New results from the XENON10 direct dark matter search

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TeV Particle Astrophysics 2007, Venice

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

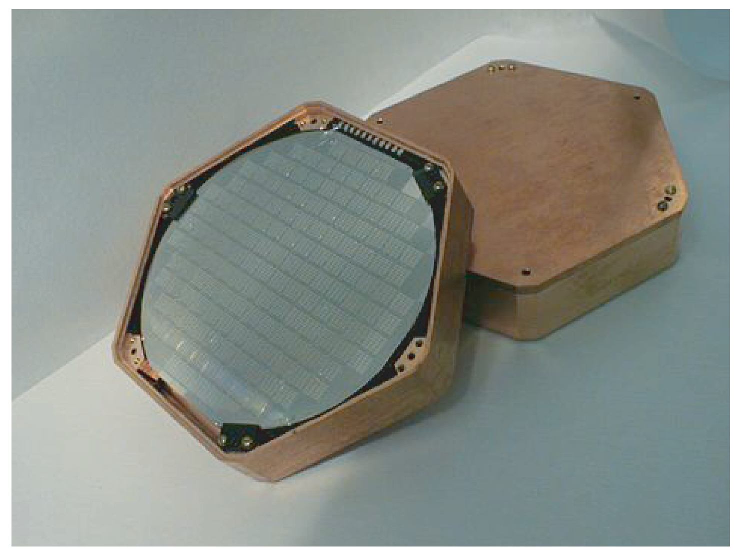
R = N □ < □ v >

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)

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

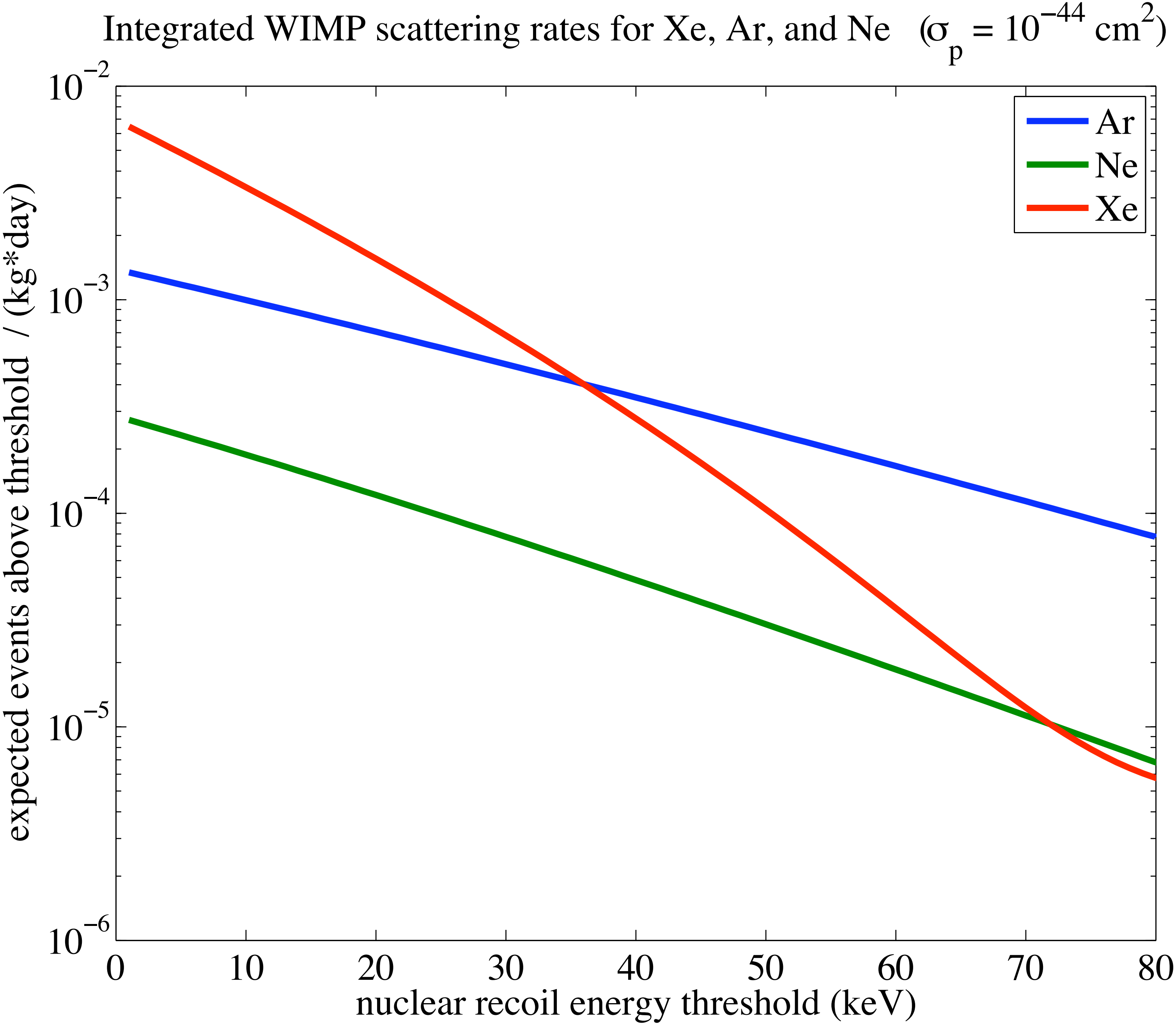
- noble liquids do not absorb their own scintillation
- 30,000 to 40,000 photons/MeV
- modest quenching factors for nuclear recoils

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)

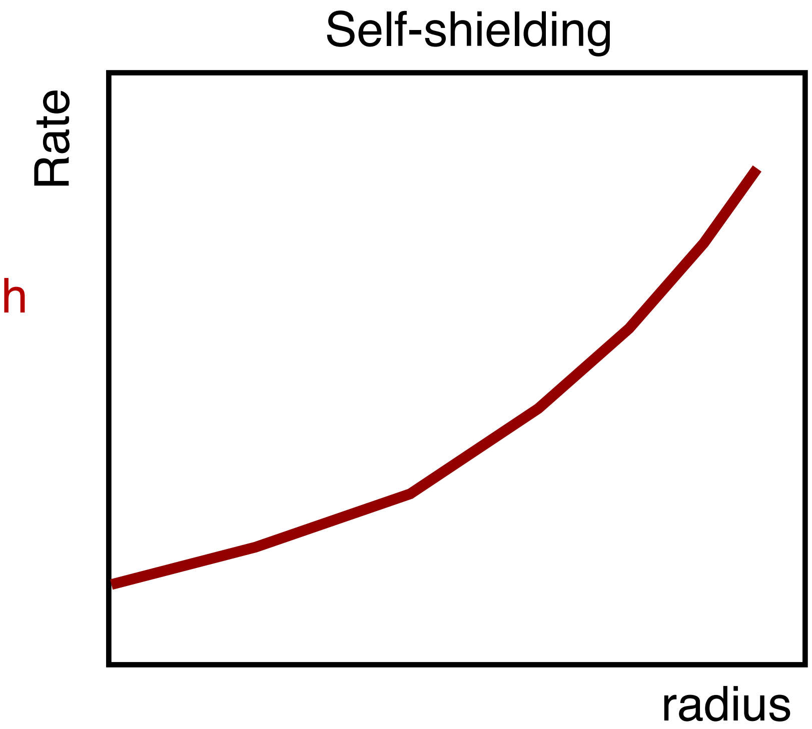
Strategies for Electronic Recoil Background Reduction in Scintillation Experiments

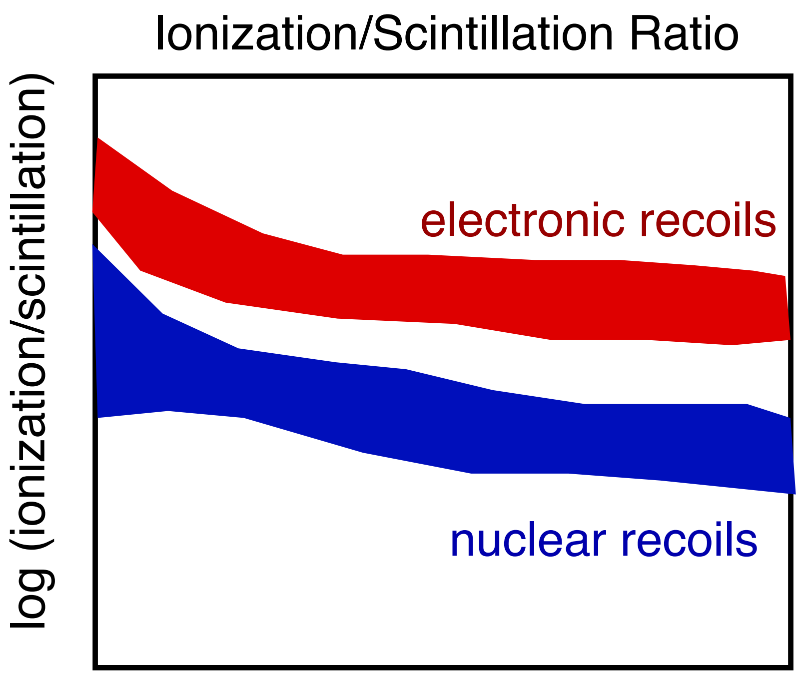
Require < 1 event in signal band during WIMP search

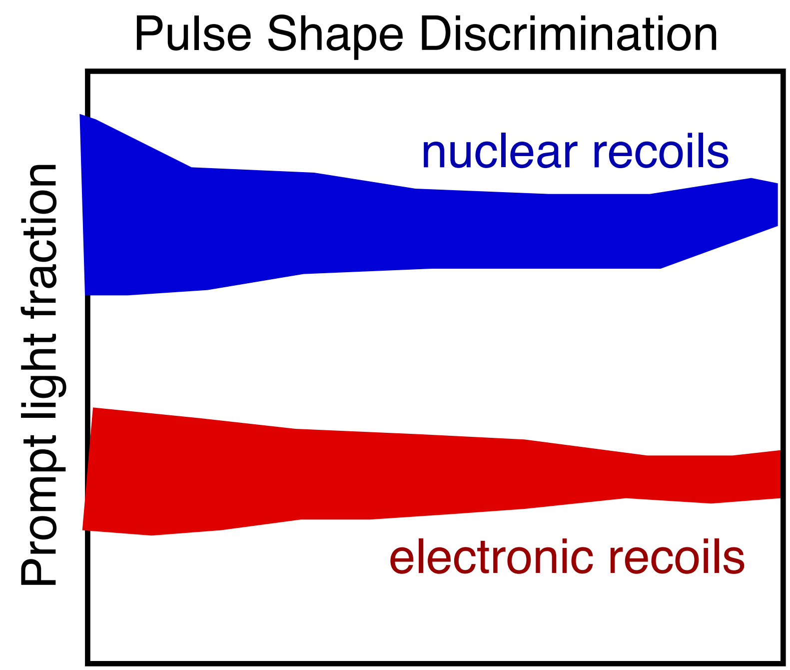
LXe: Self-shielding, Ionization/Scintillation ratio best

LAr: Pulse shape, Ionization/Scintillation ratio best

LNe: Pulse shape, Self-shielding best



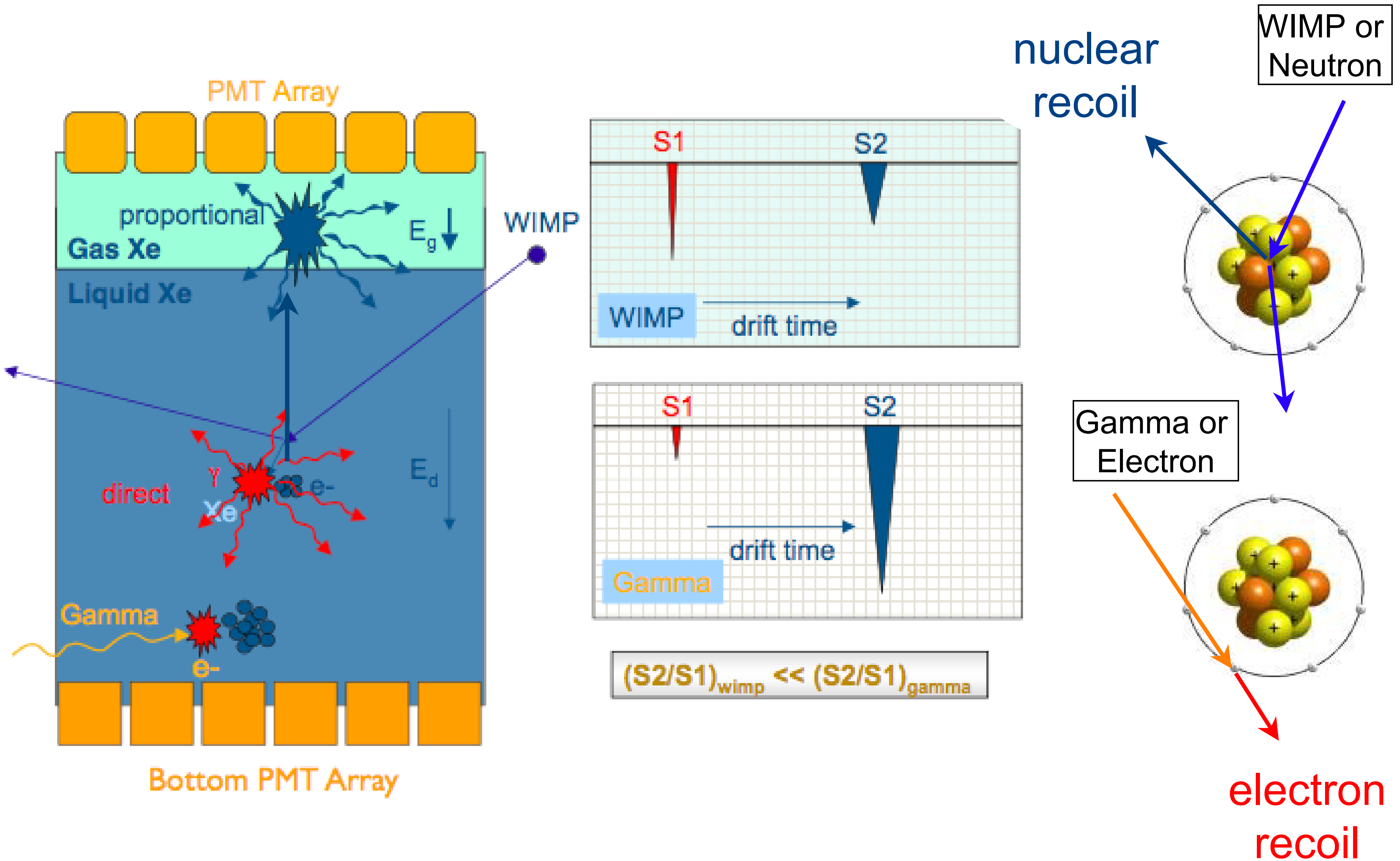




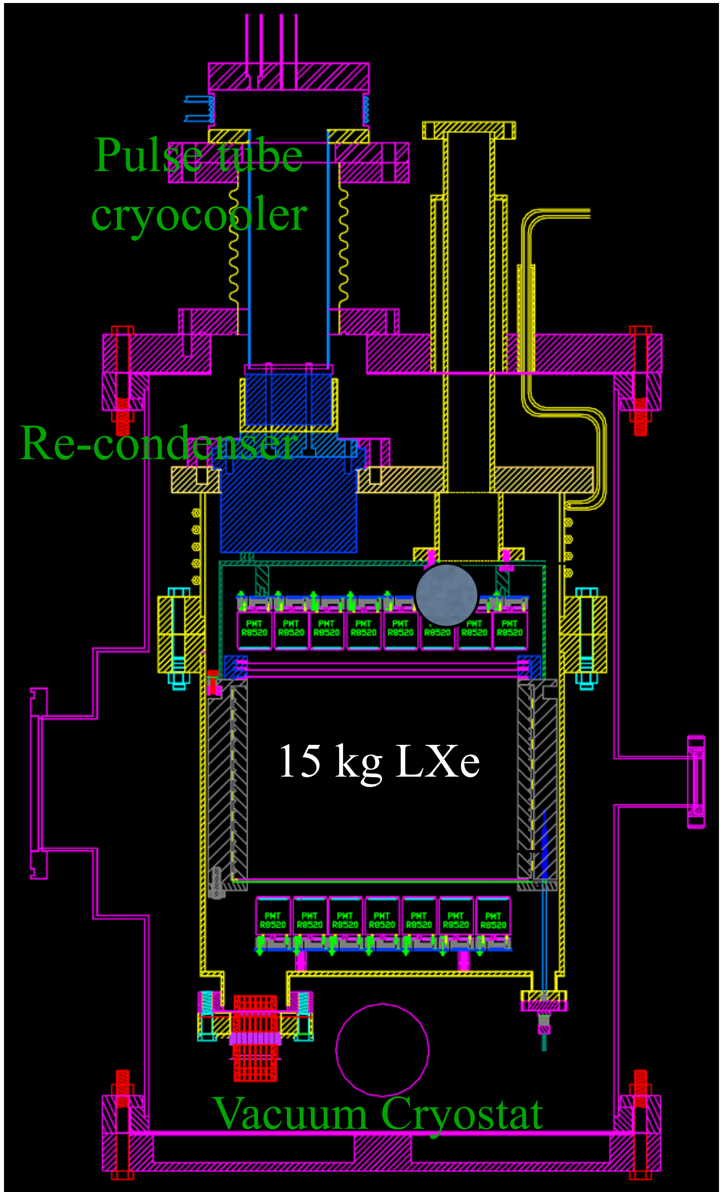
The XENON10 Collaboration

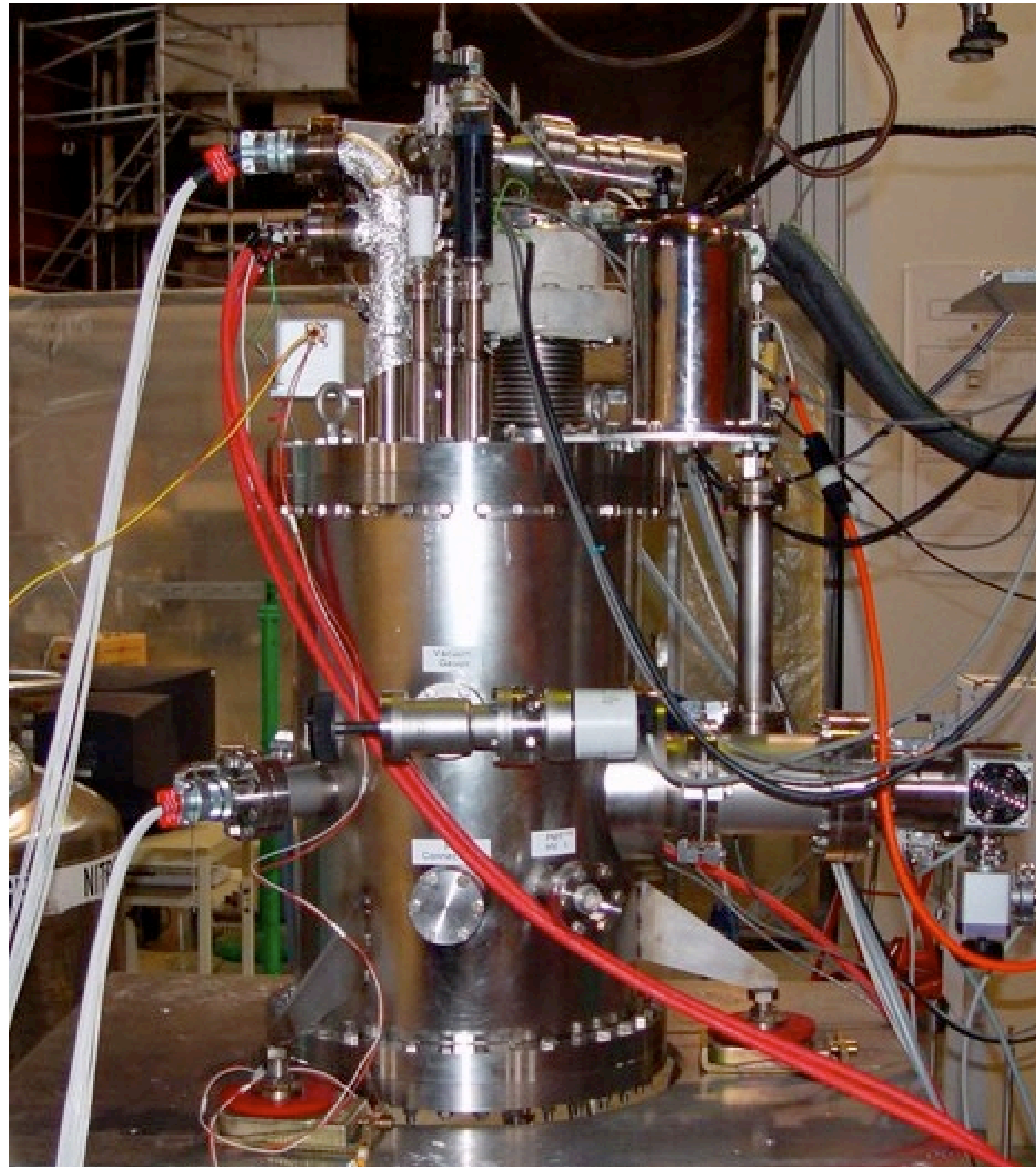
Columbia University Elena Aprile, Karl-Ludwig Giboni, Maria Elena Monzani, Guillaume Plante, Roberto Santorelli and Masaki Yamashita
University of Zürich Laura Baudis, Jesse Angle, Aaron Manalaysay, J. Orboeck, and Stephan Schulte
Brown University Richard Gaitskell, Simon Fiorucci, Peter Sorensen and 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
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



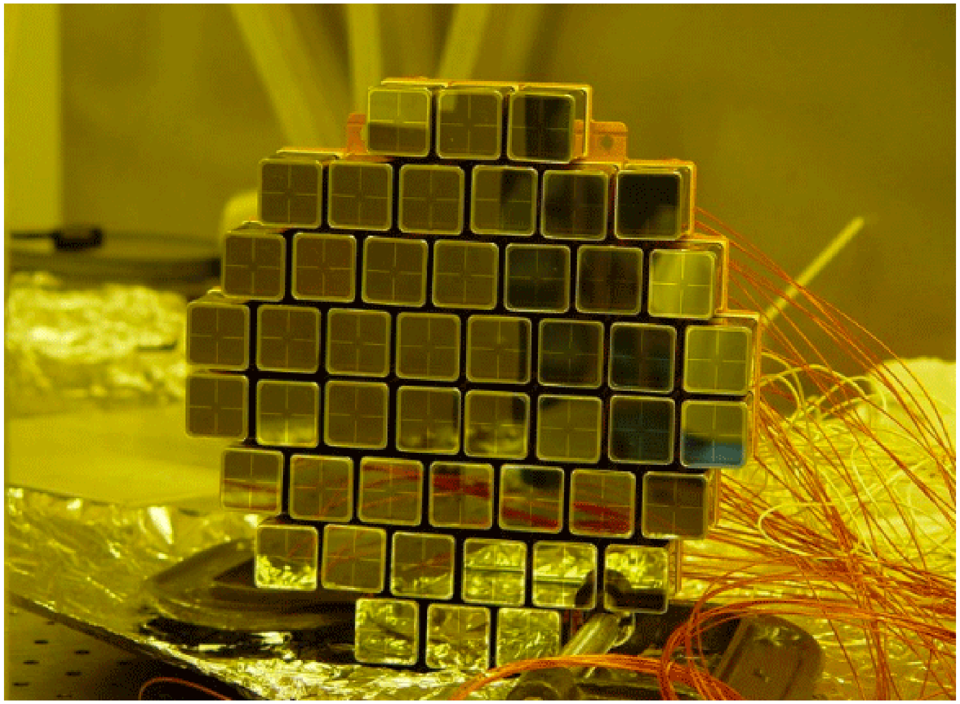
The XENON10 Detector



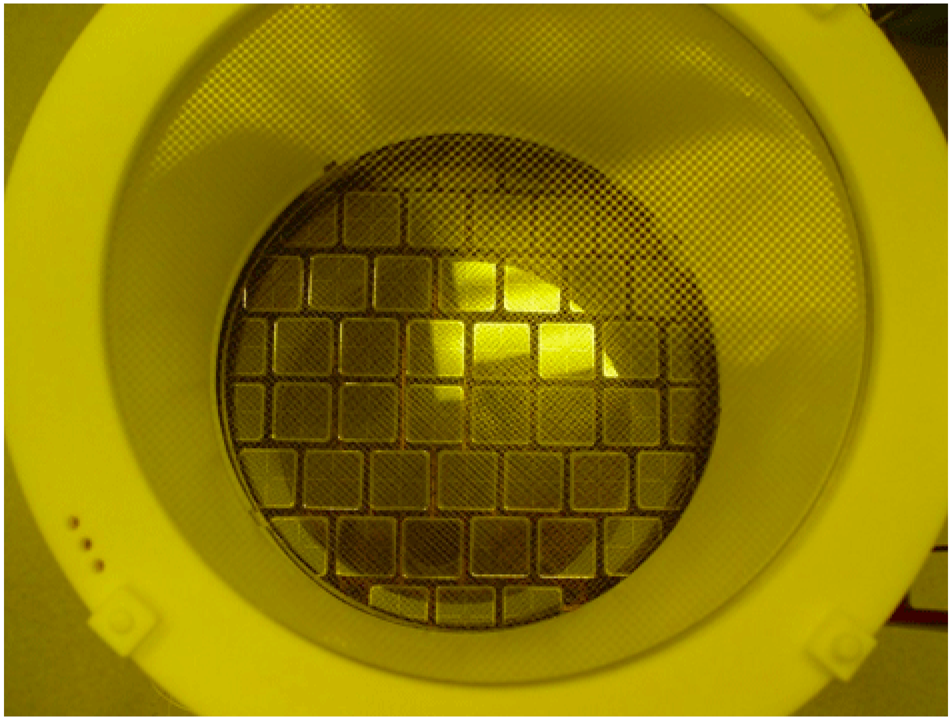


The XENON10 Photomultipliers

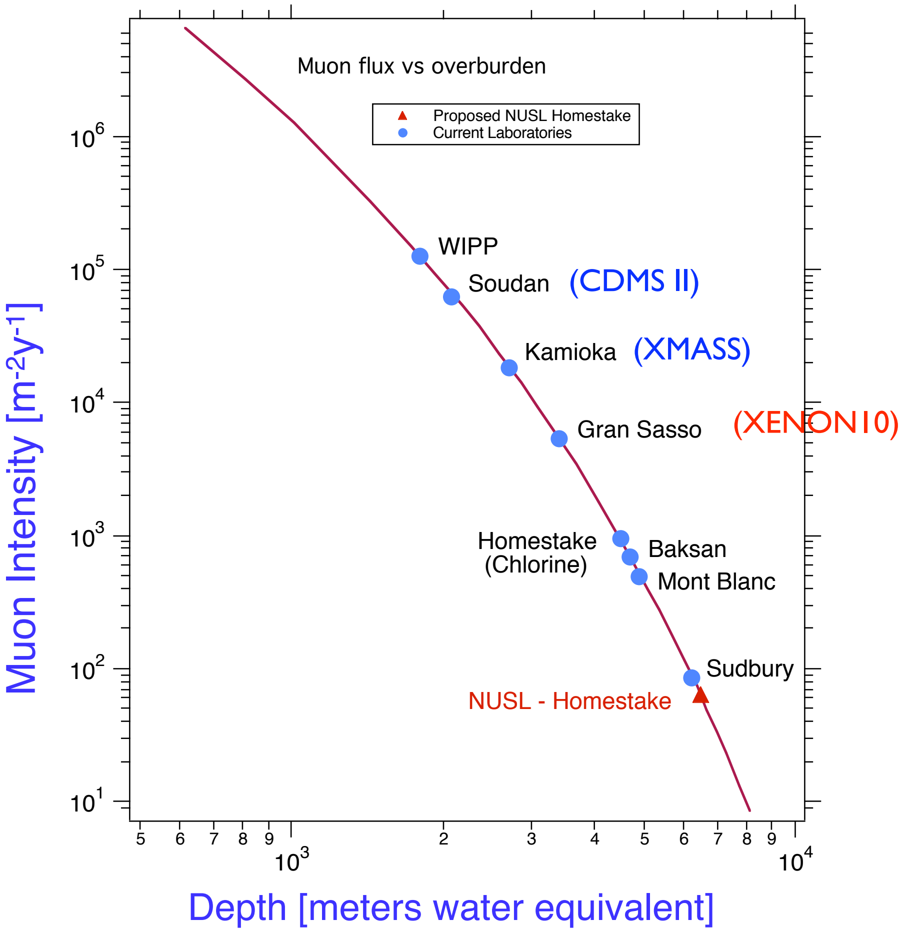
Hamamatsu 8520-06-AL 2.5 cm x 3.5 cm
Bialkali photocathode Rb-Cs-Sb
10 dynodes
Quartz window
U/Th/K/Co = 0.17/0.20/0.09/0.56 mBq/PMT
Quantum efficiency > 20% at 178 nm

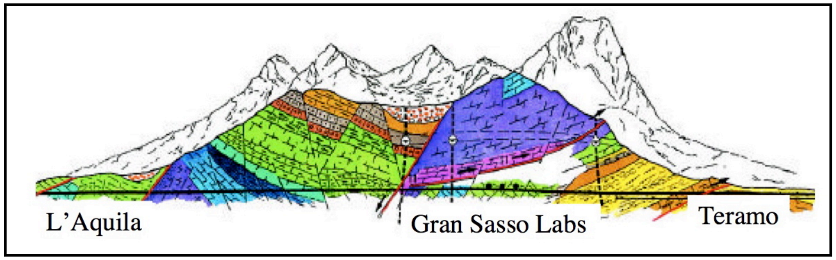


Angel Manzur (Yale) individually testing PMTs



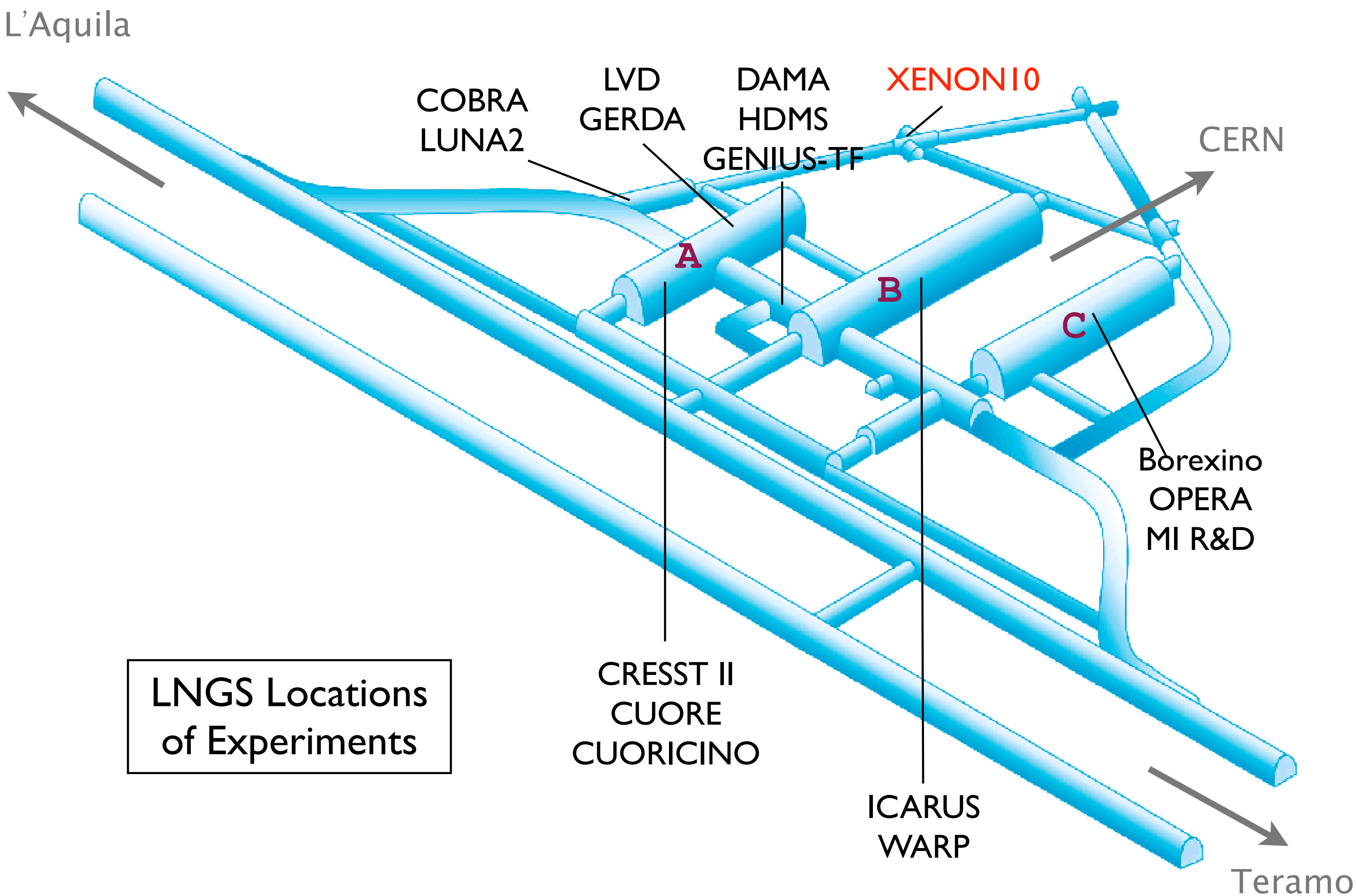
The INFN Gran Sasso National Lab (LNGS)





1400 m rock overburden (3500 mwe)

XENON10 @ LNGS

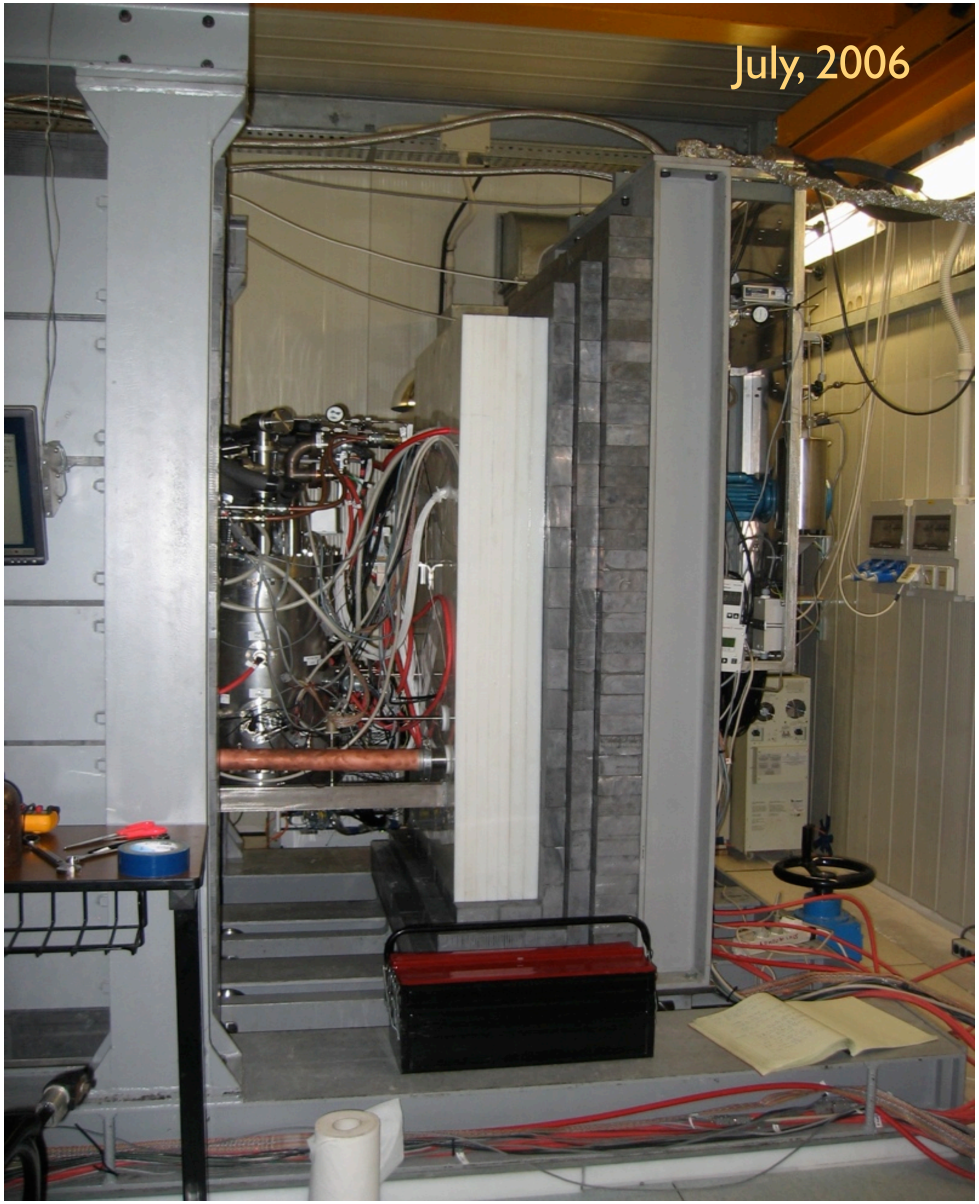


XENON10 teams begin work at Gran Sasso, spring 2006

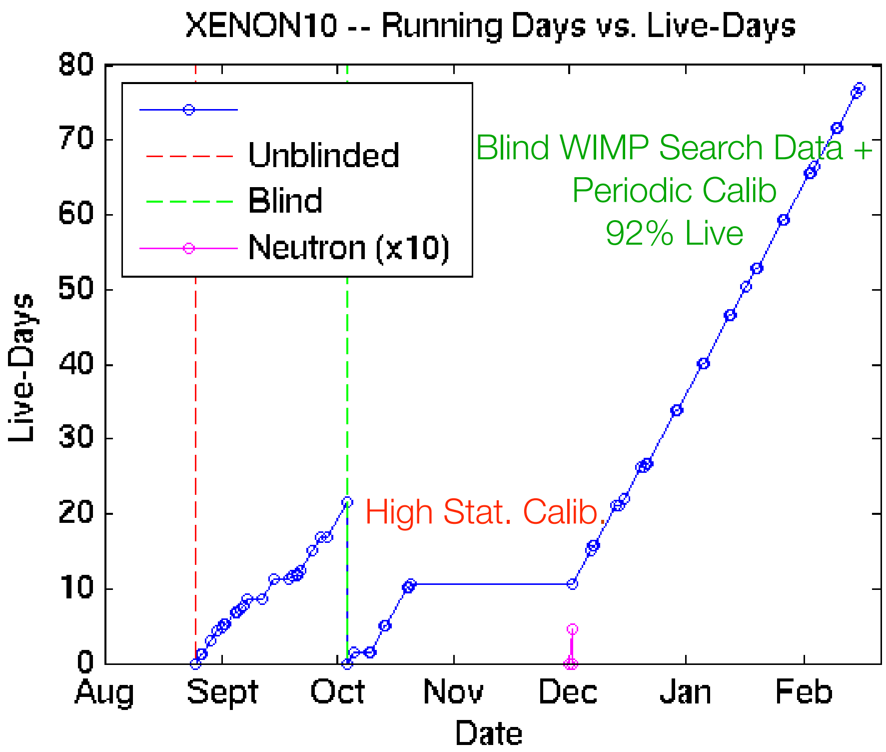
Offices and above-ground laboratories at Gran Sasso

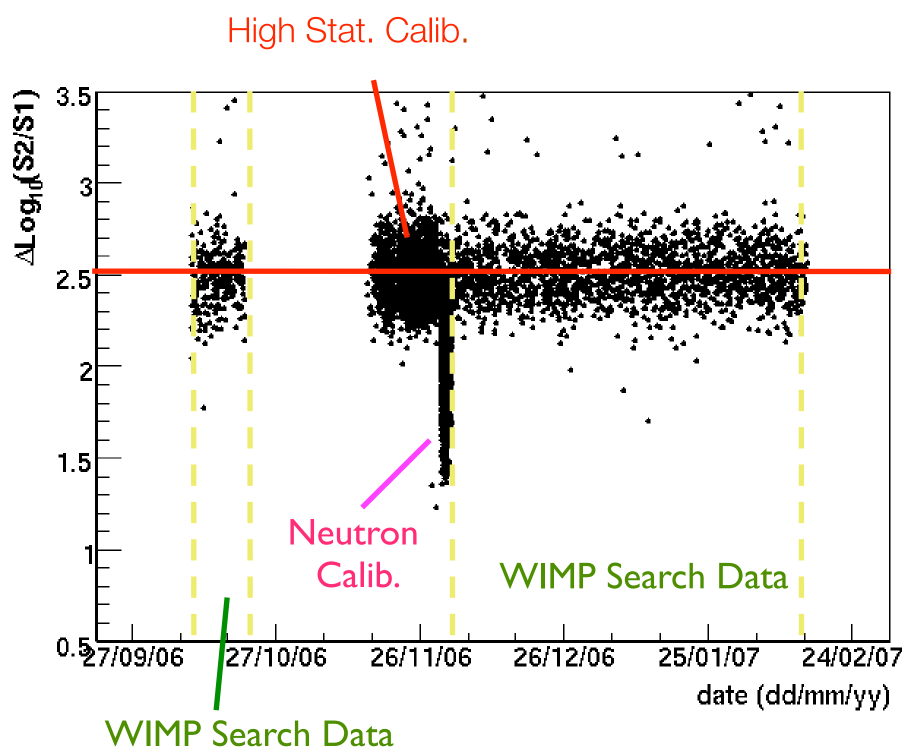
Yalies at Gran Sasso, 7/2006:
Angel Manzur (grad student),
Ruth Toner (undergrad),
Kaixuan Ni (postdoc)

XENON10 at the Gran Sasso Laboratory

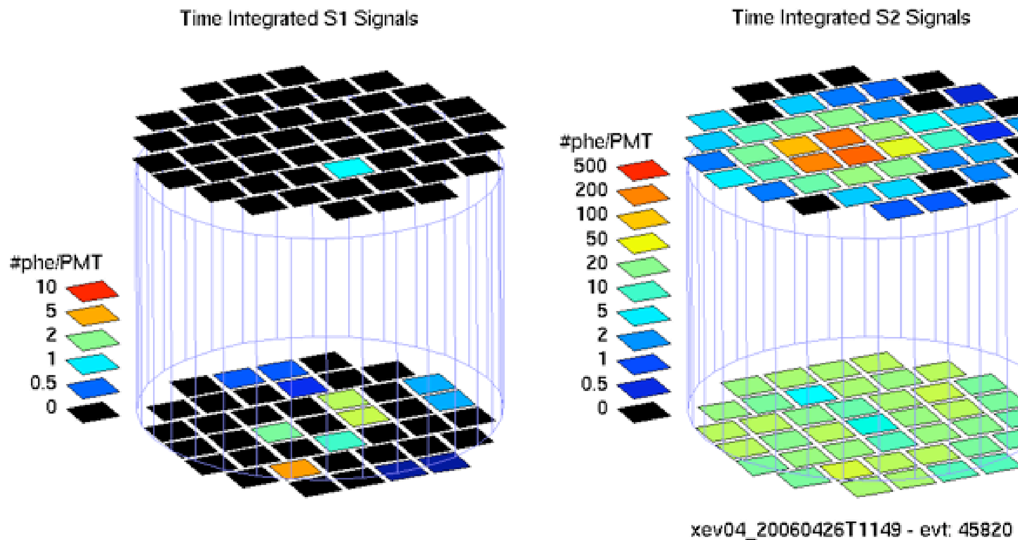


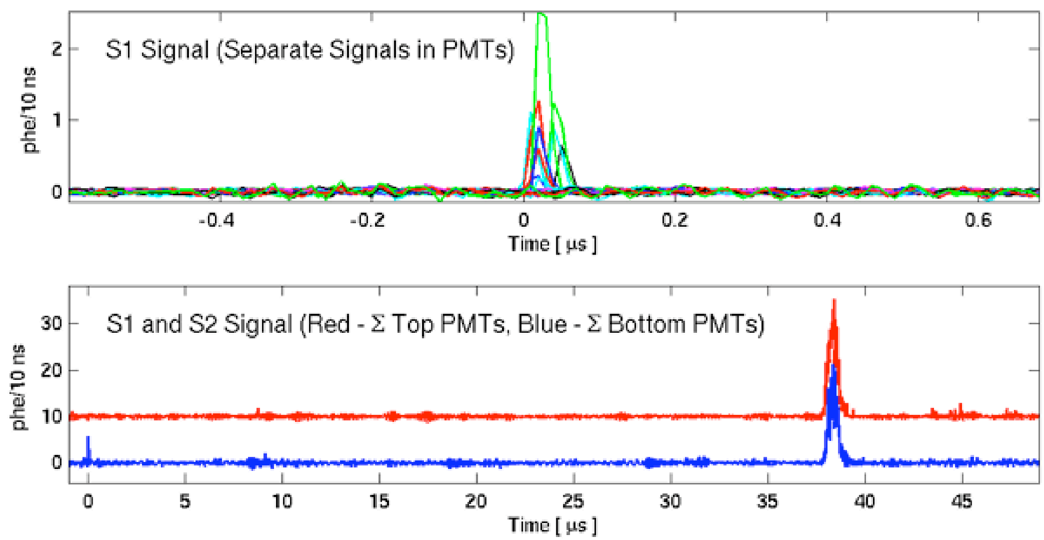
XENON10 Live-Time / Dark Matter Run Stability





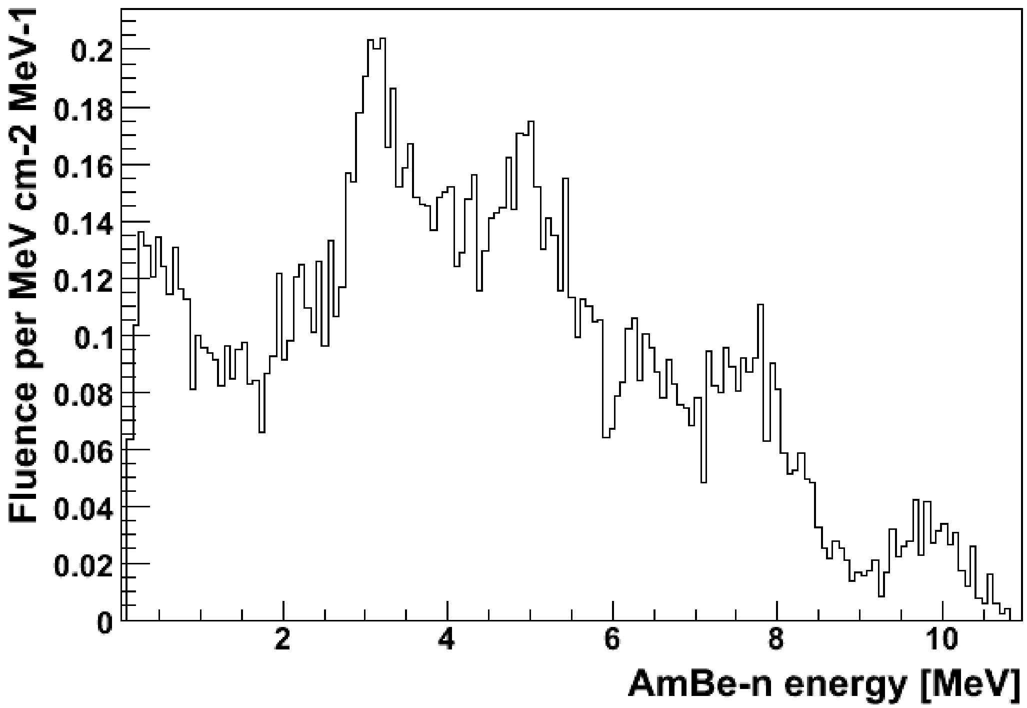
XENON10 Calibration runs @ LNGS





AmBe source

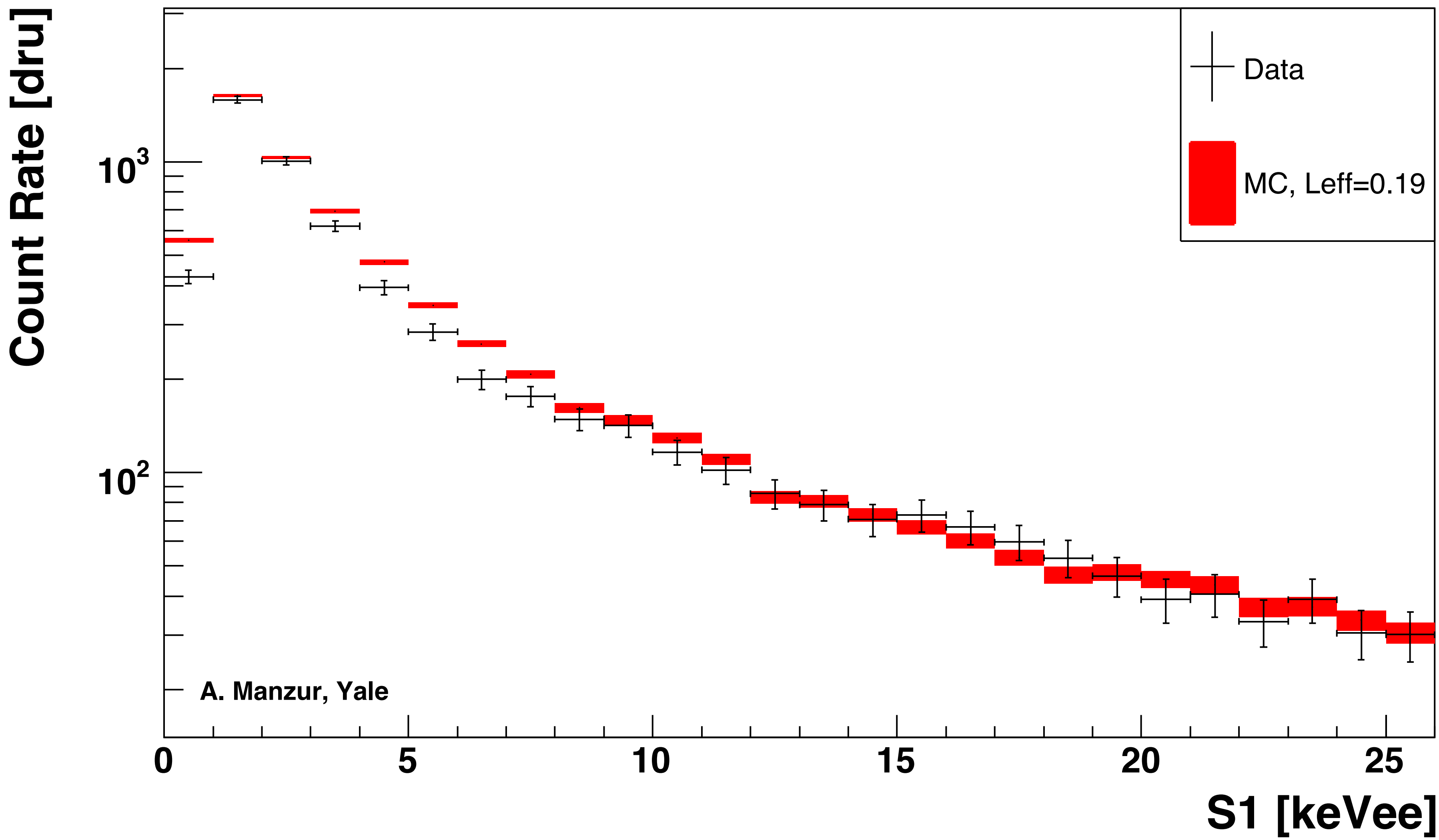
J W Marsh et al, NIM A 366 (1995) 340



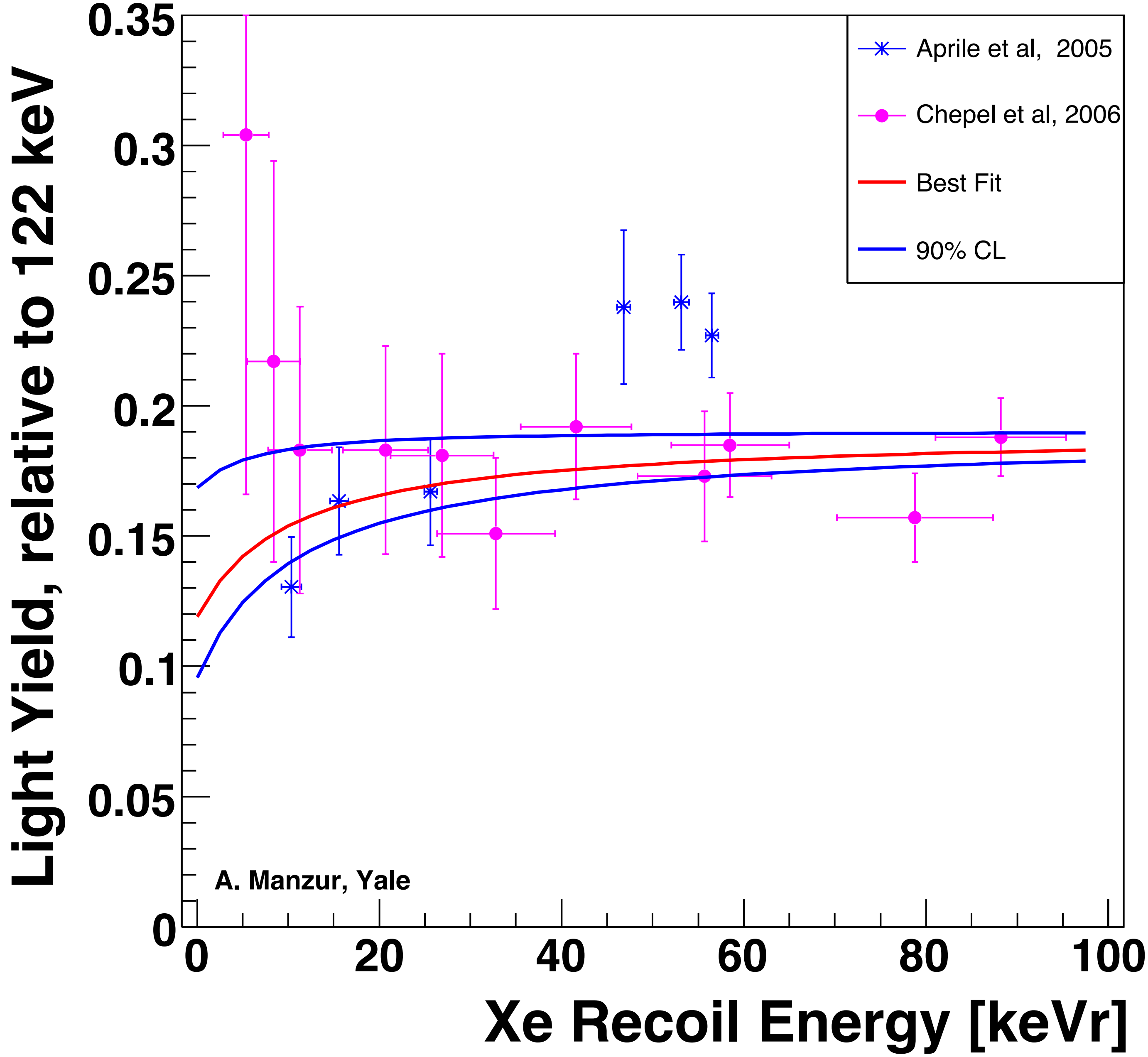
Neutron spectrum

- 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

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

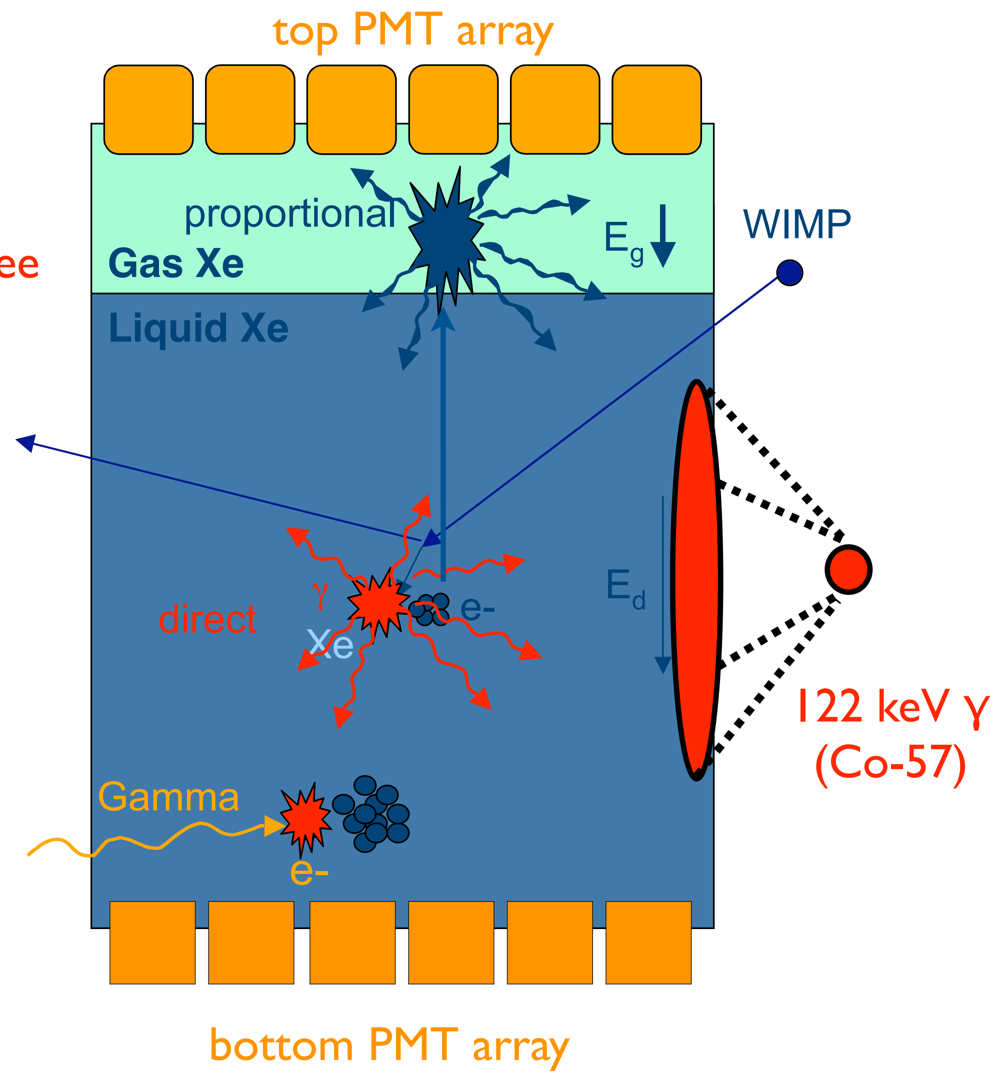
light yield for 122 keV γ in pe/keVee

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

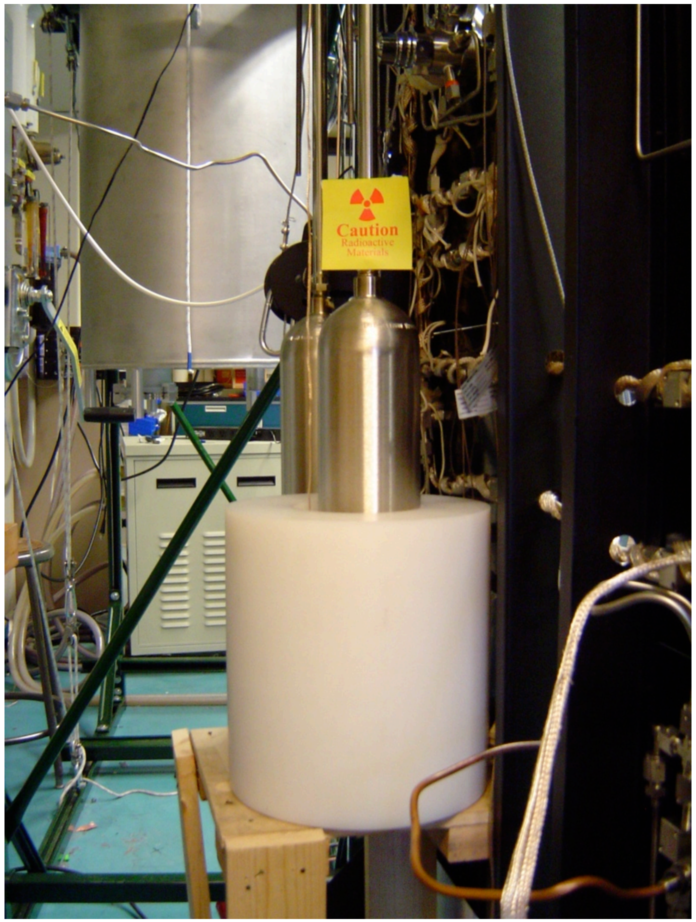
relative scintillation efficiency of NRs to 122 keV γ's at zero field

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

quenching of scintillation yield for NRs due to drift field



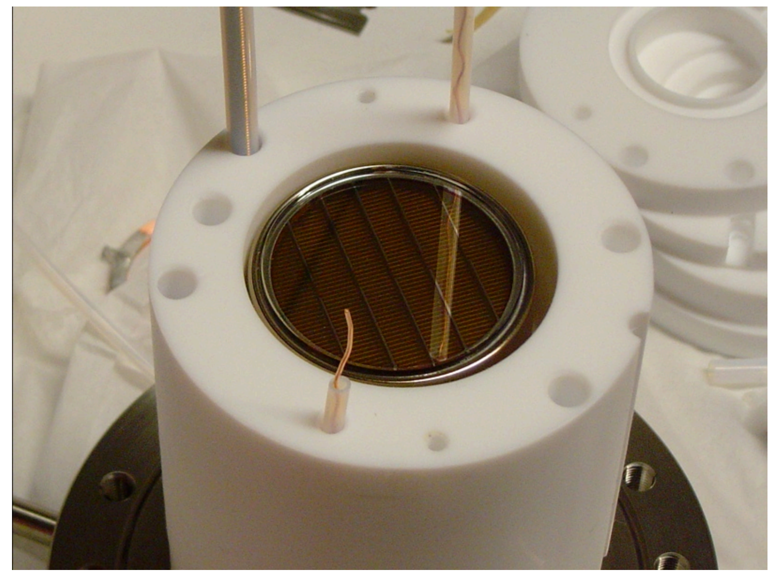
Xenon Activation with Cf-252 at Yale



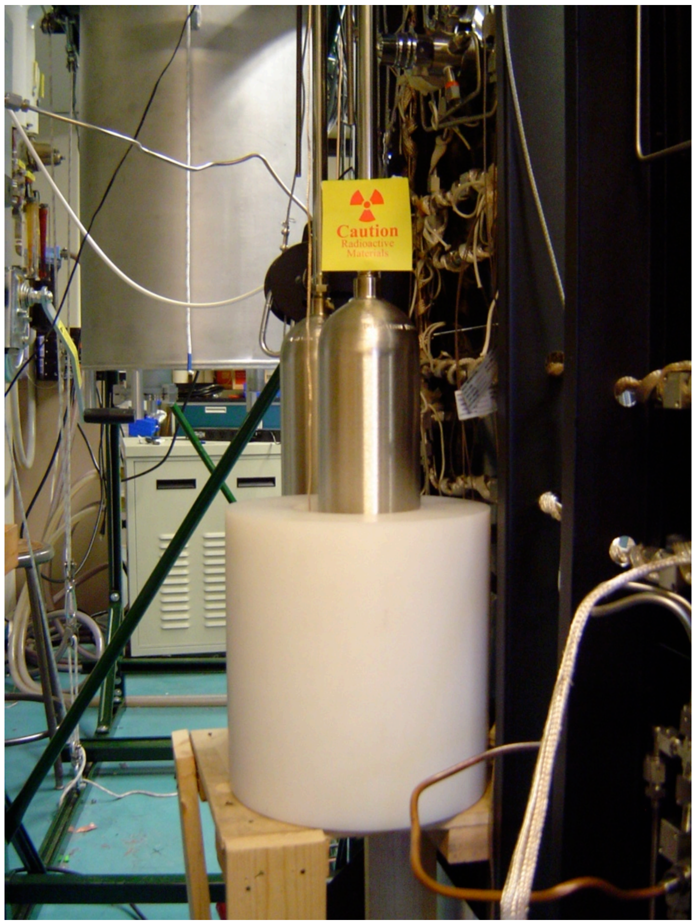
continuous activating Xe gas with a 5×10^5 n/sec Cf-252 source for 12 days

→

measure the scintillation light in a liquid Xenon cell

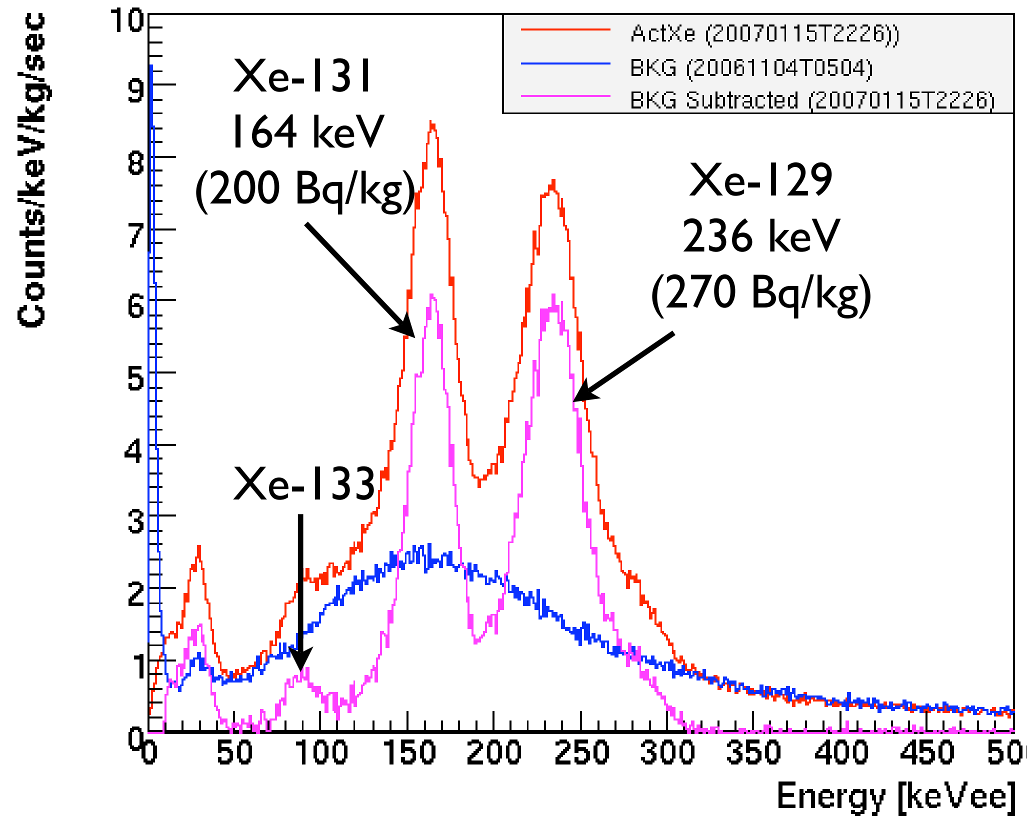


Xenon Activation with Cf-252

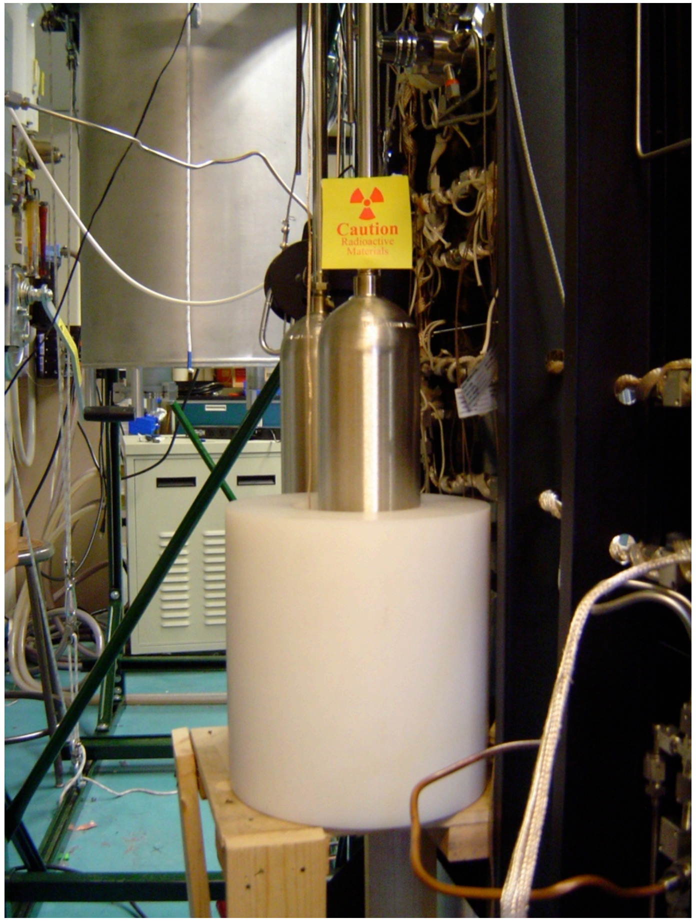


continuous activating Xe gas with a $5x10^5$ n/sec Cf-252 source for 12 days

after 12-days of activation ...



Xenon Activation with Cf-252

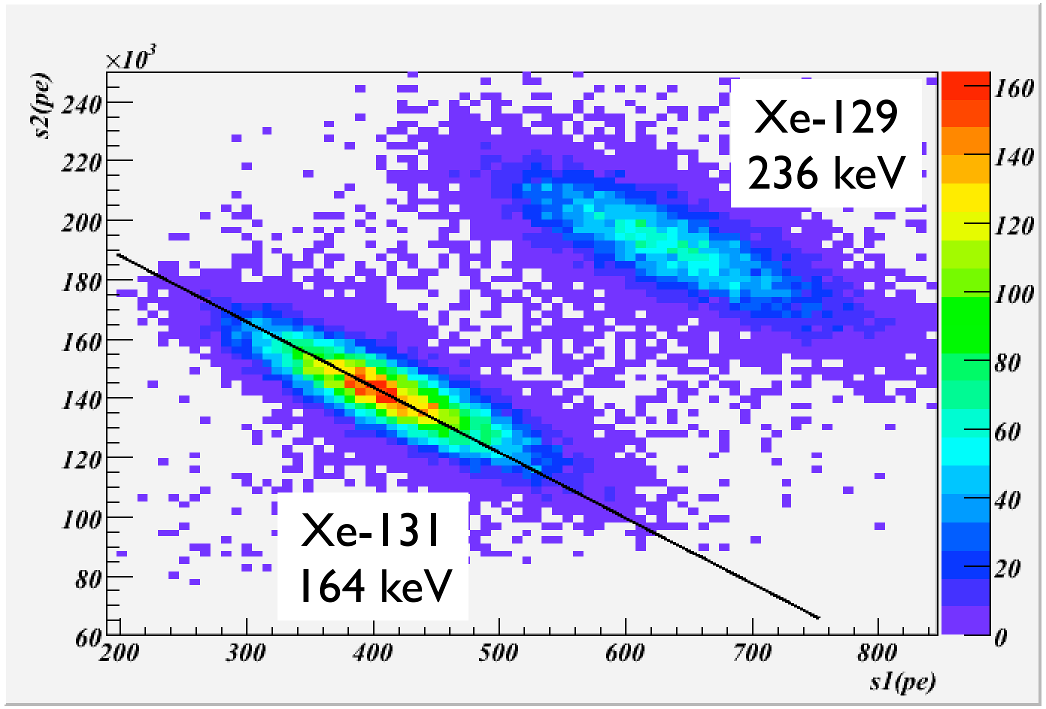


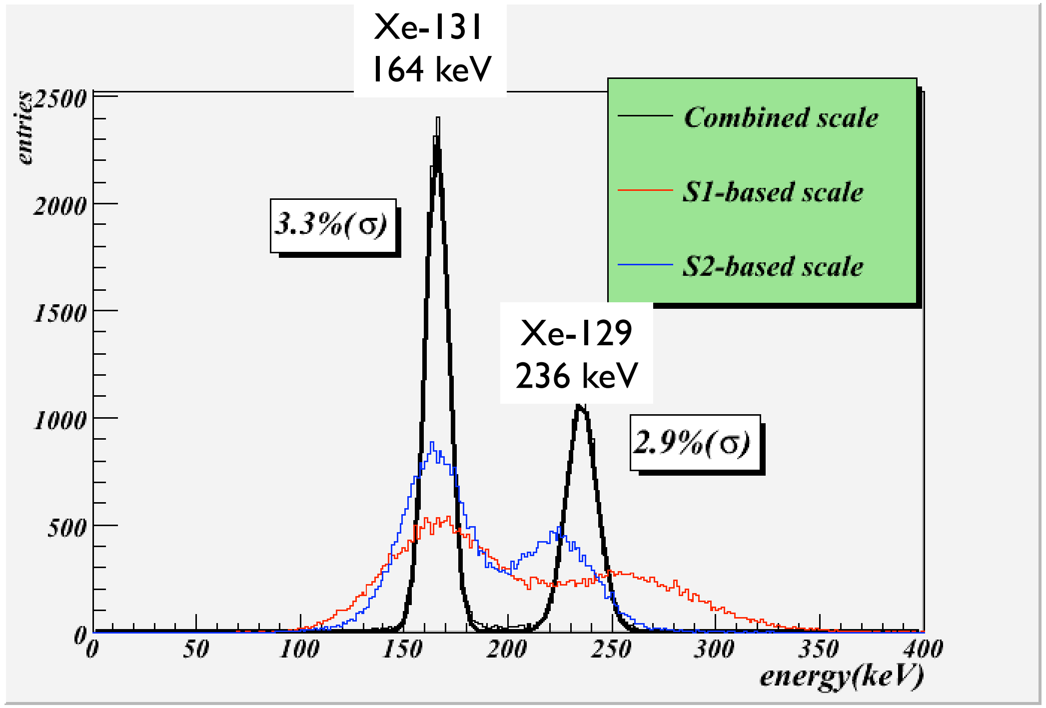
Yale (USA)

~ 1 week

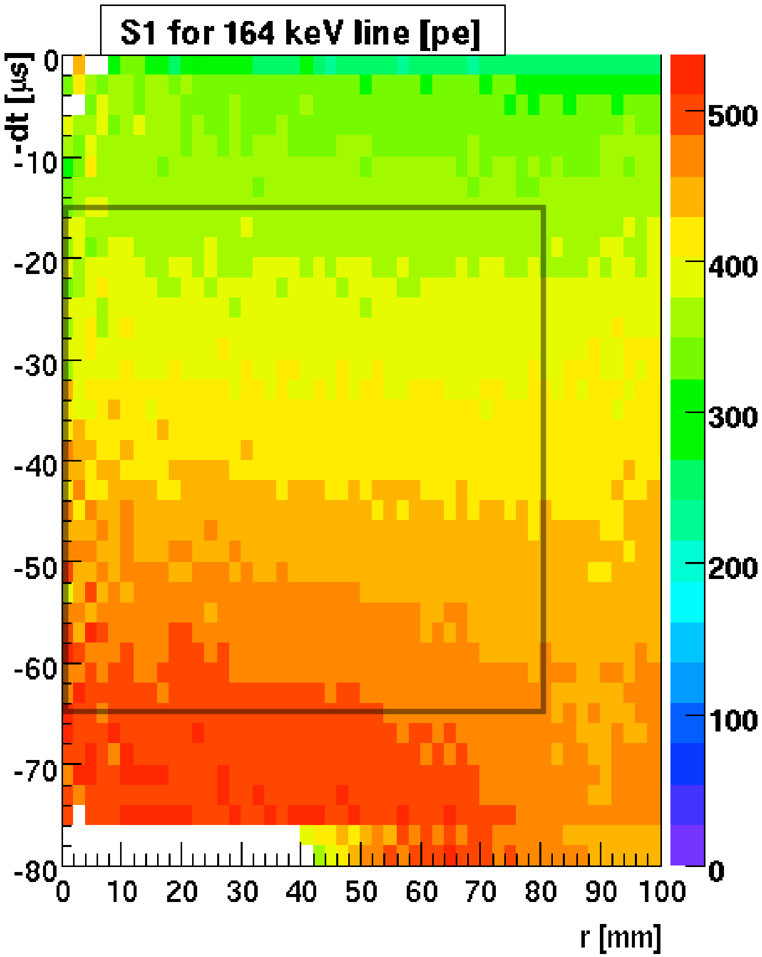
XENON10
Gran Sasso (Italy)

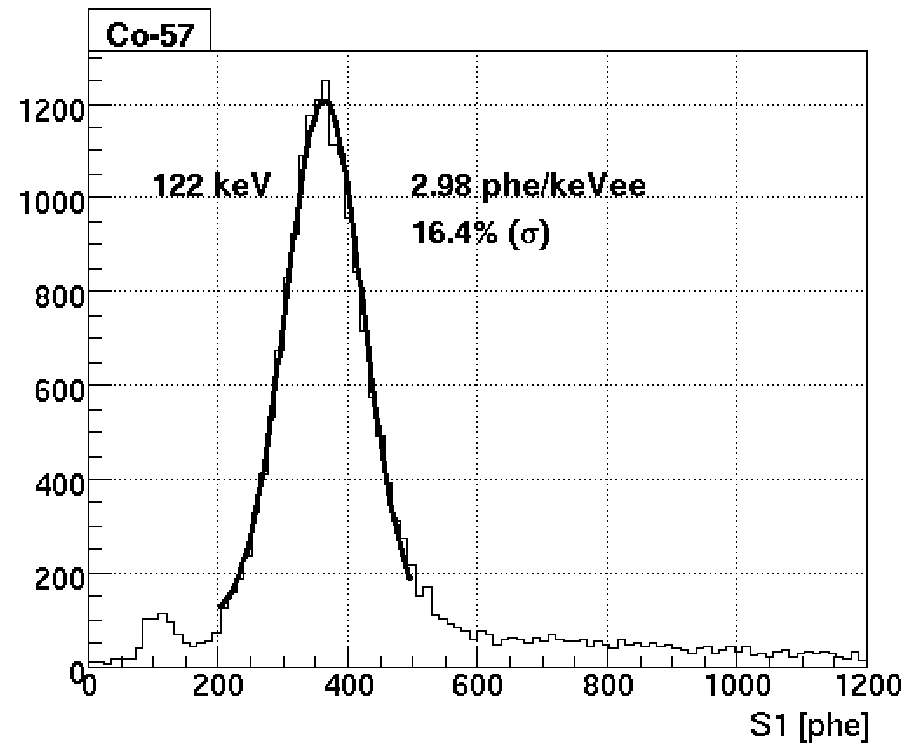
Activated Xenon Lines in XENON10





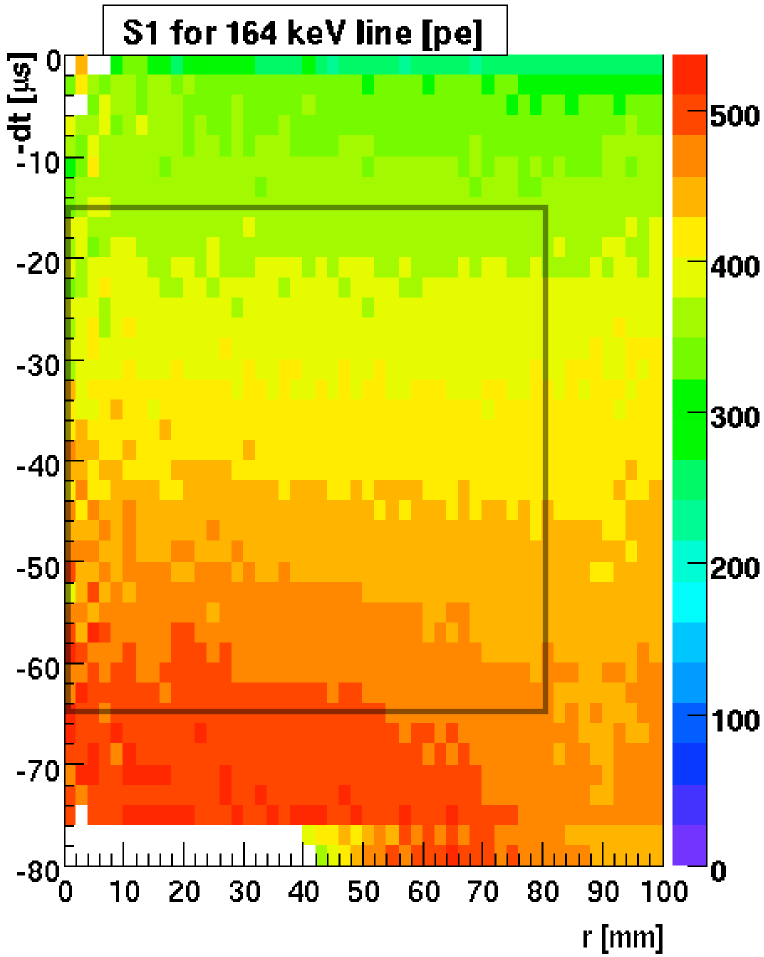
Position dependence of S1 signals in XENON10

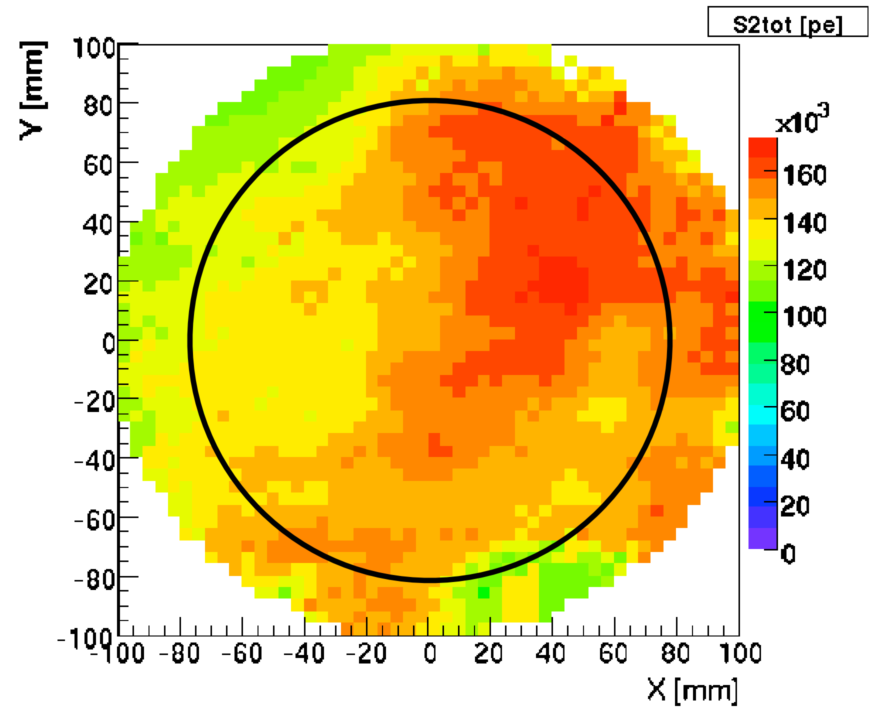




after position-dependent corrections

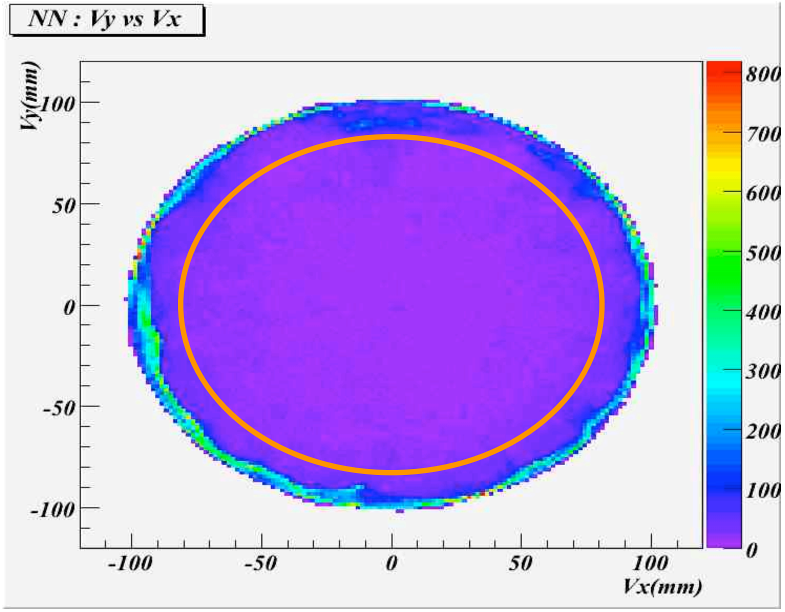
Position dependence of S1 and S2 signals

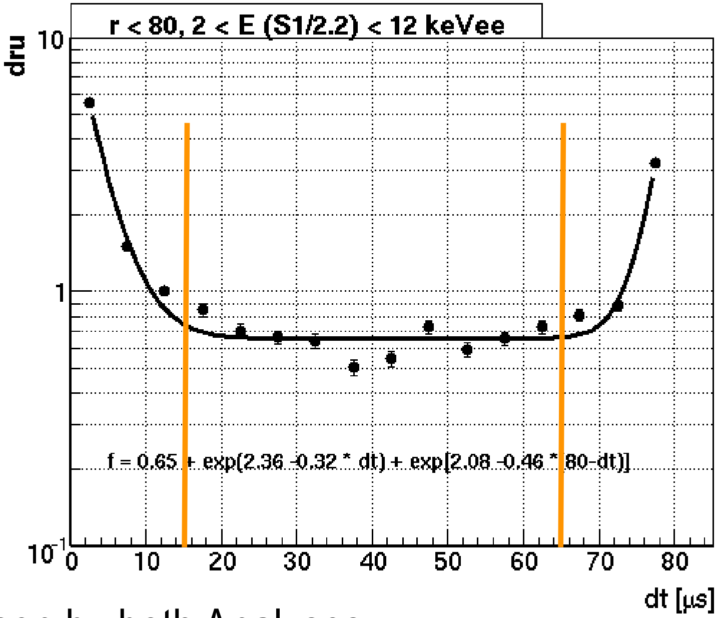




The XENON10 results are from position-dependent corrected signals by using these maps obtained from activated-Xe calibration

XENON10 Fiducial Volume cuts





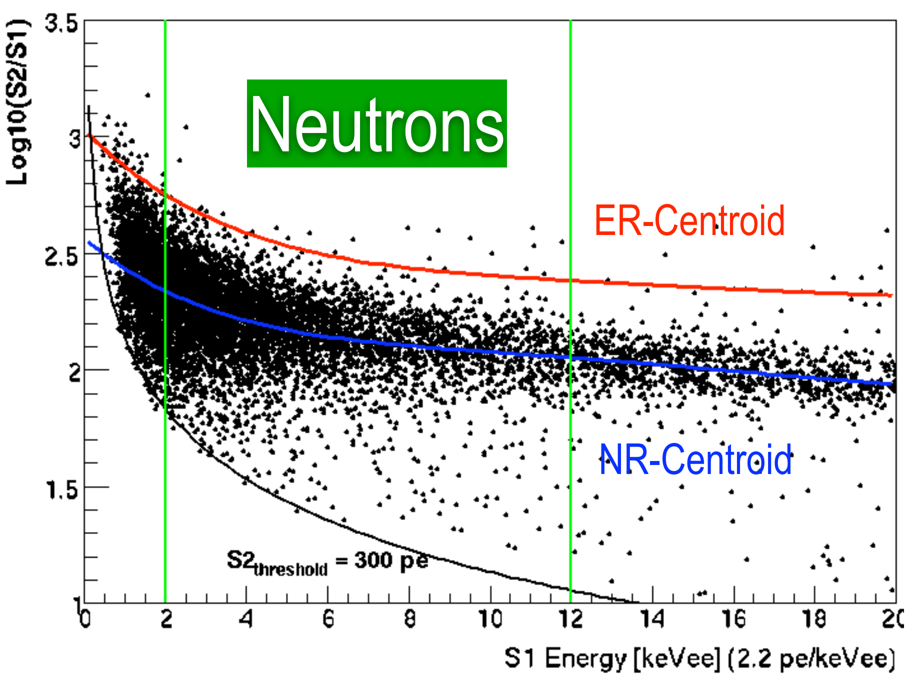
Fiducial Volume chosen by both Analyses:

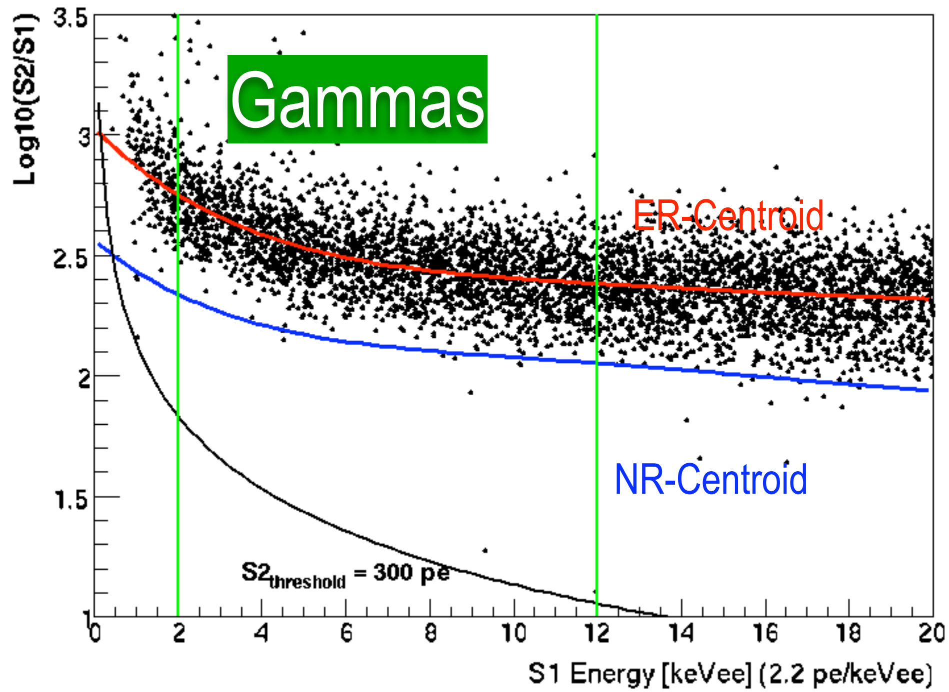
15 < dt < 65 us, r < 80 mm

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

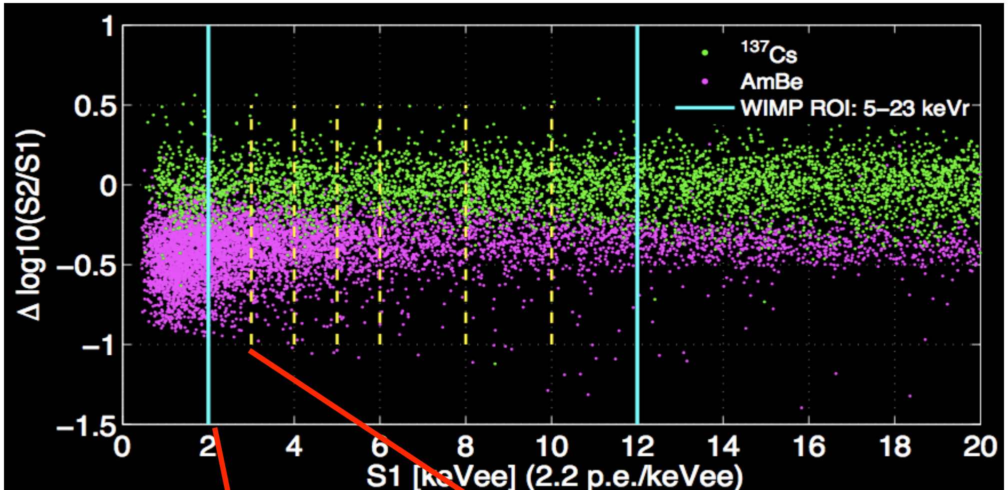




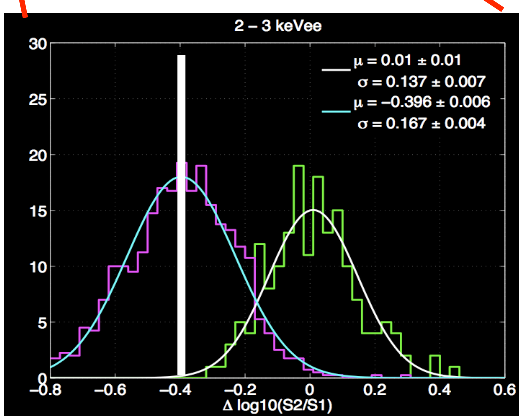
AmBe Neutron Calibration (NR-band)

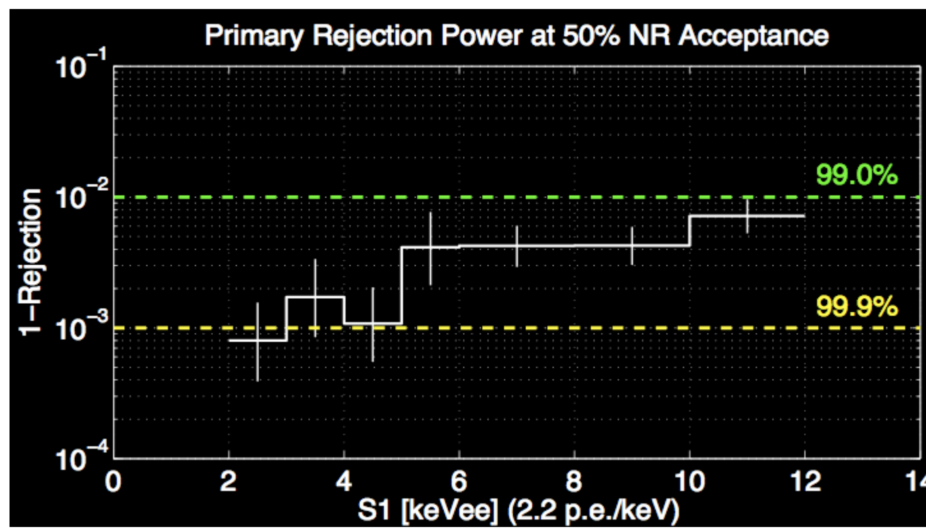
Cs-137 Gamma Calibration (ER-band)

Gamma background rejection efficiency



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



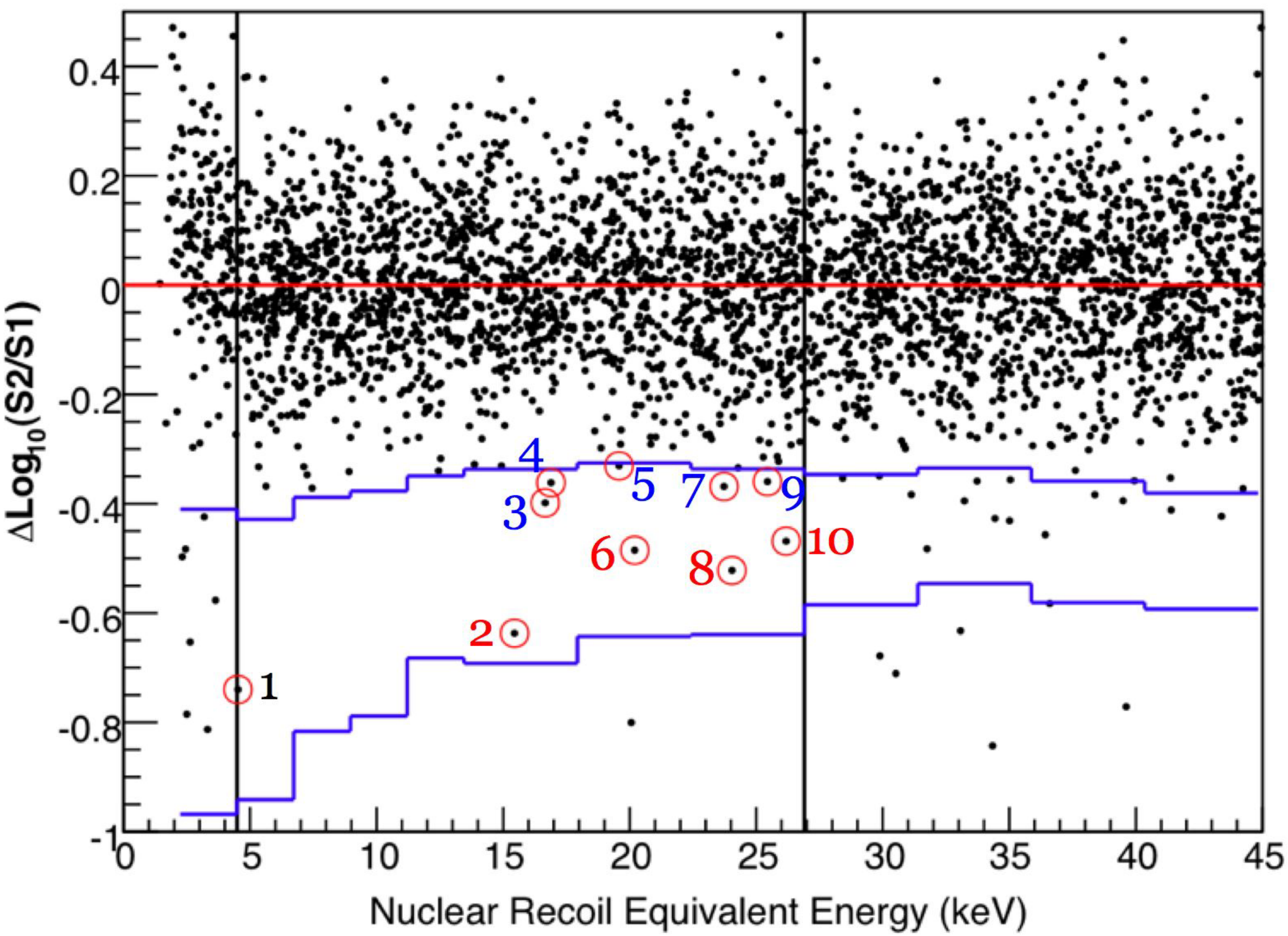


XENON10 WIMP Search Data (Blind Analysis)

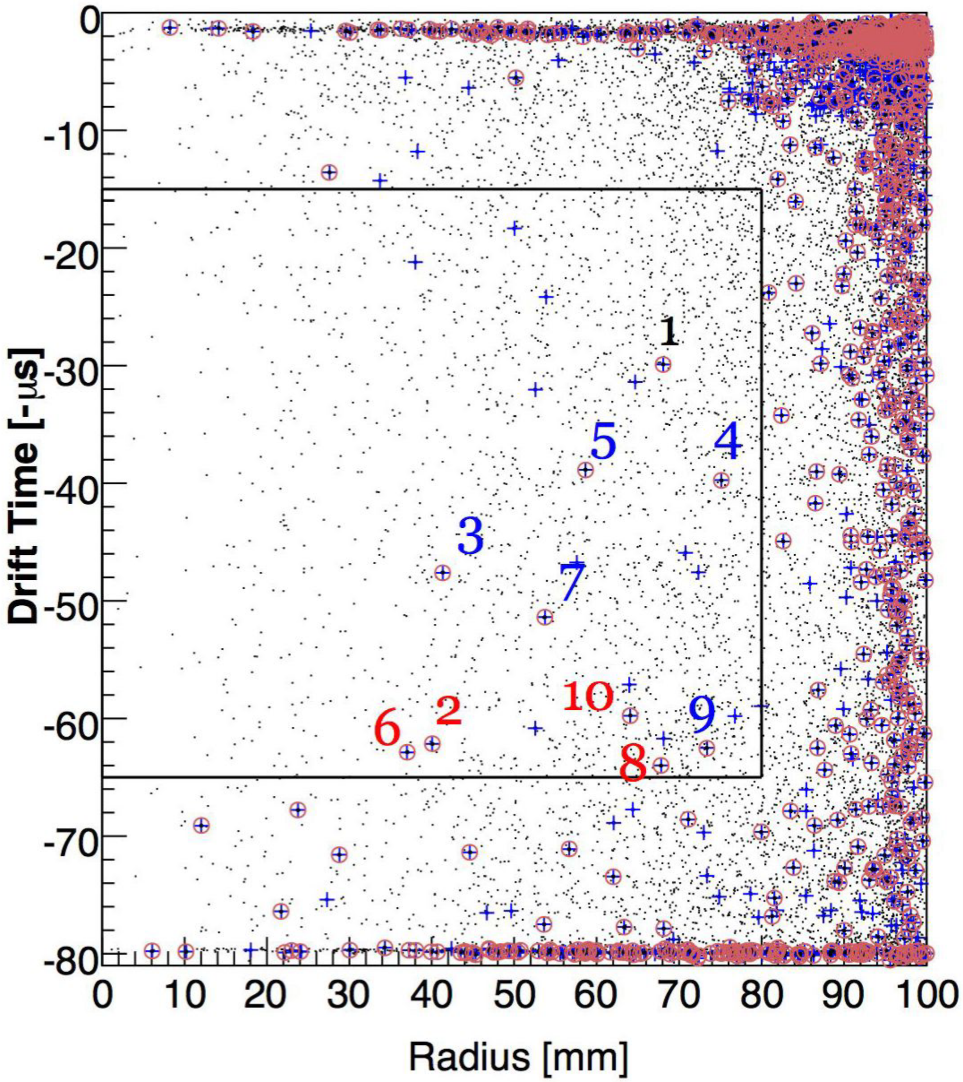
136 kg-days Exposure= 58.6 live days x 5.4 kg x 0.86 cut efficiency x 0.50 (50% NR)
Nuclear recoil energy scale based on 19% quenching factor

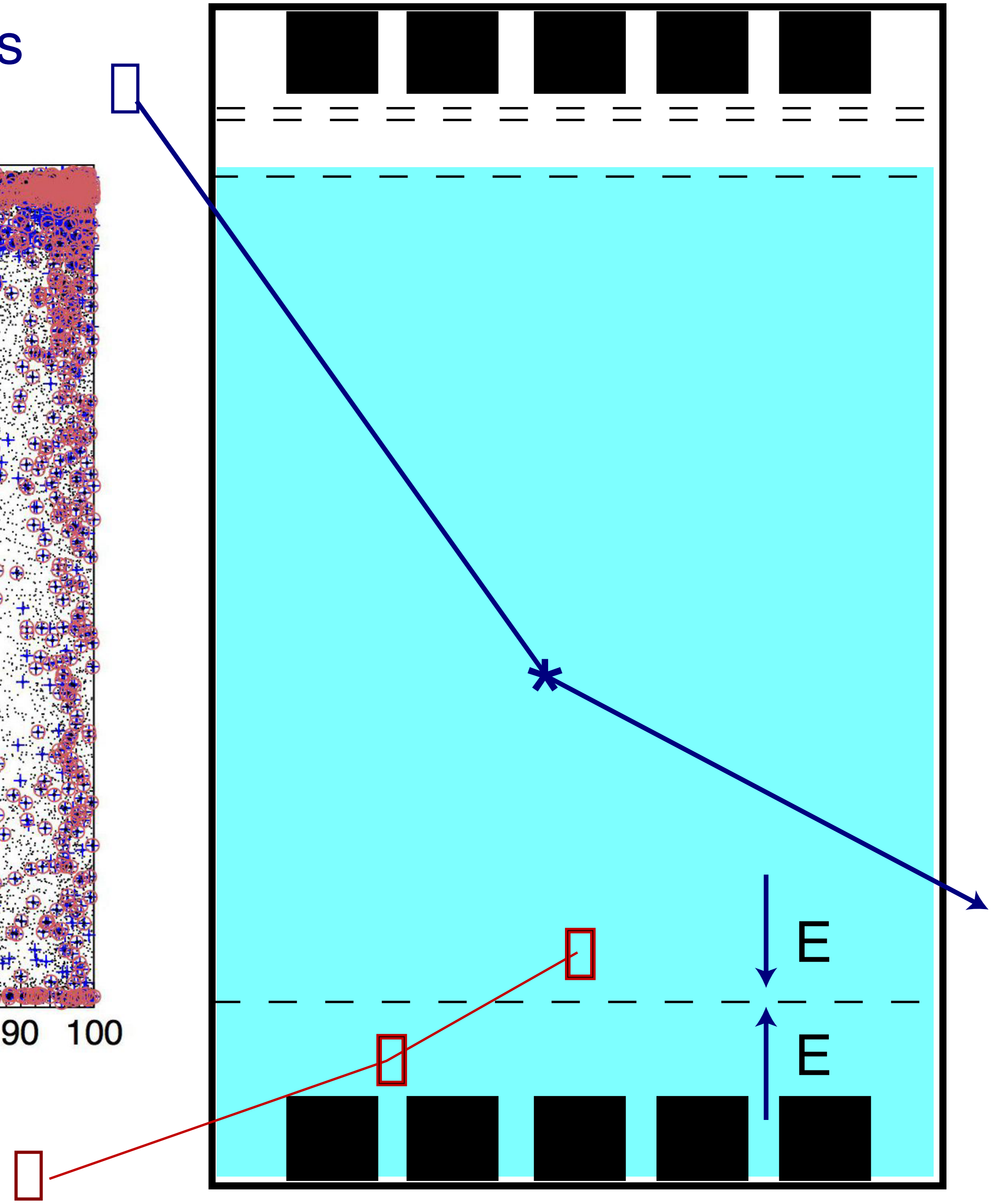
10 background events after cuts:

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



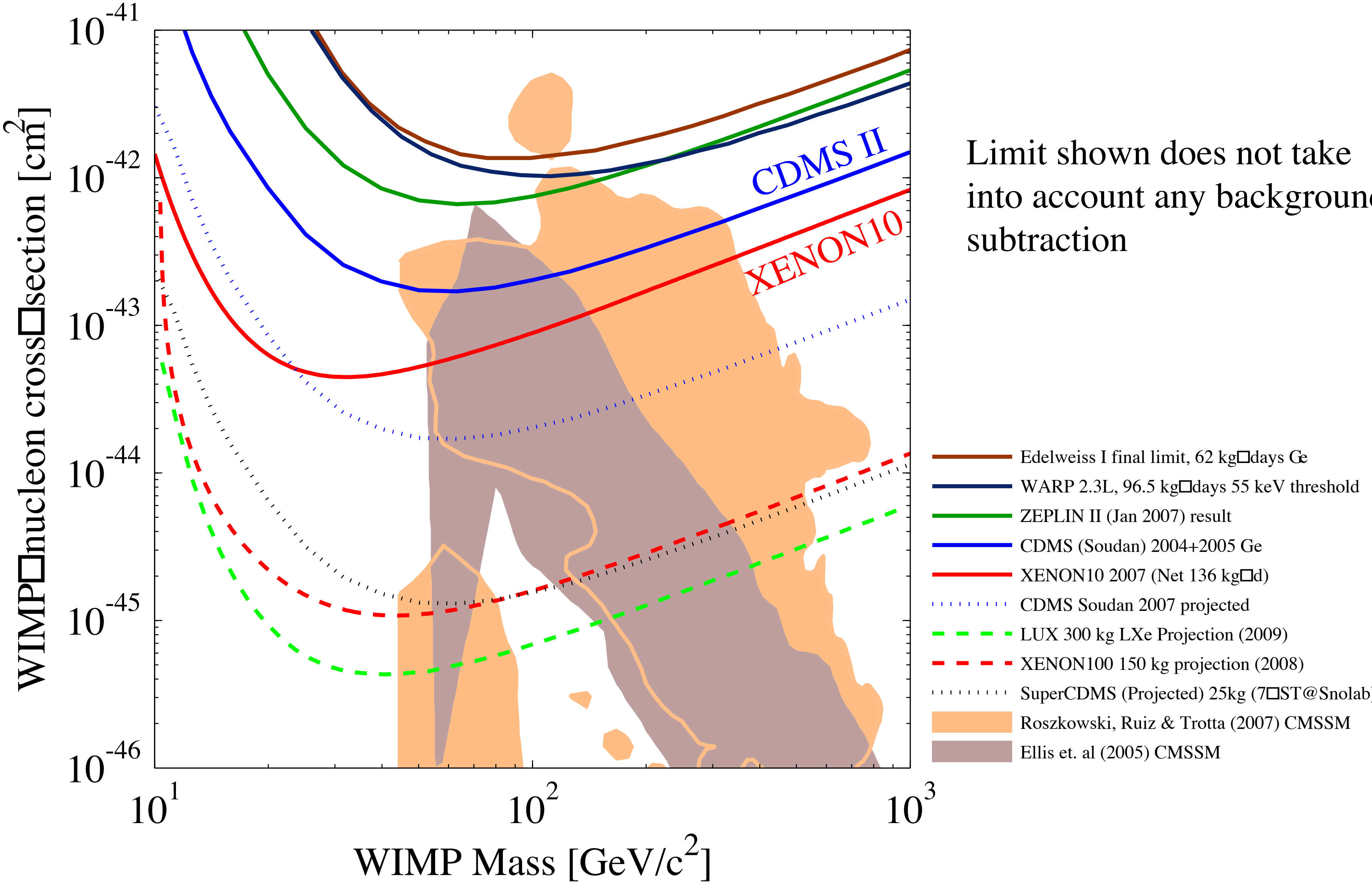
XENON10 backgrounds





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

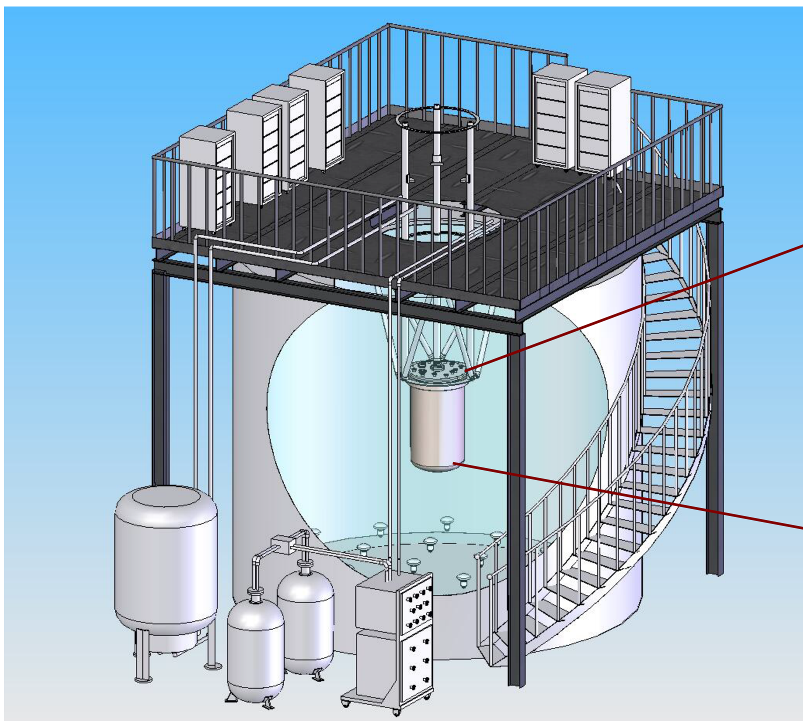
watch for arXiv submissions in coming 2 months...

The LUX Dark Matter Experiment

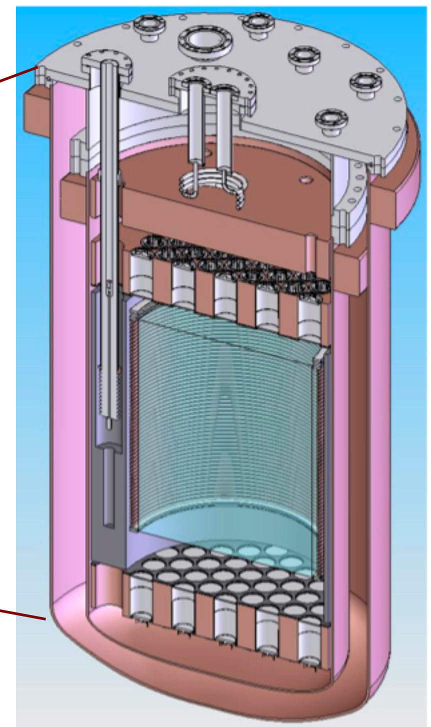
Brown [Gaitskell], Case [Shutt], LBNL [Lesko] , LLNL [Bernstein], Rochester [Wolfs], Texas A&M [White], UC Davis [Svoboda/Tripathi], UCLA [Wang/Arisaka/Cline], Yale [McKinsey]

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

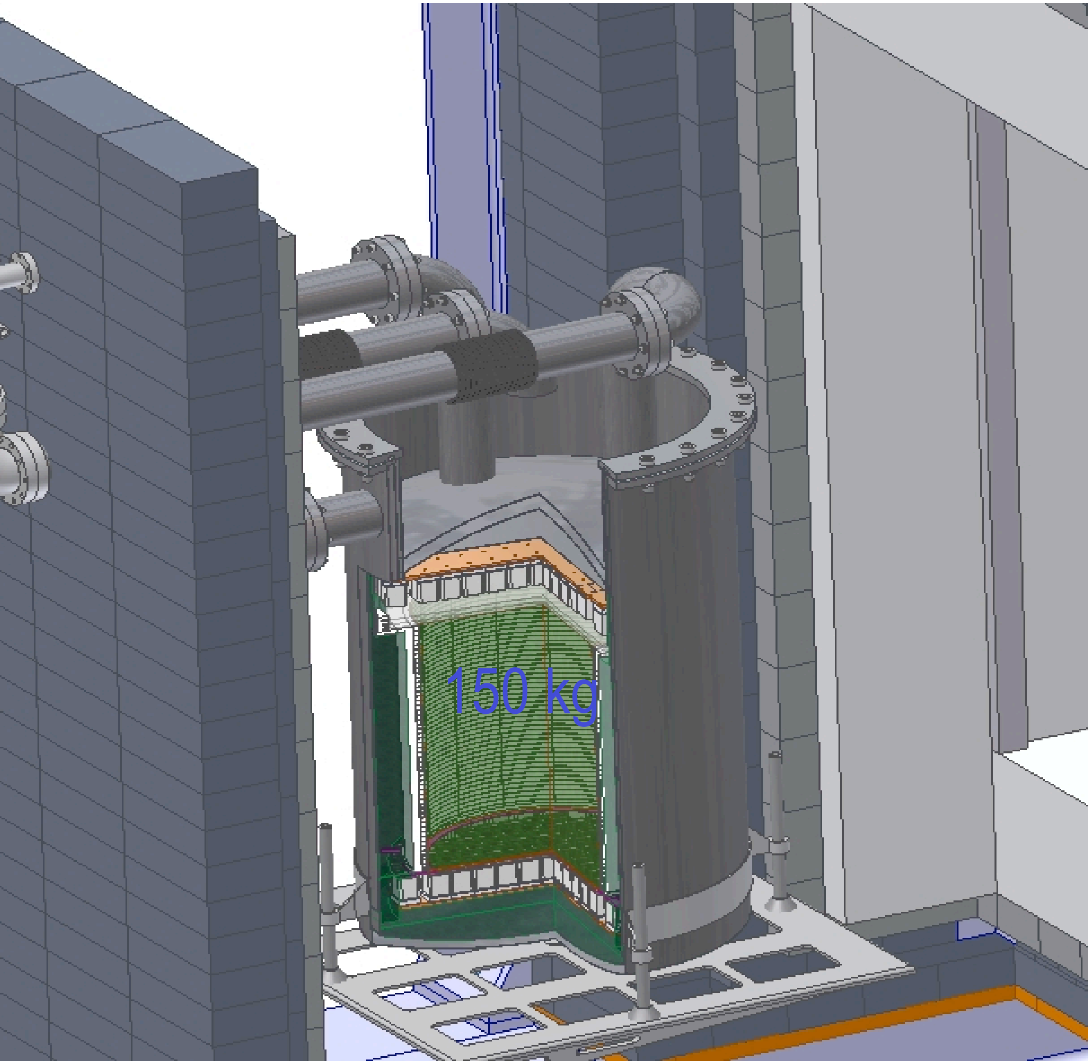


Two-phase LXe detector

LUX Cryostat Assembly
(Case Western)

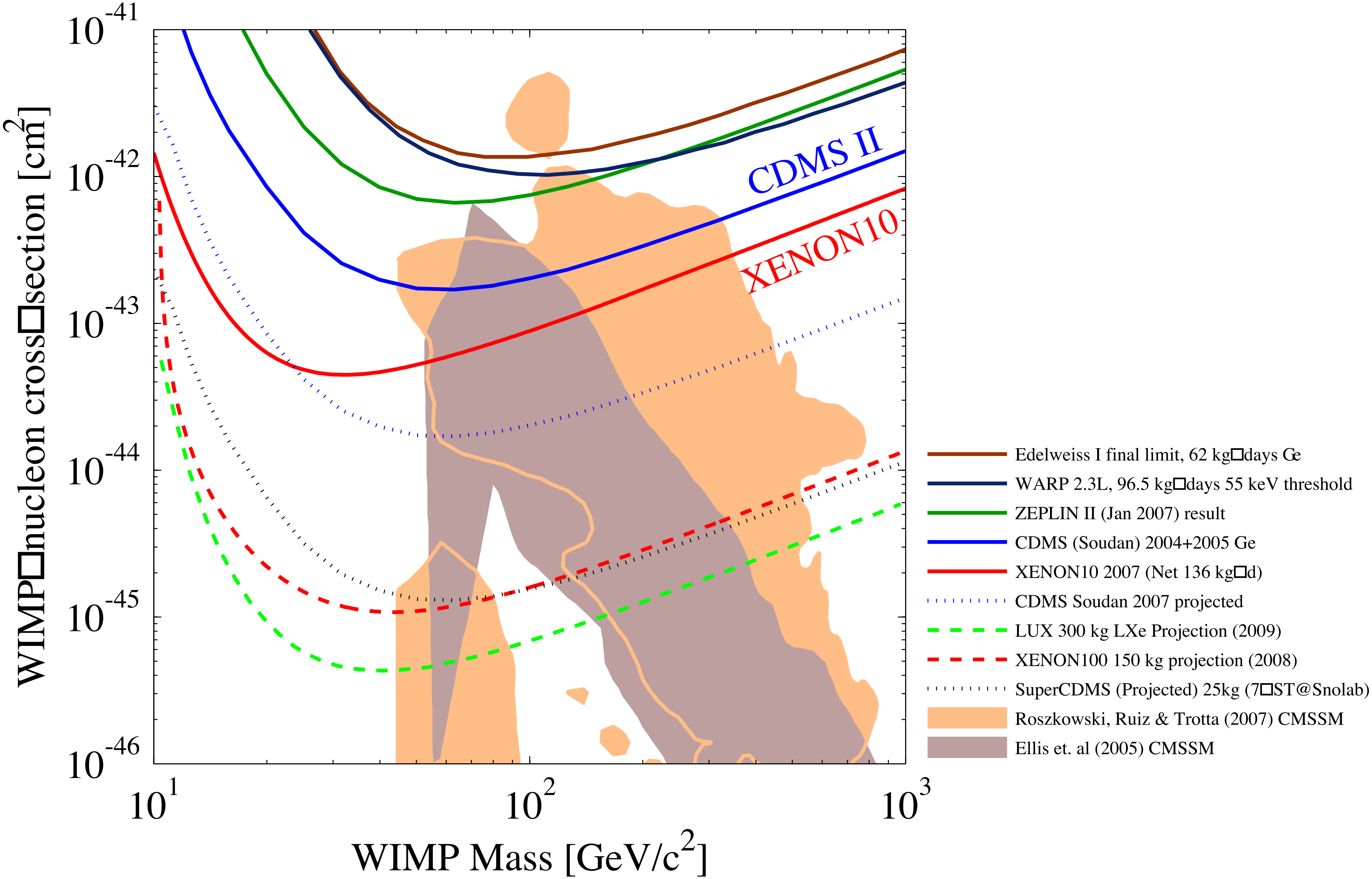
XENON100 : 2007-2008

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

Current and Projected WIMP Limits



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.

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