Petawatt High Energy Laser for Heavy Ion Experiments

and the new Accelerators

AP Workshop December 2002

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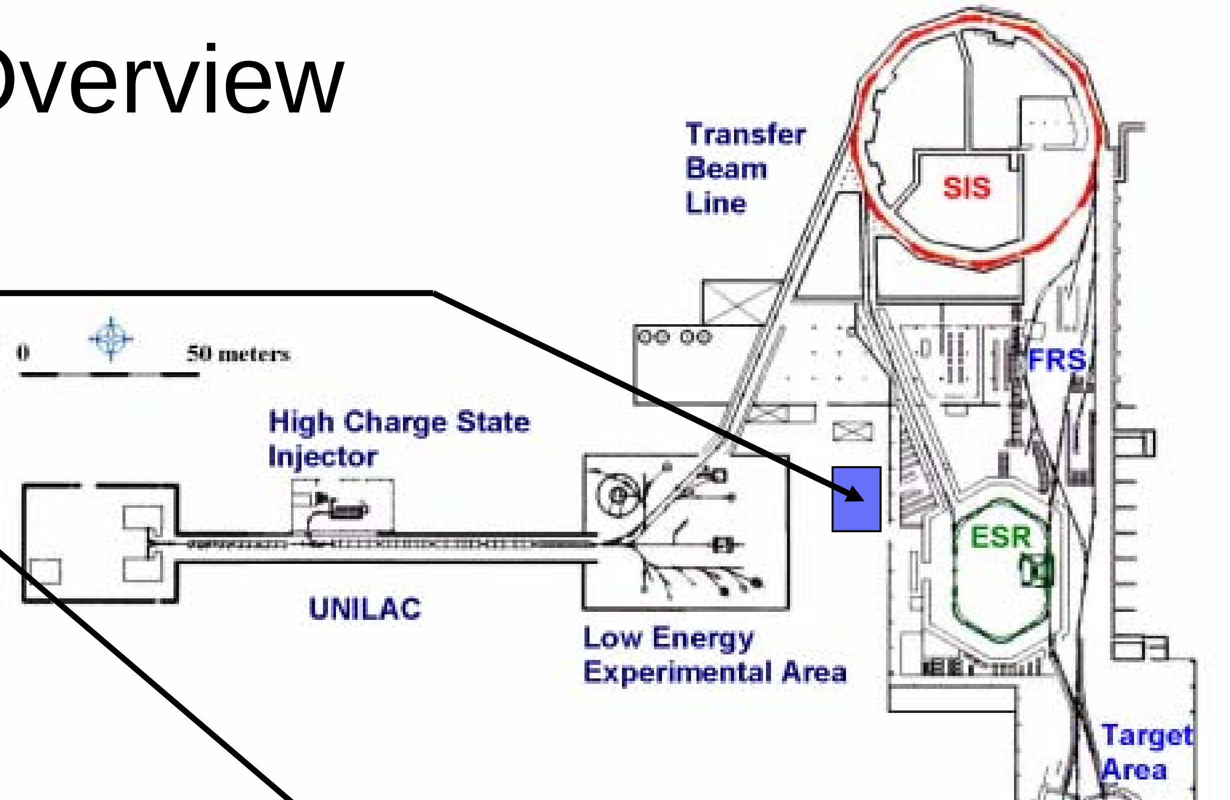
Overview

PHELIX

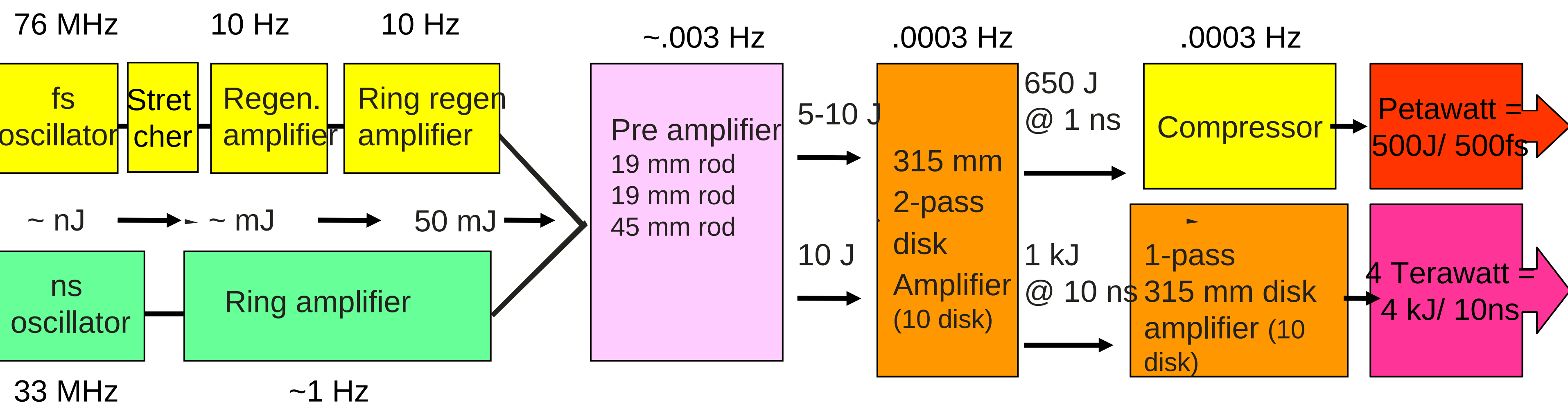


Schematic Overview

Frontend

Pre amplifier

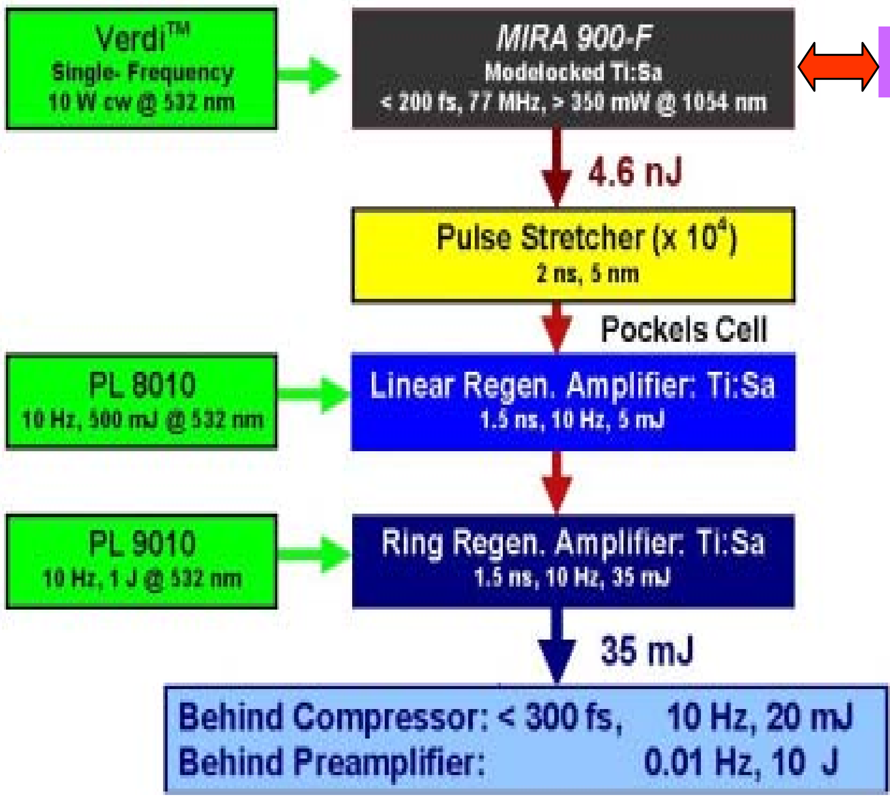
Main amplifier

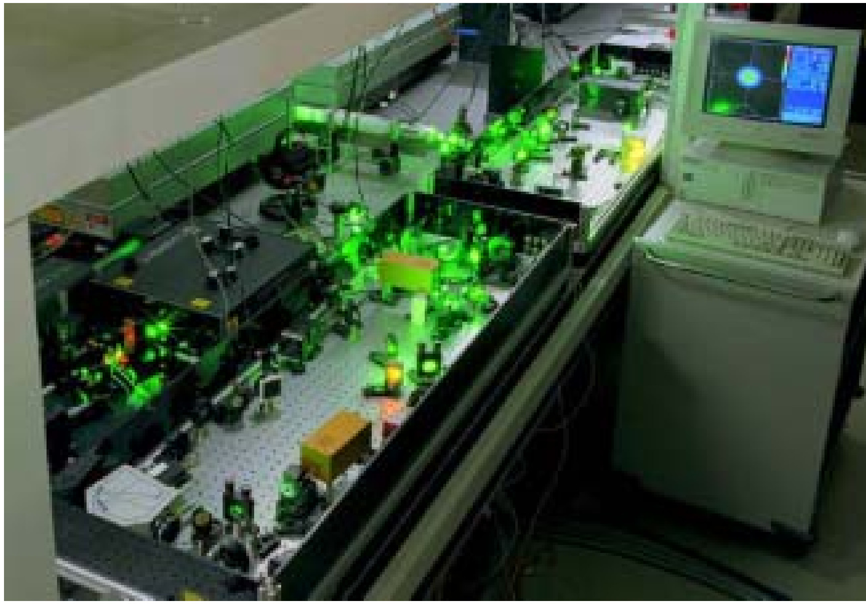


	Fluence	Pulse Energy	Duration
fs-Frontend + Preamplifier		5 -10 J	1ns, 350 fs*
ns-Frontend + Preamplifier		> 10 J	5 – 20 ns
Double –Pass (shortpulse)	1.1 J/cm^2	620 J	1ns, 450 fs
Double –Pass (long pulse)	1.6 J/cm^2	1000 J	5 – 20 ns
Booster (long pulse)	6 J/cm^2	> 4000 J	5 – 20 ns

*after recompression

Femtosecond Frontend

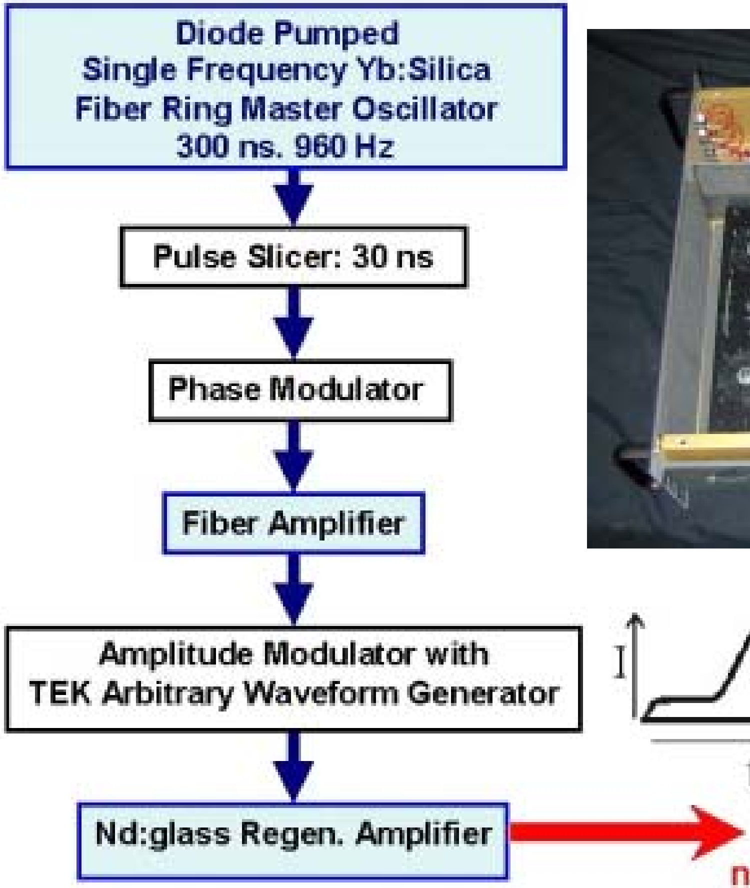


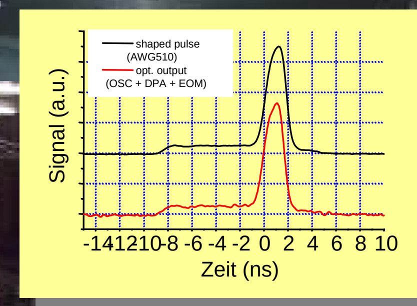


✓
- > 40 mJ output out of regenerative amplifier
- synchonization operating
- mode quality and stability up to specification

➡ install interlocks and remaining controls

Nanosecond Frontend

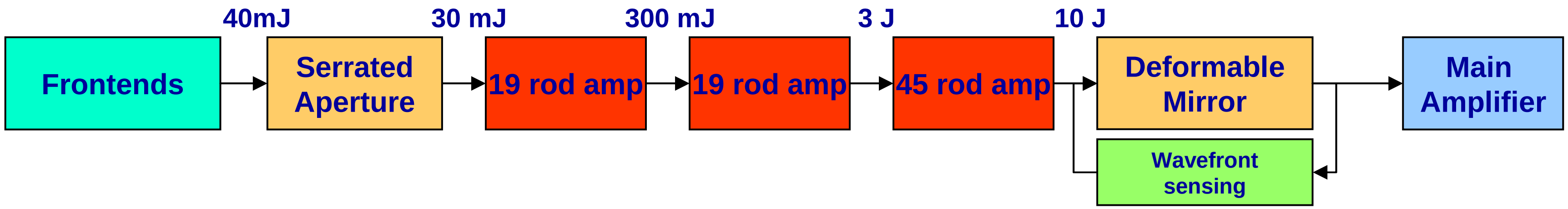


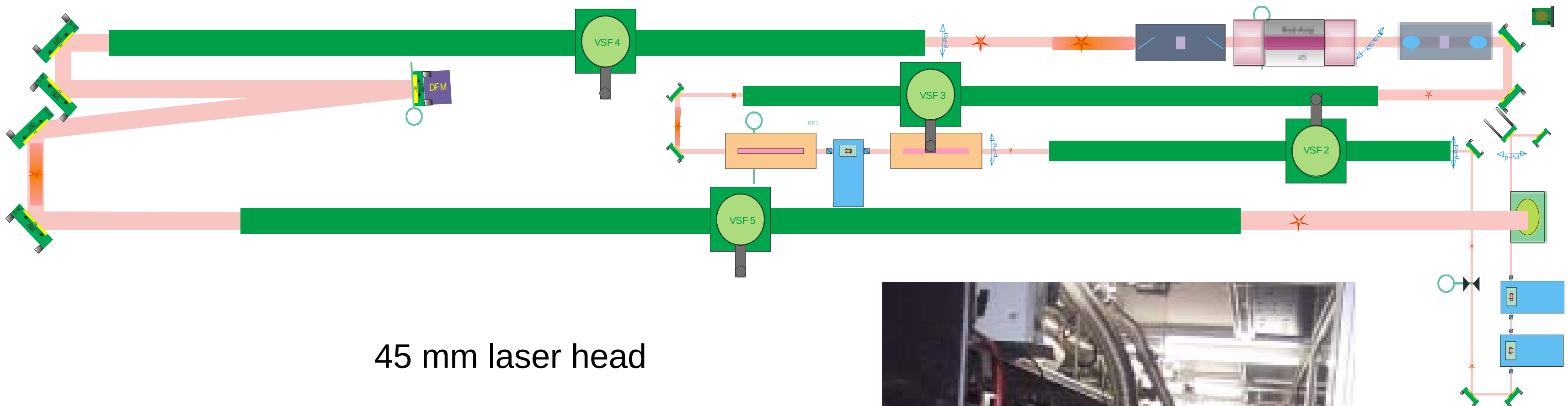


- 40 mJ output out of regenerative amplifier
- pulse shaping tested
- fail/safe system tested at LLNL (M. Roth)

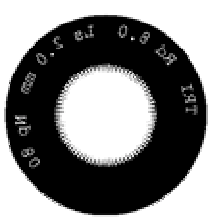
- install fail/safe system at Phelix
- install phase modulator
- optimize output to 50 mJ
- install interlocks and remaining controls

Frontends:Pre-Amp Scheme

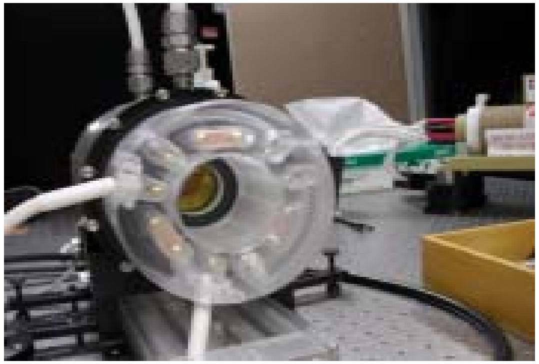




serrated aperture



45 mm laser head



Main amplifier



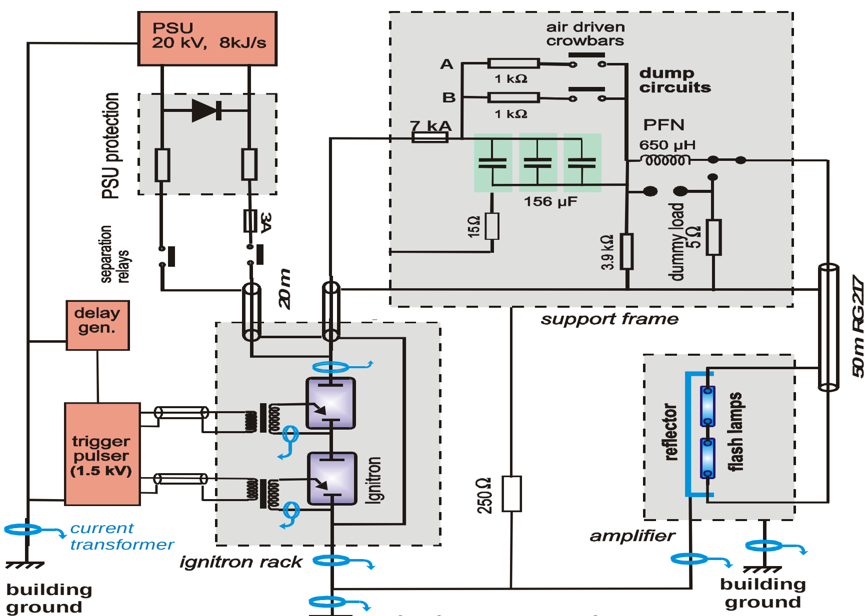

High Voltage for MainAmplifier

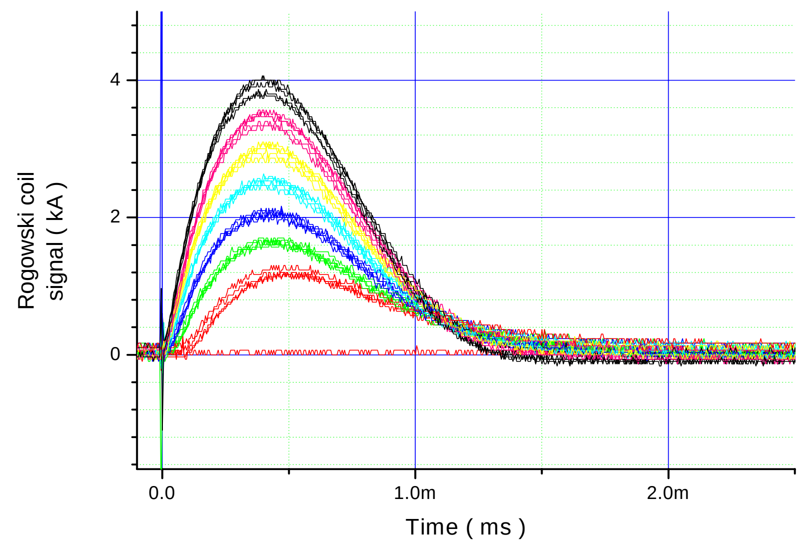
PHELIX

Charging units

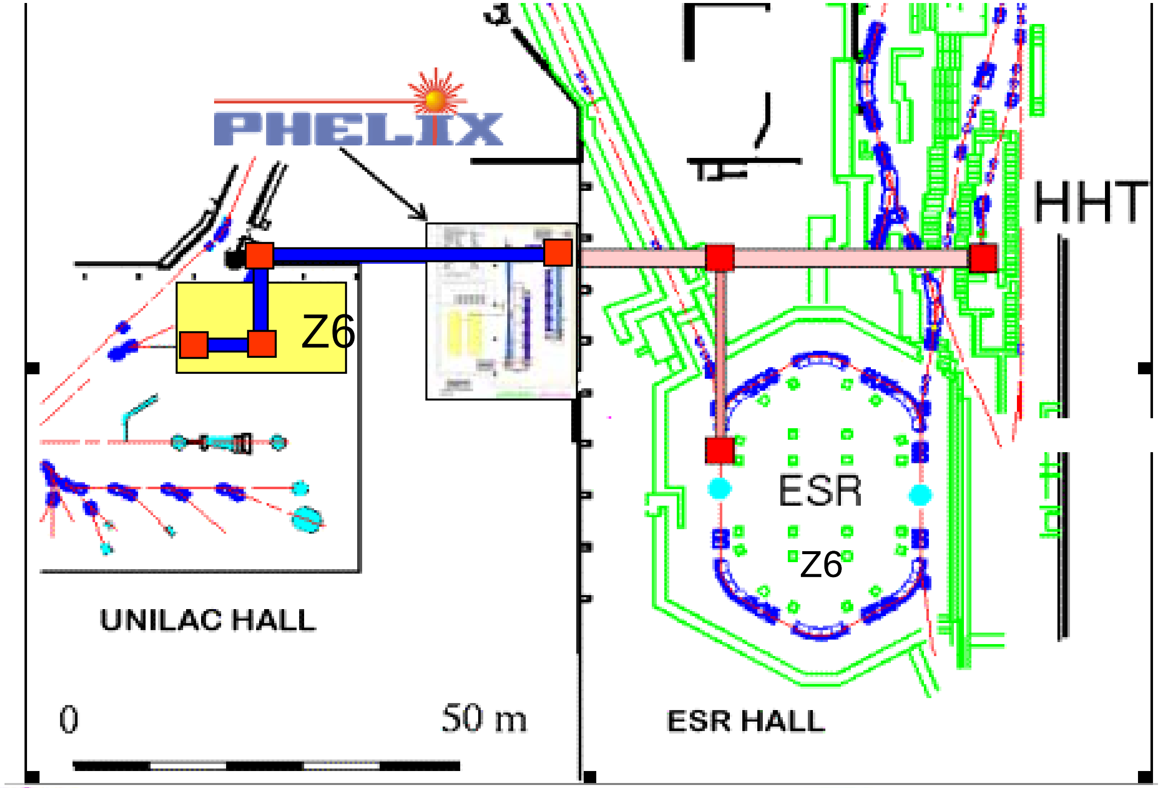
2/12 ignitrons switches

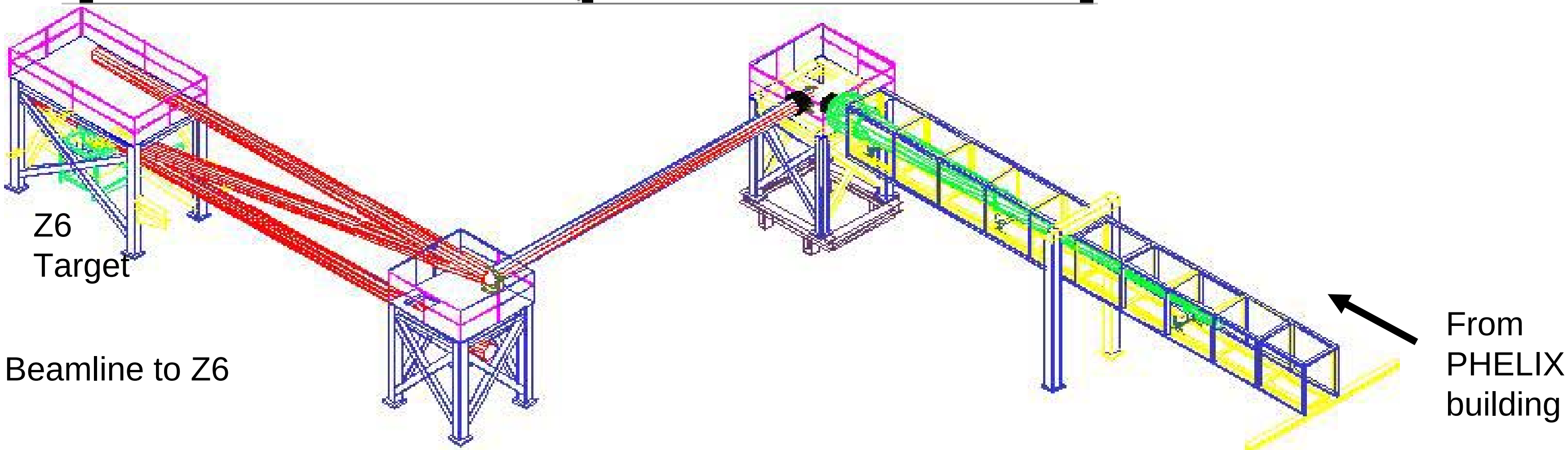
30 % of the 3 MJ capacitor bank for main amplifier



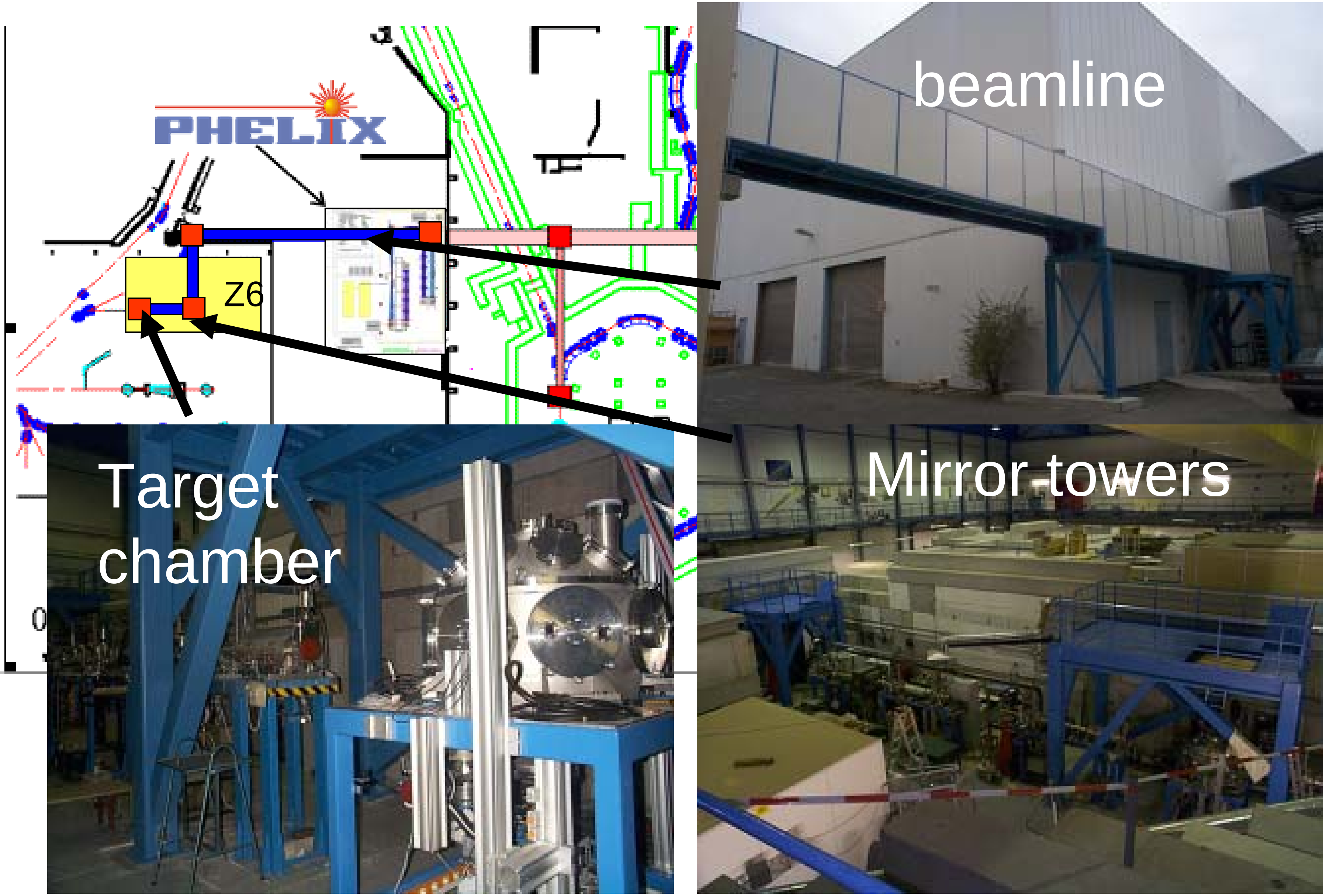


Beamtransport to Experiments



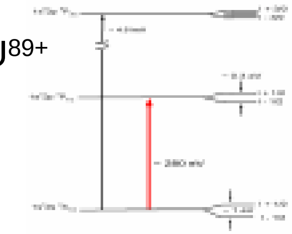


Beamtransport to Experiments

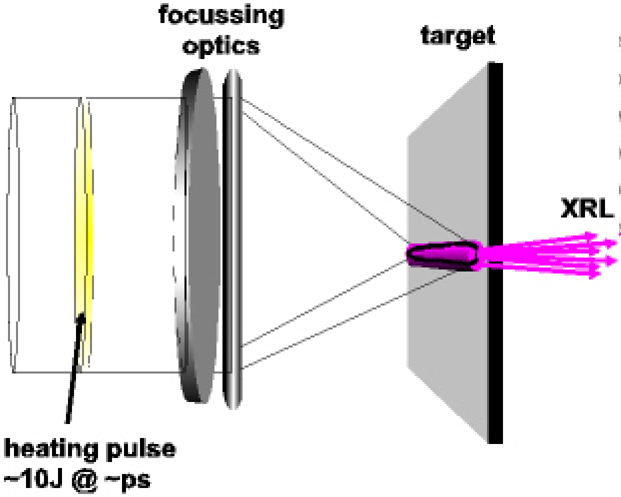


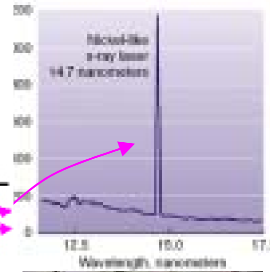
X-Ray Laser Spectroscopy on Lithium-like radioactive nuclei

U^{89+}

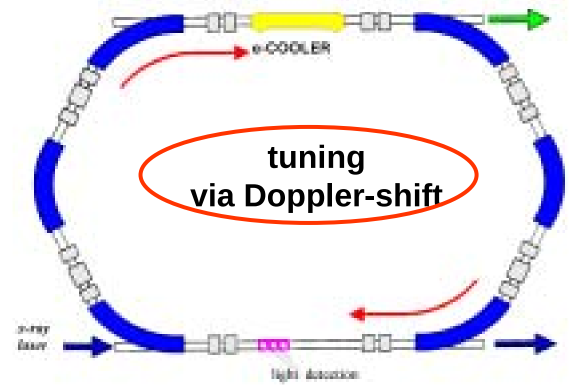


Principle of an X-Ray Laser





Excitation in the ESR

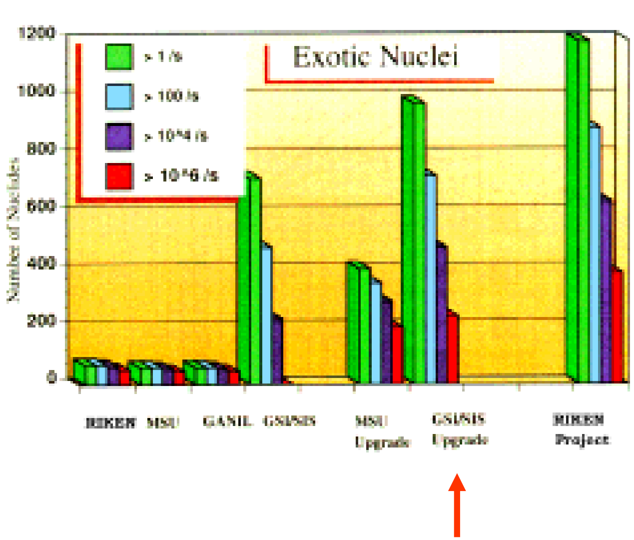


up to Z=92 possible

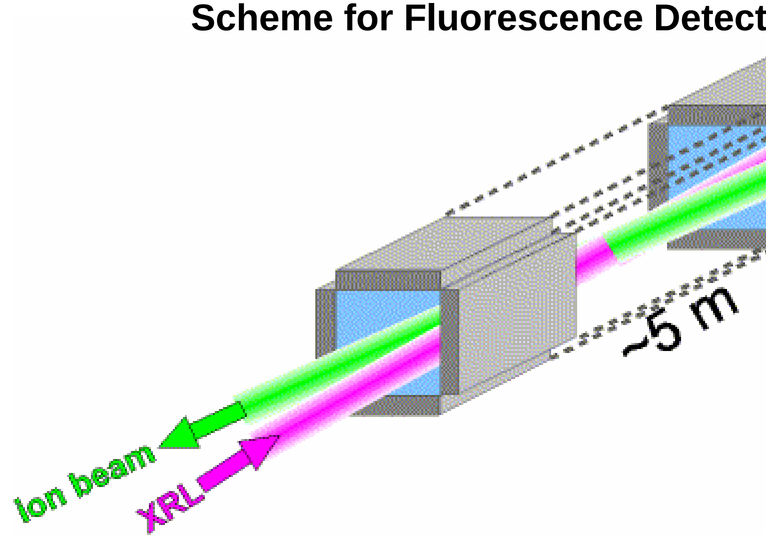
Δp/p~5x10-5

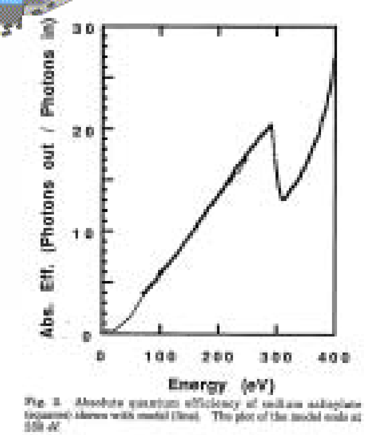
⇒ ΔE/E~xx achievable

Wide Range of Accessible Ions



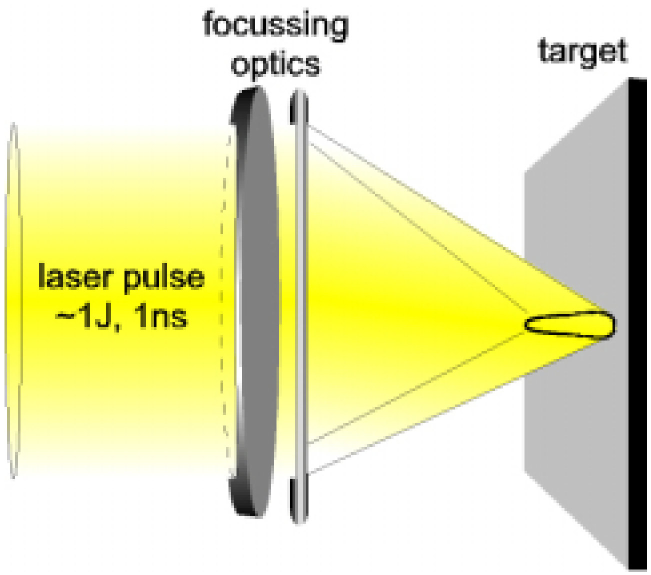
Scheme for Fluorescence Detection



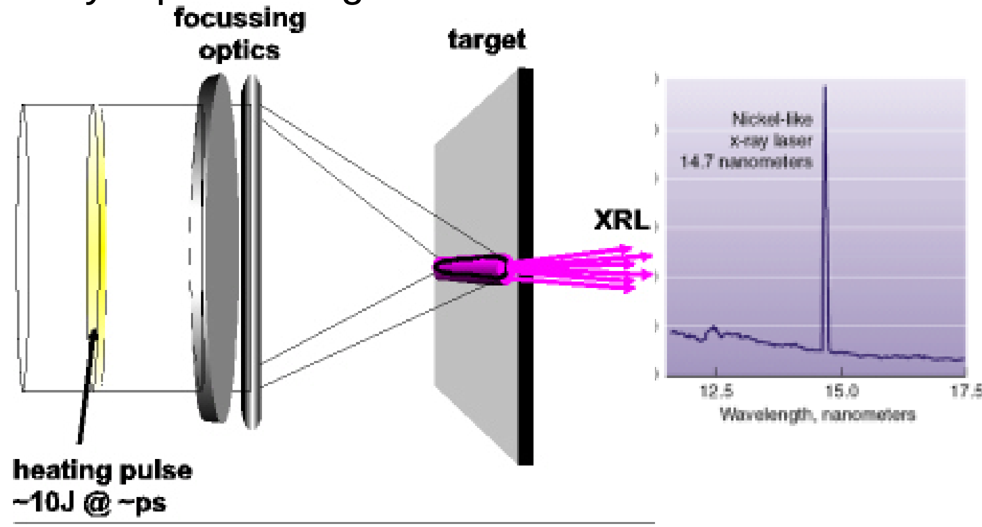


Most successful scheme to realize X-Ray Lasing

Creation of high aspect ratio preplasma



Creation of high transient gain by rapid heating ⇒ ASE



<u>typical parameters:</u>

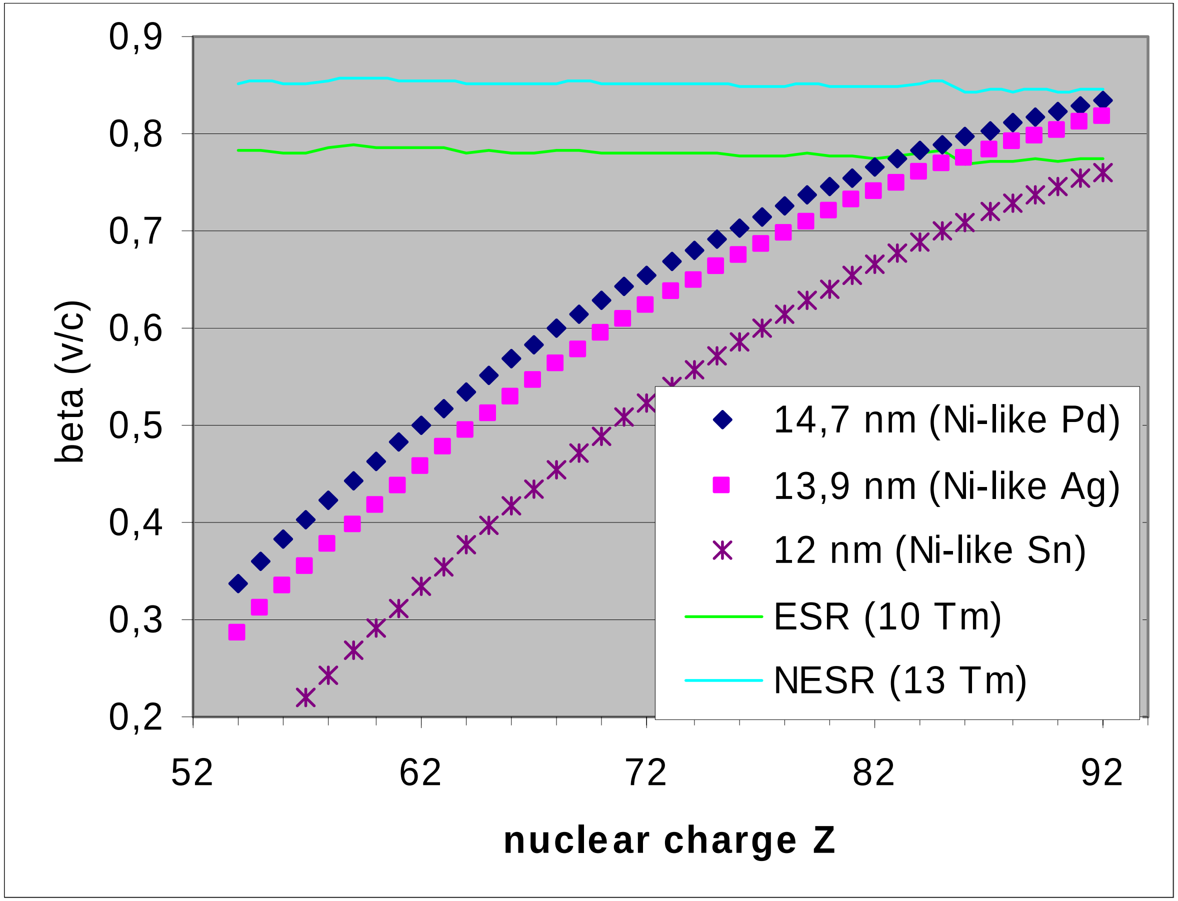
λ_{XRL} 12 – 20 nm (60-100 eV)
E_{XRL}~10 μJ
τ_{XRL}~10 ps
rep. rate ~ 1/10 min

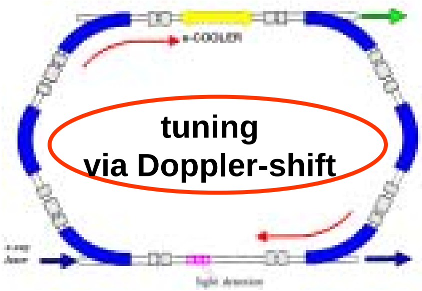
→ Sufficient to perform experiments with ~10^6 ions/fill
Expected future improvements: shorter λ, higher rep. rates

divergence ~ few mrad
pointing stability ~ few mrad

→ Good XUV optics available ⇒ collimation over 10 m feasible

Excitation of $2_{1/2}$ – $2p_{1/2}$ in Li-like Ions for wide range of Z





$\Delta p/p \sim 5x10^{-5}$

$\Rightarrow \Delta E_{Dopp.}/E \sim 10^{-4}..10^{-5}$ achievable

up to Z=92 possible

- almost no experimental data available for Z= 54-91
- high intensities of exotic nuclei in NESR allows new research

X-ray laser peak spectral brightness

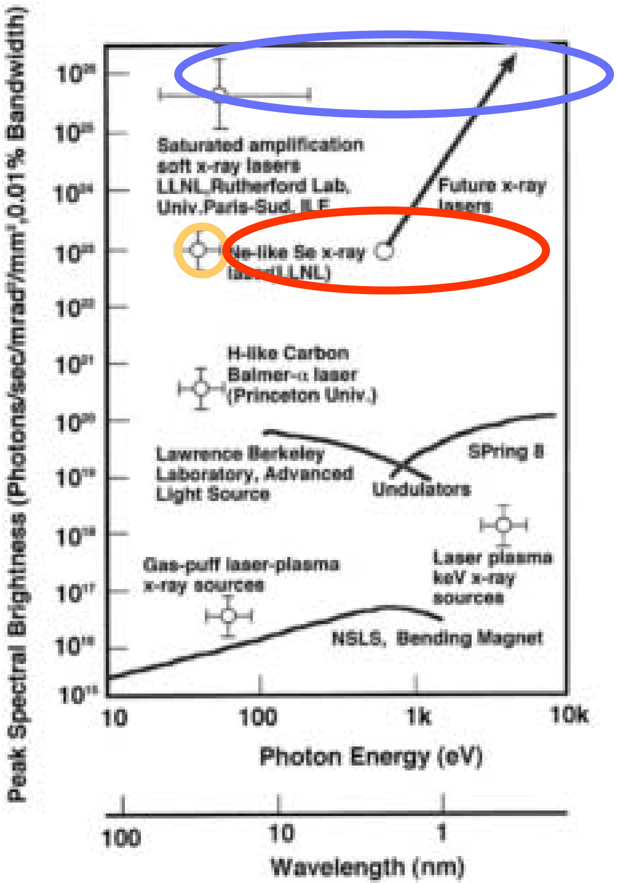


Figure 1. Peak brightness of the present x-ray sources as a function of the photon energy in keV (x-ray wavelength in nm). Soft x-ray lasers in the saturated amplificatio n regime such as LLNL, Rutherford Lab, University of Paris-Sud and ILE are the world highest brightness source in these spectral ranges. Undulators deliver high brightness x-ray in the wide spectral range shown in the ... e such as SPring 8 and Lawrence Berkeley Labs. Laser-plasma sources are the compact cost effective x-ray source.

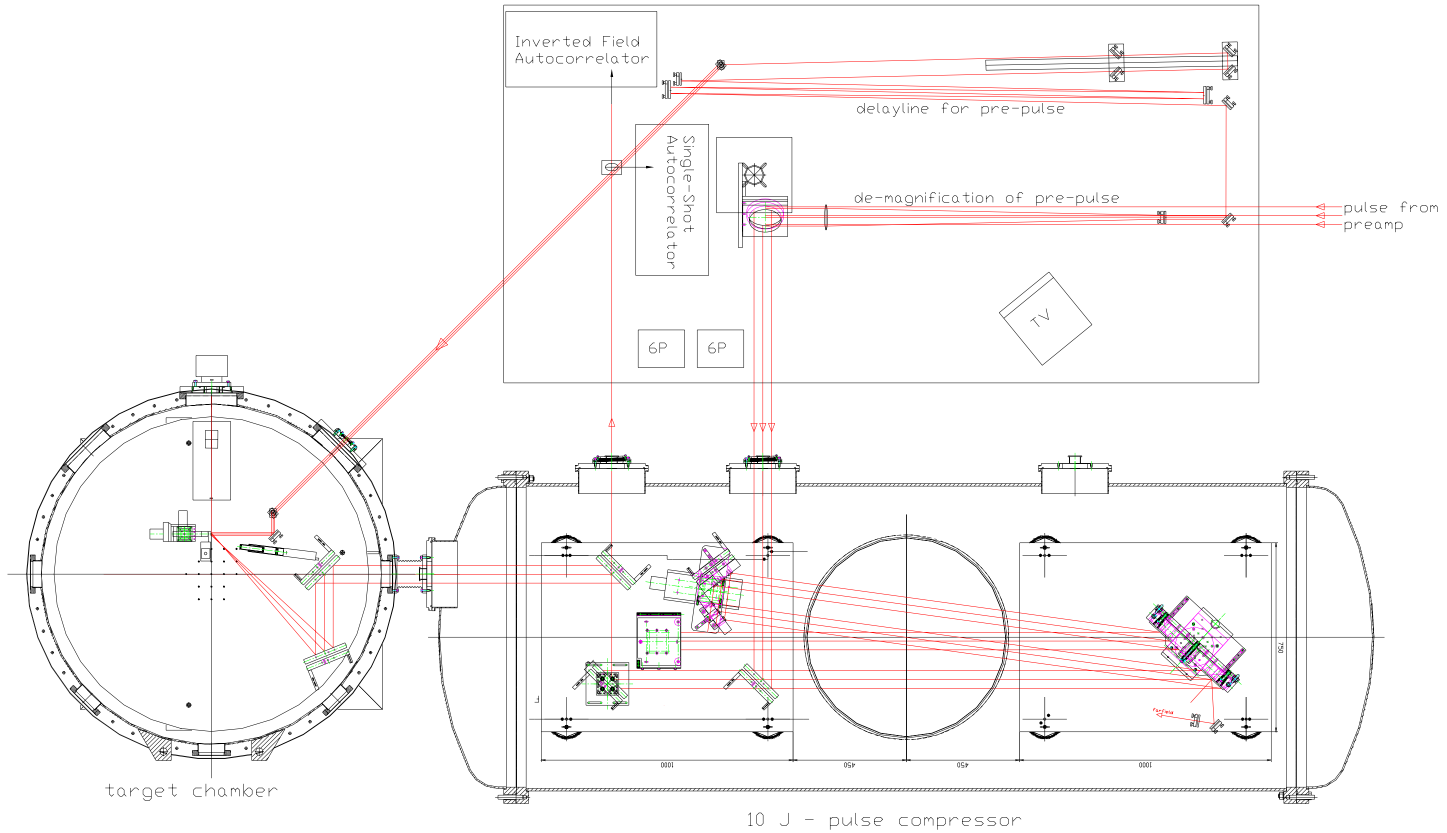
Current status of x-ray lasers

Current laser at SIS200

PHELIX pumped x-ray laser at SIS200

We present here the peak brilliance of the similar XRL from the H. Daido paper in Reports of Progress in Physics 65, Sept. 2002, p. 1513

Current Setup of XRL at GSI

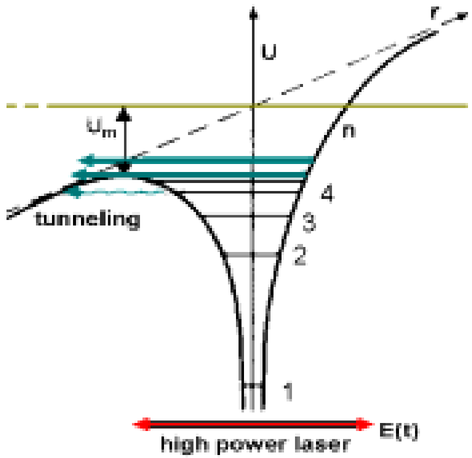



work in progress

Ultra-High Intensity Laser Pulses

Interaction with highly charged ions

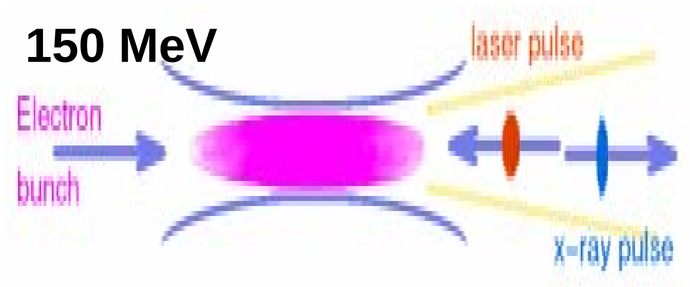
In the intense field of a laser, atomic electrons are subject to violent accelerations and highly relativistic velocities. Due to the strong binding field no direct ionization occurs. The “quivering” electrons and high harmonics in the keV region can interact with the nucleus.



Interaction with energetic electrons

A bunched electron beam of high brilliance as proposed for the electron elastic scattering experiments will add the possibility of experiments using hard X-rays generated by laser-electron scattering.

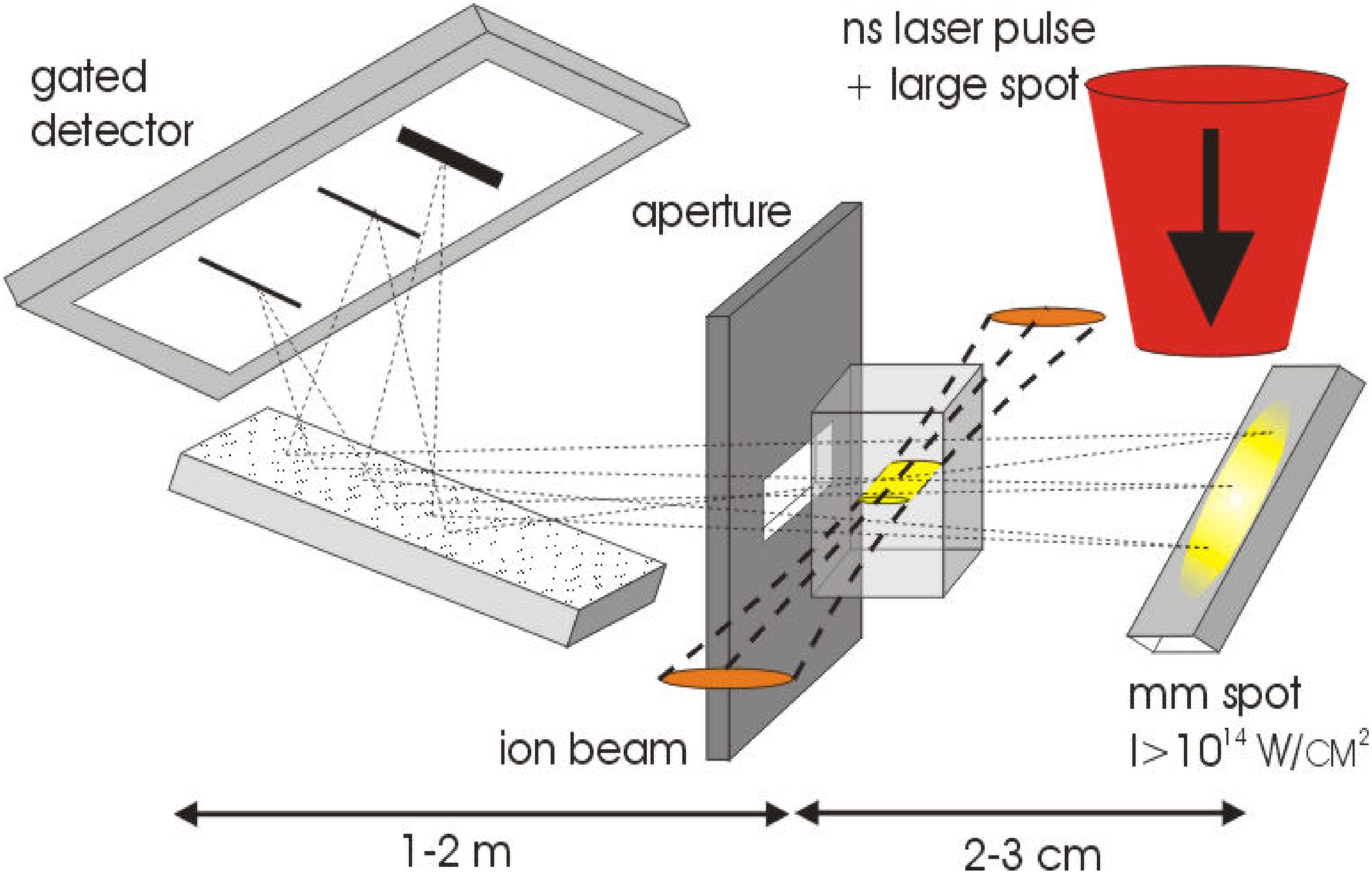
1 eV



$$E_{x-ray} = 4 \cdot \gamma^2 \cdot E_{photon}$$

= 360 keV

X-Ray-Backlighting



Warm Dense Matter (WDM) Research

Energy deposition: creation of high energy density matter by intense, fast heavy ion beam

→ ***Warm Dense Matter*** **("between" solid and plasma)**

challenge for scientific research:

- no expansion parameter in theory exist
- clean benchmark experiments are highly requested

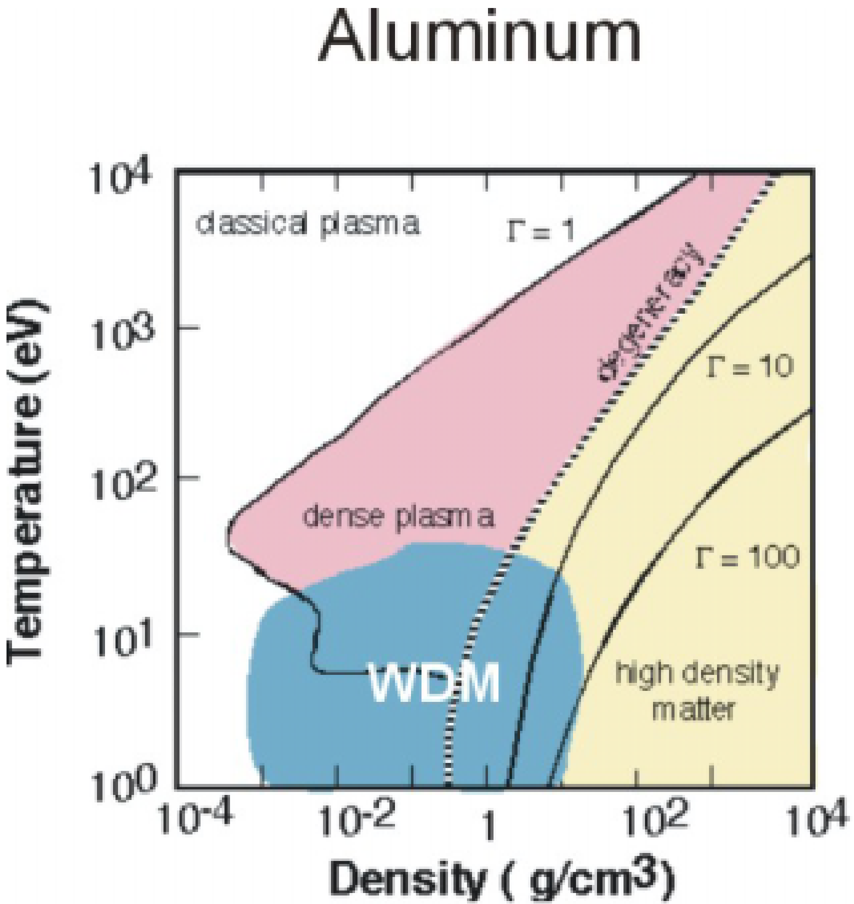
Due to the low temperature, X-ray scattering seems to be the most suitable method: X-ray scattering (some keV) at WDM samples

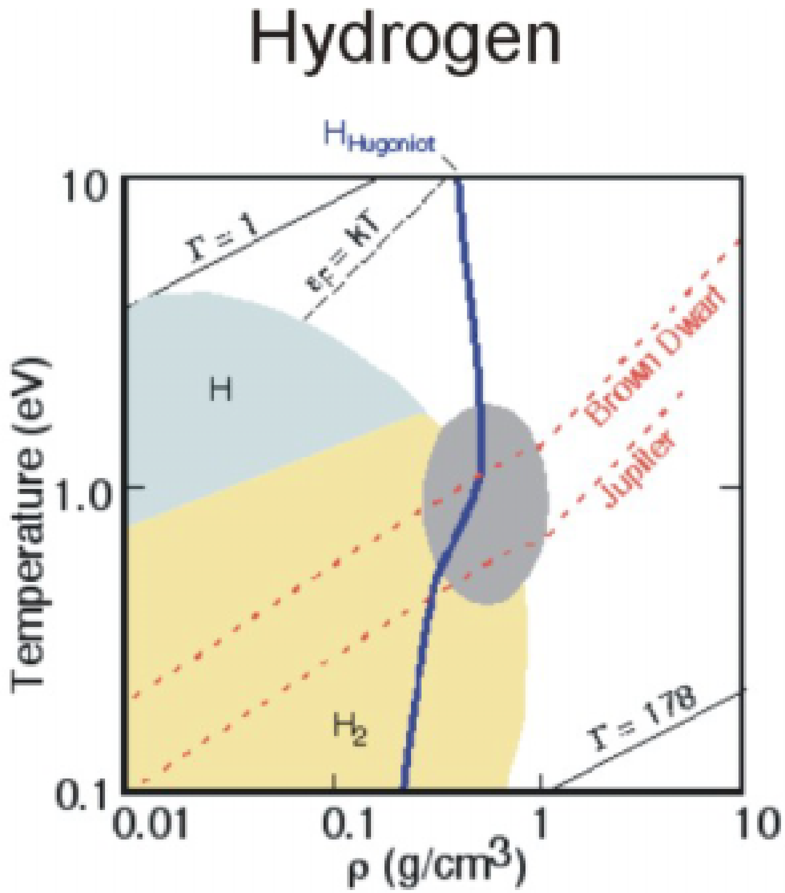
PHELIX : a unique diagnostic tool for WDM Research

- atomic physics studies, band structures, level depression, line shifts
- non-ideal plasma properties, EOS
- absorption and scattering of radiation
- emission properties induced by heavy ion beams itself (inner-shells)

Parameter regimes of Warm Dense Matter

Coupling parameter: $\Gamma = \frac{Coulomb - Energy}{Thermal\ Energy} \propto \frac{Z^2 n_i^{1/3}}{T_i}$



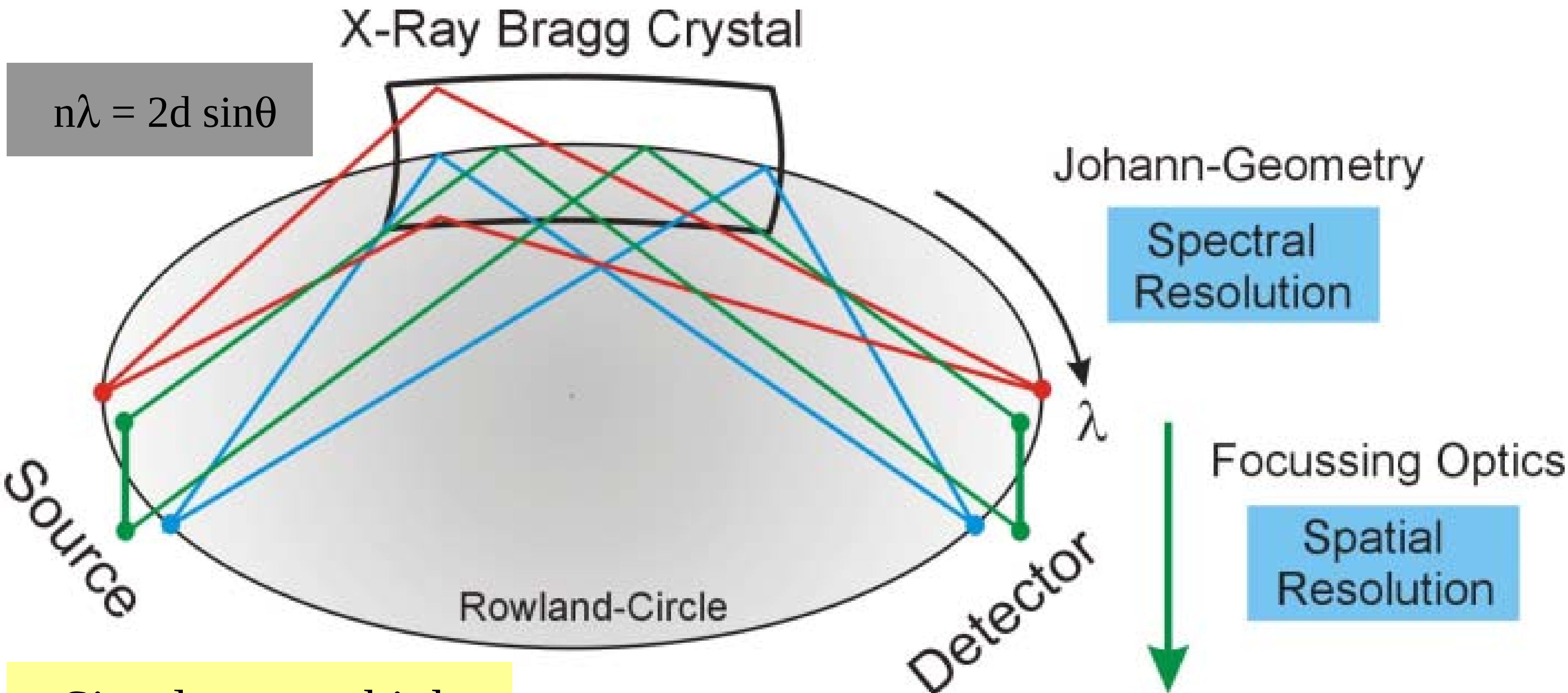


From R.W. Lee, private communication

F.B. Rosmej

X-ray spectromicroscopy with 2D-curved Bragg crystals

$n\lambda = 2d \sin\theta$



Simultaneous high spectral and spatial resolution while maintaining high luminosity *(no slit !)*

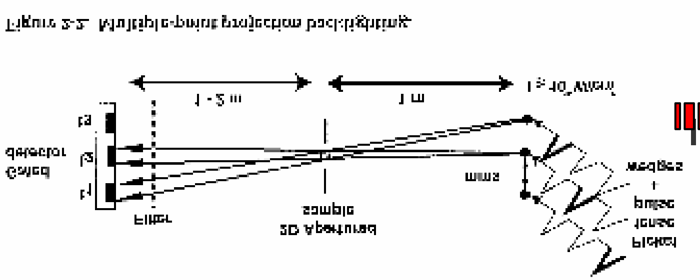
spectral Resolution: $\lambda/\delta\lambda$ **= 1.000 – 7.000**
spatial resolution: δx **= 6 – 30 μm**

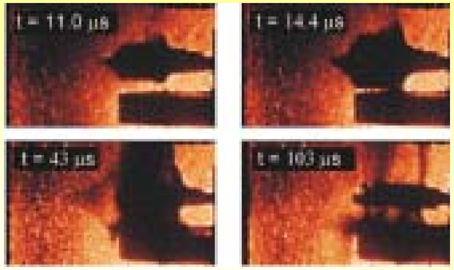
GSI: $\lambda/\delta\lambda = 7.000$ **and** $\delta x = 7$ μm

F.B. Rosmej

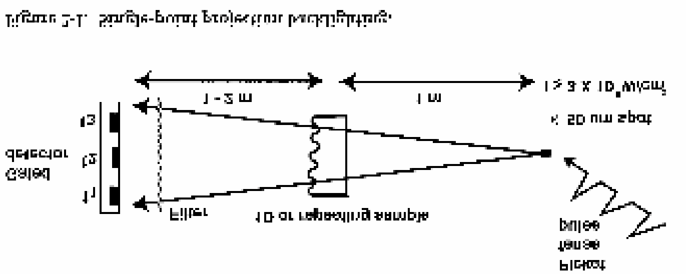
Laser plasma: Mica, spherical, R_c = 150 mm, He_β of Mg at 7 Å

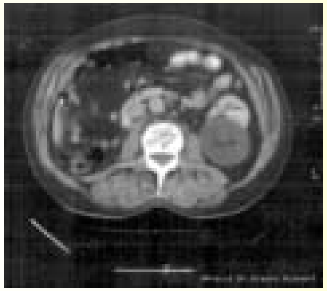
Phelix has versatile capabilities of probing target conditions generated by the SIS-200



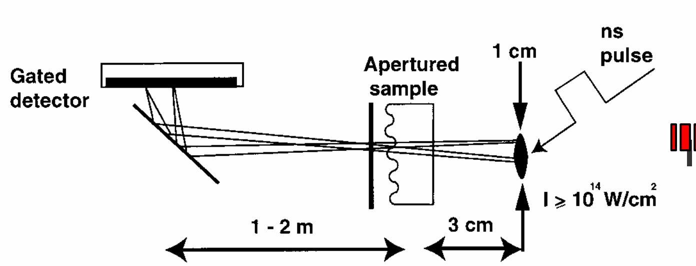


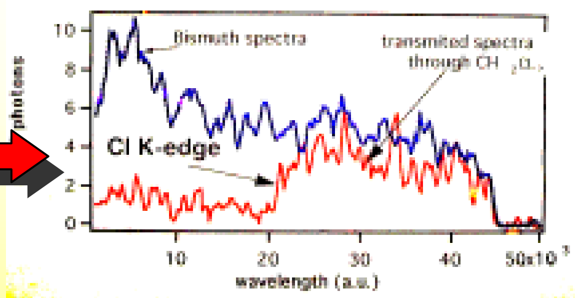
Single point projection with multiple, nano-second pulses for the temporal evolution of the target





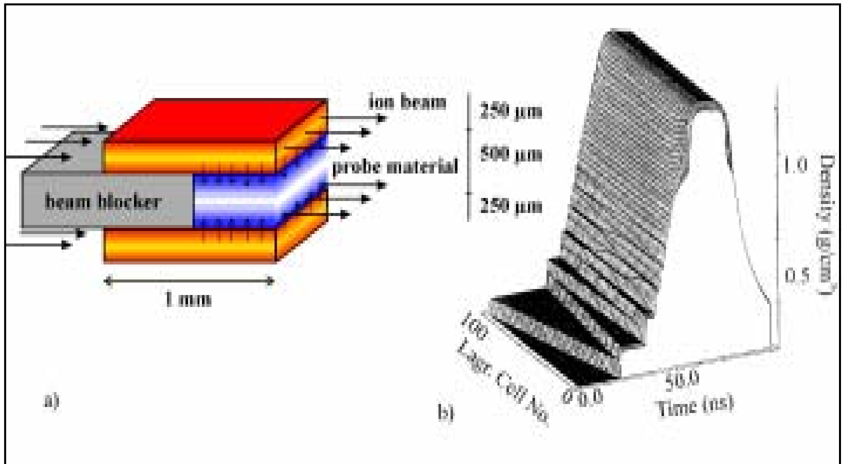
Multiple point projection with multiple, nano-second pulses for the density tomography of the target



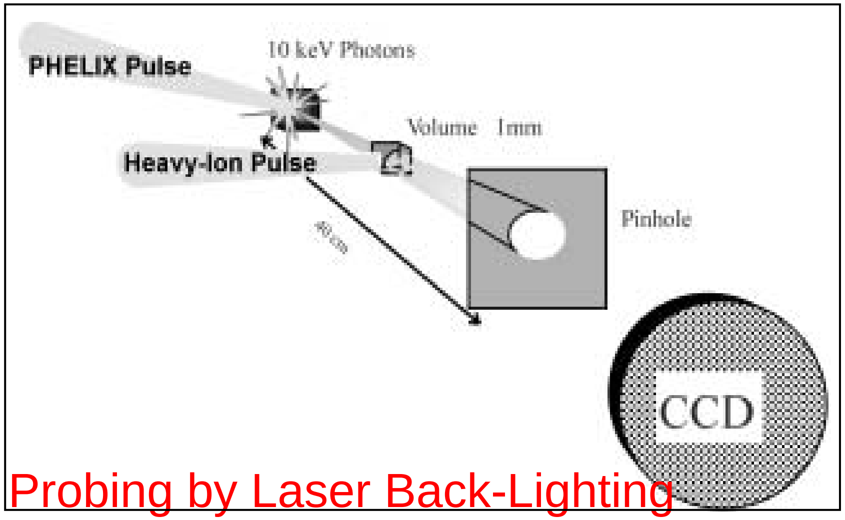


Large area projection and absorption spectroscopy for opacity measurements of the target

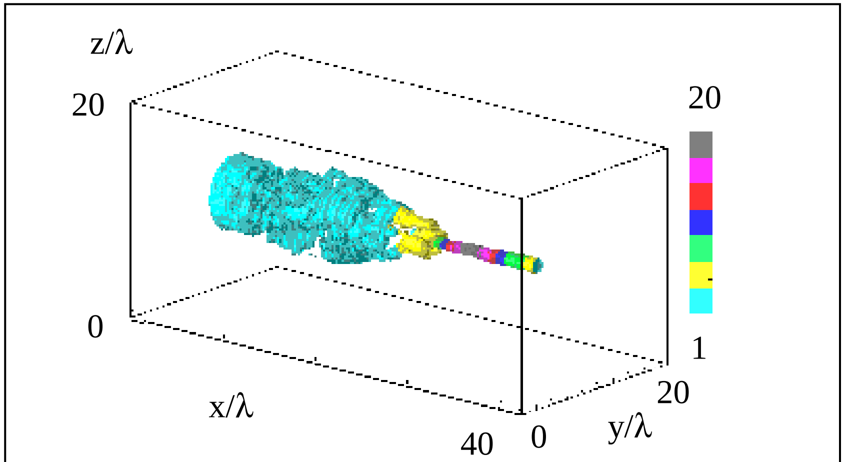
Laser & Ion diagnostics



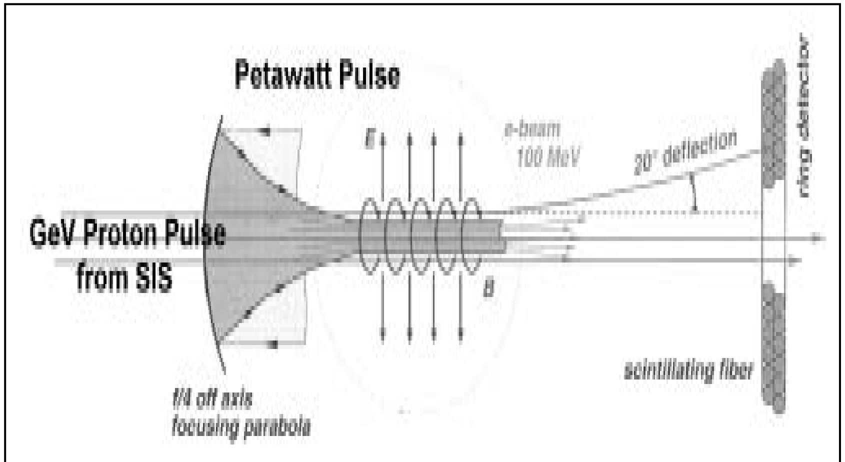
"Cold" Compression by Heavy Ions



Probing by Laser Back-Lighting



Channnel of Relativistic Electrons



Probing by Protons or Heavy Ions

Conclusion

• combination of PHELIX and ion accelerator offer many possibilities to study new extreme physics

•atomic physics can be applied to new regime of parameters

• at GSI is a unique combination of laser and accelerator

• Future GSI expands oportunities for research much further