Nuclear data needs for NIF-based cross section measurements

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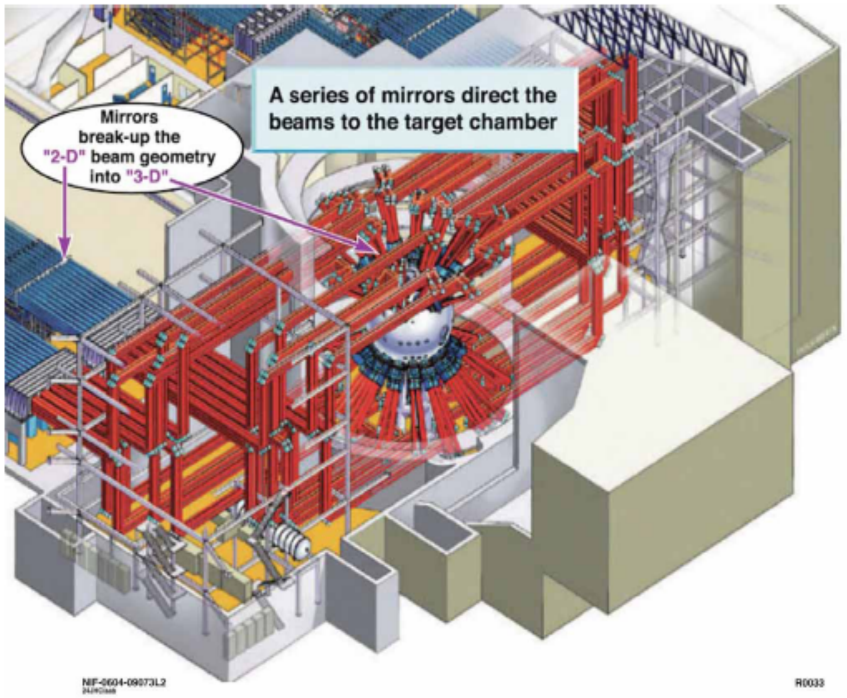
U.S. Department of Energy by Lawrence Livermore
National Laboratory under Contract DE-AC52-07NA27344.

NIF-National Ignition Facility



NIF Laser System: 192 laser beams produce 1.8 MJ, IR-UV→ 3ω=352nm, 2+ ns, $5x10^{14}$ Watt in $1mm^2$ spot)

Diagnostics (≈$90 M in FY11)

•X-ray diagnostics: ≈20 spectral, imaging and time-resolved diagnostics are planned/operational (developed over 25 years at NOVA, Omega etc.)

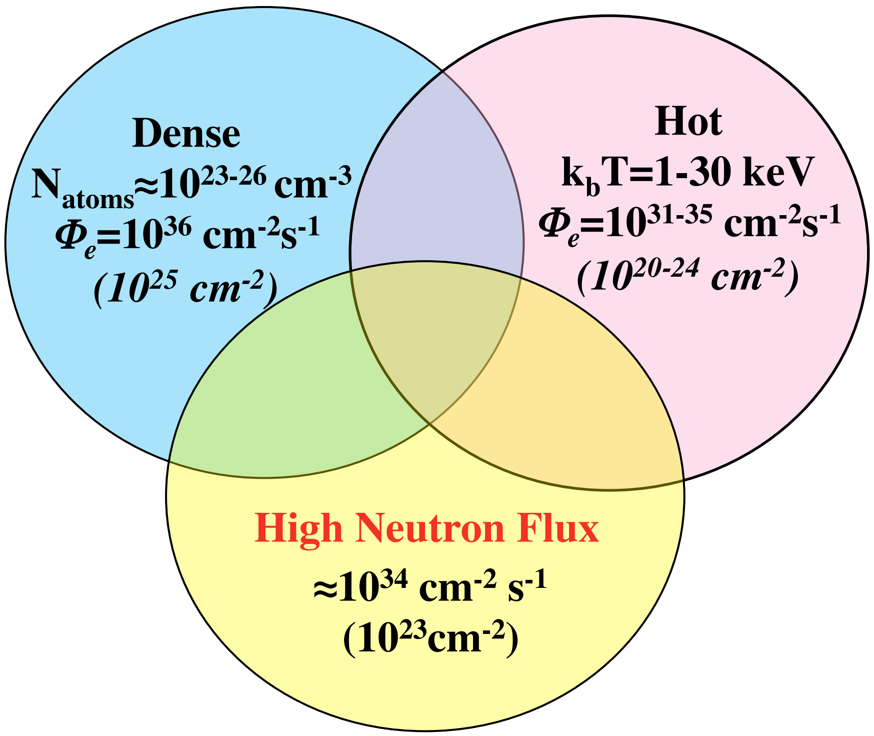
Very mature field

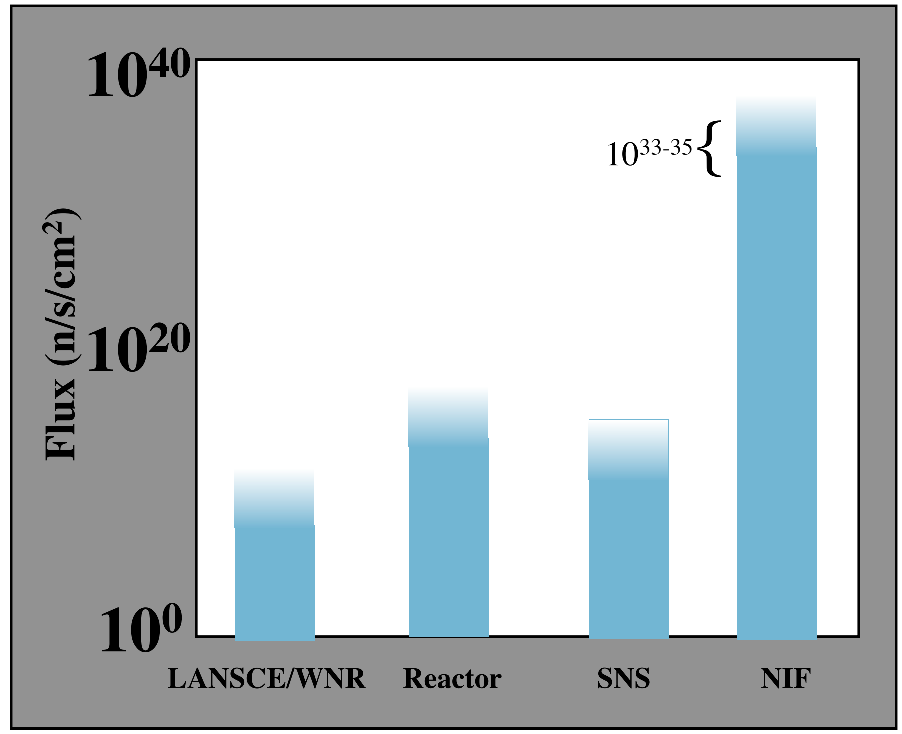
•Nuclear Diagnostics: 10 types of diagnostics are planned/operational

- nToF, Neutron imaging, Activation, Charged-particle spectrometry, Radchem, *Gamma Reaction History*

What you will hear about today is one of the first eight approved science proposals (the only one on nuclear physics)

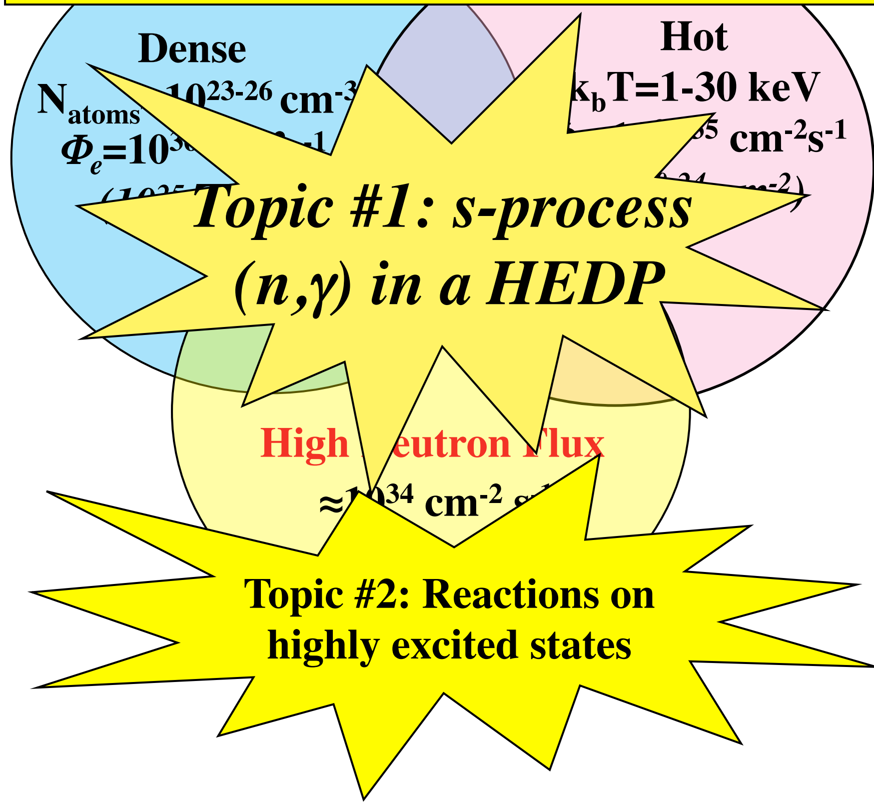
NIF open new avenues of research in nuclear physics

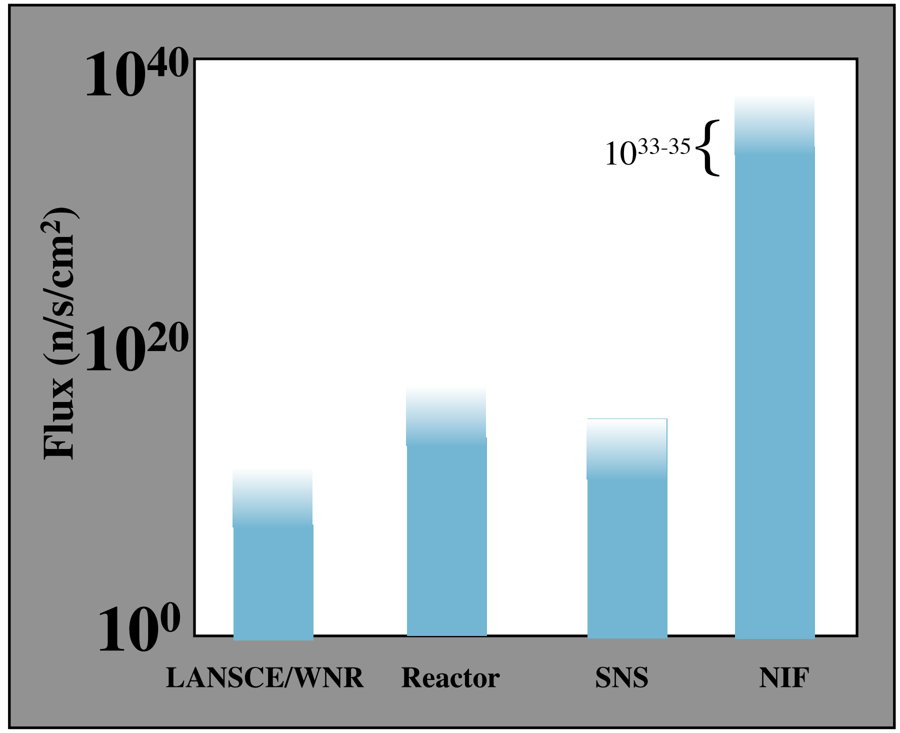




NIF open new avenues of research in nuclear physics

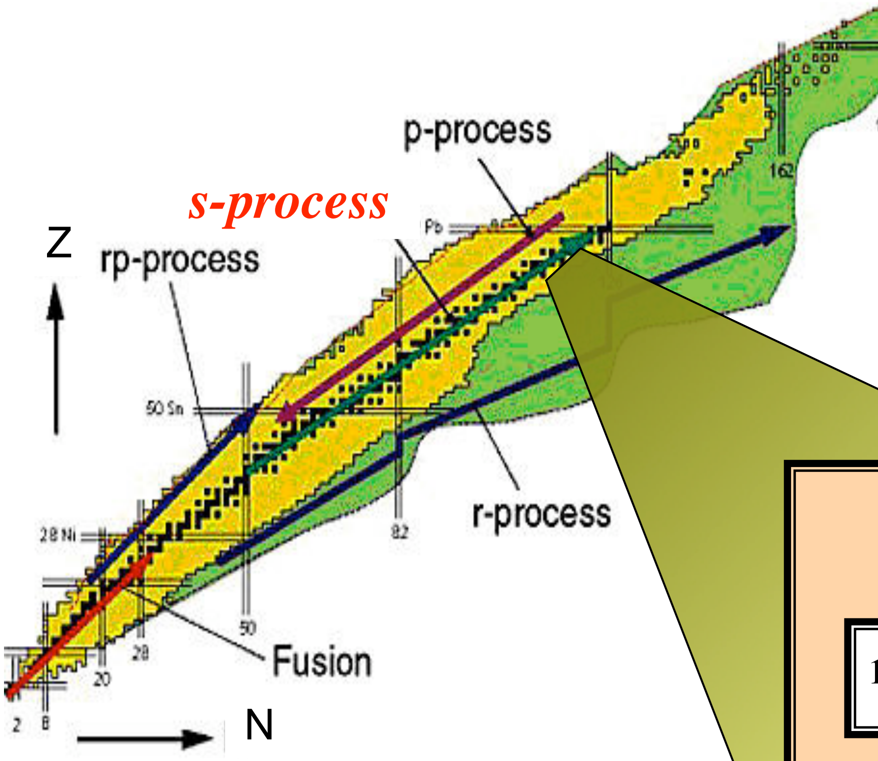
Come to Dennis McNabb's talk on Friday

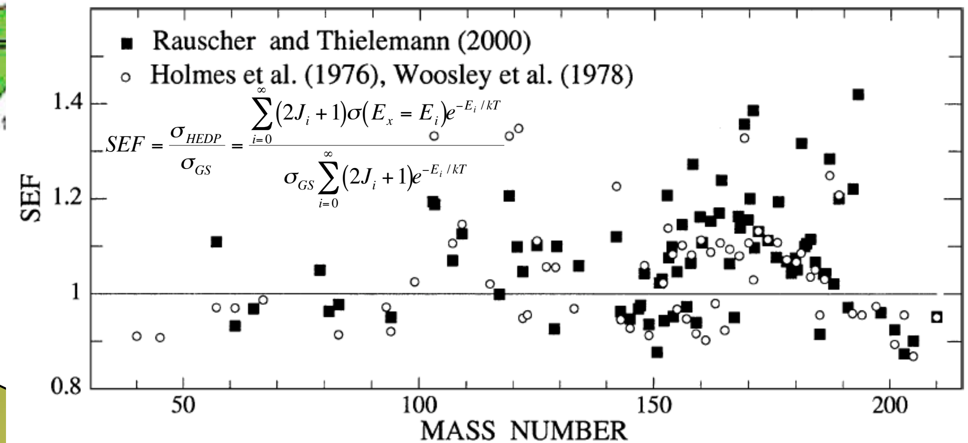


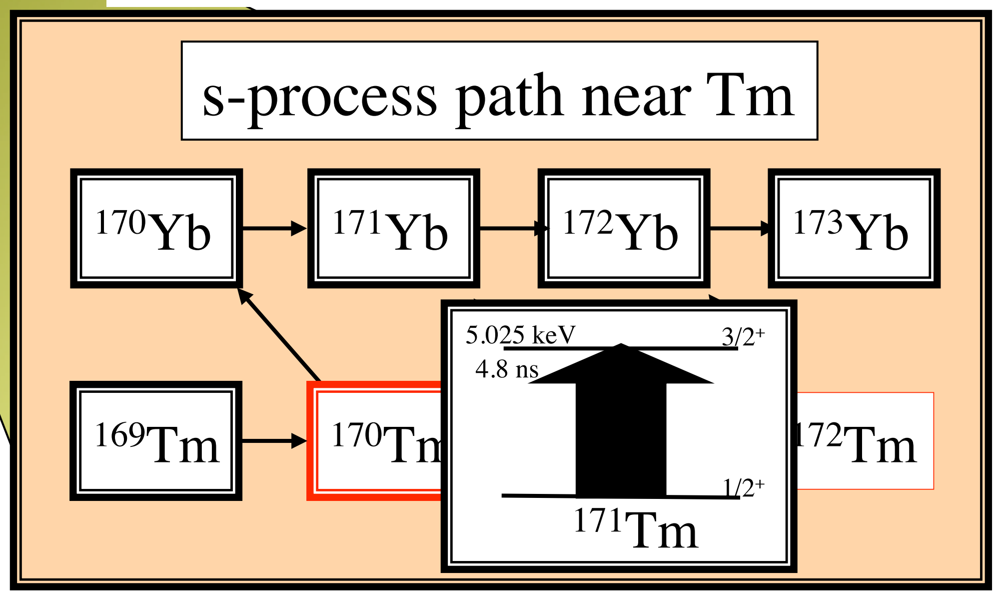


Common theme: Reactions on excited states

Most of the heaviest elements (A>56) are made via "slow" neutron capture (s-process) @ 8, 25 keV in massive stars







Important Branch Points*

^{79}Se, ^{85}Kr, ^{147}Pm, ^{151}Sm, ^{163}Ho, ^{170,171}Tm, ^{179}Ta, ^{204}Tl, ^{205}Pb ^{185}W

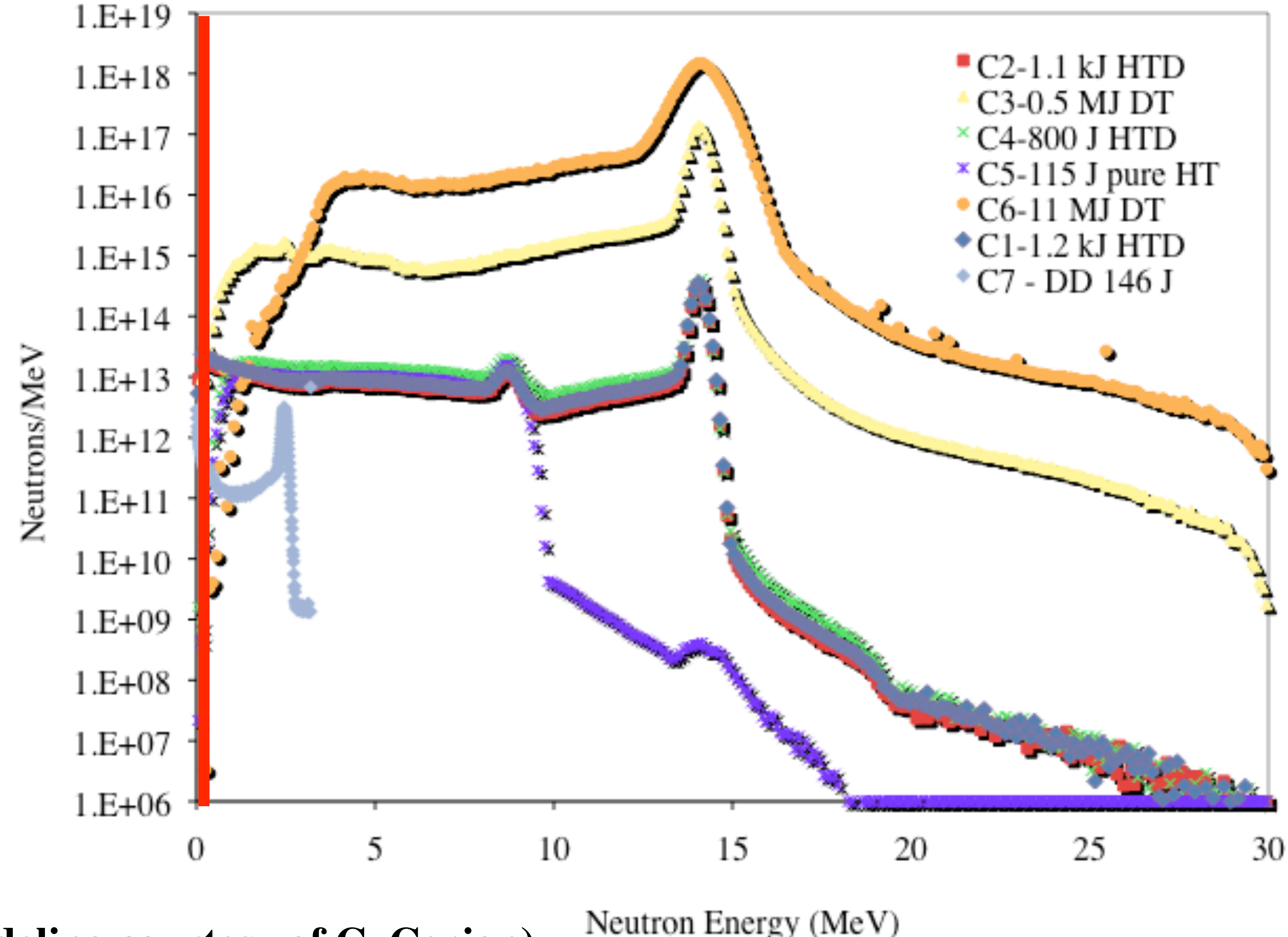
*Bao & Kappeler At. Dat. Nucl. Dat. Tables **76,** 70–154 (2000)

How do you measure an astrophysical (n,γ) cross section at NIF?

1. Create the correct environment (neutrons, T, ρ)
   - Fuel load and moderation environment
2. Get the material into the capsule
   - Ion-implantation
3. Measure target areal density
   - Energy resolved X-ray imaging
4. **Measure the number of (n,γ) reactions that took place and the neutron spectrum**
   - **Prompt γ-ray detection using Gas Cerenkov Detectors**

Quasi-continuum properties are critical

Step 1: Varying the fuel loaded creates wide range of neutron spectra



(Modeling courtesy of C. Cerjan)

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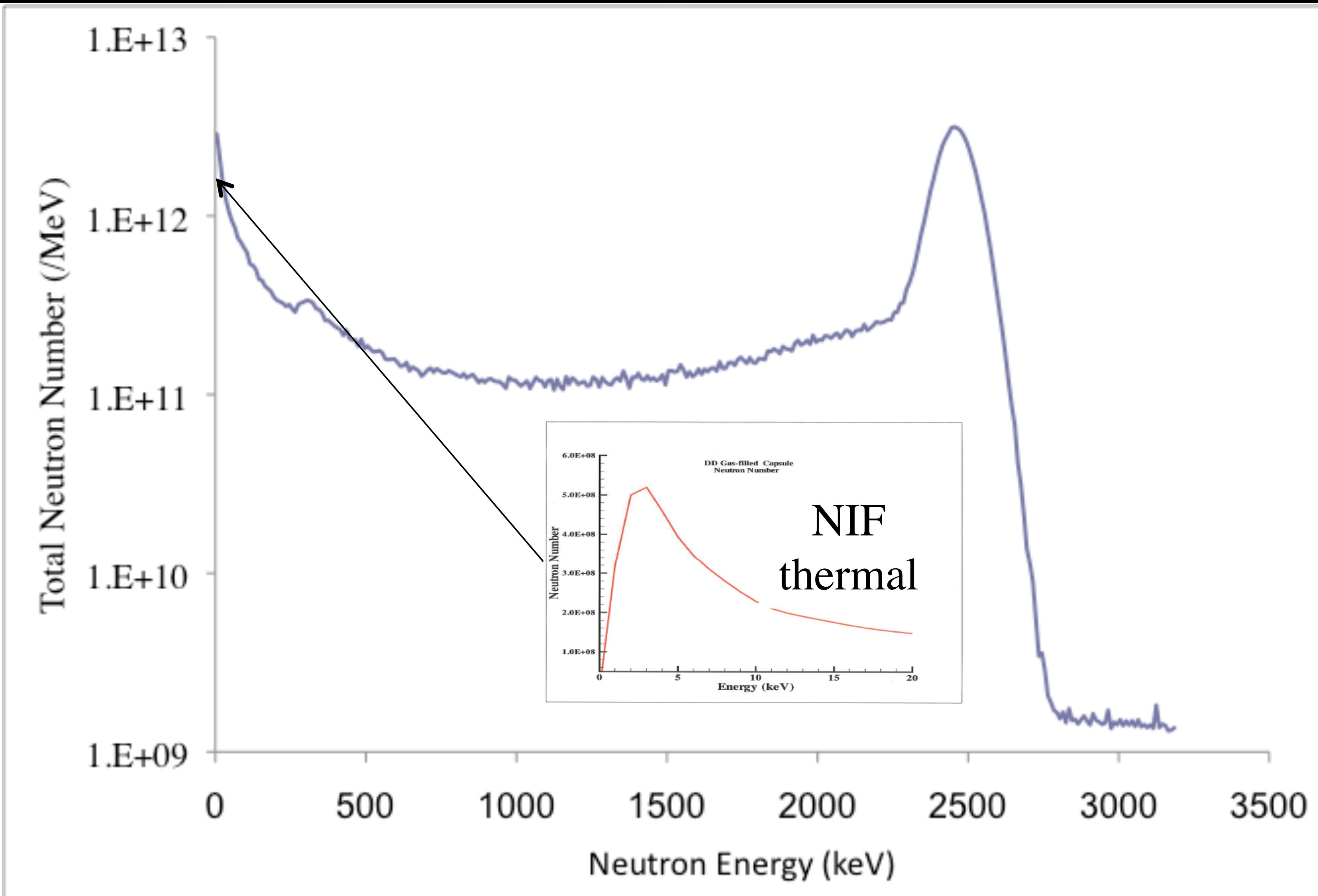
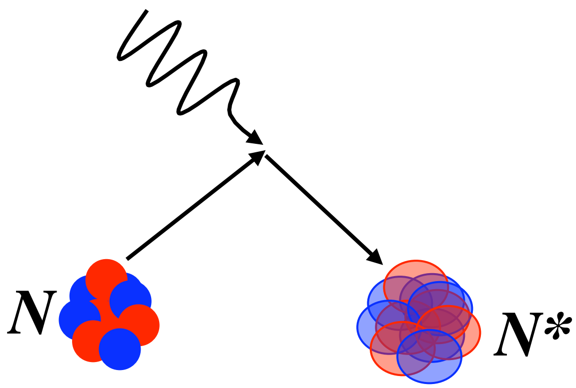


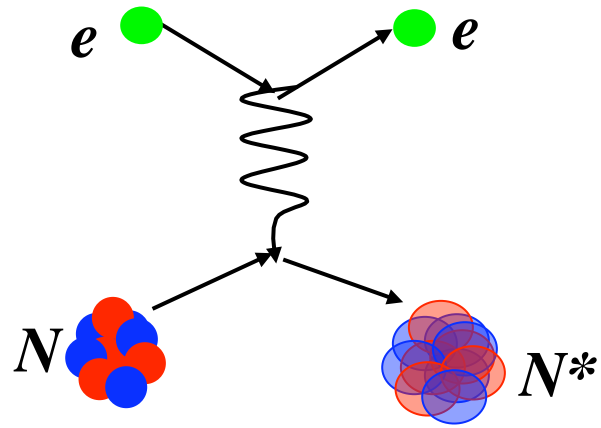
(Modeling courtesy of C. Cerjan)

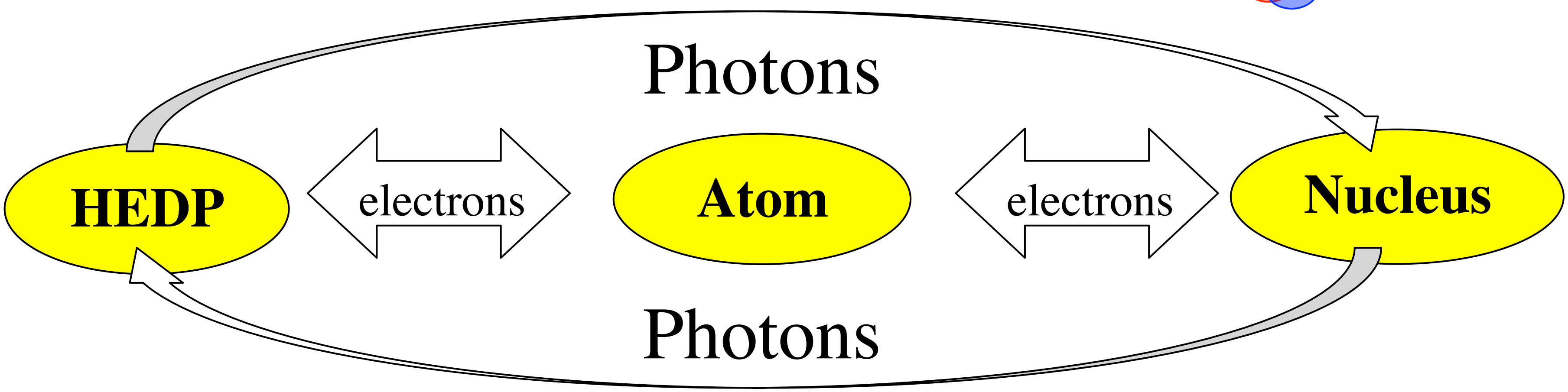
Step 1: Nuclear-plasma interactions in the HEDP can cause thermal population of low-lying nuclear states

Photo-absorption
Time Reverse: γ-ray decay



Atomic-nuclear (electron) interactions
NEEC, NEET, IES*
Time Reverse: IC-decay





Electron-mediated interactions are most important at *T*≈keV

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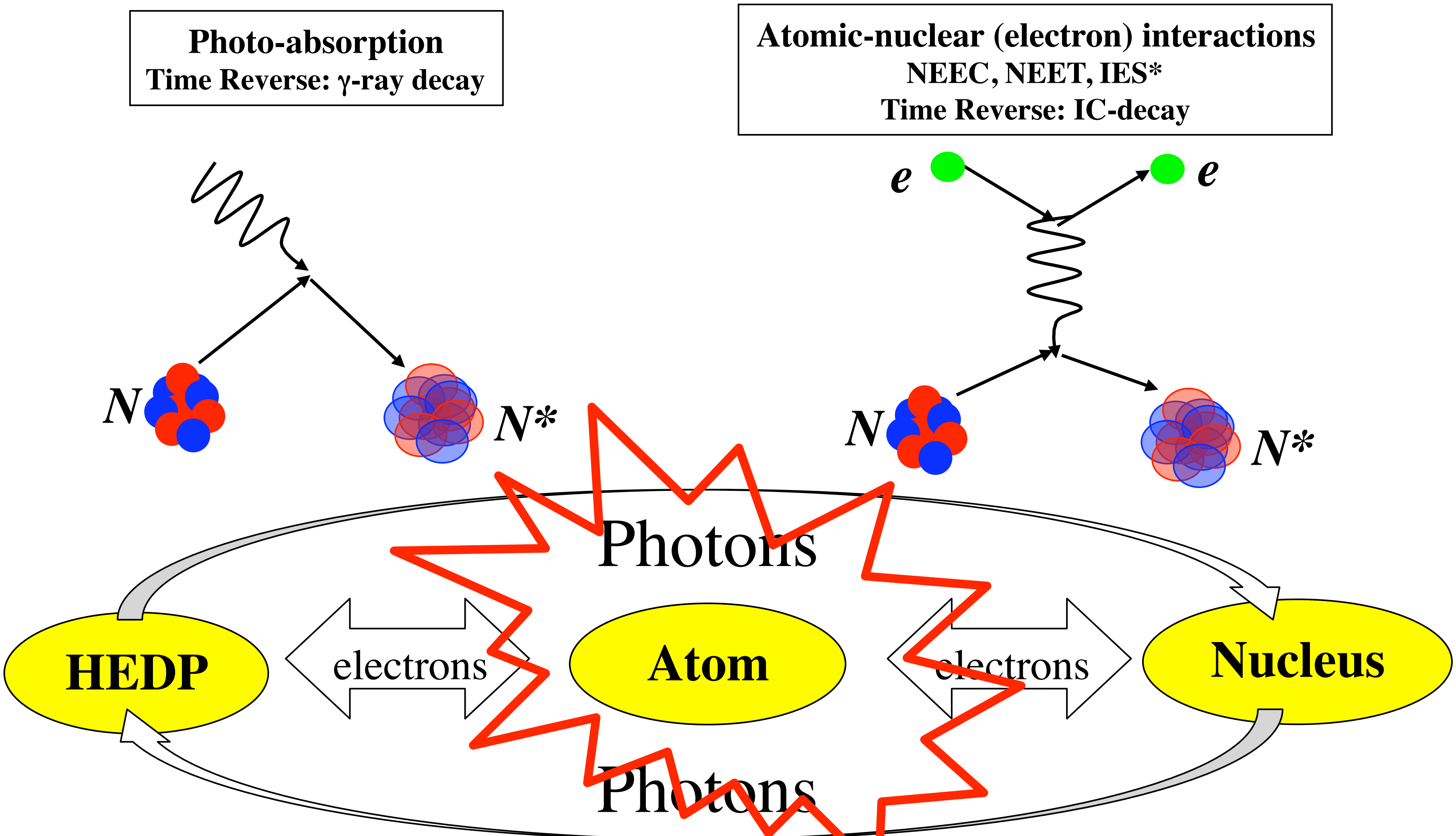
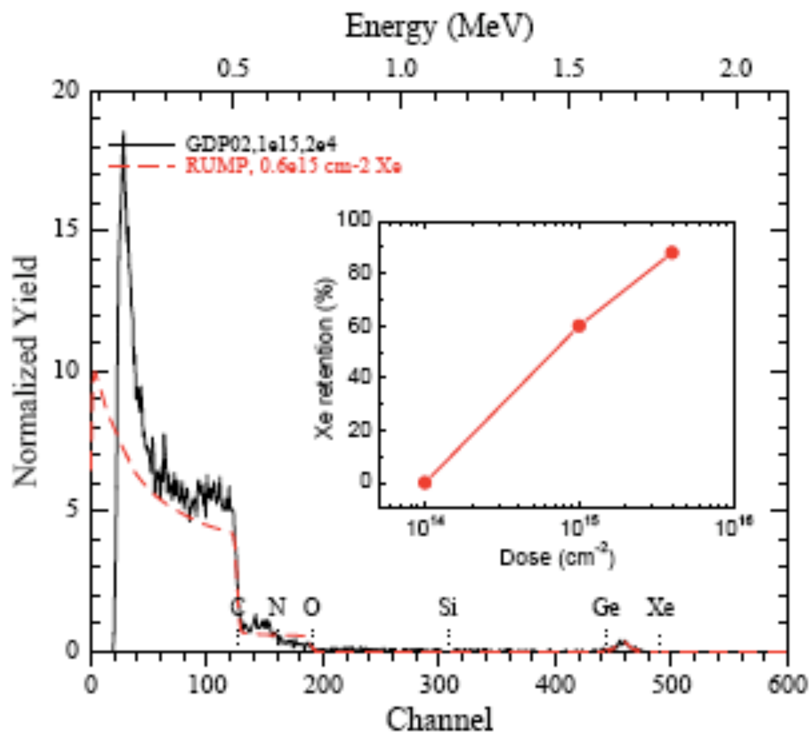
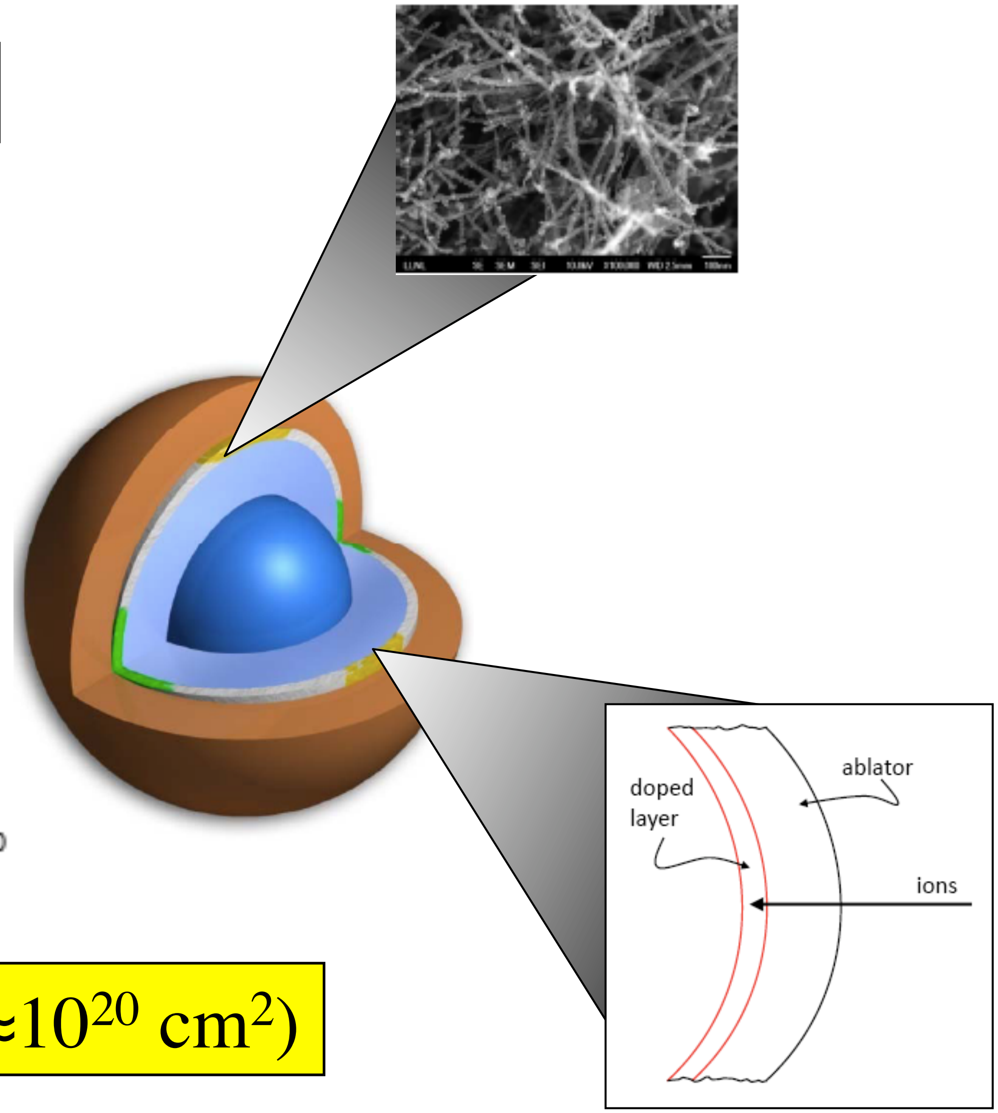


Electron-mediated interactions are most important at *T*≈keV

Step 2: D-loaded capsules can be made using a Carbon nanofoam “scaffold” into which ions are implanted*

Ion implantation of Xenon

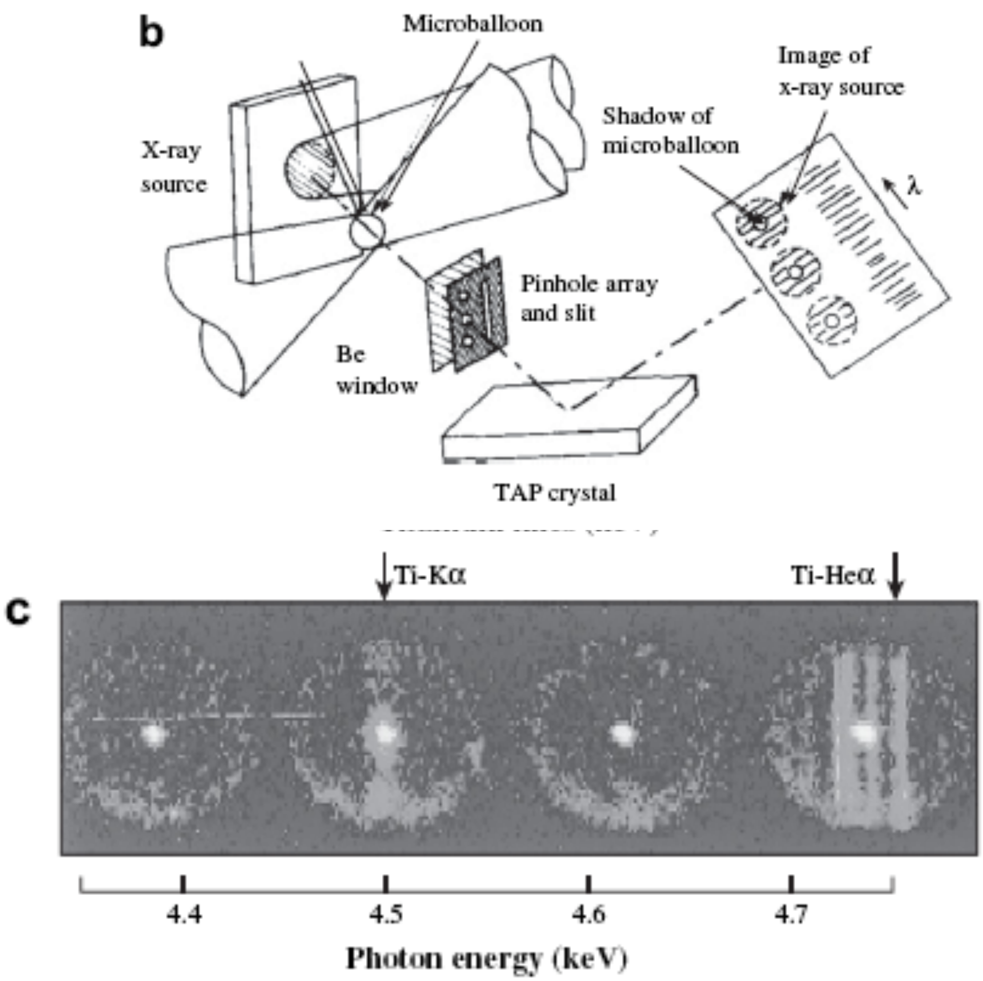


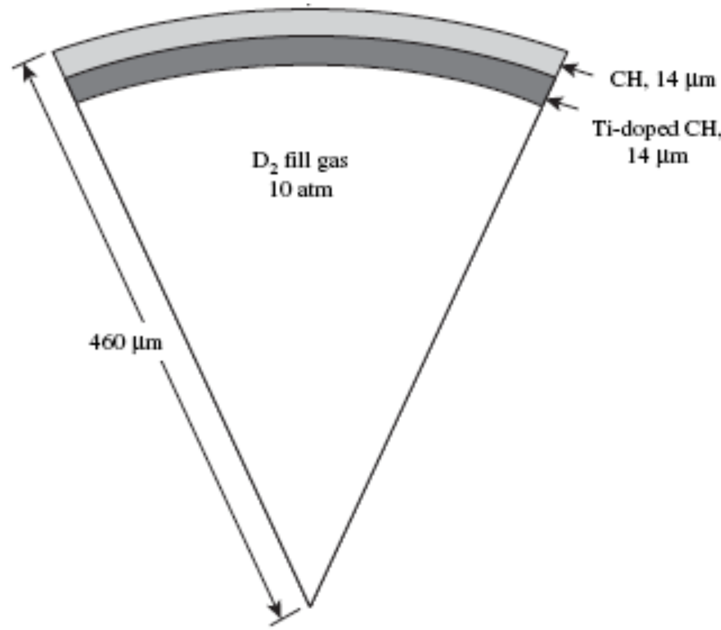


Maximum loading: 10^{16} ($\approx 10^{20}$ cm^2)

*courtesy of S. Kucheyev/A. Hamza

Step 3: The areal density (ρR) of the seeded nuclei can be determined using established X-ray imaging techniques*

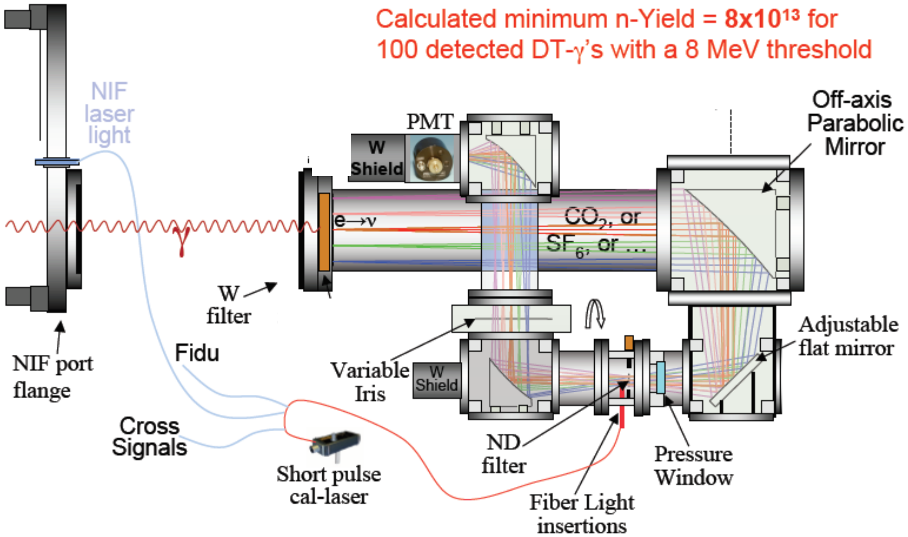


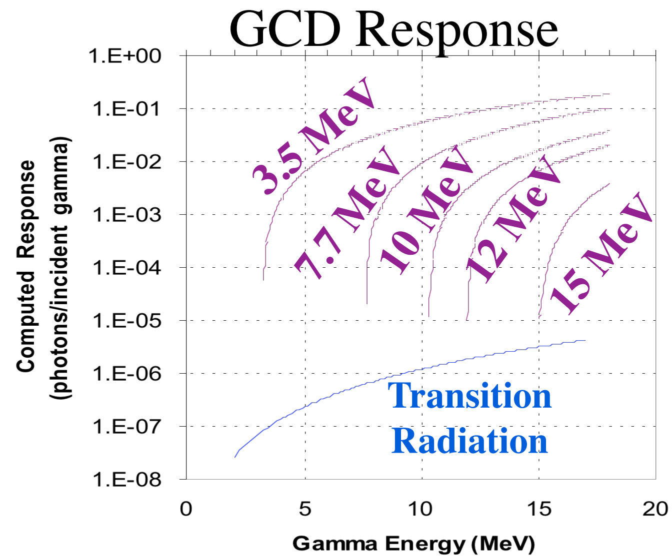


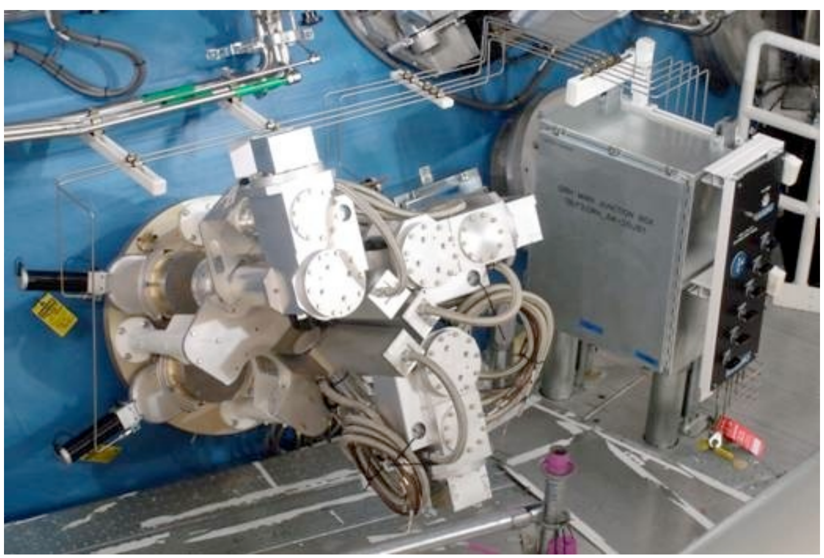
High resolution spectroscopy using crystals allows for detailed tracking of seed nuclei during compression

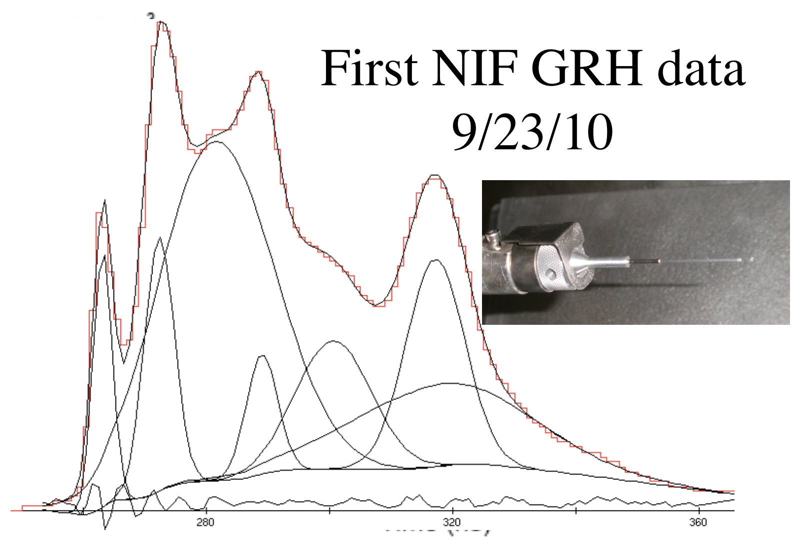
*S.P. Regan *et al*., High Energy Density Physics 5 (2009) 234–243

Step 4: Prompt γ-rays can be measured with the Gas Cerenkov detector-based Gamma Reaction History (GRH) system





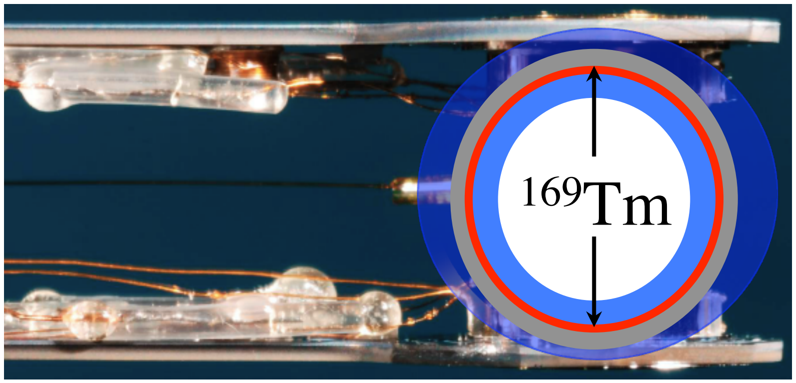


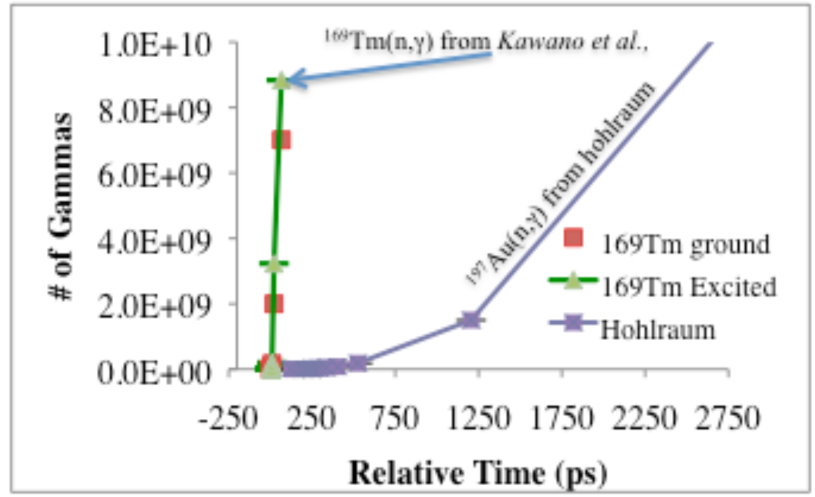


First NIF GRH data 9/23/10

(H. Herrmann & W. Stoeffl)

What γ-ray production rate does GRH see for a D-fuel capsule loaded with a (n,γ) "seed" nucleus





What we want

$$\frac{N_{\gamma}^{Tm}}{N_{\gamma}^{Au}} = \frac{\int \varepsilon_{Tm}^{\gamma}(\rho R)_{Tm}\,\sigma_{Tm}(E_n)\,\phi(E_n)\,dE_n}{\int \varepsilon_{Au}^{\gamma}(\rho R)_{Au}\,\sigma_{Au}(E_n)\,\phi(E_n)\,dE_n}$$

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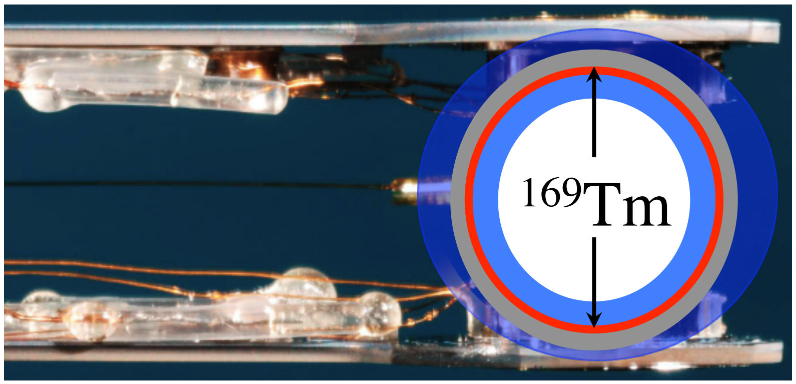
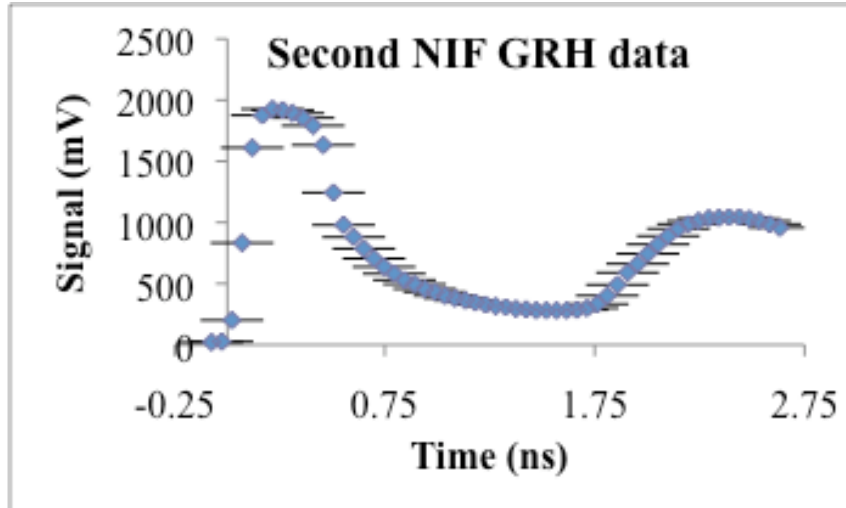




From X-rays: $\delta_{\rho R\text{-}Tm} \approx 10\%$

What we need

What we want

From hohlraum Late time signal

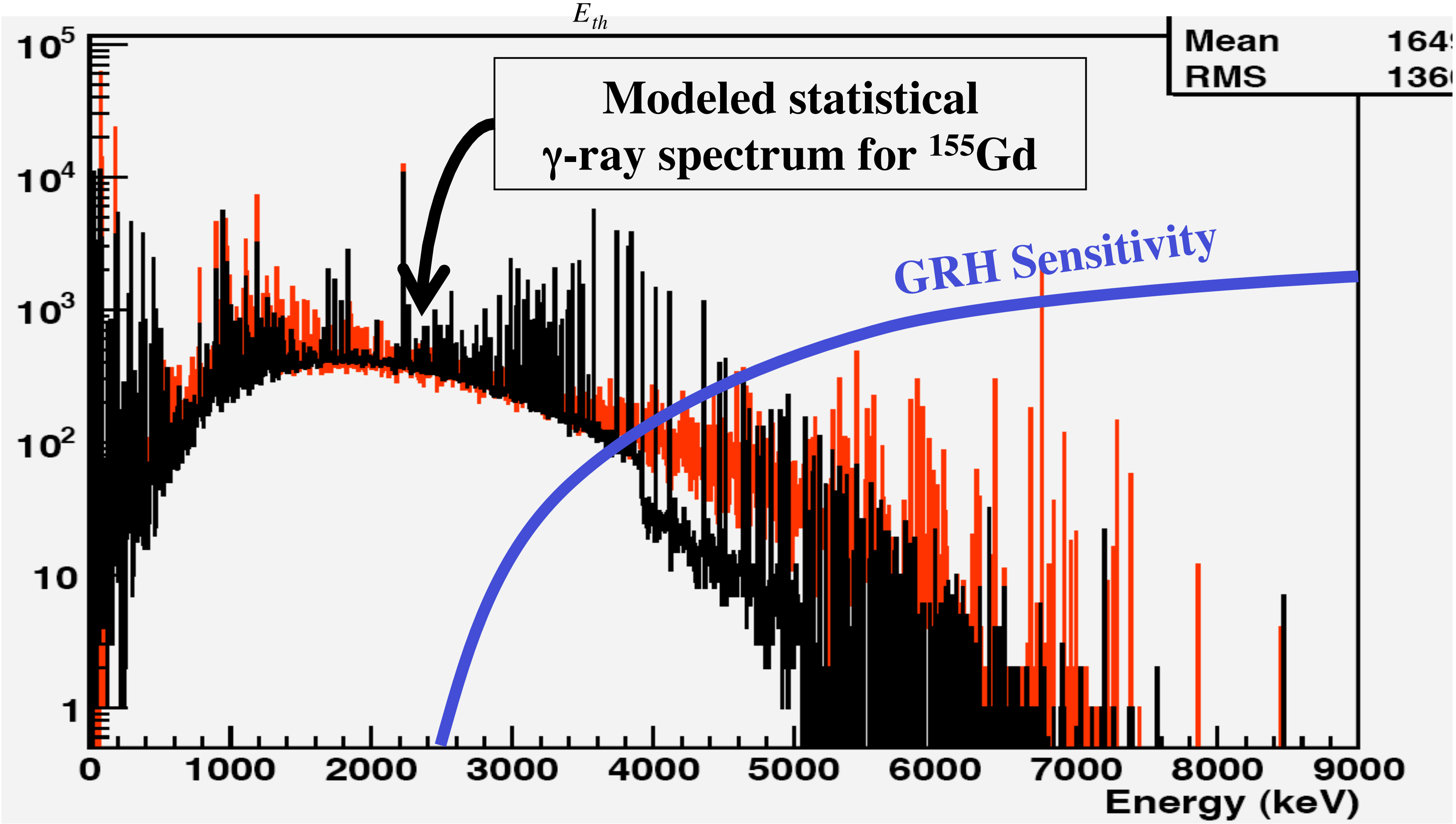
$$\frac{N_\gamma^{Tm}}{N_\gamma^{Au}} = \frac{\int \varepsilon_{Tm}^{\gamma} (\rho R)_{Tm} \sigma_{Tm}(E_n) \phi(E_n) dE_n}{\int \varepsilon_{Au}^{\gamma} (\rho R)_{Au} \sigma_{Au}(E_n) \phi(E_n) dE_n}$$

$\delta_{\rho R\text{-}Au} \approx 5\%$

$\delta_{\sigma-Au} \approx 2\%$

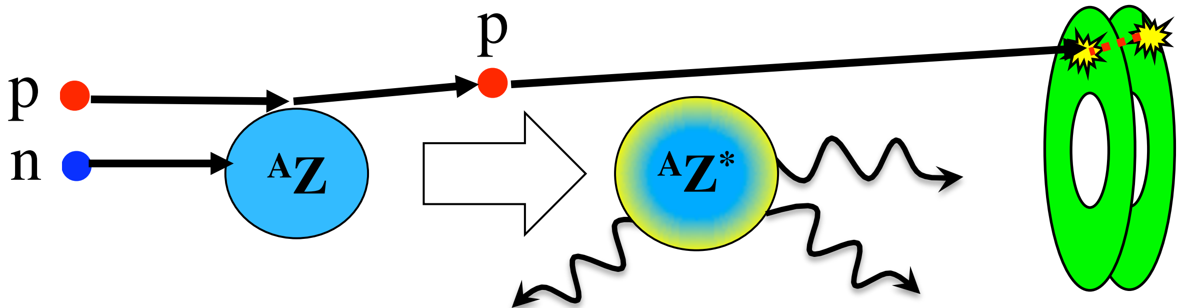
The main uncertainty in GRH's ability to "tag" (n,γ) is the production of statistical γ-rays from the CN

$$\varepsilon_{stat}^{i} = \int_{E_{th}}^{Q} \varepsilon_{GRH}\left(E_\gamma\right) \otimes S_i^\gamma\left(E_\gamma\right) dE_\gamma$$

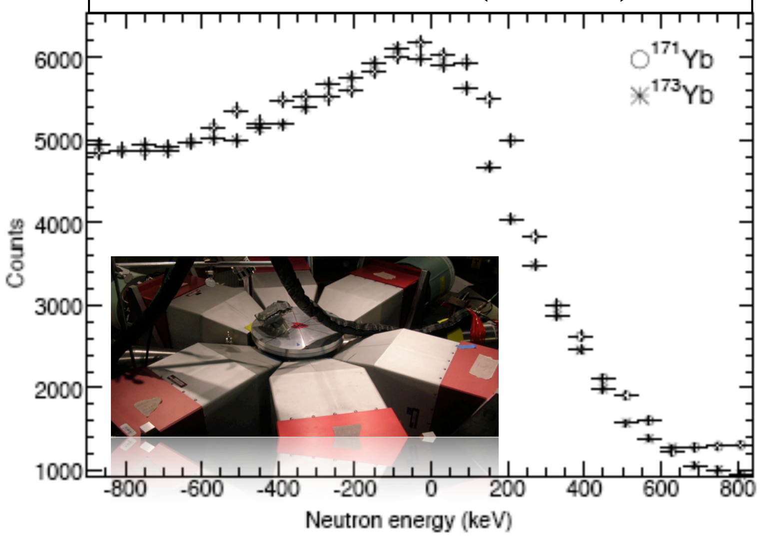


We would like to measure S_γ for $E_\gamma \geq 3$ MeV at the 10% level

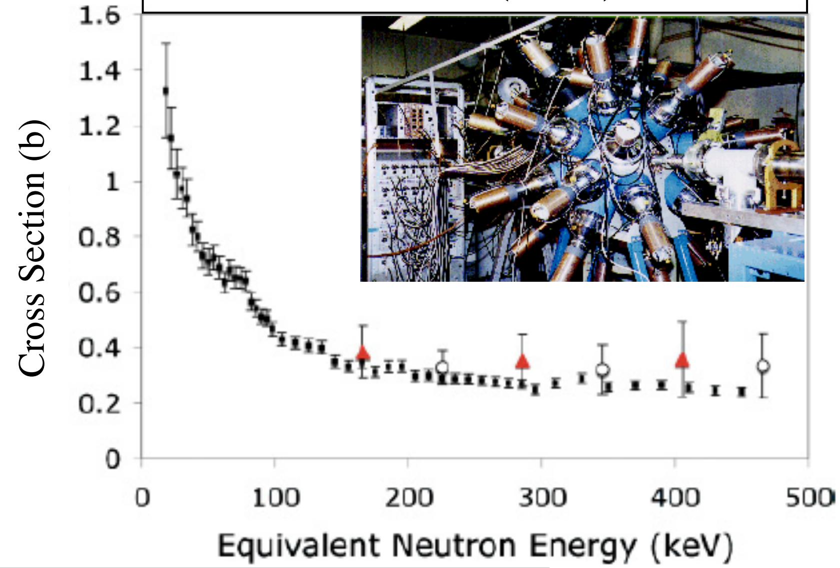
The statistical γ-ray spectrum for a (n,γ) product could be measured as part of a surrogate reaction experiment



$^{171}Yb(d,p)^{172}Yb$ using STARS +LIBERACE (LBNL)*



$^{170}Yb(^{3}He,\alpha)^{171}Yb$ using CACTUS (Oslo)**

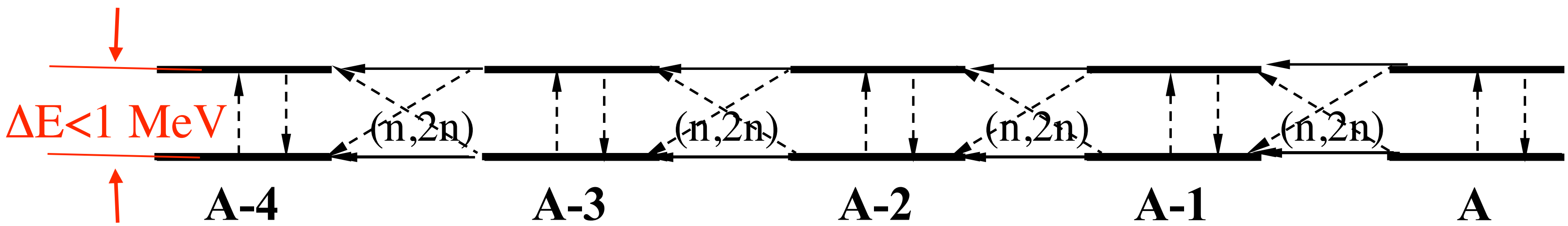


"Killing two birds with one stone"

*R. Hatarik. et al., Phys. Rev. **C81** 011602(R) (2010)

B.F. Lyles, *et al*., Phys.Rev. **C78, 064606 (2008)

<u>Topic #2:</u> In a DT-capsule the huge 14 MeV neutron flux means that highly-excited states could become targets



$N_{A-4}=P^4N_A$ $N_{A-3}=P^3N_A$ $N_{A-2}=P^2N_A$ $N_{A-1}=PN_A$ N_A

- The probability that a nucleus *A* will be converted via (n,2n) to a nucleus *A-1* is given by:

$$P_A = \sigma_{(n,2n)}\rho R_A \Phi_n \approx 10^{-1} - 10^{-4} \; for\, NIF\, DT\, capsules$$

- Only long-lived isomers need to be considered as “targets”
  - Isomers generally have low E_x → reaction Q-value only slightly affected

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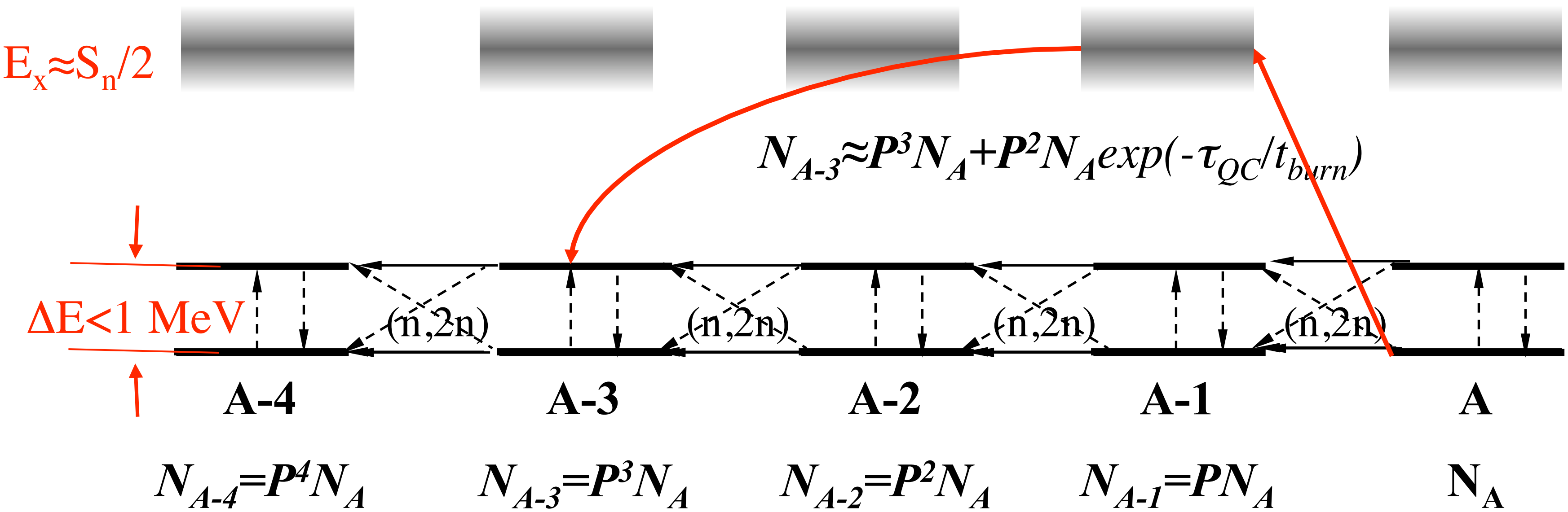

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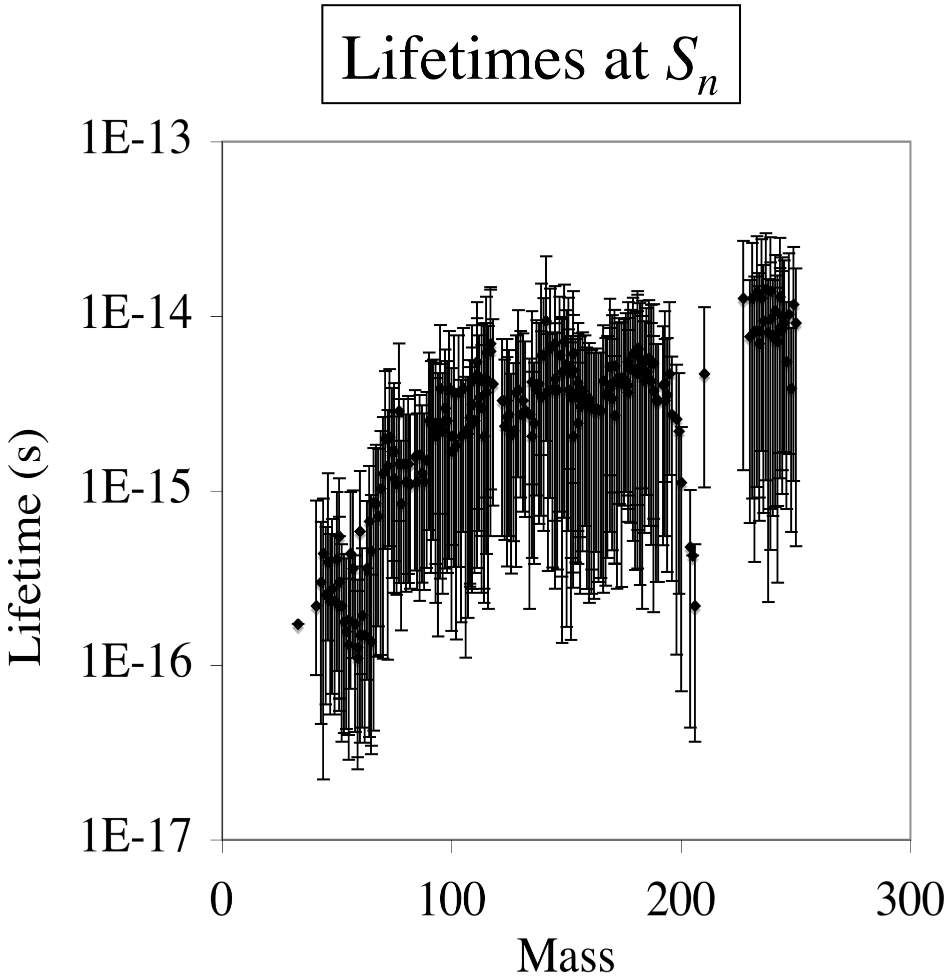
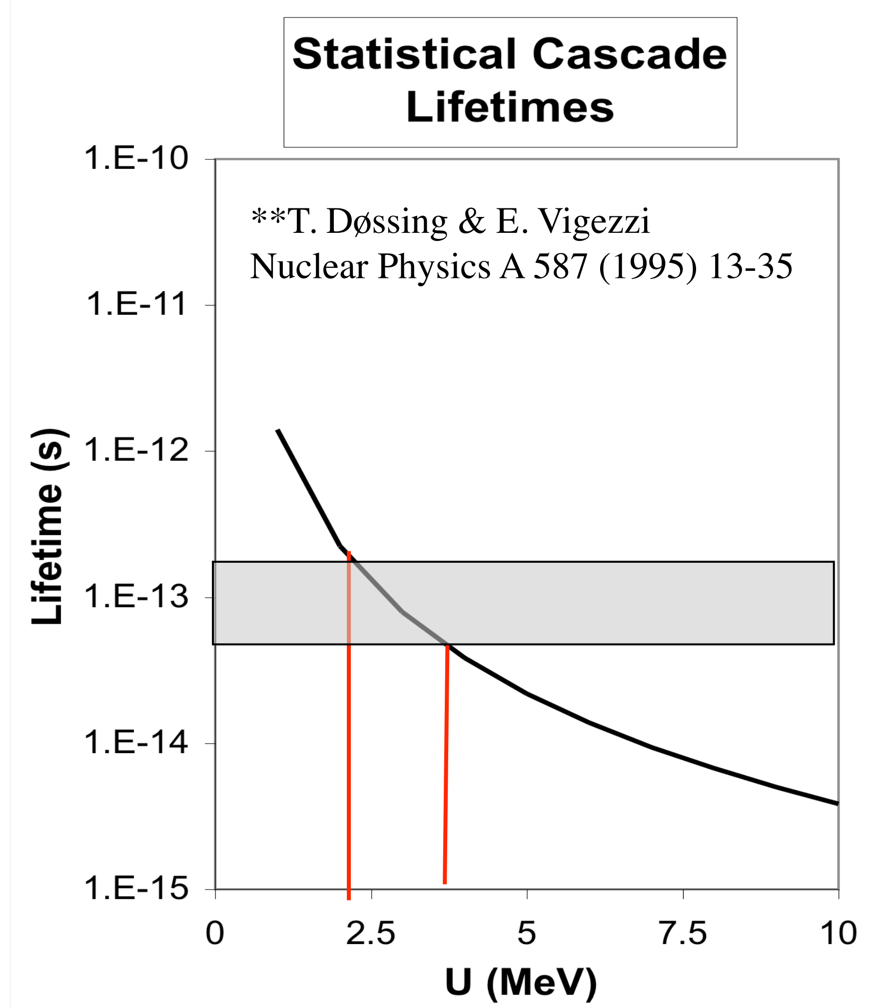
Reactions on highly excited states need to be considered if $P \geq exp(-\tau_{QC}/t_{burn})$

A survey of (n,γ) resonance widths* shows that $E_x \approx 4\text{-}5$ *MeV* quasi-continuum lifetime are on the order of $\tau_{DT\text{-}burn}/P$

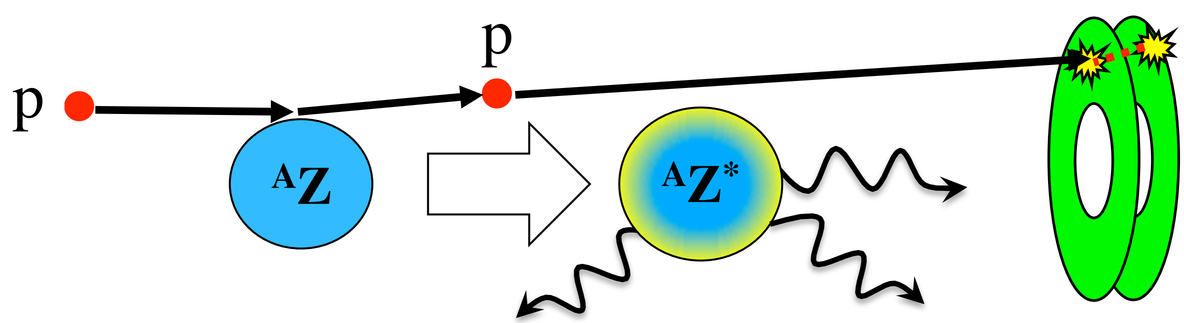


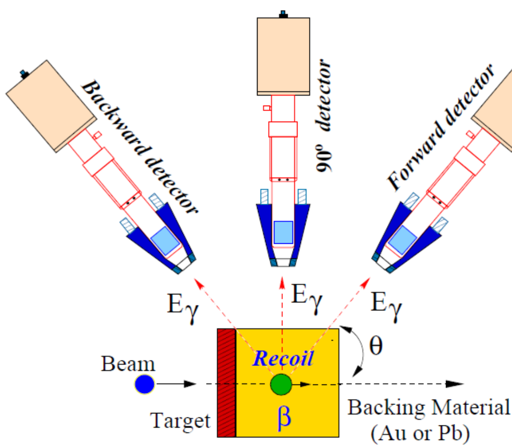


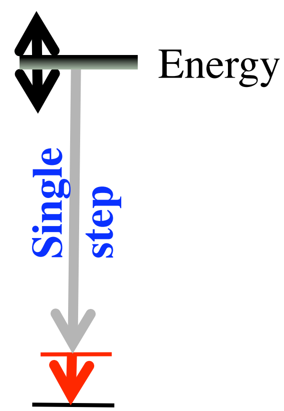
Product yields are ***very*** sensitive to quasi-continuum lifetimes

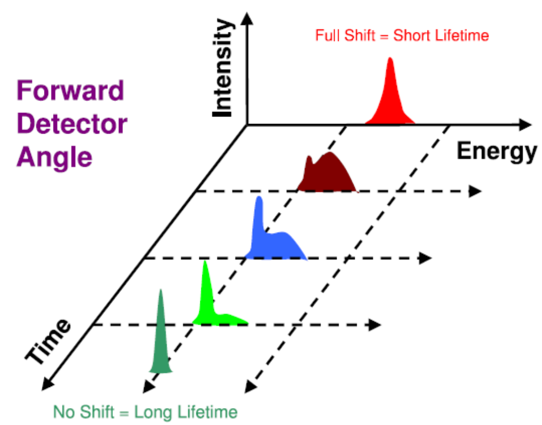
*RIPL-2 "obninsk" compilation

Measuring τ_{QC} via DSAM (M. Wiedeking)









Differences in the shift in discrete transitions using different particle gates will provide information on the average lifetimes of the gated quasi-continuum region.

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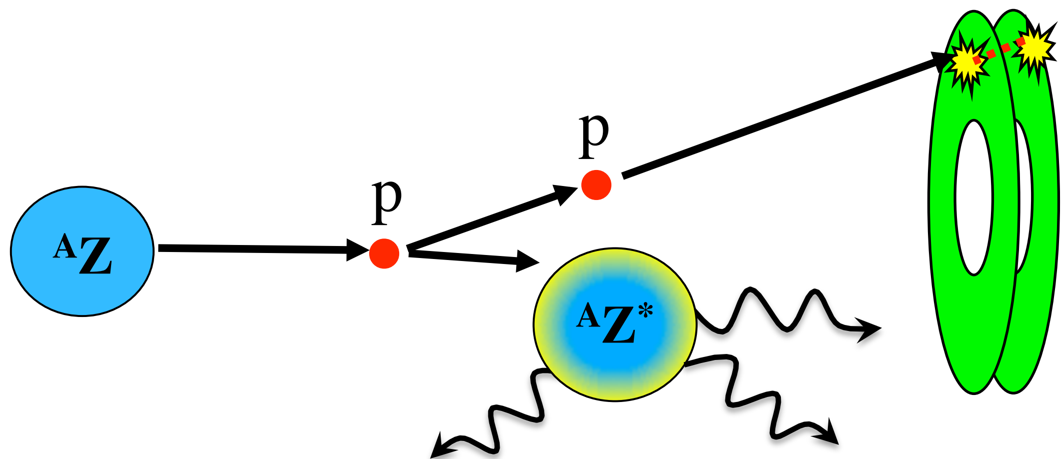

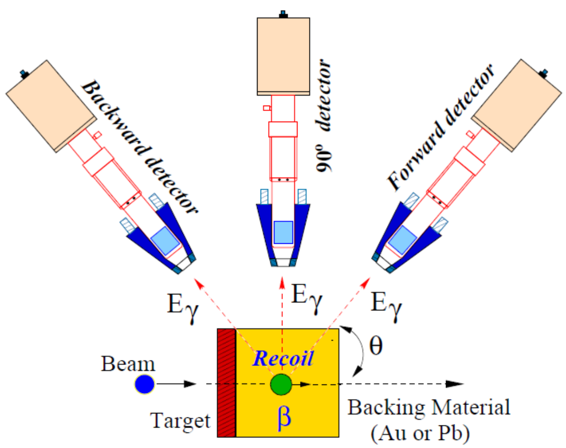

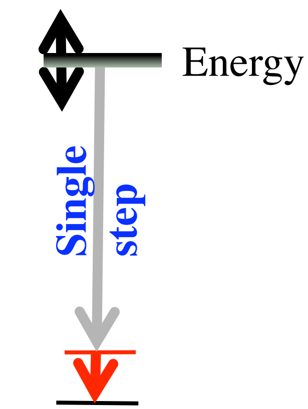

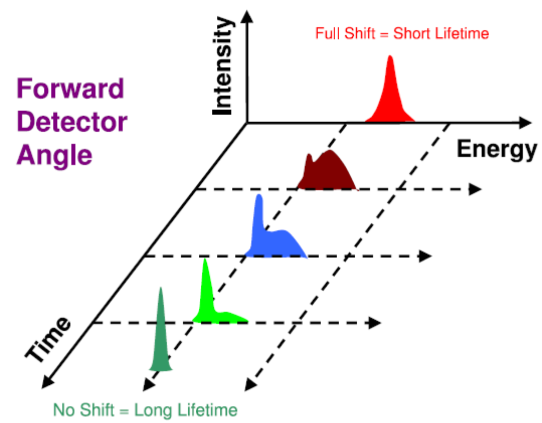

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Conclusions

- NIF is a totally novel laboratory for studying nuclear physics in a stellar-like environment
  - A large suite of diagnostics are operational at NIF now and more are planned for the next 2+years
- (n,γ) reactions can be studied at NIF using prompt γ-ray detection using the GRH detector system
  - Statistical γ-ray spectra are required to interpret this data.
- (n,x) on quasi-continuum states can occur in DT capsules
  - These reactions are highly dependent on quasi-continuum lifetimes (which are in turn dependent on photon strength and level densities for $E_x < S_n$)
- ***Statistical nuclear properties are critical for interpreting these results***

Early "calibration" experiments (using Ge in the capsule) are planned for 2011

A collaboration is being established to explore nuclear physics @ NIF & statistical γ-ray spectra

Plus any of you that are interested