



Petawatt High-Energy Laser for Heavy-Ion Experiments

Developments at PHELIX and
prospects for cooperations with
PALS in the frame of Laserlab

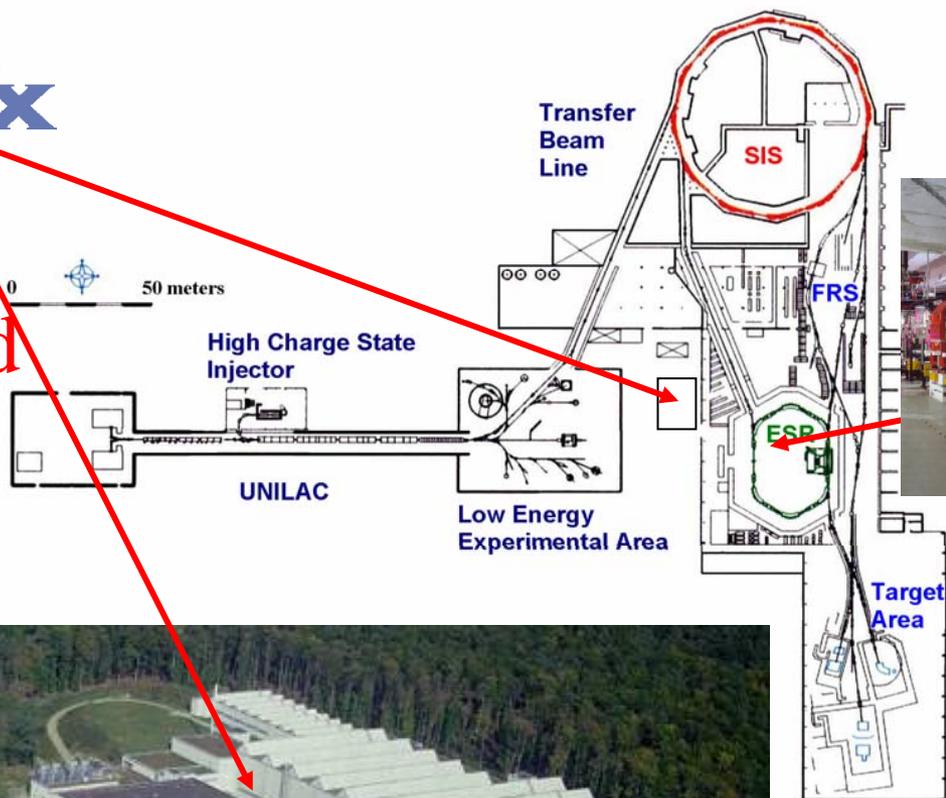
T. Kühl
GSI- Helmholtz-Centre Darmstadt,
and
Johannes Gutenberg-University, Mainz

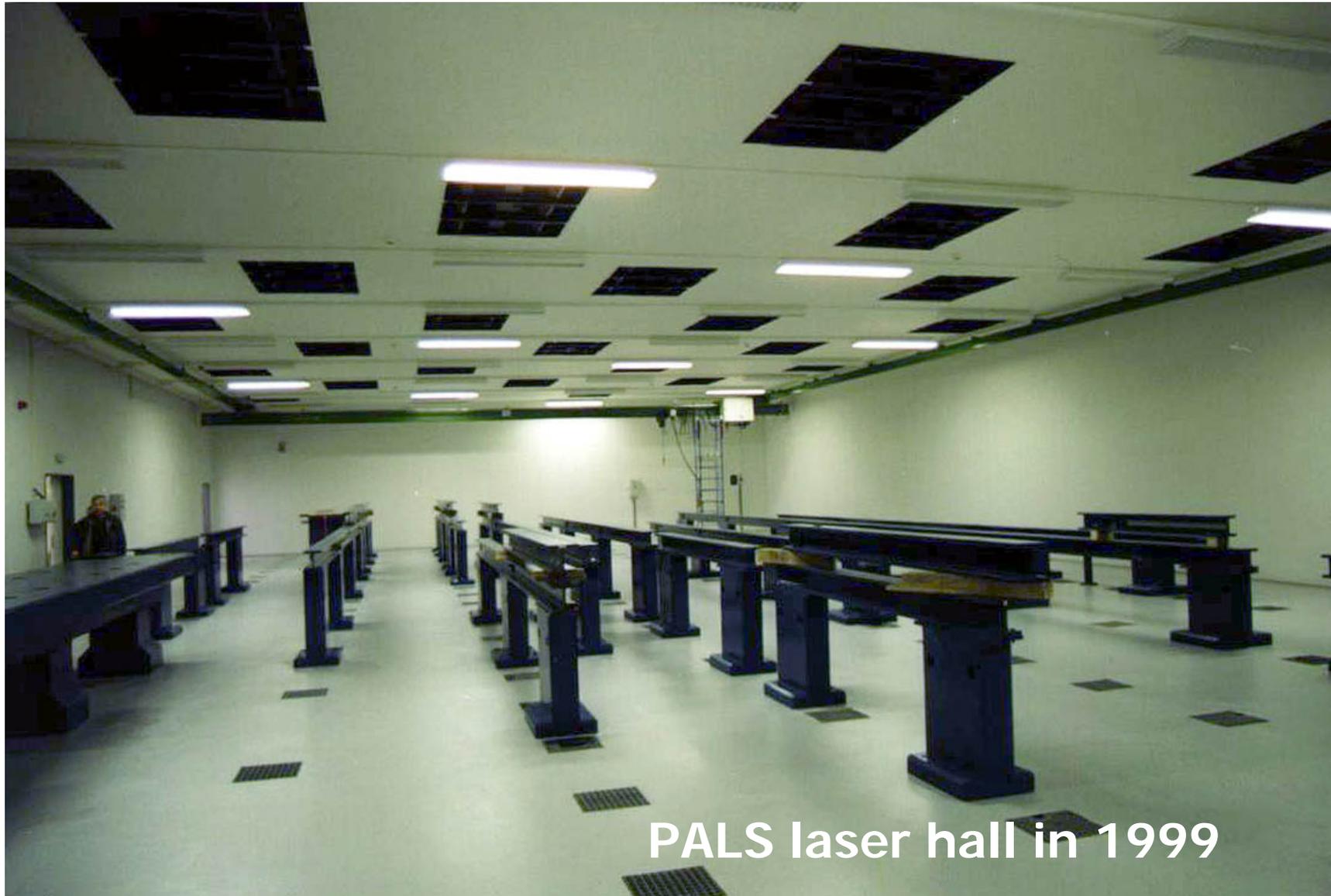


The specialty of PHELIX is the combination with heavy ions !

PHELIX

Proposal accepted
in 1998





PALS laser hall in 1999

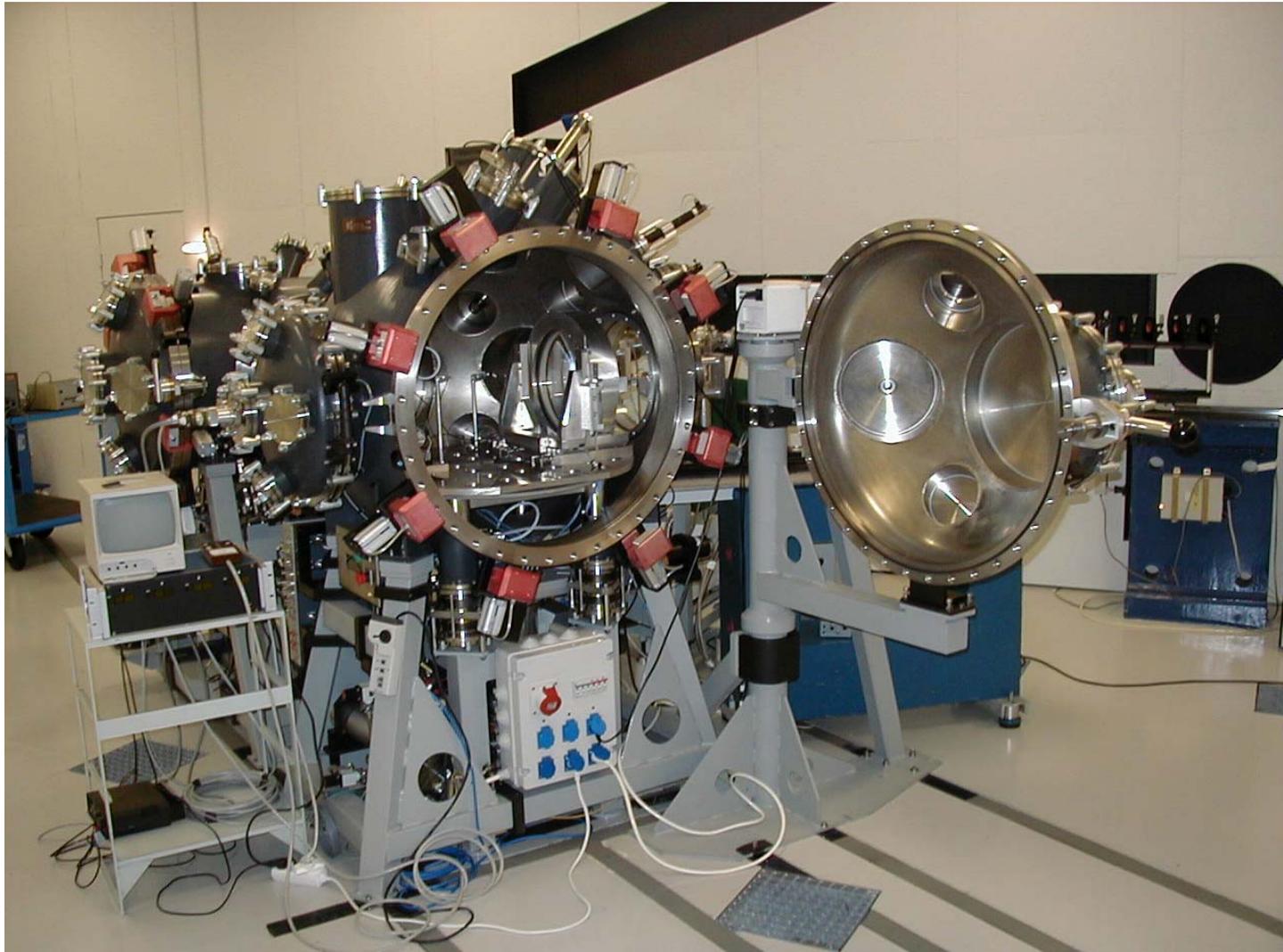
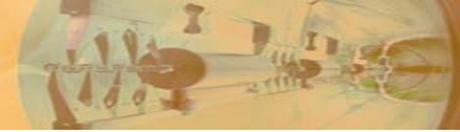
PALS Laser Hall in 2000 with installed ASTERIX components



System seen from the oscillator table



PALS twin-target chamber in 2000



DoE- BMBF agreement

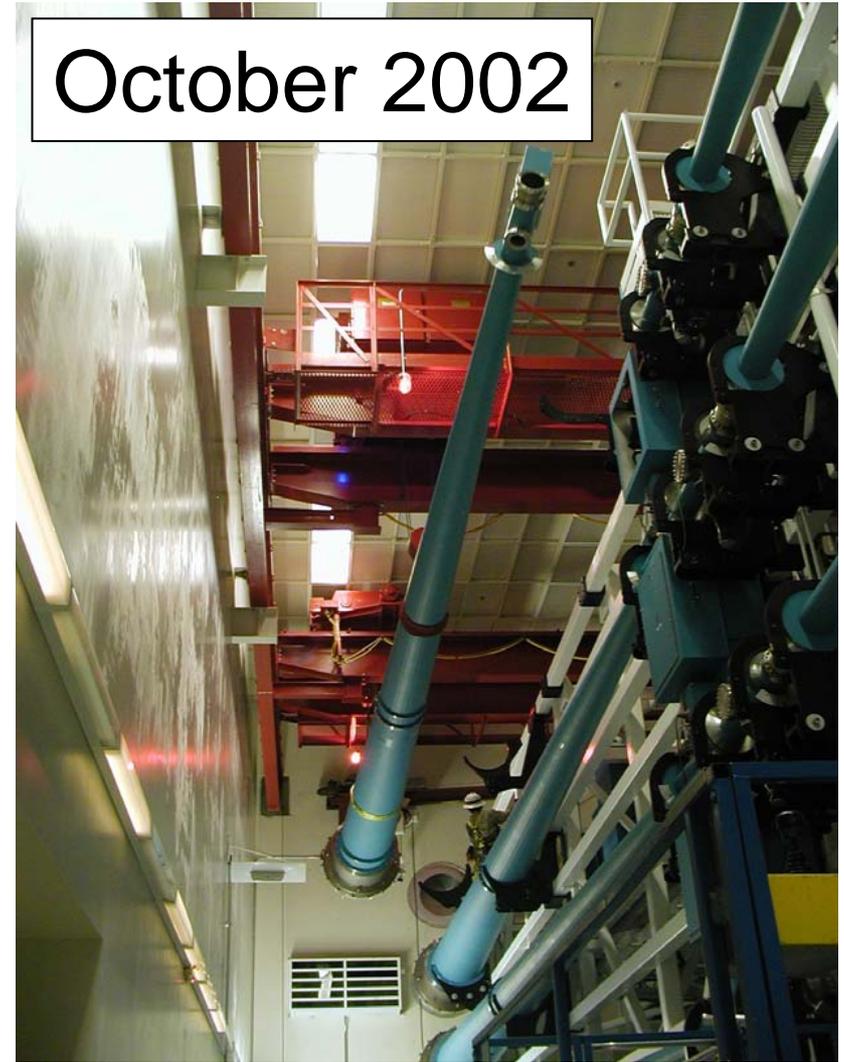


June 5th 2002: Signatures between BMBF and DoE for Nova parts

Transport of Nova Components



7.5 m telescope section (SF6)



15 m telescope section (SF7)

Packing up at LLNL



60 Tons of Material in 110 Boxes

Unpacking at GSI February 2003

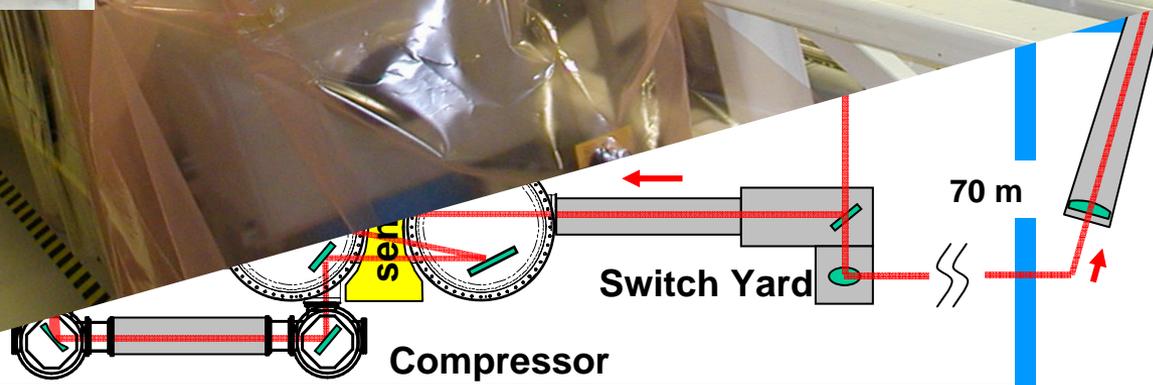


PHELIX uses modern front-ends together with parts from the former Phebus and Nova lasers

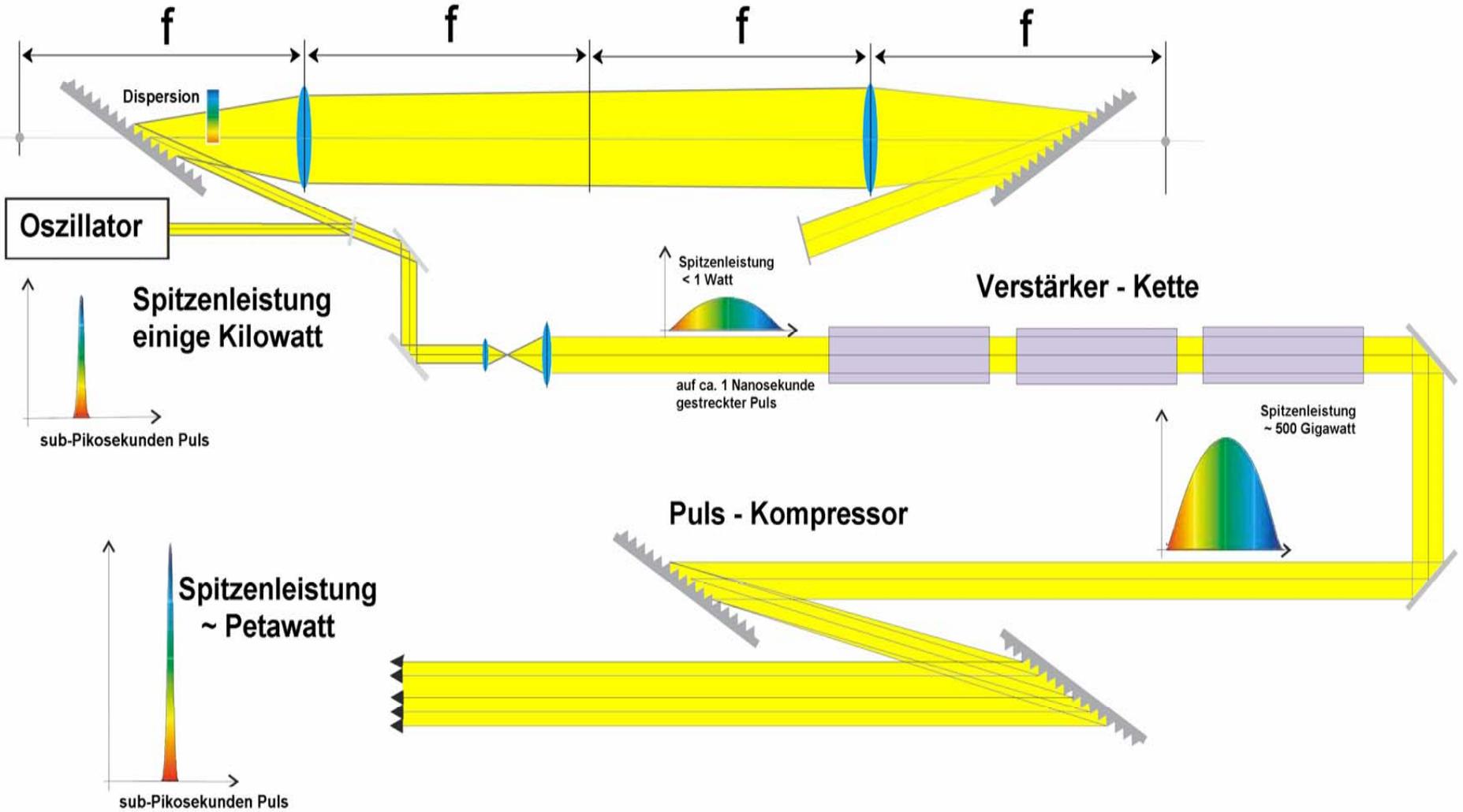
First experiments 12/ 2006, routine operation since 6/2008

fs Front

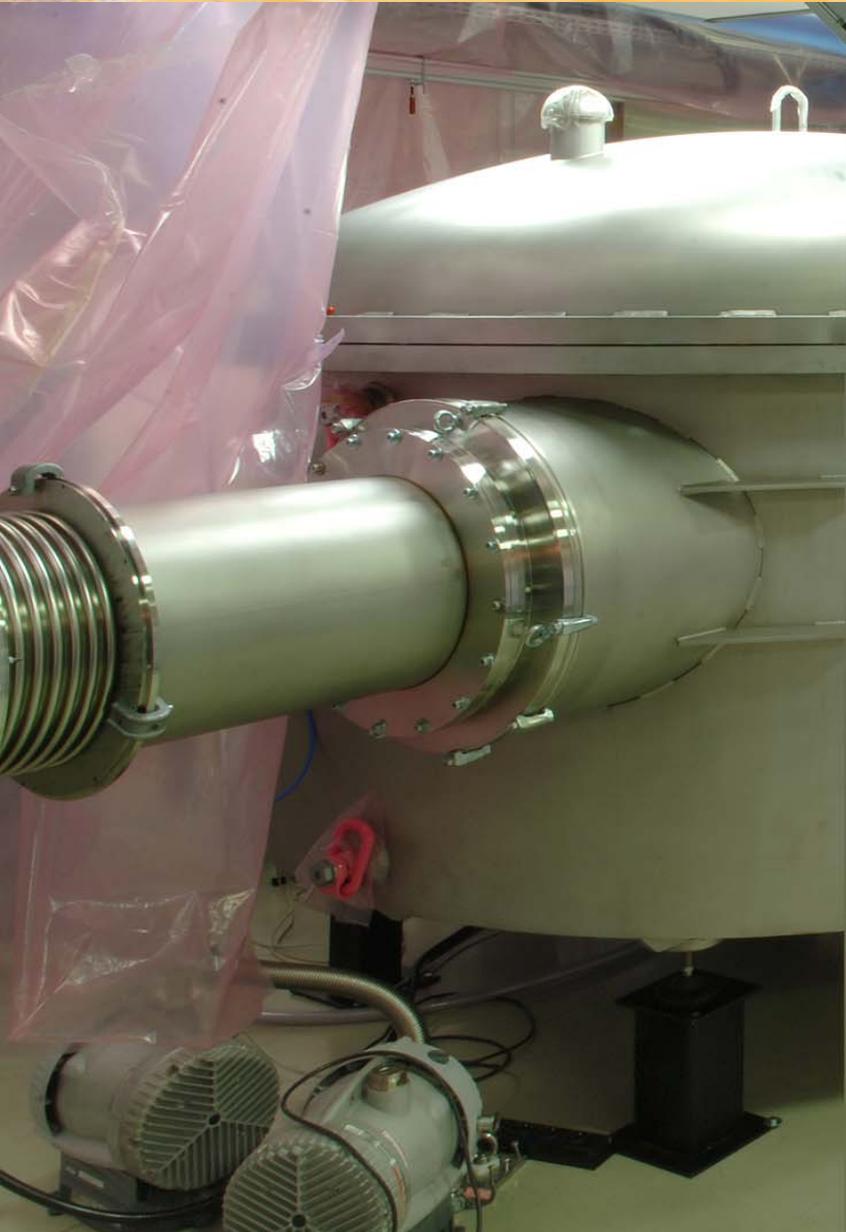
5 Amplifiers with 30 cm beam size provide output energies in excess of 1 kJ (presently operated up to 1 kJ)



Chirped-Pulse Amplification



Compressor vacuum tanks (and experiment)



Presently installed gratings supply performance up to ~200 J @ 400 fs due to damage threshold issues experienced in other laboratory

1000 Shots of PHELIX delivered
by the end of 2009



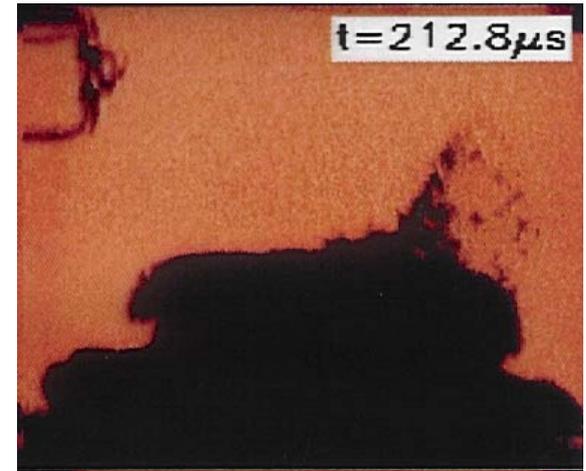
*B. Aurand, V. Bagnoud, A. Blazevic,
S. Borneis, B. Ecker, U. Eisenbarth,
J. Fils, S. Goette, T. Hahn, D. Hochhaus,
F. Knobloch, M. Kreutz, T. Kuehl,
S. Kunzer, T. Merz-Mantvill,
P. Neumayer, E. Onkels, D. Reemts,
O. Rosmej, T. Stoehlker, A. Tauschwitz,
B. Zielbauer, D. Zimmer*

Heavy-Ion Plasma Physics : High Energy Density Matter

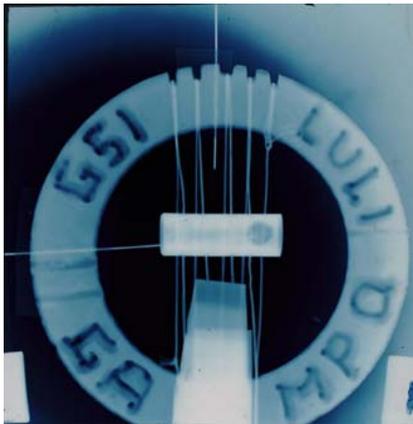
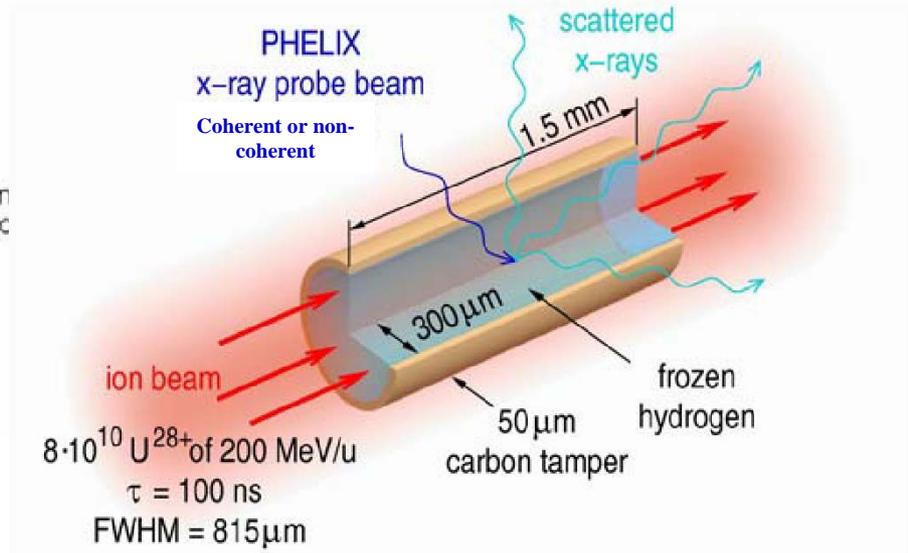
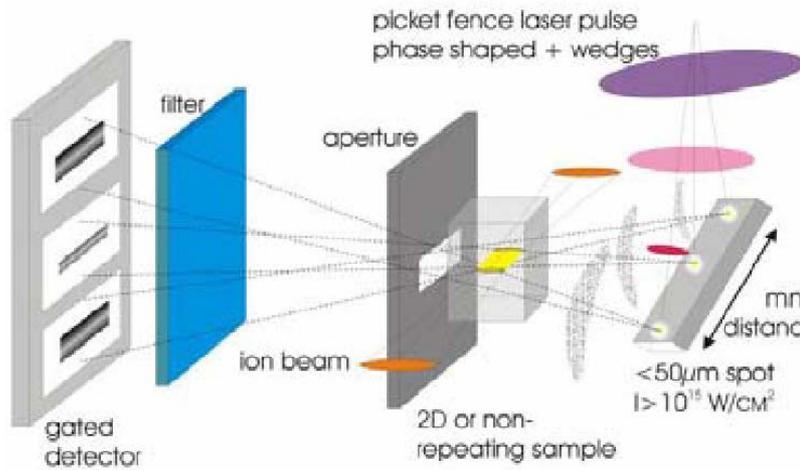
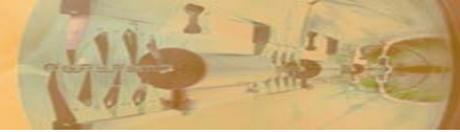
Heavy ions with up to 1000 MeV/u

focused on < 1 mm target spot

- large volume of sample (mm³)
- fairly uniform physical conditions
- high entropy @ high densities
- high rep. rate and reproducibility
- any target material



Intense heavy ion beam is an excellent tool to generate large-volume uniform HED samples !



Example: Backlighting by laser accelerated protons

Roth, Cowan, Gauthier et al.,
LULI 2000)

Plasma-based QSS XUV Zn laser

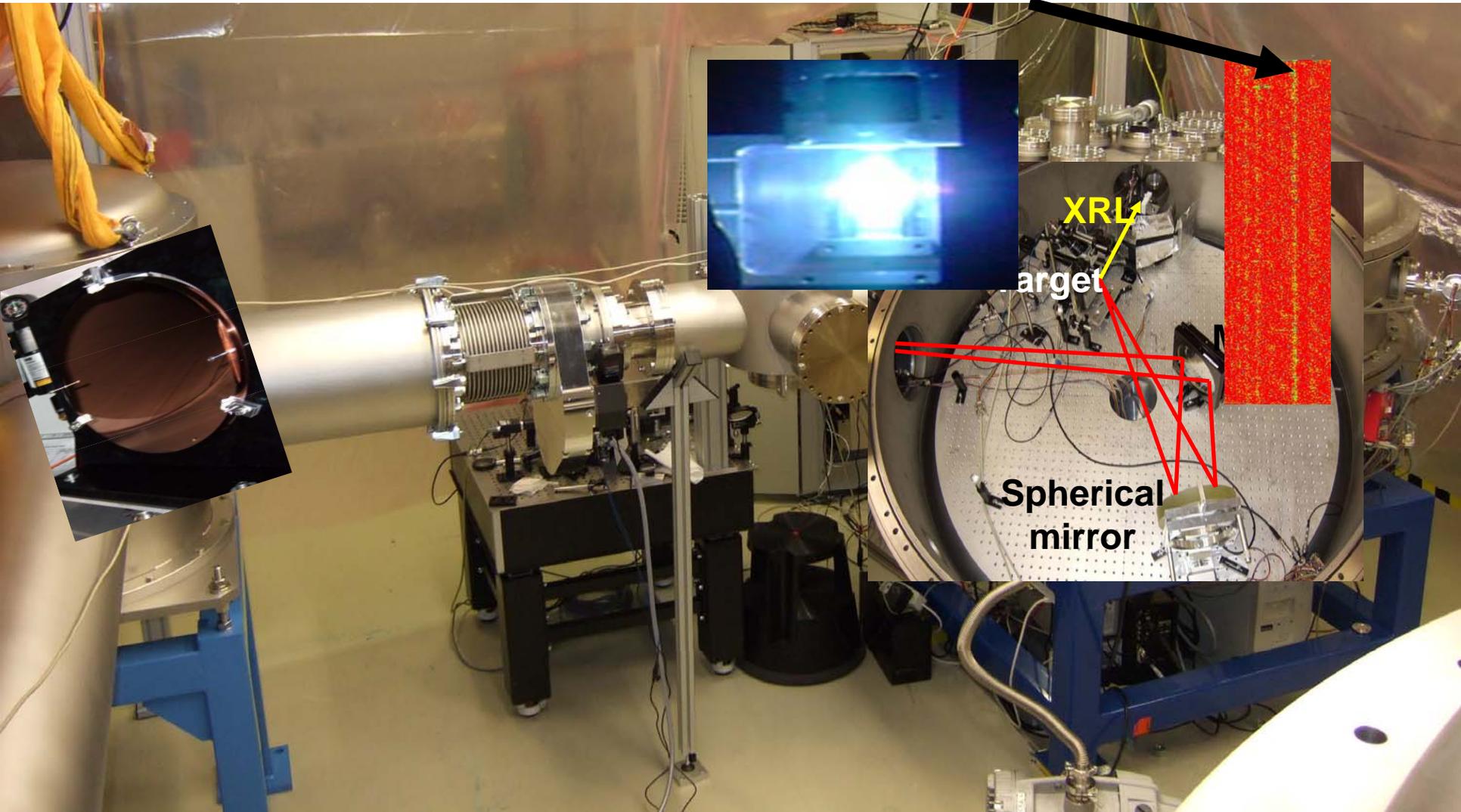
working wavelength 21, 2 nm
double-pss, saturated

Unique features:

- record brightness of all laboratory EMG sources
- suitable for routine science & technology applications
- maximum intensity at the shortest wavelength

A 180 eV collisionally excited X-Ray Laser at PHELIX

Ni-like Samarium lasing line: 7.3nm (170eV XRL)

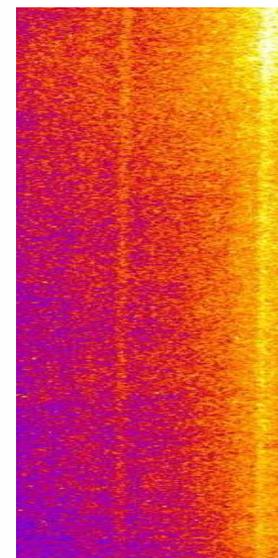
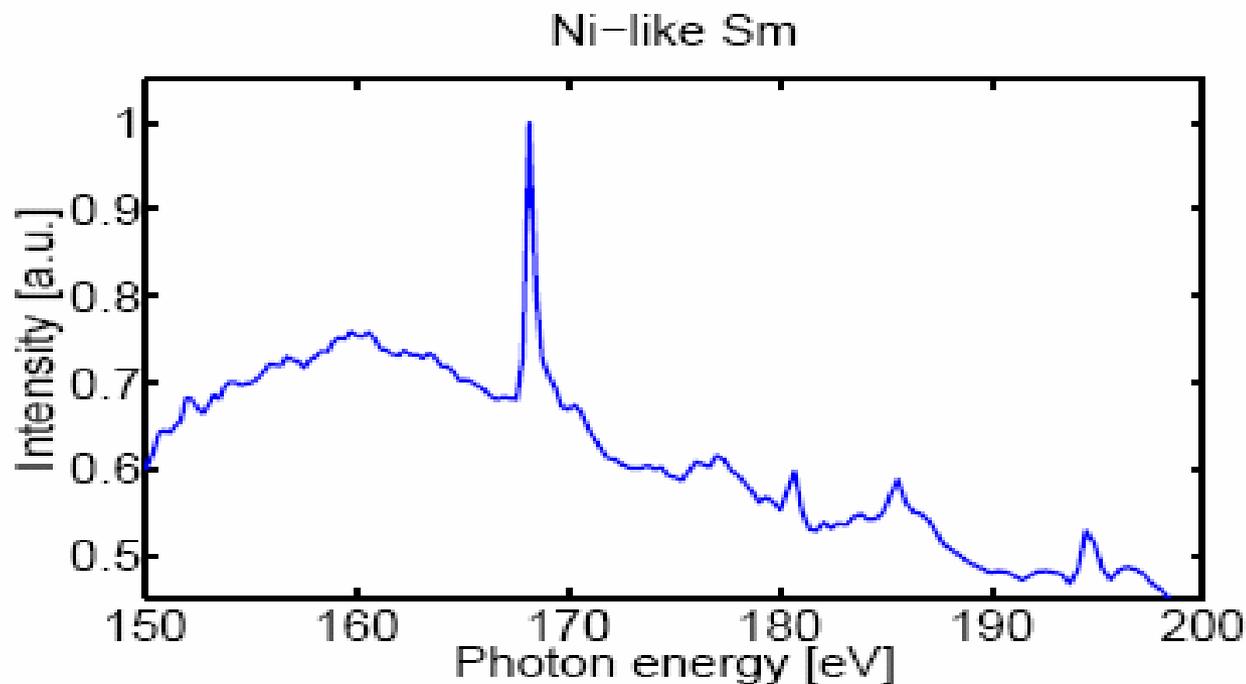


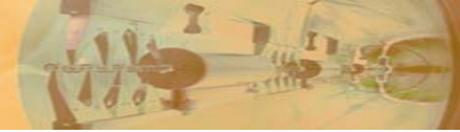
X-ray laser in the sub-10 nm regime



- We are using PHELIX to pump X-ray laser with Ni-like Samarium and recently Ni-like Dysprosium (photon energy > 200 eV)
 - We have developed an innovative two pulse scheme* to create transient collisionally excited (TCE) plasma X-ray laser (DGRIP)

Together with D. Ros et al. , LASERIX





Amplification of soft x-rays in the regime of 40 eV and about 260 eV with a small signal gain of up to 8×10^3 was observed using the PHELIX front-end. The parametric amplification of high-order harmonics as a seed is explained by a simple model of energy transfer into the x-ray field.

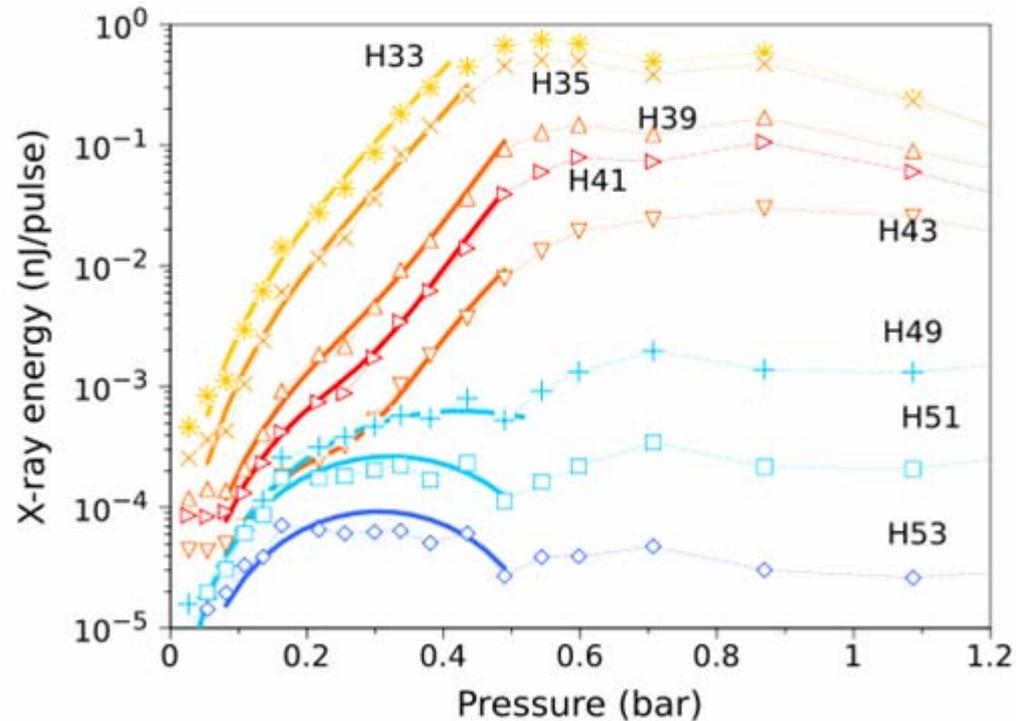
$$I_{\text{XPA}} = I_0 \frac{e^{gL} - 2e^{gL/2} \cos(\Delta kL) + 1}{(\Delta kL)^2 + (gL/2)^2}$$

$$g_{k,\text{max}} \approx \sigma_{eq} n_0 - \alpha_k$$

Potential for a new powerful x-ray source !

In collaboration with Ch. Spielman and J. Seres, Uni Jena

Nature Physics 4/2010

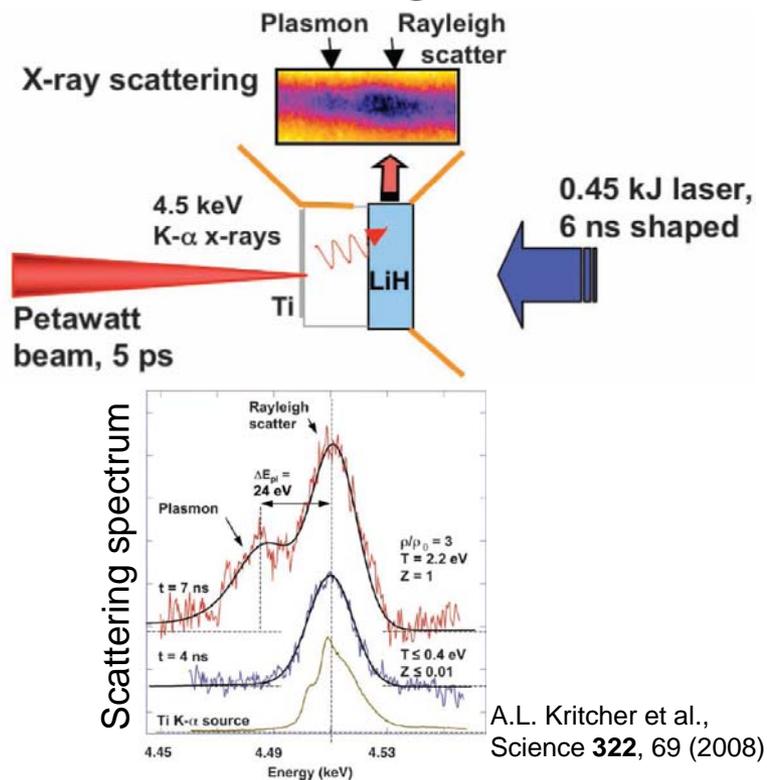


Laser-generated K-alpha sources

Large application potential in High Energy Density Science experiments

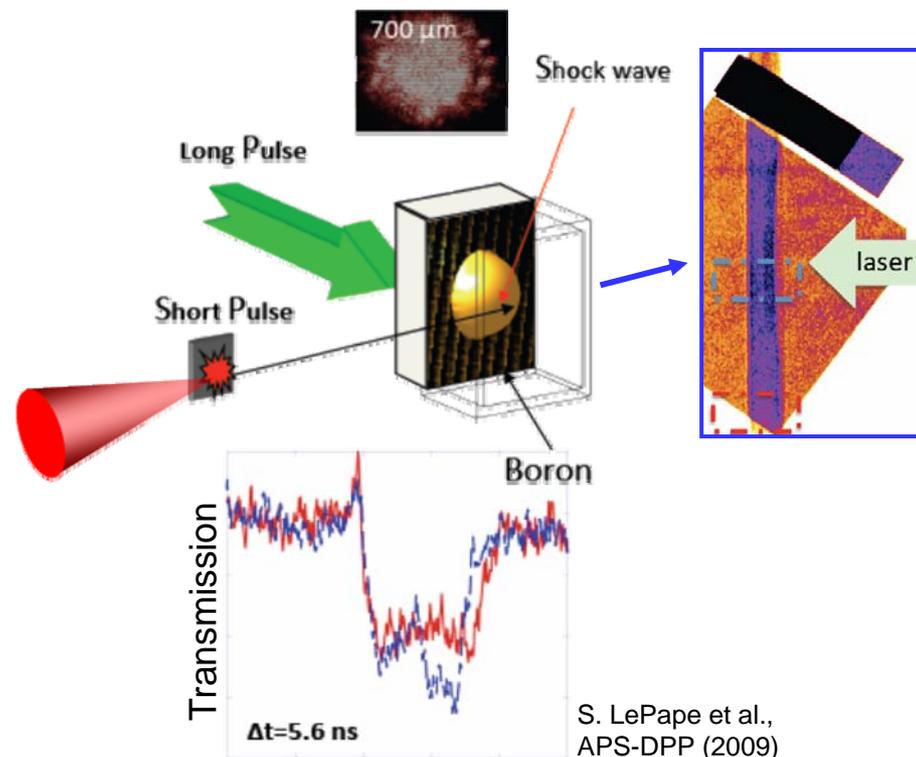


Spectrally resolved X-ray Thomson scattering



- Spectral quality (satellite-free)
- Temporal resolution (~ 10 ps)

High-resolution X-ray radiography



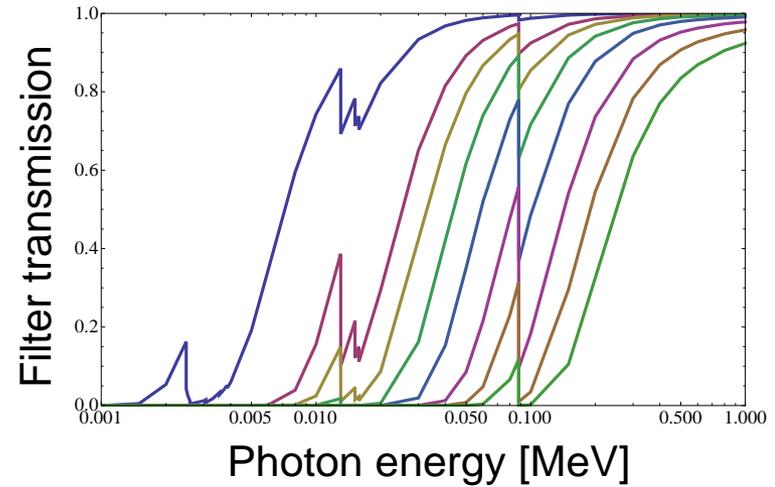
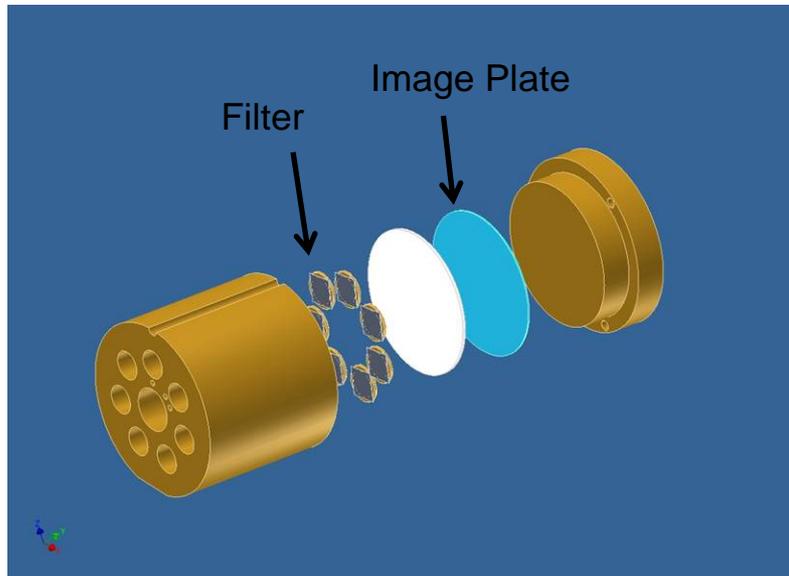
- Small source size ($< 10 \mu\text{m}$)
- Temporal resolution (~ 10 ps)
- Z-scaling

Experiments:

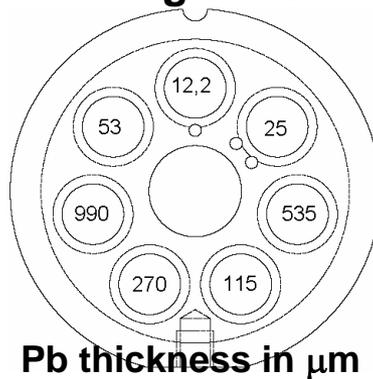
Ch. Labaune, P. McKenna, P. Neumayer, O. Rosmej, et al

Hard X-Ray Detector

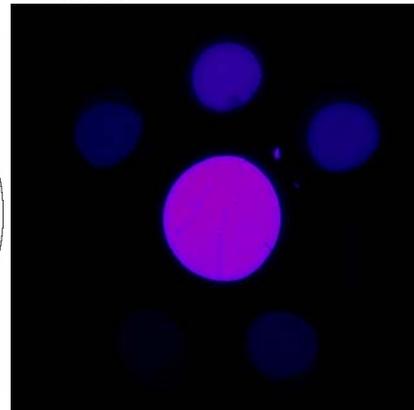
measures the high-energy bremsstrahlung emission



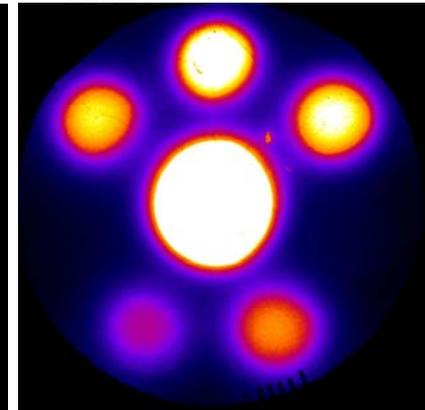
HXRD filter configuration



$I_{\text{laser}} \sim 10^{18} \text{ W/cm}^2$



$I_{\text{laser}} > 10^{19} \text{ W/cm}^2$



FAIR GmbH will be founded as a multinational GmbH on October 6th !



Physics in Extreme Fields

hydrogen

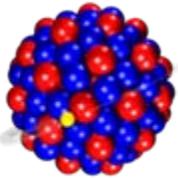


$$Z=1$$

$$E_b = 13.6 \text{ eV}$$

$$Z \cdot \alpha \ll 1$$

uranium ion



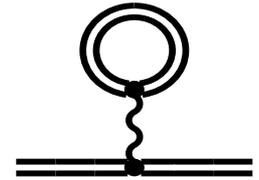
$$Z=92$$

$$E_b = 132 \text{ keV}$$

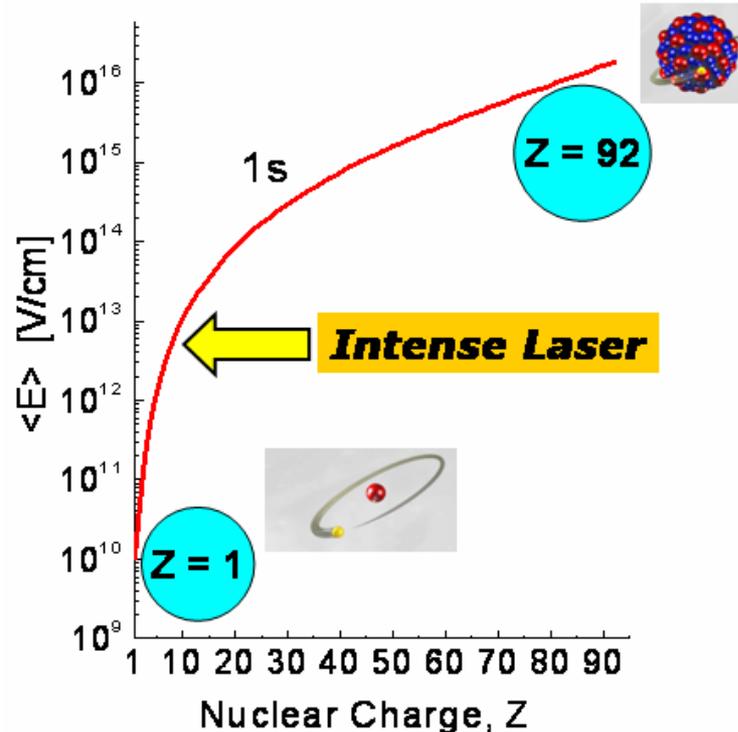
$$Z \cdot \alpha \approx 1$$



Strong Field QED

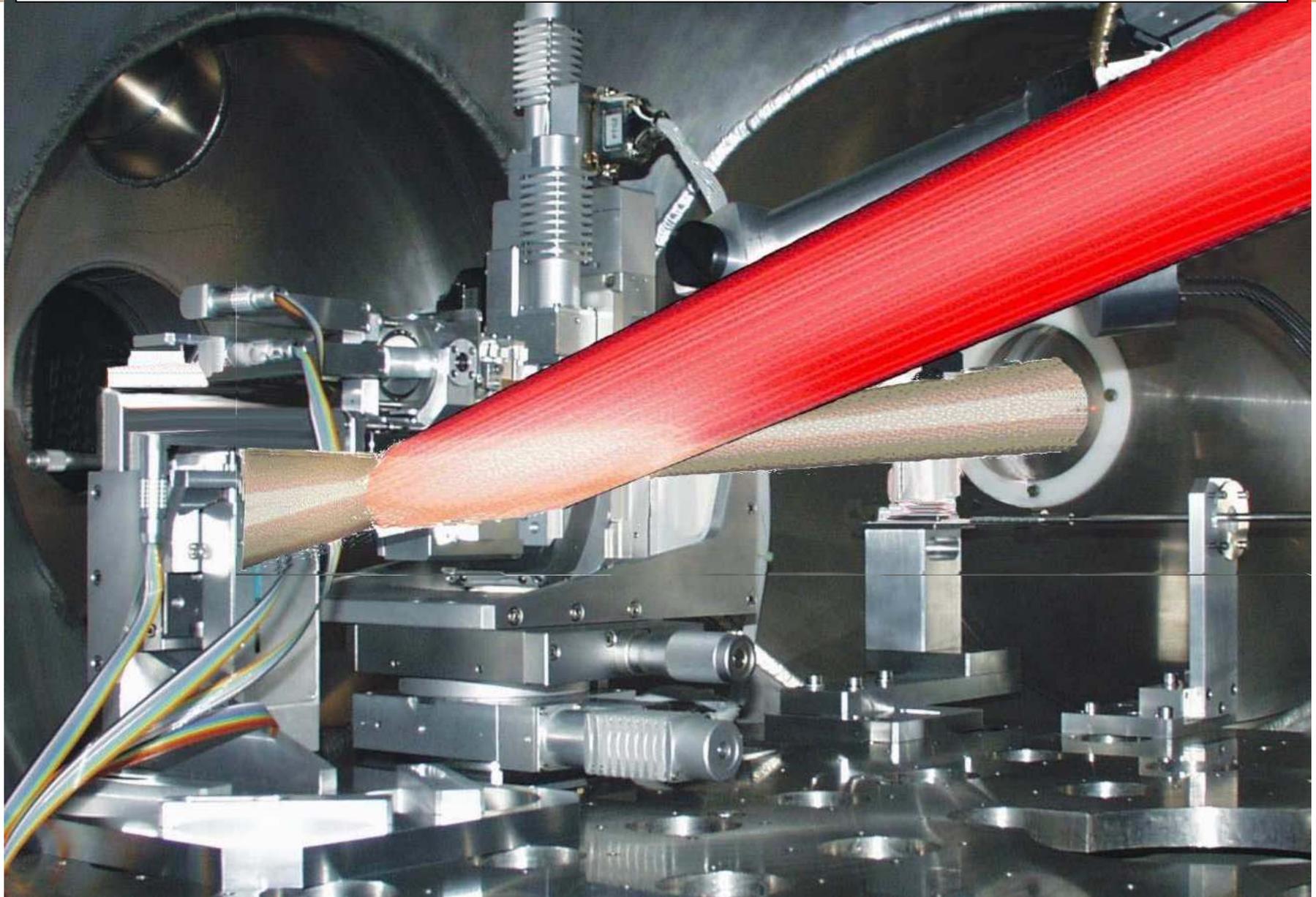


Nature stops at $Z = 93$?



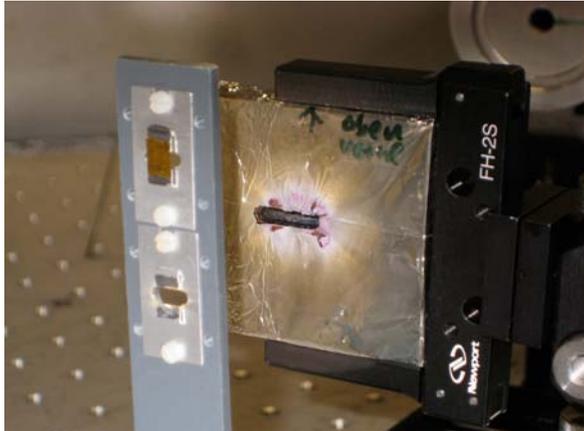
- 1s-Lamb Shift
- g-factor
- hyperfine structure
- towards super-critical fields
- border line to nuclear physics

Secondary sources : X-Rays

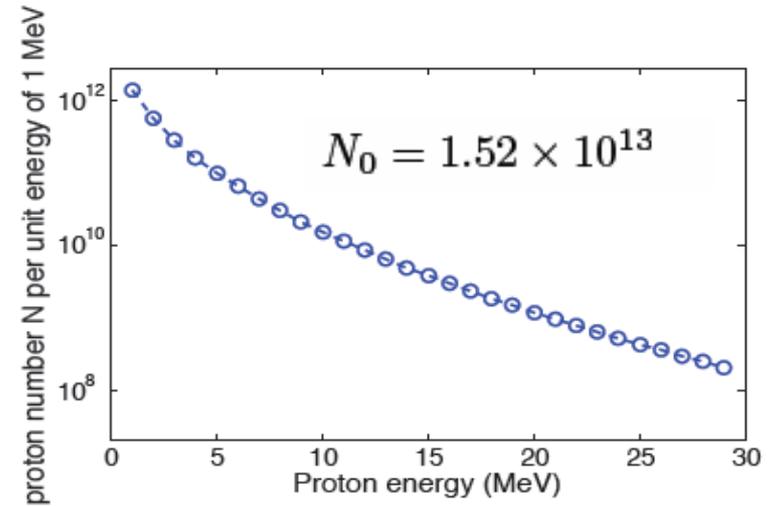
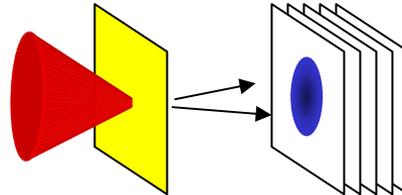


Secondary sources : Protons

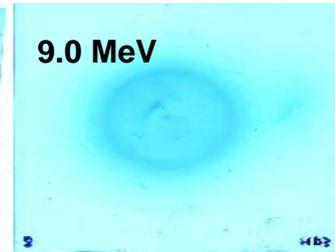
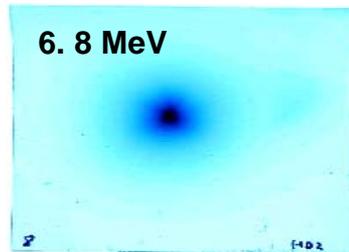
With courtesy of I. Alber, K. Harres, and M. Roth TUD, A. Tauschwitz and M. Kreutz GSI



Setup to test proton production



Stack located 405 mm from the target

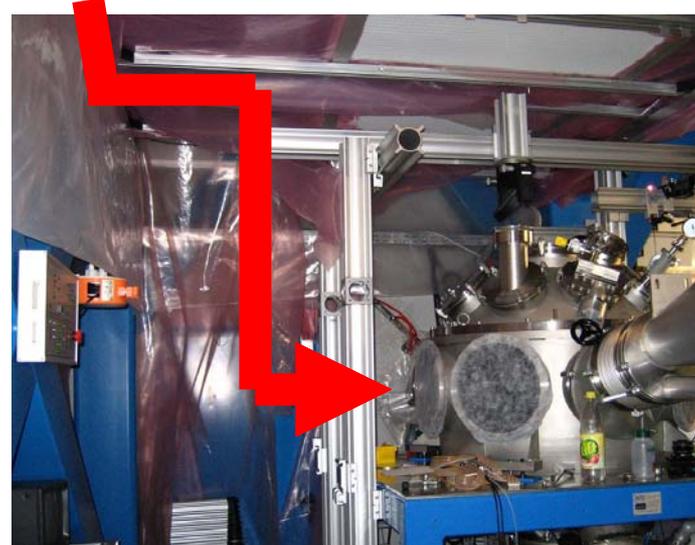
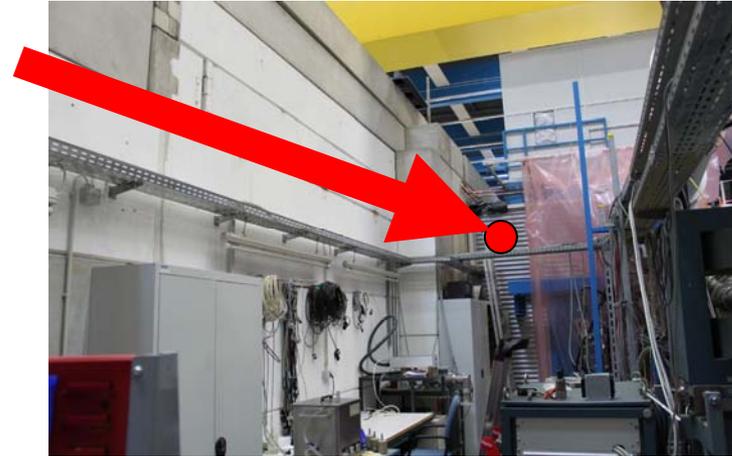


Converging proton beams

Progress in particle acceleration (Courtesy of K. Harres, T. Cowan, M. Roth, et al.)

Up to 14 MeV protons were collimated using a coil developed at FZD

Secondary sources : Proton Beams





A bright future for PALS and PHELIX !

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