The LUX Dark Matter Experiment

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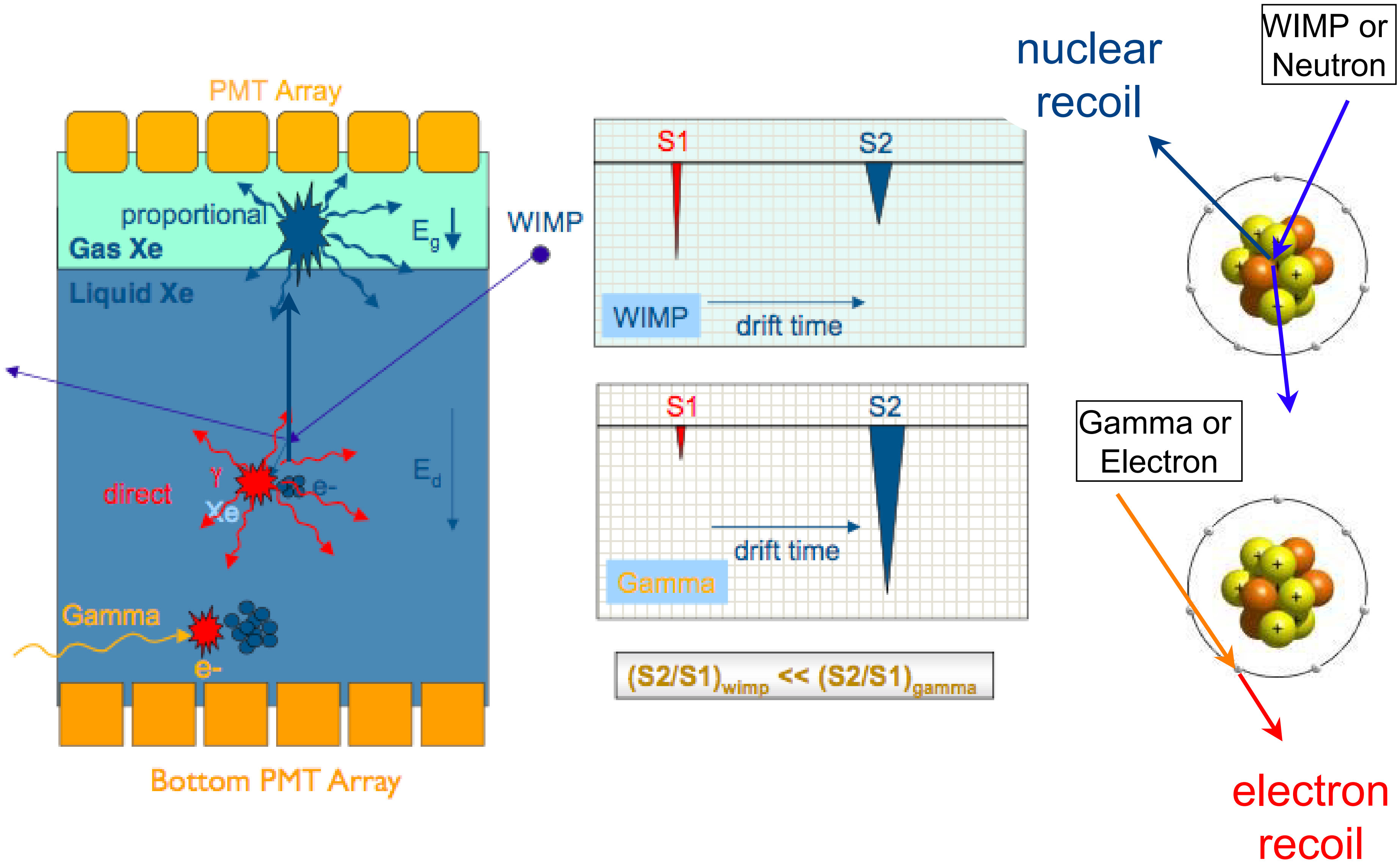
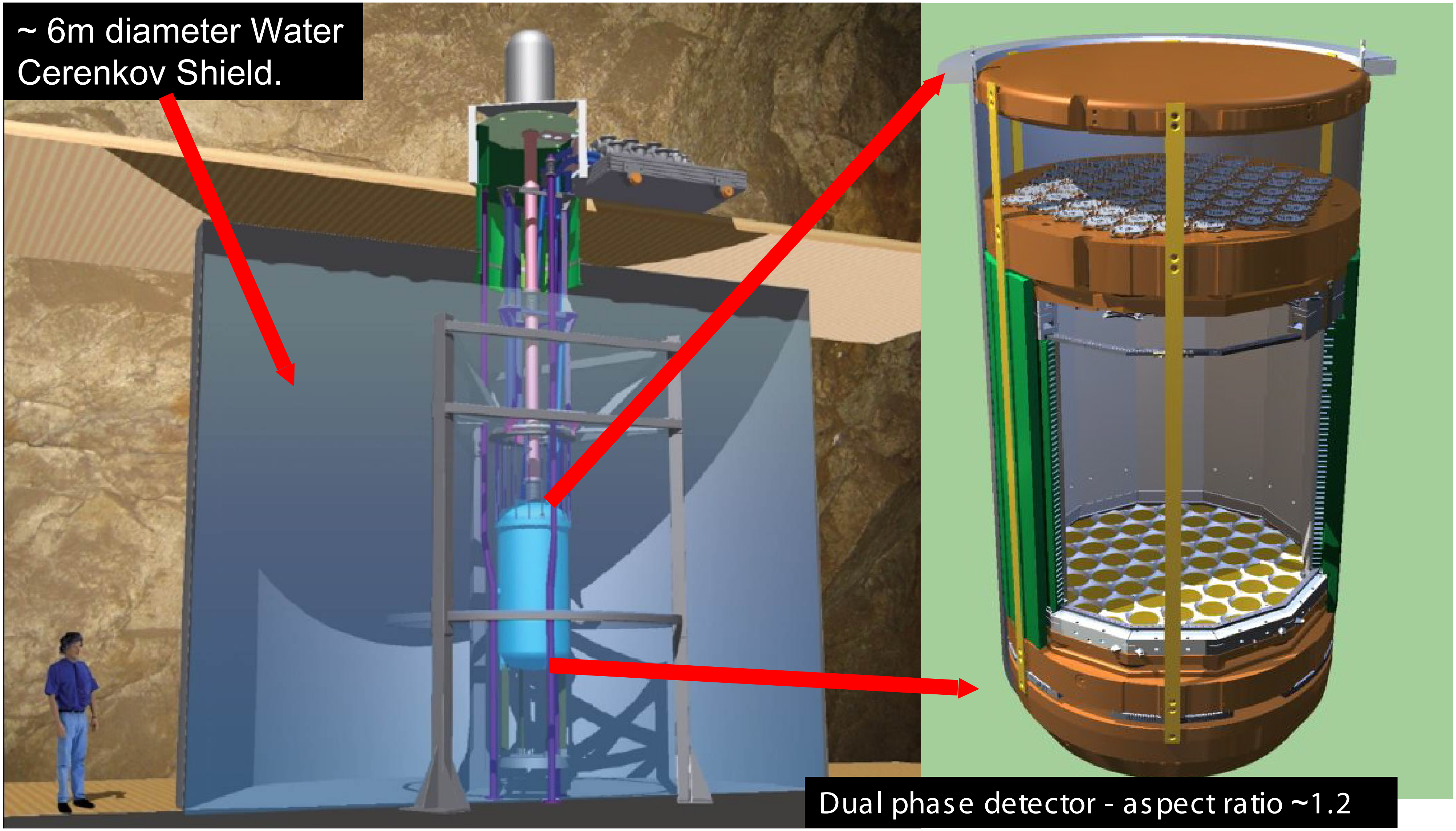
September 17, 2009

WIN 2009, Perugia

Two-phase xenon detectors



The LUX Detector



350 kg Dual Phase Liquid Xenon Time Projection Chamber, fully funded by NSF and DOE
2 kV/cm drift field in liquid, 5 kV/cm for extraction, and 10 kV/cm in gas phase.
122 PMTs (Hamamatsu R8778) in two arrays
3D imaging via TPC eliminates surface events, defines 100 kg fiducial mass

The LUX-350 Collaboration

Brown University: Richard Gaitskell, Simon Fiorucci, Carlos Hernandez Faham, Jeremy Chapman, David Malling, Luiz de Viveiros

Case Western Reserve University: Dan Akerib, Adam Bradley, Ken Clark, Mike Dragowsky, Patrick Phelps, Thomas Shutt

Harvard University: Masahiro Morii

Lawrence Berkeley National Laboratory: Kevin Lesko, Yuen-Dat Chan, Brian Fujikawa

Lawrence Livermore National Laboratory: Adam Bernstein, Steven Dazeley, Peter Sorensen, Kareem Kazkaz

Moscow Engineering Physics Institute: Alexander Bolozdynya

South Dakota School of Mining and Technology: Xinhua Bai

Texas A&M: Rachel Mannino, Tyana Stiegler, Robert Webb, James White

UC Davis: Tim Classen, Britt Holbrook, Richard Lander, Jeremy Mock, Robert Svoboda, Melinda Sweany, John Thomson, Mani Tripathi, Nick Walsh, Michael Woods

University of Maryland: Carter Hall, Douglas Leonard

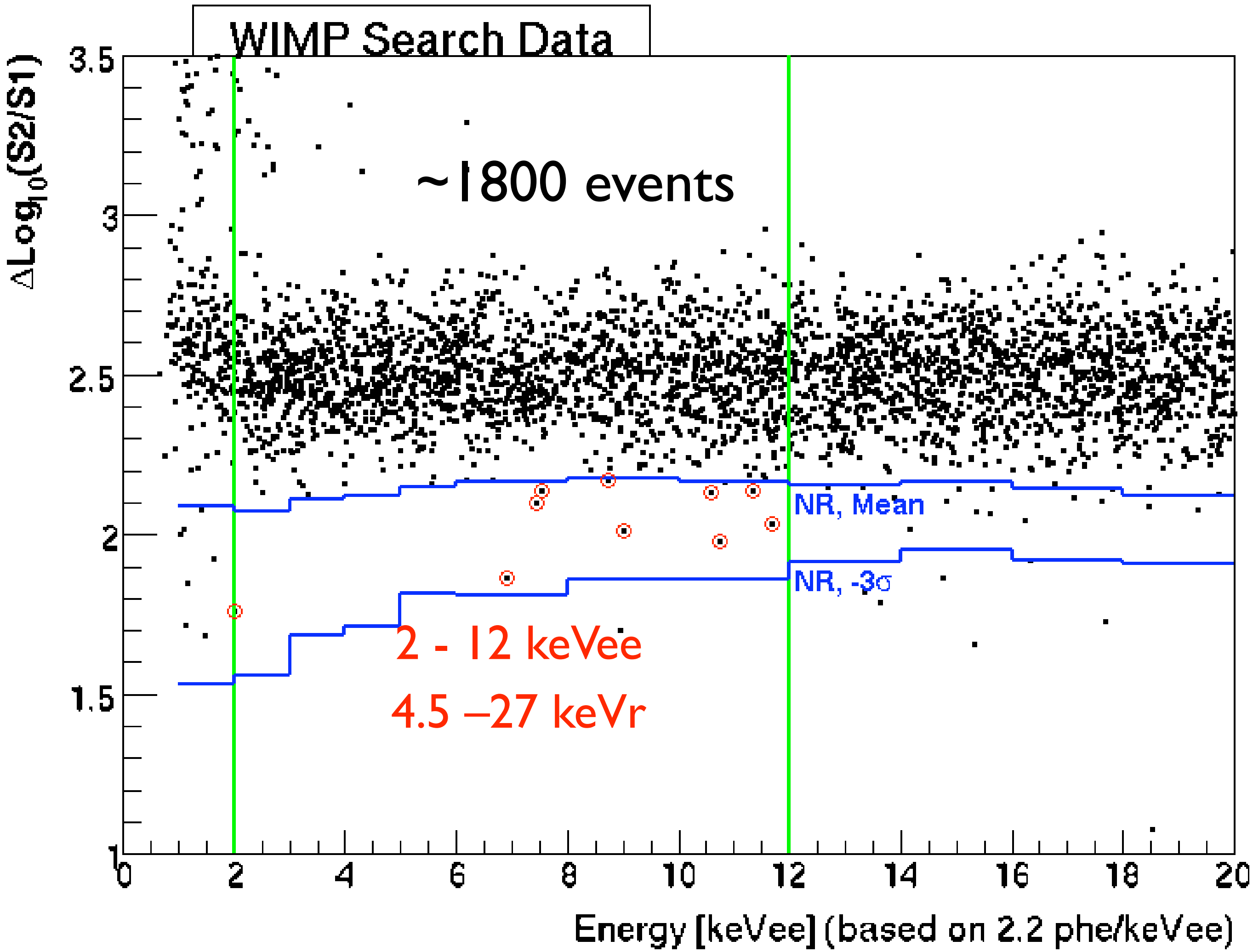
University of Rochester: Eryk Druszkiewicz, Udo Schroeder, Wojtek Skulski, Jan Toke, Frank Wolfs

University of South Dakota: Dongming Mei

Yale University: Susie Bedikian, Sidney Cahn,Alessandro Curioni, Louis Kastens, Alexey Lyashenko, Daniel McKinsey, James Nikkel

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

LUX-350 is a background-free experiment

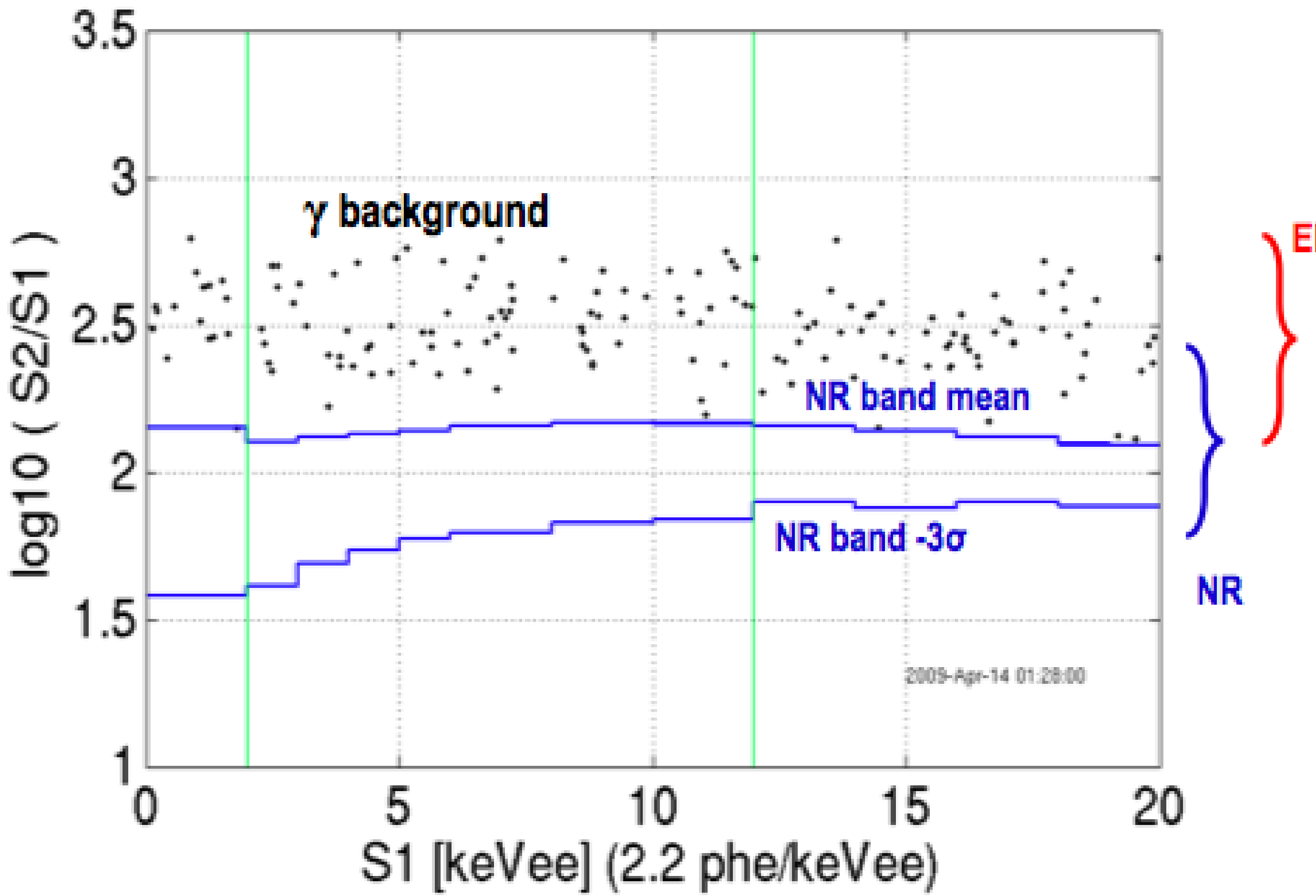
Self-shielding drastically reduces gamma-ray background in the fiducial volume
By defining a fiducial volume, gamma ray backgrounds drop enormously, scaling as exp[-L/Ls], where L is the size of the active volume, and Ls is the gamma ray scattering length. Electron recoil background ~2.6×10^{-4} events/keVee/kg/day (from simulations)

300 days acquisition

100 kg fiducial mass

$L_{eff} = 0.19$

Using same ER and NR bands as XENON10



Titanium

Grade CP1 generally good.
CP2 had high counts in 2 samples.

Sample activated in air transport
Not a problem for construction
Materials. 86 days half-life

	Sample Type	Grade	Dim.	# of piece	Total weight	Counted At	U		Th		K-40		Sc-46
							ppb	mBq /kg	ppb	mBq /kg	ppm	mBq/ kg	mBq/ kg
Ti1	3/8" plate	CP1	2.5" x 6"	4	1.87 kg	Oroville	<0.2	< 2.5	<0.4	< 1.6	<0.2	< 6.2	4.8
Ti2	3/16" plate	CP2	4" x 6"	20	7.55 kg	SOLO	10.4	130	17.5	70		--	
Ti3	0.358" plate	CP2	~ 1.3" x 6"	8	1.55 kg	SOLO		85		35			
Ti6	3/16" plate	CP1	4" x 6"	20	7.98 kg	Oroville	<0.03	<0.4	< 0.2	<0.8	<0.05	<1.6	23
Ti7	1" plate	CP1	2" x 6"	8	7.201 kg	Oroville	<0.02		<0.05		<0.04		2.5
Ti8	0.063" sheet	CP1	4" x 6"	40	4.399	Oroville	<0.1		<0.4		<0.3		6

Fast neutron backgrounds from bulk materials in LUX

PMTs are the dominant source of fast neutron background:

- fission neutrons negligible (1.5% of goal)
- (,n) reactions on light elements dominate

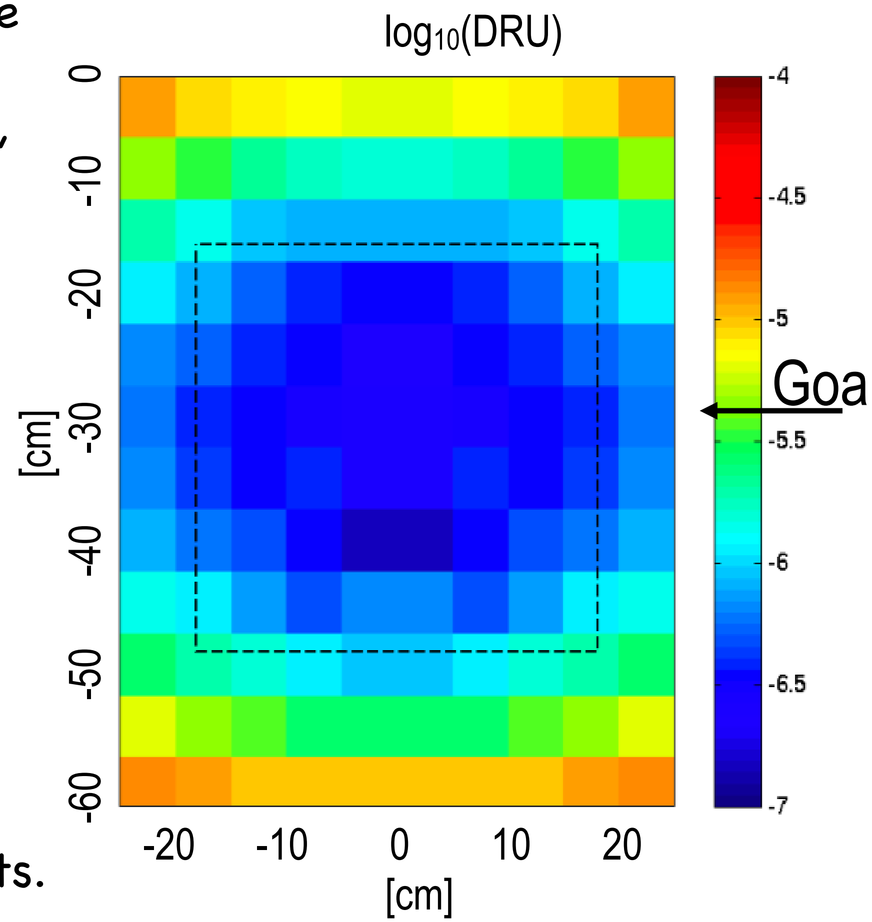
Assuming U/Th/K/Co = 18/17/30/8 mBq/PMT,

=> 1.5 neutrons/yr/PMT

If the U/Th activity is confined entirely to the PMT glass stem and other glasses and insulators, this comes to 5 n/PMT/year.

After a multiple scattering cut, 5 n/PMT/yr results in a nuclear recoil background well below the goal of 5E-6 events/keVr/kg/day.

(,n) reactions in PTFE are subdominant (8/year) assuming Heusser U/Th measurements. (Even lower assuming EXO numbers).



multiple scatter veto for neutrons!

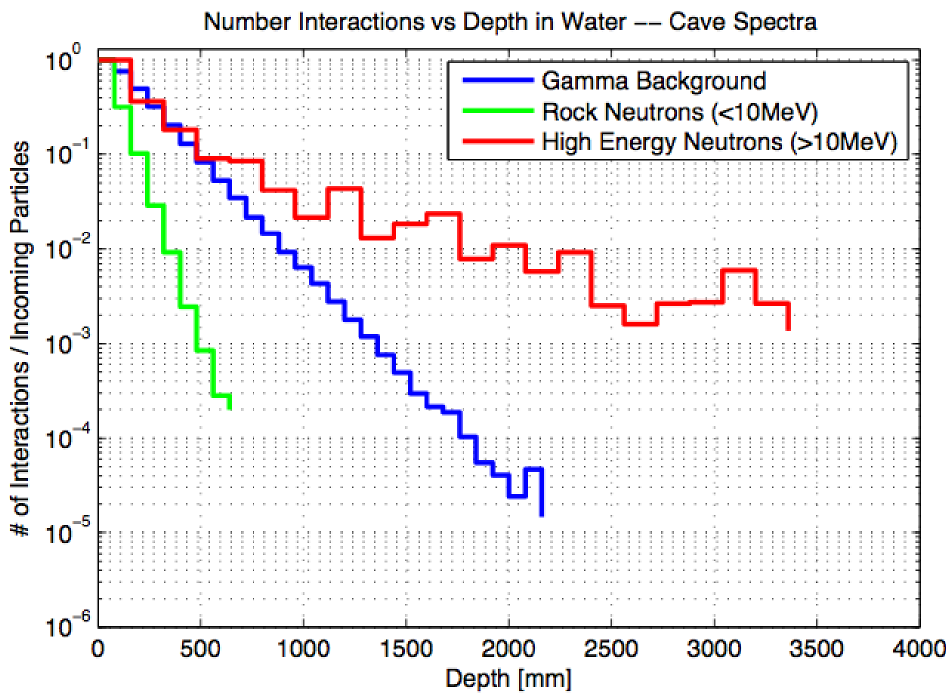
Water Shield

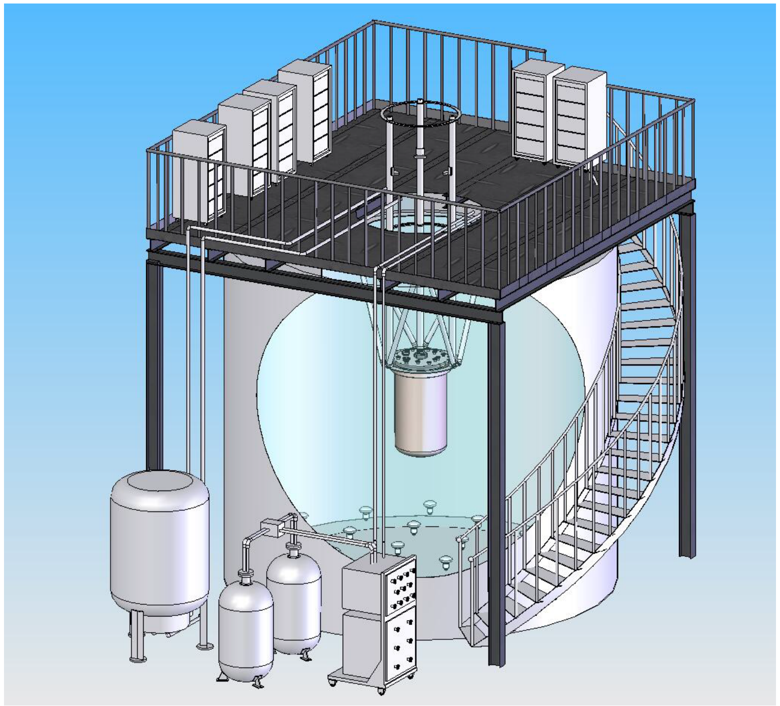
2.5 meters of instrumented water shielding

Gamma rays from rock contribute < 2% of total electronic recoil background.

Fast neutrons from rock are moderated and captured extremely efficiently => negligible.

Muon-induced neutrons in rock: < 0.01 events/year in detector.





Internal Backgrounds

Kr-85: Beta decay, 687 keV endpoint.
Normally at ppm in commercial Xe, though can purchase at 5 ppb
LUX requirement is 5 parts per trillion
Achieved by charcoal column separation (< 2 ppt demonstrated at Case)

^{14}C, T, U,Th: Removed efficiently by getter

Radon: Pb-210 daughter removed by getter. Surface daughter backgrounds removed by fiducial cut. Pb-214 makes a "naked" beta, which sets the LUX requirement = 16 mBq, compared to XENON10 measured rate of 1.6 mBq.

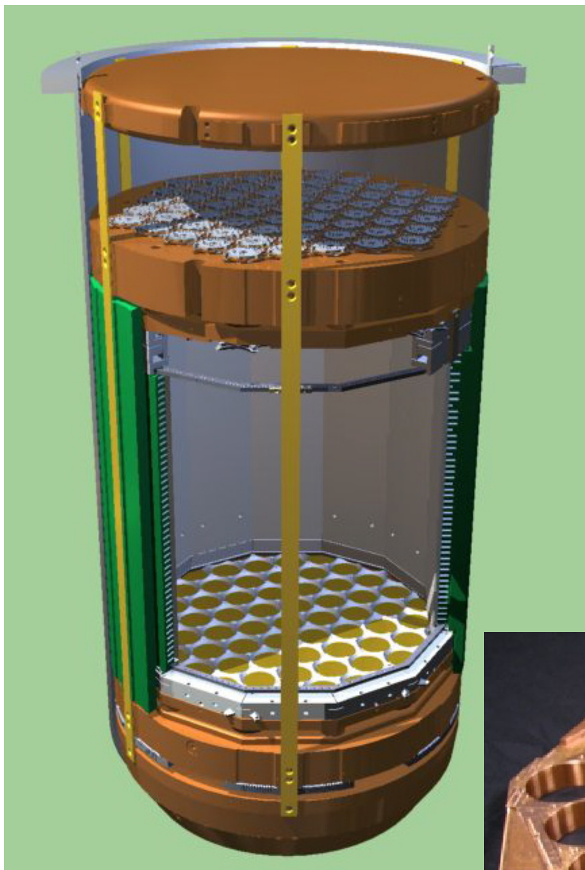
pp ν's: Elastic scattering of neutrinos from electrons gives background of 6E-8 events/keVee/kg/day, after discrimination.

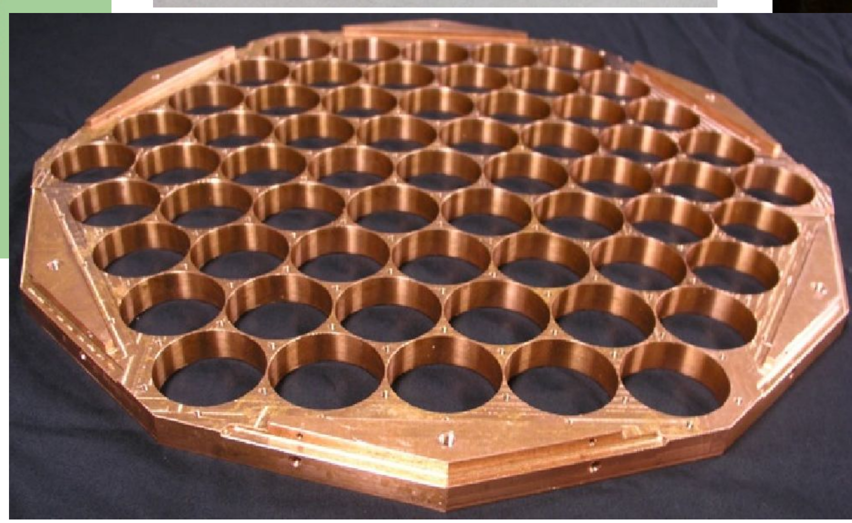
Xe-136: Double beta decay background of 1.5E-8 events/keVee/kg/day, assuming $\tau_{1/2} = 0.8 \times 10^{22}$ years (current lower limit).

Chemically active cosmogenic activation products removed by getter.

Xe-131m, Xe-129m decay away with ~ 10 days half-lives.

LUX Internals Assembly



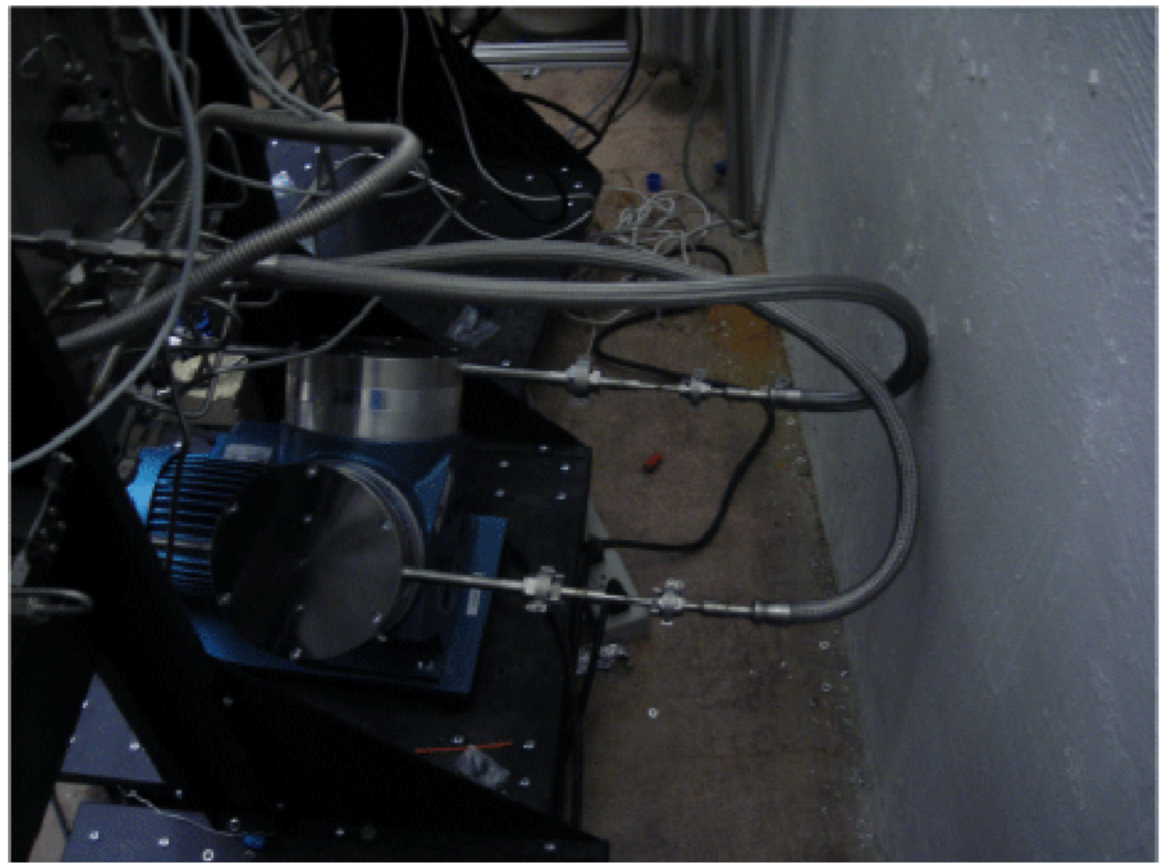


Circulation and Purification System

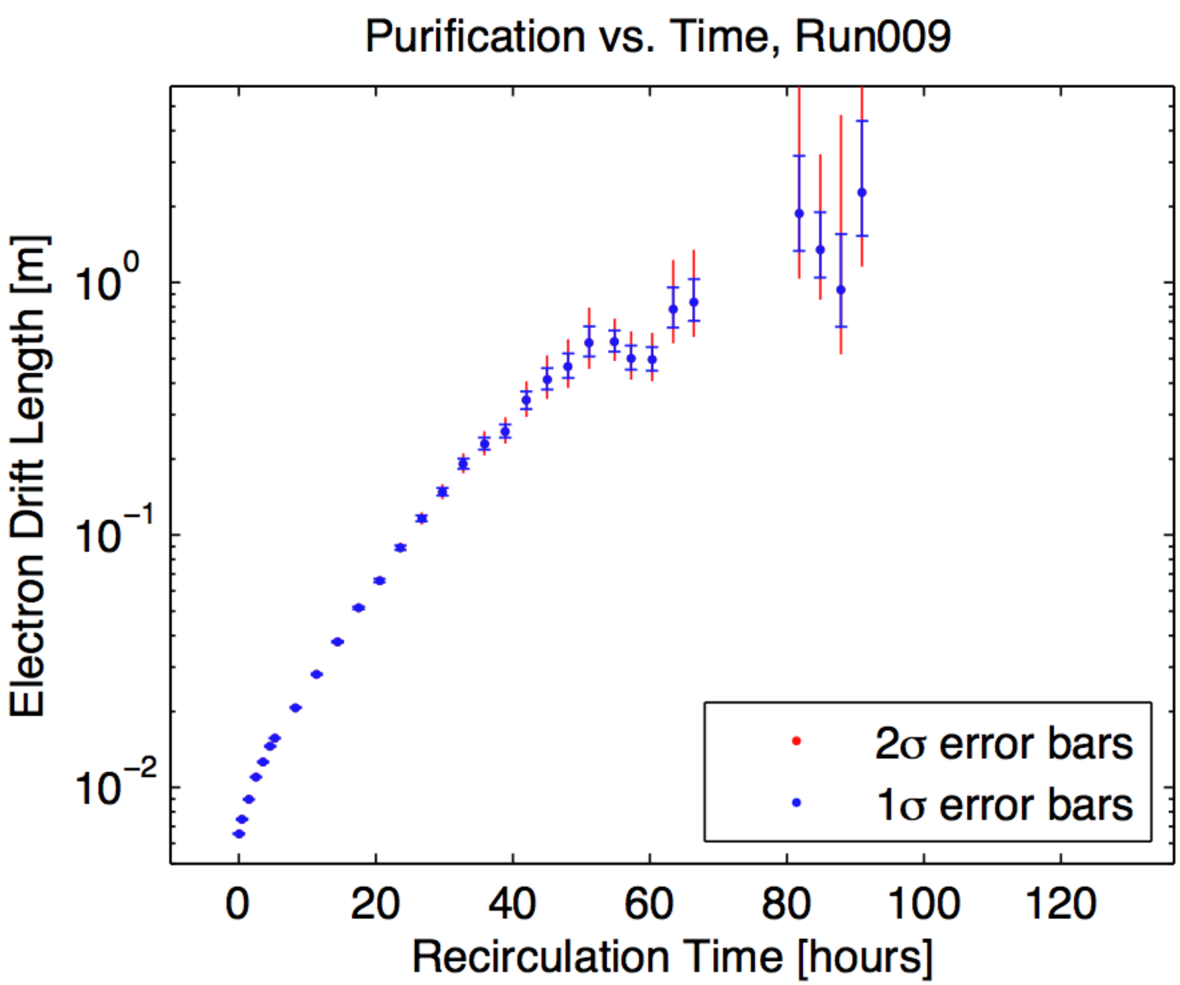
Gas-phase purification using SAES getter
Demonstrated flow rate of 50 standard liters per minute

Gas panels

Circulation pump

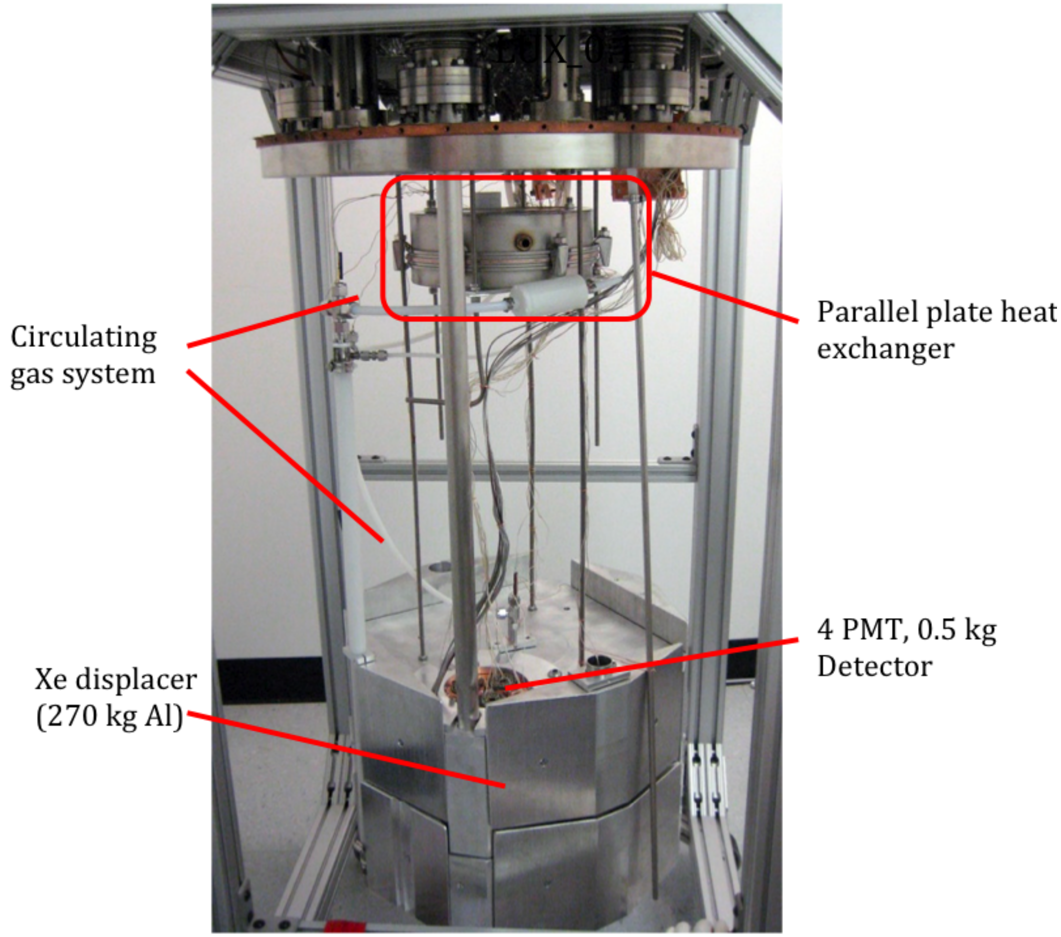


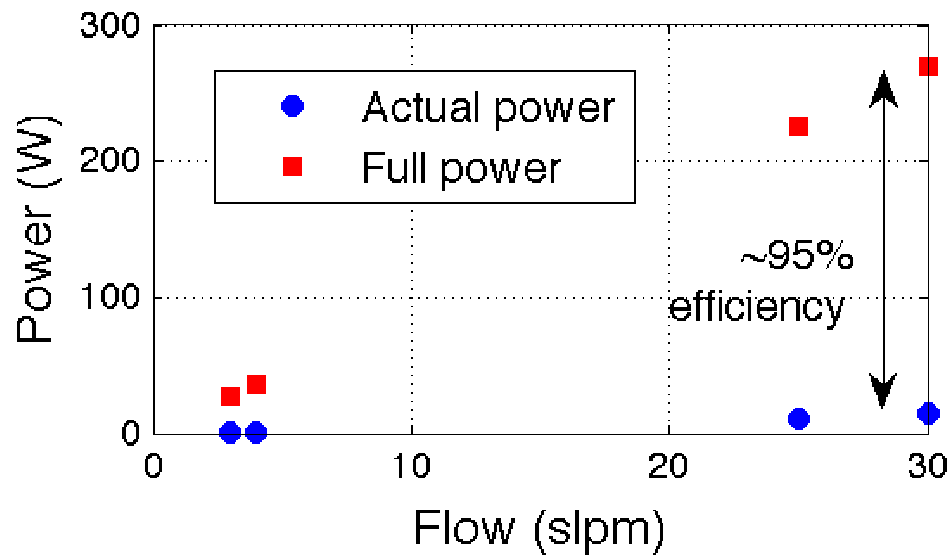
LXe purification tests in LUX 0.1



- ~9 hr purification time constant
- > 2 m electron drift length
- This is an order of magnitude faster recirculation than achieved before

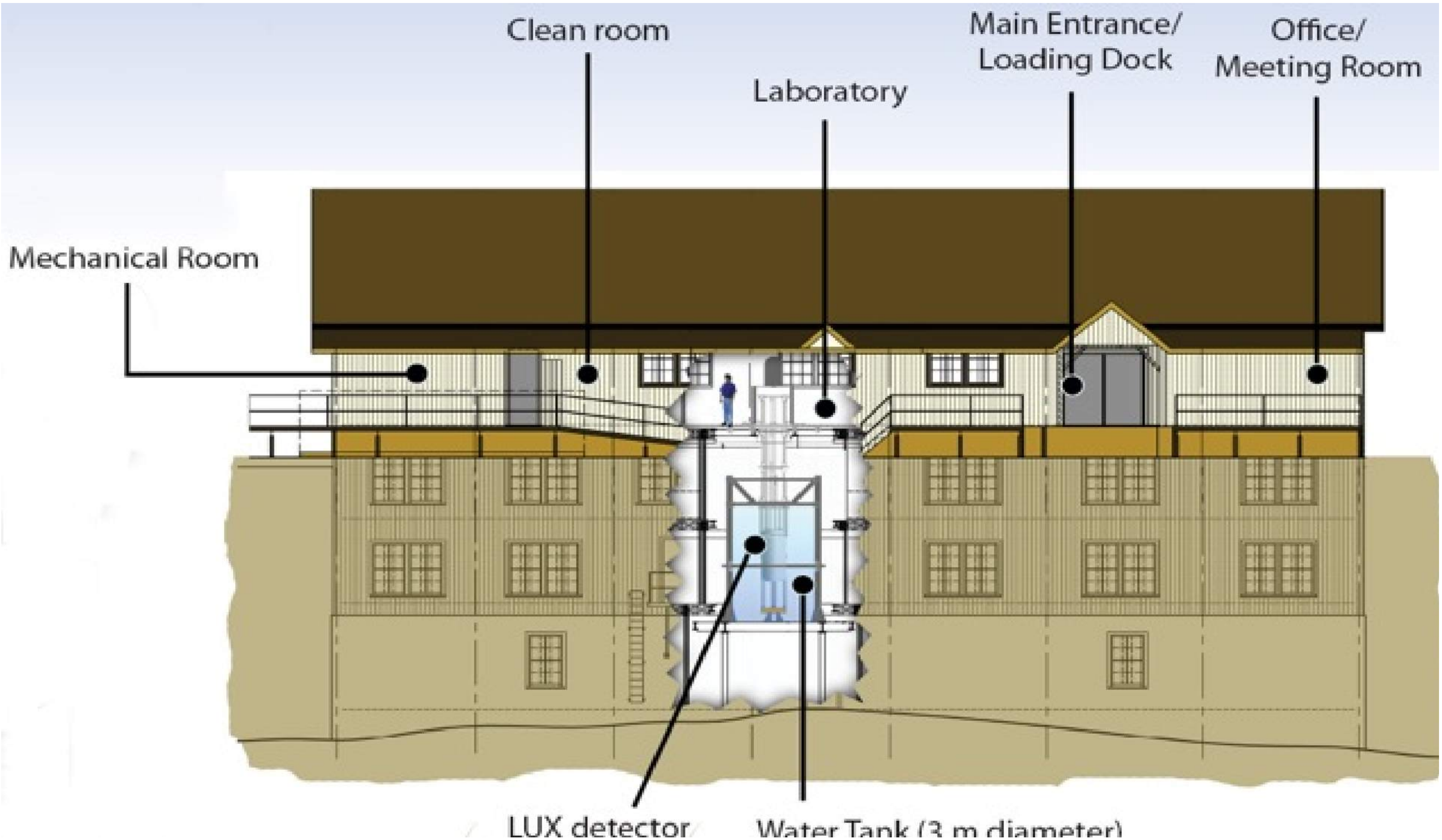
Heater exchanger tests at Case



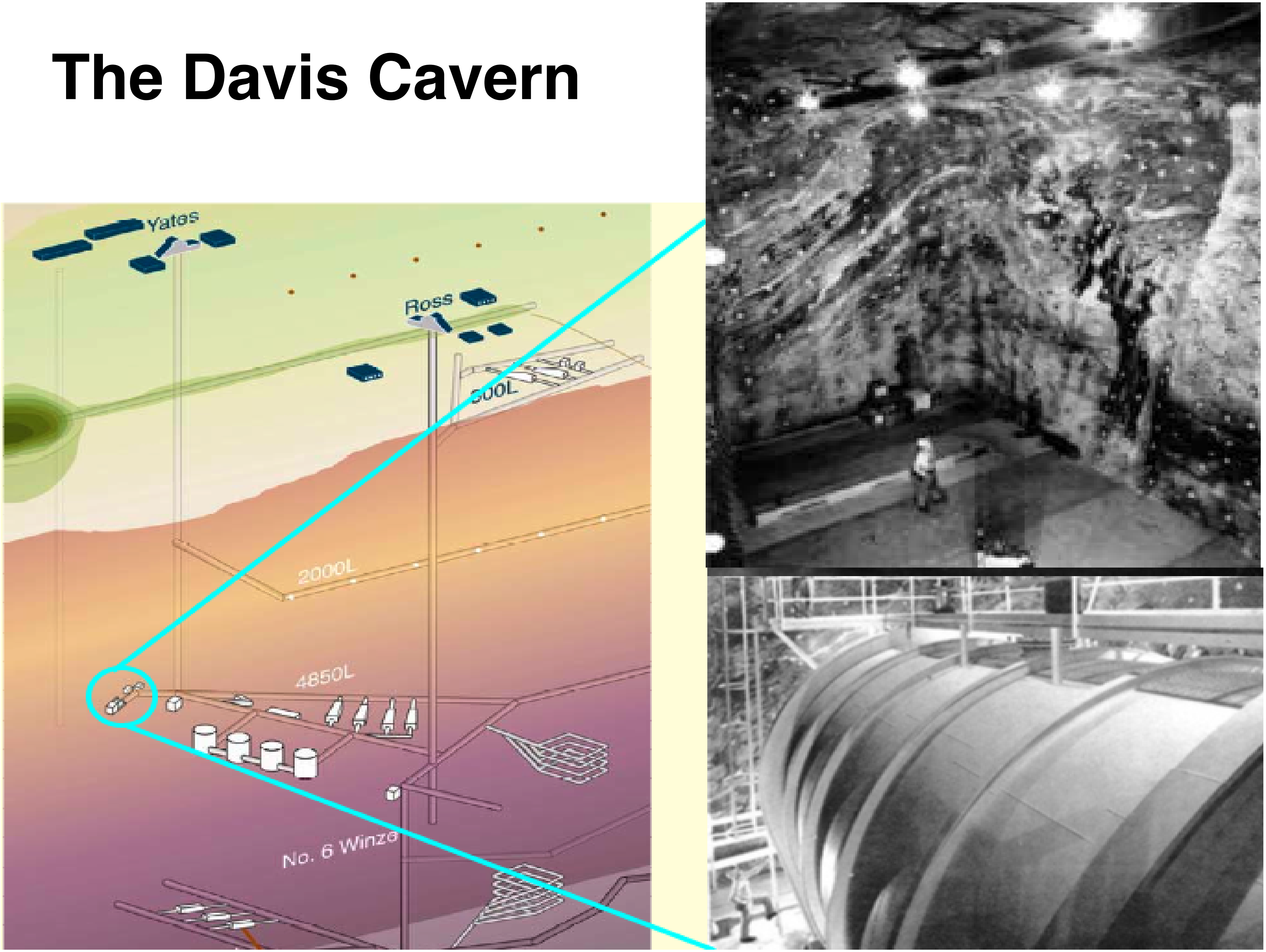


Surface Facility at Homestake

LUX integration planned for October 2009



The Davis Cavern

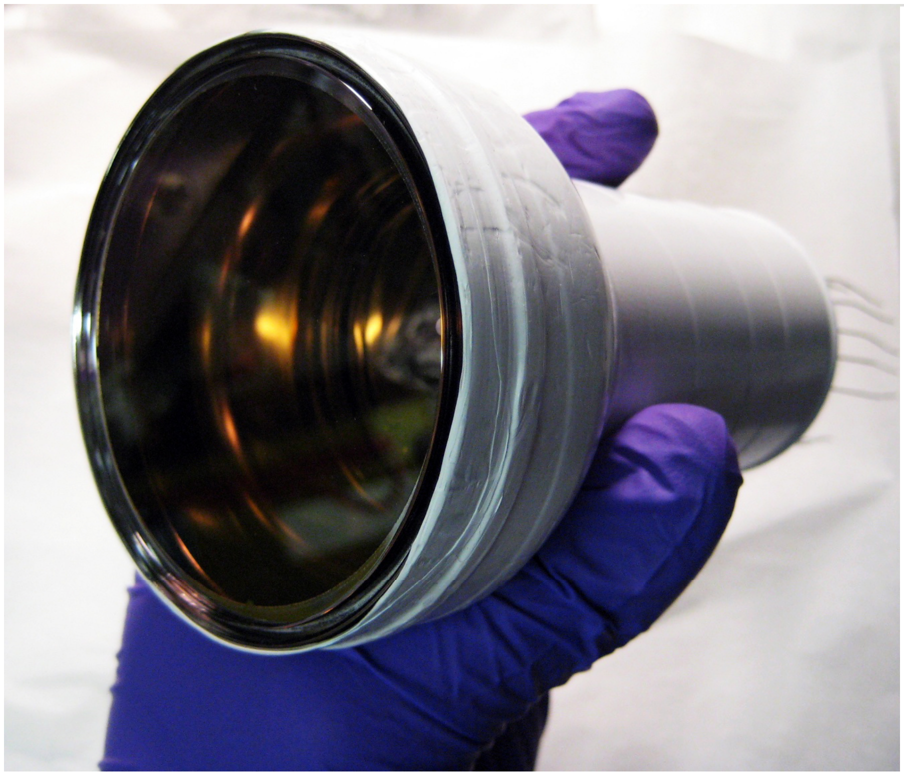


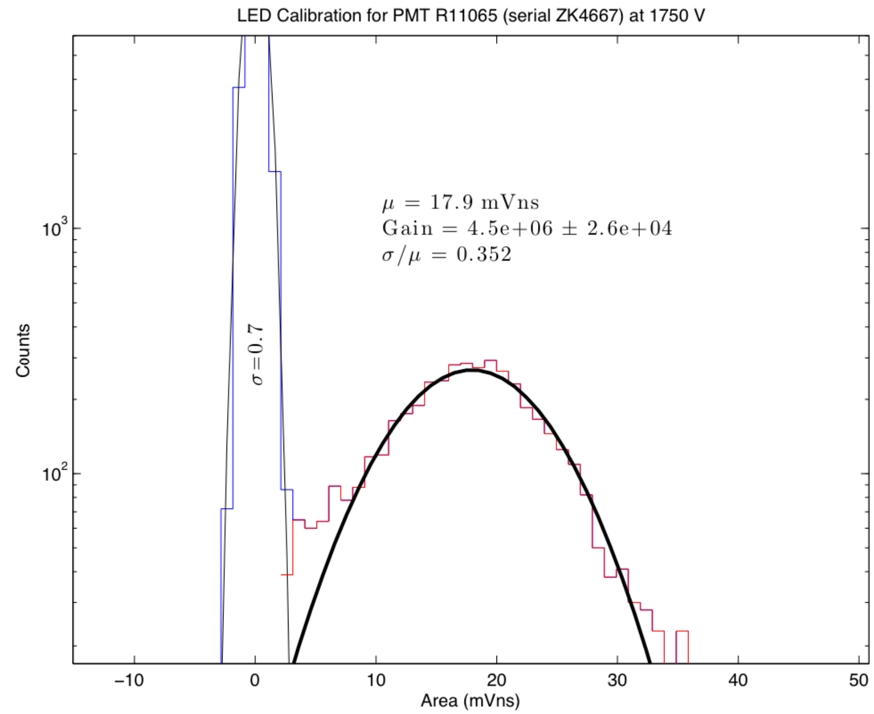
Dewatering Milestone

LUX

Sanford Lab

Photomultiplier R&D





New 3" PMTs -- Hamamatsu R11065

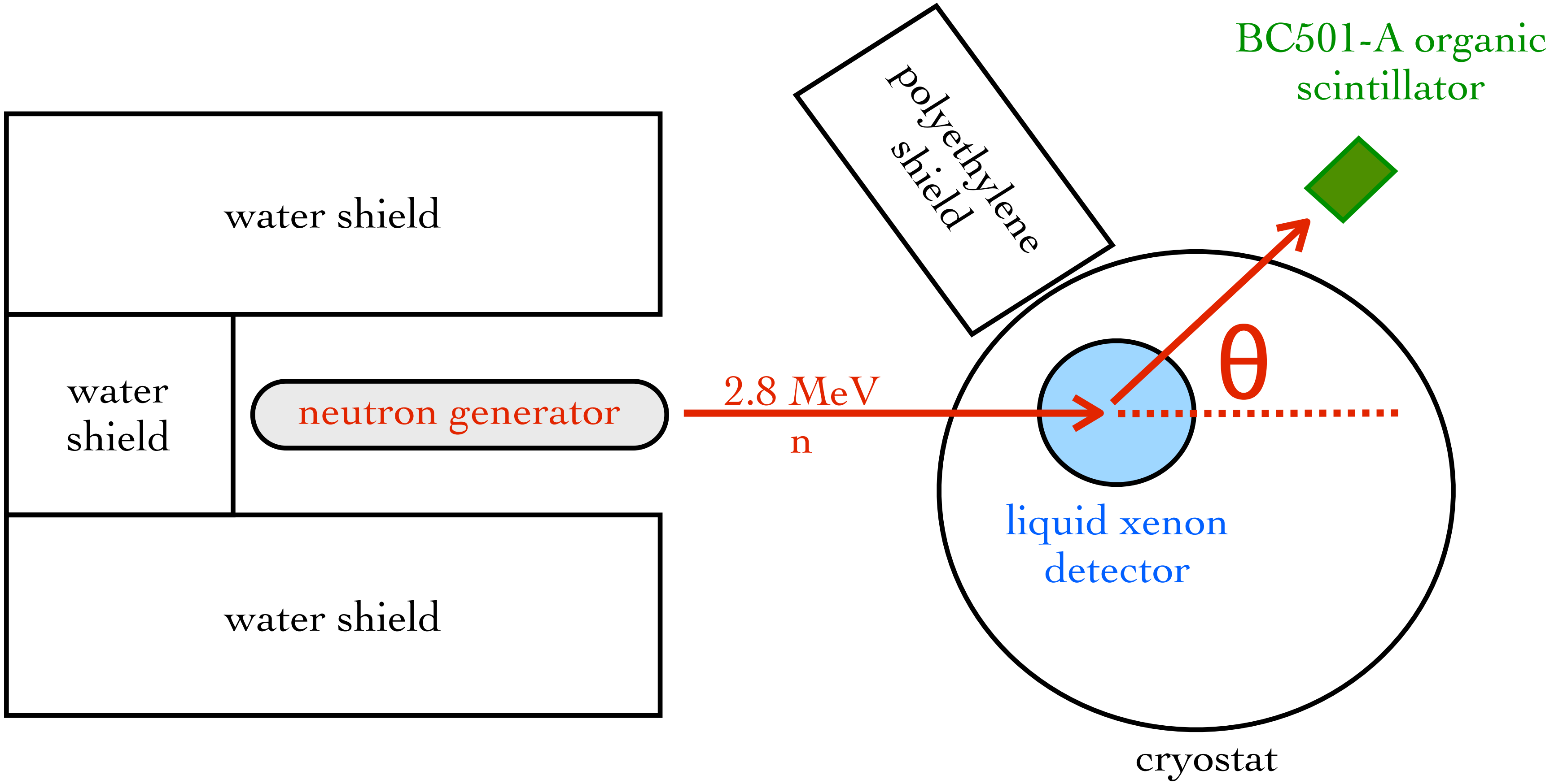
With 2x collection area of R8778

Background target: U/Th of 1/1 mBq

Single photoelectron resolution obtained from first articles of Hamamatsu.

Tested immersed in LXe, including Xe primary scintillation detection

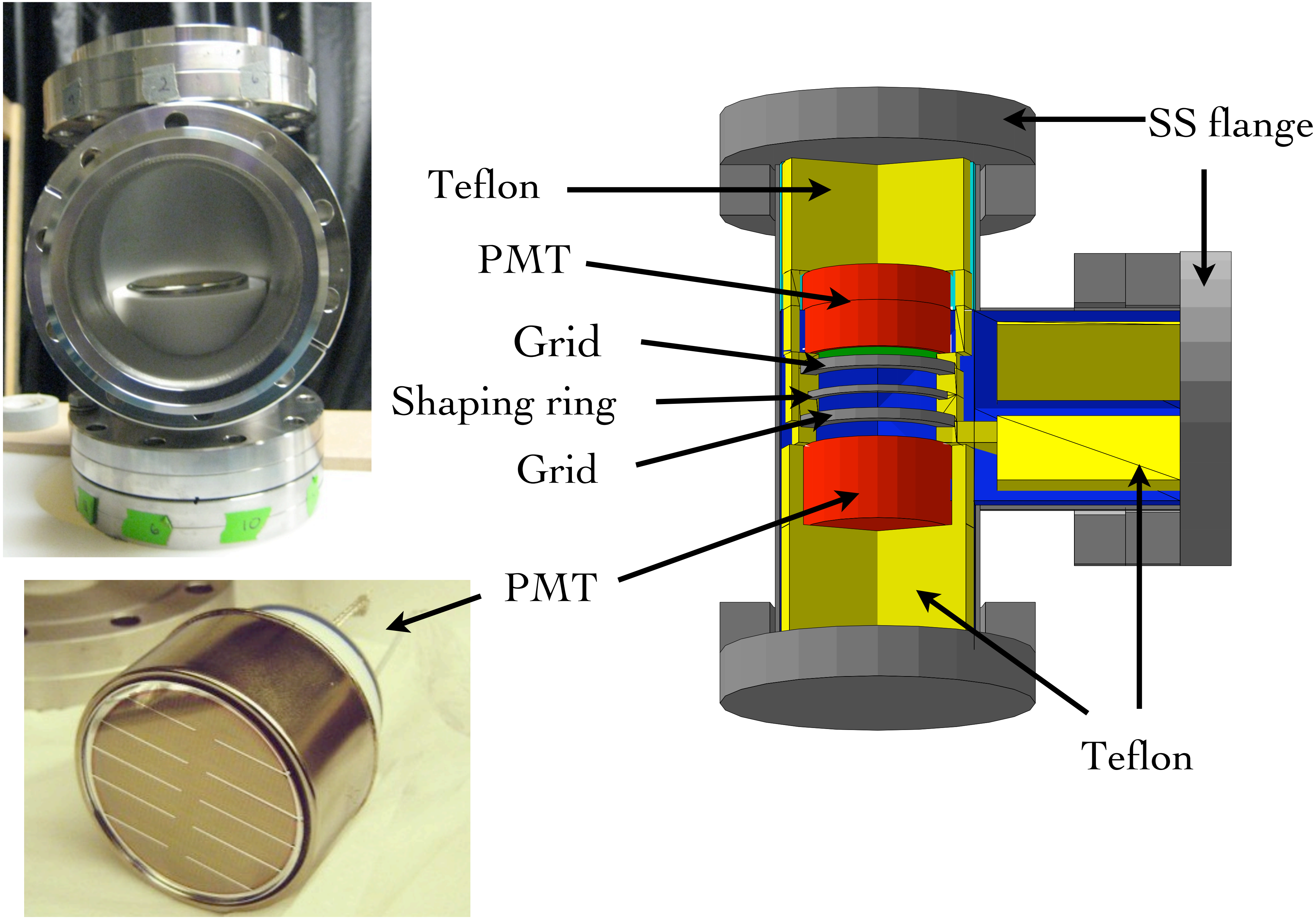
Experimental setup



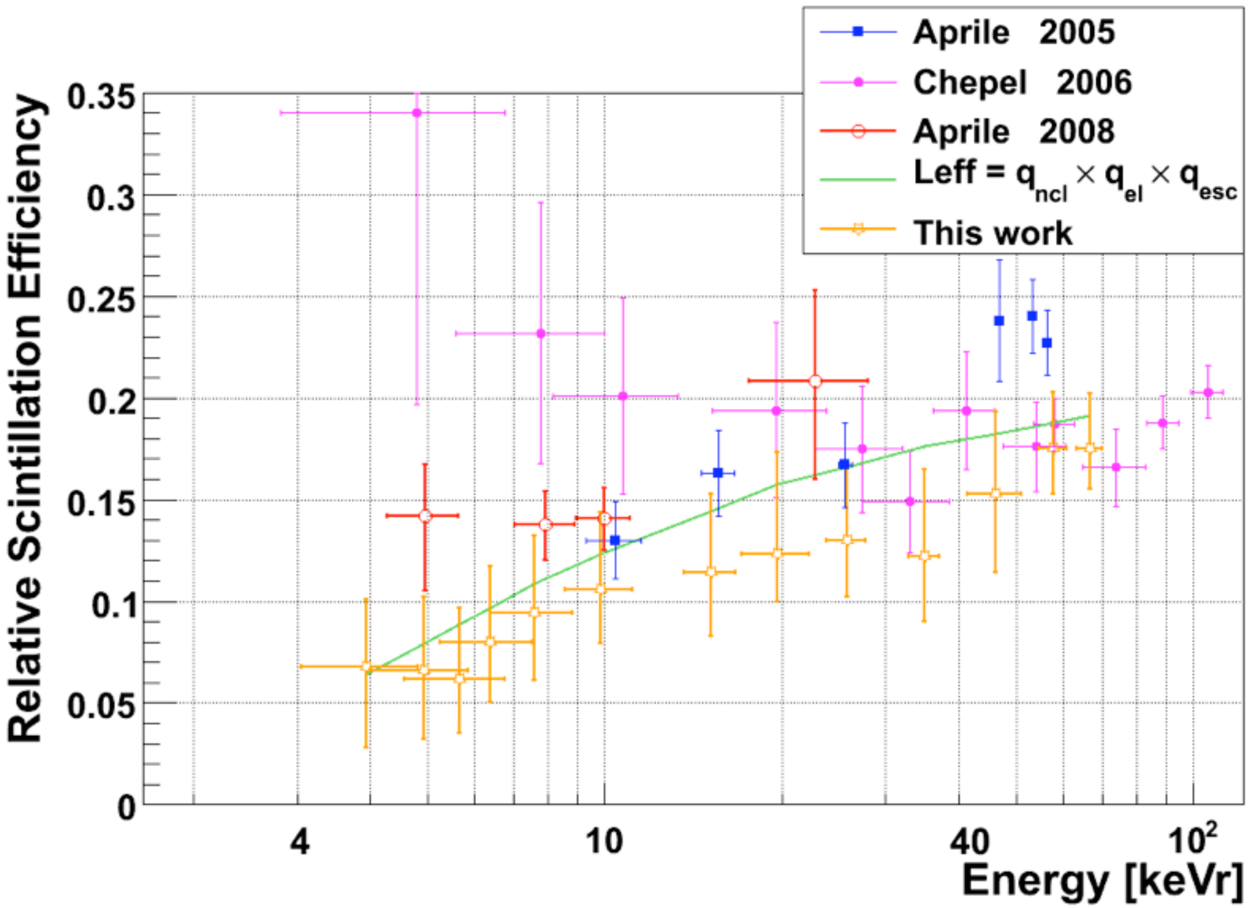
$$E_R = E_n \frac{2m_n M_{Xe}}{(m_n + M_{Xe})^2}(1 - \cos\theta)$$

Energies: 4 - 66 keVr

Liquid xenon cell



Results



- No significant dependence on field.
- The Leff decreases with decreasing energy.
- Escape electrons seem to be an important contributor to Leff

$\mathcal{L}_{eff}$ model

$$\mathcal{L}_{eff} = q_{ncl} \times q_{el} \times q_{esc}$$

- q_{ncl} nuclear quenching (Lindhard factor), energy goes into heat.
- q_{el} electronic quenching. Bi-excitonic collisions

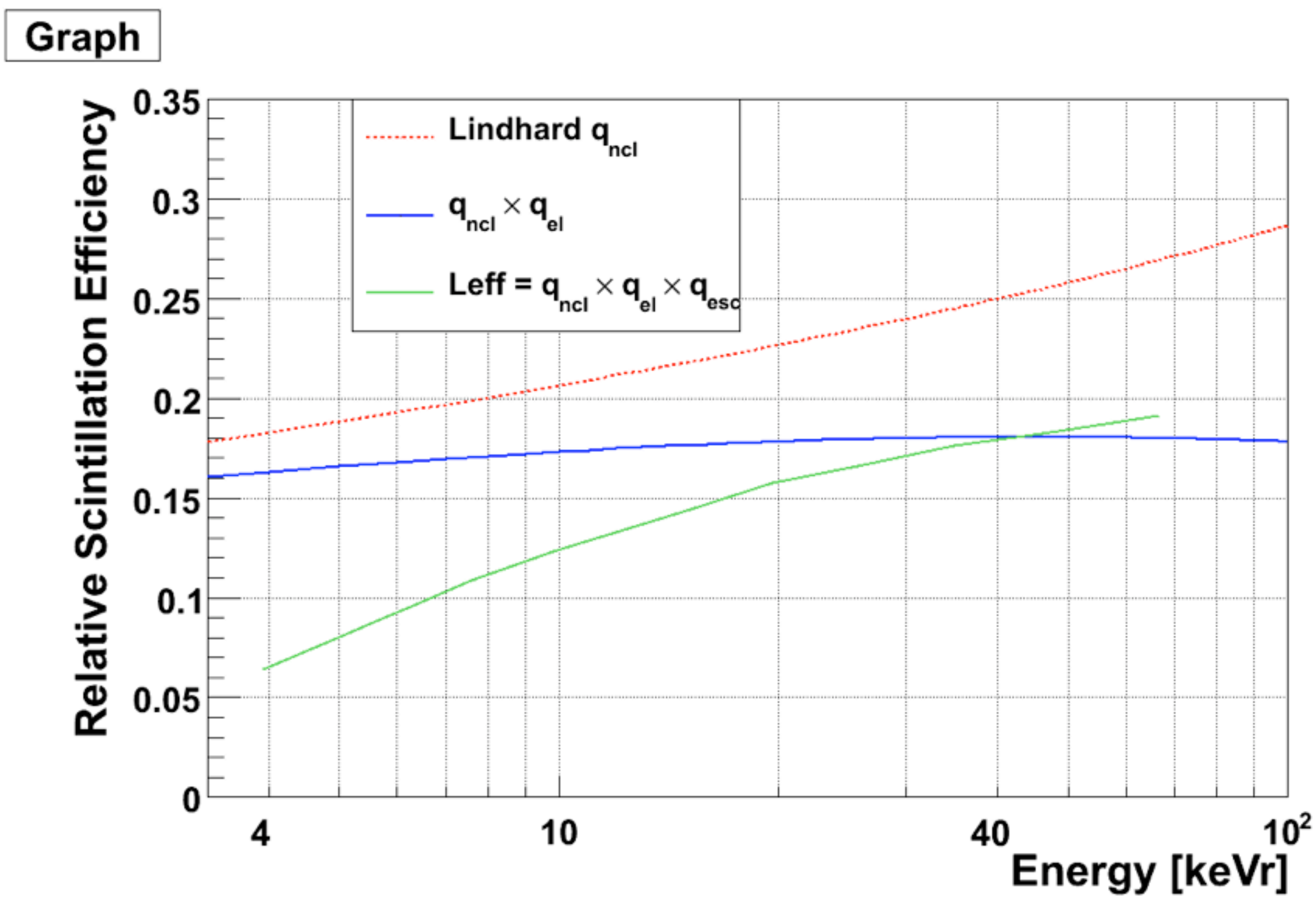
$$\mathrm{Xe}^* + \mathrm{Xe}^* \rightarrow \mathrm{Xe} + \mathrm{Xe}^+ + e^-$$

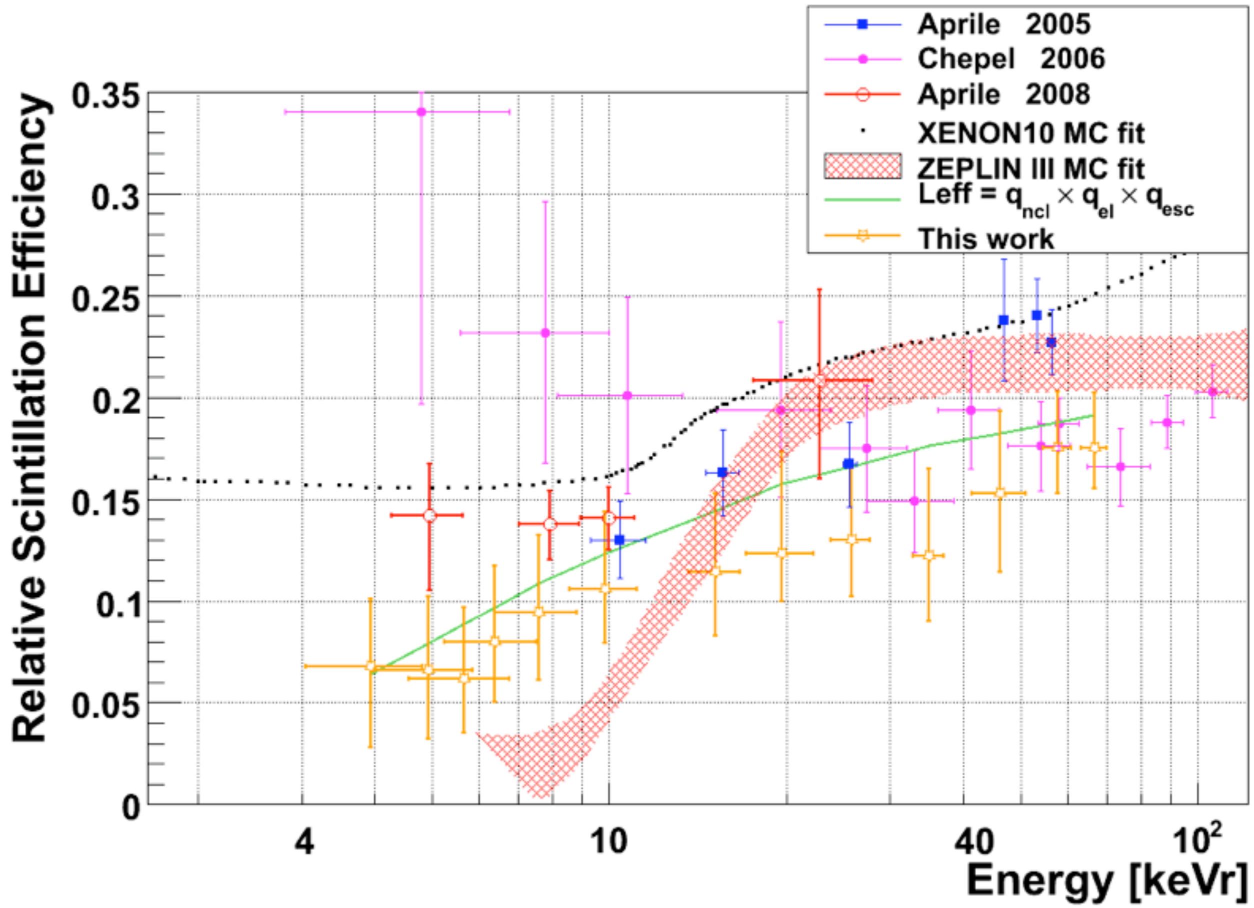
$$q_{el} = \frac{1}{1 + k\frac{dE}{dx}}$$

- Escape electrons

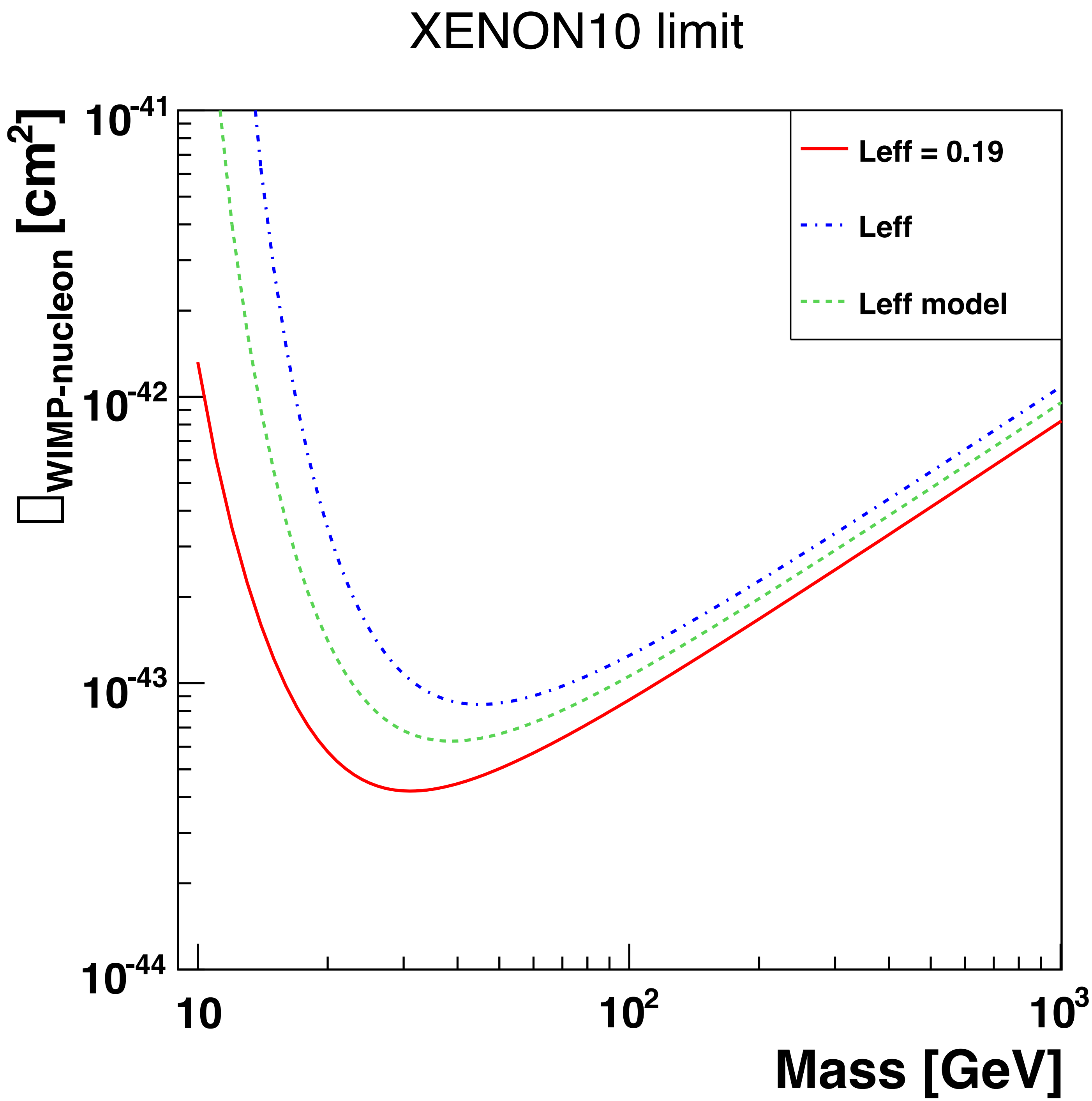
$$q_{esc} = \frac{N_{ex} + N_i - N_{esc}}{N_{ex}^{122} + N_i^{122} - N_{esc}^{122}} = \frac{\alpha + 1 - \beta}{\alpha + 1 - \beta^{122}}$$

$\mathcal{L}_{eff}$ model



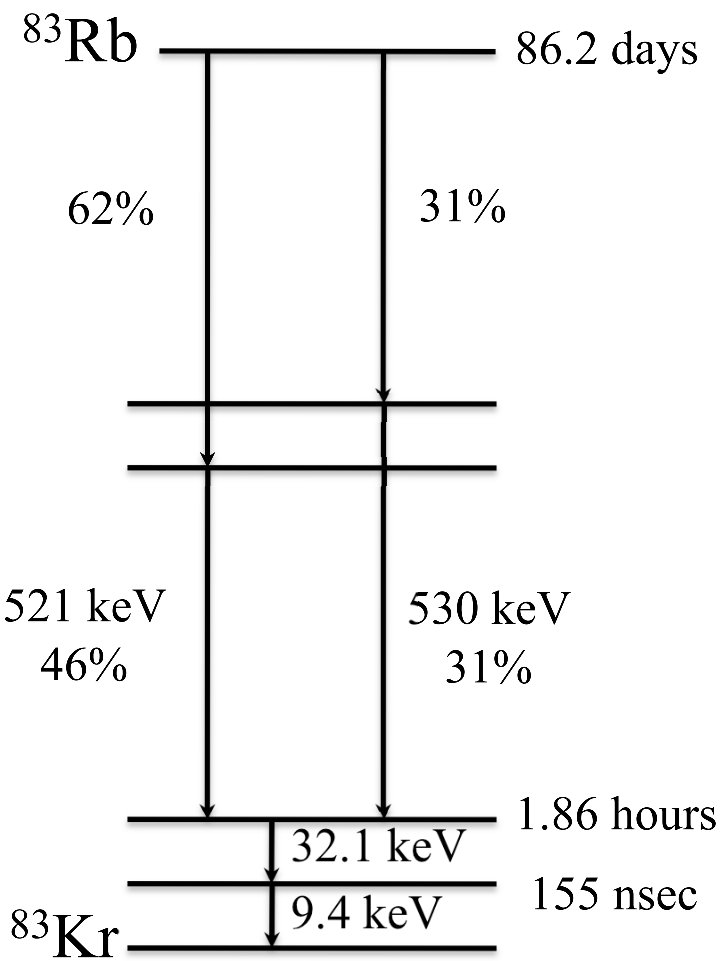


Aprile 2005
Chepel 2006
Aprile 2008
XENON10 MC fit
ZEPLIN III MC fit
Leff = $q_{ncl} \times q_{el} \times q_{esc}$
This work
Relative Scintillation Efficiency
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
4
10
40
10^2
Energy [keVr]

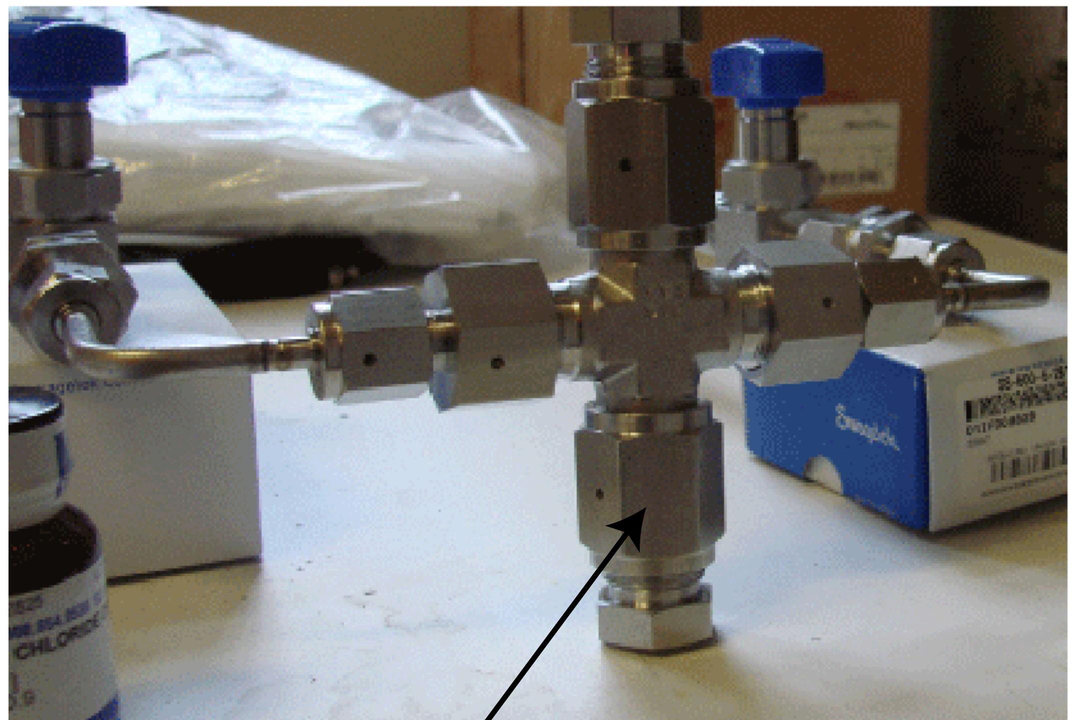


XENON10 limit
Leff = 0.19
Leff
Leff model
WIMP-nucleon [cm2]
Mass [GeV]
10-41
10-42
10-43
10-44
10
102
103

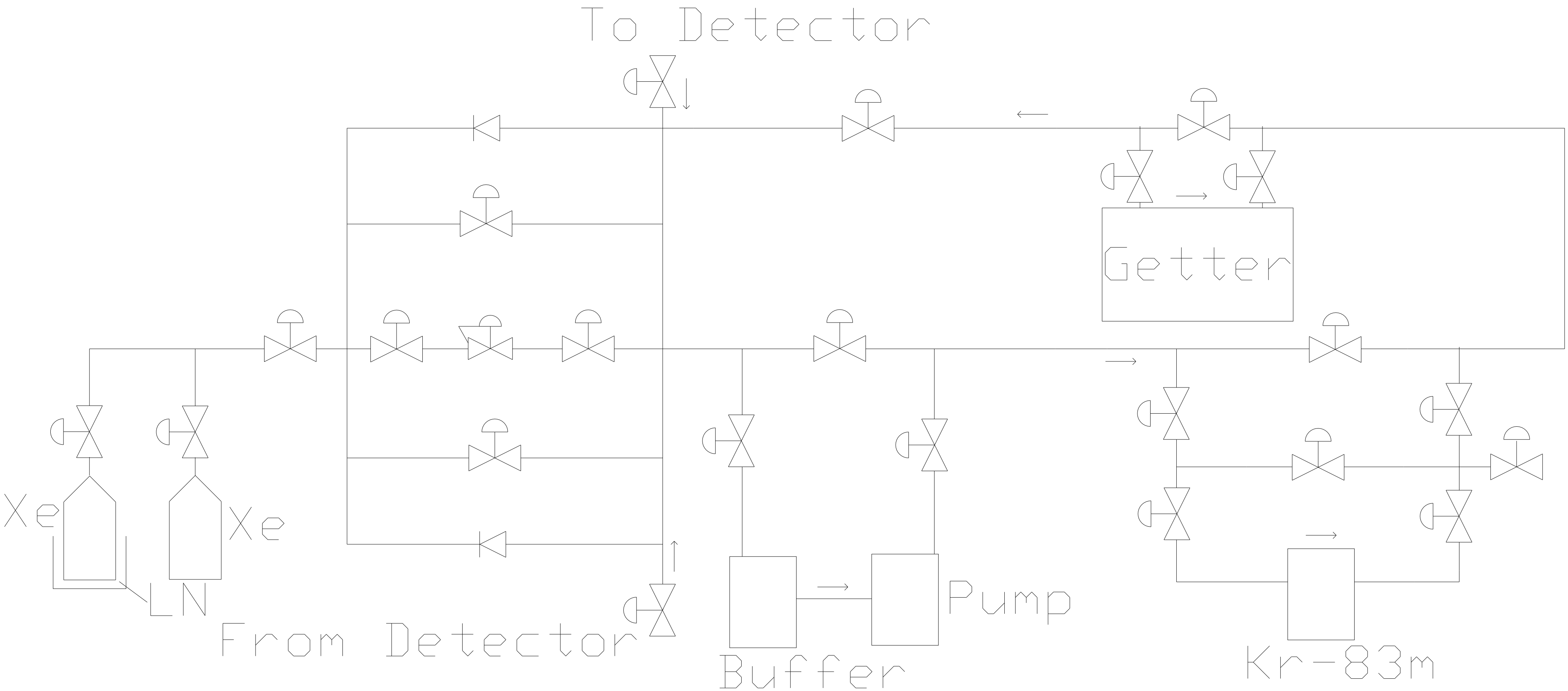
Kr-83m calibration source development at Yale



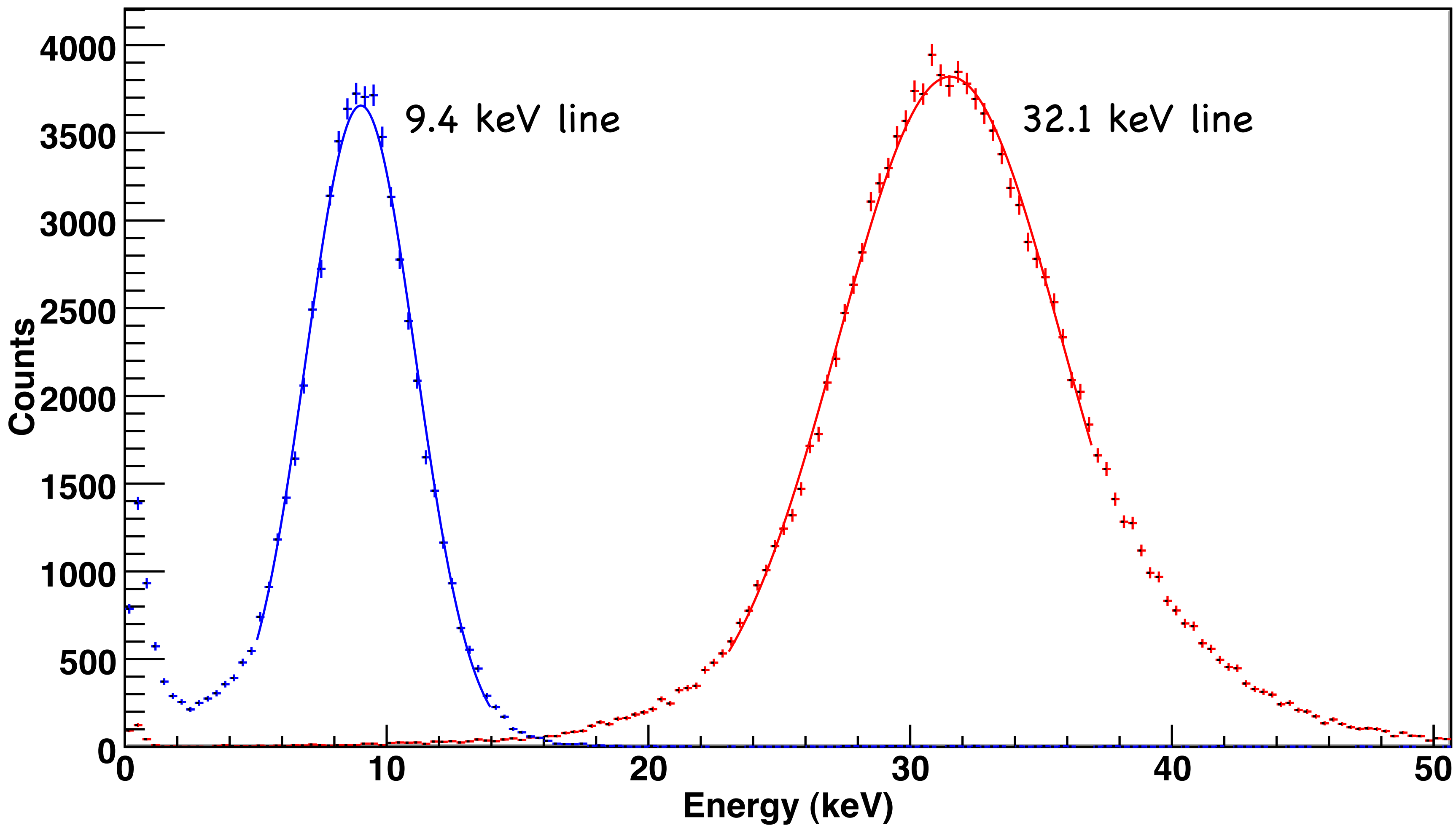
Rb-83 purchased in aqueous solution, then coated on zeolite. Continually emits Kr-83m, which can then be used to calibrate the liquid xenon detector response.



Rb-83 adsorbed
on zeolite beads,
in vacuum plumbing


To Detector
Getter
Xe
Xe
LN
From Detector
Buffer
Pump
Kr-83m

LXe scintillation data from Kr-83m dissolved into LXe



L. Kastens et al, arXiv:0905.1766 (accepted to Phys. Rev. C)

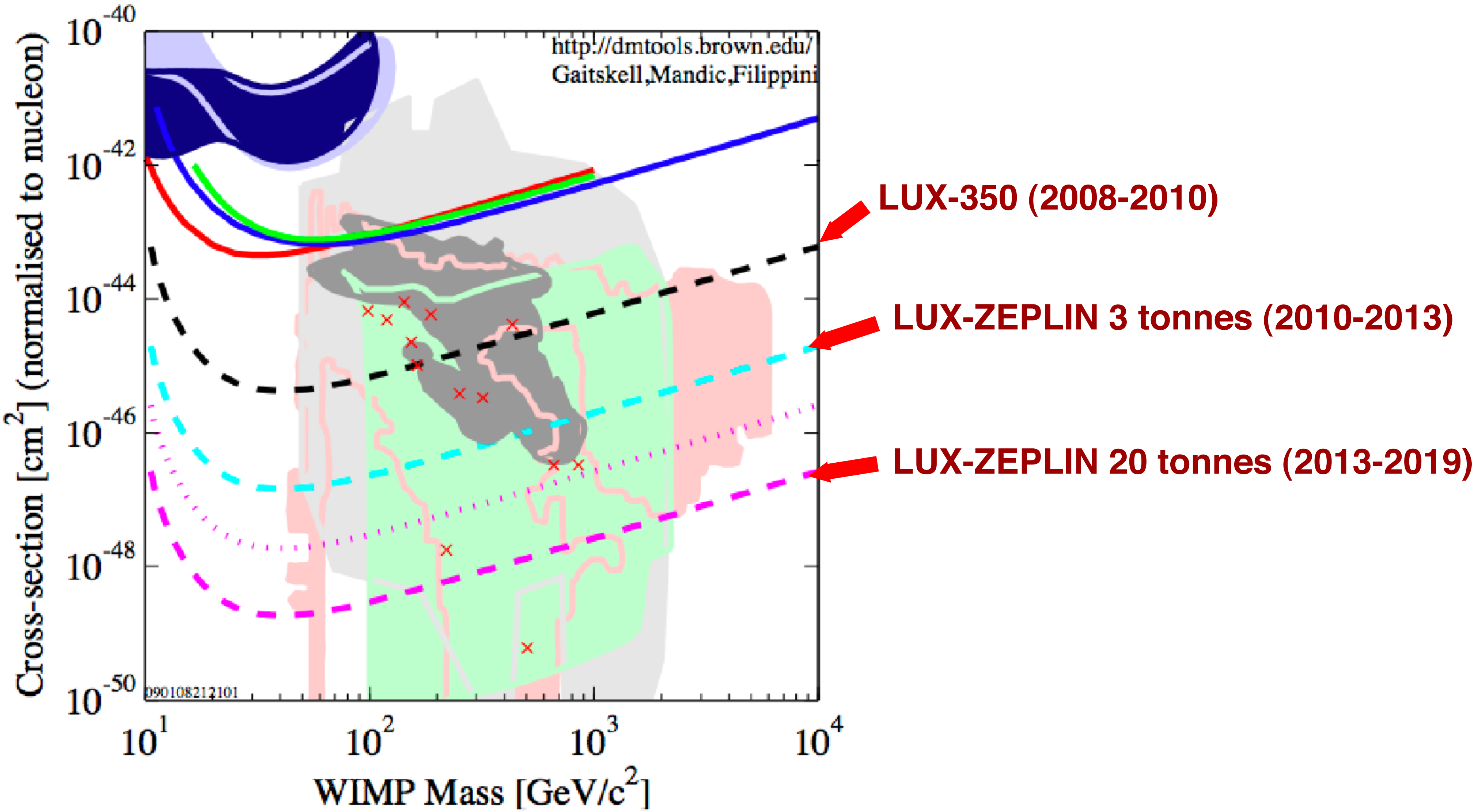
The Future Beyond LUX-350

Proposed 1.5 ton instrument, LZ-S, to be installed in the same water tank at SUSEL, replacing LUX-350

Design study for 20 ton instrument, LZ-D,to be built at DUSEL, funded by DUSEL S4 grant. Can address topics in neutrino physics (neutrinoless double beta decay in Xe-136, pp-solar neutrinos), in addition to WIMP dark matter.

New institutions: ZEPLIN-III collaboration (Imperial, RAL, Edinburch, LIP-Coimbra, ITEP) plus new US institutions (Caltech, UC Berkeley, UC Santa Barbara),

Long Term Program



Extra Slides

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

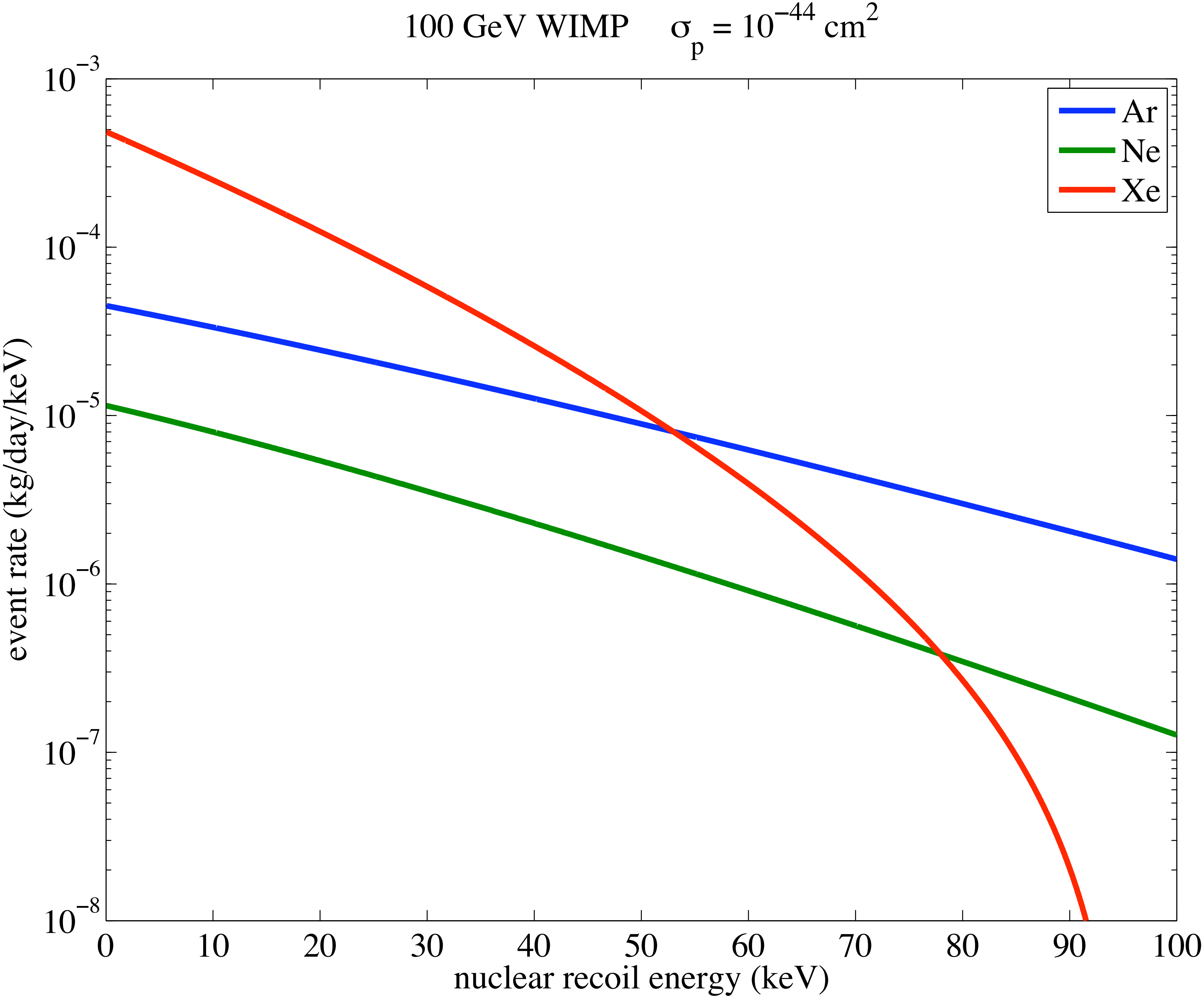
- noble liquids do not absorb their own scintillation
- 30,000 to 40,000 photons/MeV
- modest quenching factors for nuclear recoils

Easy construction of large, homogeneous detectors

Liquified Noble Gases: Basic Properties

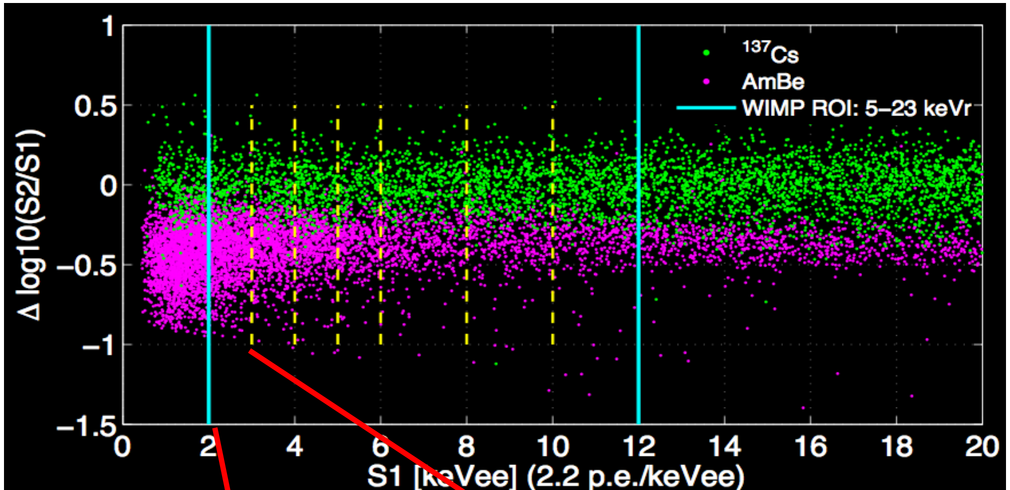
Dense and homogeneous
Do not attach electrons, heavier noble gases give high electron mobility
Easy to purify (especially lighter noble gases)
Inert, not flammable, very good dielectrics
Bright scintillators

	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

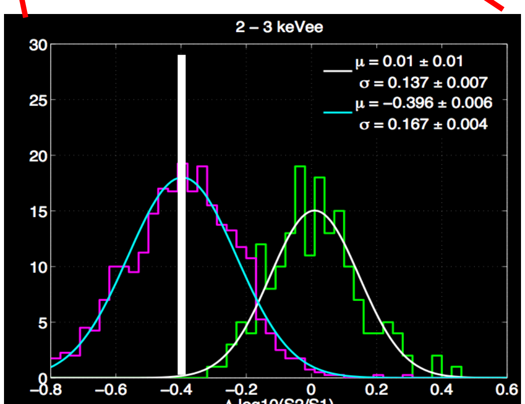


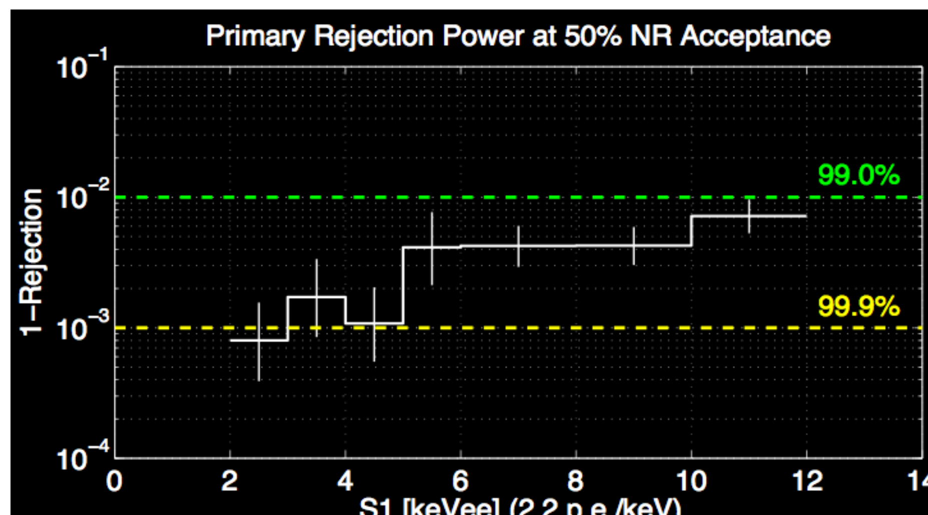
100 GeV WIMP σp = 10−44 cm2
Ar
Ne
Xe
event rate (kg/day/keV)
10−3
10−4
10−5
10−6
10−7
10−8
0
10
20
30
40
50
60
70
80
90
100
nuclear recoil energy (keV)

XENON10 measured discrimination power



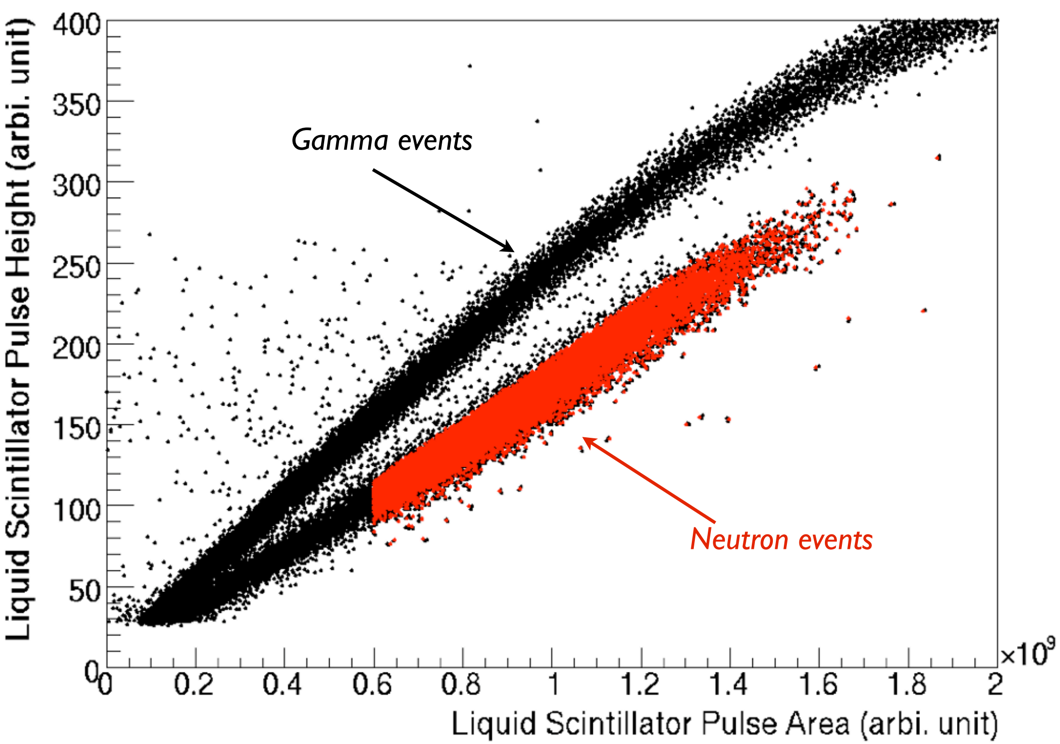
~ 99.5% electron recoil rejection (improves to 99.9% at low energy (50% nuclear recoil acceptance).

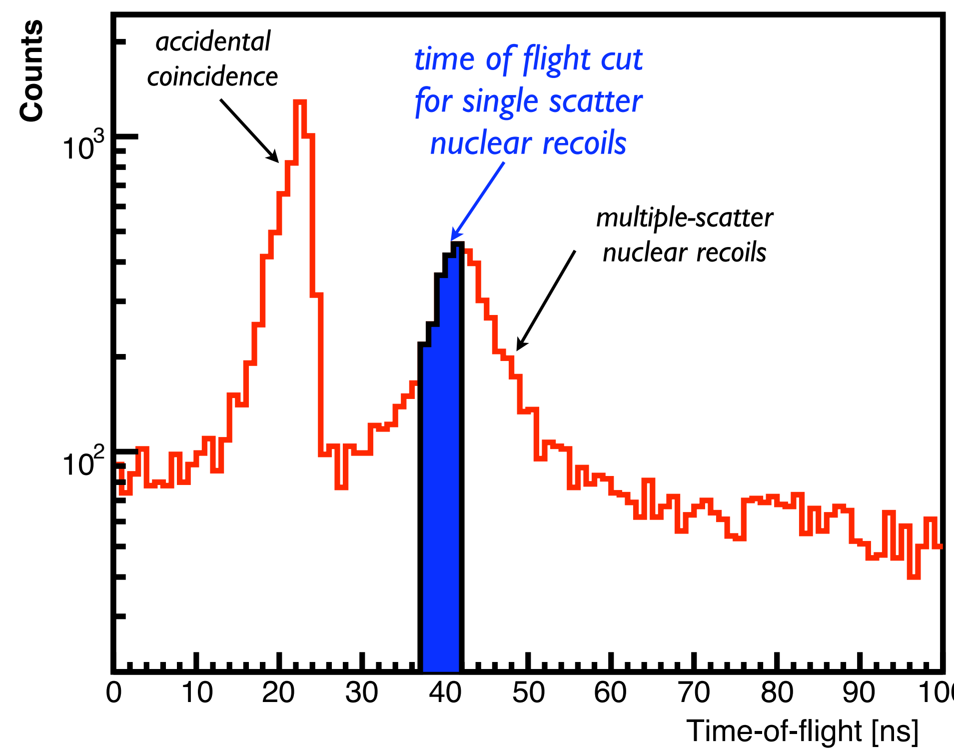




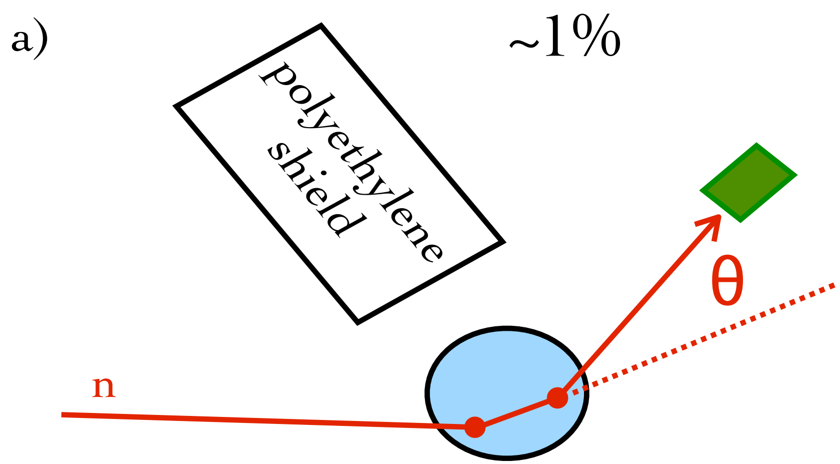
Selecting single nuclear recoils

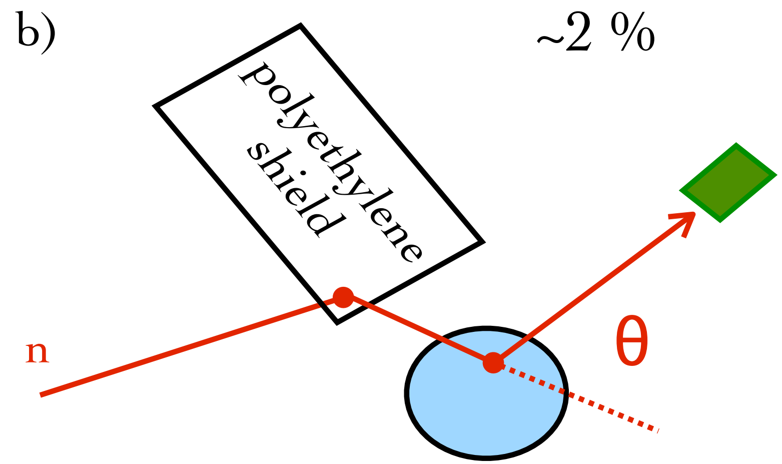
- Quality cuts Q0: remove noise event, high energy events, S1 asymmetry
- Select neutrons using PSD and time of flight (TOF)

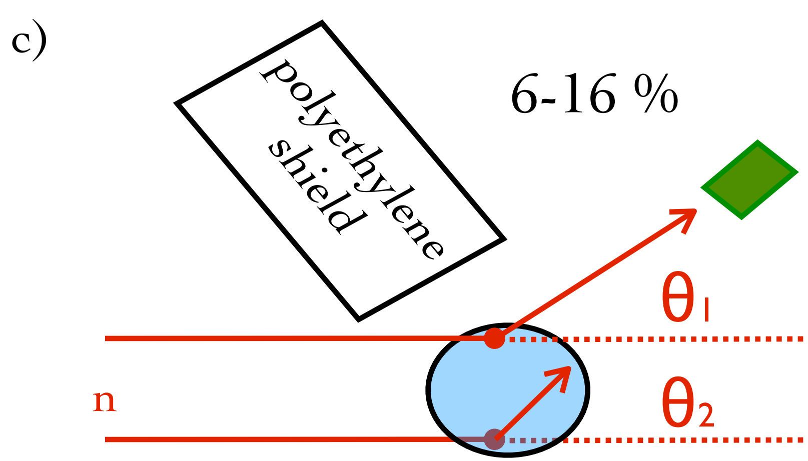




Systematic error



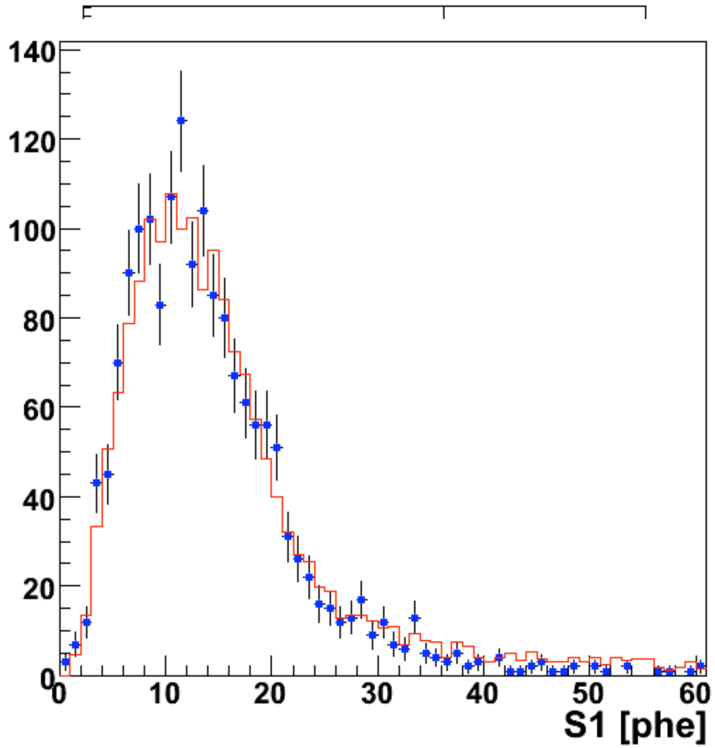


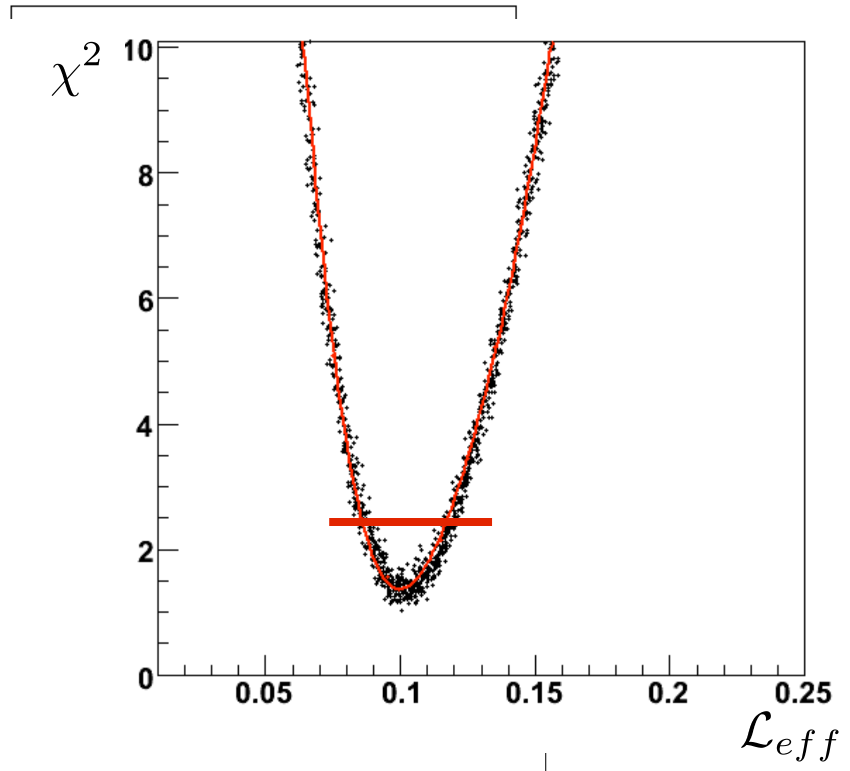


- a) Multiple elastic scatters
- b) Outside scatters
- c) Size and position
- d) Cross-section database ~2 - 4%

Comparing data & Monte Carlo

$E_R = 10\ \mathrm{keV}_r$





To compare MC & data:

1 $E_R \rightarrow E_e$

2 $\sigma = 3.2\sqrt{N_{phe}}$

3 software + trigger efficiency