Development of Short Pulse X-Ray Radiography at GSI

P. Neumayer

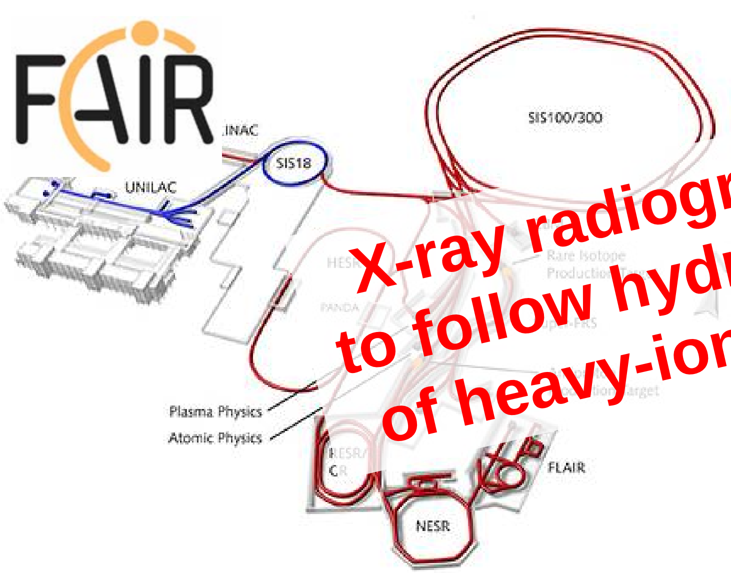
EMMI Workshop
Plasma Physics with Intense Heavy-Ion and Laser Beams
Darmstadt, May 2-4, 2011

The FAIR facility will offer exciting new schemes to produce plasmas at high-energy density

TECHNICAL PROPOSAL FOR DESIGN, CONSTRUCTION, COMMISSIONING AND OPERATION OF THE:

HEDgeHOB

High Energy Density Matter Generated by Heavy Ion Beams



X-ray radiography is an ideal tool to follow hydrodynamical evolution of heavy-ion driven dense targets

Heavy Ion Heating and EXpansion

LAboratory PLAnetary Science

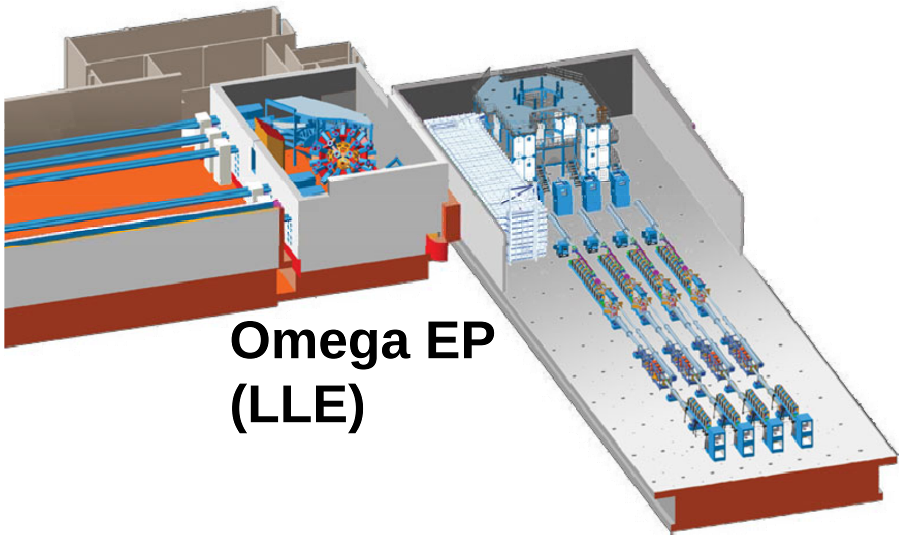
Both schemes rely on large hydrodynamic evolution of the ion beam heated matter

3.6 Backlighting with HEPW laser

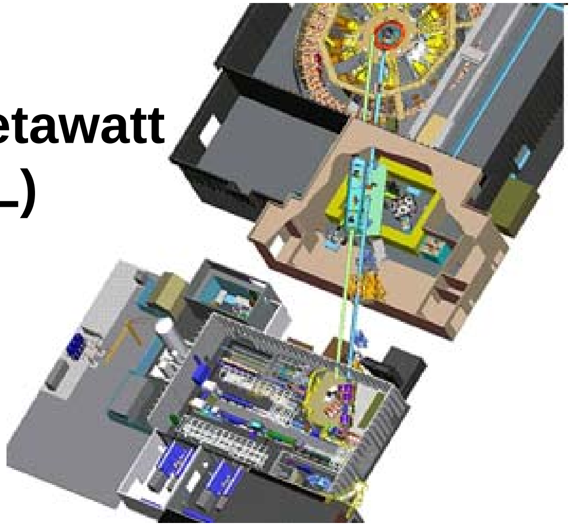
For the research in the dense plasma regime it is crucial to develop diagnostics in the X-ray regime, because most of the standard diagnostic methods will fail due to the high opacity, low temperature and transient behavior of the irradiated sample.

X-ray and particle radiography is an experimental technique in which an external source of X-rays or fast particles is used to penetrate and determine the evolution of a complex object. It is a critical

Generating high-brightness x-ray photon fluxes requires intense drivers

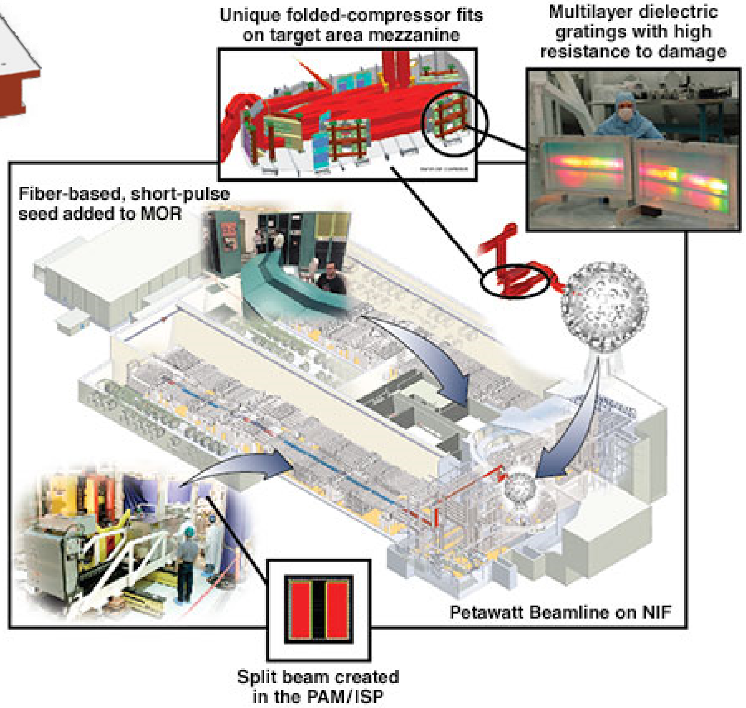


Omega EP (LLE)



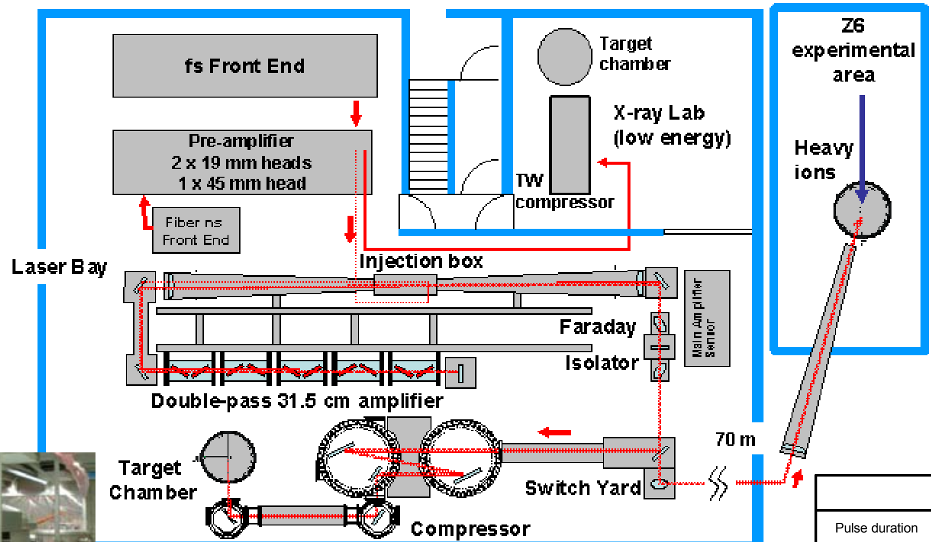
Z-Petawatt (SNL)

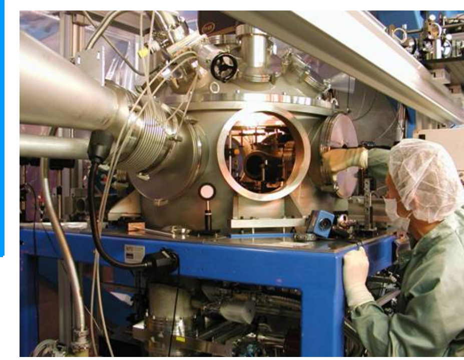
ARC (LLNL)



At GSI: PHELIX – a Petawatt High Energy Laser for heavy Ion eXperiments

Hybrid Ti:Sa/Nd:glass CPA laser

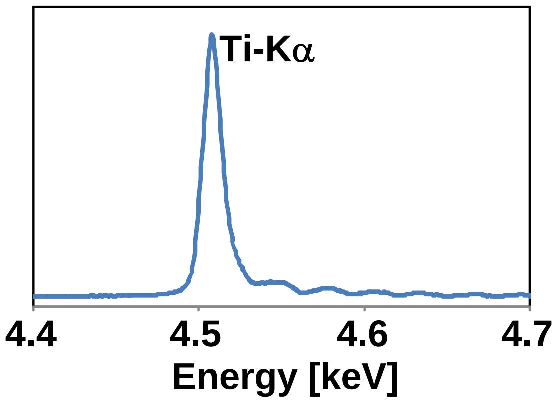




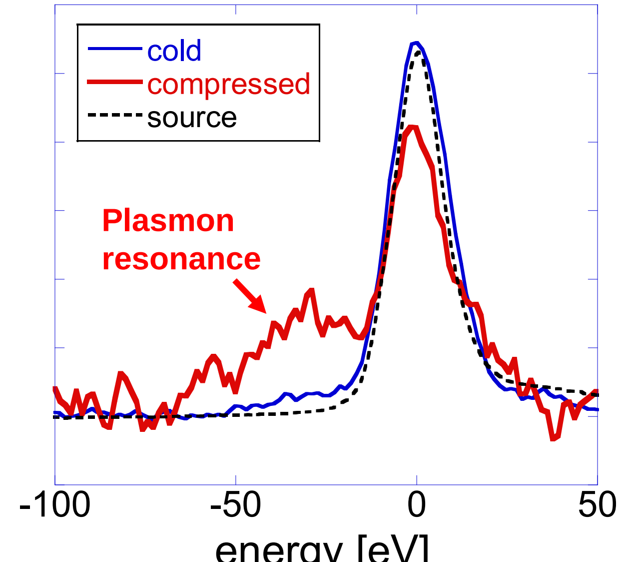
	Long pulse	Short pulse
Pulse duration	0.7 – 20 ns	0.7- 20 ps
Energy	0.3 – 1 kJ	120 J
Max intensity	10^{16} W/cm^2	10^{20} W/cm^2
Rep rate	1 shot every 90 min	
Contrast	50 dB	60 dB

Properties of laser driven K-alpha sources

Spectral quality

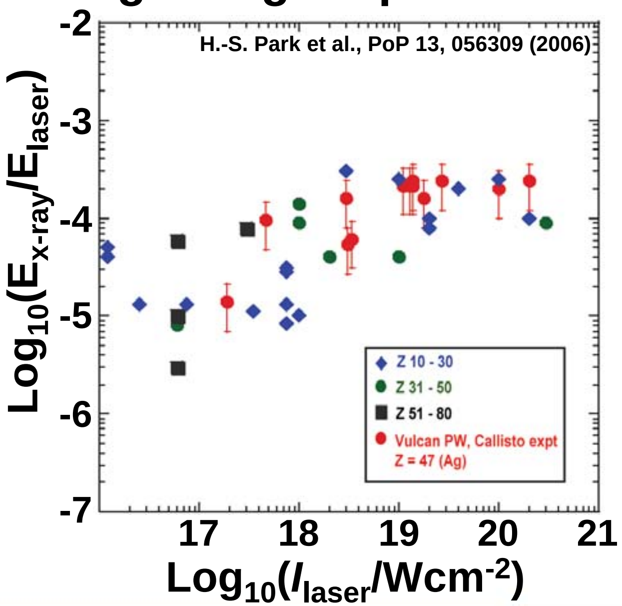


→ Resolve Plasmon resonances in XRTS



P. Neumayer et al., PRL **105**, 075003 (2010)

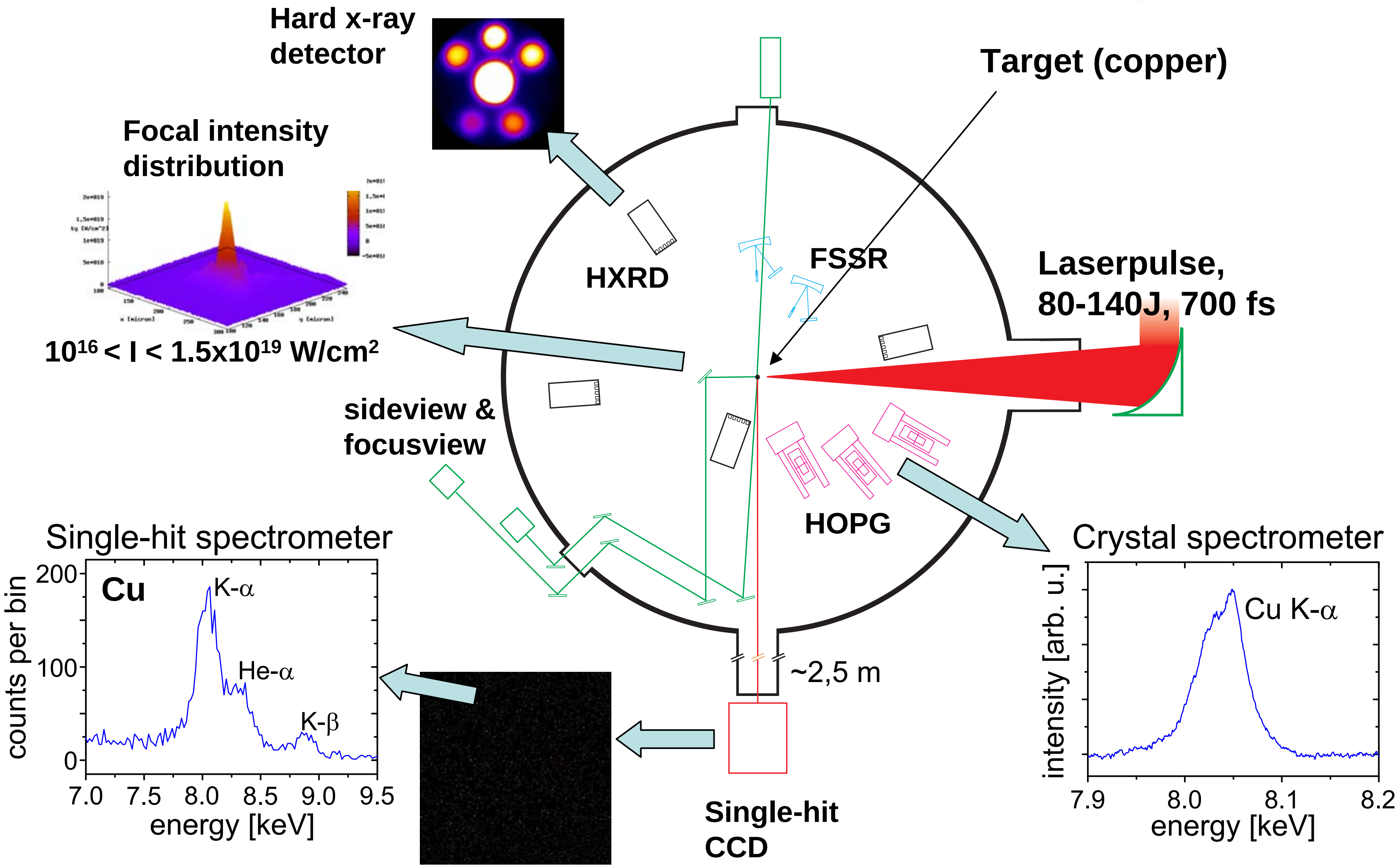
Scaling to higher photon energies



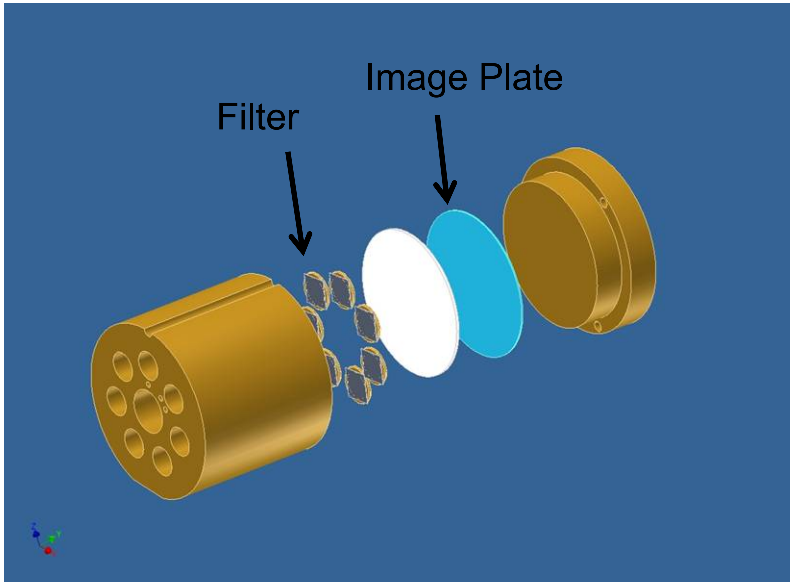
Other outstanding features

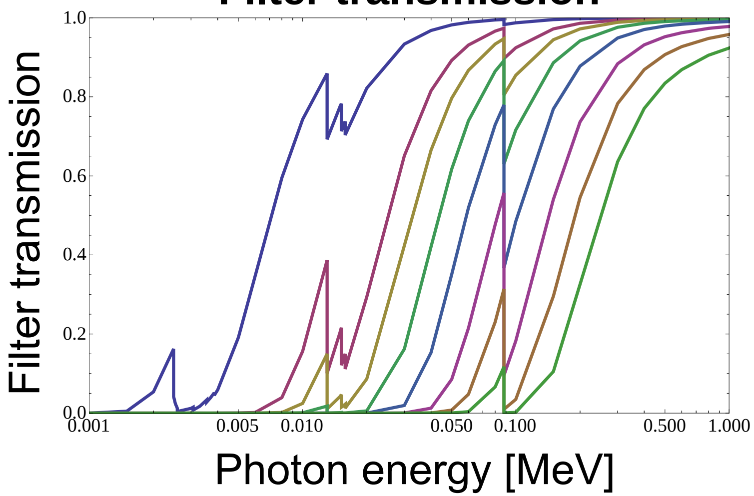
- Temporal resolution: 10 ps
- spatially confined to target dimensions

K-alpha X-ray backlighter optimization at PHELIX

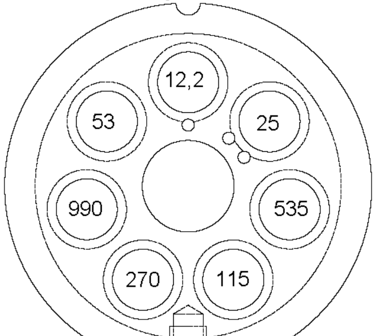


Hard X-Ray Detector measures the high-energy bremsstrahlung emission



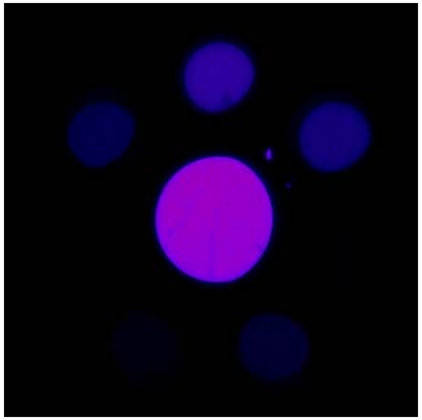


HXRD filter configuration

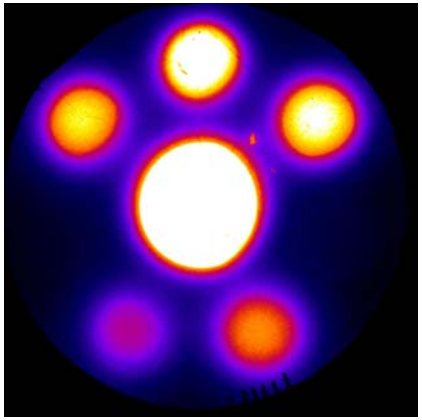


Pb thickness in μm

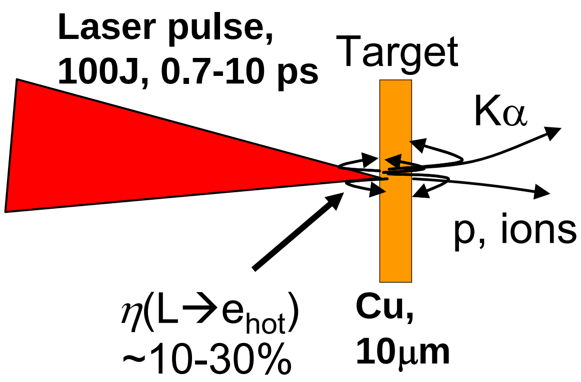
I_{laser}~10^{18} W/cm^2

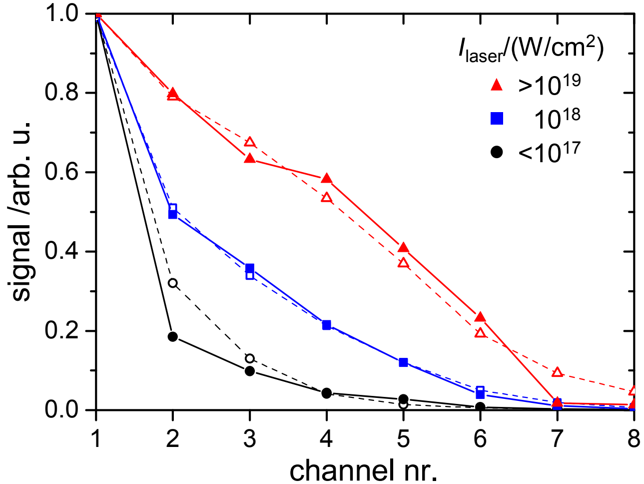


I_{laser}>10^{19} W/cm^2



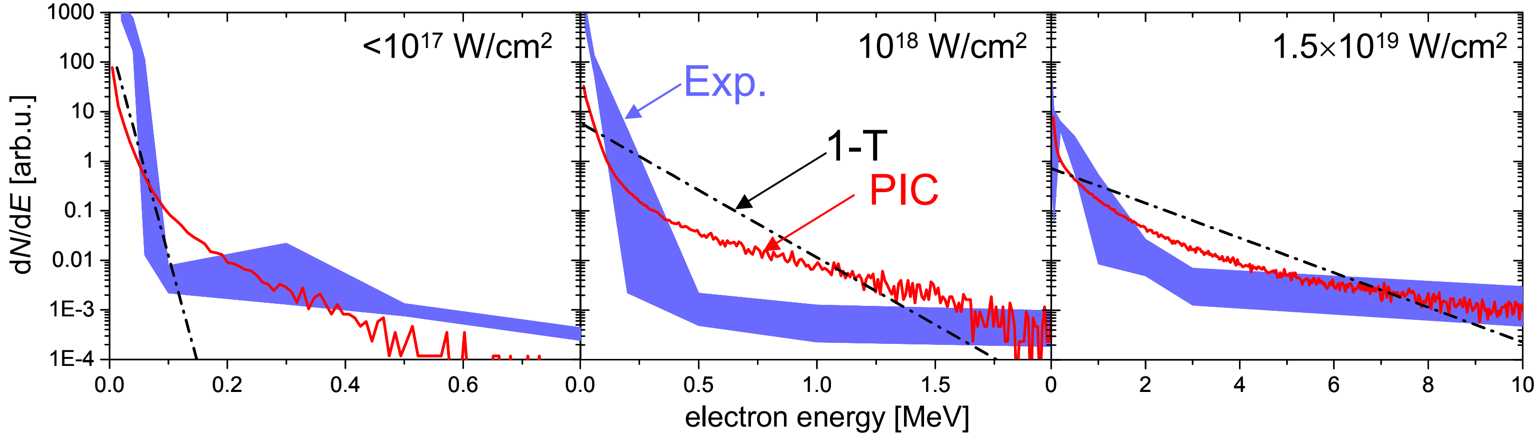
Measurement of the hot-electron distribution





Hot electron distribution inferred from bremsstrahlung emission

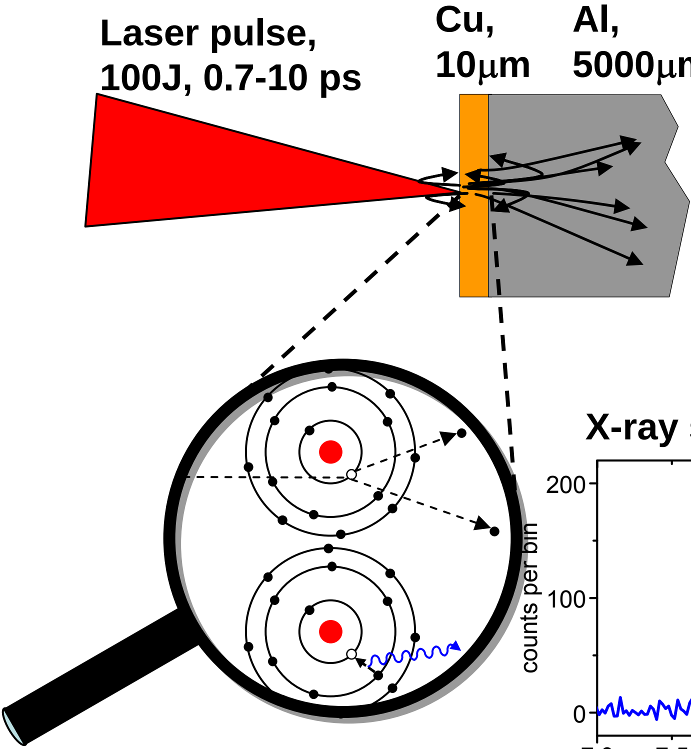
Genetic algorithm



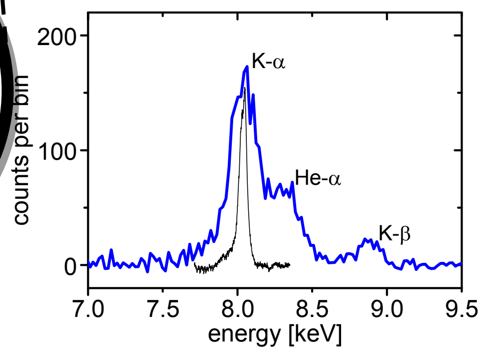
Hydro-calculations by An. Tauschwitz (EMMI) and M. Basko,
PIC calculations by P. Gibbon and A. Karmakar (EMMI)

K-alpha backlighter optimization at PHELIX

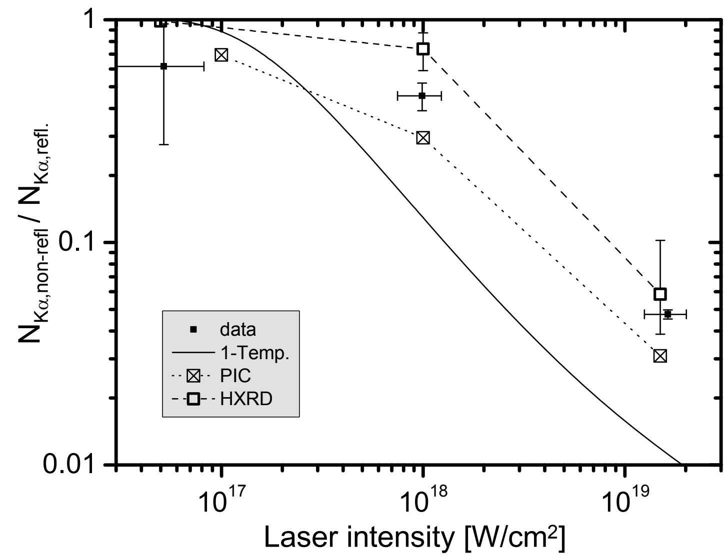
Experimental setup



X-ray spectrometers



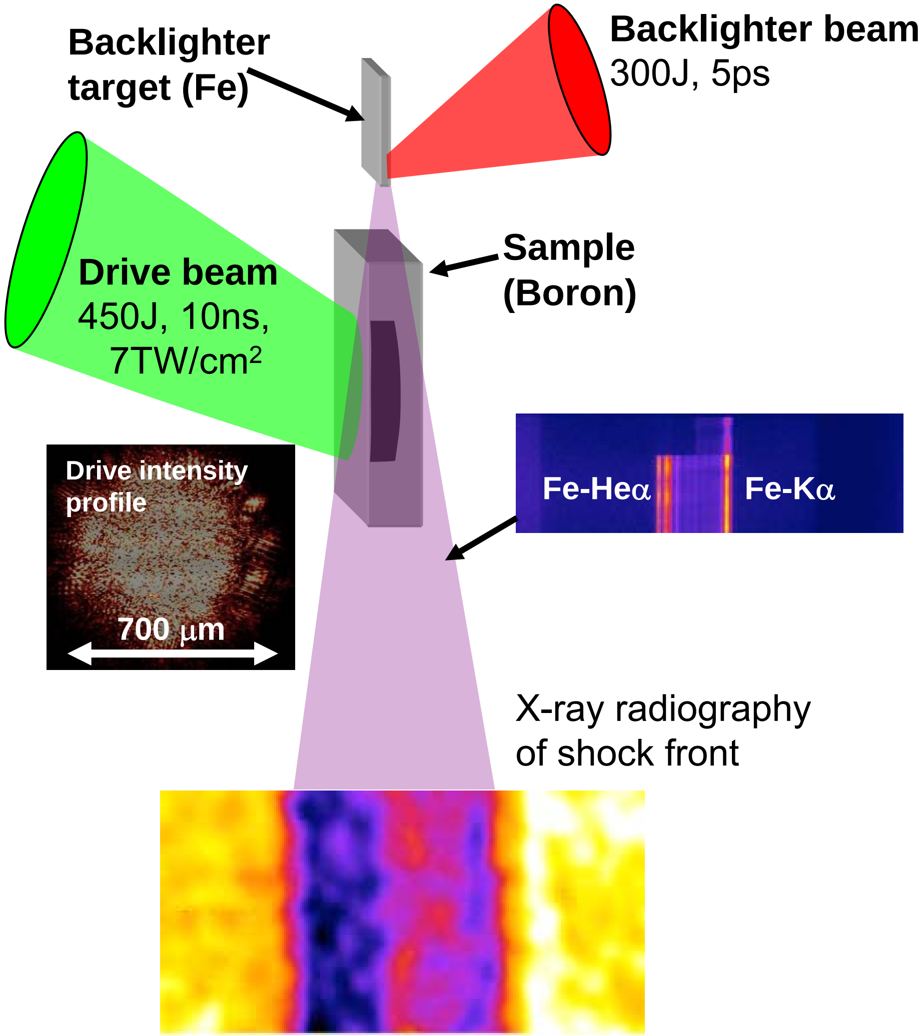
Modeling of the K-alpha yield



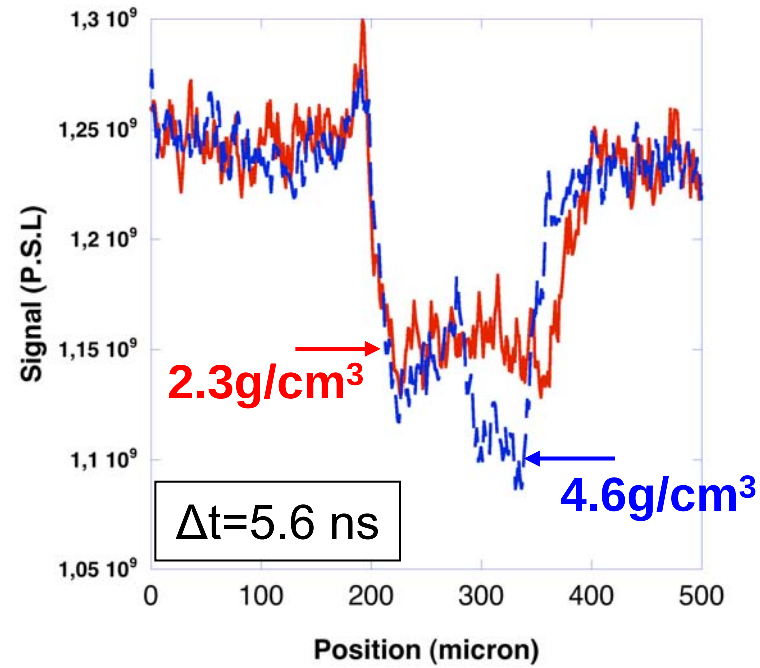
Refluxing electrons can make up >95% of the total K-alpha yield!

P. Neumayer et al., Phys. Plasmas **17**, 103103 (2010)

X-ray radiography of a shock front (at Titan/LLNL)



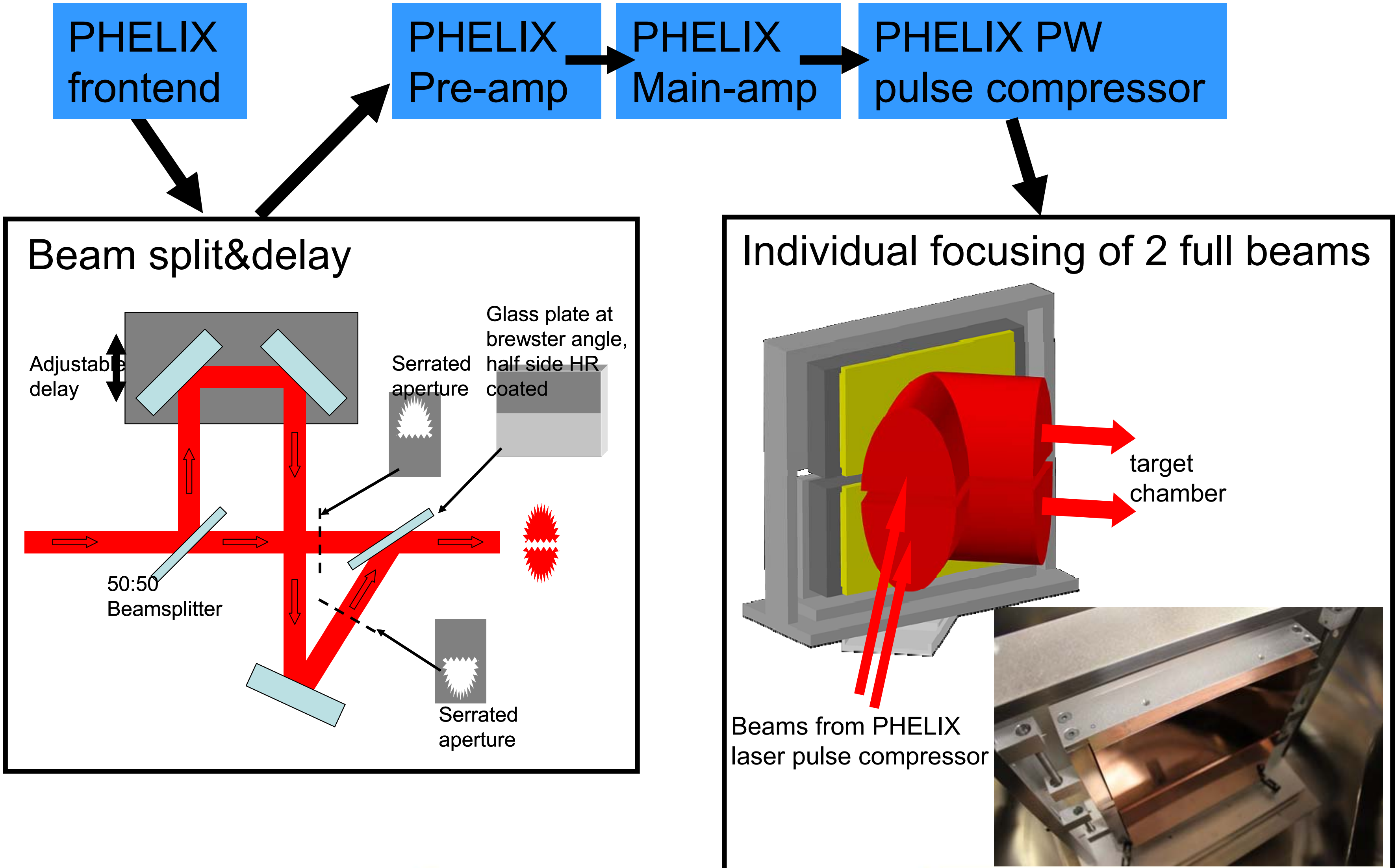
Careful source characterization
→ absolute density measurement



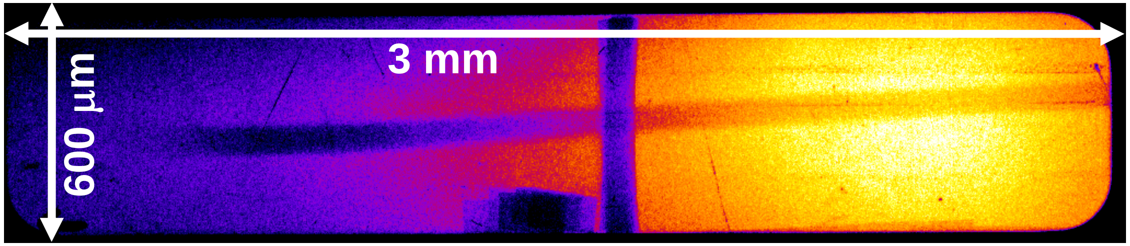
Good agreement with rad-hydro calculations and x-ray Thomson scattering measurements!

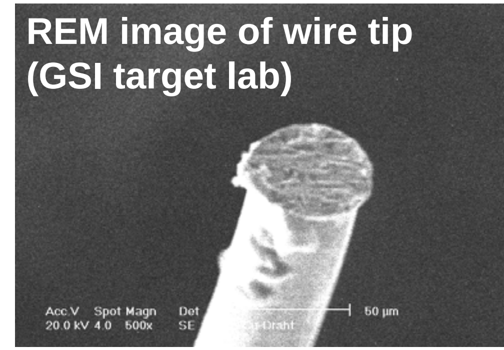
S. Le Pape et al., Phys. Plasmas **17**, 056309 (2010)

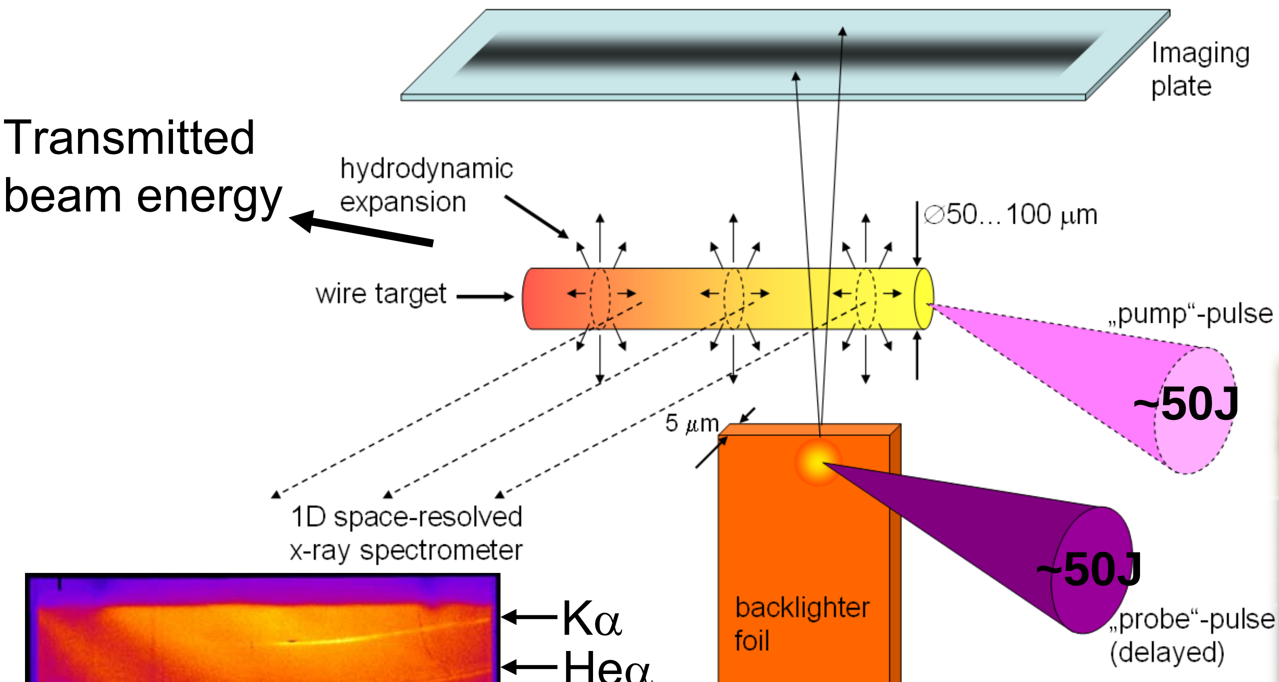
Collaboration with PHELIX laser operations team: Implementation of 2-beam capability at PHELIX

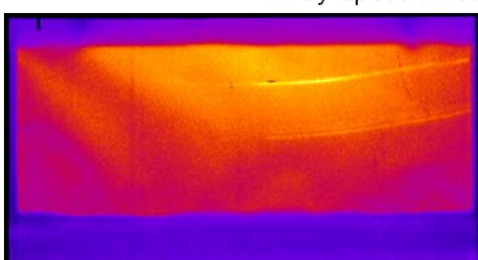


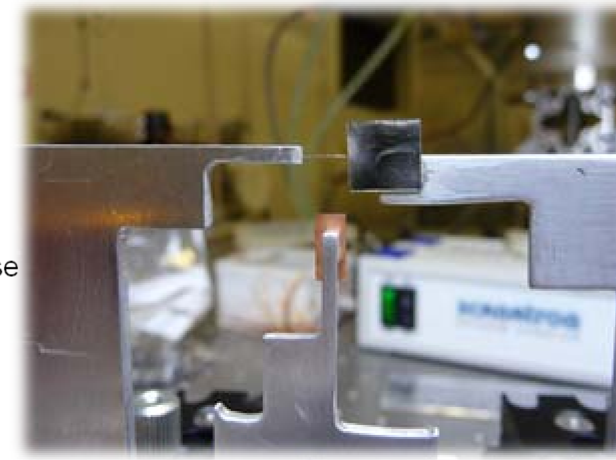
X-ray radiography on short-pulse laser heated wires – experimental setup









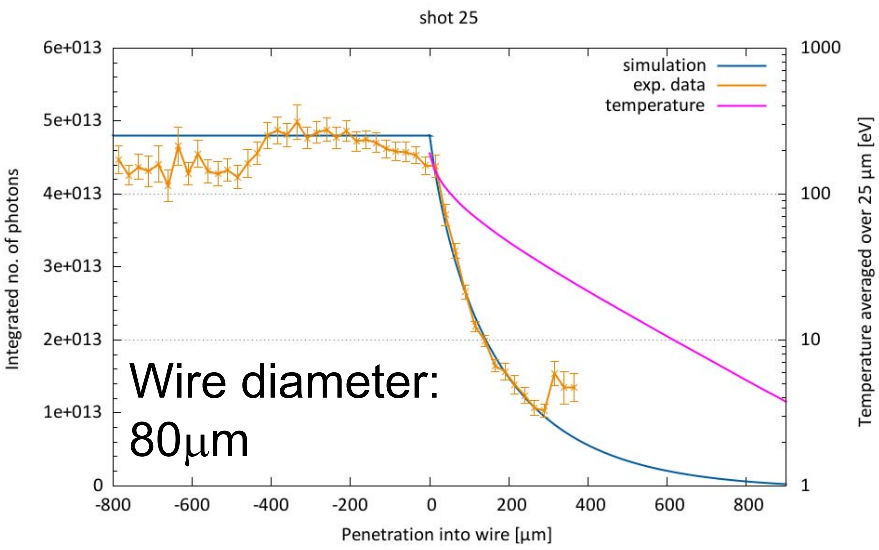


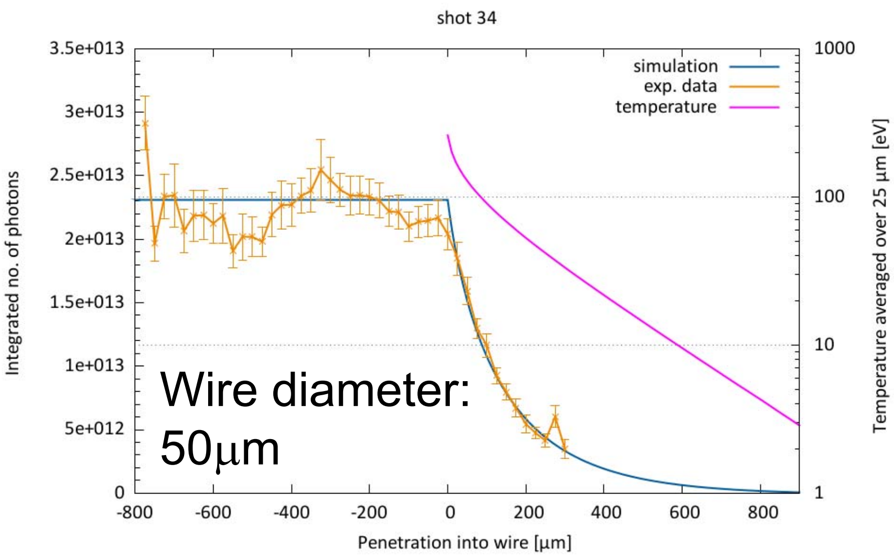
- Background
- Elongated source

Spatially resolved spectroscopy of wire K-shell fluoroscence shows hot-electron transport

<u>Wire material:</u>
Titanium (→$E_{K\alpha}$~4.5keV)

<u>Spectrometer:</u>
•Spectral coverage Kα...Heα
•Resolution ~25um (along wire)
•Absolute calibration



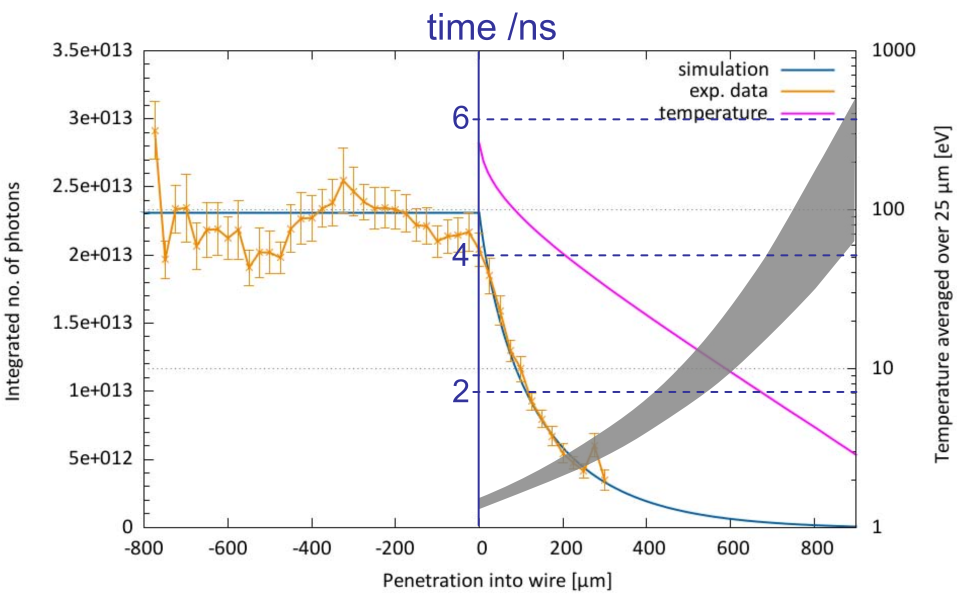


- Fit with hot-electron collisional transport model → T_{hot}, $\eta_{Laser \rightarrow ehot}$, deposited energy
- Equation-of-State → T_{bulk}

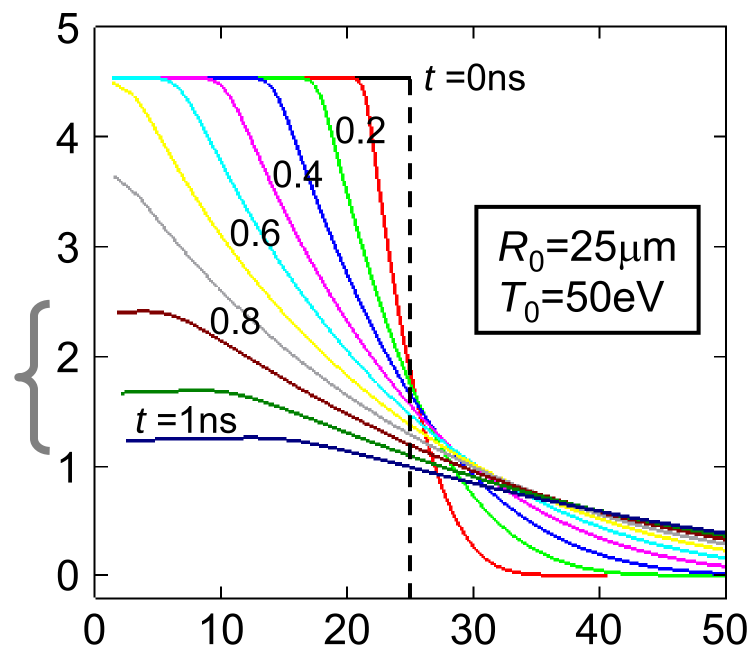
Thinner wires achieve higher temperatures
(hot electron energy confined due to refluxing)

Calculation of hydrodynamic wire expansion using measured energy deposition

Temperature inferred from K-alpha calorimetry

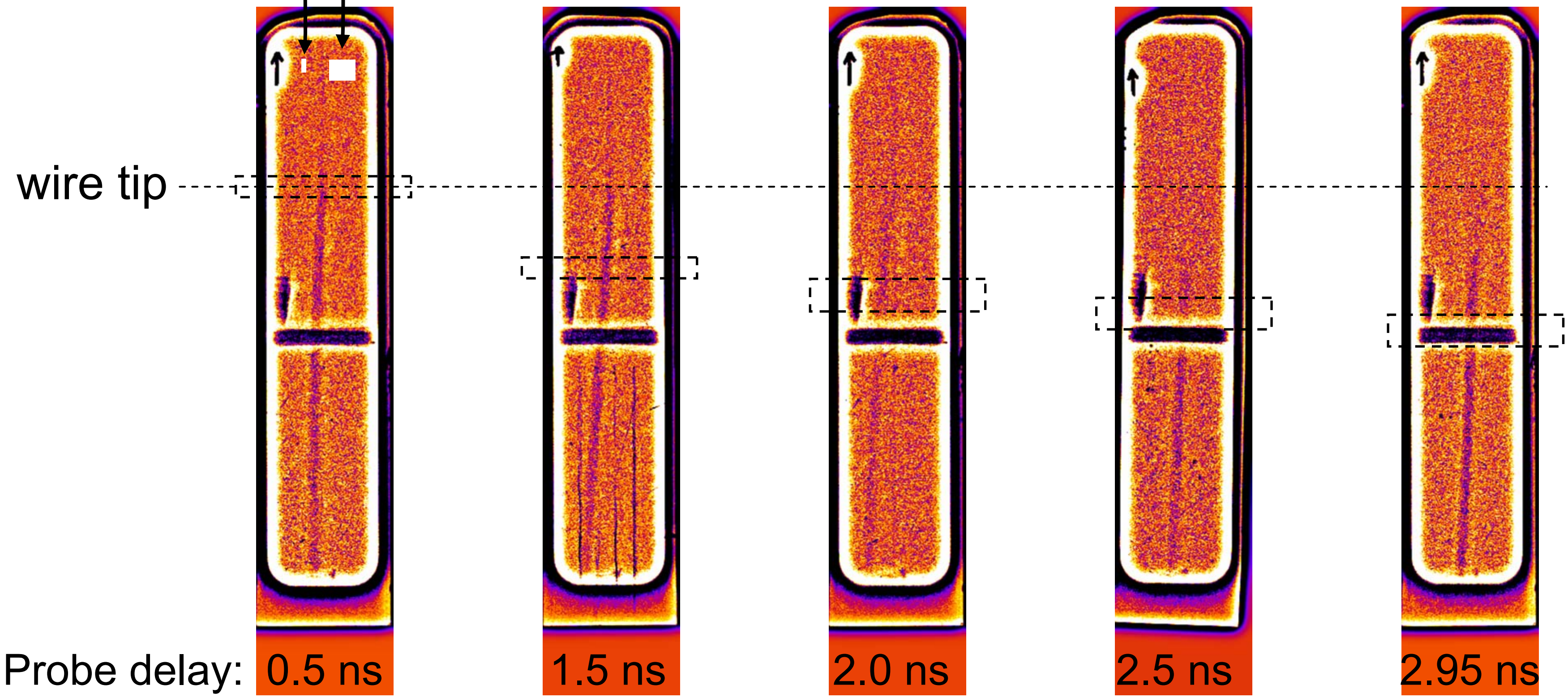


1D radiation hydrodynamic calculation (HELIOS)



K-alpha radiography shows wire explosion

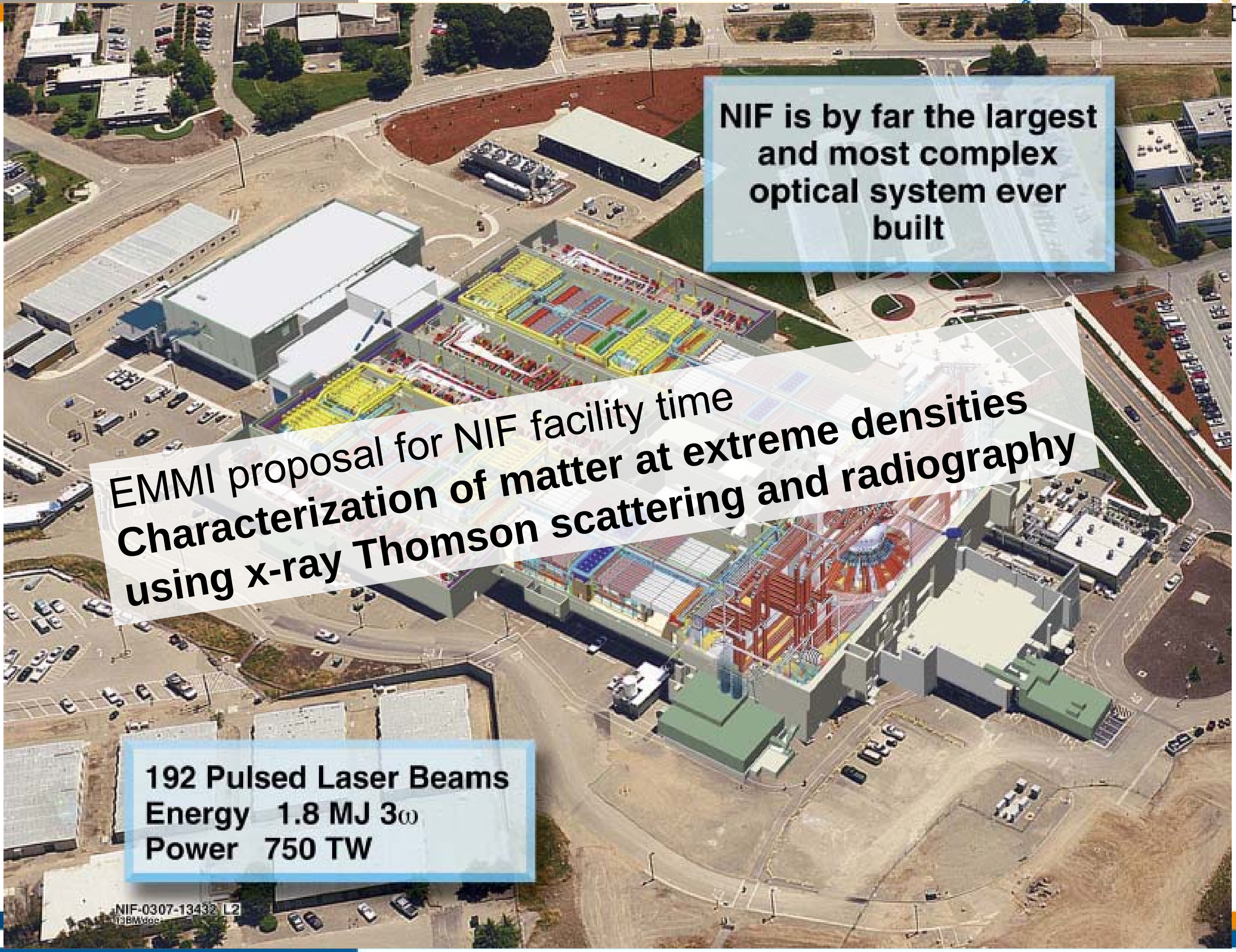
- Resolution ~20x60um (expected <10μm)
- Absolute position accuracy ~100x100um
- Expected temporal resolution ~10ps



In progress:

- Energy deposition from fits using Hybrid-PIC code
- Density profile along wire

2009 call for proposals for fundamental high-energy-density science experiments at NIF in FY2010-2012



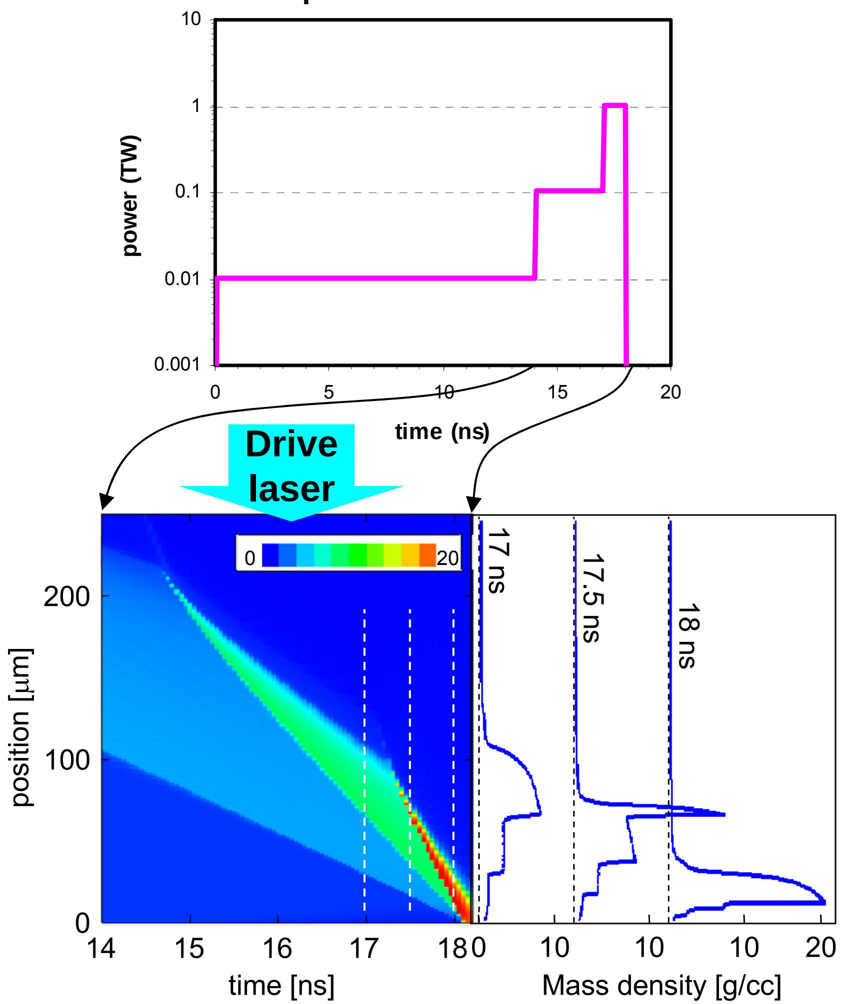
We will use NIF to compress matter extreme densities of >20x solid, while staying on low isentrope

EMMI

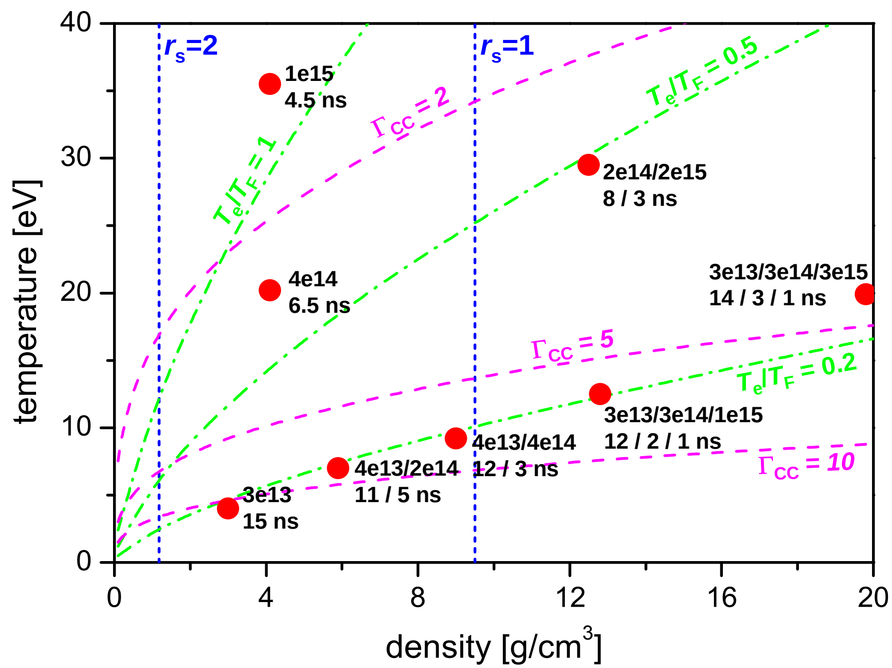
HELMHOLTZ ASSOCIATION

GSI

Use NIF pulse shaping capability to launch multiple successive shocks

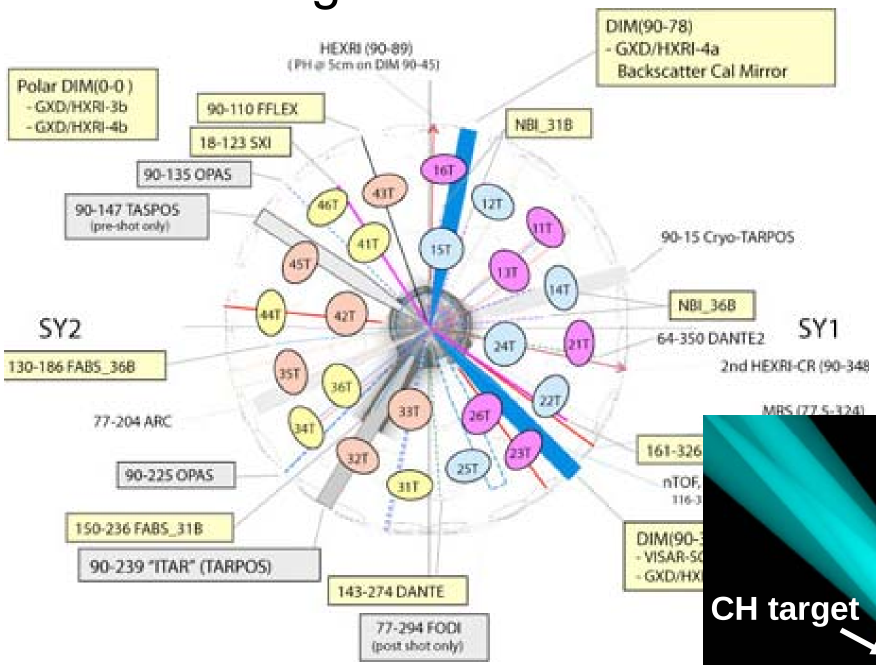


Rad-hydro calculations of multi-shock compression at NIF

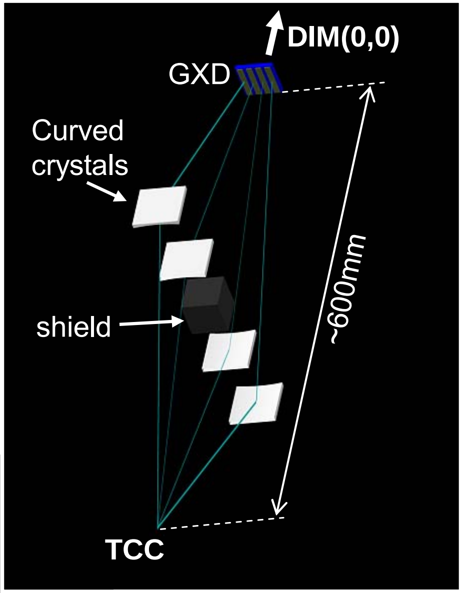


Multi-angle X-ray Thomson scattering and radiography characterize the compressed material

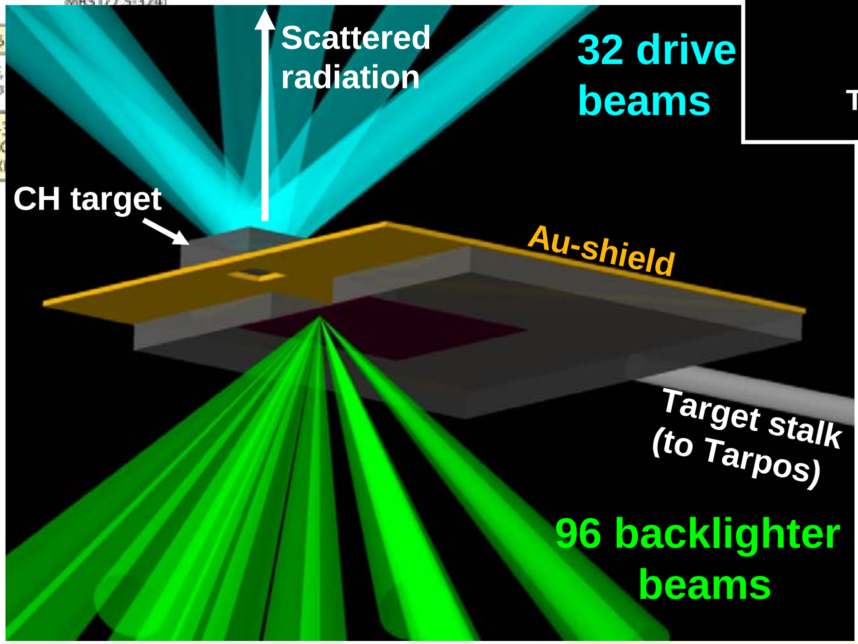
NIF target chamber



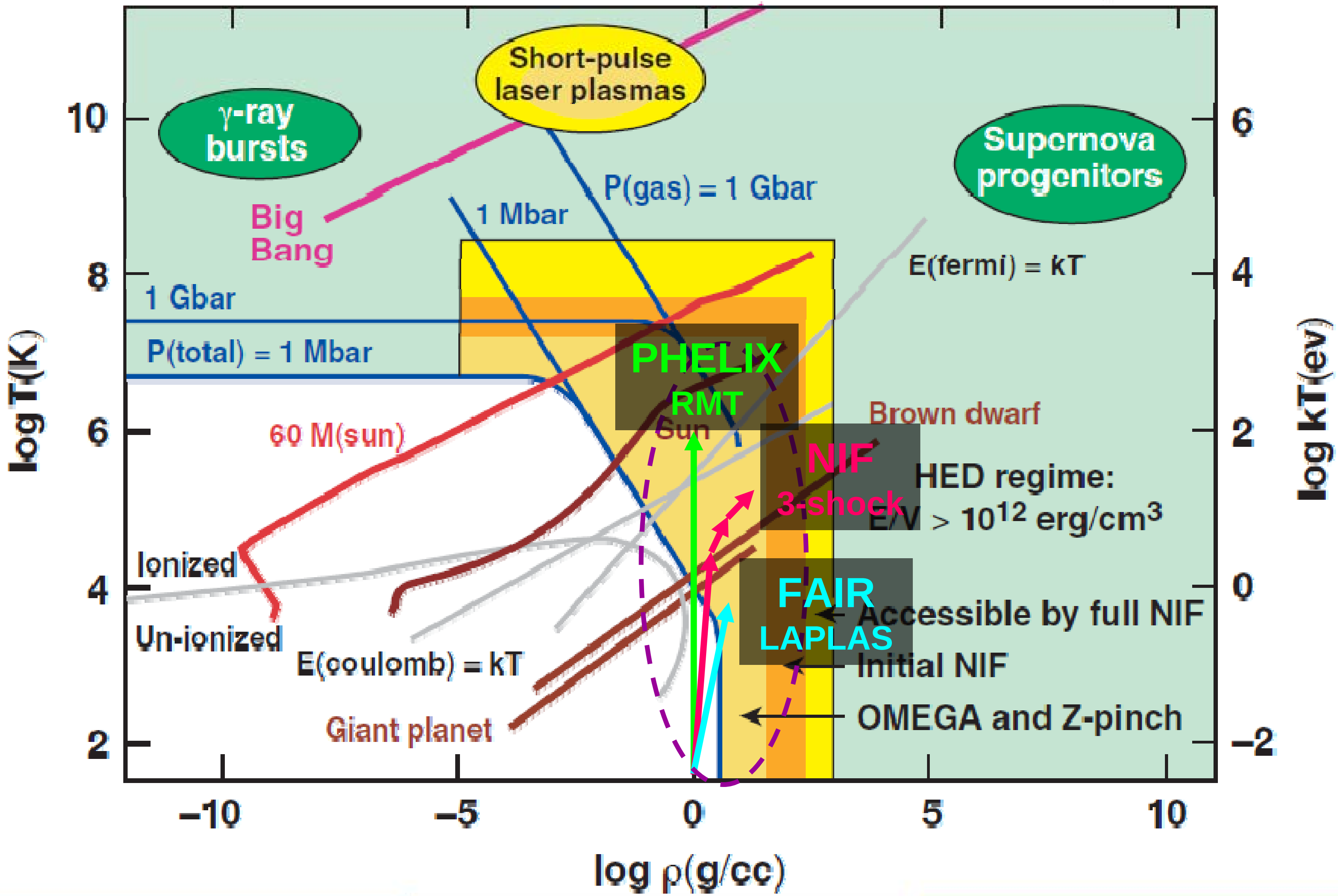
Multi-channel spectrometer design



Experimental setup



Summary: x-ray radiography as a tool to follow hydrodynamic evolution of HED matter



Summary/Conclusion

- PHELIX laser has been used to pump high-brightness multi-keV Kα sources
  - Hot-electron refluxing is crucial in achieving high efficiencies
- First pump-probe experiment at PHELIX demonstrates x-ray radiography with high spatial and temporal resolution
  - Warm-dense matter was created by short-pulse irradiation of thin wire targets (refluxing)
- X-ray backlighting techniques are powerful tools to characterize warm-dense matter
  - Radiography, Thomson scattering, …)

- **P. Spiller: Focusing magnets for U^{28+} at HHT would allow pulses of $>10^{10}$ ions at HHT**
- **Let us reconsider sending the PHELIX laser beam to HHT !**

•Many unique HEDS experiments can be done at HHT until 2018

•Develop our experimental capabilities in preparation for Plasma Physics at FAIR