Review of RF photoinjector for radiation chemistry

Univ. Tokyo

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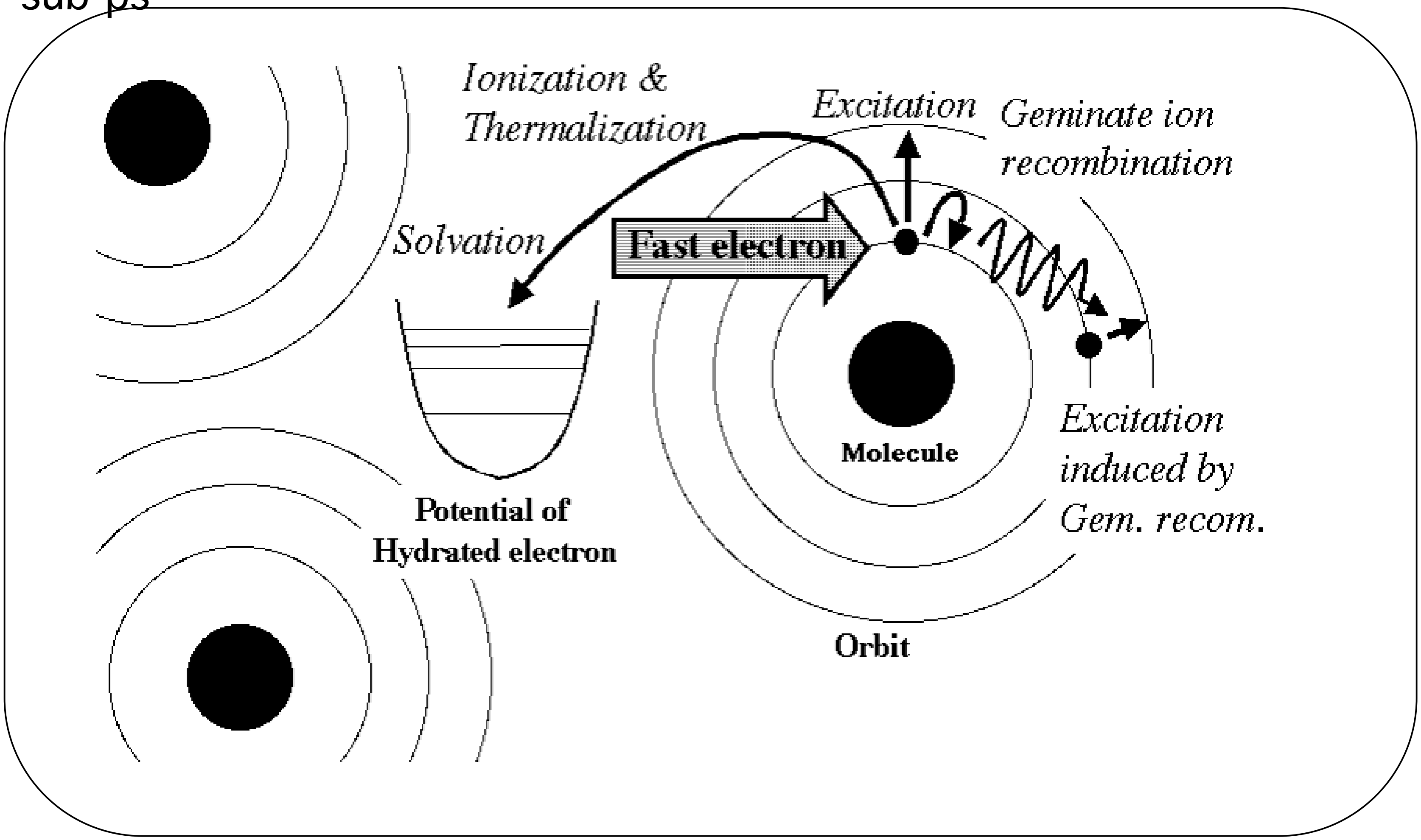
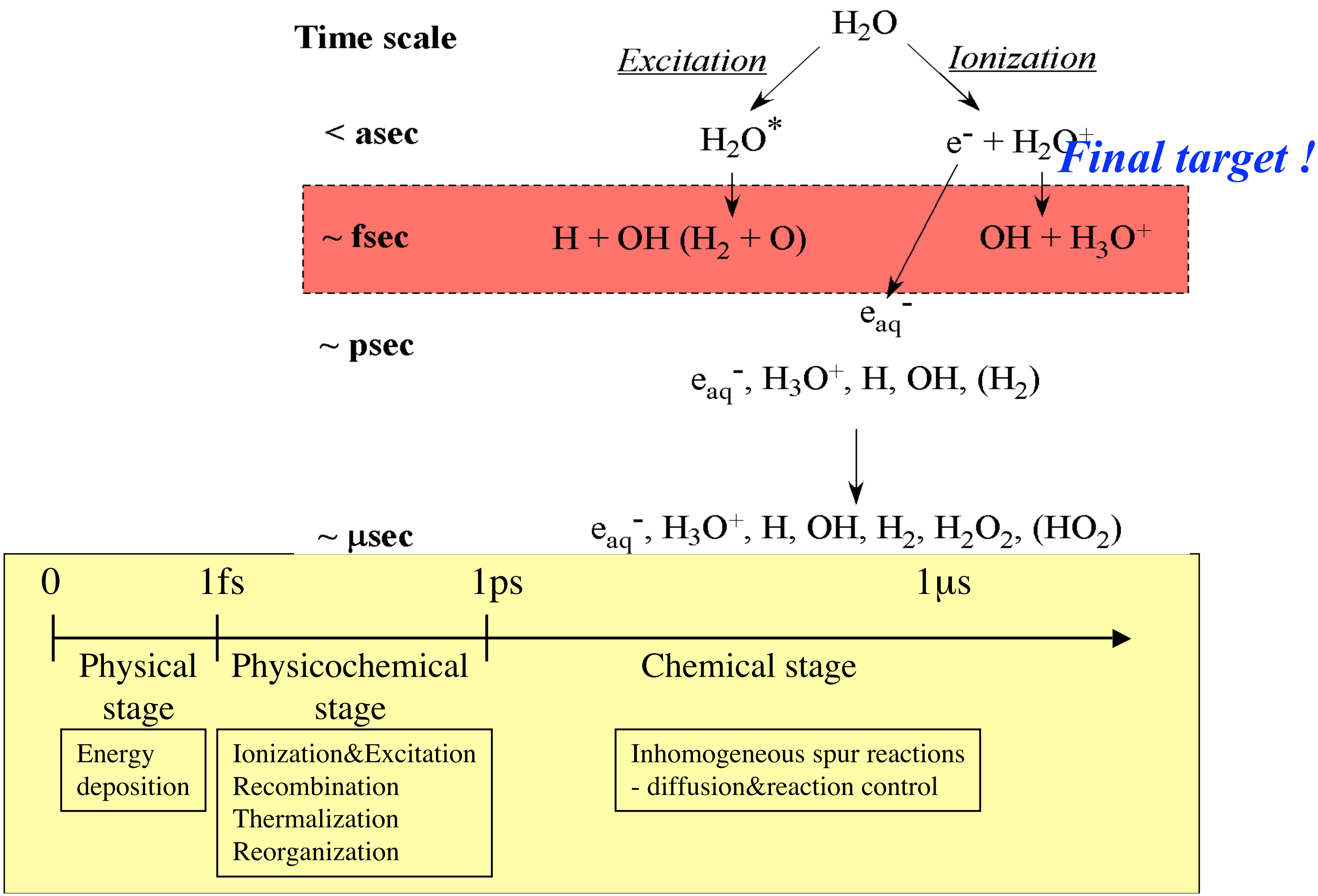
Application for ultra-short pulse
—Radiation Chemistry experiments

Purpose of the sub-ps pulse radiolysis

- Investigation of the elementary process of radiation induced phenomena which occur in the time scale of ps, even sub-ps

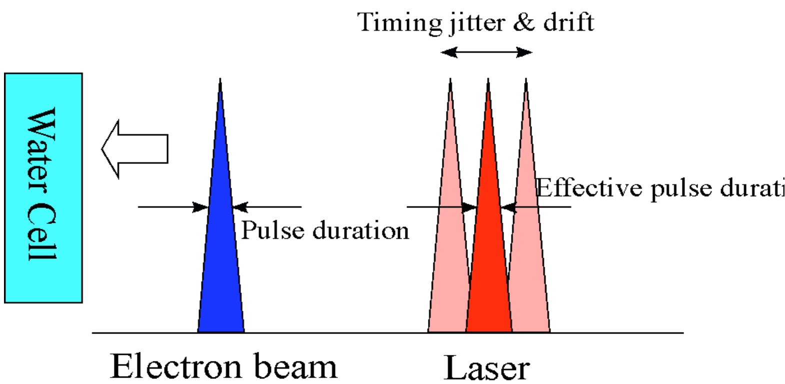


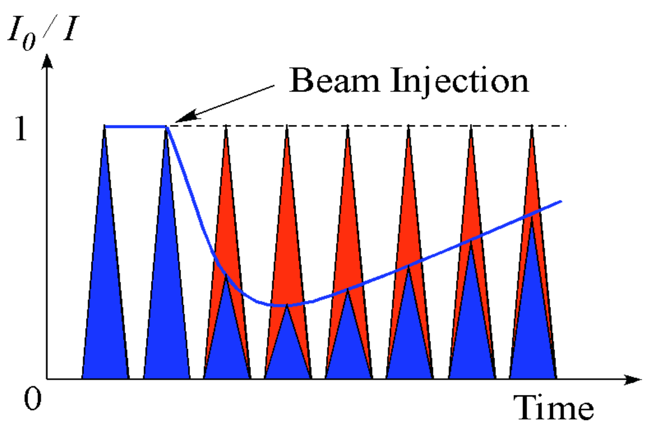
Application for ultra-short pulse
– Radiation Chemistry experiments



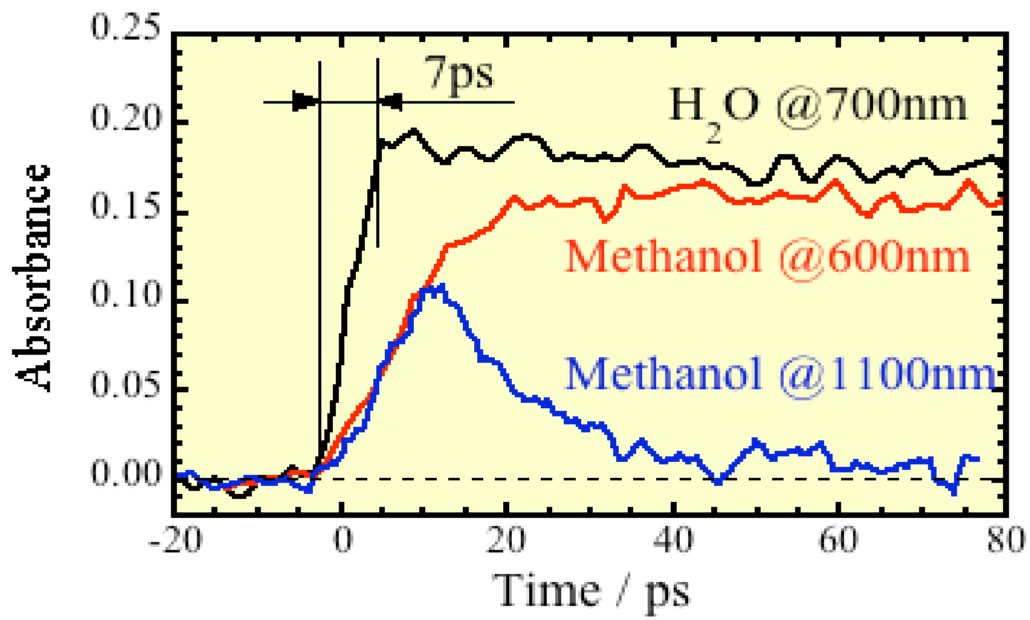
Radiation Chemistry

Pulse radiolysis method





Chemical reaction of water



NERS U. Tokyo Y. Muroya et al.,

Requirements

Pulse radiolysis in a time range of sub-picosecond

I Ultra-short bunch and laser

II Stable synchronization

III Intense electron bunch

For Pumping beam

Short pulse
Single beam, low dark current
High intensity

For Probe beam

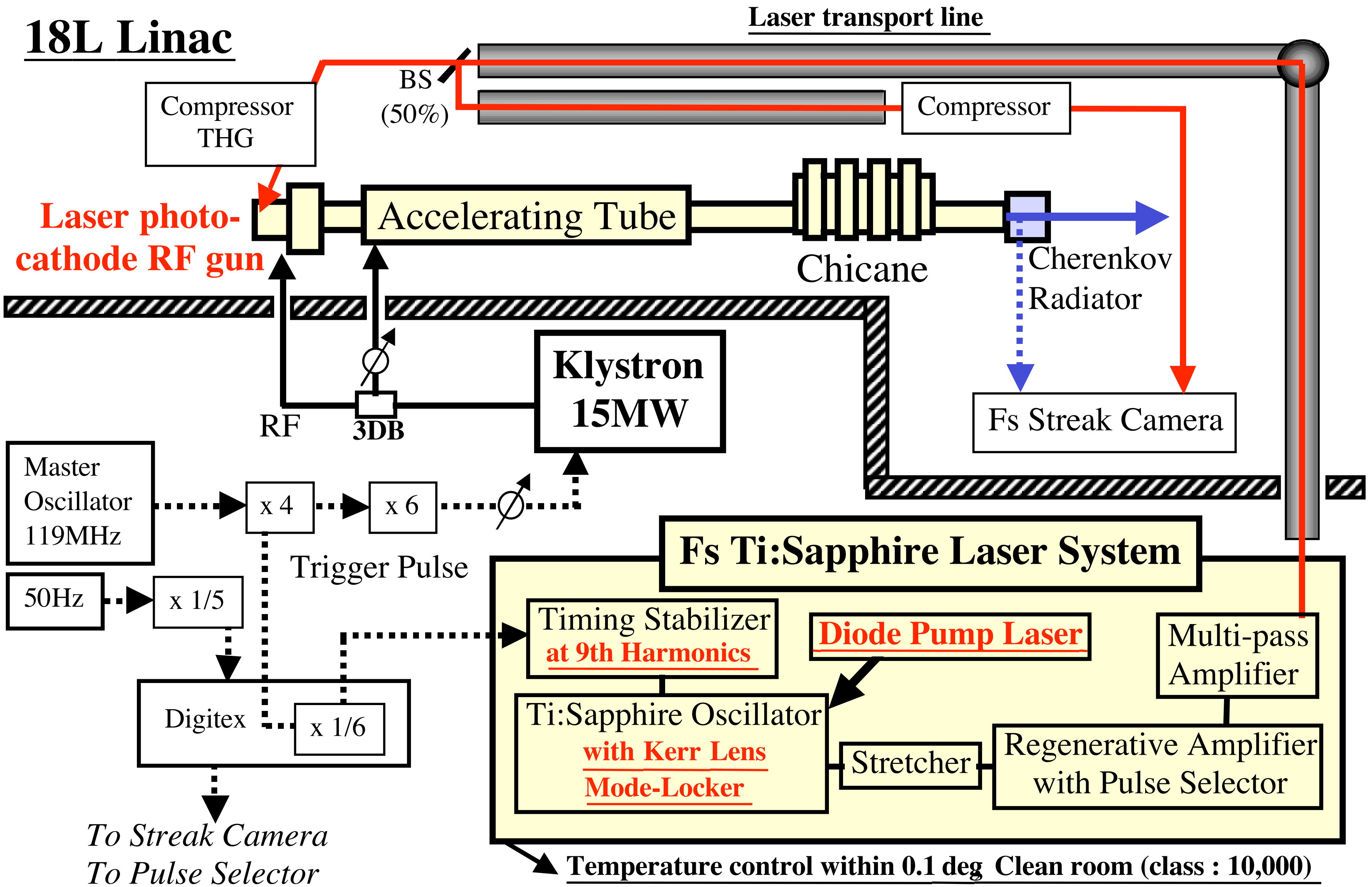
Short pulse
Synchronization to pumping beam
Tunable wavelength

fs laser(Ti:Sapphire laser)
+
Photocathode RF gun

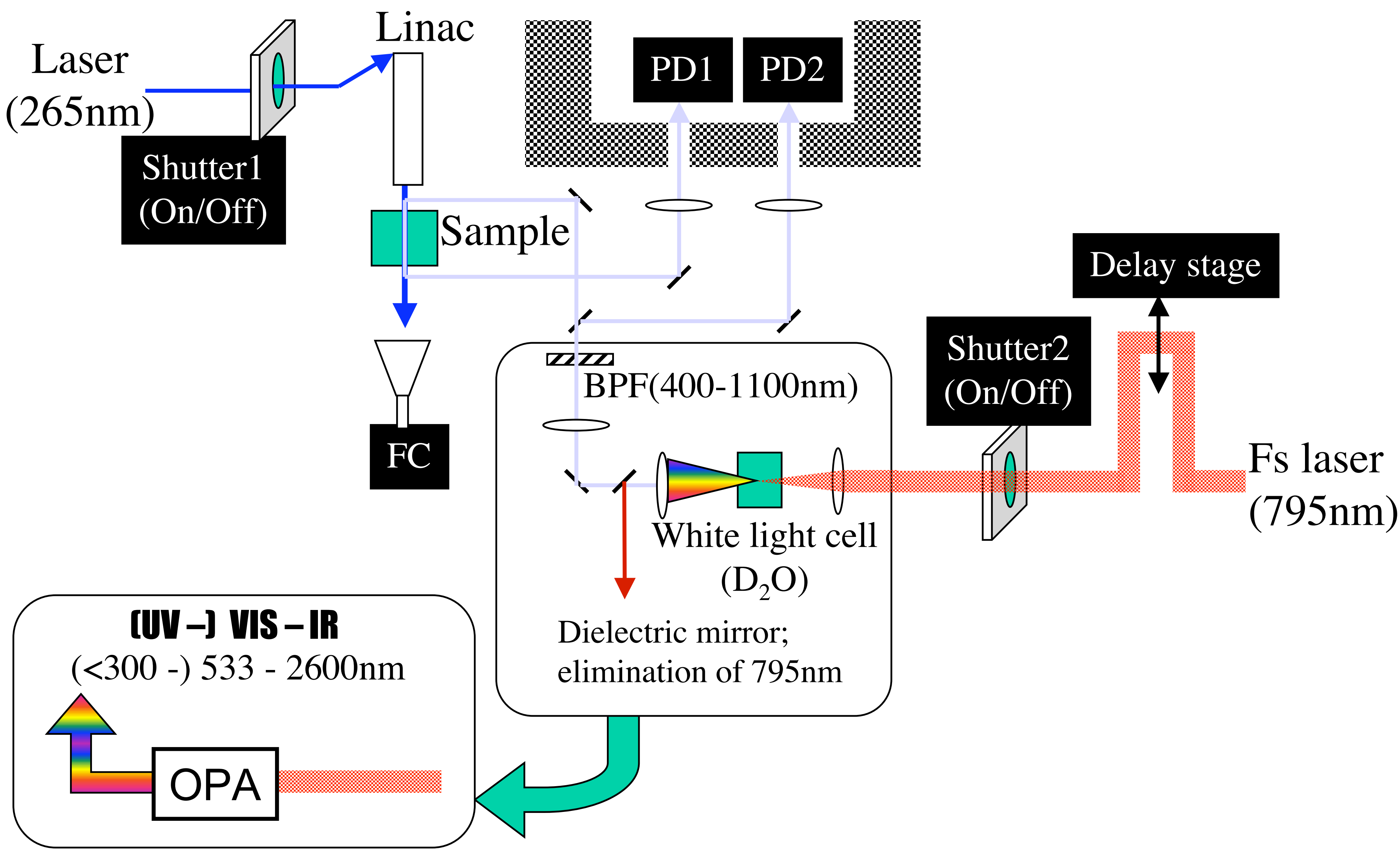
Suitable combination

Precise Synchronization System at UTNS

Beam-Material Interactions
www.utns.jp/~beam



Measurement system



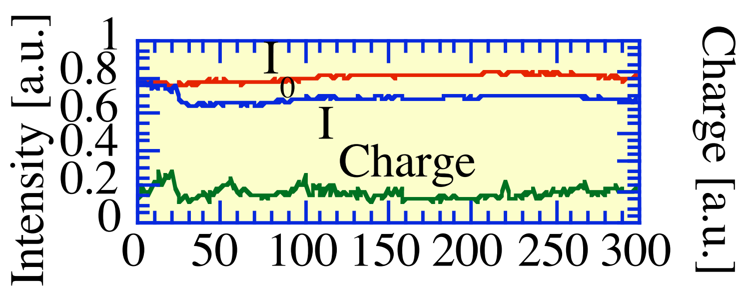
Preliminary Pulse Radiolysis; 795 nm

Condition

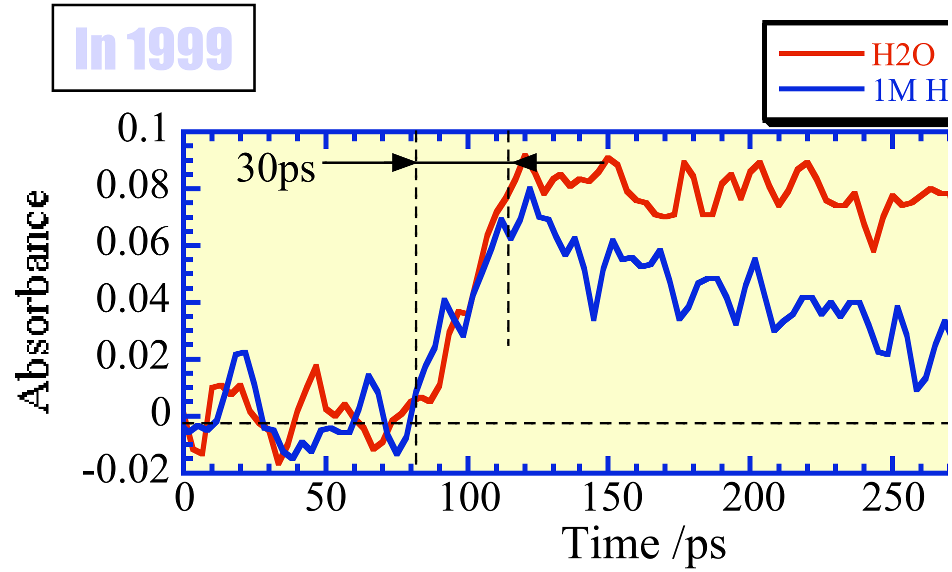
	H_2O&1M H^+	H_2O
l / mm	20 mm	5 mm
Charge Beam size Pulse width	0.8-1.0nC 4mm 7ps	0.8-1.0nC 4mm 3ps
Wavelength	795nm	
Average	64	16
Time resol.	30ps	9ps

Results

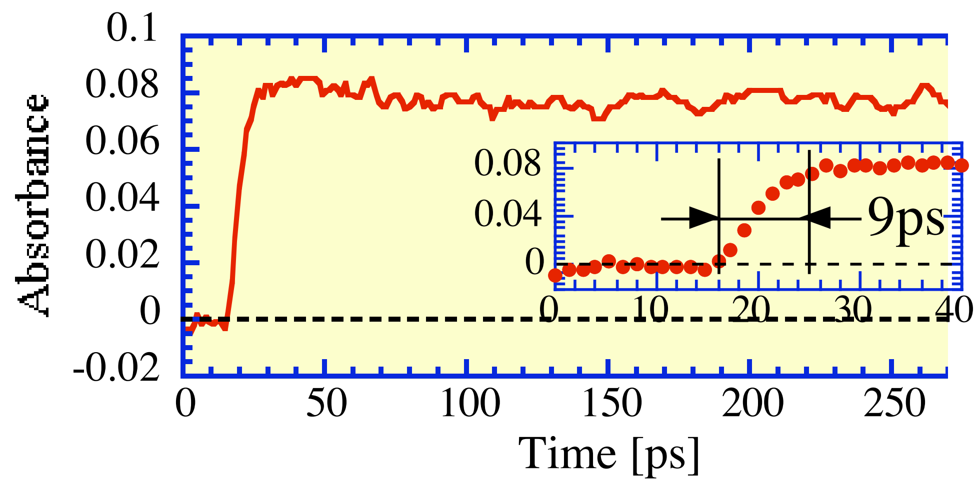
- O.D. still low



In 1999



In 2002



Pulse radiolysis using white light continuum

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

Results

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

Good agreement

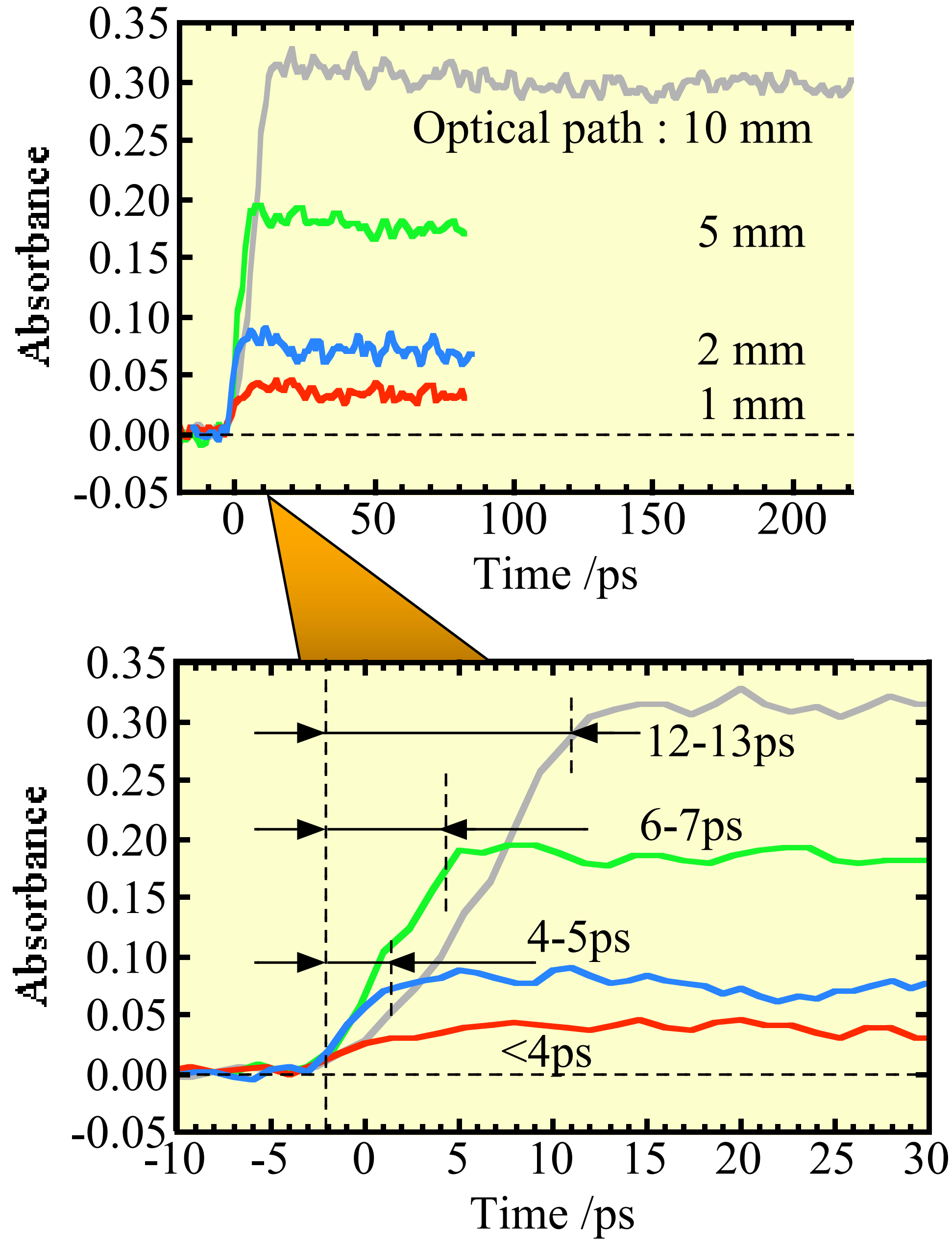
Time resol. /ps	12.2ps	7.2ps	5.2ps	3.2ps

Time resolution: δ_{total}

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

Dominant factor : δ_{diff}

due to refractive index n=1.33



Improvement of the e-beam

Comparison with conventional linac

	Conventional linac		Photocathode	
	Long-pulse mode	Single-pulse mode	In 2000	**Current**
Charge	8~20nC	0.5~0.6nC	0.8~1.0nC	**1.7~2.0nC**
Beam size	15x6mm	4mm	4mm	**3mm**
Dose/shot	**30~50Gy**	**7~8Gy**	13~15Gy	**>40Gy**
Pulse width	**10-100ns**	**10ps**	7ps	**3ps**

Dominant factors for time resolution

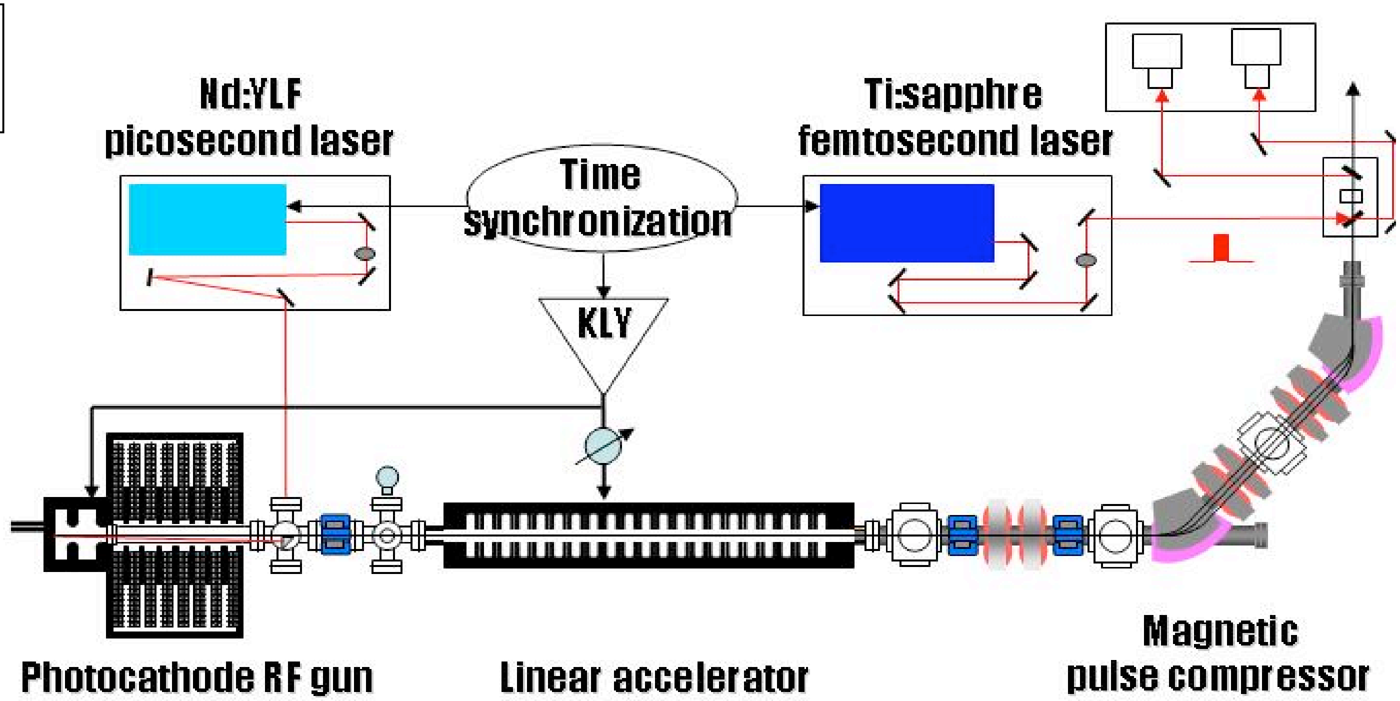
(1) <3ps : *pulse width of EB*
(2) 100fs : *pulse width of laser*
(3) <1ps : *synch. jitter*

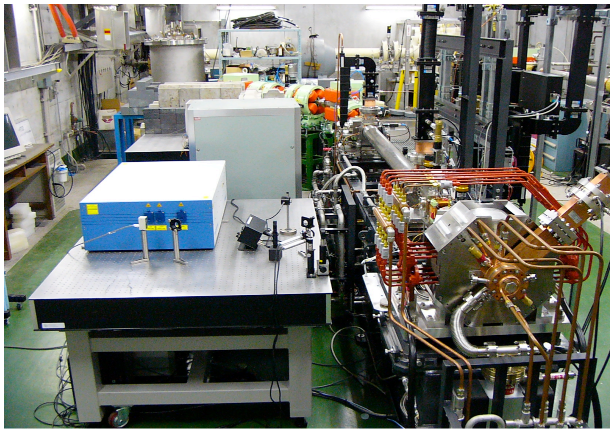
} **Not so bad**

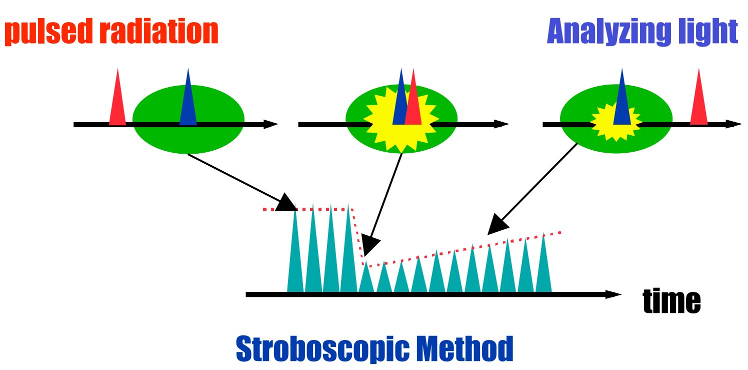
(4) 10ps /10mm : *Δt_{EB-L} in H_2O* → Thinner cell, but OD ↓ → **High-Brightness EB**

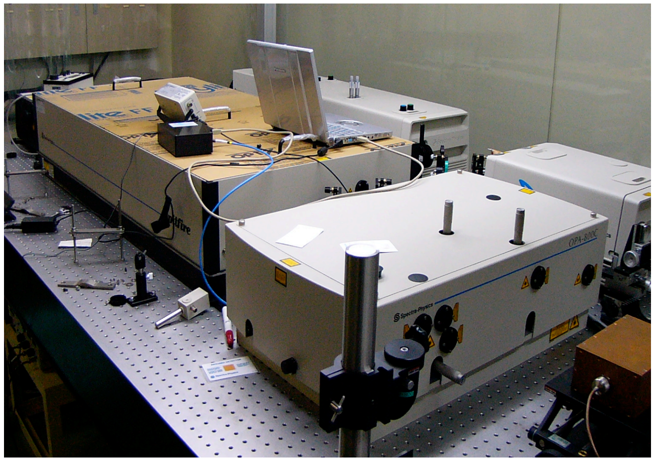
Femtosecond electron beam and femtosecond pump-probe experiment in Osaka University

Osaka Univ.



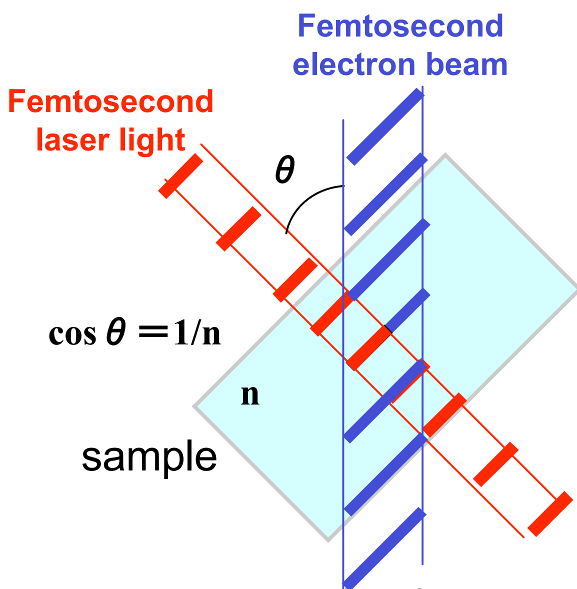


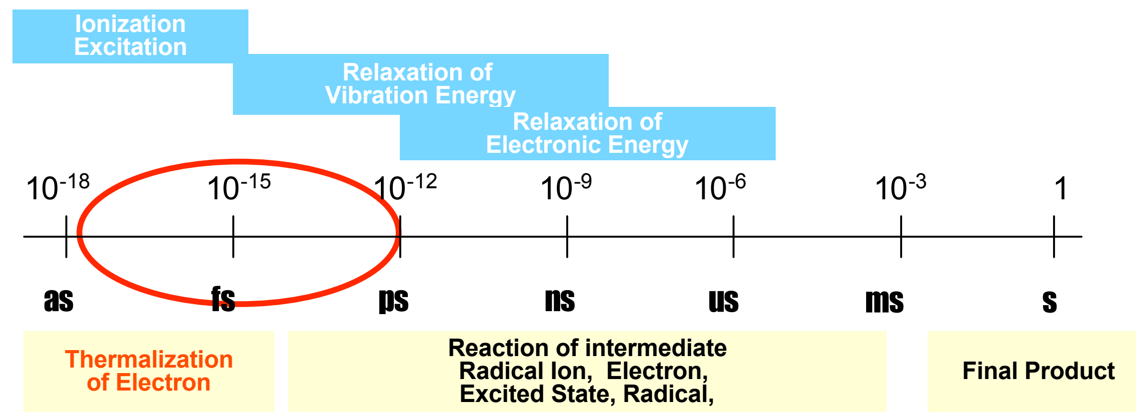




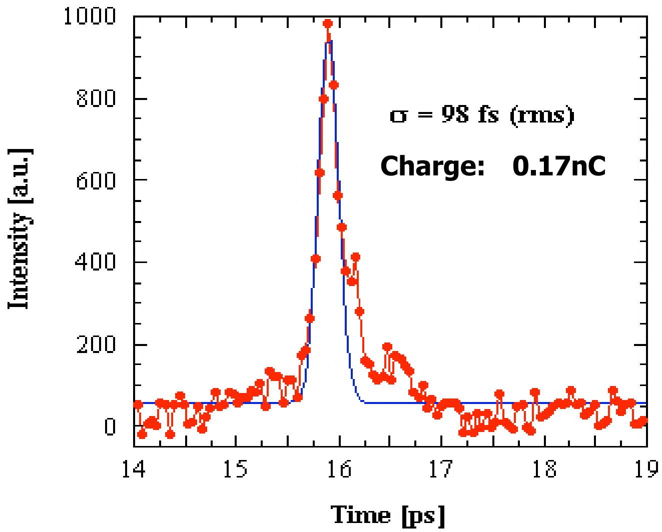
Osaka Univ.

A new concept of "equivalent velocity spectroscopy" for studies of ultrafast electron-induced reactions

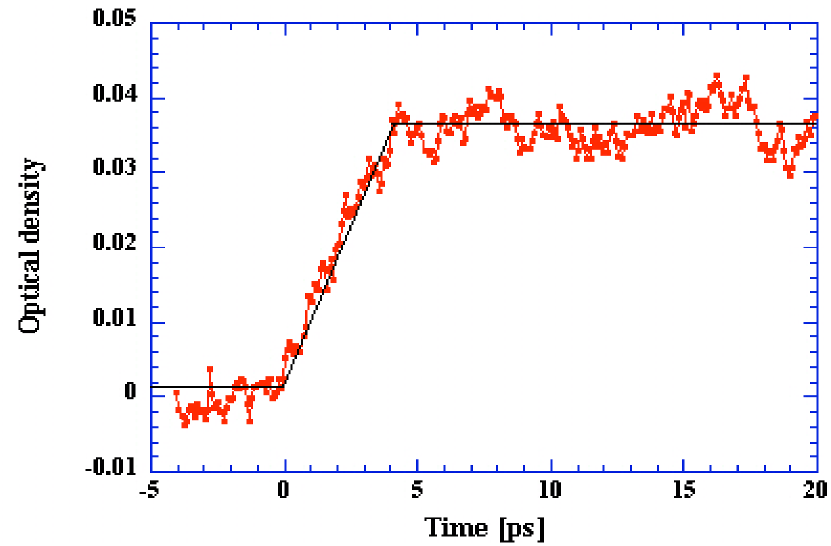




Temporal distribution of 98 fs electron bunch measured by the streak camera at 0.17 nC

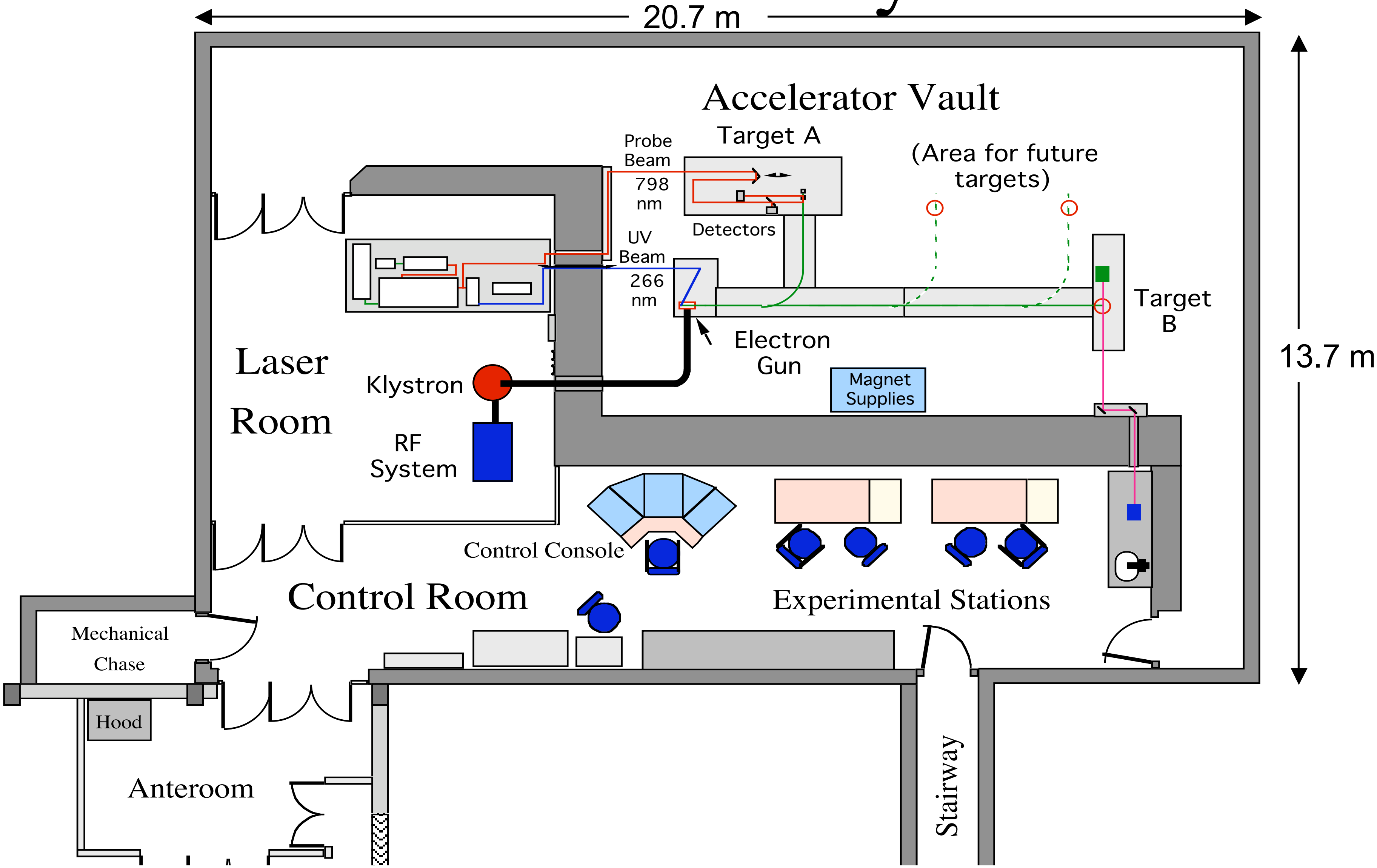


Transient absorption kinetics of hydrated electrons measured in water at wavelength of 800 nm



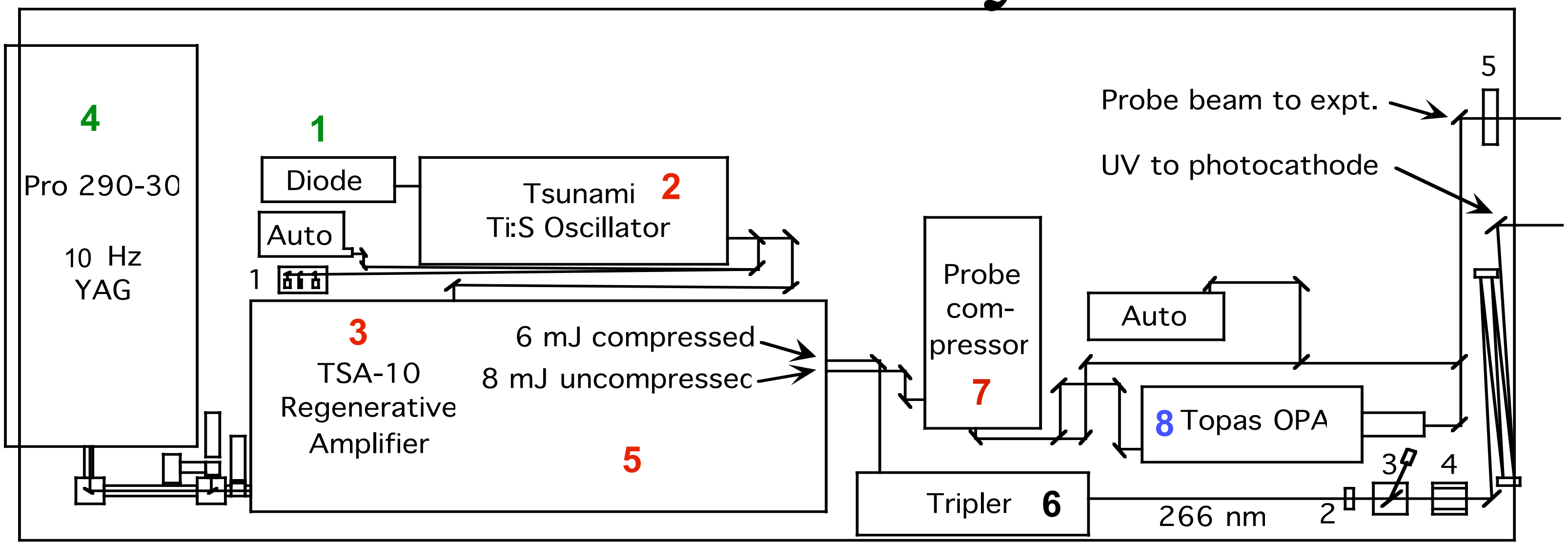
LEAF

LEAF Facility Layout



LEAF

LEAF Laser System



1) **Diode-pumped Nd:YVO$_4$ laser, 5 Watts, 532 nm, pumps picosecond Ti:Sapphire laser.**

2) **Ti:Sapphire oscillator produces ~50 fs pulses, ~ 7 nJ energy, 798 nm, at 81.60 MHz.**

3) **Pulse stretcher stretches oscillator pulse to > 200 ps, then injects the pulse into the Ti:Sapphire regenerative amplifier.**

4) **Simultaneously, the doubled, Q-switched Nd-YAG laser pumps the Ti:Sapphire regen.**

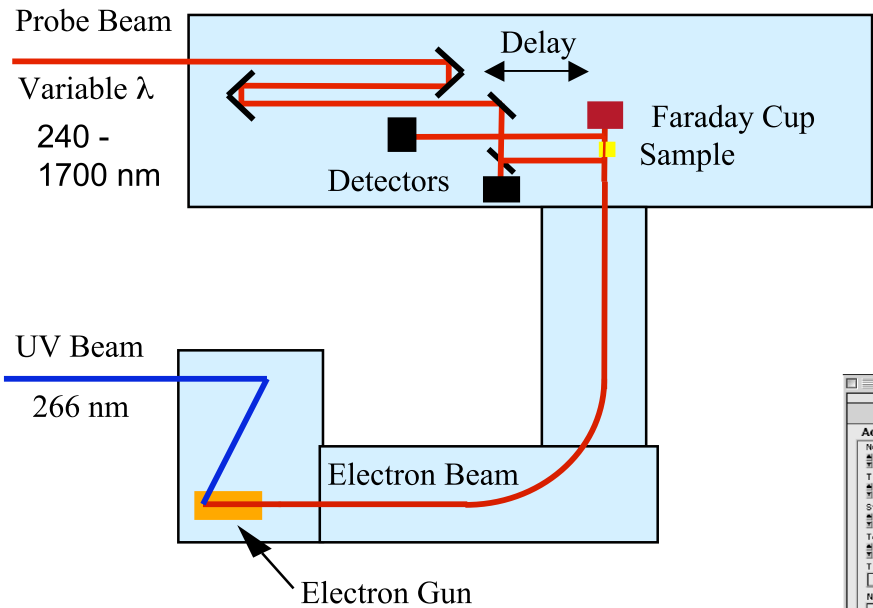
5) **Stretched ~200 ps pulse is amplified to ~12 mJ level. Half is compressed to 1-3 ps for THG**

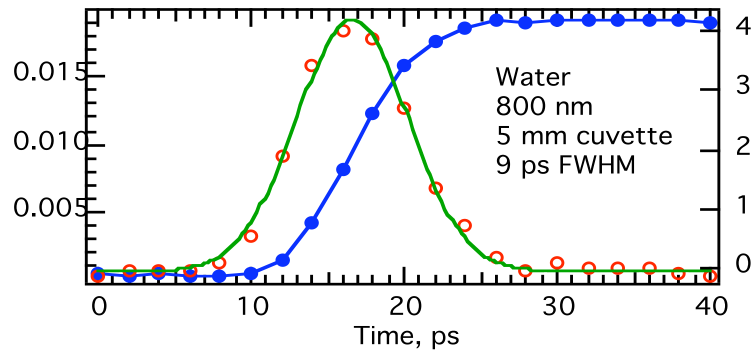
6) **1-3 ps pulse is frequency tripled to 266 nm (≤ 0.4 mJ) for excitation of Mg photocathode.**

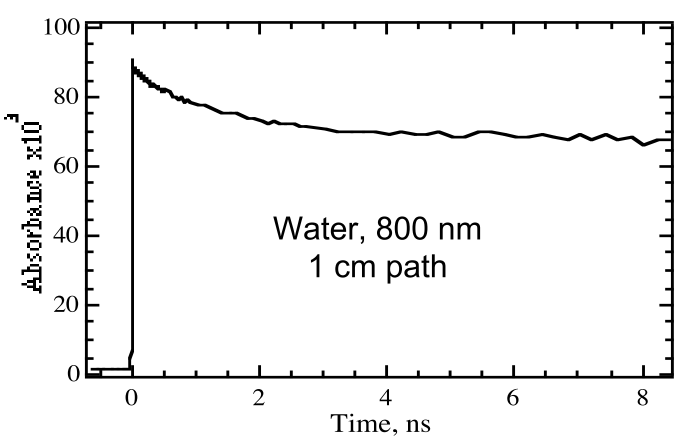
7) **Half of regen output compressed to ~100 fs for use as probe or TOPAS OPA pump (8)**

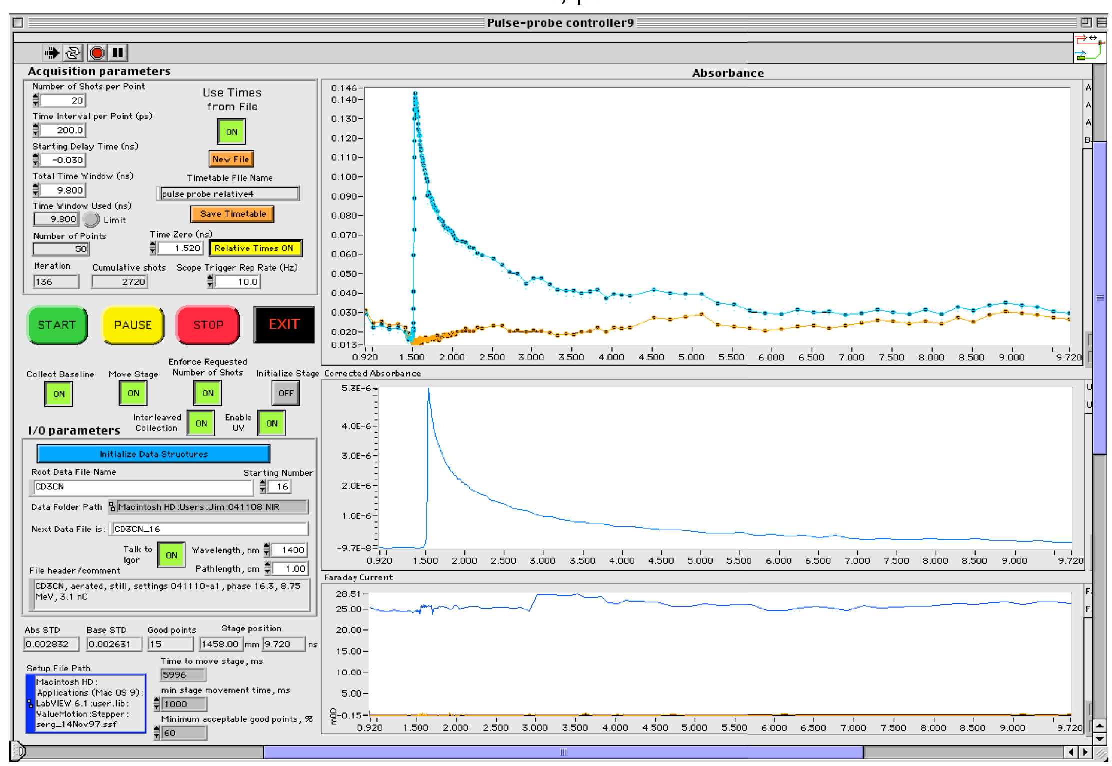
LEAF

Pulse-Probe Experiment







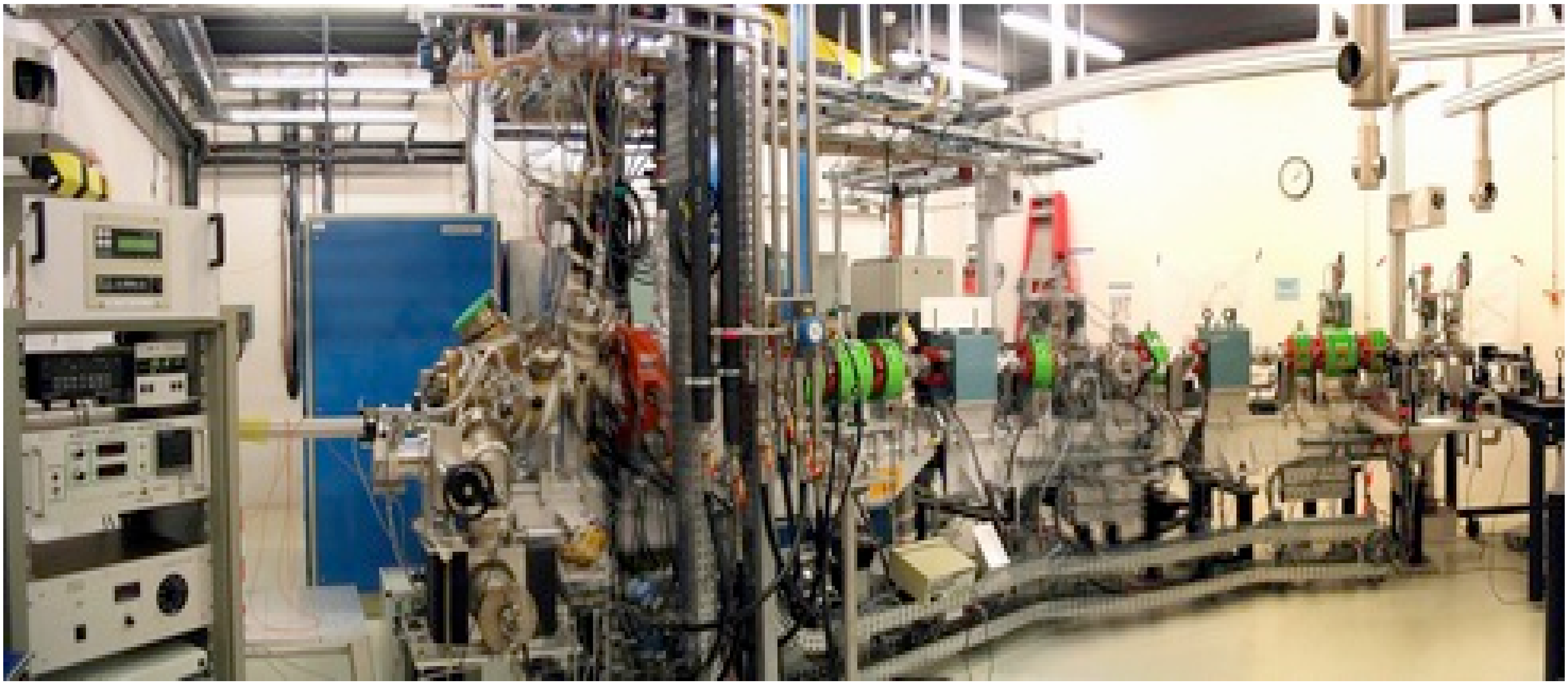


LEAF Pulse-probe transient absorption spectroscopy

LEAF

- Time resolution ≥ 7 ps
  - A factor of pulse width and sample depth.
- Optical Parametric Amplifier (240 - 2600 nm)
  - New diodes extend range from 1000 to 1700 nm
  - Color separation needs work, far-field mode varies
- Better Signal/Noise than before
  - Improved LabVIEW acquisition software
    - Interleaved collection, measurement selection criteria (dose, laser intensity, modulator and laser timing), using consistent cathode recovery time
  - More proficient laser and electron beam alignment
- Igor-based analysis software
- Flow system volumes reduced (~4 ml or ≥ 15 ml)

ELYSE,Orsay



ELYSE, Picosecond Pulse Radiolysis

ELYSE,Orsay

Photoinjector Accelerator

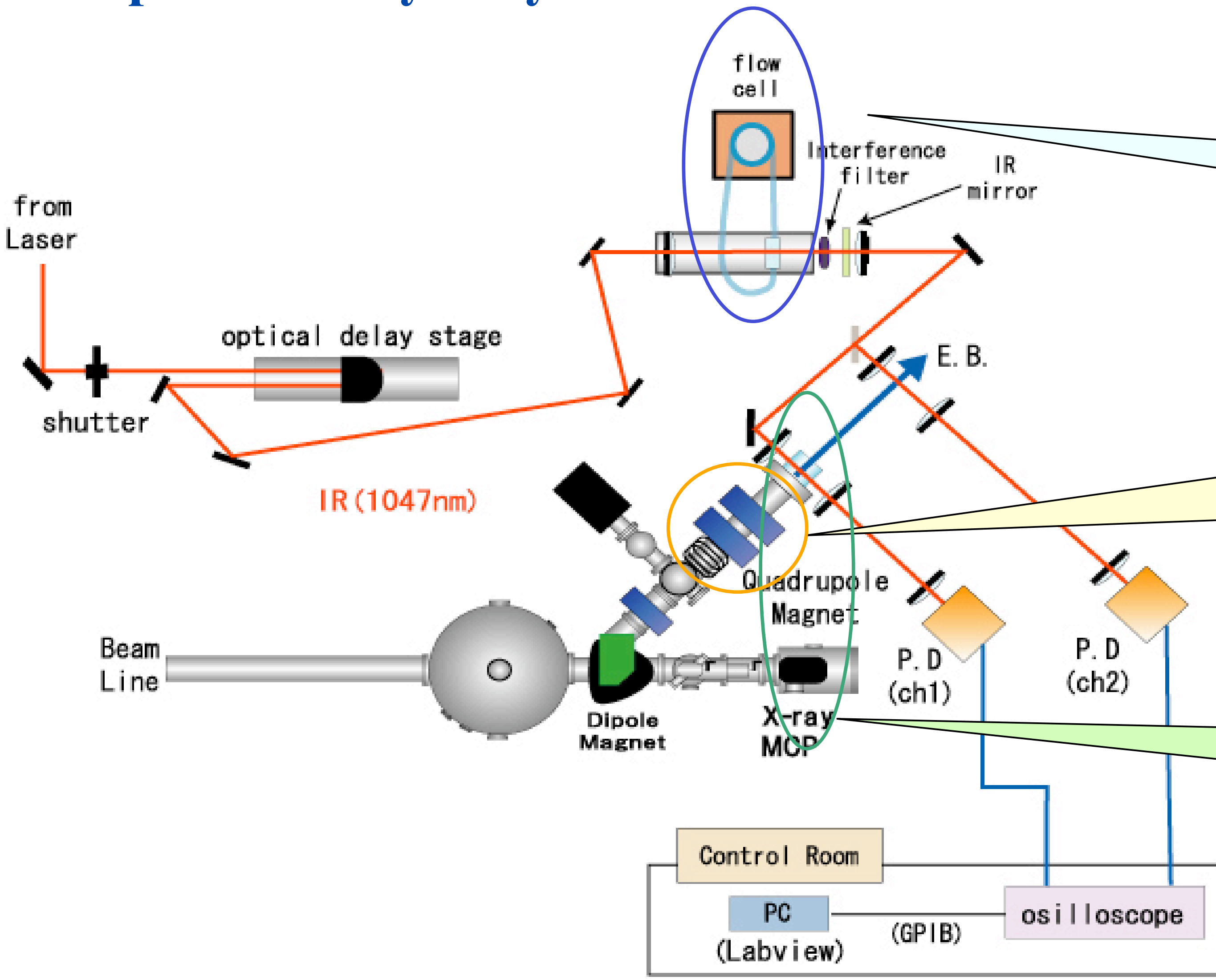
- Pulse length ≤ 7 ps
- ♣ Charge ≥ 1 nC
- ♣ Energy 4 to 9 MeV
- ♣ Repetition Rate ≤ 50 Hz
- ♣ Energie Dispersion ≤ 2,5 %
- ♣ Spot Diameter ≤ 2 à 20 mm
- ♣ Pulse-Probe

Accelerator build and installed (SERA)

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

New pulseradiolysis system

[improvement]

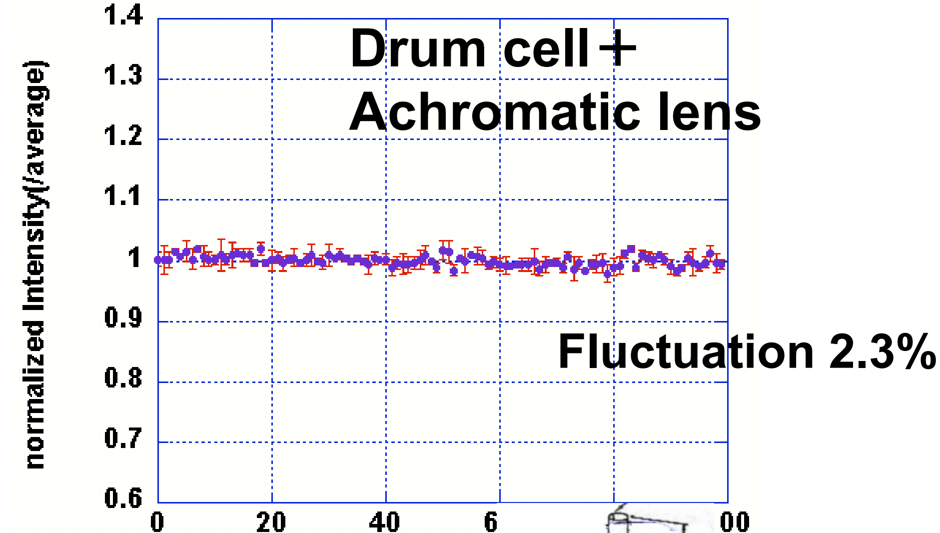


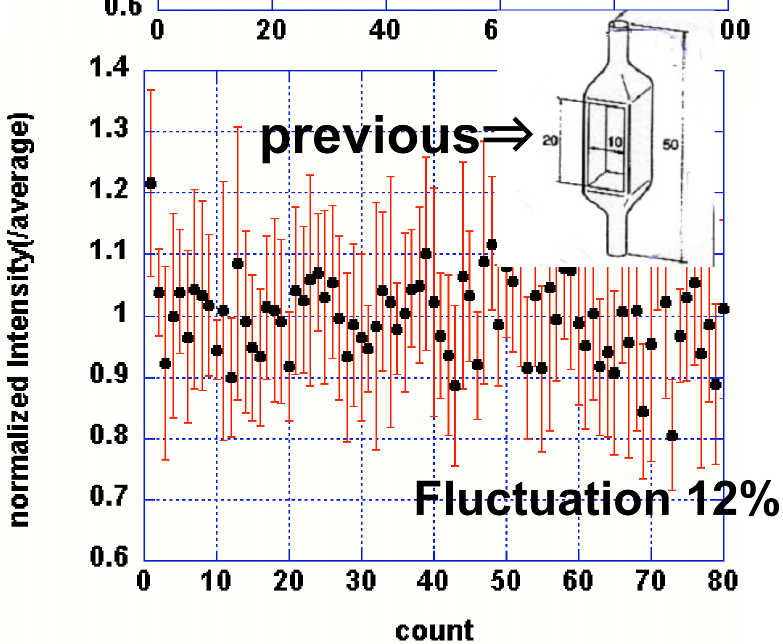
③Stabilizing white light→noise decreasing

②Quadropole for beam de-sizing →high time resolution

①Easy setup →Easy to experiment

Stability of Probe light intensity





Experimental results (right water)

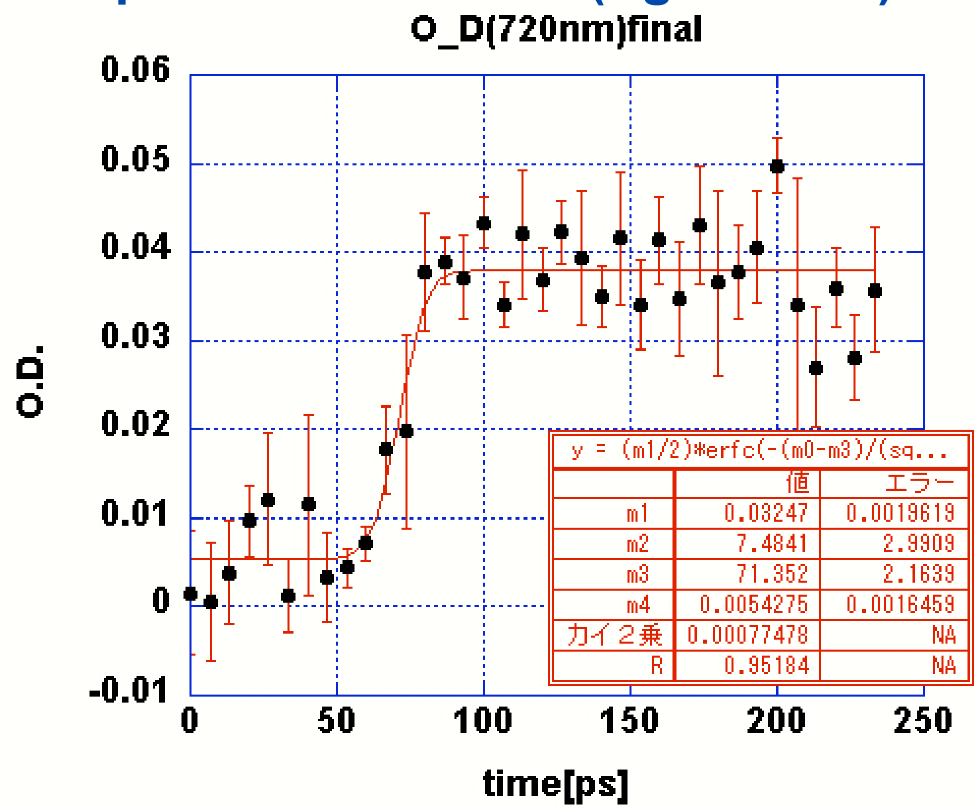


Fig.12　O.D.

previous（26[ps]）: Current 8[ps]

	Beam energy	Beam Current	Beam width	Beam size	Target path Length	Synchro-nization	Laser pulse width	Total time Resolution
U. Tokyo	4+18= 22MeV	2nC	1ps	3mm	1mm	<1ps(rms)	100fs(532nm-2600nm)OPA (400-1100nm) white light made by Ti:Sa	3ps(white light)
LEAF,BNL, USA	9MeV	2-8nC	≥ 7 ps		10mm(right water)	Pico-sec.	100fs(240-2600nm)OPA	>7ps(pulse-probe)
ELYSE, France	4 to 9 MeV	≥ 1 nC	≤ 7 ps	2-20mm				~7ps?
Waseda Univ.	4MeV	0.4-0.6nC						8ps
Osaka Univ.	38MeV	>0.2nC	<1ps				100fs	~5ps

Summary

Photocathode RF gun with fs laser(Tt:Sa) is suitable combination for the Application of Radiation Chemistry

In order to measure the phenomena at sub-pico or picosecond region, we need;

-high brightness beam with short pulse(<1ps)

-Thin target(~mm)

-Stable system
  Timing (within 1ps)
  Position
  Beam Intensity (both laser and electron beam)

Special thanks to

LEAF, BNL

ELYSE, Orsay

Univ. Osaka

Waseda Univ.

Univ. Tokyo

Physicochemical stage

- Factor of the thermalization distance

$$\lambda_m = (n\sigma)^{-1}$$

$$\lambda = [-\lambda_m \, ln \, (P \, \lambda_m)]/\alpha$$

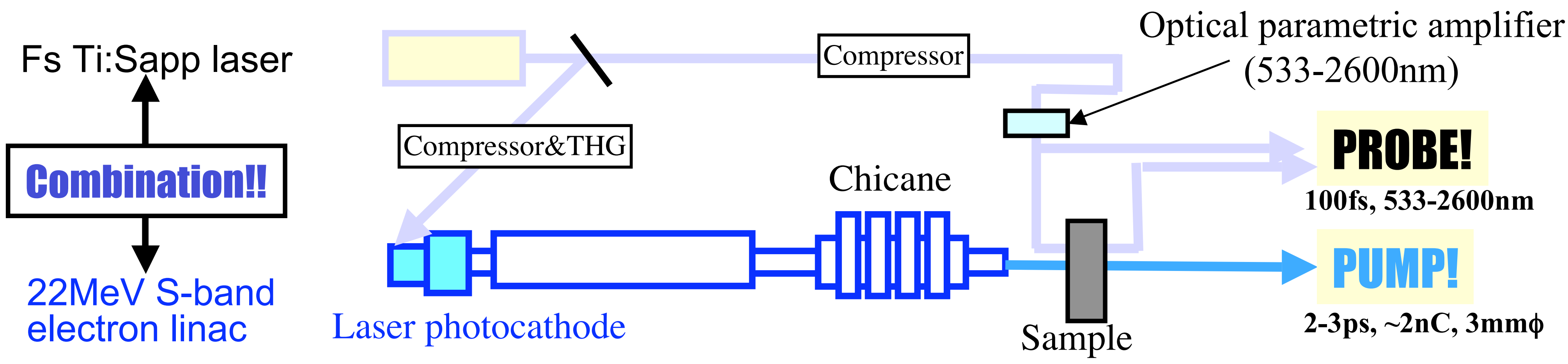
- Factor of the cross section of geminate ion recombination

$$\sigma_{rec} \sim 3 \text{ x } 10^{-20} \, E^{-1.86} \text{ x } \beta$$

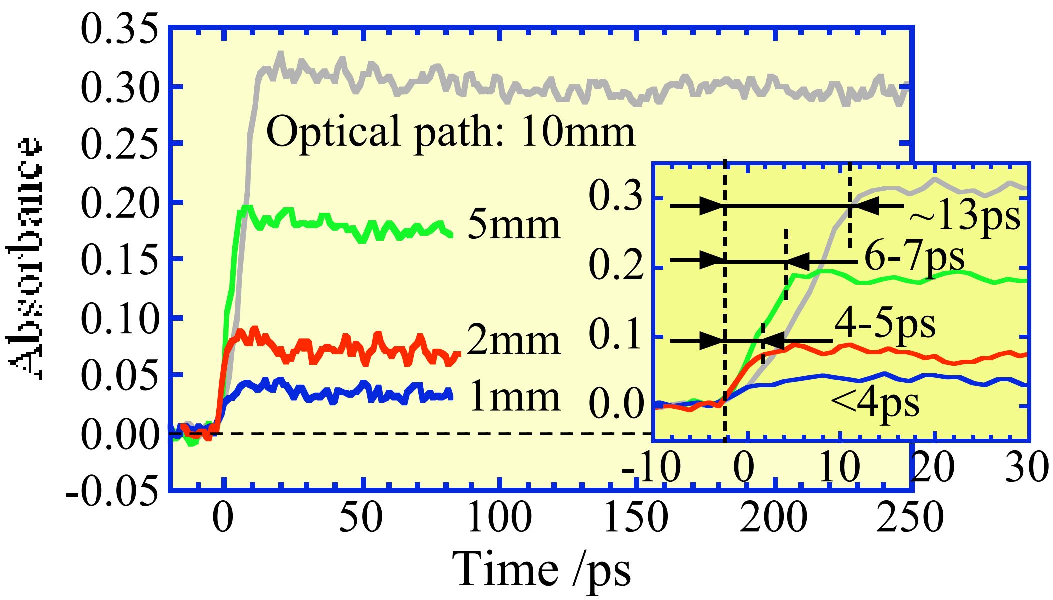
- Branching ratios in physicochemical stage stems from ionization and excitation

		Probability		Probability	Reaction No.
Decay of the directly excited water molecules					
$H_2O^*(A^1B_1)$	→ H_2O	P1			(1)
	→ H + OH	P2			
$H_2O^*(B^1A_1)$	→ $H_2O^+ + e^-$	P6			(4)
	→ H_2O	(1-P6)P1			(1)
	→ dissociation	(1-P6)P2	→ H + OH	P3	(2-1)
			→ 2H + O(3*P*)	P4	(2-2)
			→ H_2 + O(^1D)	P5	(2-3)
Decay of the excited states results from the recombination					
H_2O^*	→ H_2O	P1			(1)
	→ dissociation	P2	→ H + OH	P7	(3-1)
			→ 2H + O(3*P*)	P8	(3-2)
			→ H_2 + O(^1D)	P9	(3-3)

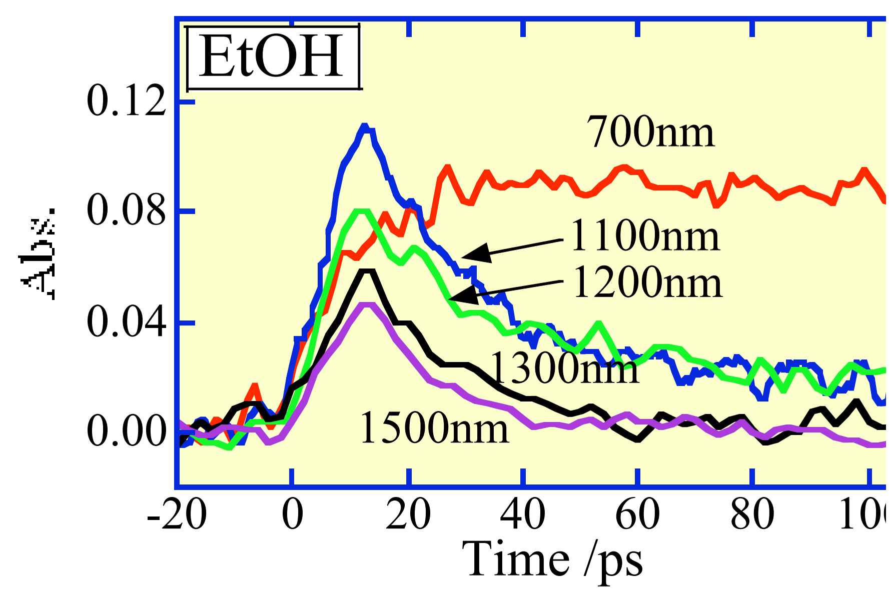
Ultra-fast pump-and-probe pulse radiolysis study : radiation induced fast processes



Time behaviors of hydrated electrons in water:
Solvation time < time resolution < 10ps

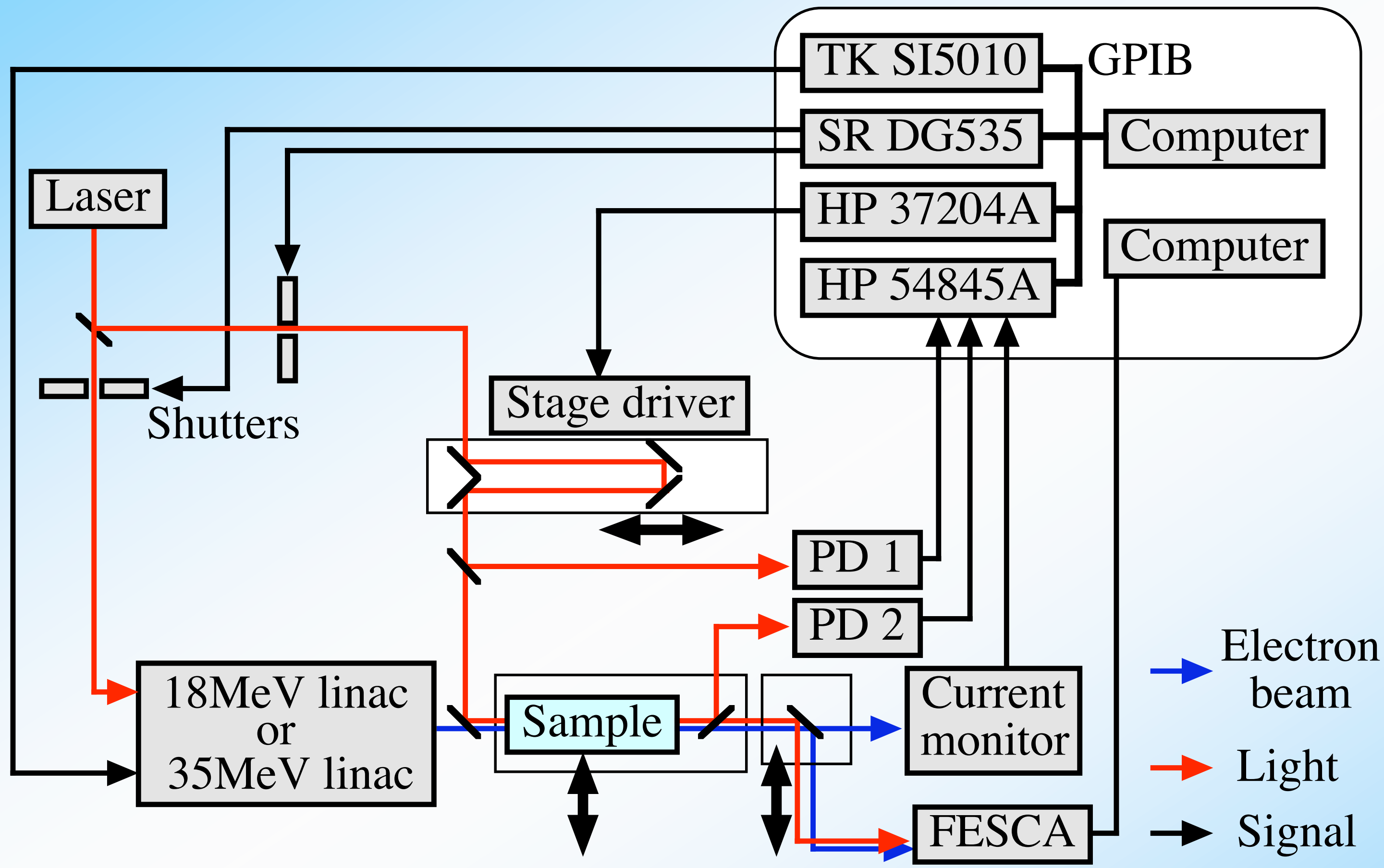


Time behaviors of solvated electrons in ethanol:
Observation of solvation process ($e^-_{pre} \rightarrow e^-_{sol}$)



Sub-ps Pulse Radiolysis - Measurement System

Beam-Material Interactions, UTNs



Data acquisition

- Measurement of laser intensity and charge
  - B : Both beam and light → $I_M(B)$ and $I_R(B)$
  - L : Light only → $I_M(L)$ and $I_R(L)$
  - P : Beam only → $I_M(P)$ and $I_R(P)$
  - N : Neither beam nor light → $I_M(N)$ and $I_R(N)$
  - Charge → C

  (I_M : Main light, I_R : Reference light)

- Calculation of precise absorbance

$$Absorbance \equiv \log_{10}\frac{I_0}{I} = \frac{C_{ave}}{C}\cdot\log_{10}\left[\frac{I_M(L)-I_M(N)}{I_R(L)-I_R(N)}\cdot\frac{I_R(B)-I_R(P)}{I_M(B)-I_M(P)}\right]$$

(C_{ave} : Average of charges)