Recent progress on physical cryptographic verification of nuclear warheads

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Nuclear warhead verification is both a political and technical challenge

- Global warhead stockpiles (primarily US and Russia) still total over 15 000.

- Future disarmament efforts will likely require *verification* of compliance.

The disarmament verification problem:

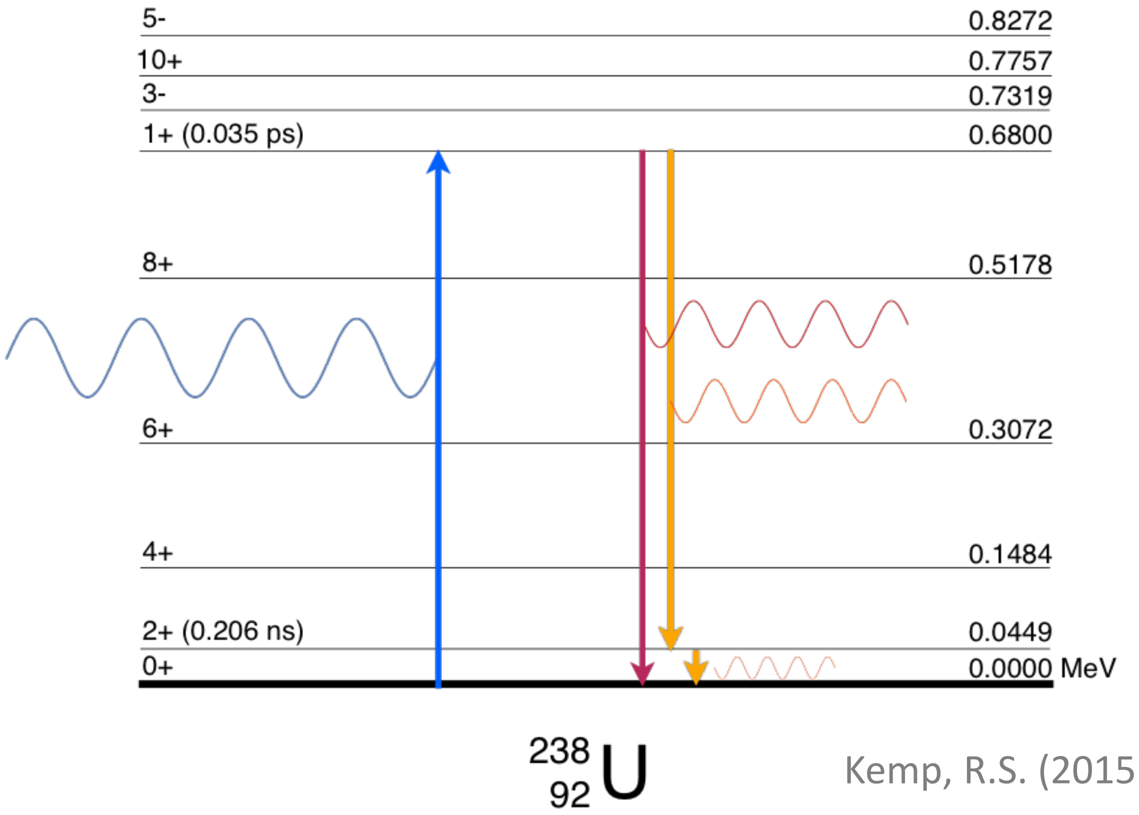
How can a warhead be reliably identified as authentic without revealing classified information?

MIT Physical Cryptographic Verification Protocol

Outline

1. The protocol
2. Summary of recent results
3. Experimental run at HVRL
4. Validation of G4NRF
5. Future work

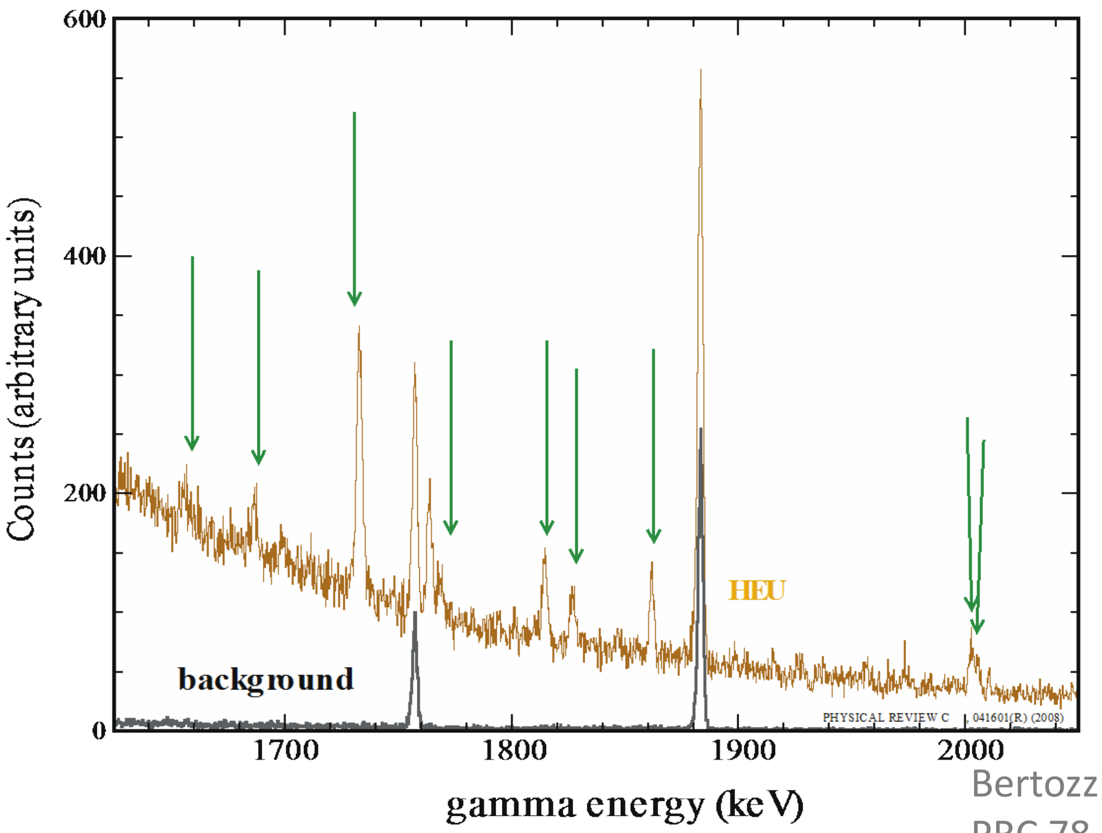
Nuclear resonance fluorescence (NRF) is used to make isotope-specific measurements



Kemp, R.S. (2015)

emission energy determined by nuclear energy levels

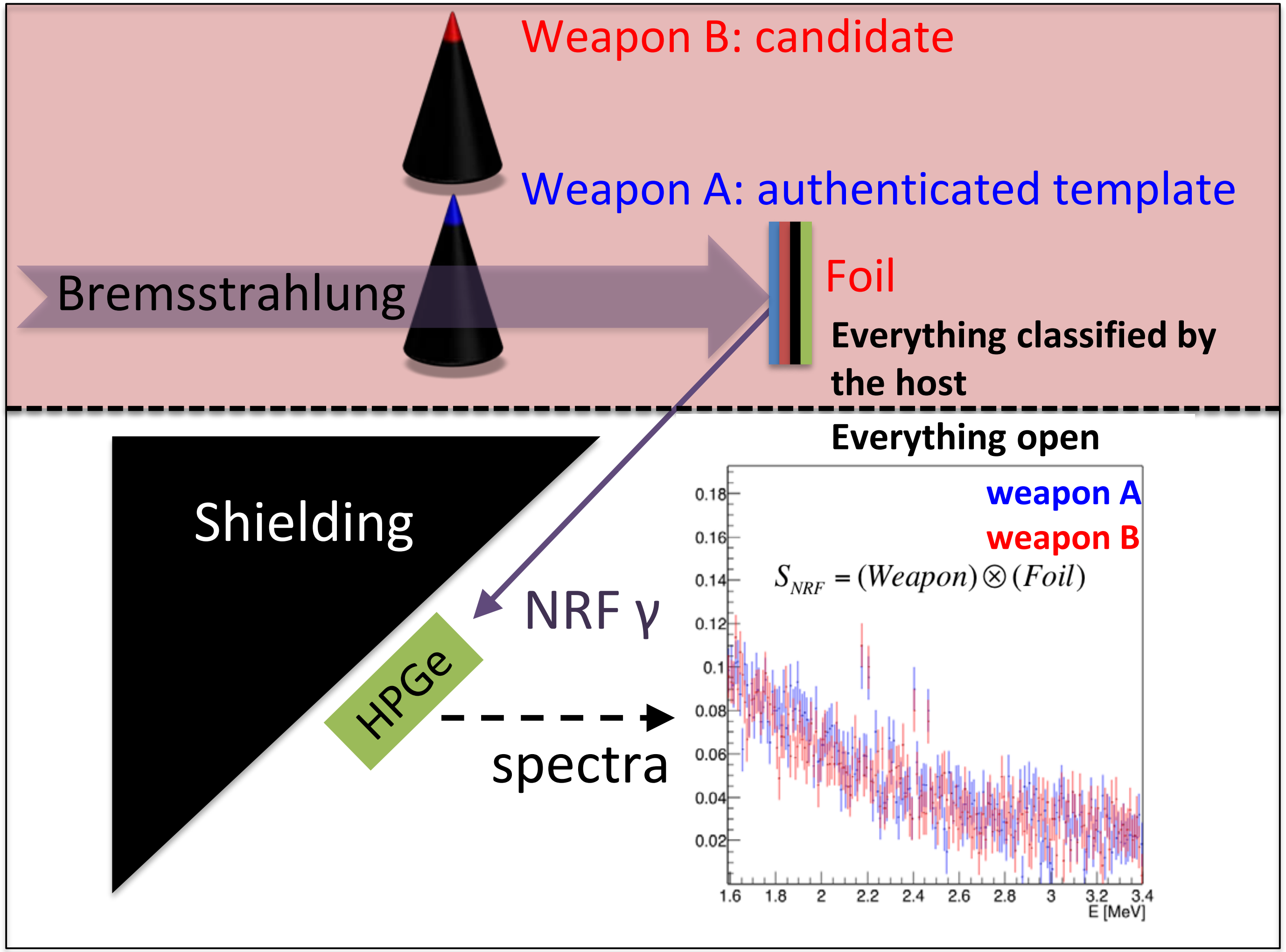
U-235 NRF emission spectrum



Bertozzi *et al.*, PRC 78 (2008)

sharp emission lines + continuum

The verification protocol avoids direct measurements of the warhead, protecting sensitive design information



Compare NRF signals:

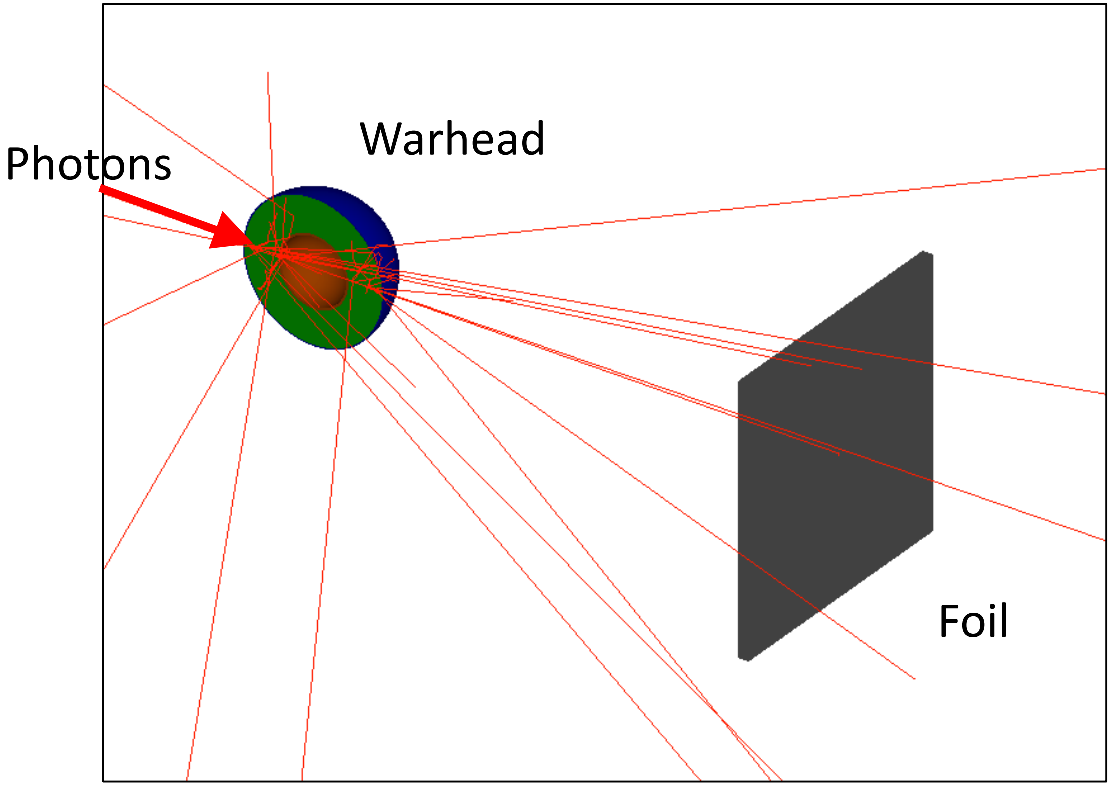
(Weapon A) x (Foil)

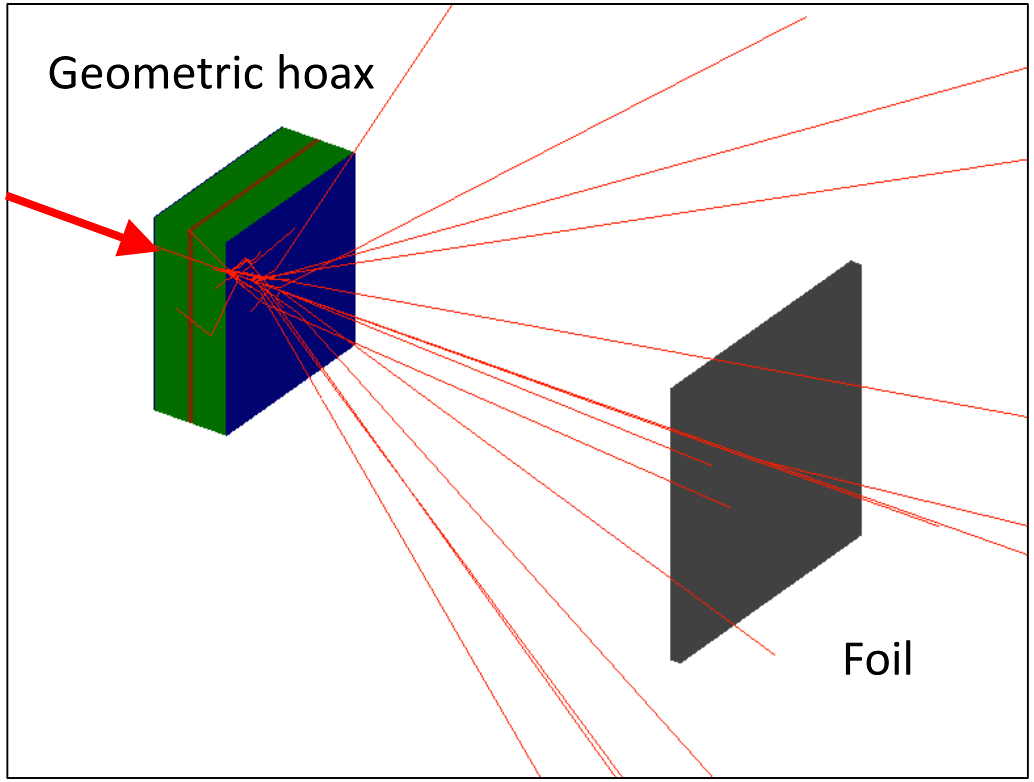
vs

(Weapon B) x (Foil)

Encryption by a physics process, not by software

We first proved the physical cryptographic concept using Geant4





Signal photons: $\vartheta \leq \pi/4$ energy spectrum

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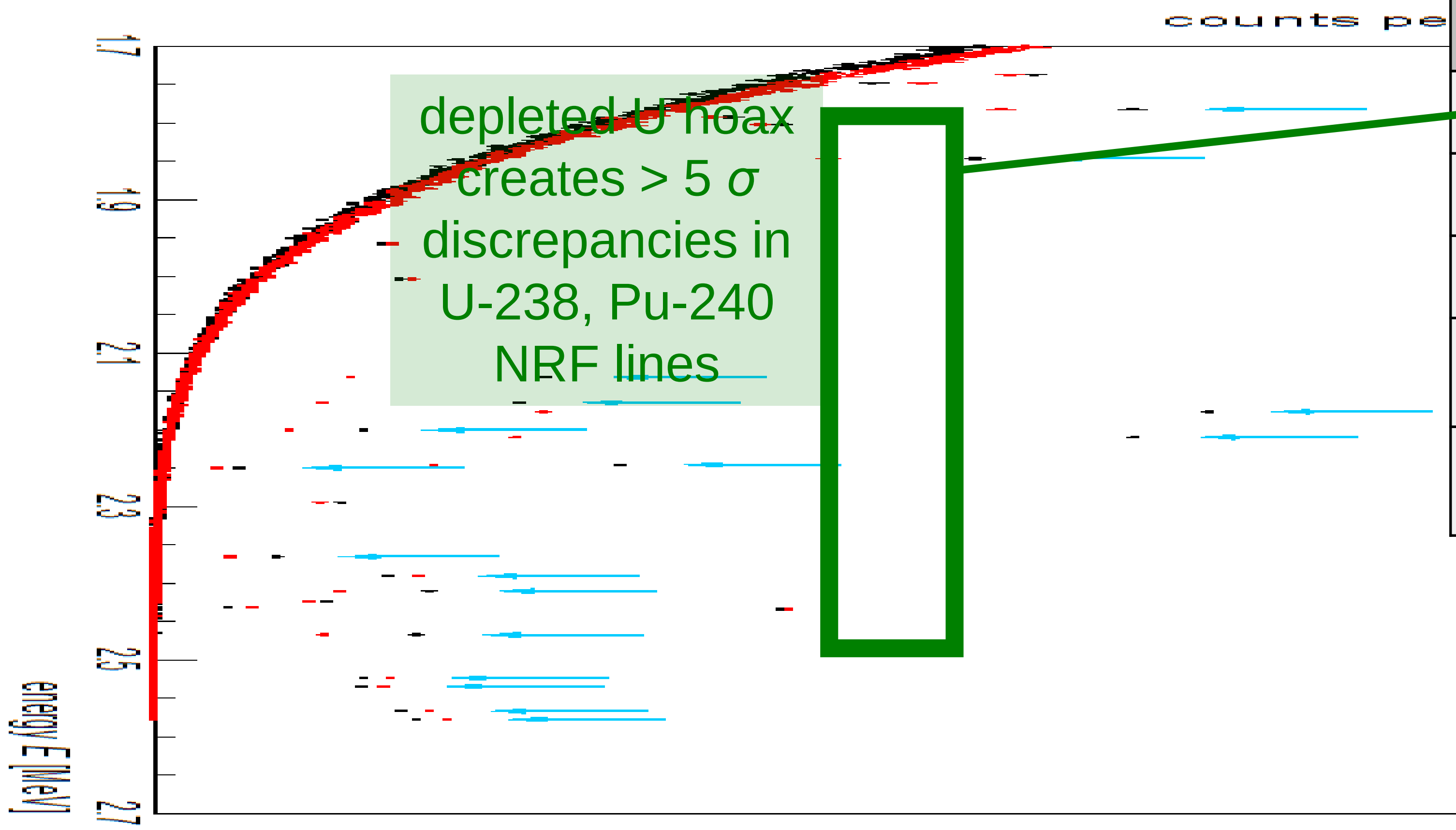
Canonical hoax scenarios are detectable in tens of minutes



Hoax scenario	Strongest discrepancy (σ)
WGPu → U-238	127
WGPu → RGPu	7.16
Geometric hoax, 0°	1.81
Geometric hoax, 10°	8.83
Geometric hoax, 30°	76.7

R.S. Kemp, A. Danagoulian, R. Macdonald, J.Vavrek, *Physical cryptographic verification of nuclear warheads*, PNAS 113 (2016) 31.

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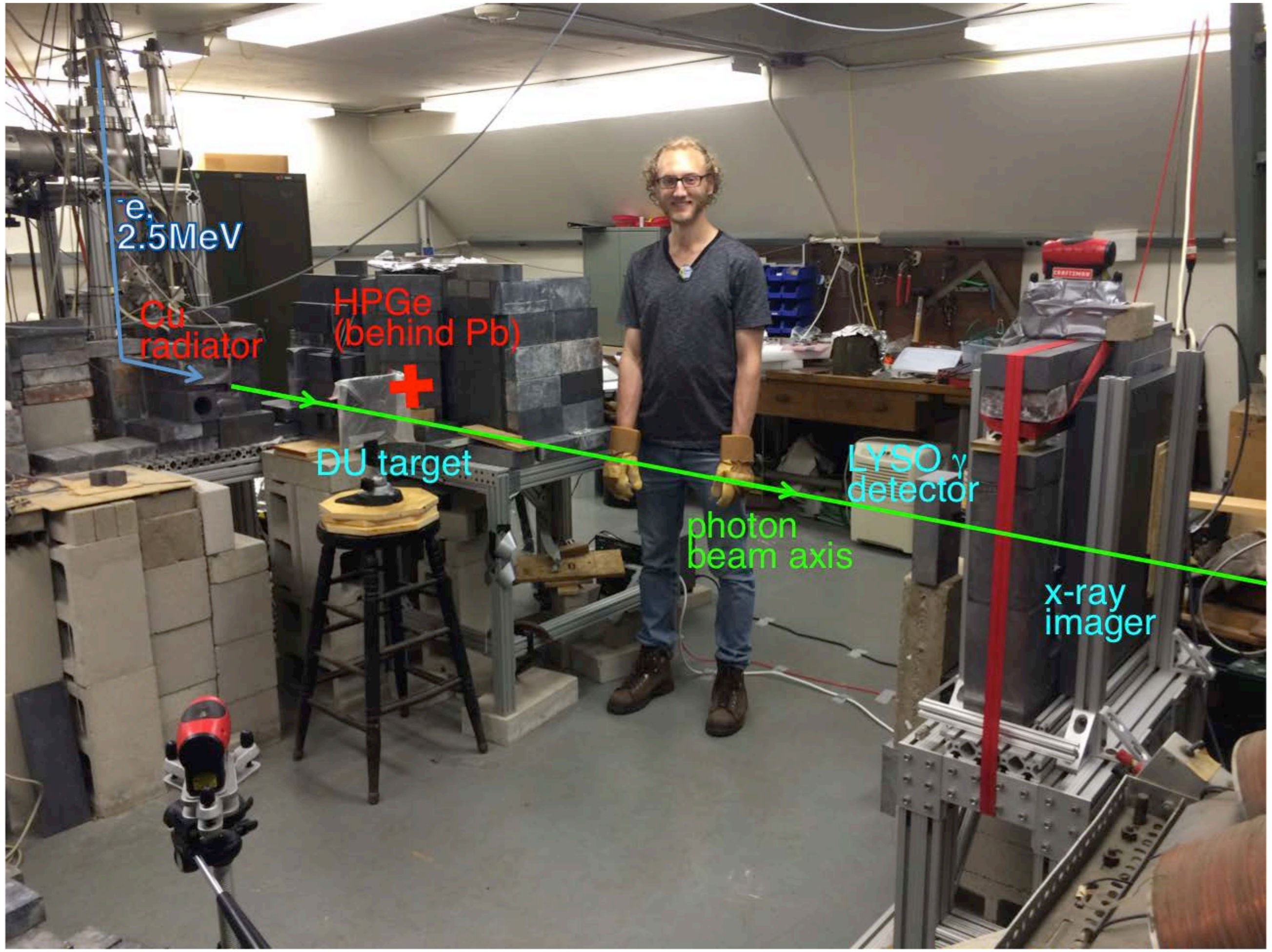
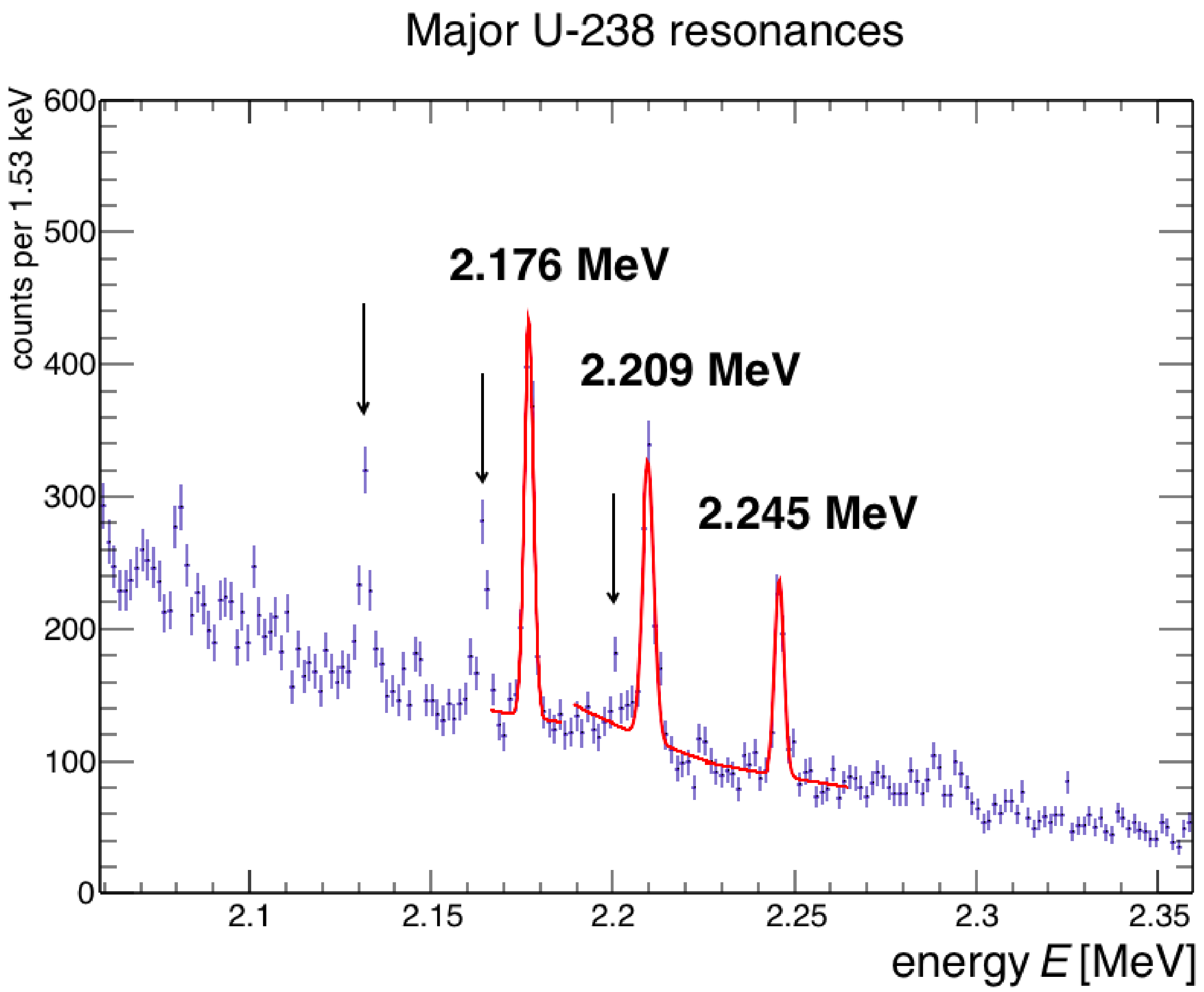
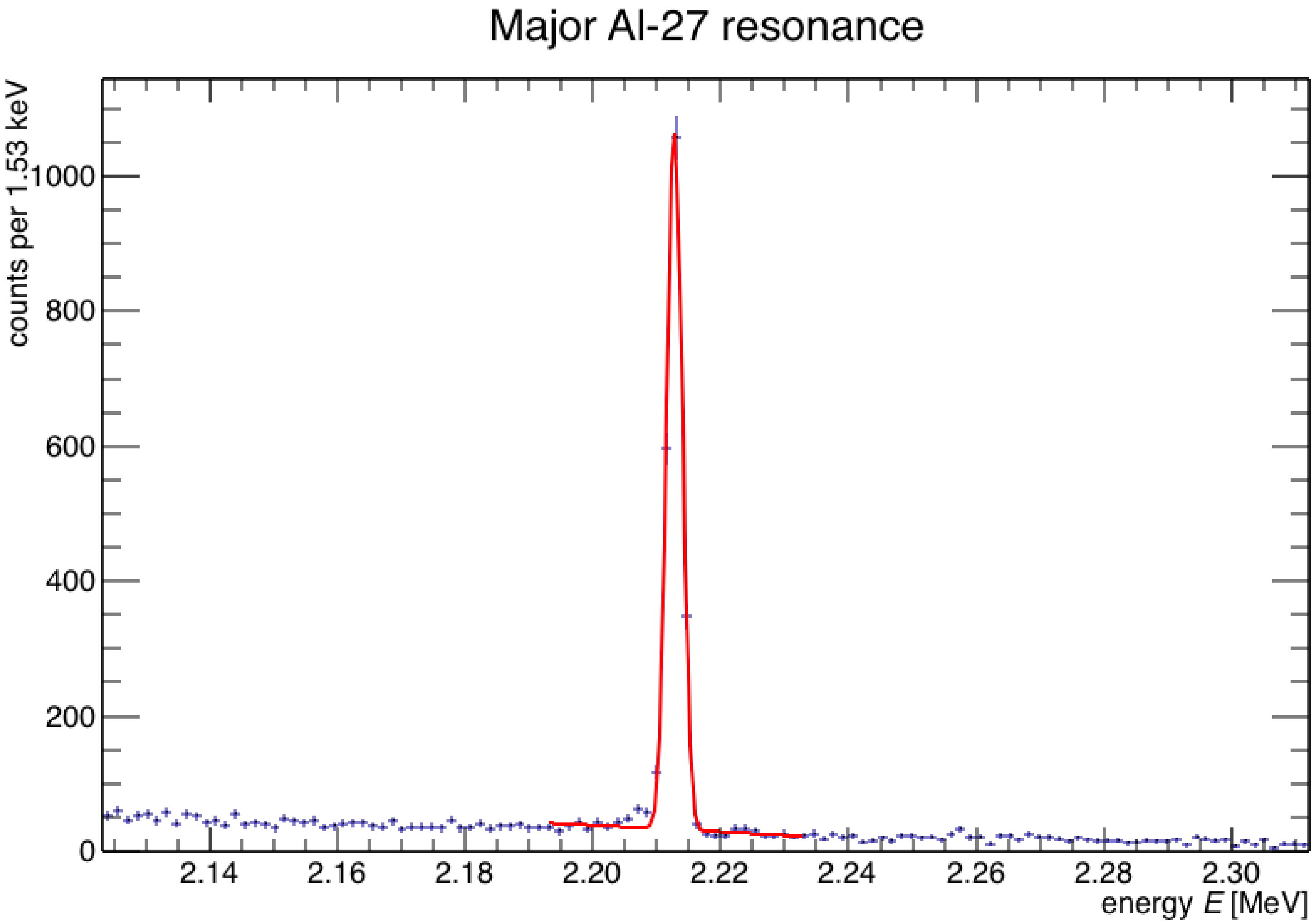
We measured NRF spectra for U-238 and Al-27, and established additional diagnostics



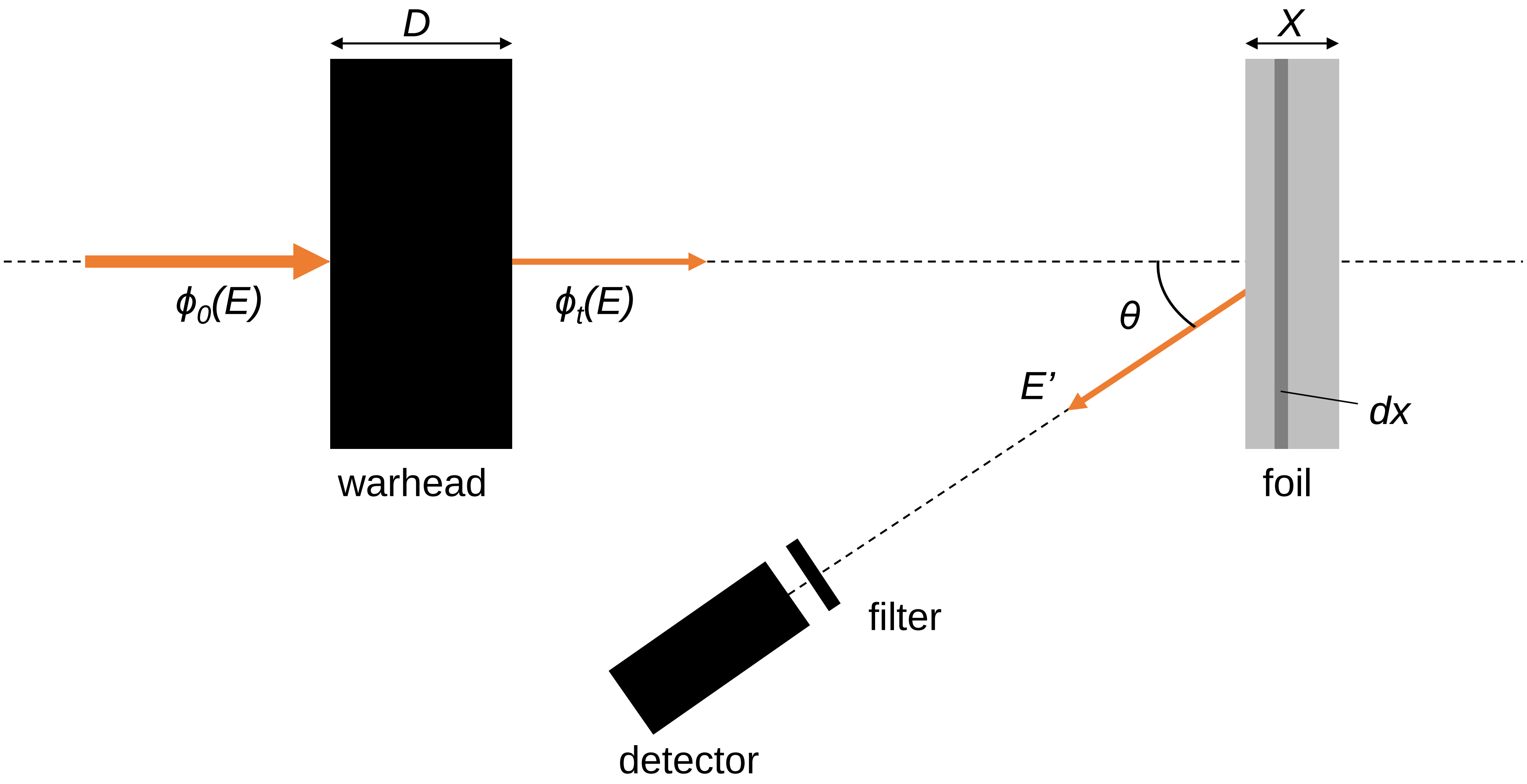
The three major U-238 resonances (and branches) are clearly observed



The Al-27 line at 2.212 MeV is useful for normalization



Using a simplified model, we can predict the detected NRF count rate



The model gives good results for relative (normalized) measurements

theory: $$\left(\frac{n_{2212}}{n_{2209}}\right)_{\mathrm{num}} = 4.70.$$

experiment: $$\left(\frac{n_{2212}}{n_{2209}}\right)_{\mathrm{exp}} = 5.5 \pm 0.8$$

preliminary

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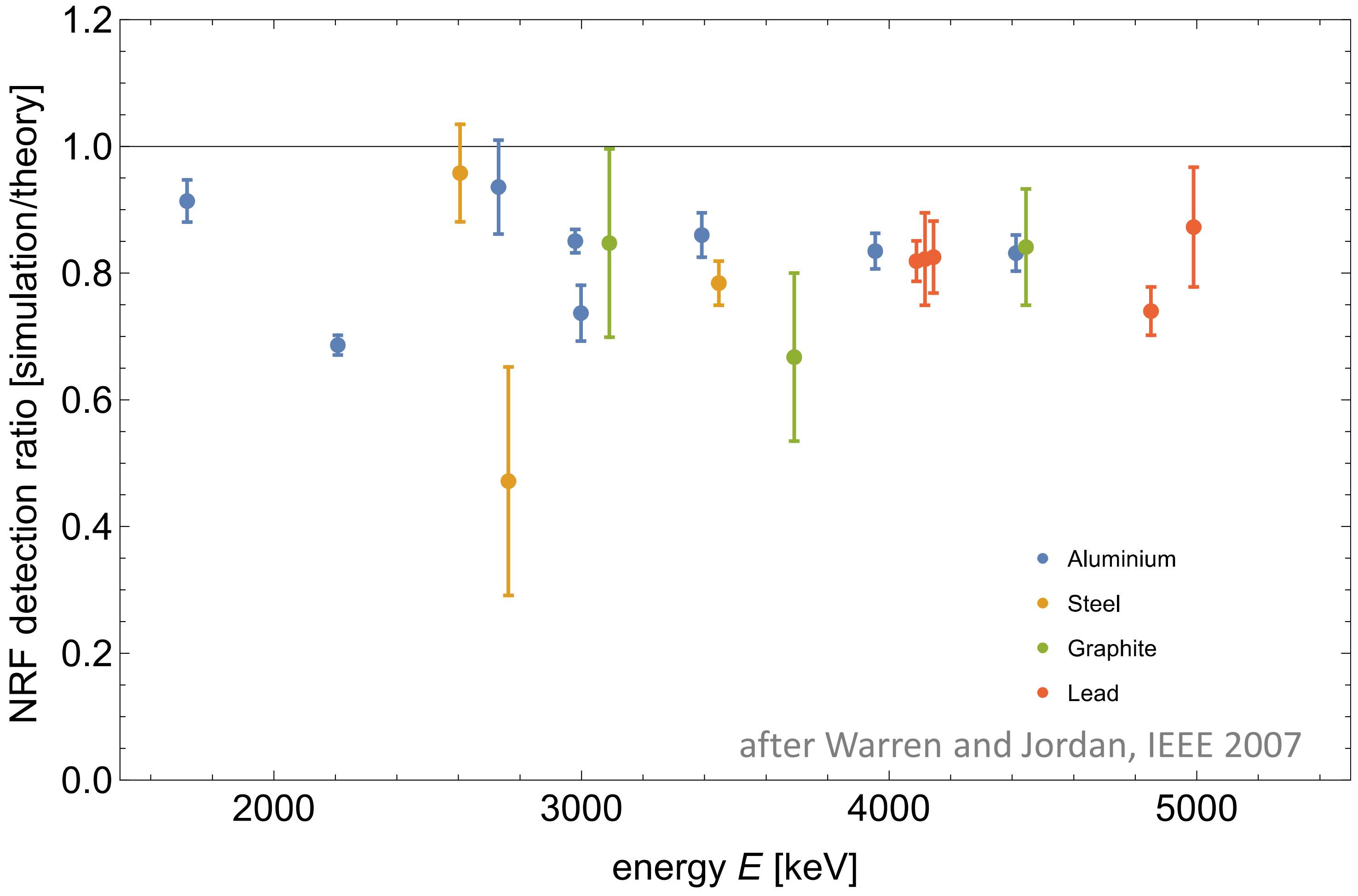
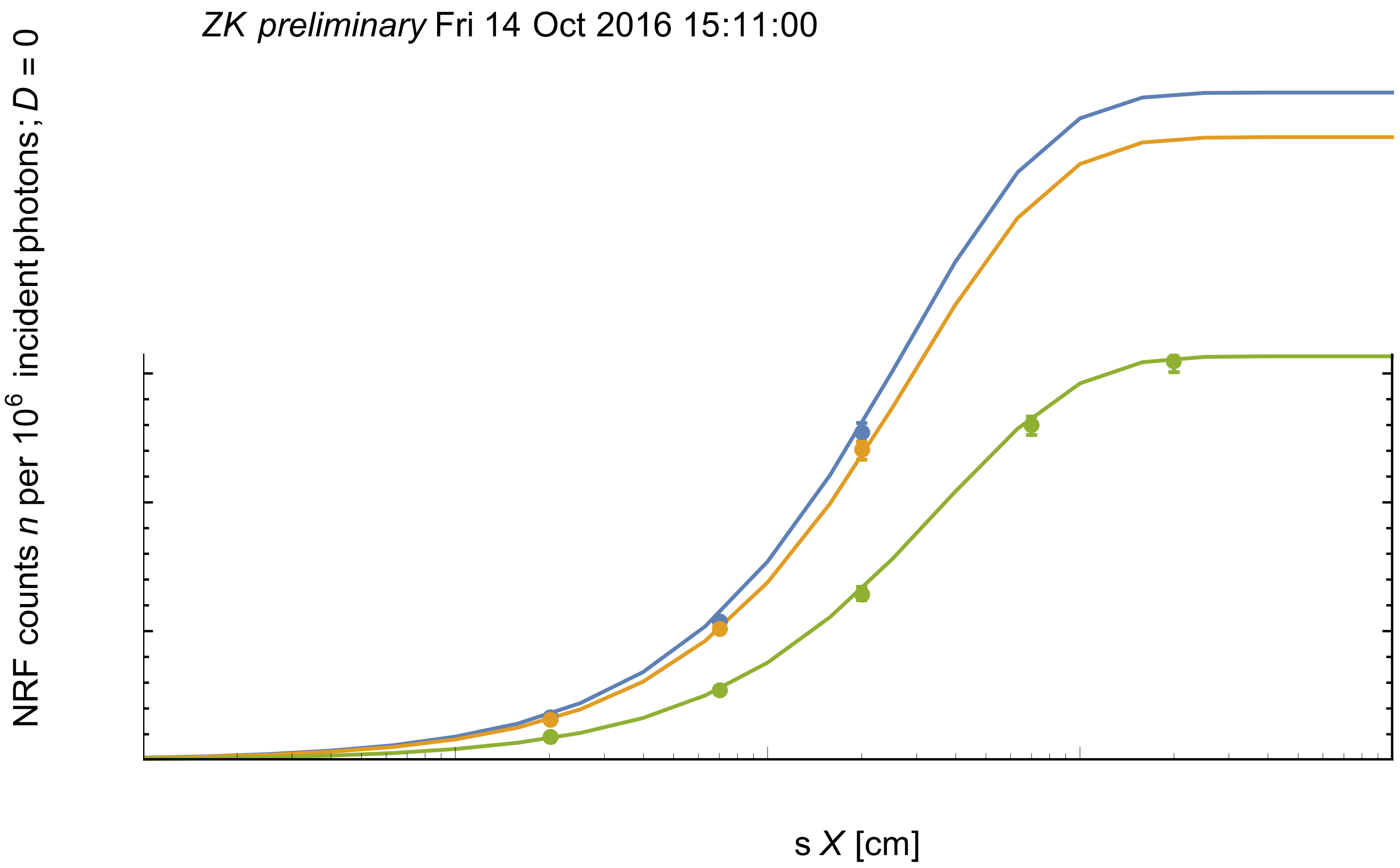
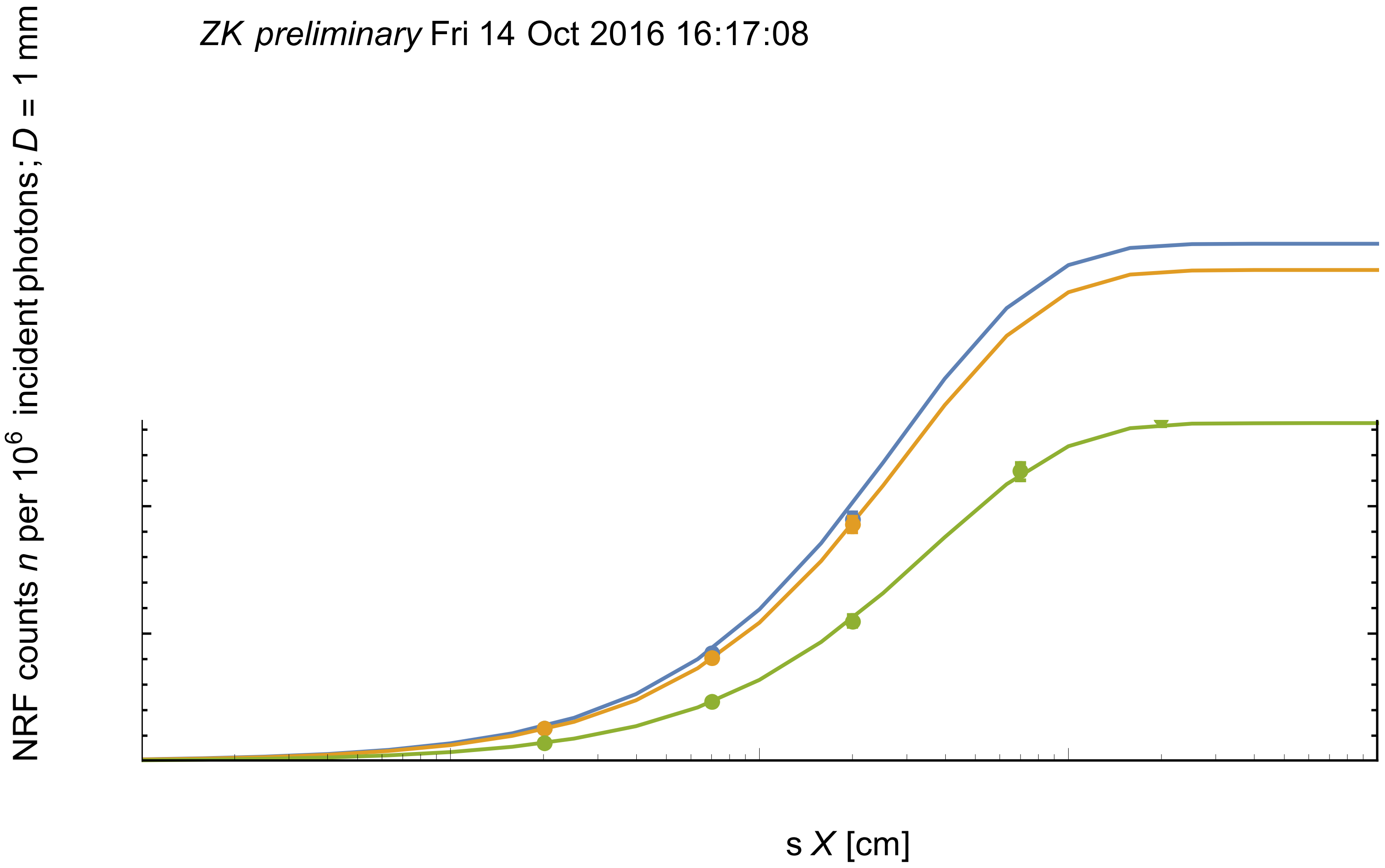
Previous results from PNNL showed agreement to 20%



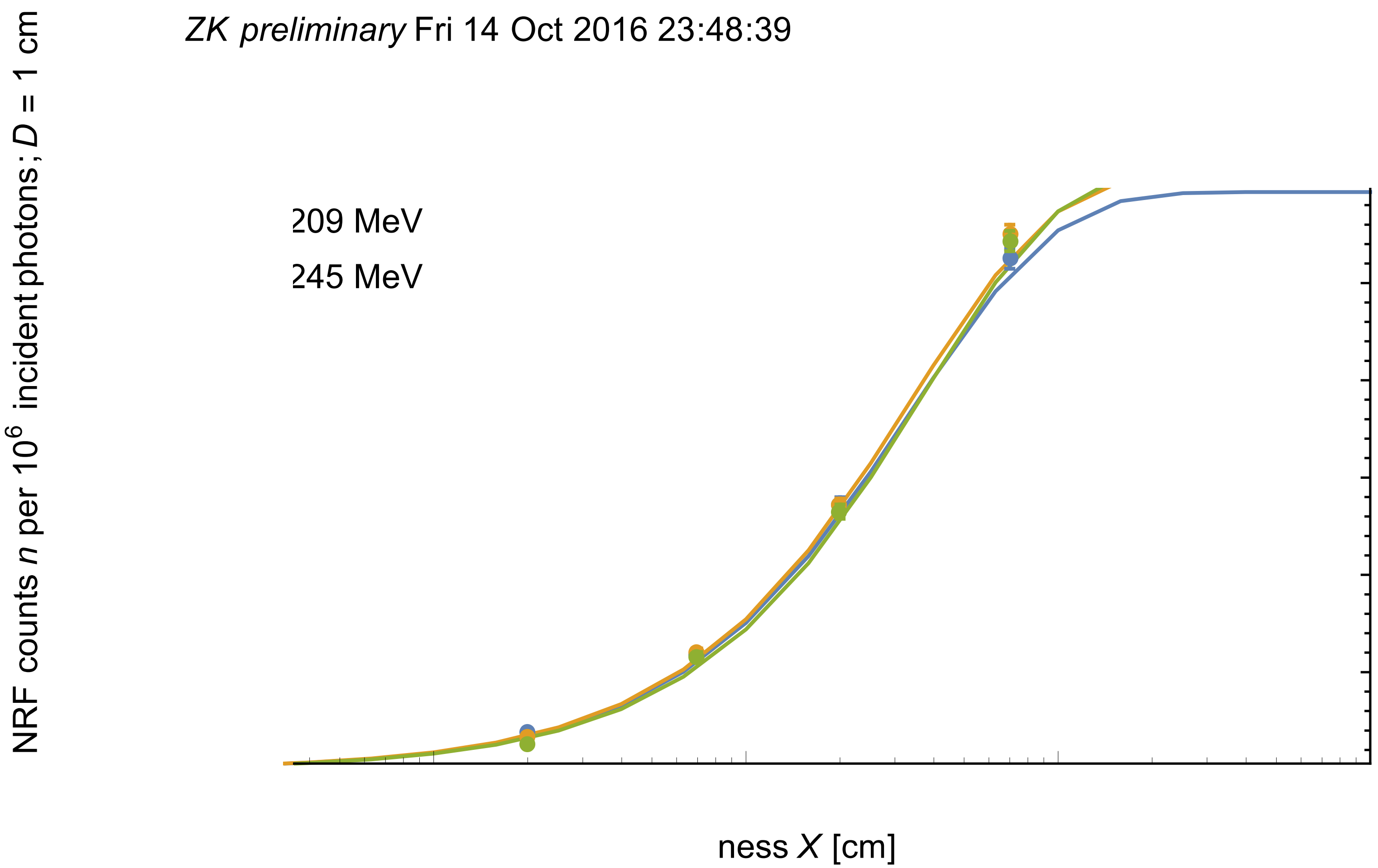
Preliminary results with a simple flux show closer to 5% agreement with no target…



…and similar results for thin targets…



…but thick target analytical models may need a notch refill correction



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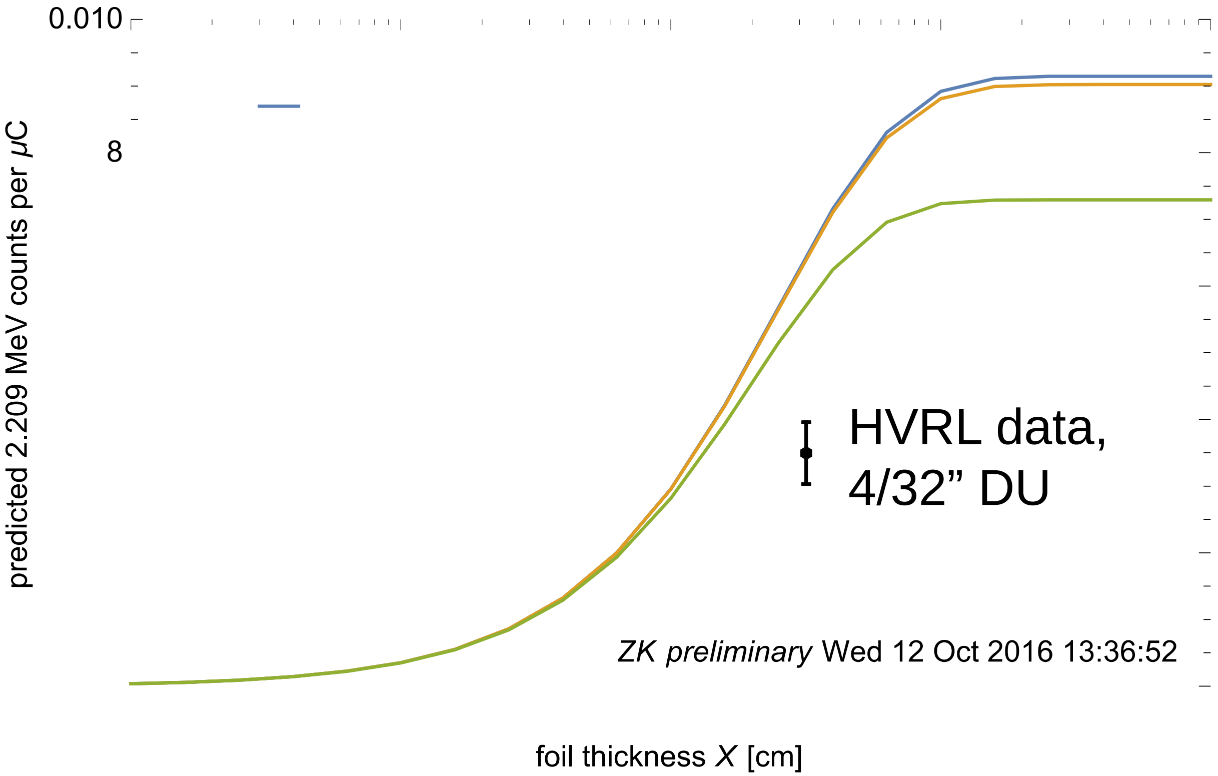
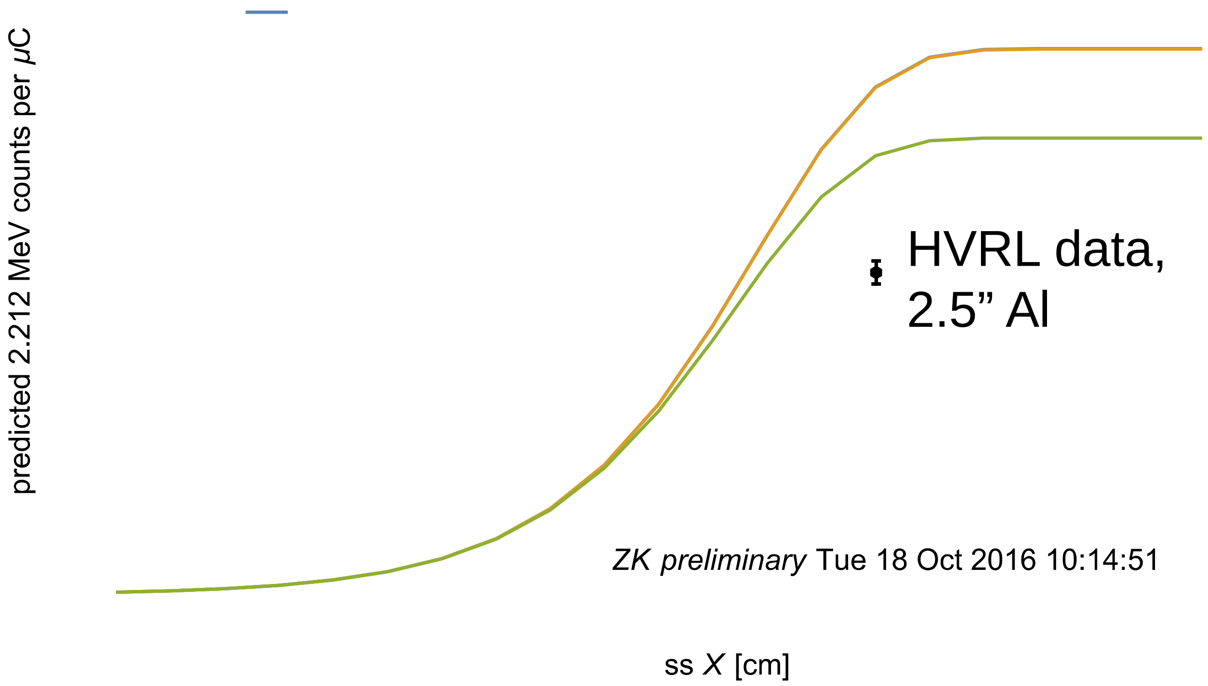
Can we make absolute count rate predictions for an *experiment*, not just a simulation?





similar factor of ~1.5 low in both experiments:
systematic discrepancy in photon beam?

Can we quantify the sensitivity of the experiment?

- Cross section evaluations
- Temperature-dependence of cross sections

- Bremsstrahlung beam configurations
- Misalignments

- Small diversions of SNM
- More elaborate hoaxes

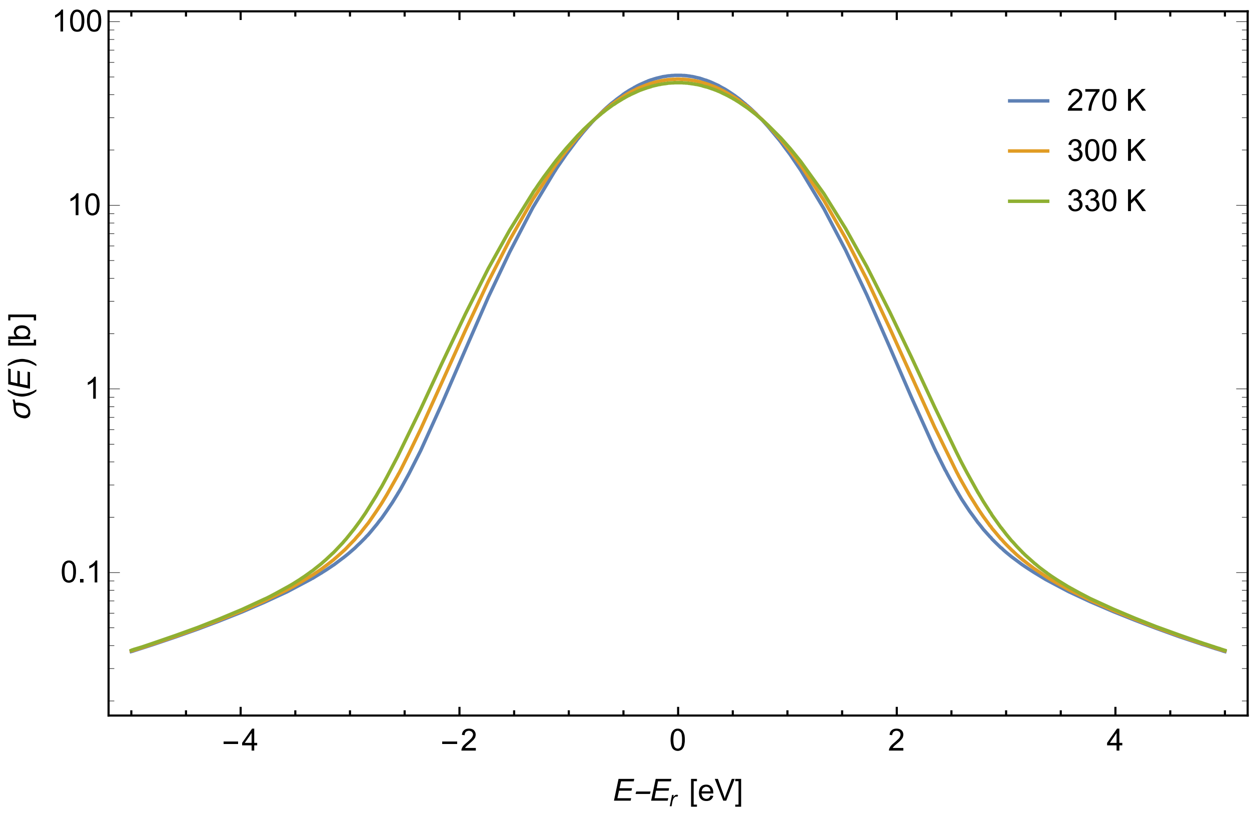
Physical cryptographic verification is a promising technique, but there are still technical challenges to resolve

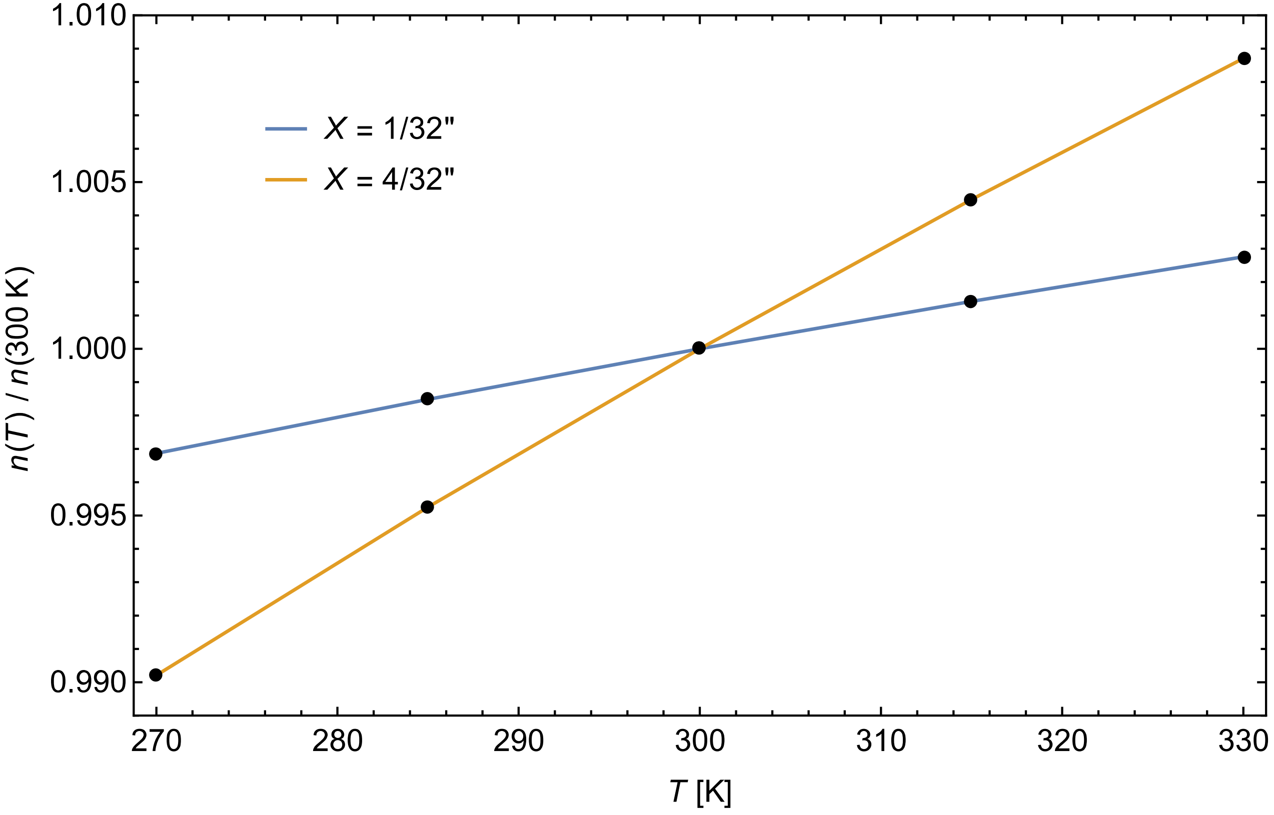
Questions?

Backup: analytical model

$$\frac{d^3n}{dE\,d\Omega\,dx} = \phi_t(E) b\,\mu_{\mathrm{NRF}}(E)\frac{W(\theta)}{4\pi}\exp\left\{-x\left[\mu_{\mathrm{NRF}}(E)+\mu_{\mathrm{nr}}(E)+\frac{\mu_{\mathrm{nr}}(E')}{\cos\theta}\right]\right\}\epsilon_{\mathrm{int}}(E')P_f(E')$$

Backup: temperature-dependence





U-238, 2.176 MeV

preliminary