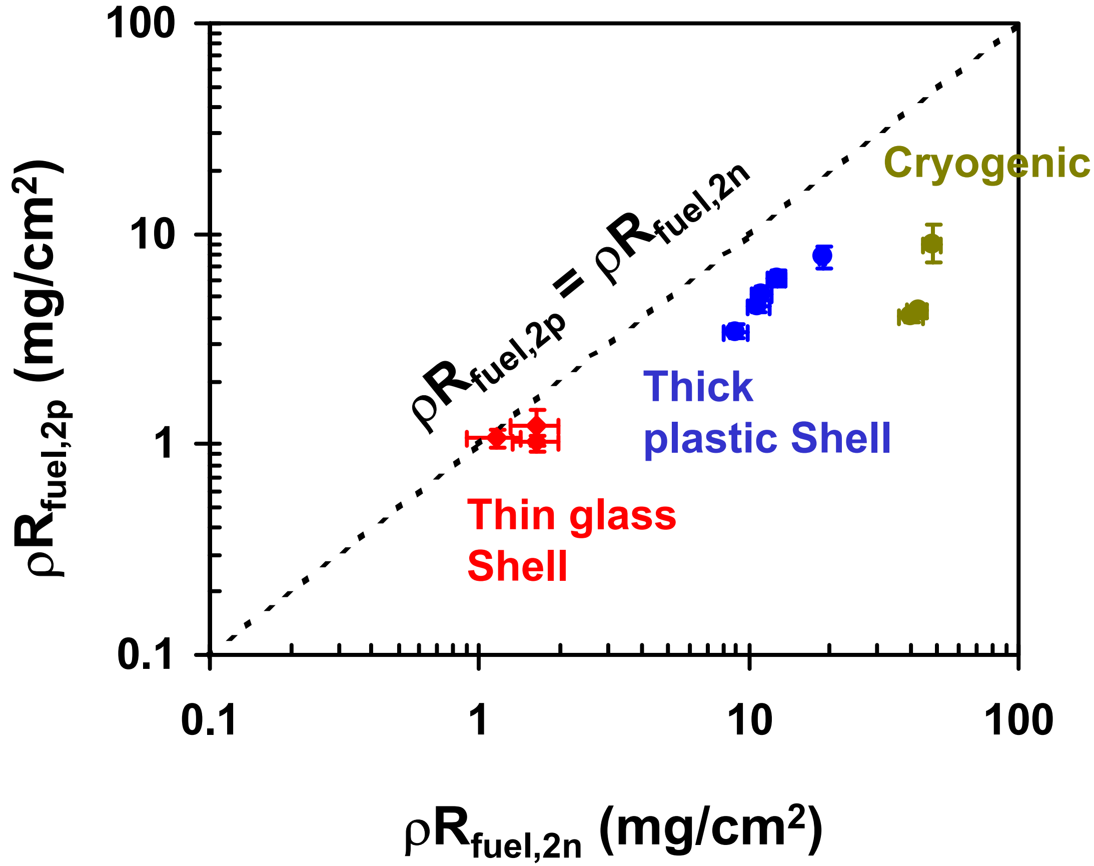
Relationship of secondary nuclear production to implosion characteristics at OMEGA



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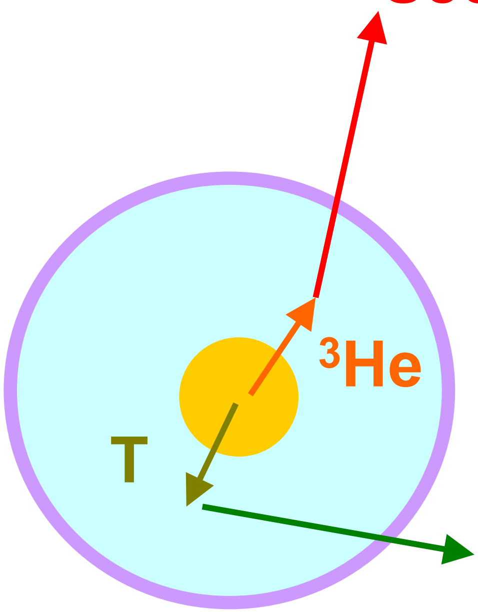
Outline

- Two models ("hot-spot" and "uniform") are commonly used to relate secondary yields to ρR_{fuel} but give slightly different results.
  - Does either model represent real implosions well?
- ρR_{fuel} inferred from secondary proton and neutron yields are often very different.
  - Is one of them more accurate?
  - Is the theory wrong?
- We use simulations to predict the effects of capsule structure on the accuracy of the diagnostic method.
- We investigate some issues experimentally by comparing new results for thin (~2 μm) glass shell capsules to previous results for thick (~20 μm) plastic shell capsules.
  - Do inferred $\rho R_{fuel,proton,\ hot\text{-}spot\ (uniform)}$ and $\rho R_{fuel,neutron,\ hot\text{-}spot\ (uniform)}$ agree better for thin shell targets, which have:
    - Higher T_e and lower ρR_{fuel} (which decreases "saturation" effects for secondary protons)
    - less fuel-shell mix

Two species of secondary products 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]

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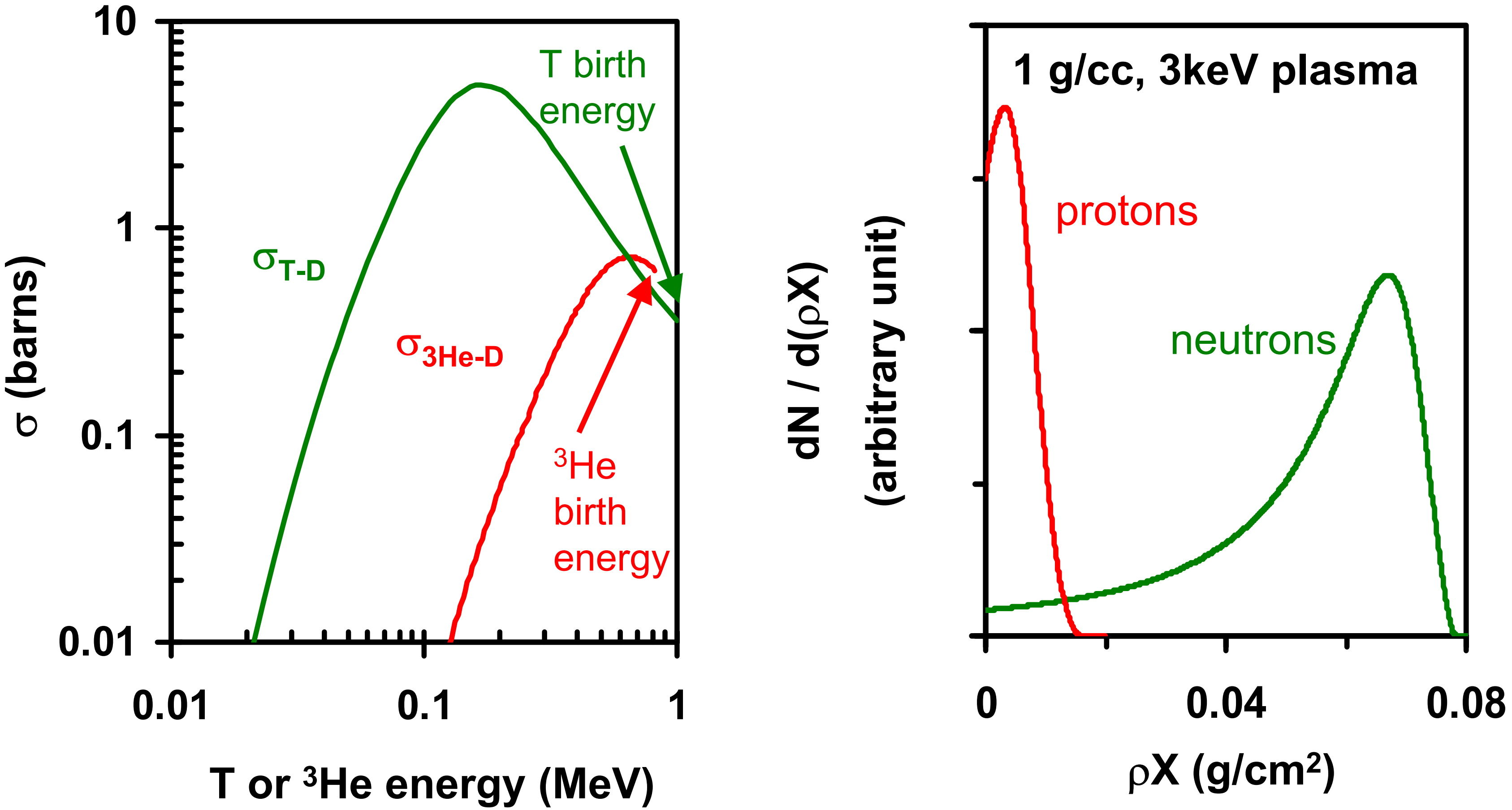
Secondary protons and neutrons are produced in different regions of the plasma



Hot-spot and uniform models are commonly used to relate secondary yield to ρR_{fuel}

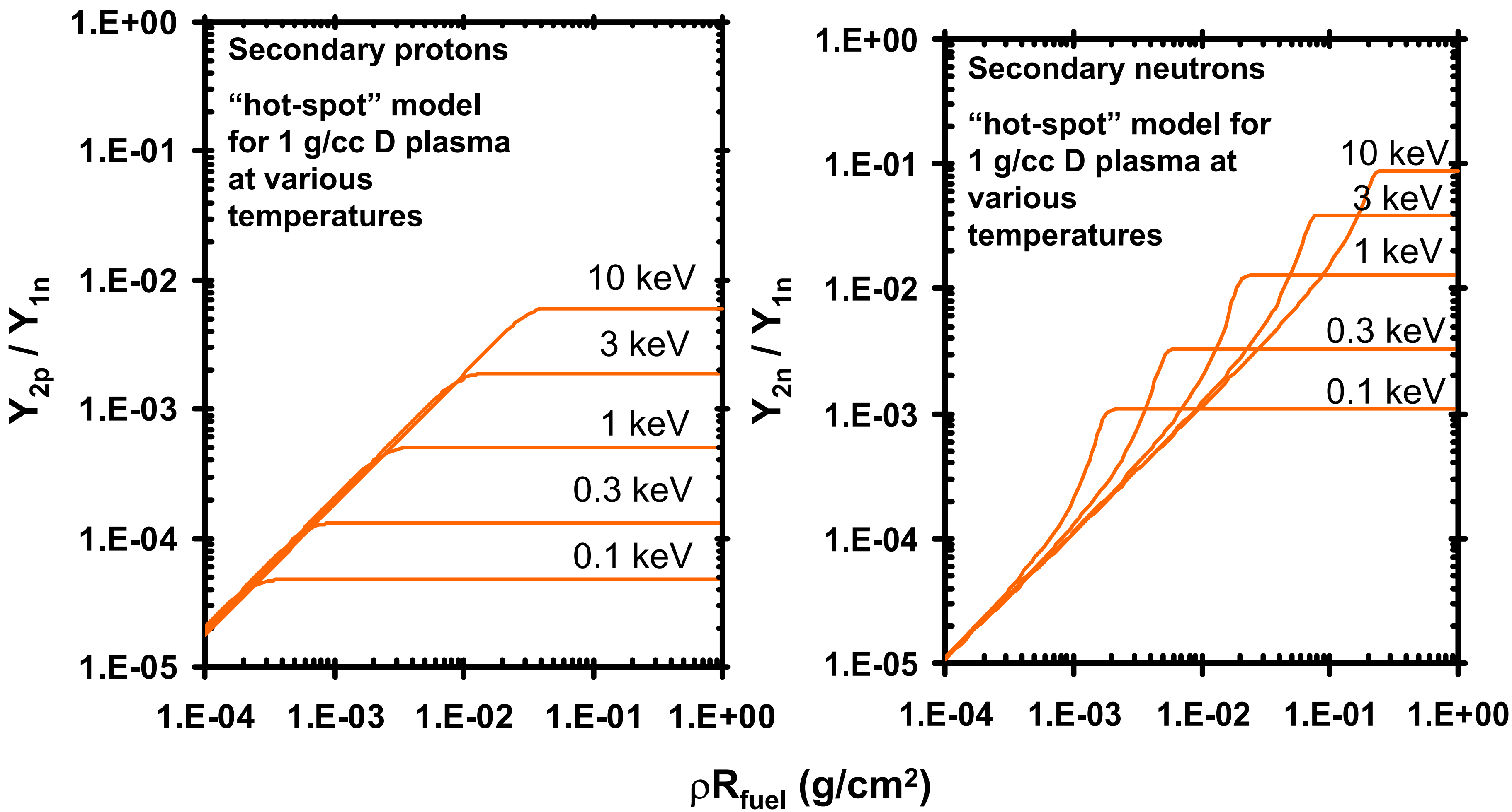
Hot-spot model

- Capsules have constant temperature and density
- All the primary particles are generated at the center of a capsule

Uniform model

- Capsules have constant temperature and density
- Primary particles are generated uniformly in a capsule

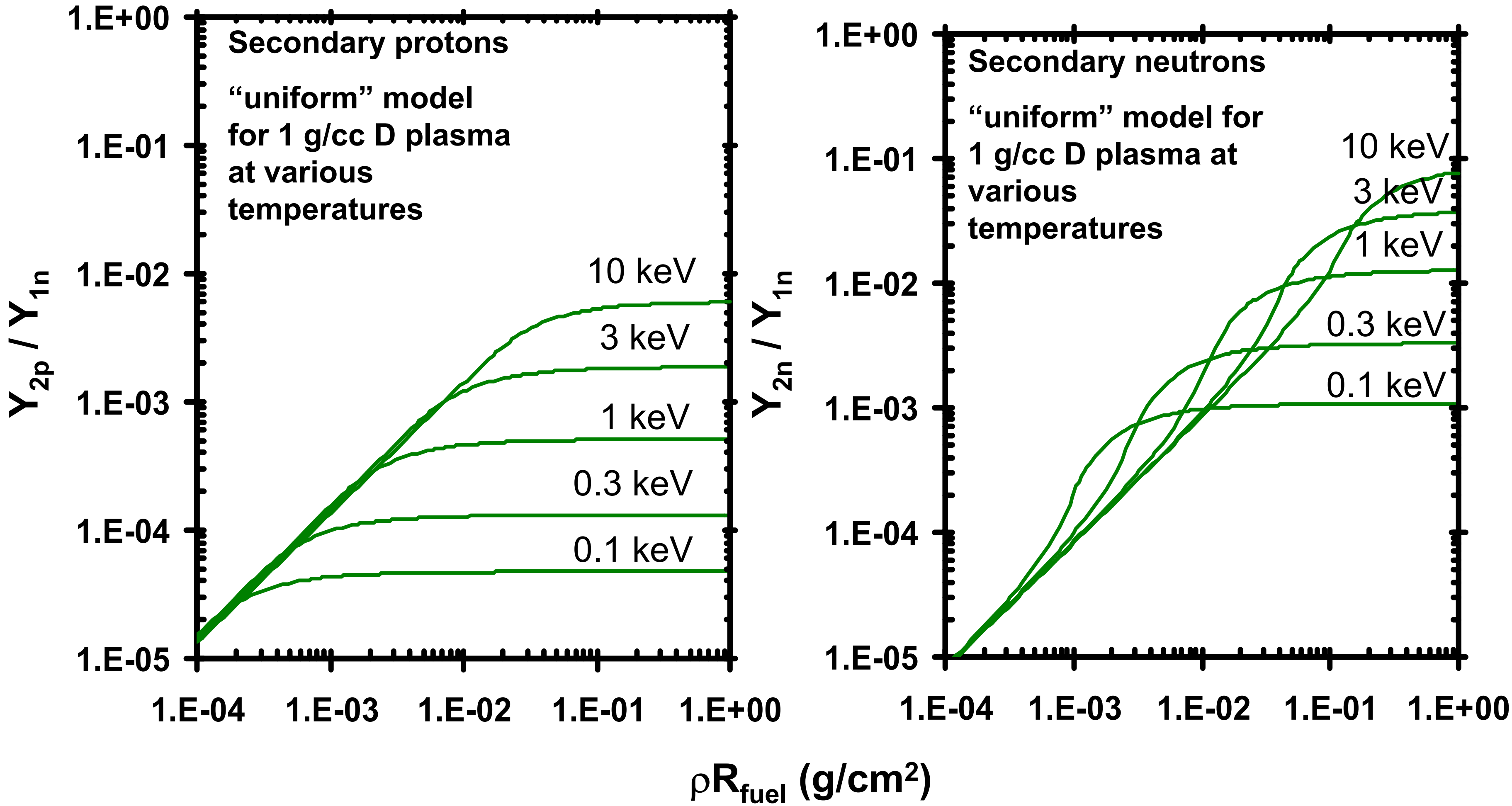
Ratio of secondary proton and neutron yields to primary neutron yield (Y_{2p}/Y_{1n} and Y_{2n}/Y_{1n}) are used to infer ρR_{fuel}*



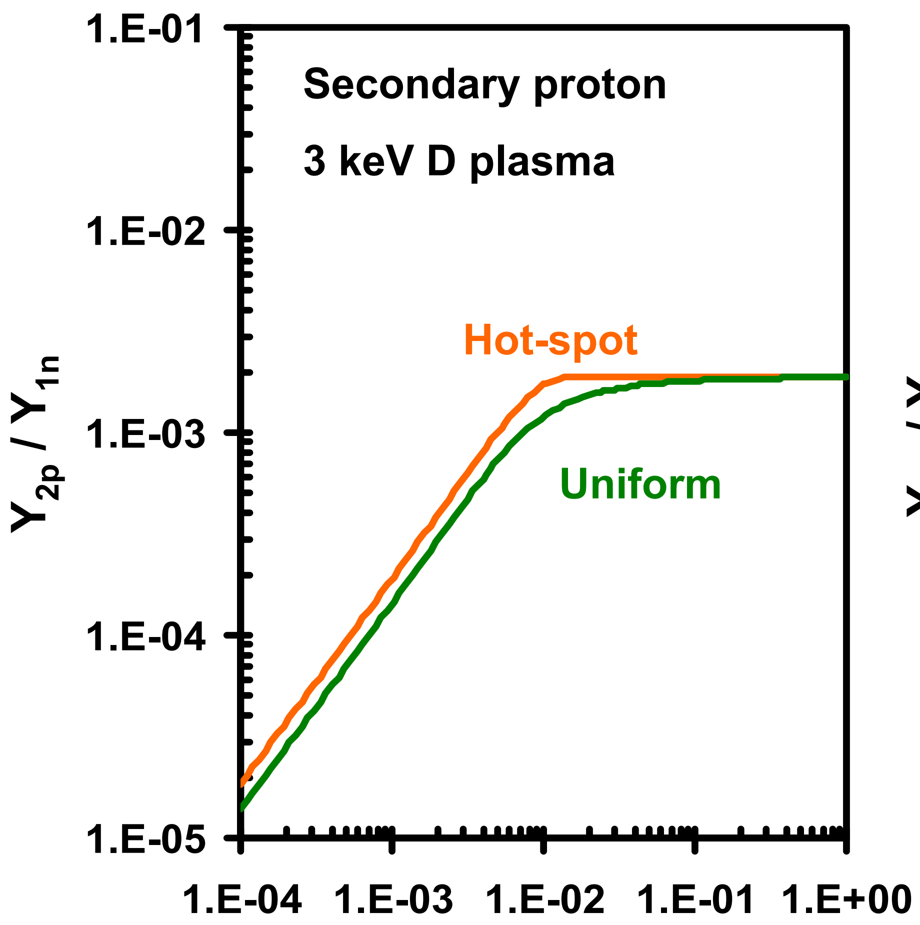
*H. Azechi *et al.,* Appl. Phys. **52**, 2608 (1981).

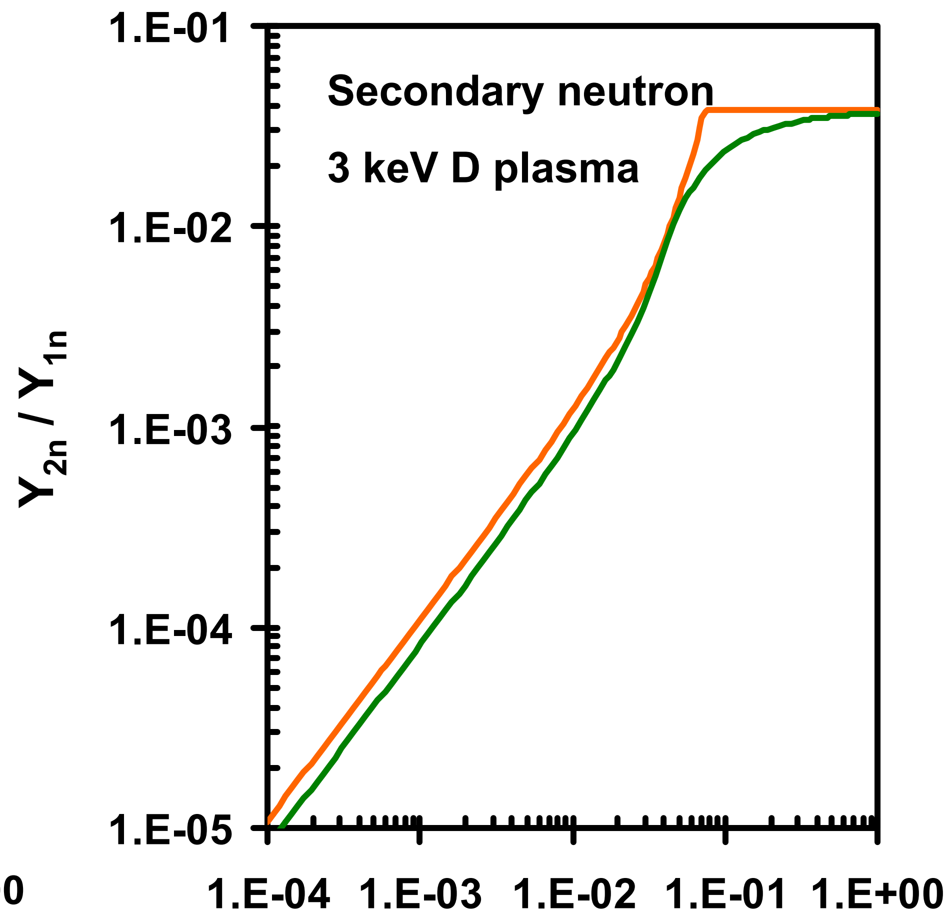
*F. H. Séguin *et al*., Phys. Plasmas **9**, 2725 (2002).

Ratio of secondary proton and neutron yields to primary neutron yield (Y_{2p}/Y_{1n} and Y_{2n}/Y_{1n}) are used to infer ρR_{fuel}



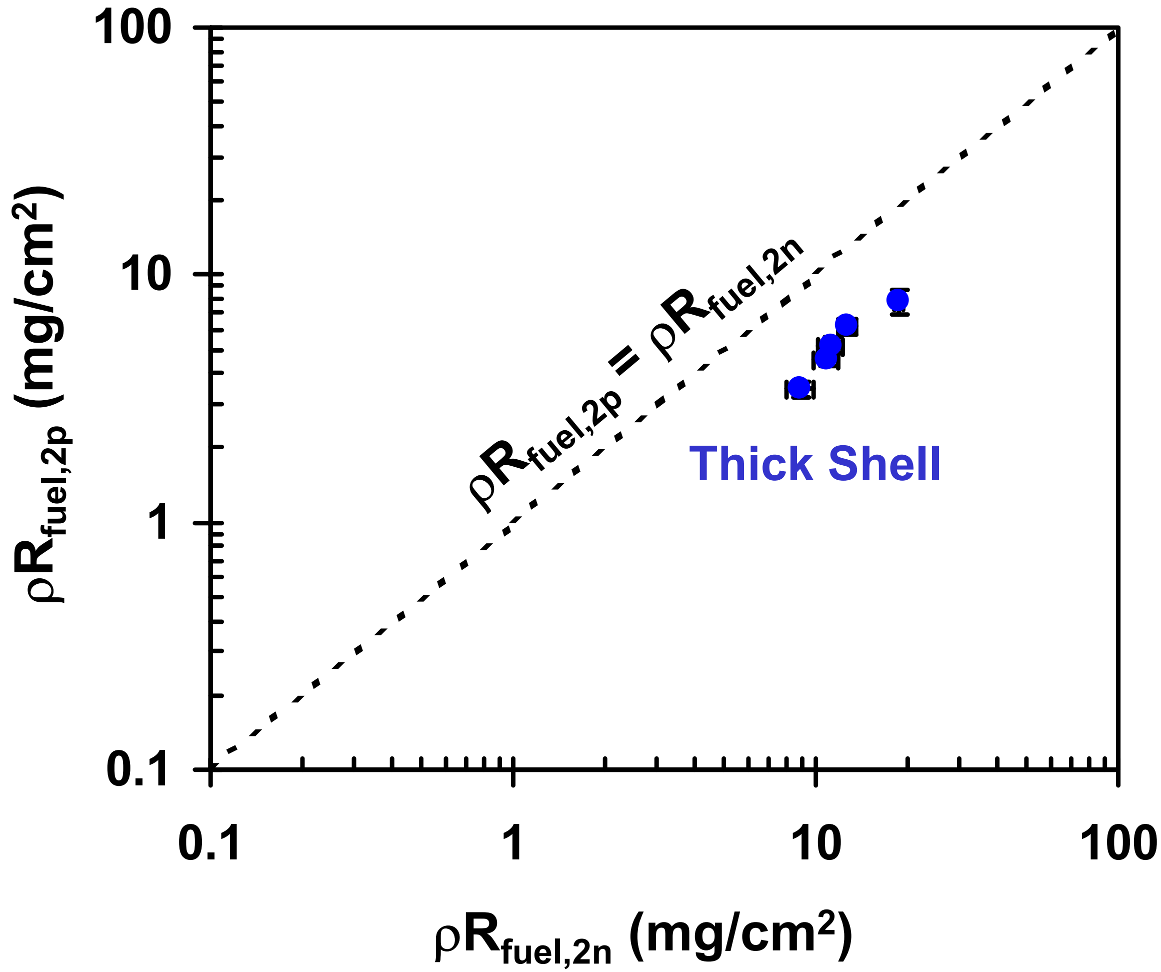
Hot-spot and uniform models give slightly different results



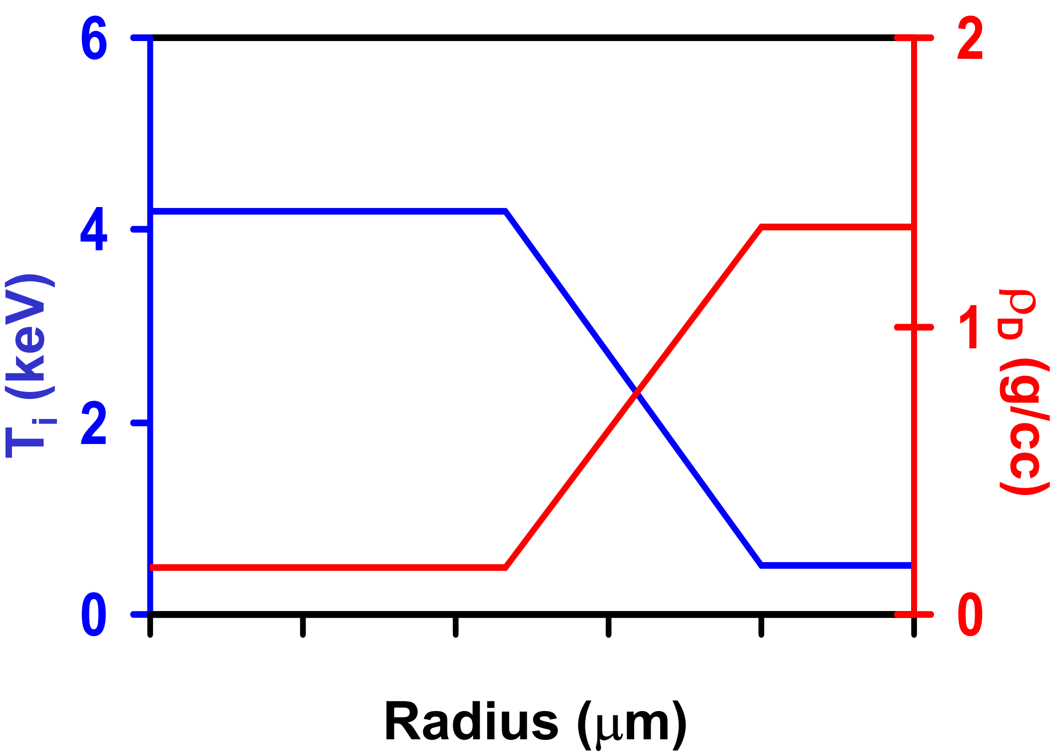


ρR_{fuel} (g/cm^2)

$\rho R_{fuel,2p}$ and $\rho R_{fuel,2n}$ disagree for thick (~20μm) shell capsules



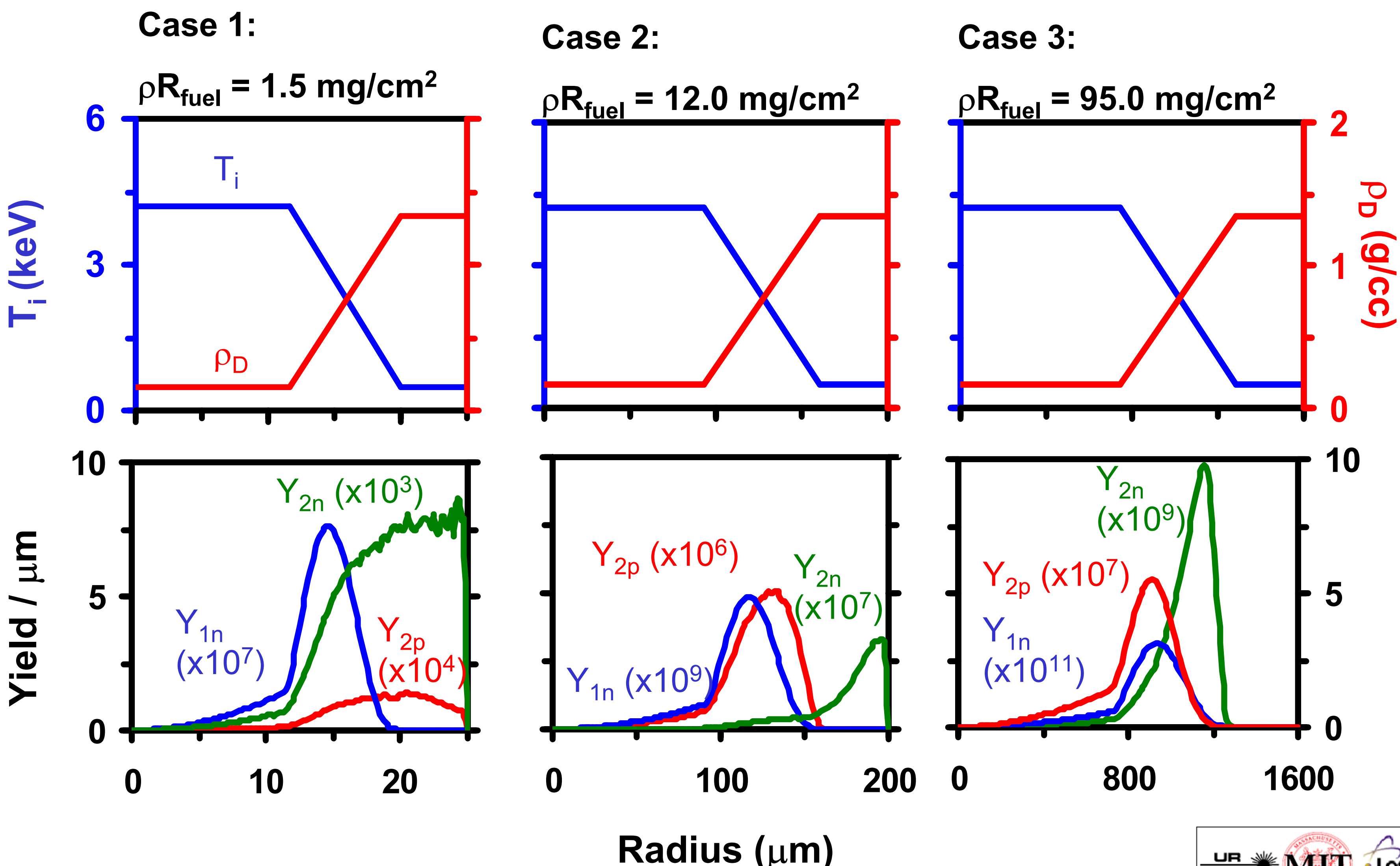
To predict effects of capsule structure, a simple peaked T_i profile was assumed



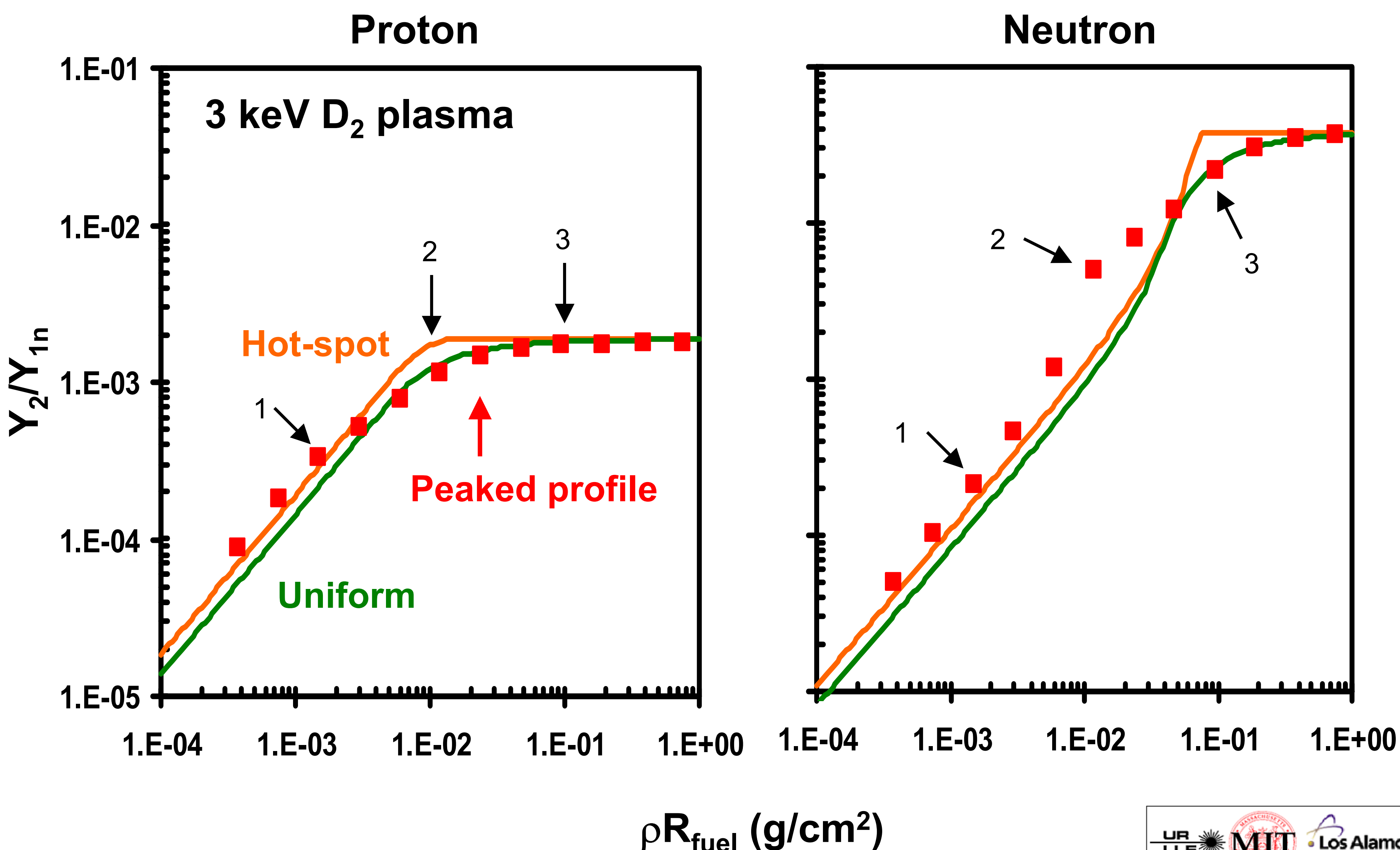
- $\langle T_i \rangle$ = 3.0 keV
- $\langle \rho_D \rangle$ = 1.0 g/cc
- Radius of each layer was adjusted to give different values of ρR_{fuel}

Related modeling has been published by
P. B. Radha *et al*., Phys. Plasmas **9**, 2208 (2002)
C. K. Li *et al*., Phys. Rev. Lett. **89**, 165002-1 (2002)

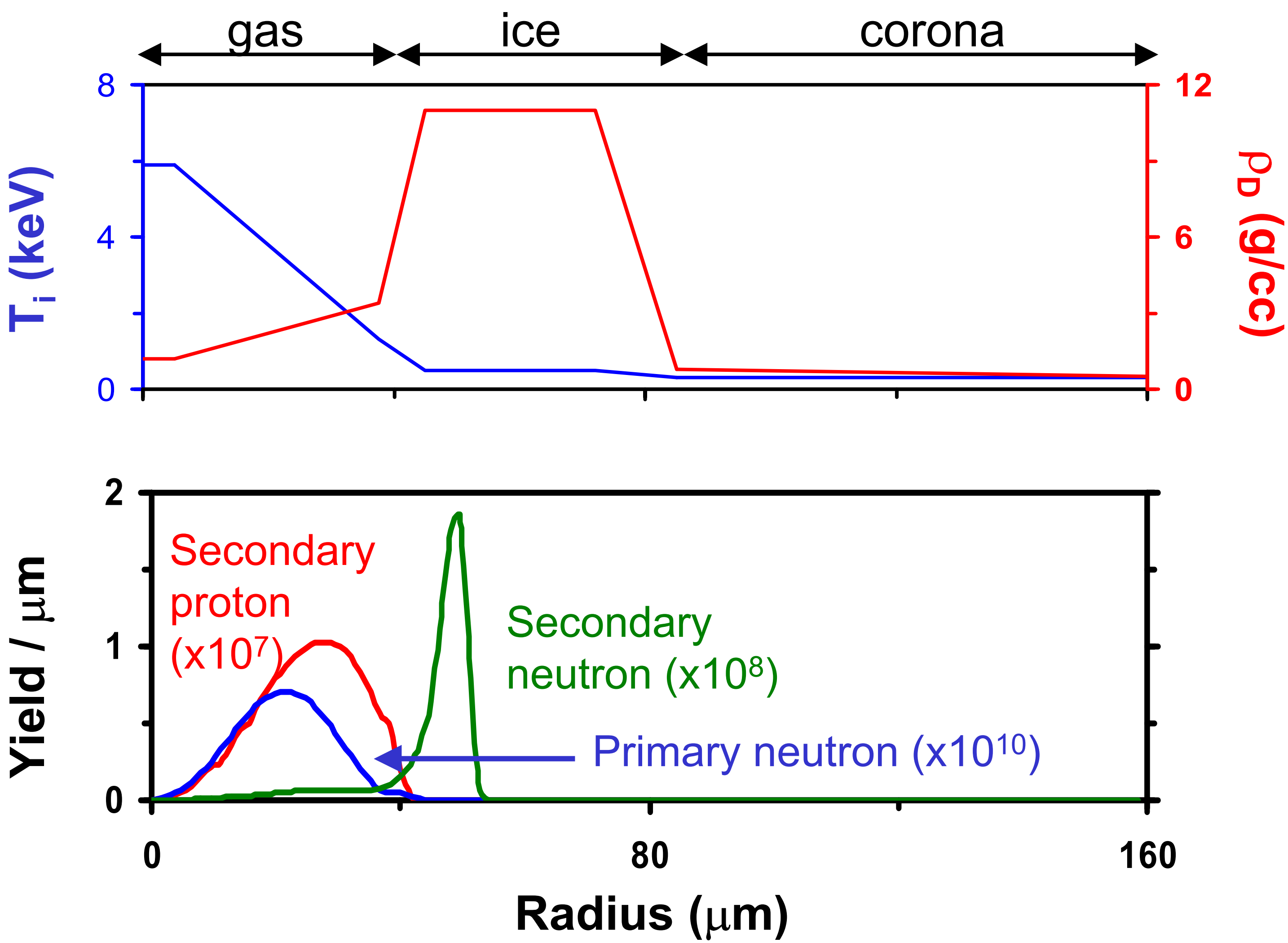
Secondary protons and neutrons can sample different temperatures and densities



Simulations for the peaked temperature profile agree well with the hot-spot model for low ρR_{fuel} but deviate at higher values.



For cryogenic targets, yields of secondary particles need to be used more carefully since they are produced in a limited region of the fuel.



This profile was obtained by matching Y_{1n}, Y_{2p}, Y_{2n}, $\langle T_i \rangle$ and ρR_{total} to experimental values from shot 28900.

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Comparison of experiment and simulation for cryogenic shot 28900

Experimentally Determined Values	Values From the Simulation
Y_{1n}: 1.24E+11	Y_{1n}: 1.41E+11
Y_{2p}: 2.21E+8	Y_{2p}: 2.25E+8
Y_{2n}: 1.17E+9	Y_{2n}: 1.28E+9
$\langle T_i \rangle$: 3.6 keV	$\langle T_i \rangle$: 3.56 keV
ρR_{total}: 61 mg/cm^2 *	ρR_{total}: 55.4 mg/cm^2
	ρR_{hot}: 8.1 mg/cm^2 **

Inferred Values	Inferred Values
$\rho R_{fuel,\ 2p,hot\text{-}spot}$: 14.3 mg/cm^2	$\rho R_{fuel,\ 2p,hot\text{-}spot}$: 8.12 mg/cm^2
$\rho R_{fuel,\ 2n,\ hot\text{-}spot}$: 47.9 mg/cm^2	$\rho R_{fuel,\ 2n,\ hot\text{-}spot}$: 46.7 mg/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)

Several diagnostics are used to detect fusion products

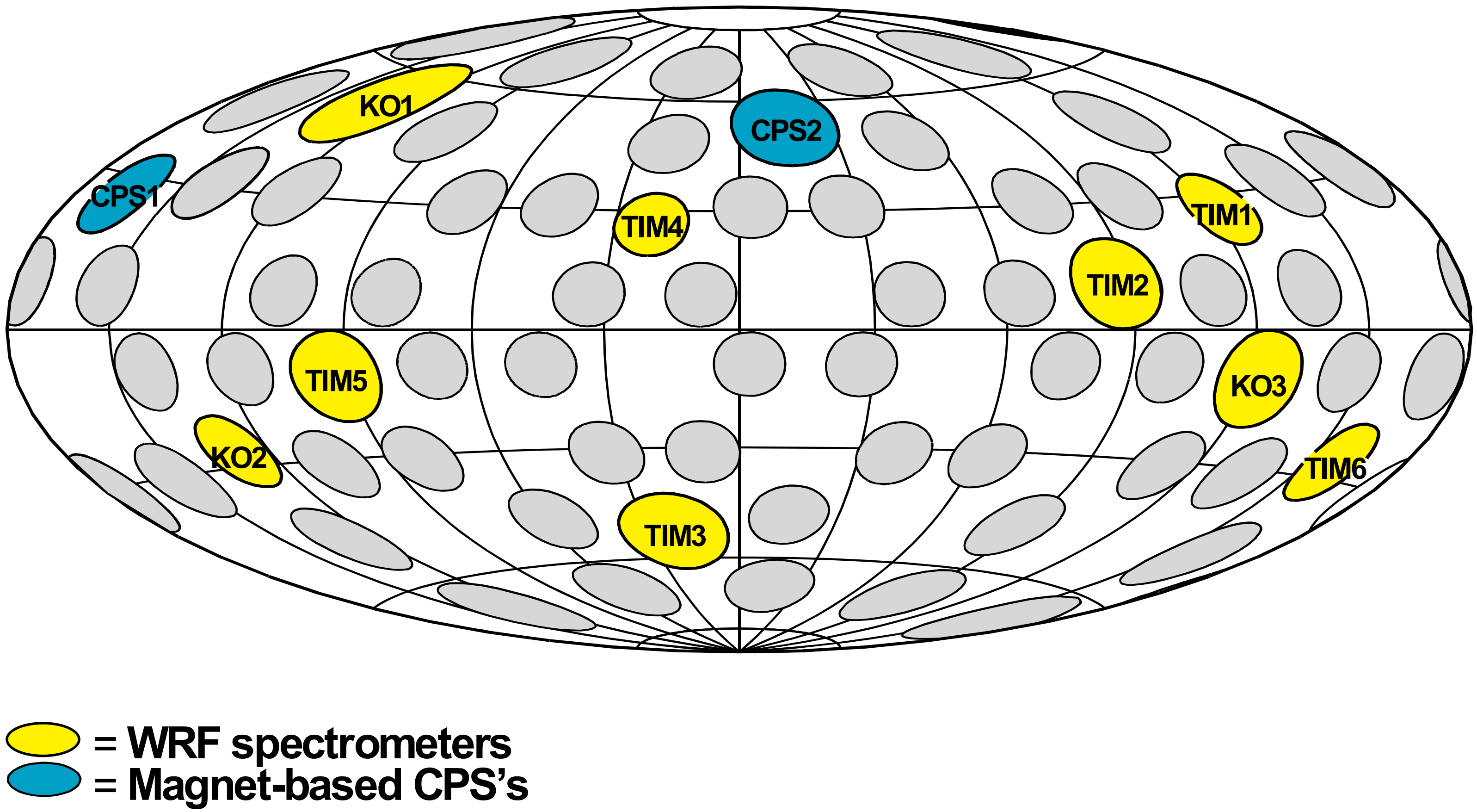
protons

- Magnet-based Charged-particle spectrometers (CPS)
- Wedge-range-filter spectrometers (WRF)

neutrons

- Indium activation (primary neutron)
- Copper activation (secondary neutron)
- neutron Time-of-Flight (secondary neutron)

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



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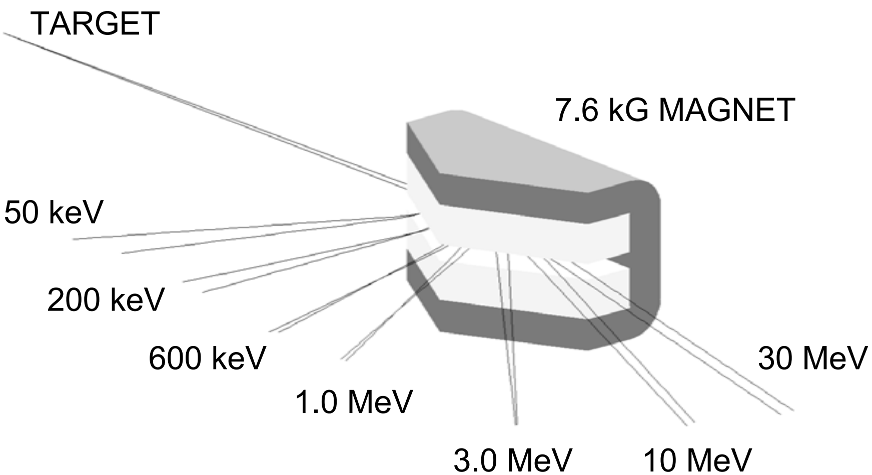
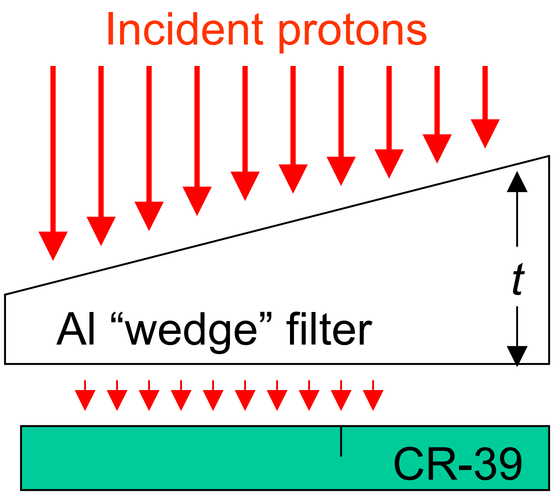
Two kinds of spectrometers* are used to get proton spectra

Magnet-based Spectrometers (CPSs)



Particle energies identified from trajectories.

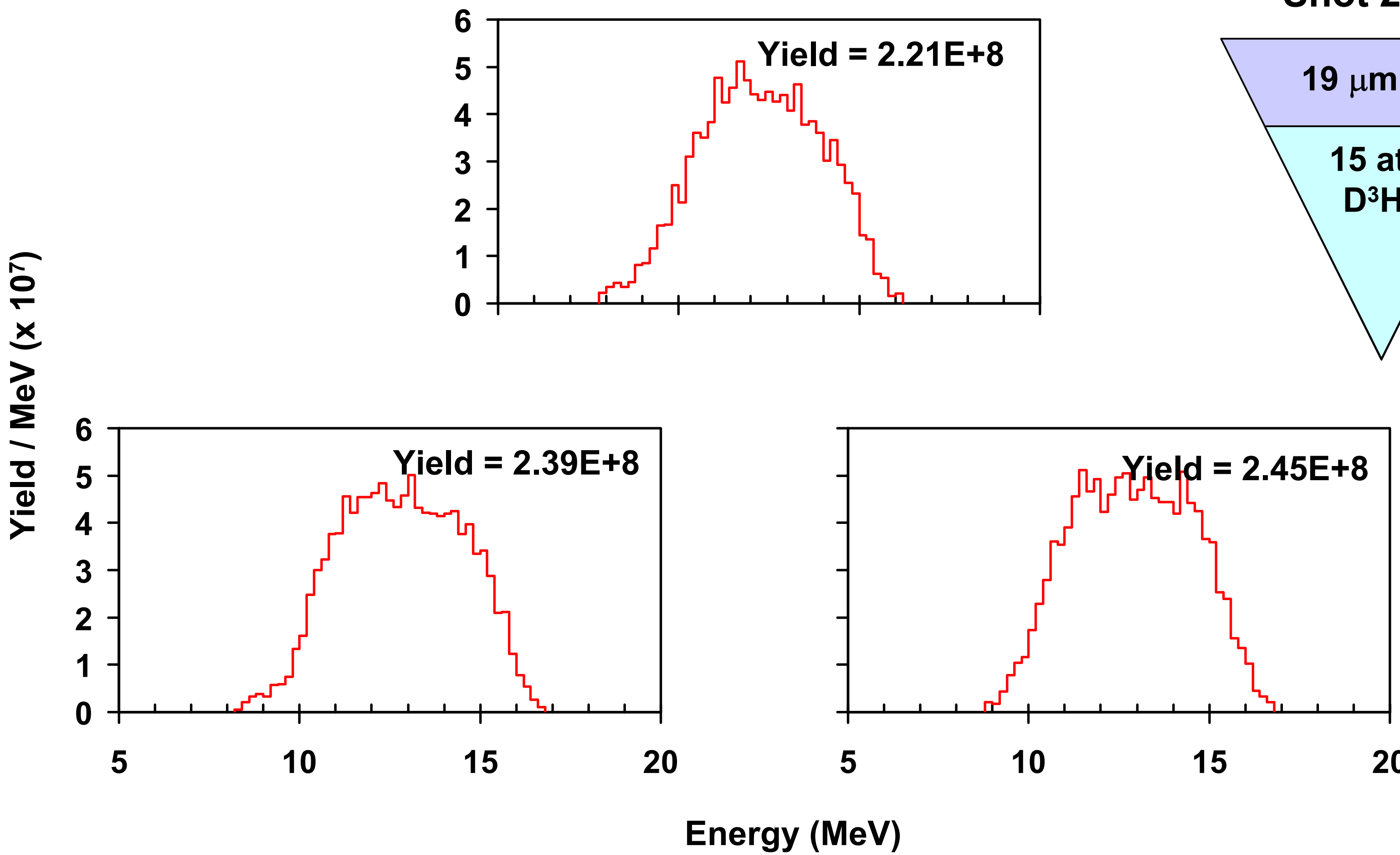
"Wedge-Range-Filter" Spectrometers (WRFs)

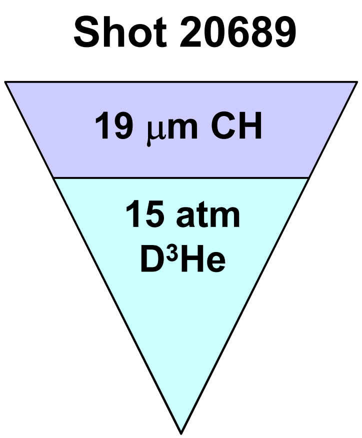


Particle energies identified from local thickness *t* and diameter of etched proton tracks in CR-39.

*F. H. Séguin *et al*., "Spectrometry of charged particles from inertial-confinement-fusion plasmas", Rev. Sci. Instrum. (to be published).

Secondary proton spectra from a single thick-shell shot





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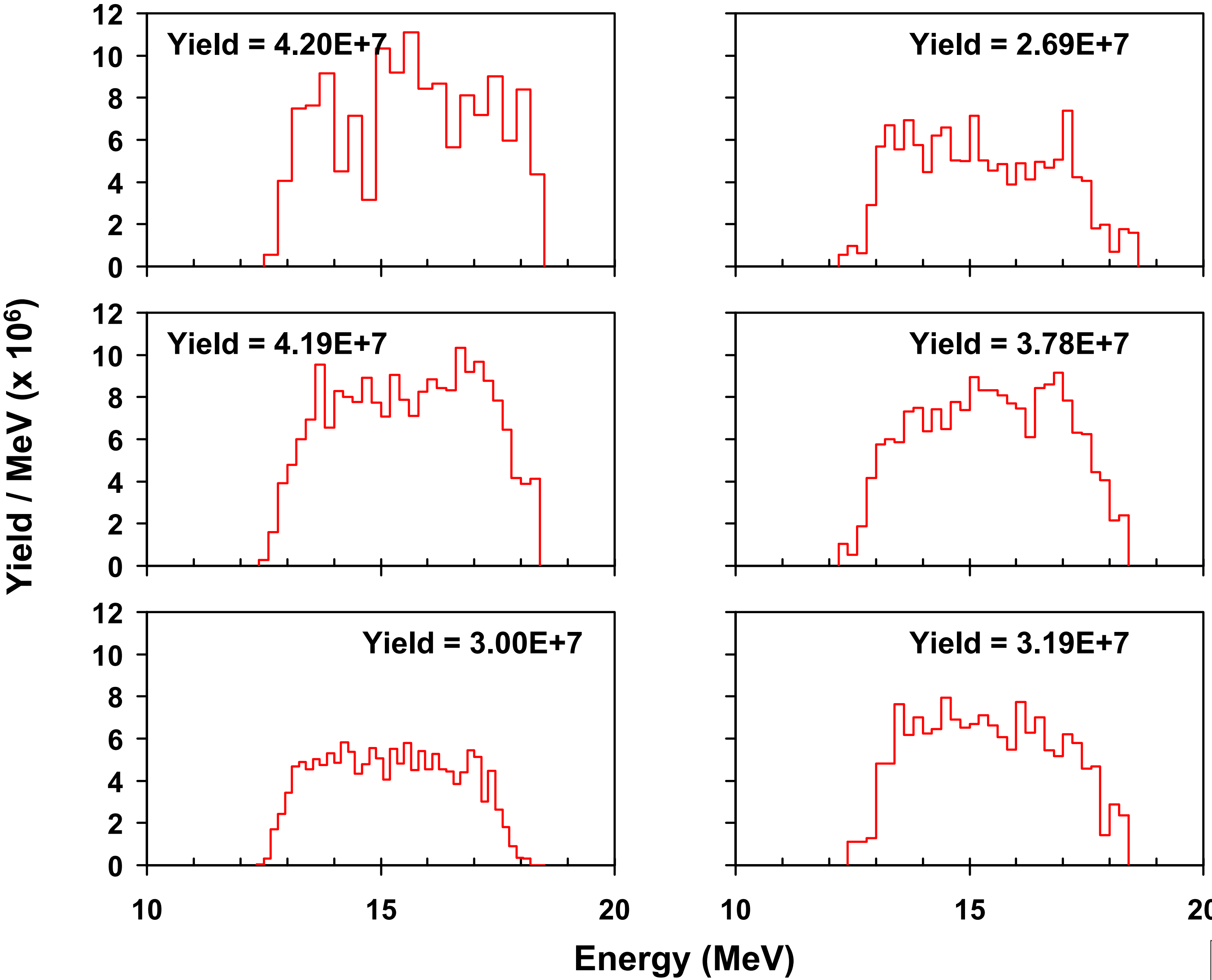
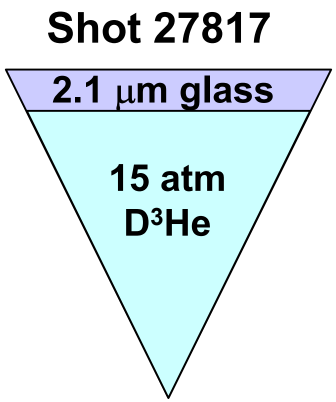
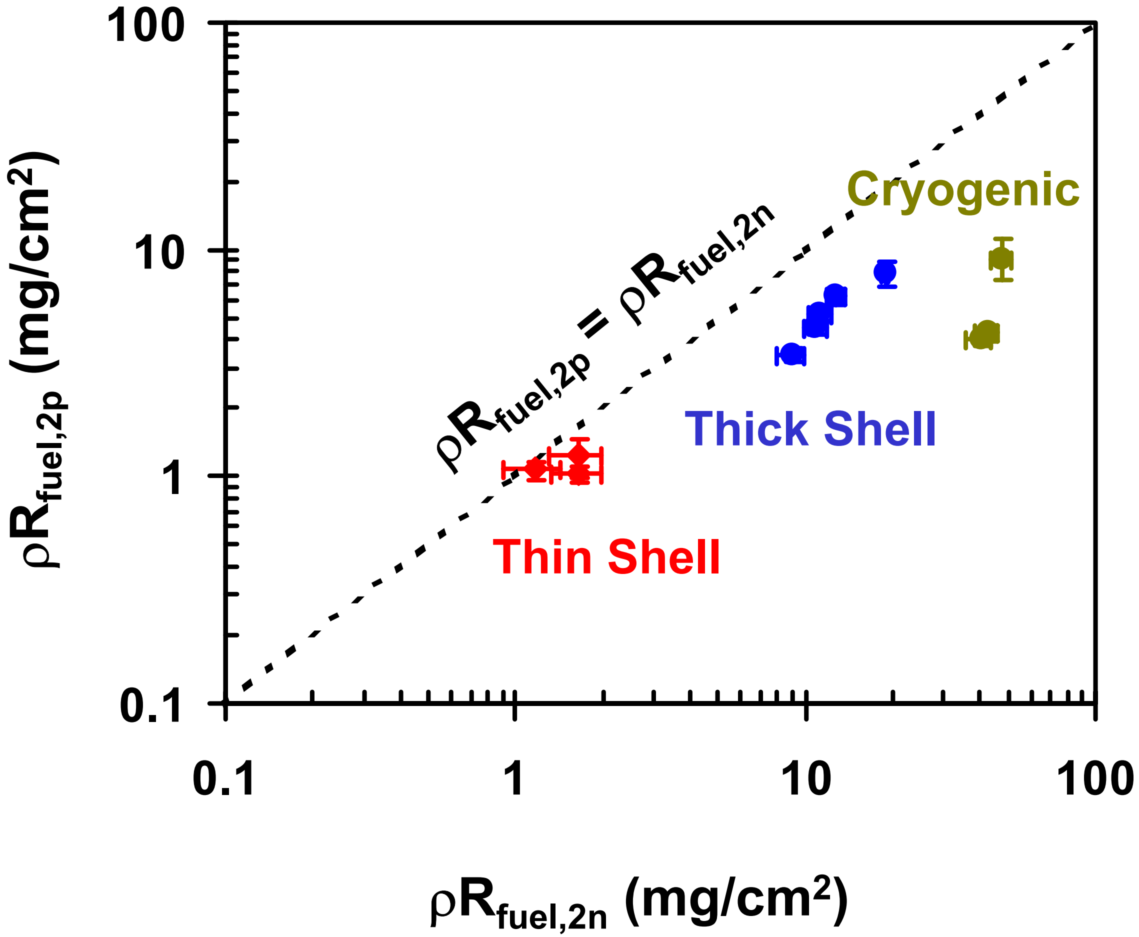




Experimental data from thin-shell capsules show better agreement between $\rho R_{fuel,2p}$ and $\rho R_{fuel,2n}$ than thick-shell and cryogenic capsules.



Summary

- Simulations with peaked temperature profile agree with the hot-spot model at low ρR_{fuel} but deviate at high values for both protons and neutrons.
- Simulations suggest that when $\rho R_{fuel} \cong 10$ mg/cm^2 secondary neutron ρR_{fuel} can only be used as upper limit.
- For cryogenic targets, secondary yields need to be used more carefully because
  - Protons are produced mostly in the region of deuterium gas and D_2 ice mix
  - Neutrons are produced mostly in the inner part of D_2 ice region
- Secondary neutrons and protons give nearly the same results for thin-shell capsules, which have:
  - Less fuel-shell mix
  - Higher T_e and lower ρR_{fuel} (which decreases “saturation” effects for secondary protons)

Future work

- Simulation using more realistic temperature and density profiles
- Collect more data from thin-shell capsules (2~3 shots are scheduled in the week of December 2, 2002).