Karlsruhe Institute of Technology

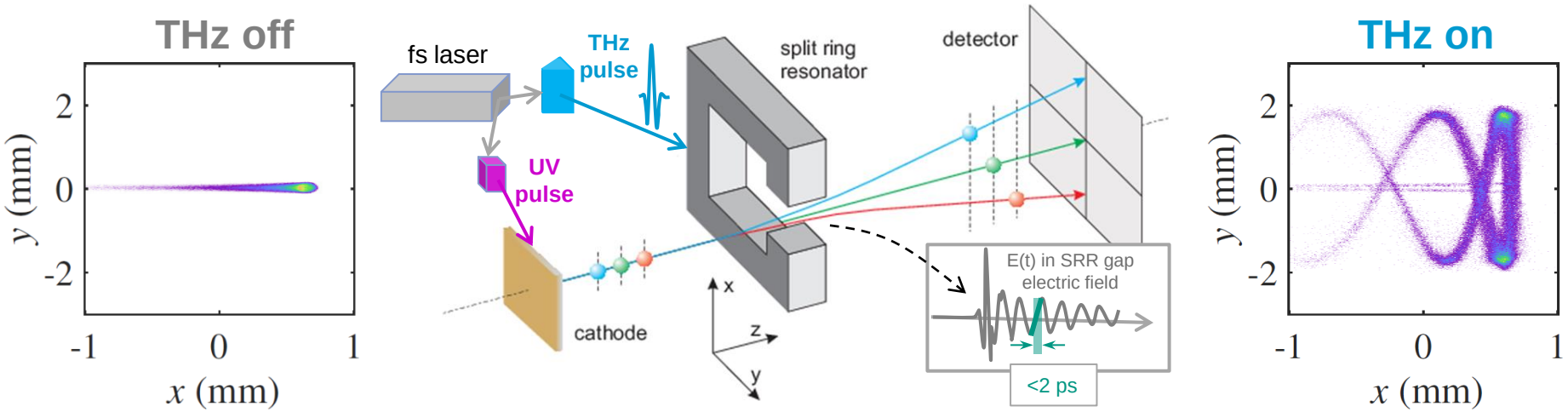
FLUTE
Institut für Beschleunigerphysik und Technologie

THz Streaking with Split Ring Resonator at FLUTE

M. Yan (KIT) for the collaboration

Presenter: E. Bründermann (KIT)

Karlsruhe Institute of Technology (KIT), Paul Scherrer Institute (PSI), University of Bern



Research Team and Acknowledgements

Collaboration: KIT, PSI, University Bern

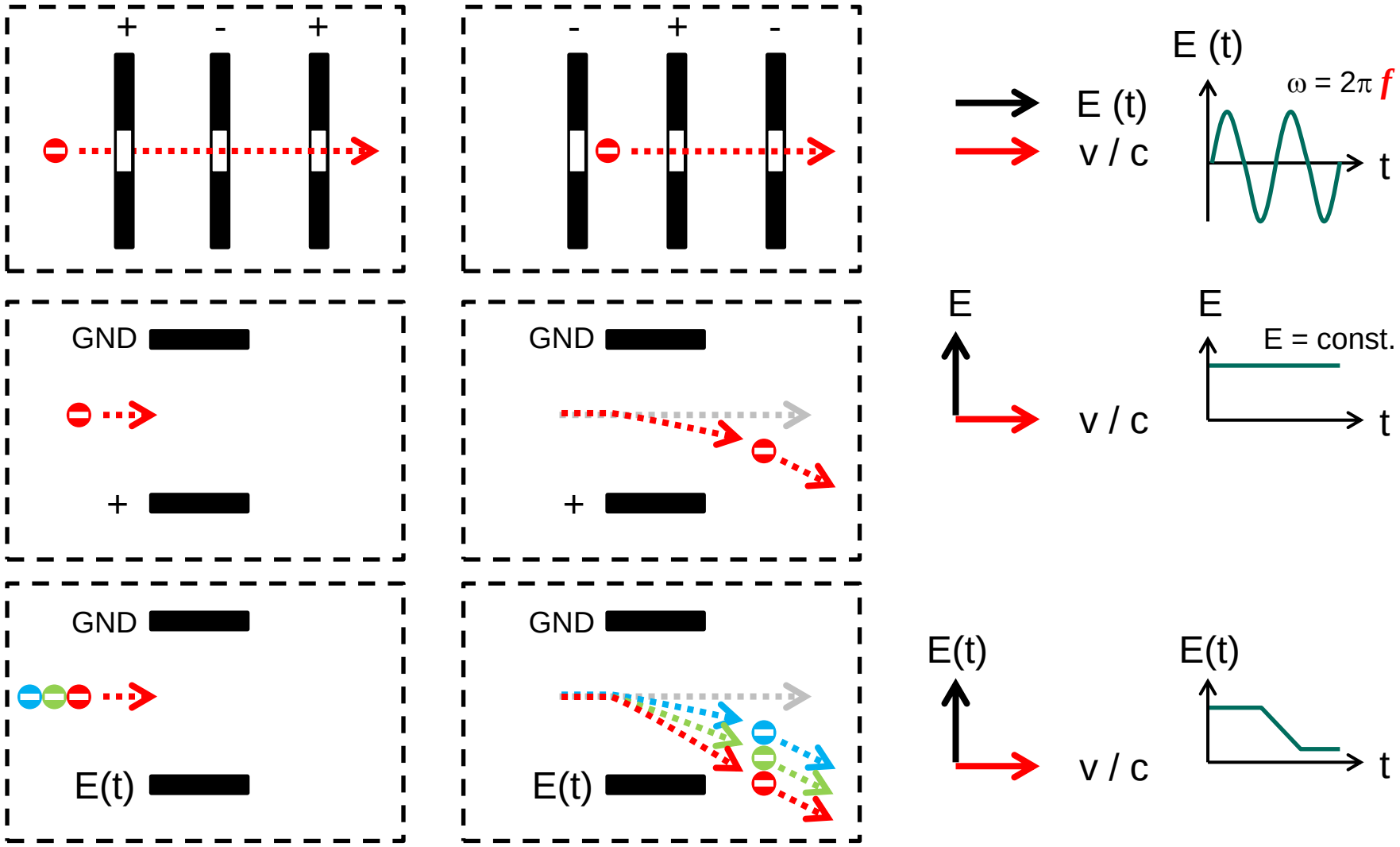
Andreas Breitenstein, Erik Bründermann, Stefan Funkner, Anke-Susanne Müller, Michael J. Nasse, Gudrun Niehues, Robert Ruprecht, Manuel Schedler, Thiemo Schmelzer, Markus Schwarz, Marcel Schuh, Minjie Yan

Micha Dehler, Eugenio Ferrari, Franziska Frei, Rasmus Ischebeck, Matthias Moser, Volker Schlott

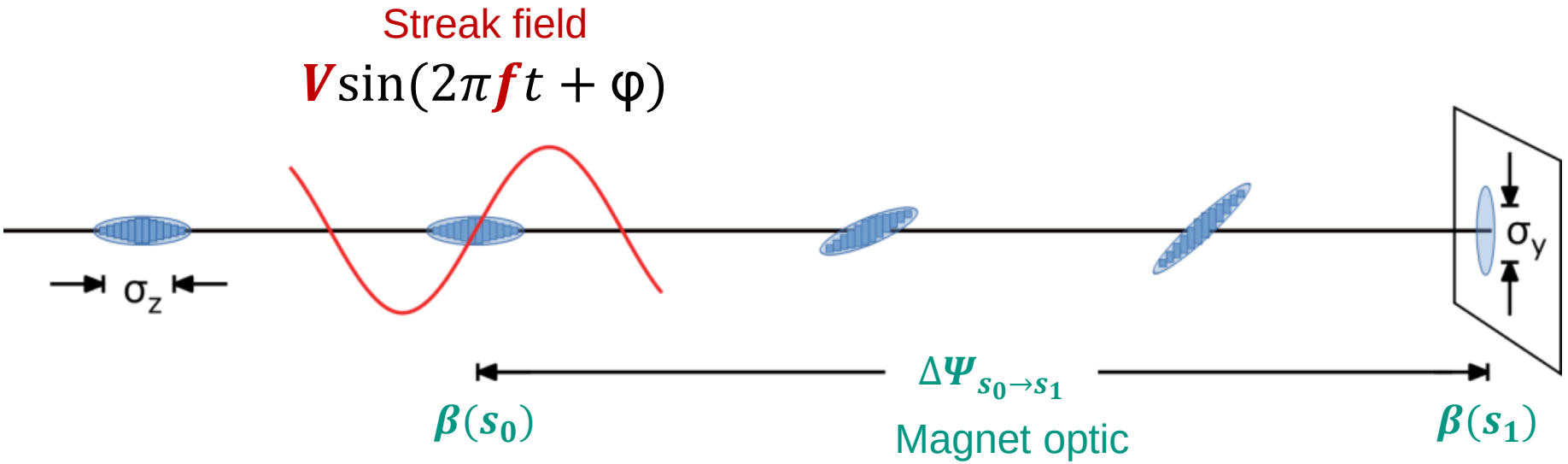
Thomas Feurer, Mozhgan Hayati, Zoltan Ollmann, Roxana Tarkeshian

… and additional support by the technical teams

Acceleration vs. deflection vs. streaking



Principle of electron bunch streaking



- At zero-crossing of streak field: $y \propto z$
- Streaking strength: $S = \sqrt{\beta(s_0)\beta(s_1)}\,\sin(\Delta\Psi_{s_0 \to s_1})\,\frac{eV}{E}\,\frac{2\pi f}{c}$
- Resolution: $\frac{\sigma_{y0}}{S} = \frac{\sqrt{\varepsilon_y}}{\sqrt{\beta(s_0)}}\,\frac{1}{\sin(\Delta\Psi_{s_0 \to s_1})}\,\frac{E}{eV}\,\frac{c}{2\pi f}$

Principle of SRR diagnostics

„Split ring resonator based THz-driven electron streak camera featuring femtosecond resolution“

J. Fabiańska, G. Kassier, T. Feurer, Sci. Rep. 4, 5645 (2014)

- THz-range => **high frequency *f***
  - $LiNbO_3$ crystal => 35 fs pulse at 800 nm (FLUTE laser) converted to THz pulse
- Field enhancement in SRR gap => **large “kick” voltage *V***
  - Enhancement factor ~100 (at 0.3 THz, λ = 1 mm, $(10\ \mu m)^3$ gap volume)

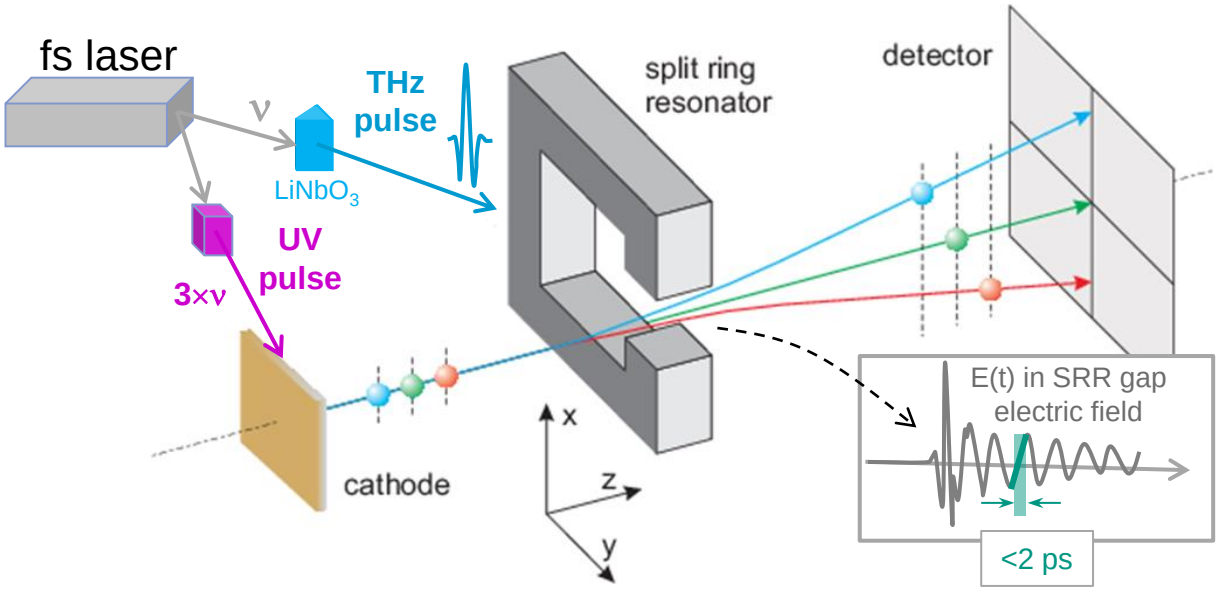
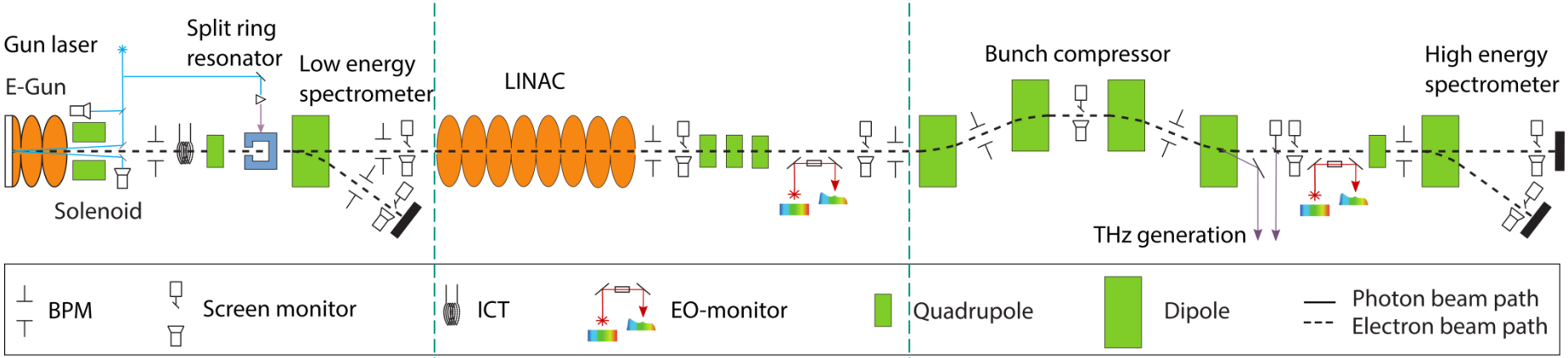
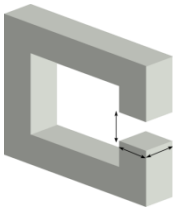


Image adapted from: J. Fabiańska, G. Kassier, T. Feurer. Sci. Rep. 4, 5645 (2014)

FLUTE (**F**erninfrarot **L**inac- **u**nd **T**est-**E**xperiment)



Gun	LINAC	Compressor	Bunch
1…3000	1…3000	1…3000	Charge / pC
7	41	41	Energy / MeV
250…2500	250…2500	few…500	Length / fs

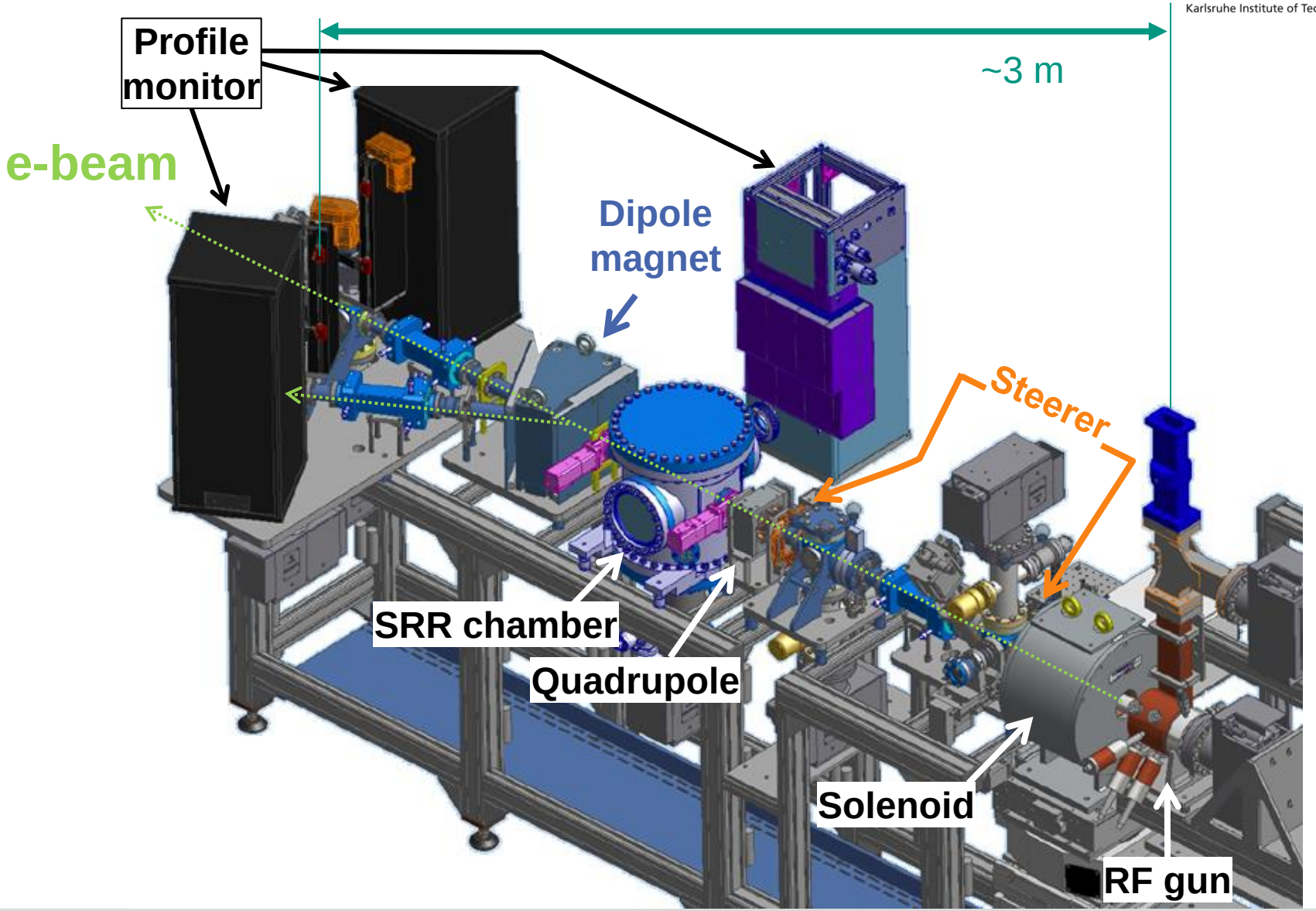


SRR experiment

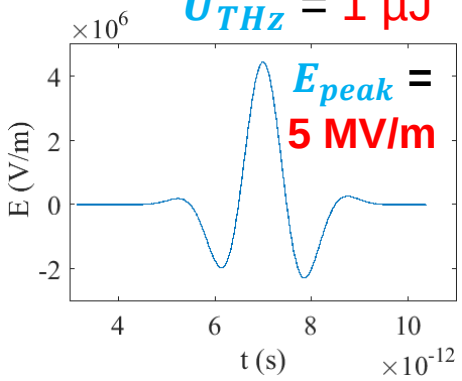
Your experiment here!

Open for suggestions …

Split ring resonator experiment at FLUTE



Simulation procedure & estimated values



NIR → THz: ζ = 0.05%
$LiNbO_3$ - tilted pulse front

estimate E_{peak} for focus
d = 6 mm (at 0.05 THz)

U = 2 mJ

Laser

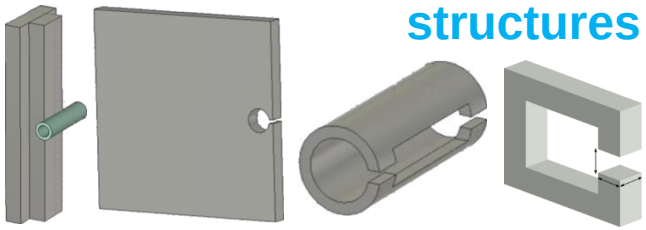
$\lambda = 800$ nm
$d = 11$ mm
$t = 35$ fs

×3

Gun

$f_{rep} = 10$ Hz

ASTRA



CST

6D EM field map complex ($\vec{E}$,$\vec{B}$) in SRR gap

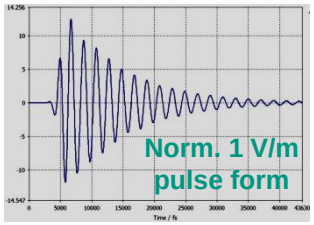
ASTRA

Energy spectrometer screen

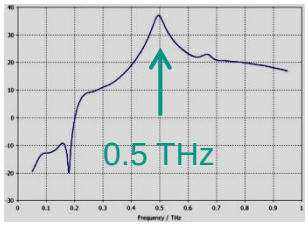
3D (x,y,z) ($\vec{E}$,$\vec{B}$) field map
(cw, norm. 1 V/m, 5×…6×)

Single point example

Time domain E(t)



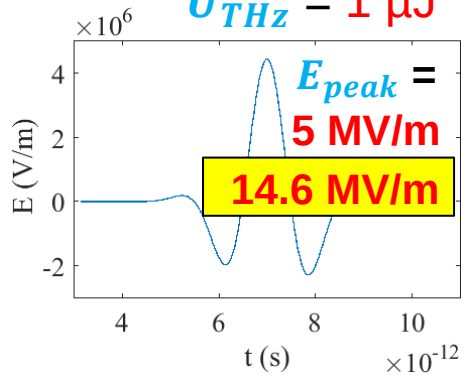
Spectral domain E(ν)



Simulation procedure & measured values

0.8 µJ

U_{THz} = 1 µJ



NIR → THz: ζ = 0.05%
$LiNbO_3$ - tilted pulse front

U = 2 mJ

estimate E_{peak} for focus
d = 6 mm (at 0.05 THz)

ζ = 0.024%

3.35 mJ

Horizontal × Vertical FWHM
0.92 mm × 1.15 mm (at 0.3 THz)

Laser

$\lambda = 800$ nm
$d = 11$ mm
$t = 35$ fs

×3

Gun

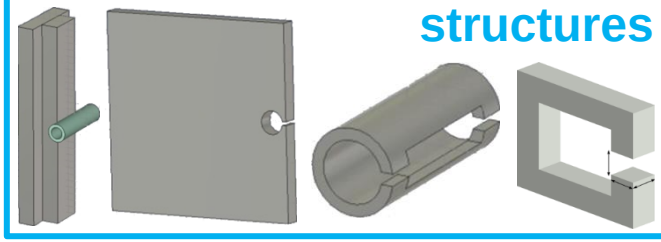
$f_{rep} = 10$ Hz

ASTRA

6D EM field map complex ($\vec{E}$,$\vec{B}$) in SRR gap

ASTRA

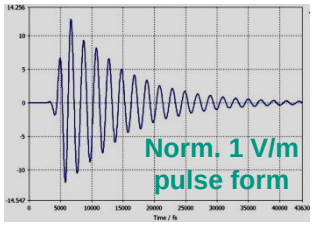
Energy spectrometer screen



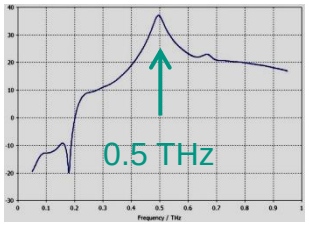
CST

3D (x,y,z) ($\vec{E}$,$\vec{B}$) field map
(cw, norm. 1 V/m, 5×…6×)

Time domain E(t)



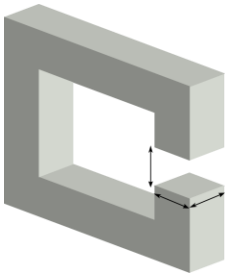
Spectral domain E(ν)



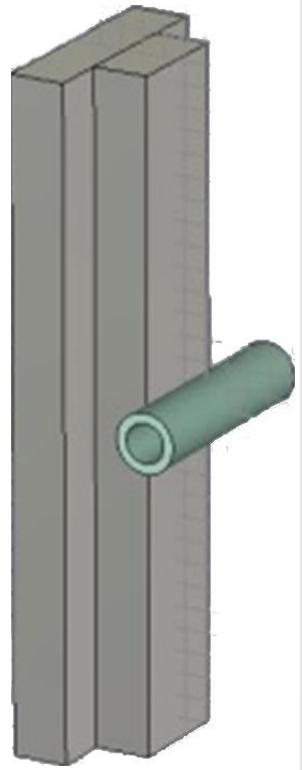
Single point example

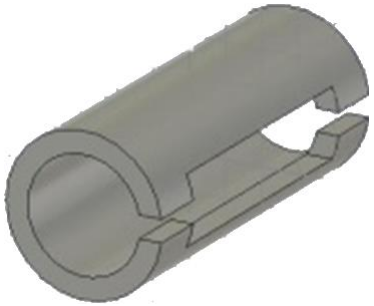
Simulation results for various structures

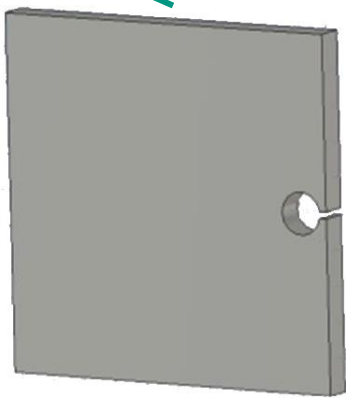
Beam “kick” normalized to SRR (typical ranges 1 to 10 keV / c)



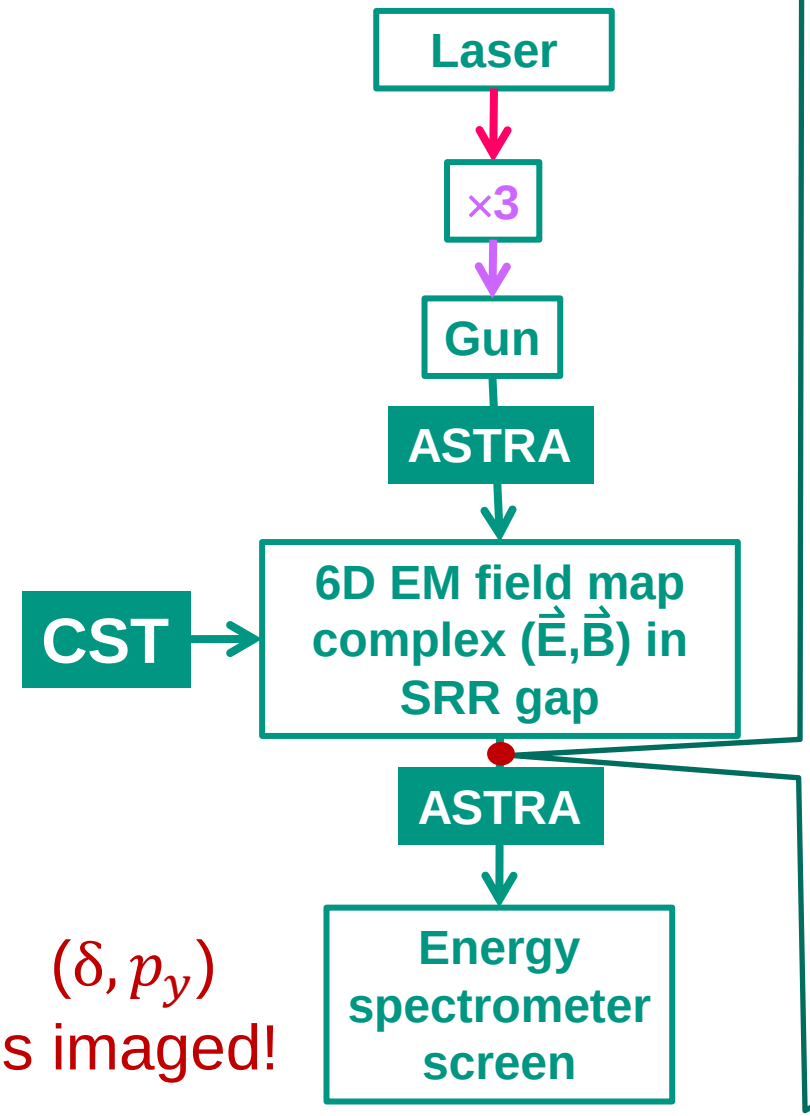
	Beam kick / %	Resonant f / THz
SRR cubic gap	100	0.3
Slotted tube	60	0.5
Tube (com.)	420	0.5
SRR plate	180	0.5



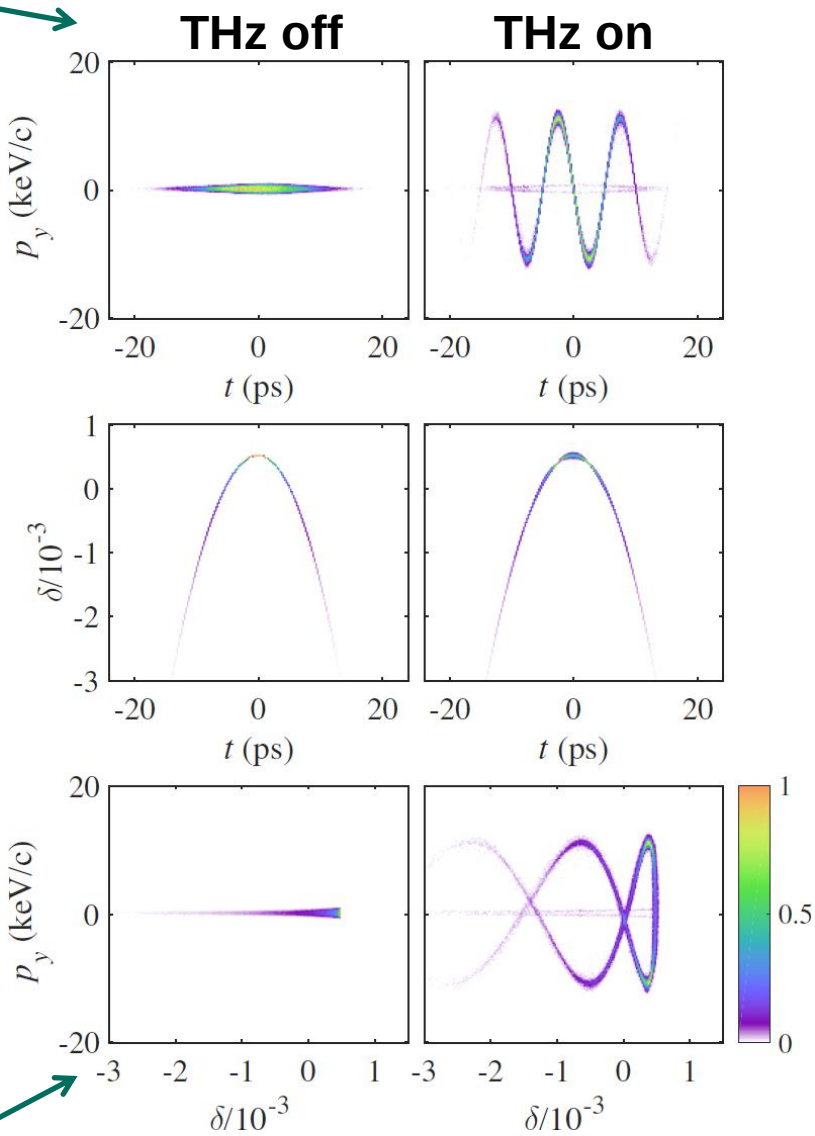




Simulation results: beam “kick” = 10 keV /c



(δ, p_y) is imaged!

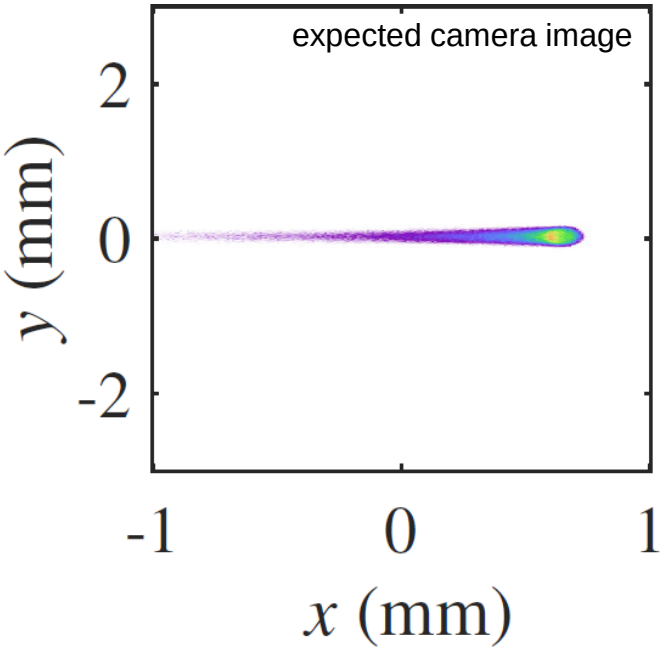


Measurement: electrons incident on camera

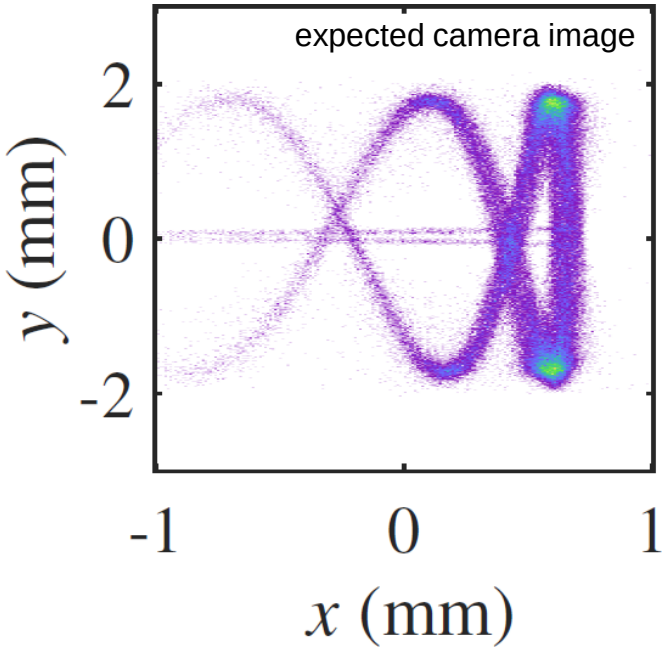
Energy spectrometer screen

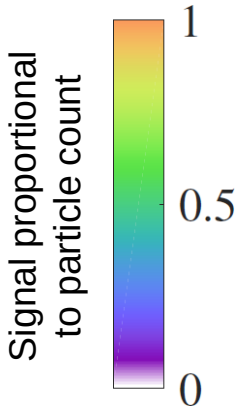
$p_y(t)$
$\delta(t)$
} (δ, p_y) is imaged!

THz off



THz on





Temporal resolution

$$\frac{\sigma_{y0}}{cS} = \frac{\sqrt{\varepsilon_y}}{\sqrt{\beta(s_0)}} \frac{1}{\sin(\Delta\Psi_{s_0 \to s_1})} \frac{E}{eV} \frac{1}{2\pi f}$$

use FLUTE parameters

	SRR deflector	Unit
Bunch charge	50	fC
E	7	MeV
Norm. ε_y*	3	nm
V	10	kV
f	500	GHz
$\sqrt{\beta(s_0)}$	1	$\sqrt{\text{m}}$

$$\frac{\sigma_{y0}}{cS} \sim 3 \text{ fs}$$

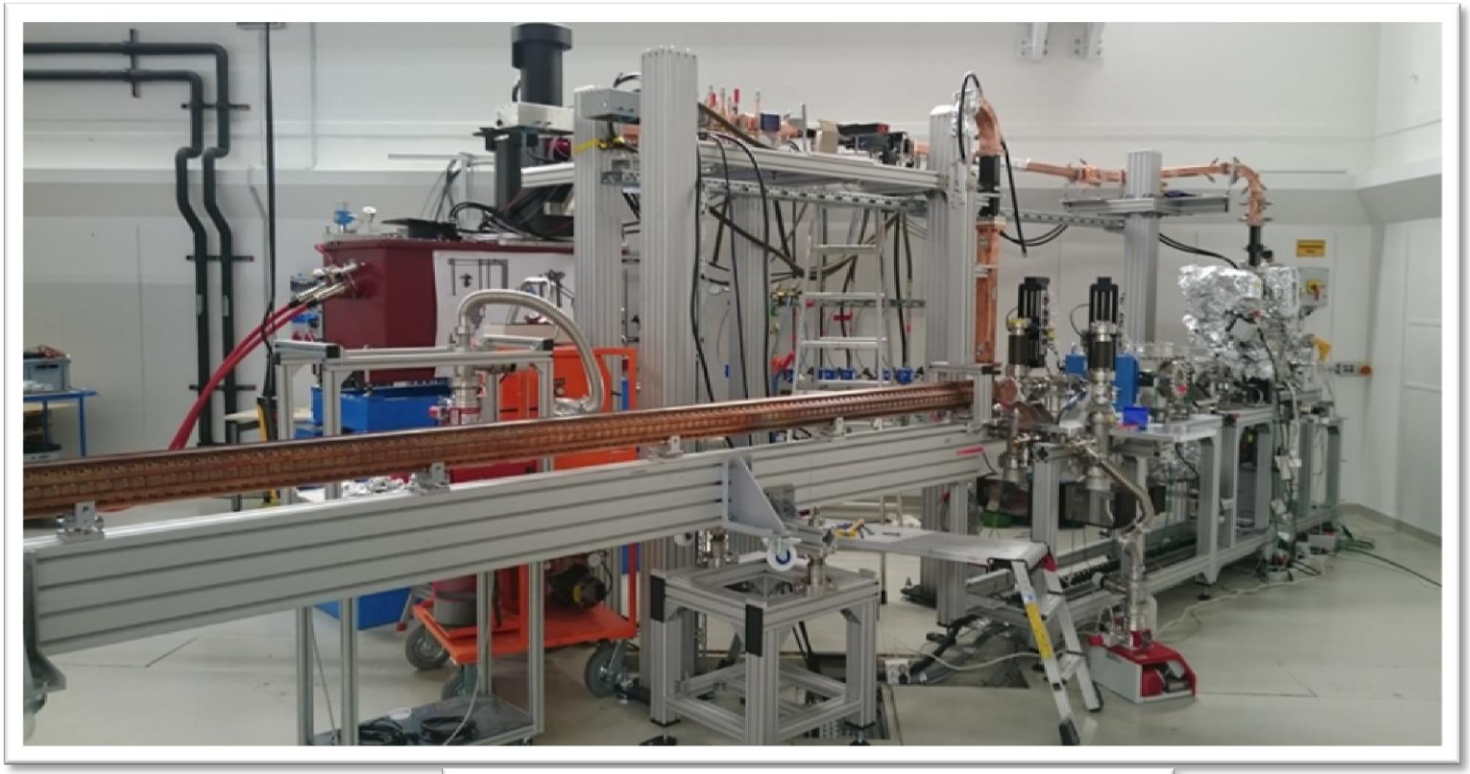
Better $\frac{\sigma_{y0}}{cS}$

- with different SRR design
  → larger field enhancement
- for SRR array
  → more “kick”

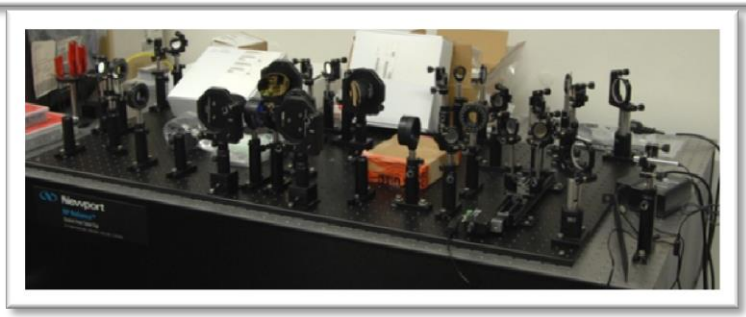
- for high energy e-beams
  - smaller emittance
  - larger beta-function $\sqrt{\beta(s_0)}$ is ok
    → e-beam still fits through SRR gap

Tasks status KIT

- **FLUTE: accelerator**



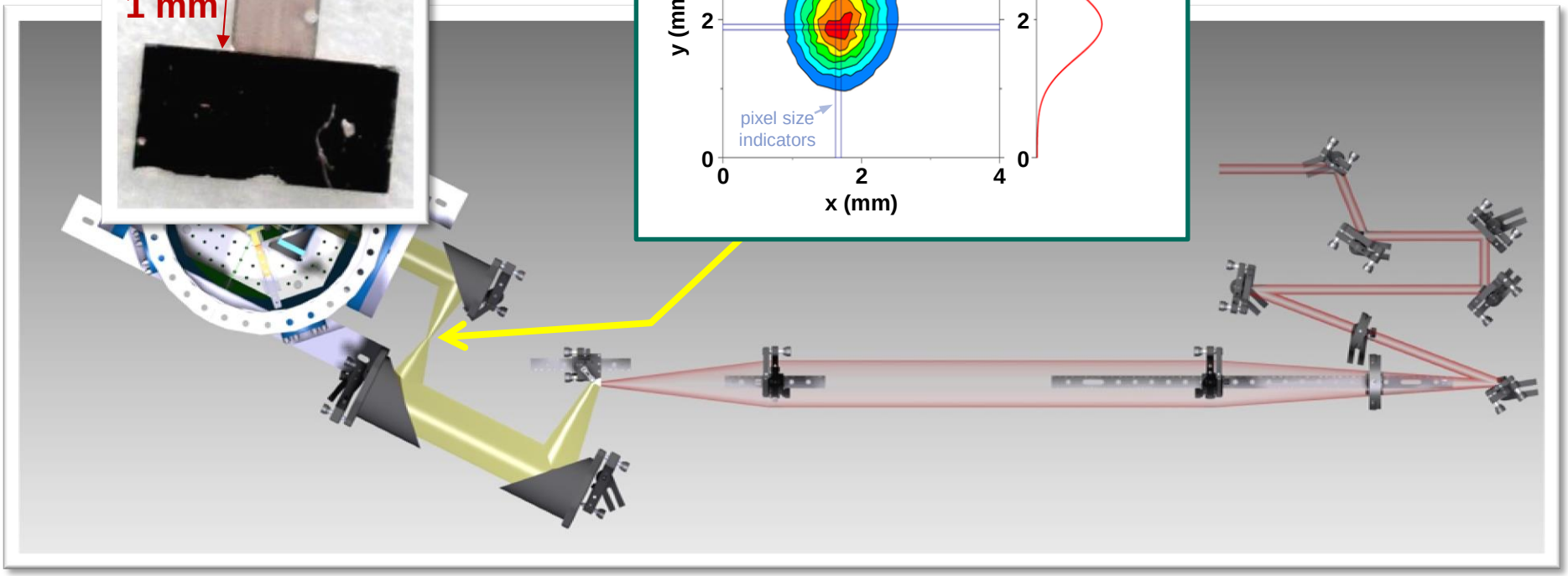
- **THz diagnostics**



THz measurements
broadband (preliminary)
span: $\Delta\nu$ = 0 … 20 THz
risetime: τ ~18 fs

Tasks status University Bern

- **THz generation**
  - Design at Bern
  - Set-up & test at Bern
  - Installation at KIT
- **SRR structures**

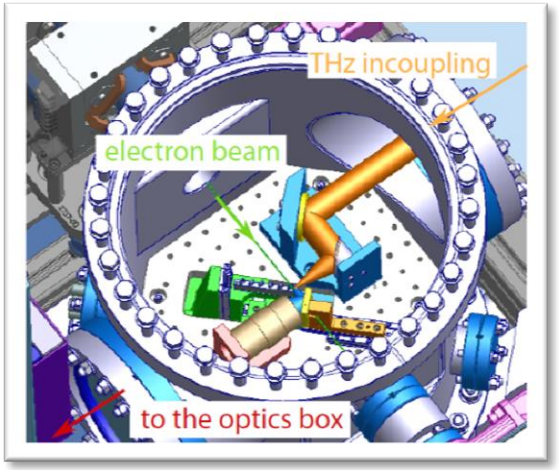


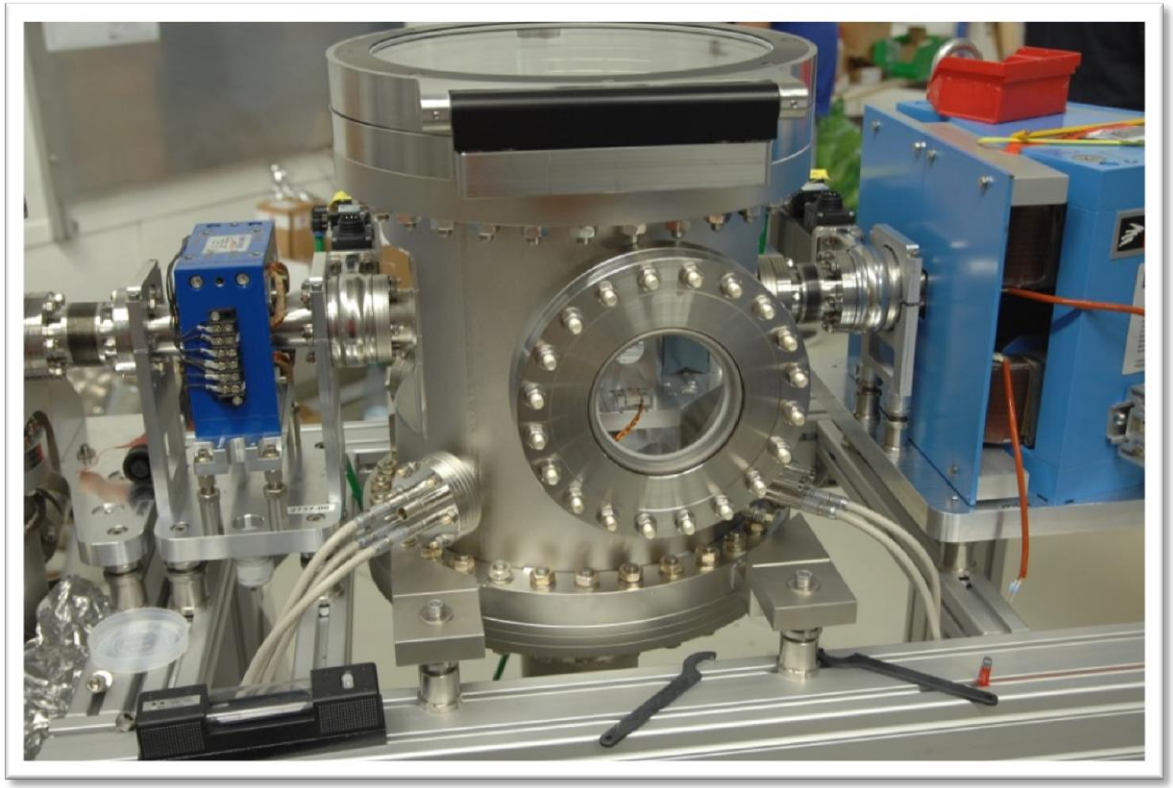
Profile measured with FLUTE laser at KIT

Horizontal × Vertical FWHM
0.92 mm × 1.15 mm (at 0.3 THz)

Tasks status PSI

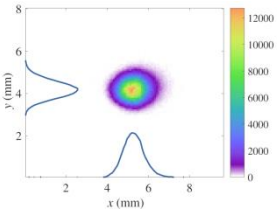
- **Vacuum chamber**
  - Design at PSI
  - Manufacturing at PSI
  - Installation at KIT



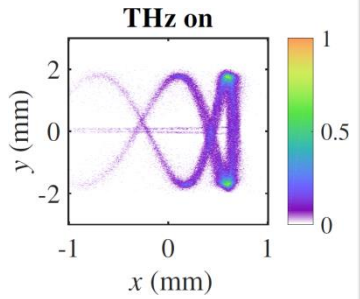


Summary

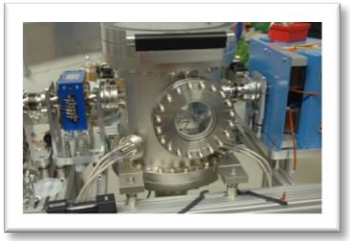
- Preparation for the 1st experiment at FLUTE *in progress*
  - Vacuum chamber installed
  - THz pulse generation & beam profile measured



- For 50 fC: potential time resolution $\frac{\sigma_{y0}}{cS} \sim$ 3 fs



- Proof-of-principle experiment at FLUTE for 7 MeV
- Support by many of the SRR collaboration …



"Split ring resonator based THz-driven electron streak camera featuring fs resolution"