Design and construction of ultrafast pulse radiolysis system using laser photocathode rf-gun combined with fs laser

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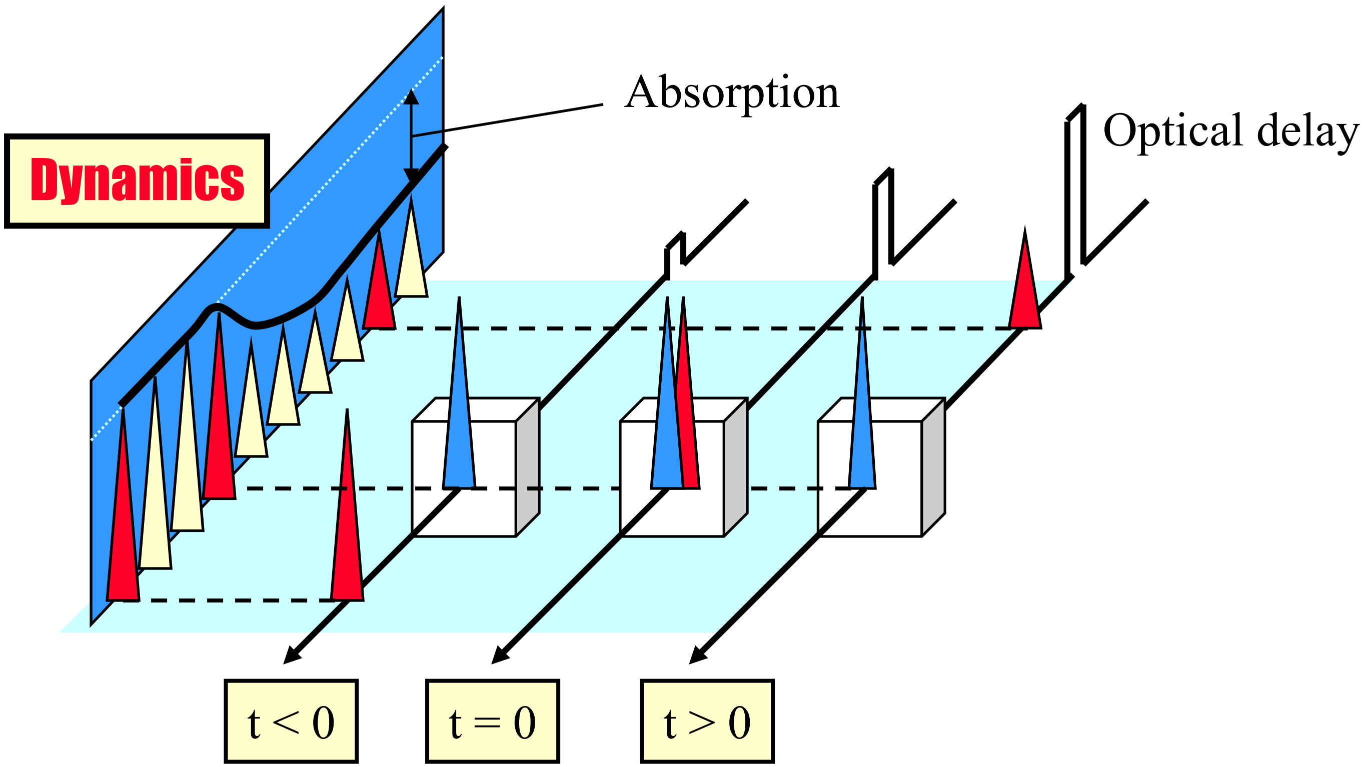
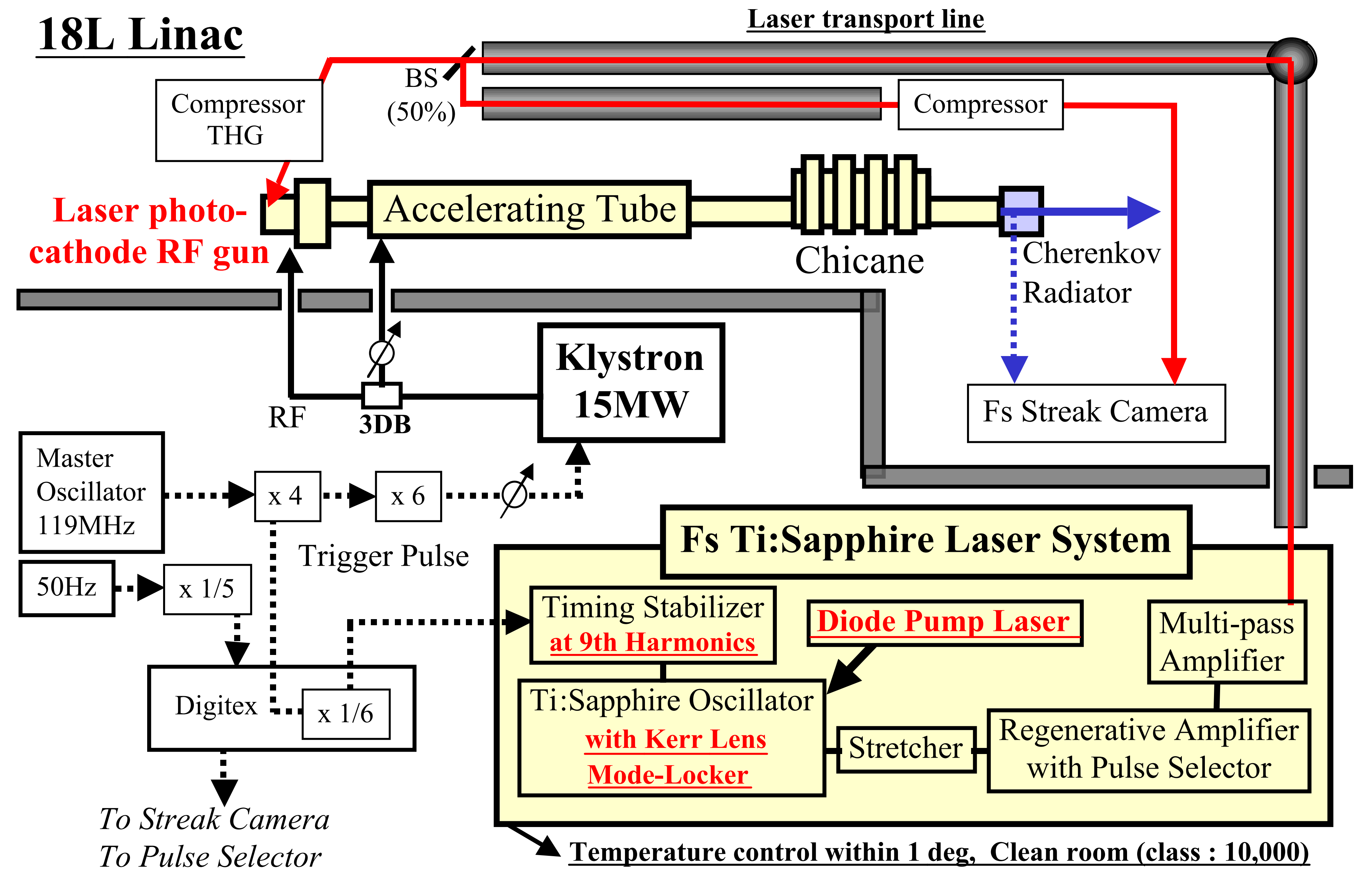
Development of new pulse radiolysis system

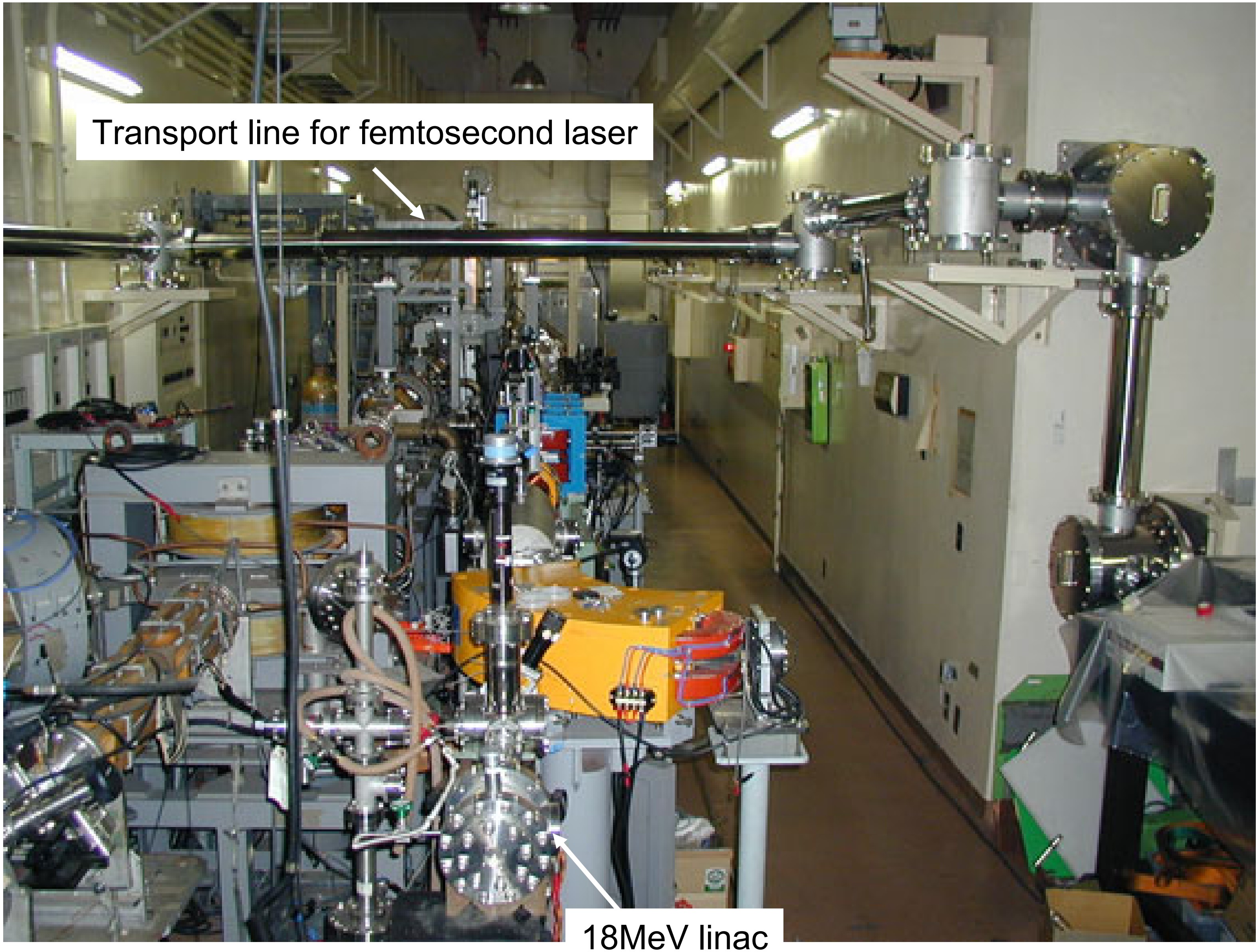
- Time resolution : ~50ps → ≤10ps
- Stroboscopic method (pump-and-probe)
  - Laser photocathode rf-gun and/or fs laser
  - Projects in progress in the world
    BNL, Pari-sud, Waseda Univ., Sumitomo Heavy Industries, Osaka Univ., ANL etc.



Precise Synchronization System at NERL

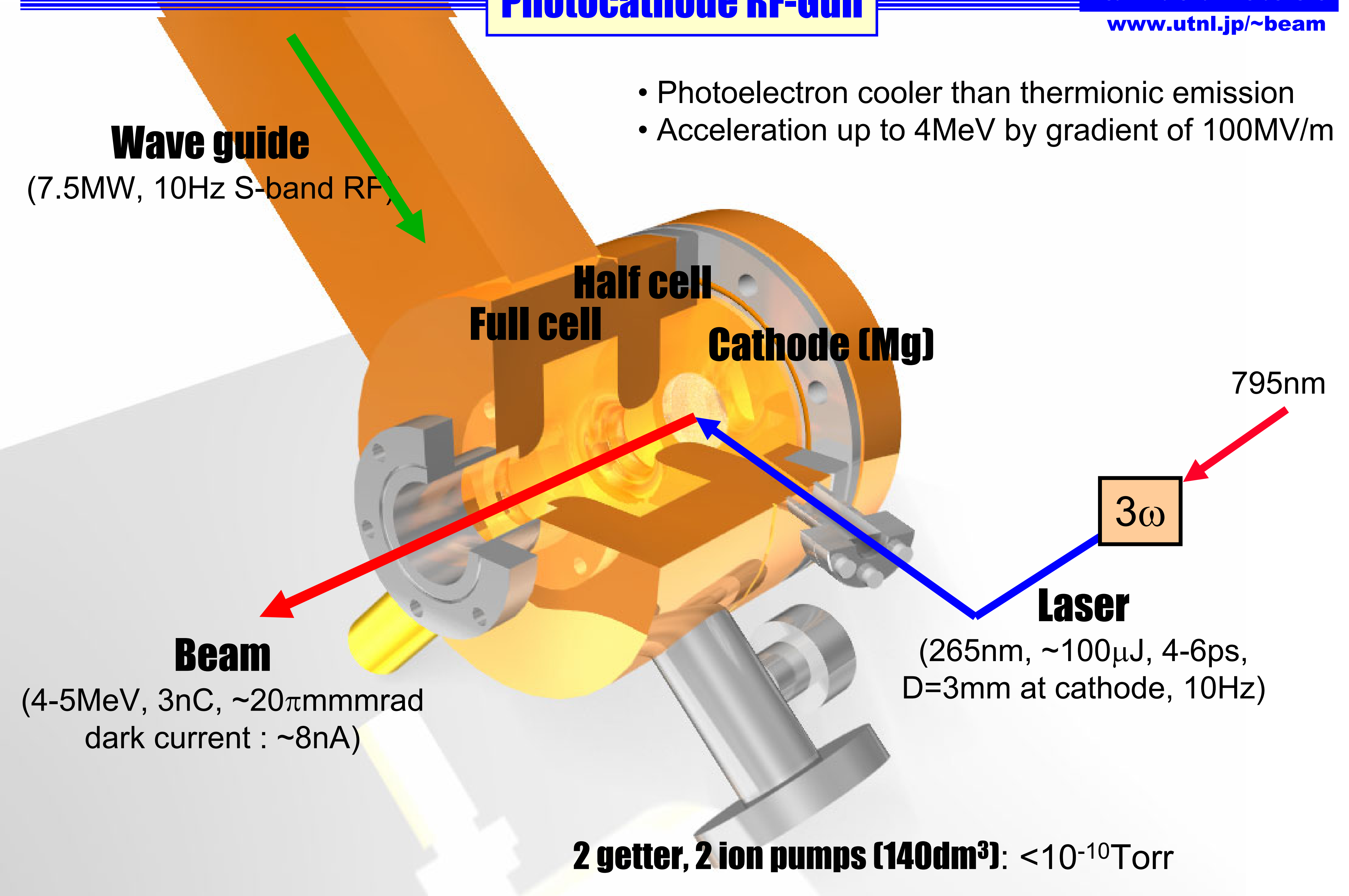


Synchronization System at NERL



Photocathode RF-Gun

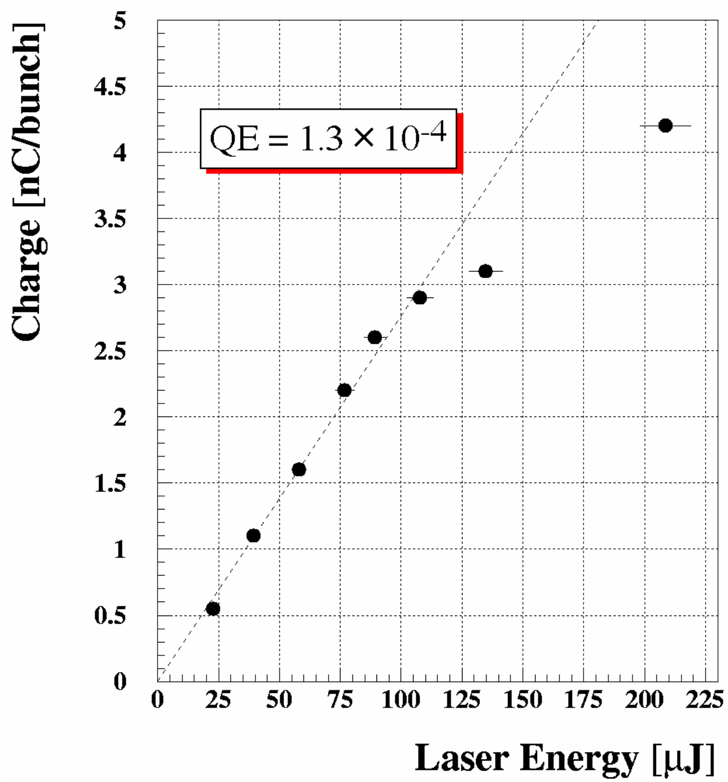
- Photoelectron cooler than thermionic emission
- Acceleration up to 4MeV by gradient of 100MV/m

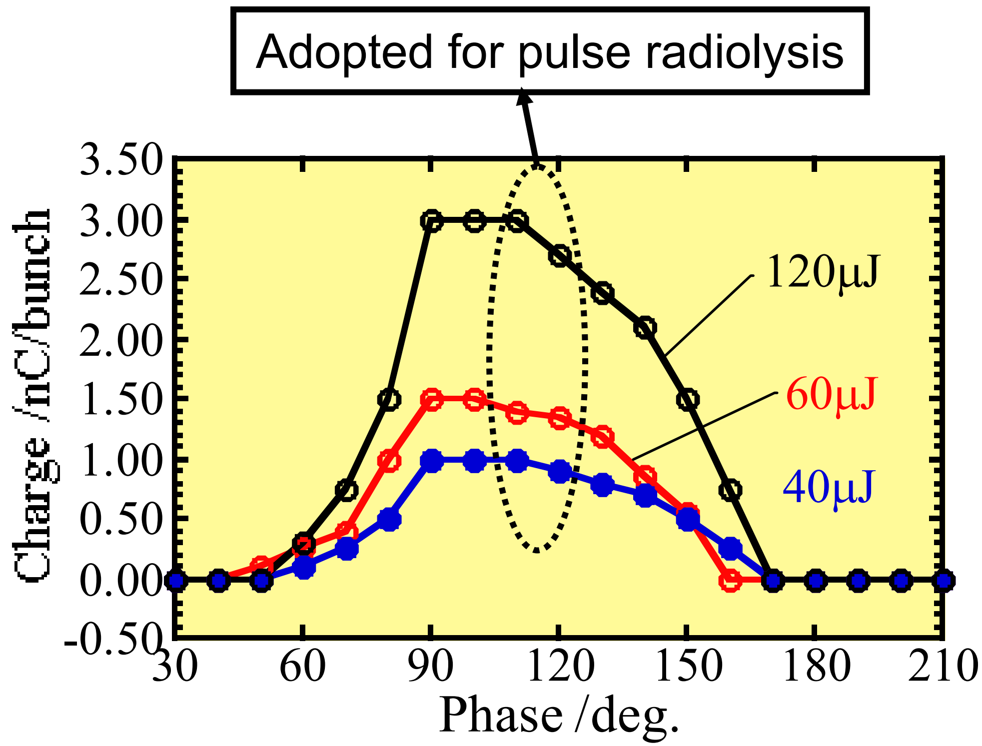


Generation of ultra-short electron beam

RF-gun study

- QE: ~1.2×10^{-4}
- Emittance: 20π (hor.) and 20π (vert.) mmmrad
- >3nC/pulse@90deg





Generation of ultra-short electron beam

Charge transportation

- Laser(265nm) : ~100μJ
- Gun phase : ~120deg
- ACC phase : ~80deg
- 80~90% transmission (Oct. 2003)

Optimized electron beam

Sections in linac	Photo-cathode	ACC	Chicane	Linac end (no slit)	Linac end (3mm slit)
Charge /nC Dark current /nC	2.5 ~0.8	2.5 ~0.2	2.4 ~0.05	2.3 ~0.05	1.7-2.0 nC ~0.05nC
Pulse width /ps	7			<1	2ps(FWHM)
Energy /MeV	4-5		22±0.1MeV		

→ >40Gy/pulse is available

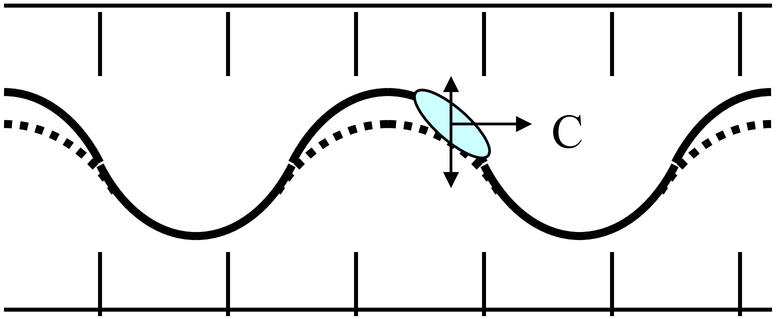
2 factors affecting timing jitter

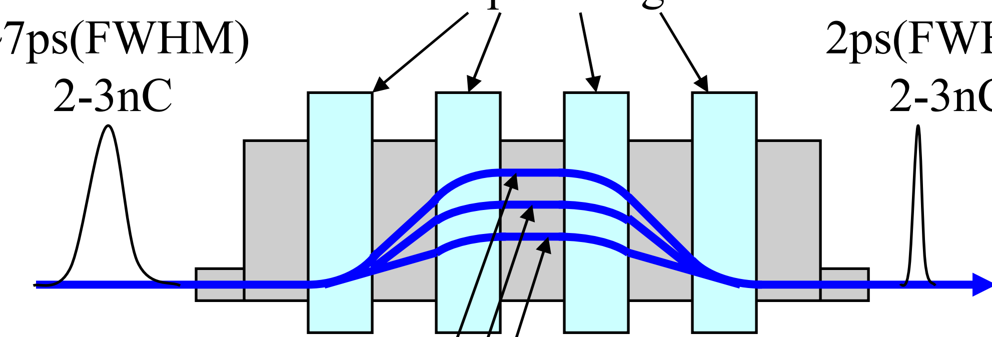
σ_1 : Timing stabilization in laser oscillator
- 100fs by passive mode-lock

σ_2 : Fluctuation of RF power & phase

Synchronization System

Stable acceleration(1) : stable RF

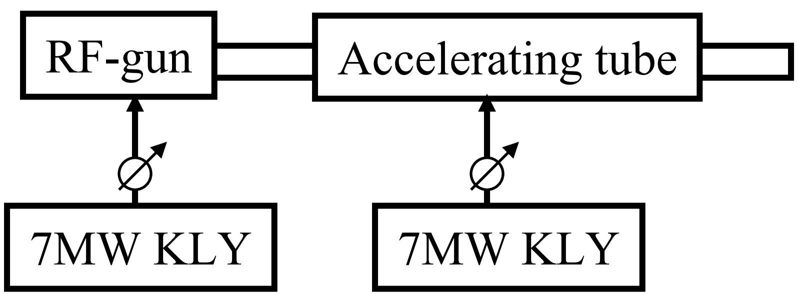


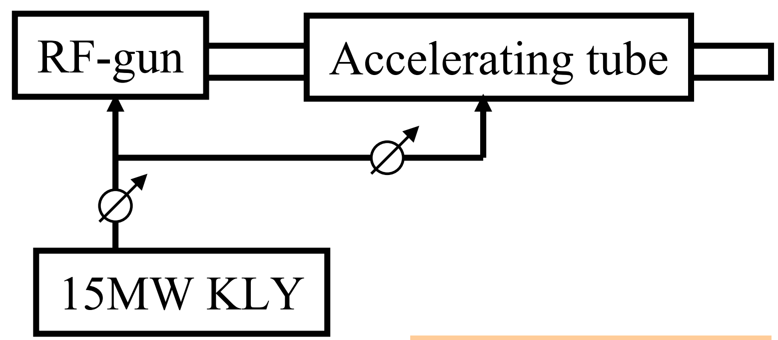


Fluctuation of RF power/phase → Fluctuation of energy → Fluctuation of arrival time

1%, 1deg will induce 300fs jitter

Stable acceleration(2) : mutual jitter



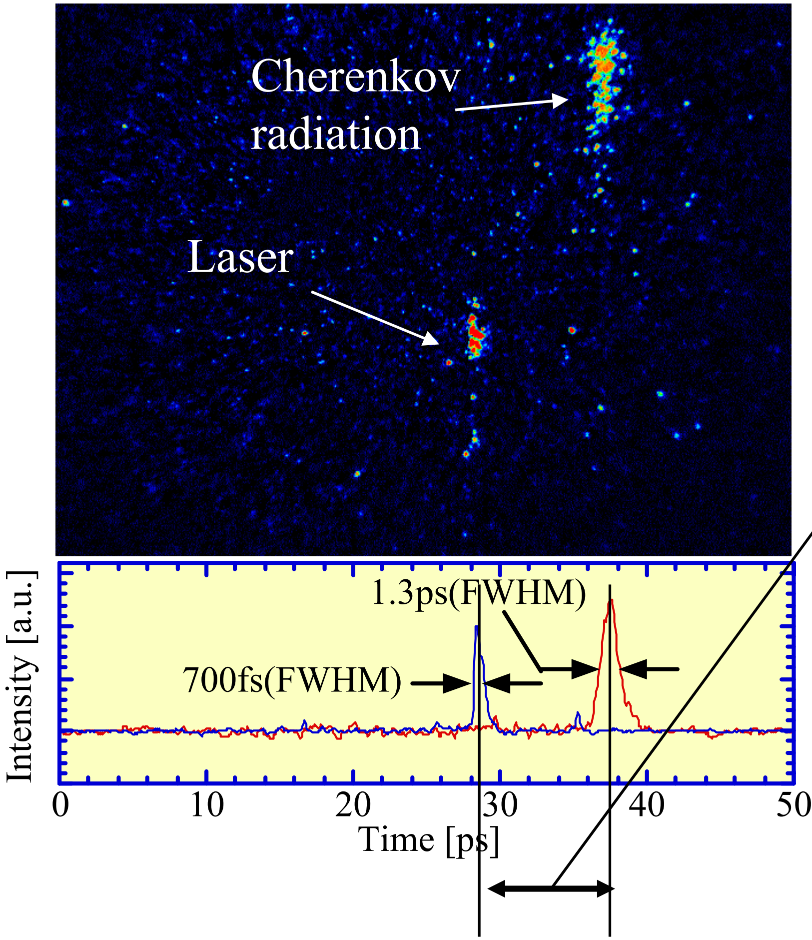


Independently supplied RF : mutual jitter
~ps

No mutual jitter
<ps

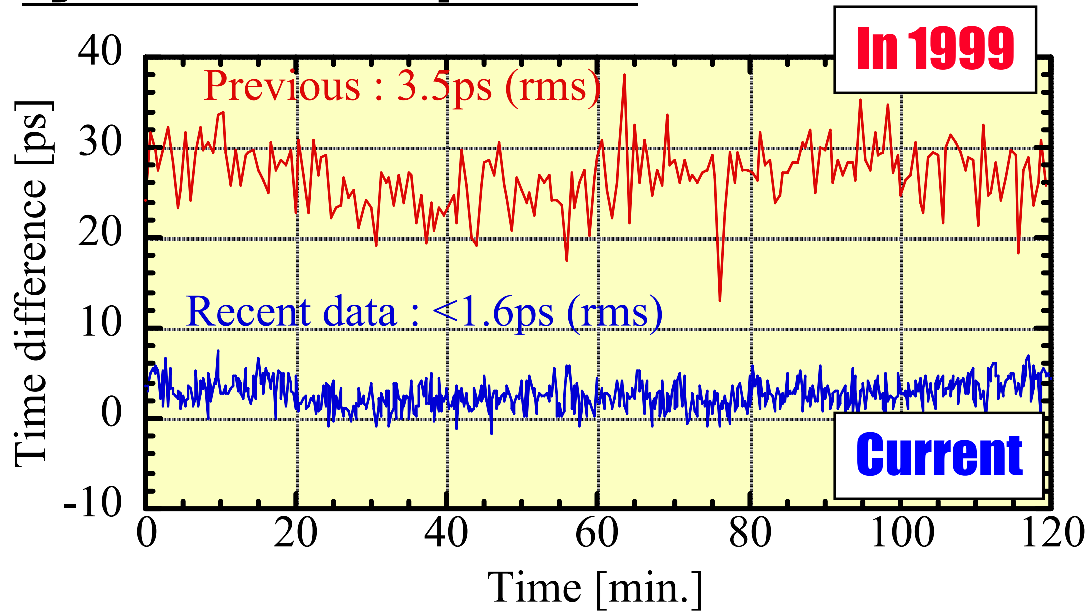
Progress of synchronization system

Synchronization of electron beam and laser by FESCA



• Xe chamber used for Cherenkov radiator

Synchronization experiment

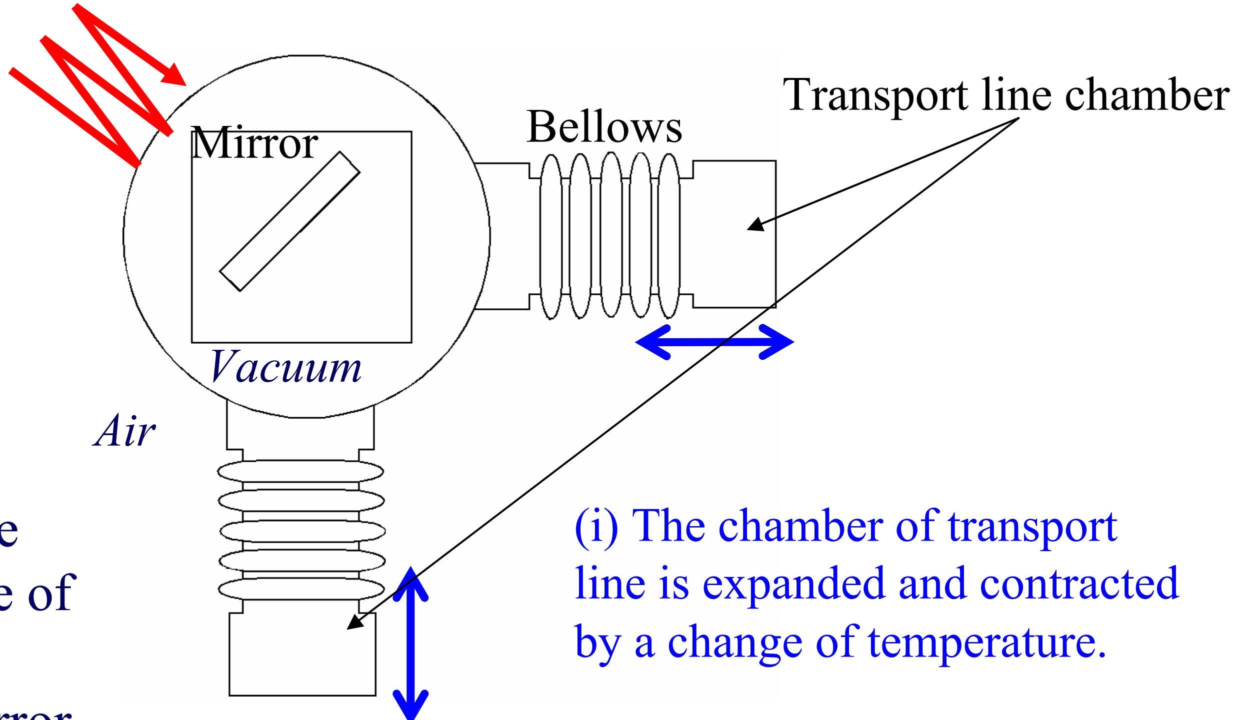


- Timing jitter during minutes: <500fs(rms)
  - Stabilized RFs, passive mode-lock
  - Simulation by PARMERA : 330fs(rms)
- Large drift
  - (1) Cooling system in ACC: $\Delta T < 0.01K$
  - (2) Temp. control in rooms: $\Delta T < 0.5K$
  - (3) N_2 purge in 50m transport line
- Pulse radiolysis : 40~60min./data → <1ps(rms)

Progress of synchronization system

The laser transport line is 50 m long, and 14 bellows are used.

(iii) The mirror chamber with flexibility due to the bellows is moved by the pressure.



(ii) The pressure difference between inside and outside of the transport line chamber applies the force to the mirror chamber.

(i) The chamber of transport line is expanded and contracted by a change of temperature.

- In the chembers… Vacuum ⇒ Atmospheric pressure N_2 gas.

To suppress the pressure effect!

Improvement : problems solved

Time resolution vs. dose

(1) 2~3ps : *pulse width (EB)*
(2) 100fs : *pulse width (laser)*
(3) <1ps : *synch.*
} OK
(4) 5ps /5mm : *Δt passing through H_2O*

→ Thinner cell & focused EB

Note: O.D. = $\varepsilon C l$
l↓ for better time resolution, but O.D.↓
then, C↑ for O.D.→

Introduction of white light continuum

- 795nm → white
- Worse stability of intensity
- S/N↓ then average↑

	Previous	Current
Wavelength	Fundamental 795nm	White 400-1100nm
Average	16	64
Noise	~0.005 OD	~0.015 OD

Improvement

	Previous	Current
Charge	0.8-1.0nC	1.7-2.0nC
Beam size	4mm	3mm
Dose	13-15Gy	>40Gy/pulse
Pulse width	3ps	2ps

Dose increase
&
Wide measurement wavelength

Radiolysis of water measured at 700nm

- Time behaviors of e_{aq}^- at 700nm

Results

l /mm	10	5	2	1
O.D.	0.32	0.19	0.08	0.04
S/N	15	10	5	3
Dose	40Gy	47Gy	50Gy	50Gy
Time resol. /ps	12-13ps	6-7ps	4-5ps	<4ps

Good agreement

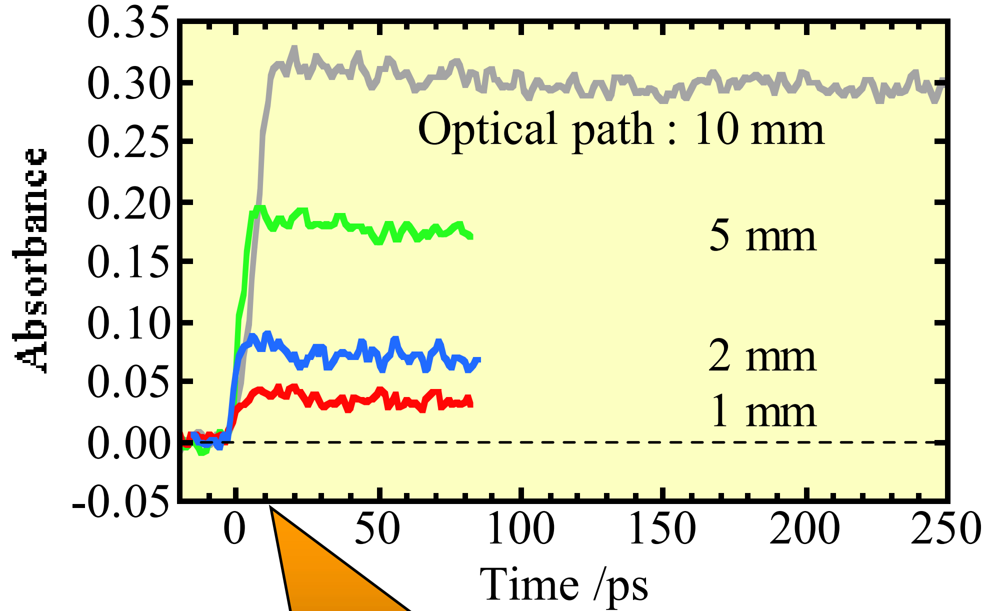
Time resol. /ps	12.2ps	7.2ps	5.2ps	3.2ps

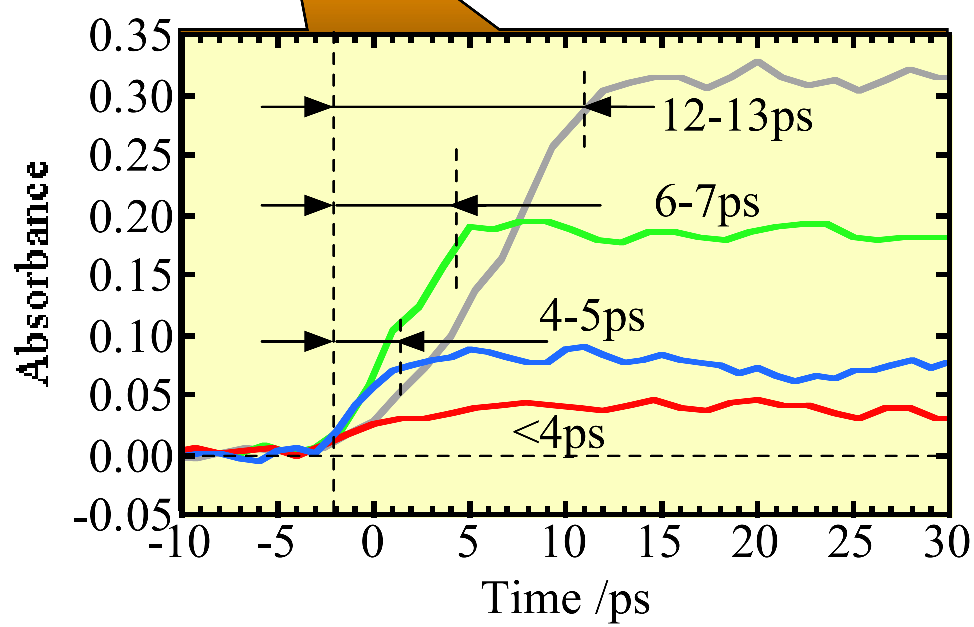
Time resolution: δ_{total}

$$\delta_{total} = \delta_{diff} + (\delta_E^2 + \delta_L^2 + \delta_{sync}^2)^{1/2}$$

Dominant factor : δ_{diff}

due to refractive index n=1.33





Summary

- A new pulse radiolysis system combined with laser photocathode rf-gun and fs white light continuum has been developed.

- Some problems have been pointed out. Consequently, most of those were improved.

- <4ps time resolution has been attained.

- Future works

  Introduction of OPA for extending measurement wavelength