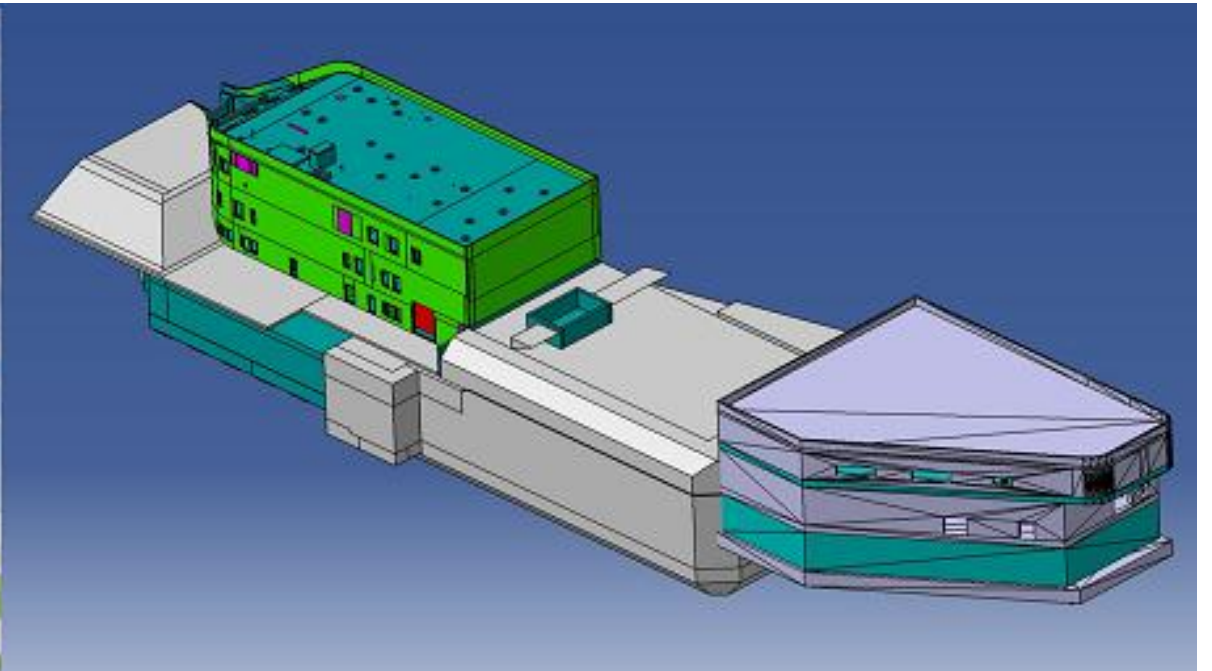


Plasma Physics and Fusion Research - Activities at GSI -

V. Bagnoud

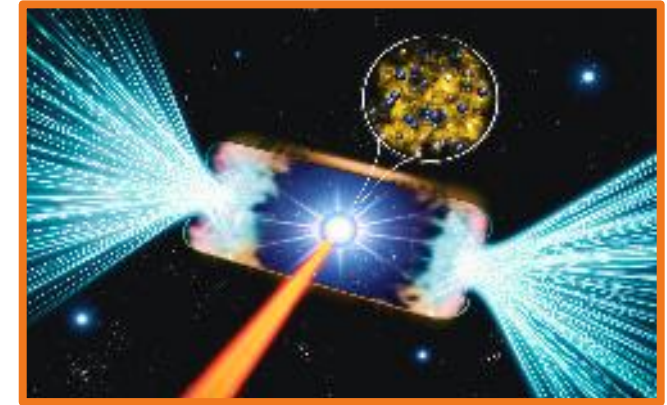


- GSI has a strategic interest to contribute to fusion research (in particular Inertial Fusion Energy)
- A first immediate measure is an upgrade of PHELIX (ULEP) for laser-plasma instability studies
- GSI's 10 year goal is SIRIUS: a laser facility coupled to the APPA cave for
 - hybrid laser-ion studies and the full realization of the program of the HED@FAIR collaboration
 - support the IFE research community
- Collaboration opportunities exist for R&D activities relevant for SIRIUS
 - laser technology as well as physics at APPA cave
 - many funding opportunities exist (Helmholtz, BMFTR, Europa)

Strategic positioning of GSI and FAIR towards Fusion



- Laser-driven fusion is a high-risk highly-speculative topic with huge implications for energy science and society
 - high-risk: laser-driven fusion is not an engineering problem (low TRL)
 - highly speculative:
 - capital risk investors put a lot of pressure for rapid return (bubble)
 - lack of experimental data in science and technology to support a roadmap
 - high impact: energy is strategic issue at the geopolitical level
- The local context is an incentive to strengthen GSI plasma physics research
 - 08/2026: founding of the IFE Vanguard Ecosystem for GAIN (VEGA) Hub in Biblis, Hesse
 - 08/2026: 1st step for the establishment of a LOEWE center for energy photonics (ZE-Φ) validated



Nature 618 (2023)

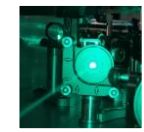


feasibility study for the BIBLIS industrial area (2025)

R&D phase: Upgrade of the LPI Experiment area at PHELIX (ULEP)

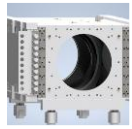
- Major upgrade project for PHELIX (7,5 Mio€)
 - Partners: TU Da, Focused Energy, TH Bingen, HI-Jena (for simulations)

Upcoming areas of development:



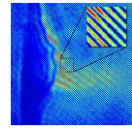
Pulse Generation

- Development of drive-laser front-ends
 - Broadband pulse generation
 - Temporal smoothing



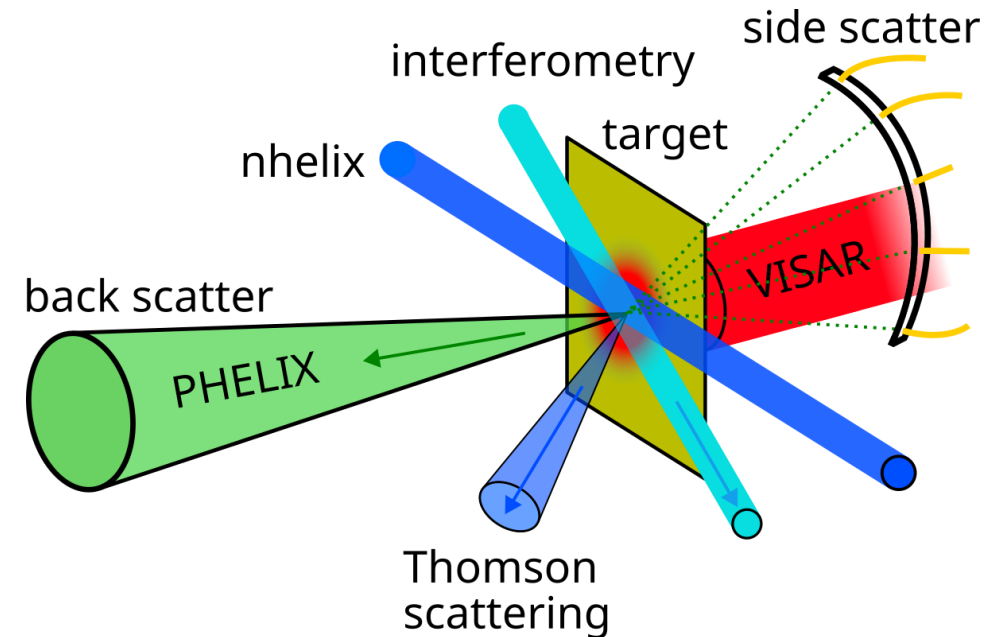
Amplifier Development

- Shot-rate improvement
 - Cooled glass amplifier concept
 - Active real-time beam control



LPI Experiment Area

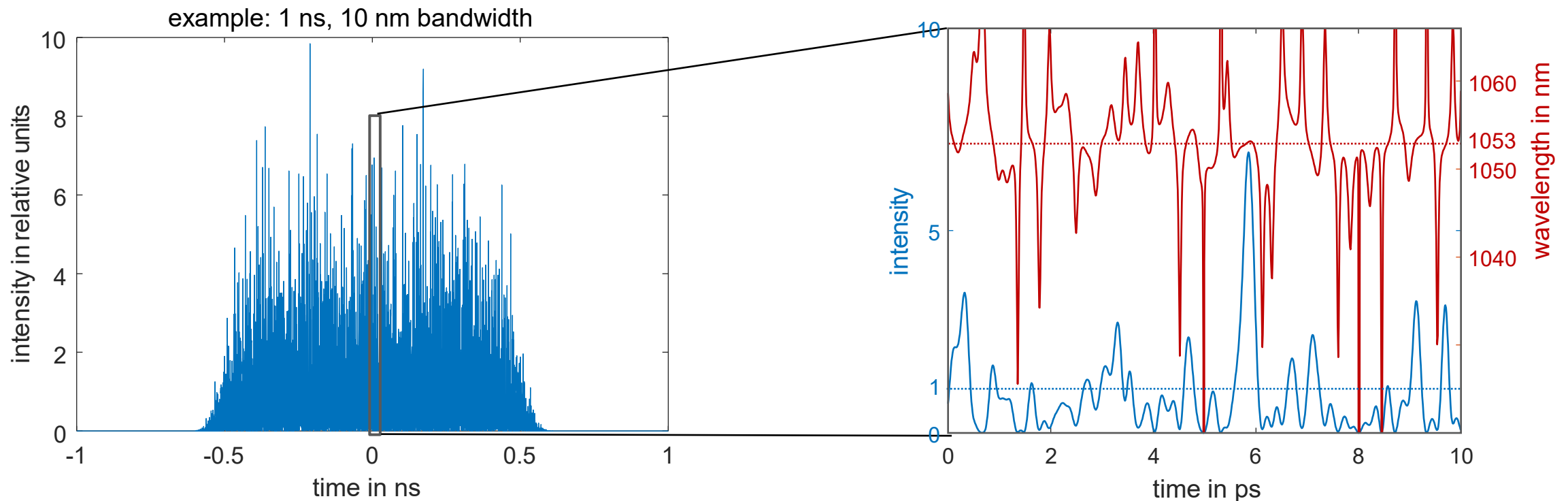
- Extension of diagnostic capabilities
 - Stationary laser-scatter diagnostics
 - Extended plasma diagnostics



Schematic for different plasma diagnostics

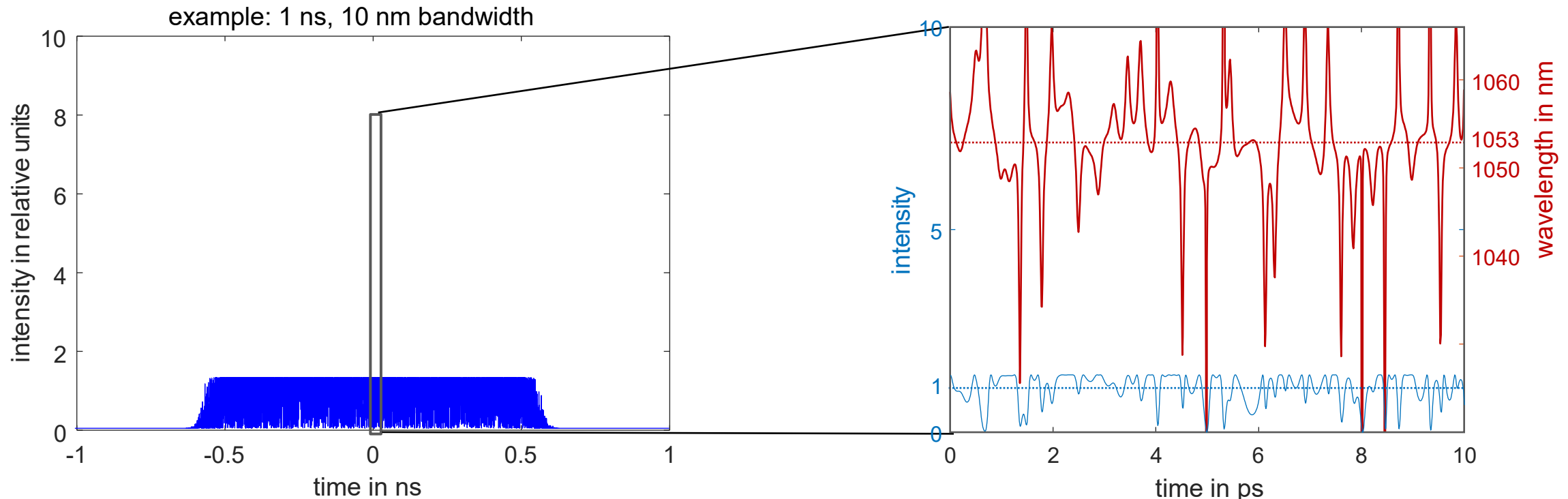
Upgrade of the front end: spectrally incoherent nanosecond pulses

- Stochastic nanosecond pulses originate from random photon emission (amplified spontaneous emission, optical parametric generation)



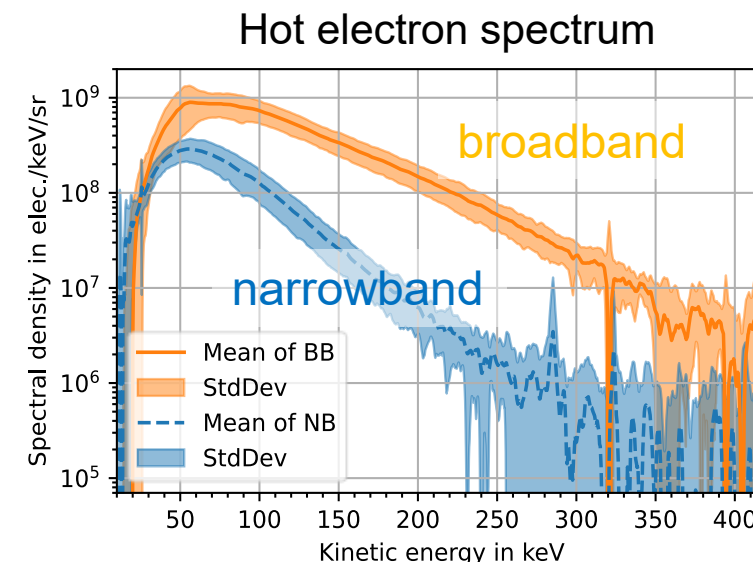
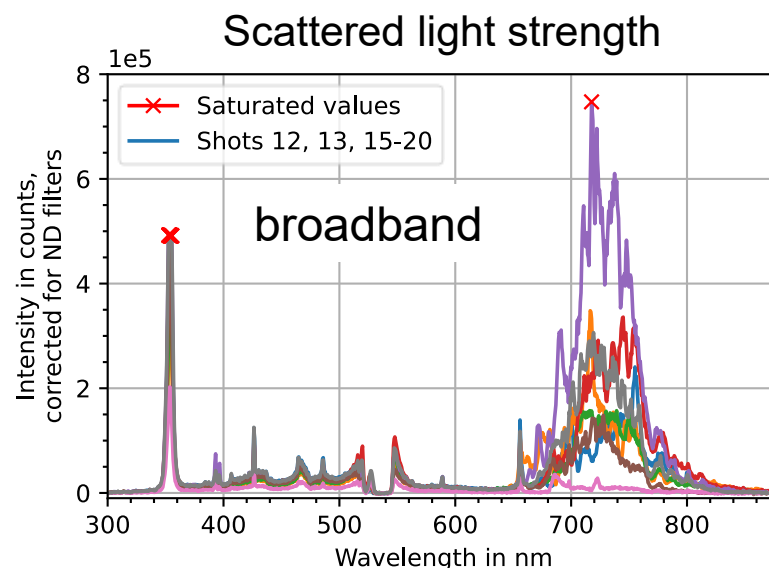
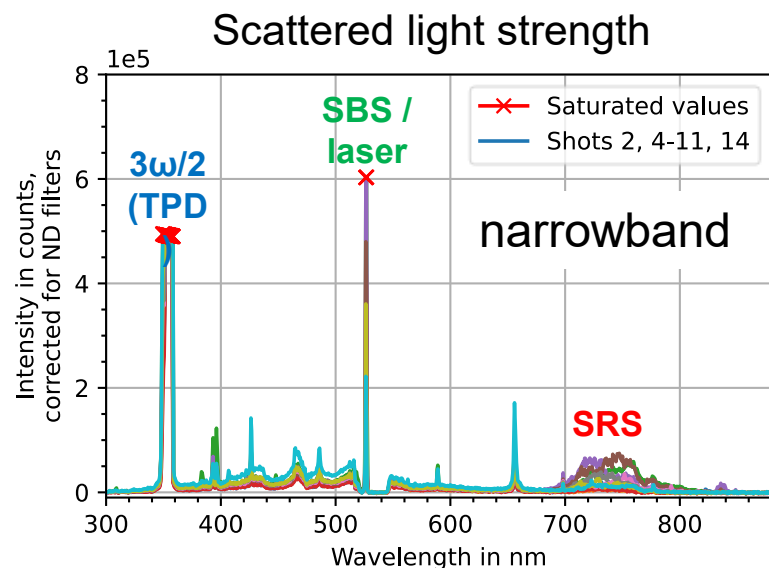
Upgrade of the front end: spectrally incoherent nanosecond pulses

- Stochastic nanosecond pulses originate from random photon emission (amplified spontaneous emission, optical parametric generation)
- Nanosecond pulse engineering (with linear and nonlinear filters) adds control over the pulse profile (GSI patent: 2026060816312850DE)



The intricate coupling between laser and plasma with broadband nanosecond pulses*

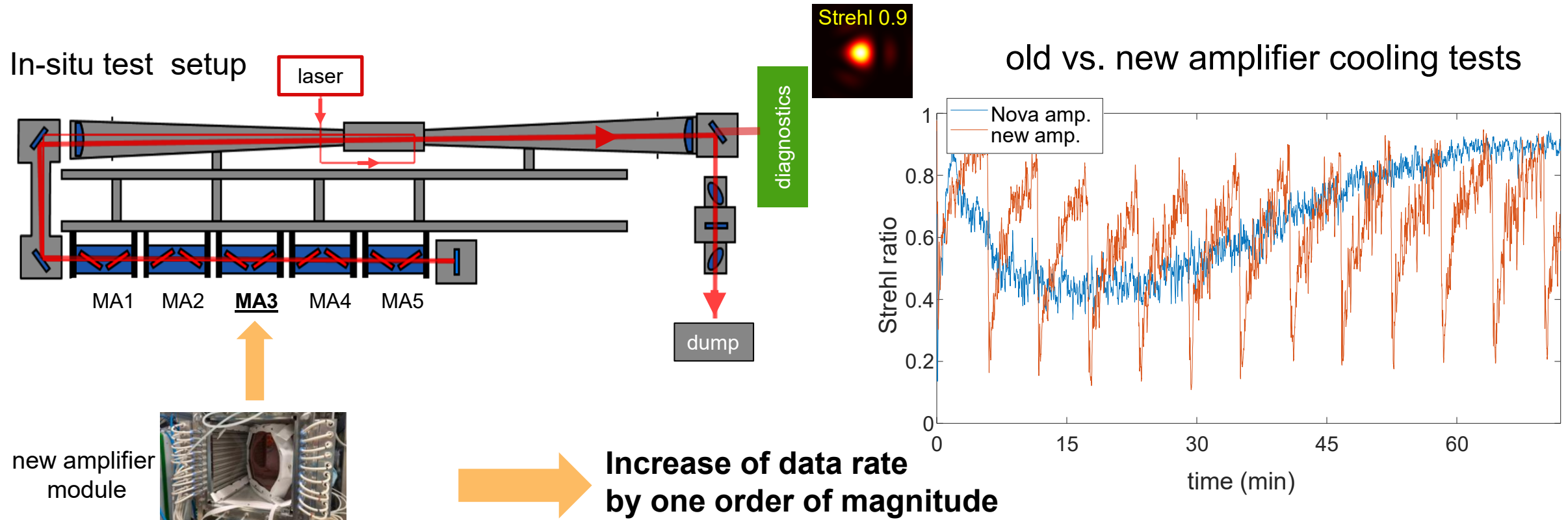
- Goal: to control laser-plasma instabilities experimentally
 - First experiments at PHELIX with spectrally incoherent pulses (0.5% bandwidth) show reduction of Brillouin backscattering (SBS)
- Open physics questions:
 - How much bandwidth is required? Can it be realized experimentally?
 - How do three-dimensional effects come into play?



* C. Kanstein et al., Plasm. Phys. Contr. Fusion (2025)

Main technology developments within ULEP

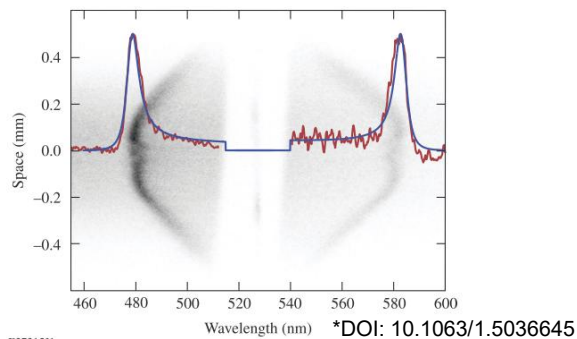
- New front end with better control over the nanosecond pulse generation
- Procurement of the world's largest DKDP crystal for second harmonic conversion (300-mm)
- New amplifier modules with better thermal properties (prototype developed over 10 years)



Upgrade of the target station Z6 for LPI studies

- Shut down of PHELIX will be moderate (8 months in 2028-29)
- First light experiment in 2028 with old setup – full experiment capability in 2030
- Development of a side-scatter and stationary back-scatter LPI diagnostics
- Development of additional plasma diagnostics

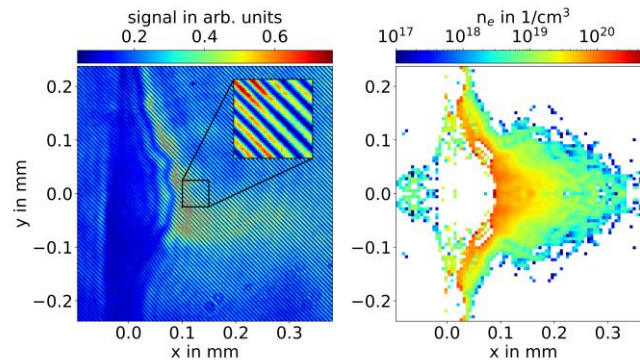
Thomson scattering



E2721511

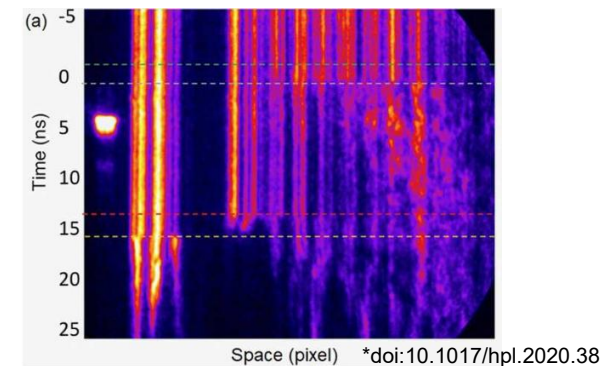
Temperature & density

Interferometry

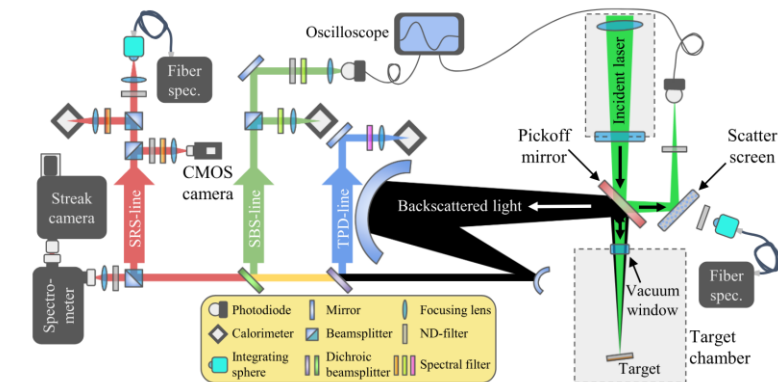


2-D density map

VISAR

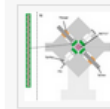


shock velocity



Experimental LPI setup

- Successfully-pumped Nd:YLF as regenerative amplifier with commercial LEDs
- Active collaboration with ams-OSRAM for new LED with power densities $> 200 \text{ W/cm}^2$
 - pumping of Nd:glass
 - pumping of active mirrors (Nd:YAG ceramics)
- Projects (Fusion2040 + IPCEI): 2027-2031, 1.8 Mio€



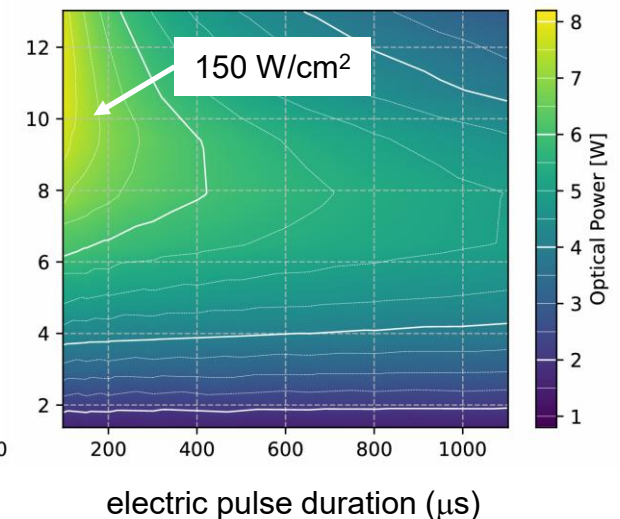
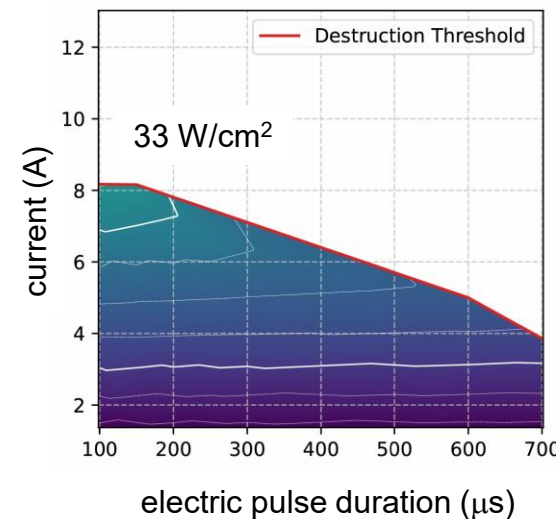
An LED-pumped 3-mJ TEM₀₀ Q-switched Nd:YLF laser

L. Dauerer, F. Wasser, D. Schumacher, M. Roth, and V. Bagnoud

Opt. Express 34(19), 35637-35648 (2026) View: [HTML](#) | [PDF](#)

Editors' Pick

commercial LED (Best-SMD) $3.2 \times 2.8 \text{ mm}^2$ Purpose-built LED(ams-OSRAM) $2.75 \times 2 \text{ mm}^2$



GSI proposes SIRIUS: a laser facility coupled to the APPA cave for hybrid laser-ion studies

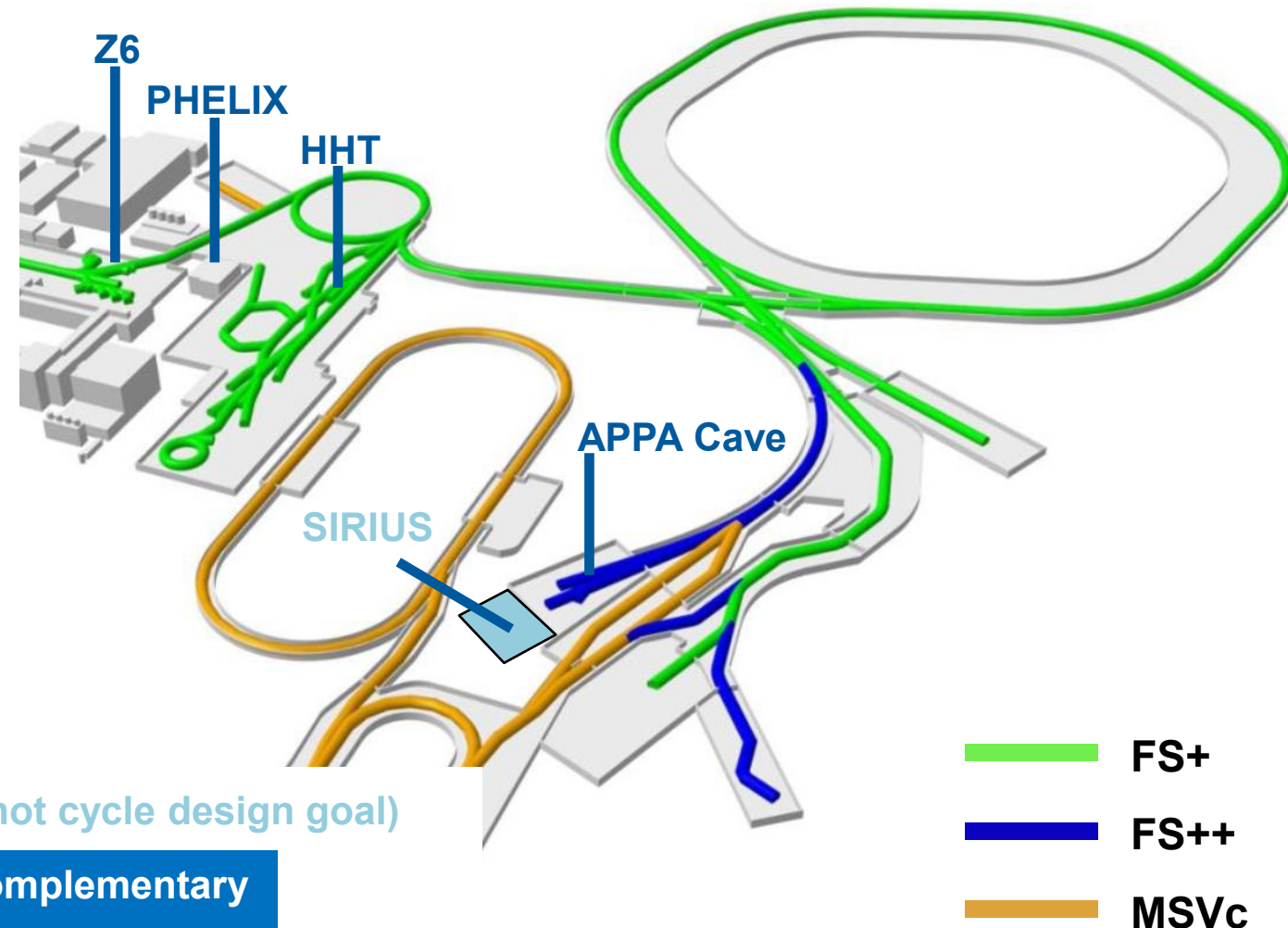
■ GSI/FAIR brings together:

- High-energy heavy-ion beams
- HED experimental infrastructure
- PHELIX experience and user community
- HIHEX volumetric heating
- LAPLAS high-density isentropic compression
- PRIOR proton microscopy
- Dynamic material loading capability
- Diagnostics, targets, theory, and simulation

■ SIRIUS adds:

- Multi-kJ, multi-beam laser pump/probes
- ns + short-pulse operation
- Flexible pulse shaping
- Broadband laser operation
- Increased experimental throughput (15 min shot cycle design goal)

Benefit: Users gain access to multiple drivers and complementary probes within one HED research environment.



Timeline for SIRIUS

- 07/2026: Application to German research infrastructure roadmap
- 01/2027: Start of PHELIX upgrade (pending final approval)

Tasks	2027		2028		2029		
Application research infrastructure roadmap							preparation
R&D activities : path to TDR, prototyping							
PHELIX Upgrade (ULEP Project)							



Ongoing & high visibility

Tasks	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7		
Building design															building
Building construction															
Laser procurement															laser
Module assembly															
Installation and commissioning															



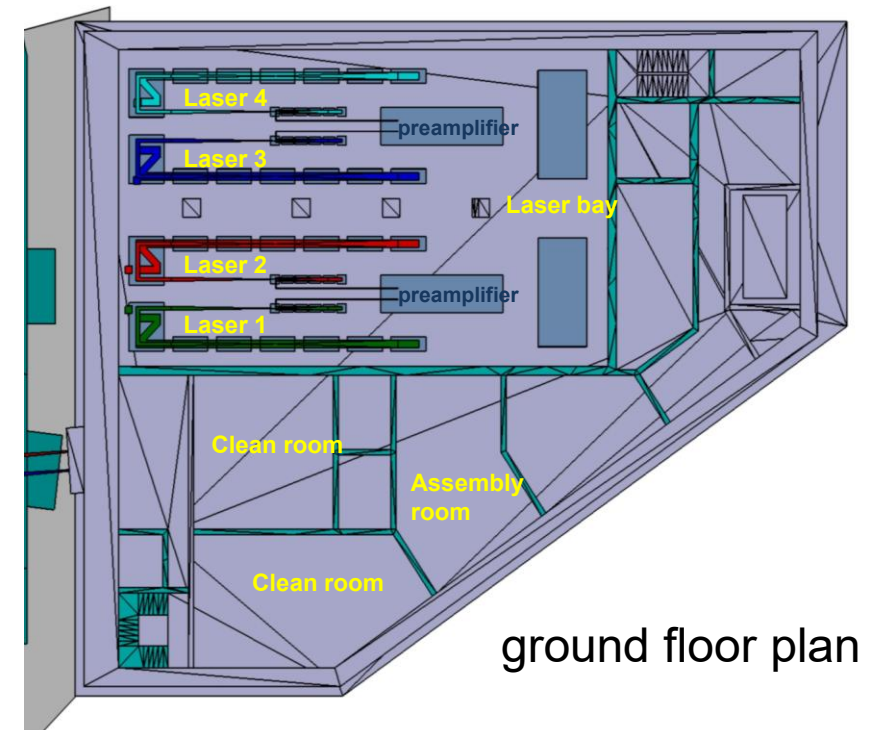
Starting point
in discussion

Main features of the new facility (I)

- More energetic beams:
 - up to 10 kJ in 4 beams (x 50 increase)
 - up to 5×10^{11} ions per bunch (translates to 1-10 eV plasma) in APPA cave
- New capabilities with broadband nanosecond pulses
- Shot rate $> 1/15$ min

4 independent beamlines with variable configurations

Beamline	1		2		3				4	
	a	b	a	b	a	b	c	d	a	b
Energy (J)	2,500	2,500	2,500	2,500	2,500	2,500	50	20	2,500	2,500
Pulse duration	ns	0.15 - 10 ps	ns	0.15 - 10 ps	ns	0.15 - 10 ps	10 ps	20 fs	ns	0.15 - 10 ps
Bandwidth (%)	> 1	N/A	> 1	N/A	> 1	N/A	> 10	N/A	> 1	N/A
Wavelength (nm)	527	1053	527	1053	527	1053	527	800	527	1053



ground floor plan

Main features of the new facility (II): unique selling points



Objective	Broadband nanosecond pulses	Fast ignition	Code benchmarking	FAIR target backlighting	Energy loss measurement in plasma
Unique selling points	• GSI's patented technology • World leading expertise • Top priority topic for IFE research	• Up to 10 kJ allows scaling to IFE conditions	• Contributes to establishing German competence	• Worldwide unique combination with ions	• High-precision setup • Accelerator expertise

- SIRIUS fulfills long term goals of the HED@FAIR collaboration
- SIRIUS incorporate unique capabilities to support the German and European IFE roadmaps

- Laser technology
 - Frontend development: spectrally incoherent pulses, spatio-temporal coupling, high temporal contrast, diagnostics
 - High-energy amplification: mixed-glass amplification, high-energy OPA, optical isolation, material sourcing
 - Beam control: real-time AO, target AO, large-aperture AO
 - Beam transport and conditioning, high-energy pulse compression, frequency conversion, LIDT
 - Simulations and digital twin: around OPOSSUM
 - Open science: electronic lab book, metadata, data visualization
- Physics topics
 - LPI and hydro instability mitigation, fast ignition, code benchmarking, energy loss in plasma, magnetized plasma
 - Diagnostics development: new diagnostics, online diagnostics, remote handling

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