Results from the Antonella experiment

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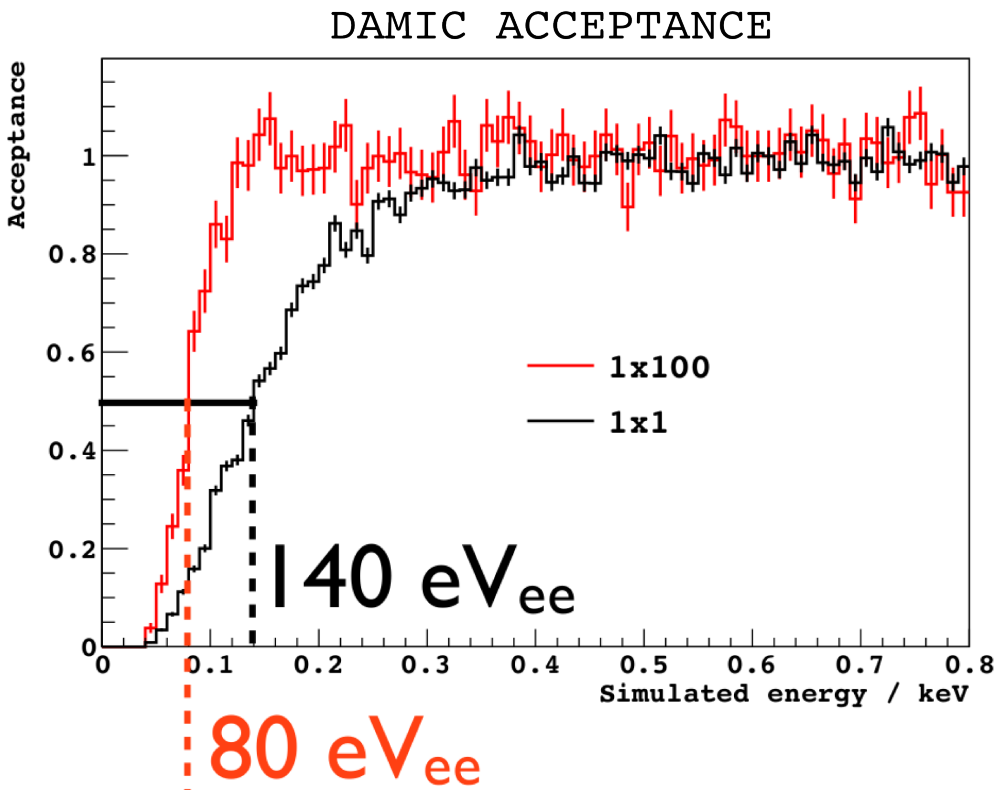
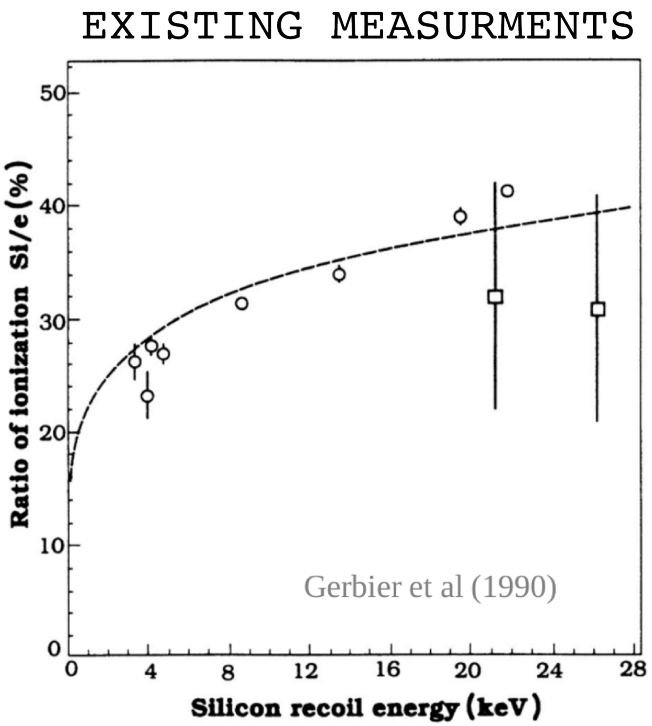
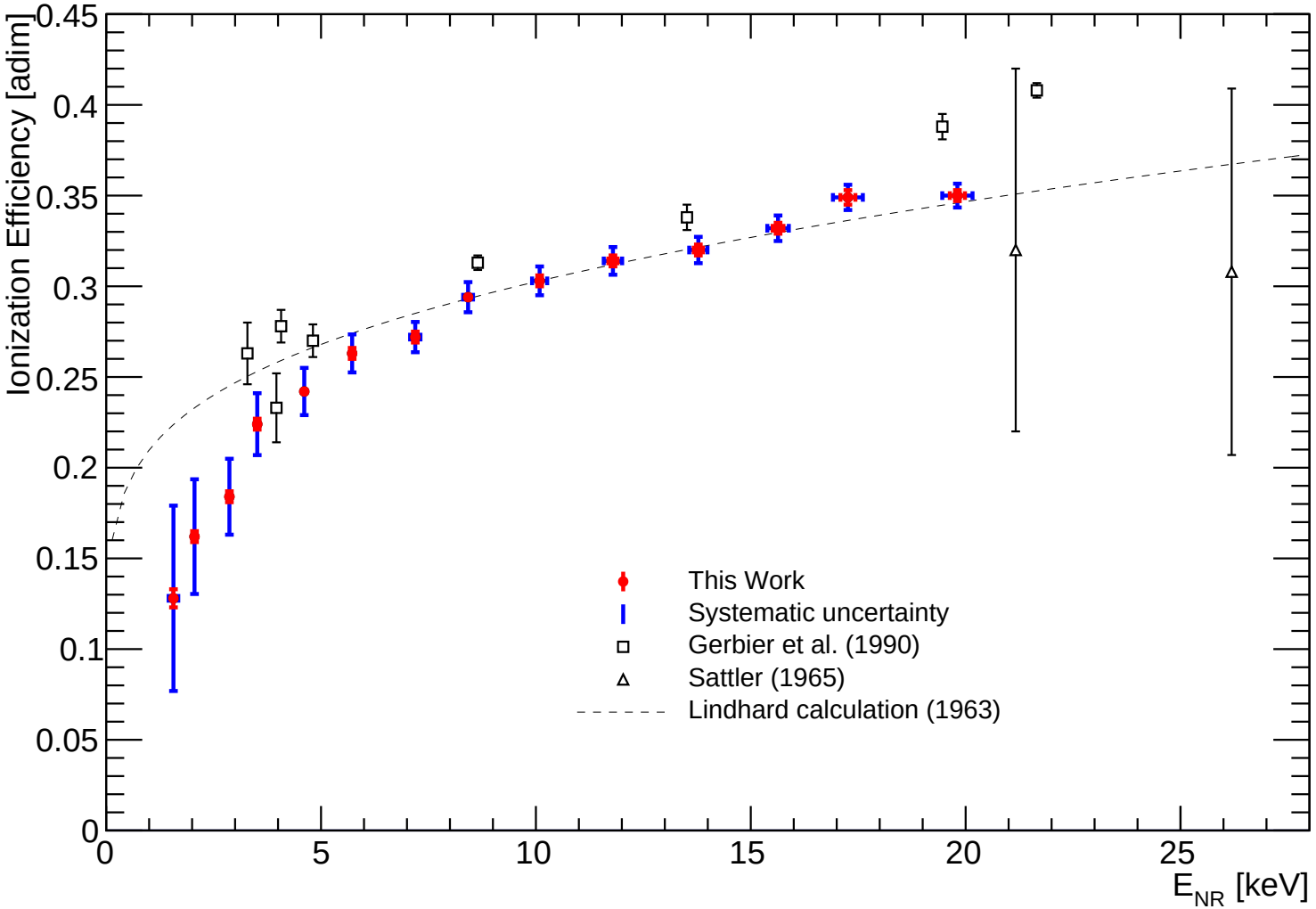
Low threshold Silicon detectors: DAMIC, SuperCDMS Si





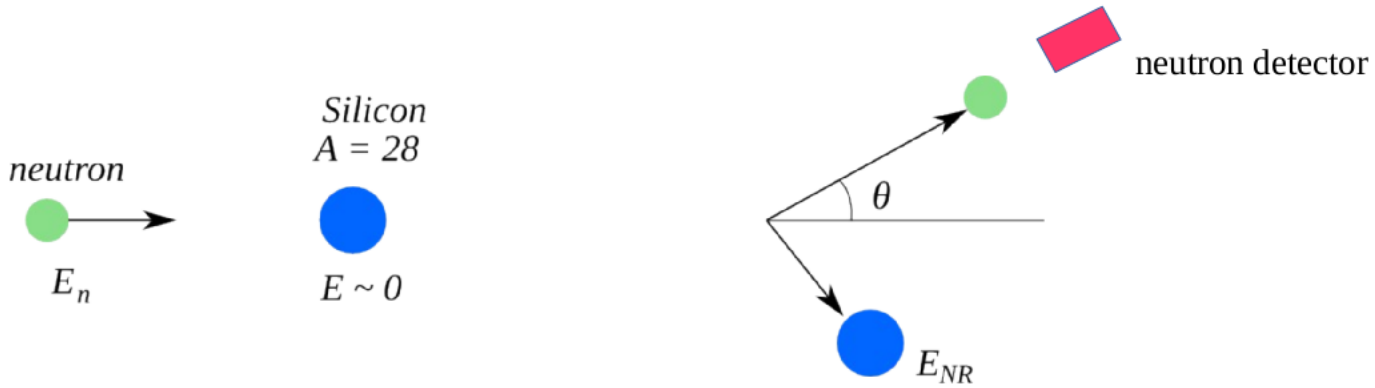
No Nuclear recoil calibration data for ROI

Ionization efficiency vs Nuclear Recoil energy



Textbook scattering experiment

Monochromatic neutrons



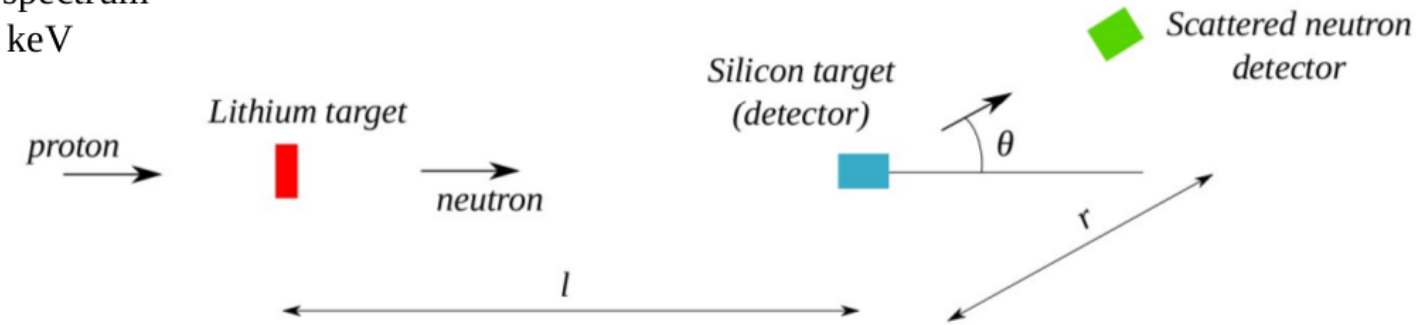
$$E_{NR} = E_n \frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right]$$

- θ Scattering angle
- A Atomic mass
- E_n Neutron energy
- E_{NR} Energy of Nuclear recoil

$$Ion_{Eff} = \frac{E_{ionization}}{E_{NR}} \rightarrow \frac{\textit{measured in a silicon detector calibrated with electron recoils}}{\textit{calculated from kinematics}}$$

ToF scattering experiment

Broad neutron spectrum
E_n in [50, 600] keV



$$E_n = \frac{m}{2(\Delta t)^2}\left[l + r\,\frac{(A+1)}{\cos\theta + \sqrt{A^2 - \sin^2\theta}}\right]^2 \qquad (1)$$

Δt = neutron total Time-of-flight

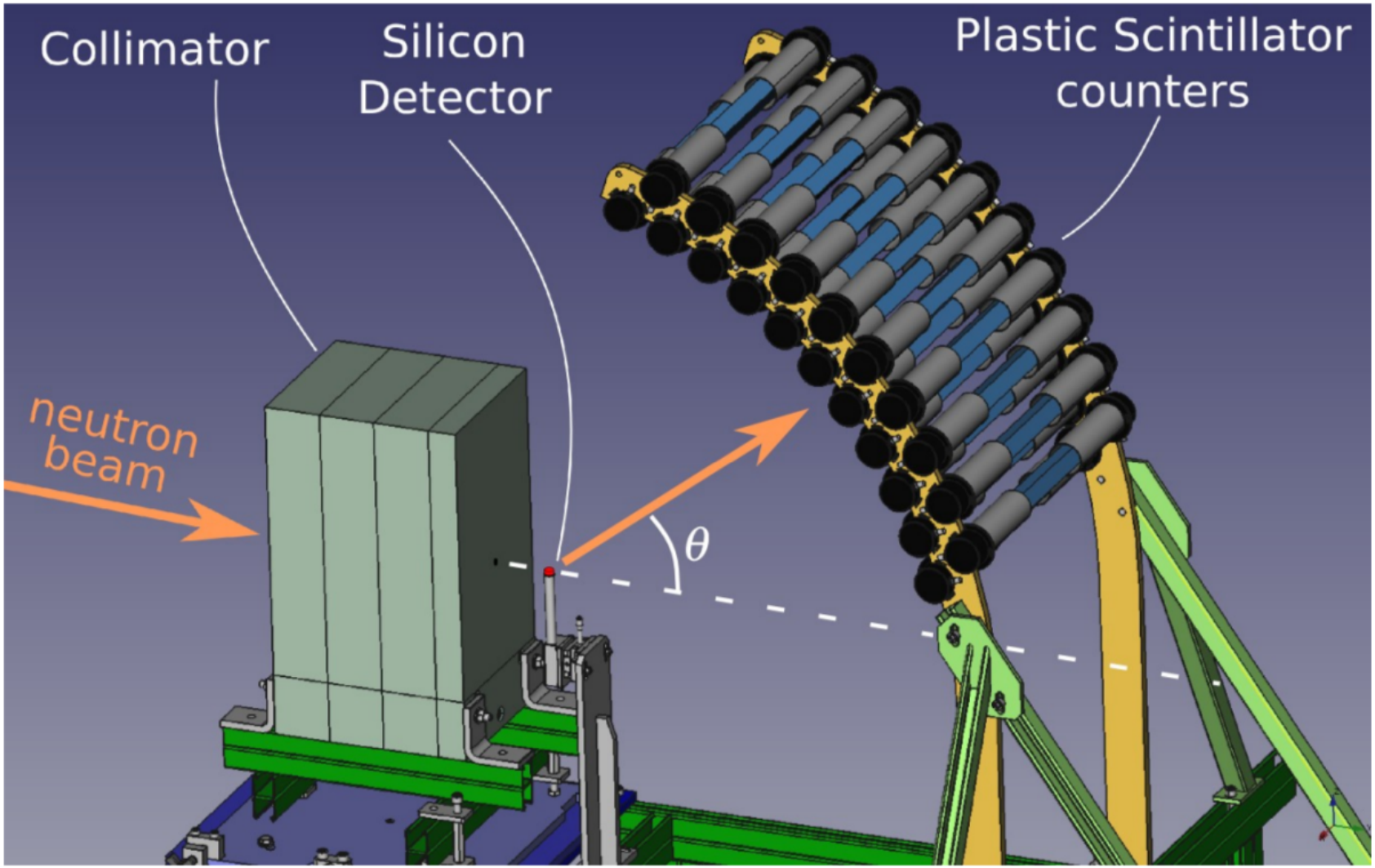
$$E_{NR} = E_n\,\frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right] \qquad (2)$$

Program:

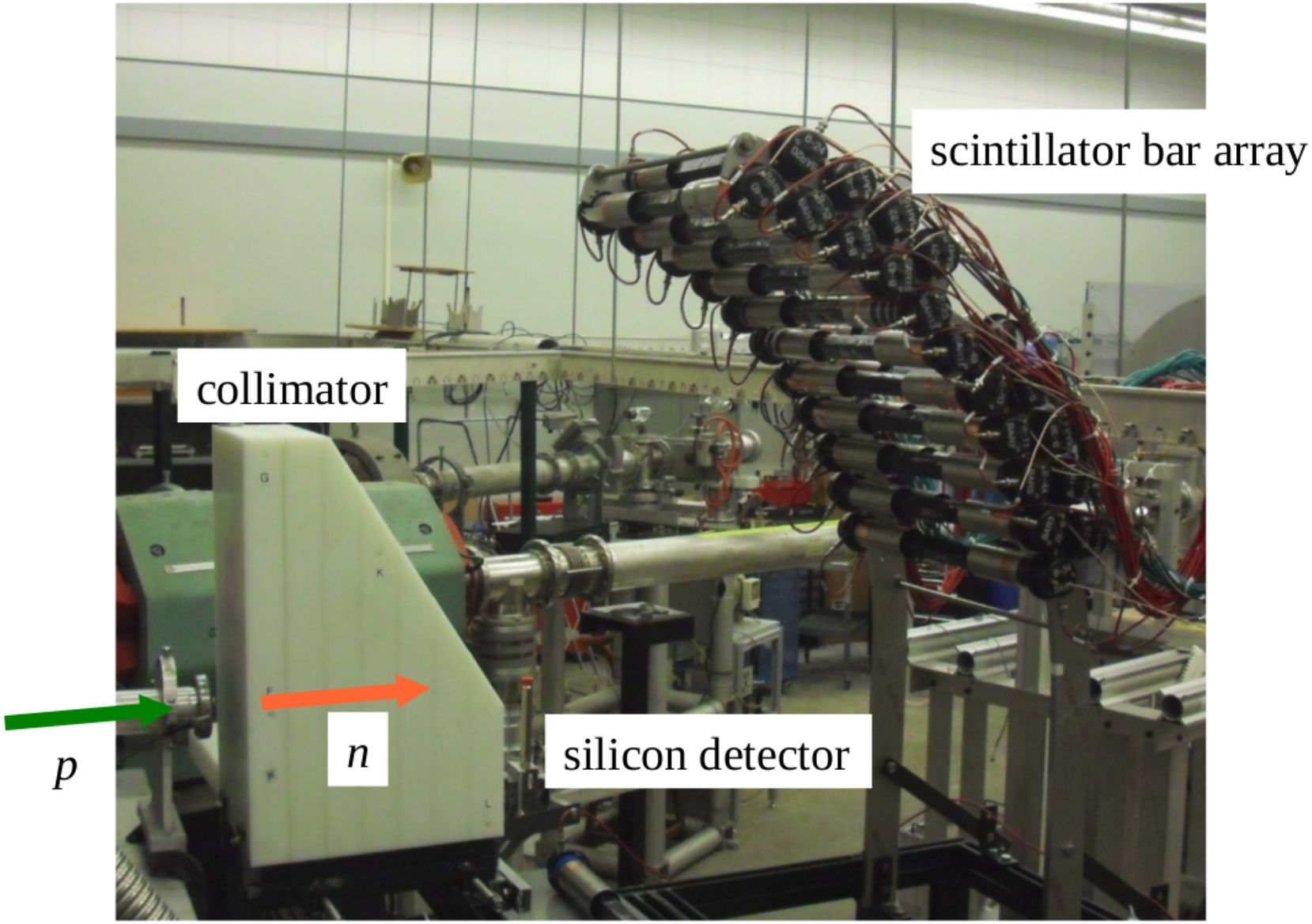
1. Measure neutron energy by time-of-flight (1)
2. Detect a scattered neutrons in a neutron detector
3. Measure charge produced by ionization
4. Calculate the nuclear recoil energy with kinematics (2)

$$Ion_{Eff} = \frac{E_{ionization}}{E_{NR}}$$

Our setup


Collimator
Silicon Detector
Plastic Scintillator counters
neutron beam
θ

Our setup at ND University beam



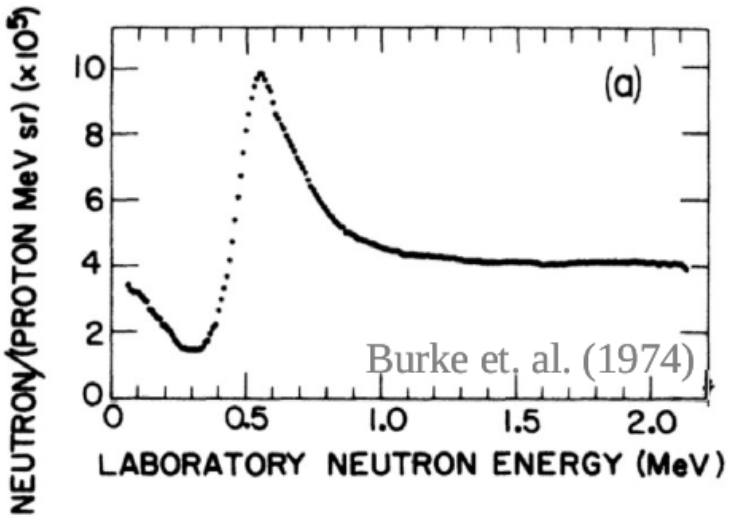
Neutron beam at ND University

University of Notre Dame, Indiana, USA
Tandem Van de Graaff, 10 MV

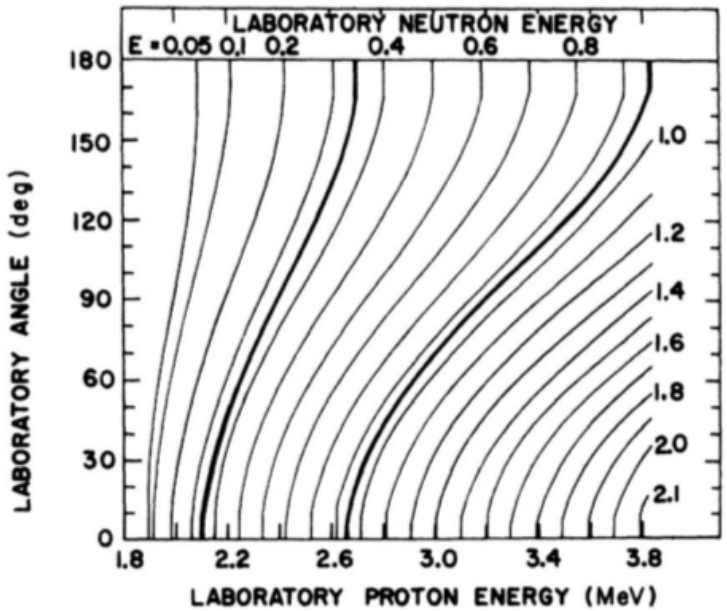
- $^{7}Li(p,n)^{7}Be$ reaction on thick *LiF* target
- 2.3 MeV proton energy
- Bunched beam. 1 μs bunch separation
- 20 nA nominal proton current at this bunch separation
- 1-2 ns bunching resolution

Neutron beam at ND University

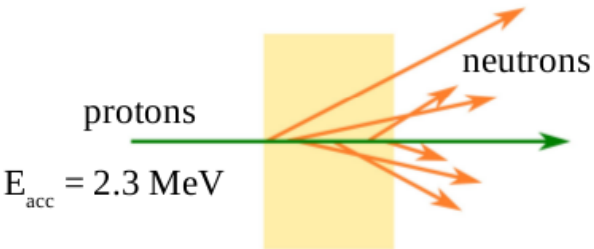
Broad neutron spectrum
E_n in [50, 600] keV



Burke et. al. (1974)



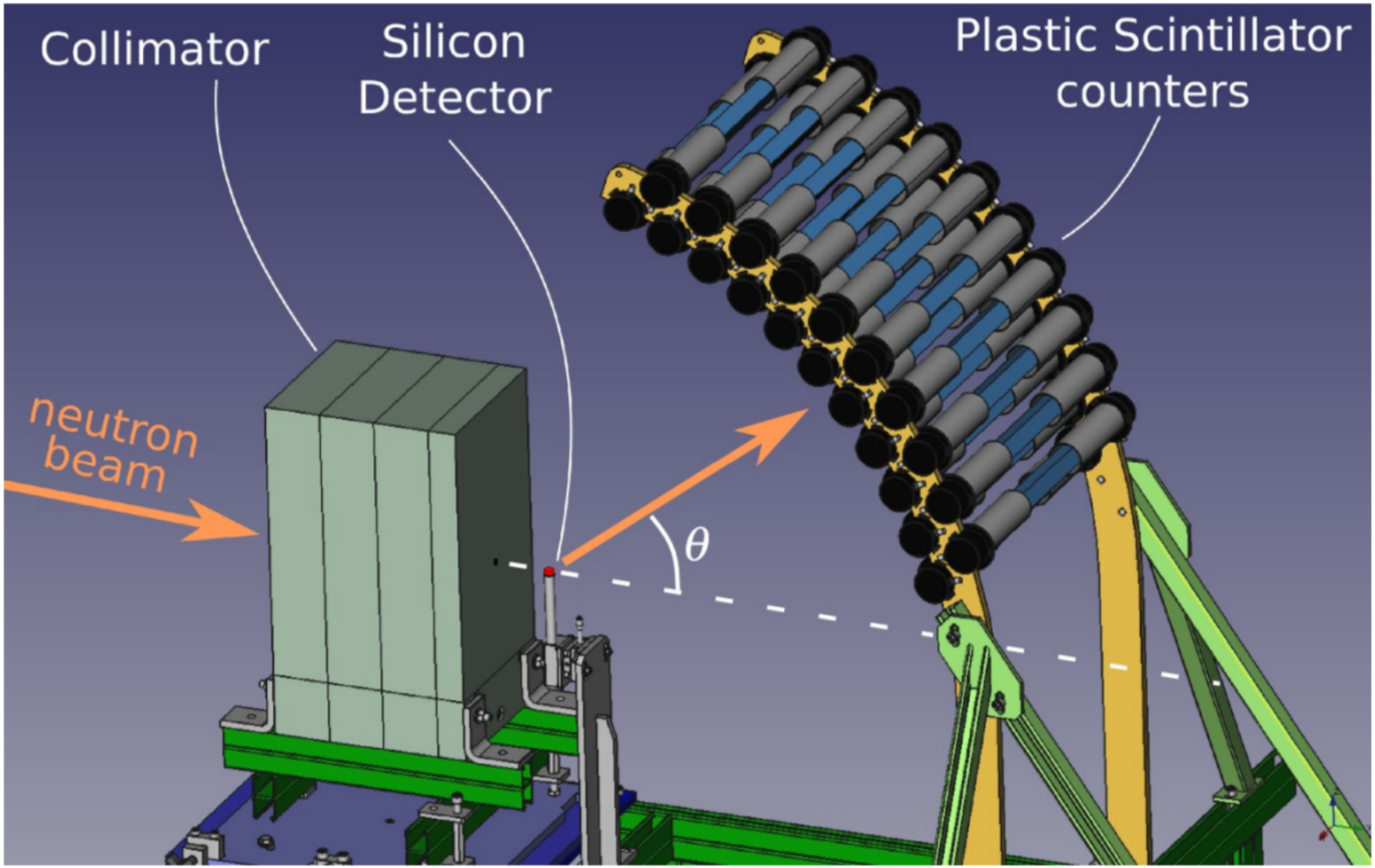
LiF: Lithium Fluoride
actual target material → Background: (p,γ) reactions



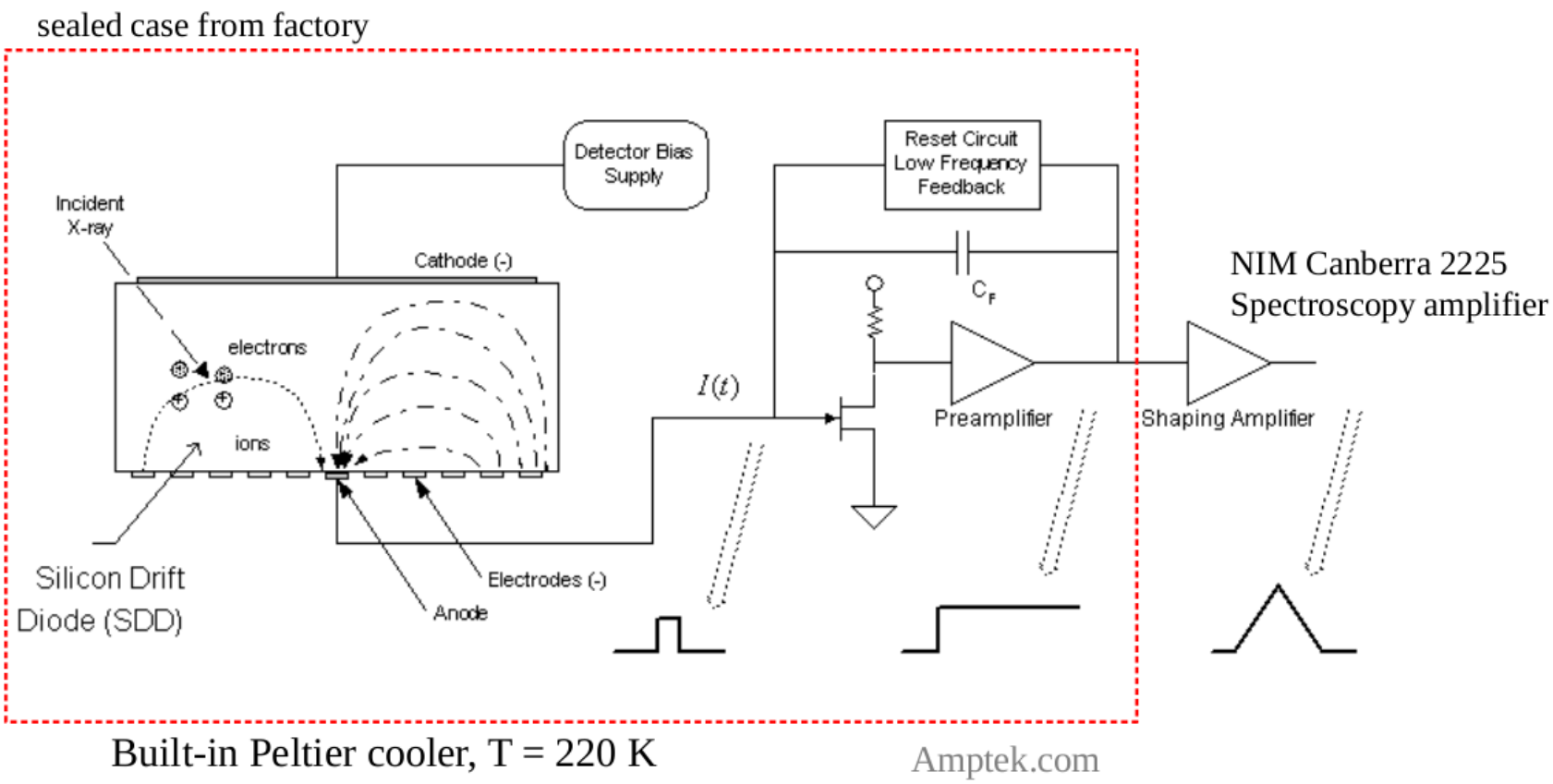
$(dE/dx)_{LiF}$ = 26 keV/µm

Target thickness = 18 µm → Maximize the neutron yield

Our setup - SiDet



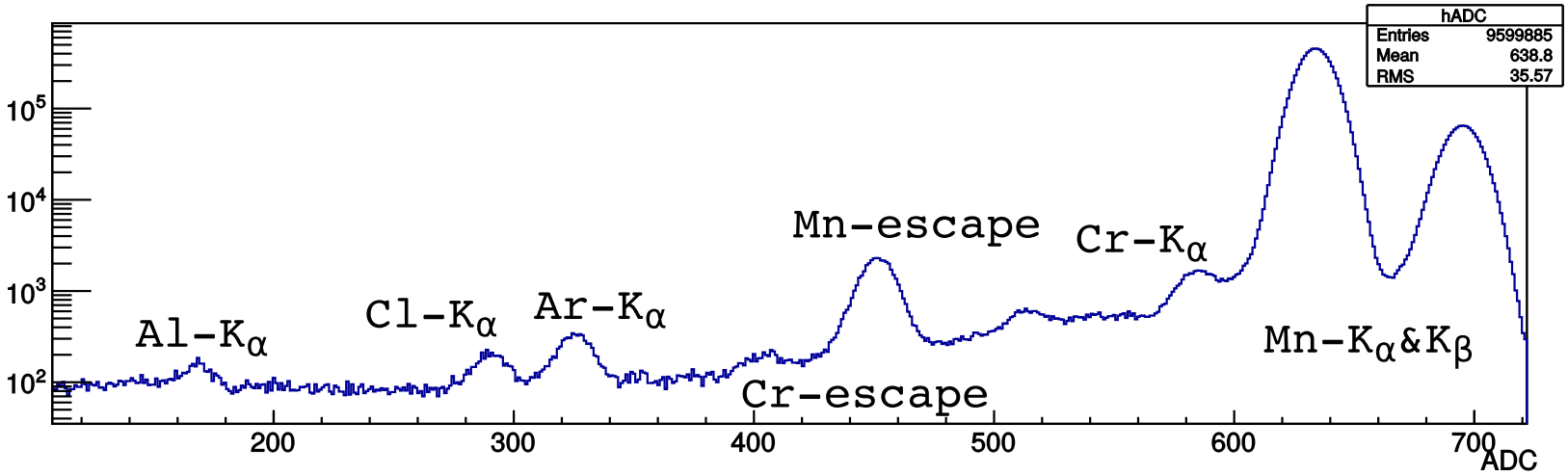
Detector: Silicon Drift Diode, commercial XRay detector)

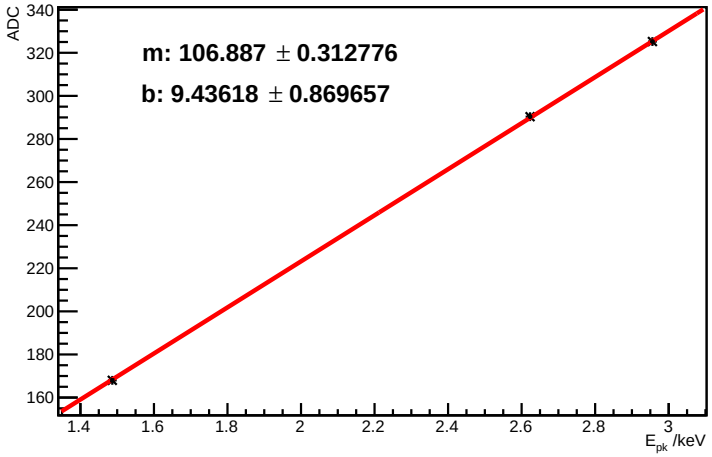


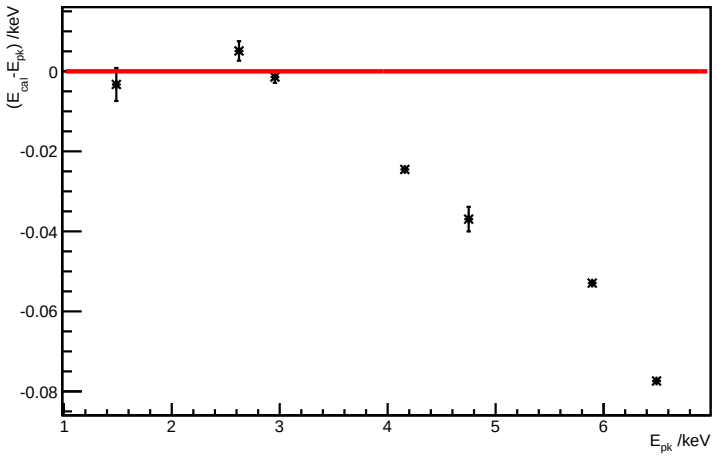
- Detector used in the Neutron Star Interior Composition Explorer (NICER), at ISS (NASA, USA)

Detector mass is only 29 mg

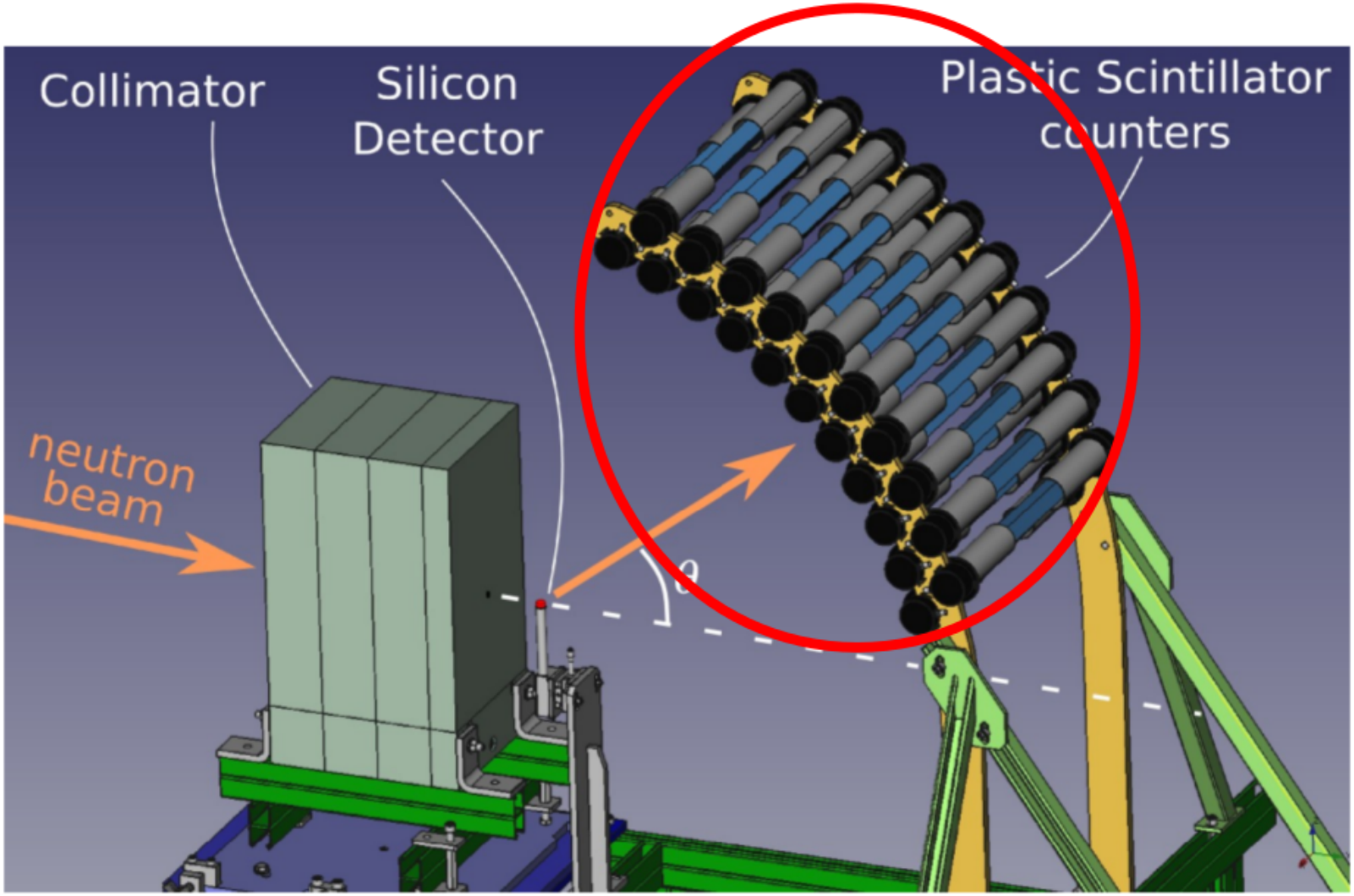
Calibration using an ^{55}Fe source







Main source of systematic uncertainty


Collimator
Silicon Detector
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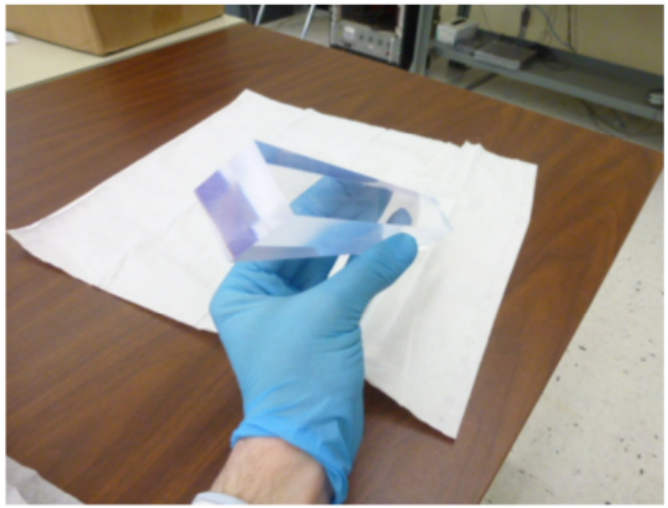
neutron beam
θ

Neutron detectors: plastic scintillator bars + PMTs



- Bar dimensions: 3 x 3 x 25 cm^3
- Plastic scintillator: EJ-200
- Base polymer: polyvinyl toluene ($C_{27}H_{30}$)

1. The neutron transfers kinetic energy to ^1H
2. The recoiling ^1H produces the scintillation light (same for ^{12}C, but less efficiently)

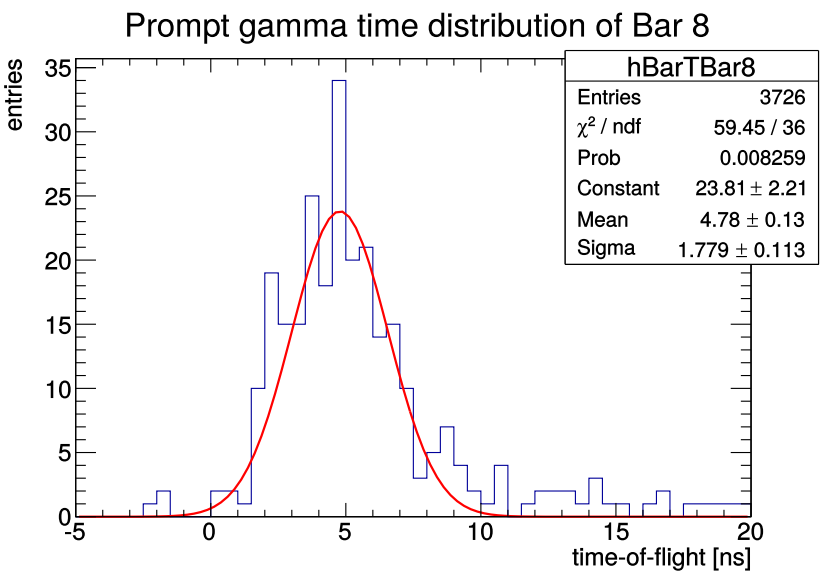
- PMTs from CDF central hadronic calorimeter
- EMI 9854KB

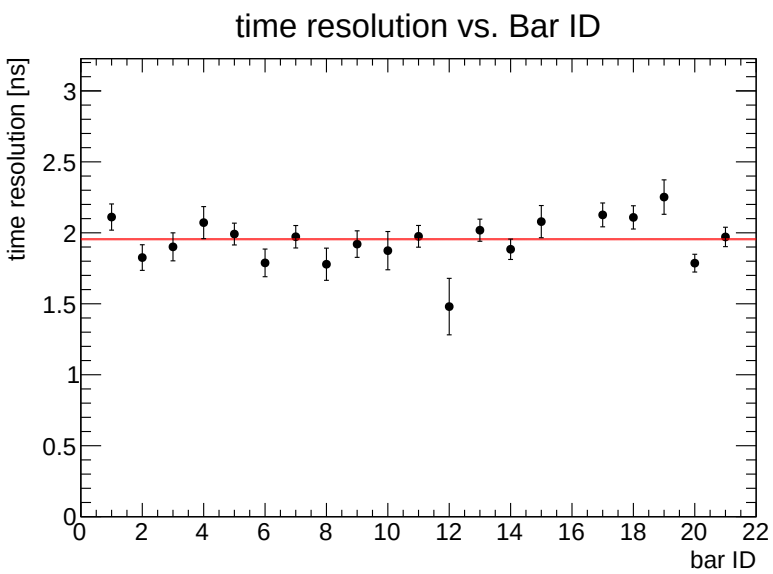
Triggered at 0.2 p.e.

One PMT at each end → Request coincidence

Reduce the neutron detection threshold to less than 50 keV

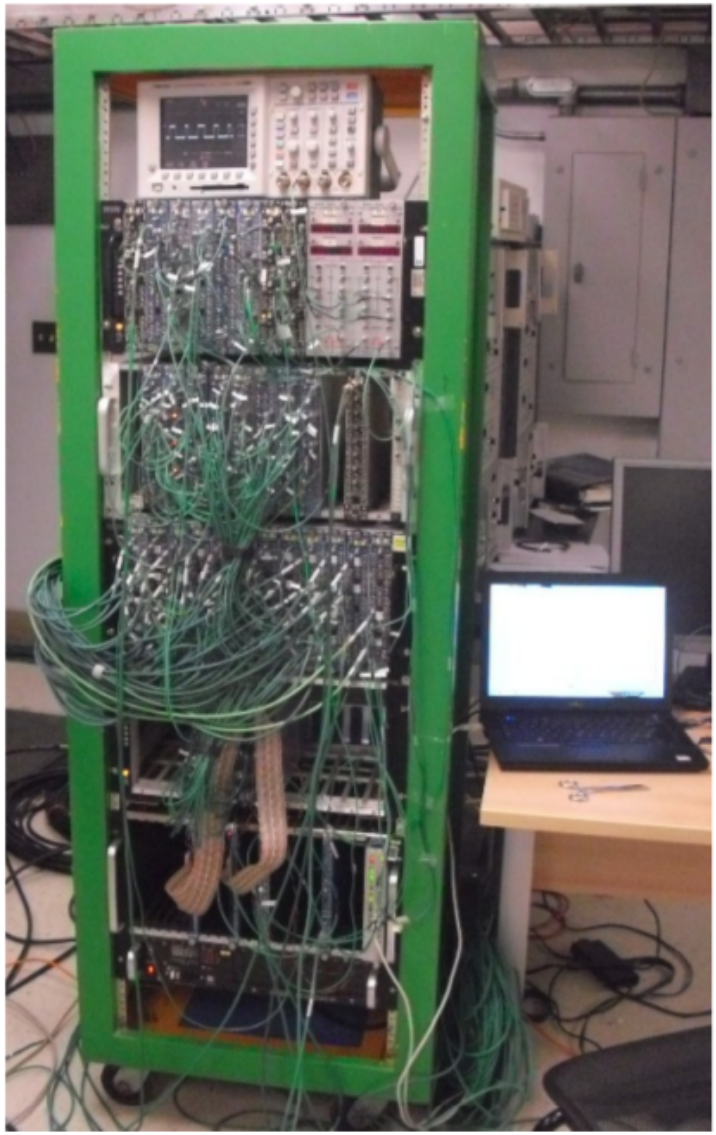
Neutron detectors: plastic scintillator bars + PMTs





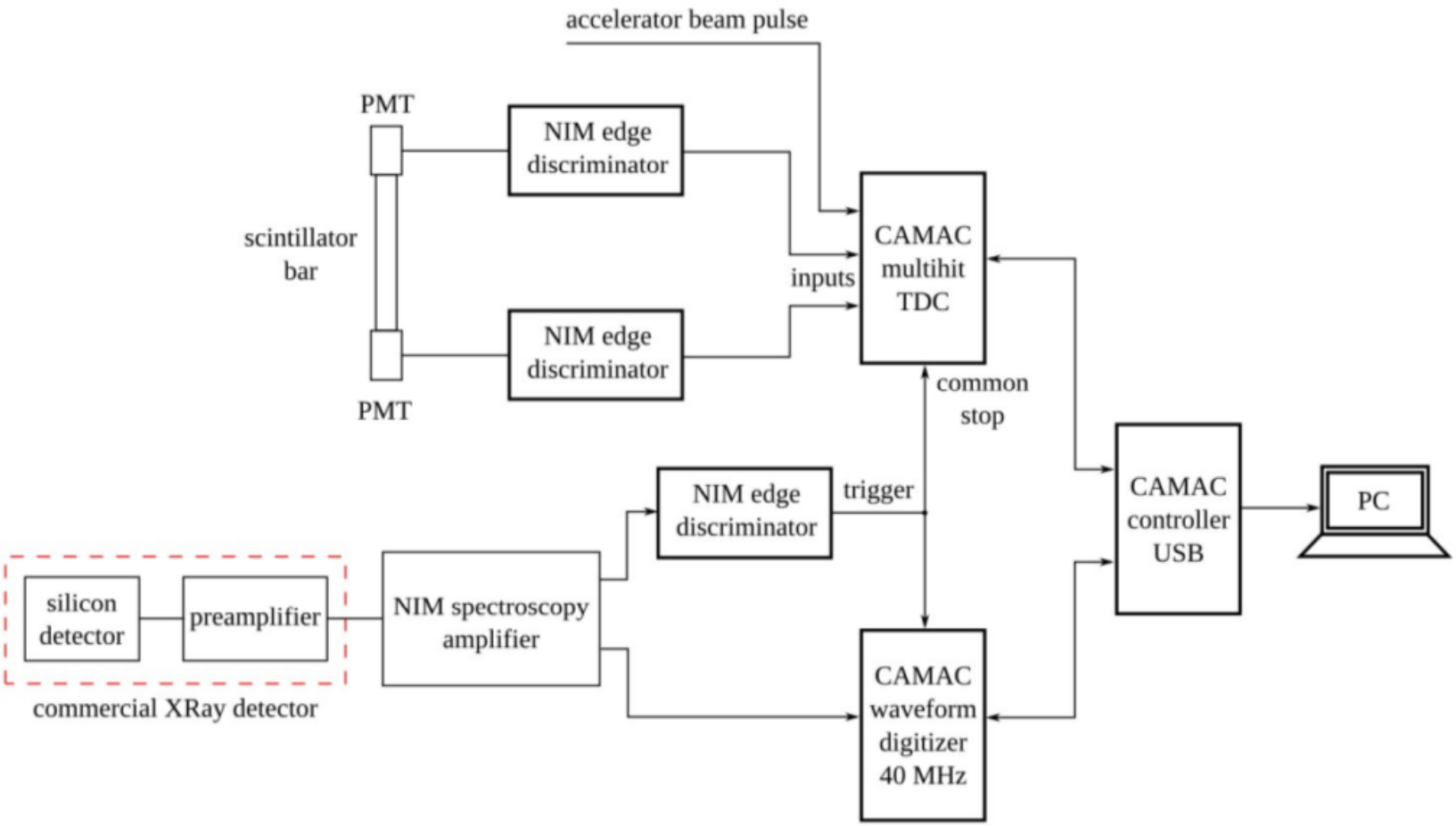
2 ns resolution translates to $\frac{\sigma_{E_{NR}}}{E_{NR}} \sim 1 - 5\%$

DAQ system



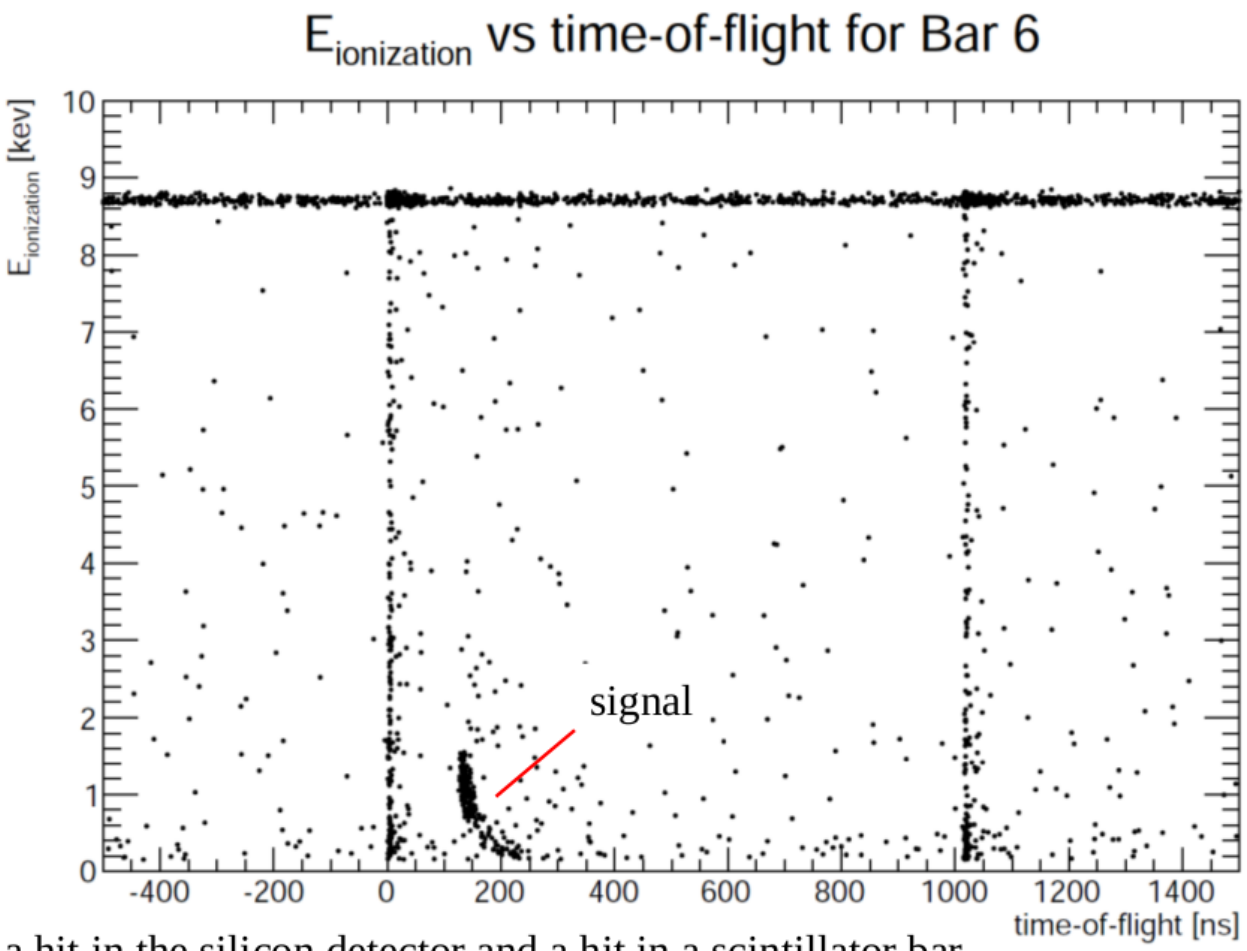
PREP

DAQ system



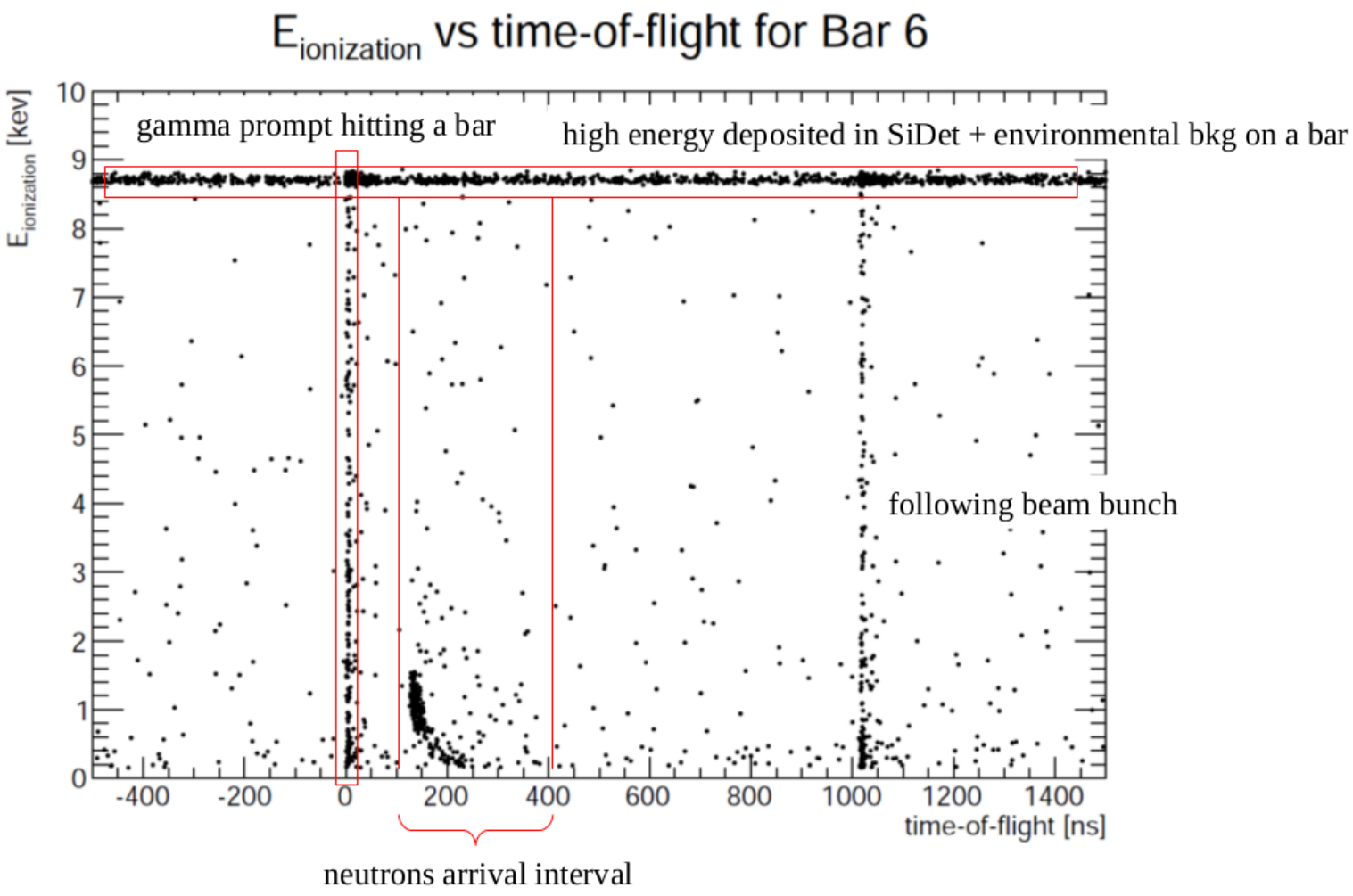
Trigger on the siDet → read the whole detector state

Raw data



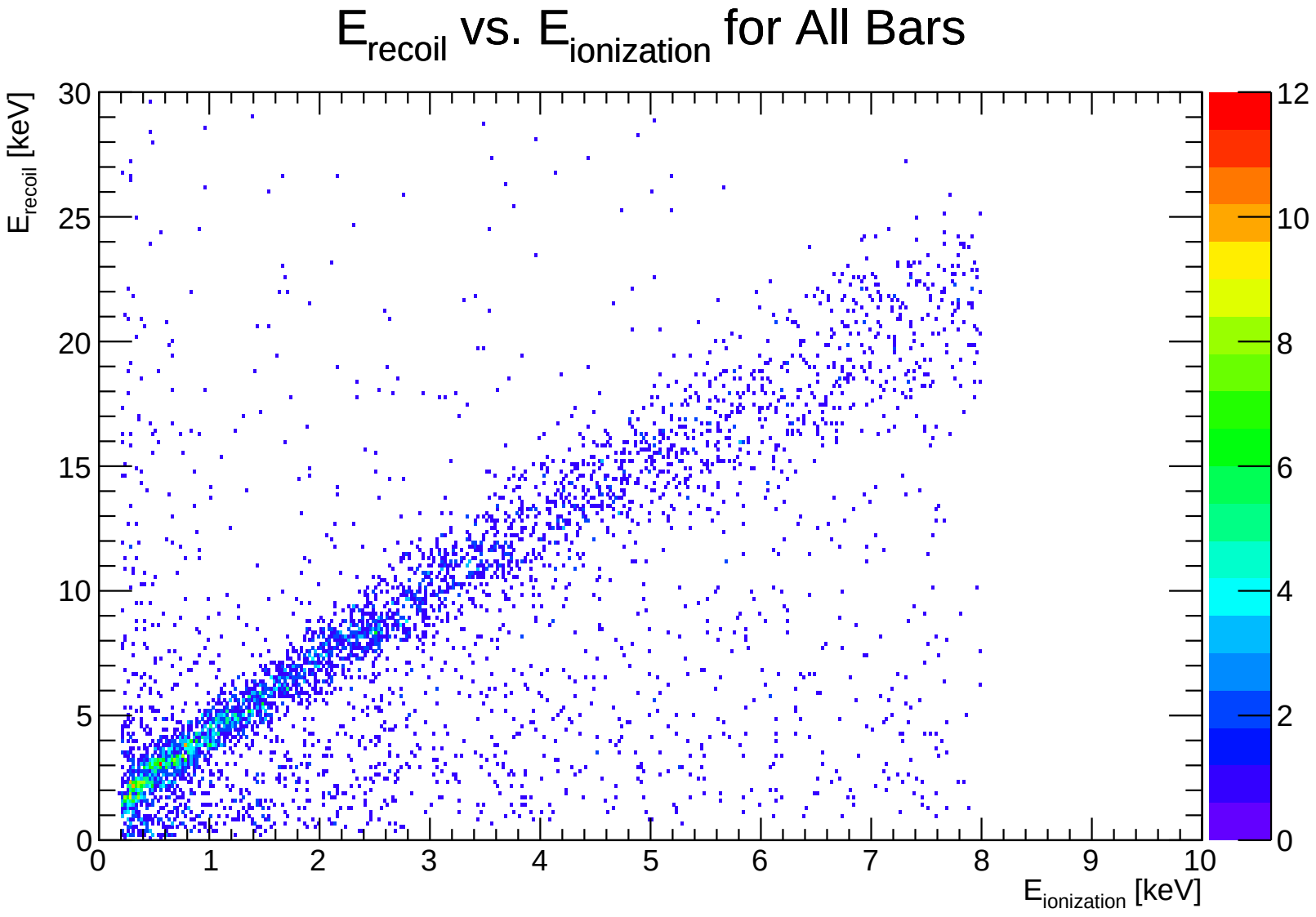
Points: a hit in the silicon detector and a hit in a scintillator bar

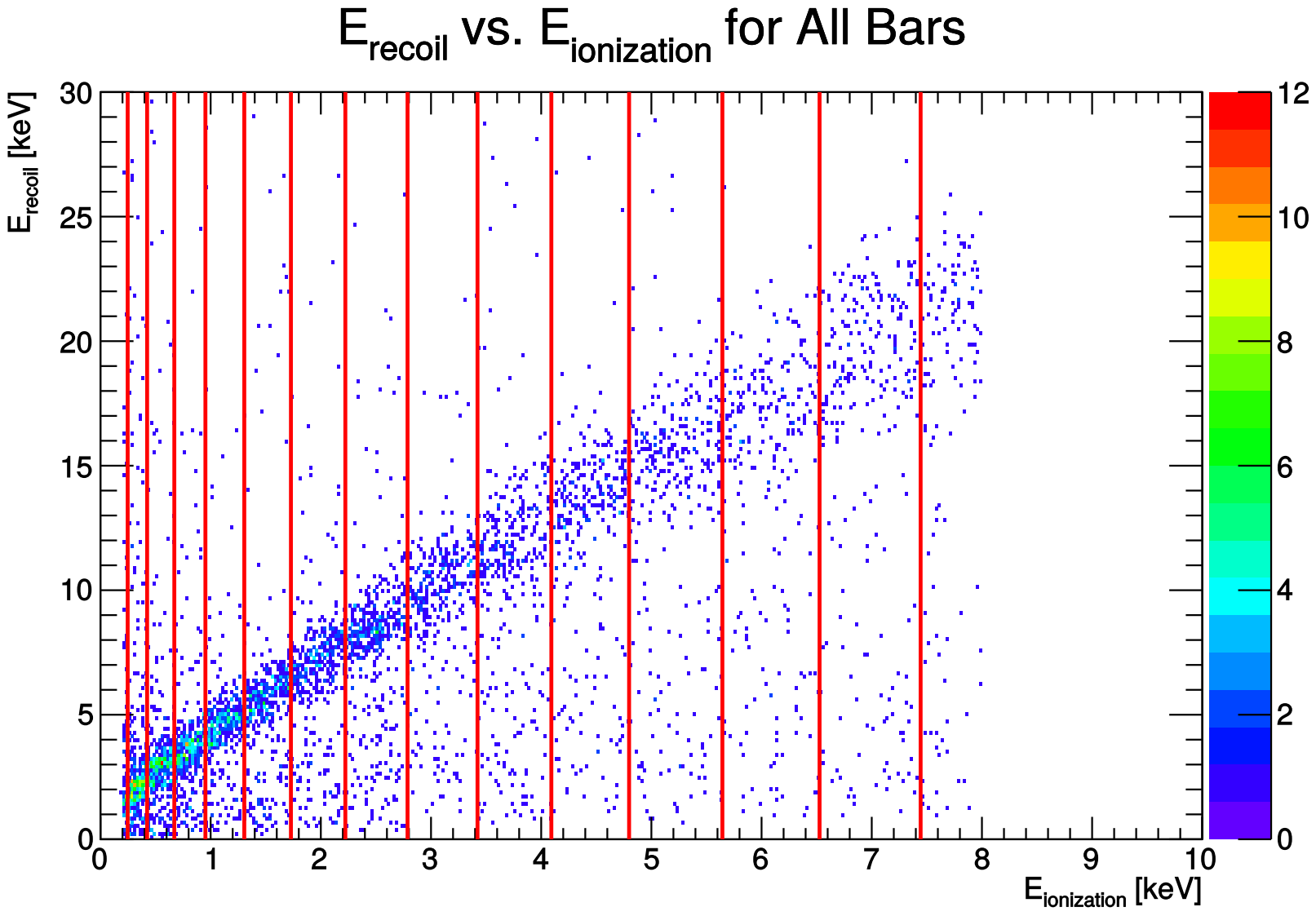
Raw data

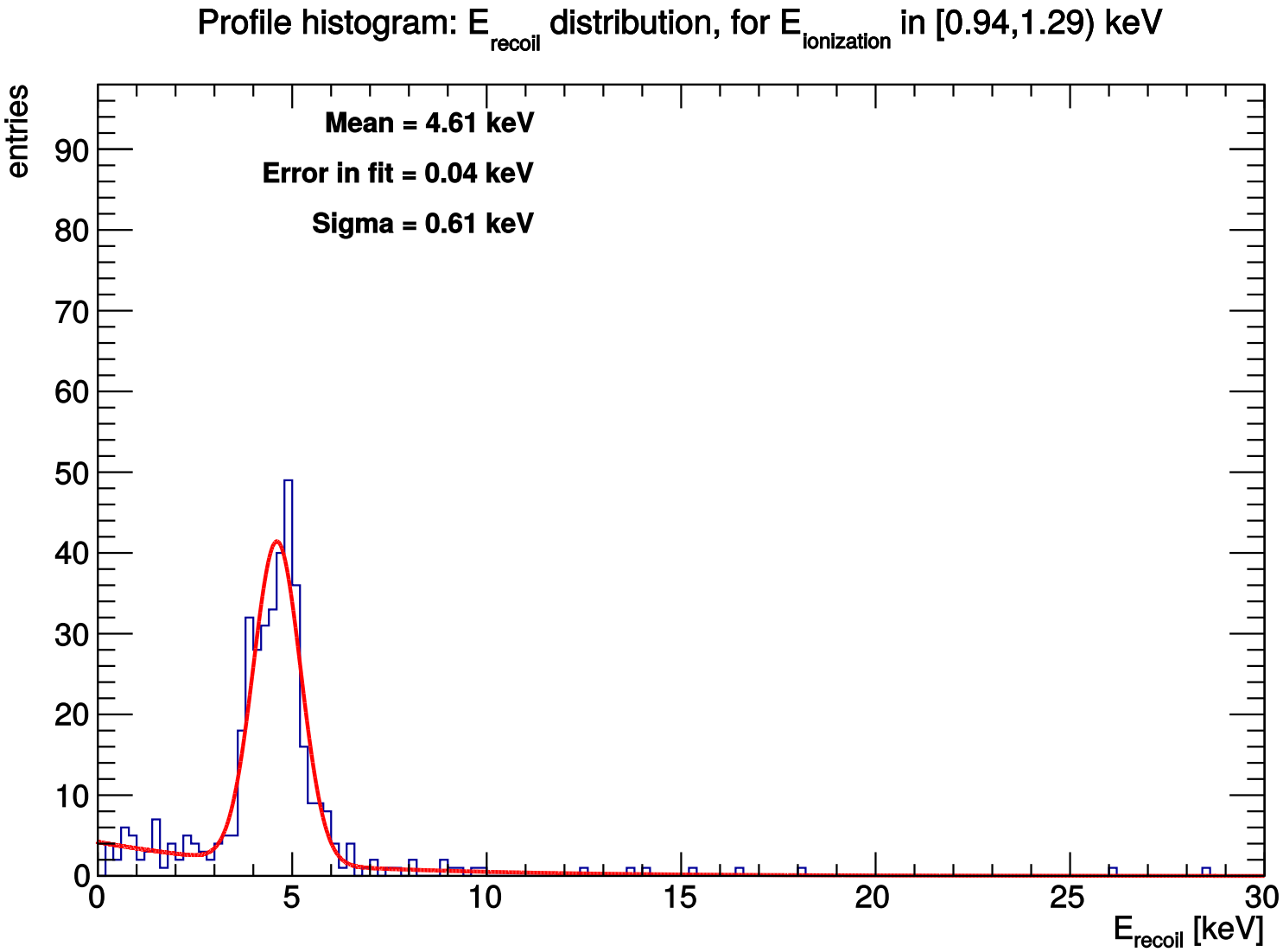

E_ionization vs time-of-flight for Bar 6
E_ionization [kev]
time-of-flight [ns]
gamma prompt hitting a bar
high energy deposited in SiDet + environmental bkg on a bar
following beam bunch
neutrons arrival interval

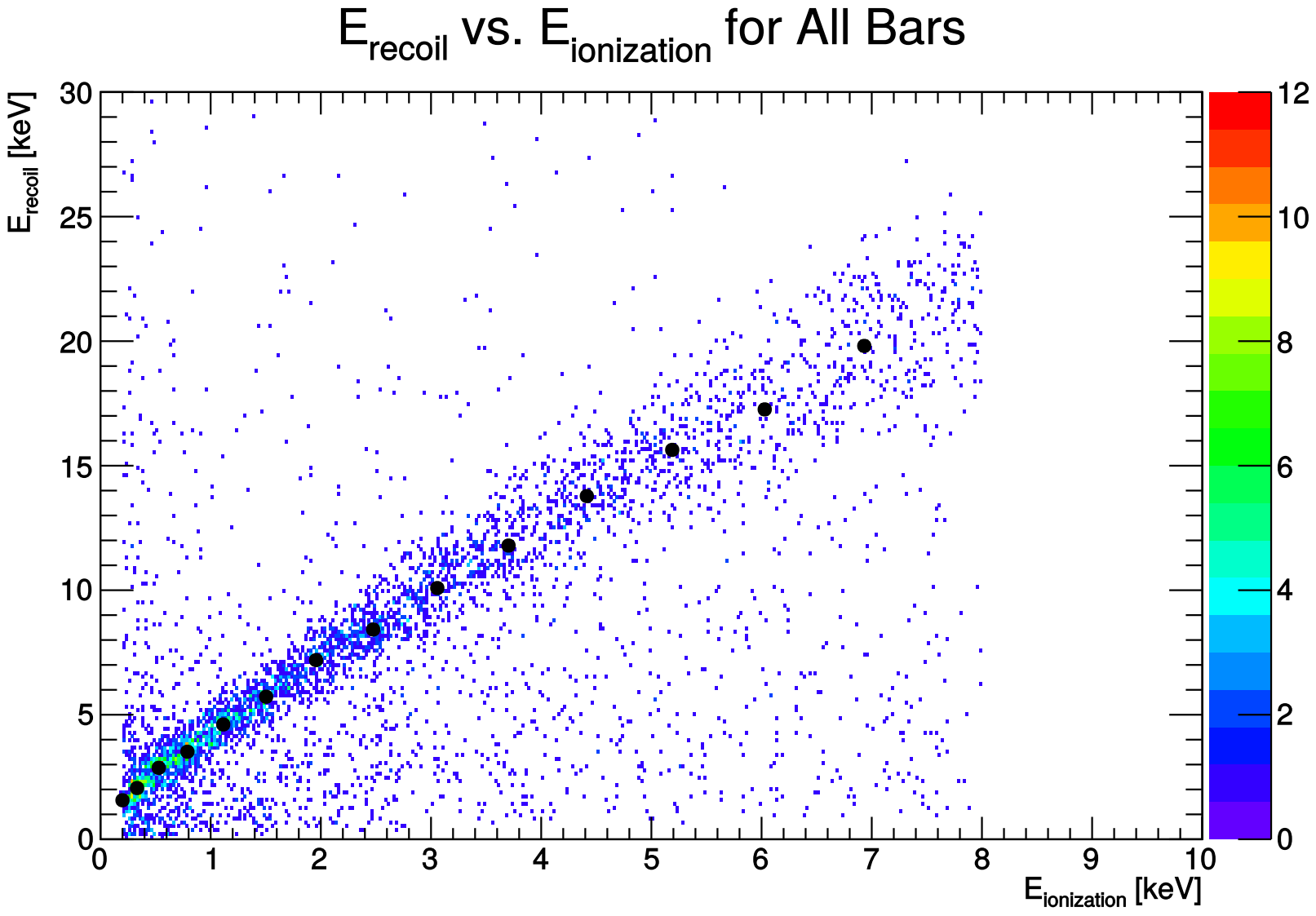
Science Run

- Took data for 10 days
- $\sim 10^6$ gamma+neutron hits in silicon detector
- Trigger rate $\sim$ 170 Hz (of which $\sim$ 4 Hz real particles hitting the silicon detector)
- 1.5 10^8 triggers, mostly noise from the silicon detector
- 1.8 10^5 events, after requesting hit in a Bar (PMT in coincidence)
- 5.1 10^3 events, after timing and no-saturation cuts (reject gamma prompt)

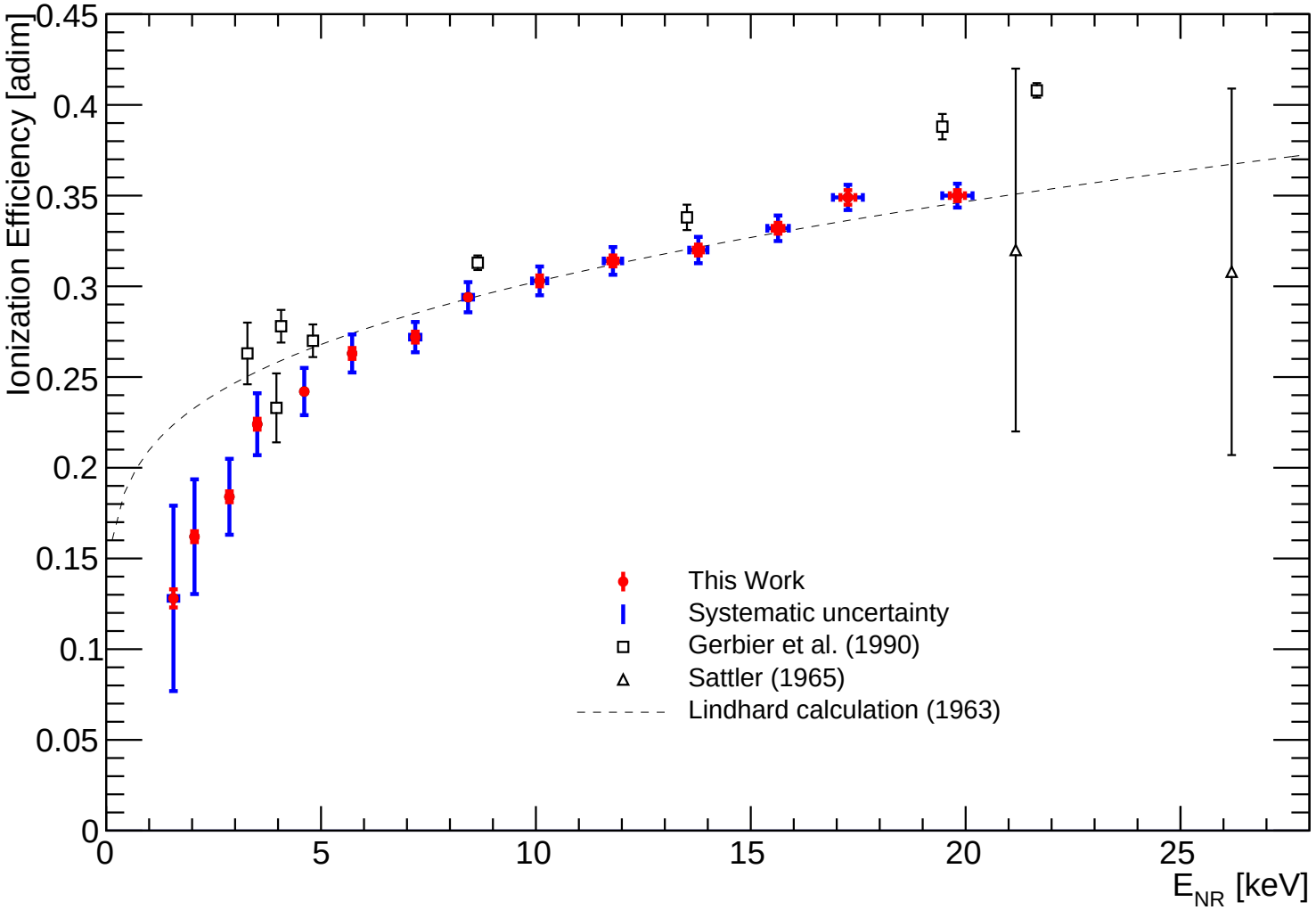

E_{recoil} vs. $E_{ionization}$ for All Bars
E_{recoil} [keV]
$E_{ionization}$ [keV]
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12

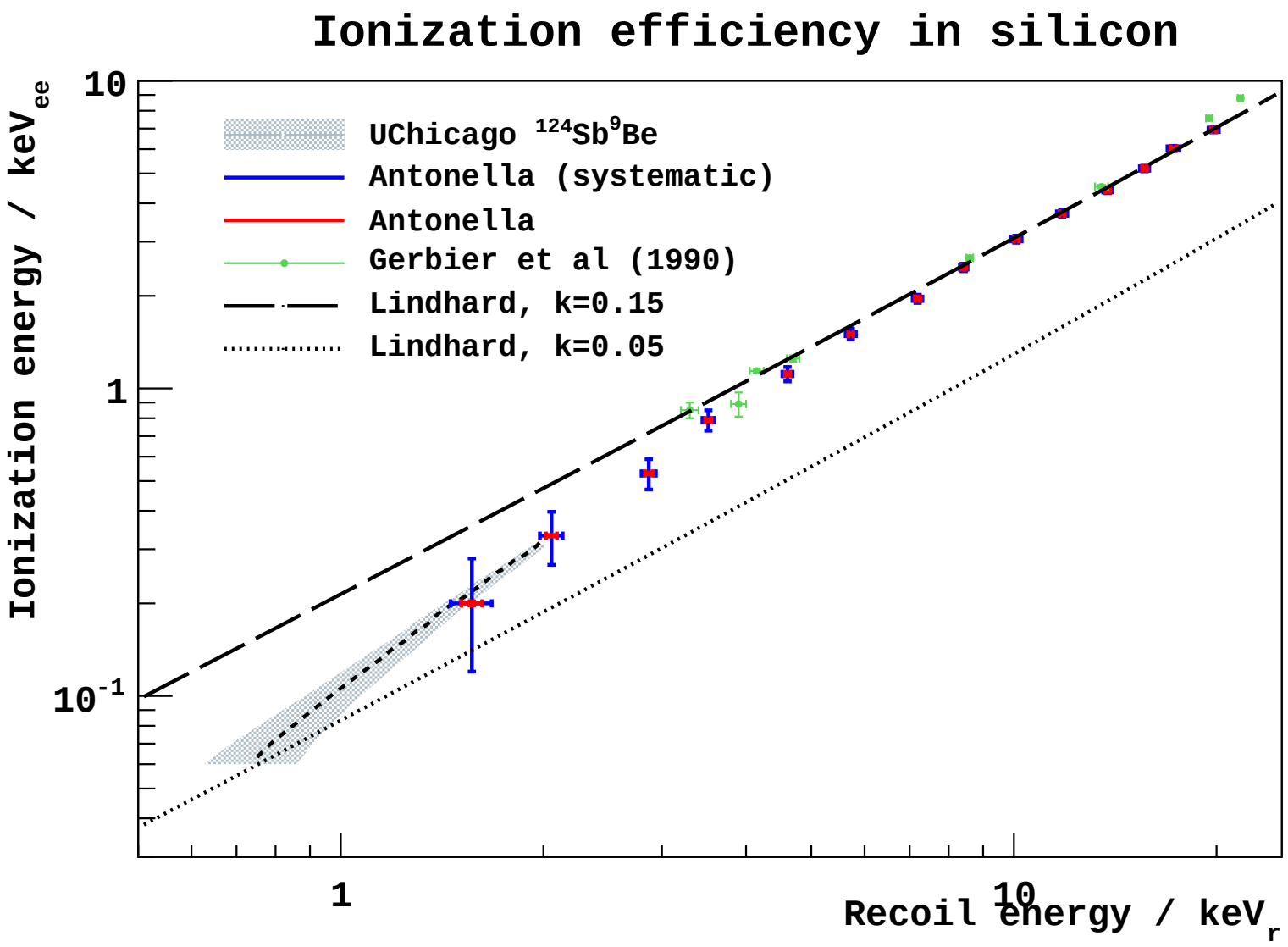

E_{recoil} vs. $E_{ionization}$ for All Bars
E_{recoil} [keV]
$E_{ionization}$ [keV]
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12


Profile histogram: E recoil distribution, for E ionization in [0.94,1.29) keV
Mean = 4.61 keV
Error in fit = 0.04 keV
Sigma = 0.61 keV
entries
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
E recoil [keV]


E_{recoil} vs. $E_{ionization}$ for All Bars
E_{recoil} [keV]
$E_{ionization}$ [keV]
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12

Ionization efficiency vs Nuclear Recoil energy



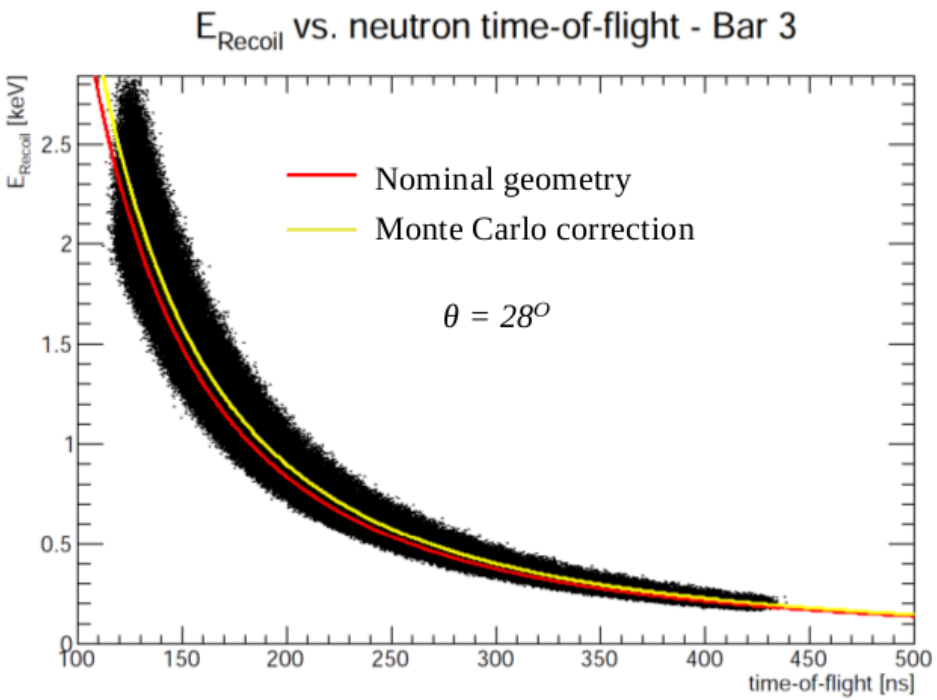


Next talk by Alvaro.

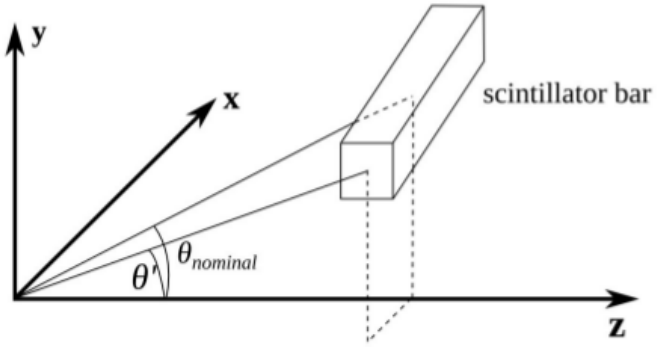
$$E_n = \frac{m}{2(\Delta t)^2}\left[l + r\,\frac{(A+1)}{\cos\theta + \sqrt{A^2 - \sin^2\theta}}\right]^2 \qquad (1)$$

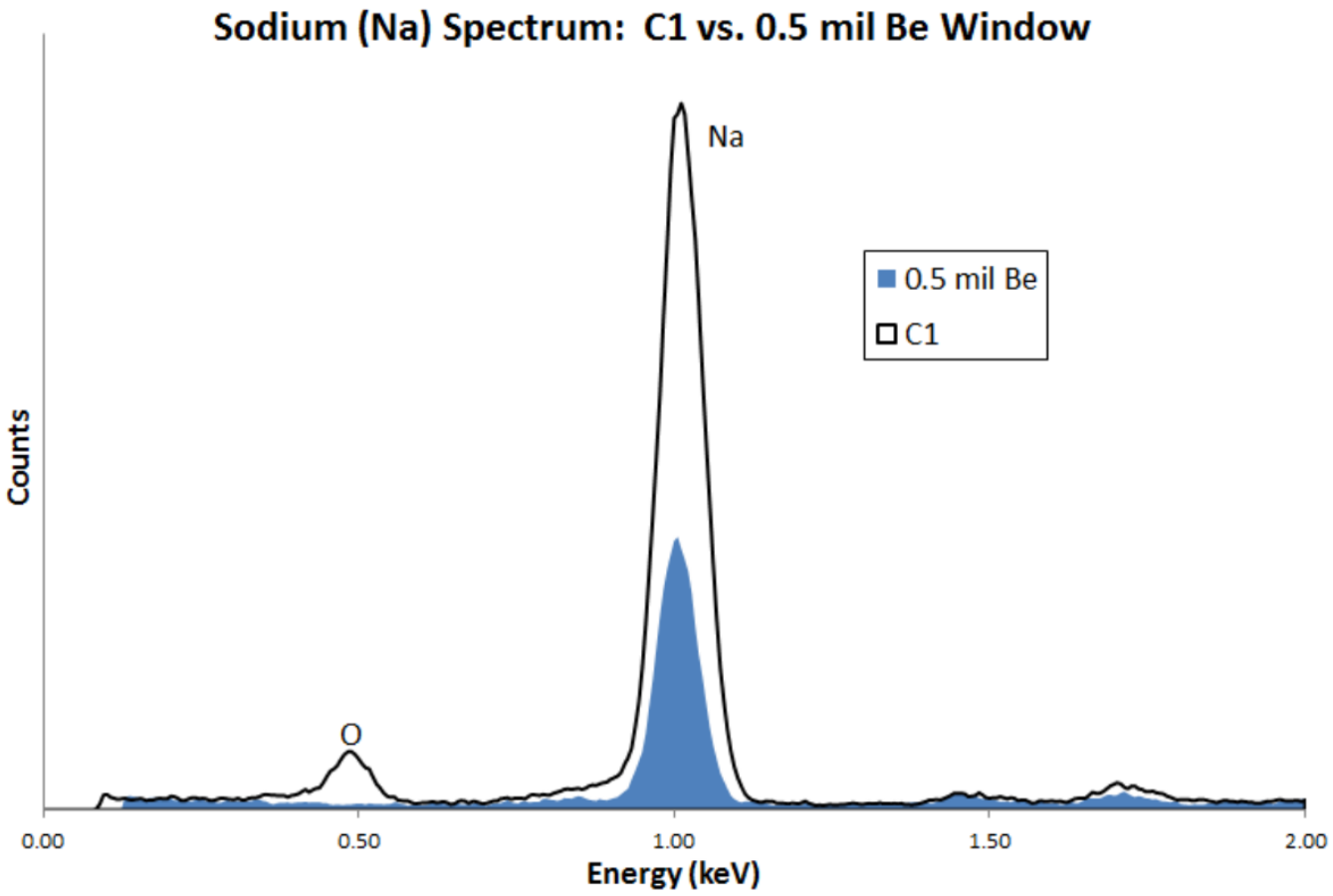
$$E_{NR} = E_n\,\frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right] \qquad (2)$$

Δt = neutron total Time-of-flight



Overall MC correction below 15 %




Sodium (Na) Spectrum: C1 vs. 0.5 mil Be Window
Na
O
0.5 mil Be
C1
Counts
0.00
0.50
1.00
1.50
2.00
Energy (keV)