Results from the CLEAN R&D Program

The Hunt For Dark Matter
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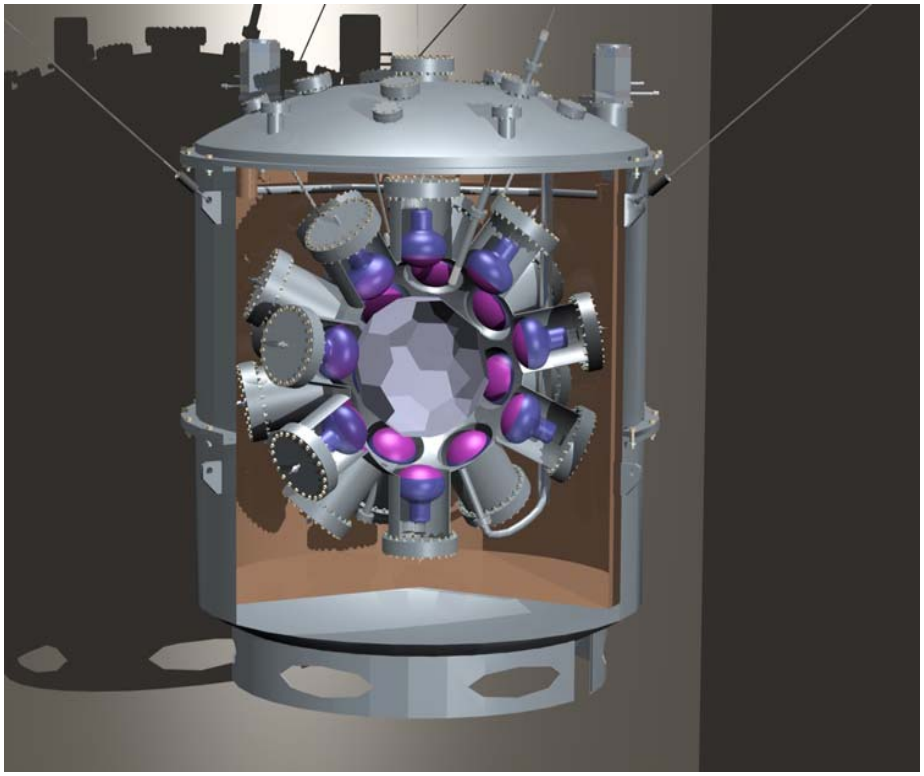
Outline

- Micro-CLEAN Argon Data
  - Quenching factor
  - PSD
- Pico-CLEAN Neon Data
- Conclusions

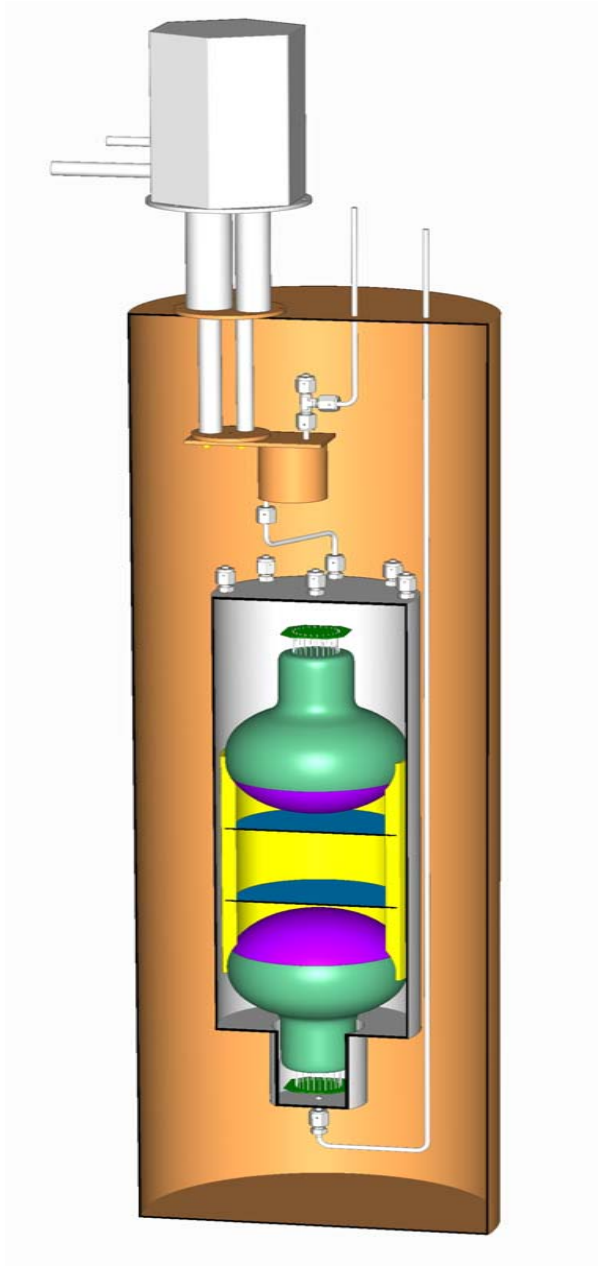
DEAP/CLEAN Dark Matter Detector

- Search for WIMPs by detecting scintillation light in 1 tonne liquid argon detector
- ~1 Bq/kg from ^{39}Ar gives ~10^9 events in region of interest in one year
- Timing information of scintillation light allows for pulse shape discrimination (PSD) to distinguish electronic recoils from nuclear recoils
- PSD must be powerful enough to eliminate ^{39}Ar and gamma ray backgrounds
- Switch LAr target for LNe to simulate beam ON/OFF experiment

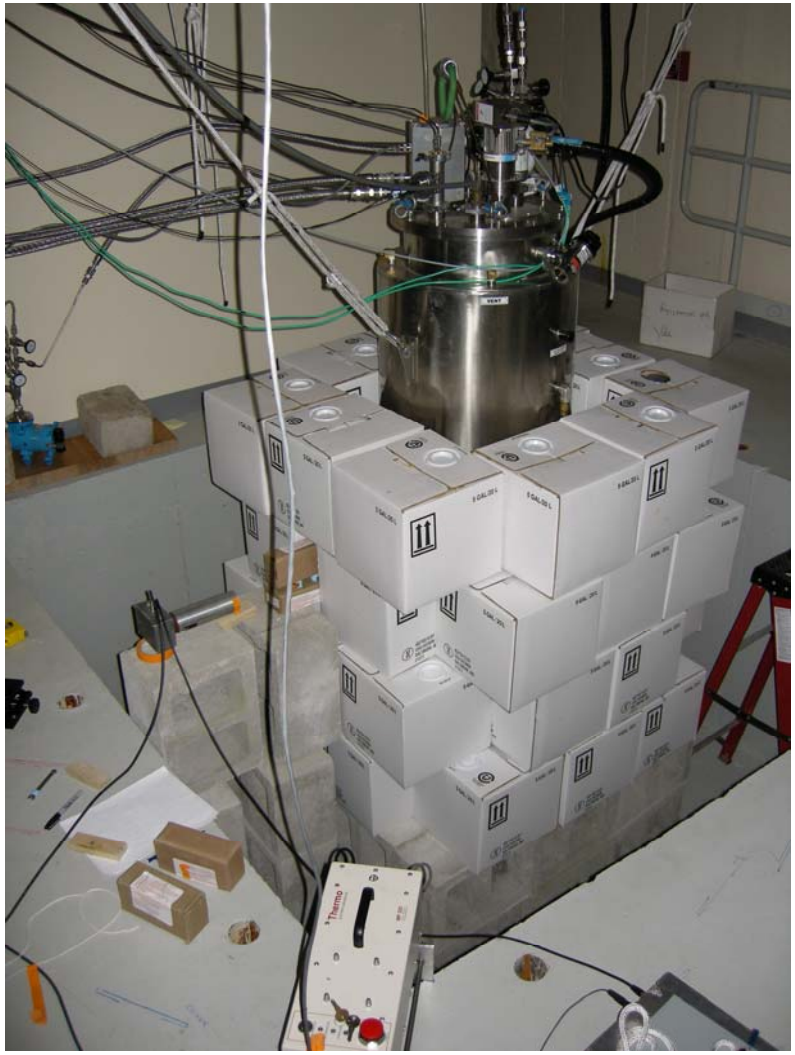


Micro-CLEAN detector

- Active volume of Micro-CLEAN is 4 kg LAr
- 20 cm diameter, 10 cm long teflon cylinder, coated with wavelength shifter (TPB)
- Two 20 cm PMTs view the cell through windows, also coated with TPB
- Cell, PMTs are immersed in liquid



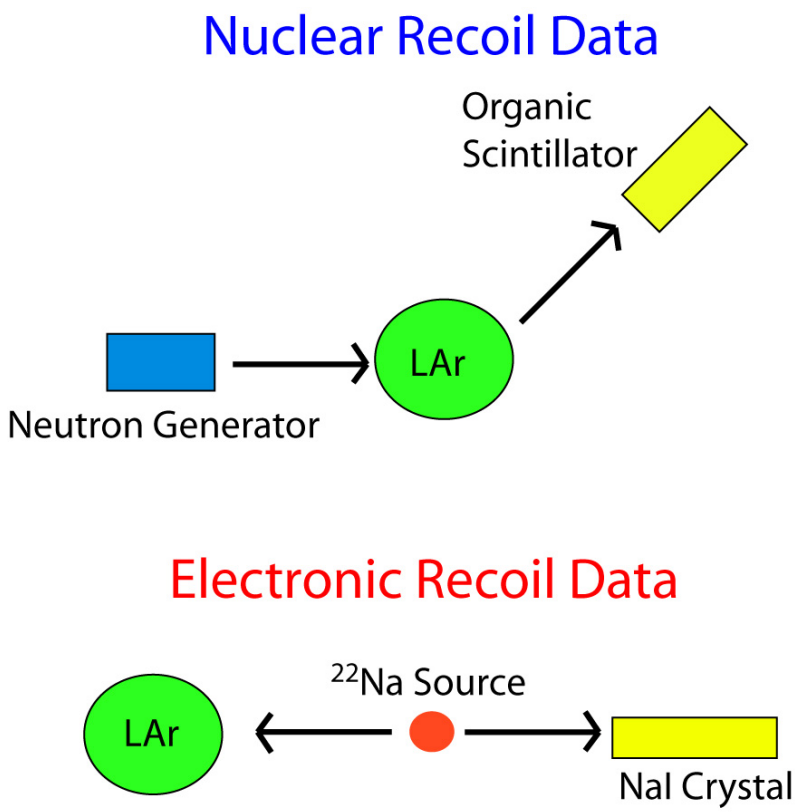
MicroCLEAN Pictures



Data Types

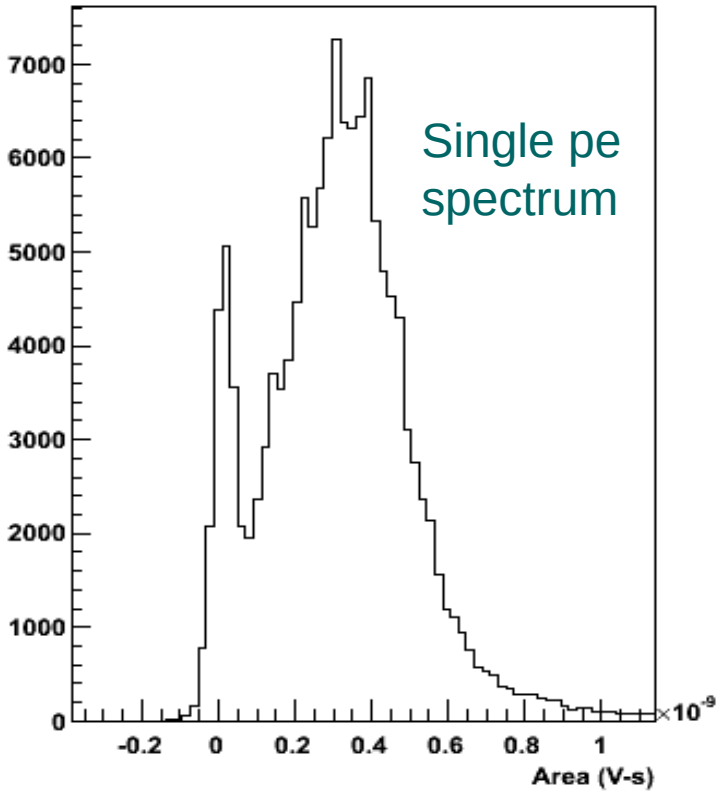
- Daily calibration using ^{57}Co source -122 keV gamma line
- D-D Neutron generator provides 2.8 MeV monoenergetic source of neutrons to investigate nuclear recoils
  - Require coincidence with organic scintillator
- 10 microCurie ^{22}Na source – 511 keV gammas produce a continuum of electronic recoils
  - Require coincidence with a NaI crystal scintillator to tag the second 511 keV

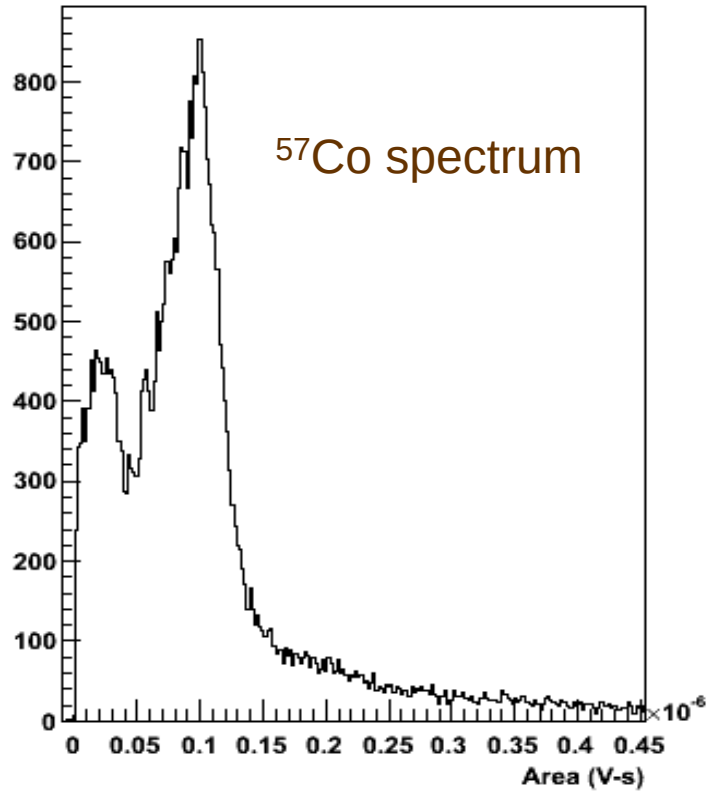
Data Tagging and Quality



- Require coincidence with external detector
- Time of Flight cut
- PSD cut in organic scintillator
- Energy cut in NaI crystal
- Asymmetry cut in the PMTs

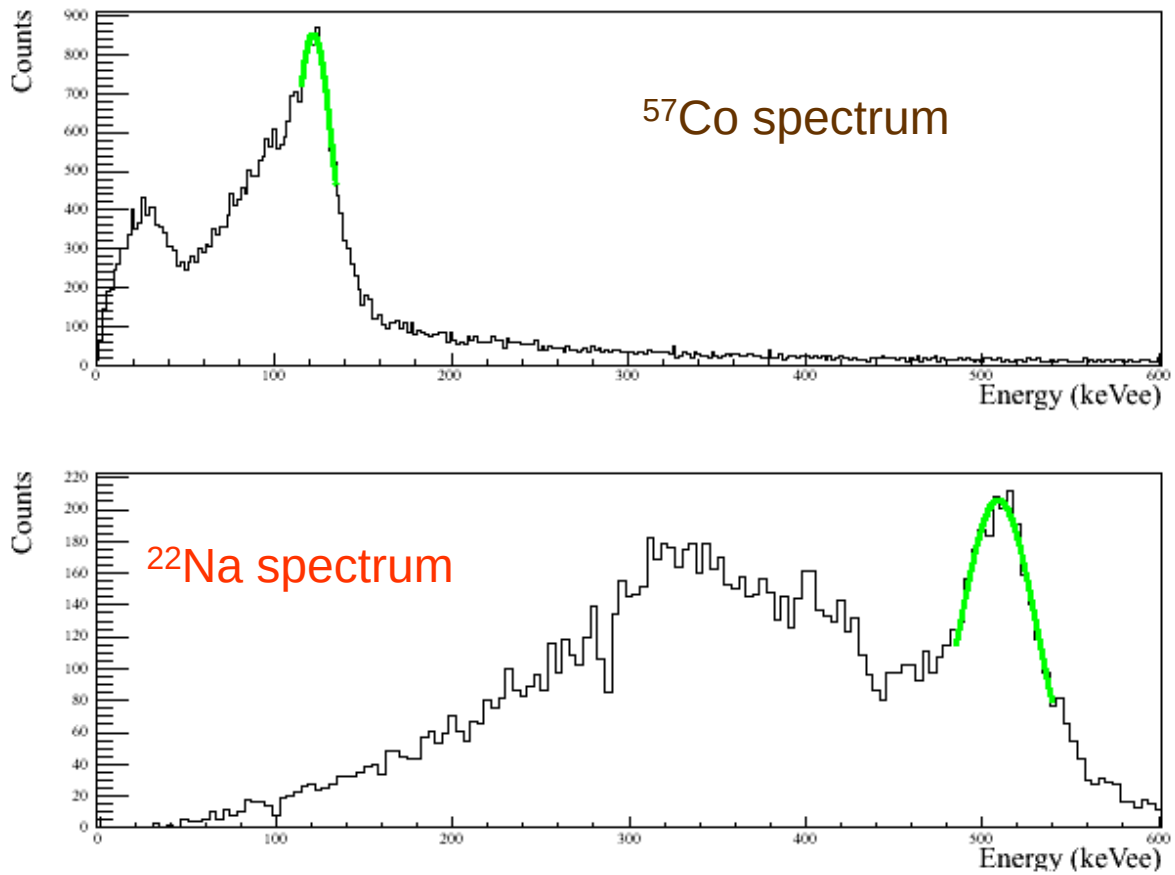
Light Yield





- Single photoelectron spectrum and cobalt peak for one of the PMTs
- Measure the light yield to be 4.9 pe/keVee

Energy calibration

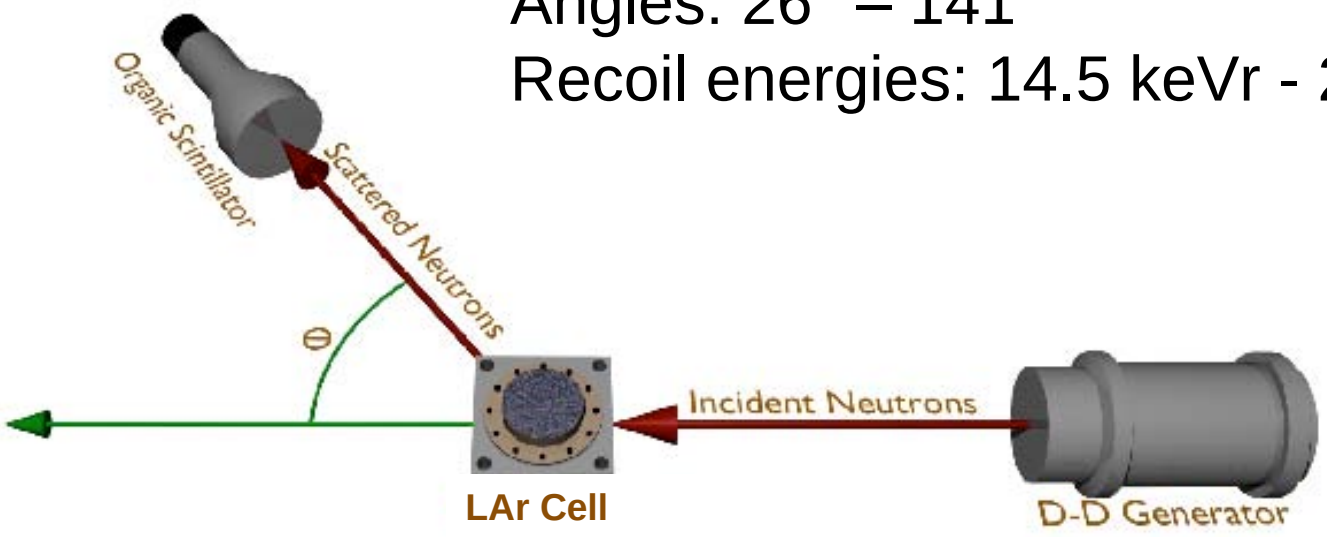


- Calibration from cobalt peak
- Fit to sodium peak gives 509(1) keVee

Quenching Factor Measurement

- Nuclear recoils produce less light than electronic recoils
  - "Quenching factor" or nuclear recoil scintillation efficiency
- 2.8-MeV neutrons from D-D generator
- Coincidence between LAr and organic scintillator
- Select LAr recoil energy with organic scintillator angle
- Quenching factor = keVee / expected recoil energy

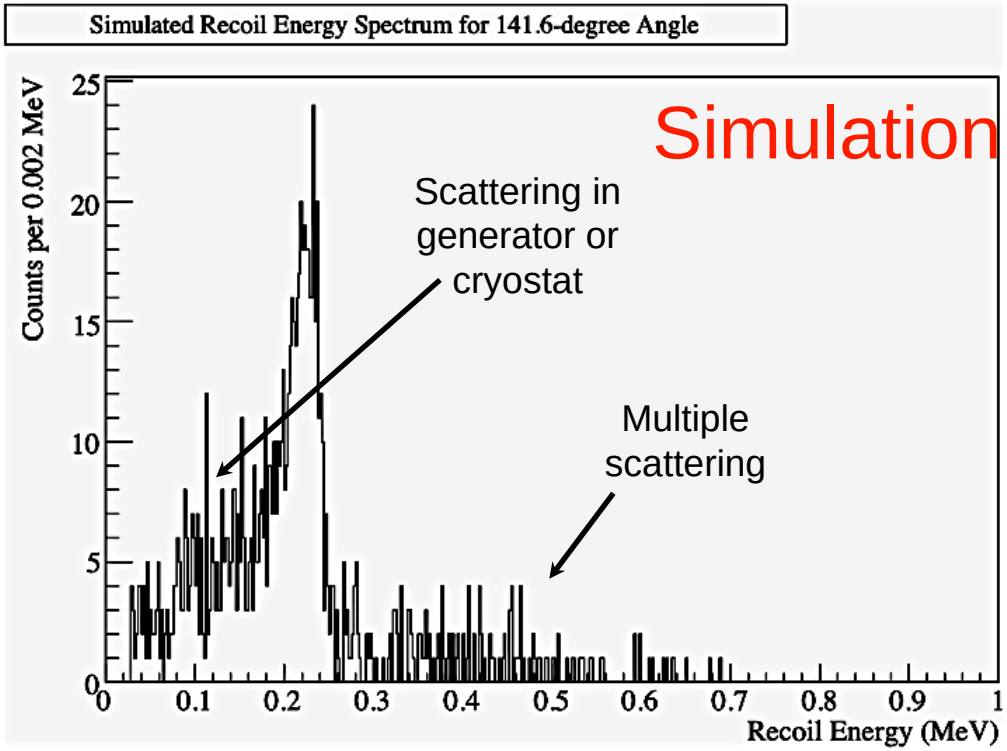
Angles: 26° – 141°
Recoil energies: 14.5 keVr - 240 keVr



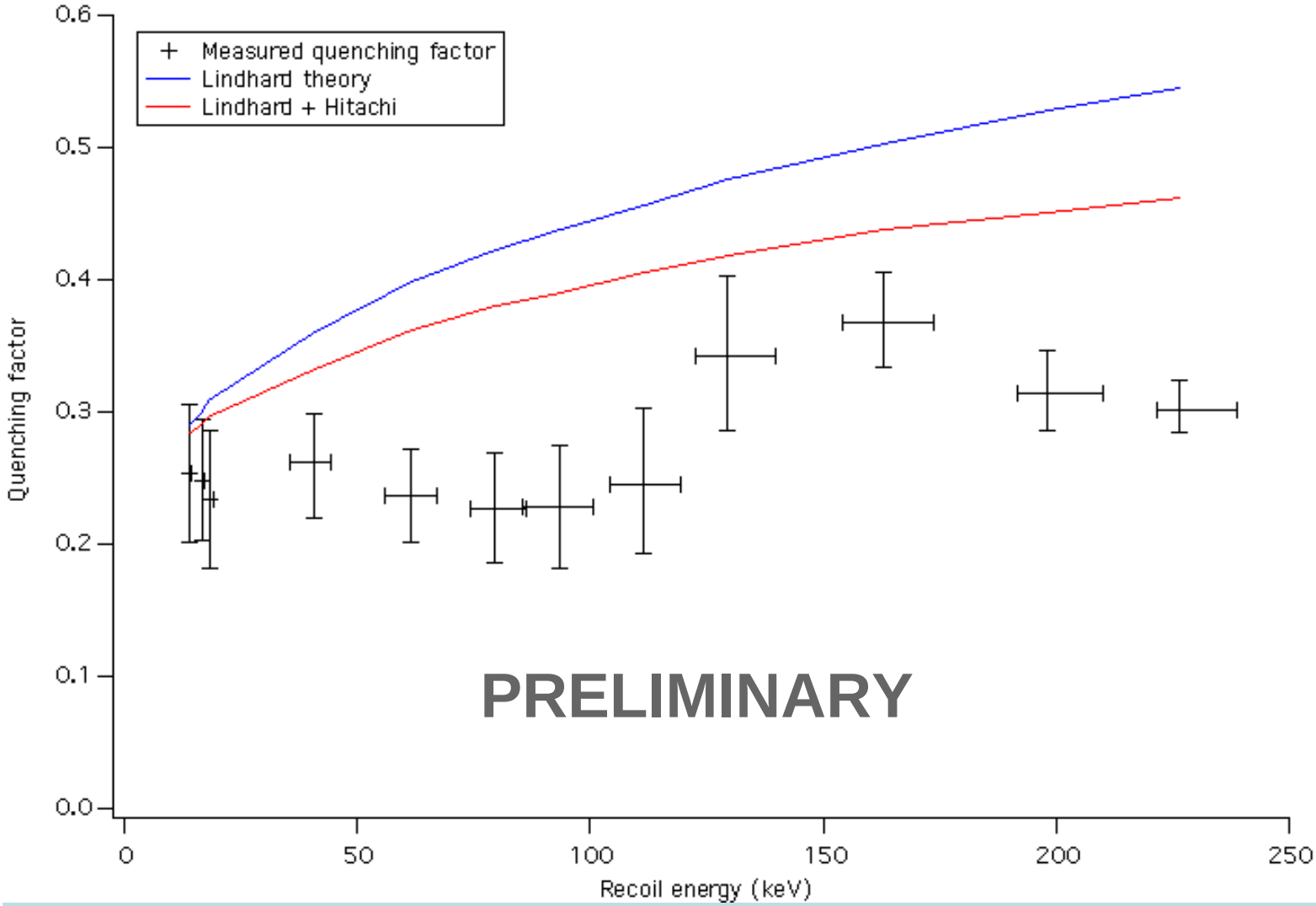
Recoil Energy

$$E_{rec} = \frac{2E_{in}}{(1+A)^2}[1+A-\cos^2(\theta)-\cos(\theta)\sqrt{A^2+\cos^2(\theta)-1}$$

- Calculate recoil energy from kinematics
- Also use simulation
- Energy loss from scattering in generator, cryostat, etc

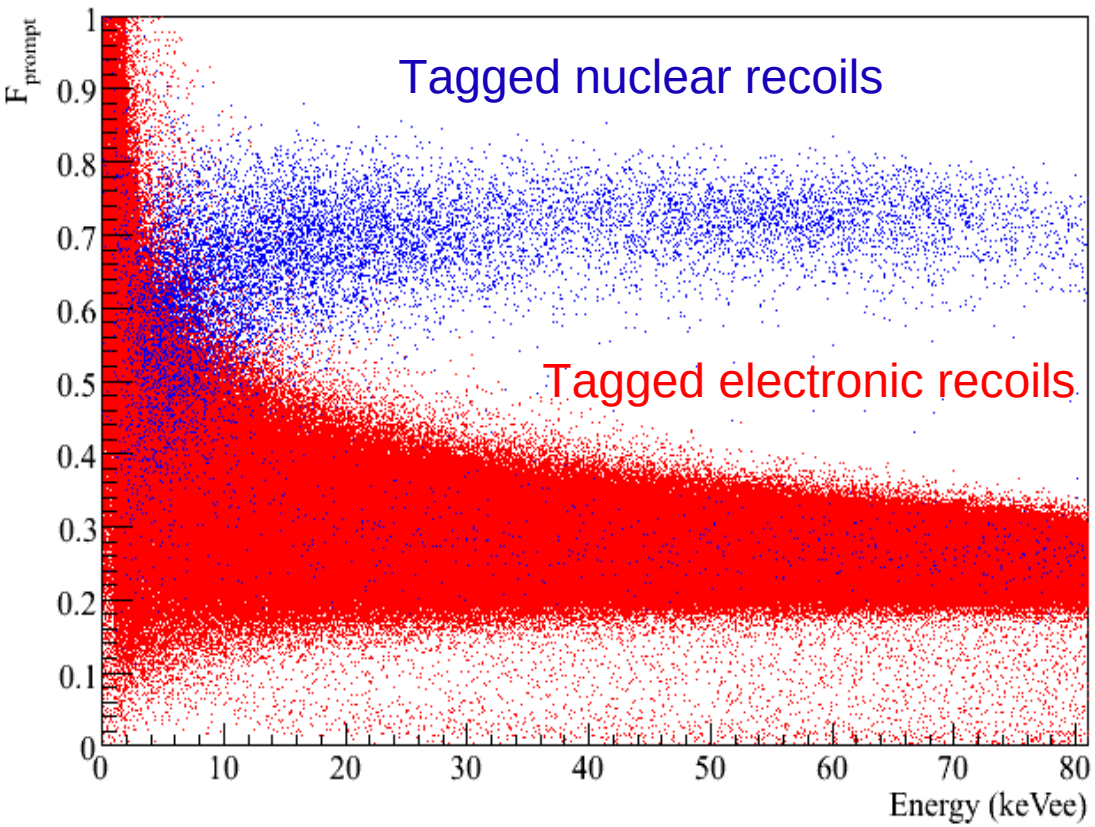


LAr Quenching Measurements



Prompt Fraction Discrimination

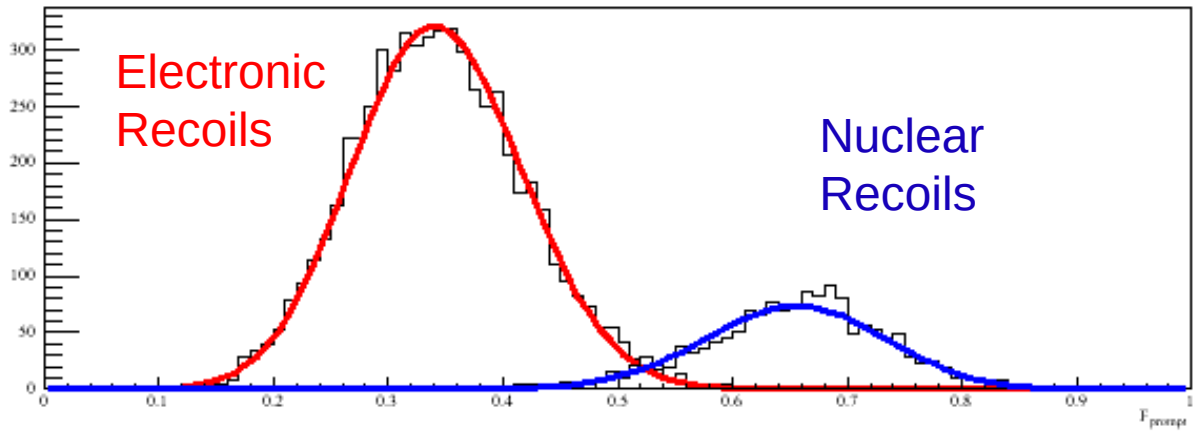
- F_{prompt} is fraction of light arriving in first 100 ns
  - 100 ns chosen to effectively separate fast and slow components of scintillation
- F_{prompt} for electronic recoils is ~0.3, versus ~0.7 for nuclear recoils



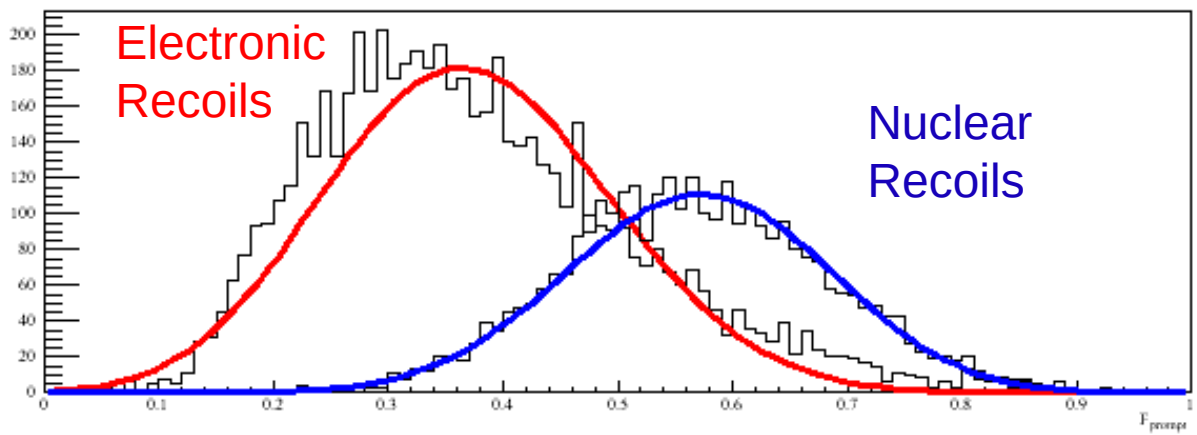
- Project the F_{prompt} scatter plot onto the y-axis to measure the distributions

F_{prompt} Projection Fits

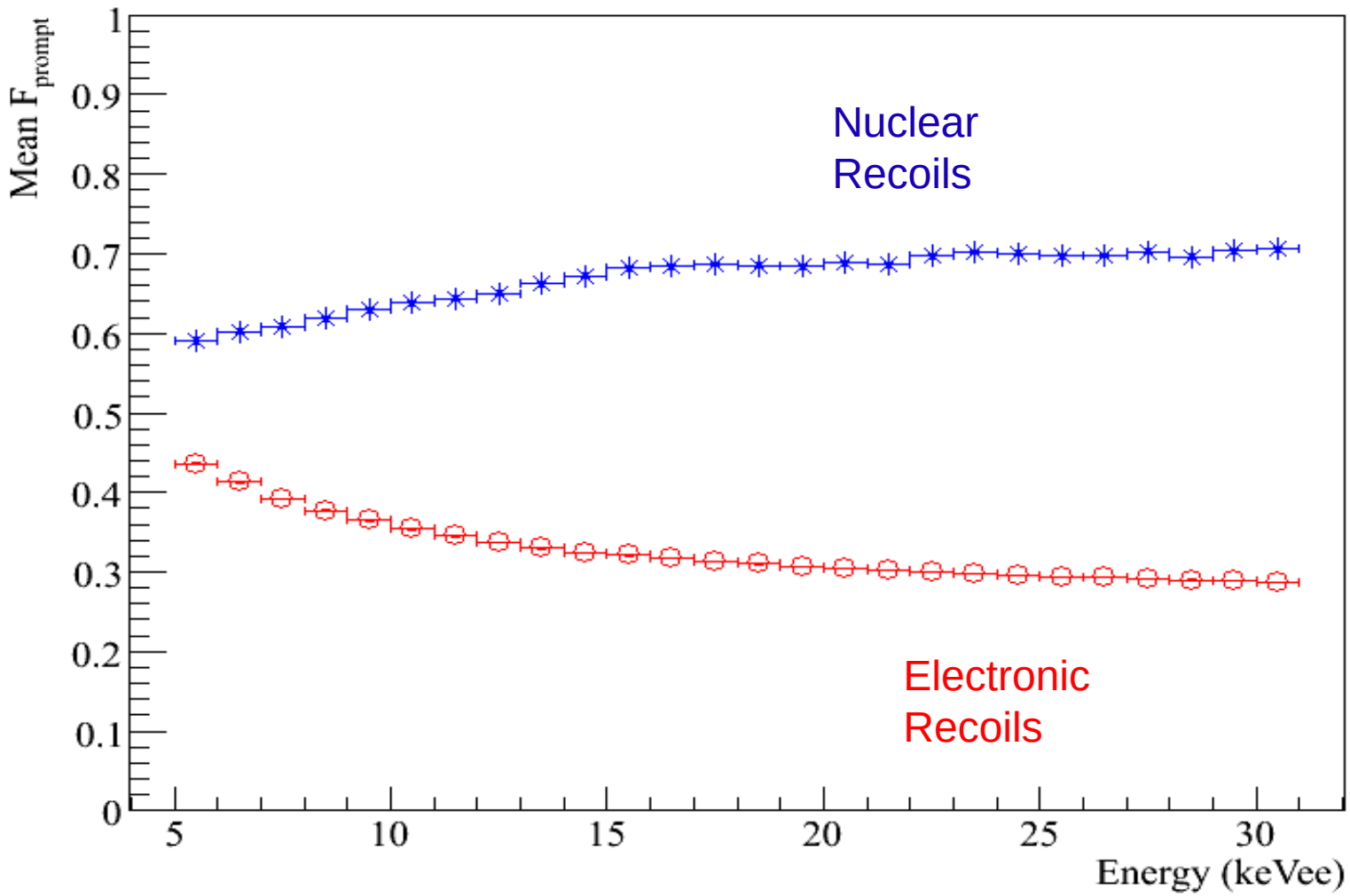
15-16 keVee



5-6 keVee



Mean F_{prompt} v. Energy

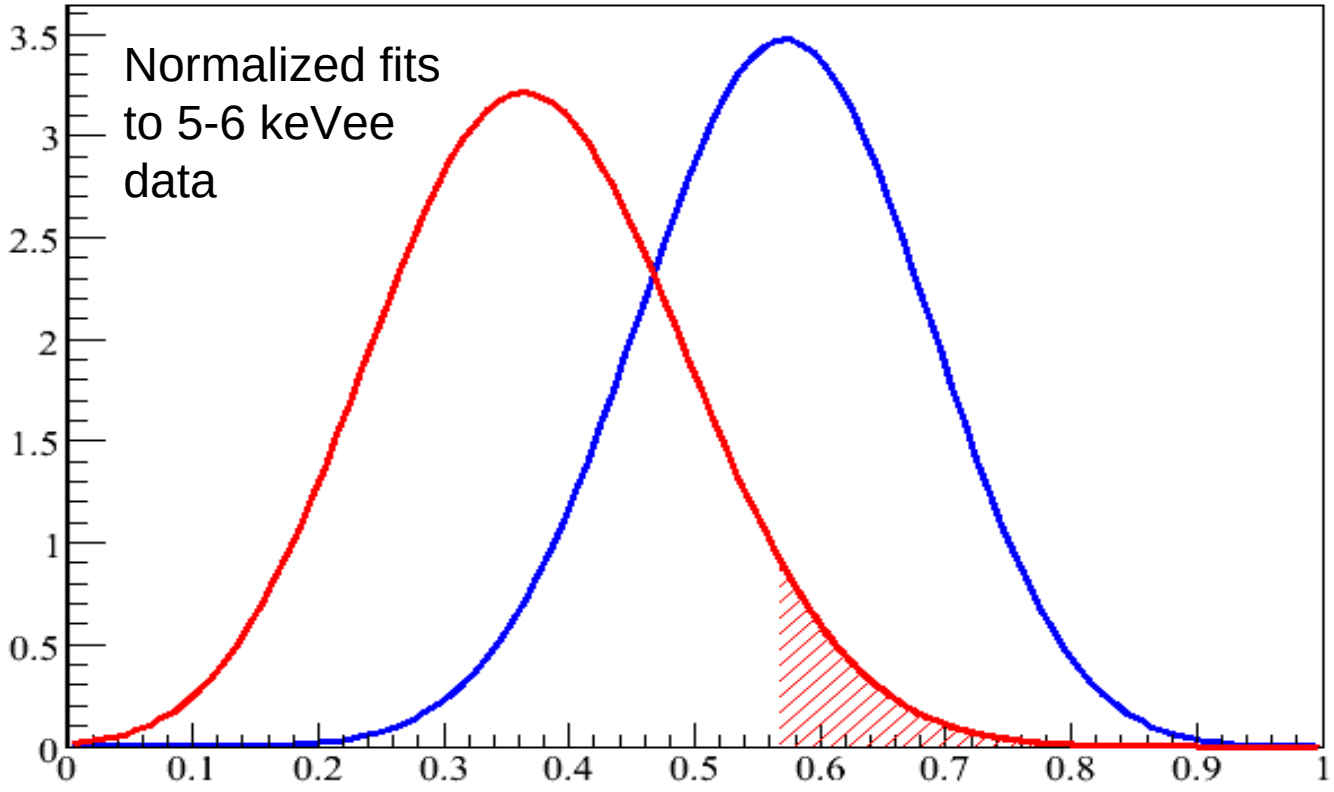


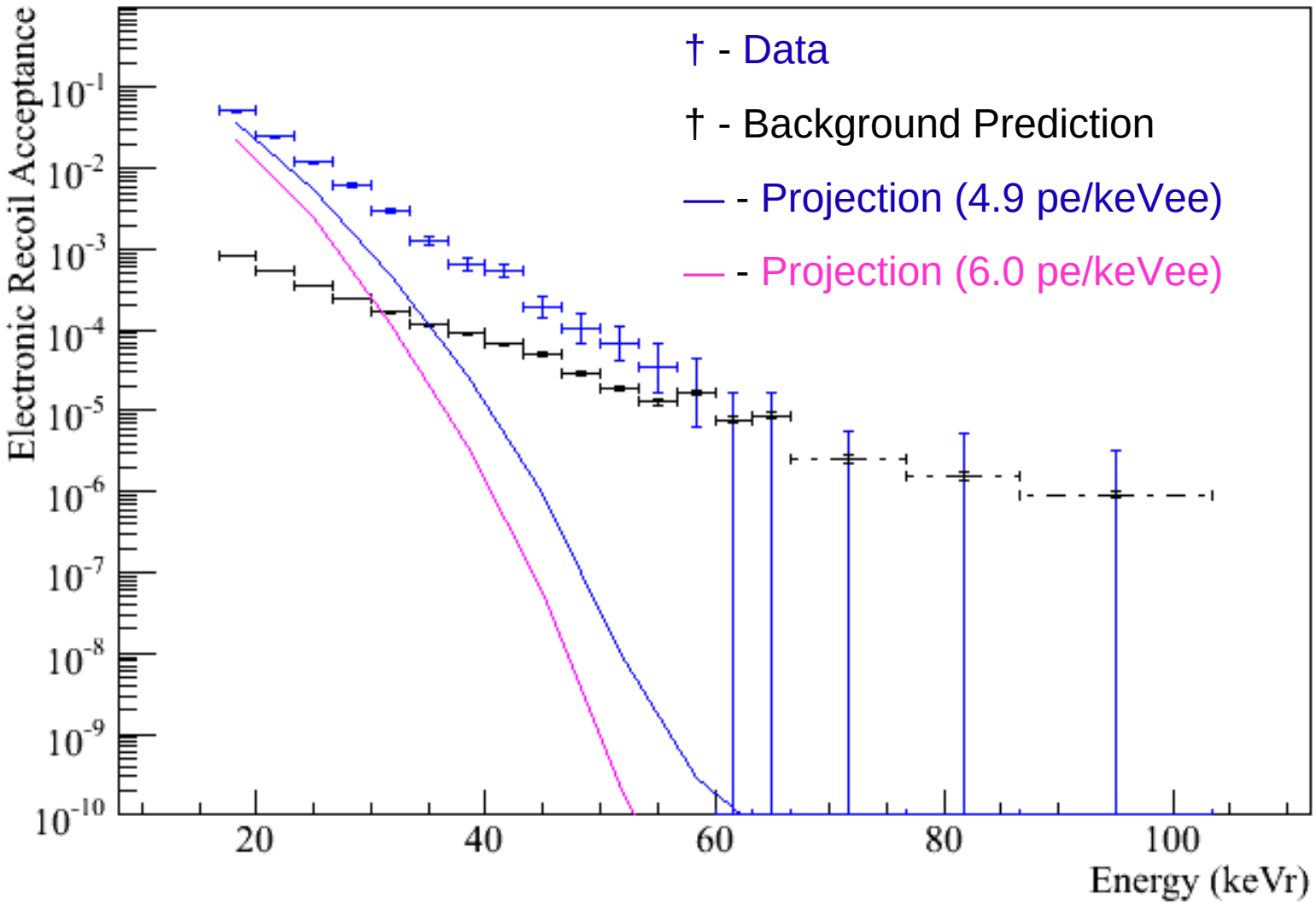
PSD from Data and Background Prediction

- Count “nuclear recoil events” – the number of events with F_{prompt} above the 50% nuclear acceptance level - between 5 and 31 keVee and divide by total events in each bin
- Background projection based on runs taken with no source present and without the NaI additional coincidence
  - Assume uncorrelated backgrounds
  - Count “nuclear recoil events” in background run to determine background rate
  - $R_{background} \times R_{gamma,NaI} \times 2*TOF \times LiveTime =$
    # of Expected Background Counts

Analytic Projections

- Analytically integrate area underneath electronic recoil curve above 50% nuclear recoil acceptance level
- Scale fitted binomial widths linearly with light yield, relative to 4.9 pe/keV in microCLEAN

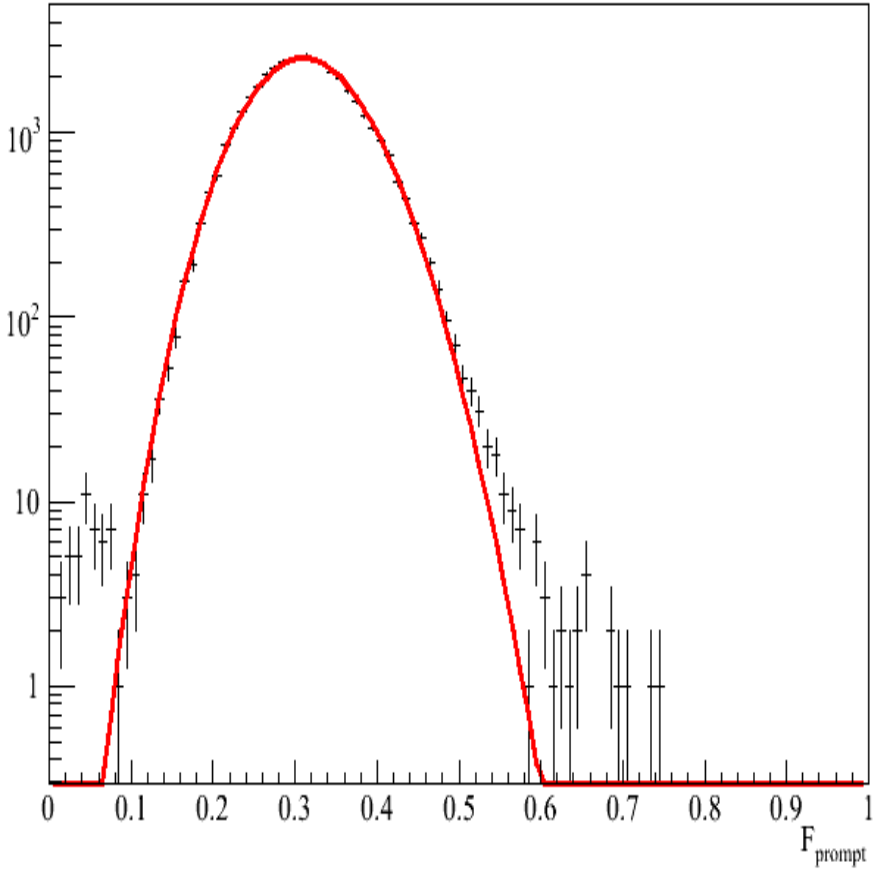




- Binning set to have relatively equal counts in the high energy background bins
- From 60-103 keVr, we have 0 “nuclear recoil events” – better than 1.25 x 10^{-6} rejection

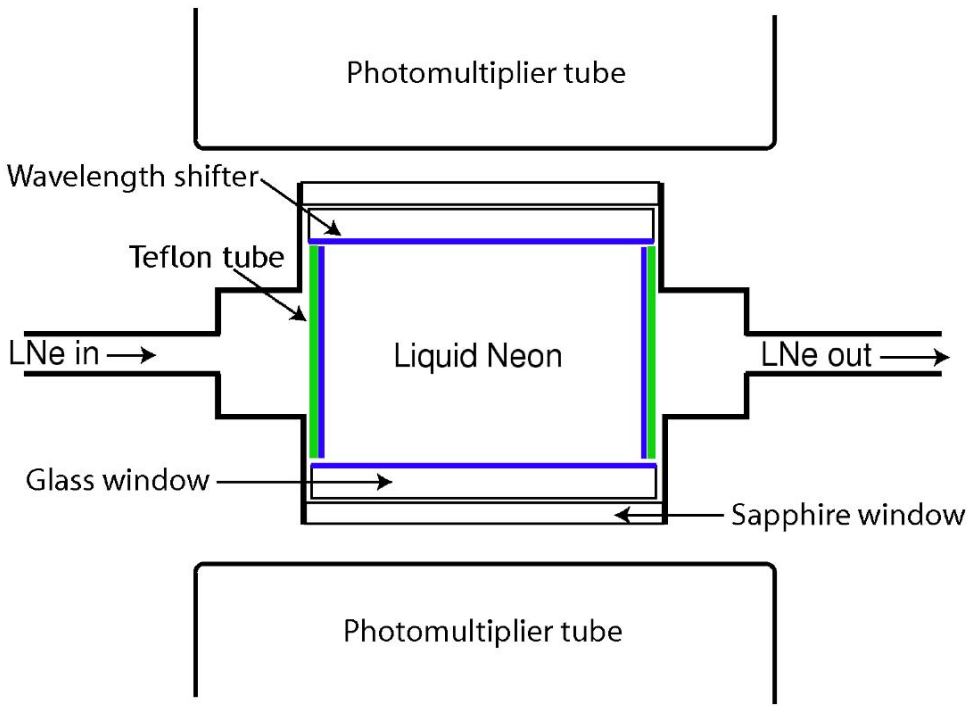
PSD Discrepancy

- Between 25-60 keVr, there is a clear discrepancy between the binomial projection and the data – not getting the tail right
  - PMT noise
  - Gain dispersion in the PMTs
  - Surface effects in the detector

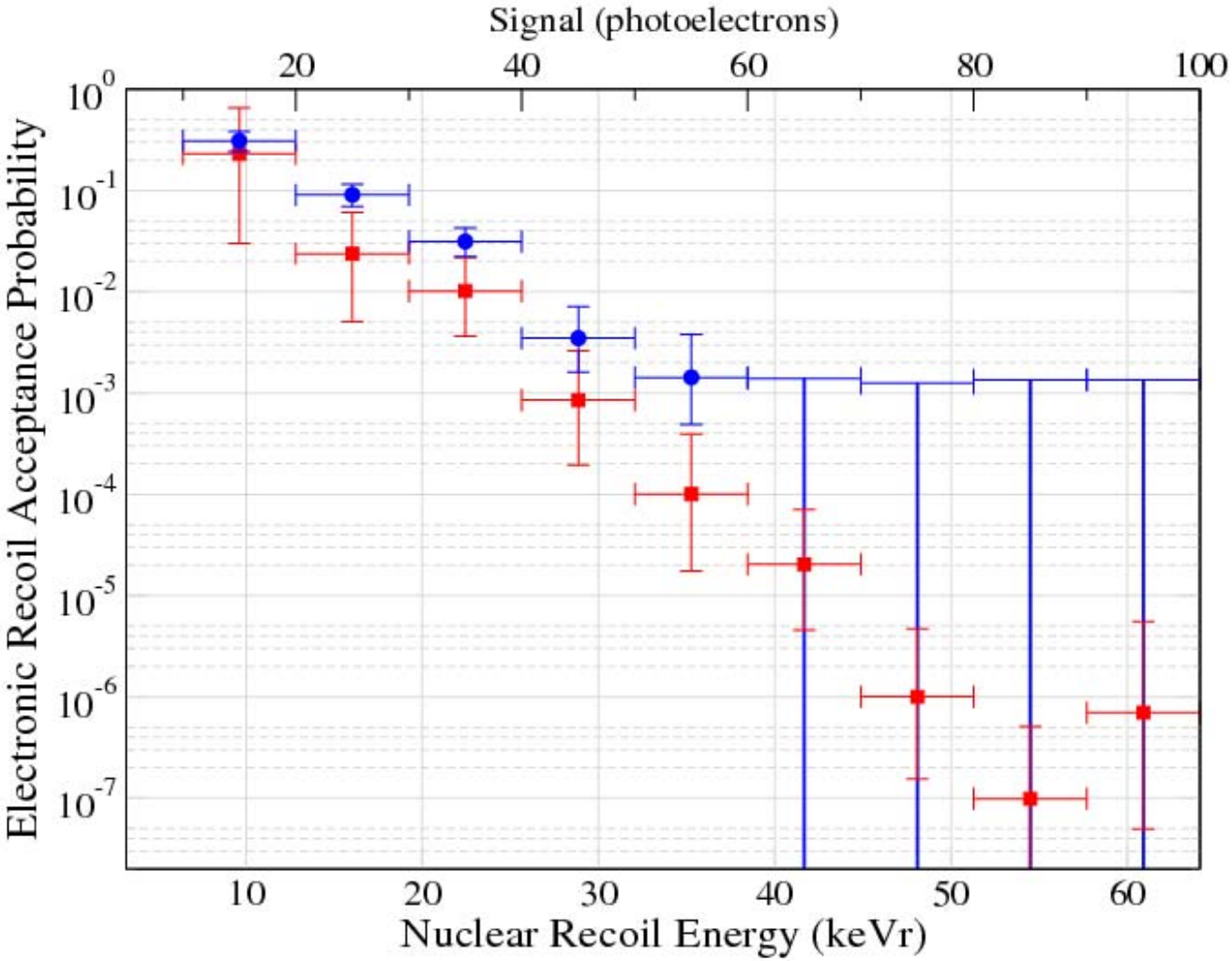


Neon Measurements using pico-CLEAN Detector

- 48 mm diameter x 38 mm tall - ~69 ml active volume
- 0.93 pe/keVee light collection
- Measured a quenching factor of 0.26 for 387 keV nuclear recoil



Neon PSD from pico-CLEAN



Conclusions and Further Work

- Taking more data with 4.9 pe/keV
  - Retake nuclear recoil data to confirm quenching factor measurement
  - Understand tails to F_{prompt} distributions
- Refine Prompt Fraction Method – optimize time division for different energies and light yields
- Develop Maximum Likelihood Method for discrimination using probability density functions
- Do quenching and PSD measurements in liquid neon