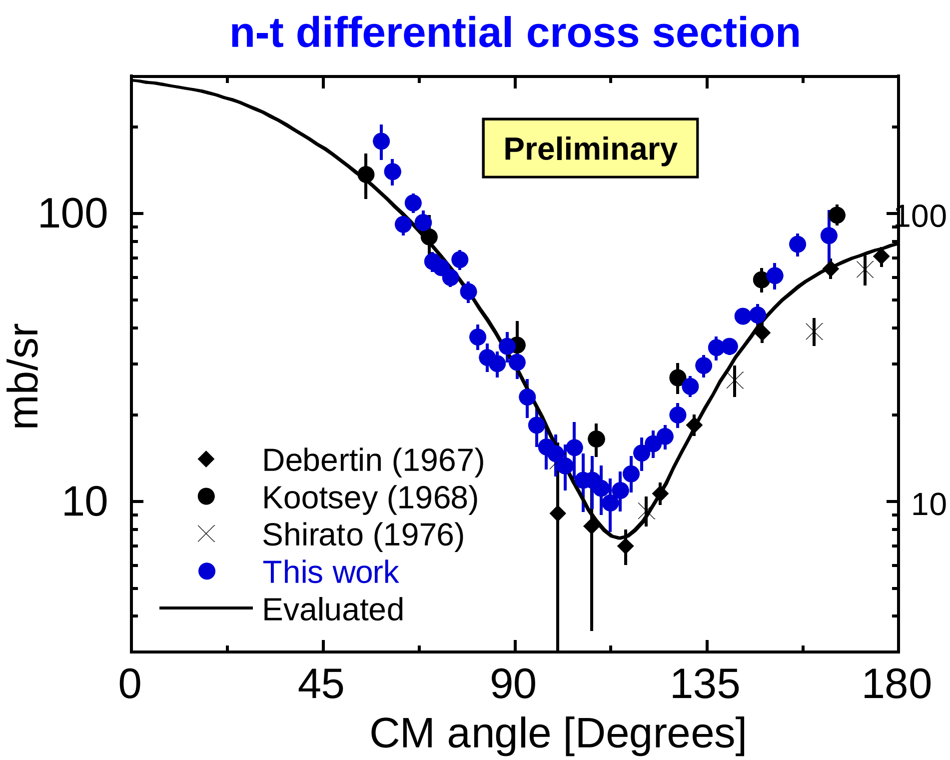
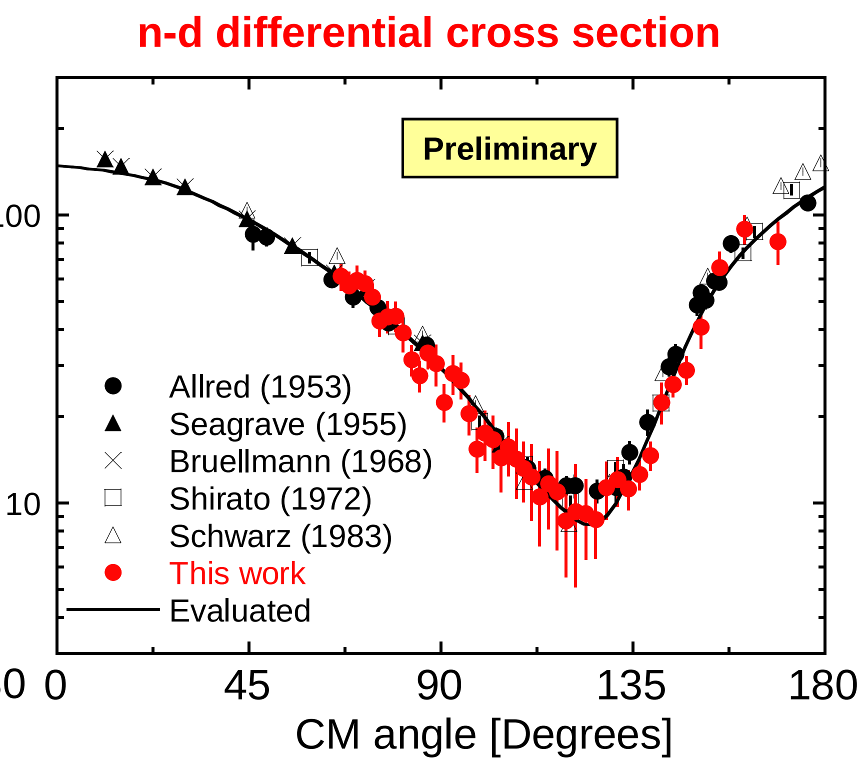
# First measurements of the differential n-d and n-t cross sections using an Inertial Confinement Fusion facility





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**OMEGA Laser User's Group**
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# References

**n-d:**

1. J.C. Allred et al., Phys. Rev. 91, 90 (1953).
2. J.D. Seagrave, Phys. Rev. 97, 757 (1955).
3. M. Bruellmann et al., J. Helvetica Physica Acta, 41, 435 (1968).
4. S. Shirato et al., Nuclear Phys. A120, 387 (1968).
5. P. Schwarz et al., Nuclear Phys. A398, 1 (1983).

**n-t:**

1. K. Debertin et al., (1967). (ENDF nuclear data base)
2. J.M. Kootsey, Nuclear Phys. A113, 65 (1968).
3. S. Shirato et al., Nuclear Phys. A267, 157(1976).

# Collaborators

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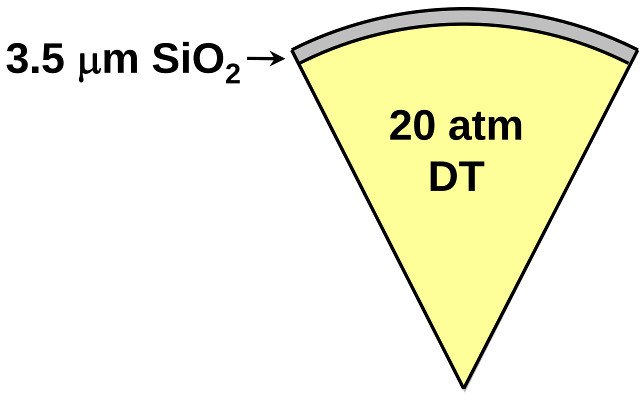
# Abstract

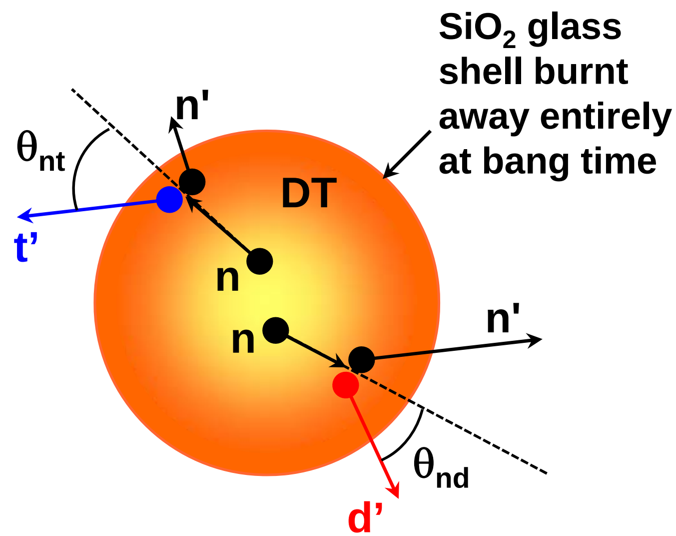
Since the 1960's, the differential cross section for the neutron-triton (n-t) elastic scattering at 14.1 MeV has been subject to extensive experimental and theoretical studies. Although significant efforts have been made to quantify this fundamental cross section, it is still poorly known. An attempt was therefore made to measure this cross section to an accuracy better than currently available, as that would improve the accuracy in, for instance, simulating absolute neutron spectra from Inertial Confinement Fusion (ICF) capsule implosions. This measurement was performed, for the first time, using an Inertial Confinement Fusion (ICF) facility. In these experiments, carried out at the OMEGA laser system, University of Rochester, DT-gas-filled thin-glass capsules were imploded. The energy spectra of the emitted deuterons and tritons, elastically scattered by the 14.1-MeV neutrons, were simultaneously measured using a magnetic spectrometer. From the measured spectra of the deuterons and tritons, the differential cross sections for the n-d and n-t elastic scattering were obtained after small corrections were applied to the data. Only small corrections are necessary, as the Doppler broadening, spectrometer-response and energy-ranging down effects in the plasma are minimal. In this poster, we present preliminary results on the n-d and n-t differential cross sections at 14.1 MeV, which are contrasted to the evaluated and measured cross sections currently available in the EXFOR and ENDF nuclear data bases.

Experiments

# DT-gas-filled thin-glass implosions were used for measurements of the differential n-d and n-t elastic scattering cross sections

**30 kJ**
**1-ns square pulse**
**$Y_n$ = 4-5×$10^{13}$**
**$\langle T_i \rangle_n$ = 8-9 keV**



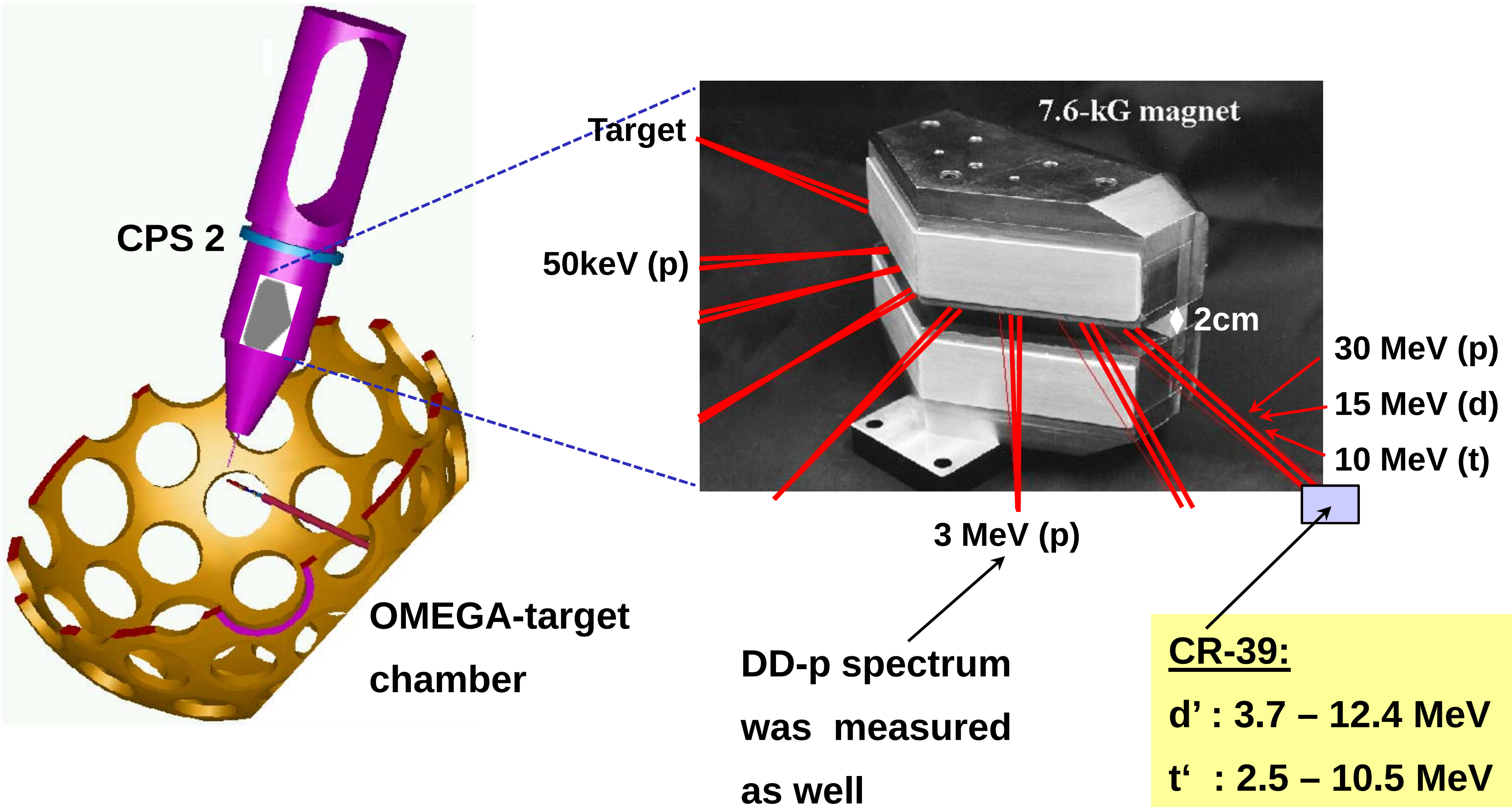

- **Elastically scattered deuterons (d'):** $E_{d'} = (8/9) \times E_n \times \cos^2\theta_{nd}$

  **n + D → n' + D' (<12.4 MeV)**

- **Elastically scattered tritons (t'):** $E_{t'} = (3/4) \times E_n \times \cos^2\theta_{nt}$

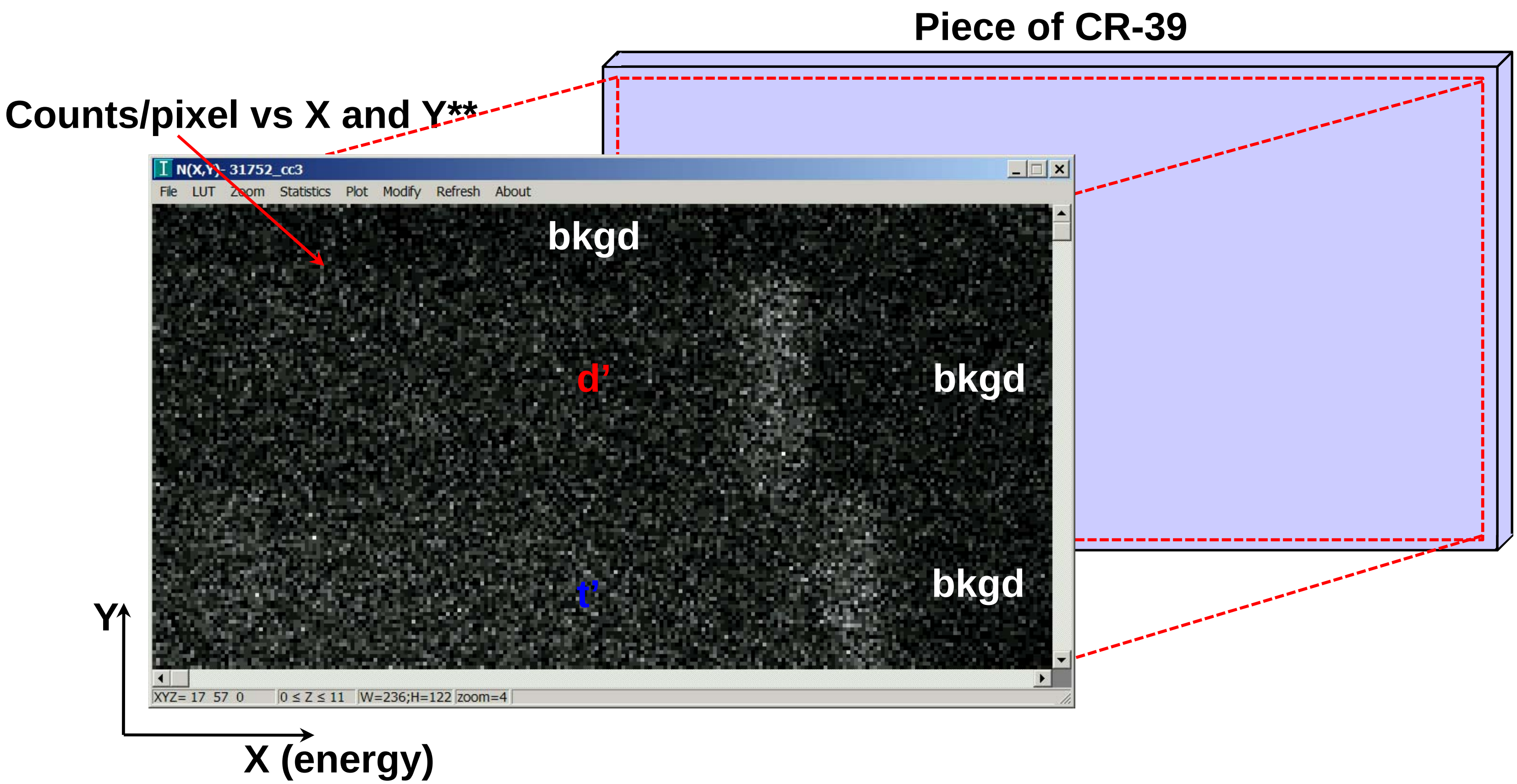
  **n + D → n' + t' (<10.5 MeV)**

# Simultaneous measurements of the d' and t' spectra were performed with a Charged Particle Spectrometer (CPS)



Experimental data

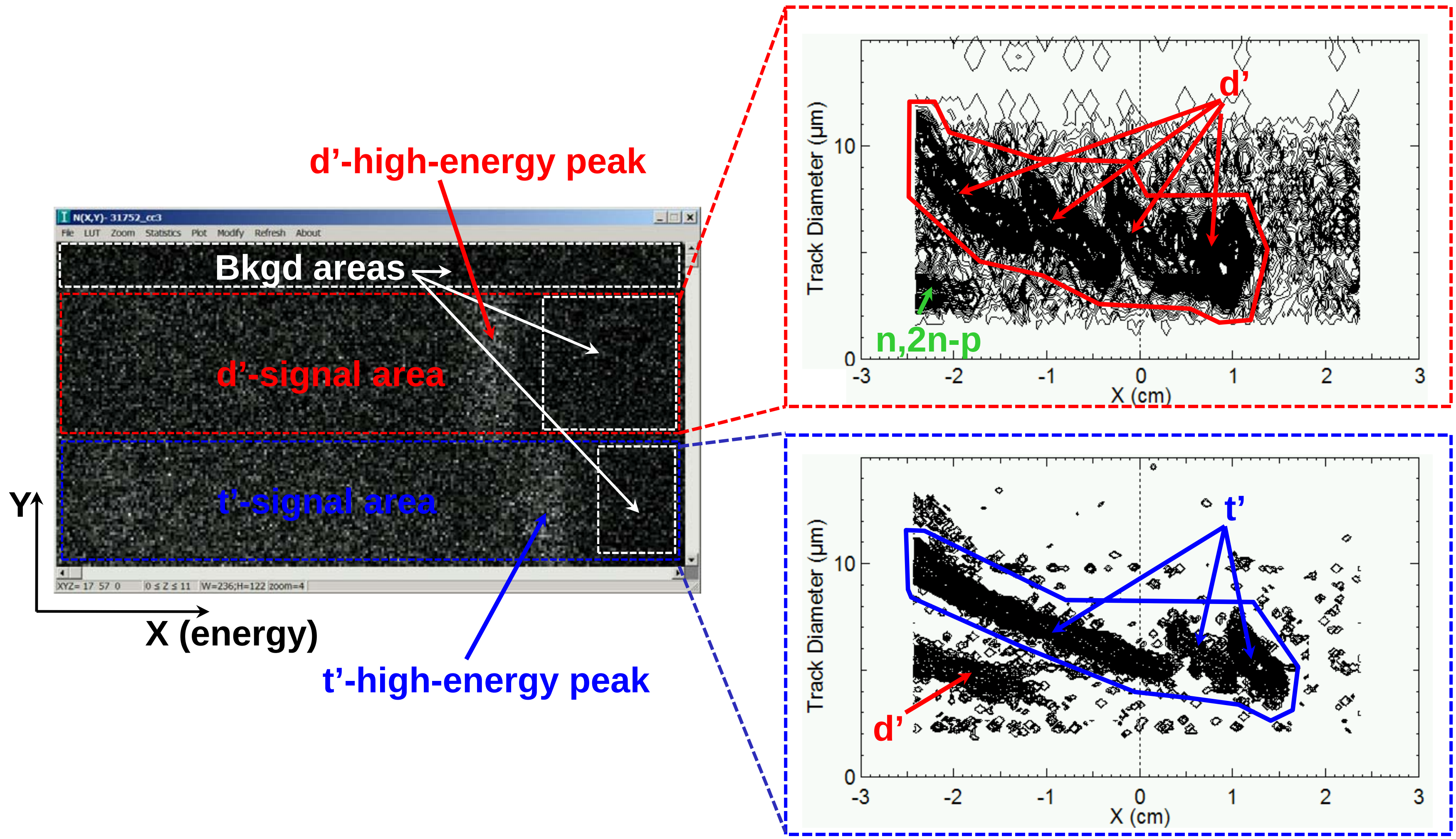
# The d’ and t’ spectra were recorded simultaneously on one piece of CR-39 fielded at the high-energy end of CPS 2




** With correct filtration in front of the CR-39, three region were obtained: background region (top, and to the right), a d’-signal region (middle), and a t’-signal region (bottom).

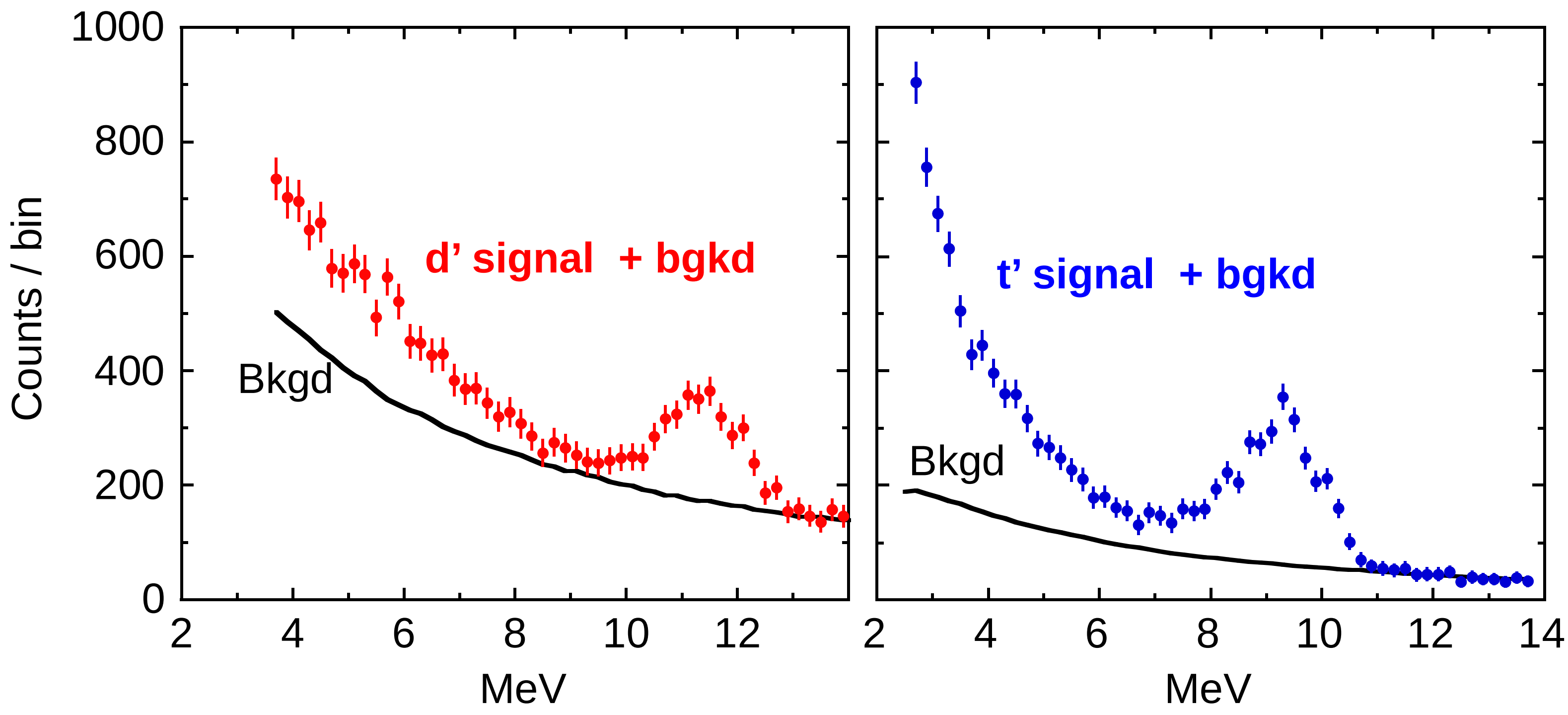
Experimental data

# Signal is extracted from the measured data by selecting signal and background areas and putting constraints on the diameters and darkness of the tracks



**Experimental data**

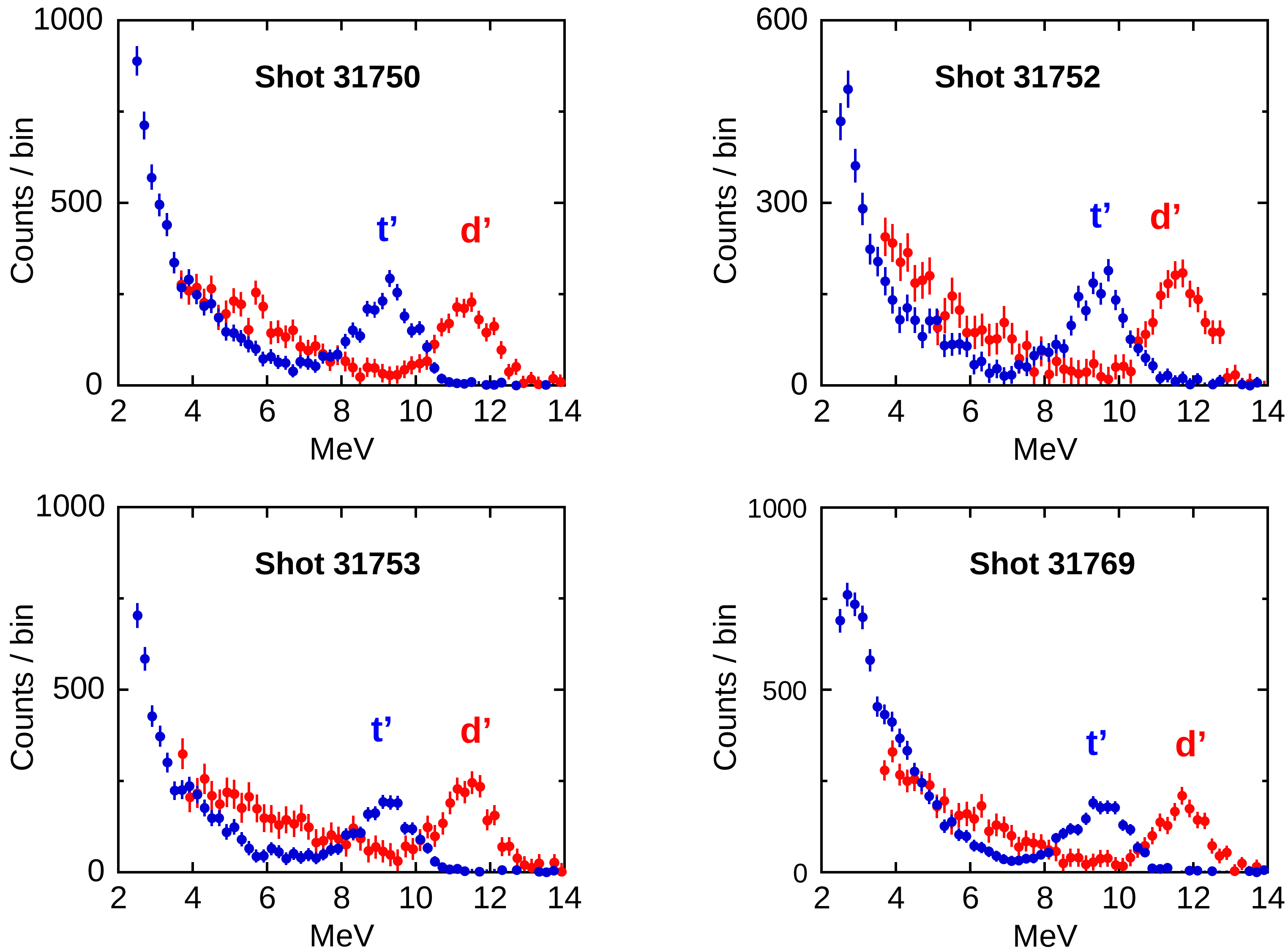
# Resulting signal and background** spectra from a single shot (31750)




** Different constraints on track diameter and track contrast are applied to the d' and t' data, resulting in different levels of background.

Experimental data

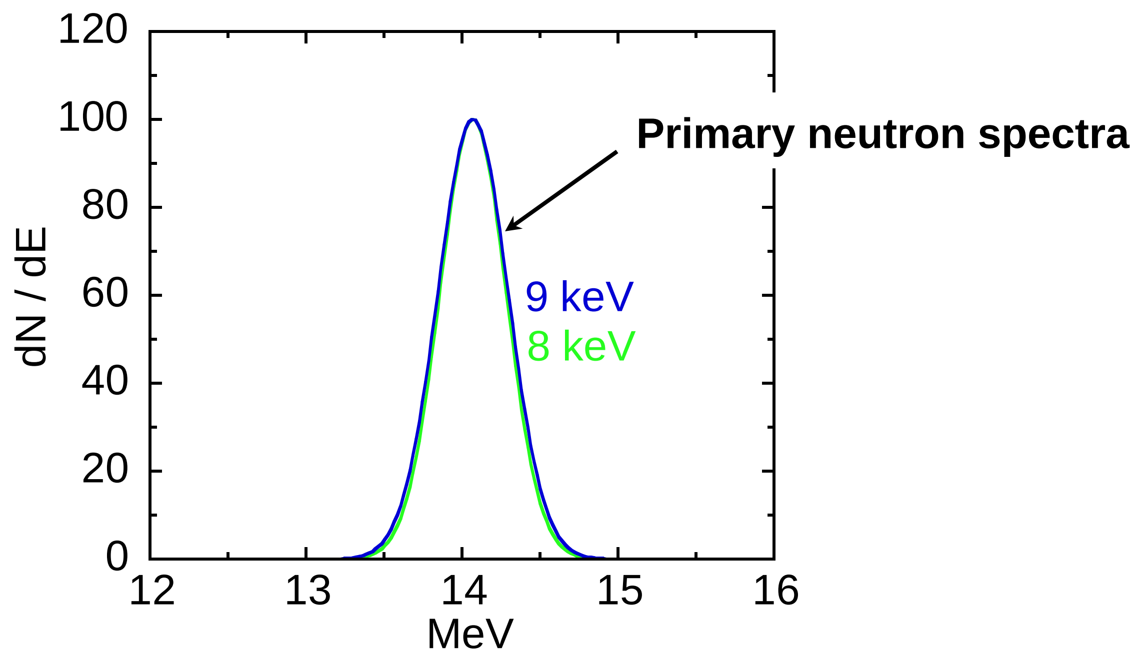
# d' and t' spectra were obtained simultaneously for four different shots



Data analysis

# Doppler broadening must be deconvolved from the measured d' and t' spectra

- **A $T_i$ of 8-9 keV results in a Doppler broadening of ~500 keV.**

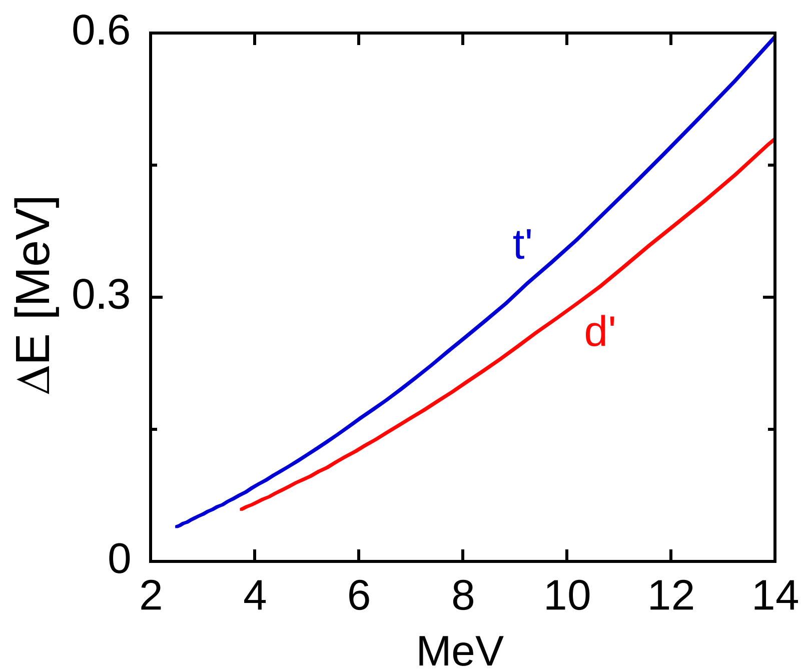



- **The uncertainty in $T_i$ of ±0.5 keV does not significantly impact the analysis.**

Data analysis

# The CPS2-response function must be deconvolved from the measured d' and t' spectra

- The CPS2-response function has a box-car shape that varies with energy and particle specie.

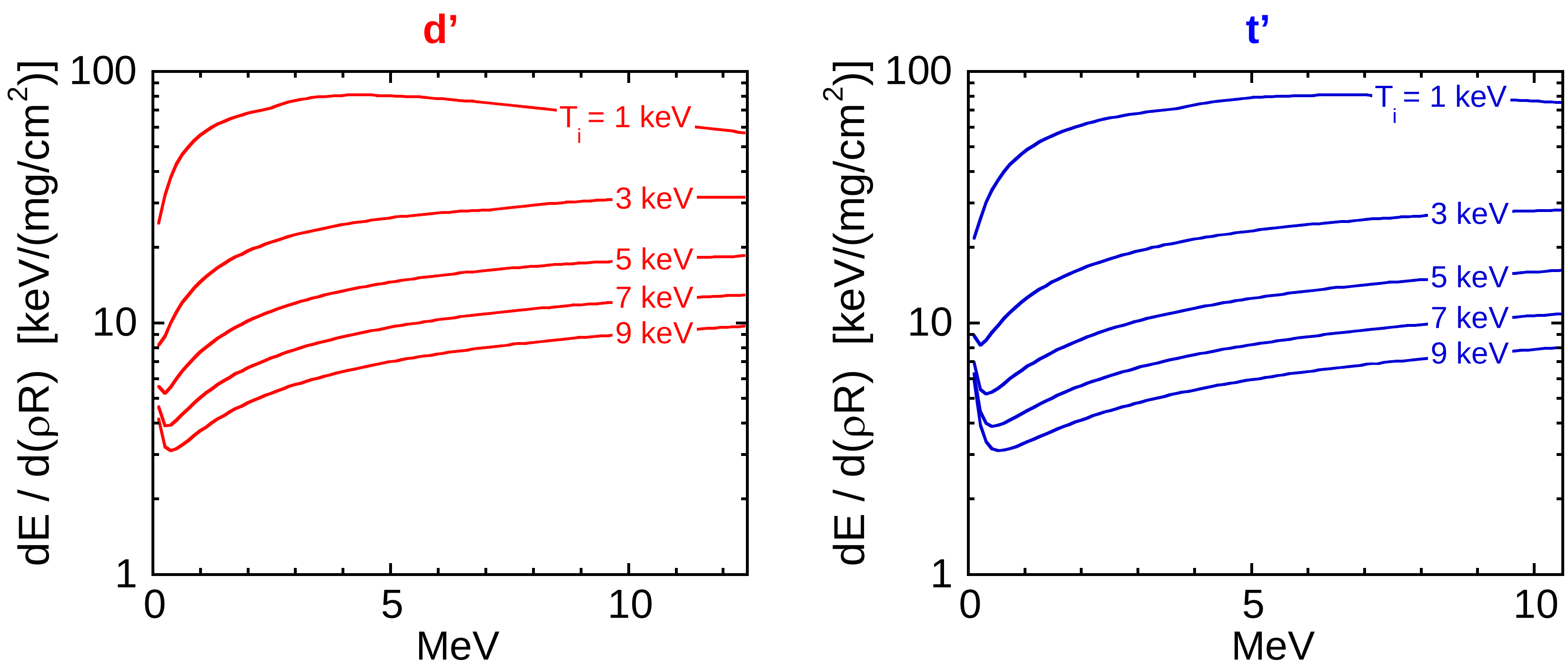



- The ±100 keV uncertainty in the energy calibration must be accounted for as well.

** As the CPS 2 is only a bending magnet, a 2-mm wide magnet aperture results in boxcar-response function that varies with energy.

Data analysis

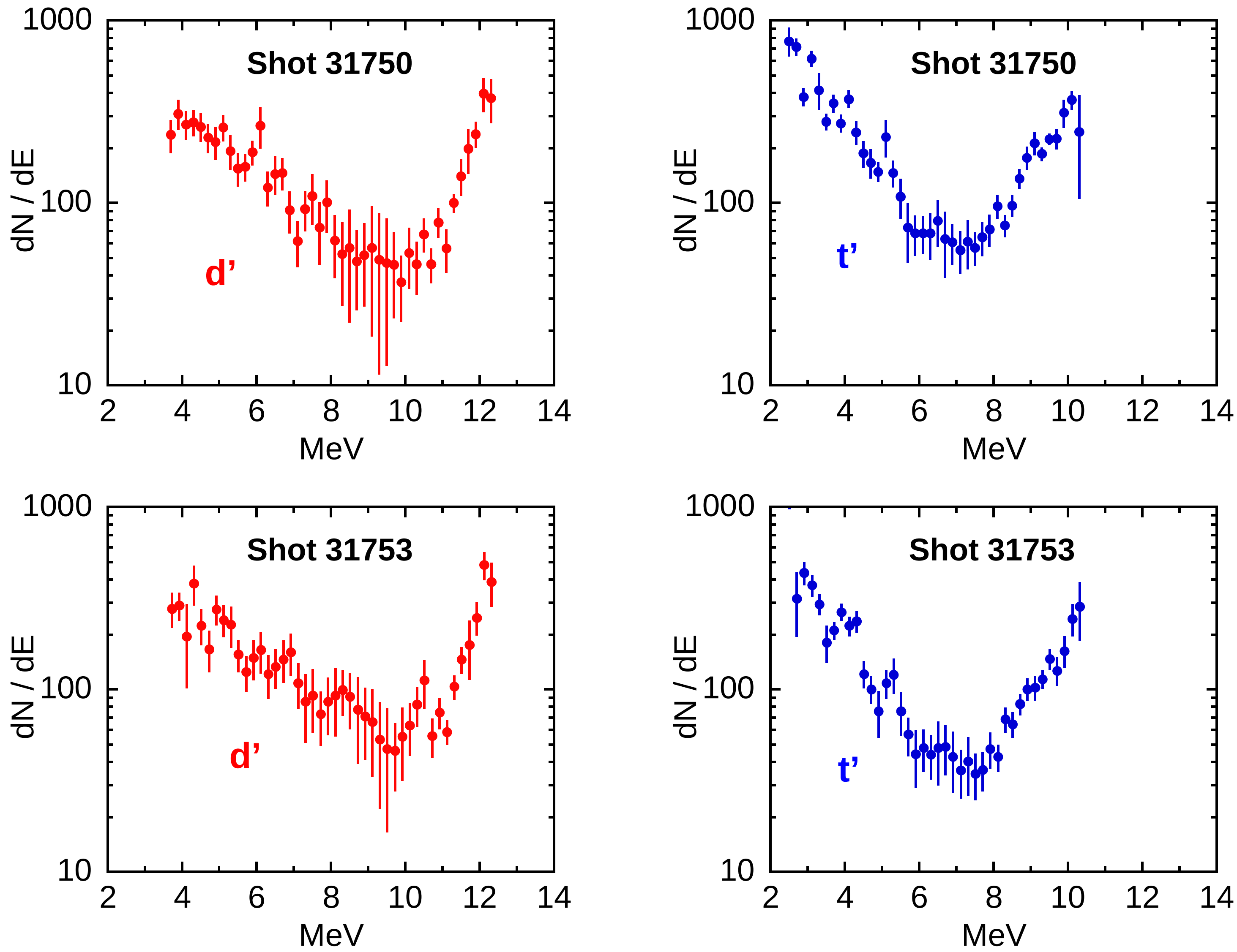
# The d' and t' energy loss in the plasma is small, and does not have to be considered in the analysis




**As the total ρR is ~2 mg/cm² and burn-averaged $T_i$ is 8-9 keV, the expected energy loss in the plasma is ~20 keV or less for both deuterons and tritons**

**Unfolded data**

# Unfolded d’ and t’ spectra (dN/dE) for two shots



Experimental data

# The unfolded d' and t' spectra (dN/dE) are equivalent to the differential n-d and n-t elastic scattering cross sections given in the central-mass (CM) system

$$dN = n_i t \frac{d\sigma}{d\Omega_{lab}} d\Omega_{diag} \Rightarrow \left\{ \begin{array}{l} d\Omega_{diag} = 2\pi Sin\theta d\theta \\ \frac{d\sigma}{d\Omega_{lab}} = 4Cos\theta \frac{d\sigma}{d\Omega_{CM}} \end{array} \right\} \Rightarrow dN = 8\pi n_i t Sin\theta Cos\theta \frac{d\sigma}{d\Omega_{CM}} d\theta$$

$$\Rightarrow \boxed{\frac{dN}{d\theta} \propto Sin\theta Cos\theta \frac{d\sigma}{d\Omega_{CM}}}$$

$$E = \frac{4A}{(A+1)^2} Cos^2\theta \Rightarrow \boxed{\frac{dE}{d\theta} \propto Sin\theta Cos\theta}$$

$$\frac{dN}{dE} = \frac{dN}{d\theta} \Big/ \frac{dE}{d\theta} \propto \frac{d\sigma}{d\Omega_{CM}} \Rightarrow \boxed{\frac{dN}{dE} \propto \frac{d\sigma}{d\Omega_{CM}}}$$

$n_i$: Number density of recoil nucleus

$t$: Effective target thickness

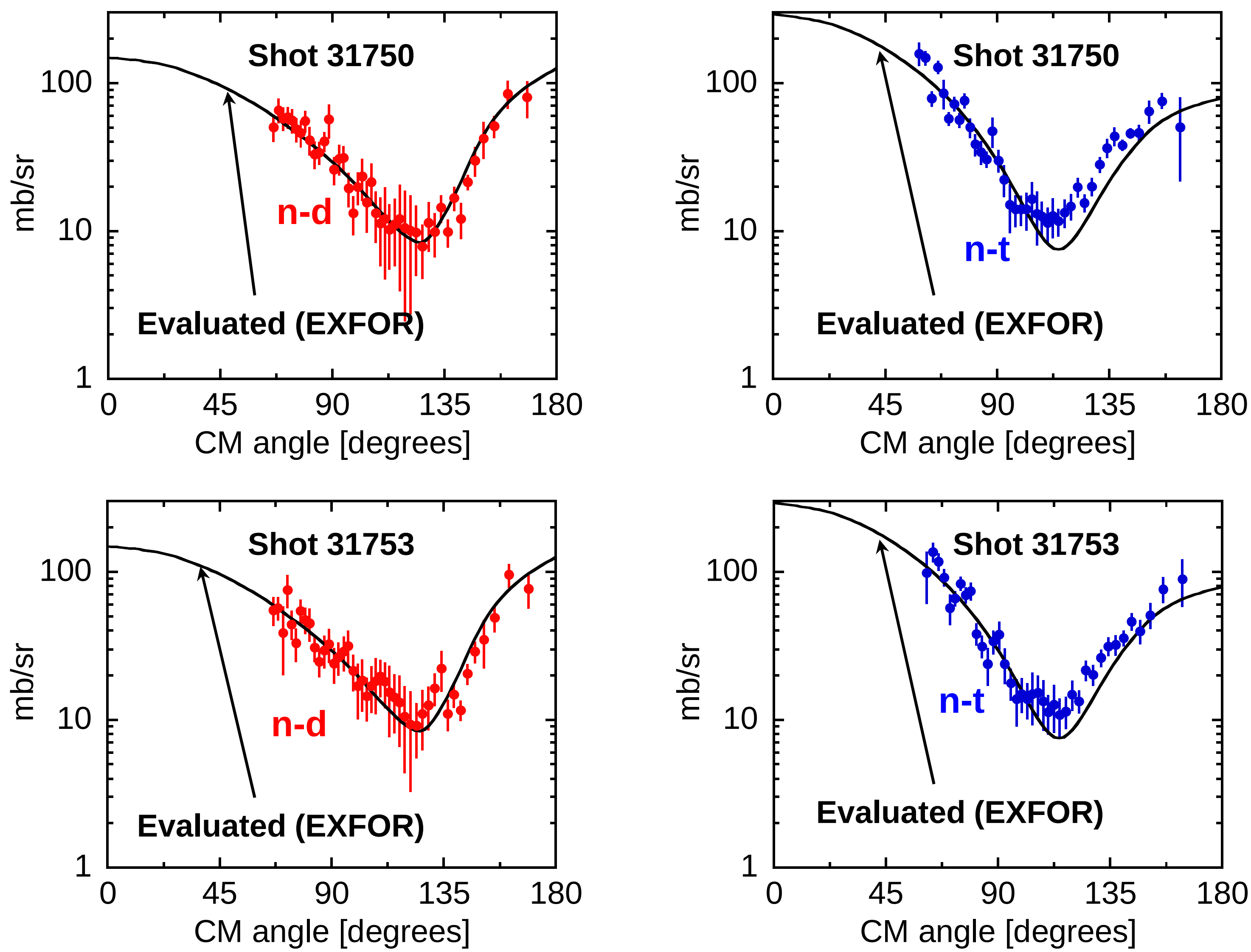
$E$: Energy of recoil nucleus

$A$: Mass number of recoil nucleus

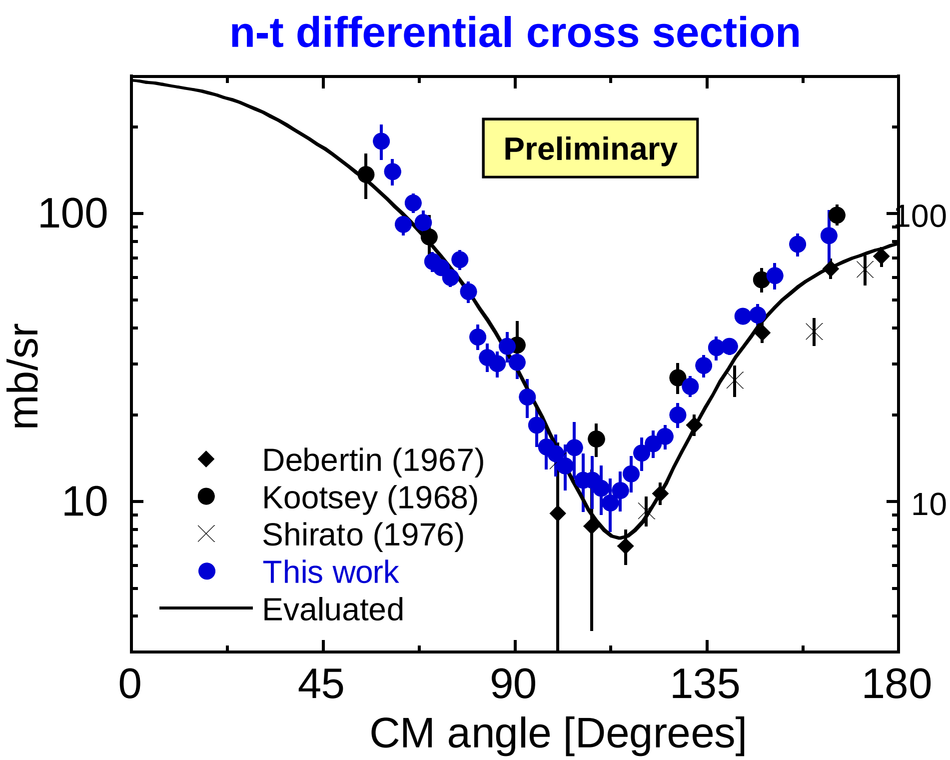
$\theta$: Scattering angle of recoil nucleus

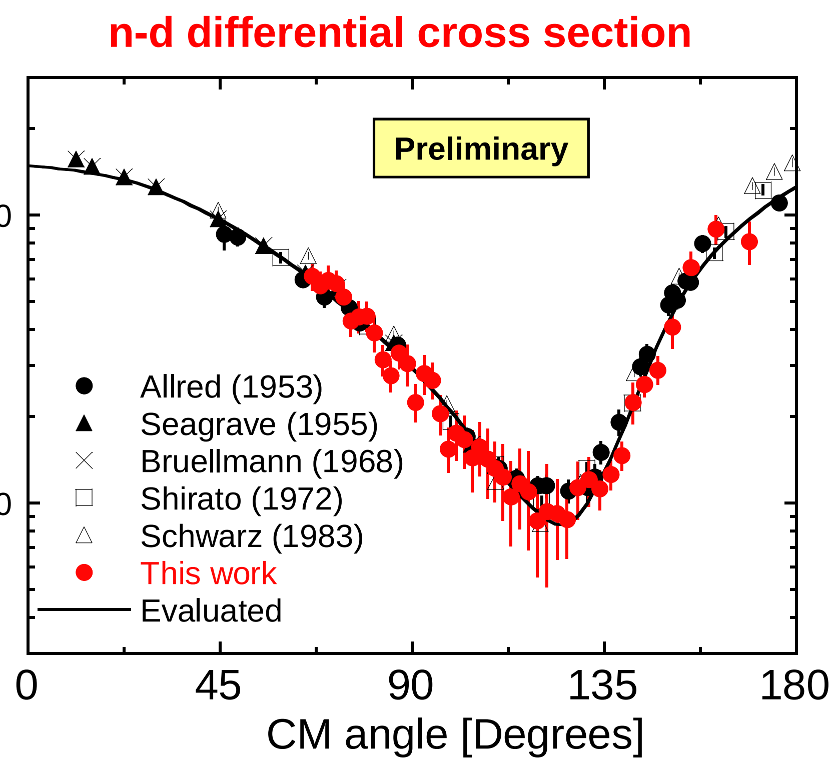
Unfolded data

# The absolute n-d and n-t differential cross sections were determined by normalizing the measured n-d to the evaluated n-d cross section



# The n-t differential cross section determined in this work agrees with the evaluated n-t cross section at small scattering angles but not at large scattering angles

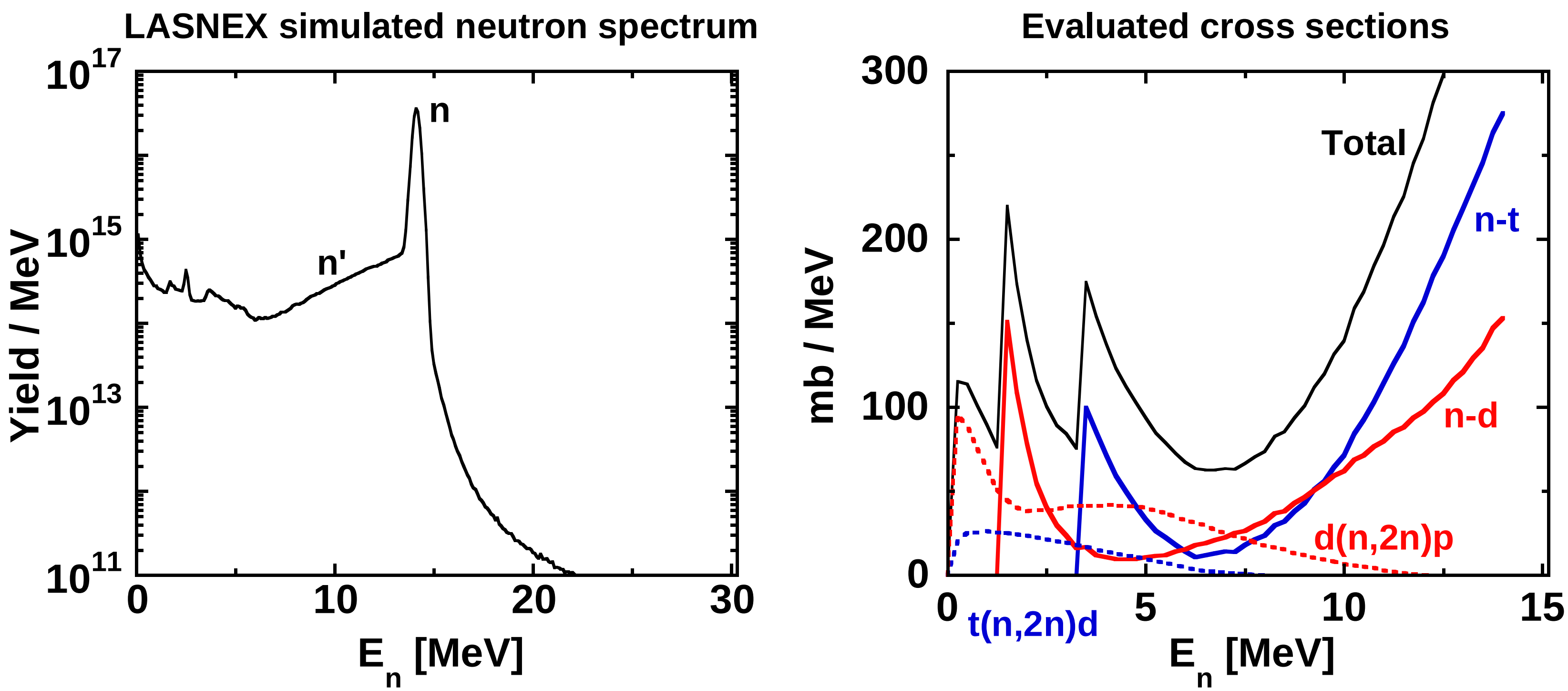



**The data sets are averages of four shots**

Implications for the NIF

# As a consequence of this work, more accurate simulations of the absolute ICF-neutron spectrum can now be done




**Simulations of the absolute spectrum of elastically scattered neutrons (n') depends primarily on the evaluated n-t and n-d differential cross sections**

# Future work

- Improve the deconvolution technique used in the analysis. The current one, which is "home made", is numerically unstable.

- Interpretation of the obtained n-d and n-t differential cross sections.