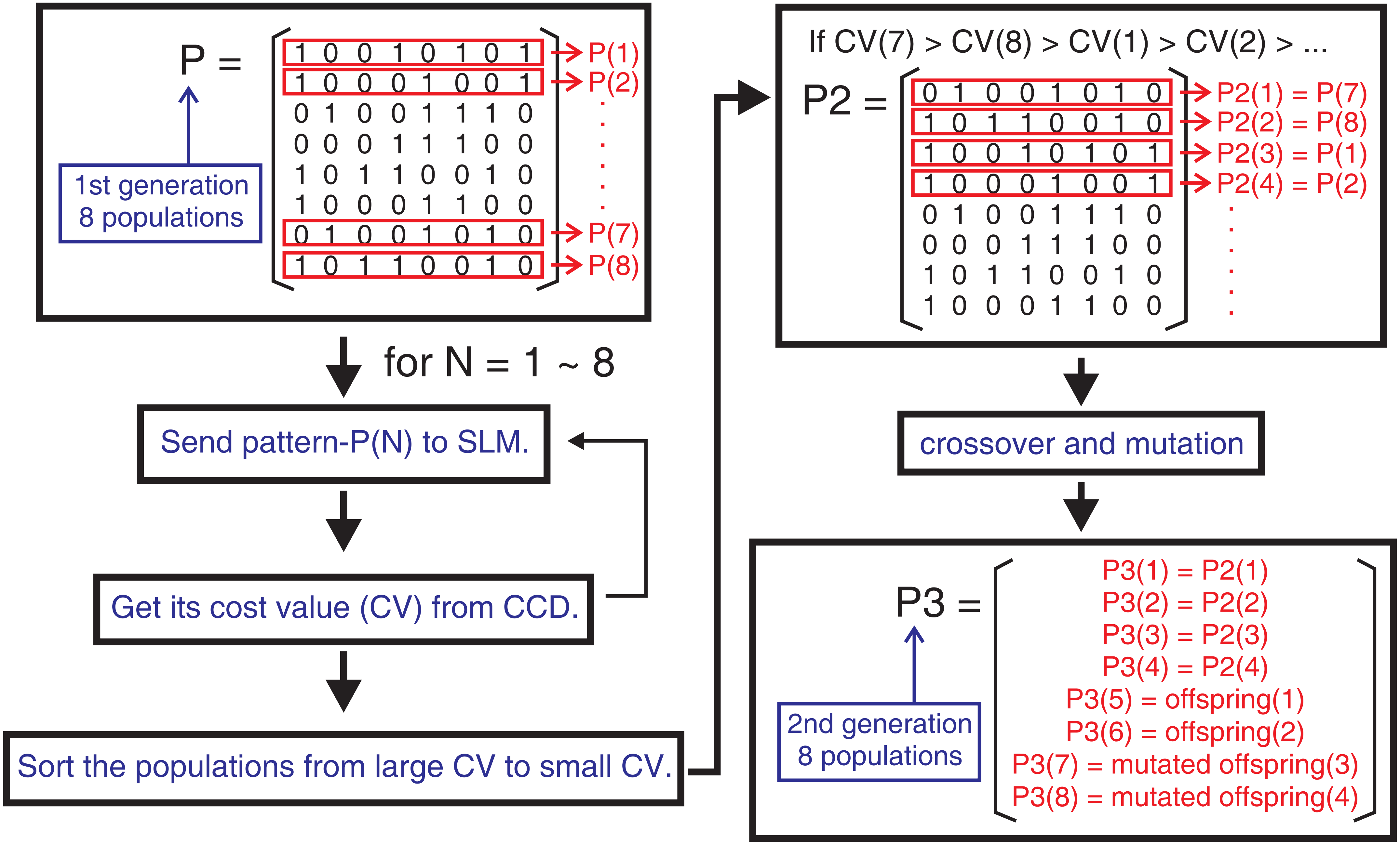
starting strip: 170
ending strip: 270
length of unit strip (um): 15

Input parameters of CCD

x-starting point: 640
x-ending point: 720
y-starting point: 10
y-ending point: 245



How to generate offspring?



Crossover and mutation

Choose father and mother: top to bottom paring

mother: P2(1) and P2(3)
father: P2(2) and P2(4)

Choose crossover mode: uniform

0 1 0 0 1 0 1 0 → P2(1)
1 0 1 1 0 0 1 0 → P2(2)
0 1 1 1 0 0 1 1 → Randomly generate a mask.
True(1) for exchange.
False(0) for preservation.

0 0 1 1 1 0 1 0 → offspring(1)
1 1 0 0 0 0 1 0 → offspring(2)

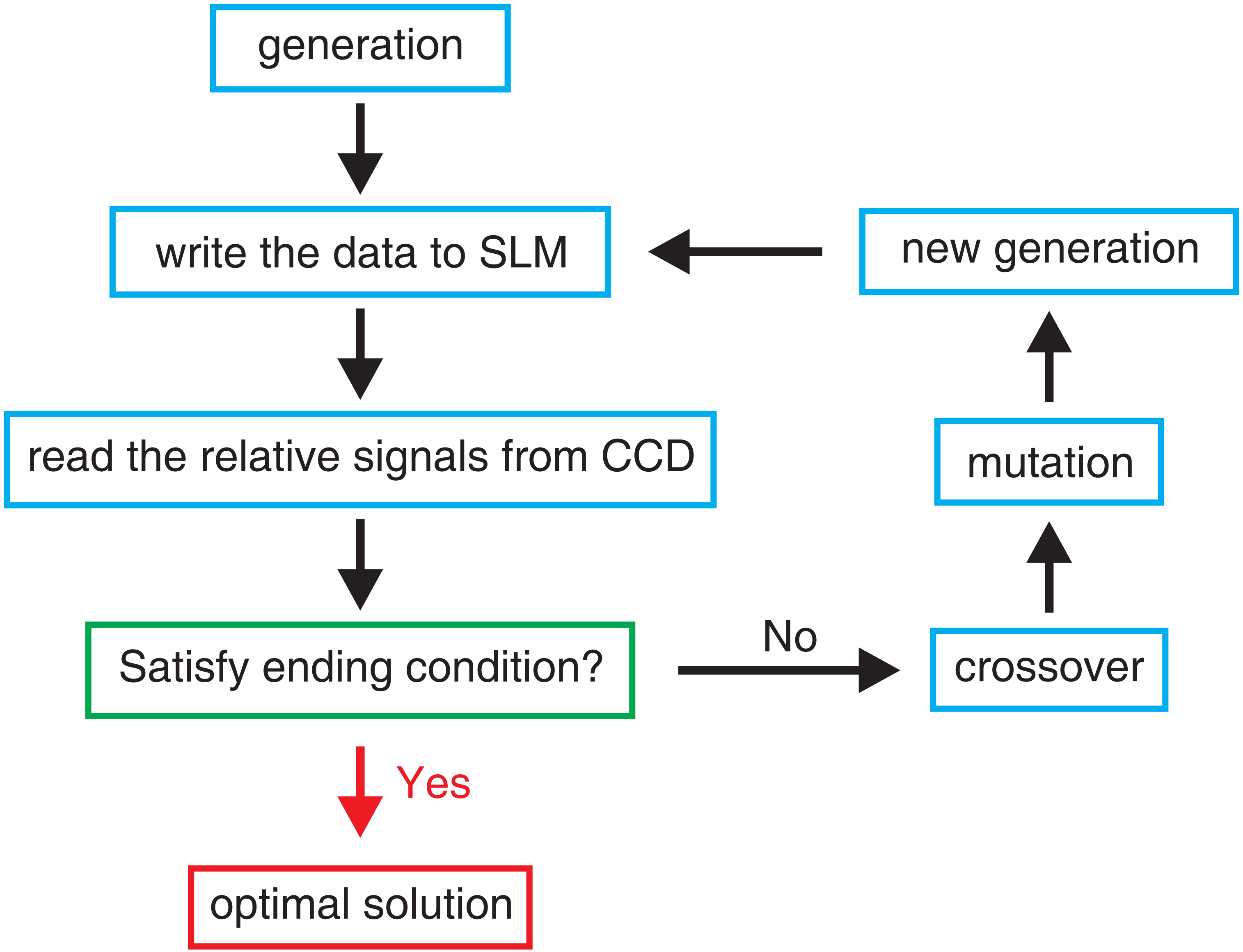
Mutation

If mutation rate = 0.3

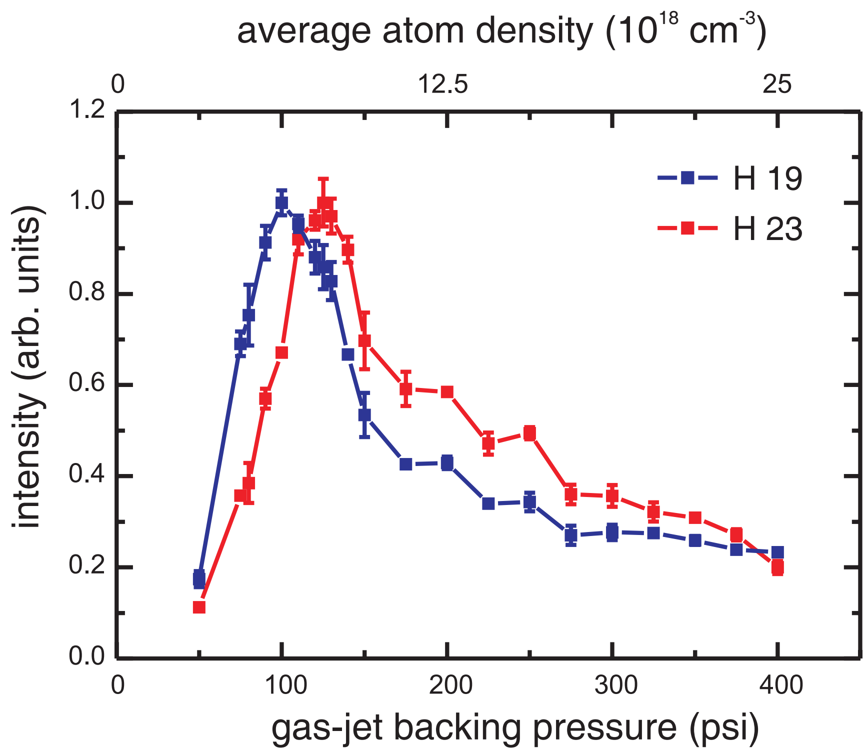
$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 & 0 & 1 \end{bmatrix} \begin{matrix} \rightarrow \text{offspring(3)} \\ \rightarrow \text{offspring(4)} \end{matrix} \longrightarrow \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix} \begin{matrix} \rightarrow \text{mutated offspring(3)} \\ \rightarrow \text{mutated offspring(4)} \end{matrix}$$

number of mutation = or < round(M × N × 0.3) = 5

Flowing chart



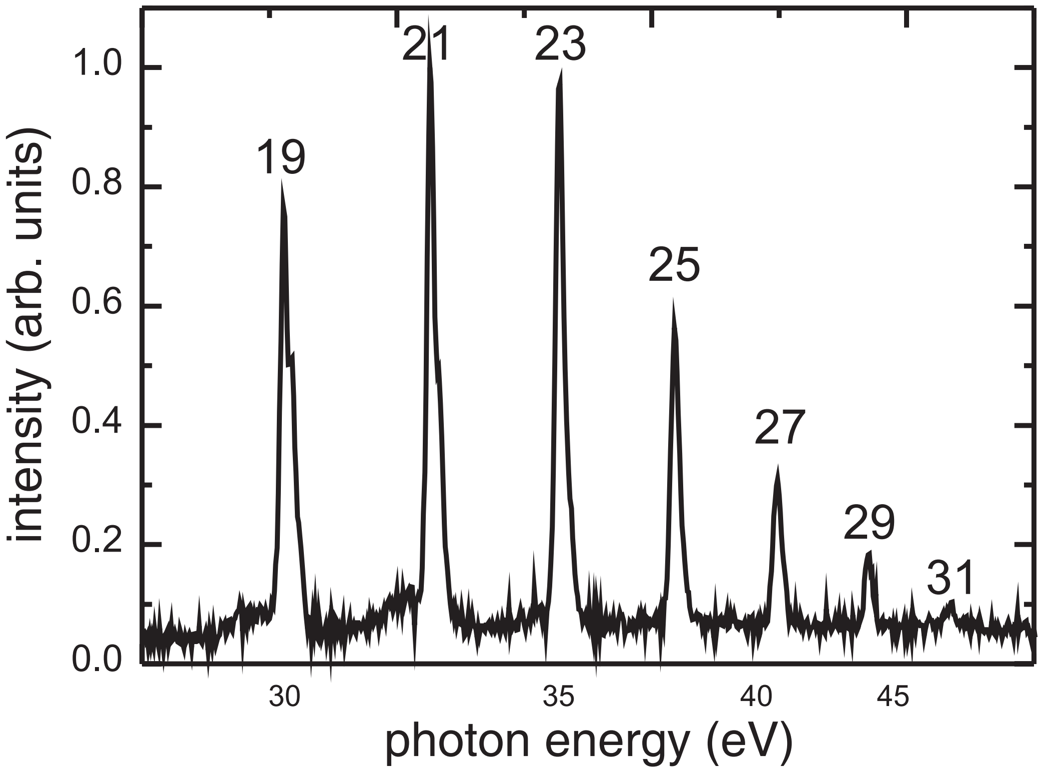
Optimal backing pressure

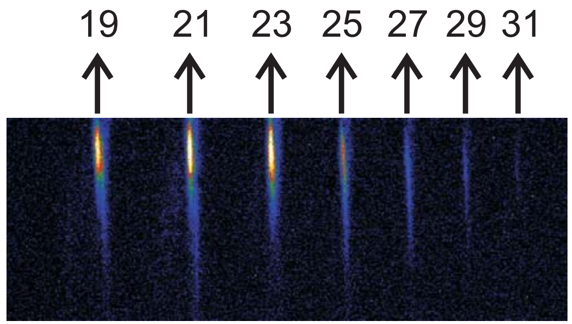


pump energy: 3.8 mJ
pump pulse duration: 150 fs
gas type: mixing gas (Ar : H_2 = 2 :1)

- There is an optimal cluster-jet backing pressure for maximizing the energy of harmonics and it increases with increasing harmonic order. (100 psi for the 19th harmonic, and 125 psi for the 23rd harmonic)

Harmonic spectrum at optimal point

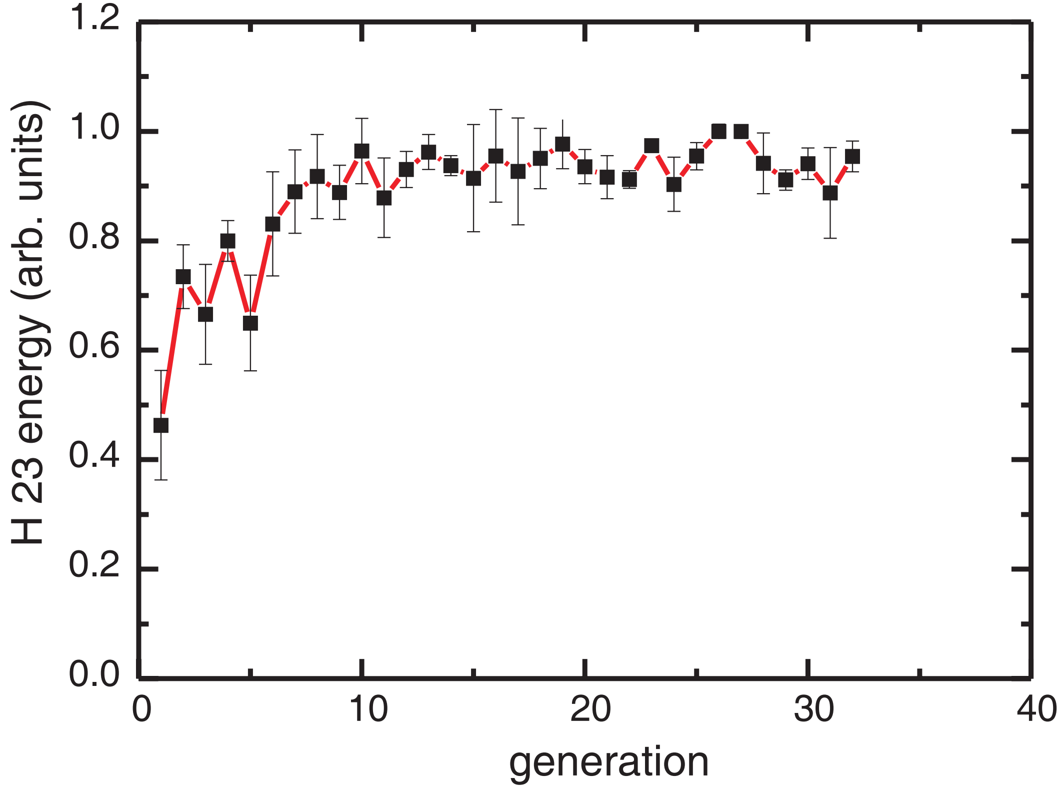




pump energy: 3.8 mJ
pump pulse duration: 150 fs
peak intensity: 1.2×10^{15} W/cm^2
gas type: mixing gas (Ar : H_2 = 2 :1)
backing pressure: 125 psi

- There is a phase-matched harmonic signal at its optimal backing pressure, giving a high conversion efficiency ~ 10^{-6}.

Adaptive feedback optimization

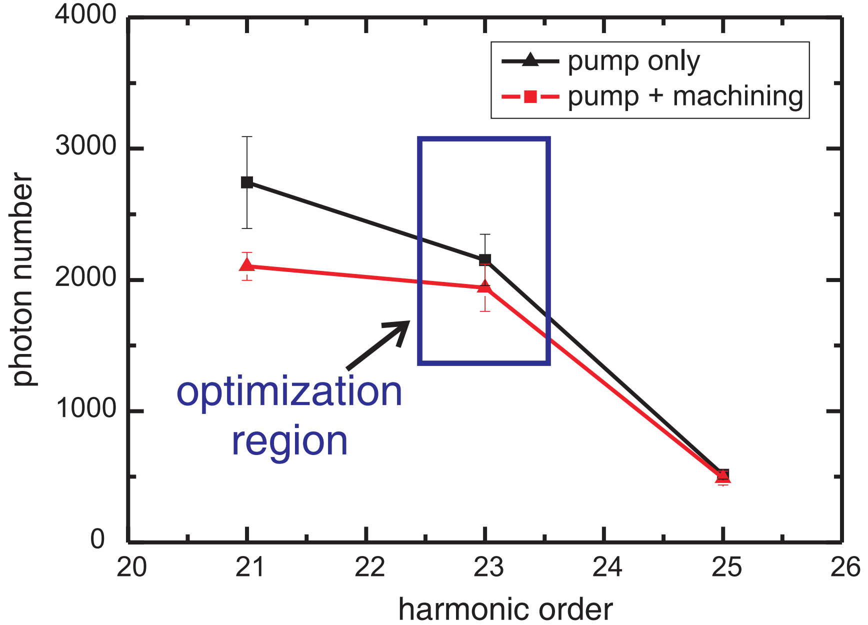


members per generation: 8
samples per member: 5
shots per sample: 1

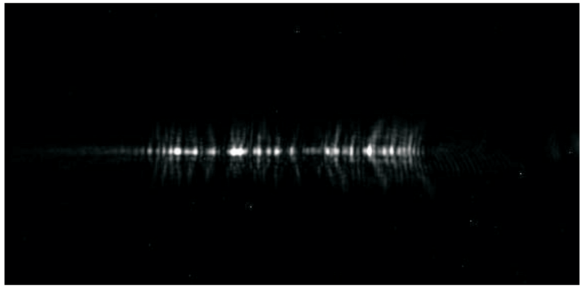
pump energy: 3.8 mJ
pump pulse duration: 150 fs
machining-beam energy: 20 mJ
machining-beam pulse duration: 45 fs
gas type: mixing gas (Ar : H_2 = 2 :1)
backing pressure: 125 psi
machining-beam delay: 5.3 ns

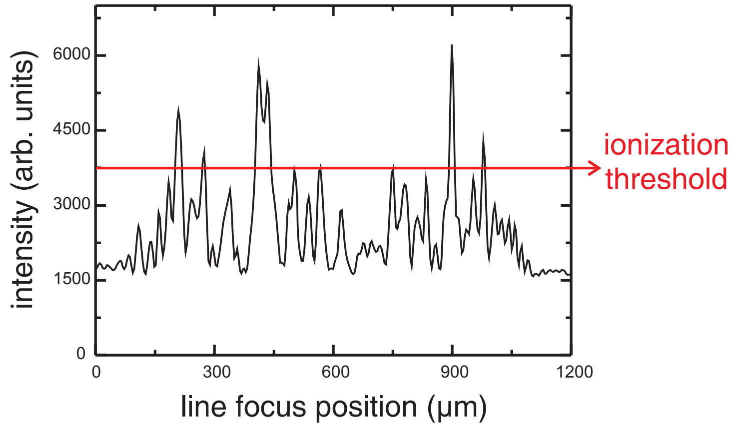
- At the optimal conditions, the 23rd harmonic energy is almost the same after the 10th generation.

Adaptive feedback optimization



line-focus image



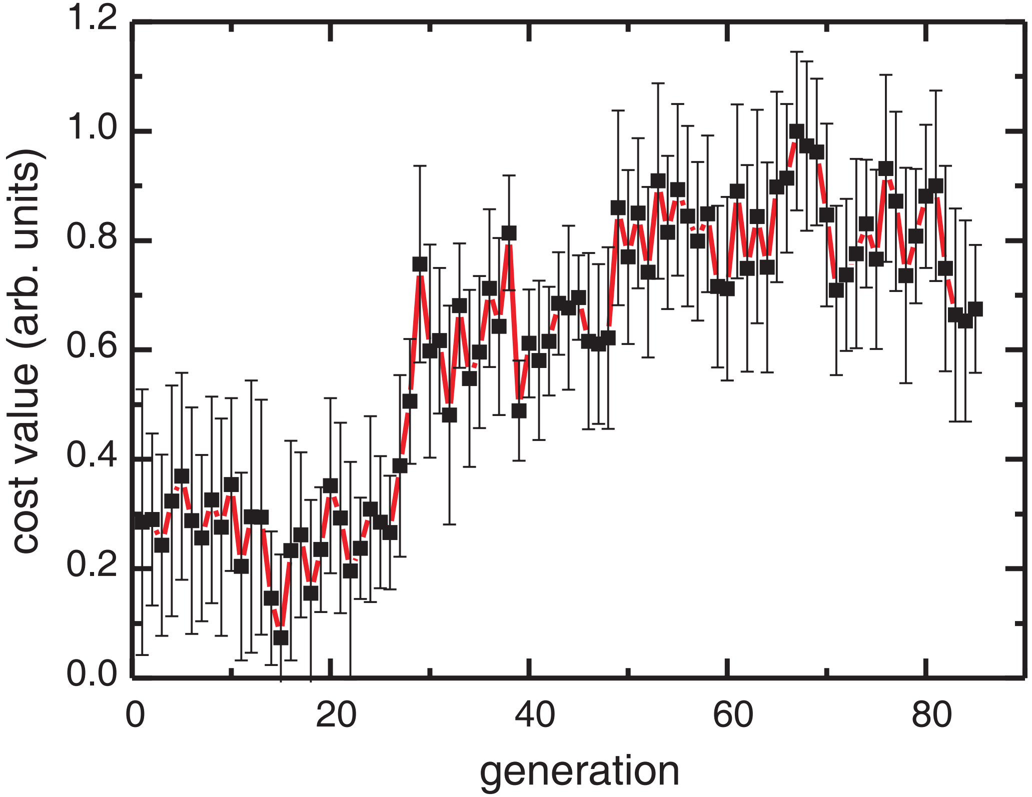


pump only

pump + machining

- The 23rd harmonic energy with both pump and machining pulses is close to that with pump pulse only.

Adaptive feedback optimization

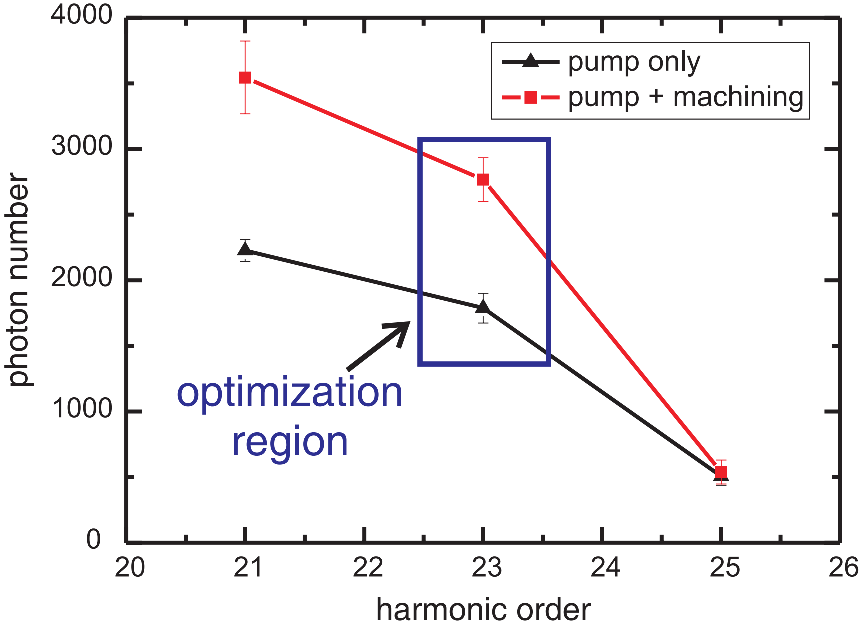


members per generation: 8
samples per member: 3
shots per sample: 1

pump energy: 2.0 mJ
pump pulse duration: 150 fs
machining-beam energy: 20 mJ
machining-beam pulse duration: 45 fs
gas type: Ar cluster
backing pressure: 125 psi
machining-beam delay: 1.9 ns

- At non-optimal conditions, the 23rd harmonic energy is almost the same after the 50th generation.

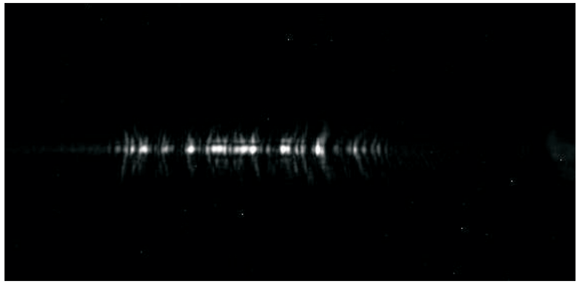
Adaptive feedback optimization

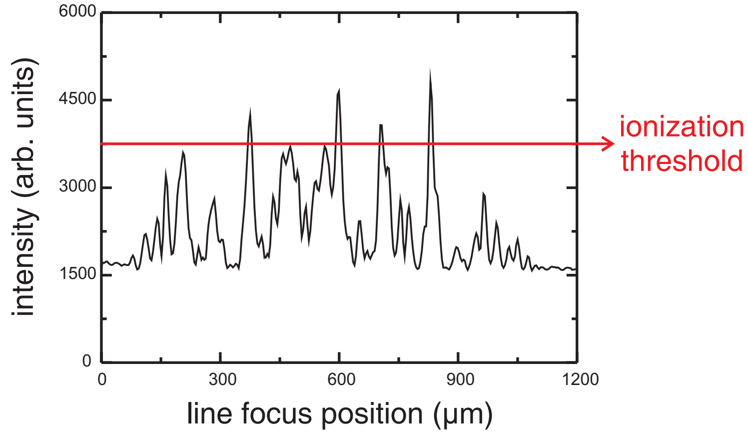


pump only

pump + machining

line-focus image





- The 23rd harmonic energy with both pump and machining pulses is larger than that with pump only.

The improvements of next experiment

- Change the size of gas-jet nozzle from 1 mm to 2 mm.

  → Enhance the 23rd harmonic energy by a factor of two.

- Reduce B-integral of the machining beam.

  → Increase enclosed energy of the machining beam.

- Use a longitudinal prepulse (collinear to pump pulse) to pre-ionize gas.

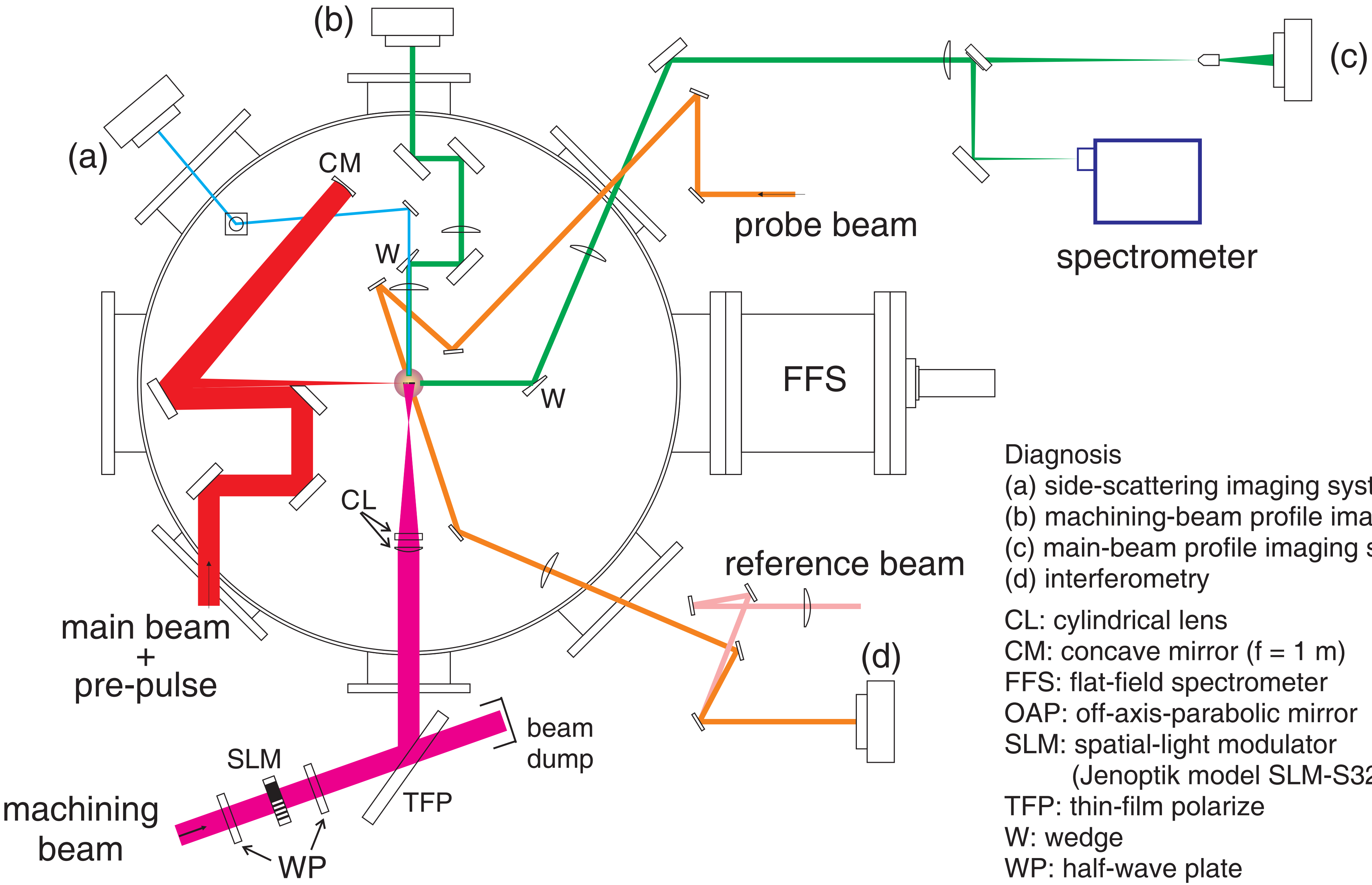
  → Control refraction index of the nanoplasma.

- Change the type of gene generation.

  → Save time.

Next experiment

Experimental setup



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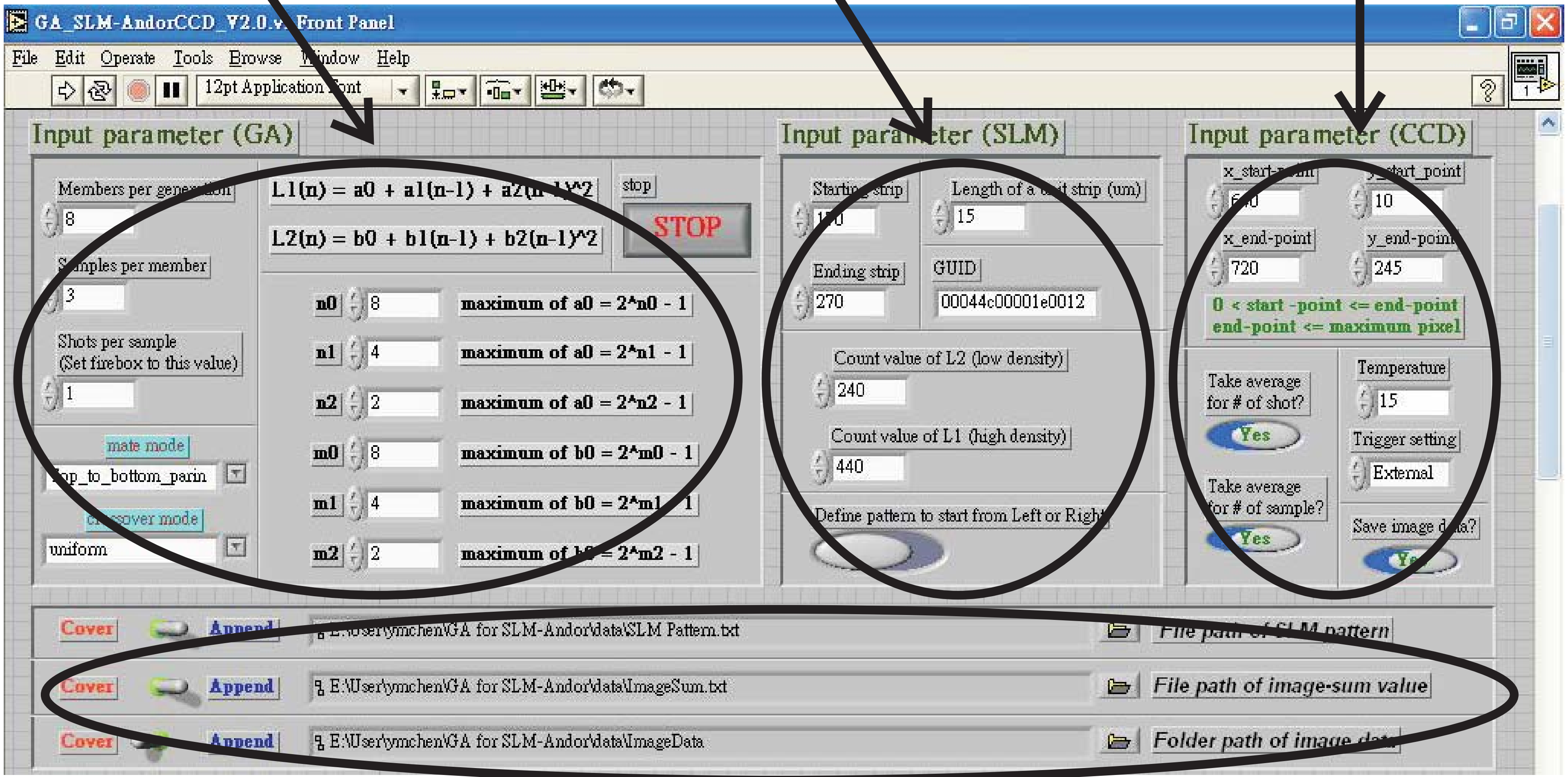
FFS: flat-field spectrometer
OAP: off-axis-parabolic mirror
SLM: spatial-light modulator
(Jenoptik model SLM-S320)
TFP: thin-film polarize
W: wedge
WP: half-wave plate

Genetic algorithm program - 2

input parameters of GA

input parameters of SLM

input parameters of CCD



save-file paths

Input parameters of GA2-program

Input parameters of GA

members per generation: 8
samples per member: 3
shots per sample: 1 (set fire box to this value)

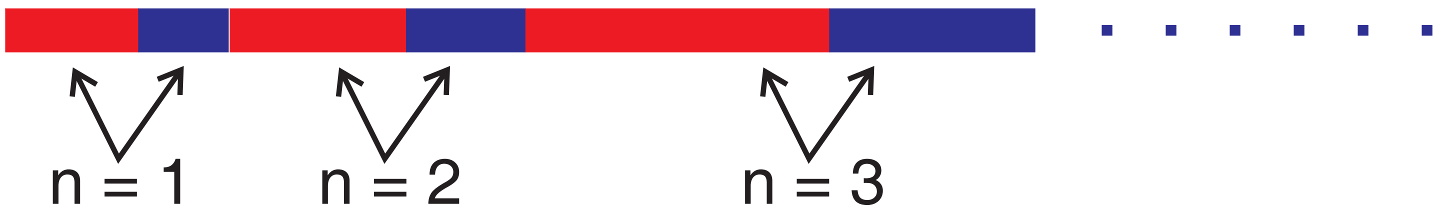
n_0: 7 (maximum of $a_0 = 2^{no} - 1$), $0 < a_0 < 2^7 - 1$
n_1: 3 (maximum of $a_1 = 2^{n1} - 1$), $0 < a_1 < 2^3 - 1$
n_2: 2 (maximum of $a_2 = 2^{no} - 1$), $0 < a_2 < 2^2 - 1$
m_0: 7 (maximum of $b_0 = 2^{mo} - 1$), $0 < b_0 < 2^7 - 1$
m_1: 3 (maximum of $b_1 = 2^{m1} - 1$), $0 < b_1 < 2^3 - 1$
m_2: 2 (maximum of $b_2 = 2^{mo} - 1$), $0 < b_2 < 2^2 - 1$

$$L1(n) = a_0 + a_1 \times (n-1) + a_2 \times (n-1)^2$$

L1(n): high density region

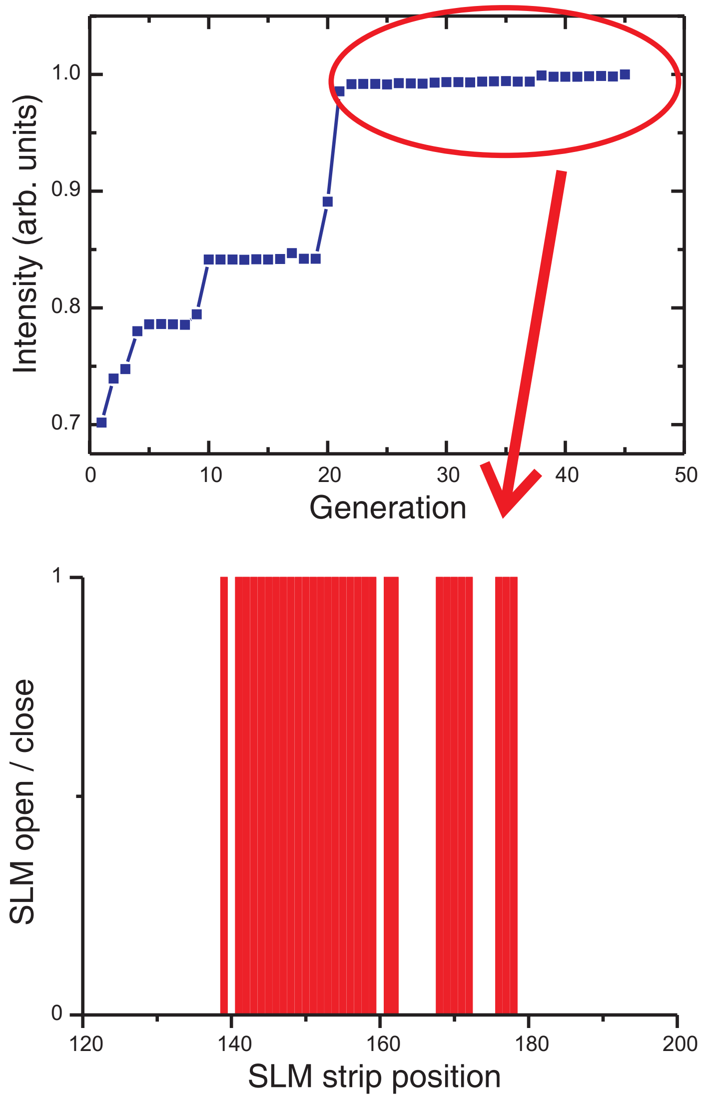
$$L2(n) = b_0 + b_1 \times (n-1) + b_2 \times (n-1)^2$$

L2(n): low density region

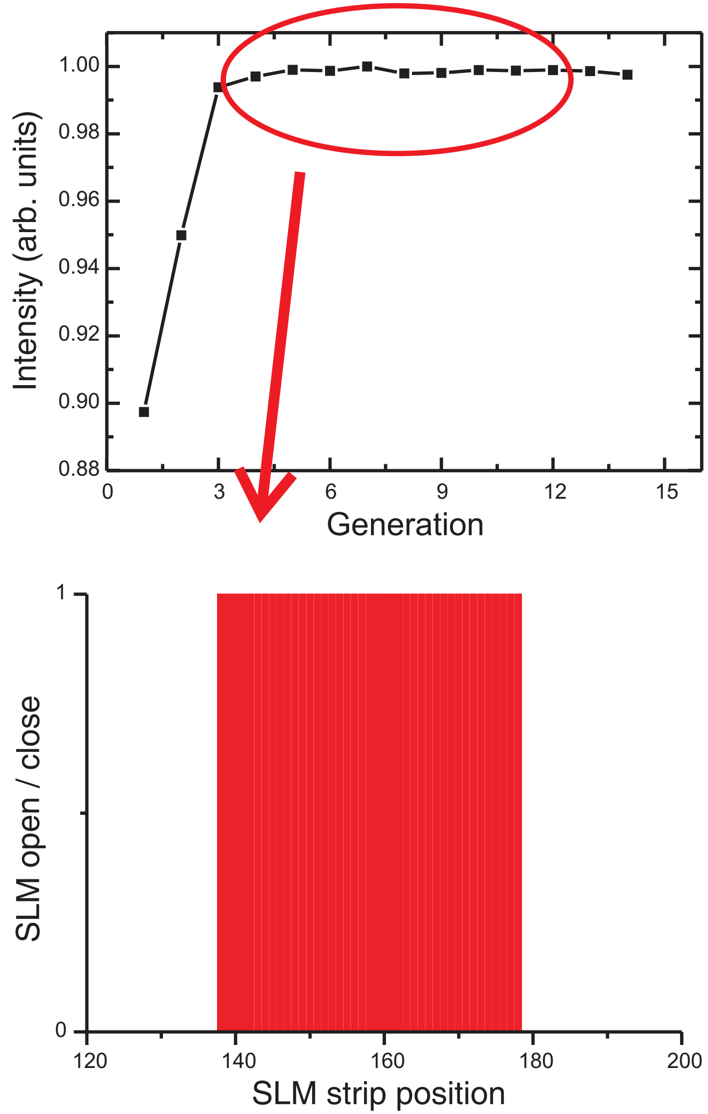


Comparison of two programs

GA1



GA2



Experiment procedure

Traveling-wave-phase-matched high-harmonic generation (TWPM HHG)

Quasi-phase-matched high-harmonic generation (QPM HHG) with adaptive feedback optimization

Spectral broadening with adaptive feedback optimization

Experiment procedure -- TWPM HHG

Optimize the HHG intensity by scanning gas pressure, pulse duration and pulse energy.

Check plasma evolution time scale (ex: resonant at 500fs) by side scattering image in pump probe scheme.

Measure HHG signals in prepulse only and prepulse-pump (separation = 0ps) conditions.

Measure HHG signals in different prepulse-pump separations(150, 300, 500 fs) and then to check if there is any Traveling-wave-phase-matching (TWPM) condition.

Yes

a. Prepulse off in fixed gas density.
b. Main pulse off in fixed gas density.
c. Change another backing pressure
   in the fixed delay.

No

Run genetic-algorithm procedure

go to top

Genetic algorithm procedure -- QPM HHG

machining-beam delay

5 ns	1 ns	500 ps	50 ps

↓

prepulse delay

close	150 fs	300 fs	500 fs

↓

At optimal condition run GA2 program.

↓

At non-optimal condition run GA2 program.
$E = \frac{1}{2} E_{opt}$, $P = \frac{1}{2} P_{opt}$, $T = \frac{1}{2} T_{opt}$

go to top

Genetic algorithm procedure -- spectral broadening

machining-beam delay

5 ns | 1 ns | 500 ps | 50 ps

↓

prepulse delay

close | 150 fs | 300 fs | 500 fs

↓

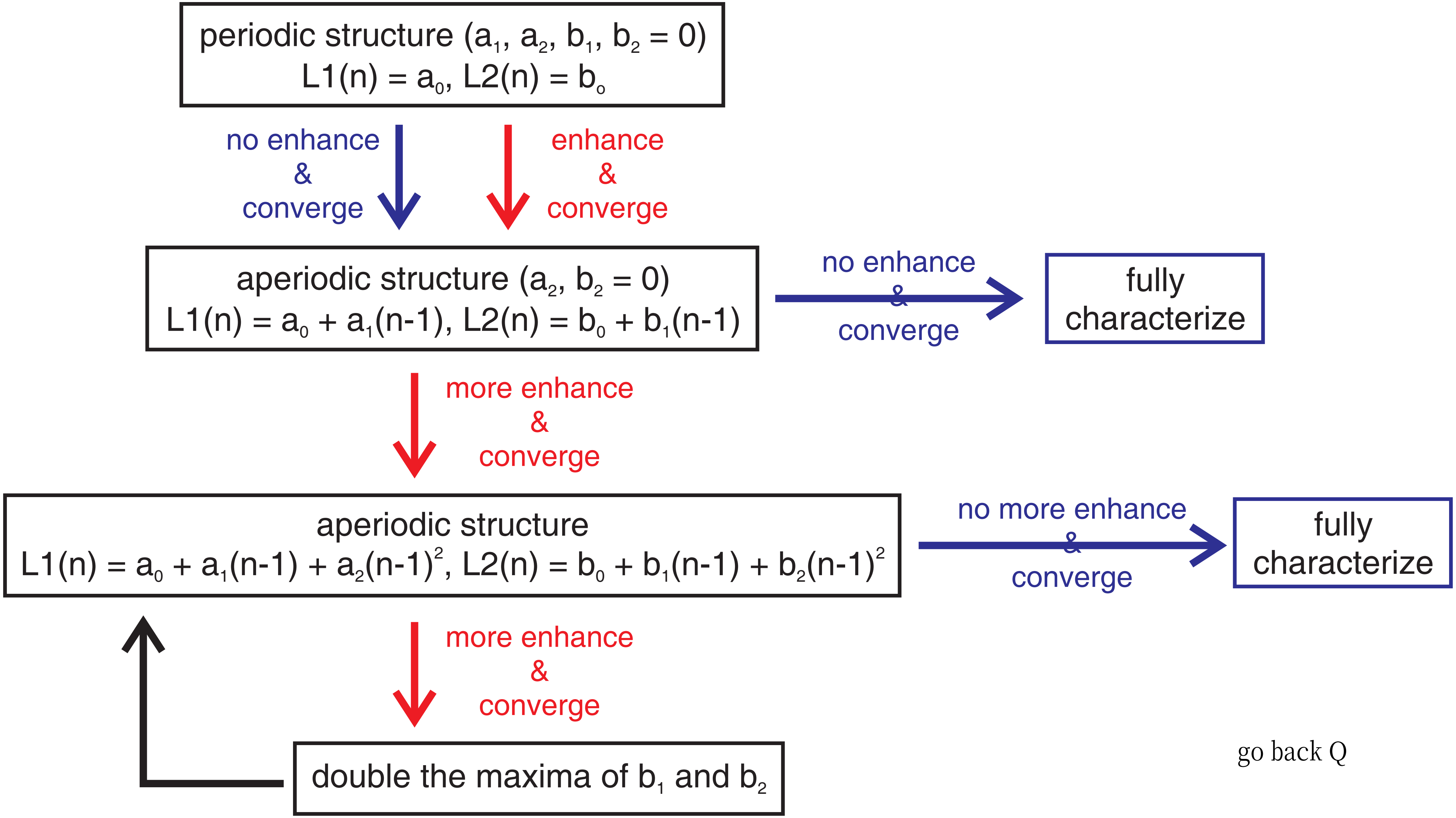
At optimal condition run GA2 program.

↓

At non-optimal condition run GA2 program.
$E = \frac{1}{2} E_{opt}$, $P = \frac{1}{2} P_{opt}$, $T = \frac{1}{2} T_{opt}$

go to top

Run GA2 program



go back Q

go back S

Full characterization

- Null test: Compare the results of the optimal point, the optimal point without the structured machining beam, and the optimal point with the entire region machined.

- Measure the growth curves of harmonic intensity and broadening bandwidth under the optimal SLM-pattern.

go back