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ZR Neutron Diagnostic Suite

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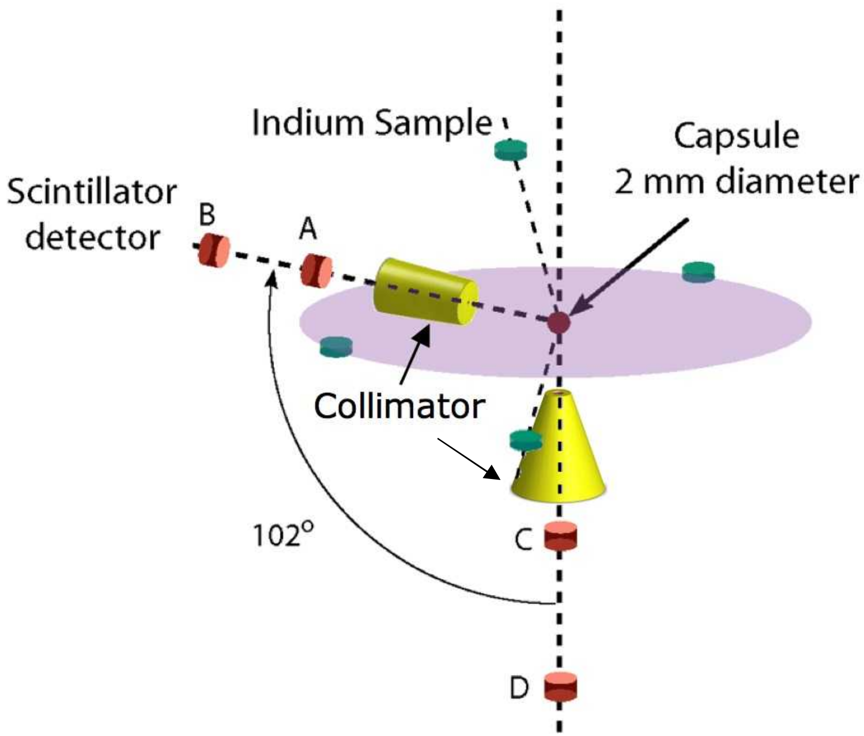

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ZR Neutron Diagnostic Suite*

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Abstract. The U. S. Department of Energy is supporting research at Sandia National Laboratories (SNL) to investigate the possibility of using pulsed power driven magnetic implosions (z-pinches) to drive inertial confinement fusion (ICF) targets on the ZR facility. This paper will focus on a new suite of neutron diagnostics that are assuming an ever-increasing importance in conducting these experiments. An important issue in developing these diagnostics is that they must operate in an intense hard x-ray bremsstrahlung background of some 10^9-10^{10} rads/s. Diagnostics that are presently being developed for initial experiments include neutron-of-flight detectors that are fielded at several polar angles to measure ion temperature and several different neutron activation detectors to measure DD and DT neutron total yields. Future neutron diagnostics that will be added to the suite include neutron imaging, neutron bang, and neutron reaction history. Finally, we are also investigating the feasibility of an n-p recoil magnetic analyzer for high precision neutron spectroscopy measurements.

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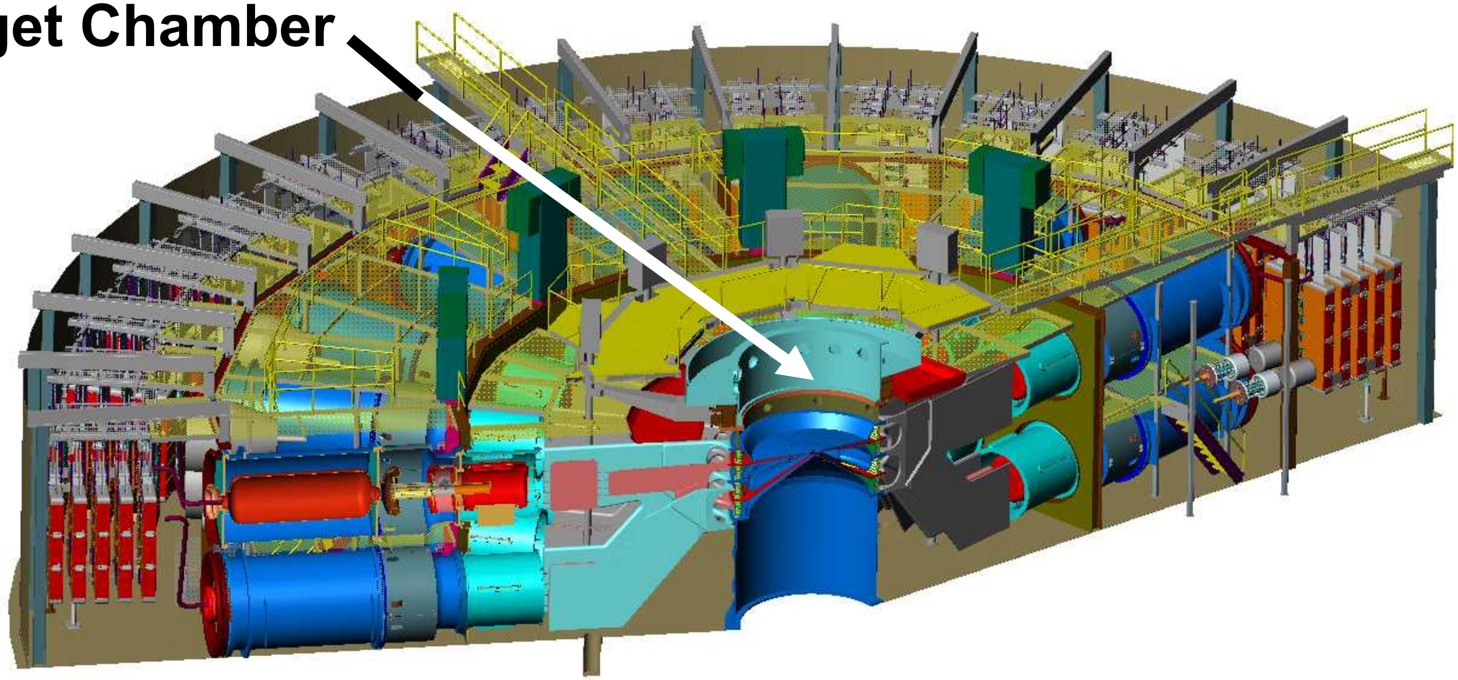
The ZR pulsed-power accelerator provides efficient time compression and power amplification for inertial confinement fusion (ICF) research

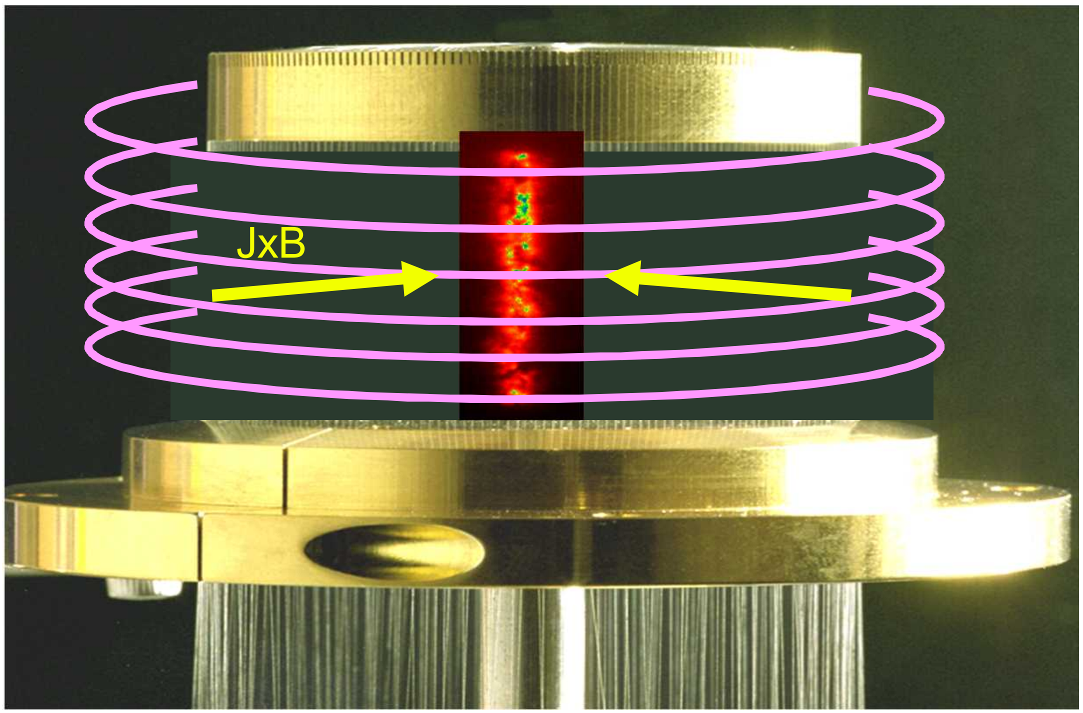
Target Chamber



ZR predicted performance:

22.0 MJ stored energy
26 MA peak load current
100 TW electrical power to load
300 TW x-ray power

Z pinch loads efficiently convert electrical energy into radiation



Initiation

Implosion

Stagnation

The largest DD neutron yields obtained in gas puff z-pinch and dynamic hohlraum (DH) driven capsule experiments on Z are shown in the table below

These experiments were all conducted on Z at peak load currents of ~ 20 MA

Target Type	DD Neutron Yield into 4π (In Activation)
Deuterium Gas Puff Z-pinch	3.7×10^{13}
2mm Diameter DH Driven Be Capsule	2.7×10^{11}
2mm Diameter DH Driven Plastic Capsule	2.6×10^{11}

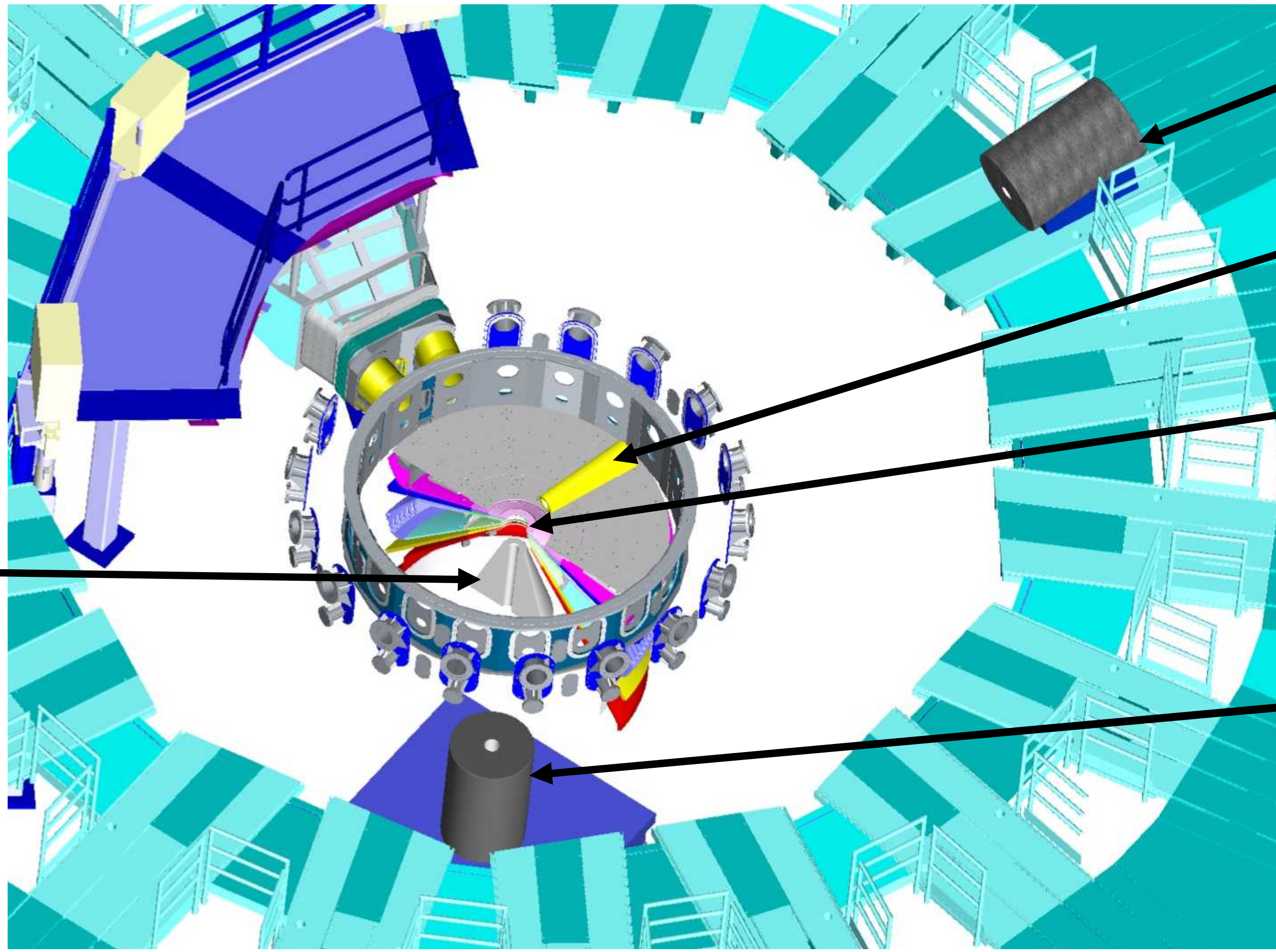
Modeling of the deuterium gas puff shots predict DD yields of 1×10^{14} on ZR at peak load currents of 26 MA

We are currently planning DT experiments on ZR that should increase the above yields by a factor of approximately 100

References: C. A. Coverdale et al., Phys. Plasmas 14, 056309 (2007)
C. A. Coverdale et al., Phys. Plasmas 14, 022706 (2007)
R. J. Leeper et al., J. Physique 133, 175 (2006)
C. L. Ruiz et al., Phys. Rev. Lett. 93, 015001 (2004)

The overall layout of the initial set of neutron diagnostics on ZR is shown here

Top View



ZR total neutron yields will be measured with three different activation detectors

Indium* (DD neutron yield)

^{115}In (n,n') ^{115m}In (E$_{thres}$=336.0 keV, E$_{\gamma}$=336.0 keV, $\tau_{1/2}$ = 4.49 hr)

Copper (DT neutron yield)

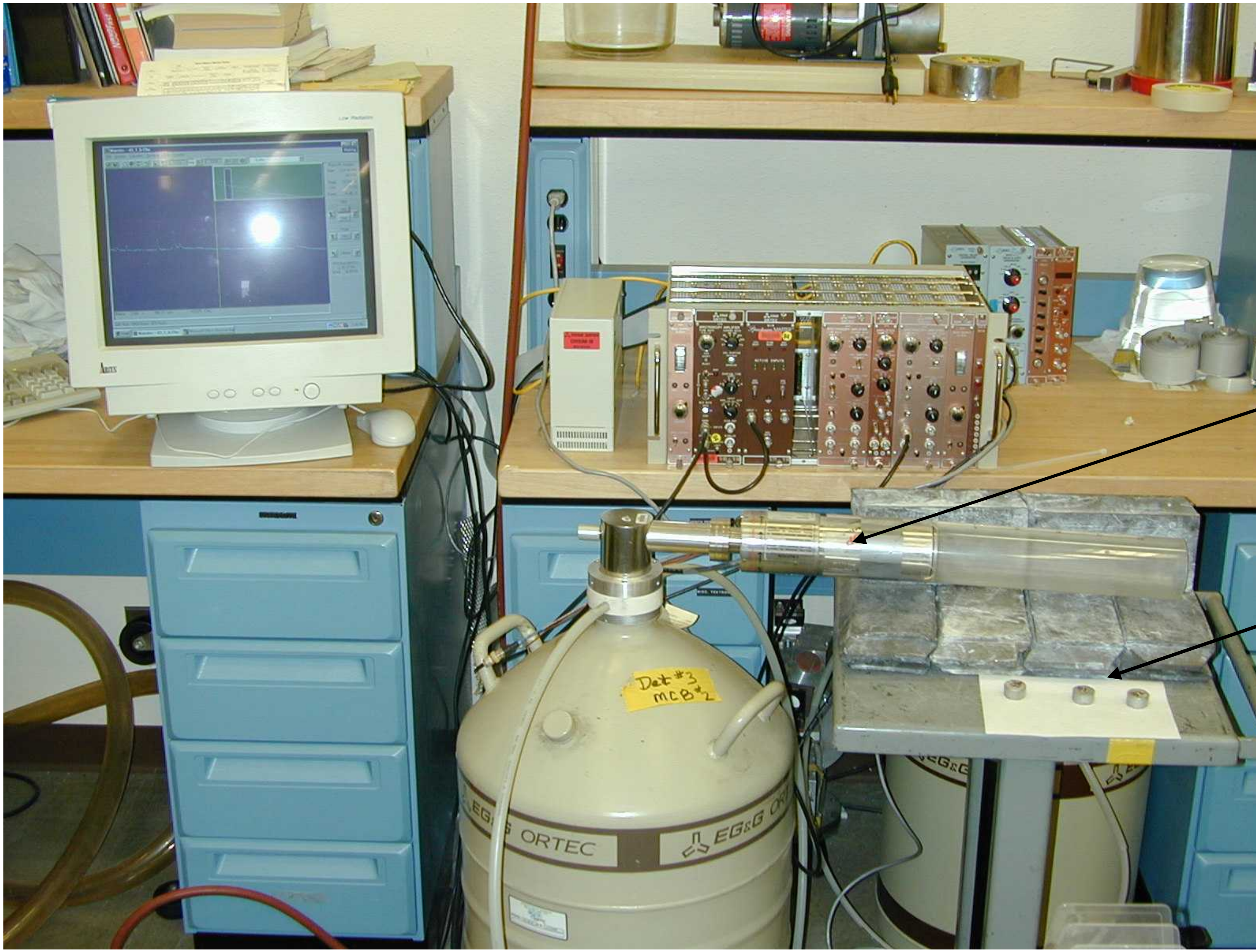
^{63}Cu(n,2n)^{64}Cu (E$_{thres}$=10.9 MeV, β+ decay, $\tau_{1/2}$ = 9.74 min)

Beryllium (DD and DT neutron yield)

^{9}Be (n,α) ^{6}He (E$_{thres}$=0.67 MeV, β^{-} with 3.5 MeV endpoint, $\tau_{1/2}$ = 0.8 sec)

* The ^{115}In (n,n') ^{115m}In reaction may also be activated by a large flux of hard x-rays via the reaction ^{115}In (γ,γ') ^{115m}In. Consequently, any hard x-ray background present in a particular experiment must be characterized to determine its possible contribution to the indium activation signal

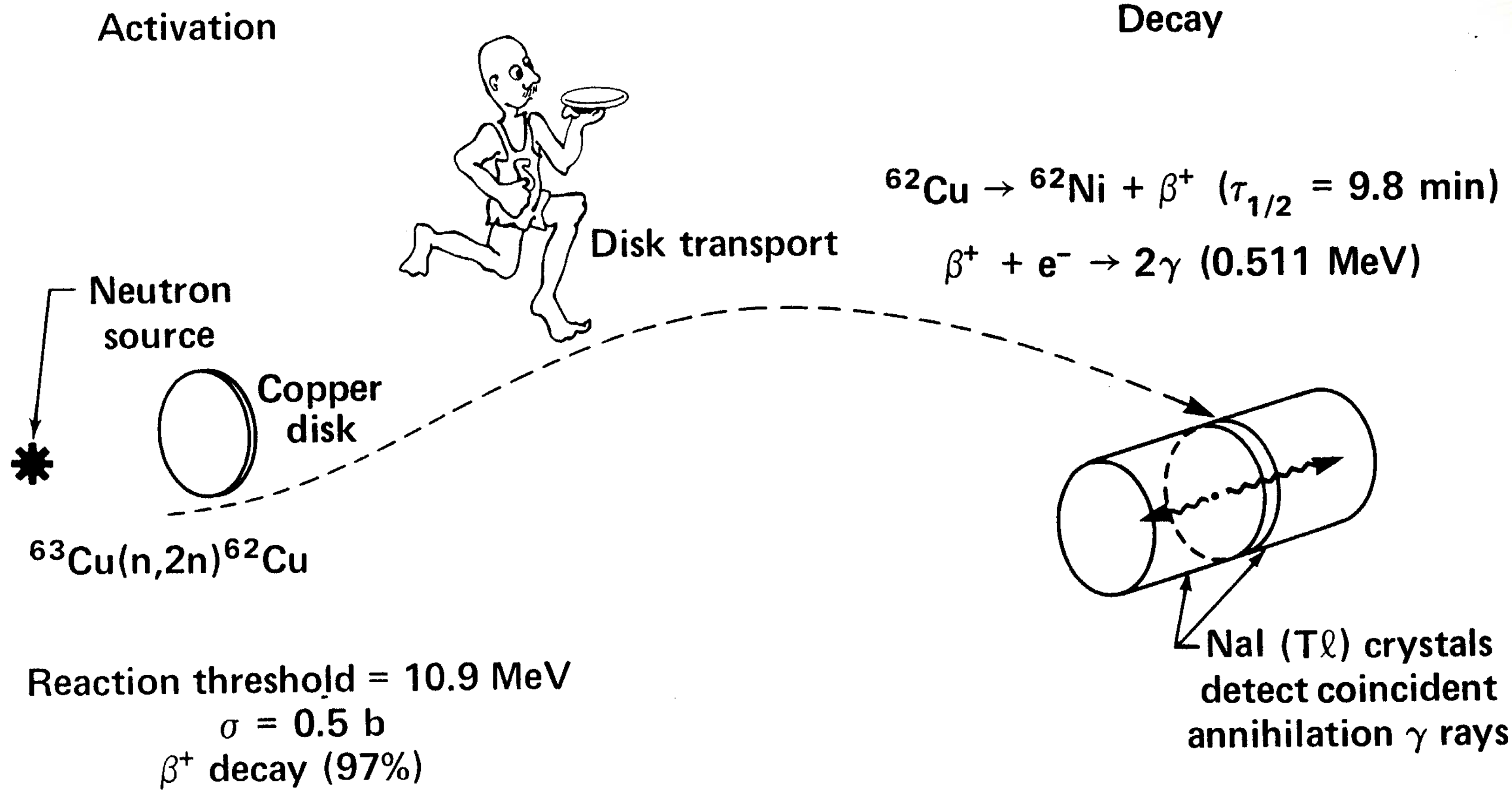
ZR In activation counting system: Germanium detector with associated electronics



HP Ge Detector

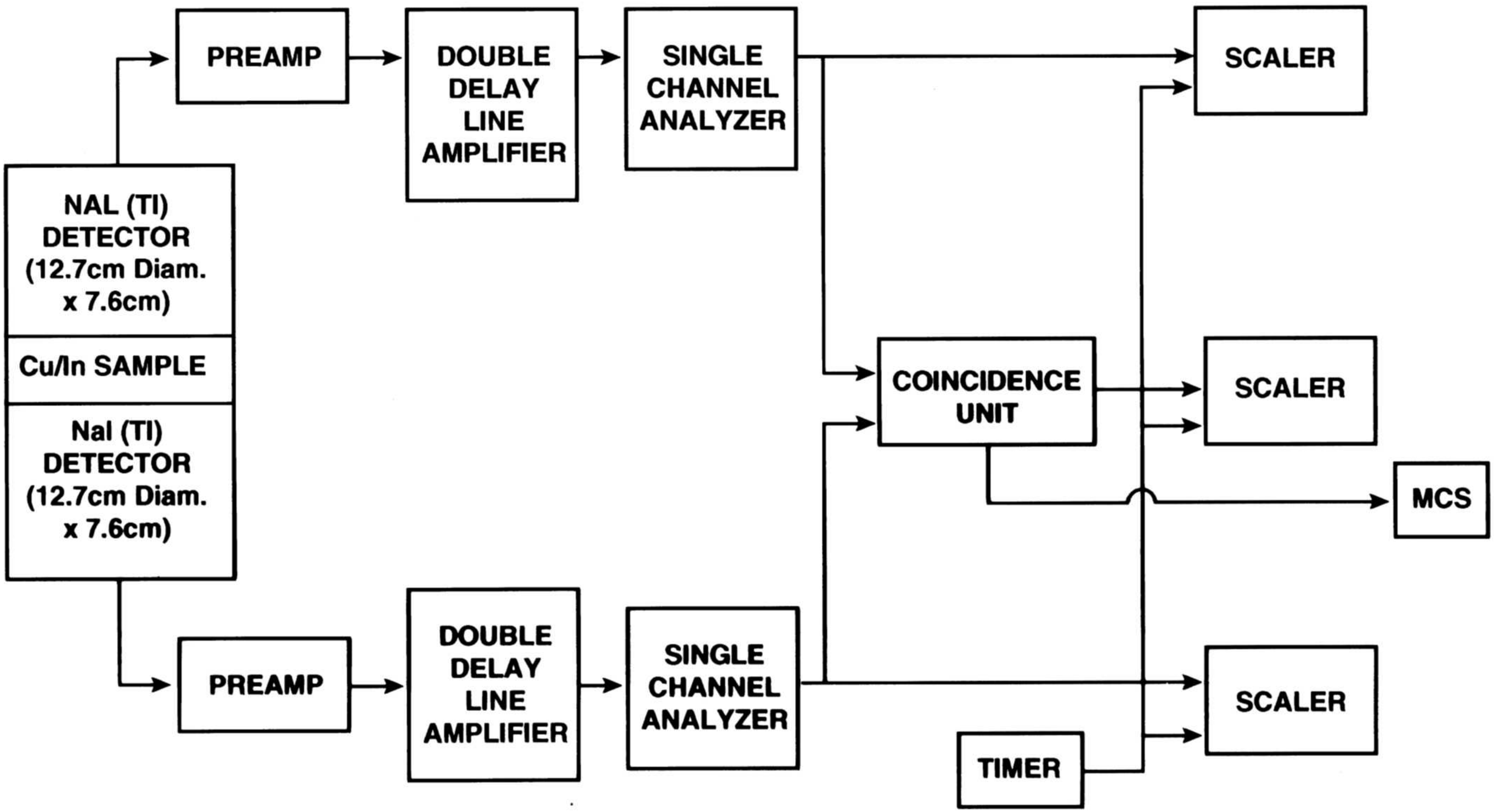
In samples

The total yield of 14.1 MeV neutrons on ZR will be measured with the $^{63}Cu(n,2n)^{62}Cu$ reaction

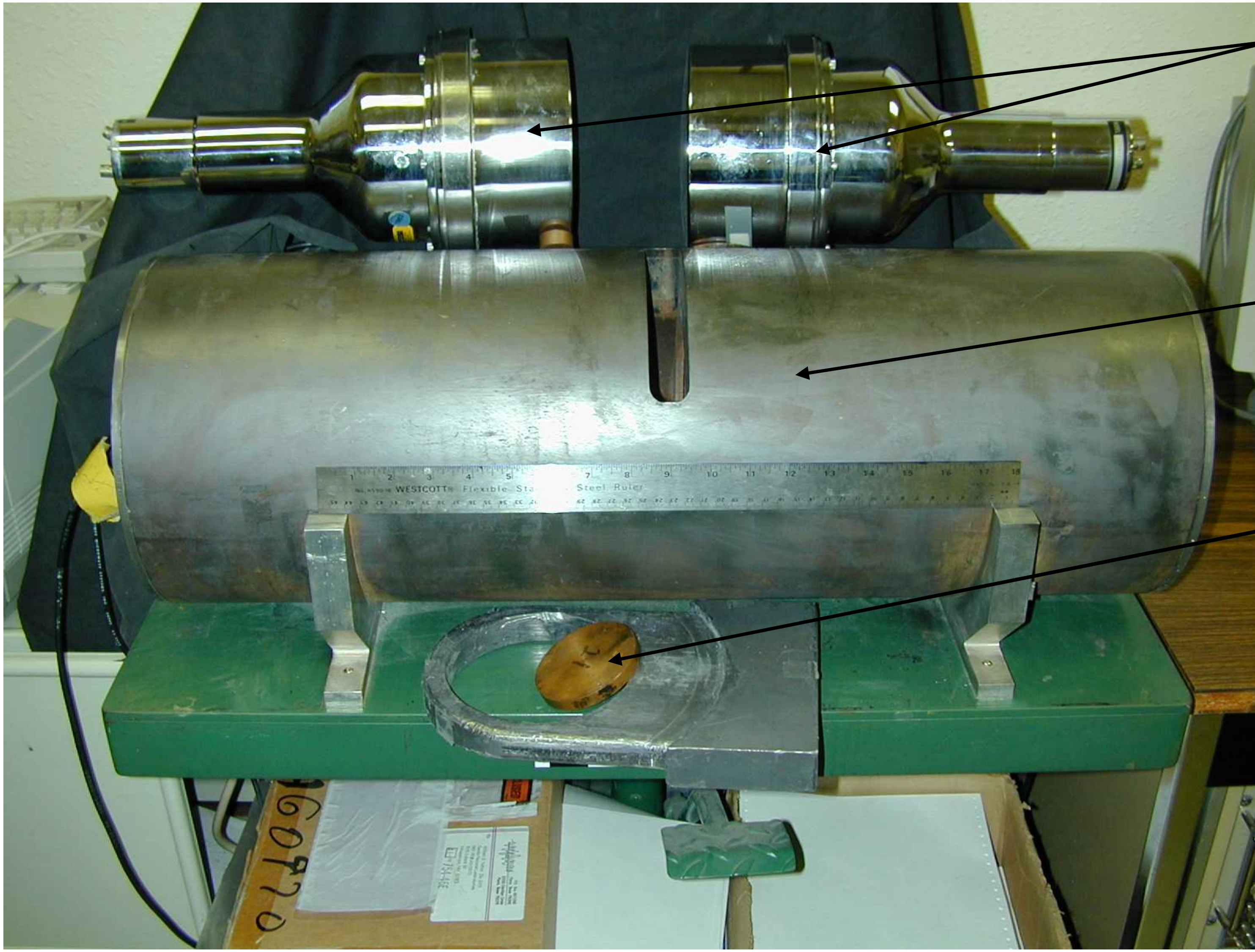


Present system
- Disk size = 76 mm dia × 9.5 mm
- Source to target distance = 41 cm
- Present detectability ≈ 10^8 neutrons

Coincidence counting arrangement that will be used on ZR to count copper activation samples is shown here



ZR Cu activation coincidence counting system: NaI detectors and Pb shield



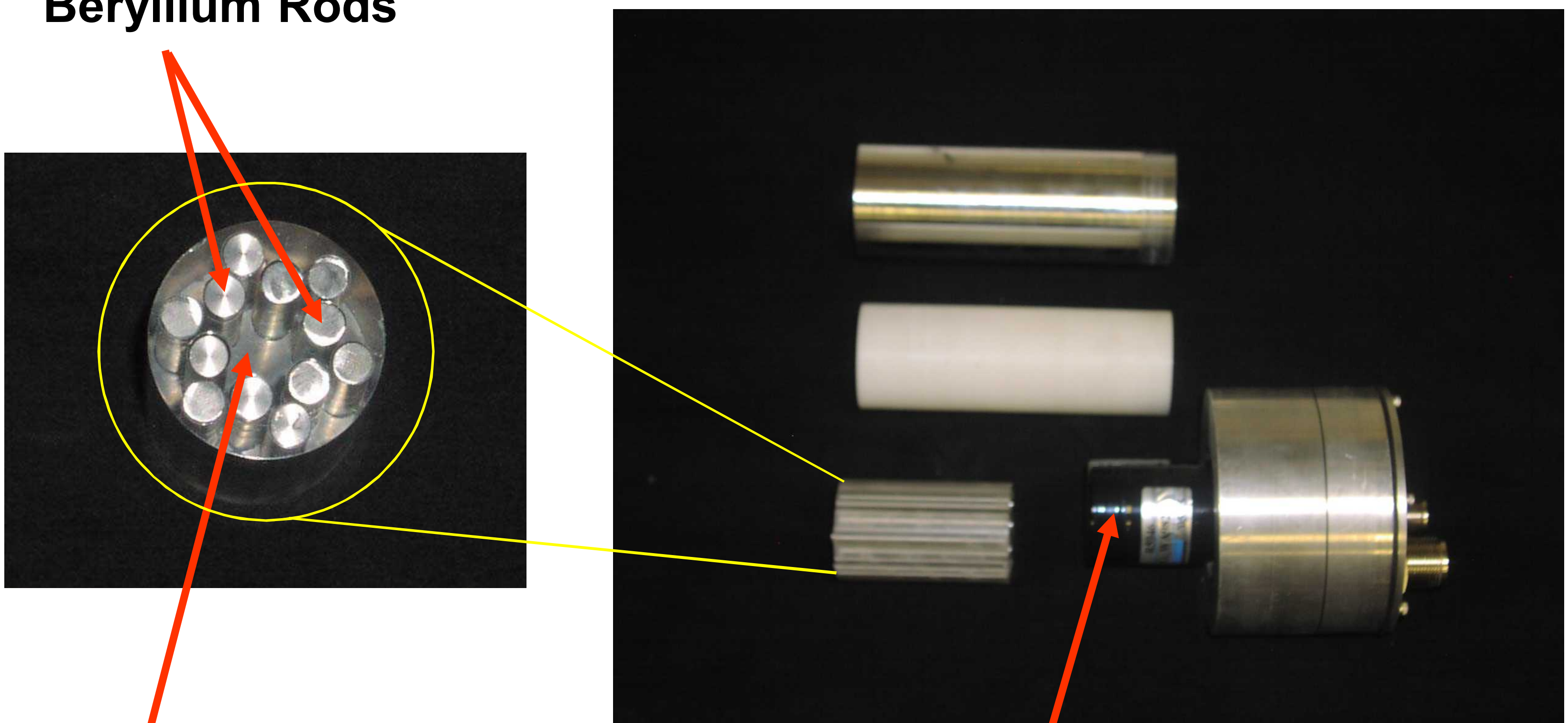
NaI Detectors

Pb Shields

Cu Sample

The components of the new Beryllium Rod Detector (BRD) activation diagnostic

Beryllium Rods



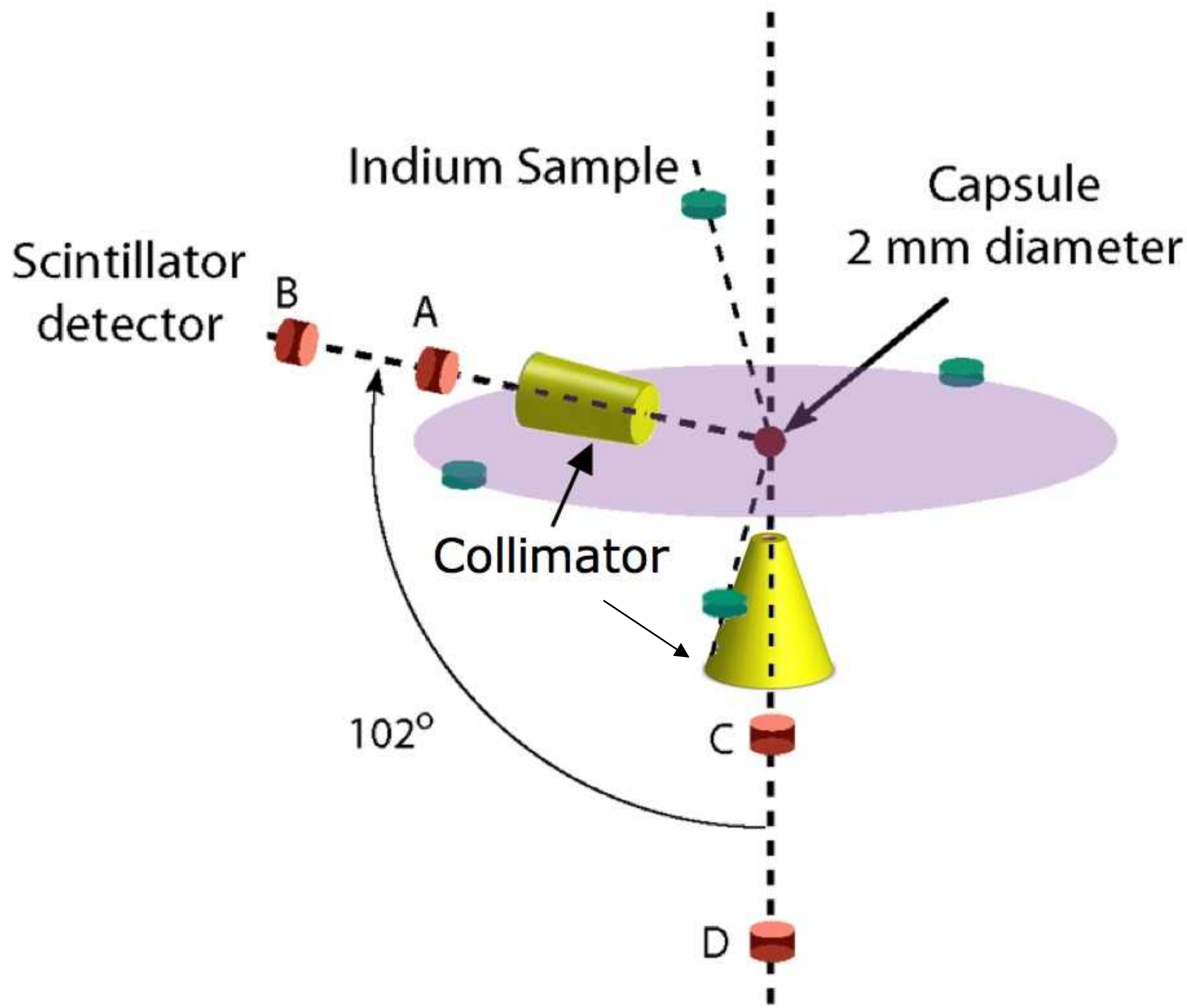
Scintillator (BC-418)

R5946 Fine Mesh PMT

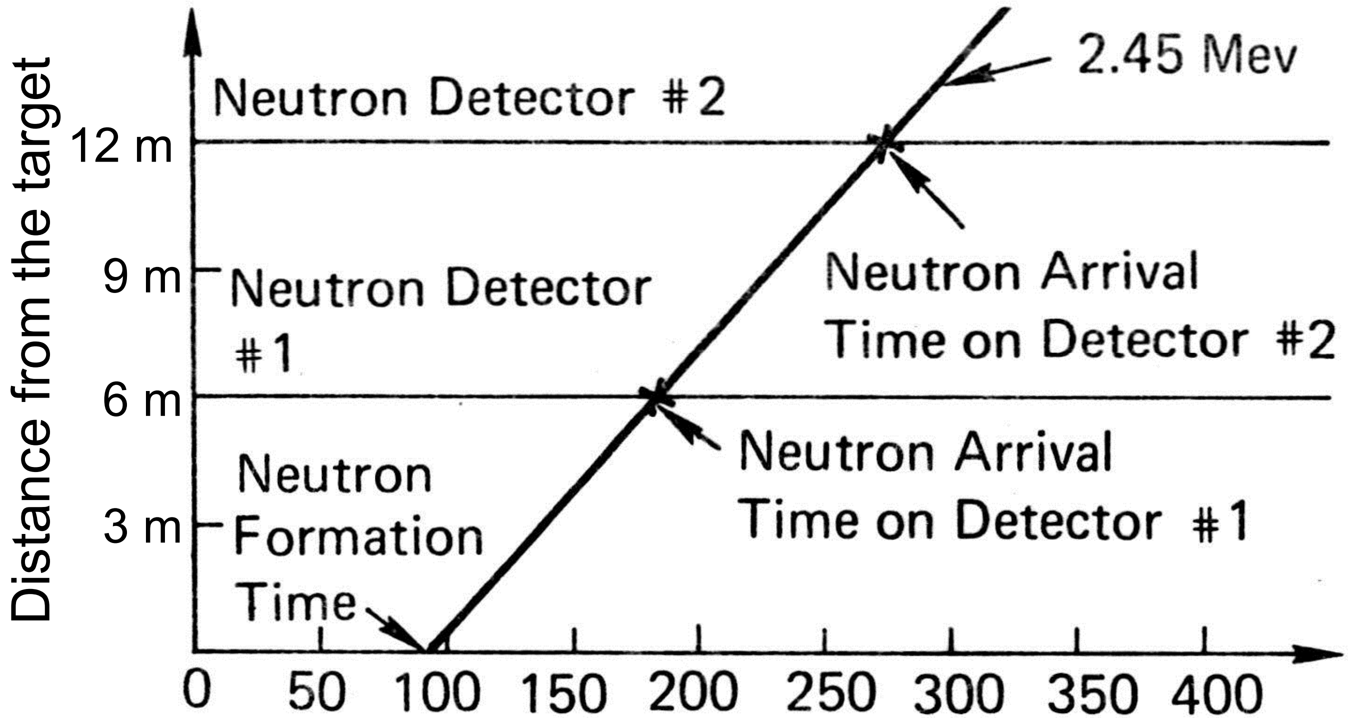
Four plastic scintillation detectors will be used in pairs to make neutron time-of-flight (NTOF) measurements on the ZR facility

- NTOF measurements on ZR will be challenging because of an expected hard x-ray bremsstrahlung background of 10^9-10^{10} rads/s
- Each scintillation detector consists of a 2.54 cm thick by 7.6 cm diameter Bicron BC-418 plastic scintillator coupled to a Hamamatsu R5946 photomultiplier tube
- The goals of paired detector configurations in NTOF technique are the absolute determination of the neutron average velocity and birth time
- The use of paired side-on and paired on-axis NTOF detectors improves our ability to identify ion beams as a contributing source of DD or DT neutrons
  - From simple kinematical considerations such ion beams, if present, are expected to be axially directed and would result in higher observed neutron energies in the axial direction
  - By measuring neutron energies axially and nearly orthogonally to the pinch z axis, ion-beam contributions to the neutron production are readily identified
- NTOF will enable the measurement of ion temperature of the fuel

Schematic of the NTOF arrangement on the ZR facility showing two sets of paired scintillation detectors

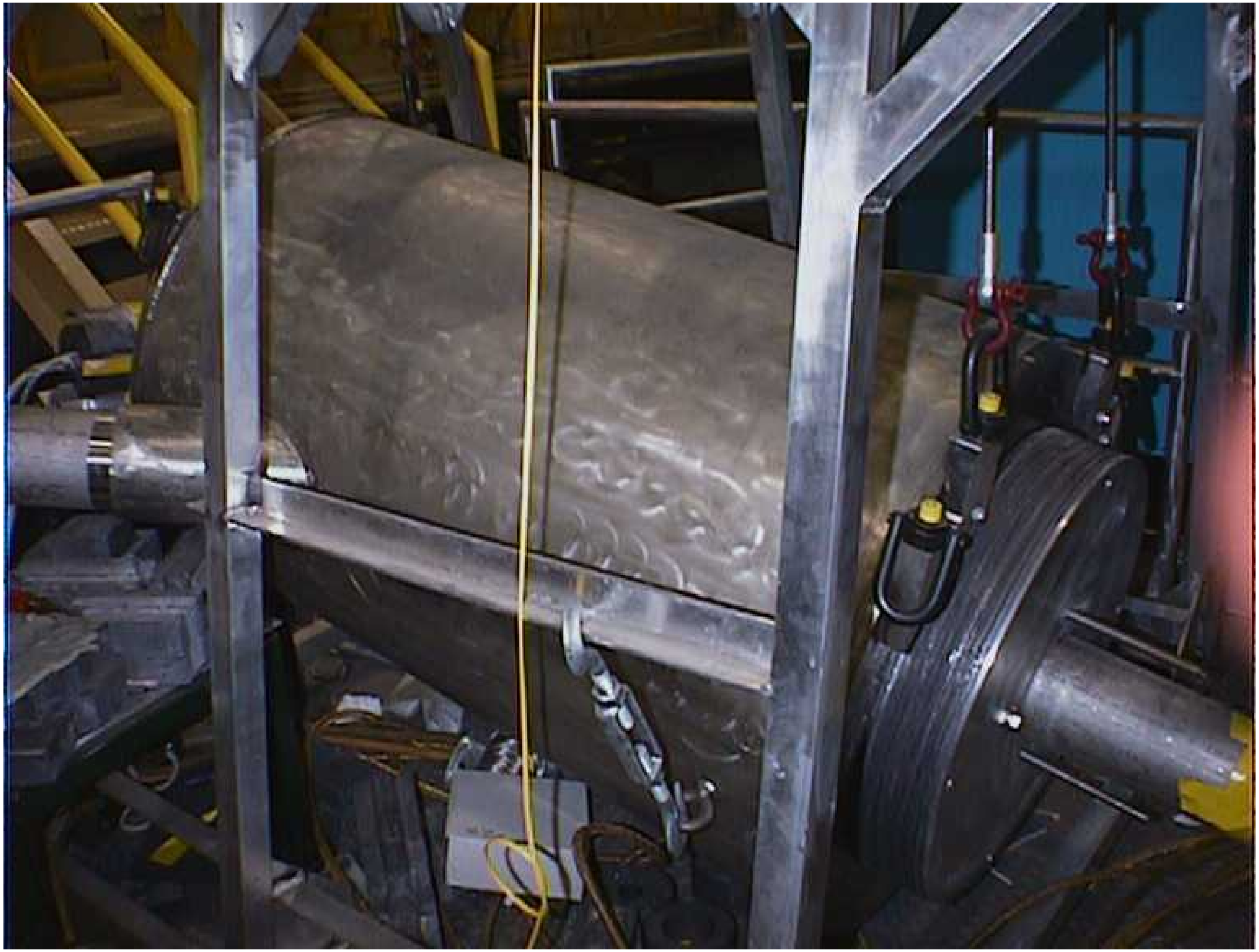


Position versus neutron arrival time from paired NTOF detectors enable neutron velocity and birth time to be directly measured at a given angle

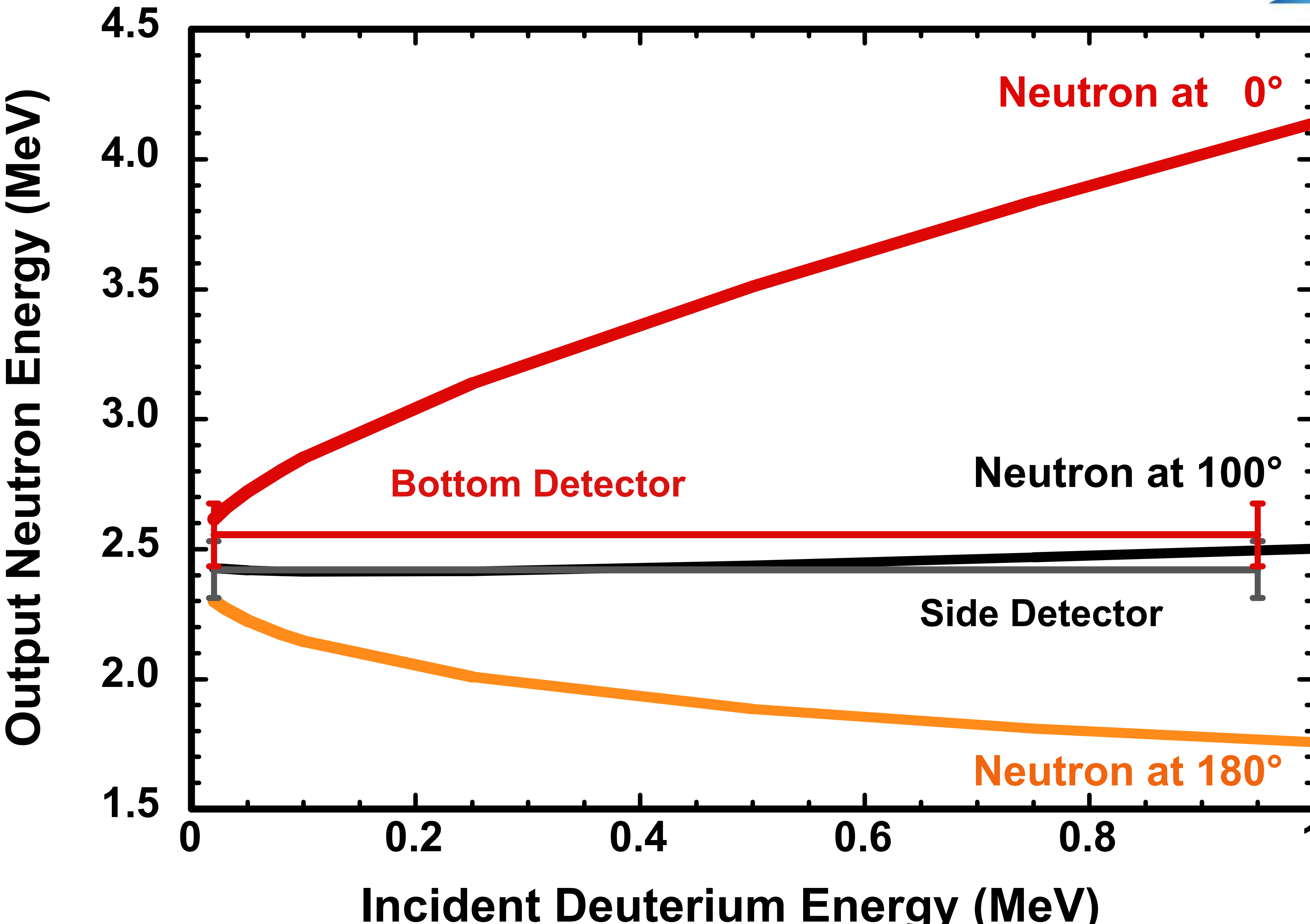


- **Neutron arrival time is determined from the sharp leading edge of the scintillator photomultiplier pulse**
- **The slope of the line connecting the neutron arrival determines the velocity or energy of the neutrons and the intercept of this line at the time axis determines the neutron formation time**

A heavy Pb shields and collimators will be required in initial neutron time-of-flight measurements on ZR because of the expected hard bremmstrahlung background



The measured side and on-axis neutron energies restricts the possibility of a beam induced neutron mechanism



Ion temperatures on ZR will be determined using neutron time-of-flight techniques

The energy spread of an instantaneous point source of fusion neutrons appears as a temporal spread at a distant detector

E_0

t_0

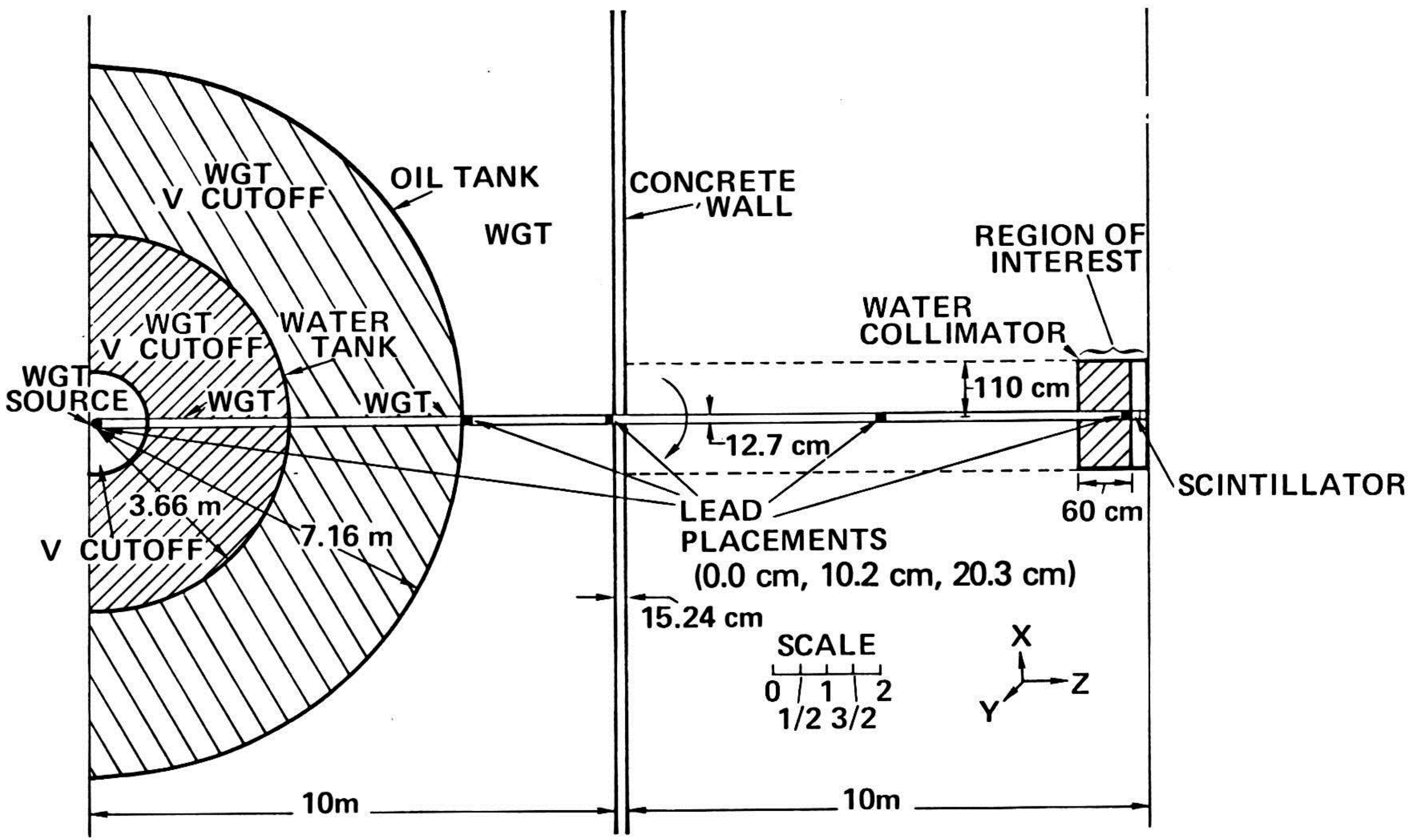
Ion temperature T_i is obtained from the neutron time-of-flight spread ΔE using the relationship

$$T_i=(c_1\Delta t/d)^2$$

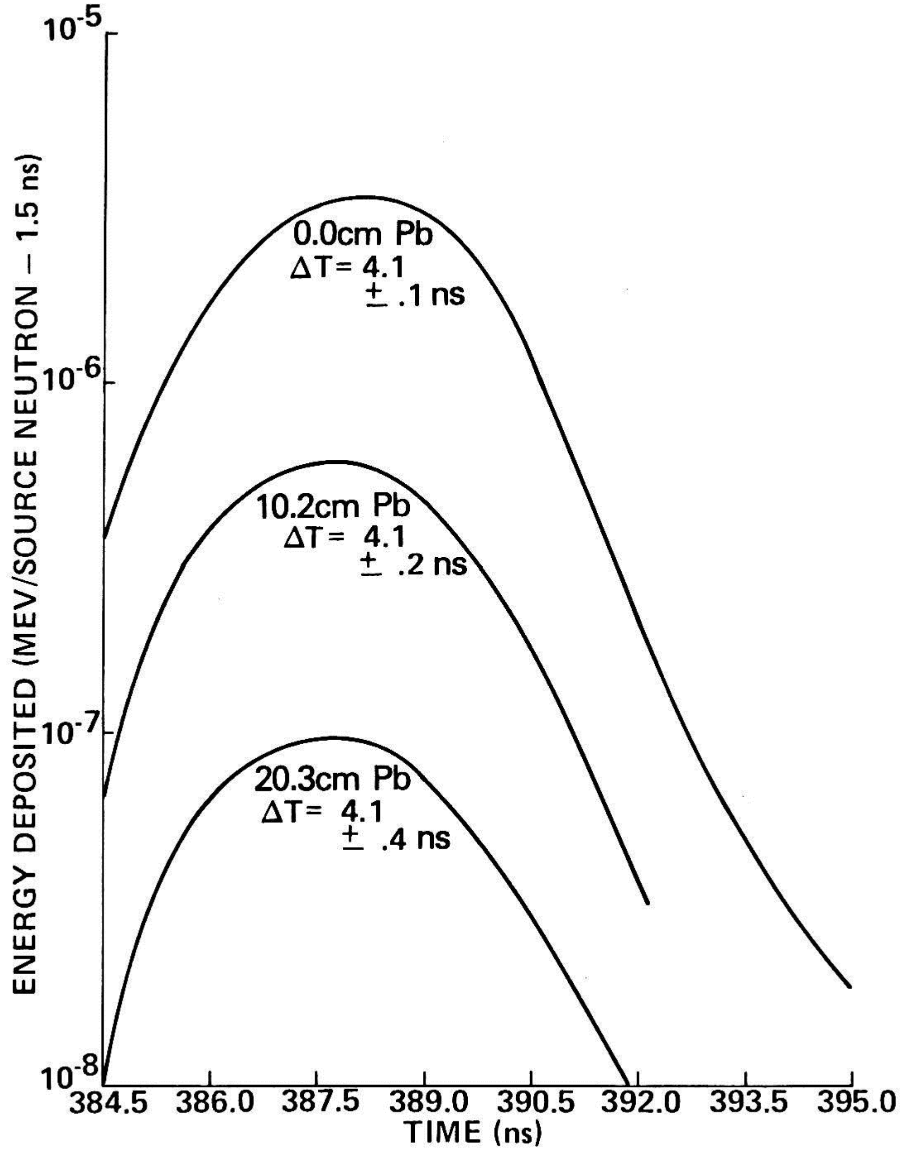
where T_i is in units of keV, Δt is the full width at half-maximum (FWHM) of the neutron time distribution at the detector in ns, d is the neutron flight path in m, and c_1 is 1.30 for 2.45 MeV neutrons and 8.20 for 14.1 MeV neutrons

Horizontal line-of-sights that penetrate the water and oil sections offer a clean collimated geometry for future neutron time-of-flight measurements on the ZR facility

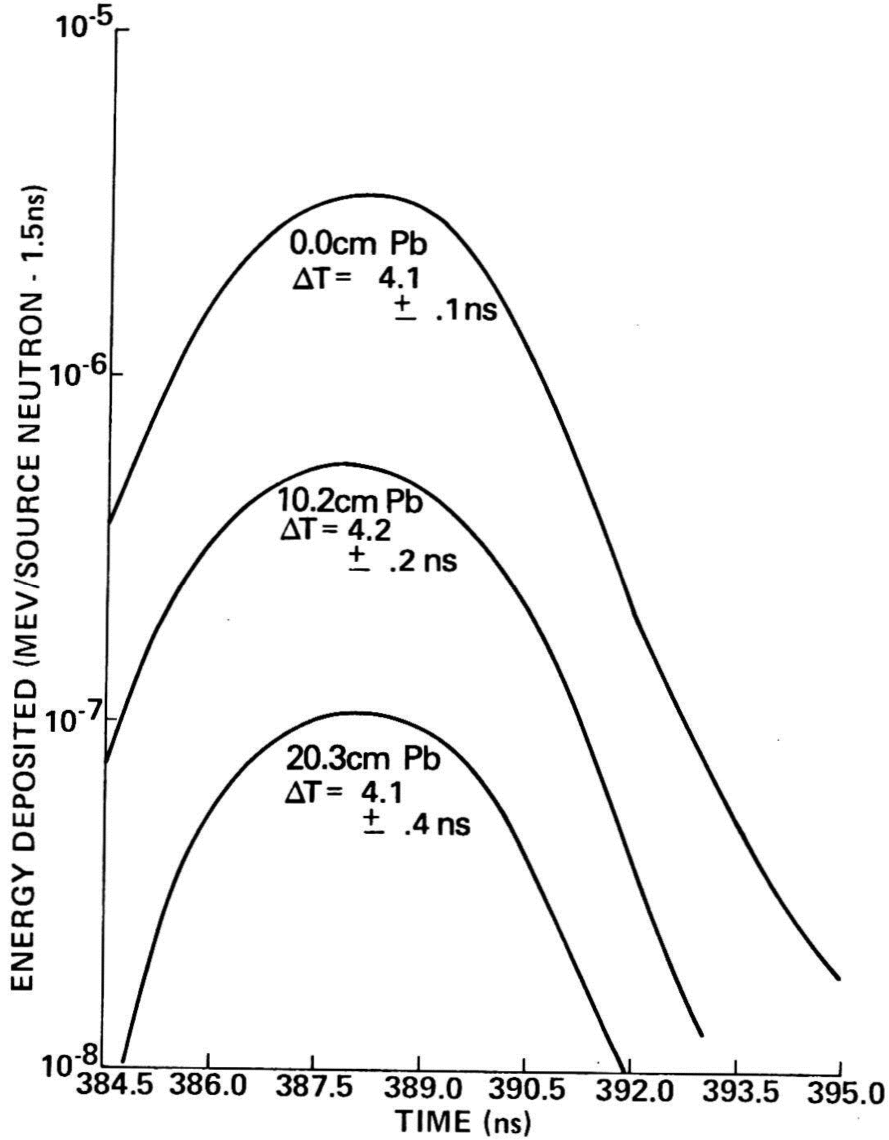
Monte Carlo calculations of a similar geometry with high Z lead filters for hard Bremsstrahlung attenuation show the feasibility of this approach



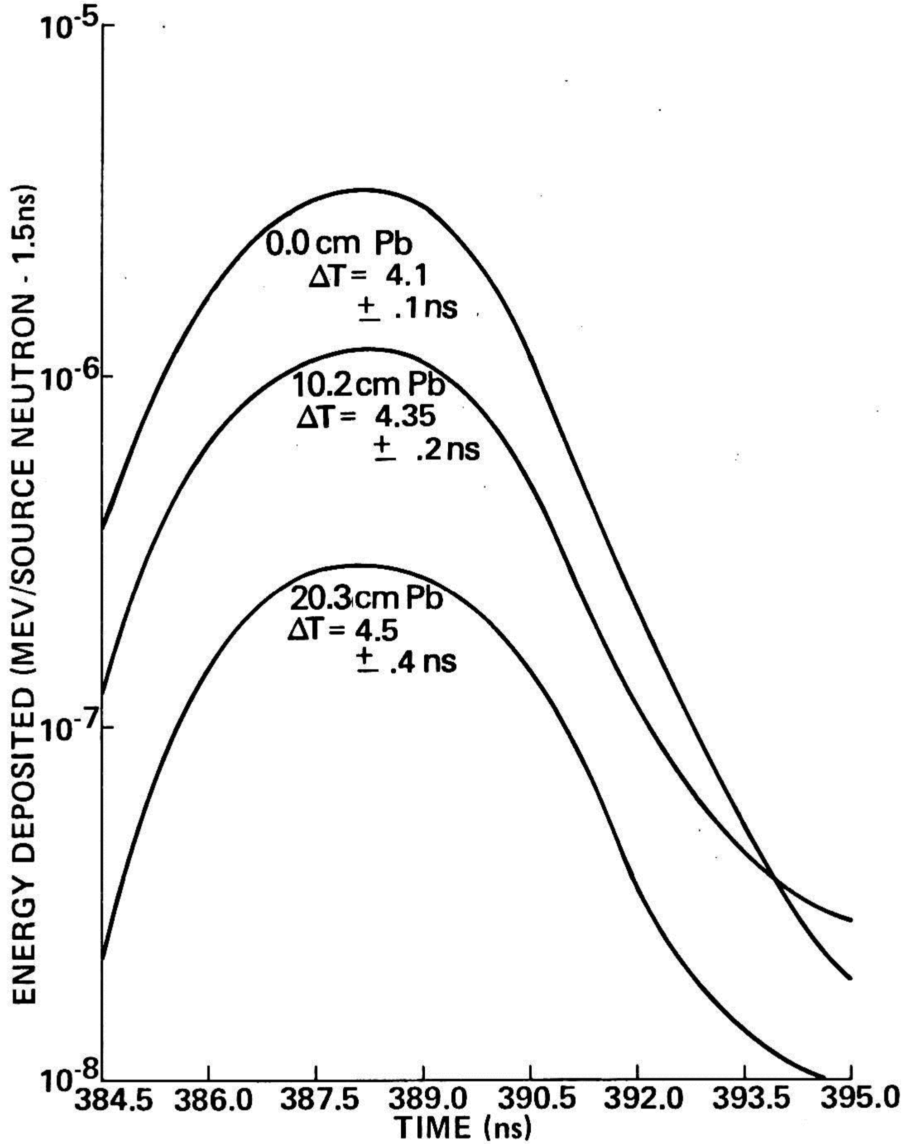
Scintillator energy deposition with lead filter 730 cm from source



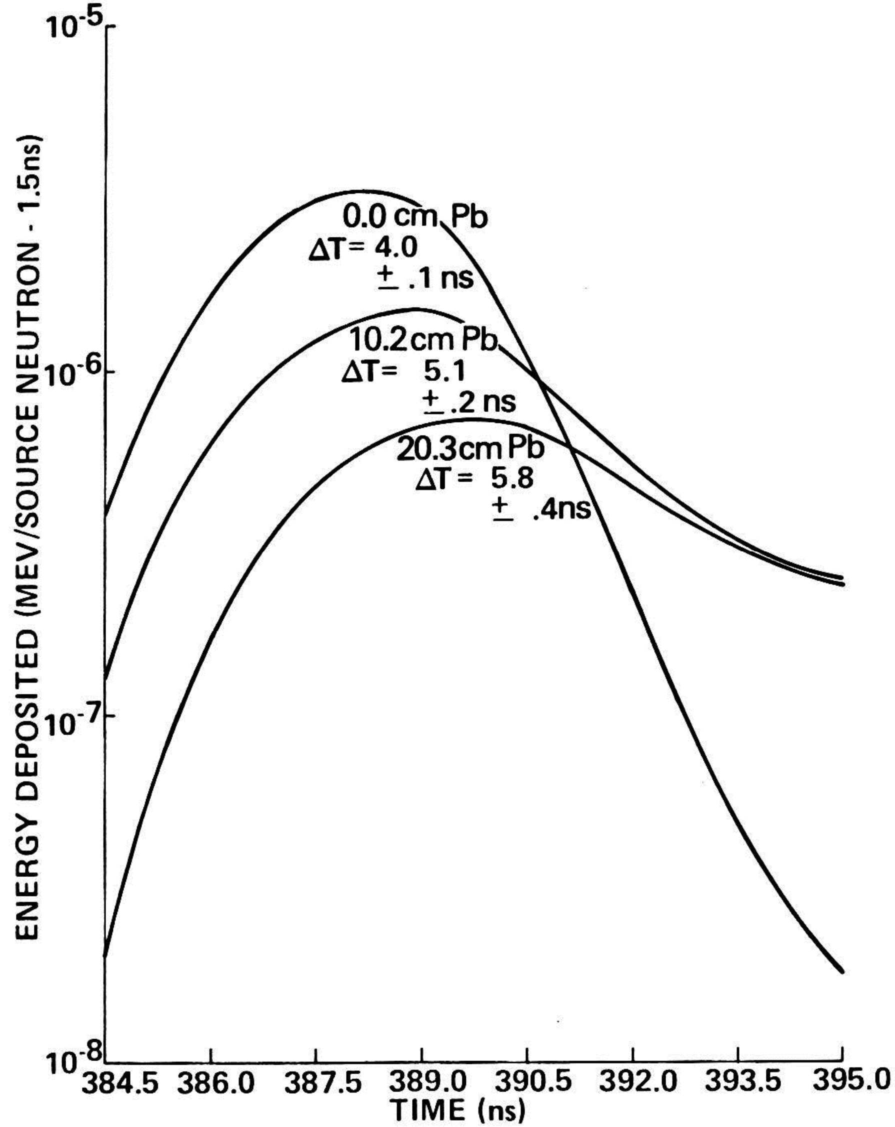
Scintillator energy deposition with lead filter 980 cm from source



Scintillator energy deposition with lead filter 1980 cm from source



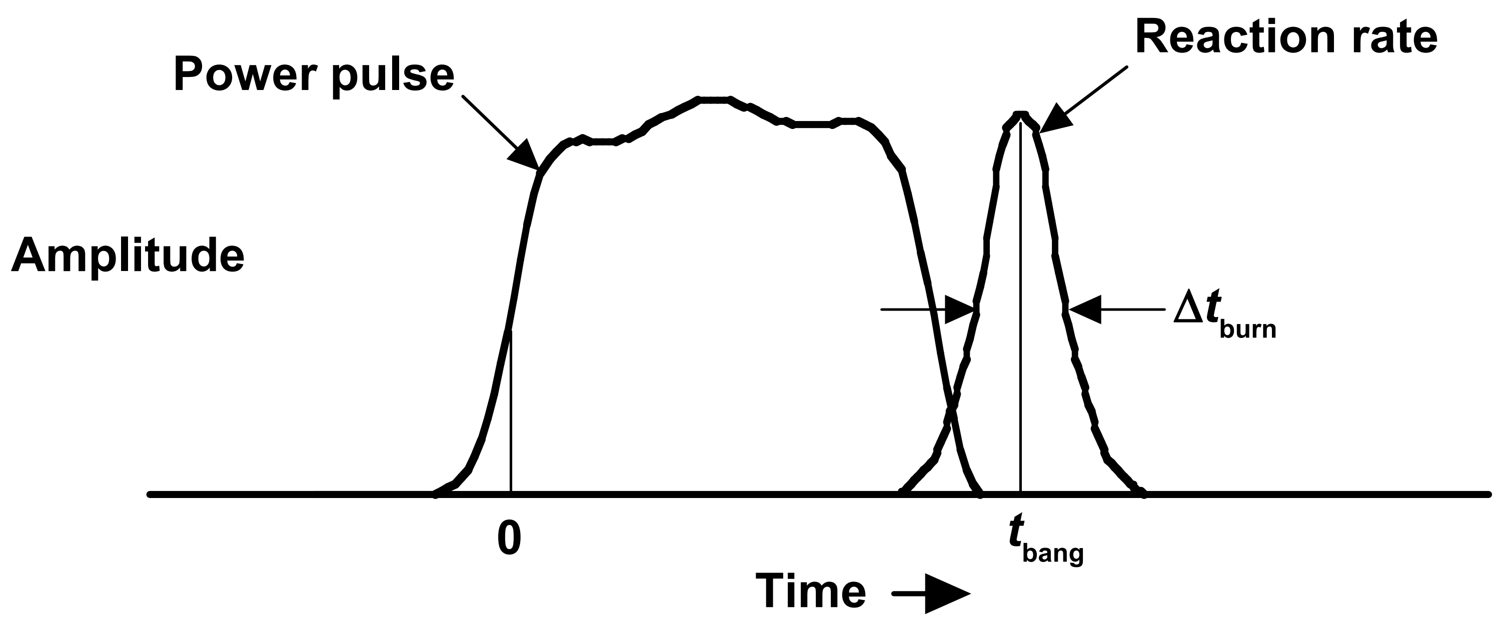
Scintillator energy deposition with extra lead shielding surrounding detector with no water collimator present



Fusion reaction rate provides information about plasma conditions in an ICF target

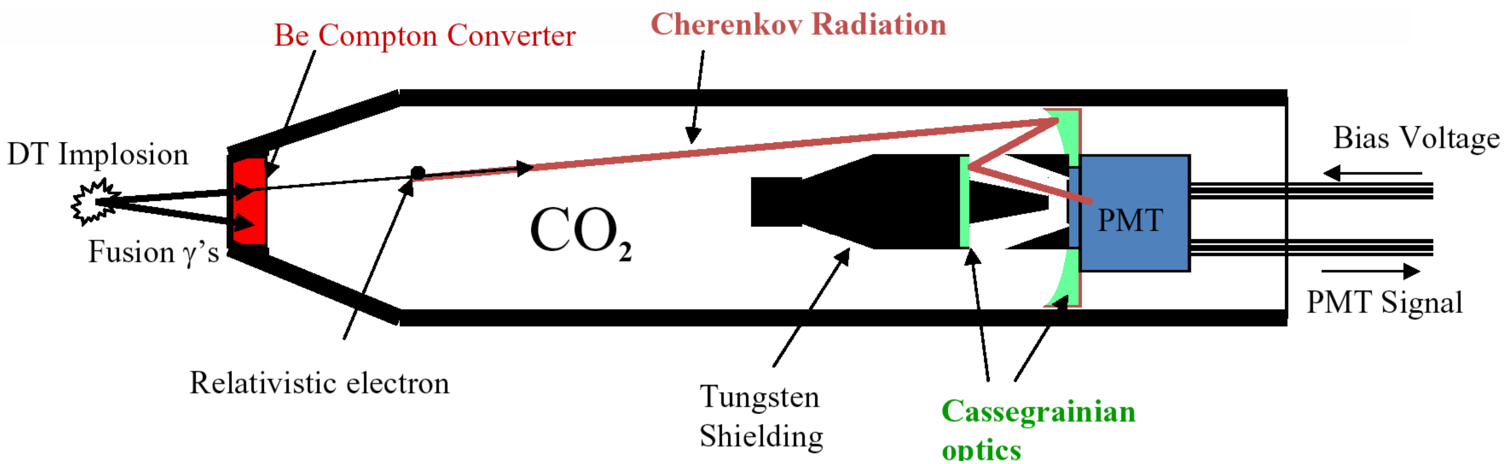
Burn history is an observable quantity

- Depends on target hydrodynamics
- Related to plasma conditions
- Sensitive indicator of modeling accuracy



Burn history can be measured from the 16.7 MeV gamma produced in the reaction D + T ⟶ ^{5}He + γ reaction

Los Alamos National Laboratory Cherenkov Detector Design



Gas Press (psia)	Energy Threshold (MeV)
30	12
100	6.3

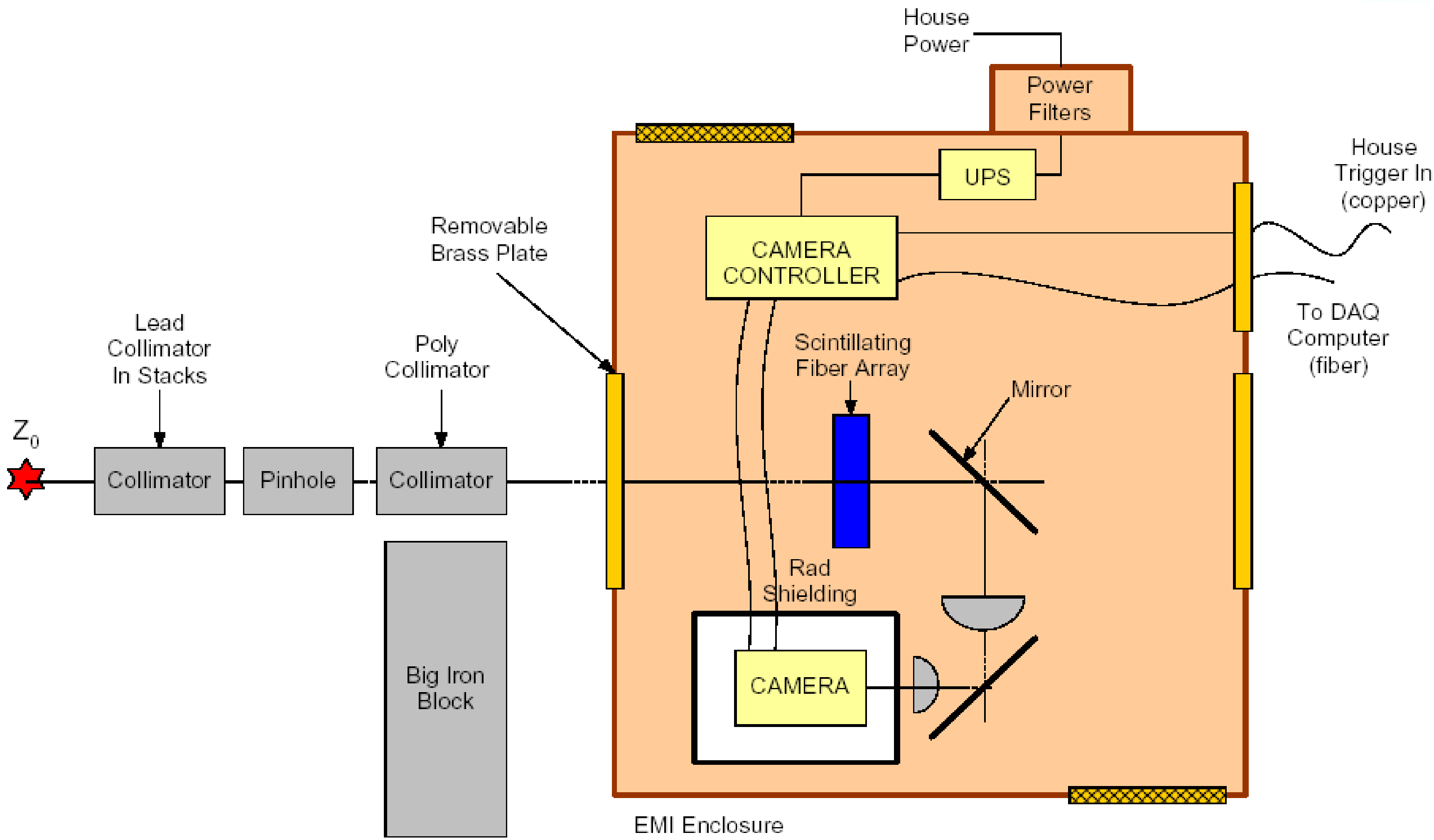
D + T ⟶ ^{5}He + γ reaction branching ratio is 5×10^{-5}

Why use gammas?

- **No Doppler spreading enables high bandwidth measurement at large standoff**
- **Speed of light signal makes it possible to temporally discriminate γ signal from later signals**
- **Energy thresholding allows fusion γ's to be distinguished from hard bremsstahlung backgrounds**

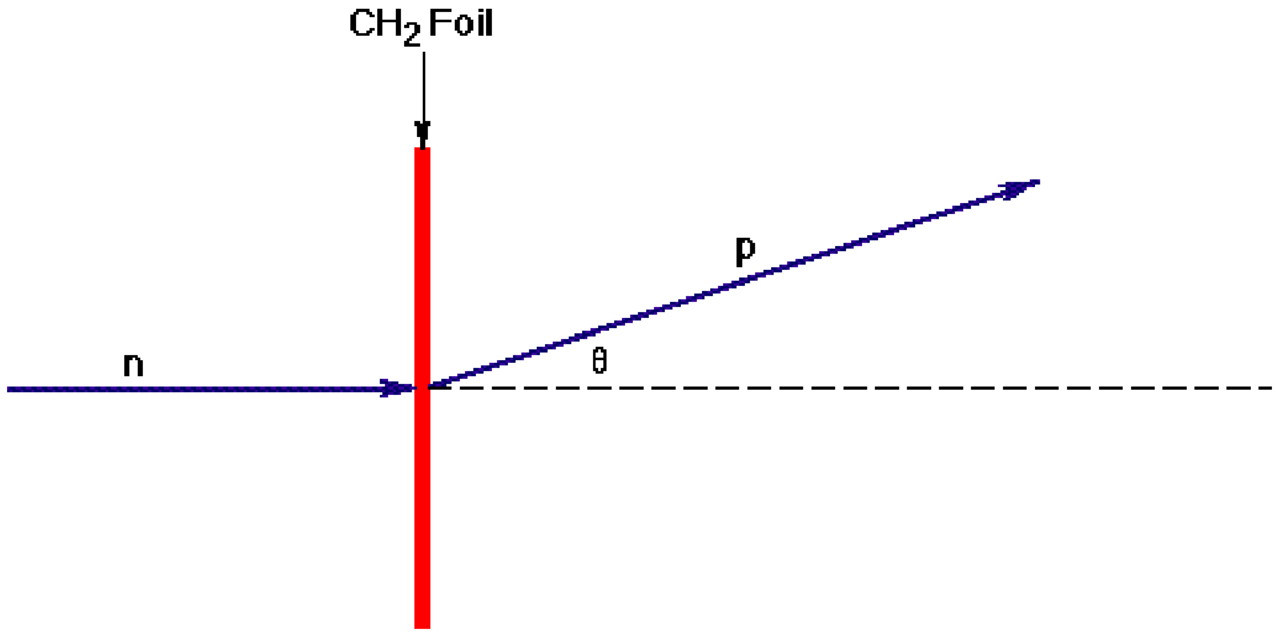
See J. M. Mack et al., Rev. Sci. Instrum. 77, 10E715 (2006)

Schematic of neutron pinhole camera being developed for ZR facility



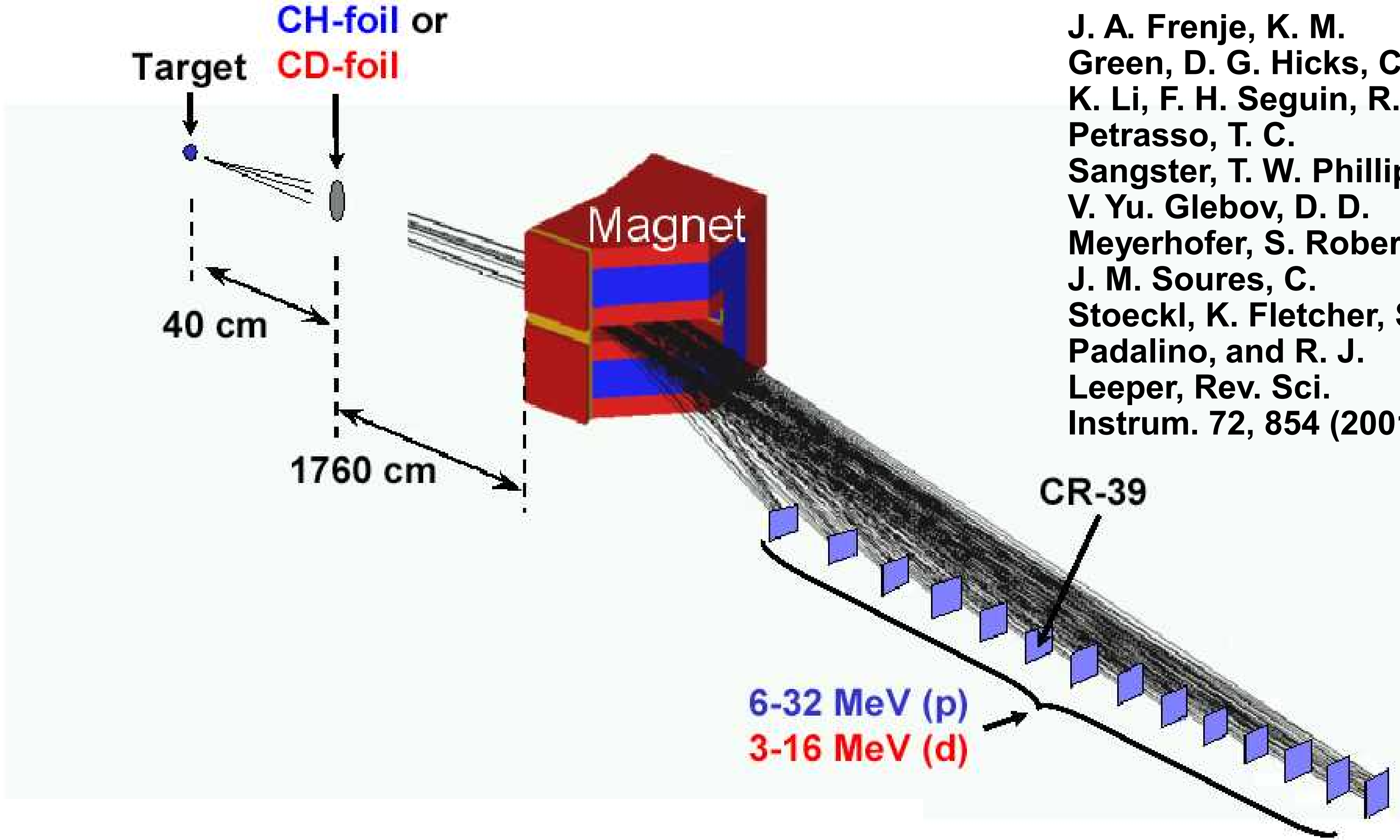
Work in collaboration with Lawrence Livermore National Laboratory

A schematic of the basic concept of a thin target proton recoil diagnostic for neutron spectral measurements is shown here



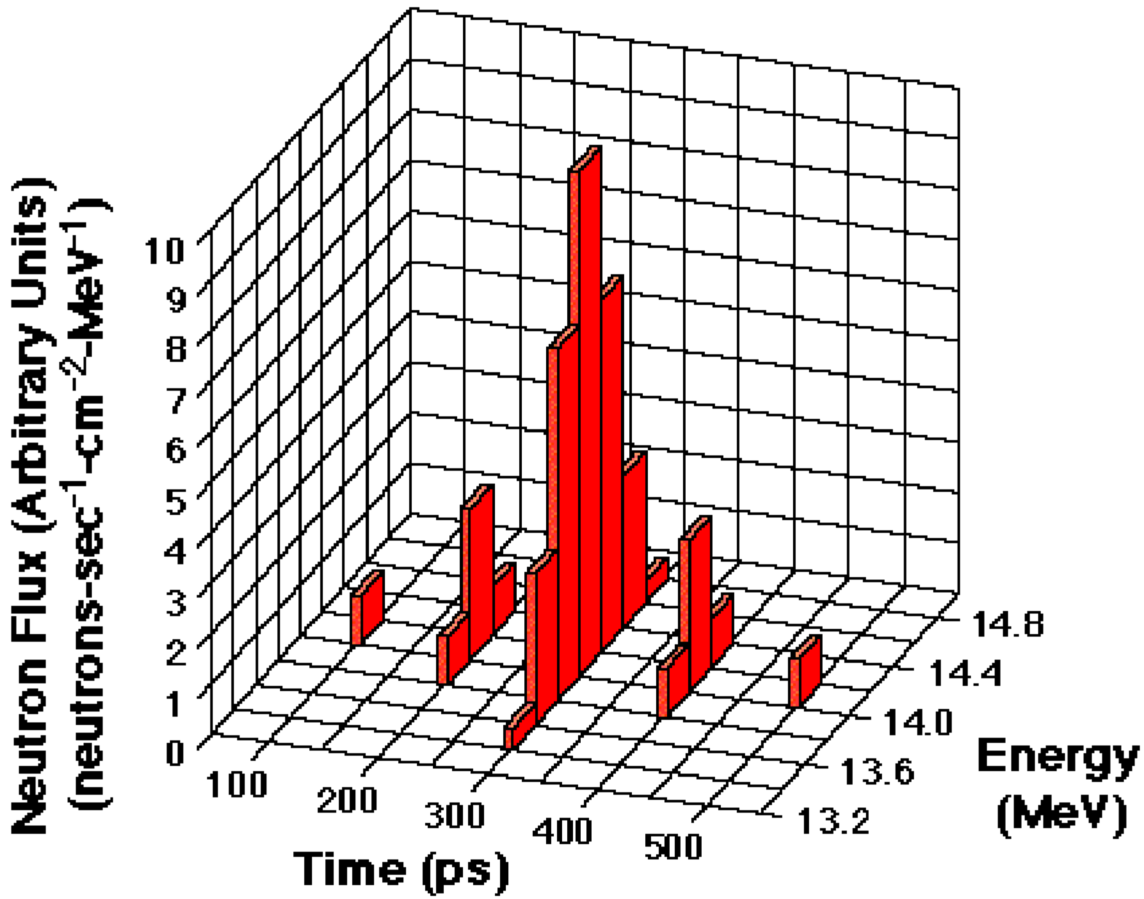
- Recoil protons from a thin (e. g., 10 mg/cm^2) CH_2 foil are detected at near forward angles
- Proton energy E_p at θ is related to the neutron E_n by $E_p(\theta)=E_n\cos^2(\theta)$
- At 14.1 MeV, the n-p cross-section $d\sigma/d\Omega$=233 mb/sr and is known to better than 2 %
- Proposed by Kallne and Enge for tokamak neutron measurements (J. Kallne and H. Enge, Nucl. Instrum. Meth. A311, 595 (1992))

Proton recoil spectrograph has been designed to measure the neutron energy spectrum on NIF ignition experiments by MIT/LLE/LLNL/SNL



J. A. Frenje, K. M. Green, D. G. Hicks, C. K. Li, F. H. Seguin, R. D. Petrasso, T. C. Sangster, T. W. Phillips, V. Yu. Glebov, D. D. Meyerhofer, S. Roberts, J. M. Soures, C. Stoeckl, K. Fletcher, S. Padalino, and R. J. Leeper, Rev. Sci. Instrum. 72, 854 (2001).

A n-p recoil magnetic spectrograph on the ZR facility could provide the following information



- **Neutron energy ΔE(t) is a measure of the time-dependent ion temperature**
- **With standoff, the burn-history can be reconstructed by tracing each energy bin backward in time to the target -- as limited by the energy resolution of the instrument**

Summary

- ZR, a major refurbishment of Sandia National Laboratories' Z facility is in the final stages of becoming operational
- A number of neutron experiments are being planned for this facility including deuterium gas puff z-pinch loads as well as indirect drive capsule experiments
- As part of this effort, a new suite of neutron diagnostics is being developed
- This suite will include improved neutron activation and neutron time-of-flight diagnostics for initial experiments
- Future diagnostics being planned for the ZR facility include neutron imaging, neutron bang, neutron reaction history, and a neutron-proton recoil magnetc analyzer