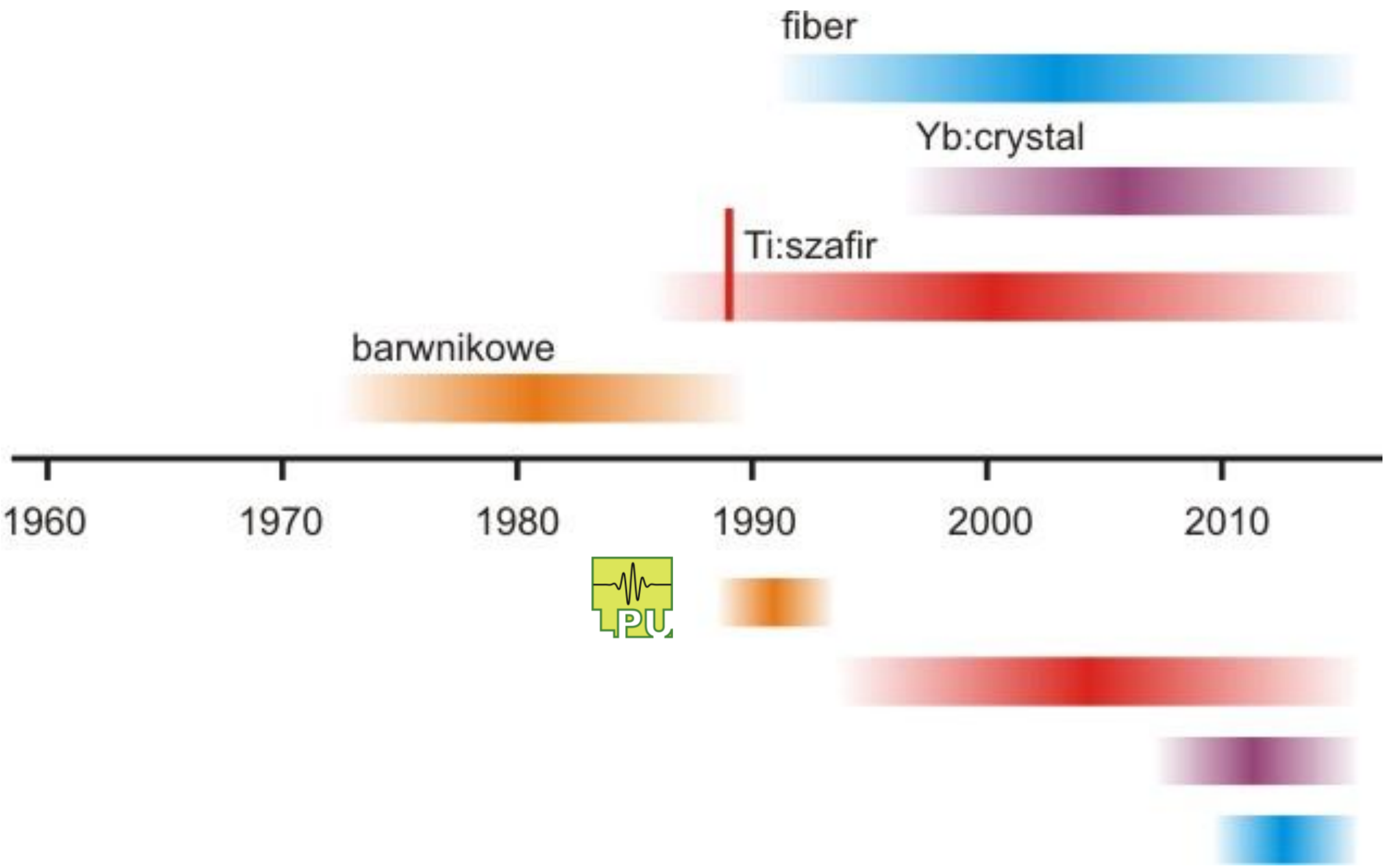
Ultrakrótkie impulsy światła – wytwarzanie, pomiary, zastosowania

Ultrakrótkie impulsy laserowe – szkic historii

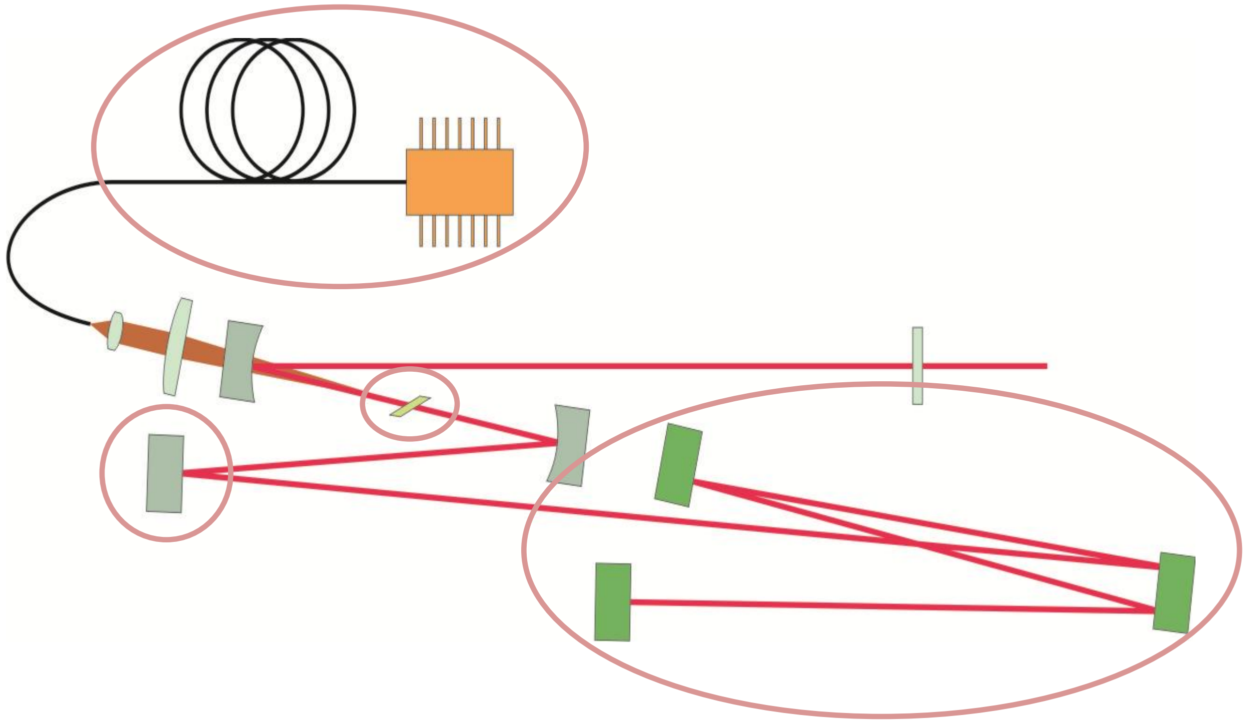
- Muybrigde – 1878
- Abram, Lemoigne – 1899 – Kerr cell
- Harold Edgerton – 1950-60 – mikrosekundy
- barwniki – 1970 – 10 ps
- - 1980 – 100 fs
- - 1985 – 10 fs
- Ippen – 1974 – SPM in CS_2 fiber
- 1978 – SM fiber (nJ)
- Nisoli – 1996-7 – gas fiber (mJ)
- Corkum – HHG, 3-step model, as
- Sansone – 2006 – single 160 as pulse (Science 314, 443)

- ps era – 10 ps ->100 fs – 25 lat
- fs era – 100 fs -> 5 fs – 18 lat
- as era – 5 fs -> 100 as – ok. 15 lat

Ultrakrótkie impulsy laserowe – krótka historia



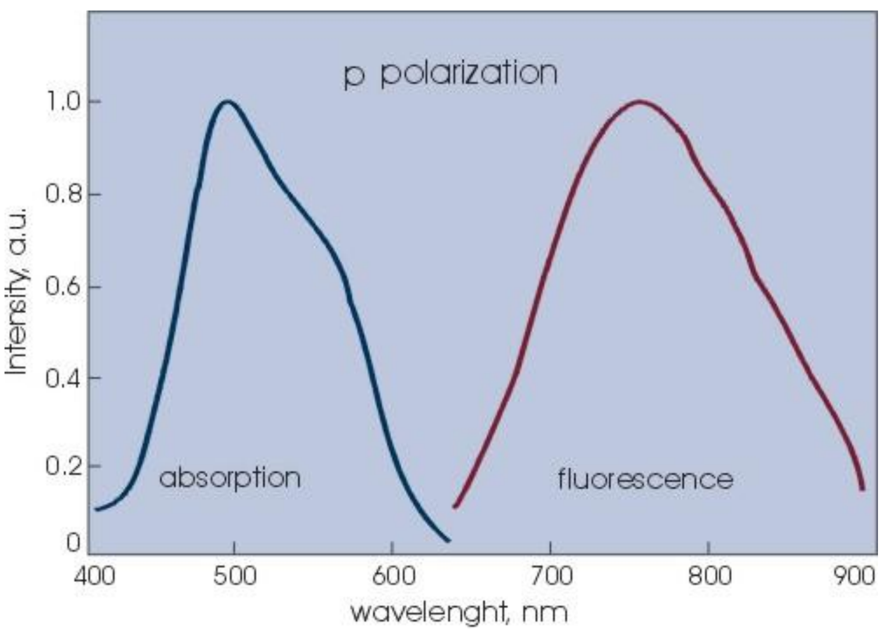
Ultrakrótkie impulsy laserowe – przepis

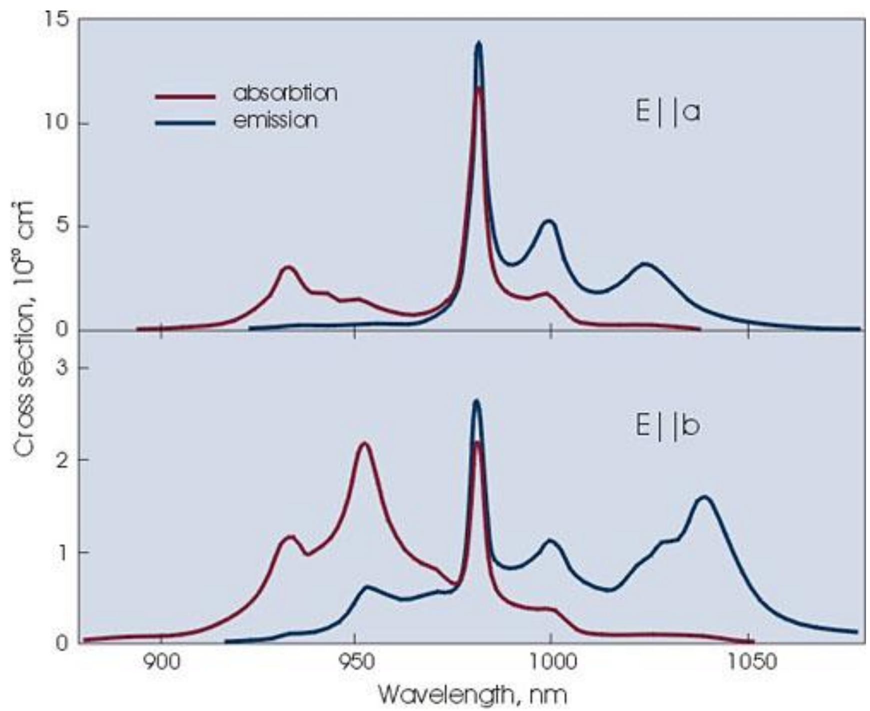


- kryształ z szerokim pasmem emisji (Ti:szafir, Yb:KYW)
- wydajne pompowanie (jakość wiązki!)
- kontorla dyspersji wnęki (para pryzmatów i/lub lustra z ujemną dyspersją)
- lustra z nasycalną absorpcją (SESAM)

Laser femtosekundowy – ośrodek wzmacniający

kryształ	Ti:szafir	Yb:KYW
Pasmo emisji [nm]	>200 nm	ok. 10 nm
Pasmo absorpcji [nm]	Ok. 150 nm w okolicach 500 nm	główny pik 3 nm na 980,5 nm
Pompowanie	Ar^+ SH Nd:YVO	diody AlGaInAs
Defekt kwantowy	np. 532 – 800 nm QD = 34 %	980 – 1030 nm QD = 5 %

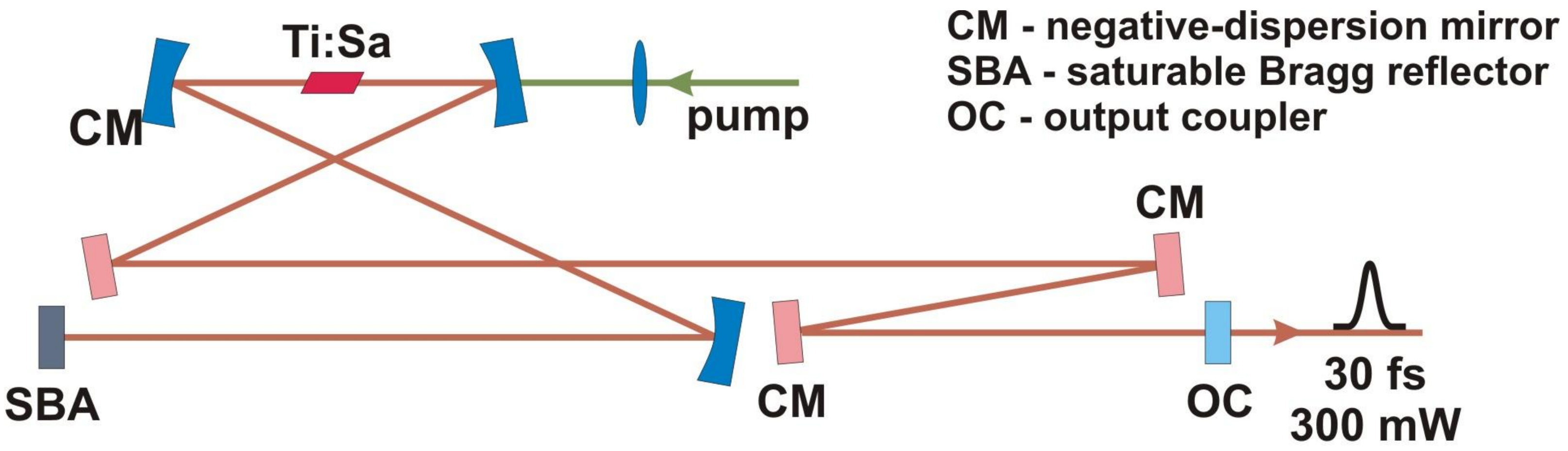

p polarization
1.0
0.8
0.6
0.4
0.2
0
Intensity, a.u.
absorption
fluorescence
400
500
600
700
800
900
wavelenght, nm

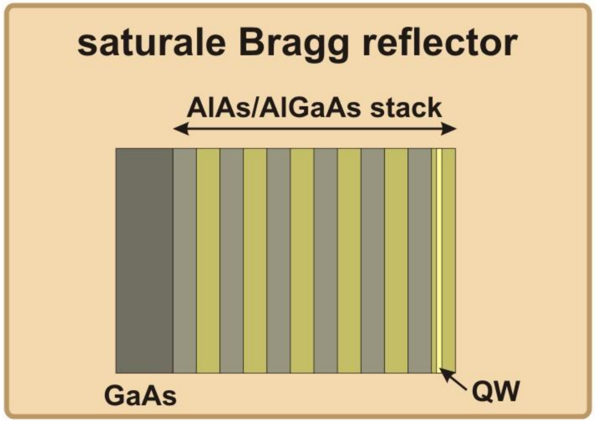

15
10
5
0
3
2
1
0
absorbtion
emission
E||a
E||b
Cross section, 10 cm
900
950
1000
1050
Wavelength, nm

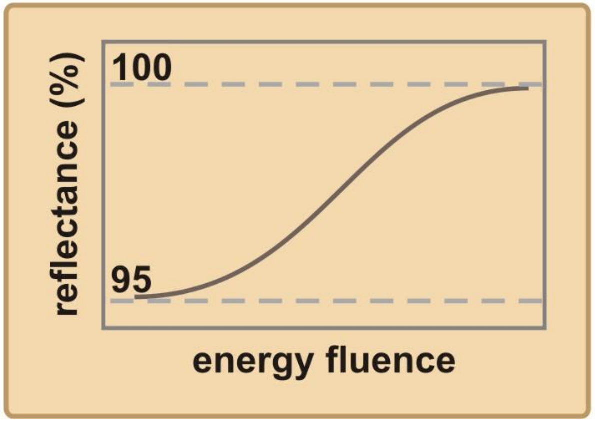
Laser femtosekundowy – pompowanie

pompa	Verdi V-5 (532 nm, Coherent)	Dioda (980 nm, Bookham)
Moc [W]	5	0,75
Cena [USD]	60 000	2 200
Cena za wat	12 000	3 000
Czas życia	15 000 h	100 FIT *
* failures in 10^9 device-hours		

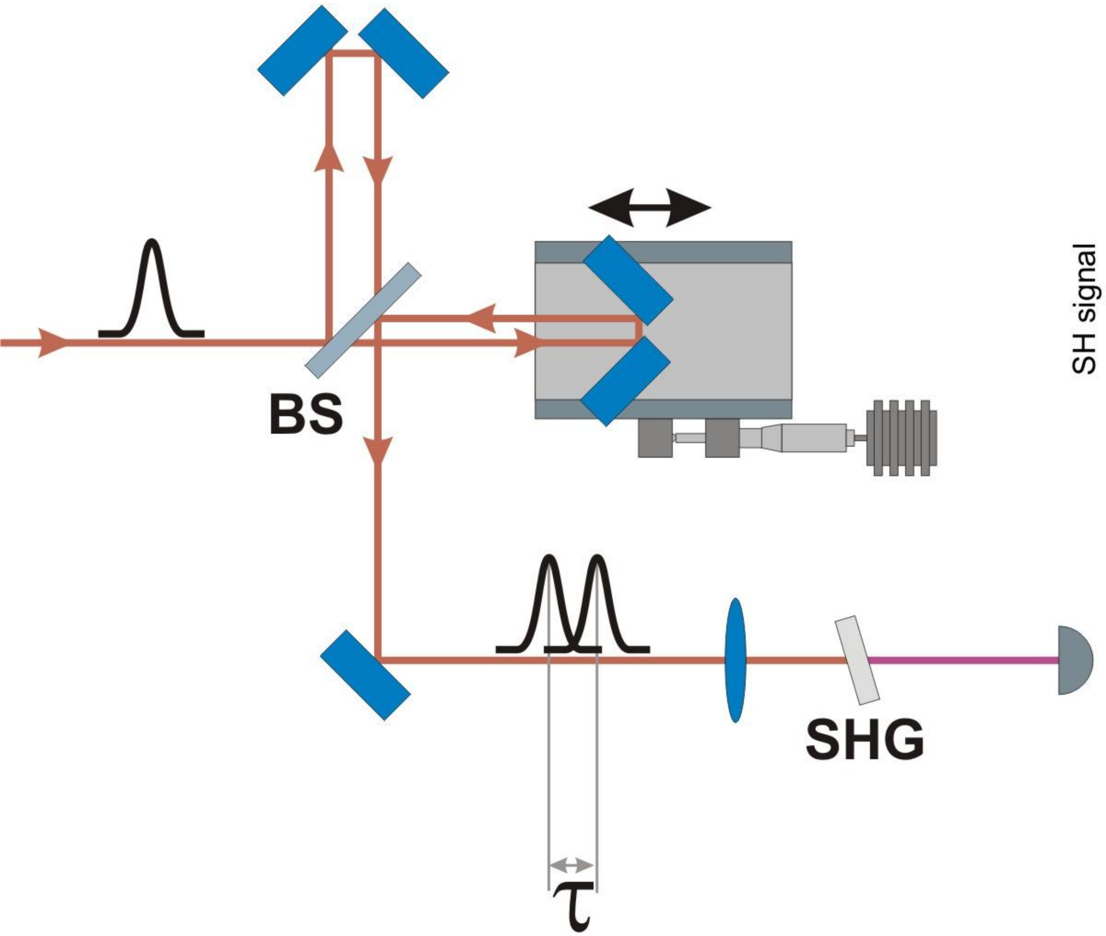
Współczesny laser femtosekundowy

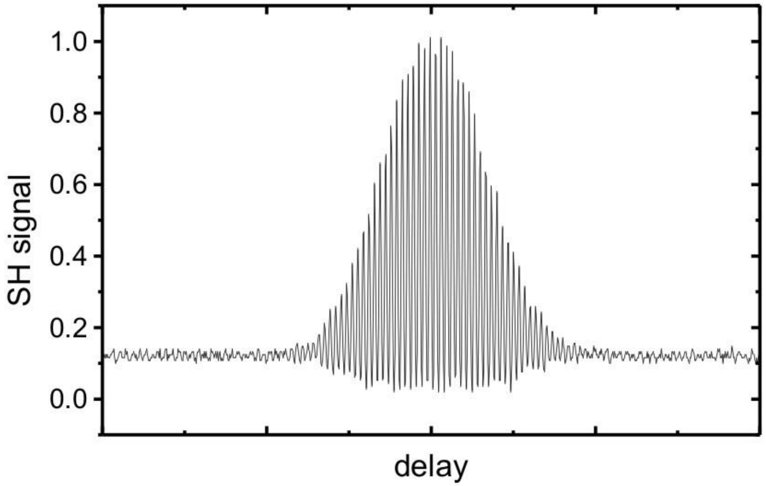






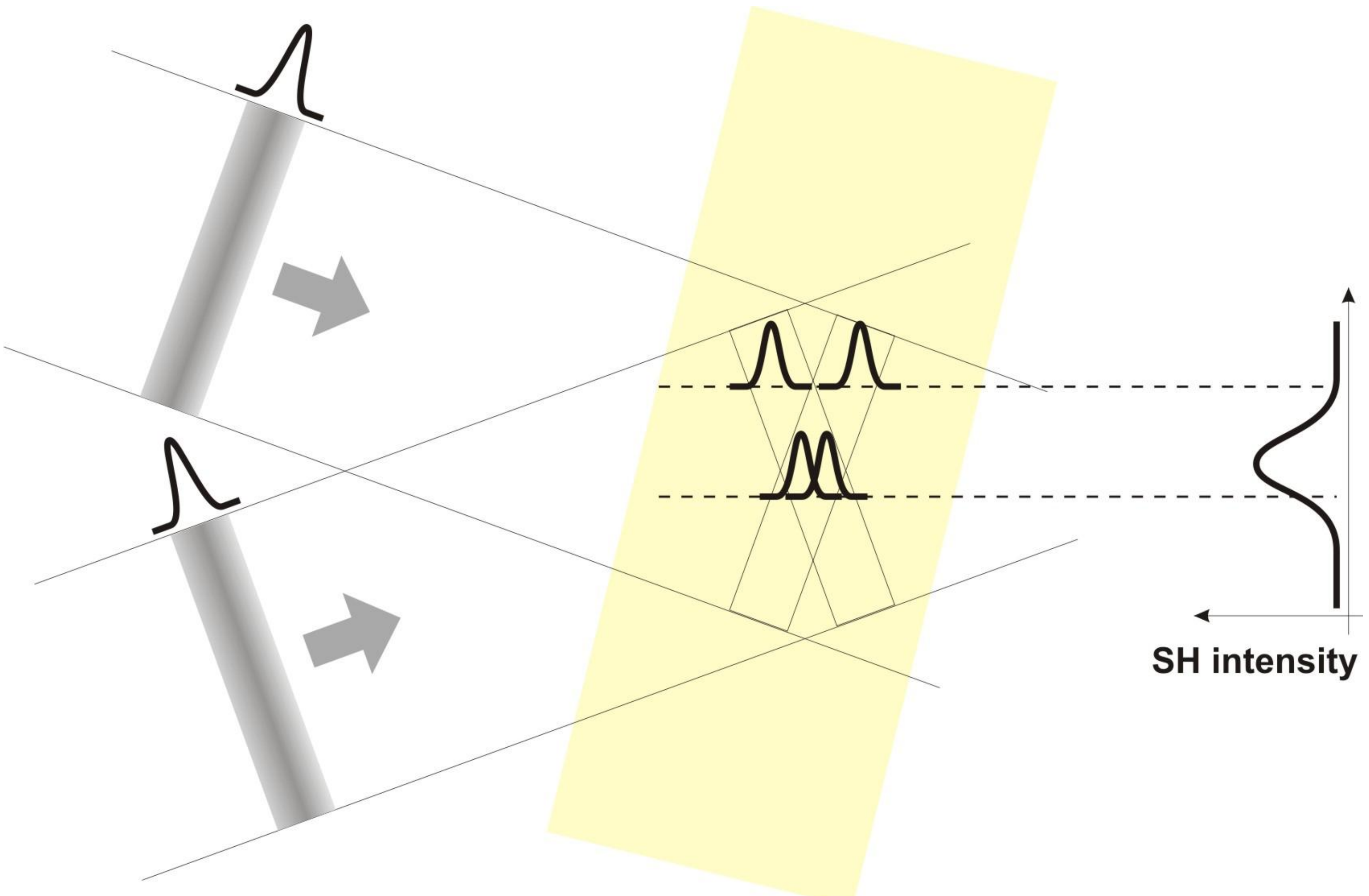
Najprostszy pomiar - autokorelacja



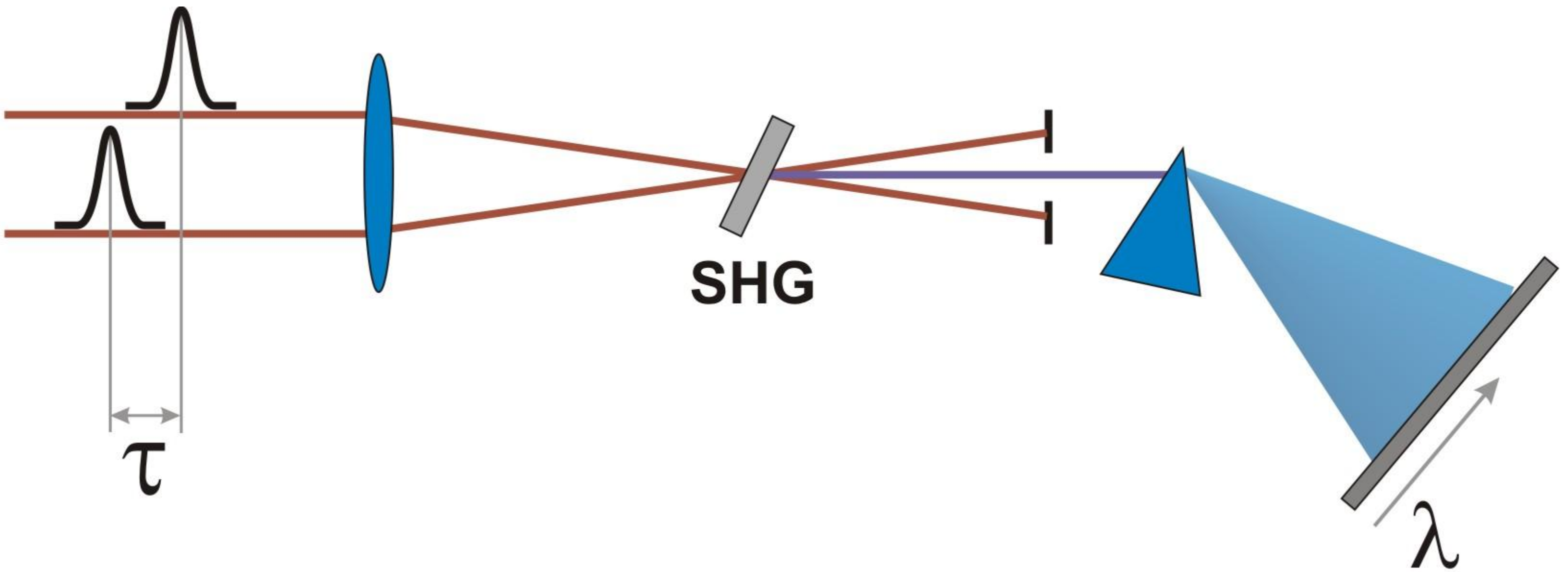


$$S(\tau) = \int E(t)E(t-\tau)dt$$

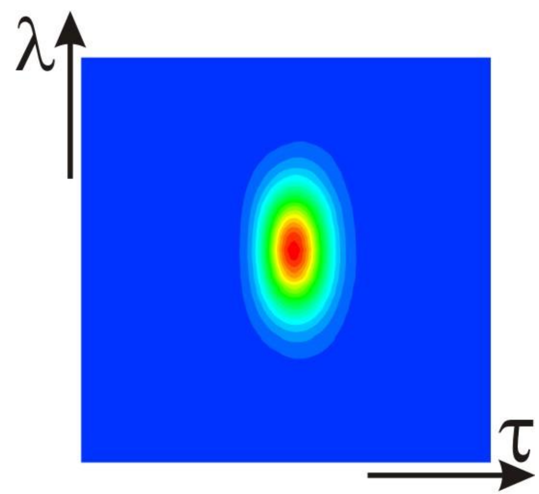
Pomiar autokorelacji pojedynczego impulsu



FROG - idea



$$I_{FROG}(\omega,\tau) \propto \left| \int_{-\infty}^{\infty} E(t)E(t-\tau)\exp(-i\omega t)dt \right|^2$$



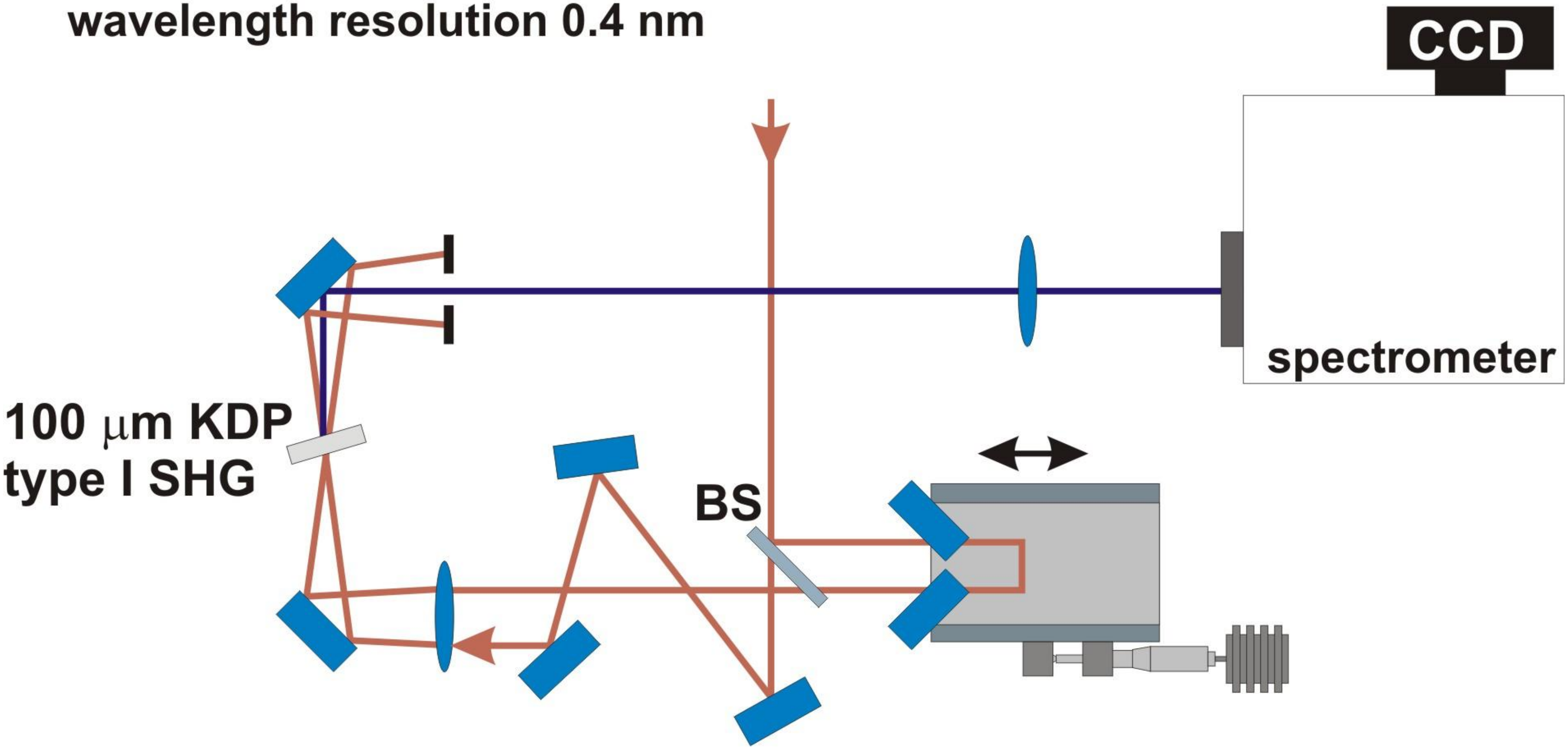
FROG – odzyskiwanie pola elektrycznego

$$G(t,\tau) = E(t)E(t-\tau)$$

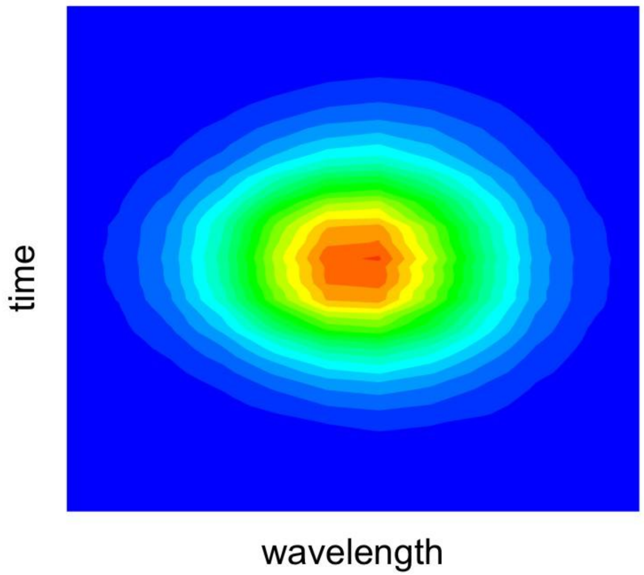
$$
\begin{tikzcd}
 & & \sqrt{I_{FROG}(\omega,\tau)} \arrow[d] & \\
 & G(\omega,\tau) \arrow[rr] & {} & G'(\omega,\tau) \arrow[d, "\mathcal{F}^{-1}"] \\
E(t) \arrow[r] & G(t,\tau) \arrow[u, "\mathcal{F}"] & {} & G'(t,\tau) \arrow[ll] \\
 & & Z = \iint \left| G(t,\tau) - E(t)E(t-\tau) \right|^2 dt\, d\tau \arrow[u] &
\end{tikzcd}
$$

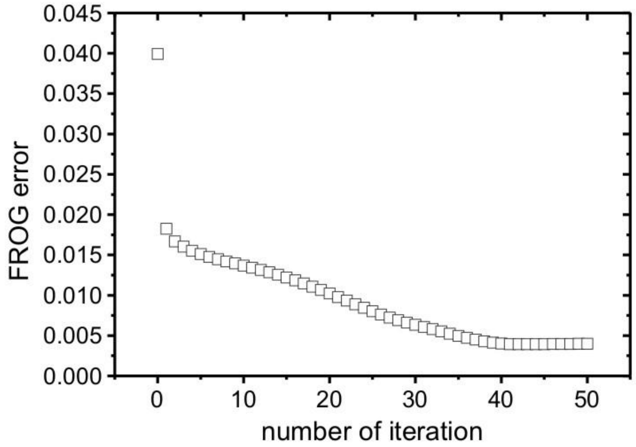
FROG – praktyczna relalizacja

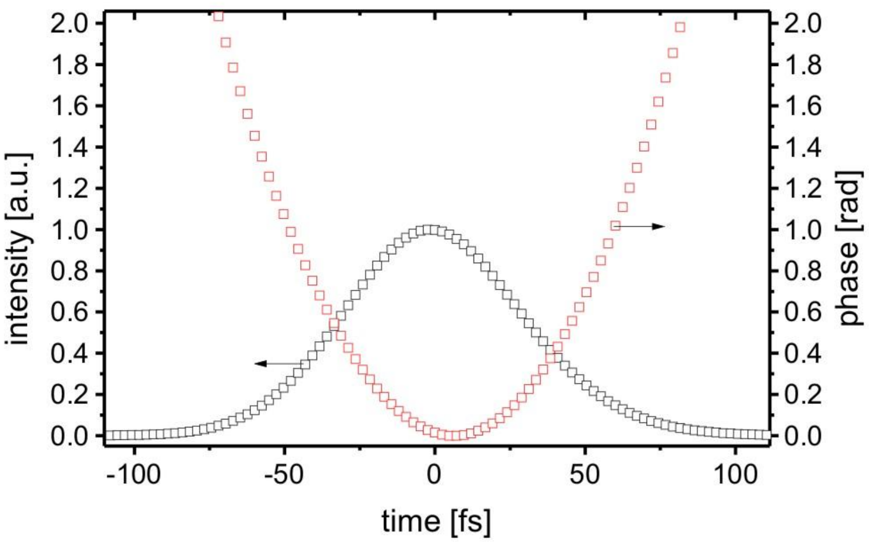
time resolution ⩾ 0.8 fs
wavelength resolution 0.4 nm



FROG – przykładowy wynik



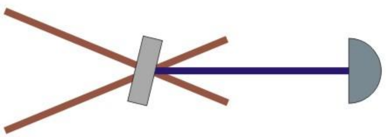




63 time points
24 wavelength points

FROG – inne nieliniowości

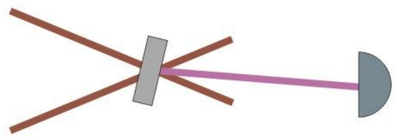
2nd Harmonic Generation



$$G(t,\tau) = E(t)E(t-\tau)$$

- most sensitive (second order process)
- ambiguity in time direction
- requires phase matching

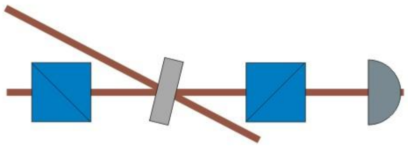
3rd Harmonic Generation



$$G(t,\tau) = E^2(t)E(t-\tau)$$

- quite sensitive
- unintuitive traces
- large bandwidth

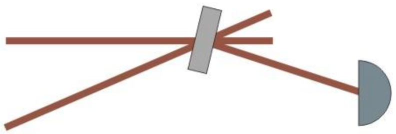
Polarization Gate



$$G(t,\tau) = E(t)|E(t-\tau)|^2$$

- requires polarizers
- intuitive traces
- no phase matching

Self-Diffraction

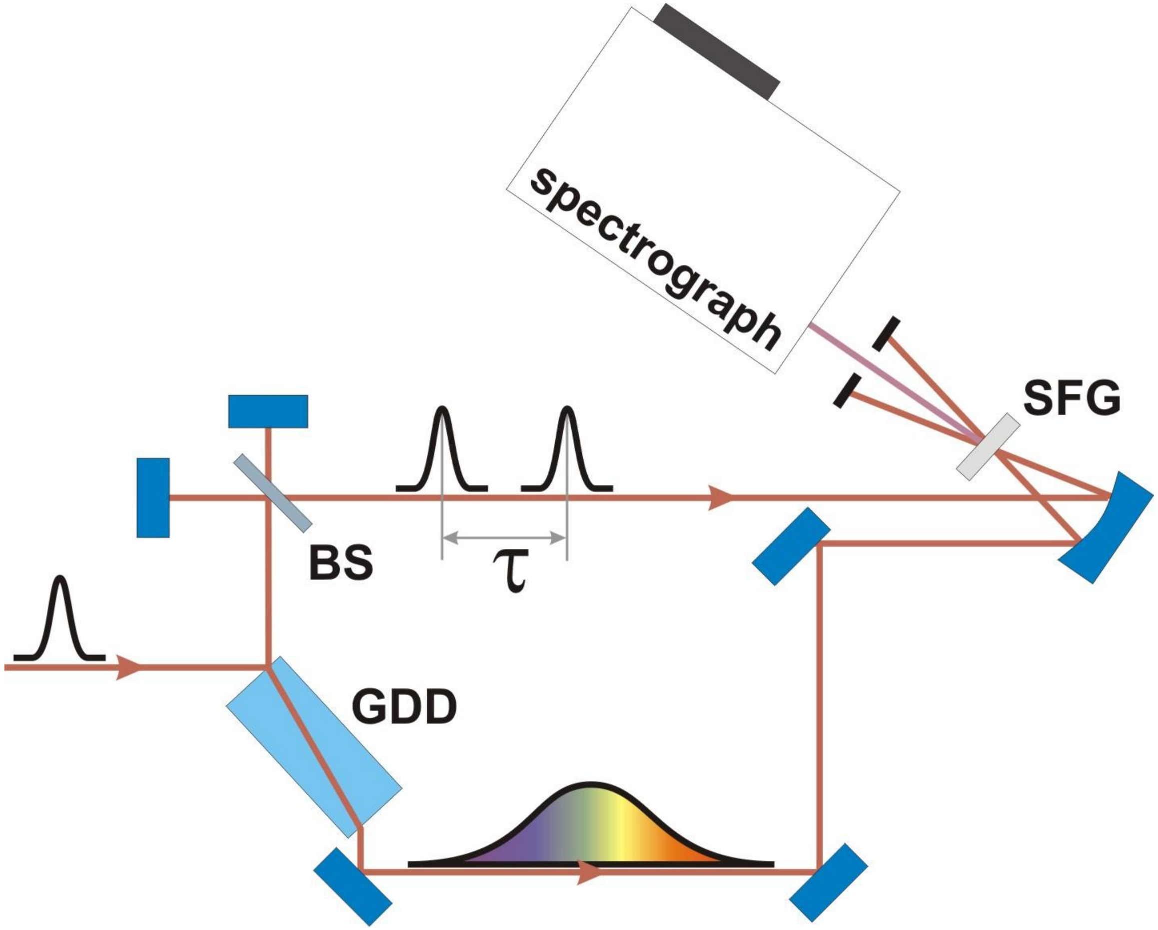


$$G(t,\tau) = E^2(t)E^*(t-\tau)$$

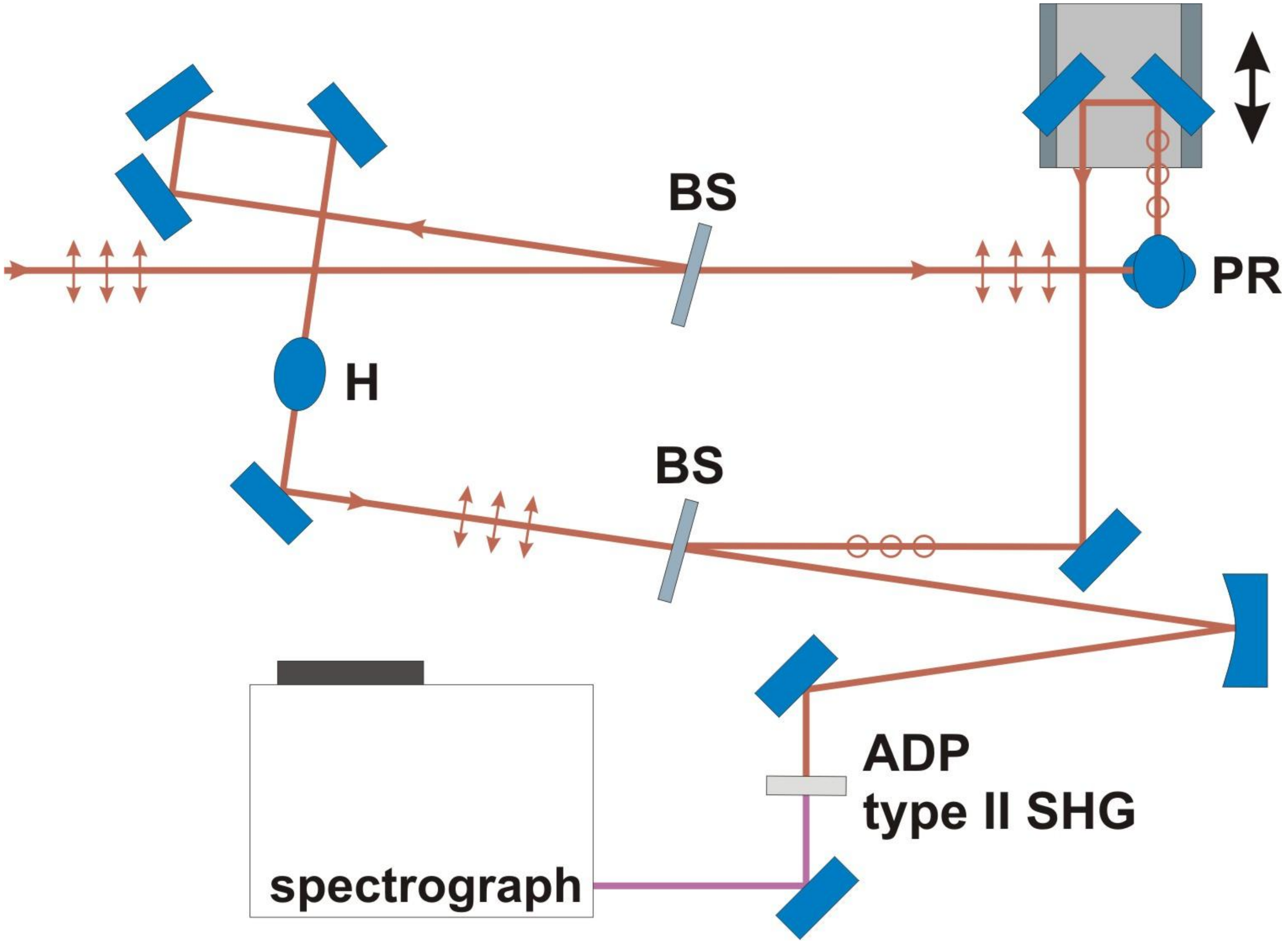
- least sensitive
- intuitive traces
- requires thin medium

SPIDER

SPectral Interferometry for Direct E-field Reconstruction

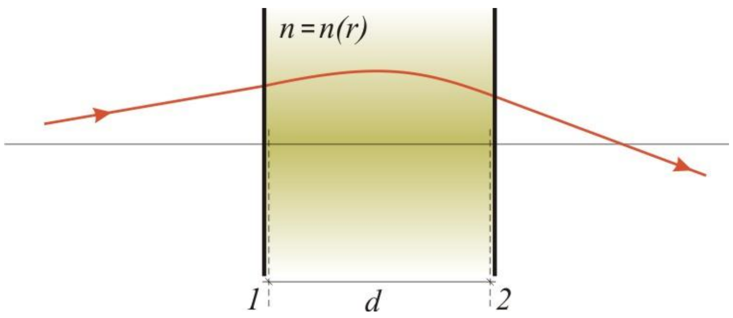


Pomiar naprawdę krótkiego impulsu – 5 fs



Macierze ABCD w optyce geometrycznej

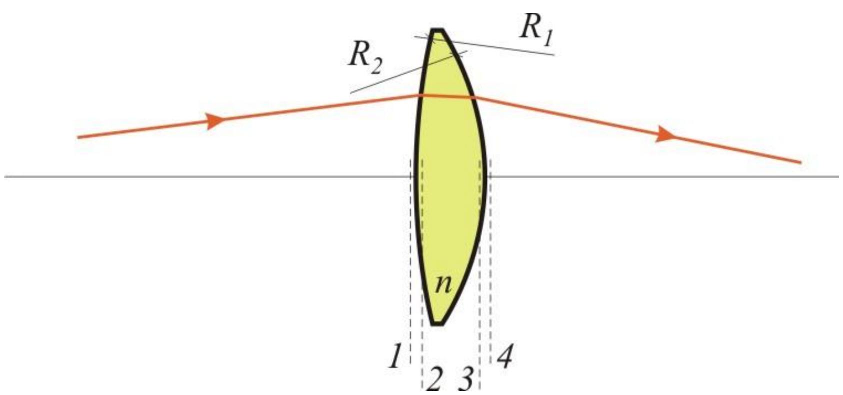
Soczewka GRIN (Graded Refractive INdex)



$$n(r) = n_0\left(1 - \frac{a^2 r^2}{2}\right)$$

$$T_{GRIN} = \begin{bmatrix} \cos(ad) & \frac{1}{a}\sin(ad) \\ -a\sin(ad) & \cos(ad) \end{bmatrix}$$

Cienka soczewka – złożenie dwóch sferycznych granic



$$T_{sphere} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{bmatrix}$$