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THz driven structures: a streaking deflector

M. Dehler et al

Paul Scherrer Institut, Switzerland

T. Feurer et al.

Institute for Applied Physics, U. of Berne, Switzerland

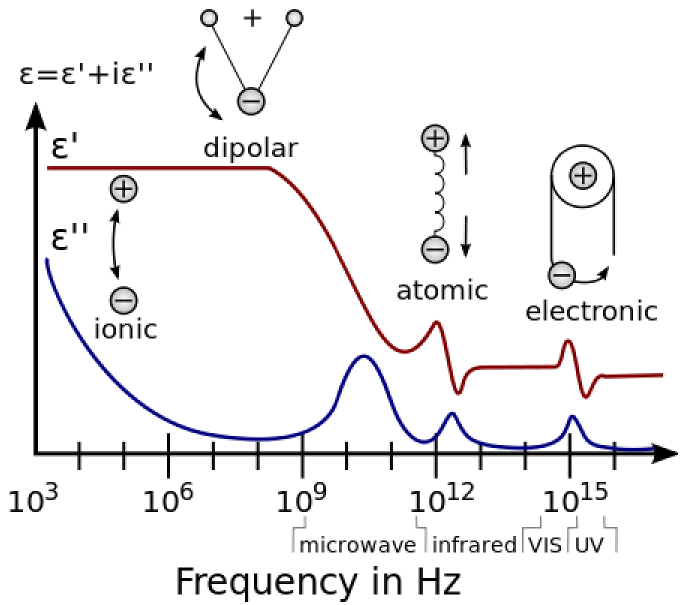
M. Yan et al

Karlsruhe Institute of Technology, Germany

- High gradients in the THz region
- A proof of principle streaking experiment
- Next steps

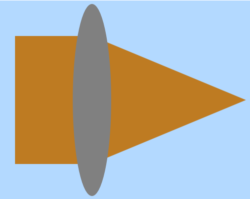
High gradients with THz?

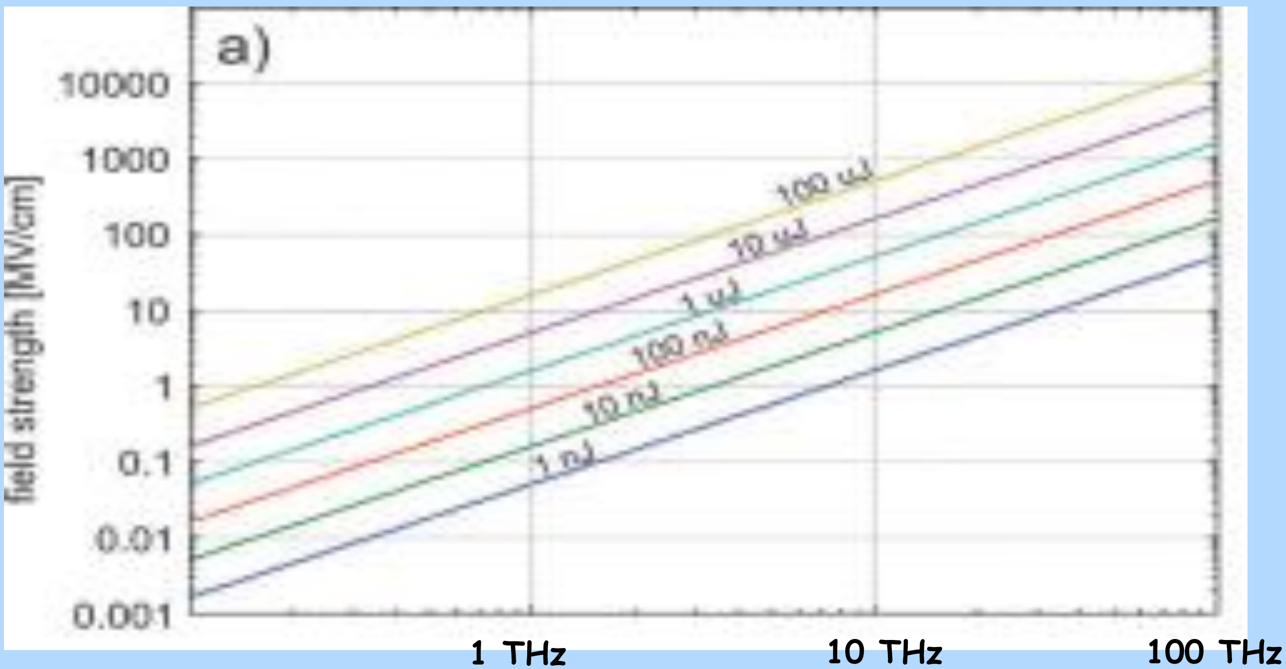
- Elevated losses in metallic conductors due to high frequency
- Permittivity behaviour in transition region between dipolar/atomic displacement and electronic resonances, often also quite lossy



- Good applicability for pulsed applications, ideally in the single to few cycle range

assumptions:
- single cycle
- focusing with F# = 1

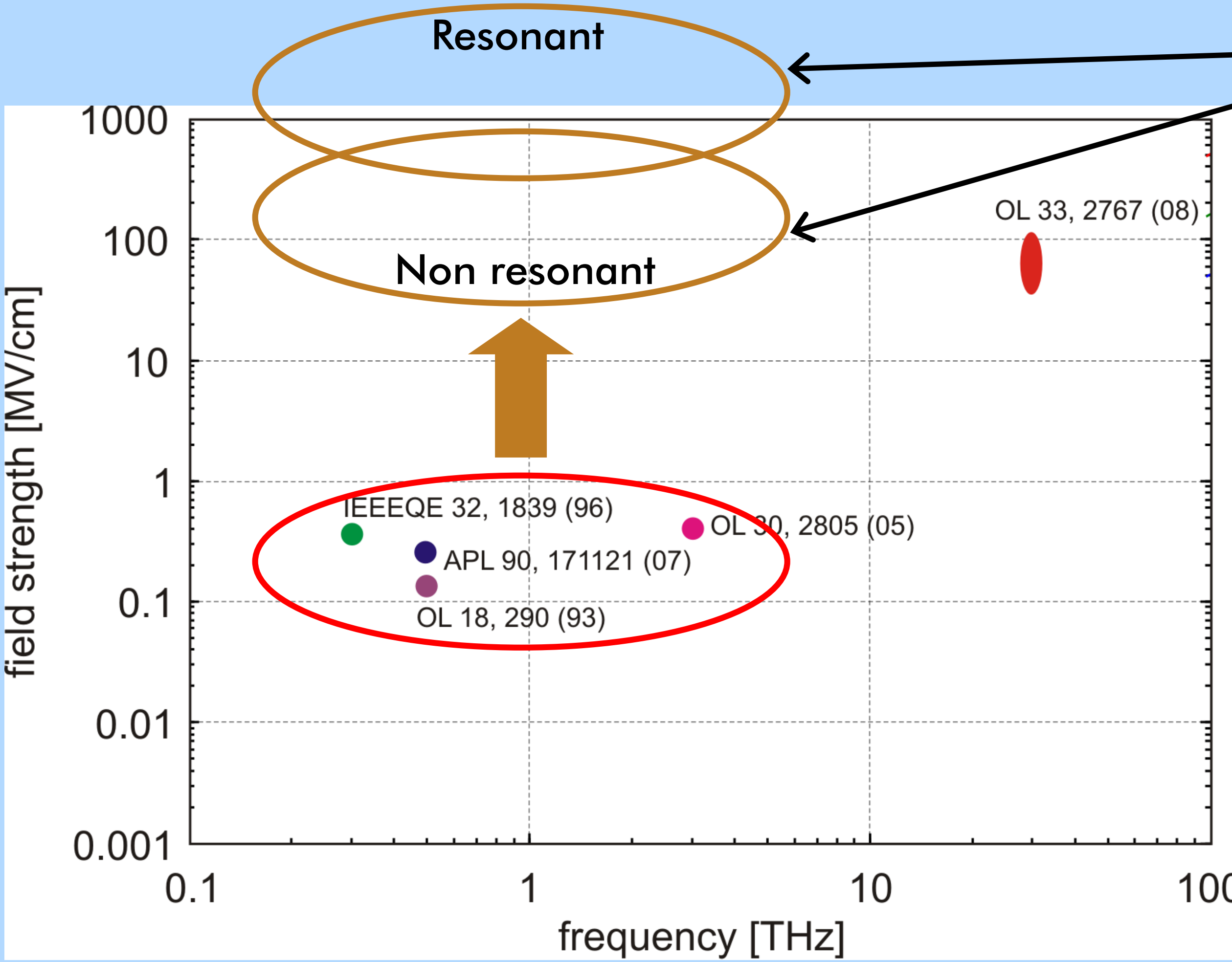


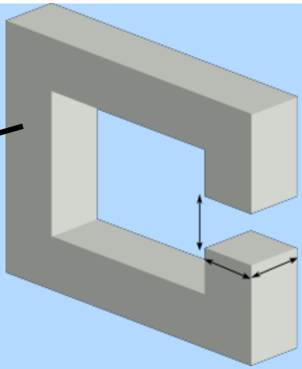


Without any structure already elevated gradients with tiny amounts of energy

(T. Feurer et al CHIMIA 65 (2011) 316-319)

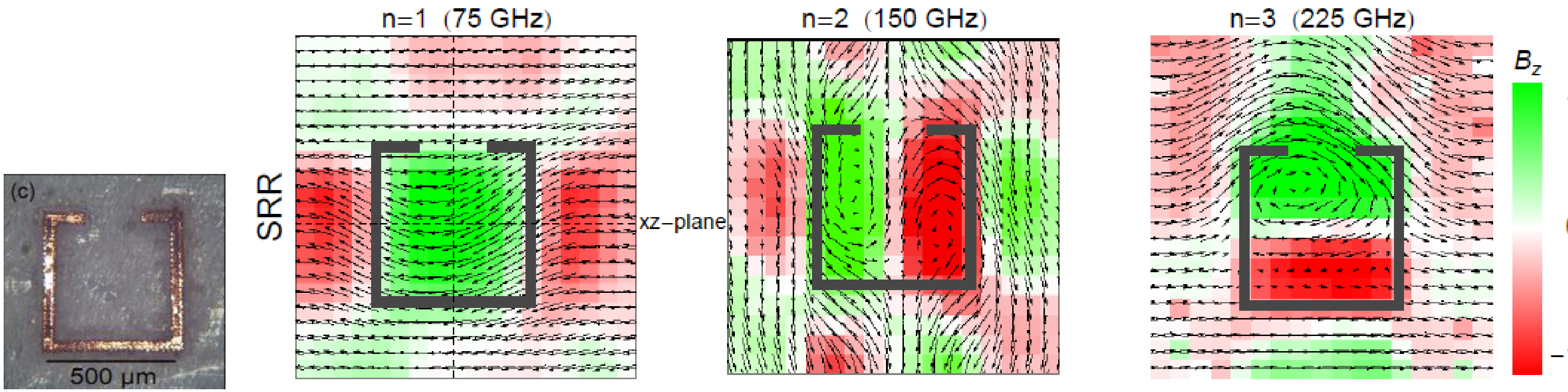
Option to further concentrate fields by metallic structures

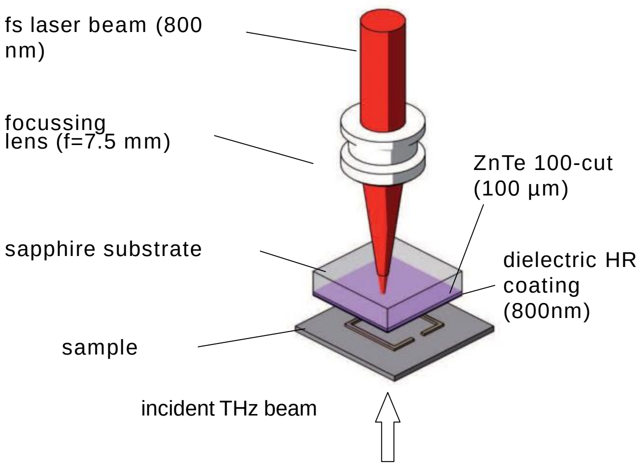




(T. Feurer et al CHIMIA 65 (2011) 316-319)

Near-Field Measurements





A. Bitzer et al.; OE 19, 2537 (2011)

THz Sources

CO_2 laser pumped gases

Coherent Synchrotron Radiation

Transition Radiation

Diffraction Radiation

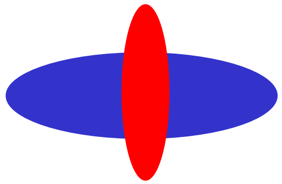
Free Electron Lasers

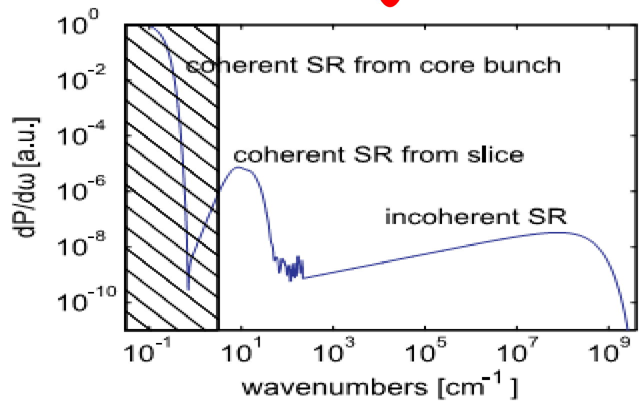
Microwave sources plus mixers

Quantum Cascade Lasers

Photoconductive antenna

Plasma Filaments



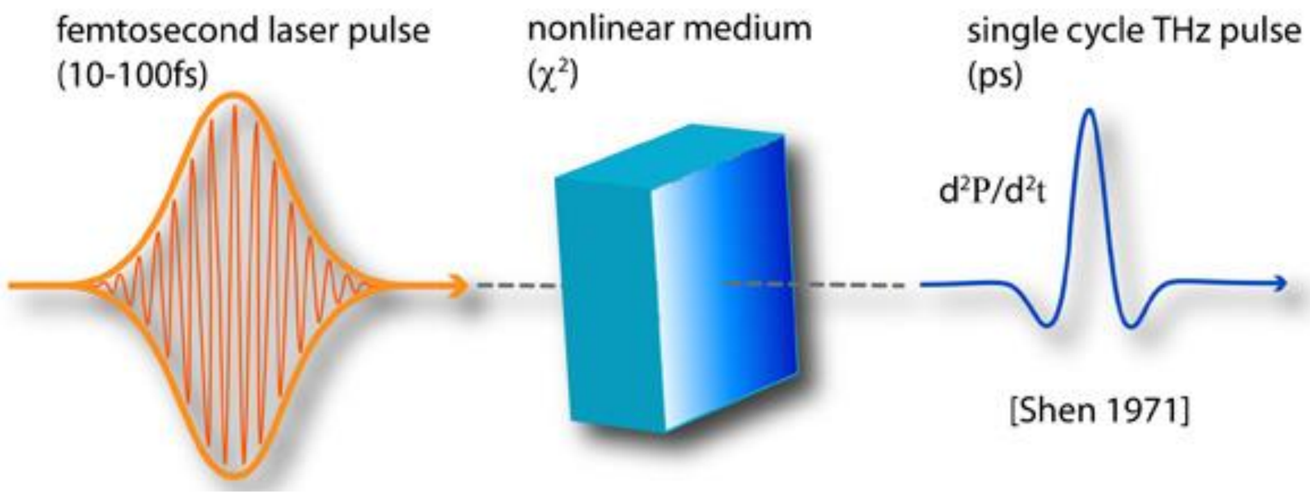


$$\nabla \times \nabla \times \vec{E}(\vec{r},t) + \frac{1}{c^2}\frac{\partial^2 \vec{E}(\vec{r},t)}{\partial t^2} = -\mu_0 \frac{\partial \vec{j}(\vec{r},t)}{\partial t} - \mu_0 \frac{\partial^2 \vec{P}(\vec{r},t)}{\partial t^2}$$

Difference Frequency Generation

Optical Rectification

For high amplitude, short pulse use optical rectification



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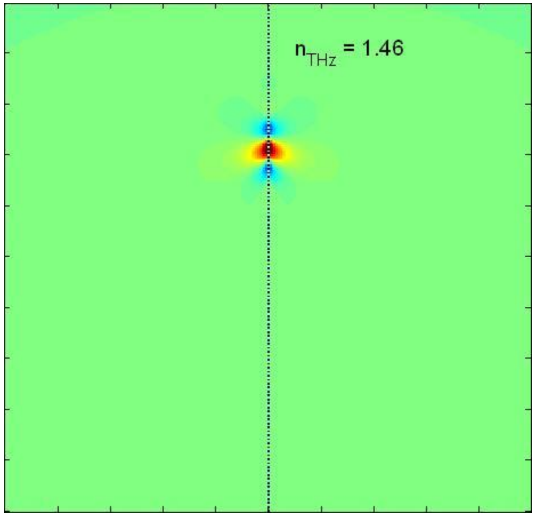
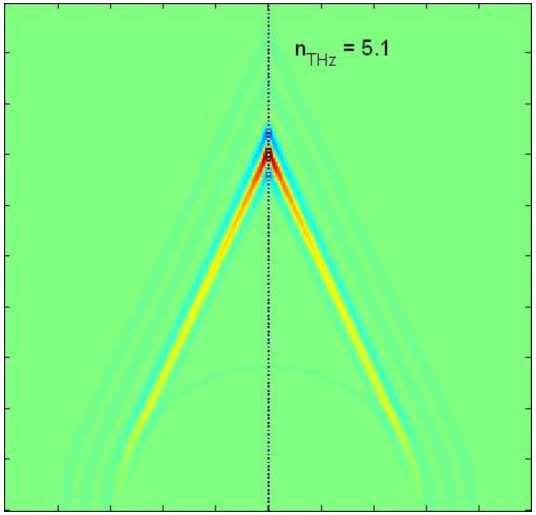
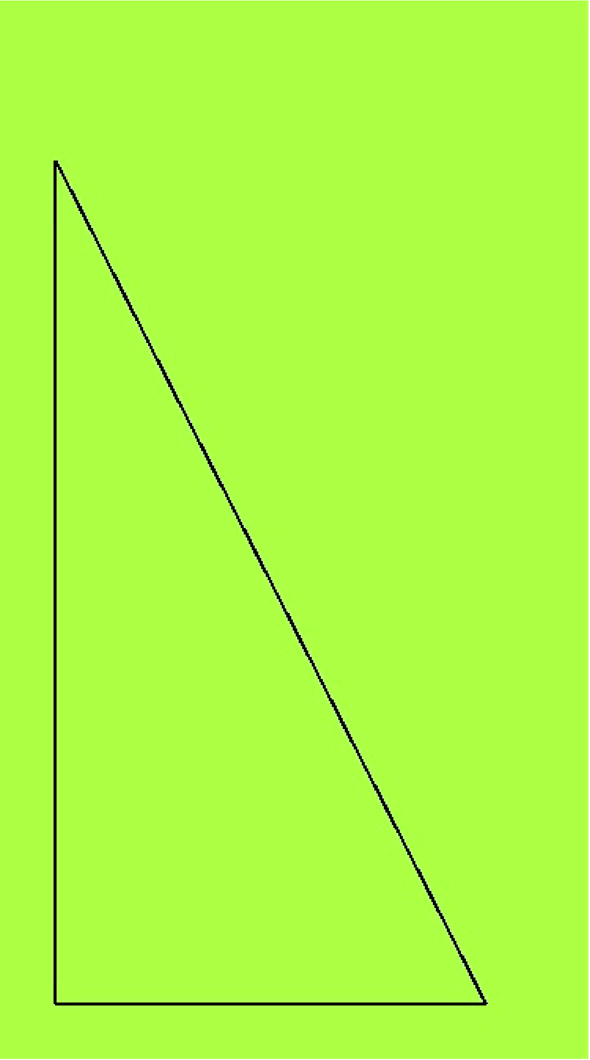


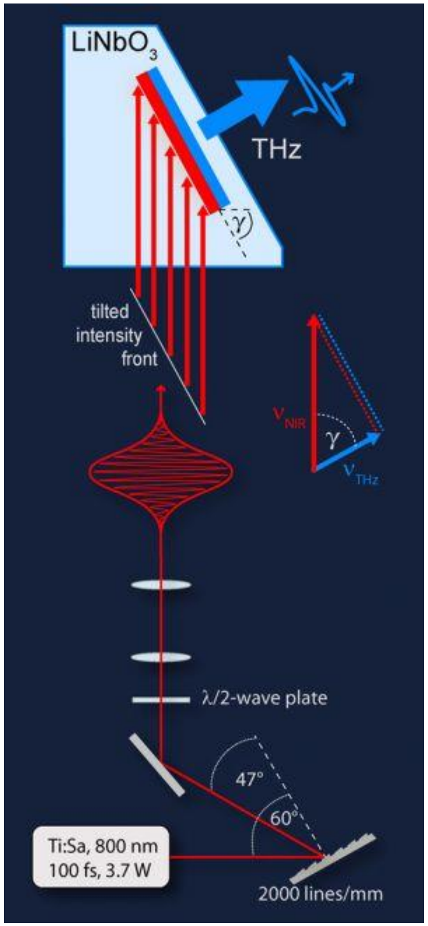
e./g. ZnTe, GaP,

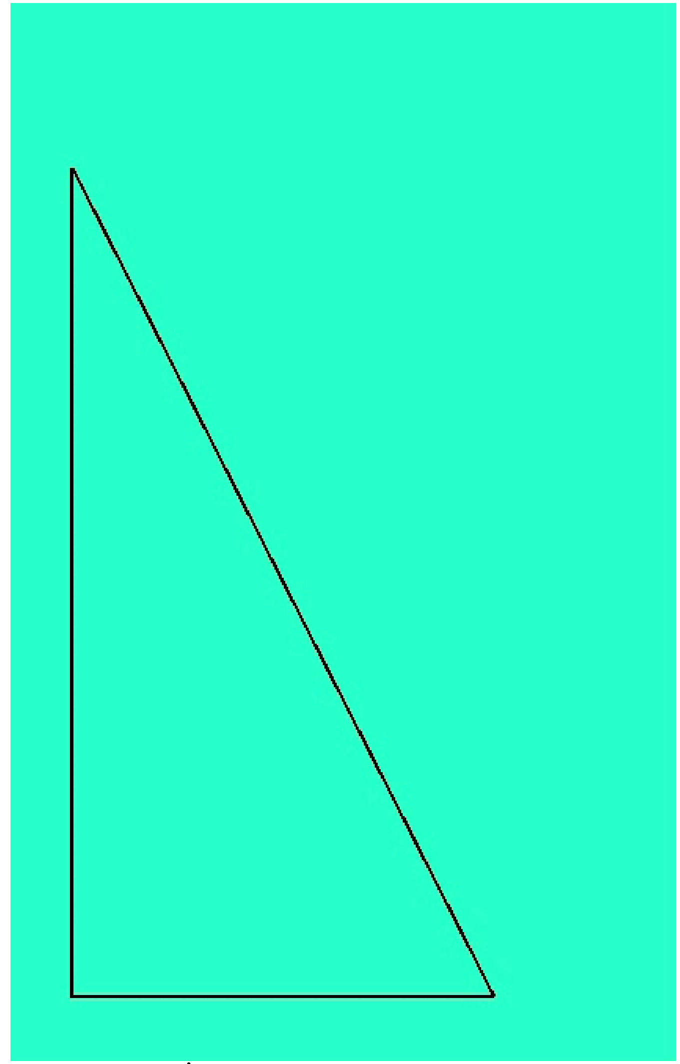


e.g. $LiNbO_3$, $LiTaO_3$



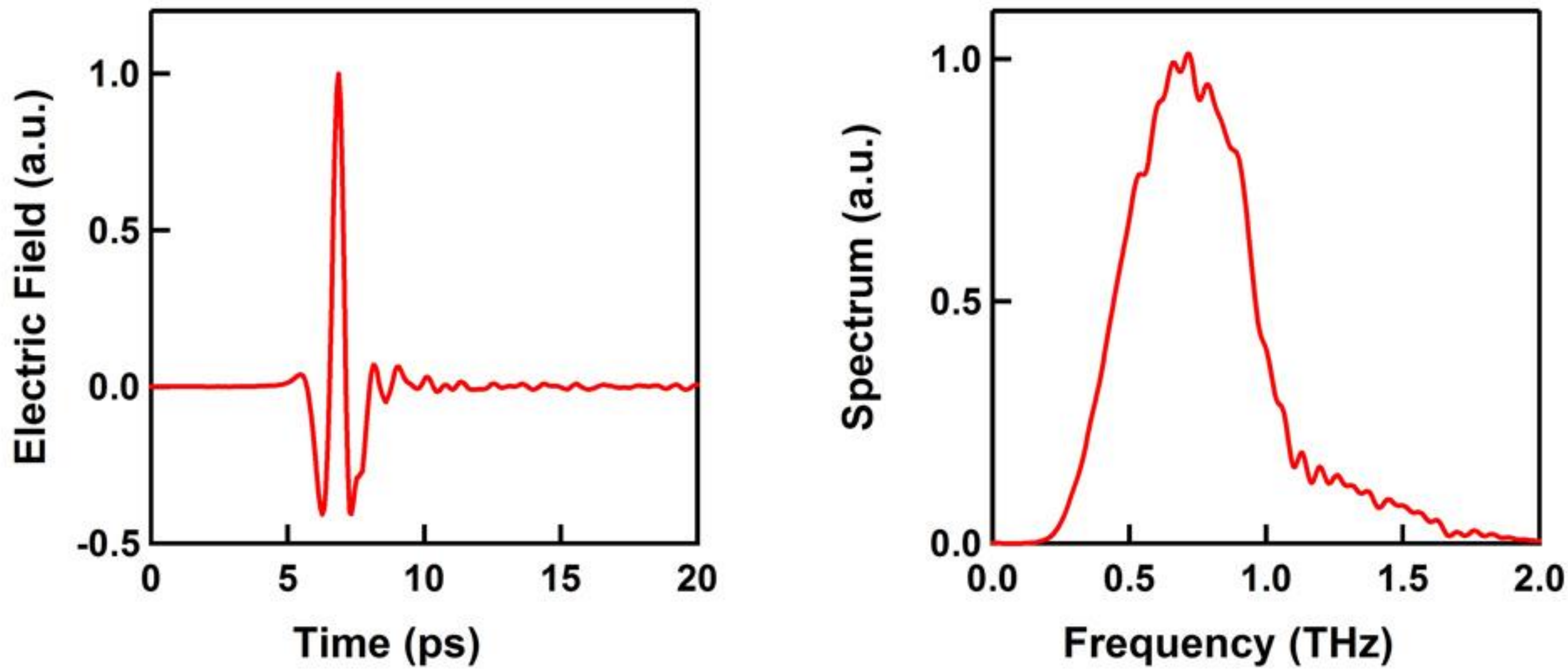
Tilted pulse front for higher efficiency





(A. Cavalleri, Max Planck Institute for the Structure and Dynamics of Matter)

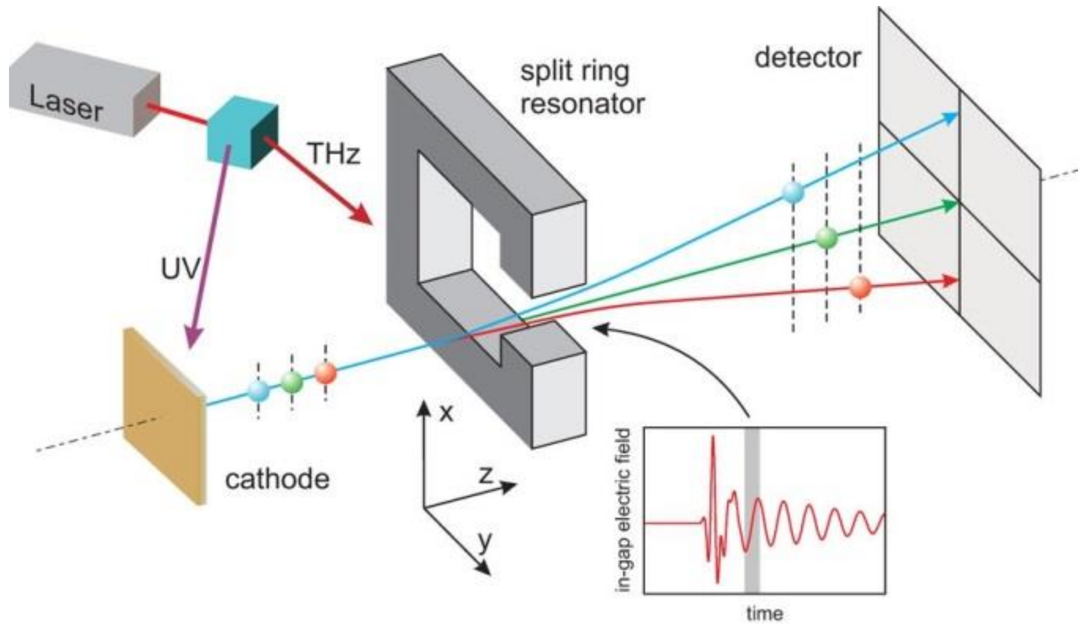
Typical pulse shapes and spectra



(A. Cavalleri, Max Planck Institute for the Structure and Dynamics of Matter)

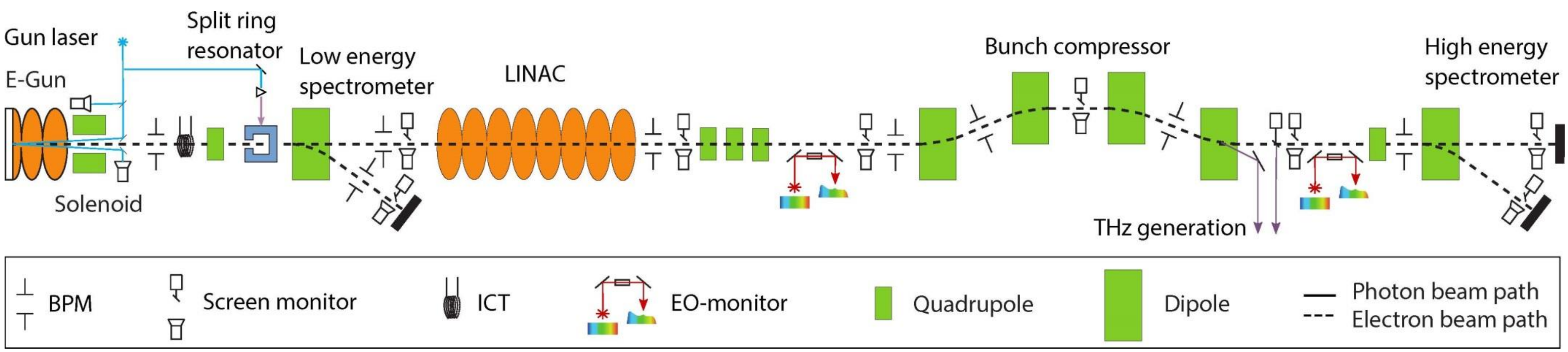
Concept of THz based streak camera

- Resolution of streak camera systems determined by slew rate of the deflecting element, proportional to amplitude and the frequency.
- THz driven electron streak cameras as interesting option to reach femto to sub femto-seond resolution

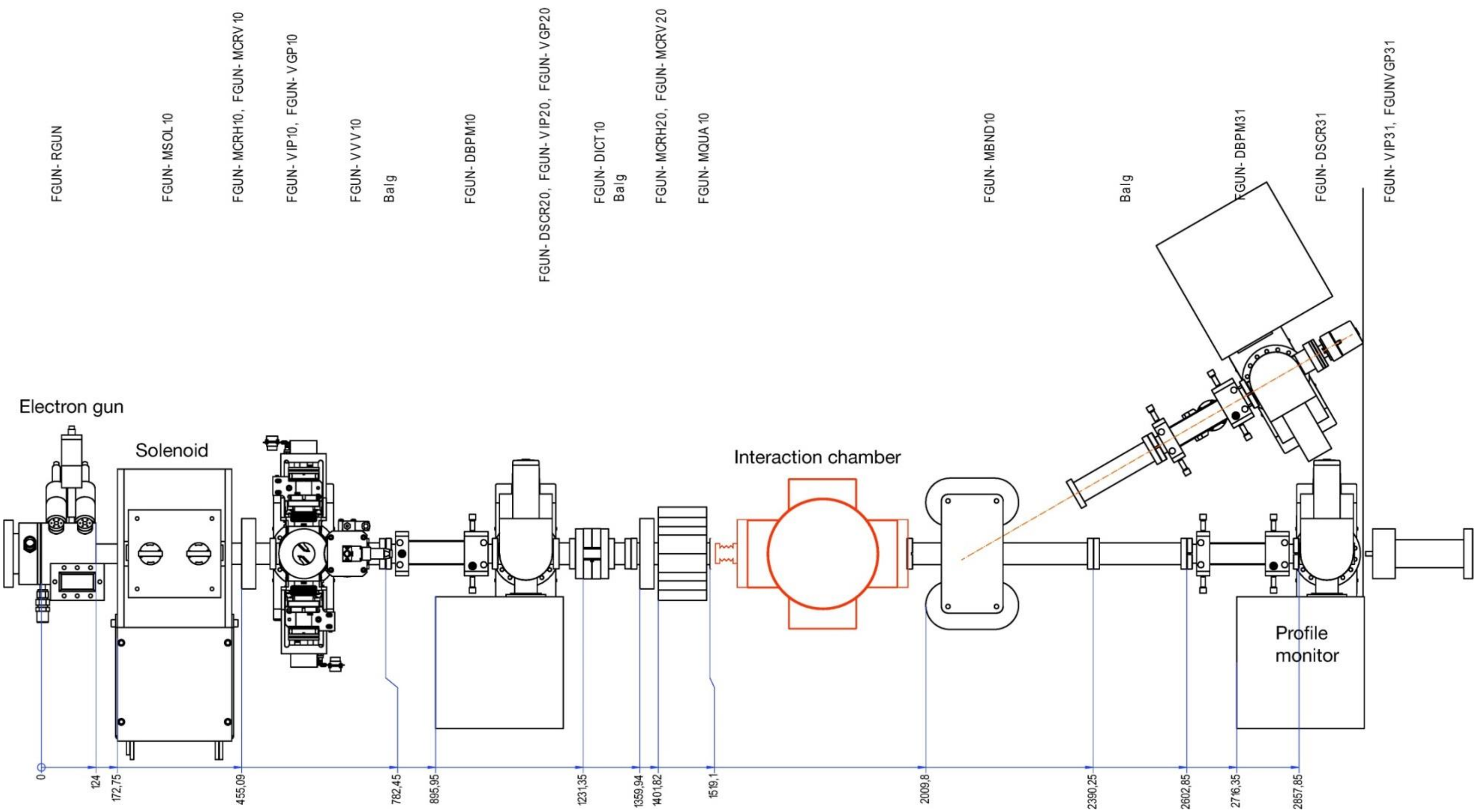


- Concept for proof of principle system
- – Split ring resonator excited by THz pulse
- – THz generation by optical rectification
- – E- beam generated by RF photo gun

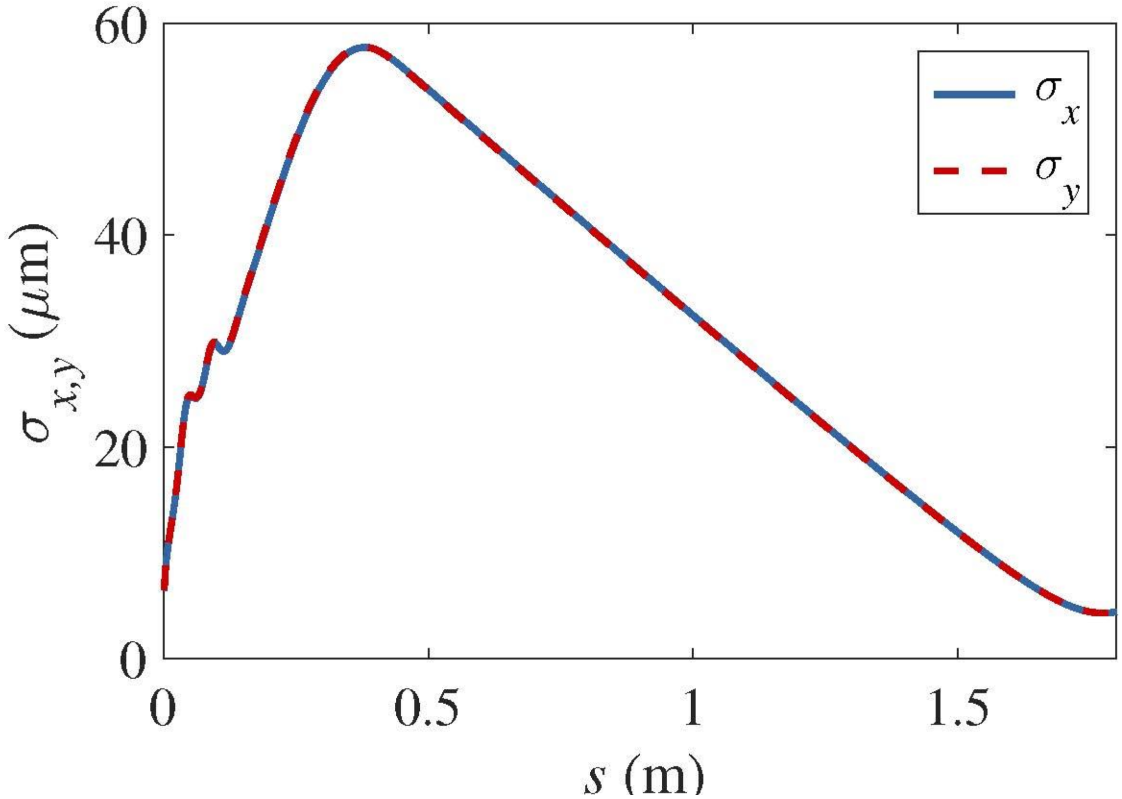
SRR experiment at FLUTE (KIT)



A closer look



Beam envelope from gun to SRR placement

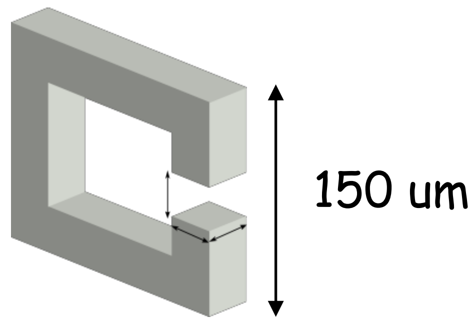


Accelerator settings	
Laser rms pulse length	2 ps
Laser rms transverse size	5 μm
Bunch charge	50 fC
Gun gradient	120 MV/m
Gun phase	0 degree
Solenoid magnetic field	0.24 T
Bunch energy	7 MeV
Normalized rms transverse emittance	2.7 nm

SRR gap of 20 um sufficient

Deflector structure

Originally started with a 'classical' split ring resonator design (model from nonlinear THz spectroscopy):



Fabrication from glass, gold coated

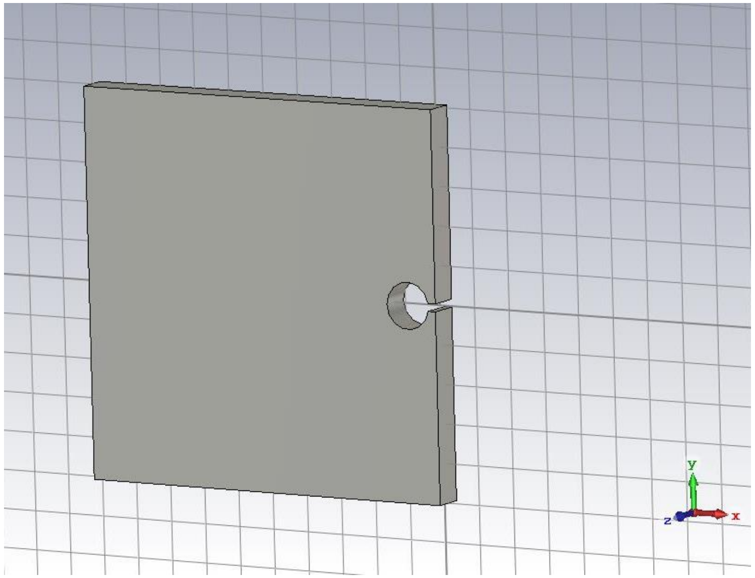
Challenges:

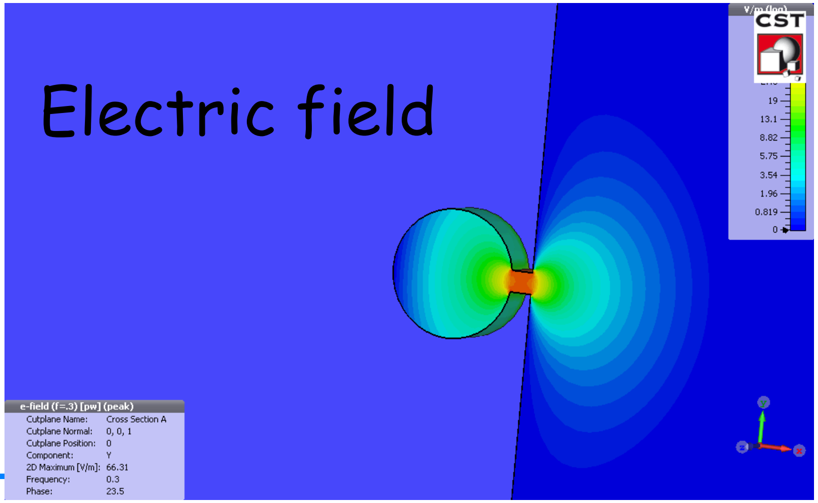
- Mechanically stable mounting
- How to avoid charging by halo electrons?
- Heatup of structure due to halo electrons

'Inverse' SRR

Strategy:

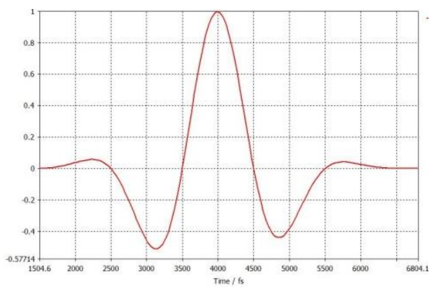
- Cut out resonator geometry from metallic sheet (multiple λ size), which can be mounted directly to macroscopic holder
- Sheet thickness 80 μm
  - Gives stability
  - Larger gap length (= more kick at same field)



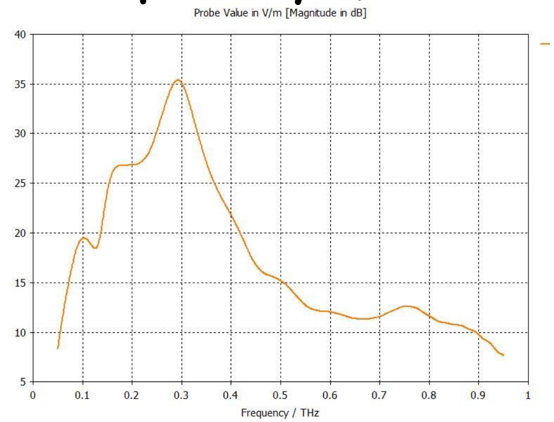


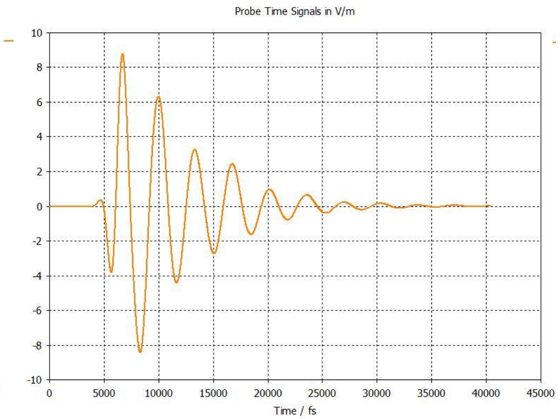
Pulse response

ISRR designed for 0.3 THz center frequency (better resonance)

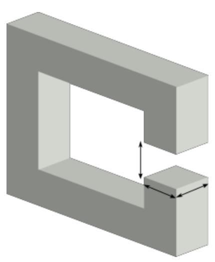


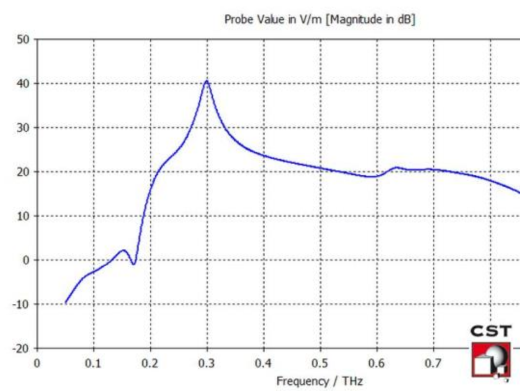
Exciting pulse shape:
Bandwidth: 0.05-0.95 THz
Similar to examples found on web

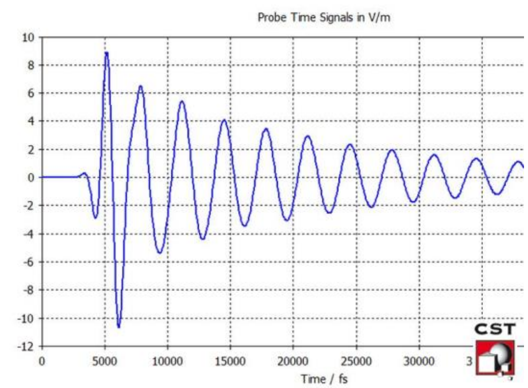




For comparison response of standard SRR design (f=0.3 THz, 20 µm thickness







SRR shows a more resonant behaviour (not of interest, just need the slope around one zero crossing) and approx 30% higher amplitude, which should be more than compensated by factor 4 larger gap length of ISRR.

What to expect in terms of field strength

FLUTE laser

Pump laser λ = 800 nm

W = 1mJ (pulse energy)
f_{rep} = 1 kHz
d = 11mm (diameter)
t = 35 fs (Gauss)

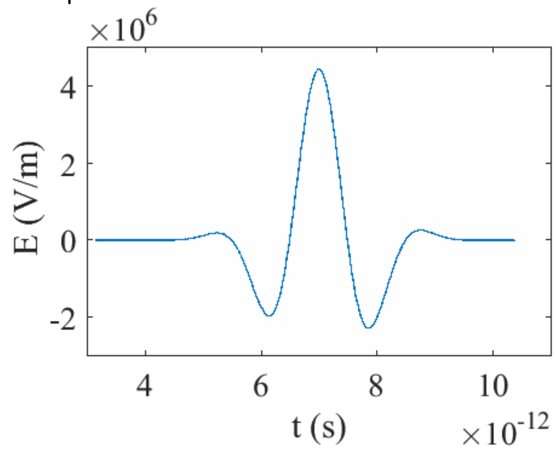
ζ = 0.1 %
(conversion efficiency)

THz generation

Focused THz pulse
W_{THz} = 1mJ * 0.1% = 1 uJ
d = 6mm (~ 0.05THz)

$w_{THz} = W_{THz} / A = \varepsilon_0 \int E(t)^2 dt$

Scaled THz pulse in time-domain:
E_{peak} = 5 MV/m



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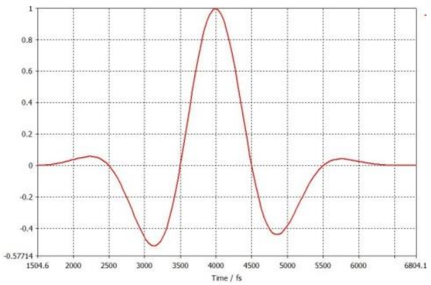
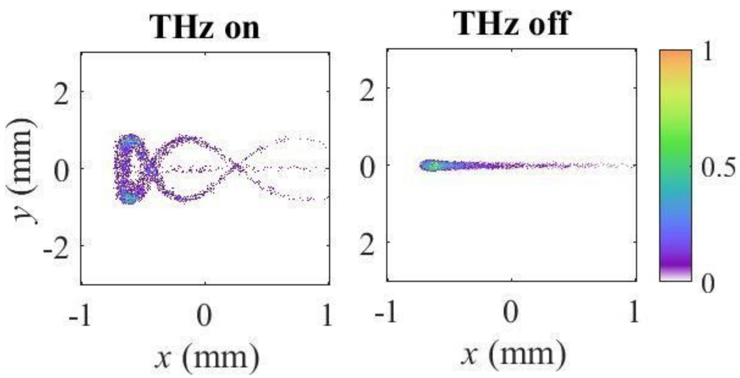
Simulated results assuming THz pulse of 5 MV/m peak



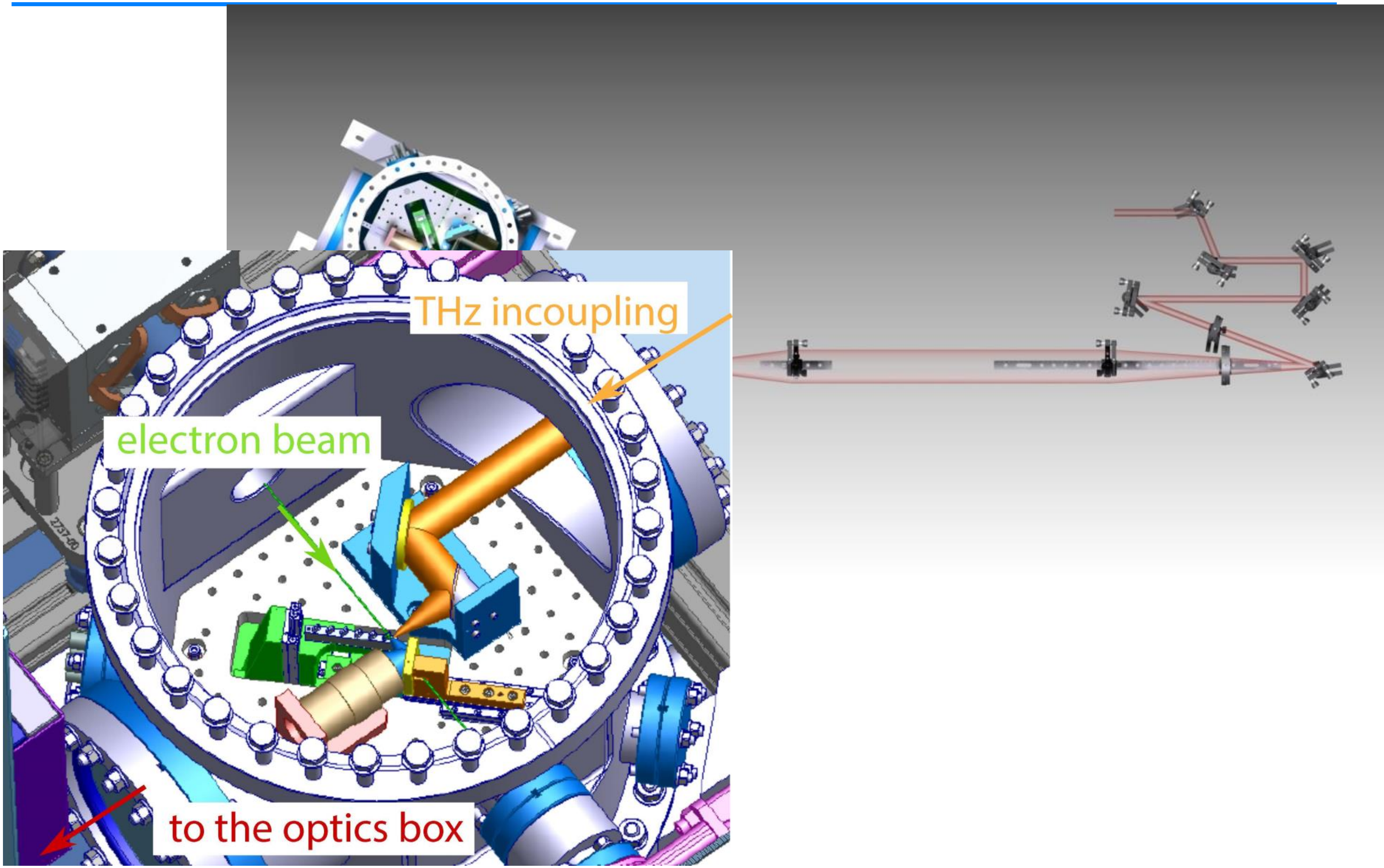
	Resonant freq (THz)	Kick (keV/c)
IBIC SRR (20x20x20)	0.3	2.5
EpsTube	0.3	10.5
ISSR	0.3	4.5

Example: effect of 5 keV/c

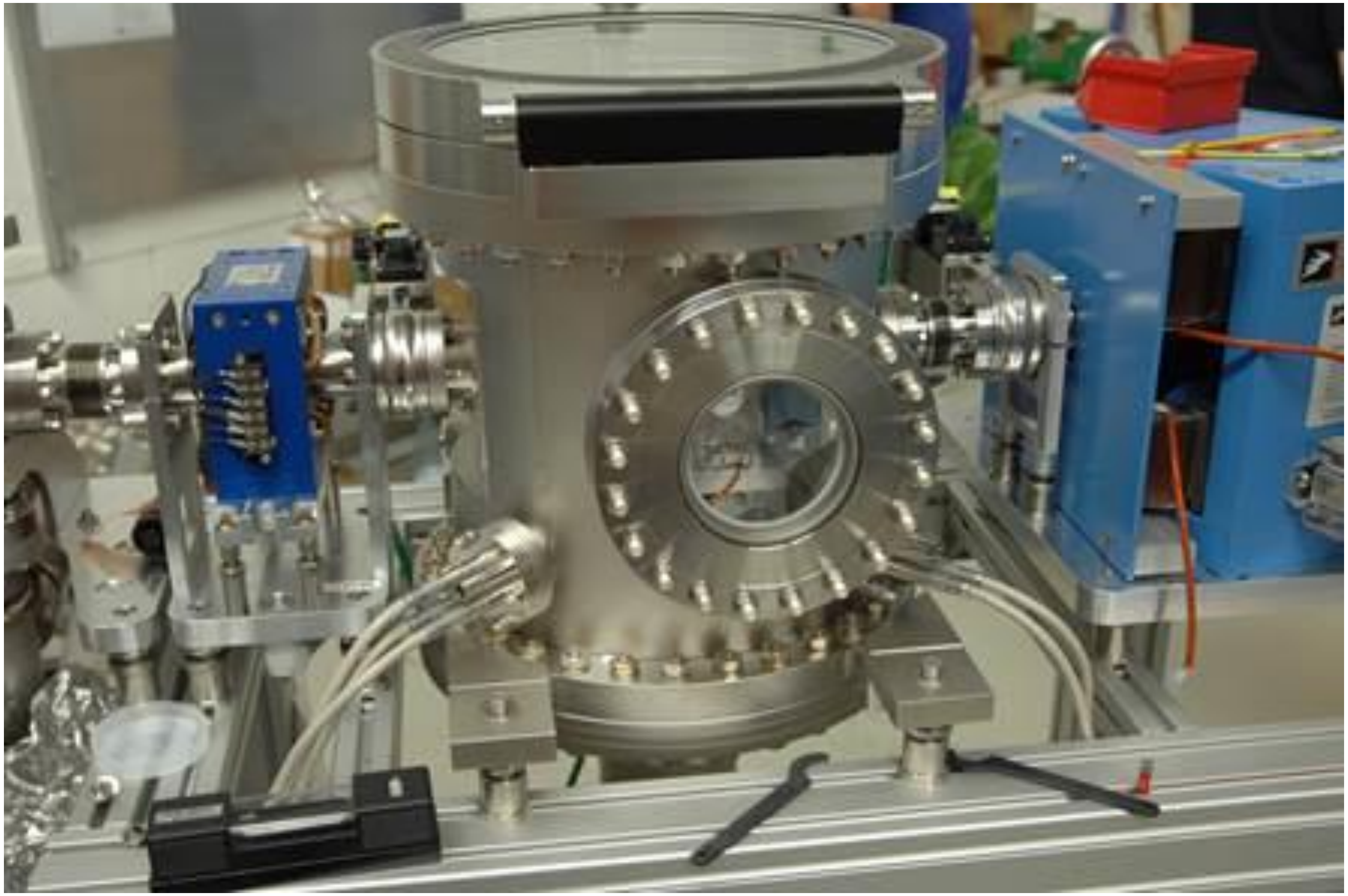


Expect no problems in detecting streaking

Interaction chamber



Chamber installed in May 22 at FLUTE/KIT



Next steps

- Deflector structures under production
- Setup for THz generation will be installed at KIT in summer
- Expect proof of principle experiment in autumn/end of 2017
- How to continue:
  - Think about setups for few GeV beams (as in SwissFEL)
  - Frequency higher by 50-100 compared to std RF deflectors → high resolution even with small amplitudes
  - Beam dynamics much easier, since beam size already typically in micron range
  - Need more efficient array of deflector structures
  - New challenges as e.g. synchronization

Thanks a lot!