Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Entwicklung eines portablen, laserbasierten Spannungsimpulsstandards

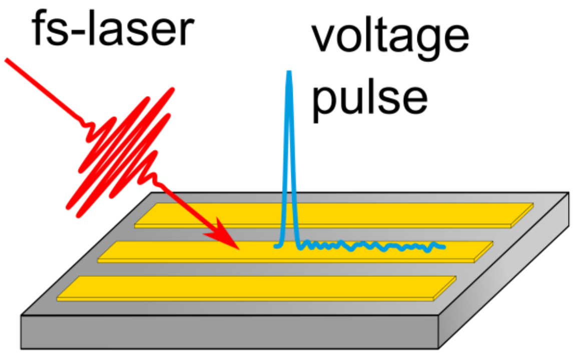
Paul Struszewski und Mark Bieler

Motivation

Femtosecond laser systems enable measurements with bandwidths > 1 THz

Advantage: → **Traceable, accurate measurements**

Drawback: → **Large experimental setup, not portable**

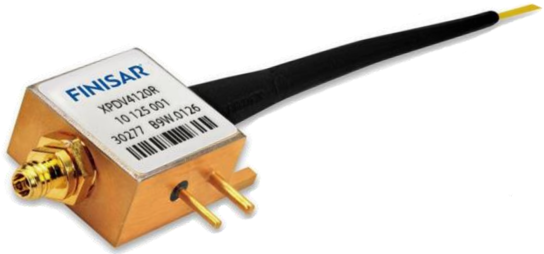


Solution:

Construct a portable ultrashort voltage pulse standard with small footprint

Two step approach:

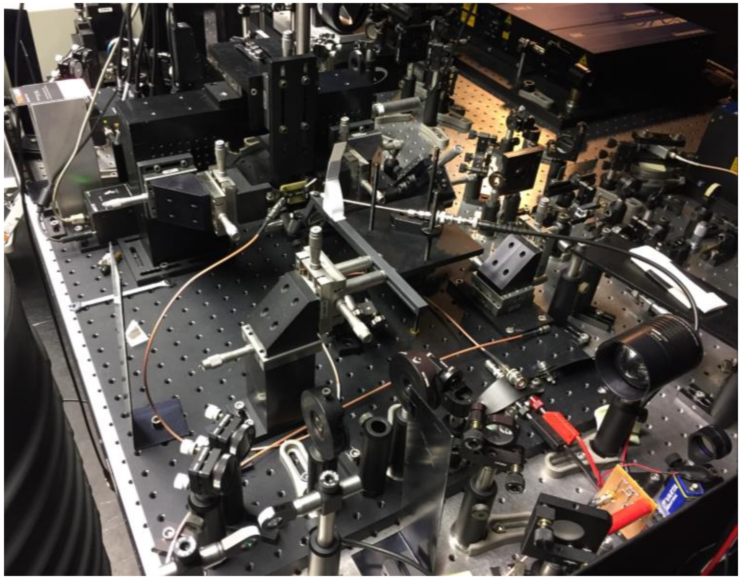
1. Characterization of a high-speed photodetectors
2. Integration in a device with a footprint of 25×30 cm^2



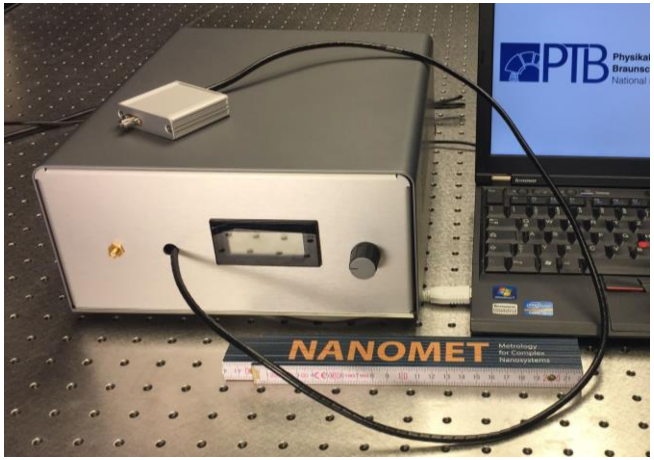
https://www.finisar.com/optical-components/xpdv412xr

Motivation

Conventional measurement setup



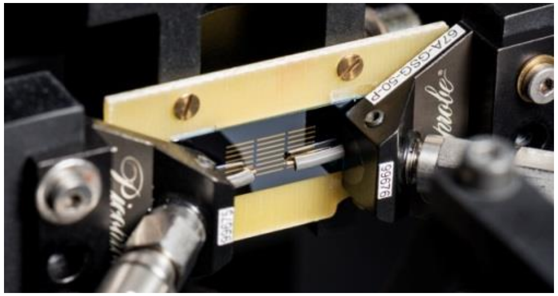
Portable voltage pulse standard



Outline

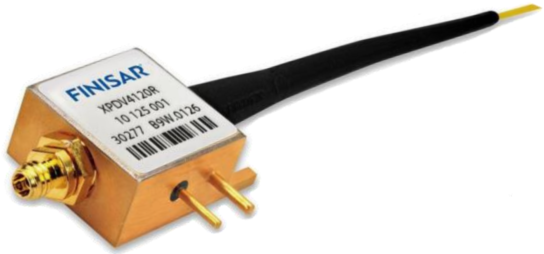
Experimental basics

- Electro-optic sampling
- Ultra-short voltage pulses



Characterization of high-speed photodetector

- Reflection coefficient
- Scattering parameters
- High-speed photodetector



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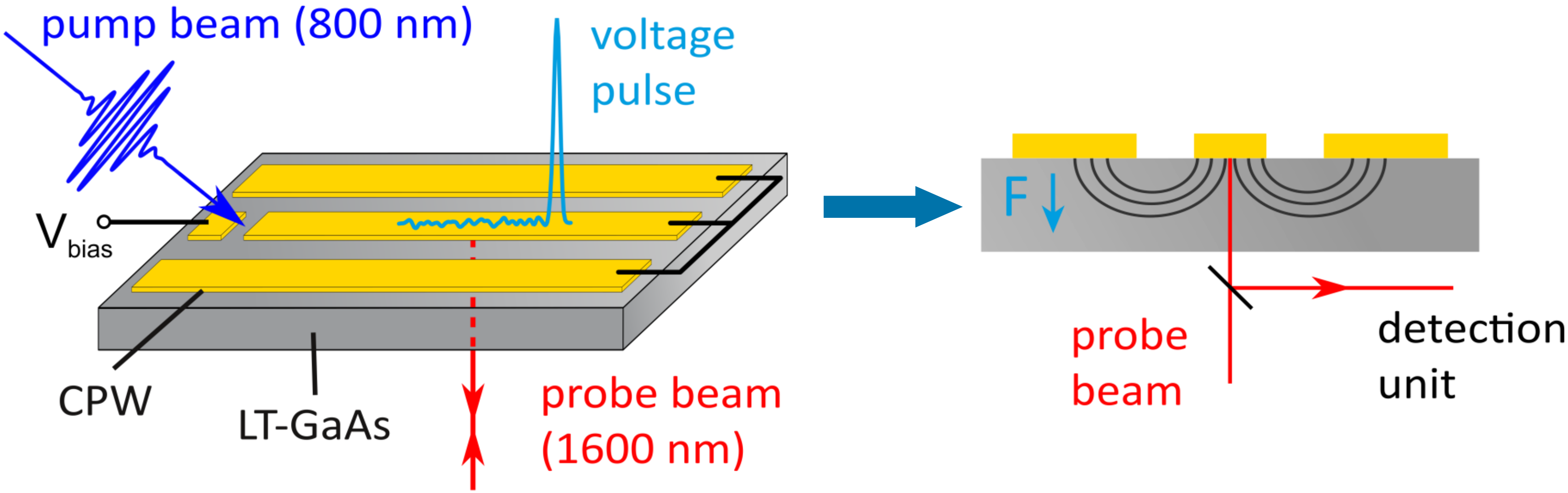
Portable voltage pulse standard

Detection of ultrashort voltage pulses

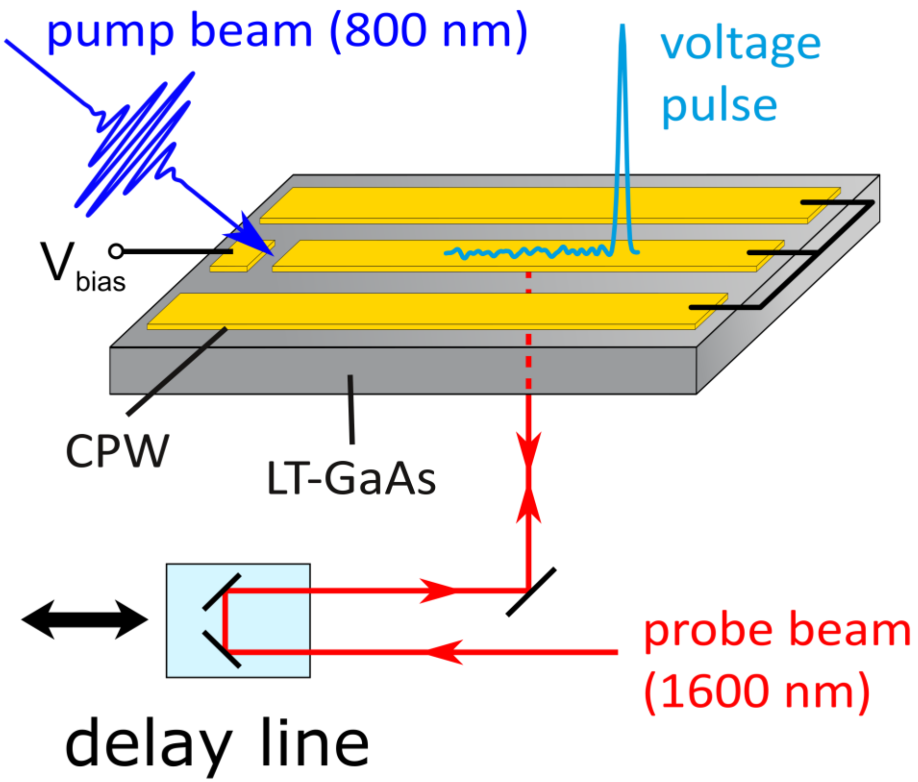
Photoconductive switch is incorporated into a 50 Ω coplanar waveguide (CPW)



Electrical field changes the refractive index (electro-optical effect) → Polarization change of the probe beam → Relative polarization change (∝F) is detec-ted by ellipsometric techniques

Detection of ultrashort voltage pulses

Photoconductive switch is incorporated into a 50 Ω coplanar waveguide (CPW)



Properties:

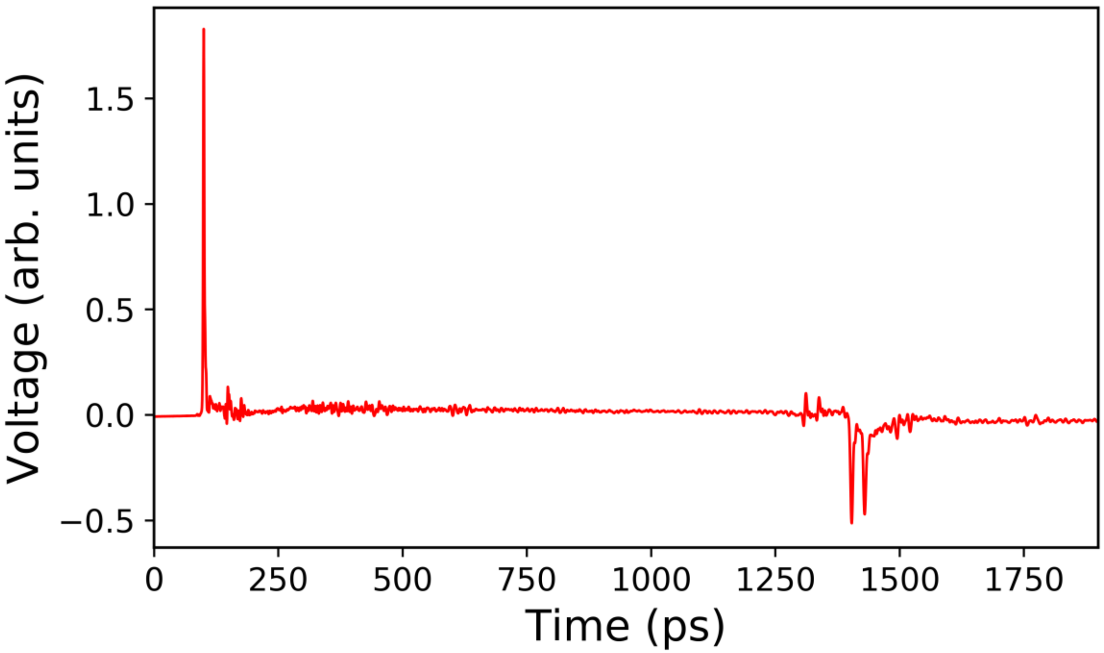
- bandwidth of ~500 GHz
- frequency spacing of 500 MHz
- dynamic range of > 50 dB

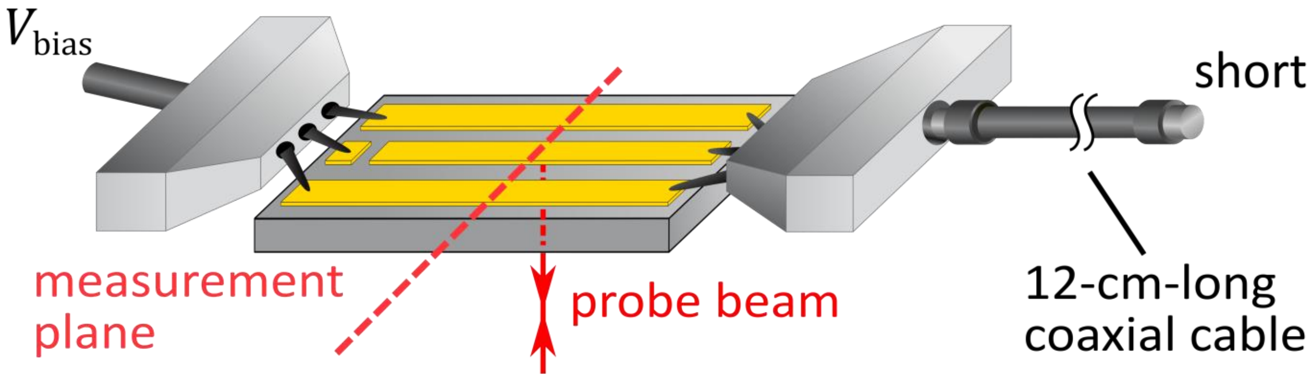
- directly traceable to the unit of length (time)

- impedance matching

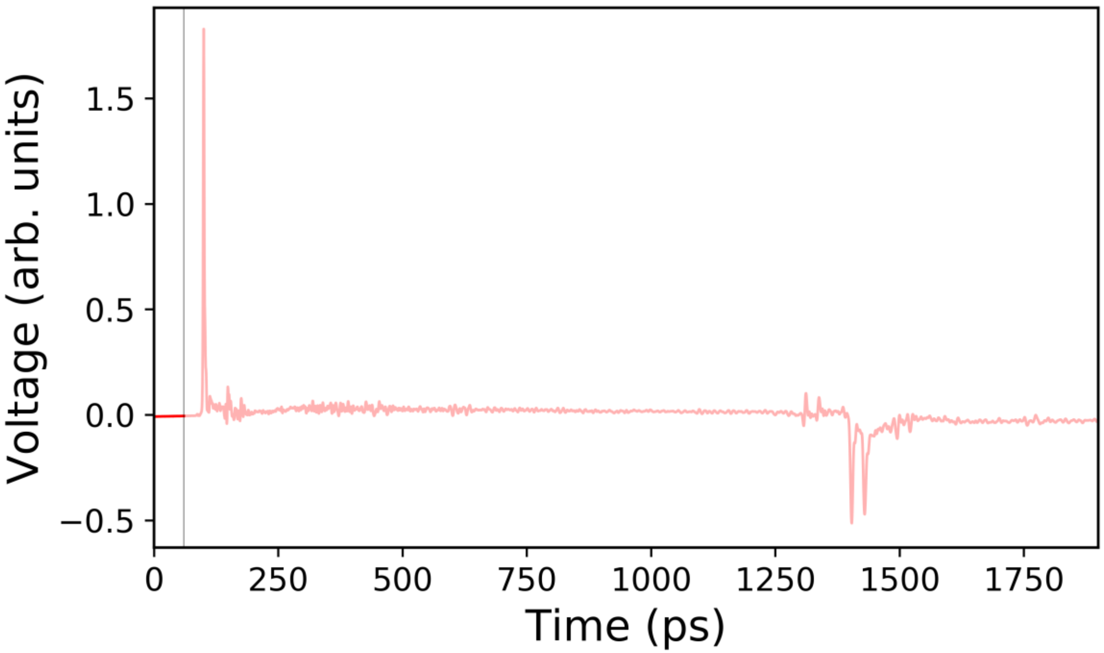
Reason for using laser-based techniques!

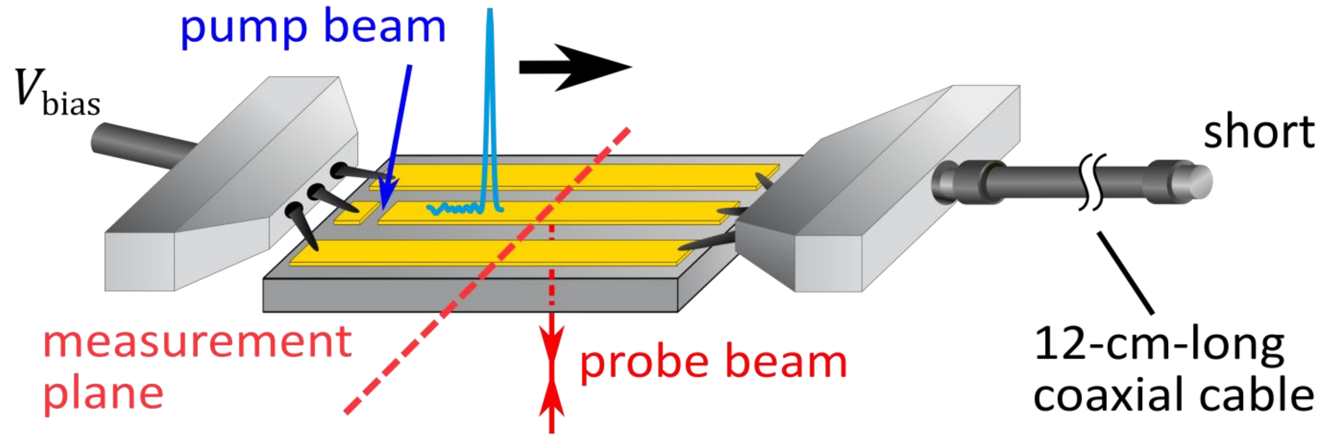
Ultrashort voltage pulses



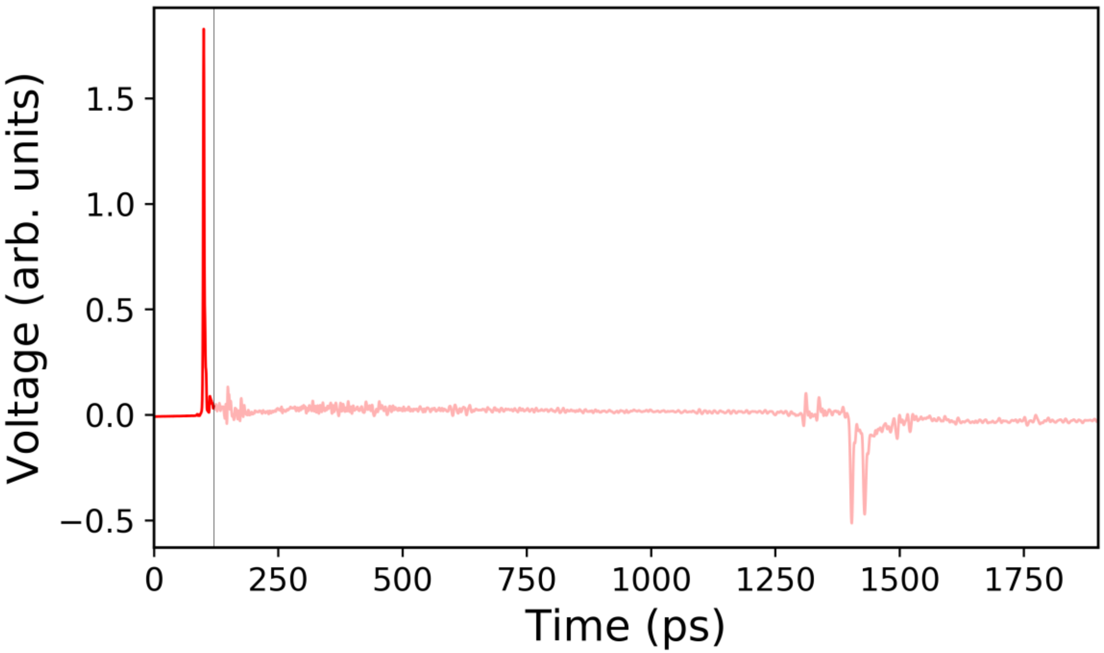


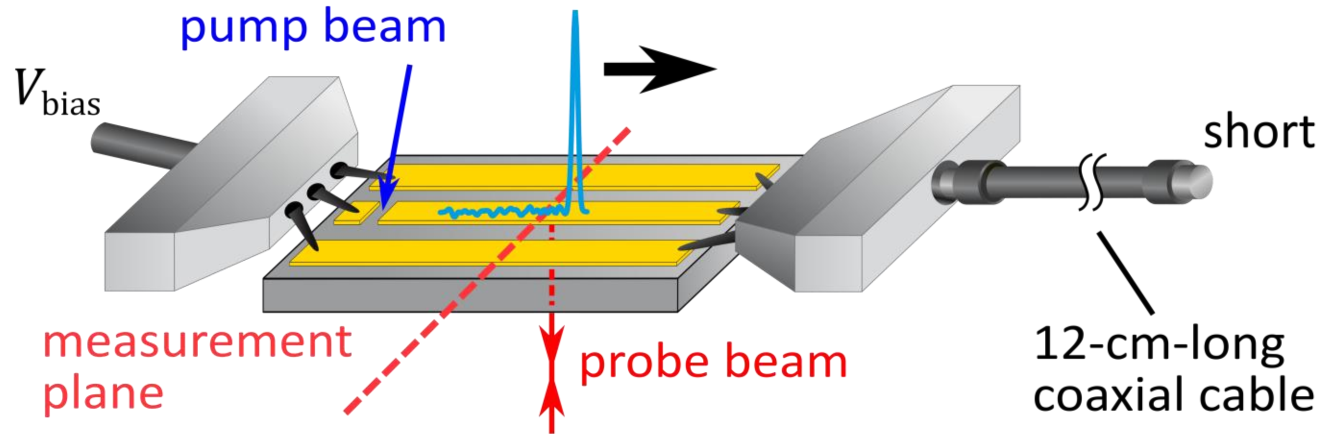
Ultrashort voltage pulses



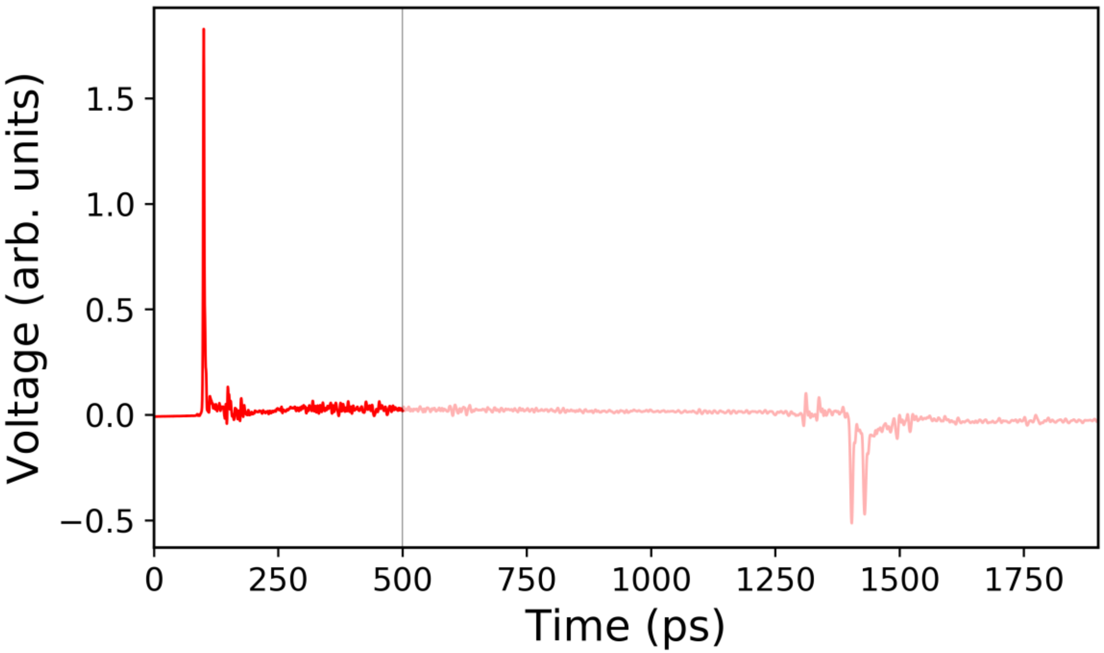


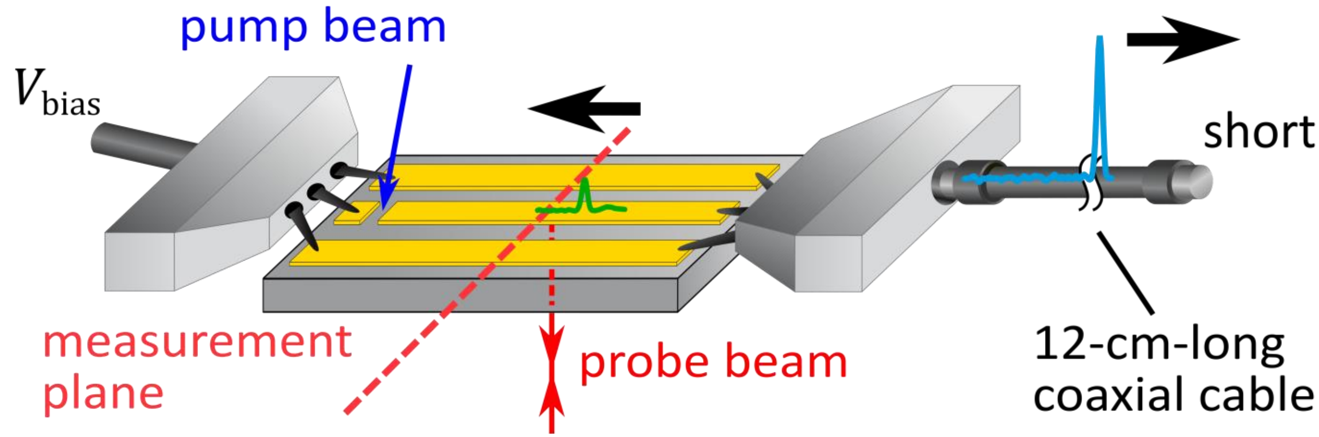
Ultrashort voltage pulses



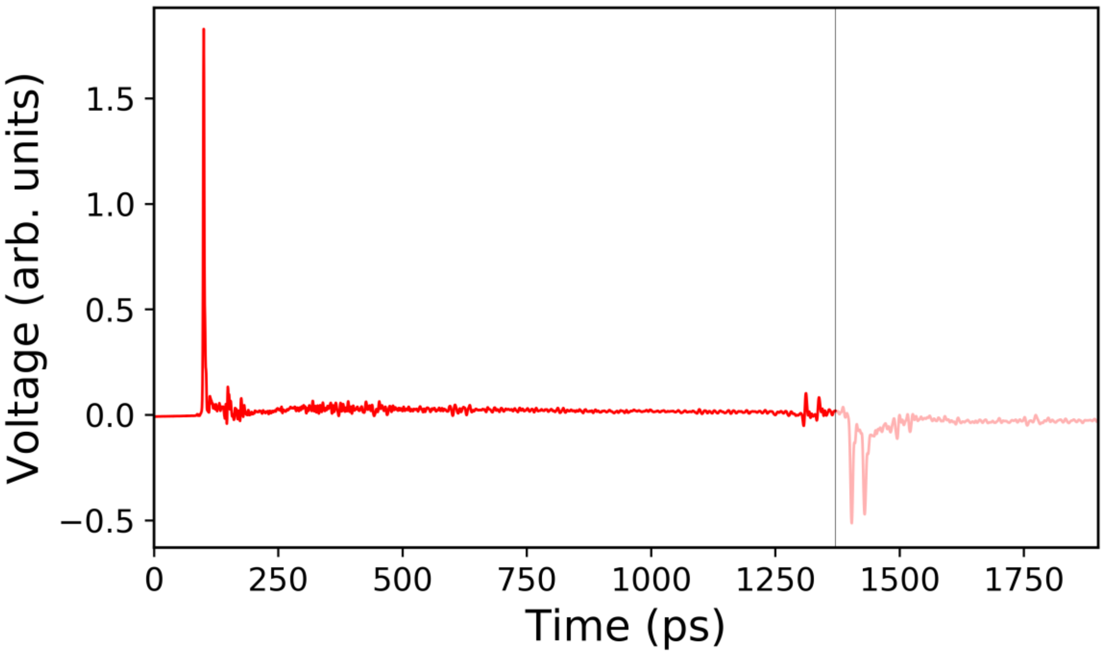


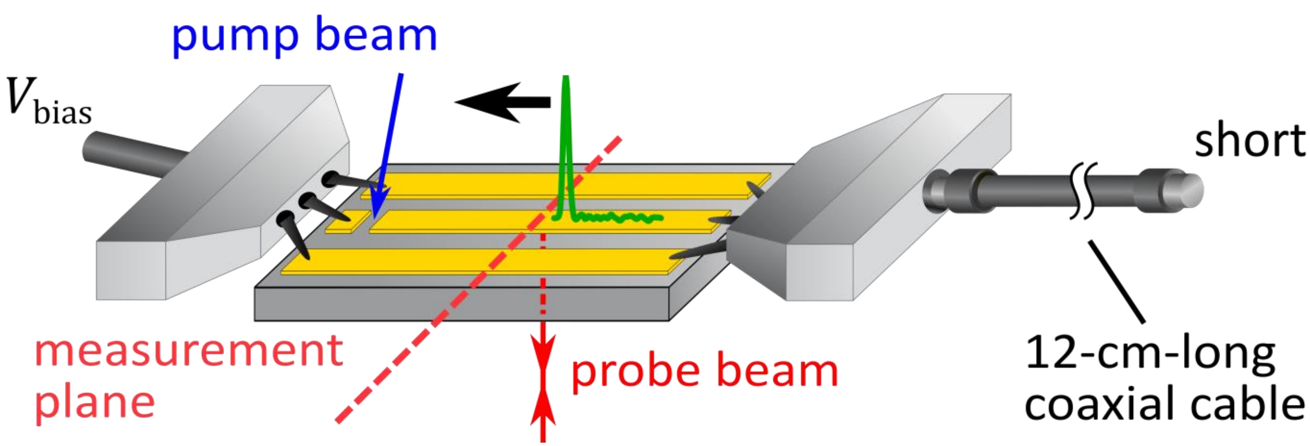
Ultrashort voltage pulses



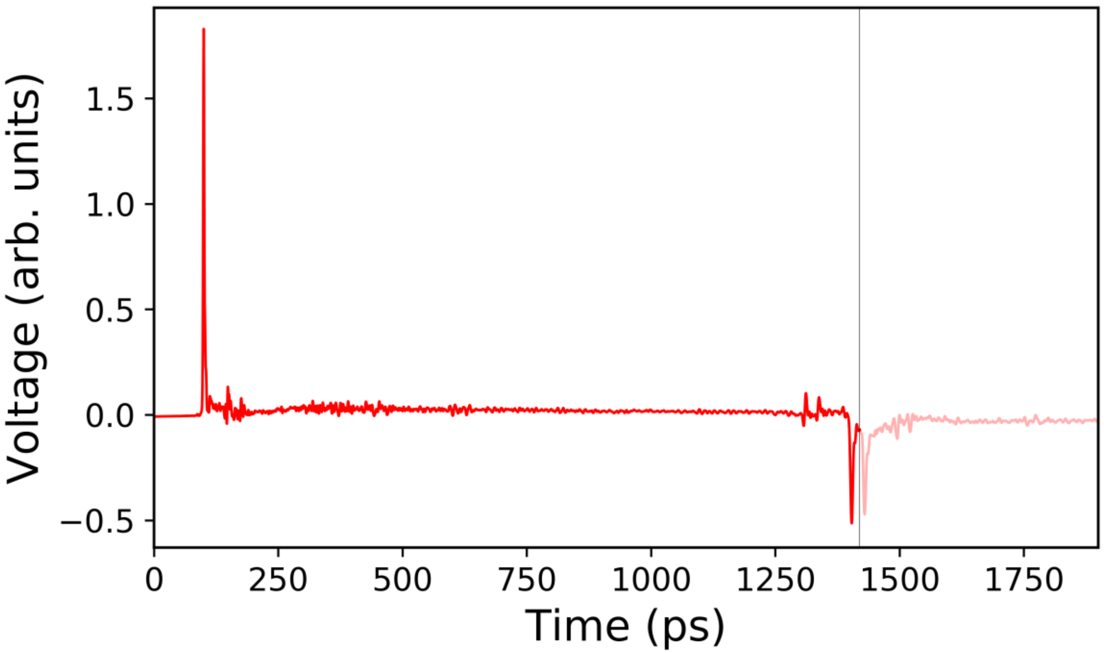


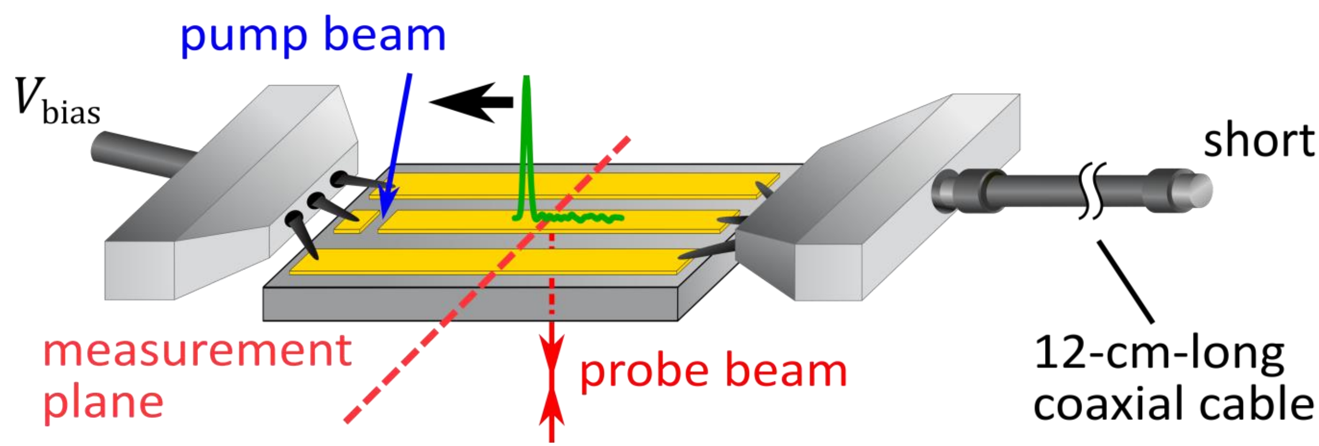
Ultrashort voltage pulses



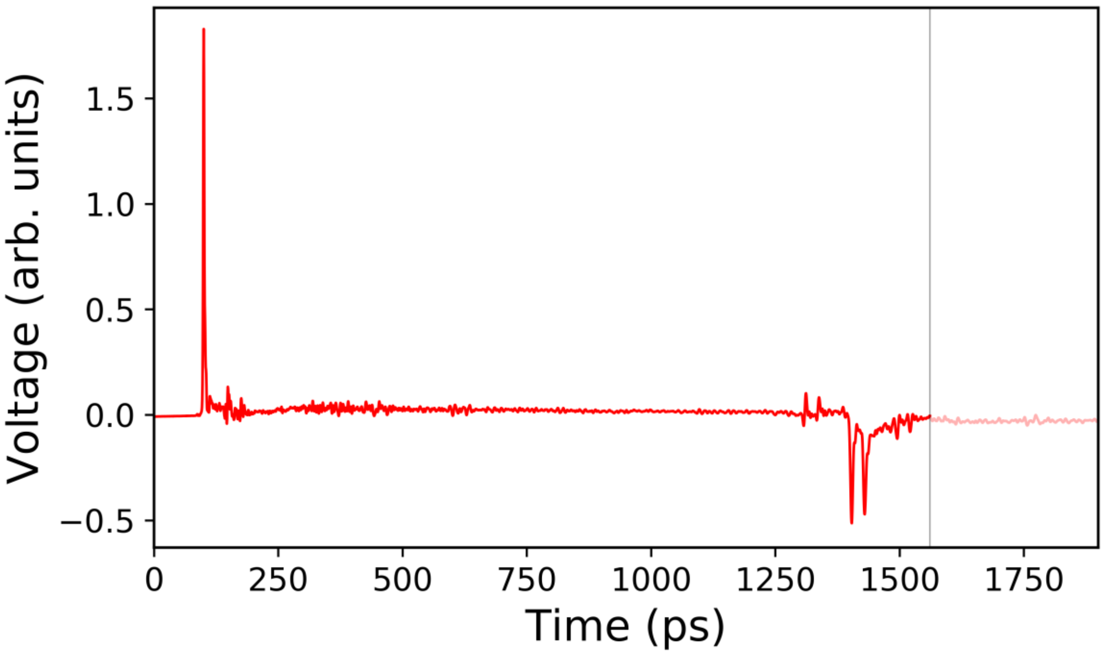


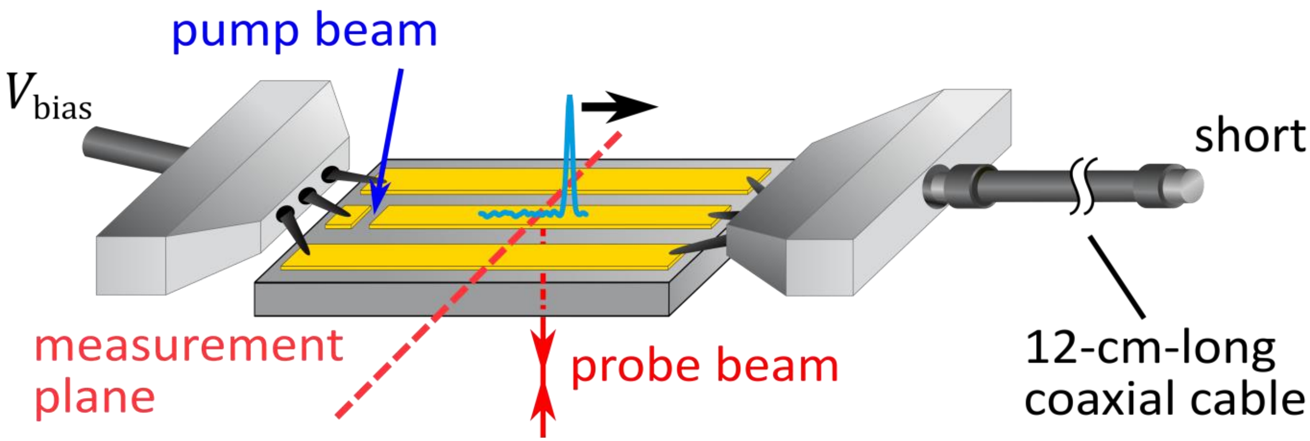
Ultrashort voltage pulses



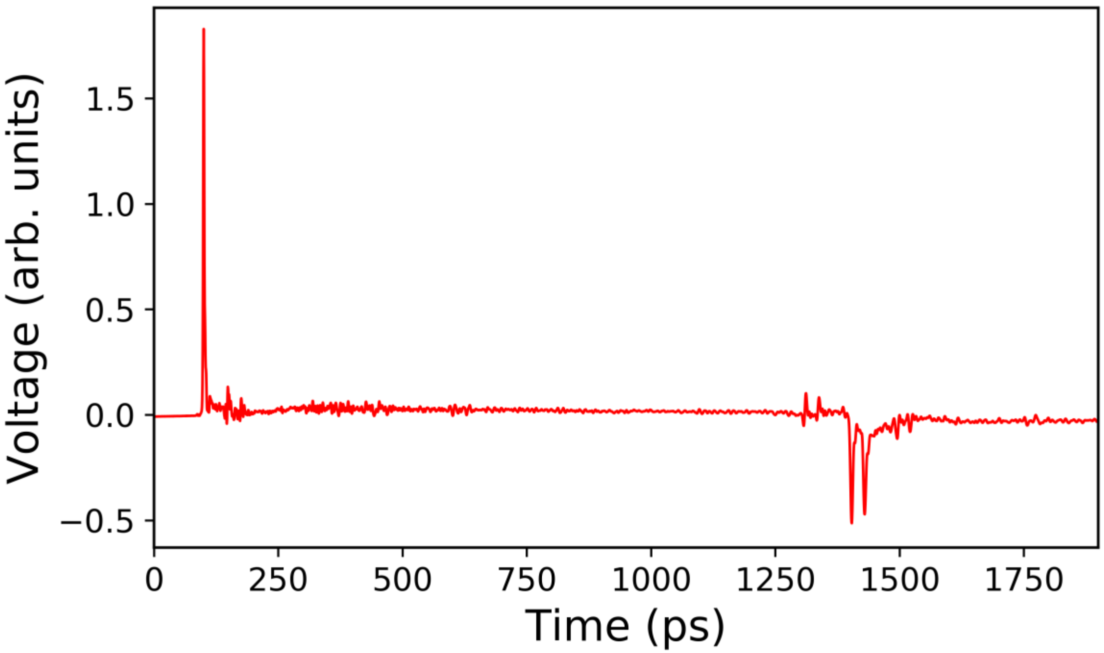


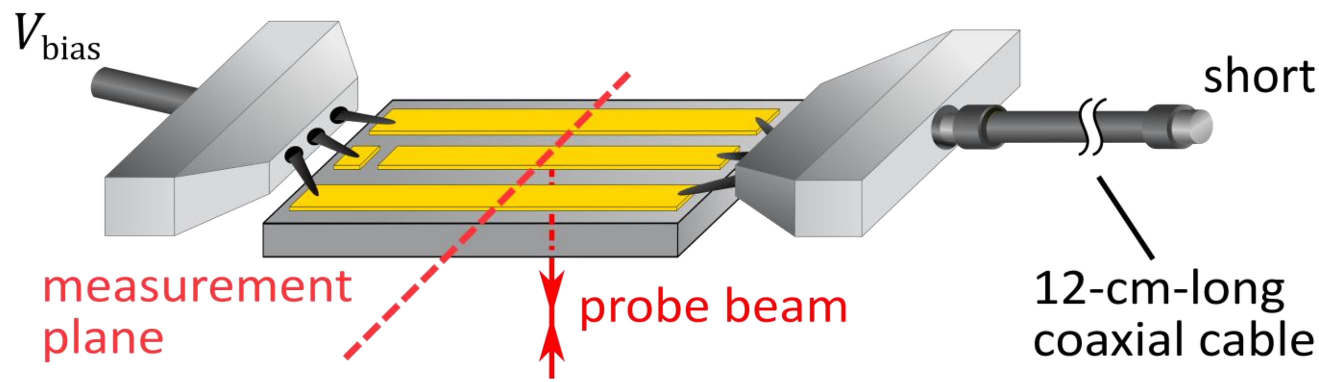
Ultrashort voltage pulses



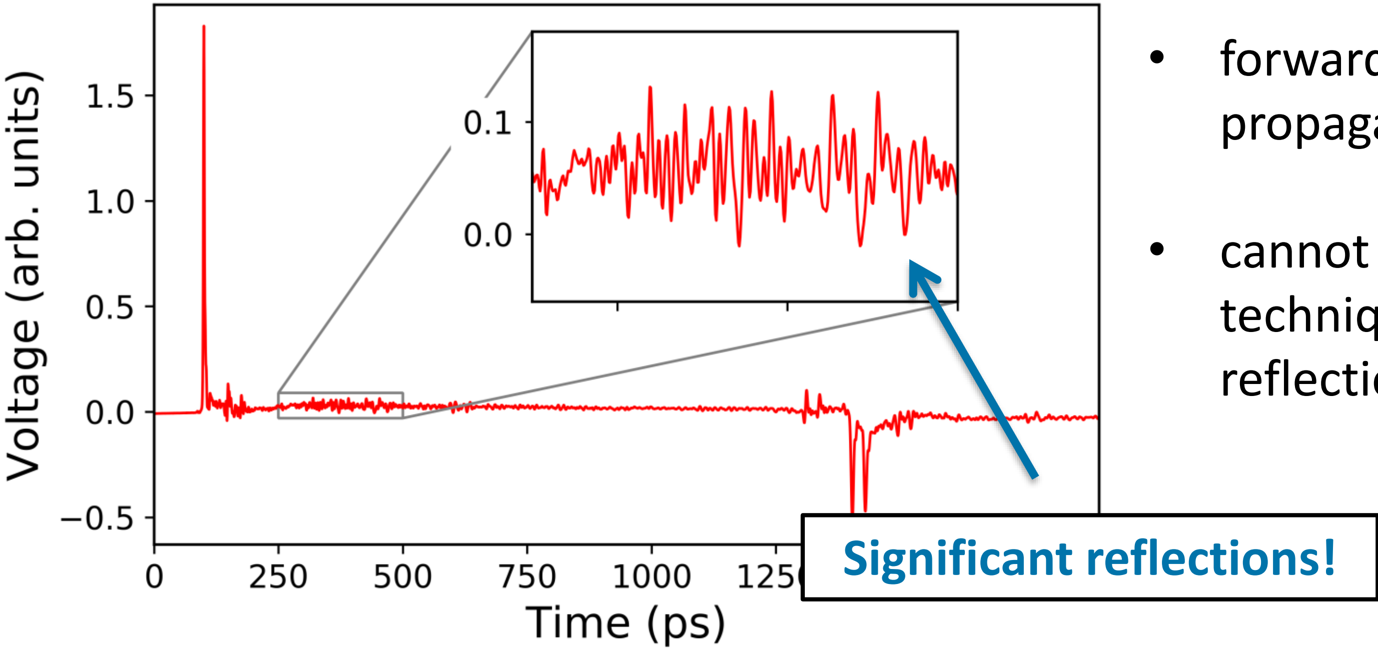


Ultrashort voltage pulses



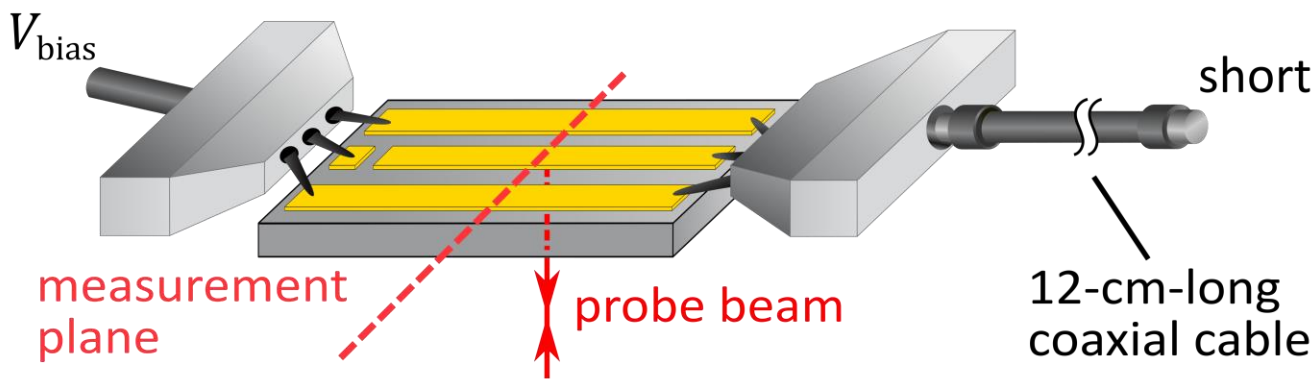


Ultrashort voltage pulses



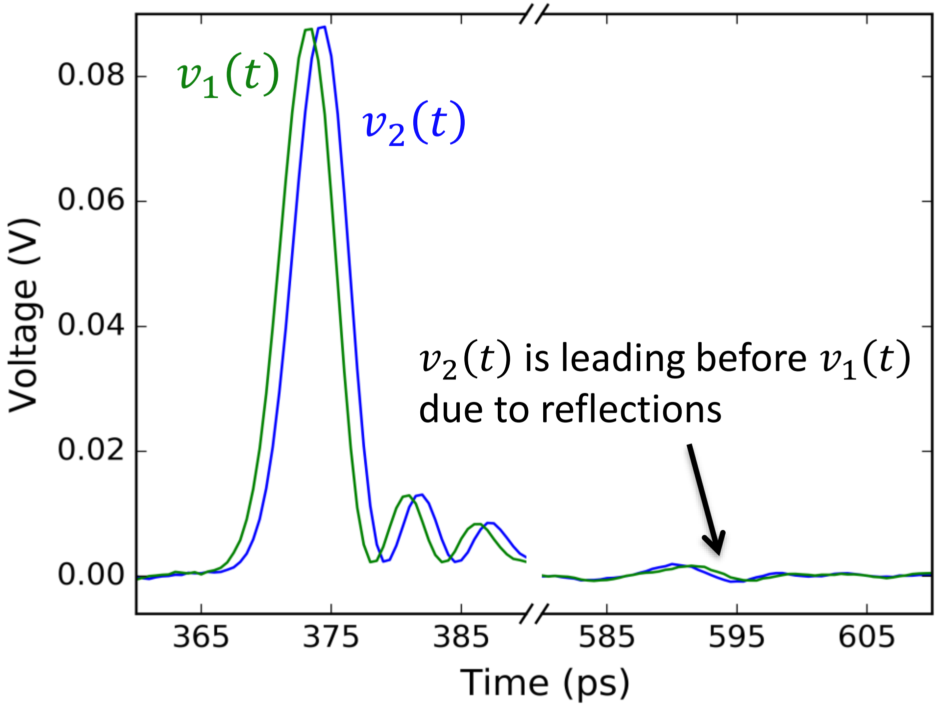
- forward and backward propagating signals overlap
- cannot use windowing techniques to determine reflections

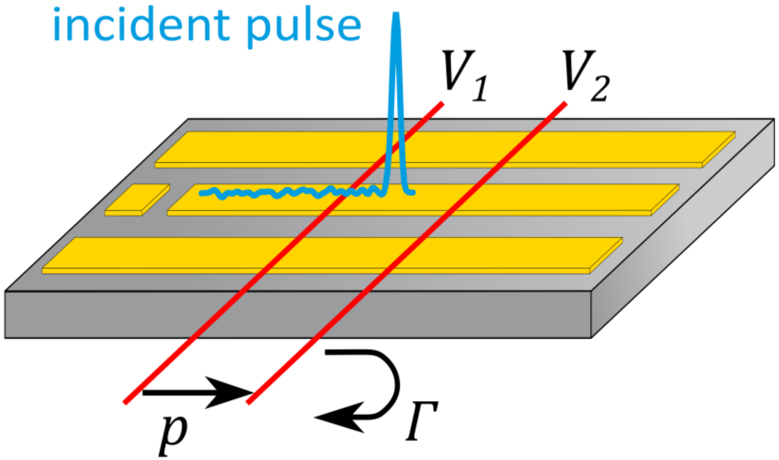
All devices have 50 Ω impedance!



Reflection coefficient

Method: determine reflection coefficient Γ by measuring voltage pulses at two positions on the CPW [1]





p : transfer function between V_1 and V_2

Γ: (spectral) reflection coefficient

[1] M. Bieler, H. Füser, and K. Pierz, "Time-Domain Optoelectronic Vector Network Analysis on Coplanar Waveguides," IEEE Transactions on Microwave Theory and Techniques, vol. 63, no. 11, pp. 3775–3784, Nov. 2015.

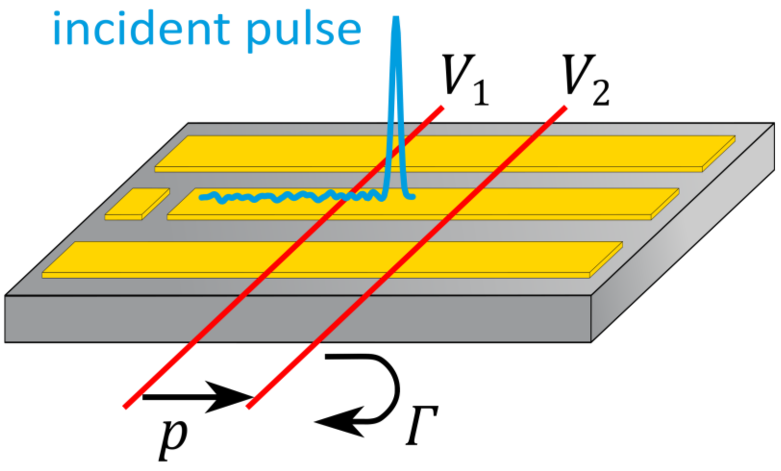
Reflection coefficient

1) Use the first 40 ps of the time traces to determine transfer function p

$$p(\omega) = \frac{V_{2,\mathrm{cut}}(\omega)}{V_{1,\mathrm{cut}}(\omega)}$$

2) Use the full time traces and p to determine Γ

$$\Gamma(\omega) = \frac{V_2 - pV_1}{p(V_1 - p\,V_2)}$$

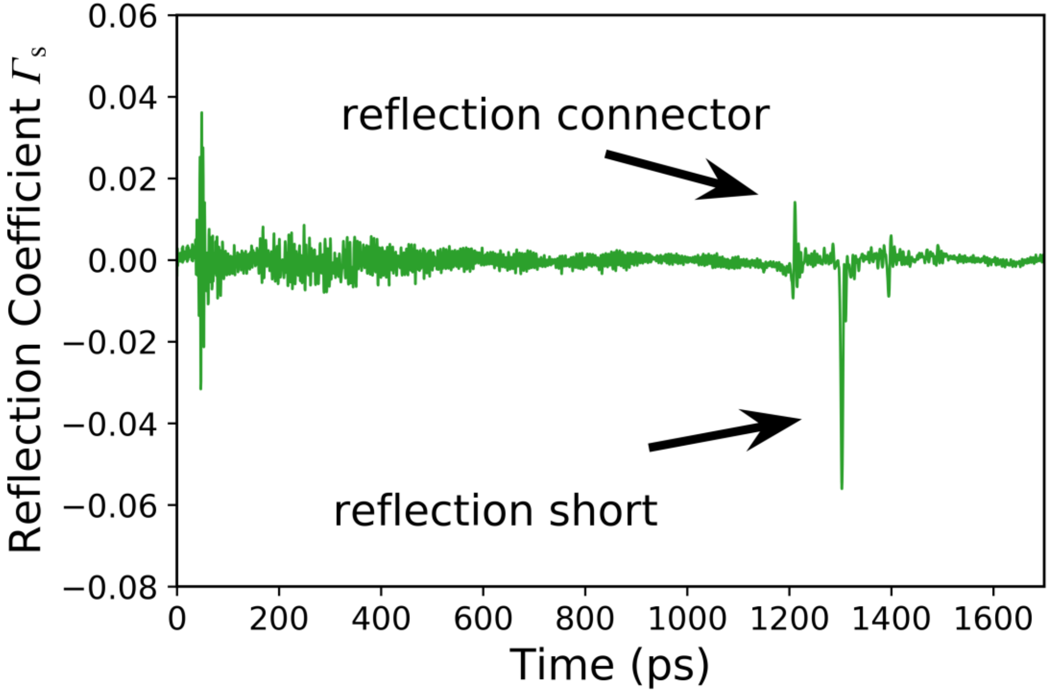


p : transfer function between V_1 and V_2

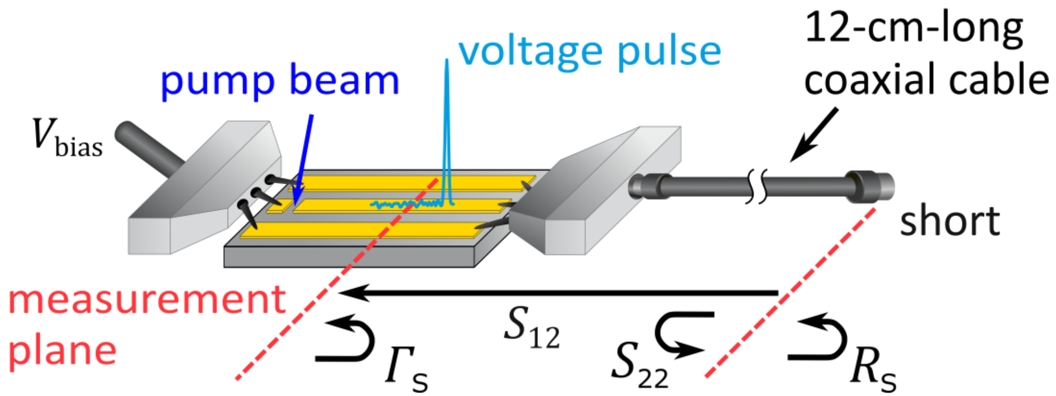
Γ: (spectral) reflection coefficient

Reflection coefficient

Termination with coaxial short

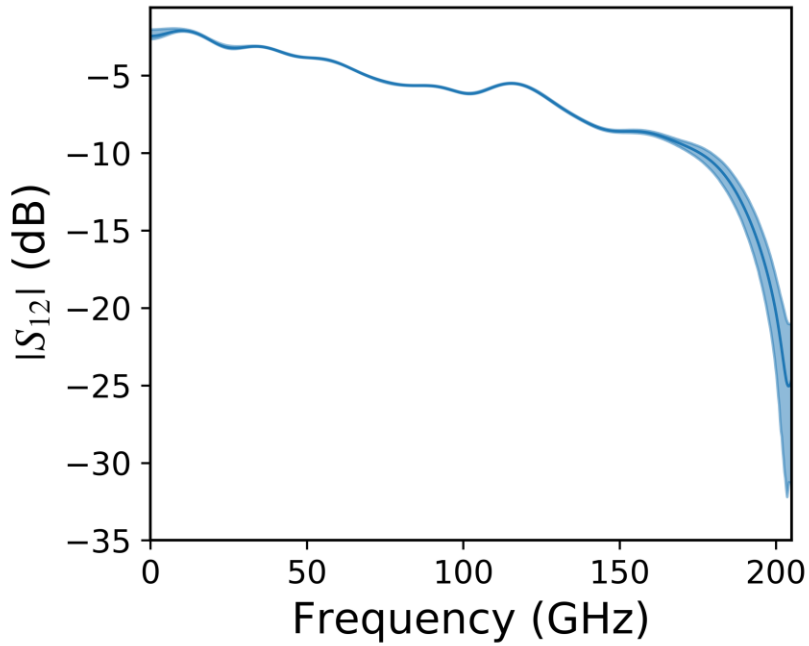


$$\Gamma_S(\omega) = S_{11} + \frac{S_{12}S_{21}R_S}{1 - R_S S_{22}}$$



Scattering parameter

S_{12} scattering parameter



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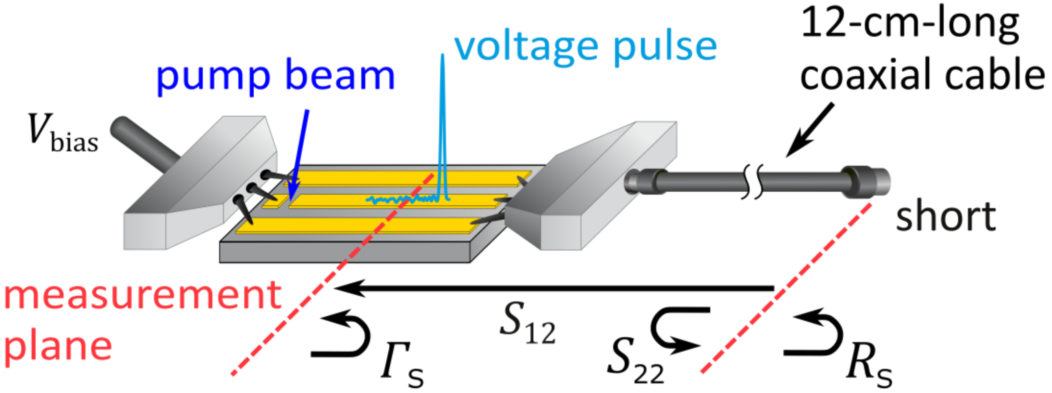
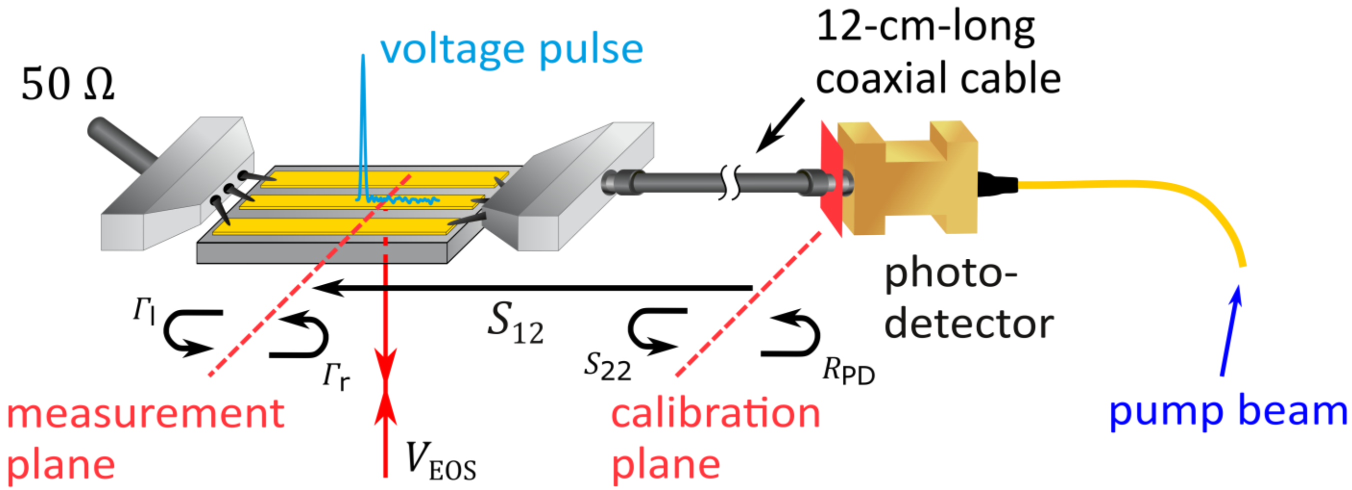


High-speed photodetector



$$V_{PD}(\omega) = \frac{V_{CPW}}{S_{12}\, Z_R\, H_{EOS}} \frac{(1 - \Gamma_r \Gamma_l)(1 - S_{22} R_{PD})}{1 + \Gamma_l}$$

Γ_l, Γ_r : Reflection coefficients

S_{12}, S_{22} : Scattering parameter

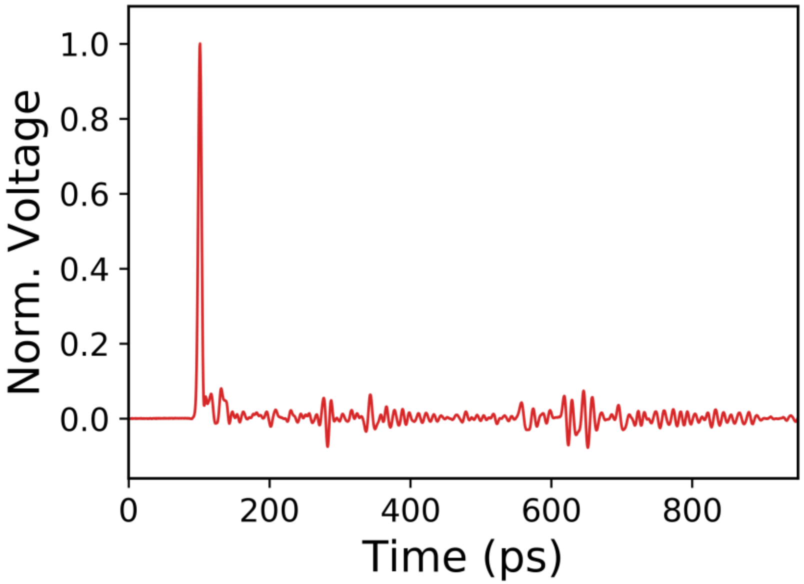
H_{EOS} : EOS transfer function

Z_R : Impedance ratio (CPW, coax)

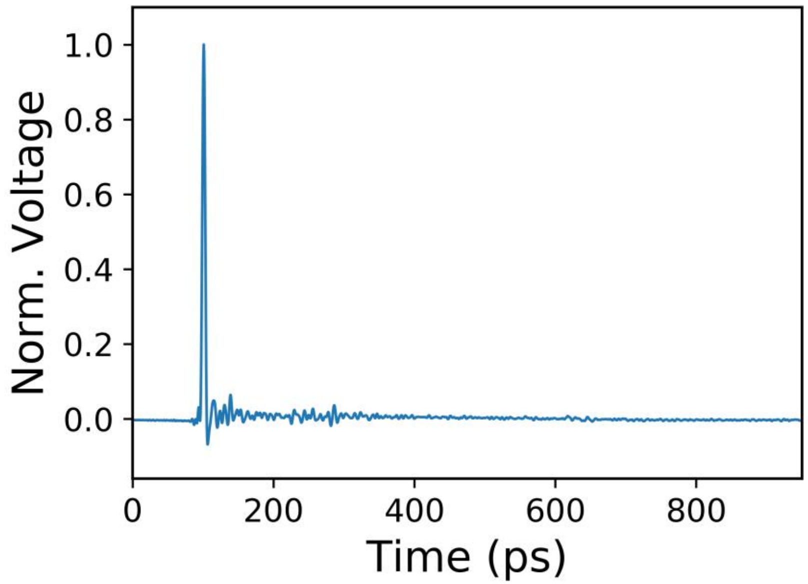
High-speed photodetector

Example: 100 GHz photodetector

Measured voltage V_{CPW}



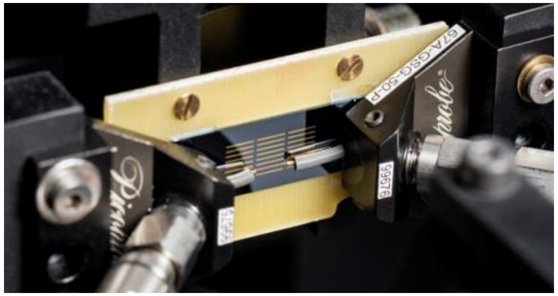
Photodetector response V_{PD}



Outline

Experimental basics

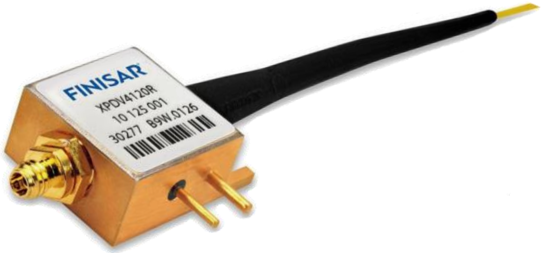
- Electro-optic sampling
- Ultra-short voltage pulses



Characterization of high-speed photodetector

- Reflection coefficient
- Scattering parameters
- High-speed photodetector

Portable voltage pulse standard

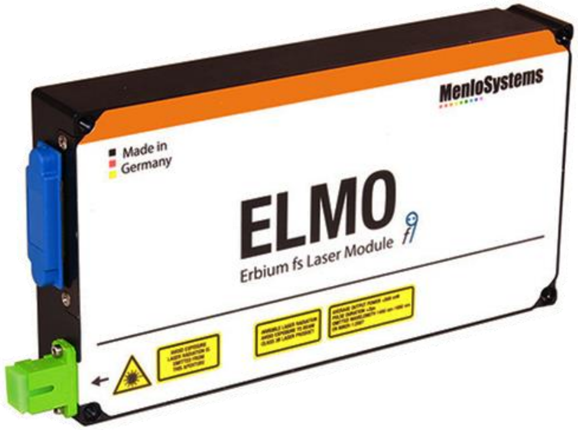


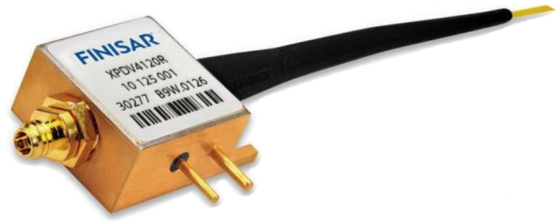
https://www.finisar.com/optical-components/xpdv412xr

Portable pulse standard

Portable femtosecond fiber laser (at 1550 nm)

Characterized high-speed photodetector (70 or 100 GHz)

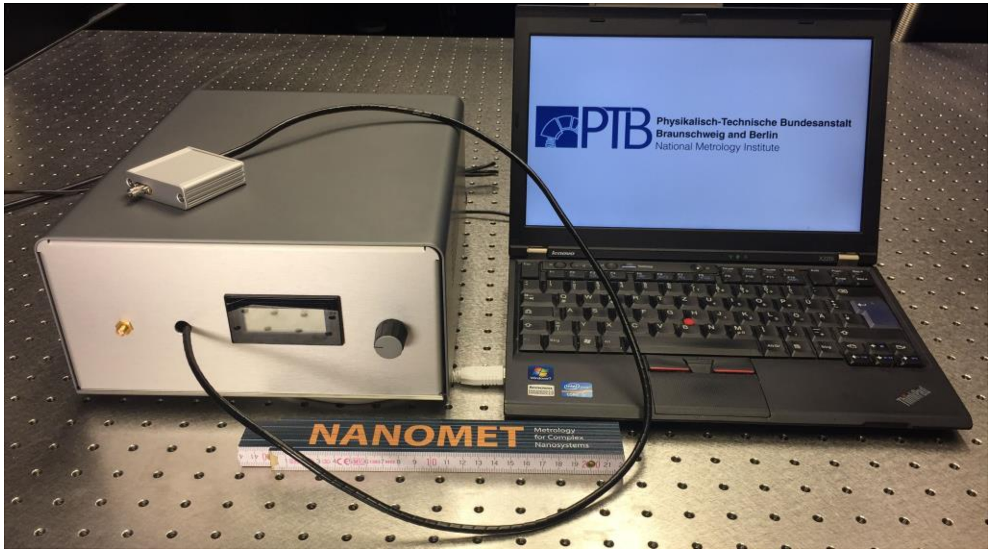




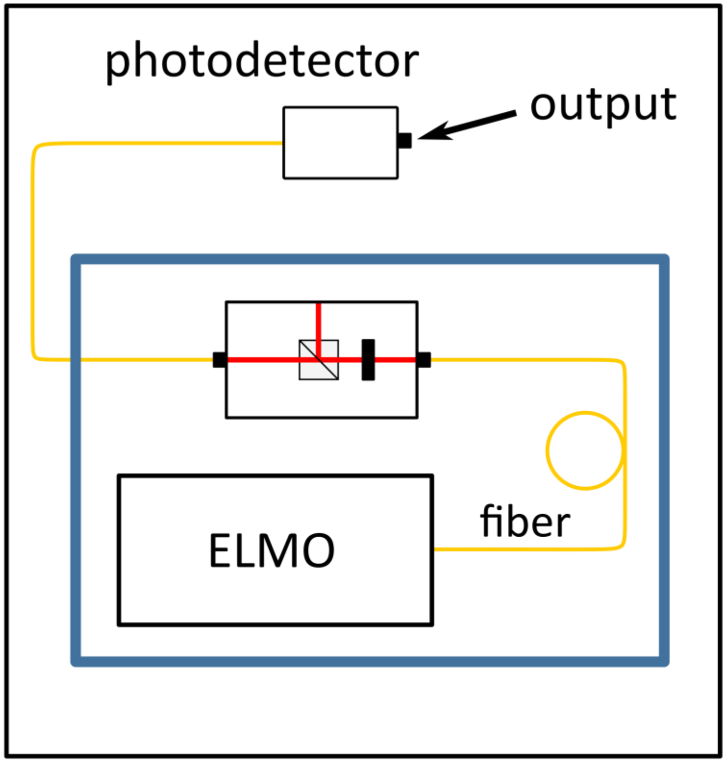
(Dimension: 195 x 95 x 28 mm³)

Portable pulse standard

Device:



Setup:



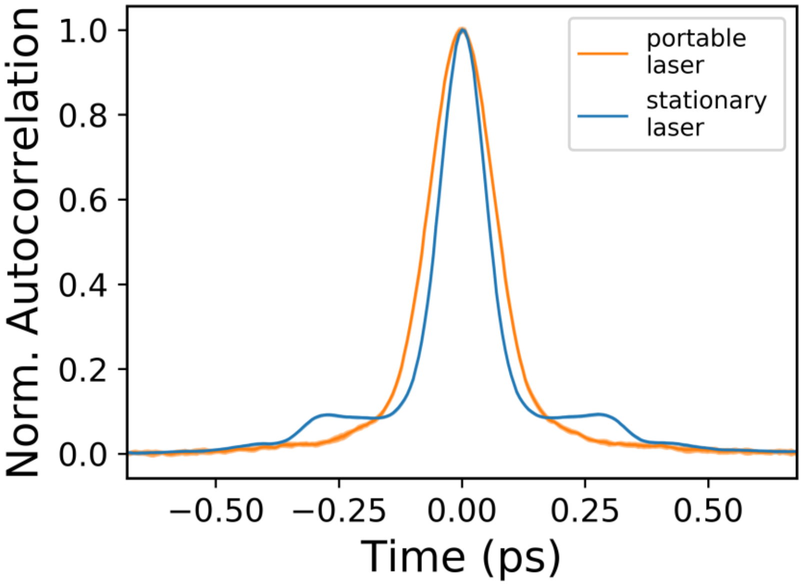
(without electrical connections)

Footprint	250 × 300 mm^2
Photodetector head dimensions	55 x 53 x 16 mm^3

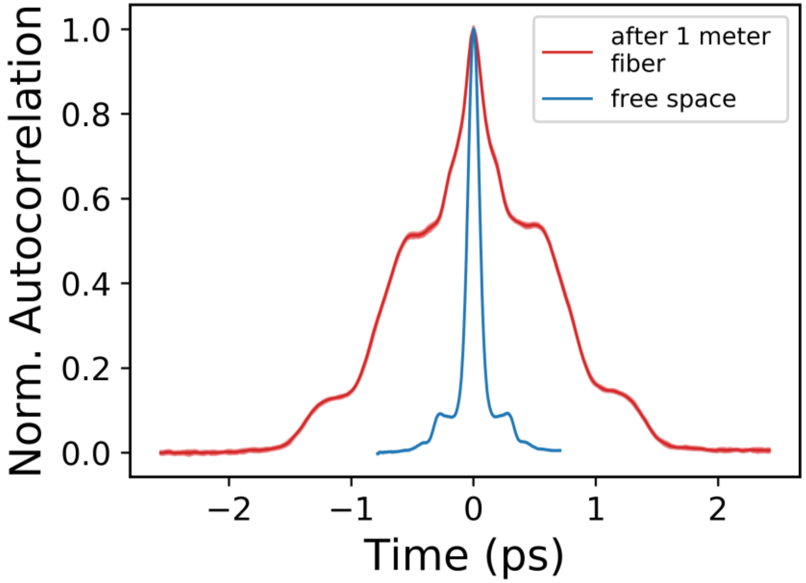
Portable pulse standard

Laser pulse characterization:

Compare optical pulse widths of stationary laser and portable laser

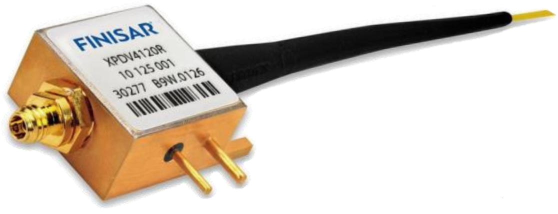


Consider optical pulse broadening through the PD's one-meter long fiber

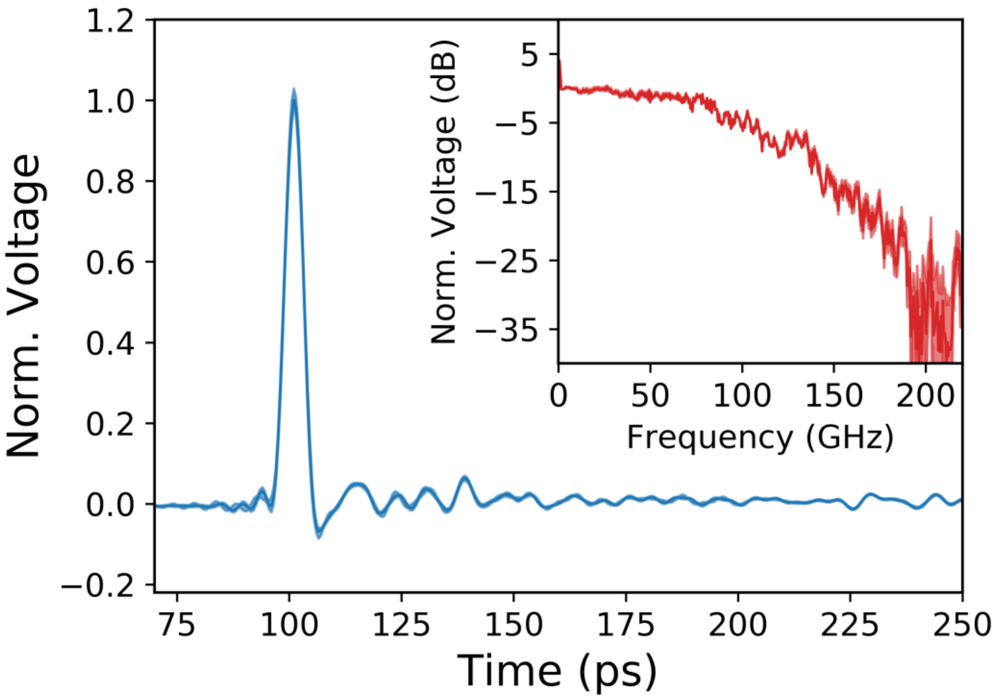


Portable pulse standard

High-speed photodetector
(nominal bandwidth 100 GHz)



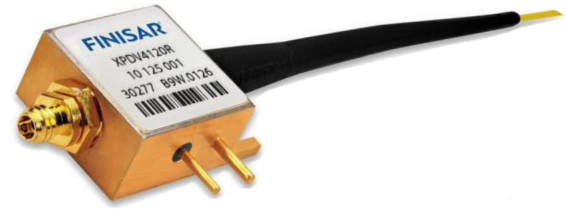
(XPDV4120R, u2t/Finisar)



- pulse width: 4.6 ps
- flat spectrum up to 130 GHz
- frequency components up to ~180 GHz

Portable pulse standard

High-speed photodetector
(nominal bandwidth 100 GHz)



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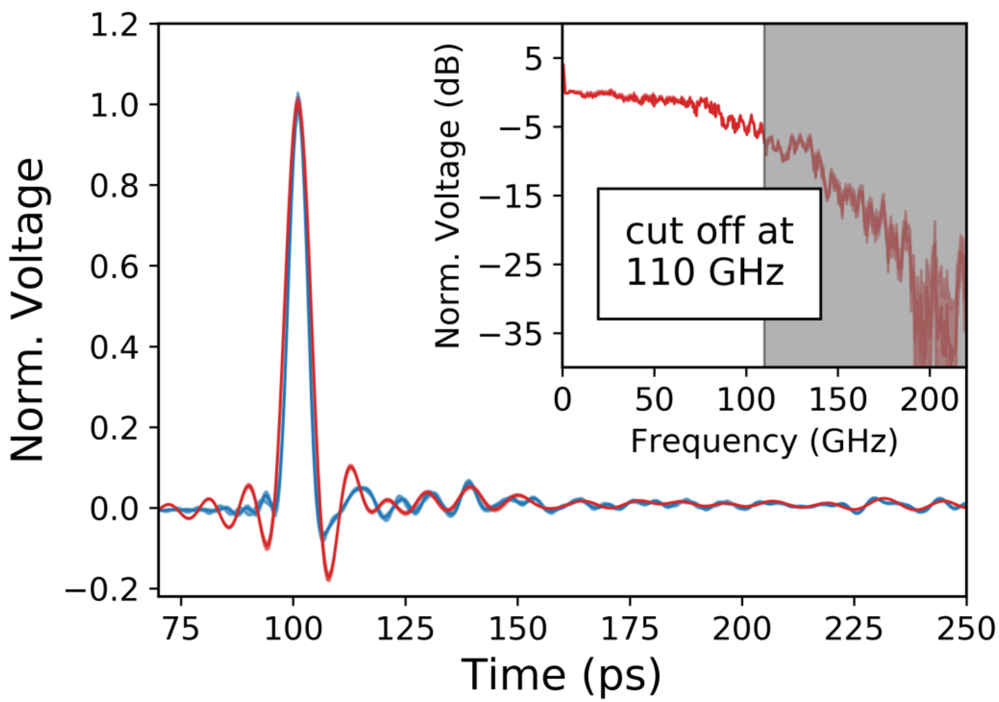


- pulse width: 4.6 ps
- flat spectrum up to 130 GHz
- frequency components up to ~180 GHz

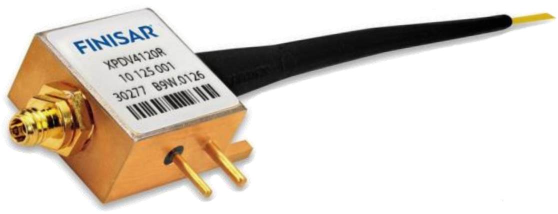
- cut-off at 110 GHz leads to significant changes in the time-domain response (pulse width: 5.9 ps)

Summary and Outlook

- EO measurements at different positions on a planar waveguide to determine reflection coefficients
- Characterization of a high-speed photodetector including full mismatch correction
- Demonstration of a portable pulse standard with pulse width of 4.6 ps

Next steps:

- Integrate a microcontroller into the device to simplify the handling
- PD comparison among different National Metrology Institutes
(results by the end of this year)



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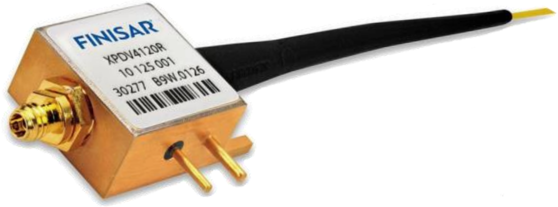
Thanks to …

PTB



Finisar corporation (Andreas Umbach
And Andreas Steffan)

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Programme of EURAMET

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