Northwestern

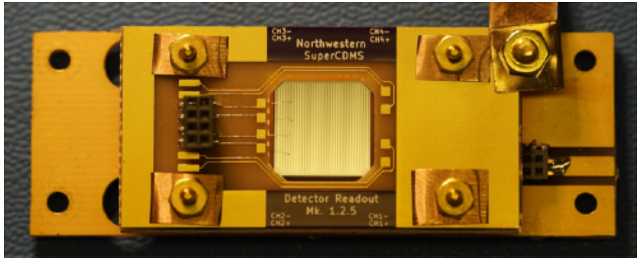
SUPER CDMS
Cryogenic Dark Matter Search

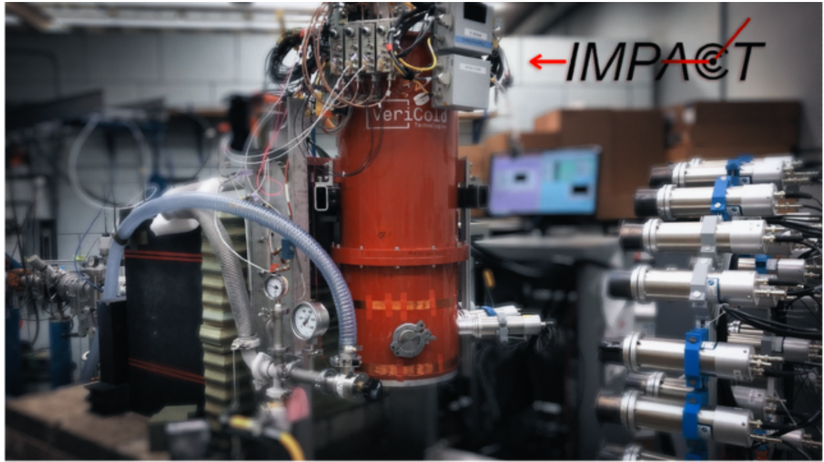
TUNL
Triangle Universities Nuclear Laboratory

IMPACT
Ionization Measurement with Phonons at Cryogenic Temperatures

A sub-keV nuclear recoil ionization yield measurement in Si

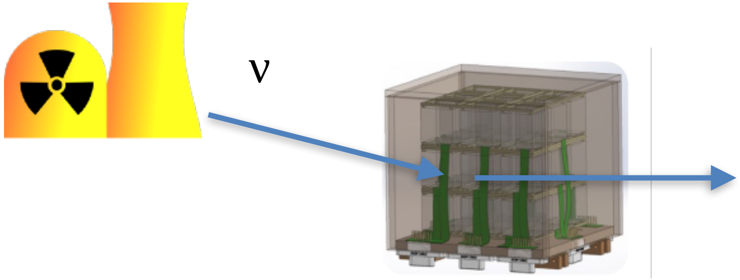
Ben Schmidt for the SuperCDMS collaboration



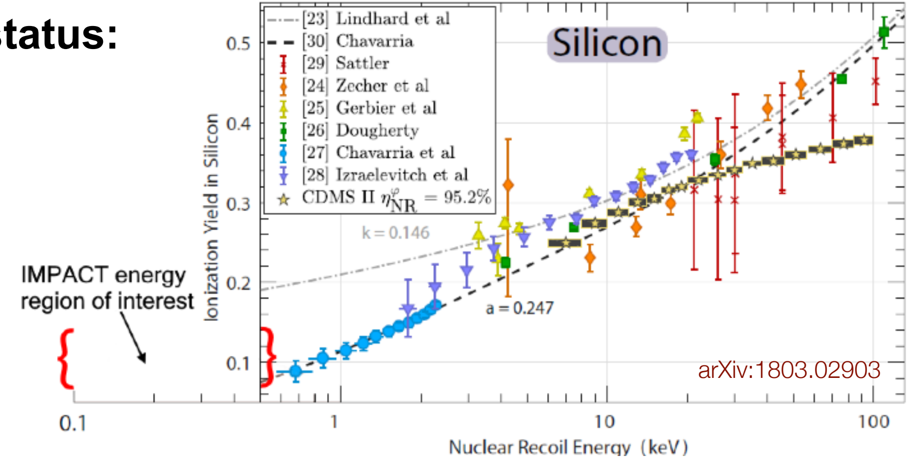


Introduction

Nuclear recoil Ionization yield: Fundamental detector response for ionization sensitive detectors to assess sensitivity to nuclear recoils (WIMP scattering, CEvNS interactions)



Current status:



Measurement with pulsed n-beam

$$E_r = 2E_n \frac{M_n^2}{(M_n+M_T)^2}\left(\frac{M_T}{M_n} + \sin^2\theta - (\cos\theta)\sqrt{\left(\frac{M_T}{M_n}\right)^2 - \sin^2\theta}\right)$$

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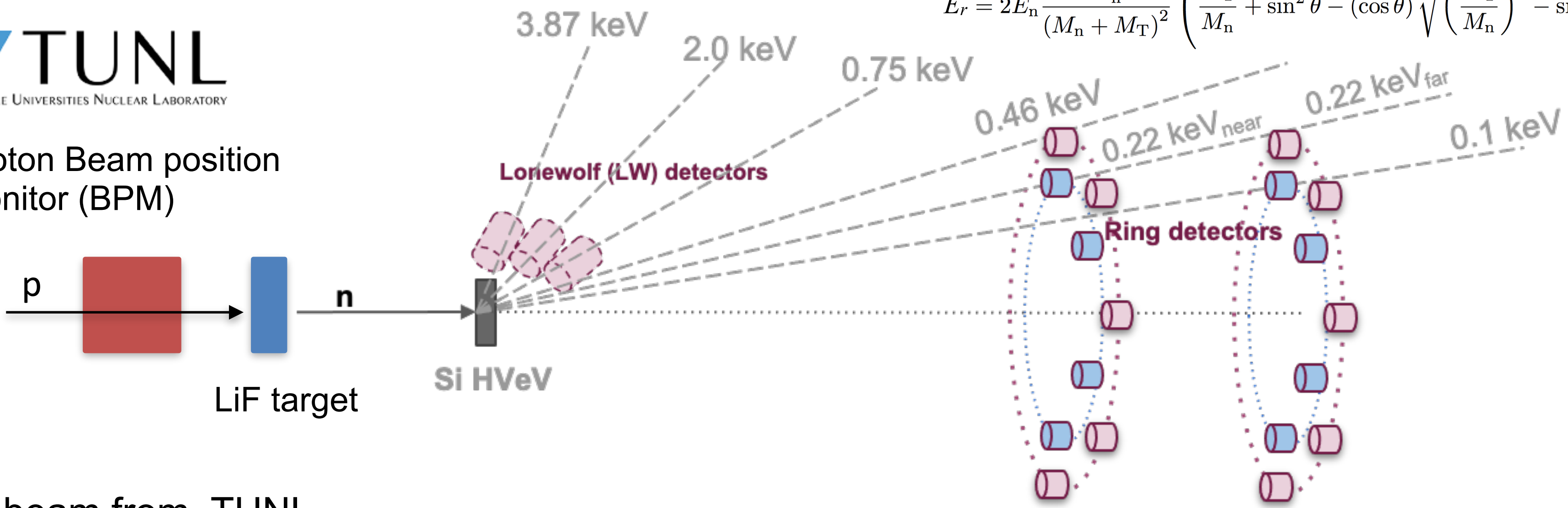
Proton Beam position monitor (BPM)



N-beam from TUNL

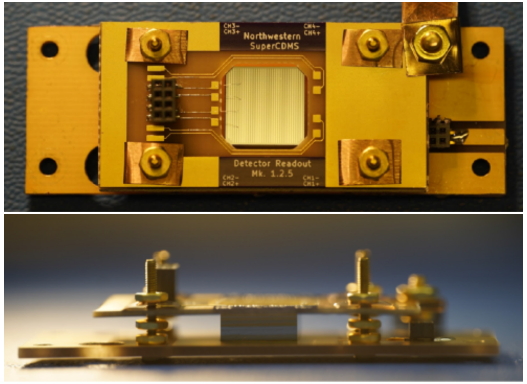
- 1.889 MeV protons with 2.5 MHz pulsing
- LiF-on-Ta target -> ~56 keV low energy n-beam
- Aim for ^{28}Si elastic scattering resonance at 55.7 keV

Detectors

- 1 g Si HVeV detector (SuperCDMS)
- EJ-301/309 liquid scintillator detectors (neutron tag) with PMT

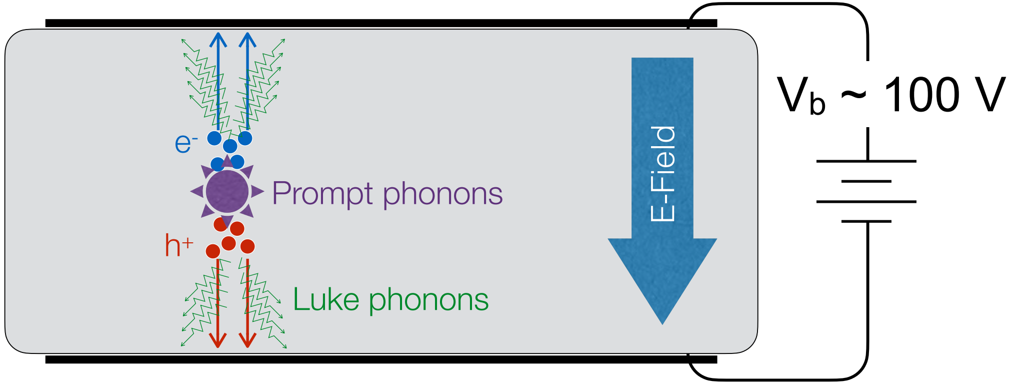
Si HVeV detector

- SuperCDMS HVeV detector
  - Operated at ~50 mK in an adiabatic demagnetization refrigerator (ADR)
  - 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$^+$ (100 V HV)



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

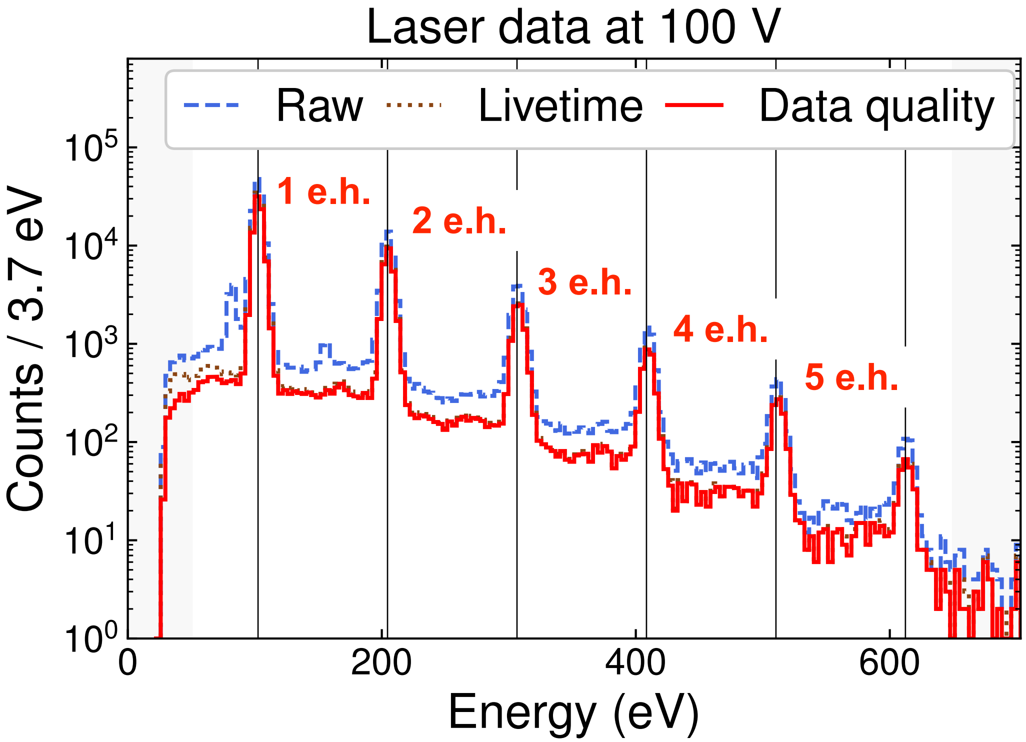
➡0V mode $V_b = 0$: Total energy = Recoil energy
➡HV mode $V_b \neq 0$: Total energy = Recoil energy + NTL energy

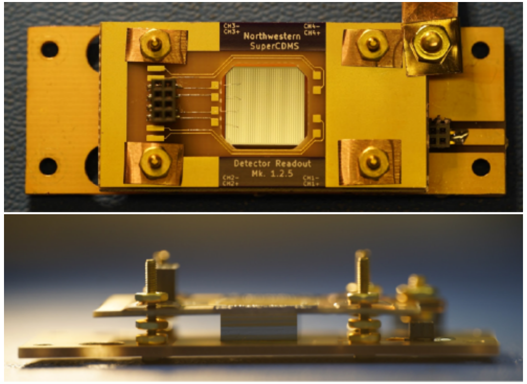


Si HVeV detector

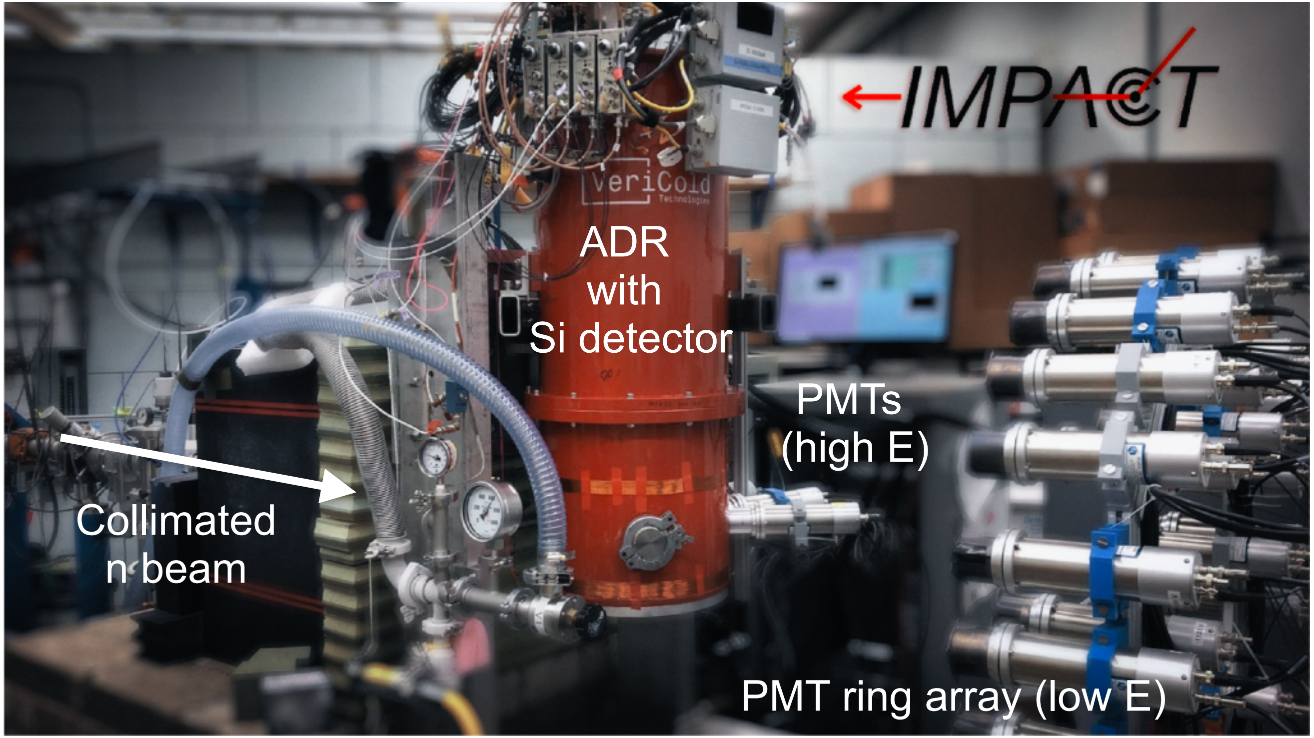
Phys. Rev. D 103, 032010

- SuperCDMS HVeV detector
  - Operated at ~50 mK in an adiabatic demagnetization refrigerator (ADR)
  - 1x1x0.4 cm^3 Si crystal (0.93 g)
  - 2 channel TES readout
  - Energy resolution: $\sigma_{ph} \sim 3$ eV
  - Charge resolution: $\sigma_{eh} \sim 0.03\ e^-h^+$ (100 V HV)





Measurement set-up at TUNL

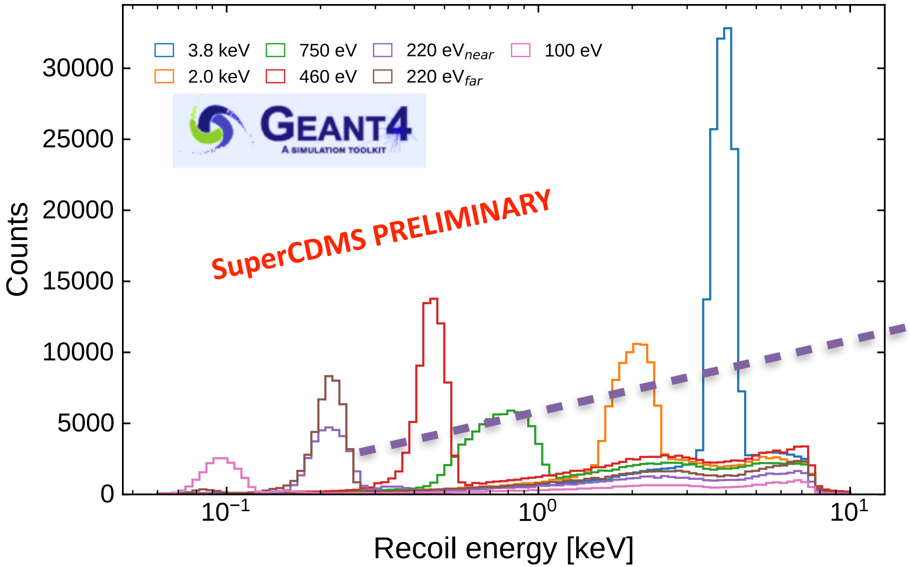


Data taking 2019:

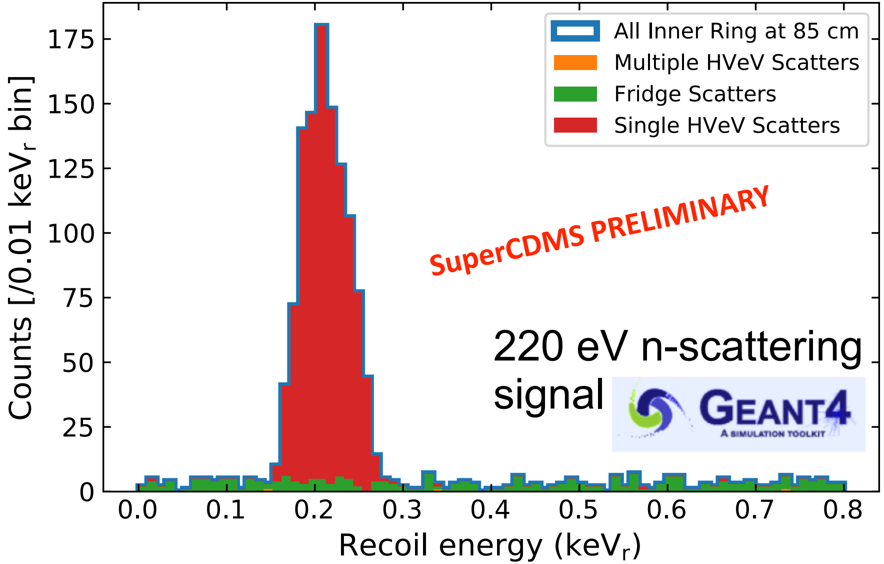
- 3 weeks of data
- 50% duty cycle (ADR cycle)
- Two days at 0 V (Validation data)
- Data taken at 20, 100, and 180 V for exploring yield dependence on the electric field
- **Here: Present 0 V cross-check & 100 V NR yield measurement**

Signal simulation

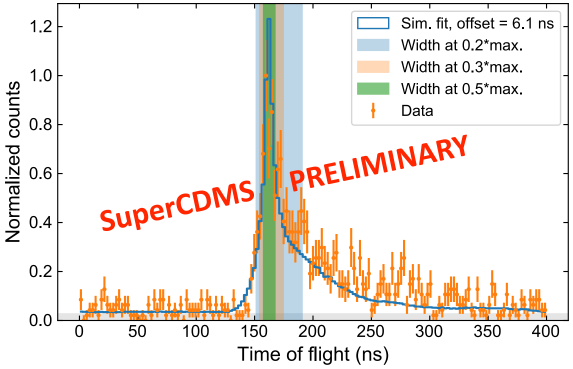
Kinematic n-scattering energy selection

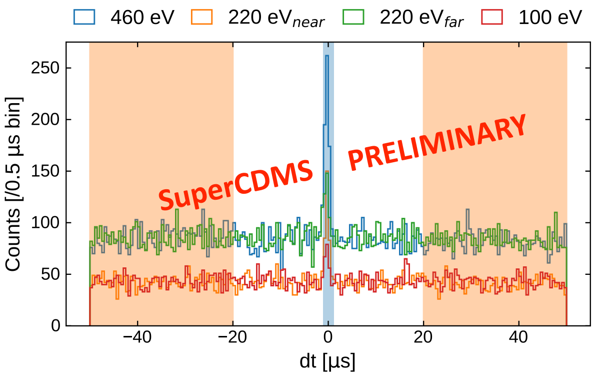


Small Si detectors size suppresses multiple scatters



Data: Coincidence tagging (BPM, PMT, Si)





Small detector
Data quality cuts

+

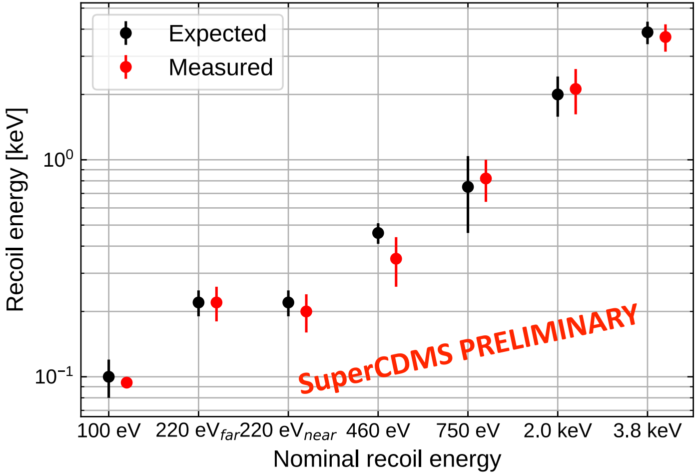
TOF between TUNL **Beam Position Monitor** and **EJ301/EJ309 liquid scintillator**

+

Time difference between **Si HVeV detector** and **PMT backing array**

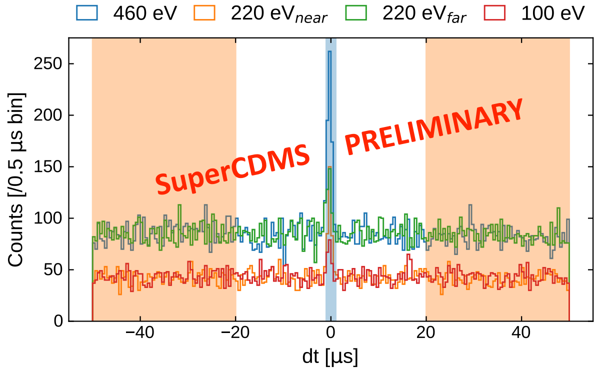
Strong background suppression
Expect a very clean signal

0V cross-check result

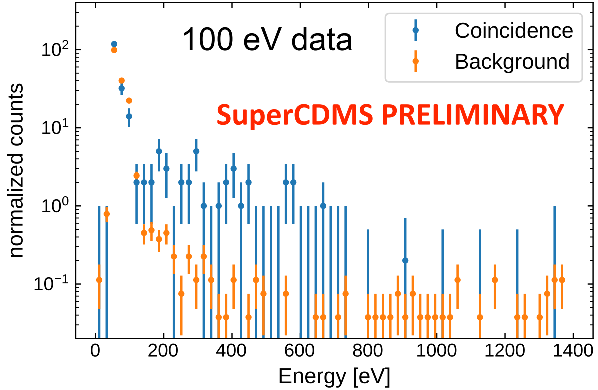


Data consistent with expectation

Data: Coincidence tagging (BPM, PMT, Si)



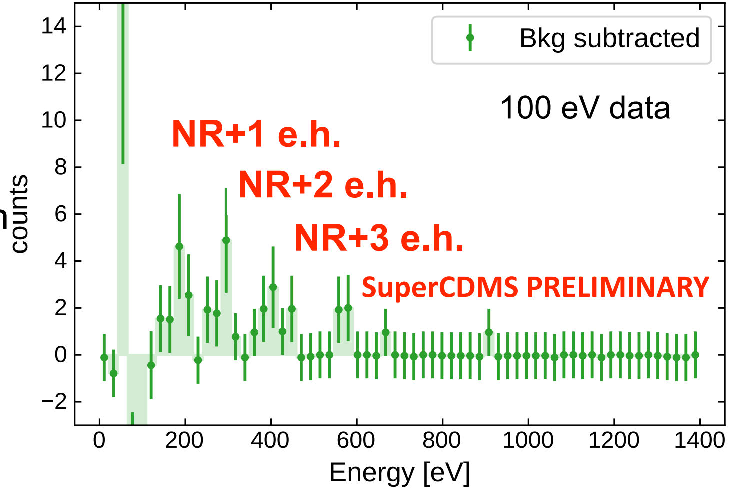
Time difference between **Si HVeV detector** and **PMT backing array**



Blue n-scatter signal
Orange off-beam Bkg estimated from sidebands

Bkg subtraction

100 V Data
Observe quantization!



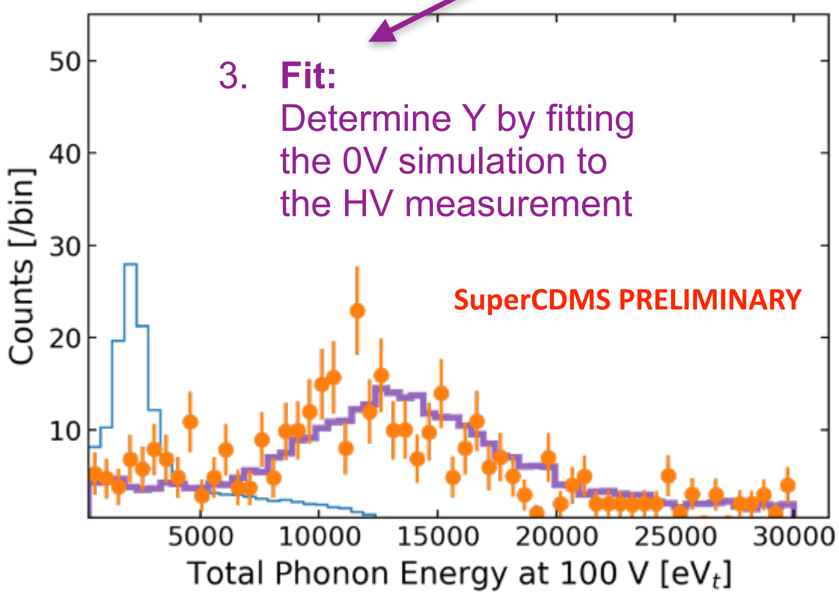
$$E_{total} = E_{recoil} + n_{eh} e V_b = E_{recoil}(1 + eV_b/\epsilon_{eff} \cdot Y)$$

Analysis scheme - Yield measurement

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

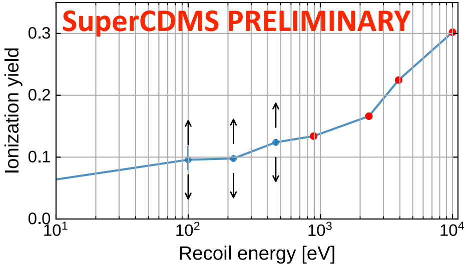


4. **Systematic Uncertainty:**
   - Coincidence timing window
   - Time of flight window
   - Neutron beam energy
   - Detector energy calibration
   - Impact ionization / Charge trapping
   - Fano factor

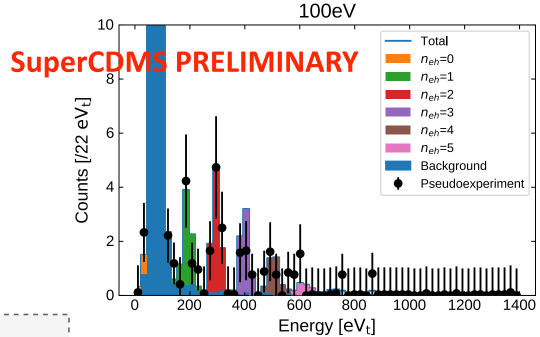
Comp. Phys. Commun.180, 2197

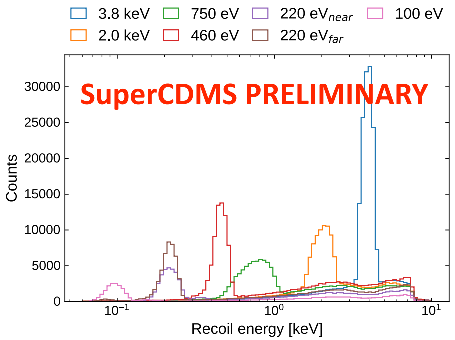
Bayesian Analysis Toolkit

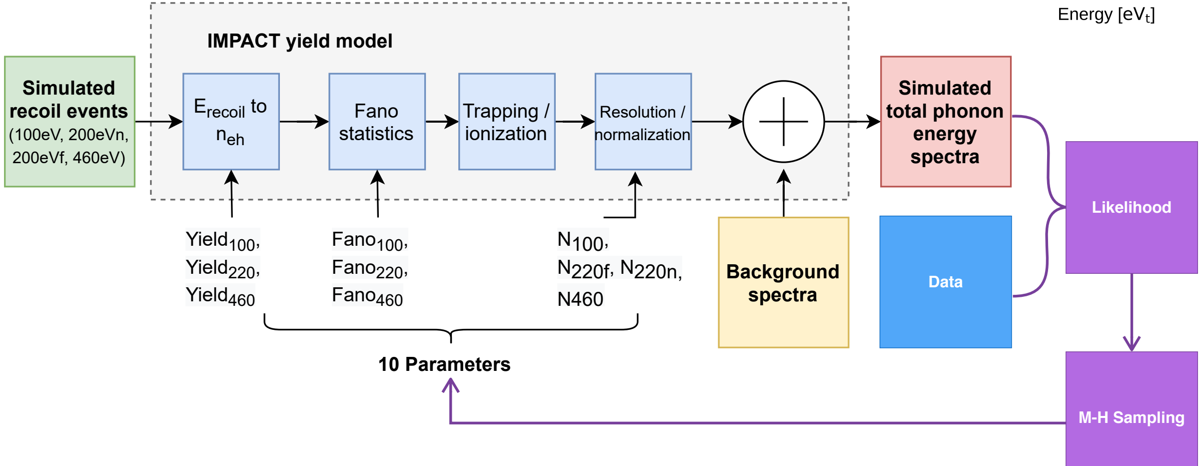
Analysis scheme - 1st fit iteration



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



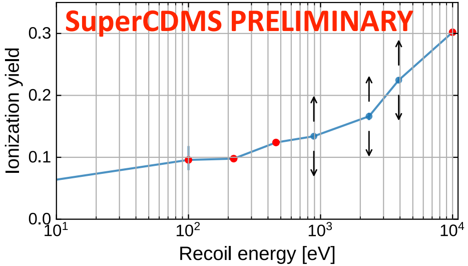




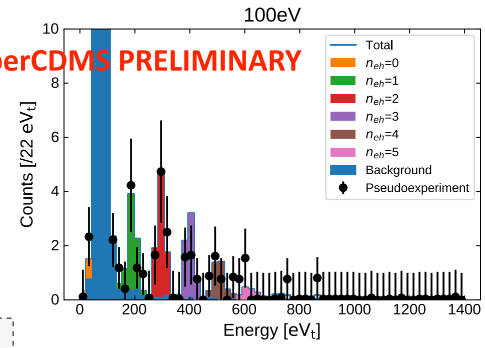
First fit the ring detectors

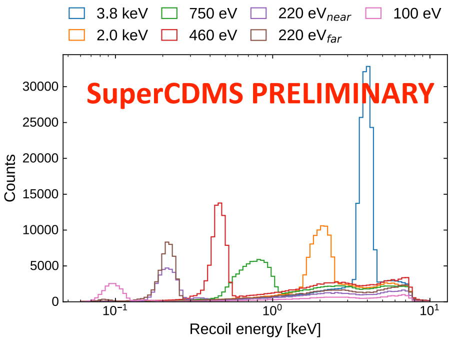
Bayesian Analysis Toolkit

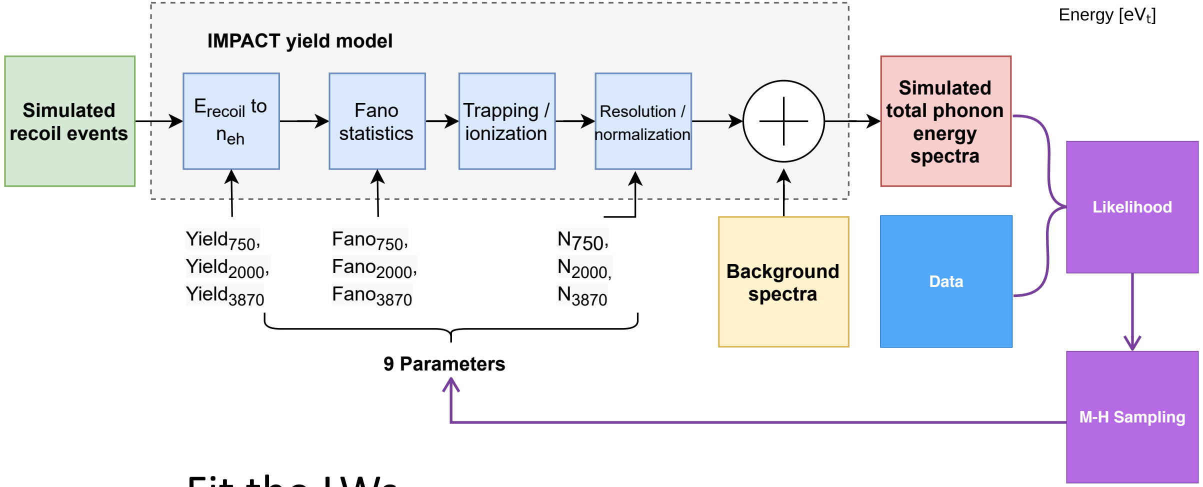
Analysis scheme - 2nd fit iteration



- Linear interpolation between points
- Yield(0 eV) = 0
- Yield (100, 220, 460 eV) as fit (1st it.)
- Yield(10 keV) = $Y_{Chavarria}$



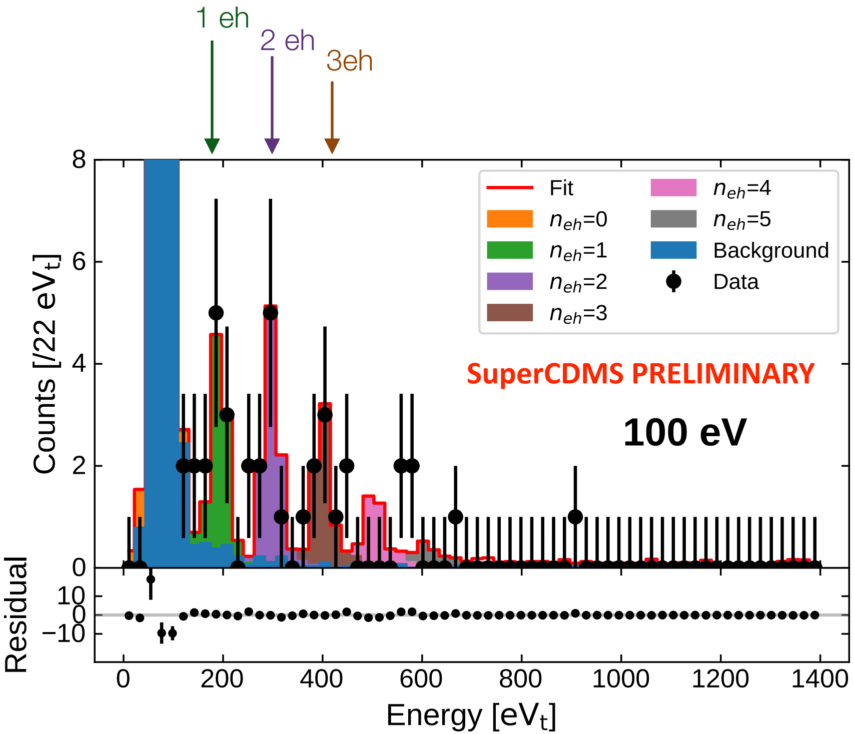


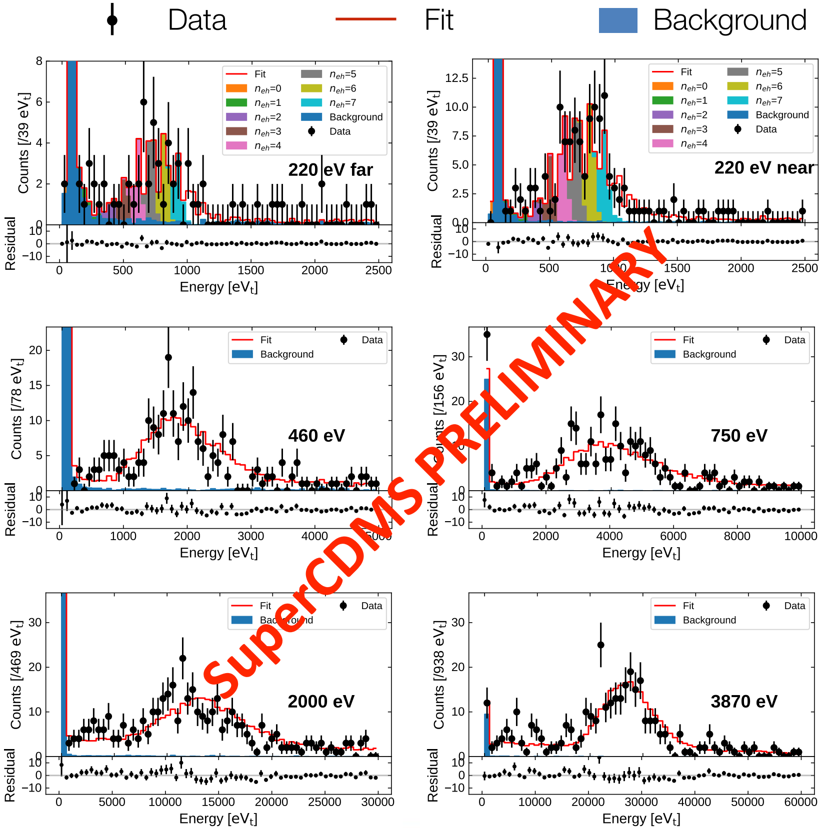


Fit the LWs

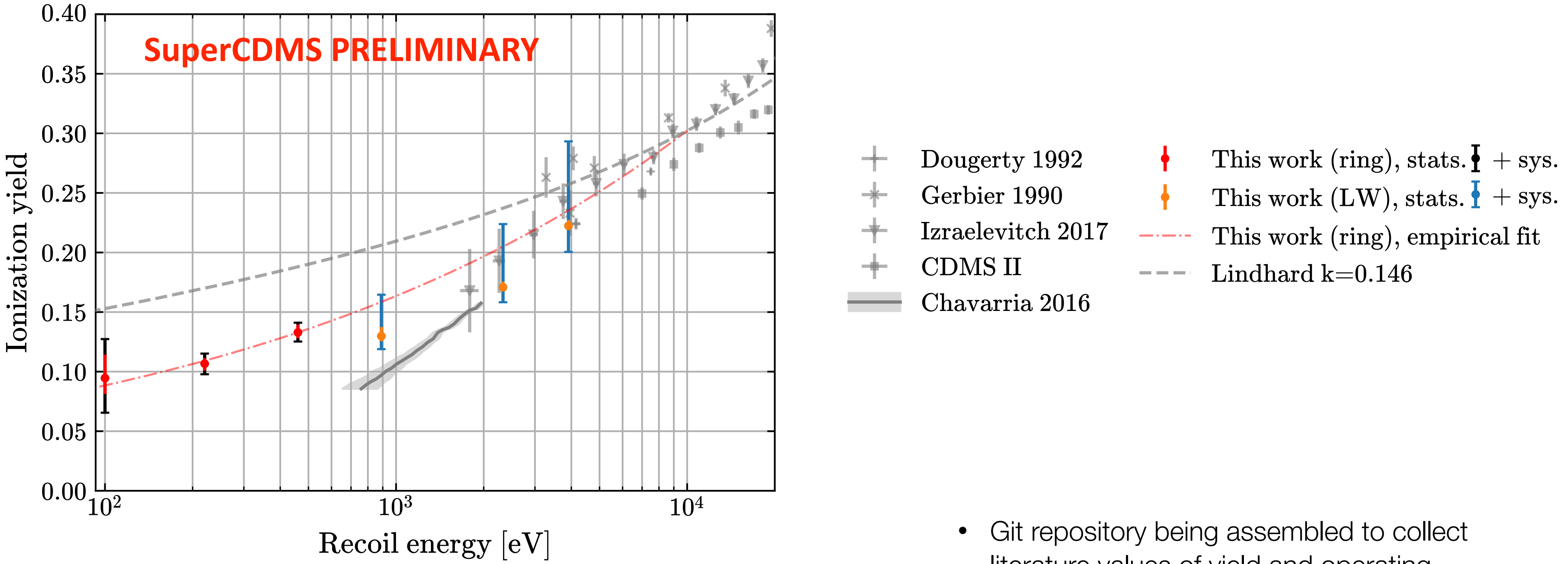
Bayesian Analysis Toolkit

Results: 3rd fit iteration

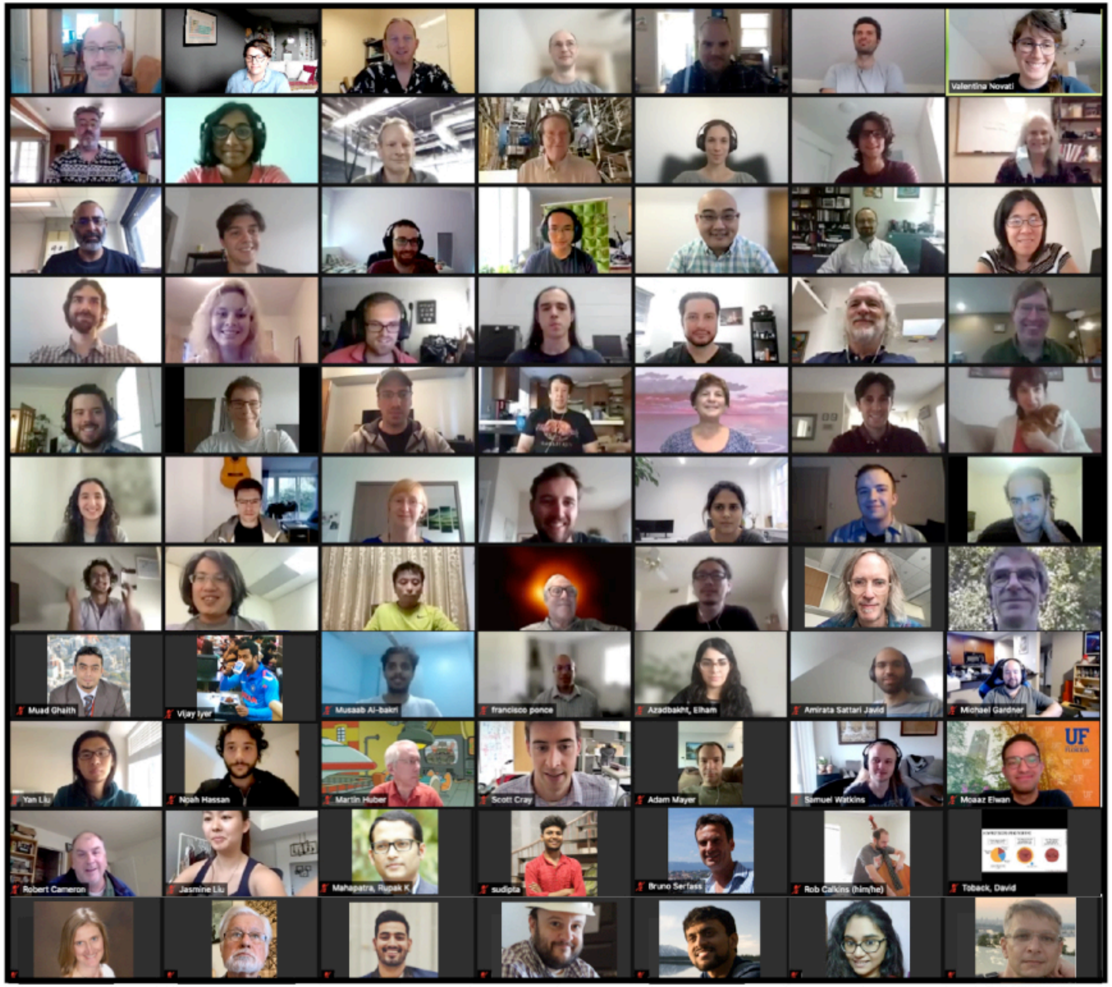




Results



- Git repository being assembled to collect literature values of yield and operating conditions



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Thank you &
we thank the team at

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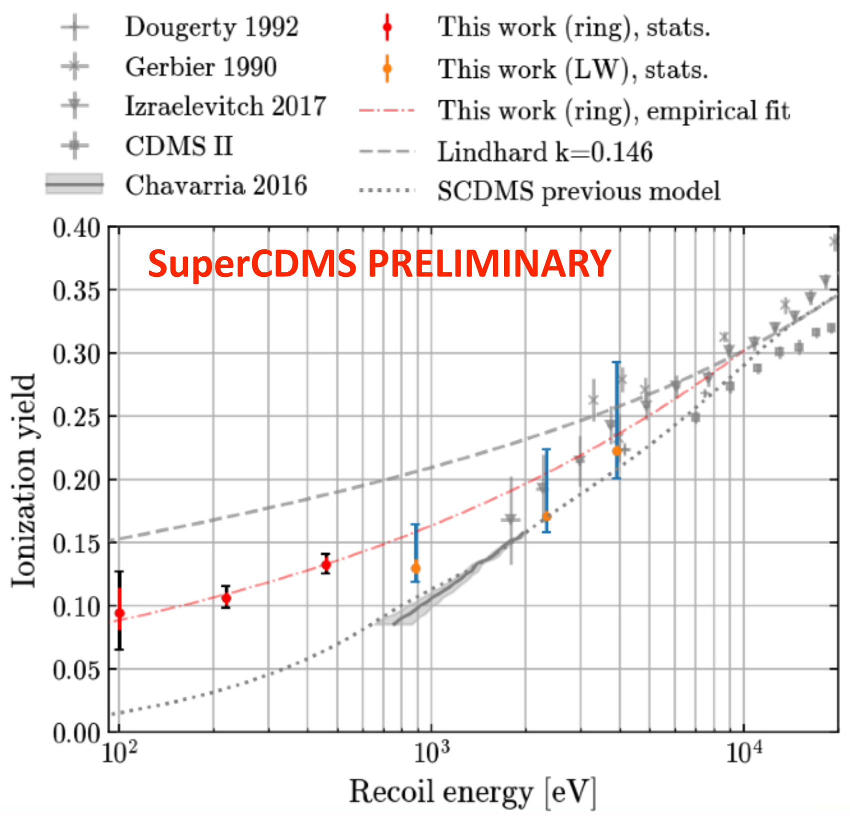

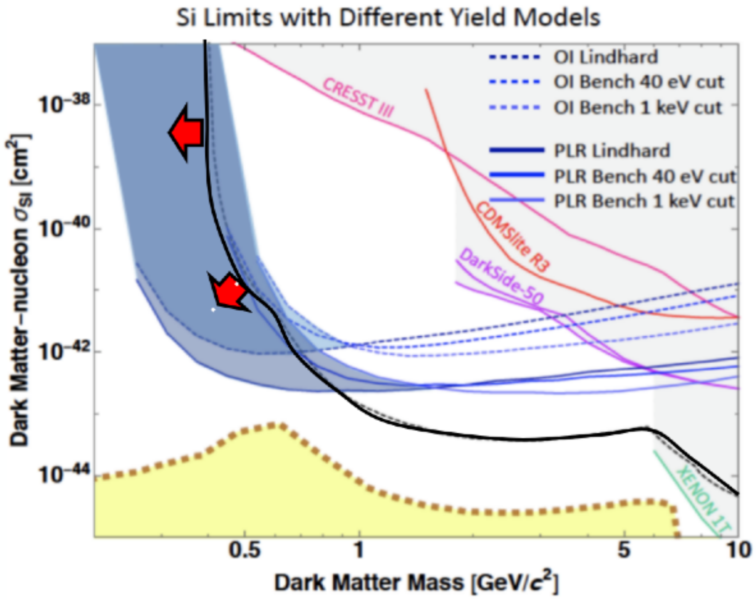

All our Si project limits were all based on a modified Lindhard that passes through Chavarria '16

Systematics on NR ionization yield