# New results from the XENON10 dark matter experiment

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High Energy Physics seminar
University of Pennsylvania
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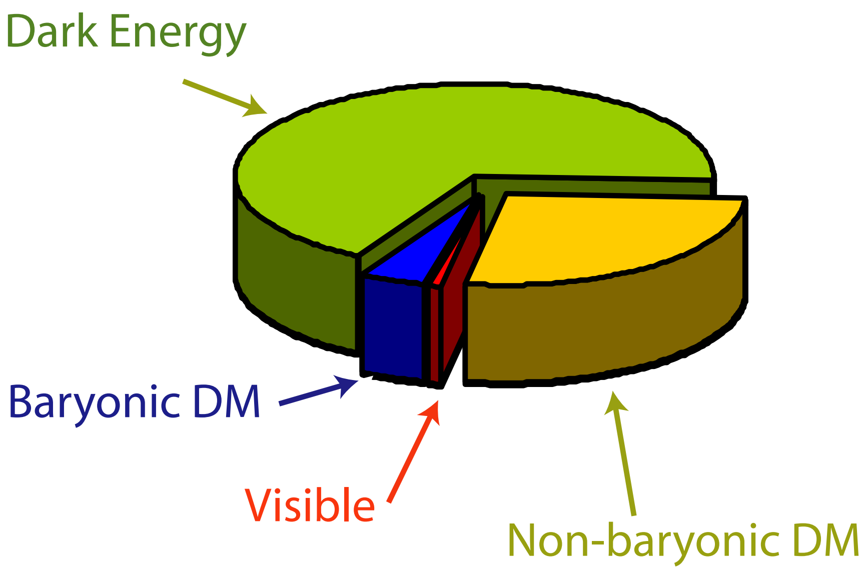
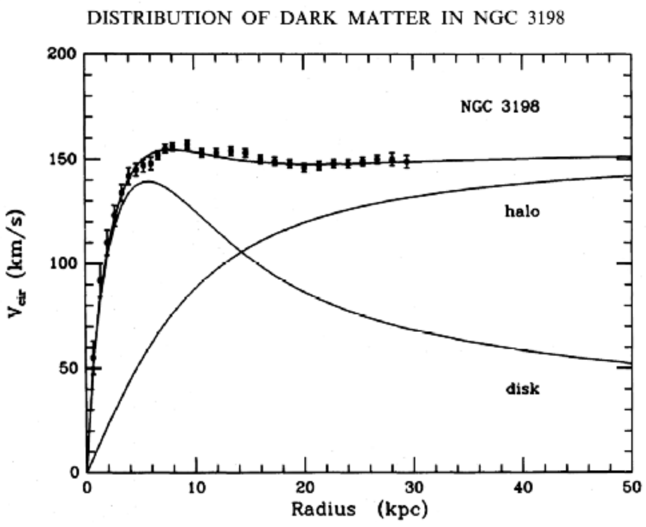
# The Universe is mostly dark

Dark Energy = 73%
Non-baryonic dark matter = 23%
Baryonic dark matter = 3.5%
Visible = 0.5%



This conclusion is supported by a variety of evidence:

Cosmic microwave background (most recently WMAP)
Type Ia supernovae
Gravitational lensing
Galaxy rotation curves
....



# Weakly Interacting Massive Particles (WIMPS)

## A new particle interacting via the weak force could form Cold Dark Matter

- Formed in massive amounts in the Big Bang
- Non-relativistic freeze-out. Decouples from ordinary matter.
- Would exist today at densities of about $1000/m^3$

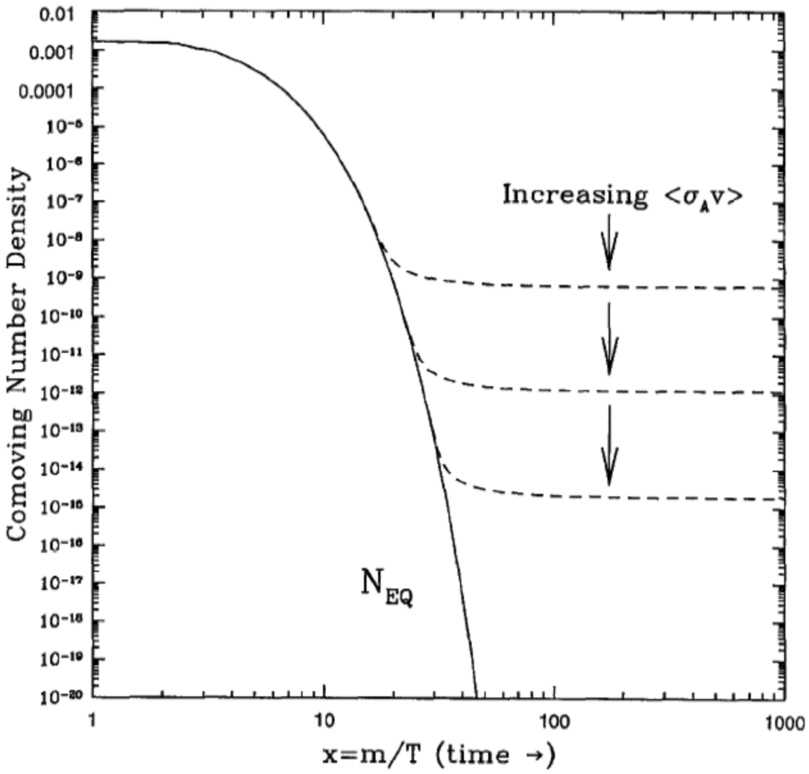
## Supersymmetry provides a plausible candidate: the neutralino

- Lowest mass superposition of photino, zino, higgsino
- Mass window $40\ \text{GeV} < m_{\chi} < 1000\ \text{GeV}$
- Charge neutral
- Stable! (by R-parity conservation)

## Universal Extra Dimensions: predicts stable Kaluza-Klein (KK) particles

- Cosmological mass window $600\ \text{GeV} < m_{KK} < 1000\ \text{GeV}$
- Similar direct detection properties as neutralino
- Distinguishable from neutralinos at accelerators

# WIMP Relic Density



The amount of dark matter left over is inversely proportional to the annihilation cross-section:

$\Omega_{DM} \sim < \sigma_A v >^{-1}$

Suppose $\sigma_A = k\alpha^2/m^2$

Then $\Omega_{DM} \sim m^2$

For $\Omega_{DM} \sim 0.1$, m ~ 100 GeV to 1 TeV

G. Jungman et al, Physics Reports 267 (1996) 195-373

A weakly interacting massive particle is a natural candidate for the dark matter

# Searching for WIMPs

Accelerators: Look for dark matter candidates at the LHC.

Squark and gluino decays result in leptons, jets, and missing energy.

BUT:
1) can't show that dark matter candidate is stable
2) hard to determine couplings/interactions of dark matter candidate
3) can't prove that candidate particle actually makes up the dark matter

Indirect Searches: Look for □□ annihilation in form of high energy cosmics, neutrinos

Direct Searches: Look for anomalous nuclear recoils in a low-background detector

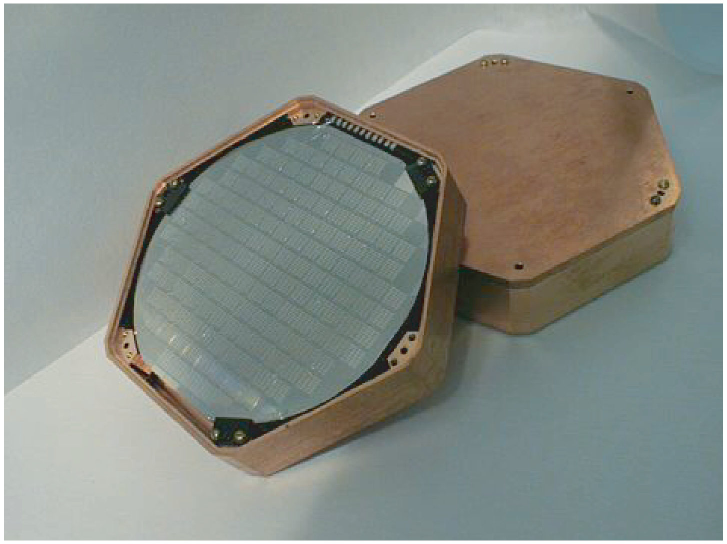
R = N □ < □ v >

From <v> = 220 km/s, get order of 10 keV

Key technical challenges:

- Low radioactivity
- Low energy threshold
- Gamma ray rejection
- Scalability

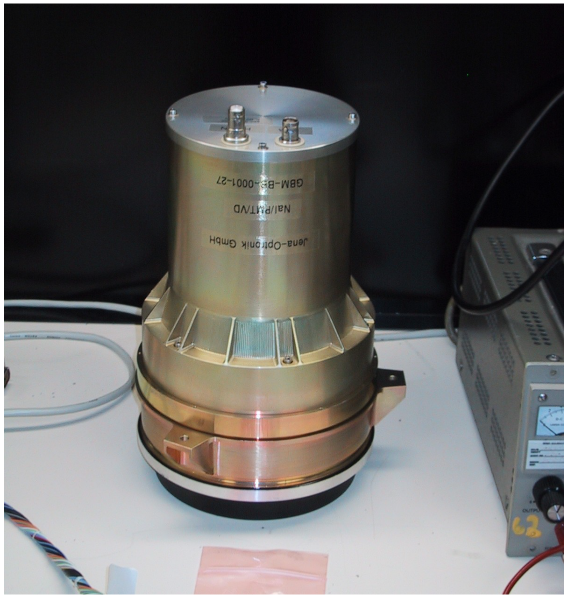
Detect heat, light, or ionization
(or some combination)



Germanium detector
(as in CDMS, Edelweiss)

# Some standard radiation detectors

Geiger counter



Sodium iodide crystal

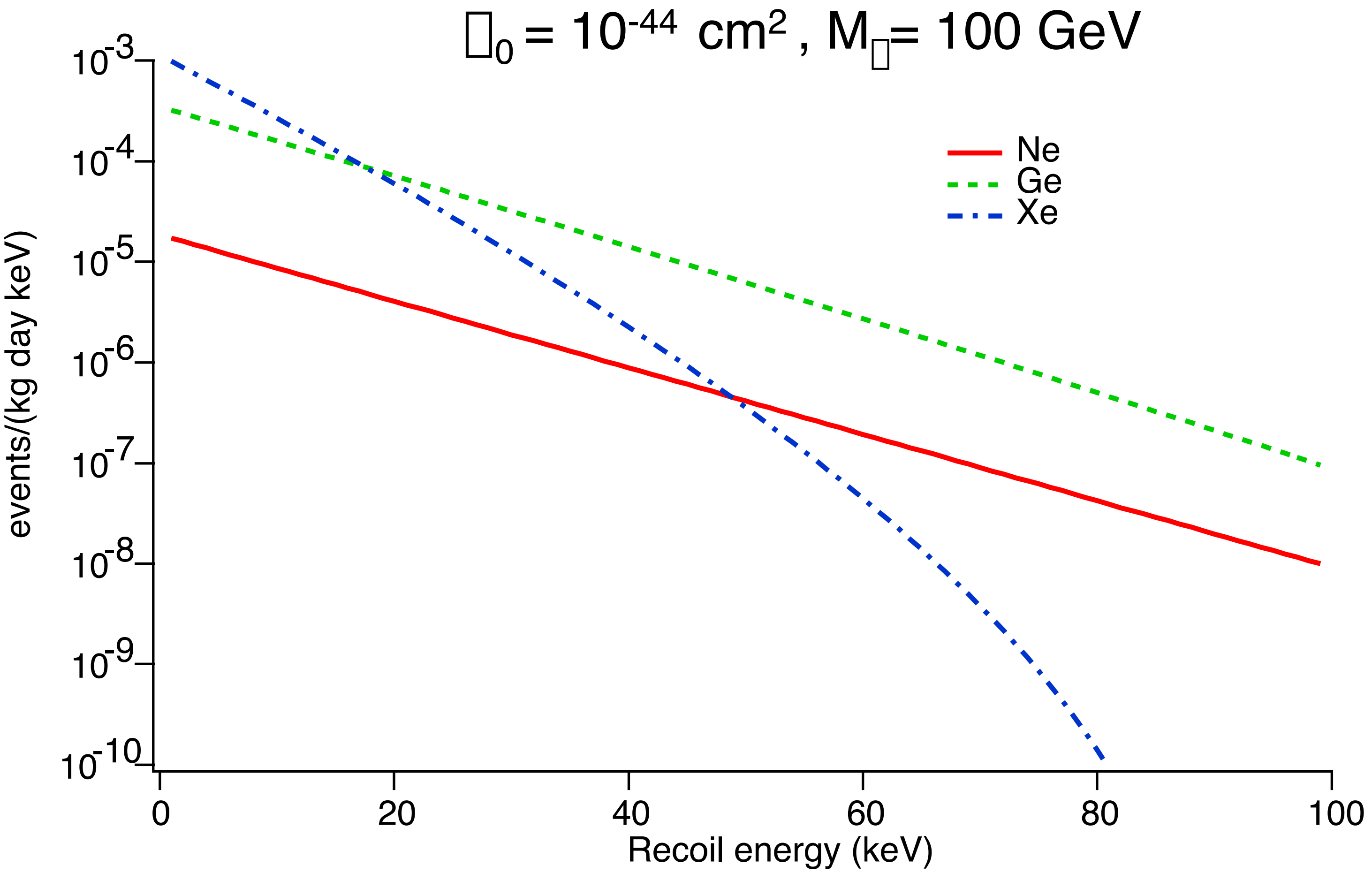
Germanium

Gamma ray interaction rate is proportional to
(# of electrons in detector) x (gamma ray flux)

Typical count rate = 100 events/second/kg = 10,000,000 events/day/kg
put it in a good lead shield ---> rate drops to 100 events/day/kg.

State-of-the-art dark matter detectors ---> sensitive to 0.01 events/kg/day

# WIMP recoil spectra



$\sigma_0 = 10^{-44}\ \mathrm{cm}^2$, $M_\chi = 100$ GeV

Scattering rate

Sun's velocity around the galaxy

WIMP velocity distribution

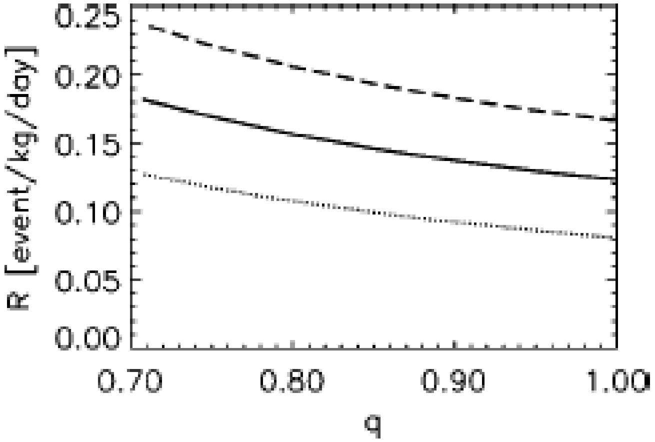
$$\mathrm{d}R/\mathrm{d}Q = (\rho_0 \sigma_0 / \sqrt{\pi}\, v_0\, m_\chi m_r^2)\, F^2(Q)\, T(Q)$$

WIMP energy density, 0.3 GeV/cm³

Form factor

# Astrophysical Uncertainties in WIMP Event Rates

During gravitational collapse and subsequent virialization, the collisionless dark matter should form a halo that is roughly spherical. Differences from a spherical isothermal model only affect event rates by order 10% for velocity distributions consistent with galaxy formation models; maximal rotation can change the event rates by roughly 30%.



Kamionkowski and Kinkhabwala,
Phys. Rev. D 57, 3256 (1998).

FIG. 4. Total detection rate as a function of halo flattening *q* for nonrotating (solid), maximally corotating (dashed), and maximally counterrotating (dotted) halos.

The local density and distribution of dark matter can be inferred by studying the rotational curve of our galaxy. Clumps in the dark matter should be destroyed through tidal interactions, resulting in a homogeneous distribution (Helmi et al, Phys. Rev. D 66, 063502 (2002)). The biggest astrophysical uncertainty comes from estimates of the local dark matter density:

□ ~ 0.34 GeV/cm$^3$ : Bahcall et al, Astrophys. J. 265 (1983) 730.
□ □ 0.23 GeV/cm$^3$ : R. R. Caldwell and J. P. Ostriker, Astrophys. J. 251 (1981) 61.
□ = 0.34 - 0.73 GeV/cm$^3$ : E. I. Gates et al., Astrophys. J. 449 (1995),L123.
□ = 0.2 - 0.8 GeV/cm$^3$ : L. Bergstrom et al, Astropart. Phys. 9 (1998), 137.

# The Noble Liquid Revolution

Noble liquids are relatively inexpensive, easy to obtain, and dense.

Easily purified

- low reactivity
- impurities freeze out
- low surface binding
- purification easiest for lighter noble liquids

Ionization electrons may be drifted through the heavier noble liquids

Very high scintillation yields

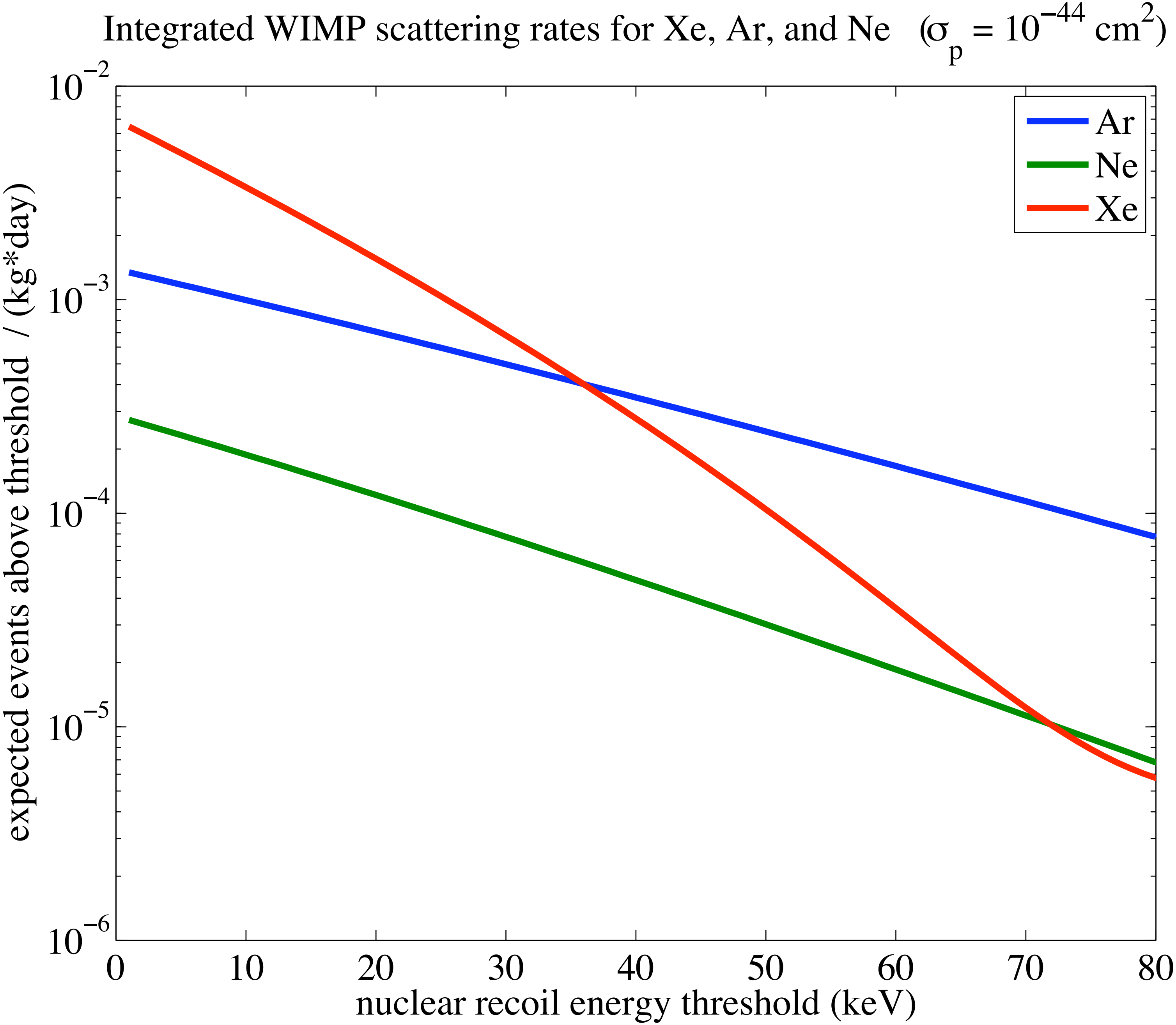
- noble liquids do not absorb their own scintillation
- 30,000 to 40,000 photons/MeV
- modest quenching factors for nuclear recoils

Easy construction of large, homogeneous detectors

# Liquified Noble Gases: Basic Properties

Dense and homogeneous
Do not attach electrons, heavier noble gases give high electron mobility
Easy to purify (especially lighter noble gases)
Inert, not flammable, very good dielectrics
Bright scintillators

| | Liquid density (g/cc) | Boiling point at 1 bar (K) | Electron mobility (cm$^2$/Vs) | Scintillation wavelength (nm) | Scintillation yield (photons/MeV) | Long-lived radioactive isotopes | Triplet molecule lifetime (μs) |
|---|---|---|---|---|---|---|---|
| LHe | 0.145 | 4.2 | low | 80 | 19,000 | none | 13,000,000 |
| LNe | 1.2 | 27.1 | low | 78 | 30,000 | none | 15 |
| LAr | 1.4 | 87.3 | 400 | 125 | 40,000 | $^{39}$Ar, $^{42}$Ar | 1.6 |
| LKr | 2.4 | 120 | 1200 | 150 | 25,000 | $^{81}$Kr, $^{85}$Kr | 0.09 |
| LXe | 3.0 | 165 | 2200 | 175 | 42,000 | $^{136}$Xe | 0.03 |



Integrated WIMP scattering rates for Xe, Ar, and Ne ($\sigma_p = 10^{-44}$ cm$^2$)
Ar
Ne
Xe
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
expected events above threshold / (kg*day)
0
10
20
30
40
50
60
70
80
nuclear recoil energy threshold (keV)

# The XENON10 Collaboration

**Columbia University** Elena Aprile, Karl-Ludwig Giboni, Maria Elena Monzani, Guillaume Plante, Roberto Santorelli and Masaki Yamashita

**University of Zürich** Laura Baudis, Jesse Angle, Aaron Manalaysay, J. Orboeck, and Stephan Schulte

**Brown University** Richard Gaitskell, Simon Fiorucci, Peter Sorensen and Luiz DeViveiros

**Lawrence Livermore National Laboratory** Adam Bernstein, Norm Madden and Celeste Winant

**Case Western Reserve University** Tom Shutt, Peter Brusov, Eric Dahl, John Kwong and Alexander Bolozdynya

Text

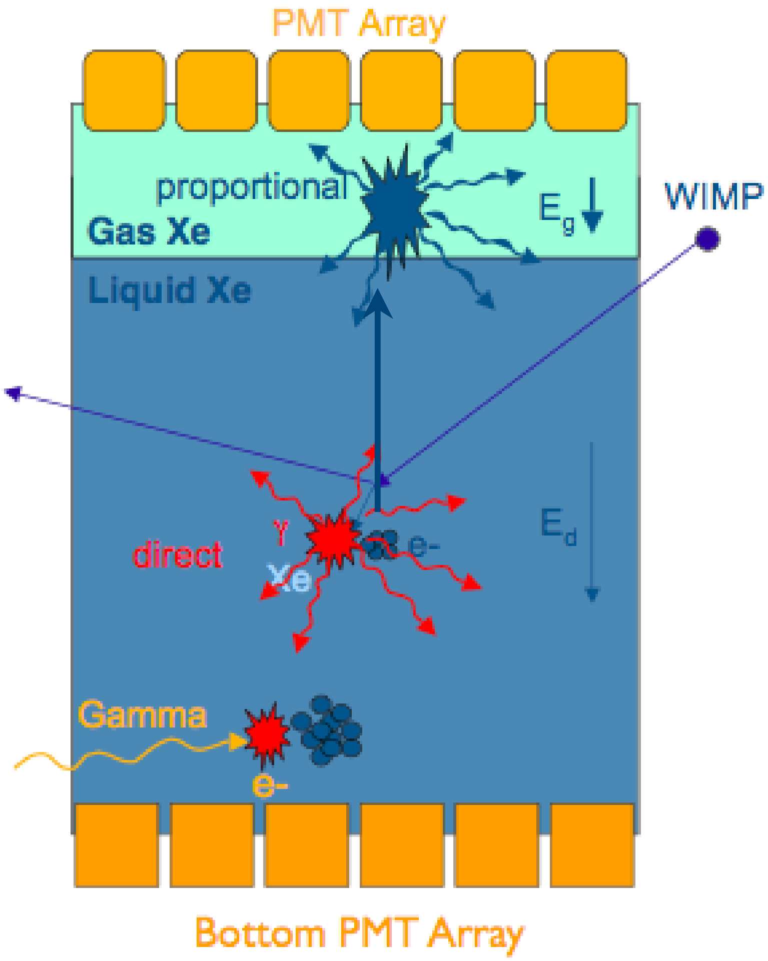
**Rice University** Uwe Oberlack, Roman Gomez, and Peter Shagin

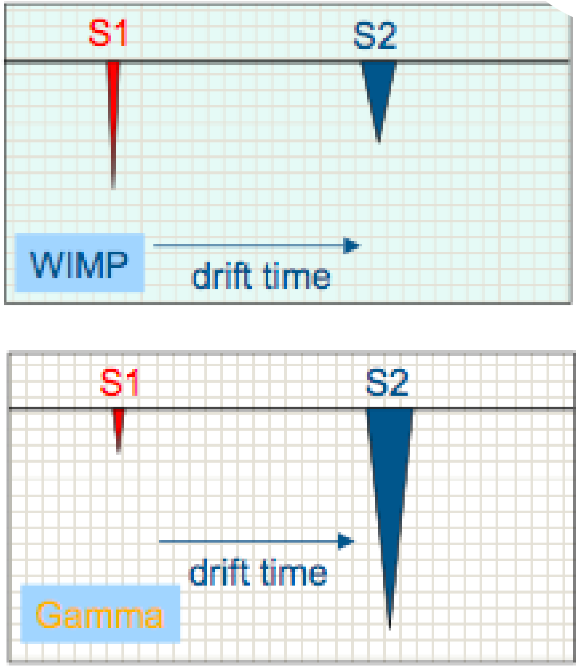
**Yale University** Daniel McKinsey, Richard Hasty, Louis Kastens, Angel Manzur and Kaixuan Ni

**LNGS** Francesco Arneodo and Alfredo Ferella

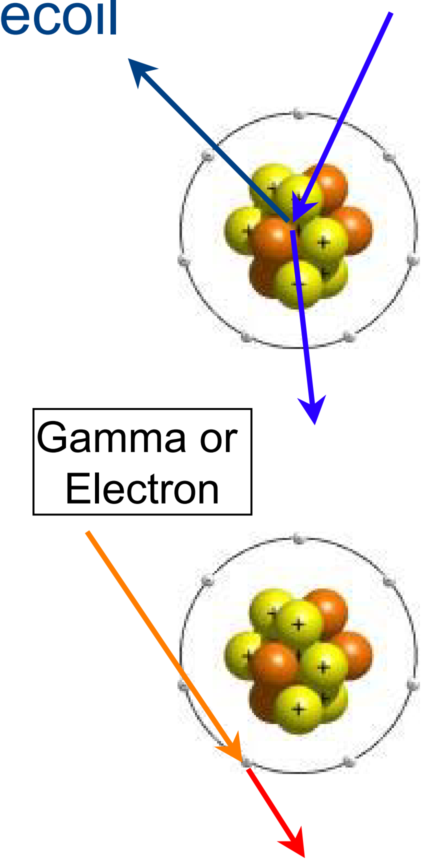
**Coimbra University** Jose Matias Lopes, Luis Coelho, Luis Fernandes and Joaquin Santos

# The XENON Detector: How It Works





$(S2/S1)_{wimp} \ll (S2/S1)_{gamma}$



nuclear recoil

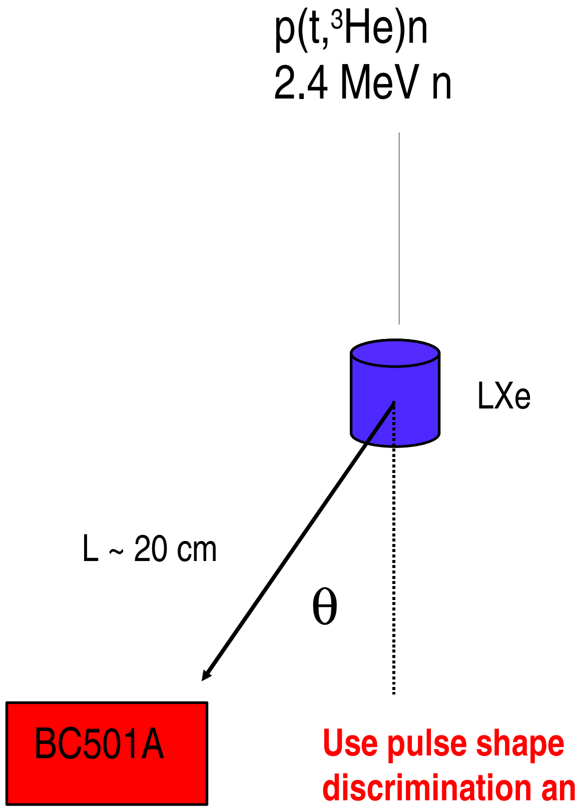
WIMP or Neutron

Gamma or Electron

electron recoil

# Threshold: Nuclear Recoils

$$E_r = E_n \frac{2M_n M_{Xe}}{(M_n+M_{Xe})^2}(1-\cos(\theta))$$



p(t,$^3$He)n
2.4 MeV n

LXe

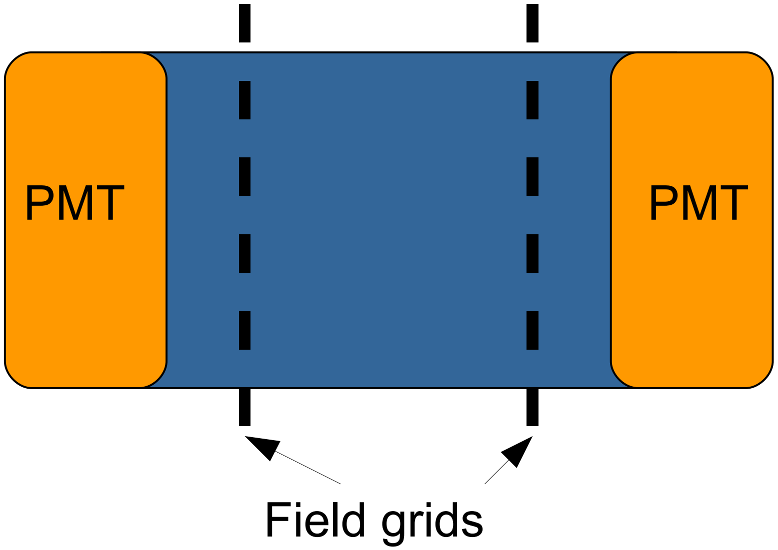
L ~ 20 cm

$\theta$

BC501A

**Use pulse shape discrimination and ToF to identify n-recoils**

Nuclear recoil efficiency measured with a single phase primary scintillation only cell

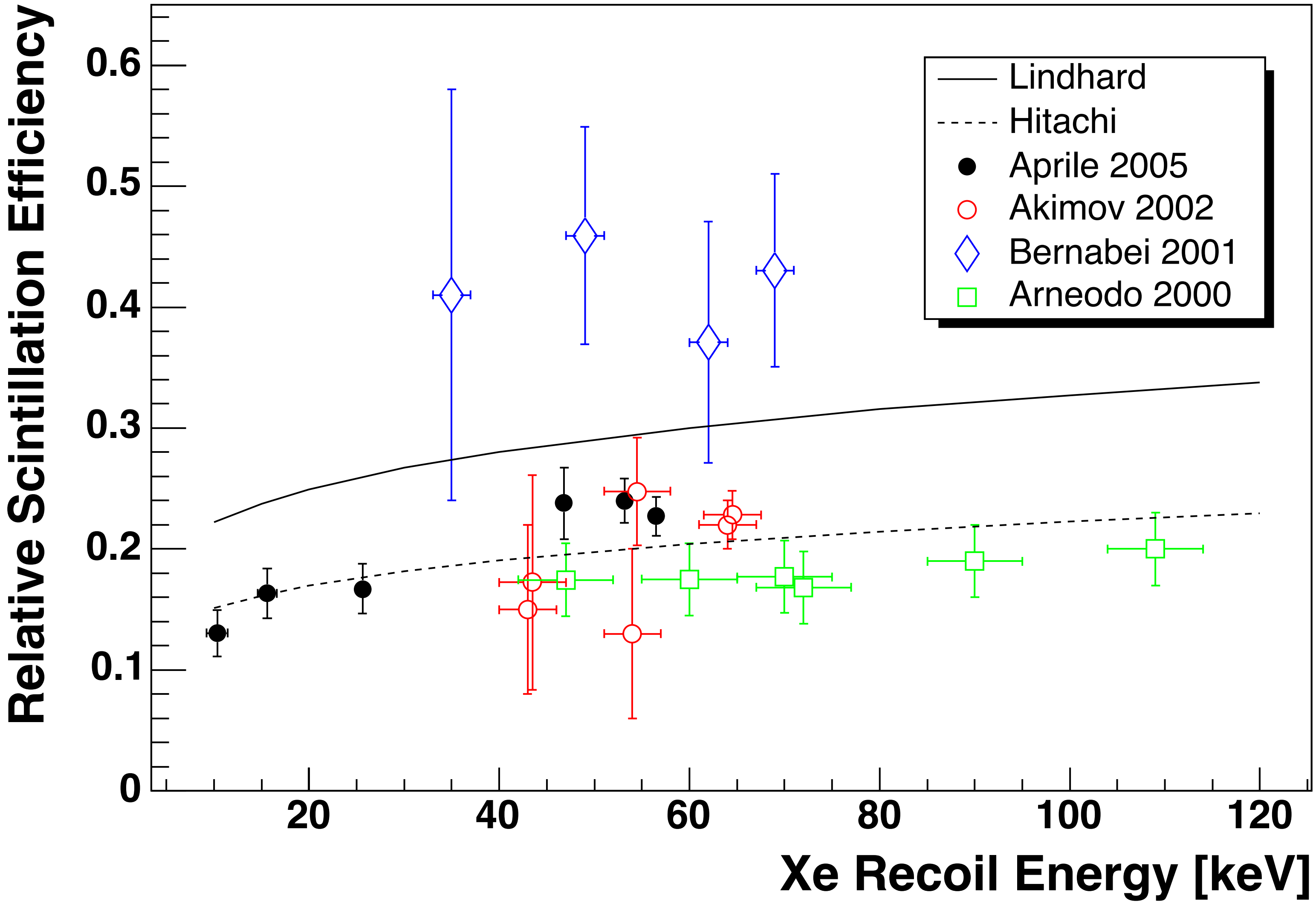


PMT

PMT

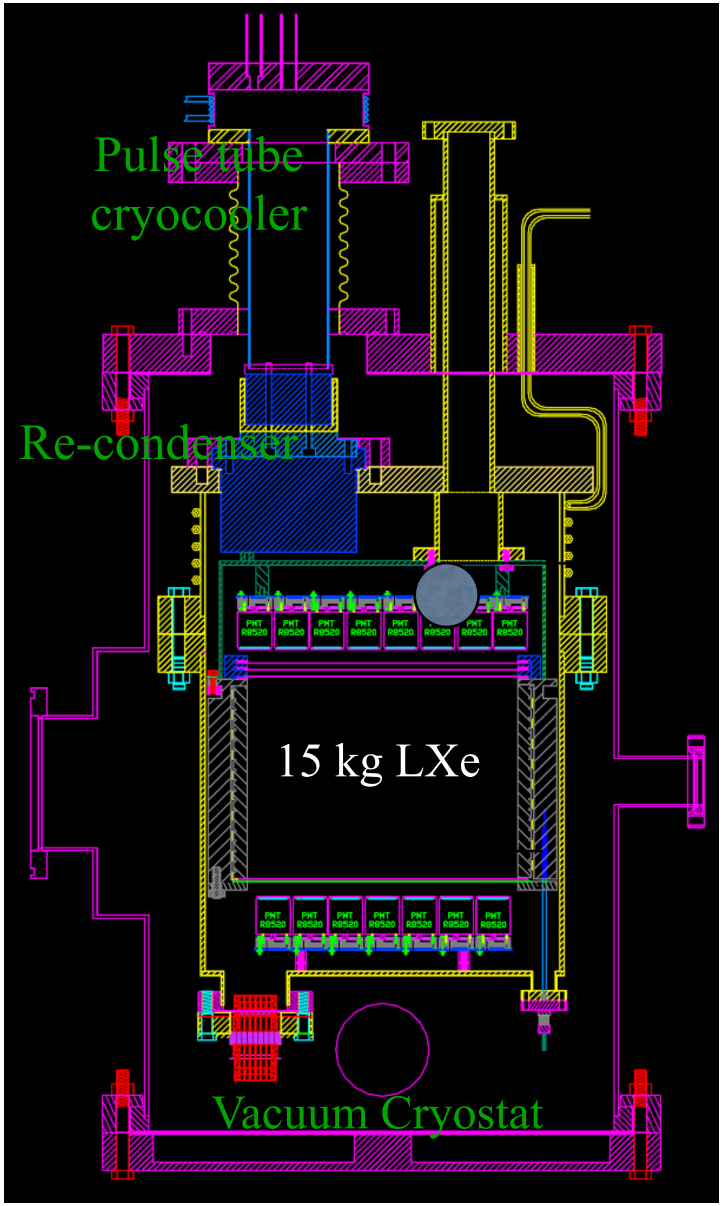
Field grids

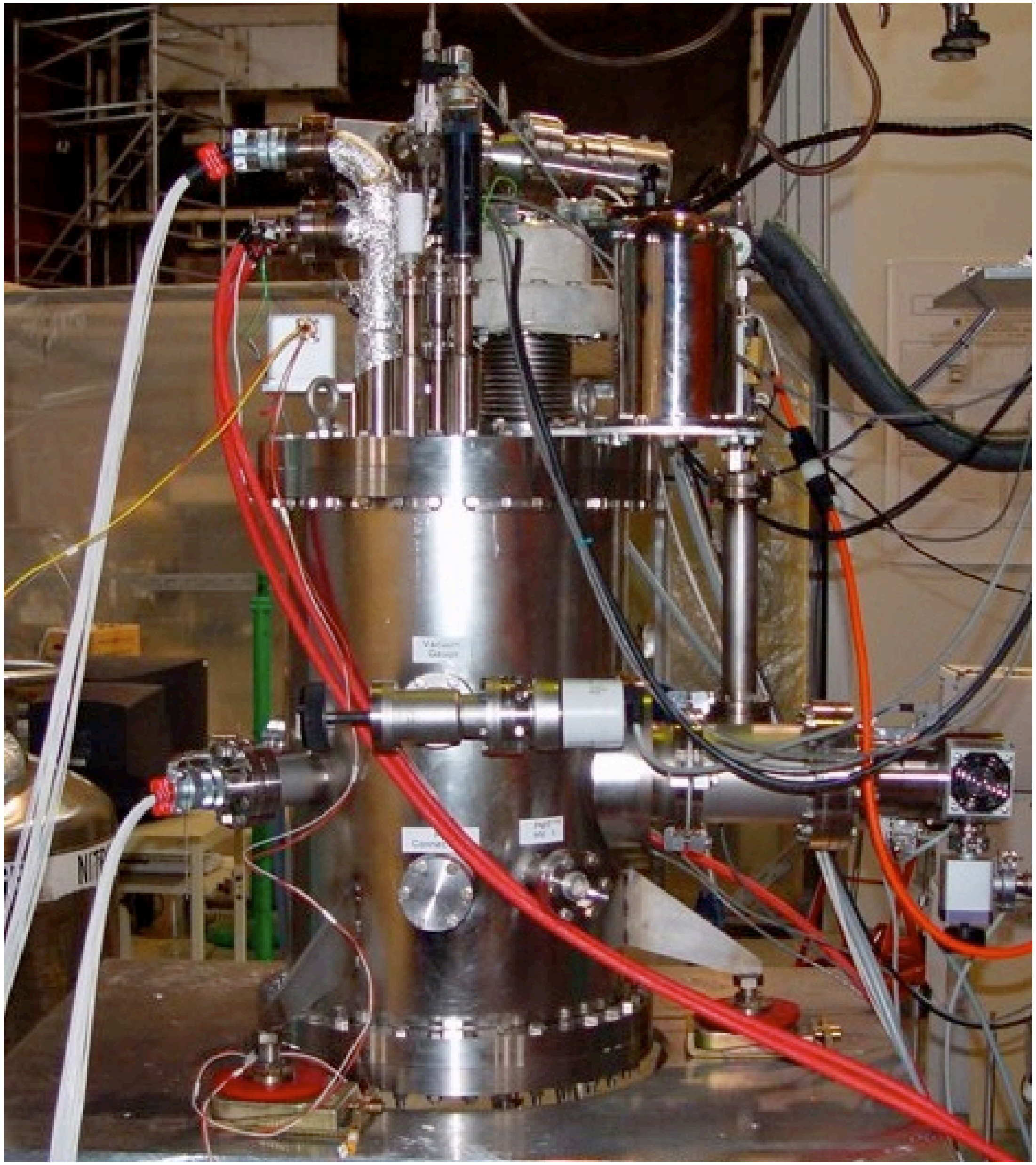
Field grids also allow investigation of scintillation efficiency as a function of field



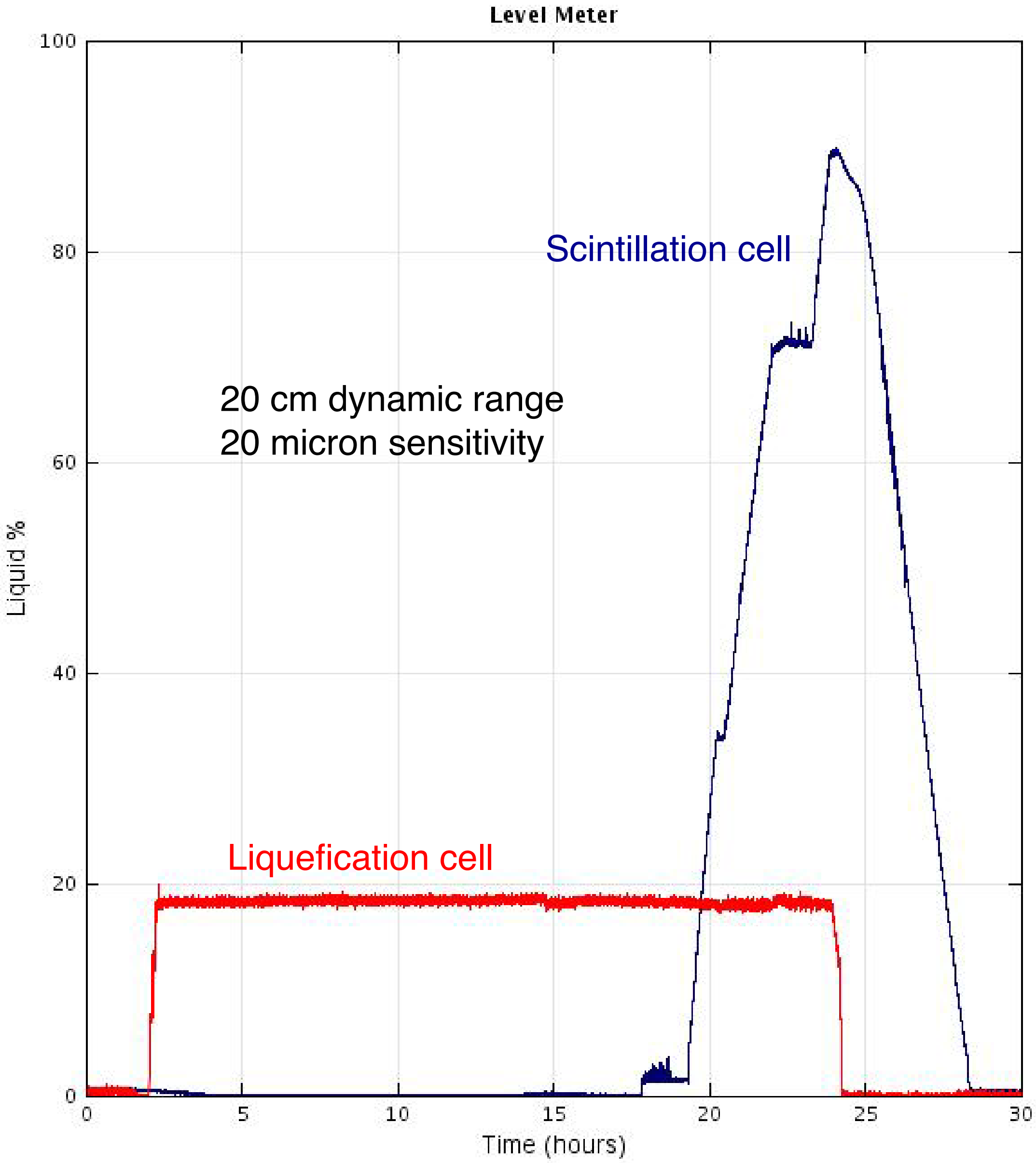
Yale/Columbia, Phys. Rev. D **72**, 072006 (2005)

# The XENON10 Detector





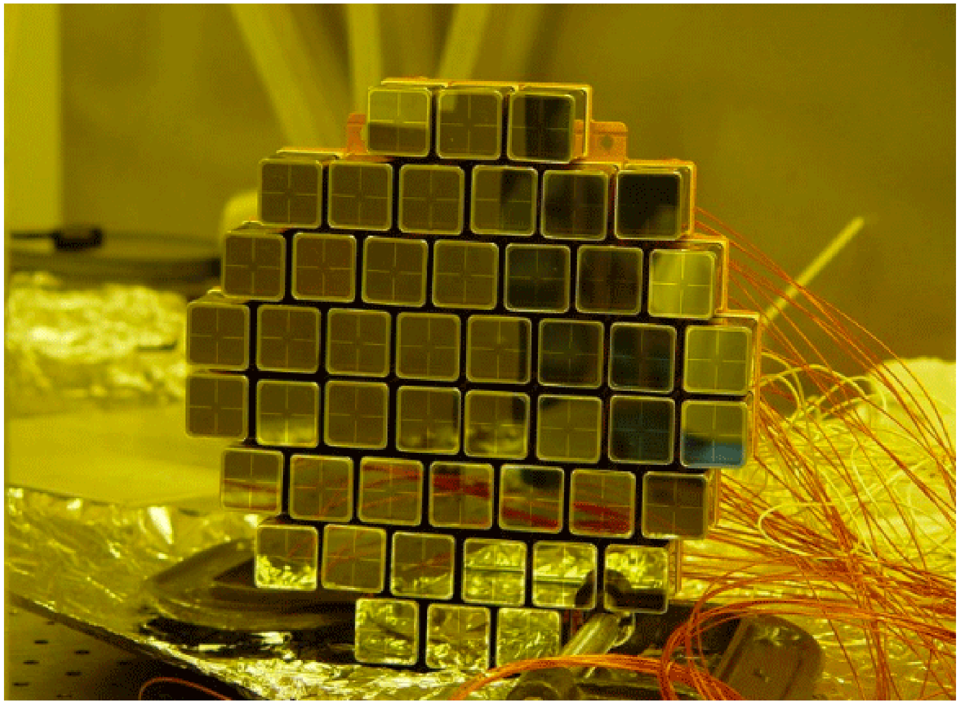
# LXe level meters



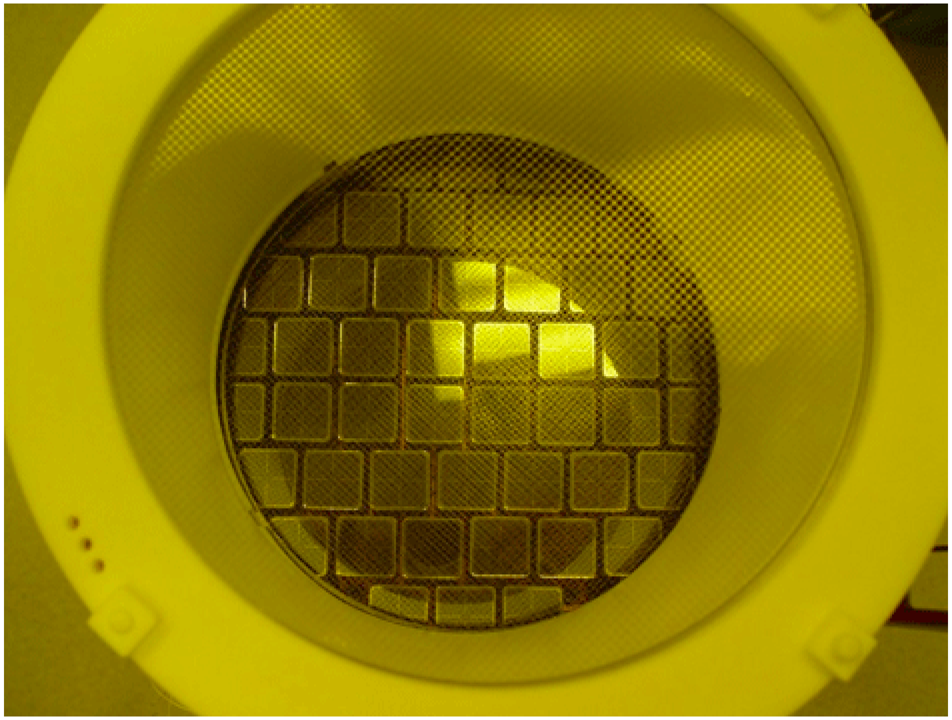
20 cm dynamic range
20 micron sensitivity

# The XENON10 Photomultipliers

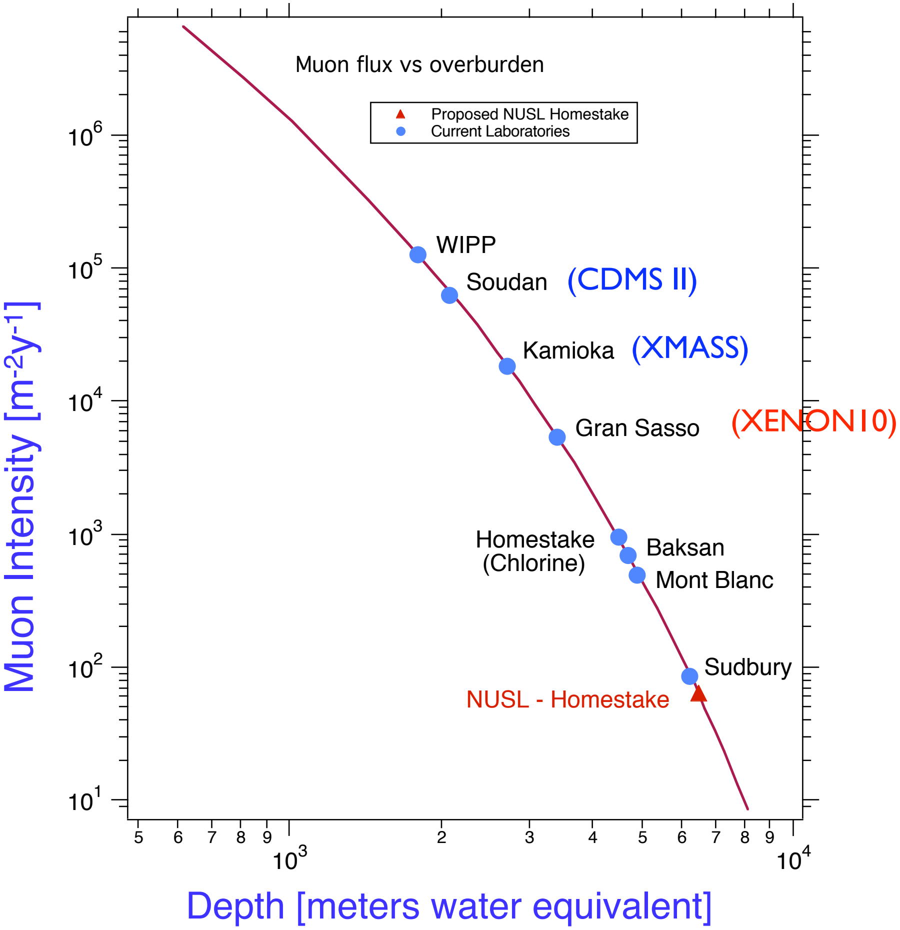
Hamamatsu 8520-06-AL 2.5 cm x 3.5 cm
Bialkali photocathode Rb-Cs-Sb
10 dynodes
Quartz window
U/Th/K/Co = 0.17/0.20/0.09/0.56 mBq/PMT
Quantum efficiency > 20% at 178 nm

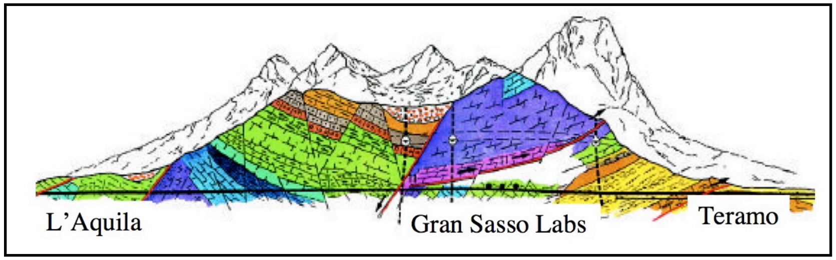


Angel Manzur (Yale) individually testing PMTs



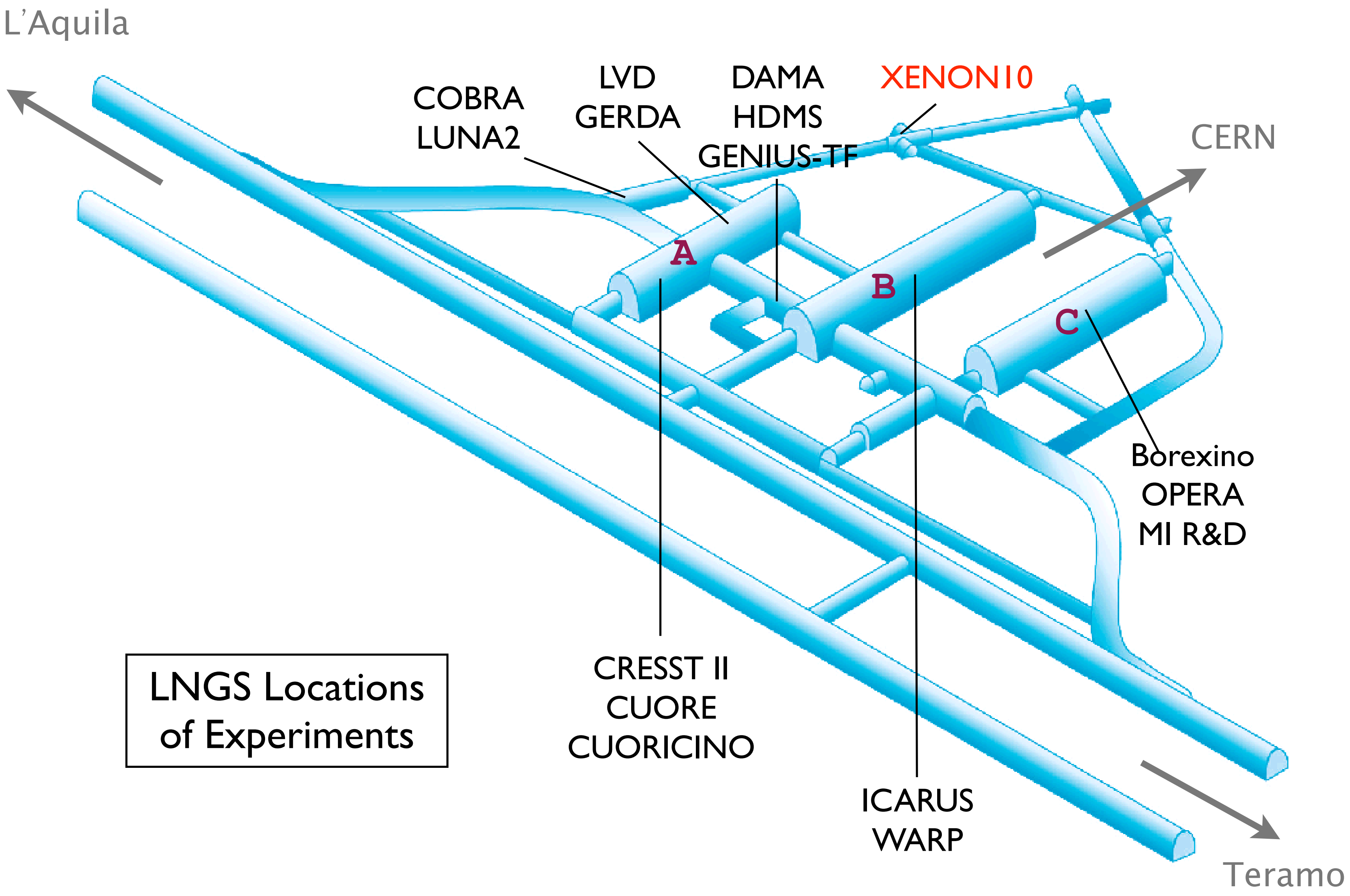
# The INFN Gran Sasso National Lab (LNGS)





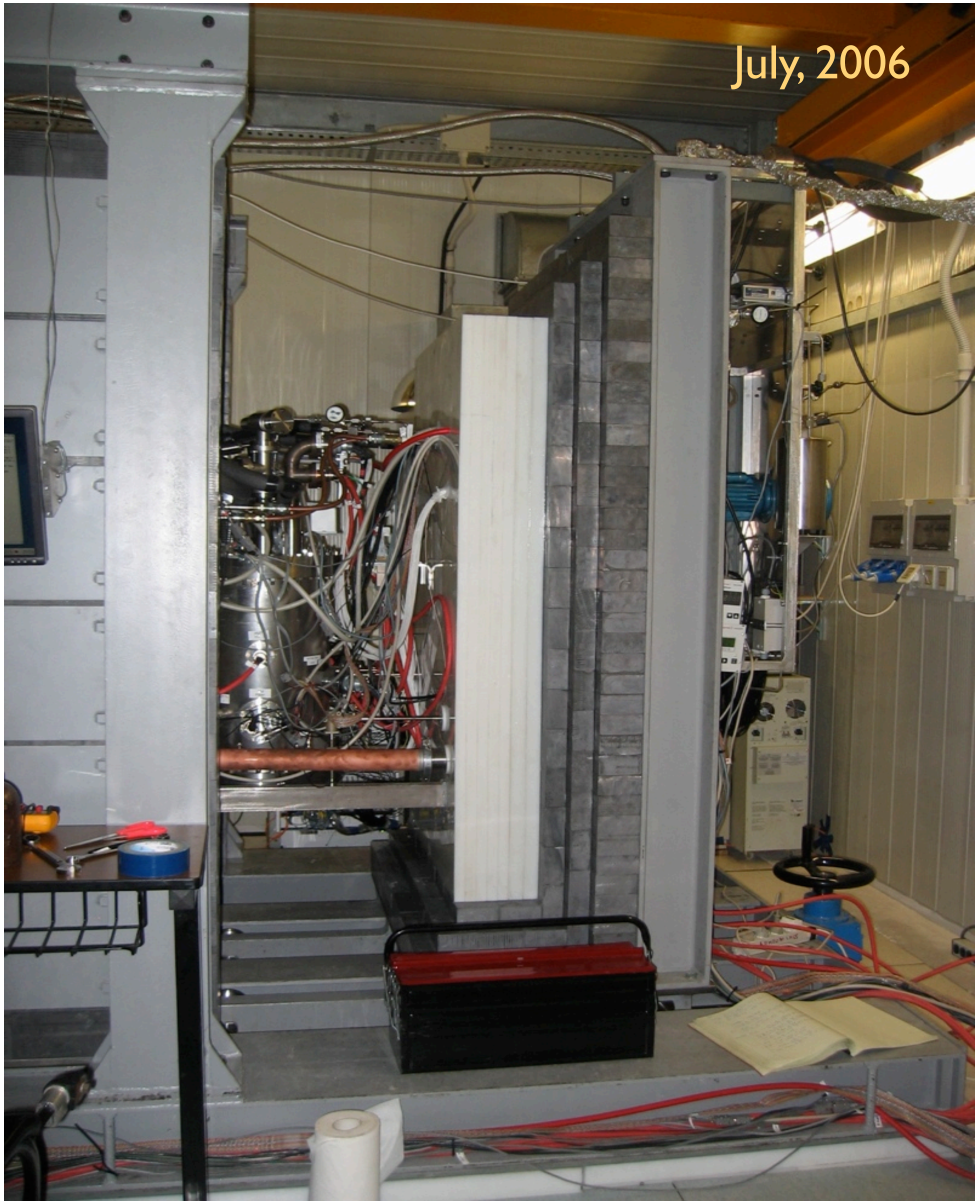
1400 m rock overburden (3500 mwe)

# XENON10 @ LNGS



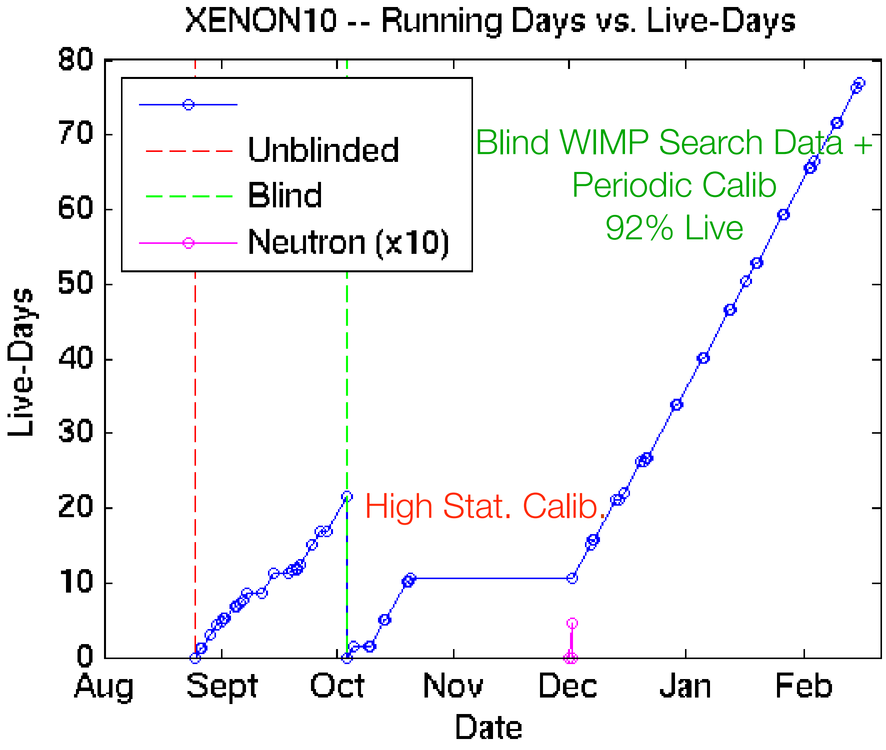
LNGS Locations of Experiments

# XENON10 at the Gran Sasso Laboratory



July, 2006

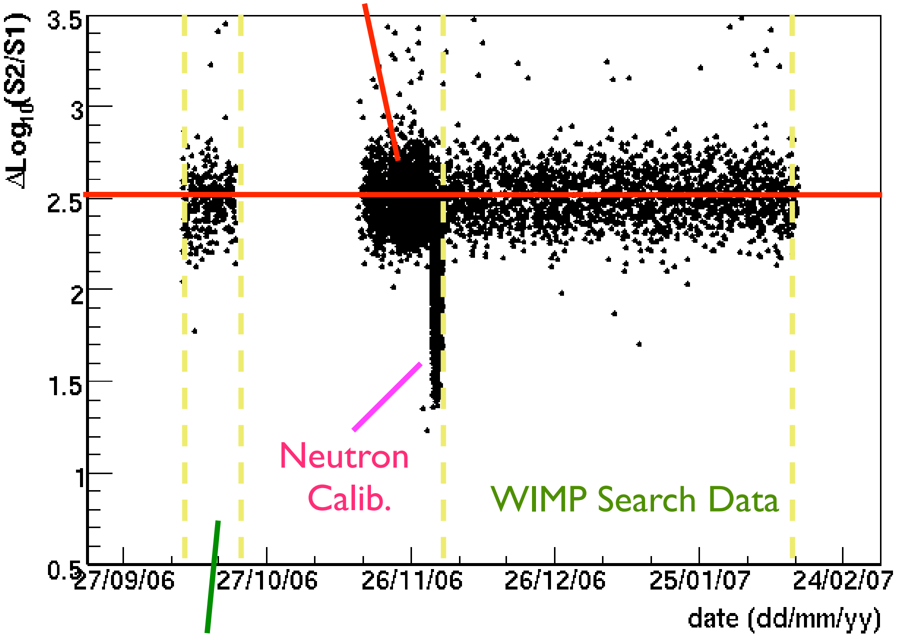
# XENON10 Live-Time / Dark Matter Run Stability



Blind WIMP Search Data + Periodic Calib 92% Live

High Stat. Calib.

High Stat. Calib.

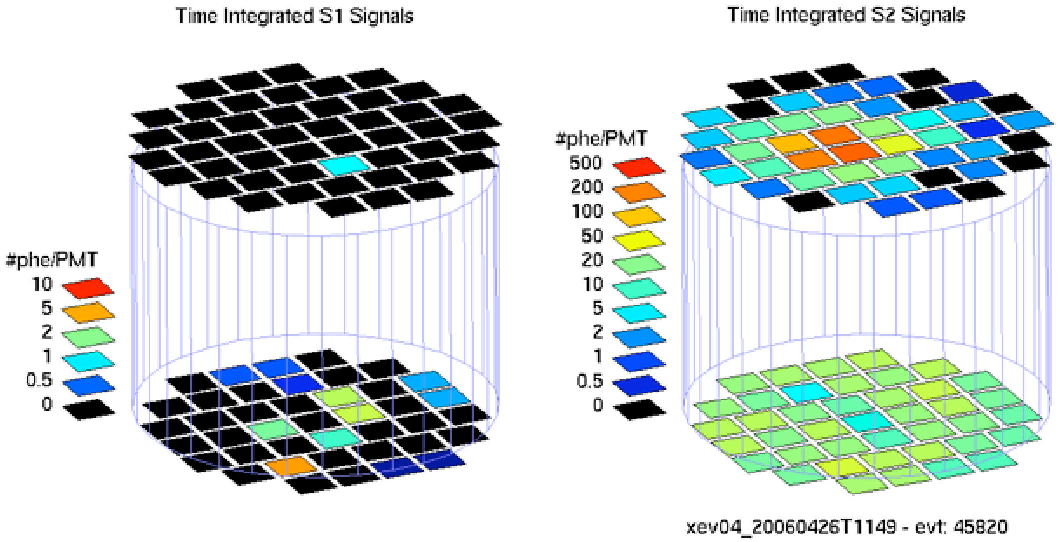


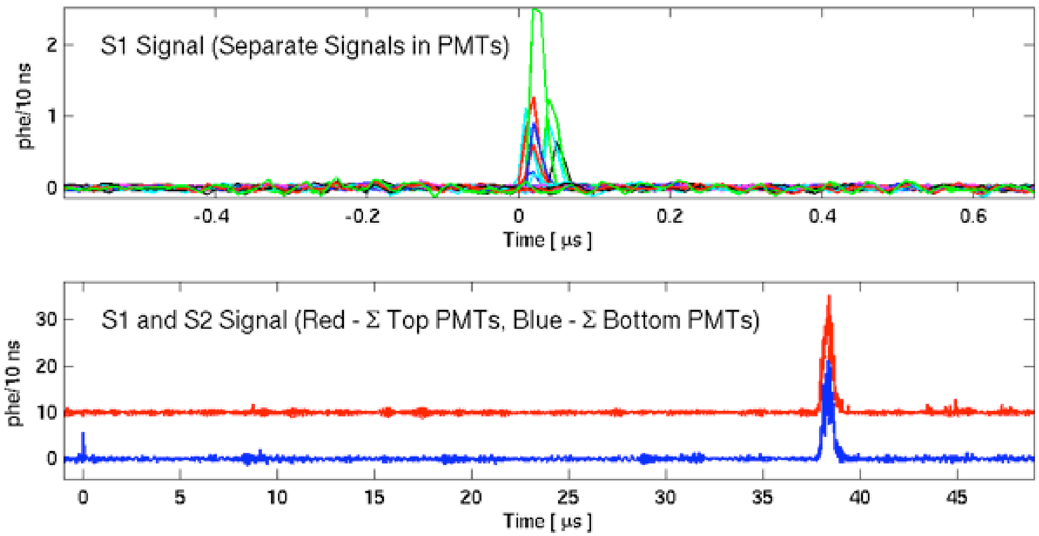
Neutron Calib.

WIMP Search Data

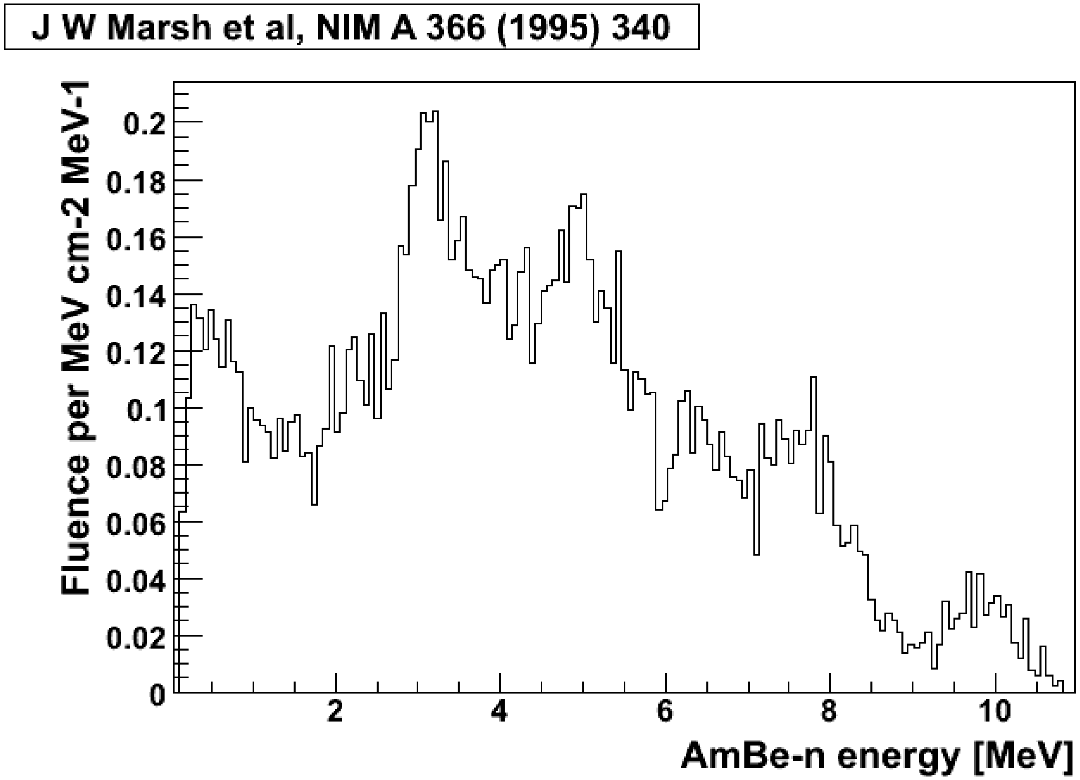
WIMP Search Data

# XENON10 Calibration runs @ LNGS





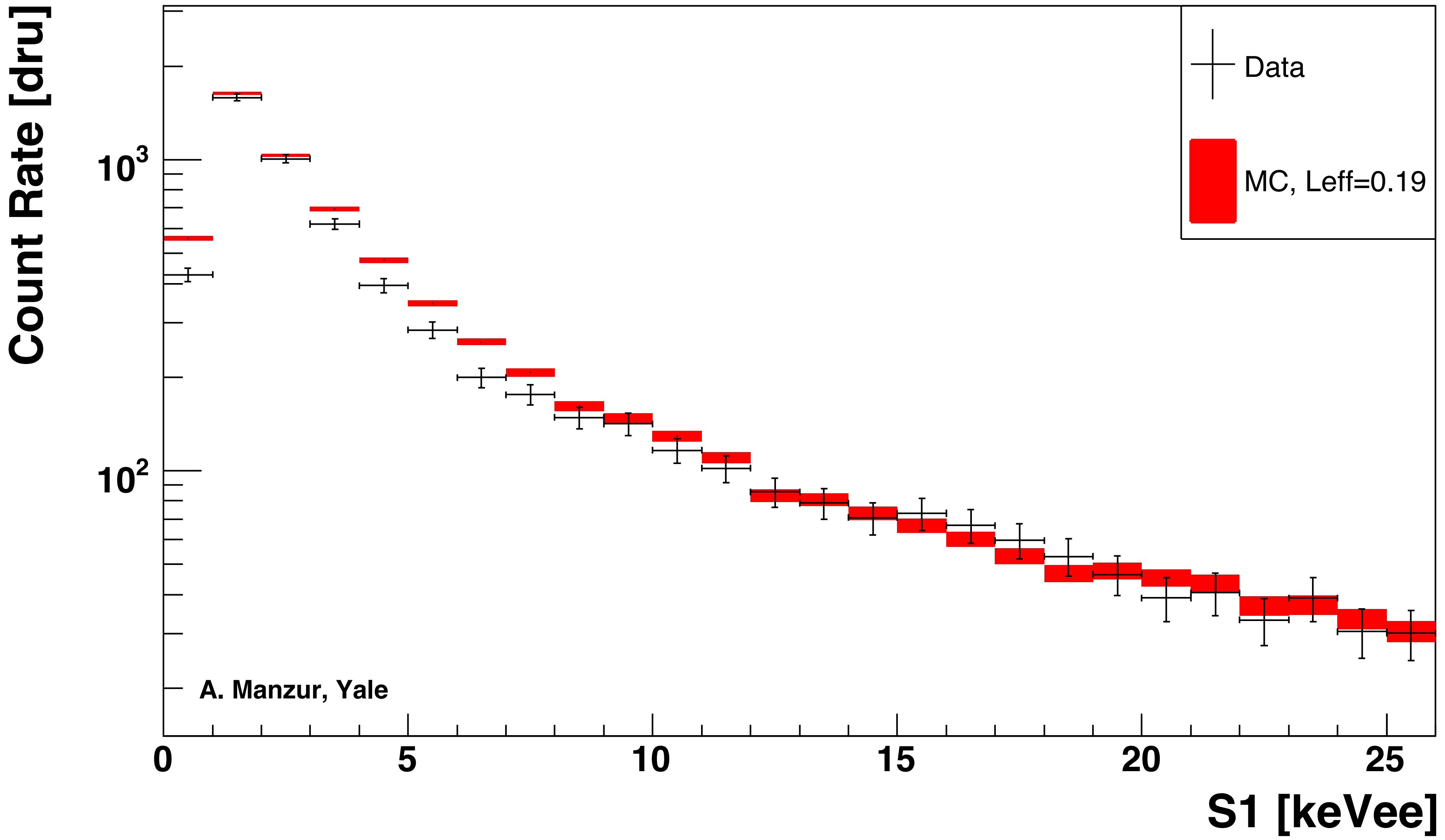
# AmBe source



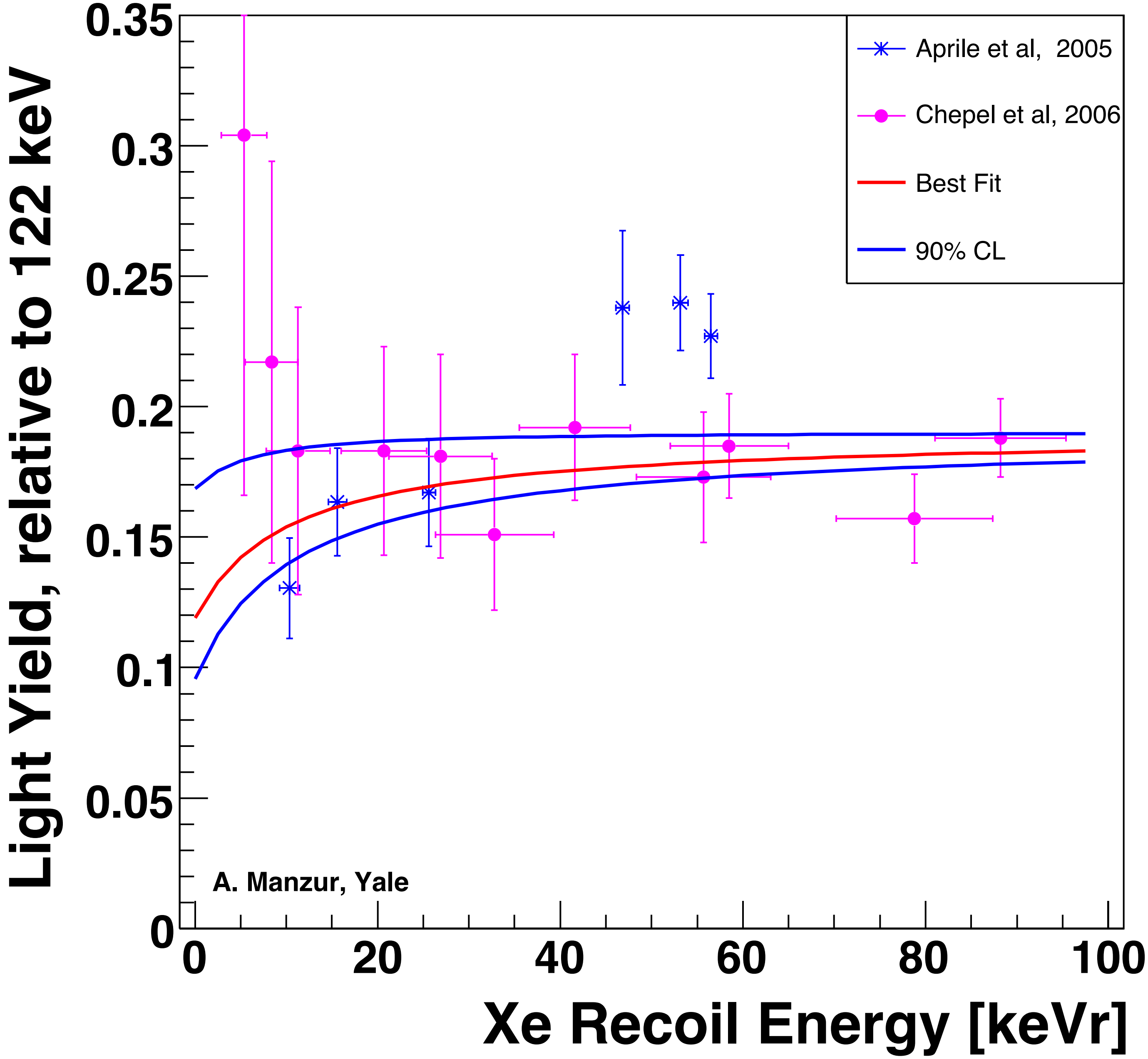
Neutron spectrum

- AmBe source. 3.7 MBq (220 n/sec) $\pm 15\%$
- 5 cm of lead between the detector and the source to stop the $\gamma$
- 12 hour run at trigger rate ~14 Hz

# Nuclear recoil energy spectrum from AmBe neutrons



# Constraints on nuclear recoil light yield from XENON10



# Energy Calibration: determine the energy of nuclear recoils

energy of nuclear recoils (NRs)

measured signal in # of pe

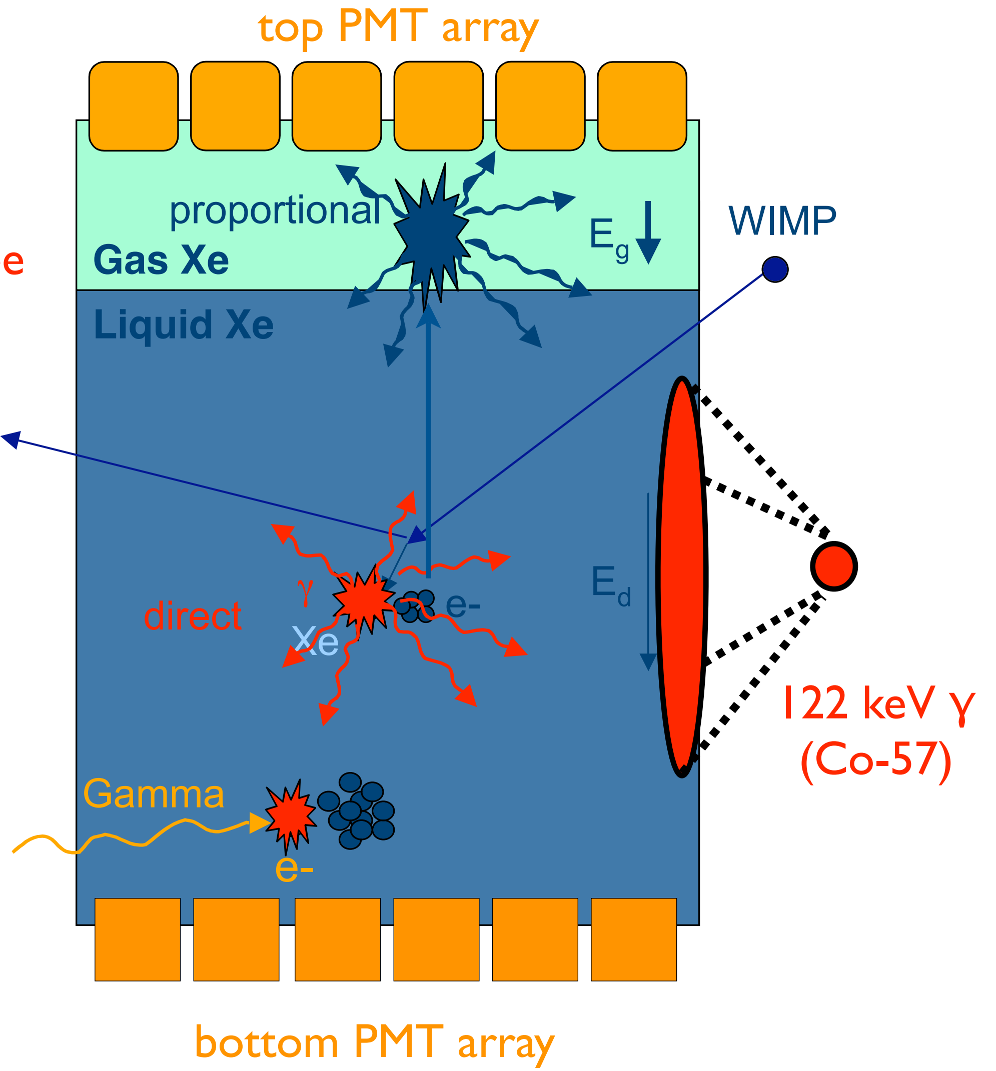
light yield for 122 keV γ in pe/keVee

$$E_{nr} = S1/L_y/\mathcal{L}_{eff} \cdot S_{er}/S_{nr}$$

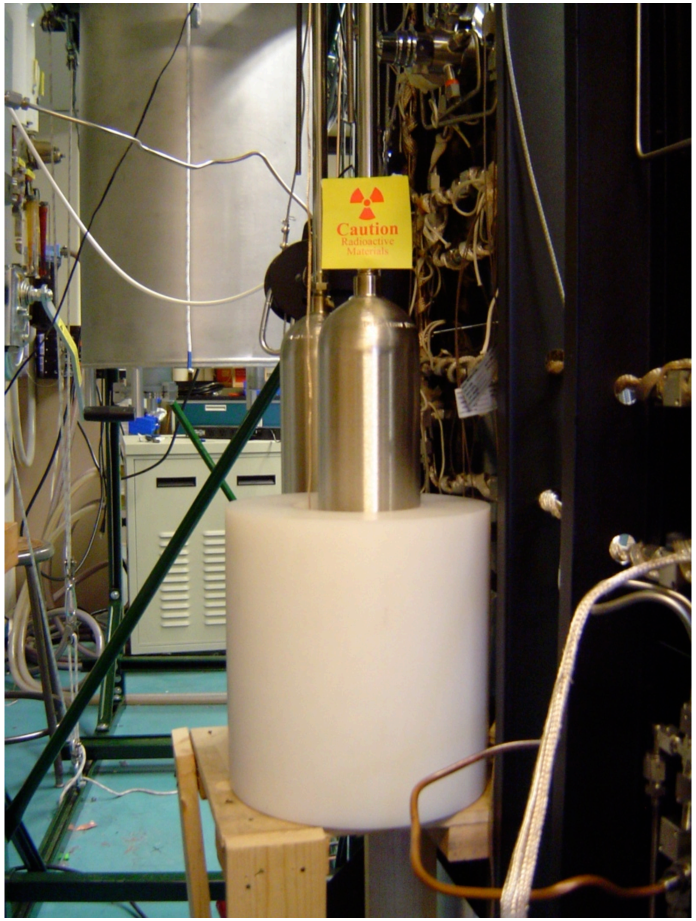
relative scintillation efficiency of NRs to 122 keV γ's at zero field

quenching of scintillation yield for 122 keV γ's due to drift field

quenching of scintillation yield for NRs due to drift field

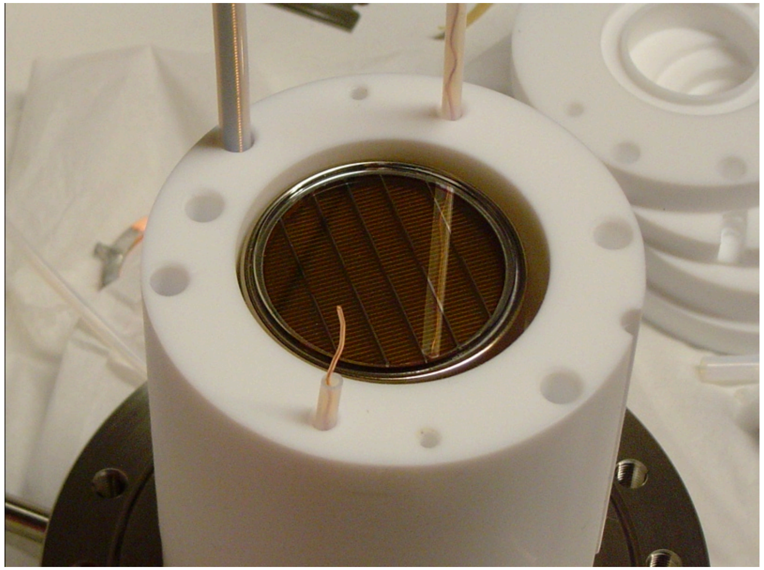


# Xenon Activation with Cf-252 at Yale

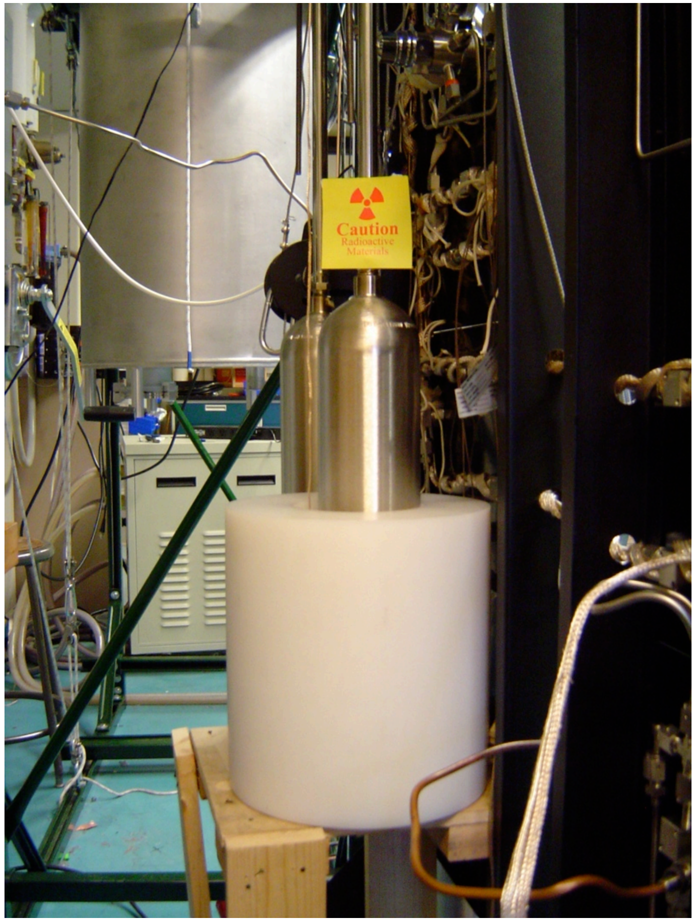


continuous activating Xe gas with a $5\times10^5$ n/sec Cf-252 source for 12 days

measure the scintillation light in a liquid Xenon cell

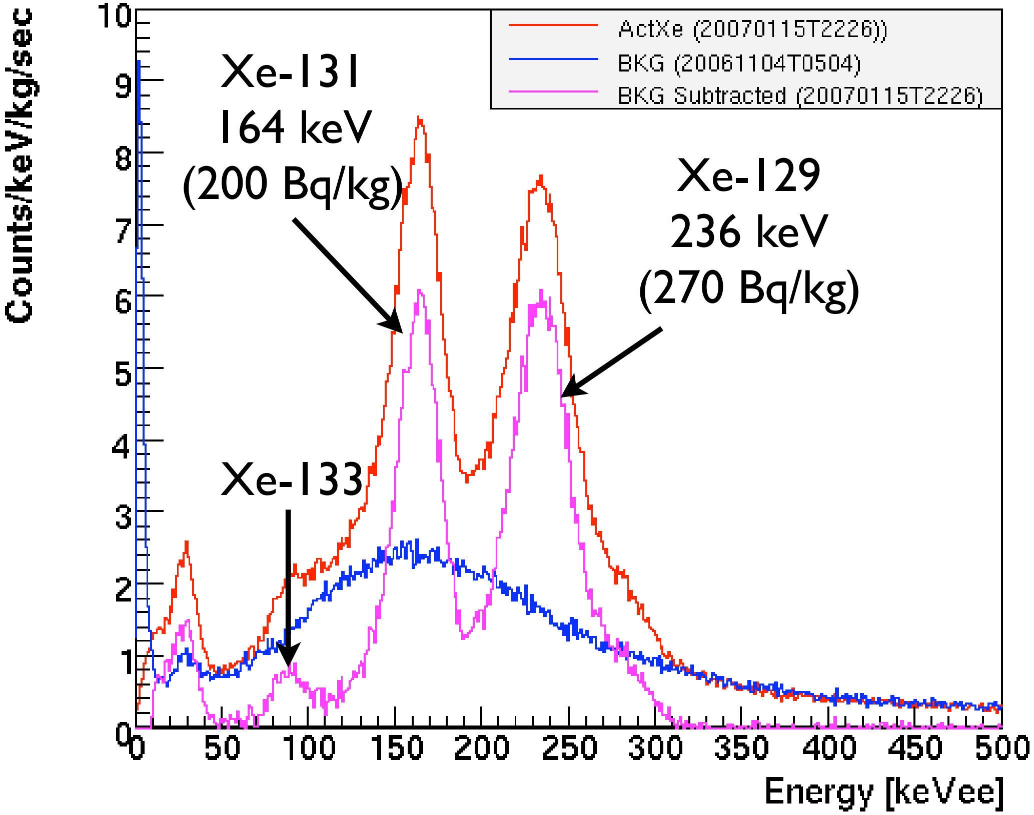


# Xenon Activation with Cf-252

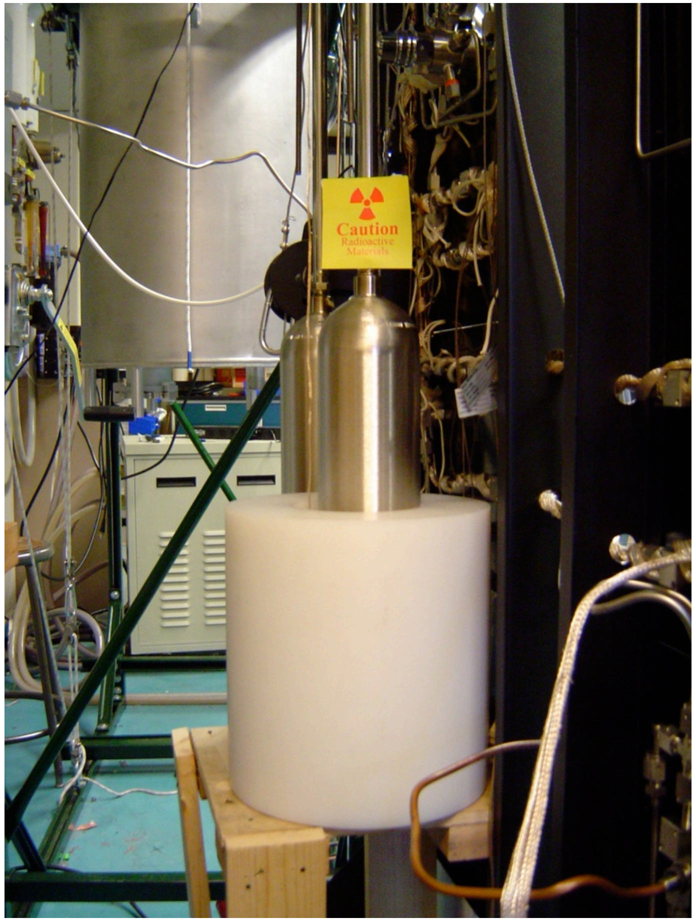


continuous activating Xe gas with a $5 \times 10^5$ n/sec Cf-252 source for 12 days

after 12-days of activation ...



# Xenon Activation with Cf-252

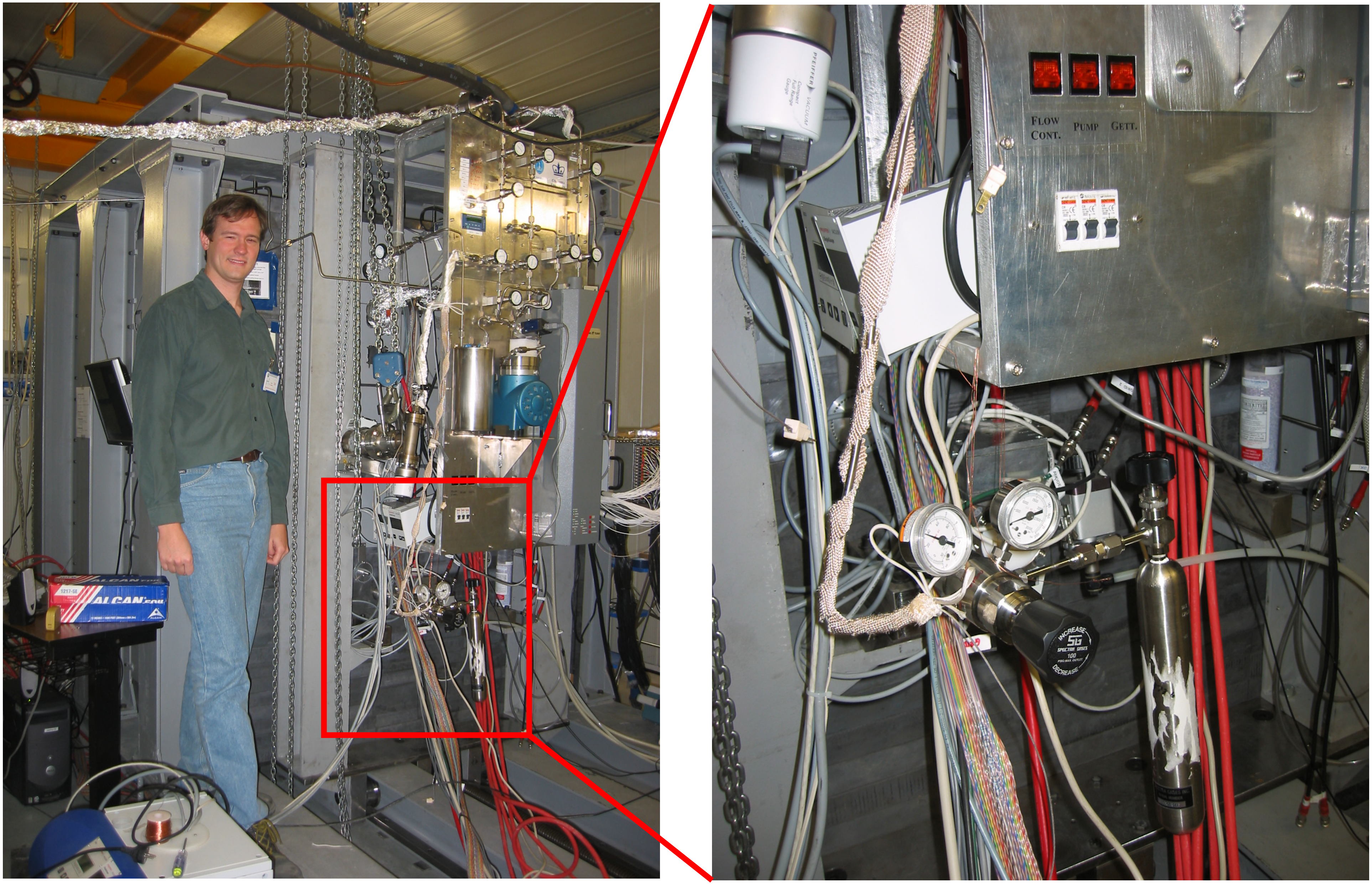


Yale (USA)

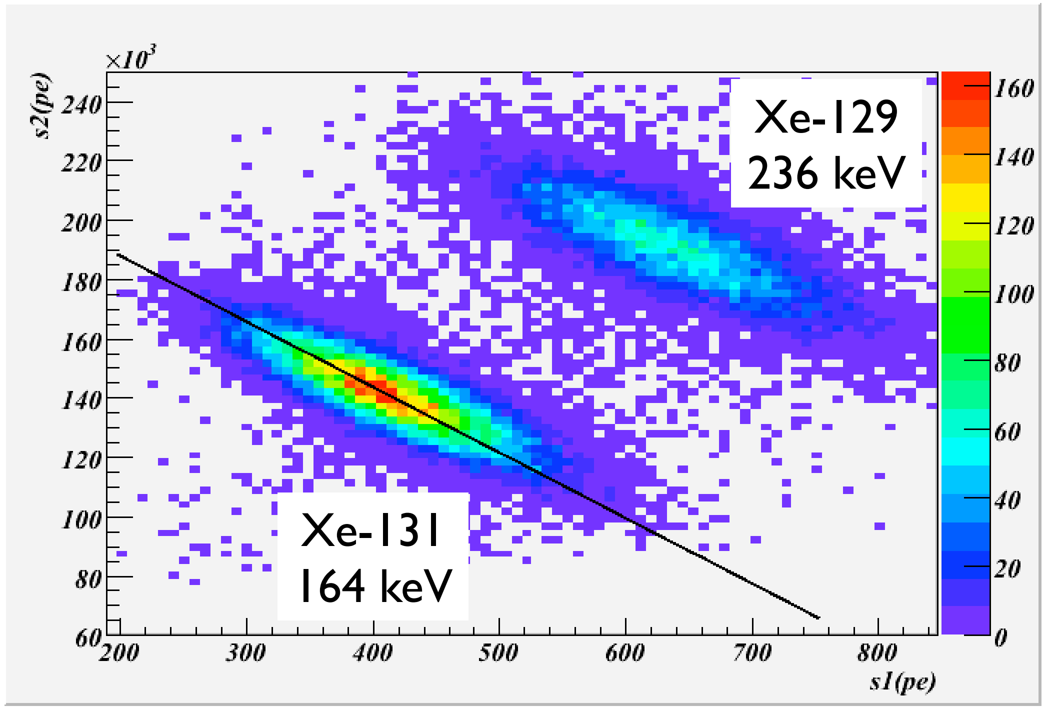
~ 1 week

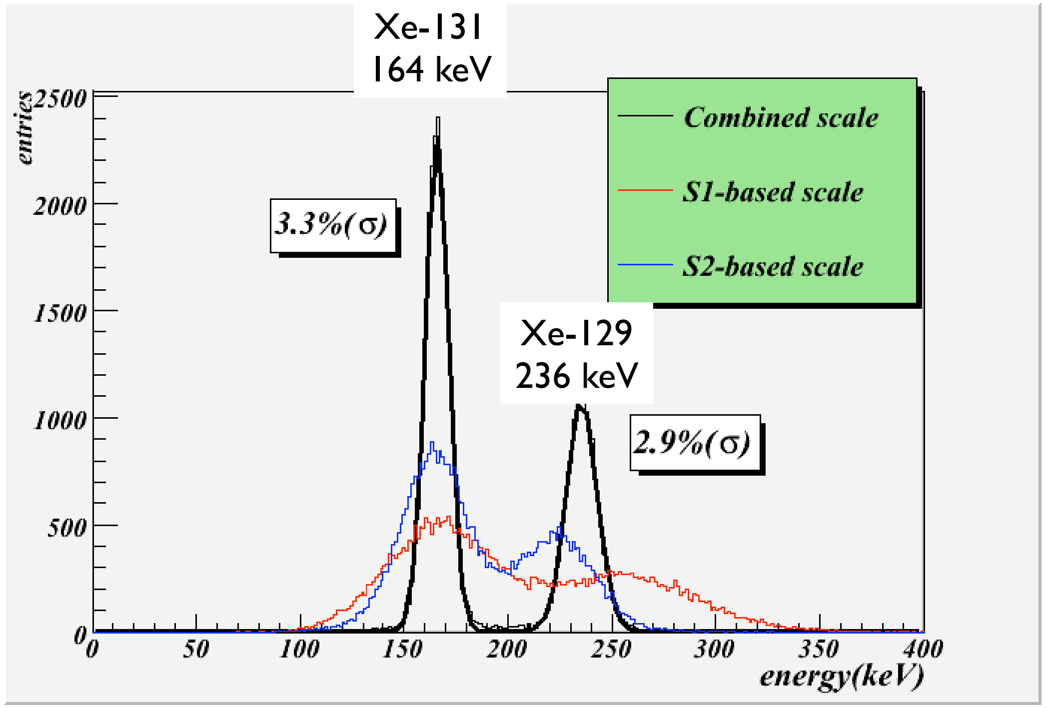
XENON10
Gran Sasso (Italy)

# Neutron-activated xenon added to XENON10

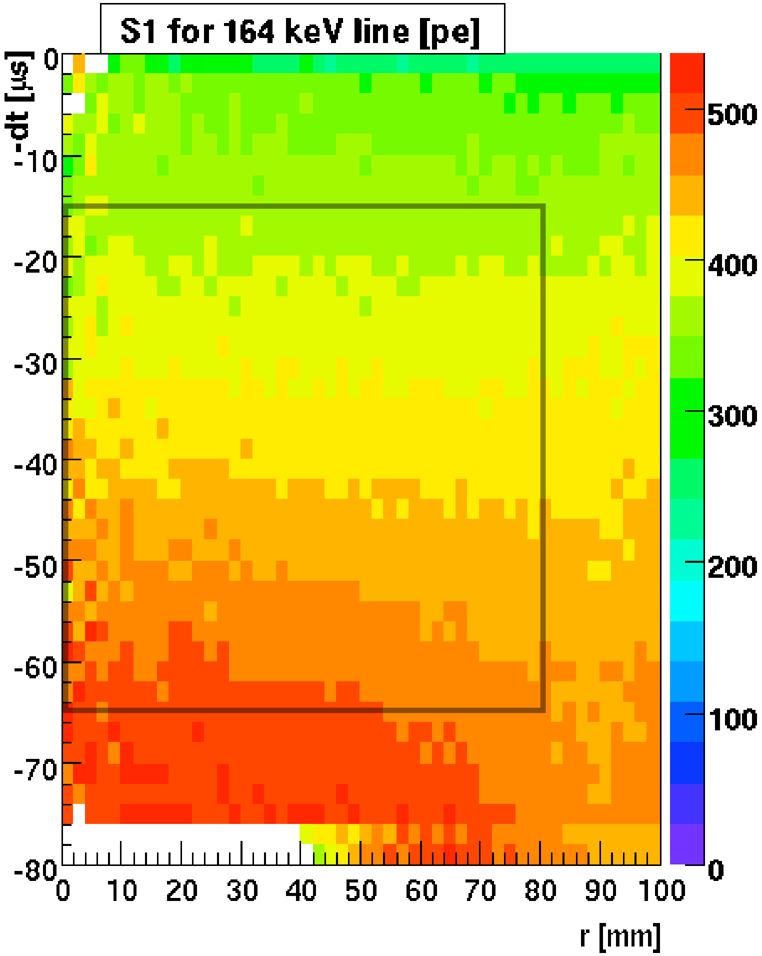


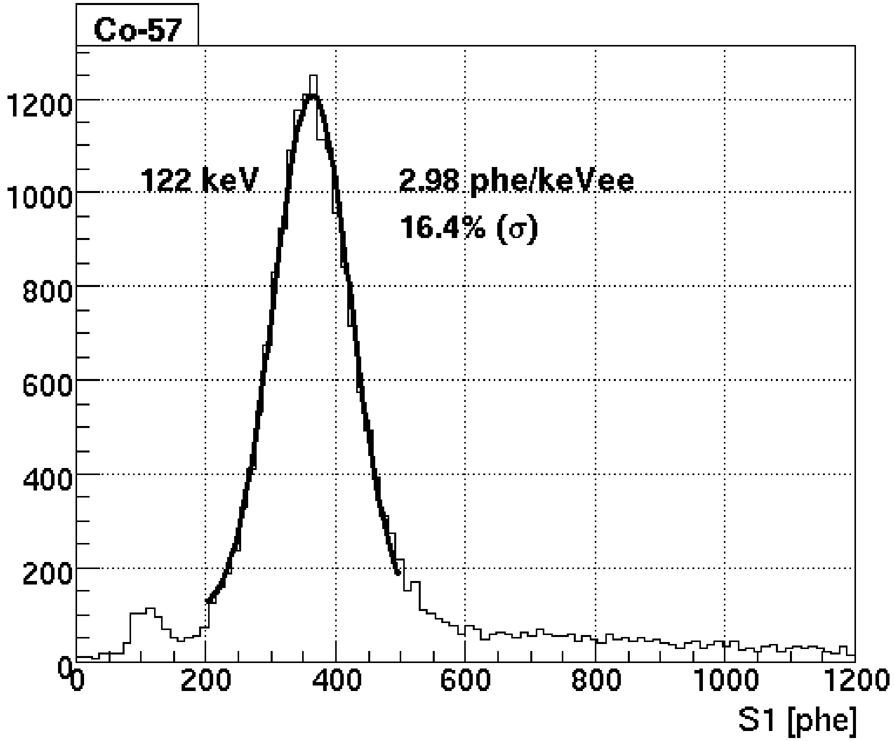
# Activated Xenon Lines in XENON10





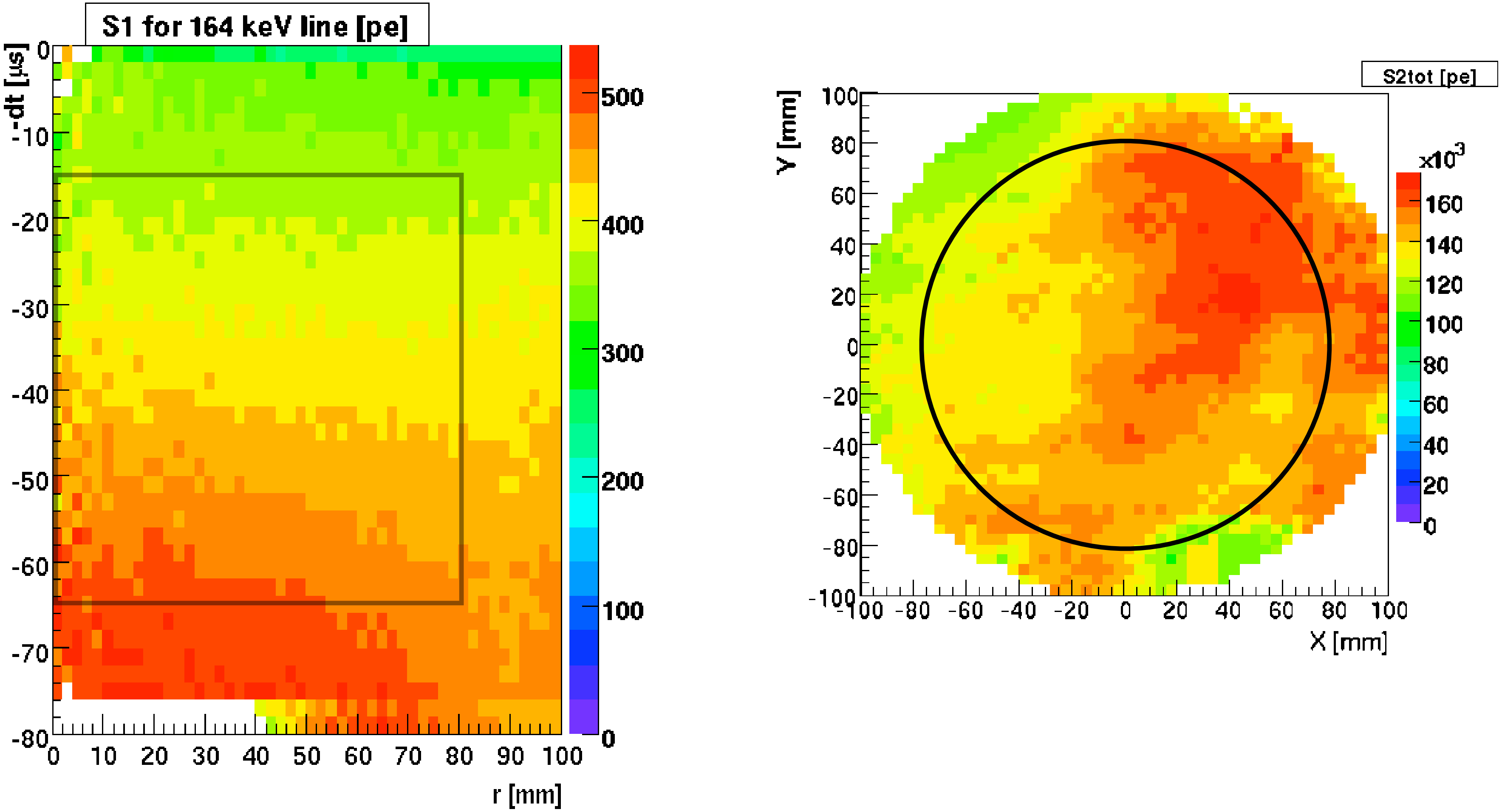
# Position dependence of S1 signals in XENON10





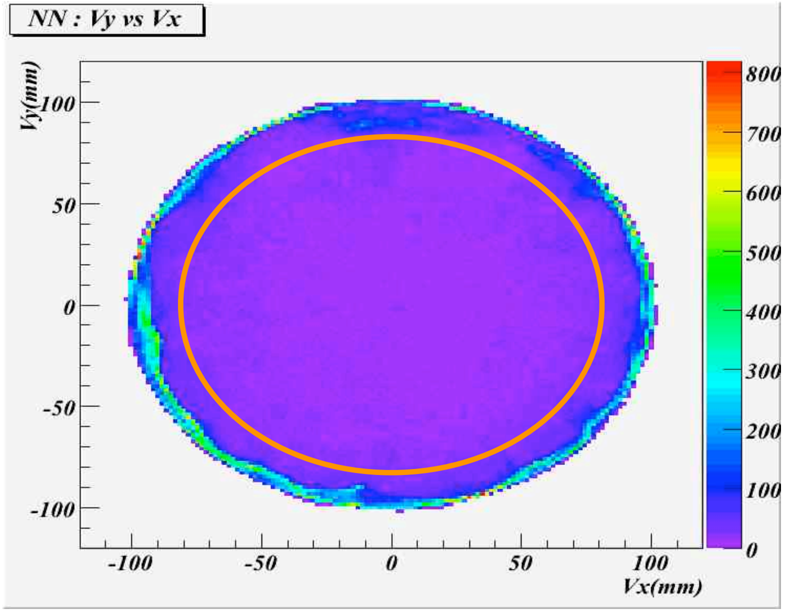
after position-dependent corrections

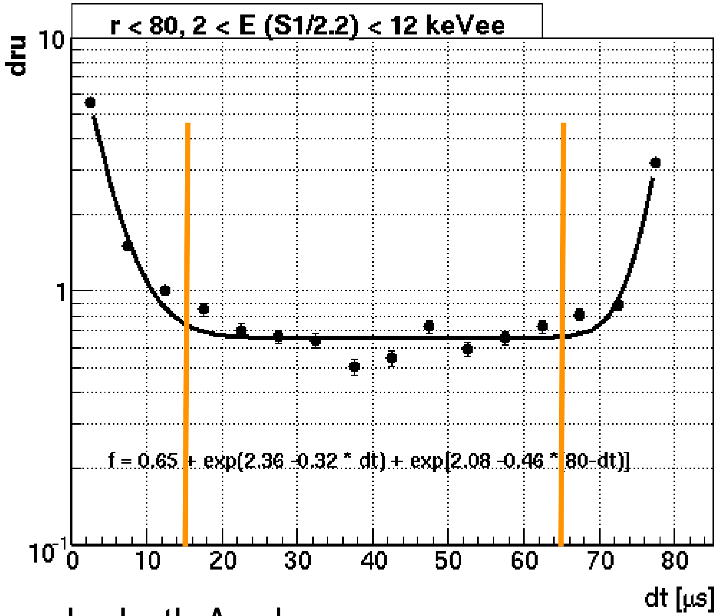
# Position dependence of S1 and S2 signals



The XENON10 results are from position-dependent corrected signals by using these maps obtained from activated-Xe calibration

# XENON10 Fiducial Volume cuts





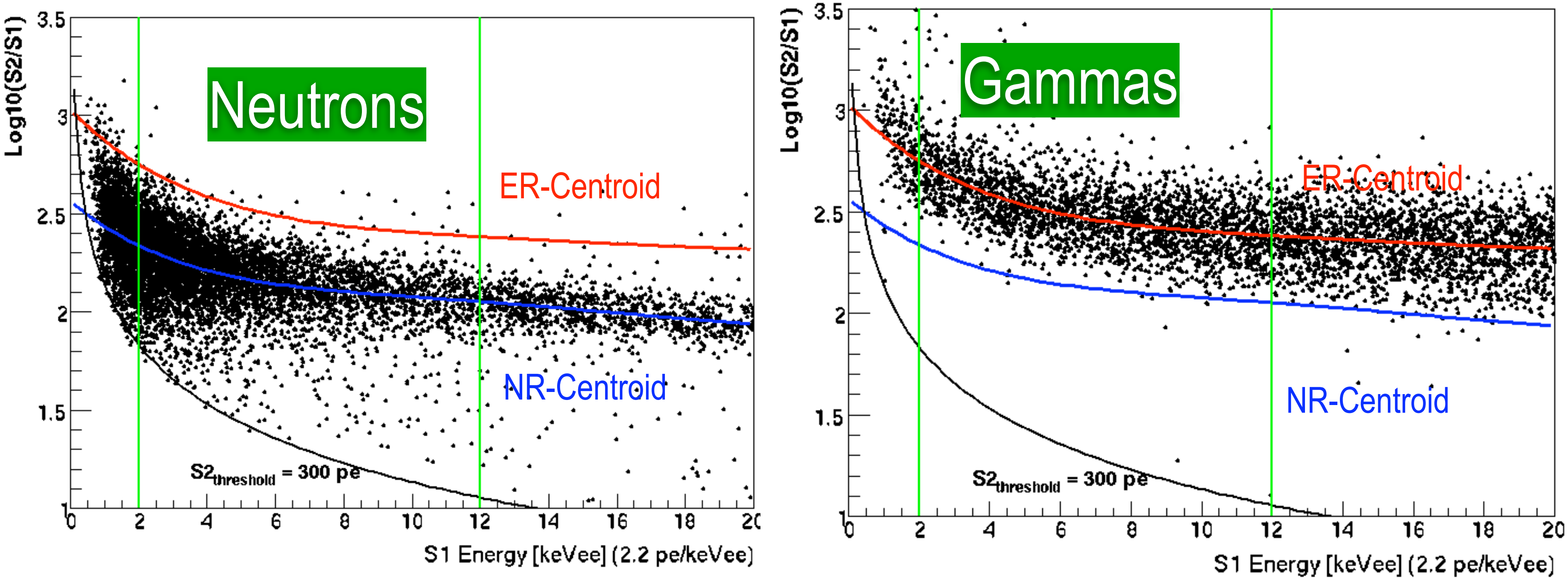
Fiducial Volume chosen by both Analyses:

15 < dt < 65 us, r < 80 mm

Fiducial Mass= 5.4 kg (reconstructed radius is algorithm dependent)

Overall Background in Fiducial Volume ~0.6 event/(kg d keVee)

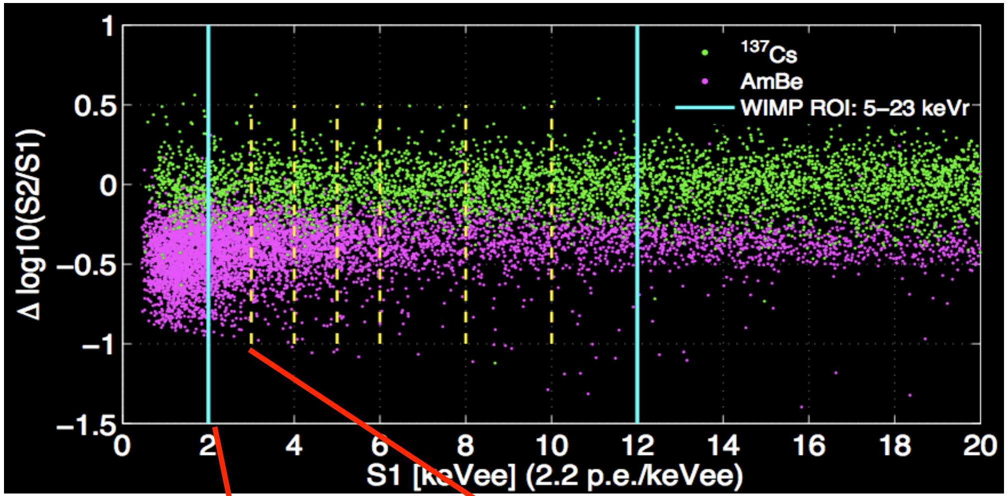
# XENON10 Gamma/Neutron calibration



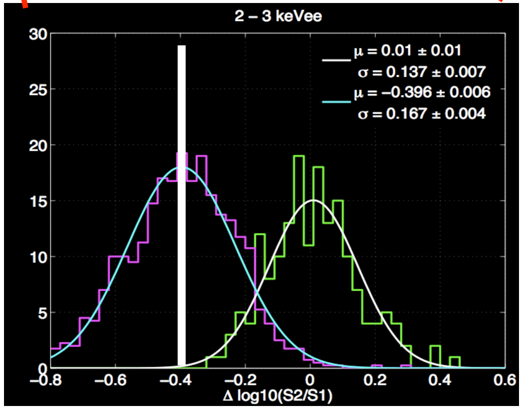
AmBe Neutron Calibration (NR-band)

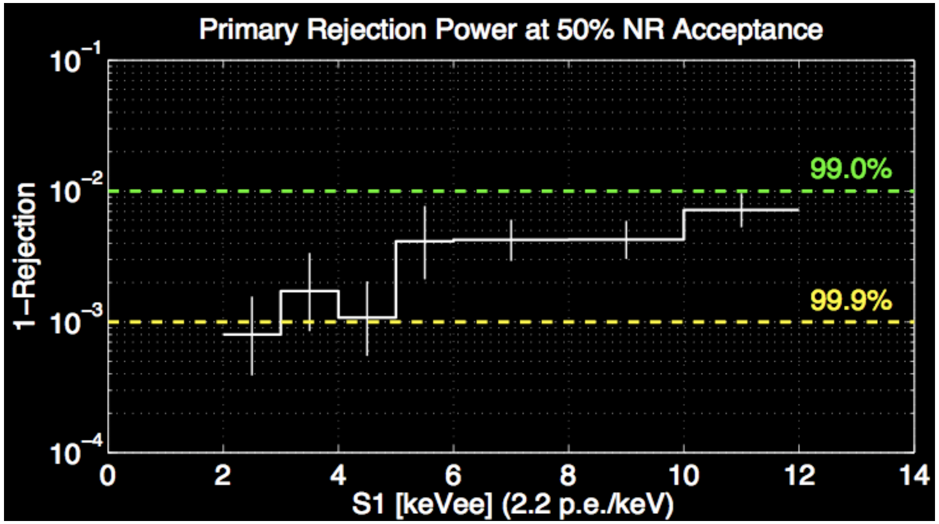
Cs-137 Gamma Calibration (ER-band)

# Gamma background rejection efficiency



~ 99.5 % rejection power (improves to 99.9 % at low energy) at 50% Nuclear Recoil Acceptance



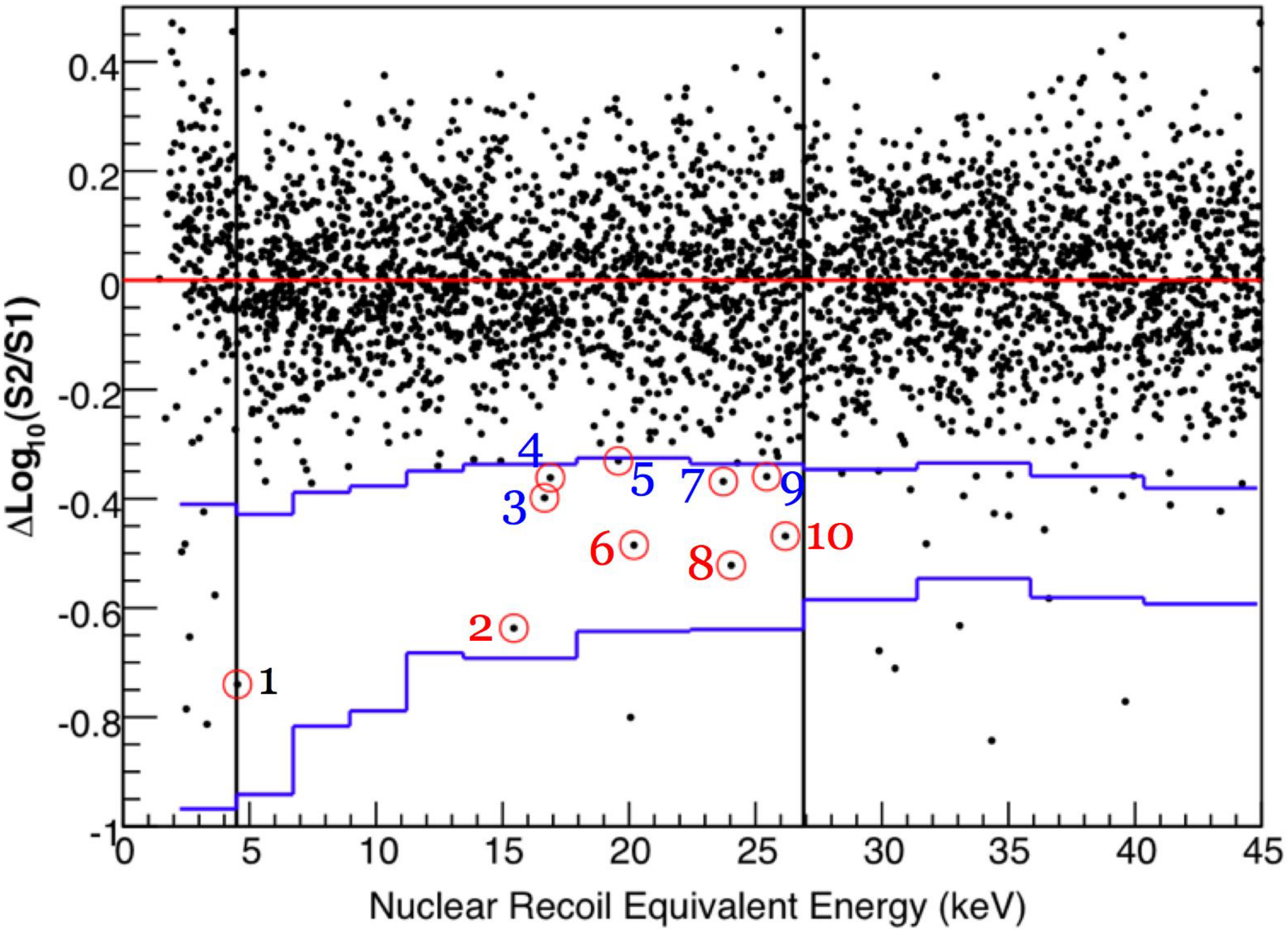


# XENON10 WIMP Search Data (Blind Analysis)

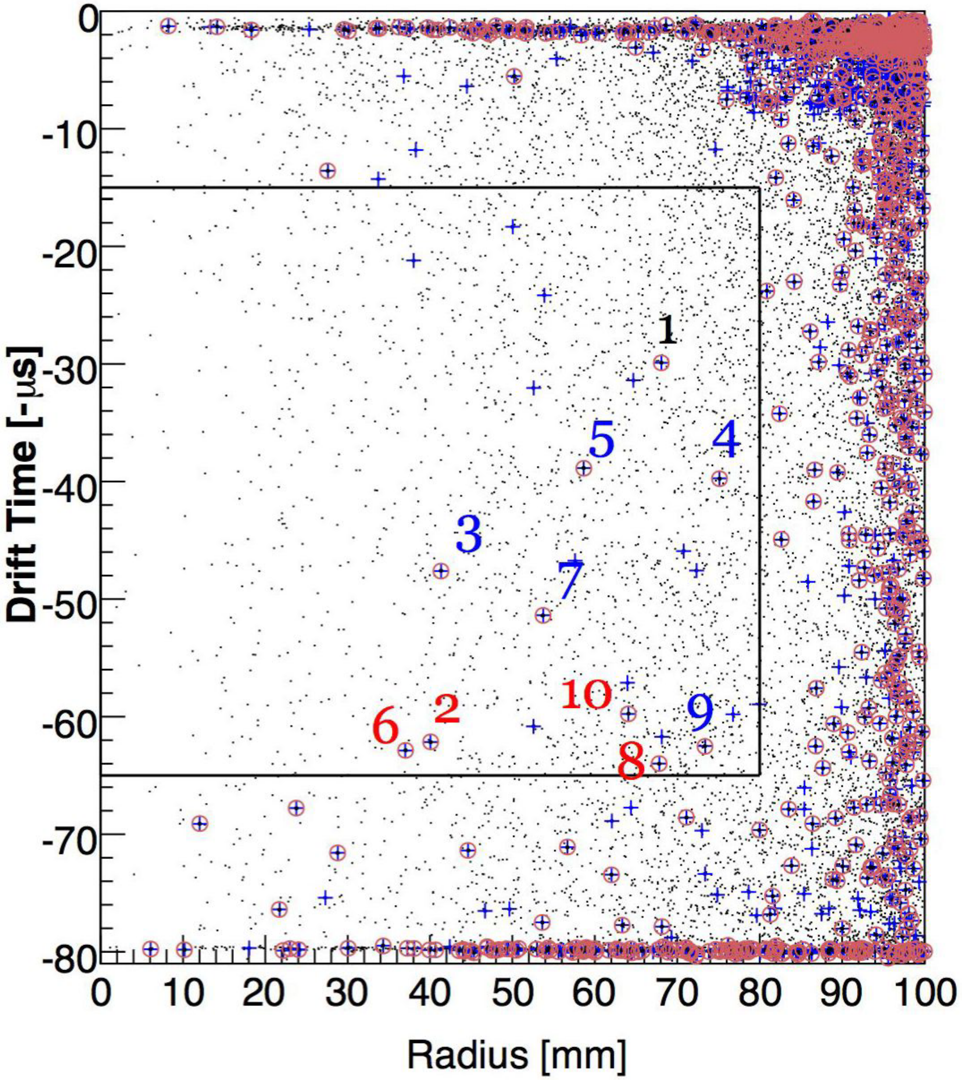
136 kg-days Exposure= 58.6 live days x 5.4 kg x 0.86 cut efficiency x 0.50 (50% NR)
Nuclear recoil energy scale based on 19% quenching factor

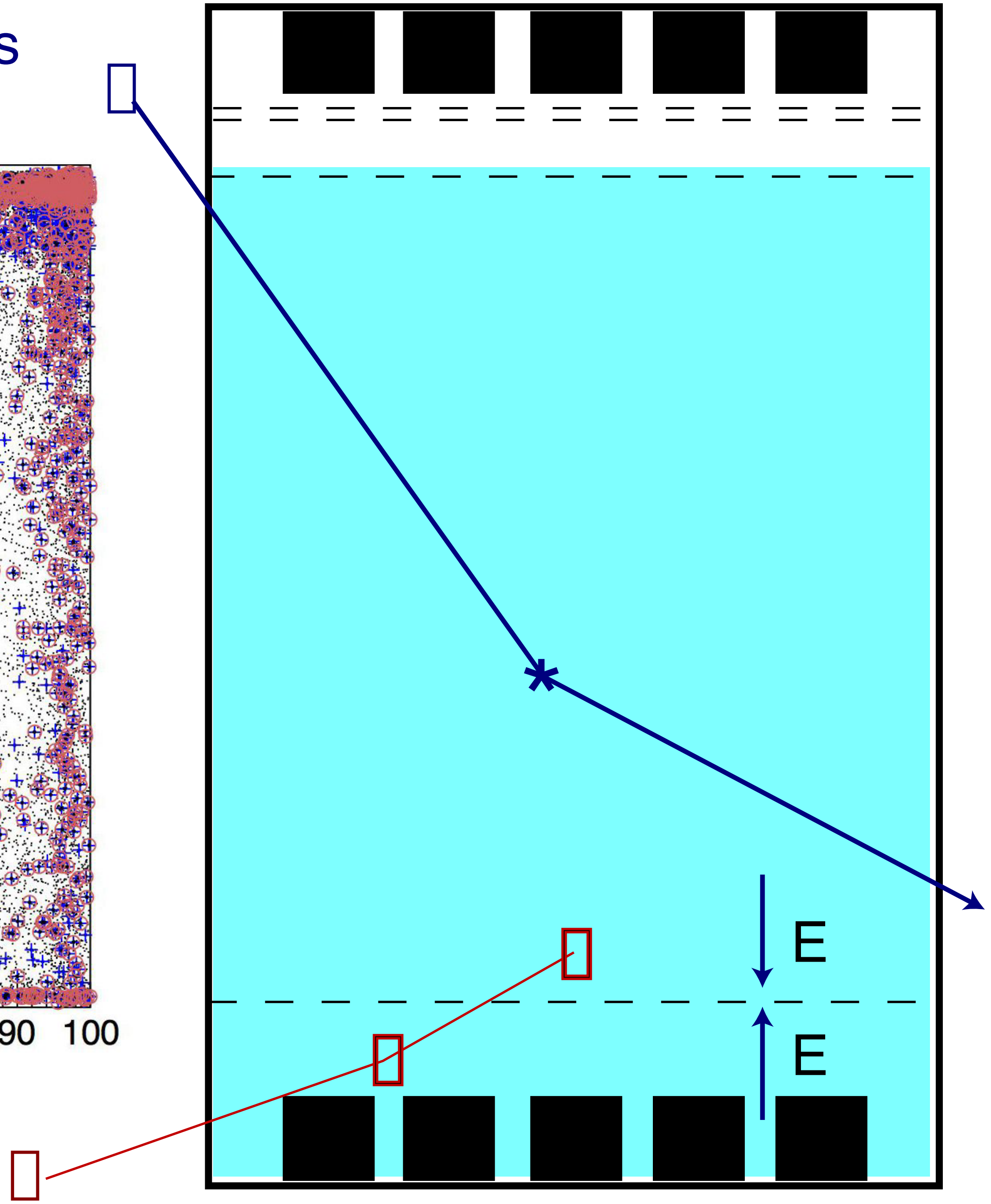
10 background events after cuts:

- 5 events consistent with statistical leakage
- 4 events consistent with reverse field effects
- 1 event remains



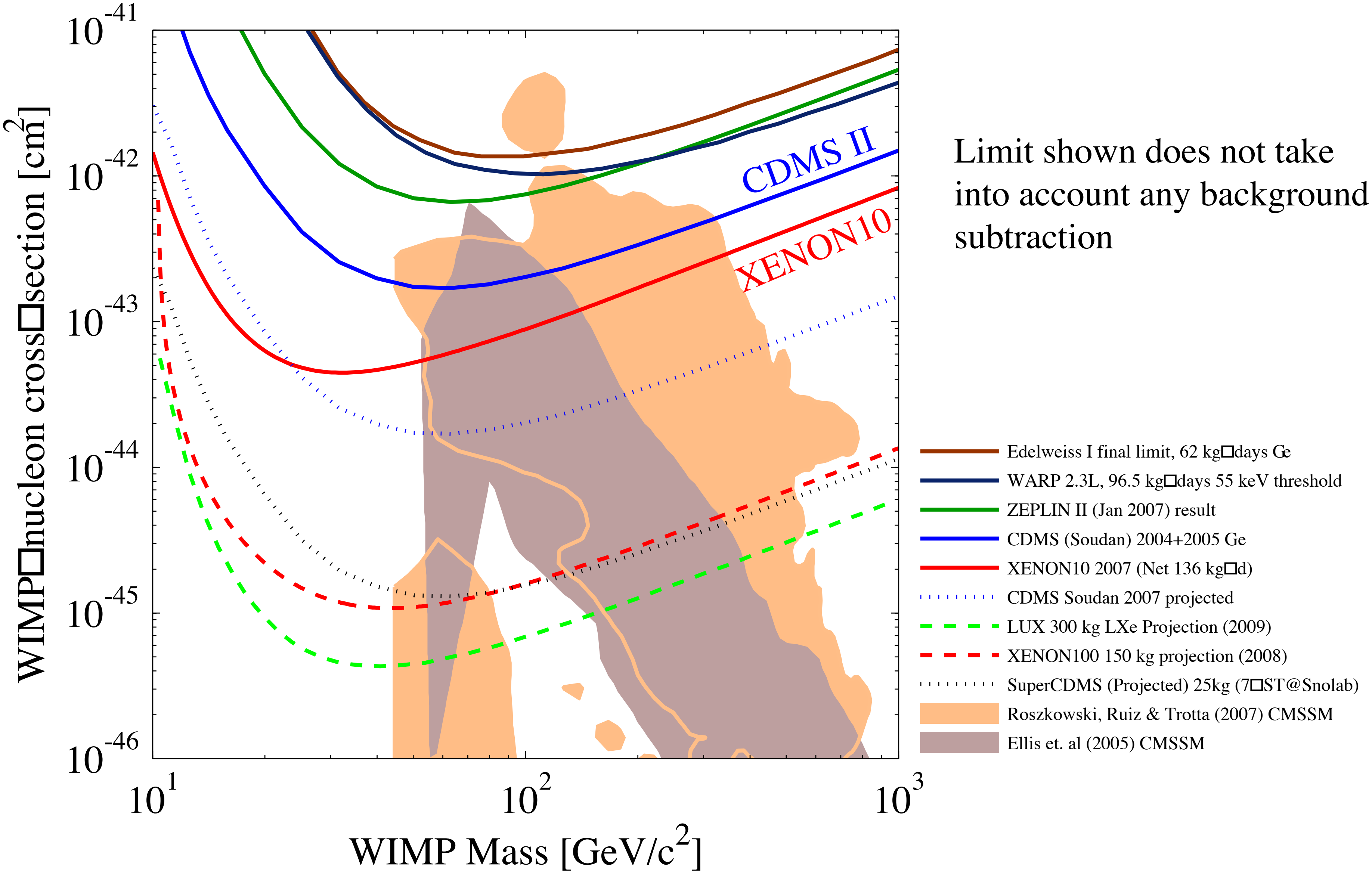
# XENON10 backgrounds





# New XENON10 WIMP dark matter limit, announced at April APS meeting

see arXiv:0706.0039, submitted to Phys. Rev. Lett.



Limit shown does not take into account any background subtraction

# Other XENON10 papers in progress:

1) Spin-dependent limits

2) Detailed paper on the detector

3) Nuclear recoil response of XENON10

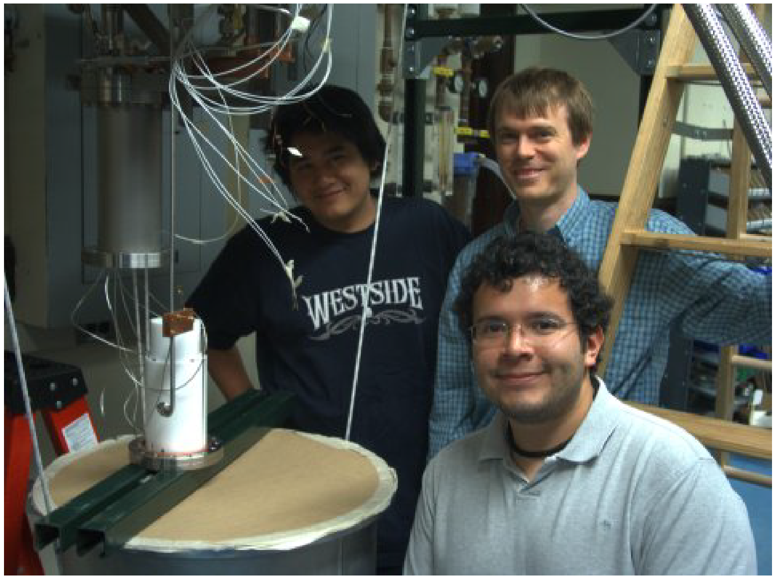
4) Radioactive backgrounds in XENON10

watch for arXiv submissions in coming 2 months...

# LXe cell at Yale

used for level meter development,
LXe scintillation for nuclear recoils,
PMT testing in LXe, GEM testing

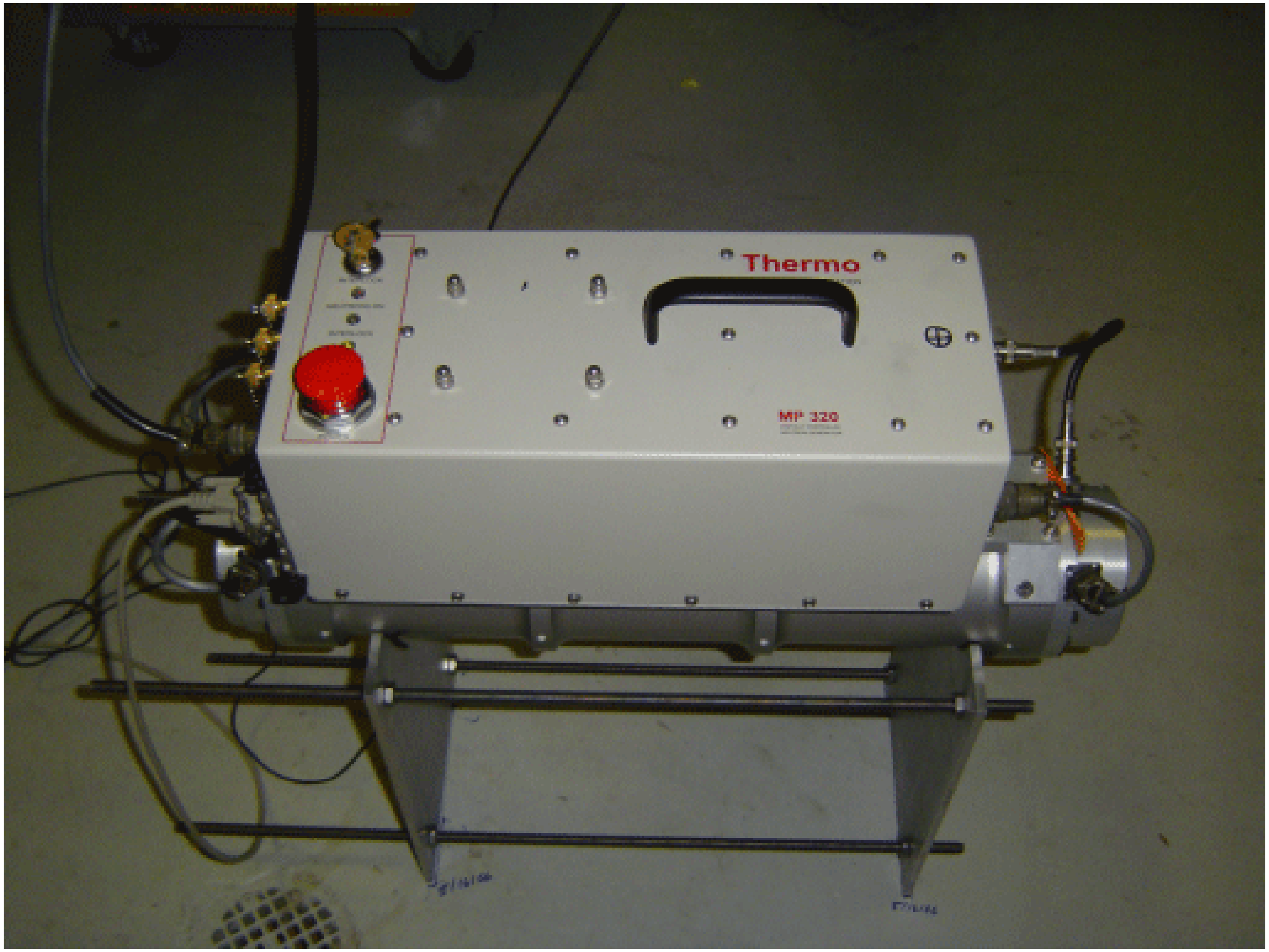


# DD Neutron Generator at Yale

$$d + d \longrightarrow {}^{3}He + n$$

Produces $10^6$ neutrons / second @ 2.8 MeV

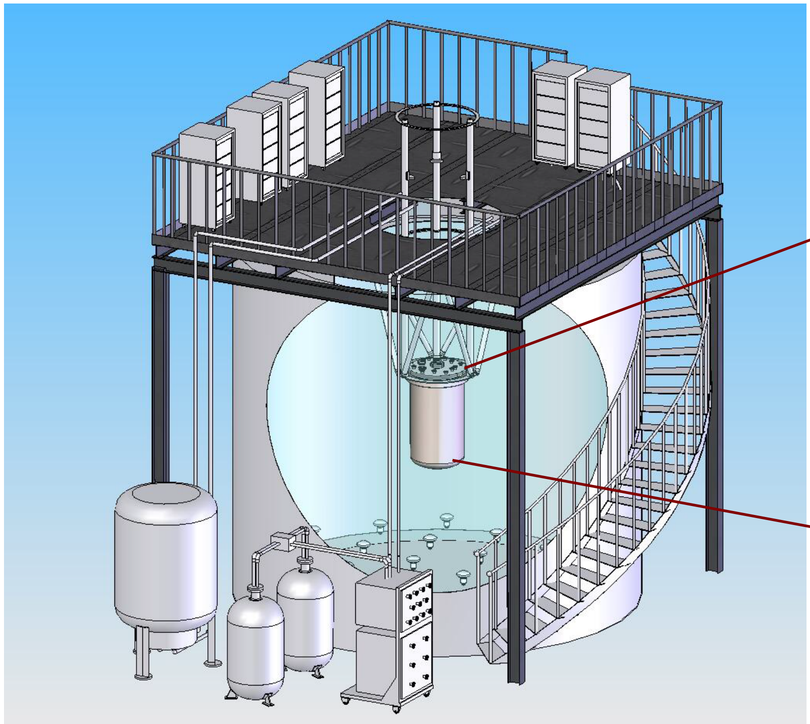


# The LUX Dark Matter Experiment

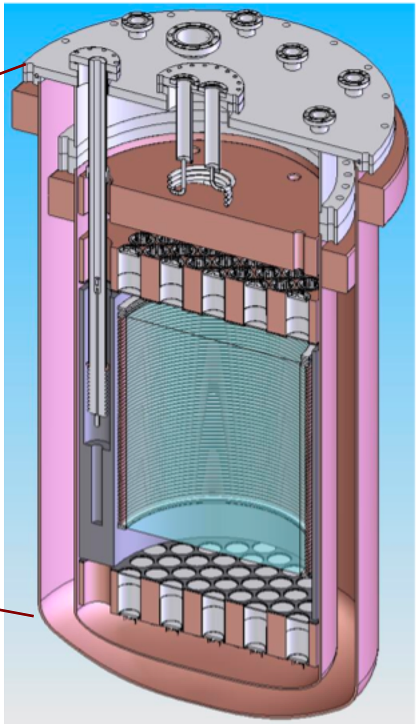
Brown [Gaitskell], Case [Shutt], LBNL [Lesko] , LLNL [Bernstein], Rochester [Wolfs], Texas A&M [White], UC Davis [Svoboda/Tripathi], UCLA [Wang/Arisaka/Cline], Yale [McKinsey]

300 kg active LXe target, with 100 kg fiducial mass
Background rate in fiducial < 8 x $10^{-4}$ events/keVee/kg/day

Projected dark matter reach in 10 months: 7 x $10^{-46}$ $cm^2$ at 100 GeV



6 meter diameter water shield

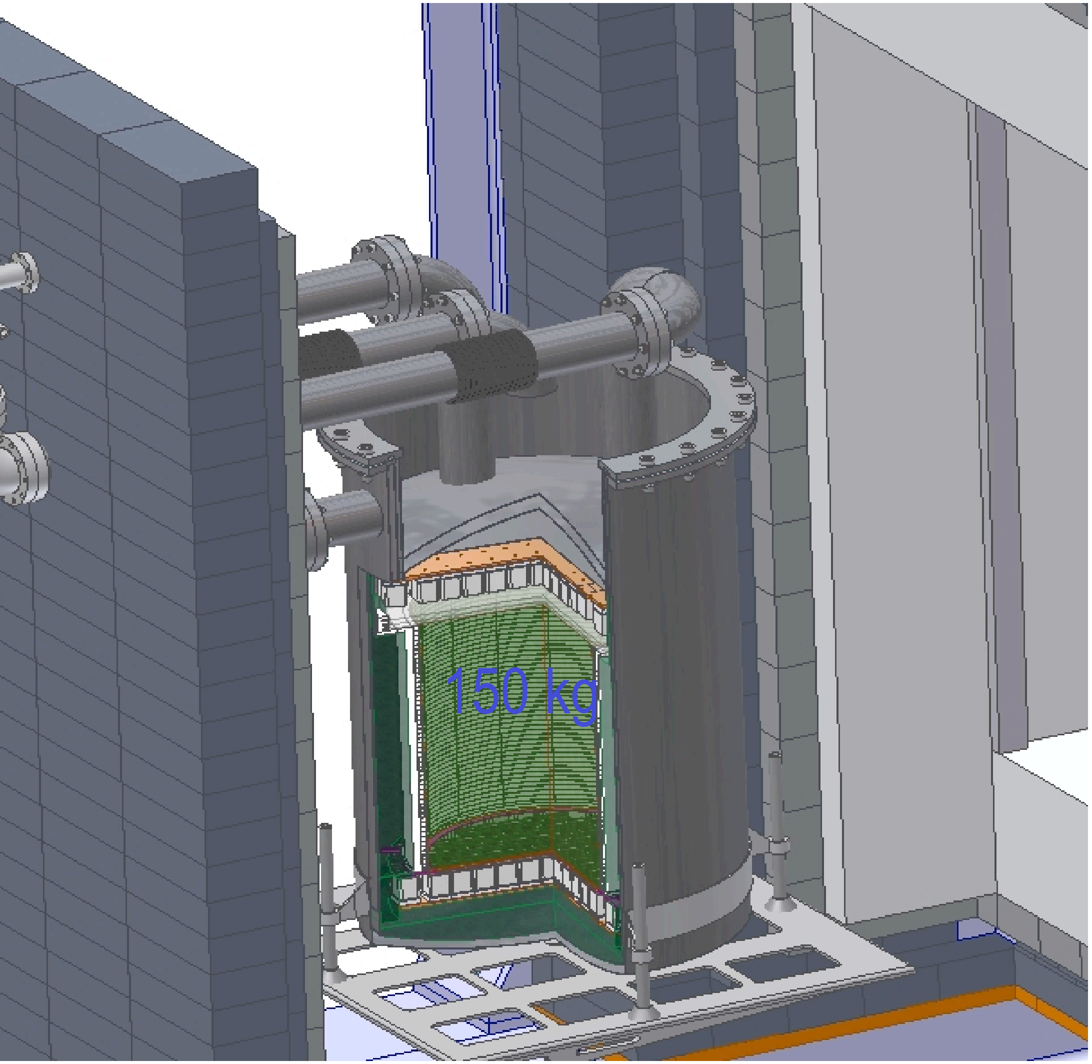


Two-phase LXe detector

# LUX Cryostat Assembly
# (Case Western)

# XENON100 : 2007-2008

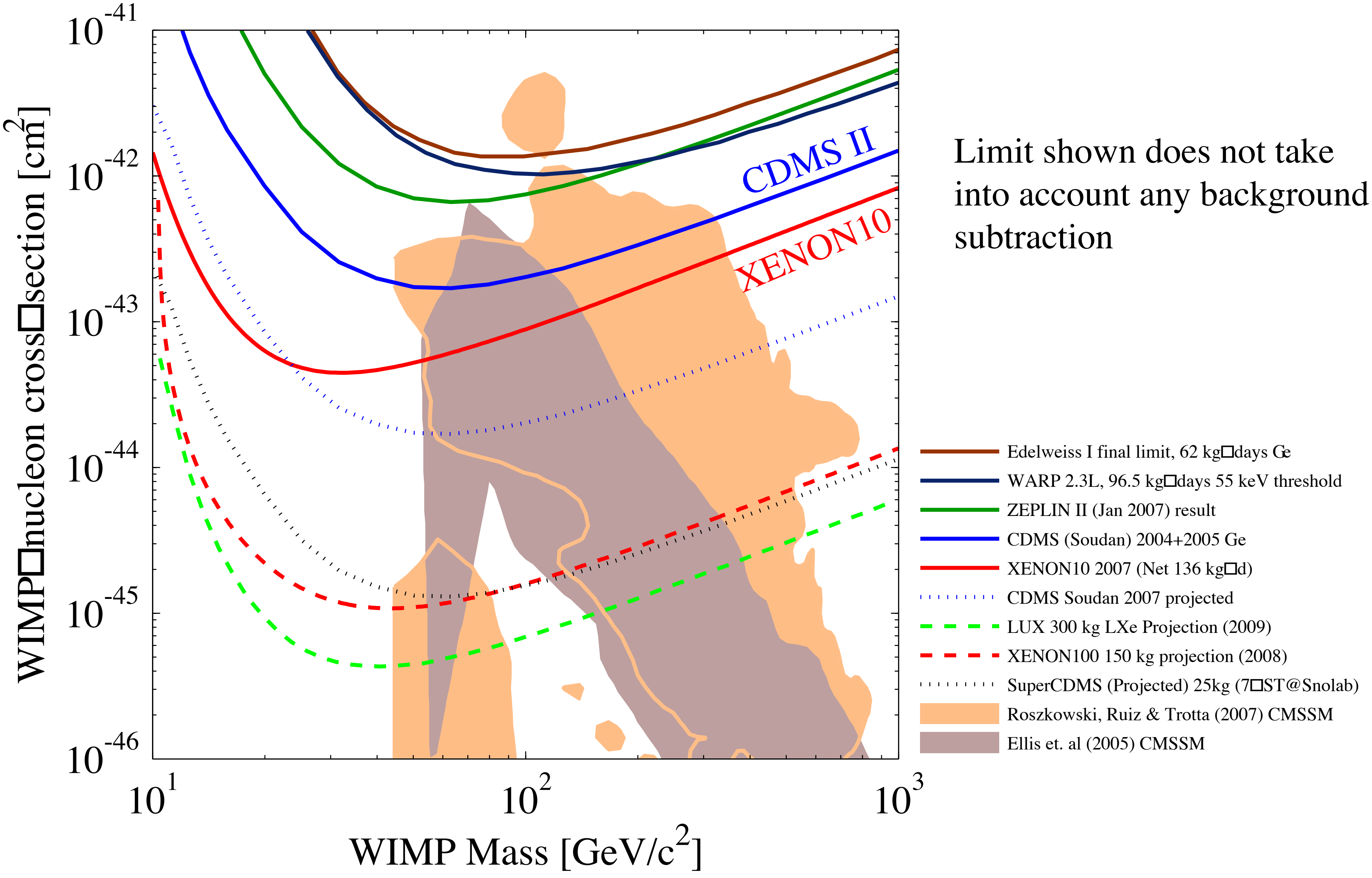
## Columbia, Coimbra, LNGS, Rice, Zurich



- New detector in current shield
- 150 kg total active mass
- 70 kg target in active LXe veto
- Low activity PMTs and cryostat
- All materials screened at LNGS
- 100 x less background than XENON10
- High light collection for <10 keVr
- New QF data for < 10 keVr recoils
- Commissioning by end 2007
- Install XENON100 in current shield
- Dark Matter Search in 2008 @LNGS

# New XENON10 WIMP dark matter limit, announced at April APS meeting

see arXiv:0706.0039, submitted to Phys. Rev. Lett.



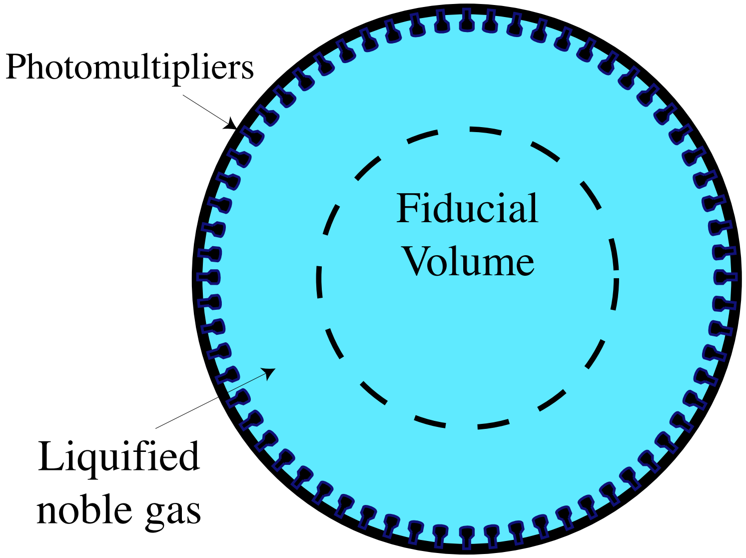
Limit shown does not take into account any background subtraction

# The Mini-CLEAN Approach

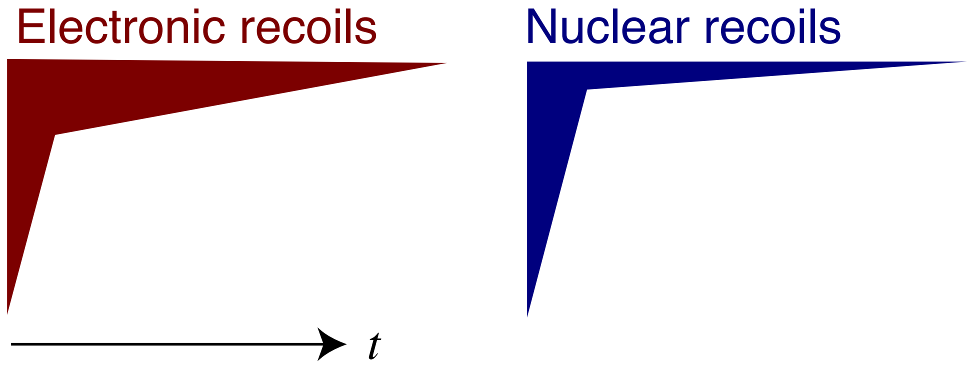
Scaleable technology based on detection of scintillation in liquified noble gases. No E field.
Ultraviolet scintillation light is converted to visible light with a wavelength-shifting film.

Liquid neon and liquid argon are bright scintillators (30,000 - 40,000 photons/MeV).
Do not absorb their own scintillation.
Are inexpensive (Ar: $2k/ton, Ne: $60k/ton).
Are easily purified underground.
Exhibit effective pulse shape discrimination.
Exchange of targets allows better characterization of radioactive backgrounds

## Self-shielding



## Pulse-shape discrimination



Fast component: < 10 ns
Slow component: 1.6 μs (LAr), 15 μs (LNe)
Discriminate based on fraction of light in
first 100 ns (Fprompt)

D. N. McKinsey and J. M. Doyle, J. Low Temp. Phys. 118, 153 (2000).
D. N. McKinsey and K. J. Coakley, Astropart. Phys. 22, 355 (2005).
M. Boulay, J. Lidgard, and A. Hime, nucl-ex/0410025
M. Boulay and A. Hime, Astropart. Phys. 25, 179 (2006).

# Noble liquid detectors: Advantages of Ar & Ne over Xe

## Cost.

Commercial price of Xe is $1500/kg, compared to $2/kg for Ar and $60/kg for Ne.
For a 10-ton experiment, this is $15M for Xe, $20k for Ar, and $600k for Ne.

## Purity:

LXe is a very good solvent, and easily dissolves charge and light absorbers from chamber walls, insulator materials, PMT bases, cabling, etc. Impurities in LAr and LNe are more apt to "freeze out", and outgassing is much less because of their lower temperatures (87K and 27 K respectively, vs. 165 K for LXe). Impurites can severely limit scalability.

## Discrimination:

LXe discrimination is limited to 99% to 99.9% in the optimal energy range (5-30 keV)
LAr discrimination is projected to be 99.99999999% at threshold, and
LNe discrimination is projected to be 99.9999% at threshold.
Both LAr and LNe discrimination improve at higher energies - not true of LXe.

## Nuclear Recoil Scintillation Efficiency:

This is the scintillation yield for nuclear recoils divided by the yield for electron recoils
LXe scintillation efficiency drops to 12% at energy threshold (Aprile et al, 2005)
LAr scintillation efficiency is about 25% at energy threshold (Micro-CLEAN data)

## Disadvantages:

Ar: Internal radioactivity of Ar-39, at 1.0 Bq/kg.
Ne: Lower WIMP rate/kg.

# Noble liquid detectors: Advantages of single-phase over double-phase

**Light collection is more efficient.**

Discrimination efficiency (i.e. ability to reject electron-like backgrounds) at a given energy threshold improves exponentially with light collection efficiency.

$4\pi$ photomultipler coverage results in significantly better light collection than in a two-phase detector, where electric field rings and insulator materials limit optical access.

**No extremely high voltages.**

Only high voltages are to PMTs (about 1.5 kV). Two-phase detectors require about 1 kV/cm, or about 100 kV/cm for a 100 cm drift length, a non-trivial engineering task to perform within a complicated detector.

**Event pile-up less of an issue (esp. compared to 2-phase Ar).**

At an electron drift speed of 1 mm/us, a 100-cm tall, 1-ton, 2-phase LAr experiment has 1,000 Hz of Ar-39 background, and a time between events of 1 ms. Charge and light signals from individual events become difficult to match up properly.

**Disadvantage:** Poorer position resolution, based on PMT hit pattern rather than charge drift time

# CLEAN/DEAP Collaboration

*Yale University:* W. H. Lippincott, D. McKinsey*, J. Nikkel

*Boston University:* D. Gastler, E. Kearns

*Carleton University:* K. Graham, K. McFarlane

*Los Alamos National Laboratory:* A. Hime*, F. Lopez, J. Oertel, L. Rodriguez, K. Rielage,
L. Stonehill, J. Wouters

*National Institute for Standards and Technology:* K. J. Coakley

*Queen's University:* M. Boulay, A. Hallin, J. Lidgard, R. Matthew, A. McDonald, P. Skensved

*SNOLAB:* F. Duncan, C. J. Jillings, I. Lawson

*University of North Carolina:* R. Henning

*University of South Dakota:* D. Mei

*University of Texas:* R. Hegde, J. Klein, S. Seibert

* Mini-CLEAN Co-Spokespersons

# The CLEAN/DEAP family

A series of detectors based entirely on scintillation in LNe, LAr.

No electric field!

This allows very efficient light collection with 4π photodetector coverage.

Pico-CLEAN: 200 g of LNe. Completed LNe scintillation R&D.

DEAP-0: 1 kg LAr. Completed LAr scintillation R&D.

Micro-CLEAN: 4 kg of LNe or LAr. LAr R&D complete, LNe R&D underway.

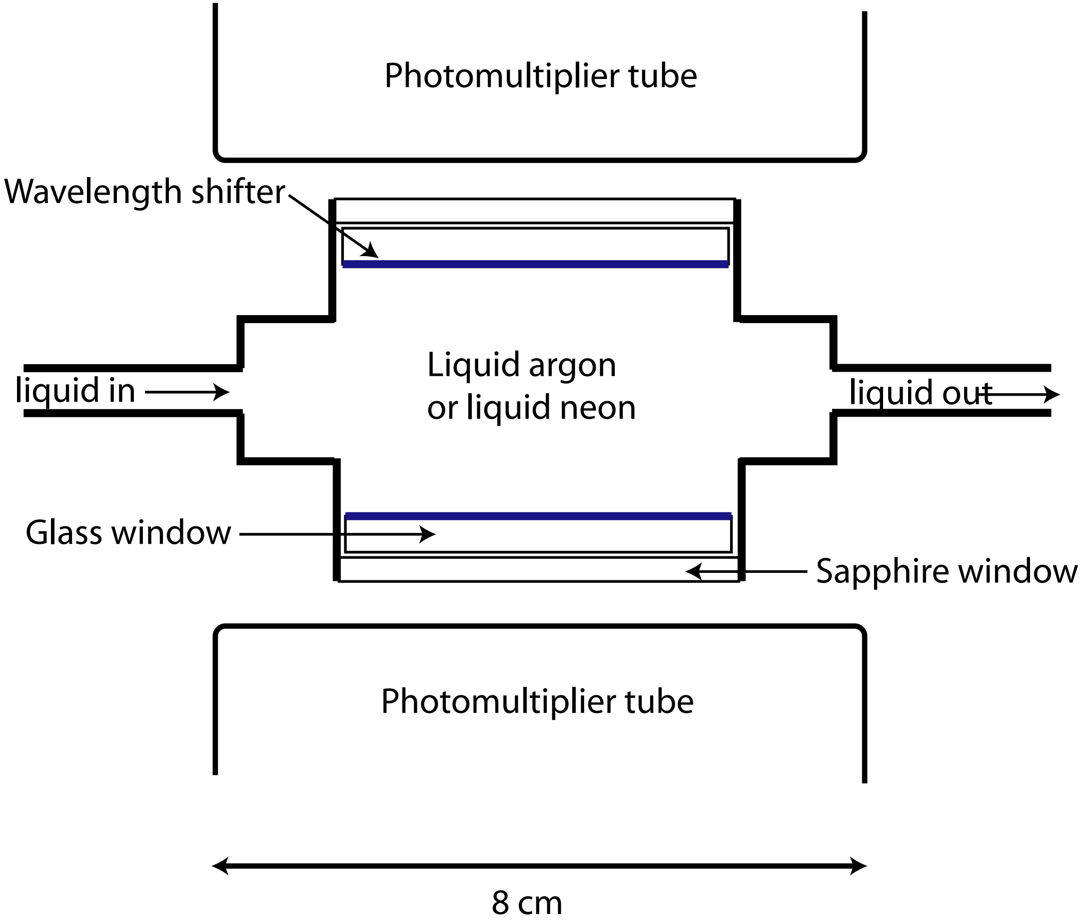
DEAP-I: 7 kg LAr. R&D, DM search at SNOLAB. To go underground in 2007.

Mini-CLEAN-360: 100 fiducial kg LNe/LAr. DM search. Begin operations 4Q 2008.

CLEAN/DEAP-3600: 1 fiducial ton LAr/LNe. DM search. Begin operations 4Q 2010.

CLEAN-100 ton: 10 fiducial tons LNe. pp neutrinos, DM search. Begin 2014.

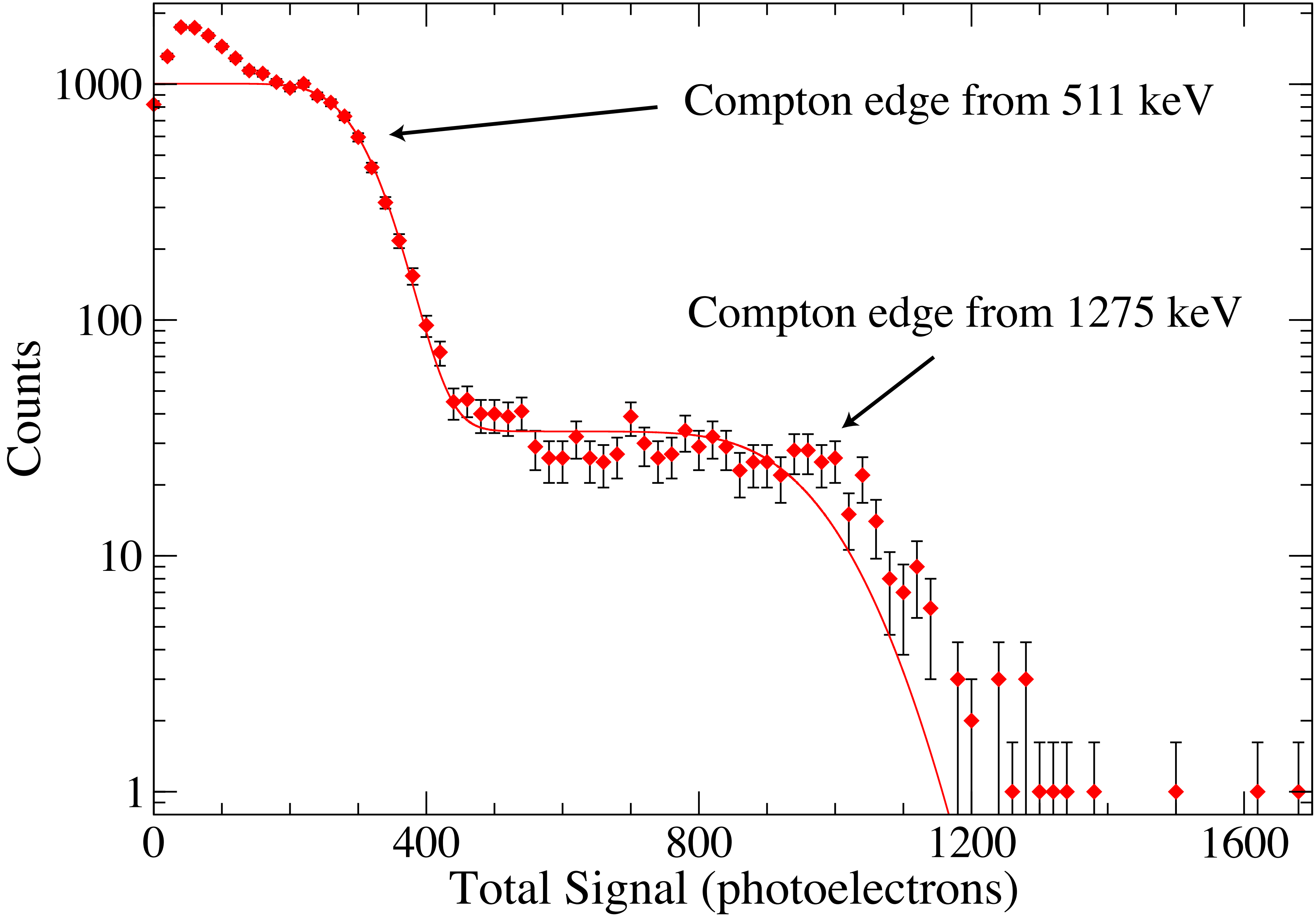
# Pico-CLEAN at Yale



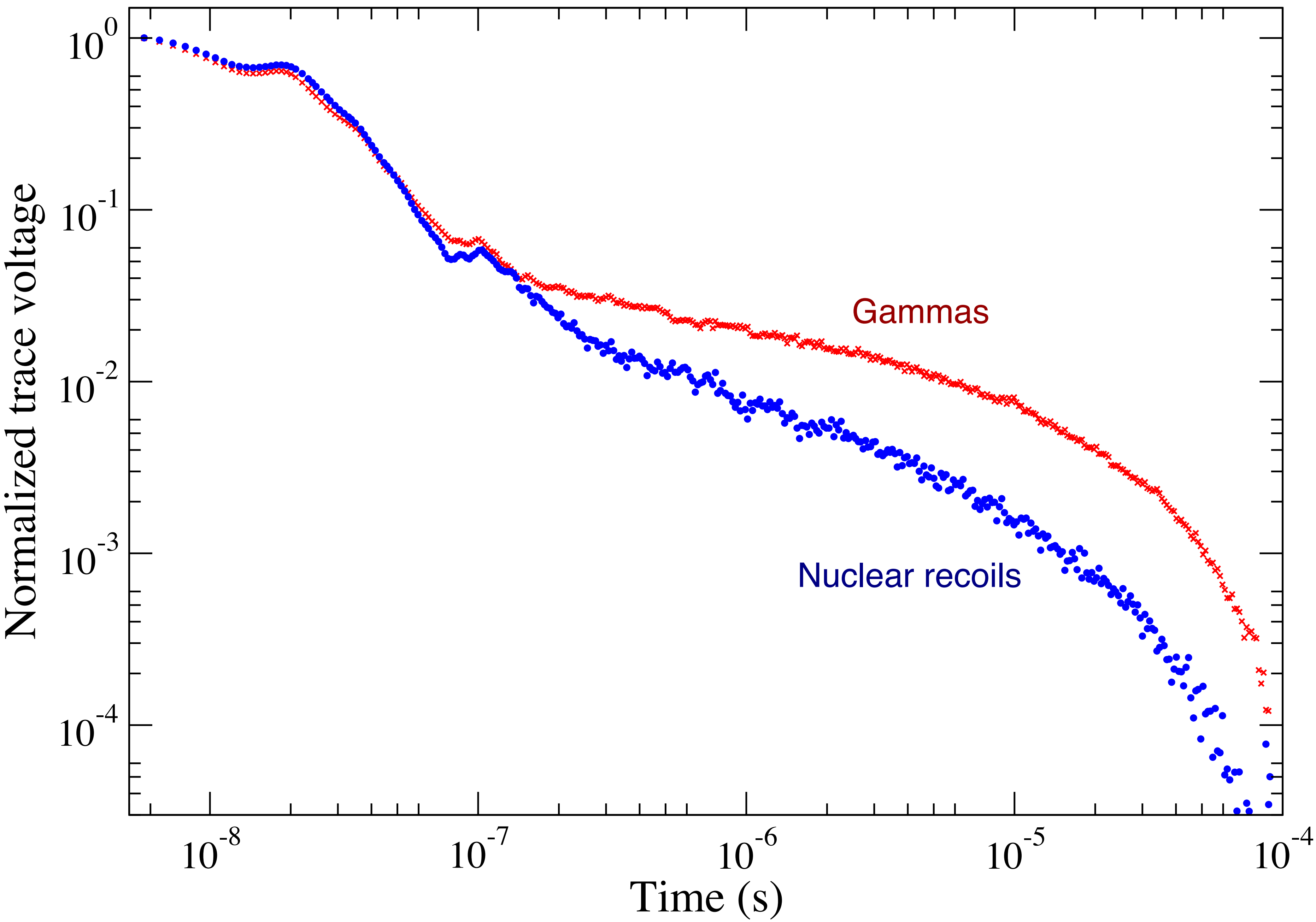
Dan McKinsey, Yale University

Liquid Neon calibration with Na-22 gamma rays gives 0.9 pe/keV

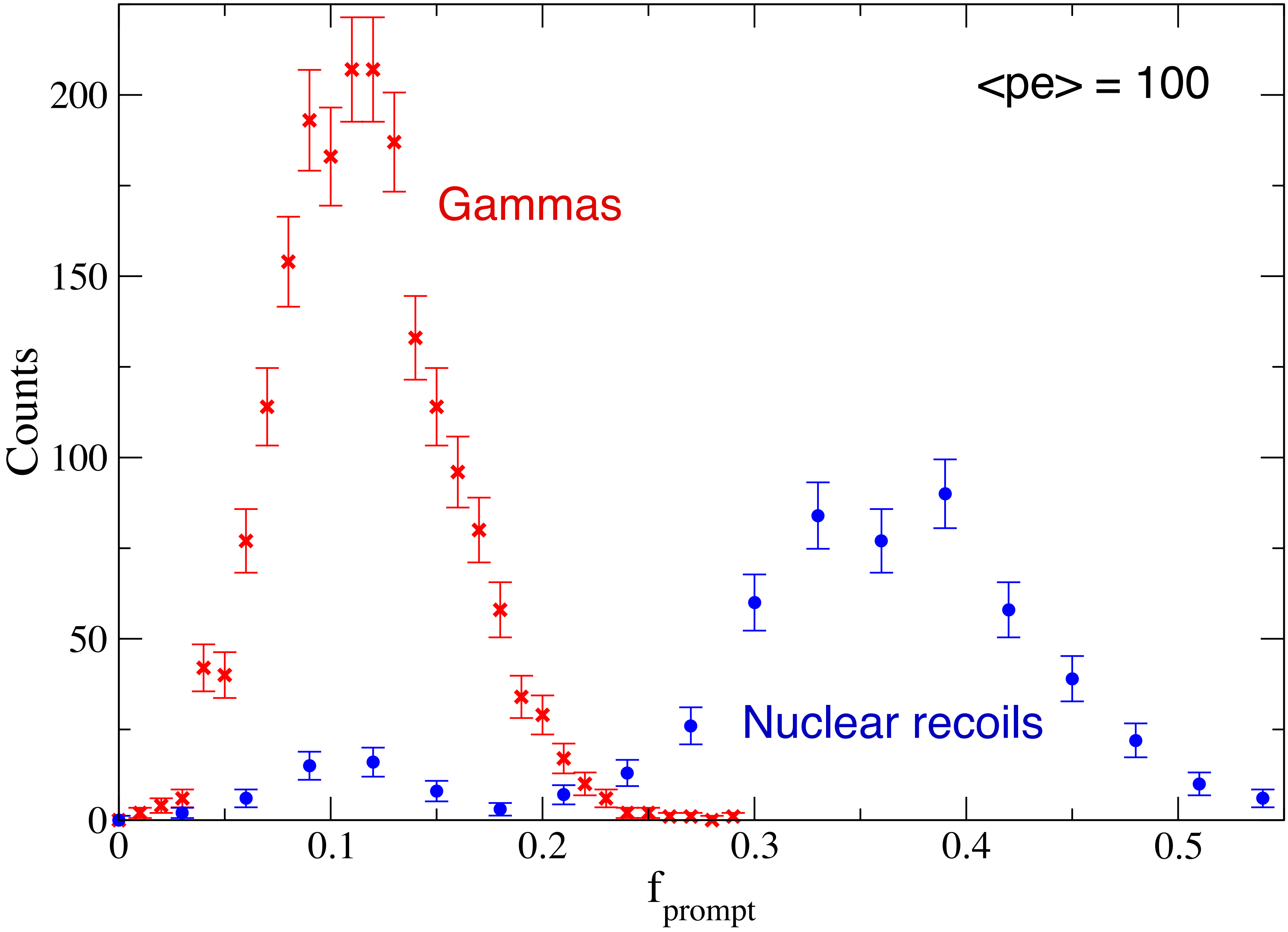
→ 30,000 photons/MeV



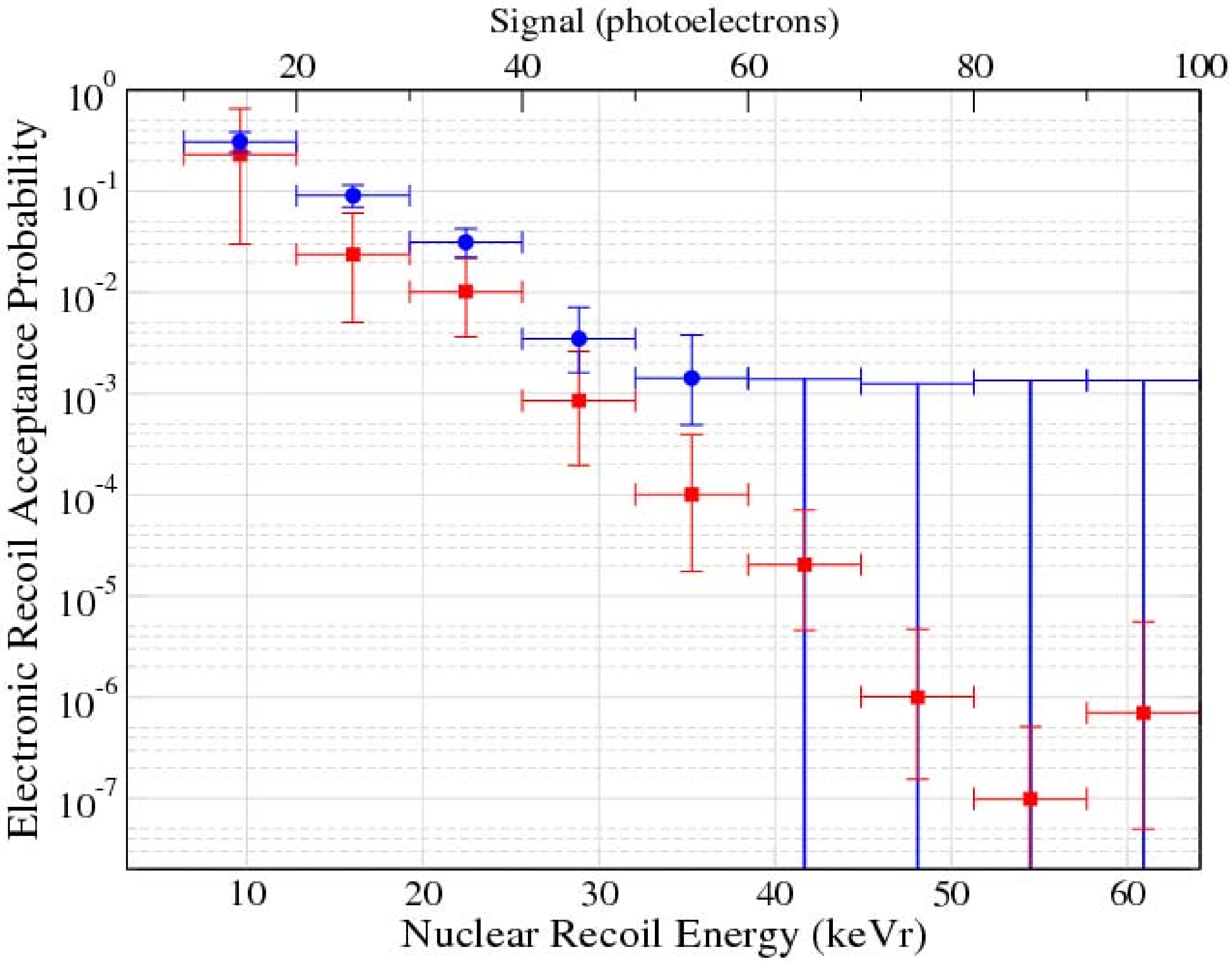
# Scintillation Time Dependence in LNe



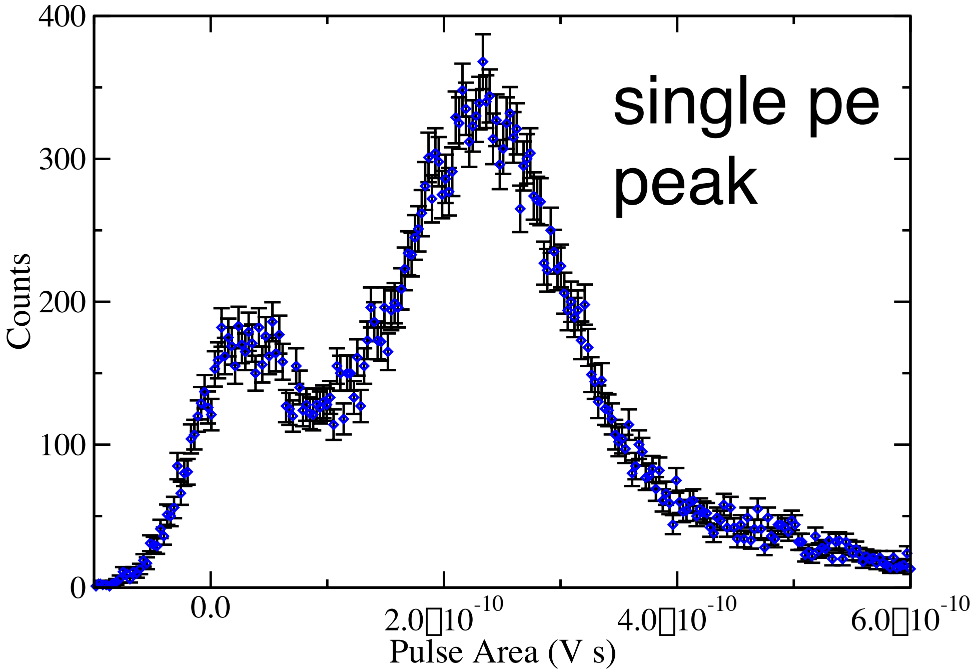
# Pulse shape discrimination in LNe



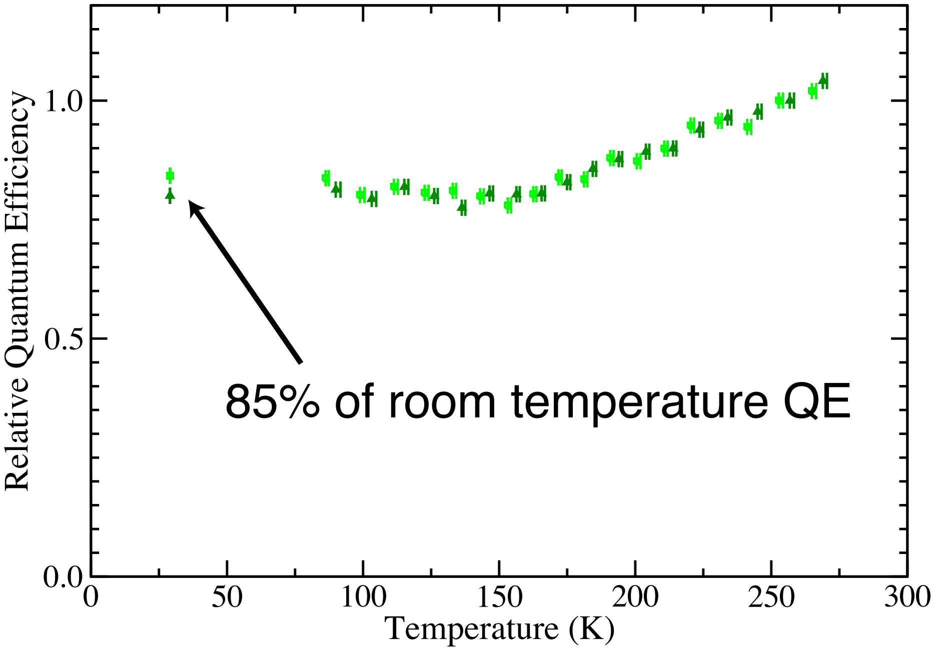
# Neon PSD from pico-CLEAN



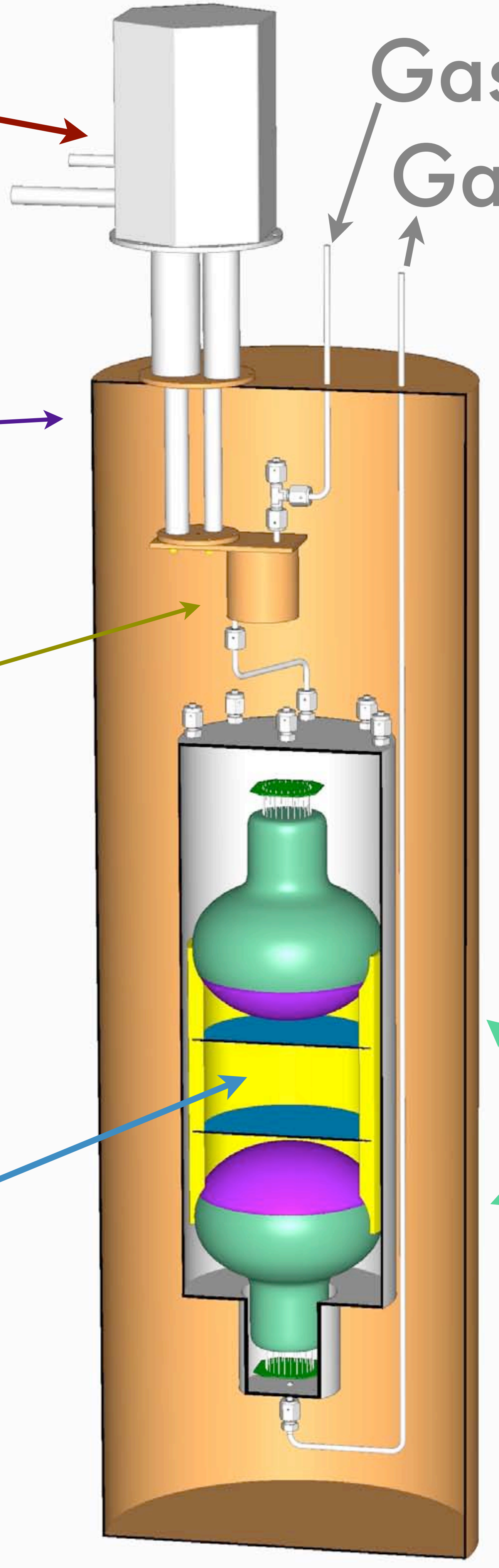
# PMT testing at 27 K



single pe peak



85% of room temperature QE



PT805 Pulse Tube Refrigerator

Gas in

Gas out

Heat Shield on 1st Stage

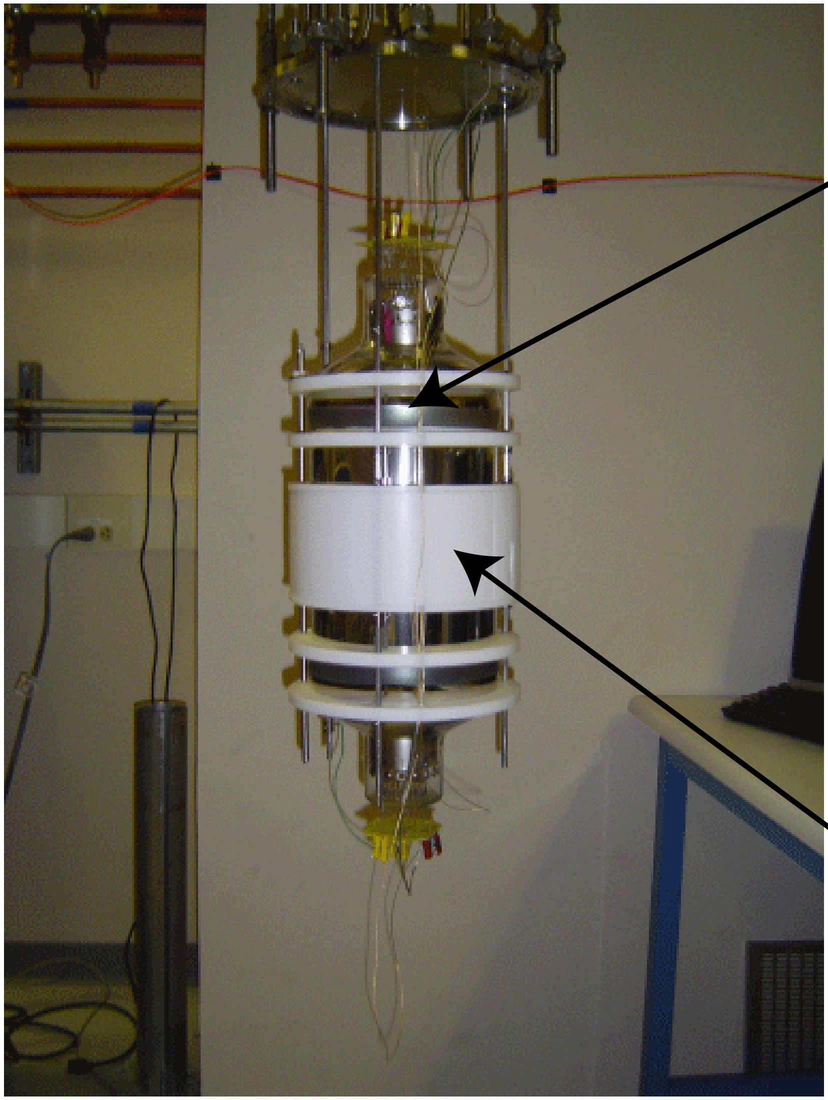
Liquefier on 2nd Stage

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

Central volume:
20 cm diameter
10 cm high
3.1 litres

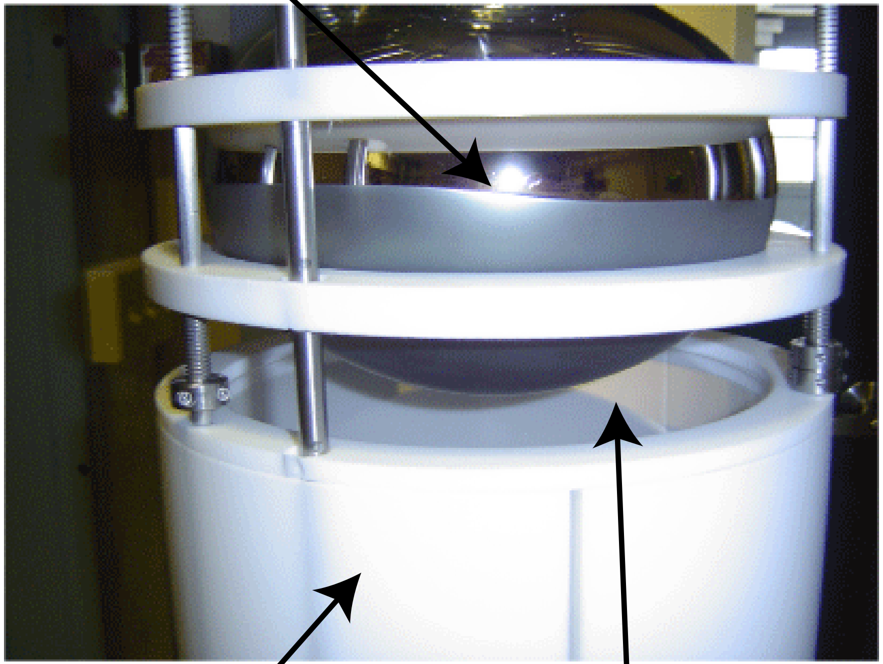
Hamamatsu R5912-02-MOD 20 cm PMTs

# Close-up shots of micro-CLEAN



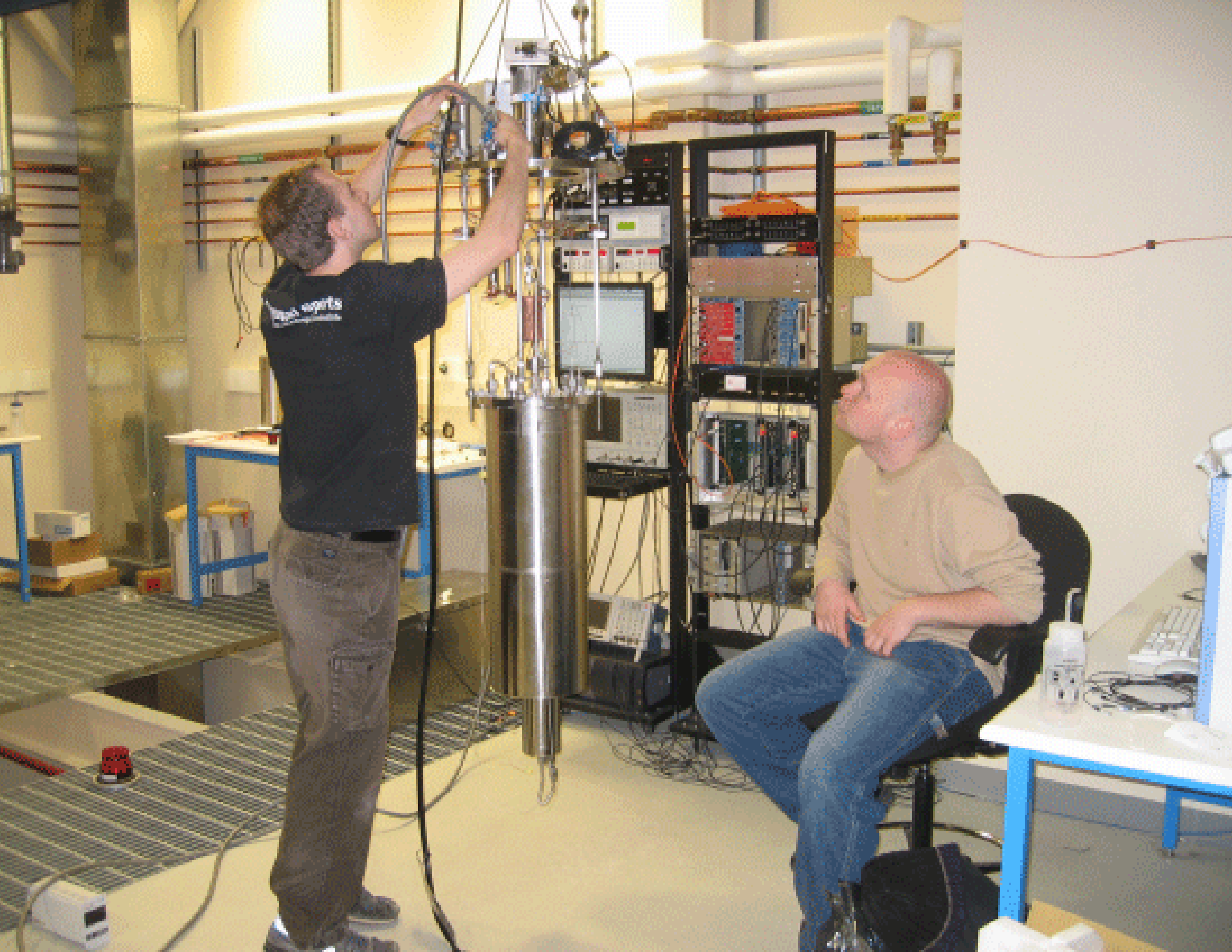
PMTs

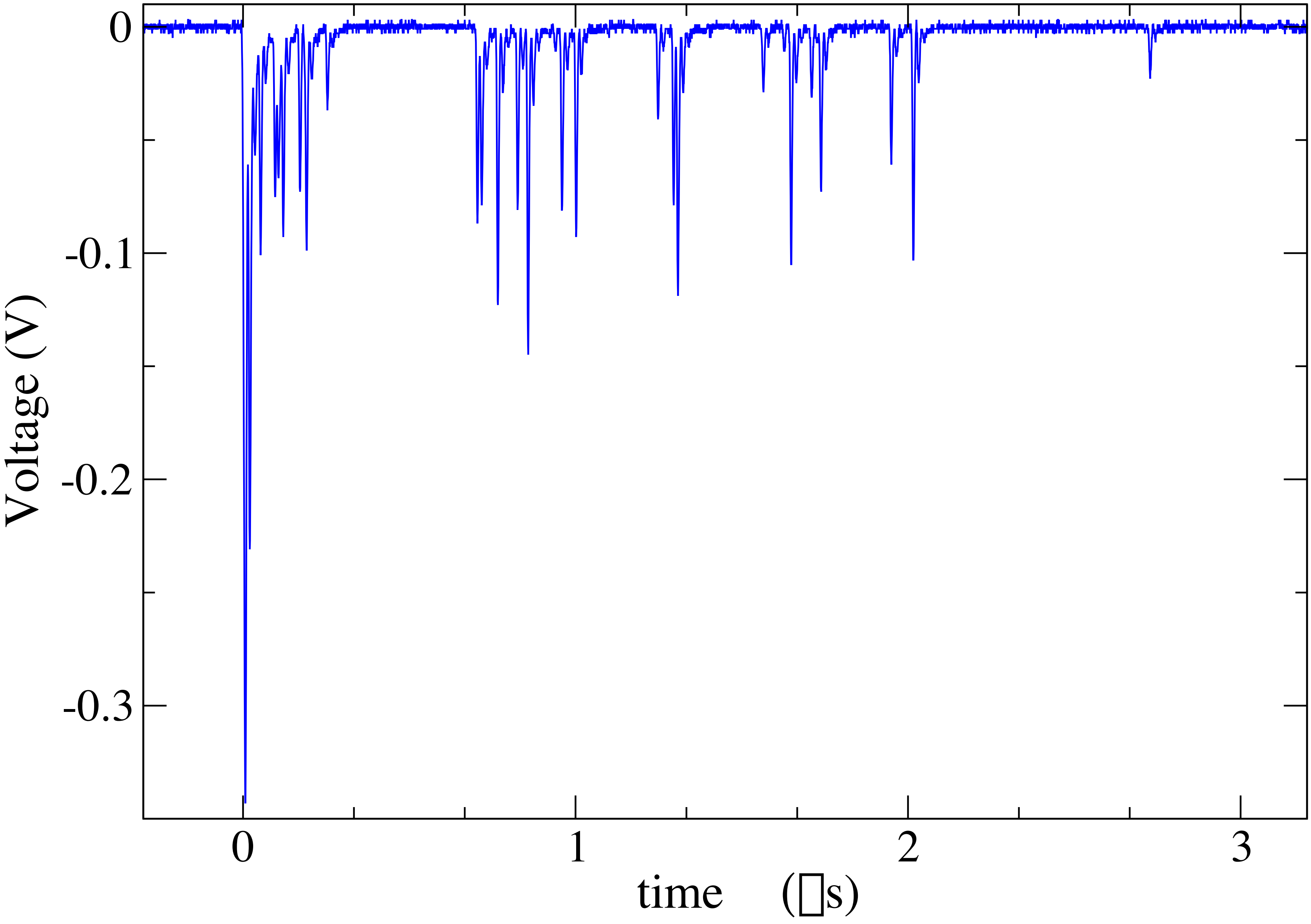
(aluminized mylar
light guide removed)



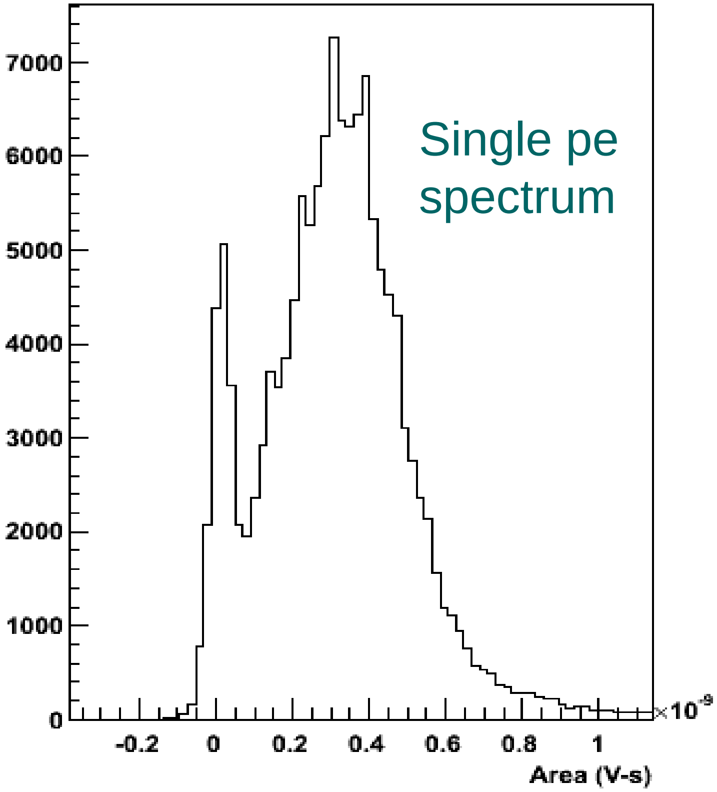
Teflon tube

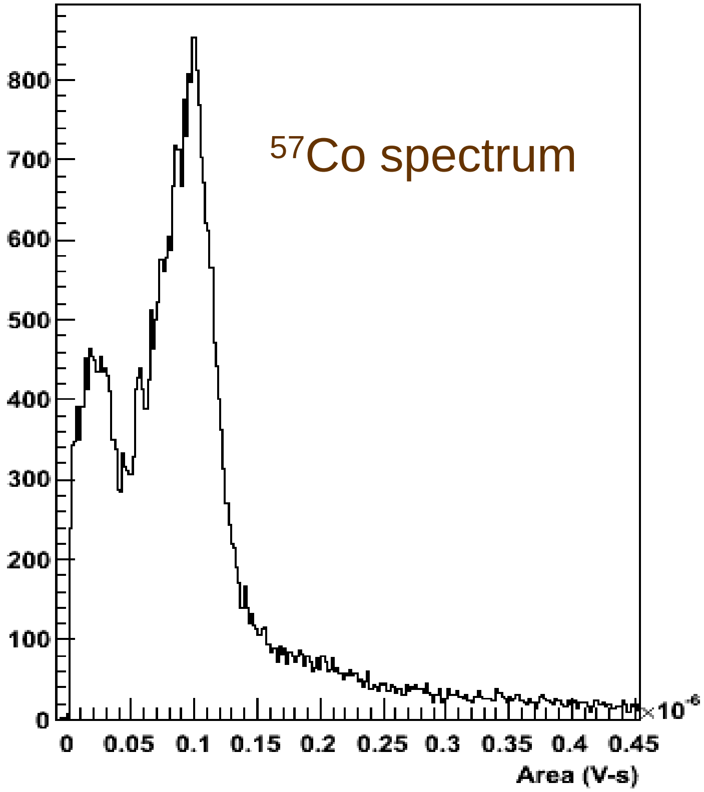
Fused silica window
with wavelength shifter


sports


Sample scintillation pulse (gamma Compton scatter in LAr)

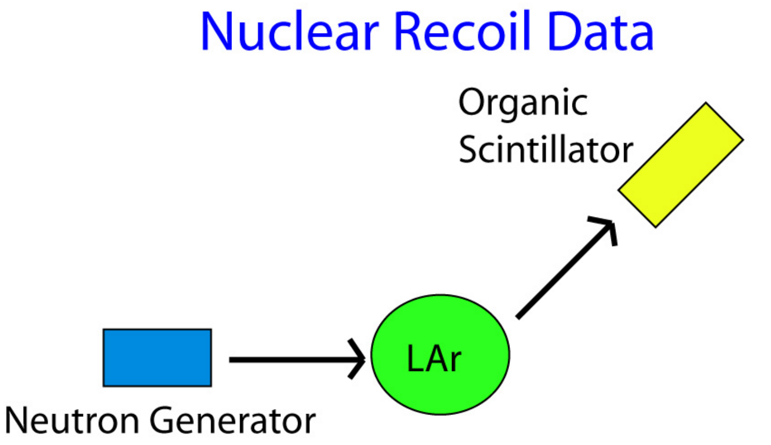
# Light Yield

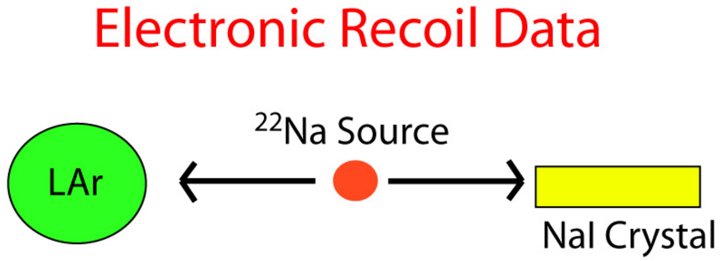




- Single photoelectron spectrum and cobalt peak for one of the PMTs
- Measure the light yield to be 4.9 pe/keVee

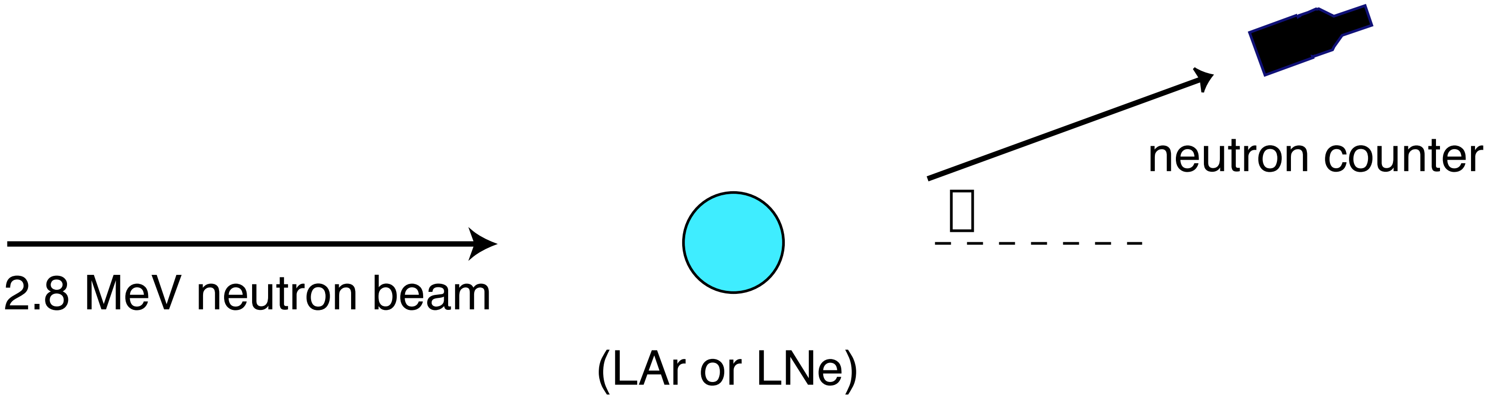
# Data Tagging and Quality





- Require coincidence with external detector
- Time of Flight cut
- PSD cut in organic scintillator
- Energy cut in NaI crystal
- Asymmetry cut in the PMTs

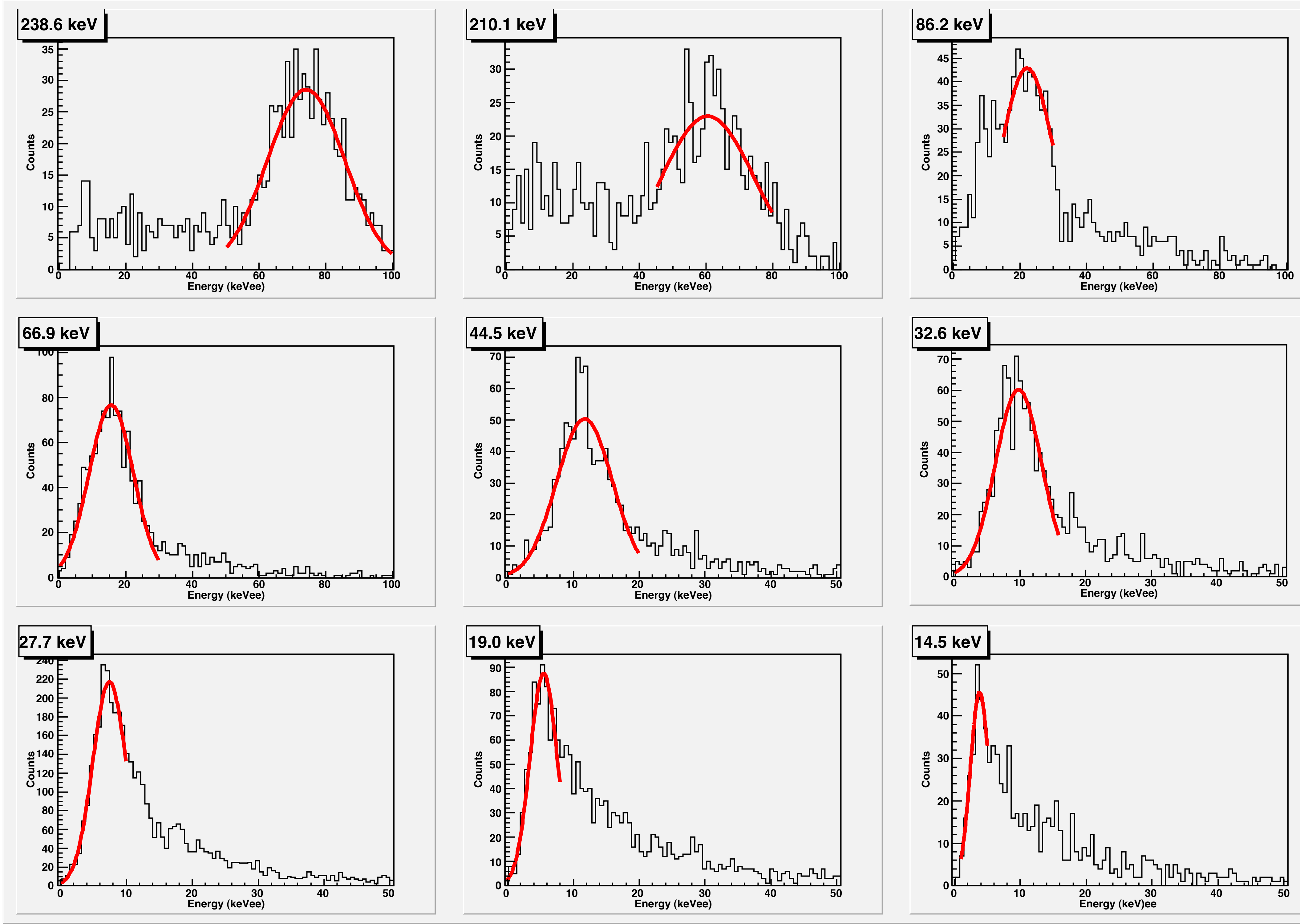
# Calibration of nuclear recoil-induced scintillation in LAr and LNe



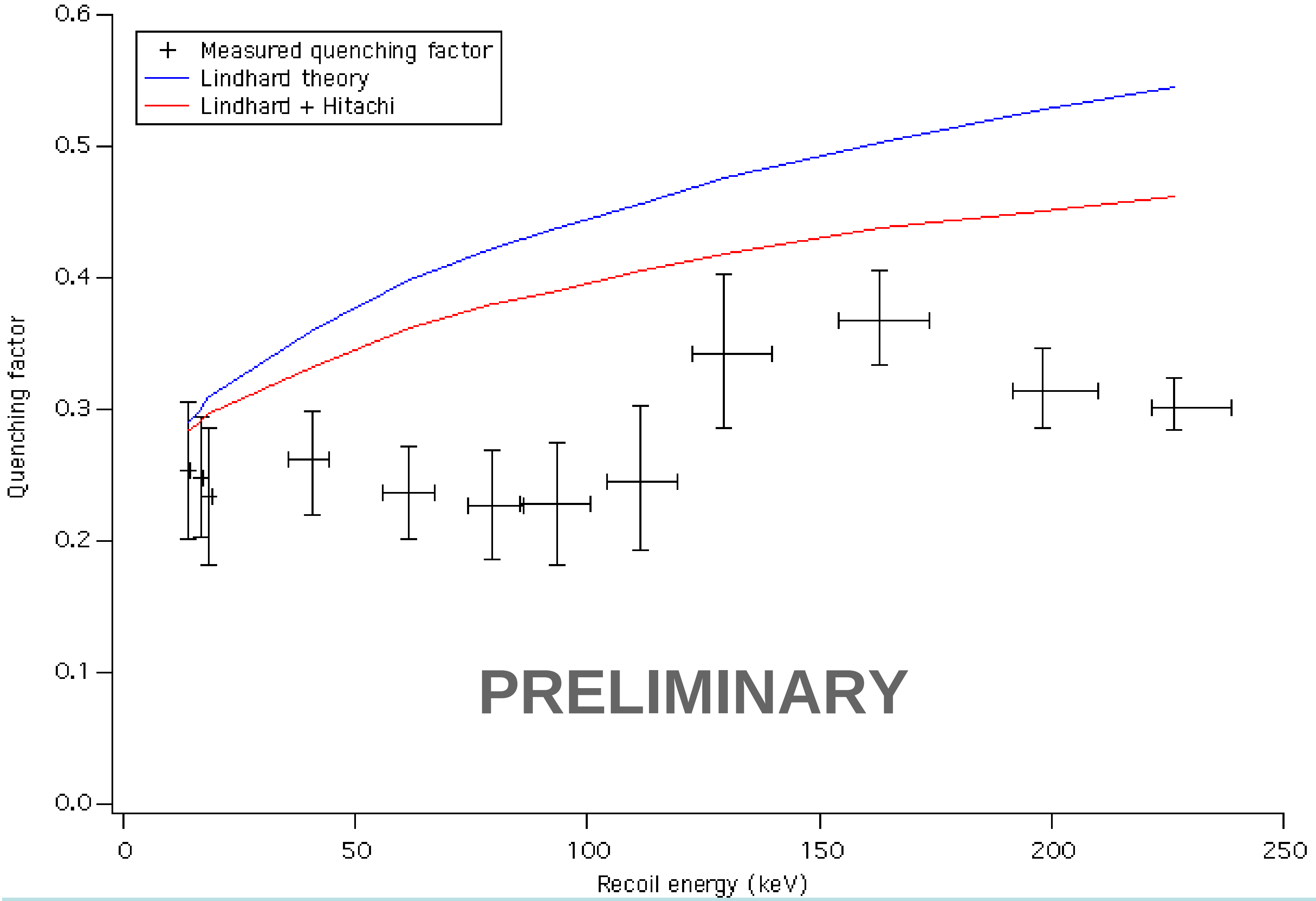
Require delayed coincidence between cryogenic scintillator and neutron counter

$$E_A = E_n \frac{2M_n M_A}{(M_n + M_A)^2} (1 - \cos \square)$$

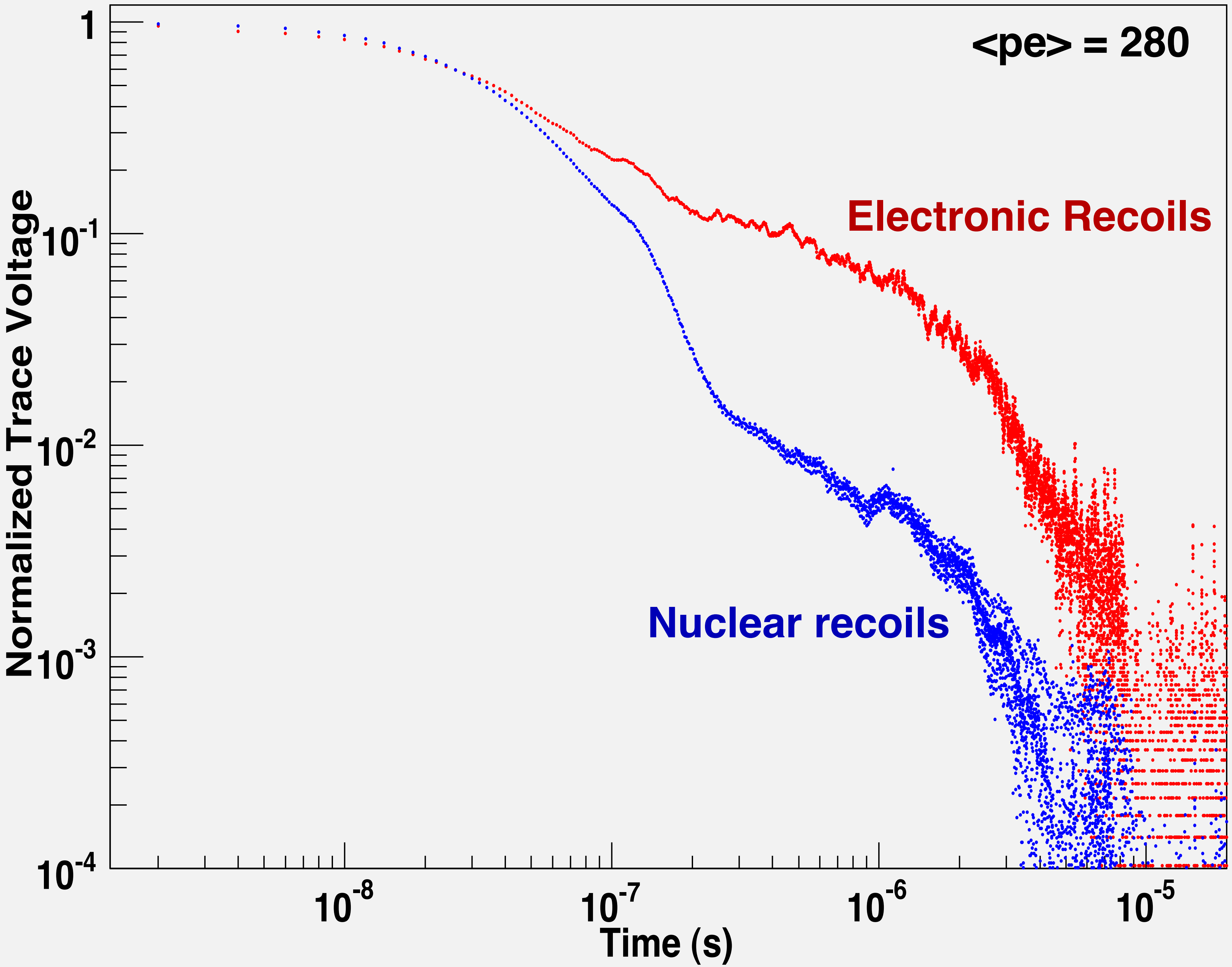
# Neutron Peaks at a Variety of Scattering Angles in LAr

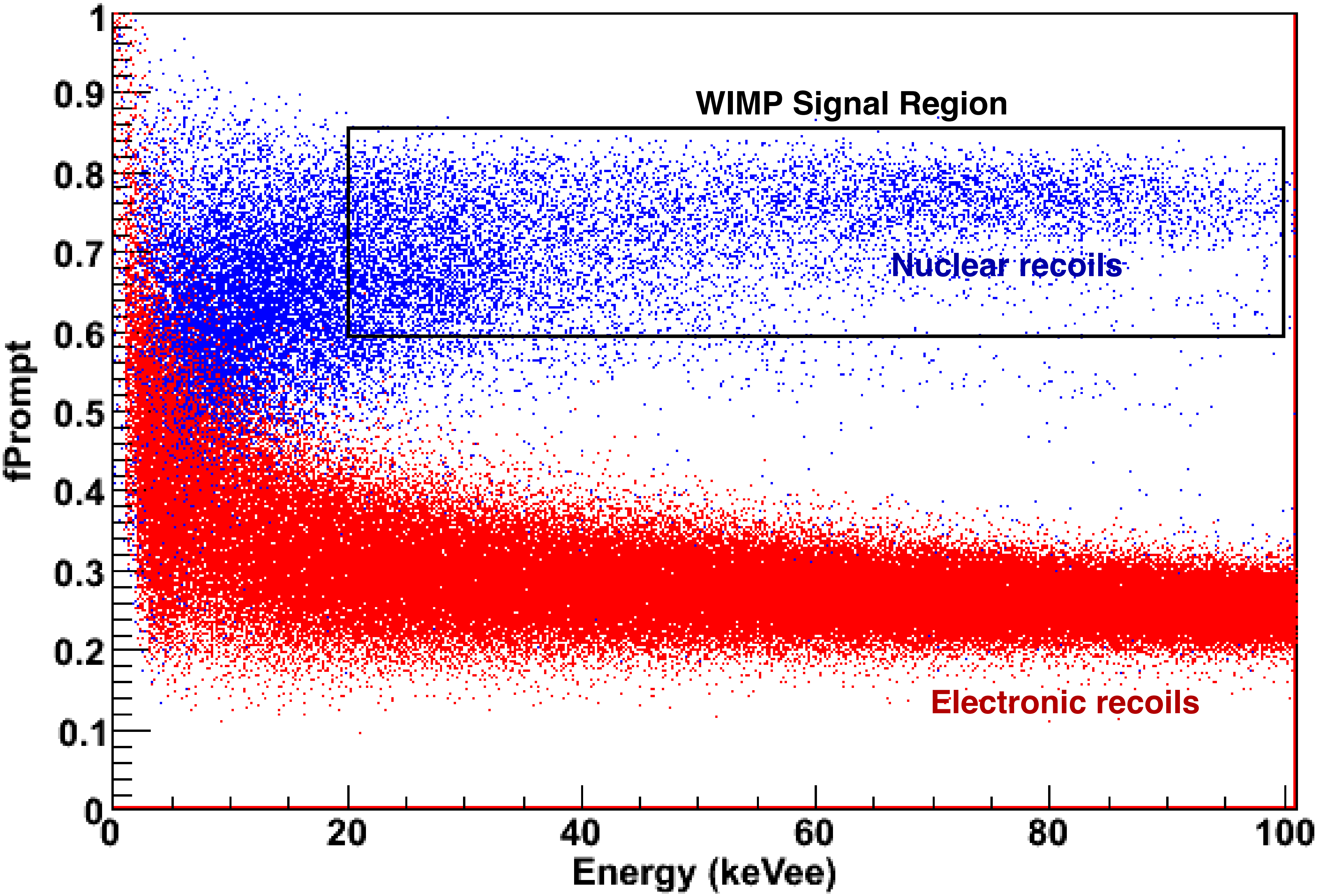


# LAr Quenching Measurements

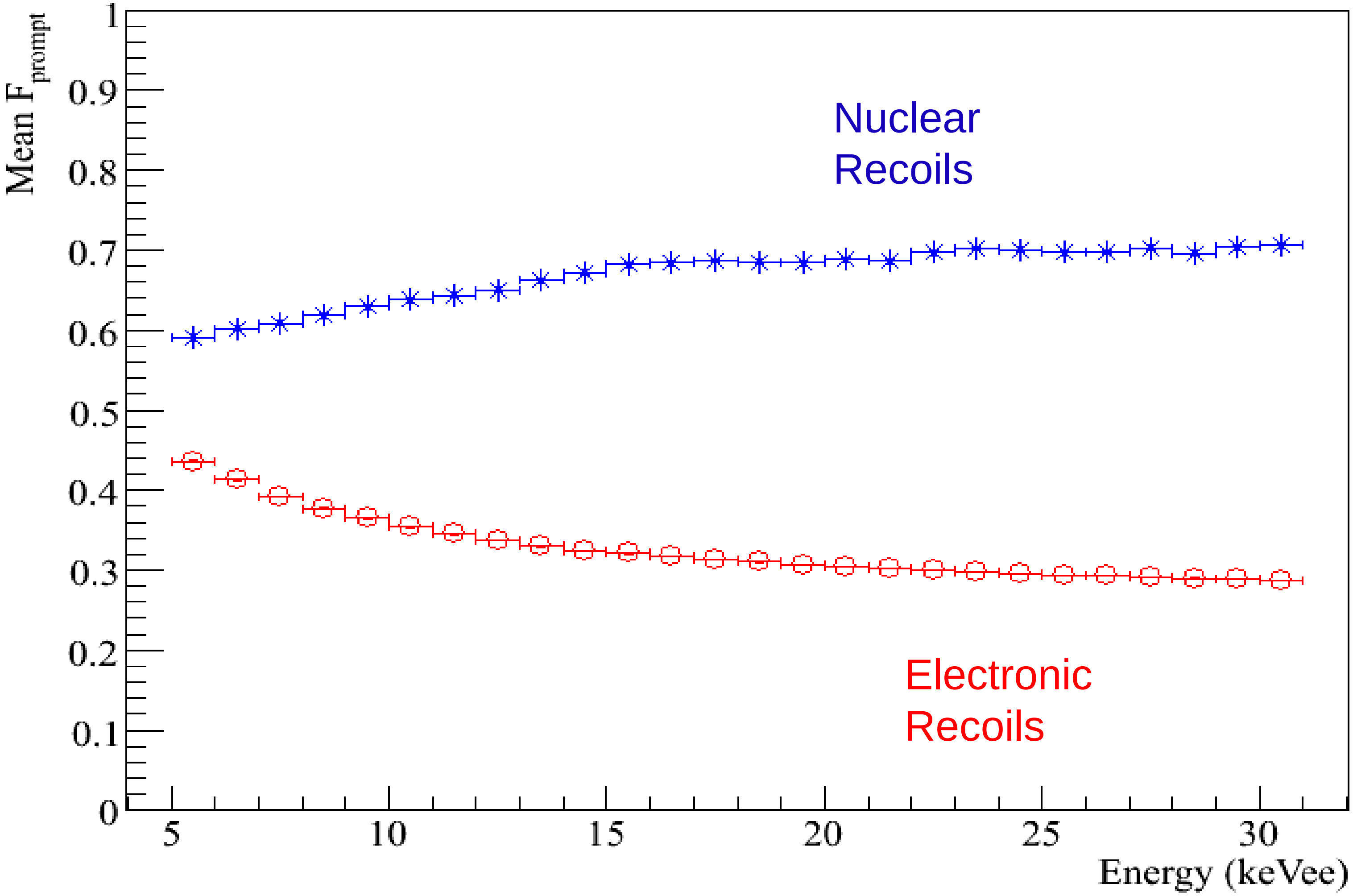


Time Dependence of Liquid Argon Scintillation



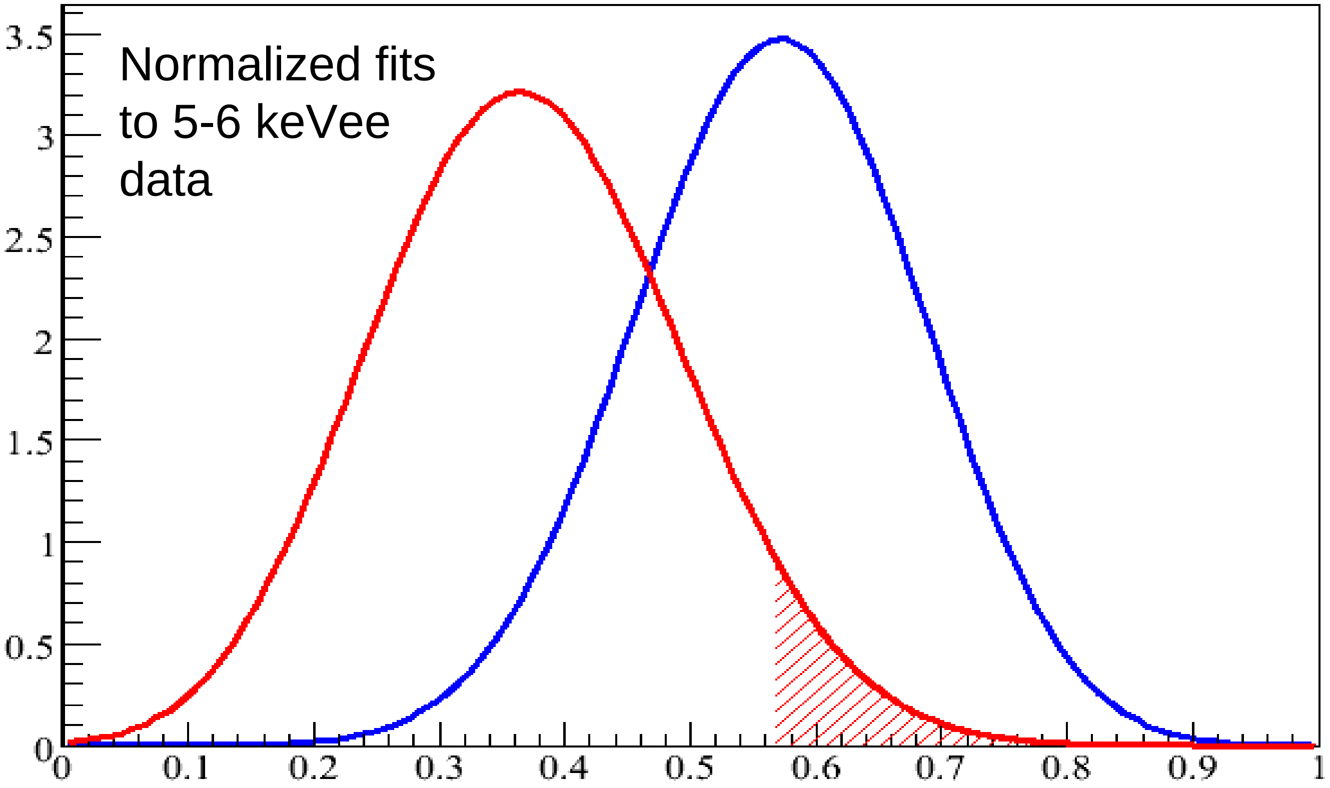

WIMP Signal Region
Nuclear recoils
Electronic recoils
fPrompt
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
100
Energy (keVee)

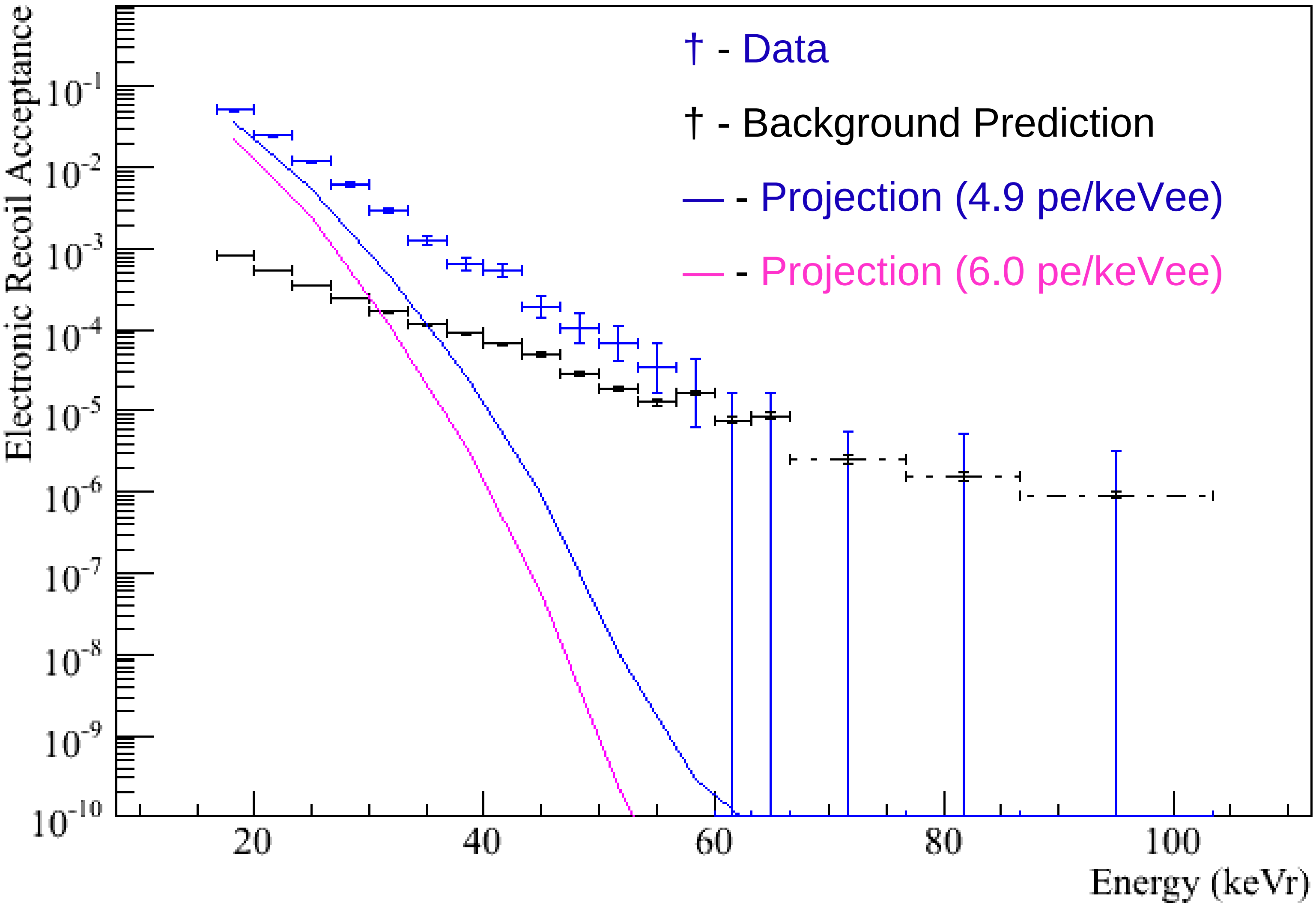
# Mean $F_{prompt}$ v. Energy



# Analytic Projections

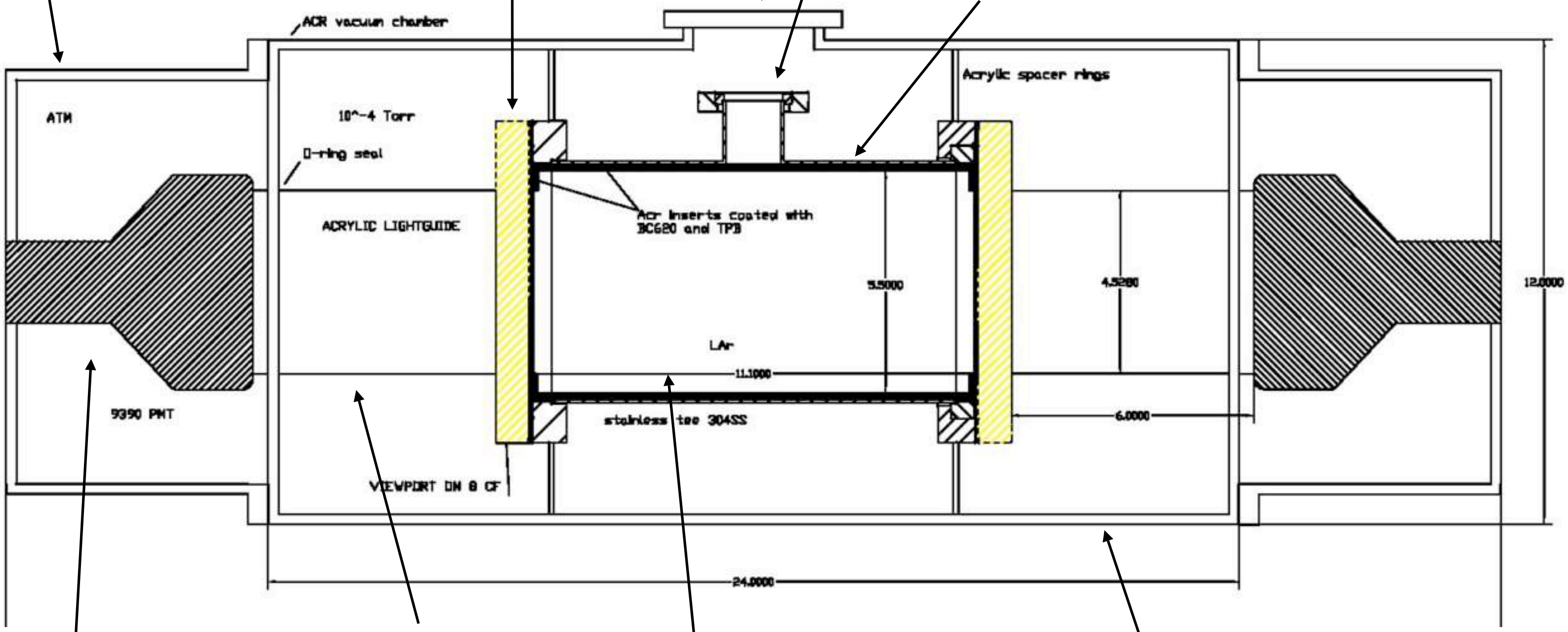
- Analytically integrate area underneath electronic recoil curve above 50% nuclear recoil acceptance level
- Scale fitted binomial widths linearly with light yield, relative to 4.9 pe/keV in microCLEAN





- Binning set to have relatively equal counts in the high energy background bins
- From 60-103 keVr, we have 0 “nuclear recoil events” – better than 1.25 x $10^{-6}$ rejection

# DEAP-1 design



Quartz windows

Neck connects to vacuum and
Gas/liquid lines

poly PMT supports

11” x 6” (8” CF) tee

6” acrylic guide

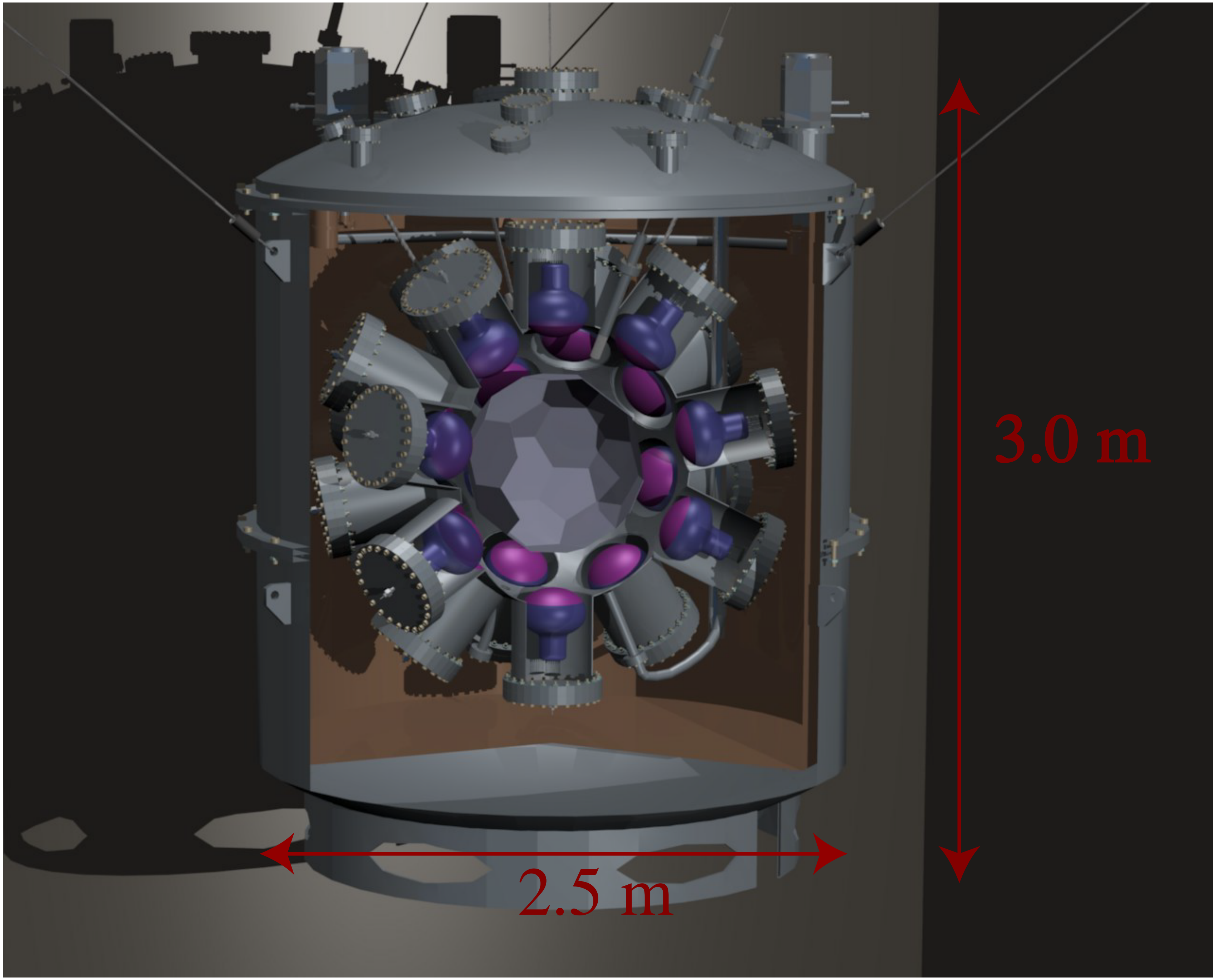
ET 9390 PMT 5”

Acrylic vacuum chamber

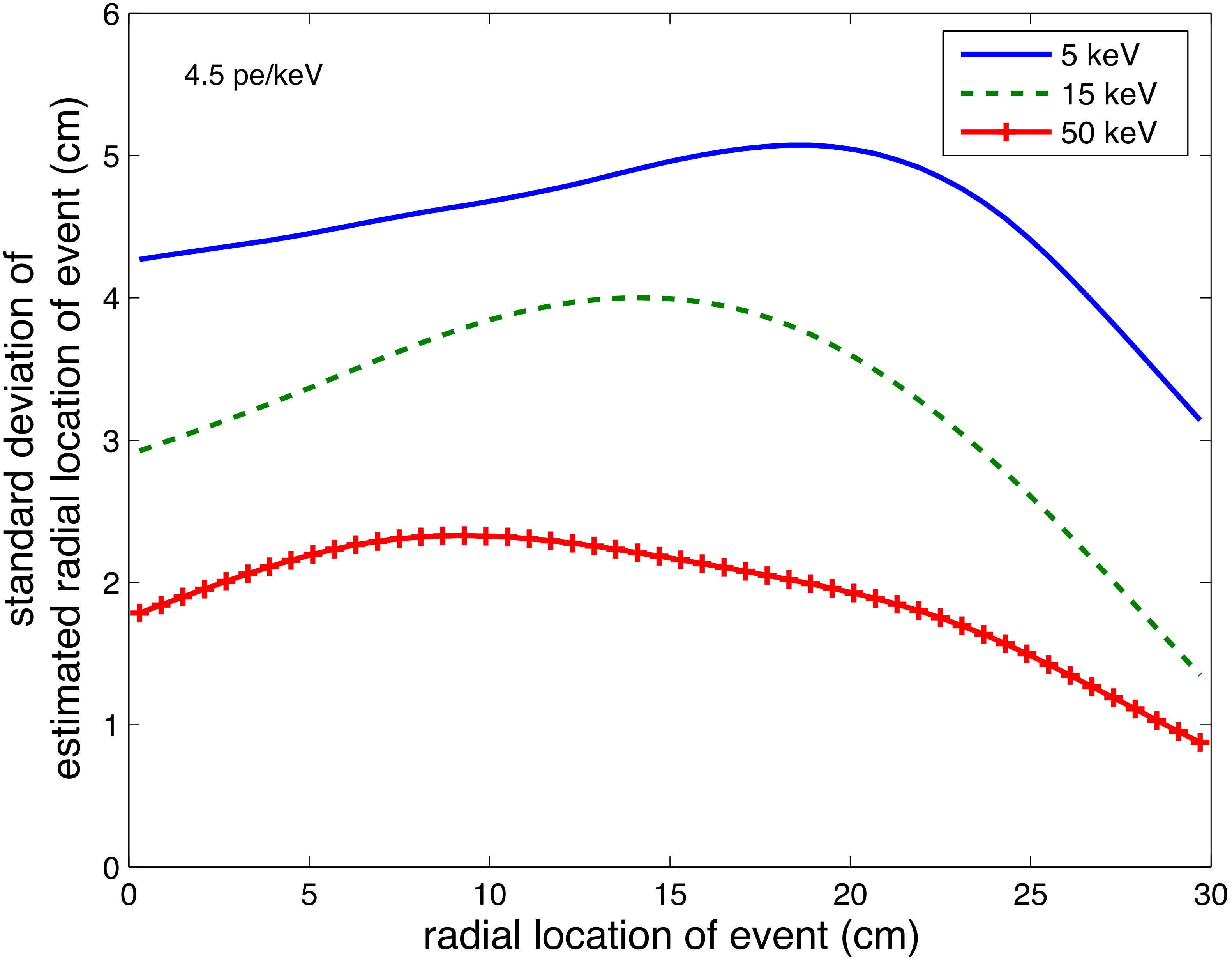
inner surface 97% diffuse reflector,
Covered with TPB wavelength shifter

# Mini-CLEAN 360

Fiducial (total) mass: ~100 (~360) kg of LAr or LNe.   Expected signal yield > 6 pe/keV



# Projected position resolution in mini-CLEAN
(Monte Carlo + Maximum Likelihood)



Dan McKinsey, Yale University

# Neutron Background Study for LAr-Mini-CLEAN

Mei & Hime

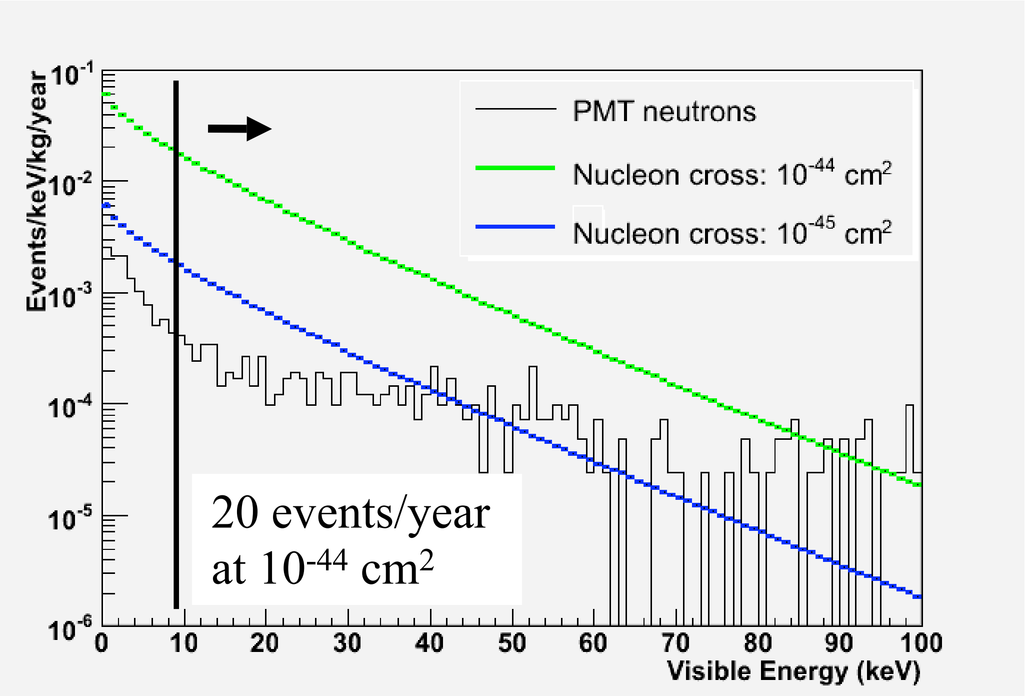
| **Component** | **Material** | **U/Th** | **Yield (n / yr)** | **Yield in Target (n / kg /yr)** | **Yield in ROI (n / kg /yr)** | **Yield in ROI* (n / kg /yr)** |
|---|---|---|---|---|---|---|
| **Fiducial Sphere** | **15 kg Quartz** | **3 ppb** | **19** | **0.090** | **0.047** | **0.0042** |
| | **5 kg SS** | **3 ppb** | **4** | **0.021** | **0.005** | **0.0006** |
| **PMT Sphere** | **20 kg $SiO_2$** | **30 ppb** | **256** | **0.020** | **0.011** | **0.0023** |
| | **4 kg $B_2O_3$** | **30 ppb** | **2304** | **0.340** | **0.100** | **0.0238** |
| | **85 kg SS** | **3 ppb** | **68** | **0.010** | **0.003** | **0.0006** |
| **Outer Cryostat** | **125 kg SS** | **3 ppb** | **100** | **0.020** | **0.003** | **0.0008** |
| | | | | | | |
| **Total** | | | **2751** | **0.510** | **0.169** | **0.032** |

**$R_f \sim 26$ cm for $M_f \sim 100$ kg**

**$R_{PMT} \sim 38$ cm**

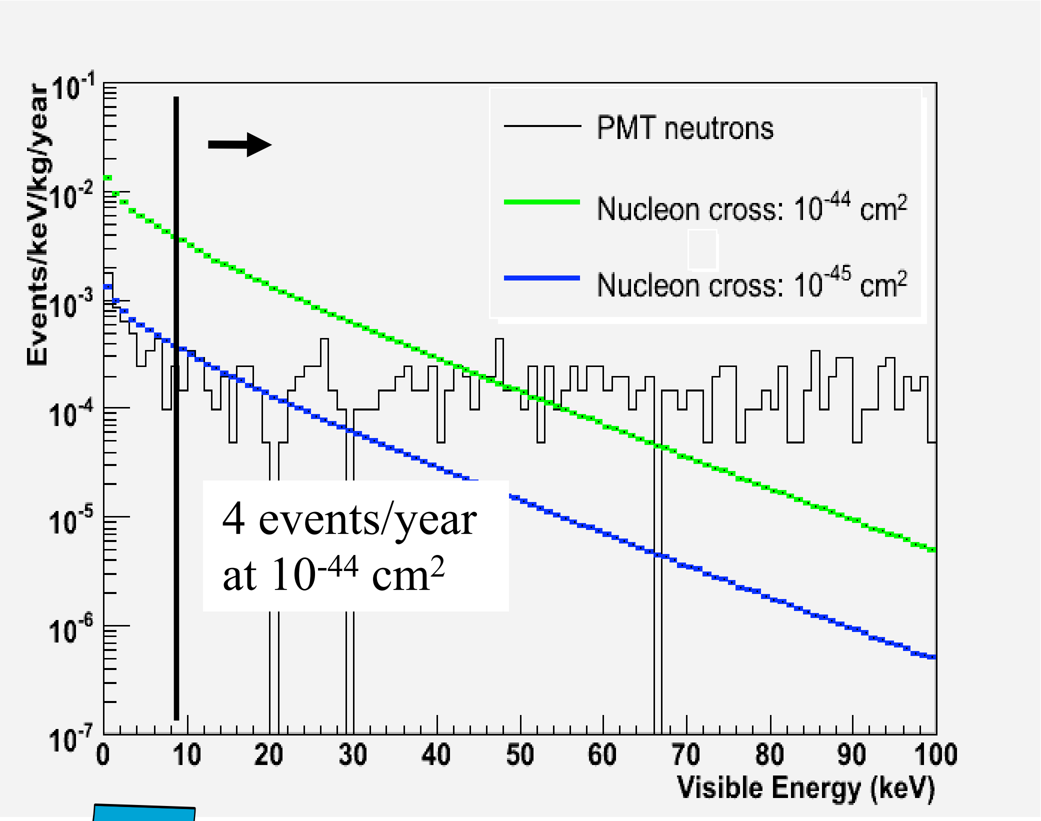
**$R_C \sim 46$ cm**

100kg Mini-CLEAN-LAr



20 events/year at $10^{-44}$ cm$^2$

100kg Mini-CLEAN-LNe



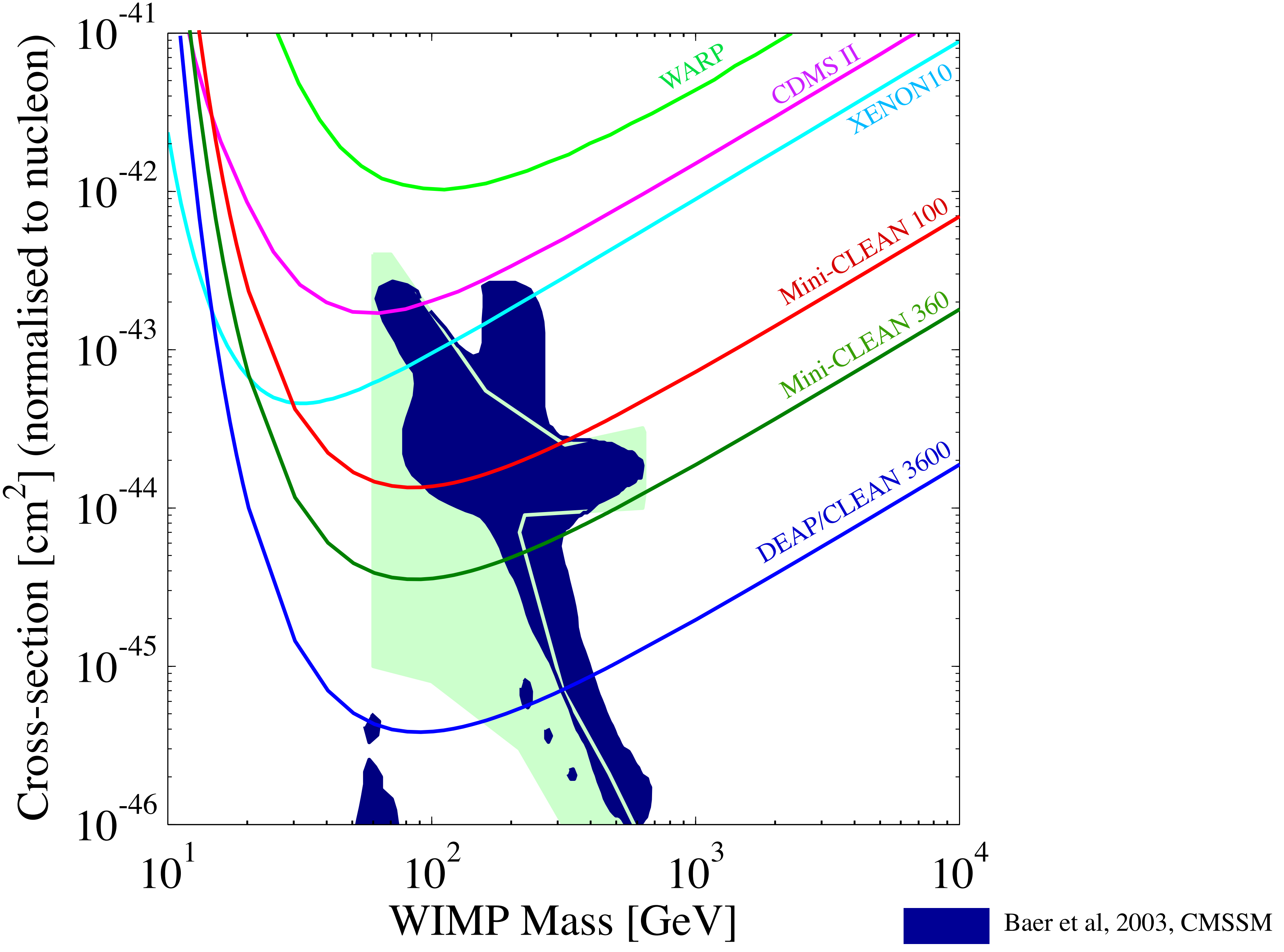
4 events/year at $10^{-44}$ cm$^2$

Exchange Target in Identical Detector to "Exercise" Signal v.s. BGND

**assuming a 100 GeV WIMP**

$$\left\{ \begin{array}{c} S_{Ar} \sim 5 \text{ x } S_{Ne} \\ B_{Ar} \sim B_{Ne} \end{array} \right\}$$

**& similar energy threshold**



http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini

From the Dark Matter Scientific Assessment Group (DMSAG) report:

Recommendation 4: Noble Liquid Detectors

We recommend that the R&D required for the next stage of technology development for noble liquid detectors be strongly supported. In some cases, this means that demonstration projects need to be completed, while in others it means that the next-scale detector should be constructed. For the short-term program, the emphasis should be on developing detectors using larger target masses with decreased backgrounds to reach ever-greater sensitivity.

To capitalize on recent impressive results, the sub-panel recommends that a significant fraction of the total funding resources be devoted to noble liquid target experiments, successors of the present WARP, XENON10, and ZEPLIN-II prototypes. However, given the tight funding situation and the large range of new and promising ideas, the sub-panel also believes that it cannot support duplicate development programs in the U.S. using the same target and technique. Therefore:

a) The sub-panel supports the development of one two-phase xenon-based detector at the 100 kg scale and above.

b) The sub-panel supports the development of detectors using liquid argon and/or liquid neon technology. WARP and miniCLEAN/DEAP represent two quite different technologies in their application to liquid argon. Both of these techniques should be explored to discover which has greater potential.

## DMSAG Recommendation 8: Priorities

Following on the above recommendations, if the comprehensive program we have described above is not able to be fully funded, then we recommend that the funding priorities during the next few years be allocated as follows. In establishing these priorities, we have considered both the experimental evidence of promise in a particular technique and our estimation of its readiness for producing significant experimental results. In addition, all else being equal, predominantly US efforts are given somewhat higher priority.

1. Equal priorities between (A) and (B):
    - A) Continuing the on-going CDMS and ADMX experiments and the initial construction of SuperCDMS in Soudan with two super-towers.
    - B) Funding the expansion of the noble liquids with priorities i), ii) and iii):
        - i) The expansion of the liquid Xenon experimental efforts to their next level.
        - ii) The U.S. participation in the WARP detector development.
        - iii) The next stage of the CLEAN Argon/Neon detector development.

(Note on funding guidance: As we have noted elsewhere, we do not yet know which technique is the best route to the ton and larger scale. Consequently, there is a need to keep the three noble liquid techniques moving in parallel to that goal. As progress is achieved in each project, the levels of relative funding may need to change, independent of present priorities, in order to make fair evaluation of potential.)

2. The development of superheated liquid detectors and detectors capable of determining WIMP direction. Although these ideas have great promise, they still have significant R&D questions remaining to be answered.

# The McKinsey group at Yale

2 research scientists, 3 postdocs, 5 graduate students, 3 undergraduate students

XENON10, LUX: Kaixuan Ni, Angel Manzur, Louis Kastens, Susie Bedikian, Taritree Wongjirad
Mini-CLEAN: James Nikkel, Hugh Lippincott, Danny Hakim
He molecules in superfluid helium: Sidney Cahn, Alessandro Curioni, David Wright, Wade Rellergert, Jordan Hanson

# Summary

1) Noble liquids (LXe, LAr, LNe) are promising for WIMP direct detection experiments, primarily because of their scalability.

2) The XENON10 experiment has recently performed the most sensitive WIMP search to date, with a 90% C.L. limit of 8.8E-44 cm^2 at 100 GeV.

3) Future two-phase experiments with liquid Xe (XENON100, LUX) are likely to make rapid advances in testing even lower WIMP-nucleon cross-sections.

4) Dark matter experiments based on single-phase LAr and LNe are highly scalable, have been endorsed by DMSAG, and will enable sensitive WIMP detection with alternate materials.

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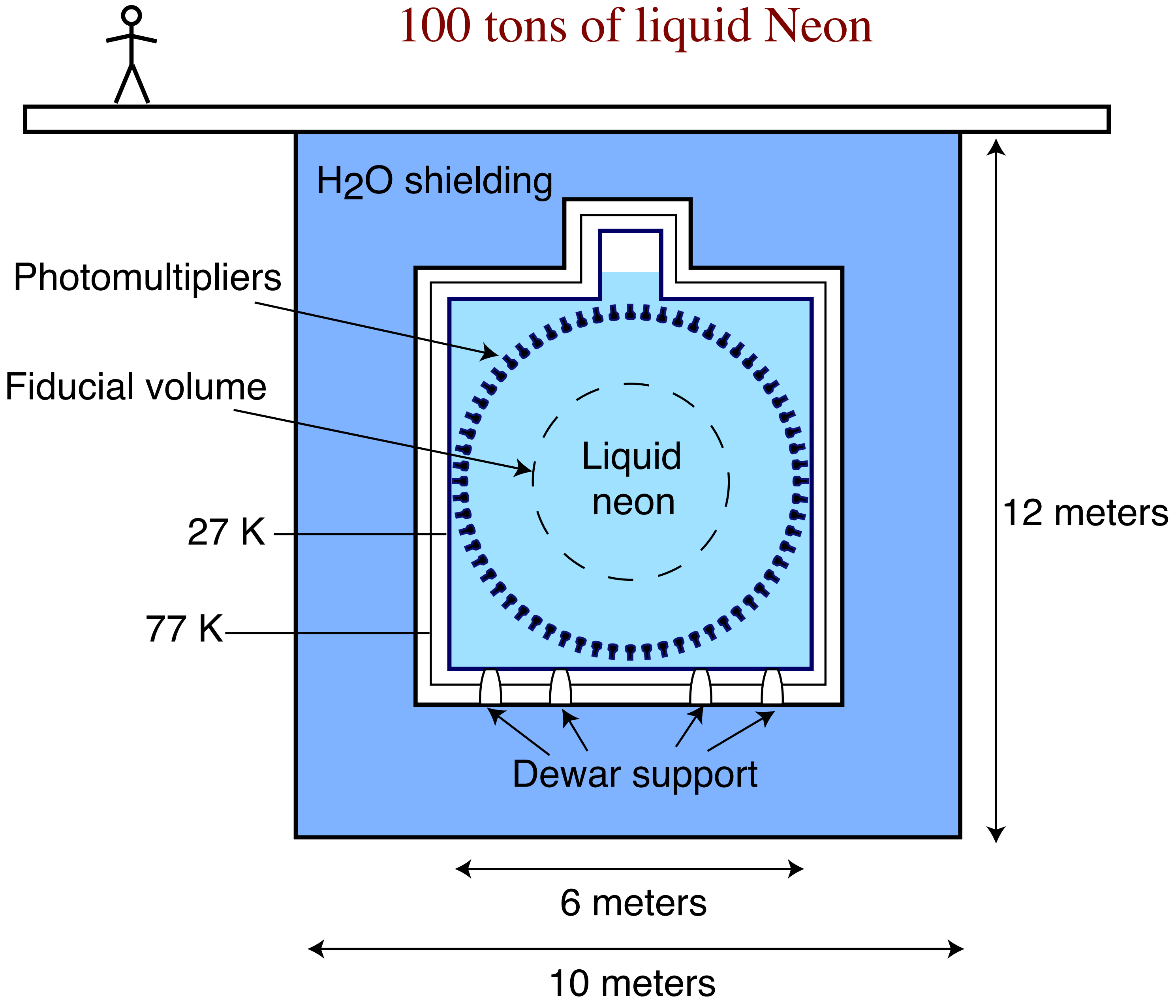
# CLEAN

## 100 tons of liquid Neon



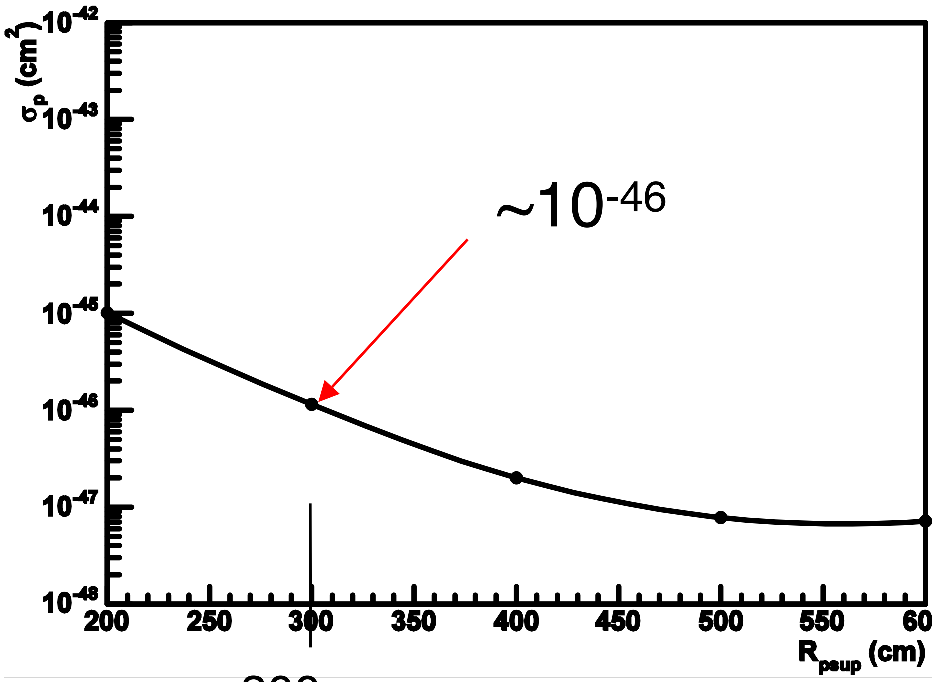
DM and J. M. Doyle, J. Low Temp. Phys. 118, 153 (2000)
DM and K. J. Coakley, Astropart. Phys. 22, 355 (2005)

Requires > 6000 m.w.e.

# Monte Carlo simulation: M. Boulay, A. Hime, J. Lidgard, nucl-ex/0410025

Simulations performed with GEANT4
15,000 photons/MeV
60 cm Rayleigh scattering length
75% PMT coverage, 15% QE
100% photon-to-photon wavelength shifter efficiency
Background dominated by (commercially available) PMT glass: 30 ppb U/Th, 60 ppm K

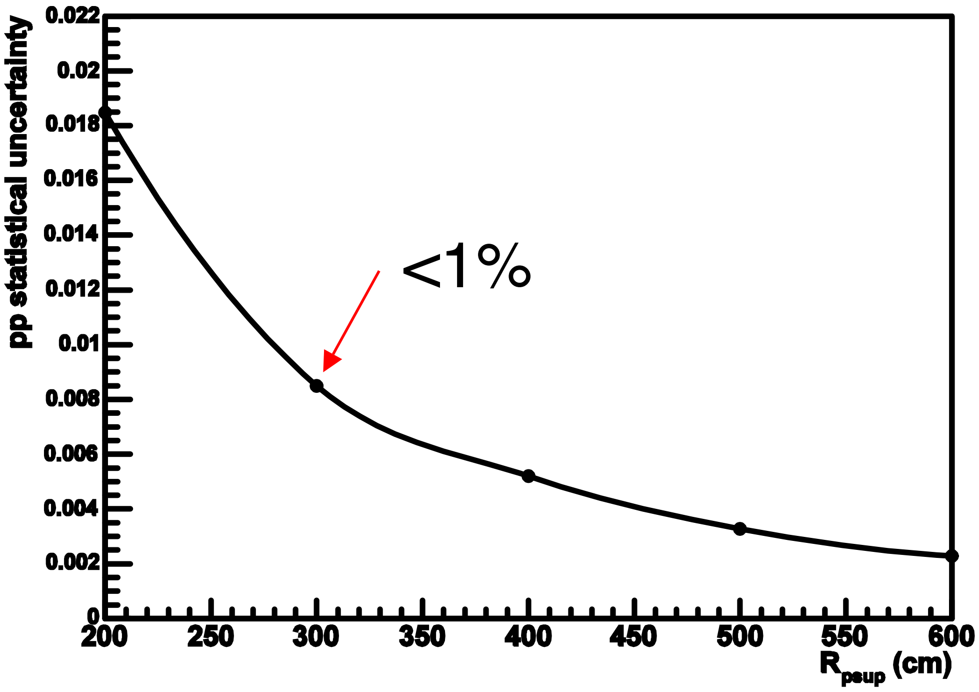
WIMP sensitivity



~$10^{-46}$

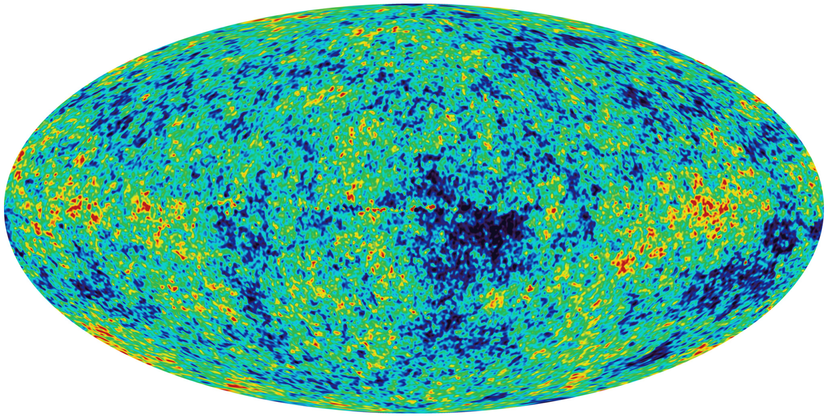
300 cm

pp statistical uncertainty



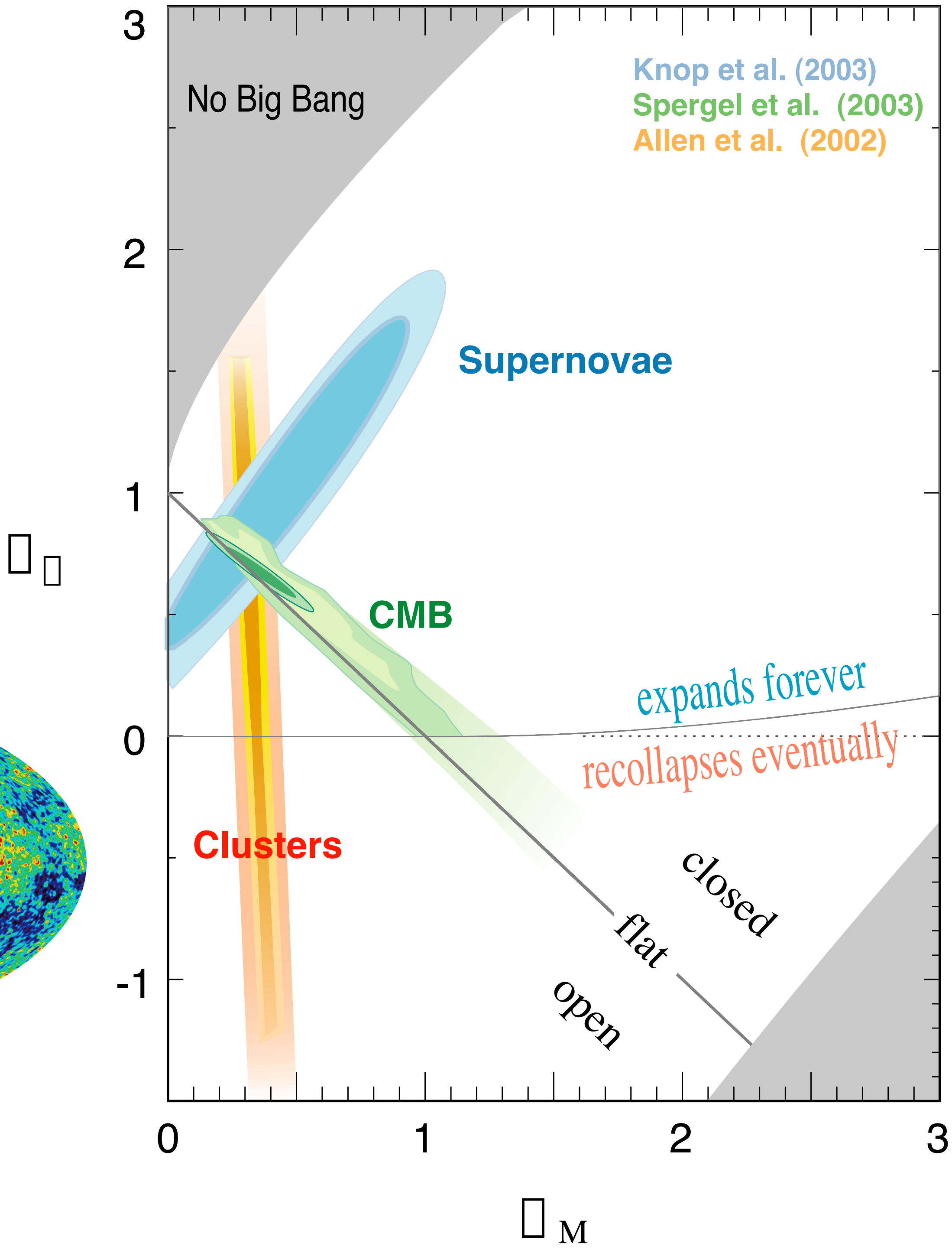
<1%

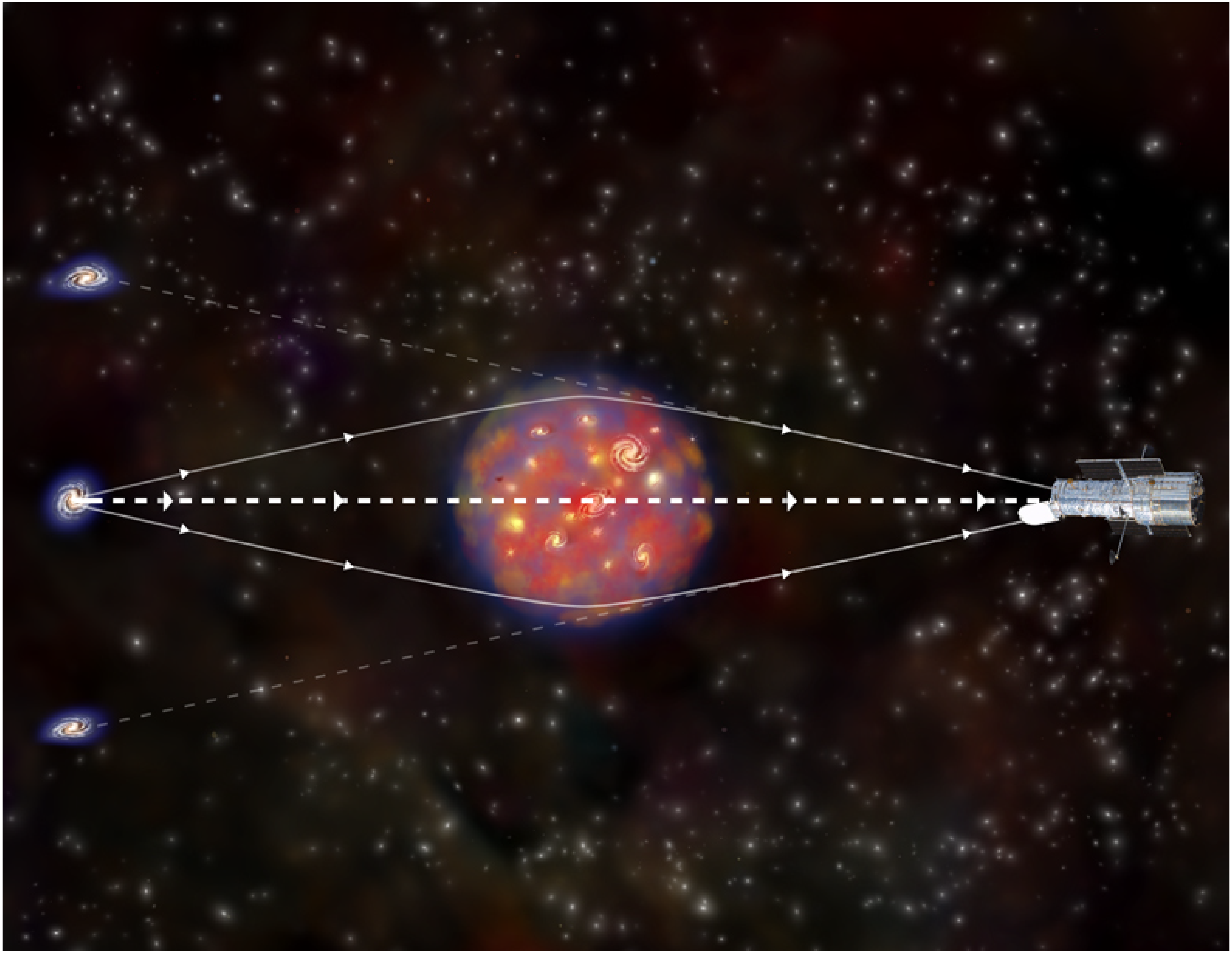
Colley, Tyson, and Turner



WMAP collaboration

Supernova Cosmology Project

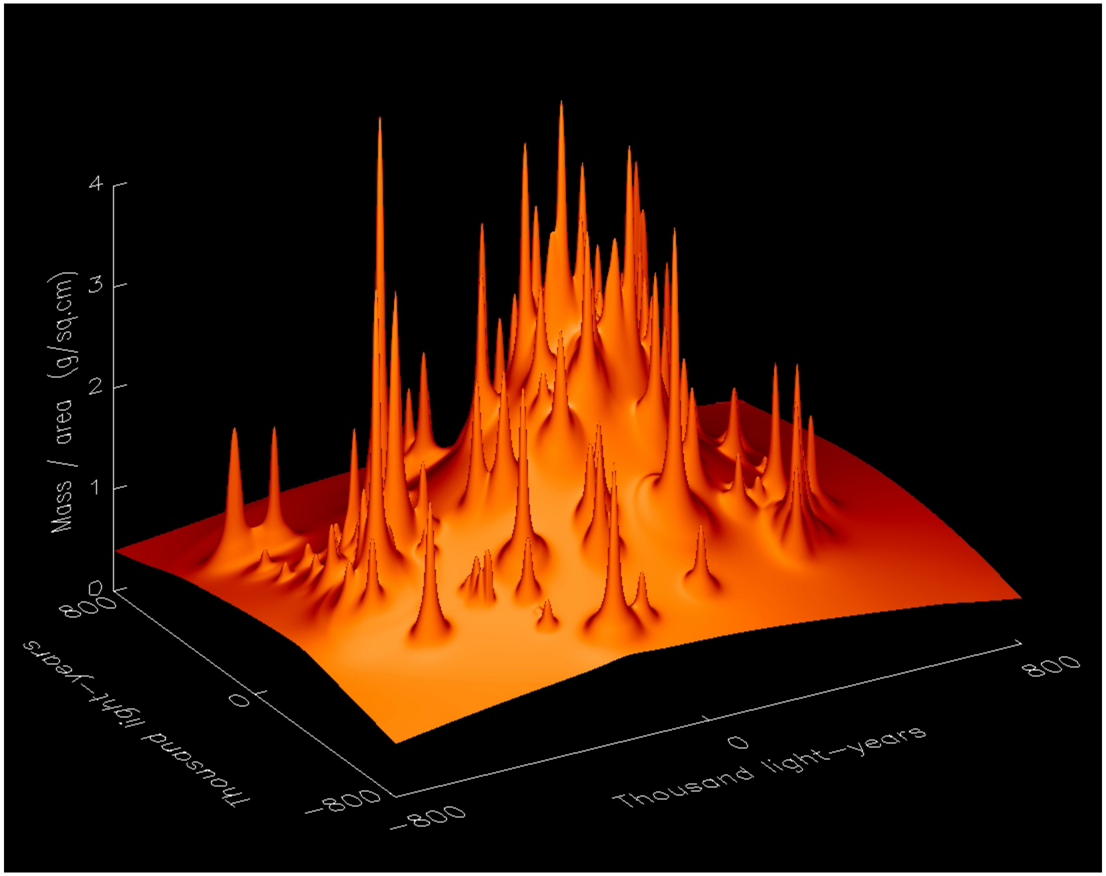




*NASA/CXC/M.Weiss*

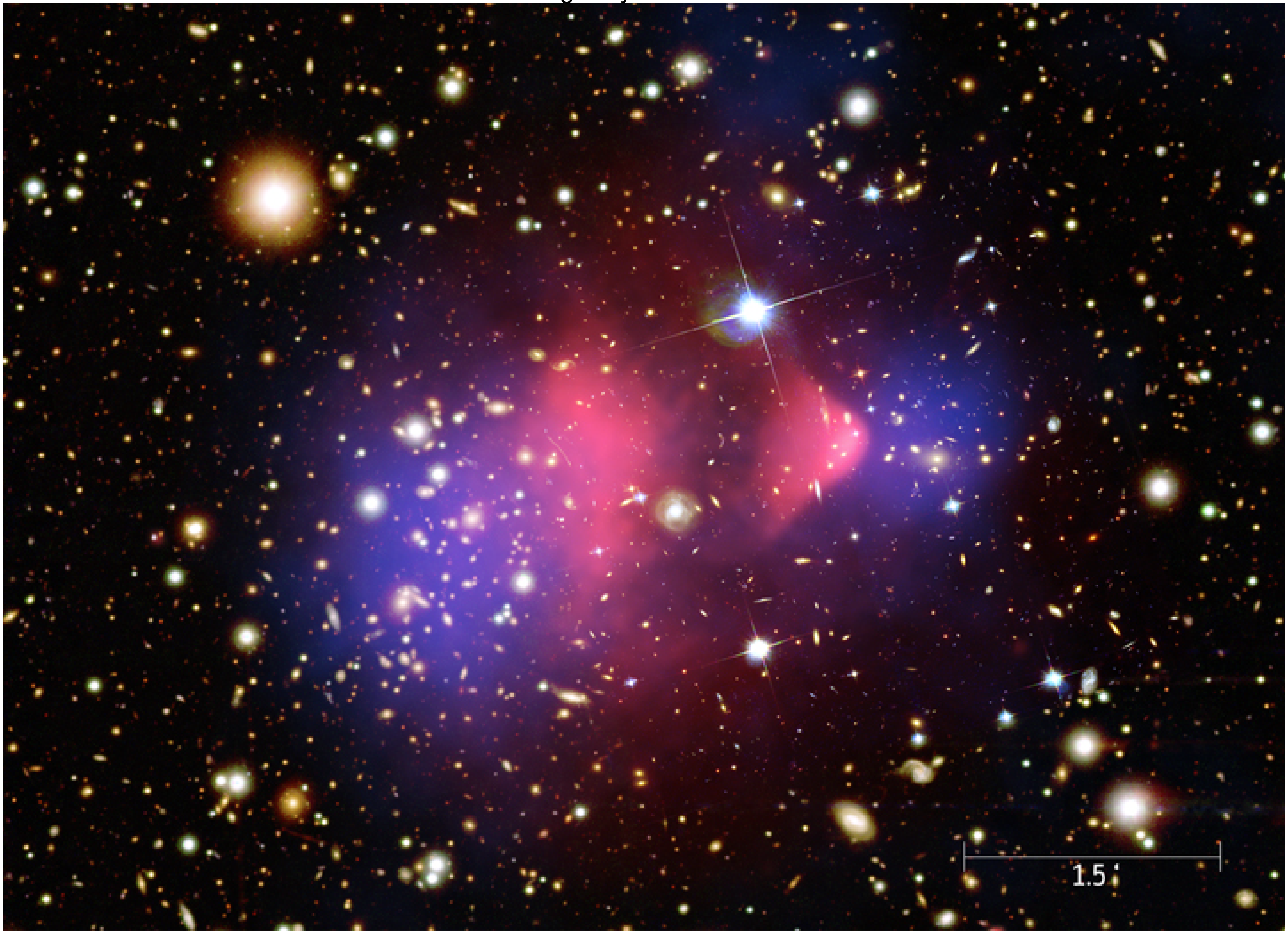
# Imaging of dark matter halos through analysis of gravitational lensing

The foreground cluster of galaxies gravitationally lenses the blue background galaxy into multiple images.
W.N. Colley, J.A. Tyson and E. Turner.



A parametric inversion for the strength and shape of the lens shows a smooth background component not accounted for by the mass of the luminous objects.
J.A. Tyson, G.P. Kochanski and I.P. Dell'Antonio,
Ap. J. Lett. 498, 107 (1998).

The galaxy cluster 1E 0657-56



*X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.*