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THE ARGON RESPONSE TO IONIZATION AND SCINTILLATION EXPERIMENT

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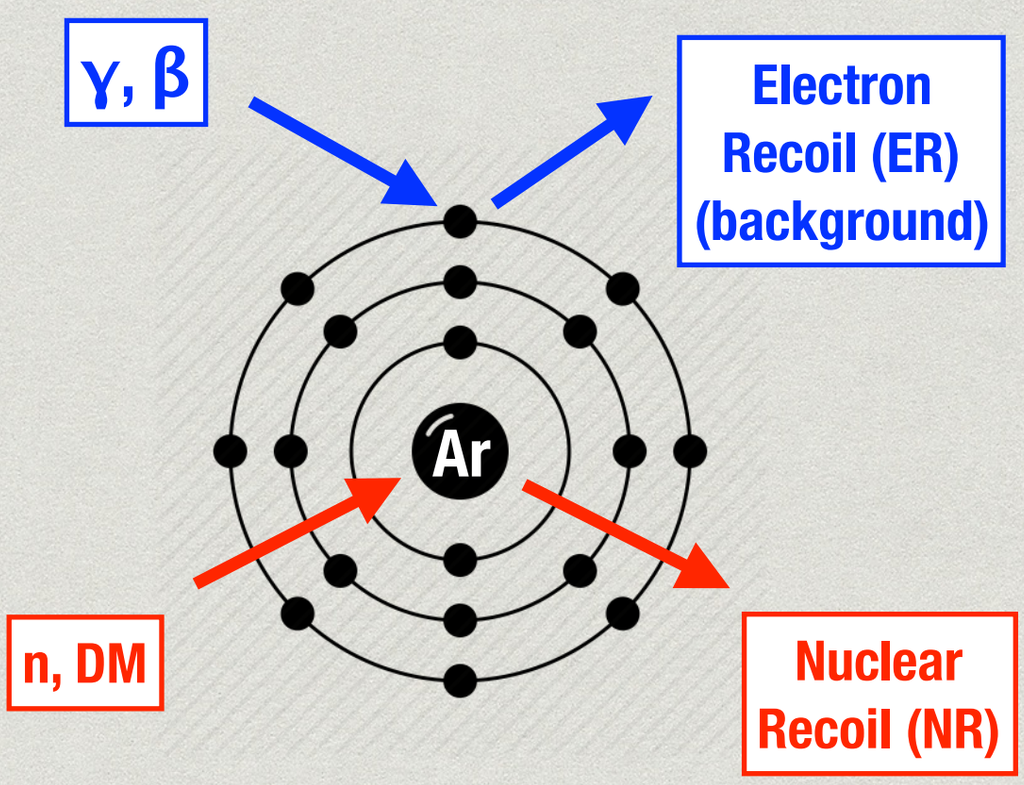
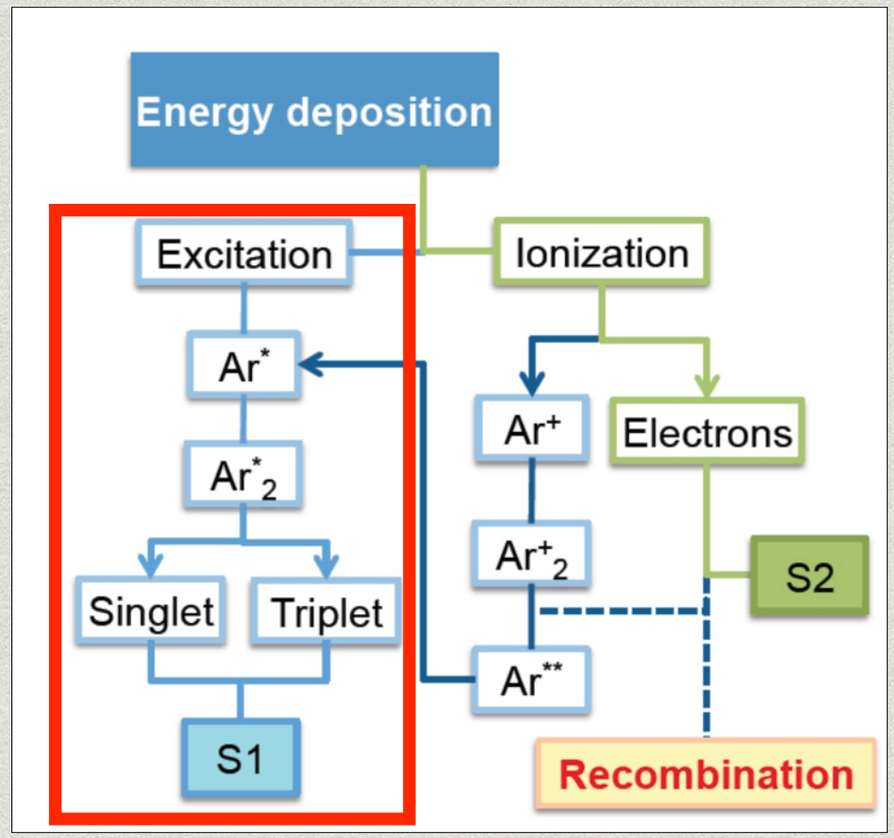
NORCAL HEP-EXCHANGE

DEC 2 2017

Searching for Dark Matter with Liquid Argon (LAr)

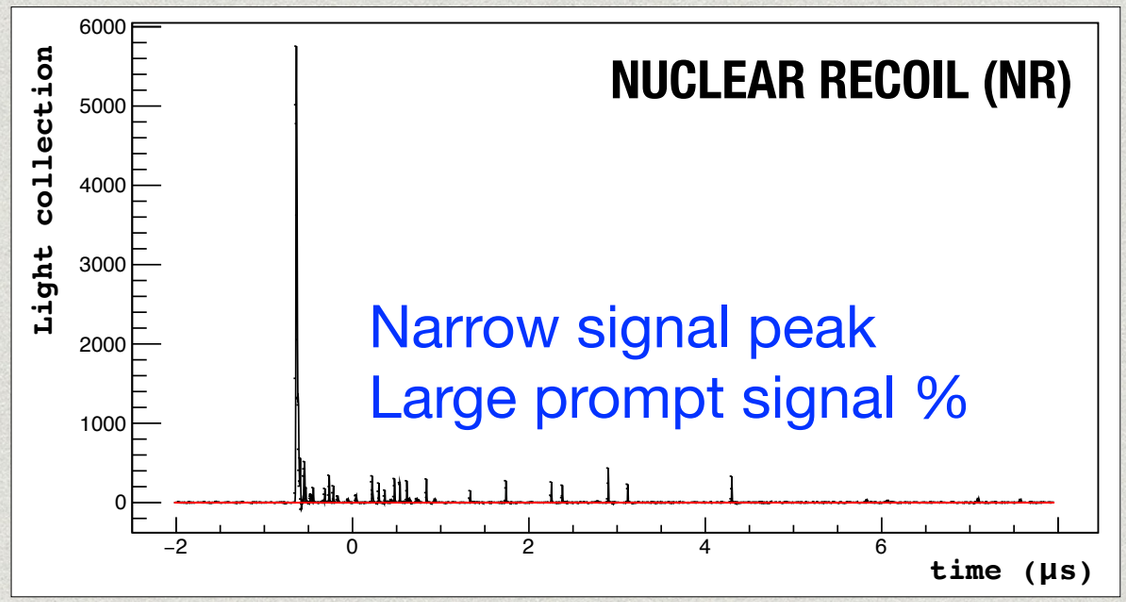
A dark matter search ideally provides as much target medium as possible to maximize the likelihood of a nuclear recoil (the target signal), while minimizing all external backgrounds.

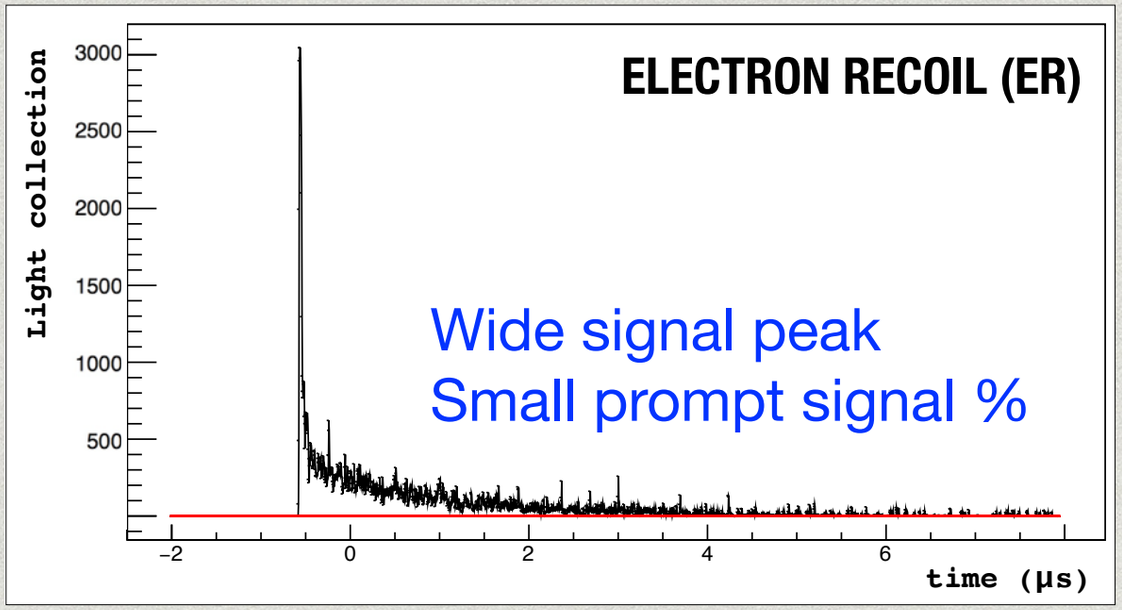




Time profile of primary scintillation in LAr allows **pulse shape discrimination** for extremely powerful background rejection.

LAr Response





Understanding the response of nuclear and electronic recoils in LAr is **crucial** for using this medium in a dark matter search.

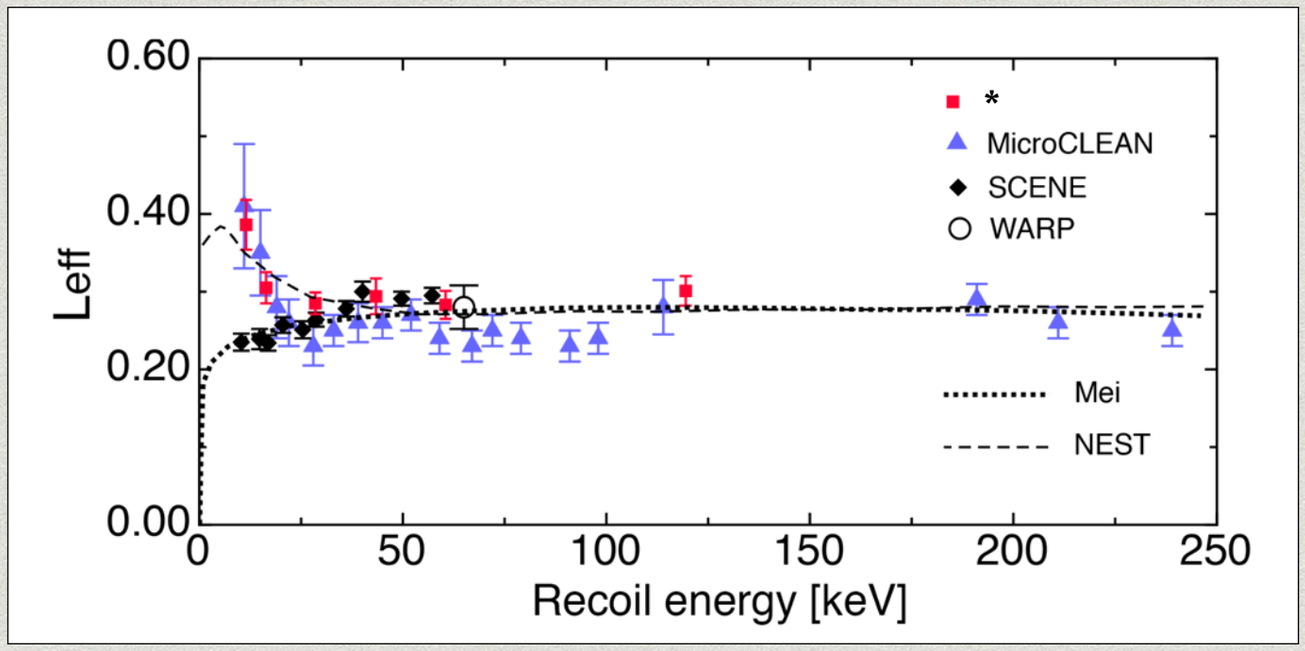
To fully exploit pulse shape discrimination, we need to experimentally determine:

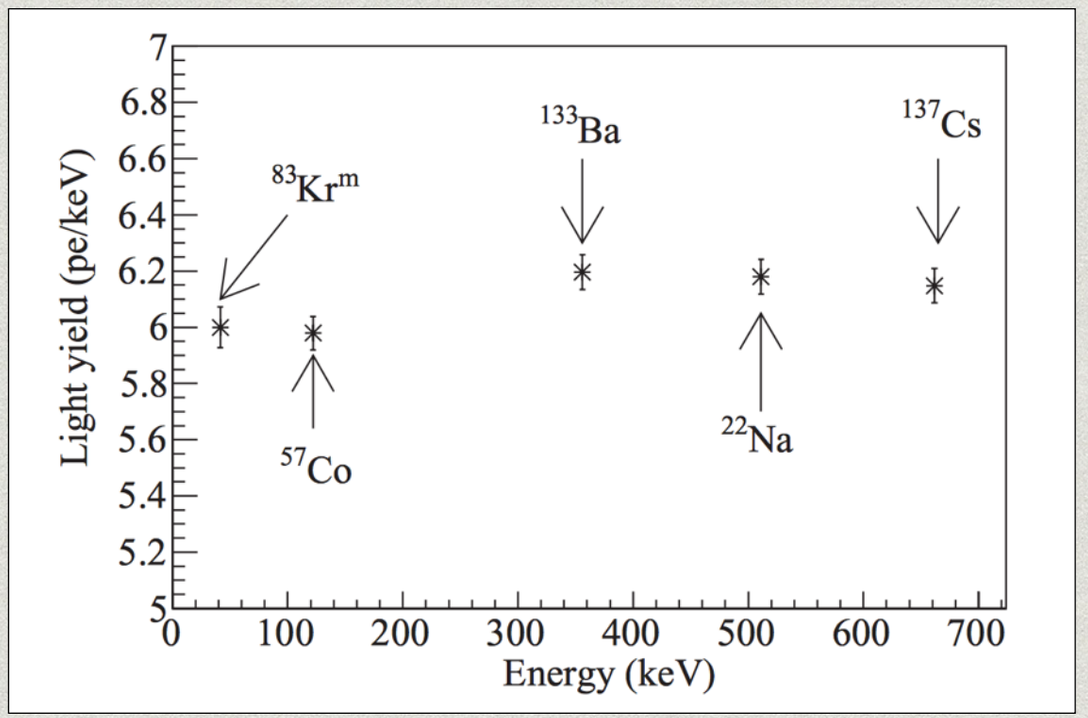
- What is the relative scintillation yield between nuclear and electronic recoils (L_{eff})?
- How does the light yield vary as a function of energy?

Previous Measurements

Relative scintillation measurements show a large variation at low recoil energies.

*from W. Creus et al., JINST 10, P08002 (2015)



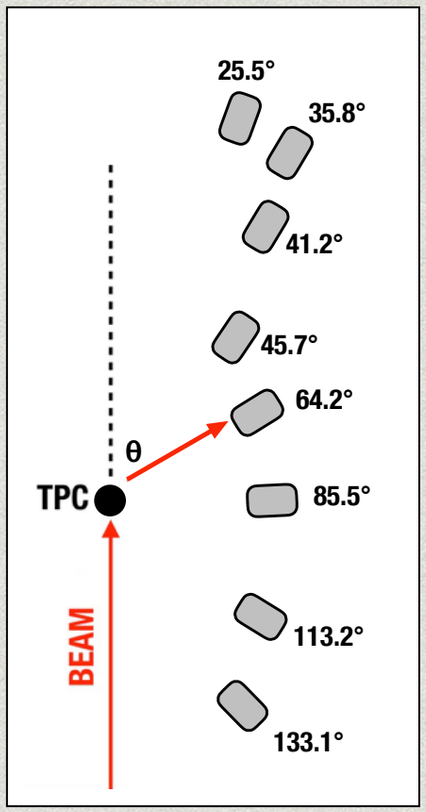


Energy dependence of light yield has been measured with source data at single energies. These results show a constant light yield to within 2%.

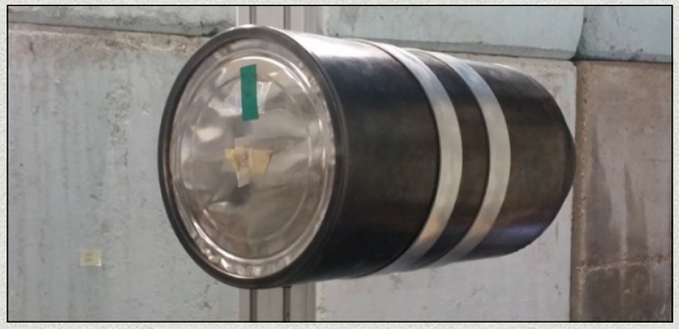
*W. H. Lippincott et al., Phys. Rev. C 81, 045803 (2010).

ARIS Hardware and Setup

Neutron detectors surrounding the TPC allow tagging specific recoil energies with high precision.



ARIS experiment geometry viewed from above

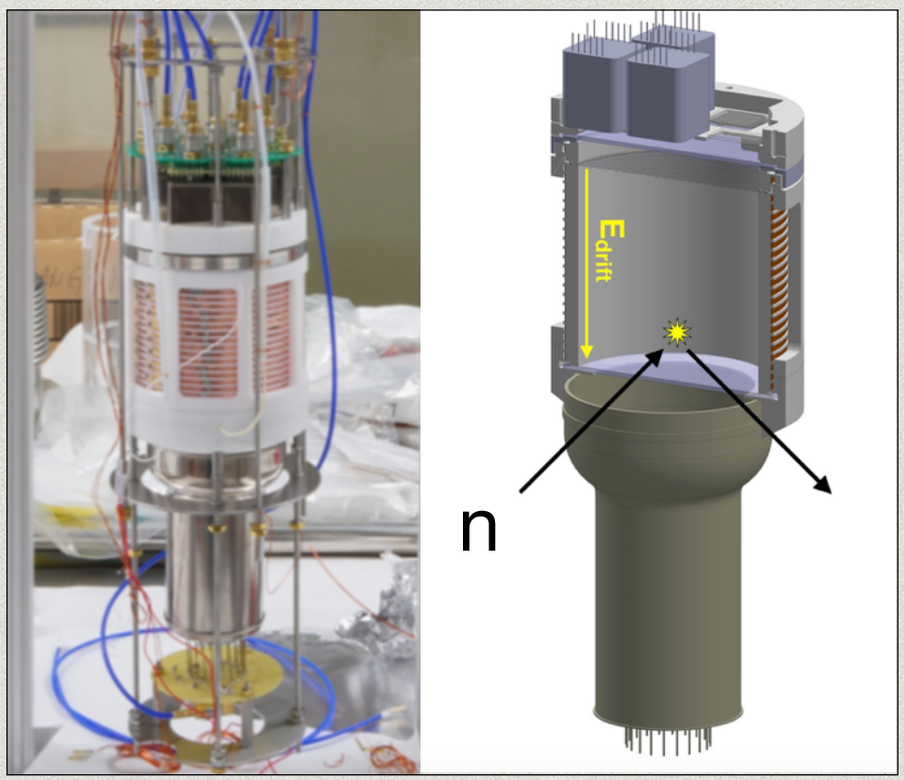


Liquid scintillator detectors from the EDEN experiment.

	Scattering Angle [deg]	Mean NR Energy [keV]
A0	25.5	7.1
A1	35.8	13.7
A2	41.2	17.8
A3	45.7	21.7
A4	64.2	40.5
A5	85.5	65.4
A6	113.2	98.1
A7	133.1	117.8

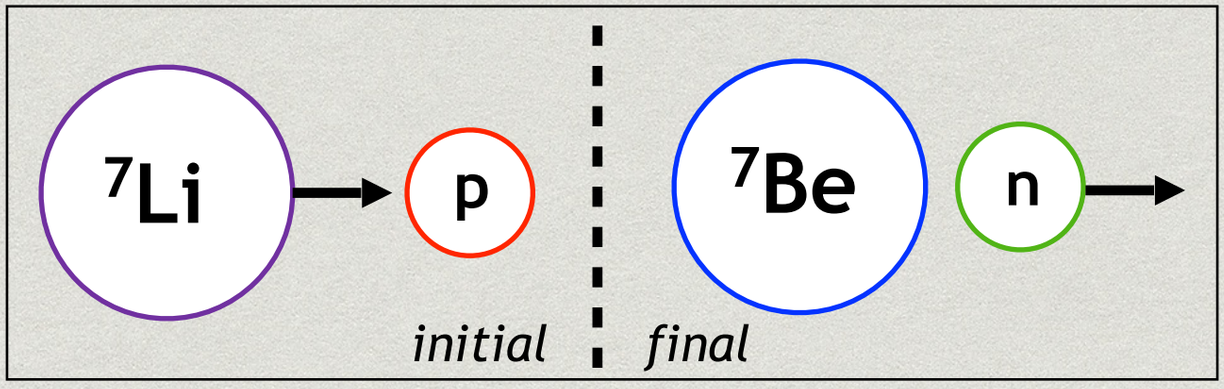
TPC:

- ~0.5 kg LAr
- Seven 1” Hamamatsu PMTs above LAr, one 3” PMT below
- Applied electric field created via ITO plated fused-silica windows
- PTFE reflector with wavelength shifting TPB coated surfaces to maximize light collection

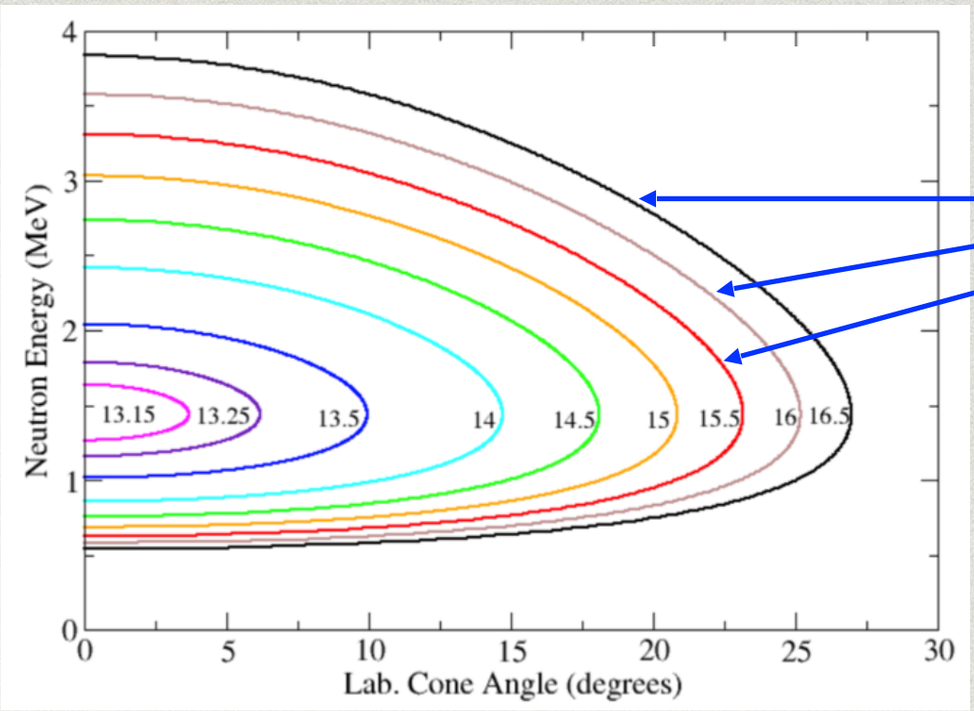


The LICORNE Neutron Source

Neutrons and associated gamma flash produced via:
$^{7}Li + p \rightarrow {}^{7}Be + n$

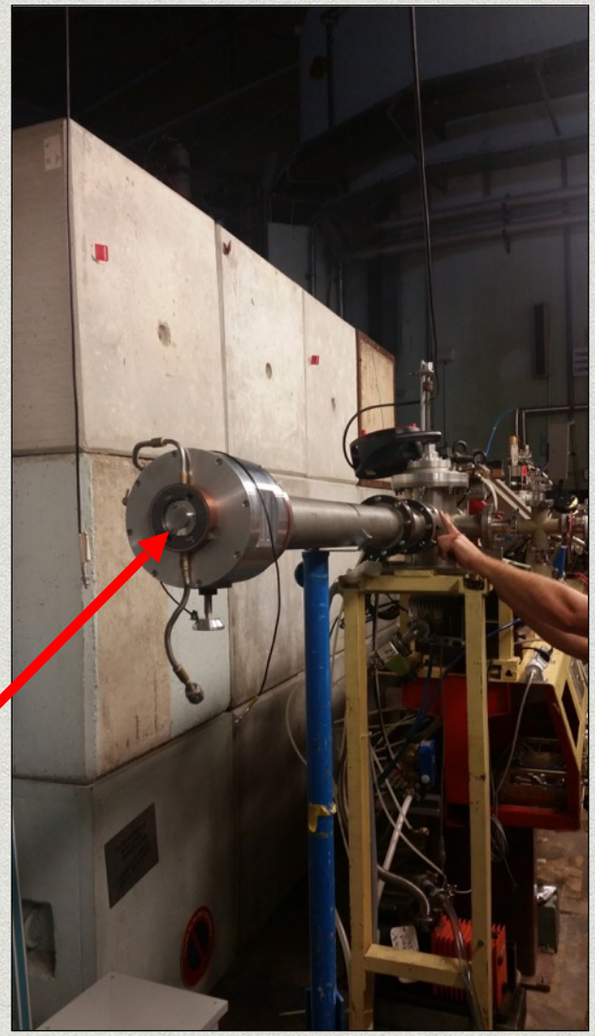


Inverse kinematics allows for very precise beam energy



Neutron energy spread for different ^{7}Li incident energies

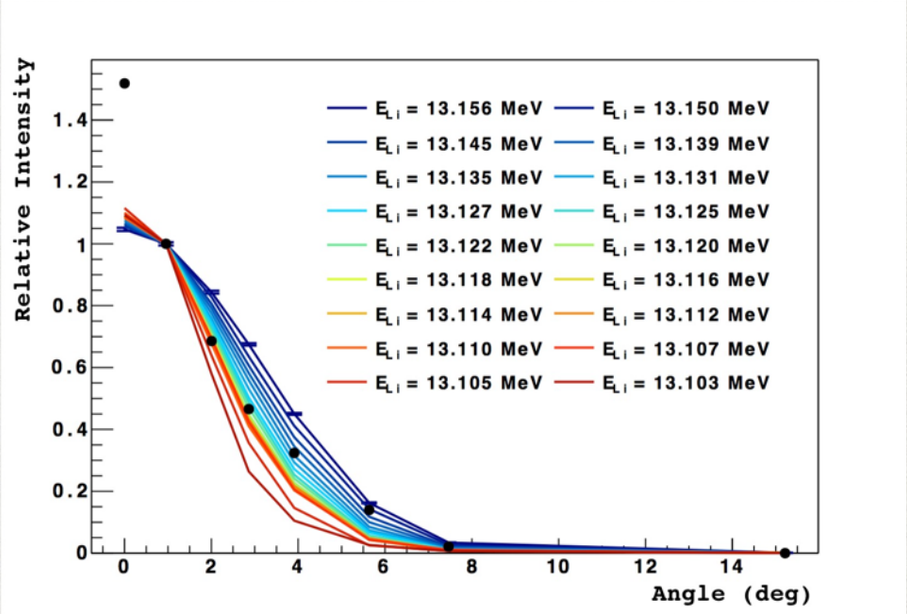
Hydrogen gas target

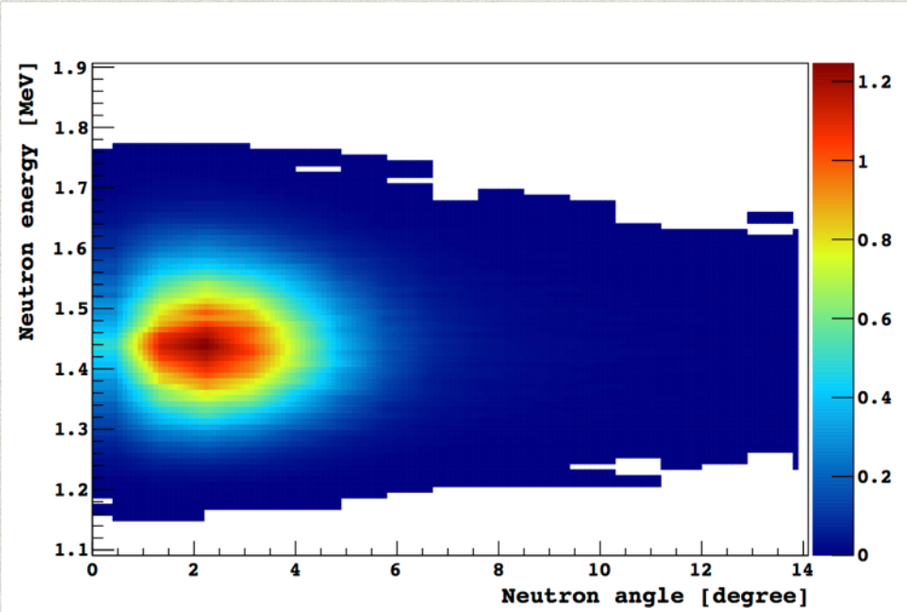


*J. Wilson et al., Physics Procedia 59, 31 (2014)

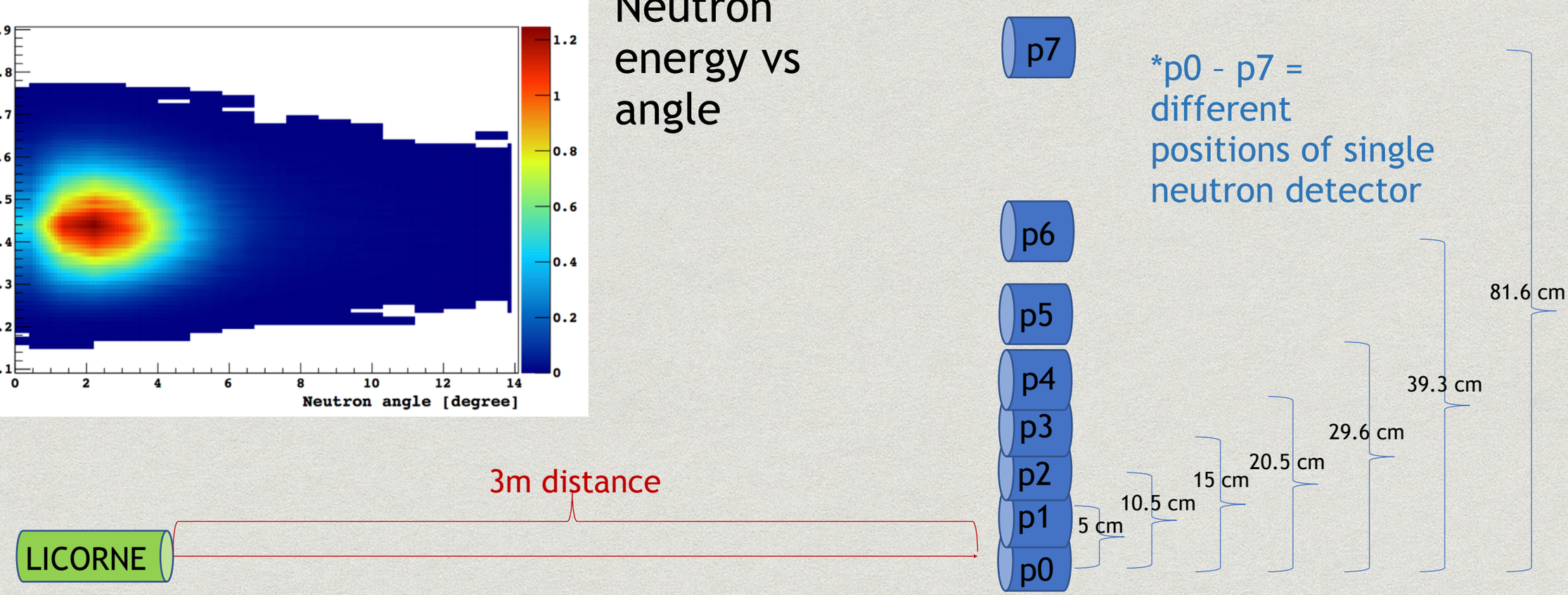
Neutron Beam Characterization

- Measured incident ^{7}Li energy on ^{1}H target by measuring the neutron cone's profile and matching to results from an IPNO simulation package
- Best fit result: $13.13^{+0.02}_{-0.01}$ MeV
- Beam profile integrated into ARIS Monte Carlo





Neutron energy vs angle



TPC Calibration

Regular LED calibrations

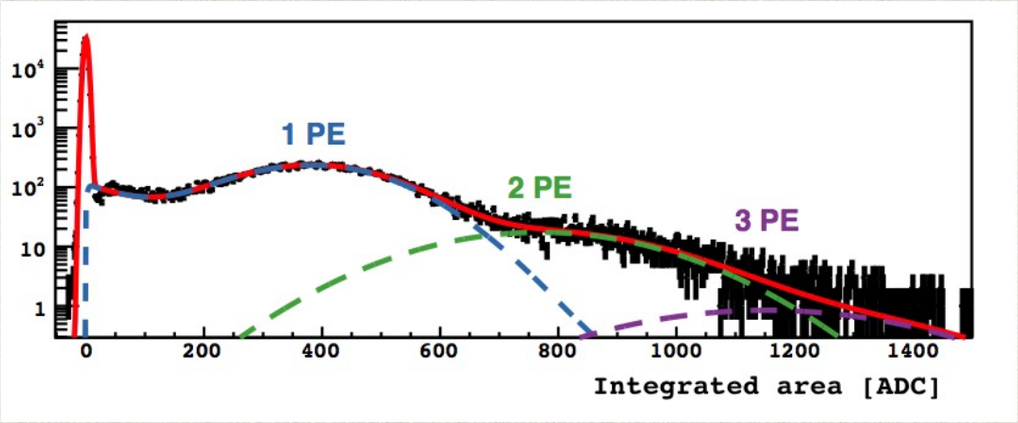
- Optical fiber feeds light pulses into the TPC

^{241}Am (59.5 keV) and ^{133}Ba (81.0 keV) source runs

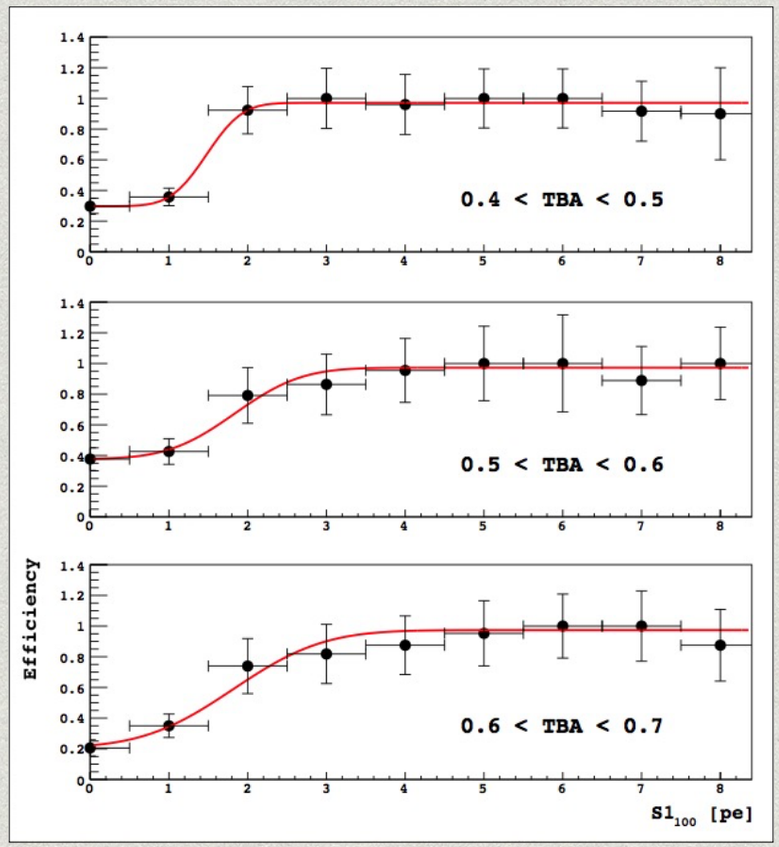
- Monitor TPC light yield stability over time
- Measure light yield at various electric fields

^{22}Na trigger efficiency calibration

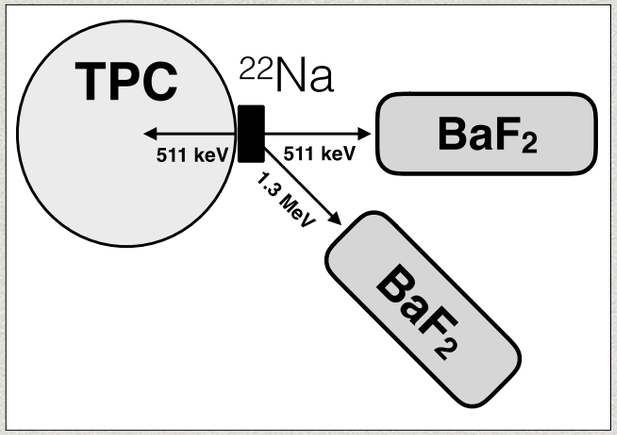
- Measure how many events are missed by TPC trigger at low energy



LED calibration: fit to 1" PMT response



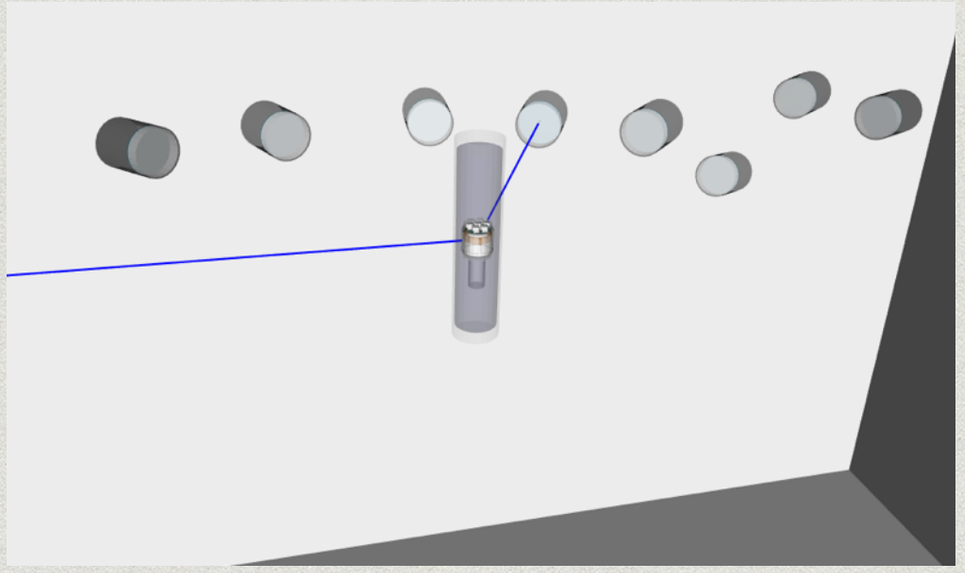
BaF_2 / TPC geometry for trigger efficiency measurement



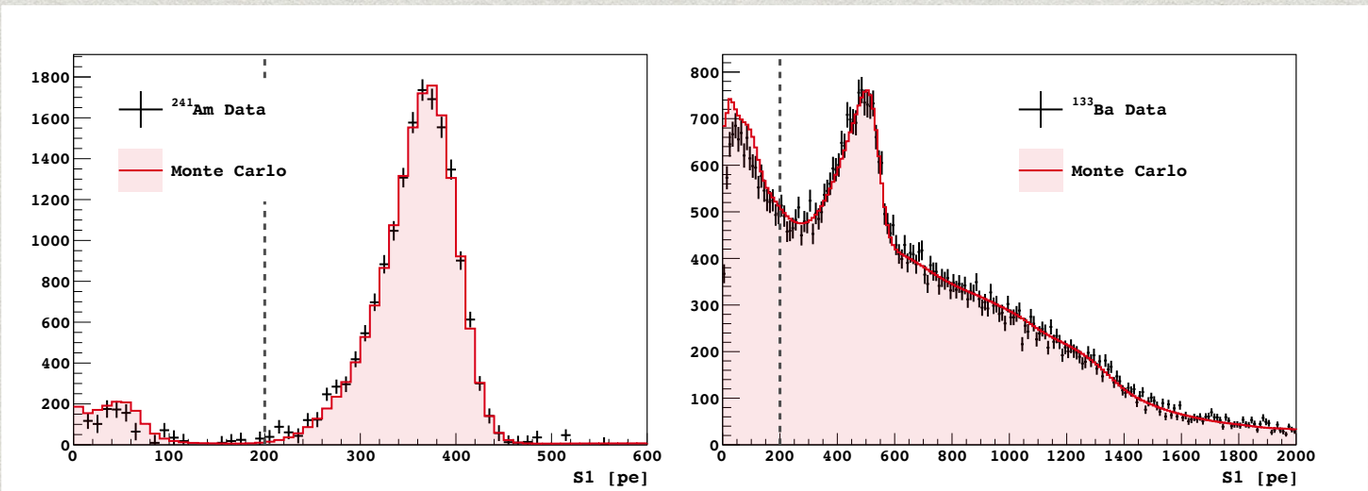
Efficiency measured as a function of prompt signal and Top-Bottom-Asymmetry (TBA)

Monte Carlo (MC)

Detailed ARIS geometry implemented in GEANT4 including TPC, cryostat, and neutron detectors.

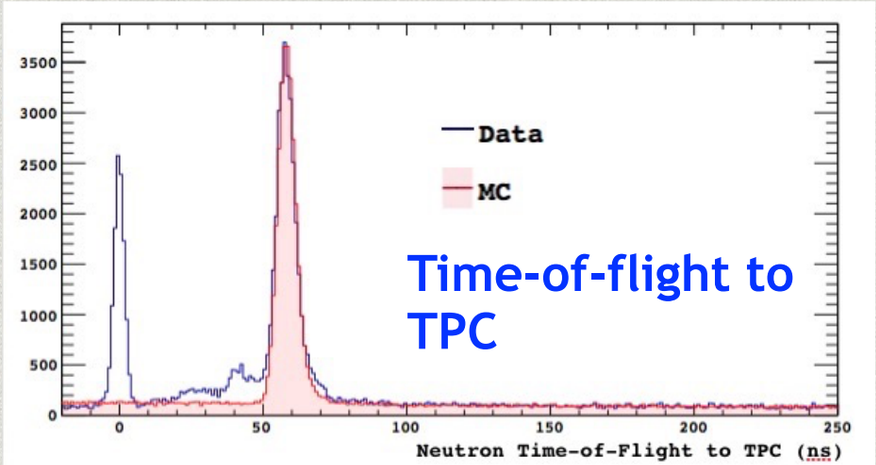


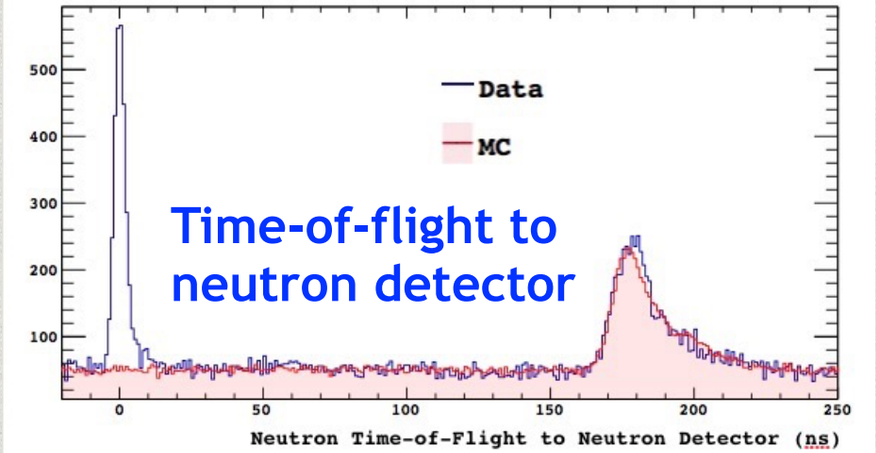
^{241}Am & ^{133}Ba MC-data S1 comparison



Excellent agreement between source data and MC in energy spectrum shape…

…as well as in neutron kinematics





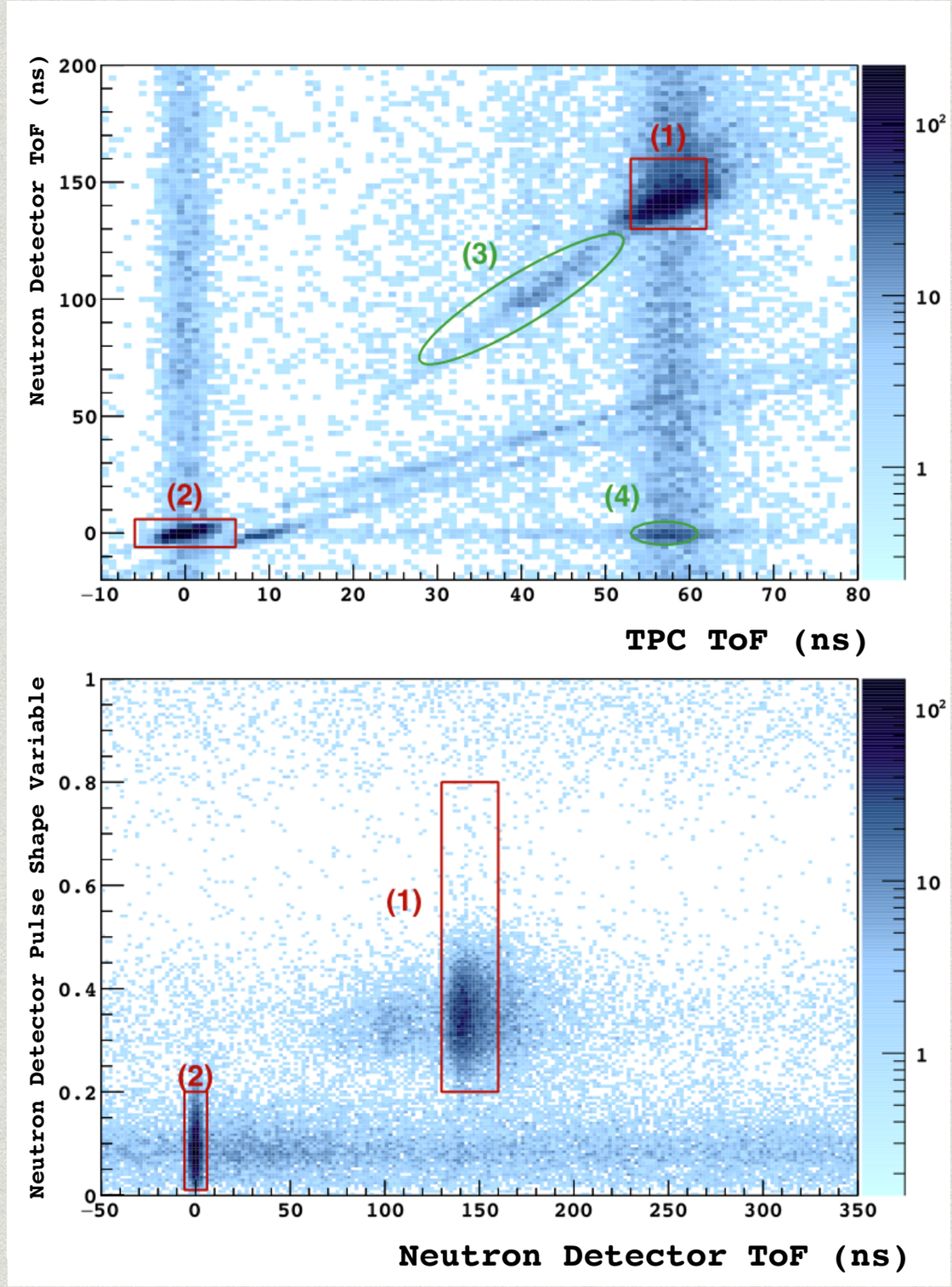
Neutron Data Selection

Three variables are used to select event populations:

- Neutron time of flight to the TPC
- Neutron time of flight to the neutron detector
- Pulse shape variable from scintillation time profile in the neutron detector

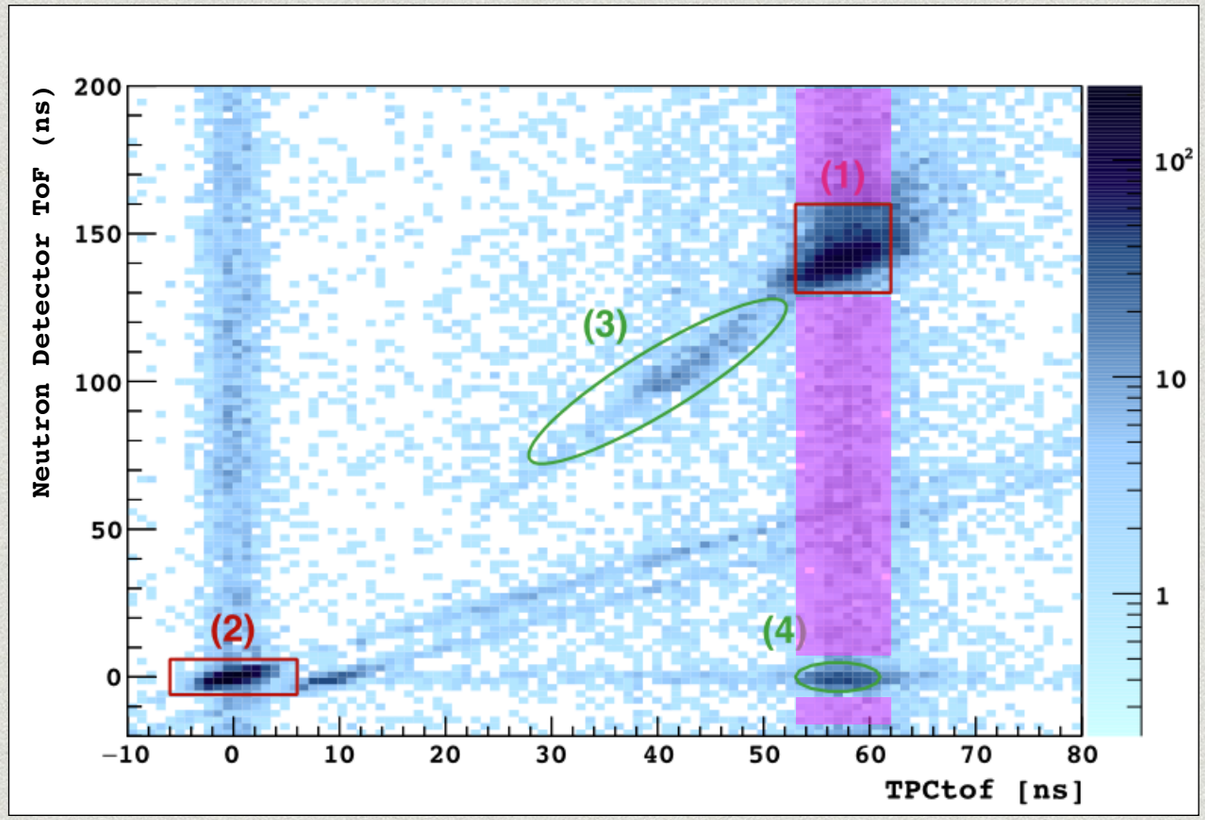
Four event populations can be seen numbered in the plots:

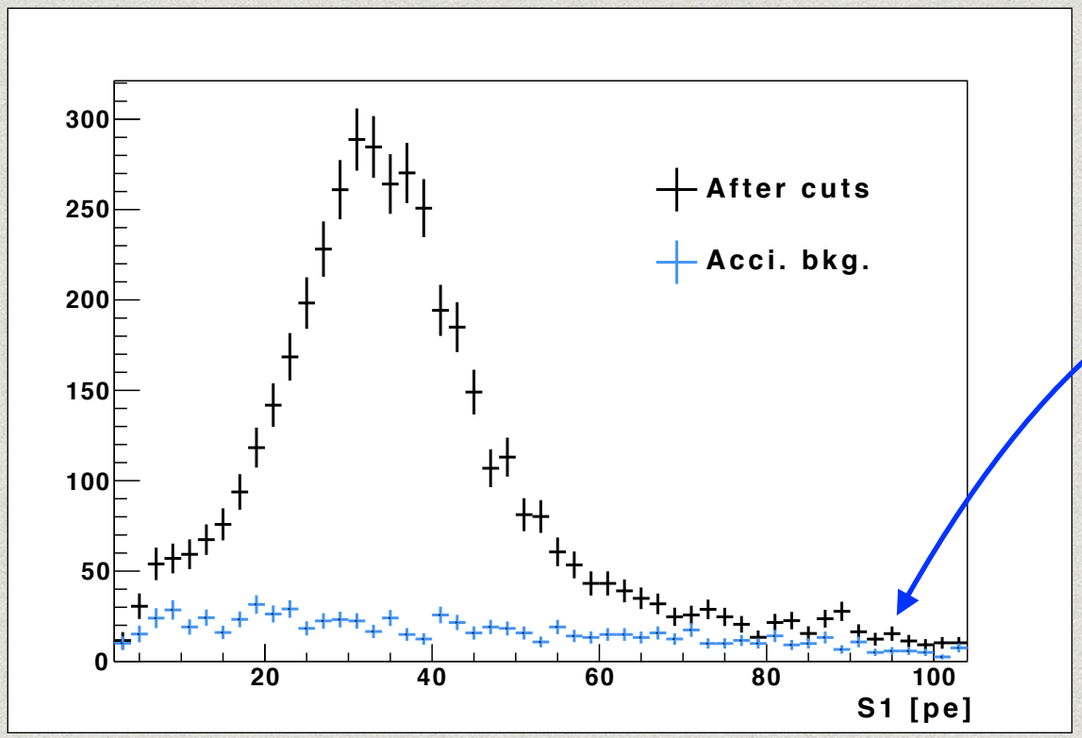
1. Neutrons from $p(^{7}Li, ^{7}Be)n$ reaction
2. Gamma "flash" associated with the beam from 478 keV $^{7}Li^{*}$ de-excitation
3. Fusion evaporation events caused by impurities in the LICORNE beam pipe
4. Accidental coincidence between neutron in the TPC and a gamma in the neutron detector



Accidental Background Subtraction

An accidental background probability distribution function is assembled from off-axis events within the TPC time of flight acceptance window (highlighted in pink)





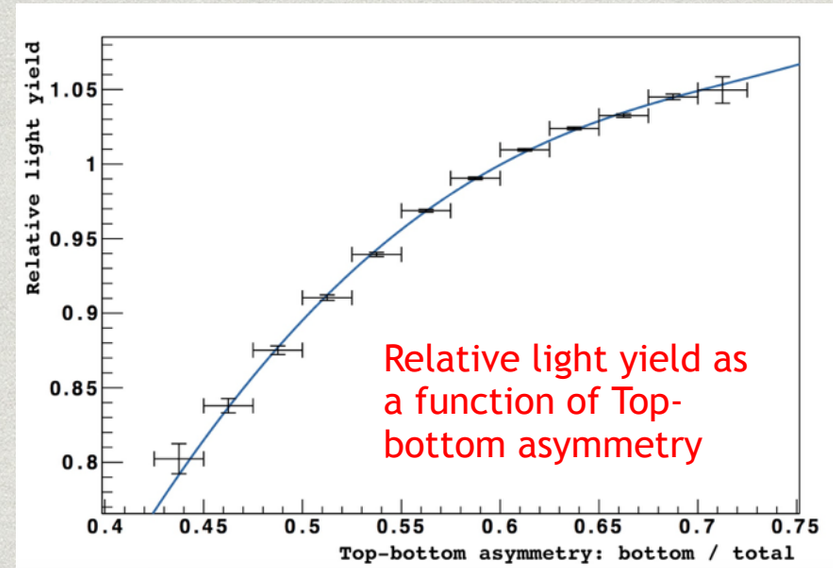
Background pdf is normalized to the tails of selected energy spectra above the main peak

Shown are the normalized accidental background and selected data for mean NR energy of 21.5 keV

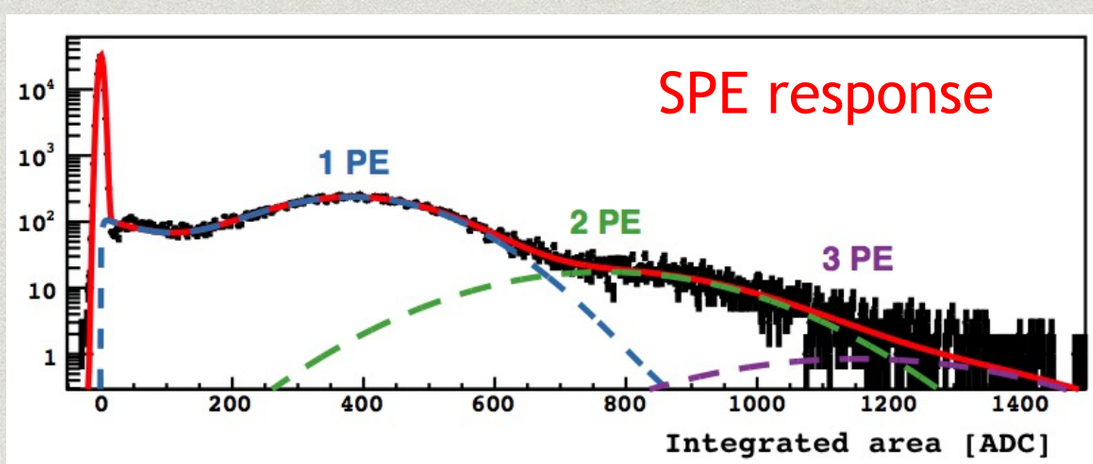
Simulating TPC Response In MC

A response map is generated to simulate TPC response to MC generated S1 spectra:

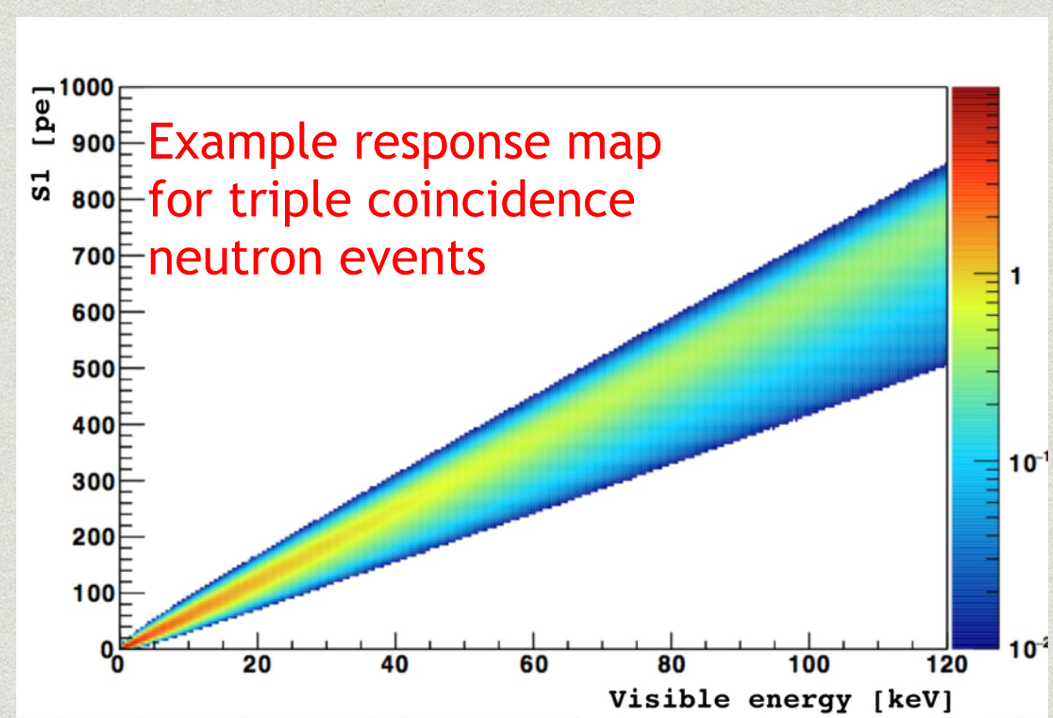
1) Visible energy spectrum is multiplied by the average light yield and smeared by Poisson statistics



2) Correct light yield for Top-bottom asymmetry



3) Smear each photon by the average single photoelectron response distribution



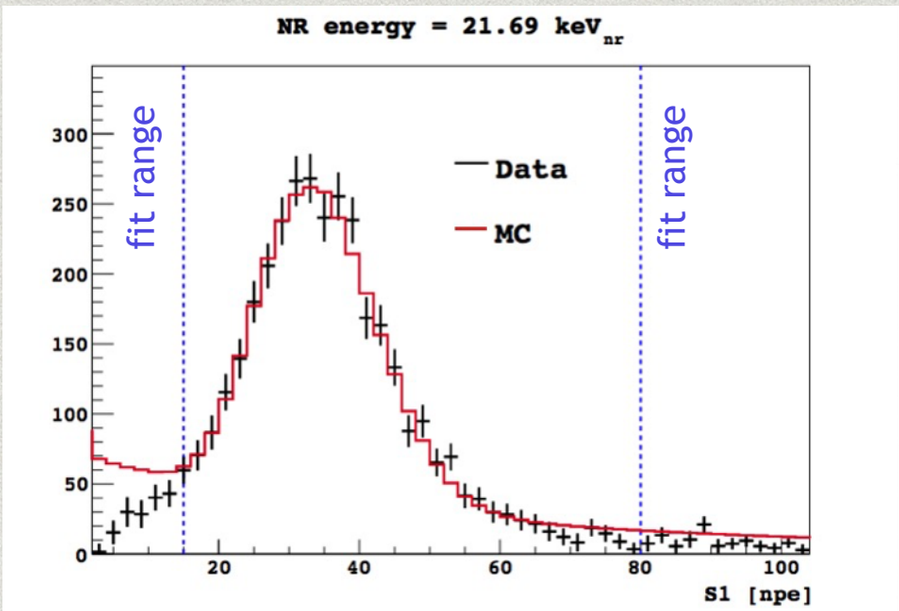
L_{eff}: Relative NR Scintillation Response

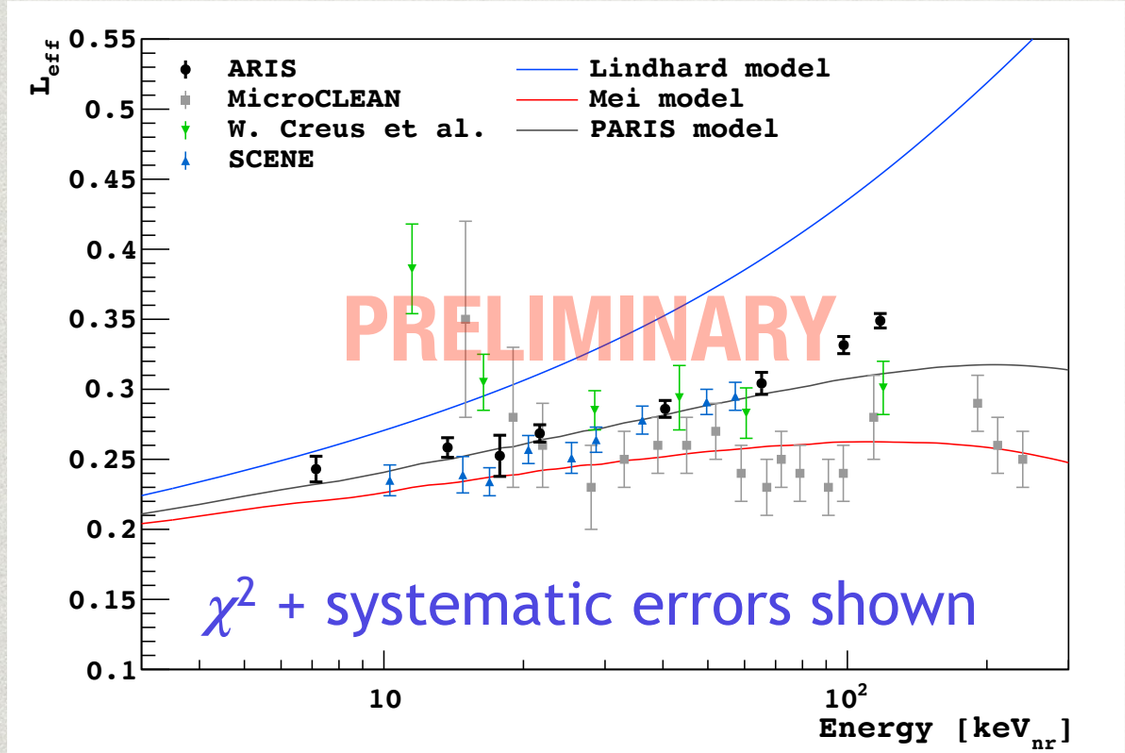
Relative scintillation of nuclear recoils is measured by fitting MC spectra after application of the response map to background subtracted neutron data.

L_{eff} and amplitude are free parameters of the fit.

Preliminary results agree with the SCENE experiment results at low energies.

Sample MC fit to neutron S1 data



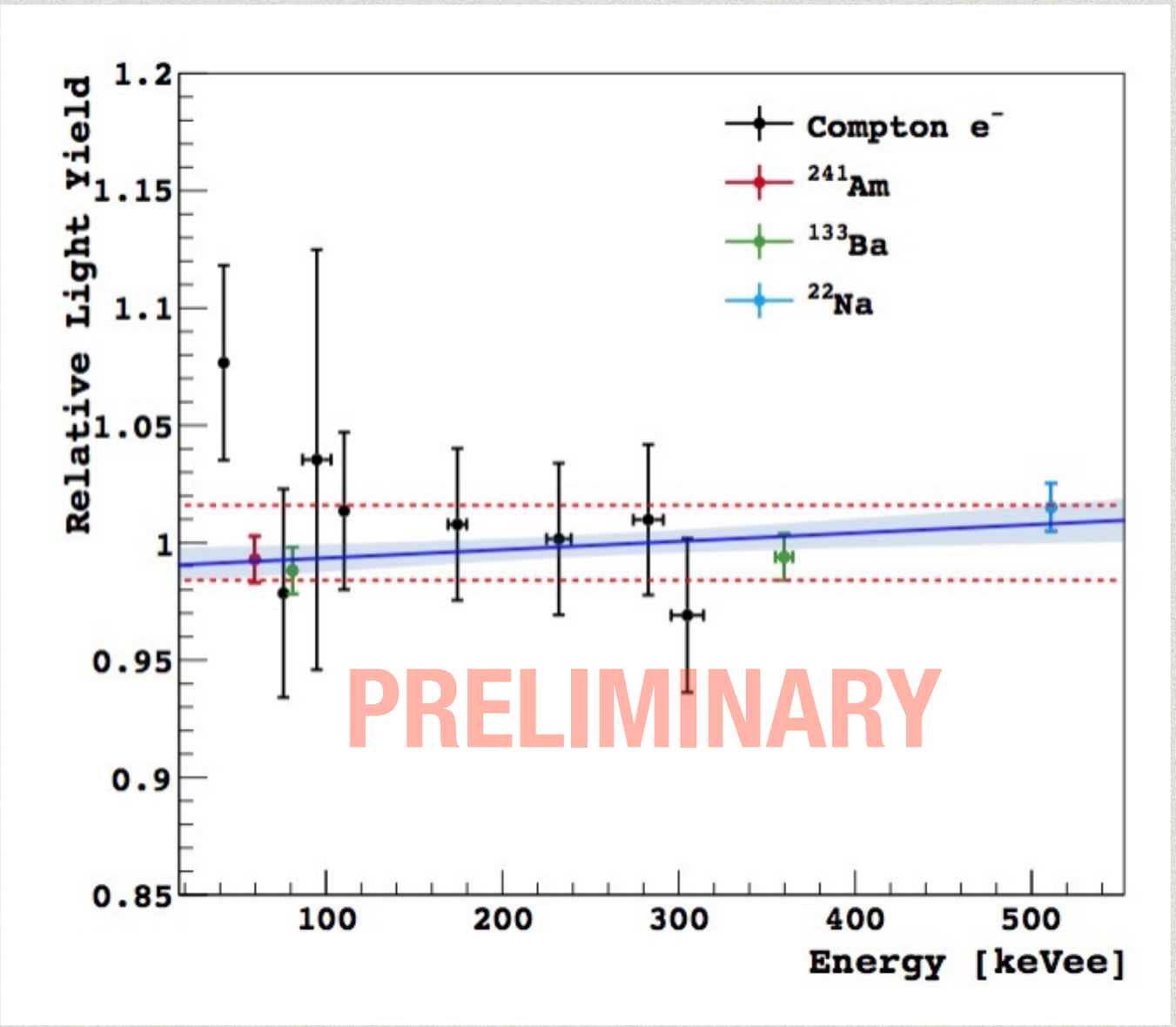


Energy Dependence of Light Yield

Gammas produced in the beam provide a unique source of candles to test the TPC light yield (LY) as a function of energy.

Results from Compton single-scatter ER events are combined with ^{241}Am, ^{133}Ba, and ^{22}Na source data.

LY in the [41.5, 511] keV range is found to be constant within 1.6% at 1σ CL.



Conclusions

- A LAr scintillation cell was exposed to the highly collimated LICORNE neutron beam at the Institute de Physique Nuclaire Orsay to precisely measure signals from nuclear and electronic recoils.
- The relative nuclear scintillation response L_{eff} has been precisely measured at 8 energies between [7,120] keV.
- Compton single-scattered electrons from the 478 keV gamma-flash are combined with source data to measure the energy dependence of the light yield in liquid argon between [41.5,511] keV to within 2%.
- Results from ARIS will be useful in simulating LAr response and optimizing search windows of direct dark matter search experiments utilizing LAr.