Updates of the THz SASE FEL at PITZ

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Abstract

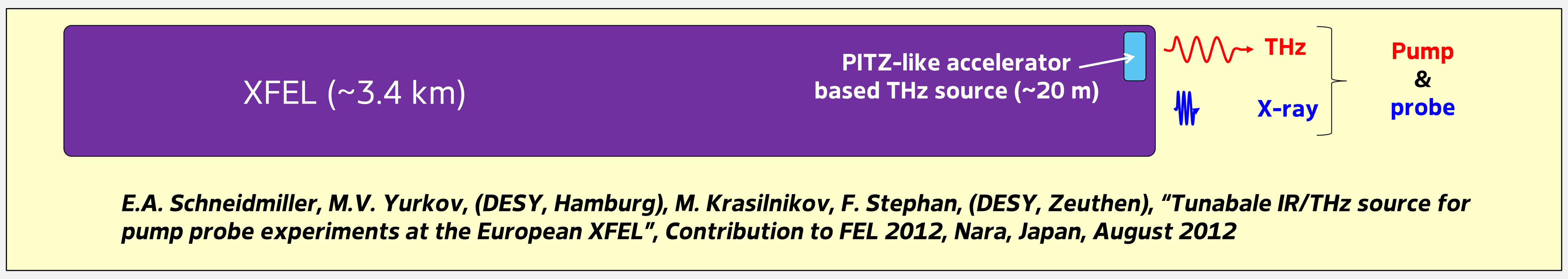
Research and development of an accelerator-based THz source prototype for pump-probe experiments at the European XFEL are ongoing at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). Proof-of-principle experiments have been performed to generate a high-gain THz Free-electron Laser (FEL) based on the Self-Amplified Spontaneous Emission (SASE) scheme. The first lasing with a central wavelength of 100 μm (3 THz) was observed in the summer of 2022.

This contribution presents updates of the THz SASE FEL at PITZ, including recent optimization of beam transport and matching resulting in a measured FEL pulse energy of more than 80 μJ, recent FEL gain curves measurements, and an upgrade plan of THz diagnostics..

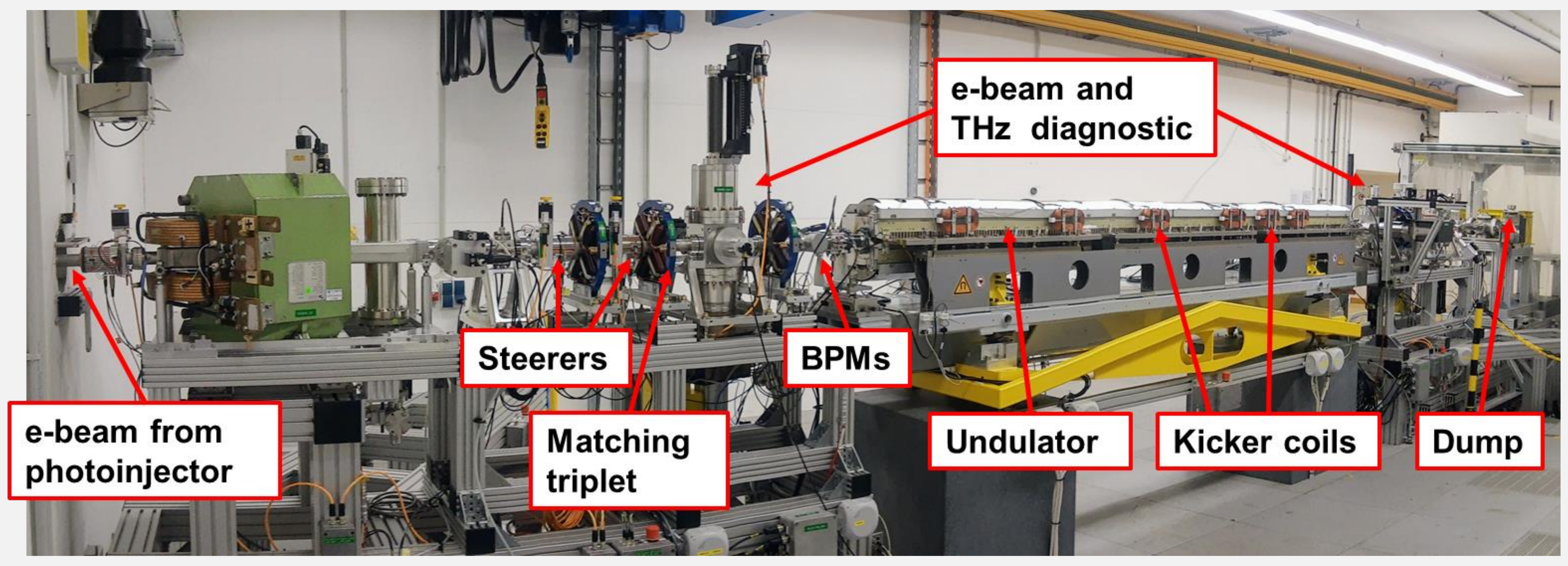
Machine, Measured Beam and FEL Parameters

Laser distribution	Gaussian
Laser pulse duration	7 ps FWHM
Gun gradient	57.55 MV/m
Gun phase w.r.t. MMMG	0 degree
Booster gradient	12.25~15.93 MV/m
Booster phase w.r.t. MMMG	0~45°
Undulator period	3 cm × 113 periods
Undulator parameter	3.49
Vacuum chamber size	11 mm and 5 mm
Vacuum chamber length	3.4 m
Bunch charge	0.1-3 nC
Bunch length	5.8 ± 0.3 ps
Peak current	~165 A
Beam emittance	>1.5 mm mrad
Beam momentum	17 MeV/c
Beam momentum spread	98 keV/c
FEL central wavelength	100 μm
Maximum FEL pulse energy	83.8 ± 13.3 μJ
Spectral bandwidth	≤ 12 μm FWHM

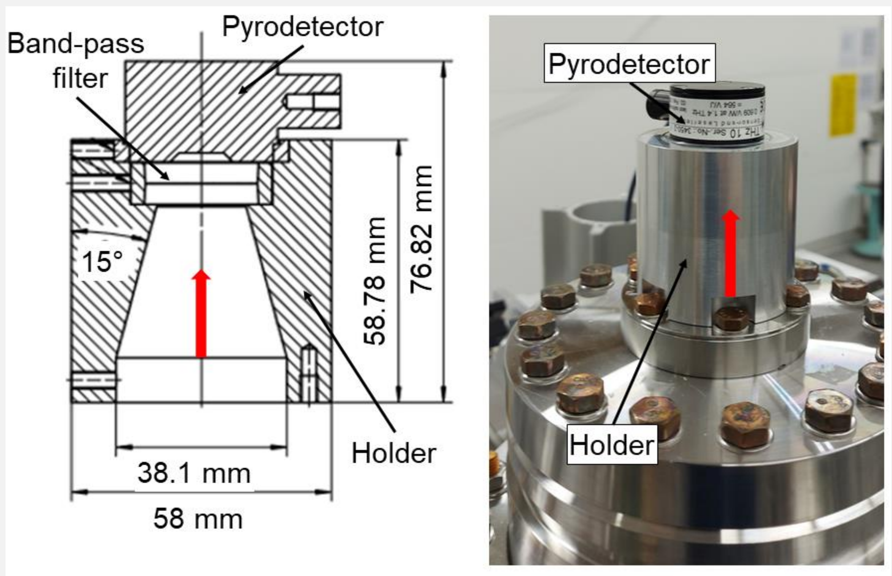
Motivation



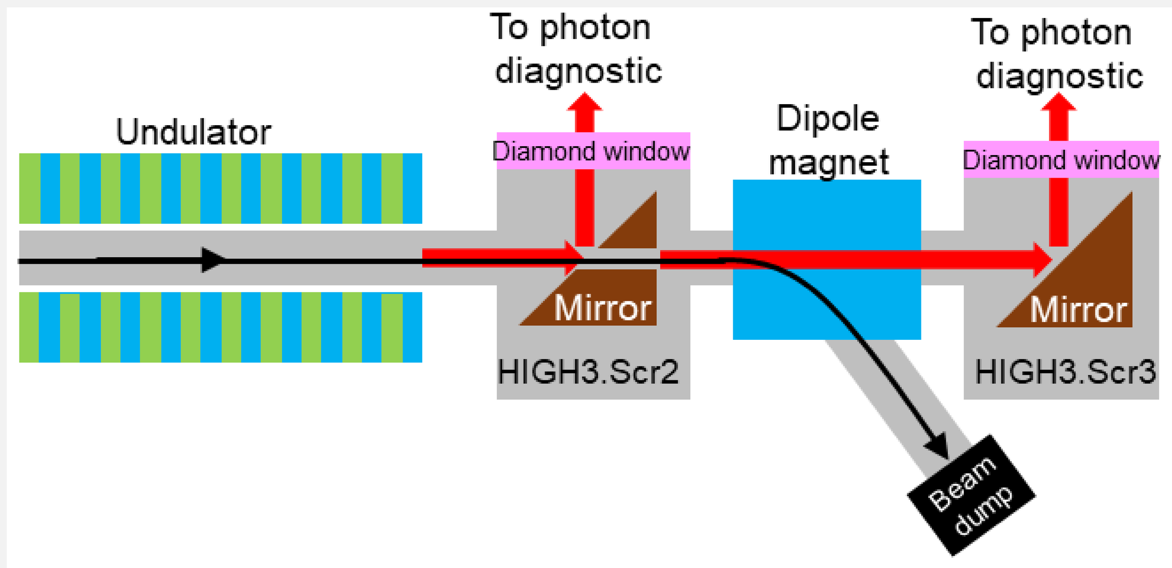
PITZ Beamline in the tunnel annex



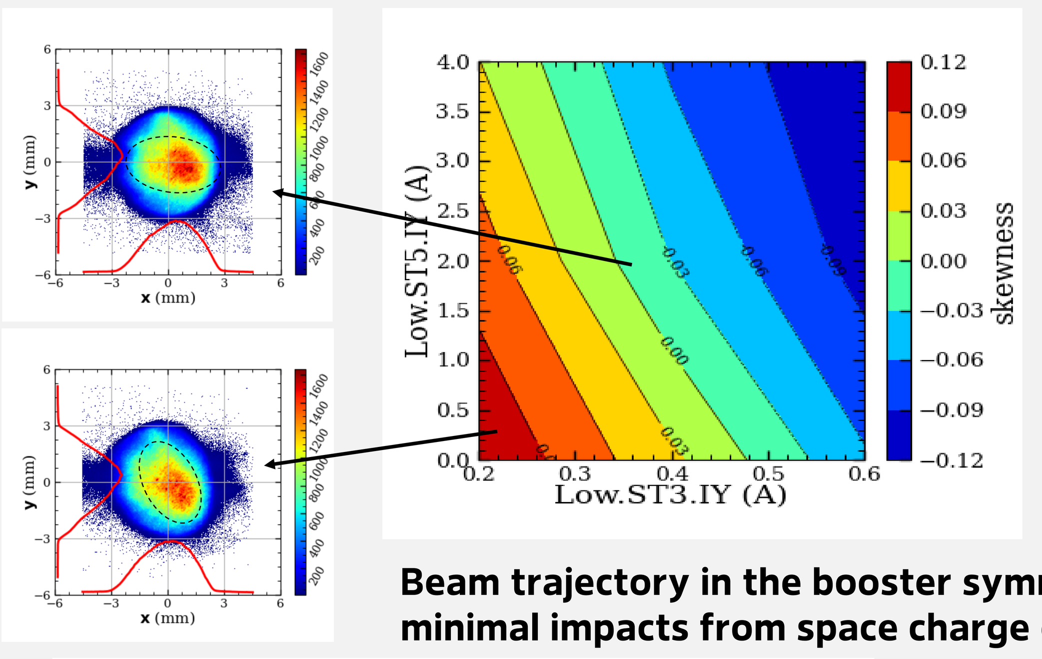
Photon diagnostic setup



Scheme of the photon diagnostics



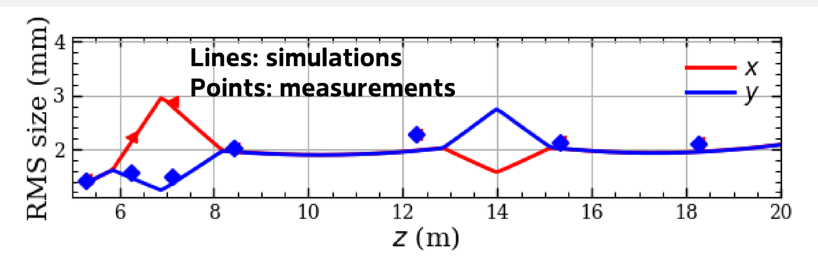
Electron beam transport



Fine scan of steerers:

$$s = \frac{\mu_3}{\sigma^3} = \frac{\langle (x-x_c)^3 \rangle}{\langle (x-x_c)^2 \rangle^{3/2}}$$

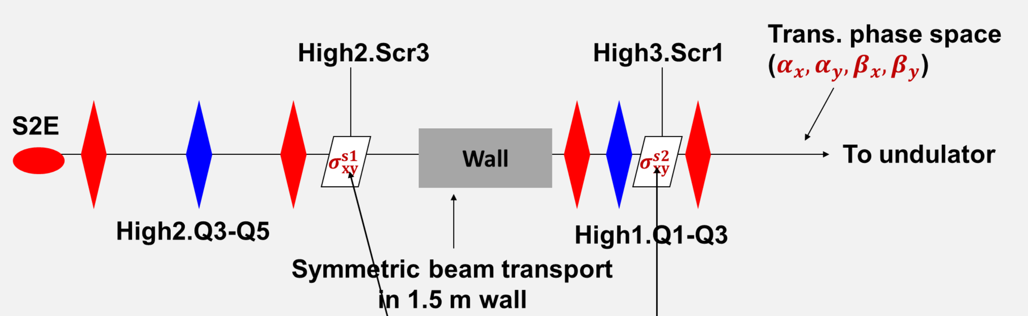
Beam trajectory in the booster symmetrized also for minimal impacts from space charge effects and wakefields

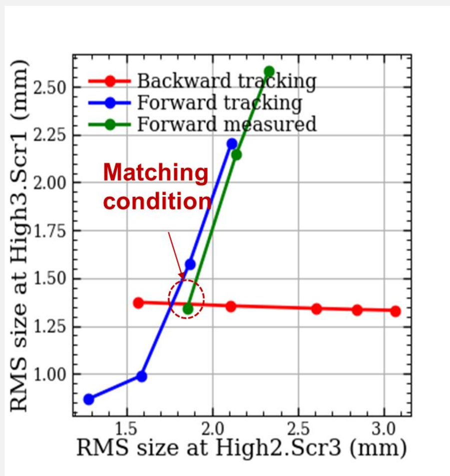


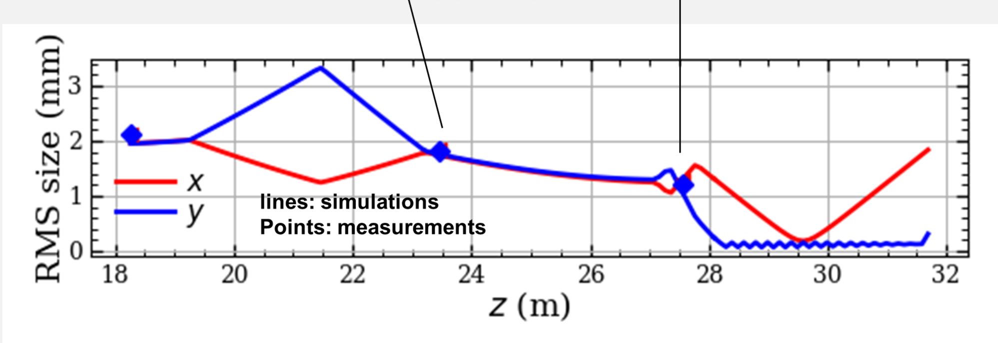
Smooth and symmetric beam transport after the accelerator

Beam matching into the undulator

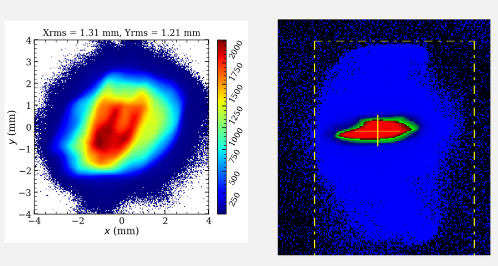
- Beam envelope development is determined by **Twiss parameters + space charge**
- Symmetric beam transport ($\alpha_x, \alpha_y, \beta_x, \beta_y$) in front undulator→ ($\sigma_{xy}^{s1}, \sigma_{xy}^{s2}$) at two screens
- Forward tracking (or experiments) + backward tracking → **Matched beam sizes**





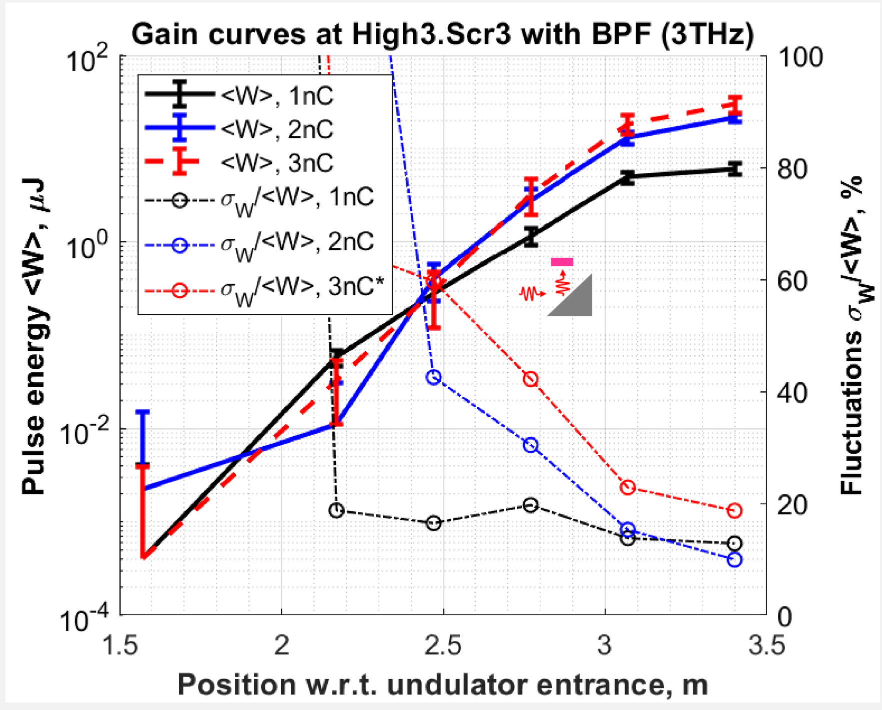


Matched beam transport in front of and inside the undulator



Measured beam before and after the undulator

Gain curve measurements at HIGH3.Scr3 with 3-THz band-pass filter

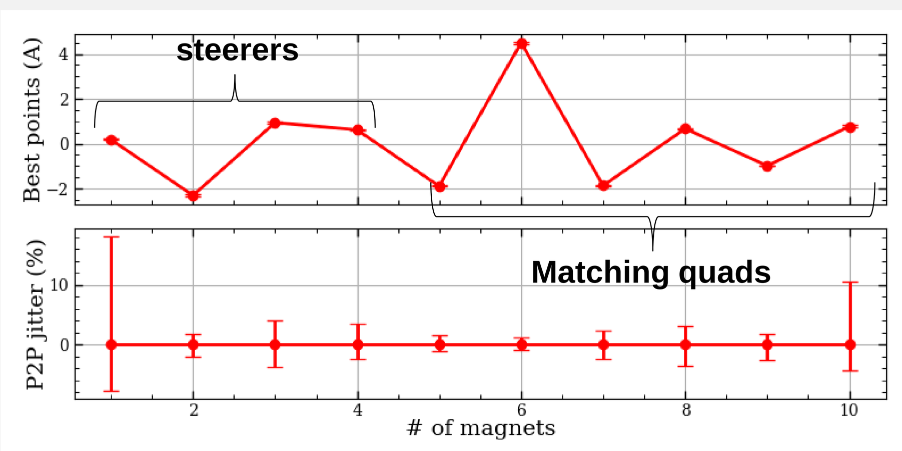


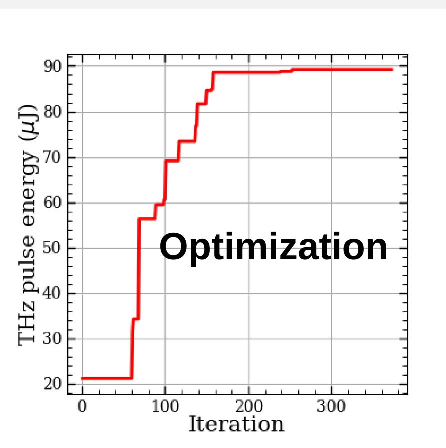
Bunch charge	1st lasing, no BPF	Tuning, BPF
1nC	0.36 uJ (σ~32%)	6.12uJ (σ~13%)
2nC	0.55uJ (σ~52%)	21.44uJ (σ~10%)
3nC*	2.26uJ (σ~78%)	29.67uJ (σ~19%)

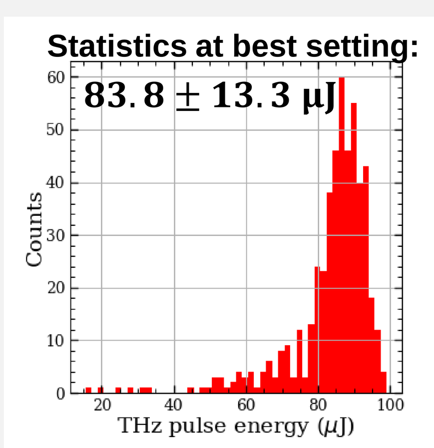
*** Not fully optimized**

Bayesian optimization

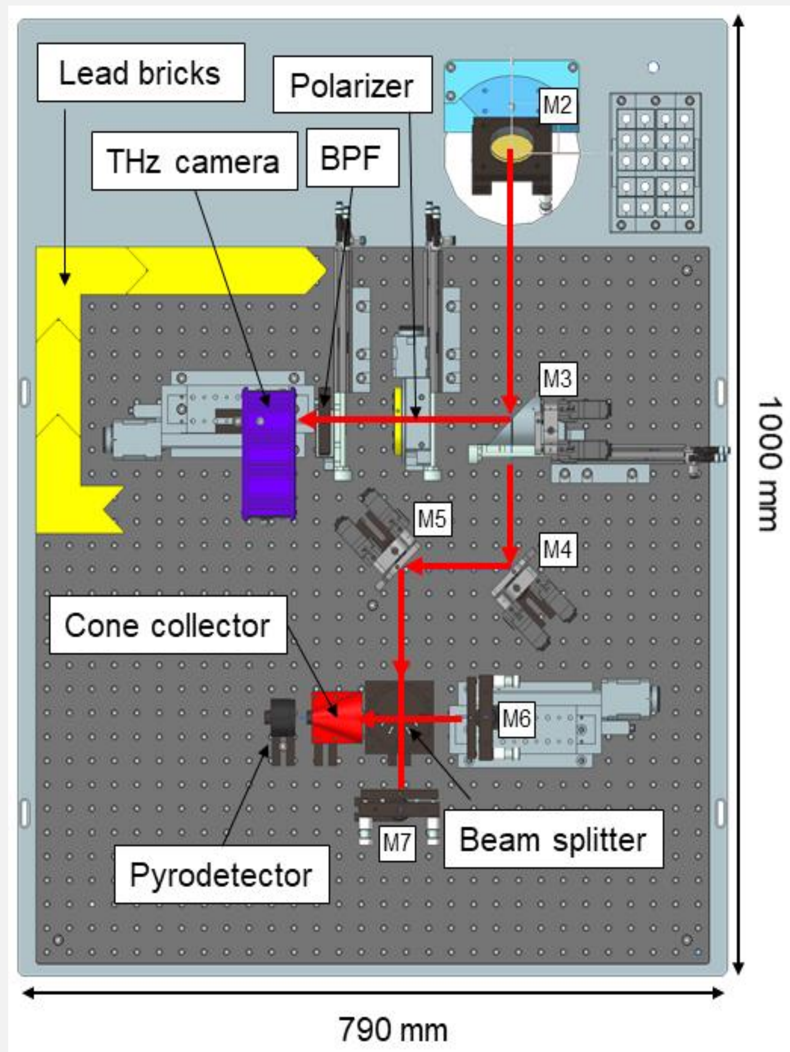
- A **few to ten uJ THz** pulse energy can be obtained by **manual tuning** of steerers, compensation coils and matching quadrupoles
- Global optimization with the Bayesian optimization algorithm has been developed in **Matlab** and has helped to reach almost **100 uJ (peak)**
- Hysteresis from quadrupoles is the source of fluctuation of best setting







Layout of the upgrade photon diagnostic setup at HIGH3.Scr3



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PITZ Photo Injector Test Facility Zeuthen

European XFEL

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