Current Performance of the PHELIX Facility

Vincent Bagnoud

GSI - Helmholtzzentrum für Schwerionenforschung GmbH
Darmstadt, Germany. V.bagnoud@gsi.de

EMMI workshop, May 14-15, 2009
Moscow, Russia

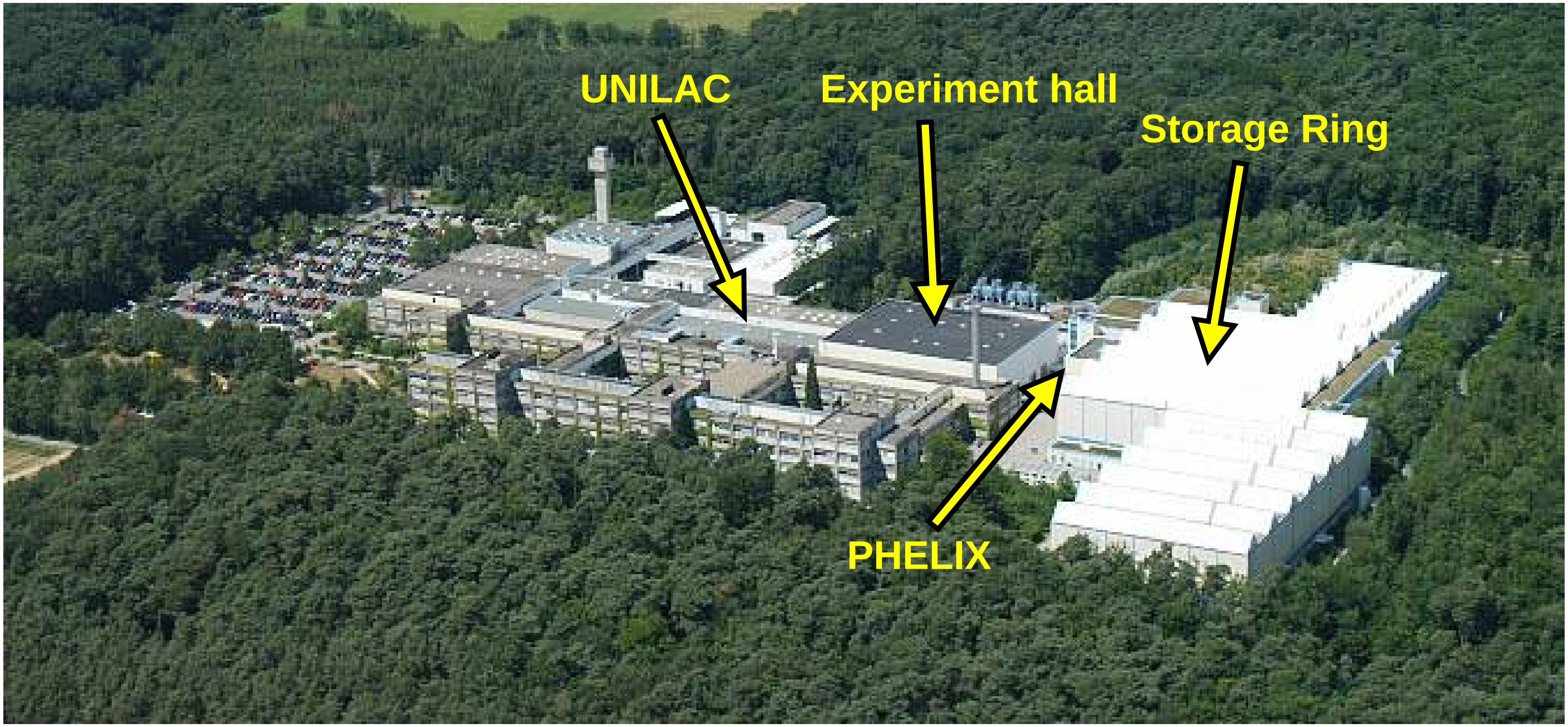
summary

PHELIX has delivered more than 100 shifts since its commissioning

- **PHELIX has been commissioned for use with short pulses (120 J, 700 fs) and nanosecond pulses (300 J - 1kJ)**
- **Emphasis is put on pulse control, beam shaping, and cost efficient focusing technology**
- **The laser has been successfully applied to:**
  - **ion stopping in plasmas**
  - **Particle acceleration**
  - **X-ray generation**
- **The next call for proposal will run from June 1st to August 8th 2009.**

PHELIX

PHELIX is ideally located at the heart of the GSI



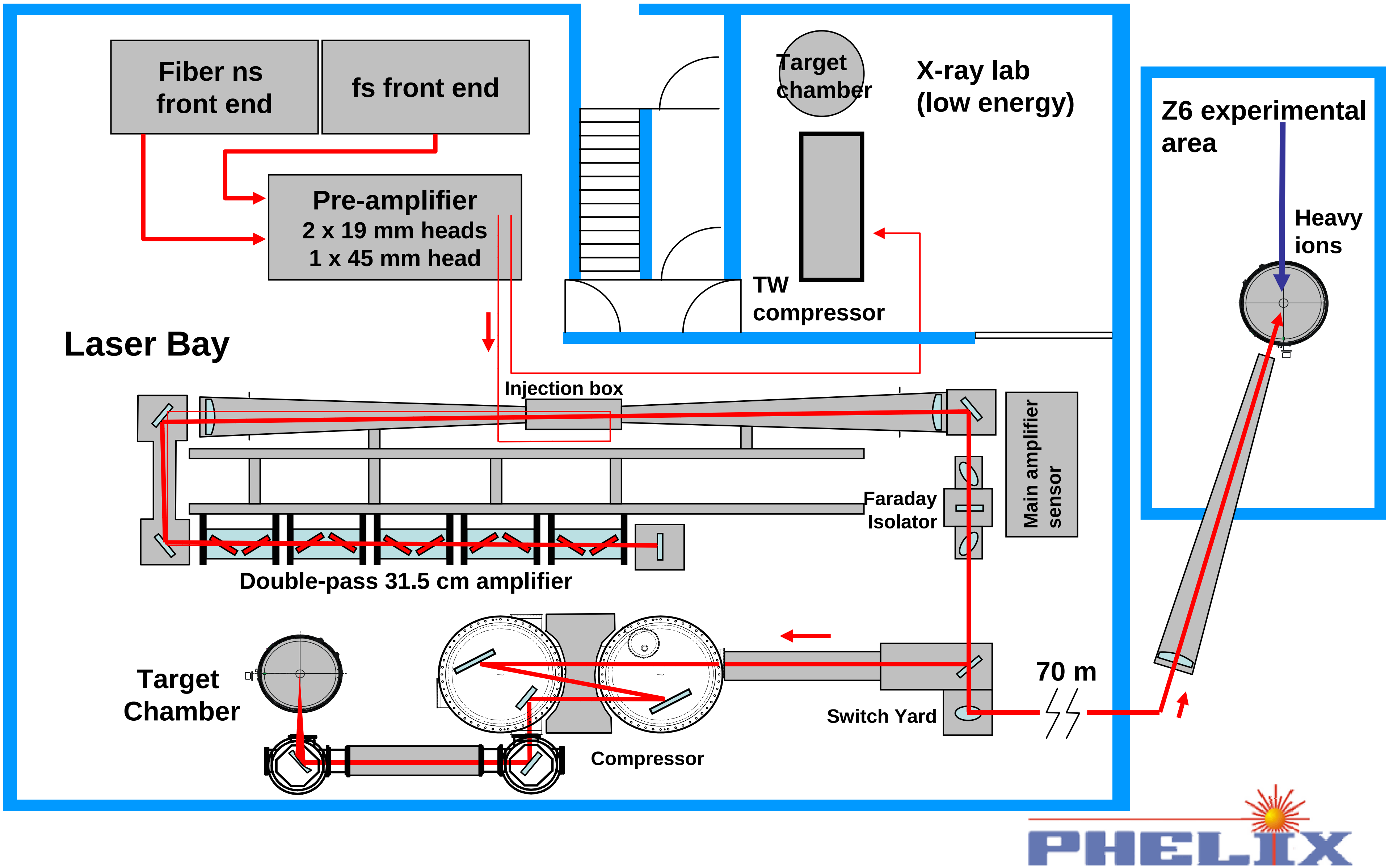
PHELIX has been completed in 2008

- **PHELIX is a versatile nanosecond and sub-picosecond pulse laser based on large-aperture glass amplifier from the former Nova and Phebus lasers**
- **PHELIX was completed in 2008; it is the laser with the highest energy and power in Germany**
- **In 2008, PHELIX provided 70 shifts, about ½ of the targeted annual beamtime (130 Shifts)**

Laser parameters

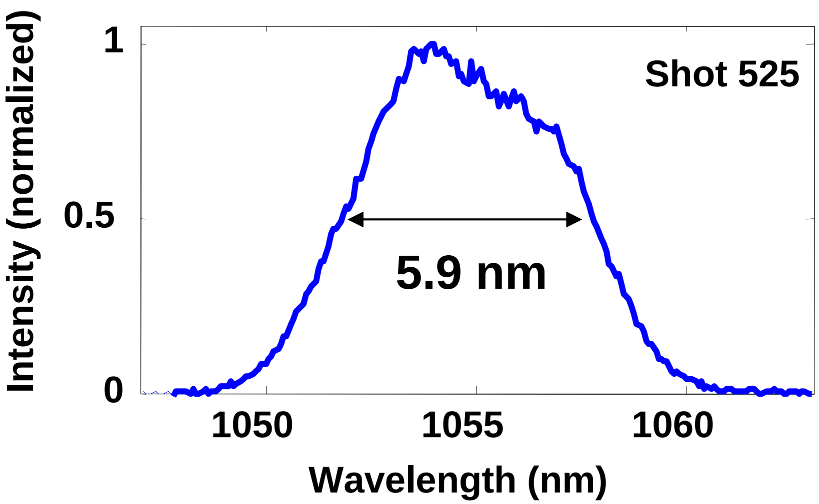
	Long pulse	Short pulse
Pulse duration	0.7 – 20 ns	0.7- 20 ps
Energy	0.3 – 1 kJ	120 J
Max intensity	10^{16}W.cm^{-2}	10^{20}W.cm^{-2}
Repetition rate at maximum power	1 shot every 1h 45	
Temporal Contrast	50 dB	60 dB

The PHELIX laser serves three experimental areas



We use a birefringent filter* in the front-end to pre-compensate gain narrowing

- The PHELIX two-regenerative-amplifier front-end is particularly suited to the method,
- Without loss in output energy, a birefringent plate and a polarizer are introduced between the amplifiers to spectrally shape the spectrum and create a hole at the gain peak of the glass amplifier,
- Spectra > 5 nm wide are routinely obtained at the end of the main amplifier, capable of supporting < 350 fs (Fourier transform limited) pulses.

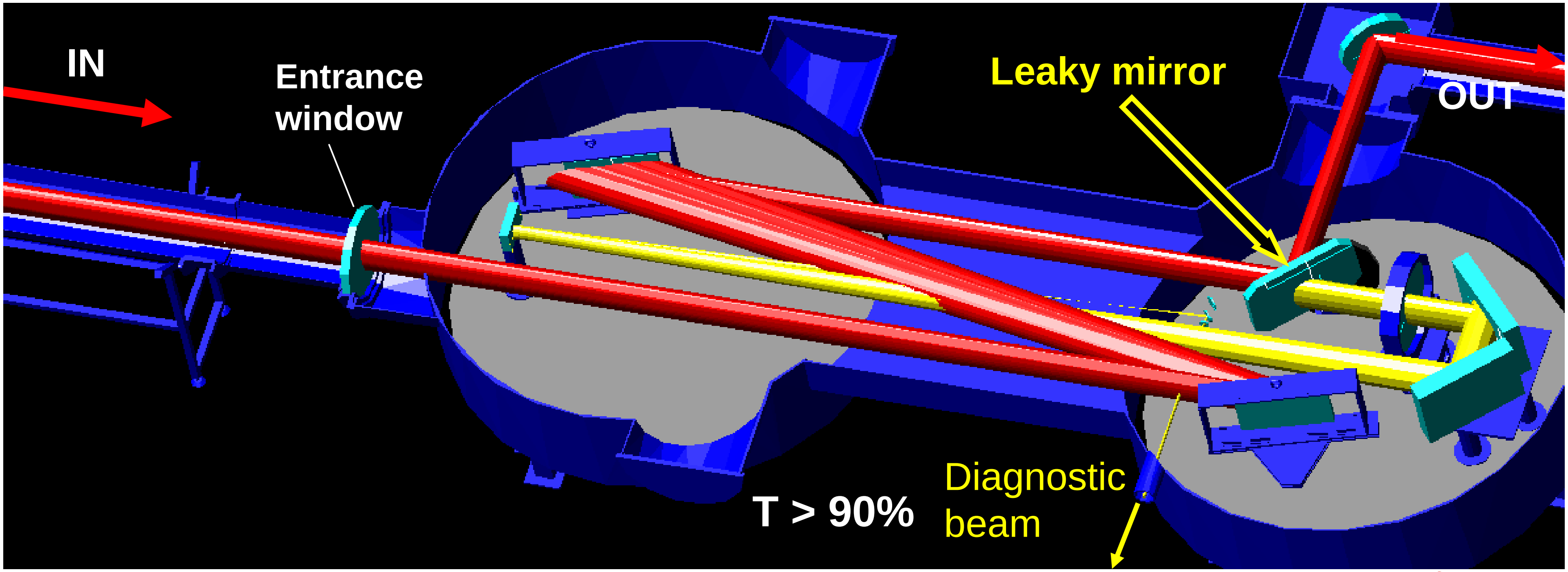


* Barty et al.: Optics Letters, Vol. 21 Issue 3, pp.219-221 (1996)

PHELIX

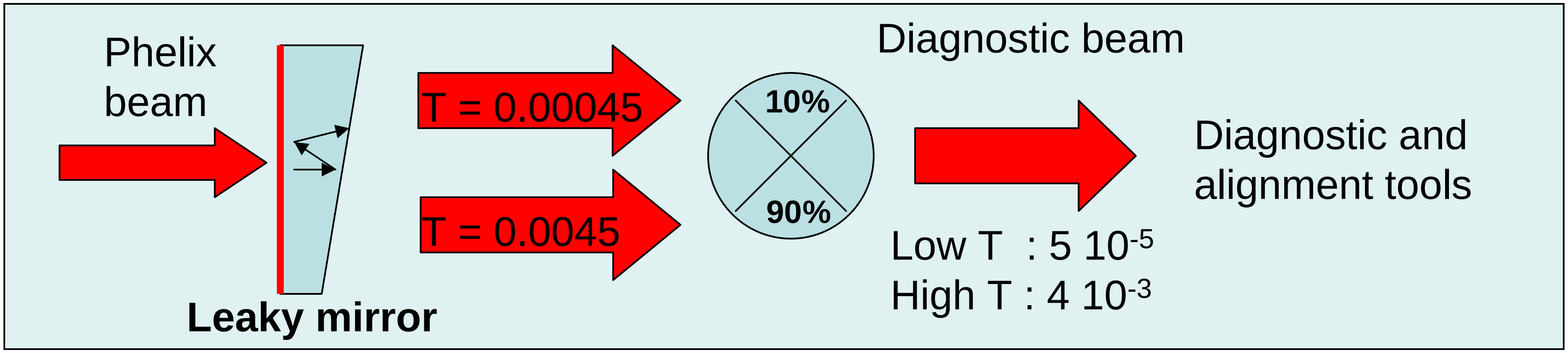
The short pulse diagnostics are ready for use with high-energy pulses

- **The diagnostic beamline has been available for alignment only (in yellow).**
- **At high energy, the main issue is peak-power mitigation in the diagnostic beamline.**
- **The amount of acceptable leakage is a trade-off between beam uniformity and energy attenuation.**



The diagnostics path is optimized for B-integral mitigation without compromising alignment needs

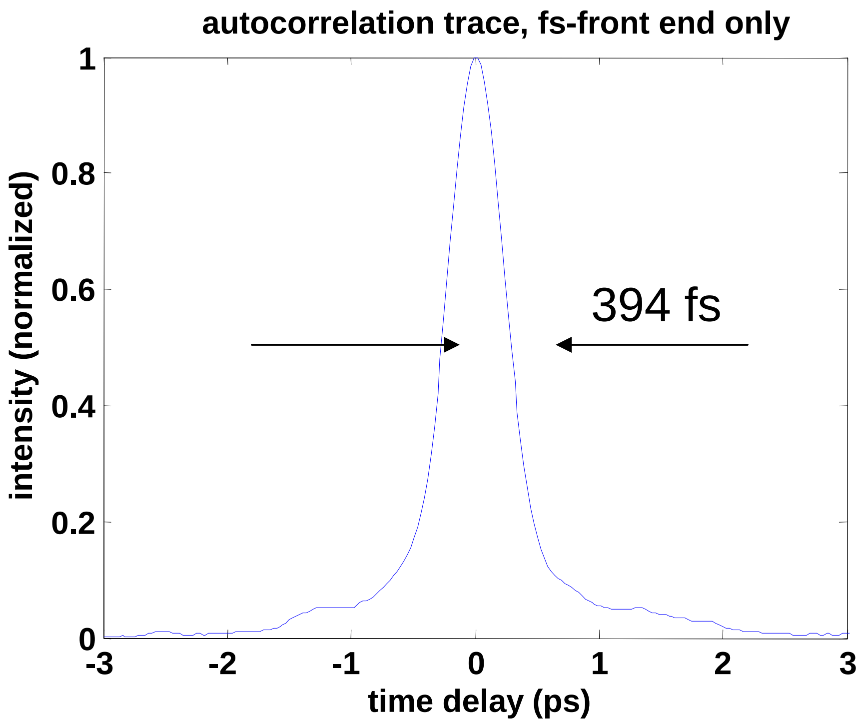
- The B-integral is maintained at low level by using the first internal reflection in the leaky mirror, which attenuates the energy by a factor of 10 but,
  - The drawback is a tight specification on the leaky mirror (surface flatness and refraction index homogeneity).
- The main transmitted beam is used for alignment after it is combined back with the main diagnostic beam.
- All the setup is installed in vacuum.



PHELIX

The compressor shows good performance

- Short pulses in the sub- 500 fs range have been measured (fs-front end only)
- More data will be available in the spring as the short pulse diagnostic channel becomes available to confirm the data at high power

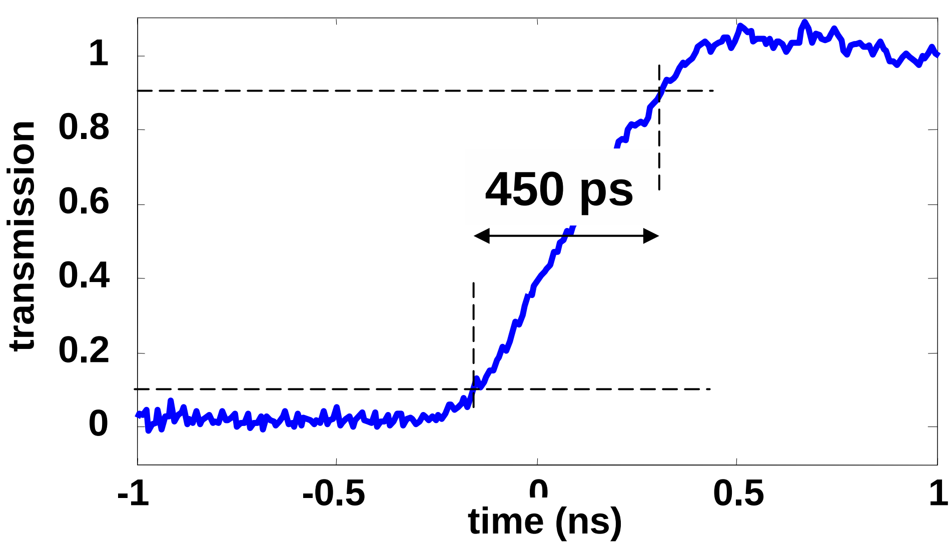


PHELIX

Pre-pulse mitigation

- For the nanosecond pulse, the 50-dB contrast fulfills all requirements.
- For the short pulse, the contrast is affected by pre-pulses and ASE:
  - Pockels cells are used in the front end as pulse cleaners
    - 1 PC is located in the femtosecond front end,
    - 2 PCs are located at the output of the femtosecond front end, including a fast Pockels cell driver,
  - 1 PC is located in the pre-amplifier.

Optical transmission of the fast Pockels cell



Time before pulse	Contrast
> 5 ns	> 90 dB (< 100 nJ/pre-pulse)
2 – 5 ns	> 60 dB (< 100 µJ/pre-pulse)
2 - 0 ns	60 dB (ASE)* (~ 1Joule)

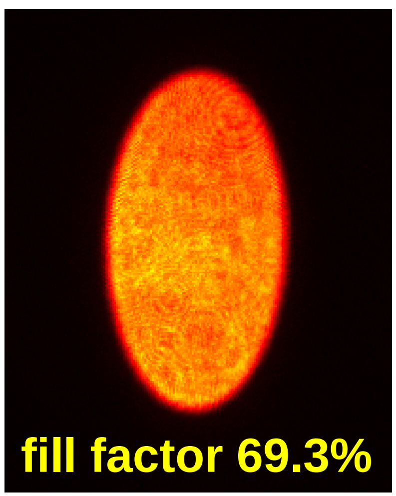
* Improvements are planned for 2010

PHELIX

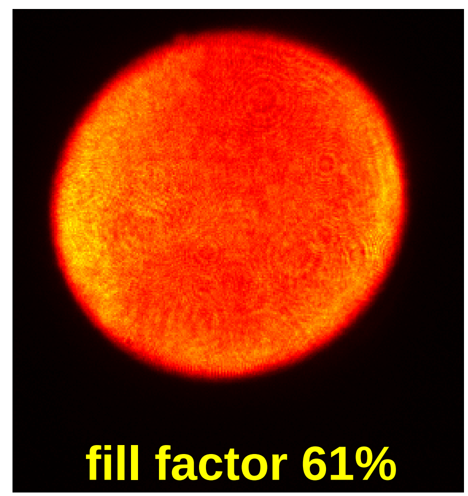
Beam control has a direct impact on the available on-target energy

- The available on-target energy is limited by the laser-induced damage threshold of optical components like the Faraday rotator in nanosecond regime and the compression gratings for short pulses
- We characterize the beam quality with the "fill factor" (ratio of measured beam energy to an ideal "top hat" beam)
- Shaped beams are also used for filling gratings in the compressor

Elliptical beam for optimum use of the compressor



Round 28 cm beam

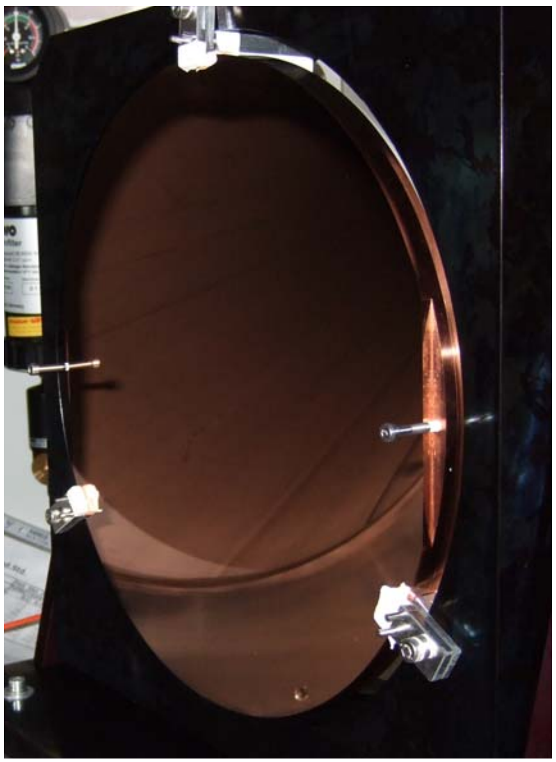


PHELIX

A 90-degree low-cost off-axis metallic parabola achieves good focusing capability.

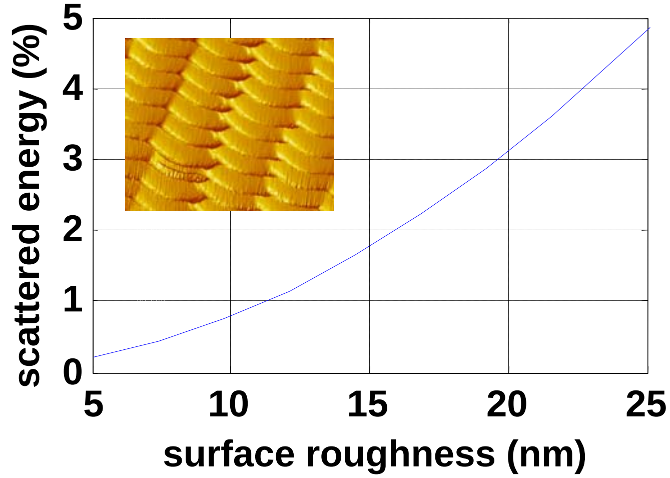
- **The 90-degree massive metallic mirror is machined to ~1 micron accuracy (PV),**
- **The surface roughness and machining precision have to the balanced to get the best trade-off between scattering losses and wavefront error.**

Mirror in its Holder



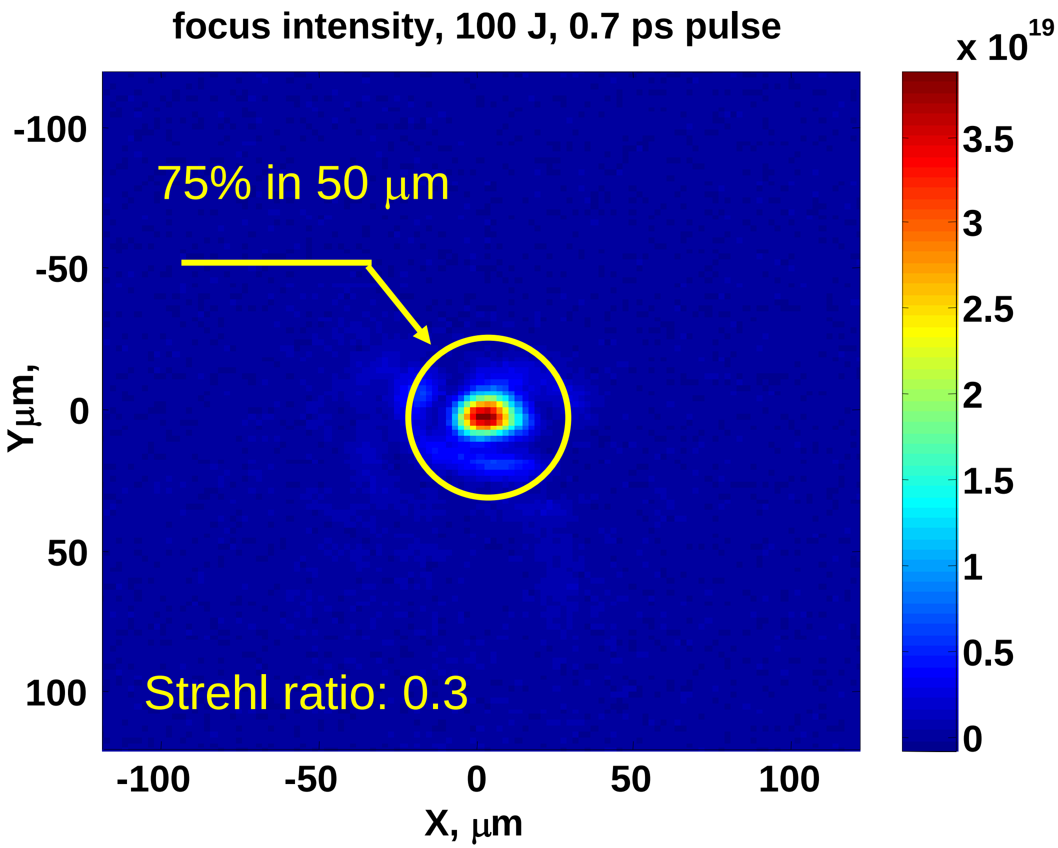
Back View

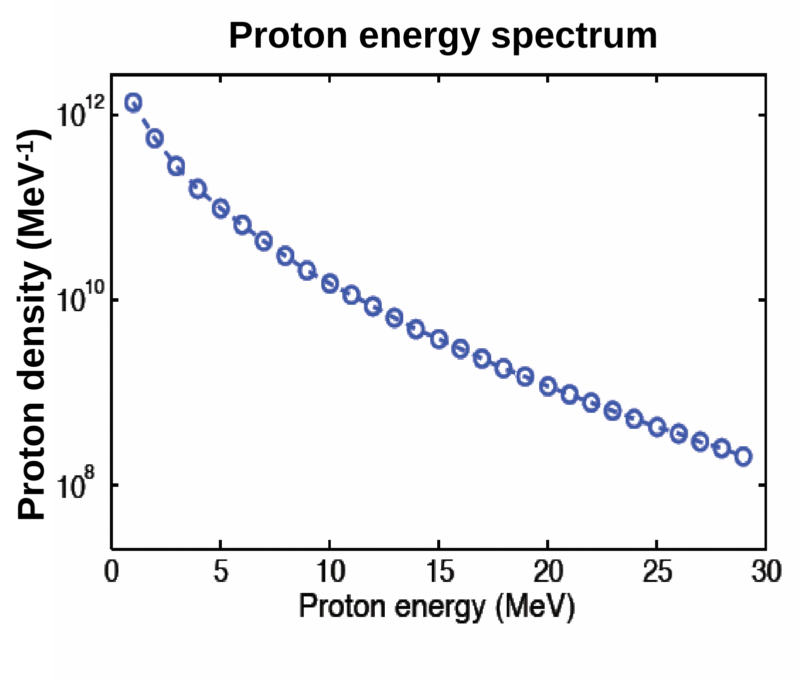
Estimation of scattered energy based on simulated surface roughness



Experimental evidence indicates an on-target intensity > 10^{19} W.cm^{-2}

- **A calculation based on the far-field intensity distribution yields 3.5 10^{19} W.cm^2**
- **According the accelerated proton spectra obtained by the Technical University Darmstadt (TUD), the intensity is rather ~10^{20} W.cm^2**

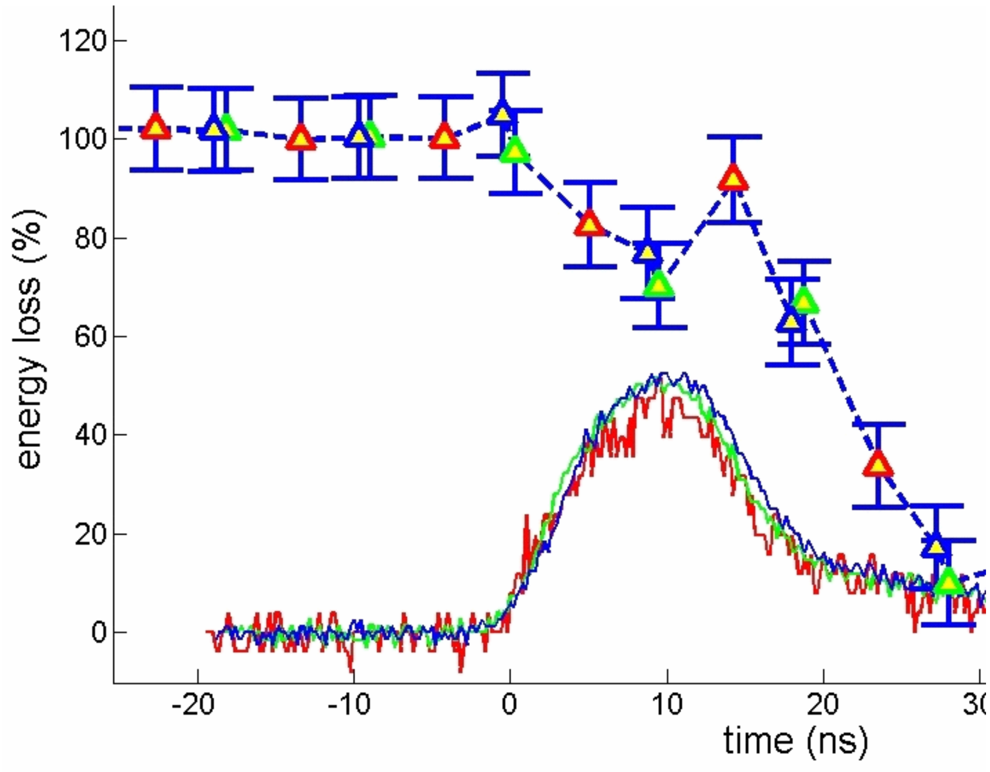




4 beamtimes (52 shifts) were conducted where ions and the laser pulse were combined

- **In the context of inertial fusion with heavy ions, we study the energy loss of ions in laser-generated plasma,**
- **We used PHELIX pulses with 7-15 ns and 50 - 315 J, to compare to measurements done at lower energy using nhelix:**
  - **1-mm focal spot achieved with 4-m lens + phase mask and,**
  - **UNILAC S 15+ and Ar 16+; 0.3 mm diameter.**
- **We measure the ion-energy loss via time-of-flight measurements.**
- **In a plasma, the theory predicts that ion-energy loss is dominated by free electrons but our experiments do not only illustrate this.**

Time evolution of the ion-energy loss
100 corresponds to the cold target

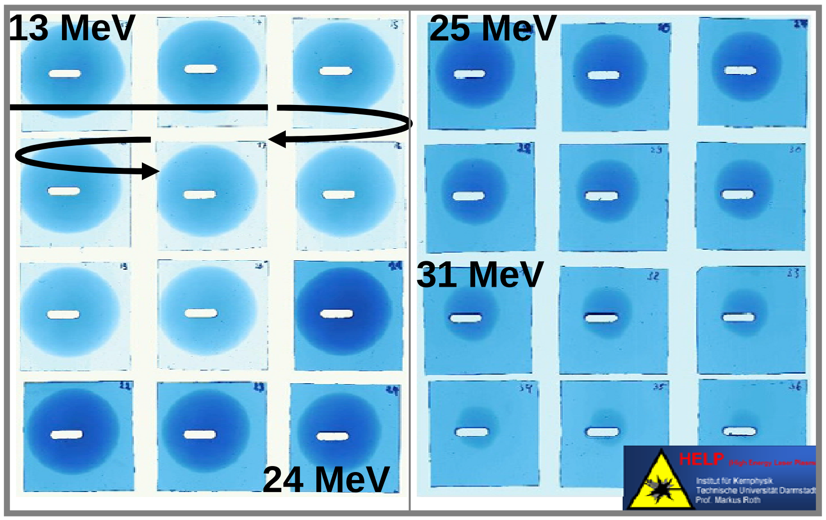


PHELIX

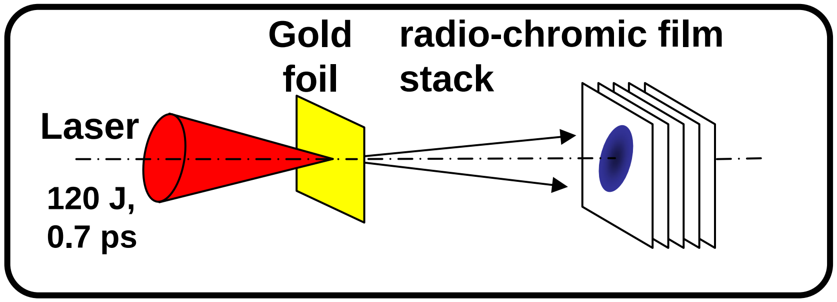
PHELIX has successfully been applied to proton acceleration

- **Proton acceleration is interesting for backlighting and coupling into conventional accelerator structures.**
- **One beamtime was conducted to investigate protons accelerated with PHELIX in "standard" conditions.**
- **So far > 30 MeV protons have been accelerated with PHELIX, indicating that high intensity conditions (~ 10^{20} W.cm2) are obtained at the focus.**

Radiochromic films

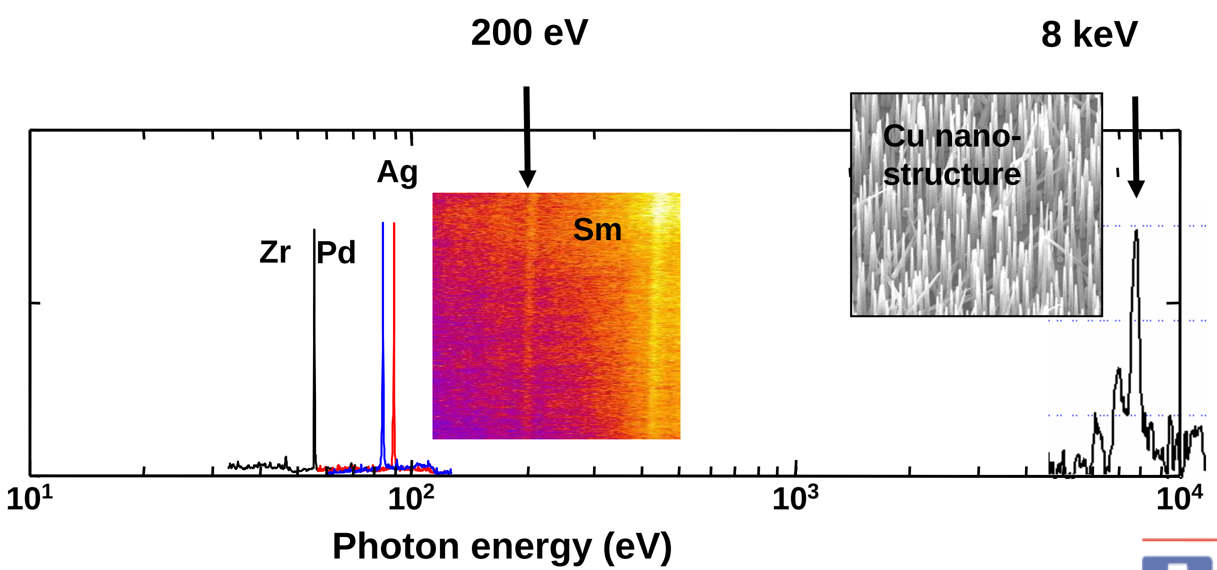


setup



X-ray generation with PHELIX covers a wide range

- **GSI has an extensive experience with X-ray lasers.**
- **The main focus is on short wavelength developments and improvement of the coherence of such lasers via seeding.**
- **The direct application of the x-ray laser is the spectroscopy of stable and radioactive highly-charged ions at ESR/NESR.**
- **Promising first investigations on narrowband intense x-ray source have started in 2008 with the goal of developing the tools for backlighting and Thomson scattering.**



The laser performance will be further enhanced during the next years

- Temporal contrast enhancement of the laser pulse and short pulse capability development at Z6
  - X-ray generation and particle acceleration will be enhanced after the temporal contrast is improved by 60 dB
  - Laser accelerated particles can be best manipulated at Z6 because of existing capabilities, requiring the building of a short pulse beamline to Z6
- Hohlraum heating at Z6 will be possible thanks to the completion of frequency doubling and tight focusing of the PHELIX beam
  - Hohraums create homogeneous non-fully-ionized plasma conditions necessary to support the further studies of stopping power in plasma