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Plasma Physics with X-Ray Sources at the Limit of Today's Technologies

Applied Physics Colloquium

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Sandia National Laboratories

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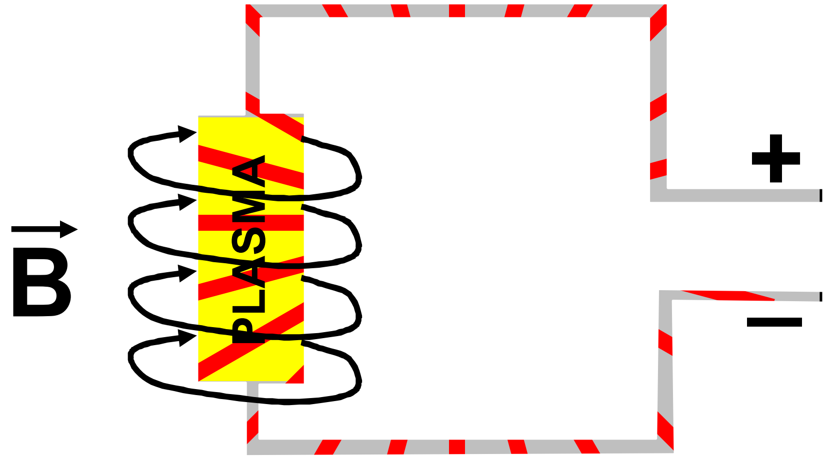
Introduction

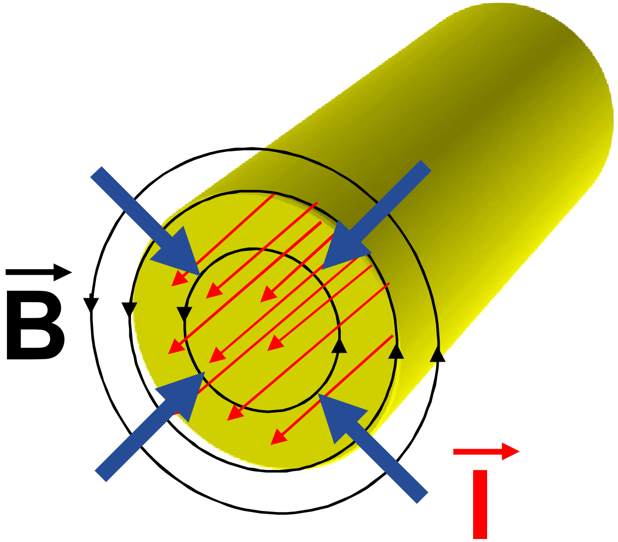
What is a Z Pinch?



What is a

Pinch?

PINCH !!

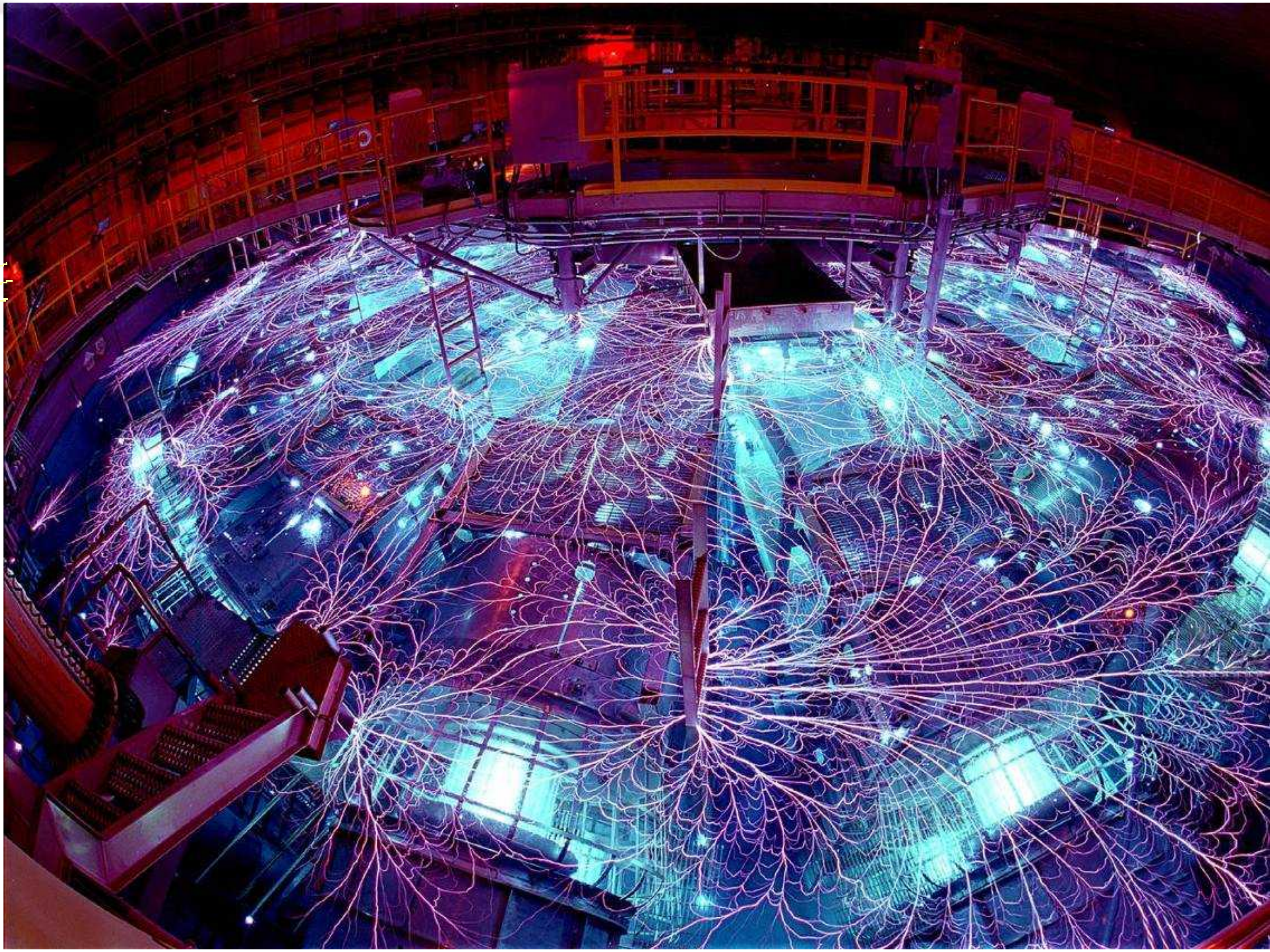


Introduction

World's largest

Z pinch

95 kV / 26 MA

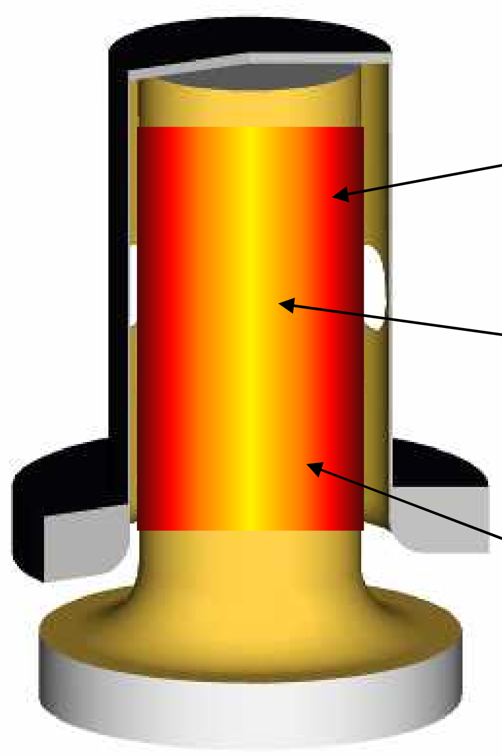


Outline

- Fusion Experiments on Z
- Expanding the Capacity of Z
- Looking 'Through' Z with Z Backlighter
- Many Uses for Z-Petawatt

Fusion Experiments

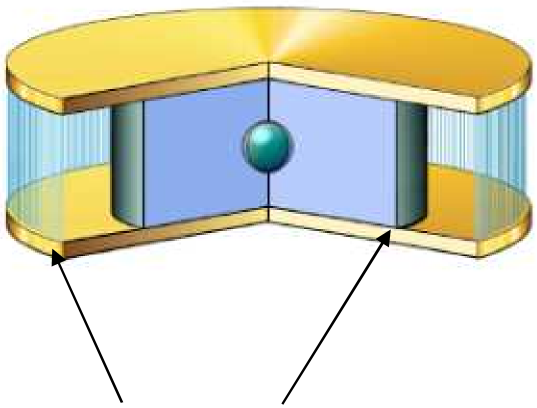
'Double Ended Hohlraum'



- Peak density ~ 40 g/cc
- CR up to 20
- T_e up to 100 eV (10^6 °C)

Fusion Experiments

‘Dynamic Hohlraum’

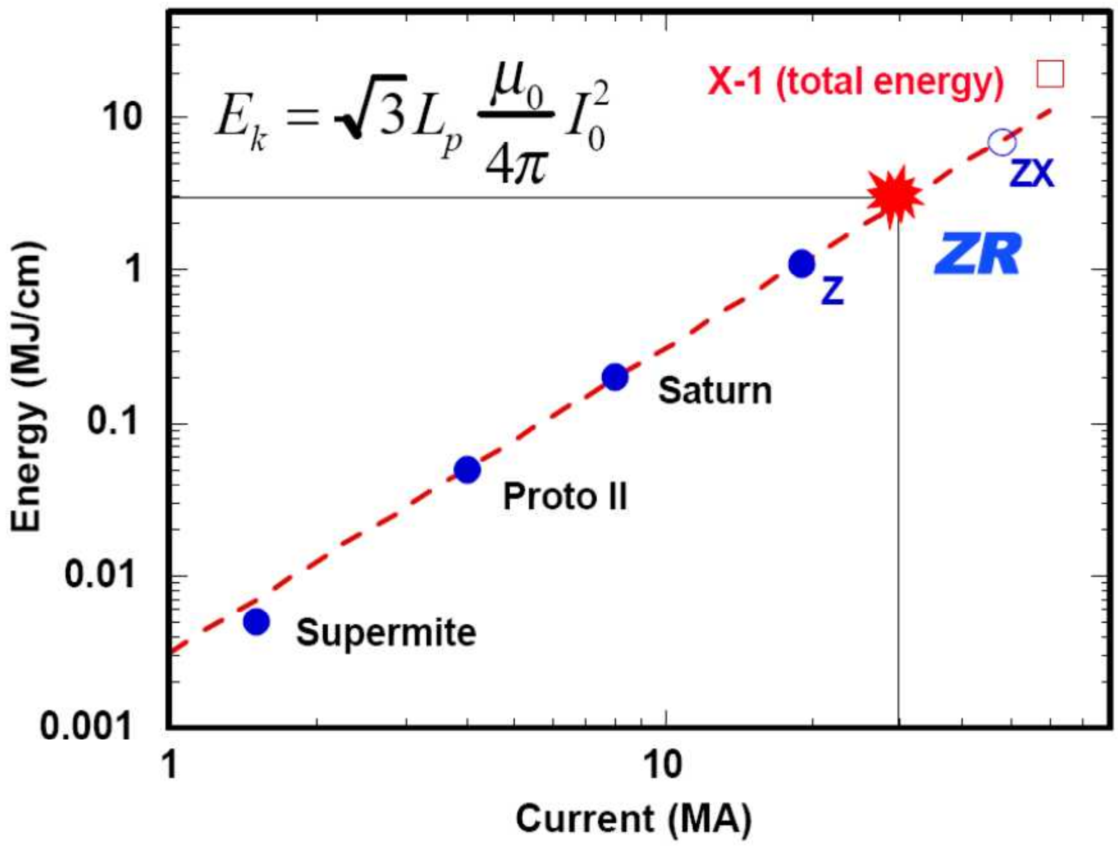


Two nested, colliding, current carrying liners (pinches)

Demonstrated D-D neutrons

- Maximum yield: > 10^{11} neutrons
- Convergence ratio: ~ 10
- Hohlraum temperature: ~ 220 eV
- Absorbed X-ray energy: ~ 24 kJ

Upgrading from Z to ZR



The ZR upgrade:

ZR = Z Refurbishment

Design Parameters

X-ray power: 350TW

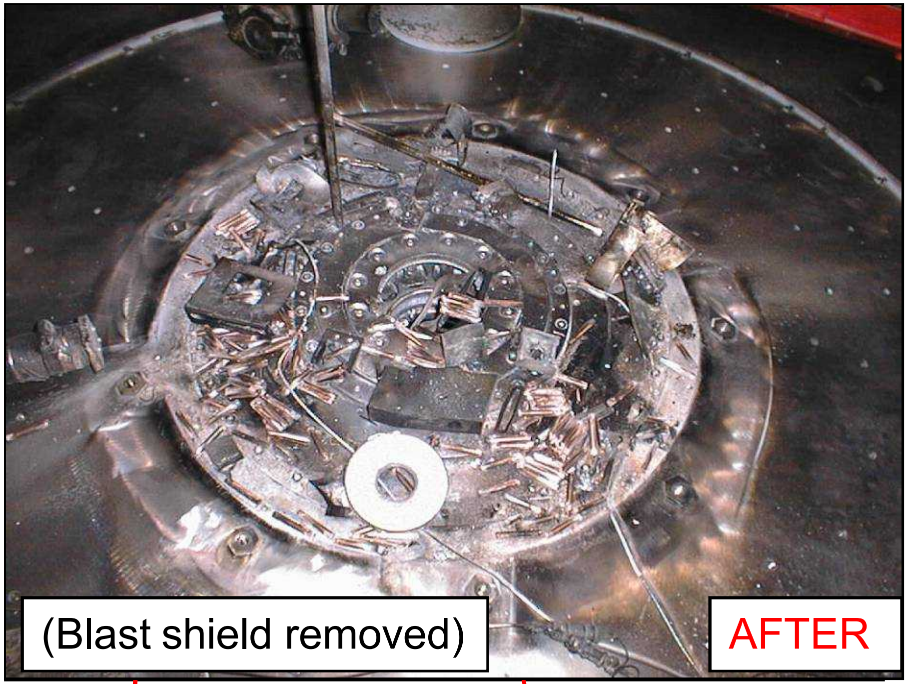
X-ray energy: 3 MJ

Max. current: 26 MA

Conv. Ratio ~ 25

How to Acquire Hydro-Data?

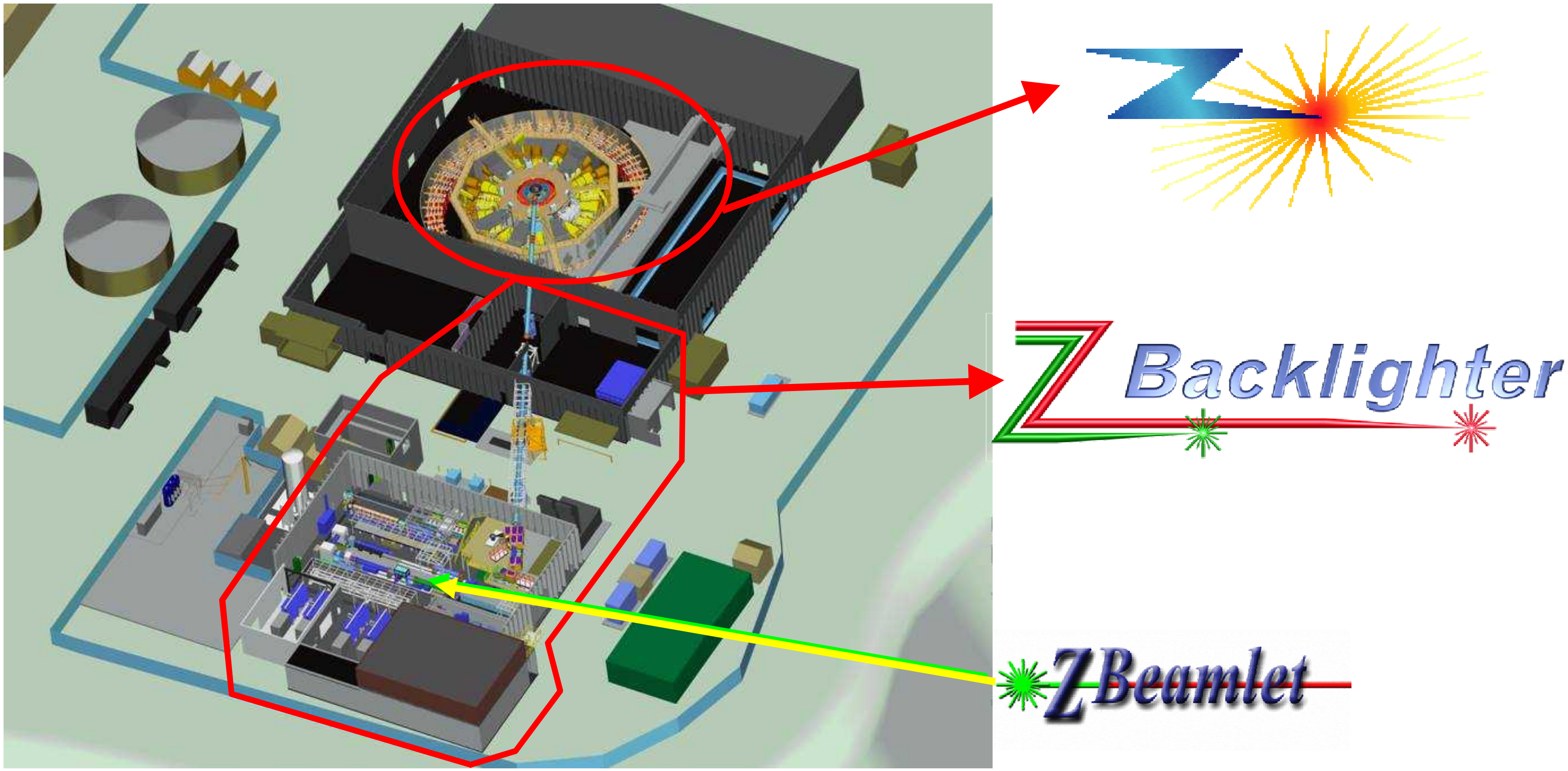
A Hostile Environment



Blast shield

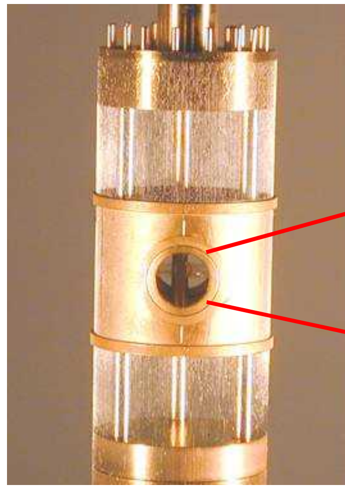
Wire array

Facility Overview

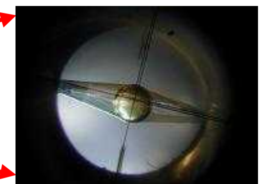


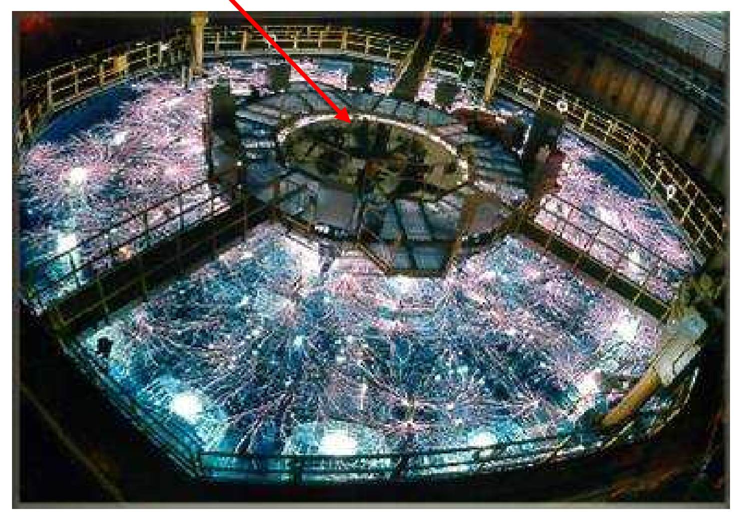
Backlighting on Z

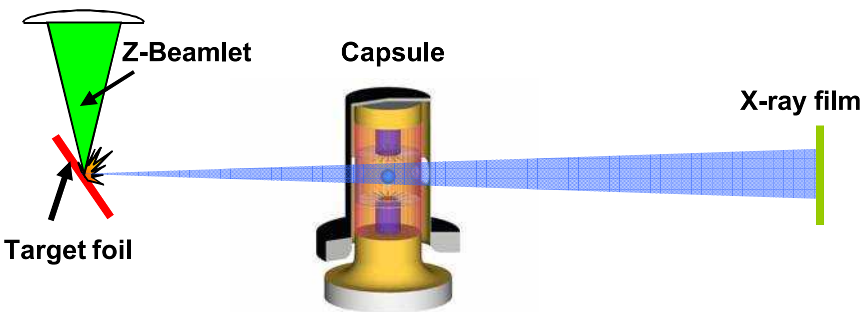
M.E. Cuneo *et al.*, PRL, 2002
G.R. Bennett *et al.*, Ph. Pl., *2003*



ICF capsule

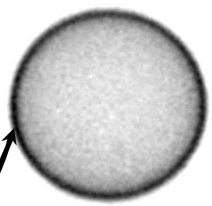




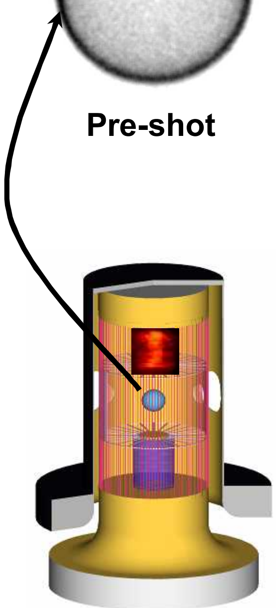


Compression on

ICF Spherical implosions



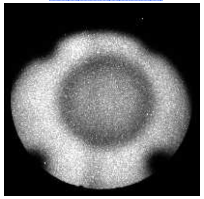
Pre-shot



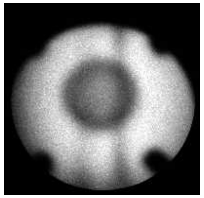
Double-Pinch

Hohlraum

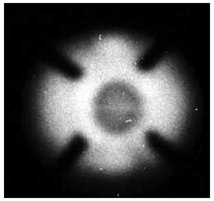
Z830



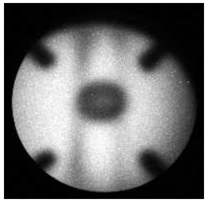
Z831

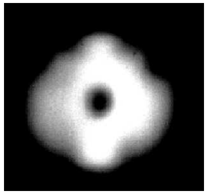


Z839

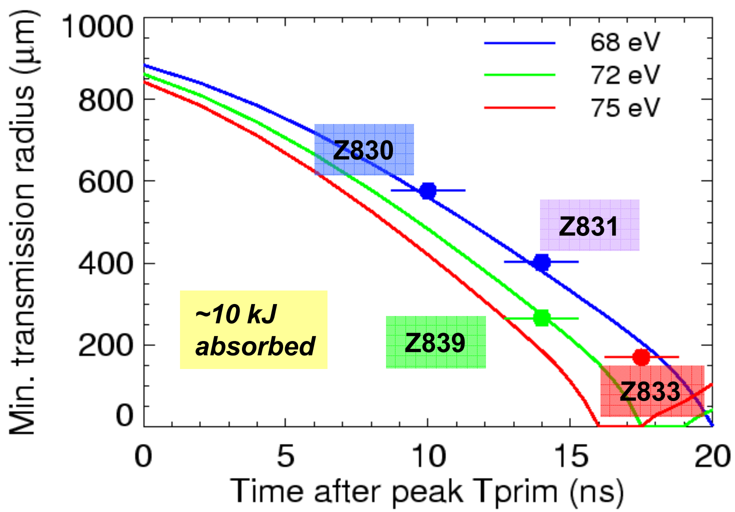


Z833

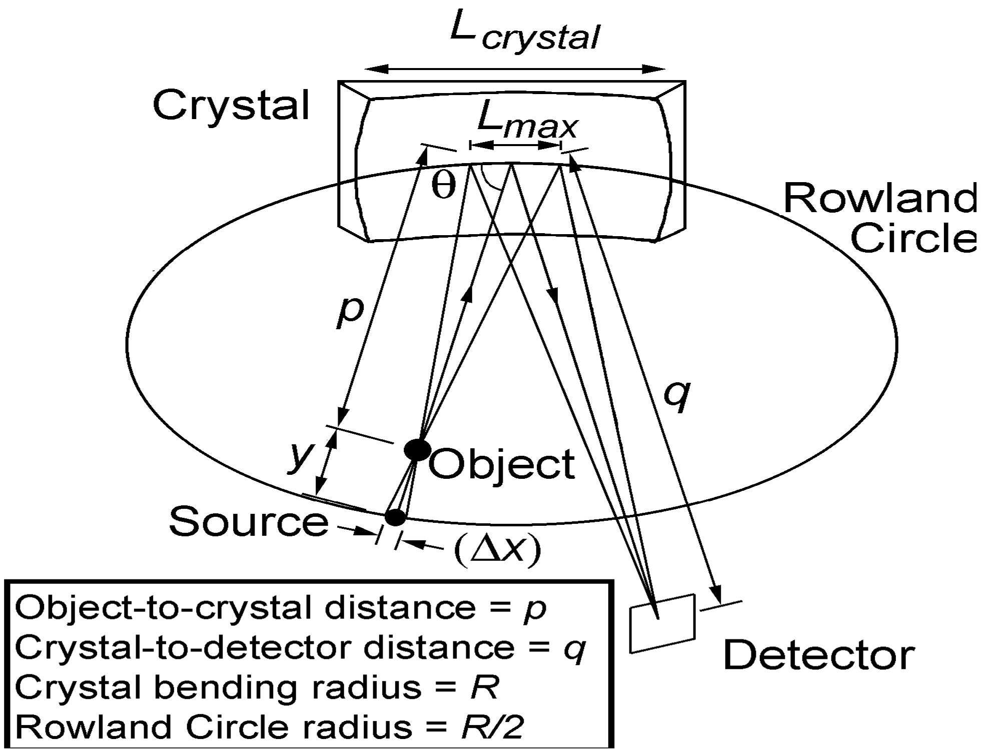




Radius vs. time



Crystal Backlighting



D.B. Sinars *et al.:*
Rev. Sci. Inst., 2002

Benefits:

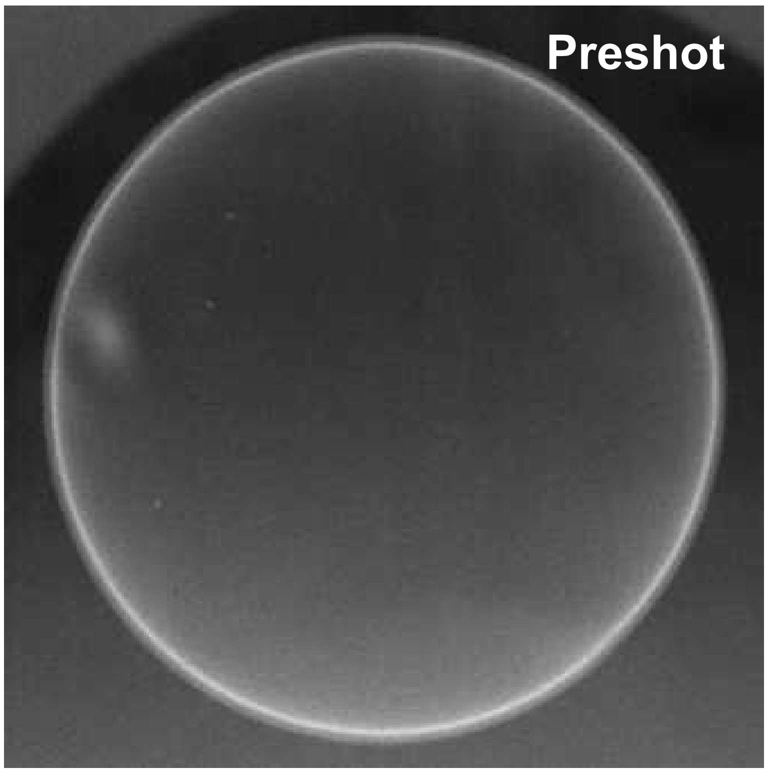
High spatial resolution thanks to excellent imaging

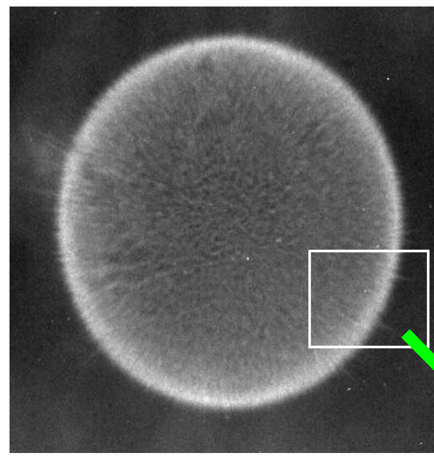
High spatial AND temporal resolution thanks to monochromatic radiation

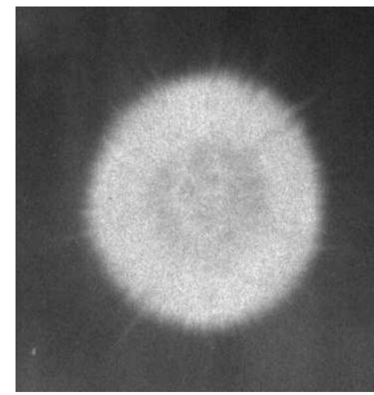
High spatial resolution bent-crystal imaging system revealed new features in imploding capsules

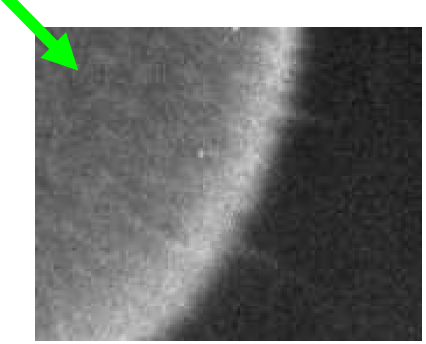
3.4-mm diameter plastic ICF capsule

Capsules had 100s of known defects on surface that apparently produced a myriad of small jets





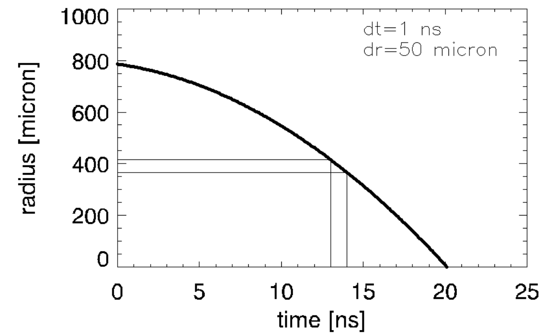




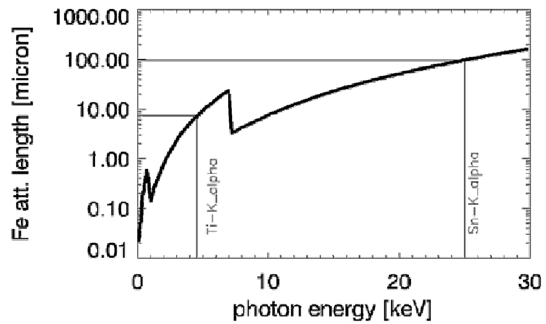
~20 μm diameter jets visible

Challenges for Improved Backlighting

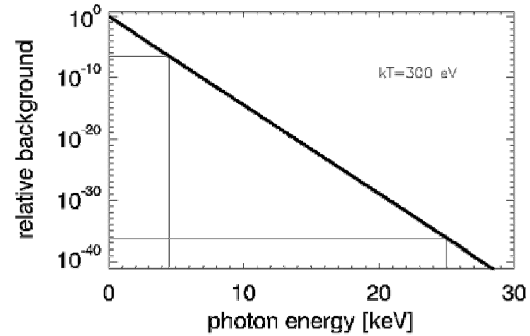
Motion Blur
- ➢ Shorter Pulses



Higher Densities
- ➢ Higher Photon Energies
  - ➢ Higher Laser Intensities



Higher Source Background
- ➢ Higher Photon Energies
  - ➢ Higher Laser Intensities

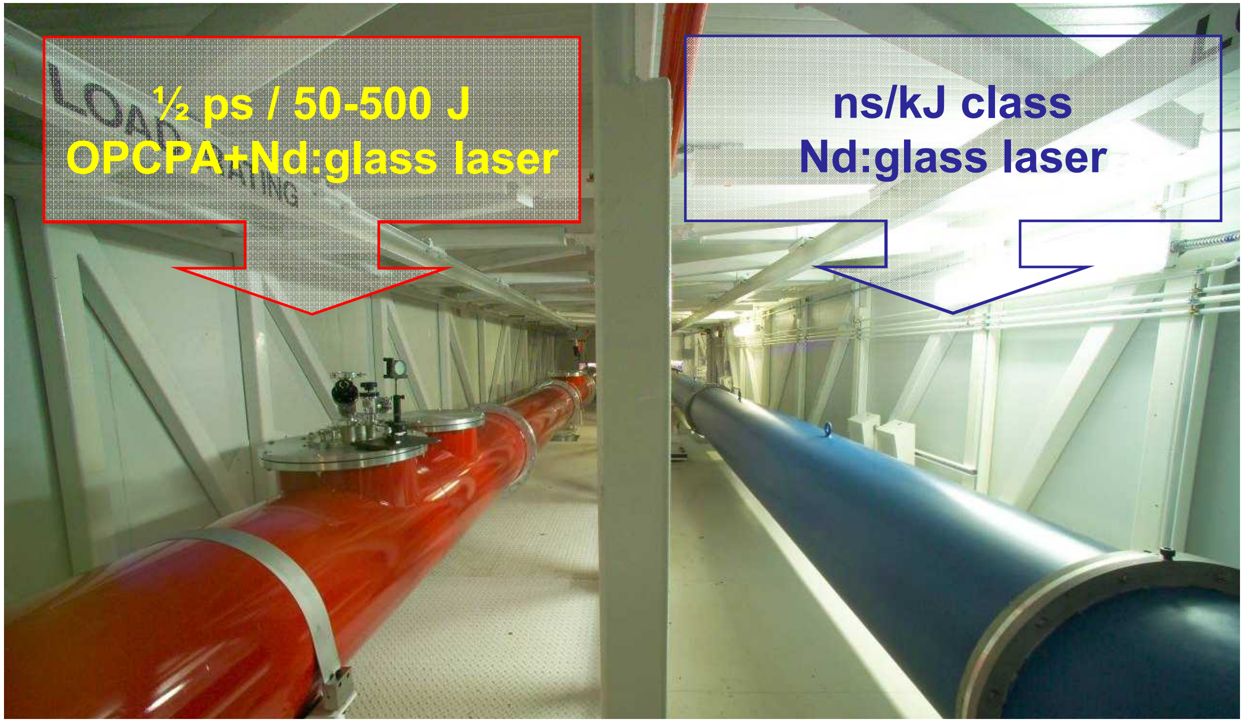


More Motivations for Energetic Radiation

- Isochoric Heating of Matter
  - # Warm Dense Matter
  - # Equations of State
- Solid Matter Probing
  - # Shock Physics
  - # Material Sciences
- Detector Development and Calibration
  - # Neutron Radiography
  - # X-ray Imaging
- Advanced Particle Beam Sources
- Astrophysics

Facility Overview

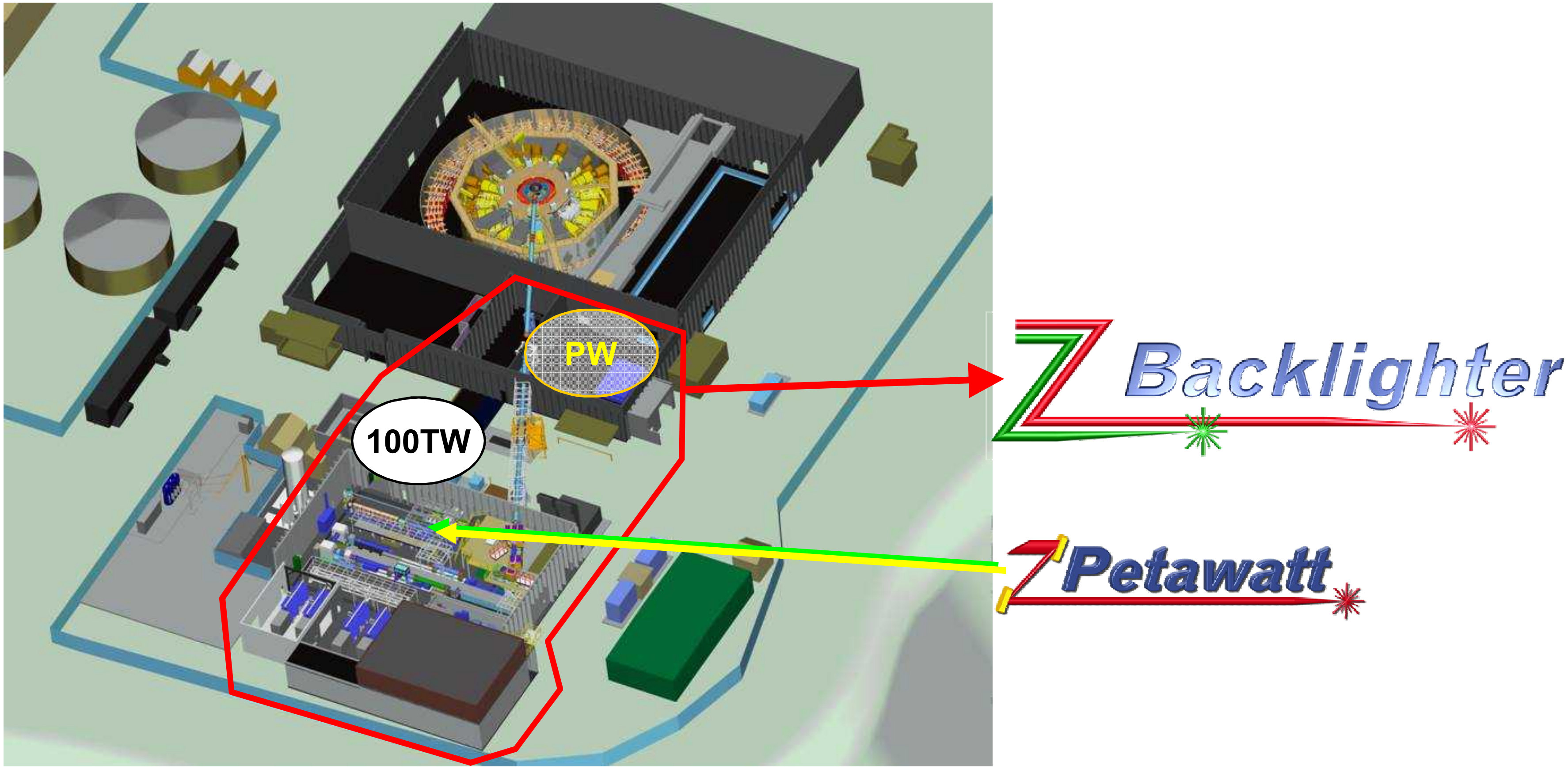
Z Backlighter



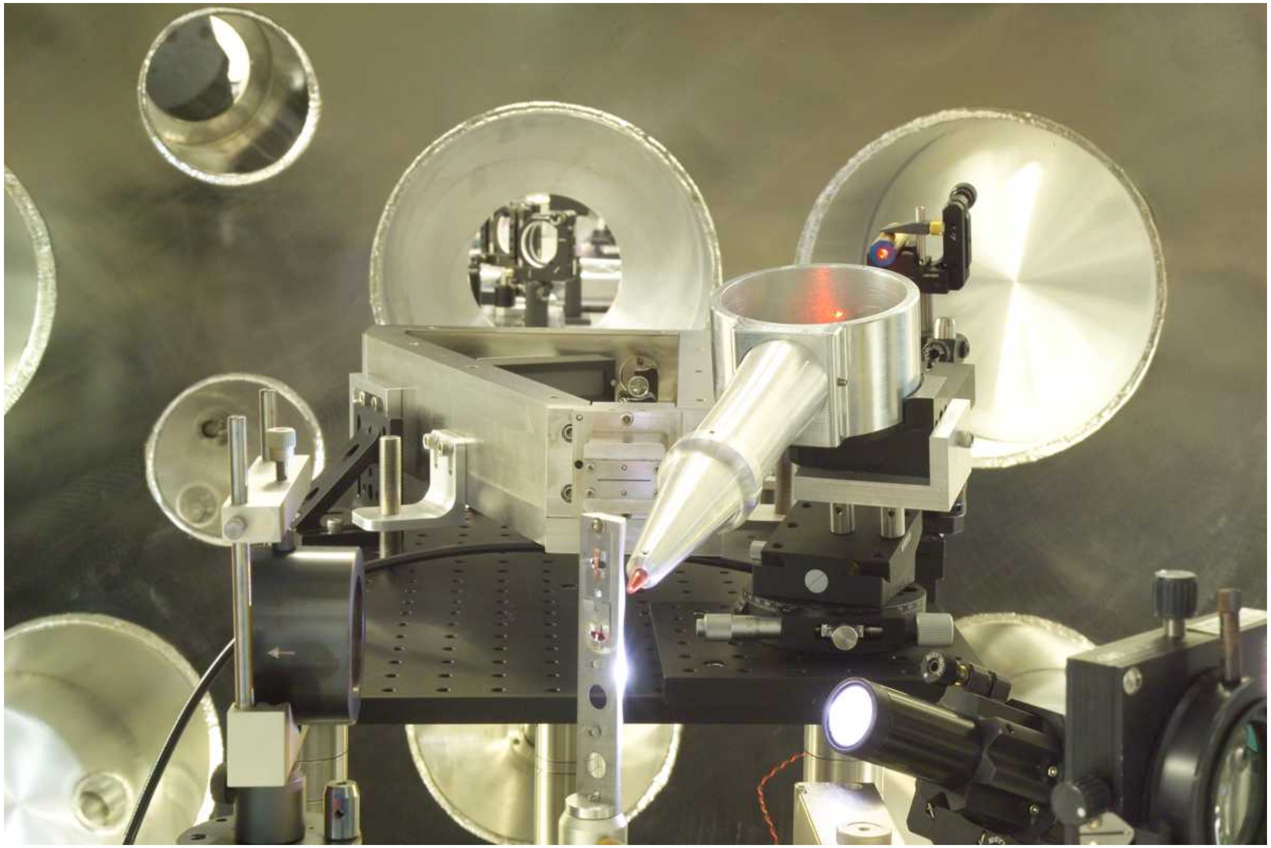
Z Petawatt

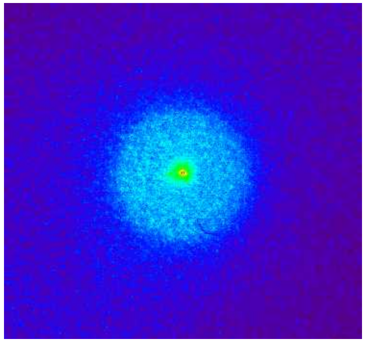
Z Beamlet

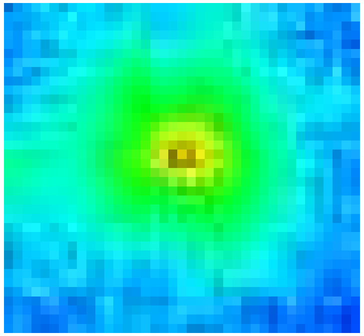
Facility Overview



Characterization of X-Ray Sources



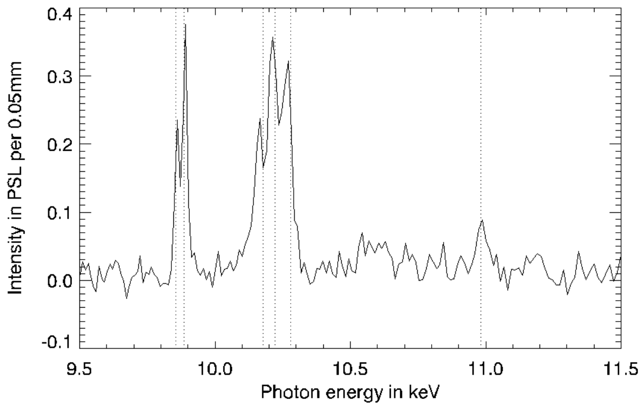




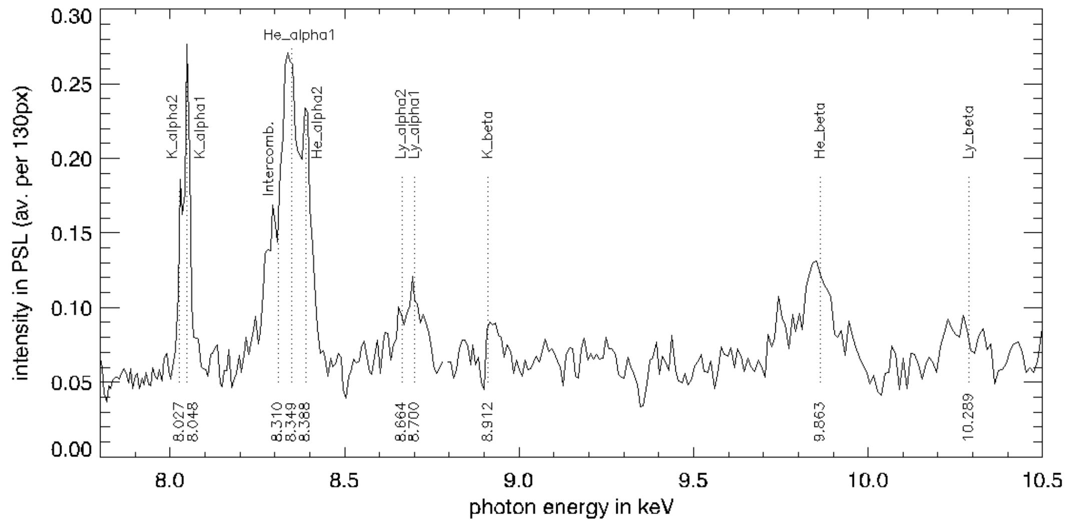
45 J shot on 100 μm Cu,
FWHM = 11 μm,
-> 8E19 W/cm²

Characterization of X-Ray Sources

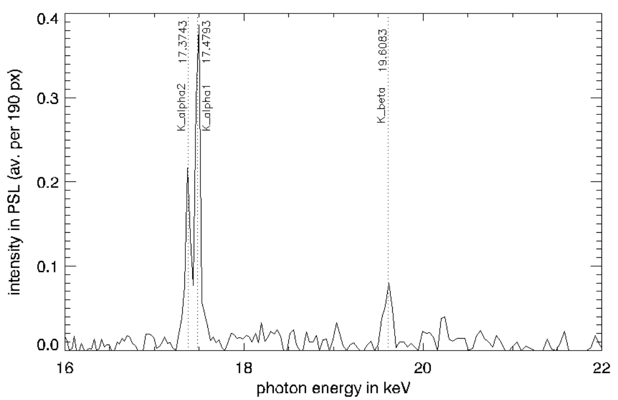
500 µm Ge



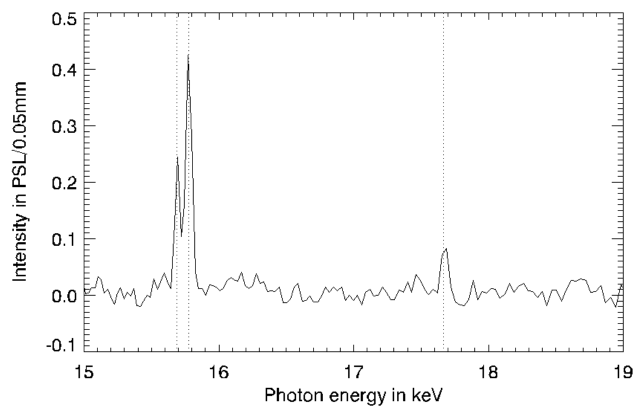
100 µm Cu



20 µm Mo

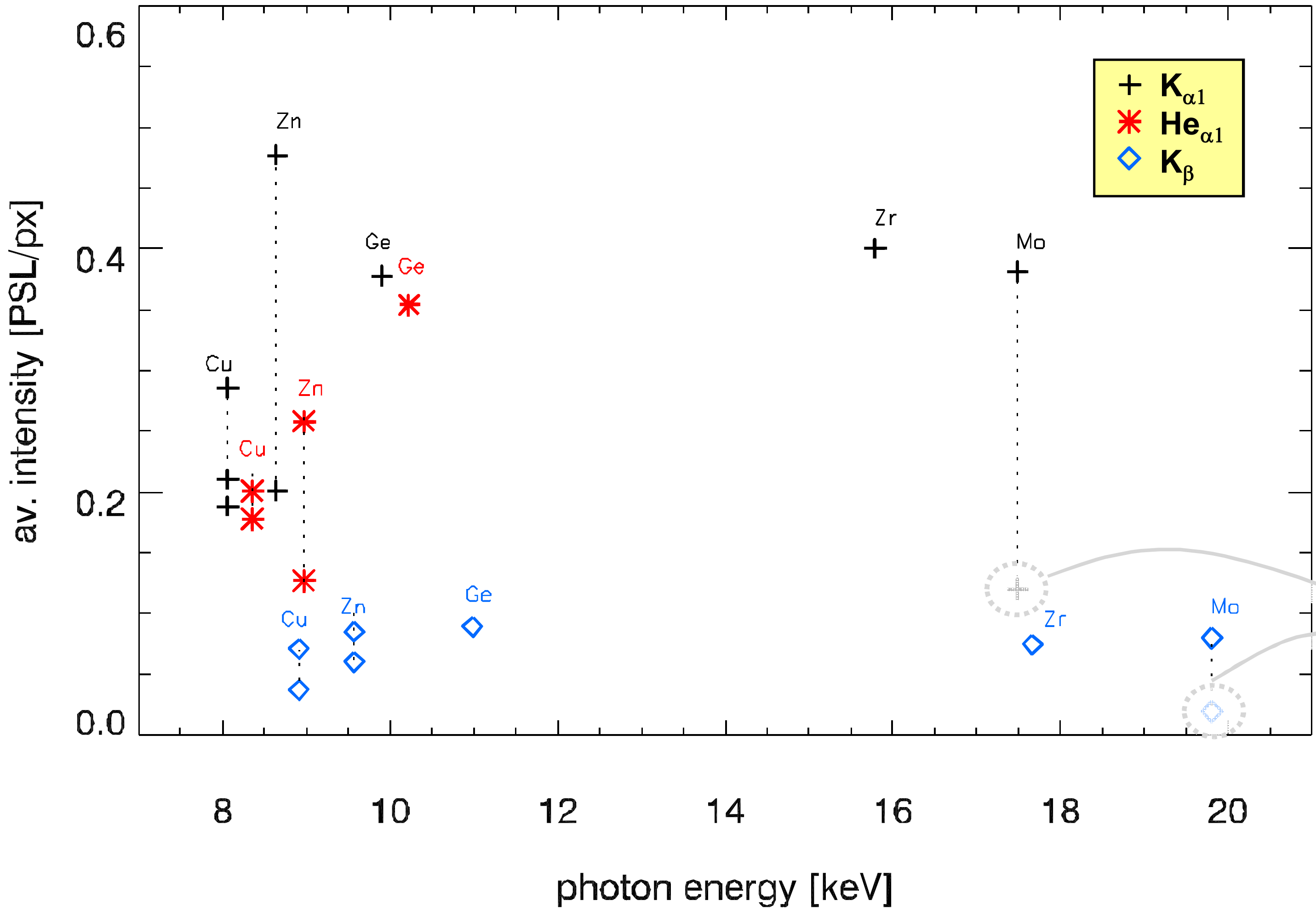


100 µm Zr



Characterization of X-Ray Sources

Maximum Line Intensities (normalized to 41J Laser Energy*)

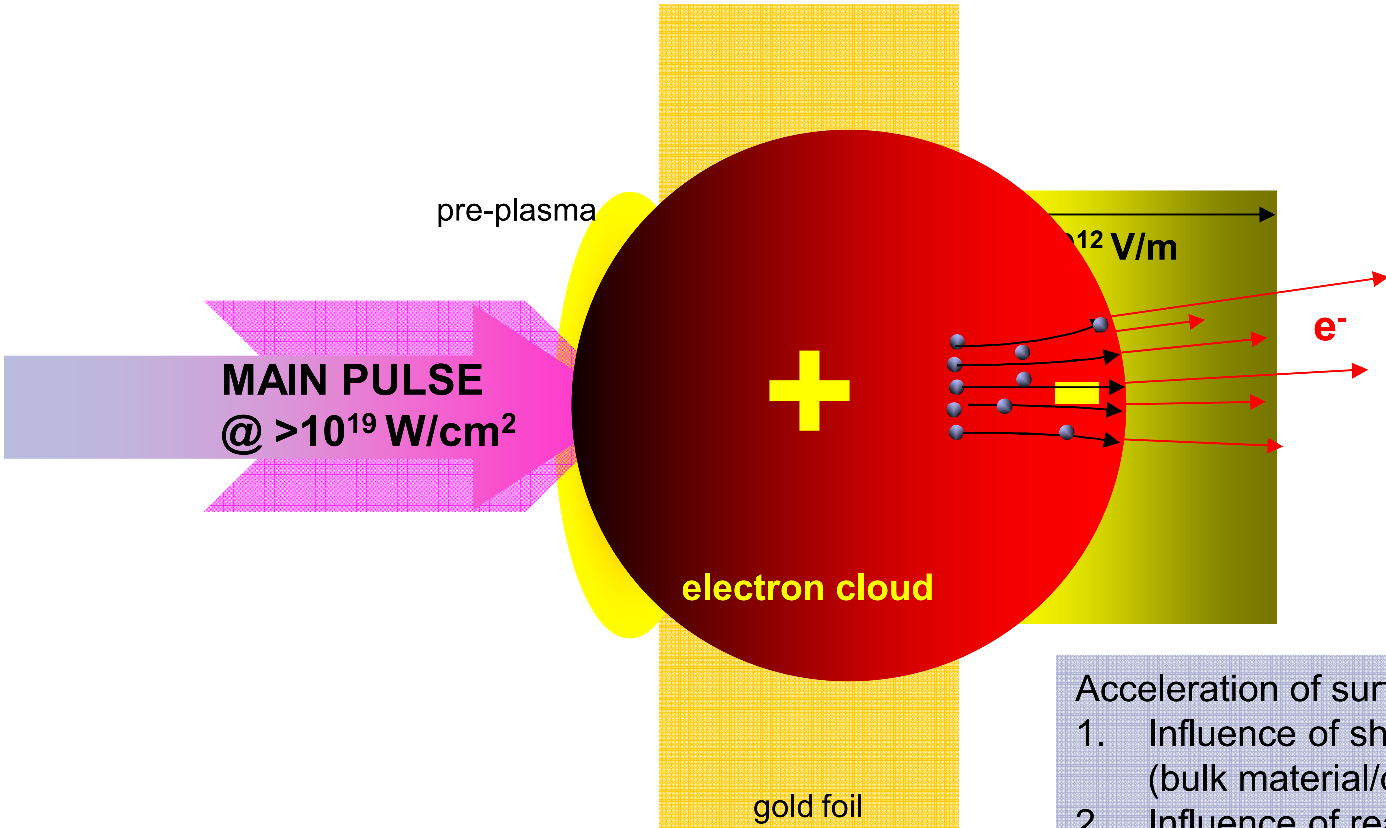


Shot series performed at 41±3.8J

3-day readout delay

Laser Accelerated Ions

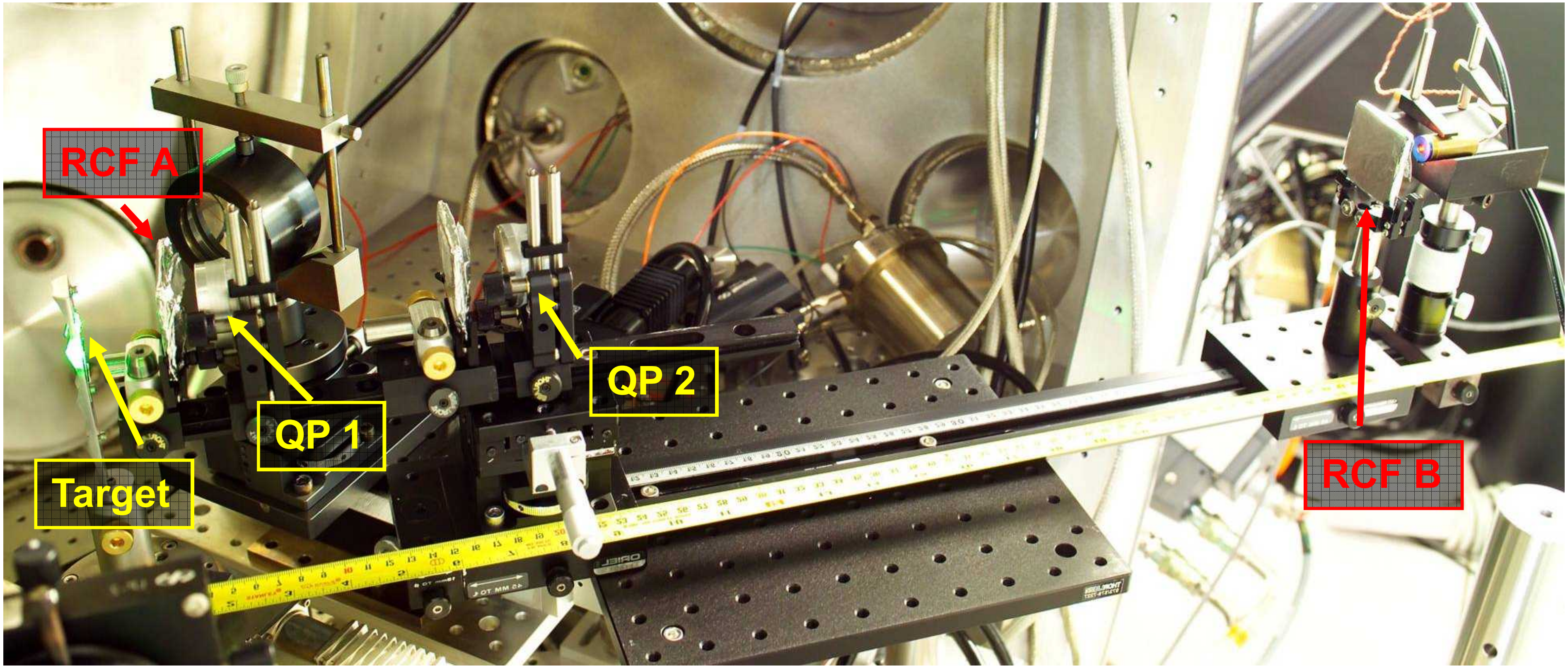
Target Normal Sheath Acceleration:
An alternative source of probe radiation?



Acceleration of surface contaminants

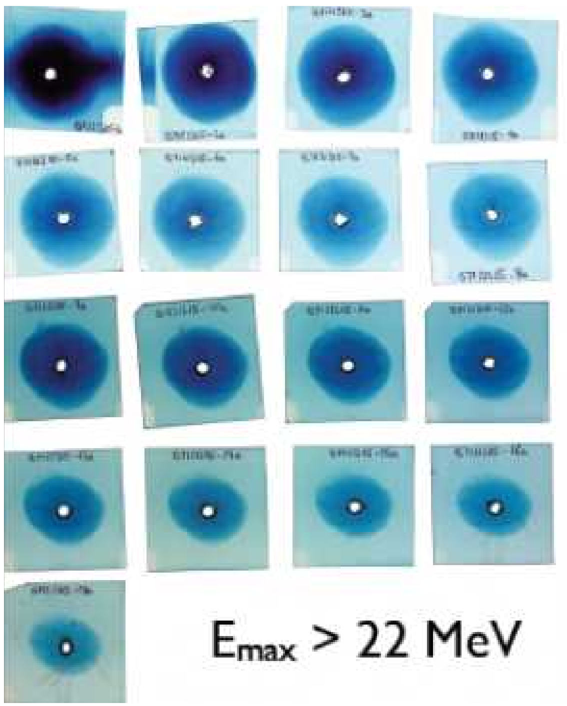
1. Influence of sheath formation (bulk material/conductivity)
2. Influence of rear surface (roughness/features/curvature)

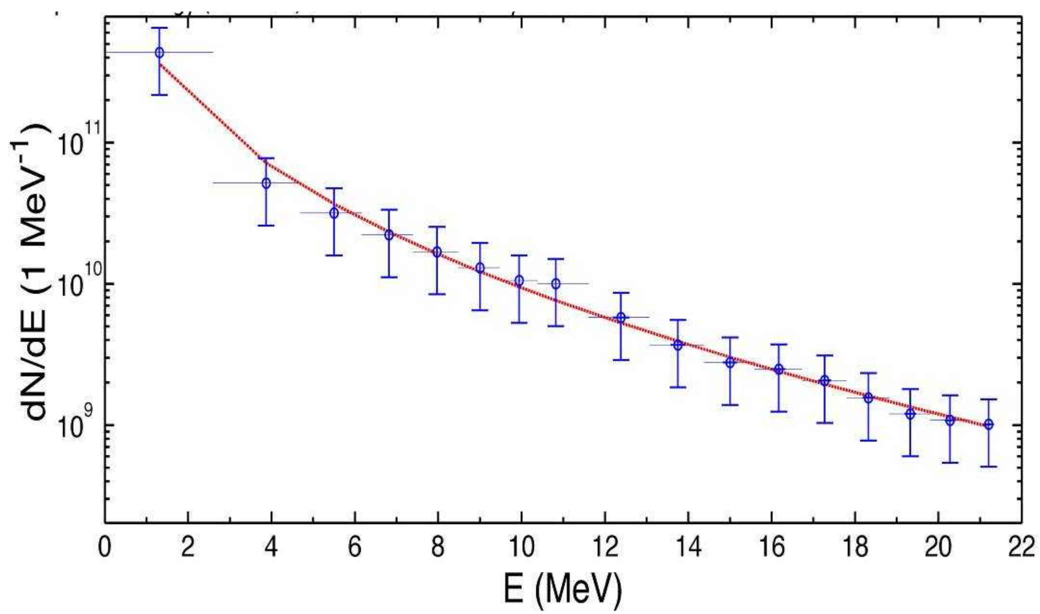
Proton Focusing (Magnetic)



Proton Focusing (Magnetic)

RCF A

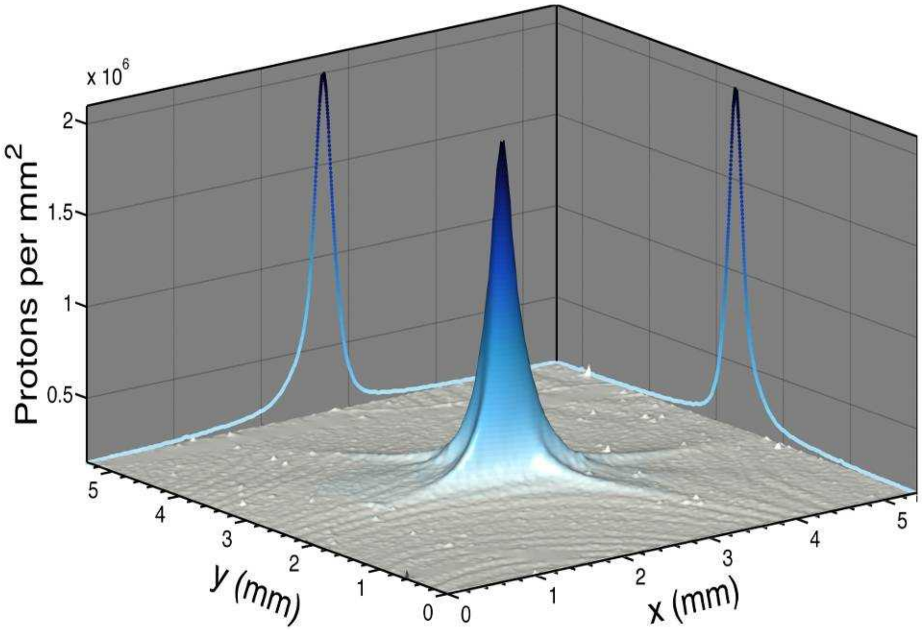




E_{las}=39J
kT_{fit}=1.24MeV
η(las → prot>4MeV) ~ 1%

Proton Focusing (Magnetic)

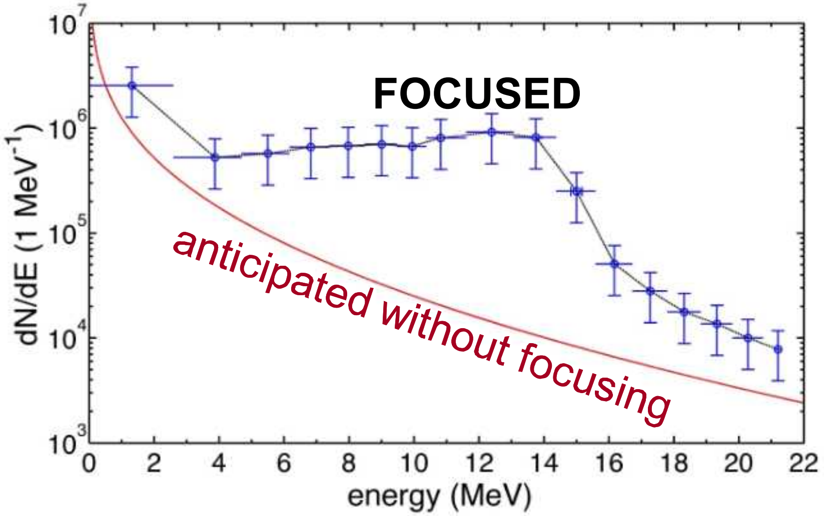
RCF B

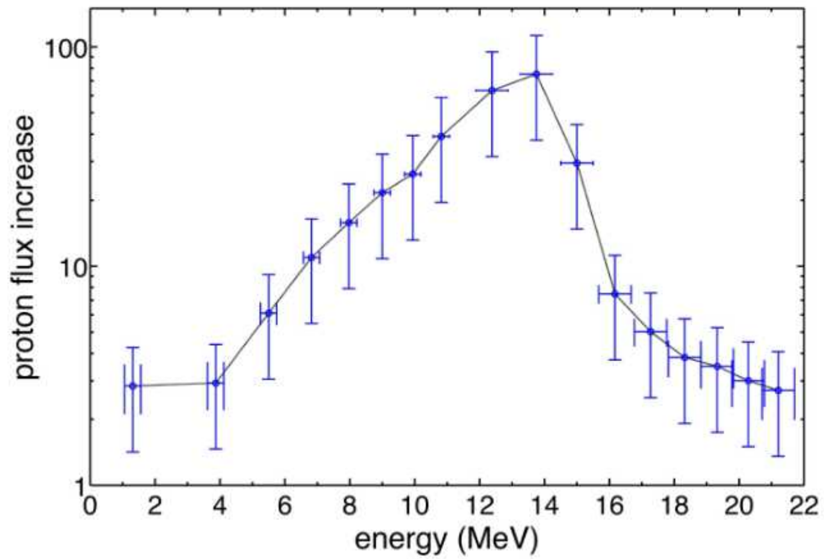


~200µm x 300µm FWHM @ 14 MeV

Proton Focusing (Magnetic)

Introducing an Aperture at the Focus





A dramatic proton flux increase can be achieved for selected energies!!