Measurement of the T+T Neutron Spectrum Using the National Ignition Facility

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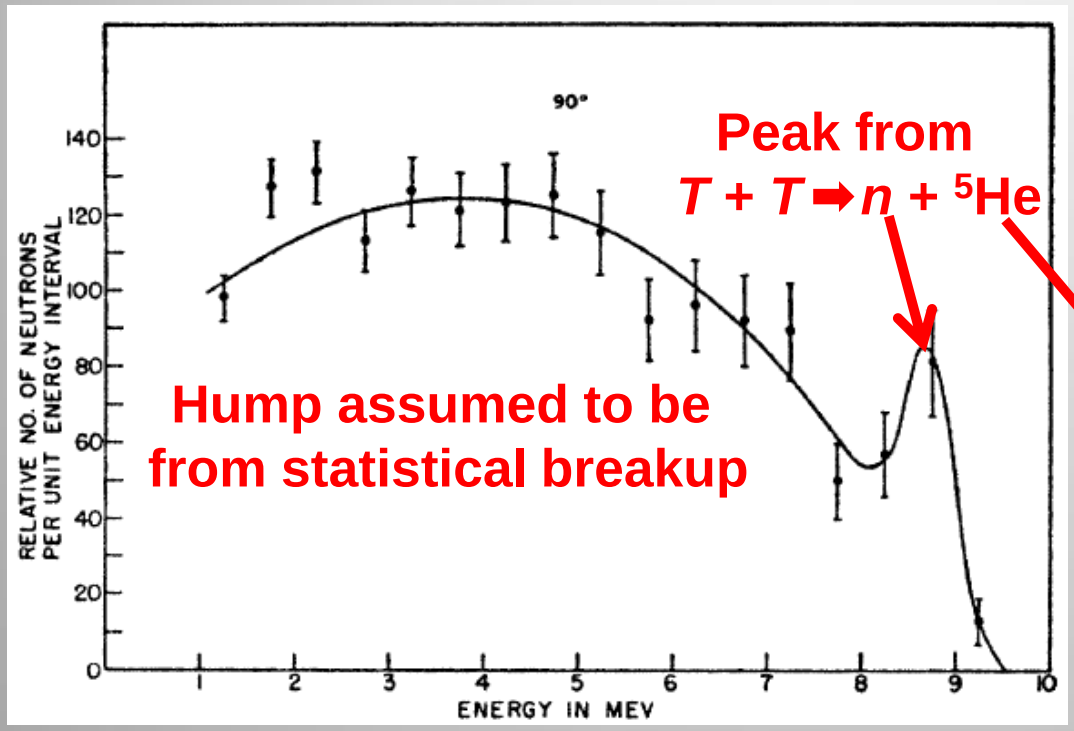
GENERAL ATOMICS

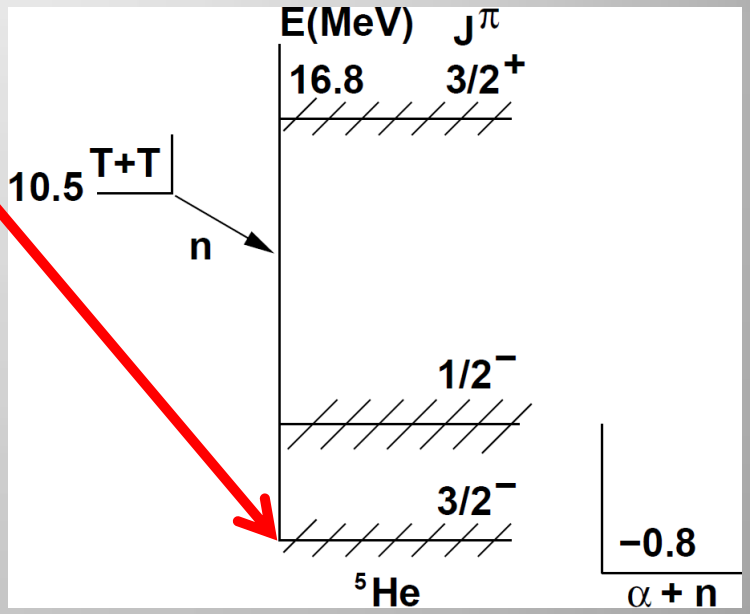
Low energy T+T neutron spectrum

- **Neutron spectrum investigations span six decades**
  - Decay properties, breakup mechanism
  - Neutron-neutron scattering length
  - Controlled fusion research
- **Variety of approaches to investigate spectrum**
  - Accelerators with proton-recoil and NTOF detectors
  - Muon-catalyzed fusion with proton-recoil detectors
  - Inertial confinement fusion with recoil deuteron magnetic spectrometer and NTOF detectors
- **Interpretation of the spectrum is challenging**
  - Quantum three-body problem

First reported measurement of spectrum

- **Letter to Editor, Allen *et al.*, Phys. Rev. 82, 262 (1951)**

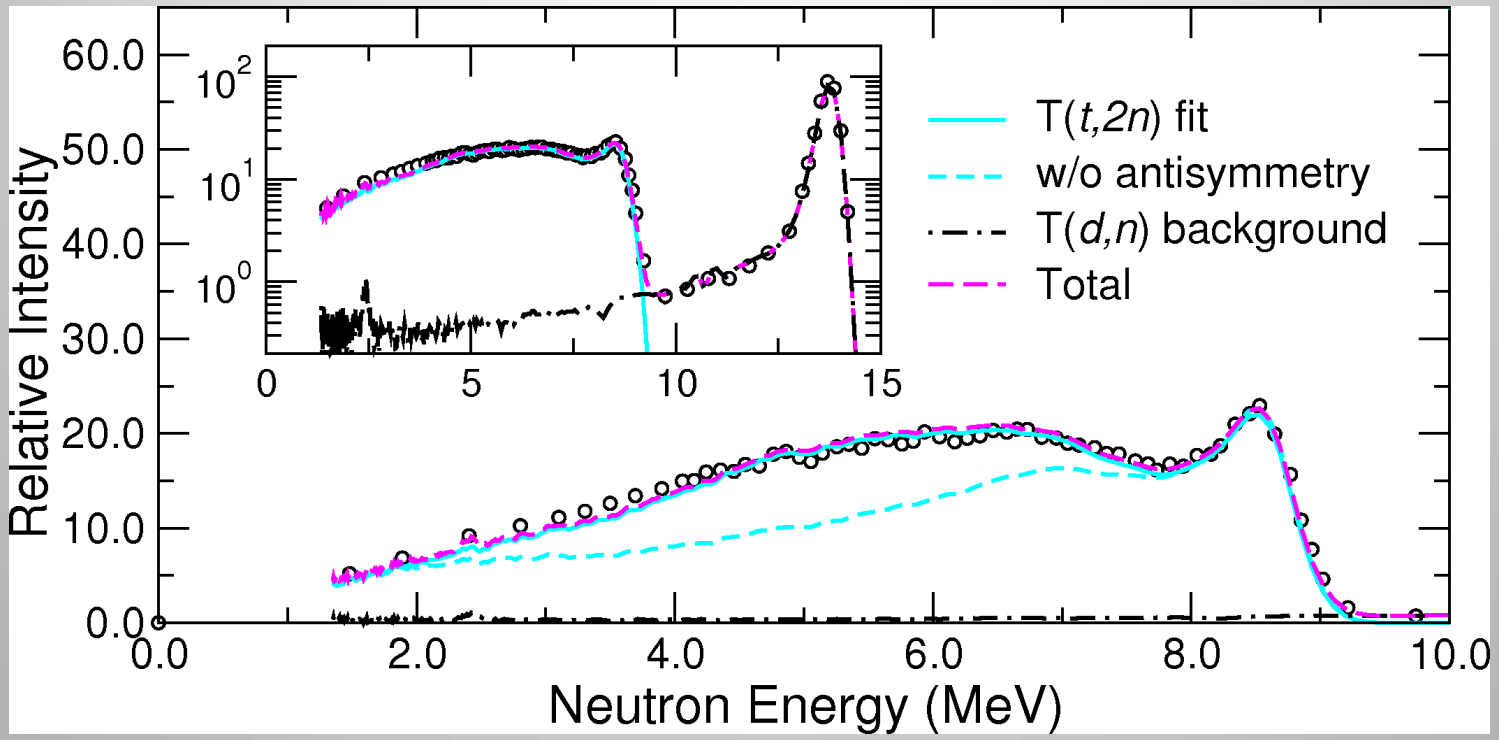




- Limited statistics and neutron energy resolution
- Spectrum attributed to decays through ^{5}He ground state and phase space

Recent measurement performed at NIF

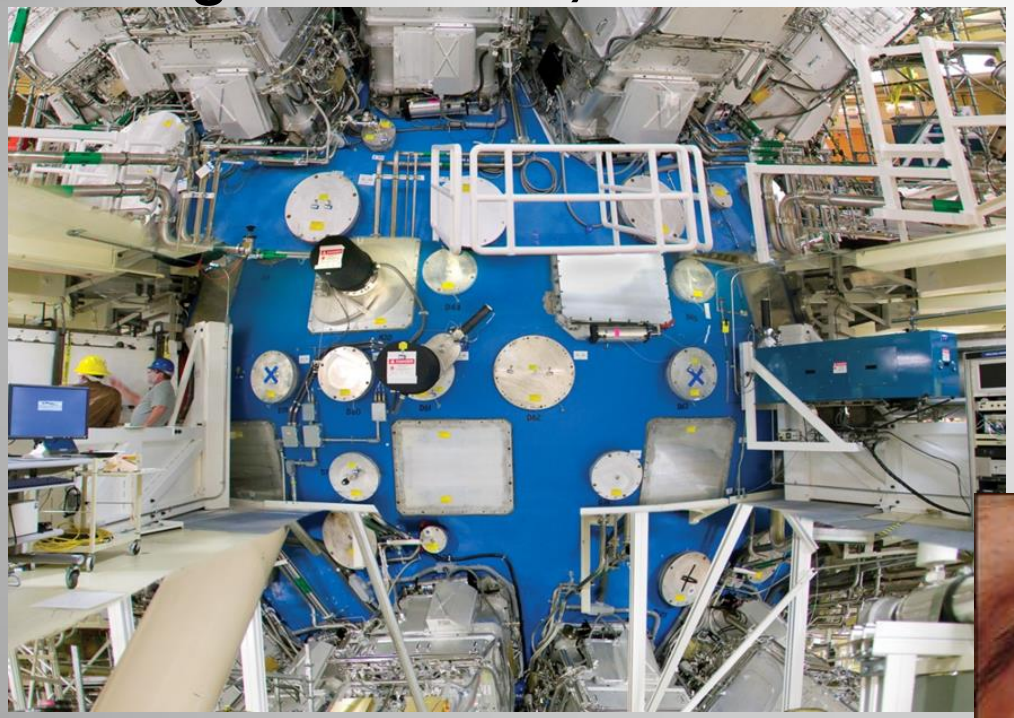
D. Sayre, C. Brune, **J. Caggiano**, **R. Hatarik** *et al.*, Phys. Rev. Lett. 111, 052501 (2013)

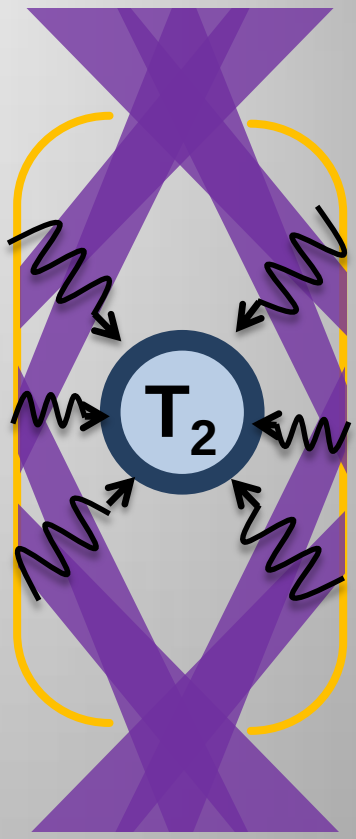


- **Excellent statistics and energy resolution**
  - 10^{13} total neutrons produced over 200ps thermonuclear burn
  - Two 20-m NTOFs measure spectrum with 280-keV resolution
  - >99% tritium target minimizes T(*d,n*) induced background

Experimental setup at NIF

NIF target chamber, 10m diameter

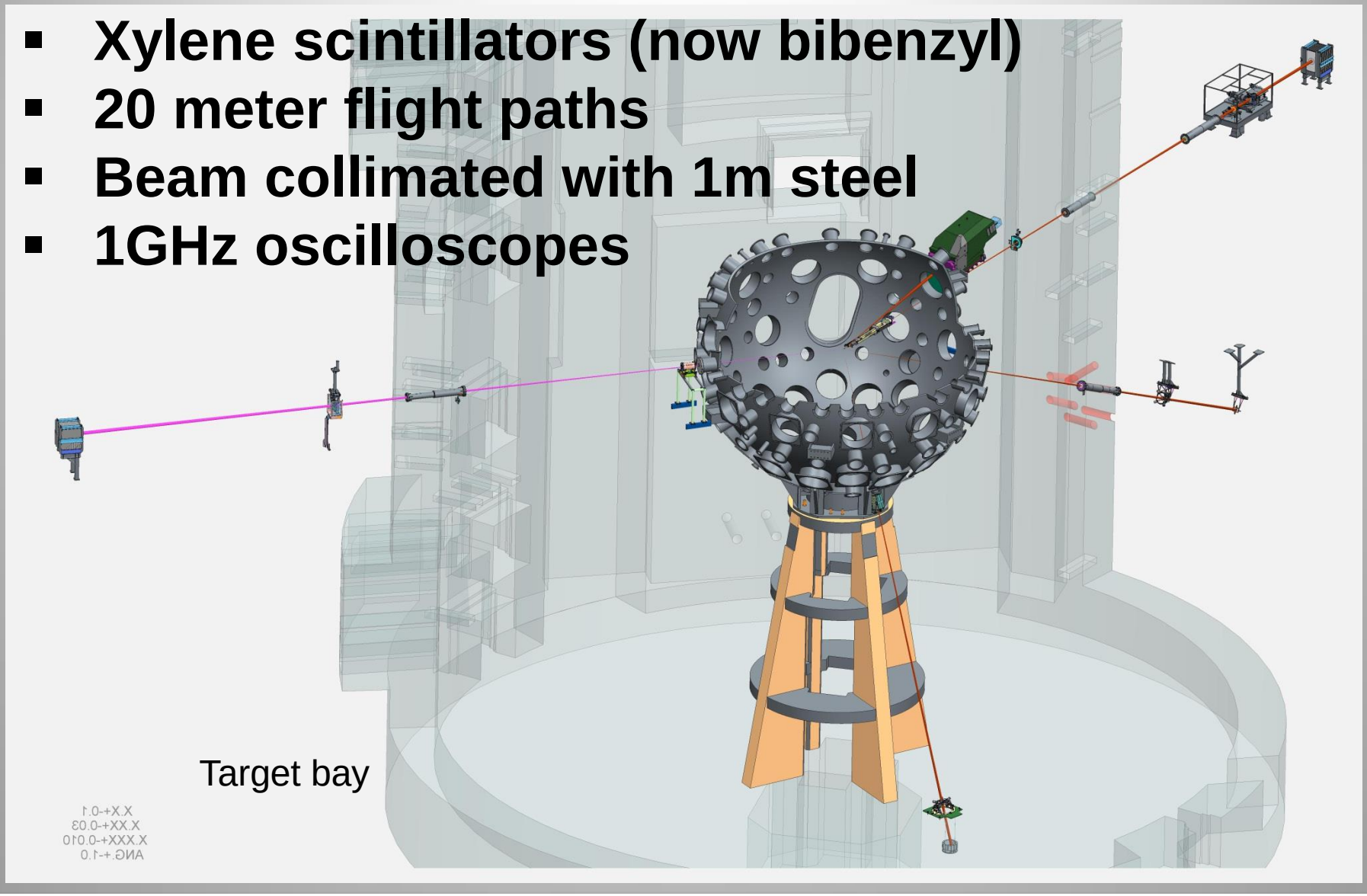




- **Indirect drive implosion**
  - Lasers incident on hohlraum walls
  - Soft x-ray field implodes plastic capsule filled with T_2
  - Neutrons from implosion detected with 20m NTOFs

NTOF detectors at NIF

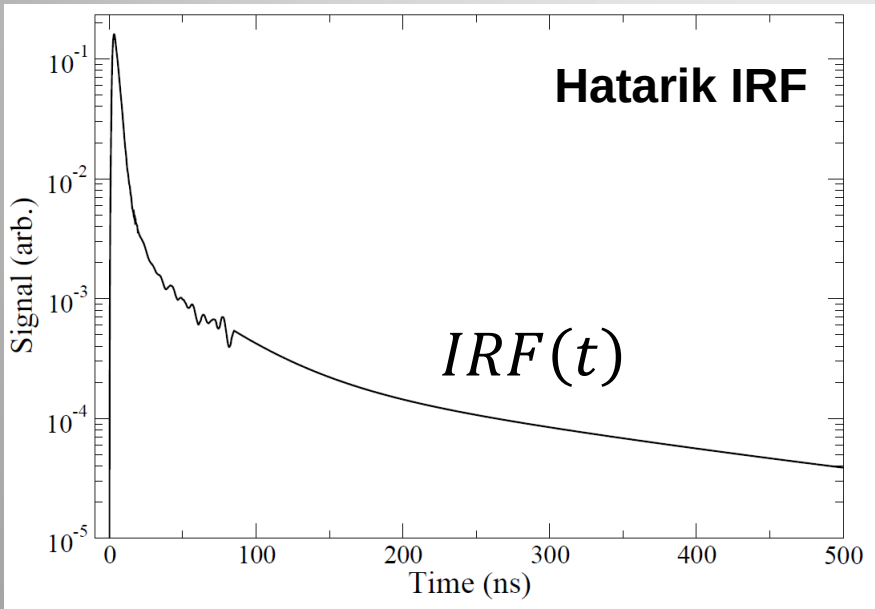
- Xylene scintillators (now bibenzyl)
- 20 meter flight paths
- Beam collimated with 1m steel
- 1GHz oscilloscopes



Experimental corrections

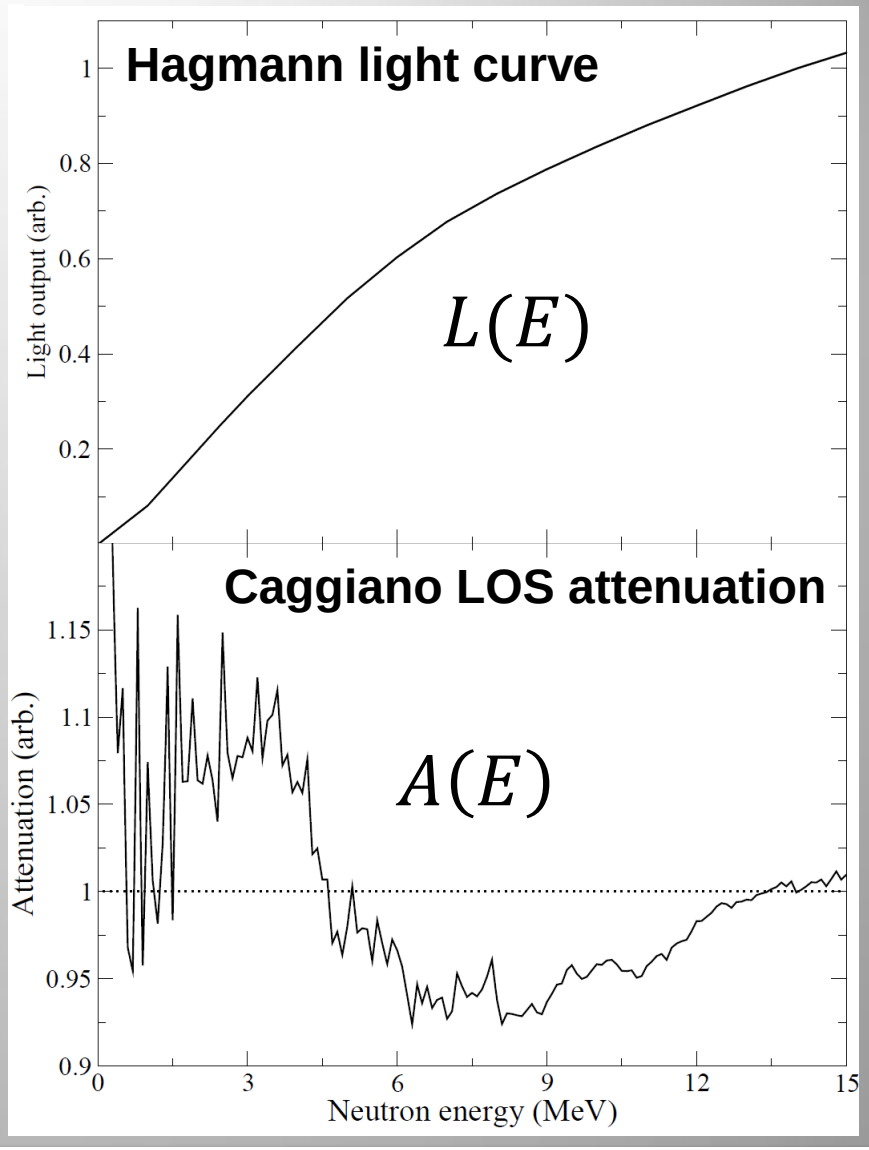
Current mode data represent a convolution

$$d(t) = \int IRF(t')g(t-t')dt'$$

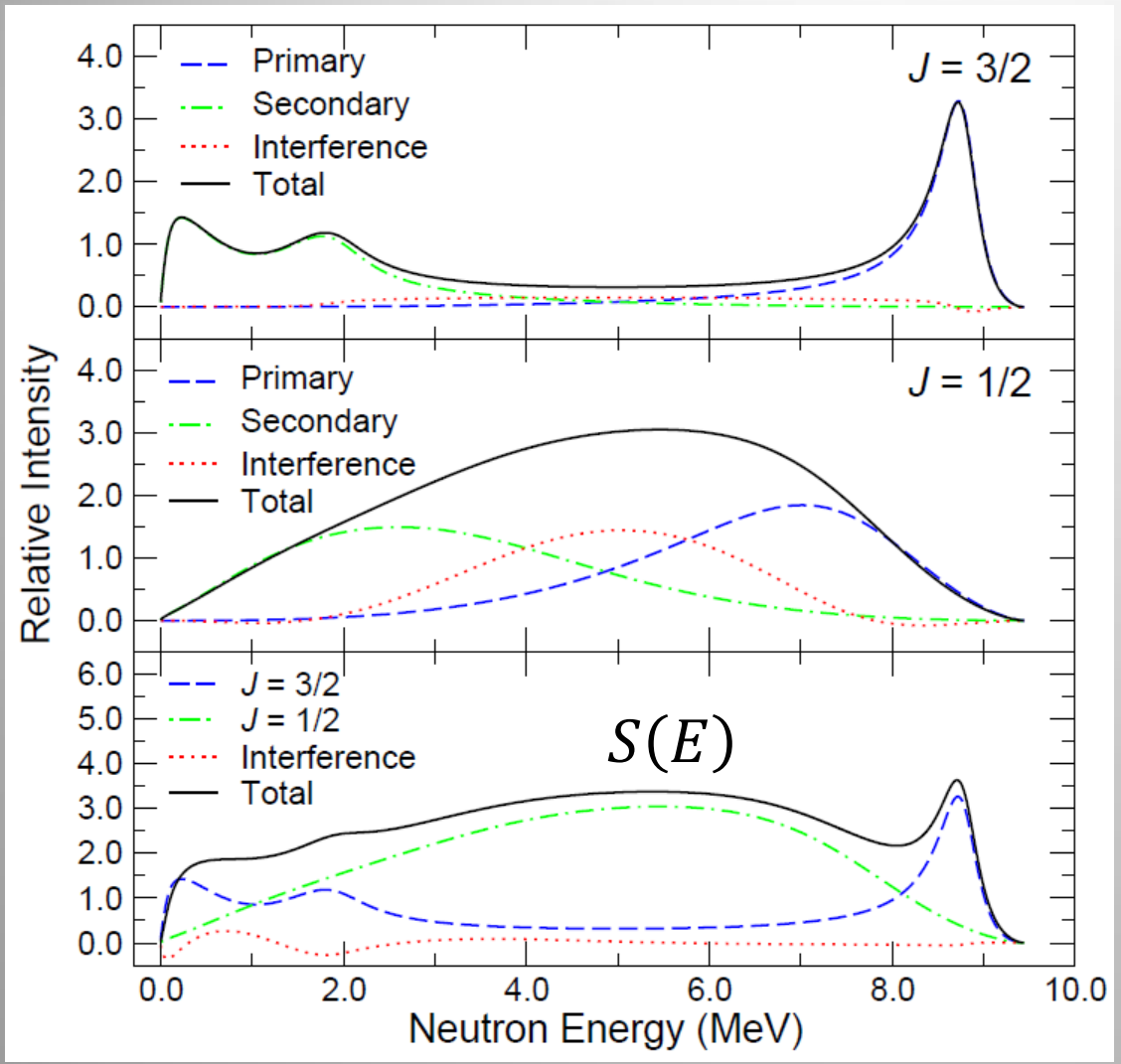


where

$$g(t) = S(E)A(E)L(E)\frac{dE}{dt}$$

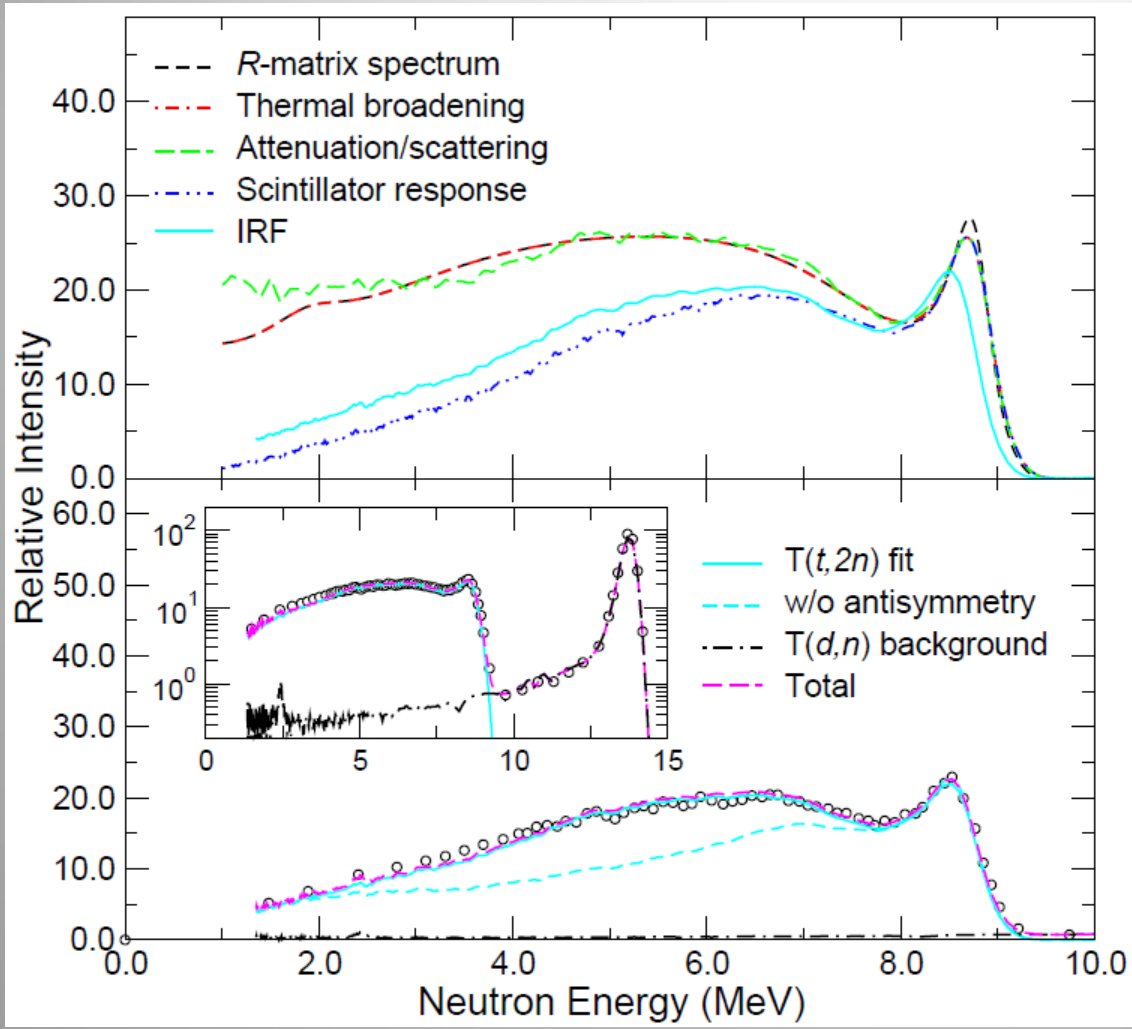


C. Brune *R*-matrix T+T neutron spectrum



- J's correspond to ground (top) and first-excited states (middle)
- Fermion symmetry leads to interference in top two panels (red dotted line)
- Antisymmetry is 30% effect for Jπ = 1/2- states
- Coherent sum of partial waves shown in bottom panel

Fitting procedure for ICF data



- Thermal broadening
- Neutron attenuation along flight path
- Neutron scattering in target
- Scintillator response
- Convolution with impulse response function
- Background from residual deuterium determined in separate measurement with 3:1 DT target

Physics described by *R*-matrix

- **Exchange symmetry of two final state neutrons**
  - Well known effect from 3α breakup of ^{12}C [D.P. Balamuth, Phys. Rev. C 10, 975 (1974)] and 2*p* breakup of ^{6}Be [D. F. Geesaman, Phys. Rev. C 15, 1835 (1977)]
- **Angular correlation between emitted neutrons**
  - Spin sequence determined by coupling two tritons in Jπ = 0+ state of ^{6}He
- **Decay channel interference of Jπ = 1/2- and 3/2- states**
- **Known decay properties of ^{5}He states**
  - Values determined from *n*-α phase shifts of Stammbach and Walter, Nucl. Phys. A180, 225 (1972)

Summary

- NIF experiment provides first direct observation of peak resulting from decay through the ground state of ^{5}He below center-of-mass energy of 100 keV
- *R*-matrix analysis shows importance of anti-symmetry in modeled spectrum for $J\pi = 1/2-$ states
- Main spectral features can be described by $l = 1$ states in ^{5}He
- Currently investigating additional decay channels and extracting the T+T reactivity

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