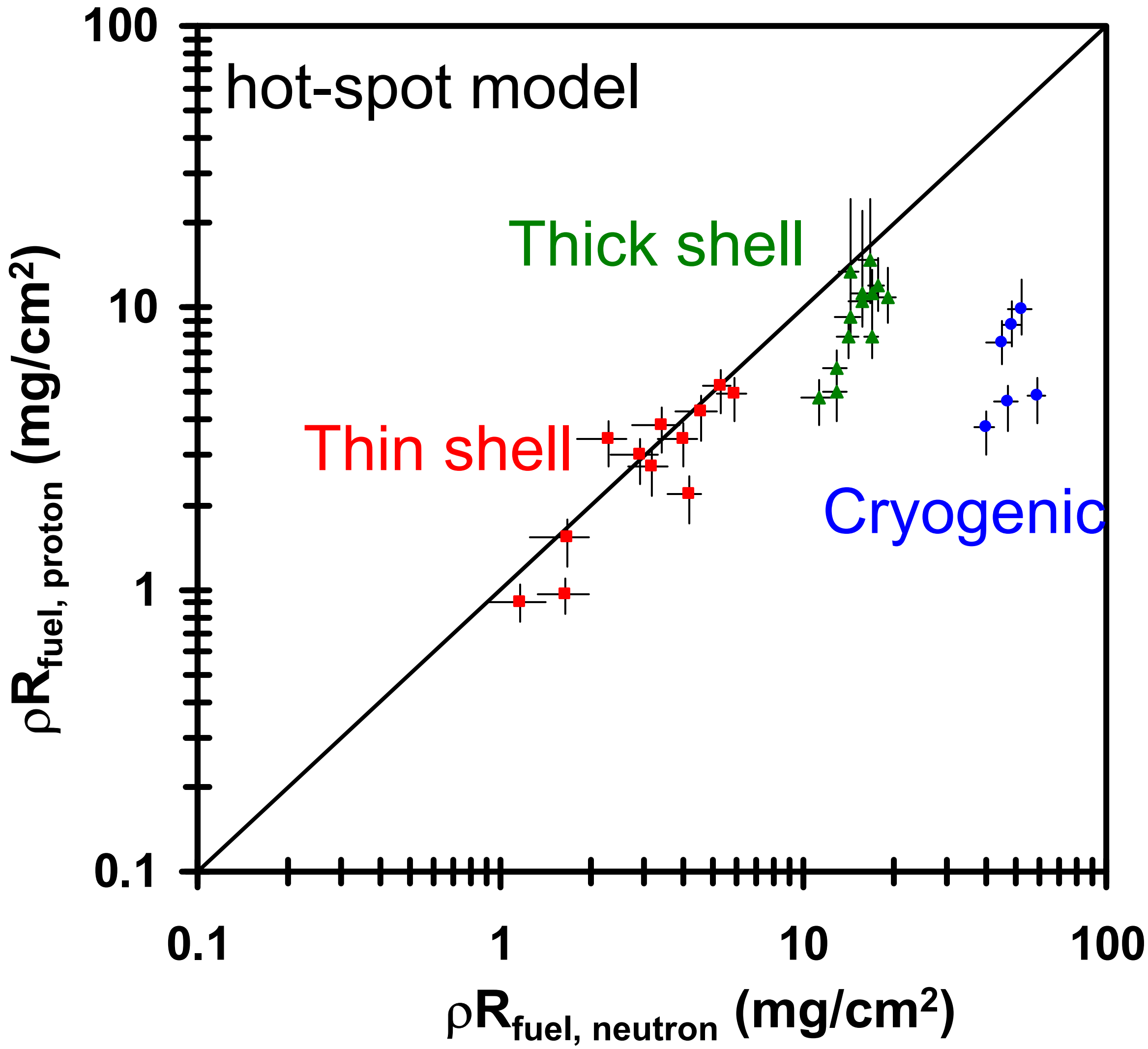
Using secondary protons and neutrons to study ρR_{fuel}



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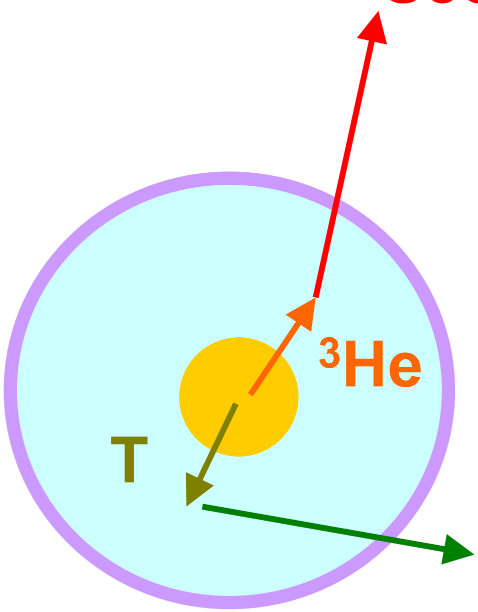
Summary

- Data from thin-shell, thick-shell and cryogenic implosions were obtained
  - WRFs provide secondary proton spectra
  - CPS-1 and -2 provide primary proton and triton spectra
  - nTOFs provide primary and secondary neutron yields
  - The 1020 Array provides secondary neutron spectra
- Data were compared with static Monte Carlo simulations using various radial profiles of density and temperature
- Conclusions:
  - For thin-shell capsules, simple hot-spot model can be used to estimate ρR_{fuel}
  - For thick-shell and cryogenic capsules, estimates of ρR_{fuel} based on either Y_{2n}/Y_{1n} or Y_{2p}/Y_{1n} are complicated by temperature dependencies of Y_{2n} and saturations of both Y_{2p} and Y_{2n}.

Two species of secondary particles can be measured at OMEGA



Secondary protons

$D + D \rightarrow n + {}^3He$ [0.82 MeV]

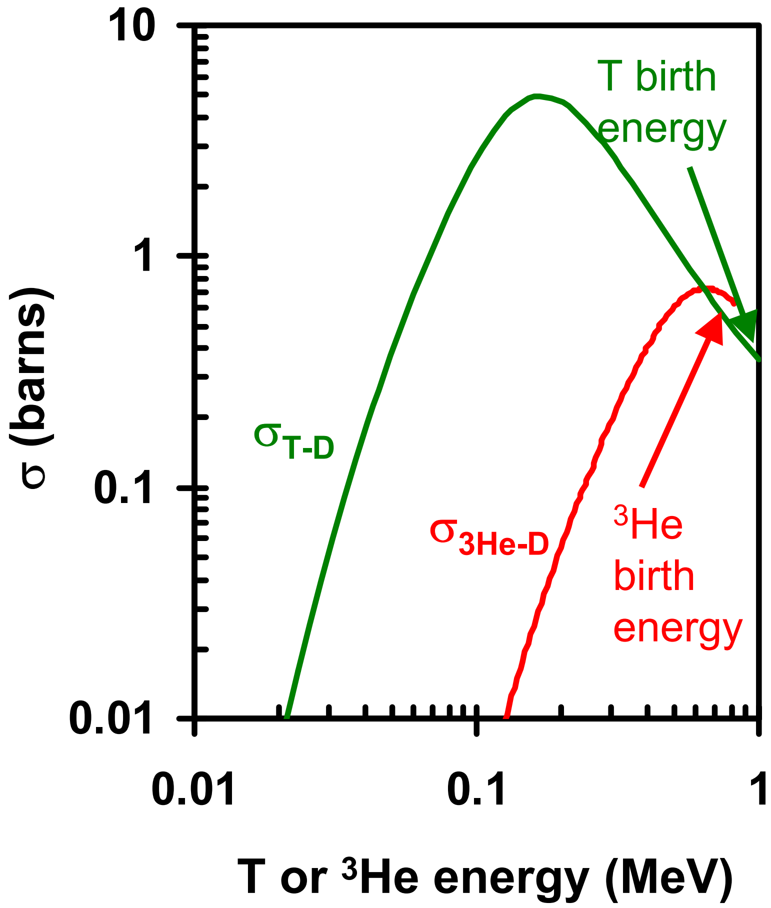
${}^3He$ [$\leq$0.82 MeV] $+ D \rightarrow \alpha + p$ [12.6-17.5 MeV]

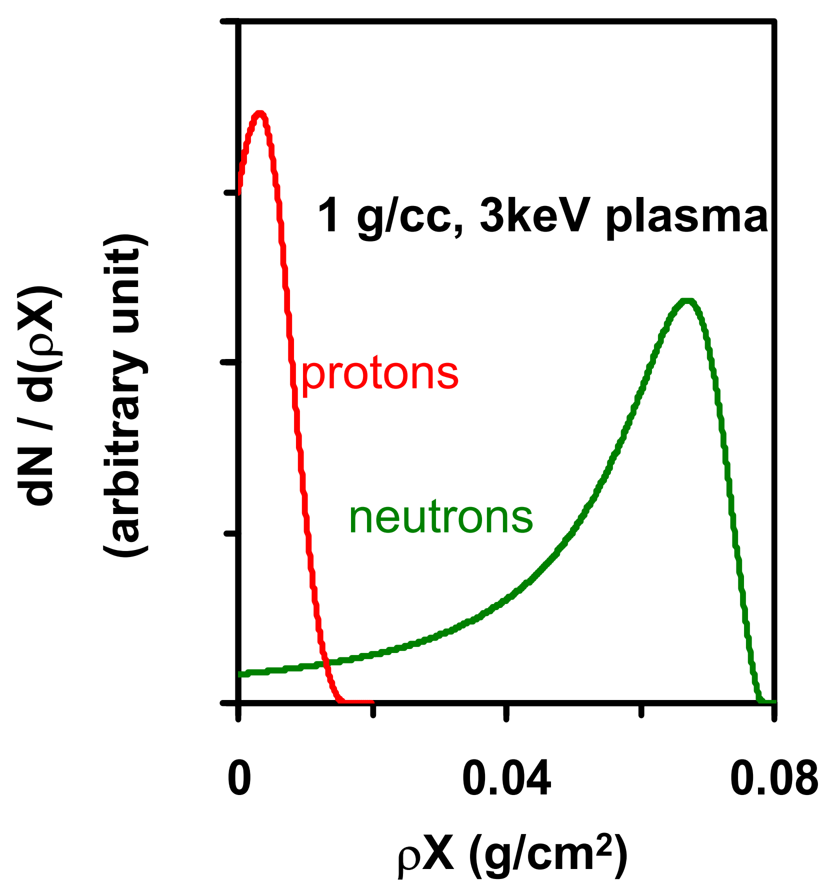
Secondary neutrons

$D + D \rightarrow p + T$ [1.01 MeV]

T [$\leq$1.01 MeV] $+ D \rightarrow \alpha + n$ [11.9-17.2 MeV]

Secondary protons and neutrons are produced in different regions of the plasma

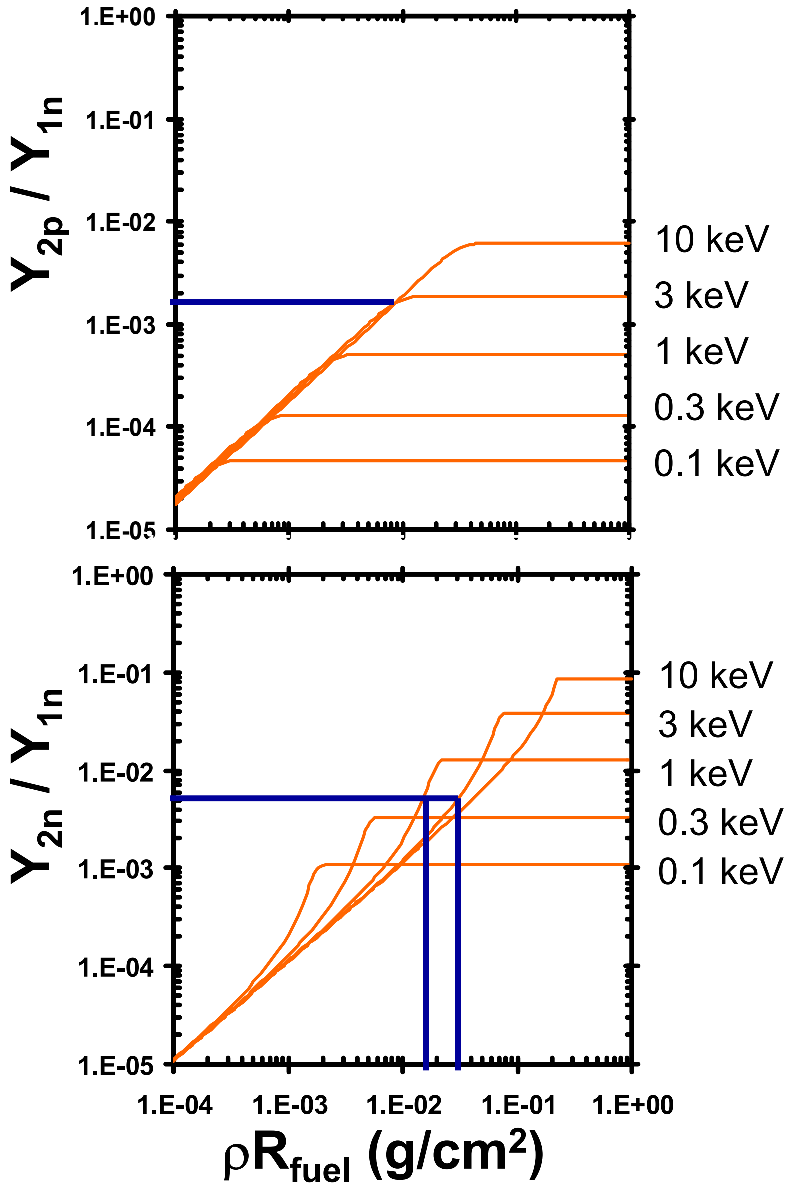




Distance from birth position of primary T or ^{3}He

Y_{2p}/Y_{1n} and Y_{2n}/Y_{1n} are used to infer ρR_{fuel} of D_2 implosions

"hot-spot" model, 1 g/cc D plasma*



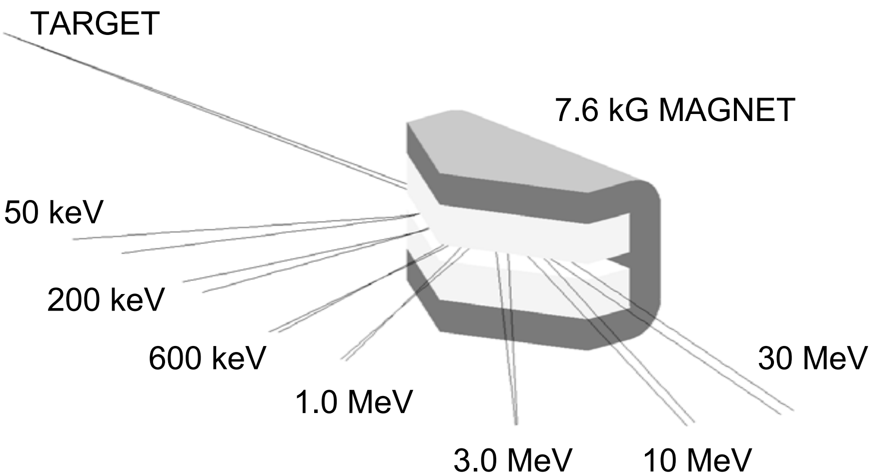
Some issues:

- Y_{2p}/Y_{1n} is fairly independent of T_e, except that it saturates at different levels for different T_e .
- Y_{2n}/Y_{1n} saturates at higher ρR_{fuel}, but is much more temperature dependent below saturation.
- In either case, the result is different for different types of density and temperature profiles.

H. Azechi, *et al*., Appl. Phys. Lett. **49**, 555 (1986).
M. D. Cable *et al*., J. Appl. Phys. **62**, 2233 (1987).
H. Azechi, *et al*., Laser Part. Beams **9**, 119 (1991).
*F. H. Séguin *et al*., Phys. Plasmas **9**, 2725 (2002).
……………………., Rev. Sci. Instrum. **74**, 975 (2003).

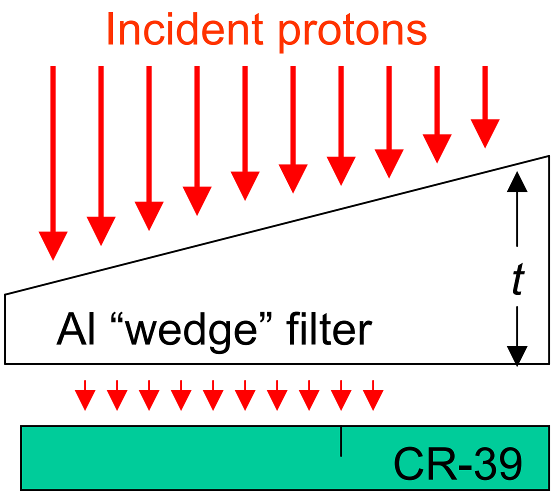
Two kinds of spectrometers* are used to get proton spectra

Magnet-based Spectrometers (CPSs)



Particle energies identified from trajectories.

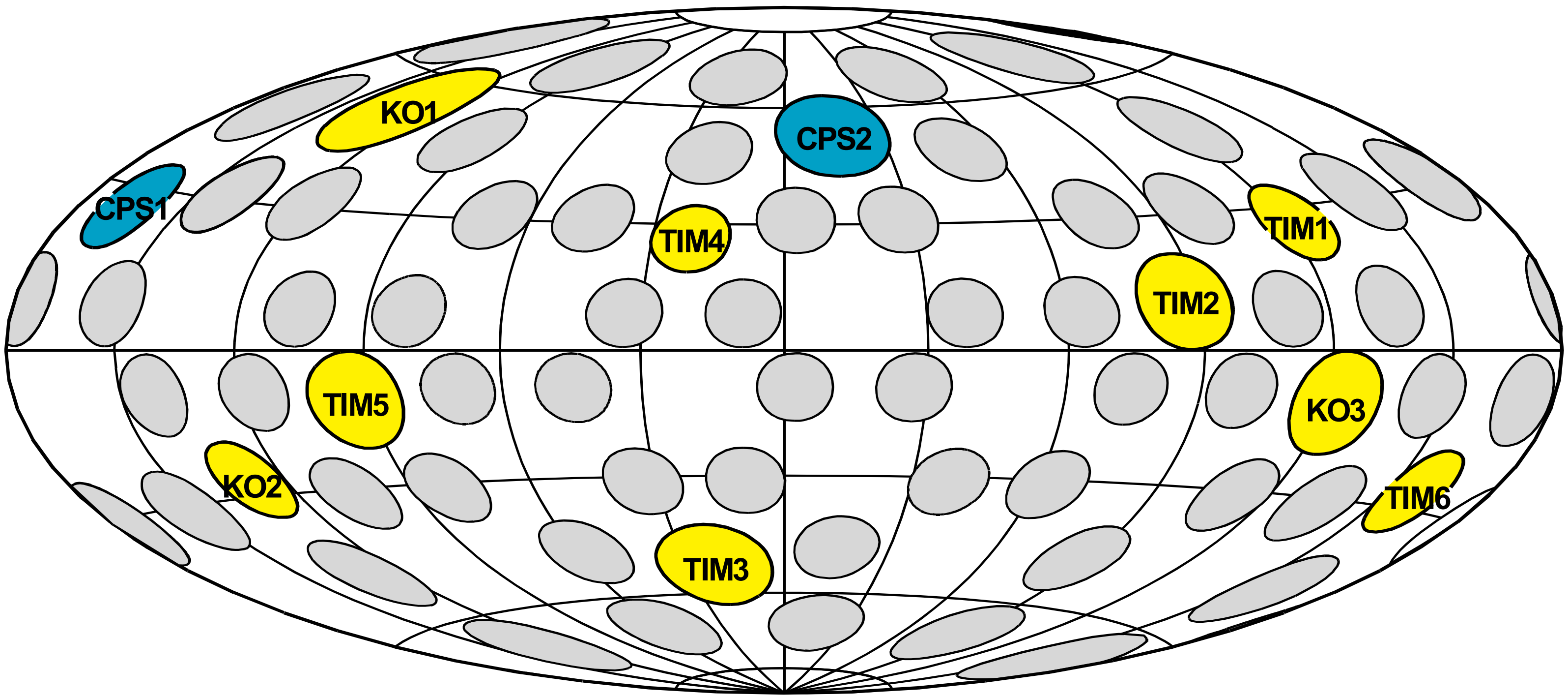
"Wedge-Range-Filter" Spectrometers (WRFs)



Particle energies identified from local thickness *t* and diameter of etched proton tracks in CR-39.

*F. H. Séguin *et al.*, Rev. Sci. Instrum. **74**, 975 (2003).

Up to 11 ports can be used for proton spectrometry on the OMEGA target chamber



= WRF spectrometers
= Magnet-based CPS's

E11199

Thin-shell implosion

Cryogenic implosion

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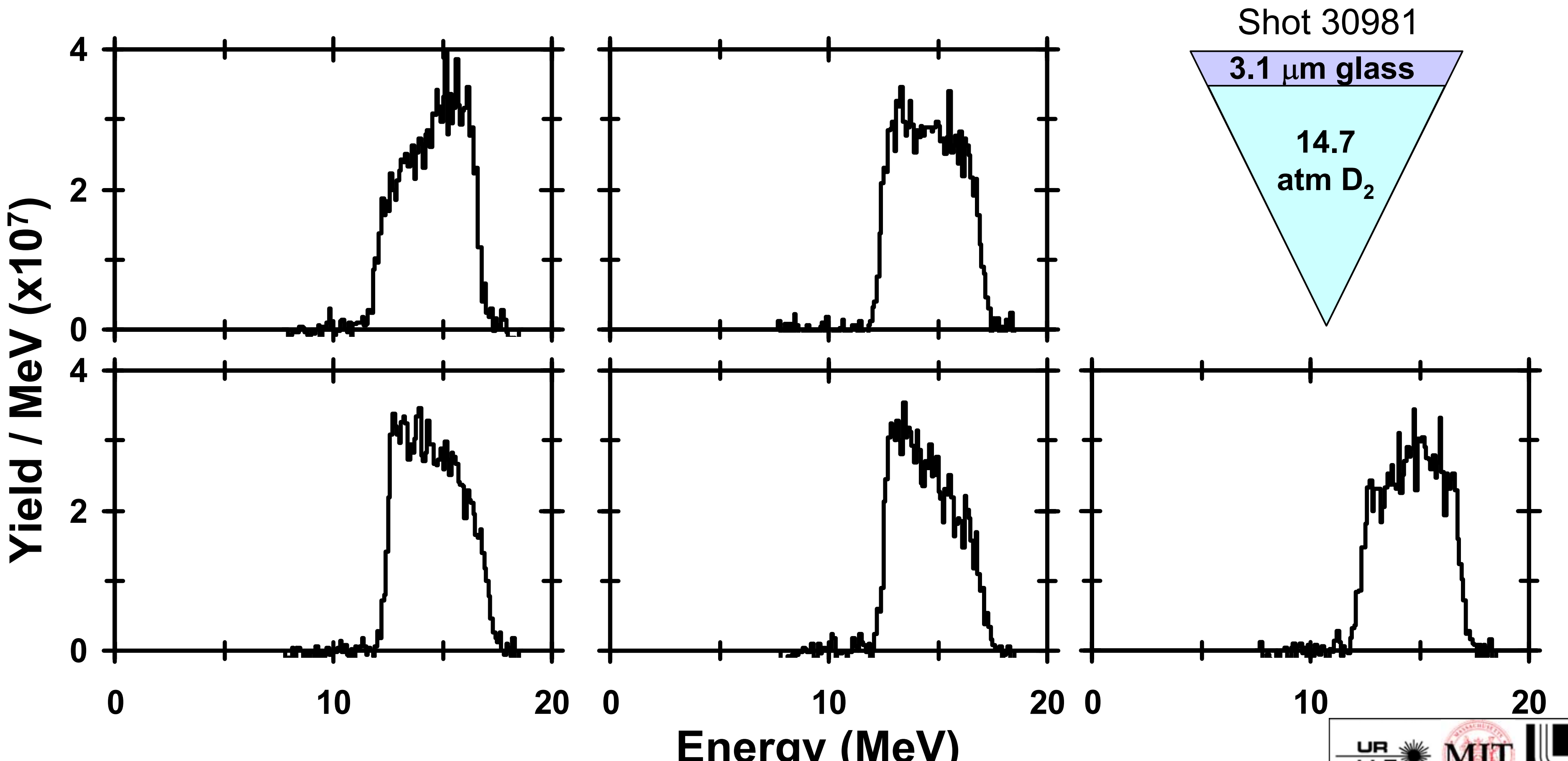
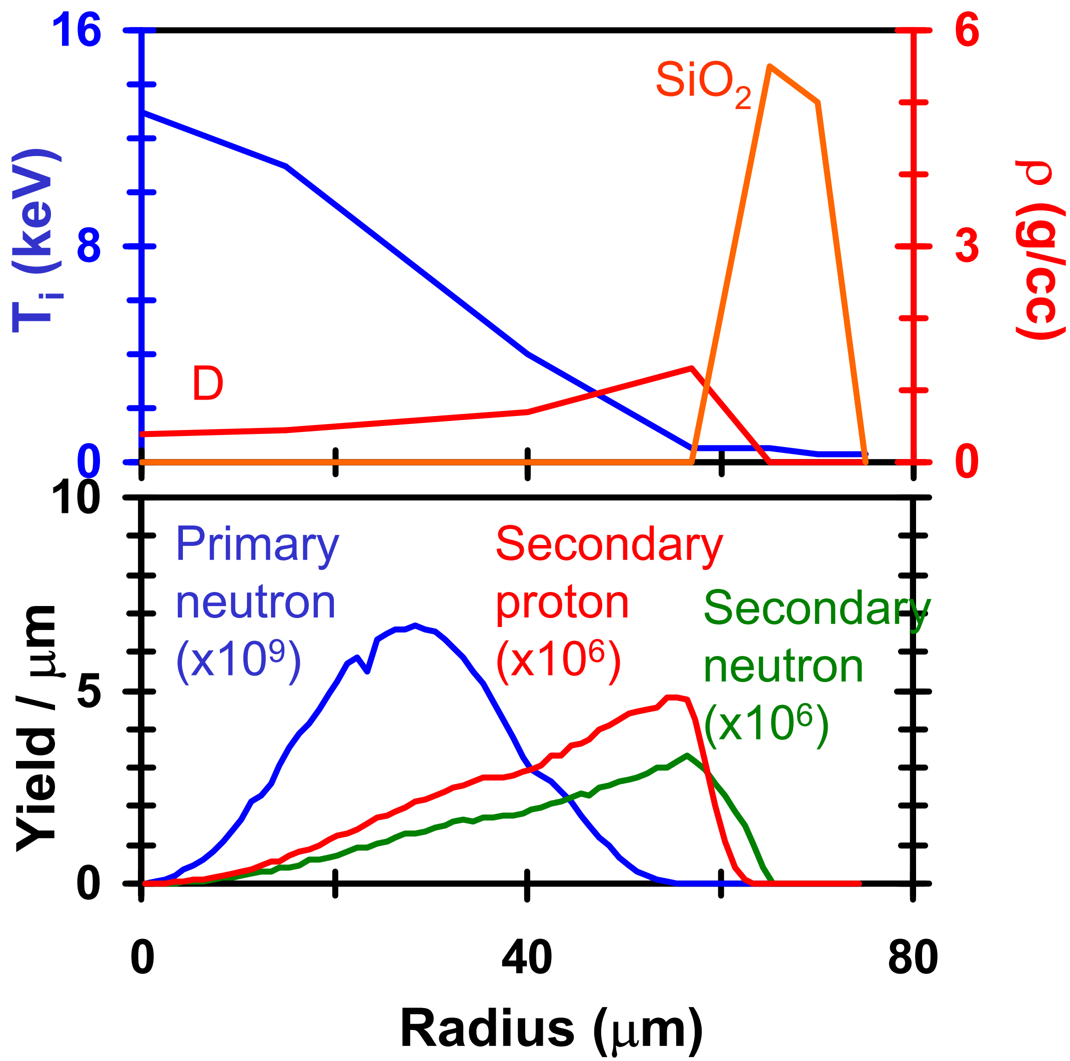
For thin-shell implosions, a simple hot-spot model can be used to infer ρR_{fuel}

Capsule	Laser	Y_{1n}	Y_{2n}	$\langle Y_{2p} \rangle$	$\langle T_i \rangle$	$\rho R_{fuel, 2n}$	$\langle \rho R_{fuel, 2p} \rangle$
D_2(14.7) SiO_2[3.1]	13.1 kJ	1.54E+11	7.92E+7	1.22E+8	8.2 keV	4.6 mg/cm^2	4.3 mg/cm^2



Monte Carlo calculation of thin-glass-shell implosion 30981

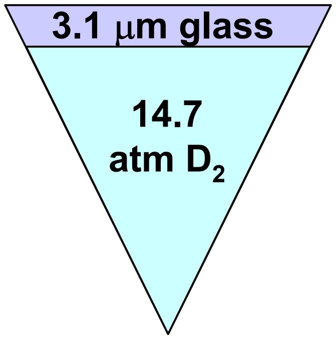


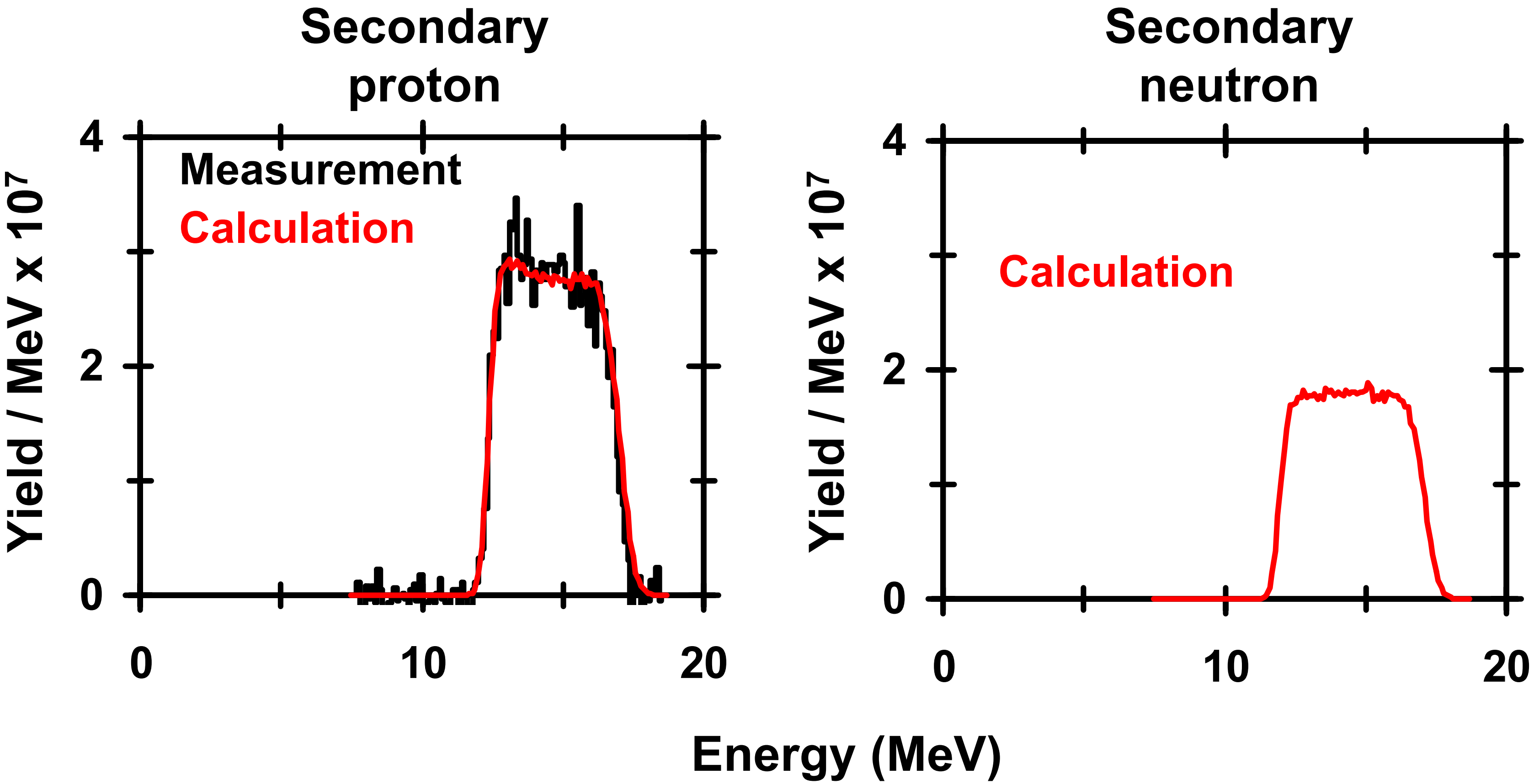
- $T_e(r)$ and $n_e(r)$ are based on LILAC, but adjusted to match measured yields and temperature

Conclusions:

- Hot-spot model can be used to infer ρR_{fuel} from both Y_{2p}/Y_{1n} and Y_{2n}/Y_{1n} when they are far from saturation.

Calculated and measured spectra for shot 30981





Comparison of experiment and static Monte Carlo calculation for shot 30981

Experimentally Determined Values

- Y_{1n}: 1.54E+11
- Y_{2p}: 1.22E+8
- Y_{2n}: 7.92E+7
- $\langle T_i \rangle$: 8.2 keV

Inferred Values

- $\rho R_{fuel, 2p, hot\text{-}spot}$: 4.3 mg/cm^2
- $\rho R_{fuel, 2n, hot\text{-}spot}$: 4.6 mg/cm^2

Values From Calculation

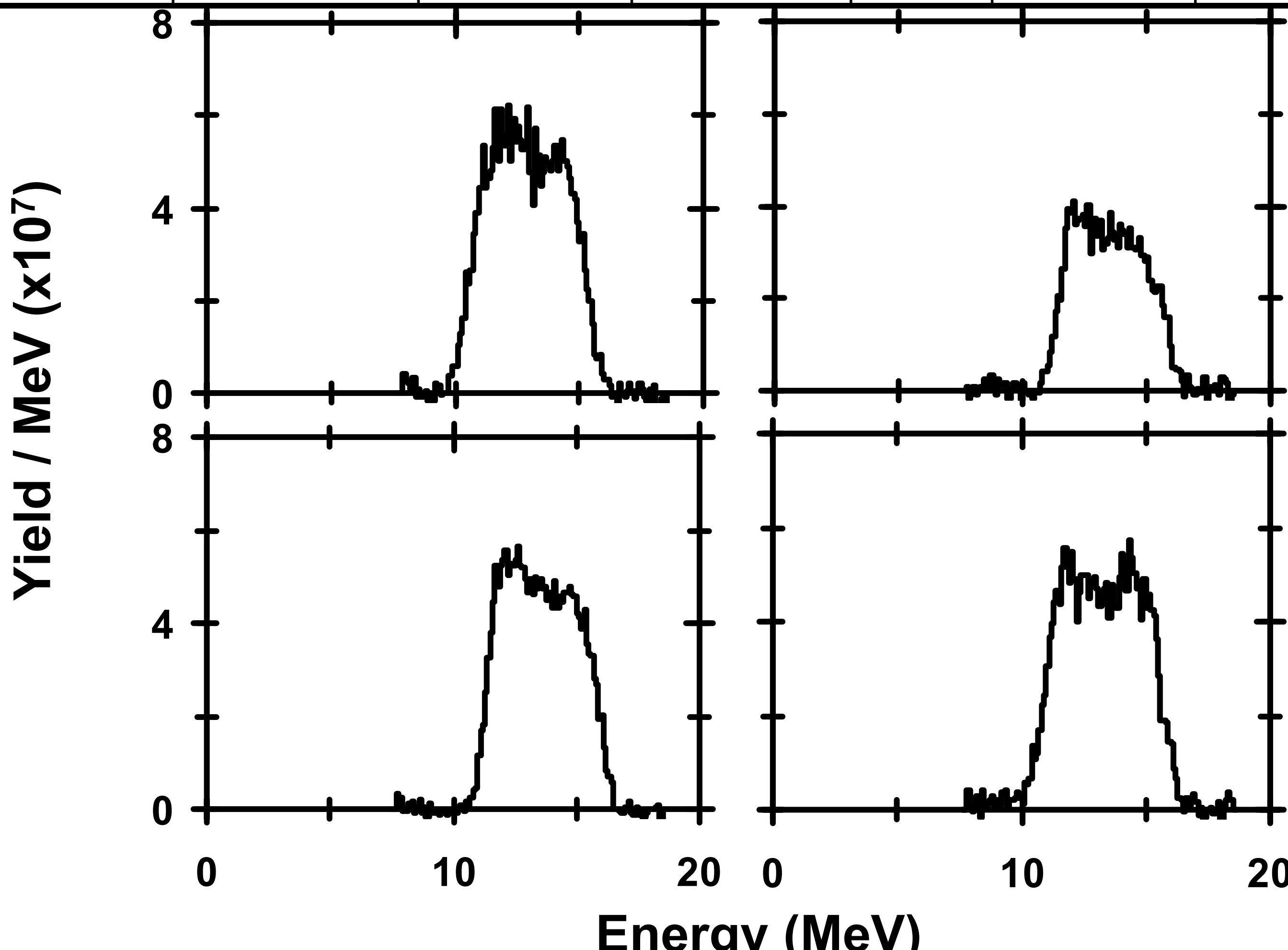
- Y_{1n}: 1.71E+11
- Y_{2p}: 1.30E+8
- Y_{2n}: 9.15E+7
- $\langle T_i \rangle$: 7.4 keV
- ρR_{fuel}: 4.3 mg/cm^2

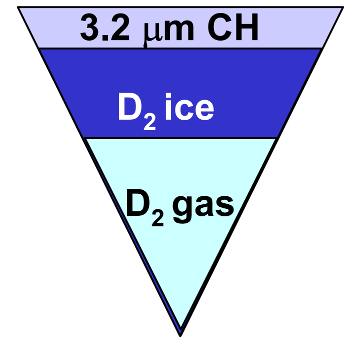
Inferred Values

- $\rho R_{fuel, 2p, hot\text{-}spot}$: 4.1 mg/cm^2
- $\rho R_{fuel, 2n, hot\text{-}spot}$: 4.8 mg/cm^2

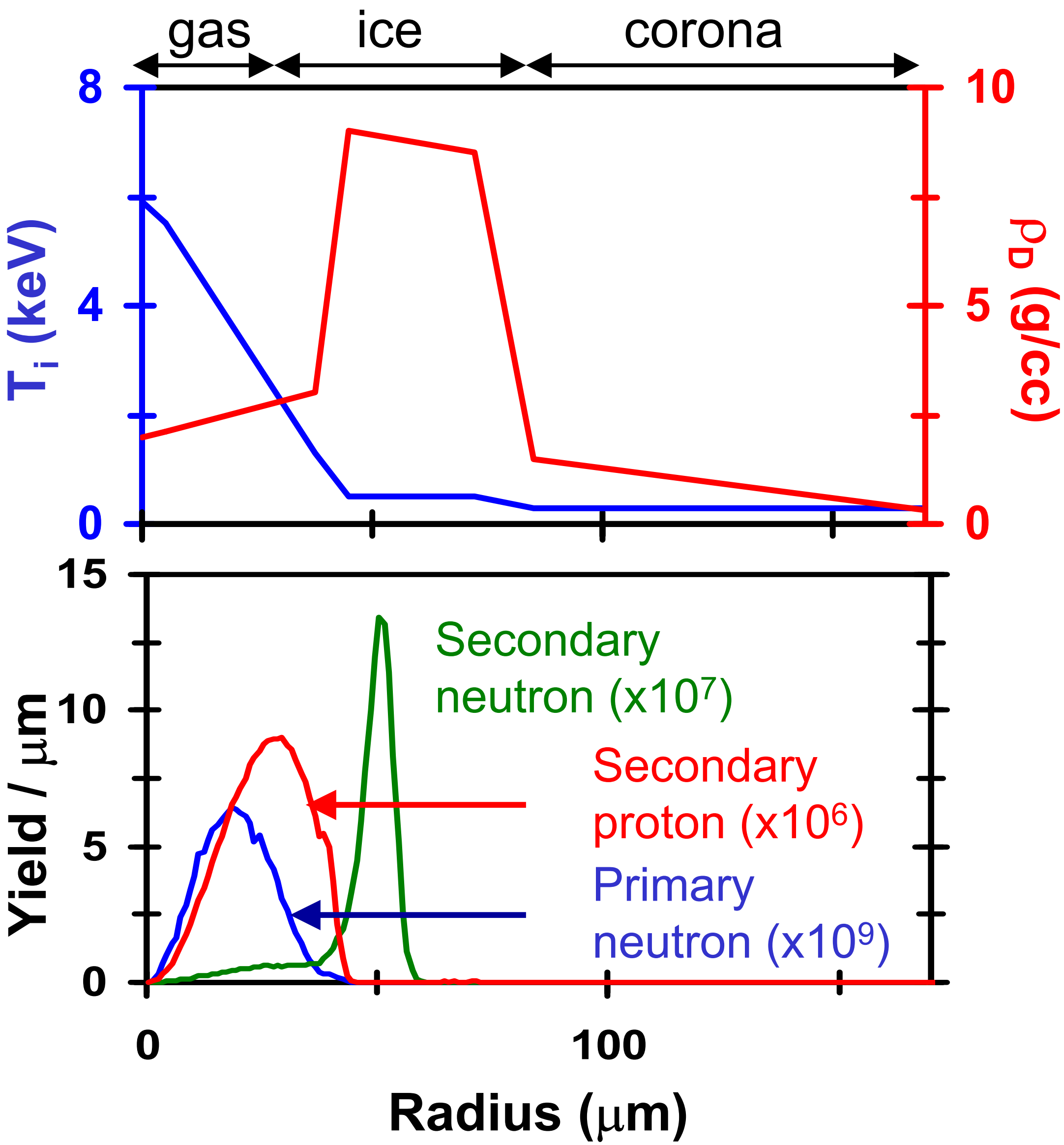
For cryogenic implosions, secondary protons measure ρR of gas while secondary neutrons measure ρR of part of D_2 ice

Capsule	Y_{1n}	Y_{2n}	$\langle Y_{2p} \rangle$	$\langle T_i \rangle$	$\rho R_{fuel,\ 2n}$	$\langle \rho R_{fuel,\ 2p} \rangle$	$\langle \rho R_{total} \rangle$
Cryogenic	1.24E+11	1.17E+9	2.13E+8	3.6 keV	47.9 mg/cm^2	8.8 mg/cm^2	56 mg/cm^2





Monte Carlo calculation of cryogenic implosion 28900

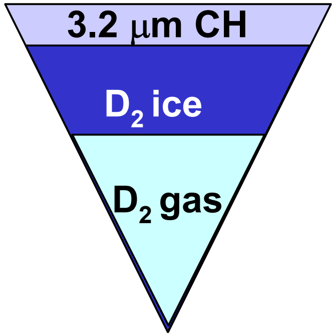


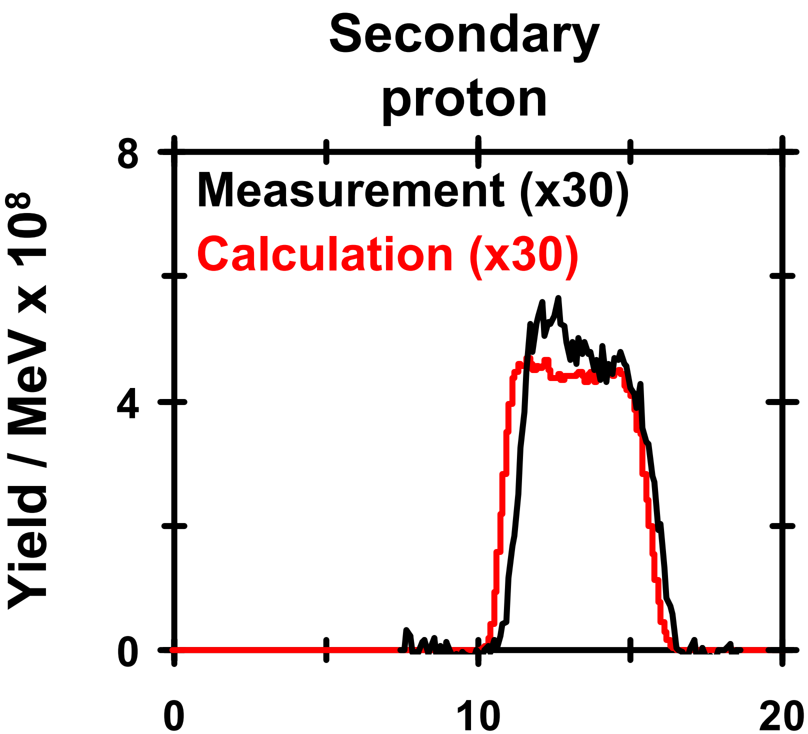
- $T_e(r)$ and $n_e(r)$ are based on LILAC, but adjusted to match measured yields and temperature

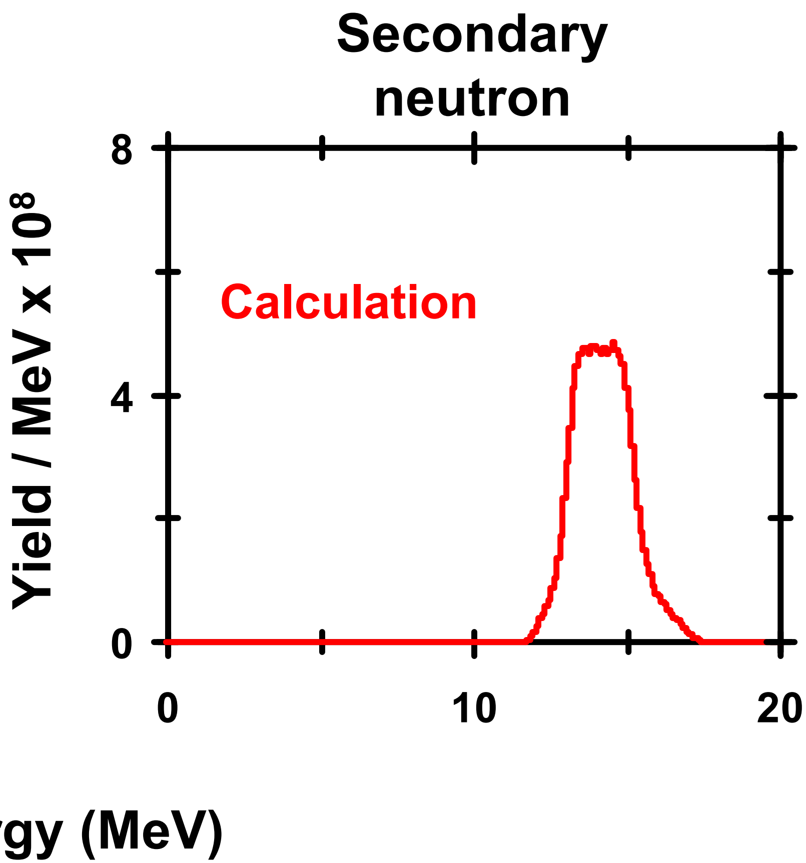
Conclusions:

- Y_{2p} reflects ρR of D_2 gas since secondary protons are produced predominantly in the D_2 gas.
- Y_{2n} reflects ρR of D_2 ice since secondary neutrons are produced predominantly in part of the D_2 Ice.

Calculated and measured spectra for cryogenic implosion 28900







Comparison of experiment and Monte Carlo calculation for cryogenic shot 28900

Experimentally Determined Values	Values From the Calculation
Y_{1n}: 1.24E+11	Y_{1n}: 1.31E+11
Y_{2p}: 2.21E+8	Y_{2p}: 2.16E+8
Y_{2n}: 1.17E+9	Y_{2n}: 1.24E+9
$\langle T_i \rangle$: 3.6 keV	$\langle T_i \rangle$: 3.6 keV
ρR_{total}: 56 mg/cm^2 *	ρR_{total}: 52.4 mg/cm^2
	ρR_{hot}: 8.1 mg/cm^2 **

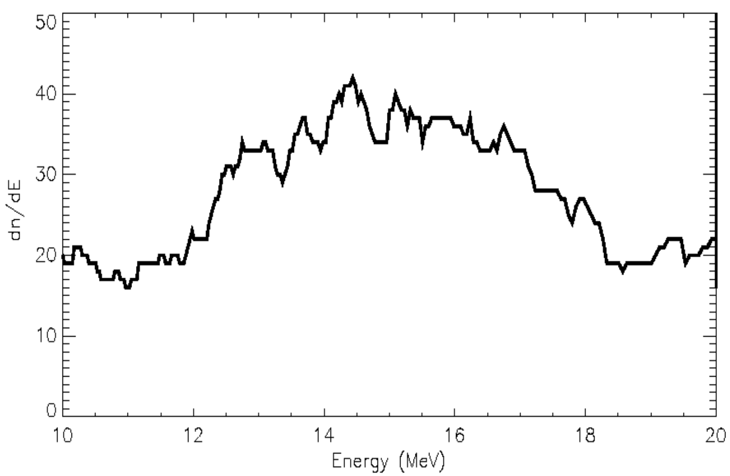
Inferred Values	Inferred Values
$\rho R_{fuel,\ 2p,hot\text{-}spot}$: 8.8 mg/cm^2	$\rho R_{fuel,\ 2p,hot\text{-}spot}$: 8.4mg/cm^2
$\rho R_{fuel,\ 2n,\ hot\text{-}spot}$: 49.1 mg/cm^2	$\rho R_{fuel,\ 2n,\ hot\text{-}spot}$: 48.9mg/cm^2

* ρR_{total} is calculated using the energy downshift of secondary proton spectrum

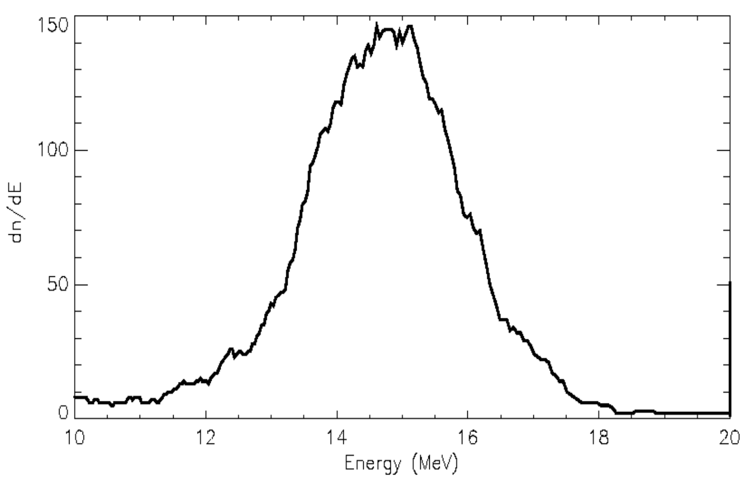
** ρR_{hot} is the areal density of the hot neutron-producing core ($T_i \geq 0.5$ keV)

Preliminary results from 1020 array* show a large change in width of secondary neutron spectra as predicted from Monte Carlo calculations

Shot 30981:
D_2(14.7) SiO_2[3.1]

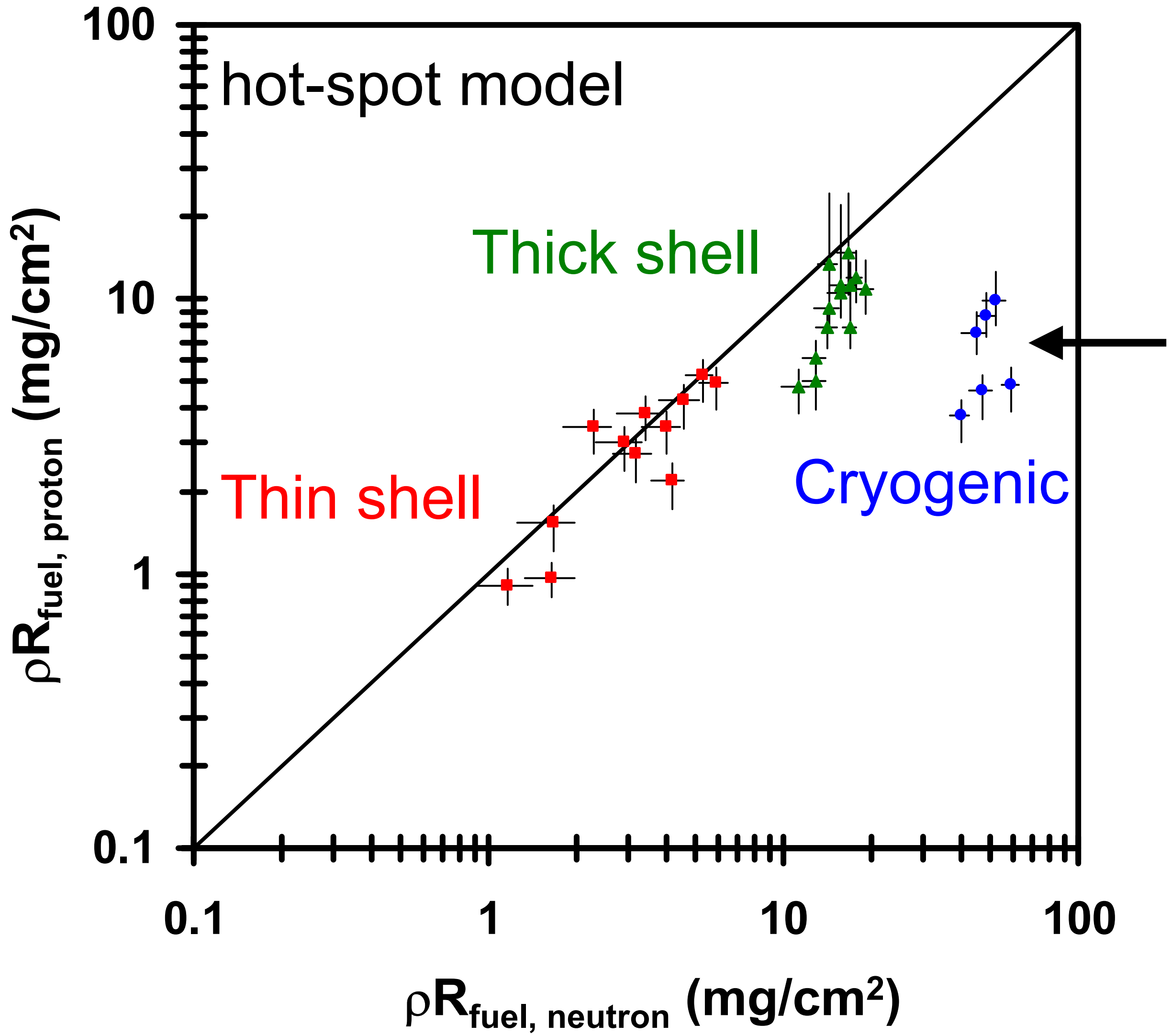


Shot 31929:
Cryogenic



*Courtesy of V. Yu Glebov

Hot-spot model is sufficient for low ρR_{fuel} implosions while more complex model is required for implosions with higher ρR_{fuel}



Protons are measuring ρR_{gas} while neutrons are measuring ρR_{ice}

Summary

- In the limit of low ρR_{fuel}, hot-spot model is sufficient to infer ρR_{fuel} from ratio of secondary neutron (proton) to primary neutron yield.

- For cryogenic capsules, great care must be exercised in using either secondary protons or secondary neutrons to infer ρR.