Karlsruhe Institute of Technology

FLUTE

# FLUTE, a compact versatile linac-based source for coherent ultra-short THz pulses

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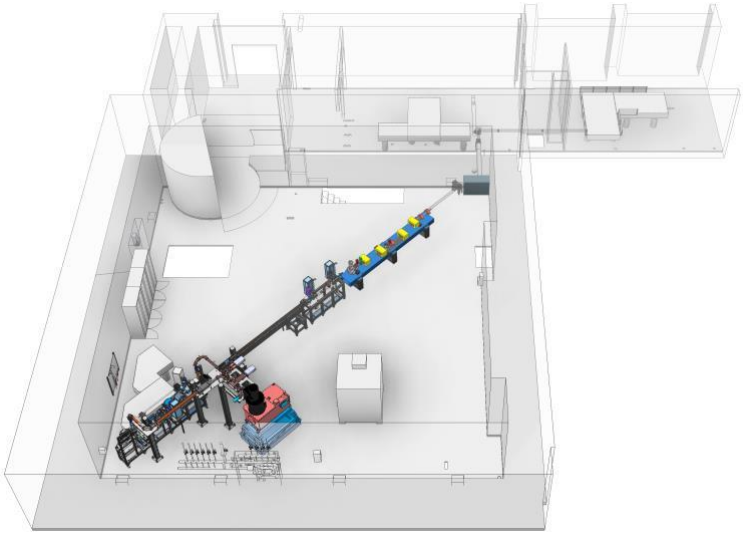
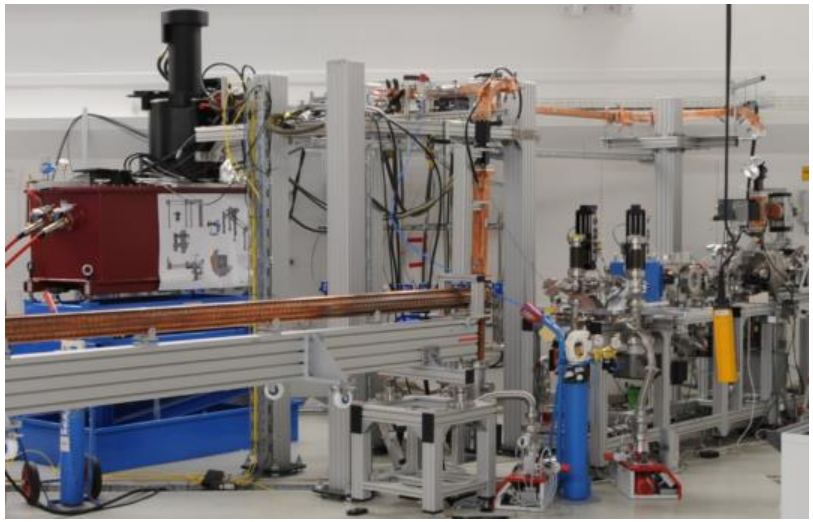
Institute for Beam Physics and Technology (IBPT)

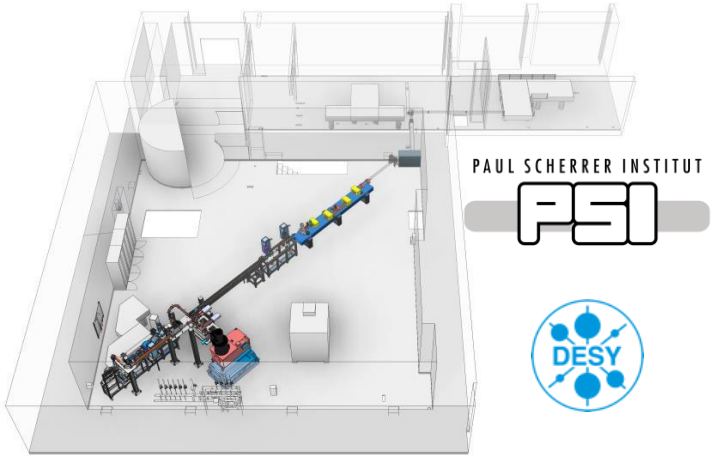




# FLUTE: Ferninfrarot Linac- Und Test-Experiment

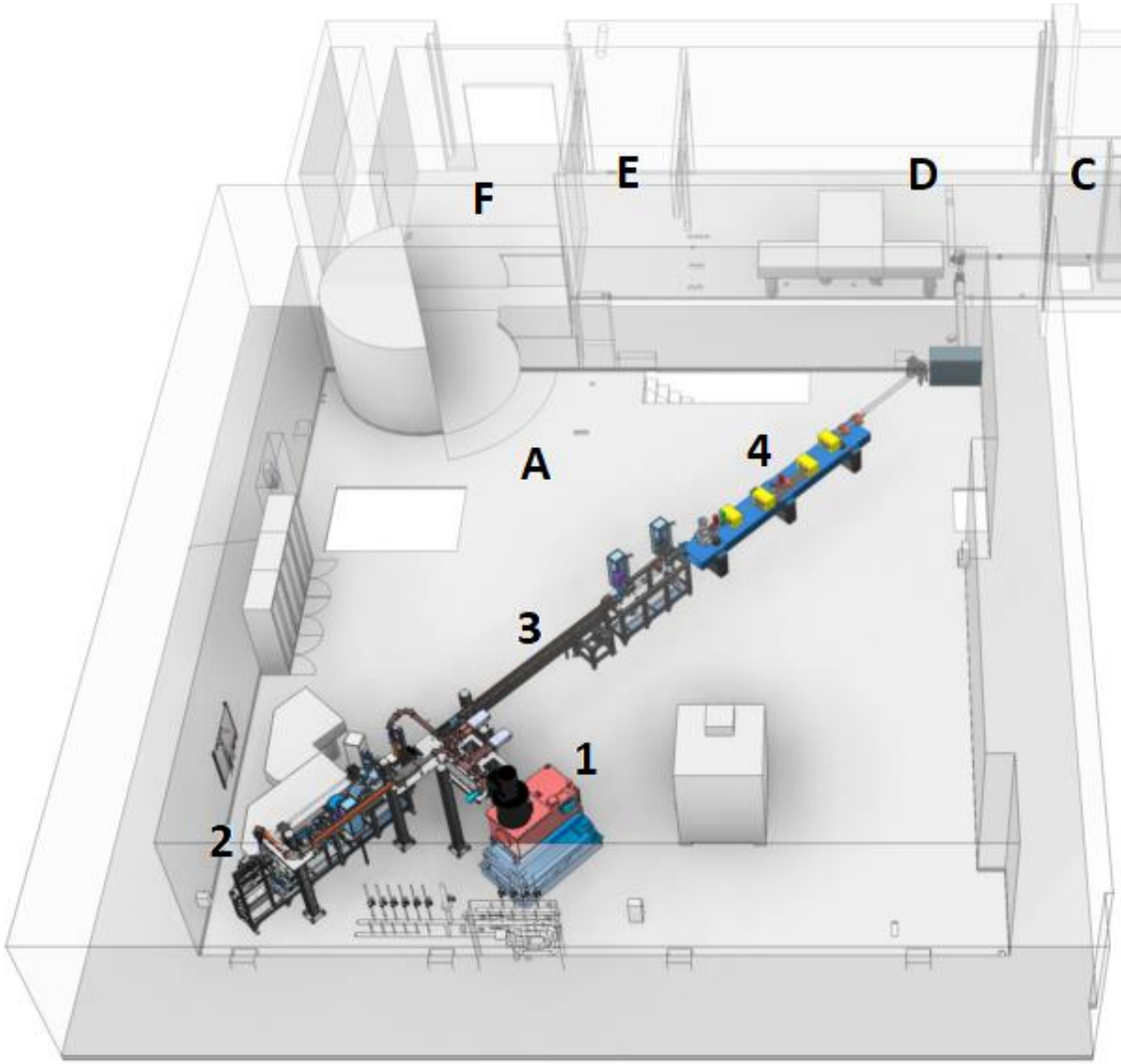
- **Main goals for FLUTE**
  - Test facility for accelerator physics
  - Experiments with THz radiation

- **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

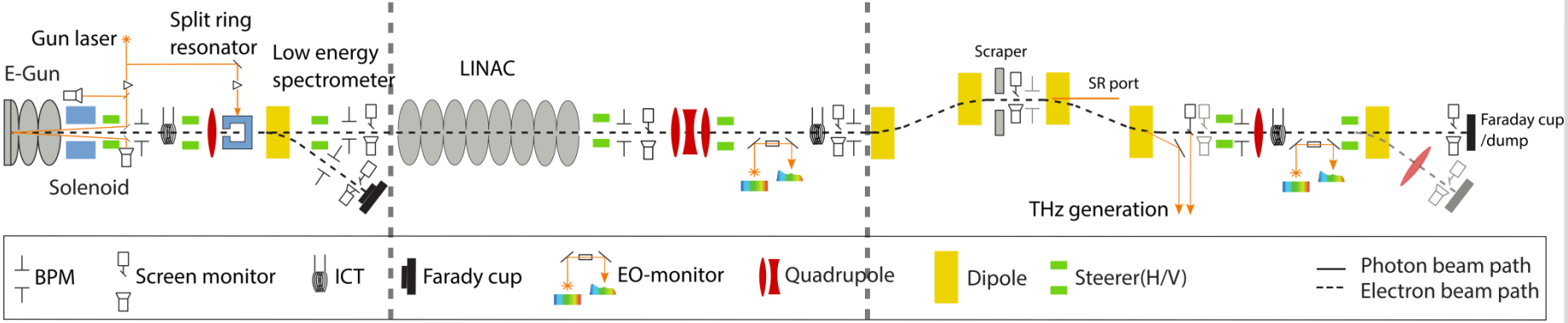
**F** – Entrance area

# FLUTE: Layout & implementation

## 5 – 7 MeV section

## 41 MeV section

## Buncher and THz section

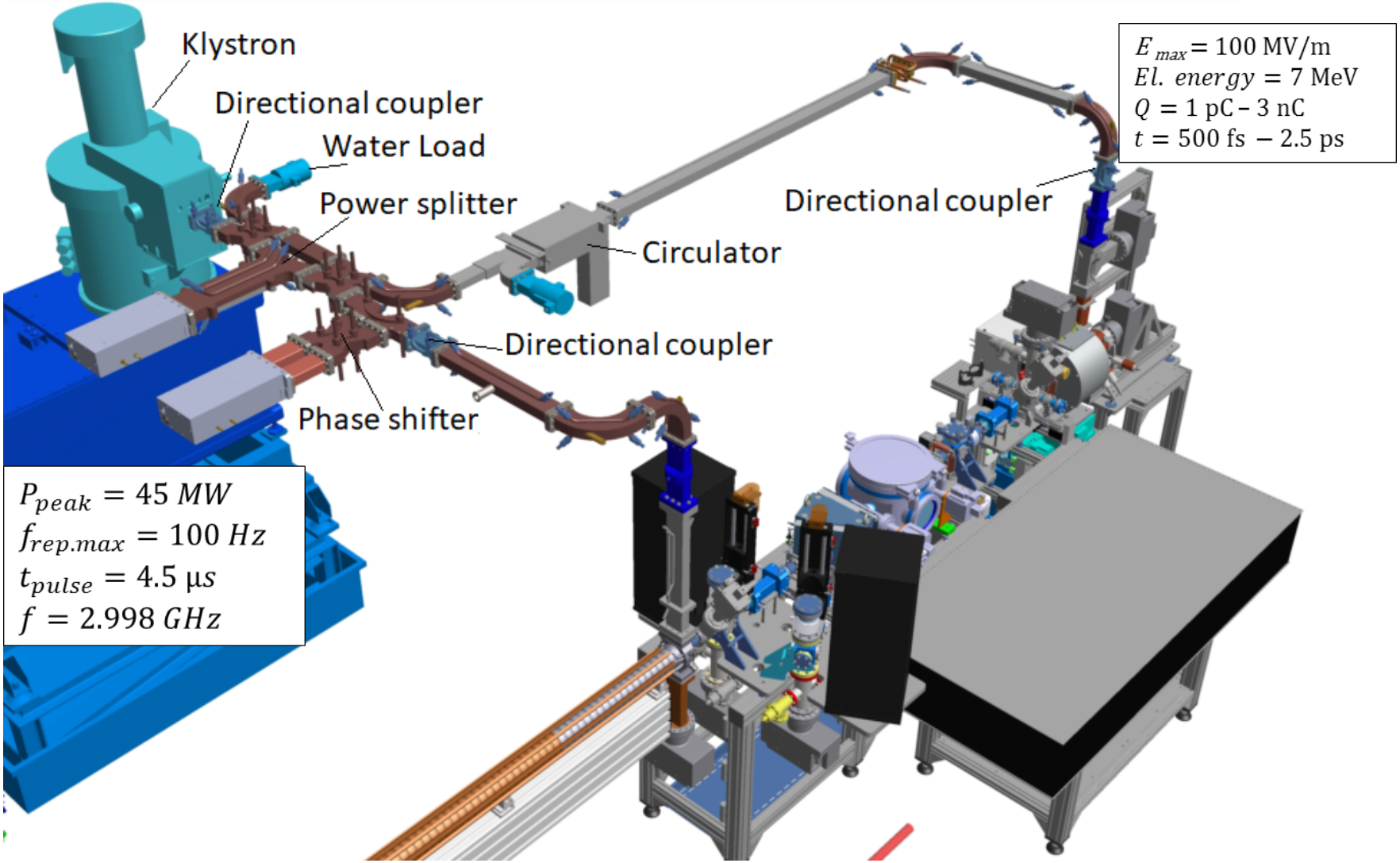



| | |
|---|---|
| Energy | 5 – 7 MeV |
| Bunch charge | **1 pC**-3 nC |
| Beam size | 0.4-4.5 mm |
| Bunch length | **500 fs**-2.5 ps |
| Energy spread | 0.14-0.8 % |
| **λ** (laser) | 266 nm |
| Spot size | 0.5 - 2.5 mm |
| Pulse length | 500 fs - 2 ps |

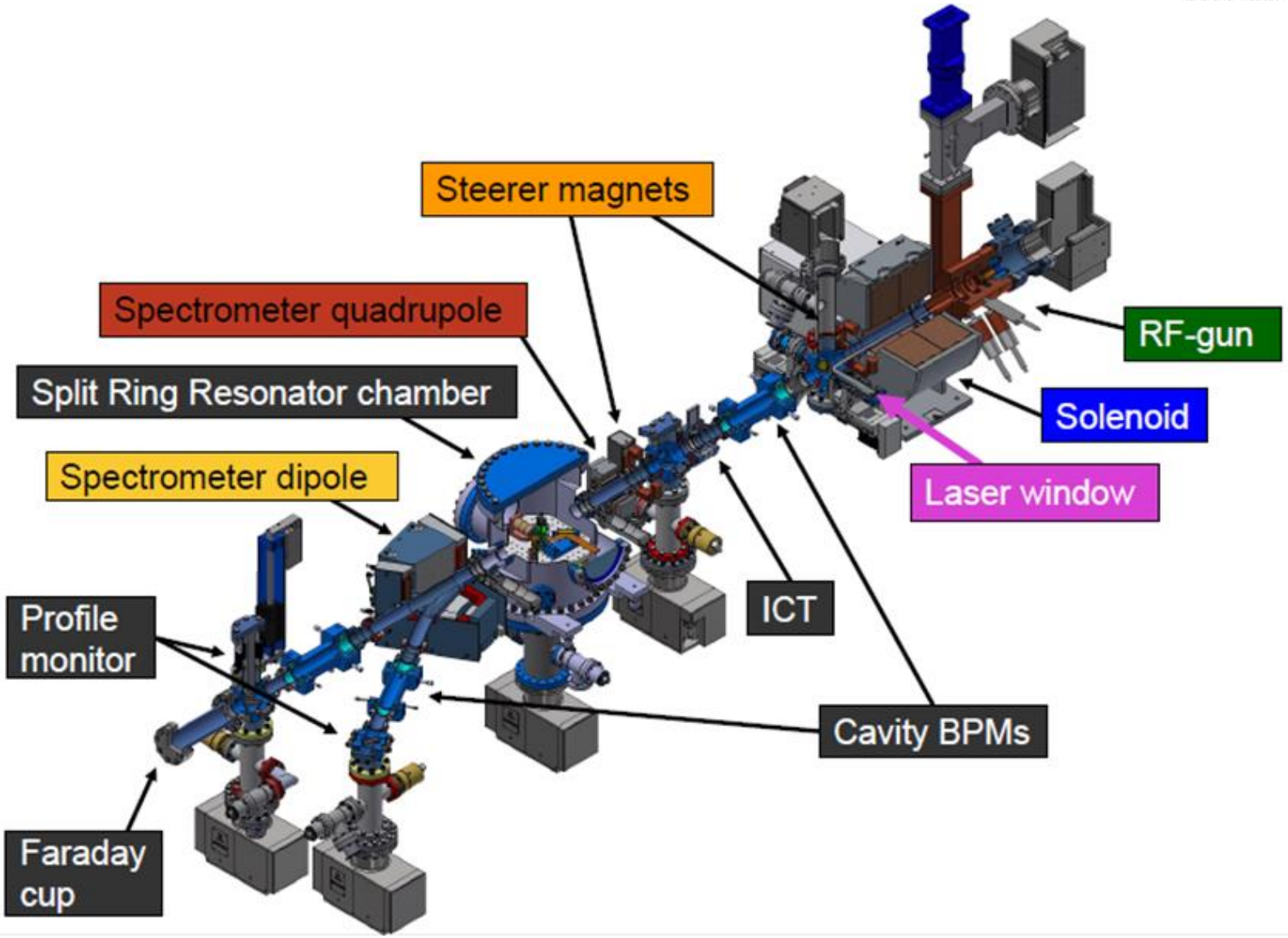
| | |
|---|---|
| Energy | **41 MeV** |
| Bunch charge | **1 pC** - 3 nC |
| Beam size | 0.4 - 4.5 mm |
| Bunch length | 500 fs - 2.5 ps |
| Energy spread | 0.24 - 1.8 % |

| | |
|---|---|
| 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

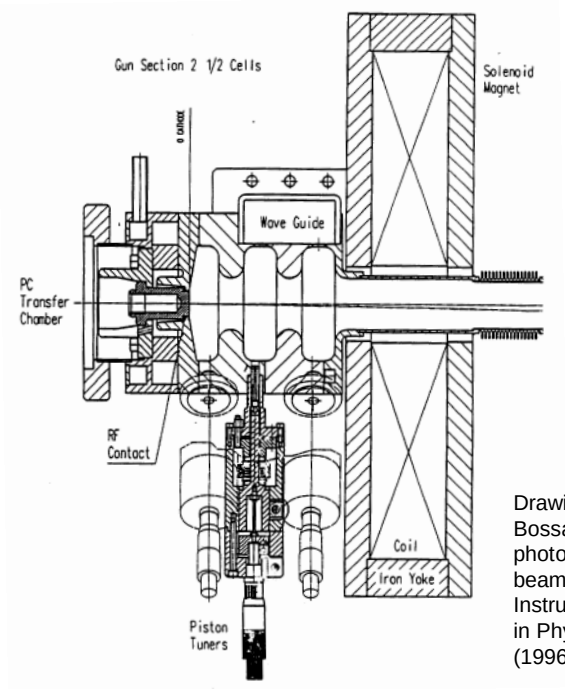


# Beam diagnostics



# RF photo-injector configuration

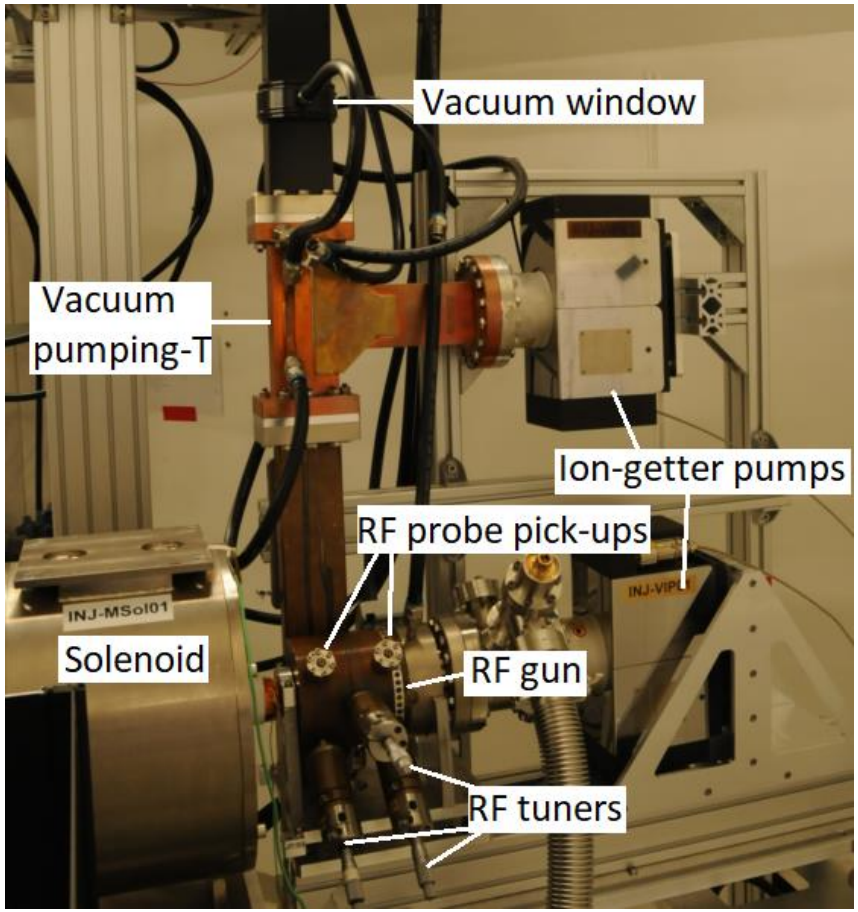
| RF photo-injector parameters | | |
|---|---|---|
| Frequency | 2.998 | GHz |
| Cells | 2.5 | |
| Peak E-field | 100 | MV/m |
| Peak power | 17 | MW |
| Output energy | 7 | MeV |




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**

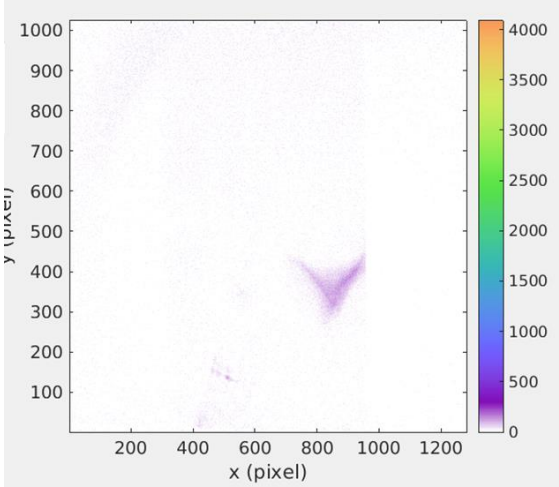


# FLUTE commissioning progress:

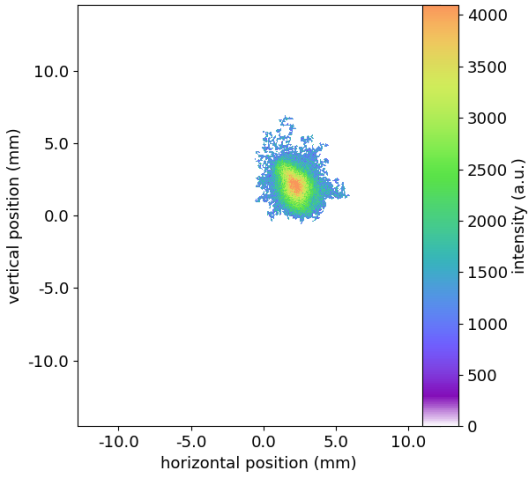
First electron beam in 2018
Commissioning of RF system and diagnostic section has been done

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



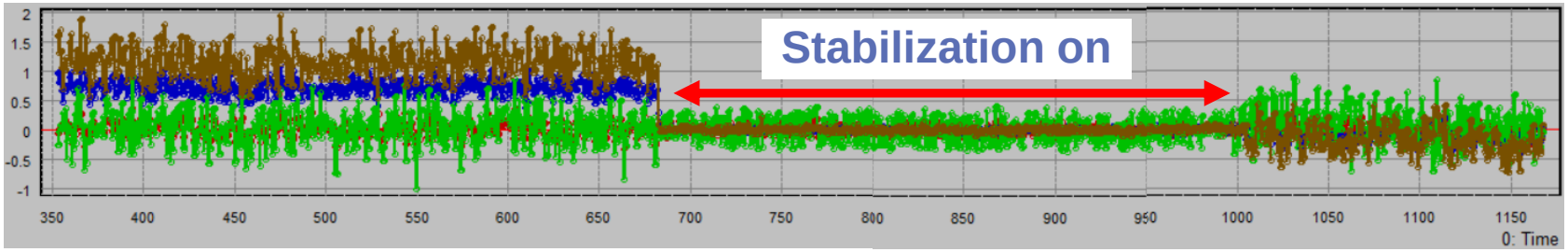

First electron beam in 2018



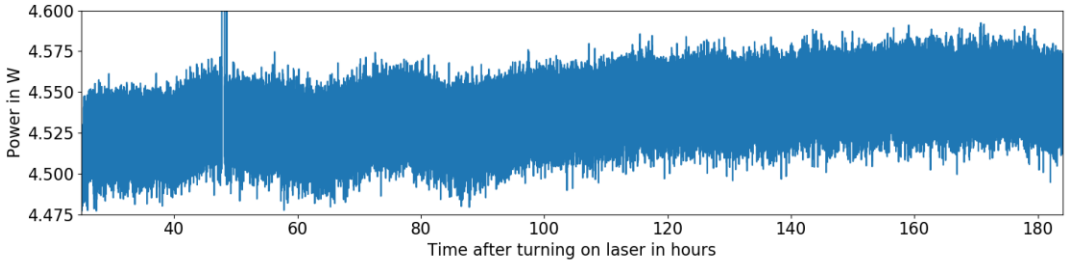

Electron beam in 2019

# Laser stability measurements

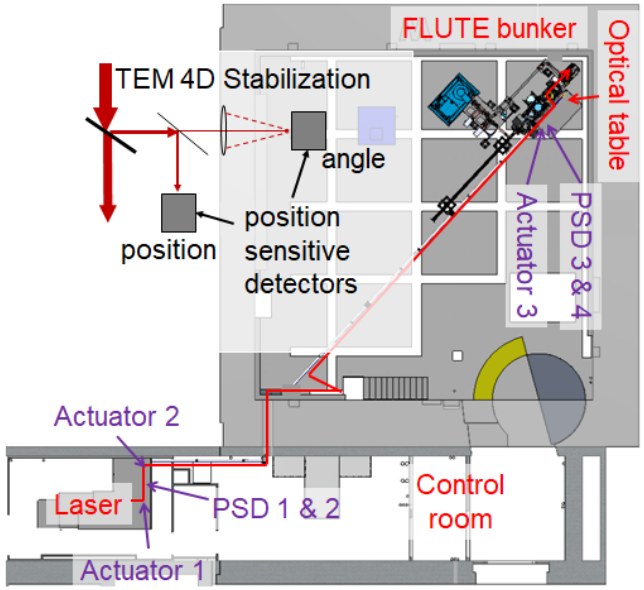
- Laser transport stabilization system
  - System from TEM Messtechnik,
    using two mirrors / actuators and two position sensitive detectors




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

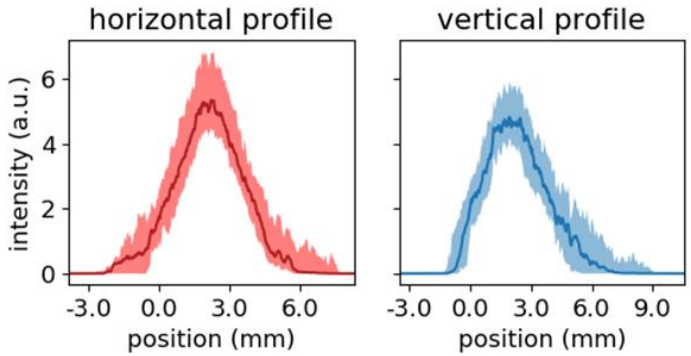


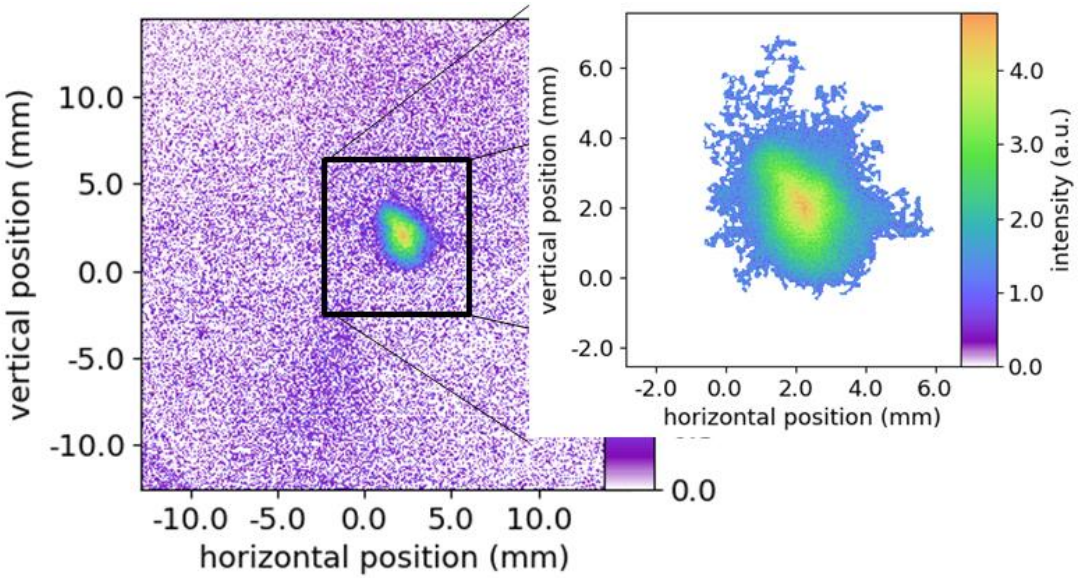

## Laser stabilization scheme



# Beam measurements with screen monitor

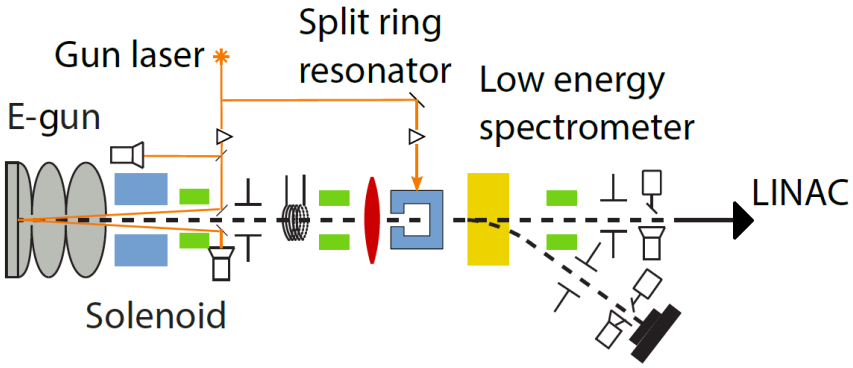
- FLUTE actual settings
  - RF power 4.2 MW, repetition rate 1 Hz, bunch charge about 5 pC
- YAG screen used for profile measurements
- Image processing
  - Dark current background subtraction
  - Search for region of interest including noise level estimation
- Statistics for 120 beam profiles
  - Beam 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



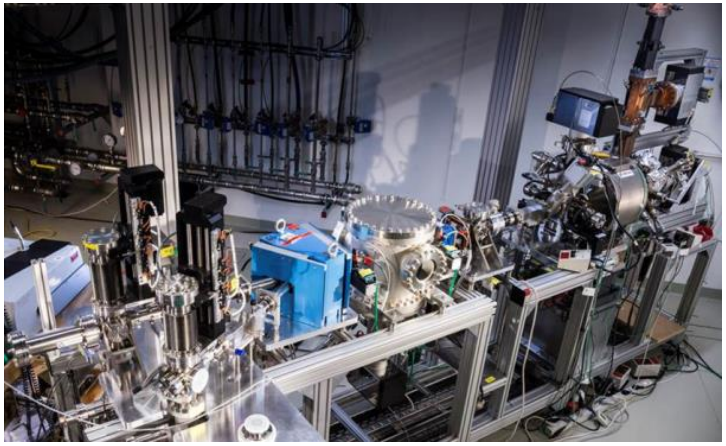



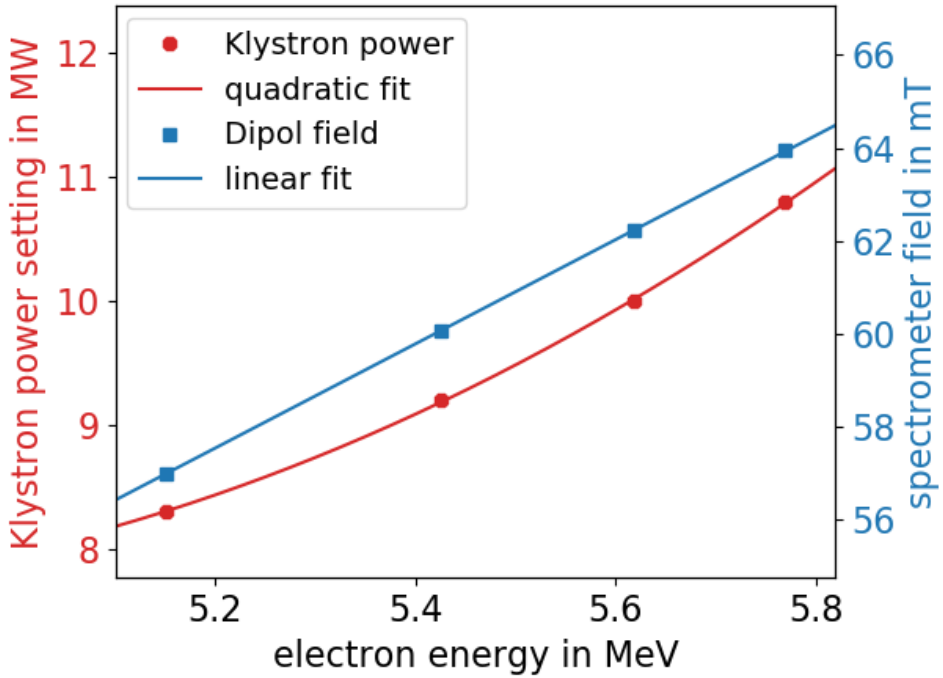
# Energy measurements with spectrometer

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

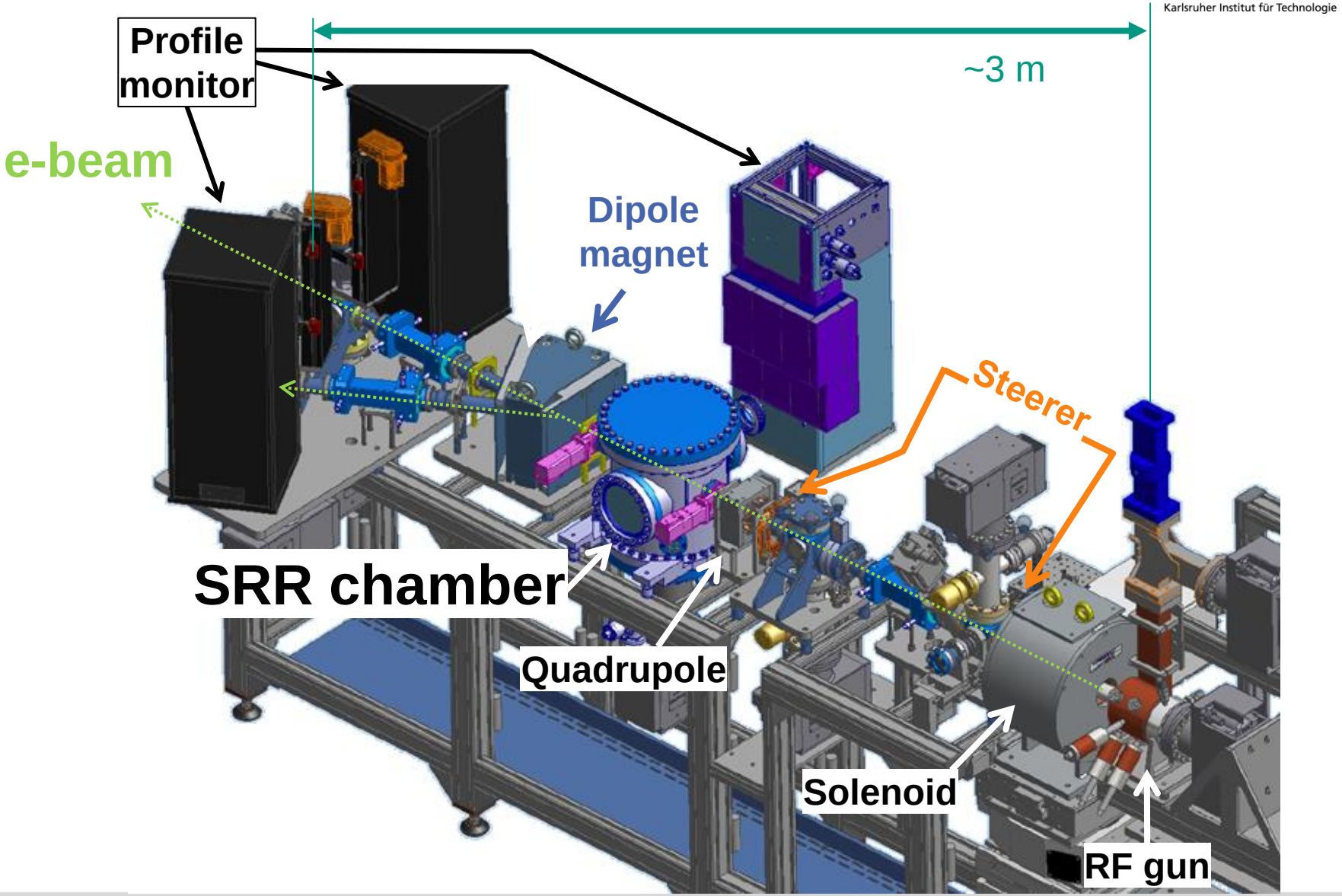



## Diagnostic section





# 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 |

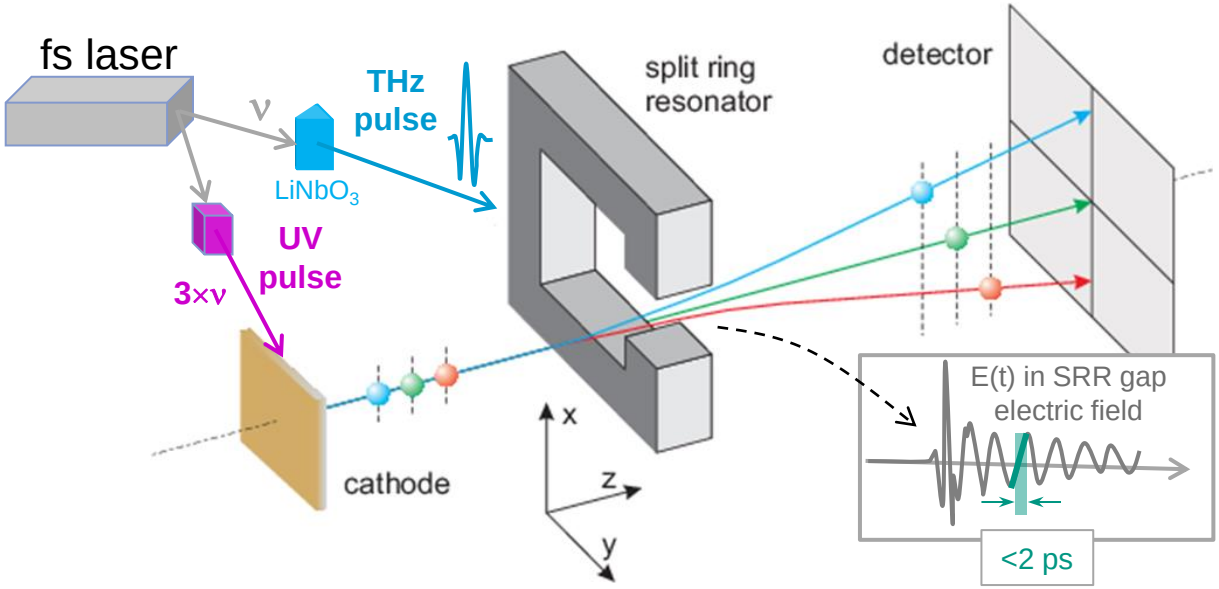
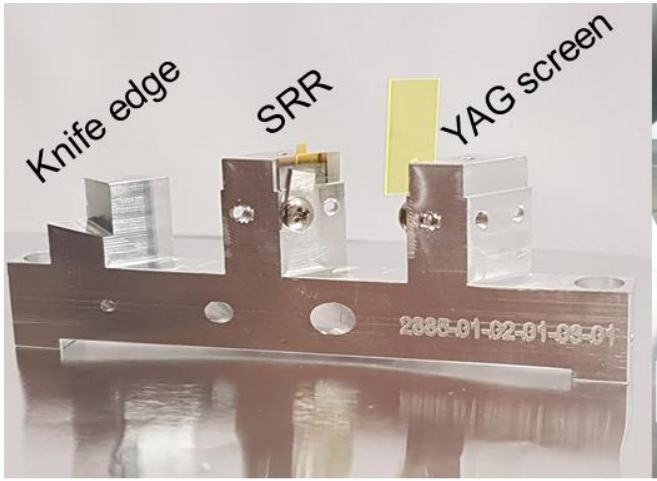


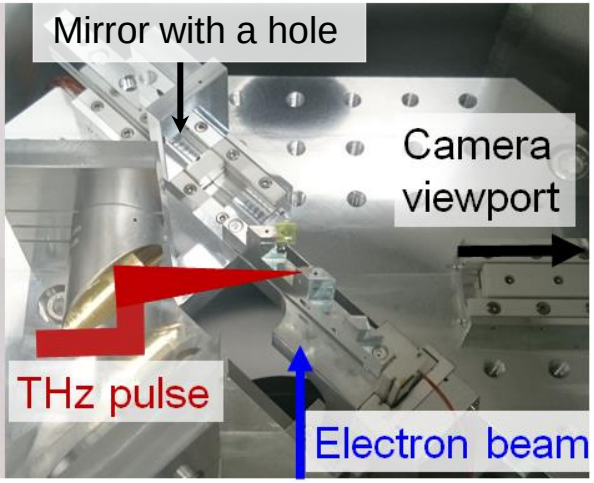

**Table: SRR parameters**

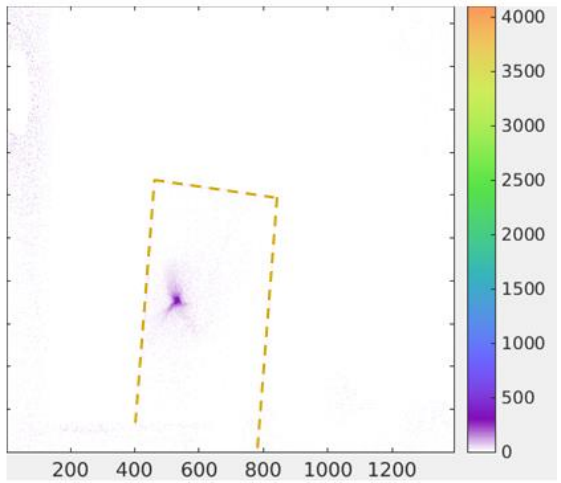
| | |
|---|---|
| Gap size in x | 20 µm |
| Gap size in y | 20 µm |
| Gap width in z | 10 µm |
| Resonant frequency | 300 GHz |
| Peak electric field | 500 MV/m |
| Integrated field | 10kV |

# 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

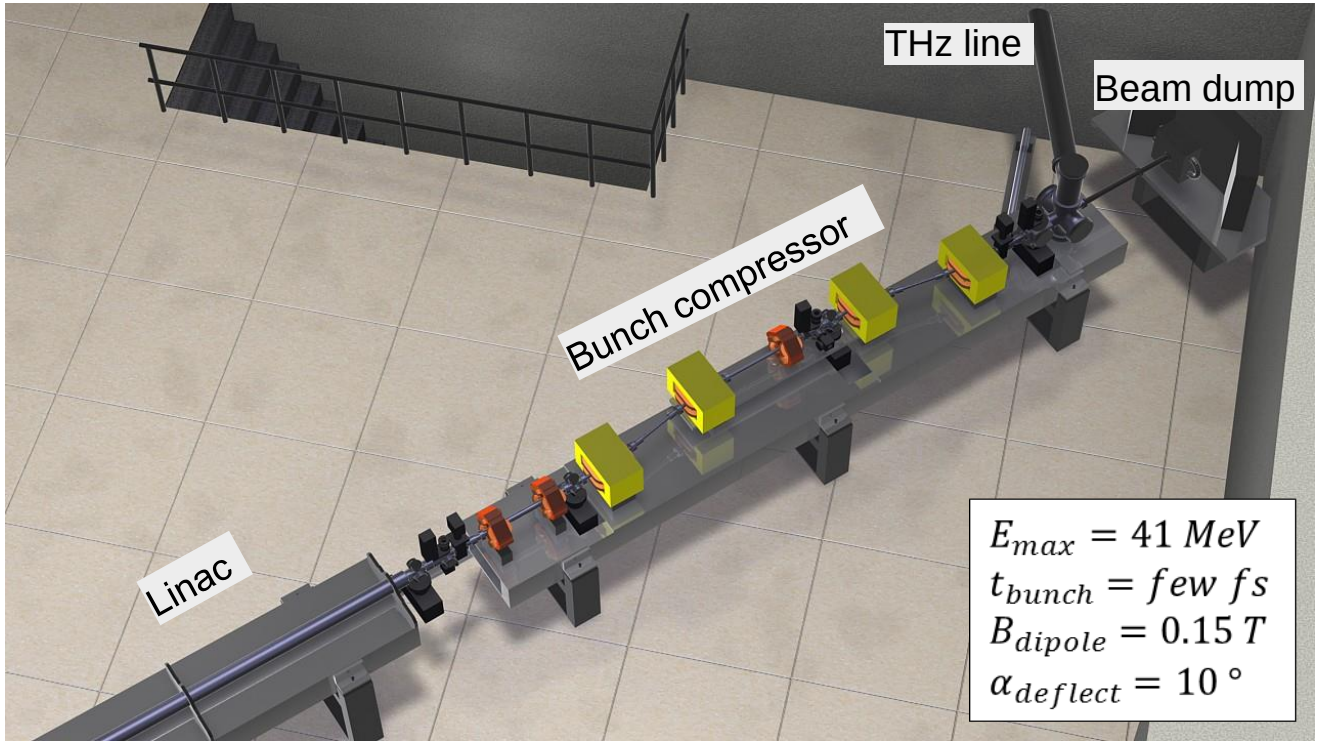


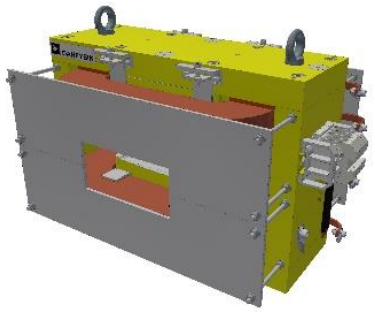



# Bunch compessor

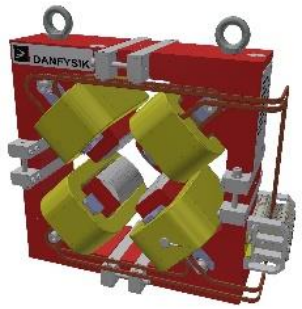
- Dipoles and quadrupoles have been delivered
- Measurement of magnetic field distribution is in progress at KIT to compared with specifications and Factory Acceptance Tests




**Dipole**



**Quadrupole**

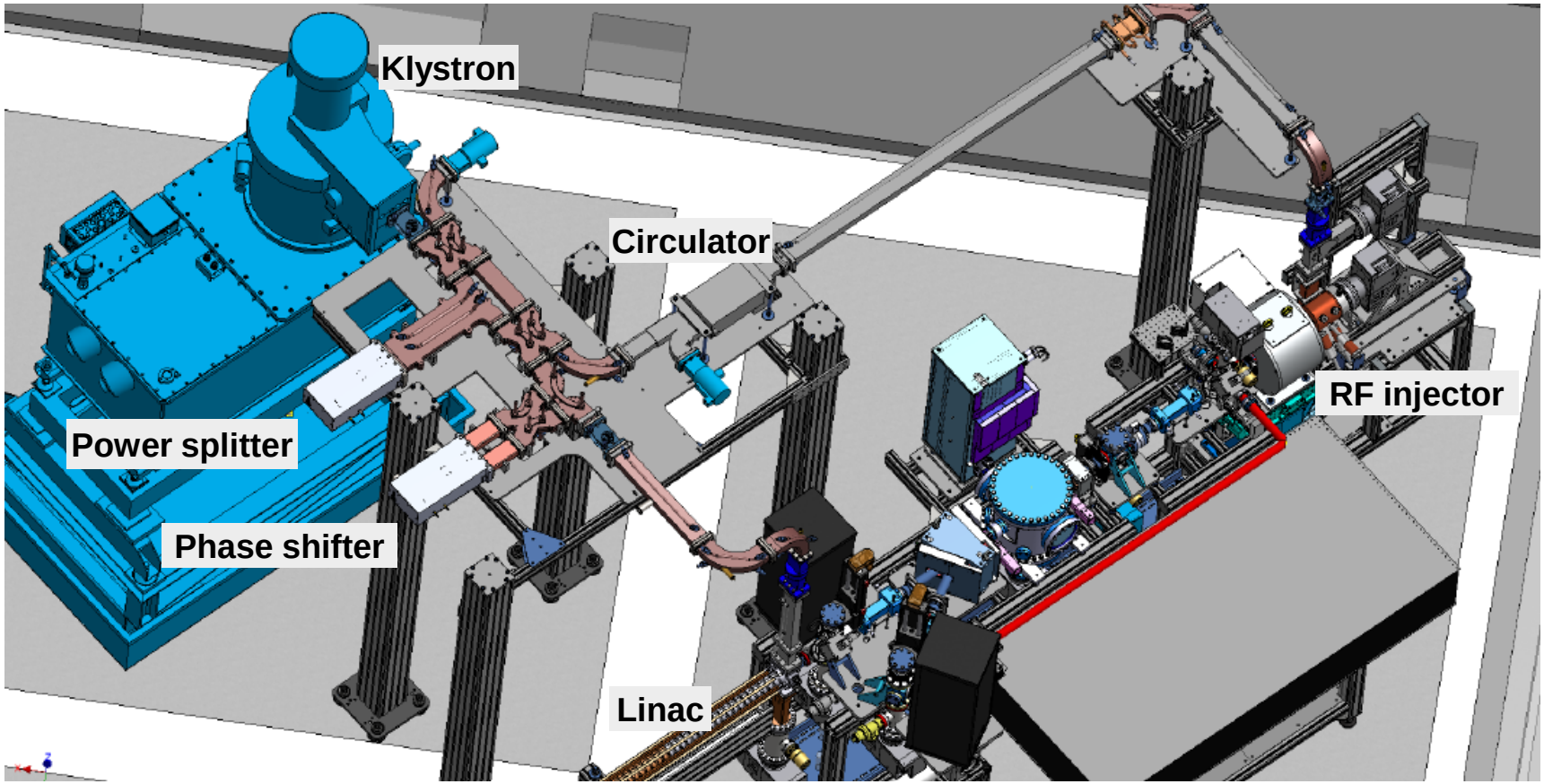


# Summary and Outlook

- 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

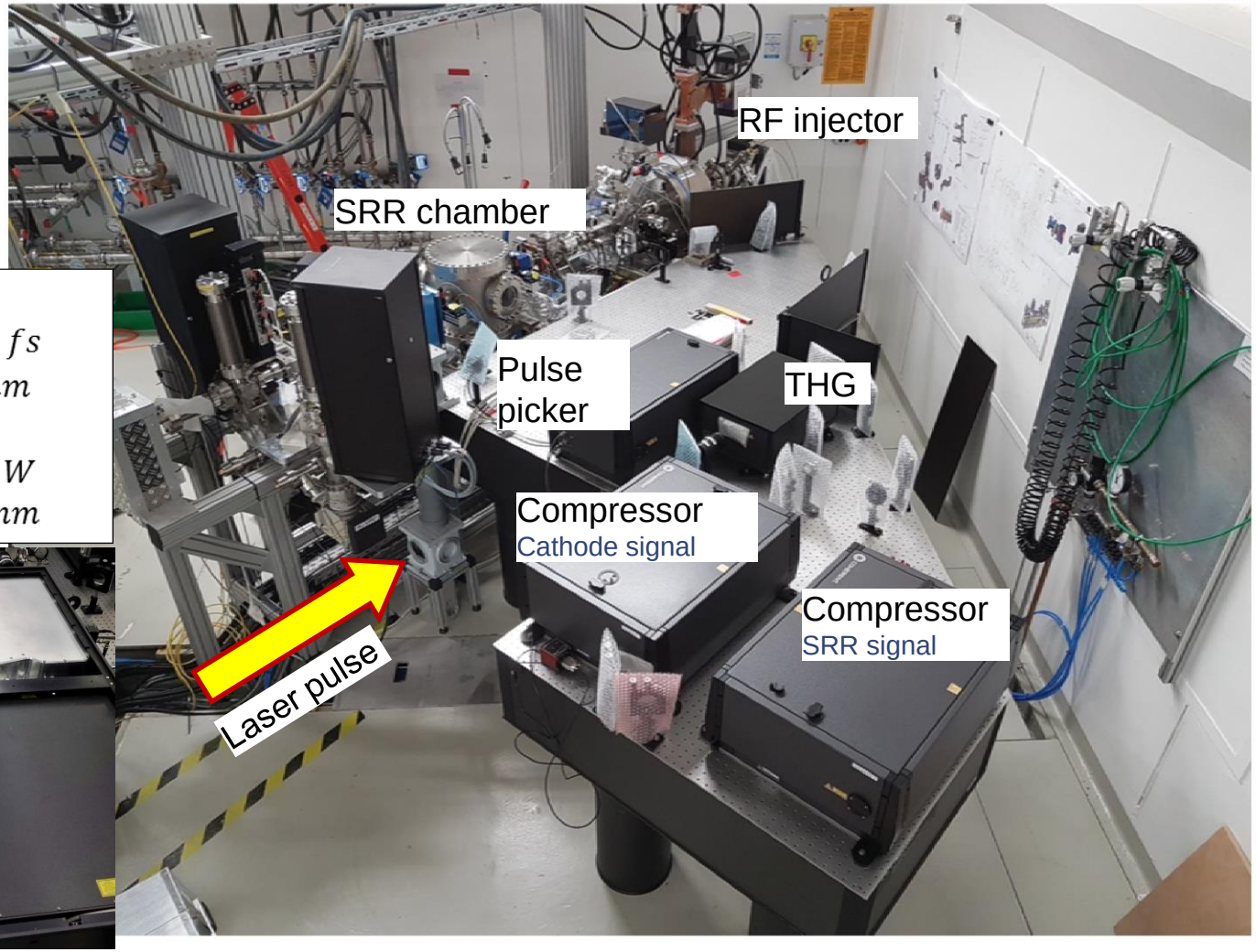
**Thank you for your attention!**

# 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.




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