Ionization Efficiency Studies for Nuclear Recoils in Silicon

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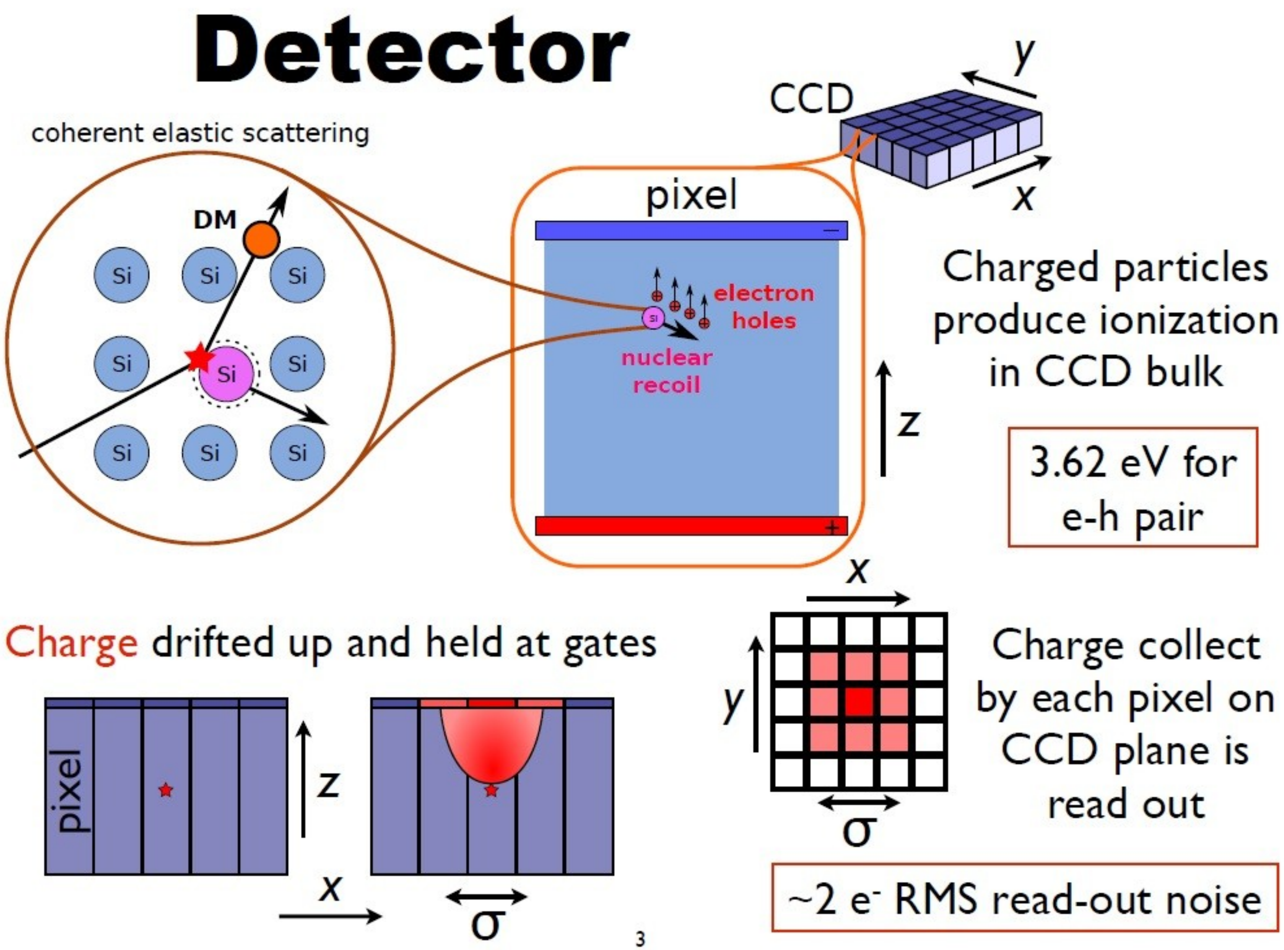
Antonella Collaboration

XV MWPF 2015

Abstract

The Damic Collaboration has set up an experimental array of Charge-Coupled Devices (CCDs) in a nickel mine, and has developed all analysis tools to discern any known trace of conventional matter from what a DM particle could produce when crossing the CCDs. In order to calibrate the signals from these CCDs, scientists in the Antonella Collaboration have designed experiments to quantify neutron-silicon interactions, assuming that neutrons can mimic DM interactions in the CCDs. Here we present preliminary results from the analysis of data obtained in these experiments, in particular, the measurement of ionization efficiencies in Silicon and a plastic scintillator.

CCD operation



Ionization efficiency studies

- Damic CCD's measure ionization energy
- Nuclear recoil energy from DM-Si interaction

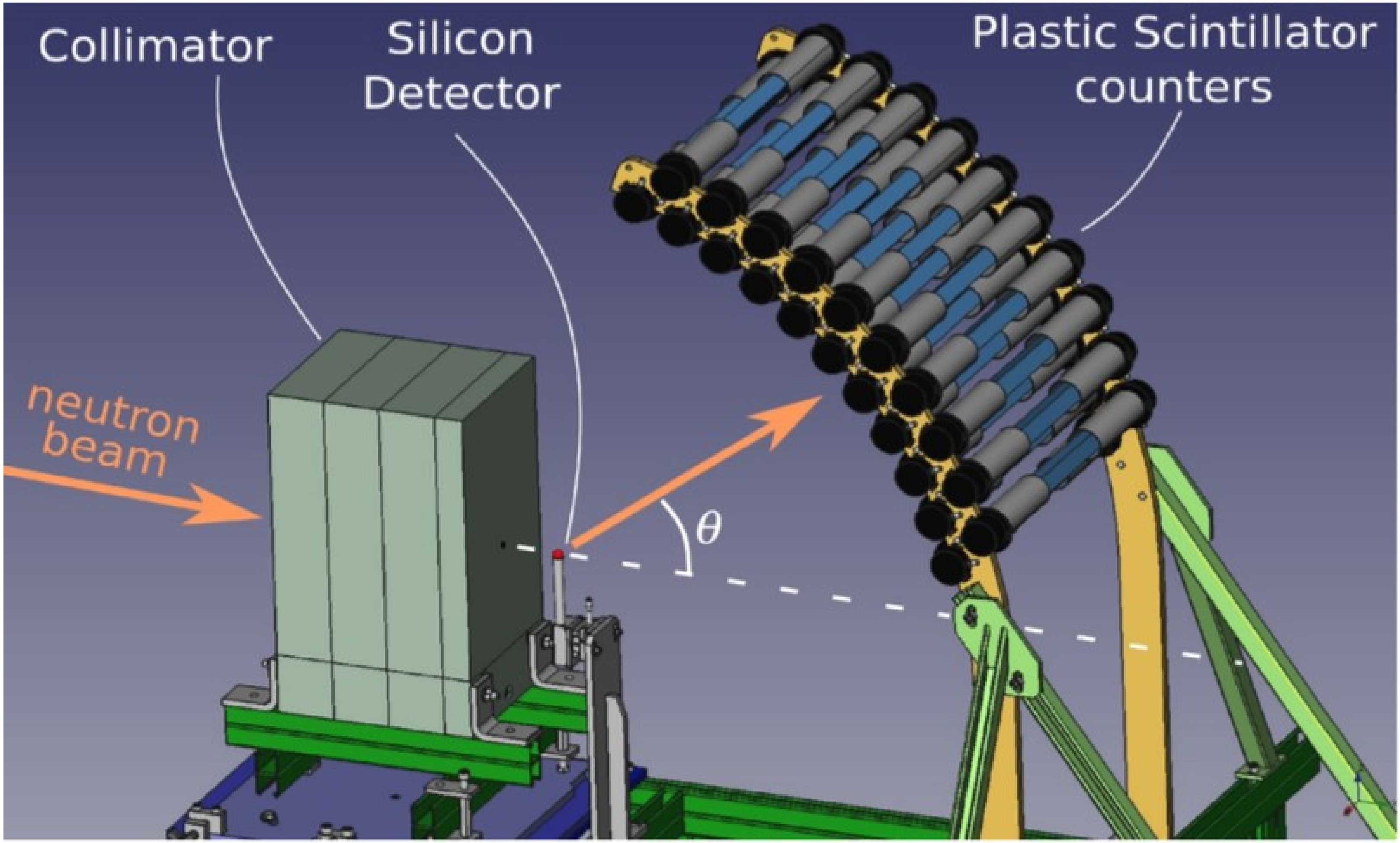
Ionization efficiency in Si

AND Ionization efficiency in plastic scintillator

Antonella Collaboration

- Prove Lindhard's model (1963) Exp: 1990

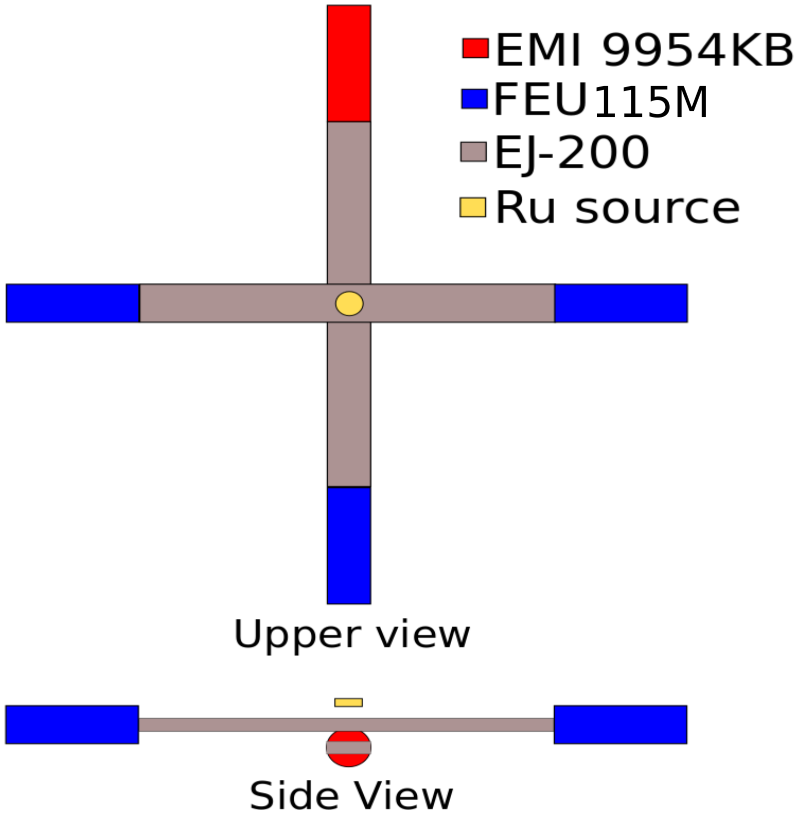
Antonella experiment



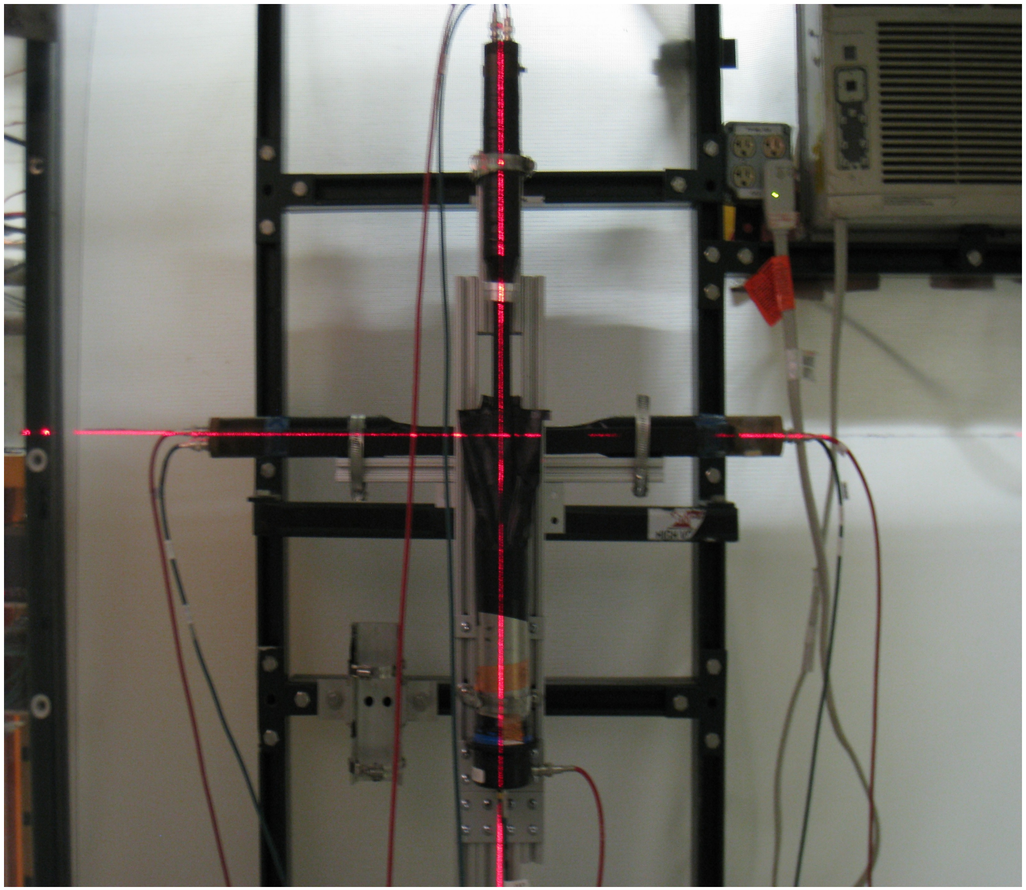
Target may be SiDet or a scintillator

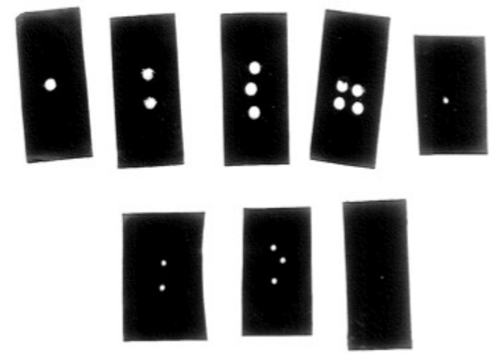
PMT's characterization

To characterize the signal in a PMT, the experimental setup consisted of two scintillator bars, with a PMT at each end of the bars



Scintillator EJ200





Experimental setup at FTB facility

ADC distributions

The ADC distributions may be calculated using a continuous approach, or a discrete approach

$$P(0) = \frac{N_{\mathrm{ped}}}{N_{\mathrm{trig}}} = e^{-\mu} \qquad \frac{P(2)}{P(1)} = \frac{\mu}{2}$$

Gaussians

$$\mathrm{SER}_0(x) = \frac{1}{\sqrt{2\pi}\sigma_0}\frac{1-p_E}{g_N}e^{-(1/2)\left(\frac{x-x_0-x_P}{\sigma_0}\right)^2}, \; x>0 \qquad g_N = \frac{1}{2}\left(1-\mathrm{erf}\left(-\frac{x_0}{\sqrt{2}\sigma_0}\right)\right).$$

x_P, x_0, σ_0

$$M(x) = \sum_{n=2}^{N_M}\frac{P(n;\mu)}{\sqrt{2n\pi}\sigma_1}e^{-(1/2n)\left(\frac{x-nx_1-x_P}{\sigma_1}\right)^2}$$

x_1, σ_1

$$x_1 = \left(x_0 + \frac{\sigma_0}{\sqrt{2\pi}g_N}\exp\left(-\frac{1}{2}\left(\frac{x_0}{\sigma_0}\right)^2\right)\right)$$

$x_n = nx_1$,

$\sigma_n^2 = n\sigma_1^2$

$$\sigma_1^2 = \left(x_0^2 + \sigma_0^2 + \frac{x_0\sigma_0}{\sqrt{2\pi}g_N}\exp\left(-\frac{1}{2}\left(\frac{x_0}{\sigma_0}\right)^2\right)\right) - x_1^2$$

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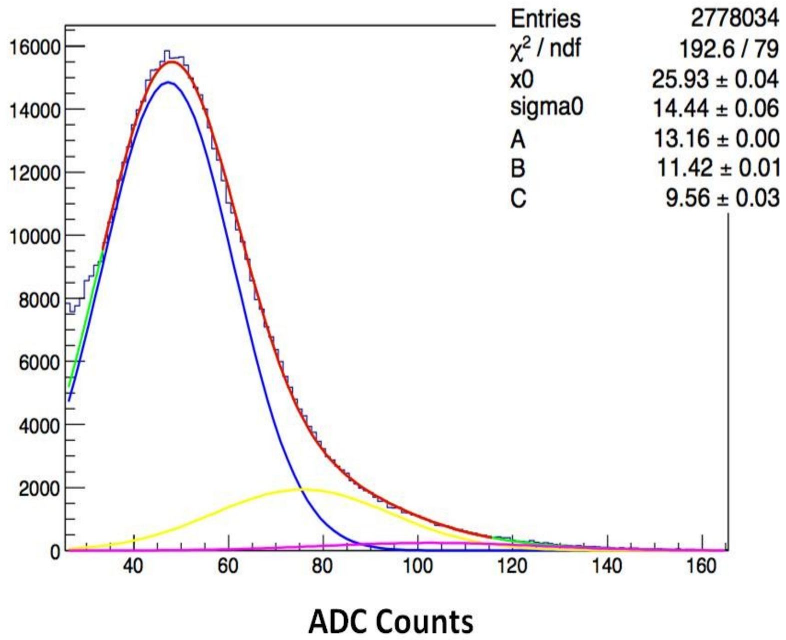
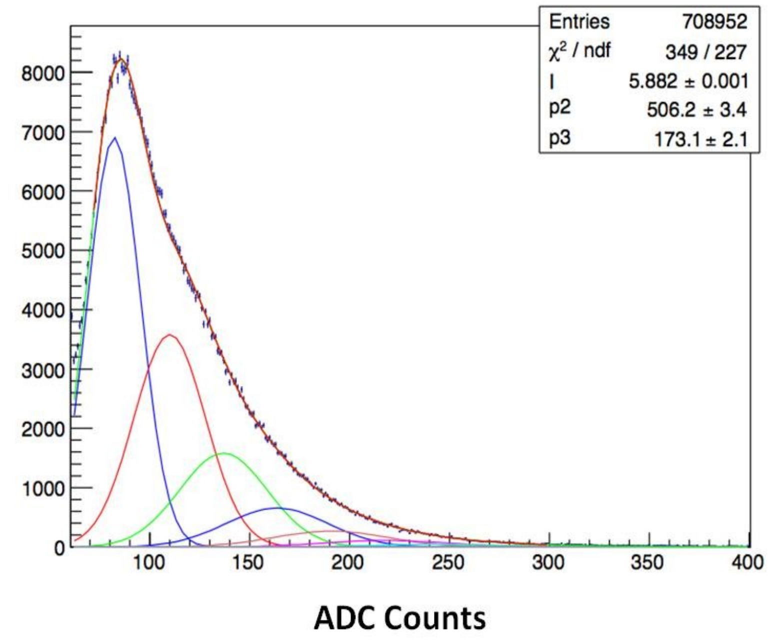
Methods for precise PE counting with PMTs (LEDs)

ADC distributions





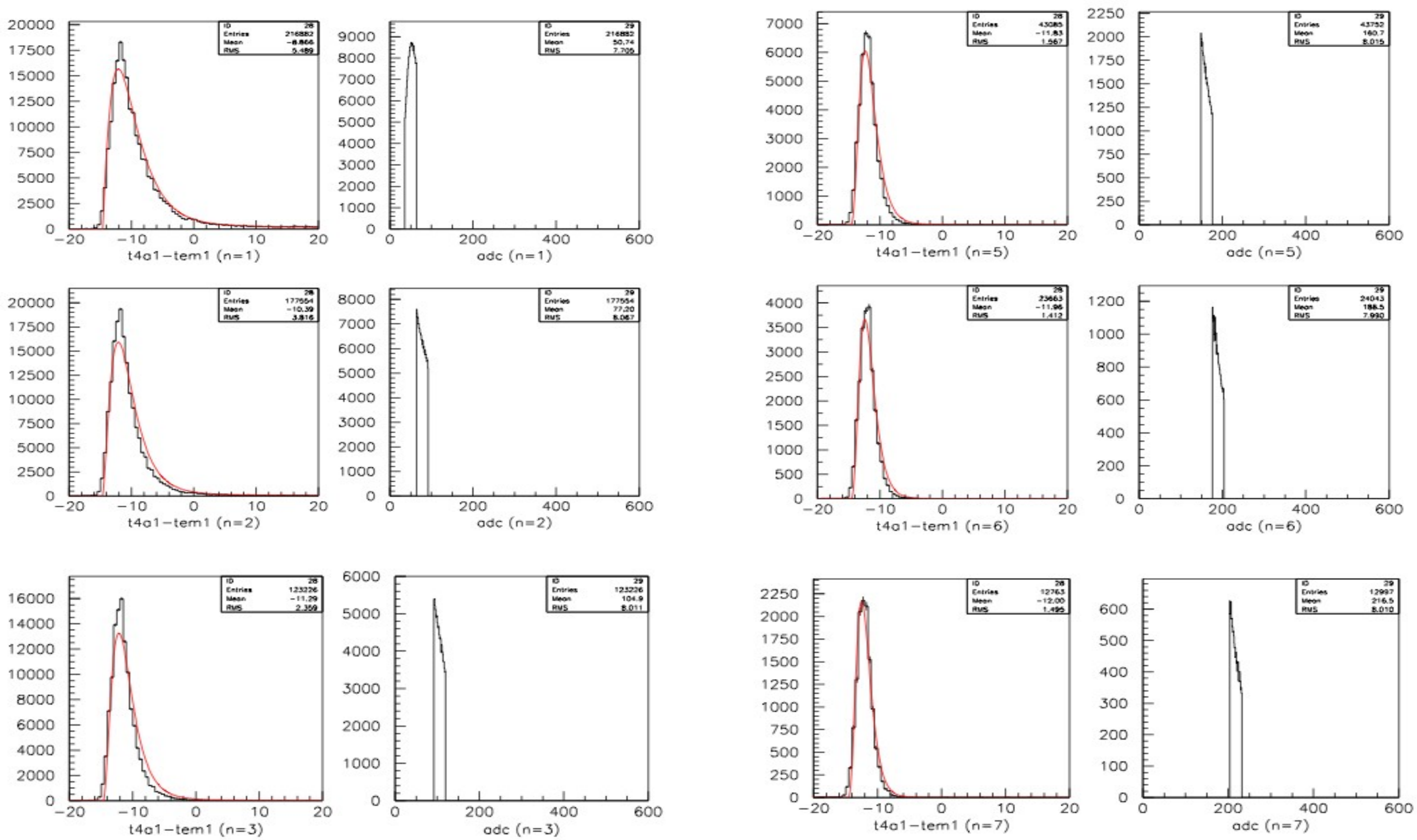
Charge distributions with two paper masks: one tiny hole of 0.035 mm in radius, and two small holes of 1.19 mm radius

TDC distributions

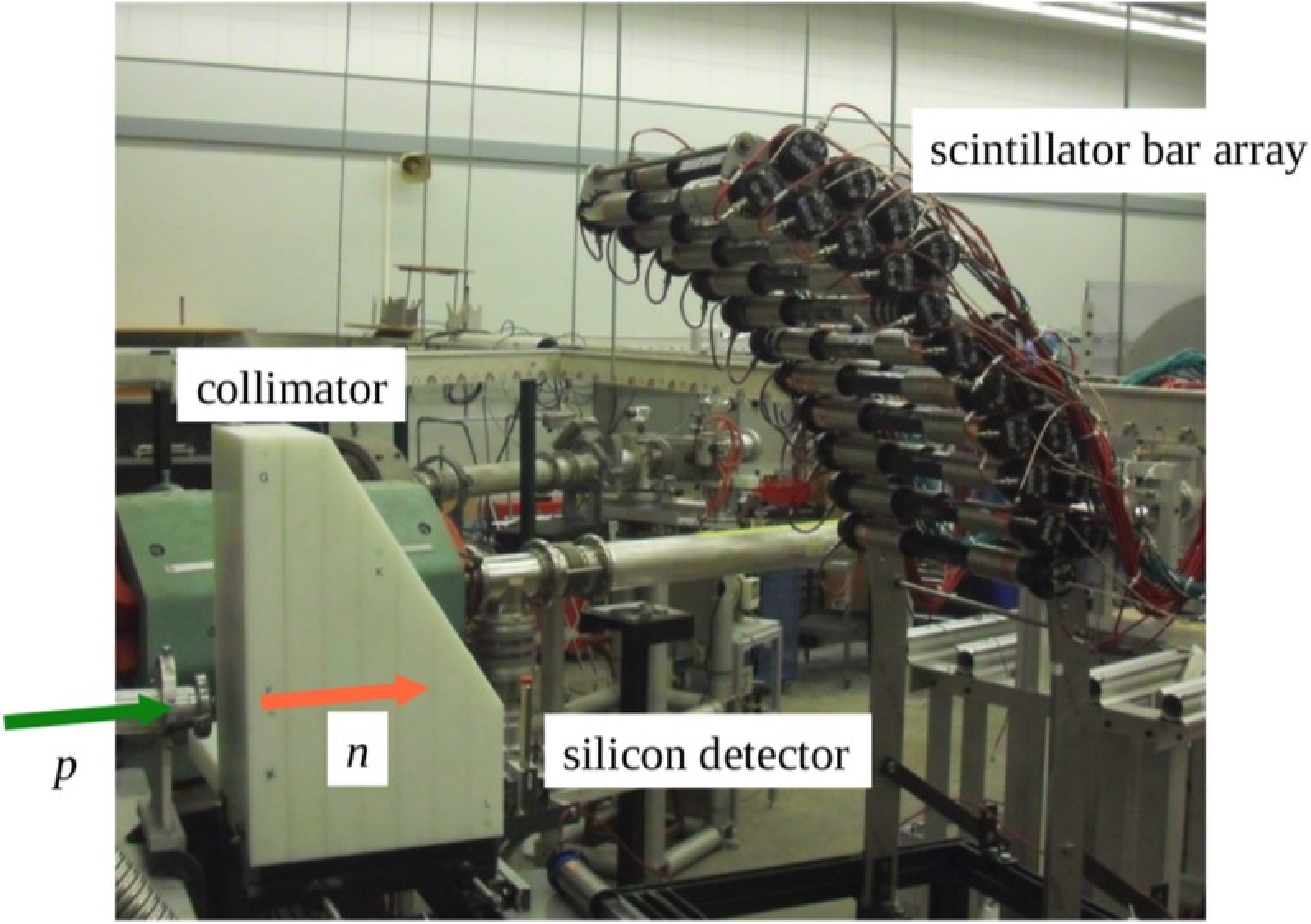
$$f(t) = \frac{p_1}{\tau_s - \tau_f}\{\exp[-(t-t_0)/\tau_s] - \exp[-(t-t_0)/\tau_f]\} +$$
$$\frac{p_2}{\tau_3 - \tau_f}\{\exp[-(t-t_0)/\tau_3] - \exp[-(t-t_0)/\tau_f]\}$$

Histogrs: TDC for selected ADC bar

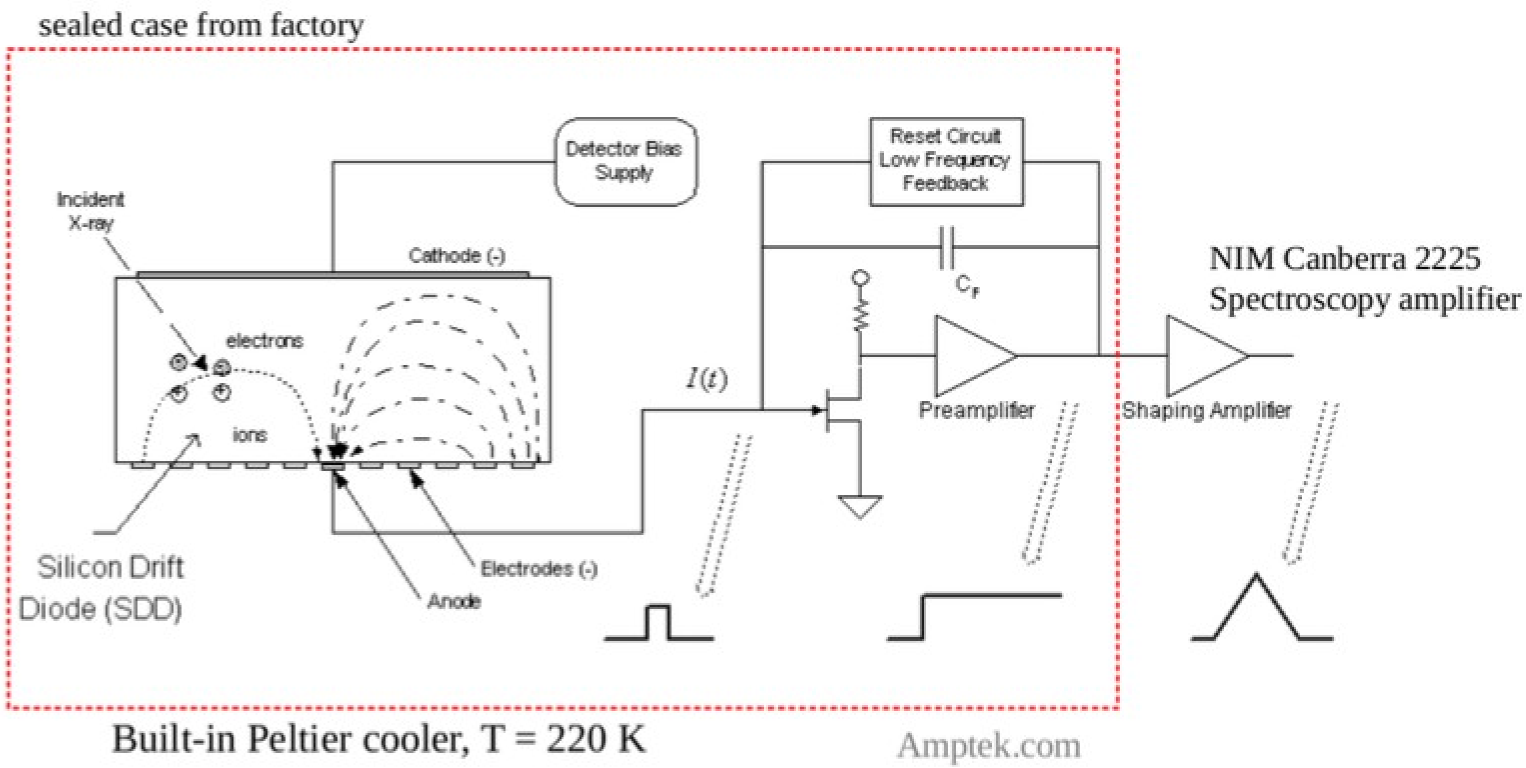
Lines: normalized TDC prediction



Antonella at UND



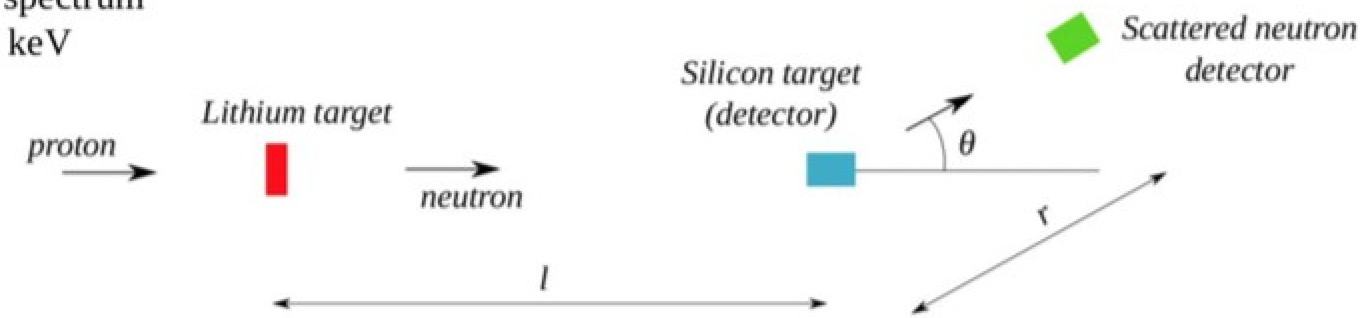
Detector



We used an X-ray detector which is a Silicon Drift Diode, 29mg mass

Ionization efficiency

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

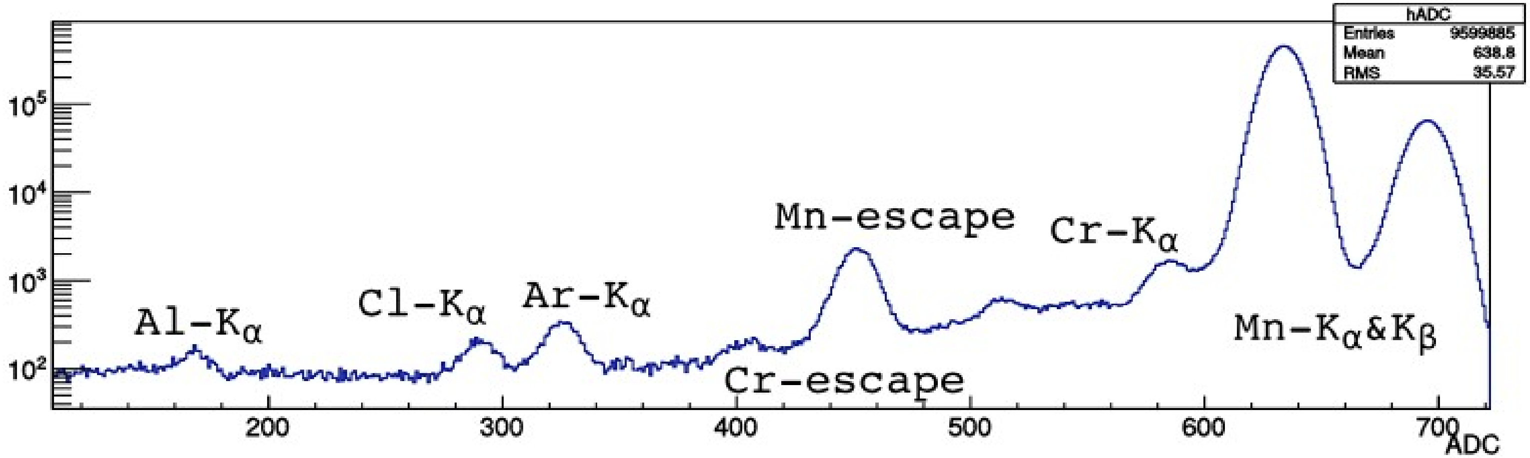
$$E_{NR} = E_n\,\frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right] \qquad (2)$$

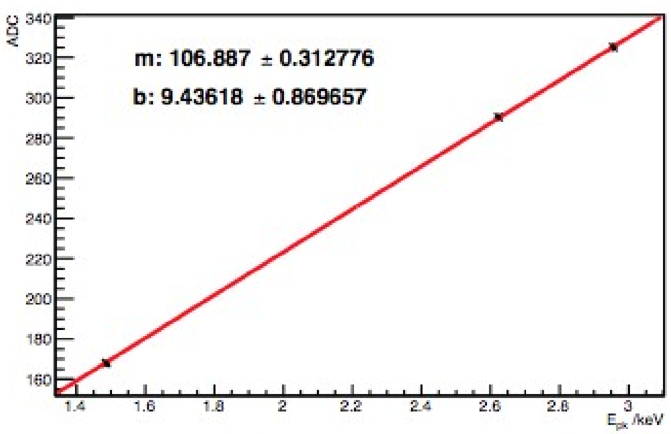
Program:

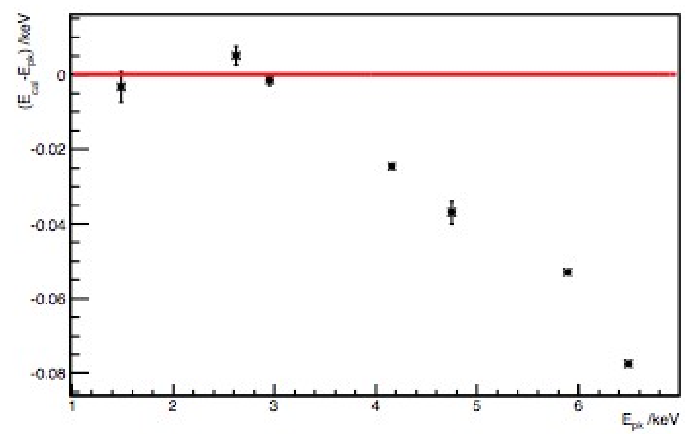
1. Measure neutron energy by time-of-flight (1)
2. Detect a scattered neutrons in a neutron detector
3. Measure charge produced by ionization
4. Calculate the nuclear recoil energy with kinematics (2)

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

Callibration: Fe source





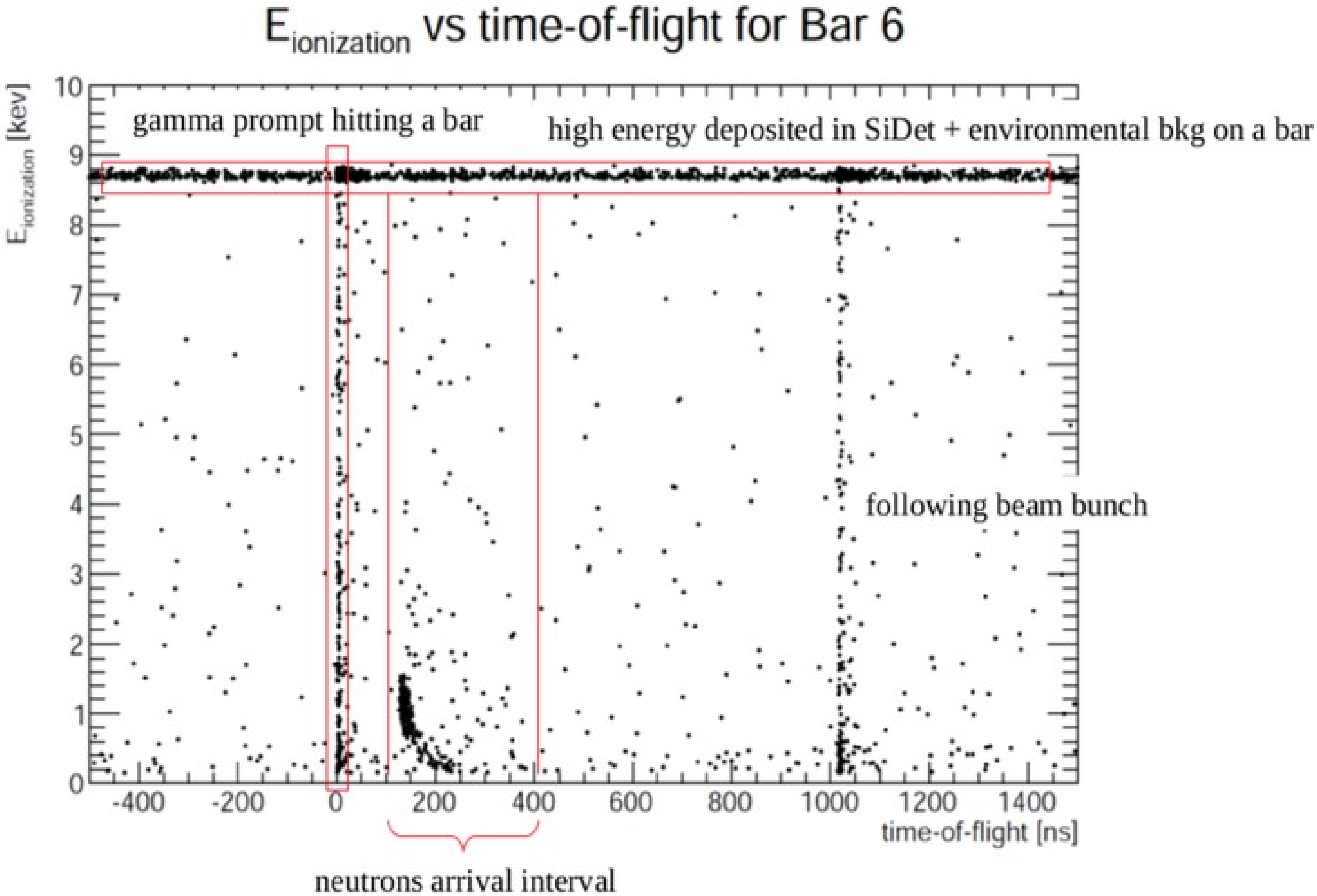


Systematic uncertainty dominated by the X-ray detector linear response

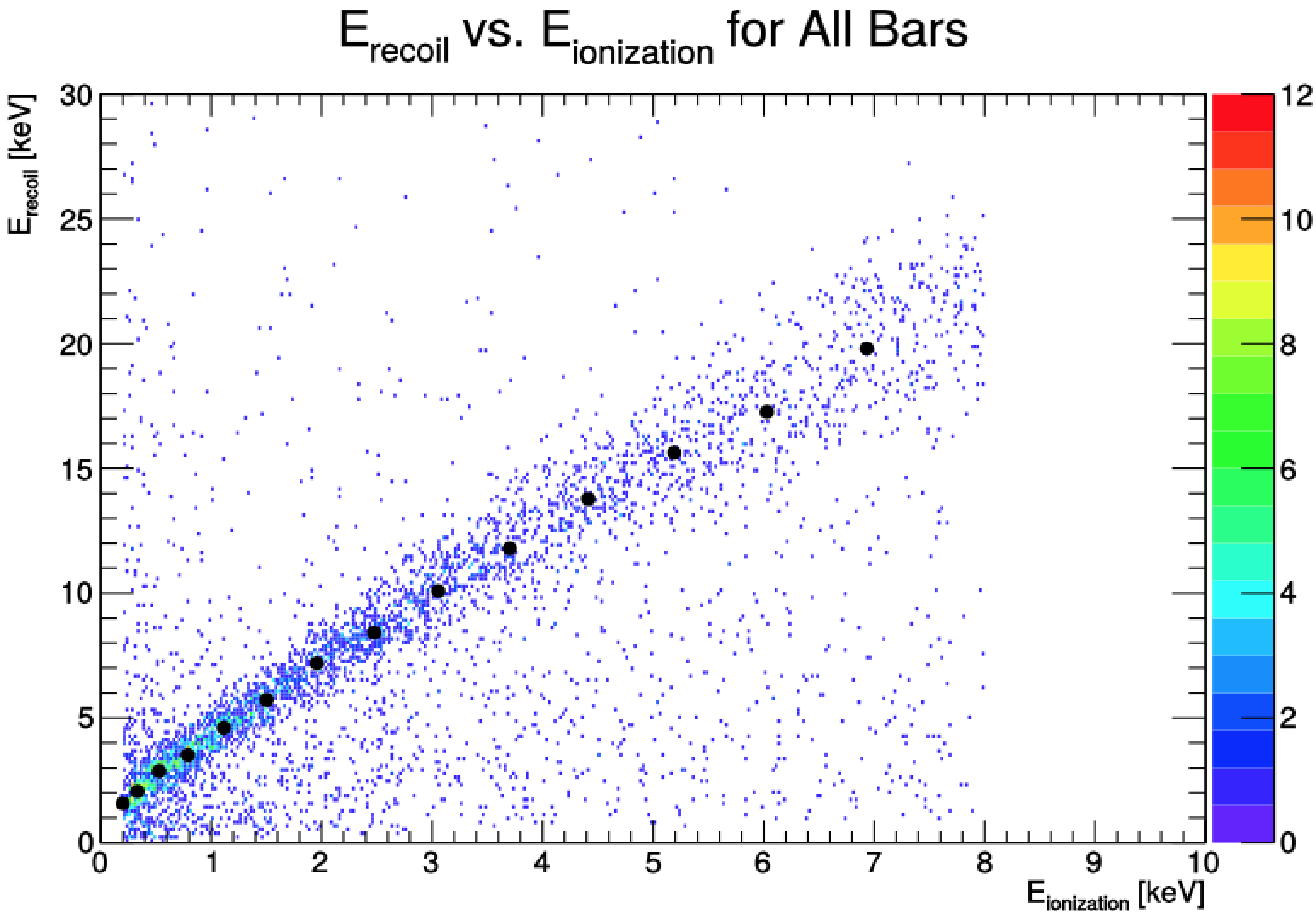
Scientific run

- Took data for 10 day
- ~ 10^6 gamma+neutron hits in silicon detector
- Trigger rate ~ 170 Hz (of which ~ 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)

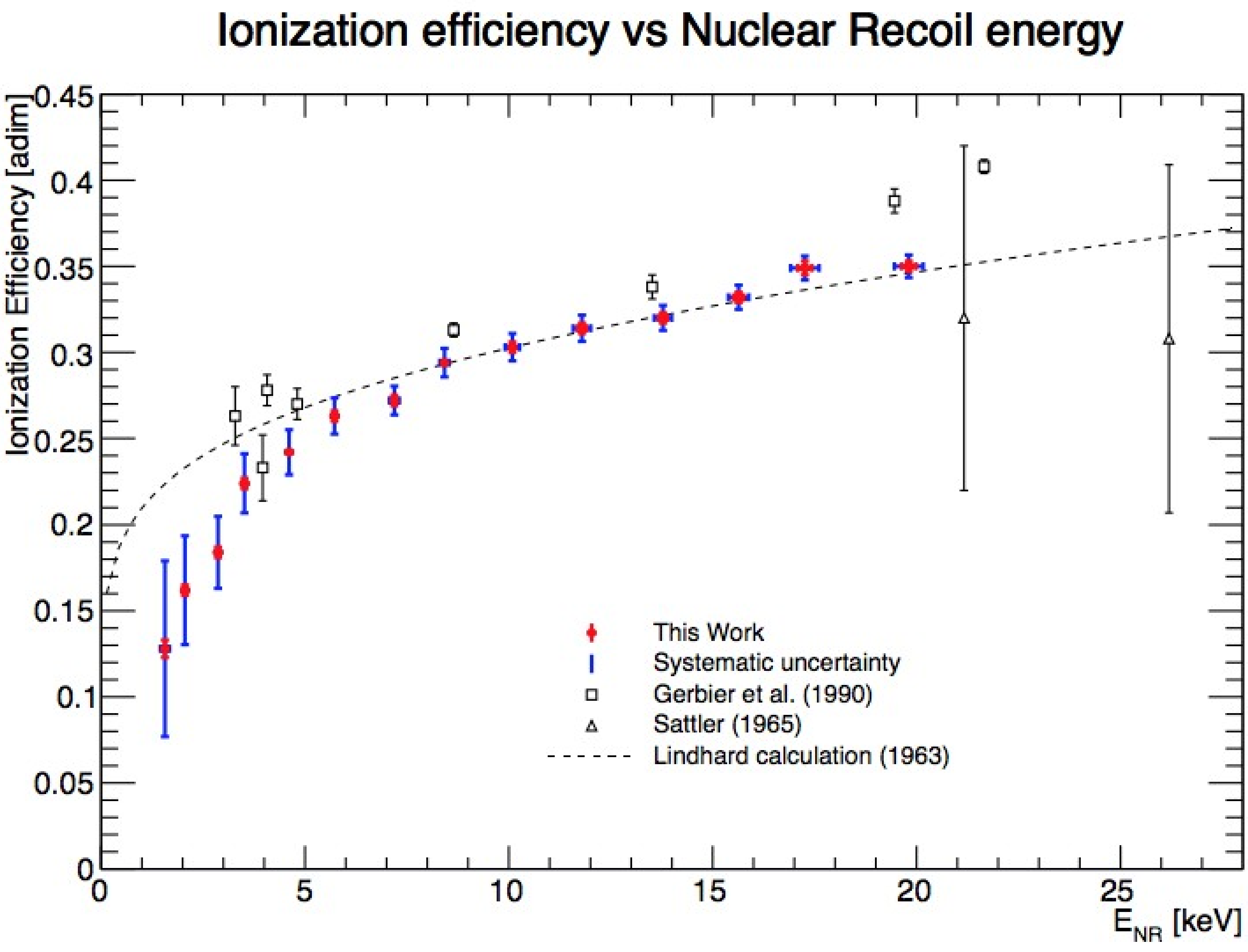
Antonella data



Antonella data



Preliminary results



Conclusions

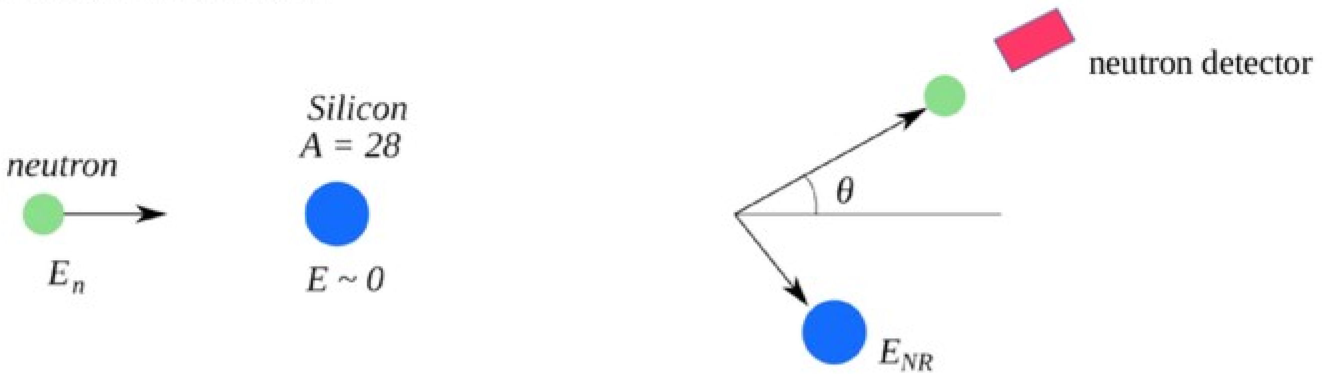
Scintillator+PMT response was studied

Antonella's results: best measurement on Si IE up to date

Ongoing analysis on scintillator IE

N-Si collisions

Monochromatic neutrons



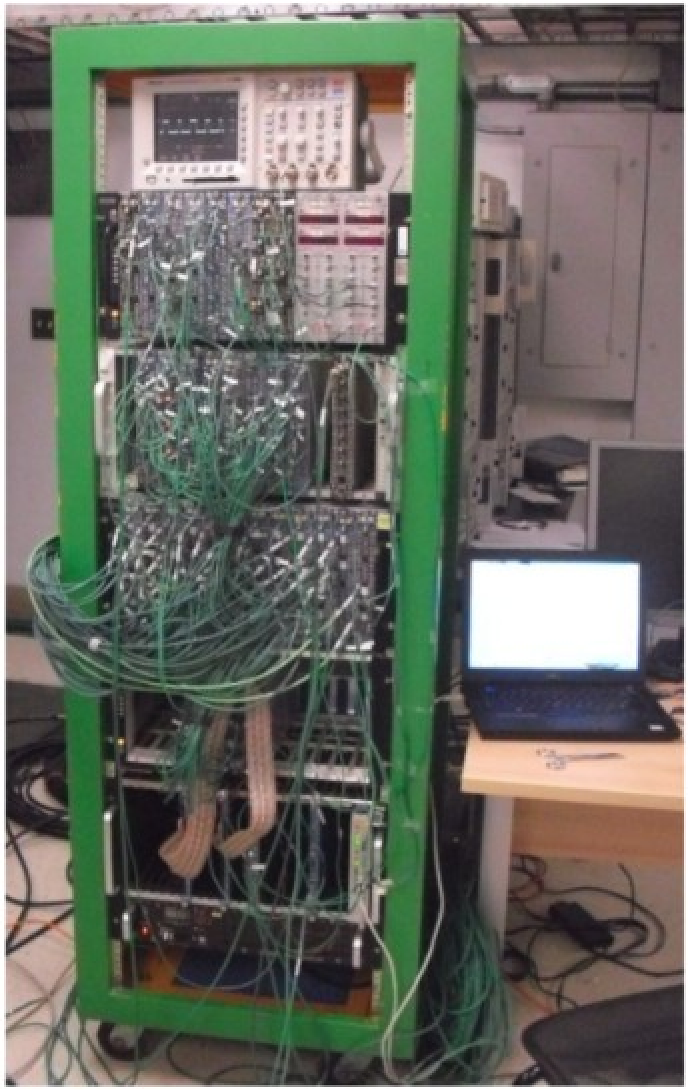
$$E_{NR} = E_n \frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right]$$

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

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

Backup slides

Antonella DAQ



PREP

Antonella DAQ