Recent Progress from the DEAP-3600 Dark Matter Direct Detection Experiment

Jocelyn Monroe,
Royal Holloway University of London

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Outline

1. DEAP-3600 Detector
2. Experimental Technique
3. Status and Outlook

DEAP-3600 Collaboration

University of Alberta **D. Grant**, P. Gorel, **A. Hallin**, J. Tang, J. Soukup, C. Ng, B.Beltran, J. Bueno, K. Olsen, R. Chouinard, T. McElroy, S. Crothers, S. Liu, P. Davis, and A. Viangreiro

Carleton University **K. Graham**, C. Ouellet, K. Brown

Queen's University **M. Boulay**, B. Cai, J. Bonatt, B. Broerman, D. Bearse, K. Dering, **M. Chen**, S. Florian, R. Gagnon, P. Giampa, V.V. Golovko, P. Harvey, M. Kuzniak, J.J. Lidgard, **A. McDonald**, C. Nantais, **A.J. Noble**, E. O'Dwyer, P. Pasuthip, L. Veloce, **W. Rau**, T. Sonley, P. Skensved, M. Ward

SNOLAB/Laurentian **B. Cleveland, F. Duncan, R. Ford**, **C.J. Jillings**, T. Pollmann

SNOLAB I. Lawson, K. McFarlane, P. Liimatainen, O. Li, E. Vazquez Jauregui

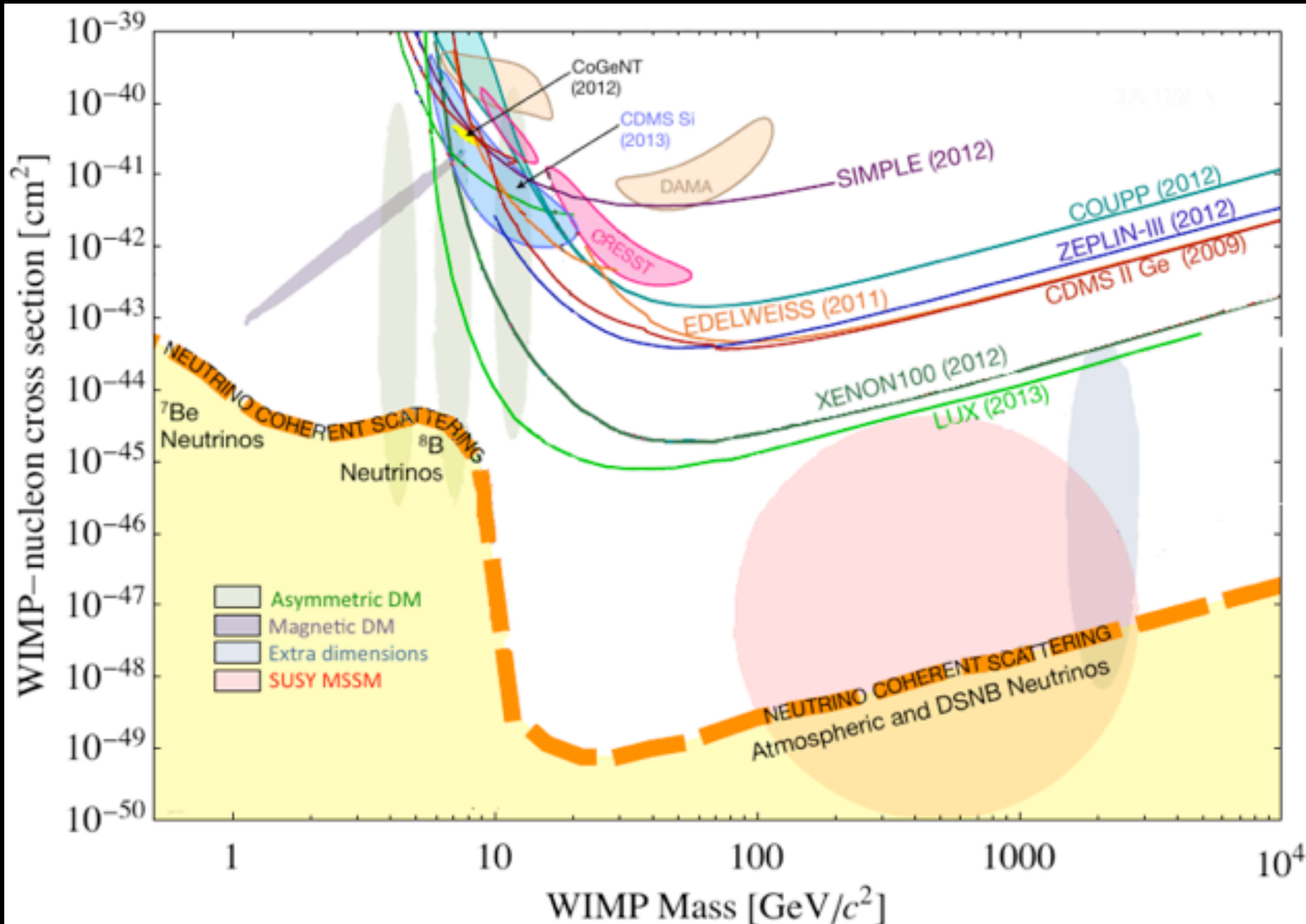
TRIUMF **F. Retiere,** P-A. Amaudruz, D. Bishop, S. Chan, C. Lim, A. Muir, C. Ohlmann, K. Olchanski , V. Strickland

Rutherford Appleton Laboratory **P. Majewski**

Royal Holloway University of London **J. Monroe,** J. Walding, A. Butcher, N. Seeburn

University of Sussex **S.J.M. Peeters**

The Low-Background Frontier: Status of SI Searches

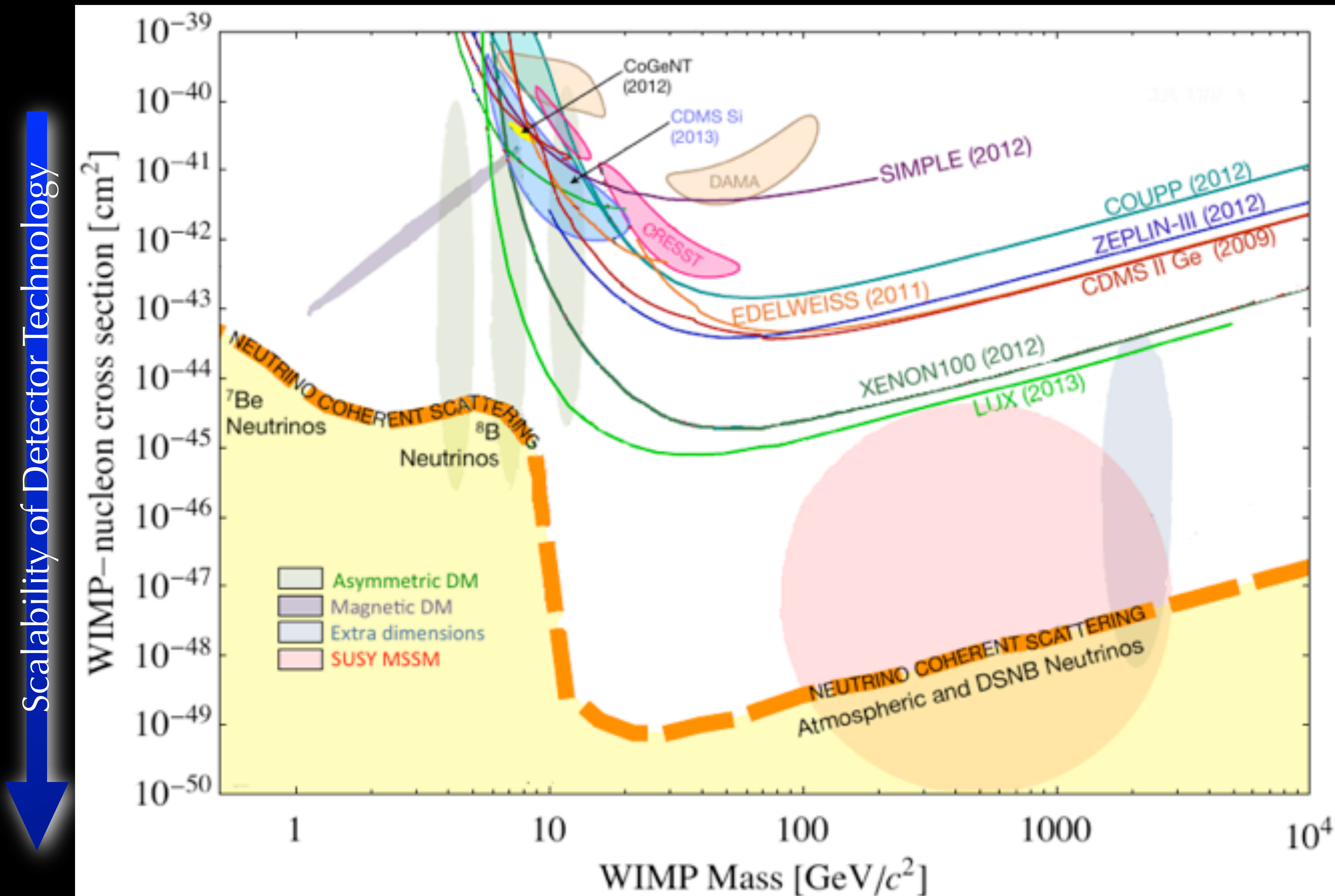


← 1 event/ kg/day

← 1 event/ 100kg/day

← 1 event/ 100 kg/ 100 days

The Low-Background Frontier: Status of SI Searches



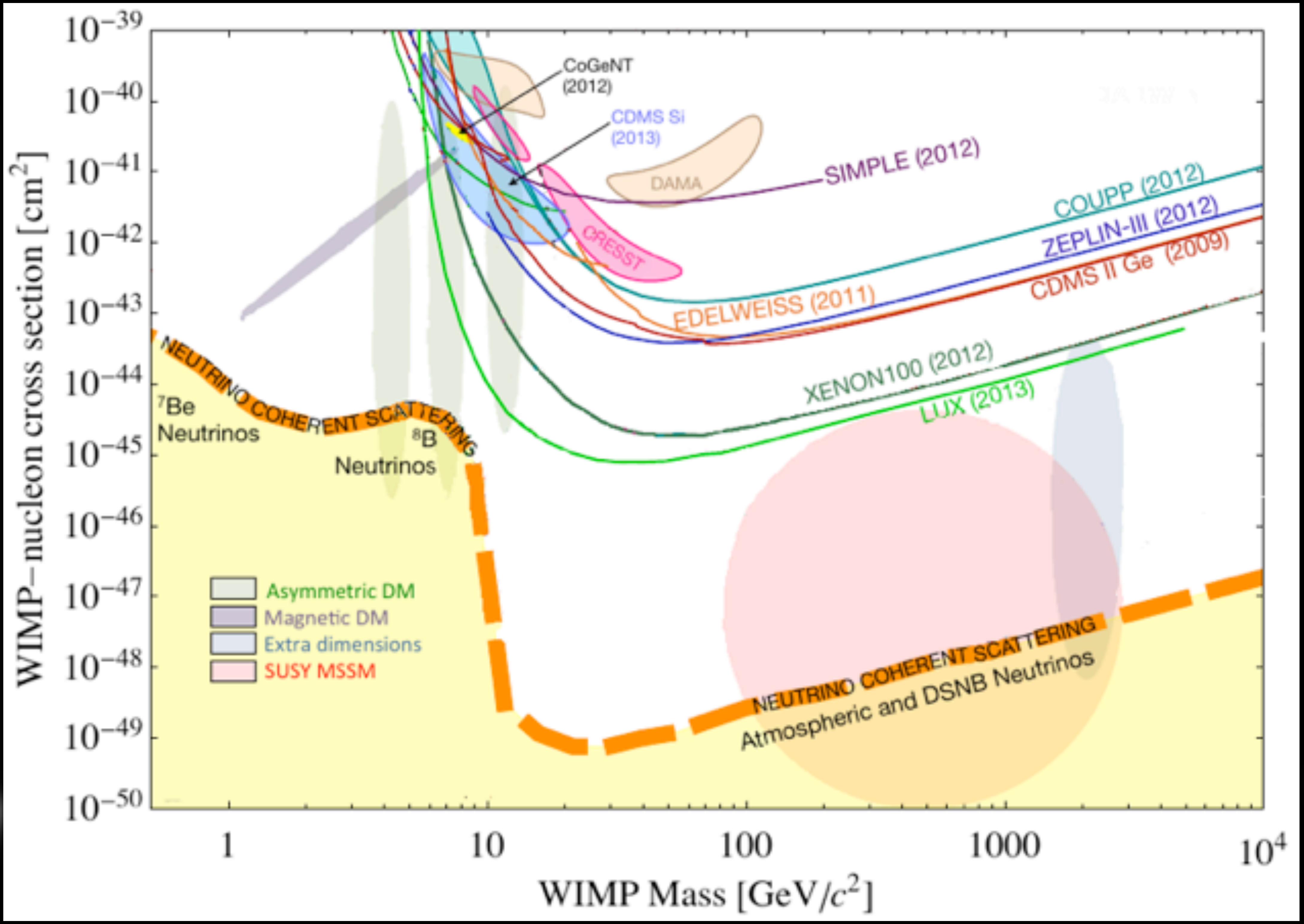
1 event/ kg/day

1 event/ 100kg/day

1 event/ 100 kg/ 100 days

The Low-Background Frontier: Status of SI Searches

Scalability of Detector Technology



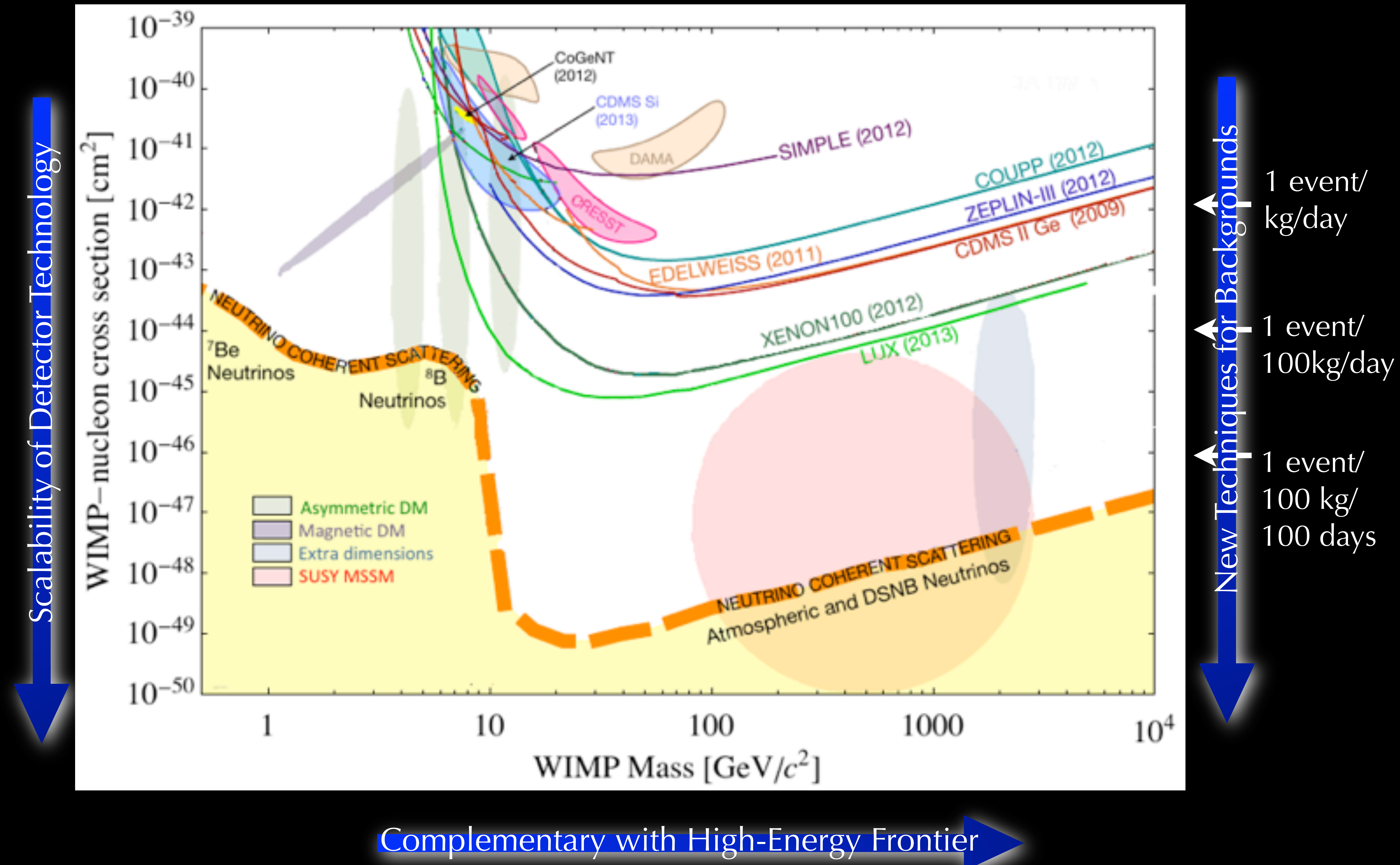
New Techniques for Backgrounds

1 event/ kg/day

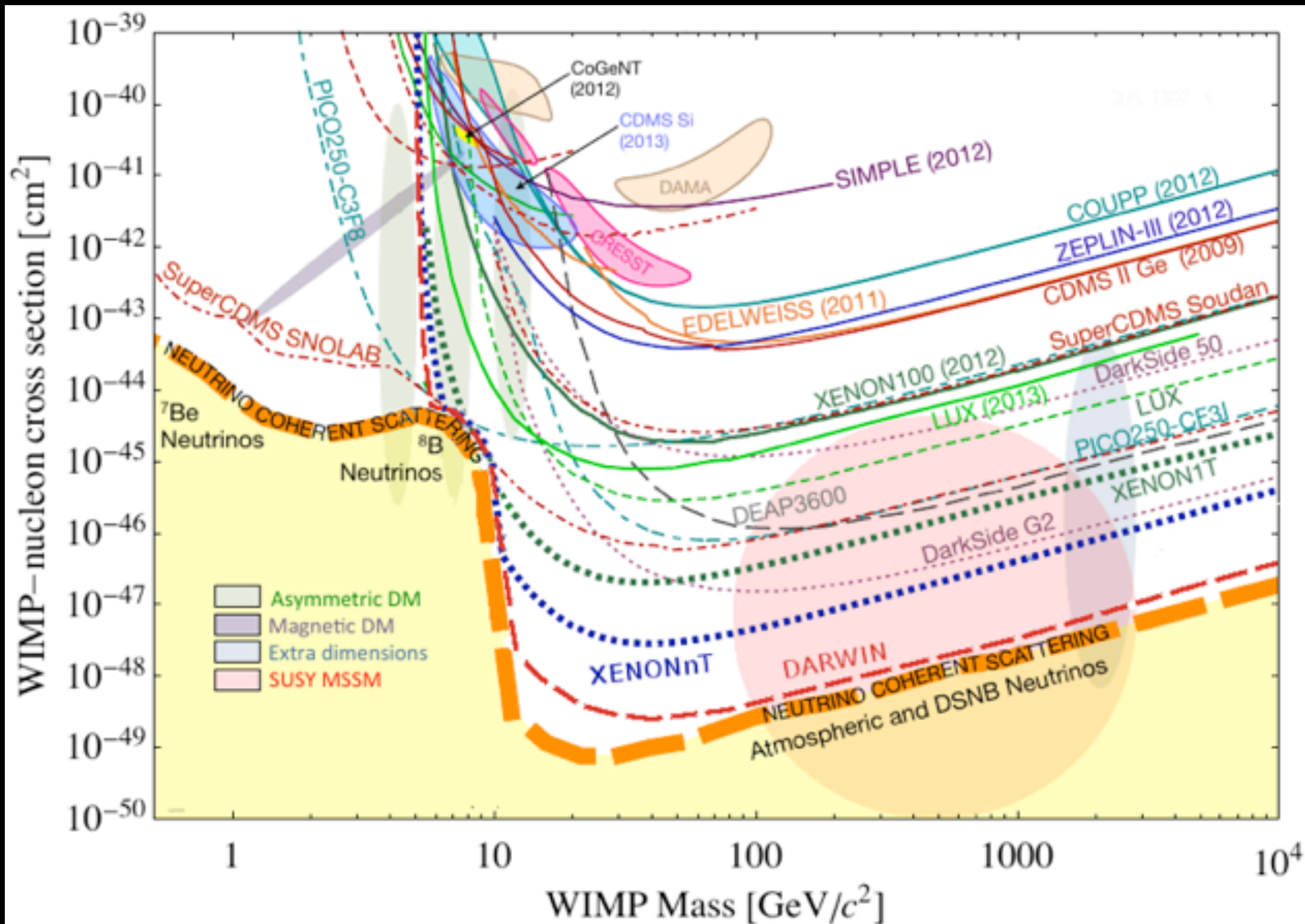
1 event/ 100kg/day

1 event/ 100 kg/ 100 days

The Low-Background Frontier: Status of SI Searches



The Low-Background Frontier: Prospects



under construction

proposed

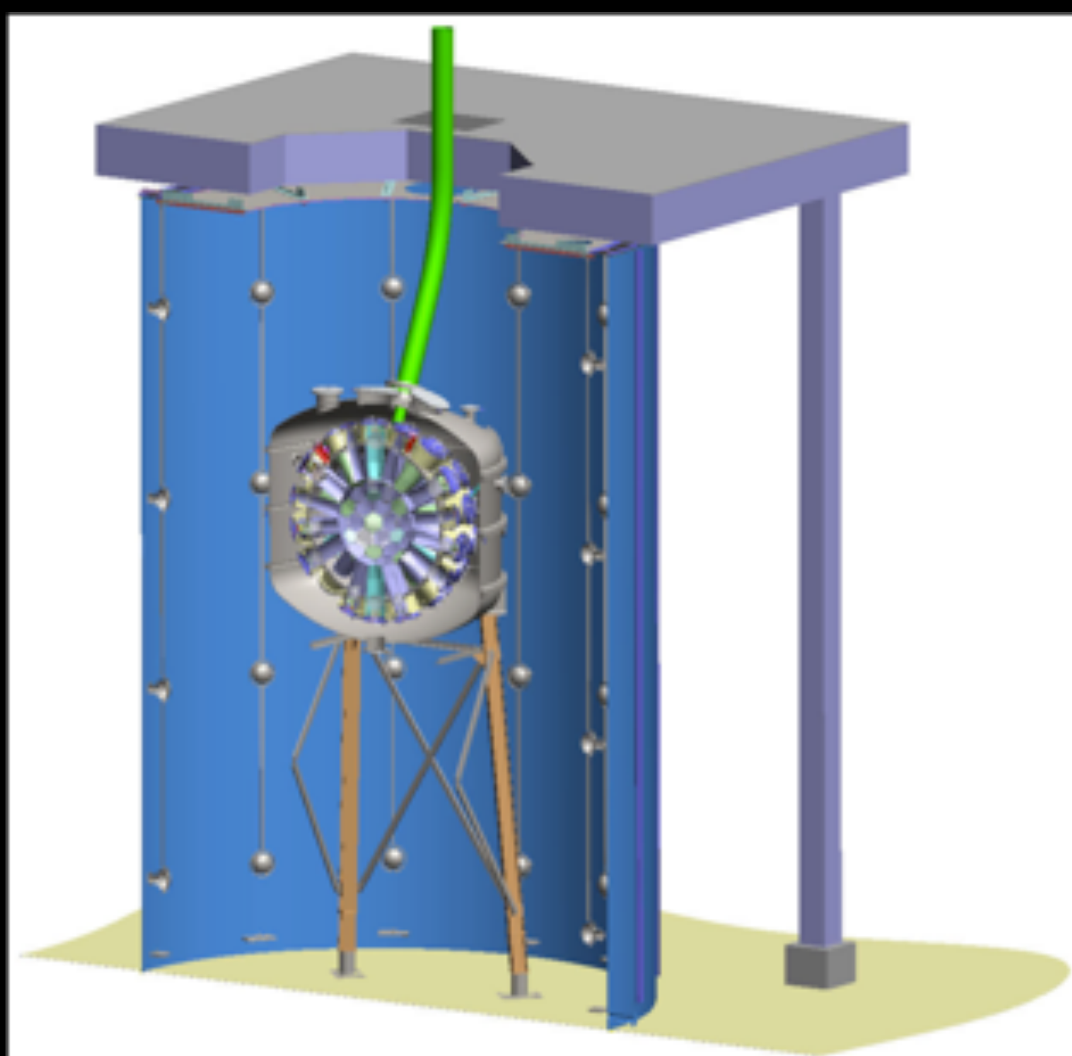
so far: <1 event at 1E-45 cm^2, therefore need minimum 1E-47 cm^2 sensitivity for 100 events to measure M_X, σ

Neutrino Lesson:

key to scalability is large, open volume simple detector design

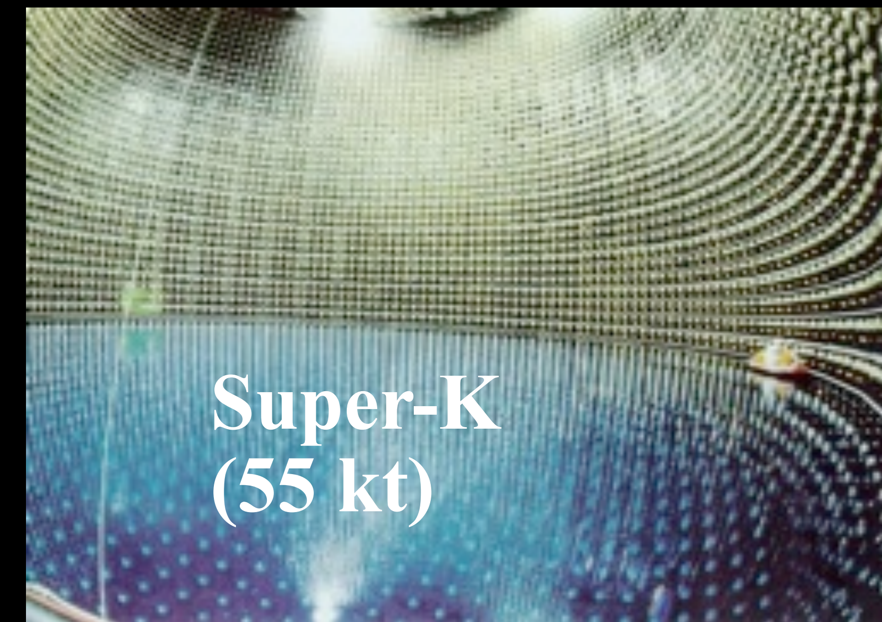
DEAP/CLEAN Strategy:

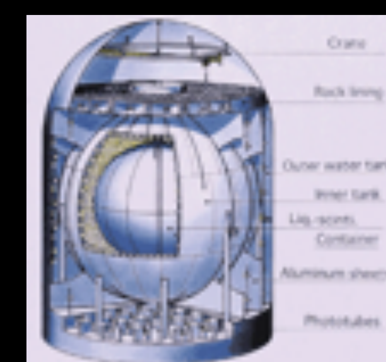
draw on design successes of large neutrino experiments



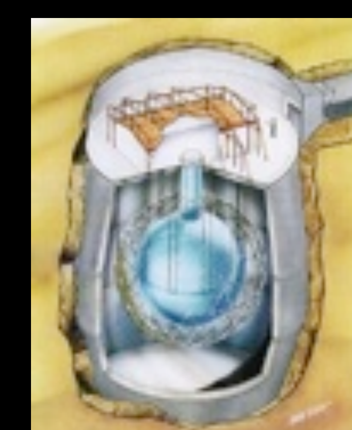
cross section (cm^2) | detector mass (ktonnes)

cross section (cm^2)	detector mass (ktonnes)
10^{-45}	100
	30
10^{-44}	10
10^{-43}	3
	1
10^{-42}	
10^{-39}	0.1

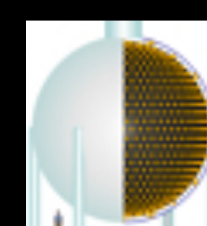




Kamland (3 kt)



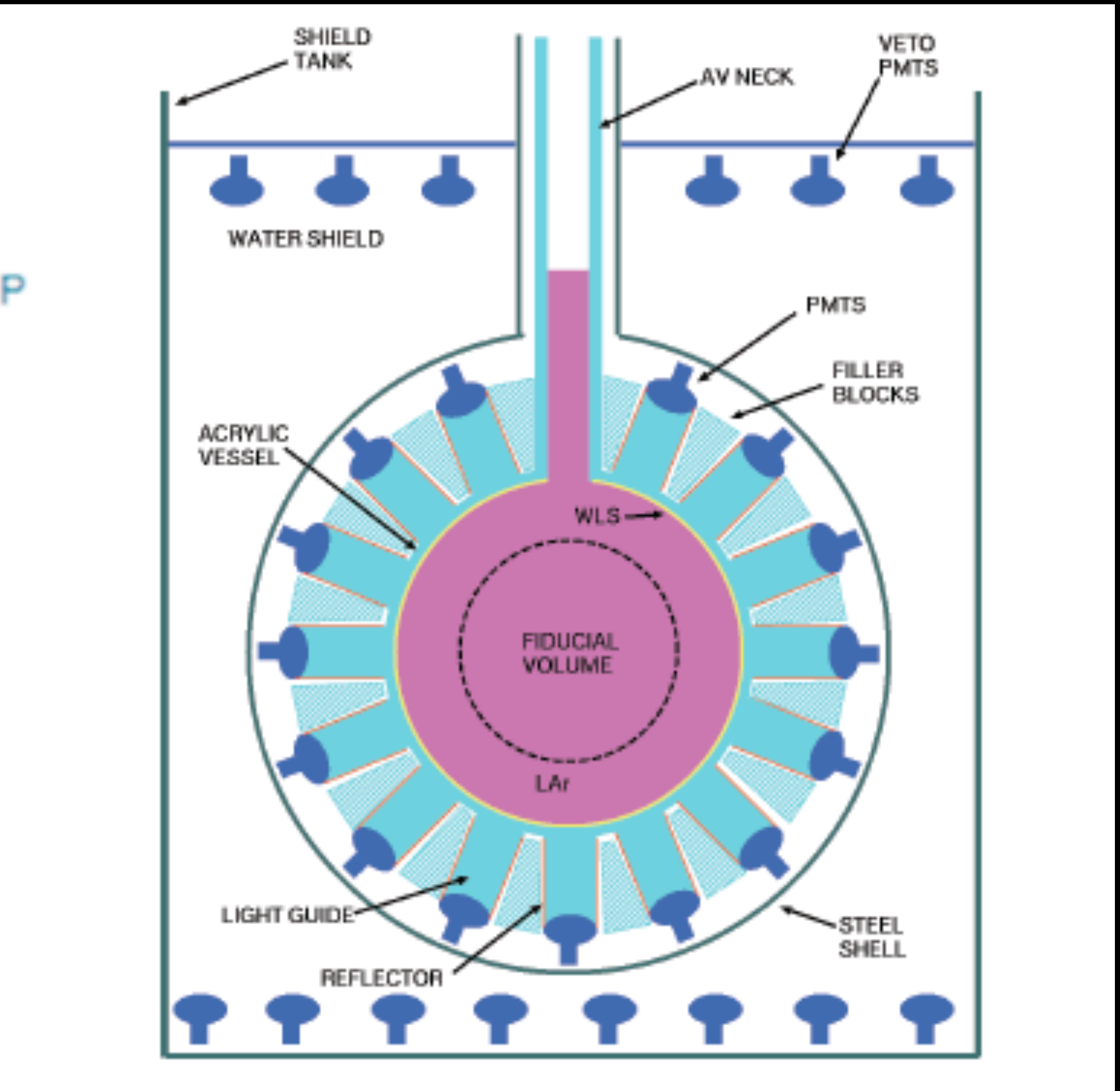
SNO (1 kt)



MiniBooNE (0.8 kt)

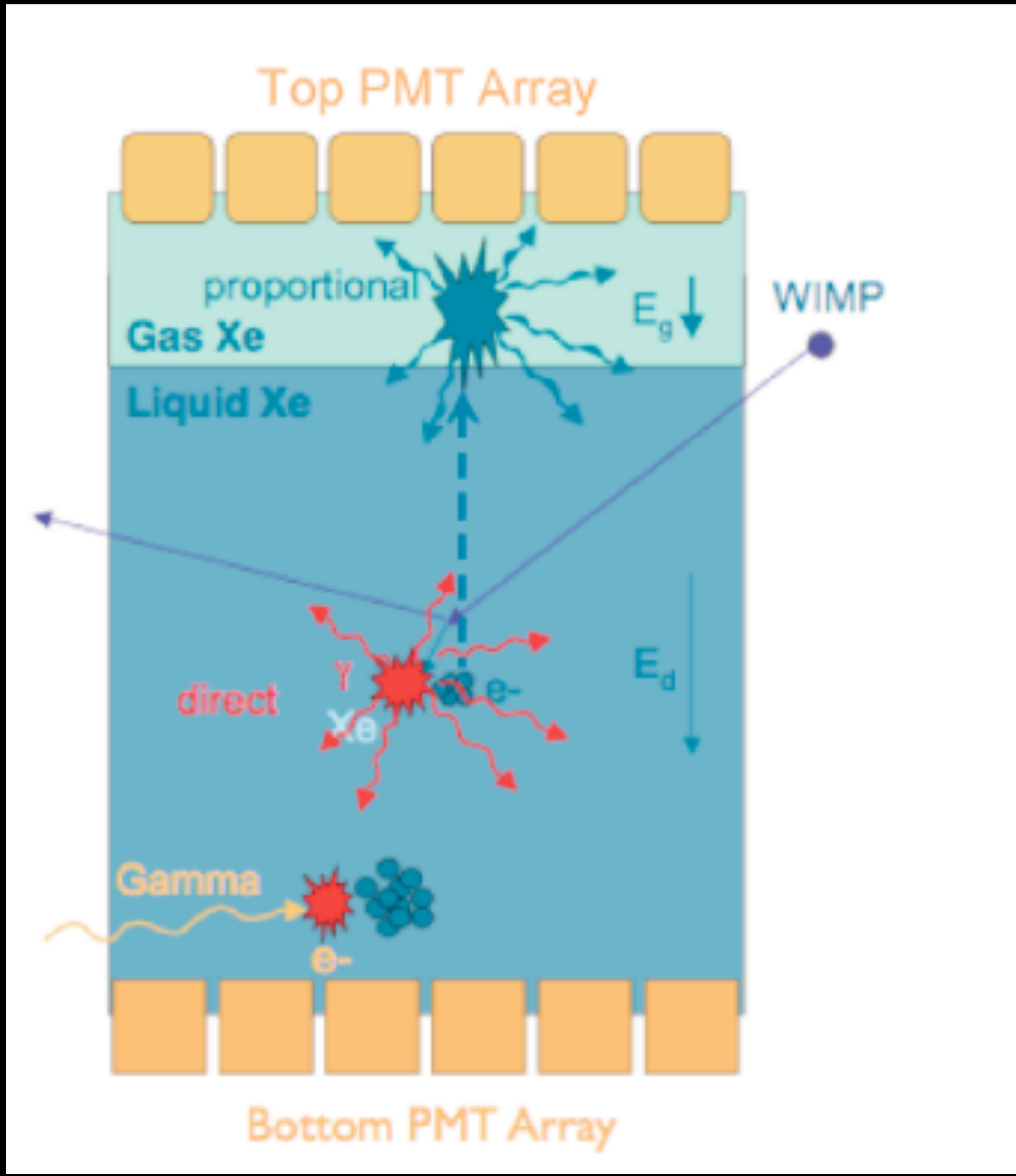
Single Phase a la Neutrinos

high light yield *and self-shielding* of target



D. N. McKinsey and J. M. Doyle, J. Low Temp. Phys. 118, 153 (2000).

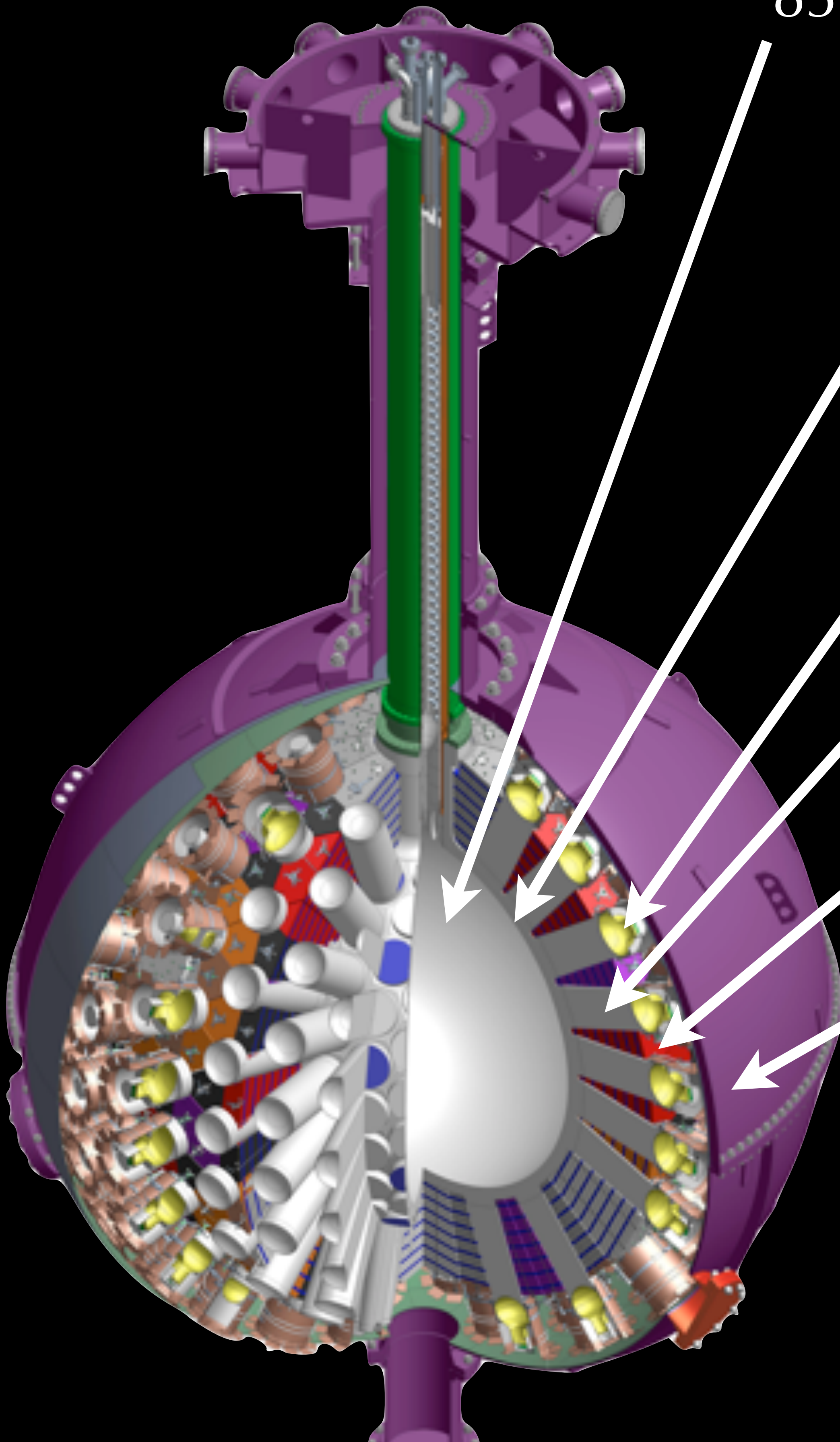
background discrimination from prompt scintillation timing...



no electric fields = straightforward scalability to kT
1) no pile-up from ms-scale electron drift in E
2) no recombination in E (high photons/keVee)
but no charge background discrimination either!

cf. Two Phase Detector: *and* charge (proportional scintillation)

DEAP-3600 Detector



85 cm radius acrylic sphere contains 3600 kg of liquid argon (LAr)

1 um of TPB coats inside surface of sphere, wavelength shift to 420 nm

viewed by 255 8″ Hamamatsu R5912 HQE PMTs (32% QE, 75% coverage)

50 cm of acrylic light guide between LAr and PMTs to mitigate PMT neutrons

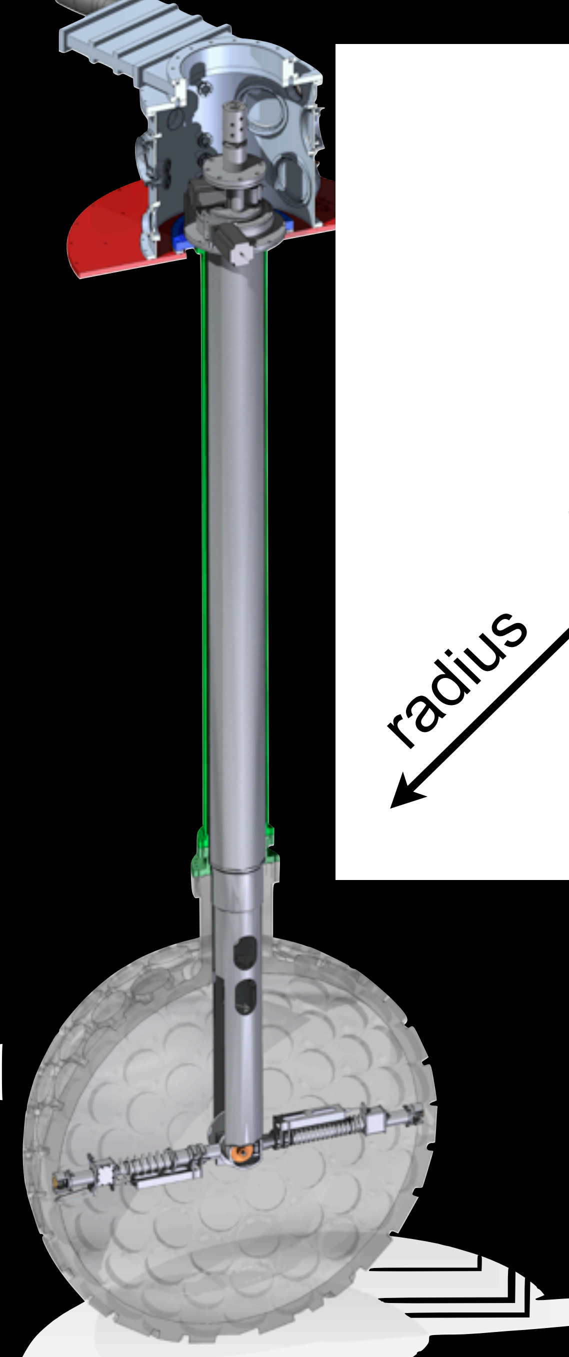
PTFE filler blocks between light guides to moderate neutrons

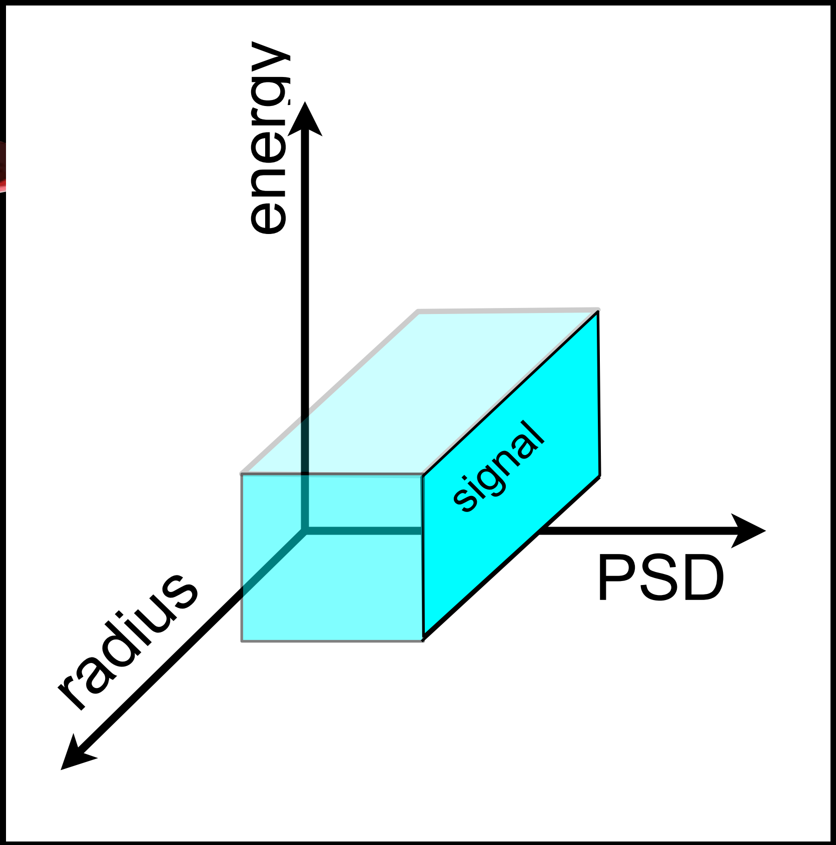
Outer steel sheel prevents LAr / water mixing (safety)

Inside 8.5 m diameter water tank, with PMTs for muon veto, and to moderate cavern neutrons and gammas

6200′ underground in SNOLAB Cube Hall

Background Strategy





Ar-39 beta decay:

- Ar-39 decay rate ~1 Bq/kg, Q=550 keV. Dominates data rate.
- mitigated with pulse shape discrimination
- threshold for PSD determines energy threshold for dark matter search

Alphas and Radon Progeny:

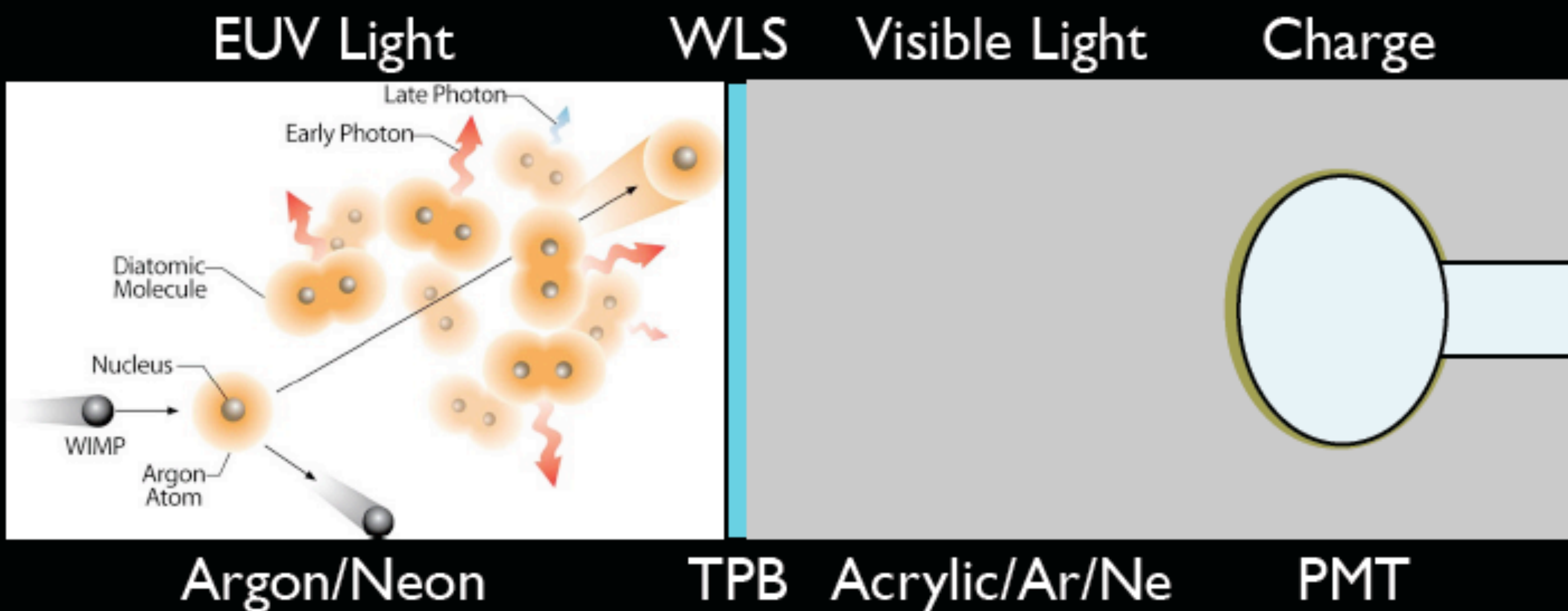
- stringent radiopurity control, ex-situ assays
- resurfacing of vessel before TPB + argon fill
- fiducialization, determines fiducial volume for dark matter search

Neutrons and Gammas:

- passive moderation
- cross-check with active tagging: measure neutron inelastic scattering gammas
- stringent radiopurity control for (alpha,n)

Background (in Fid Vol)	DEAP-3600 Goal
Radon in Ar	< 1.4 nBq/kg
Surface α's	< 100 μBq/m^2
Neutrons (all sources)	< 2 pBq/kg
Ar-39	< 2 pBq/kg
Total (3 tonne-yr)	**< 0.6 events**

Photon's-Eye View



Liquid Argon dark matter target (cold! 87 K)
LAr scintillates at 128 nm

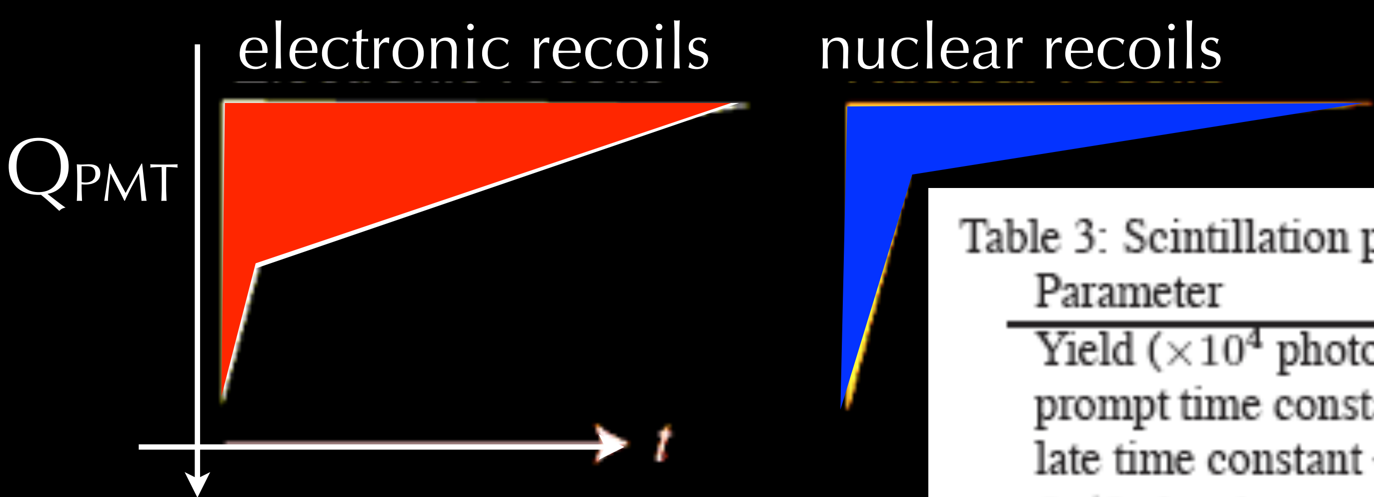
wavelength shift (TPB) to >400 nm

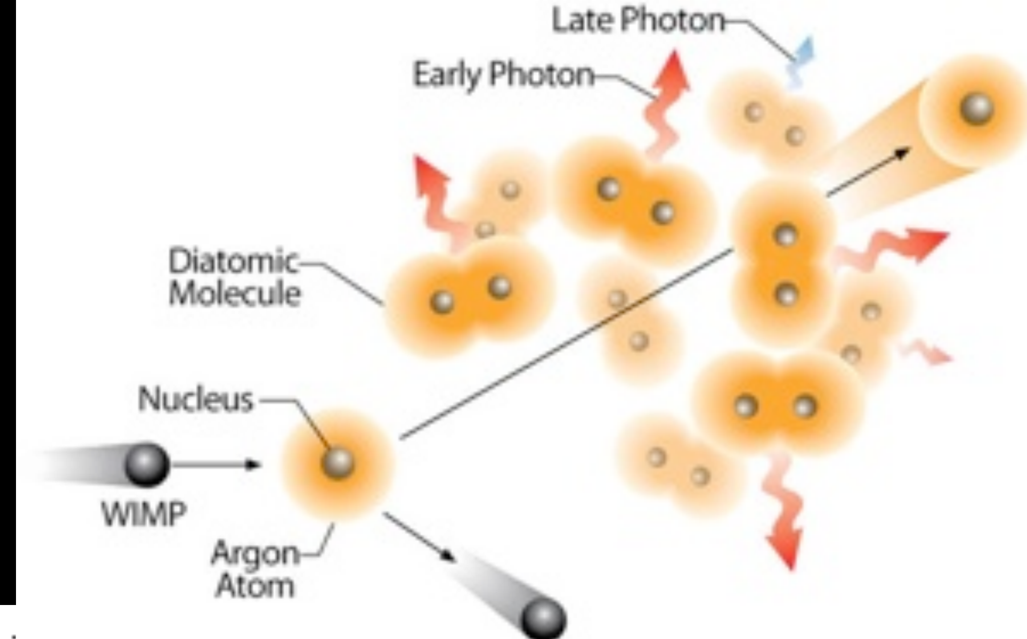
read out with PMTs, digitize at 250 MHz, maximize PE/keVee with 4π coverage

Fiducialization relies on position reconstruction from detected $N_{PE}(t)$ in each PMT.

Mitigating Electron Backgrounds

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

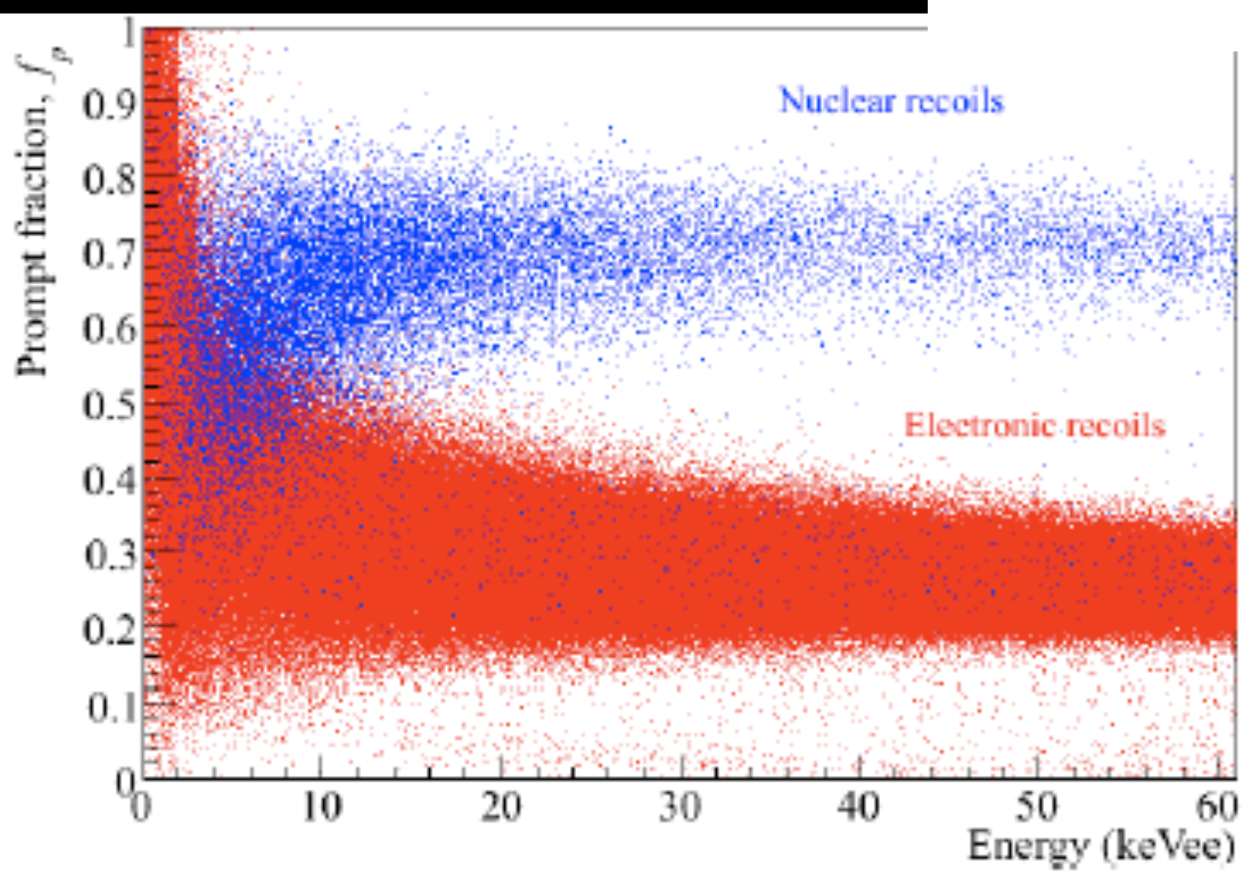




Lippincott et al., Phys.Rev.C 78: 035801 (2008)

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 τ_1 (ns)	2.2	6	2.2
late time constant τ_3	15 μs	1.59 μs	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
λ(peak) (nm)	77	128	174
Rayleigh scattering length (cm)	60	90	30



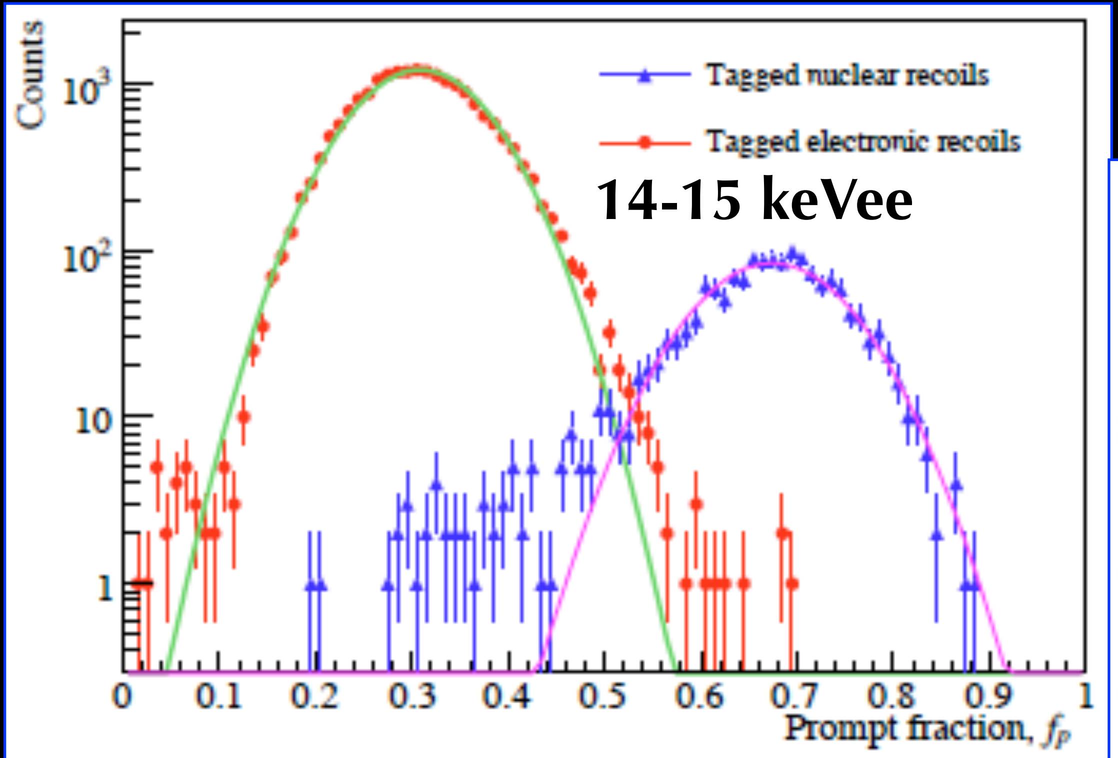
identify, reject electronic backgrounds via pulse shape vs. time difference

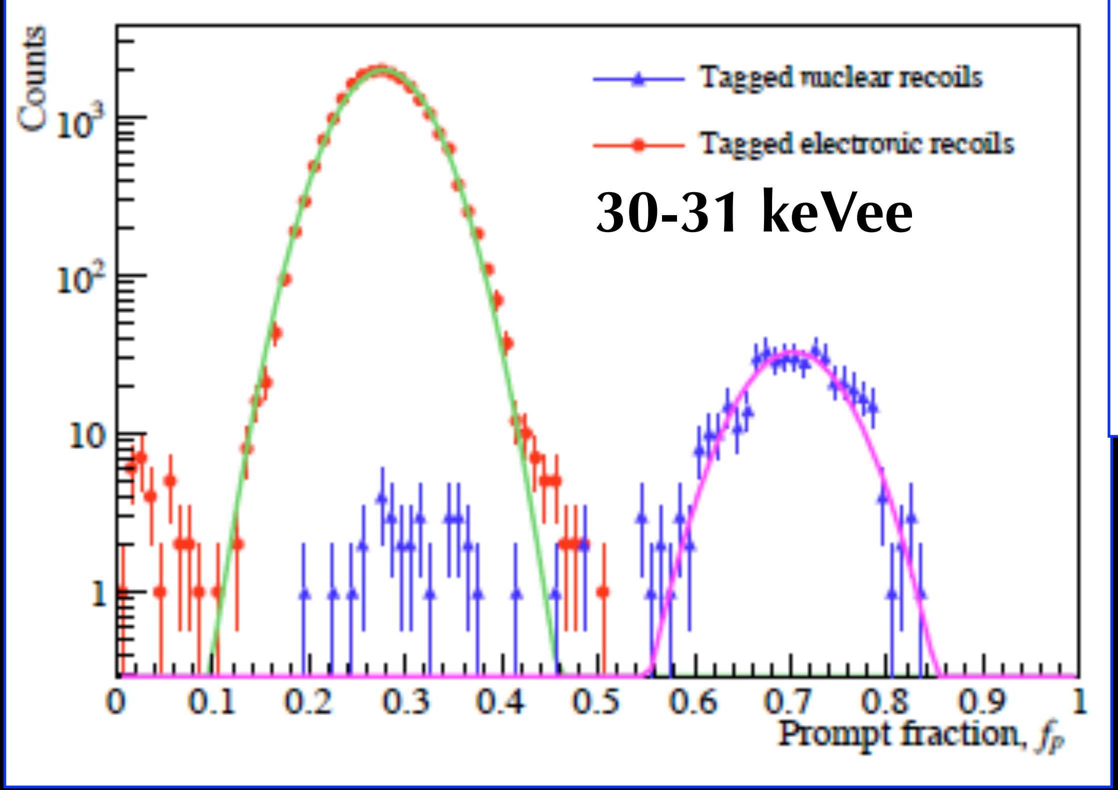
McKinsey & Coakley, Astropart. Phys. 22, 355 (2005).
Boulay and Hime, Astropart. Phys. 25, 179 (2006)

Critically important for LAr:
Ar-39 beta (1 Bq/kg)!

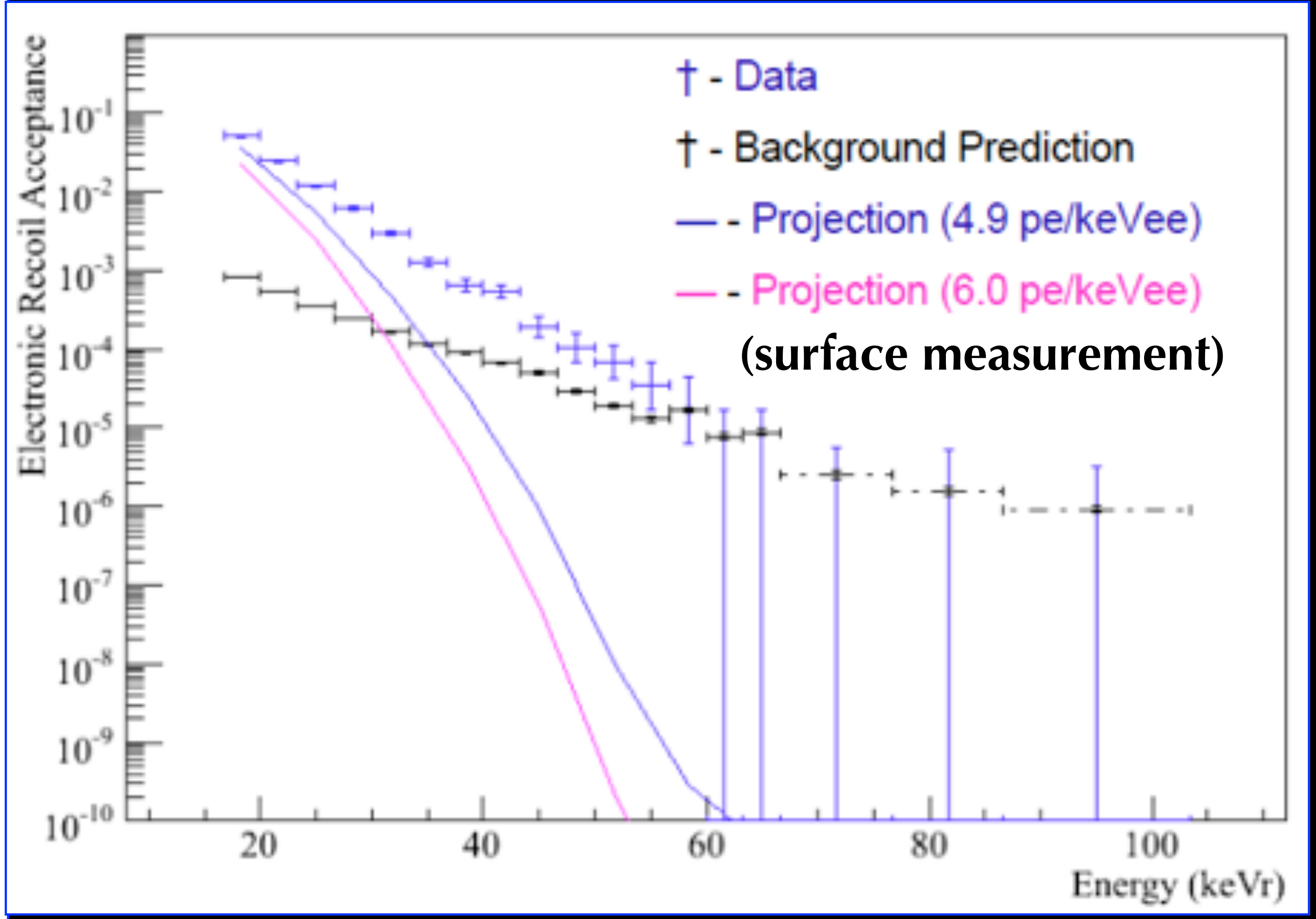
Pulse Shape Discrimination

Fraction of prompt light discriminates between electronic and nuclear recoils.





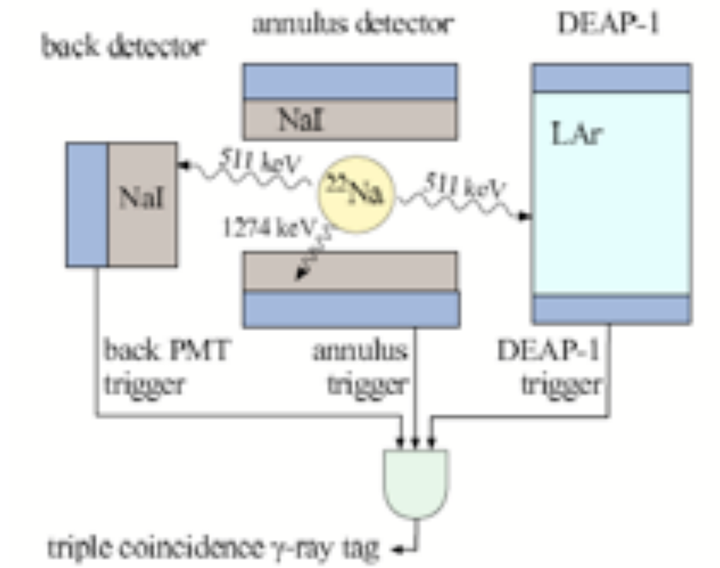
Leakage depends strongly on light yield!



Single-phase LAr detectors possible because of rejection power from timing alone: in principle, potential for kT scale detectors.

Boulay and Hime, Astropart. Phys. 25, 179 (2006)

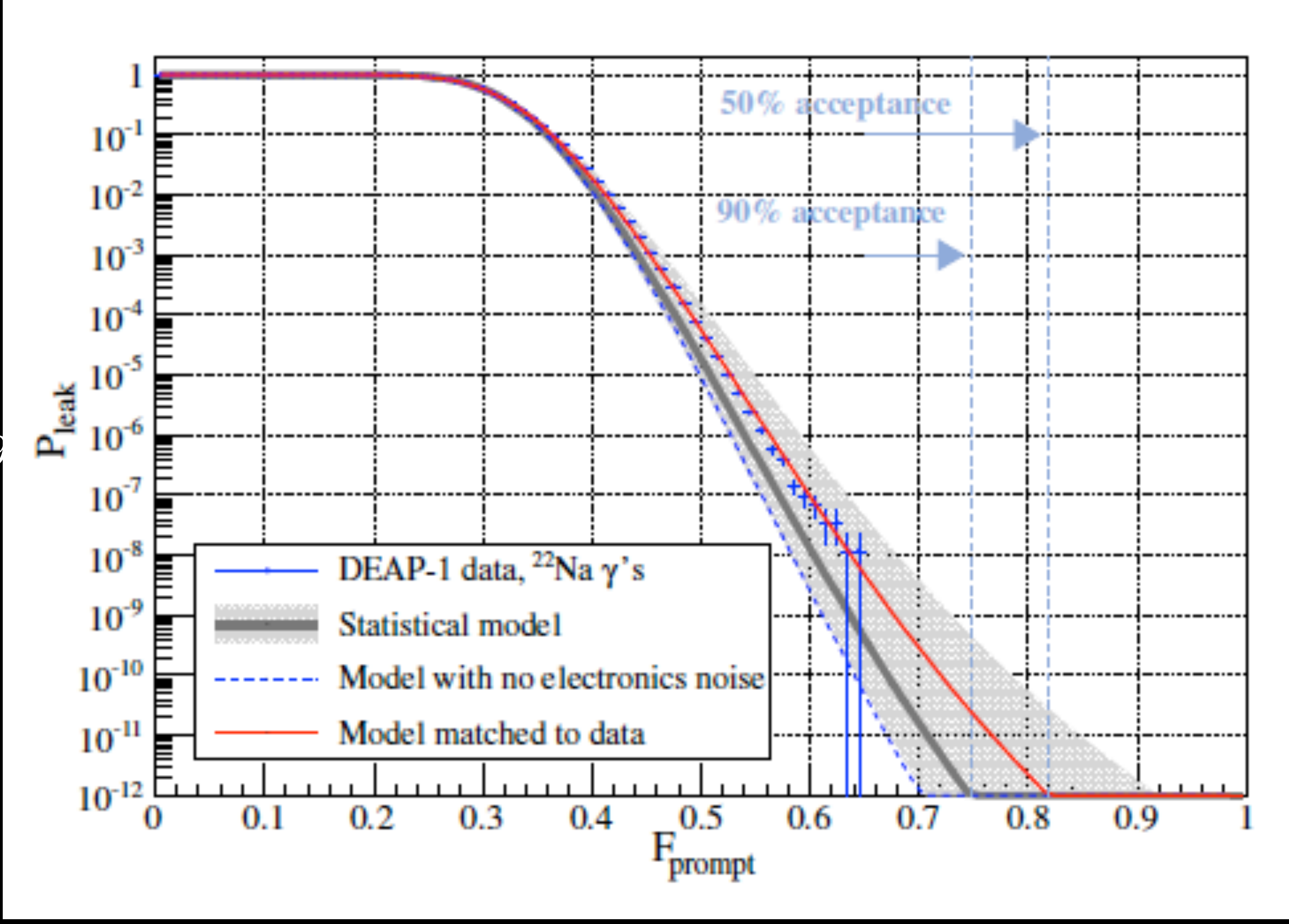
High Statistics PSD



high intensity tagged Na-22 gamma source with DEAP1 prototype detector, underground at SNOLAB
integrated 1.2E8 tagged gammas
detector light yield:
2.8±0.1 PE/keVee

PSD leakage:
< 2.8E-8 @ 90% recoil acceptance,
in 120-240 PE
(45-88 keVee in DEAP1)
Amaudruz et al., arXiv:09

simple model predicts O(E-10) leakage @ 50% recoil acceptance in 120-240 PE in DEAP-3600 with 8 PE/keVee light yield



PSD with Other Statistics

Akashi-Ronquest et al., arXiv:1408.1914

Variance of PE counting significantly affects pulse shape discrimination

Developed new Bayesian PE-counting method which reduces variance substantially:

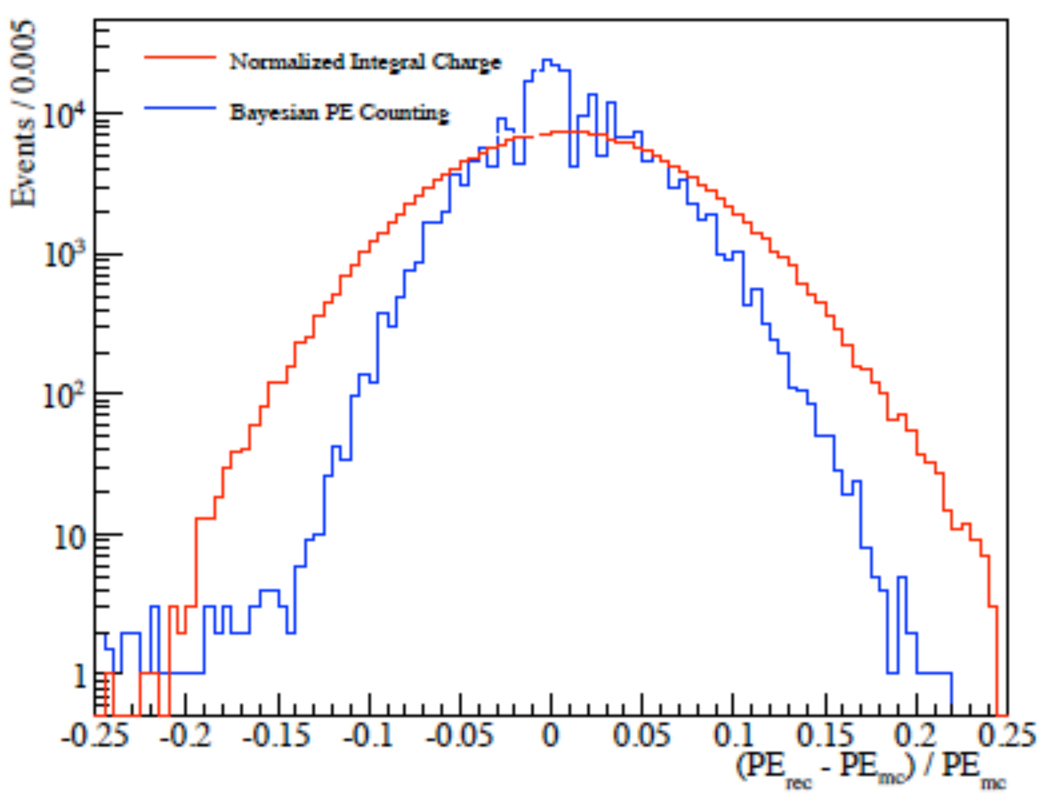


Figure 12: The ratio of estimated number of photoelectrons divided by the true number of photoelectrons for simulated ^{39}Ar decays in the MiniCLEAN. Only events between 75 and 100 PE, and radius less than 295 mm are shown.

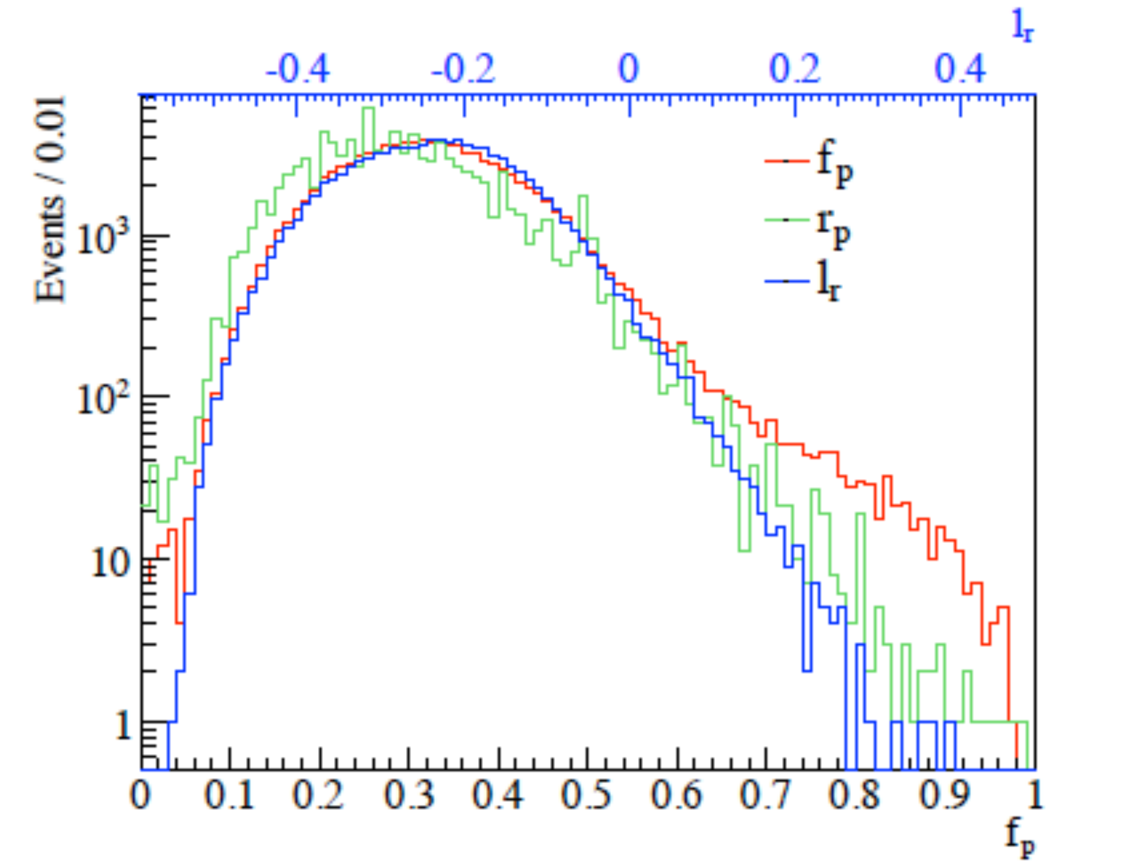


Figure 8: Distribution of f_p, r_p, and l_r test statistics for electronic recoils for ^{22}Na calibration events in DEAP-1 with 30 PE. The l_r values have been linearly transformed such that the median values for the electron and nuclear recoil distributions match those for f_p. The shift in the r_p peak relative to f_p is due to the discrete nature of the test statistic.

PSD with:

(a) fraction of prompt Q,

(b) fraction of prompt PE

(c) Lrecoil: likelihood ratio test of e- vs. nuclear recoil hypothesis

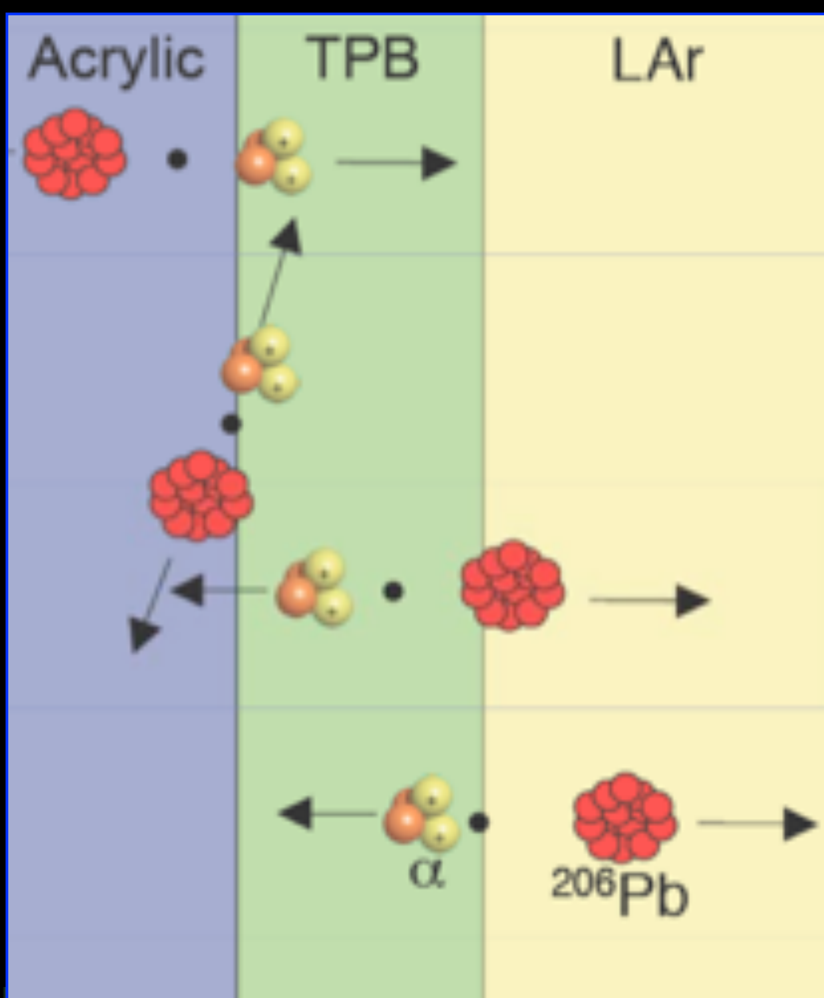
7x reduction in e- tail above f_p = 0.7

Mitigating Alpha Backgrounds

Dangerous Radon (Rn) backgrounds from decay of Rn progeny on surfaces between Acrylic Vessel (AV) and TPB, and in TPB.

Dominant source of Rn from plate-out on AV during manufacture and construction.

So, sand off 1 mm of acrylic from inside of AV before TPB deposition, x25 reduction.



With a robot!

Resurfacer testing: (movie) complete this week, start resurfacing actual AV next week!

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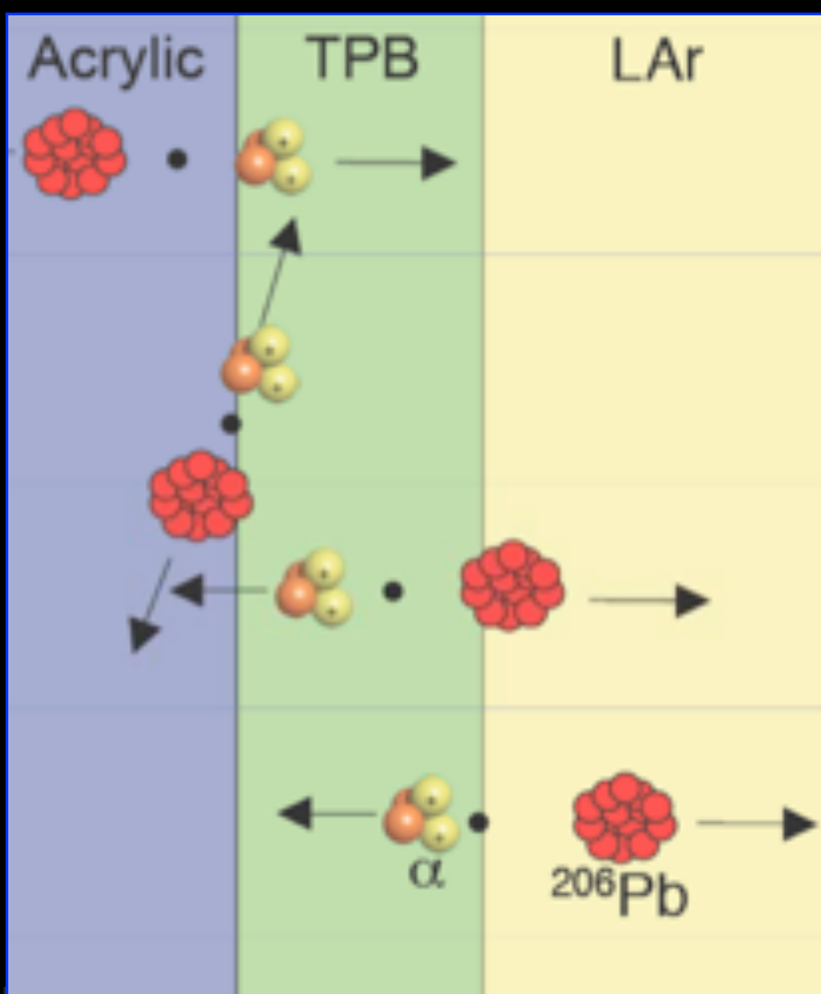

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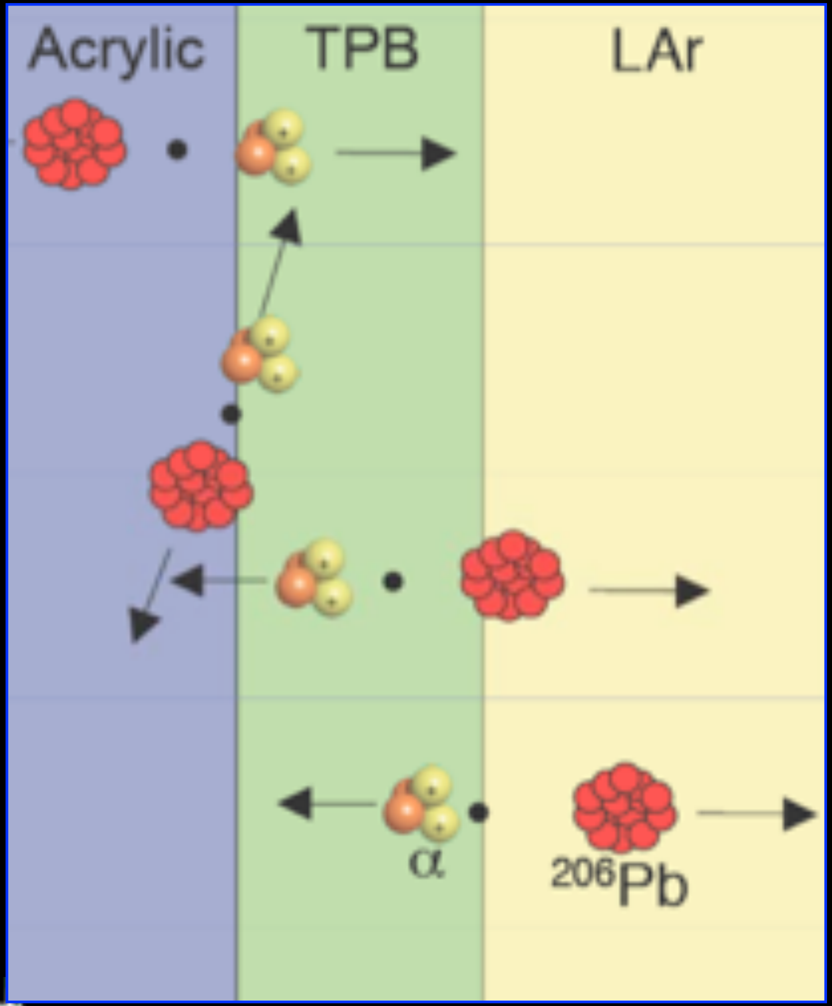

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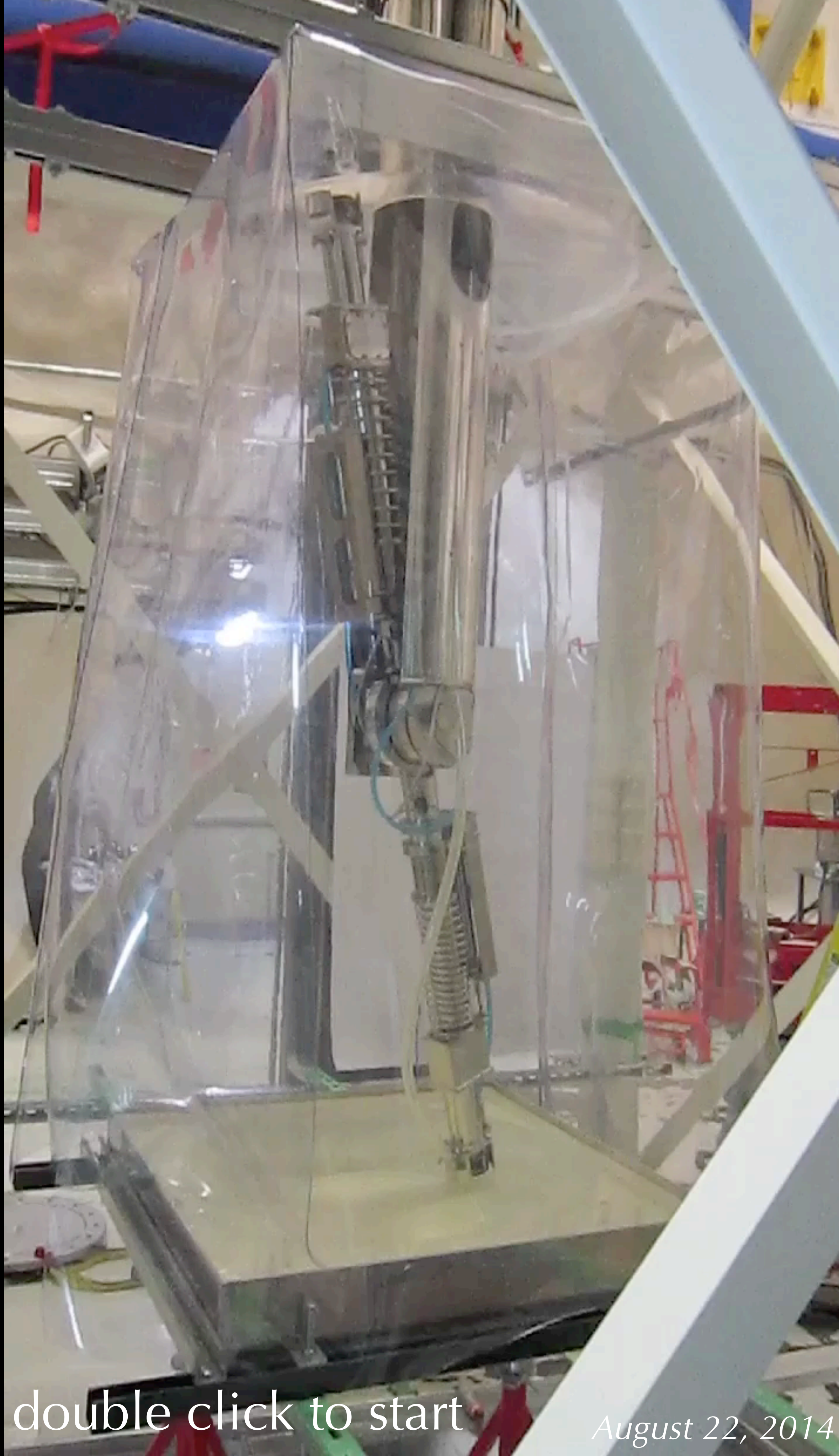


Alpha Background Fiducialization and ID

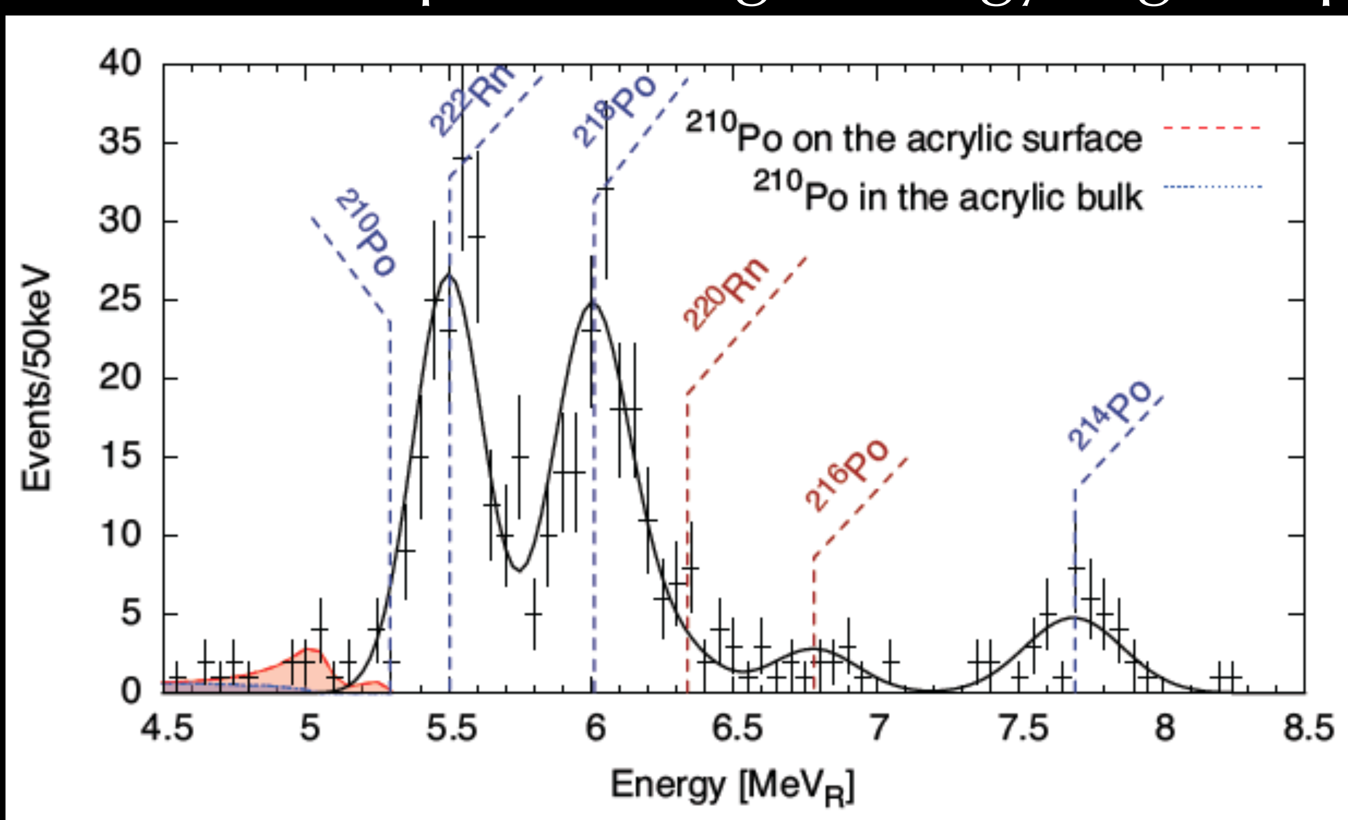
T. Pollmann et al., arXiv:1211.0909

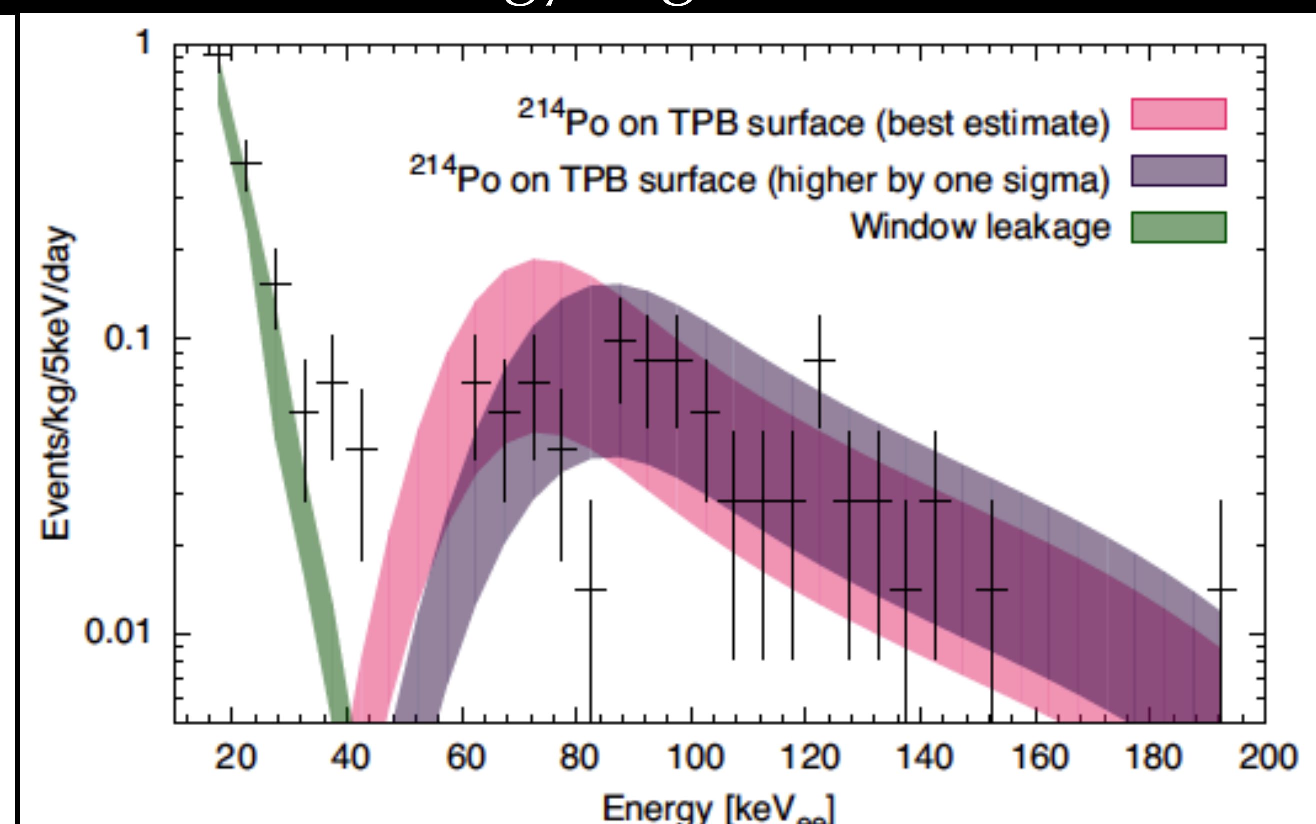
Main tools for controlling alpha backgrounds remaining after resurfacing are:

1. position reconstruction: fiducial volume cut defined on reconstructed radius
   - leakage determined by position reconstruction resolution
   - cut set for <0.6 events in 3 years run, results in 1 Tonne LAr fiducial mass

2. Radiopurity control: substantial R&D in DEAP-1 prototype detector(s):
   - 16 uBq/kg background in energy region of interest well understood, described by 1) Rn-decay on surfaces, and 3) PSD leakage at fiducial edge

measure alphas in high-energy region, predict low energy region (120-240 PE)

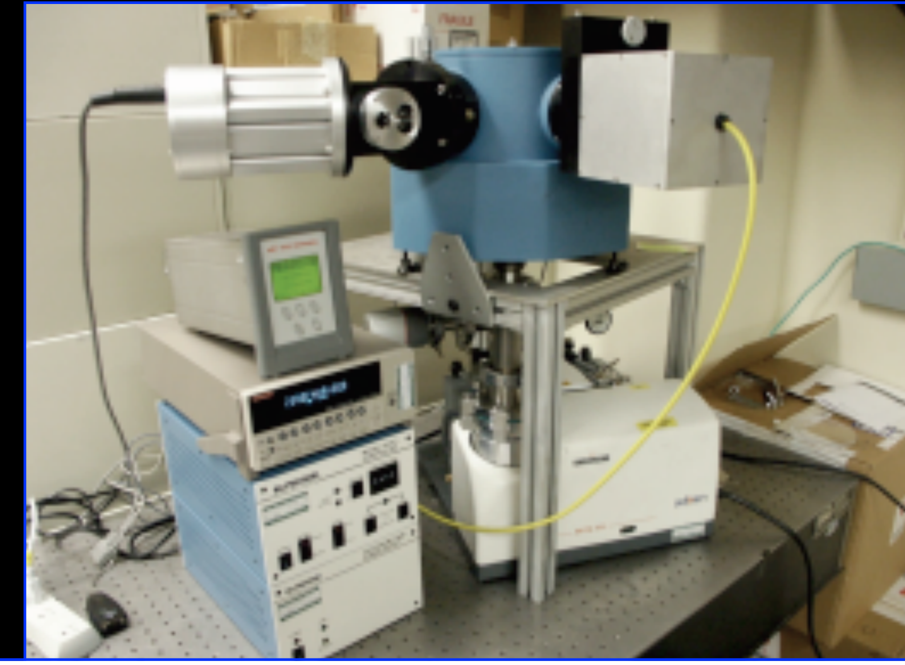


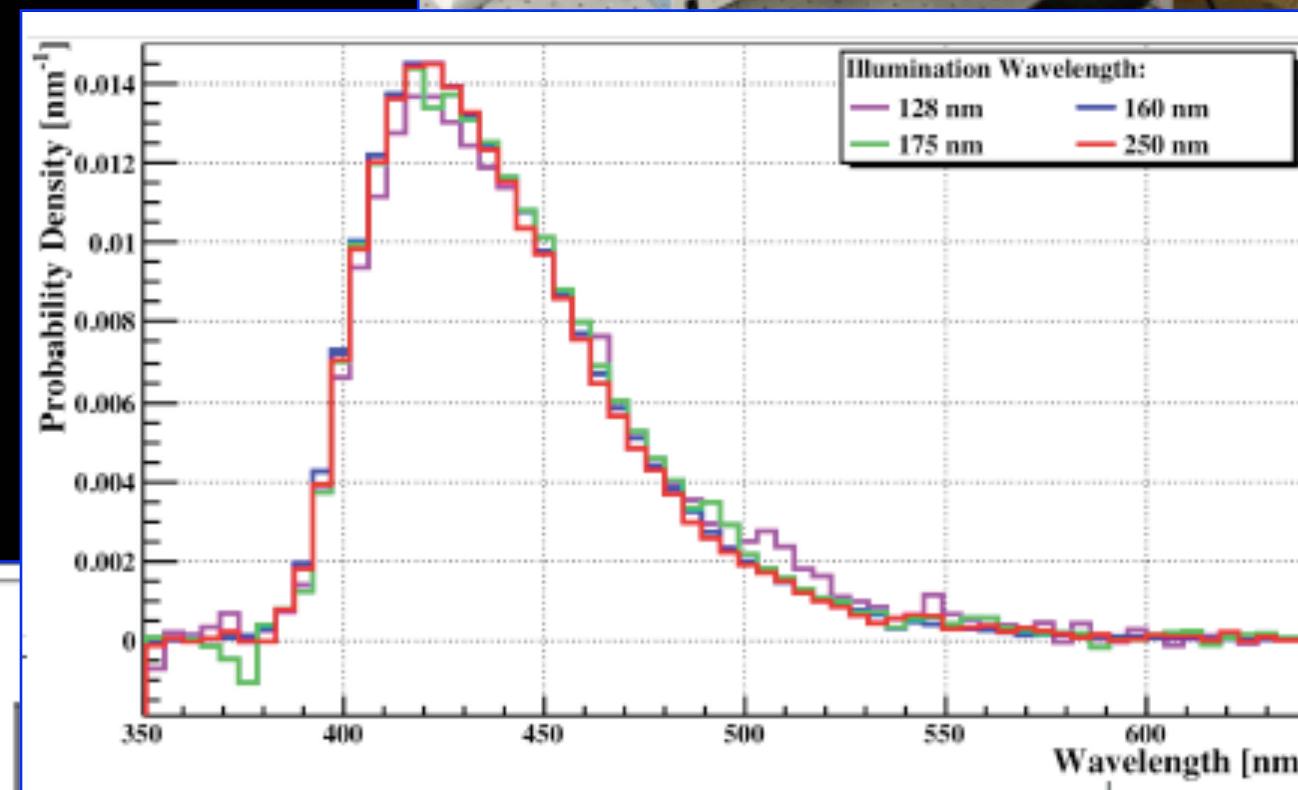


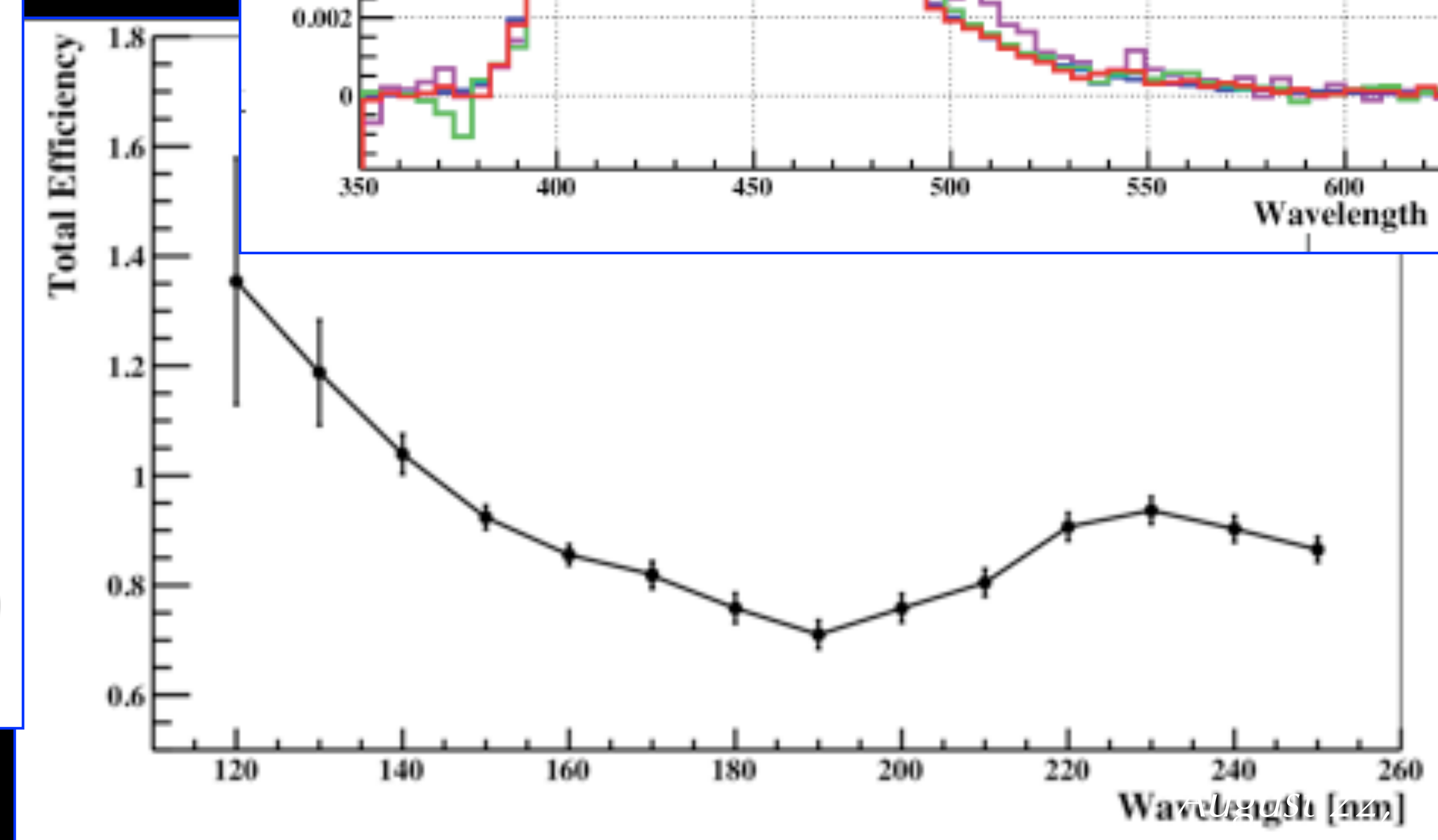
Alpha Scintillation in TPB

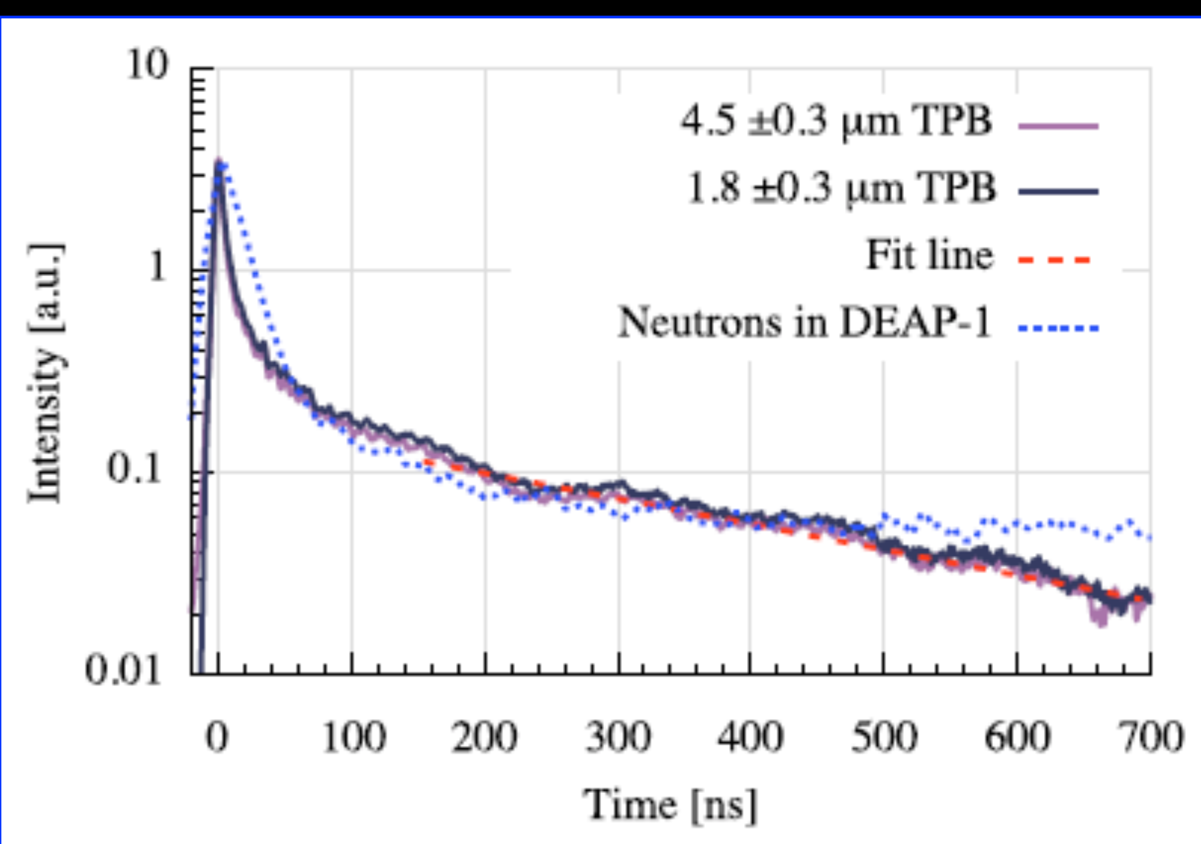
TPB wavelength-shifts from 128 nm to visible (fluorescence)
ex-situ test benches for spectrum, efficiency, angular dist.
V. M. Gehman et al., NIM A 654 1 (2011) 116-121

Alpha scintillation in TPB has rejection power, ex-situ test stand finds 11±5 and 275±10 ns fast and slow time constants, and fast:total intensity ratio of 0.67±0.03
(cf. 7 ns and 1600 ns, and 0.75)
T. Pollmann et al., NIM A 635 1 (2011) 127-130







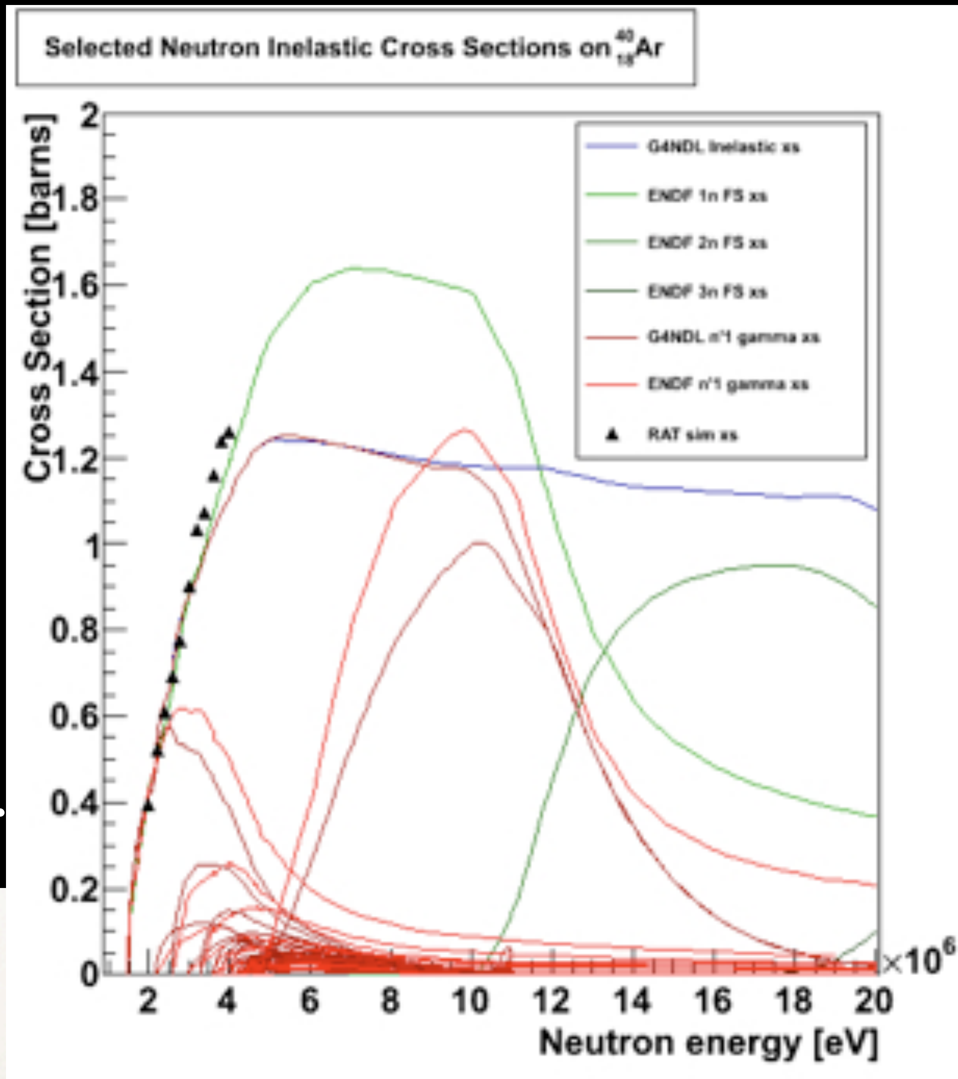


Mitigating Neutron Backgrounds

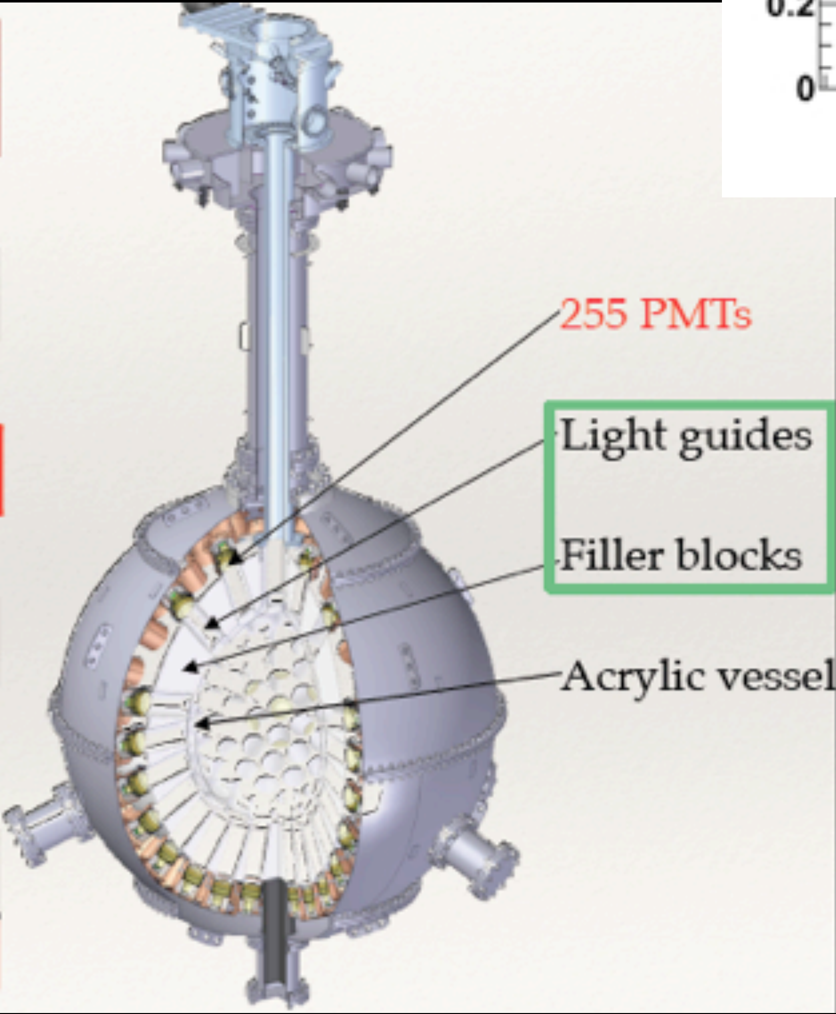
Dominant source of neutron backgrounds comes from (alpha,n) in PMT glass.

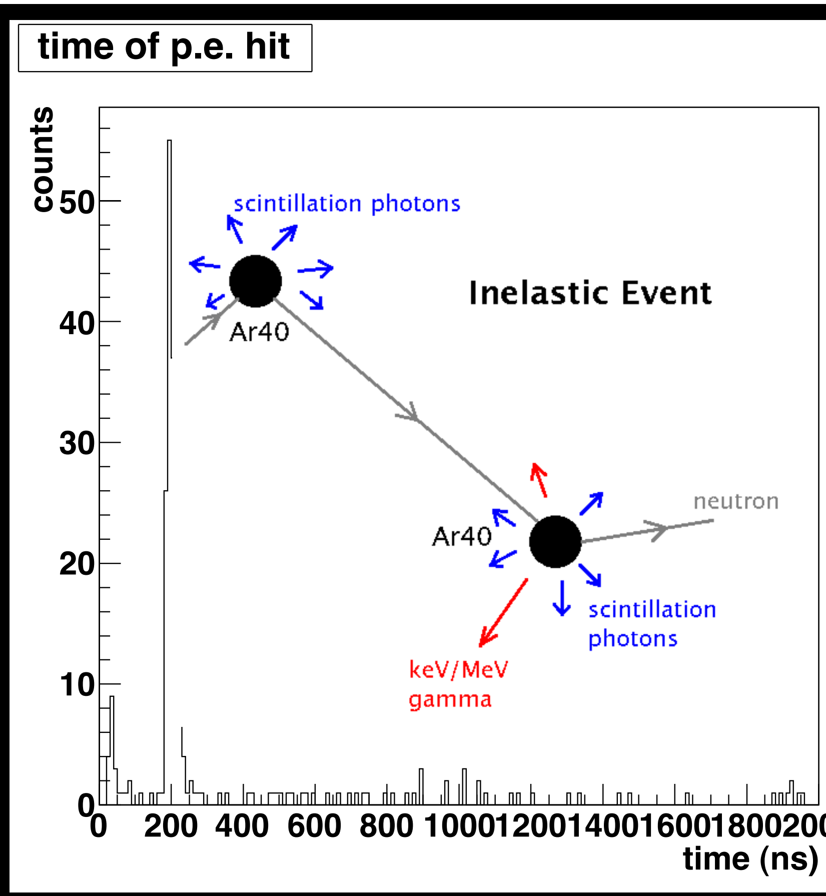
So, shield LAr target from PMTs by 50 cm of acrylic to moderate this neutron flux.

Cross-check n attenuation using external tagged AmBe source, tag internal n using inelastic gammas.



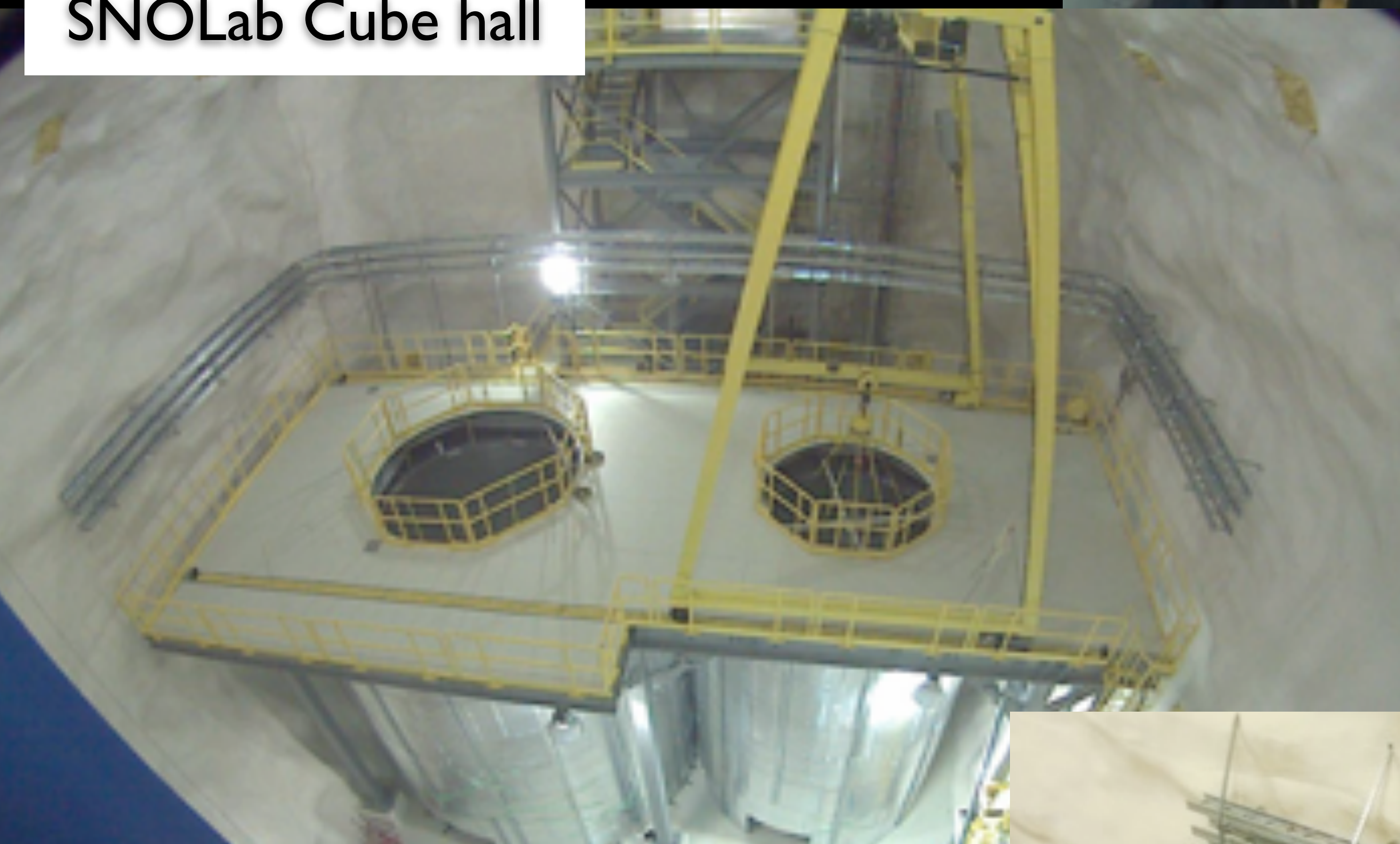
(In 3 years)	# of neutrons (produced)	Events in ROI
Acrylic vessel	<44 (Ge γ-assay)	<0.096
Light guides	<127 (Ge γ-assay)	<0.015
Filler blocks	<173 (Ge γ-assay)	<0.034
PMTs	2.6x10	0.140
PMT mounts	7565	0. 010
Rn emanation	<44	<0.081
Rn deposition (3 months	38	0.010
Other sources		0.04
Total	**<2.7x10**	**<0.35**





Construction Progress

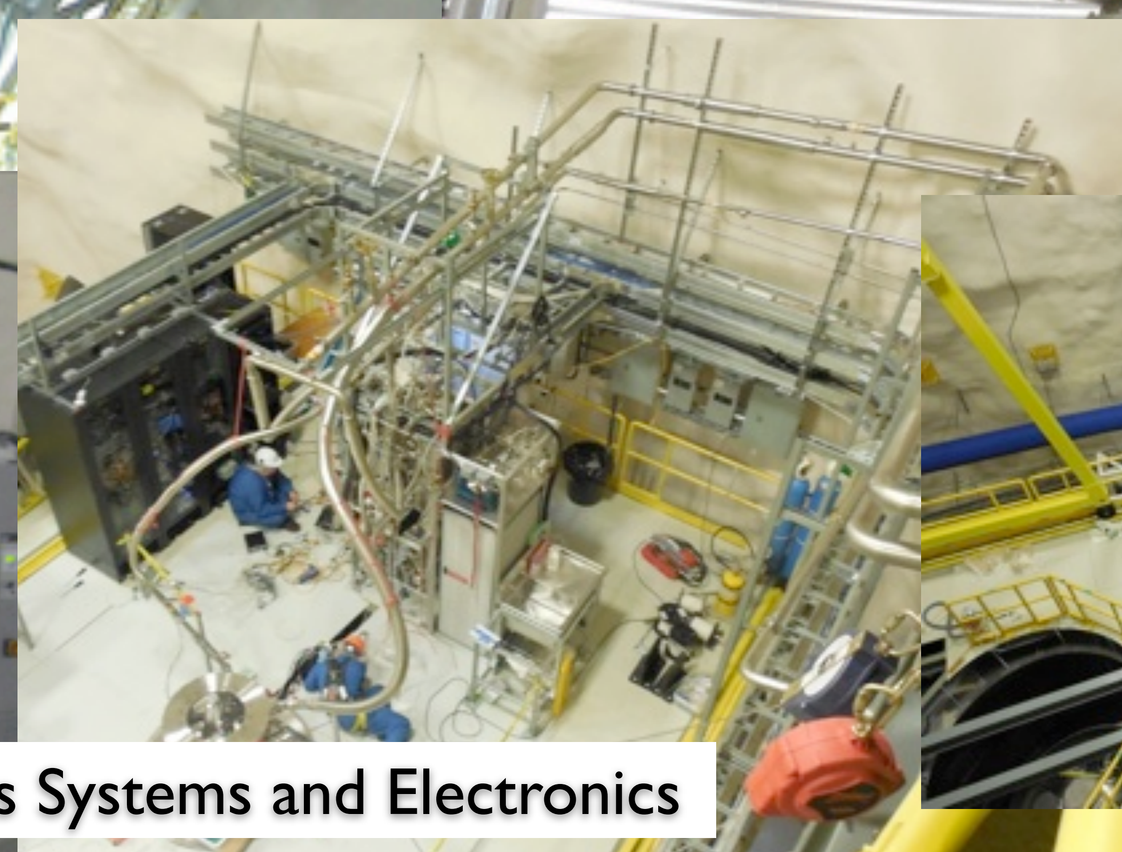
Infrastructure complete, cryo and DAQ running underground.



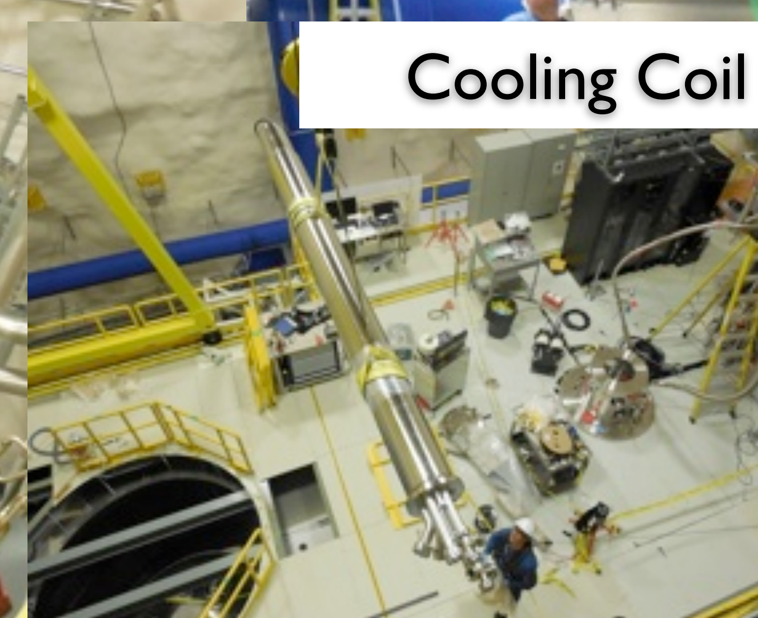
SNOLab Cube hall

Deck Installation

Steel Shell in the veto tank



Process Systems and Electronics

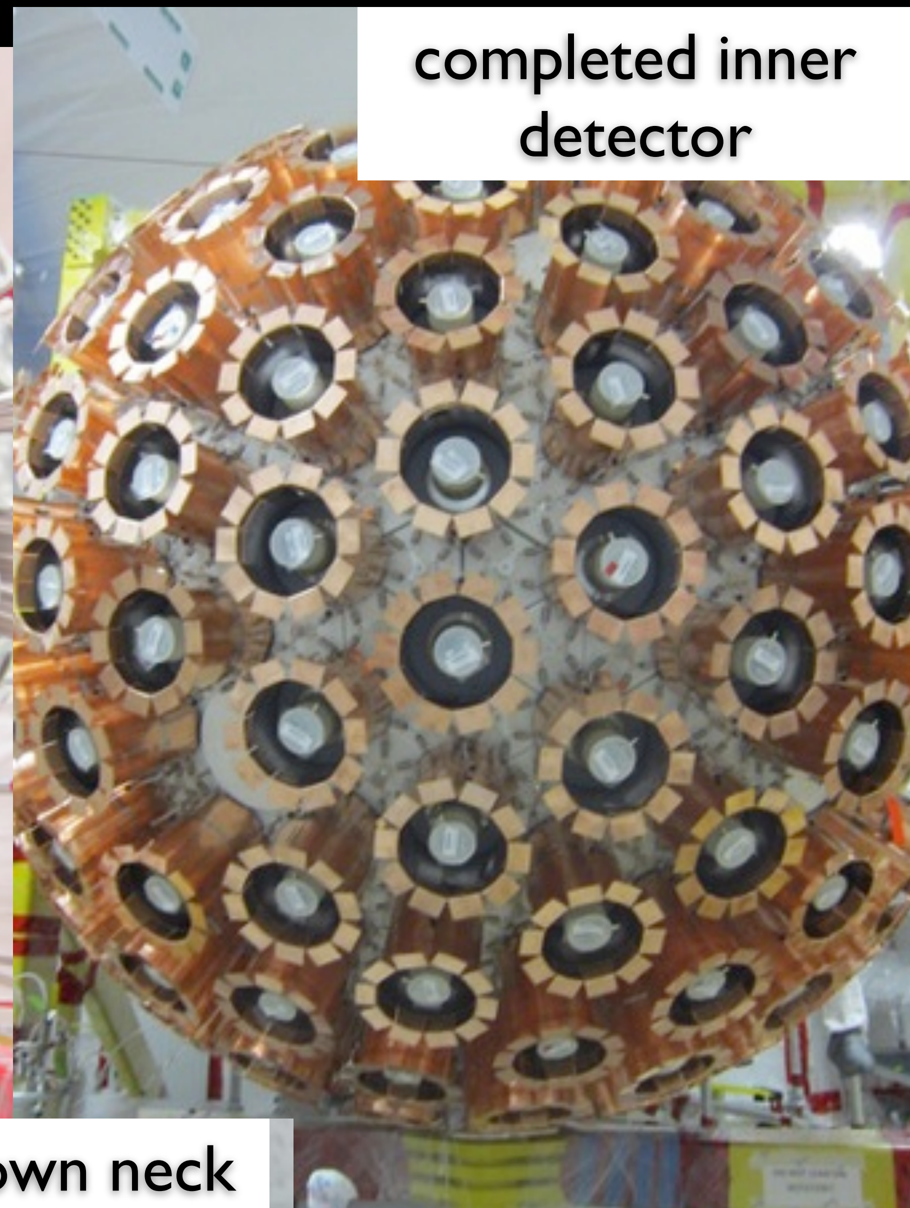


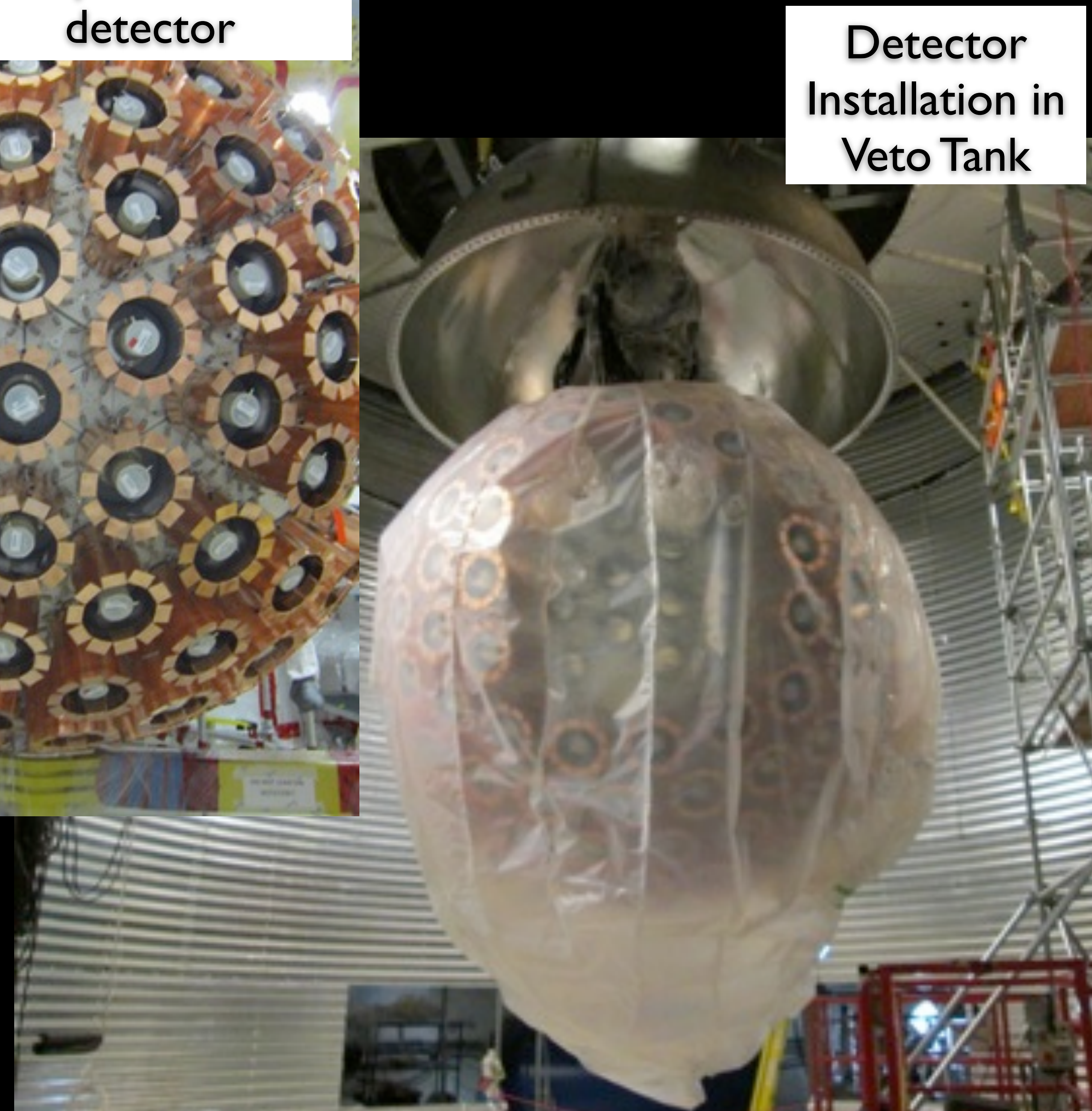
Cooling Coil

Construction Progress

Construction Progress

Internal resurfacing now, TPB evaporation next, LAr fill Fall 2014, physics 2015.





DEAP3600 Calibration System (UK)

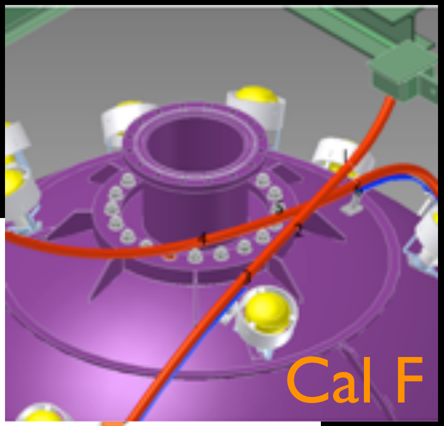
1. Sources and Ports:

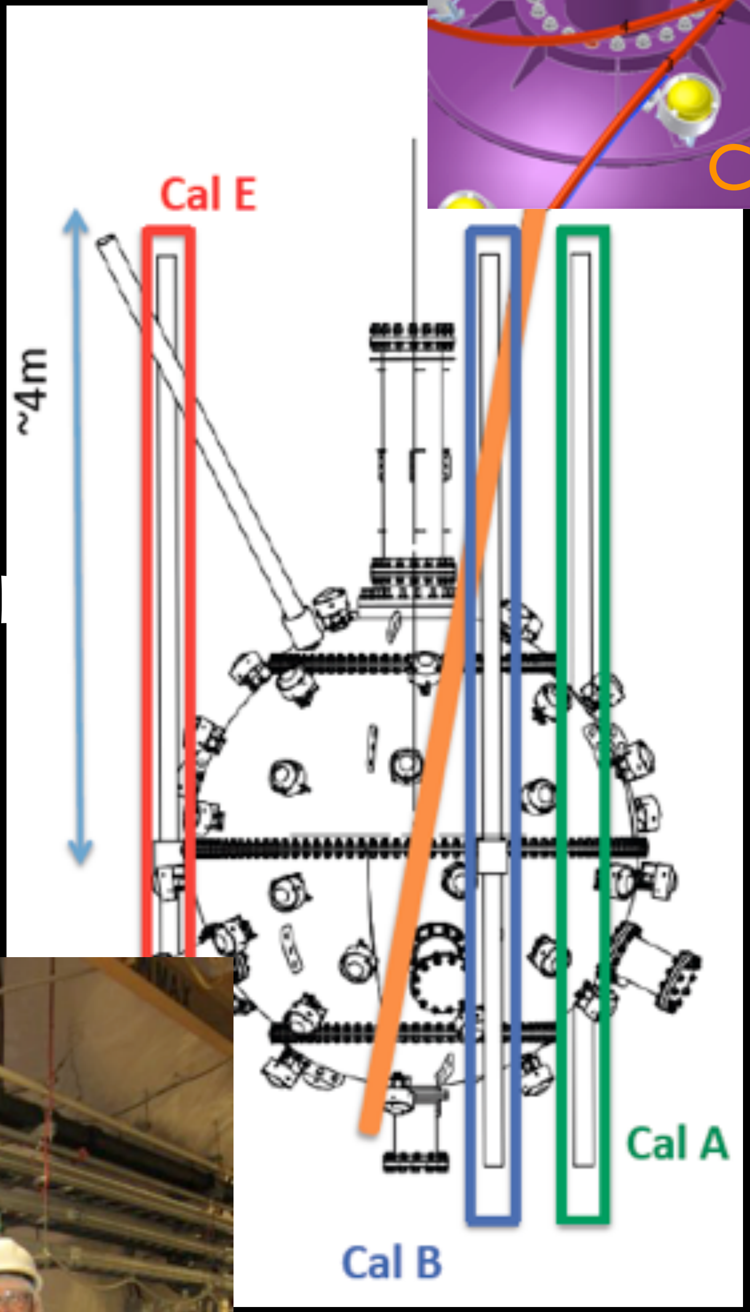
- tagged Na-22 source Cal A,B,E pipes, Cal F racetrack (RAL)
- tagged AmBe source in Cal A,B,E (RHUL)
- optical calibration sources in neck (laser- and LED-flasks), 20 PMT lightguide reflectors (fixed), and neck laser (Sussex)

2. Deployment systems:

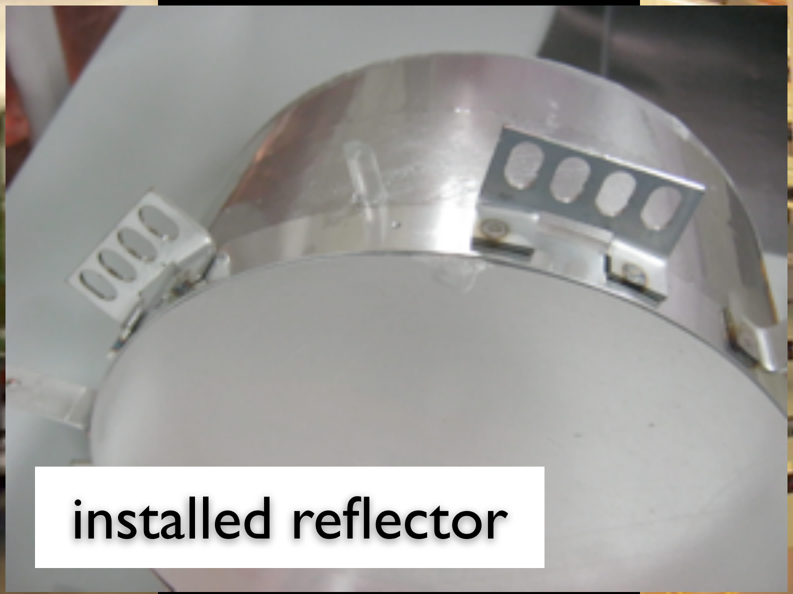
- source deployment systems for Cal F and Cal A,B,E
- neutron source deployment / HV delivery system for Cal A,
- LED flask deployment through neck
- Acrylic reflector array + fibers + LED drivers

Calibration commissioning on-site now underway!

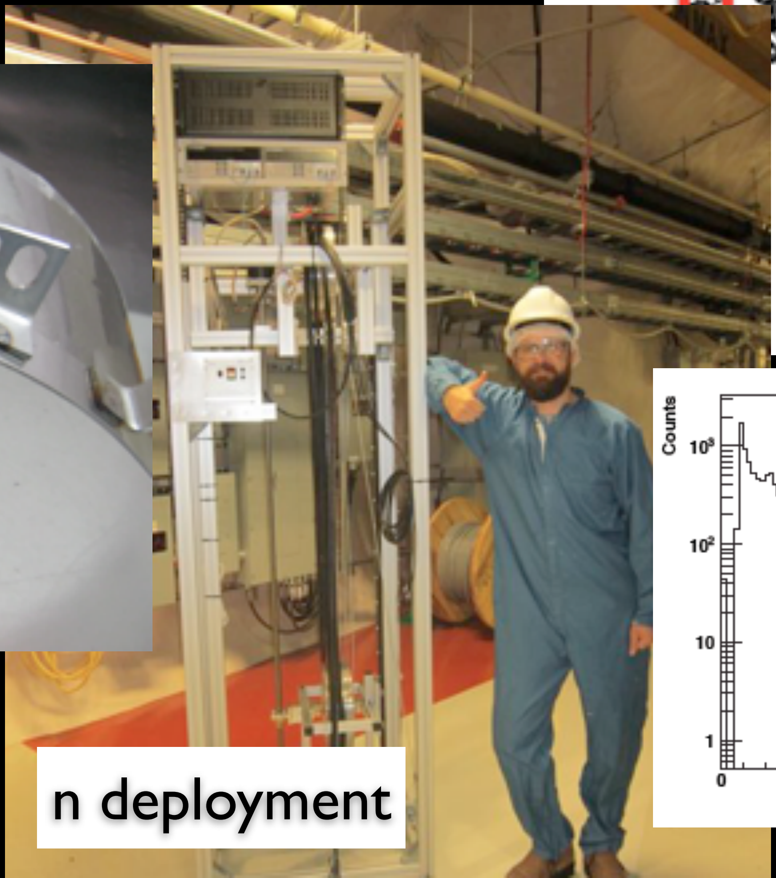




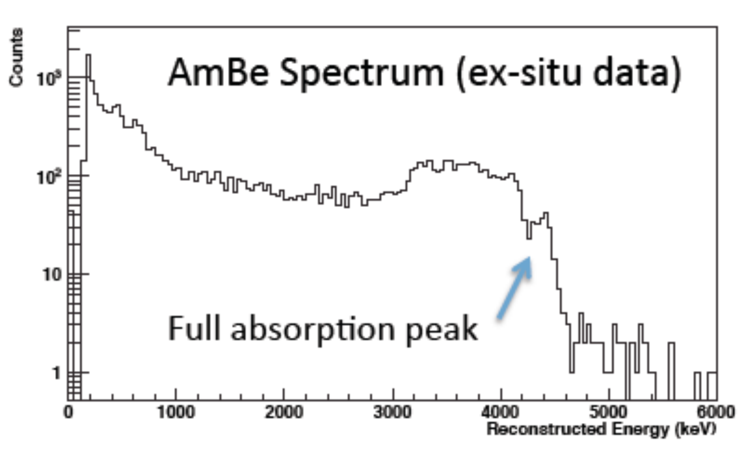
gamma system deployment test



installed reflector



n deployment

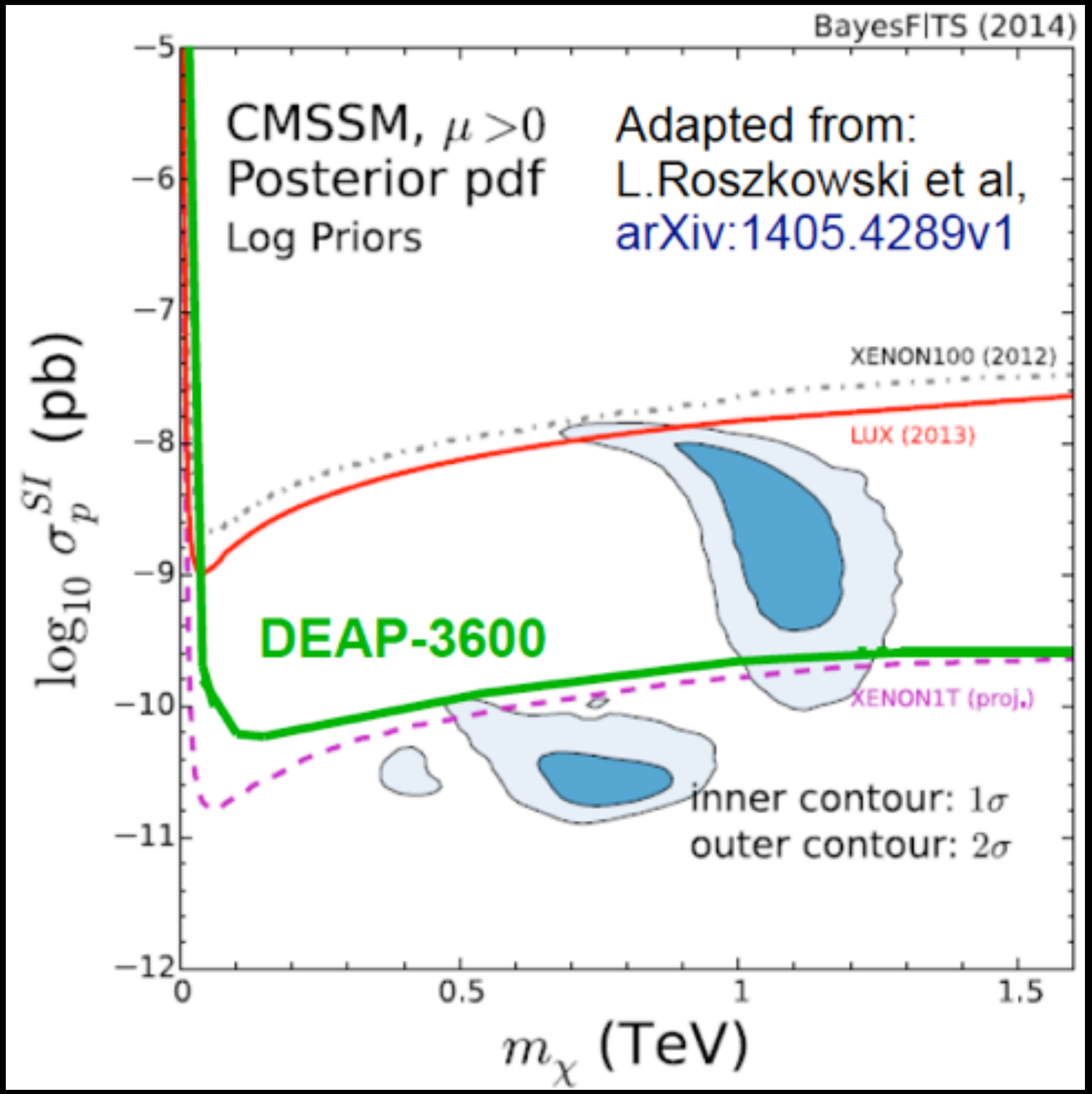


Summary and Outlook

DEAP3600 will be the first demonstration of single-phase liquid Argon technology.

DEAP/CLEAN Detector development programme:

- MiniCLEAN: measure PSD, prototype LAr/LNe target exchange to test A^2 scaling
- DEAP3600: dark matter discovery reach of 10^{-46} cm^2 in 3 tonne-yrs exposure, at conservative 60 keVr threshold.
- prototypes for kT-scale, O(10s) of keV threshold detector for 'low-energy frontier' physics



DEAP3600 construction nearly complete

- resurfacing underway, TPB evaporation next, LAr fill soon!
- process systems, DAQ, calibration commissioning underway
- physics 2015!

Stay tuned…

Other Slides

Calibration R&D (STFC PRD)

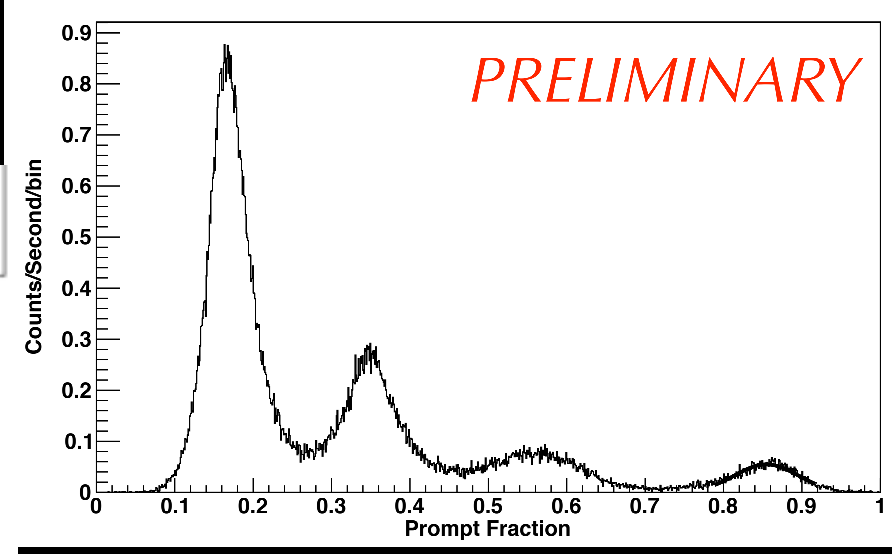
What if we see 5 events? How will we know if this is a signal?

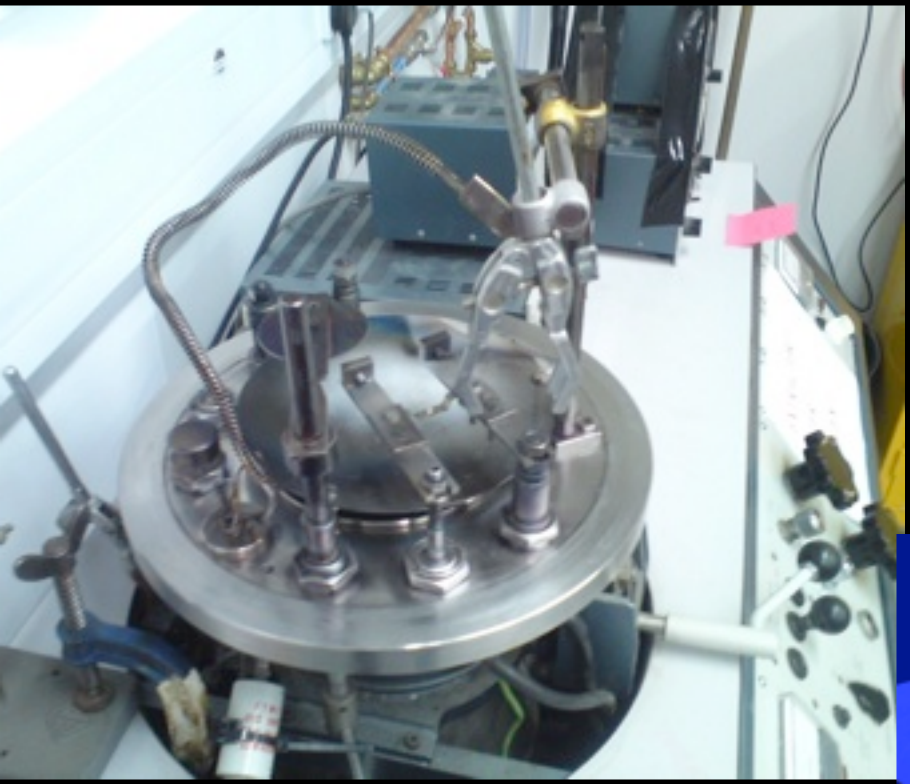
- Objectives: ex-situ measurement input to calibration analysis,
  (i) reduce systematics on energy, radius reconstruction,
  (ii) break correlations between parameters for MC tuning

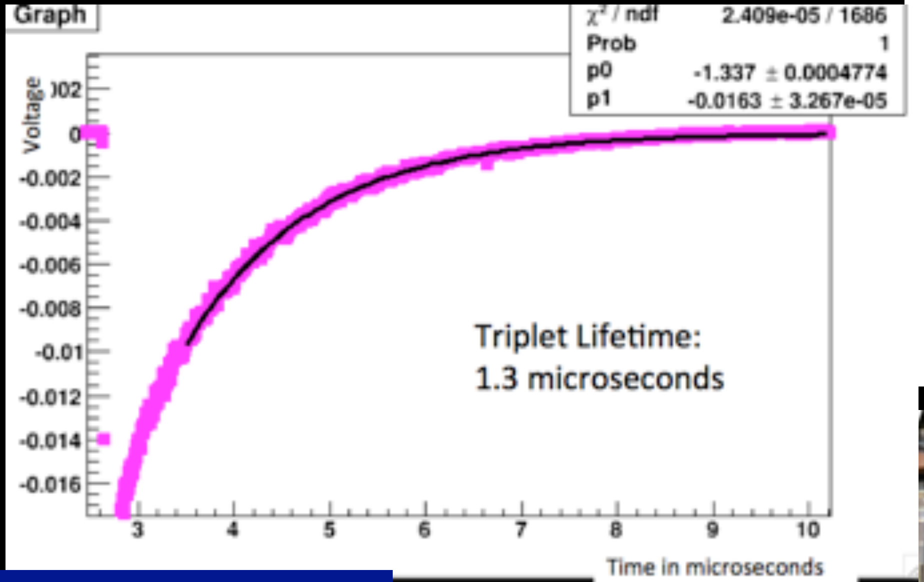
-source R&D: study modeling of source calibration (RAL)

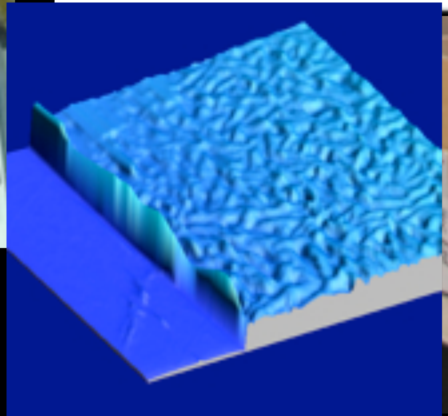
-scintillation R&D: measure the scattering length and temp. dependence in noble liquids, explore laser calibration (RHUL)

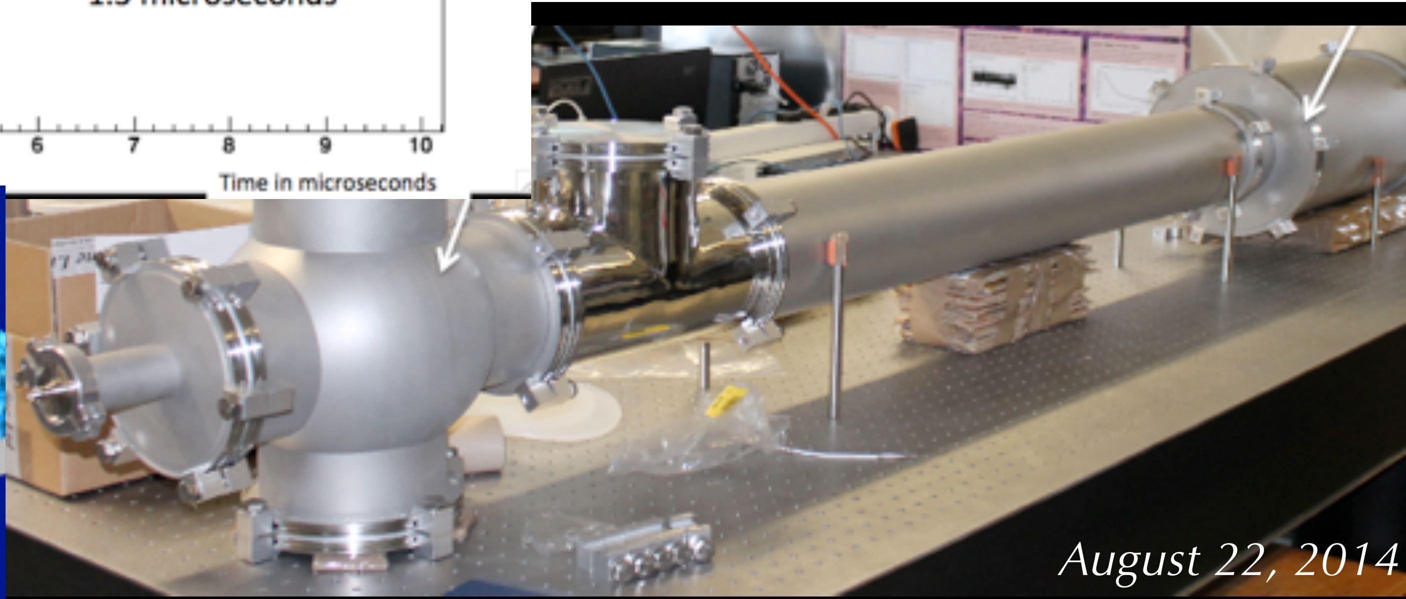
-optical response R&D: measure the optical properties of TPB wavelength shifter (University of Sussex)











Depleted Argon

A. Wright, arXiv:1109.2979

- ^{39}Ar beta decays with 565 keV endpoint, at ~1 Bq/kg with half-life 269 years
- ^{39}Ar production supported by cosmogenic activation, underground Ar has less!
- low-background Ar sources reduce Ar-39 by a factor of >50 at least (counting-only analysis)

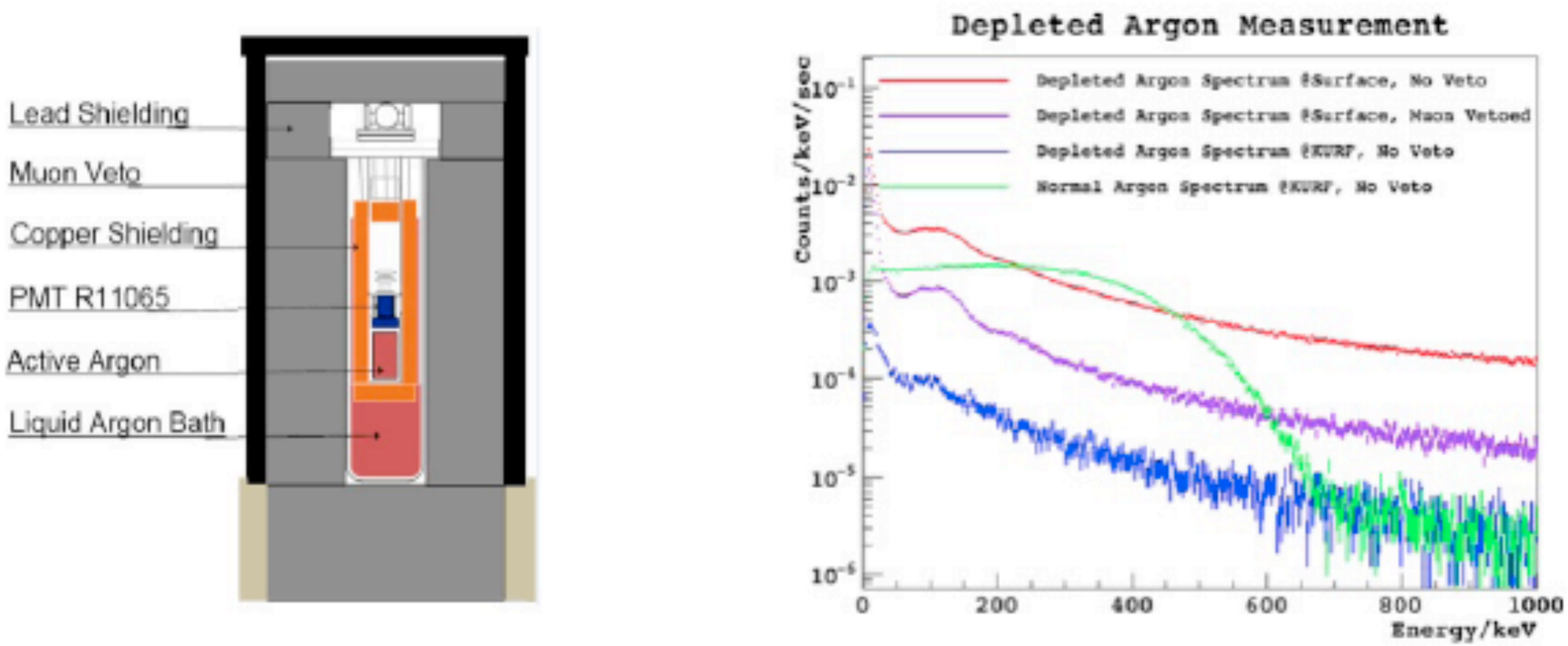


Figure 2: Left: Schematic diagram of the "Low Background Detector." Right: The depleted argon spectra obtained in various detector configurations. In the measurement at KURF, the total event rate in 300-400 keV is ~0.002 Hz, about 2% of the rate expected from ^{39}Ar in atmospheric argon. Data taken with atmospheric argon is shown for comparison (green) - in this data the ^{39}Ar spectrum is clearly visible.