# Recent Progress from the MiniCLEAN Dark Matter Experiment

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<u>Outline</u>

1. MiniCLEAN Detector
2. Experimental Technique
3. Status and Outlook

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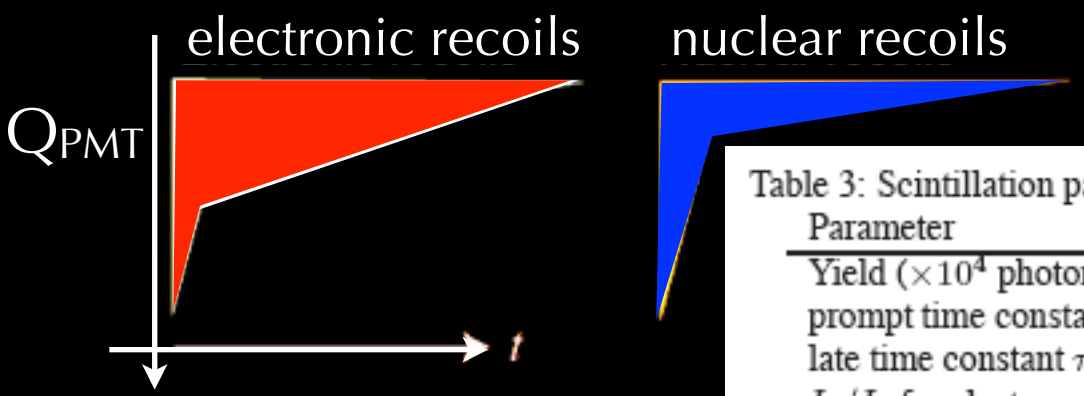
# Liquid Argon Detectors

LAr scintillates ~40 photons/keV with prompt (6 ns) and slow (250x slower) components




*Lippincott et al., Phys.Rev.C 78: 035801 (2008)*

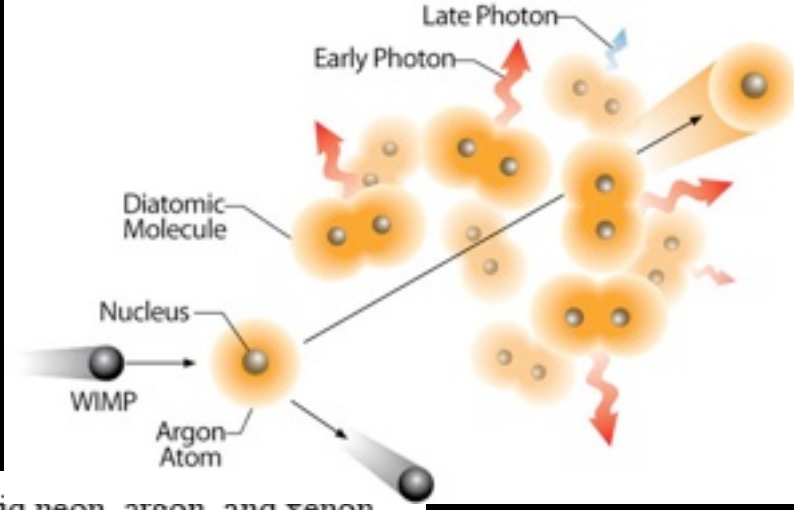
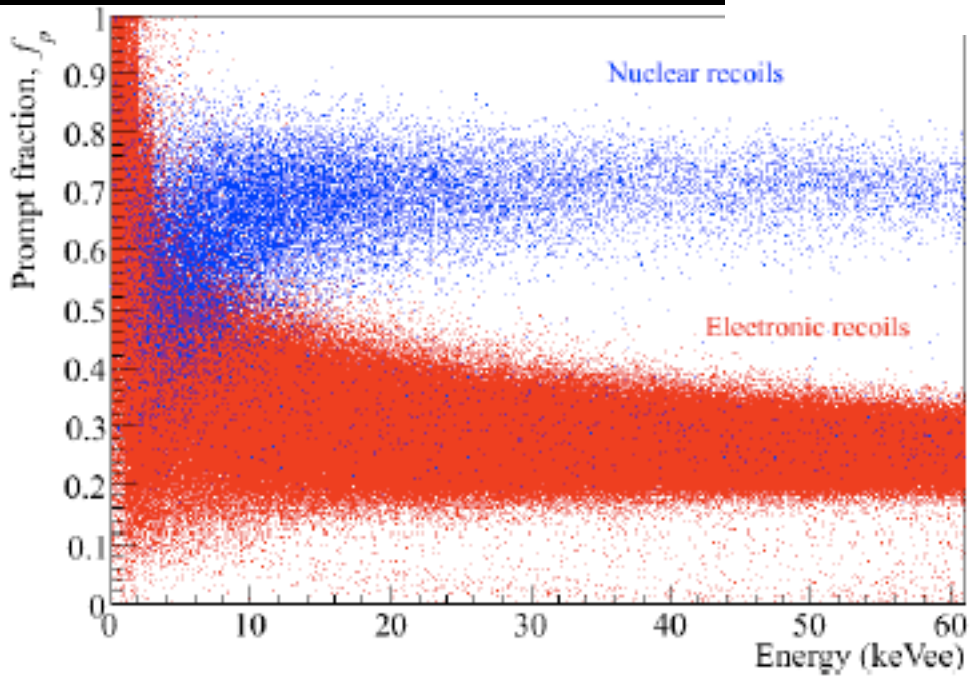



Table 3: Scintillation parameters for liquid neon, argon, and xenon.

| Parameter | Ne | Ar | Xe |
|---|---|---|---|
| Yield ($\times 10^4$ photons/MeV) | 1.5 | 4.0 | 4.2 |
| prompt time constant $\tau_1$ (ns) | 2.2 | 6 | 2.2 |
| late time constant $\tau_3$ | 15 $\mu$s | 1.59 $\mu$s | 21 ns |
| $I_1/I_3$ for electrons | 0.12 | 0.3 | 0.3 |
| $I_1/I_3$ for nuclear recoils | 0.56 | 3 | 1.6 |
| $\lambda$(peak) (nm) | 77 | 128 | 174 |
| Rayleigh scattering length (cm) | 60 | 90 | 30 |




identify, reject electronic backgrounds via pulse shape vs. time difference

*McKinsey & Coakley, Astropart. Phys. 22, 355 (2005).*
*Boulay and Hime, Astropart. Phys. 25, 179 (2006)*

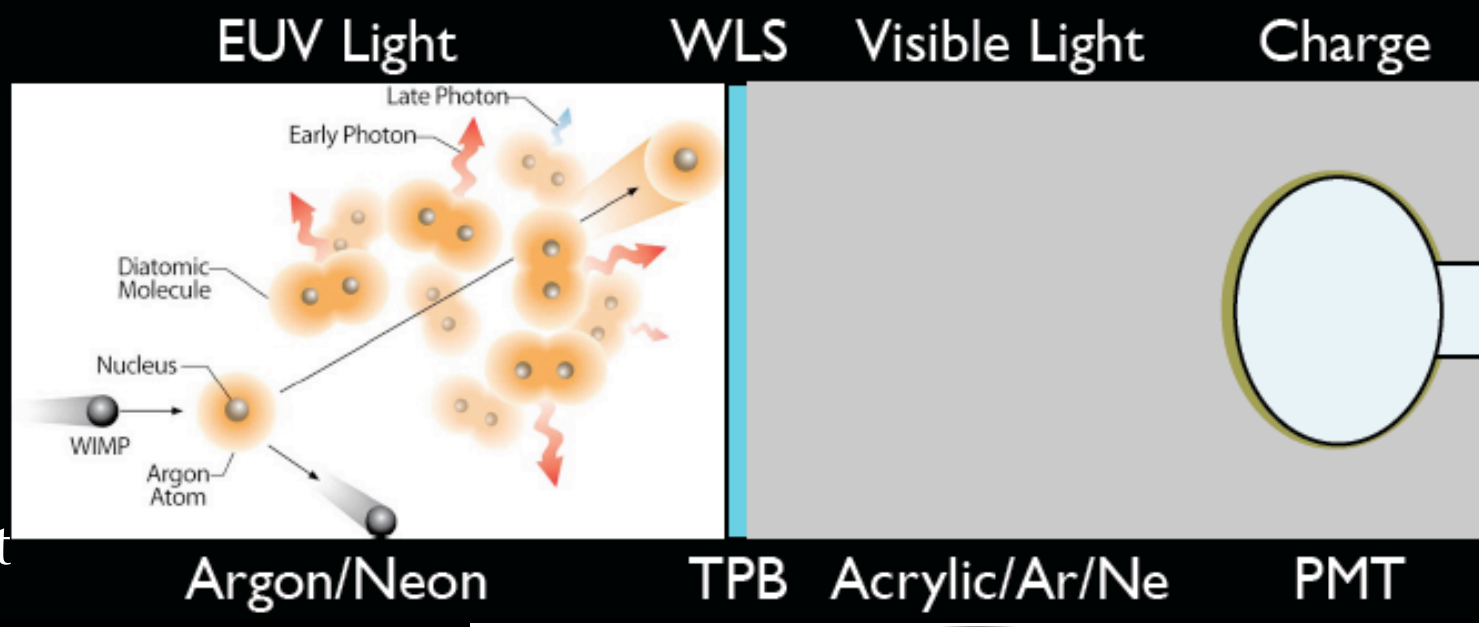
Important for LAr: Ar-39 beta (1 Bq/kg)

*Single-phase LAr detectors possible because of rejection power from timing, potential for kT scale detectors.*

# MiniCLEAN Design

LAr/LNe WIMP target scintillates at 128/80 nm

wavelength shift (TPB) to >400nm, PMT readout

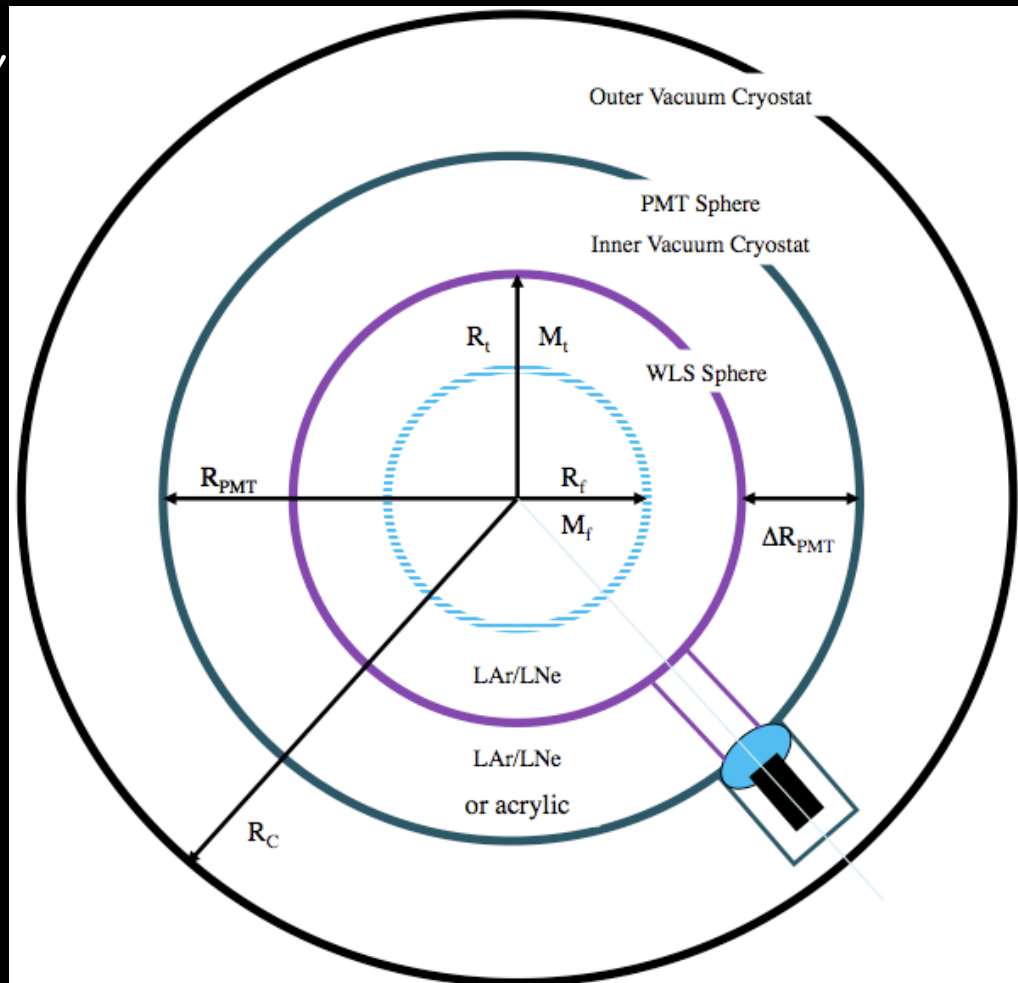



digitize PMT signals for 10 μs, at 250 MHz, with on-board zero suppression!

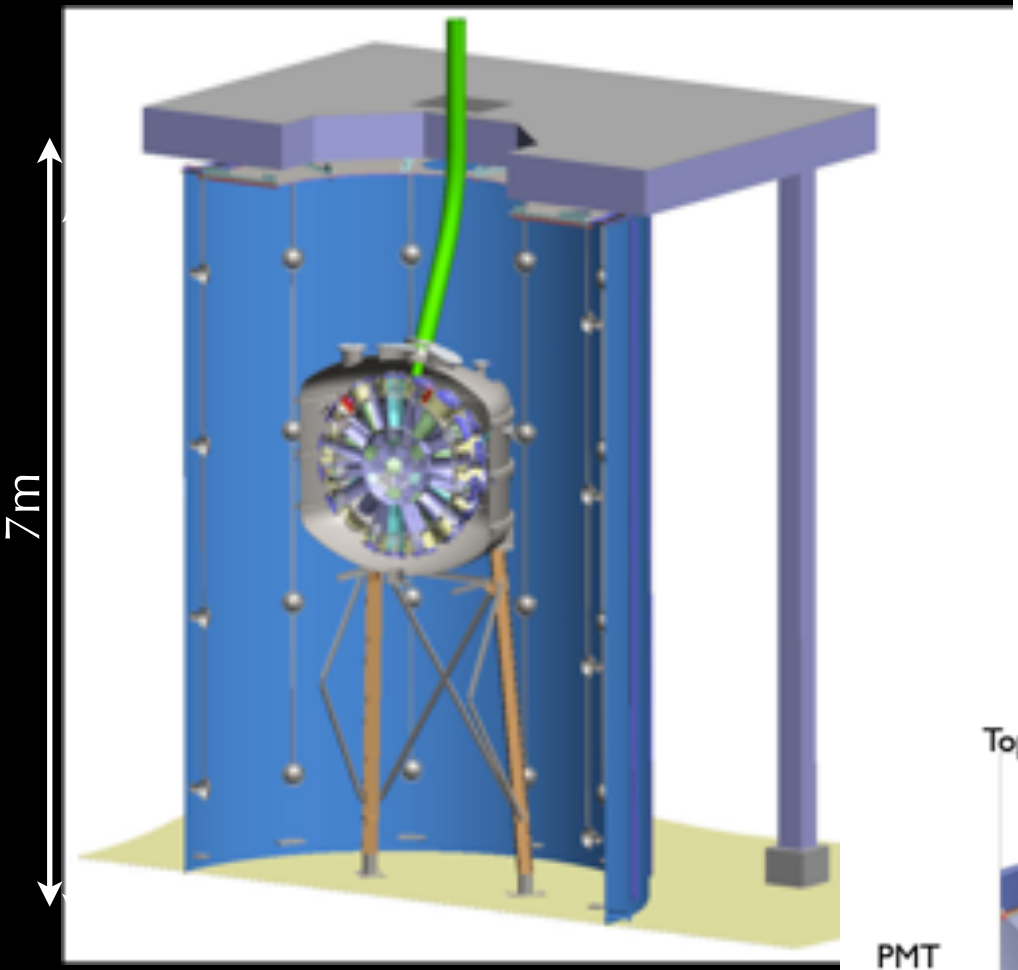
no pile-up from ms-scale electron drift in E fields (and no attachment)

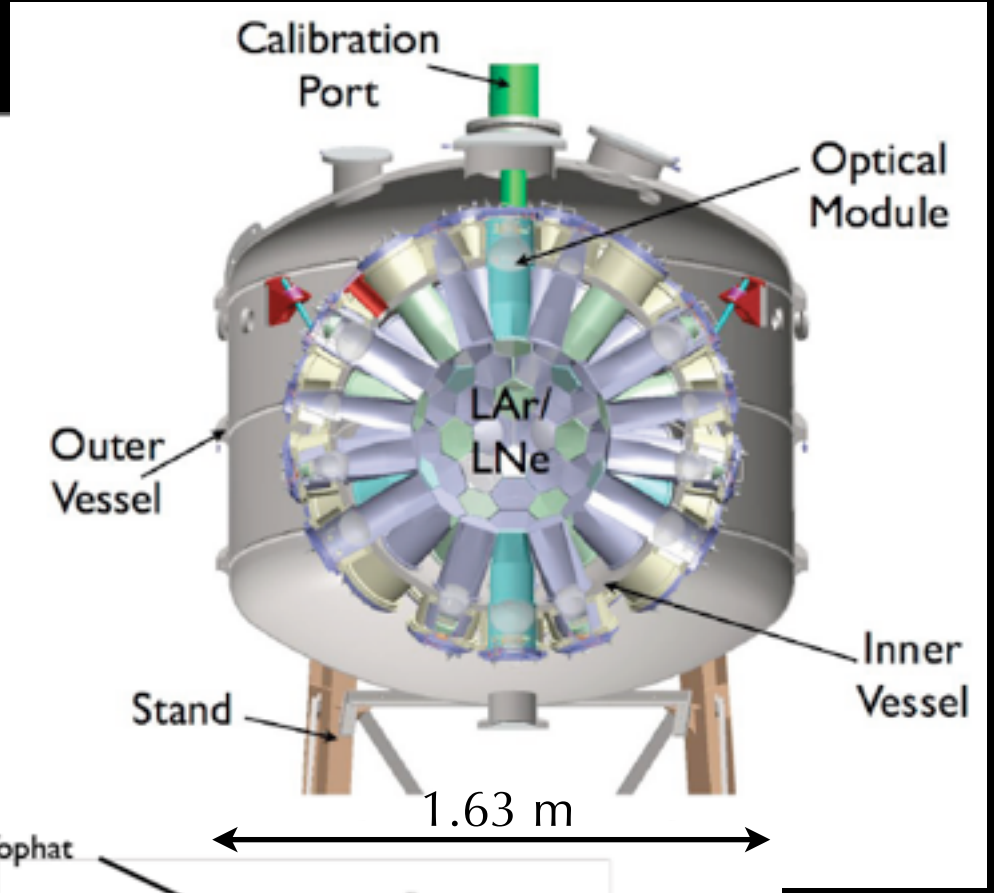
maximize photons/keVee with 4π PMT coverage (measure 6 pe/keVee in μCLEAN)
*Lippincott et al., arXiv:0911.5453*

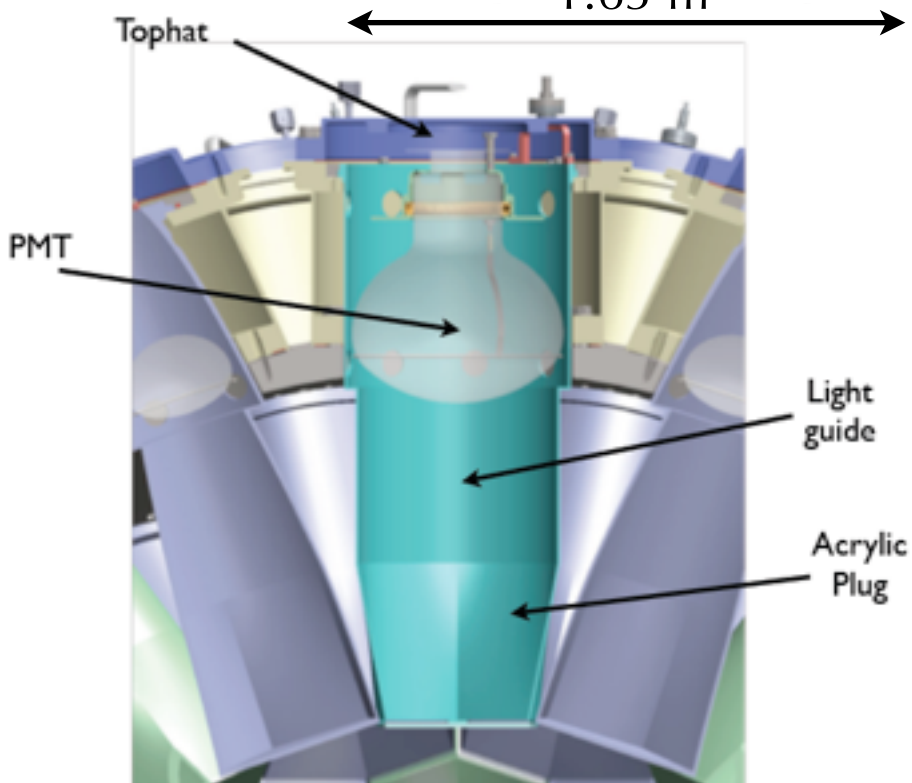
if there is a signal, verify $A^2$ dependence by Ar/Ne target exchange



# MiniCLEAN Detector




SNOLab depth (6 km.w.e.)

water shield surrounds by >= 1m

300 kg Argon inside WLS,
project 150 kg fiducial

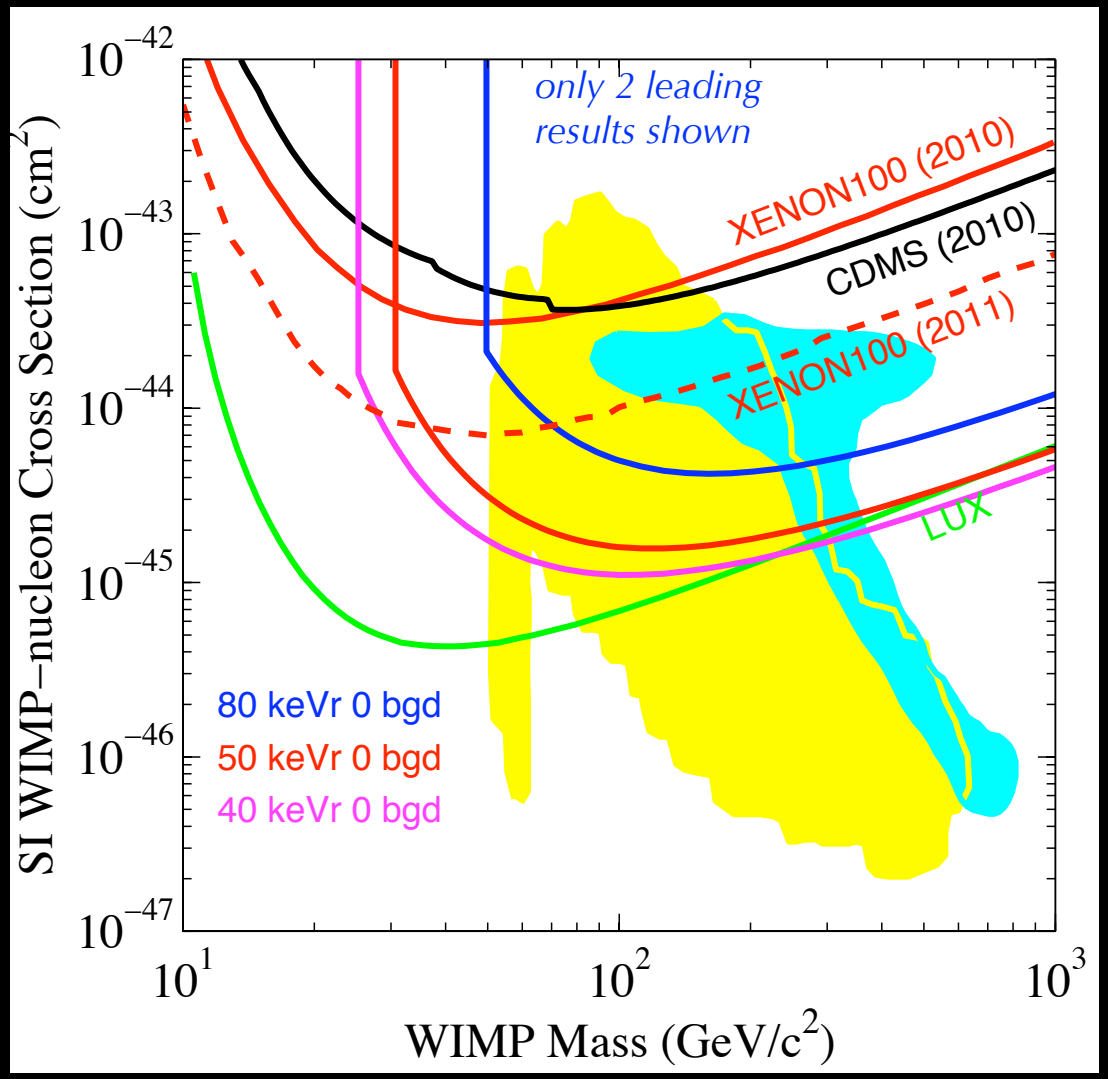
92 8″ R5912mod PMTs (cold)

light guides optically isolate PMTs

10 cm acrylic plug shields LAr from PMT glass neutrons (O(0.1) ppb U,Th)

# DEAP/CLEAN Program: Single Phase Detectors for Scalability

DEAP-1 (7 kg) 2006 → μCLEAN (4 kg) 2007 → MiniCLEAN (300 kg) 2012 → DEAP-3600 (3600 kg) 2013 → DEAP/CLEAN ("G3")




*asrophysical assumptions:*
v0 = 220 km/s, **vEsc = 544 km/s**
vSun = 12 km/s, vEarth = 15 km/s
density = 0.3 GeV/cm3

current results

MiniCLEAN (150 kg fiducial)
*construction: 2010-2012, run: 2012-2014*
*sensitivity: 2E-45 cm2*

DEAP-3600 (1 tonne fiducial)
*construction: 2010-2013, run: 2013-2017*
*sensitivity: 1E-46 cm2*

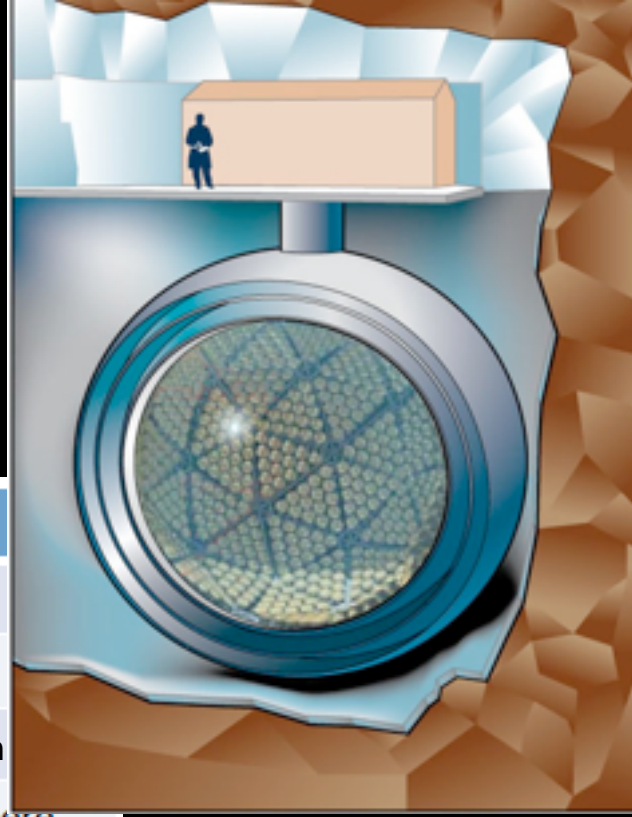
DEAP/CLEAN (10 tonne fiducial)
*future goal, 1E-47 cm2 sensitivity*

*MiniCLEAN: proof-of-principle single-phase detector with competitive sensitivity.*

# Goal: DEAP/CLEAN "G3"

*Cryogenic Low Energy Astrophysics with Noble Liquids*

Dark matter search (Argon) and precision measurements of pp solar neutrinos (Neon), supernova neutrinos



| | MiniCLEAN (G1) | DEAP-3600 (G2) |
|---|---|---|
| Target Capability | LAr / LNe | LAr |
| Target Radius | 500 kg / 150 kg | 3600 kg / 1000 kg |
| Target / Fiducial Volume | 45 cm/30 cm | 85 cm/55 cm |
| Cryogen Containment | Code-Stamped SS Pressure Vessels | Monolithic Acrylic Sphere |
| Light Collection | 92 Optical Modules PMTs Submerged "Cold" | 266 "Warm" PMTs Outside of Cryogen |
| Neutron Shielding | 10 cm Acrylic + 20 cm Cryogen | 50 cm Acrylic |
| Surface Background Mitigation | Modular Cassettes Assembled under Vacuum | In Situ Resurfacing of Inner Acrylic Surface |
| Process Systems | Pulse Tube Refrigerators With Heat Exchangers | LN-Cooled Thermal Siphon |
| Magnetic Compensation | Active | Passive+Active |
| G3 Scientific Program | Dark Matter *pp*-Solar Neutrinos Supernovae Neutrinos | Dark Matter |

DEAP/CLEAN "G3" design will build on experience with MiniCLEAN and DEAP3600, testing different technical choices

# Experimental Technique

<u>electron backgrounds:</u>
-reject using scintillation light timing

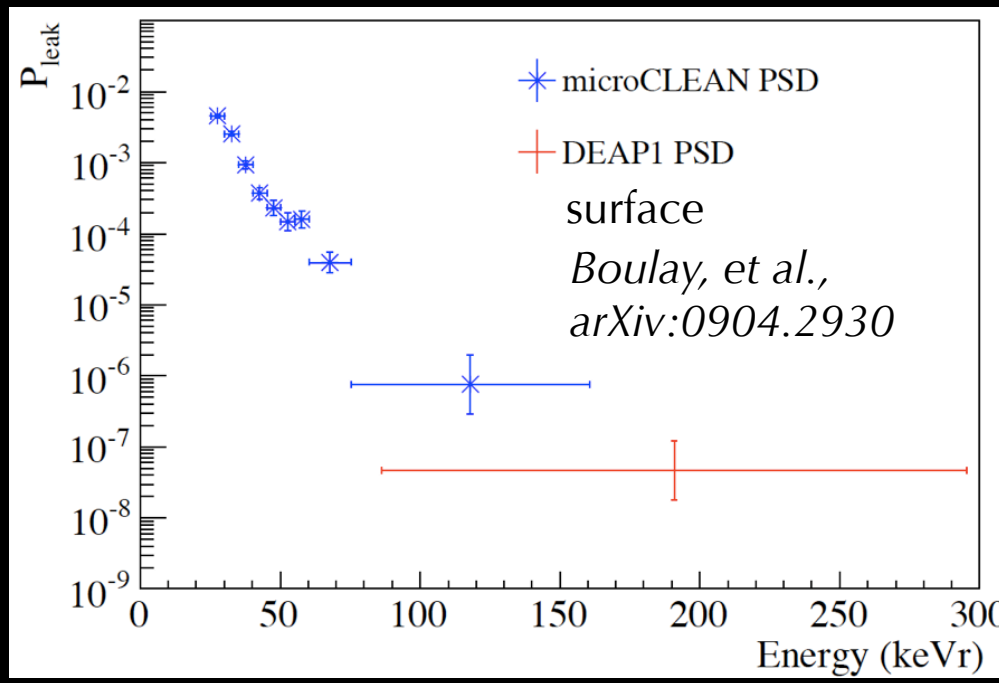
-DEAP-1 measured <3E-8 rejection in SNOLab (preliminary, 120-240 p.e.) *C. Jillings, CAP'11*

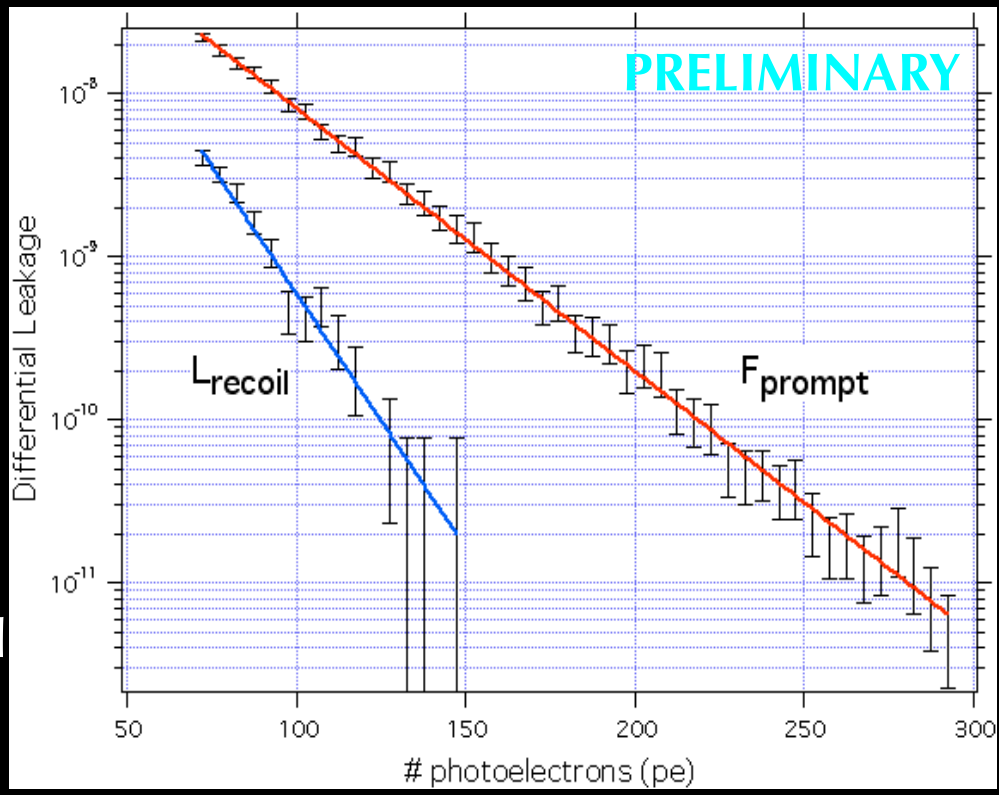
-simulate MiniCLEAN, using DEAP-1 measurement as a constraint, predict <1 event/year @ 20 keVee using Fprompt cut (@ 50% nuclear recoil acceptance)

-likelihood ratio estimator, Lrecoil, uses observed times of arrival for all PE in an event

-Lrecoil reduces effect of broad PMT charge distribution, statistic has less variance than Fprompt producing better separation between nuclear recoils and electrons

-Lrecoil simulation allows 12.5 keVee threshold with <1 electron background event (50 keVr)



# Experimental Technique

<u>alpha backgrounds:</u>

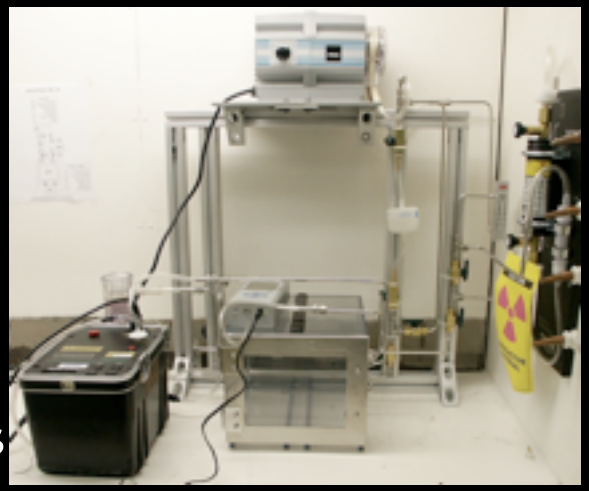
-reject using fiducial volume cut

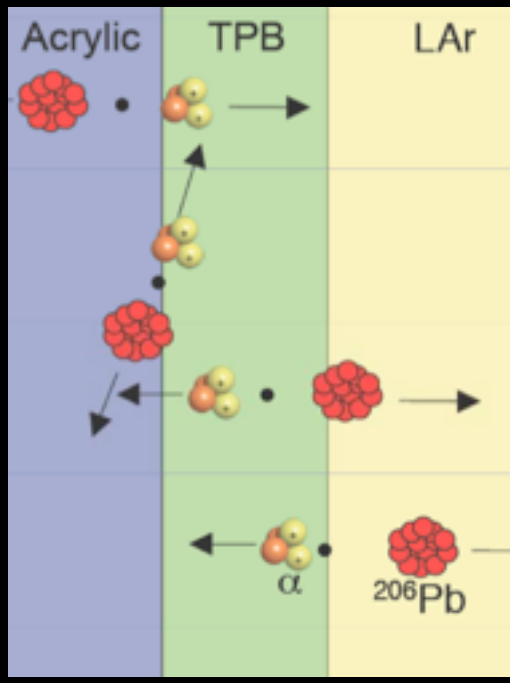
-dangerous background from Rn daughters plating out on materials

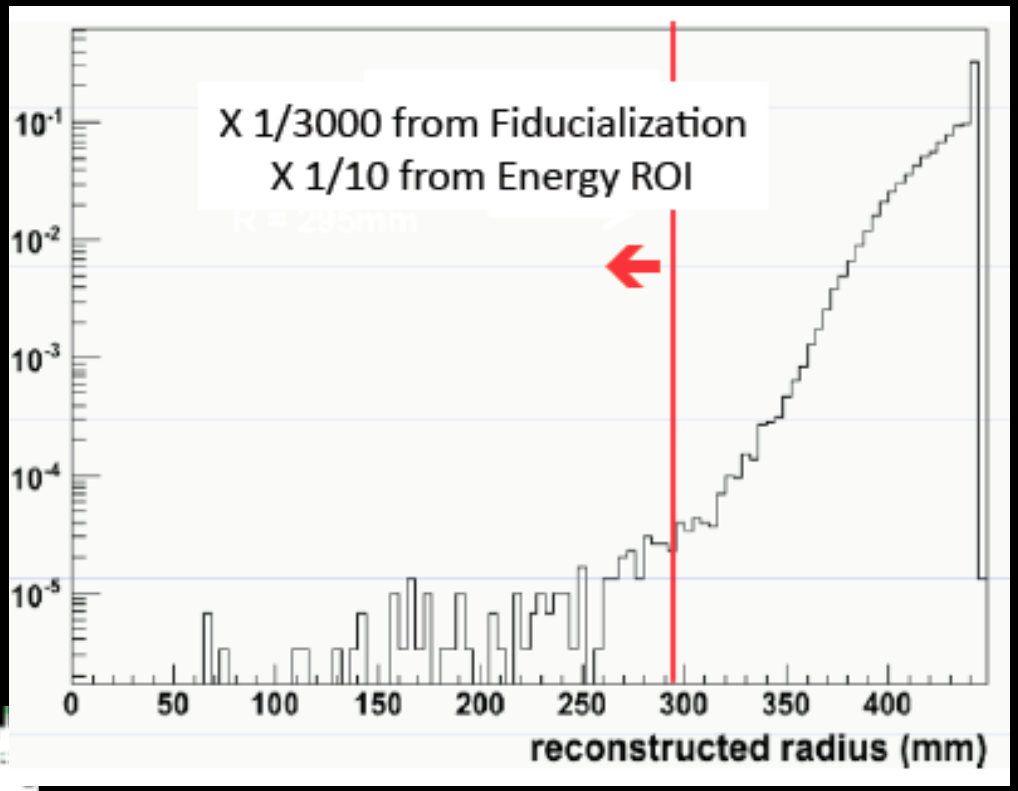
-control radiopurity O(100 ppb U, Th), minimize radon exposure (< 1α/m²/day)

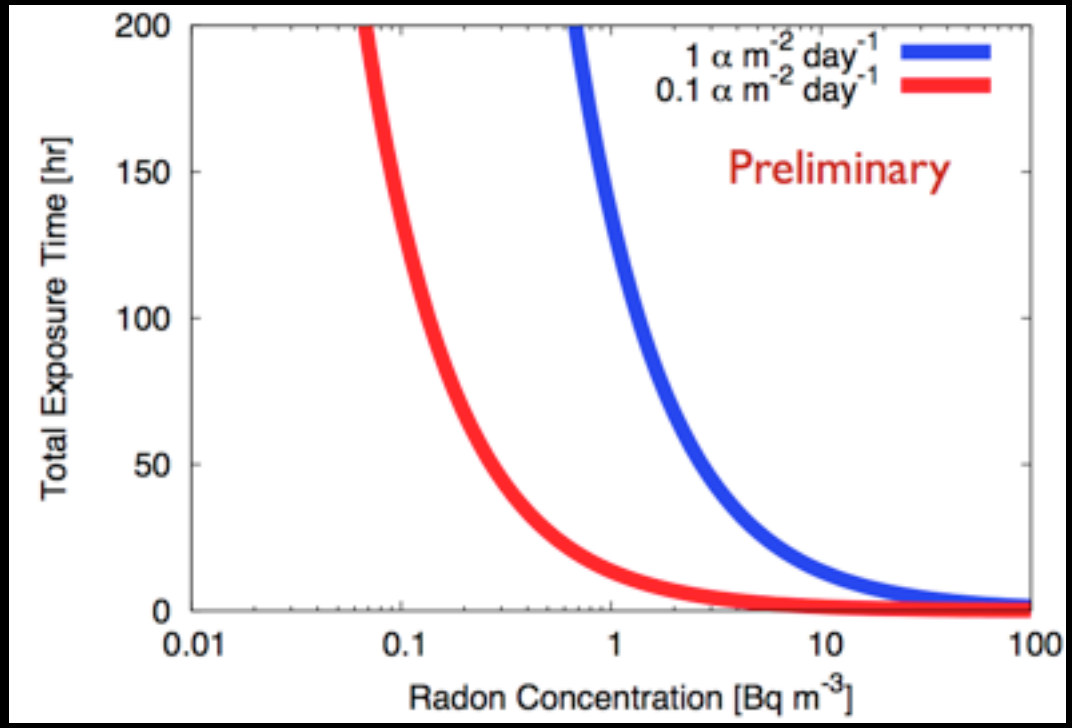
-simulate alphas with full reconstruction, find R<30 cm (=150 kg fiducial mass) gives <1 event/year above 12.5 keVee (50 keVr)

*V. Guiseppe et al., arXiv:1101.0126*





# Experimental Technique

<u>neutron backgrounds:</u>

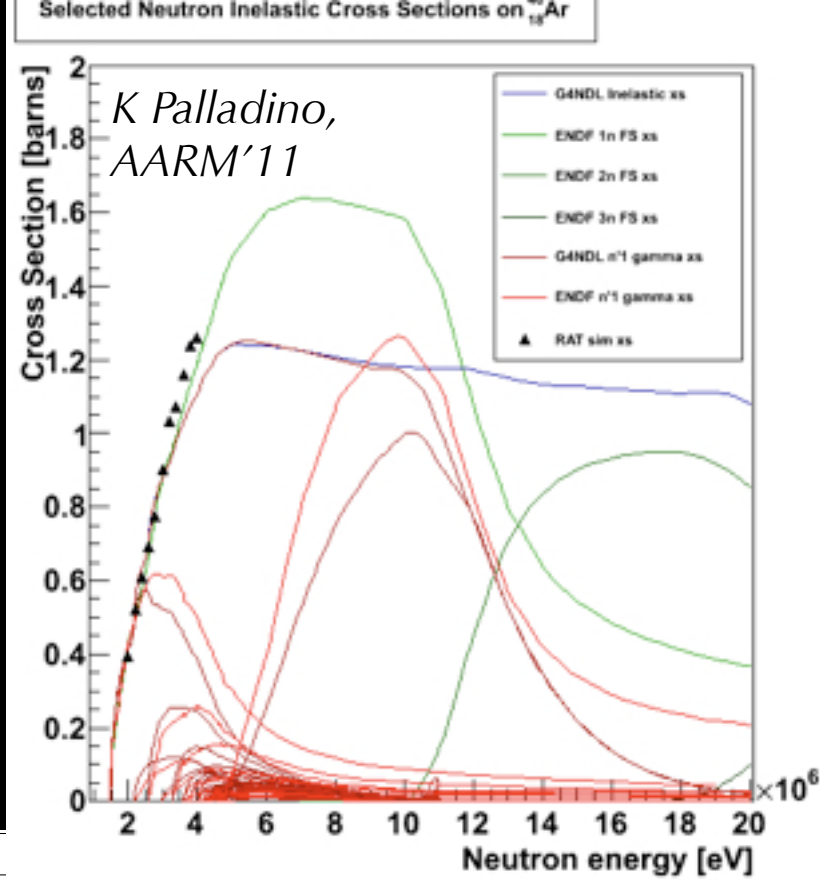
-reject using energy, radius, timing (multiple scatters)

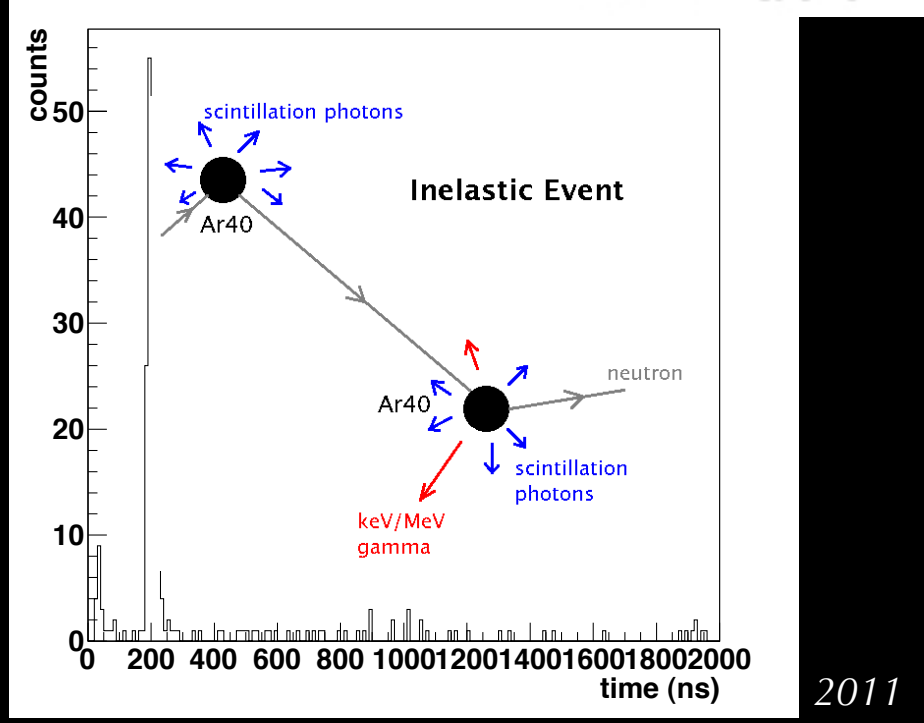
-dangerous background from U, Th (alpha,n) in PMT glass (assayed 1.27/0.69/3.62 U/Th/K Bq/kg)

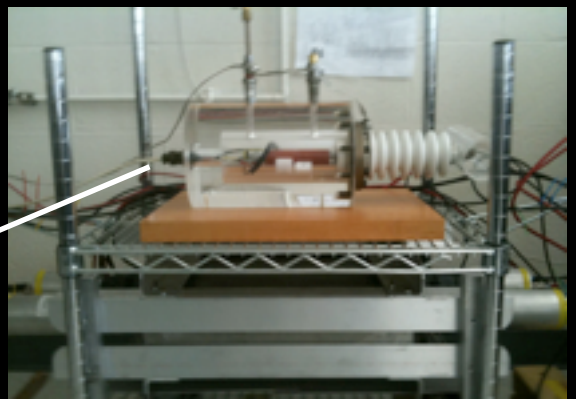
-major effort to validate Geant4 neutron physics, >90% of neutrons scatter inelastically, different time signature than single nuclear recoils (*K. Palladino, APS'11*)

-simulate neutrons with full reconstruction, estimate radius, energy, fprompt cuts leave ~2 events/yr above 20 keVee, with tagging multiple scatters, Lrecoil project <1/yr above 12.5 keVee (50 keVr)

-dedicated d-d fusion pulsed neutron calibration source to measure neutron rejection in-situ



# Experimental Technique

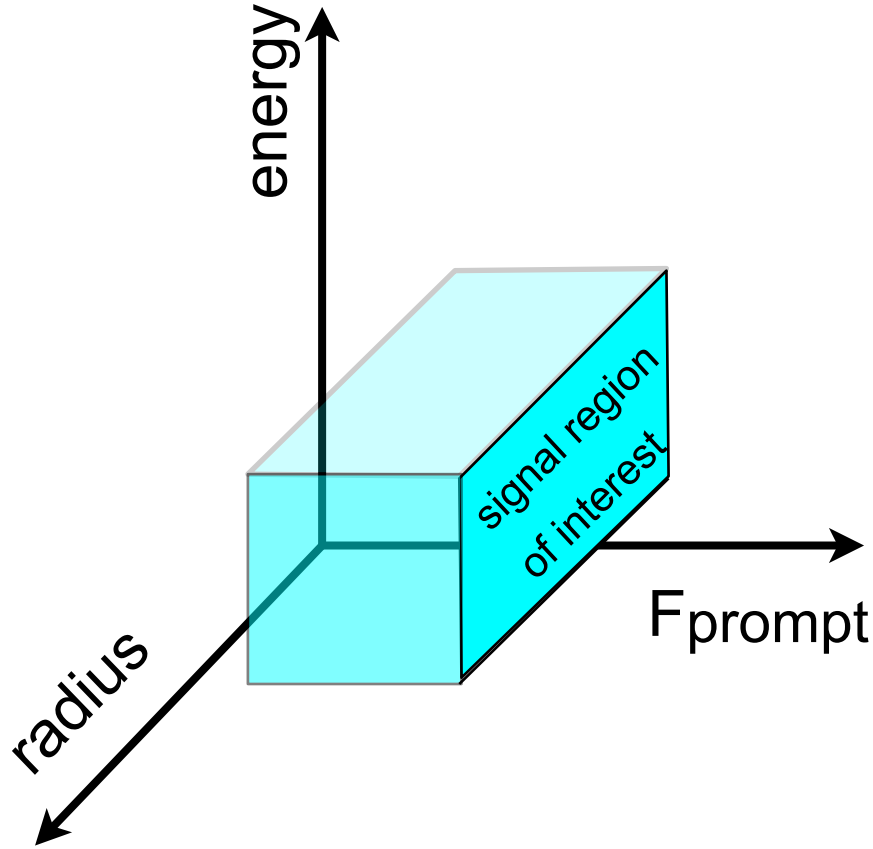
WIMP signal:

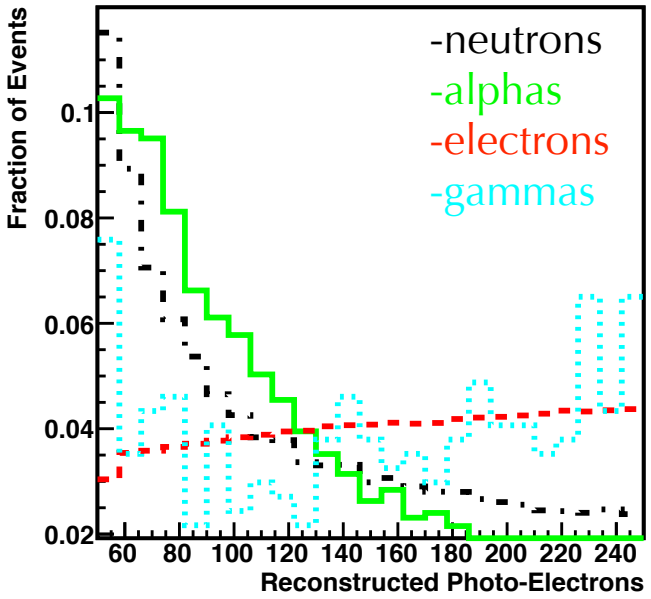
-plan two analyses:

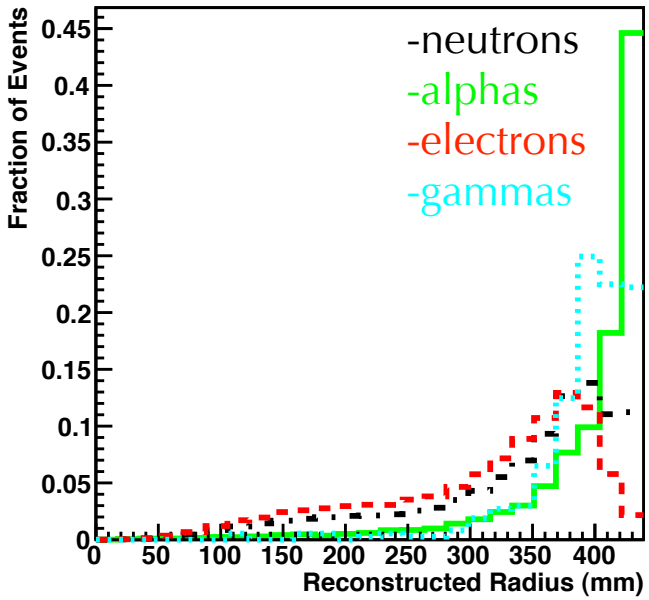
1) blind analysis signal box defined by:
   radius < 30 cm, 12.5 < energy < 25 keVee,
   fprompt > 0.7 (or Lrecoil), single scatters

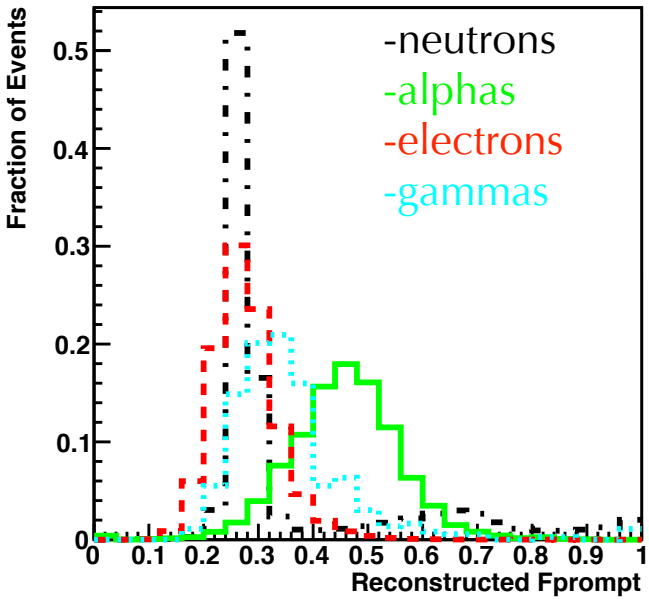
2) likelihood-based PDF fit for signal above measured background PDFs (using in-situ calibration data), a la SNO

-current simulation of reconstructed background distributions, in energy (left), radius (center, fraction of prompt photons (right), with no cuts



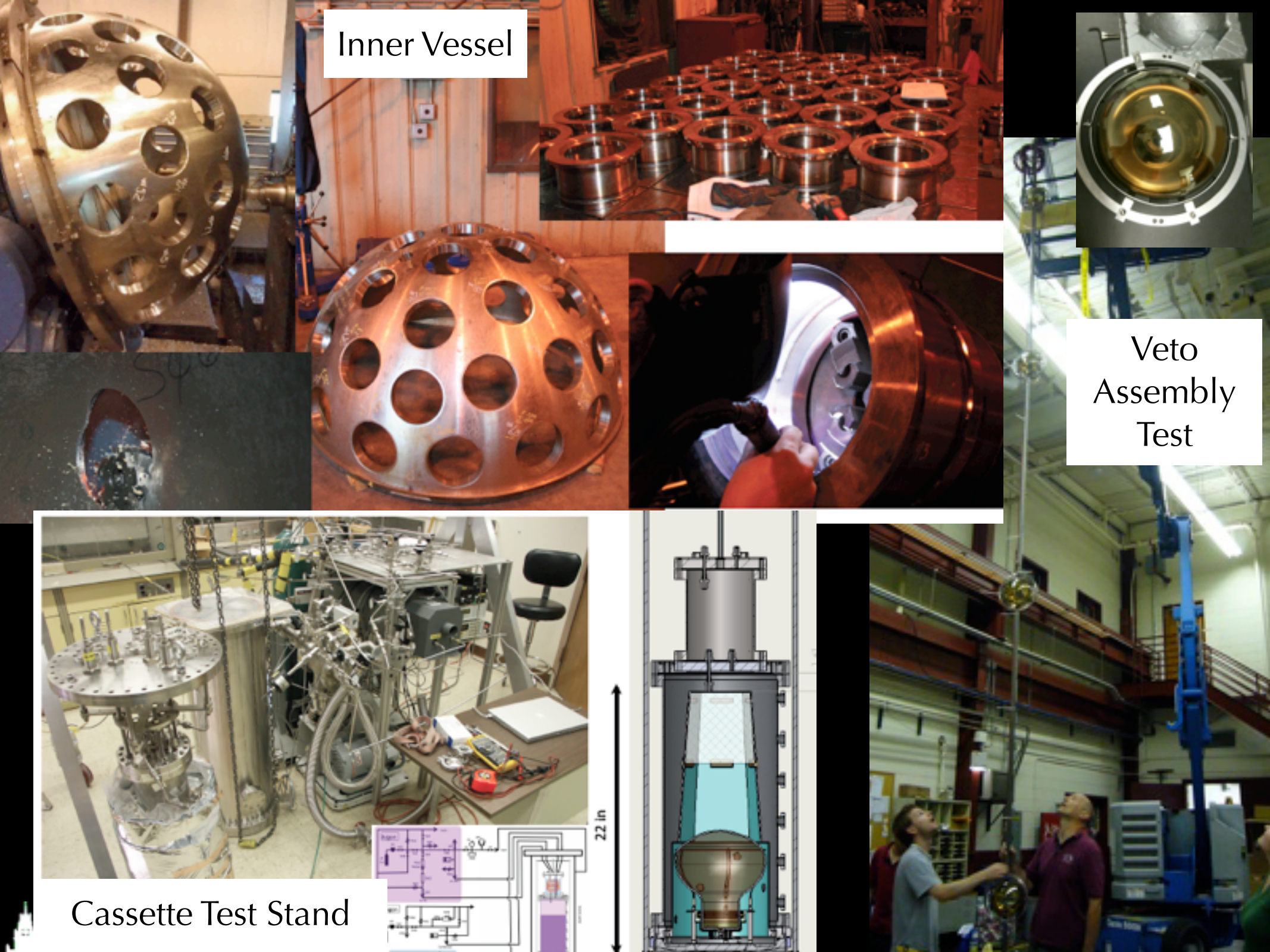



# MiniCLEAN Status




Inner Vessel
Veto Assembly Test
Cassette Test Stand
22 in

# Conclusions

MiniCLEAN's goals are to

- Perform a competitive WIMP search using signal and background distributions to maximize sensitivity
- Measure all significant background rates *in-situ*
- Develop an effective neutron tagging technique
- Constrain systematic uncertainties in detector response with calibration data
- Demonstrate a position and energy reconstruction algorithm for present and future detectors in the DEAP/CLEAN program
- Improve limit on the PSD leakage of $^{39}$Ar events

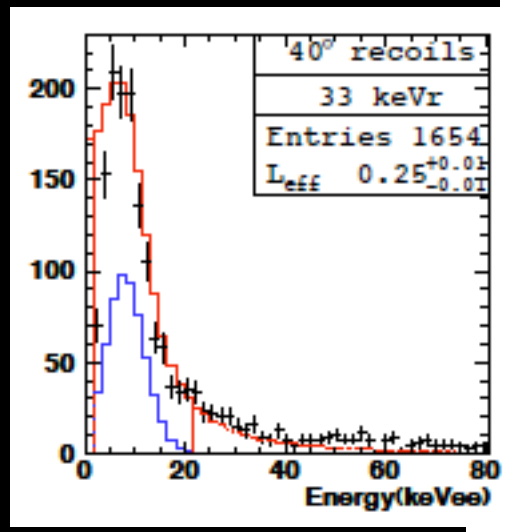
Detector construction is underway, plan to start commissioning late summer 2012, start dark matter run end of 2012. Stay tuned!

# Extra Slides

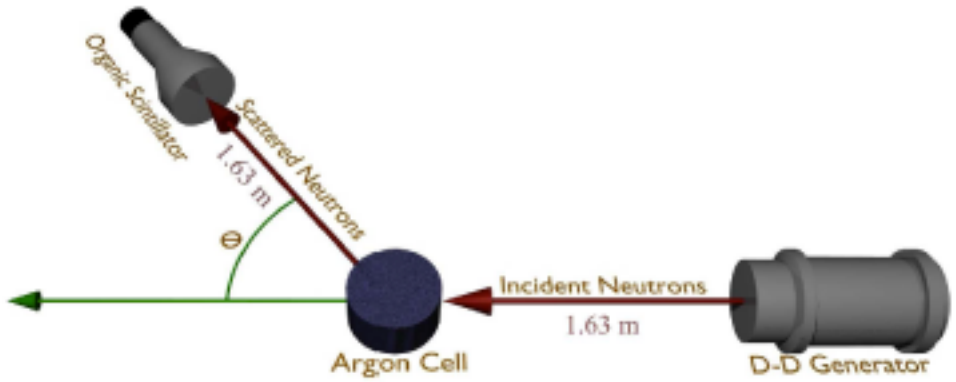
# Quenching Factor

*Gastler et al., arXiv: 1004.0373*

measured in microCLEAN prototype




mean quenching value above 20 keVr: 0.25+/-0.02+/-0.01



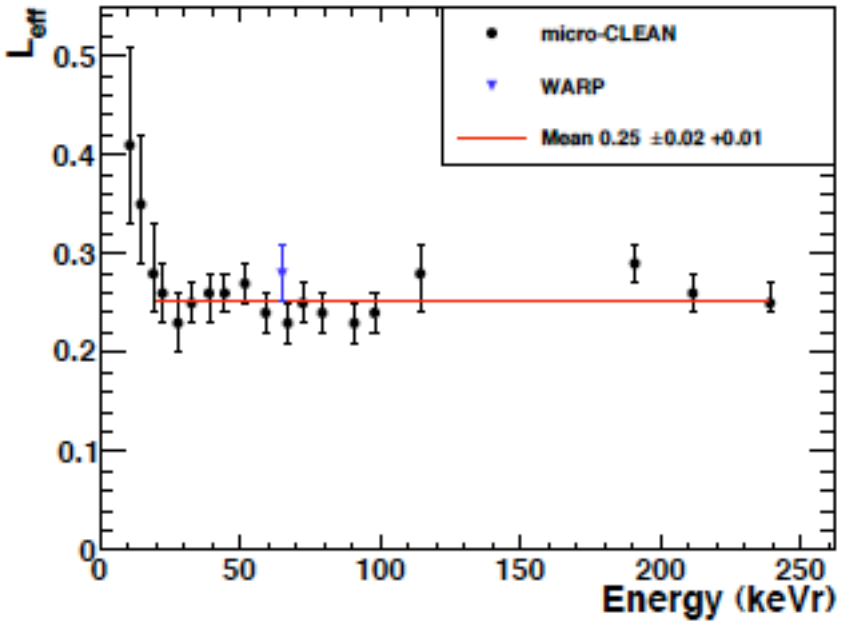
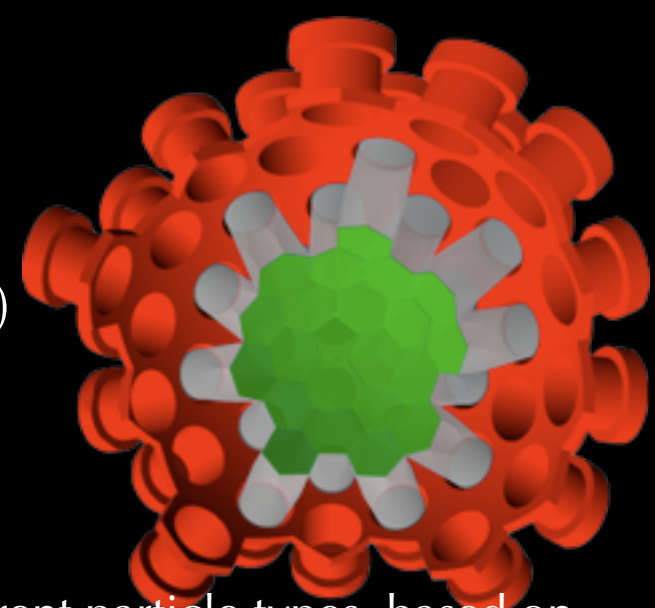




FIG. 8: (Color online) Scintillation efficiency as a function of energy from 10 to 250 keVr. The weighted mean (red line) is generated from the data above 20 keVr and puts the mean scintillation efficiency at 0.25. The value measured by WARP is 0.28 at 65 keVr [3].

# Detector Simulation



**RAT**: simulation and analysis program for PMT-based experiments (Braidwood, DEAP/CLEAN, SNO+, CLEAR)

*GEANT4*: detector geometry and particle propagation.

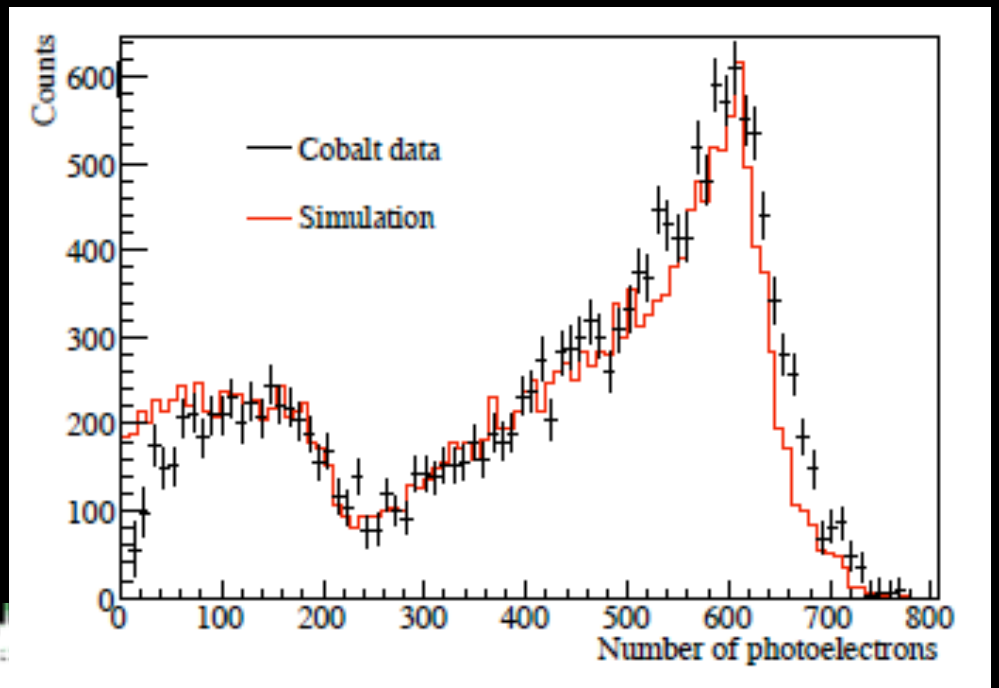
*ROOT*: Event input and output.

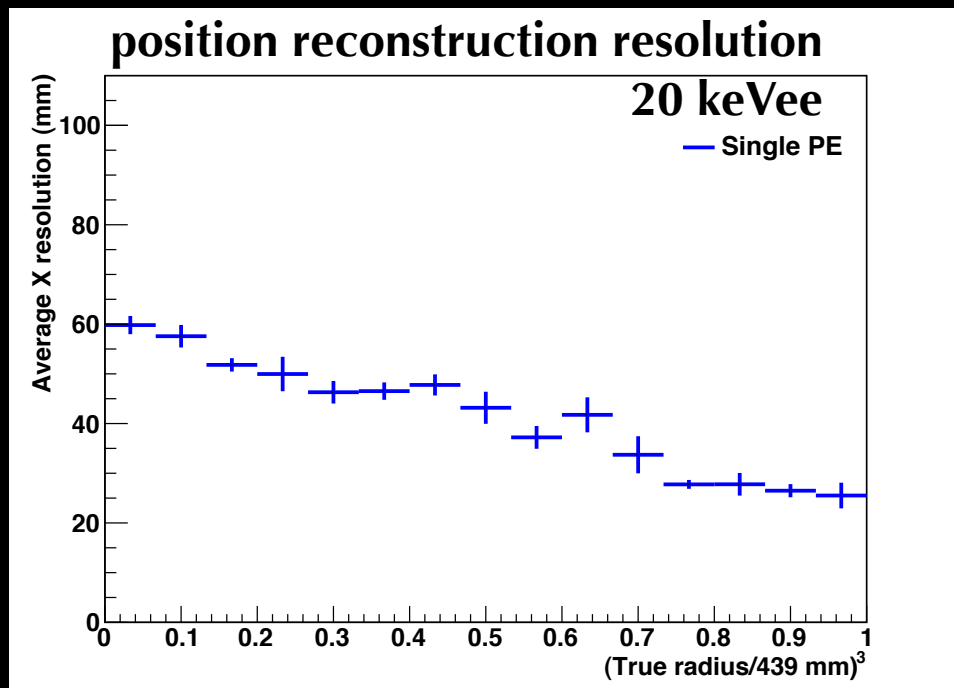
*GLG4Sim*: custom scintillation physics, PMT model, DAQ

-dE/dx dependent quenching and singlet/triplet ratios for different particle types, based on measurements in microCLEAN

-full optical transport of individual photons through detailed 3D model of the detector, optics based on ex-situ measurements

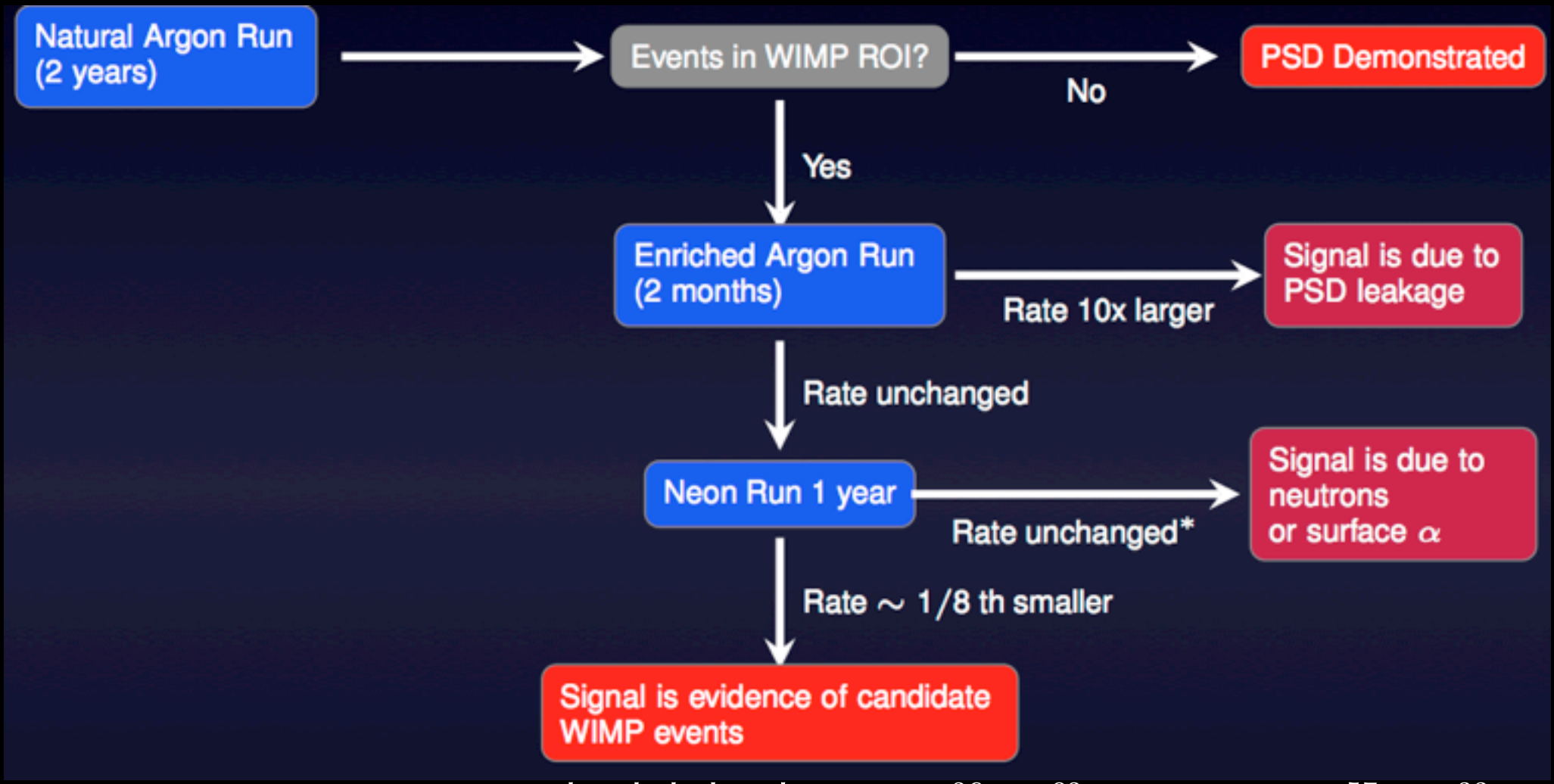
*Gastler et al., arXiv: 1004.0373*



# Calibration

Calibration program to measure background in-situ, and completely verify a positive signal in the same detector.




Sources: neutrons (AmBe, pulsed d-d), electrons ($^{39}$Ar, $^{83}$Kr), gammas ($^{57}$Co, $^{22}$Na)

# Why Argon?

greatest difference between singlet and triplet lifetimes: $10^9$ electron rejection

favorable form-factor for coherent scattering: higher energy threshold possible

excellent scintillation light yield / $$

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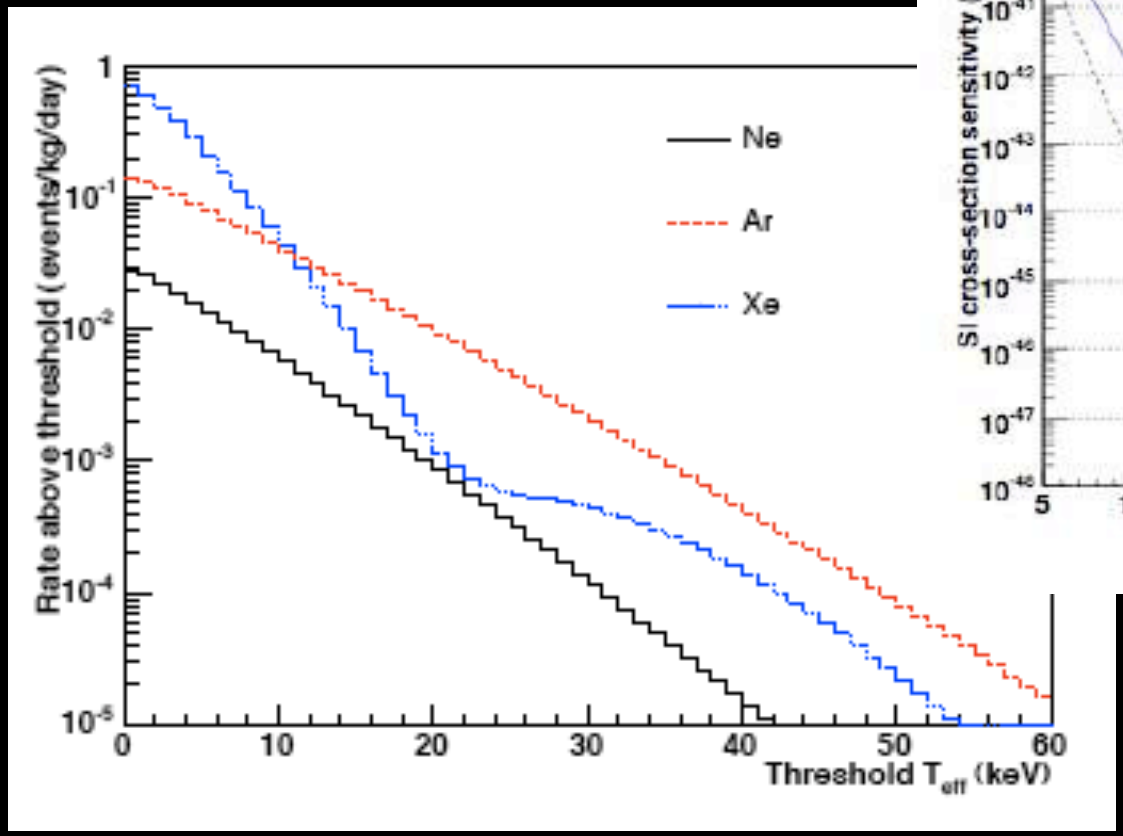


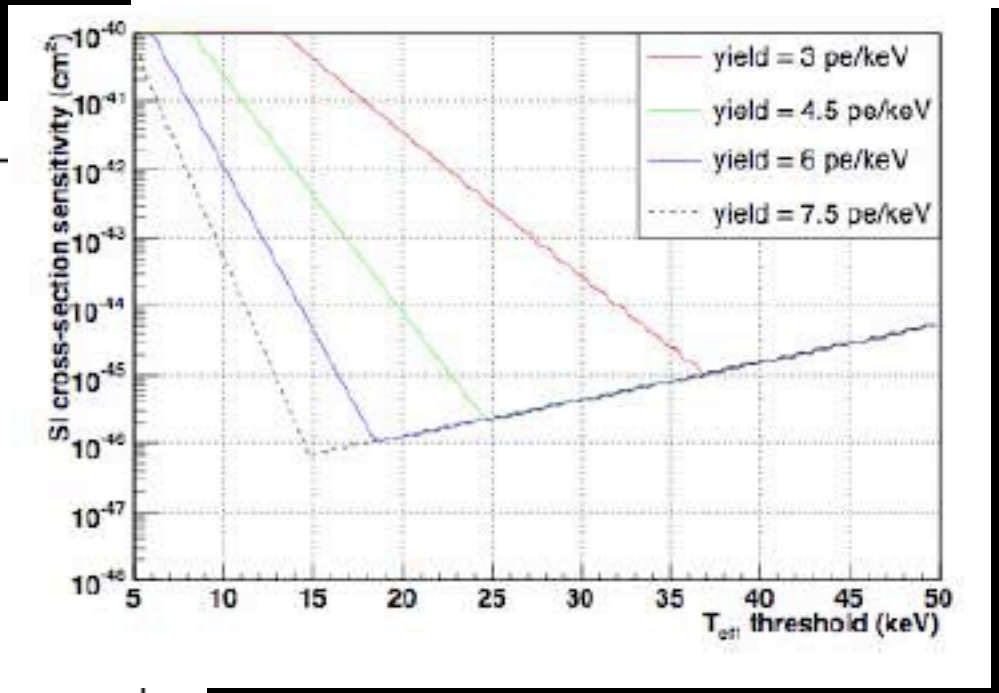


drawback: $^{39}$Ar, trade-off between background rejection and threshold, recent progress in low-bgnd LAr (x20)