New results from the XENON10 direct dark matter search

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SUSY 2007, Karlsruhe

Searching for WIMPs

Accelerators: Look for dark matter candidates at the LHC (lifetime limit < 1 ms)

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

Direct Searches:

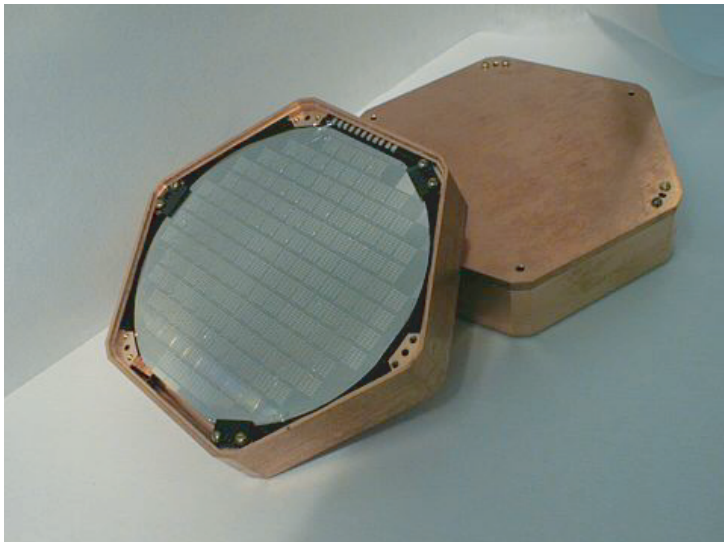
R = N □ □ <v>

From <v> = 220 km/s, get order of 10 keV deposited per nuclear recoil event

Key technical challenges:

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

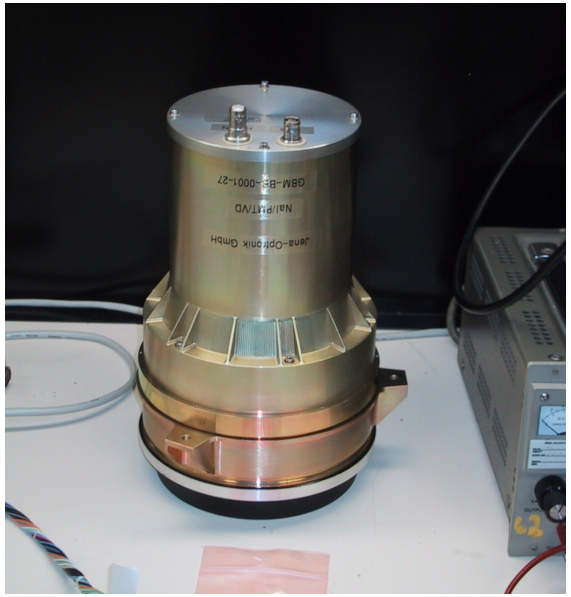
Detect heat, light, or ionization
(or some combination)



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

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

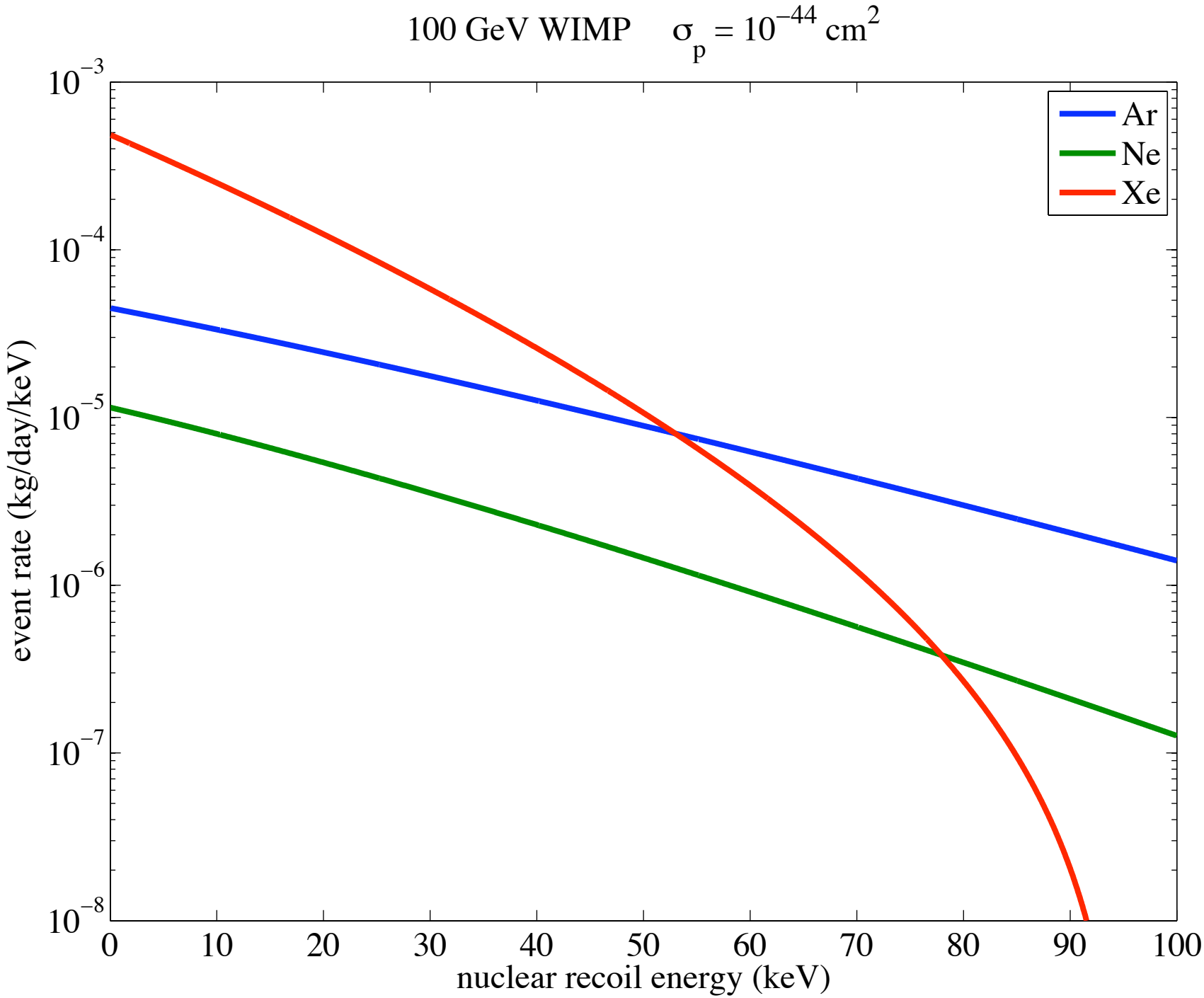
- noble liquids do not absorb their own scintillation
- 30,000 to 40,000 photons/MeV
- modest quenching factors for nuclear recoils

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


100 GeV WIMP $\sigma_p = 10^{-44}$ cm^2
Ar
Ne
Xe
event rate (kg/day/keV)
nuclear recoil energy (keV)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
10
20
30
40
50
60
70
80
90
100

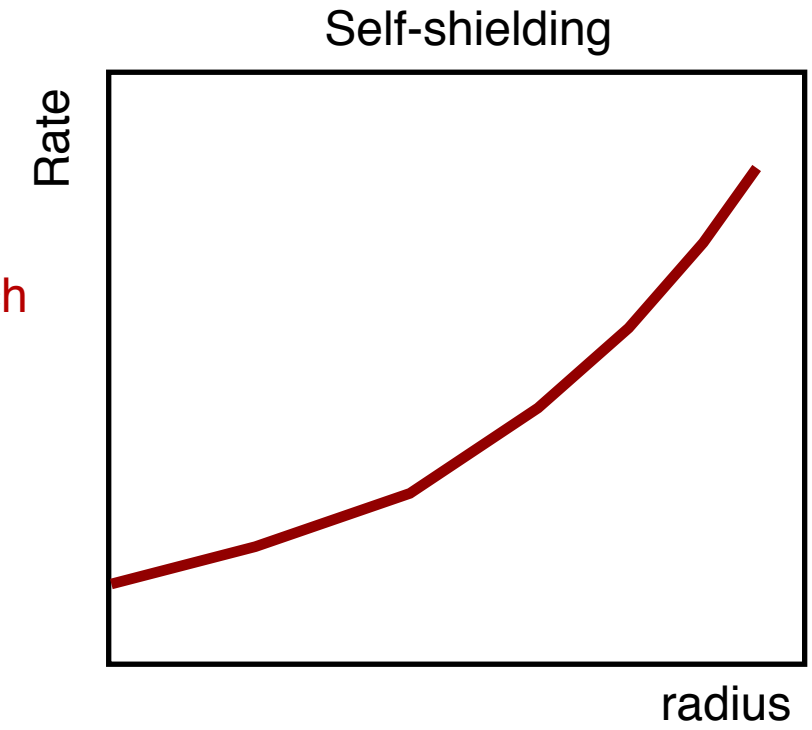
Strategies for Electronic Recoil Background Reduction in Scintillation Experiments

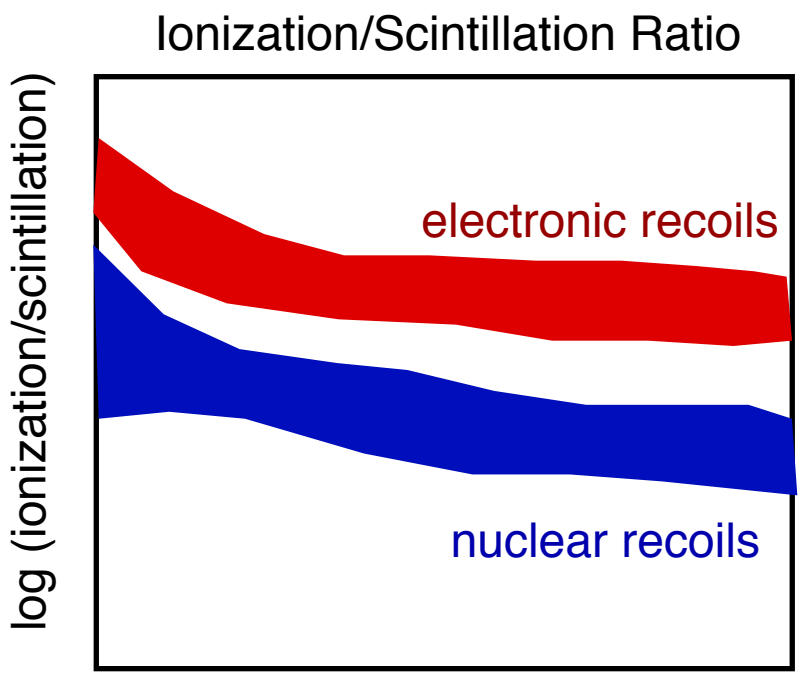
Require < 1 event in signal band during WIMP search

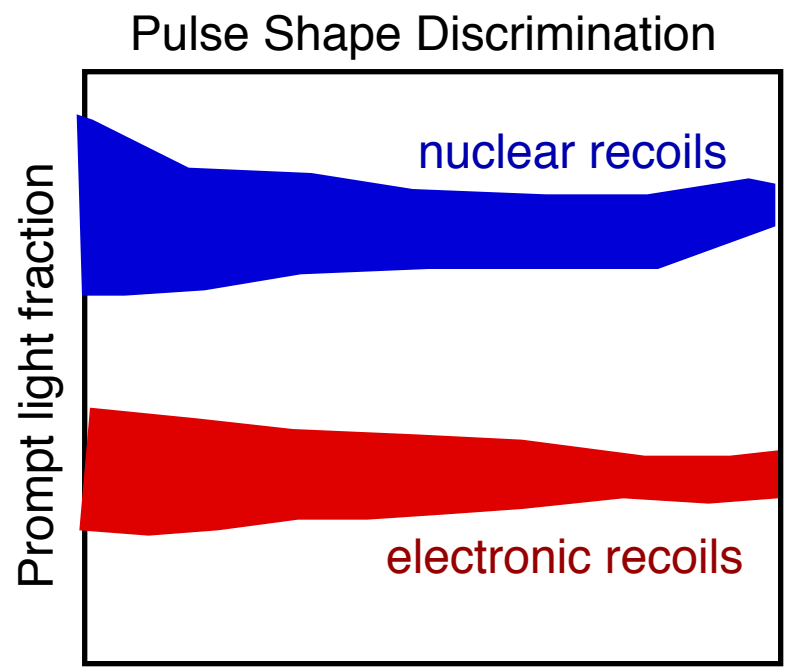
LXe: Self-shielding, Ionization/Scintillation ratio best

LAr: Pulse shape, Ionization/Scintillation ratio best

LNe: Pulse shape, Self-shielding best





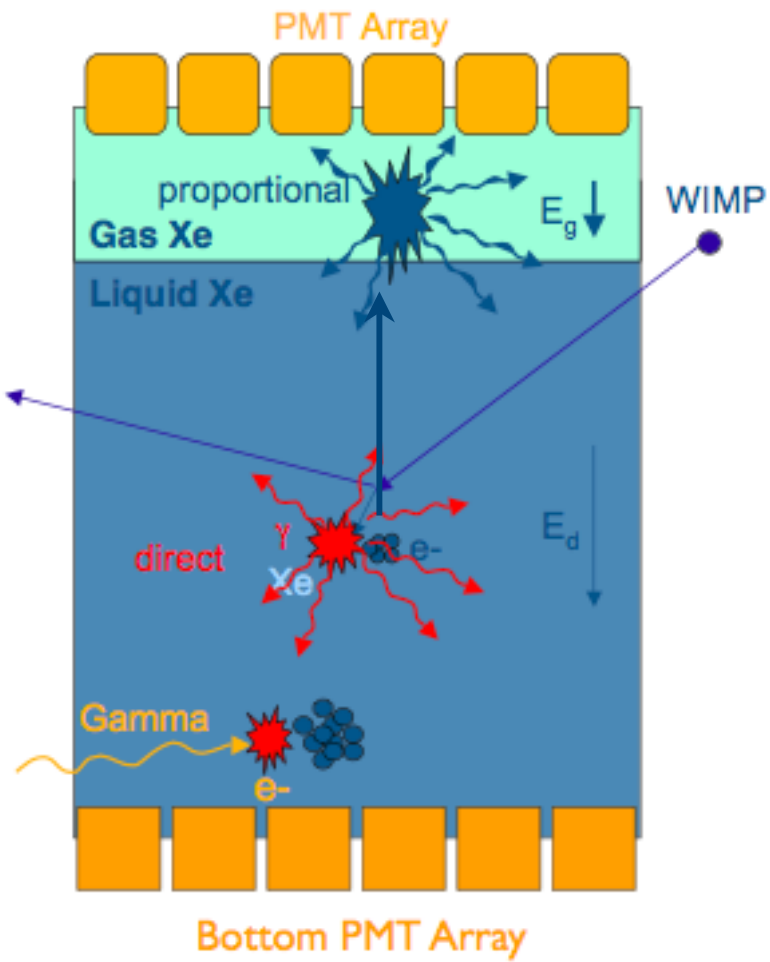


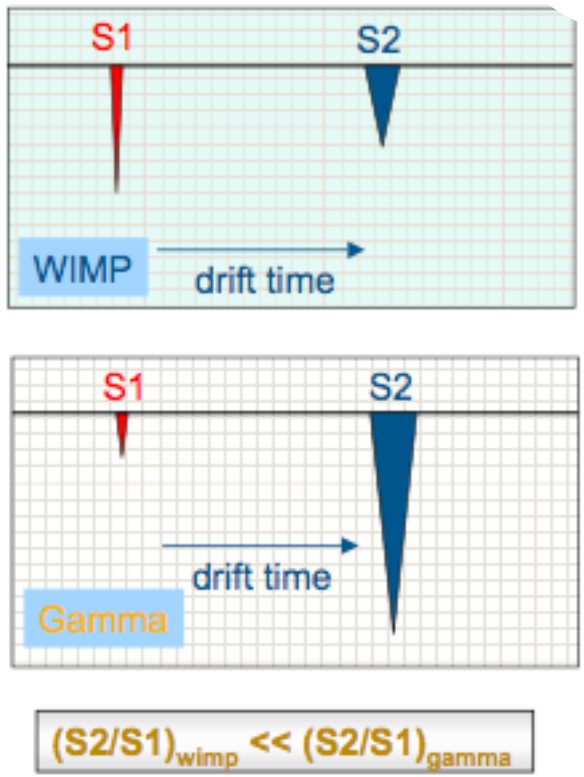
The XENON10 Collaboration

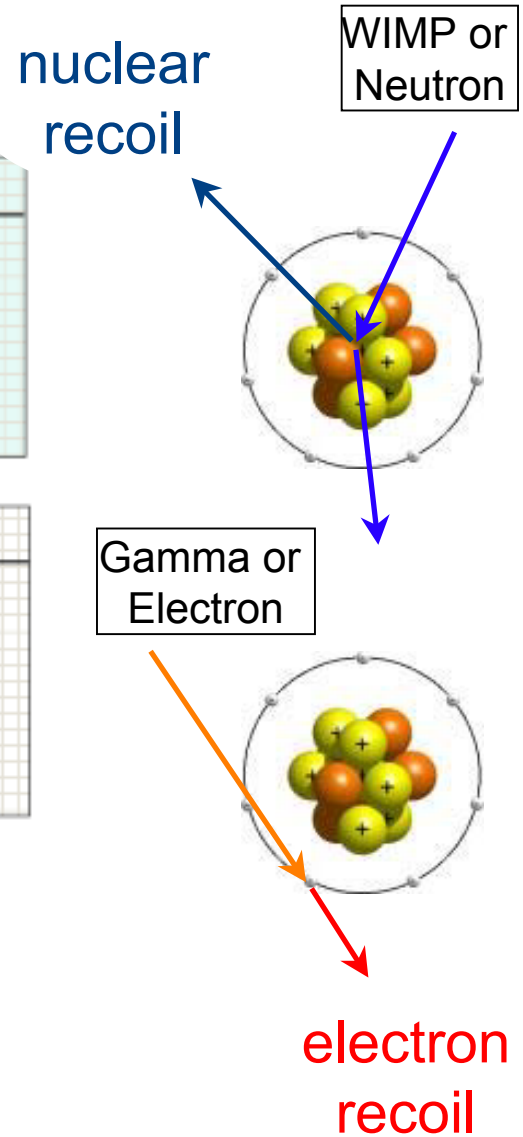
Columbia University Elena Aprile, Karl-Ludwig Giboni, Maria Elena Monzani, Guillaume Plante, Roberto Santorelli, and Masaki Yamashita
Brown University Richard Gaitskell, Simon Fiorucci, Peter Sorenson, and Luiz DeVivieiros
RWTH Aachen University Laura Baudis, Jesse Angle, Joerg Orboeck, Aaron Manalaysay, and Stephen Schulte
Lawrence Livermore National Laboratory Adam Bernstein, Chris Hagmann, Norm Madden, and Celeste Winant
Case Western Reserve University Tom Shutt, Peter Brusov, Eric Dahl, John Kwong, and Alex Bolozdynya
Rice University Uwe Oberlack, Roman Gomez, Christopher Olson, and Peter Shagin
Yale University Daniel McKinsey, Richard Hasty, Louis Kastens, Angel Manzur, and Kaixuan Ni
Coimbra University Jose Matias Lopes, Luis Coelho, Luis Fernandes, and Joaquin Santos

XENON10 is supported by the NSF and DOE

The XENON Detector: How It Works

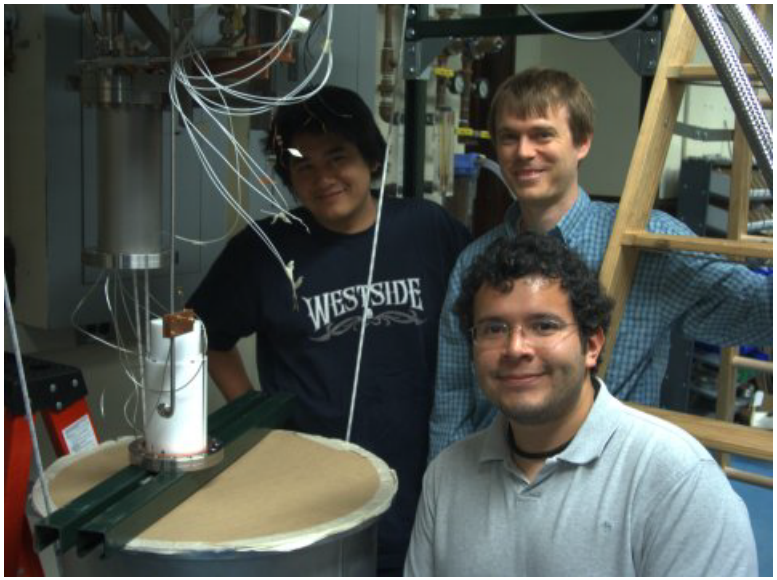




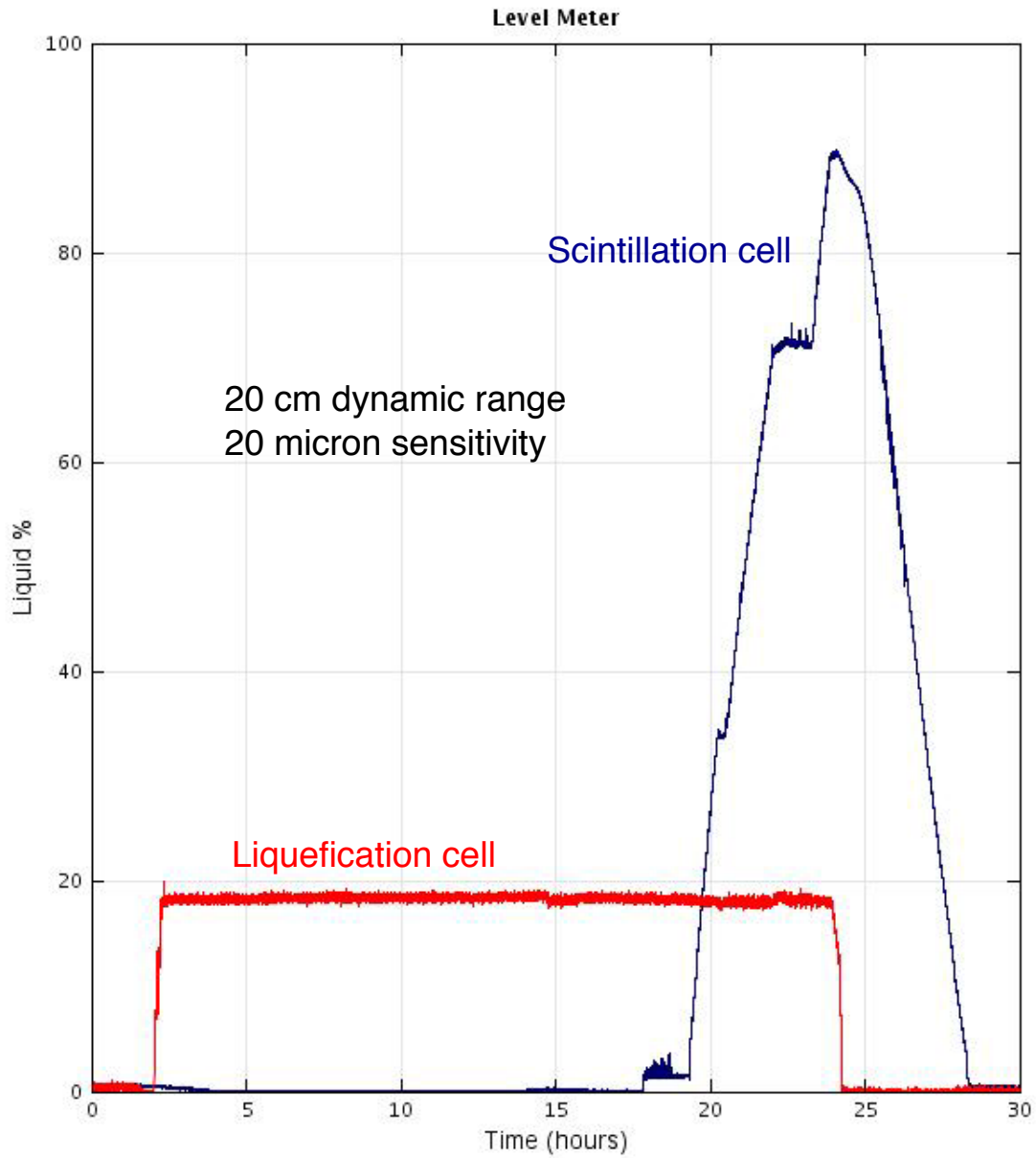


LXe cell at Yale

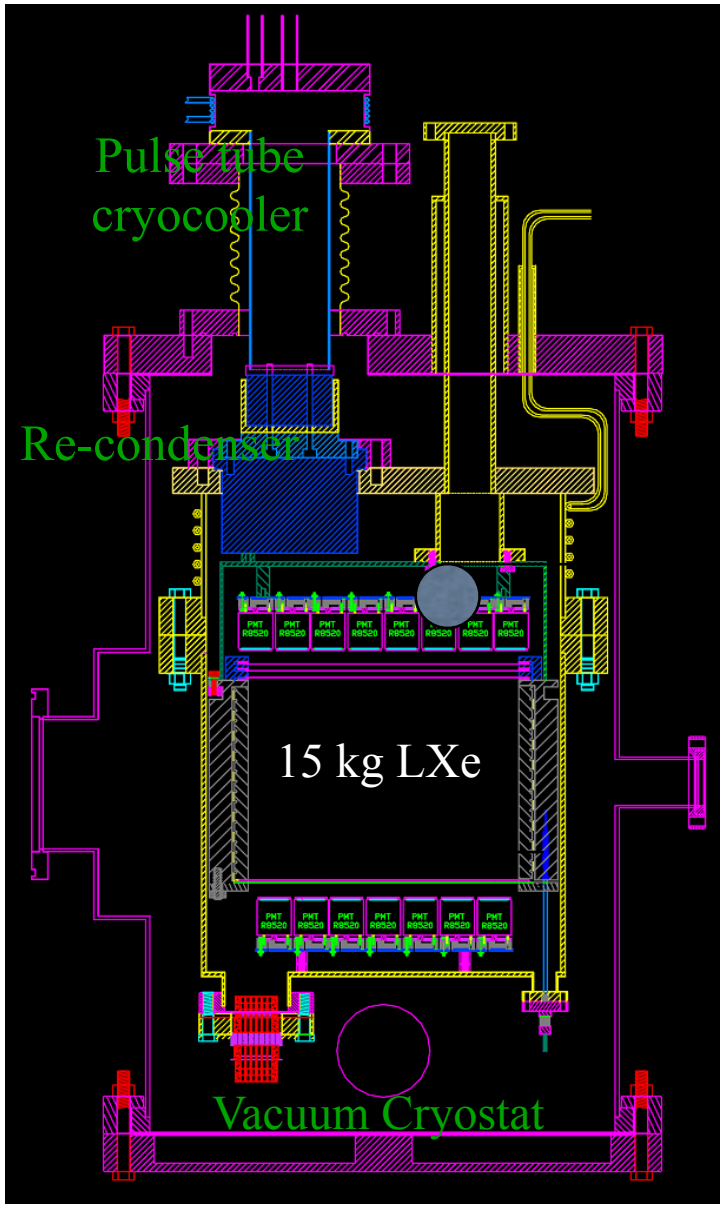
used for level meter development,
LXe scintillation for nuclear recoils,
PMT testing in LXe, GEM testing



LXe level meters

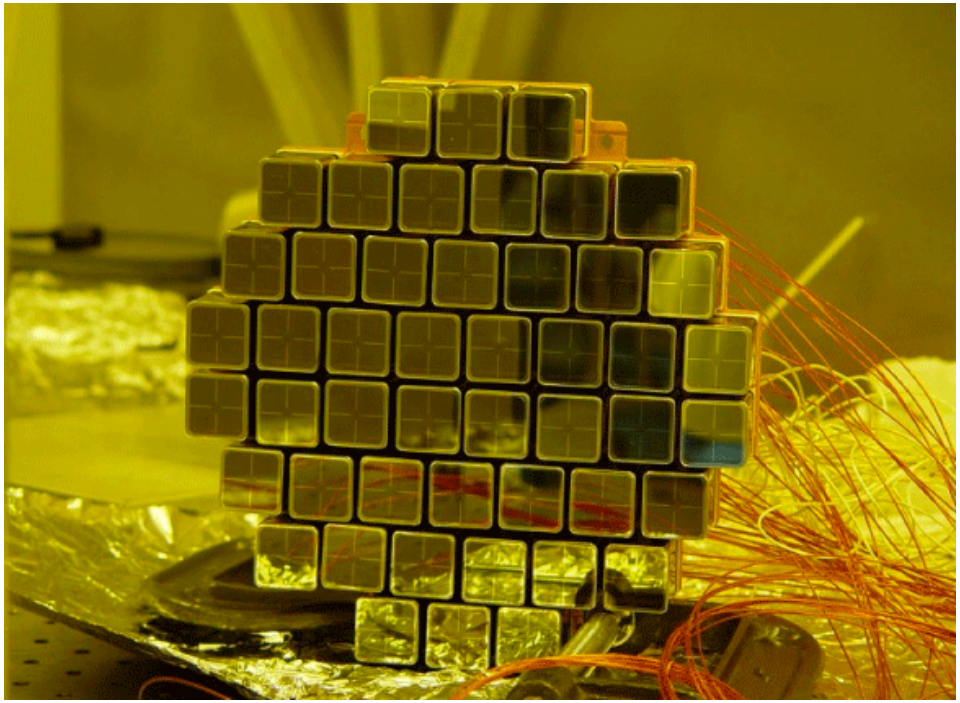


The XENON10 Detector

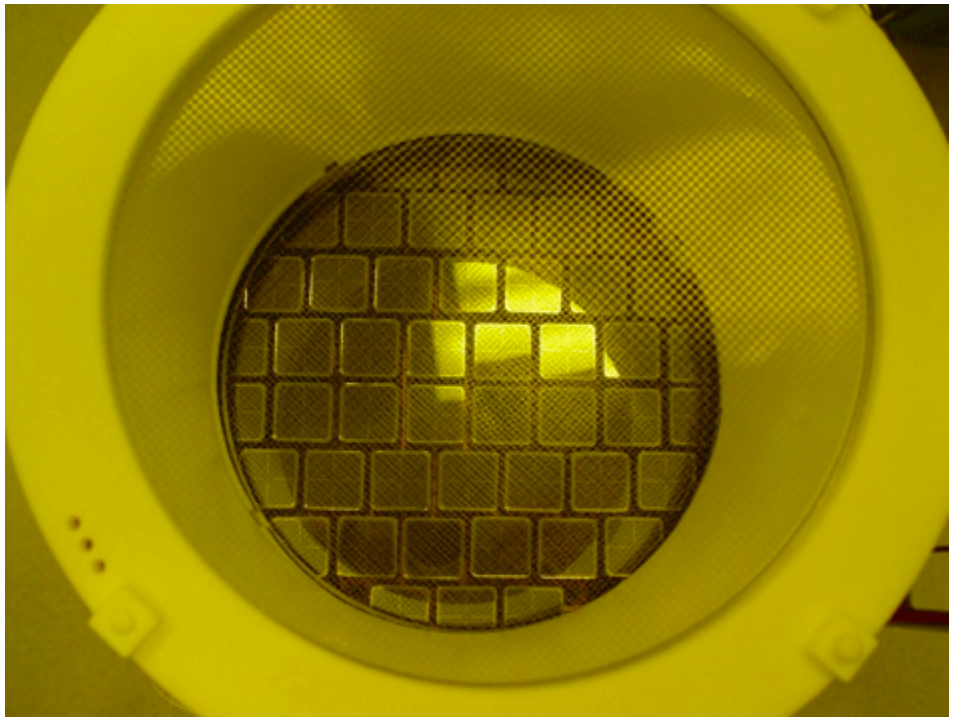


The XENON10 Photomultipliers

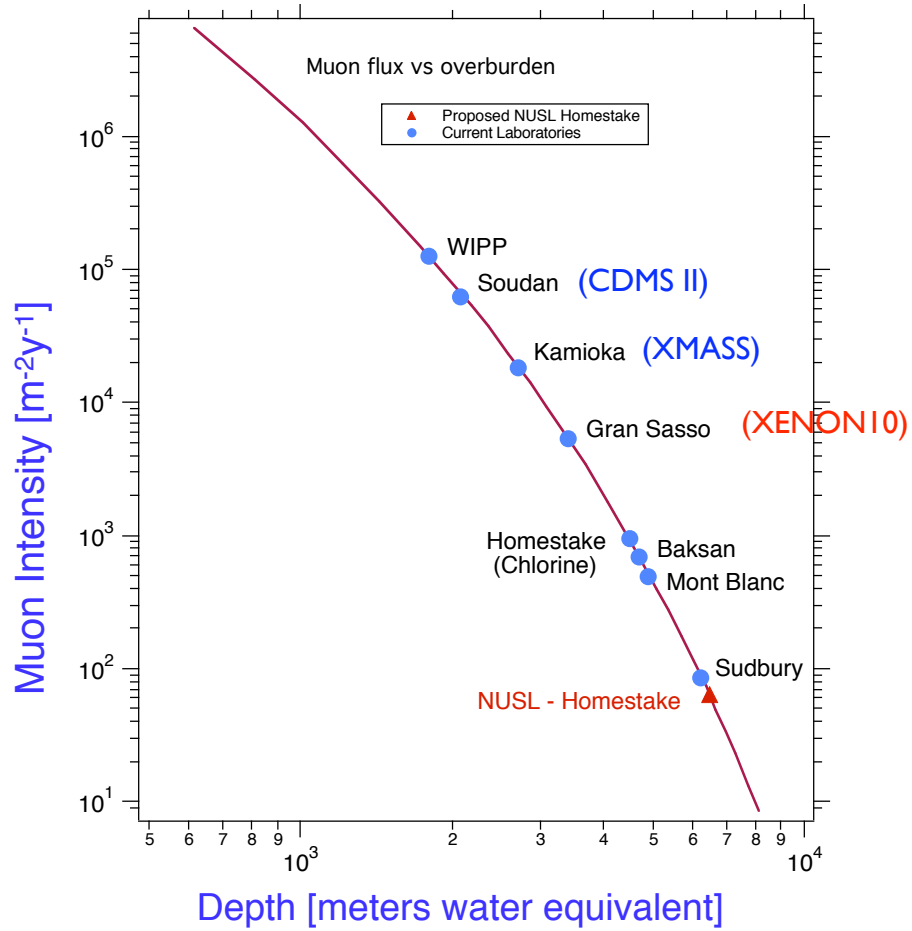
Hamamatsu 8520-06-AL 2.5 cm x 3.5 cm
Bialkali photocathode Rb-Cs-Sb
10 dynodes
Quartz window
U/Th/K/Co = 0.17/0.20/0.09/0.56 mBq/PMT
Quantum efficiency > 20% at 178 nm

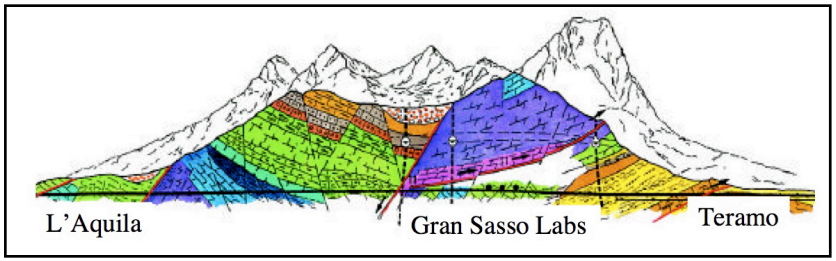


Angel Manzur (Yale) individually testing PMTs



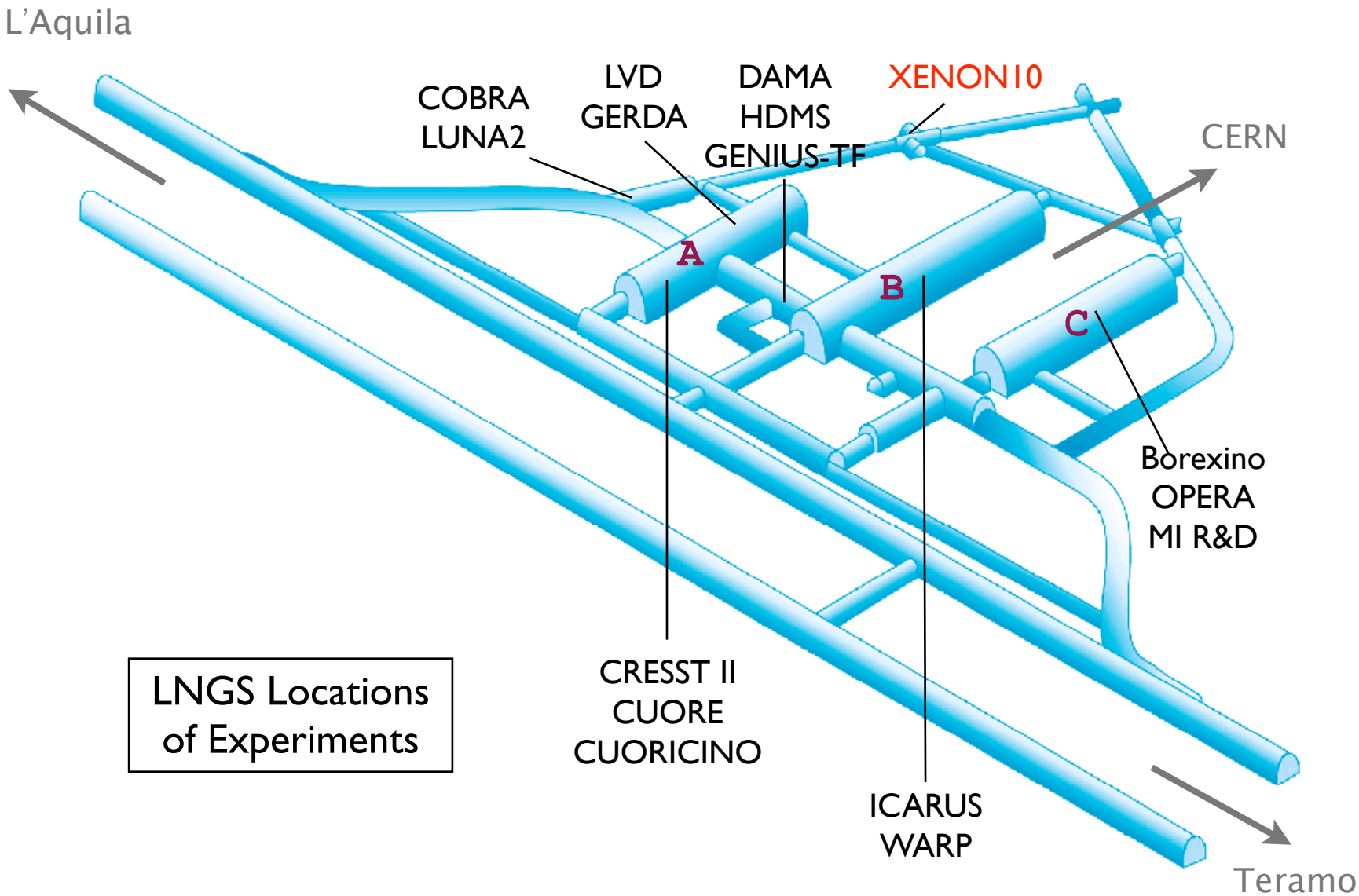
The INFN Gran Sasso National Lab (LNGS)





1400 m rock overburden (3500 mwe)

XENON10 @ LNGS



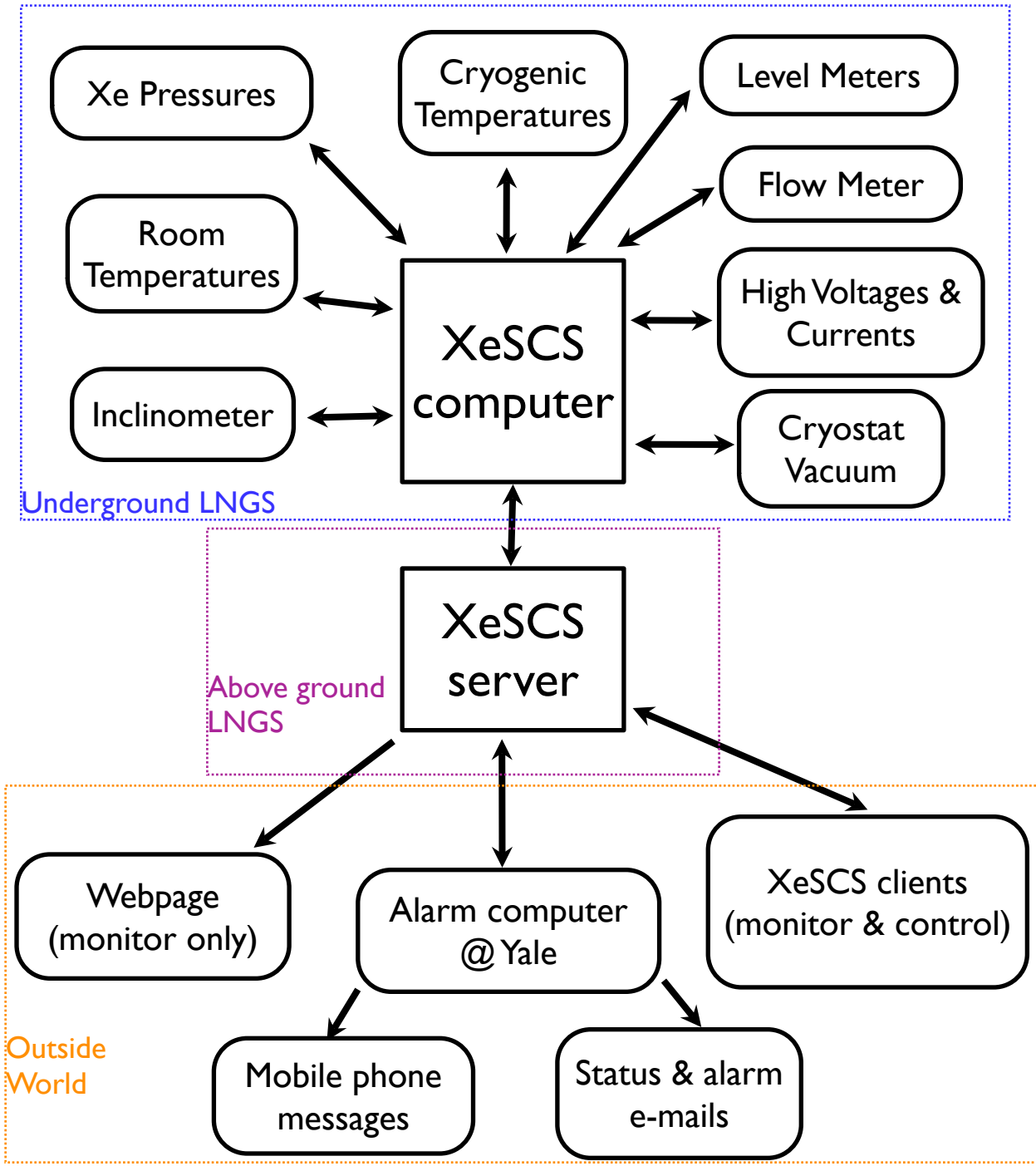
LNGS Locations of Experiments

XENON10 teams begin work at Gran Sasso, spring 2006

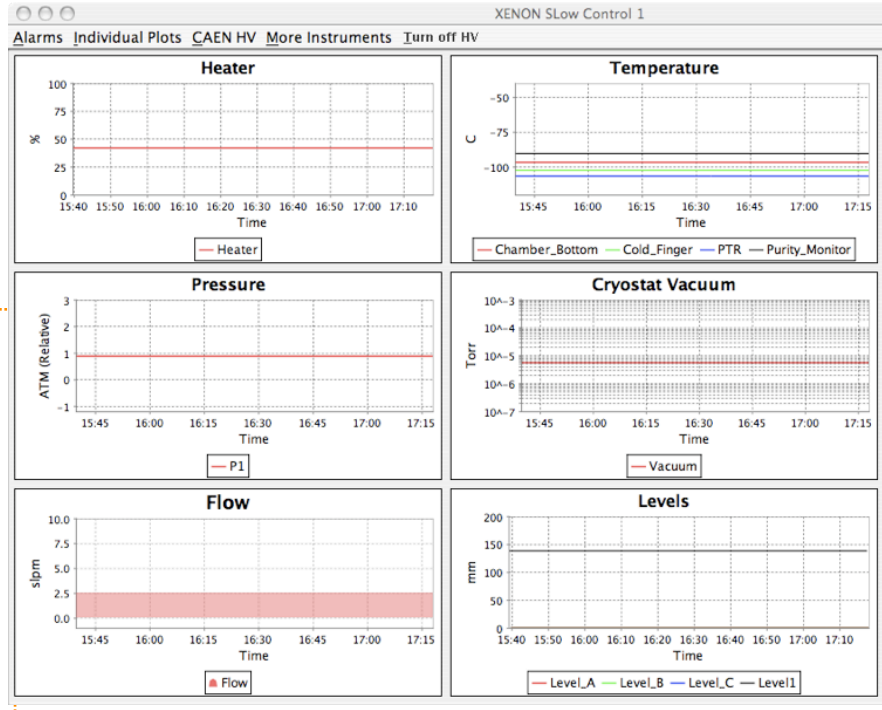
Offices and above-ground laboratories at Gran Sasso

Yalies at Gran Sasso, 7/2006:
Angel Manzur (grad student),
Ruth Toner (undergrad),
Kaixuan Ni (postdoc)

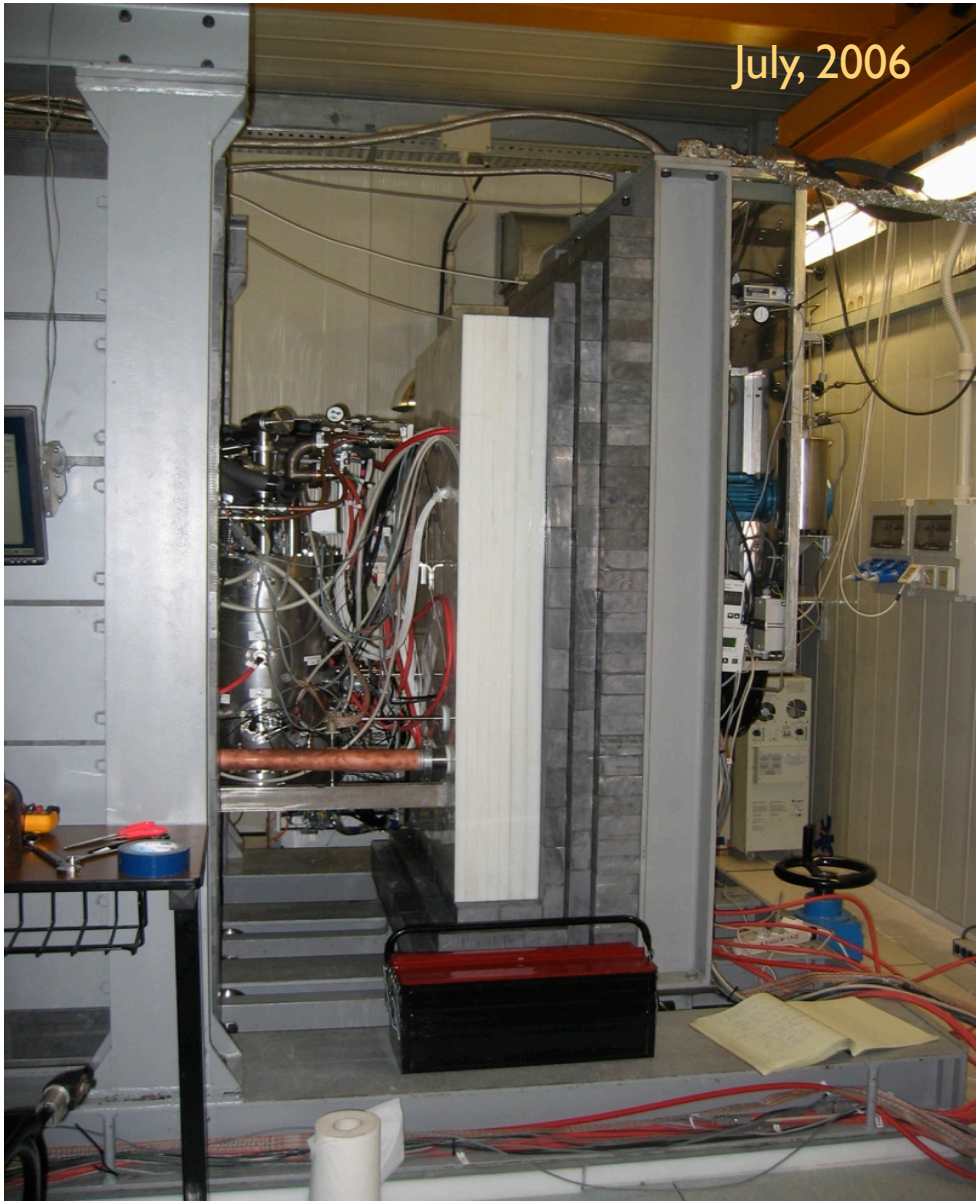
XENON Slow Control System (Yale)



- Developed in Java using Java RMI for remote interface.
- Platform Independent.
- Monitors ~330 channels.
- Remote high voltage control.
- Scalable to more instruments or computers.

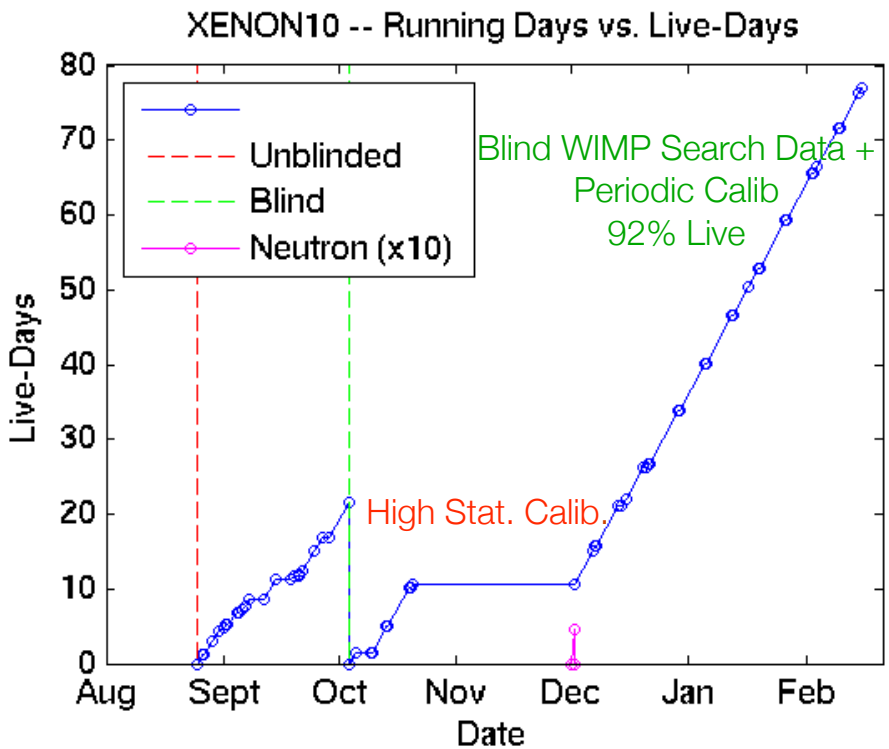


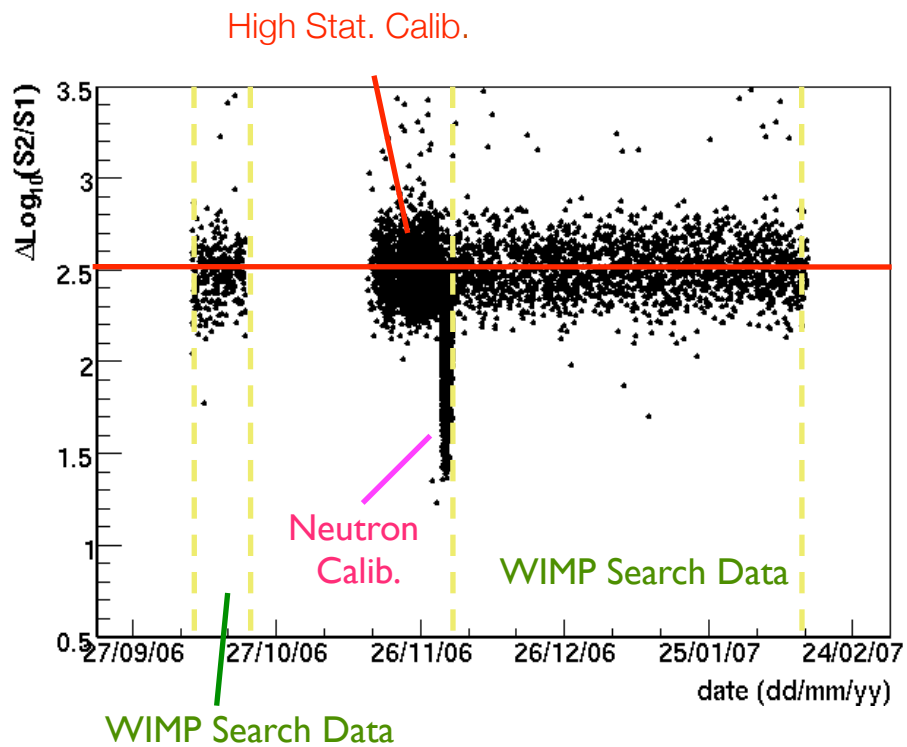
XENON10 at the Gran Sasso Laboratory



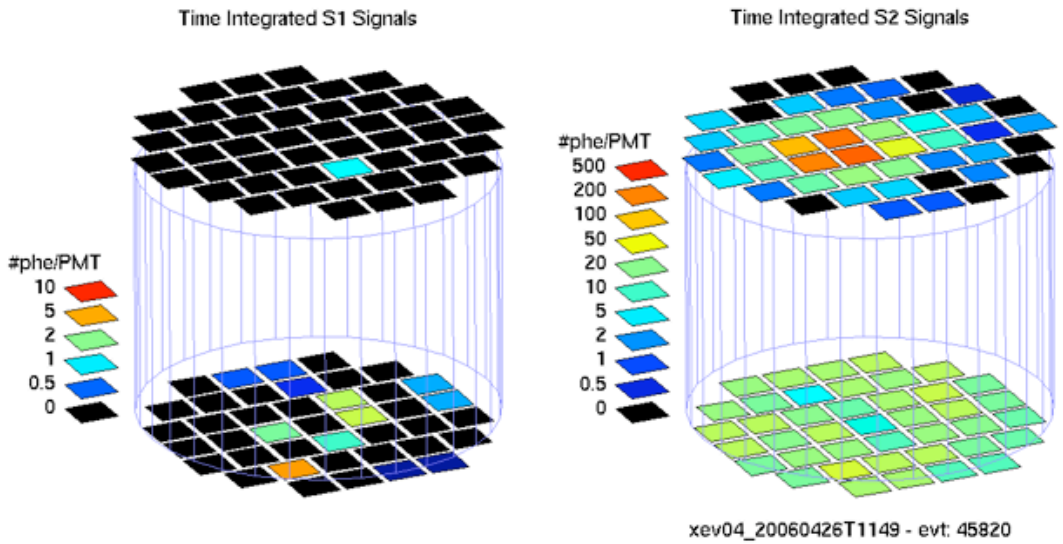
Louis Kastens and Angel Manzur (Yale grad students) and XENON10

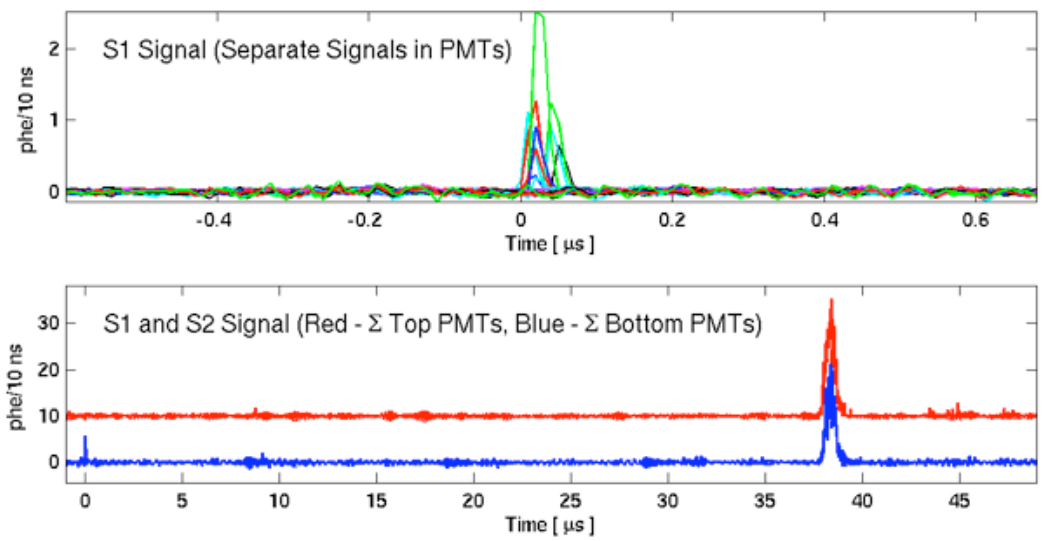
XENON10 Live-Time / Dark Matter Run Stability



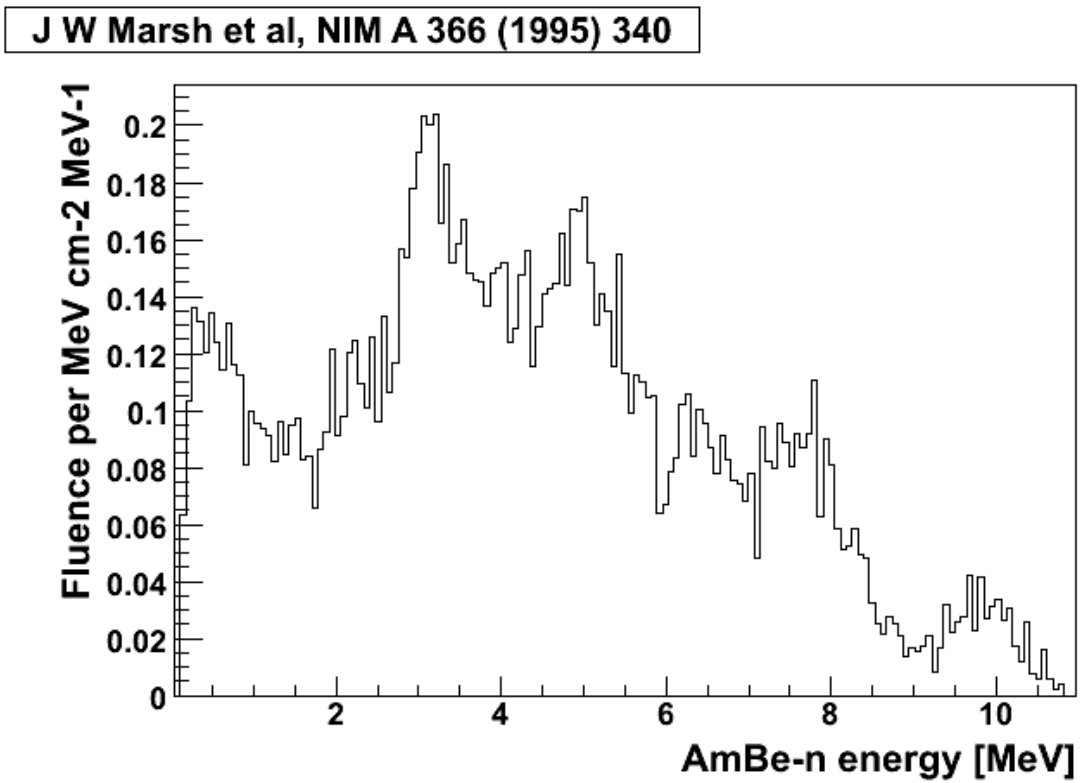


XENON10 Calibration runs @ LNGS





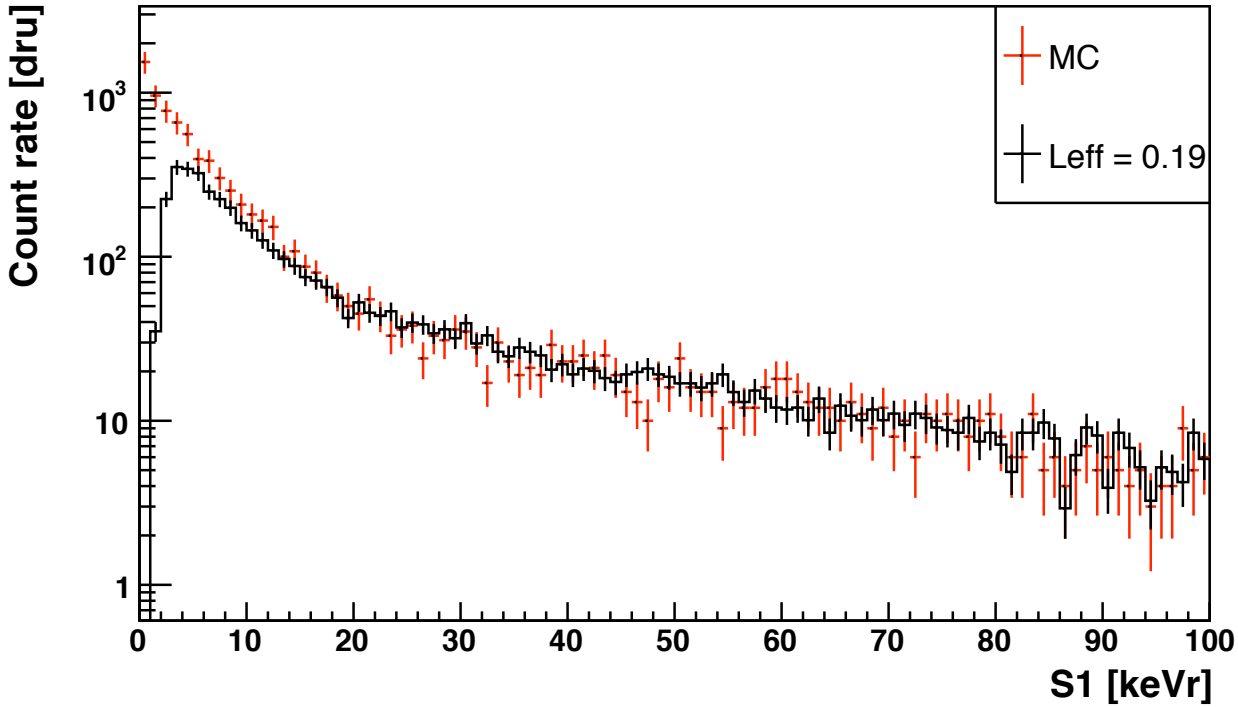
AmBe source



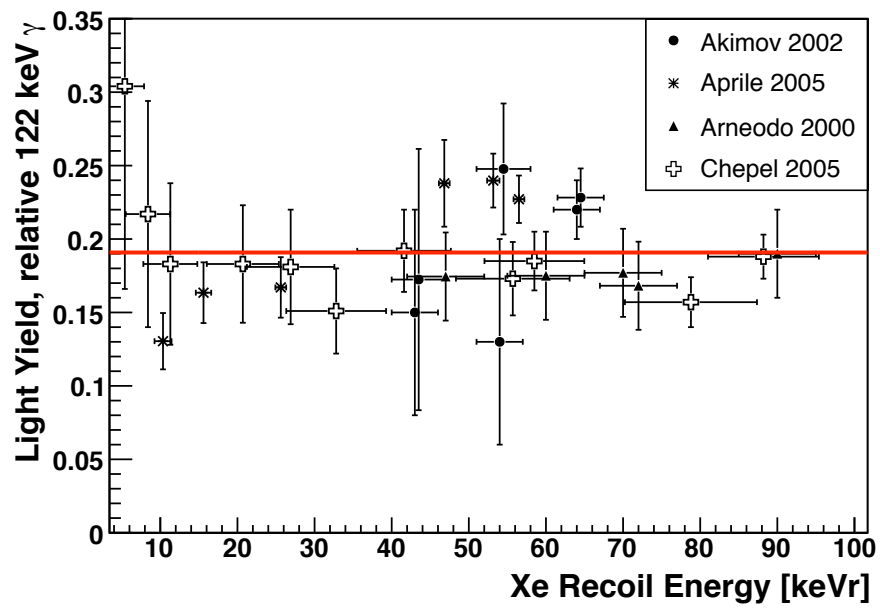
Neutron spectrum

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

Single nuclear recoils



$$E_{nr} = \frac{S1}{L_y} \frac{1}{L_{eff}} \frac{S_{er}}{S_{nr}}$$



Energy Calibration: determine the energy of nuclear recoils

energy of nuclear recoils (NRs)

measured signal in # of pe

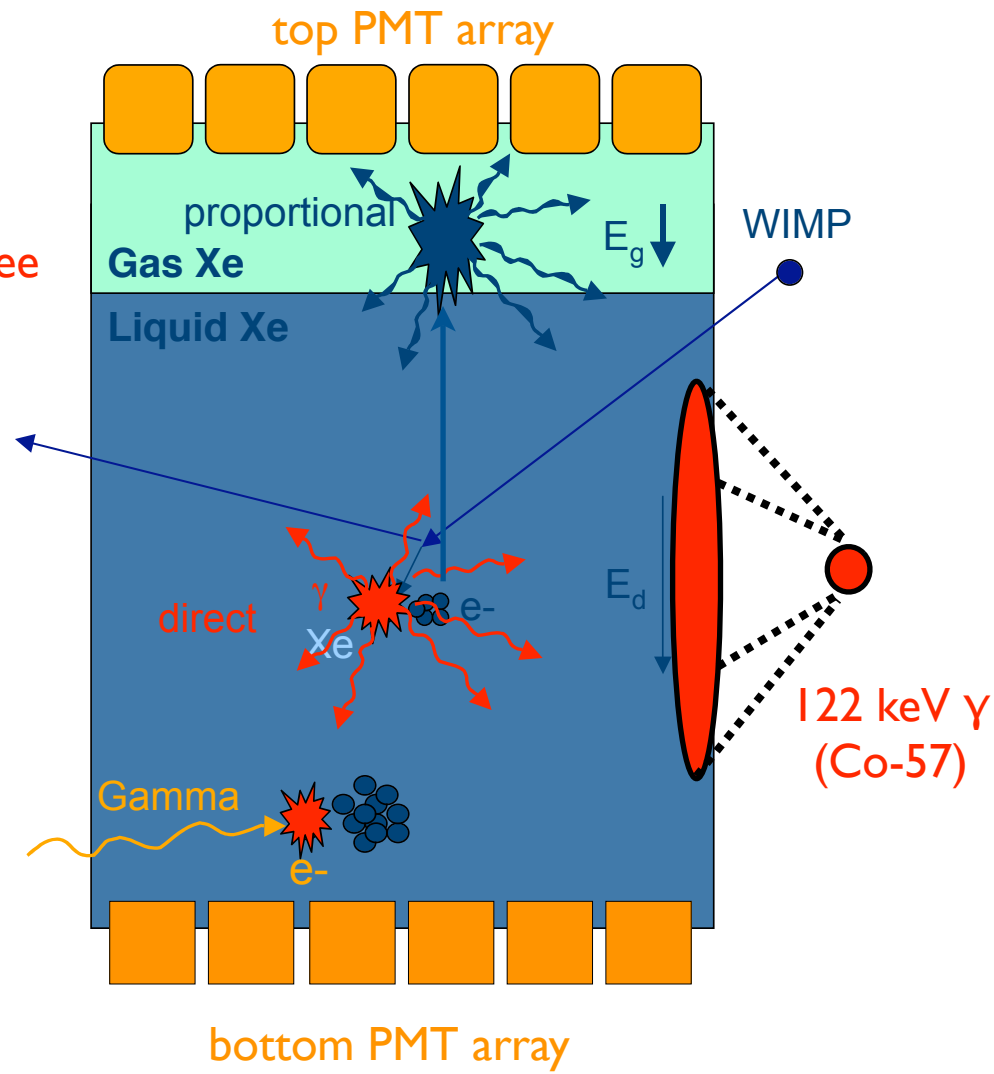
light yield for 122 keV γ in pe/keVee

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

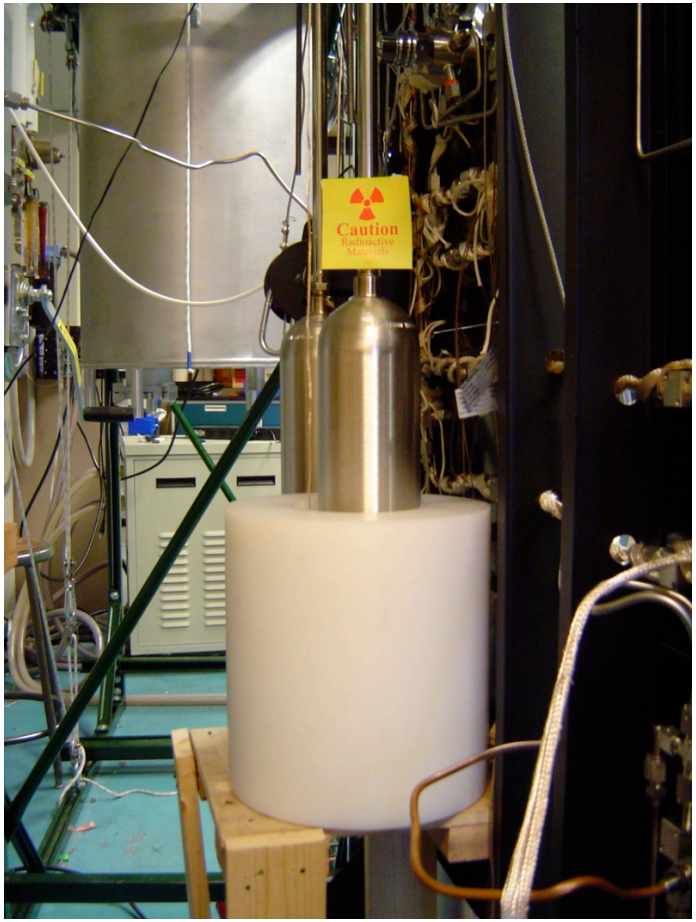
relative scintillation efficiency of NRs to 122 keV γ's at zero field

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

quenching of scintillation yield for NRs due to drift field

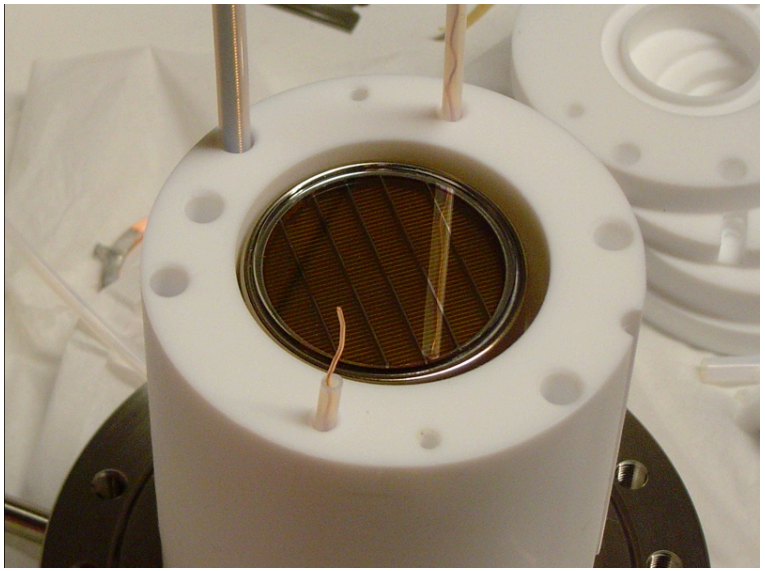


Xenon Activation with Cf-252 at Yale

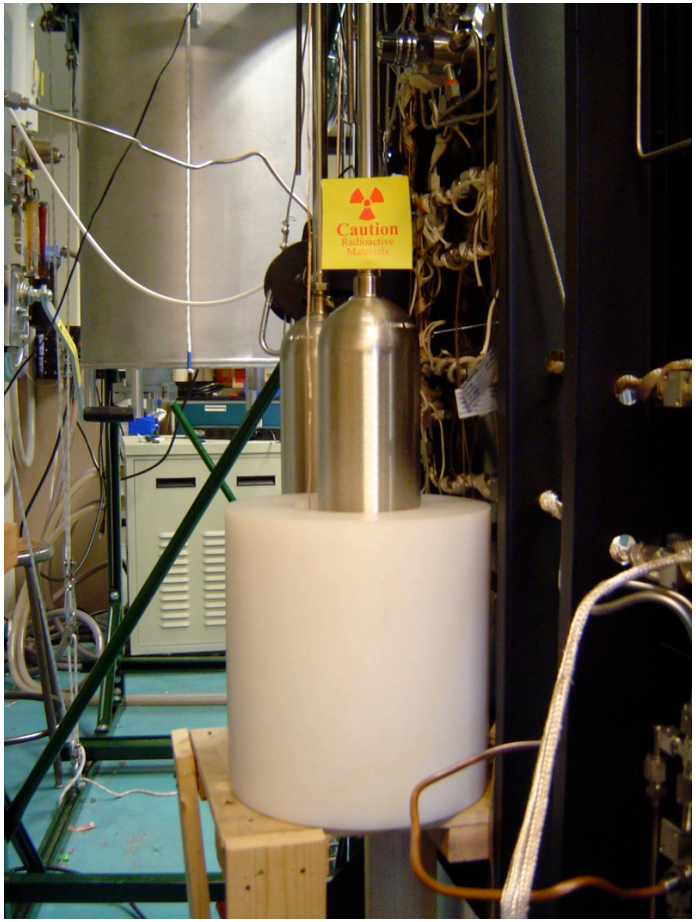


continuous activating Xe gas with a 5×10^5 n/sec Cf-252 source for 12 days

measure the scintillation light in a liquid Xenon cell

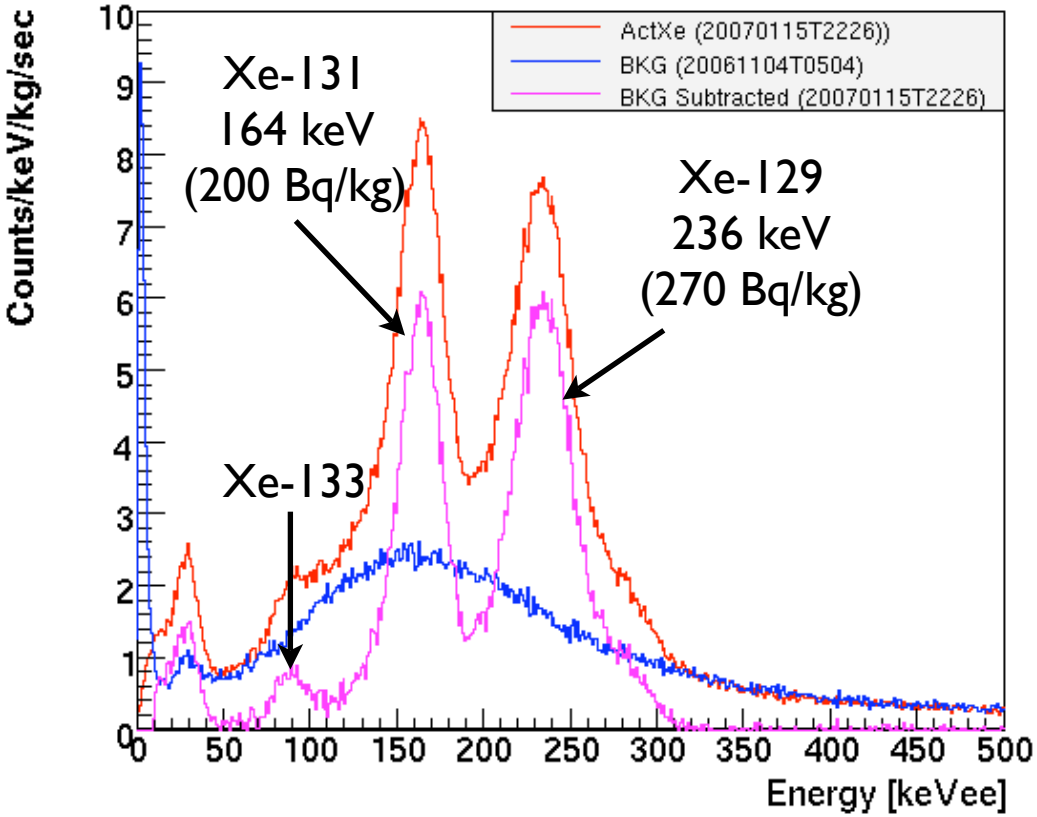


Xenon Activation with Cf-252

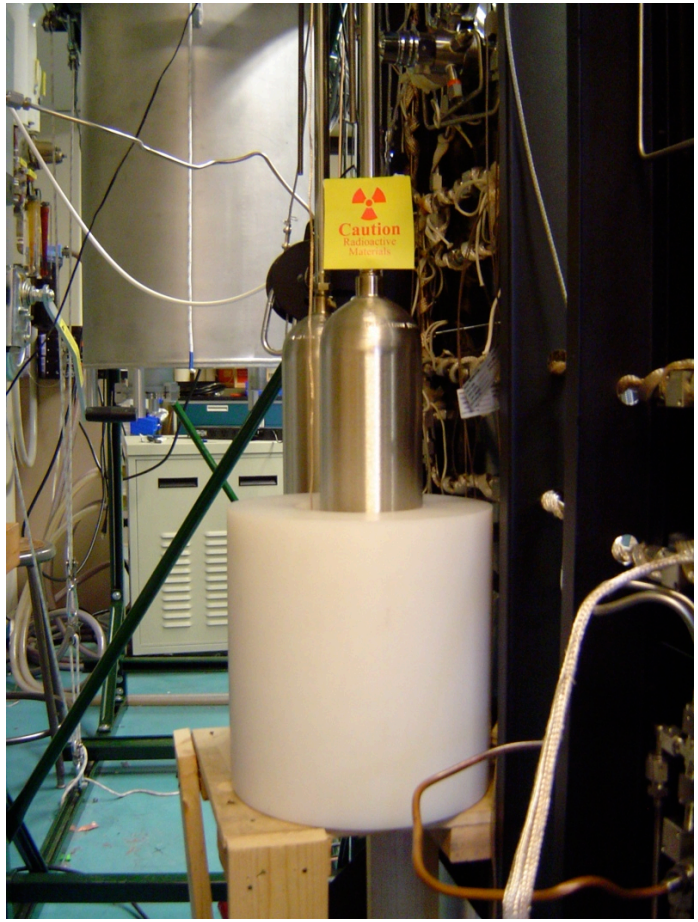


continuous activating Xe gas with a 5×10^5 n/sec Cf-252 source for 12 days

after 12-days of activation ...



Xenon Activation with Cf-252

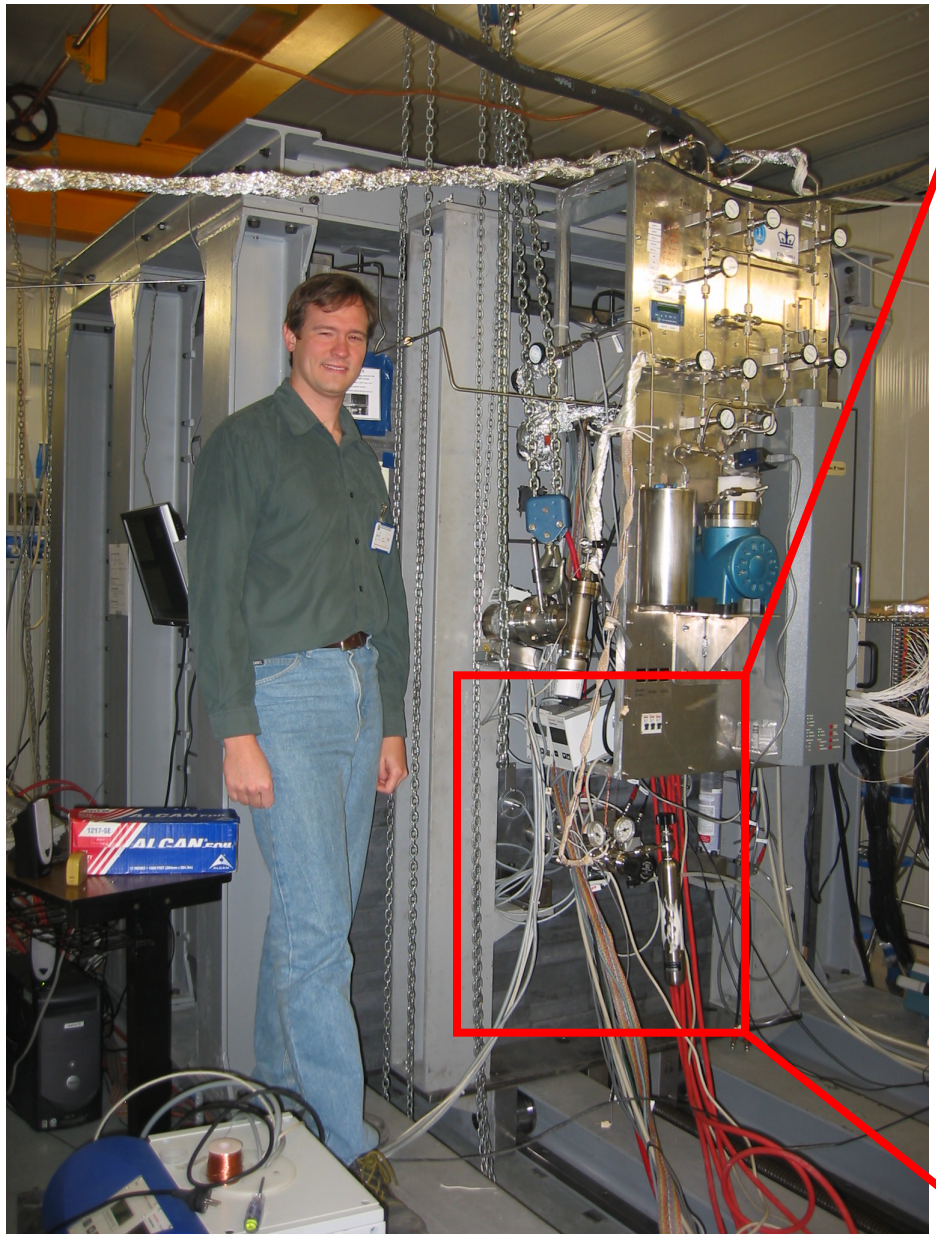


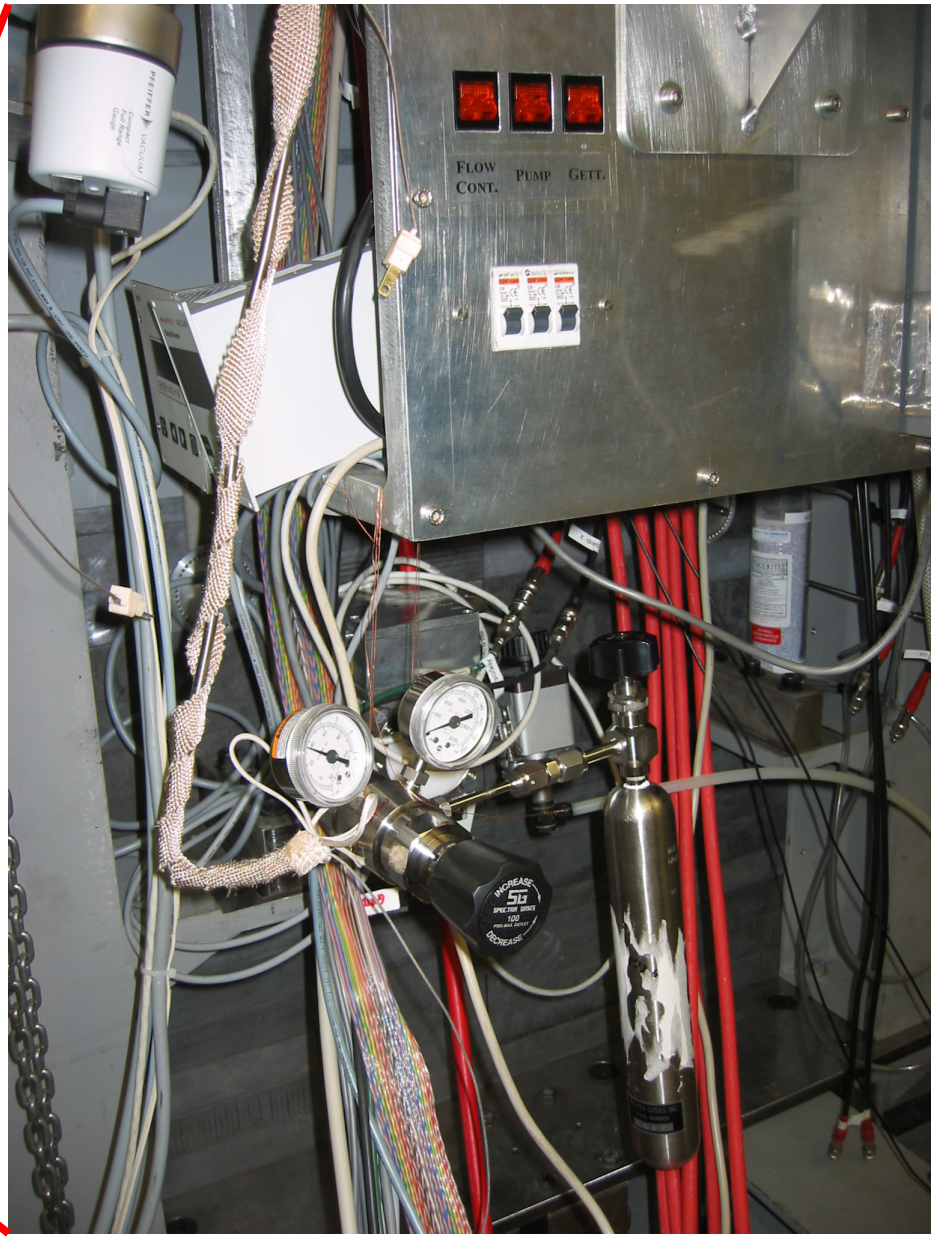
Yale (USA)

~ 1 week

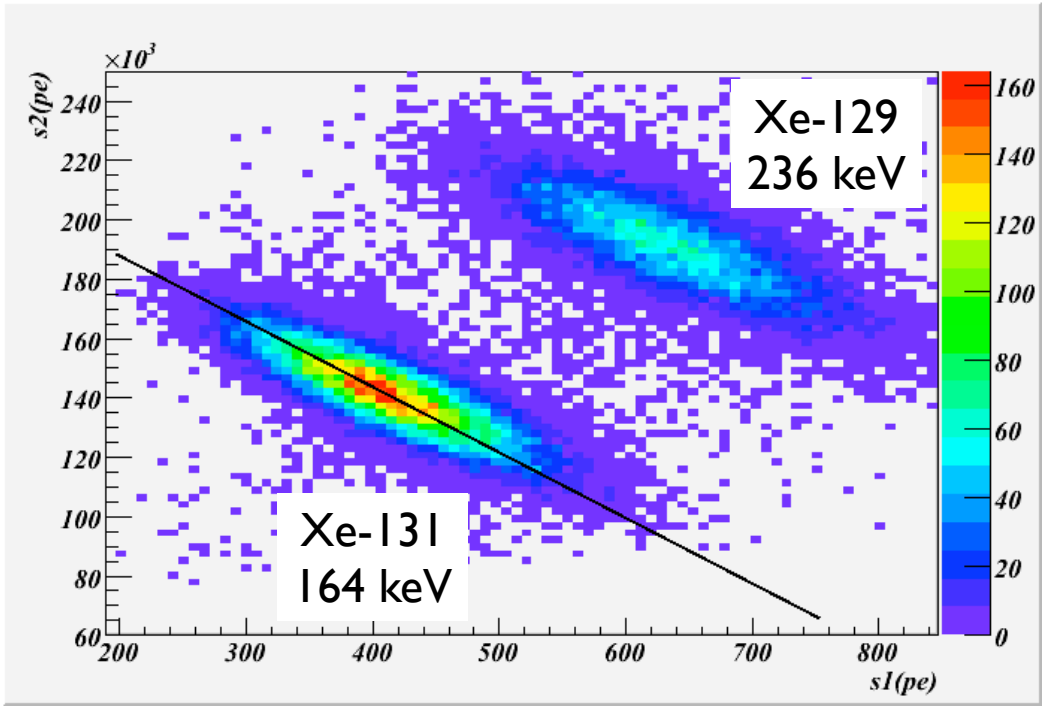
XENON10
Gran Sasso (Italy)

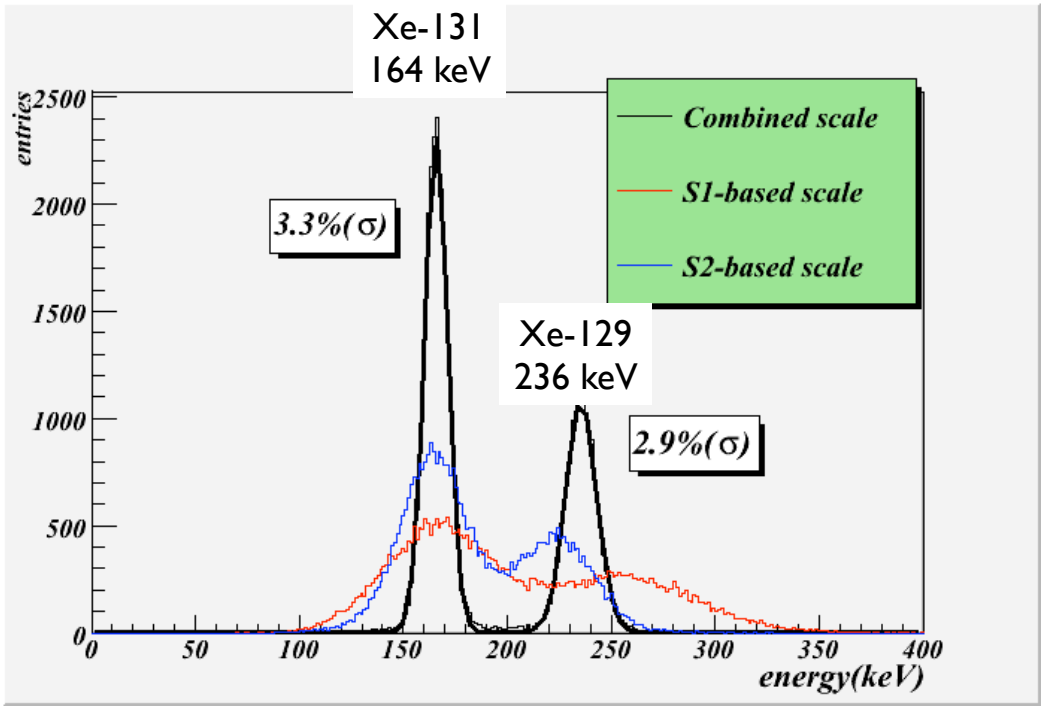
Neutron-activated xenon added to XENON10



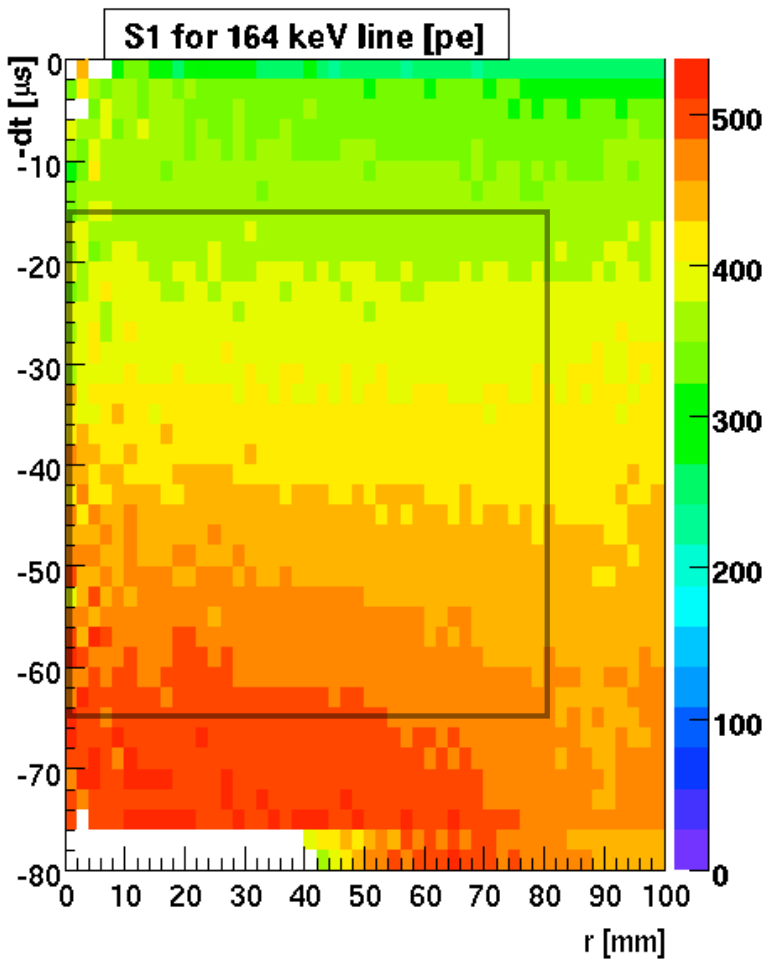


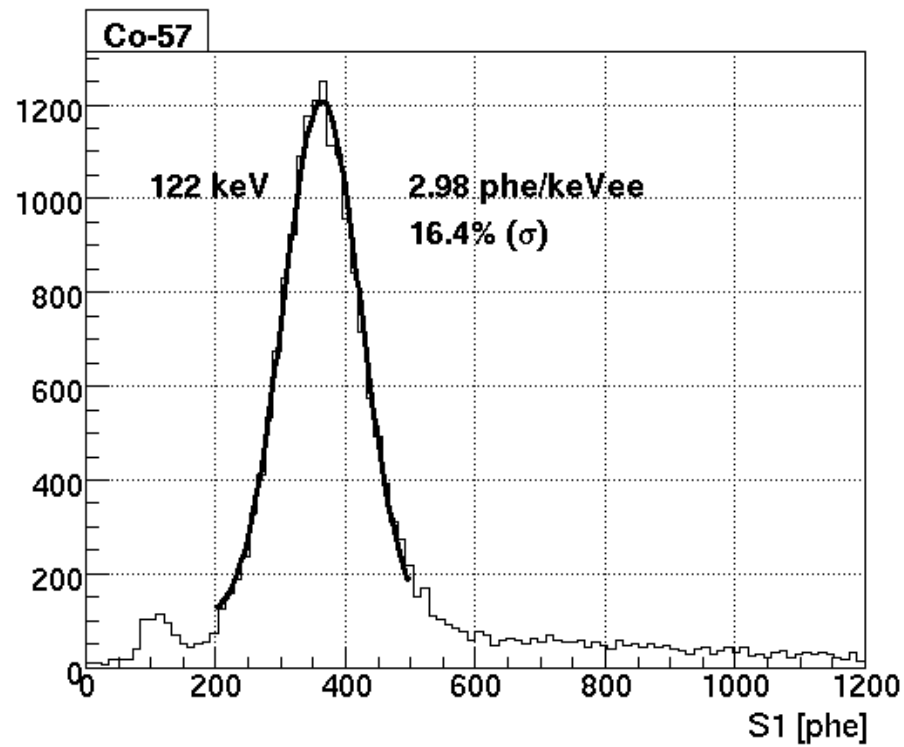
Activated Xenon Lines in XENON10





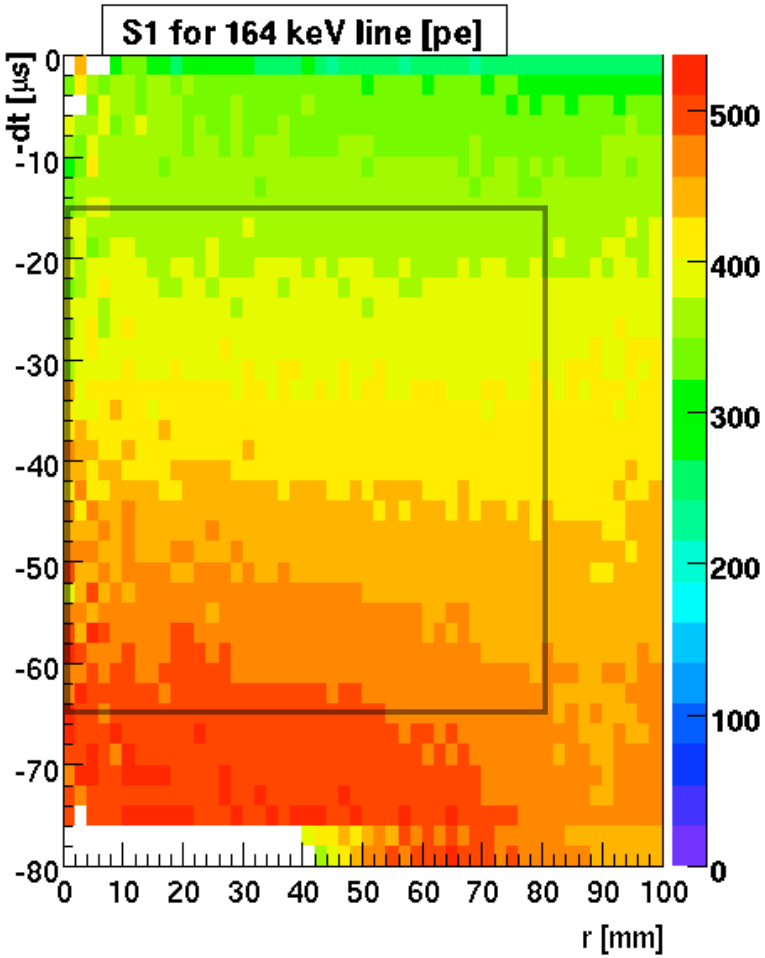
Position dependence of S1 signals in XENON10

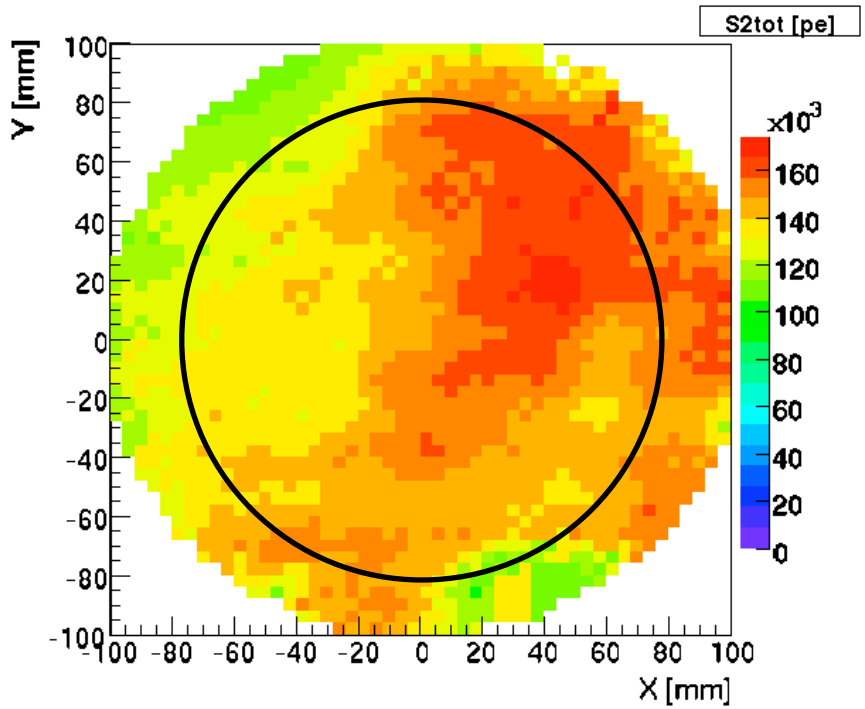




after position-dependent corrections

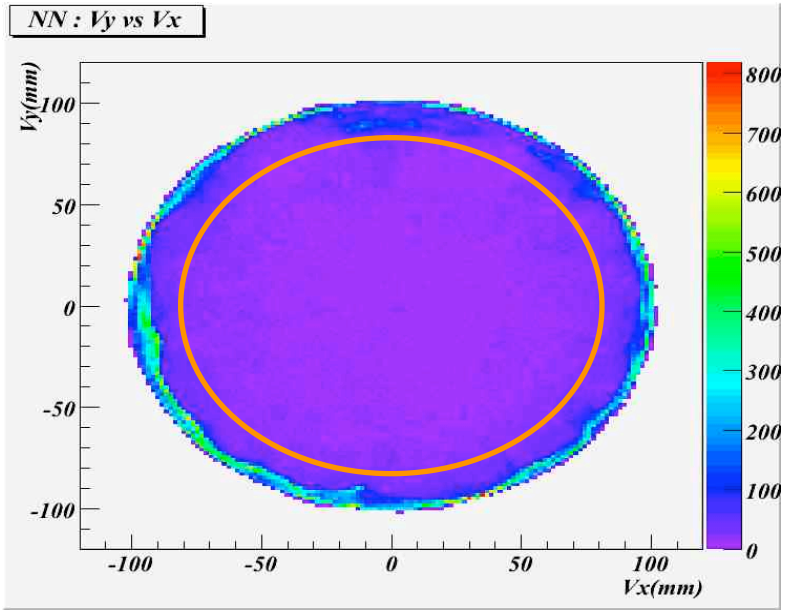
Position dependence of S1 and S2 signals

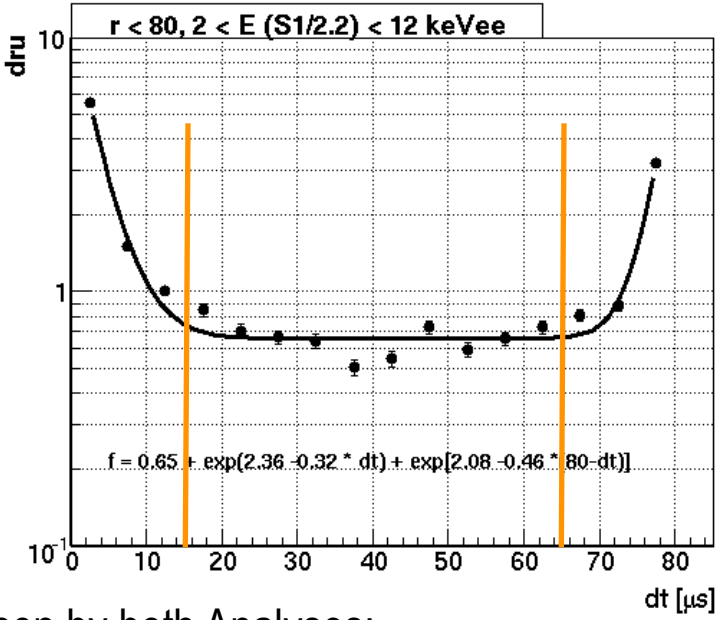




The XENON10 results are from position-dependent corrected signals by using these maps obtained from activated-Xe calibration

XENON10 Fiducial Volume cuts





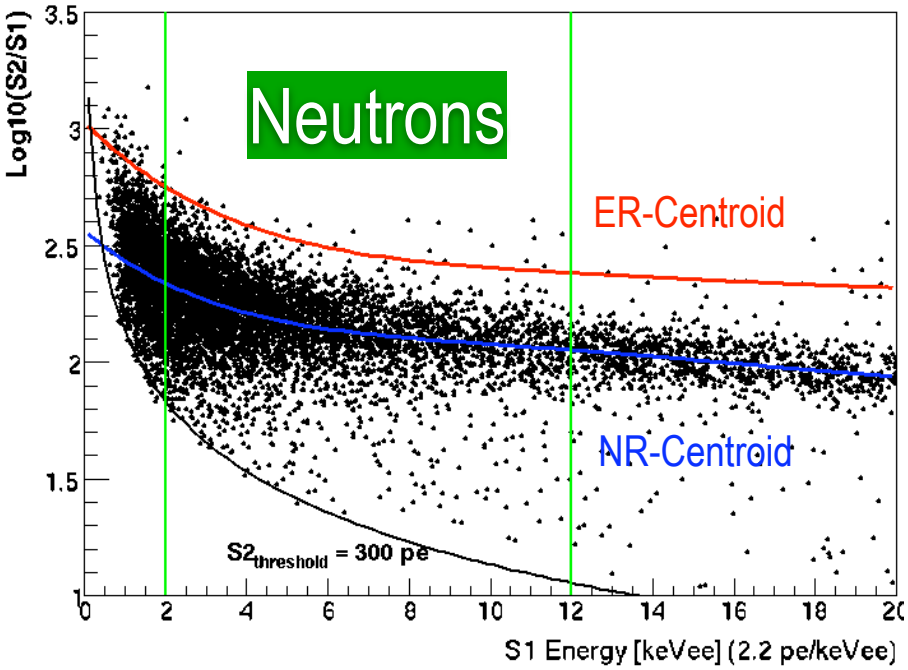
Fiducial Volume chosen by both Analyses:

15 < dt < 65 us, r < 80 mm

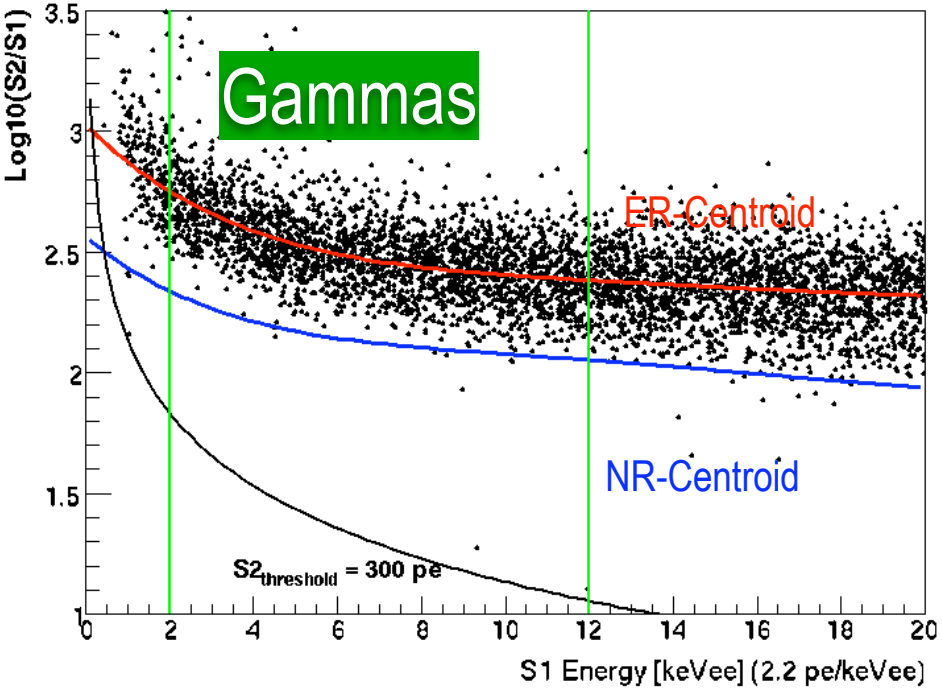
Fiducial Mass= 5.4 kg (reconstructed radius is algorithm dependent)

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

XENON10 Gamma/Neutron calibration

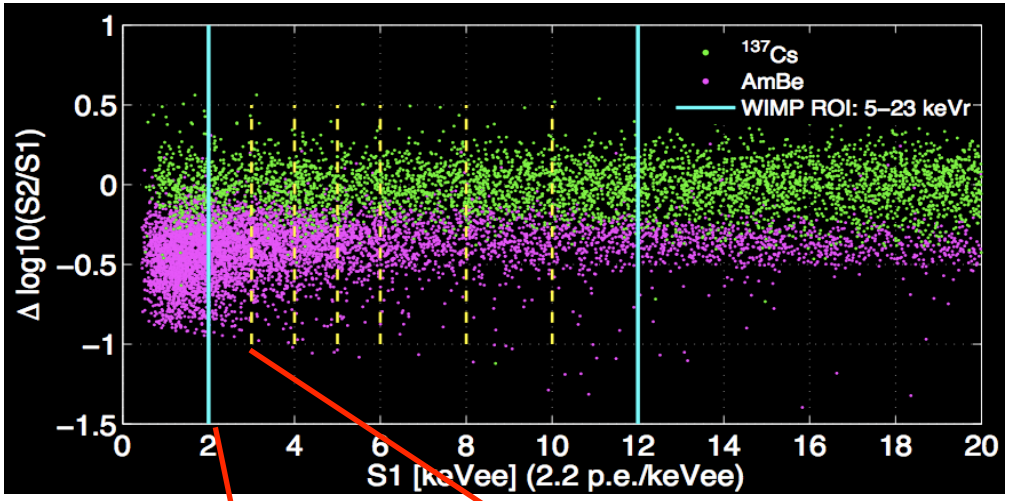


AmBe Neutron Calibration (NR-band)

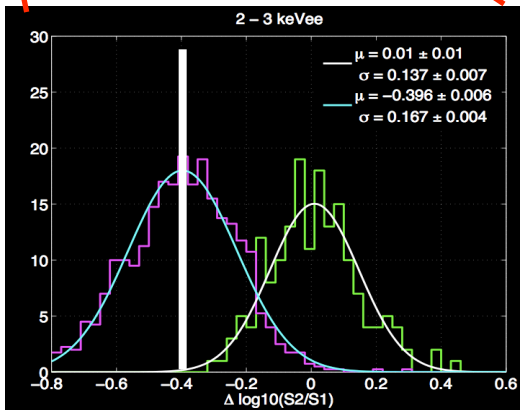


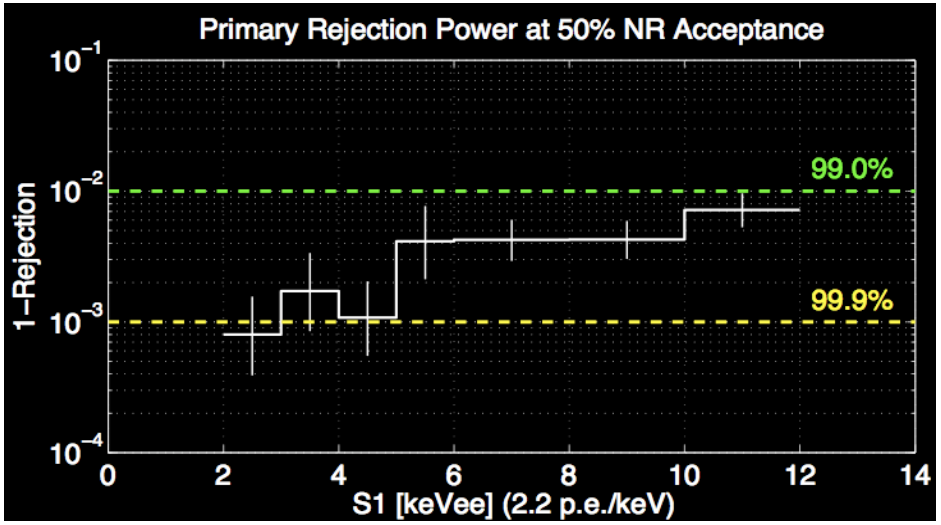
Cs-137 Gamma Calibration (ER-band)

Gamma background rejection efficiency



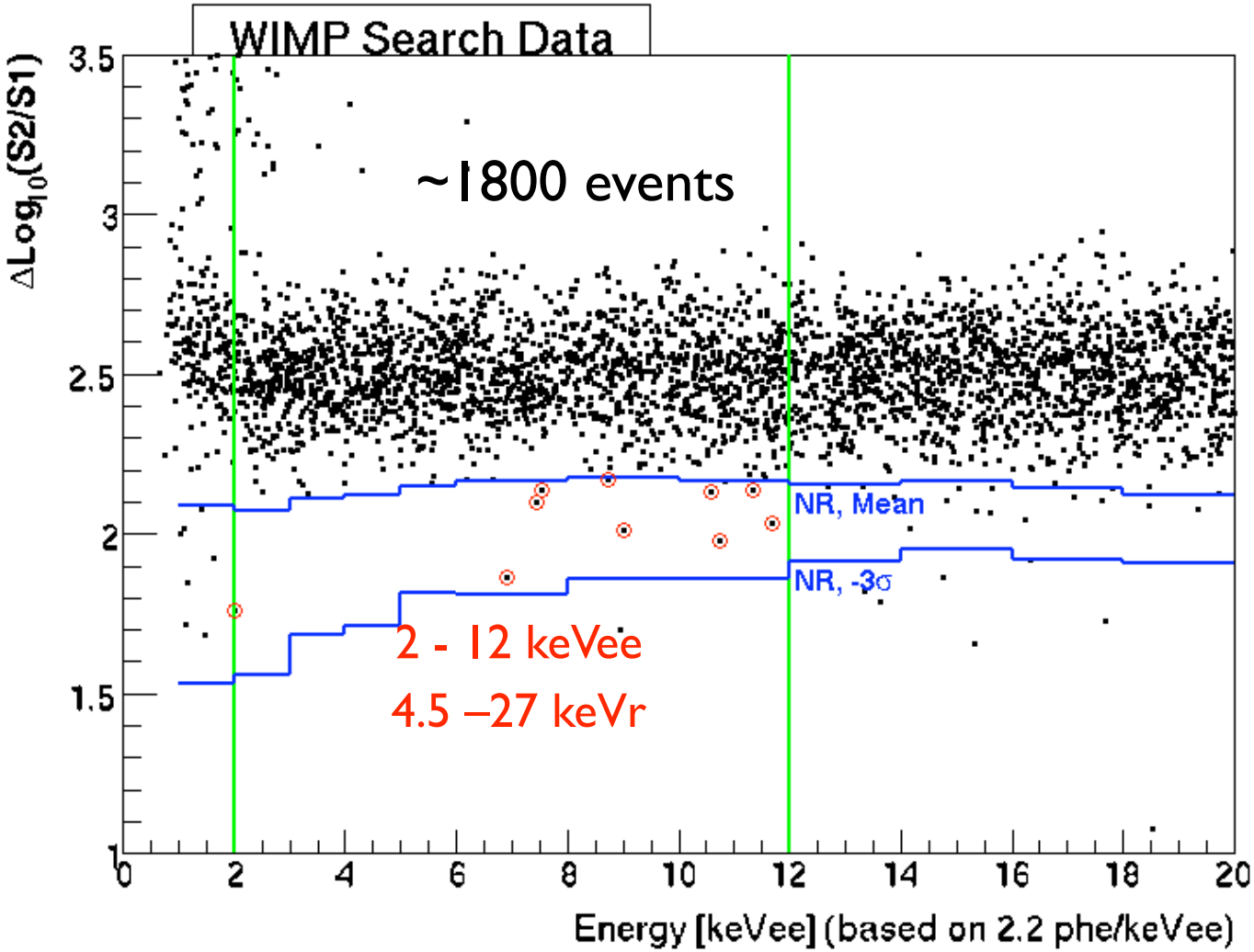
~ 99.5 % rejection power (improves to 99.9 % at low energy) at 50% Nuclear Recoil Acceptance





XENON10 WIMP Search Data

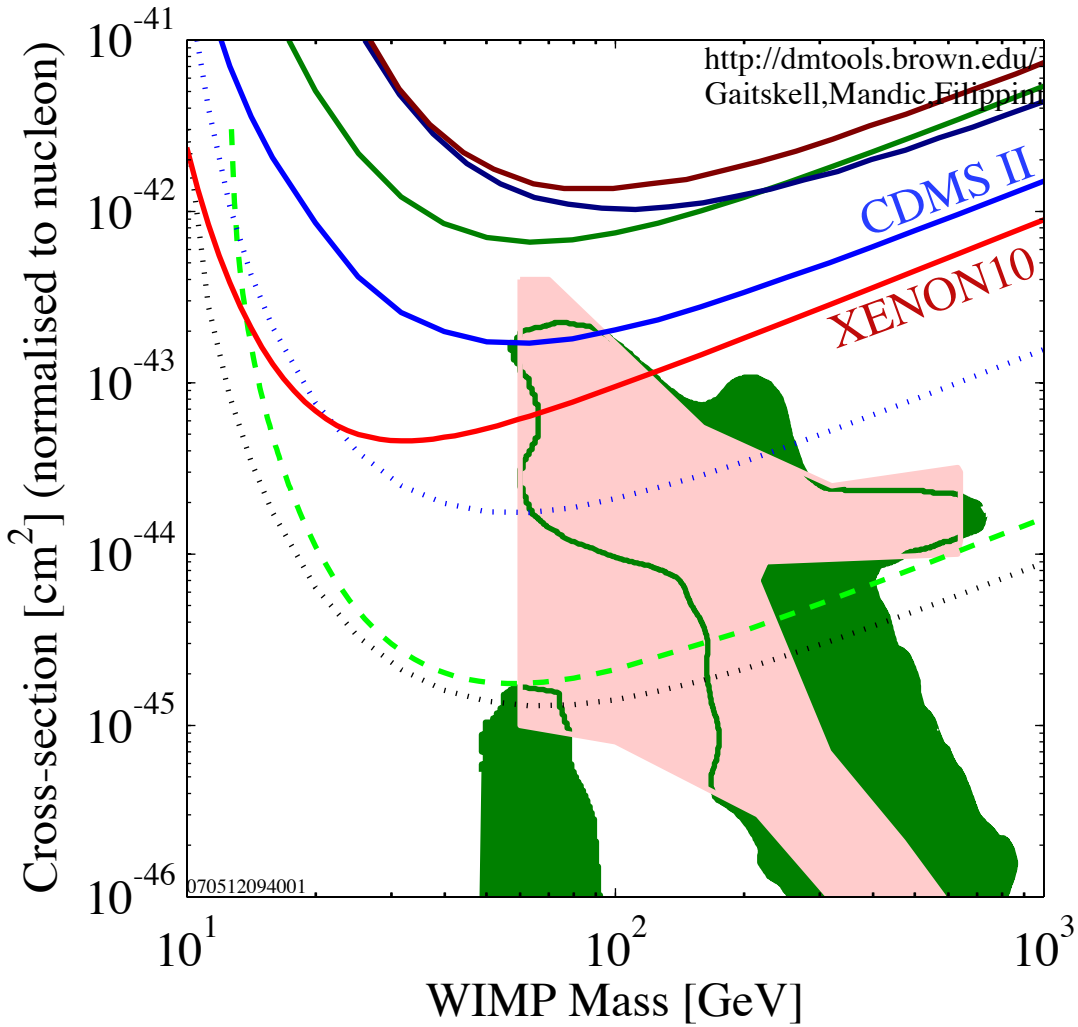
136 kg-days Exposure= 58.6 live days x 5.4 kg x 0.86 (ε) x 0.50 (50% NR)



- WIMP "Box" defined at ~50% acceptance of Nuclear Recoils (blue lines): [Mean, -3σ]
- 10 events in the "box" after all cuts in Primary Analysis
- 6.9 statistical leakage events expected from ER band
- NR energy scale based on 19% constant QF

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

- Edelweiss I final limit, 62 kg-days Ge
- WARP 2.3L, 96.5 kg-days 55 keV threshold
- ZEPLIN II (Jan 2007) result
- CDMS (Soudan) 2004 + 2005 Ge
- XENON10 2007 (Net 136 kg-d)
- CDMS Soudan 2007 projected
- LUX 300 kg LXe Projection
- SuperCDMS (Projected) 25kg (7-ST@Snolab)
- Baer et. al 2003
- Ruiz de Austri/Trotta/Roszkowski 2006, CMSSM

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...

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 are likely to make rapid advances in testing even lower WIMP-nucleon cross-sections (see LUX talk by M.Tripathi, next!)

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