Karlsruhe Institute of Technology

Zero-biased YBCO detectors for the real-time observation of coherent synchrotron radiation

KSETA Plenary Workshop, 13-15 February 2017, Durbach

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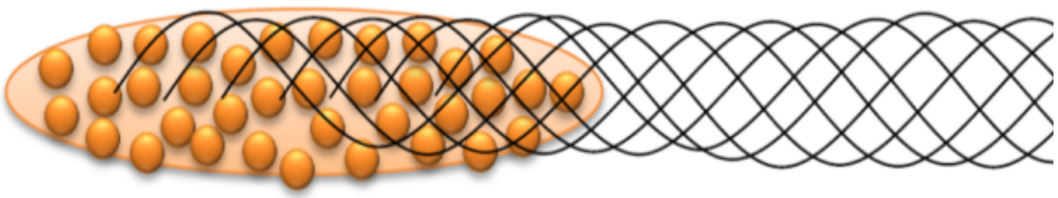
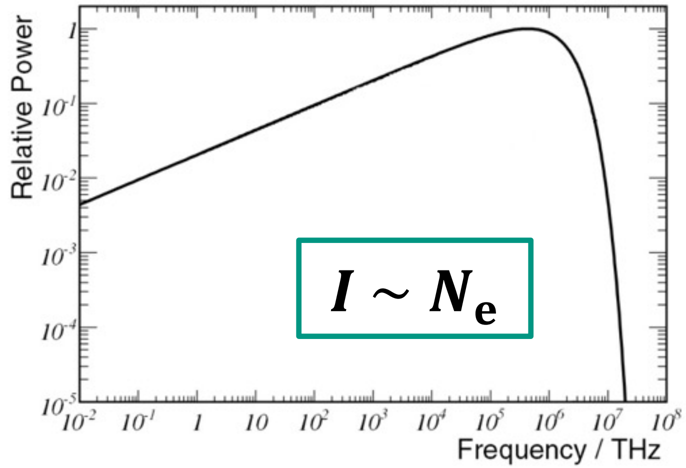
Outline

- Coherent Synchrotron Radiation & THz detectors
- $YBa_2Cu_3O_{7-x}$ detection system
- Direct detection of Coherent Synchrotron Radiation
- Single-shot THz spectroscopy
- Conclusions

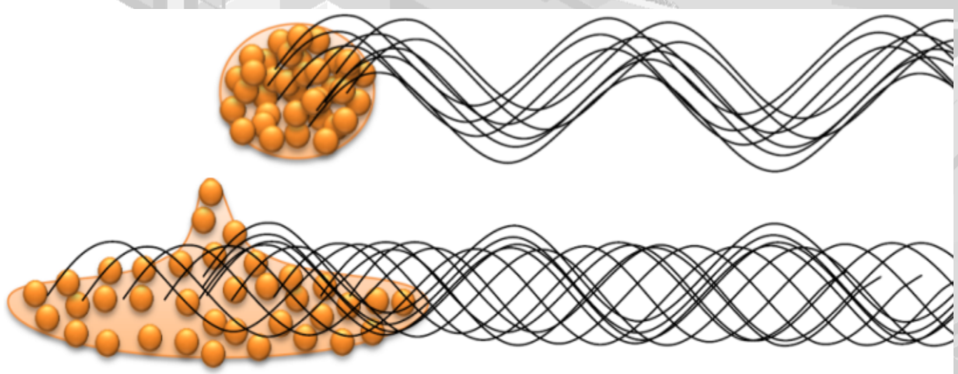
Coherent Synchrotron Radiation & THz detectors
Pulsed THz radiation from synchrotrons

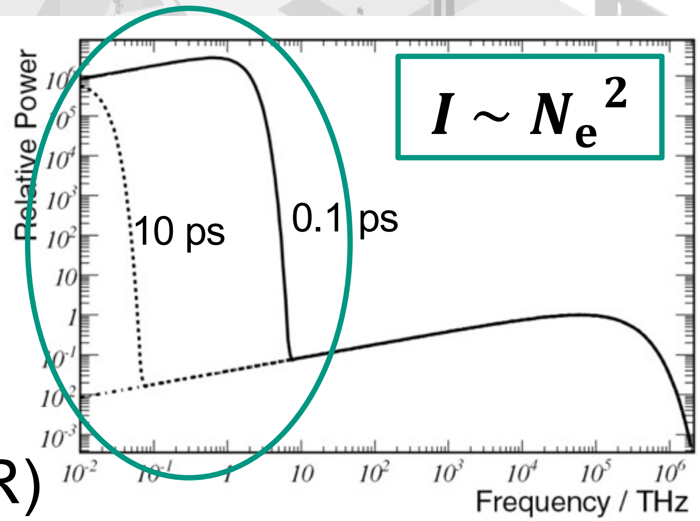
Electron bunch length >> λ





Electron bunch length ≤ λ



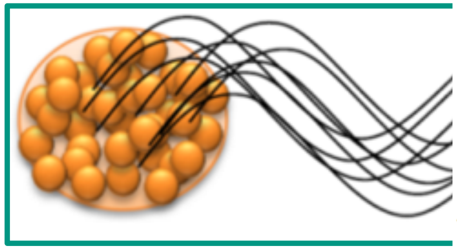


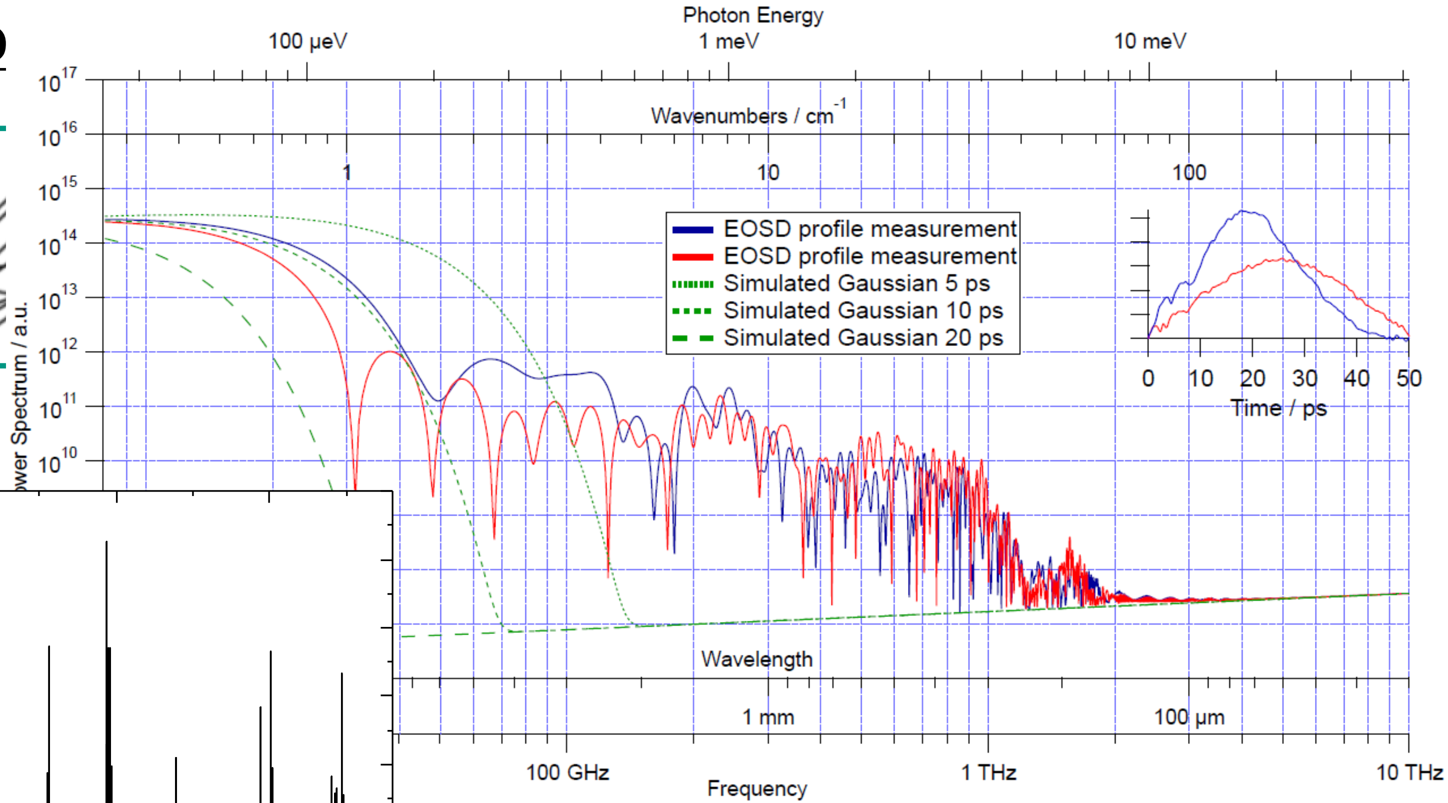
Coherent Synchrotron Radiation (CSR)

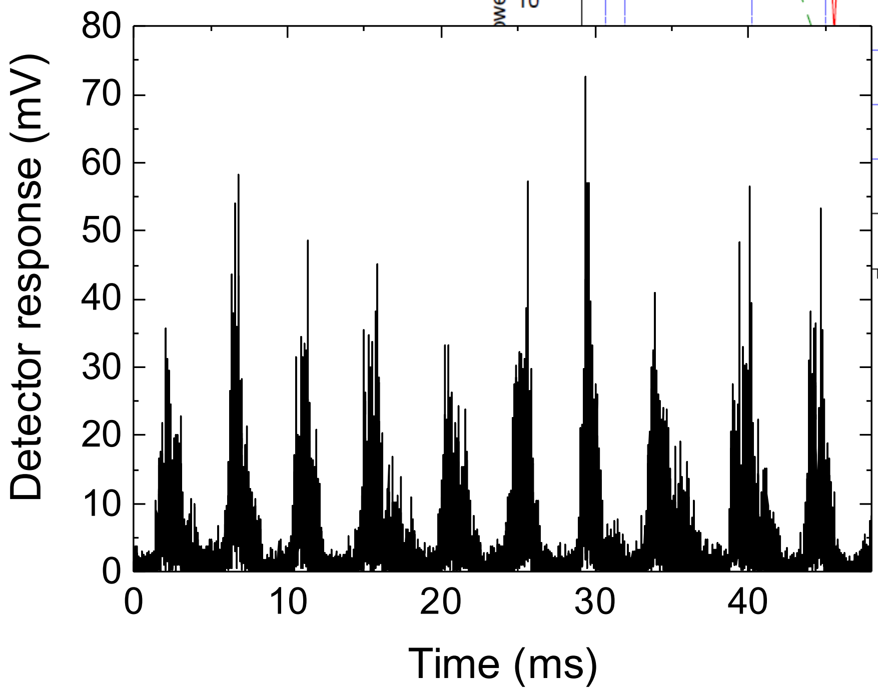
A.-S. Müller, Rev. of Acc. Sc. Tech. 3 (2010)

Coherent Synchrotron Radiation & THz detectors
Bursting CSR in low-alpha mode

Low-alpha mo

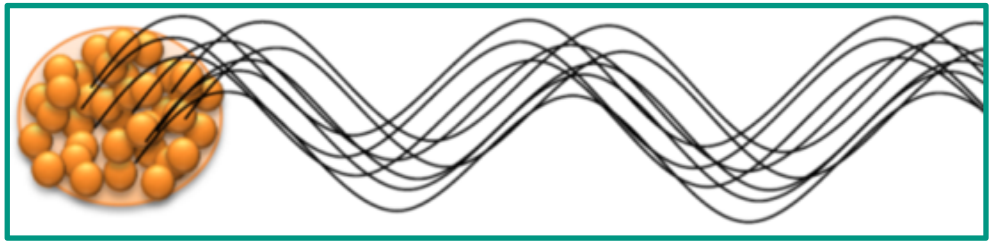


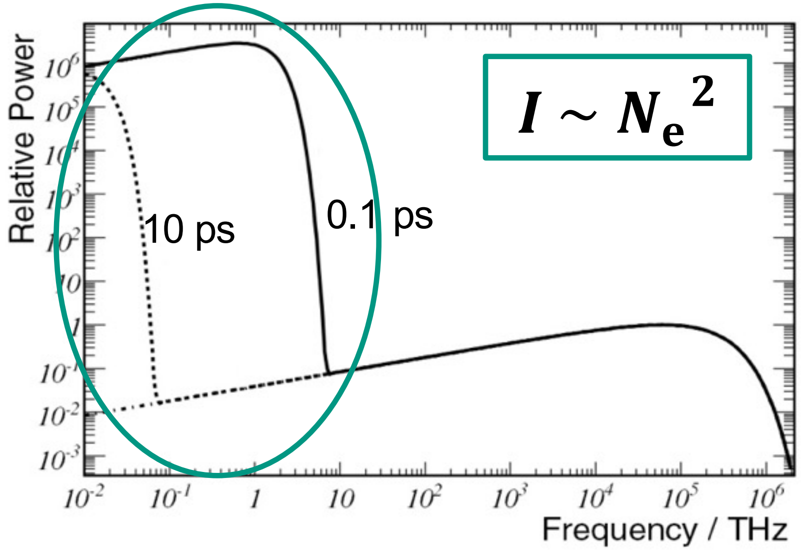




Turn-by-turn analysis of **pulse shape**

Coherent Synchrotron Radiation & THz detectors
Detector requirements





A.-S. Müller, Rev. of Acc. Sc. Tech., 3 (2010)

- Pulse widths down to 1 ps
  Repetition rate up to 1 GHz
- Variation of THz intensity

↓

- **Ultra-fast response**
- Large dynamic range
- High **sensitivity**
  → **sub-µm** detector

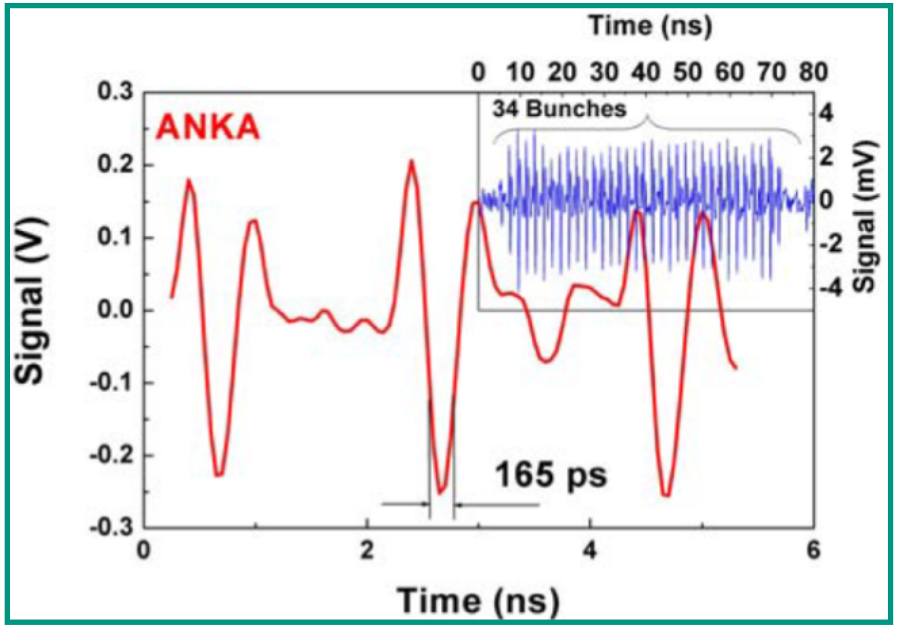
- Frequency range: 0 - 2 THz

↓

- **Broadband** THz antenna or antenna array

Coherent Synchrotron Radiation & THz detectors
Direct THz detectors for CSR

- Helium-cooled Si, Ge or InSb bolometers:
  - Response time: µs – ms
- Superconducting NbN HEB:
  - Response time: ~ 100 ps



A. D. Semenov *et al.*, Proc. of IRMMW-THz, (2009)

- Schottky diodes
  - Response time: ~ 20 ps
  - Limited in dynamic range, frequency dependent

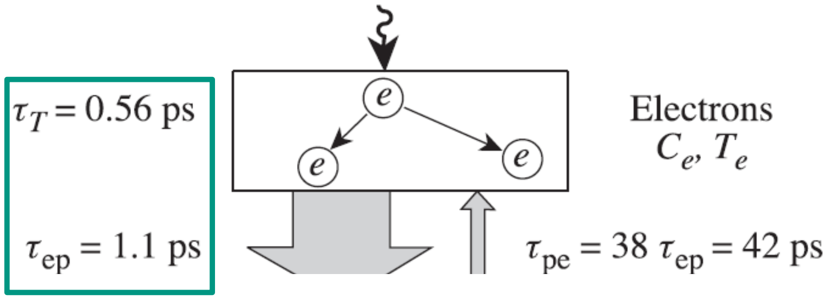
A. D. Semenov *et al.*, Proc. of IPAC, THPME097 (2014)

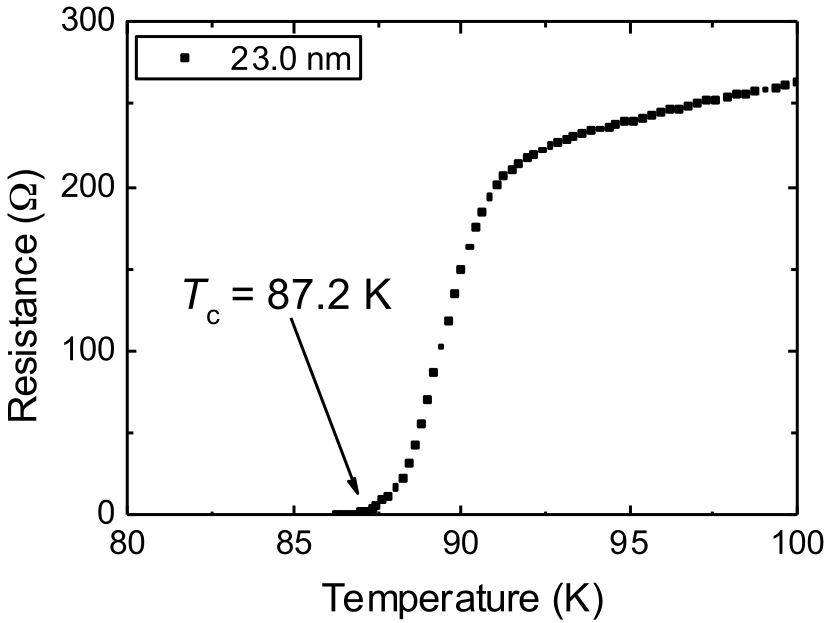
Coherent Synchrotron Radiation & THz detectors
Instrinsic response times in $YBa_2Cu_3O_{7-x}$ (YBCO)

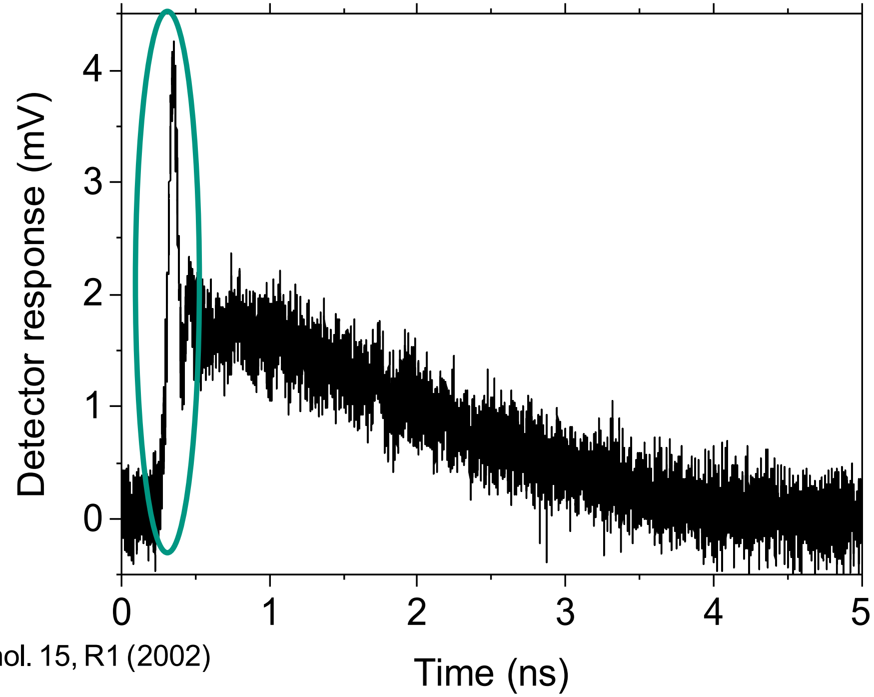
- High T_c
- Superconducting energy gap 2Δ

$$2\Delta(0) \approx 20\ \mathrm{meV}$$

- Above gap excitations







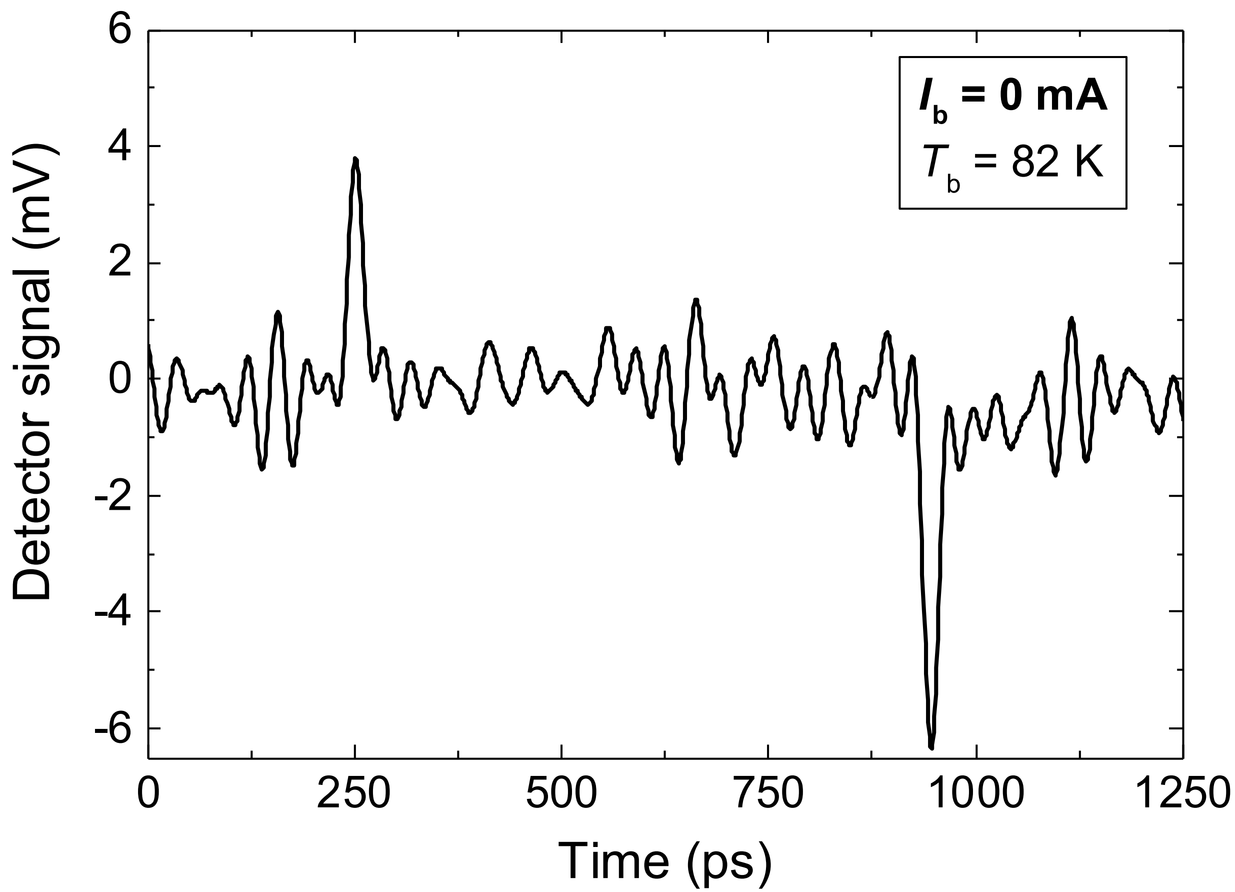
G. Deutscher, Rev. of Mod. Phys. 77(1), 109(27) (2005)
A.D. Semenov, G.N. Gol'tsman, R. Sobolewski, Supercond. Sci. Technol. 15, R1 (2002)
P. Probst *et al.*, Phys. Rev. B 85, 174511 (2012)

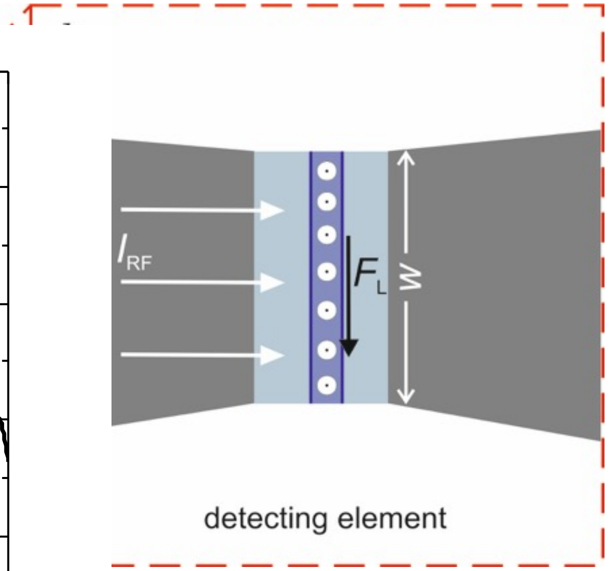
Coherent Synchrotron Radiation & THz detectors
YBCO: Electrical-field sensitive THz detector

$2\Delta(0) \approx 20\ \text{meV}$
$1\ \text{THz} \triangleq 4.1\ \text{meV}$

$\hbar\omega < 2\Delta$

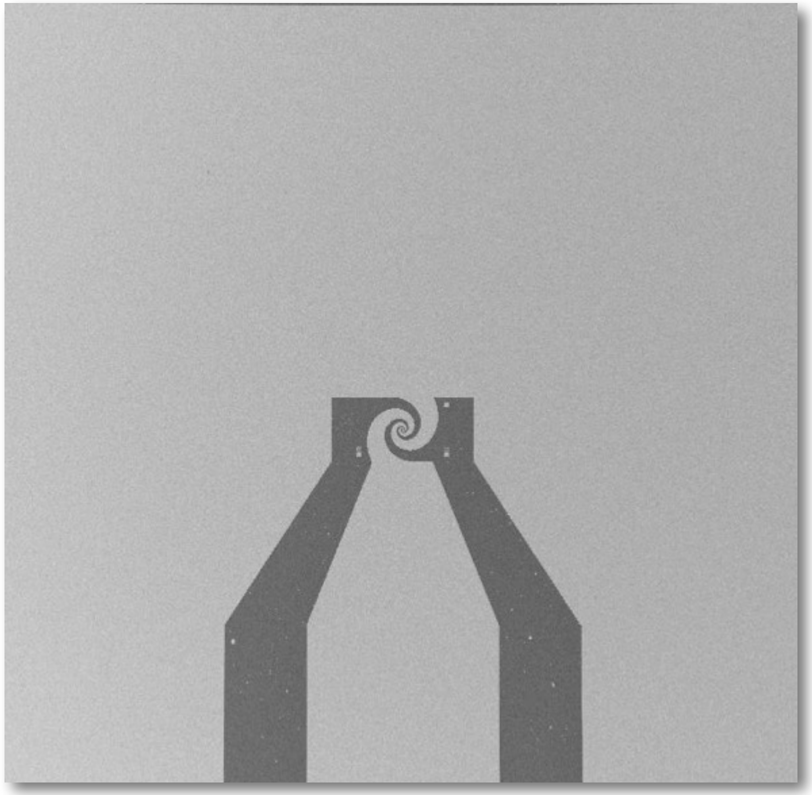
$I_{\text{bias}} = 0$

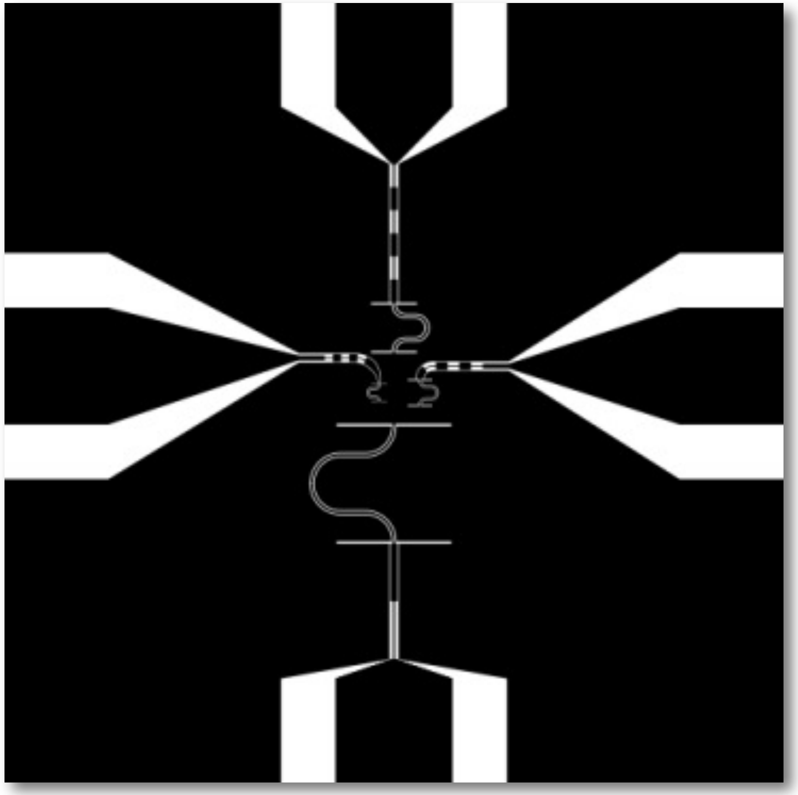




$YBa_2Cu_3O_{7-x}$ detection system
Approaches to the resolution of the bunch shape

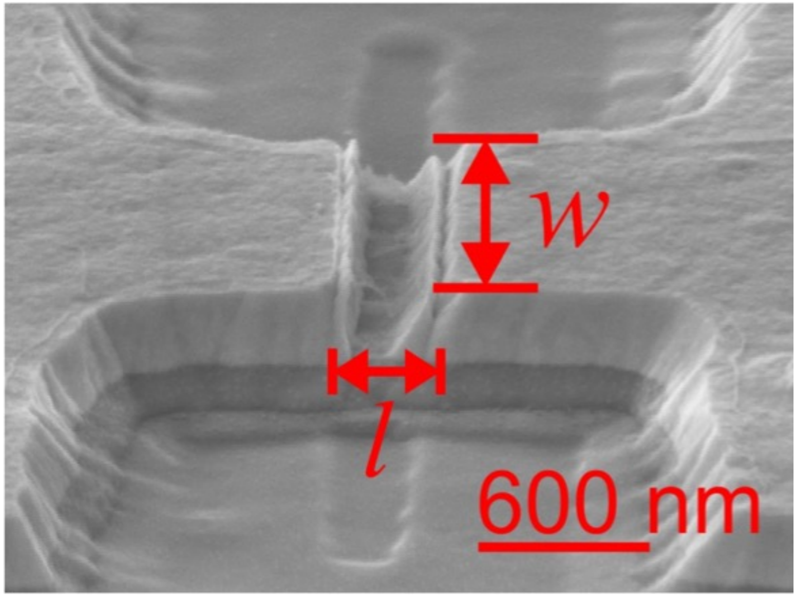
- Concept 1: Direct single-shot detection with broadband planar antenna
- Concept 2: Single-shot THz spectroscopy with integrated 4-pixel antenna array





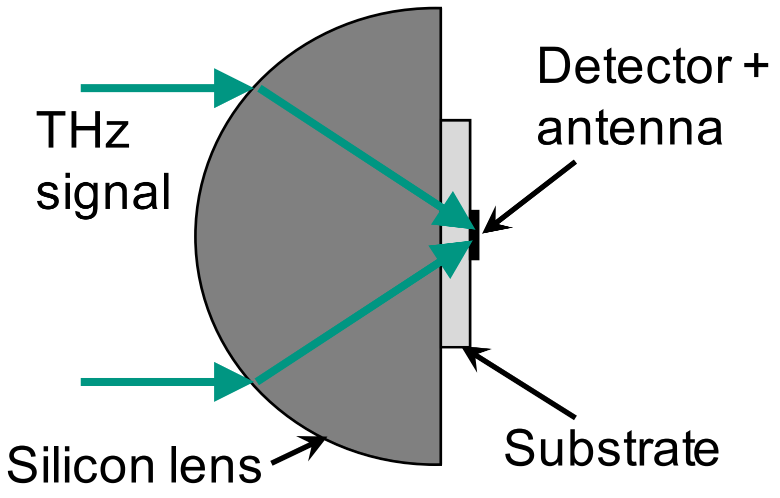
$YBa_2Cu_3O_{7-x}$ detection system
Thin-film deposition and detector patterning

Thin-film fabrication	Pulsed-Laser Deposition & DC-magnetron sputtering
Length of detecting element	Electron-beam lithography (EBL) Ion-beam (IBE)
Antenna & coplanar design	EBL & IBE

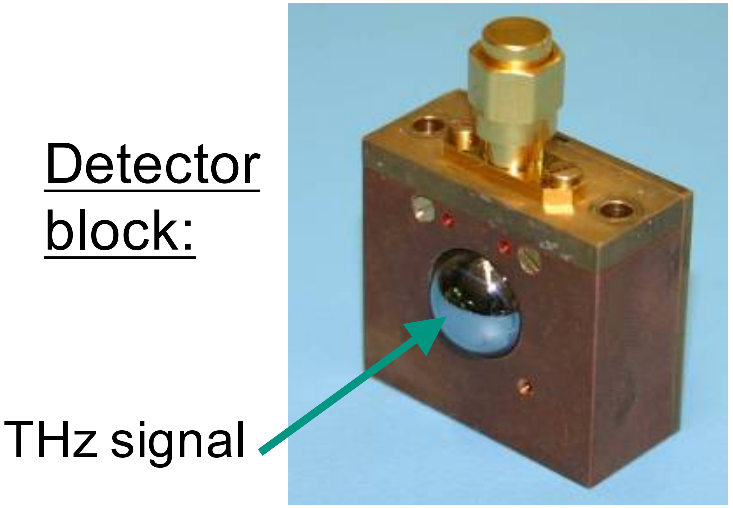


$YBa_2Cu_3O_{7-x}$ detection system
Hybrid antenna concept

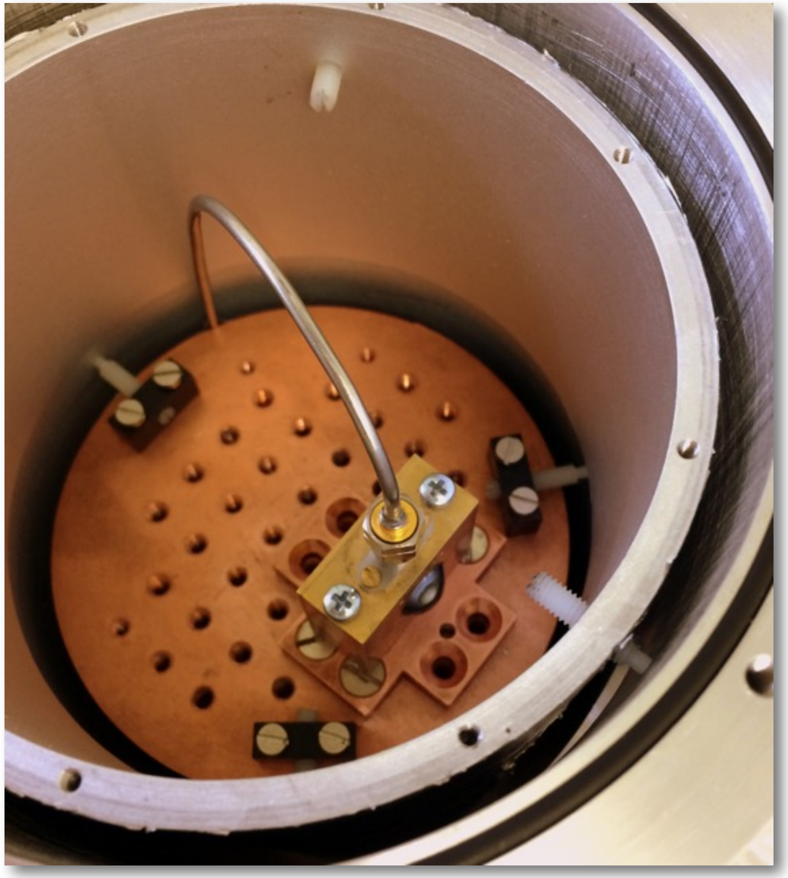
- Integrated lens antenna:



Detector block:

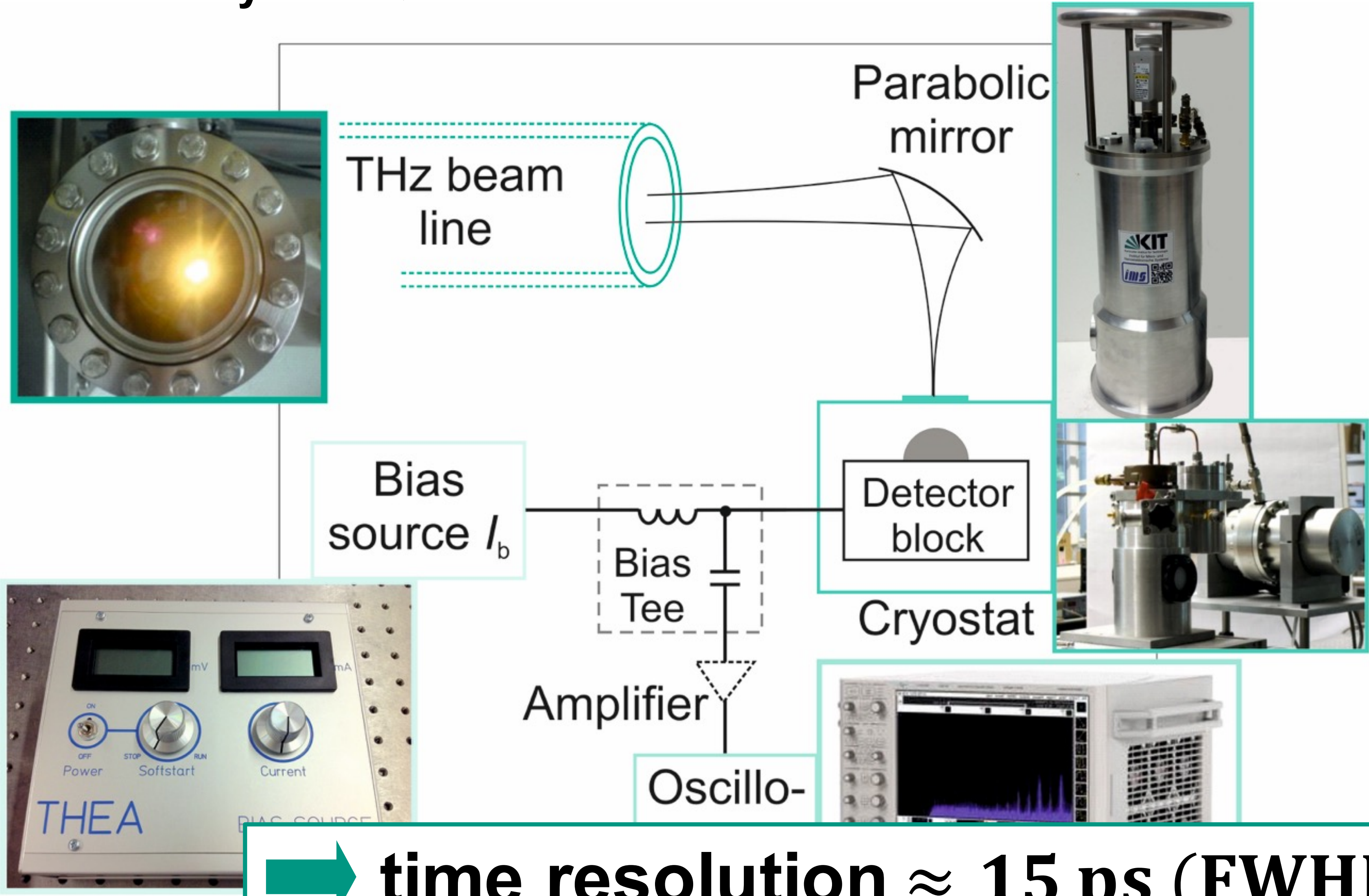


- Integration into cryostat:



P. Probst *et al.*, Phys. Rev. B 85, 174511 (2012)

$YBa_2Cu_3O_{7-x}$ detection system
Detection system & readout



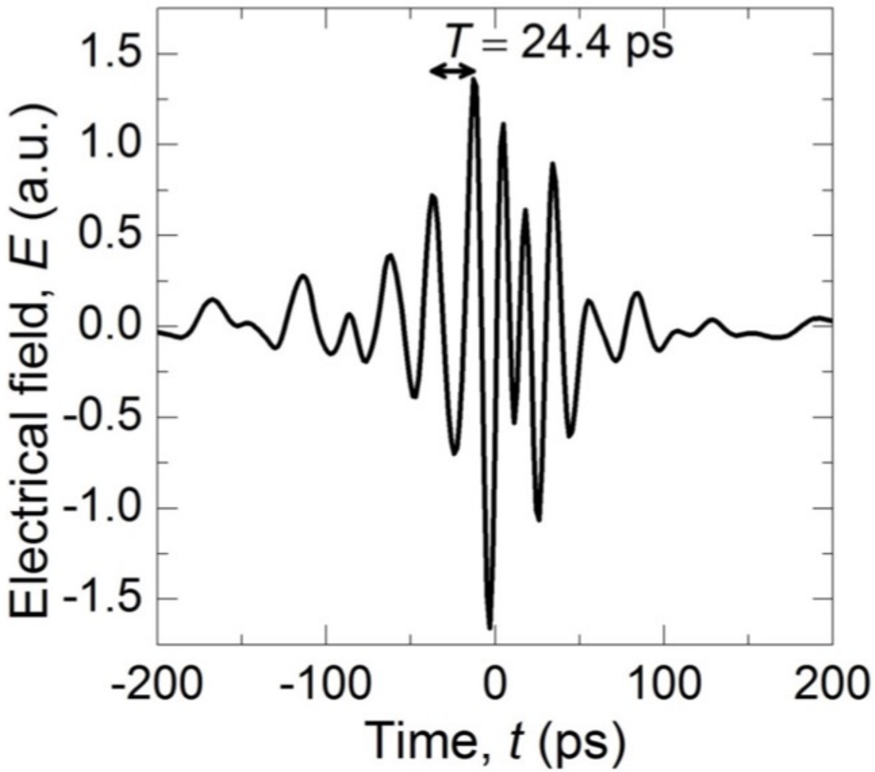
➡ time resolution ≈ 15 ps (FWHM)

P. Probst *et al.*, Appl. Phy

Direct detection of CSR Microbunching at UVSOR-III (I)

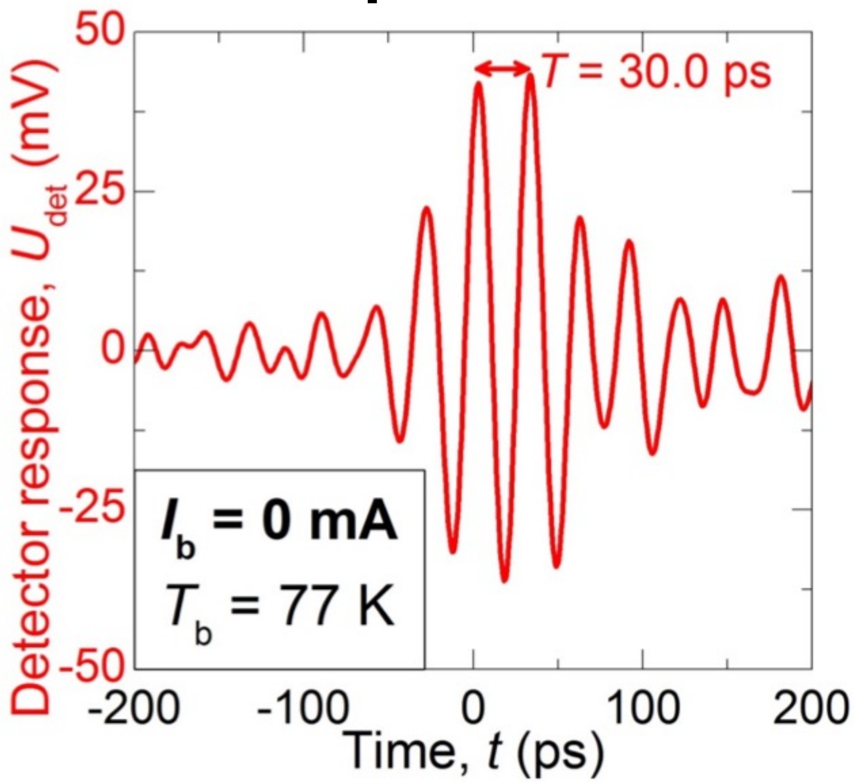
- Spontaneous CSR in microbunch
- Simulation of temporal evolution of the bunch

Simulation



E. Roussel *et al.*, Phys. Rev. Lett., 113, 094801 (2014)

Experiment



J. Raasch *et al.*, IEEE Trans. on Appl. Supercond. 25, 3 (2015)

Direct detection of CSR Microbunching at UVSOR-III (I)

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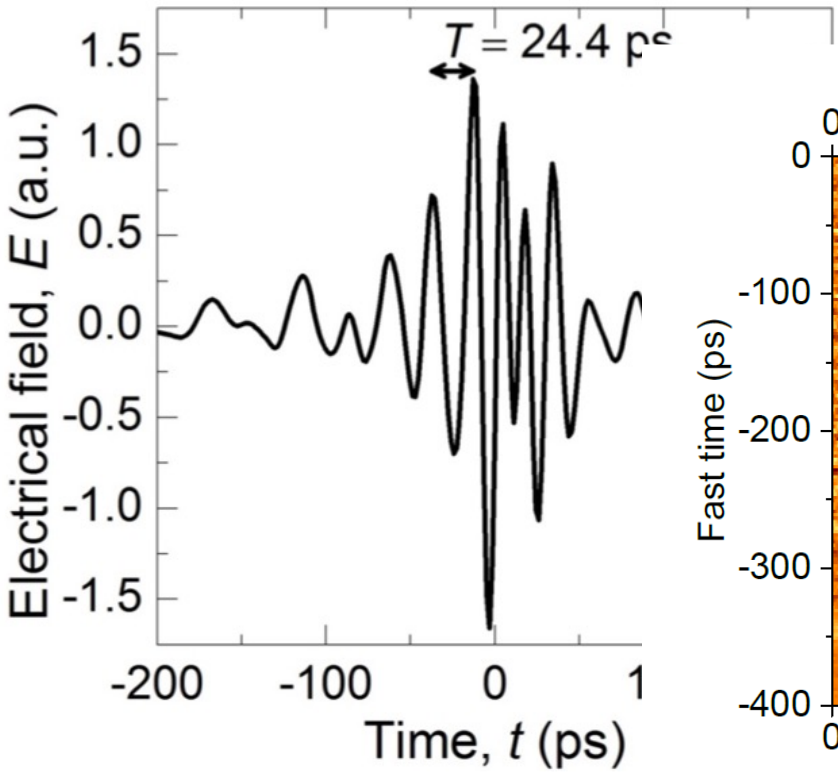
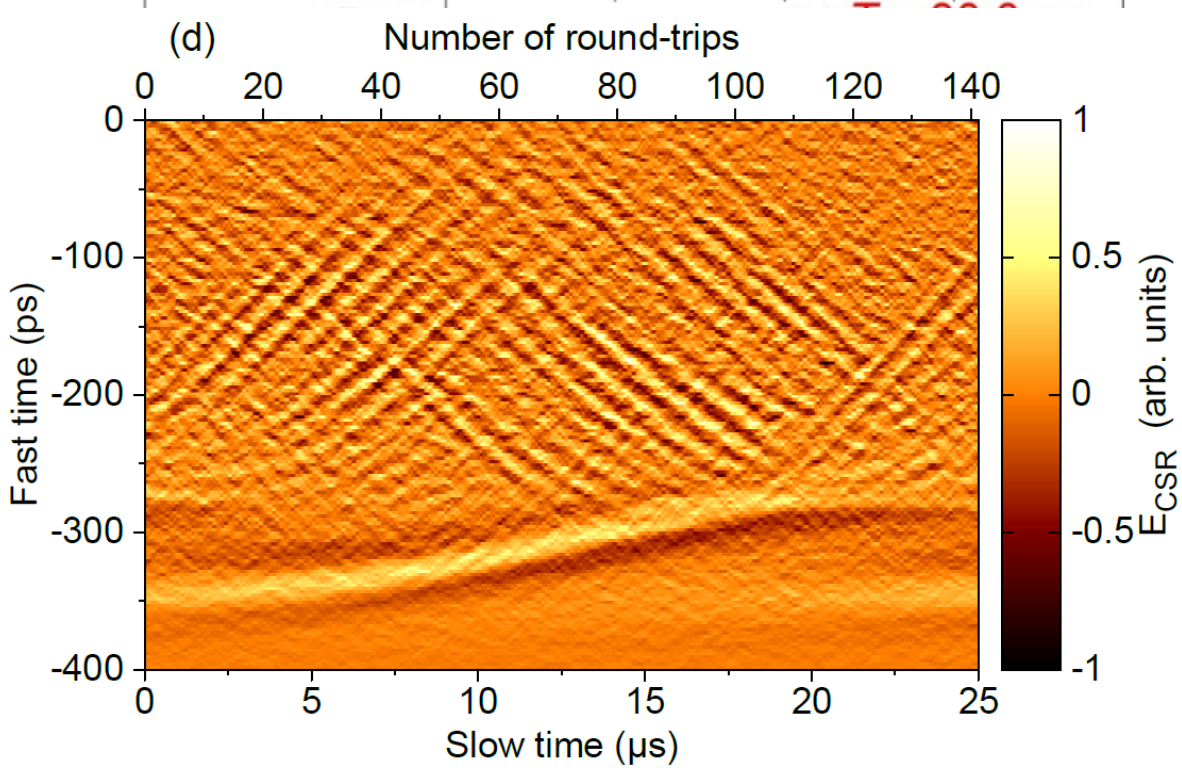
- Simulation of temporal evolution of the bunch

Simulation

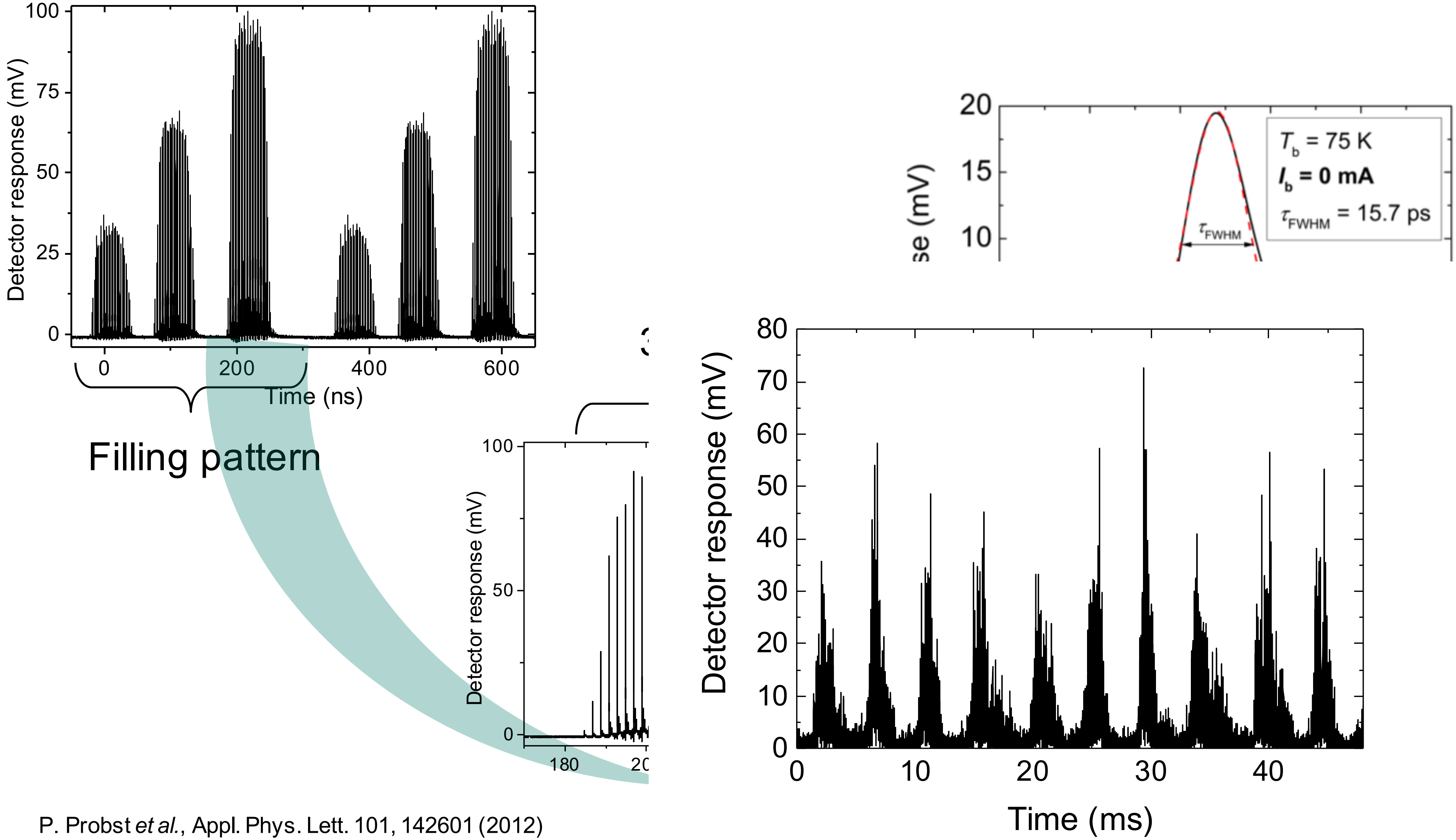


Experiment



E. Roussel *et al.*, Phys. Rev. Lett., 113, 09480

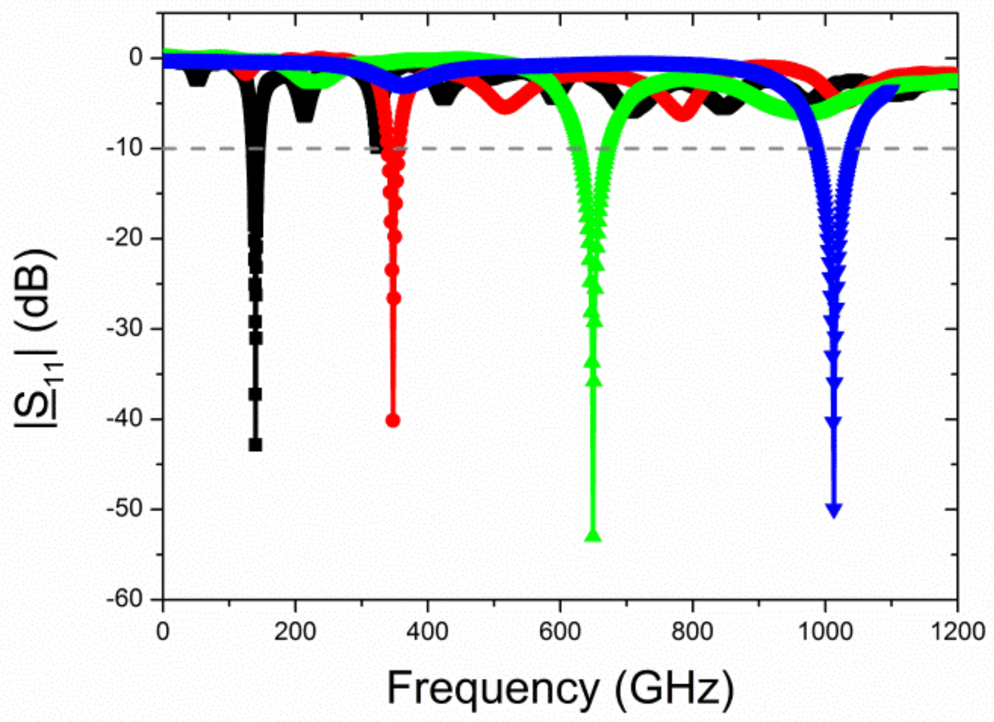
Direct detection of CSR
Filling pattern at ANKA

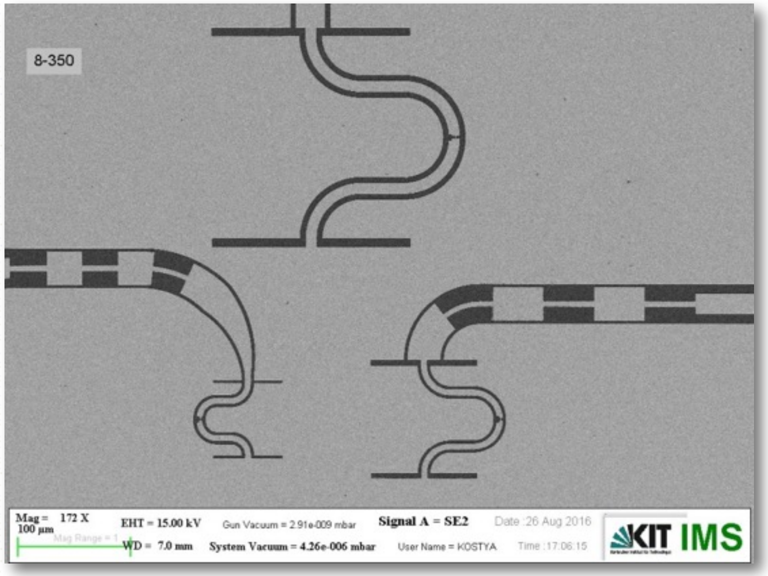


P. Probst *et al.*, Appl. Phys. Lett. 101, 142601 (2012)

Single-shot THz spectroscopy
Narrow-band THz antenna design

- Design and characterisation of 4 narrow-band double-slit antennas: 140 GHz, 330 GHz, 650 GHz, 1.02 THz

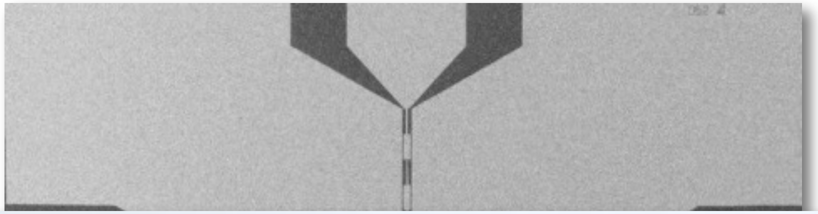




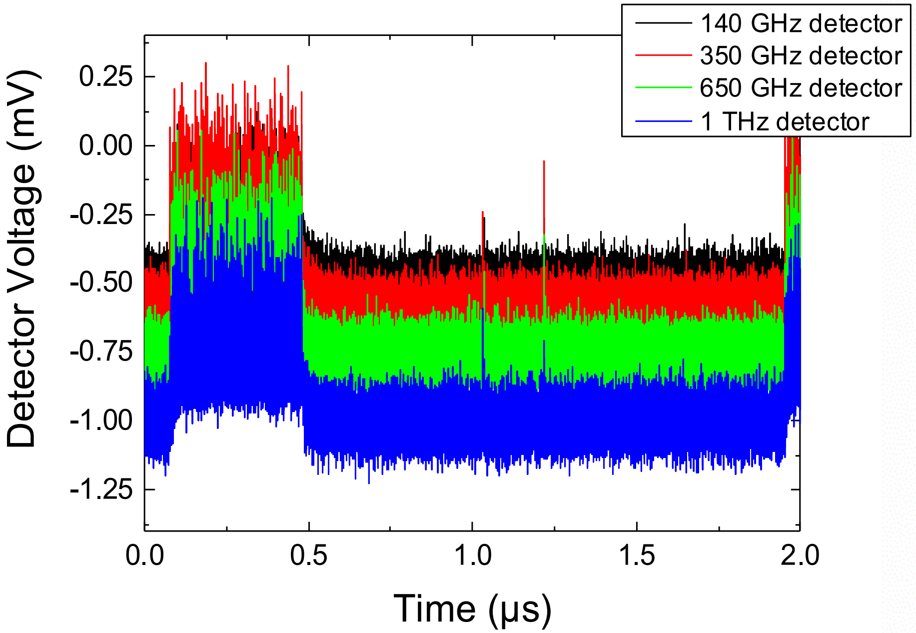
A. Schmid *et al.*, submitted to IEEE Trans. on Appl. Supercond.

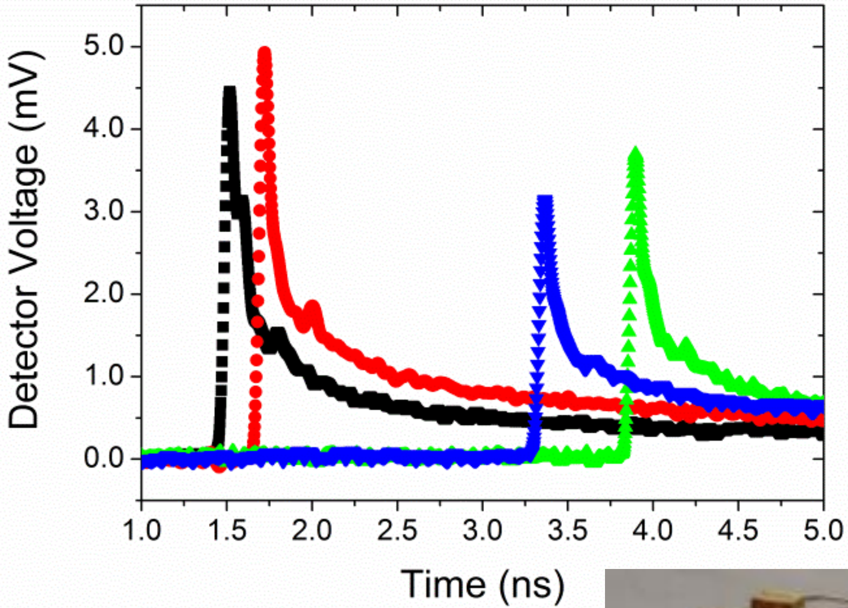
Single-shot THz spectroscopy
Detection system for multi-pixel array

- Broad-band readout lines for 4 pixels



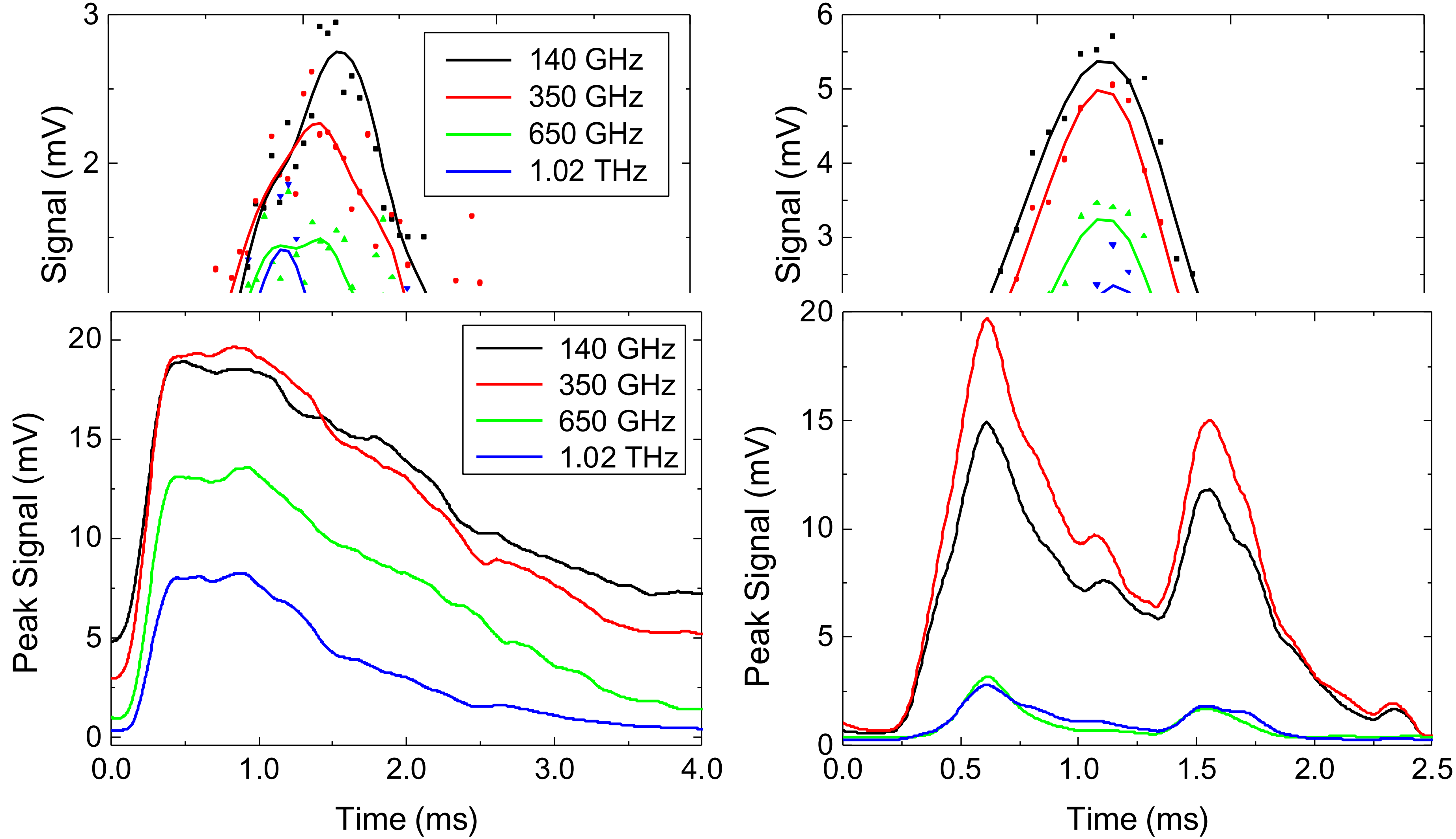
Single-shot THz spectroscopy
Simultaneous detection with 4 channels at DLS





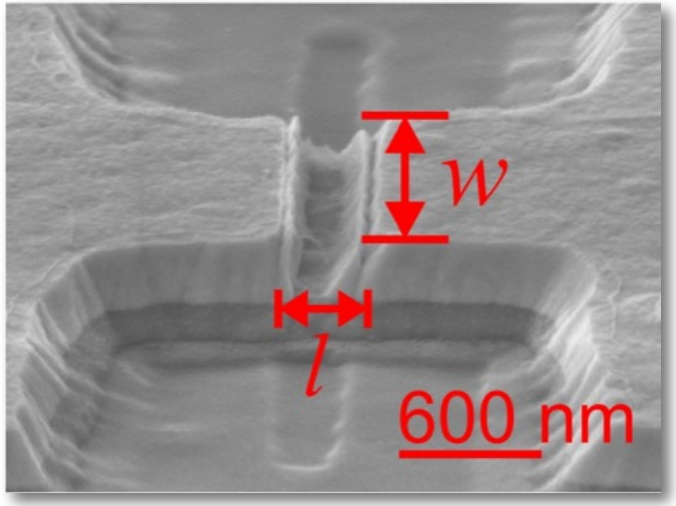
- First measurement with four-channel simultaneous readout

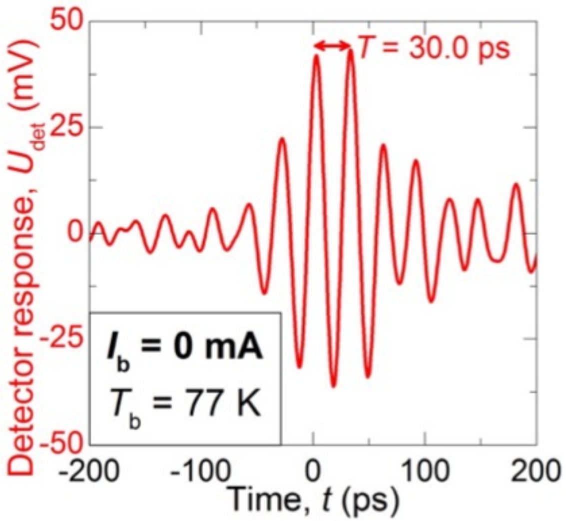
Single-shot THz spectroscopy
Bursting behaviour at ANKA and DLS

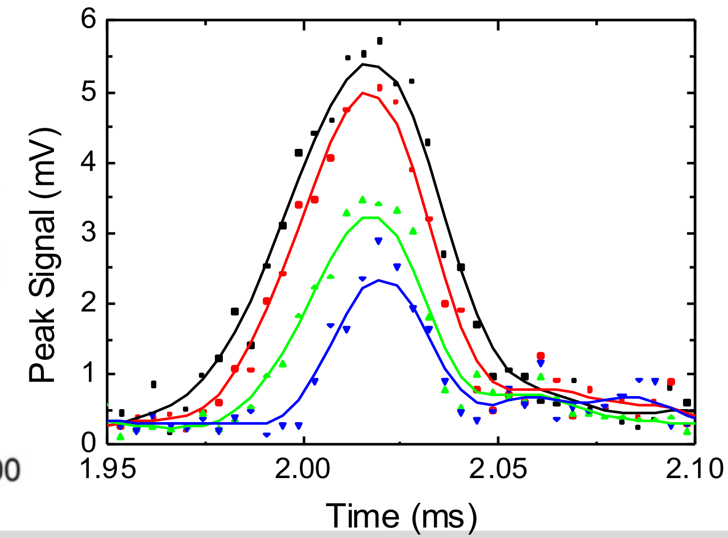


Conclusions

- Synchrotron as brilliant source of THz radiation
- Direct THz detectors: Bolometers, SBD, YBCO detector
- Novel THz detection system based on YBCO
  - 15 ps temporal resolution & Electrical field sensitivity
- Direct detection & Single-shot THz spectroscopy

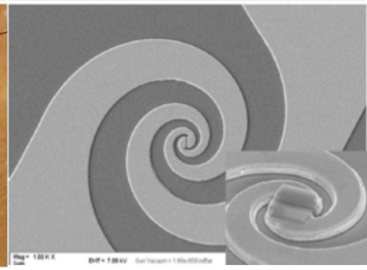
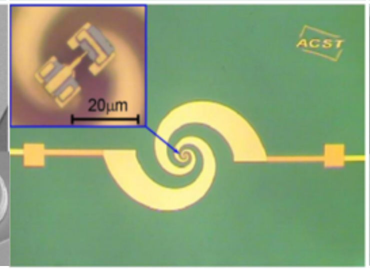


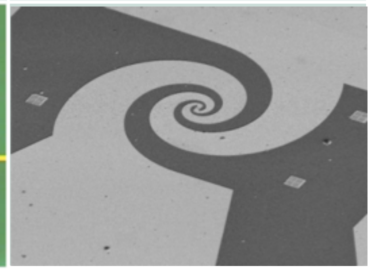




Coherent Synchrotron Radiation & THz detectors
Comparison of direct THz detector technologies

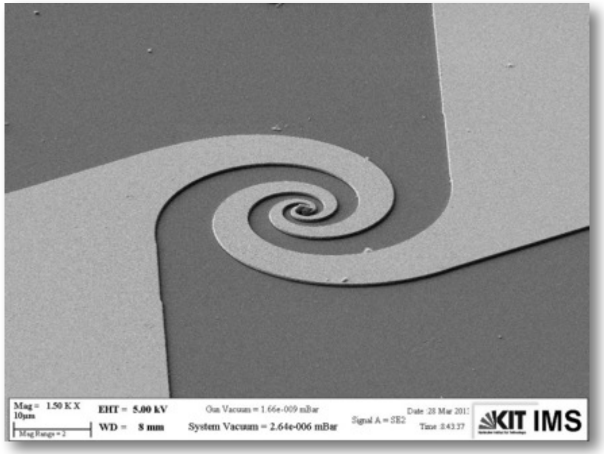
	InSb bolometer	NbN HEB	Schottky diode	YBCO detector
Bath Temperature	4.2 K	4.2 K	RT	**77 K**
NEP	**≈ 10^{-13} W/√Hz**	**≈ 10^{-13} W/√Hz**	≈ 10^{-10} W/√Hz	**≈ 10^{-10} W/√Hz**
Dynamic range		< 15 dB	≈ 25 dB	**> 30 dB**
Response time	≈ 300 ns	≈ 100 ps	≈ 20 ps	**< 15 ps**
Zero Bias	✗	✗	✓	✓
Electrical field sensitivity	✗	✗	✗	✓

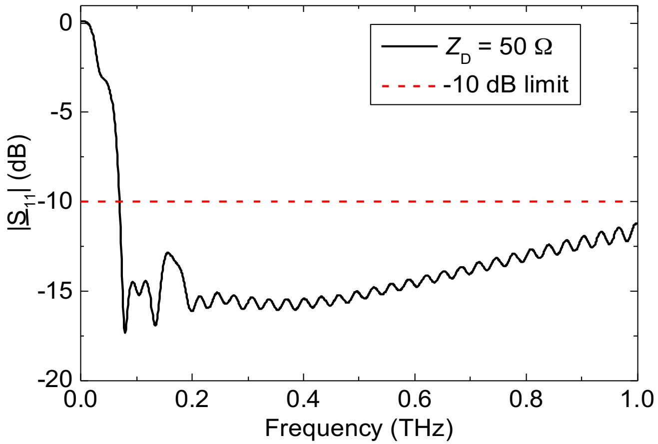






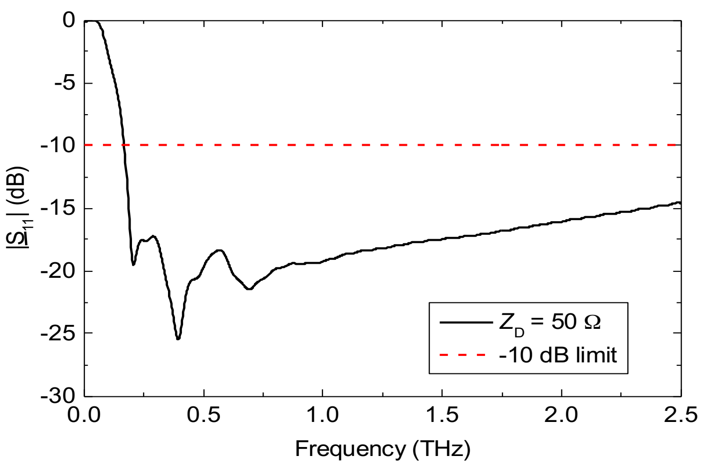
$YBa_2Cu_3O_{7-x}$ detection system
Broad-band THz antenna design

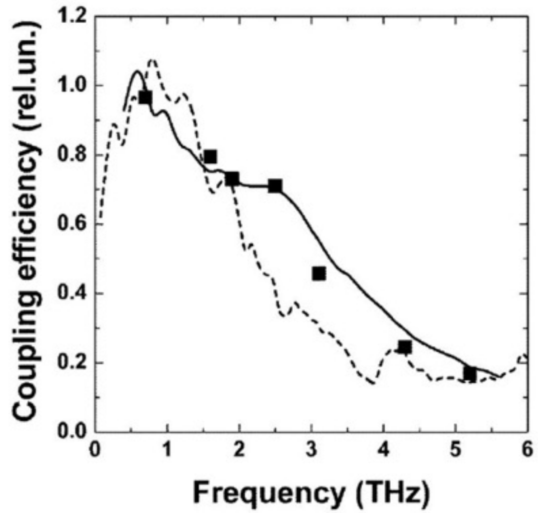
- f = 30 GHz – 1.0 THz
- f = 150 GHz – 2.5 THz
- f < 6.0 THz





P. Probst *et al.*, Phys. Rev. B 85, 174511 (2012)

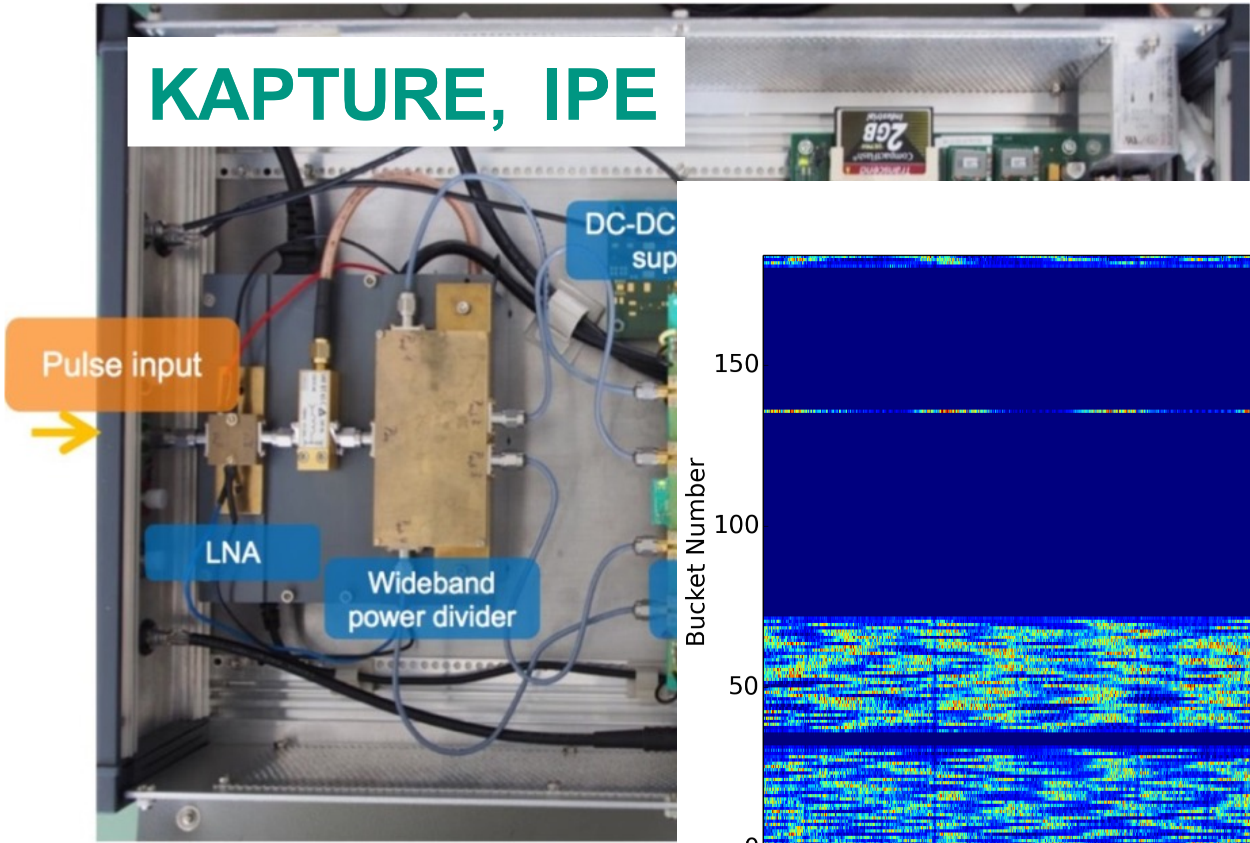


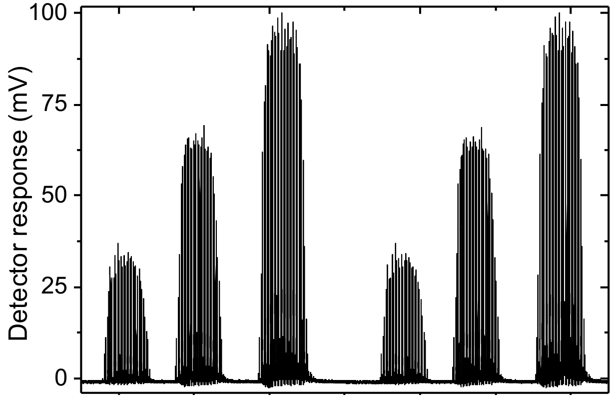


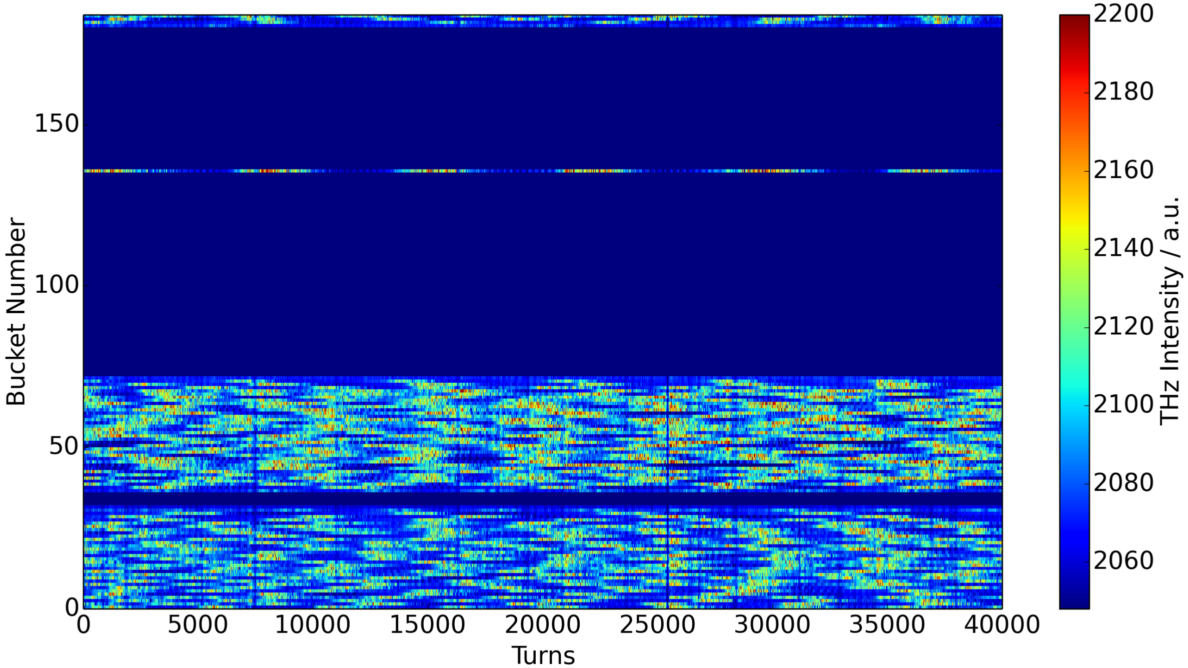
A. D. Semenov *et al.*, IEEE Trans. On Microw. Theor. and Tech. 55, 2 (2007)

Outlook
Broadband readout with KAPTURE

- **KA**rlsruhe **P**ulse **T**aking **U**ltra-fast **R**eadout **E**lectronis







M. Caselle *et al.*, Proc. of IPAC, THPME113 (2014)