Proposal to PAL from SPring-8

~ Pulse-stacker-based square pulse (>10ps) shaping system ~

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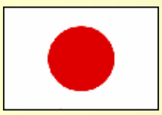
0. Intro. ~ Recent progress in UV-pulse (>10 ps) shaping ~
1. Macro-pulse (15~20 ps) generation with UV-pulse stacker
2. Passive micro-pulse preparation
   - Prism-pair UV-stretcher + Pulse Stacker
3. Adaptive micro-pulse preparation
   - UV- & IR-DAZZLER feedback sys.+ Pulse Stacker
4. Summary for generation of 15~20-ps UV- Square laser pulse

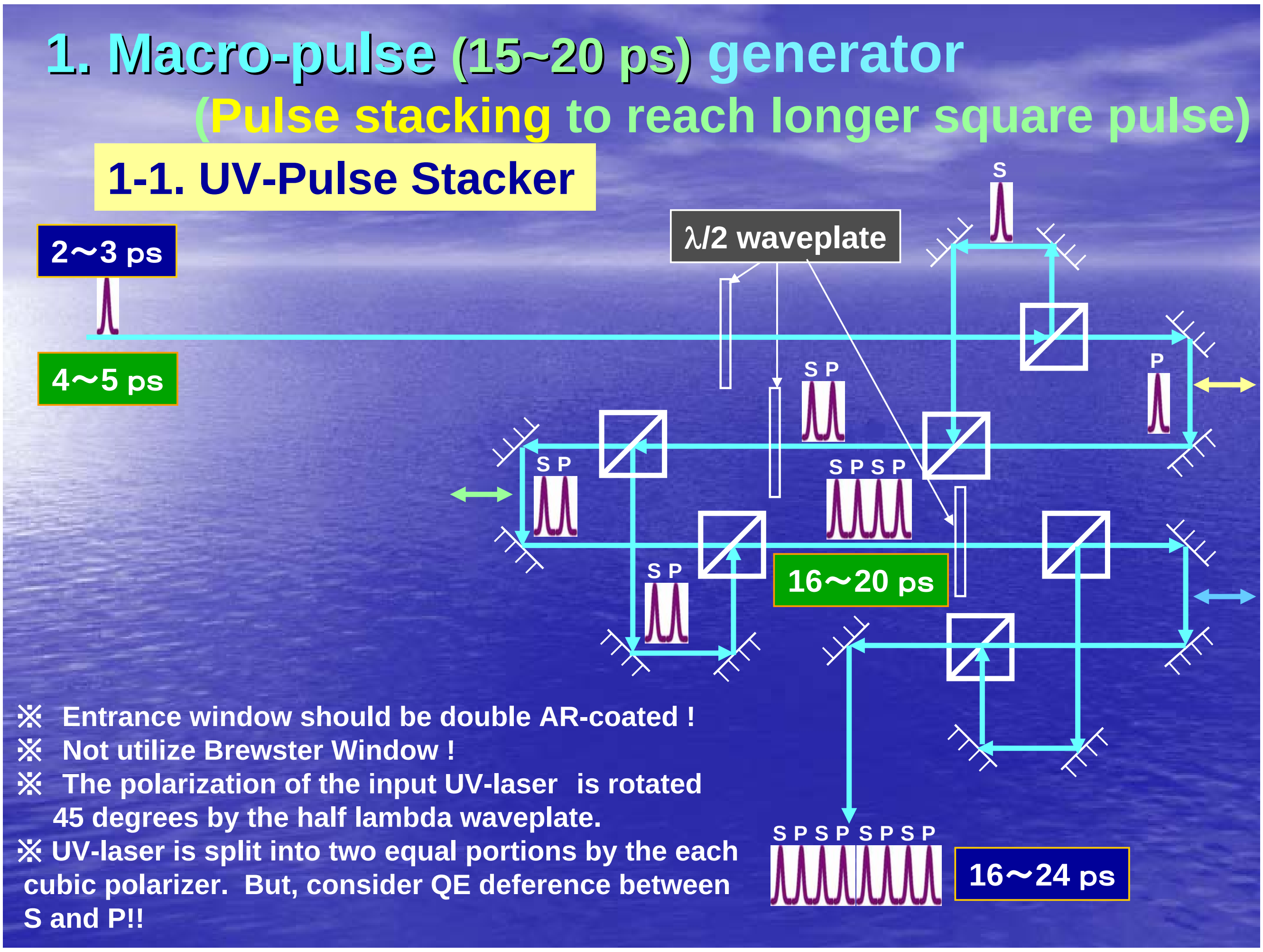
0. ~10-ps pulse-shaping development in UV (~263 nm): In the year 2006, UV-shaping technologies are matured!

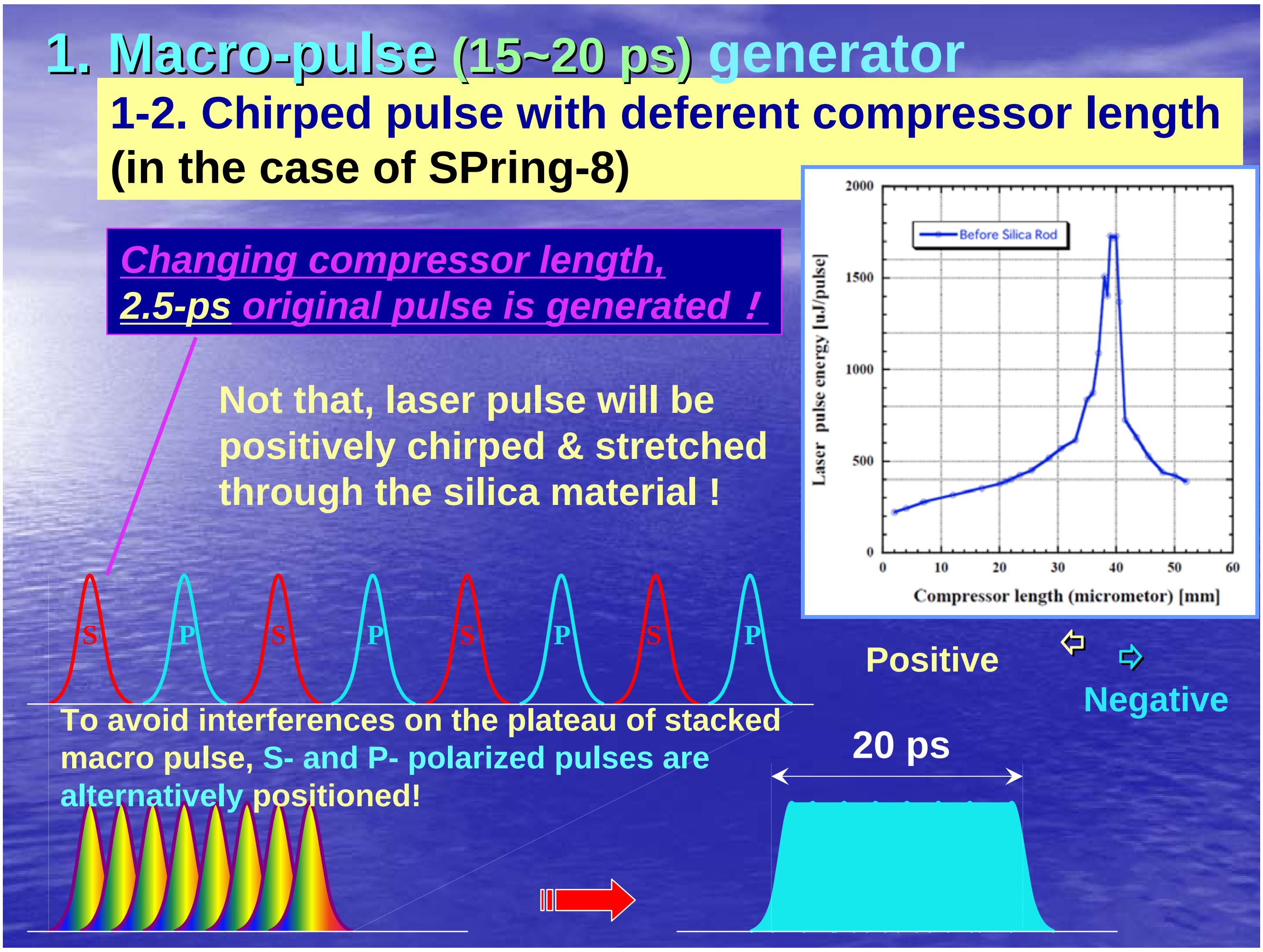
1. PAL developed Prism-pair UV-pulse stretcher (up to 6 ps with nice shape)
   Korea

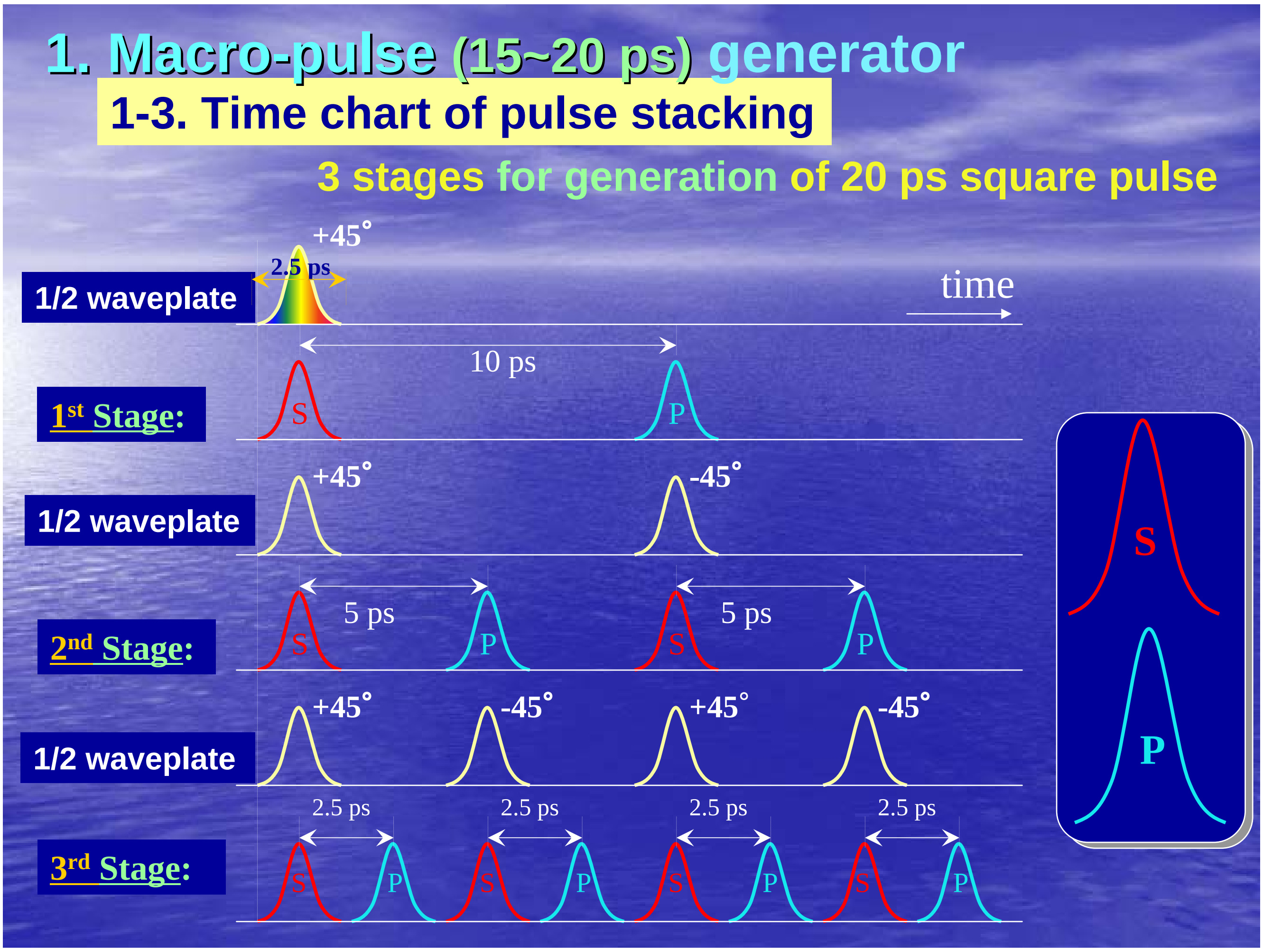
2. UV-pulse stacker was developed by SP8 and commercialized for industry.
   Japan

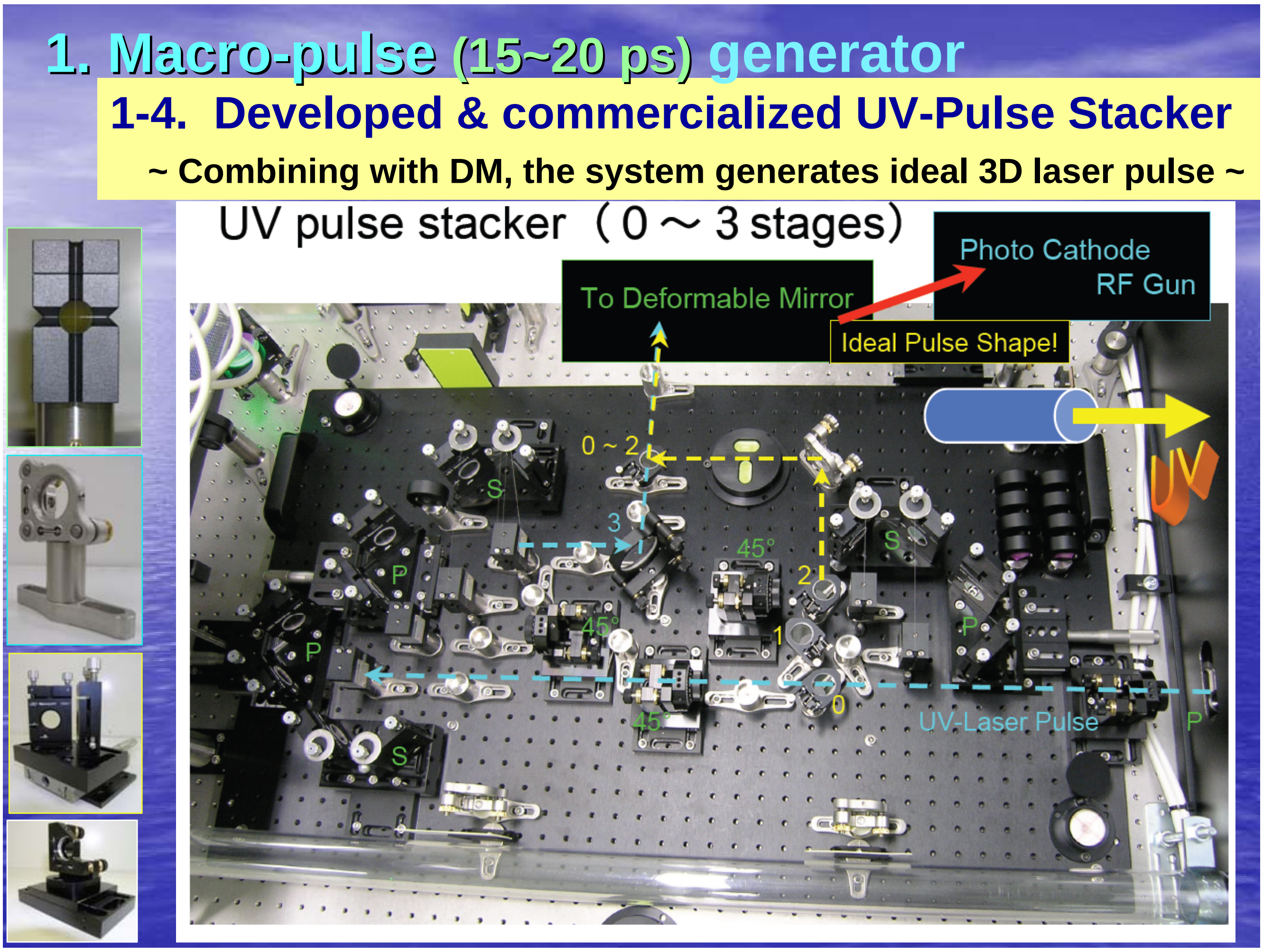


3. UV-Dazzler (AO) was completed (up to 5 ps) by Fastlite (L' Ecole poly-technique) and commercialized.
   France


1. Macro-pulse (15~20 ps) generator
(Pulse stacking to reach longer square pulse)
1-1. UV-Pulse Stacker
2～3 ps
4～5 ps
λ/2 waveplate
S
P
S P
S P
S P S P
S P
16～20 ps
S P S P S P S P
16～24 ps
※ Entrance window should be double AR-coated !
※ Not utilize Brewster Window !
※ The polarization of the input UV-laser is rotated 45 degrees by the half lambda waveplate.
※ UV-laser is split into two equal portions by the each cubic polarizer. But, consider QE deference between S and P!!


1. Macro-pulse (15~20 ps) generator
1-2. Chirped pulse with deferent compressor length
(in the case of SPring-8)
Changing compressor length,
2.5-ps original pulse is generated !
Not that, laser pulse will be positively chirped & stretched through the silica material !
Before Silica Rod
Laser pulse energy [uJ/pulse]
Compressor length (micrometor) [mm]
2000
1500
1000
500
0
0
10
20
30
40
50
60
Positive
Negative
S
P
S
P
S
P
S
P
To avoid interferences on the plateau of stacked macro pulse, S- and P- polarized pulses are alternatively positioned!
20 ps


1. Macro-pulse (15~20 ps) generator
1-3. Time chart of pulse stacking
3 stages for generation of 20 ps square pulse
1/2 waveplate
+45°
2.5 ps
time
1st Stage:
10 ps
S
P
1/2 waveplate
+45°
-45°
2nd Stage:
5 ps
5 ps
1/2 waveplate
+45°
-45°
+45°
-45°
3rd Stage:
2.5 ps
2.5 ps
2.5 ps
2.5 ps
S
P


1. Macro-pulse (15~20 ps) generator
1-4. Developed & commercialized UV-Pulse Stacker
~ Combining with DM, the system generates ideal 3D laser pulse ~
UV pulse stacker（0～3 stages)
Photo Cathode
RF Gun
To Deformable Mirror
Ideal Pulse Shape!
UV
0 ~ 2
3
2
1
0
45°
S
P
UV-Laser Pulse

1. Macro-pulse (15~20 ps) generator

1-5. 3D- Laser Beam Shaping system

~ present status at SPring-8 ~

UV- Laser source (total stability!)

- Laser Pulse Energy : 1.4% @THG
- Pointing Stability & Reproducible
- Timing Jitter < 1 ps

Spatial Profile:

Distribution: Flattop

Deformable Mirror

Temporal Profile:

Pulse duration: 2.5 ~ 20 ps

UV- Pulse Stacker

Gaussian

Pulse duration: 2.5 ps

Pulse duration: 10 ps

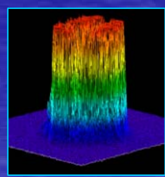
Diameter : 1 mm

Pulse Stacker

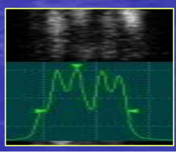
10 pps

Deformable Mirror

Flattop



Streak Image of stacked pulses



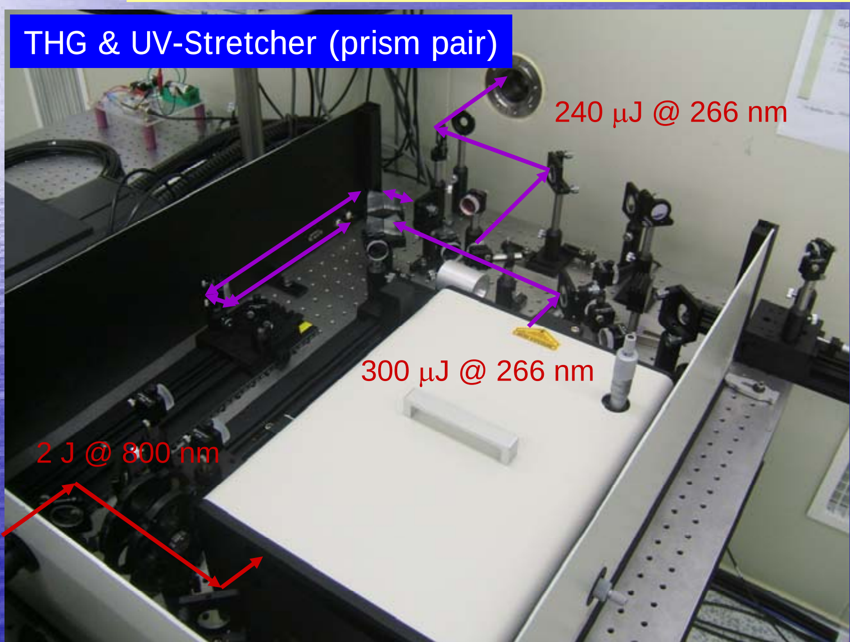
2. Passive micro-pulse preparation

- Prism-pair UV-stretcher + Pulse Stacker

2-1. THG-Stretching system

~ Combining with Pulse stacker,

it generates ideal square laser temporal pulse ~



2.5 mJ @ 800 nm

X 10% efficiency

=250 μJ @ 266 nm

X 50% Loss

=125 μJ

=>1 nC from Cathode with 10^{-5} Q.E.

Courtesy of C. Kim

2. Passive micro-pulse preparation

- Prism-pair UV-stretcher + Pulse Stacker

2-2. Prism-Pair Dispersion

- Prism pair has been traditionally designed to compensate the GVD in the laser cavity, and to compress the output pulse.
- Prism-pair produces a negative GVD

GVD= $(\lambda^3/2\pi c^2)d^2P/d\lambda^2$

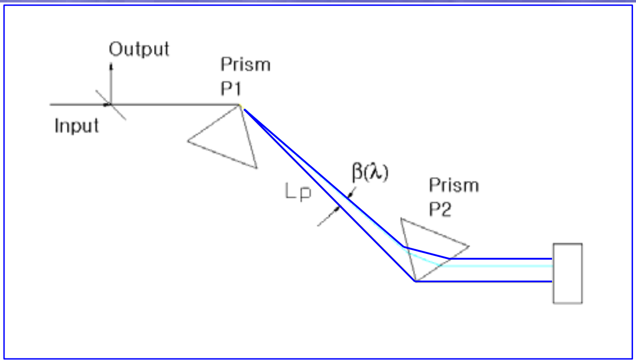
Path length $P=2L_p\cos(\beta(\lambda))$

L_p= distance between P1 & P2

GVD~ $-(4\lambda^3 L_p/\pi c^2)(dn/d\lambda)^2$

= $-550fs^2/cm \times L_p$ (cm)

for fused silica at 266nm



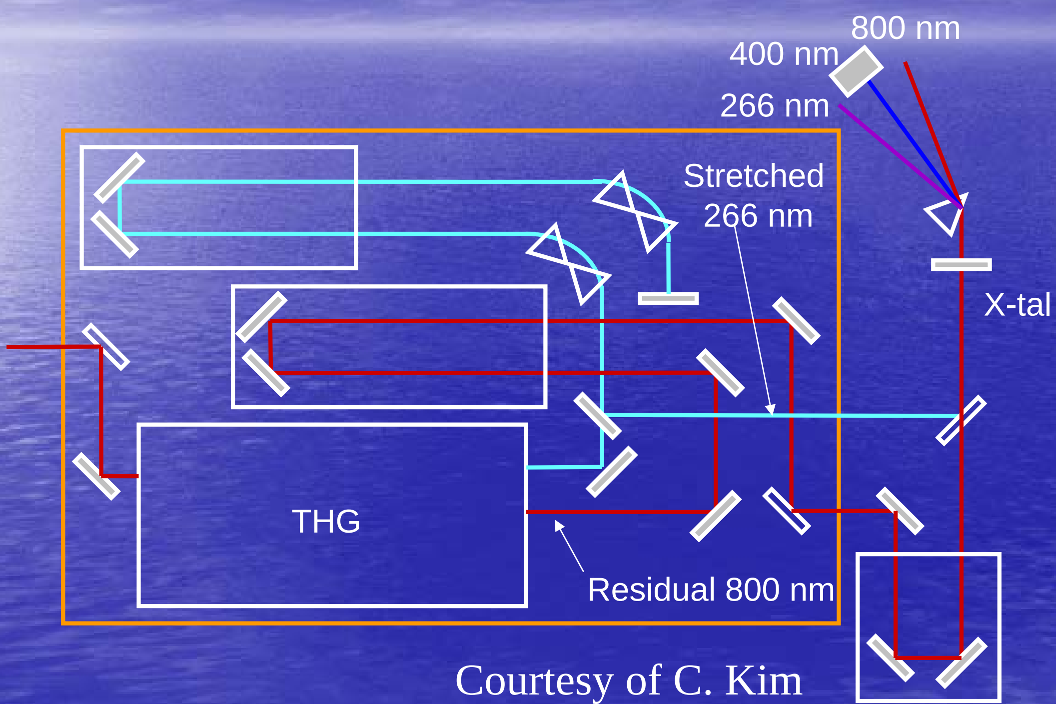
"Red" component of the pulse propagates in glass where group velocity is smaller than for the "blue" component

Courtesy of C. Kim

2. Passive micro-pulse preparation

- Prism-pair UV-stretcher + Pulse Stacker

2-3. UV-Stretcher (Prism-Pair)

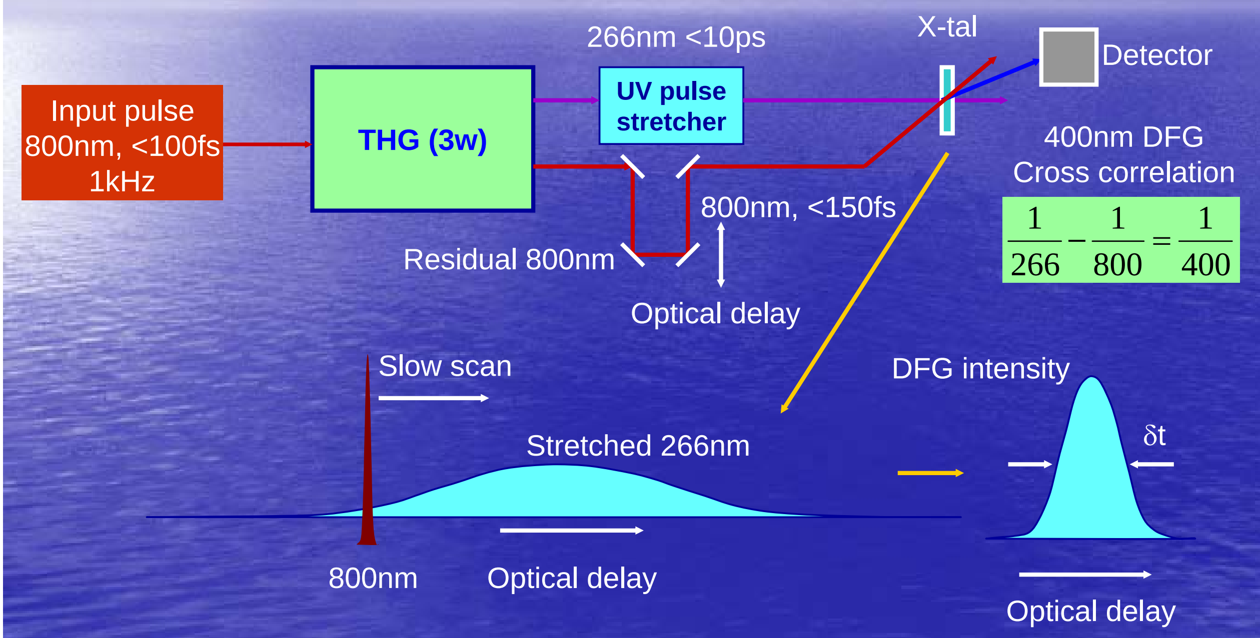


Courtesy of C. Kim

2. Passive micro-pulse preparation

- Prism-pair UV-stretcher + Pulse Stacker

2-4. UV-pulse measurement (Cross Correlator)



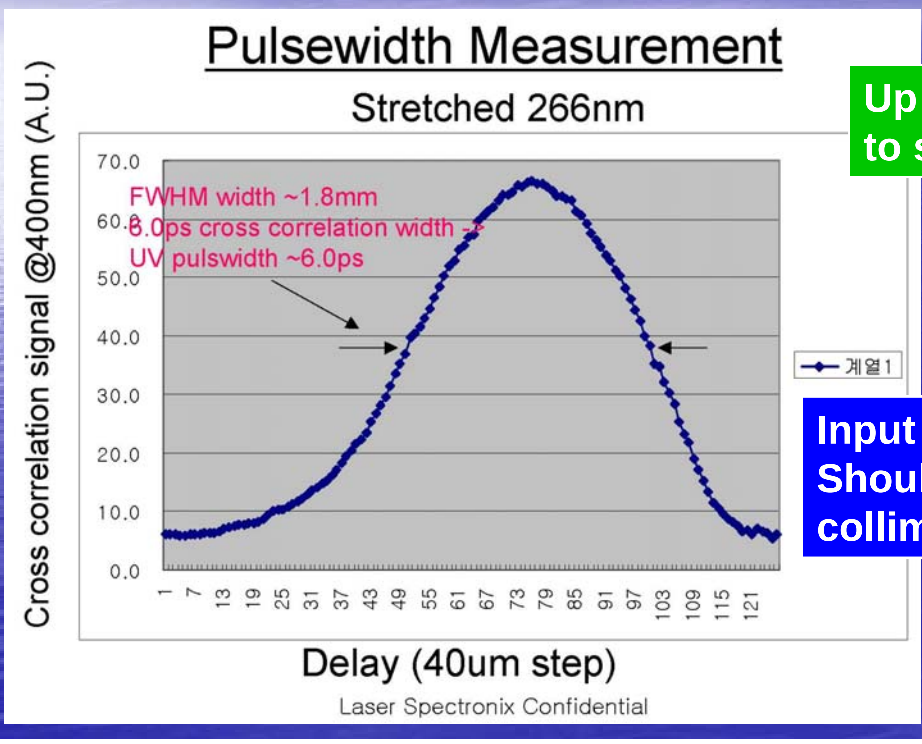
δt measurement -> UV 266nm pulsewidth calculation

Courtesy of C. Kim

2. Passive micro-pulse preparation

- Prism-pair UV-stretcher + Pulse Stacker

2-5. UV-pulse duration (with Cross Correlator)



Up to 6 ps, it possible to shape nicely.

Input UV-laser Should be perfectly collimated to prism-pair.

Courtesy of C. Kim

3. Adaptive micro-pulse preparation

- UV- & IR-DAZZLER feedback sys.+ Pulse Stacker

3-1. Candidates of SLM for UV-Laser pulse shaping

3-1-1. DAZZLER (Acousto-optics)

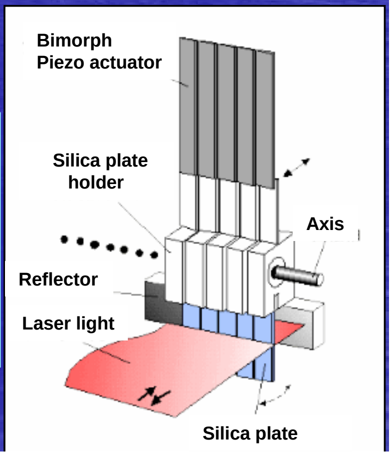
Simultaneously and independently performing both spectral Phase & Amplitude of ultrafast laser pulses. (*FASTLITE*)

3-1-2. Fused-silica based SLM

Utilizing silica plates

- Directly shaping for UV-Laser
- Higher Laser power threshold
- Possible to shape ~ms pulse train

~ However long-term drifting (At present status, very sensitive to temperature fluctuation) ~

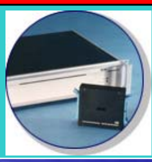


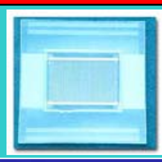
~ Computer-controllable silica plates complex ~

Simulated Annealing Algorisms (SA)

Compared with other type SLM

Maker name	Cyber Laser Inc.	CRI	Meadlark	Jenoptik	Hamamatsu	FASTLITE
Product name	SP8 test SLM	SLM-128	SSP -256 - λ	SLM640/12	X8267	T-UV200-300
wavelength	200 nm~ limited by gratings & optics	400 nm~	400 nm~	400 nm~	350 nm~	200~300nm
transparency	99%	94%	90%	95%	90% (Reflective)	50%
Total efficiency (0.1 nm/pixel)	20% in IR depends on input bandwidth (20 nm)	~ 40% in IR depends on input bandwidth (20 nm)	~ 70% in IR input bandwidth (< 26nm)	~ 70% in IR input bandwidth (< 64 nm)	~ 70% in IR input bandwidth (< 100 nm)	30-50% in UV depends on shaping
Damage threshold for amplified pulses (10 Hz)	1TW/cm^2 (100mJ/pulse)	500MW/cm^2 (50 μ J/ pulse)	500MW/cm^2 (50 μ J/ pulse)	2 GW/cm^2 (100 μ J/ pulse)	2GW/cm^2 (200 μ J/ pulse)	1GW/cm^2 (100 μ J/ pulse)
Operating speed	50ms	100 ms	100 ms	100 ms	500 ms	0.04ms
Pixel number	48	128	256	640	1024	None (No dead space)
others	Whole system is packaged	Only SLM	Only SLM	Only SLM	Only SLM	Whole system is packaged



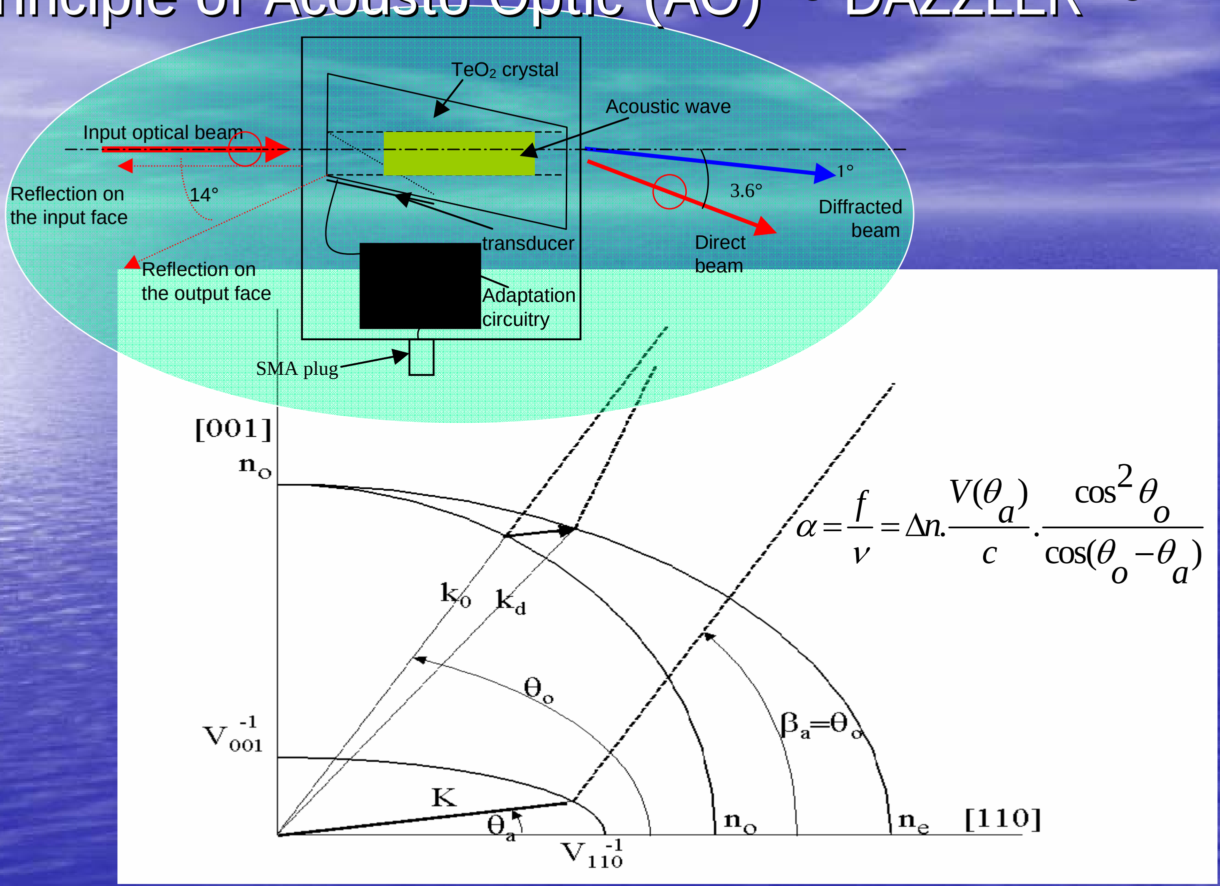
Fused silica type: Mechanical control

Liquid crystal type

Electrical addressed type

AOPDF type

Principle of Acousto Optic (AO) ~ DAZZLER ~



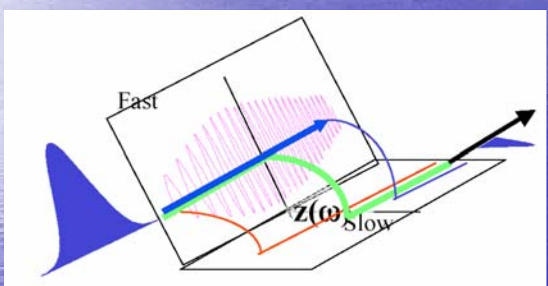
$$\alpha = \frac{f}{\nu} = \Delta n.\frac{V(\theta_a)}{c}.\frac{\cos^2\theta_o}{\cos(\theta_o - \theta_a)}$$

D.Kaplan and P.Tournois J.Phys.IV France **12** (2002) Pr5-69

Principle of AO Programmable Dispersive Filter: DAZZLER

Courtesy of Fastlite

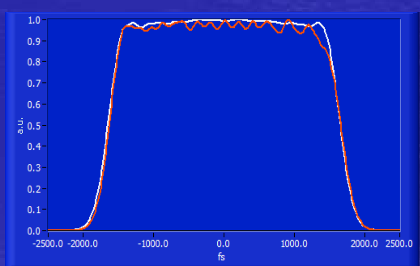
$$E_{out}(t) \propto S(t/\alpha) \otimes E_{in}(t) \quad \text{où} \quad \alpha = \frac{f_{ac}}{f_{opt}} \approx 10^{-7} \Rightarrow \boxed{E_{out}(\omega) \propto S(\alpha\omega)E_{in}(\omega)}$$



Transmitted pulse equals convolution of input pulse and acoustic wave:

- -single crystal design (few cm^3)
- -quantitative shaping in phase and amplitude
- -up to few ps shaping ability.
- -several wavelength available (from IR to UV)

Example of 4ps square pulse made with UV DAZZLER



But Damage threshold problem In the UV!

3. Adaptive micro-pulse preparation

- UV- & IR-DAZZLER feedback sys.+ Pulse Stacker

3-2. Difficulty of UV-Laser pulse measurements

3-2-1. Streak camera (Hamamatsu fesca-200)

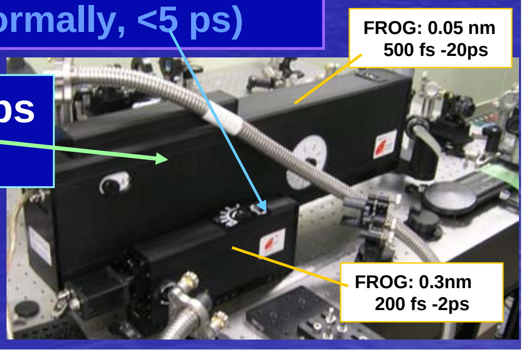
In IR temporal resolution of 200 fs, but…..

- Temporal resolution of 700 fs in UV
- Possible to measure up to 800 ps

3-2-2. FROG or SPIDER

Possible to measure just in IR (normally, <5 ps)

- Specially ordered FROG for 20 ps
- UV-Dazzler as FROG or SPIDER

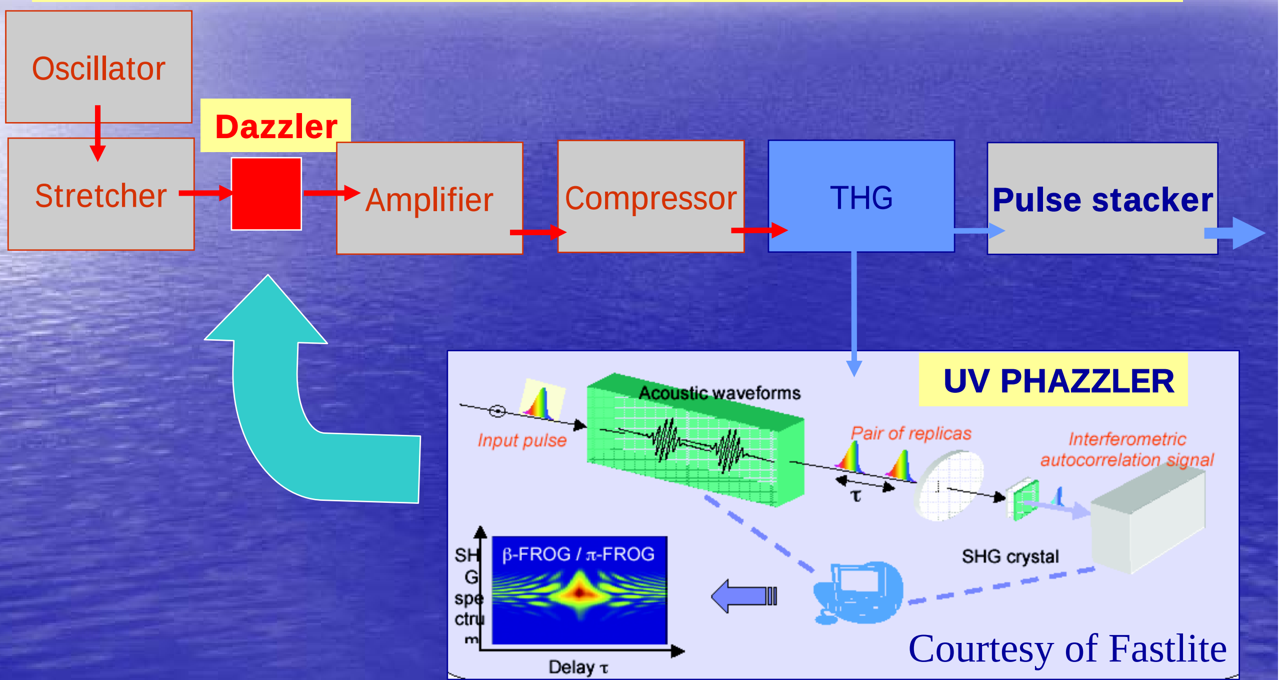


PHAZZLER (normally, <5 ps) can be one solution for micro-pulse measurement!

3. Adaptive micro-pulse preparation

- UV- & IR-DAZZLER feedback sys.+ Pulse Stacker

3-3. Combination with DAZZLER shaping in IR, and UV pulse measurement with feedback loop.



3. Adaptive micro-pulse preparation

3-4. Features of PHAZZLER MEASUREMENTS

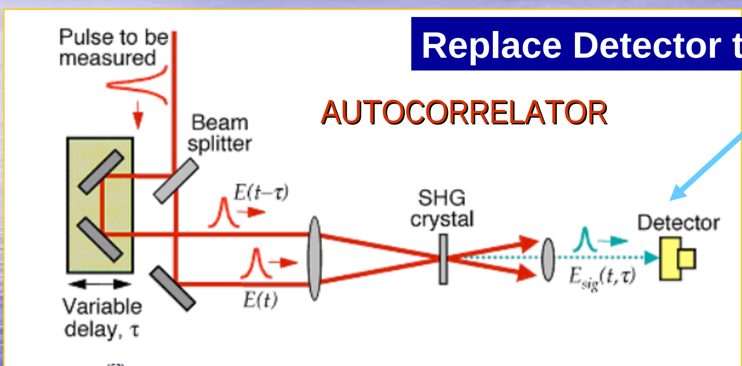
- Design based on a single beam geometry
  - Exceptional stability, reproducible results, user independent
  - Extreme ease of use (no calibration, very straightforward alignment procedure)
- FROG, SPIDER, AUTOCORRELATION within the same instrument by simply flipping a computer switch
  - Single shot, non iterative spectral phase and amplitude characterization with the SPIDER method
  - FROG (Intensimetric and Interferometric available) traces for complex pulse shapes (multiple pulses, large Time Bandwidth products)
  - Interferometric AutoCorrelation and Intensimetric Autocorrelation available
- Tunable wavelength range

3. Adaptive micro-pulse preparation

- UV- & IR-DAZZLER feedback sys.+ Pulse Stacker

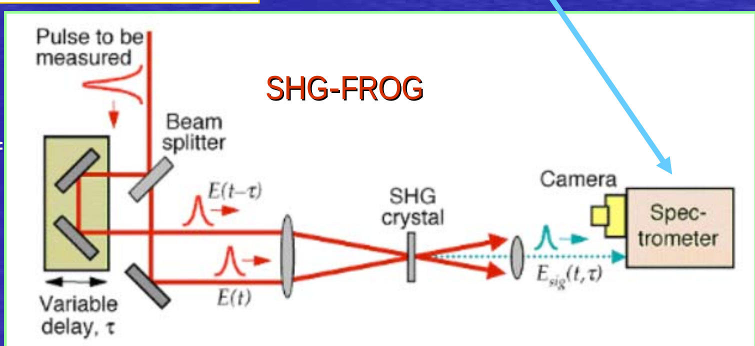
3-4-1. Conventional AUTOCORRELATOR & SHG－FROG

Replace Detector to Spectrometer for FROG



http://www.physics.gatech.edu/gcuo/images/others/

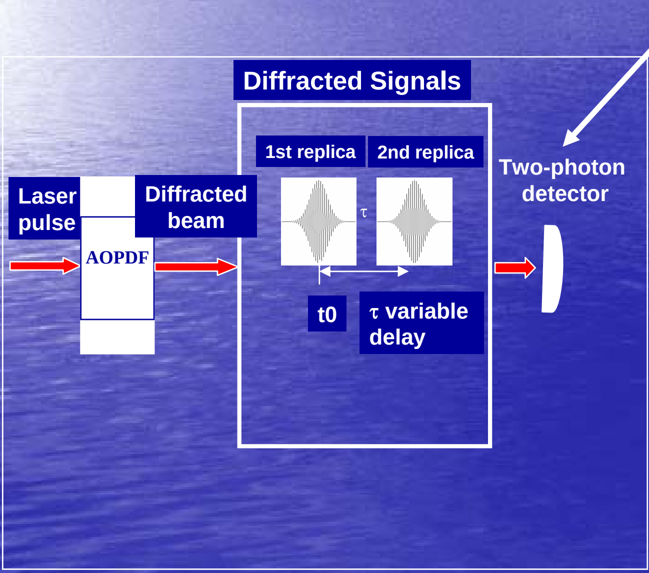
AC_fig01.gif ; FROG_fig05.gif

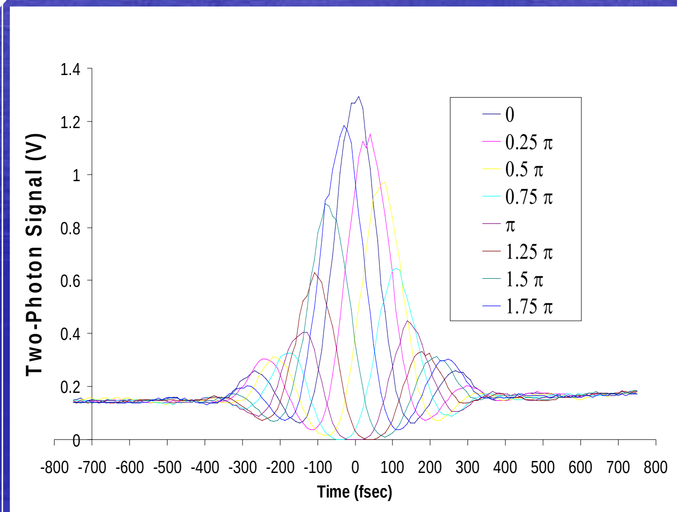


3. Adaptive micro-pulse preparation

- UV- & IR-DAZZLER feedback sys.+ Pulse Stacker

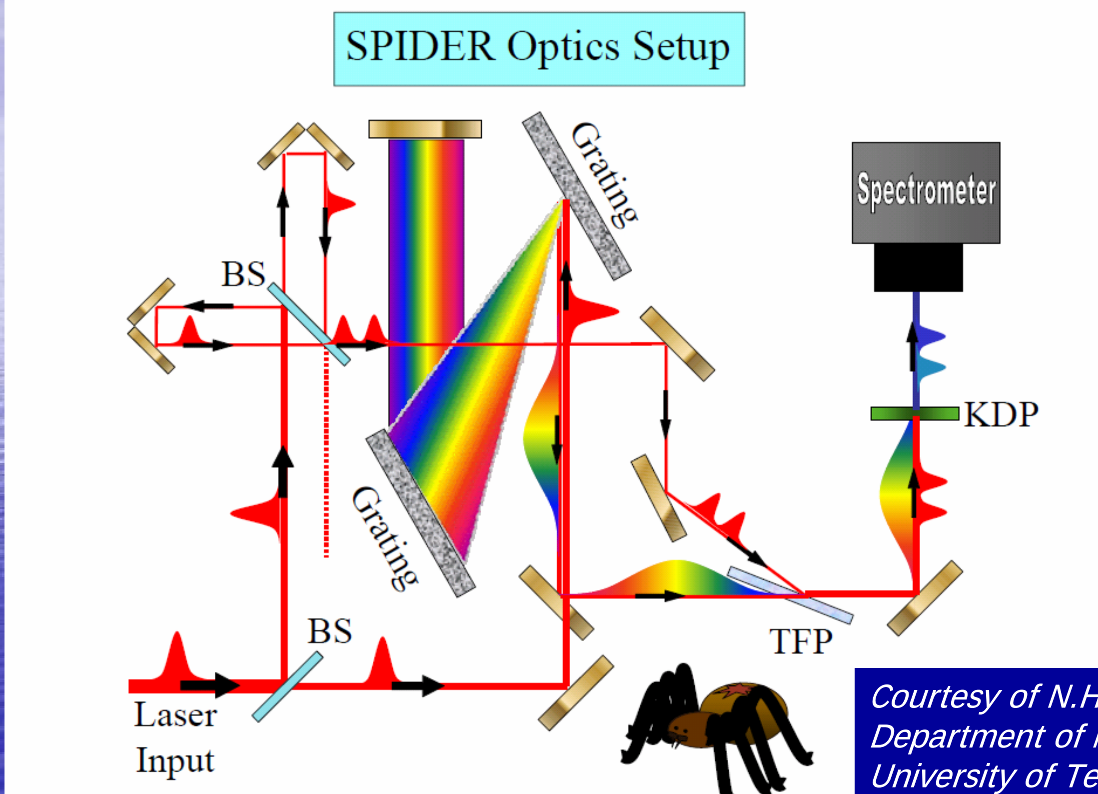
3-4-2. BASEBAND INTERFEROMETRIC AUTOCORRELATION PULSE MEASUREMENTS with DAZZLER ~ PHAZZLER ~





Courtesy of Fastlite

3-4-3. SPIDER as a perfect pulse characterization ~ Conventional SPIDER CONFIGRATION ~



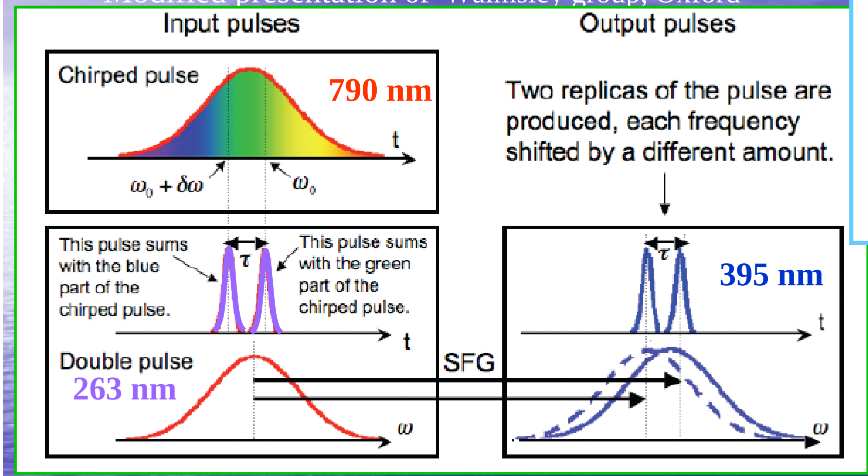
Courtesy of N.H. Matlis
Department of Physics
University of Texas

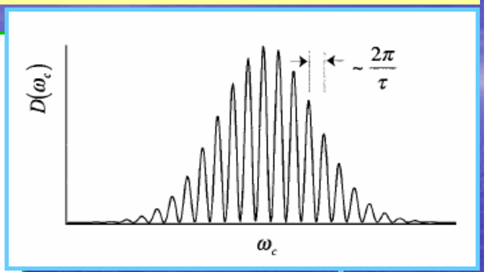
*Based on work by C. Iaconis & I.A. Walmsley (Opt.Let. /Vol. 23 No.10/May 15 1998)

3-4-4. SPIDER for characterization of macro-pulse (stacked pulse train) & micro-pulse (SP8-future plan)

~ Measuring the spectral phase: Conventional SPIDER ~

Modified presentation of Walmsley group, Oxford





Feed backing with SPIDER, Pulse stacking can be optimized!

$$S(\omega_c) = \left|\tilde{E}(\omega_c)\right|^2 + \left|\tilde{E}(\omega_c+\Omega)\right|^2 + \left|\tilde{E}(\omega_c)\,\tilde{E}(\omega_c+\Omega)\right| \cos[\phi_\omega(\omega_c+\Omega) - \phi_\omega(\omega_c) + \omega_c\tau]$$

Spectrum of Pulse 1

Spectrum of Pulse 2

Spectral Phase of Pulse 1

Spectral Phase of Pulse 2

Time Delay

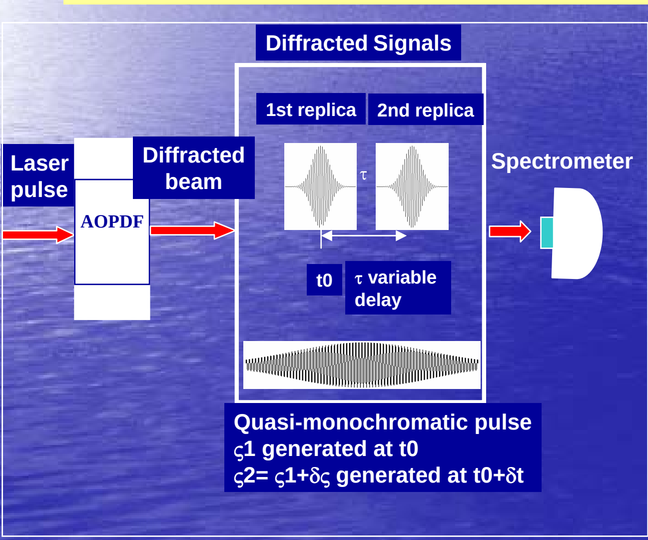
Interference term

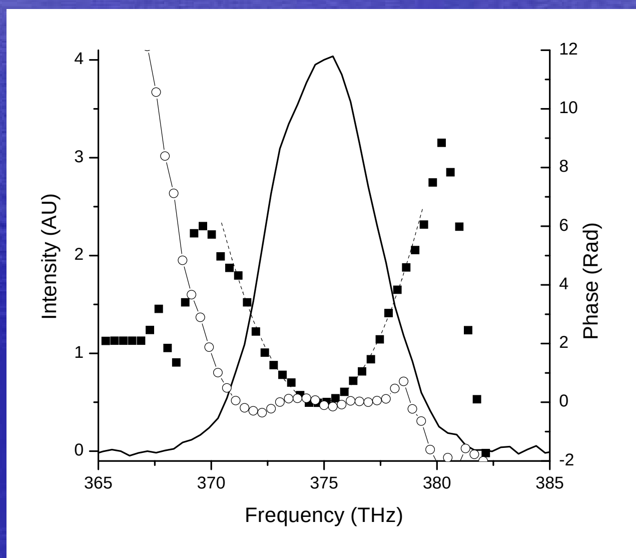
3. Adaptive micro-pulse preparation

- UV- & IR-DAZZLER feedback sys.+ Pulse Stacker

3-4-5. TIME DOMAIN SPIDER MEASUREMENTS with DAZZLER

~ PHAZZLER ~





A.Monmayrant et al. Optics Letters, 28, 4, p278-280 (Feb. 15, 2003)

4. Summary for generation of 15~20-ps UV- Square laser pulse

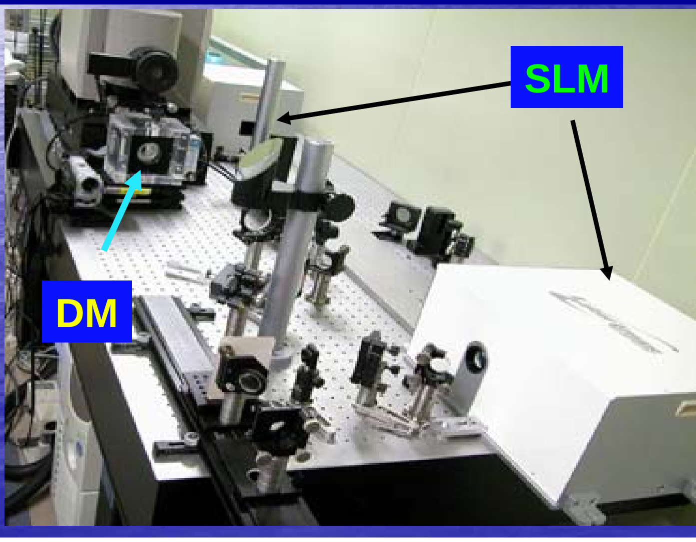
- Pulse Stacker (Macro-pulse) + Micro-pulse preparation

- 15~20-ps temporal shaping with pulse stacking could generate Square pulse!! Its flatness of the plateau depends on optimization of micro pulses!!
- Preparation & Characterization of micro-pulse (2~5 ps) It's very fine to shape : You have to exactly measure the shape of aimed laser pulse.
  - Grating compressor: It's characterized by SPIDER (SP8).
  - Prism-pair: It's characterized by Cross Correlator (PAL).
  - Adaptive DAZZLER(AO): It's characterized by itself (Fastlite).
- For 3D-laser pulse shaping, the complex system with adaptive DAZZLER & adaptive Deformable Mirror might have a lot of possibilities with fine tuning.

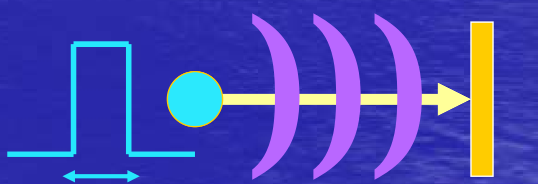
- For arbitrary 3D-laser pulse shaping, the complex system with adaptive Silica-SLM & adaptive DM should be the goal for any case. Especially, It can be utilized for multi-bunch beam shaping.

A) Computer-aided **Silica-SLM (Spatial Light Modulator)**
→ **Rectangular Pulse shaping (Arbitrary Shape)**

B) Computer-aided **DM (Deformable mirror)**
→ **Flattop spatial profile (Arbitrary Shape)**



Automatic Control Optics
- **Spatial shaping (DM)**
- **Pulse shaping (SLM)**
- **Wave front Control (DM)**



2 ~ 12 ps Fundamental
2 ~ 5 ps THG (263 nm)