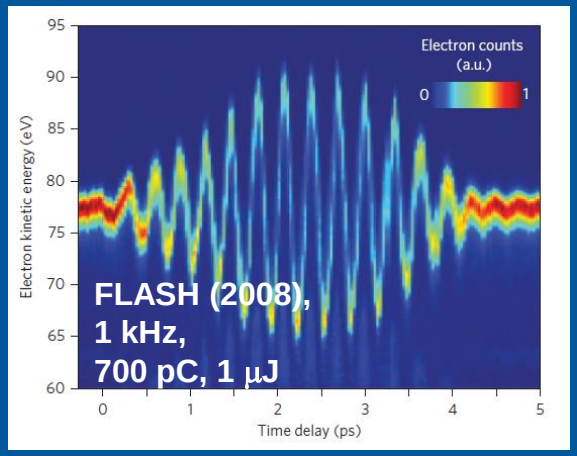
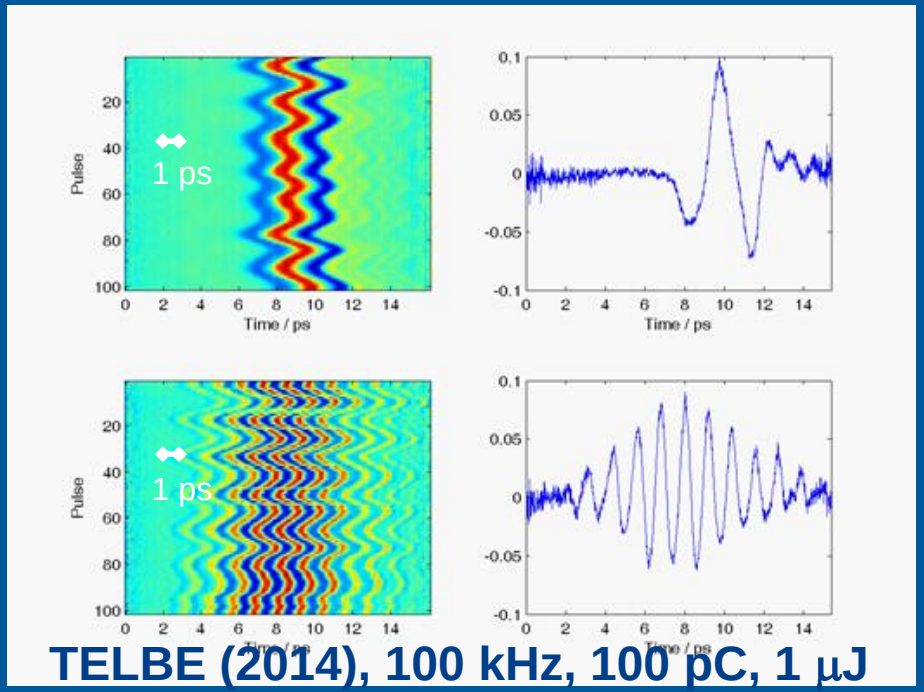
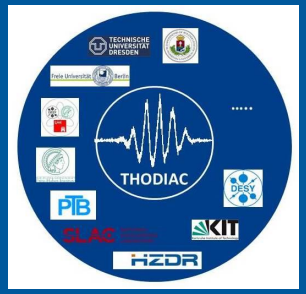
TELBE: the prototype facility for quasi-cw SRF driven high-field THz sources







M. Gensch
HZDR & THODIAC coll.

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

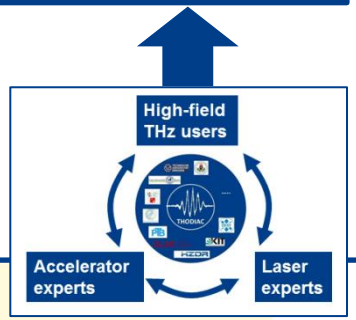
HZDR: "*research on matter under extreme conditions*"

- Europes only cw- SRF e- linac (ELBE)
  -> up to 13 MHz reprate
- high magnetic field lab (HLD)
  -> pulsed fields up to ~ 100 T
- 1 few 100 Terawatt-lasersystem
- 1 Petawatt-lasersystem

"matter under extreme cond."

HZDR: High-field THz Research

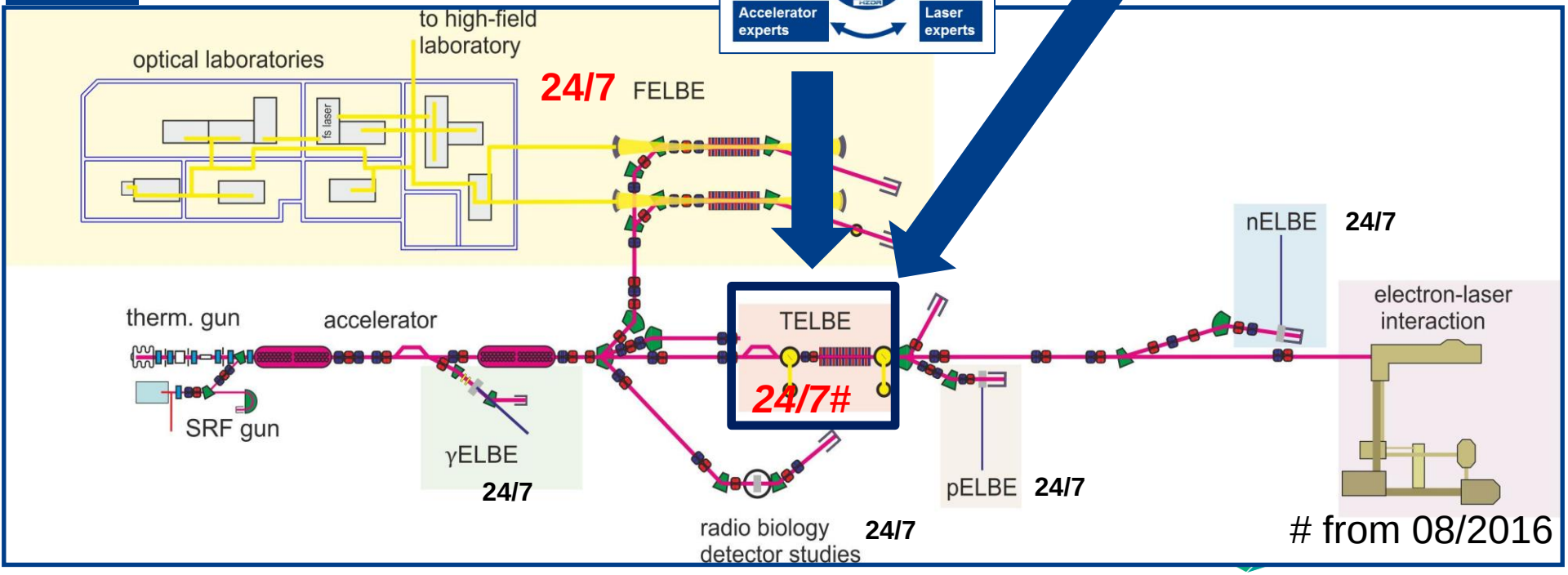
Collaborators/Advisors
THz driven dynamics:
T. Kampfrath / FHI
A. Cavalleri / MPSD
R. Huber / U Regensburg
S. Wall / ICFO
R. Tobey / U Groningen
J. Heberle / FUB…….



THz field driven phenomena group:

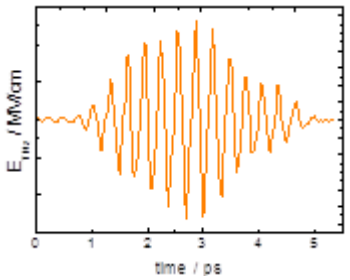
Mission:
1. high-field high-rep-rate THz science
2. scientific program TELBE
3. Instrumentation devel.
4. ARD (photon/electr. diagn.)
5. from 2016: user support

ELBE

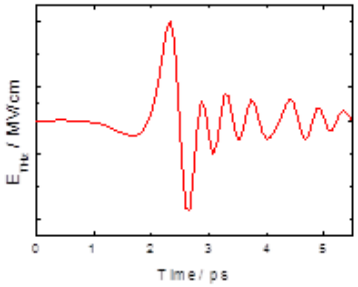


from 08/2016

HZDR: TELBE

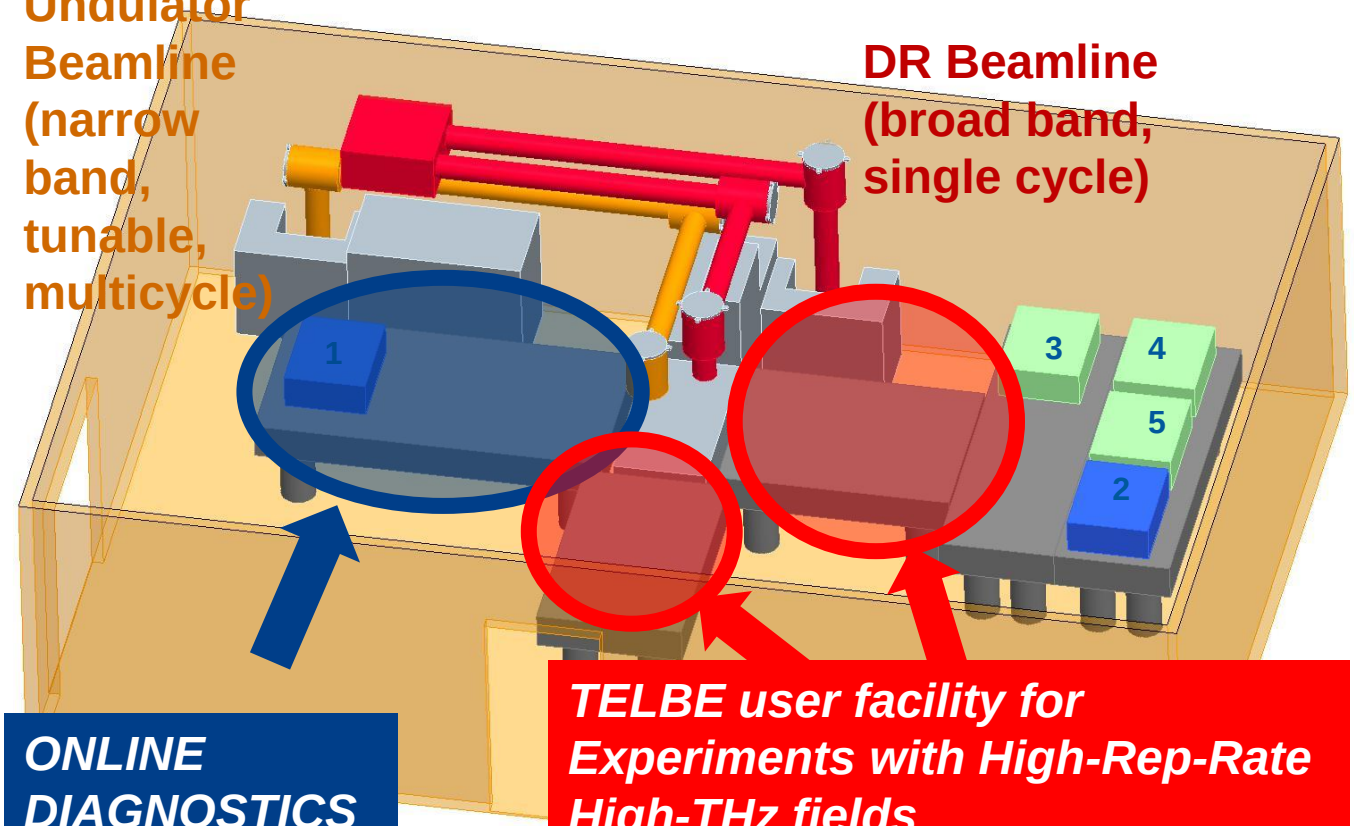


ν = 0.1 – 3 THz
> 1 μJ @ 13 MHz
>100 kHz @ 100 kHz



Undulator Beamline (narrow band, tunable, multicycle)

DR Beamline (broad band, single cycle)



ONLINE DIAGNOSTICS & ARD ST3

TELBE user facility for Experiments with High-Rep-Rate High-THz fields

Start of user-operation 08/2016

Lab infrastructure

2 x FTIR spectrometers (1&2)
- 0.03 - 119 THz
- step scan & rapid scan

1 x laser-amplifier (3) - high peak pow.
- mJ pulse energy
- 1 kHz repetition rate
- 1o0 fs pulse duraction

1 x laser-amplifier (4,5) – high rep. rate
- μJ pulse energy
- up to 250 kHz repetition rate
- 100 fs pulse duration

1 x tilted pulse front LiNb source (high-field, 1 kHz reprate)

+

various OR-based THz sources (low field, kHz - MHz reprate)

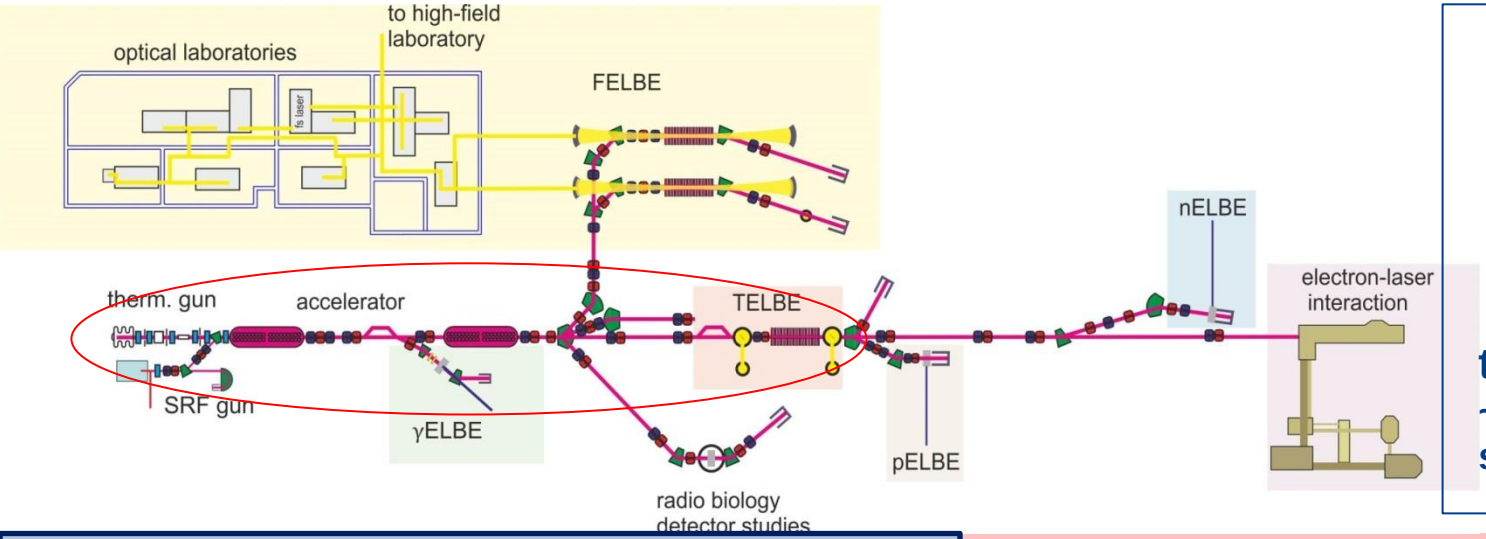
1 x 10 T split-coil magnet (09/2015)

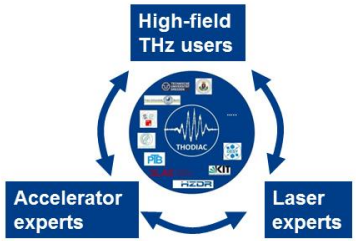
different small optical magnets in the few 100 mT range

+

THz pump TR Faraday probe endstation

TELBE THz source





typically
~ 20 ARD shifts per semester through SAC

ARD – Accelerator Research and Development

ARD Test facility for diagnostic on quasi – cw electron and photon beams:

- quasi – cw reprates: few Hz to 13 MHz (adjustable)
- e-bunch charge: few pC – 1 nC
- diagnostic table in TELBE lab (access to undulator & CTR source + fs laser + FTIR spectrometer)
- monitor test stand in e-beamline directly after THz sources
- prototype compact superradiant facility

Photon Science

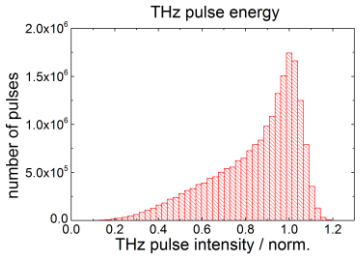
High-field THz user facility (by 2016?):

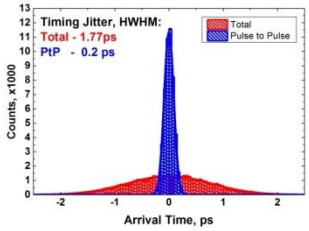
design goals:

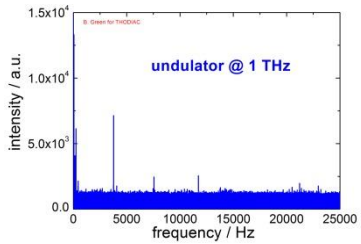
- quasi – cw rep rates: few Hz to 13 MHz (adjustable)
- pulsenergies: up to 100 μJ
- spectral properties: 0.1 – 3 THz narrow band (10-20%) / broad band
- polarization: linear/radially
- sub 100 fs synchronisation to fs-laser
- intrinsic synchonisation CTR<->undulator

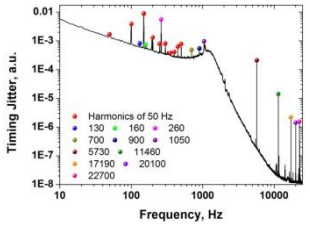
selected next steps/activities: ARD

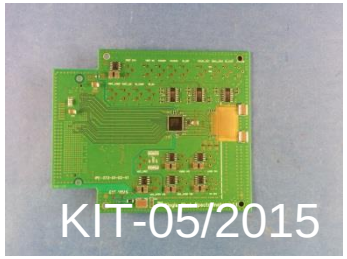
high-rep-rate pulse to pulse diagnostic:











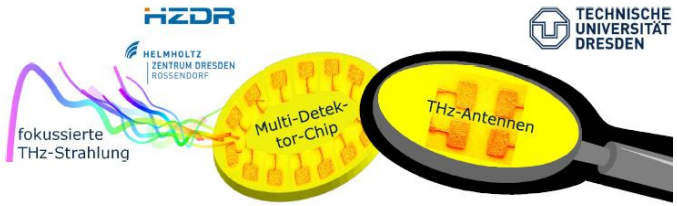
TELBE/FLASH

XFEL
(EU project
EUCALL: 187 kE)

- upgrade to
4.5 MHz (if possible 13 MHz)
- upgrade to
few fs regime

FELBE

longitudinal diagnostic:



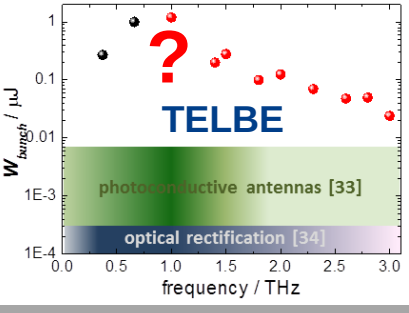
- spectrally res.
BCM monitor
- up to few GHz
rep rate

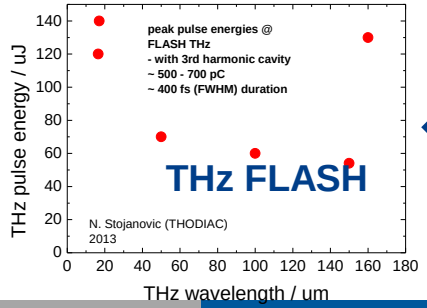
ELBE
**(BMBF Verb.
INsEL with TUD)
~ 400 kE**

XFEL, FLASH?

FLUTE, BERlinPro?

superradiant undulator radiation:





exp. <-> simul.

Study of electron beam dynamics and properties of electromagnetic radiation in free electron lasers and storage ring-based light sources

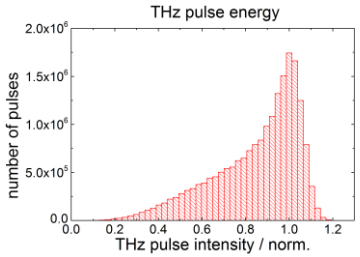
G. Geloni / X-FEL

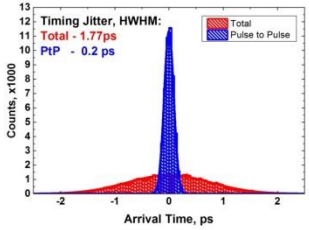
Proposal in the framework of the German-Russian call for proposals 'Ioffe-Röntgen-Institute'

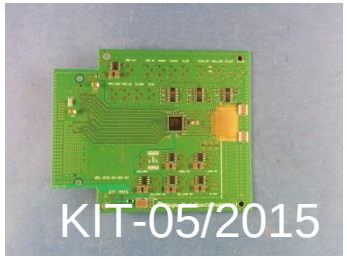
Funding period request: 01.09.2014 - 31.12.2017

selected next steps/activities: ARD

high-rep-rate pulse to pulse diagnostic:

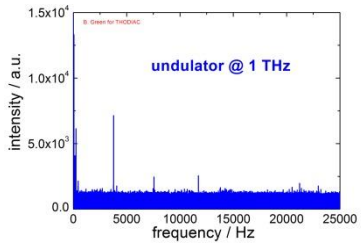


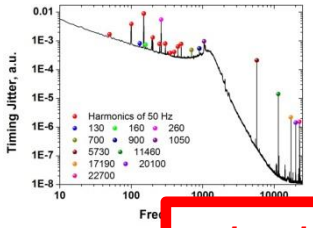




TELBE/FLASH

XFEL
(EU project
EUCALL: 187 kE)





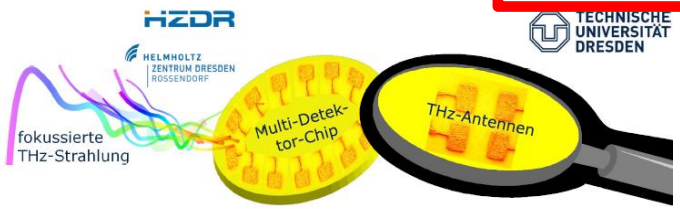
- upgrade to
4.5 MHz (if possible 13 MHz)
- upgrade to
few fs regime

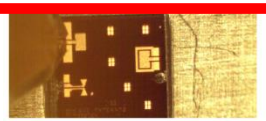
FELBE

+ testing THz SASE principle?
+ test of corrugated waveguides?

ELBE
**(BMBF Verb.
INsEL with TUD)
~ 400 kE**

longitudinal diagnostic

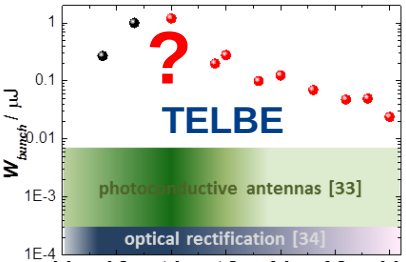


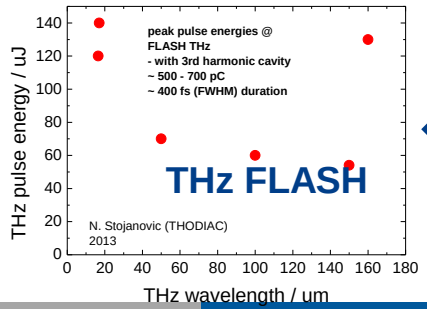


- spectrally res.
BCM monitor
- up to few GHz
rep rate

XFEL, FLASH?

superradiant undulator radiation:





exp. <-> simul.

FLUTE, BERlinPro?

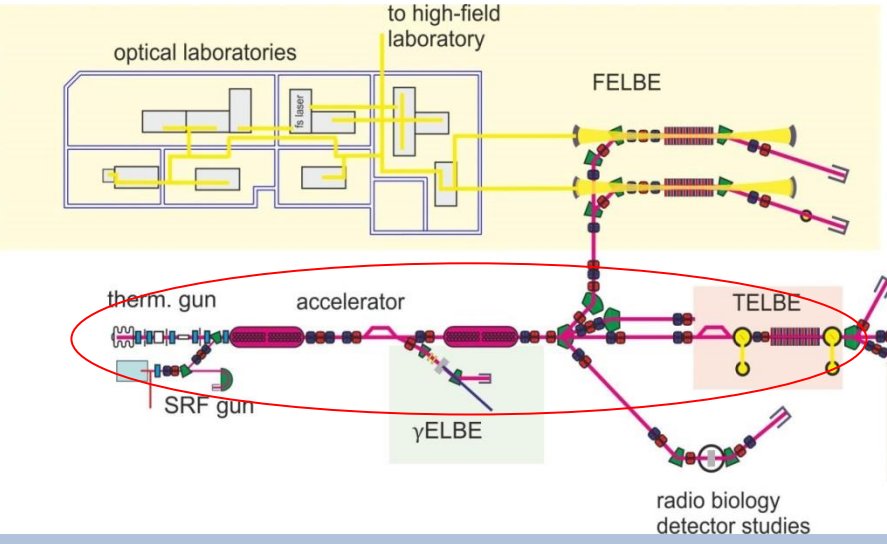
Study of electron beam dynamics and properties of electromagnetic radiation in free electron lasers and storage ring-based light sources

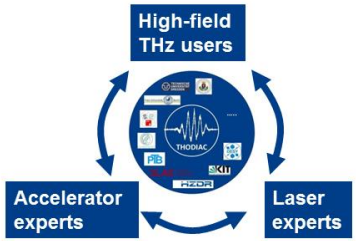
G. Geloni / X-FEL

Proposal in the framework of the German-Russian call for proposals 'Ioffe-Röntgen-Institute'

Funding period request: 01.09.2014 - 31.12.2017

TELBE THz source





typically
~ 20 ARD shifts per semester through SAC

ARD – Accelerator Research and Development

ARD Test facility for diagnostic on quasi – cw electron and photon beams:

- **quasi – cw reprates: few Hz to 13 MHz (adjustable)**
- **e-bunch charge: few pC – 1 nC**
- **diagnostic table in TELBE lab (access to undulator & CTR source + fs laser + FTIR spectrometer)**
- **monitor test stand in e-beamline directly after THz sources**
- **prototype compact superradiant facility**

Photon Science

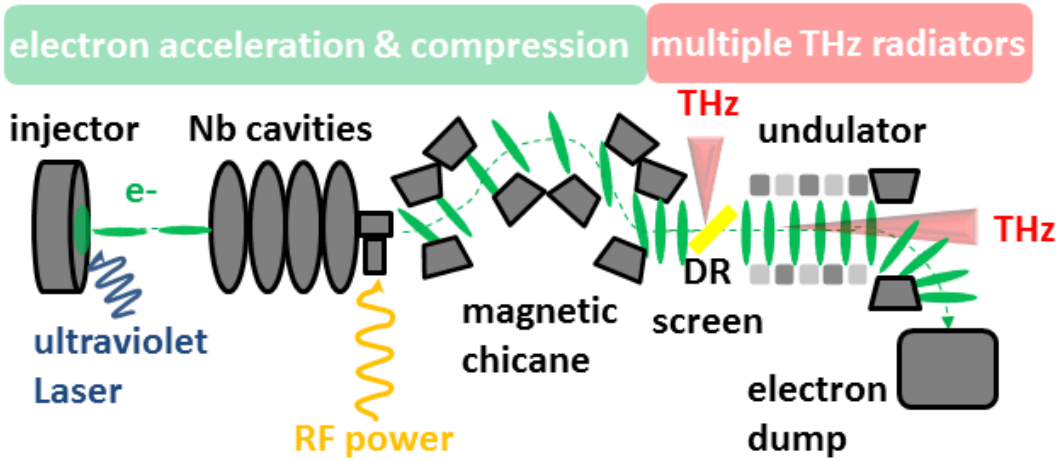
High-field THz user facility (by 2016?):

design goals:

- **quasi – cw rep rates: few Hz to 13 MHz (adjustable)**
- **pulsenergies: up to 100 μJ**
- **spectral properties: 0.1 – 3 THz narrow band (10-20%) / broad band**
- **polarization: linear/radially**
- **sub 100 fs synchronisation to fs-laser**
- **intrinsic synchonisation CTR<->undulator**

DRESDEN concept

Superradiant THz sources: compact prototype TELBE



timeline:

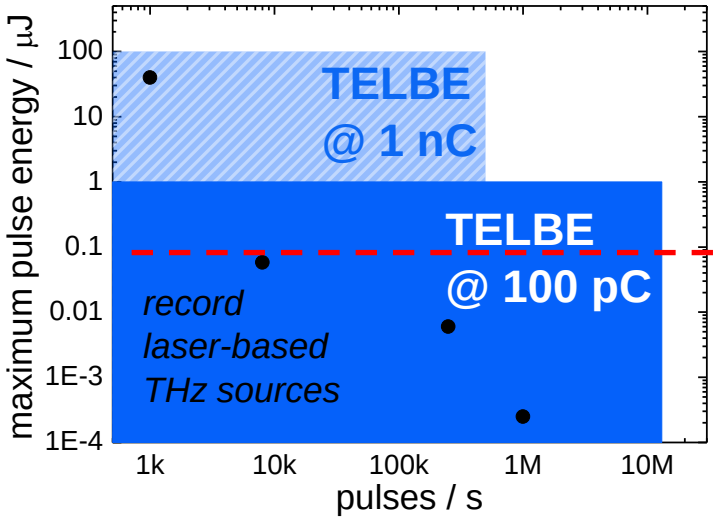
2013
- first sub ps electron bunches
- first bunches from SRF Gun
- first beam in THz laboratory

2014
- establish low charge mode
- establish high charge mode
- bunch form and arrival time meas.

2015
- 100 µJ/100 kHz @ 3 THz for 12h
- 1 µJ/ 13 MHz @ 3 THz for 12h
- sub 100 fs timing and diagnostics for 12h

2016: THz user facility?

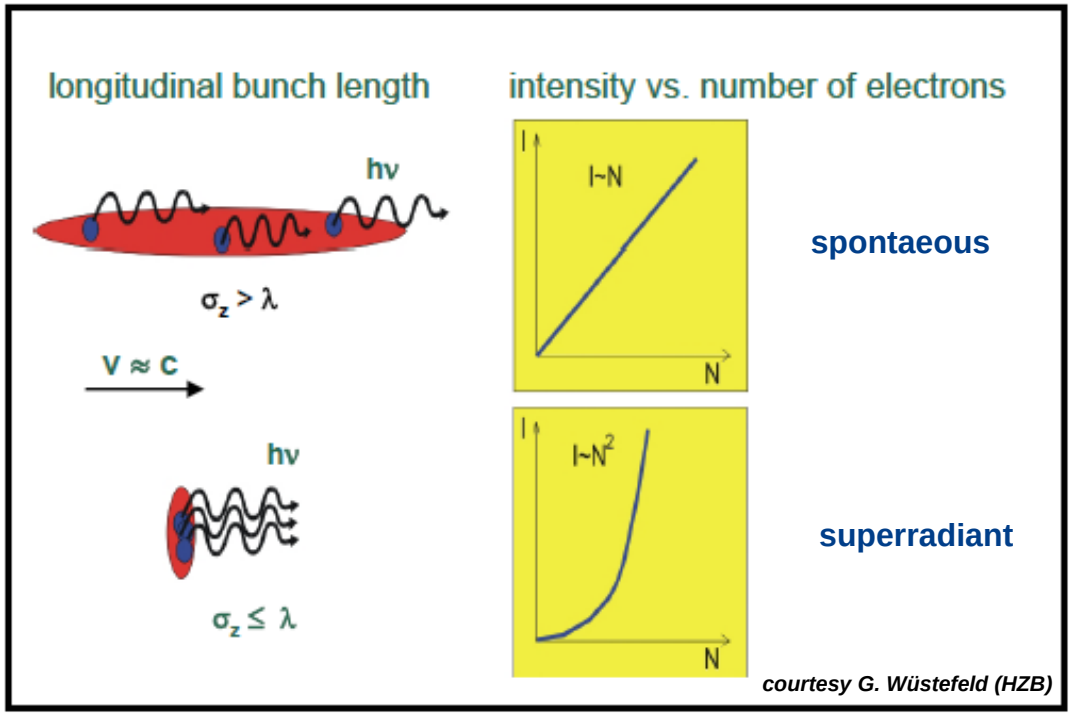
design parameters

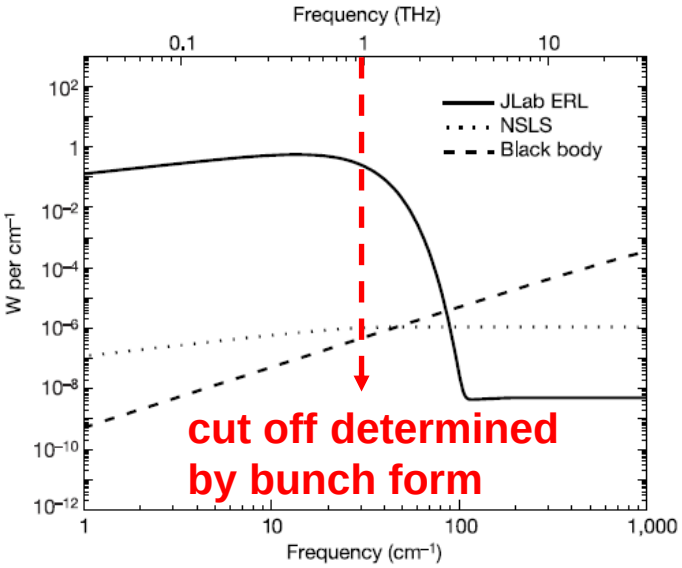


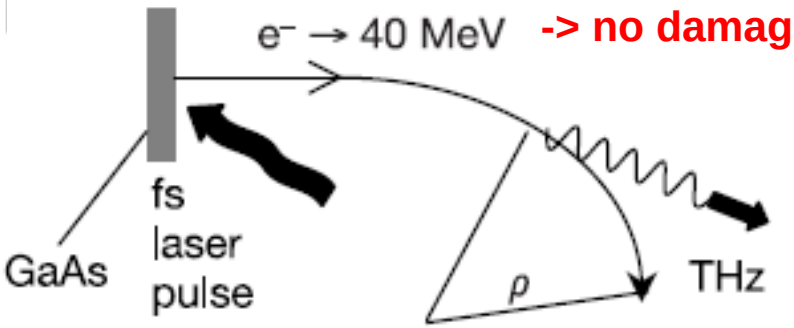
Goal:
establish feasibility of compact High-Field High-Rep-Rate THz facility

prototype for a new class of sources: "combination of compact low energy SRF linac & high-field THz source(s)" e.g. THz source at X-FEL, LCLS2, …

Superradiant THz sources: fundamental concept







in vacuum!
-> no damage threshold

world records:

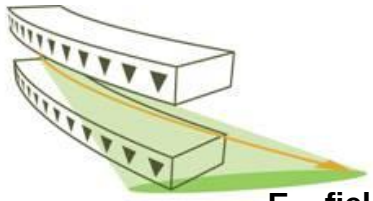
- 4 mJ / 120 Hz @ ~ 20 GeV (SLAC 2014)
- 100 μJ / 4 kHz @ 1 GeV (FLASH 2015)

-> feasible with compact high rep rate accelerators?
-> feasible at high rep-rate?

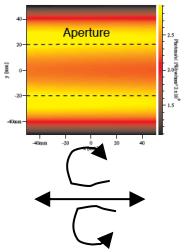
G.L. Carr et. al., Nature (2002)

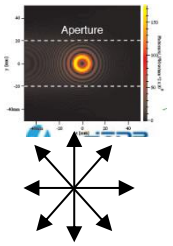
Superradiant THz sources: fundamental concepts

once e- bunches are short enough all classical “SR” radiators can be used:

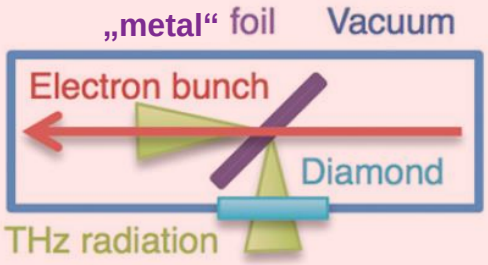


E – field:

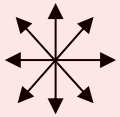


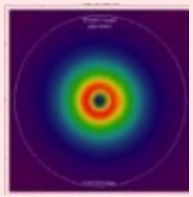


- broad-band / single cycle
- CEP stable
- mixed polarization

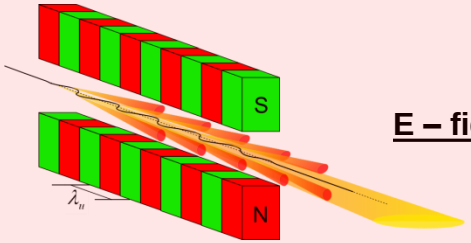


E – field:

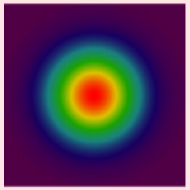




- broad-band / single cycle
- CEP stable
- radial polarization



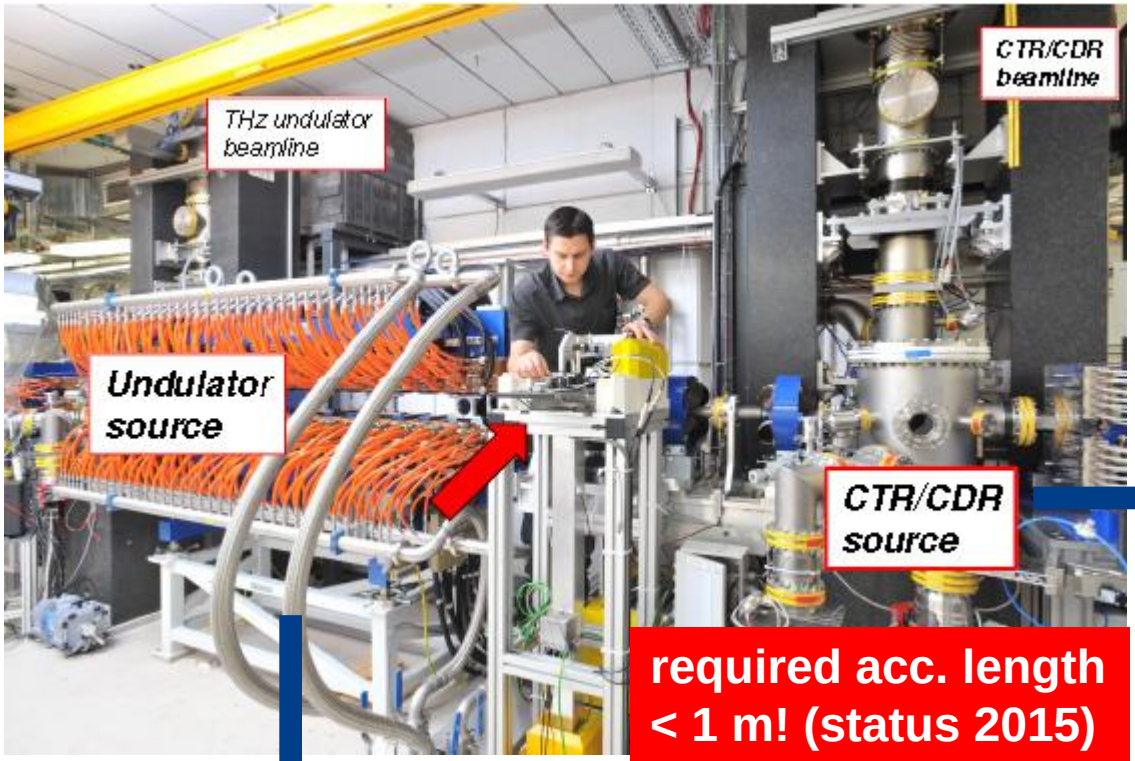
E – field:



- narrow band / multi cycle
- CEP stable
- linear polarization

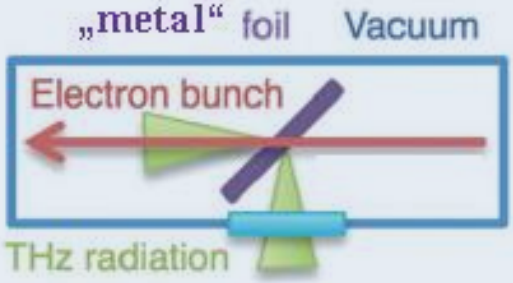
+ new concepts (e.g. corrugated waveguides – very narrowband)

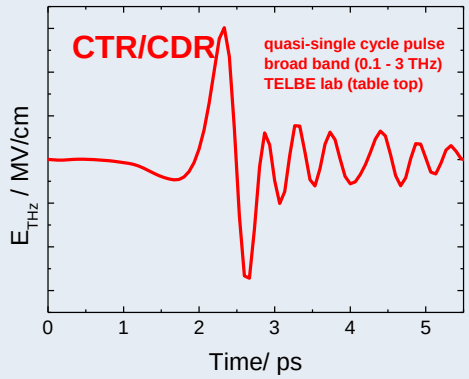
prototype THz facility TELBE: sources



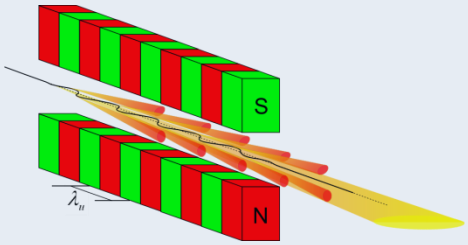
required acc. length < 1 m! (status 2015)

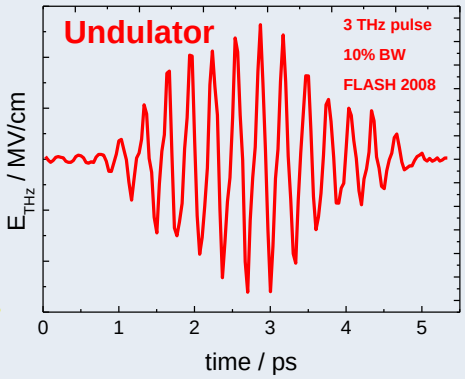
DR source





Undulator





THz pulses from the same electron bunch are naturally synchronized!*

*Tavella, Stojanovic, Geloni, Gensch, Nat. Photon. 2011

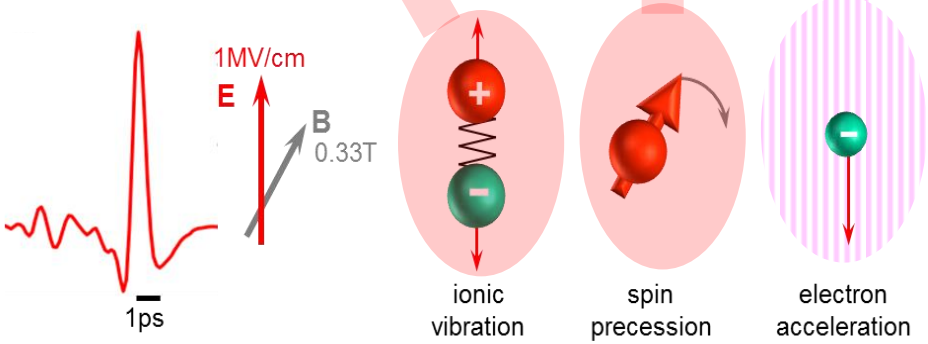
sources: table-top versus accelerator-based

High-field dream

"V/A" "10T" "GV/m"

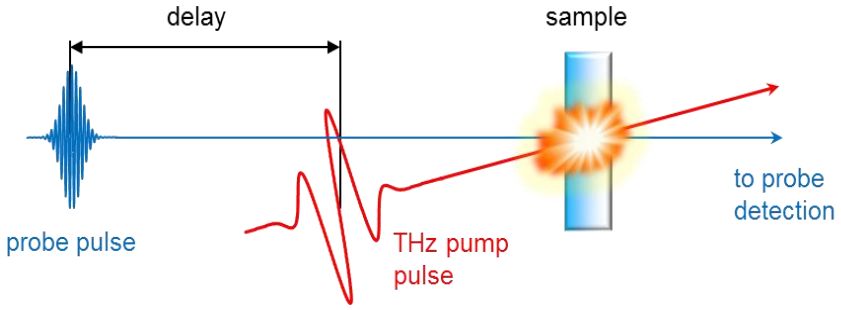
taken from:
Review article by T. Kampfrath, K. Nelson, I. Tanaka,
Resonant and non-resonant control over matter and
light by intense terahertz-transients
Nature Photonics (2013) (Review)

interactions of a THz pulse with matter



typical THz parameters:
1 μJ / 1 kHz & CEP

typical pump-probe scheme



….control superconductivity,
***spin flip**, control ion*
channel in biol. membranes,….

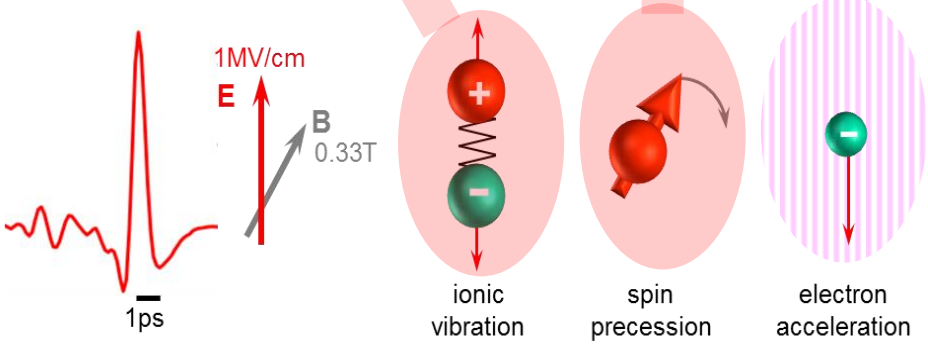
sources: table-top versus accelerator-based

High-field dream

"V/A" "10T" "GV/m"

taken from:
Review article by T. Kampfrath, K. Nelson, I. Tanaka,
Resonant and non-resonant control over matter and
light by intense terahertz-transients
Nature Photonics (2013) (Review)

interactions of a THz pulse with matter

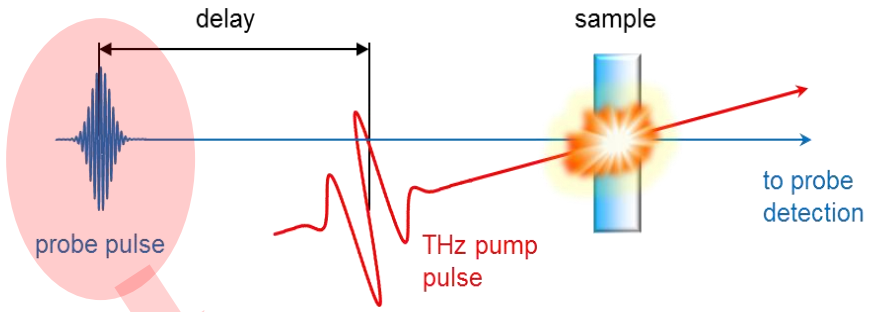


typical THz parameters:
1 μJ / 1 kHz & CEP

TELBE design parameters:
1 μJ / 13 MHz
100 μJ / 100 kHz
CEP

….control superconductivity,
***spin flip**, control ion*
channel in biol. membranes,….

typical pump-probe scheme



High-Rep-Rate dream

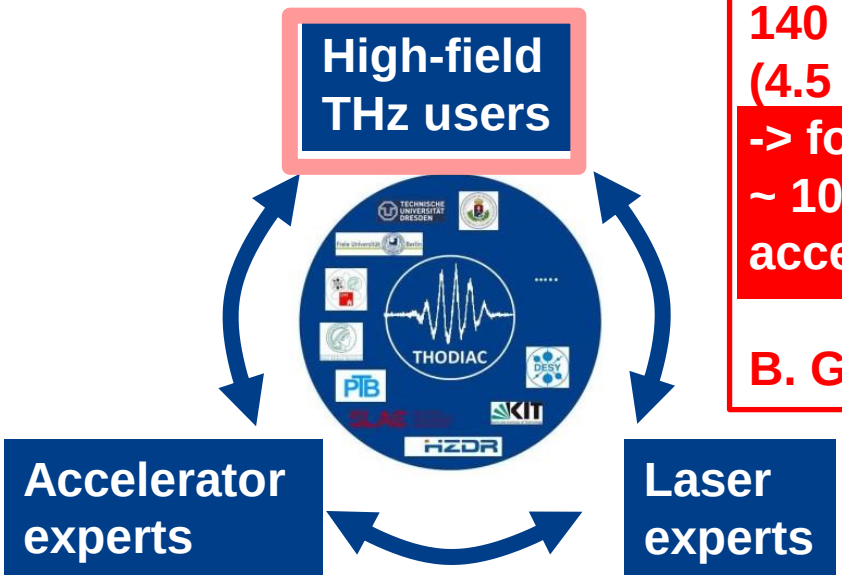
"duty-cycle hungry"

- **Brillouin scattering**
- **Raman scattering**
- **ARPES**

+ "extreme" conditions

Benchmarks – photon science

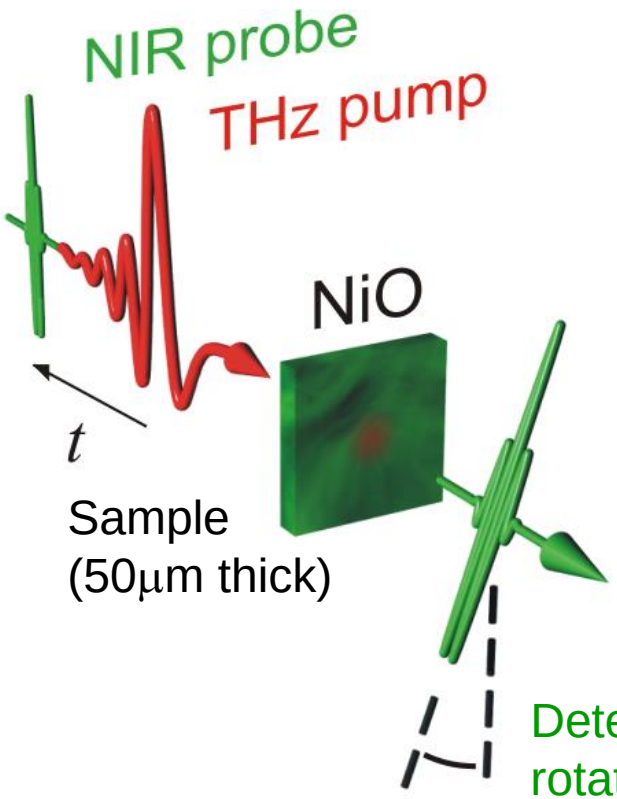
1. step:
provide temporal resolution & sensitivity of all-laser experiments (or better) @ elevated rep-rates

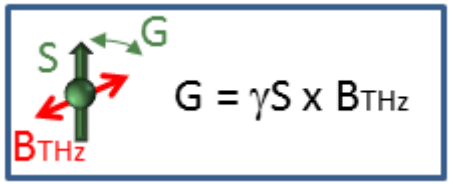


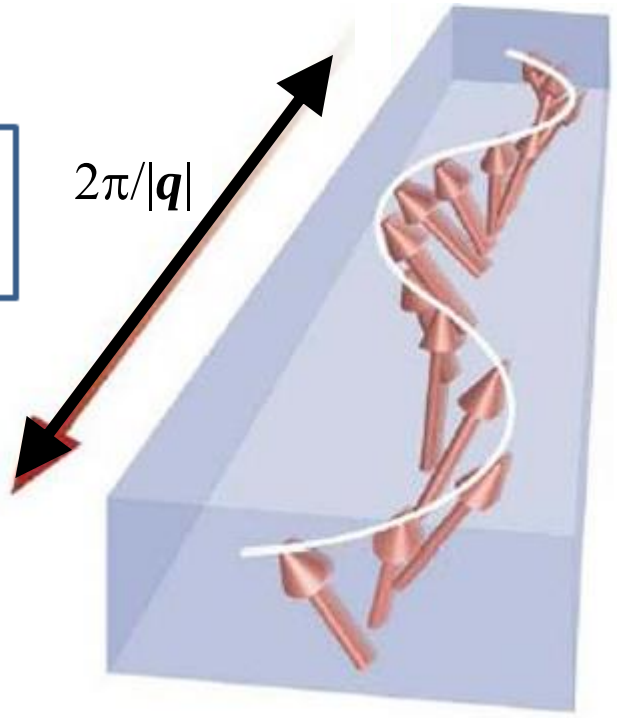
solved up to reprates of 140 kHz!!
(4.5 MHz under development)
-> for time synchronization ~ 10 fs one does NOT need accelerator feedbacks!!!

B. Green at. al, *to be submitted*

Benchmark experiment: THz control of spin waves







Detect Faraday rotation

$\theta(t) \propto \boldsymbol{k} \cdot \boldsymbol{M}(t)$

Antiferromagnetic NiO:

Magnon ($\boldsymbol{q} = 0$) at 1 THz

Sievers *et al.*, PR (1963)

T. Kampfrath *et al.,* Nat. Photon. (2011)

timeline to user TELBE operation in 2nd sem. 2016

sometime 10 – 12/2015
kick-off workshop

01 – 06/2016
increased efforts improve/stabilize performance

03/2016
final go & fixing of final parameters

Next activities/steps @ HZDR
1. add more THz cascaded sources in "ELBE I" linac
(discussed: SASE?, corrugated waveguides?, …..)
2. THz source at HIBEF / X-FEL?
3. Photonscience roadmap "ELBE II"
current proposal:
-> several electron beamlines in parallel operation
-> each feeding several cascaded superradiant THz sources

2nd semster 2016 "friendly user" operation

- **accepting proposals for:**

1. **ARD**
2. **photon science**

- **limted operation:**

20 shifts in 2 compact beamtime blocks

- start-up operational parameters (as of 05/2015):

- **time-resolution: few 10 fs**
- **repetition rate: up to 100 kHz**
- **frequency range (pump): 0.2 – 1.2 THz / @ 20% BW**
- **pulse energy (pump): few 100 nJ**
- **wavelength range (probe): 800 nm / 100 fs / few μJ / up to 300 kHz or 0.2 – 3 THz @ 100 kHz**

take home parameters (user perspective)

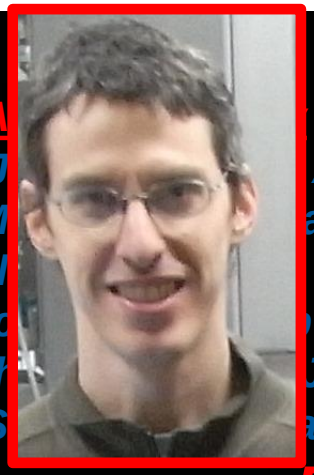
main interest (so far) @ TELBE

- **narrow band tunable for pumping resonant processes**
- **(C) DR pulse is used for timing**
- **range between 100 GHz to 3 THz particularly interesting for magnetization dynamics**
- **pump factor 2 less reprate than probe**

-> next essential step: combination with dutycycle hungry TR probe techniques

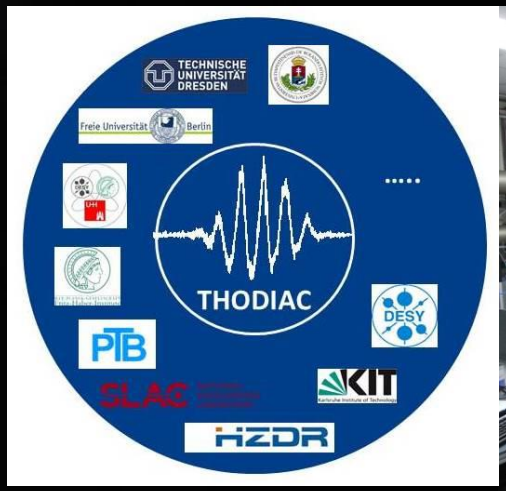
dream: chirped pulses!

Acknowledgement



N. Stojanovic, T. Golz, A (DESY), F. Tavella(HIJ, SLAC), G.
B. Faatz, T. Laarmann, J Al-Shemmary, J. Feldhaus, S. Ba
H. Wabnitz, L. Bittner, M ahn, M. Hesse, B. Schmidt,
Stephan Wesch, H. Schl E. Saldin, M.V. Yurkov,
E. Schneidmiller, S. Vilic (DESY), U. Frühling, M. Wieland
M. Krikunova, M. Dresch J. Roßberg (UHH),, H.W. Hübers,
A. Semenov (DLR), W. S aender, B. Wustmann (HZDR)

C. Bauer, S. Winnerl, H. Schneider, B. Green, S. Kovalev,
U. Lehnert, Jochen Teichert, Rico Schurig, M. Kuntzsch, M Justus, J. Hauser,



M. Vrakking (MBI),
B),
P. Michel (HZDR),
(BNL),
. Ulm (PTB), S
nasi (Budapest),
ingen)