National Ignition Facility Dilation X-ray Imager Diagnostic Instrumentation and Control System

Abstract

X-ray cameras on inertial confinement fusion facilities can determine the velocity and symmetry of target implosions by recording the x-ray emission of a back-lighter or the target itself gated as a function of time. To capture targets that undergo ignition and thermonuclear burn, however, cameras with less than 10 picosecond shutter times are needed. Collaboration between LLNL, General Atomics and Kentech Instruments has resulted in the design and construction of an X-ray camera which converts an X-ray image to an electron image, which is stretched, and then coupled to a conventional shuttered electron camera to meet this criteria. This paper discusses diagnostic instrumentation and software used to control the DIXI diagnostic and seamlessly integrate it into the NIF Integrated Computer Control System (ICCS).

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Presented by Jarom Nelson

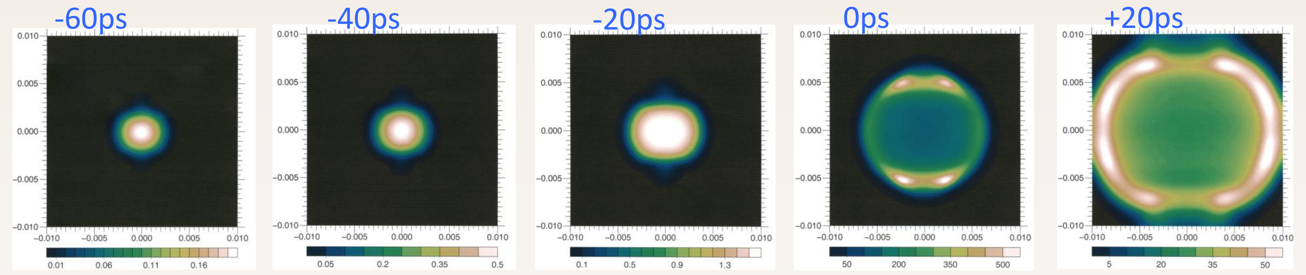
Modeling shows the need for faster imagers

- Performance of ICF targets relies on the symmetric implosion of highly compressed fuel to form a uniform central hot spot with high enough density and temperature to achieve ignition. [6]
- Currently Gated broadband x-ray images (hν > 8 keV) provide temporal (Δt = 40 to 100 ps) and spatial histories of the implosion symmetry and hot spot non-uniformities.

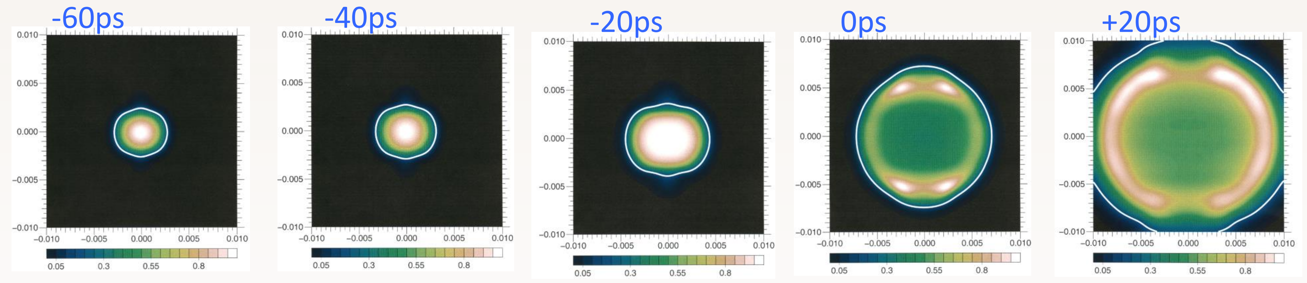
Simulations of an igniting ICF capsule:

- Spatial blurring of 10 µm.
- The white, red and blue contours are the 17% level.
- The image scales are 200 x 200 µm.
- Measureable difference in structure between 40 ps and 10 ps gate times.
- The large increase in emission at 0 ps distorts the images at between ±20 ps for the 40 ps gate.

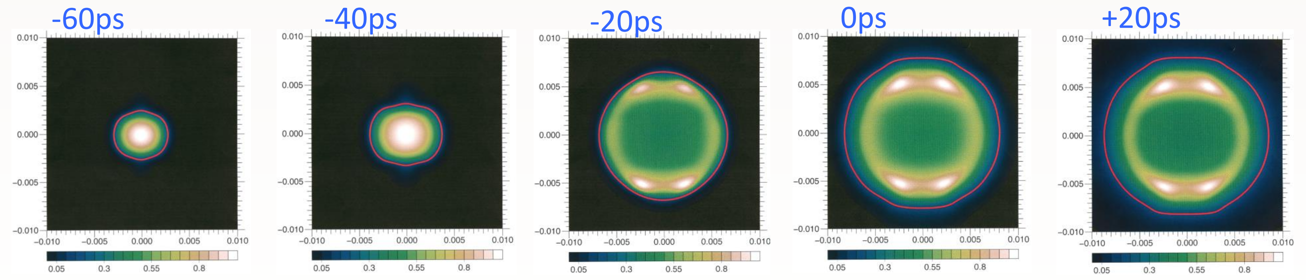
Ideal case (0 ps integration time)



DIXI (10 ps integration time)

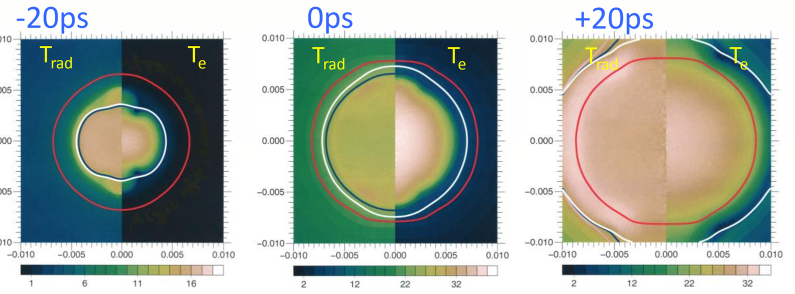


Best currently achievable (40 ps integration time)



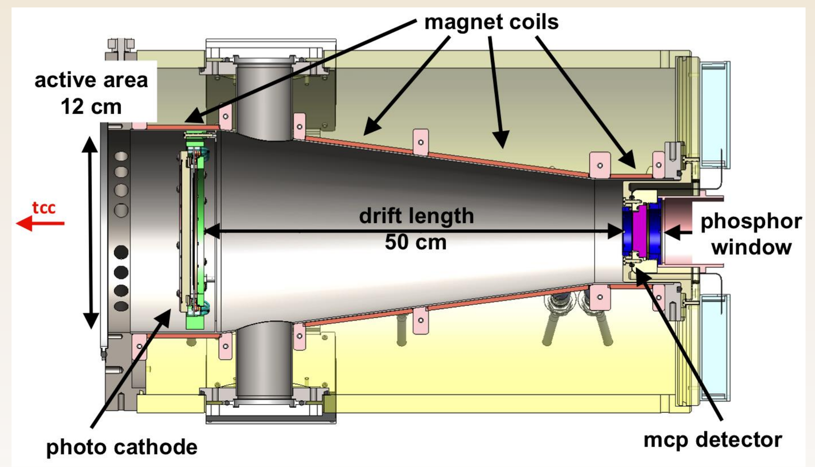
Fast gate matches the true contour better

- T_{rad} (left) and T_e (right) contours
- Color bars are descriptive of the T_e contours (keV).
- 17% contours for zero gate time (blue), a 10 ps gate (white) and a 40 ps gate (red).

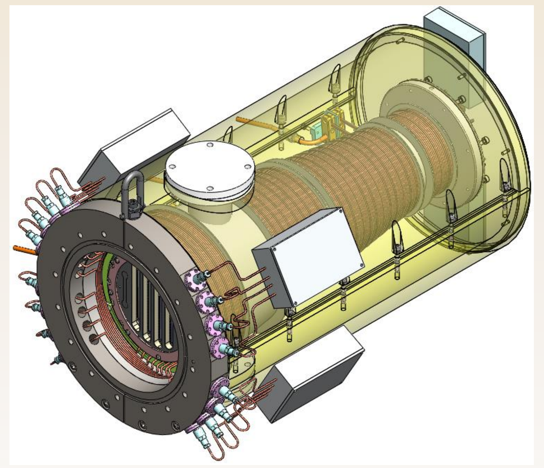


DIXI instrument and working principle

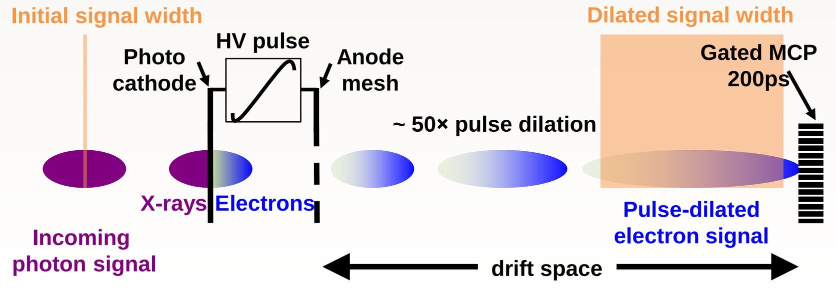
Instrument cross section



DIXI



Working principle

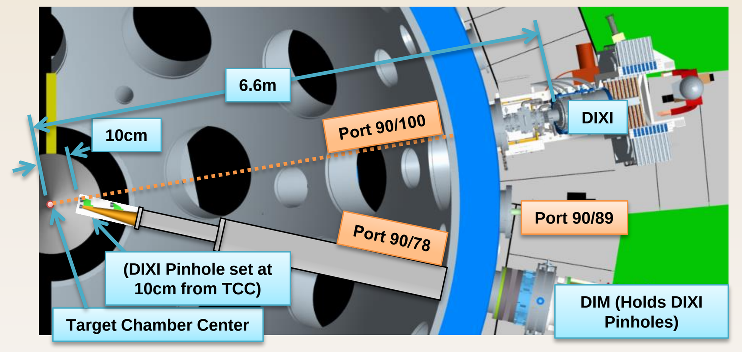


Photoelectrons → accelerated by a time varying electric field → energy dispersion → signal stretches as it traverses the drift region → sampled by gated mcp. [4]

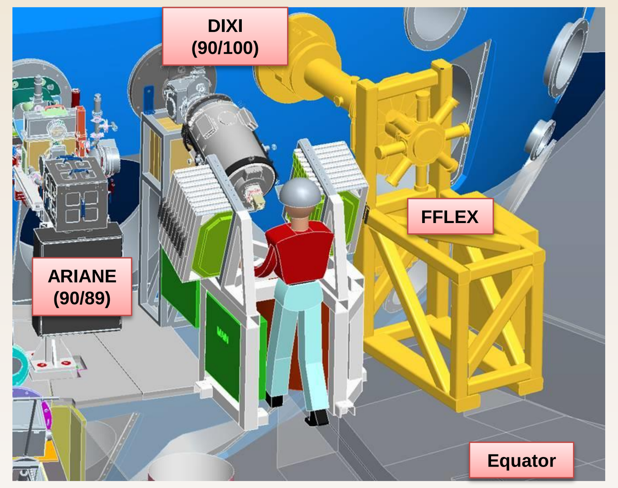
- DIXI uses pulse-dilation imaging [1] to provide x-ray imaging 5 - 10 ps temporal resolution
- The photocathode comprised of 4 strips with adjustable delay on inter-strip excitation voltage
- MCP is a single 40 mm wide strip with 200 ps gate width
- Pulsed solenoid magnets provide magnetic field to guide and de-magnify the electron pulse [2,3]

Proposed setup on NIF

Top view of the NIF chamber – equatorial plane

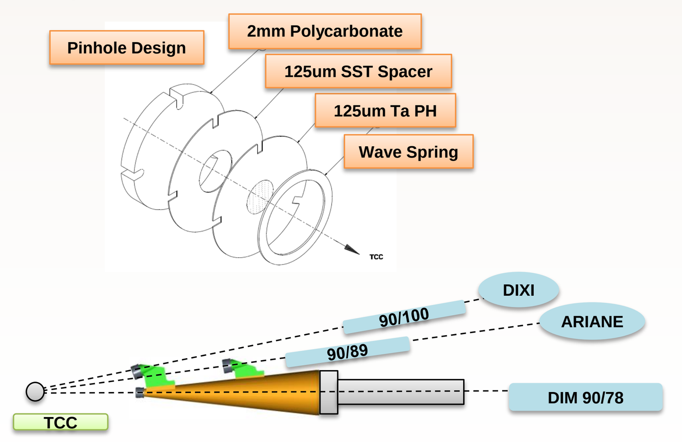


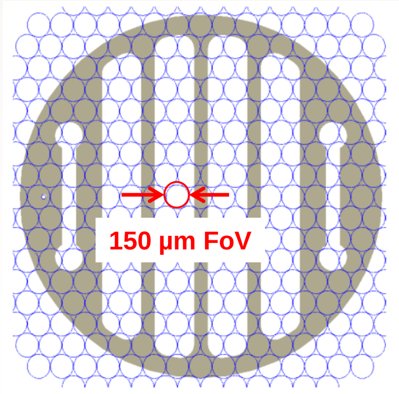
Outside the target chamber



Shielding enclosure surrounding detector and 20° tilt provides improved protection from high neutron fields on ignition shots

Pinhole design allows for large number of images



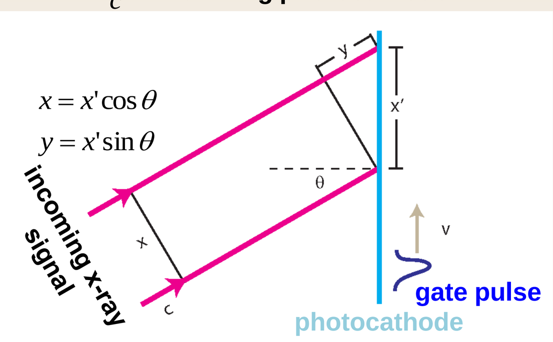


- 4 strip lines, ~240ps per strip
- Circles represent image projection of field of view (FoV)
- 150 µm image (Magnified 64x as seen on the photo cathode)

DIXI Shot Configuration

Pico seconds matter! High speed makes timing a challenge

$t_x(x') = \frac{x' \sin\theta}{c}$ time delay for x-ray signal striking photocathode



$t_v(x') = \frac{x'}{v}$ time delay for gate pulse across image plane

$t_{gate}(x') = x'\left(\frac{1}{v} - \frac{\sin\theta}{c}\right)$ effective gate time across image plane

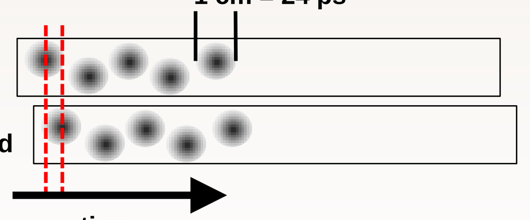
$t_{obj}(x) = x\left(\frac{1}{v\cos\theta} - \frac{\tan\theta}{c}\right)$ effective gate time across object plane

with v = 0.93 c and q = 20°

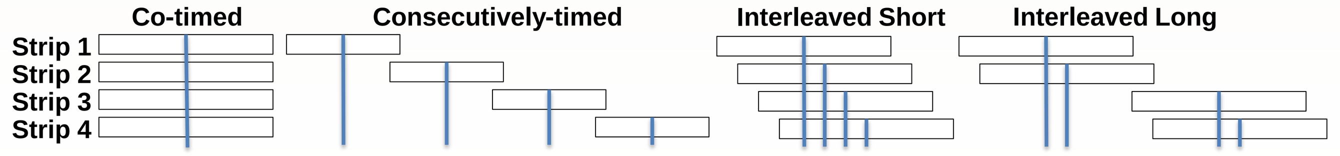
This gives a time delay of 2.4ps/mm along the strip. [4]

With 20° angled DIXI 2.4ps/mm

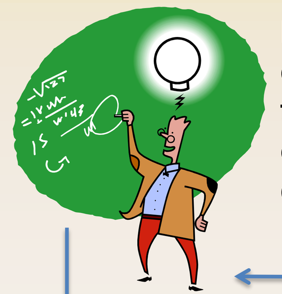
Principle of 2 photocathode strips interleaved



Proposed timing setups for the NIF



NIF Control Software



Layered architecture of software environment combines many tools to configure, setup, control, and analyze the DIXI diagnostic data.

CMT – Campaign Management Tool
ICCS – Integrated Computer Control System
LoCoS – Location Component and State
TDS – Target Diagnostic Systems
SAVI – Shot Analysis and Visualization

Scientist determines goals of the NIF shot, and enters the laser parameters, target selection, and diagnostic configuration into CMT

Data made available to the Shot Scientist

Calibration

CMT

CMT generates install orders to configure the NIF facility and diagnostics for the shot

Install Order

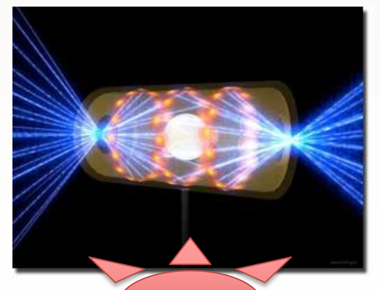
Installations are recorded in LoCoS

LoCoS

SAVI pulls installation and calibration data from LoCoS and analyzes the data in the shot archive

SAVI

ICCS loads the CMT setup data for the shot, and prepares the laser, alignment, timing system, and configures diagnostics for the shot



TDS reads the data from the diagnostic and writes to the shot archive

ICCS

Shot

TDS

Analyze the Shot Data

NIF Shot Analysis and Visualization (SAVI) tools automatically generates corrected images from shot data, flat-field, background subtraction, and warp correction

Static x-ray exposure is taken with photocathode grid mask to determine magnification and warp effect of field in drift space [5]

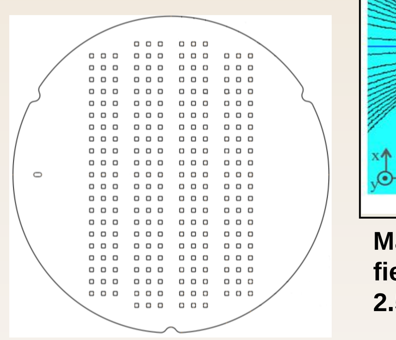
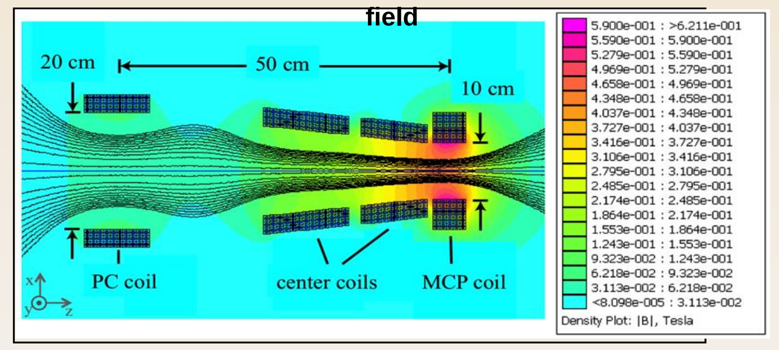
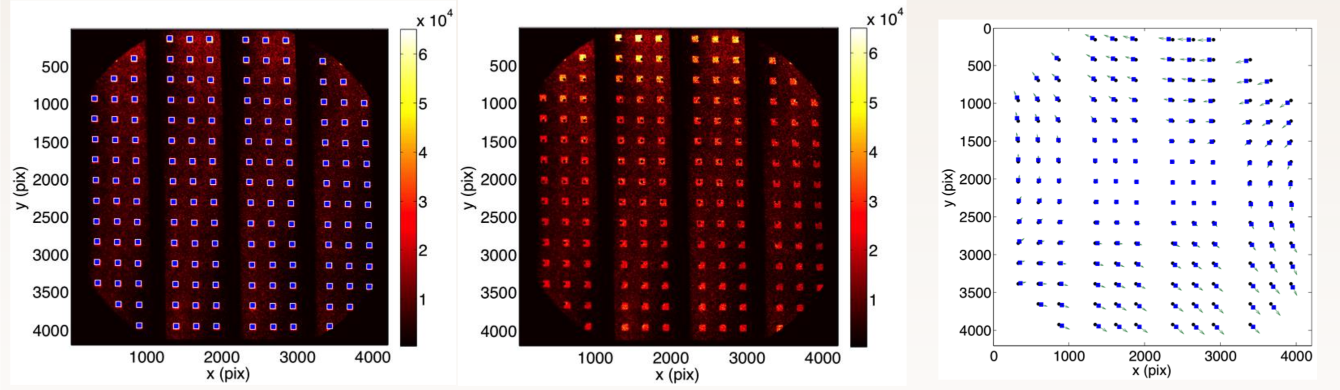


Illustration of modeled cylindrically symmetric magnetic field



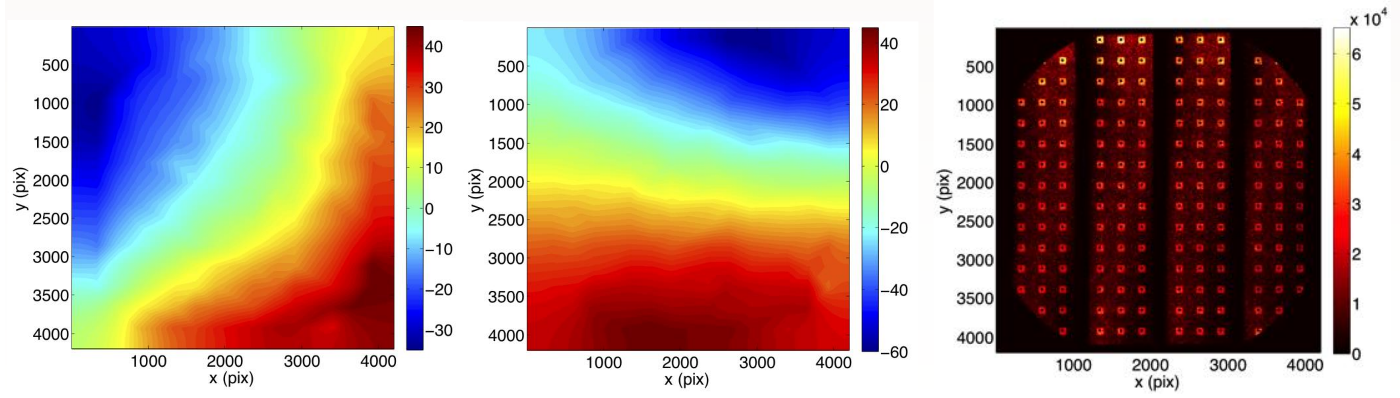
Magnetic field lines are indicated in black. The magnetic field de-magnifies the photocathode image onto MCP by 2.5×, but causes warping in the image



Position of x-ray image grid centers (blue)

Position of expected, linear position of grid (dots) vs. x-ray image (red)

Differences (arrows) between x-ray positions (squares) vs. expected (dots)



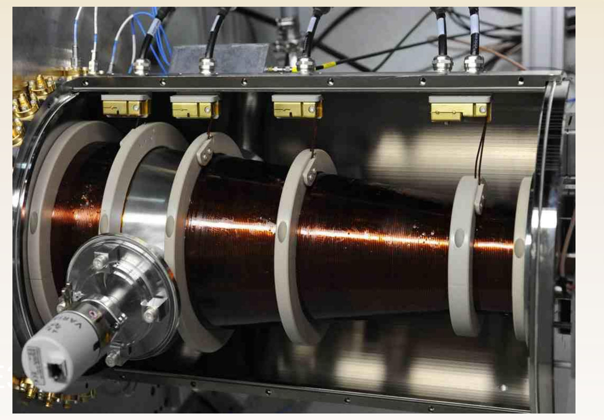
Map for de-warp in vertical/ temporal direction

Map for de-warp in horizontal direction

Result of dewarping with x-ray grid (red) matching expected centers (dots)

Summary

- DIXI can achieve a gate time <6ps, allowing observation of features that cannot be observed with current detectors.
- DIXI will operate at neutron yields up to 10^{17}.
- Installation in NIF will be completed this year.
- The software environment in NIF is prepared to automate configuration and operation of DIXI



DIXI with shield cover removed shows magnet coils.

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References:

[1] T.J. Hilsabeck *et al., Rev. of Sci. Instrum.*, 81, 10E317 (2010)
[2] J. Ayers et al., SPIE2012, 85050J (2012)
[3] J. Ayers et al., SPIE2013, Target Diagnostic Phys. and Eng. For ICF II, (2013)
[4] S.R. Nagel et al., SPIE2012, 85050H (2012)
[5] S.R. Nagel et al., SPIE2013, Target Diagnostic Phys. and Eng. For ICF II (2013)
[6] S.R. Nagel et al., Rev. of Sci. Inst., 83, 10E116 (2012)

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