DEAP/CLEAN-ing Dark Matter: the Search for Direct Detection with Liquid Argon

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Particle Physics Seminar
Birmingham University
February 8, 2012

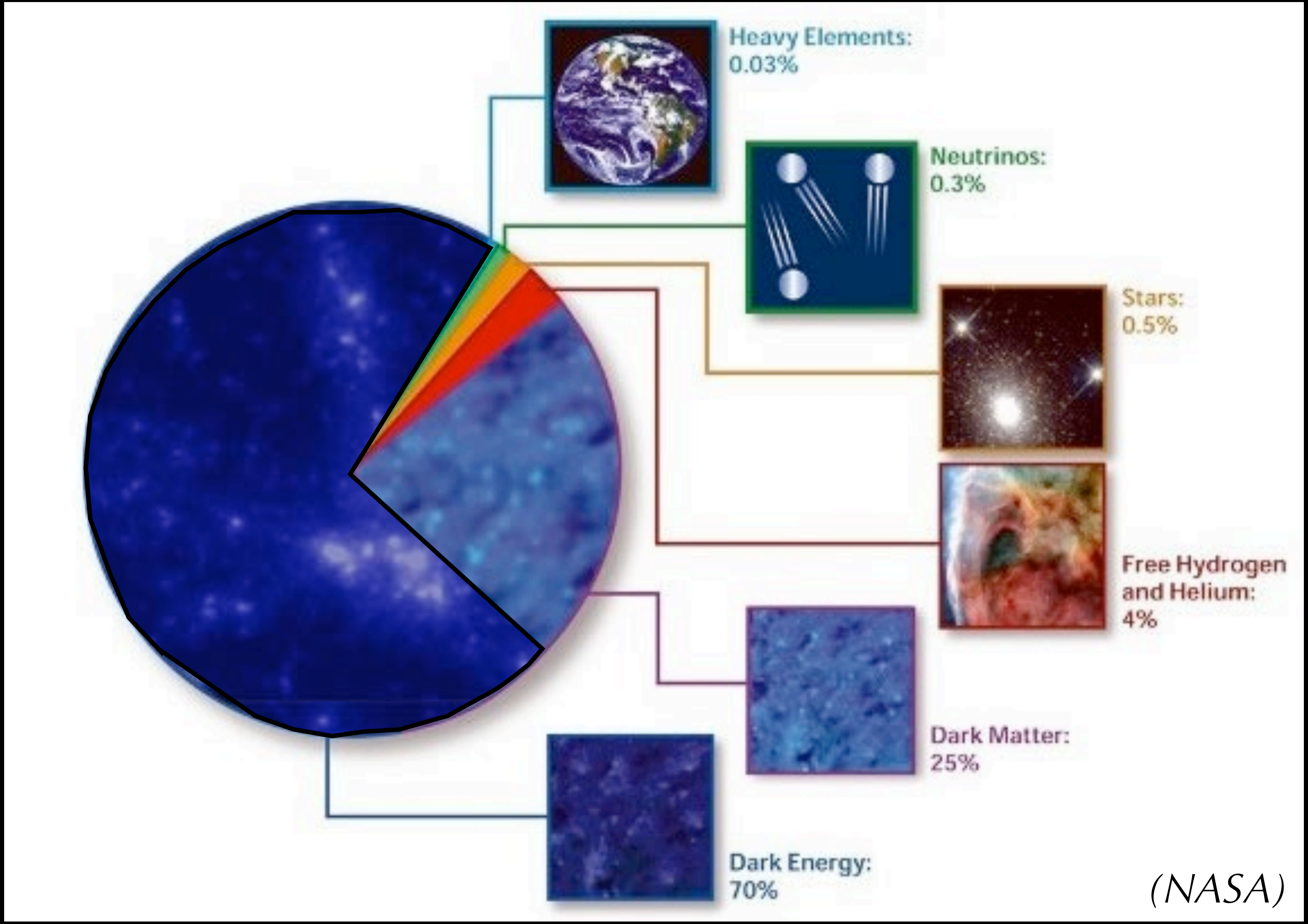
Outline

Direct Dark Matter Detection

DEAP/CLEAN Experimental Technique

How Will We Know When Dark Matter is Discovered?

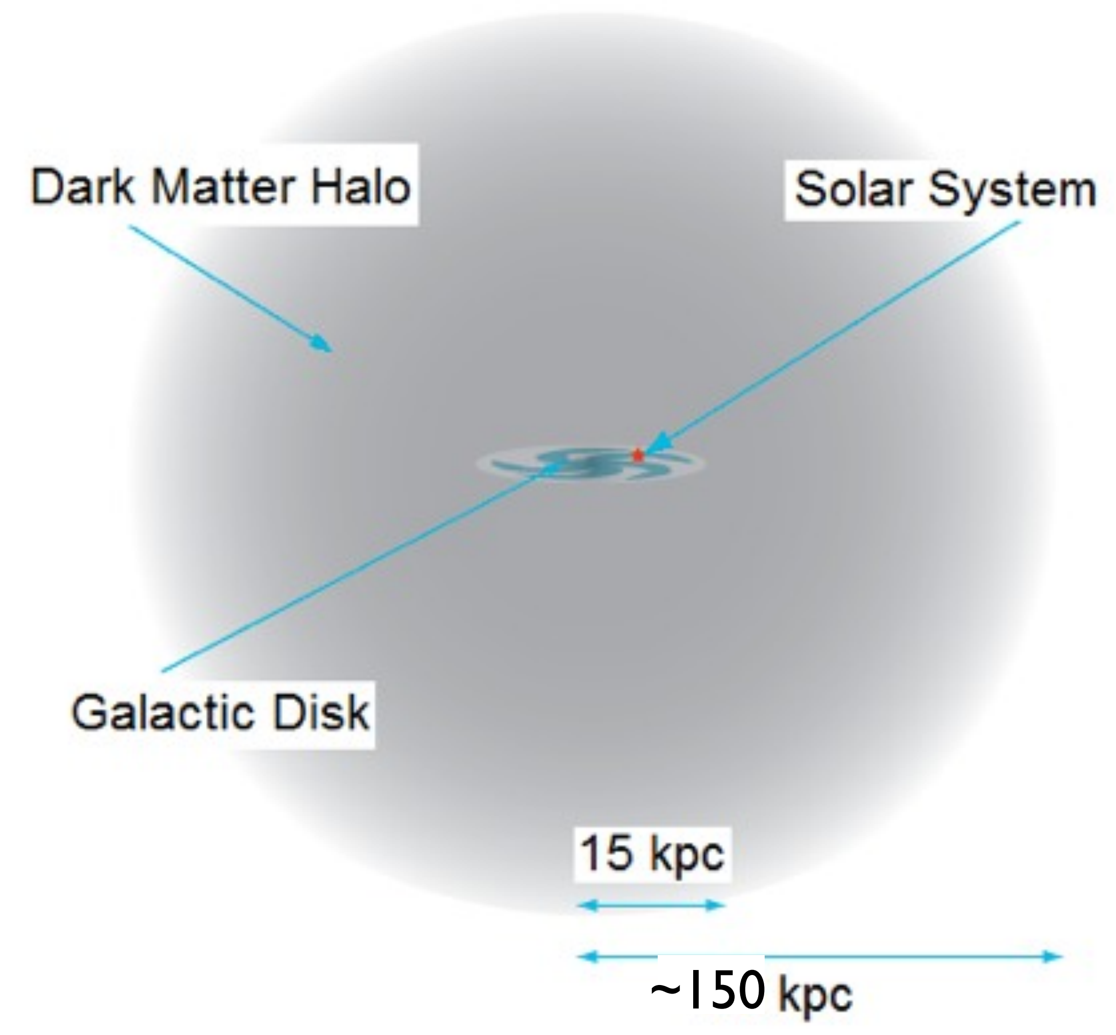
Standard Model of Cosmology



(NASA)

Dark matter is ~23% of the universe.

What do we know about Dark Matter?



optically dark

density ~ 0.3 GeV/cm^3

dark matter particle mass: ~unknown

interactions: very weak, ~collision-less

Dark Matter Candidates

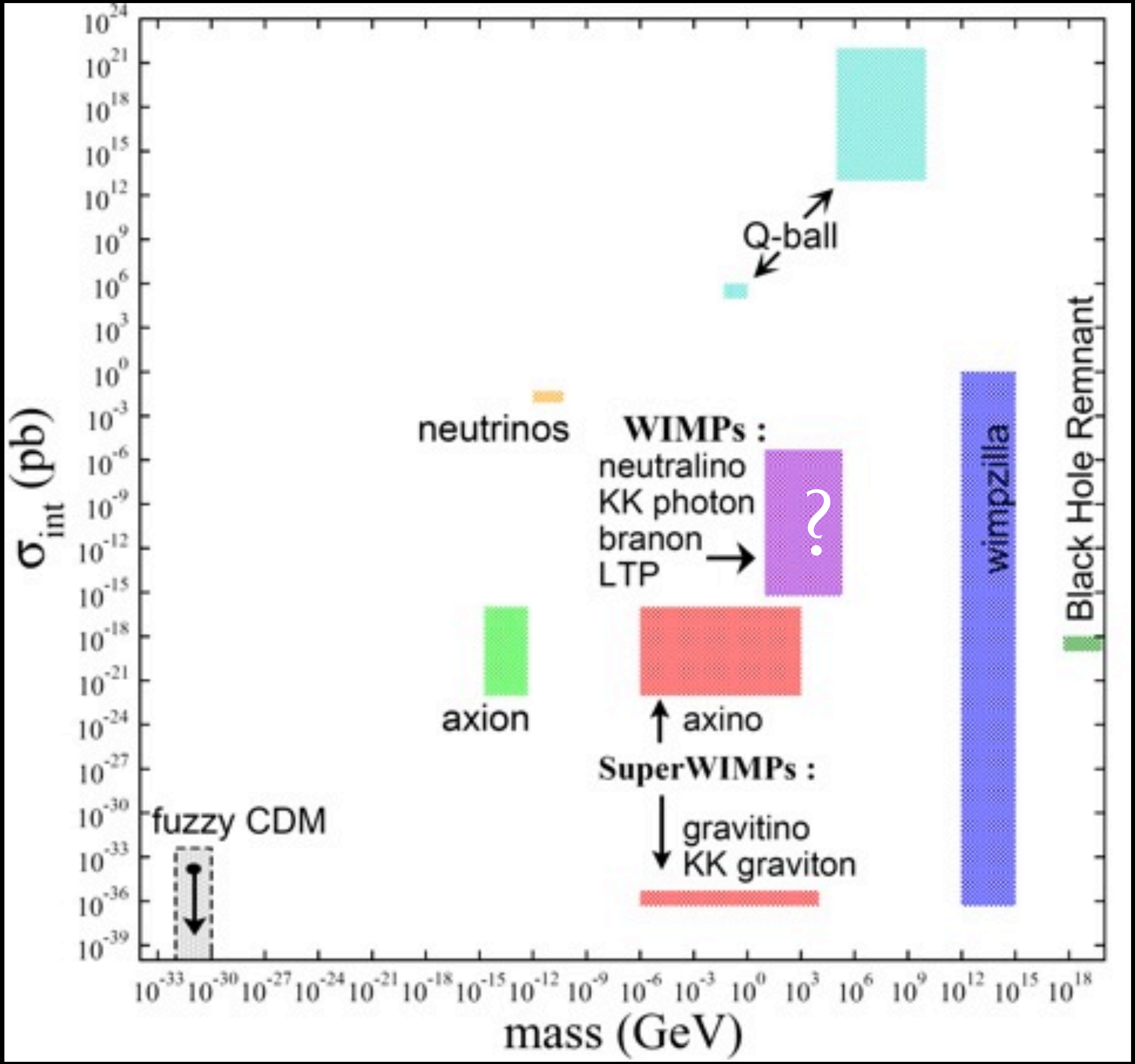
strong

e.m.

weak

gravity

interaction strengths



HEPAP/AAAC DMSAG Subpanel (2007)

masses

neutrino?

electron

t-quark

#1: What is the universe made of?

125 Questions: WHAT DON'T WE KNOW?

Science AAAS

"The quest to elucidate the nature of dark matter and dark energy is at the heart of particle physics—the study of the basic constituents of nature..."

ASTROPARTICLE PHYSICS

the European strategy

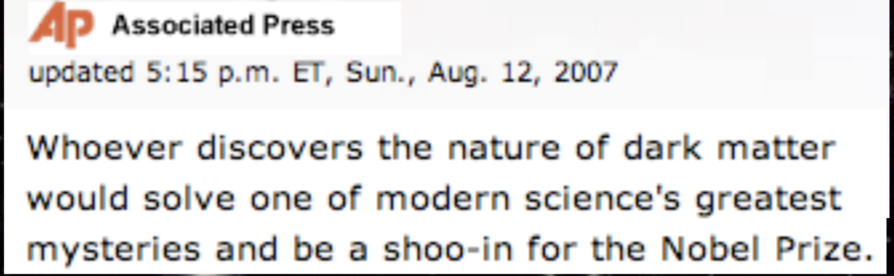
"An answer to the question [what is dark matter] would mark a major breakthrough in understanding the universe and would open an entirely new field of research on its own."

US Particle Physics: Scientific Opportunities

A Strategic Plan for the Next Ten Years

"an area of world leading science opportunity"
"significant UK leadership"
"UK involvement is essential"

UK Particle Physics Roadmap
25 September 2009
Particle Physics Advisory Panel



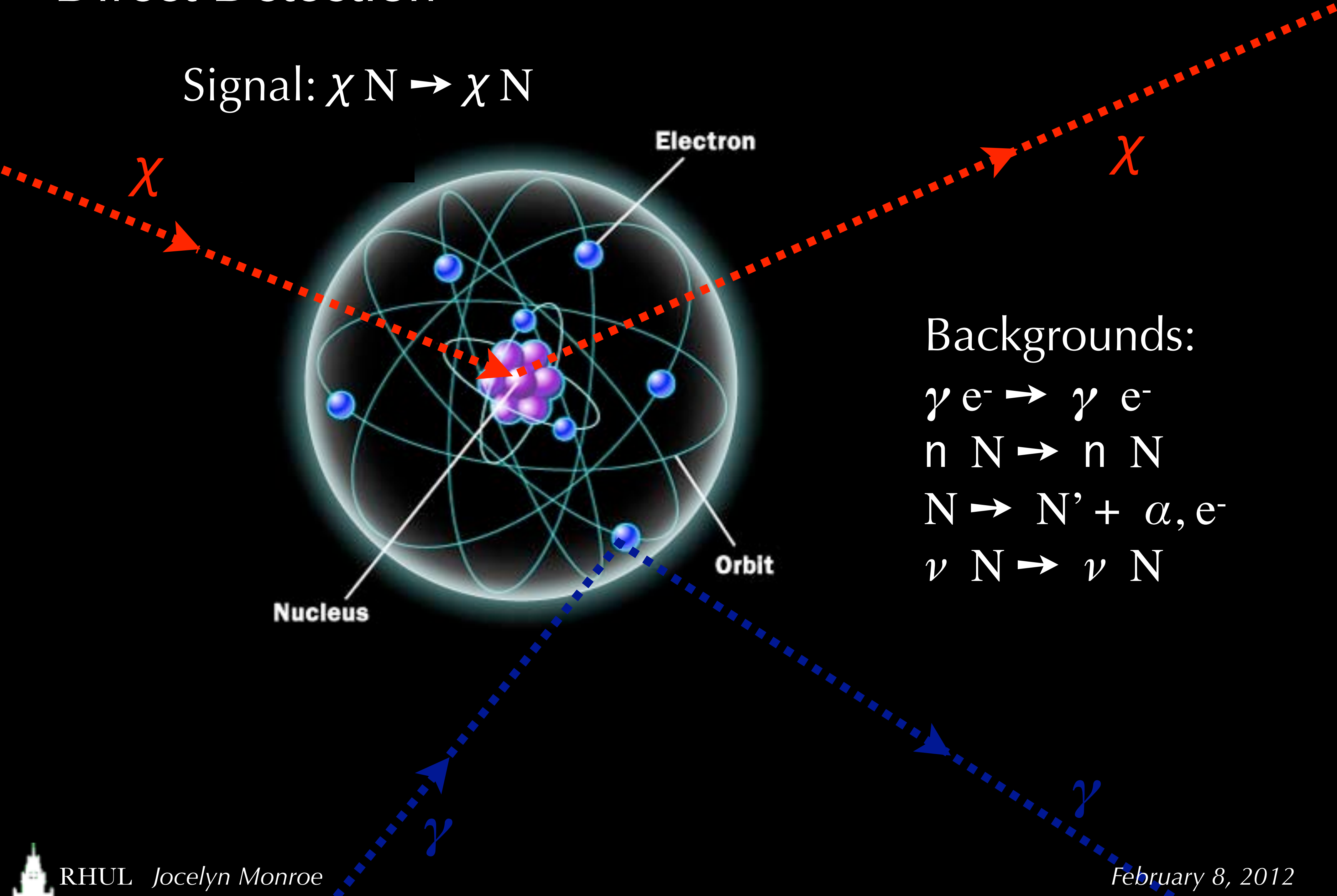
AP Associated Press

updated 5:15 p.m. ET, Sun., Aug. 12, 2007

Whoever discovers the nature of dark matter would solve one of modern science's greatest mysteries and be a shoo-in for the Nobel Prize.

Direct Detection

Signal: $\chi N \rightarrow \chi N$



Backgrounds:

$\gamma\, e^{-} \rightarrow \gamma\, e^{-}$

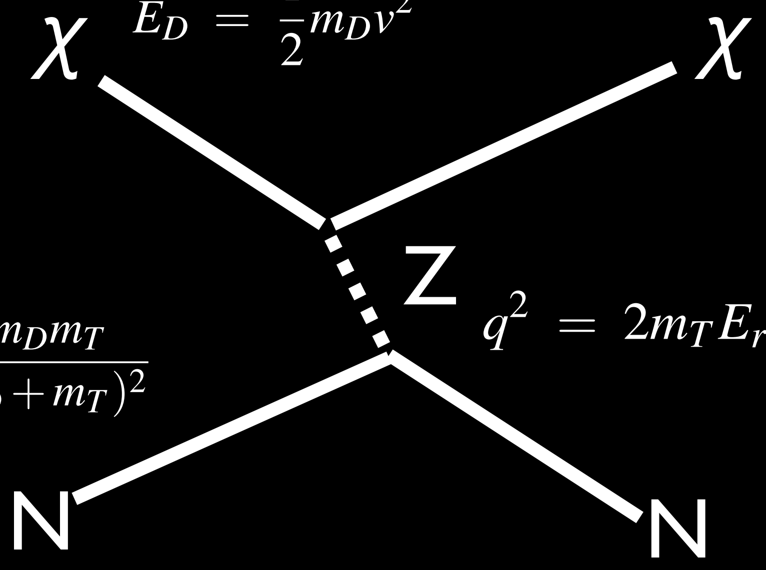
$n\, N \rightarrow n\, N$

$N \rightarrow N' + \alpha, e^{-}$

$\nu\, N \rightarrow \nu\, N$

WIMP Scattering

kinematics: *v/c ~ 8E-4!*



$$E_D = \frac{1}{2} m_D v^2$$

$$r = \frac{4 m_D m_T}{(m_D + m_T)^2}$$

$$q^2 = 2 m_T E_{recoil}$$

$$E_{recoil} = E_D r \frac{(1 - cos\theta)}{2}$$

Spin Independent:

χ scatters coherently off of the entire nucleus A: σ~A^2

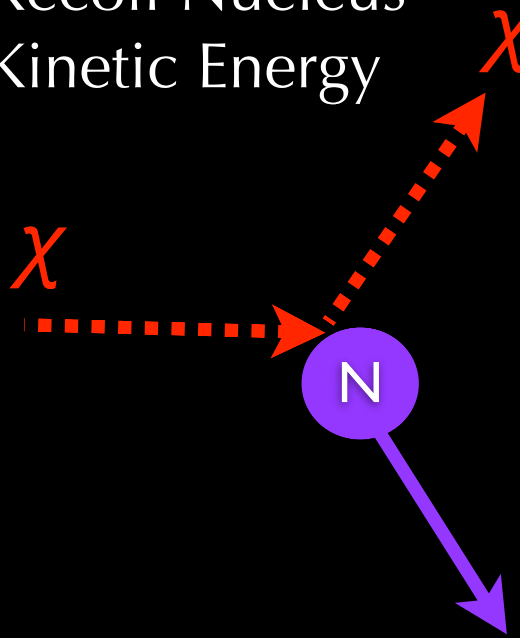
D. Z. Freedman, PRD 9, 1389 (1974)

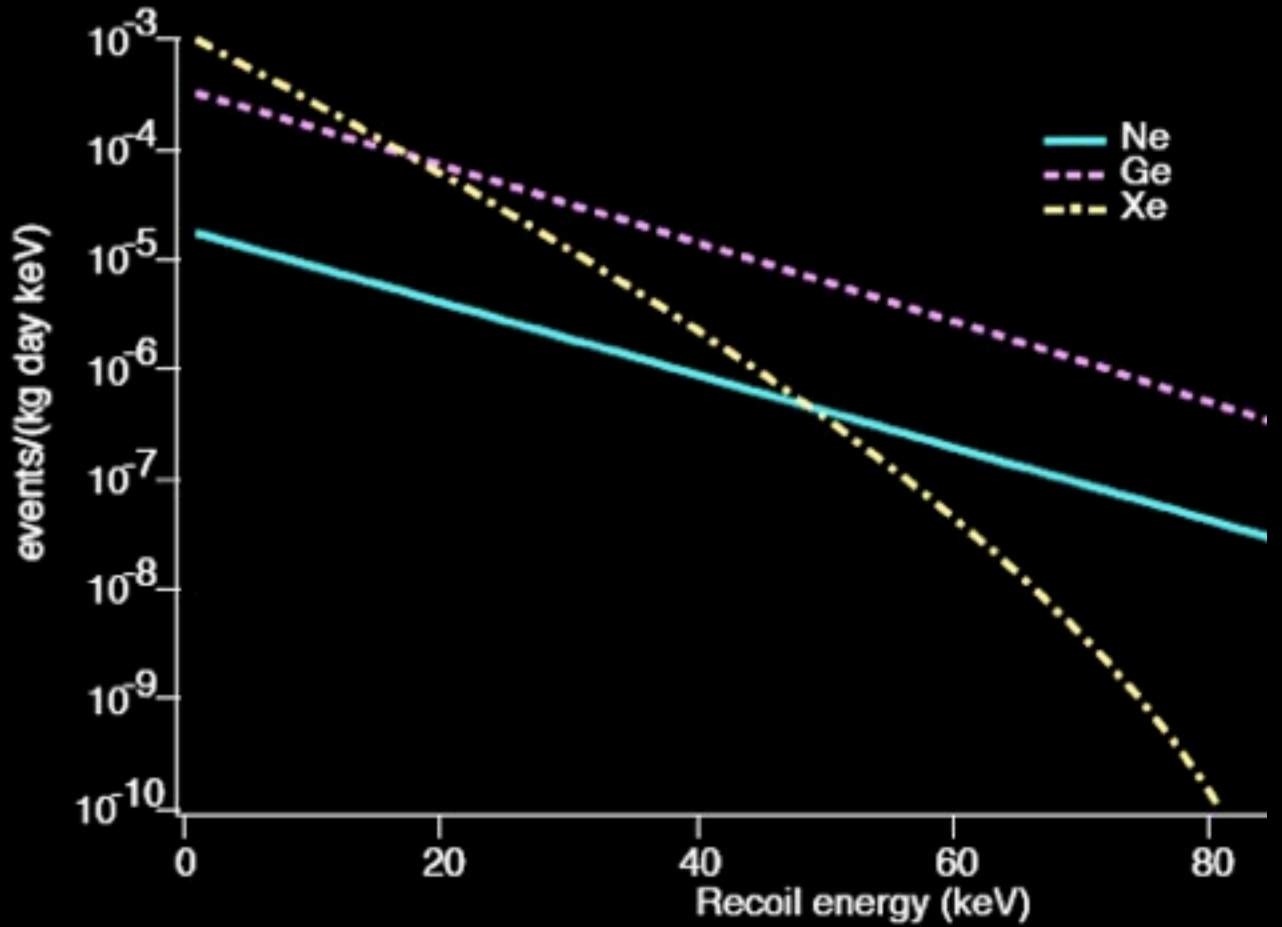
Spin Dependent:

only unpaired nucleons contribute to scattering amplitude: σ~ *J(J+1)*

Measurement

Recoil Nucleus
Kinetic Energy





Scattering rate

Sun's velocity around the galaxy

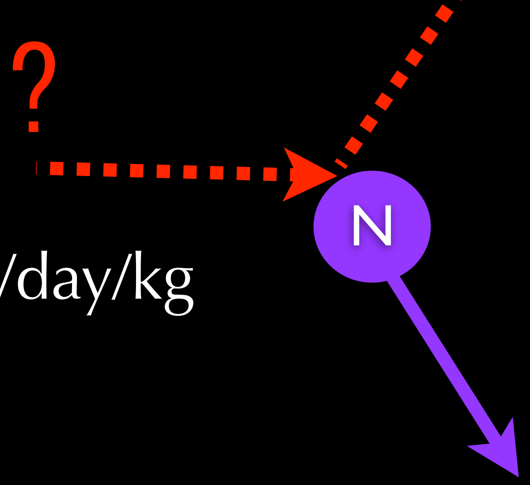
WIMP velocity distribution

$$dR/dQ \sim (\sigma_0 \rho_0 / \sqrt{\pi}\, v_0\, m_\chi m_r^2)\, F^2(Q)\, T(Q)$$

WIMP energy density, 0.3 GeV/cm³

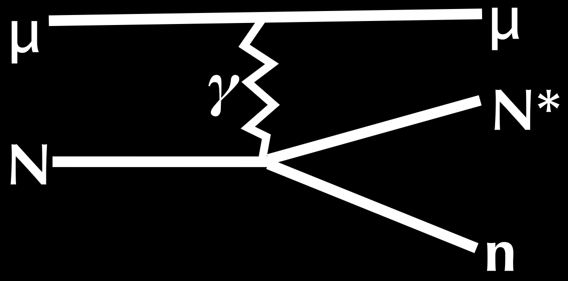
Form factor

Backgrounds

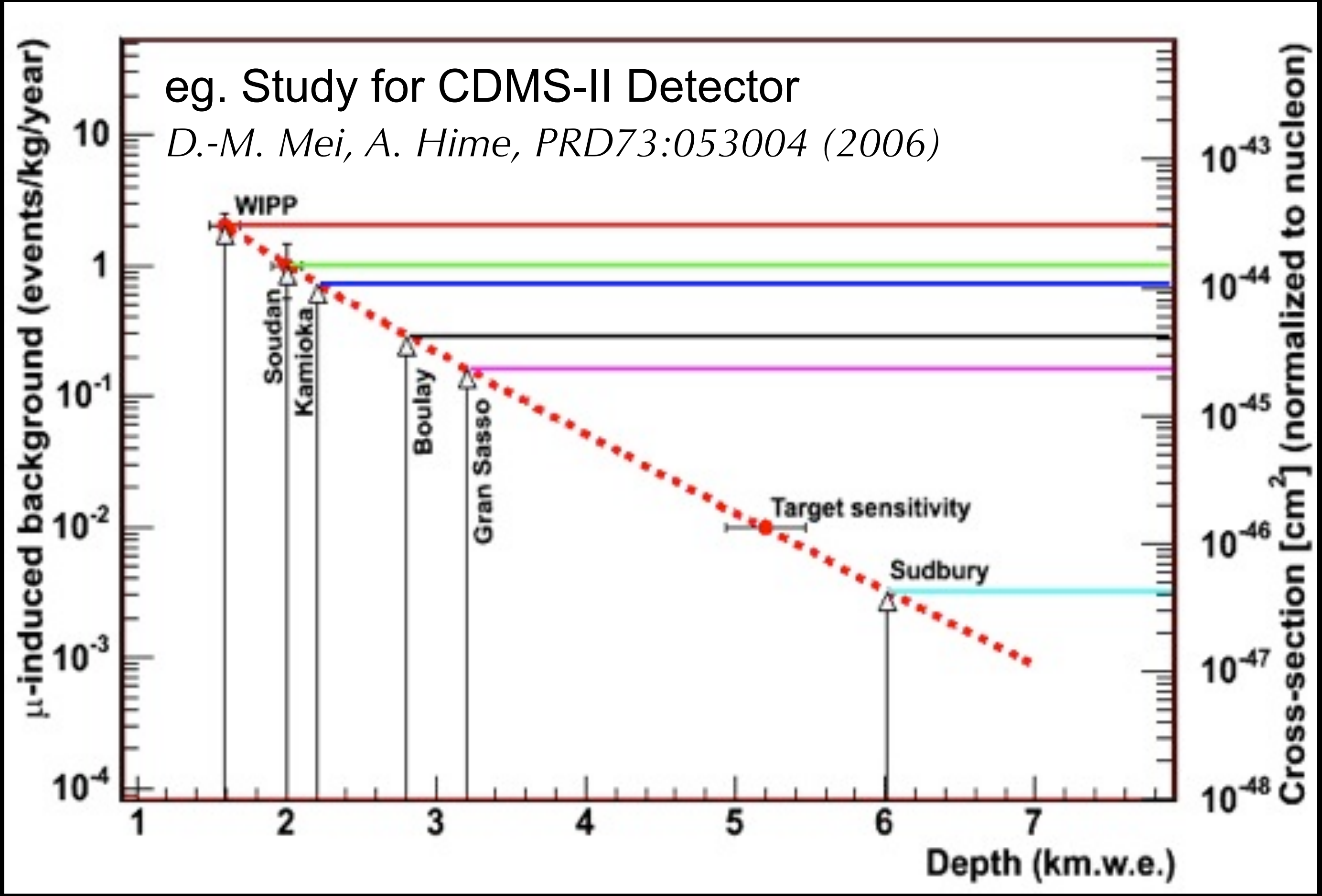


Gamma ray interactions:
rate ~ N_e x (gamma flux), typically 10 million events/day/kg
mis-identified electrons mimic nuclear recoil signals

Neutrons:
(alpha,n), U, Th fission, cosmogenic spallation

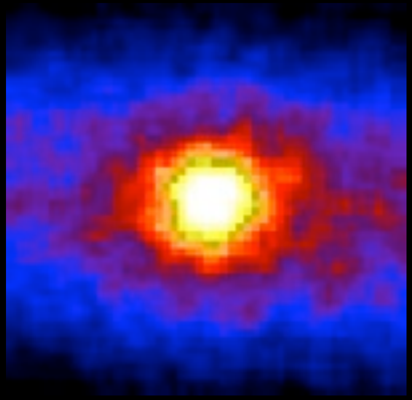


nuclear recoil final state


eg. Study for CDMS-II Detector
D.-M. Mei, A. Hime, PRD73:053004 (2006)

Contamination:
^{238}U and ^{232}Th decays, recoiling progeny and mis-identified alphas mimic nuclear recoils

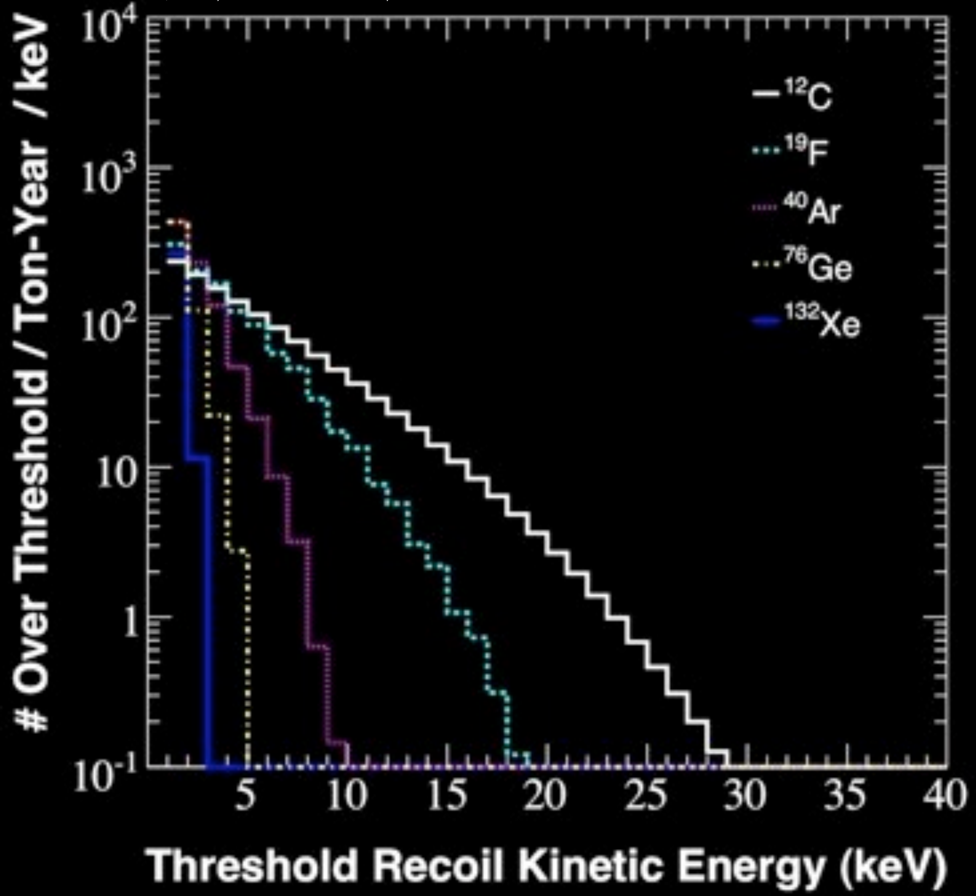
Irreducible Backgrounds

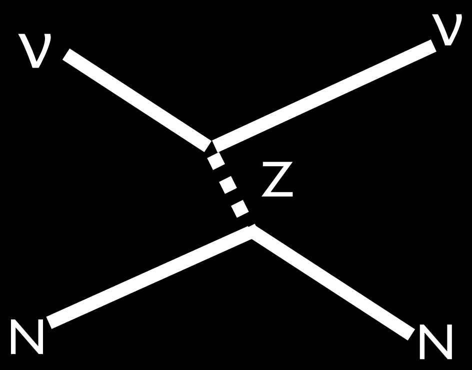


impossible to shield a detector from coherent neutrino scattering:

Φ(solar B^8) = 5.86 x 10^6 cm^{-2} s^{-1}

JM, P. Fisher, PRD76:033007 (2007)

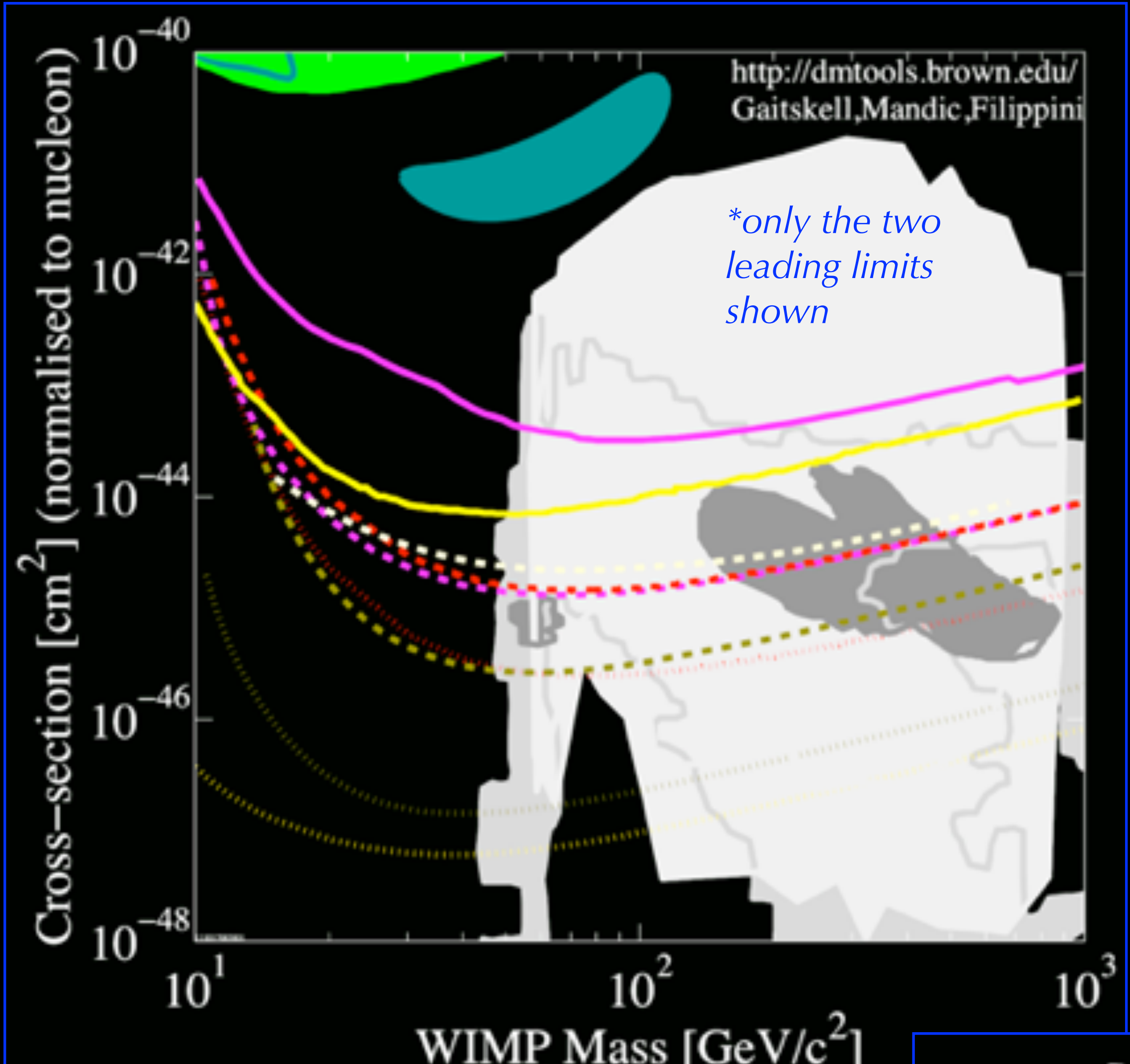




nuclear recoil final state
1 event/ton-year =~ 10^{-48} cm^2 limit
in zero-background paradigm

unless you measure
the direction!

The Low Background Frontier



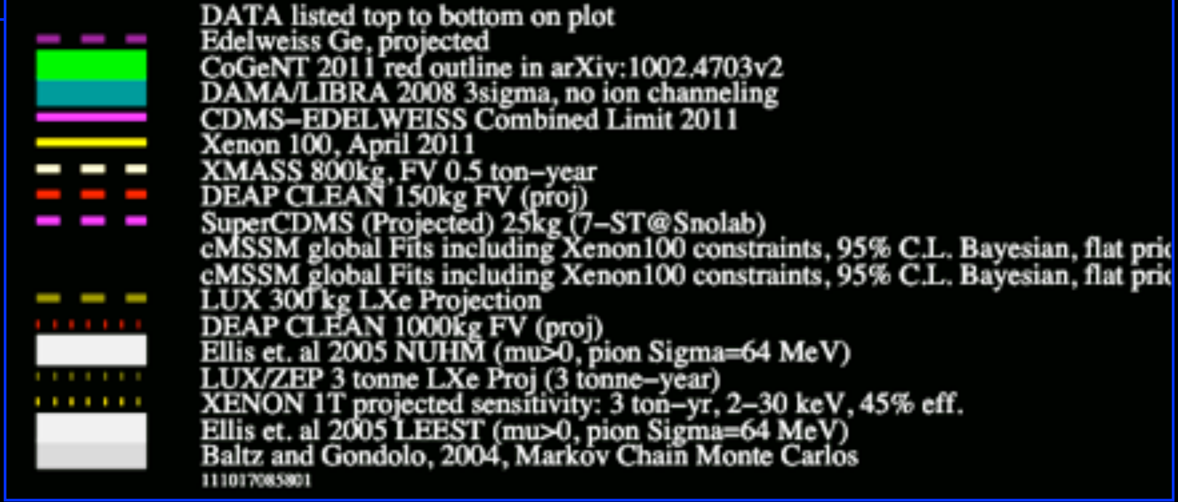
**only the two leading limits shown*

1 event/kg/day

1 event/100 kg/day

1 event/100 kg/100 days

so far: 3 years/
order of magnitude



DATA listed top to bottom on plot
– – – Edelweiss Ge, projected
🟩 CoGeNT 2011 red outline in arXiv:1002.4703v2
🟩 DAMA/LIBRA 2008 3sigma, no ion channeling
▬ CDMS–EDELWEISS Combined Limit 2011
▬ Xenon 100, April 2011
– – – XMASS 800kg, FV 0.5 ton–year
– – – DEAP CLEAN 150kg FV (proj)
– – – SuperCDMS (Projected) 25kg (7–ST@Snolab)
cMSSM global Fits including Xenon100 constraints, 95% C.L. Bayesian, flat pri
cMSSM global Fits including Xenon100 constraints, 95% C.L. Bayesian, flat pri
– – – LUX 300 kg LXe Projection
⋯ DEAP CLEAN 1000kg FV (proj)
⬜ Ellis et. al 2005 NUHM (mu>0, pion Sigma=64 MeV)
⋯ LUX/ZEP 3 tonne LXe Proj (3 tonne–year)
⋯ XENON 1T projected sensitivity: 3 ton–yr, 2–30 keV, 45% eff.
⬜ Ellis et. al 2005 LEEST (mu>0, pion Sigma=64 MeV)
⬜ Baltz and Gondolo, 2004, Markov Chain Monte Carlos
111017085801

10^4 is a lot of σ

10^{-24} cm^2: σ(neutron-A elastic scattering)

10^{-28} cm^2: σ(total inelastic pp at TeVatron)

10^{-35} cm^2: σ(gg ➔ H) at LHC (Standard Model)

10^{-39} cm^2: σ(single top) at TeVatron

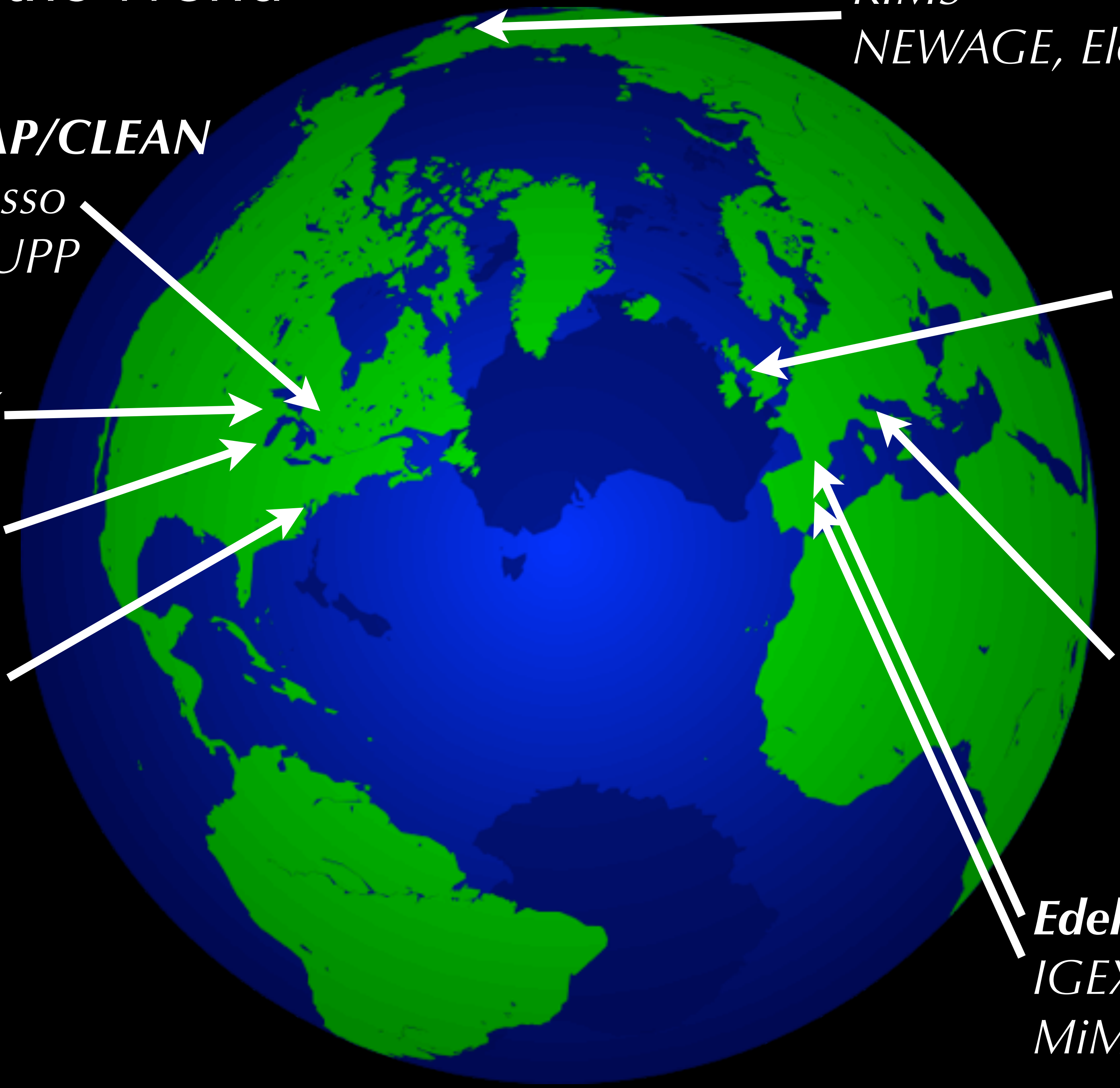
10^{-40} cm^2: σ(ν QE) at T2K

10^{-45} cm^2: σ(ν-e Elastic) for solar ν

σ(dark matter coherent scattering)? 10^{-48} cm^2

Not to Scale

Around the World



KIMS
NEWAGE, Elegants

DEAP/CLEAN
Picasso
COUPP

DRIFT
Zeplin
NaIAD

LUX

CDMS

DMTPC

Xenon10(0)
Genius
DAMA
CRESST
DarcSide

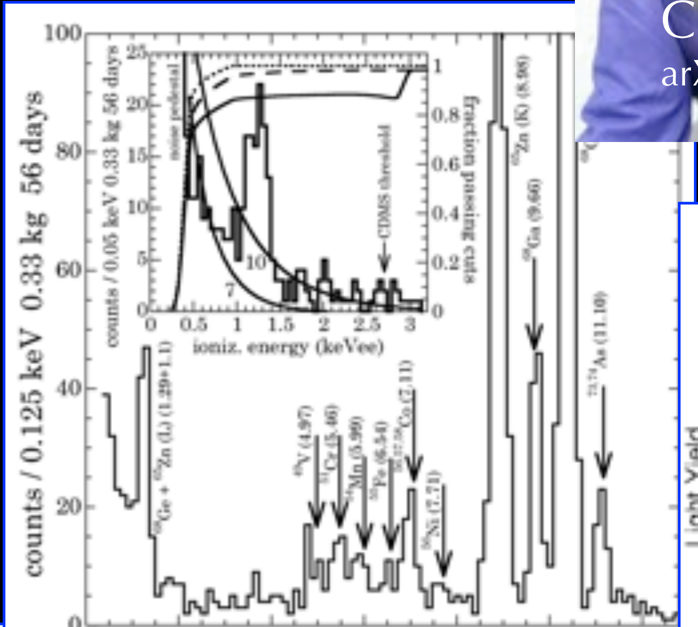
Edelweiss
IGEX, ANAIS
*MiMAC, **ArDM***

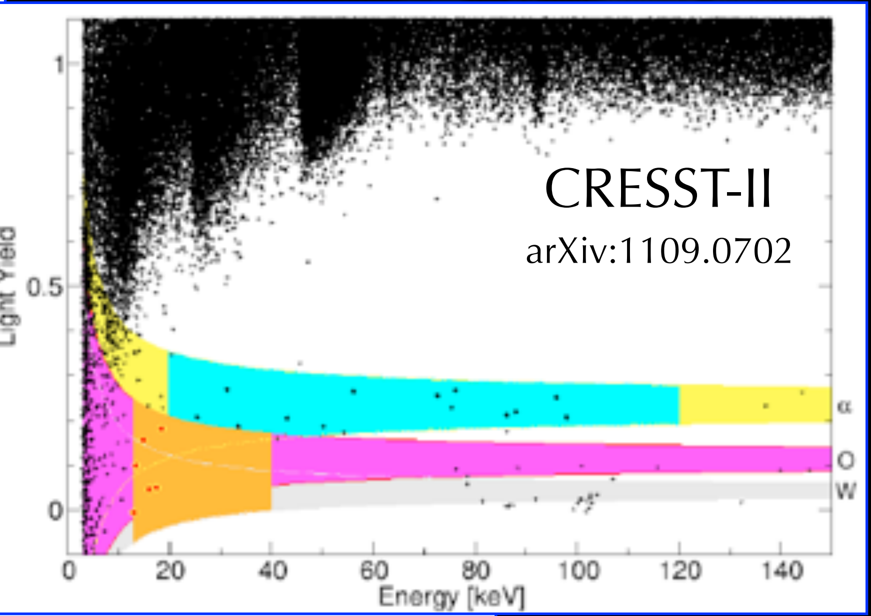
Direct Dark Matter Signals?

DAMA/Libra

COGENT

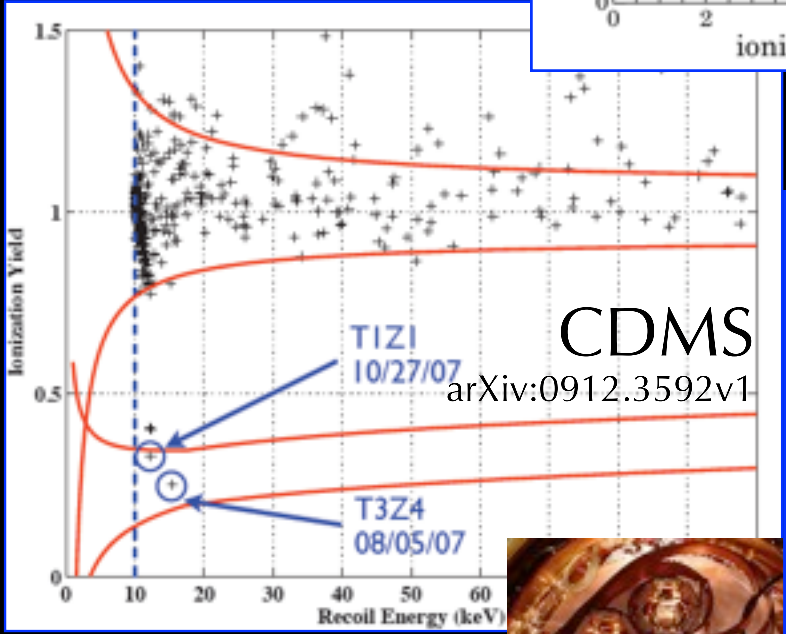
arXiv:1002.4703





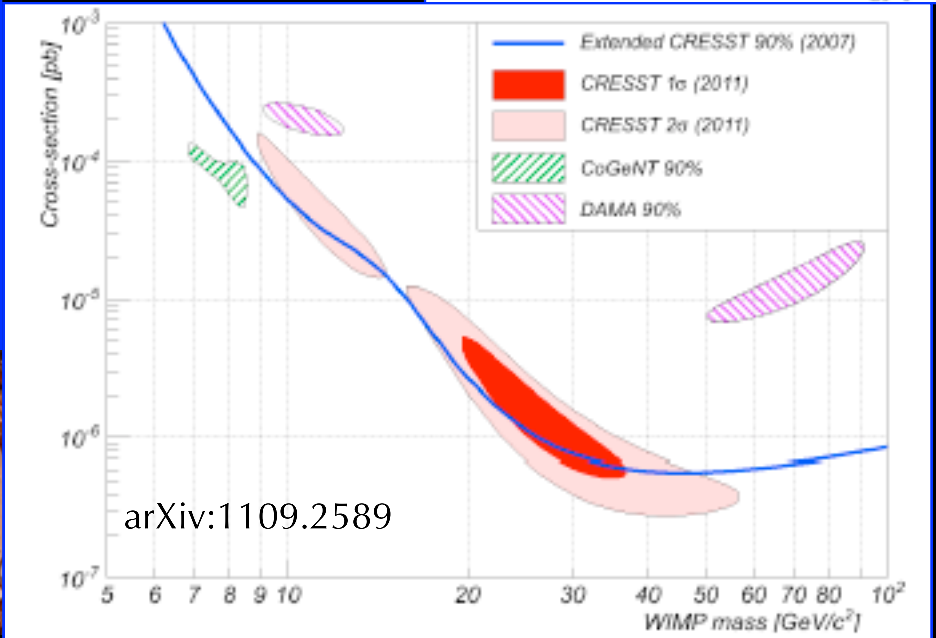
CRESST-II

arXiv:1109.0702



CDMS

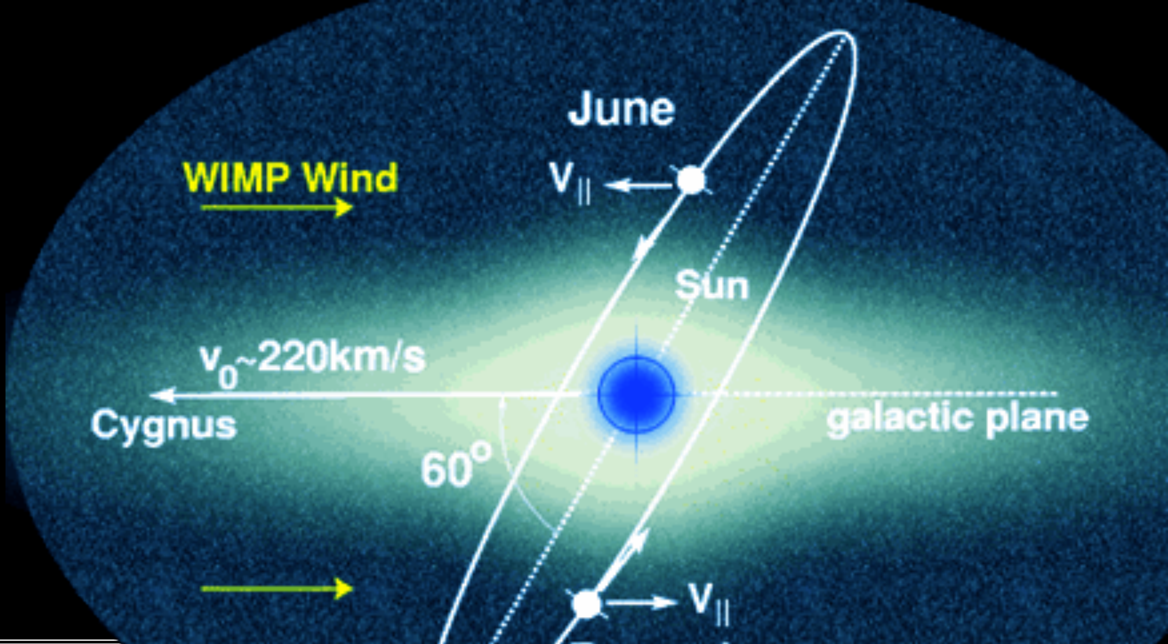
arXiv:0912.3592v1



arXiv:1109.2589

dark matter?
backgrounds?

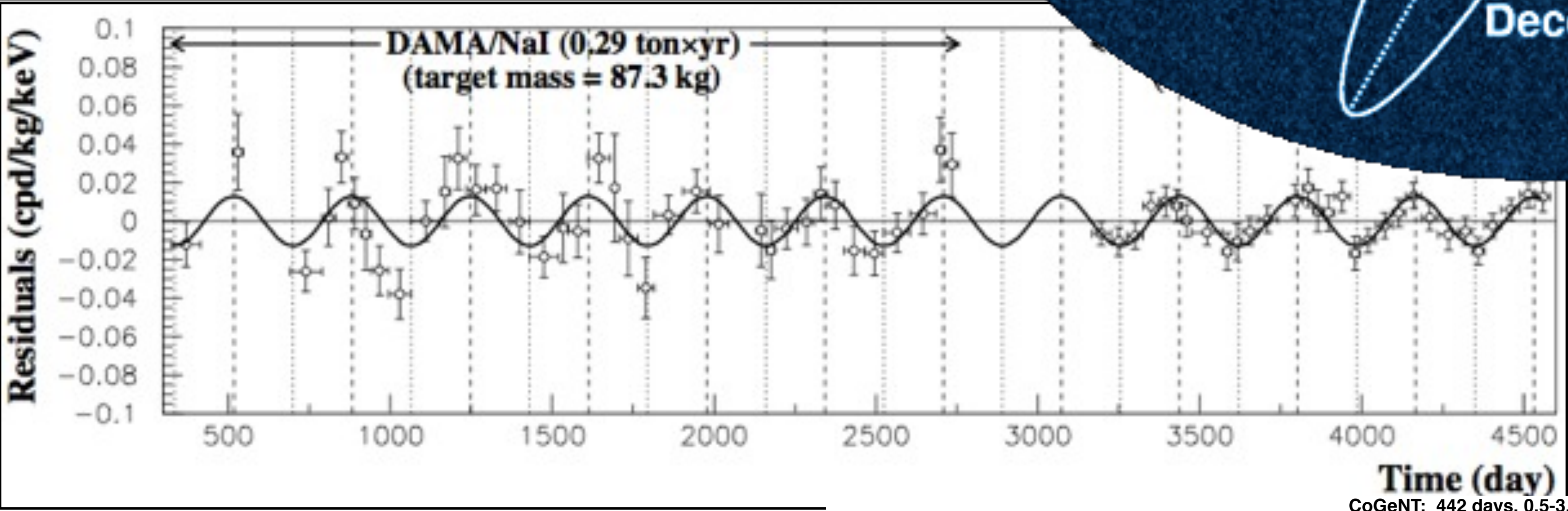
Annual Modulation?



June-December event rate asymmetry ~2-10%

Drukier, Freese, Spergel,
Phys. Rev. D33:3495 (1986)

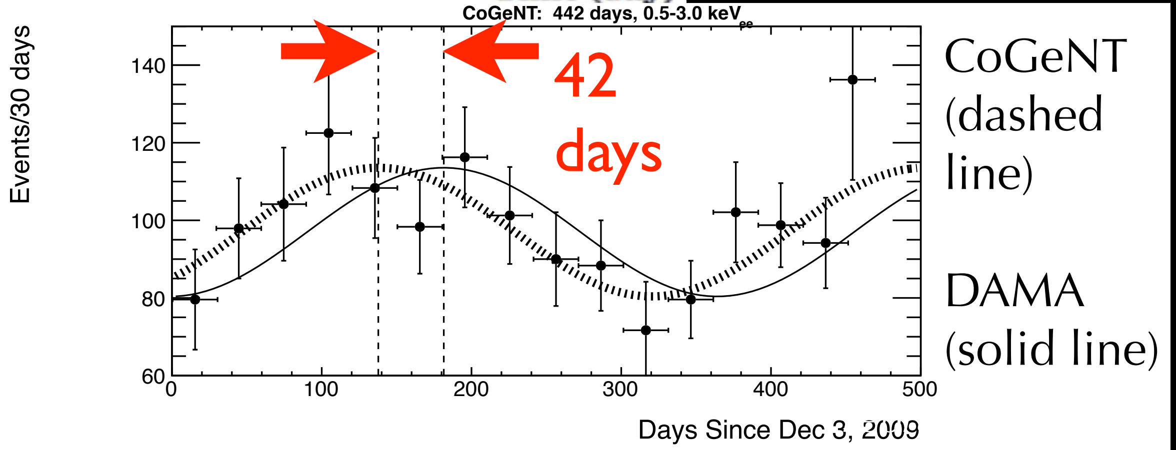
Eur. Phys. J. C56:333-355 (2008)



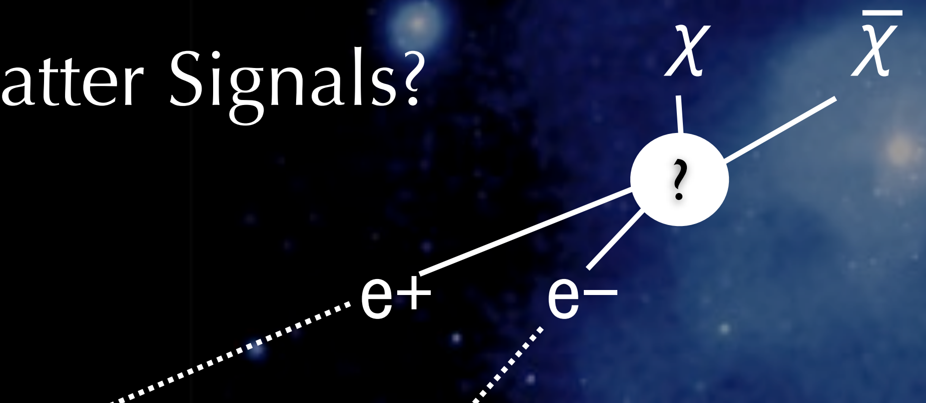
DAMA/Libra positive result, >8σ, *inconsistent with many expts*

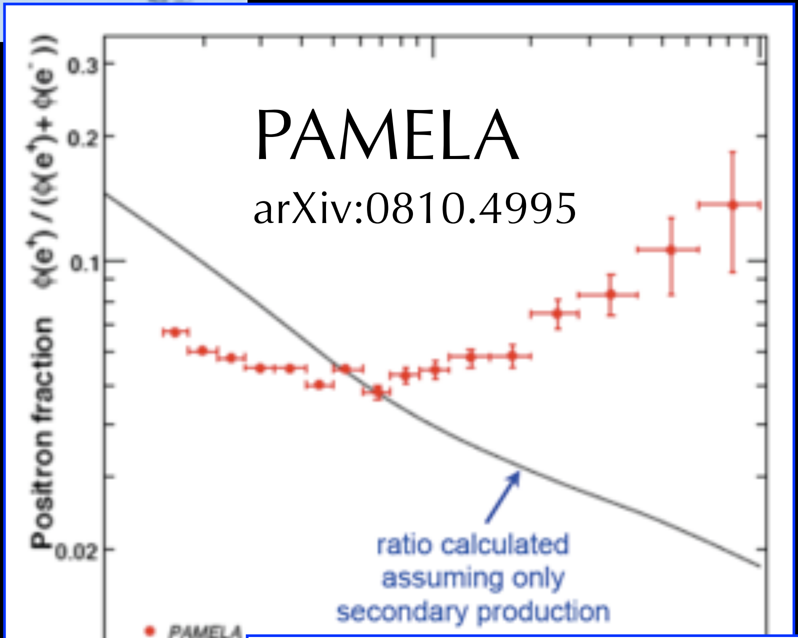
CoGeNT modulation result, 2.8σ, *~consistent with DAMA/Libra*

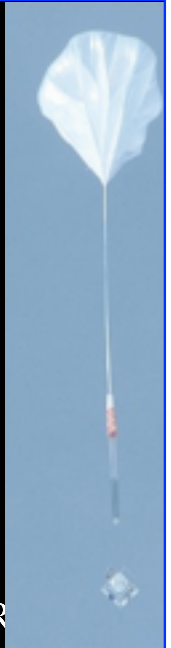
J. Collar, STSI (2011), arXiv:1106.0650v1

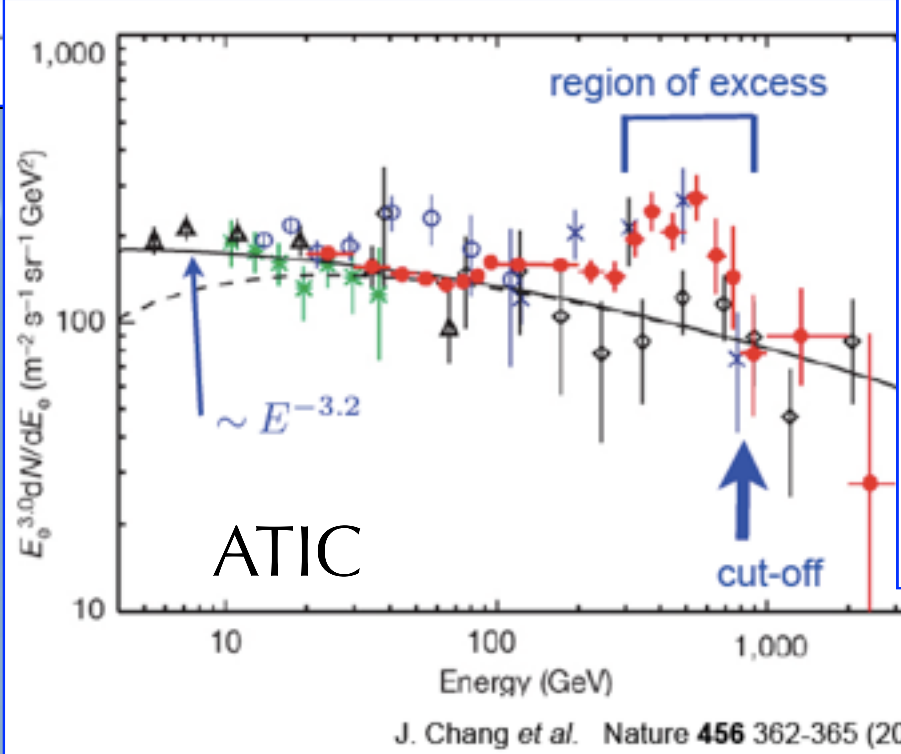


Indirect Dark Matter Signals?

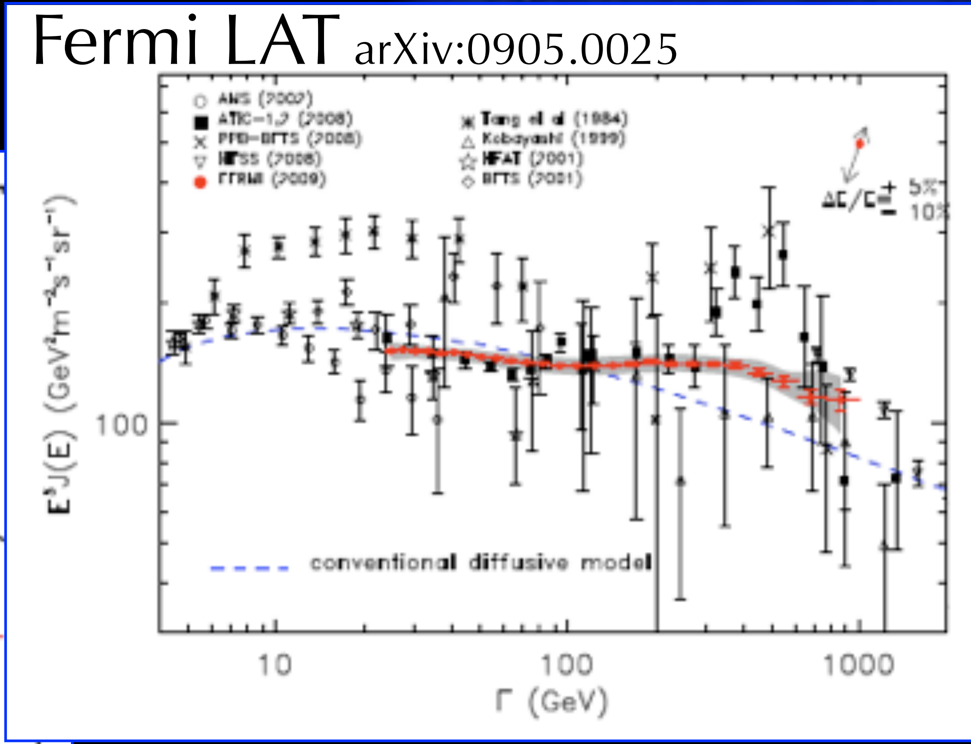



PAMELA
arXiv:0810.4995




ATIC

J. Chang *et al.* Nature **456** 362-365 (2008)


Fermi LAT arXiv:0905.0025

dark matter? local astrophysics?

Outline

Direct Dark Matter Detection

DEAP/CLEAN Experimental Technique

How Will We Know When Dark Matter is Discovered?

Path to Discovery

<u>current experiments:</u>
10-100 kg detector mass;
zero background paradigm=
any excess of events is candidate signal

<u>goal</u>: measure dark matter properties with
100-1000 events (multi-tonne experiments);
paradigm shift: search for signal above *measured*
background, in a low background observatory

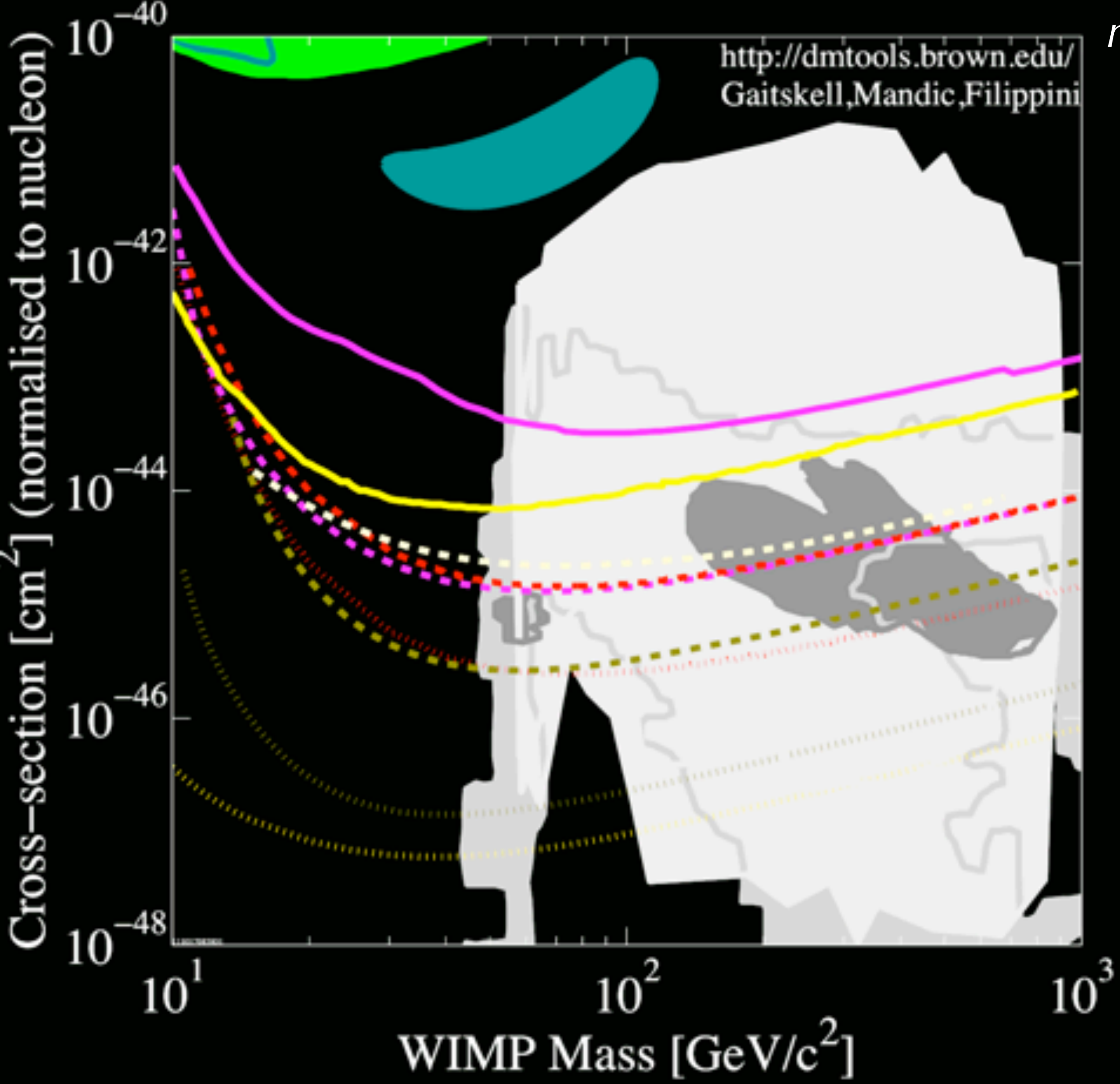
DEAP/CLEAN Objectives:

1) address **scalability** to very large detectors,
2) measure all **backgrounds** in-situ,
while producing a world-leading dark matter result

Sensitivity Projections

need 100-1000 events to measure dark matter mass, cross section

Scalability of Detector Technology



← 1 event/ kg/day

← 1 event/ 100 kg/day

← 1 event/ 100 kg/ 100 days

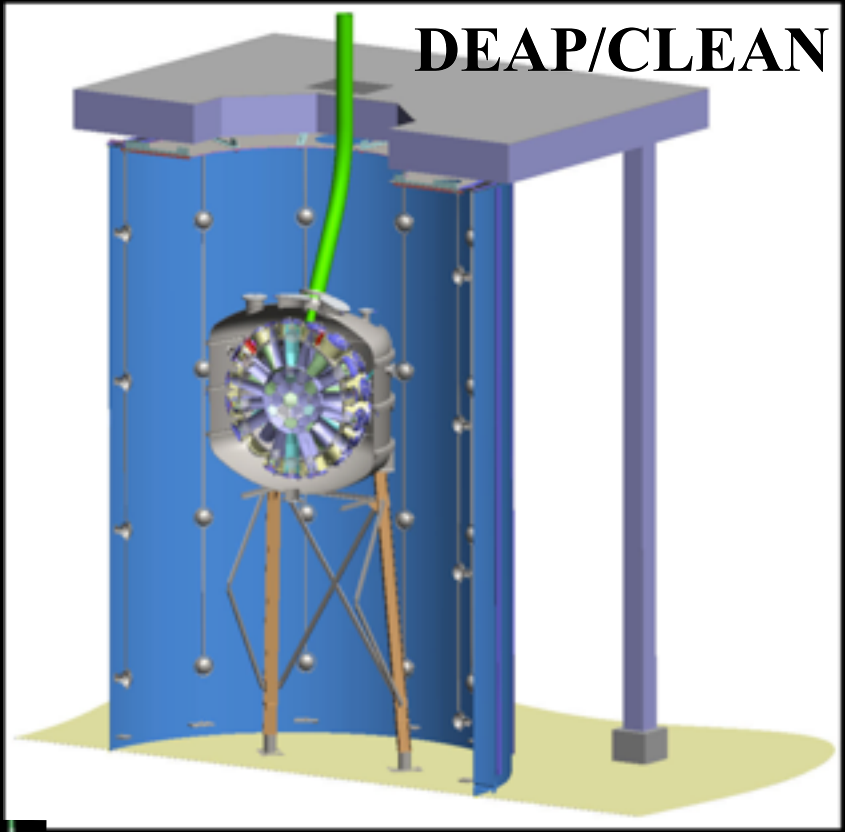
New Techniques for Backgrounds

Complementary with High-Energy Frontier

need multiple targets and techniques to verify signals

<u>Neutrino Lesson:</u>
key to scalability is
large, open volume
simple detector design

<u>DEAP/CLEAN Strategy:</u>
draw on design successes of
large neutrino experiments



DEAP/CLEAN

cross section (cm^2)

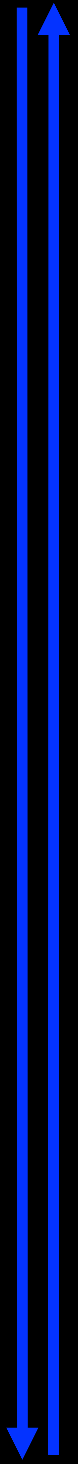
10^{-45}

10^{-44}

10^{-43}

10^{-42}

10^{-39}



detector mass (ktonnes)

100

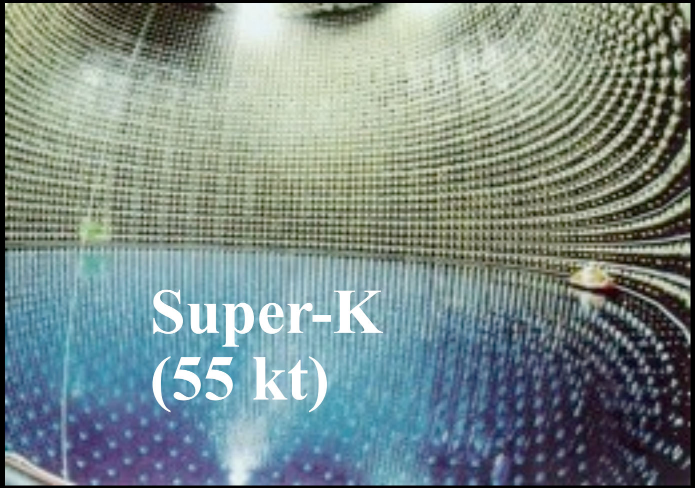
30

10

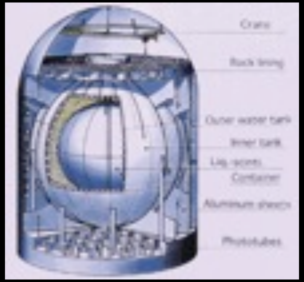
3

1

0.1

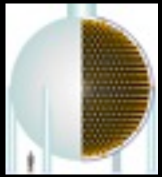


Super-K (55 kt)



Kamland
(3 kt)

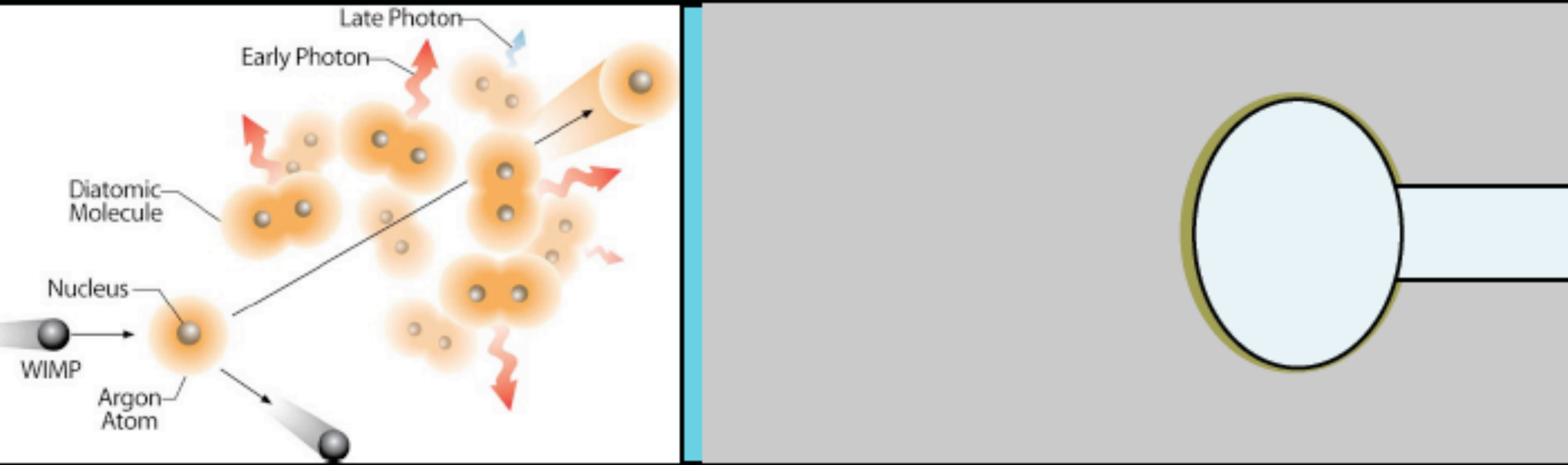
SNO (1 kt)



MiniBooNE
(0.8 kt)

DEAP/CLEAN Detector Design

EUV Light | WLS | Visible Light | Charge



Argon/Neon | TPB | Acrylic/Ar/Ne | PMT

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

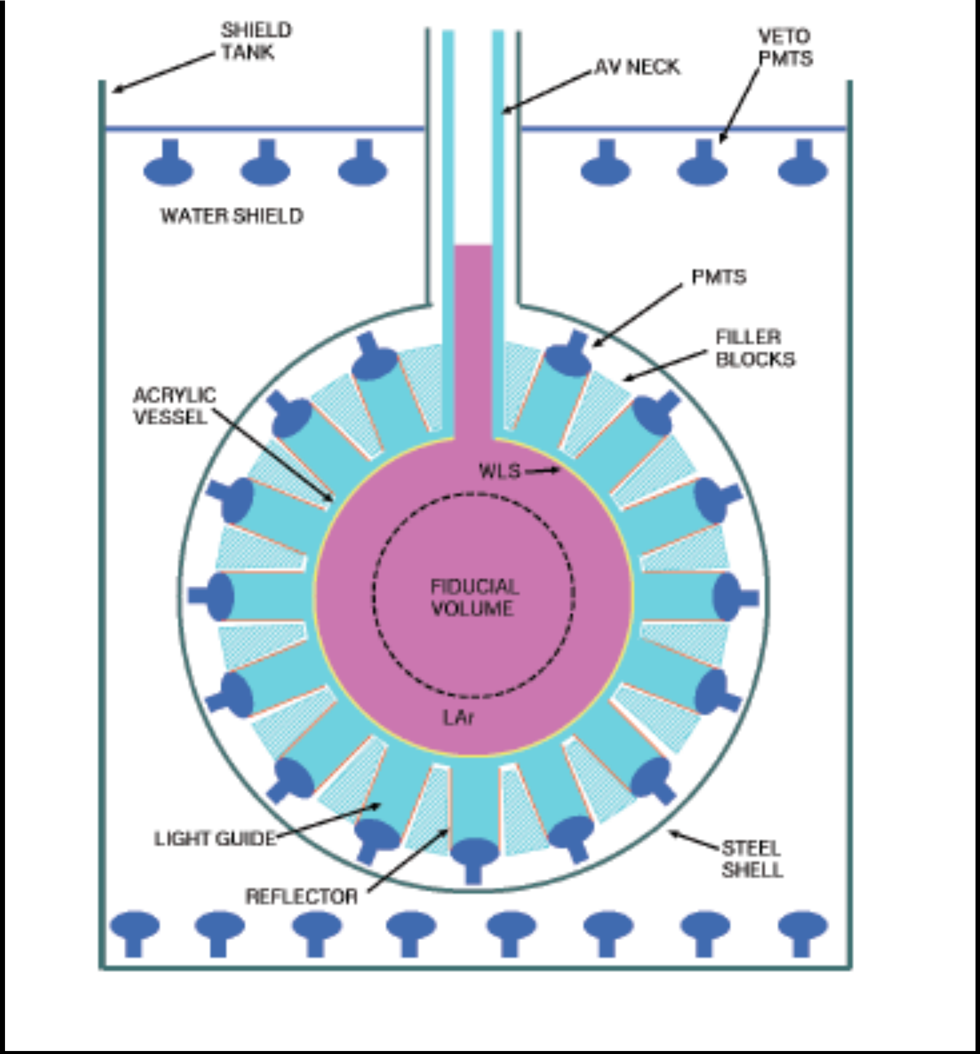
wavelength shift (TPB) to >400 nm

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

If there is a signal, verify A^2 dependence by Ar/Ne target exchange (MiniCLEAN)

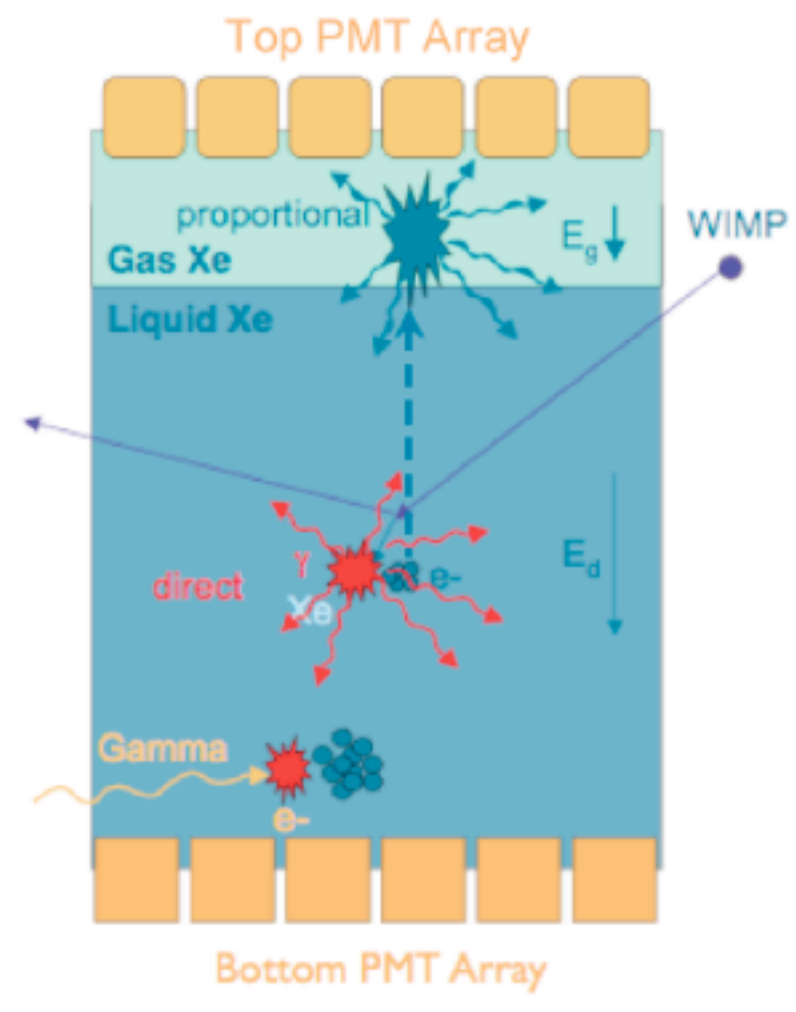
Single Phase Detector

high light yield and self-shielding of liquid noble target



no electric fields = straightforward scalability
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!

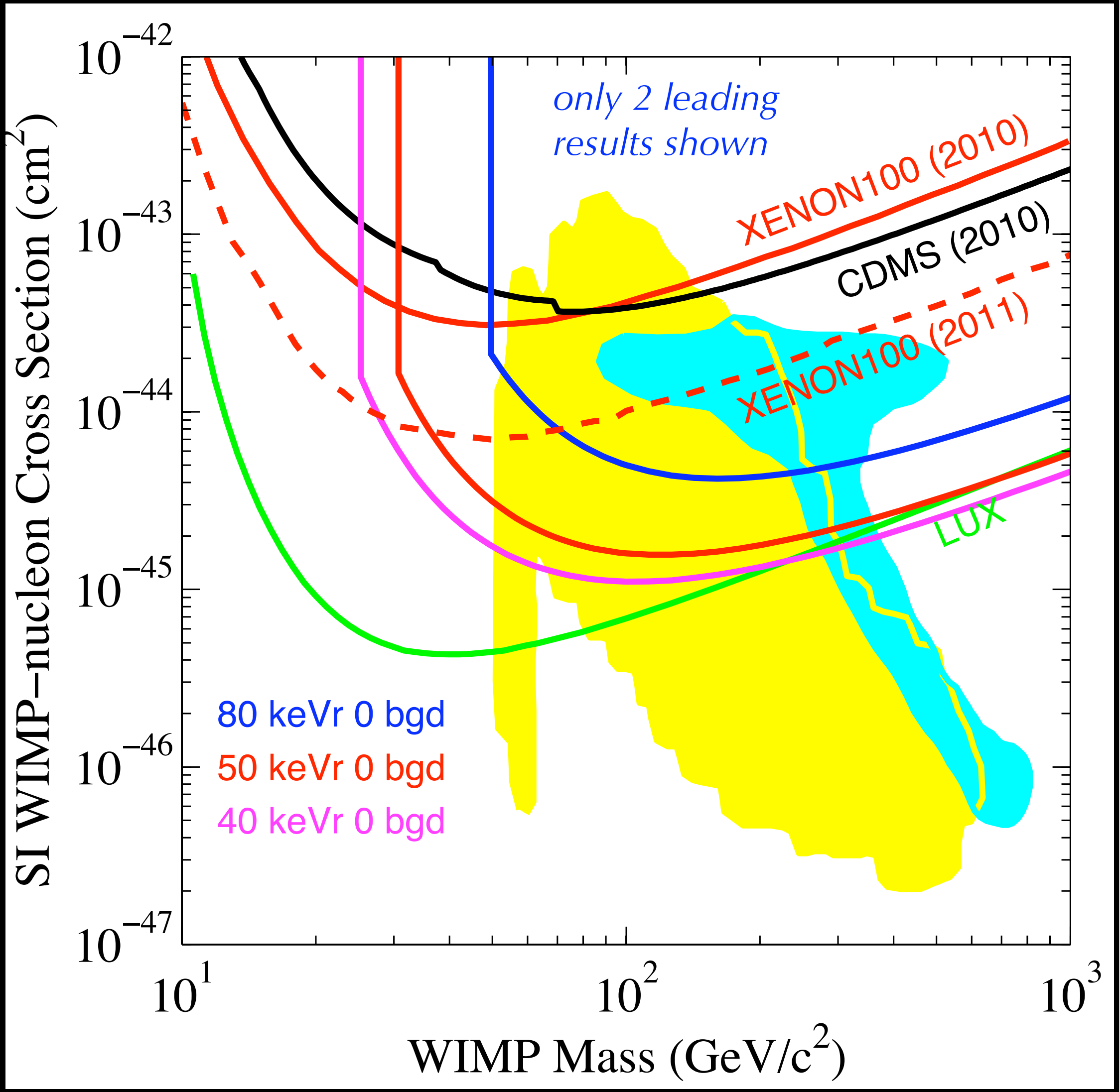
background discrimination from prompt scintillation timing...



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

DEAP/CLEAN Program: Single Phase Detectors for Scalability

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



astrophysical 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: 1E-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

DEAP/CLEAN Collaborators

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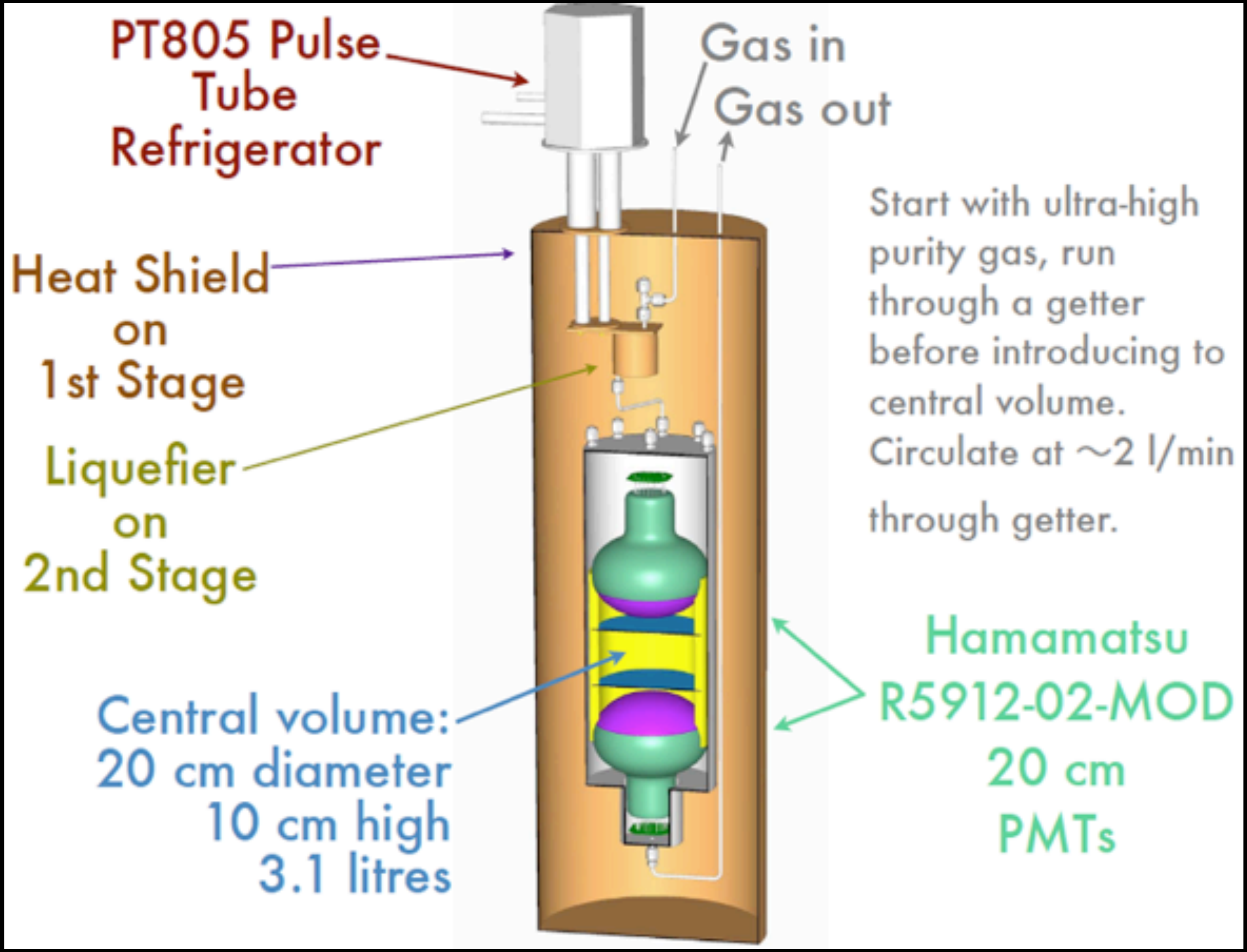
Yale University

D.N. McKinsey, J.A. Nikkel, Y. Shin

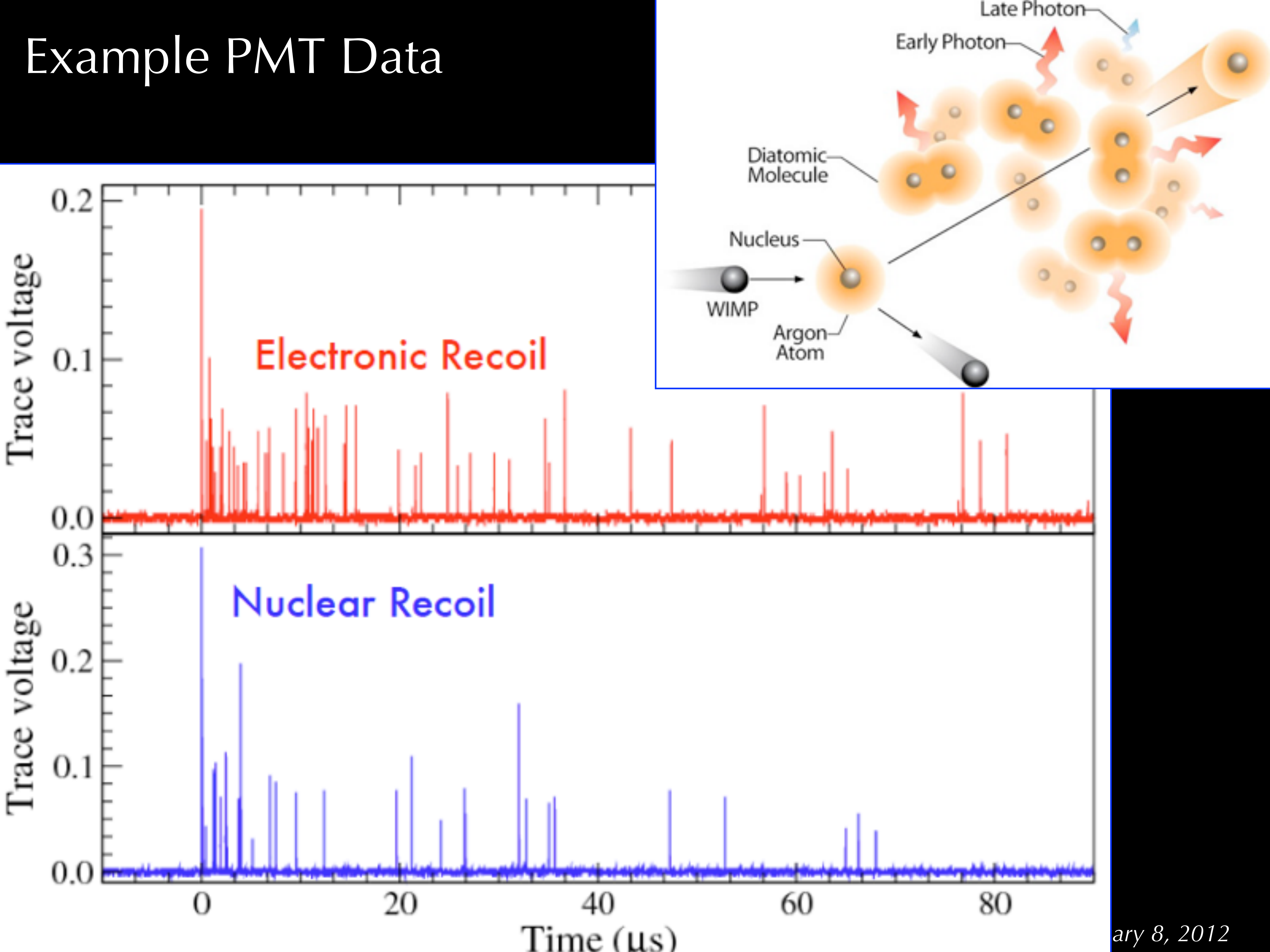
microCLEAN



Start with ultra-high purity gas, run through a getter before introducing to central volume. Circulate at ~2 l/min through getter.

4 kg LAr (active), TPB-coated PTFE reflector, TPB-coated acrylic windows; prototyping cold PMTs, PMT bases, LAr and LNe process systems

Example PMT Data



Light Yield in Liquid Argon

Lippincott et al., PRC81 045803 (2010)

LAr scintillates ~40 photons/keV, measure 6 PE detected per keV visible (keVee)

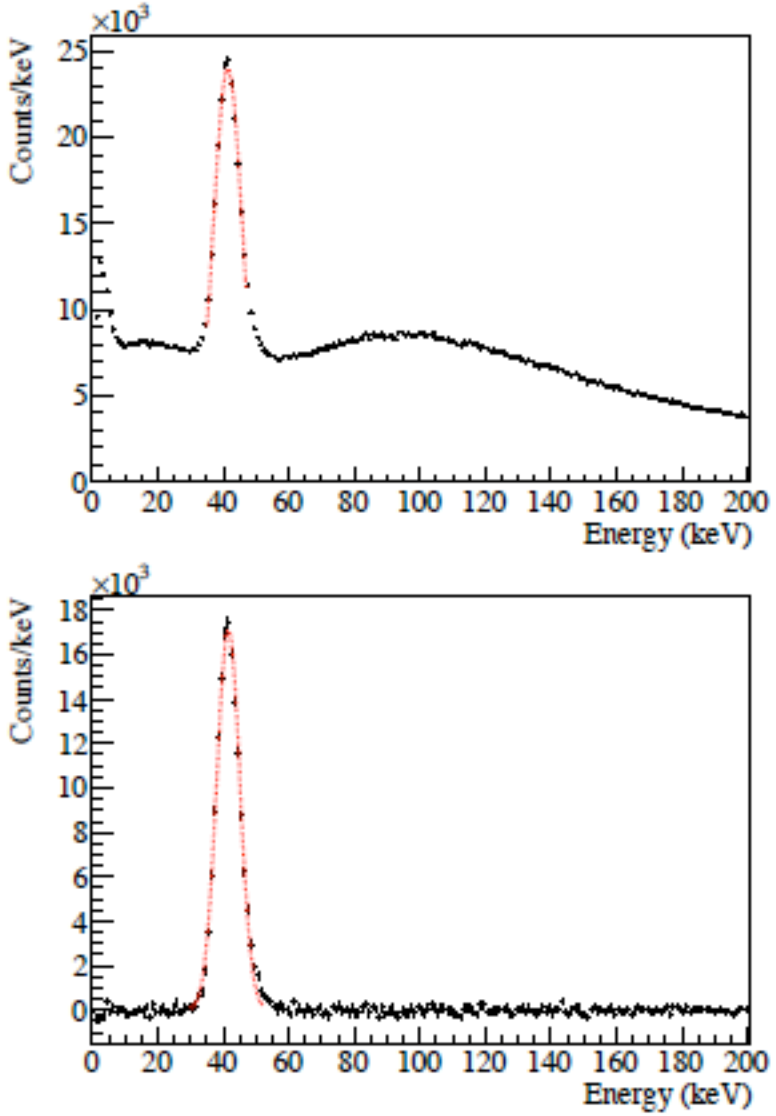


FIG. 5: (Color online) Energy spectrum of ^{83}Kr^{m} runs in argon, with (bottom) and without (top) a background subtraction. The light yield is 6.0 pe/keV and the resolution is 8.2% (σ/E) at 41.5 keV.

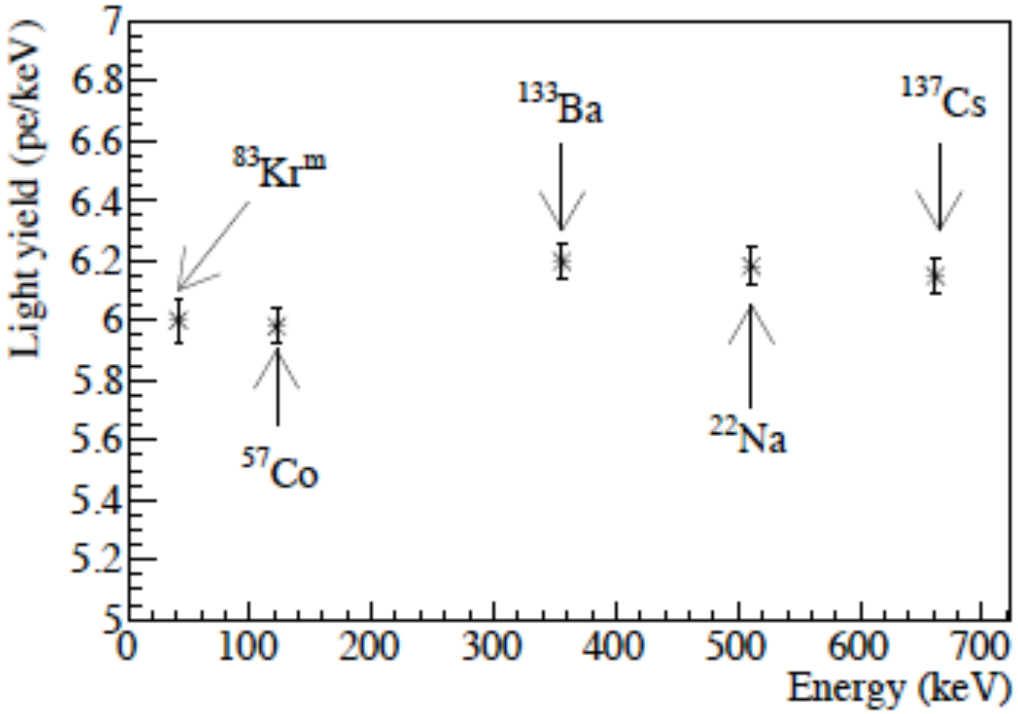


FIG. 6: Light yield versus energy in argon, referenced to the value of 6.0 pe/keV measured for the ^{83}Kr^{m} peak. There is a 1% systematic error on each point stemming from variations in the position of the ^{83}Kr^{m} peak from run to run.

Kr-83m distributed source (32.1+9.4 keV e-)
light yield calibration stable over 42-661 keVee
yield depends significantly on TPB thickness

Quenching Factor

Gastler et al., arXiv: 1004.0373

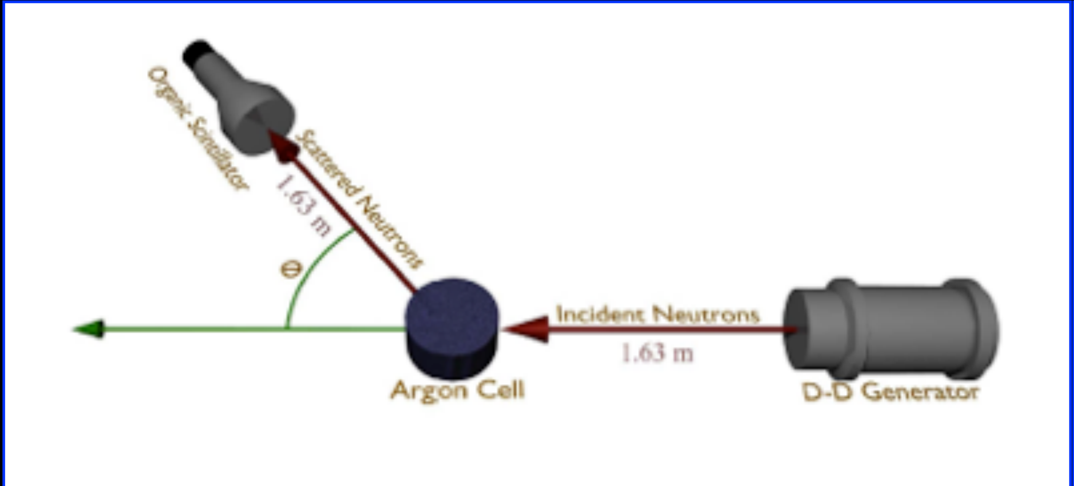
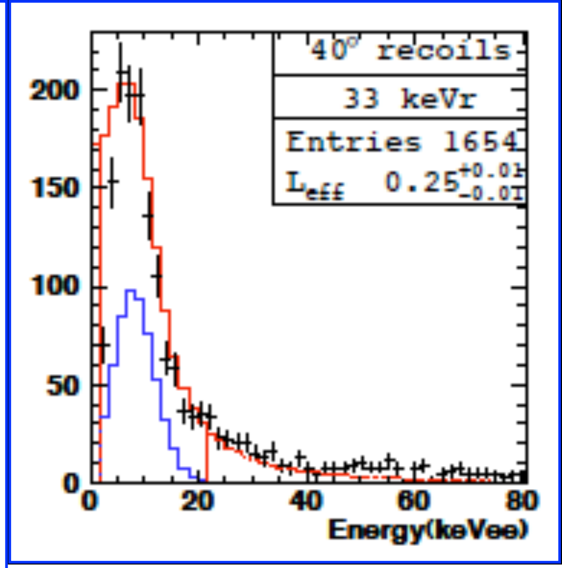
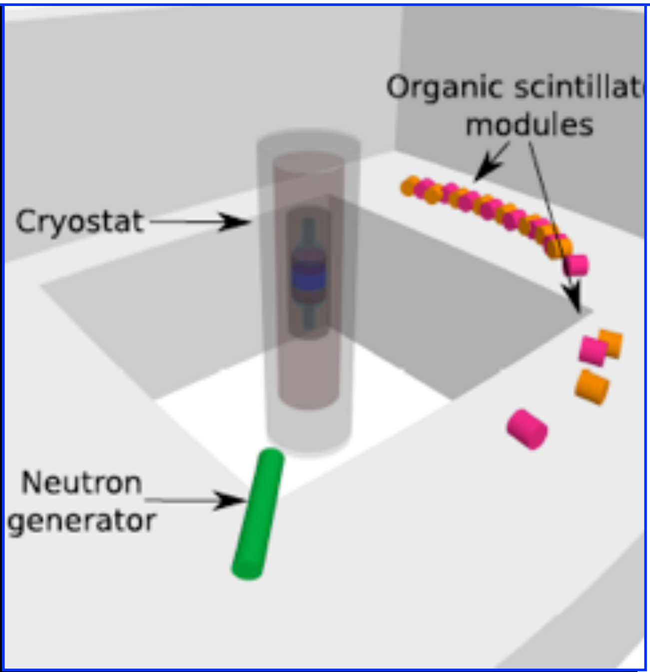


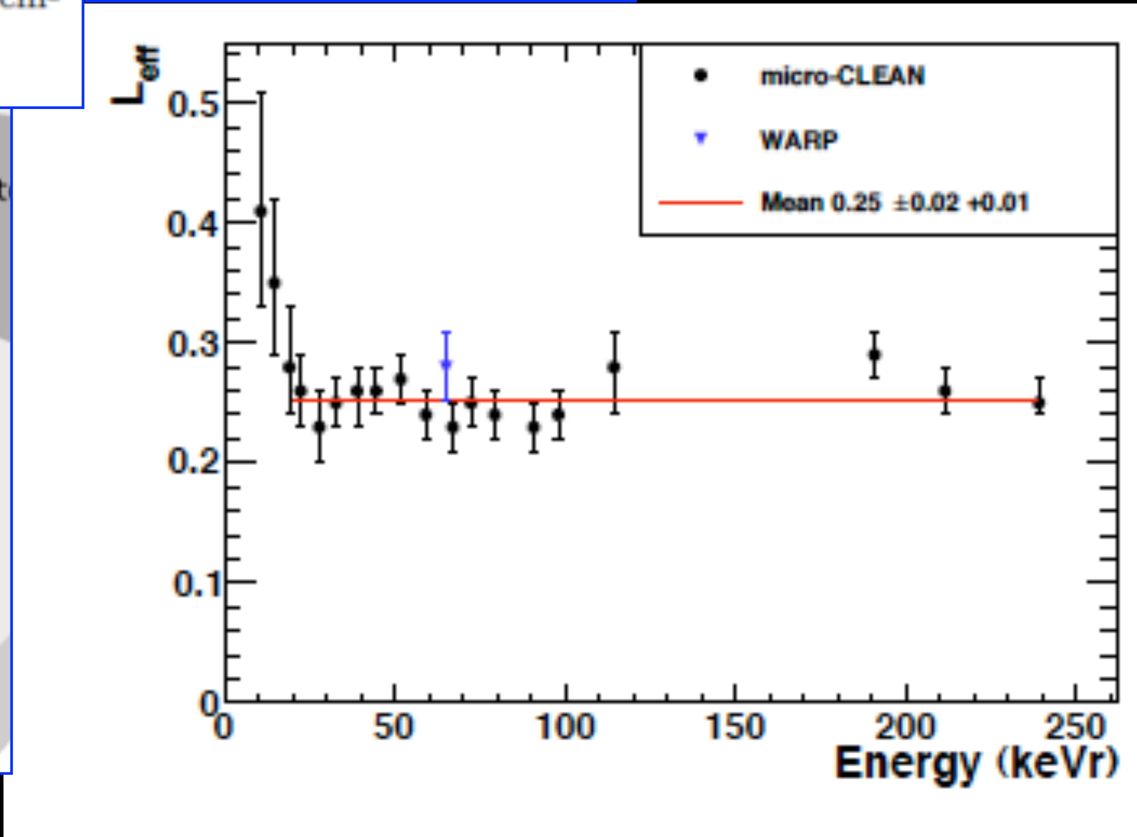
FIG. 4: (Color online) Top view of the neutron scattering setup. Shown are the neutron generator and the organic scintillator. The size of the argon cell is not representative.



mean quenching value above 20 keVr: 0.25±0.02±0.01

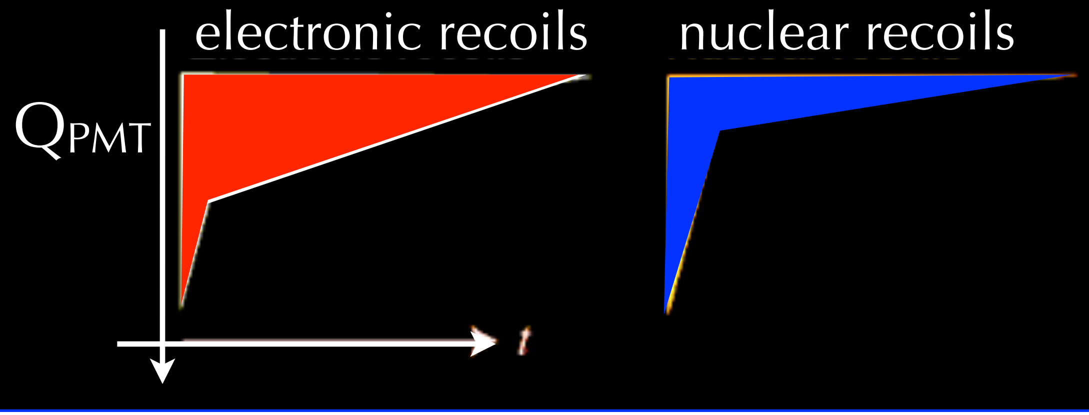
full Geant4 model of experiment, effect of laboratory geometry is important!





Scintillation Timing

scintillation time constants: 6±1 ns, 1600±100 ns



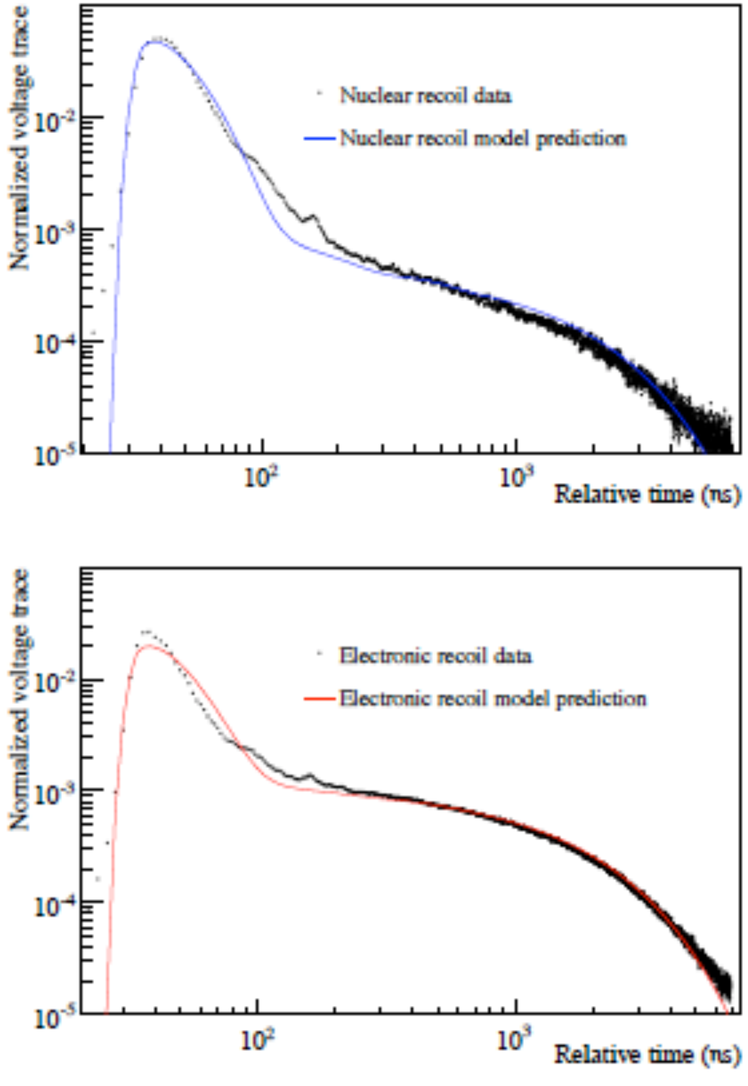


FIG. 6: Observed and predicted mean voltage traces fo
clear and electronic recoil events of 80 to 99 photoelectr

Lippincott et al., Phys.Rev.C78:035801 (2008)

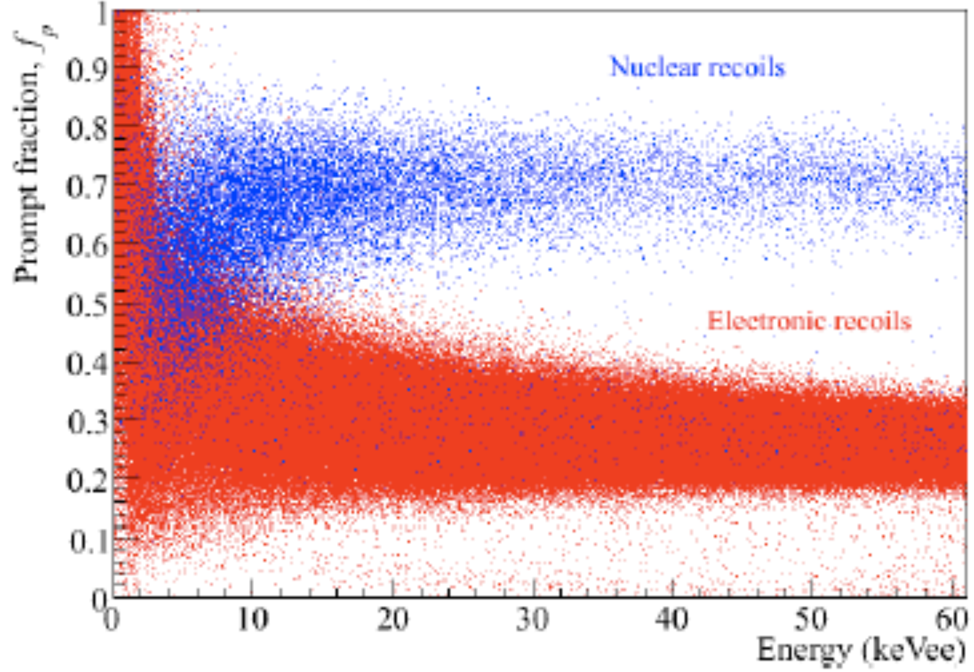


FIG. 7: A scatter plot of f_p vs. energy for tagged electronic and nuclear recoils, where $\xi = 90$ ns.

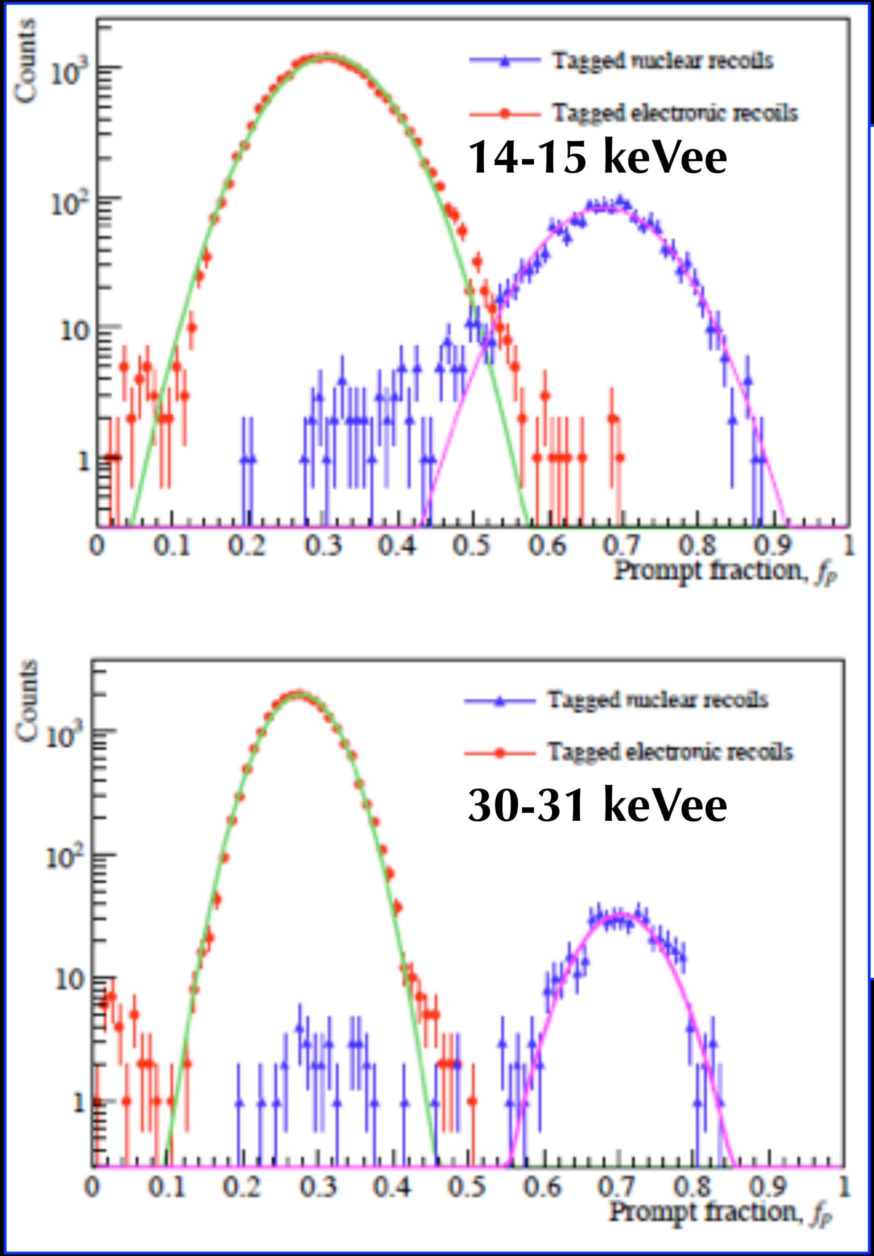
reject electronic backgrounds by pulse shape vs. time

McKinsey & Coakley,
Astropart. Phys. 22, 355 (2005)

Pulse Shape Discrimination

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

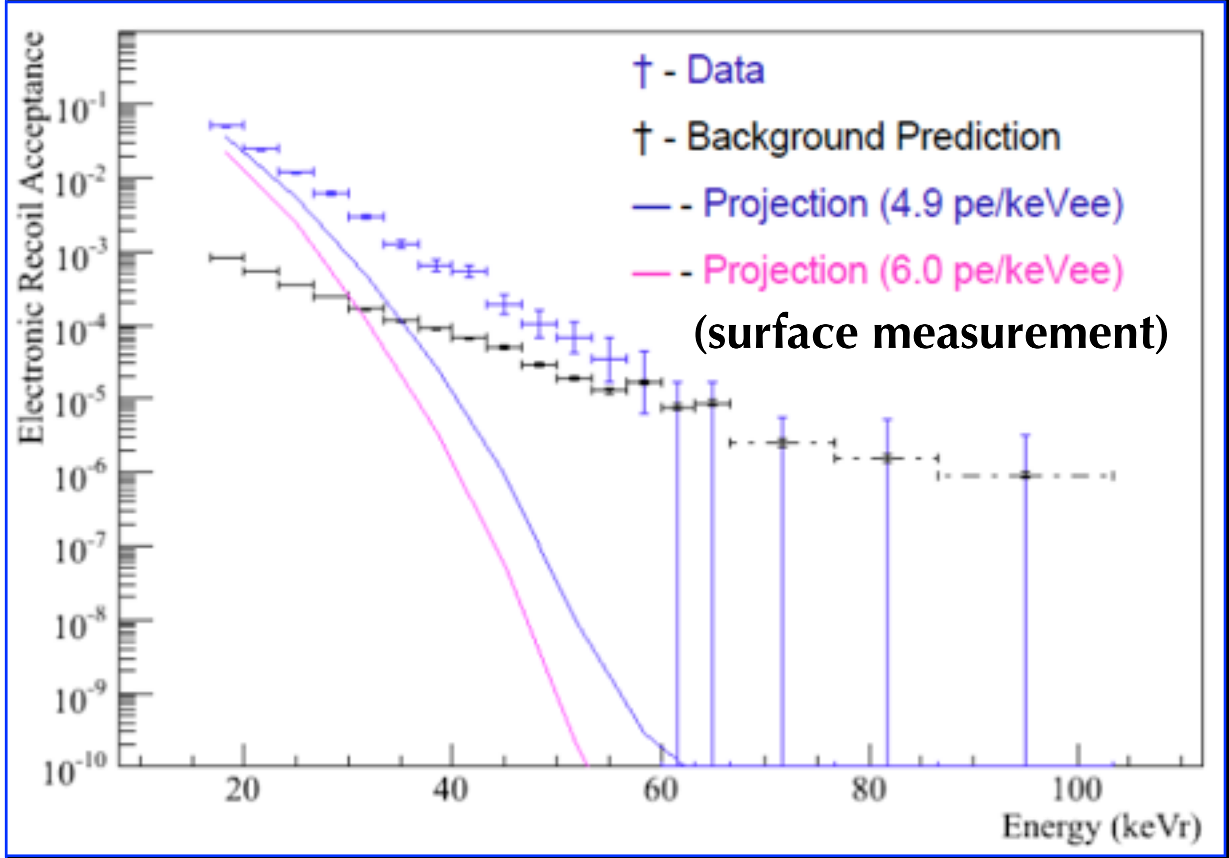
fraction of prompt light discriminates between electronic and nuclear recoils



14-15 keVee

30-31 keVee

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



(surface measurement)

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

Why Argon?

advantages: x250 difference between singlet and triplet lifetimes: 10^{10} electron rejection

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

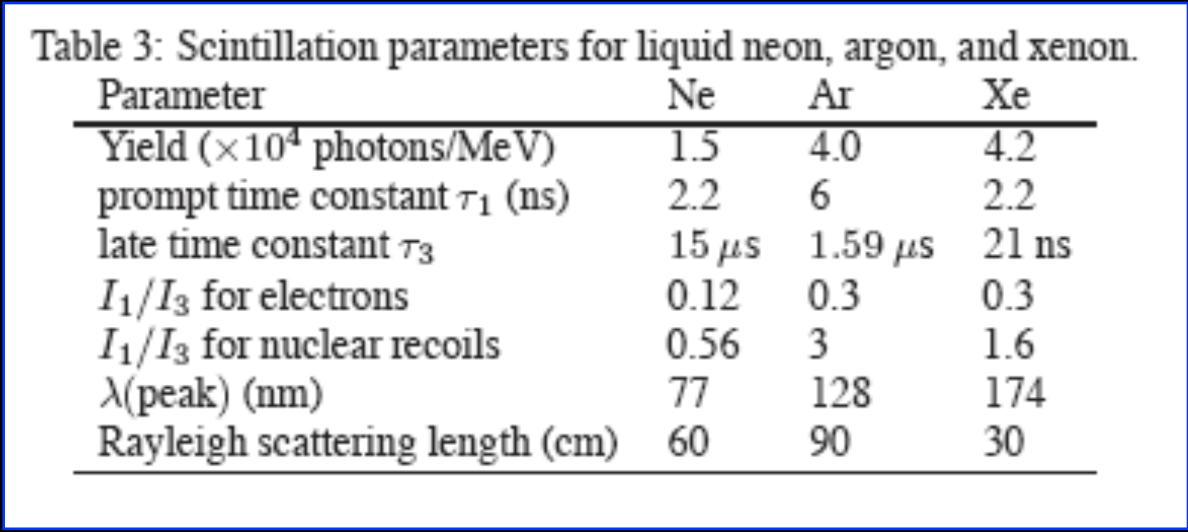
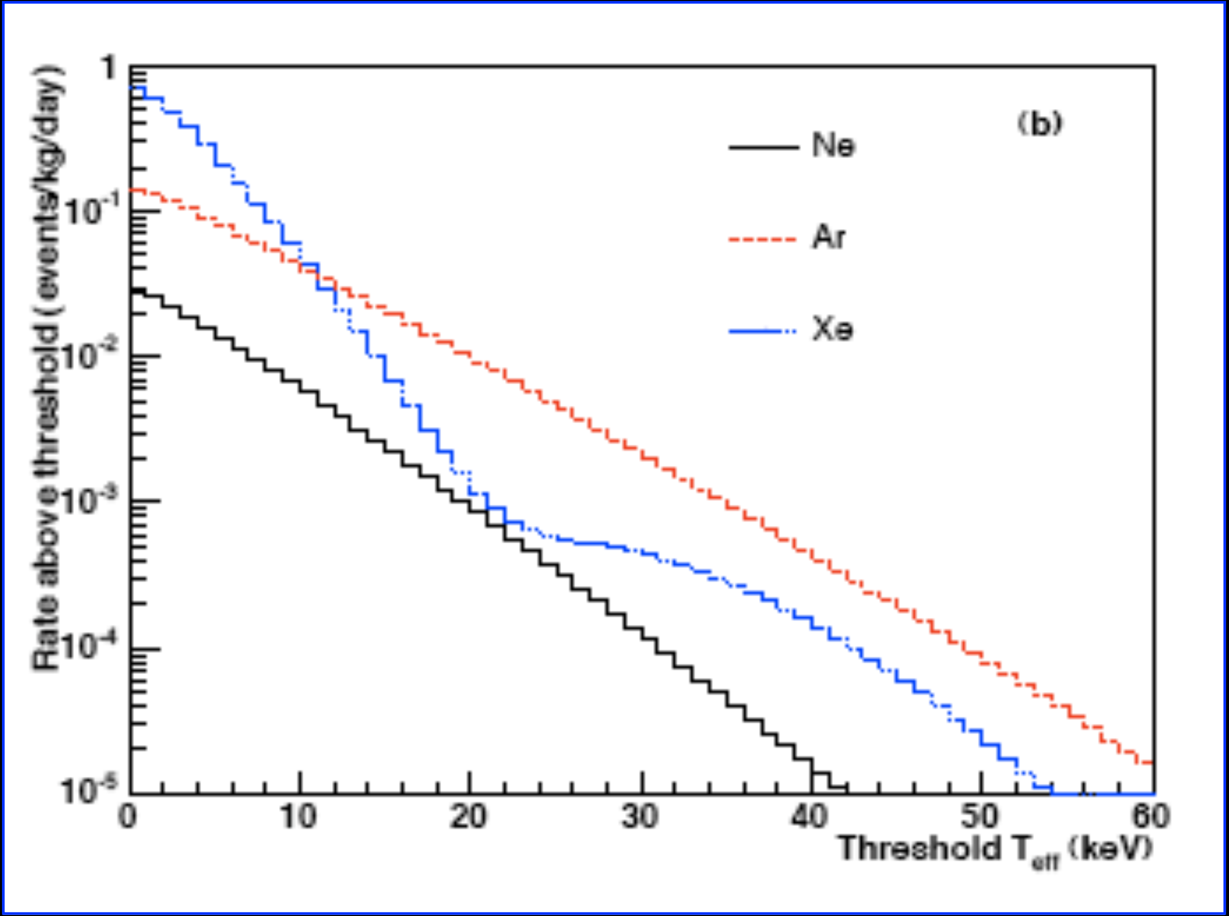


Table 3: Scintillation parameters for liquid neon, argon, and xenon.

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



practicalities:
excellent light yield / $$

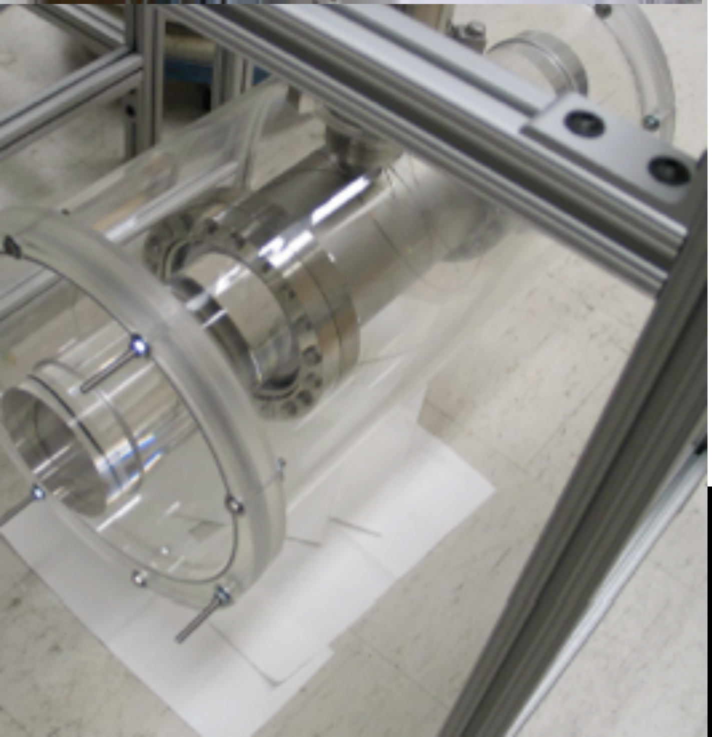
straightforward to purify

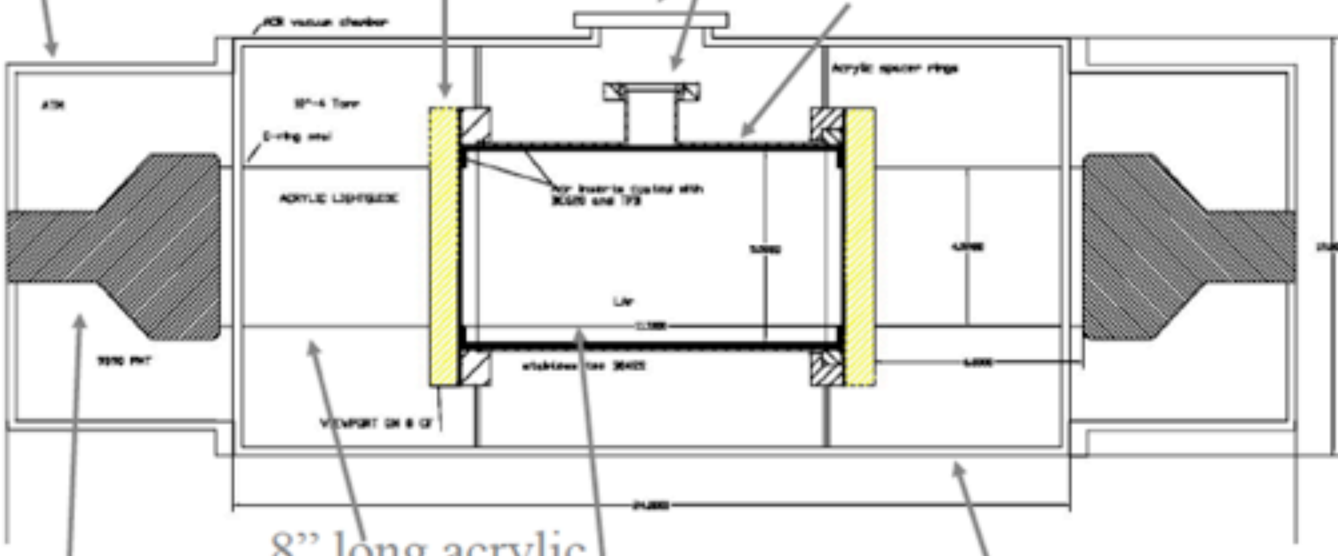
drawbacks:
smaller interaction cross section (A^2)

^{39}Ar, trade-off between background rejection and threshold

low-background Ar sources reduce Ar-39 by a factor of 50 at least
A. Wright, arXiv:1109.2979

DEAP-1





Quartz windows

Neck connects to vacuum and Gas/liquid lines

Poly PMT supports

11" x 6" (8" CF) tee

8" long acrylic guide

Acrylic vacuum chamber

5" ET 9390B PMT

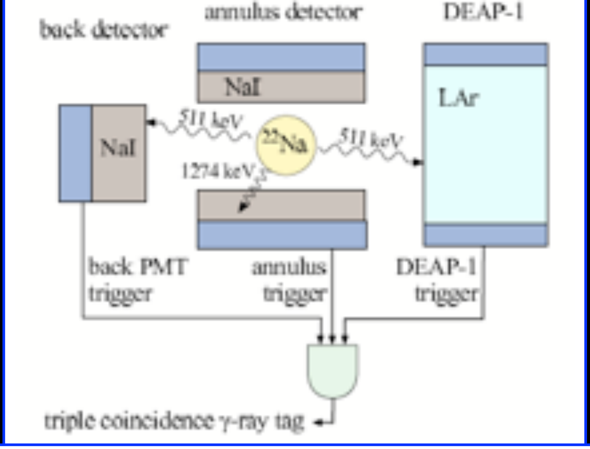
7 kg LAr

Inner surface 97% diffuse reflector, covered with TPB wavelength shifter

7 kg LAr (active), warm PMTs, quartz windows; prototyping reflectors, acrylics, operation underground

Pulse Shape Discrimination

high intensity tagged gamma source,
integrated 6.3E7 tagged gammas in surface lab
detector light yield at surface: 2.8±0.1 PE/keVee



no events observed with prompt fraction > 0.7 in 120-240 PE, leakage < 6E-8 @ full recoil acceptance, in 45-88 keVee

Boulay et al., arXiv:0904.2930

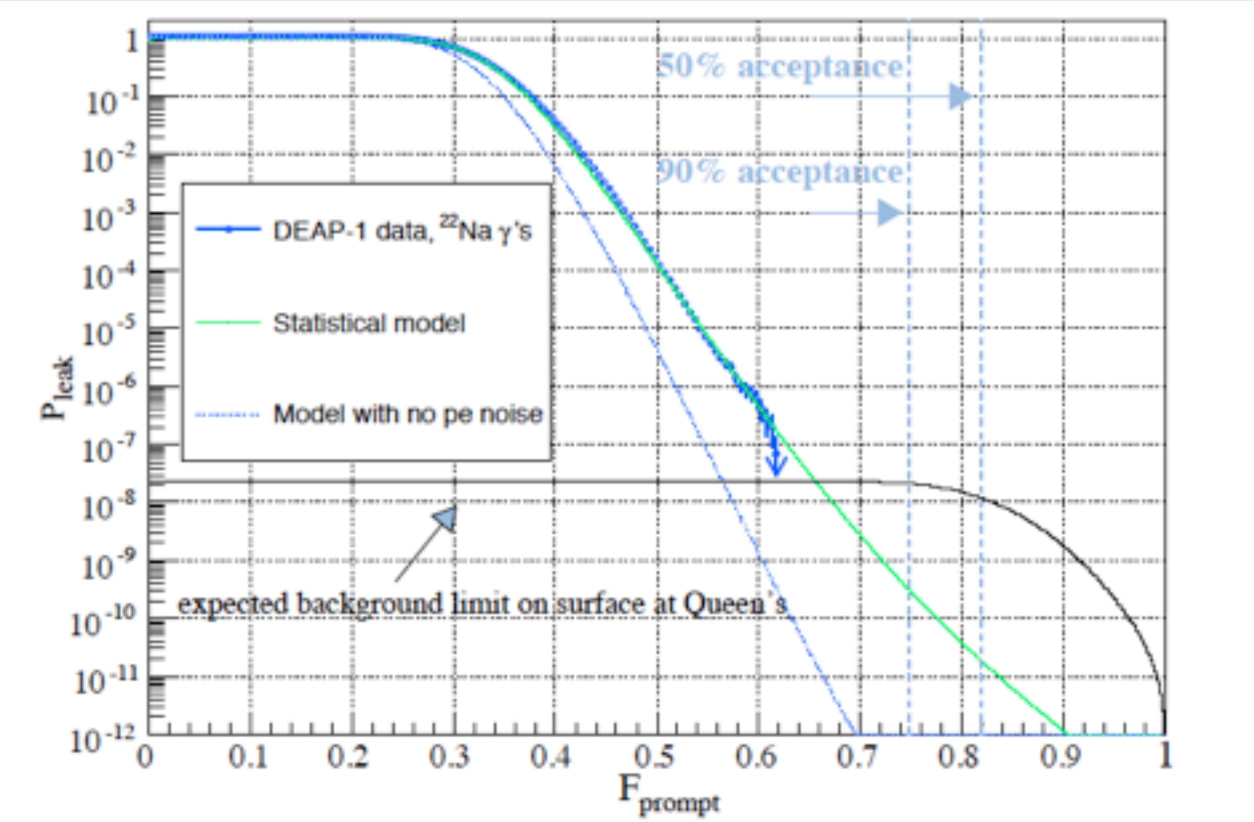
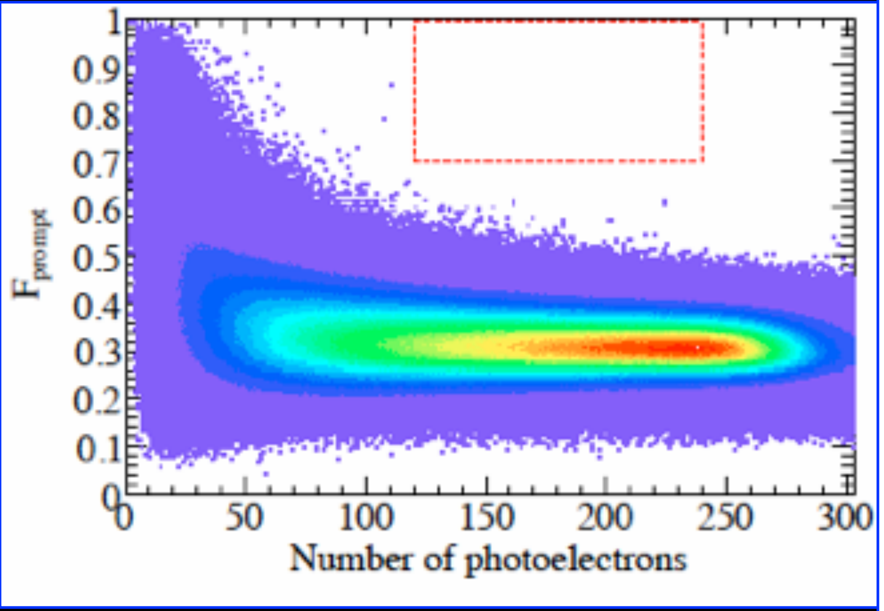


FIG. 17: P_{leak} distribution from ^{22}Na calibration data from DEAP-1, and analytic models with and without additional noise parameters for 120-240 photoelectrons. The lower curve shows the expected backgrounds in the measurements from high-F_{prompt} events.



Pulse Shape Discrimination, Underground

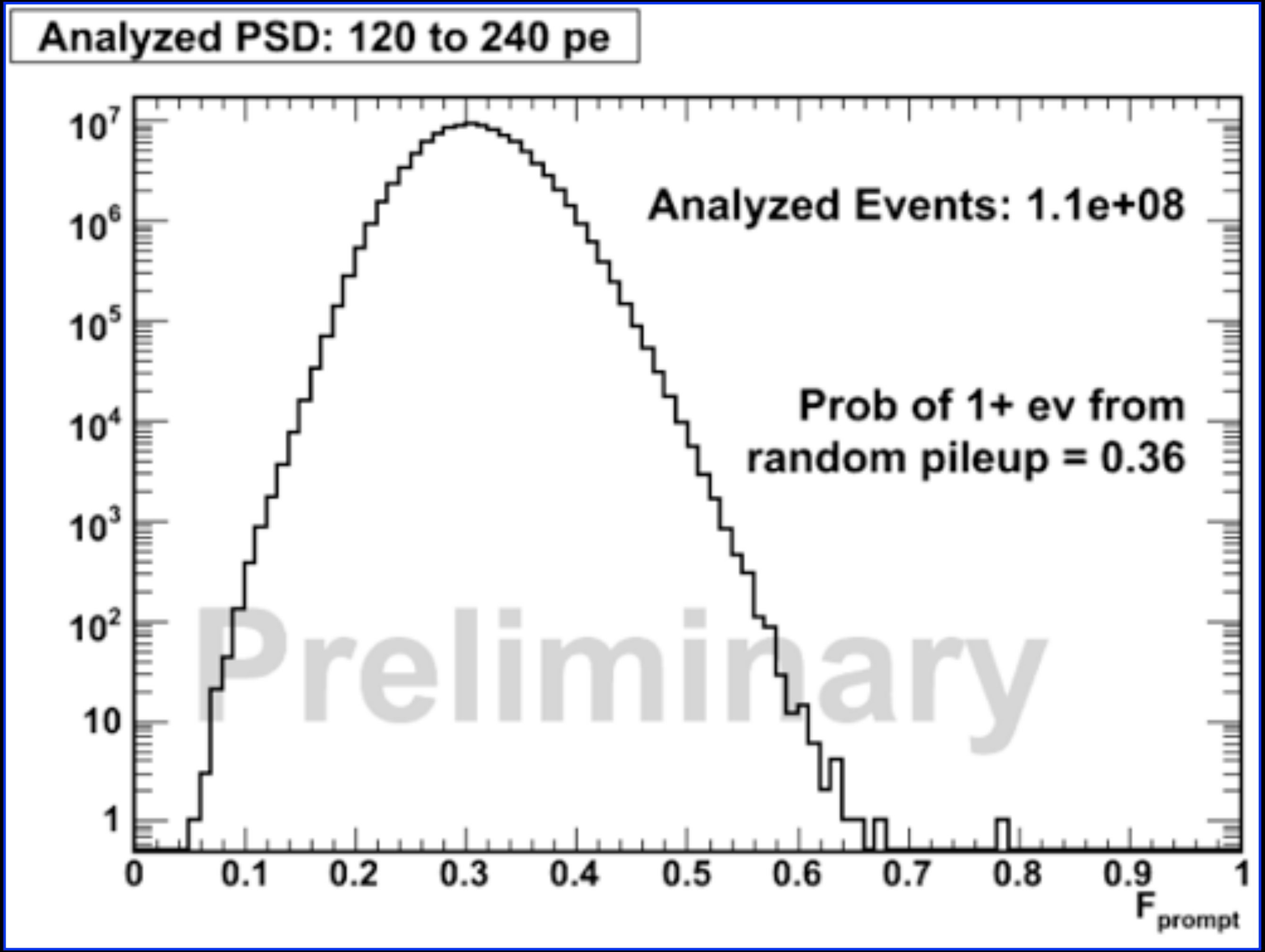
high intensity tagged gamma source deployed with DEAP-1 at SNOLAB
detector light yield: 2.8±0.1 PE/keVee; statistics: integrated 1.1E8 tagged gammas

1 event observed with prompt fraction > 0.7 in 120-240 PE

leakage < 3E-8 @ 90% CL, studies ongoing now with higher light yield

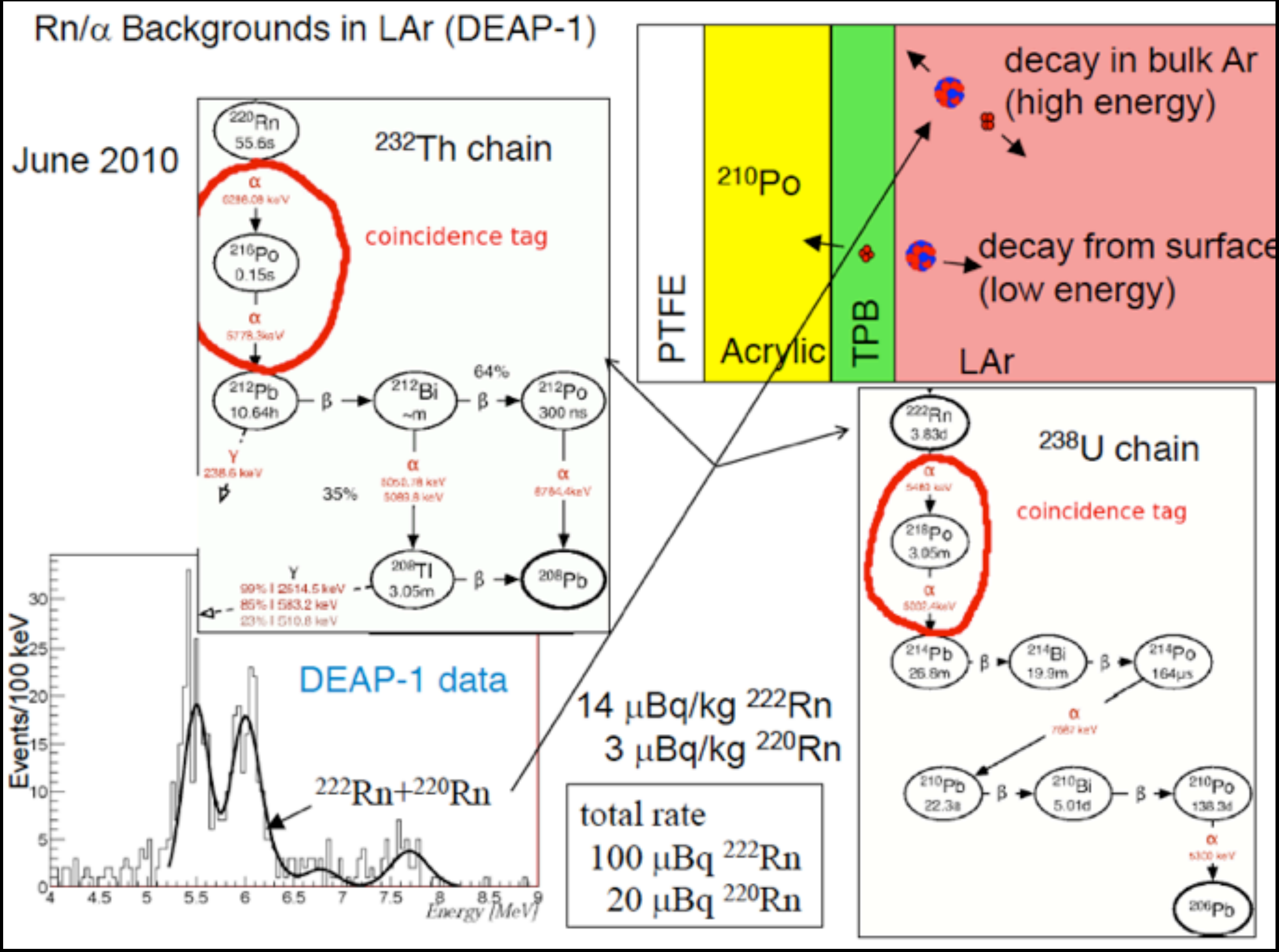
simple model of photon statistics predicts 1E-10 leakage at 120 PE
(20 keVee threshold
at 6 PE/keVee)
M. Boulay, TAUP 2011

C. Jilling, CAP 2011



Alpha Backgrounds

M. Boulay, TAUP 2011



Rn/α Backgrounds in LAr (DEAP-1)

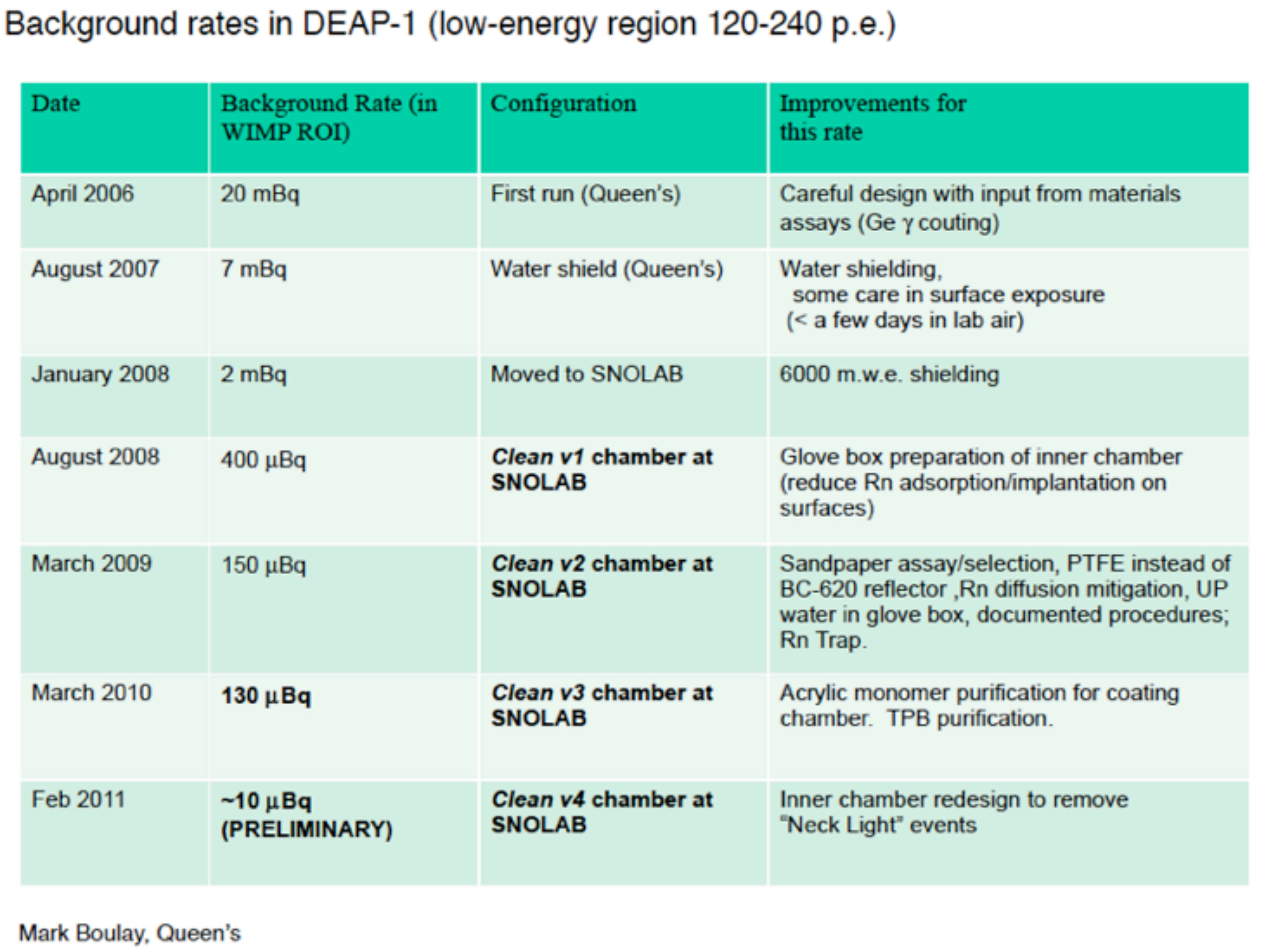
June 2010

$14\ \mu Bq/kg\ ^{222}Rn$
$3\ \mu Bq/kg\ ^{220}Rn$

total rate
$100\ \mu Bq\ ^{222}Rn$
$20\ \mu Bq\ ^{220}Rn$

This gets easier with smaller surface-to-volume ratio (large, spherical detectors).

Alpha Reduction R&D in DEAP-1



Background rates in DEAP-1 (low-energy region 120-240 p.e.)

Date	Background Rate (in WIMP ROI)	Configuration	Improvements for this rate
April 2006	20 mBq	First run (Queen's)	Careful design with input from materials assays (Ge γ couting)
August 2007	7 mBq	Water shield (Queen's)	Water shielding, some care in surface exposure (< a few days in lab air)
January 2008	2 mBq	Moved to SNOLAB	6000 m.w.e. shielding
August 2008	400 µBq	***Clean v1* chamber at SNOLAB**	Glove box preparation of inner chamber (reduce Rn adsorption/implantation on surfaces)
March 2009	150 µBq	***Clean v2* chamber at SNOLAB**	Sandpaper assay/selection, PTFE instead of BC-620 reflector ,Rn diffusion mitigation, UP water in glove box, documented procedures; Rn Trap.
March 2010	**130 µBq**	***Clean v3* chamber at SNOLAB**	Acrylic monomer purification for coating chamber. TPB purification.
Feb 2011	**~10 µBq (PRELIMINARY)**	***Clean v4* chamber at SNOLAB**	Inner chamber redesign to remove "Neck Light" events

Mark Boulay, Queen's

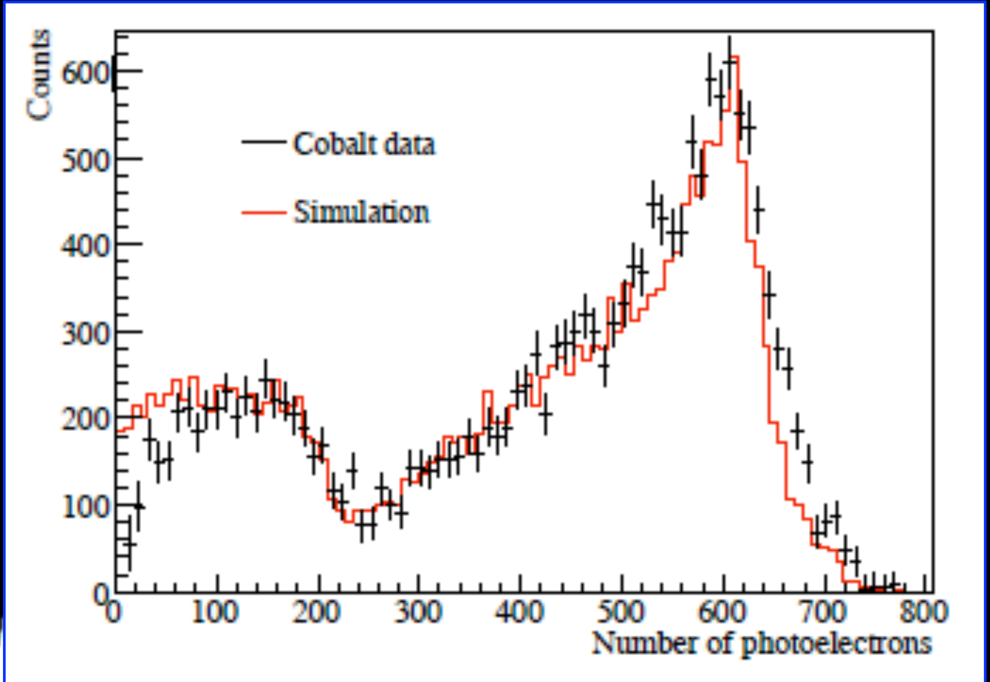
DEAP/CLEAN Detector Simulation

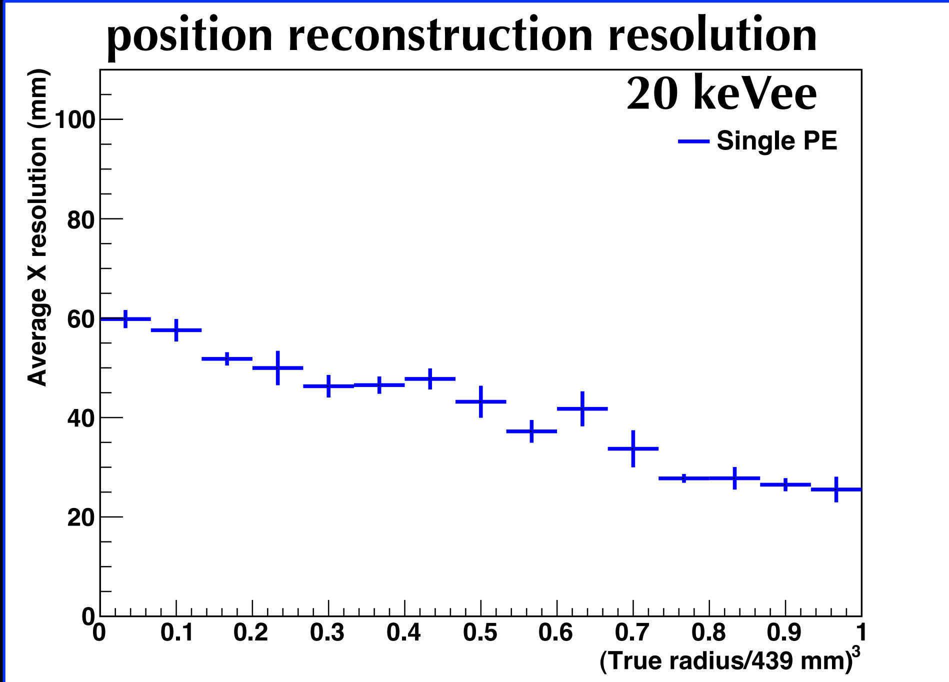
S. Seibert, PhD thesis

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

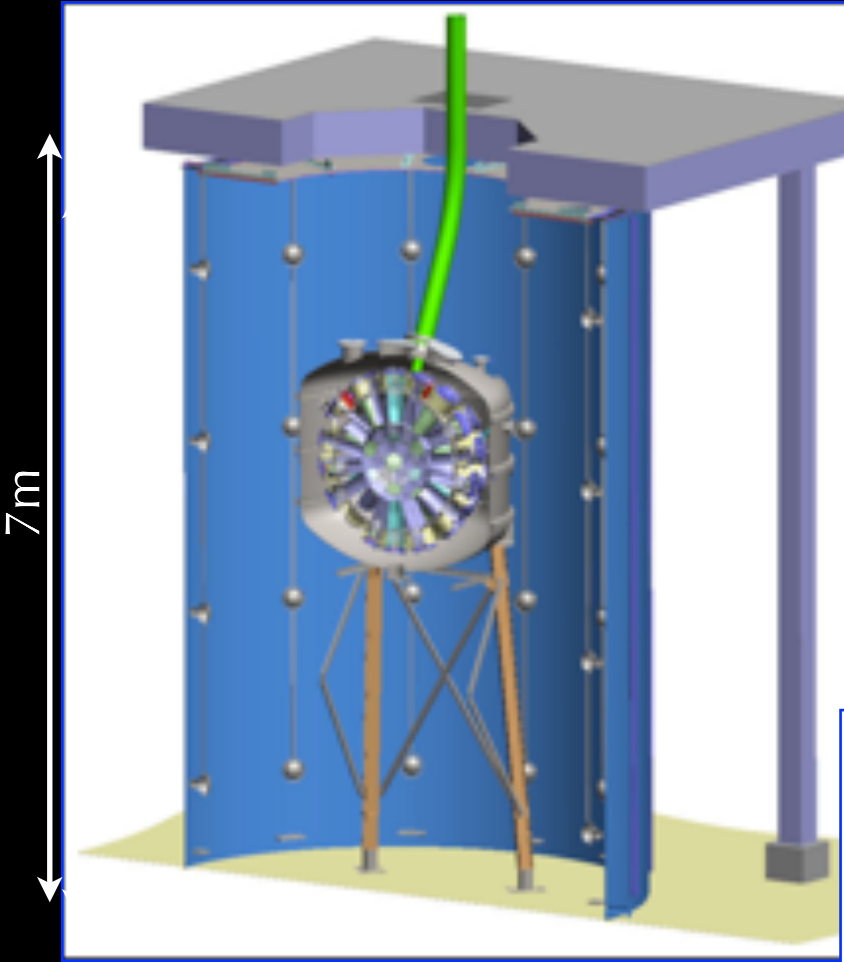
- *GEANT4*: detector geometry and particle propagation, physics validation collaboration (AARM)
- *ROOT*: Event input and output.
- *GLG4Sim*: custom scintillation physics, PMT model, DAQ
  - -dE/dx dependent quenching and singlet/triplet ratios for different particle types, based on measurements in microCLEAN
  - -full optical transport of individual photons through detailed 3D model of the detector, optics based on ex-situ measurements

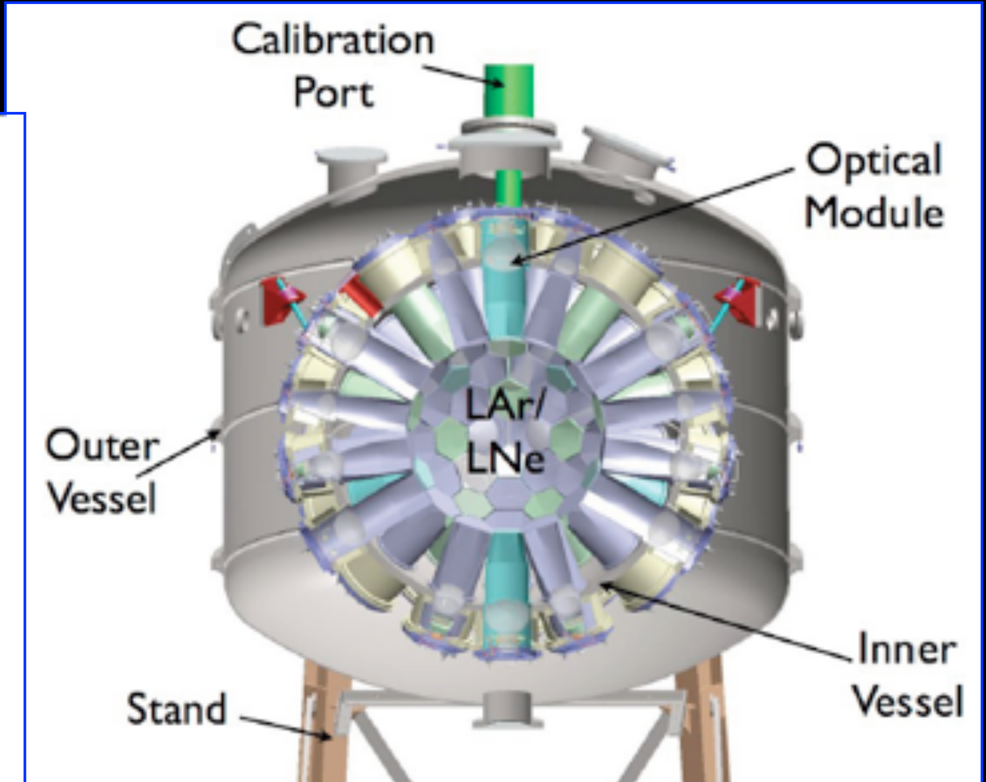
Gastler et al., arXiv: 1004.0373

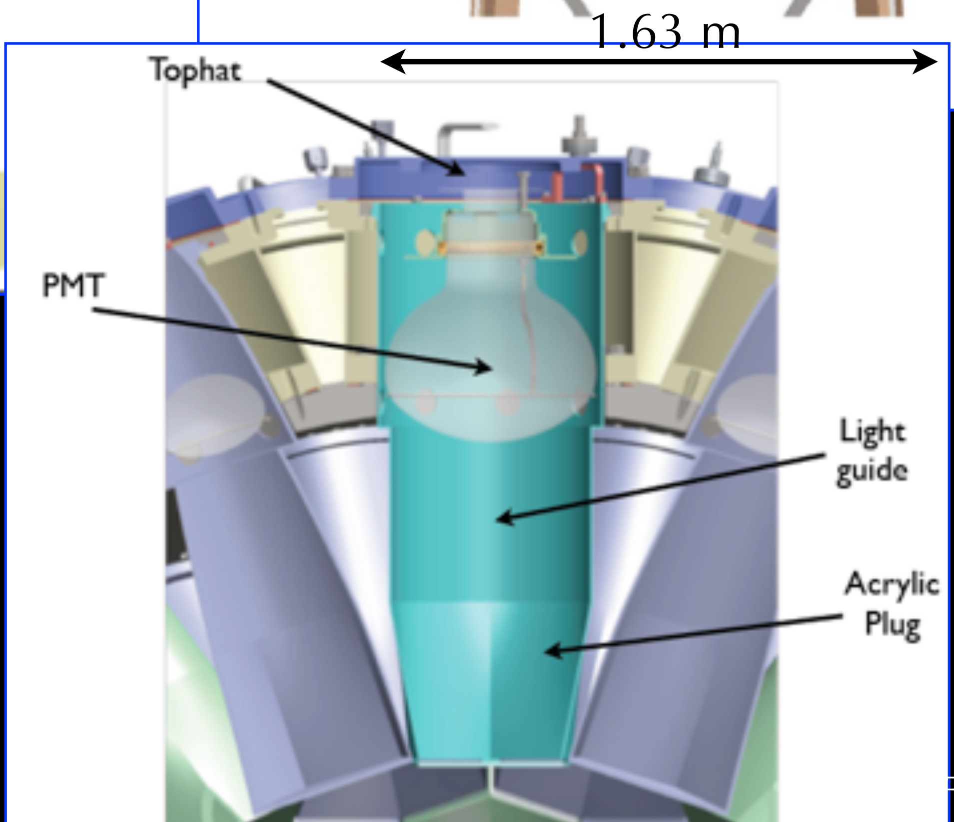




MiniCLEAN Design







light guides optically isolate PMTs

10 cm acrylic plug shields LAr from PMT glass neutrons

water shield surrounds by >= 1m

300 kg Argon inside WLS, project 150 kg fiducial

92 8″ R5912mod PMTs (cold)

Electron Backgrounds

<u>strategy:</u>

-reject using scintillation light timing

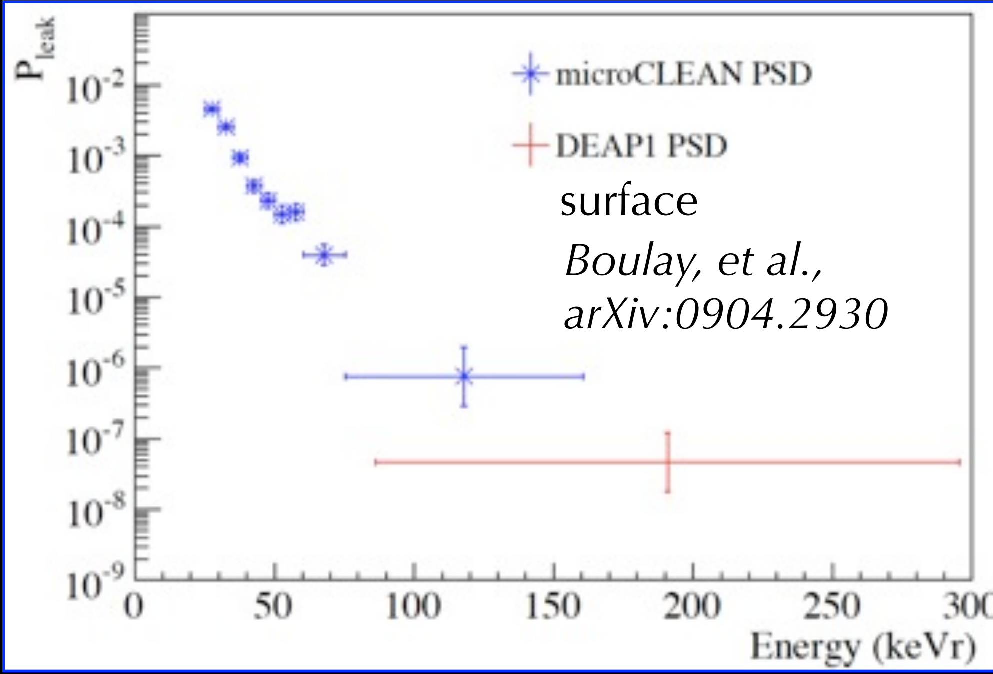
-projected light yield in MiniCLEAN:
6-8 pe/keVee, from full optical simulation

-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

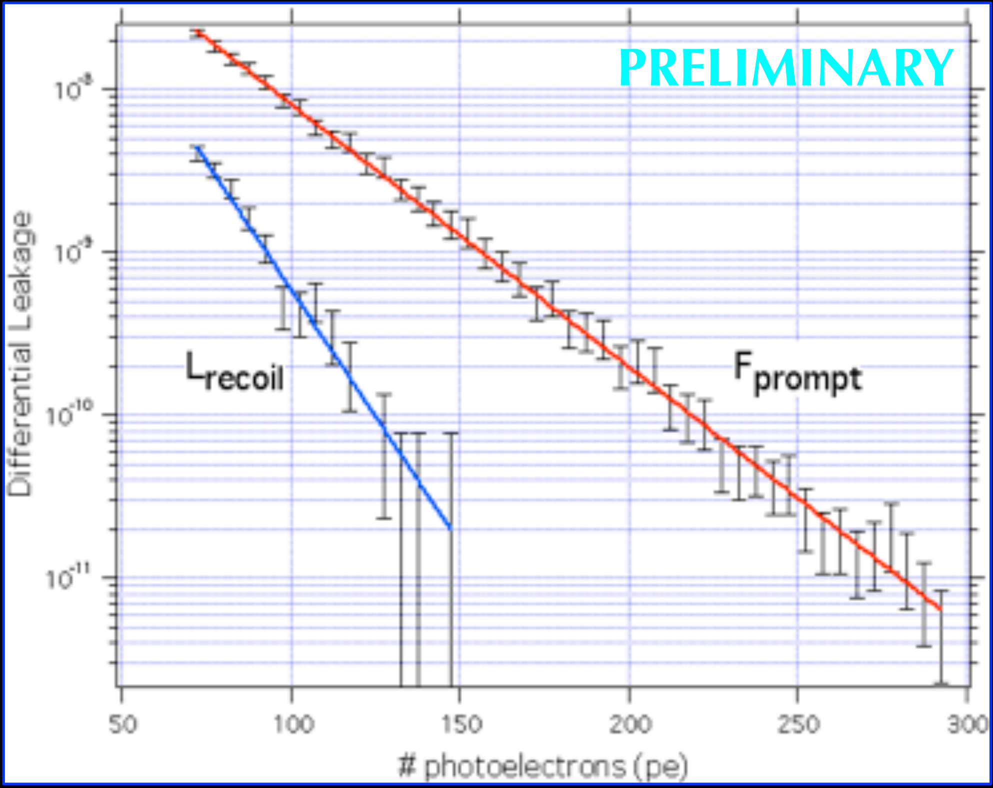
-Lrecoil reduces effect of broad PMT charge distribution, statistic has less variance than Fprompt producing better separation between nuclear recoils and electrons

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



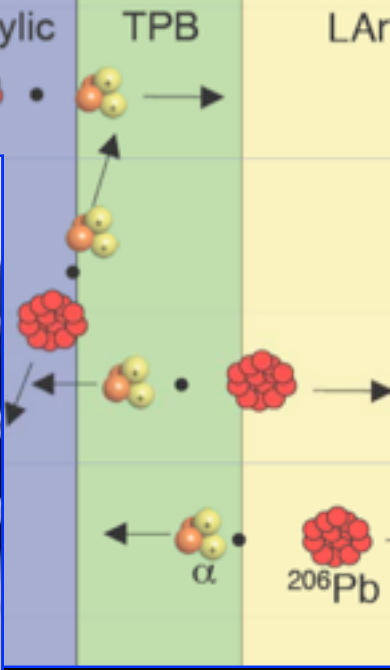
surface

Boulay, et al., arXiv:0904.2930



Alpha Backgrounds

V. Giuseppe et al., arXiv:1101.0126



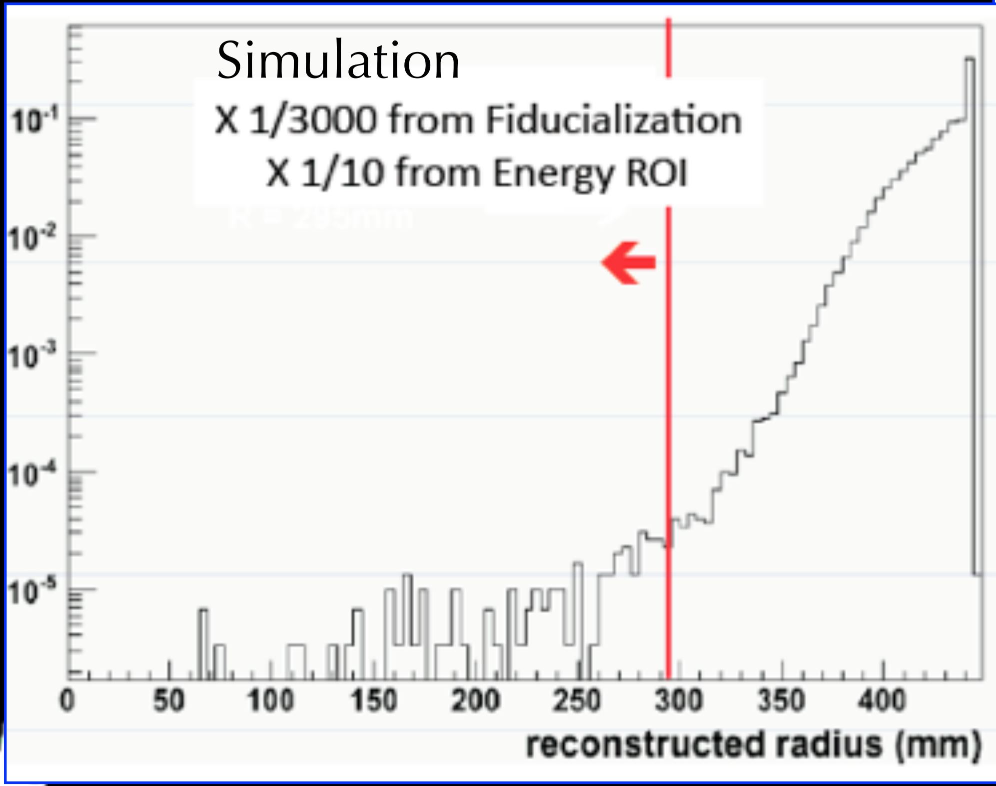
<u>Strategy:</u>

-reject using fiducial volume cut

-dangerous background from Rn daughters plating out on materials

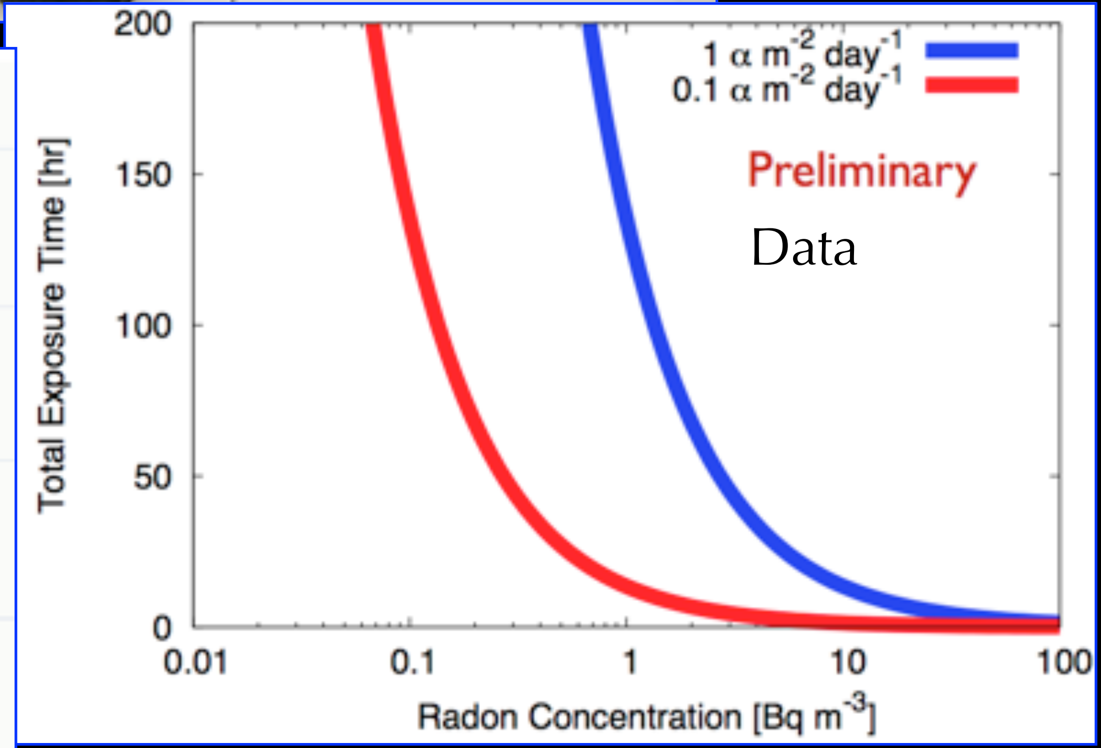
-control radiopurity O(100 ppb U, Th), minimize radon exposure (< 1α/m^2/day)

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



Simulation

X 1/3000 from Fiducialization
X 1/10 from Energy ROI



Preliminary

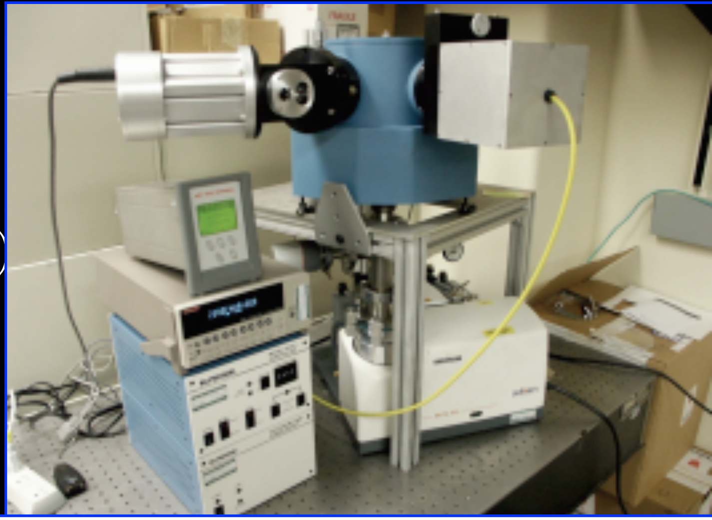
Data

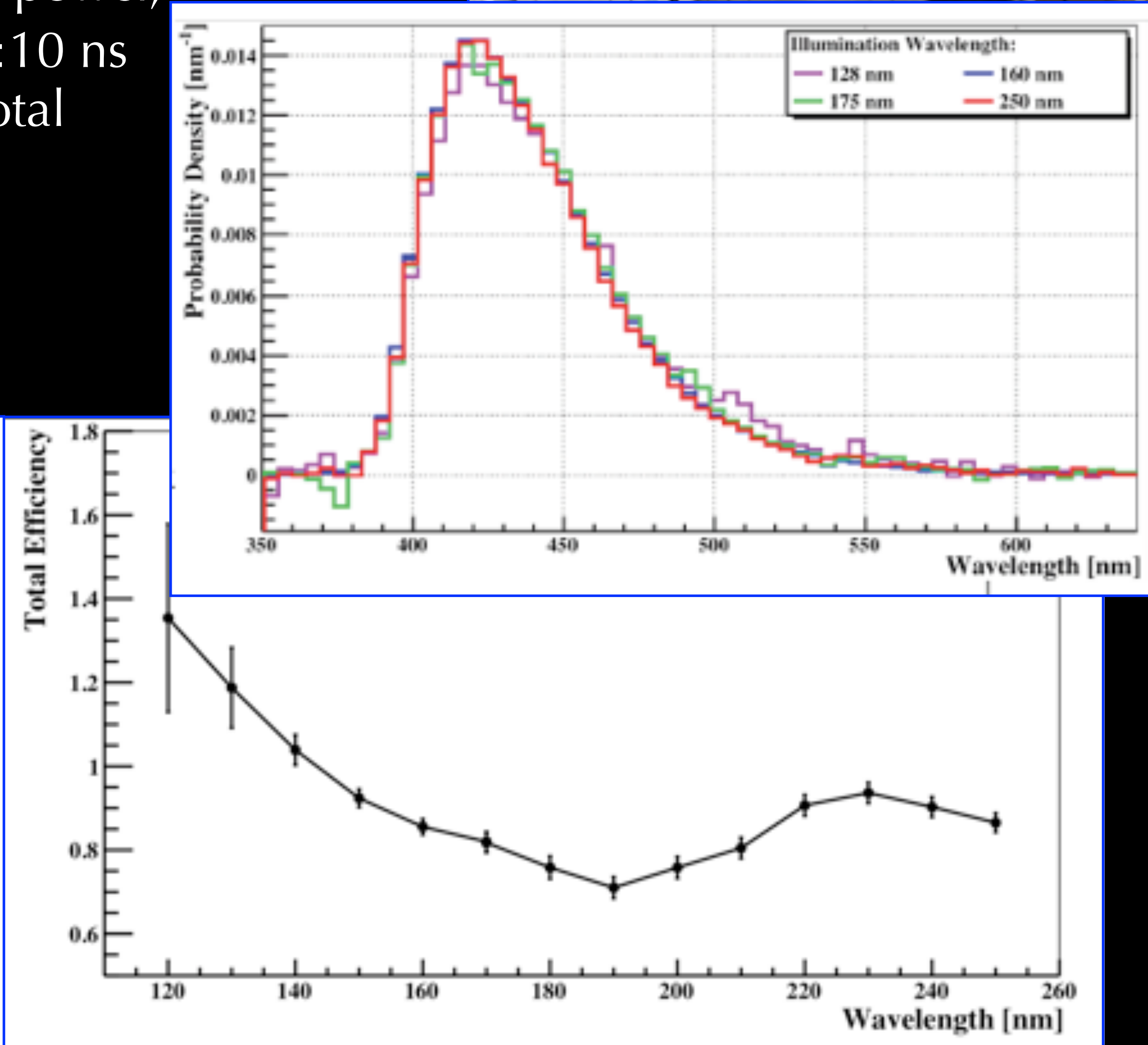
Alpha Scintillation in TPB

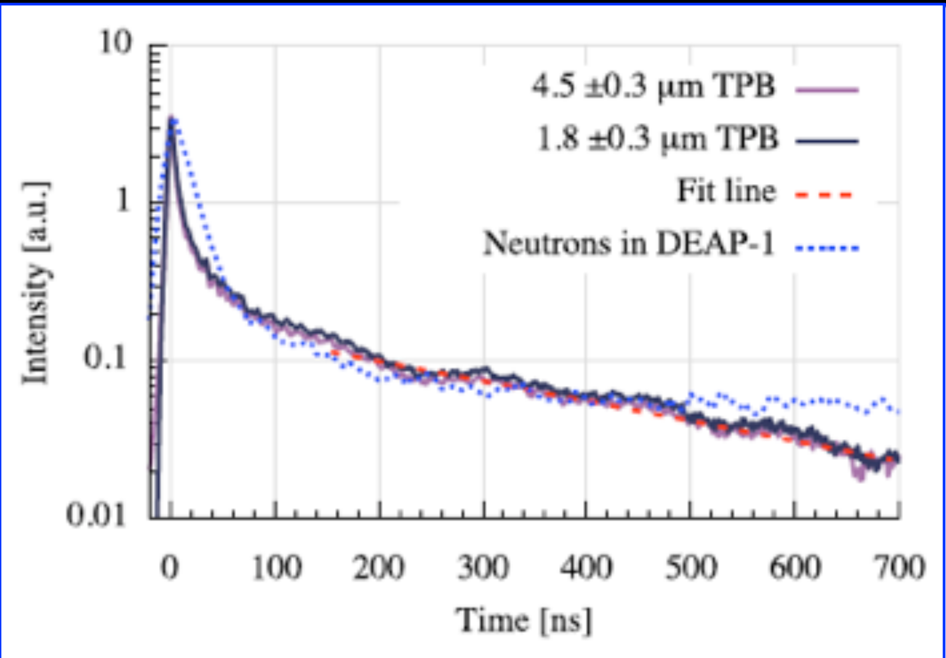
Strategy:

-TPB wavelength-shifts from 128 nm to visible (fluorescence)
ex-situ test benches for spectrum, efficiency, angular dist.
V. M. Gehman et al., arXiv:1104.3259

-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., arXiv:1011.1012







Neutron Backgrounds

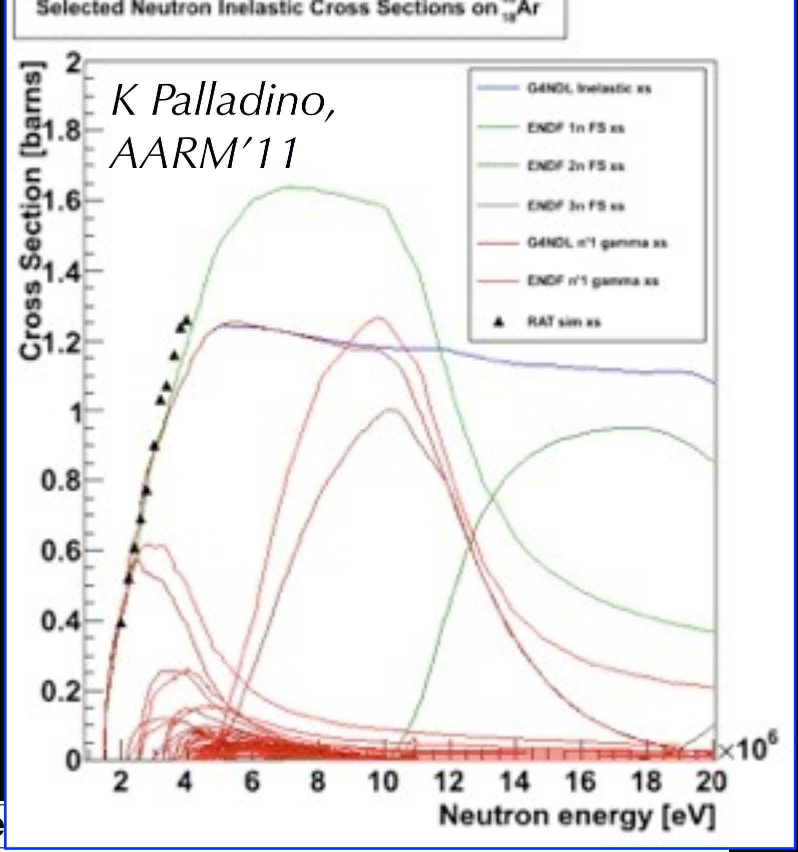
Strategy:

-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)

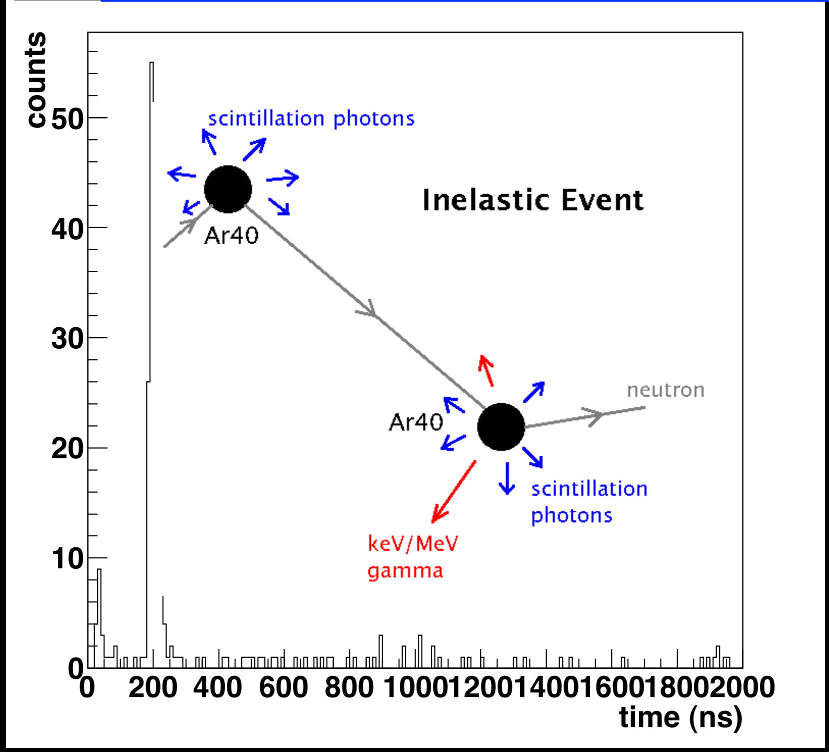
-major effort to validate Geant4 neutron physics, >90% of neutrons scatter inelastically, different time signature than single nuclear recoils (*K. Palladino, APS'11)*

-simulate neutrons with reconstruction, estimate radius, energy, fprompt cuts leave ~2 events/yr in E>20 keVee; with tagging multiple scatters and Lrecoil cut, project <1/yr in E>12.5 keVee (50 keVr)



K Palladino, AARM'11

		$0 \le E_r < 20$ keVee	$20 \le E_r < 100$ keVee
r>30 cm	multiscatter	0.53 ± 0.04	0.67 ± 0.11
	inelastic	0.042 ± 0.009	0.15 ± 0.04
	capture	0.24 ± 0.02	0.10 ± 0.04
	Ar41 decay	0.24 ± 0.02	0.10 ± 0.04
	total	0.67 ± 0.04	0.74 ± 0.12
r<30 cm	multiscatter	0.74 ± 0.07	0.94 ± 0.22
	inelastic	0.036 ± 0.012	0.14 ± 0.07
	capture	0.24 ± 0.03	0.17 ± 0.07
	Ar41 decay	0.23 ± 0.03	0.17 ± 0.07
	total	0.82 ± 0.08	0.94 ± 0.22



Neutron Calibration: Pulsed Source

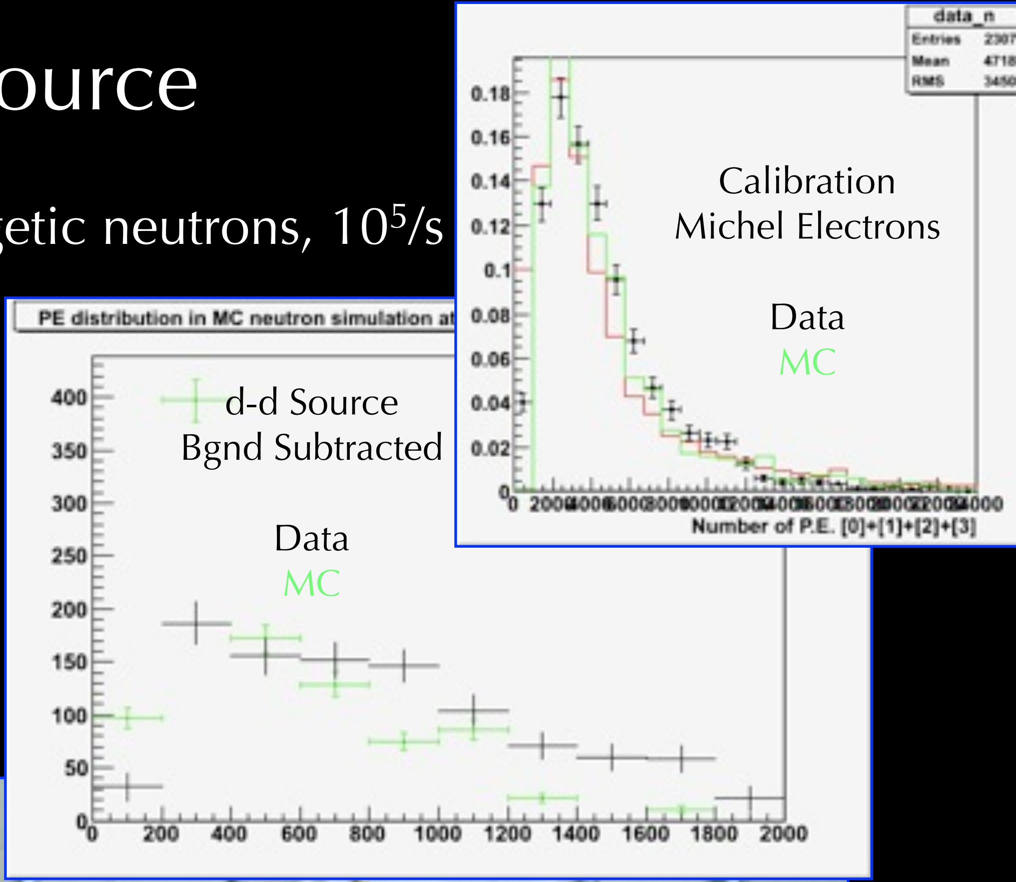
d-d source:

-Schlumberger Minitron: 2.4 MeV ~monoenergetic neutrons, 10^5/s

-calibration of n-induced ^{40}Ar recoils at energy threshold, measure neutron tagging efficiency

-characterizing source intensity, energy with liquid scintillator fast neutron detector

-UK: HV distribution/monitoring, deployment

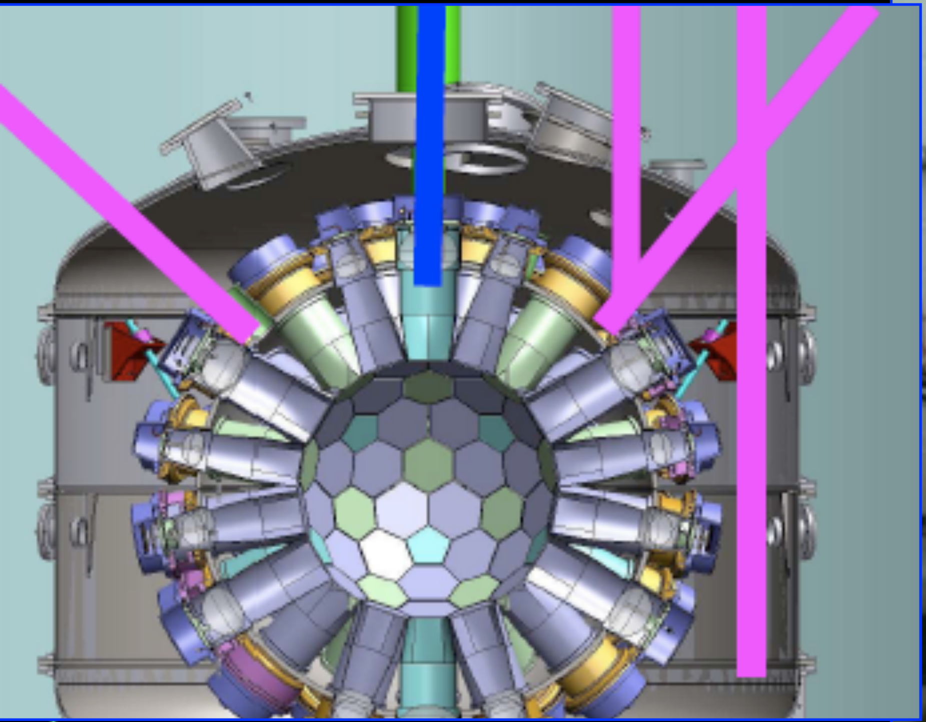


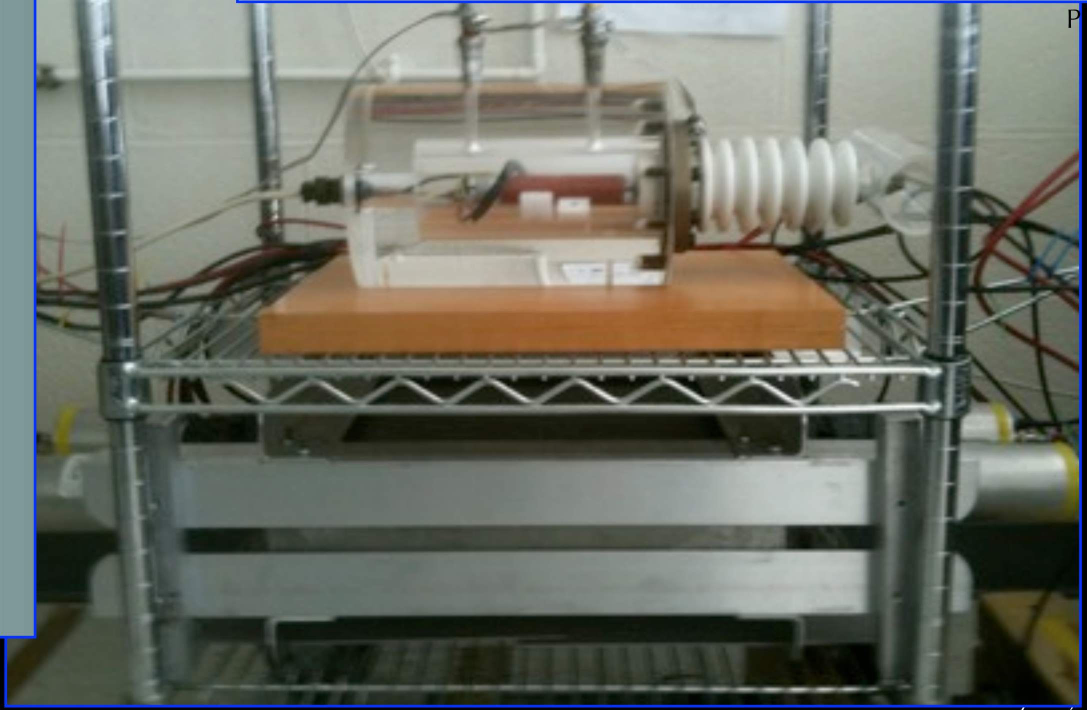
Calibration
Michel Electrons

Data
MC

d-d Source
Bgnd Subtracted

Data
MC



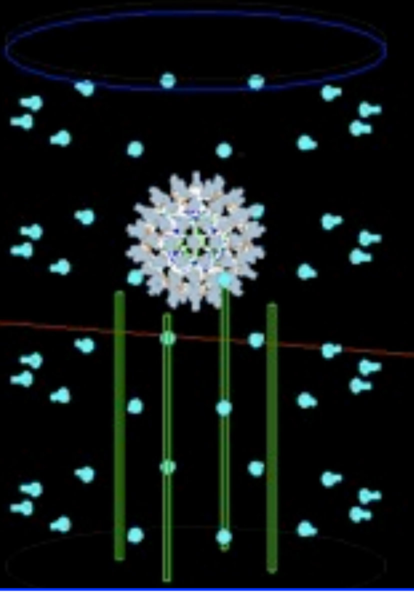


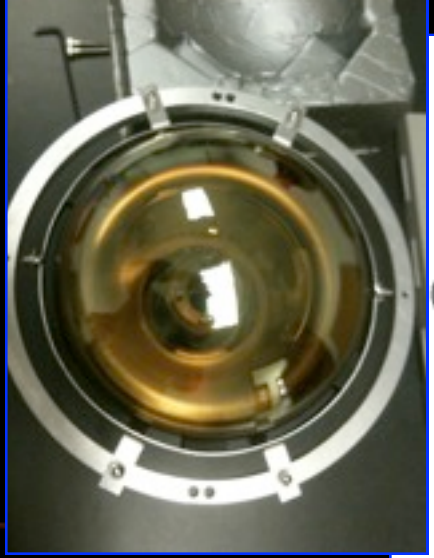
External Backgrounds

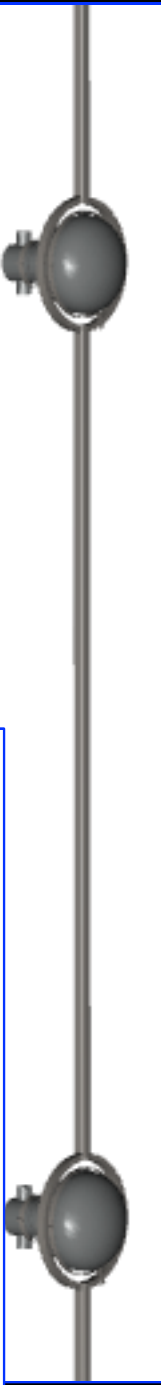
Strategy:
-shield external gammas and neutrons using water (1m on all sides), and active muon veto

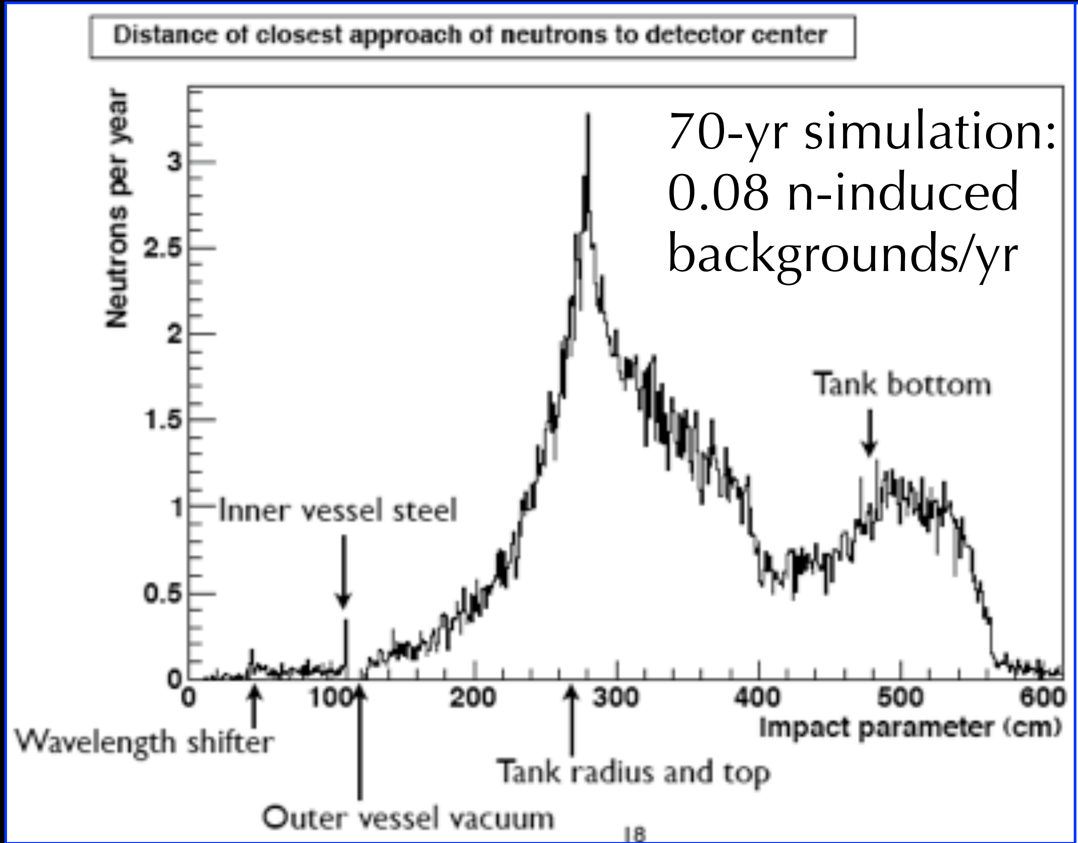
-dangerous background from cosmogenic neutrons (high energy, large uncertainty)

-UK: mechanical, HV&electronics, trigger, DAQ, simulation, analysis

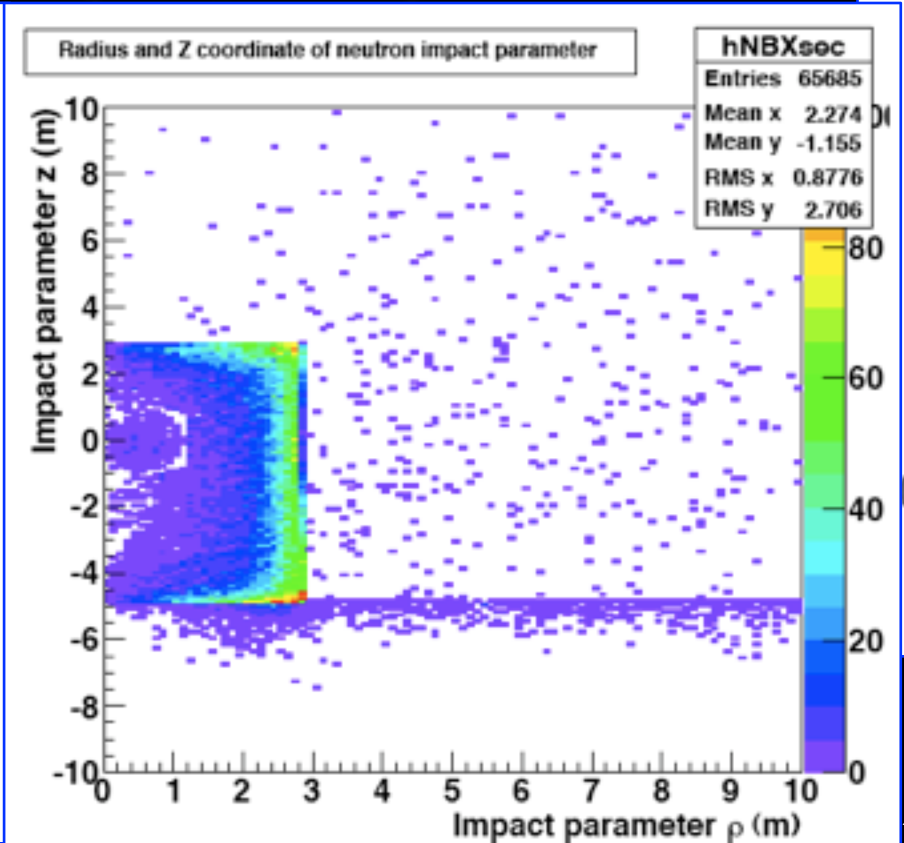








70-yr simulation: 0.08 n-induced backgrounds/yr



Experimental Technique

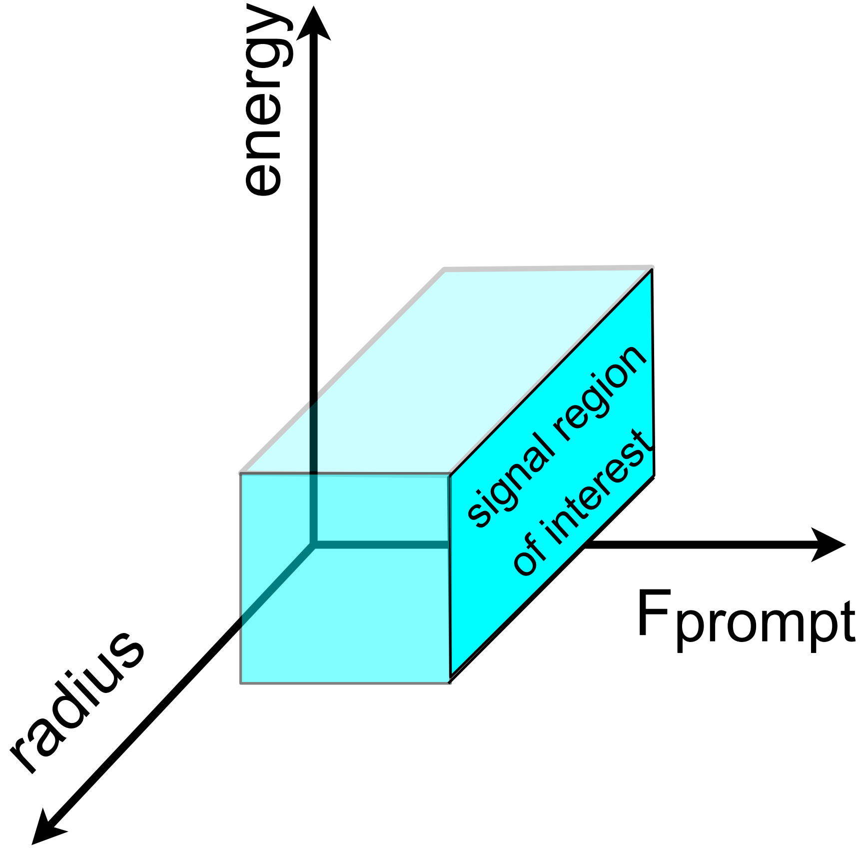
WIMP signal:

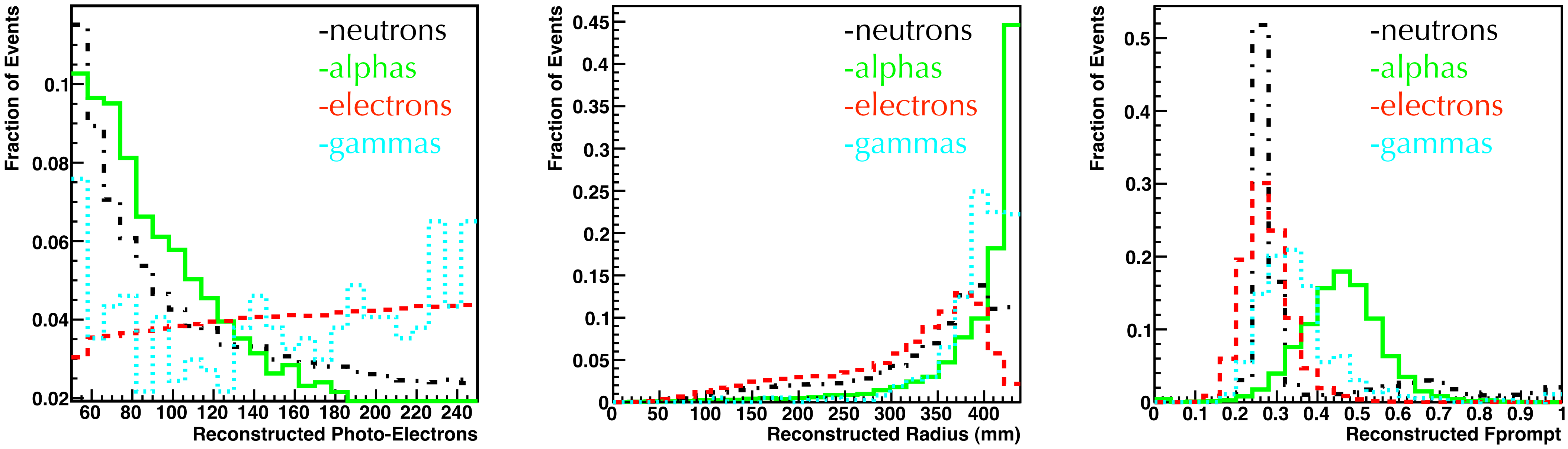
-plan two types of (blind) analyses:

1) counting, with 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





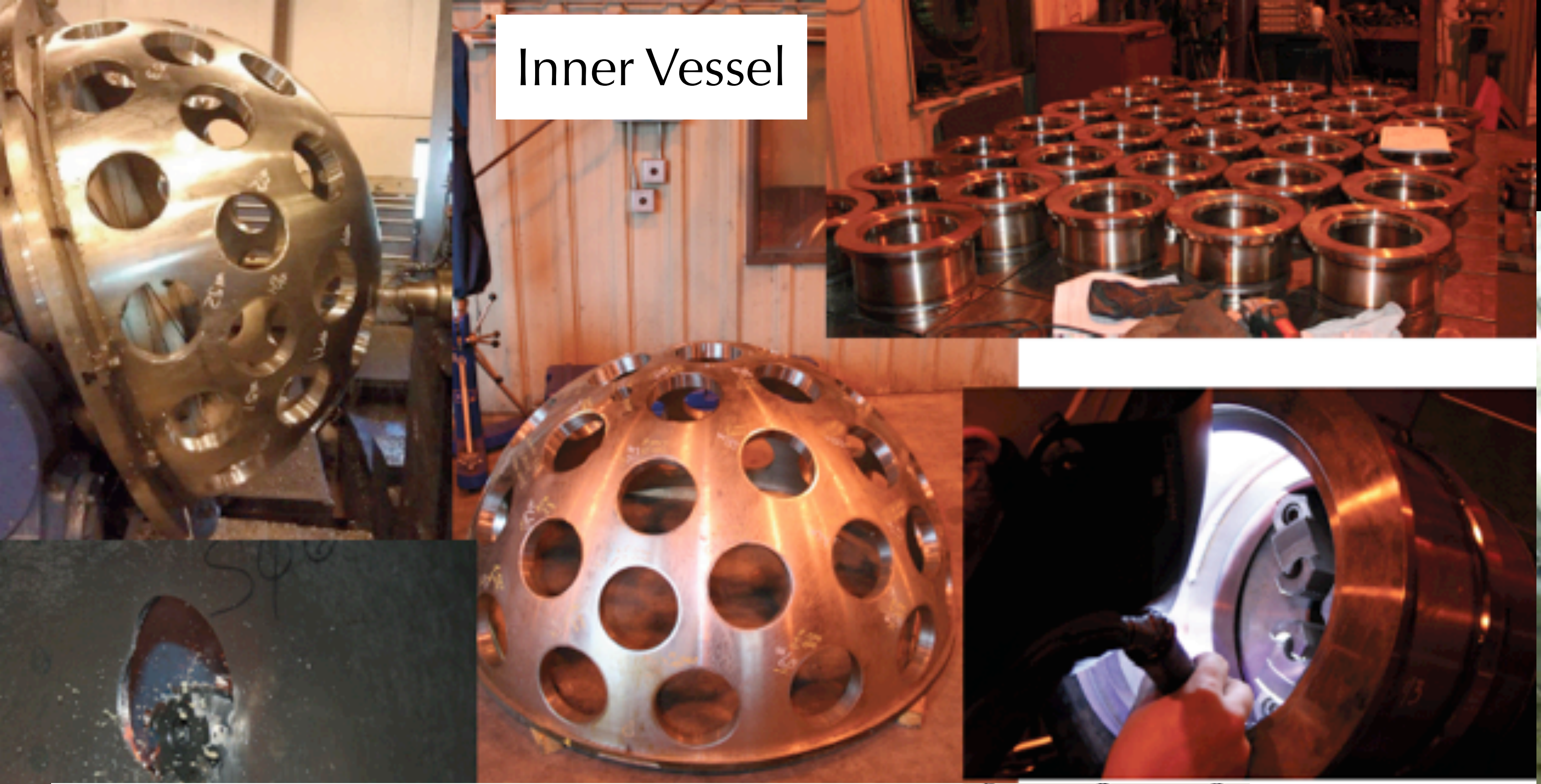
MiniCLEAN Status

Outer Vessel

SNOLab Infrastructure

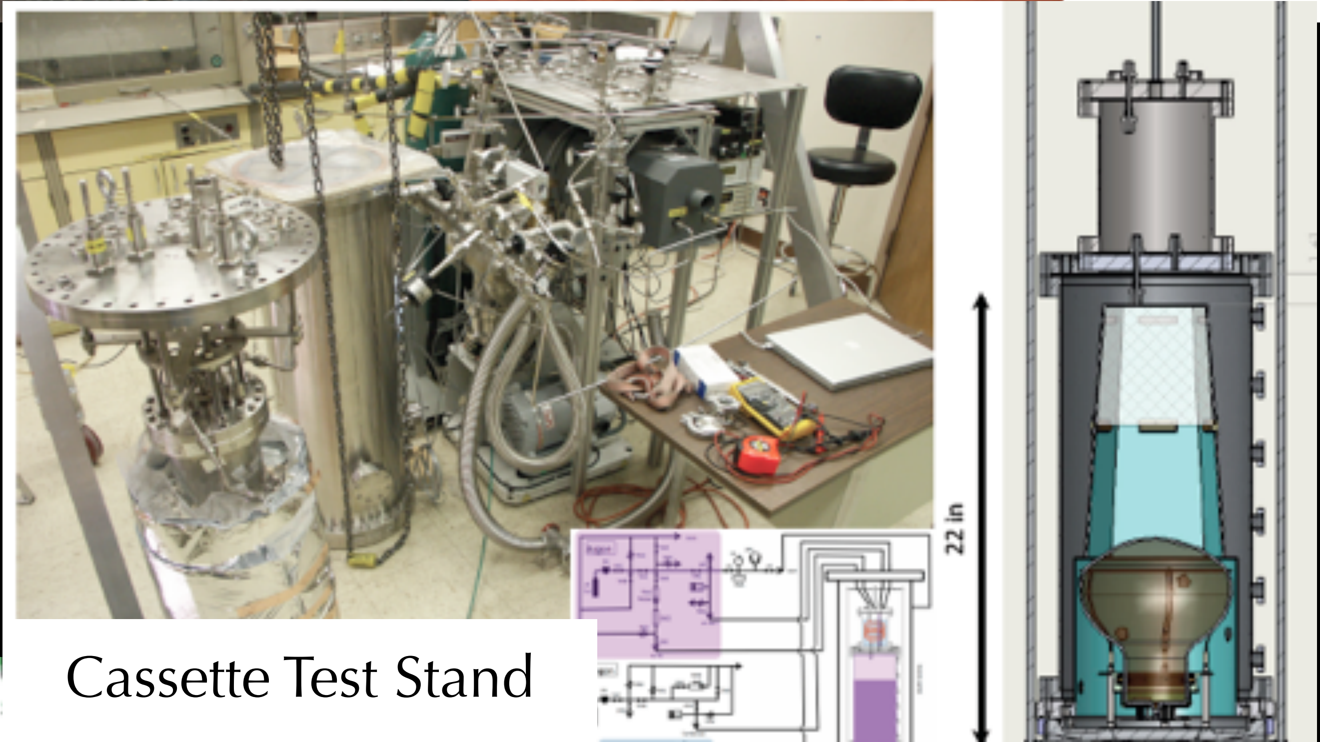
Practice!

Inner Vessel

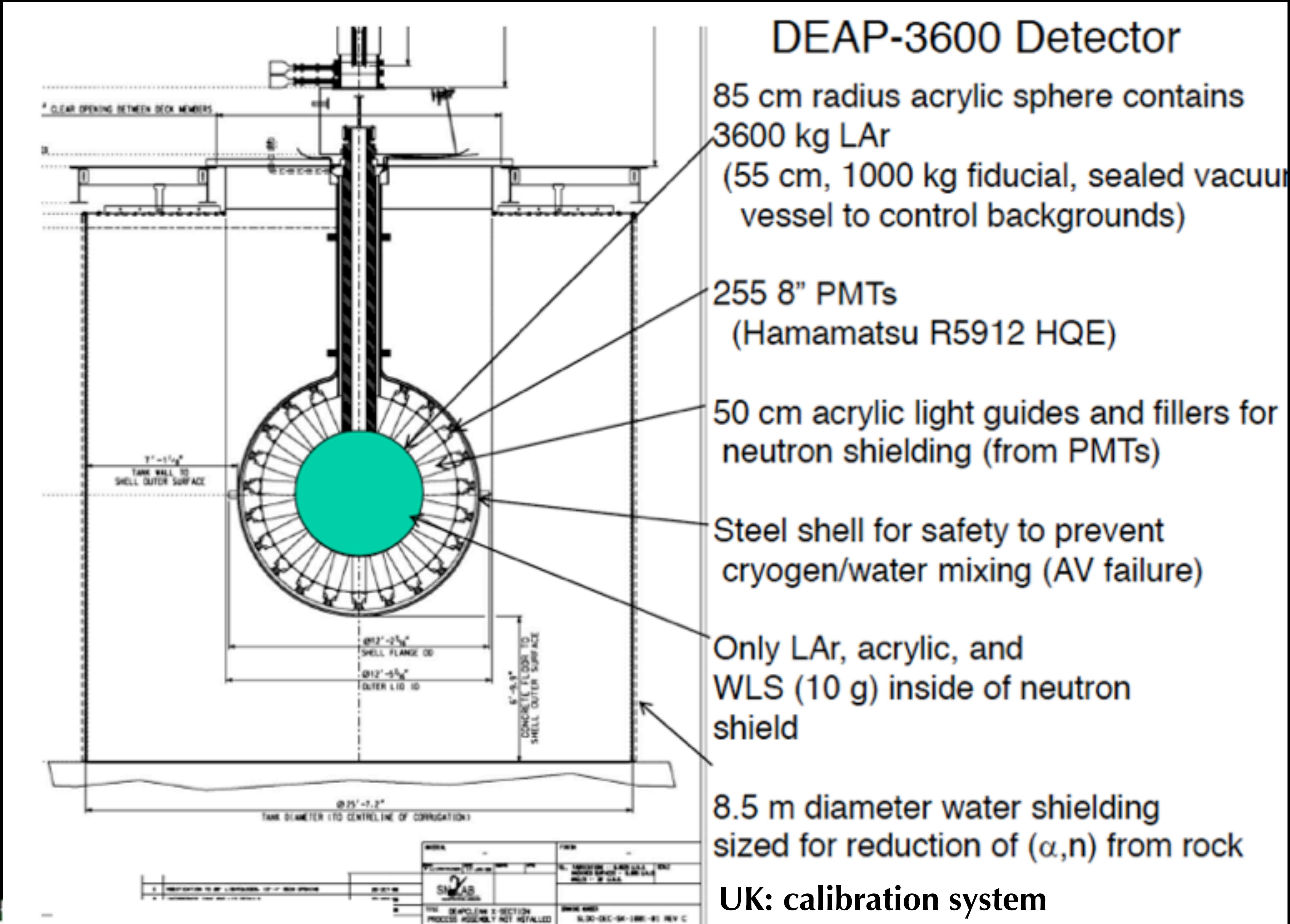


Veto Assembly Test

Cassette Test Stand



DEAP-3600



DEAP-3600 Detector

85 cm radius acrylic sphere contains 3600 kg LAr
(55 cm, 1000 kg fiducial, sealed vacuu
vessel to control backgrounds)

255 8" PMTs
(Hamamatsu R5912 HQE)

50 cm acrylic light guides and fillers for neutron shielding (from PMTs)

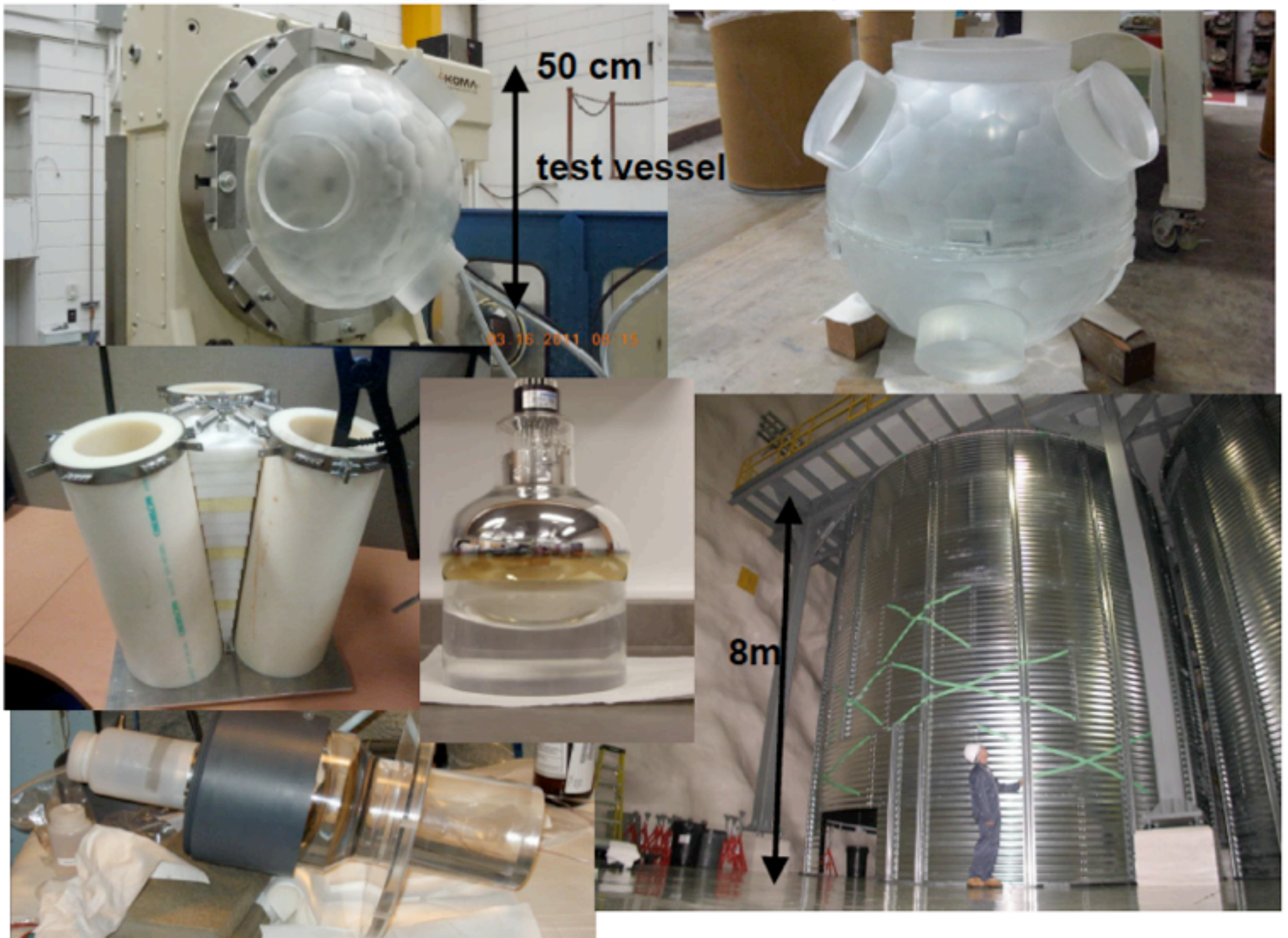
Steel shell for safety to prevent cryogen/water mixing (AV failure)

Only LAr, acrylic, and WLS (10 g) inside of neutron shield

8.5 m diameter water shielding sized for reduction of (α,n) from rock

UK: calibration system

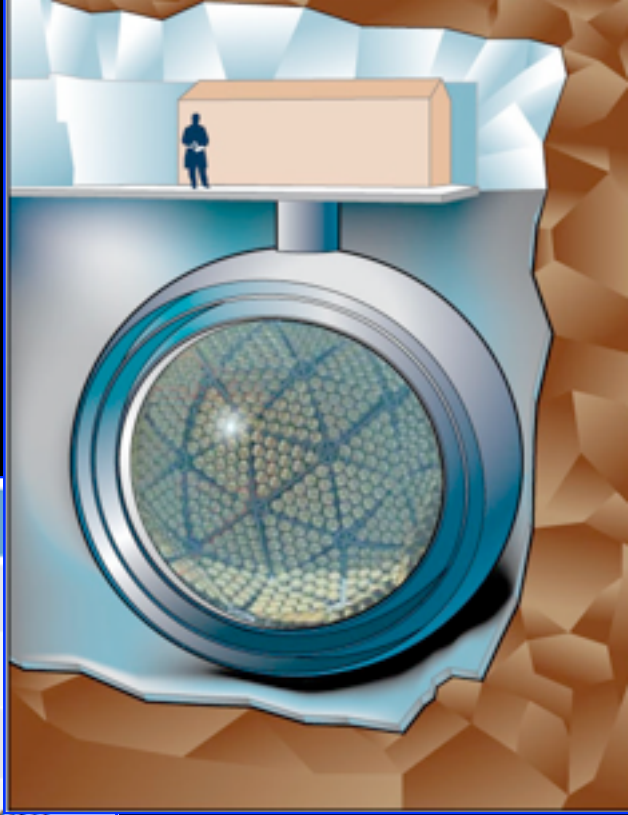
DEAP-3600 Construction and Prototyping



Goal: DEAP/CLEAN "G3" 100T Scale

Cryogenic Low Energy Astrophysics with Noble Liquids

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

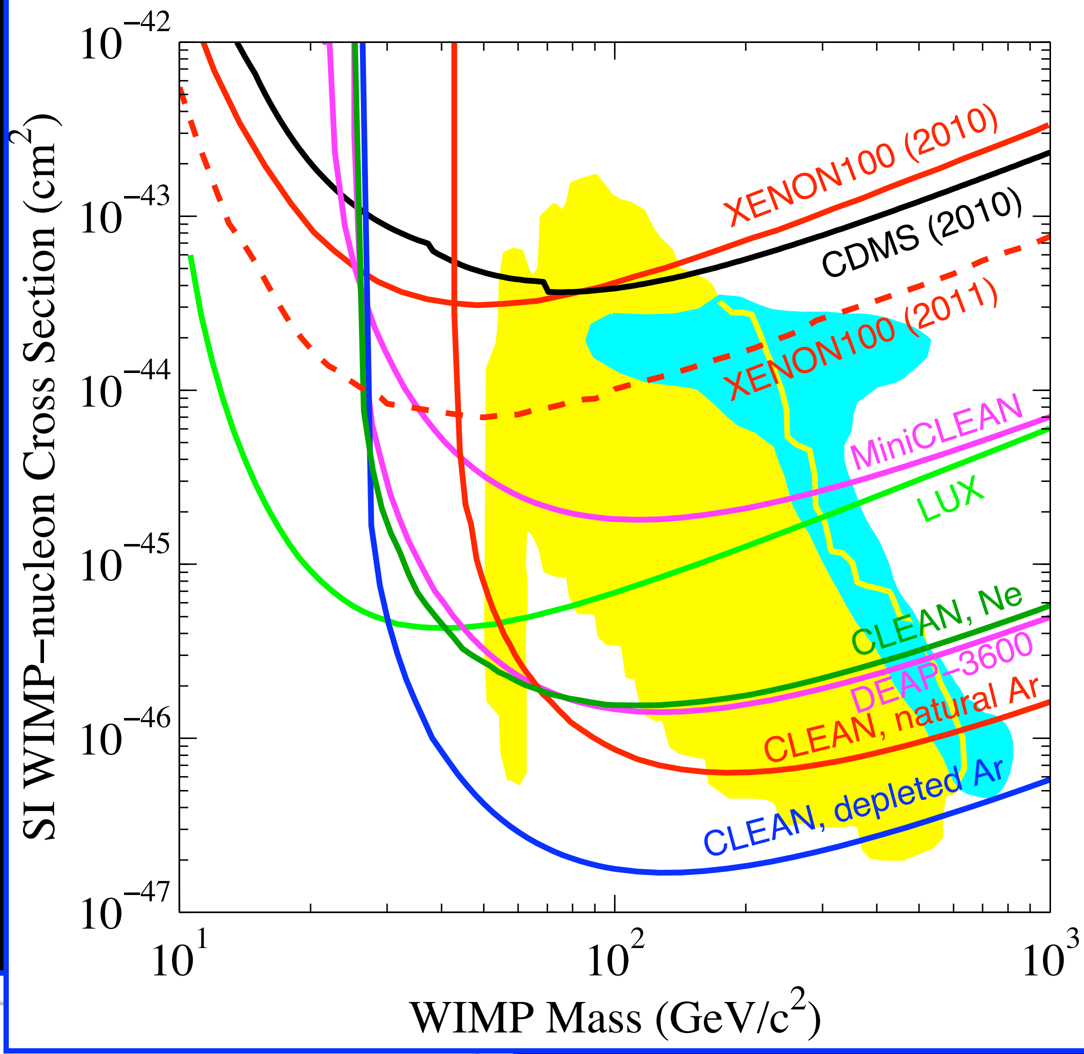


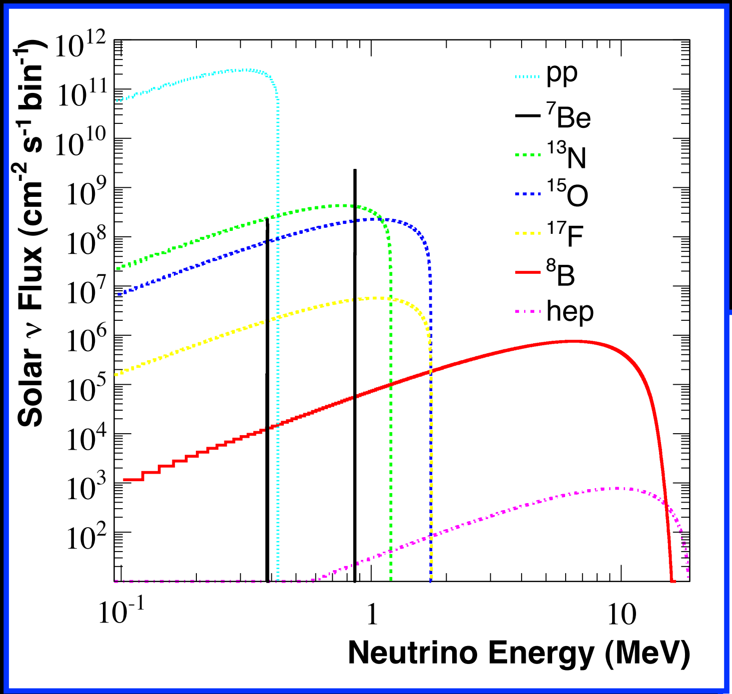
	MiniCLEAN (G1)	DEAP-3600 (G2)
Target Capability	LAr / LNe	LAr
Target Radius	500 kg / 150 kg	3600 kg / 1000 kg
Target / Fiducial Volume	45 cm/30 cm	85 cm/55 cm
Cryogen Containment	Code-Stamped SS Pressure Vessels	Monolithic Acrylic Sphere
Light Collection	92 Optical Modules PMTs Submerged "Cold"	266 "Warm" 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

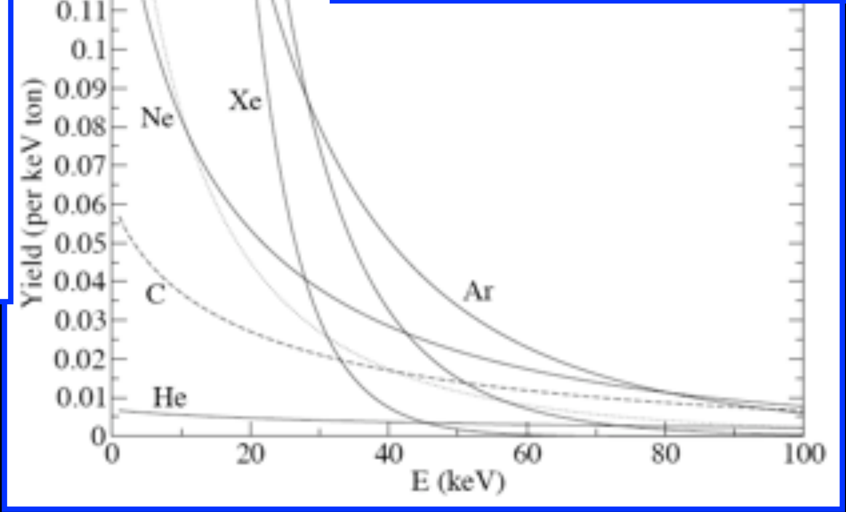
DEAP/CLEAN "G3" Physics Reach

1. dark matter
2. pp solar neutrinos
3. supernova neutrinos
4. rare event searches





McKinsey et al,
astro-ph/0402007



Horowitz et al,
astro-ph/0302071

Outline

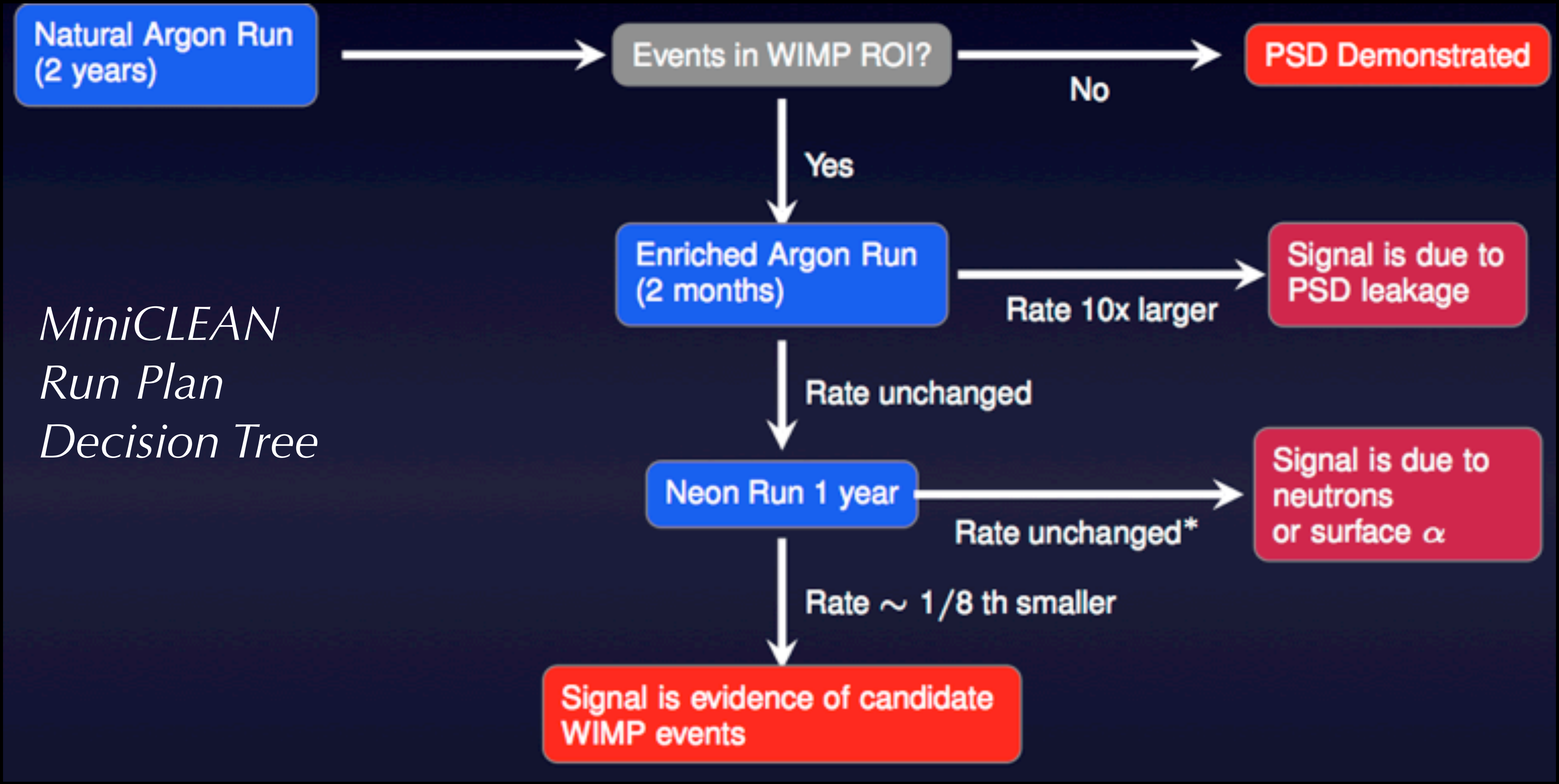
Direct Dark Matter Detection

DEAP/CLEAN Experimental Technique

How Will We Know When Dark Matter is Discovered?

Discovery

1. multiple targets (signal cross section ~ A^2), multiple technologies
2. measure the background in-situ (neutron background ~ A)



MiniCLEAN
Run Plan
Decision Tree

Natural Argon Run (2 years)

Events in WIMP ROI?

No

PSD Demonstrated

Yes

Enriched Argon Run (2 months)

Rate 10x larger

Signal is due to PSD leakage

Rate unchanged

Neon Run 1 year

Rate unchanged*

Signal is due to neutrons or surface α

Rate $\sim$ 1/8 th smaller

Signal is evidence of candidate WIMP events

3. directional detection...

Conclusions & Outlook

This is a very interesting time in dark matter direct detection!

The DEAP/CLEAN collaboration is developing single-phase detectors with emphasis on scalability and in-situ background measurement, 5-year program of prototype single-phase detector development.

MiniCLEAN (O(100 kg)) and DEAP-3600 (O(1000 kg)) detectors under construction, starting operations at SNOLab from 2012 and 2013. UK leads calibration systems and neutron background analysis.

Definitive discovery of dark matter in direct detection will require multiple targets and multiple technologies.

Stay tuned!

Extra Slides

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)

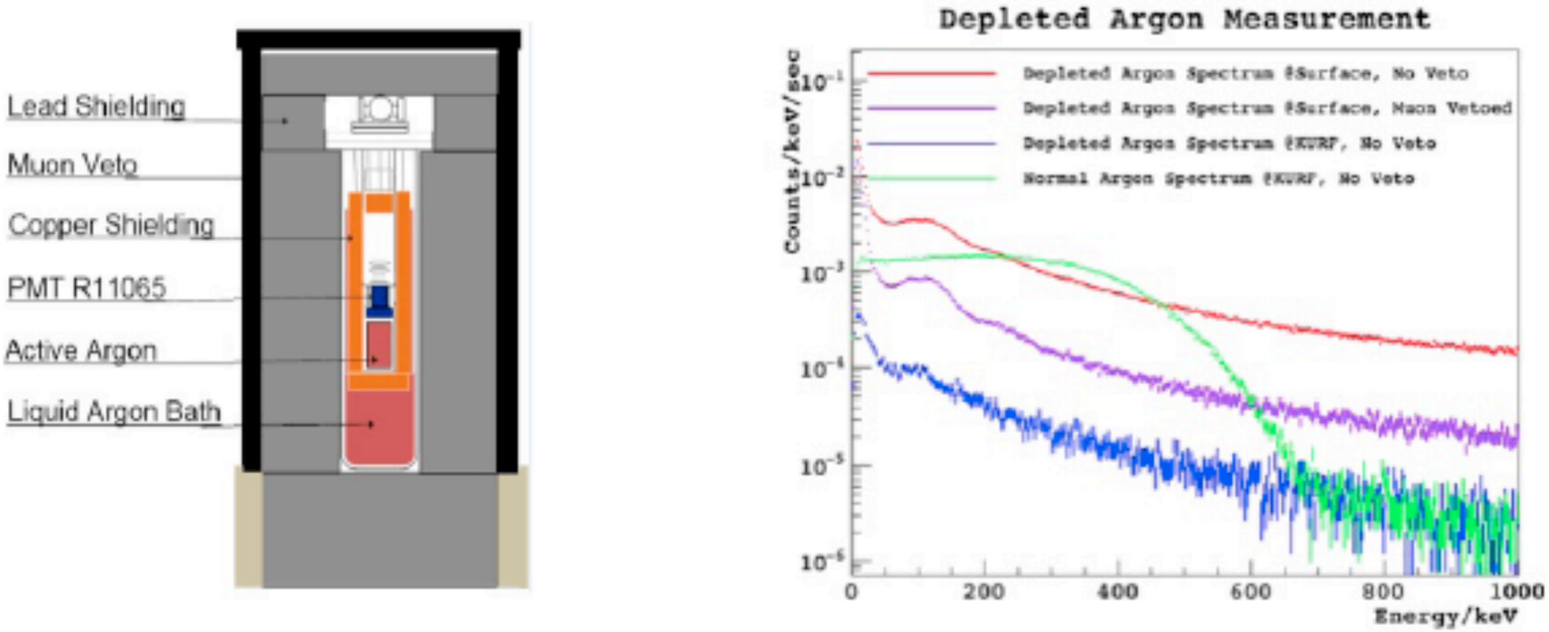


Figure 2: Left: Schematic diagram of the "Low Background Detector." Right: The depleted argon spectra obtained in various detector configurations. In the measurement at KURF, the total event rate in 300-400 keV is ~0.002 Hz, about 2% of the rate expected from ^{39}Ar in atmospheric argon. Data taken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