This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2019-12779C

Inferring the apparent ion-temperature from MagLIF implosions using a forward-fit technique

J. D. Styron[1], G. W. Cooper[1], C. L. Ruiz[3], G. A. Chandler[2], M. Mangan[2], S. Pelka[1], C. A. Weaver[1], C. Highstrete[2], J. Torres[2], G. Whitlow[2]

[1]Department of Nuclear Engineering, University of New Mexico, Albuquerque, NM 87131, USA
[2]Sandia National Laboratories, Albuquerque, NM 87123, USA
[3]Retired-Sandia National Laboratories, Albuquerque, NM 87123, USA

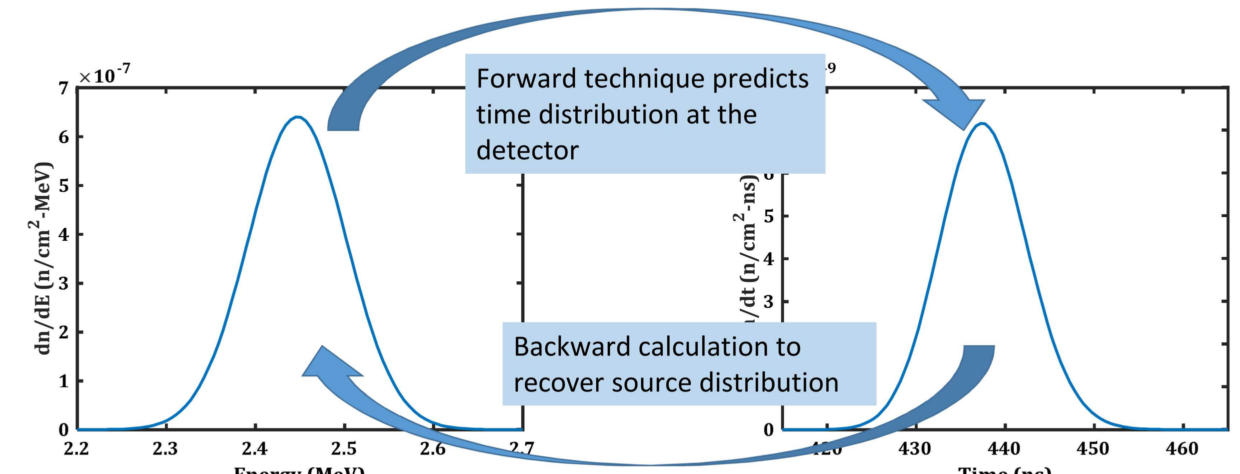
Abstract

A high-resolution neutron transport model has been developed in MCNP to simulate neutrons produced from MagLIF experiments conducted at Sandia National Laboratories' Z-Machine. Results of these simulations show that neutron interactions in the complex load hardware and bremsstrahlung shielding directly in the line-of-sight broaden the neutron time-of-flight (nToF) signal, which can lead to an overestimation of the average ion-temperature by as much as 500 eV for nominal MagLIF conditions at the 9.5m detector location. A family of potential nToF signals at different source conditions were generated in MCNP and convolved with an instrument response function and compared to experimental data. Using this technique, it is feasible to infer the apparent ion-temperature, Be liner areal density and neutron yield from a single measurement.

Under ideal conditions, time-of-flight is a direct measurement of the neutron energy distribution from which the apparent ion-temperature can be inferred[1].

$$E = \frac{m_0}{2c^2}v^2 = \frac{m_0}{2c^2}\left(\frac{d}{t}\right)^2, where\ \frac{dE}{dt} = \frac{m_o}{c^2}\frac{d^2}{t^3} = \frac{2E}{t}\ and\ \frac{dn}{dE}[MeV^{-1}] = \frac{A}{\sigma\sqrt{(2\pi)}}\exp\left(-\frac{(E-\bar{E})^2}{2\sigma^2}\right)$$

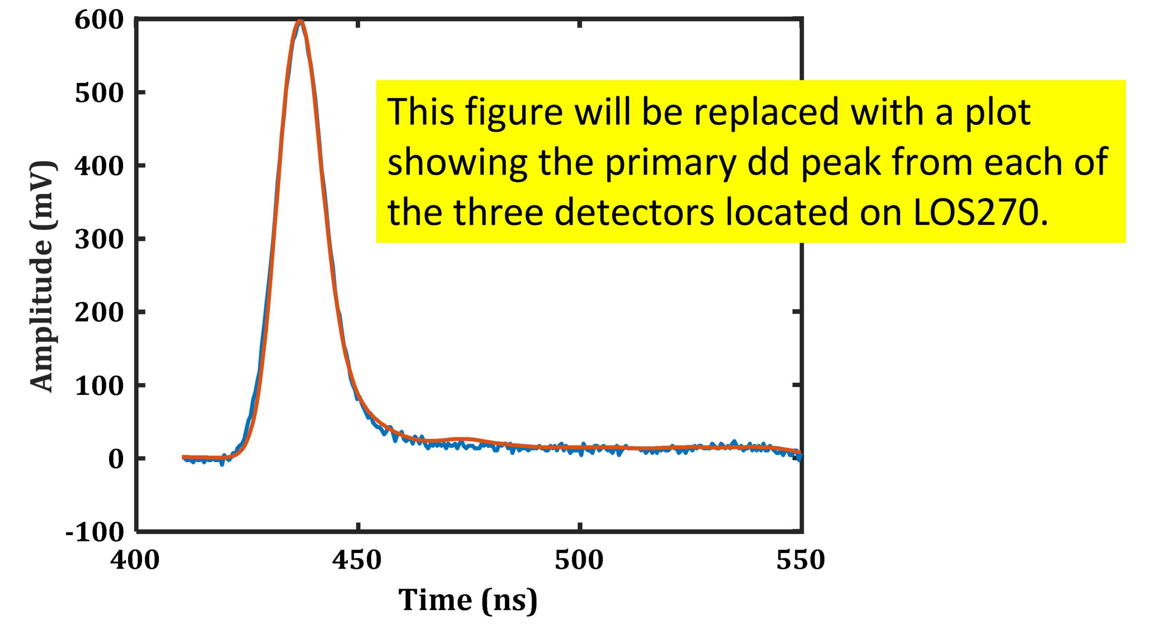
$$\frac{dn}{dt} = \frac{dn}{dE}\frac{dE}{dt} = \frac{2AE}{t\sigma\sqrt{2\pi}}\exp\left(-\frac{(E-\bar{E})^2}{2\sigma^2}\right) = \frac{11.89Ad^2}{\sqrt{kT}t^3}\exp\left(-\frac{110.99d^4}{kT}(t^{-2}-\bar{t}^2)^2\right)$$



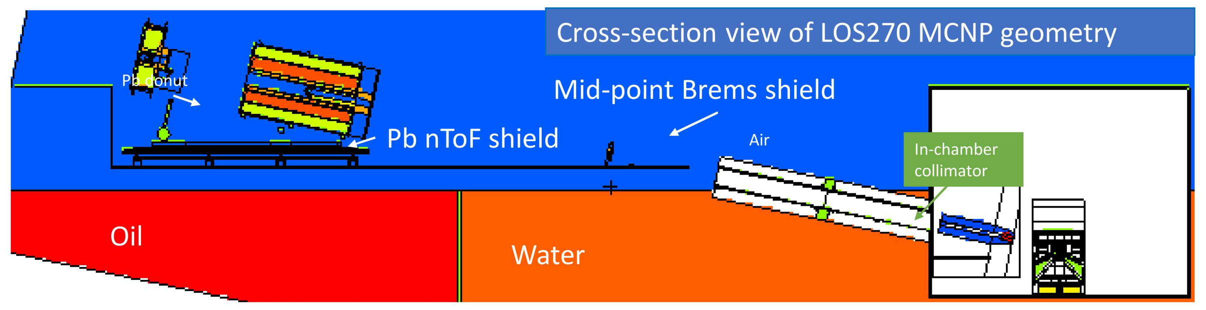
Neutron energy spectrum from a Maxwellian distribution of deuterons at 2.5 keV

Temporal response at a point detector located 9.5m from the source

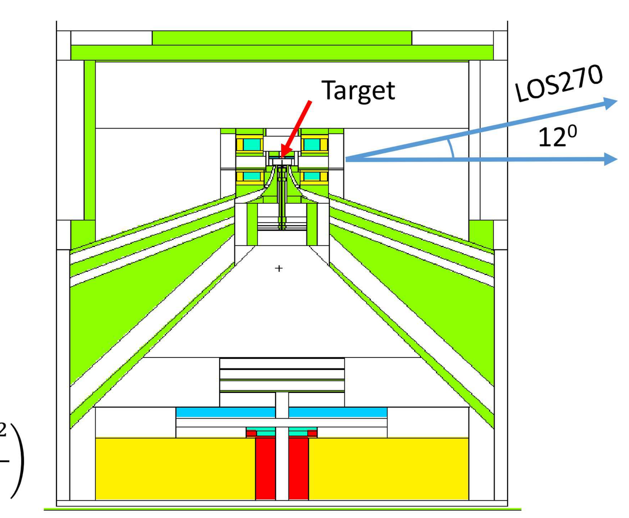
Departure from ideal conditions can be seen in the three nToF signals measured on line-of-sight 270 (LOS270). One at 9.5m and two at 11.5m.



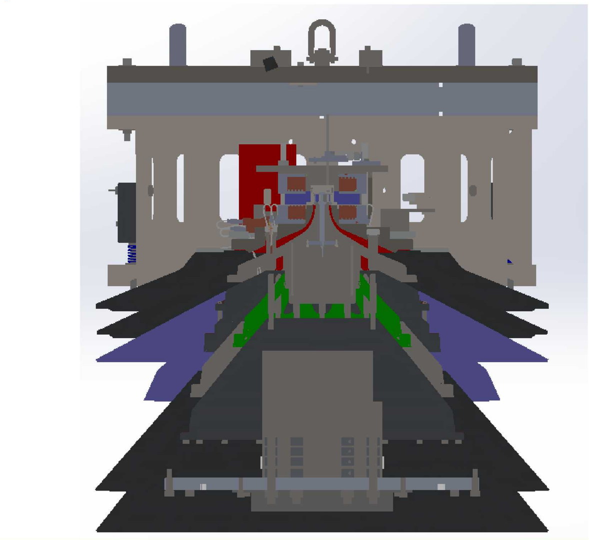
A neutron transport model of LOS270 was built in MCNP6 to correct for neutron attenuation and scattering in the nToF spectrum.



The reference MagLIF geometry is a typical 60-80 magnet coil configuration[2-8].

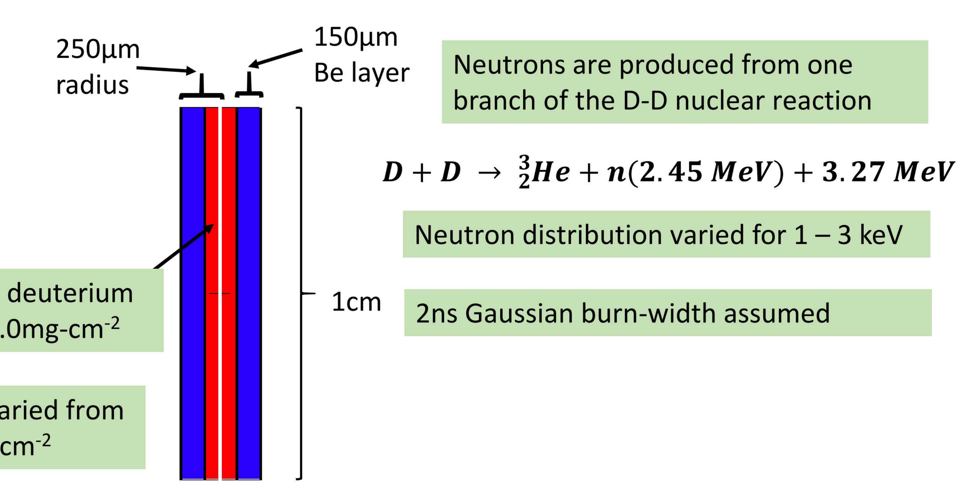


Blast shield with Roosevelt magnet (60-80) configuration modified for ZBL cutout (Original model by K. D. Hahn ~2013)



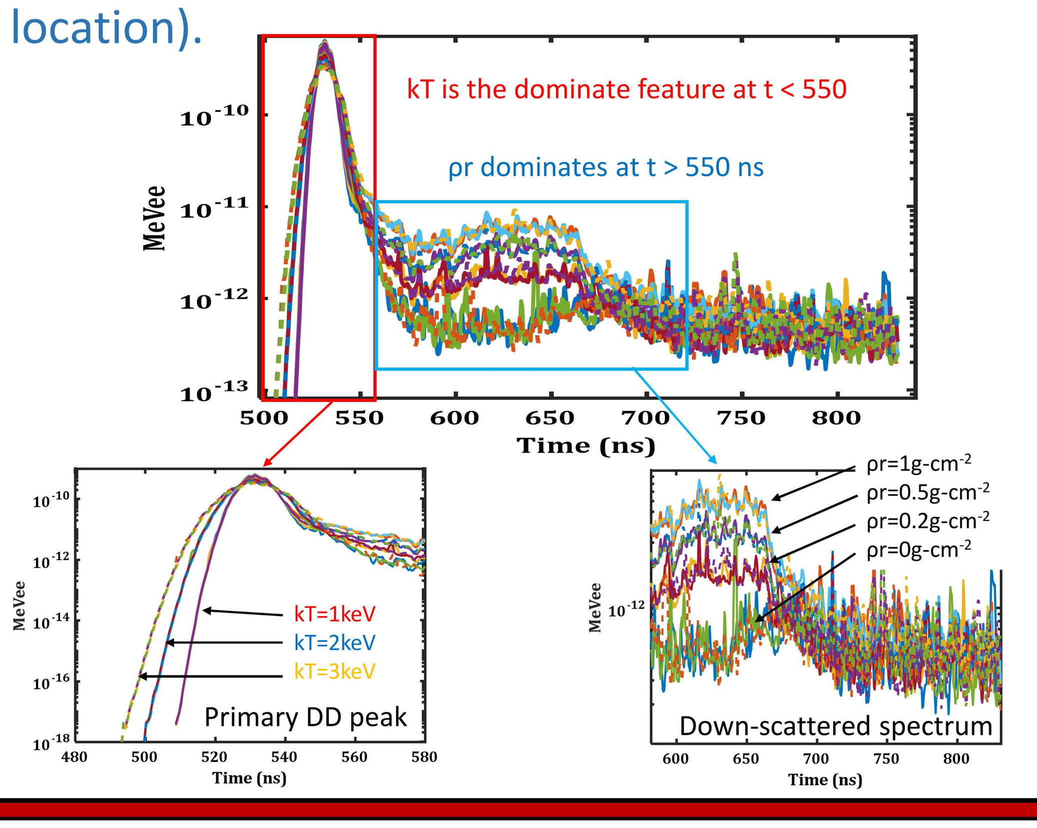
As-fielded configuration on Shot# Z3296 (80-60) (MagLIF Morphology 18b, 08-27-18) Dave Ampleford, PI

The source parameters were varied to cover the expected parameter space for a MagLIF implosion.

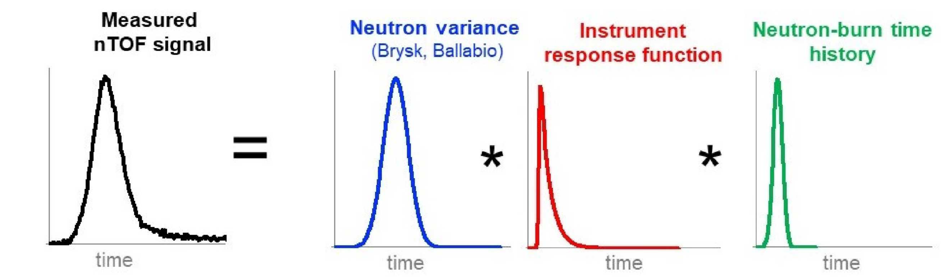


Source at stagnation conditions

Synthetic nToF spectra were produced at both the 9.5 and 11.5m nToF locations (Data shown for the 11.5m location).



The synthetic nToF spectra is then convolved with an assumed 2-ns Gaussian burn-width and an experimentally obtained Instrument Response Function (IRF) [9-10].

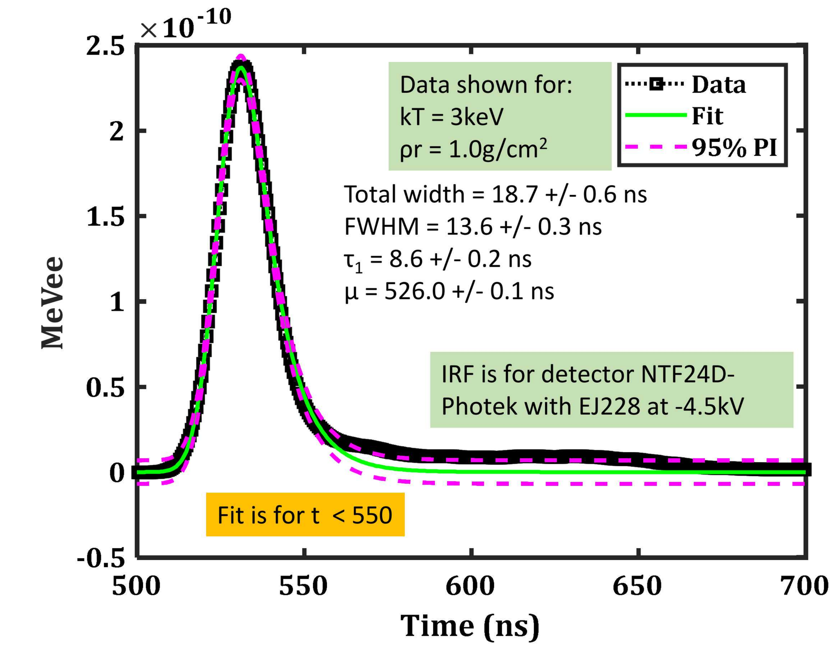


The convolved data is fit with an exponentially convolved Gaussian function.

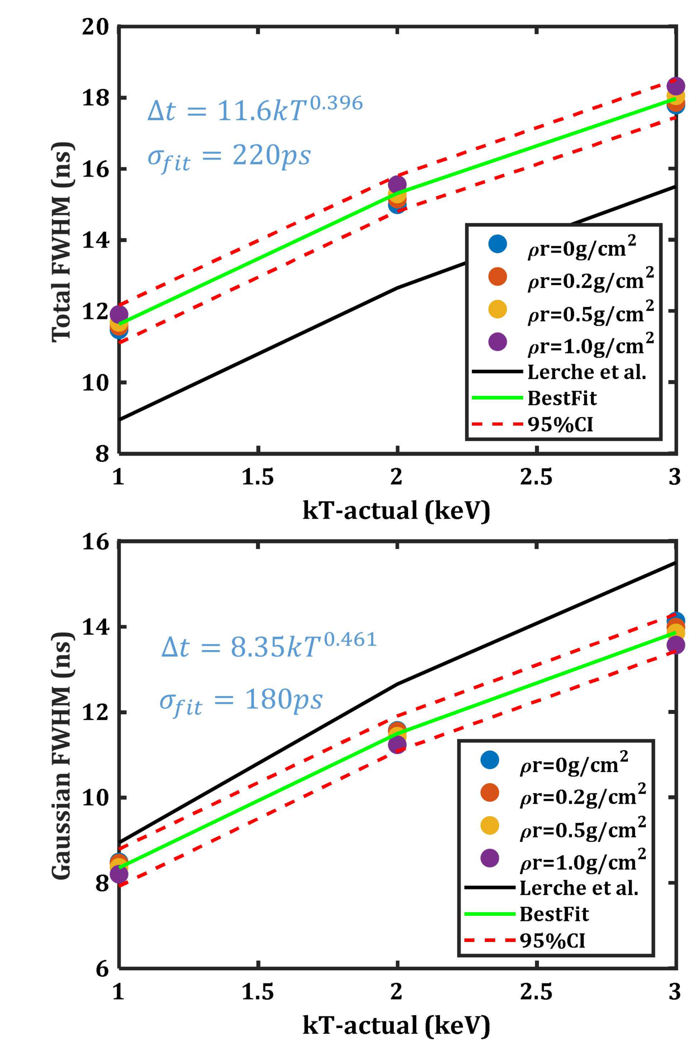
$$y(t) = g(t) \otimes h(t) = \frac{Q}{2\tau}\exp\left(-\frac{t-\mu}{\tau}\right)\exp\left(\frac{\sigma^2}{2\tau^2}\right)\left(1+\operatorname{erf}\left(\frac{t-\mu-\frac{\sigma^2}{\tau}}{\sqrt{2\sigma^2}}\right)\right)$$

$$where\ \sigma = \sigma_{burn} + \sigma_{kT} + \sigma_{IRF} + \delta\sigma_{scat}$$

$$and\ \tau = \tau_{IRF} + \tau_{scat}\ and\ \mu = t_0 + t_{flight} + t_{transit} + t_{cable}$$

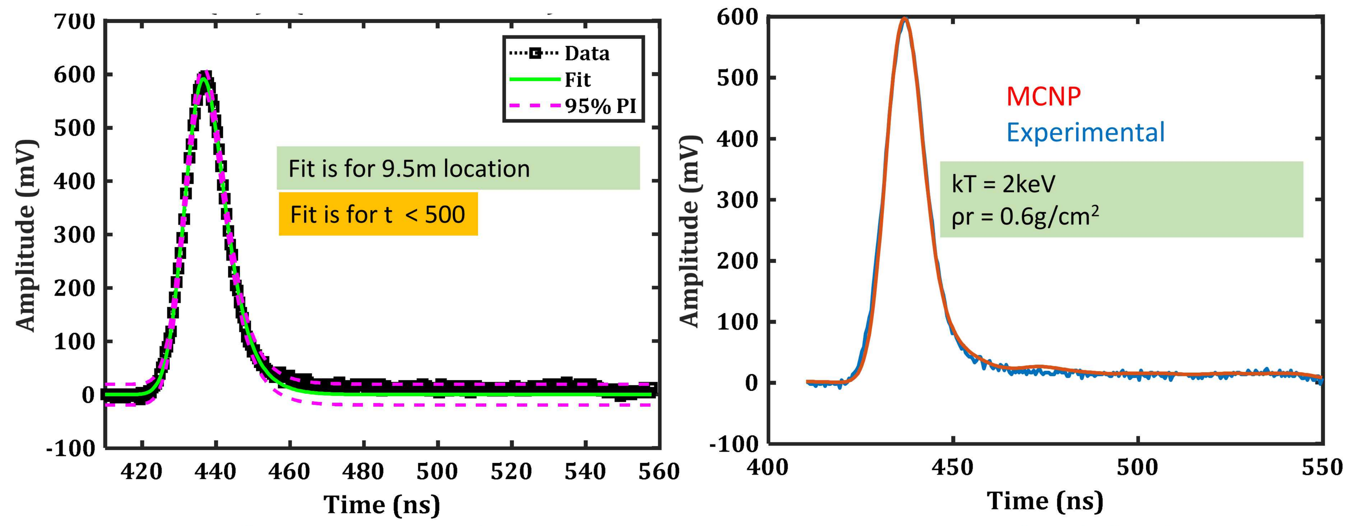


Two correlations for the apparent ion-temperature, kT can be determined from the total full-width at half-maximum (FWHM) and the Gaussian FWHM.

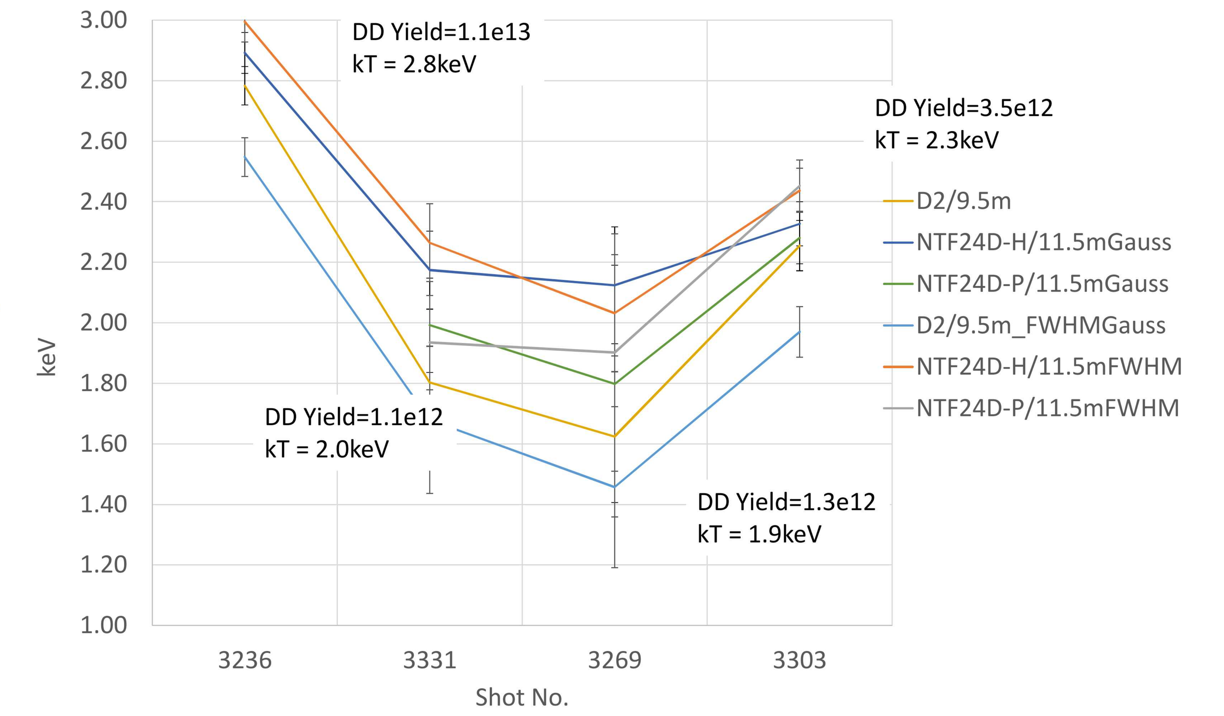


The inverse process is applied to experimental data.

- nToF spectrum is shifted in time to the expected arrival time of a 2.45-MeV neutron.
- Data is fit with an exponentially convolved Gaussian over the same interval as the synthetic data
- kT is inferred from the correlation established for each detector at each location.
- Areal-density of the Be liner is inferred from the downscattered spectrum (not discussed here).
- The appropriate model can then be compared to the experimental data.



The average ion temperature measured with three detectors for four different shots agree within the uncertainty of the formalism (+/- 300eV).



Conclusions

Coupling synthetic data generated in MCNP with experimental IRFs provides a way to bound the inferred average ion-temperature in MagLIF implosions.

References

[1] H. Brysk, *Plasma Physics*, **15**, pp. 611-617, (1973).
[2] S. A. Slutz et al., Physics of Plasmas, **17**, (2010).
[3] A. B. Sefkow et al., Physics of Plasmas, **21**, (2014).
[4] M. R. Gomez et al., Phys. Rev. Lett., **113**, (2014).
[5] P. F. Schmit et al., Phys. Rev. Lett., **113**, (2014).
[6] P. F. Knapp et al., Physics of Plasmas, **22**, (2015).
[7] S. B. Hansen et al., Phys Plasmas 22, (2015).
[8] K. D. Hahn et al., Journ. Of Phys., **717**, (2016).
[9] J. D. Styron et al., Rev. Sci. Instr., **89** (2018).
[10] T. J. Murphy et al., Rev. Sci. Instr. **68** (1997).

SAND-

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

The views expressed in the article do not necessarily represent the views of the U.S. Department of Energy or the United States Government.