Proton light yield of water-based liquid scintillator

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Introduction and Motivation

Established antineutrino signal emanates from active nuclear reactors

Upcoming NEO detector at AIT will be sensitive to reactor-ν inverse-beta-decays (IBDs)

"Fast" neutrons (10 MeV scale) from surrounding rock form coincidence background

Using water-based liquid scintillator (WbLS), could distinguish signal from background --- but need to know what protons "look like"

Mission Relevance

- Facilitates new capabilities for nuclear reactor discovery and exclusion
- Development of a new technology for monitoring and verification of reactor operations for proliferation detection

“Preventing nuclear weapons **proliferation** and reducing the threat of nuclear and radiological terrorism around the world are key U.S national security strategic objectives that require constant vigilance.”

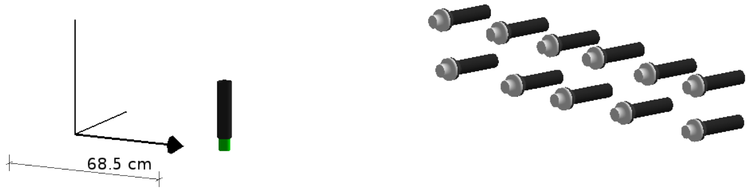
“NNSA's Office of Defense Nuclear Nonproliferation works globally to prevent state and non-state actors from **developing nuclear weapons** or acquiring weapons-usable nuclear or radiological materials, equipment, technology, and expertise.”

Technical Approach

"Double time-of-flight" method: Pulsed deuteron beam on Be target + PID-capable secondary detectors

Collaboration with **B**ay **A**rea **N**eutron **G**roup (BANG --- UCB/LBNL)

→ Brown et al, Jour. Appl. Phys. **124**, 045101 (2018)

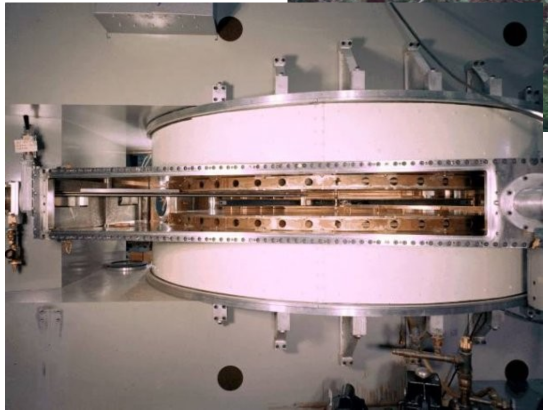


Protons excited *via n-p* elastic scattering *internal to measurement sample*

Two kinematic measures of neutron energy (before/after scattering)

→ *Three* measures of proton energy

→ Enforce consistency with beam-neutron hypothesis

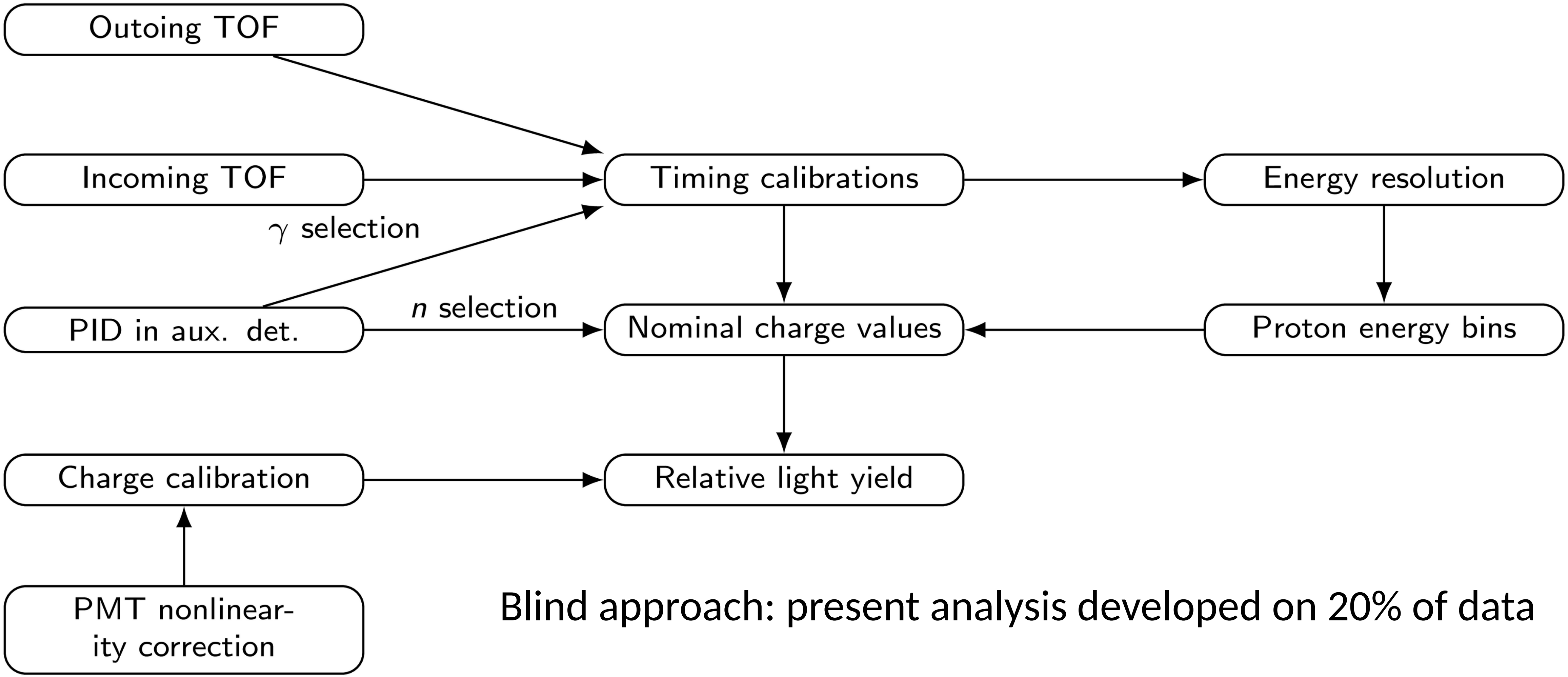


Charge collected in photomultipler tube (PMT) used as proxy for light

Measure two samples: 5% WbLS and LAB + 2 g/L PPO (from Yeh et al, BNL)

→ Existing LABPPO measurement: von Krosig et al, Euro. Jour. Phys. C **73**, 2390 (2013)

Technical Approach

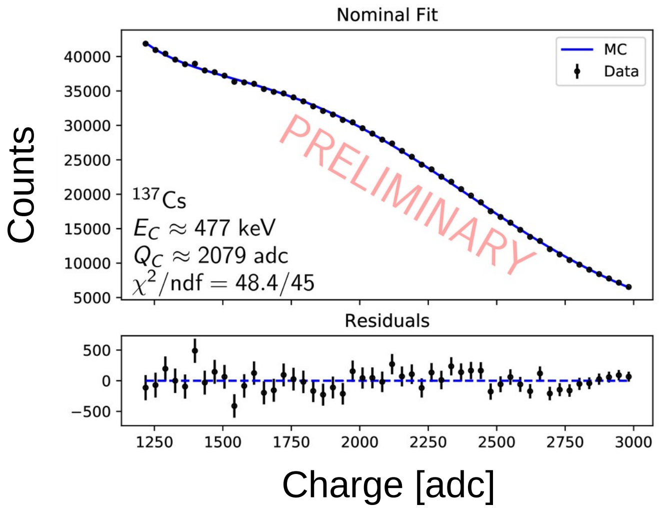


Blind approach: present analysis developed on 20% of data

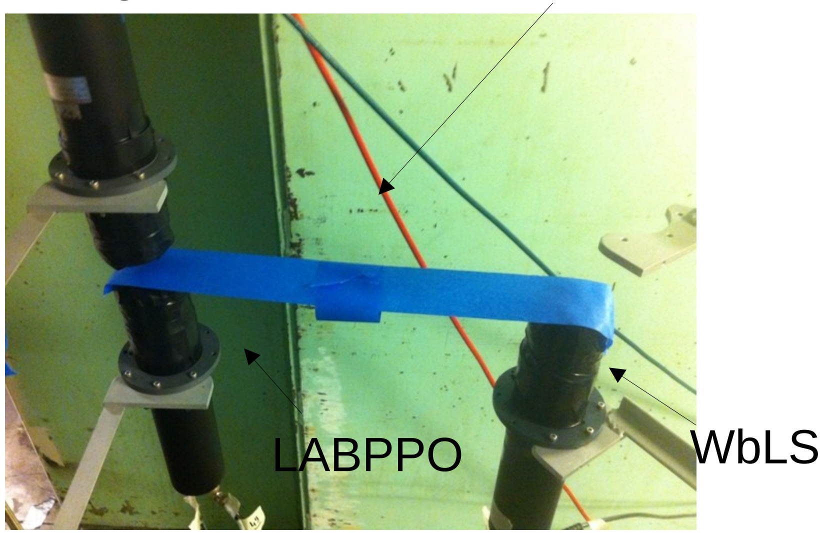
Technical Approach

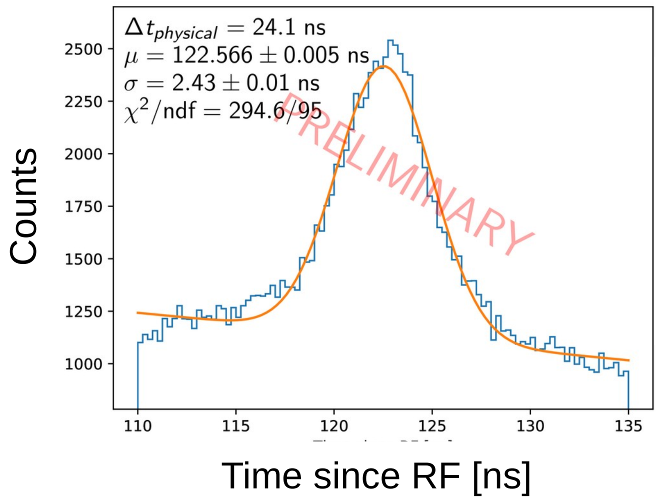
Calibrate PMT charge (corrected for PMT nonlinearity)

- → Compton edge of γ *source*

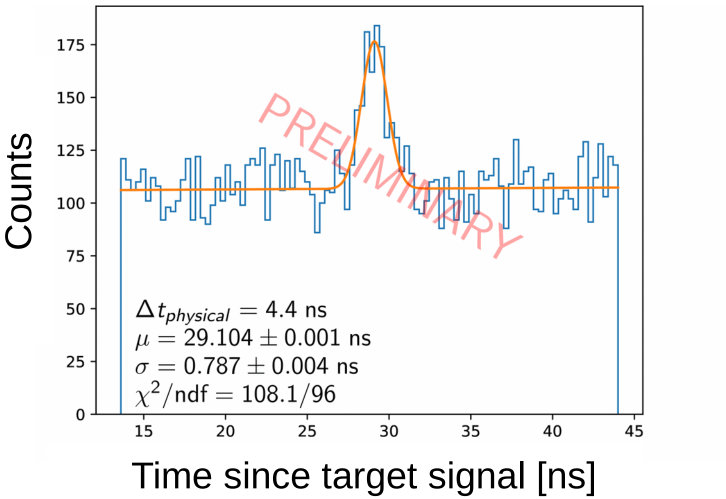


Charge calibration with caesium source





Measured incoming time-of-flight

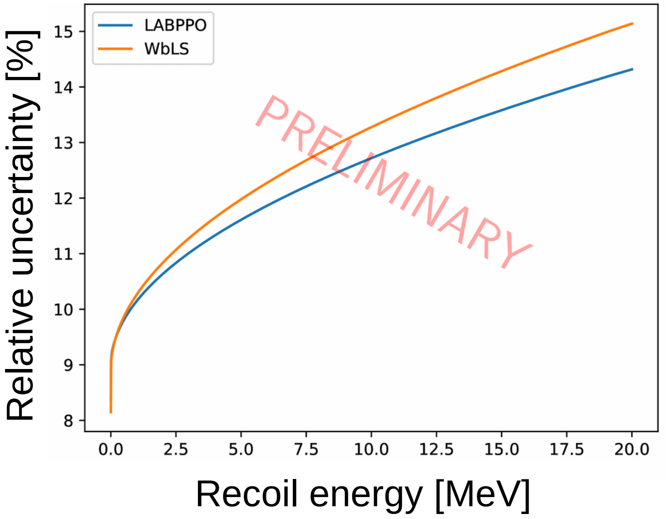


Measured outgoing time-of-flight

Calibrate neutron times-of-flight using *beam-produced γs*

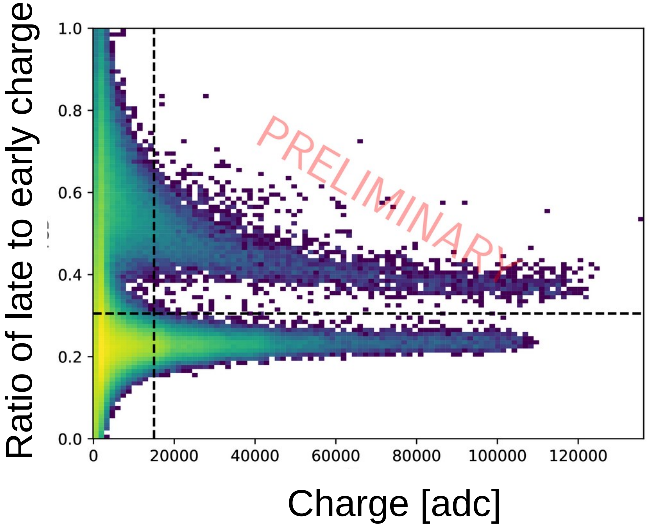
Technical Approach

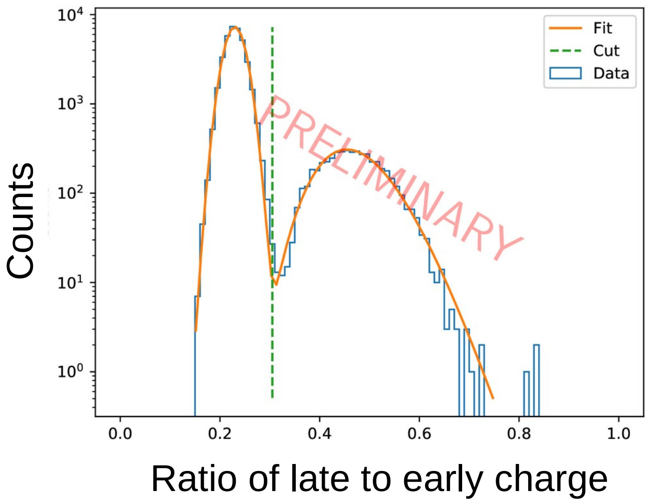
Bins in proton energy defined, guided by expected proton energy resolution



Proton energy resolution determined by timing resolution and geometry

Neutron selection achieved via secondary detector PID





Example PID in auxiliary detector

Charge distribution in each bin fit with empirical signal + background form

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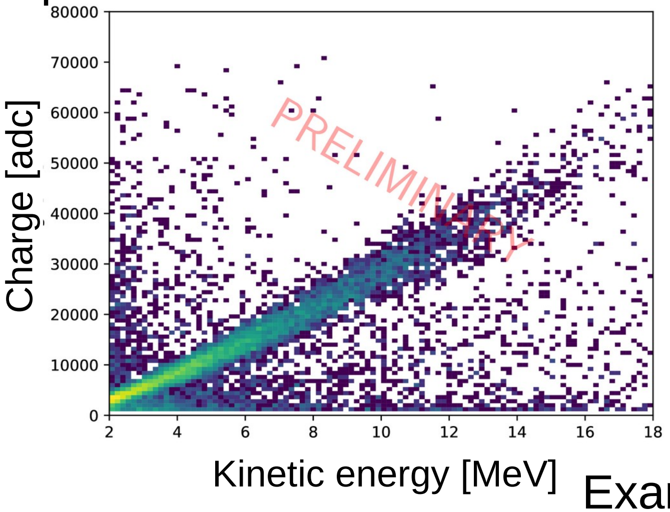
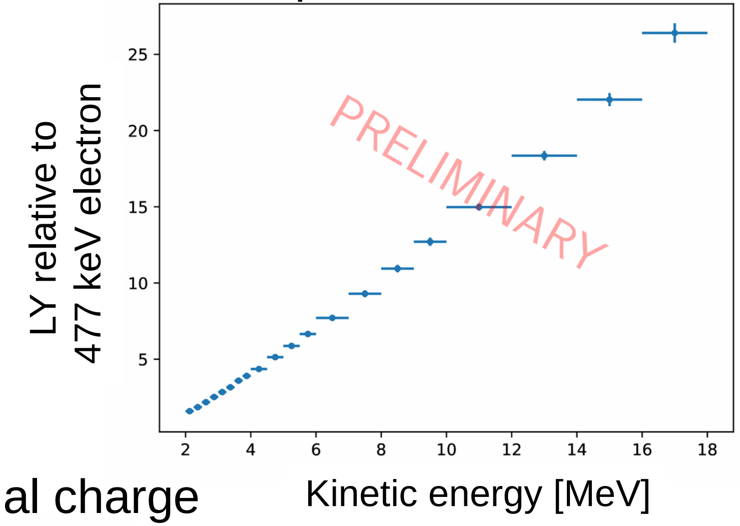
Light Yield Results

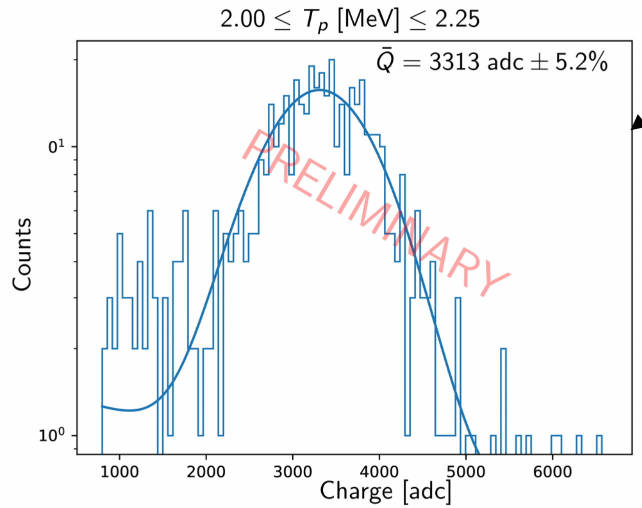
2D Population of neutron-like events

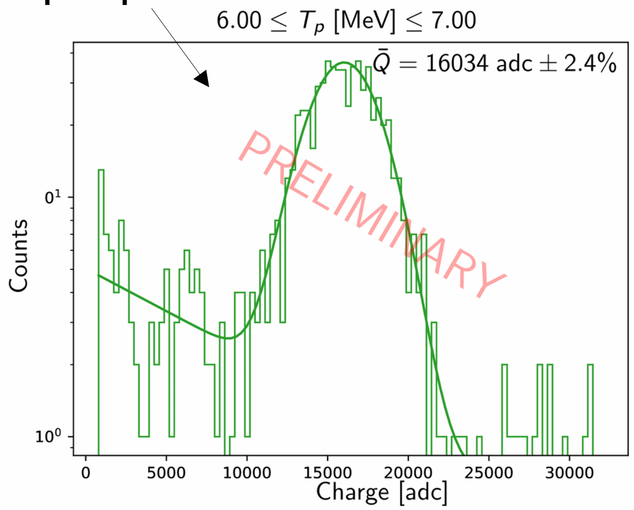


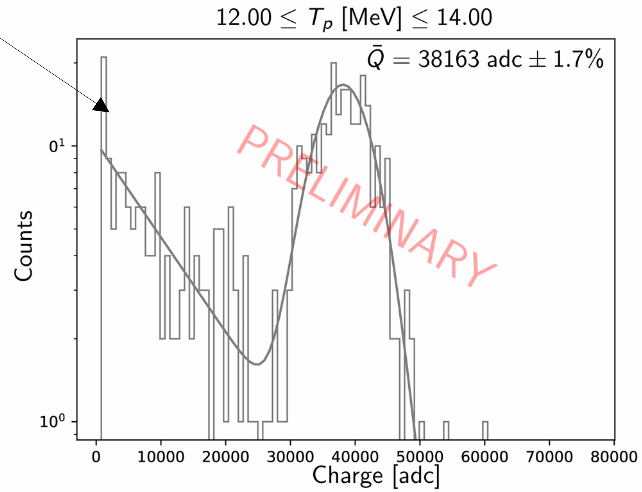
1D dependence of LY on energy



Example per-bin fits for nominal charge







Next Steps

PMT nonlinearity correction

→ Necessary for continuous measurement over wide energy range

→ Methodology exists, implementation underway

Investigate compatibility with LY models (e.g. Birks' Law?)

Full data set

→ Analysis development has been on random ~20% data set

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Expected Impact

Allows for investigation of fast-neutron classification

→ Ideally, this is effective in suppression of IBD background

Enables possibility of flavor-inclusive supernova neutrino energy spectrum measurement in a WbLS detector

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MTV Impact

Professional development

→ Work with 88-Inch Cyclotron

→ Exposure to breadth of research encompassed in consortium

→ Development of technical skills valuable within NNSA enterprise

Cross-consortium collaboration

→ Engage with Nuclear Science and Security Consortium

Technology transitions

→ Potential WbLS deployment in upcoming NEO detector

Conclusion

- Proton light yield data acquired using 88-Inch Cyclotron
- Ongoing analysis makes sense, converging on final results
- PMT nonlinearity correction underway
- Thanks!

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Acknowledgements

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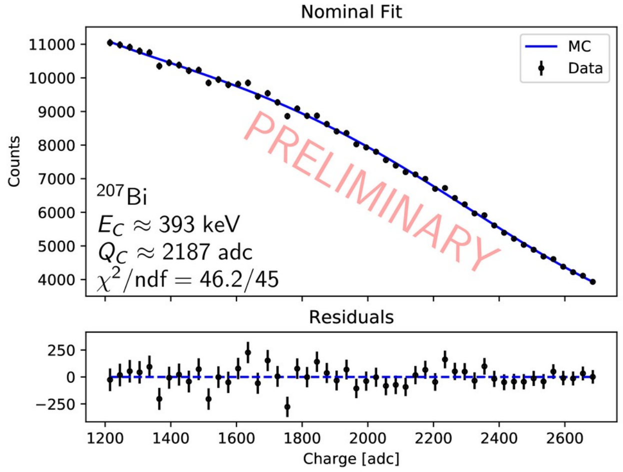
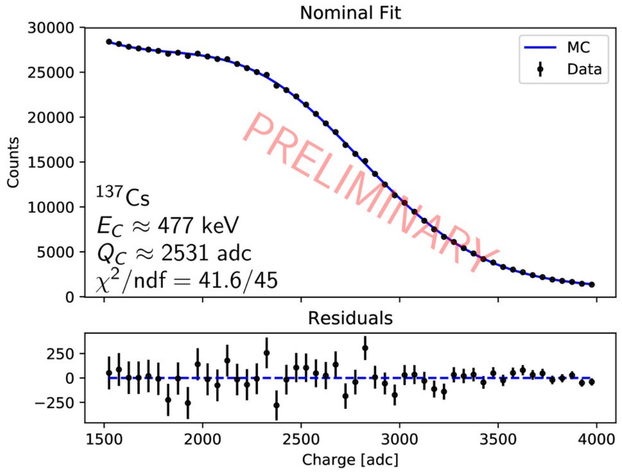
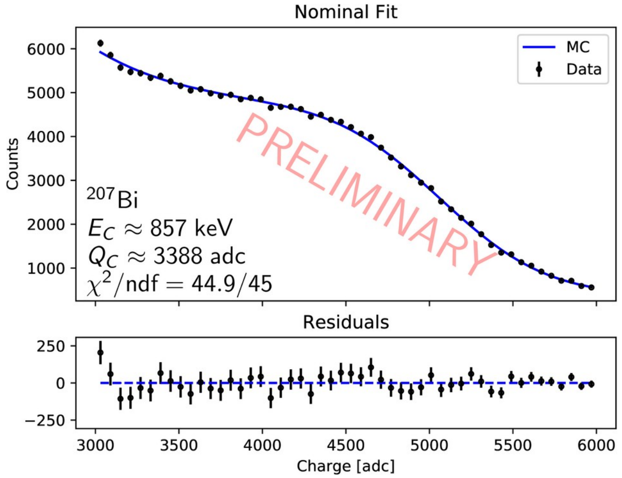
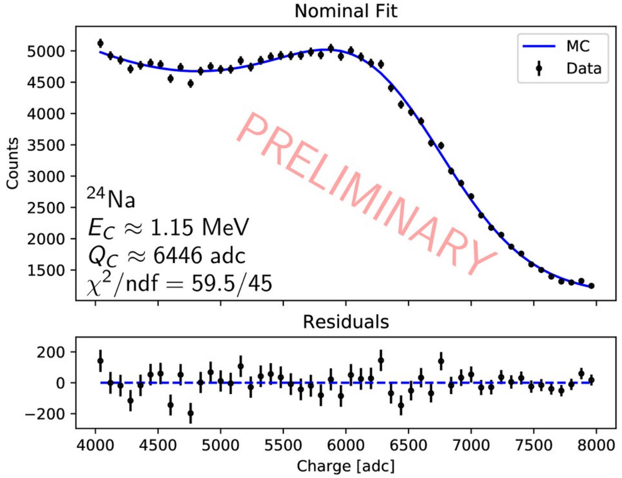
BACKUP

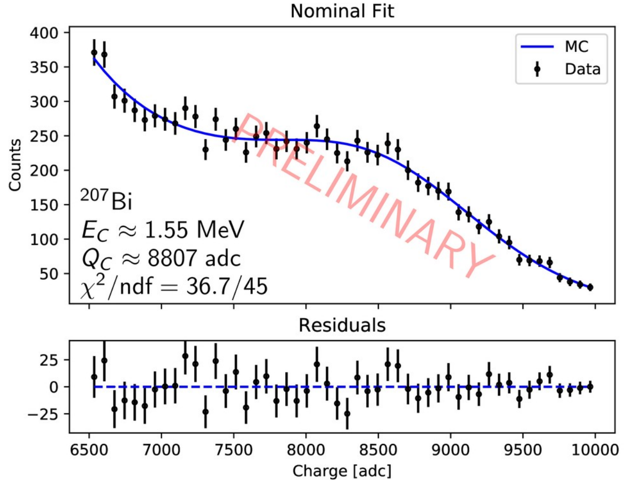
LABPPO Compton Fits

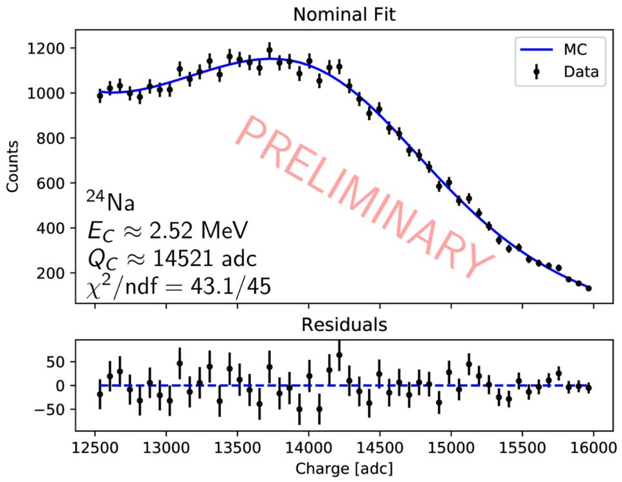




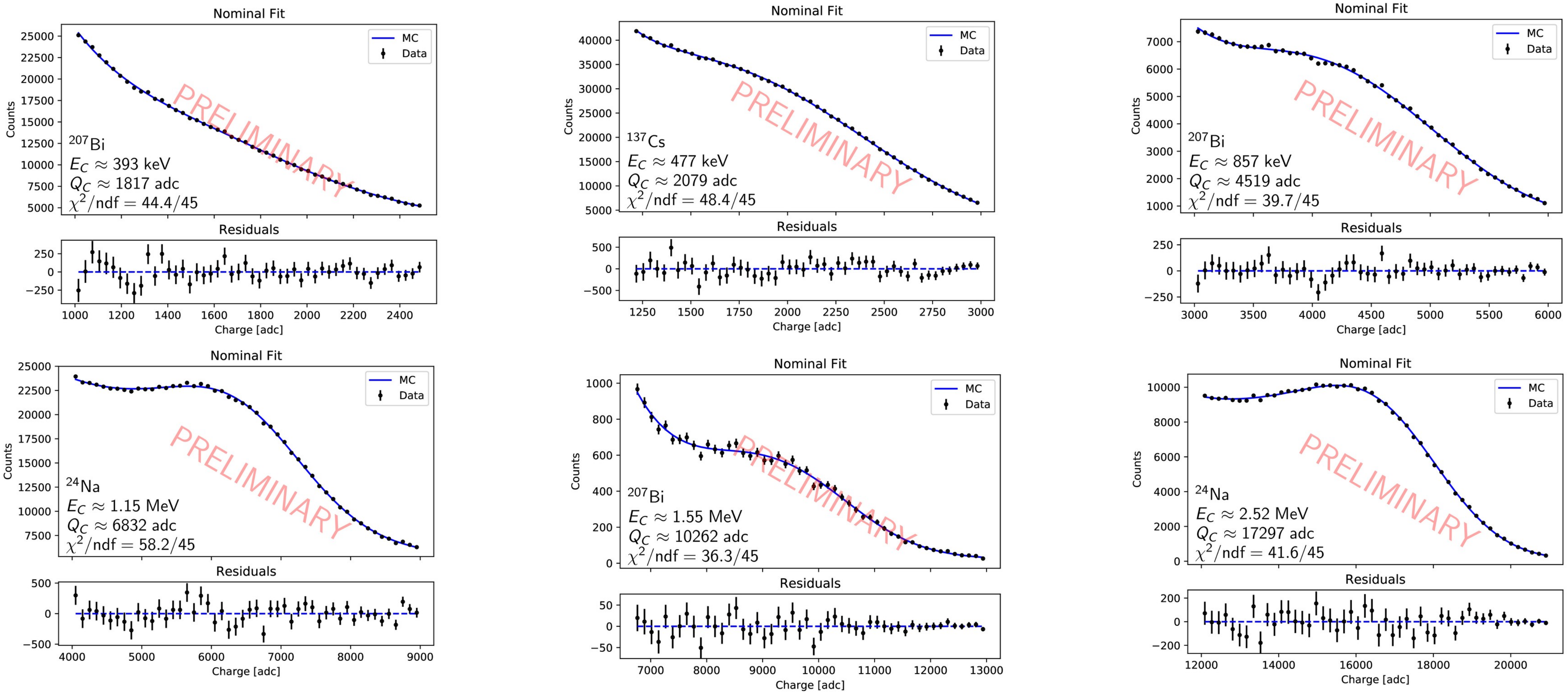




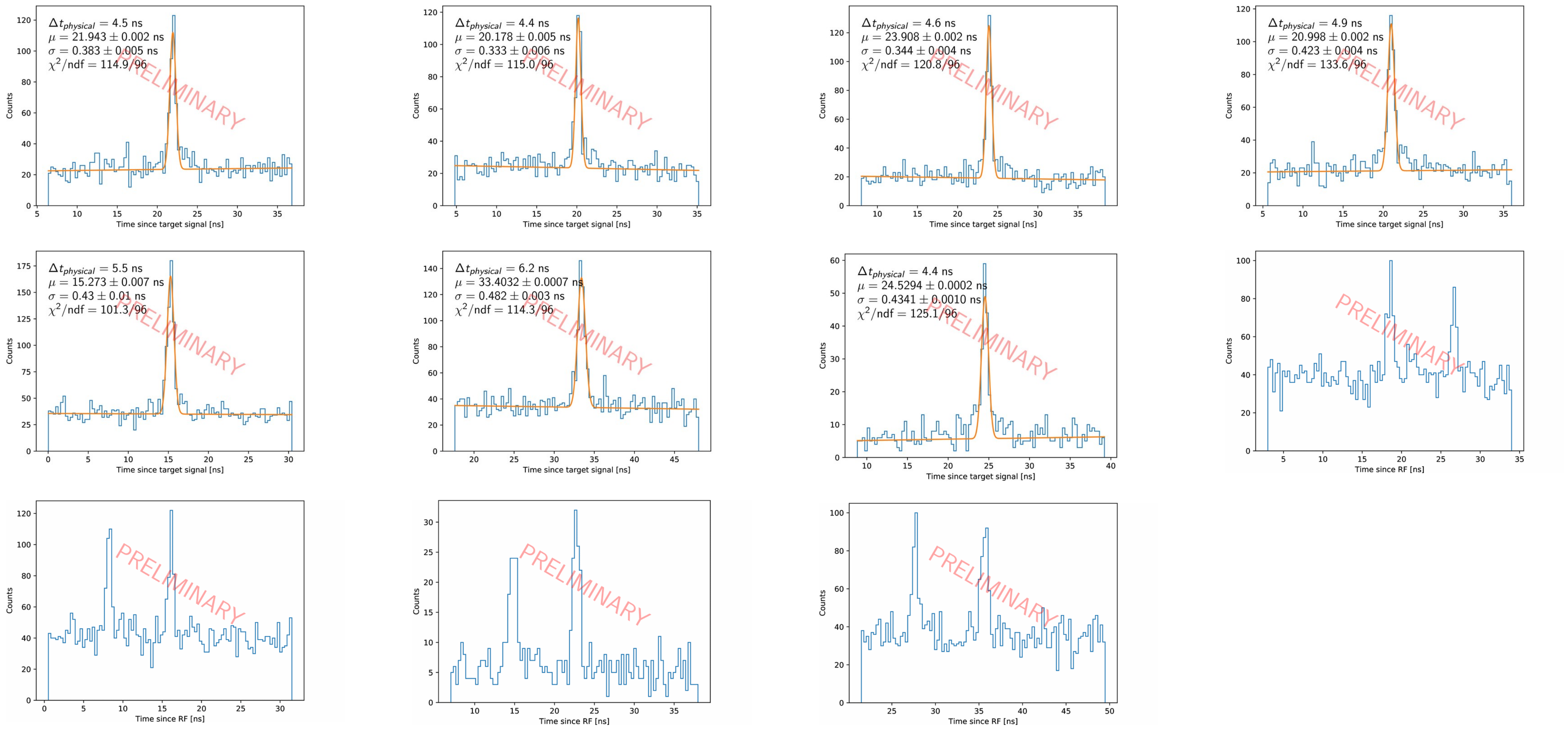




WbLS Compton Fits



LABPPO outgoing times-of-flight



WbLS outgoing times-of-flight