SuperCDMS ←IMPACT

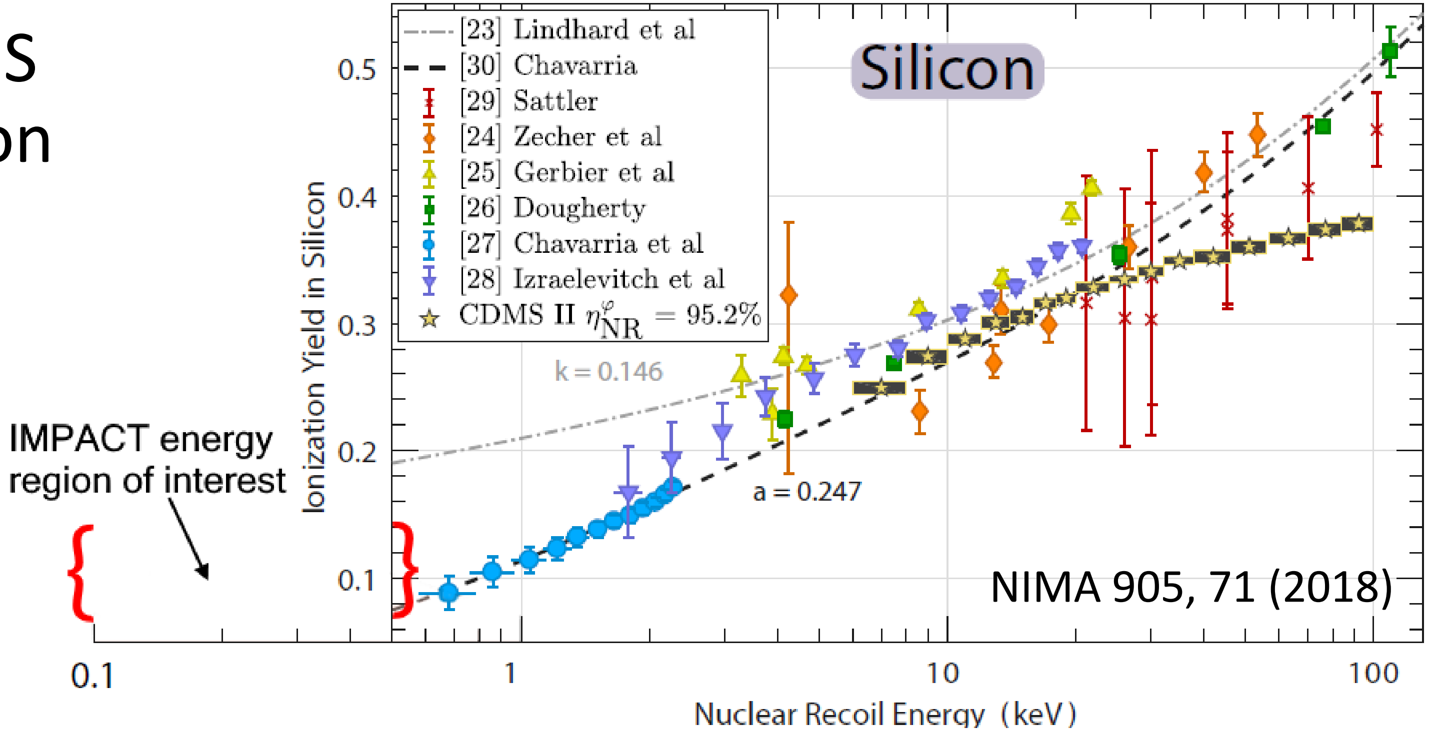
Measuring the sub-keV Ionization Yield in Cryogenic Solid-State Detectors

UNIVERSITY OF TORONTO

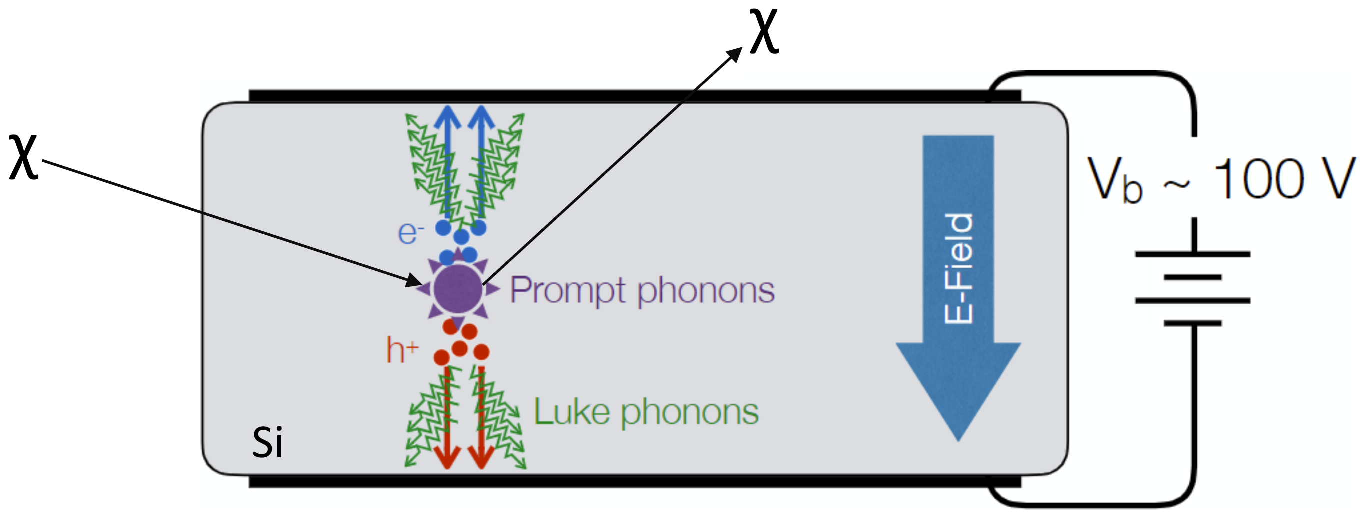
SUPER CDMS Cryogenic Dark Matter Search

Ionization Yield

- Dark matter search and CEvNS experiments can use ionization signals for detection
- Yield = amount of ionization produced per unit deposited energy
  - A material property!
- Recent experiments show deviation from theory



HVeV Detector

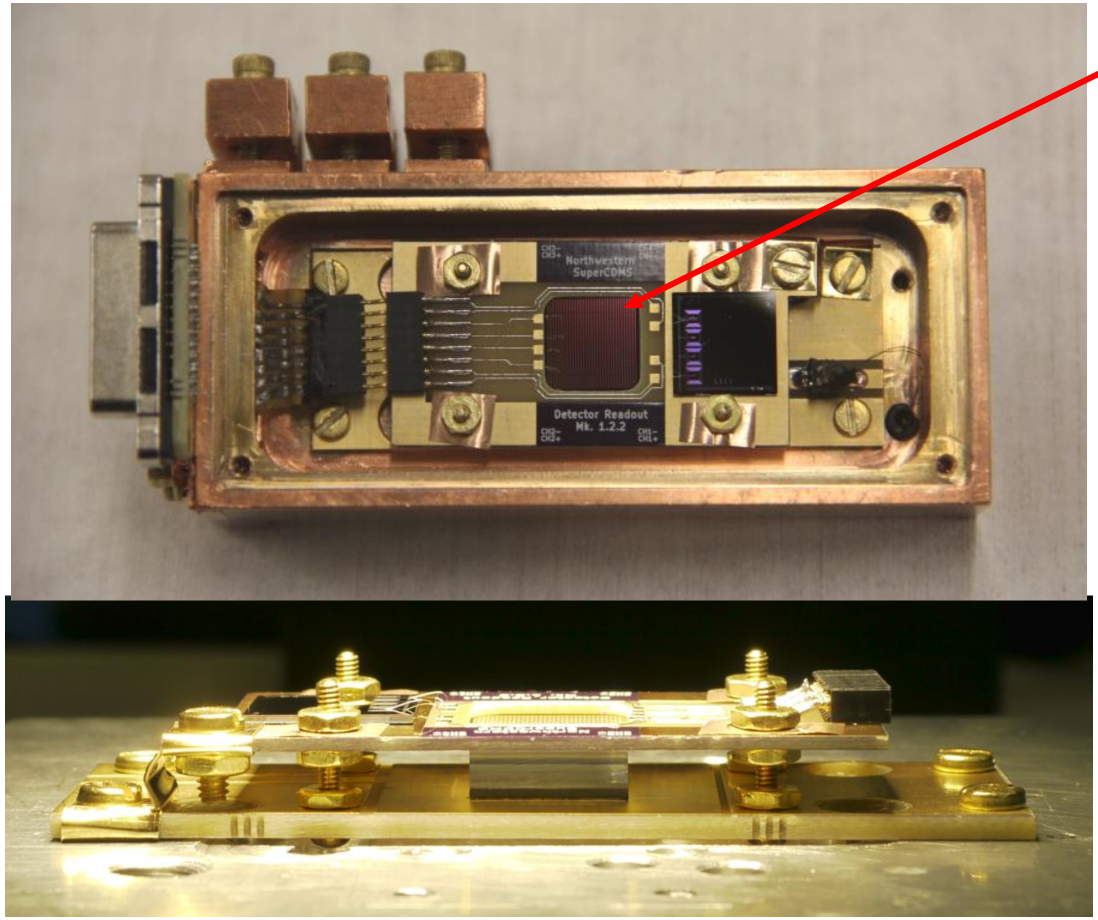


- Particle interactions in Si crystal generate phonons and electron-hole pairs
- NTL effect leads to amplification of total phonon energy

$$E_t = E_R + n_{eh} e V_b$$
$$= E_R\left(1 + Y(E_R)\frac{eV_b}{\varepsilon_{eh}}\right)$$

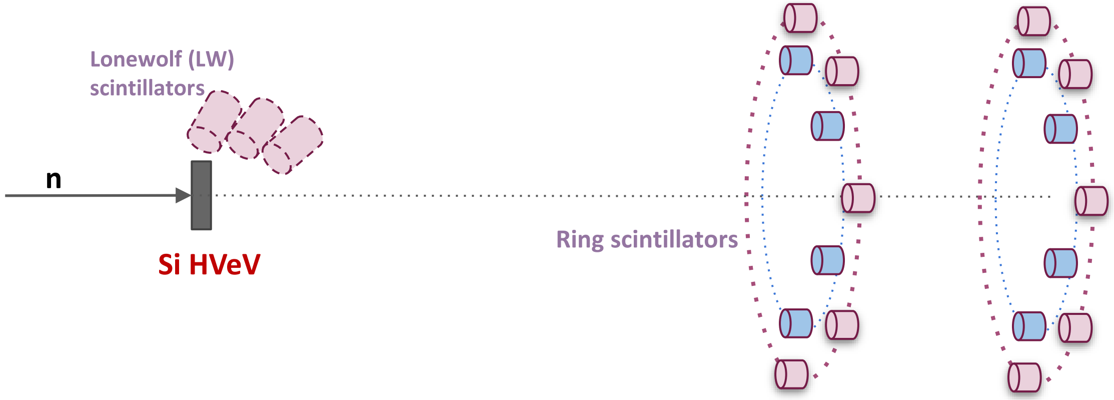
- E_R – recoil energy
- $Y(E_R)$ – ionization yield
  - Y = 1 for electron recoils
  - Y < 1 for nuclear recoils
- ϵ_{eh} = 3.8 eV – average electron-hole pair production energy in Si

HVeV Detector



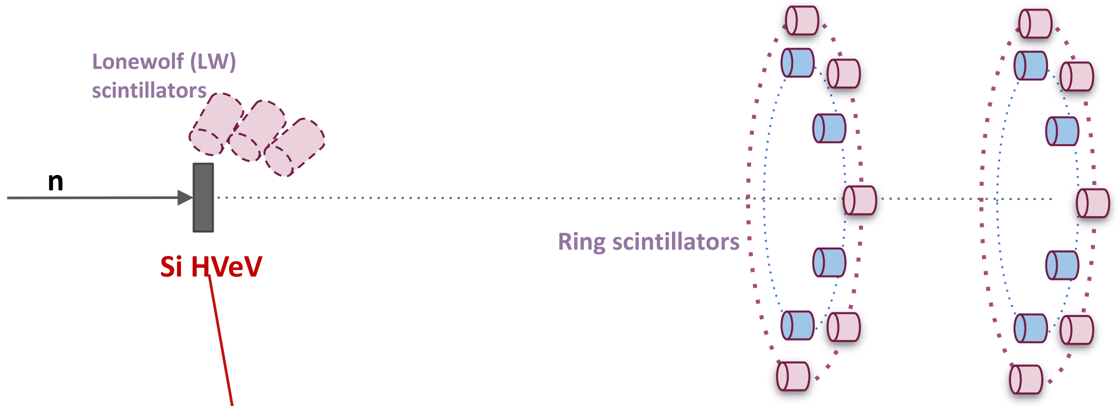
- 1 g Si chip (4 mm x 1 cm^2)
- 3 eV resolution
- Two channel readout
- More details: PRD 104, 032010

IMPACT: Measuring the Yield



$$E_t = E_R\left(1 + Y(E_R)\frac{eV_b}{\varepsilon_{eh}}\right)$$

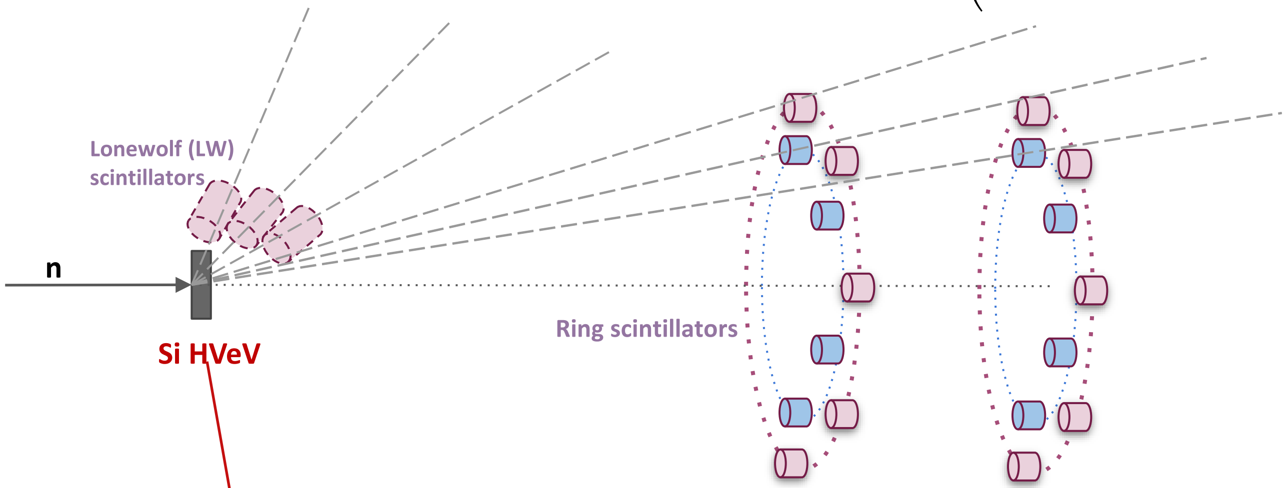
IMPACT: Measuring the Yield



$$E_t = E_R\left(1 + Y(E_R)\frac{eV_b}{\varepsilon_{eh}}\right)$$

IMPACT: Measuring the Yield

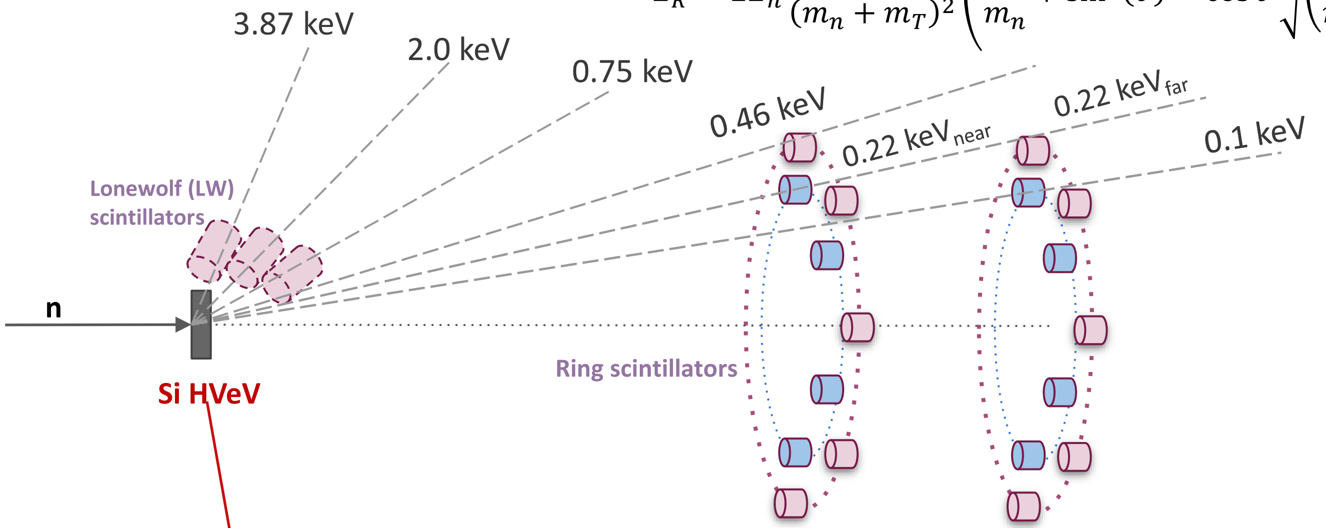
$$E_R = 2E_n \frac{m_n^2}{(m_n + m_T)^2}\left(\frac{m_T}{m_n} + \sin^2(\theta) - \cos\theta \sqrt{\left(\frac{m_T}{m_n}\right)^2 - \sin^2(\theta)}\right)$$



$$E_t = E_R\left(1 + Y(E_R)\frac{eV_b}{\varepsilon_{eh}}\right)$$

IMPACT: Measuring the Yield

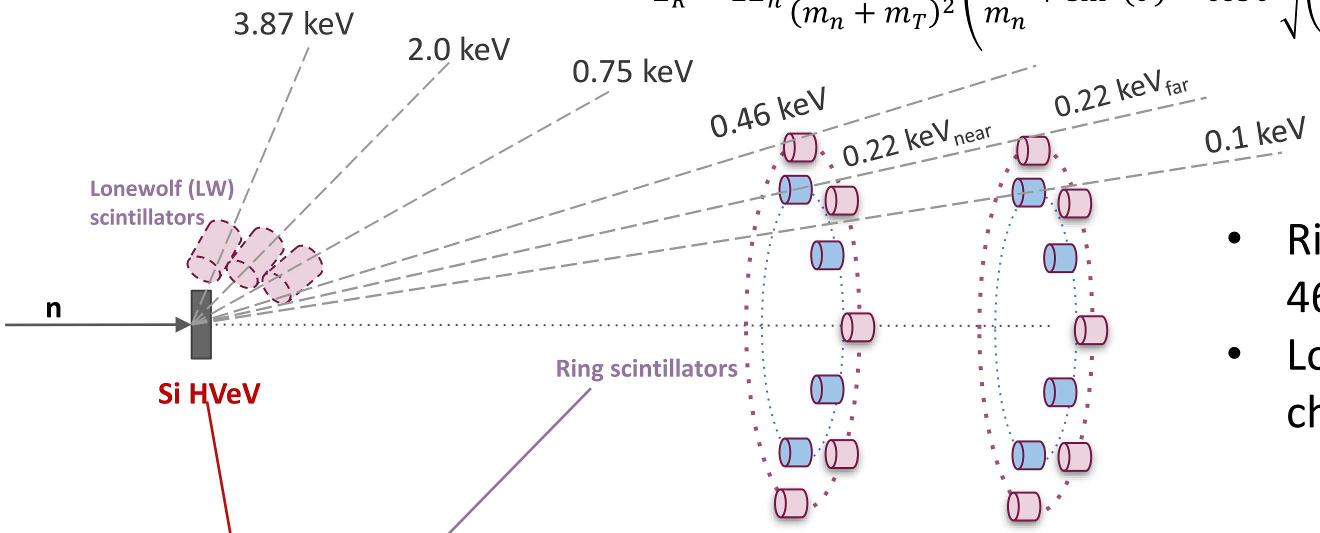
$$E_R = 2E_n \frac{m_n^2}{(m_n + m_T)^2}\left(\frac{m_T}{m_n} + \sin^2(\theta) - \cos\theta \sqrt{\left(\frac{m_T}{m_n}\right)^2 - \sin^2(\theta)}\right)$$



$$E_t = E_R\left(1 + Y(E_R)\frac{eV_b}{\varepsilon_{eh}}\right)$$

IMPACT: Measuring the Yield

$$E_R = 2E_n \frac{m_n^2}{(m_n + m_T)^2}\left(\frac{m_T}{m_n} + \sin^2(\theta) - \cos\theta \sqrt{\left(\frac{m_T}{m_n}\right)^2 - \sin^2(\theta)}\right)$$



$$E_t = E_R\left(1 + Y(E_R)\frac{eV_b}{\varepsilon_{eh}}\right)$$

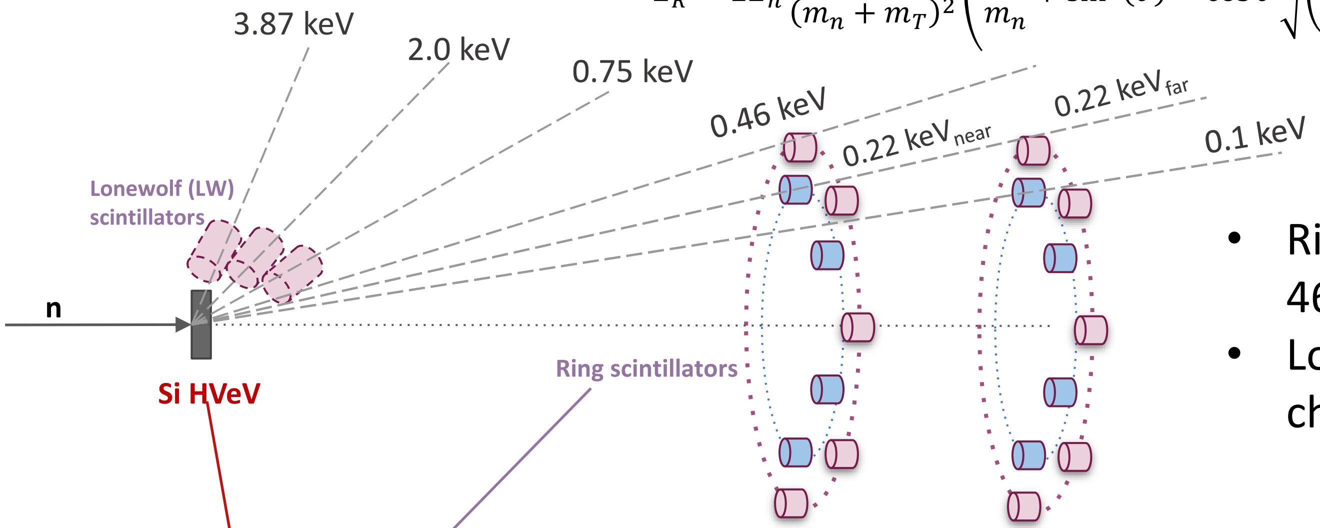
- Ring detectors (100, 220, 460 eV) – new territory
- Lone wolves (0.75, 2, 3.87 keV) – characterized by previous data

UNIVERSITY OF TORONTO

SUPER CDMS Cryogenic Dark Matter Search

IMPACT: Measuring the Yield

$$E_R = 2E_n \frac{m_n^2}{(m_n + m_T)^2}\left(\frac{m_T}{m_n} + \sin^2(\theta) - \cos\theta\sqrt{\left(\frac{m_T}{m_n}\right)^2 - \sin^2(\theta)}\right)$$



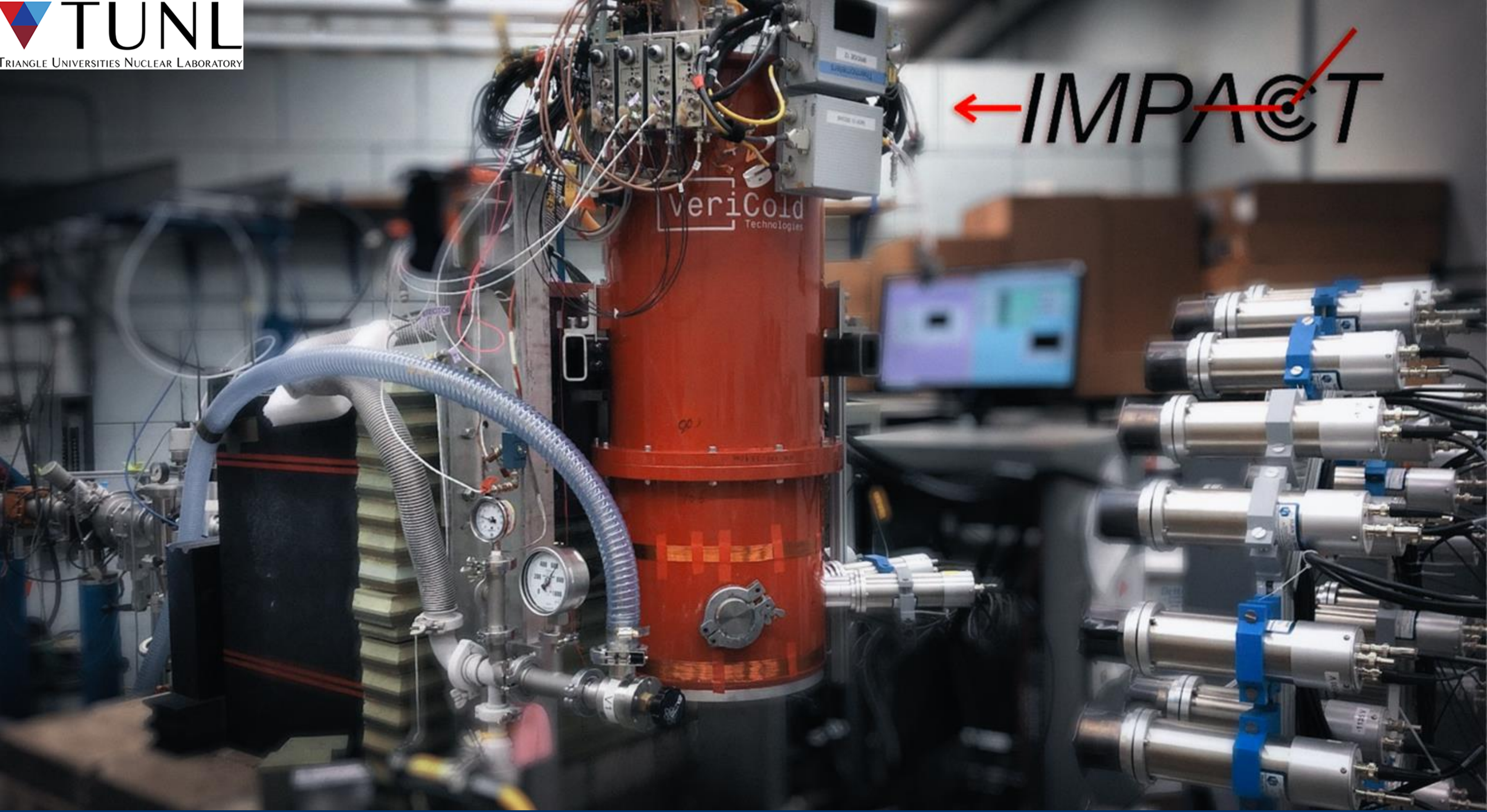
- Ring detectors (100, 220, 460 eV) – new territory
- Lone wolves (0.75, 2, 3.87 keV) – characterized by previous data

$$E_t = E_R\left(1 + Y(E_R)\frac{eV_b}{\varepsilon_{eh}}\right)$$

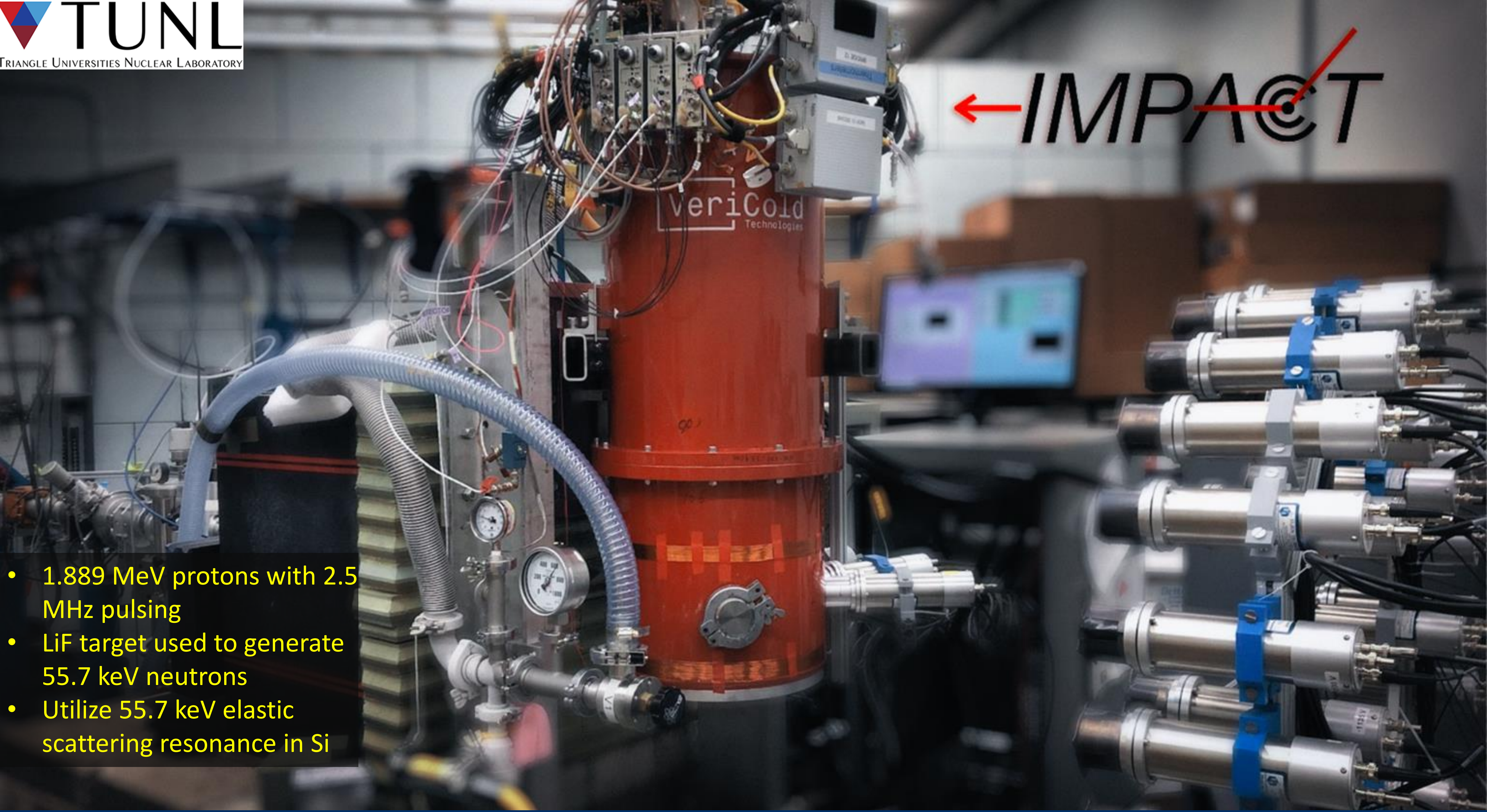
- 0 V – validation of setup
- 20, 100, 180 V – explore electric field dependence
    - This talk covers the 0 V and 100 V data (14 days)

TUNL
Triangle Universities Nuclear Laboratory

IMPACT



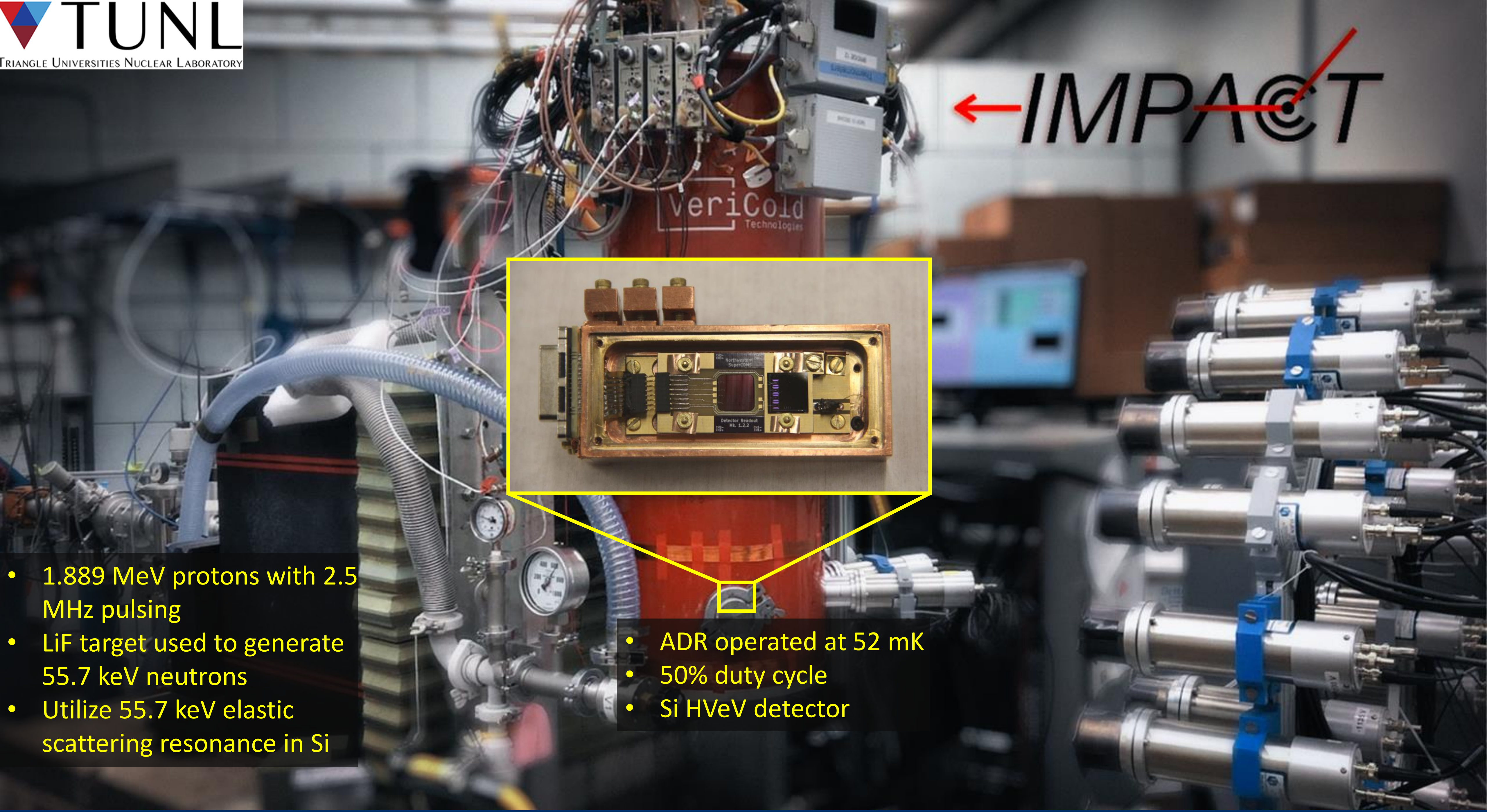
TUNL
Triangle Universities Nuclear Laboratory



- 1.889 MeV protons with 2.5 MHz pulsing
- LiF target used to generate 55.7 keV neutrons
- Utilize 55.7 keV elastic scattering resonance in Si

TUNL
Triangle Universities Nuclear Laboratory

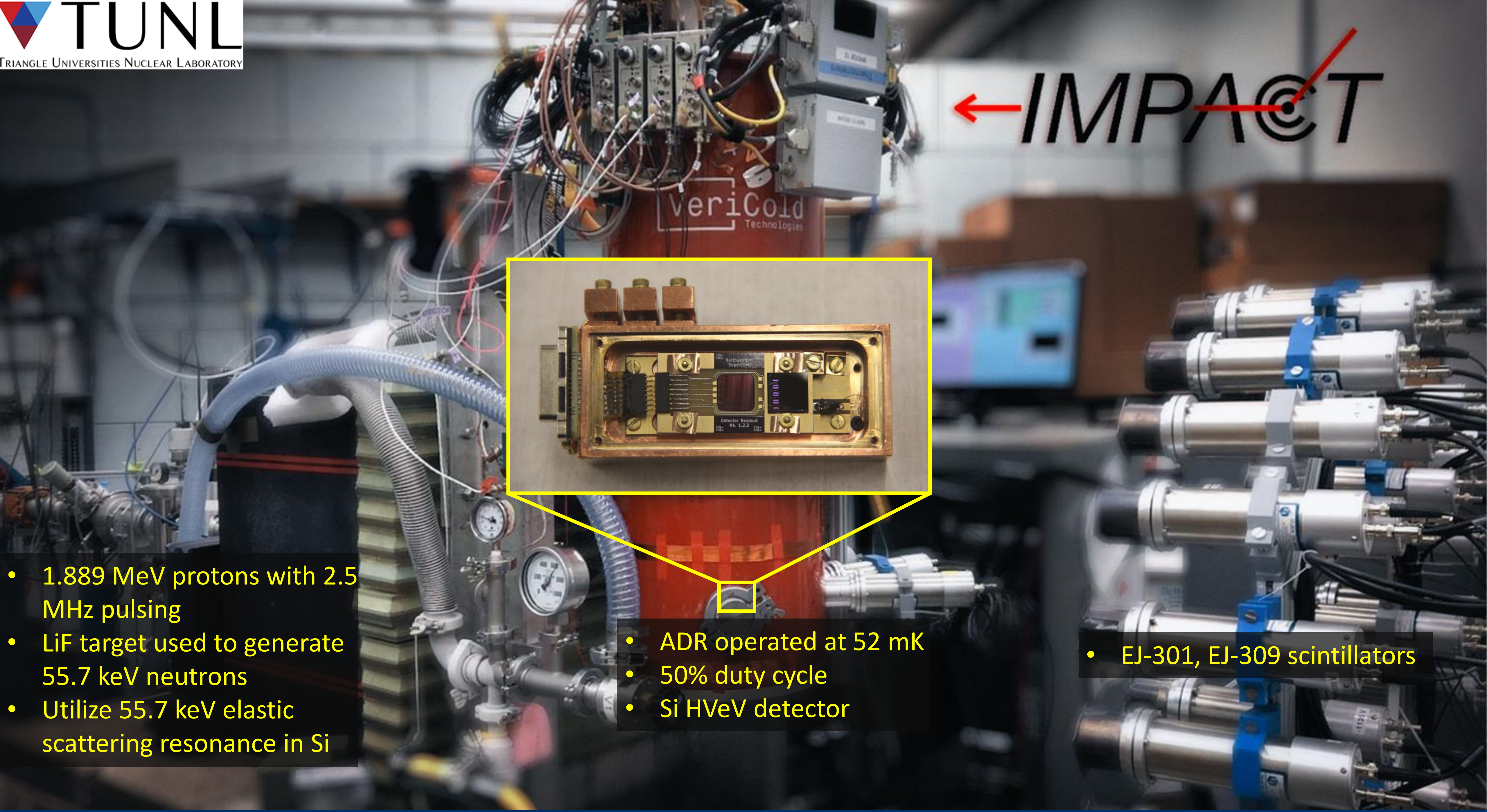
IMPACT



- 1.889 MeV protons with 2.5 MHz pulsing
- LiF target used to generate 55.7 keV neutrons
- Utilize 55.7 keV elastic scattering resonance in Si

- ADR operated at 52 mK
- 50% duty cycle
- Si HVeV detector

TUNL
TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

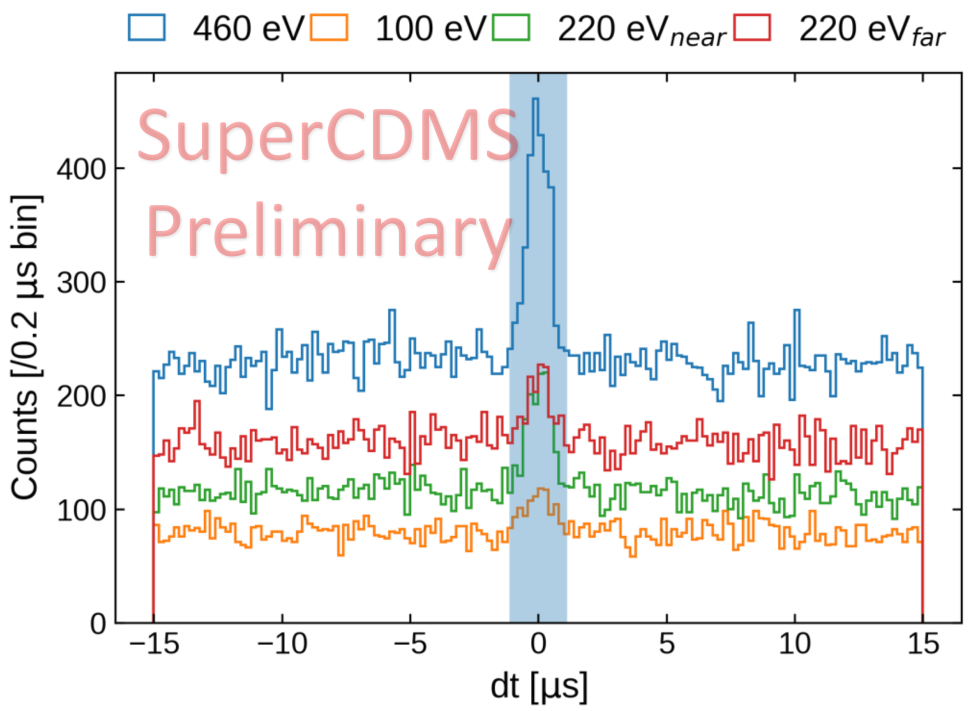


- 1.889 MeV protons with 2.5 MHz pulsing
- LiF target used to generate 55.7 keV neutrons
- Utilize 55.7 keV elastic scattering resonance in Si

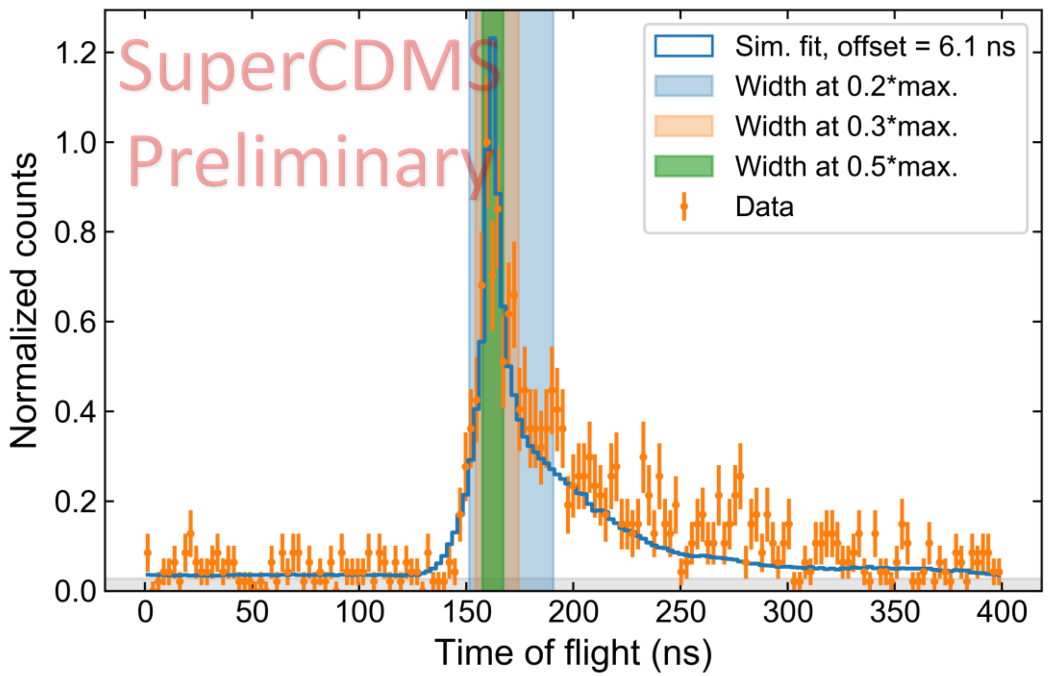
- ADR operated at 52 mK
- 50% duty cycle
- Si HVeV detector

- EJ-301, EJ-309 scintillators

Data Analysis: Cuts

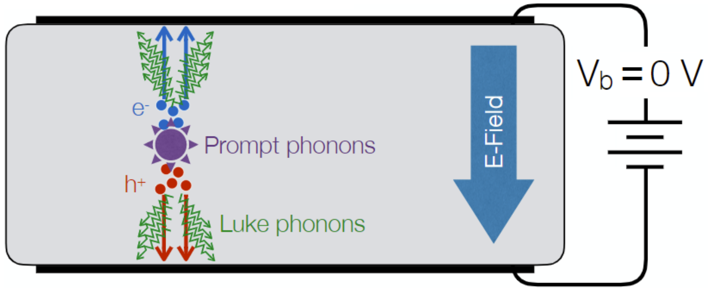


Cut on time difference between energy depositions in Si detector and PMTs to remove random coincidence



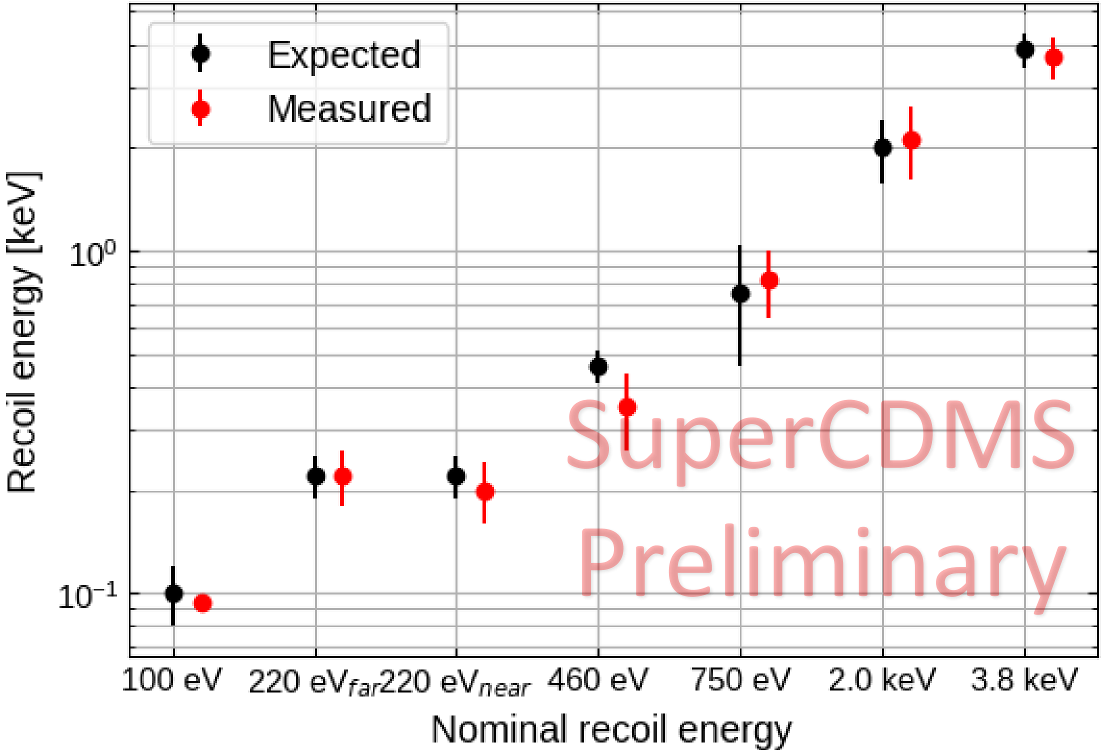
Cut on time of flight between beam pickup monitor and PMT energy deposition to reduce neutron backgrounds

Data Analysis: 0 V Validation



$$E_t = E_R + n_{eh} e V_b$$
$$= E_R$$

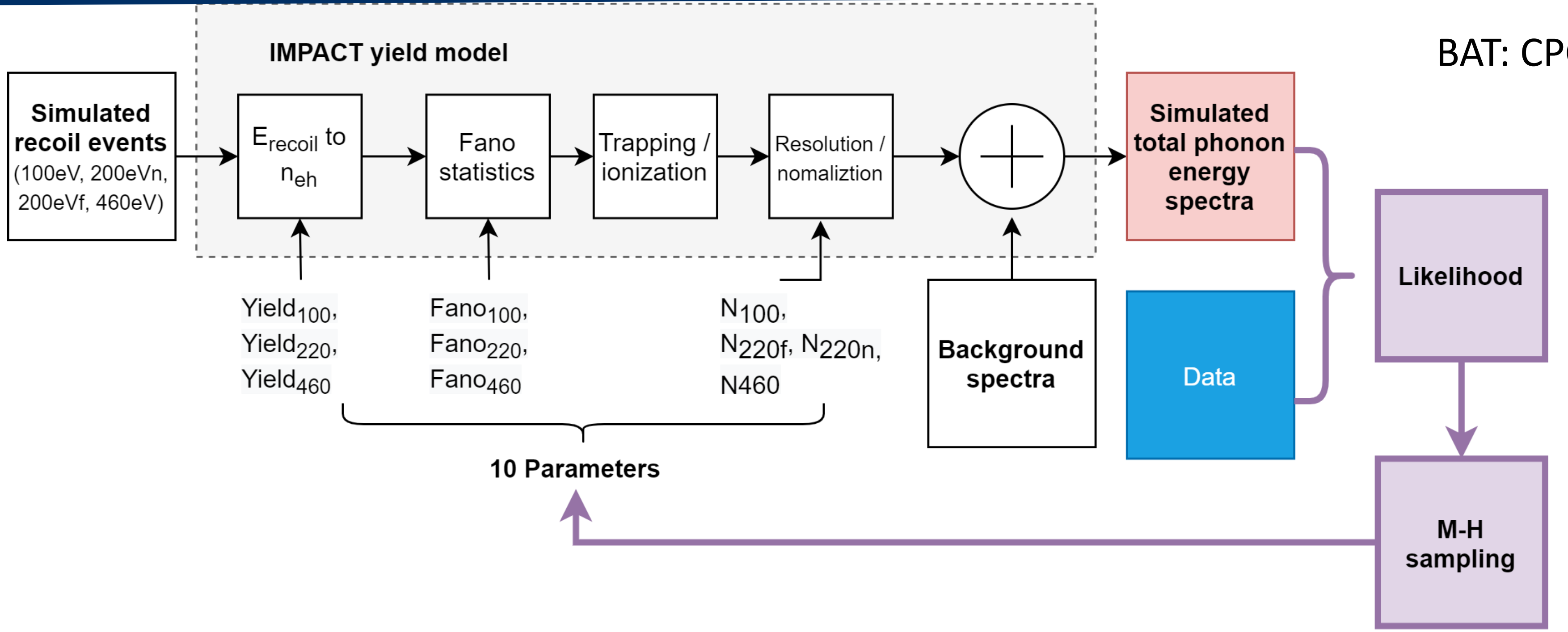
Si detector data at 0 V provides validation of recoil energies measured by PMTs



Extracting the Yield with BAT

BAYESIAN ANALYSIS TOOLKIT

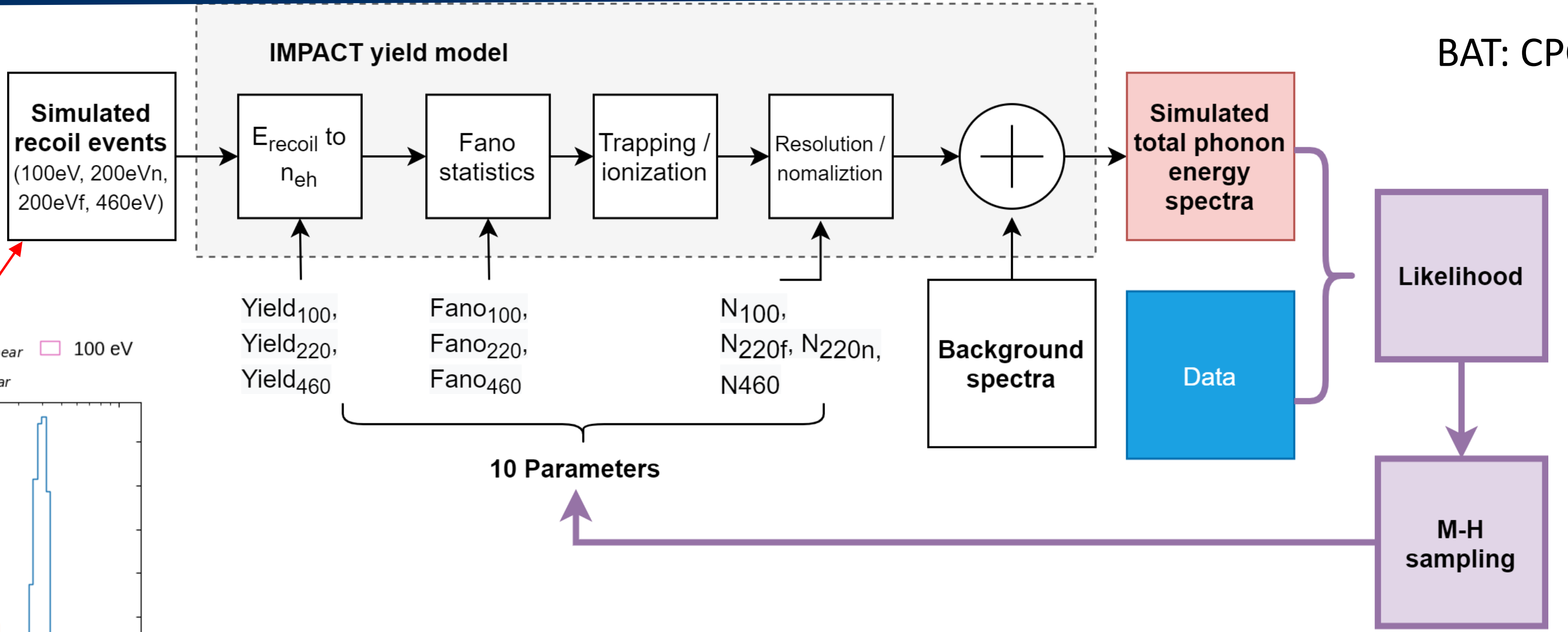
BAT: CPC 180 2197

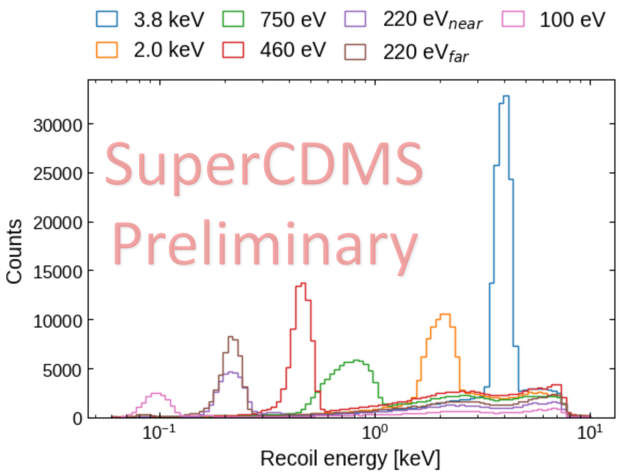


Extracting the Yield with BAT

BAYESIAN ANALYSIS TOOLKIT

BAT: CPC 180 2197

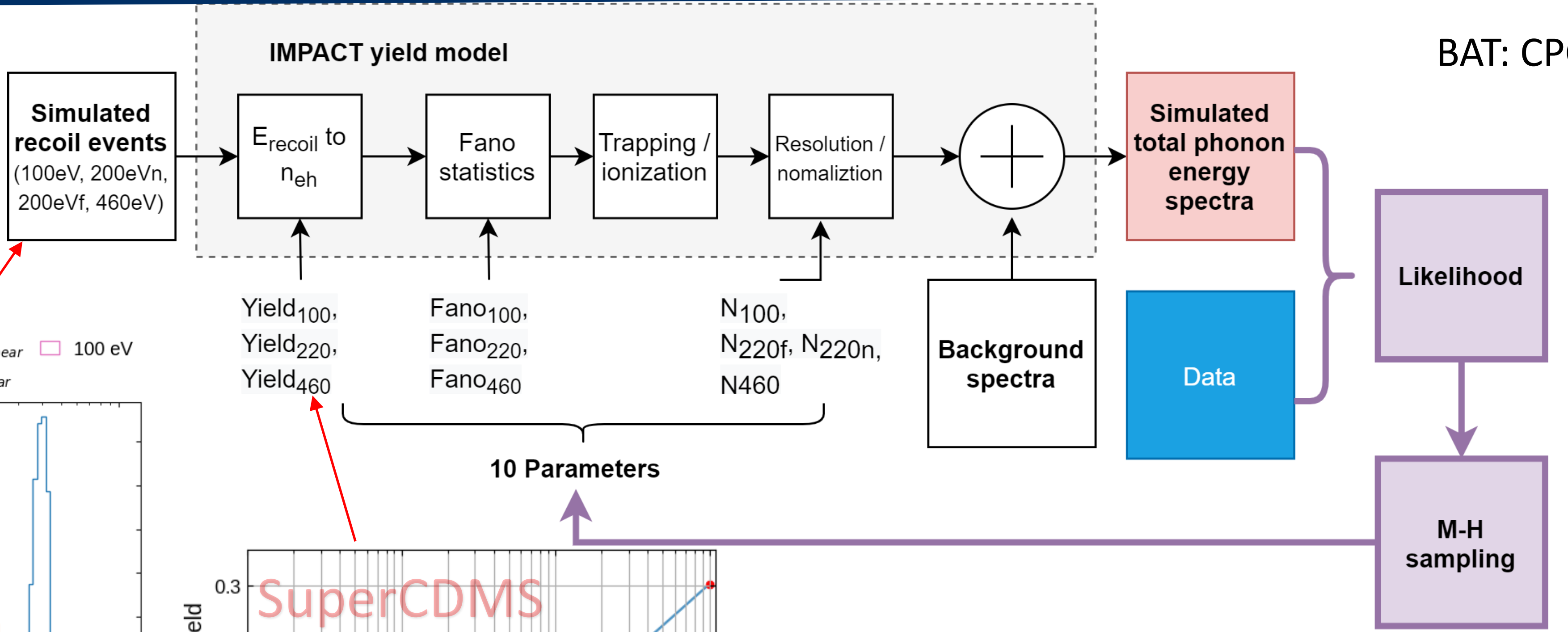


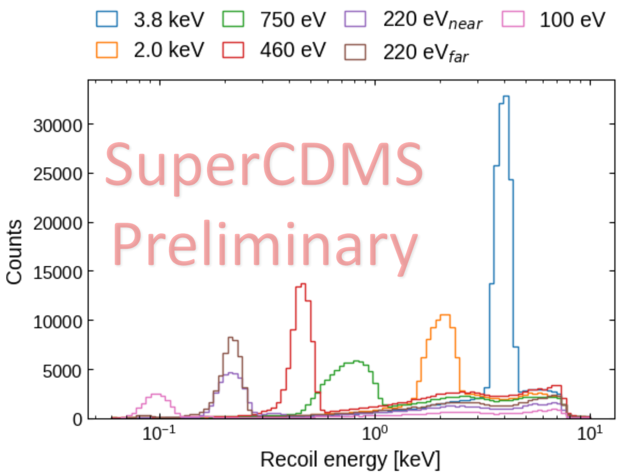


Simulate neutron kinematics with GEANT4 (PRA 506 250)

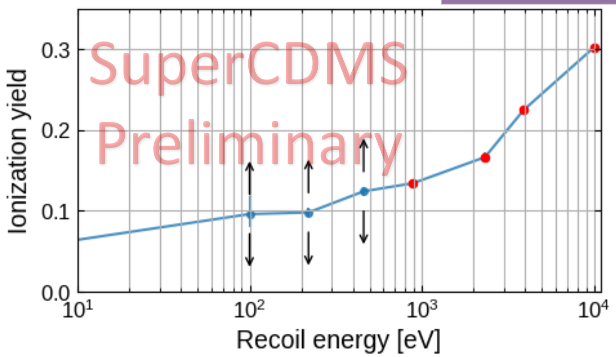
Extracting the Yield with BAT

BAT: CPC 180 2197





Simulate neutron kinematics with GEANT4 (PRA 506 250)



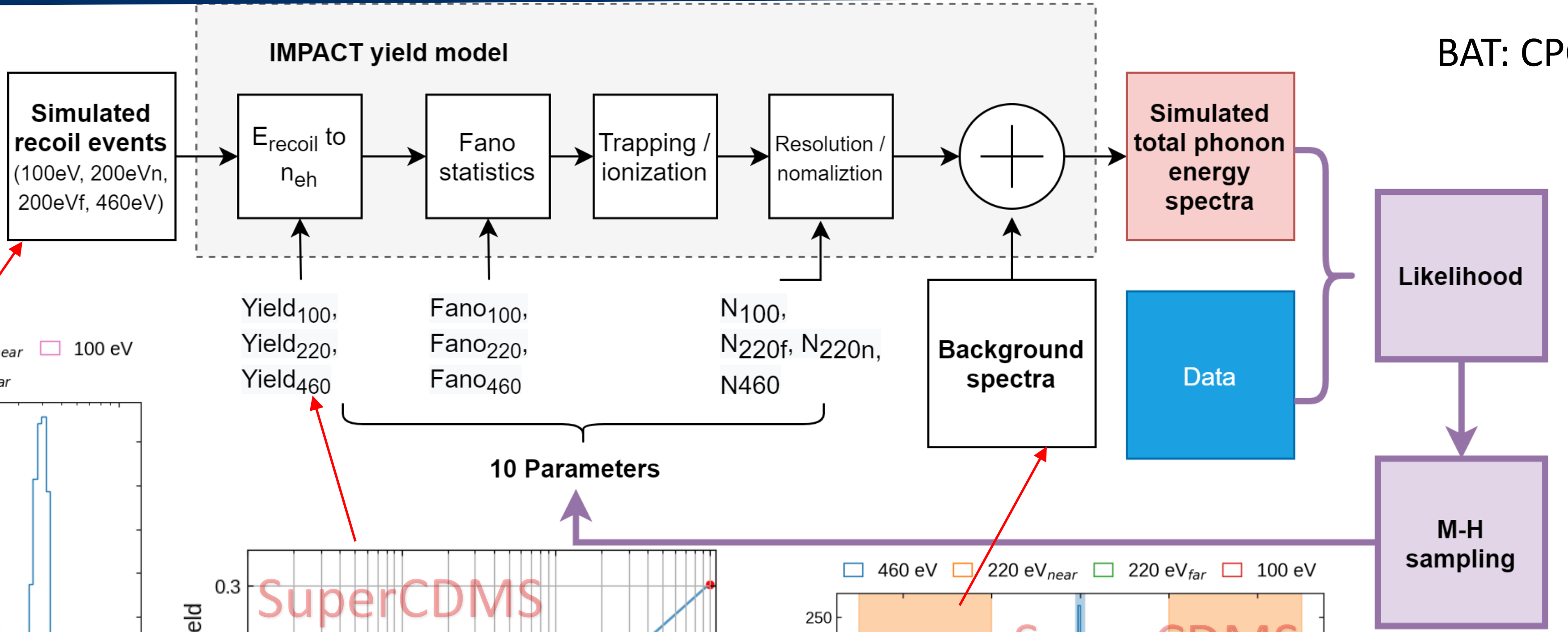
Y(0 keV) = 0

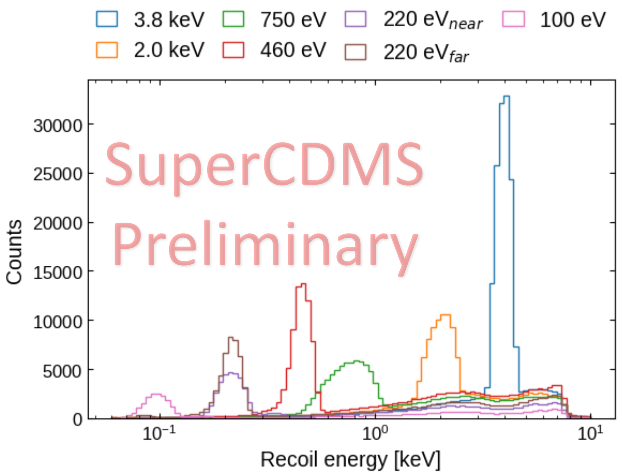
Y(10 keV) = PRD 94 082007

Extracting the Yield with BAT

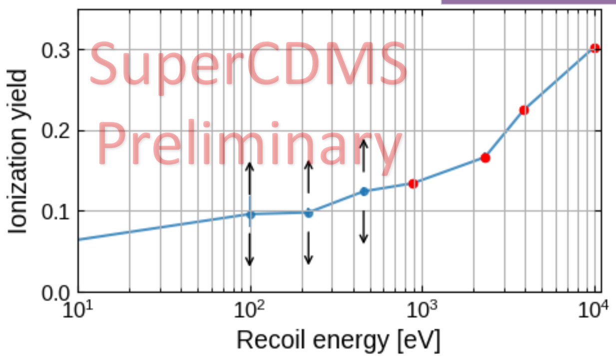
BAYESIAN ANALYSIS TOOLKIT

BAT: CPC 180 2197

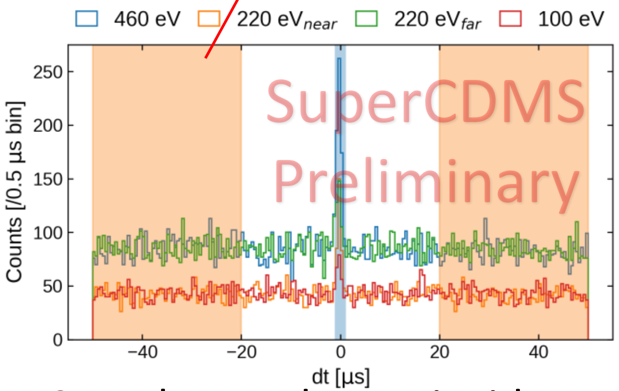




Simulate neutron kinematics with GEANT4 (PRA 506 250)



Y(0 keV) = 0
Y(10 keV) = PRD 94 082007

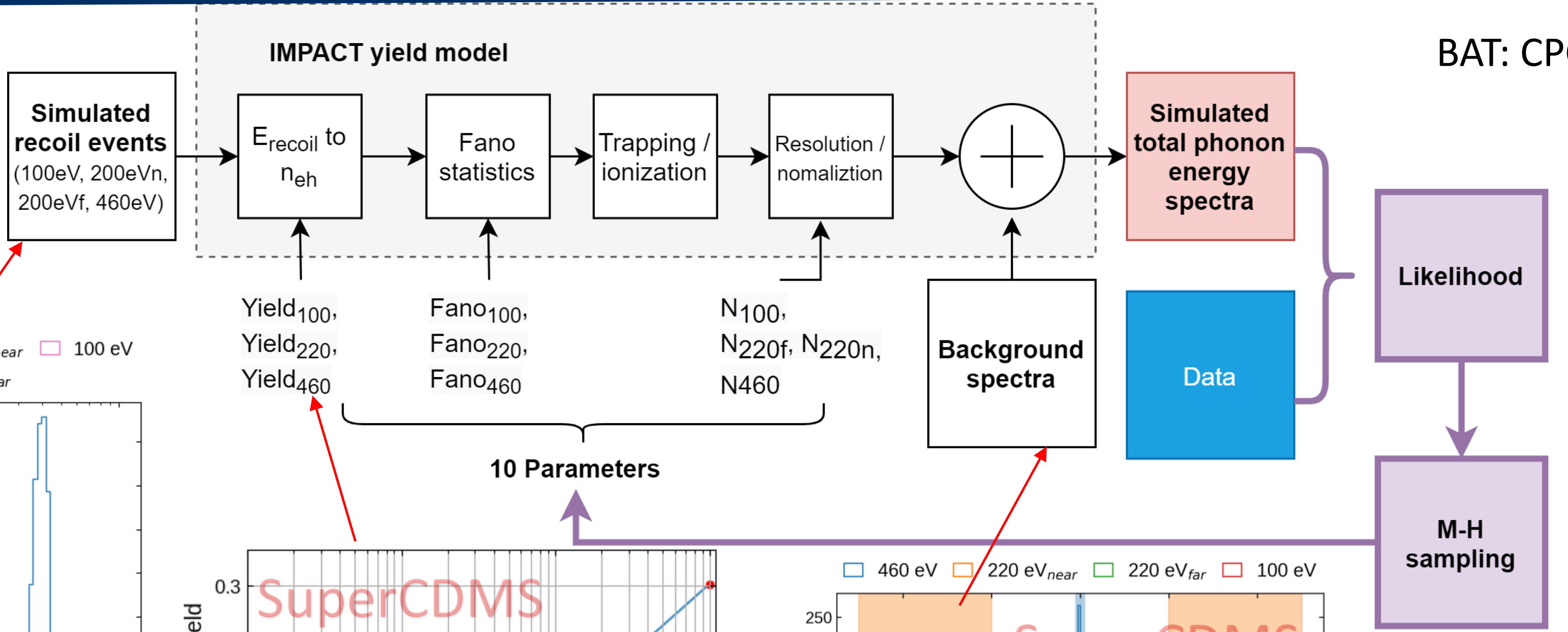


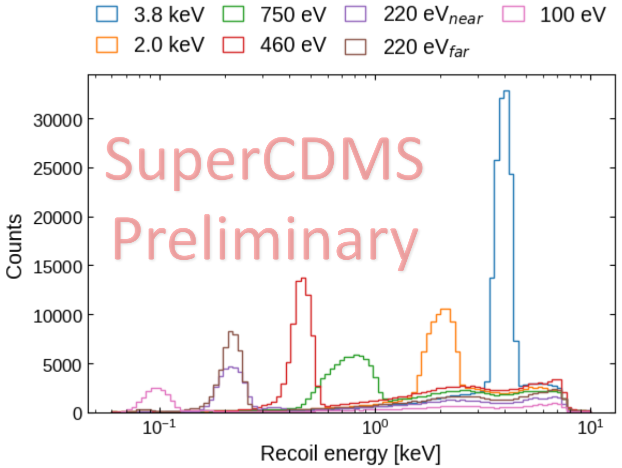
Samples random coincidence background from orange region

Extracting the Yield with BAT

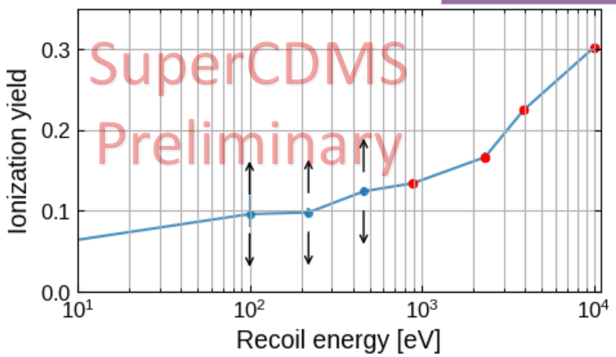
BAYESIAN ANALYSIS TOOLKIT

BAT: CPC 180 2197



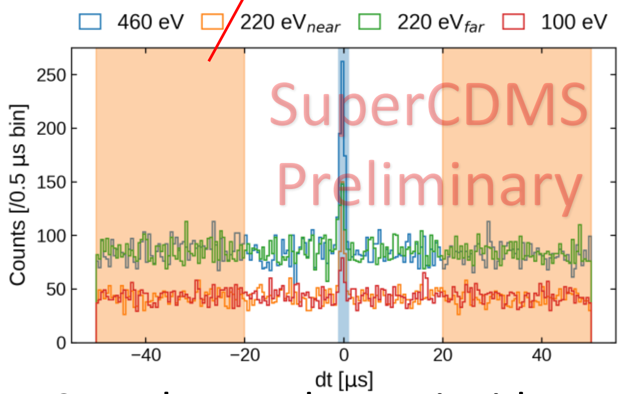


Simulate neutron kinematics with GEANT4 (PRA 506 250)



Y(0 keV) = 0

Y(10 keV) = PRD 94 082007

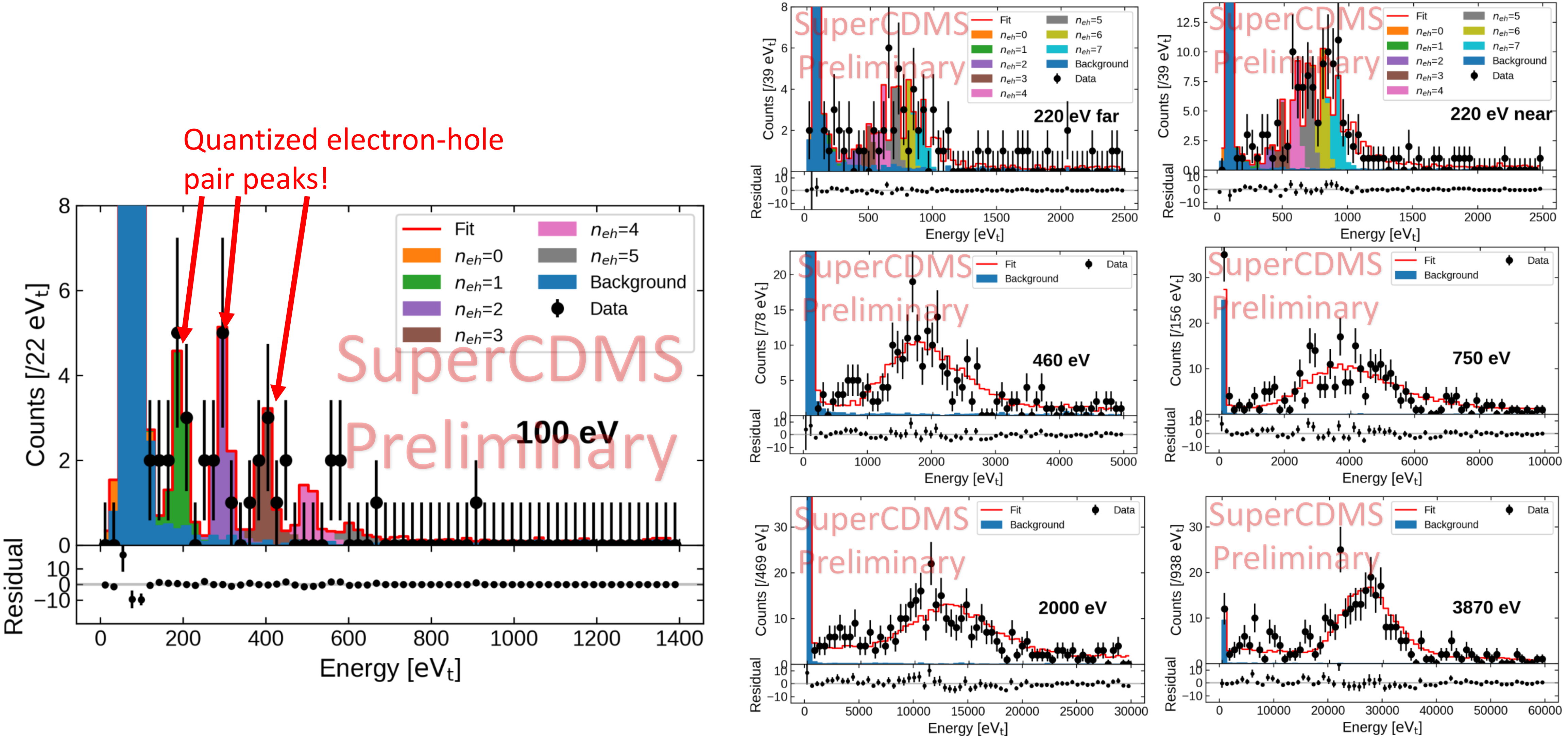


Samples random coincidence background from orange region

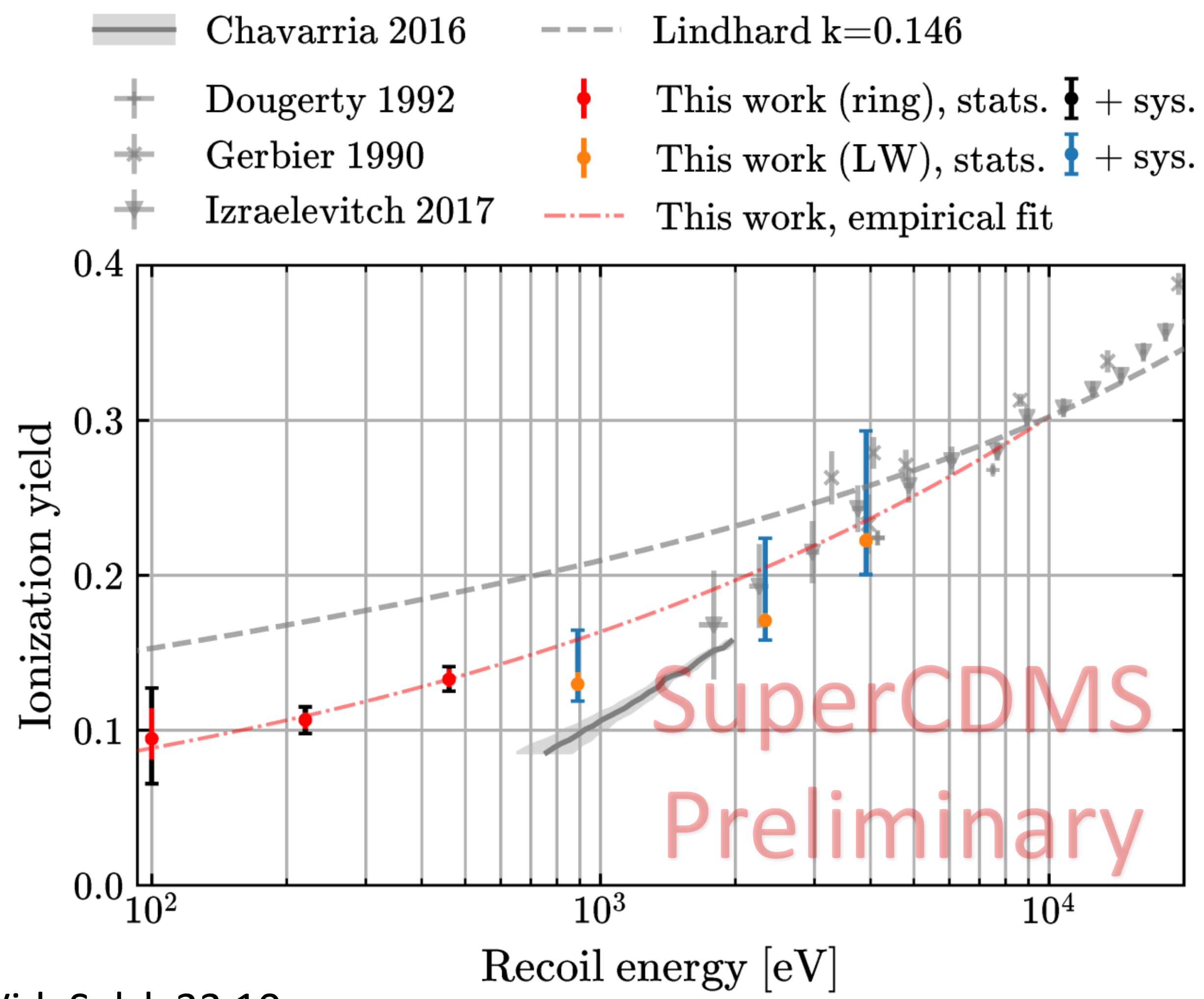
1. Fit yields for ring detectors
2. Fit yields for lone wolves
3. Fit ring detectors again

Results: Fit Spectra

Quantized electron-hole pair peaks!



Results: Ionization Yield



Chavarria PRD 94 082007
Dougherty PRA 45 2104
Gerbier PRD 42 3211
Izraelevitch JINST 12 P06014
Lindhard Mat. Fys. Medd. Dan. Vid. Selsk 33 10

Thank you!

Backup Slides

Systematics