Karlsruhe Institute of Technology

FLUTE

Compact linear accelerator FLUTE: status update

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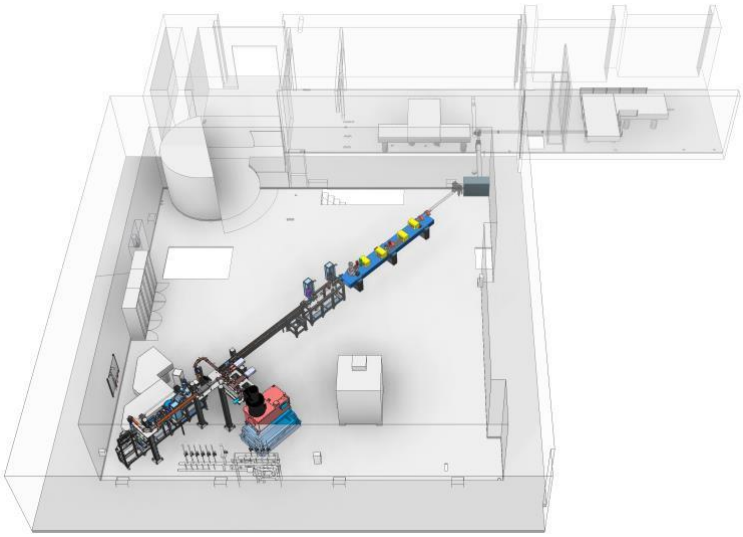
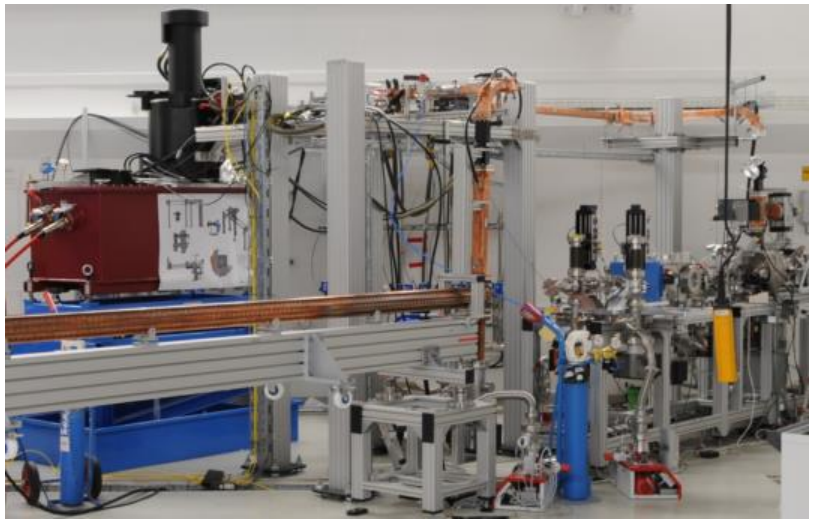
Institute for Beam Physics and Technology (IBPT)

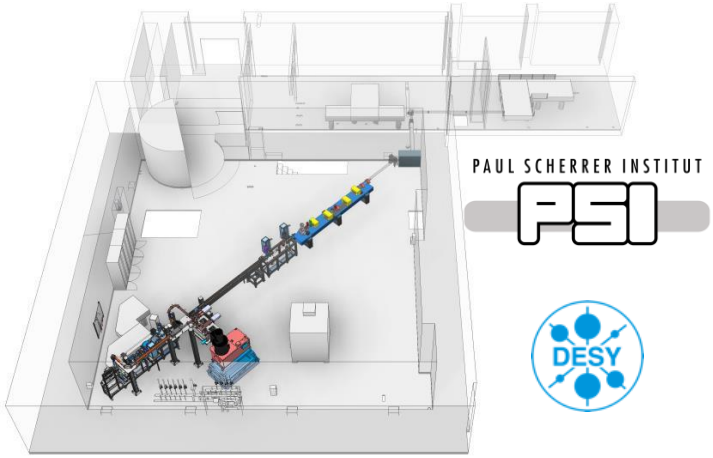




FLUTE: Ferninfrarot Linac- Und Test-Experiment

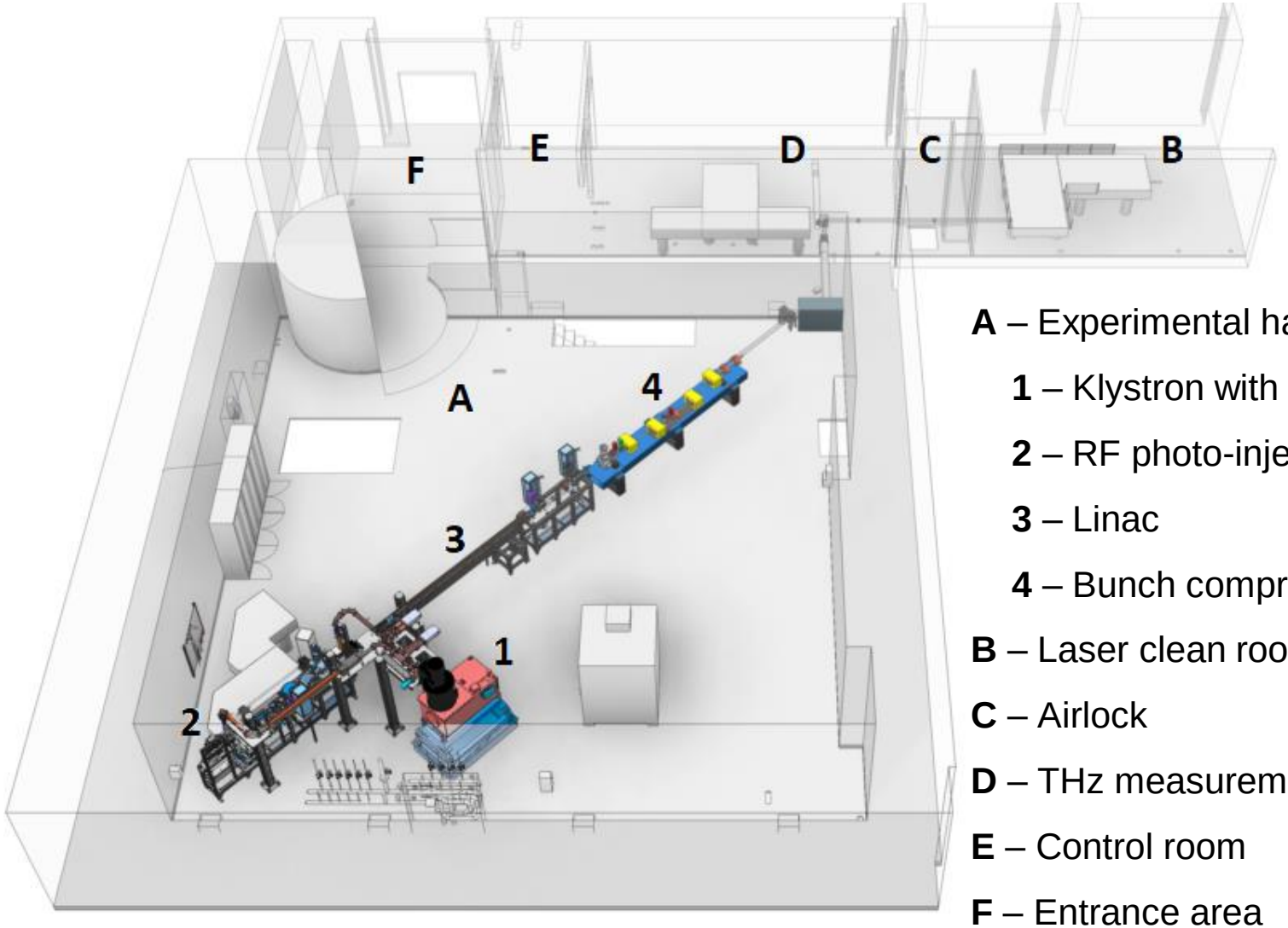
- **Main goals for FLUTE**
  - Test facility for accelerator physics
  - Experiments with THz radiation

- **R&D topics**
  - Test bench for new beam diagnostics
  - Systematic bunch compression and THz generation studies
  - Develop single-shot fs diagnostics
  - Synchronize on a femtosecond level



Final electron energy	~ 41 MeV
Electron bunch charge	1 pC - 3 nC
Electron bunch length	1 - 300 fs
Pulse repetition rate	10 Hz
THz E-Field strength	up to 1.2 GV/m

FLUTE: Layout



A – Experimental hall:

- **1** – Klystron with auxiliaries
- **2** – RF photo-injector gun
- **3** – Linac
- **4** – Bunch compressor

B – Laser clean room

C – Airlock

D – THz measurement room

E – Control room

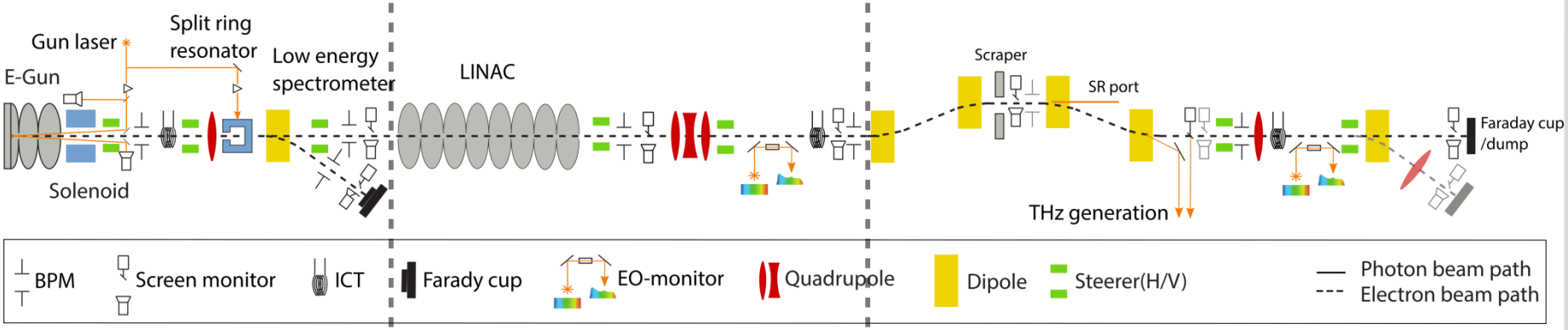
F – Entrance area

FLUTE: Layout & implementation

5 – 7 MeV section

41 MeV section

Buncher and THz section

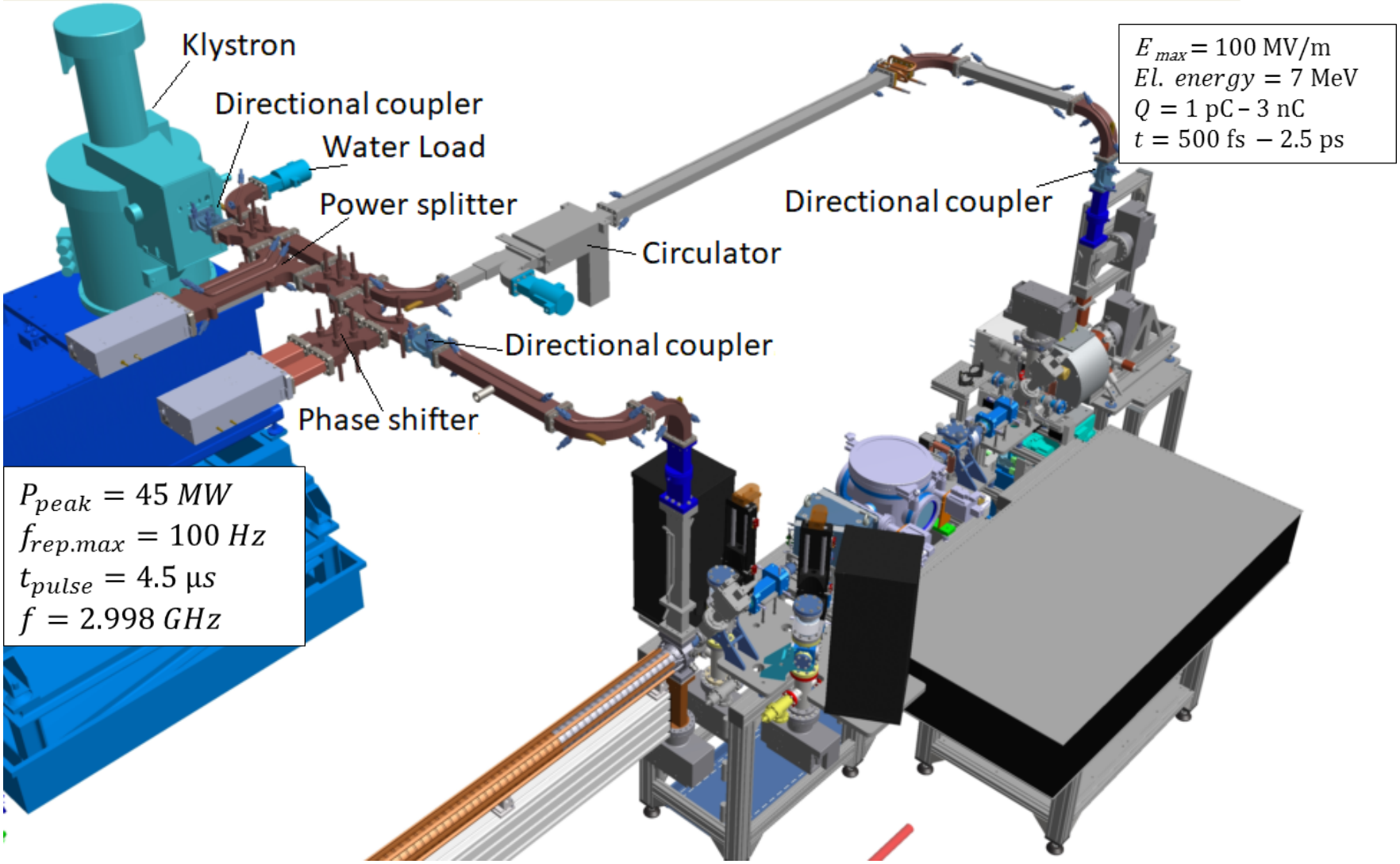


Energy	5 – 7 MeV
Bunch charge	**1 pC**-3 nC
Beam size	0.4-4.5 mm
Bunch length	**500 fs**-2.5 ps
Energy spread	0.14-0.8 %
λ (laser)	266 nm
Spot size	0.5 - 2.5 mm
Pulse length	500 fs - 2 ps

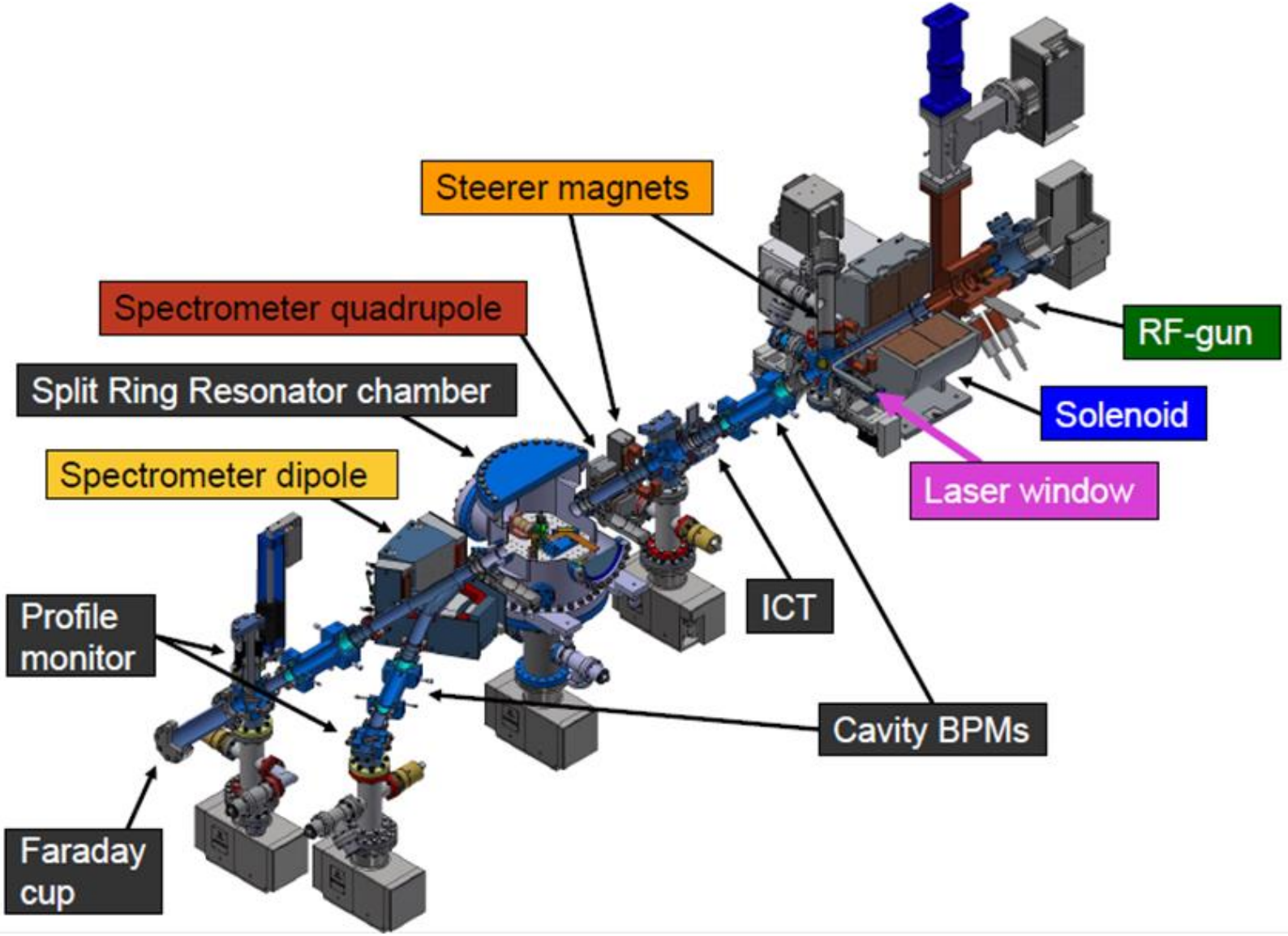
Energy	**41 MeV**
Bunch charge	**1 pC** - 3 nC
Beam size	0.4 - 4.5 mm
Bunch length	500 fs - 2.5 ps
Energy spread	0.24 - 1.8 %

Energy	41 MeV
Bunch charge	**1 pC** - 3 nC
Beam size	40µm - 3 mm
Bunch length	**few fs** - 500 fs
Energy spread	0.24 - 1.8 %

RF system configuration

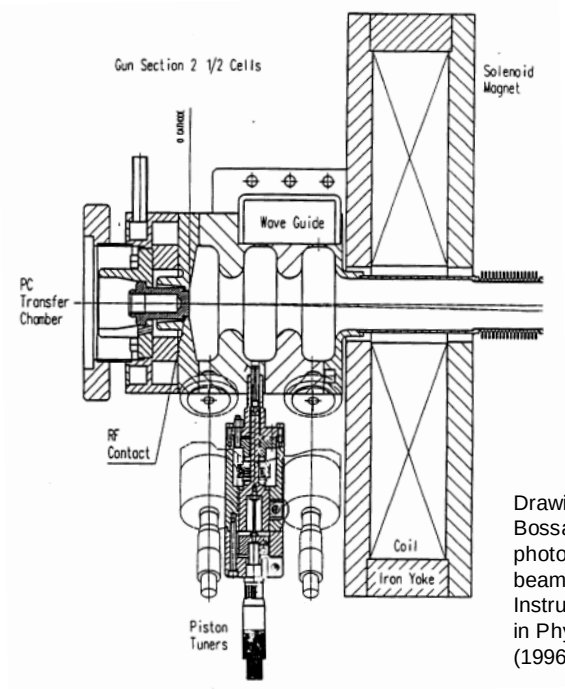


Beam diagnostics



RF photo-injector configuration

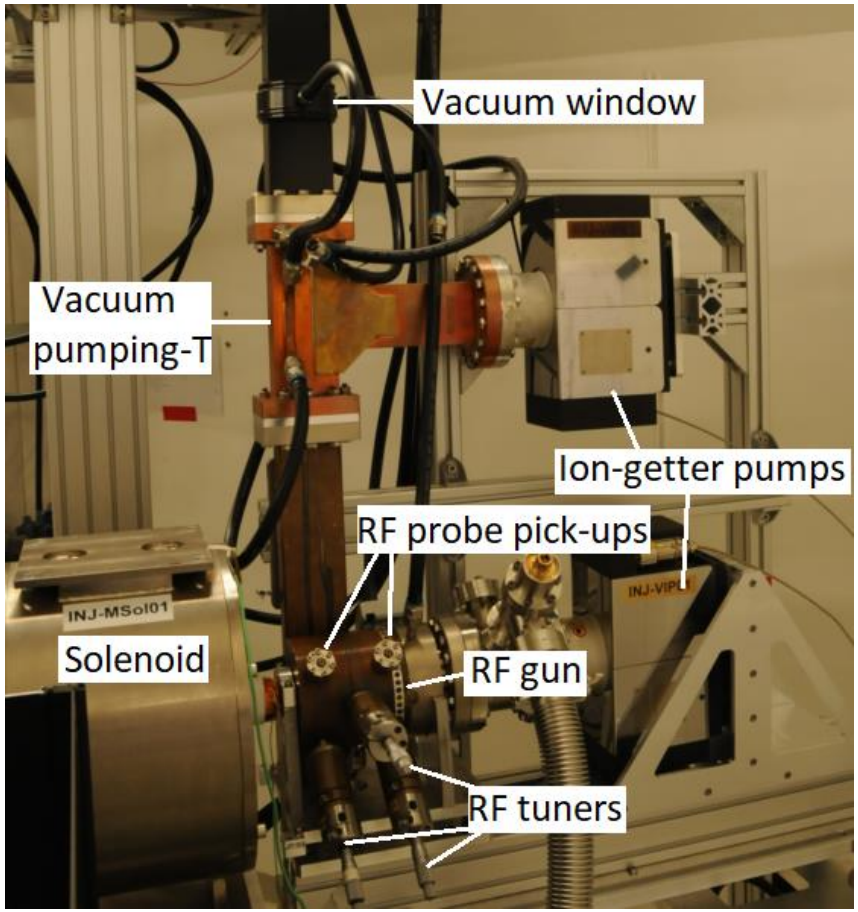
RF photo-injector parameters		
Frequency	2.998	GHz
Cells	2.5	
Peak E-field	100	MV/m
Peak power	17	MW
Output energy	7	MeV



Drawing taken from: R. Bossart, et. al. "A 3 GHz photoelectron gun for high beam intensity", Nuclear Instruments and Methods in Physics Research, A 375 (1996) ABS 7 – ABS 8.

Maximum charge extracted from cathode per short:

- **Cu** cathode up to **700 pC** (assembled)
- with **Cs_2Te** cathode up to **3 nC**

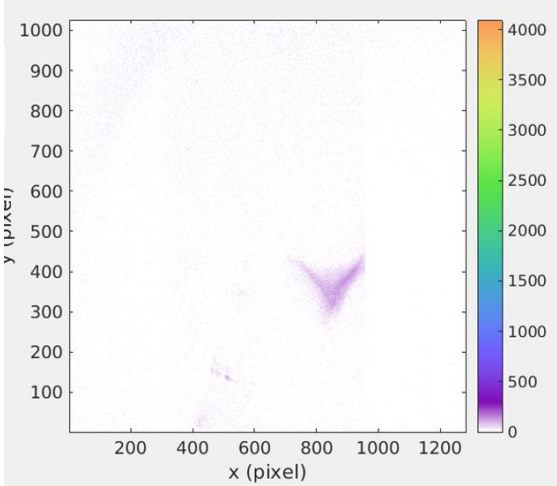


FLUTE commissioning progress:

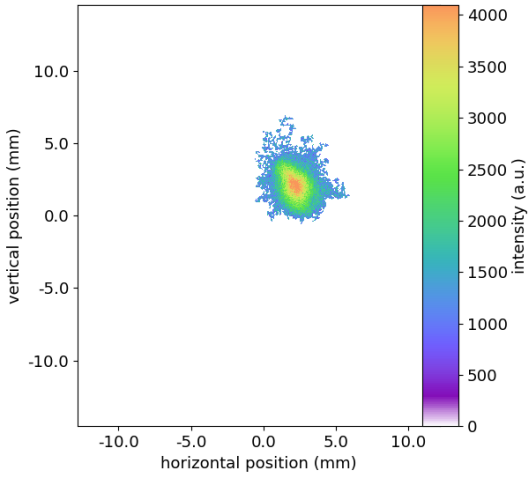
First electron beam in 2018
Commissioning of RF system and diagnostic section has been done

Improvements up to now:

- RF power increased from 4 MW to 13 MW during photo-injector conditioning
- new circulator: insertion loss decrease from 1.7 dB to 0.14 dB
- Laser-to-RF synchronization successfully implemented with timing jitter ~110 fs
  ⇒ laser phase-locked to RF pulse, reproducible bunch acceleration
- Improved synchronization with 50 Hz line voltage and re-cabling of the klystron heater, supplies and grounds ⇒ RF power noise considerably reduced from 2.2 % to 0.3%
- Result: reproducible electron beam, energy increased from 2.5 MeV to 5.8 MeV



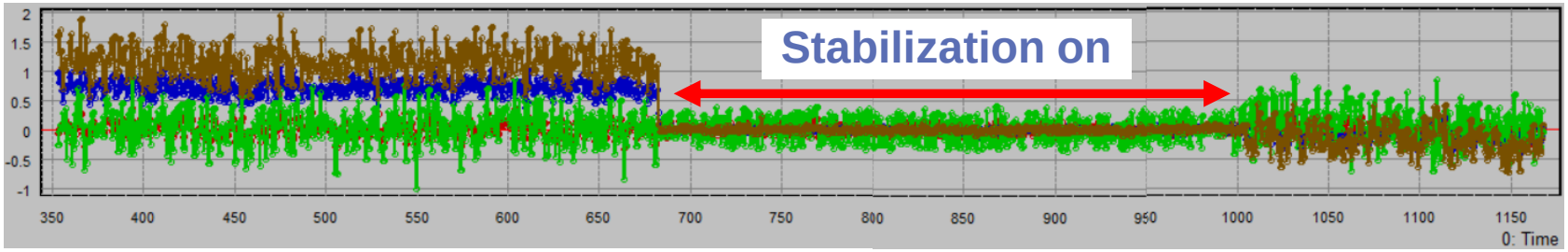
First electron beam in 2018



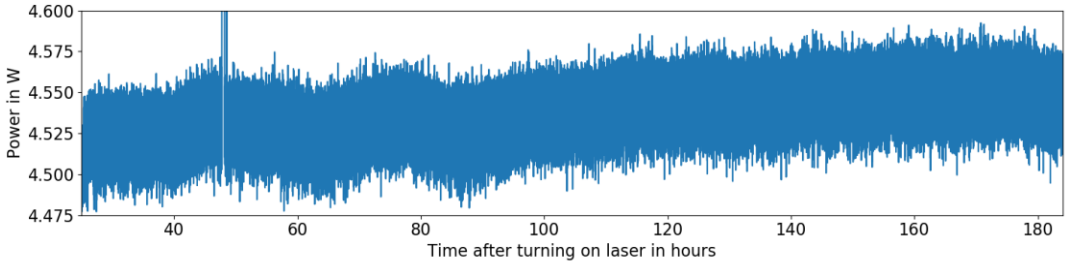
Electron beam in 2019

Laser stability measurements

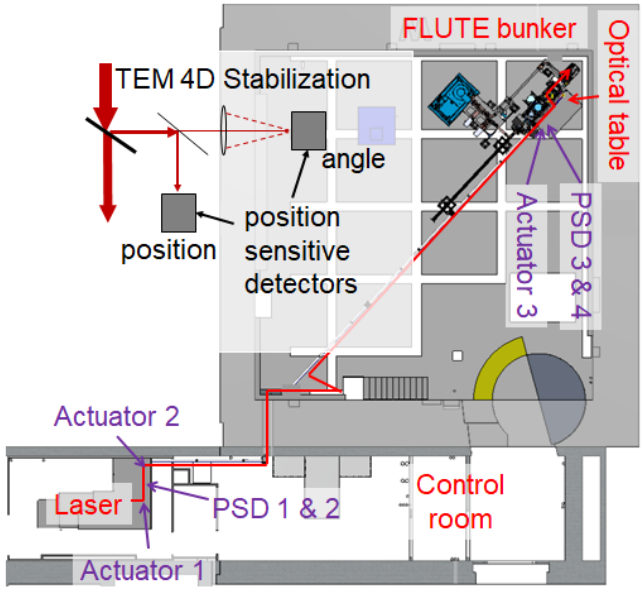
- Laser transport stabilization system
  - System from TEM Messtechnik,
    using two mirrors / actuators and two position sensitive detectors



- Laser power stability:
  - 25 hours after turning on the laser
  - Continuous operation over 6 days

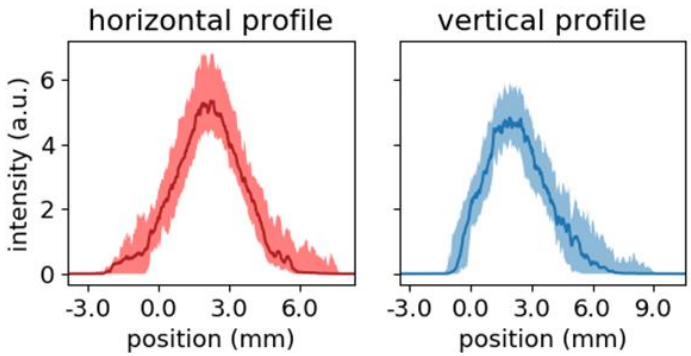


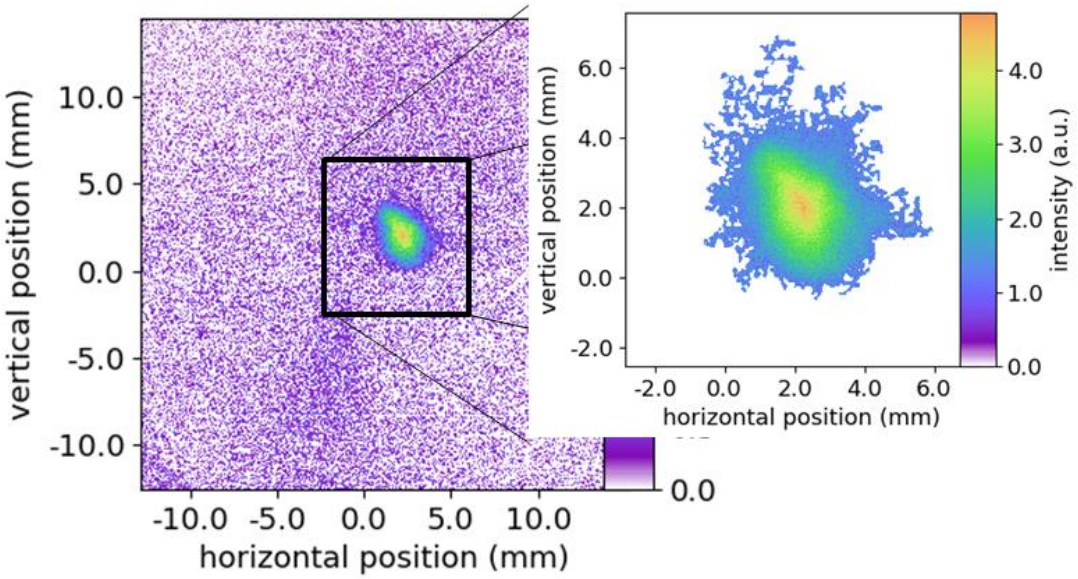
Laser stabilization scheme



Beam measurements with screen monitor

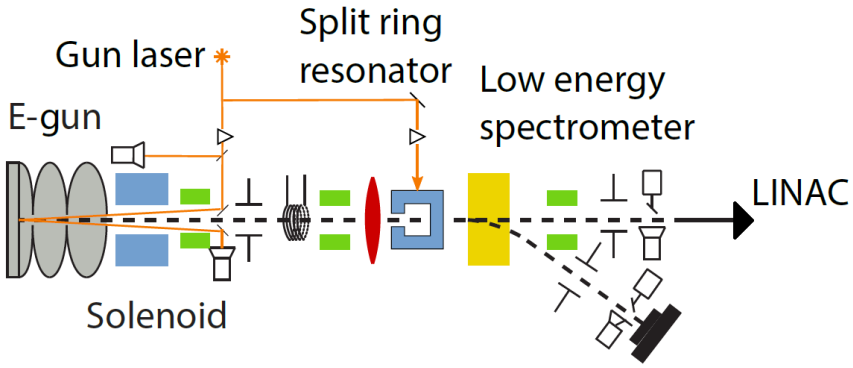
- FLUTE actual settings
  - RF power 4.2 MW, repetition rate 1 Hz, bunch charge about 5 pC
- YAG screen used for profile measurements
- Image processing
  - Dark current background subtraction
  - Search for region of interest including noise level estimation
- Statistics for 120 beam profiles
  - Beam position
    - H: 2.06 ± 0.09 mm,
    - V: 2.30 ± 0.14 mm
  - RMS beam width:
    - H: 1.41 ± 0.08 mm
    - V: 1.46 ± 0.13 mm



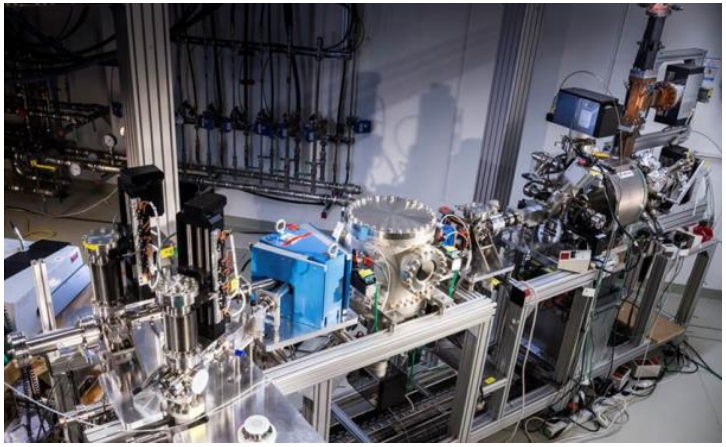


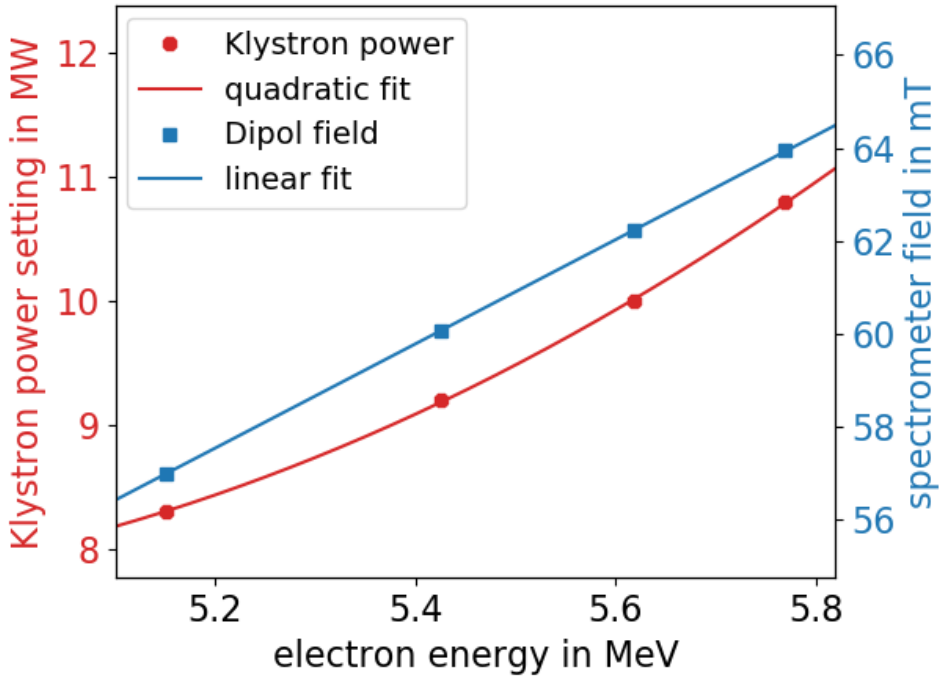
Energy measurements with spectrometer

- First energy measurements with spectrometer were performed:
  - Focusing electron beam with solenoid on the screen
  - Electron beam is placed at the center

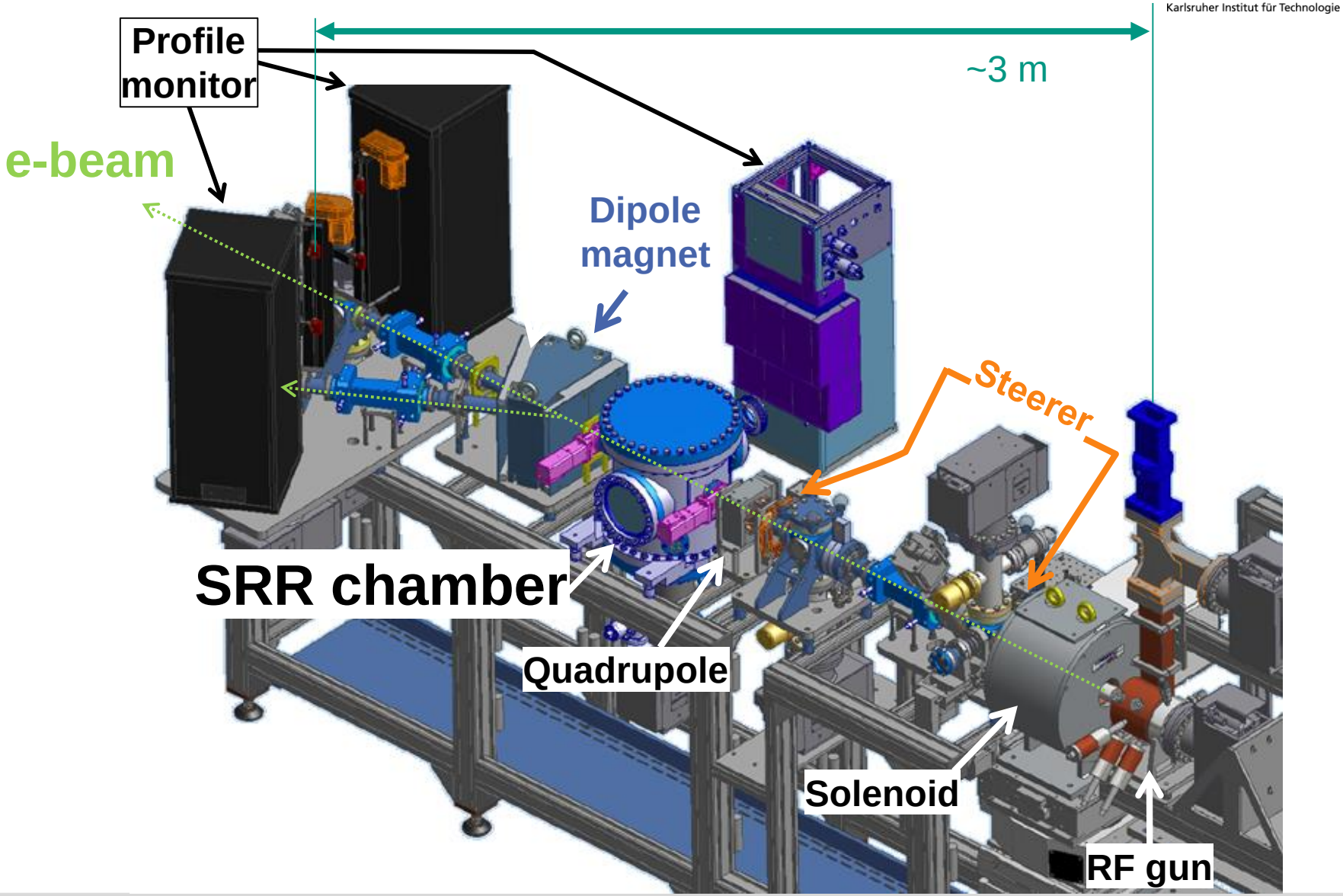


Diagnostic section





Split Ring Resonator (SRR) experiment at FLUTE



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)

M. Yan et al., TUPG56, IBIC 2016, Barcelona, Spain.

- THz-range => **high frequency *f*** (FLUTE RF 3 GHz)
  - $LiNbO_3$ crystal => 35 fs pulse at 800 nm (FLUTE laser) converted to THz pulse
- Field enhancement in SRR gap => **large electric field**
  - Enhancement factor ~100 (at 0.3 THz)

Table: 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	2.7nm

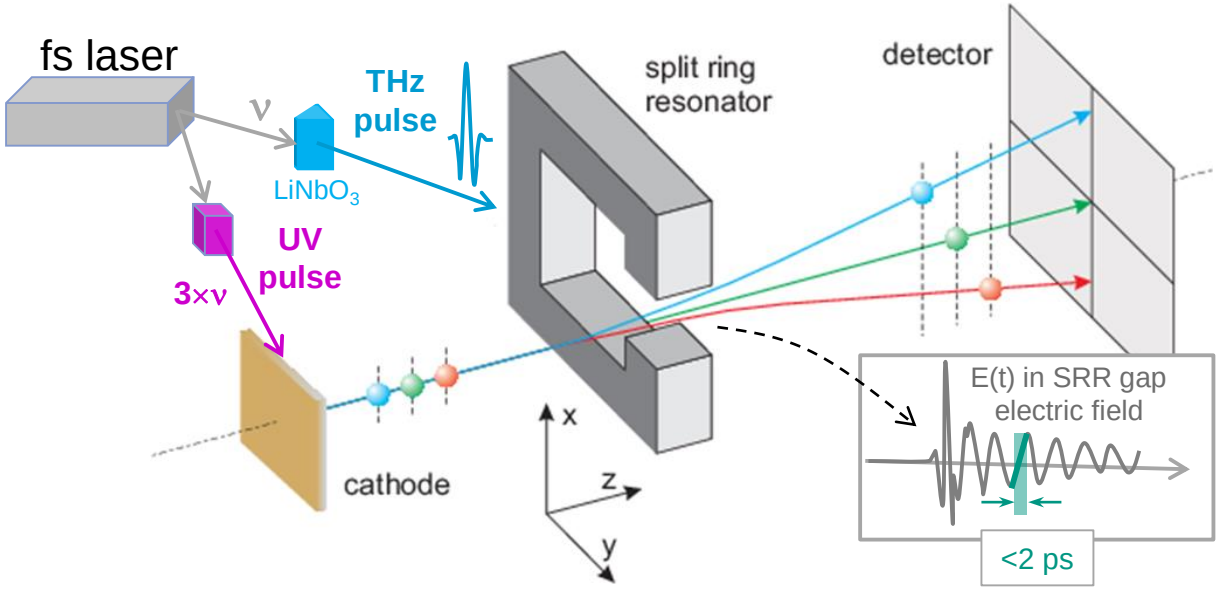
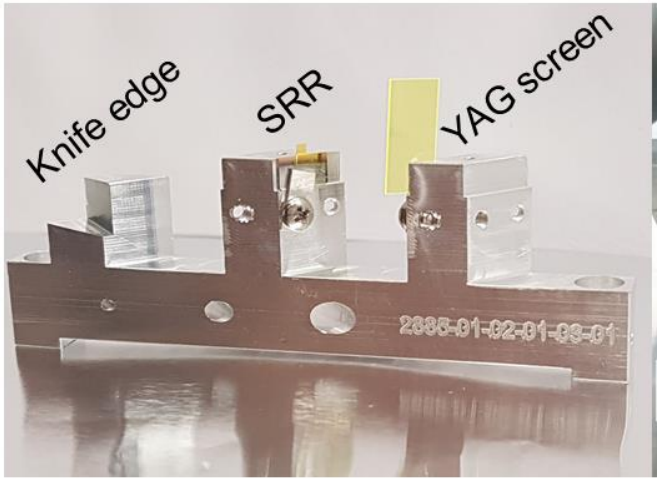


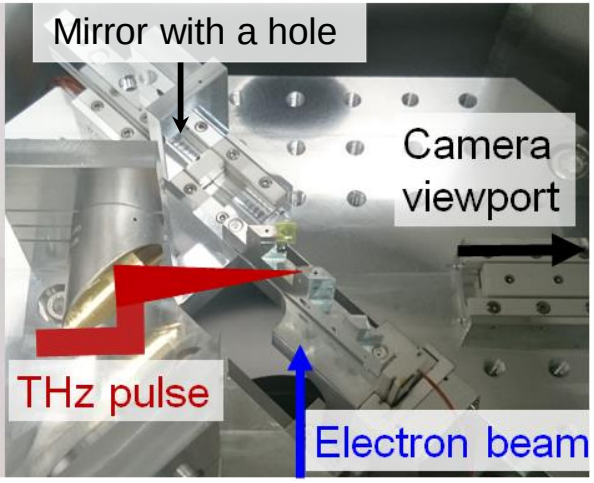
Table: SRR parameters

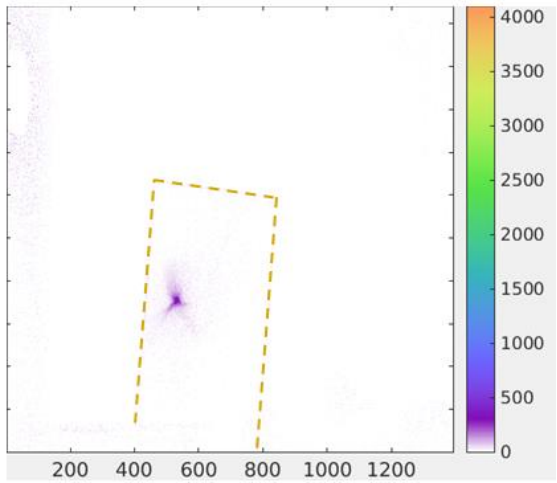
Gap size in x	20 µm
Gap size in y	20 µm
Gap width in z	10 µm
Resonant frequency	300 GHz
Peak electric field	500 MV/m
Integrated field	10kV

Progress on SRR experiment

- System of a knife edge, SRR and YAG screen mounted on a holder and a mirror with hole on the second holder integrated in FLUTE vacuum chamber
- First tests with electron beams, guiding through the hole in mirror for imaging onto YAG screen
- Planned steps: assembly of THz setup onto optical table, measuring and optimizing beam size and parameters at resonator position

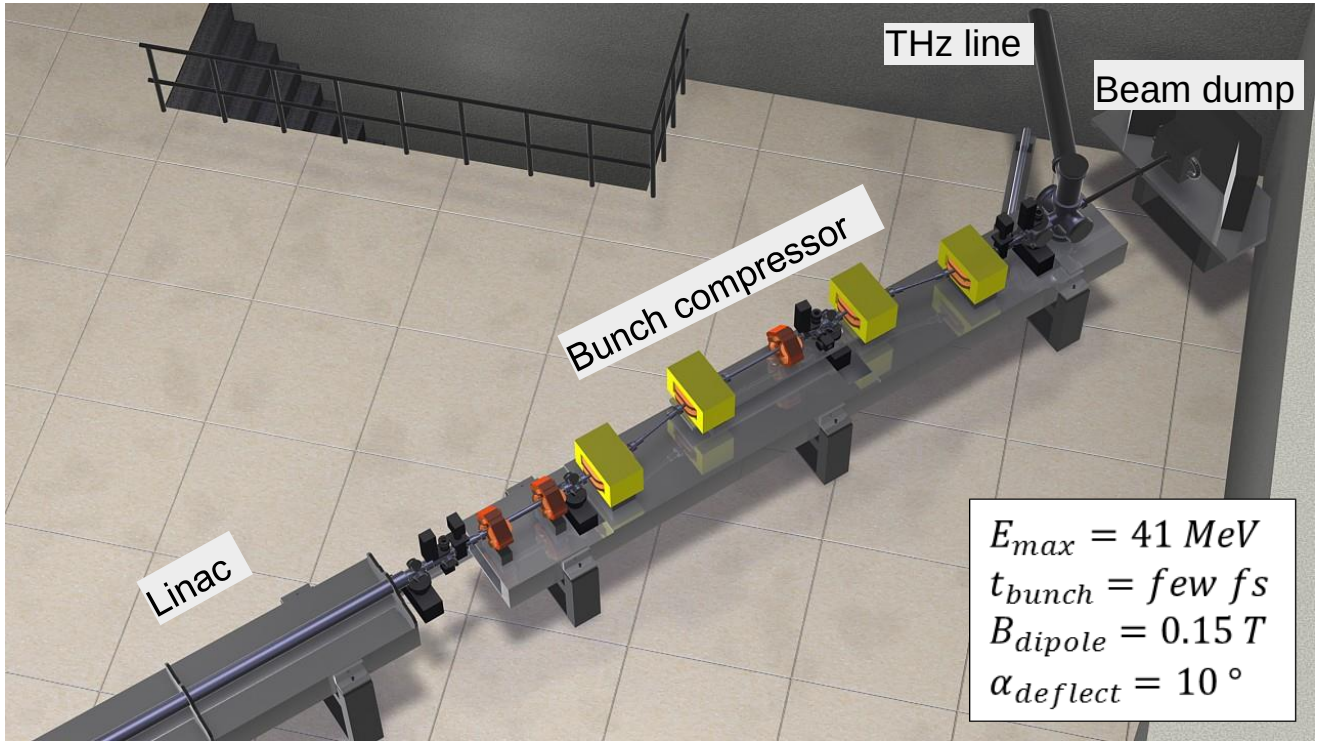




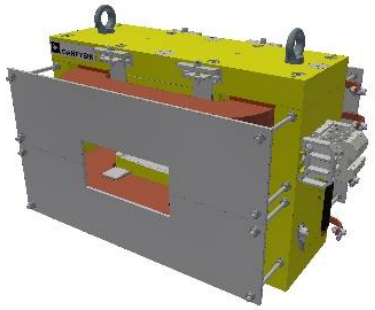


Bunch compessor

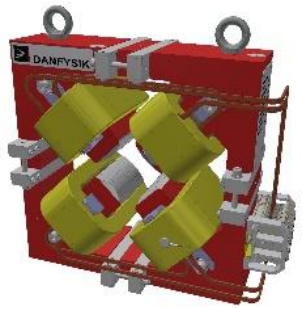
- Dipoles and quadrupoles have been delivered
- Measurement of magnetic field distribution is in progress at KIT to compared with specifications and Factory Acceptance Tests



Dipole



Quadrupole

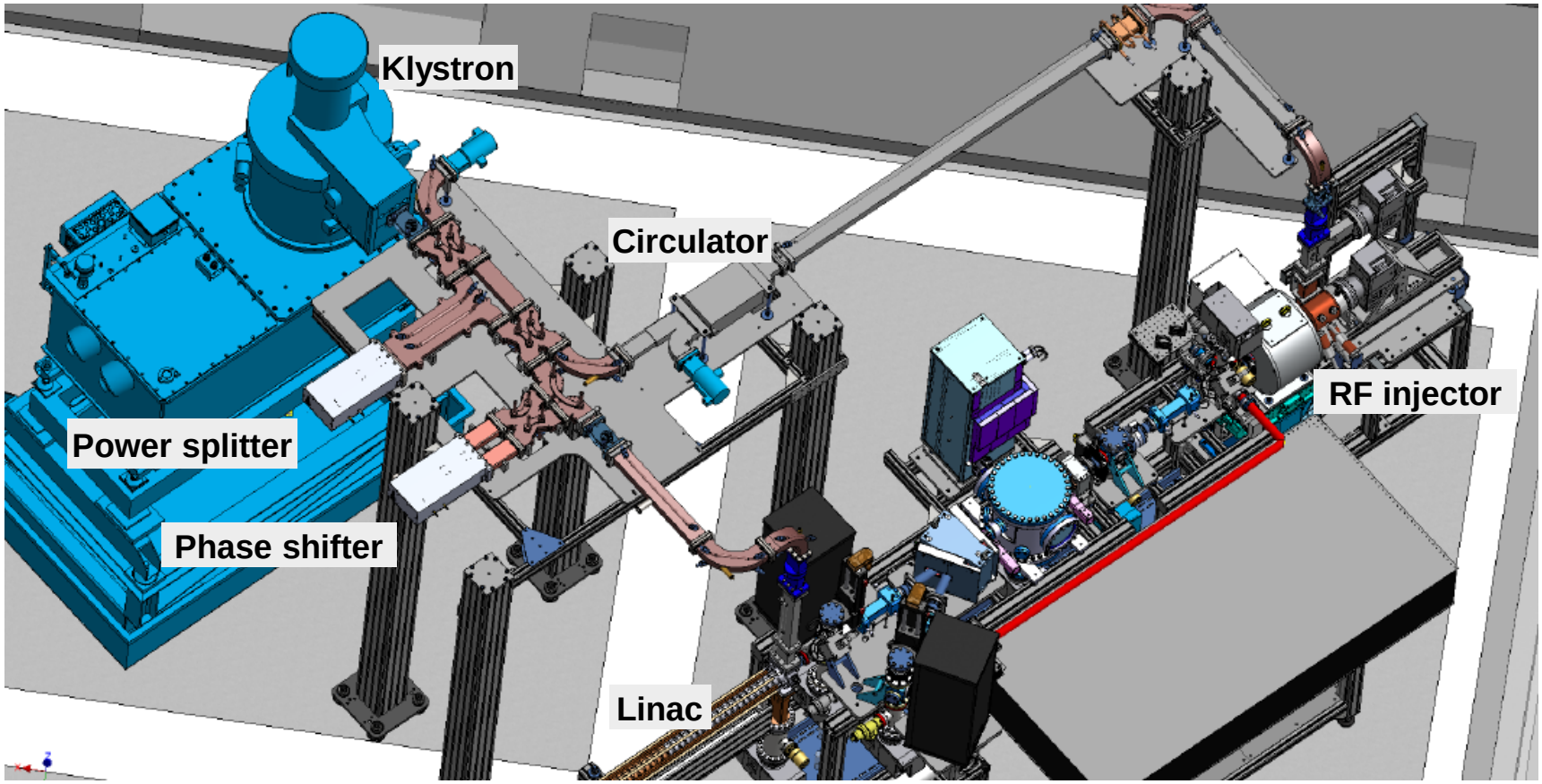


Summary and Outlook

- Experience on FLUTE section with RF photo-injector and dedicated diagnostics: conditioning and optimization ongoing
- Achieved results:
  - Electron beam energy up to 5.8 MeV, repetition rate 1 Hz
  - RF power 13 MW, RF pulse length 4.5 µs, Laser pulse 1 ps
- A split ring resonator (SRR) is mounted in the vacuum chamber, THz setup for generating laser pulses is designed, being set up
- Next steps:
  - Experiments with electron beams on Split Ring Resonator
  - Commissioning of the linac and the linac RF system
  - Finishing design, manufacturing and assembly of the bunch compressor and its dedicated diagnostic section

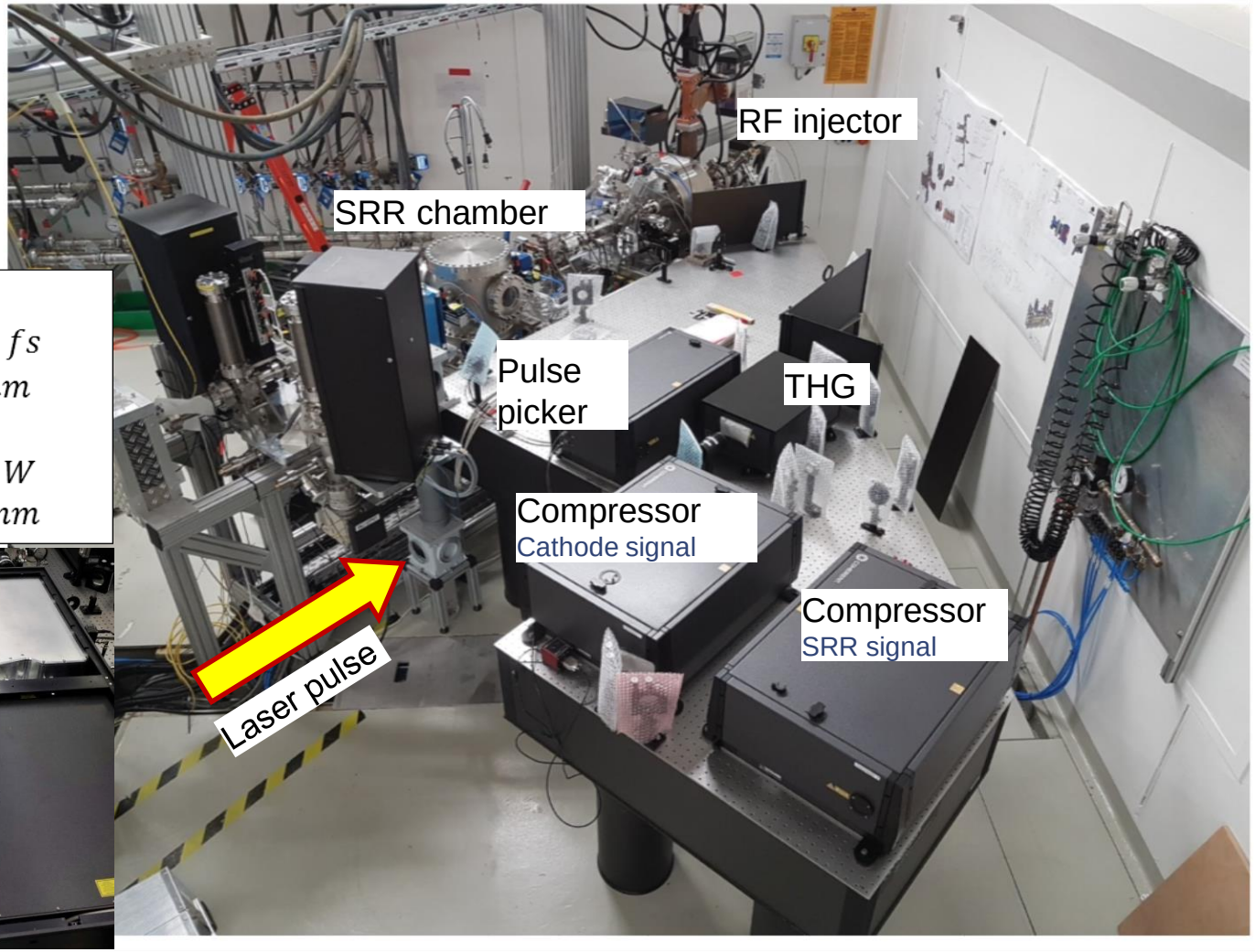
Thank you for your attention!

RF system


Klystron
Circulator
RF injector
Power splitter
Phase shifter
Linac

Laser system modifications:

New optical table has been installed next to the beam diagnostics section.



$P_{out} = 6\ W$
$t_{pulse} = \sim 35\ fs$
$\lambda_{out} = 800\ nm$
$f_{rep} = 1\ kHz$
$P_{THG} = \sim 1.2\ W$
$\lambda_{THG} = 266\ nm$