Measuring NR Yield in Si & Ge

The SuperCDMS SNOLAB Experiment

EXCESS 2022

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SUPER CDMS
Cryogenic Dark Matter Search

Outline

- ~~Intro:~~
- Yield in a Ge CDMSlite detector
  - Photo-neutron technique
- Yield in a Si HV detector
  - Neutron capture technique
- Yield in a Si HVeV detector
  - Neutron beam technique
- ~~Conclusion?~~
  - ~~If there is time~~

3 brand new results

12 minutes

30 slides

Let's go!

The SuperCDMS Collaboration

SUPER CDMS
Cryogenic Dark Matter Search

I. The Photo-neutron Measurement in Ge

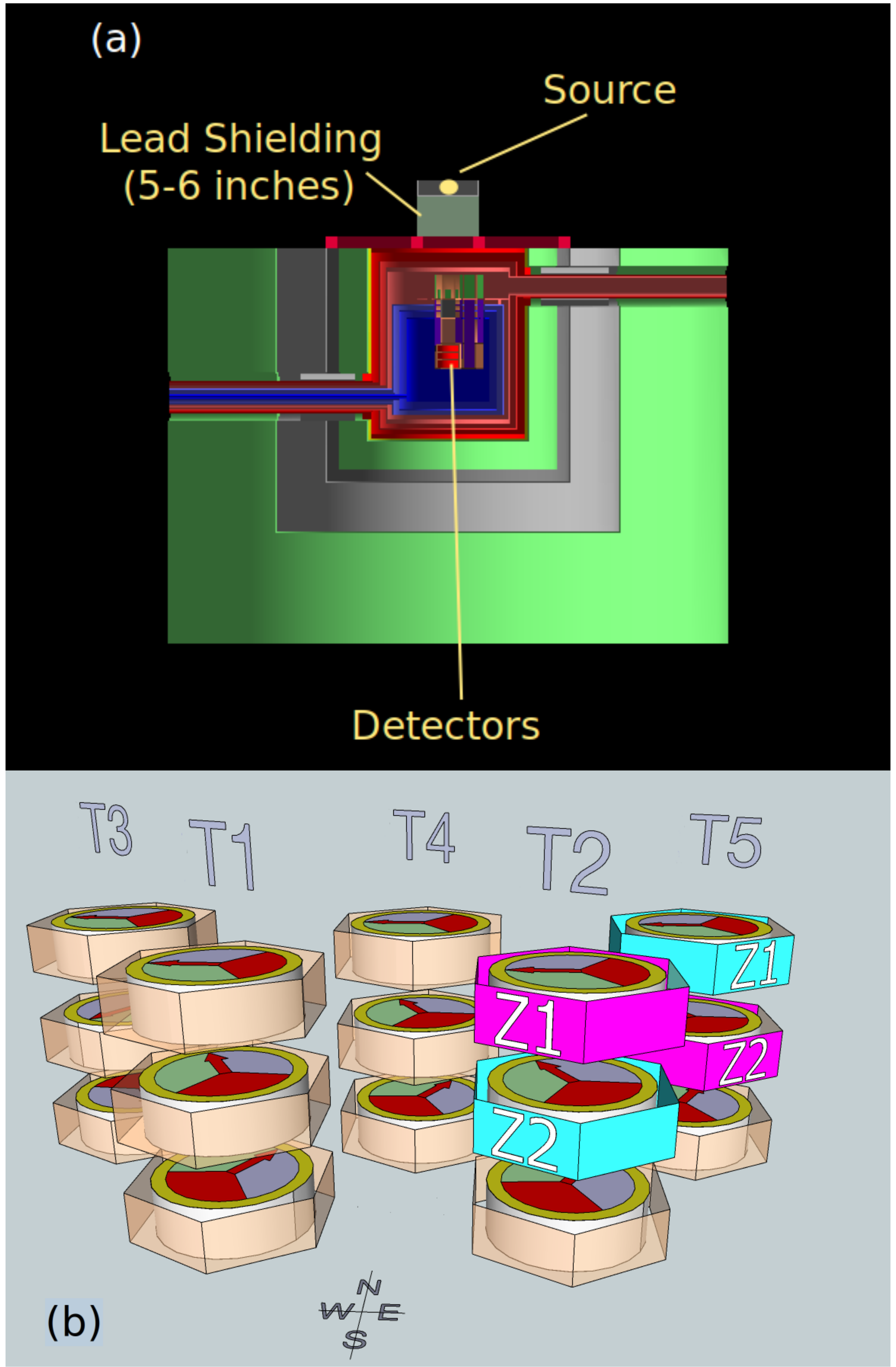
A γ walks into a Ber(illum wafer)

The SuperCDMS Photo-Neutron Measurement

- Used 2 Soudan Ge detectors operated in CDMSlite mode
- Acquired data with ^{88}Y ^{9}Be & ^{124}Sb ^{9}Be neutron sources over 144 days
- Detectors operated at multiple bias voltages

Source	n Energy	Duration	Detector	V_b
^{124}Sb / ^{124}Sb ^{9}Be	24 keV	62 days	T5Z2	70 V
^{88}Y / ^{88}Y ^{9}Be	152 keV	42 days	T5Z2	70 V
^{88}Y / ^{88}Y ^{9}Be	152 keV	38 days	T2Z1	25 V

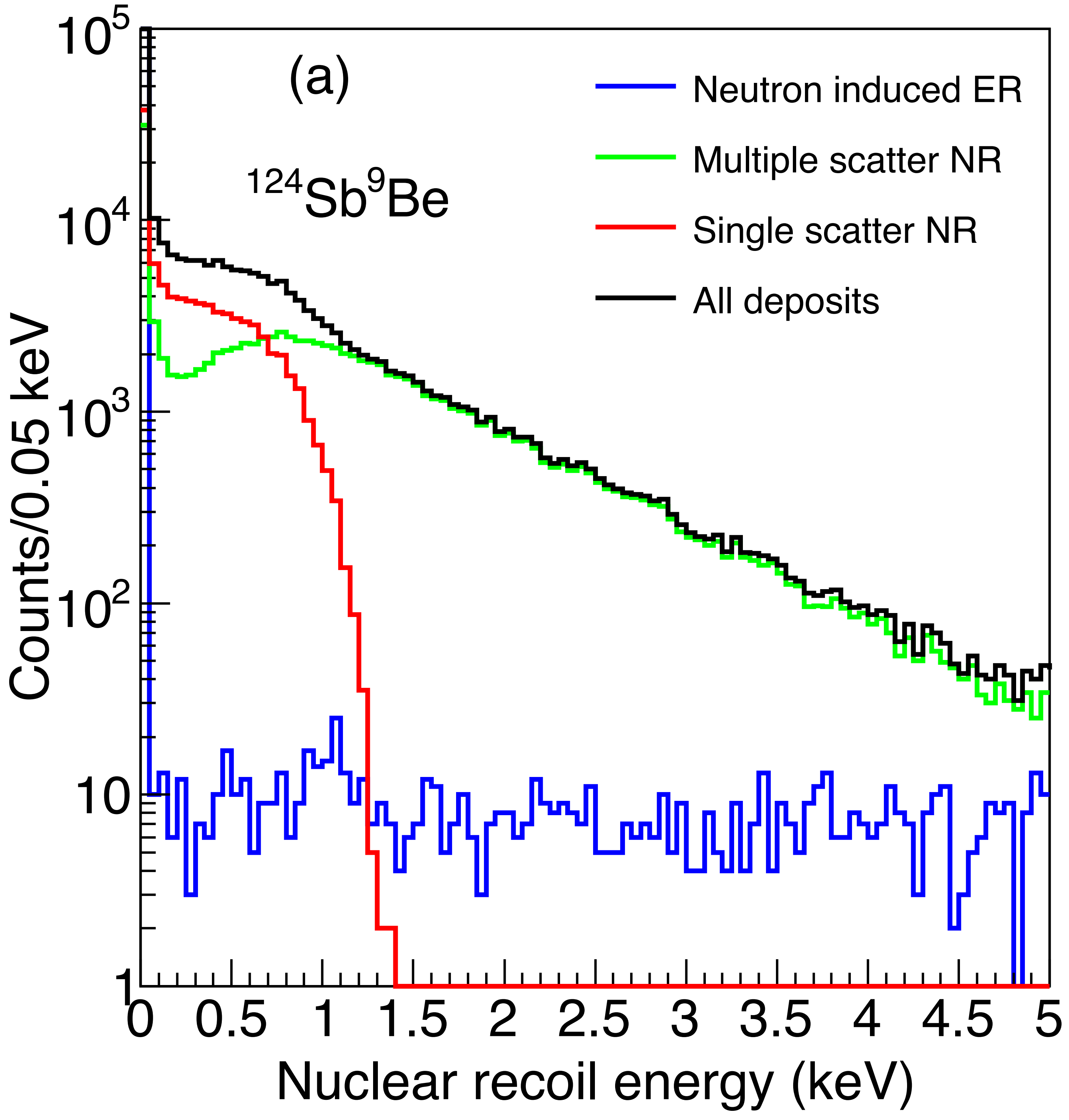
arXiv:2202.07043



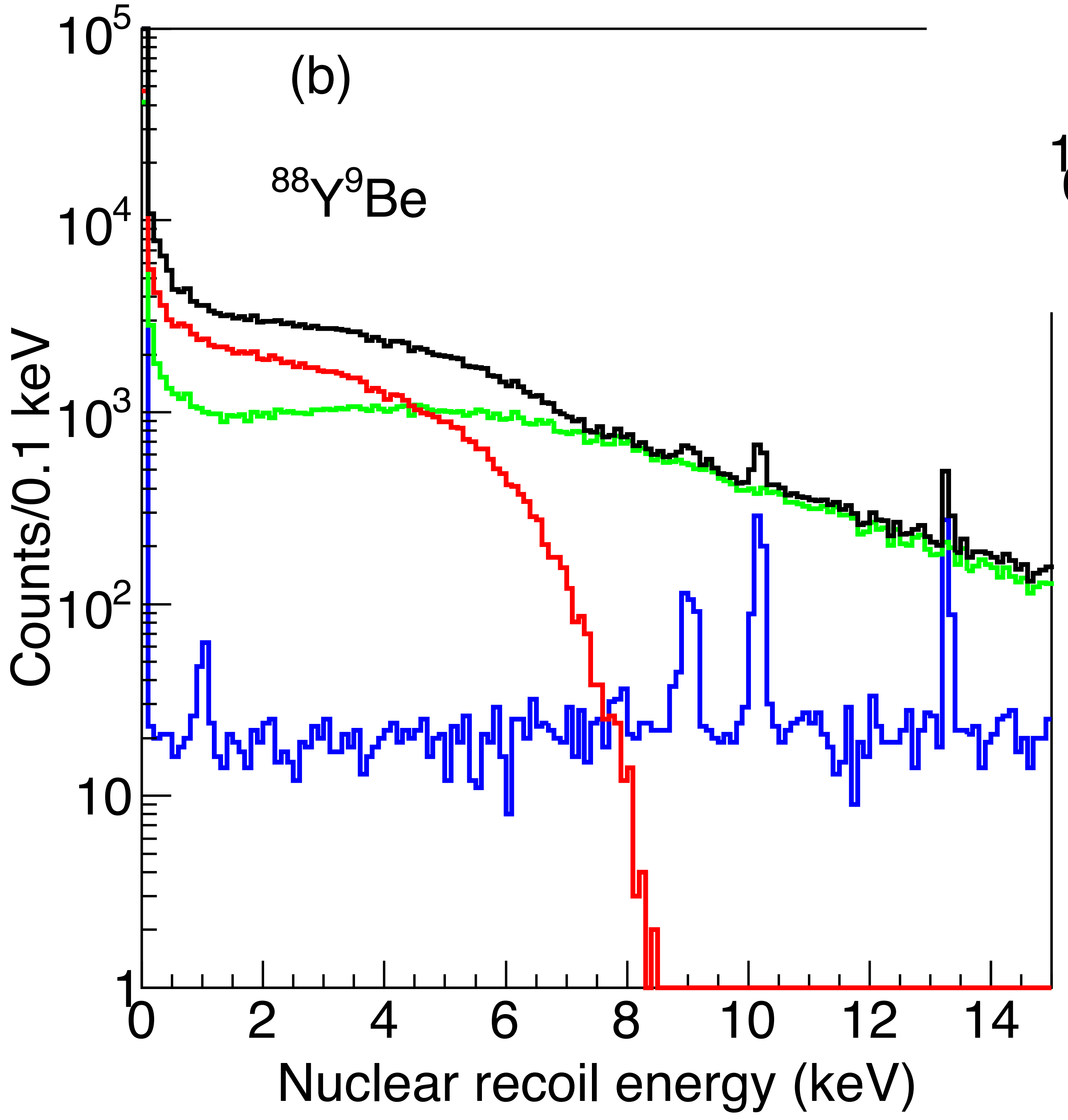
Data Selection

- Data analysis focused on selecting high quality sample of signal & background events
- Energy estimated with Non Stationary Optimal Filter
  - Template based on two time constant decay pulse
  - Pulses, additionally compared to multiple noise templates
- Data Selection Cuts
  - Livetime: Remove data “chunks” associated with anomalous run conditions
  - Data Quality: Remove individual events inconsistent with a nominal neutron interaction
  - Threshold: Ensures tigger efficiency was uniform (~100%) over analysis energy range

Signal & Background Expectations

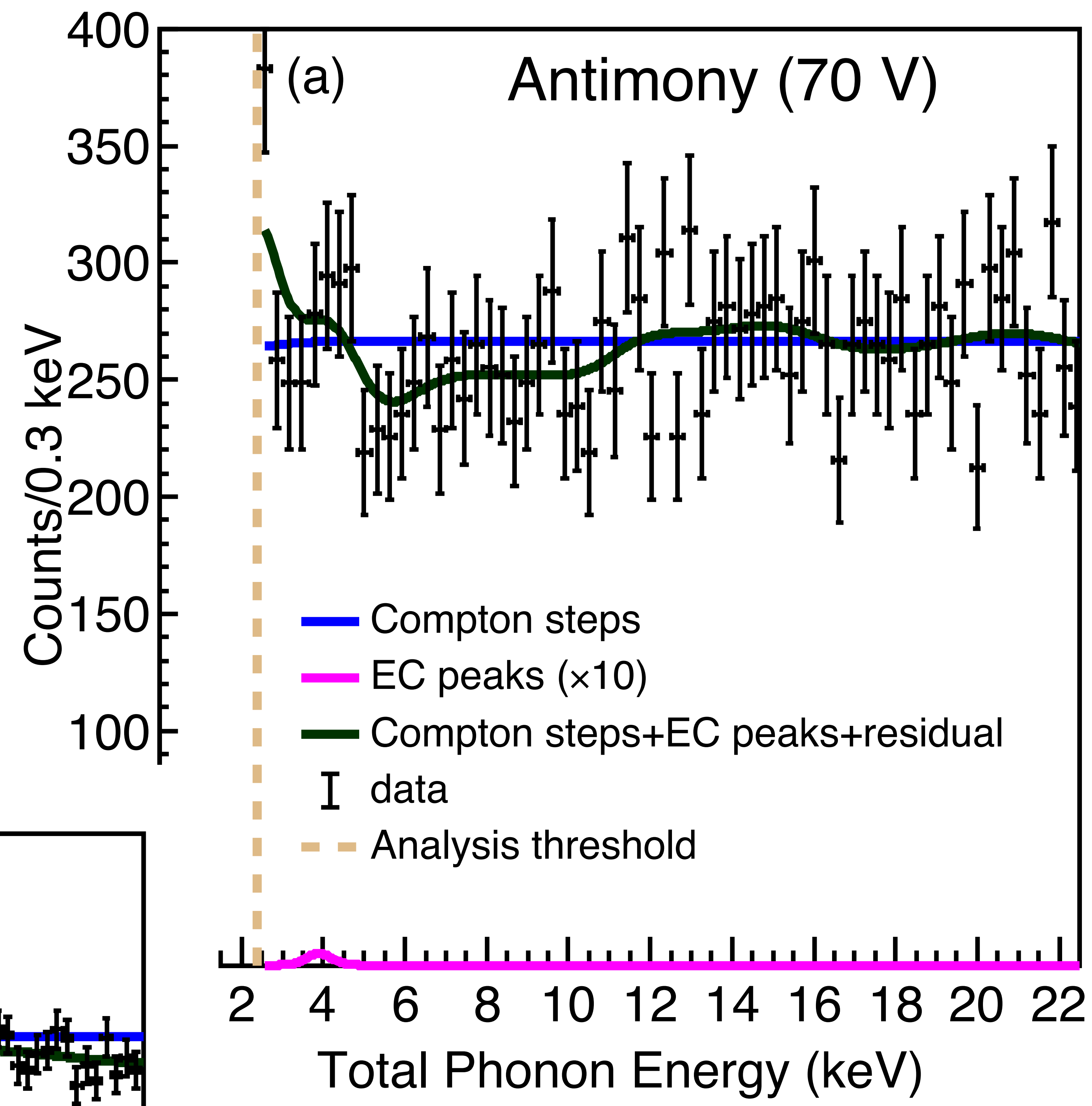


- Signal spectrum (for the various source configurations) simulated with Geant4
- $1.2\text{x}10^{9}$ neutrons propagated through geometry
- Made use of NeutronHP physics model & G4NDL4.6 cross-section package
- Single scatter NR endpoint energy
  - ~1.3 keV for ^{124}Sb ^{9}Be, ~8.5 keV for ^{88}Y ^{9}Be
- Multiple scatter NR obscure the single scatter NR endpoint
- NR induced gamma spectrum is flat and subdominant



Signal & Background Expectations

- Electron recoil background spectrum determined from neutron-OFF data
  - ^{124}Sb & ^{88}Y without a ^{9}Be wafer
- Compton scattering and Electron Capture components modeled with a fit of analytical spectral shapes to the data
  - Smoothed fit residual was added to the model to account for any extraneous un-modeled components



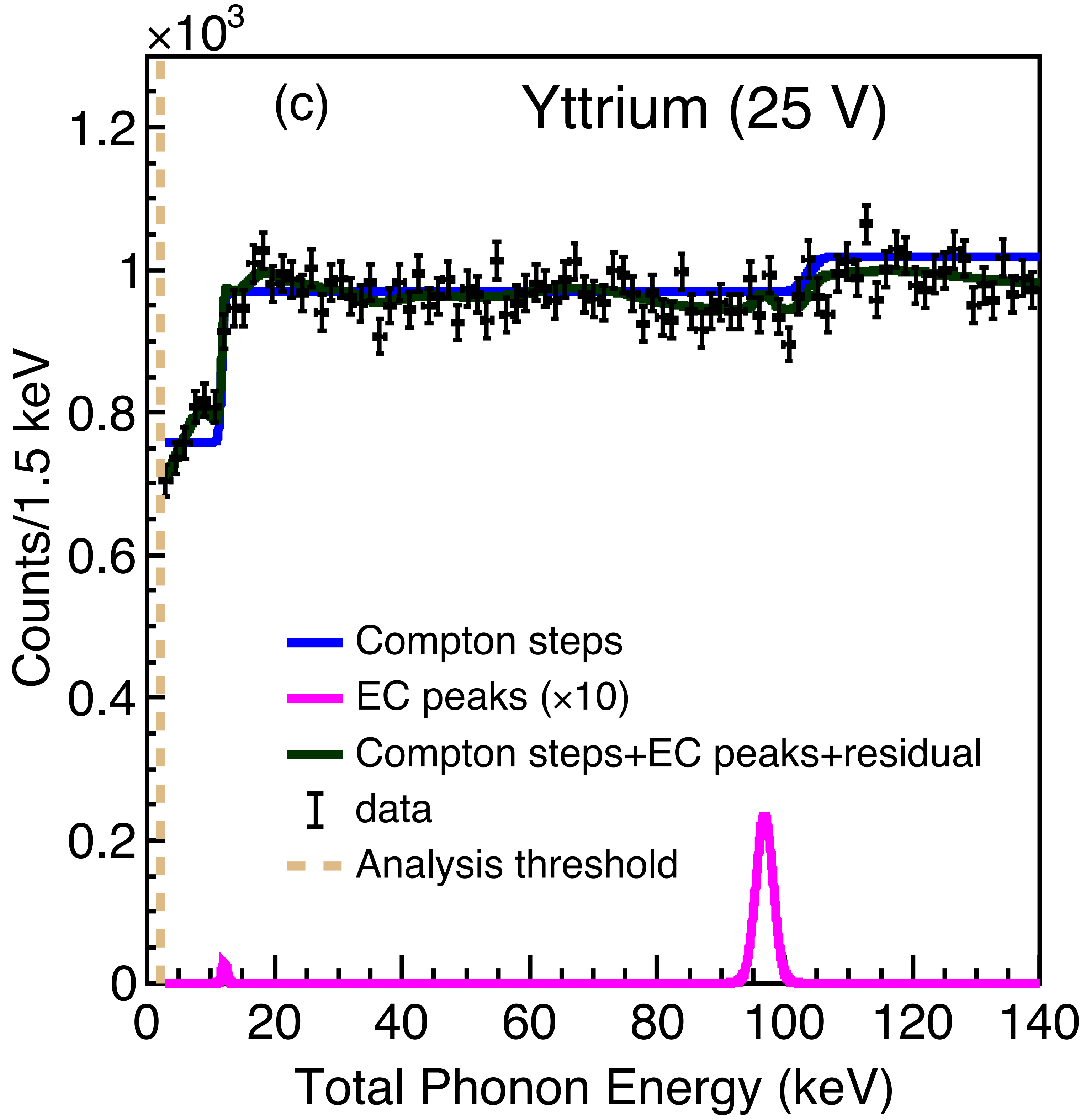


Photo-Neutron Analysis Scheme in 1 Slide

- Likelihood approach was used to determine best fit yield model consistent with the three data sets
- Used a modified Lindhard nuclear recoil yield model model
  - $k(E_r)$ was allowed to vary linearly with energy two values
- Fit free parameters included fraction of neutron recoils in the data, and the 2 k parameters
- 2-parameter model, with a linear energy dependence of the k parameter, was preferred with a significance greater than 3σ over a constant k model

$$Y_r = \frac{kg(\epsilon)}{1 + kg(\epsilon)}$$

$$k(E_r) = k_{low} + \frac{k_{high} - k_{low}}{E_{high} - E_{low}}(E_r - E_{low})$$

	Best fit value	σ_{Stat}	σ_{Sys}
k_{low}	0.040	±0.005	±0.008
k_{high}	0.142	±0.011	±0.026

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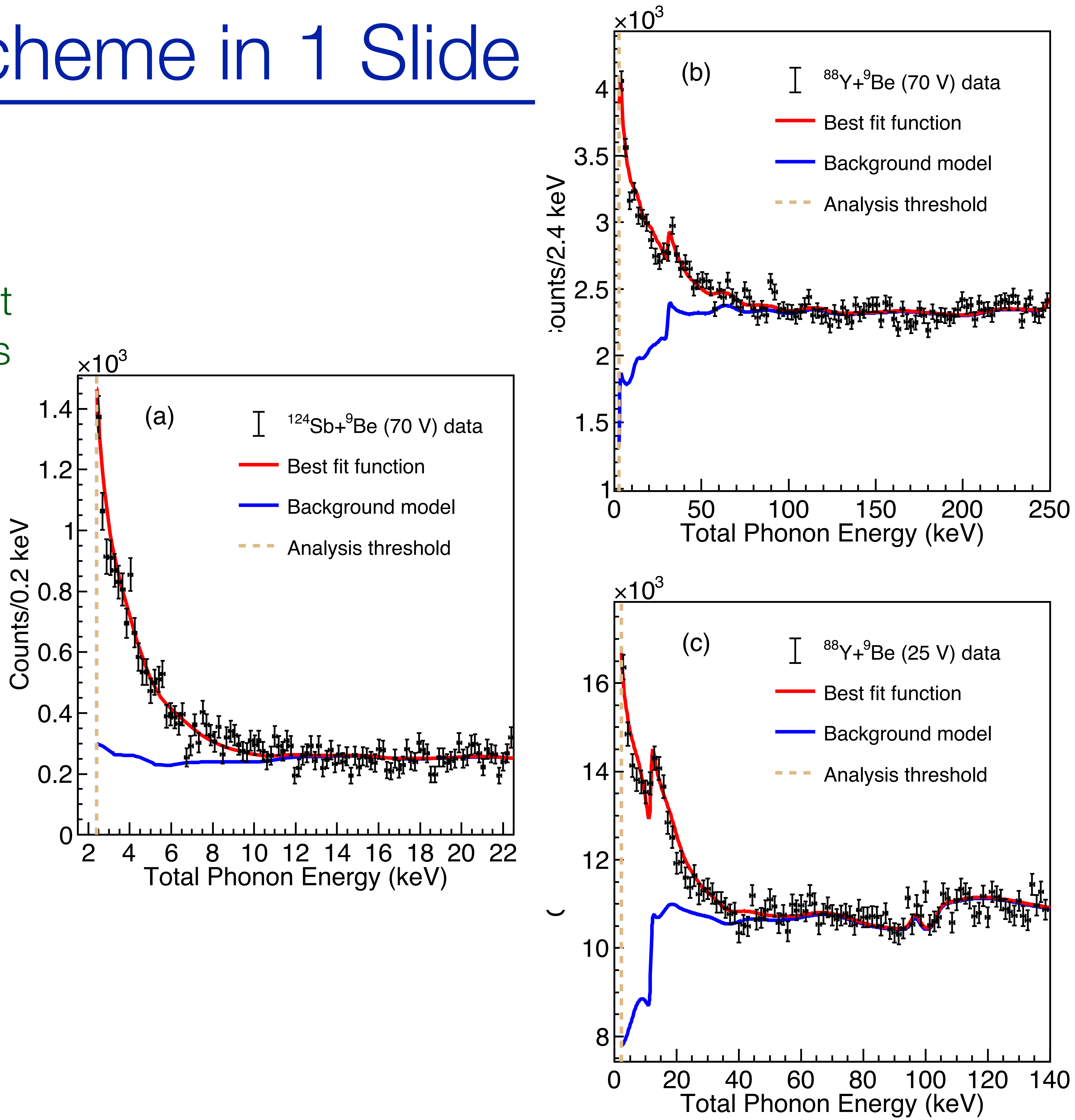


Evaluation of Systematic Uncertainties

- **Cut efficiencies:** Evaluated by varying the efficiencies with respect to their central values.
- **Fano factor:** Literature results indicate that Fano factor for nuclear recoils could be significantly higher than for electron recoils. The effect was evaluated by forcing F downward (consistent with statistical uncertainties) and upwards to a value of 10 (consistent with literature).
- **Background model shape:** Analytical only background model was evaluated.
- **Neutron elastic scattering cross-section:** Covariances of neutron resonance parameters were evaluated by generating 100 cross-section libraries and re-simulating.
- **Neutron Source Position:** Variation in source position studied and concluded to have minimal effect
- **Statistical uncertainties:** due to the finite size of the simulated neutron spectrum and of the experimental neutron-ON and neutron-OFF spectra evaluated with fits to simulated experiments.

Photo-neutron Ionization Yield Result

- Obtained yield is significantly suppressed wrt Lindhard in the few keV range
- Best fit model: linear combination of two k's
  - Inconsistent with a constant k Lindhard model
- Dominant uncertainty contributions
  - Data statistics
  - Neutron scattering cross-section input
  - Background model (at high energy)

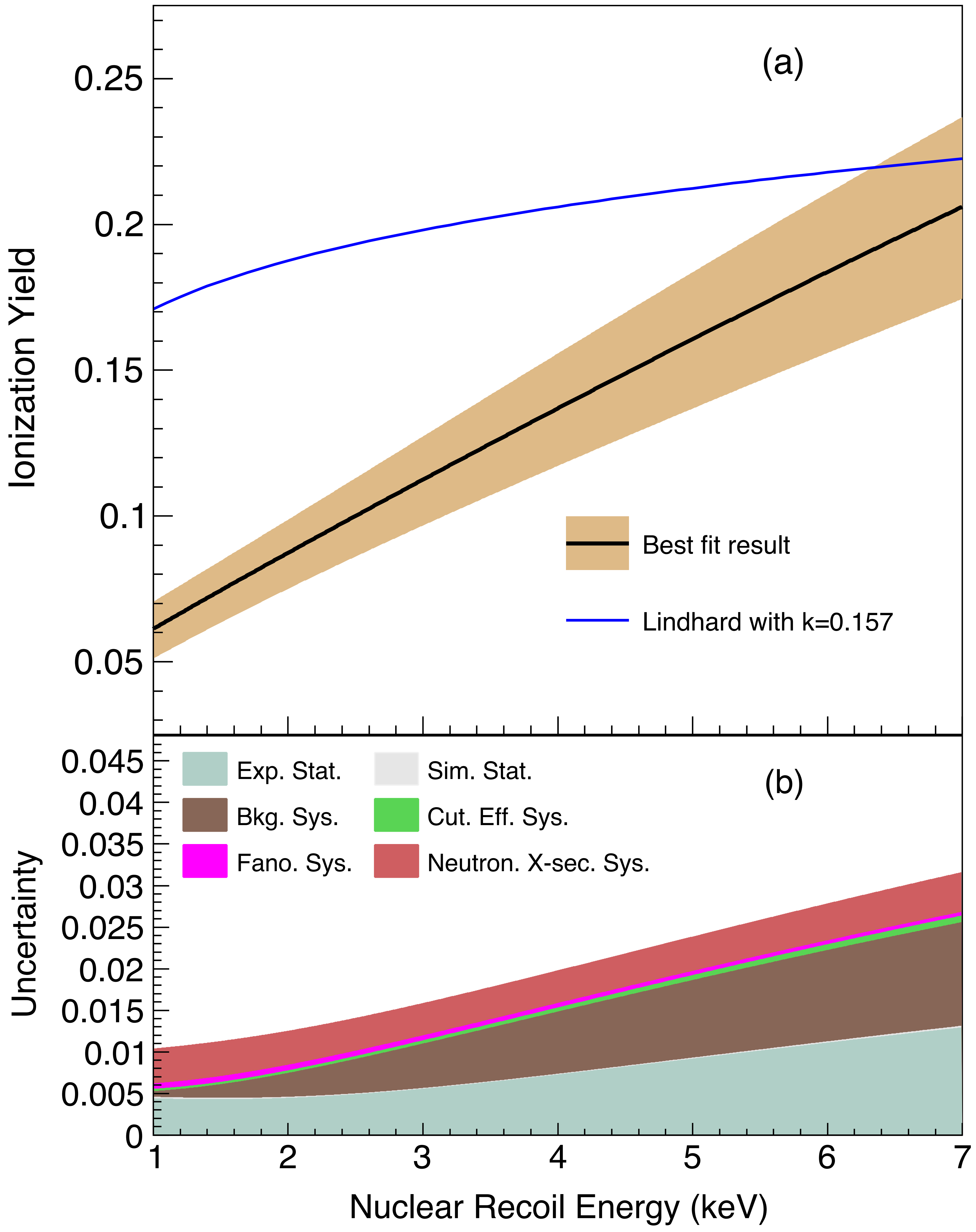
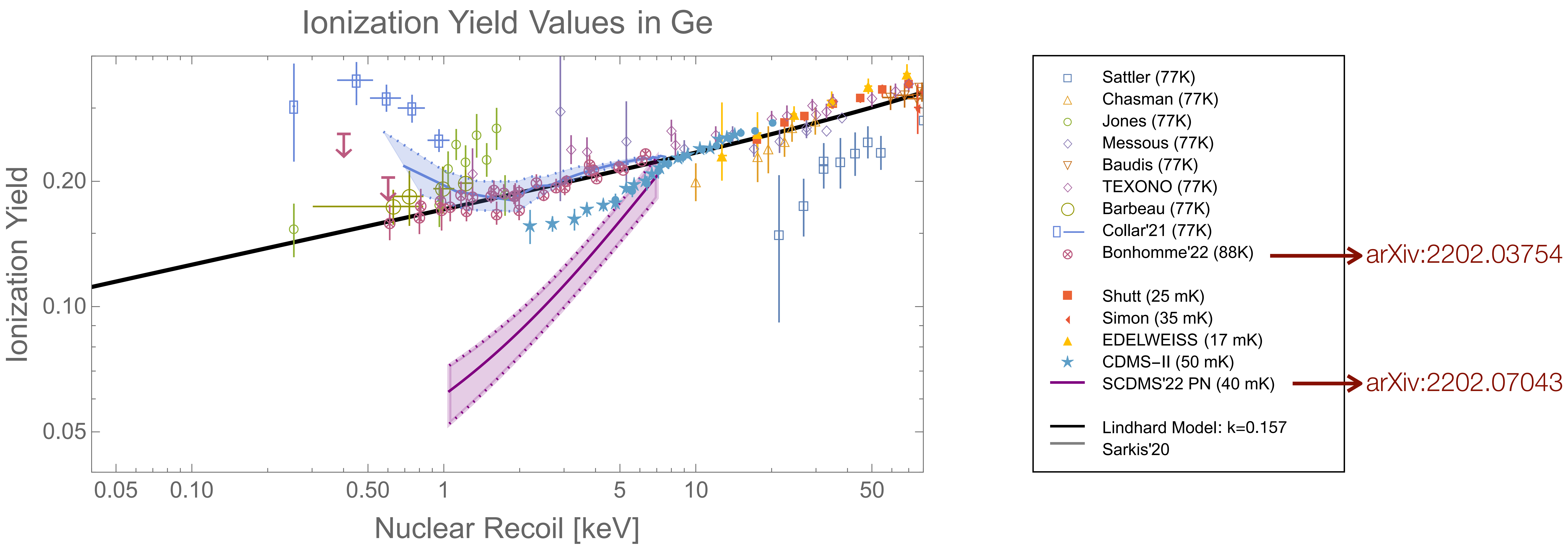


Photo-neutron Ionization Yield in Context

- Multiple yield measurements in Ge are inconsistent with each other
- Variations in operating temperature, electric field and experiment specific parameters suggest a more nuanced yield response at low recoil energies
- Git repository being assembled to collect literature values of yield and operating conditions



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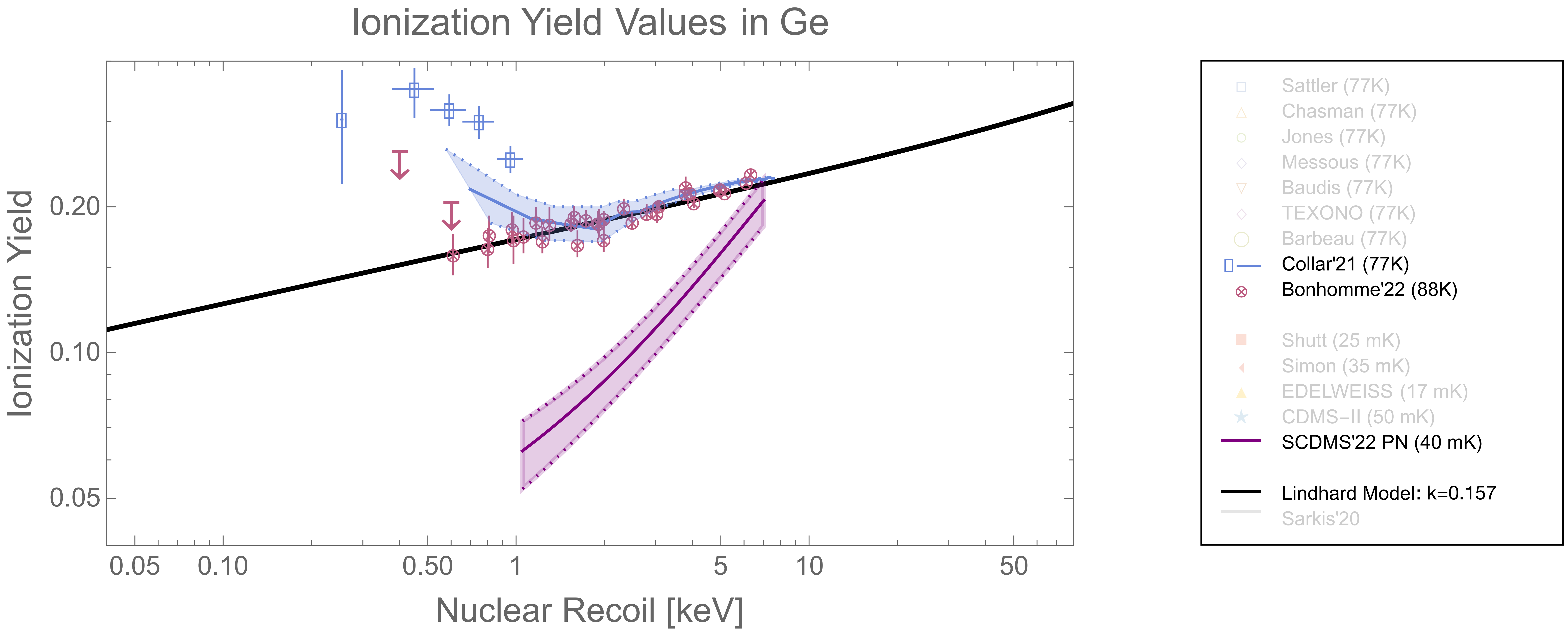


arXiv:2102.10089
arXiv:2202.03754
New result

arXiv:2202.07043

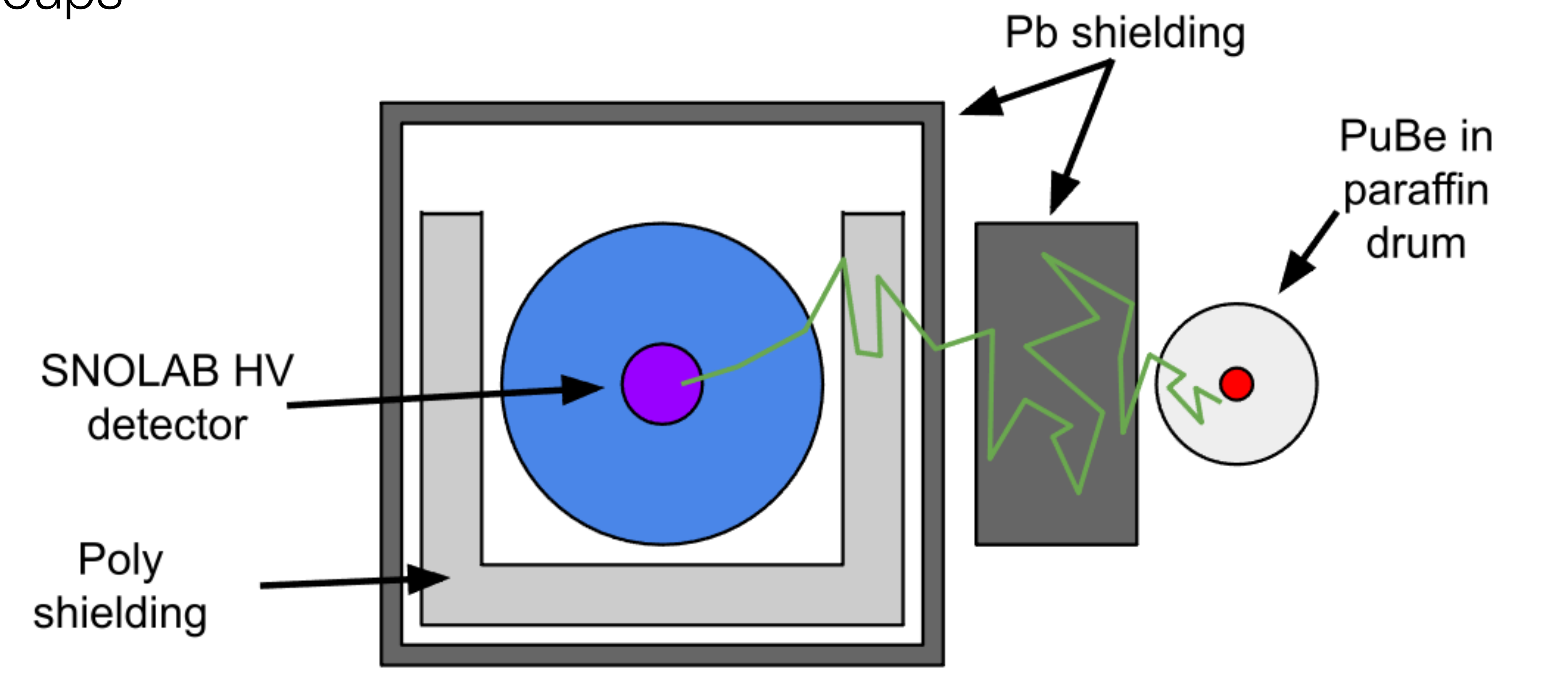
II. The Thermal Neutron Measurement in Si

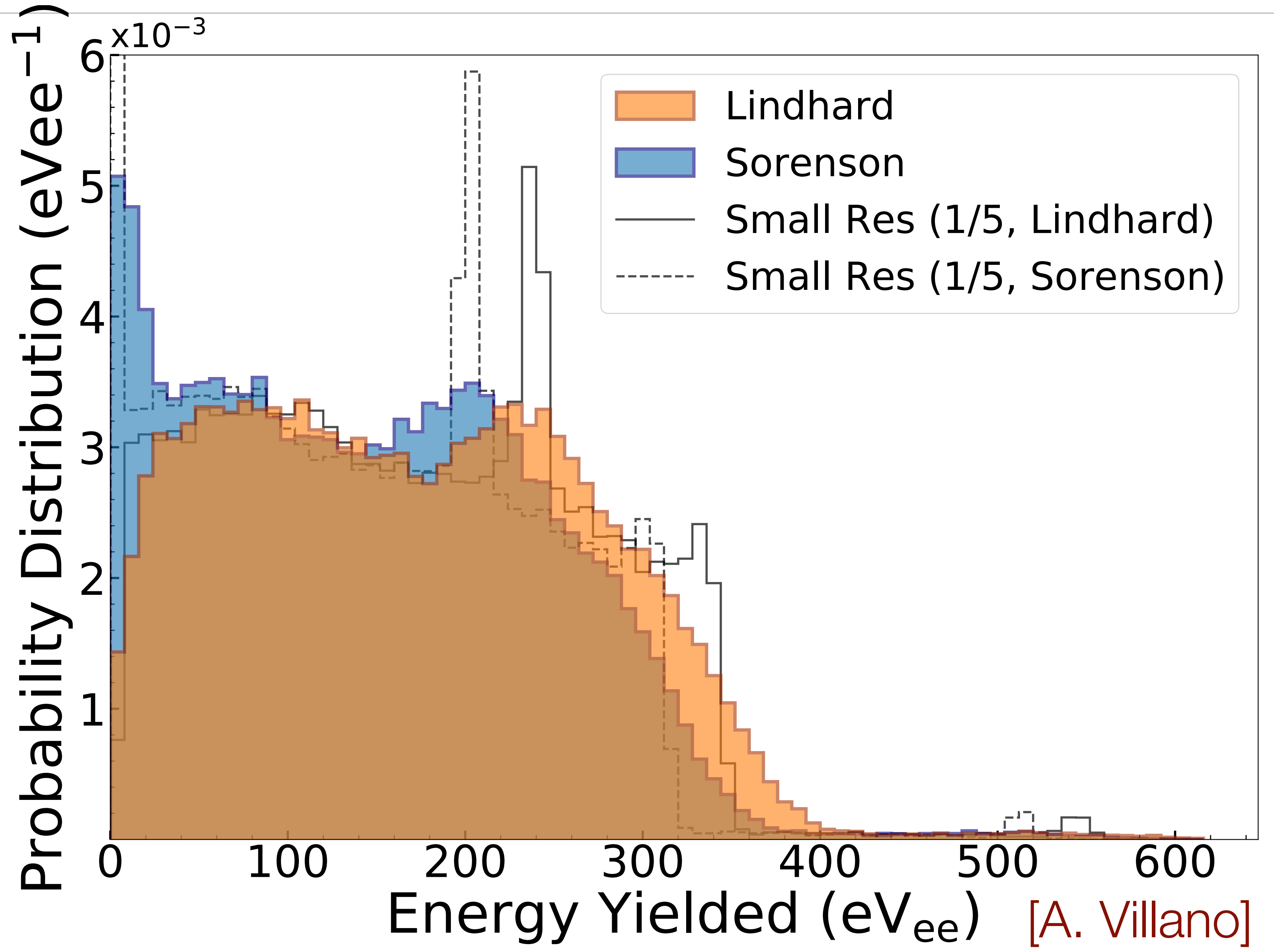
… but the NTL phonons are still athermal, right?

Isolated Neutron Capture Technique

Measurement performed by CU Denver, UMN groups

- Used a PuBe source in a barrel and put lead and poly around to thermalize neutrons
- Thermal neutron flux is about $2x10^{-1}$ n/cm^{2}s (measured), ~200x the average sea level thermal flux
- Measurement made with a SuperCDMS HV detector
- Ultimately aim to select events where the cascading gammas from n capture *all escape the immediate region of the nuclear recoil*





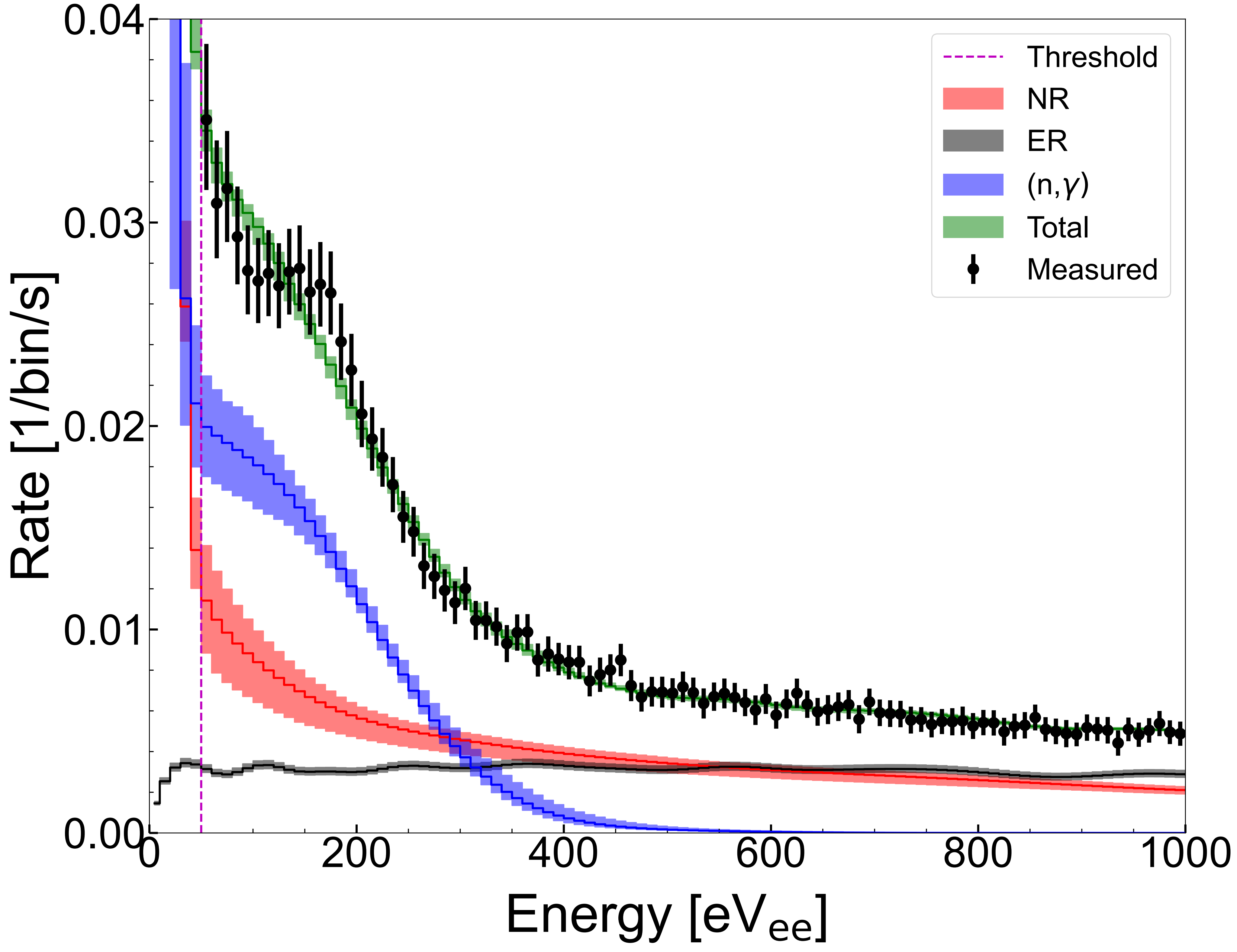
[A. Villano]

Expected Si Capture Spectrum
Comparison w/ two yield models & detector resolutions.

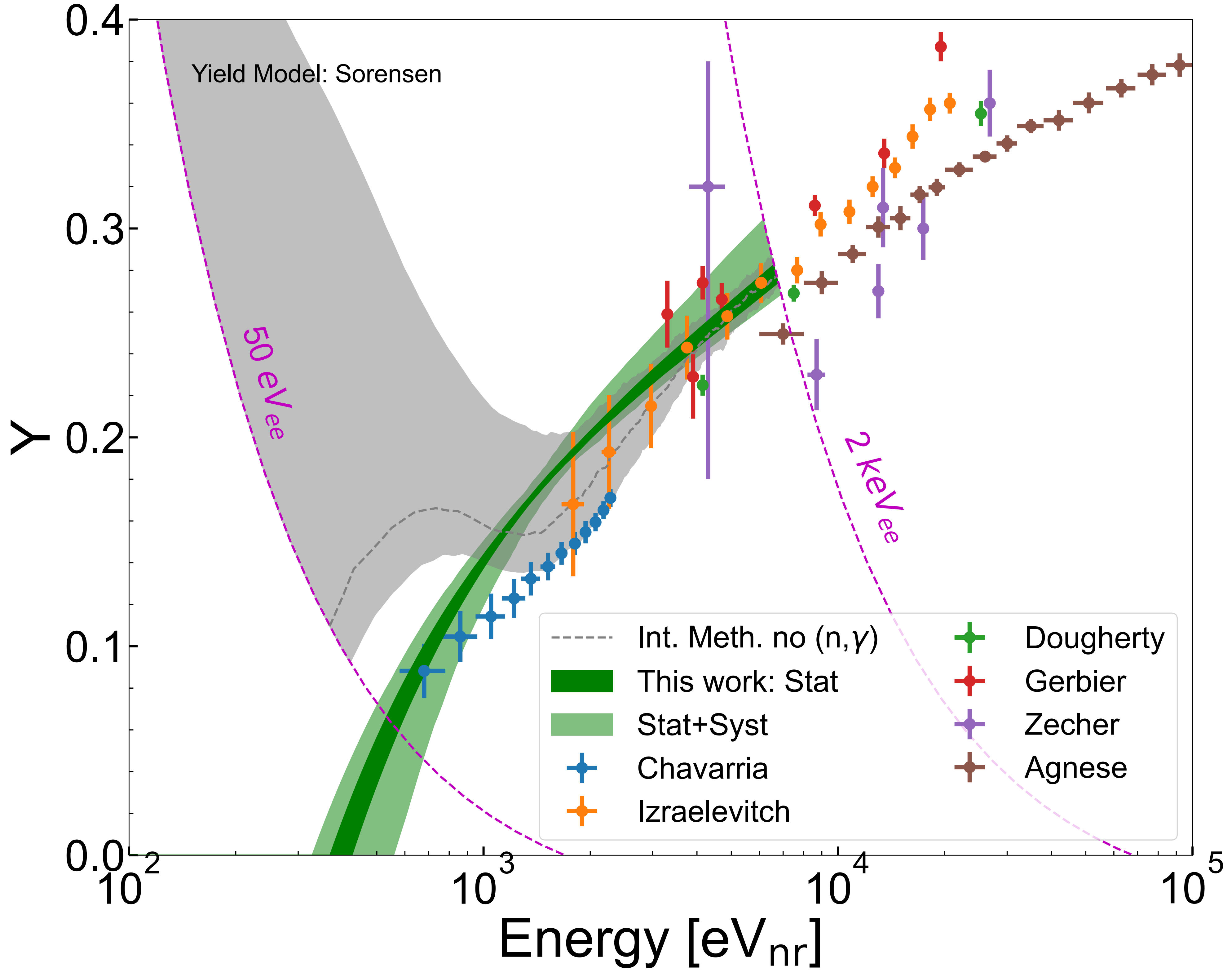
- Broad distribution similar to actual data

Neutron Capture Ionization Yield Result

- There is a feature in the spectrum strongly indicative of nuclear recoil events from neutron capture
- Best fit result using Sorensen yield model (has an ionization threshold)



- Literature models are virtually all based on Lindhard.
  - Data suggests models with better treatment of low energy physics required
- Preprints:
  - https://arxiv.org/abs/2110.02751
  - https://arxiv.org/abs/2104.02742



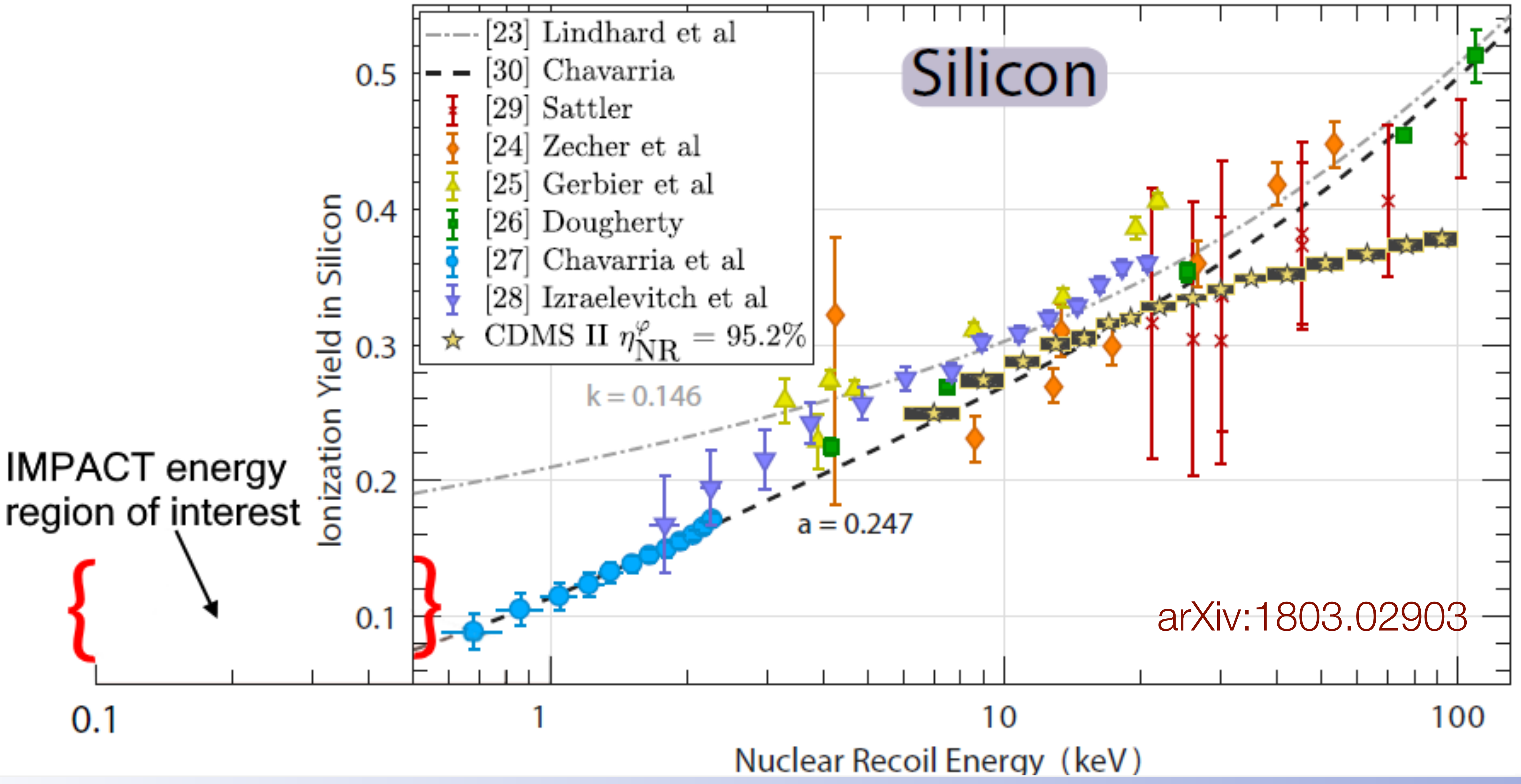
III. The Neutron Beam Measurement in Si

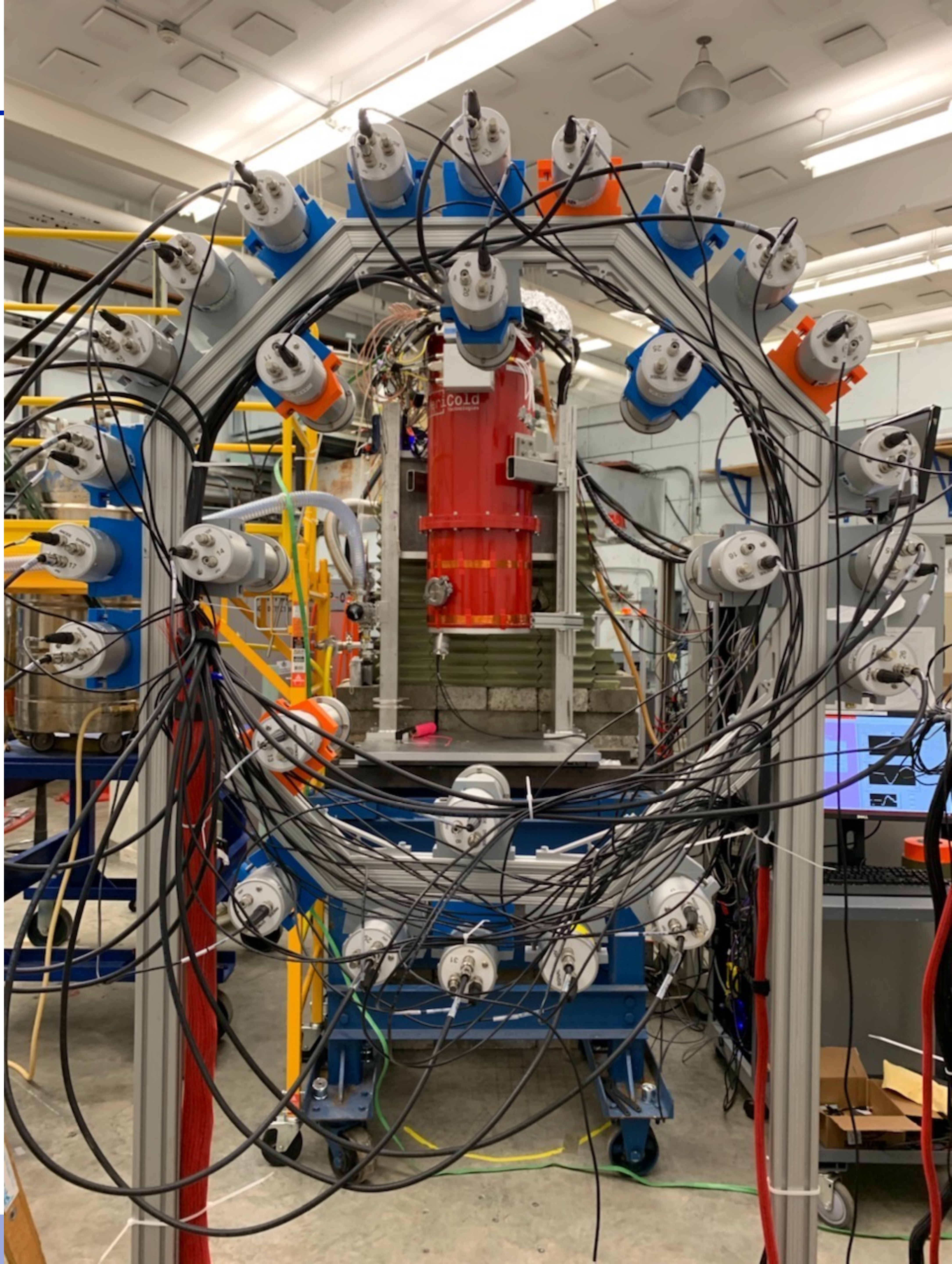
A proton, a Li atom, and a neutron ….

IMPACT

Ionization **M**easurement with **P**honons **a**t **C**ryogenic **T**emperatures

- A measurement of the nuclear recoil ionization yield down to 100 eV recoil
  - Essential to understanding the response of the HV detectors to nuclear recoils
  - Current state of knowledge in Si:





How To Impact

IMPACT

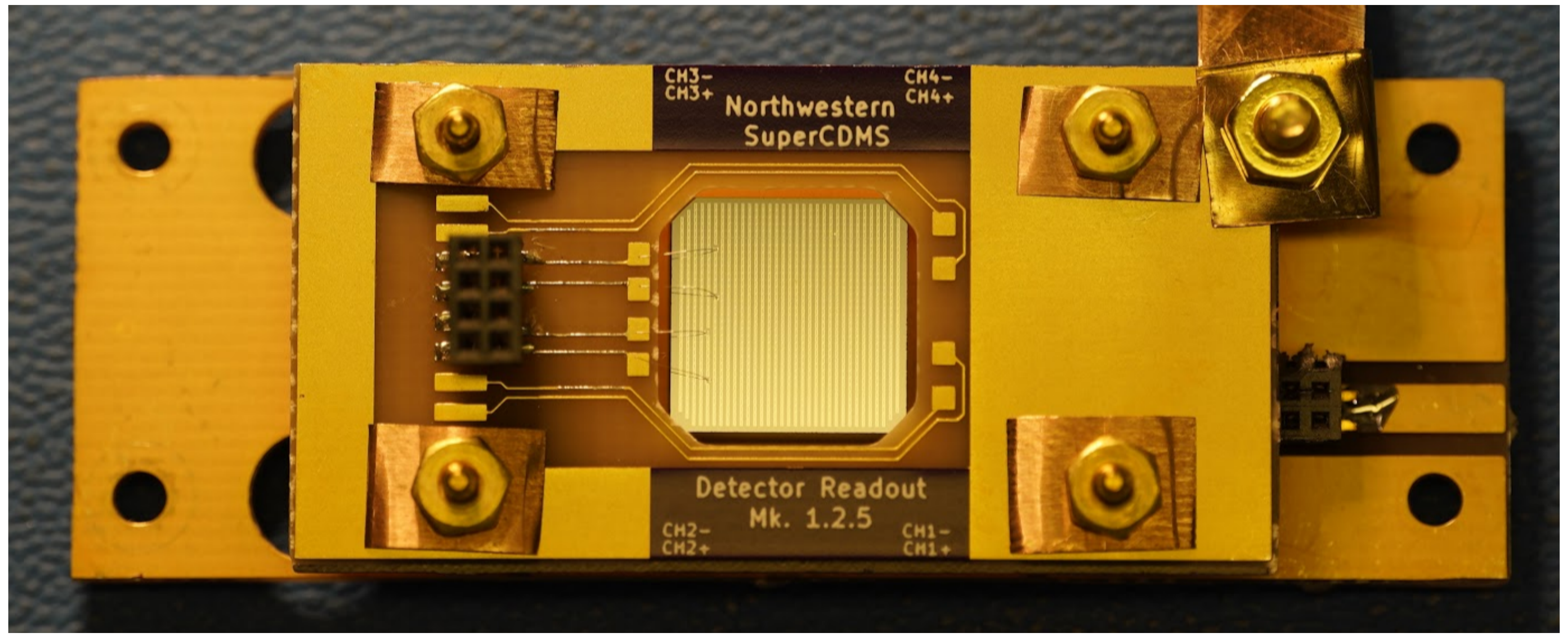
- Determination of yield via measurement of the total phonon energy in the detector and kinematic measurement of the recoil energy via a coincident detection of the scattered neutron

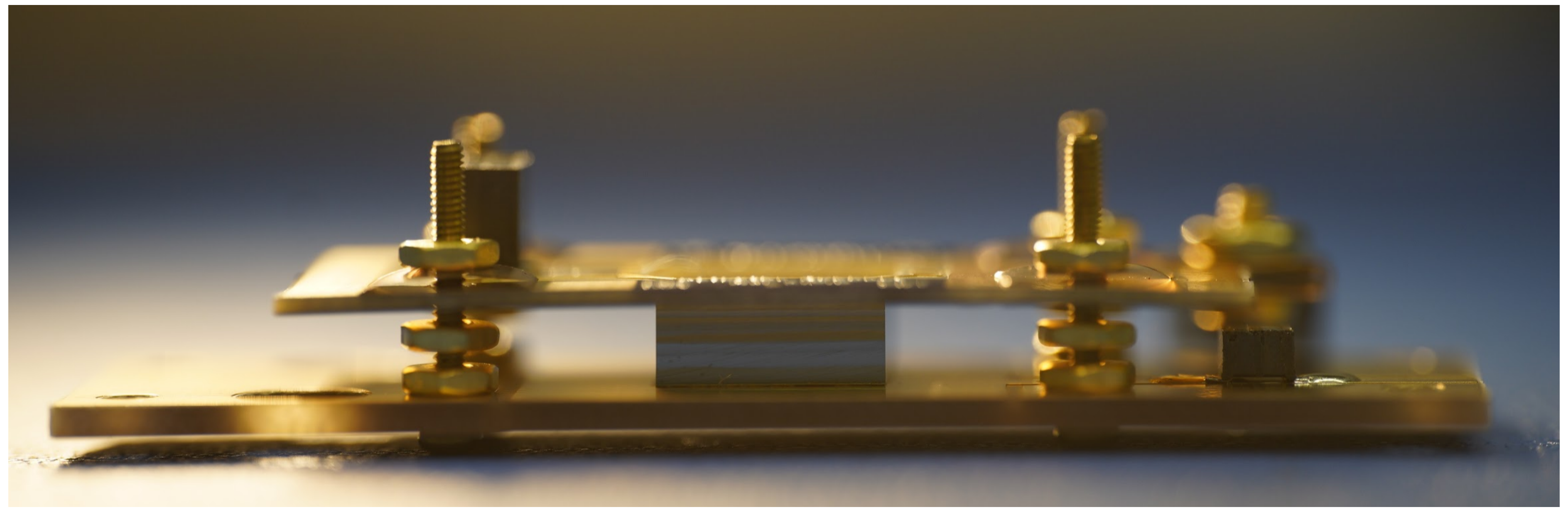
$$E_r = 2E_{\mathrm{n}} \frac{M_{\mathrm{n}}^2}{(M_{\mathrm{n}} + M_{\mathrm{T}})^2} \left(\frac{M_{\mathrm{T}}}{M_{\mathrm{n}}} + \sin^2\theta - (\cos\theta) \sqrt{\left(\frac{M_{\mathrm{T}}}{M_{\mathrm{n}}}\right)^2 - \sin^2\theta} \right)$$

- Neutrons courtesy of Triangle Universities Nuclear Laboratory
  - 1.889 MeV protons with 2.5 MHz pulsing
  - LiF-on-Ta target
  - Aim for ^{28}Si elastic scattering resonance at 55.7 keV

TUNL
Triangle Universities Nuclear Laboratory

- Same HVeV detector used for HVeV DM Run 2
  - 1x1x0.4 cm^3 Si crystal (0.93 g)
  - 2 channel TES readout
  - Energy resolution: σ_{ph} ~ 3 eV
  - Charge resolution: σ_{eh} ~ 0.03 e$^-$h$^+$





How To Impact

- Neutron detectors
  - EJ-301/309 liquid scintillators, sensitive to neutrons down to 10 keV
  - 26 detectors focused on 100 eV, 220 eV, and 460 eV recoil energy points measure y in new parameter space
  - Three detectors at 0.75 keV, 2 keV, and 3.8 keV to overlap with existing measurements

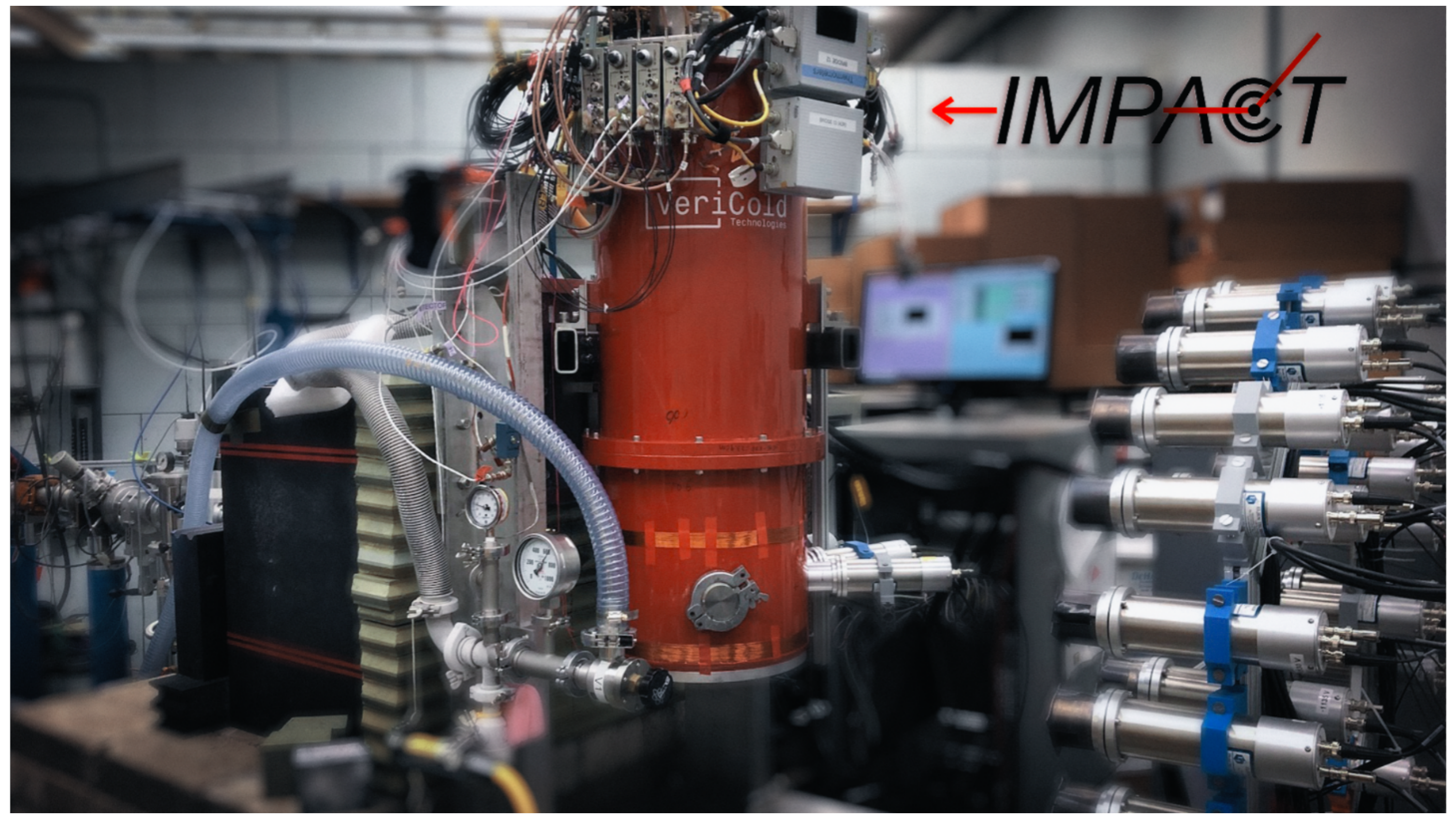


Image credit: Tom Ren

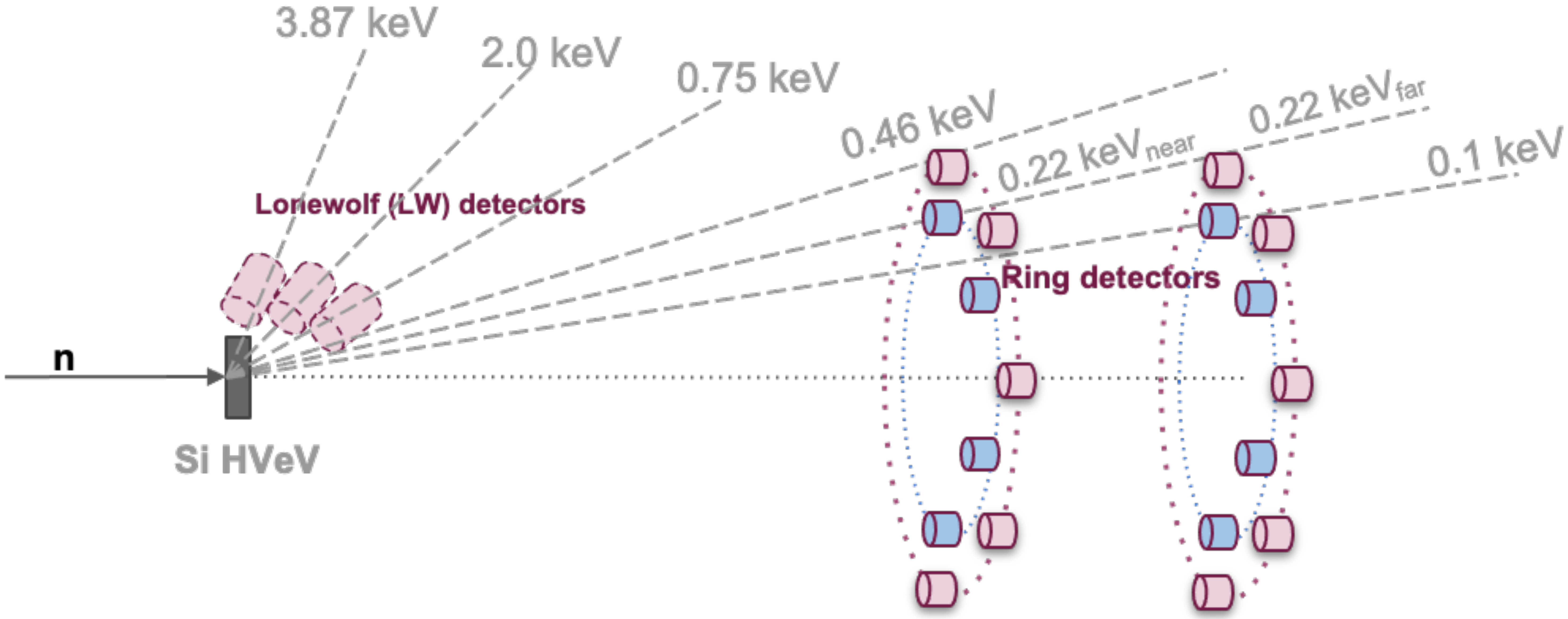


Image credit: Tom Ren

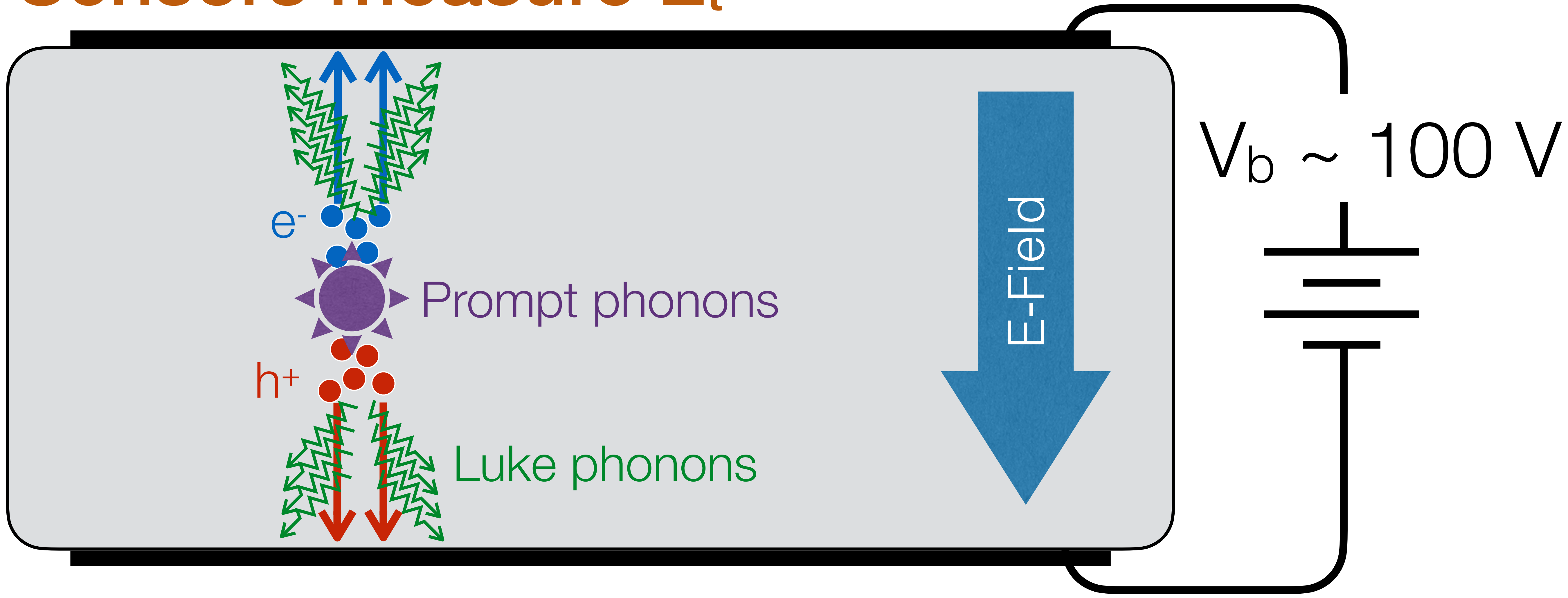
How To Impact

IMPACT @TUNL

- Data
  - 3 weeks of data taking at 50% duty cycle
  - Two days at 0 V for tuning cuts and validating HVeV—scintillator neutron coincidence technique
  - Data taken at 20, 100, and 180 V for exploring yield dependence on the electric field

$$E_{total} = E_{recoil} + n_{eh} e V_b$$
$$= E_{recoil}(1 + eV_b/\epsilon_{eff} \cdot Y)$$

Sensors measure E_t



➡0V mode $V_b = 0$: Total energy = Recoil energy
➡HV mode $V_b \neq 0$: Total energy = Recoil energy + NTL energy

IMPACT Analysis Scheme in 1 Slide

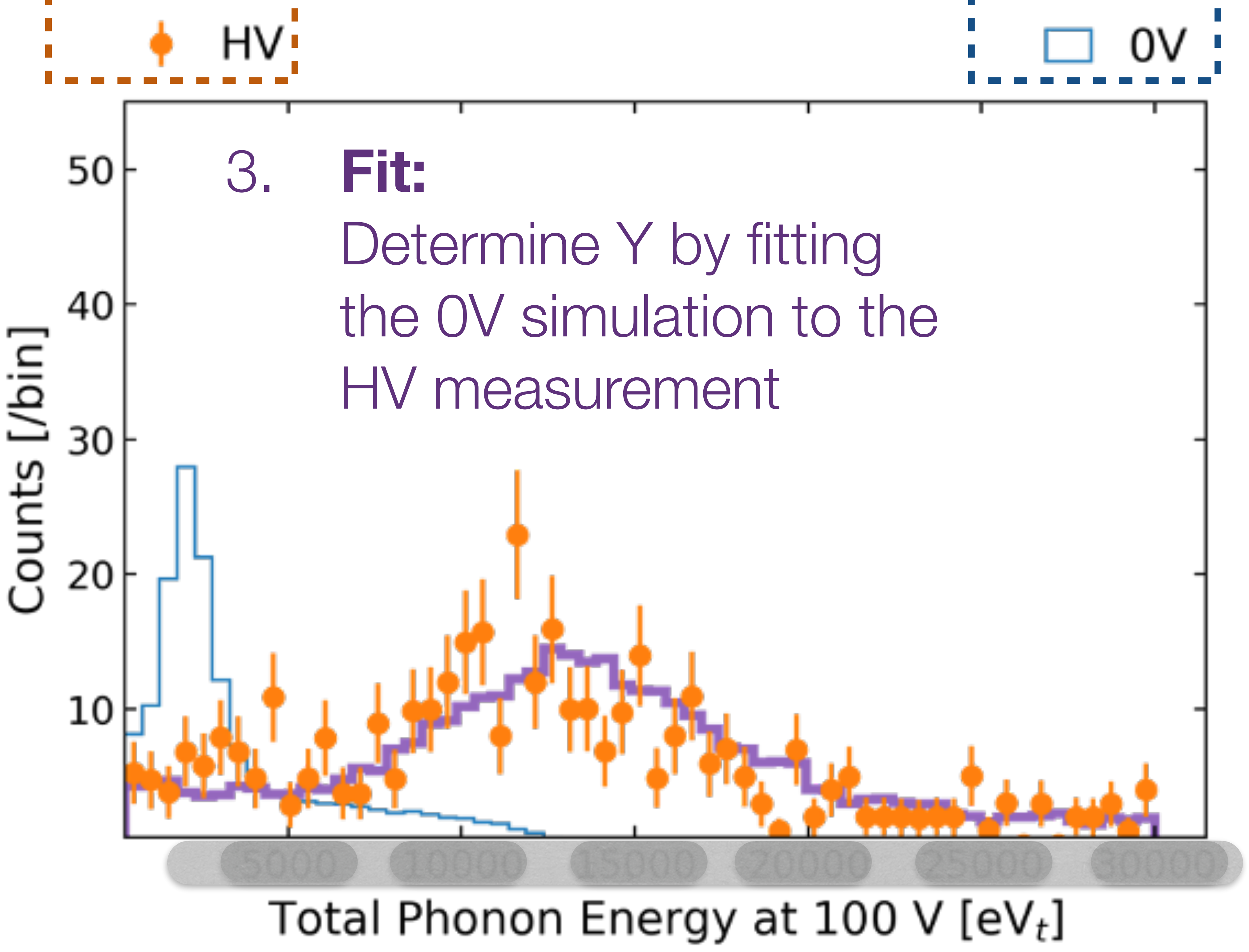
IMPACT

1. **Measurement:**
   Total phonon energy spectrum for events coincident between HVeV and PMT

$$E_{total} = (1 + eV_b/\epsilon_{eff} \cdot Y)\, E_{recoil}$$

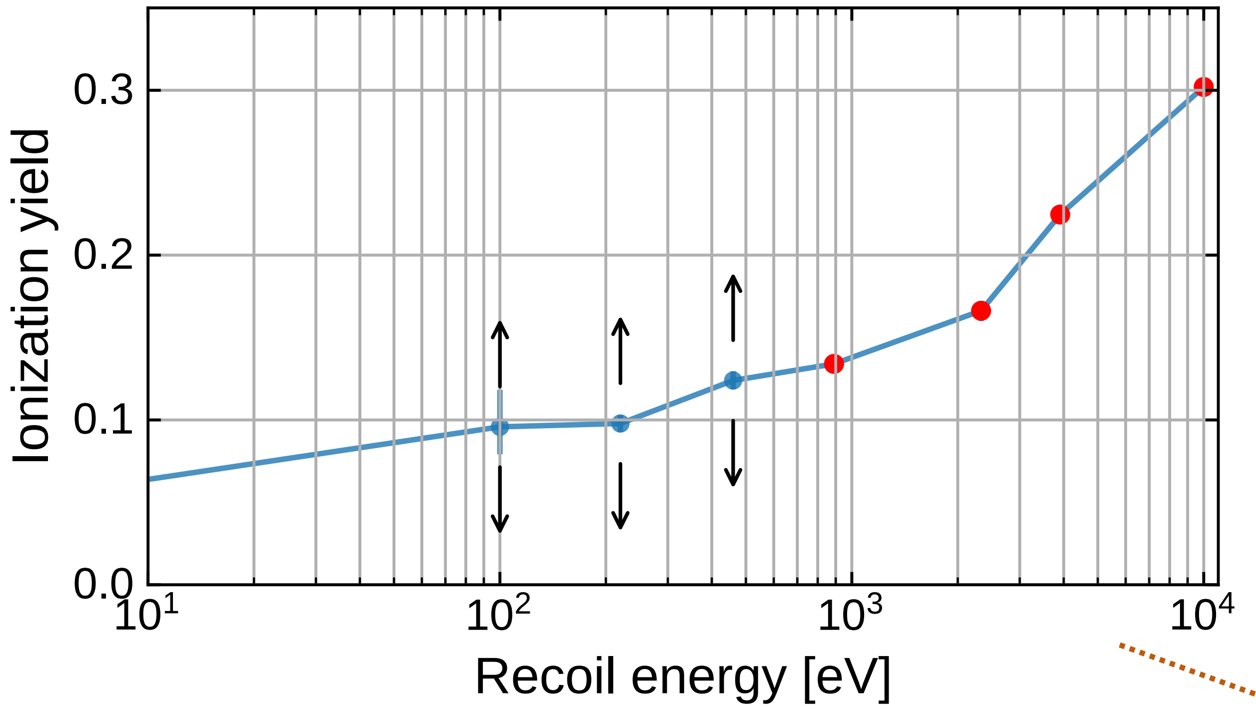
2. **Simulation:**
   Geant4 simulation of recoil energy spectrum for events coincident between HVeV and PMT

3. **Fit:**
   Determine Y by fitting the 0V simulation to the HV measurement

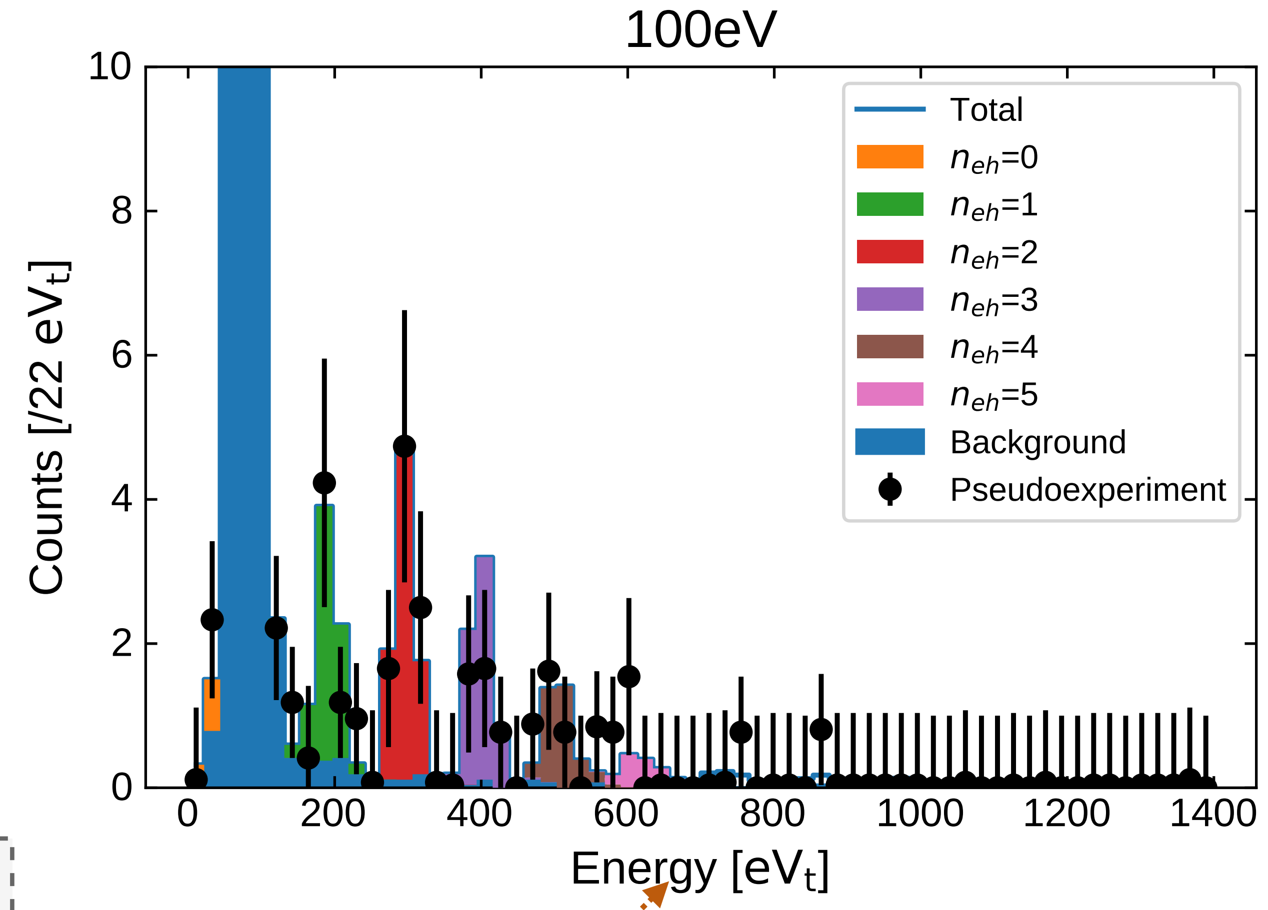


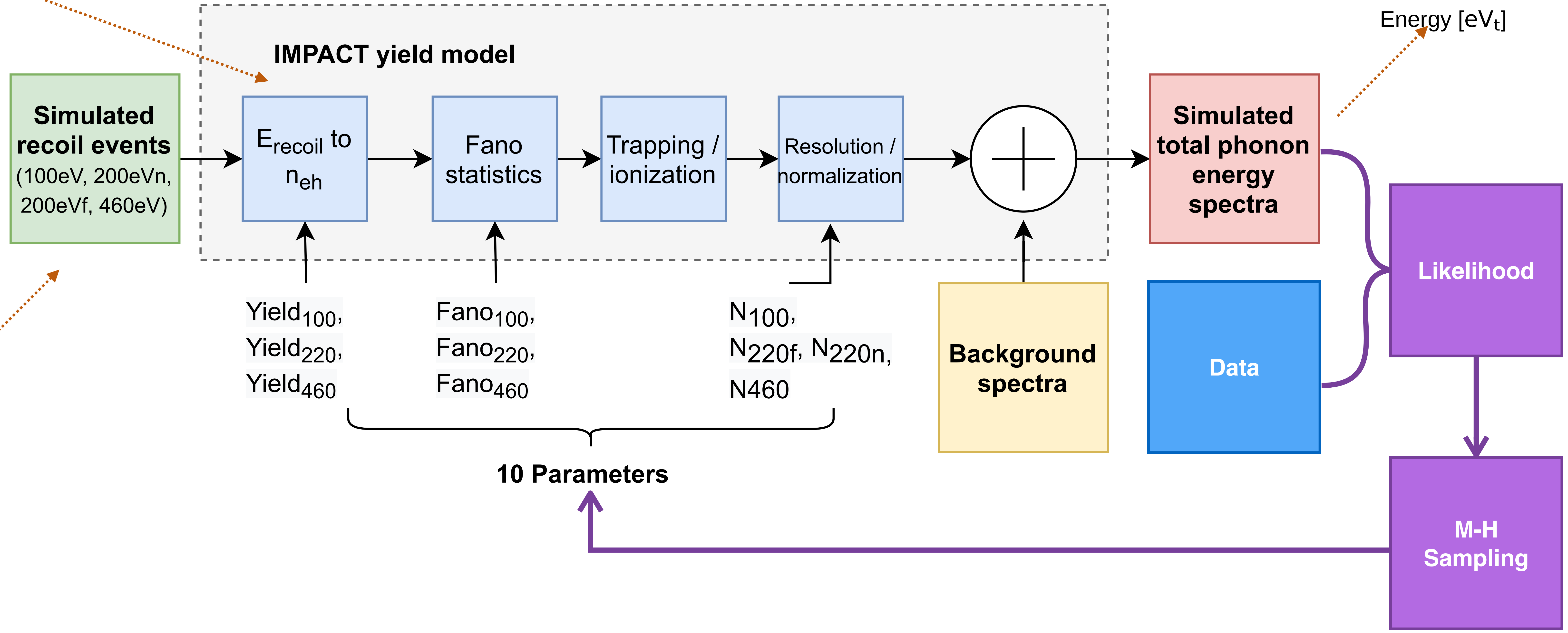
4. **Systematic Uncertainty:**
   - Coincidence timing window
   - Time of flight window
   - Neutron beam energy
   - Detector energy calibration
   - Impact ionization / Charge trapping
   - Fano factor

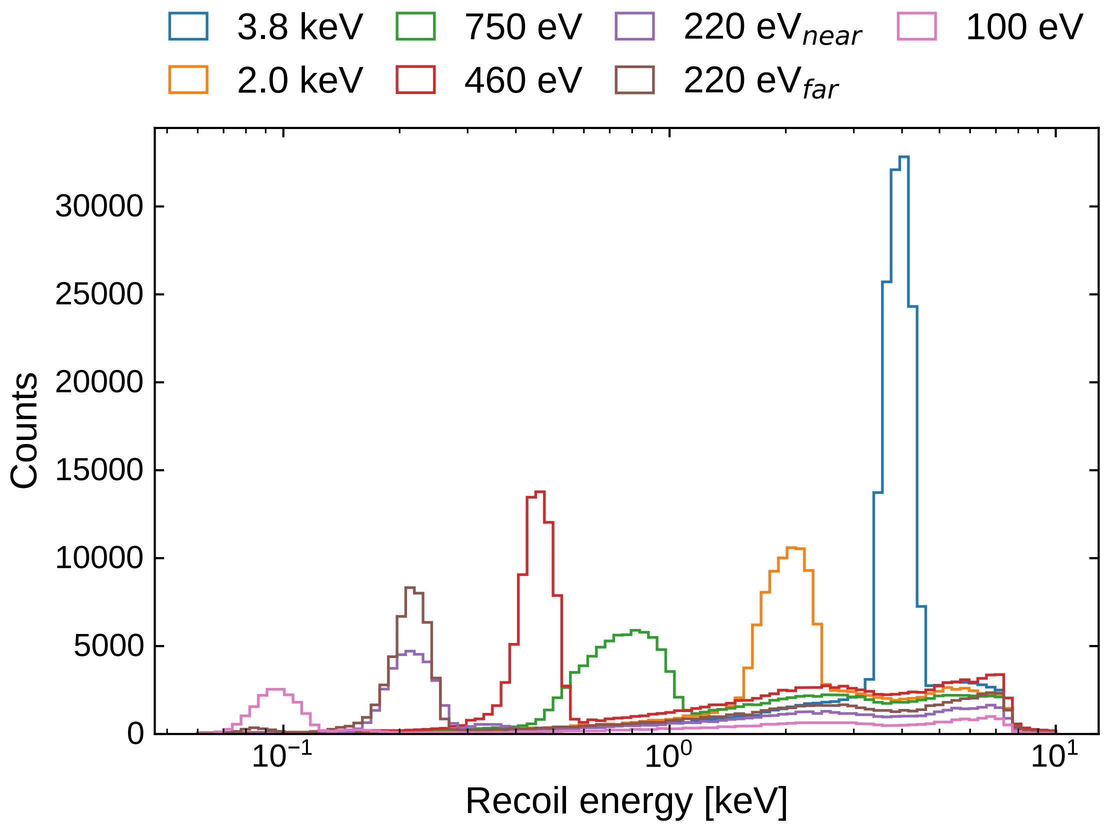
IMPACT Analysis Scheme in 2 Slides



- Linear interpolation between points
- Yield(0 eV) = 0
- Yield(10 keV and LWs) = $Y_{Chavarria}$

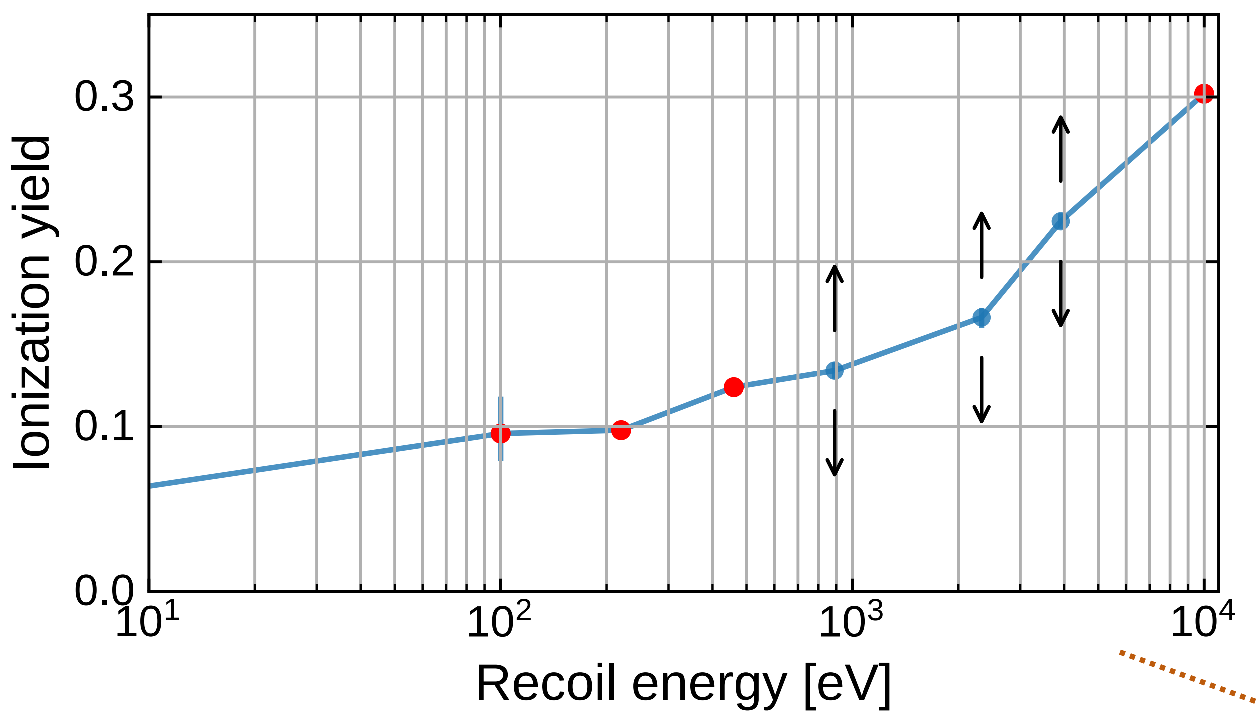






- We fit to the Ring detectors first

IMPACT Analysis Scheme in 2 Slides



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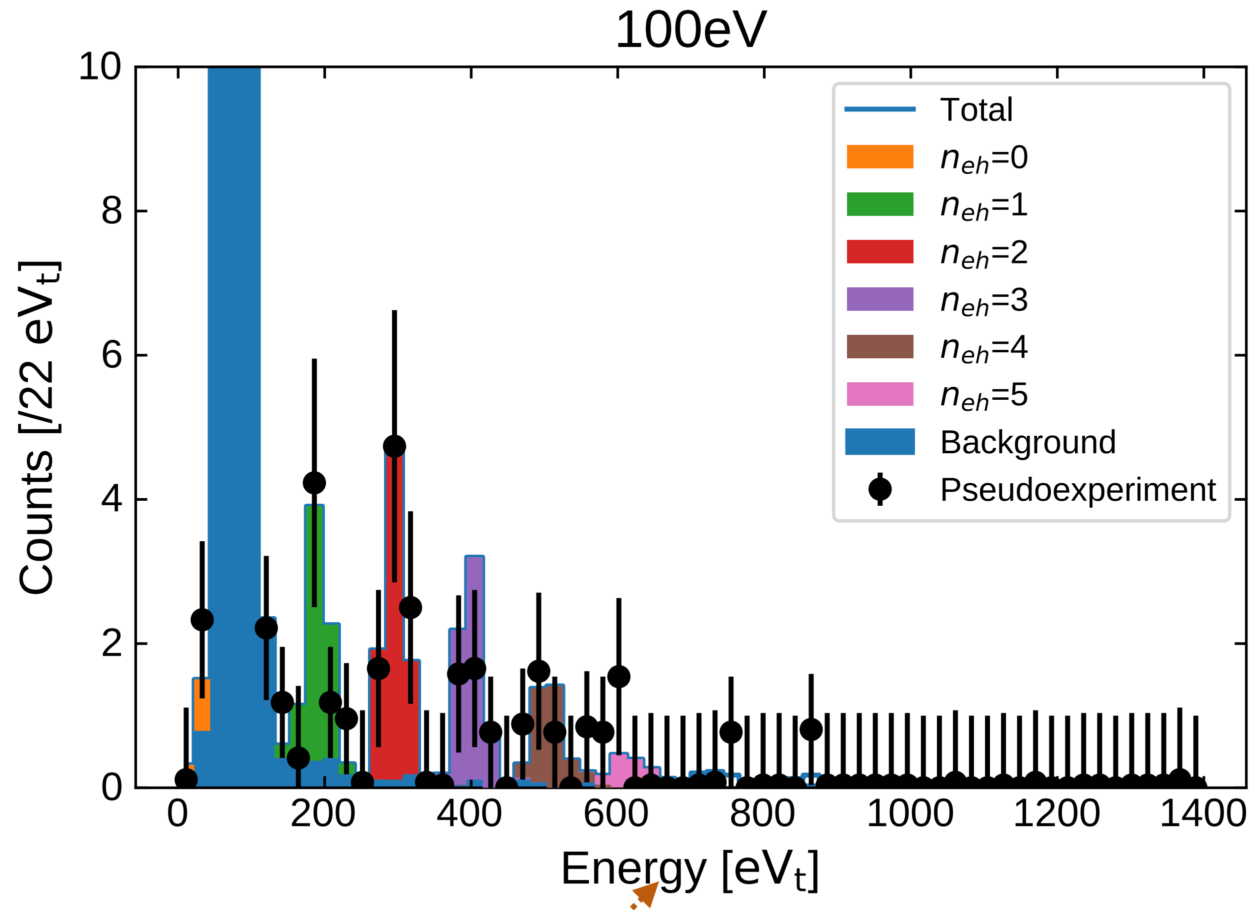
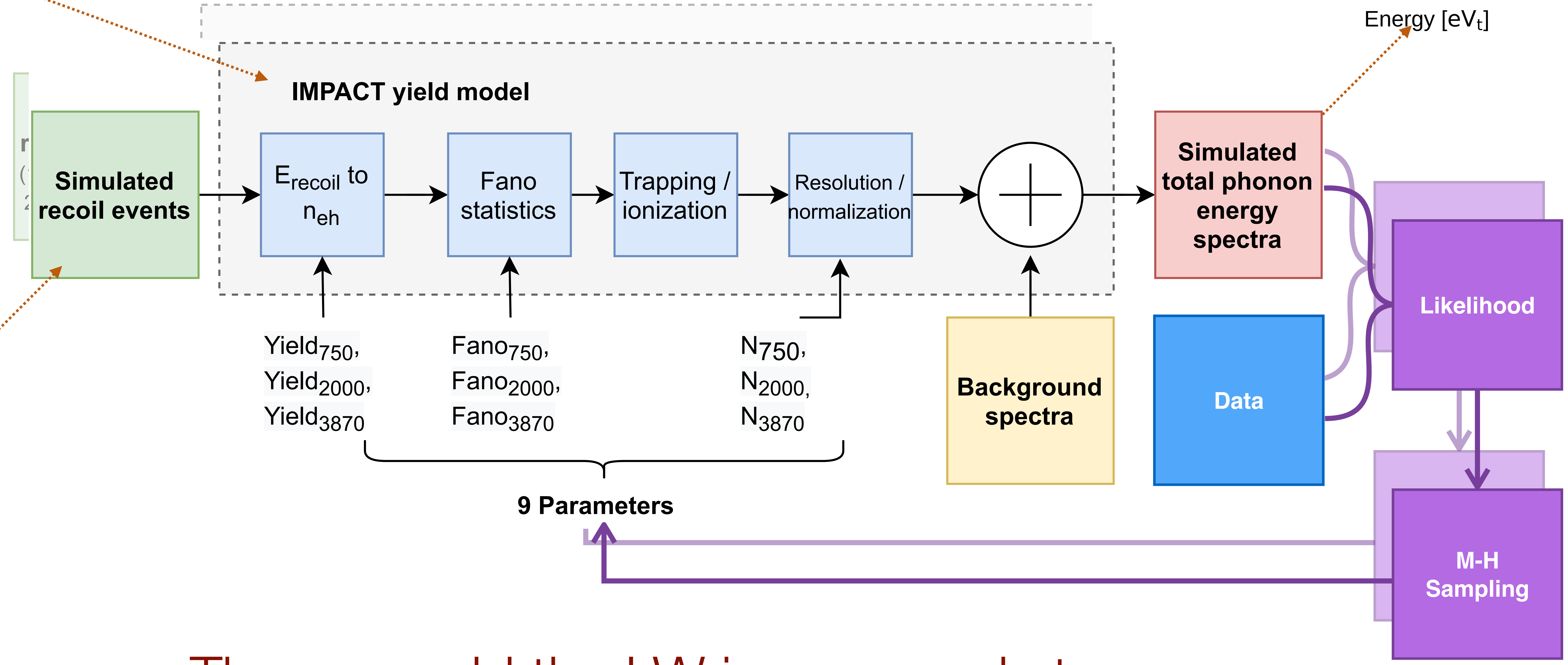
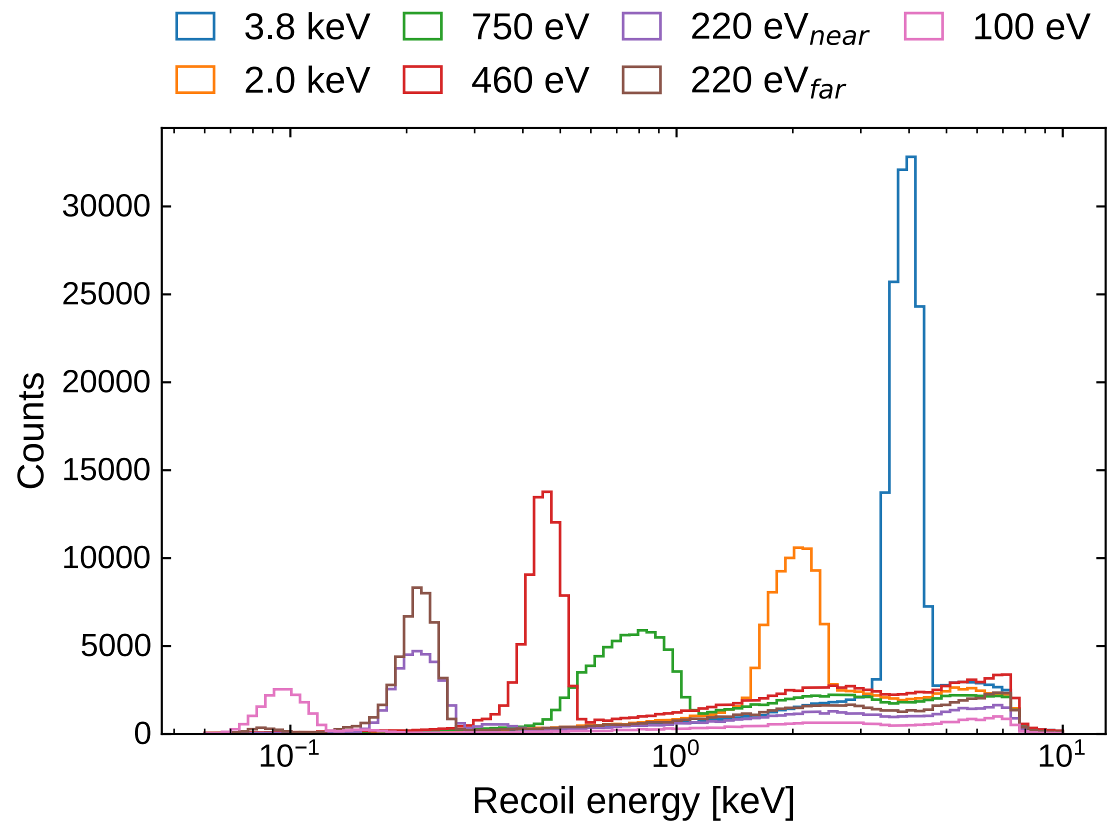


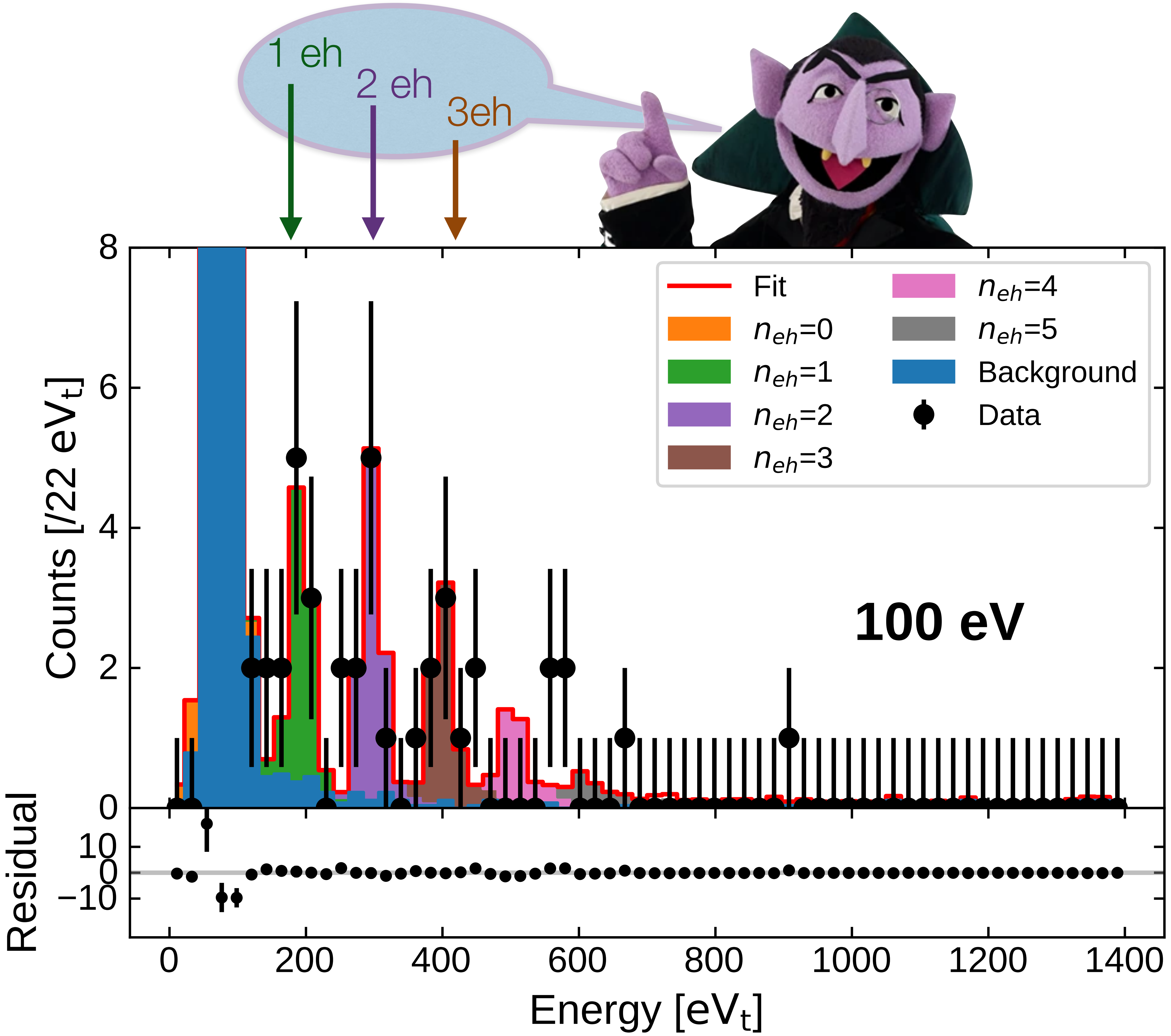


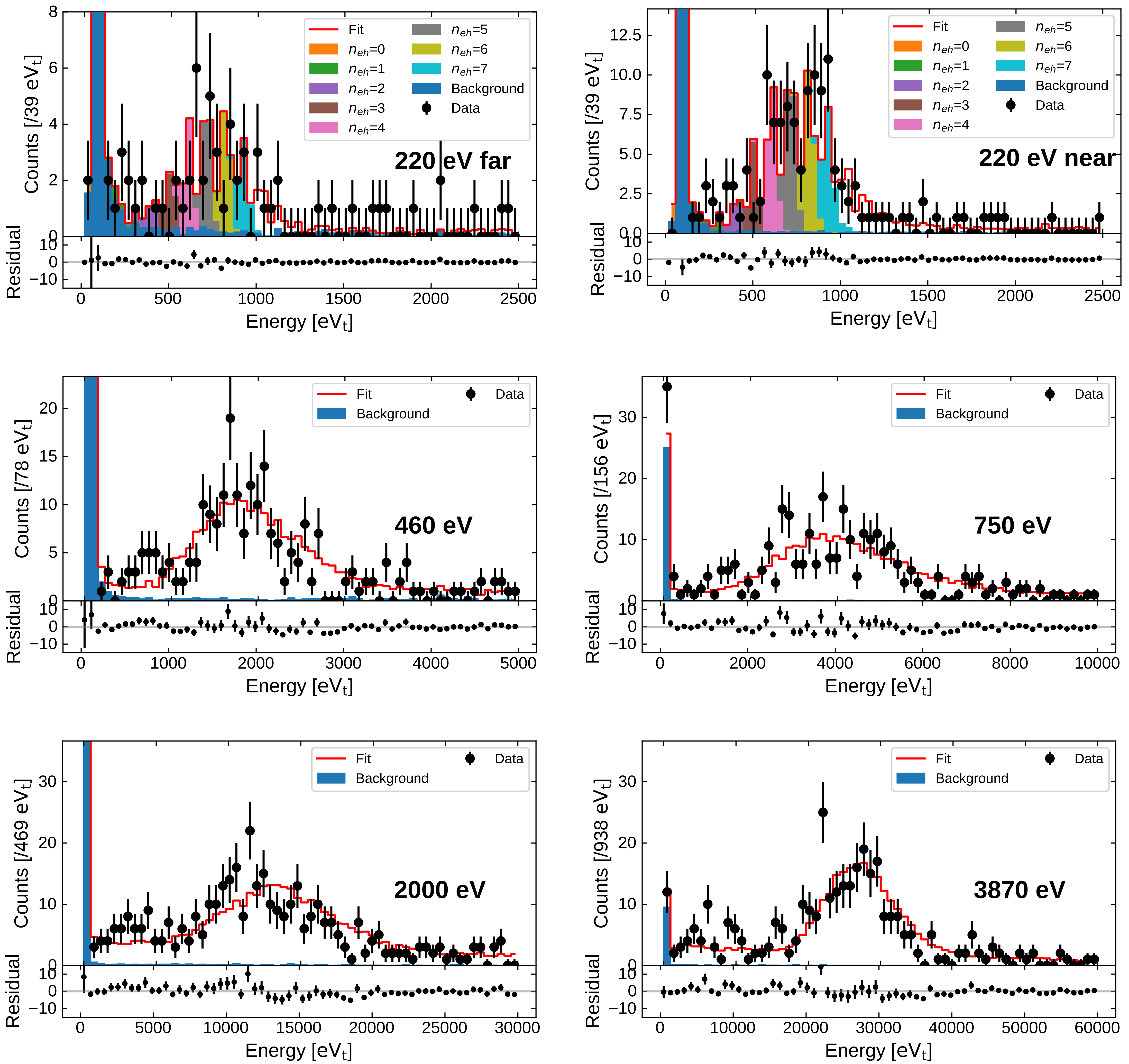


- Then we add the LW in a second step

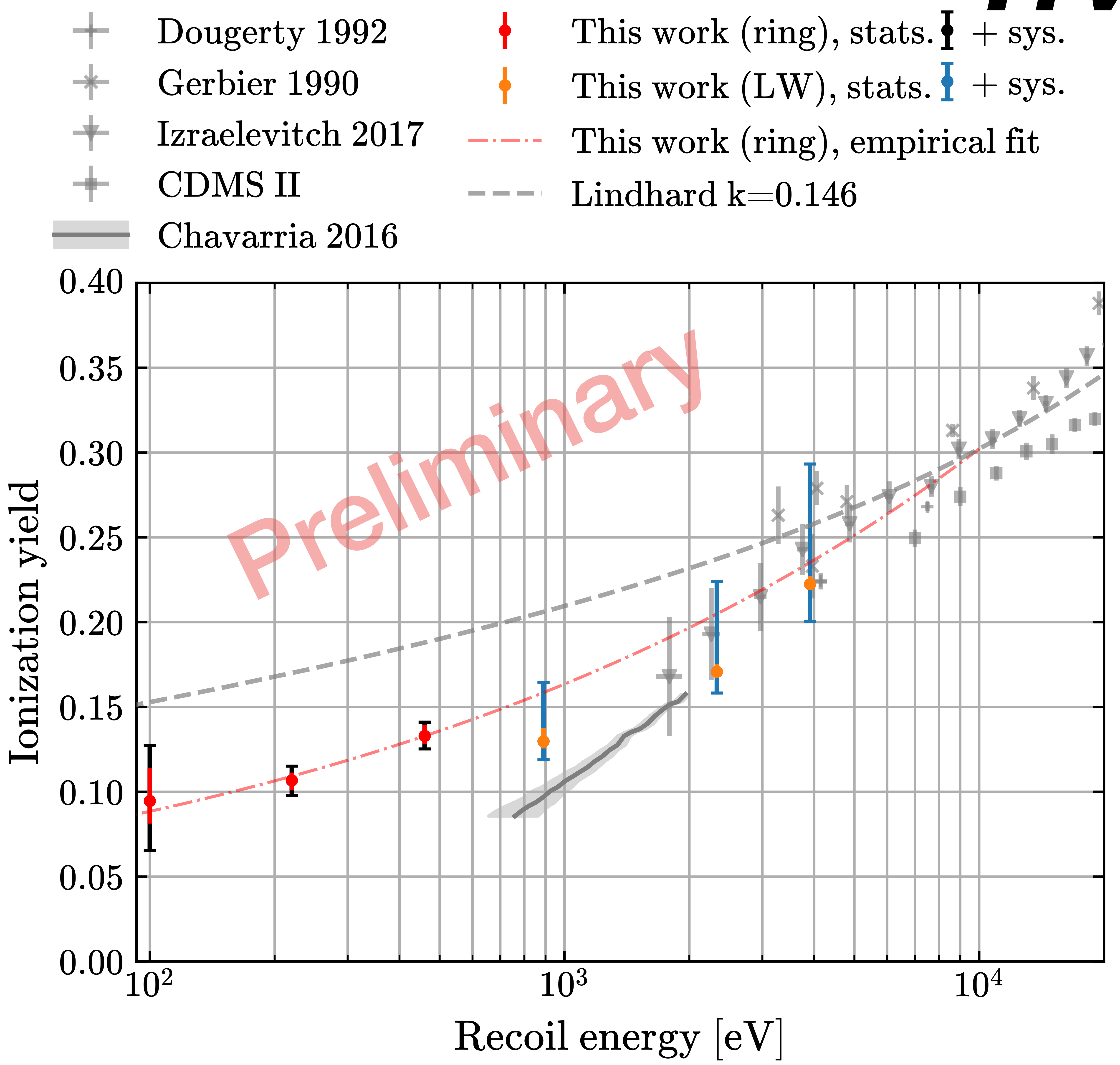
Results of Ionization Yield Fit

Data — Fit — Background



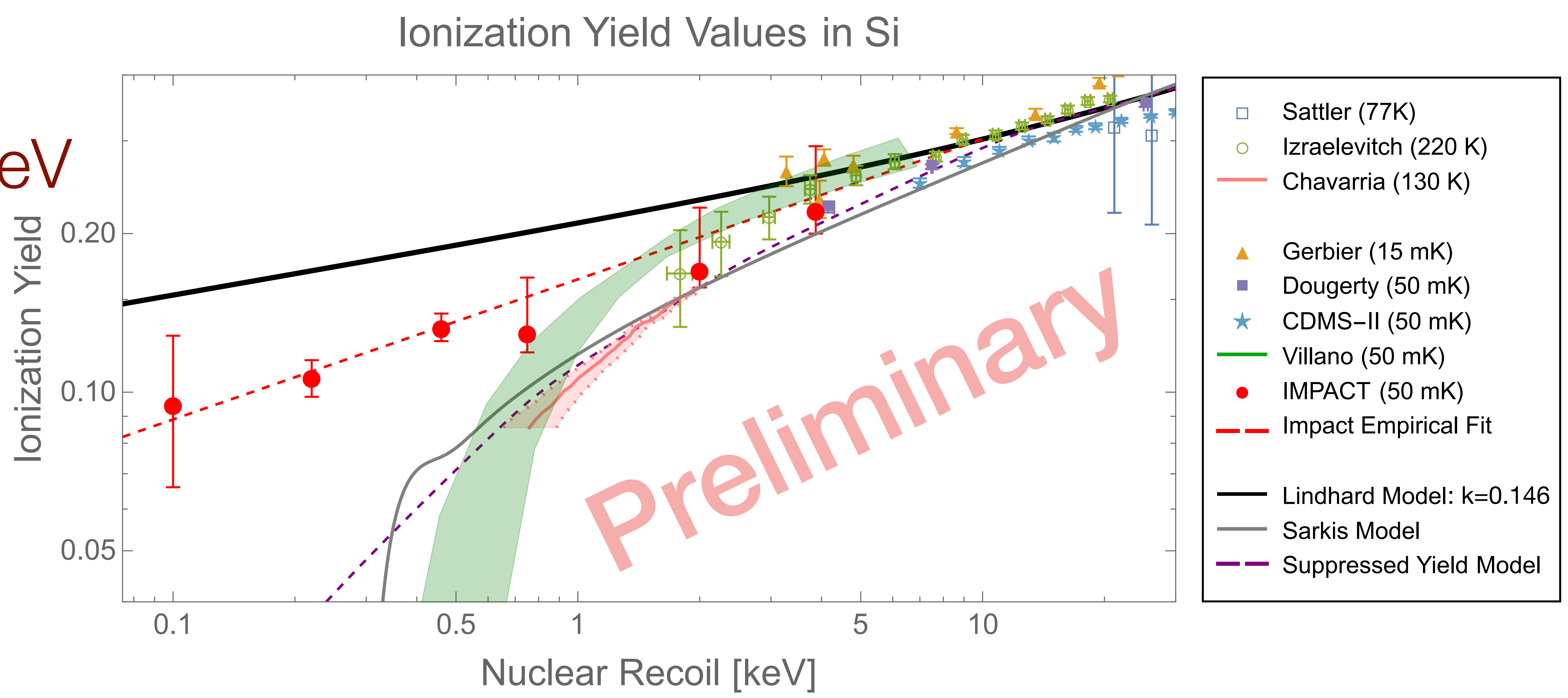


IMPACT@TUNL Si Yield

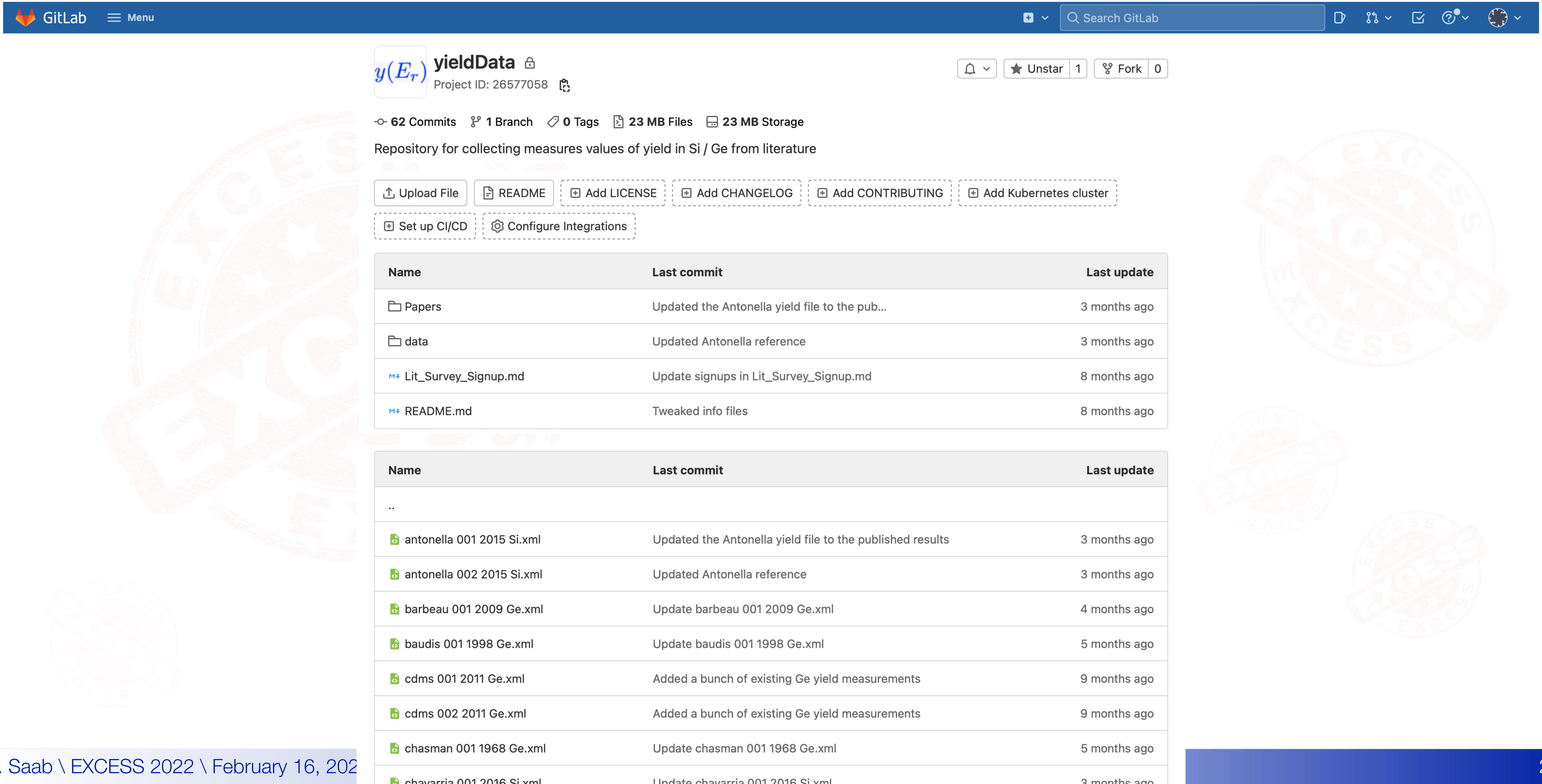


IMPACT in Context

- Variability observed among measurements below 1 keV
- Plan to study effect of electric field using 180 V data
- Evidence of continued ionization production down to 100 eV_r has significant impact for low mass reach of SuperCDMS and other Si based DM experiments
- Plan to repeat with Ge HVeV
  - Tentatively named: "GIMPACT" :)
- Git repository being assembled to collect literature values of yield and operating conditions



If it’s not in Git it’s doesn’t exist :)



If it’s not in Git it’s doesn’t exist :)

GitLab Menu Search GitLab

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Project ID: 26577058

Unstar 1 Fork 0


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Conclusion

... the end