Status of the Helmholtz Beamline at FAIR, and of the PHELIX Laser

V. Bagnoud
Plasma Physics Department/ PHELIX
GSI-Darmstadt, Germany

EMMI Workshop on High Energy Density Diagnostics at FAIR

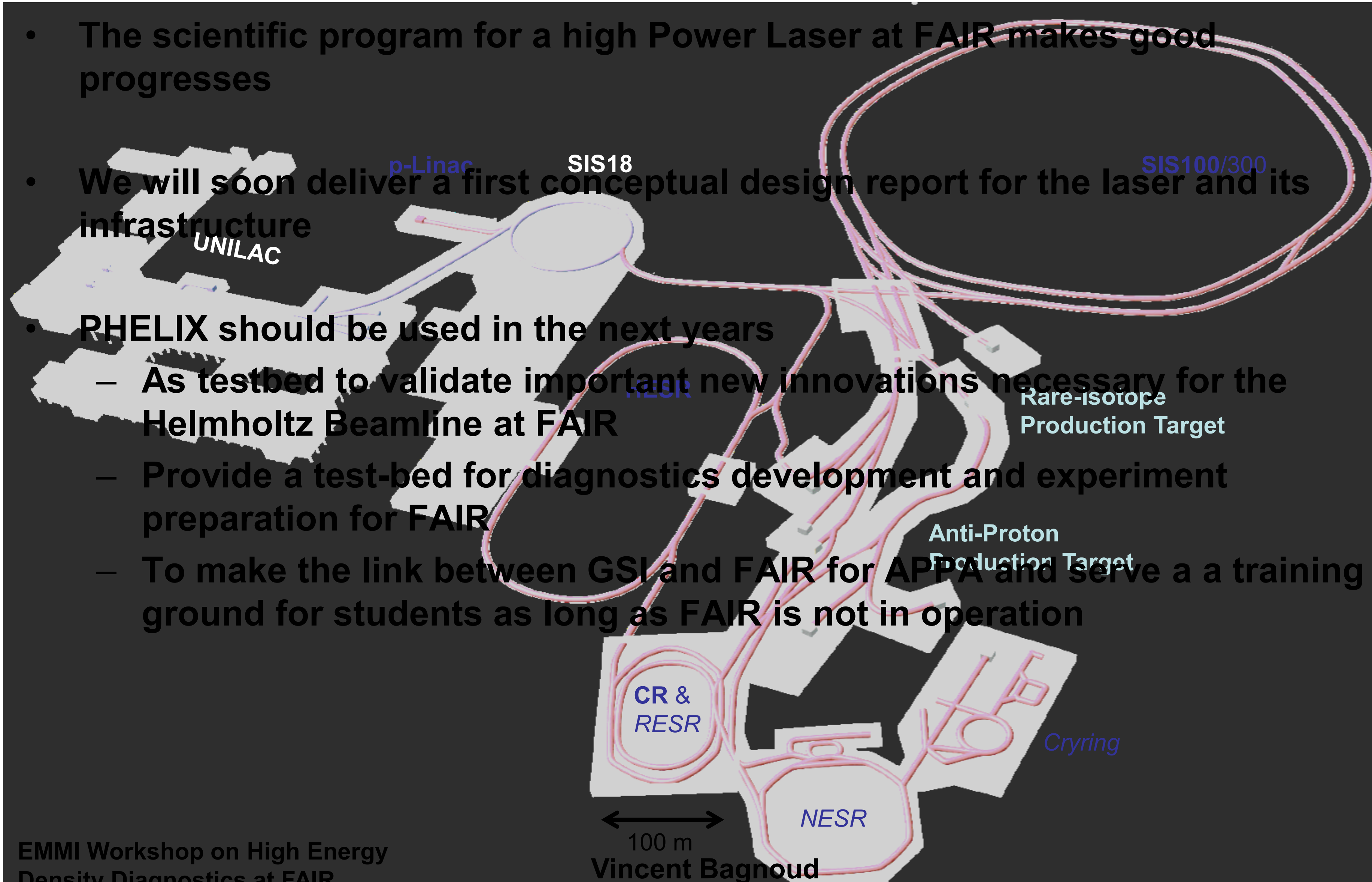
Darmstadt, Sept 30th – Oct. 2nd 2013

Helmholtz-Institut Jena

Summary

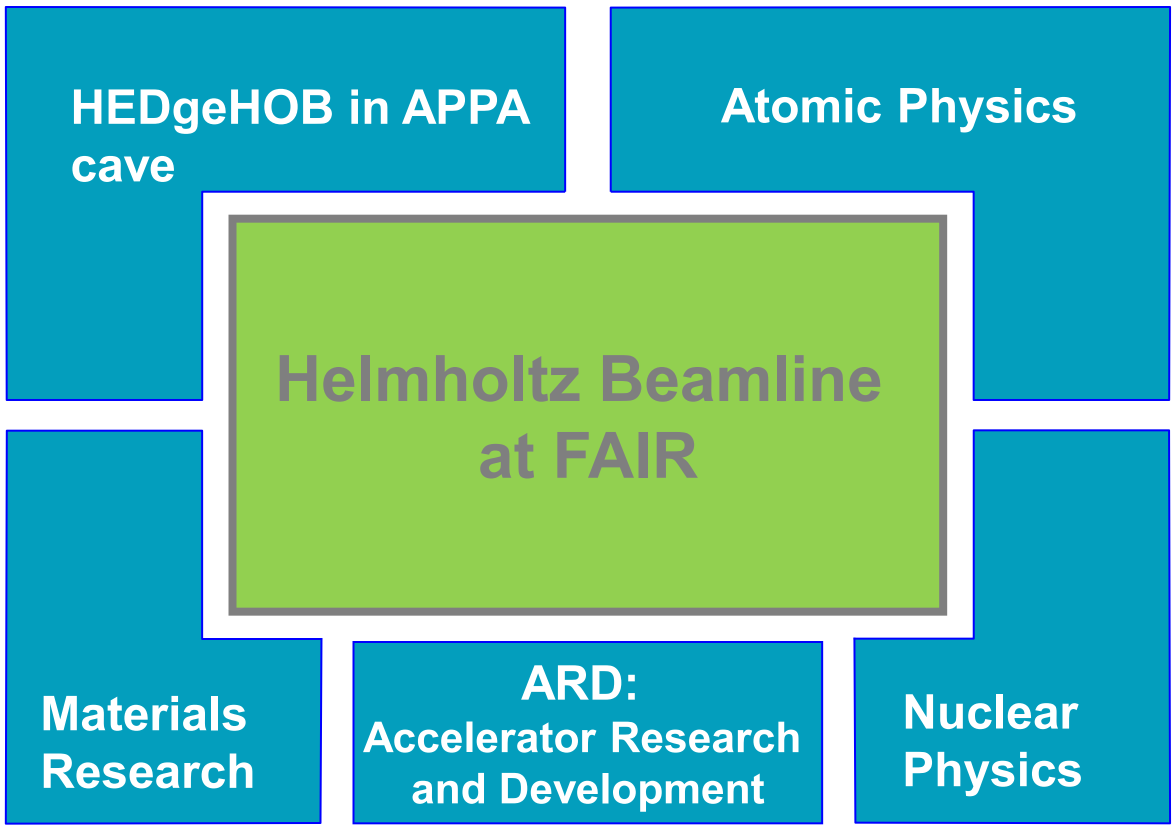
We are actively preparing a follower to PHELIX

- The scientific program for a high Power Laser at FAIR makes good progresses
- We will soon deliver a first conceptual design report for the laser and its infrastructure
- PHELIX should be used in the next years
  - As testbed to validate important new innovations necessary for the Helmholtz Beamline at FAIR
  - Provide a test-bed for diagnostics development and experiment preparation for FAIR
  - To make the link between GSI and FAIR for APPA and serve a a training ground for students as long as FAIR is not in operation



Scientific Program

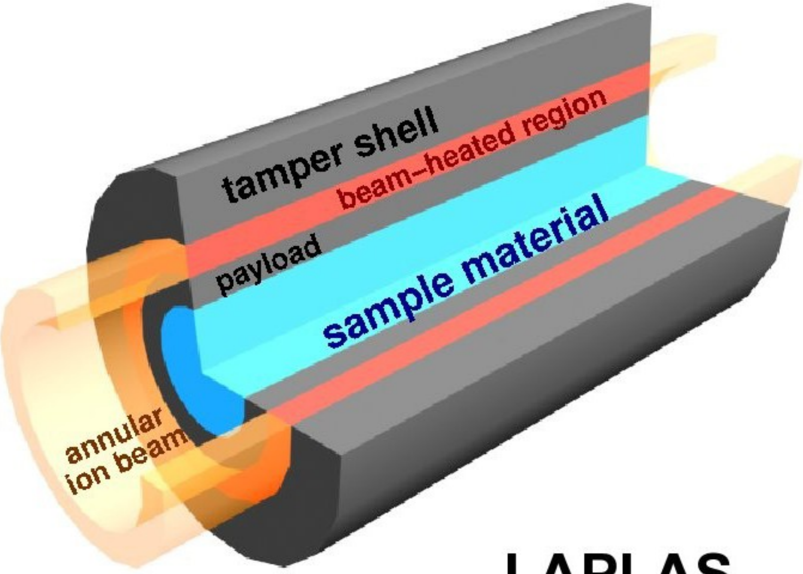
- The scientific program of the HB at FAIR is based on 5 pillars



Plasma Physics at FAIR

- **The HEDgeHOB collaboration will drive experiments on extreme states of matter relevant to planetary science in the APPA cave**

  - **The behavior of low Z materials (hydrogen and water) at high-pressure and high temperature is relevant to giant planet physics**
  - **For High-Z materials, issues like phase transitions of iron are central to understand the magnetic field of the earth**

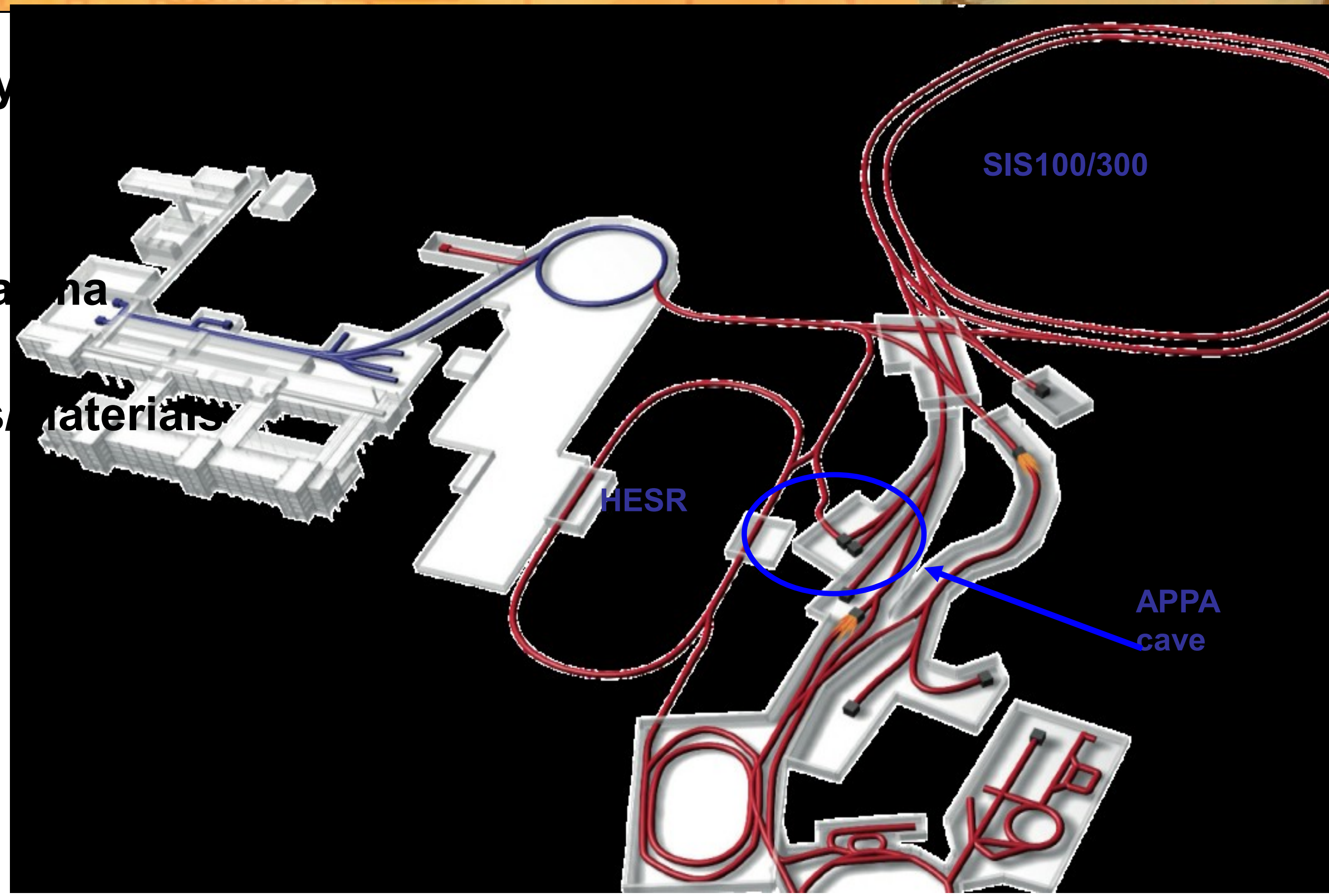


LAPLAS

Theses questions require access to high-compression facilities

The APPA cave at FAIR: a flexible target station area

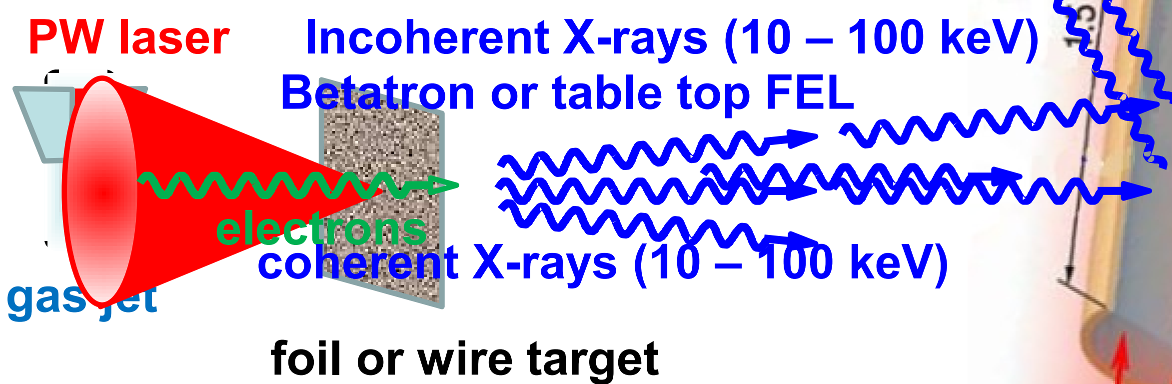
- ~ 900 m2 laboratory
- fully shielded
- two beamlines:
  - HEDgeHOB (pla na physics)
  - Atomic physics/ aterials research

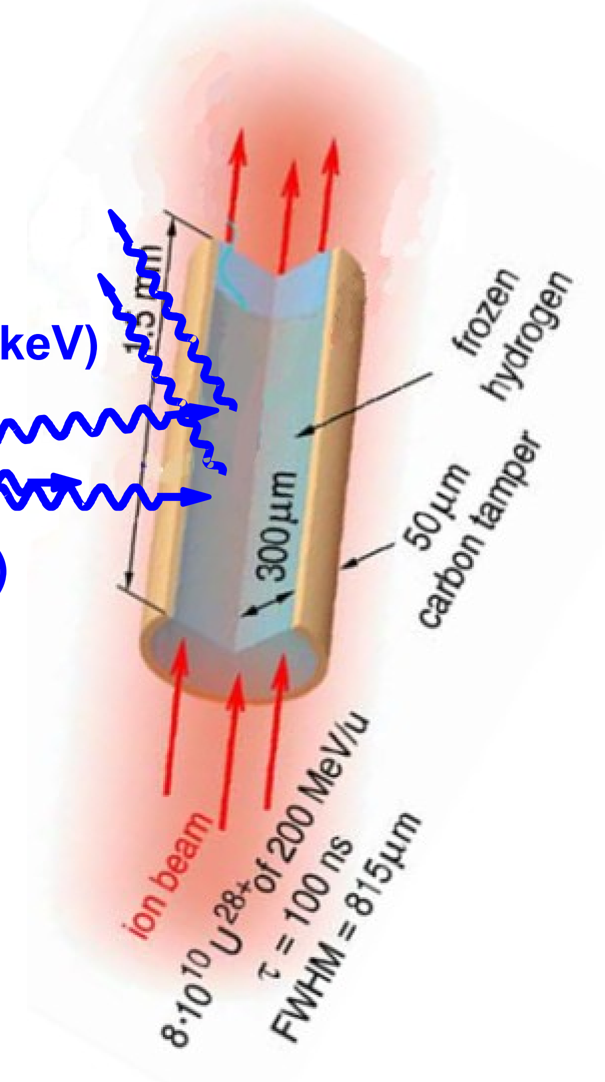


No large scale diagnostic is included for the APPA collaborations yet

Laser-based diagnostics: X-ray backlighting

- Direct information about phase transitions can be retrieved from X-ray backlighting: a robust proven scheme

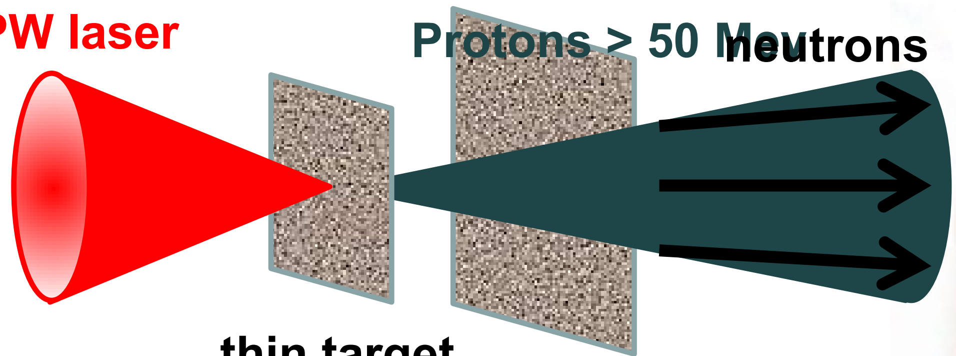


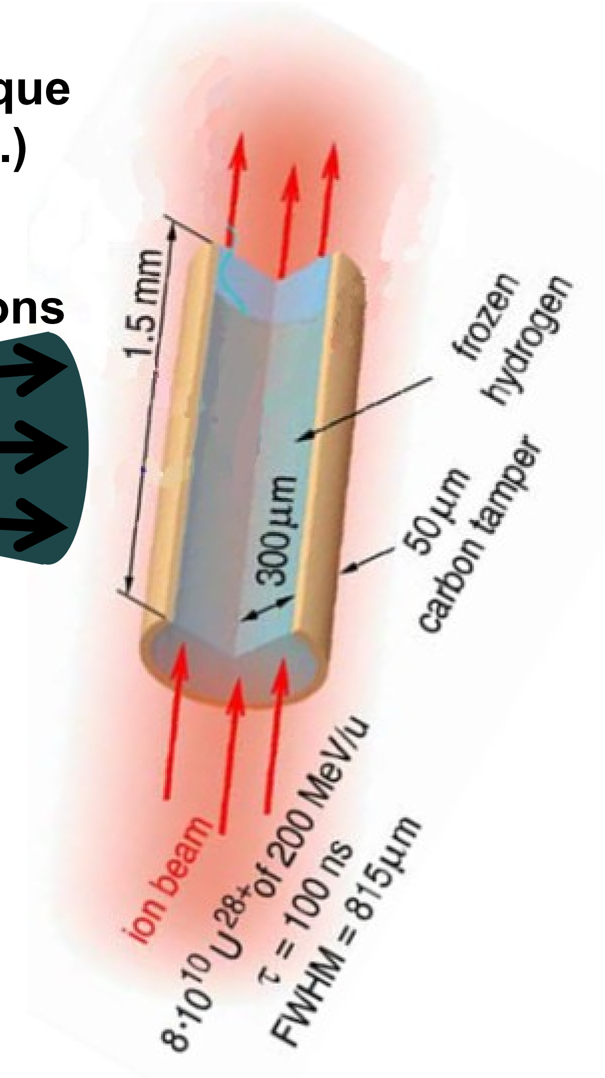


- Paving the way for more advanced schemes
  - GeV electrons can be accelerated with lasers
  - driving tertiary sources

Diagnostics based on laser-accelerated particles

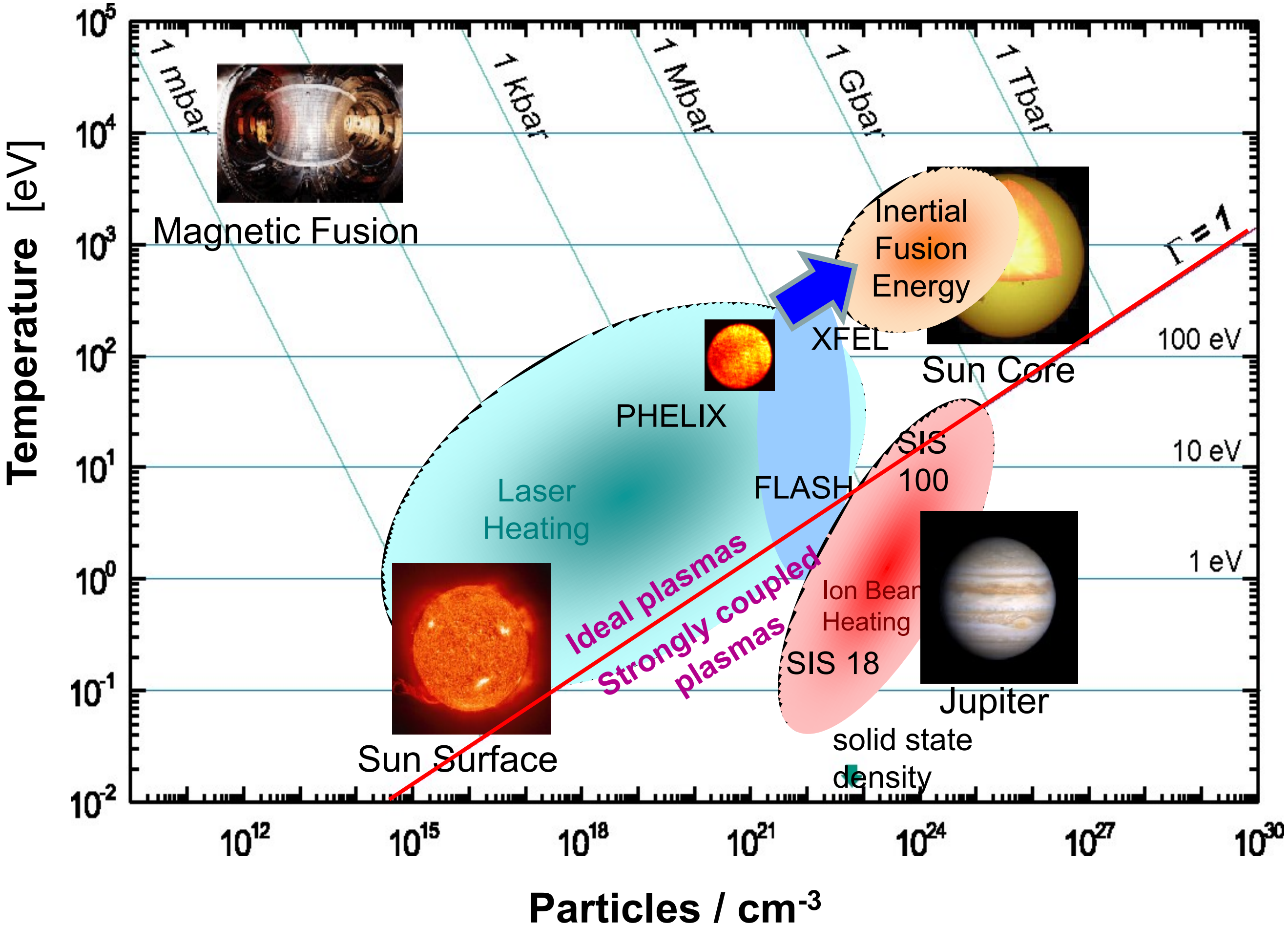
- Proton imaging can be applied exploiting the unique properties of such beams (sub ns resolution etc...)





- Advanced schemes are even more promising
  - laser driven neutron sources
  - proton beam transport

In addition, high-pressure > 1Mbar, high temperatures are in reach of laser drivers



A nanosecond high-energy laser compression/shock facility is a complementary approach to ion beam plasma physics

In particular, Materials Research would benefit from a dual nanosecond/picosecond laser source

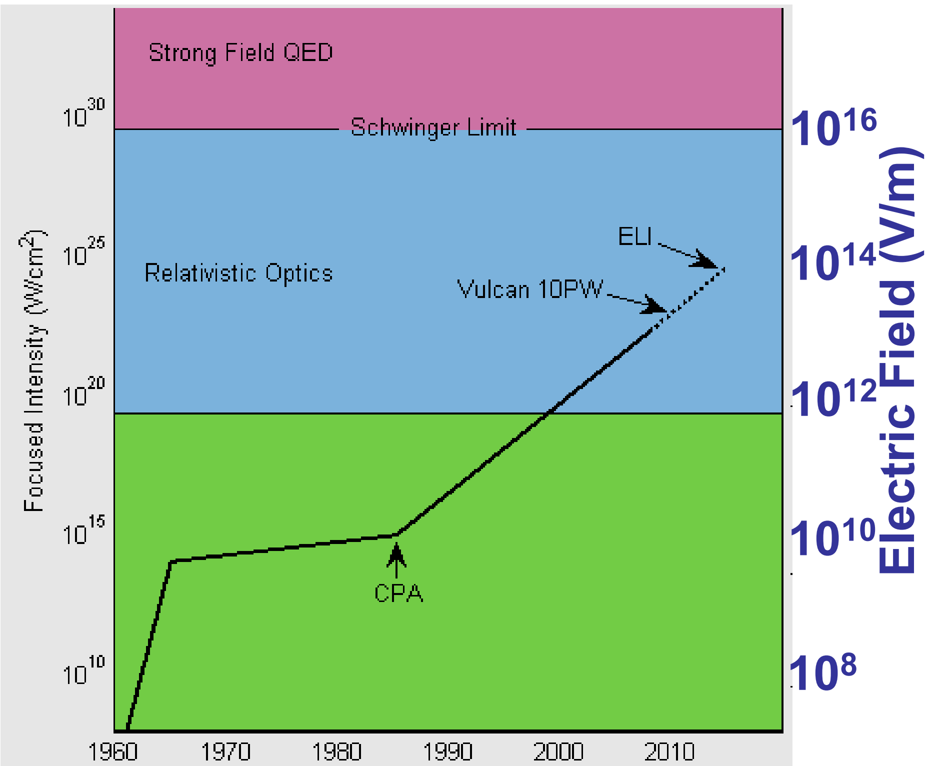
- dynamical effects at pressures above a few Mbars can be launched with lasers with application for FAIR:
  - Shock waves studies for FAIR targets and high power accelerator materials like macroscopic behavior (cracks, lifetime) of components under strong irradiation conditions
  - conditioning (hardening) of materials

- The laser offers a very precise tool to study:
  - Ultrafast timescale damage processes and defect dynamics in solids under heavy ion irradiation
  - Materials processing by pulsed ion and laser exposure

- Foreseen uses span from nanosecond kilojoule pulses to laser-driven particles (ions)

Atomic physics: extreme EM Fields in naked heavy ions

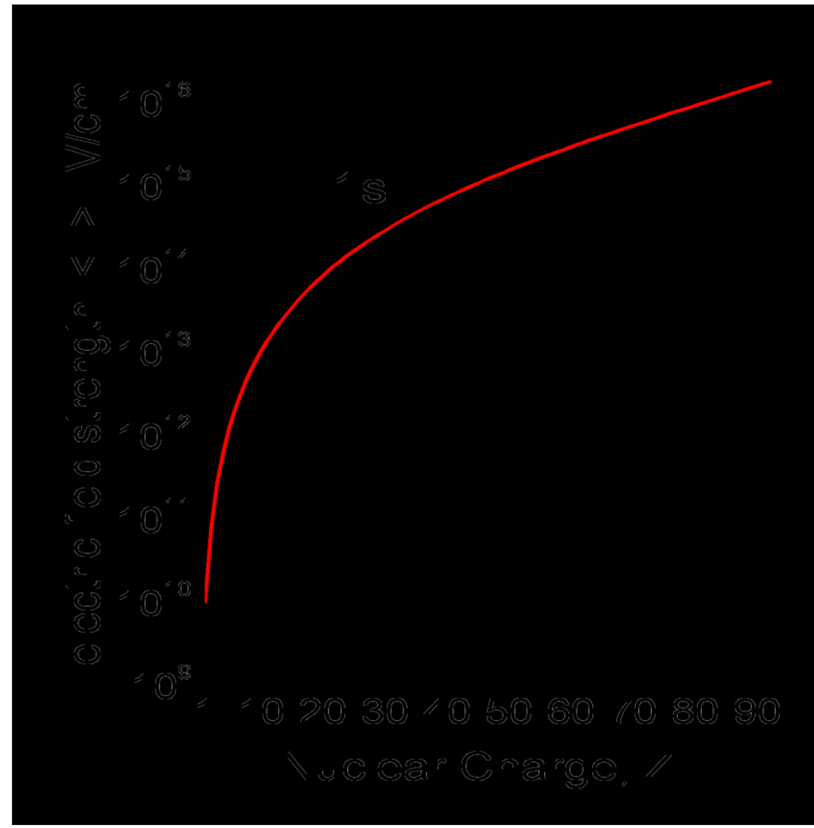
Lasers



(adapted from Mourou, Tajima, Bulanov, RMP **78**, 2006)

Sub-femtosecond pulses

Heavy ions

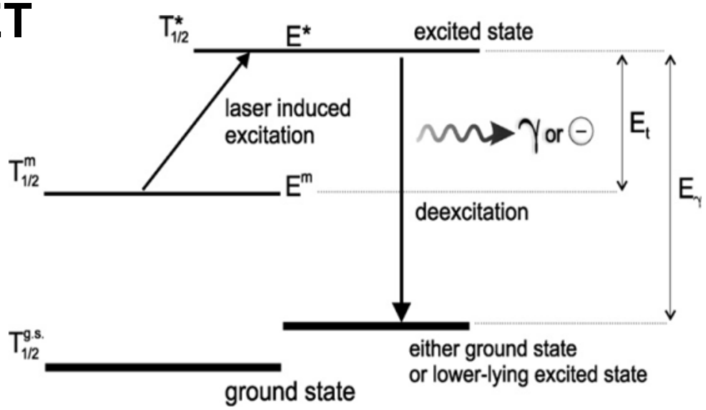


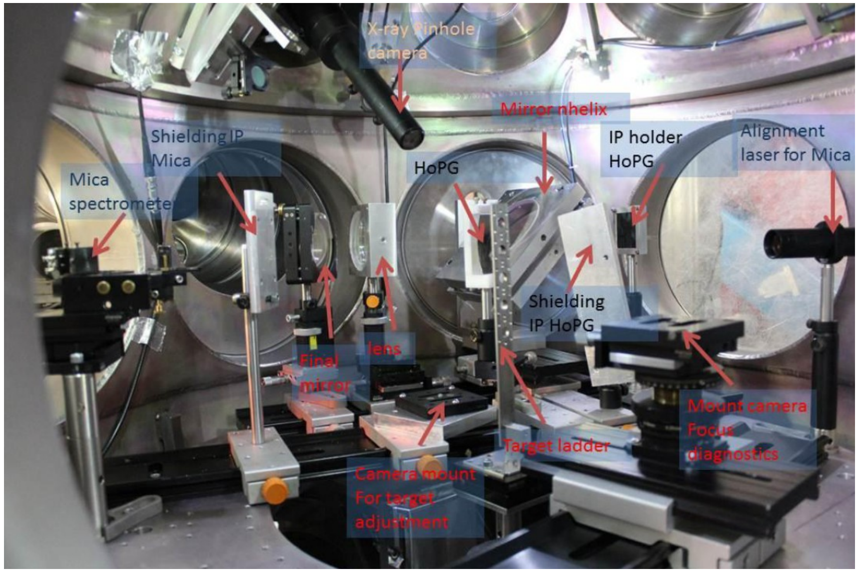
Large EM fields,
zeptosecond pulses

Nuclear physics*

- **mostly unexplored nuclear excitation processes like NEET (nuclear excitation by electron transitions) can be studied with lasers**
  - **nuclei with the right isomeric states can be prepared by the accelerator**
  - **the laser provides the plasma conditions to initiate the transition**

- **Example of NEET in Rubidium**
  - **first dimensioning experiments have been done with PHELIX showing that > 1kJoule long pulse are necessary to reach the right conditions for NEET**





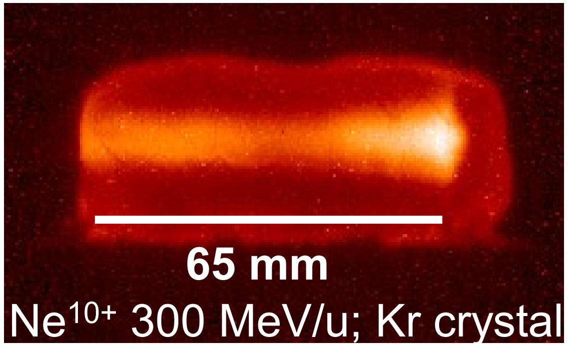
For NEET in Rb, > 2kJ, 2ω nanosecond laser pulses are probably necessary

* **see David Denis-Petit** *(BofA 10) Tuesday 10:10-10:30*

Our scientific program is deliberately complementary to the HIBEF at the XFEL

- **Heavy-Ion beams at FAIR and novel XUV photon sources are complementary**

Intense, energetic beams of heavy ions (GSI & FAIR)



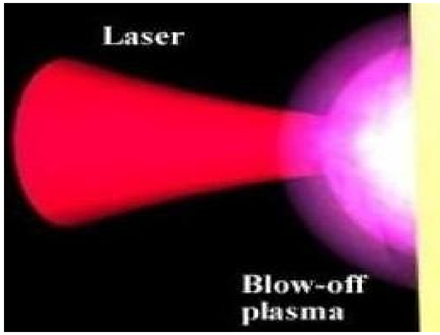
large sample volume (mm^3)
uniform physical conditions
any target material
long time scales (50 ns)

Specific energy
~ kJ/g

Temperature
up to 1 eV

Pressure
multi-kbar range

High-brilliance XUV photon sources (FLASH@DESY)



small sample volume (100 μm^3)
high gradients
low-Z target material
short time scales (100 fs)

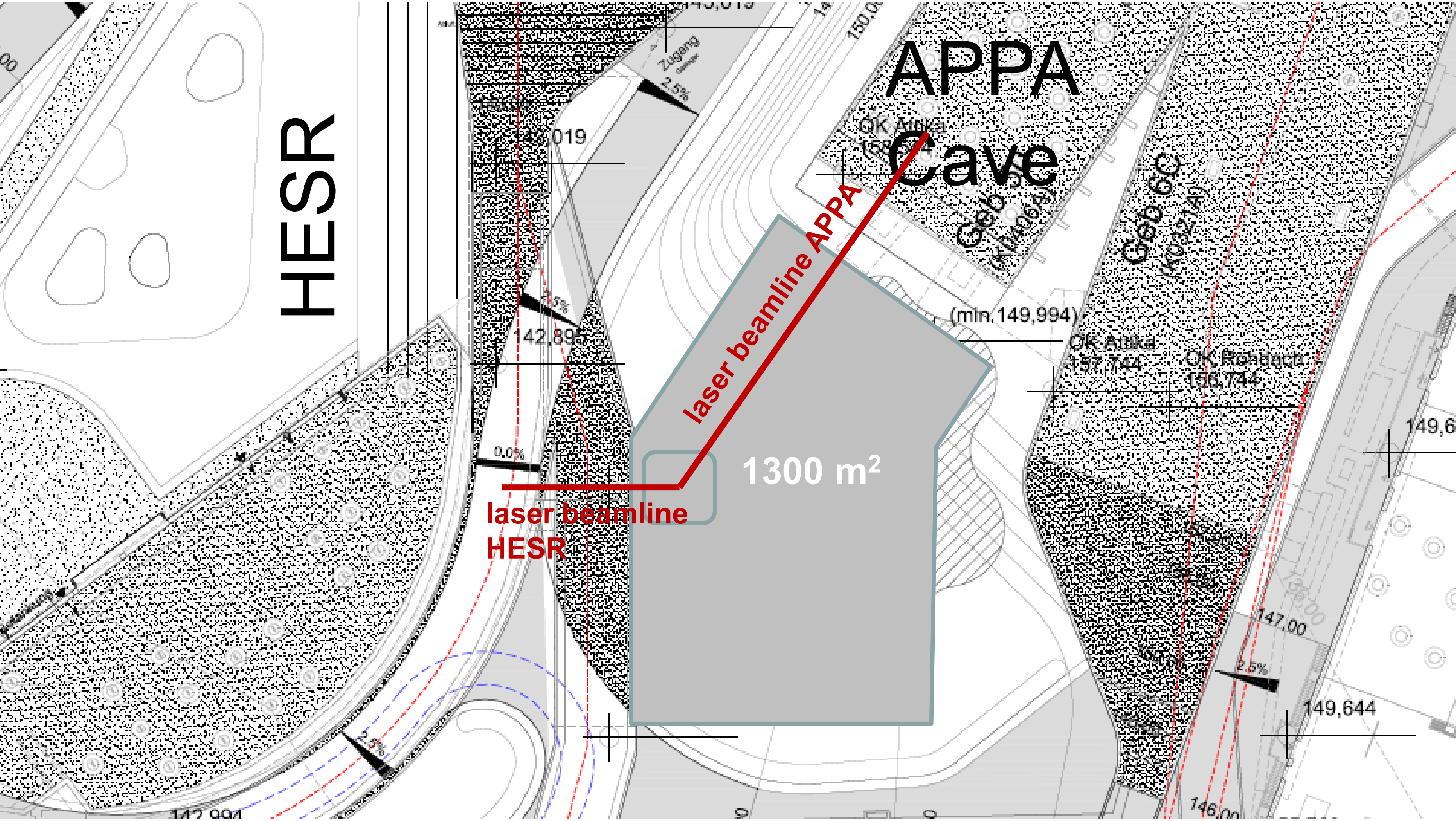
General requirements for a laser facility for FAIR

- **High energy (flash lamp-pumped Nd:glass) laser**
- **An evolution of the PHELIX architecture in order to foster on existing expertise and minimize risks**
  - **strong in kind contribution from GSI**
  - **support from Helmholtz HI Jena, HZDR**
  - **strategic positioning**
- **2 Beamlines with flexible characteristics (short and long pulses, high-temporal contrast)**
- **Moderate to high repetition rate (> 500 shots per day)**

Technical Requirements for a laser facility at FAIR

Laser parameters	Actual (PHELIX)	projection	limit
Laser energy - short pulse	250 J	400 J	1 kJ
Laser Energy - long pulse (2ω)	200 J	1 kJ	10 kJ
Pulse duration	500 fs	350 fs	150 fs
Temporal contrast	10^{-10}	10^{-12}	10^{-14}
power	400 TW	1.1 PW	7 PW
Repetition rate	1 shot/90 min	1 shot/ 1 -10 min	1 Hz
Proton energies	20 MeV	50 -100 MeV	200 MeV

Site for the implementation of the Helmholtz Beamline at FAIR



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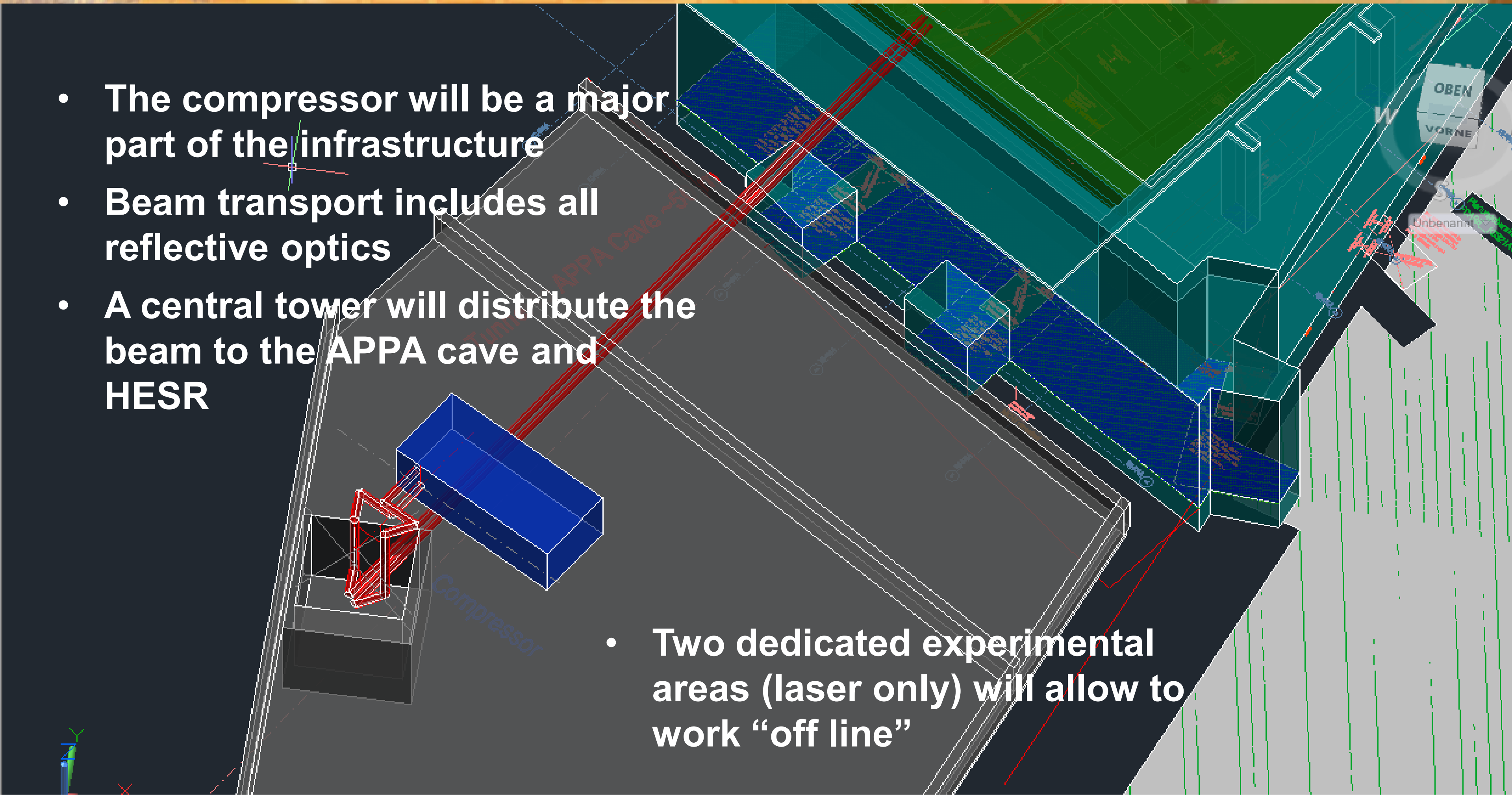
Vincent Bagnoud

PHELIX

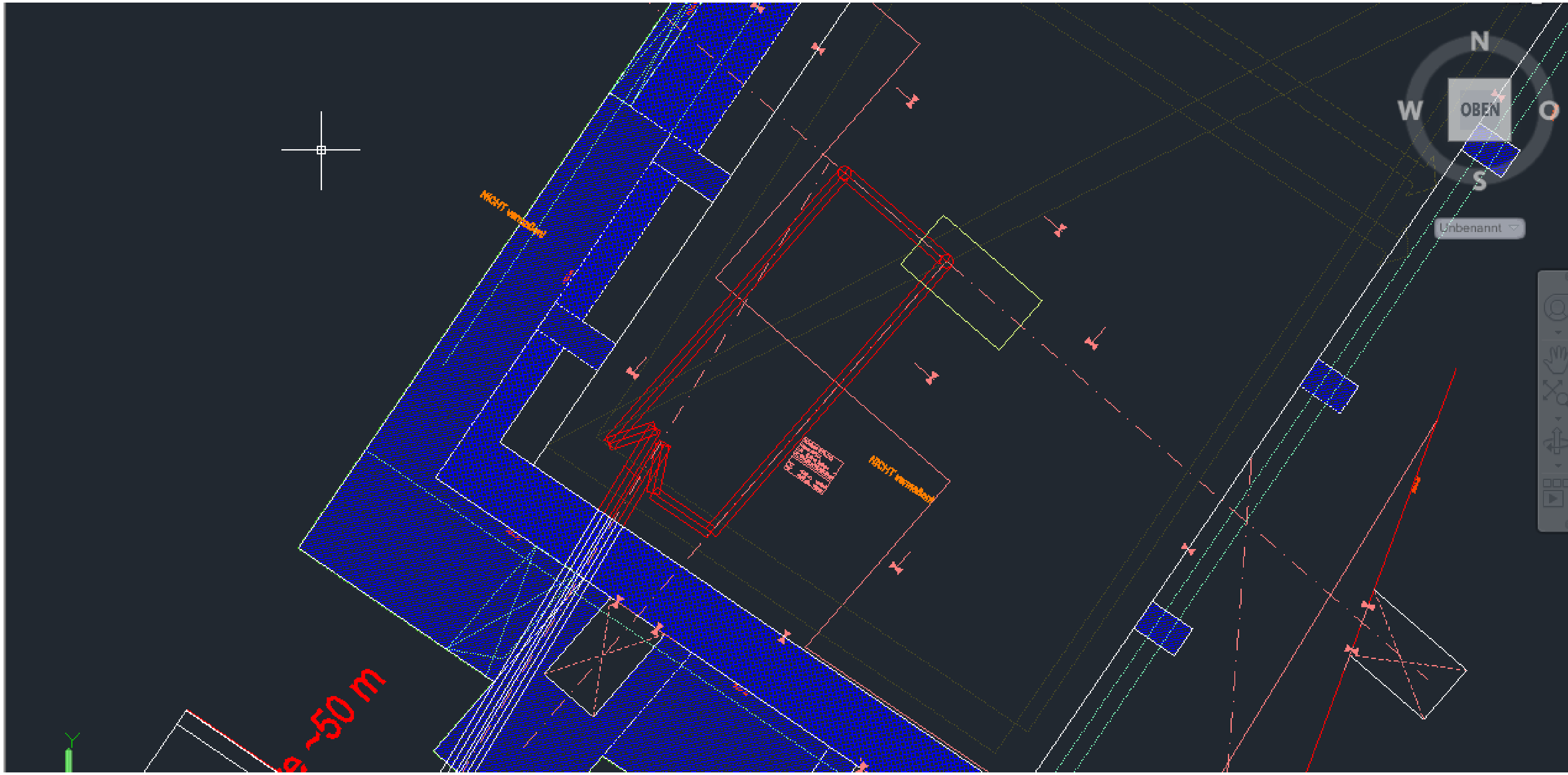
Coupling to the APPA cave

- The compressor will be a major part of the infrastructure
- Beam transport includes all reflective optics
- A central tower will distribute the beam to the APPA cave and HESR



- Two dedicated experimental areas (laser only) will allow to work “off line”

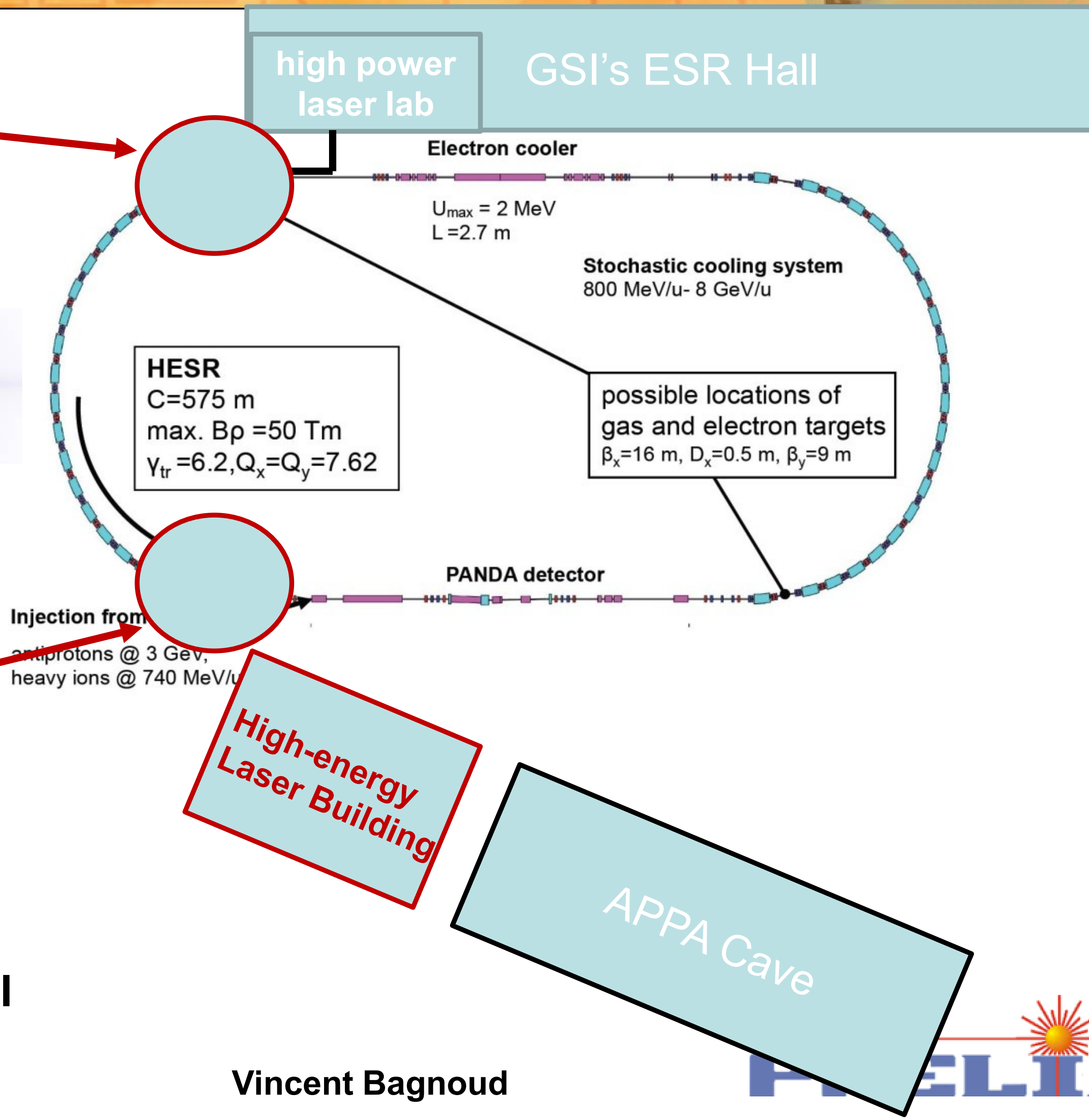
Close up view on the APPA cave



Experiments with high-power lasers at the HESR

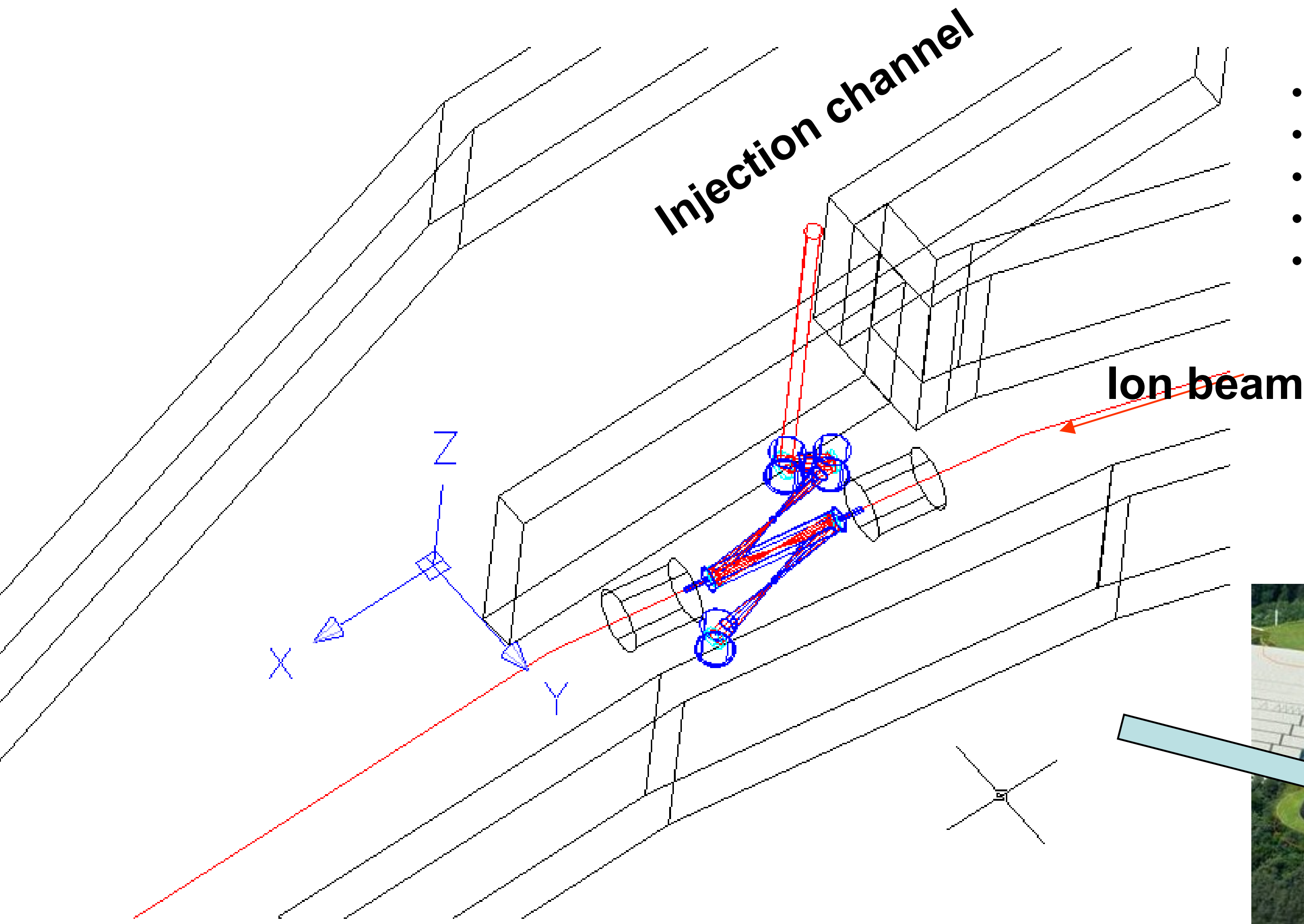
Location for spectroscopy experiments*

Location for high-field experiments



*** see talk of Thomas Kühl**

Insertion into the HESR cave of the high-energy beam

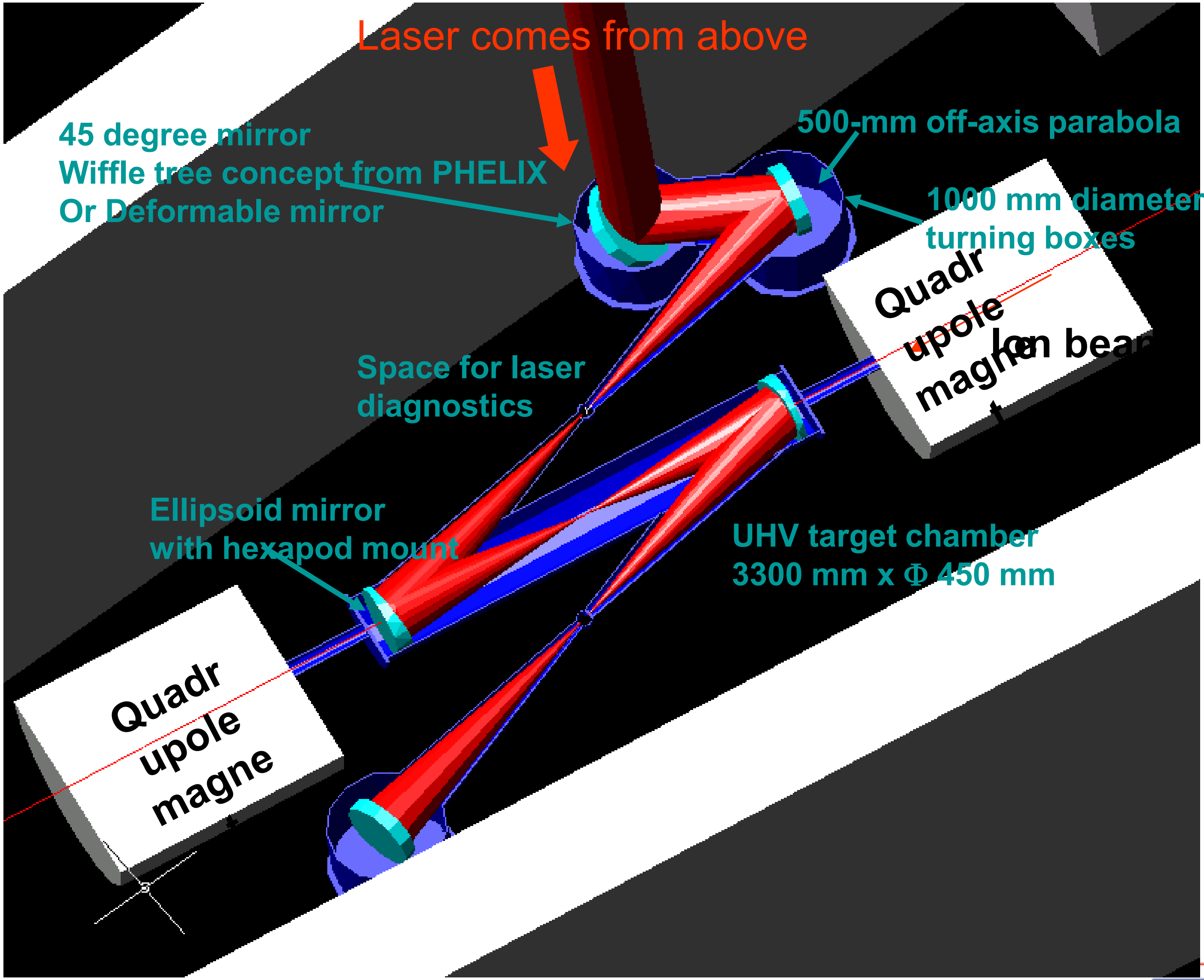


- Laser beam ϕ 400 mm
- Interaction chamber 3.3 m
- Focus ϕ 10 μm
- Laser power: 10 PW
- Intensity: 10^{21} w/cm^2

From a laser stand point, the injection channel area is the most convenient point

PHELIX

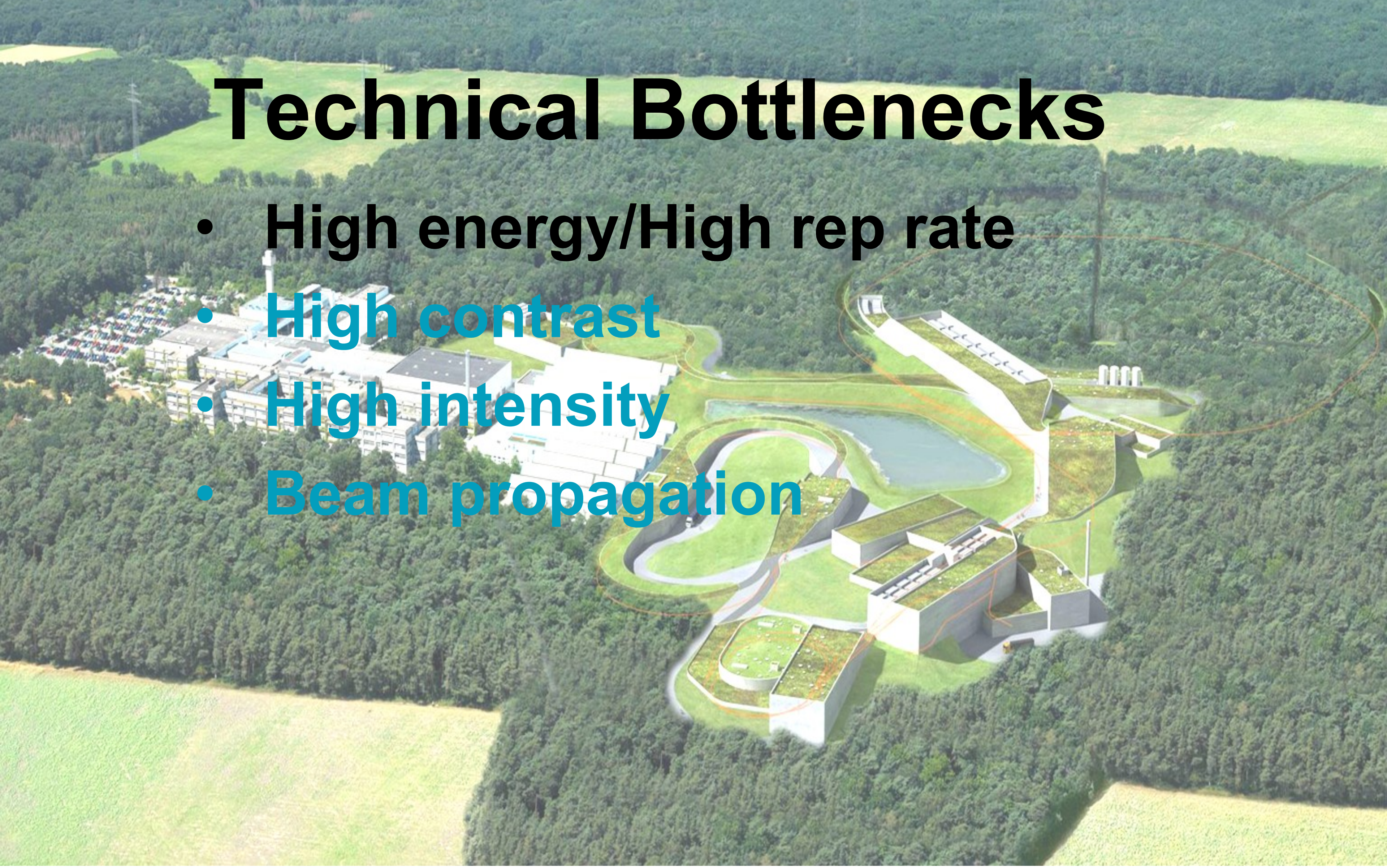
Close-up view of the target area



PHELIX

Technical Bottlenecks

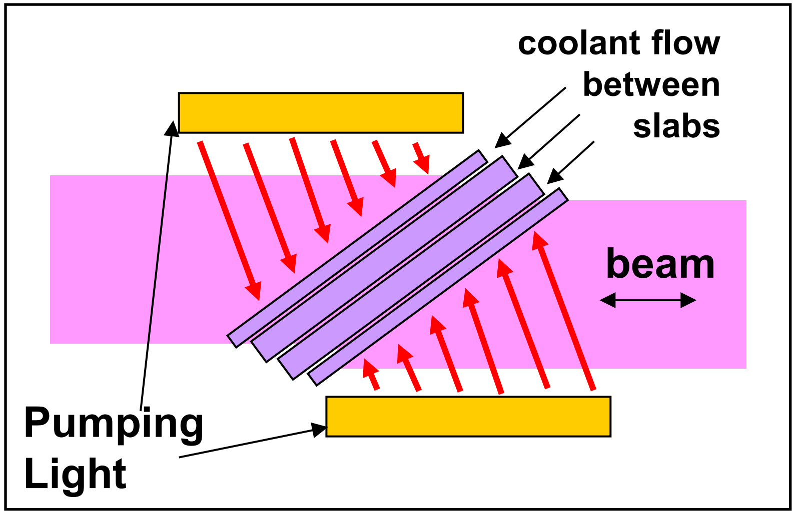
- High energy/High rep rate
- High contrast
- High intensity
- Beam propagation



Actively cooled Nd:Glass slabs could allow repetition rates down to 0.1 Hz

The key resides in solving the heat removal problem

- The cooled slab approach is the most promising one
  - In the case of Yb, cryogenic cooling may be necessary (Mercury, Polaris)
  - For Nd-doped material, a simple evolution of the existing architecture



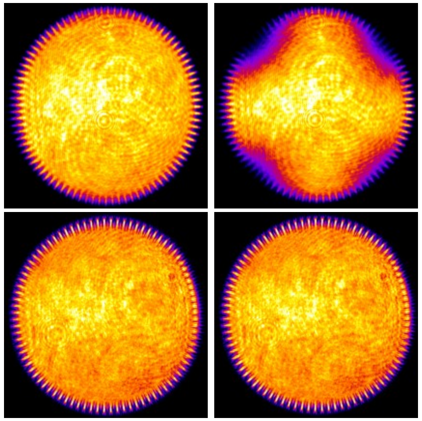
In the coming 5 years, versatile high energy (> 100 J) high average power (> 100 W) lasers will be demonstrated

PHELIX testbed: the preamplifier upgrade*

- **We have built a testbed to test most aspects related to the operation of amplifiers under high thermal load including**
  - **active correction of the wavefront distortions due to:**
    - **the average thermal loading**
    - **on-shot aberrations**
  - **Thermally induced birefringence and stress including**
    - **compensation or reduction of beam distortion**
    - **long term operation close to the mechanical breakdown limit**

cold system

after 30 shots with 1 shot per minute



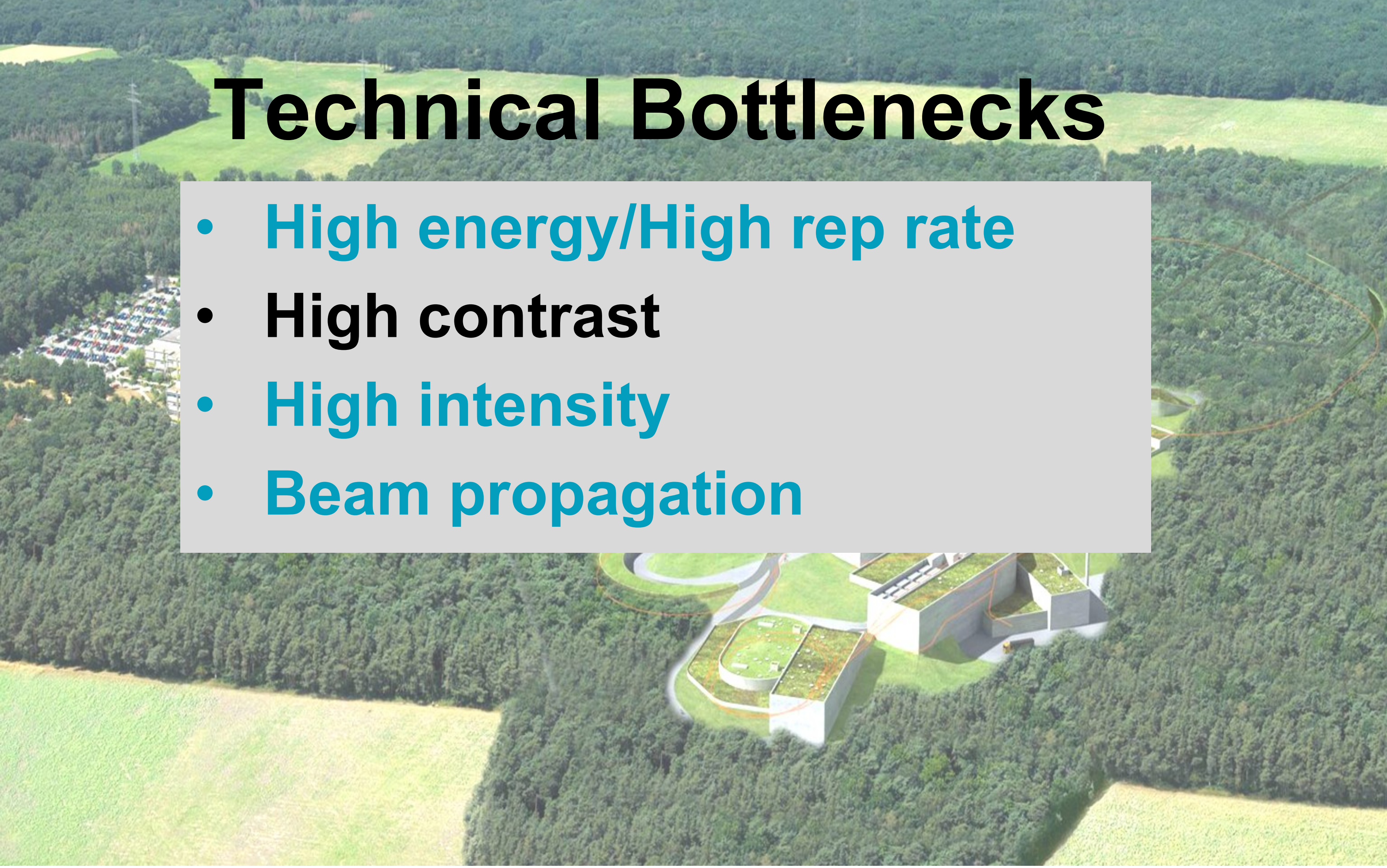
single pass

double pass with Faraday Rotator

Beam profiles of pre amplifier upgrade with and without double pass

- **In the coming years, we will buy or develop and characterize a prototype large area slab amplifier that can run at more than a shot/minute**

* see poster from C. Bratetz

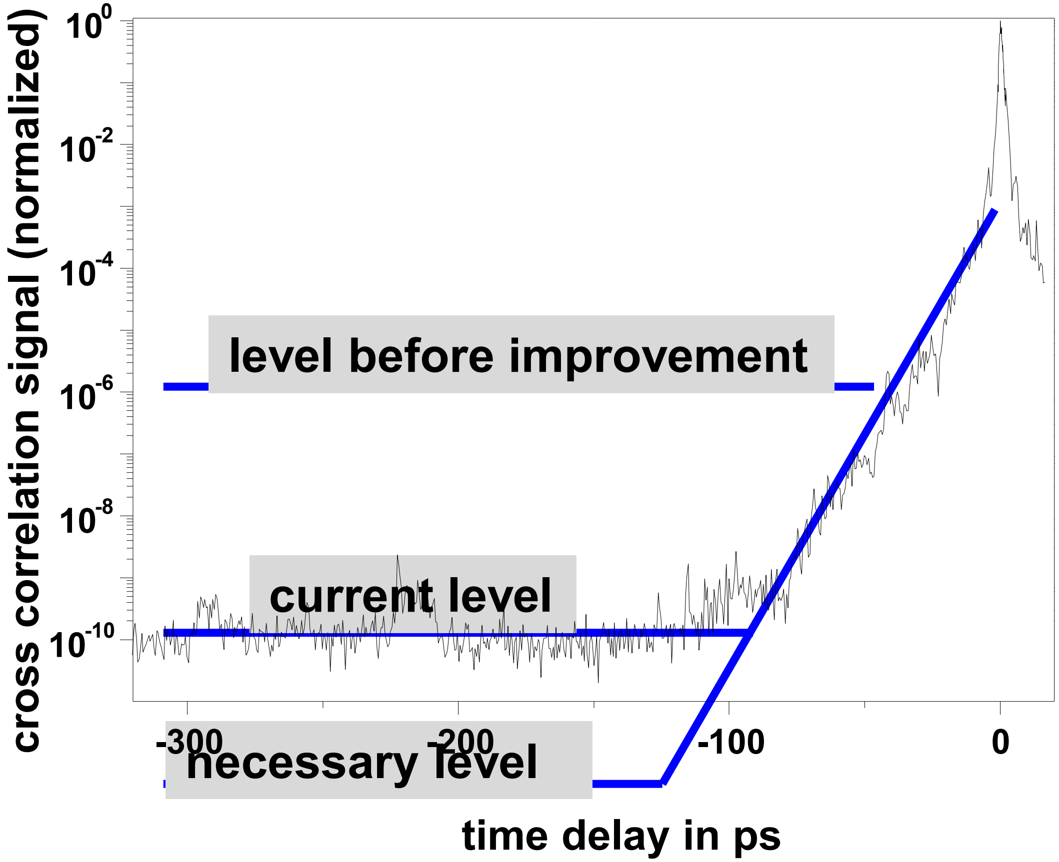


Technical Bottlenecks

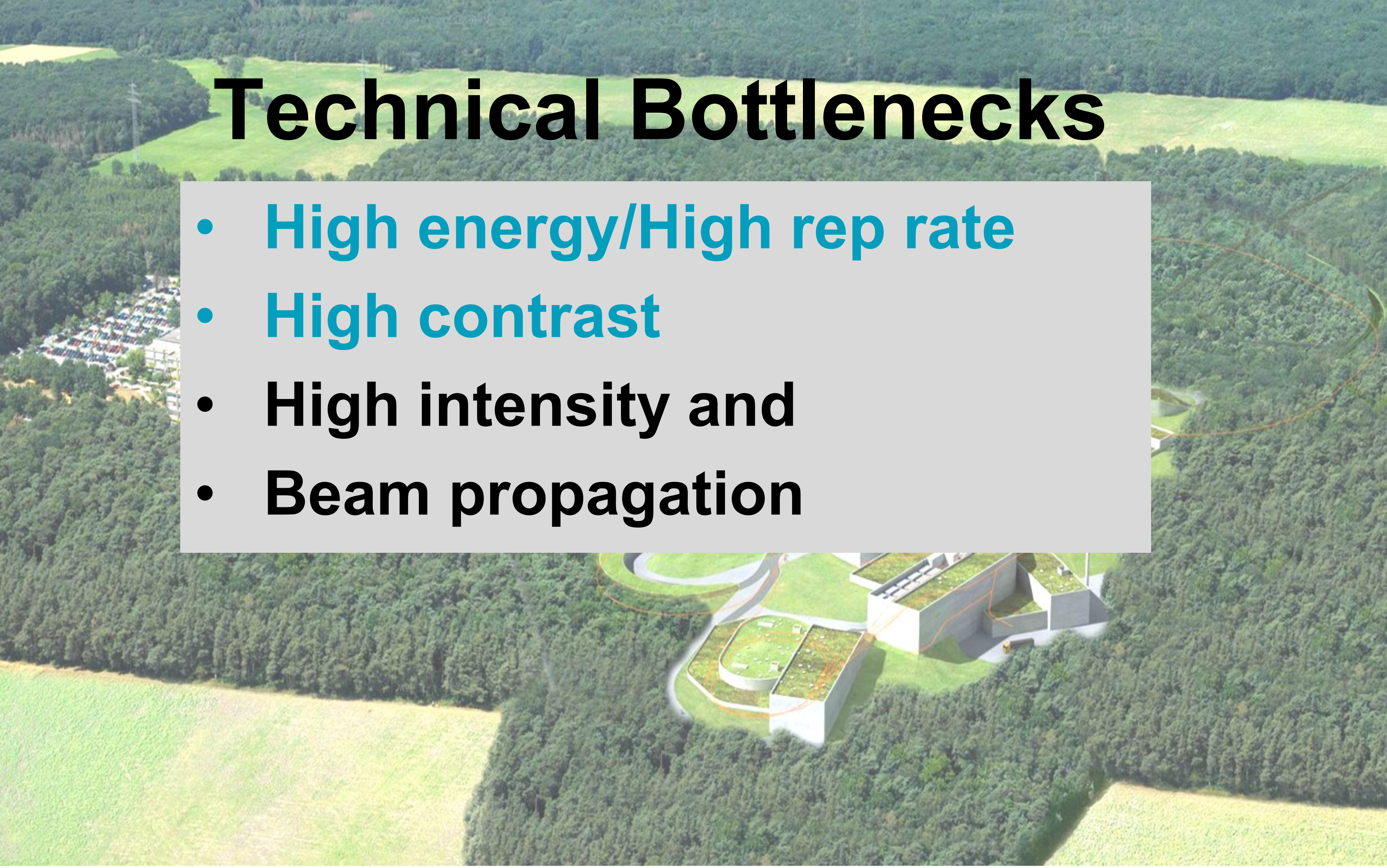
- High energy/High rep rate
- High contrast
- High intensity
- Beam propagation

PHELIX has developed a new front end with ultra-high temporal contrast

- In collaboration with HI Jena, the necessary performance will be demonstrated within the next years by scaling up our design



Technical Bottlenecks

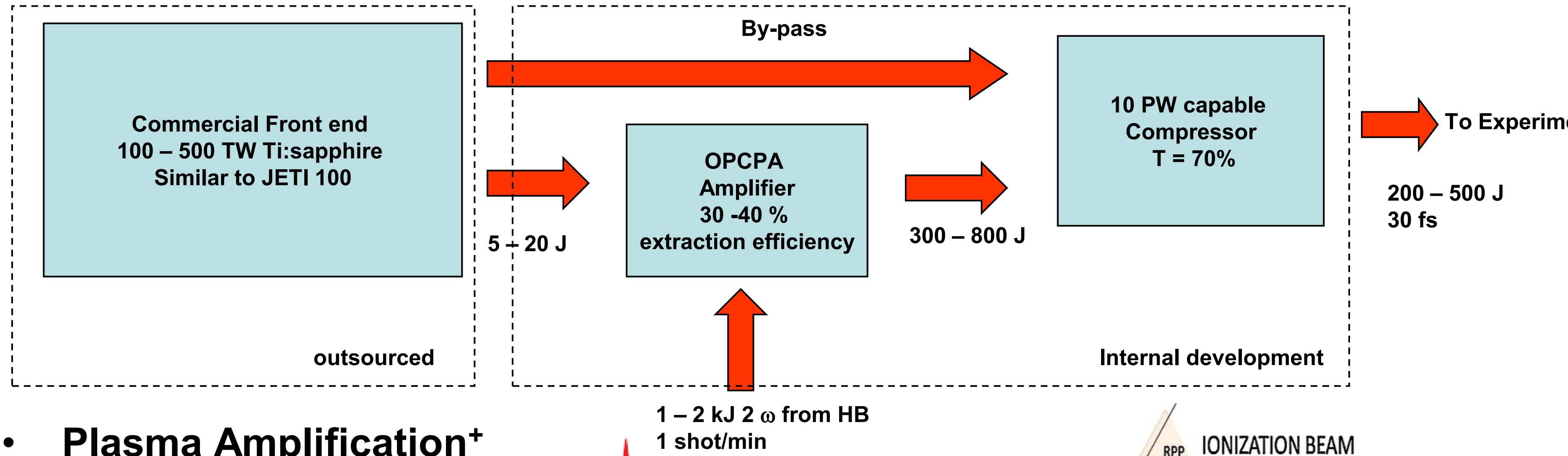


- High energy/High rep rate
- High contrast
- High intensity and
- Beam propagation

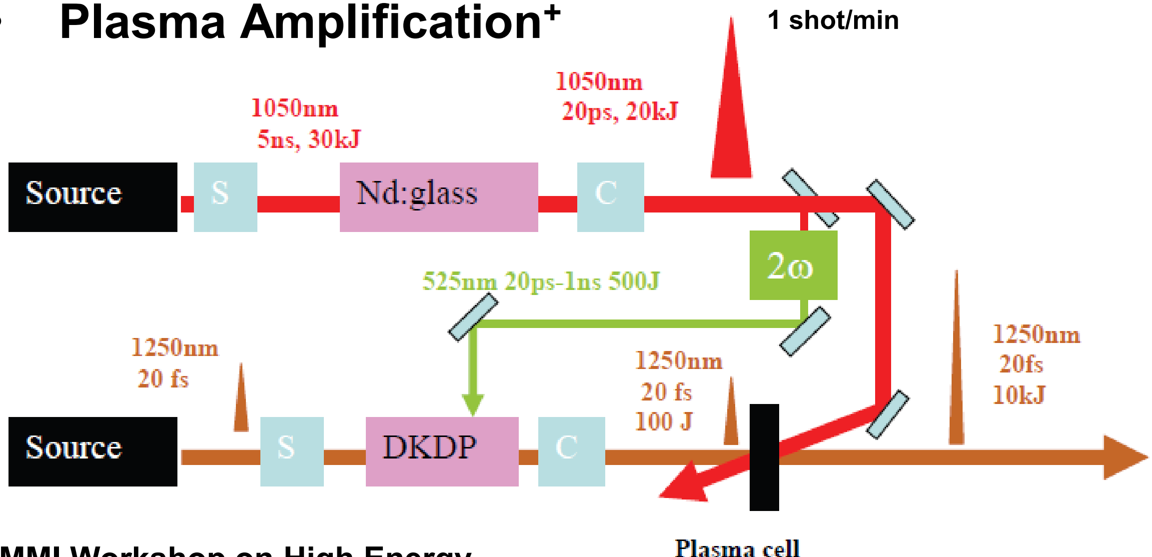
High Intensities above 10 PW will be available*

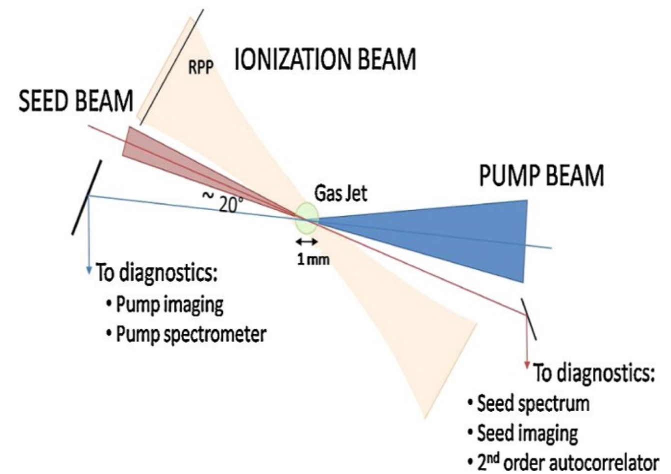
* probably in as add-on in a second step

- **OPCPA**



- **Plasma Amplification+**





+L. Lancia et al., PRL (2010)

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Beam propagation at FAIR

- Distances of ~100 m between laserbay and interaction chamber imposes image relaying of short laser pulse beams
- PHELIX has a strong expertise based on the experience with Z6 (70 m)
- Image-relaying based on off-axis parabola will be done
- PHELIX could be used in teh next years as a testbed for validating beam propagation concepts
  - initial alignment
  - drift and vibration control

The Helmholtz Beamline beneficiates from a positive environment

- Strong basis: "in kind contributions from GSI"
  - Technological development including prototyping will be done in the coming year: high rep rate, high temporal contrast, ARD: LIGHT
  - Existing PHELIX equipment could be used in the beginning
    - Compression gratings
    - Target chamber
    - Vacuum equipment

- Strong support from HZDR
  - Prototype for HIBEF high energy arm

- Reflection of high energy laser facilities in Europe

What comes next?

- In the next 1-2 Months: Conceptual design report including
  - Change request to APPA cave (input hole, connection to laser building)
  - Change Request to the HESR
  - Get permission to reserve the space for the laser building (no cable canals, no roads, containers etc…)

We need support from the FAIR team and a clear political decision to avoid delays

- in the coming years 5 years
  - the building should be actively prepared
  - and built
  - all bottlenecks will be overcome

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- We will soon deliver a first conceptual design report for the laser and its infrastructure
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