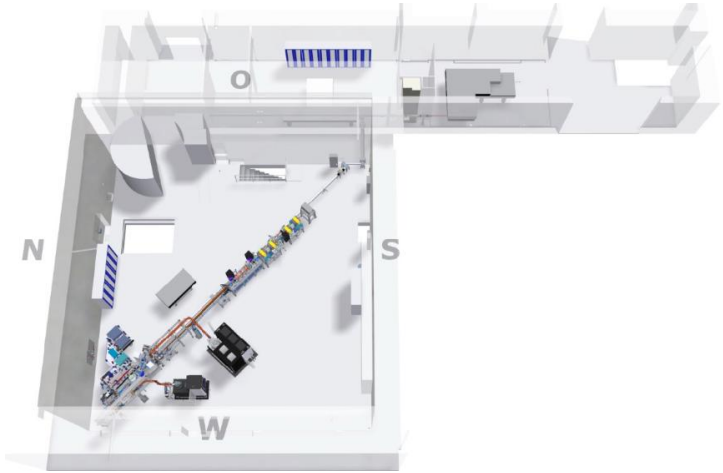
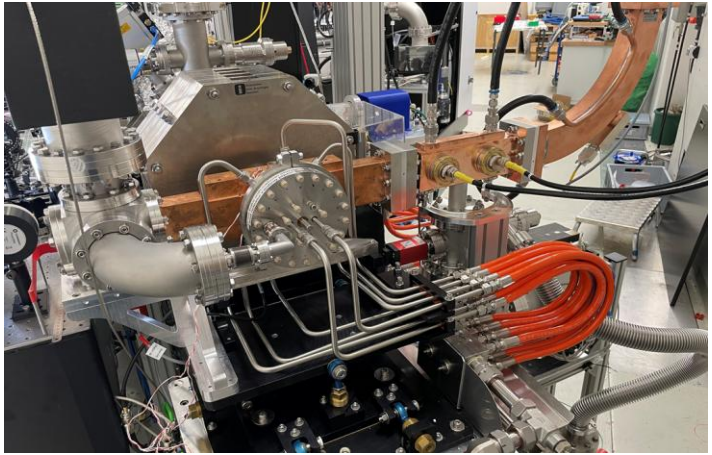
FLUTE RF system upgrade

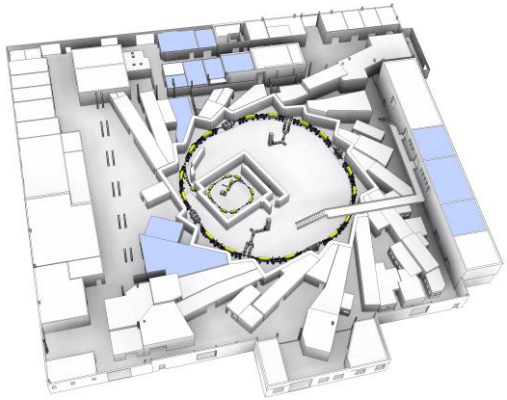
Dr. Anton Malygin on behalf of the FLUTE team



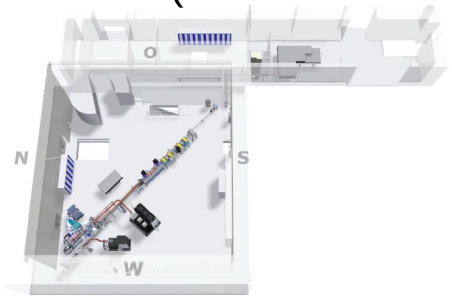


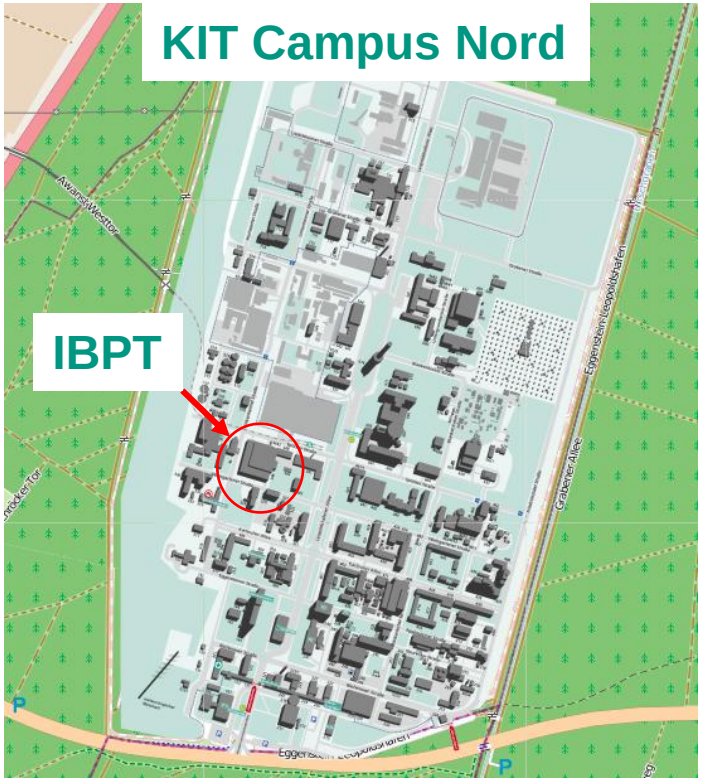
Accelerator facilities at KIT – IBPT

- KARA (KArlsruhe Research Accelerator)



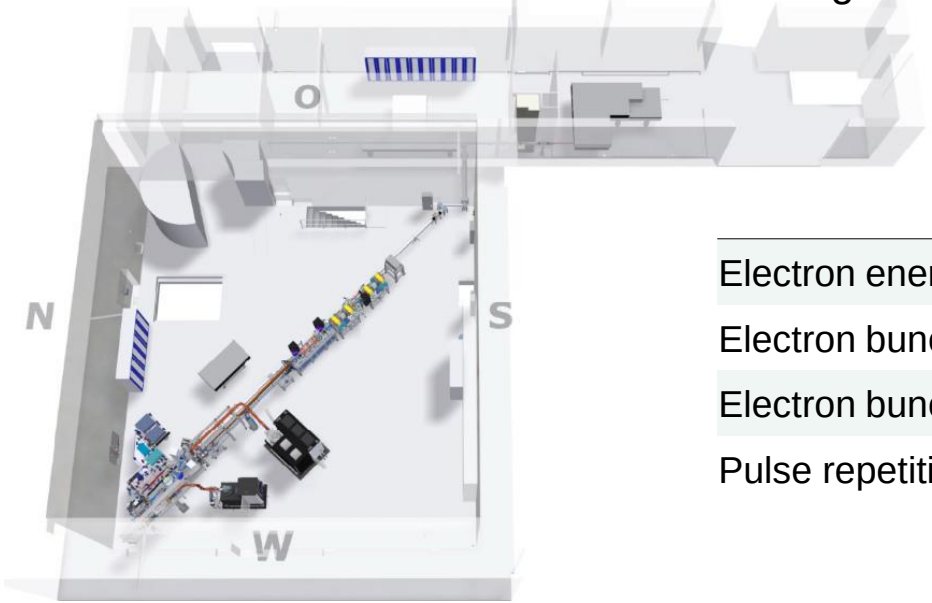
- FLUTE (Ferninfrarot Linac Und Test Experiment)





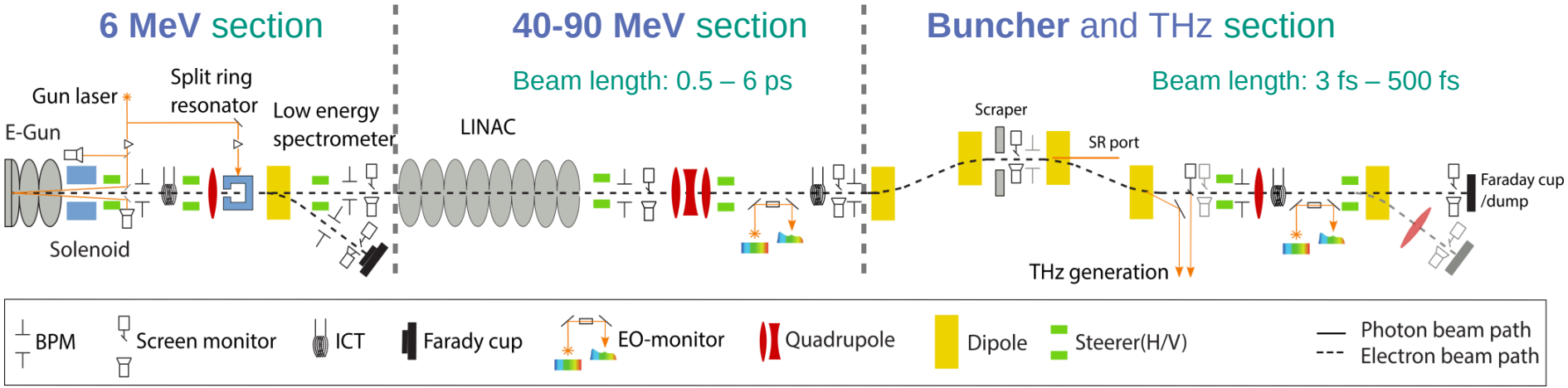
FLUTE: Linear accelerator test facility at KIT

- FLUTE (Ferninfrarot Linac- Und Test-Experiment)
  - Linac-based test facility for accelerator physics
  - Studies of THz radiation and new beam diagnostic methods

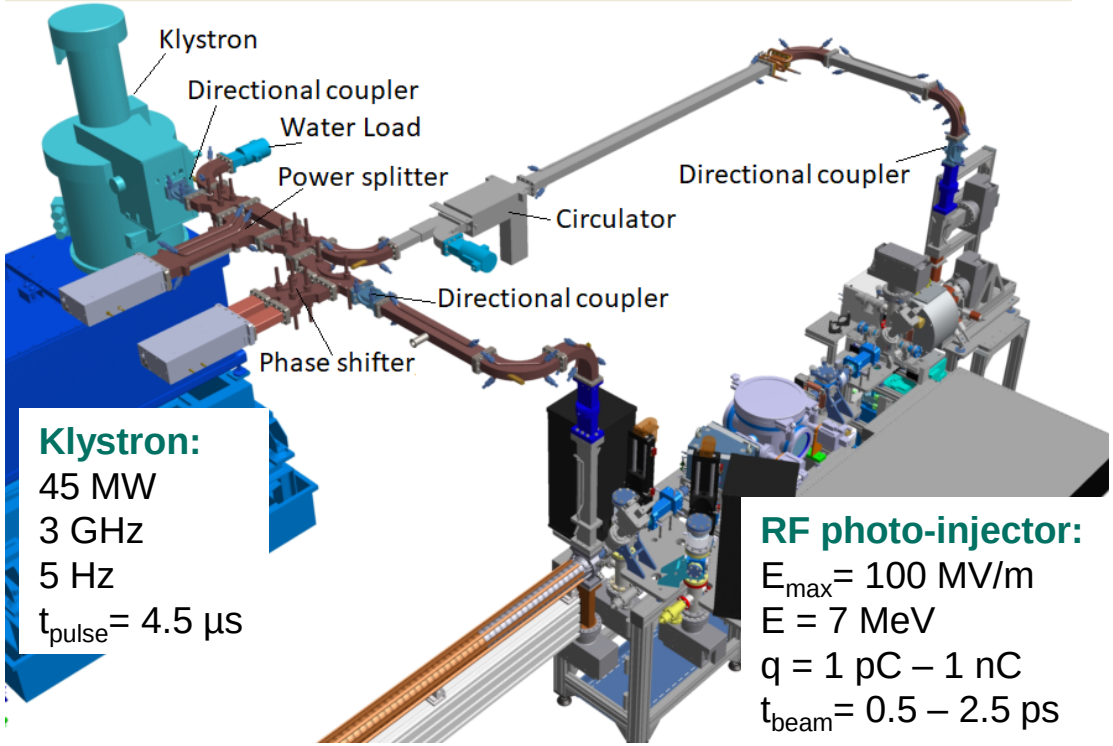


Electron energy	40 - 90	MeV
Electron bunch charge	0.001 - 1	nC
Electron bunch length	1 - 300	fs
Pulse repetition rate	50	Hz

FLUTE: Layout



FLUTE: Configuration of the first RF system

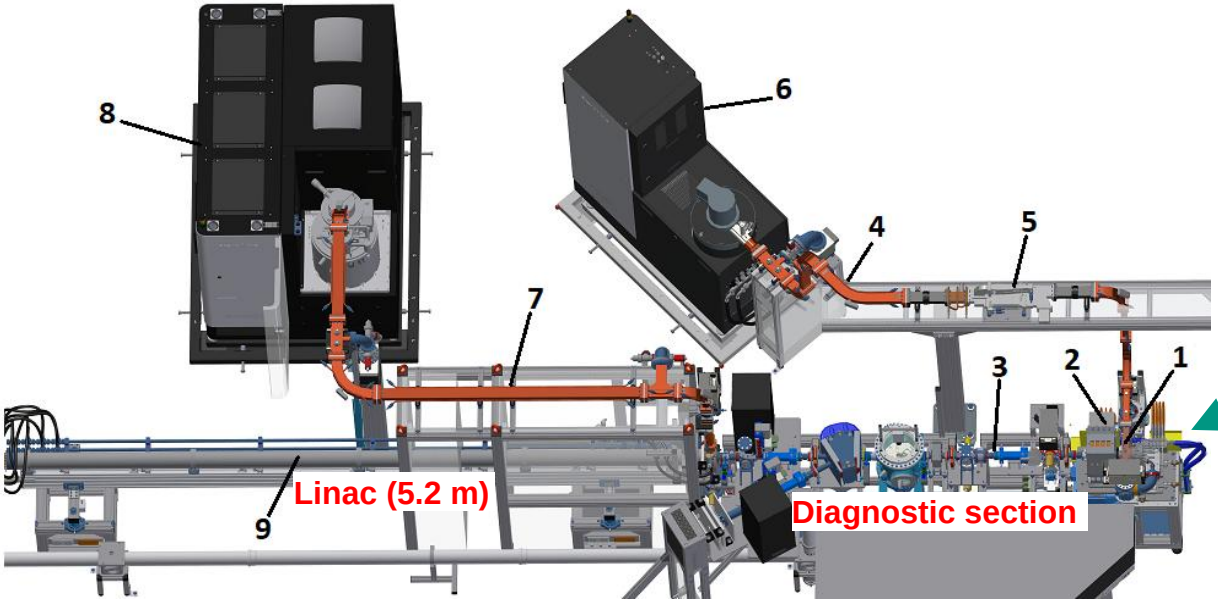


- **Main challenges of the first configuration of the RF system:**
  - Limited repetition rate of 7 Hz due to the RF photo-injector design
  - High dark current produced by the RF photo-injector (up to 1 nC)
  - Old modulator design with low stability and reliability
  - Total energy limited to 41 MeV
  - Waveguide configuration requires almost the full volume to be operated under SF_6 gas

FLUTE: New RF system configuration

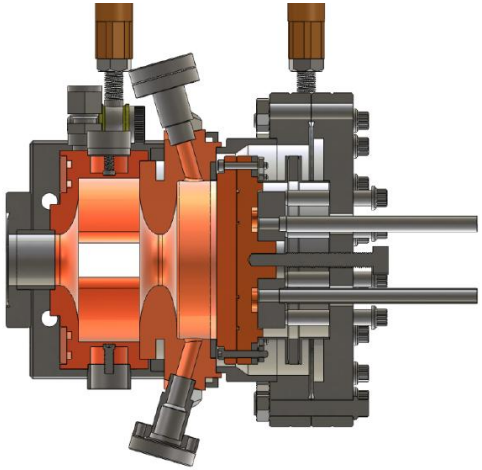
37 MW RF unit
3 GHz, 4.5 µs, 50 Hz

10 MW RF unit
3 GHz, 4.5 µs, 50 Hz



RF photo-injector

Q_e = 70 fC – 1 nC
E = 6 MeV; t = 0.5 – 8 ps
50 Hz



FLUTE: 10 MW and 37 MW RF units

Karlsruhe Institute of Technology

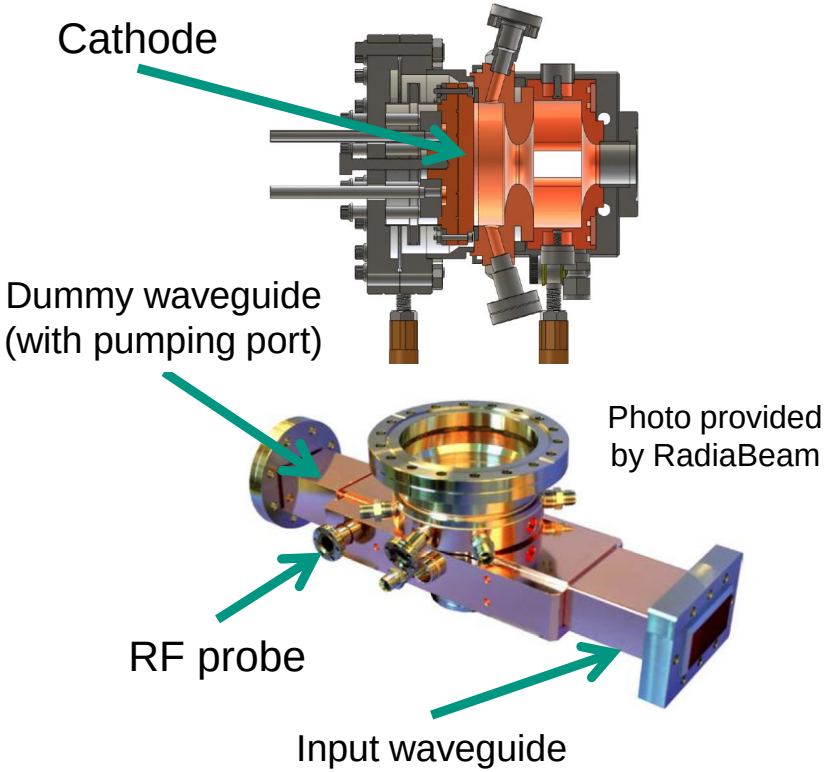
SAT results

Parameter	K100	K300	Unit
RF power	10.6	37.3	MW
Frequency	2.997		GHz
Output voltage	177	287	kV
Output current	135	329	A
RF pulse top flatness	1% for 4 usec 2% for 5 usec		
Repetition rate	50		Hz
Pulse to pulse voltage stability	18	14	ppm

10 MW RF unit – K100

37 MW RF unit – K300

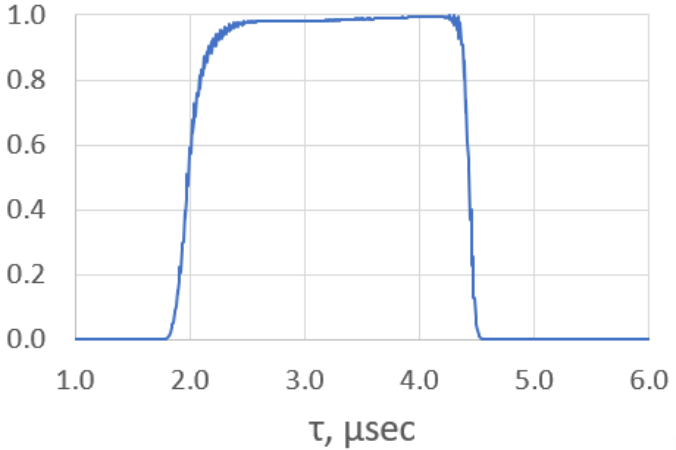
FLUTE: New RF photo-injector



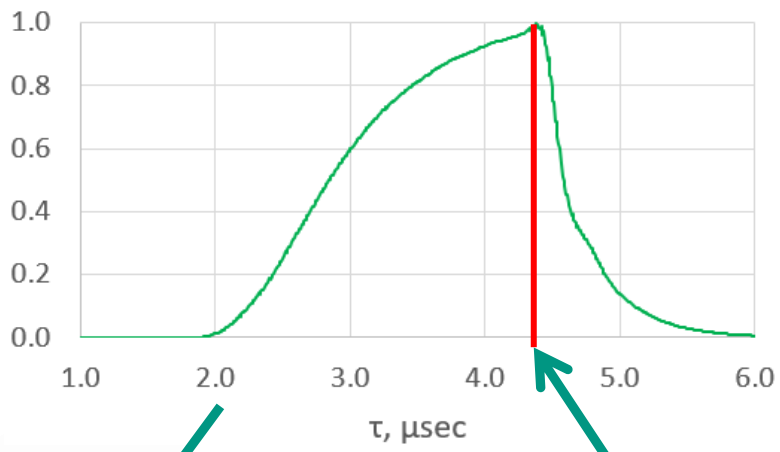
Parameter	Value
Input RF power	9.5 MW
Output Energy	6 MeV
Operating Frequency	2.997 GHz
Maximum repetition rate	50 Hz
Peak surface field	102 MV/m
Peak cathode field	120 MV/m
Maximum bunch charge	Up to 1 nC
Cathode	Removable
Laser injection	On-axis

FLUTE: New RF photo-injector

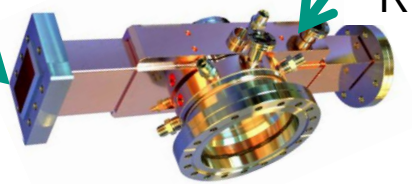
RF input power (9 MW)



RF probe (E-field inside the cavity)



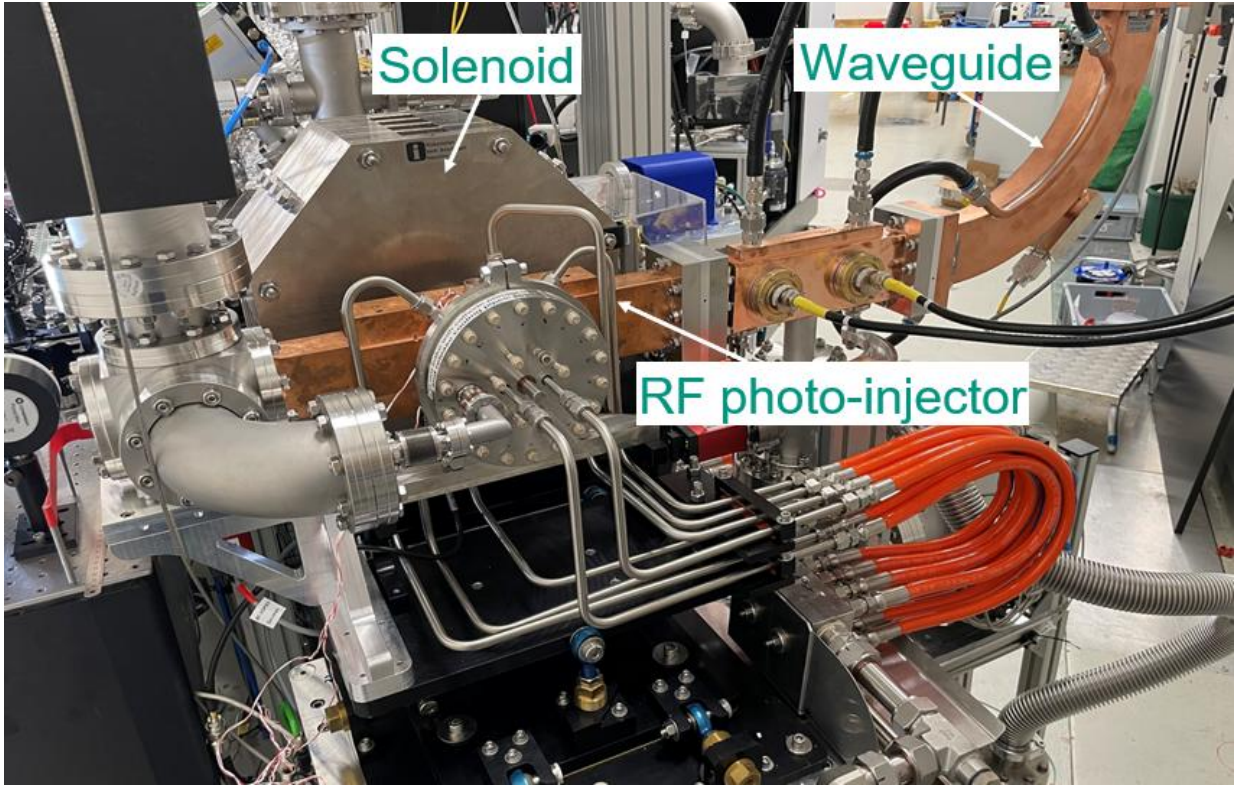
RF input

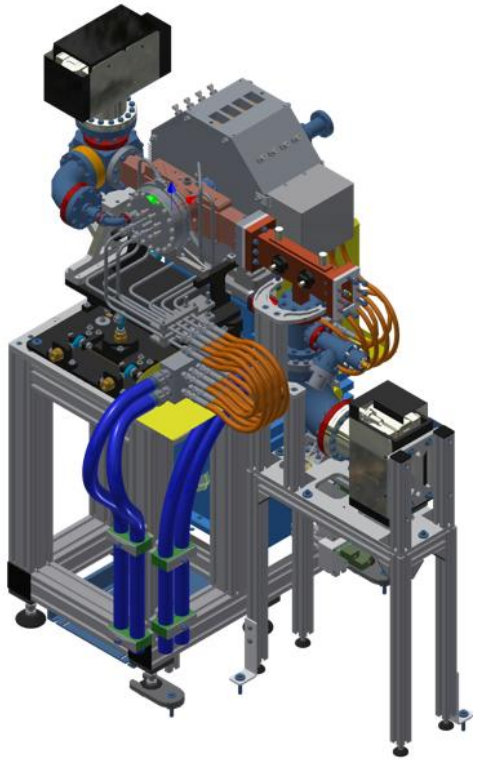


RF probe

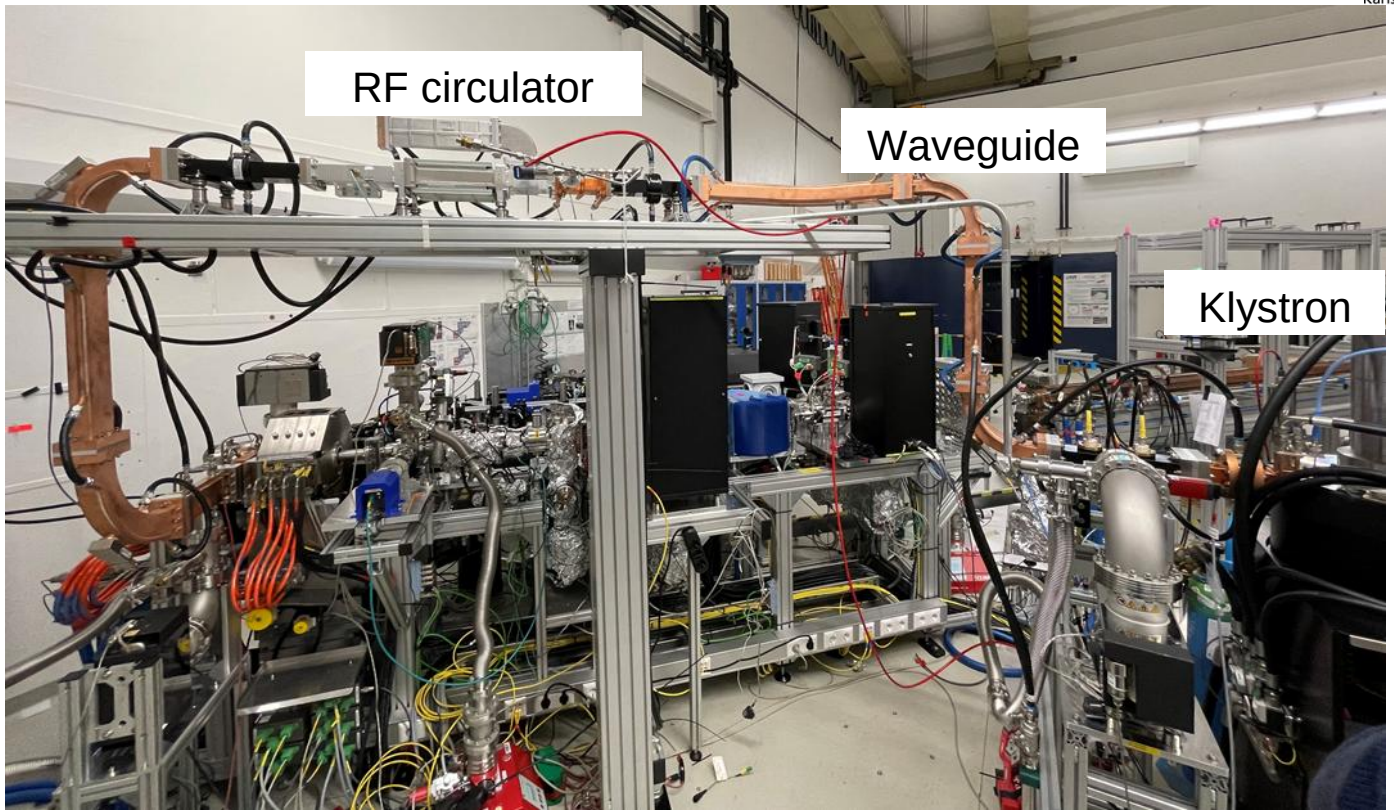
Laser pulse: 0.5 - 6 ps

FLUTE: New RF photo-injector

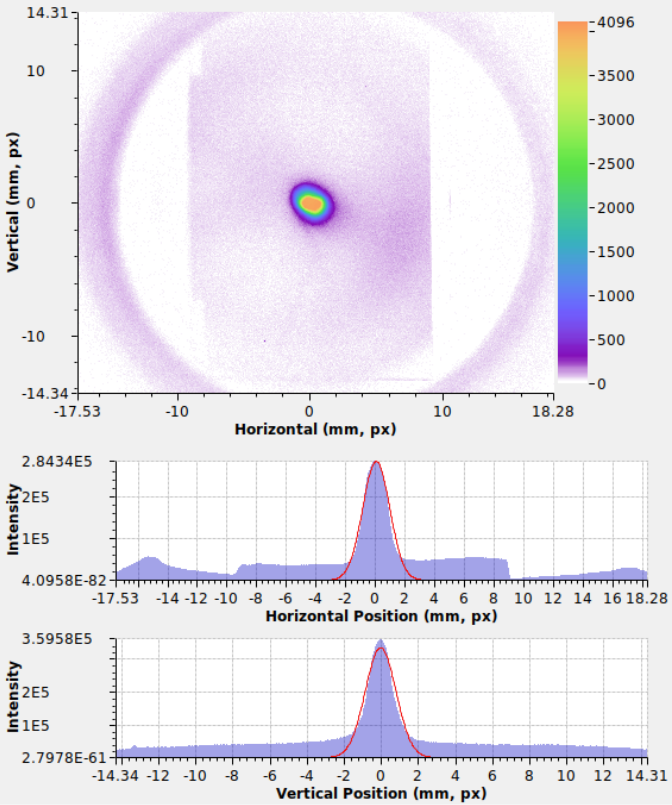


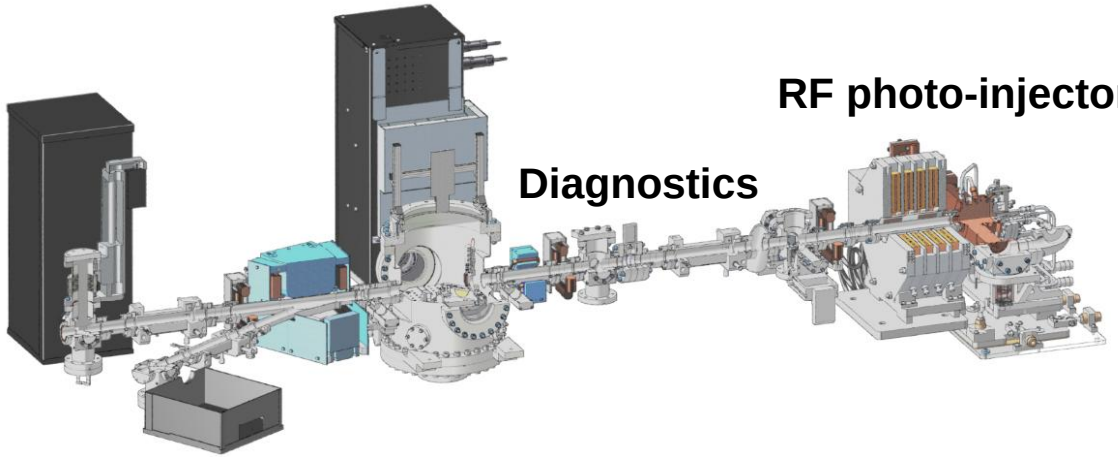


FLUTE: 10 MW RF unit + waveguide system



FLUTE: Experimental results: electron beam

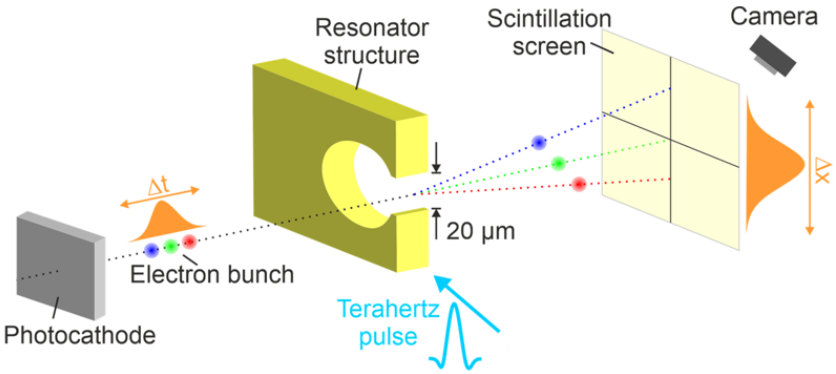


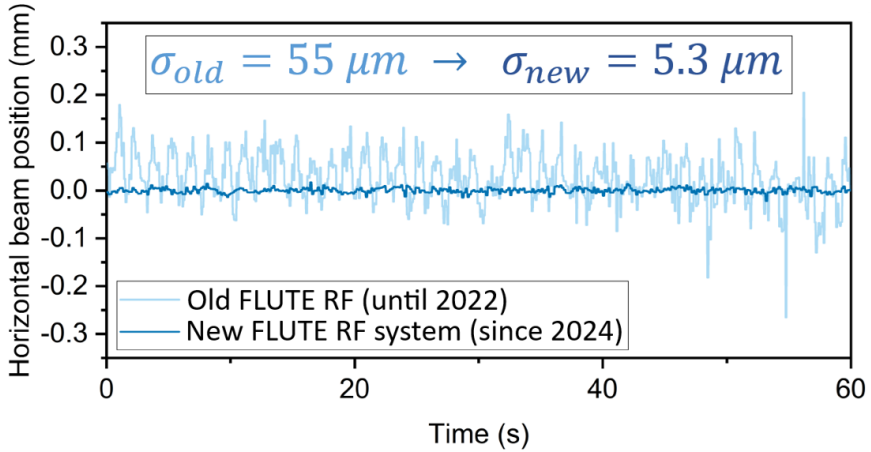


Parameter	Value
Input RF power	9.3 MW
Output Energy	6.0 MeV
Repetition rate	50 Hz
Electron beam charge	800 pC

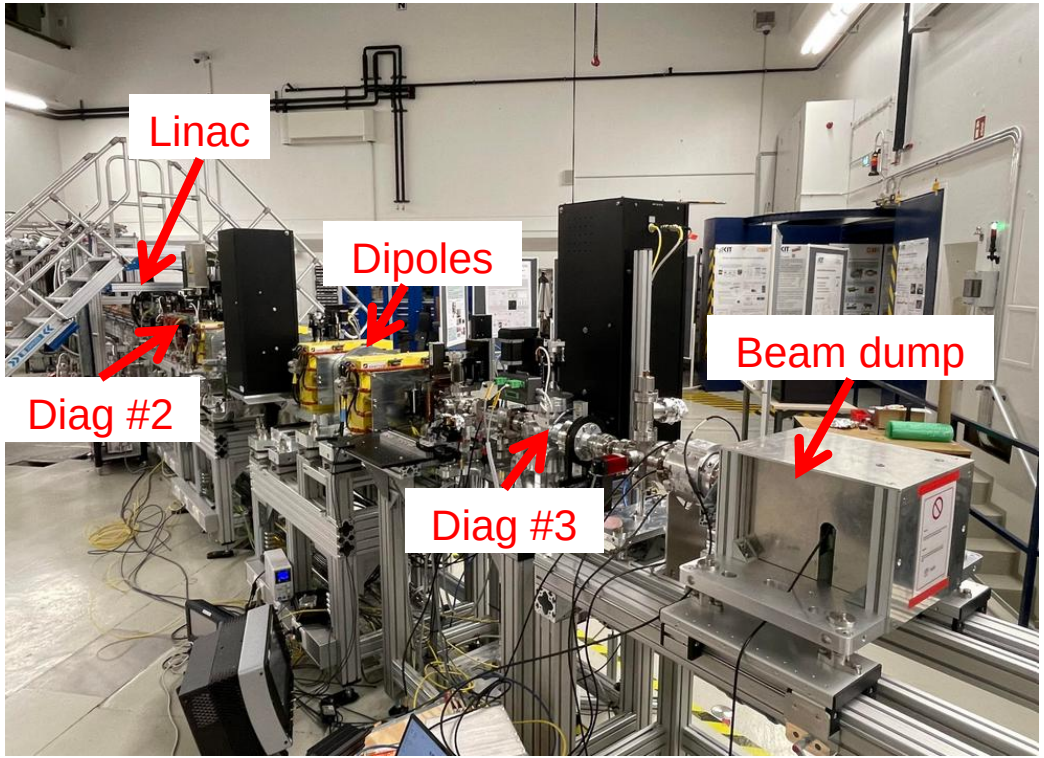
Experiments with a new beam diagnostics

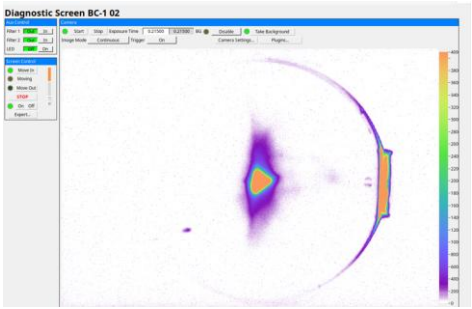
Compact Transverse Deflecting system

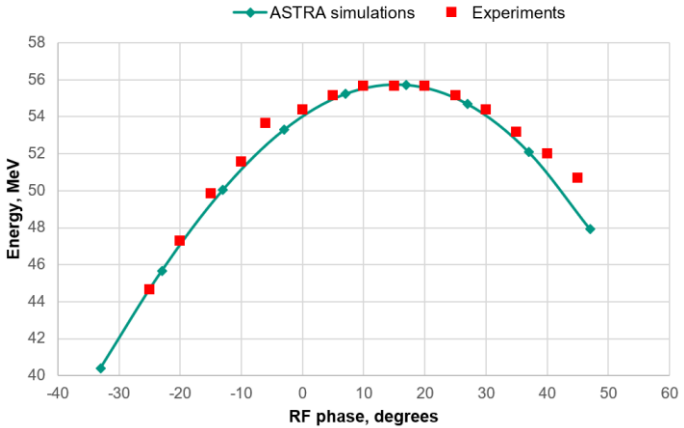




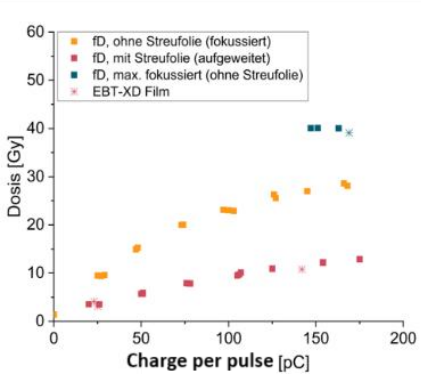
FLUTE: Experiments with high energy section

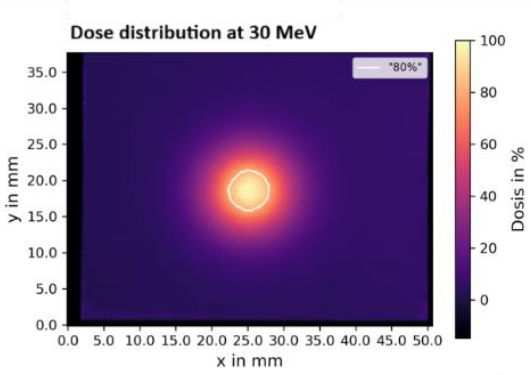




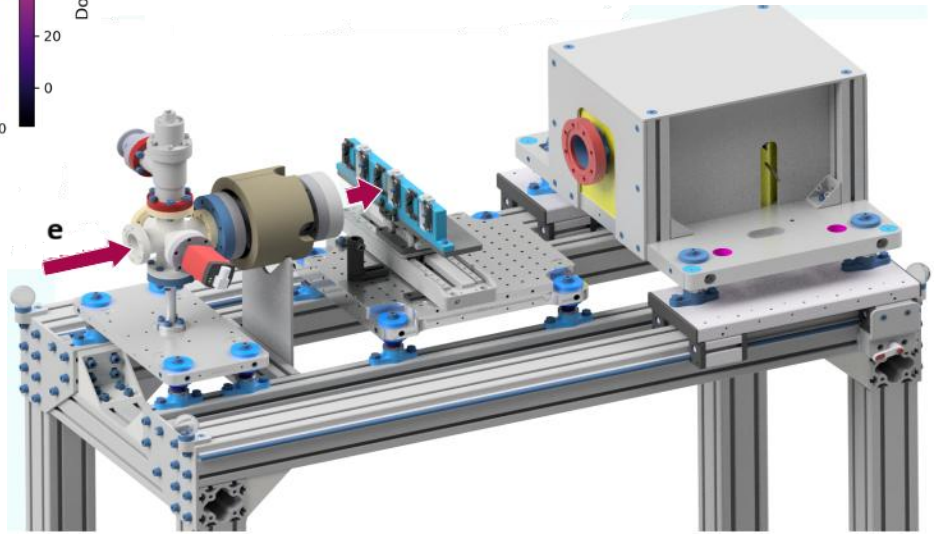


FLUTE: Experiments with high energy section





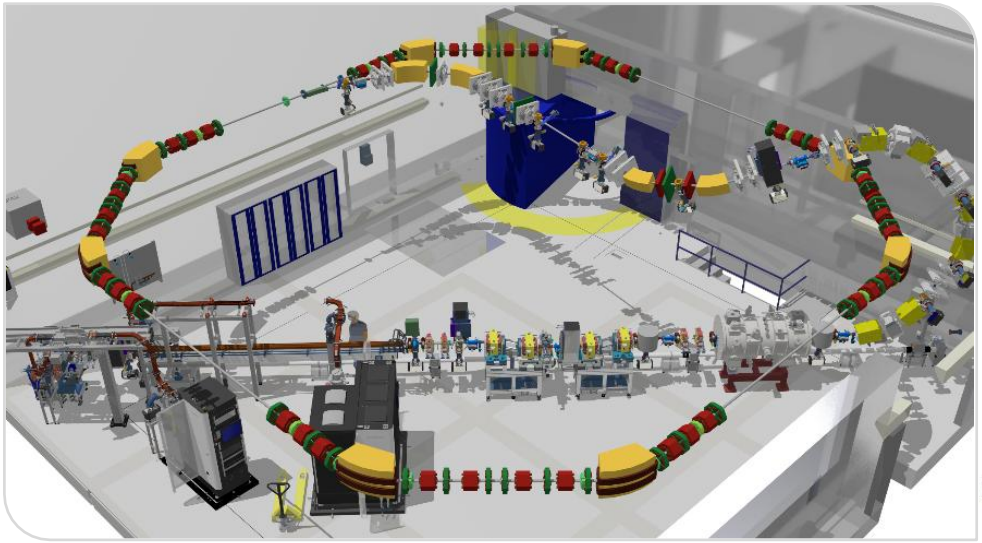
FLASH radiation therapy

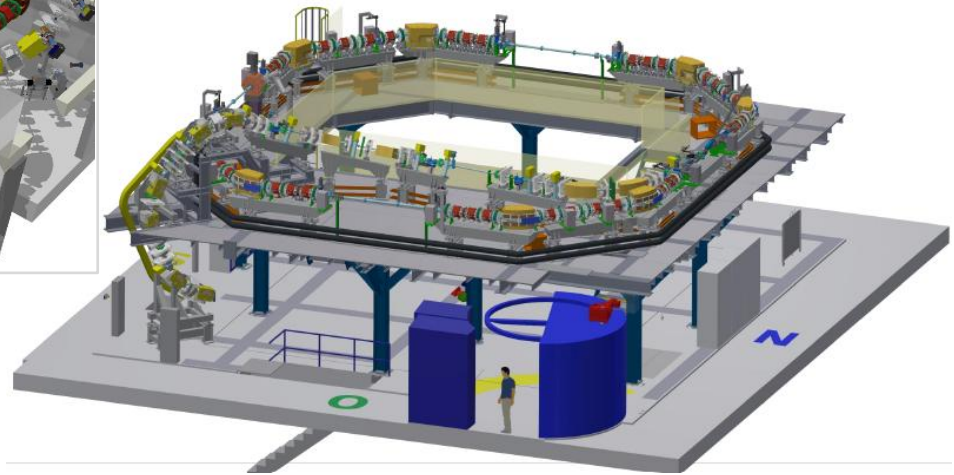


Projected dose rate at 1 nC (50 Hz): 70 Gy/s

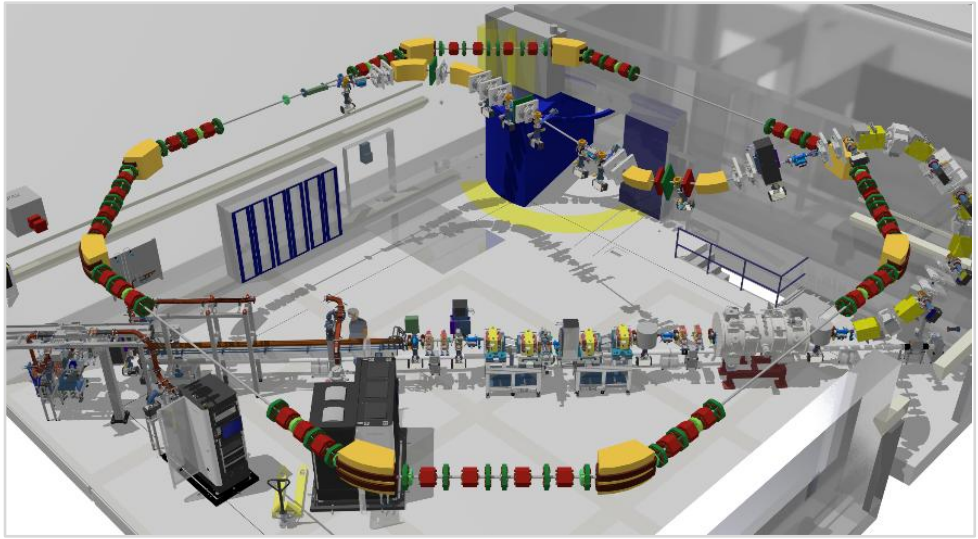
Minimum FLASH radiation therapy dose 40 Gy/s

cSTART: compact STorage ring for Accelerator Research and Technology





cSTART: Design Criteria



- storage of ultrashort electron bunches
- large acceptance of electron energies
- direct injection of ultrashort (LPA) bunches into (ultra-) low alpha lattice
- on-axis one-turn injection
- space in straights for future accelerator experiments
- vacuum chambers to enable large dynamic aperture and circulation of beams with large energy spread
- compact, energy efficient

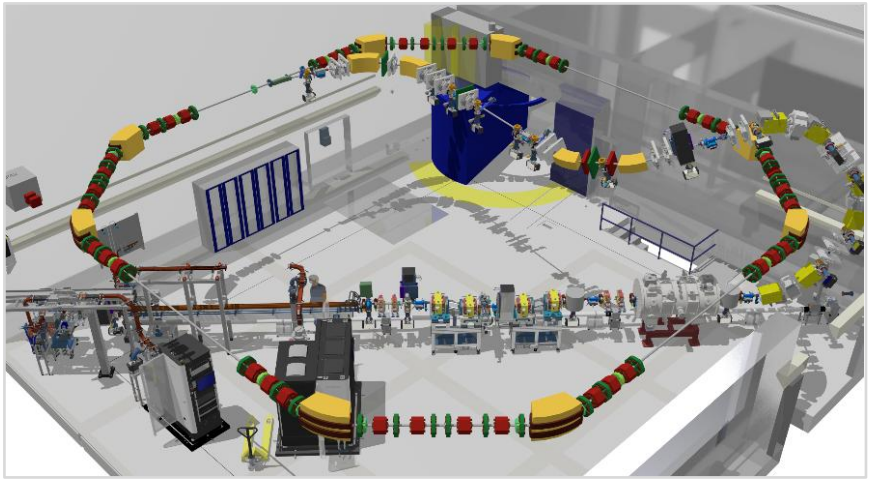
FLUTE: Summary

- RF photo-injector (low energy sector): Achieved **6.0 MeV**, **800 pC** at **50 Hz**
- Successfully conducted experiments with new diagnostics requiring high beam stability, such as the **Compact Transverse Deflecting System (TDS)**.
- Experiments with the **high-energy section** are ongoing.
- **Dose rate experiments** demonstrated the capability to reach dose rates sufficient for **FLASH radiation therapy studies**.
- **FLUTE** will be **disassembled at the end of 2025** and **reassembled in 2027 with an upgraded design as *FLUTE 2.0*.**

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101057511.

Back-up slides

cSTART: Unique Storage Ring
Motivation



- “Non-linear linear accelerator”
- Large momentum acceptance
- Direct injection of ultrashort (laser-plasma accelerator [LPA]) electron bunches
- Storage of ultrashort electron bunches
- Compact, energy efficient
- Testbed and prototype for
  - Plasma + RF accelerator experiments
  - Widely unexplored accelerator physics and technology developments
  - Future light sources with potential for transformative impact

cSTART Parameters

cSTART Parameters	
Circumference	43.2 m
Revolution period; freq	144 ns; 6.9 MHz
Energy range (no ramping)	40 MeV to 90 MeV
Damping time (h / v / l)	29.5 s / 26.5 s / 12.6 s
DBA Lattice	
Momentum compaction (nominal version)	1.5×10^{-2}
Momentum compaction (future VCF experiment)	4×10^{-7}
Momentum acceptance	± 4 %
Straight sections	Four; each 3.85 m

Electron Beam Parameters	
Beam energy	40 – 90 MeV
Bunch duration	10 fs – 1 ps
Bunch charge	1 pC – 1 nC
Energy spread	0.1 – 4 %