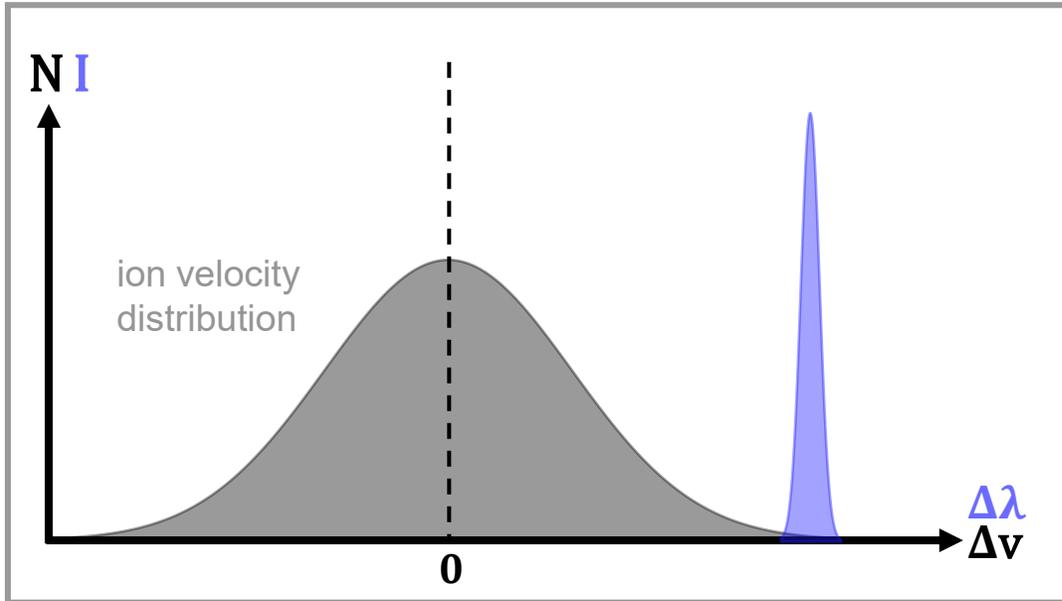# PULSED UV LASER SYSTEM FOR LASER COOLING OF RELATIVISTIC BUNCHED ION BEAMS AT THE SIS100

Tamina Grunwitz, Jens Gumm, Sebastian Klammes, Benedikt Langfeld, Denise Schwarz, Danyal Winters, Thomas Walther
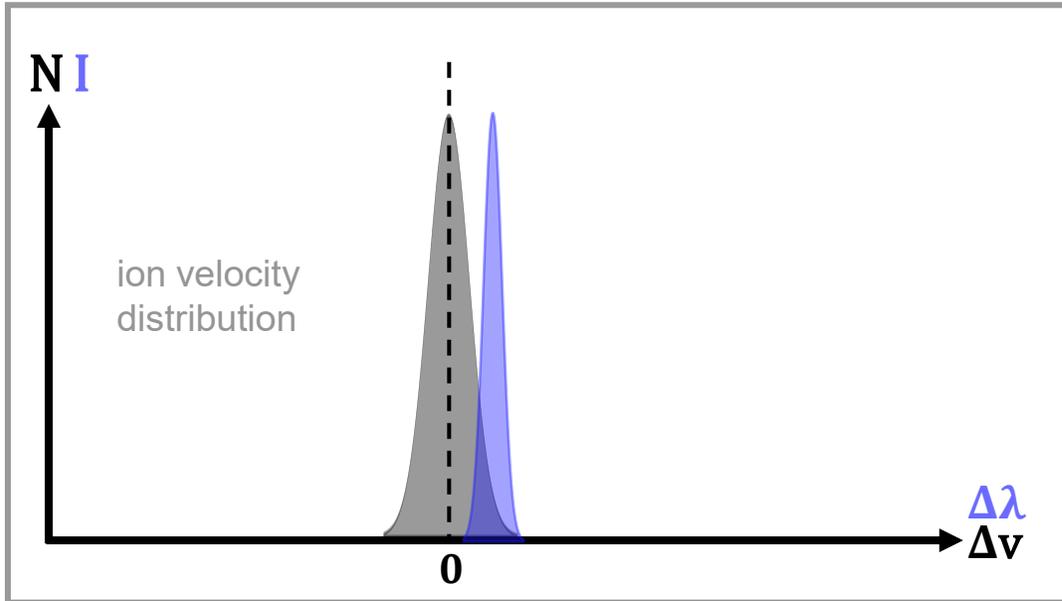
Technische Universität Darmstadt

28.10.2025

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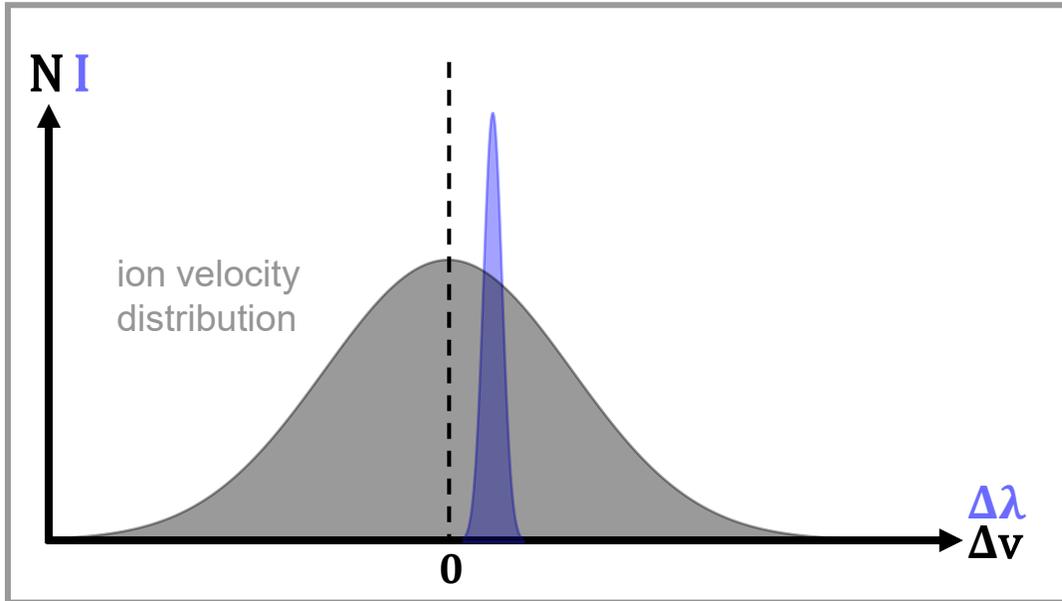# INTERACTION OF A LASER WITH AN ION BUNCH
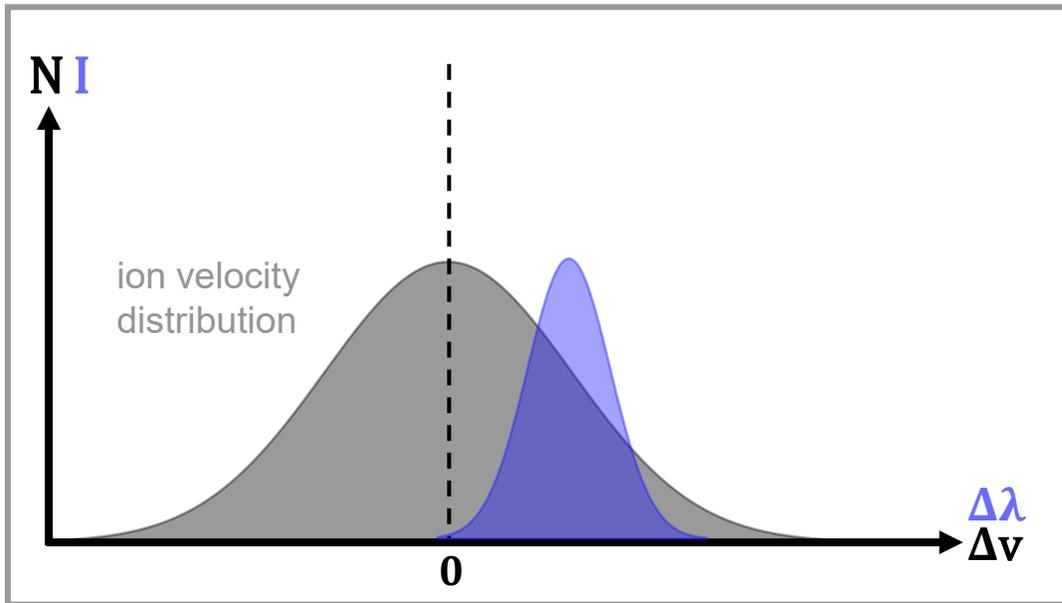
INTERACTION OF A LASER WITH AN ION BUNCH

INTERACTION OF A LASER WITH AN ION BUNCH

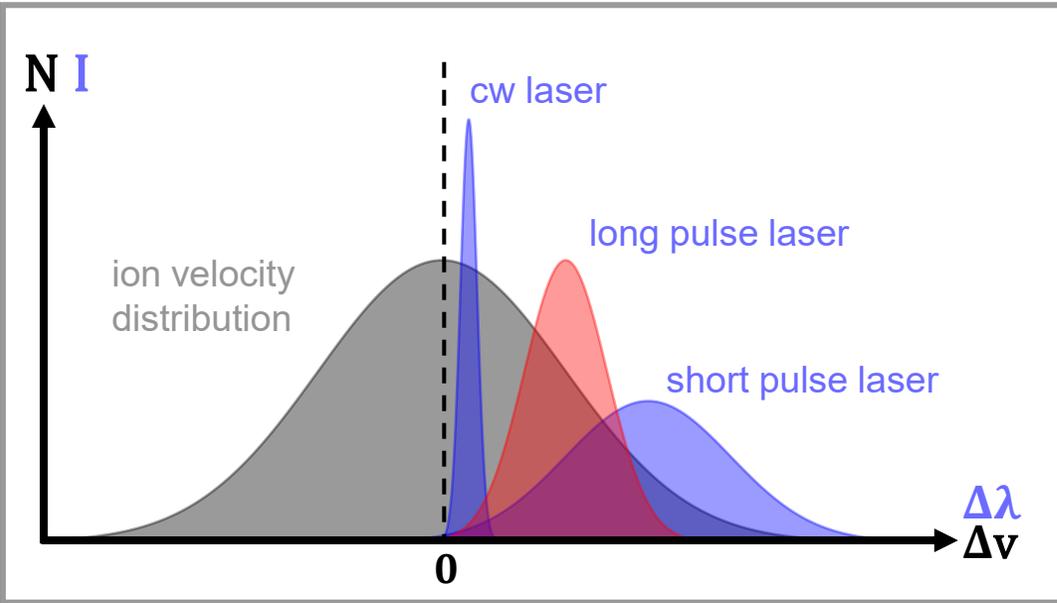# INTERACTION OF A LASER WITH AN ION BUNCH

laser force width: $\sigma_{LF} \propto \dfrac{1}{\tau_{puls}}$

lowest achievable momentum spread: $\dfrac{\Delta p}{p} \propto \sigma_{LF}$

THE LASER COOLING CONCEPT FOR THE SIS100

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laser force width: $\qquad \sigma_{LF} \propto \dfrac{1}{\tau_{puls}}$
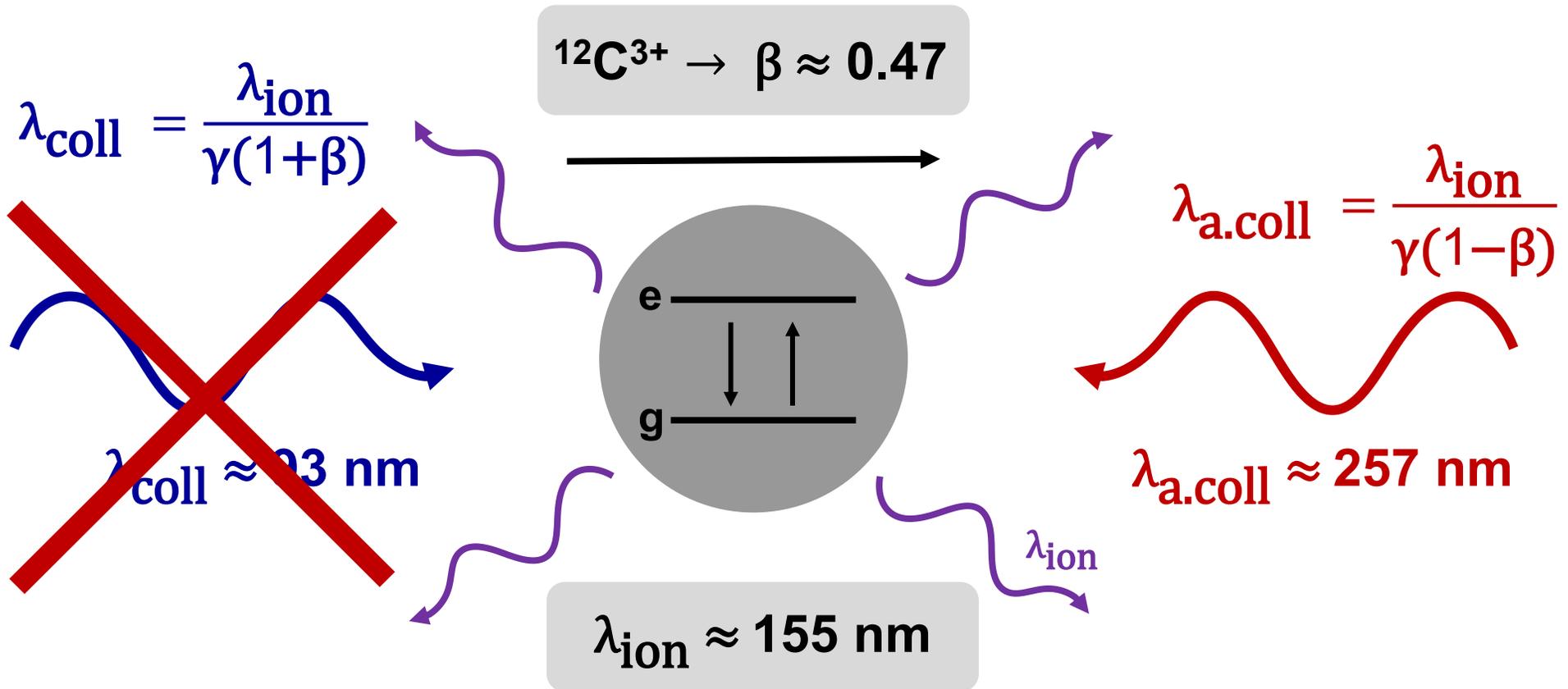
lowest achievable momentum spread: $\qquad \dfrac{\Delta p}{p} \propto \sigma_{LF}$
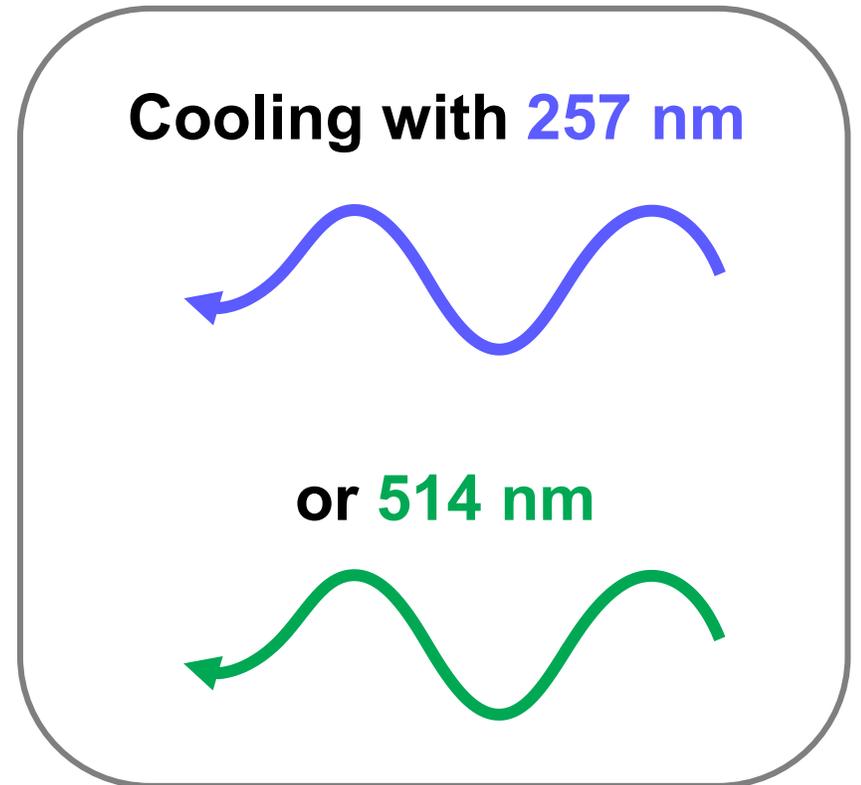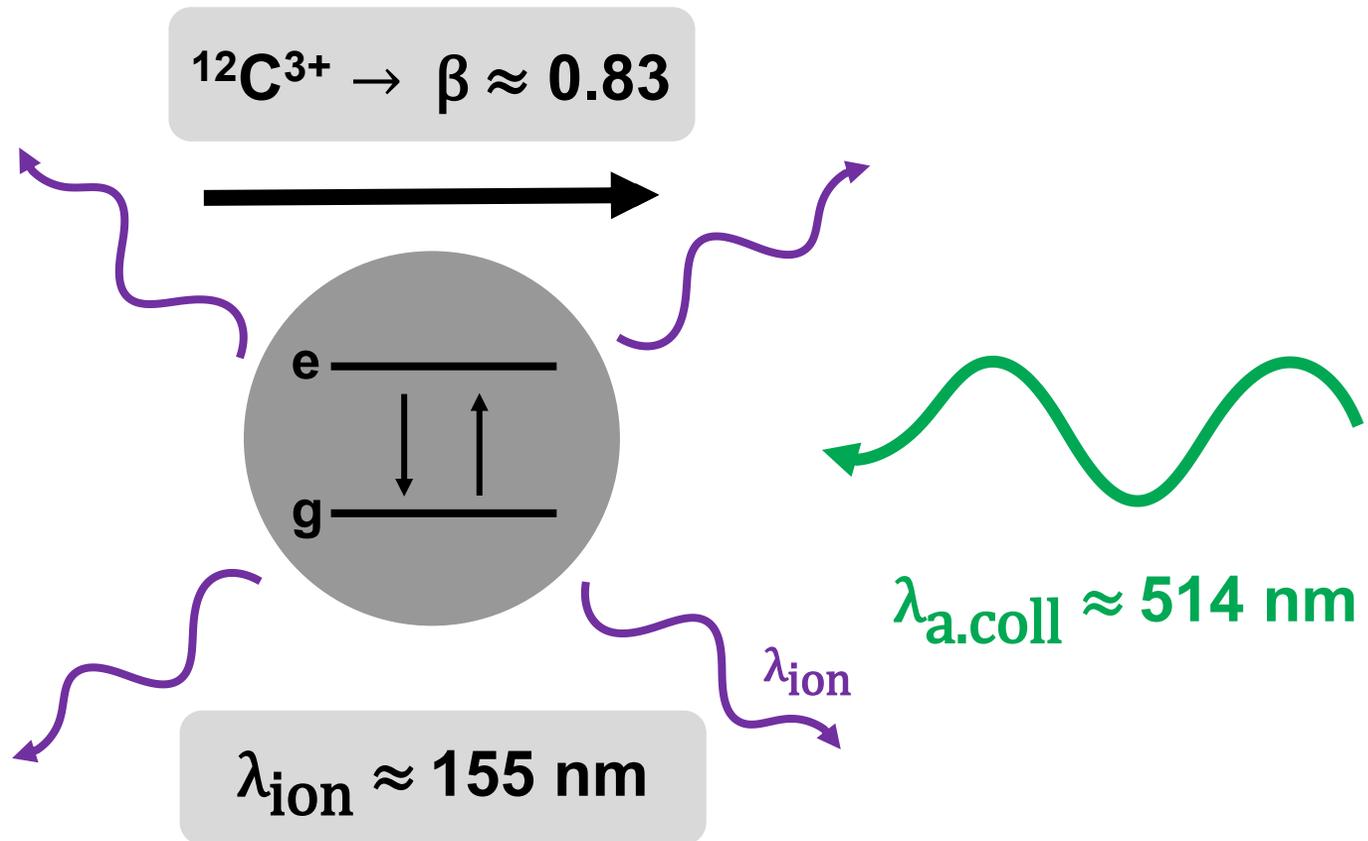
Combining **all laser systems** enables: **low final momentum spread**
short cooling times
prevention of reheating due to IBS

LASER WAVELENGTH SELECTION

$$\lambda_{coll} = \frac{\lambda_{ion}}{\gamma(1+\beta)}$$

$${}^{12}C^{3+} \rightarrow \beta \approx 0.47$$

$$\lambda_{a.coll} = \frac{\lambda_{ion}}{\gamma(1-\beta)}$$

e ___

g ___

$\lambda_{coll} \approx 93$ nm

$\lambda_{a.coll} \approx 257$ nm

λ_{ion}

$$\lambda_{ion} \approx 155 \text{ nm}$$

LASER WAVELENGTH SELECTION

$^{12}C^{3+} \rightarrow \beta \approx 0.83$

e ———

g ———

λ_{ion}

$\lambda_{ion} \approx 155$ nm

$\lambda_{a.coll} \approx 514$ nm

Cooling with **257 nm**

or **514 nm**

REQUIREMENTS FOR THE PULSED LASER SYSTEM

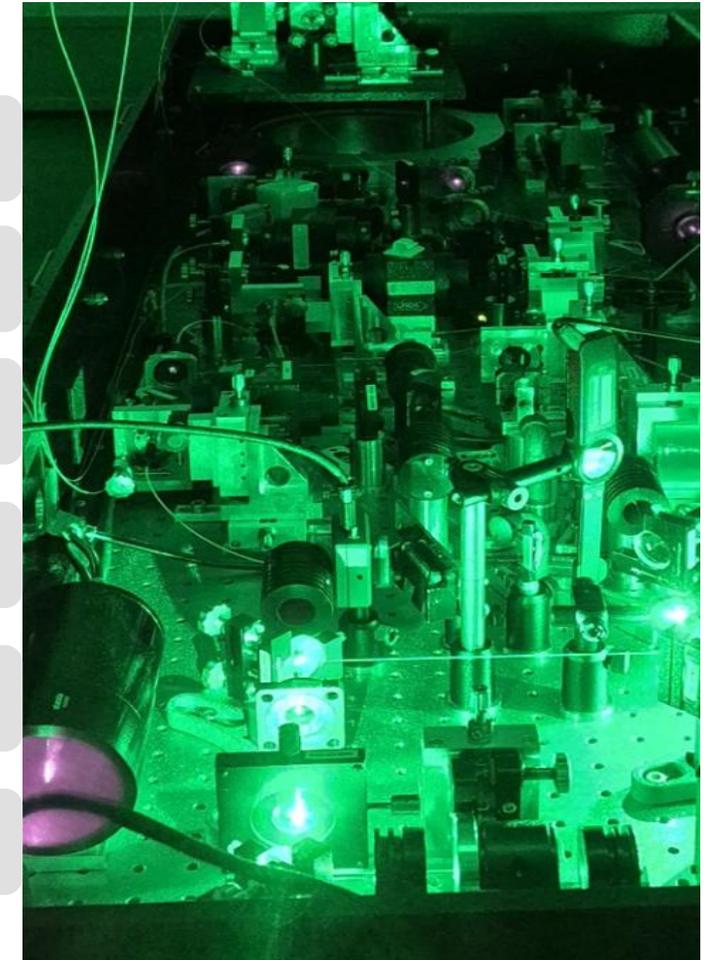wavelength: **514 nm** and **257 nm**

high average laser **power**

stable output power

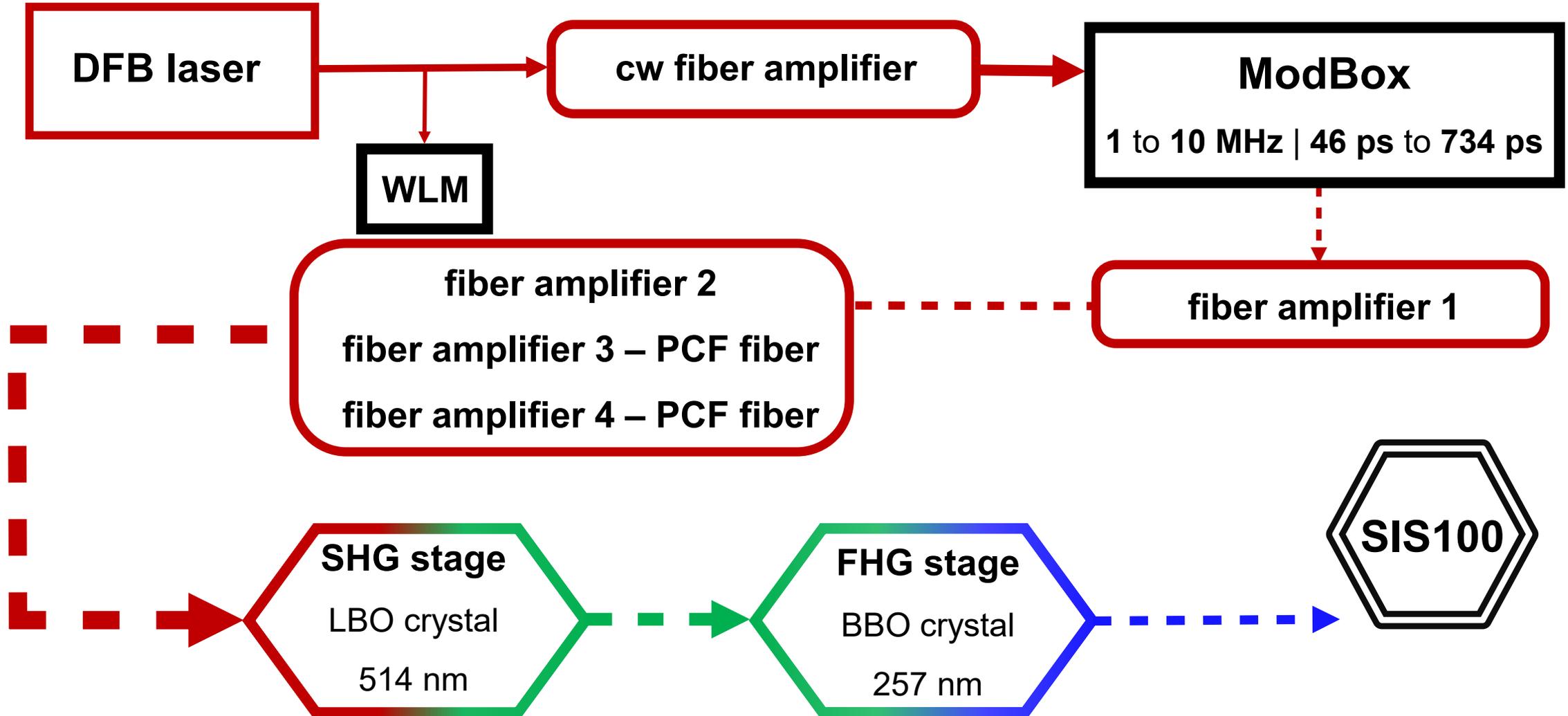adaptable **pulse duration** – variable **laser force** width

variable **repetition rate** – synchronisation with ion bunches

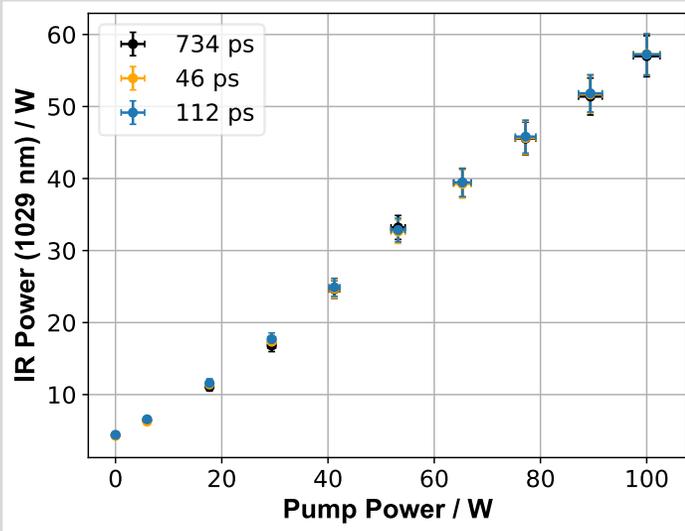**tunable wavelength** – UV range of 3.4 THz

THE LASER SYSTEM

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DFB laser → cw fiber amplifier → **ModBox**

1 to **10 MHz** | **46 ps** to **734 ps**

WLM

fiber amplifier 2

fiber amplifier 3 – PCF fiber

fiber amplifier 4 – PCF fiber

fiber amplifier 1

SHG stage
LBO crystal
514 nm

FHG stage
BBO crystal
257 nm

SIS100

POWER OUTPUT OF THE LASER SYSTEM

IR – 1029 nm

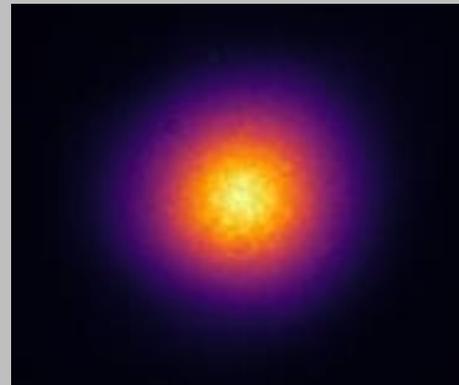**~ 57 W**

Only minor power variations due to thermal fluctuations in long-term operation

Green – 515.5 nm

Pulse duration	Average power
734 ps	17.1(4) W
112 ps	**34.2(10) W**
46 ps	30.4(9) W

Beam profile at 34 W

UV – 257.25 nm

Pulse duration	Average power
734 ps	0.60(2) W
112 ps	**4.08(10) W**
46 ps	2.10(5) W

Elliptical focus – reduction of degradation

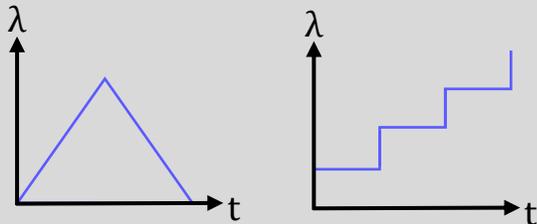Spectral width between 36.33(118) GHz and 2.05(11) GHz

WAVELENGTH TUNING AND STABILIZATION

DFB laser
1028.23 nm – 1031.21 nm

Temperature tuning

approx. **3 nm** (840 GHz)

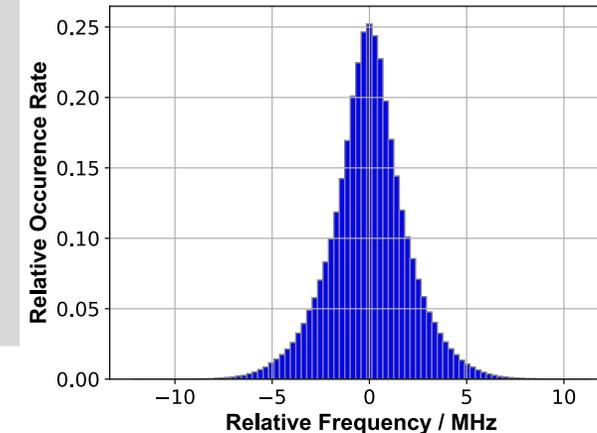Triangular scan or stepwise change of wavelength

Current tuning
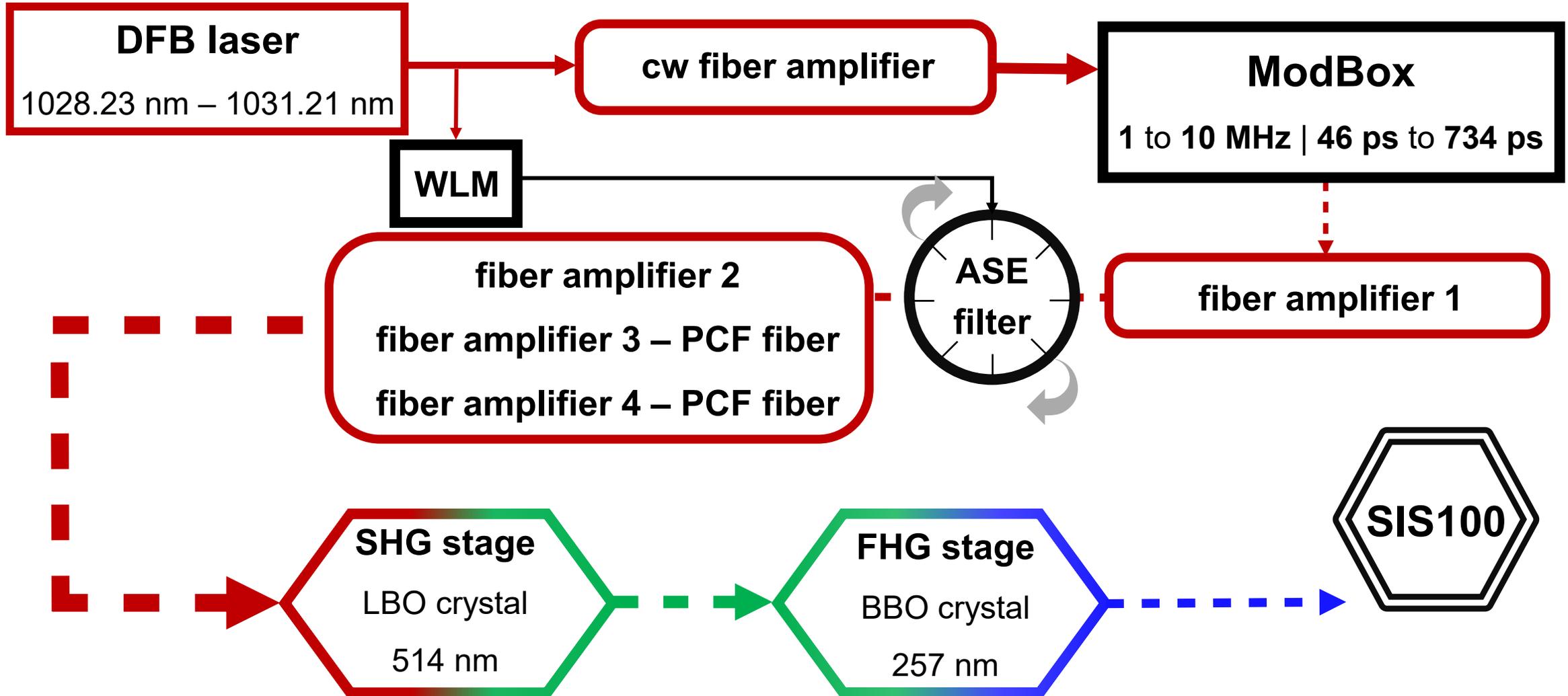
approx. 0.12 nm (35 GHz)

Arbitrary functions possible

Wavelength stabilization

Standard deviation: 2 MHz

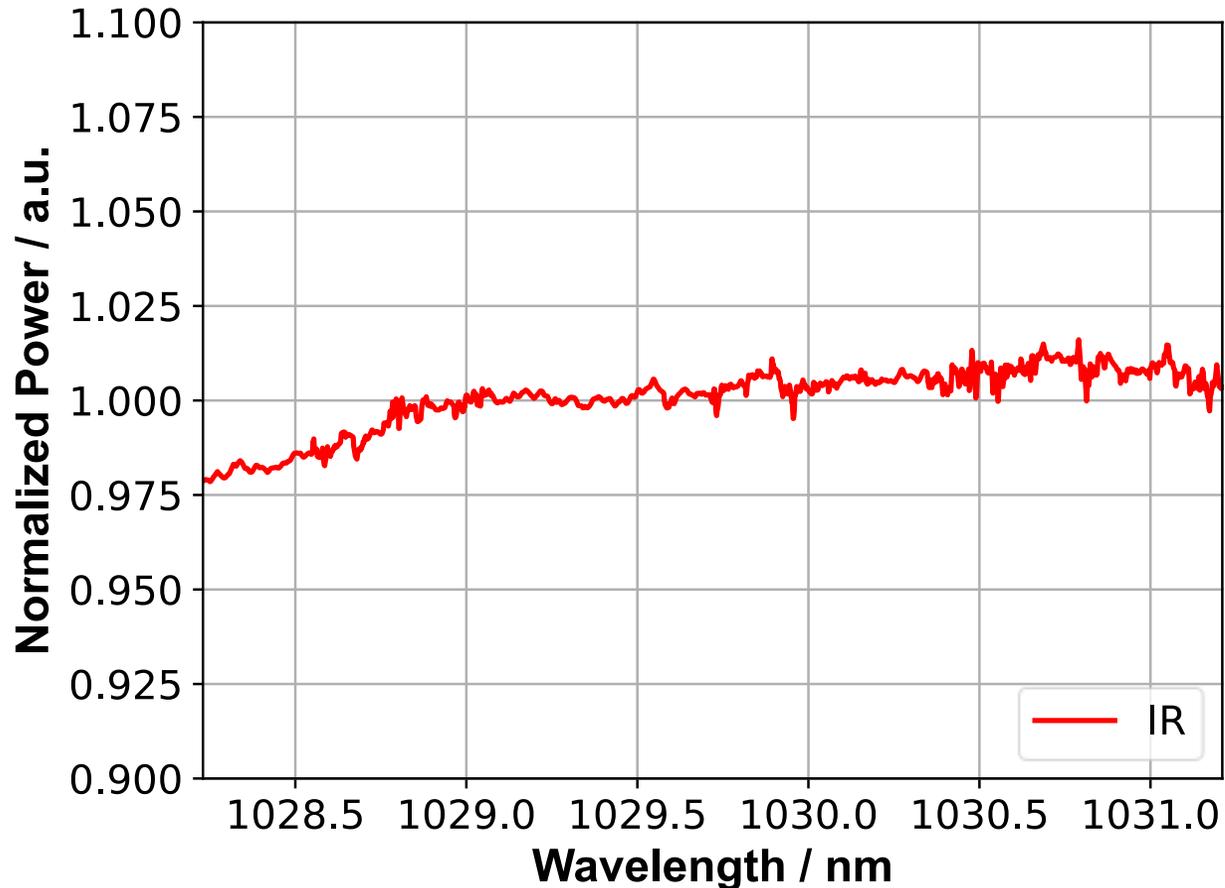Compatible with stepwise wavelength change

https://www.toptica.com/fileadmin/Editors_English/11_brochures_datasheets/05_technical_drawings

TUNING OF THE SYSTEM

Laser and Quantum Optics | Institute for Applied Physics | Tamina Grunwitz

IR POWER WITH WAVELENGTH TUNING

10 MHz 112 ps P_{mean} = 51.8 W

Peak-to-Peak power changes < 4.5 %
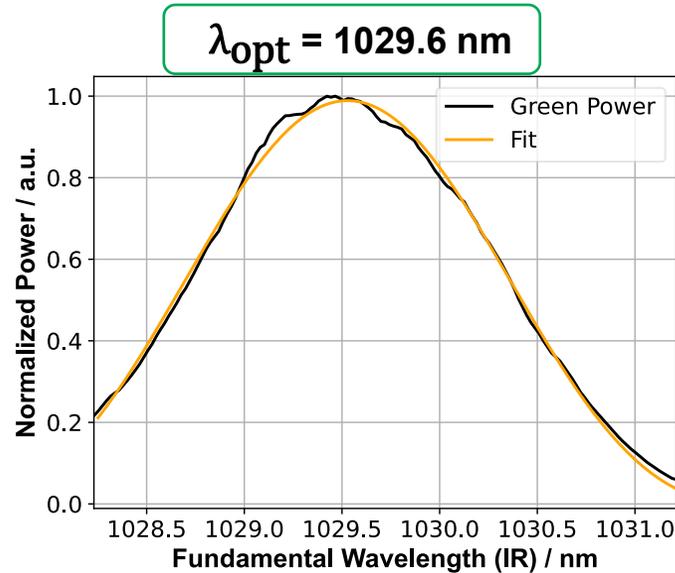
Attributable to emission spectrum of Ytterbium

Low ASE percentage → high conversion in the following SHG stage

TUNING OF THE SYSTEM – FREQUENCY CONVERSION

TUNING OF THE SYSTEM – FREQUENCY CONVERSION

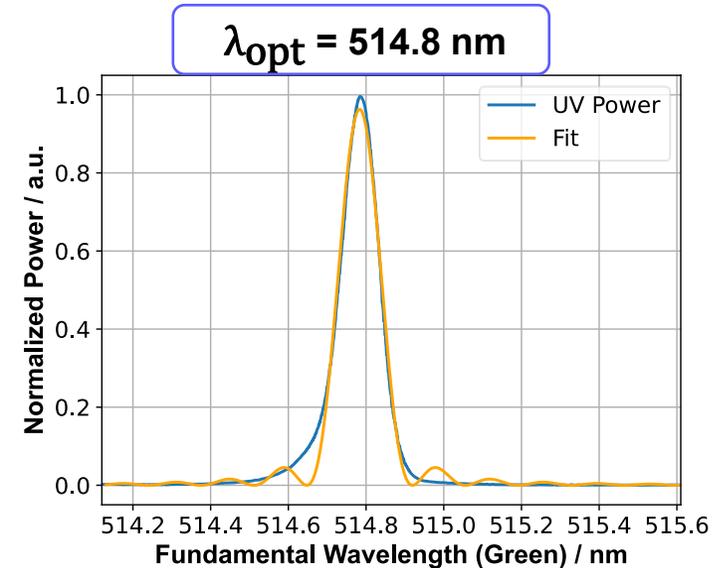λ_{opt} = 1029.6 nm

λ_{opt} = 514.8 nm

Green

Non-critical phasematching – temperature of the LBO crystal → **feed forward control**

Limit of the maximum scan speed – 0.02 nm/s (IR)
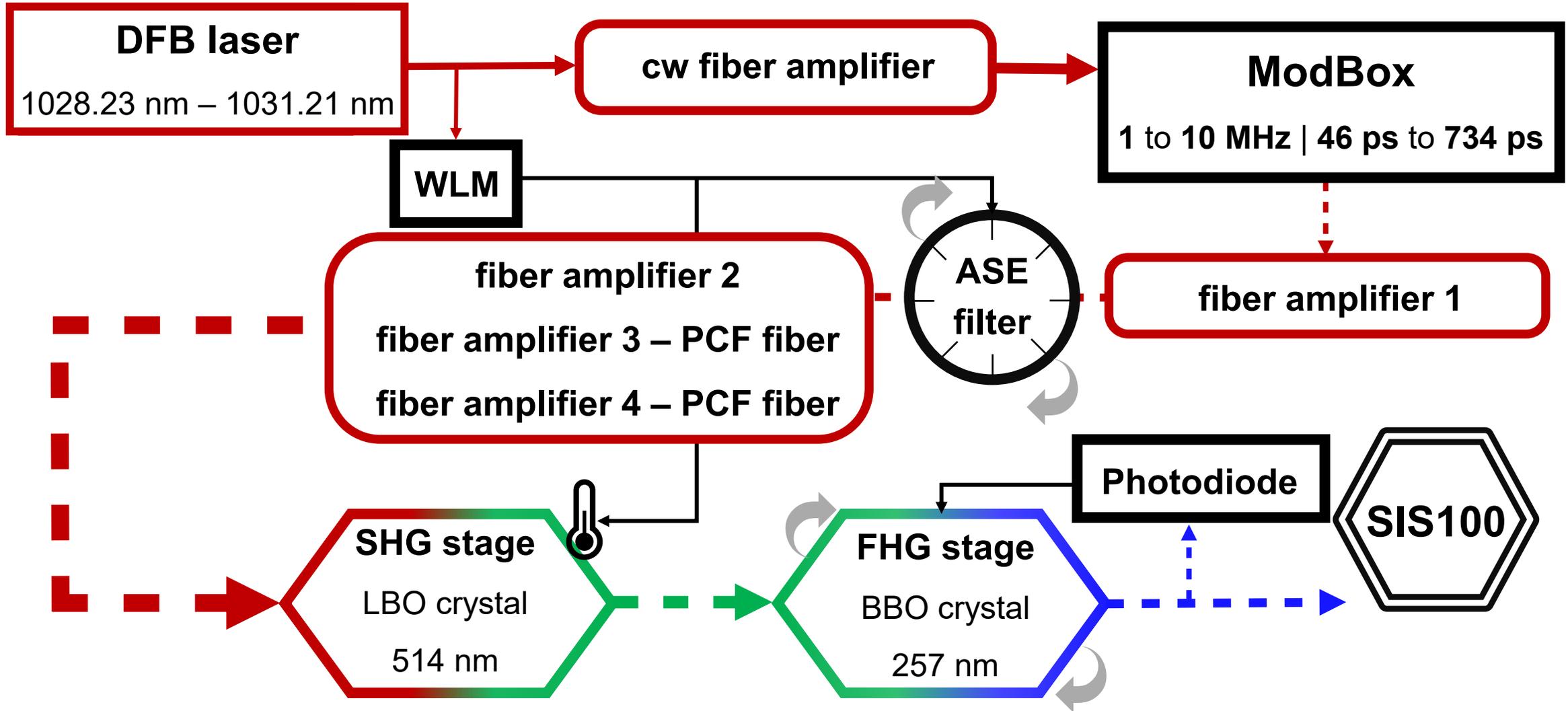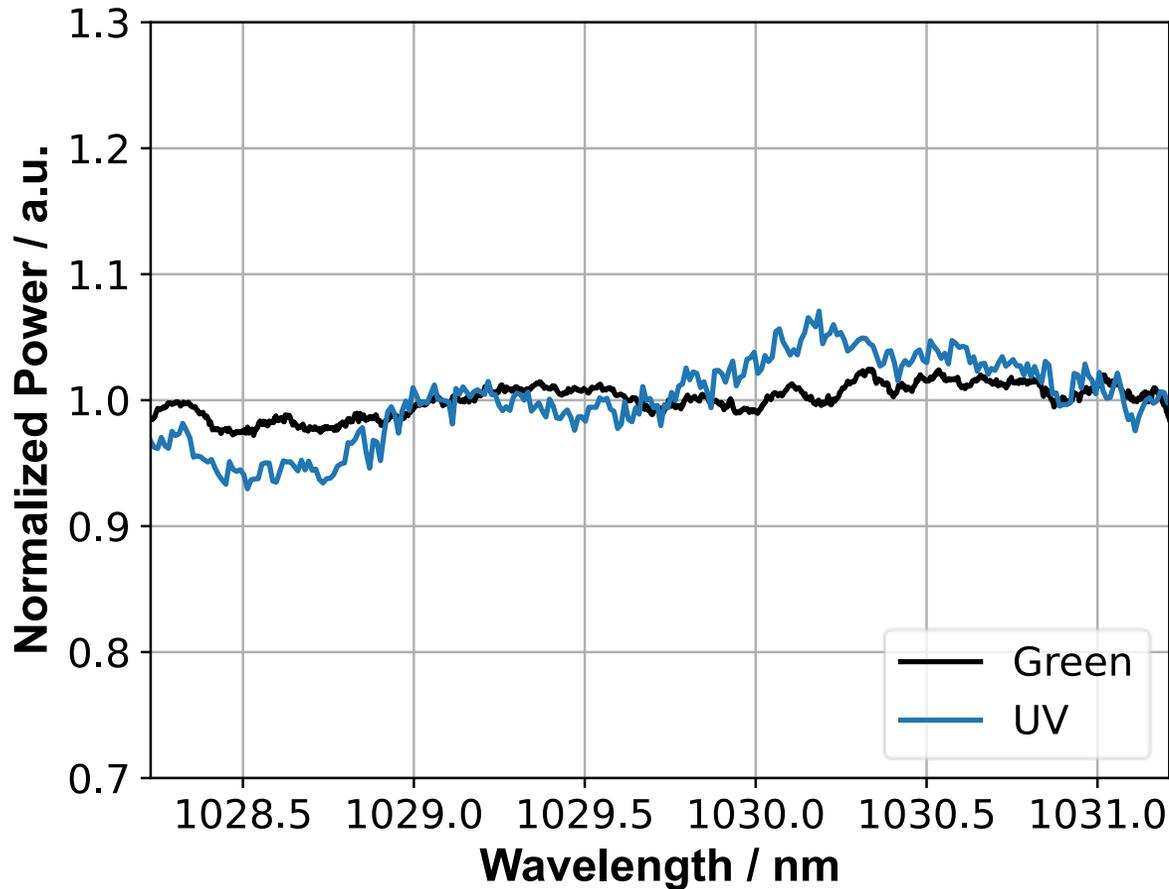
UV

Critical phasematching – angle of the BBO crystal

No feed forward control possible – **active feedback control**

TUNING OF THE SYSTEM
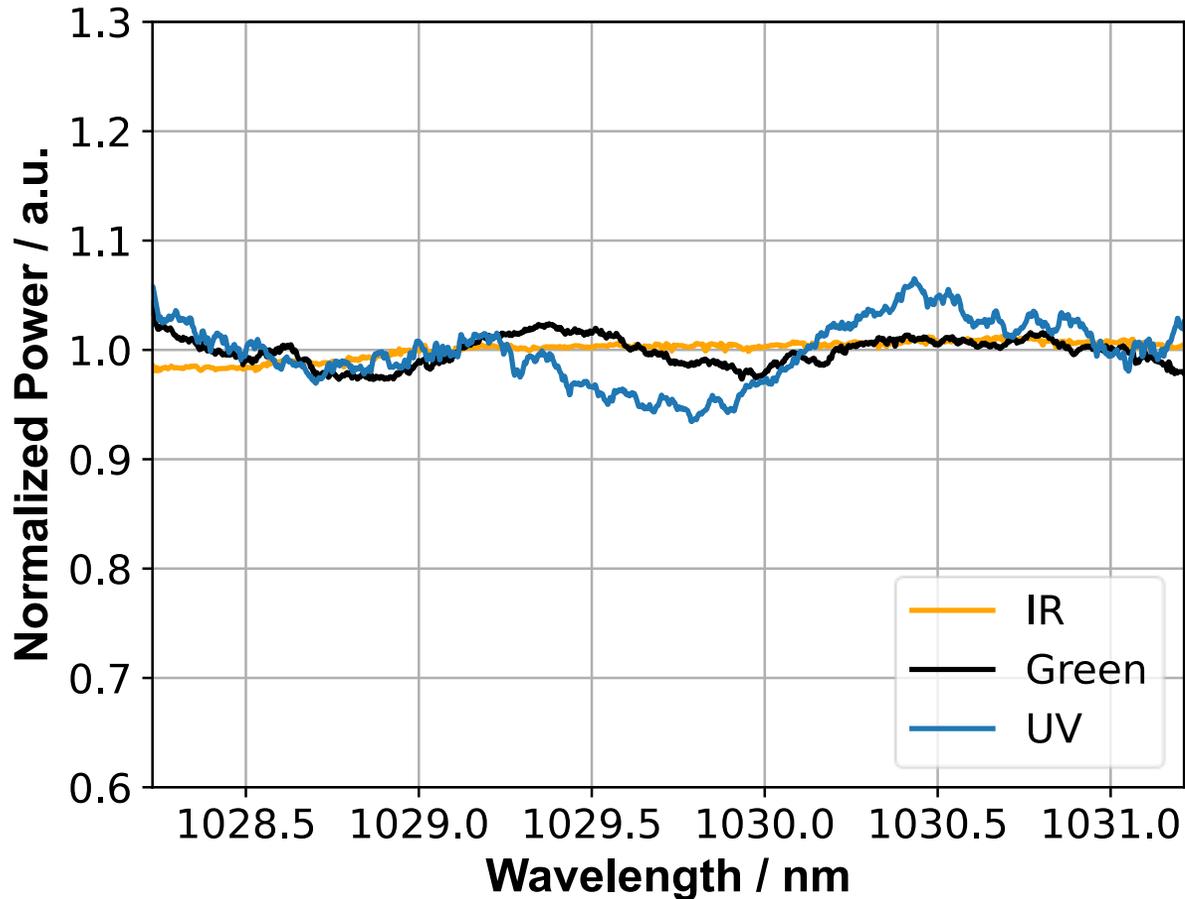
TUNING OF THE SYSTEM – ACTIVE CONTROL

10 MHz   112 ps

P_{mean} **(green) = 28.3 W |** P_{mean} **(UV) = 1.4 W**

Scan speeds up to 23 GHz/s (UV) possible

Tuning range UV: **3.4 THz**

Problem: **beam displacement** while scanning due to the angle tuning

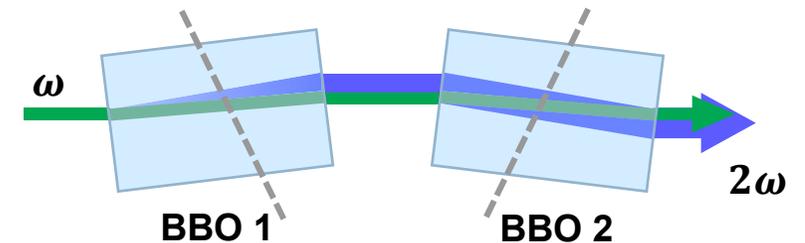# TUNING OF THE SYSTEM – ACTIVE CONTROL – DOUBLE CRYSTAL SETUP

10 MHz 112 ps

P_{mean} **(green) = 26.1 W | P_{mean} (UV) = 1.8 W**

Tuning range UV: **3.4 THz** with 5.7 GHz/s (UV)

Reduced **beam displacement**
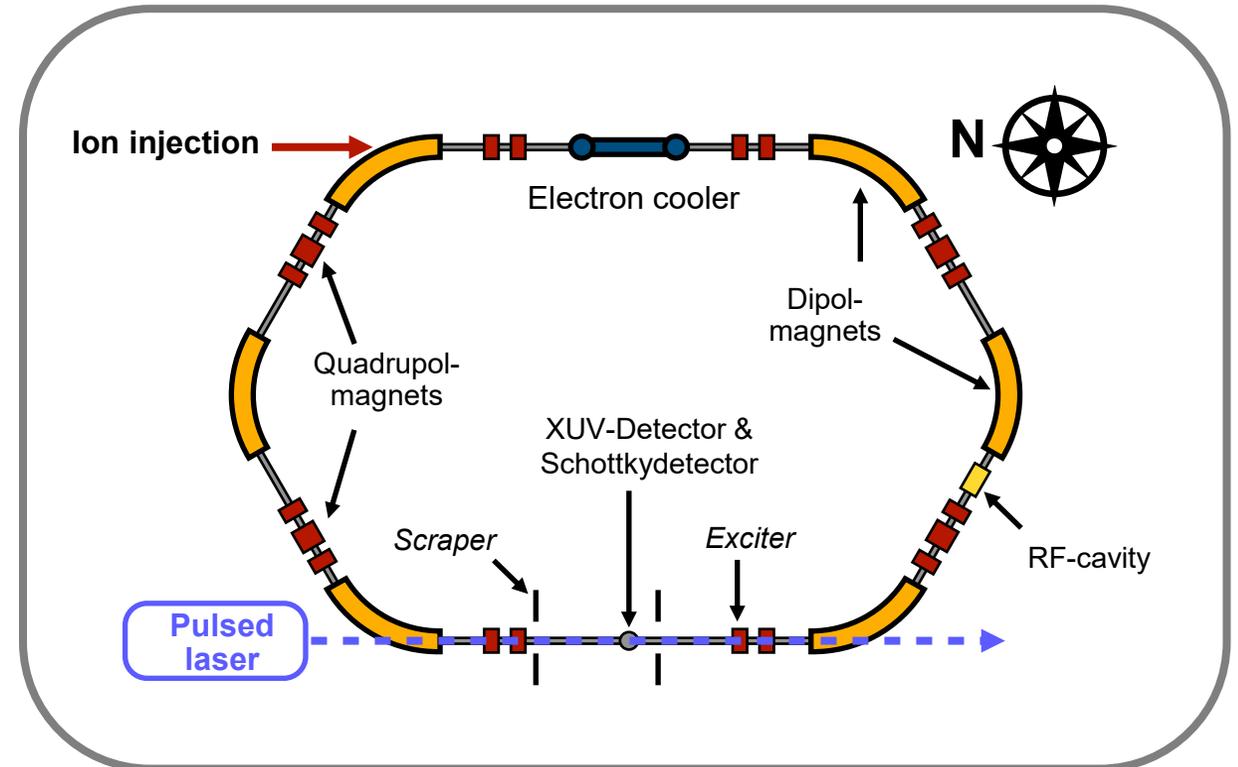
Increased UV power: max. **5.30(13) W** possible

BEAM EXPERIMENT 2021 – LASER COOLING OF $^{12}C^{3+}$

Parameters

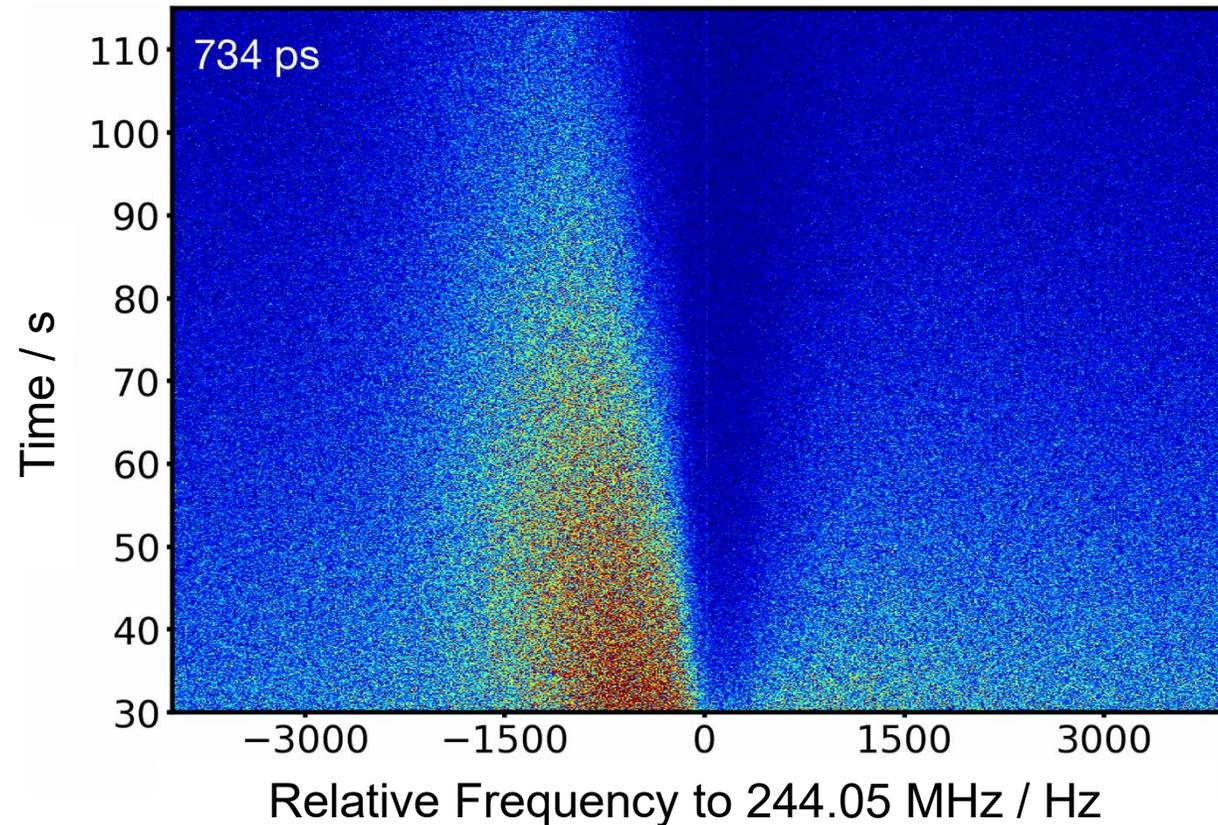|	
β	0.47
f_{rev}	1.291 278 MHz
τ	24.37(2) s
τ_{puls}	166 - 734 ps
f_{rep}	9.038 9145 MHz
λ_L	257.235 nm
P_{UV}	**200 mW**

30 s electron precooling: $\Delta p/p \approx 1.3 \cdot 10^{-5}$
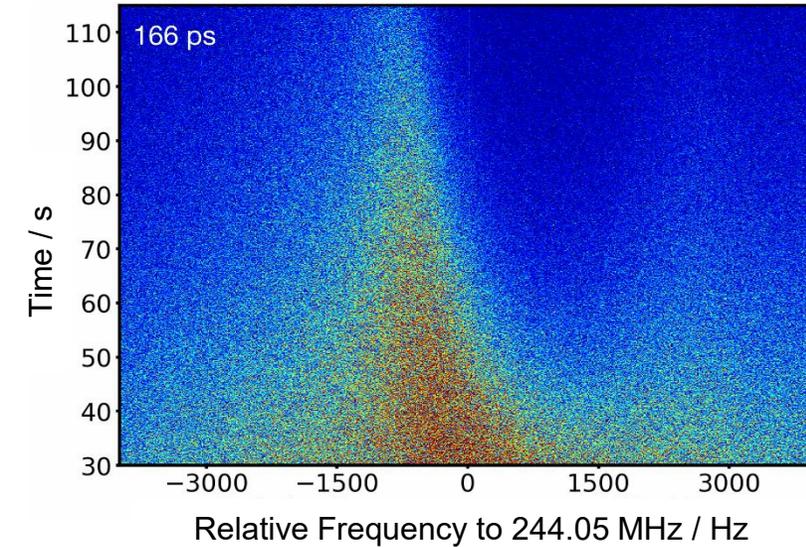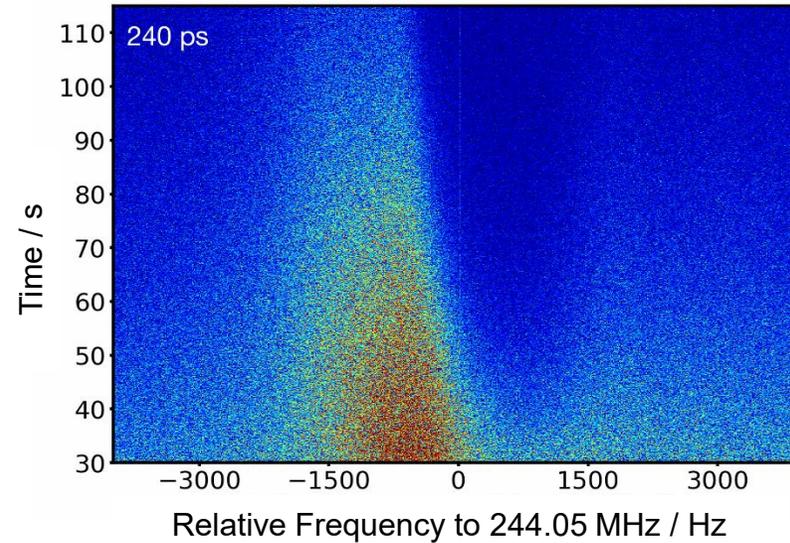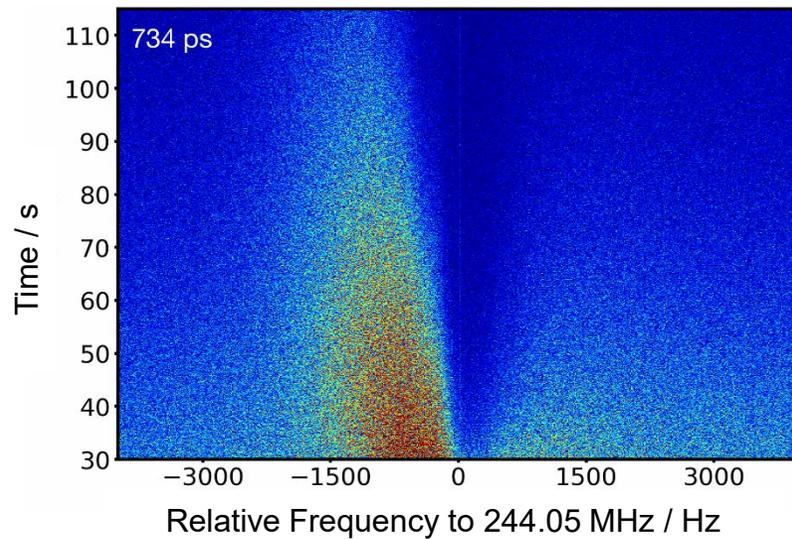
Limited UV power due to degradation effects

BEAM EXPERIMENT 2021 – LASER COOLING OF $^{12}C^{3+}$

Interaction with coasting ion beam

BEAM EXPERIMENT 2021 – LASER COOLING OF $^{12}C^{3+}$

Interaction with coasting ion beam

	Δf (Laser − FWHM)	Δf (Schottky − FWHM)	Δp/p
734 ps	2.05(11) MHz	0.56(4) kHz	$3.72(21) \cdot 10^{-6}$
240 ps	4.19(23) MHz	1.15(7) kHz	$7.65(43) \cdot 10^{-6}$
166 ps	6.12(53) MHz	1.68(15) kHz	$1.12(10) \cdot 10^{-5}$

BEAM EXPERIMENT 2021 – LASER COOLING OF $^{12}C^{3+}$

Interaction with bunched ion beam – 285 ps

h = 30
f_B = 38.738205 MHz
$\overline{P}_{avg}$ = 79.8(19) mW

approximate interaction width

Central laser frequency

Electron cooling – 30 s

SYSTEM PERFORMANCE IN BEAM EXPERIMENT 2025 – LASER SPECTROSCOPY

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UV power over 300 mW available

Long term operation (over 5 days) without need for adjustments

Stepwise wavelength **tuning over 3.4 THz**

Synchronisation with ion bunches

SUMMARY AND OUTLOOK

Average **green power** up to **34 W**

Average **UV power** up to **5.3 W**

Tuning range of approx. **3.4 THz** (UV)

Operation of wavelength tuning via graphical user interface possible

Laser cooling effects demonstrated

Long term stable (high) UV laser power

Enhancing the laser systems computer-based control

Beam experiment with cw and pulsed laser systems

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