Dark matter and Mini-CLEAN

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Yale University

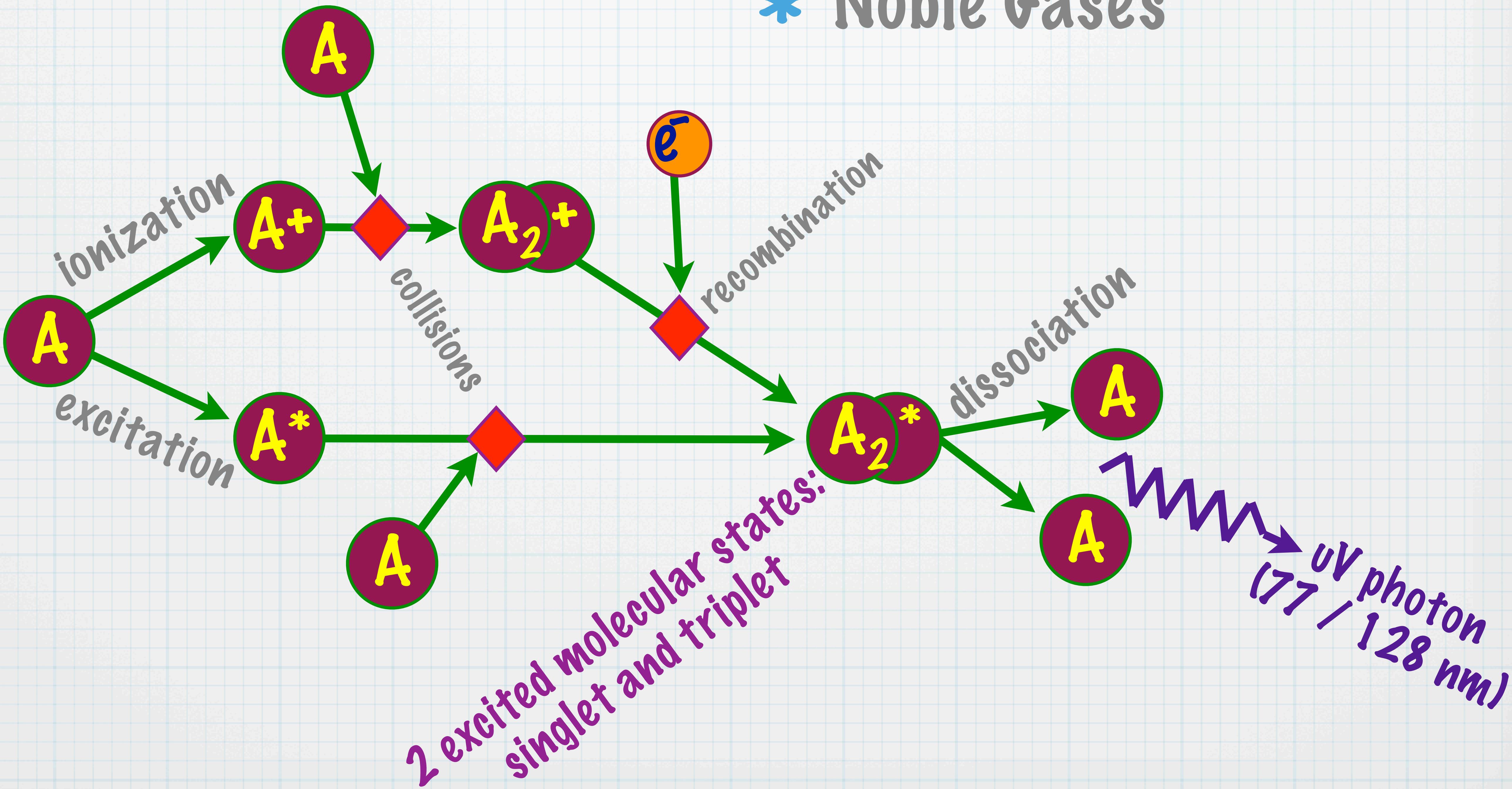
CLEAN collaboration

Collaborating Institutes:

* Boston University: E. Kearns, D. Gastler
* Carleton University: K. Graham
* LANL: A. Hime, K. Rielage, L. Stonehill, L. Rodriguez
* NIST, Boulder: K. Coakley
* University of North Carolina: R. Henning
* Queen's University: M. Boulay, A. Hallin
* SNOLAB: F. Duncan, I. Lawson, C. Jillings
* University of South Dakota: D. Mei
* University of Texas, Austin: J. Klein, S. Seibert, R. Hegde
* Yale University: D. McKinsey, J. Nikkel, H. Lippincott, S. Bhandari

CLEAN:

* Cryogenic
* Low
* Energy
* Astrophysics
* Noble Gases



Why Neon and Argon?

* Easy to purify; neon with charcoal, argon with a getter
* Transparent to own scintillation light
* Inexpensive
* Good pulse shape discrimination
* Can swap argon for neon to characterize backgrounds and test for WIMP signal without changing detector

CLEAN detectors:

* Pico-CLEAN: 100 ml test apparatus
  * measurements of scintillation efficiencies and demonstrate pulse shape discrimination
* Micro-CLEAN: 3 litre active volume R+D system
  * measurements of scintillation efficiencies and quantify pulse shape discrimination in argon
    * soon to switch to neon
* Mini-CLEAN: 100 litre active volume
  * will be installed underground as a dark matter detector
* CLEAN: 100 tonne
  * p-p solar neutrino and dark matter detector

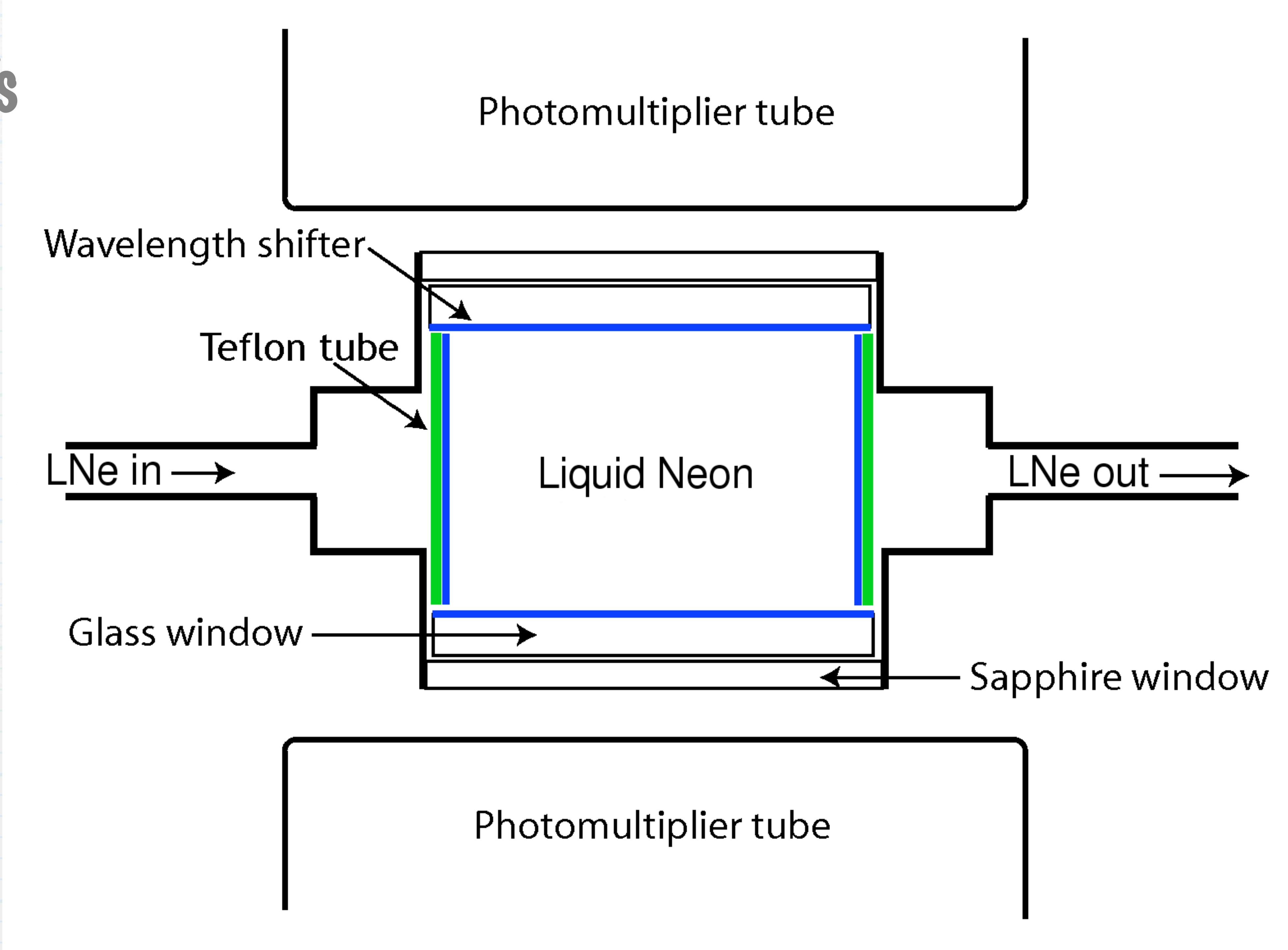
Pico-CLEAN

2 x 75 mm PMTs

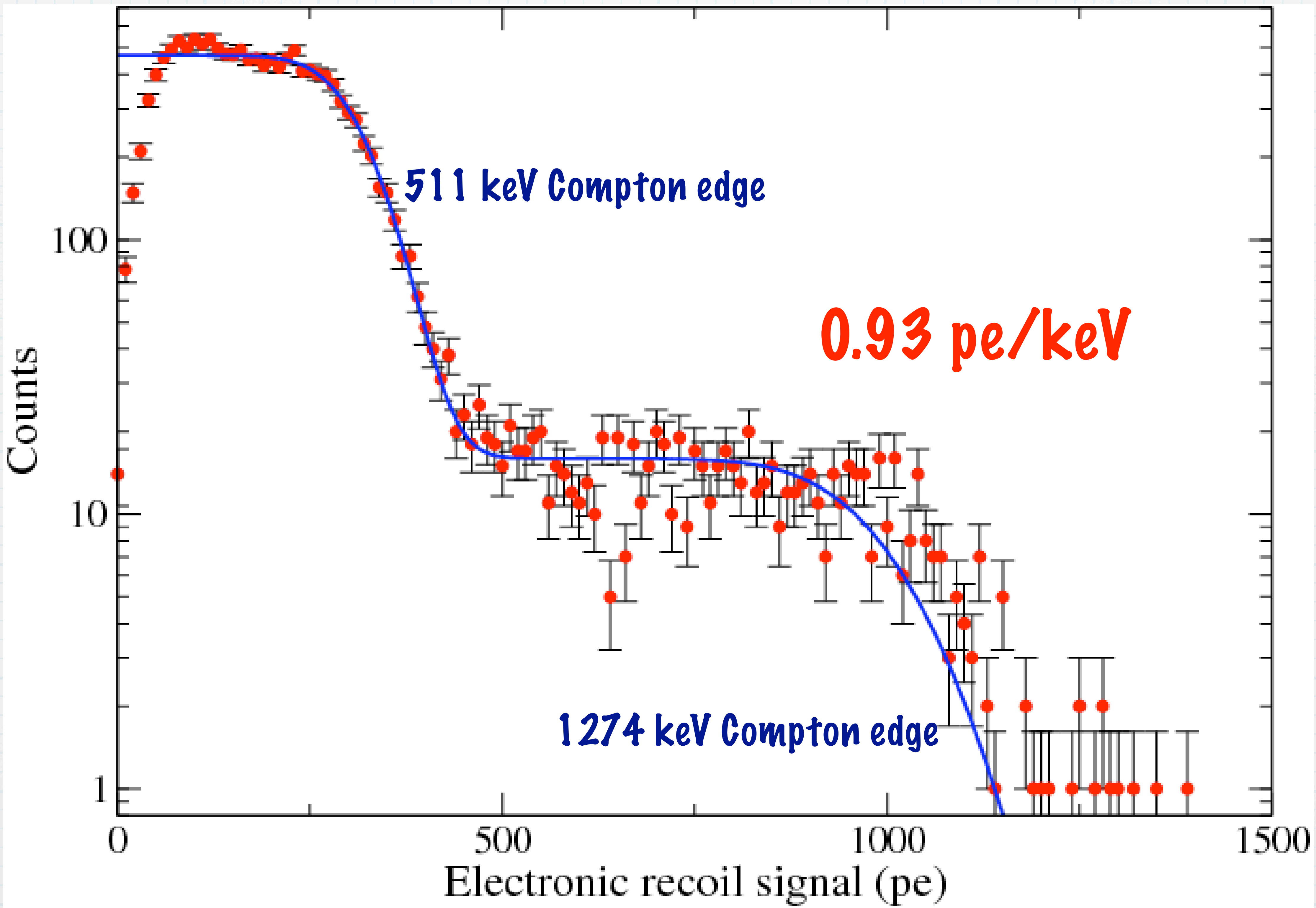
5 cm diameter
inner volume

5 cm tall
inner volume

Active volume
fully coated
with TPB



Electronic Recoil Calibration: (neon in pico-CLEAN)

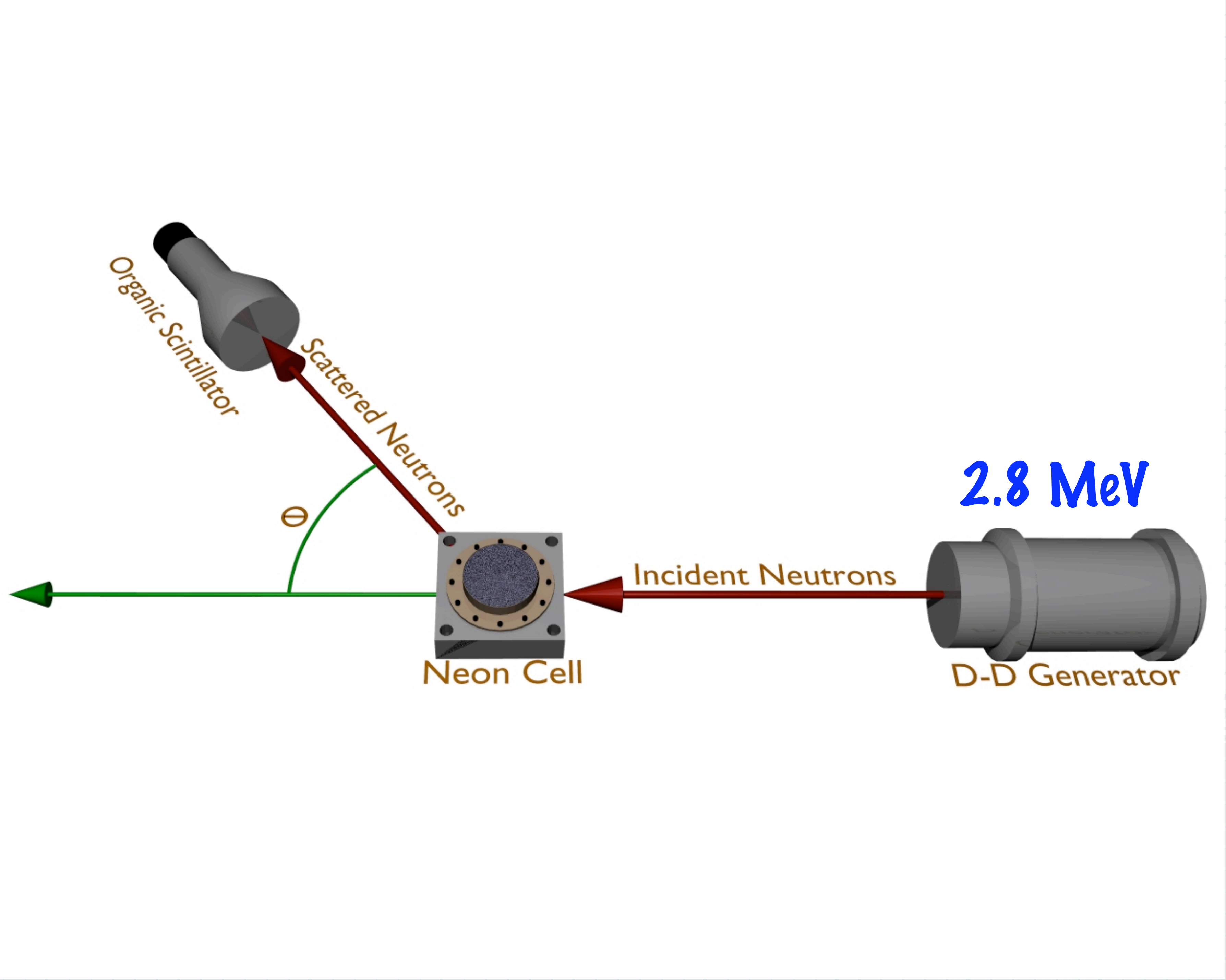


Nuclear Recoils: (neon in pico-CLEAN)

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

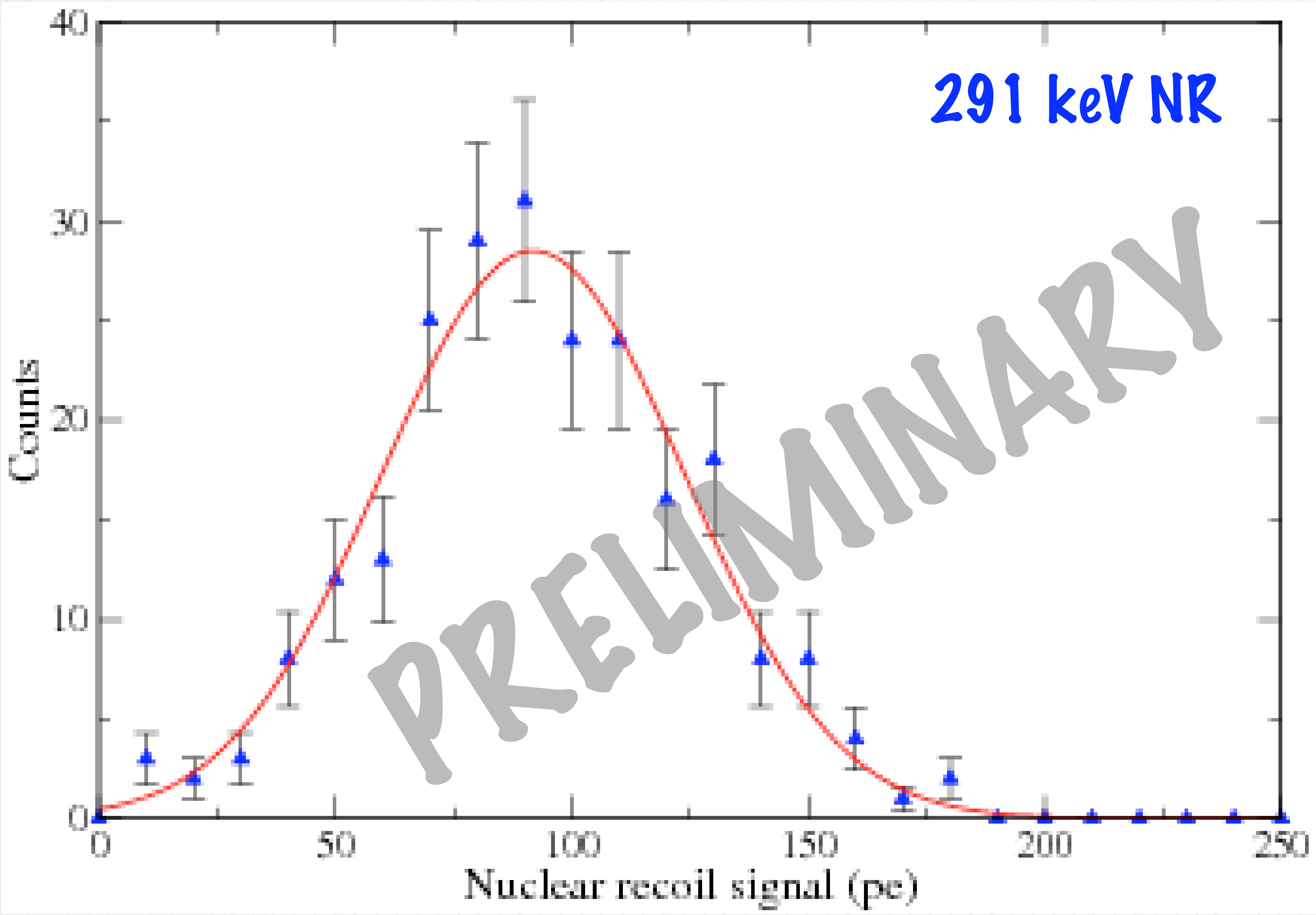
Require:

- Delayed time of flight
- Minimal asymmetry between PMTs viewing cell
- PSD in organic scintillator



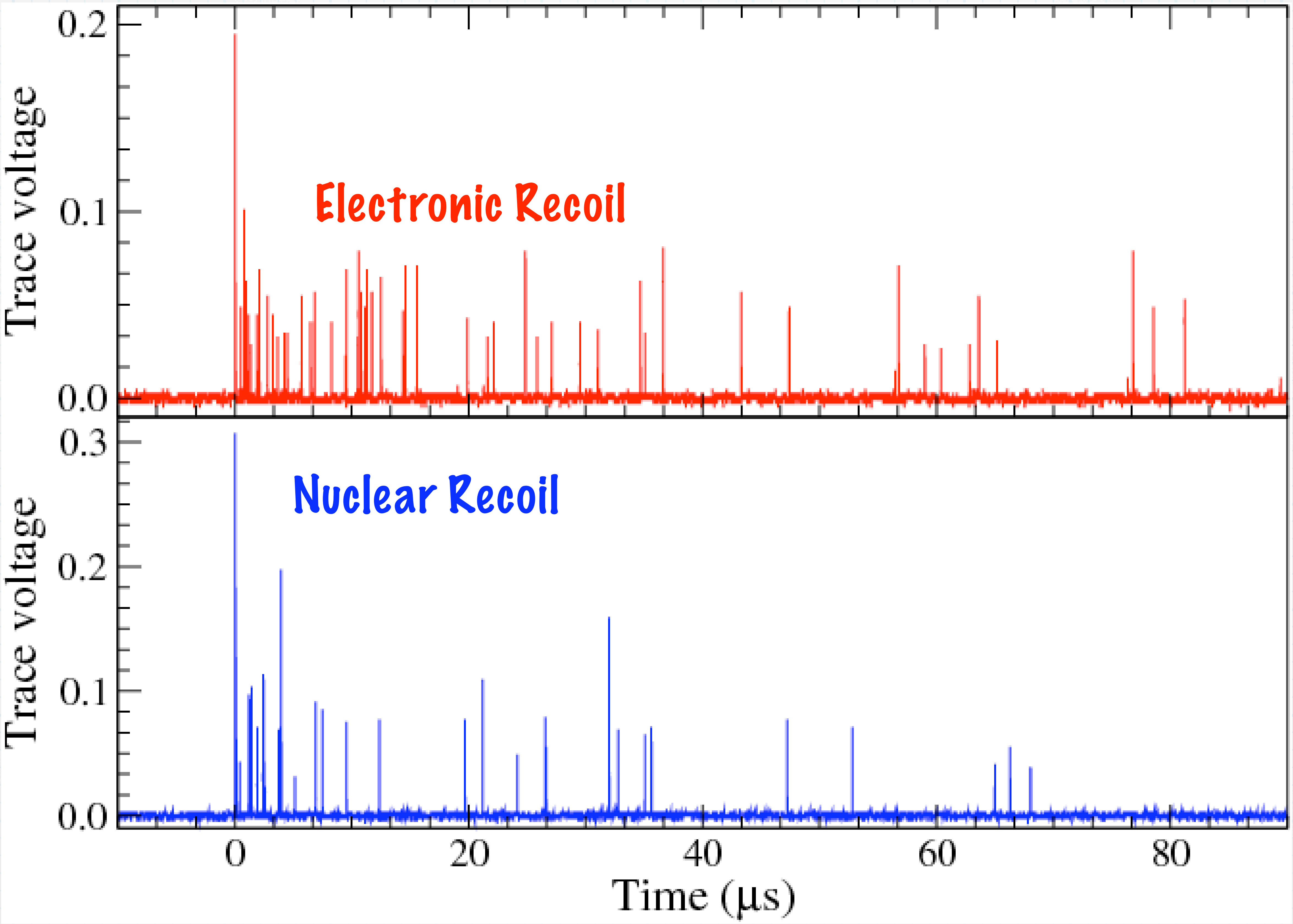
Nuclear Recoil Scintillation Efficiency:

(neon in pico-CLEAN)



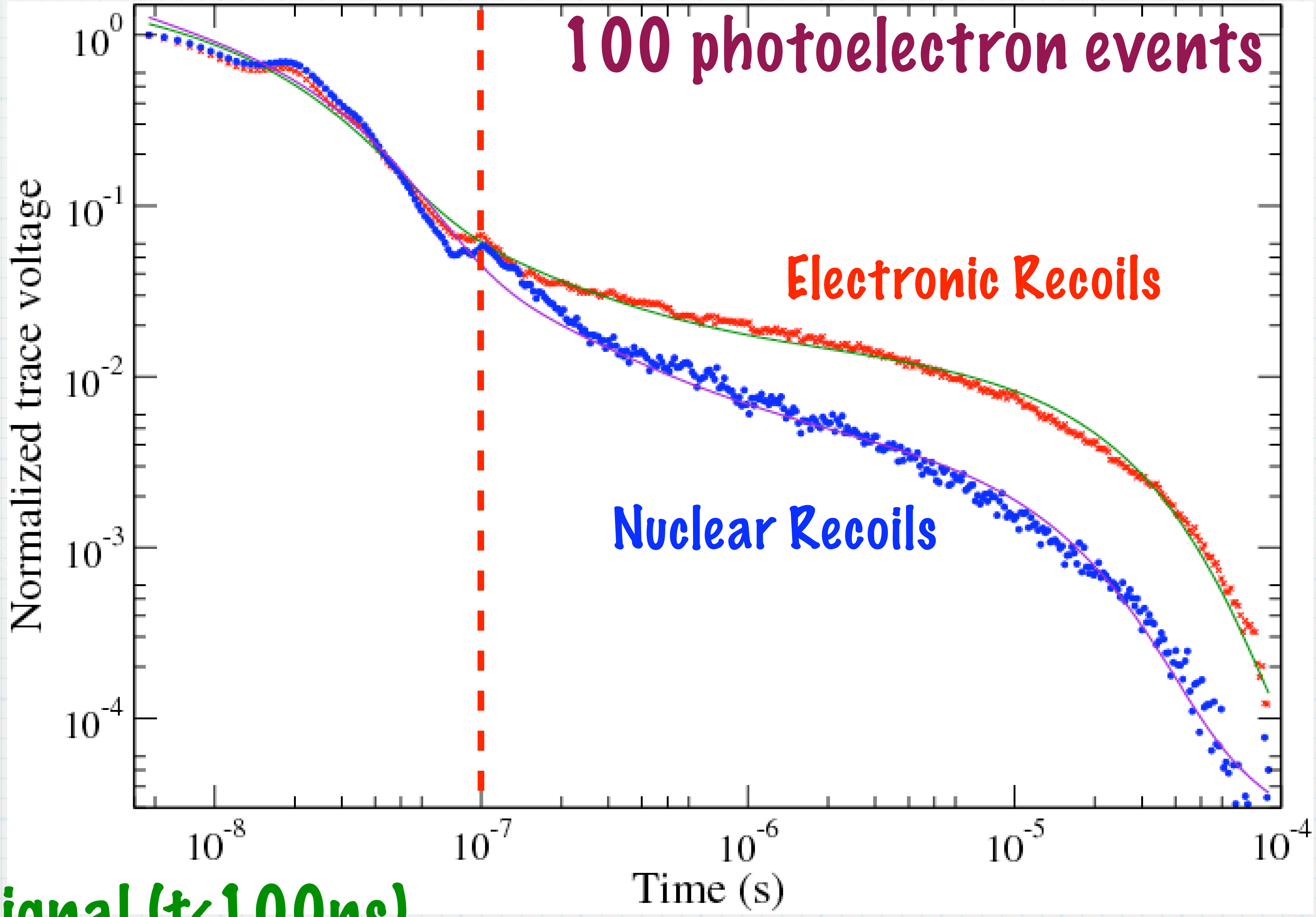
Nuclear recoil scintillation efficiency of 0.26+- 0.11 at 291 keV

Example Traces: (neon in pico-CLEAN)



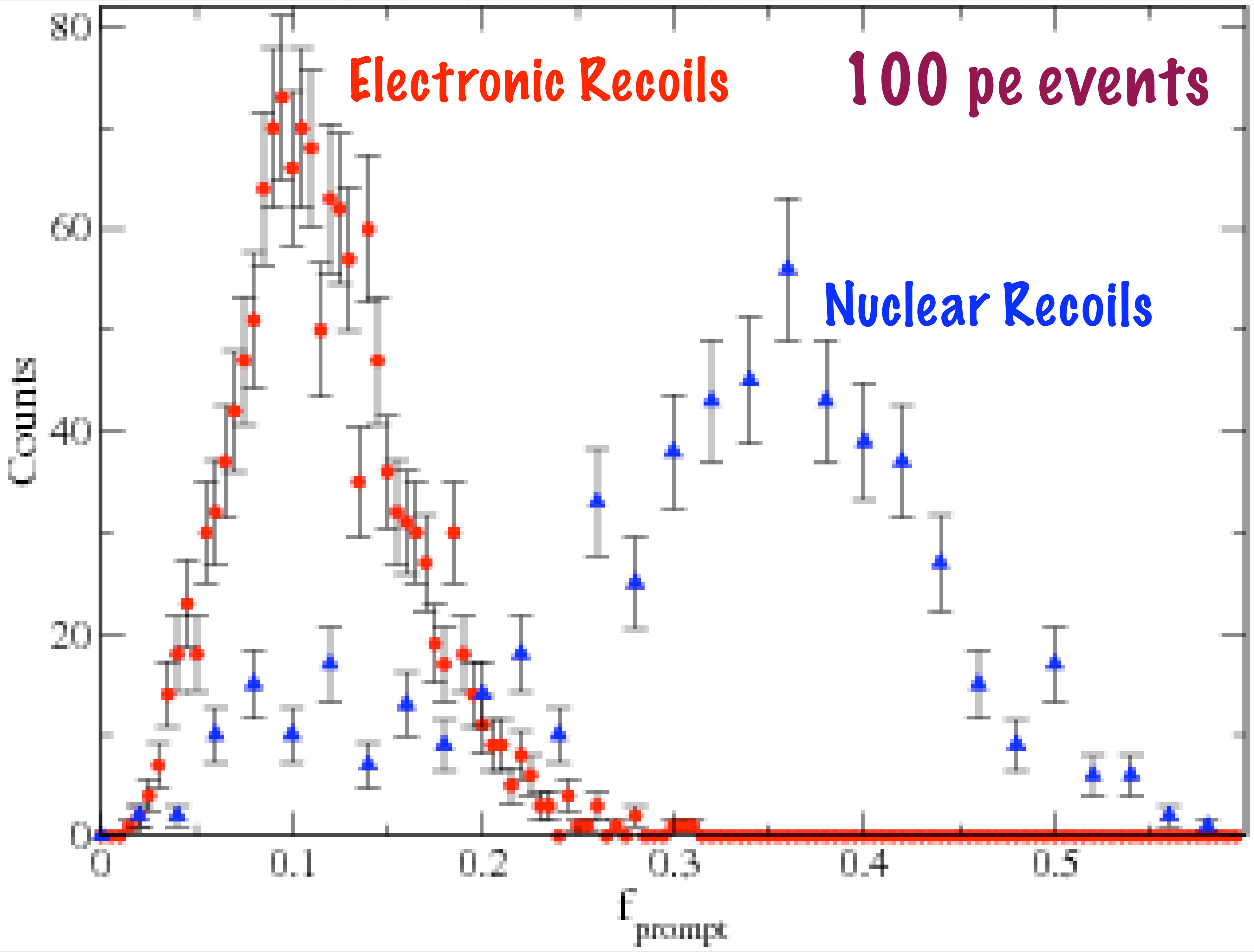
Time Dependence:

(neon in pico-CLEAN)



$$F_{prompt} = \frac{\text{Signal (t<100ns)}}{\text{Total Signal}}$$

Discrimination power: (neon in pico-CLEAN)



Electronic recoil rejection exceeds 1:1400 (>99.9%) for 100 pe events

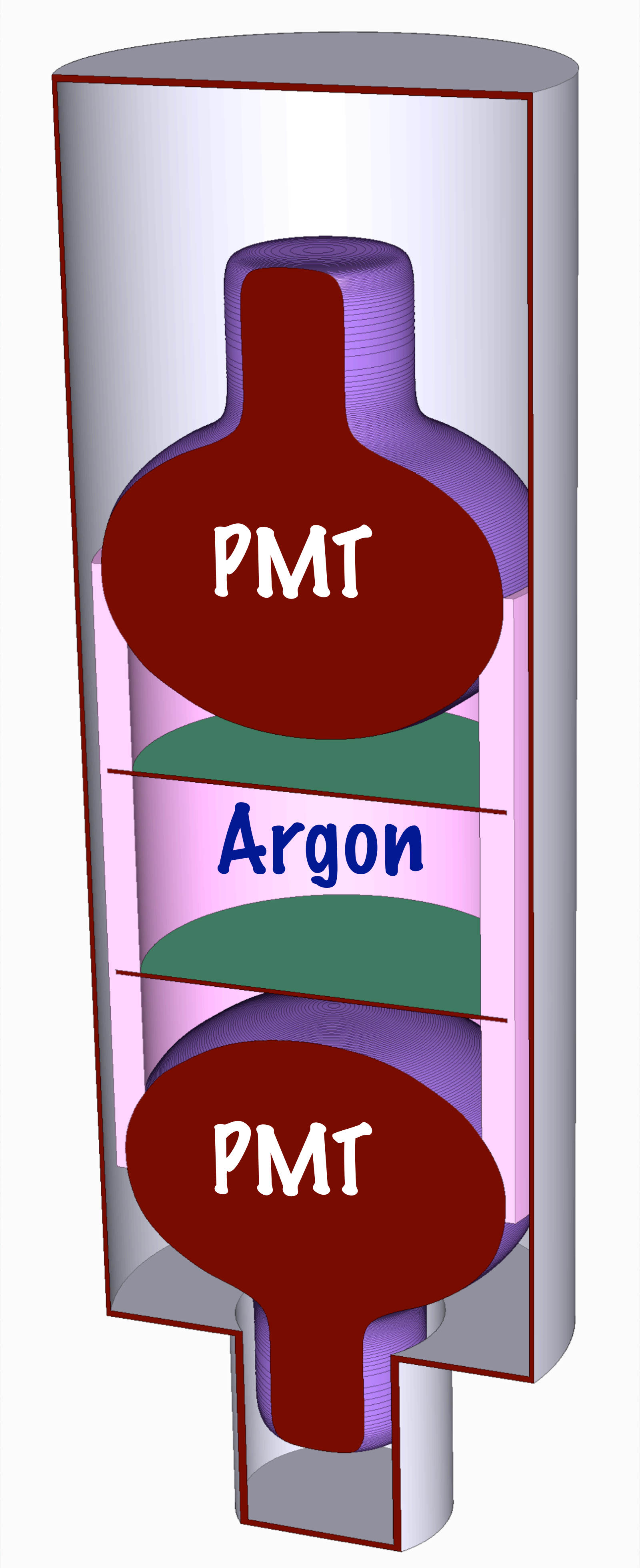
Micro-CLEAN Results

2 x 200 mm PMTs

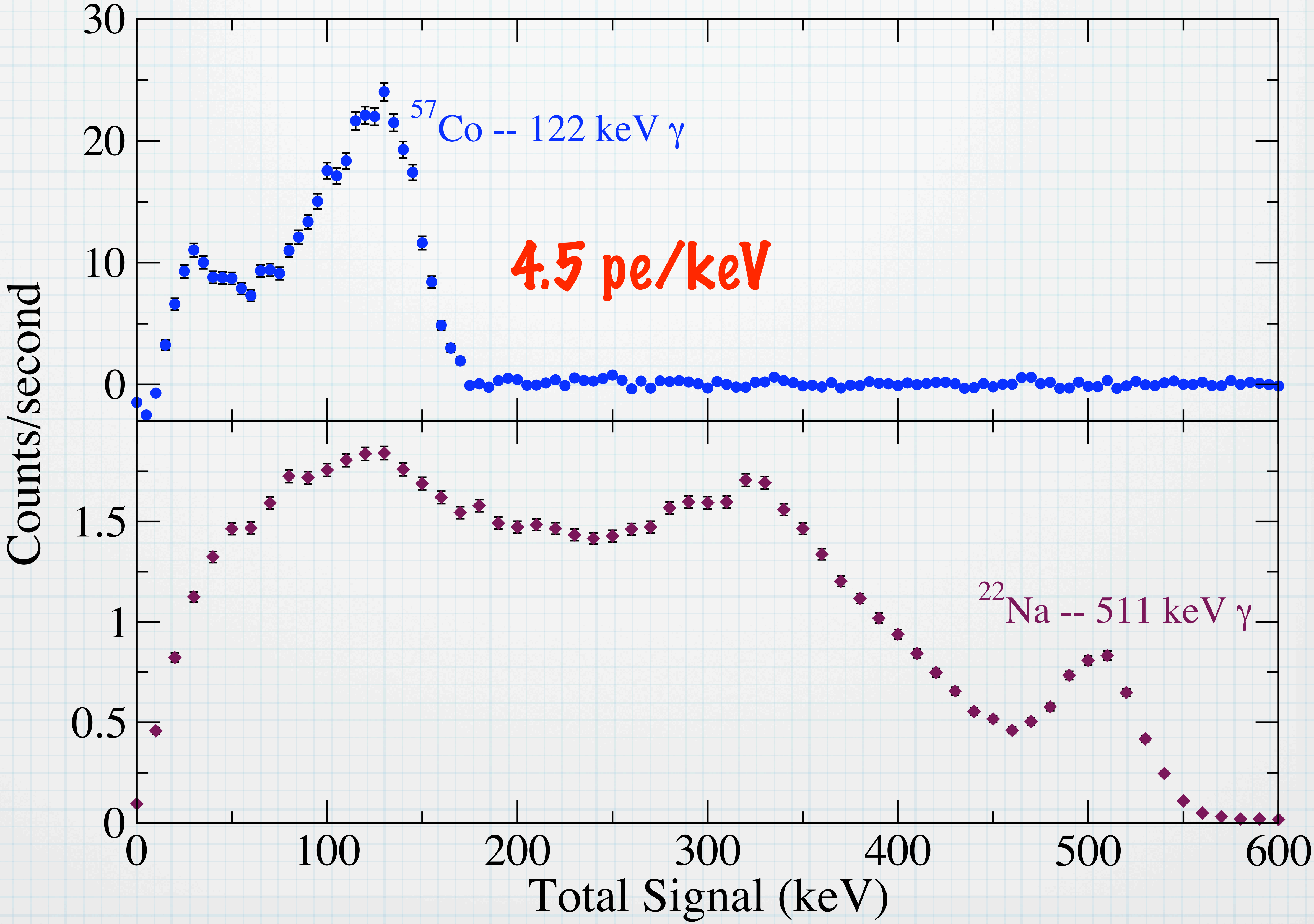
20 cm diameter
inner volume

10 cm tall
inner volume

Active volume
fully coated
with TPB



Electronic Recoil Calibration: (argon in micro-CLEAN)



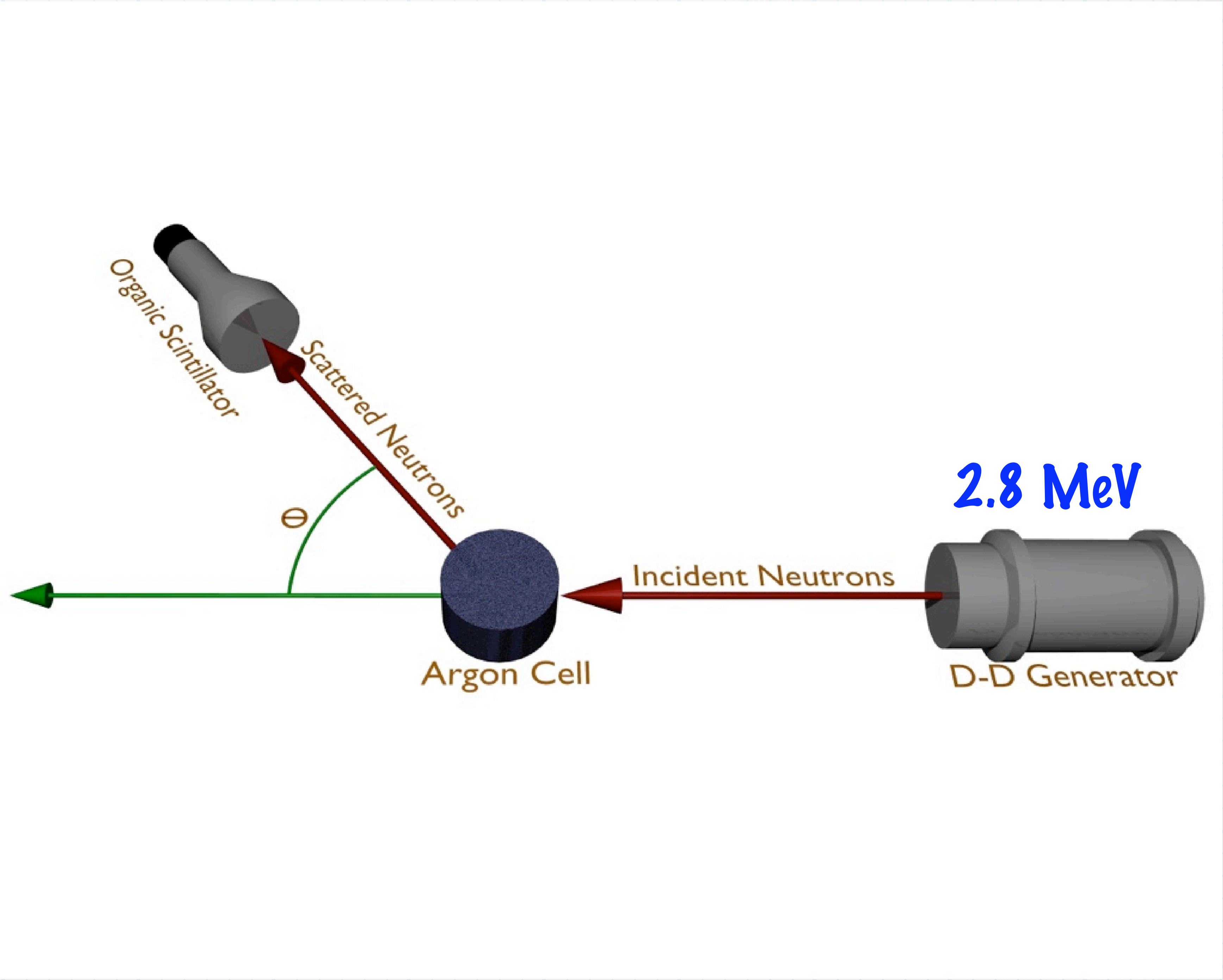
Nuclear Recoils:

(argon in micro-CLEAN)

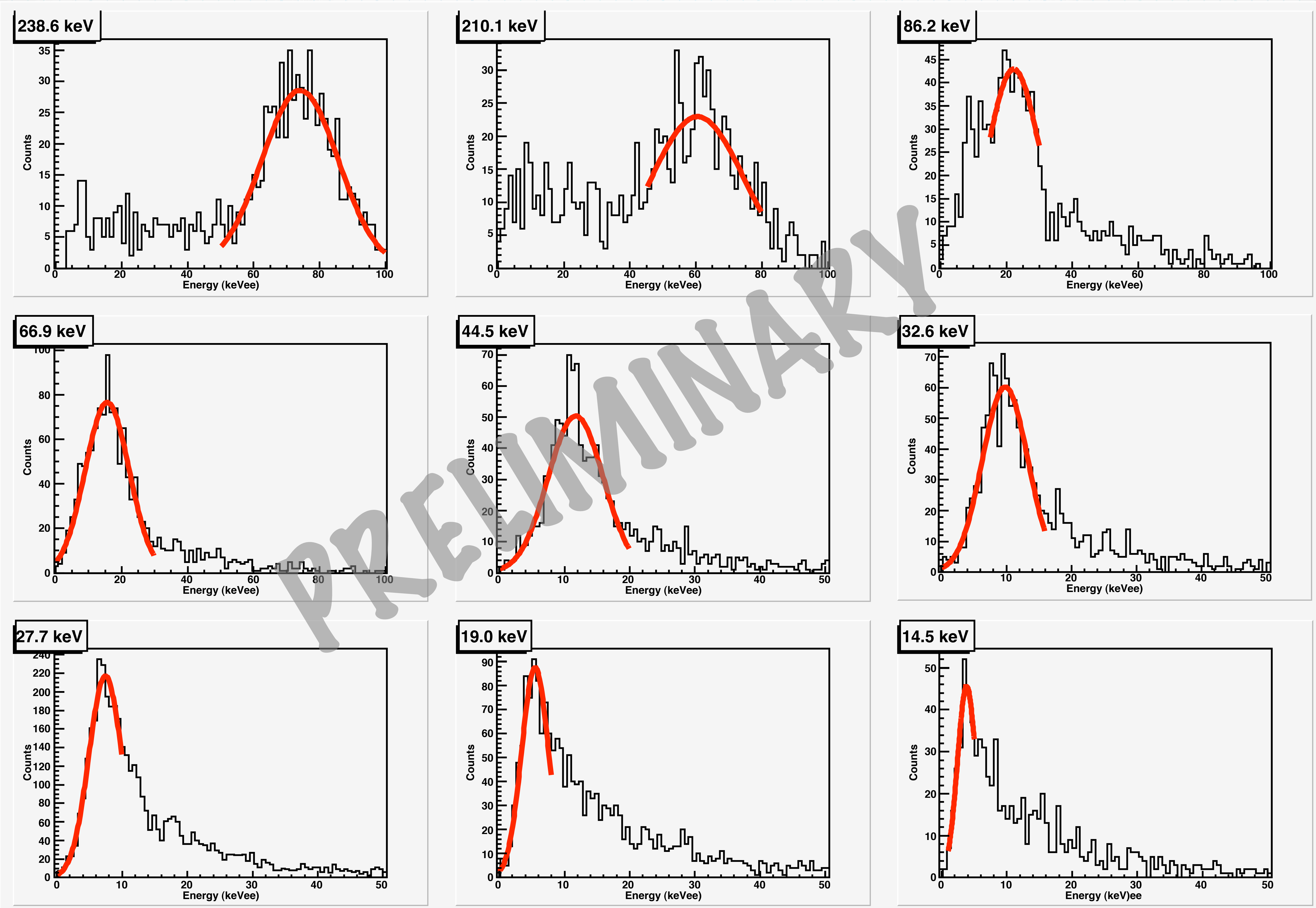
$$E_{recoil} = \frac{2E}{(1+A)^2}\left[1+A-\cos^2(\theta) - \cos(\theta)\sqrt{A^2+\cos^2(\theta)-1}\right]$$

Require:

- Delayed time of flight
- Minimal asymmetry between PMTs viewing cell
- PSD in organic scintillator

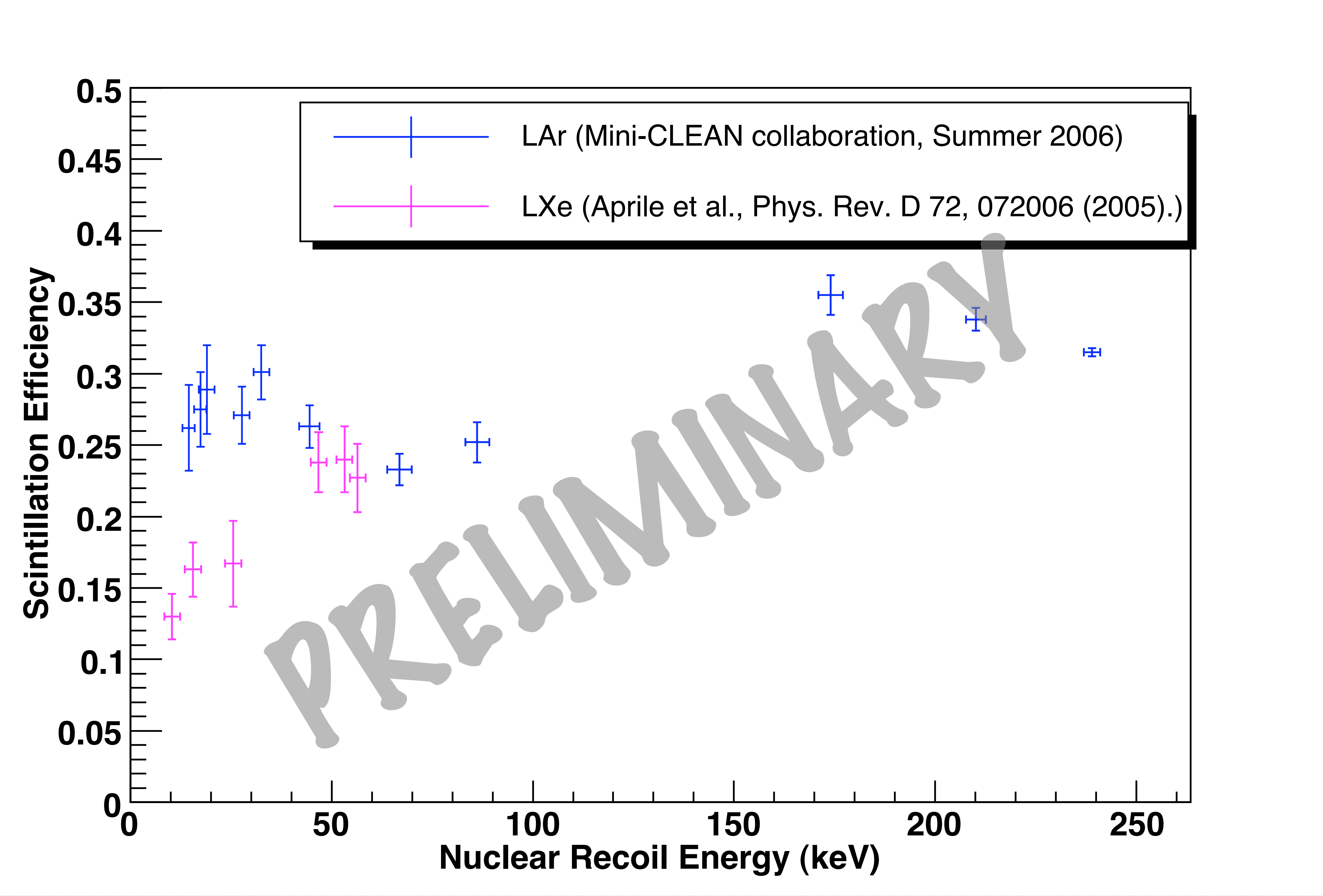


Nuclear Recoils: (argon in micro-CLEAN)



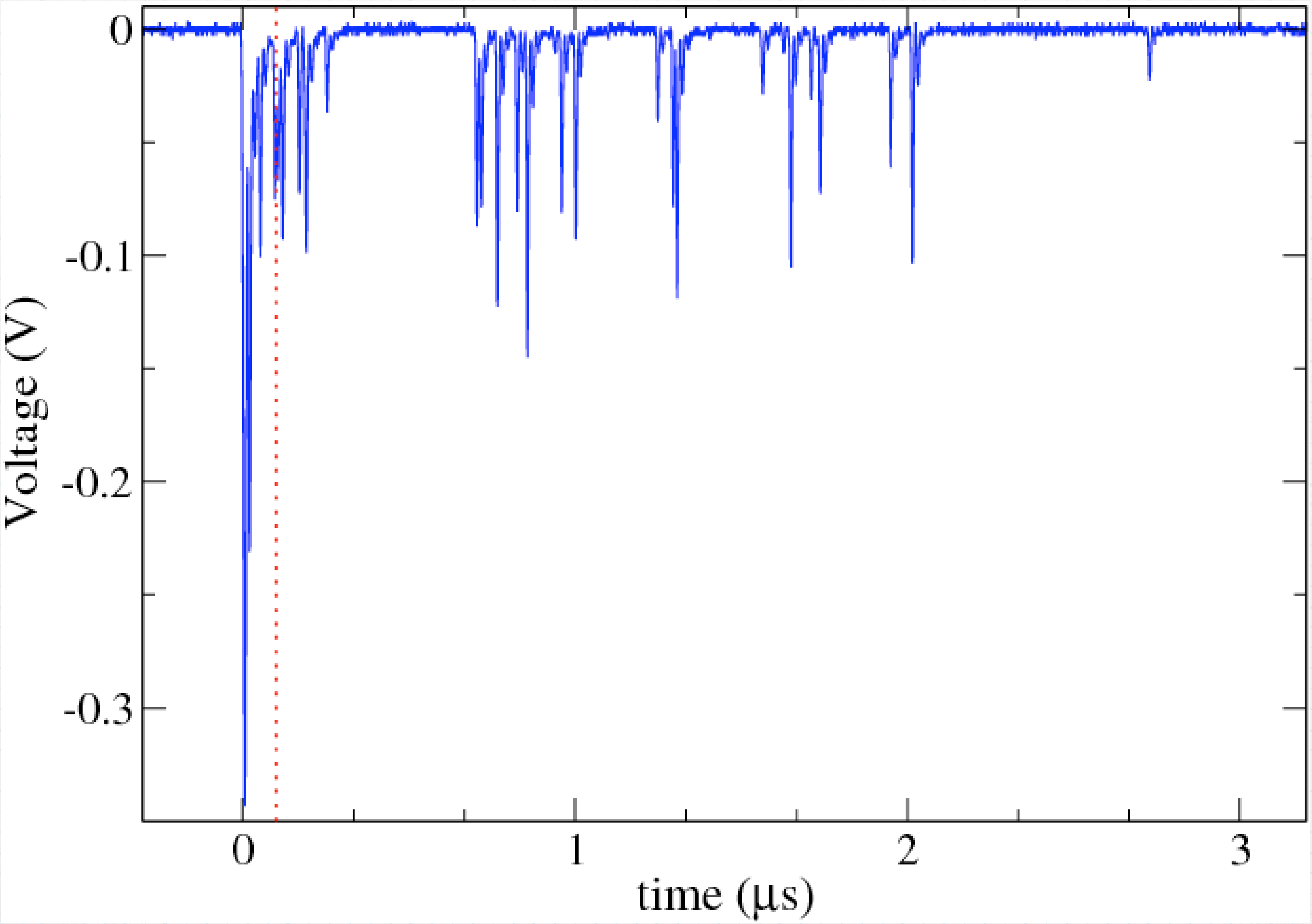
Nuclear Recoil Scintillation Efficiency:

(argon in micro-CLEAN)

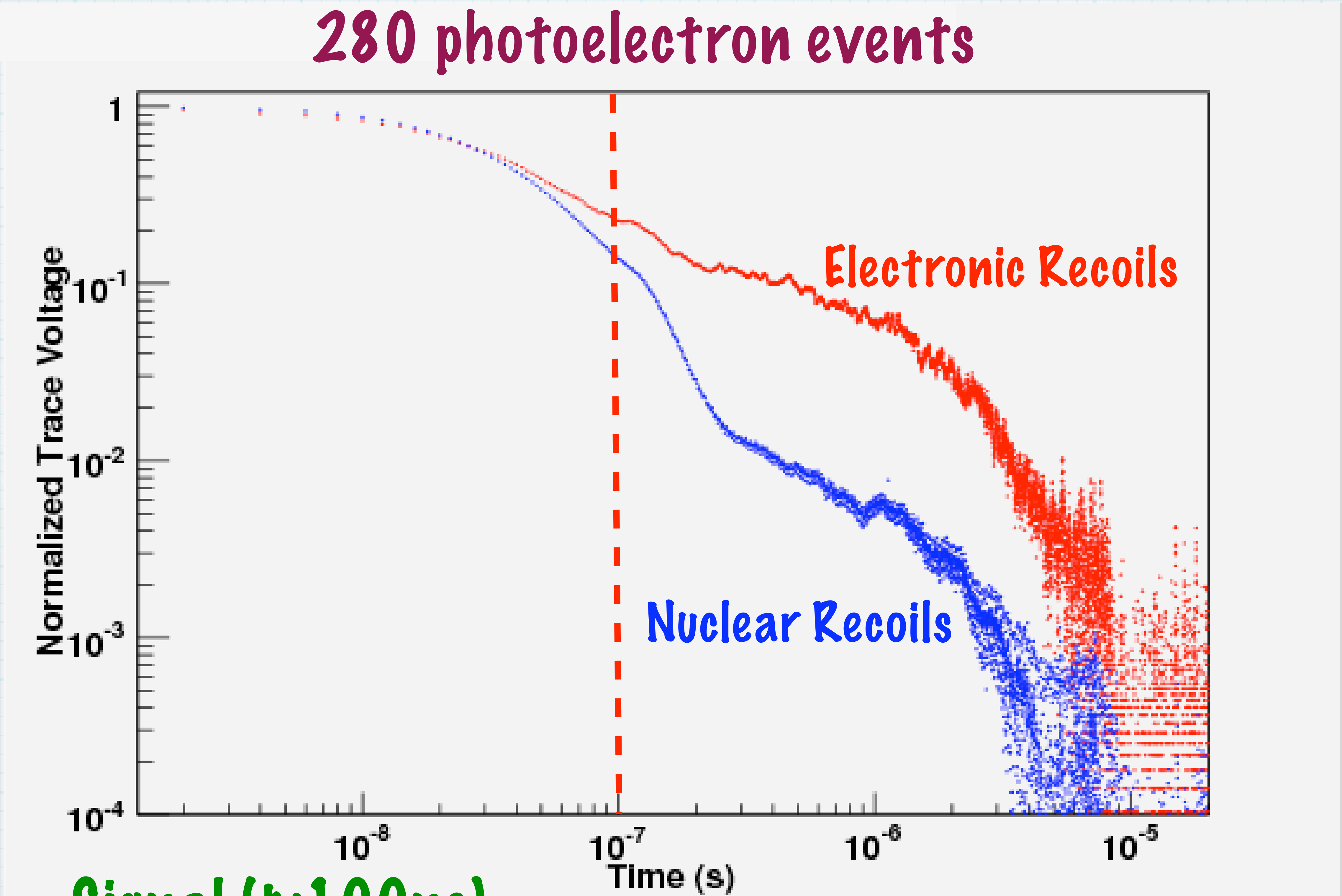


Example Trace:

(argon in micro-CLEAN)

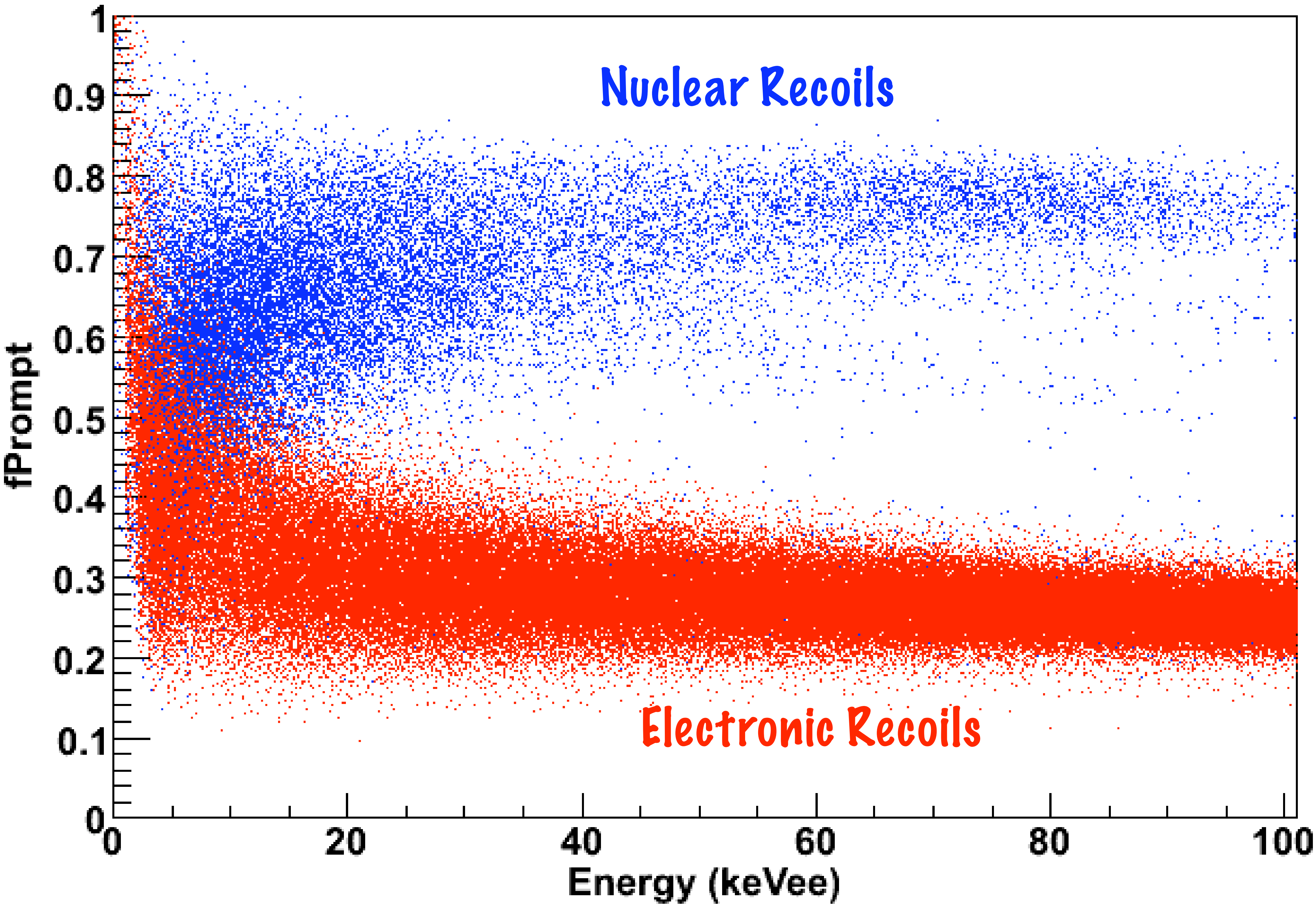


Time Dependence: (argon in micro-CLEAN)

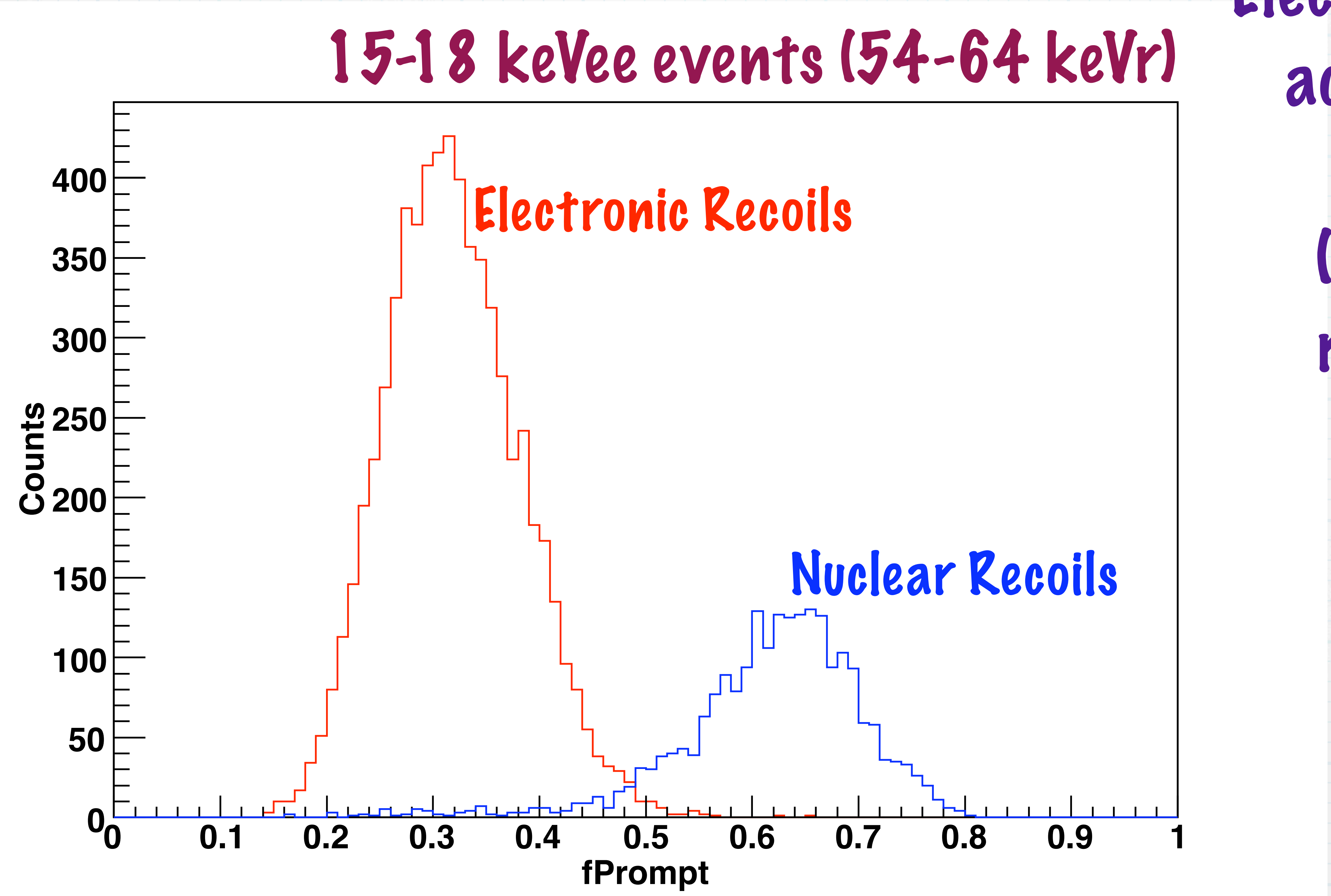


$$F_{prompt} = \frac{\text{Signal } (t<100\text{ns})}{\text{Total Signal}}$$

Discrimination power: (argon in micro-CLEAN)



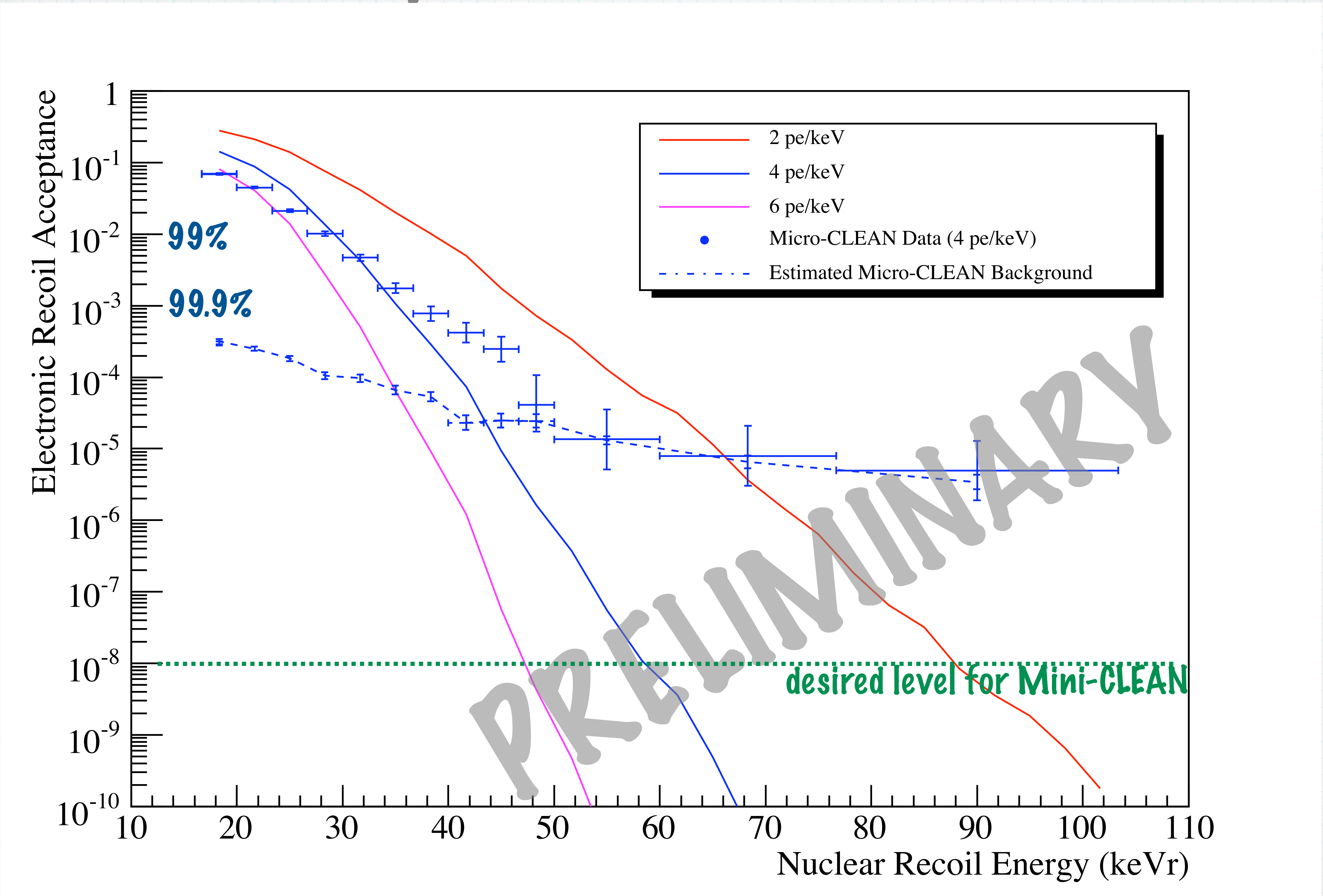
Discrimination power: (argon in micro-CLEAN)



Electronic recoil acceptance: 1.4×10^{-5} (99.999% rejection)

Projected:
1×10^{-4} at 2pe/keV
6×10^{-8} at 4pe/keV
3×10^{-11} at 6pe/keV

Discrimination power: (argon in micro-CLEAN)



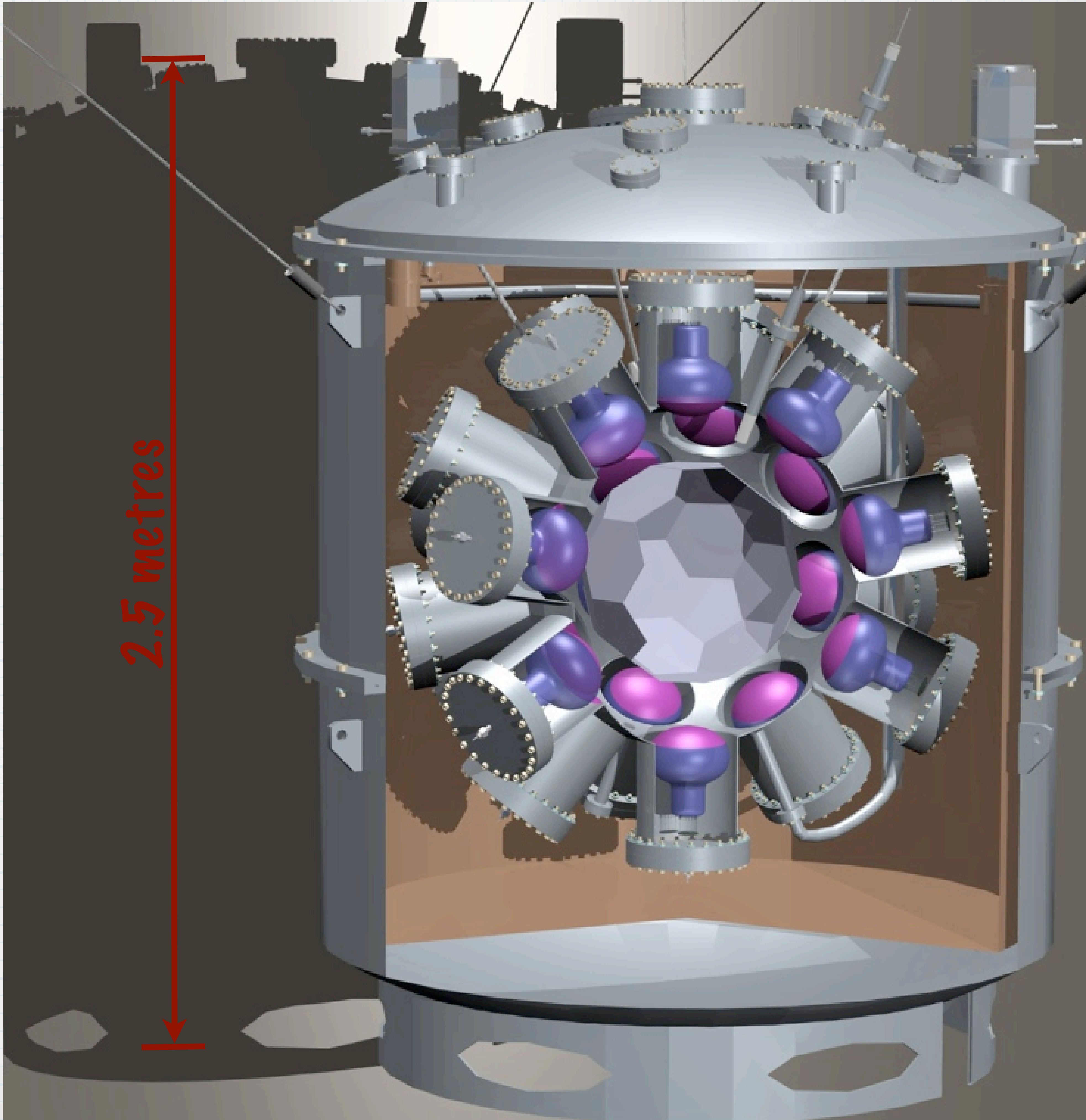
Solid lines indicate projected level assuming 50% NR acceptance

Mini-CLEAN

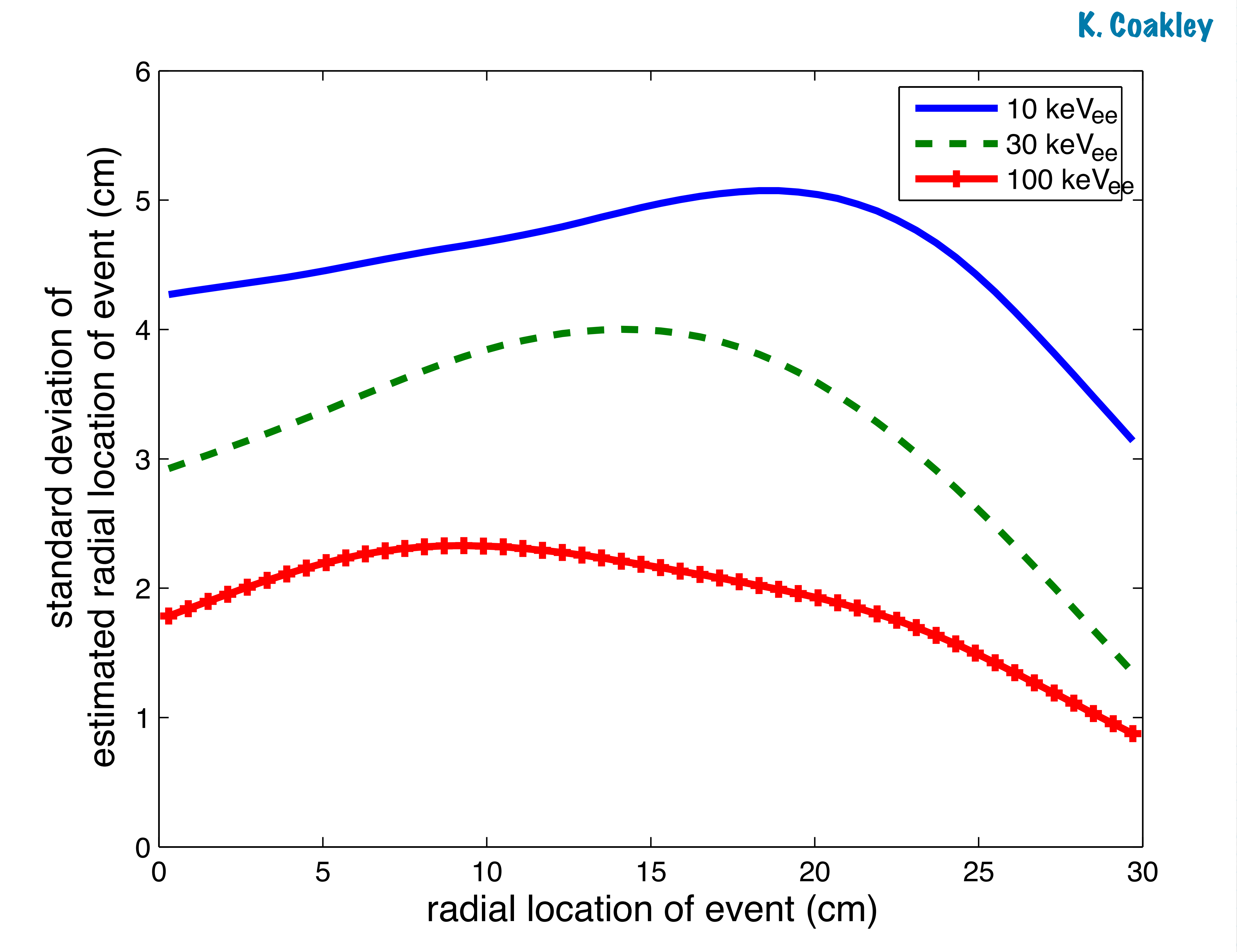
32 x 200 mm PMTs

54 cm diameter inner volume

Designed WIMP cross section limit: 10^{-45} cm^{2} for 1 year BG free



Position reconstruction: (Mini-CLEAN)



Background Study: (Mini-CLEAN)

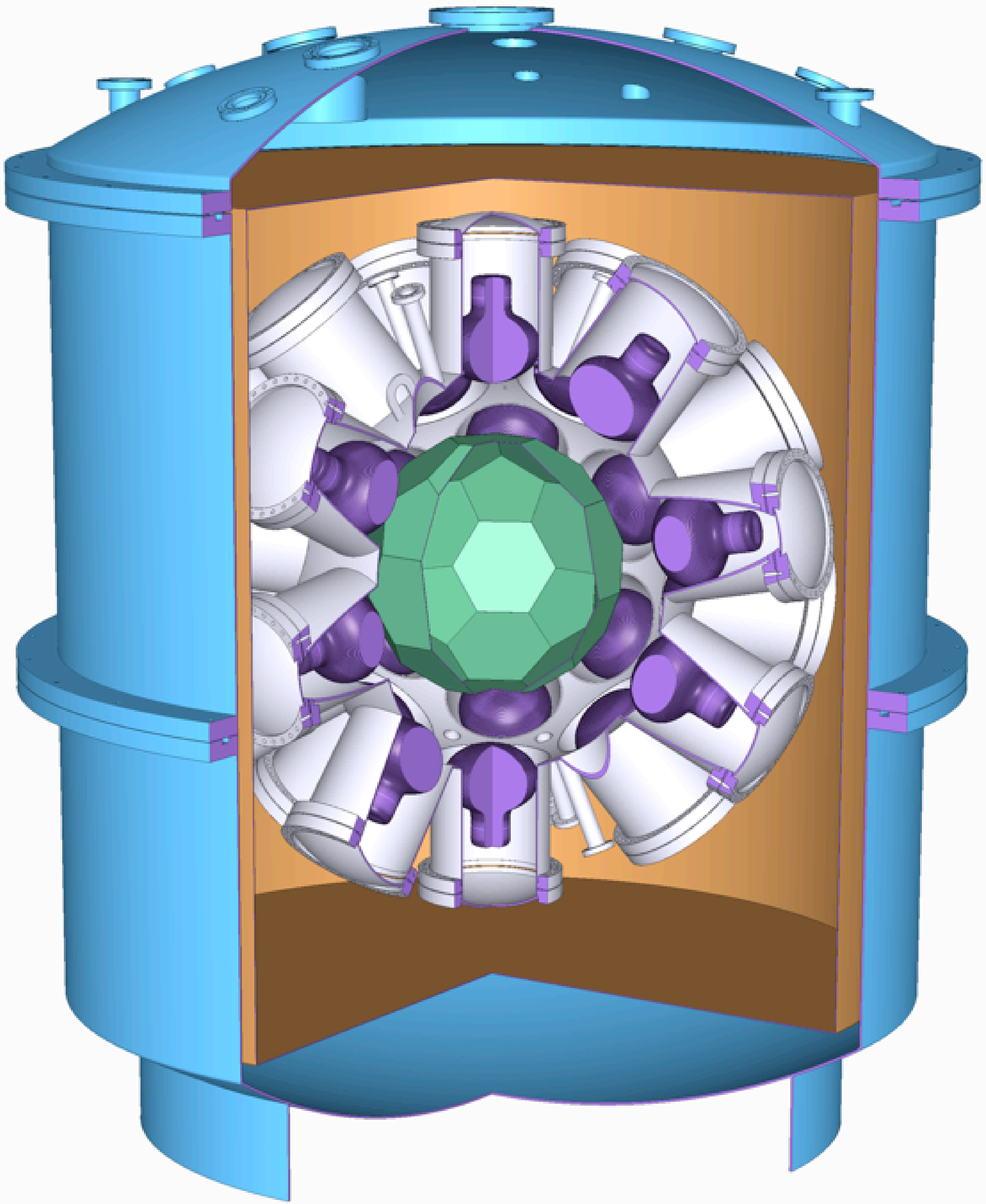
D-M. Mei & A. Hime

Component	Material	U/Th	Yield (n / yr)	Yield in Target (n / kg /yr)	Yield in ROI (n / kg /yr)	Yield in ROI* (n / kg /yr)
Fiducial Sphere	15 kg Quartz	3 ppb	19.1	0.090	0.029	0.004
	5 kg SS	3 ppb	4.0	0.009	0.003	0.001
PMT Sphere	20 kg SiO_2	30 ppb	255	0.055	0.018	0.003
	4 kg B_2O_3	30 ppb	2295	0.495	0.162	0.023
	85 kg SS	3 ppb	68.7	0.024	0.010	0.001
Outer Cryostat	125 kg SS	3 ppb	101	0.033	0.013	0.002
Total			2743	0.706	0.235	0.034

PRELIMINARY

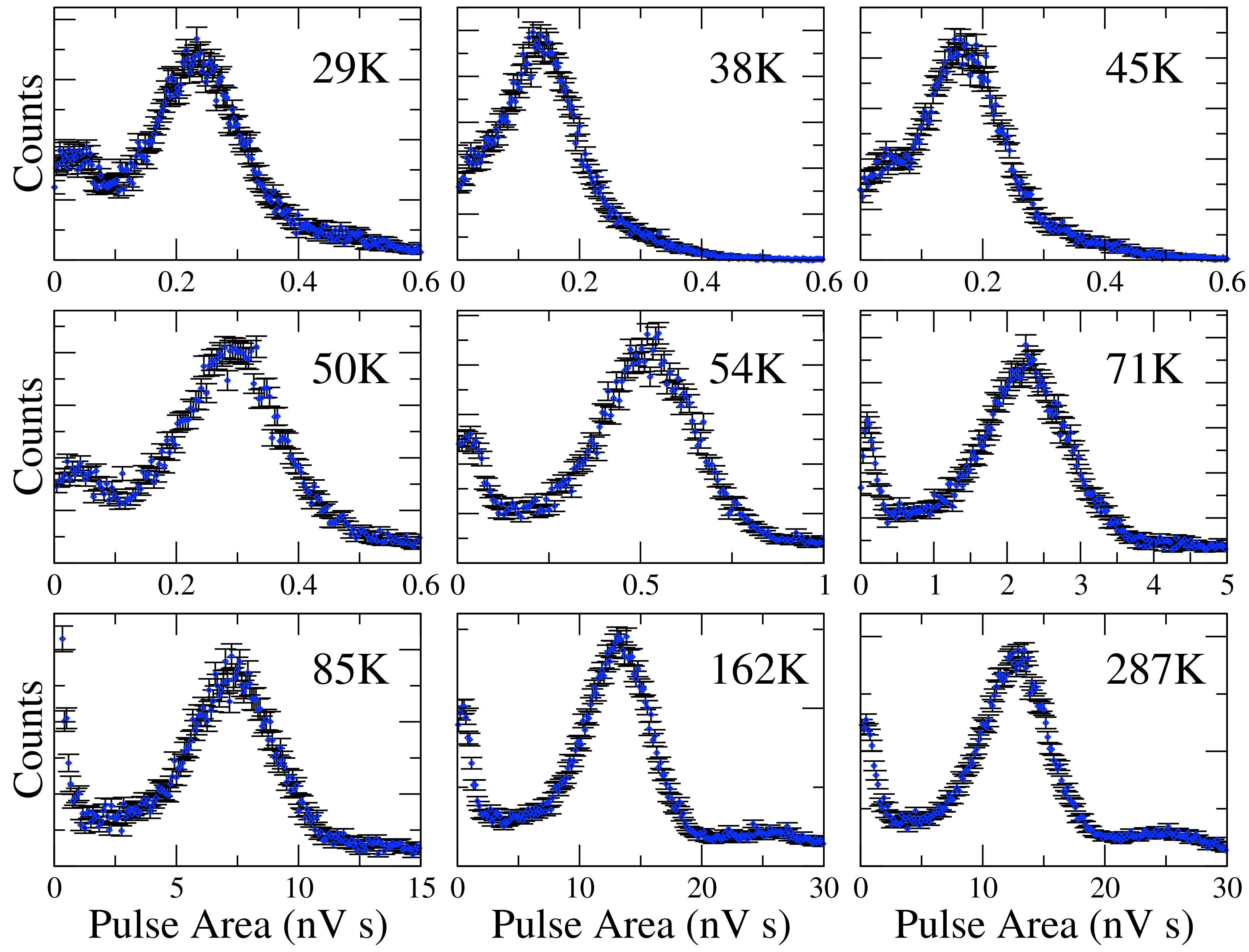
Summary

* New pulse shape discrimination results in LAr (preliminary). Discrimination measurements currently limited by ambient neutron backgrounds in above-ground laboratory
* Preliminary new nuclear recoil scintillation efficiency results for argon
* Will be filling micro-CLEAN with neon soon
* Currently commissioning Mini-CLEAN

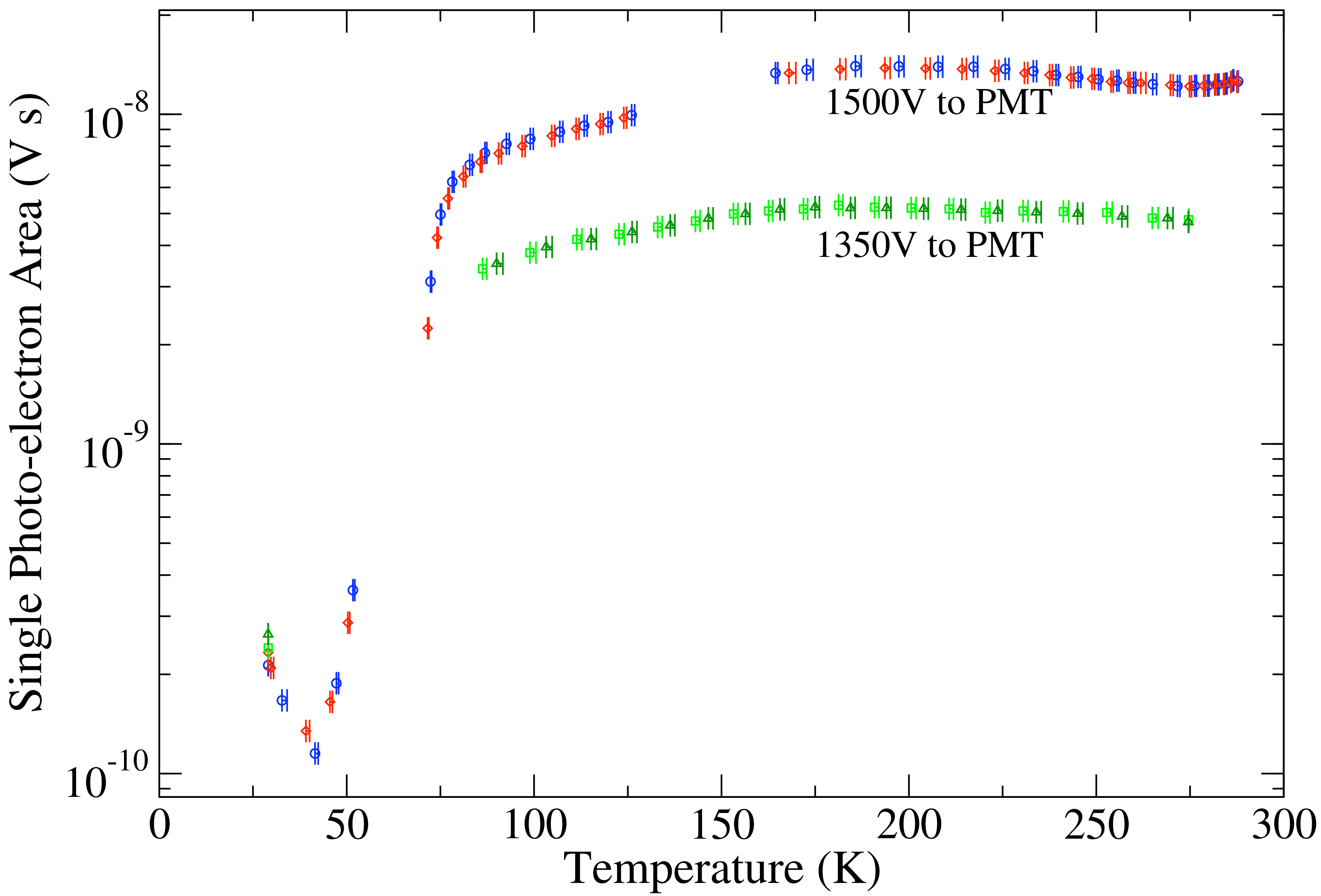


PMT Testing

Single photo-electron peaks at various temperatures

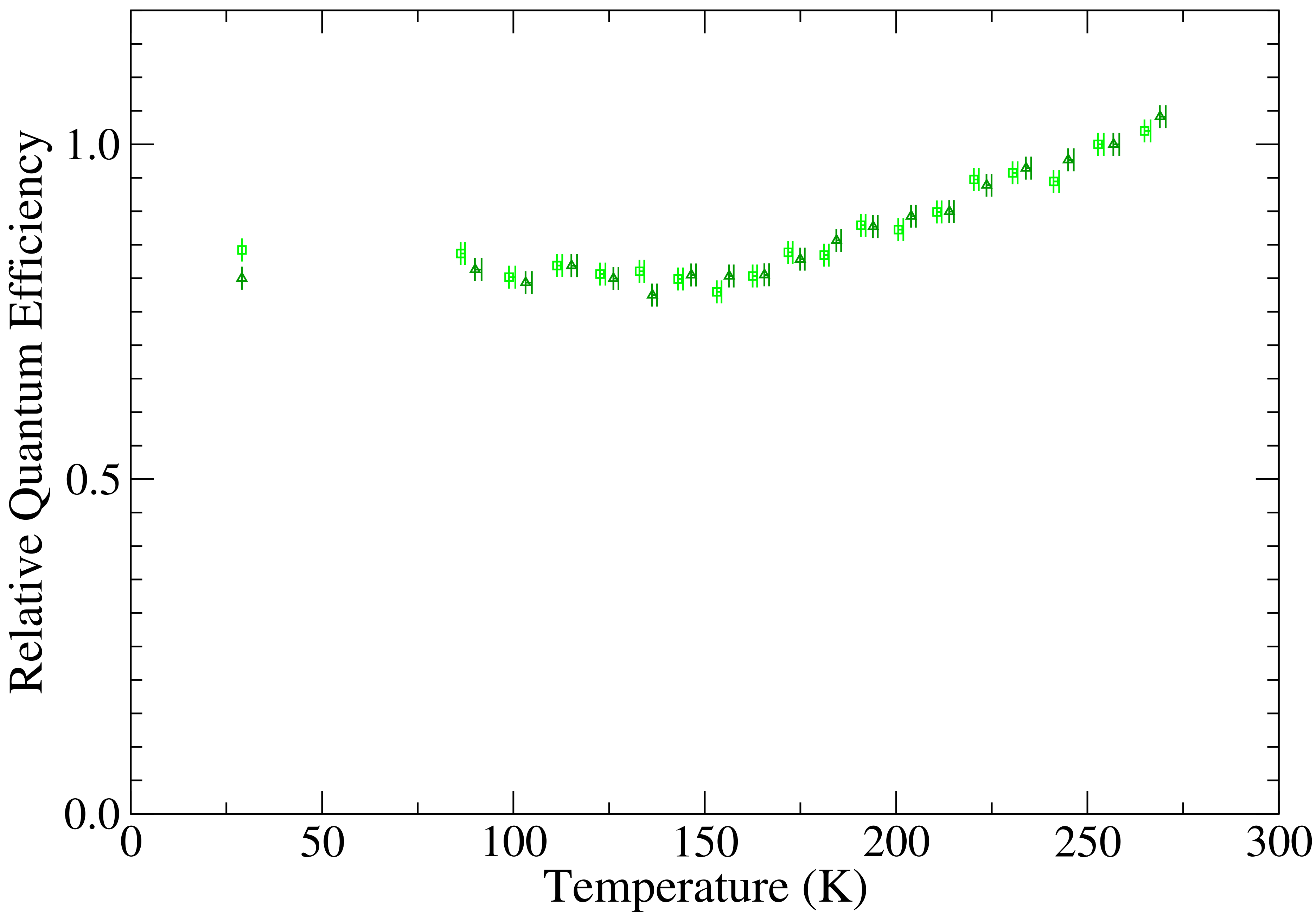


Gain Curves

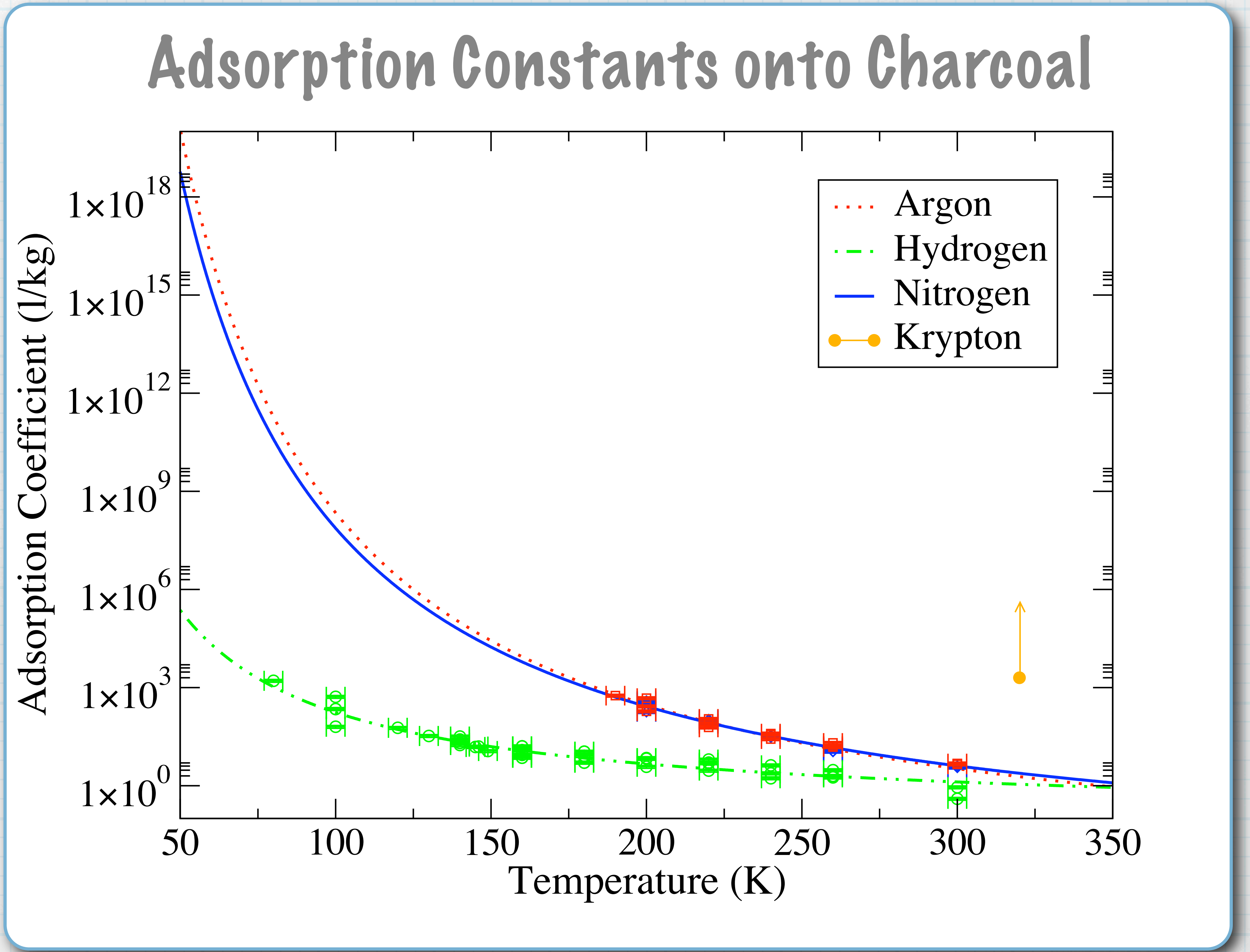


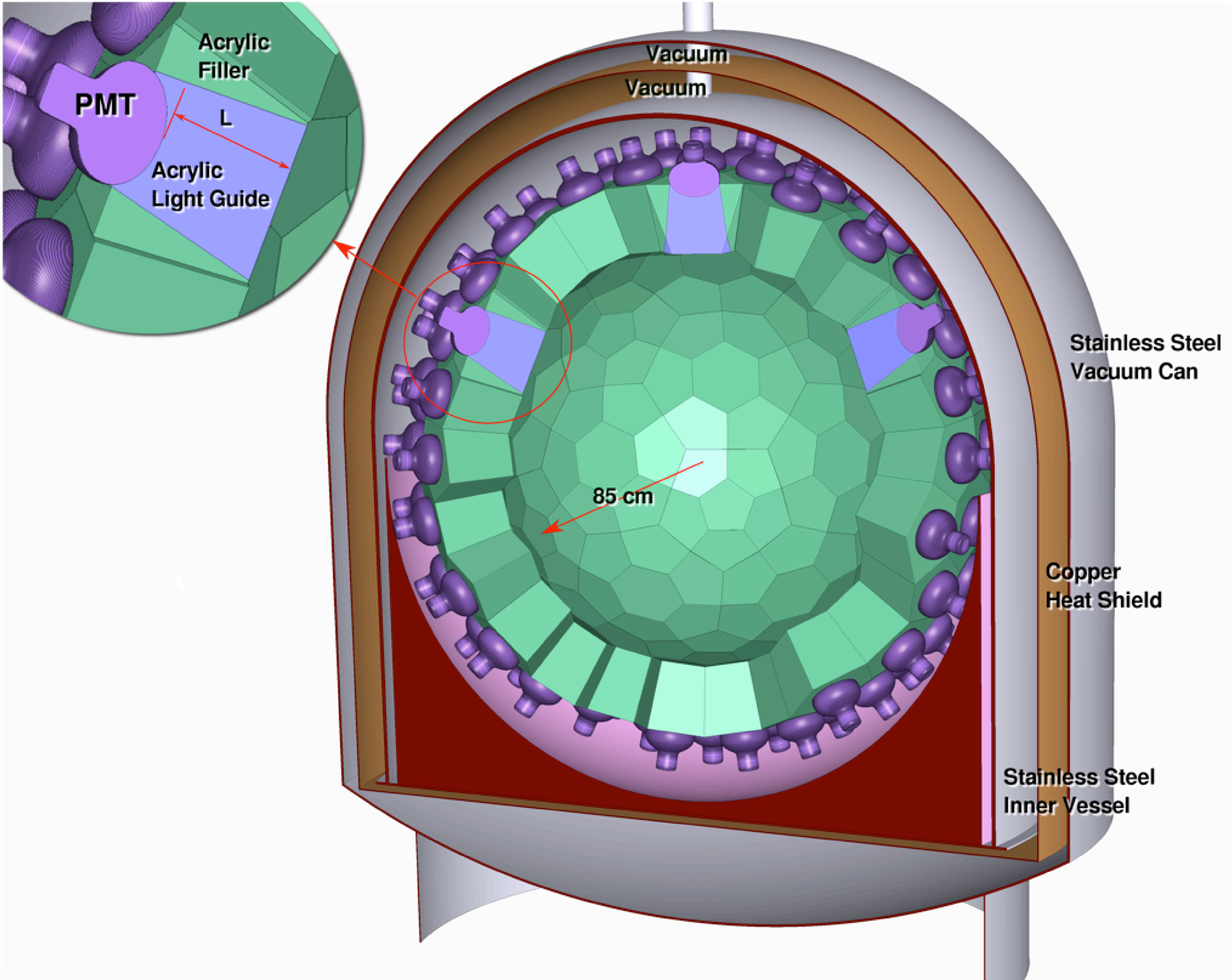
1500V to PMT
1350V to PMT
Single Photo-electron Area (V s)
10^{-8}
10^{-9}
10^{-10}
0
50
100
150
200
250
300
Temperature (K)

Quantum Efficiency



Neon Purification with Charcoal





Acrylic
Filler
PMT
L
Acrylic
Light Guide
Vacuum
Vacuum
Stainless Steel
Vacuum Can
85 cm
Copper
Heat Shield
Stainless Steel
Inner Vessel