Direct WIMP Detection by Noble Liquids : XENON100 and Beyond

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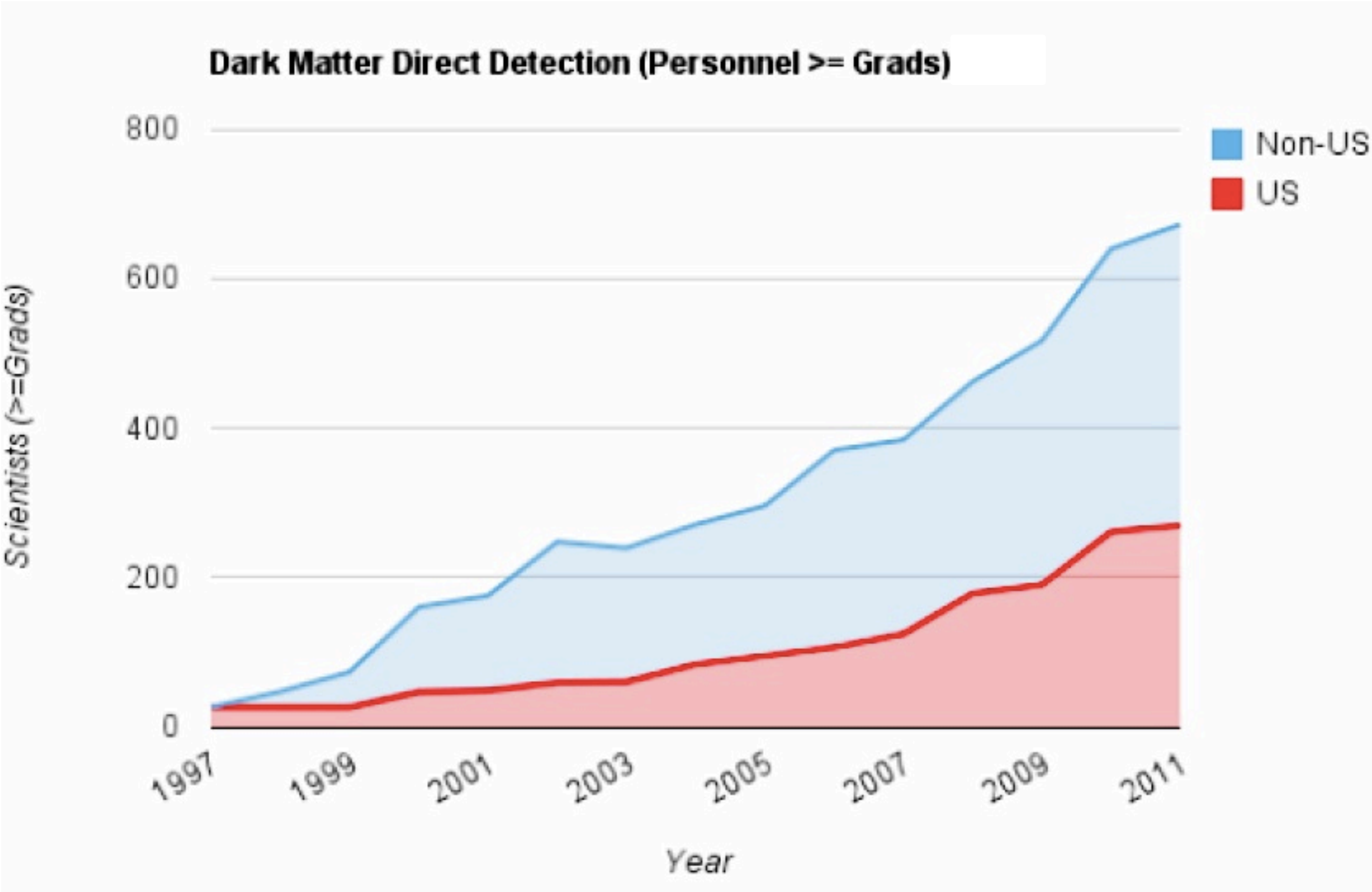
Talk Outline

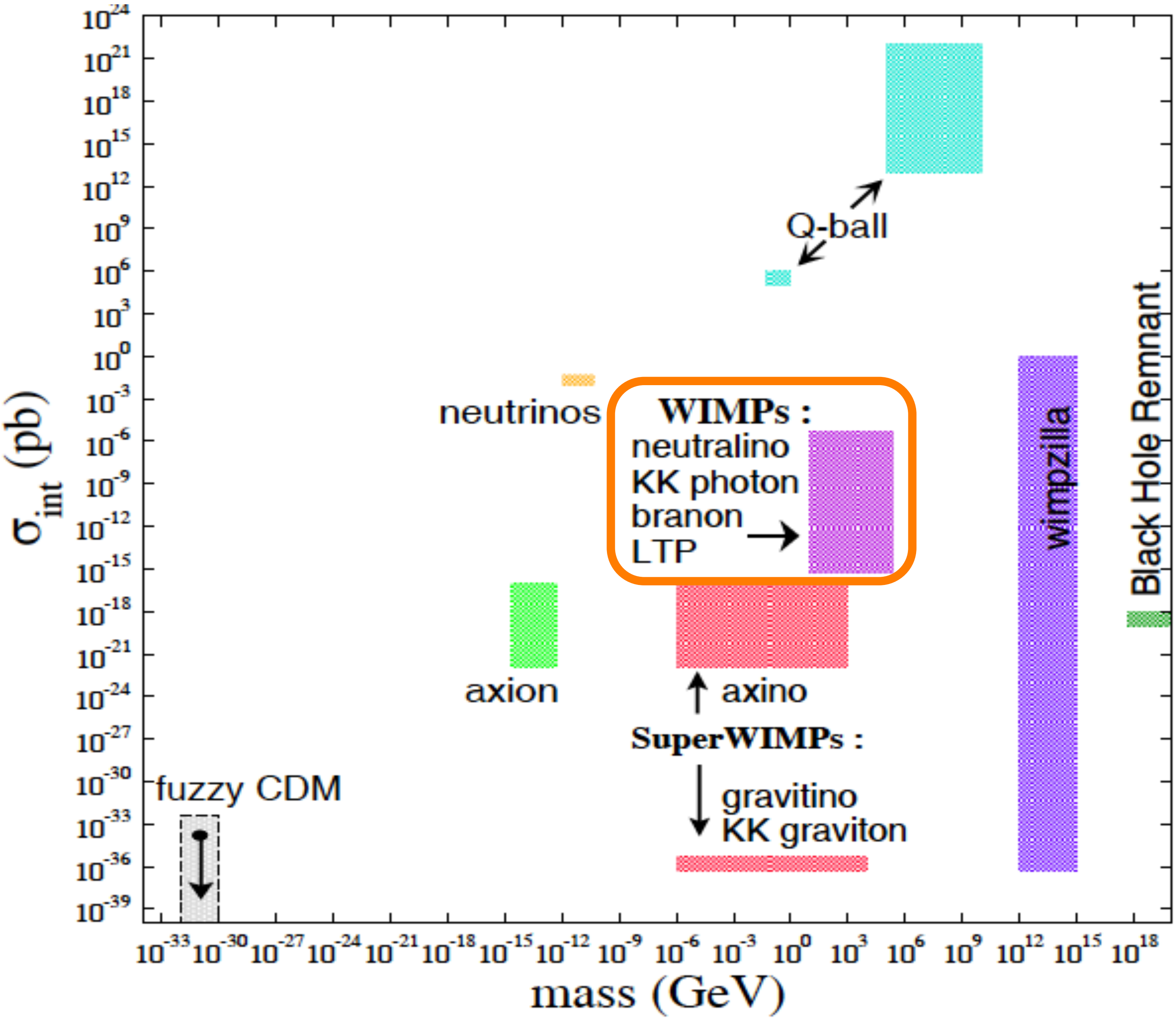
- **Introduction**
  - Why Noble Liquid?
  - Single Phase vs. Double Phase
  - Xenon – XMASS, LUX, XENON100
  - Argon – DEAP/CLEAN, WARP, DarkSide50
- **G1 : XENON100**
  - New Results
- **Future Directions**
  - G2 : XENON 1 Ton
  - G3 : LZD and MAX (Xenon 10 Ton + Argon 50 Ton)
- **XAX and Neutrino Physics**
  - Solar neutrino
  - Double beta decay
  - Supernova neutrino

Introduction

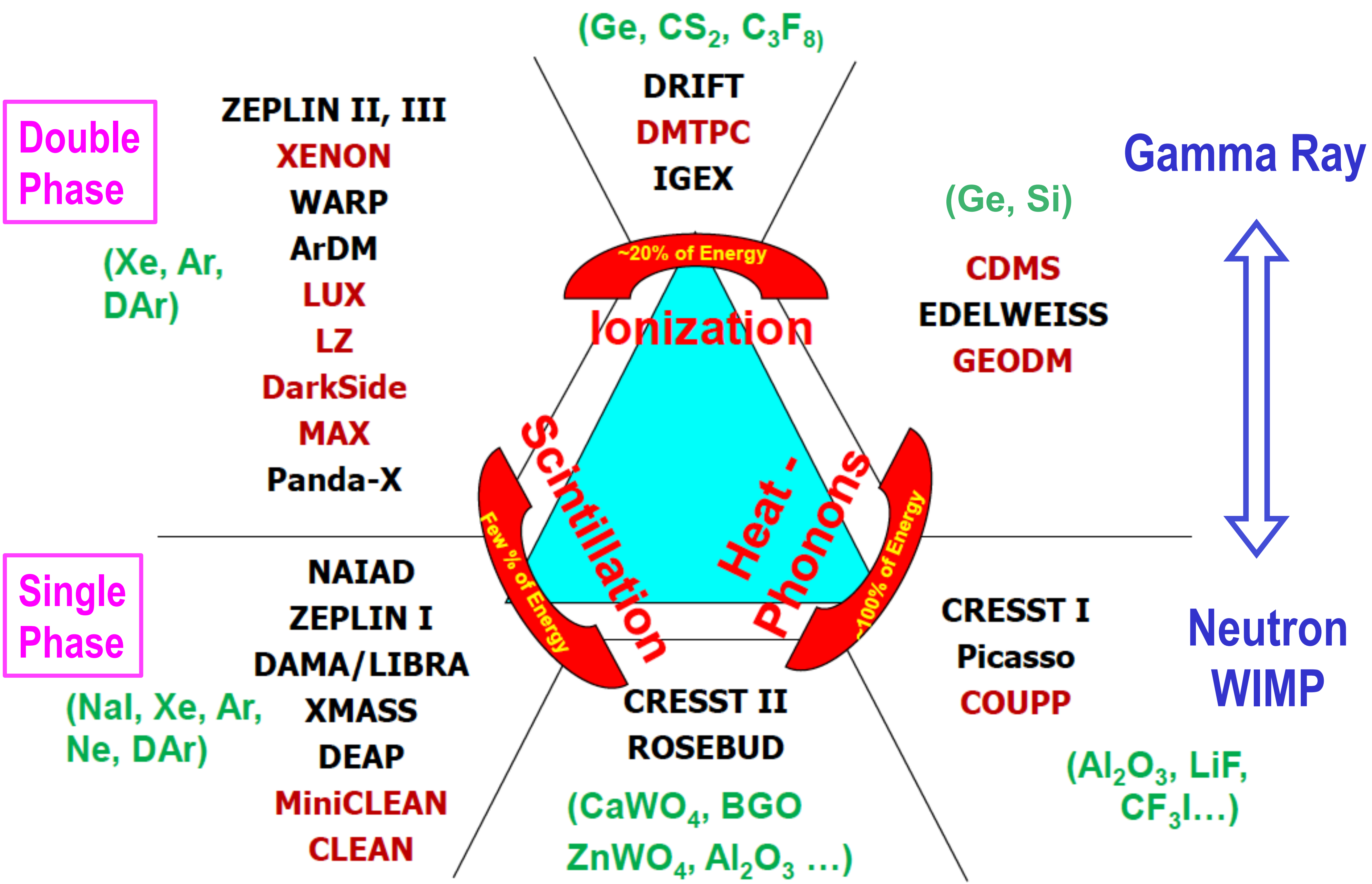
Growth of Direct Detection Community



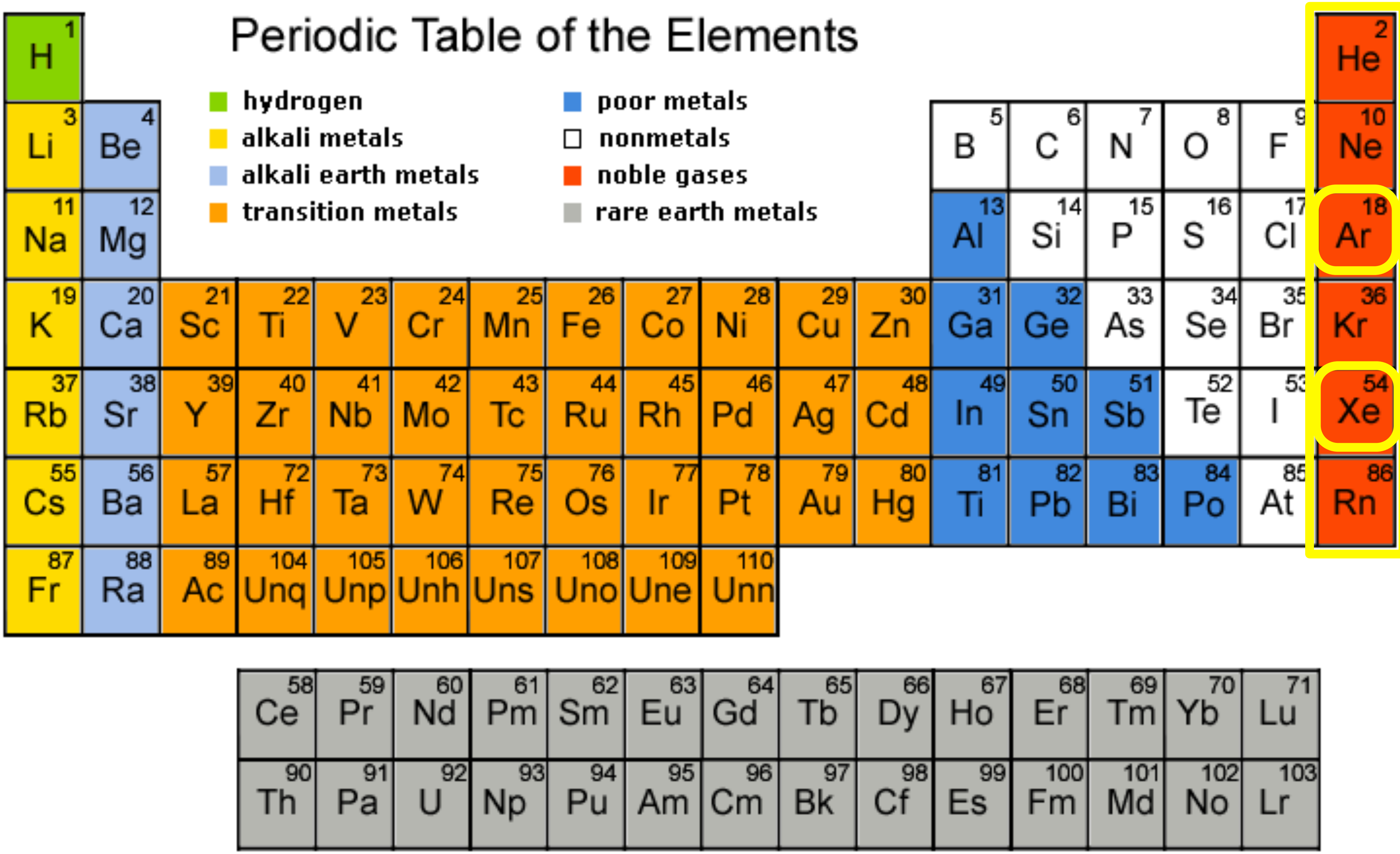
What is Dark Matter?



Detection Technique



Noble Gases

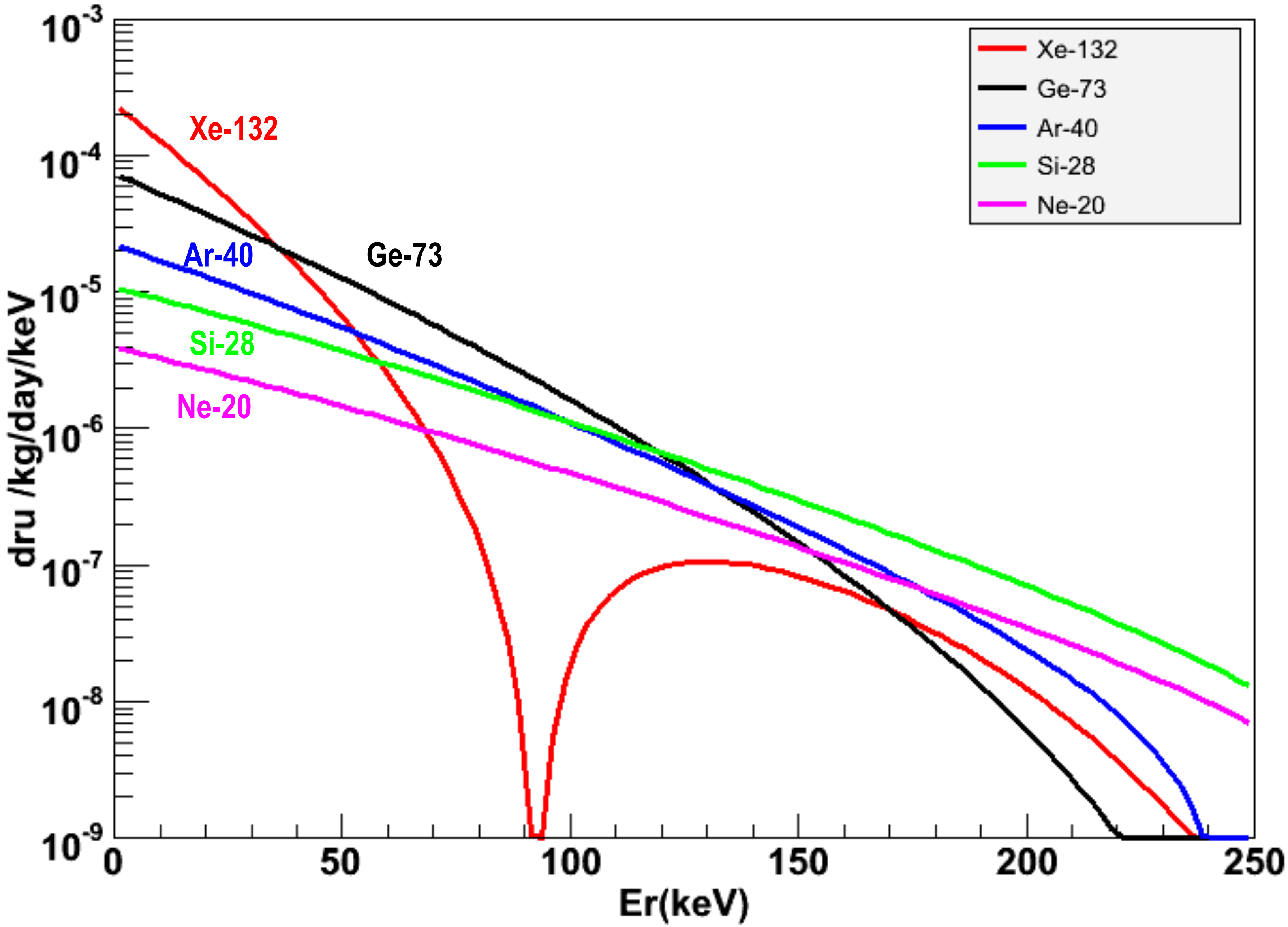

Periodic Table of the Elements
hydrogen
alkali metals
alkali earth metals
transition metals
poor metals
nonmetals
noble gases
rare earth metals
1 H
2 He
3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
55 Cs 56 Ba 57 La 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Ti 82 Pb 83 Bi 84 Po 85 At 86 Rn
87 Fr 88 Ra 89 Ac 104 Unq 105 Unp 106 Unh 107 Uns 108 Uno 109 Une 110 Unn
58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr

Properties of Noble Liqud

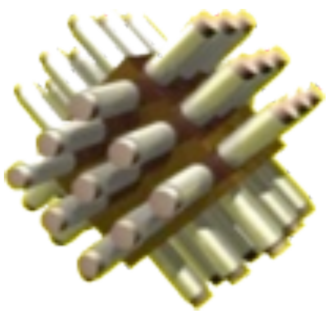
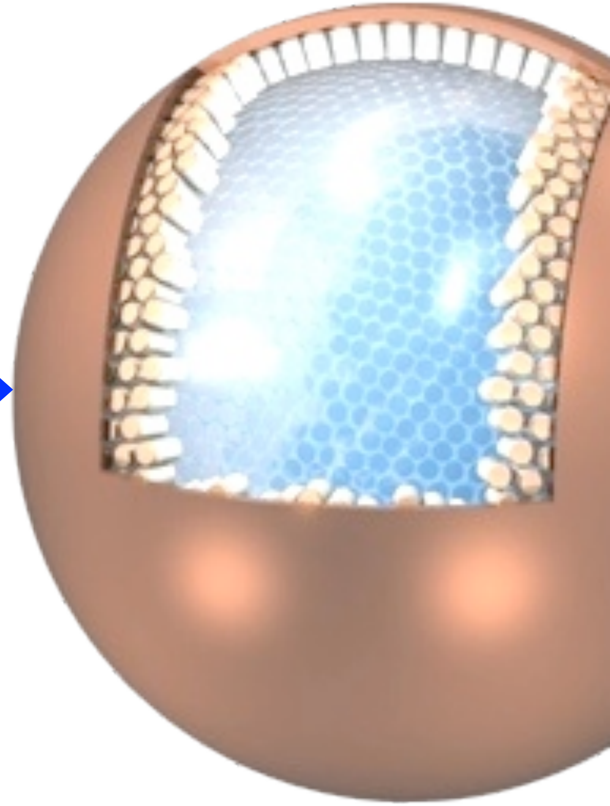
	Unit	Neon	Argon	Xenon
Z		10	18	54
A		20	40	~132
Liquid Density	*g/cc*	1.21	1.4	3.06
Energy Loss (dE/dX)	*MeV/cm*	1.4	2.1	3.8
Radiation Length	*cm*	24	14	2.8
Collision Length	*cm*	80	80	34
Boiling Temperature	*°K*	27.1	87.3	165
Scintillation Wavelength	*nm*	85	125	178
Scintillation	*photon/keV*	30	40	46
Ionization	*e-/keV*	46	42	64
Decay time (Fast Component)	*nsec*	19	7	4
Decay time (Slow Component)	*nsec*	1500	1600	26
Isotope		No	^{39}Ar (1 Bq/kg)	^{136}Xe
Price	*$ /ton*	$90k	~$2k	~$1M
Single Phase Experiments		CLEAN	DEAP/CLEAN	XMASS
Double Phase Experiments			WARP, ArDM, DarkSide, MAX	ZEPLIN, XENON, MAX LUX, LZD

Target Mass Dependence of WIMP Cross Section

cross section 10^{-44} cm^2, WIMP mass 100 GeV

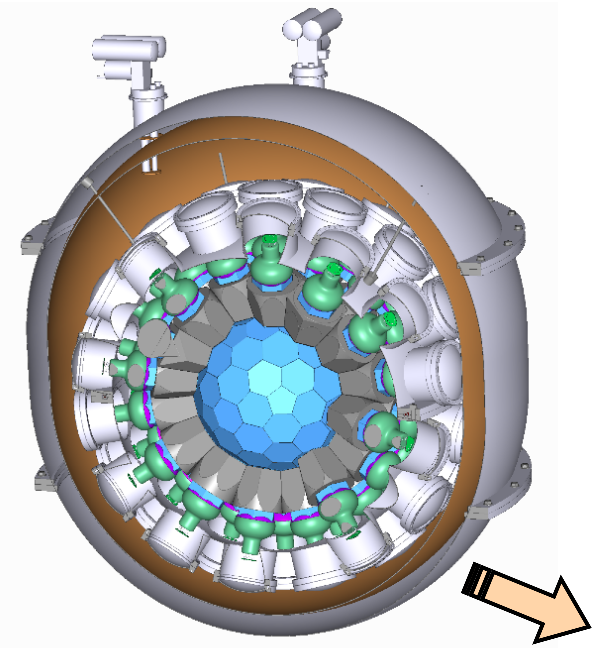


XMASS (Single Phase Xe)

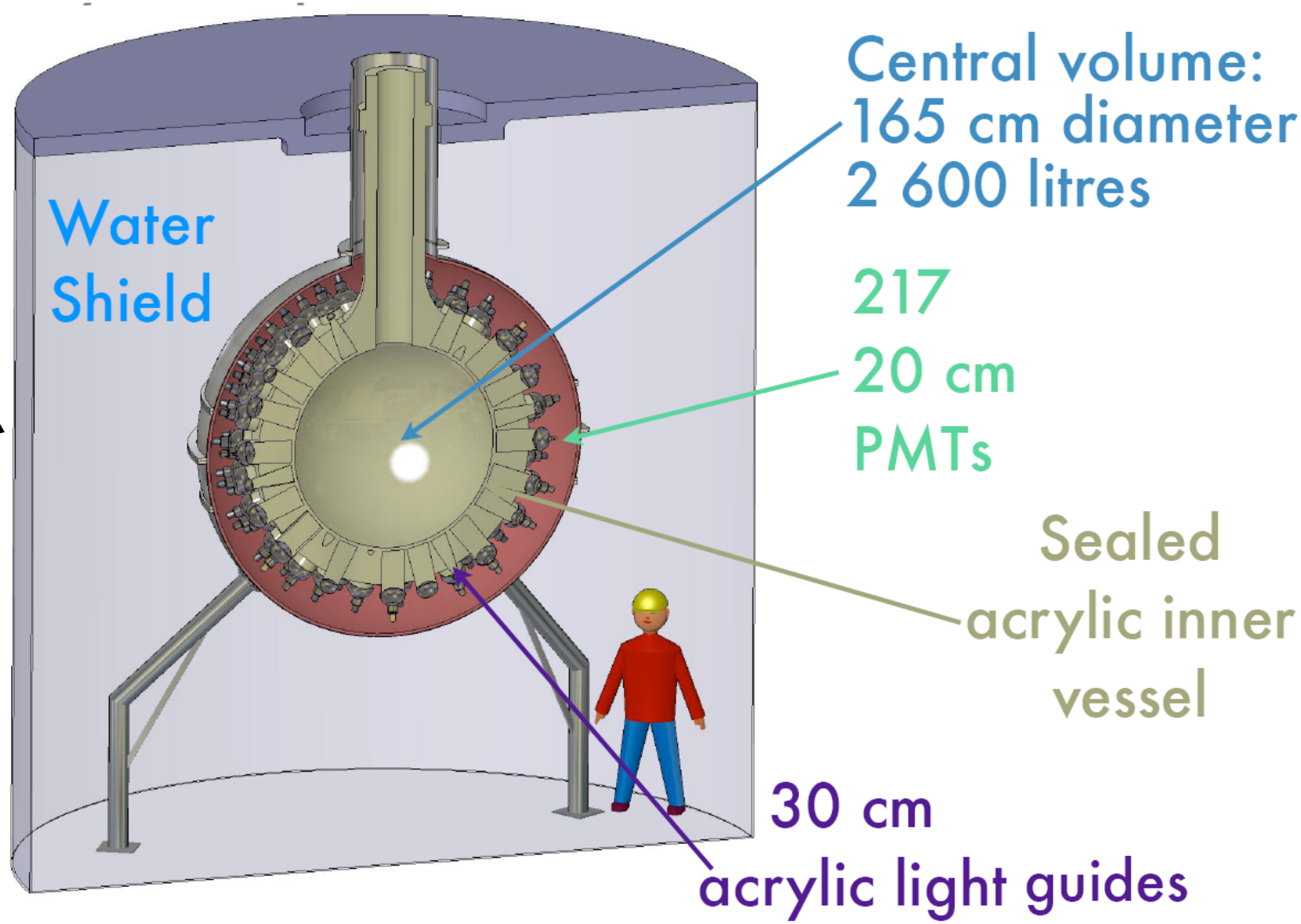
100kg Prototype (FV:30kg、30cm)	800kg Detector (FV:100kg、80cm)	20ton Detector (FV:10ton、2.5m)
		
R&D	Dark Matter	Solar neutrino Dark Matter
completed	2011 ～	Future

DEAP/CLEAN (Single Phase Ar/Ne)

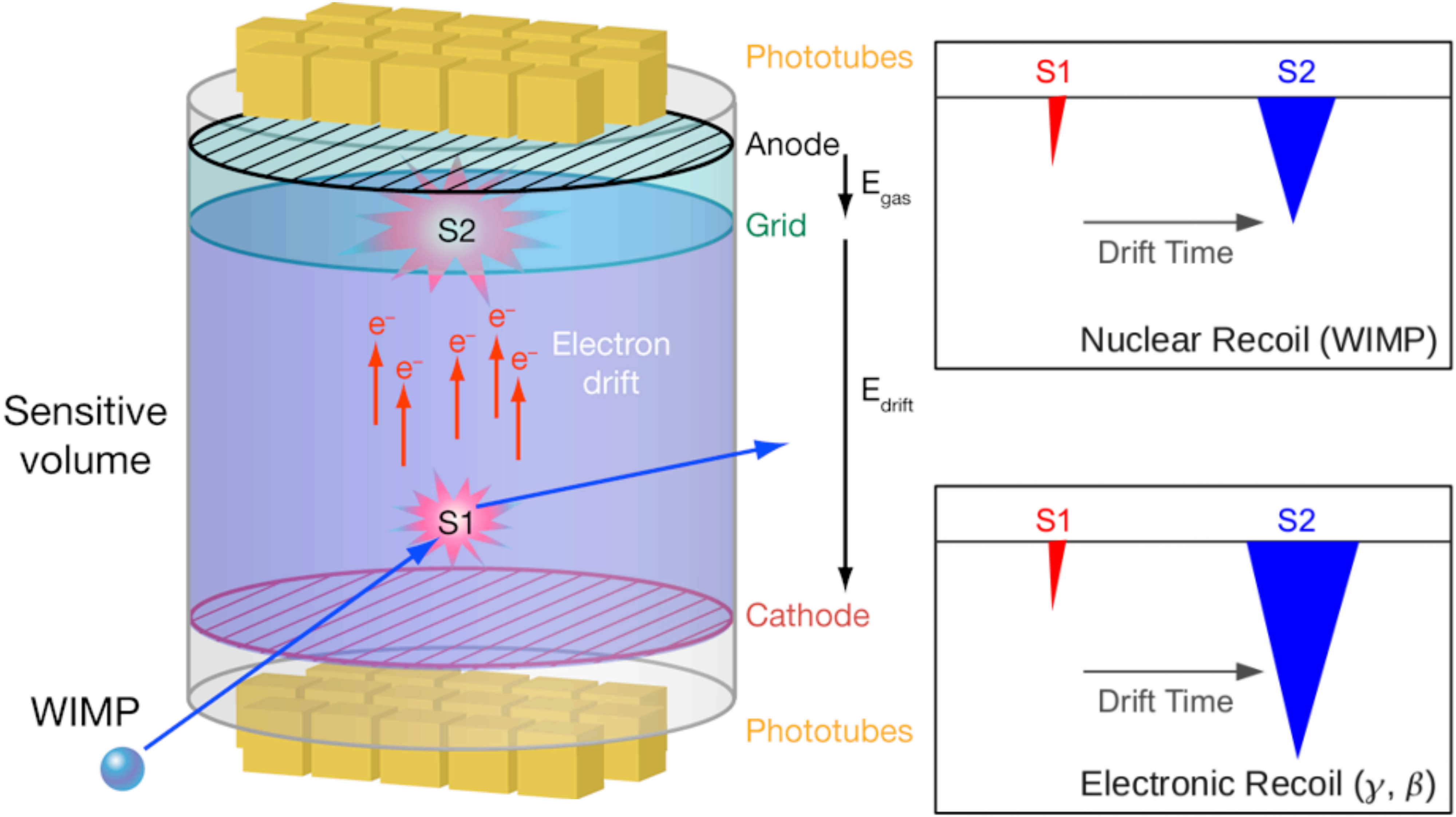
360 kg Mini-CLEAN



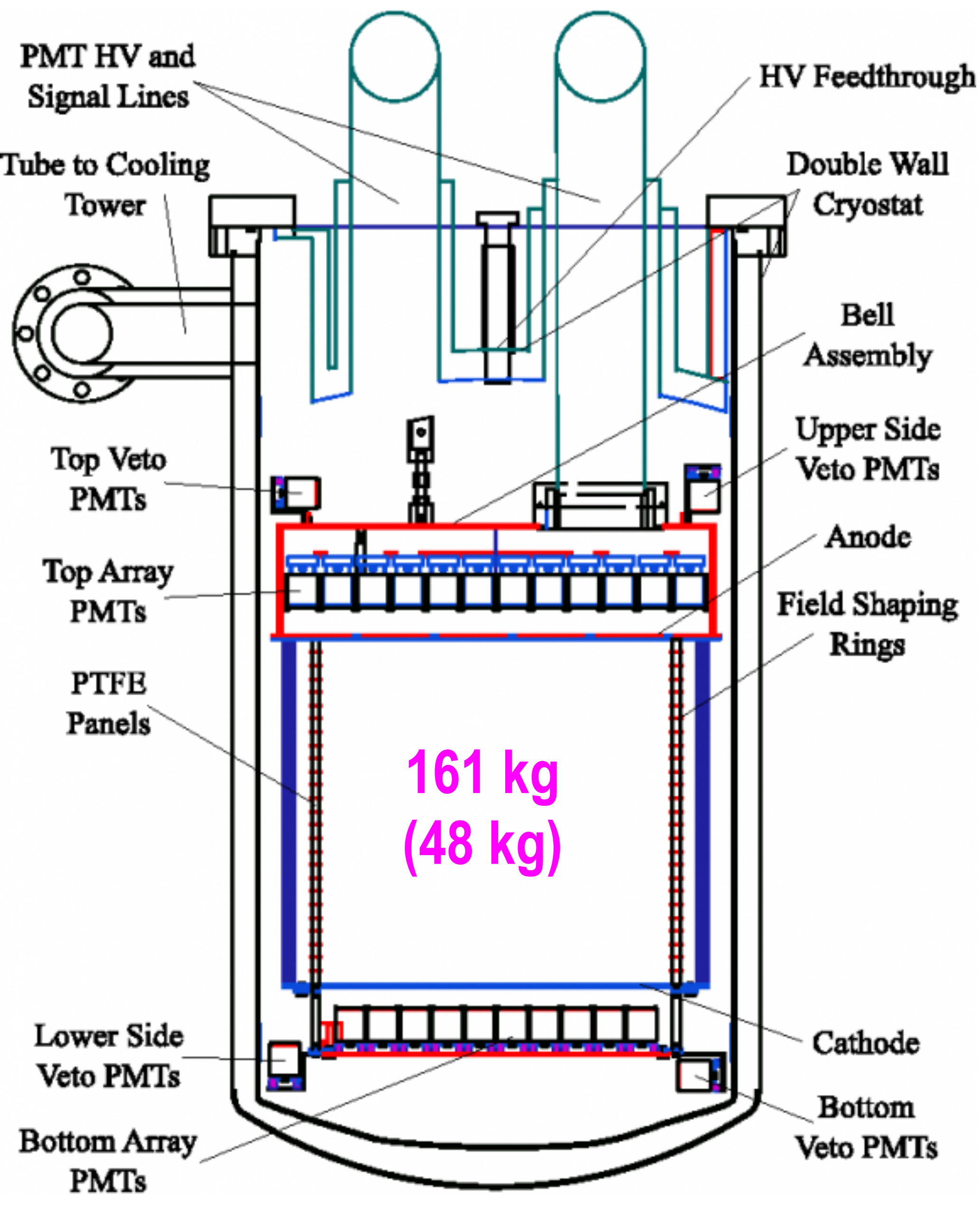
3.6 ton DEAP/CLEAN



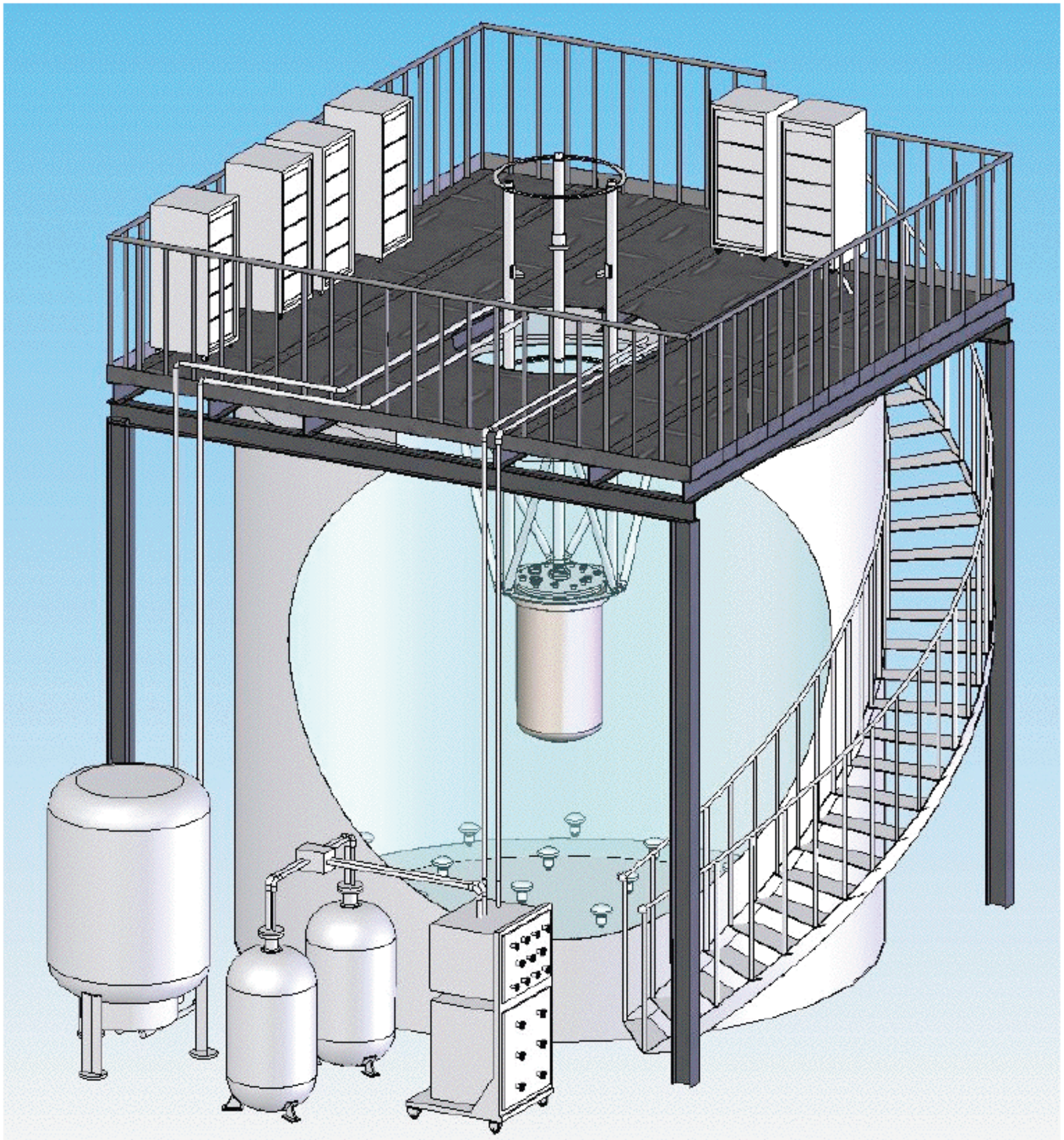
Double-Phase Noble Liquids

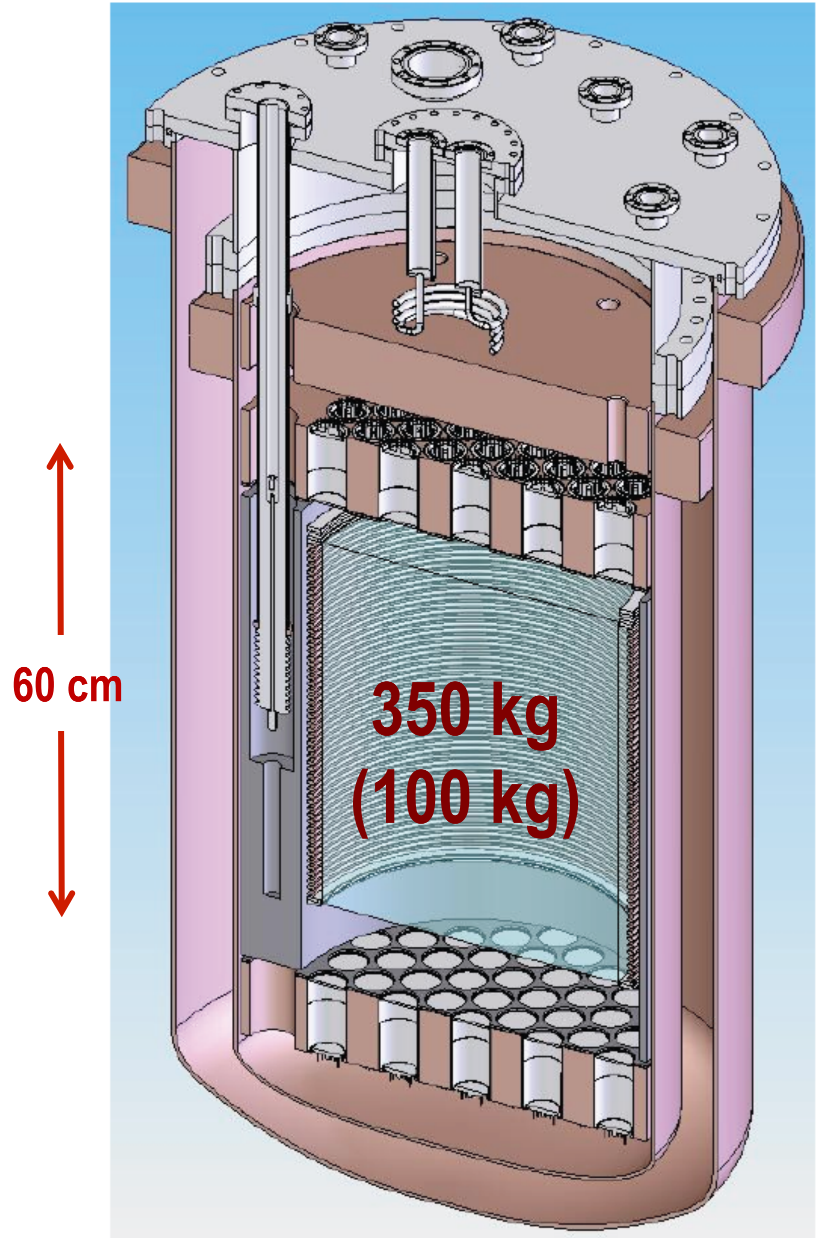


XENON100 (Double phase Xenon)

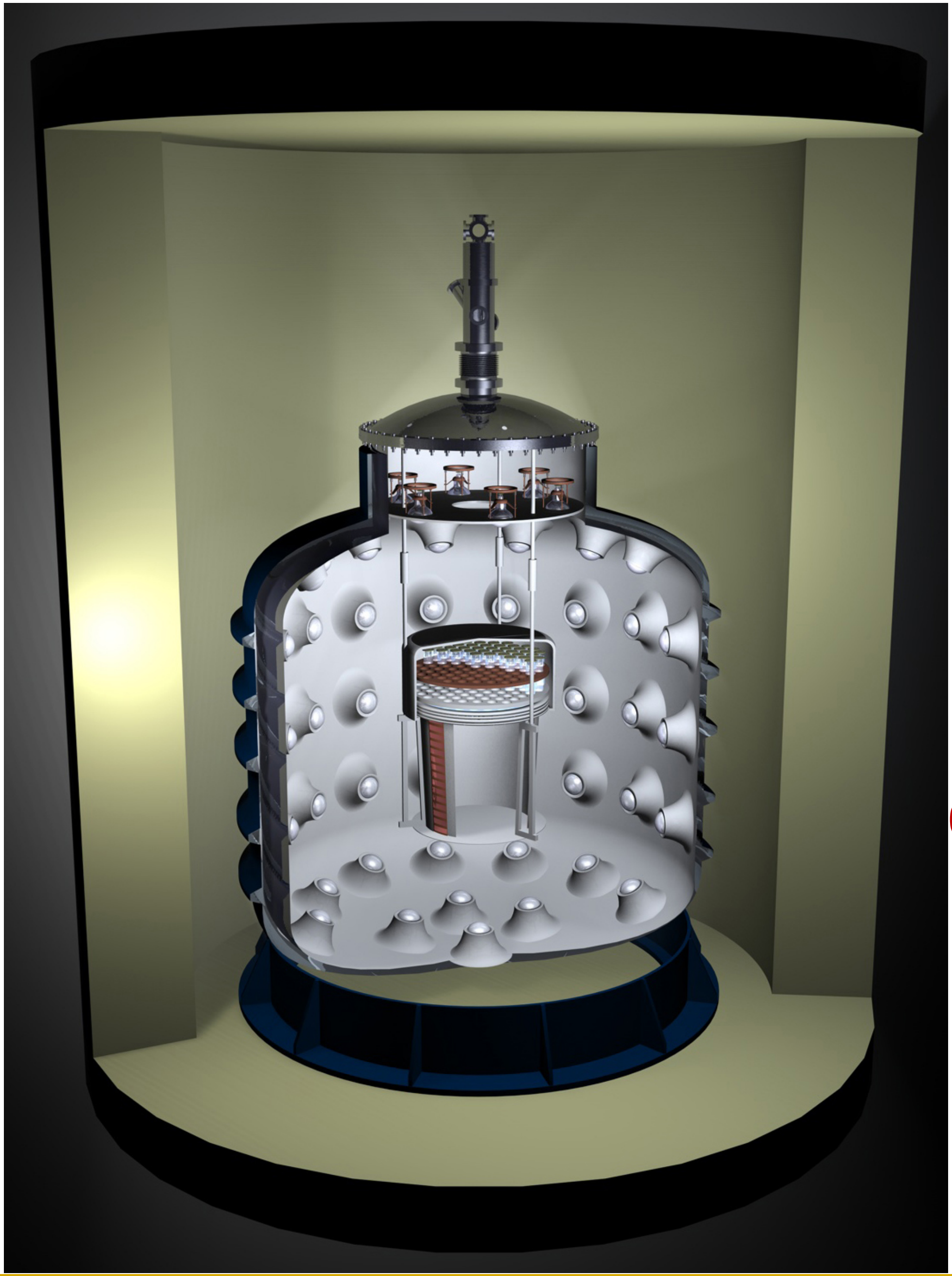


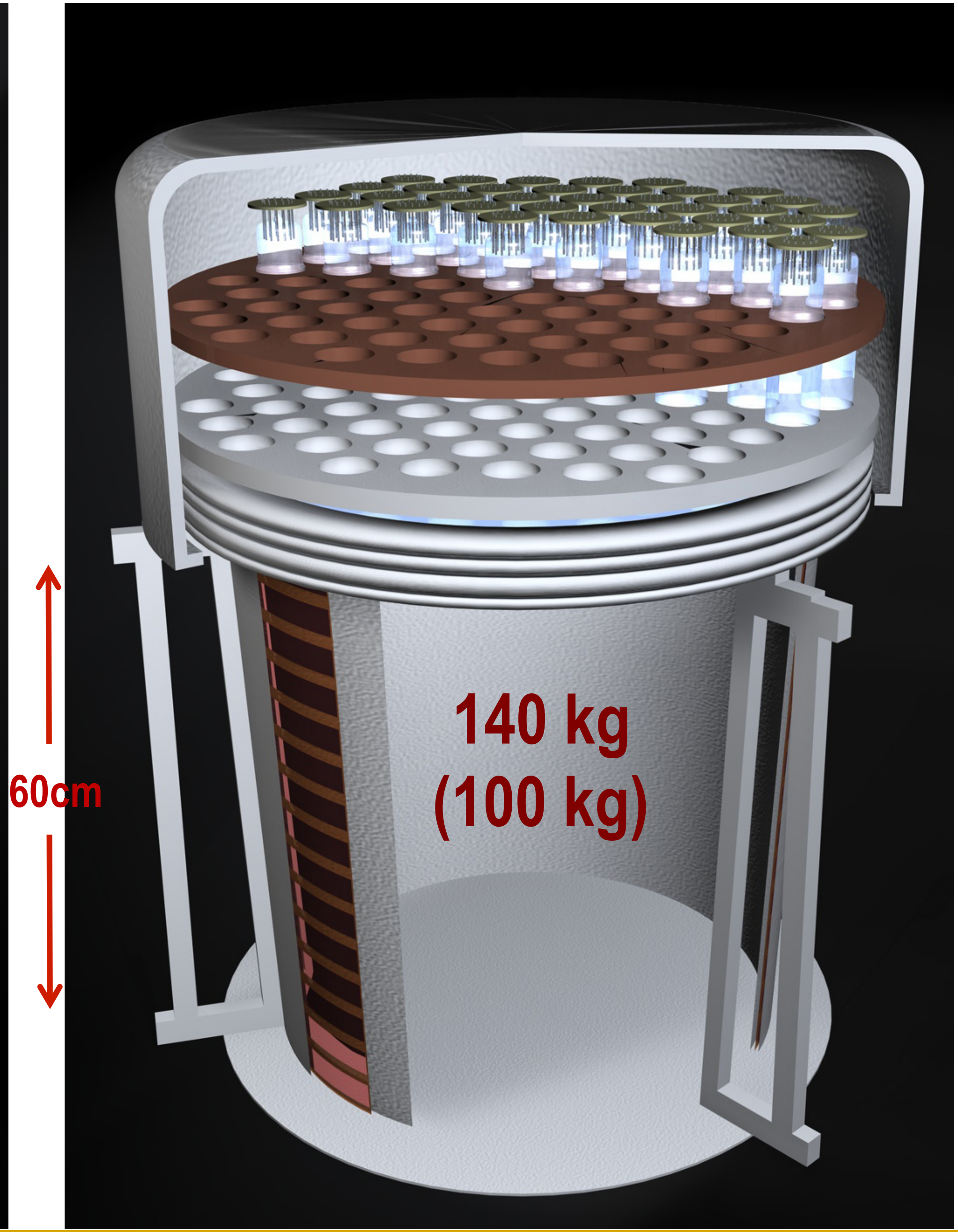
LUX 350 kg (Double phase Xenon)



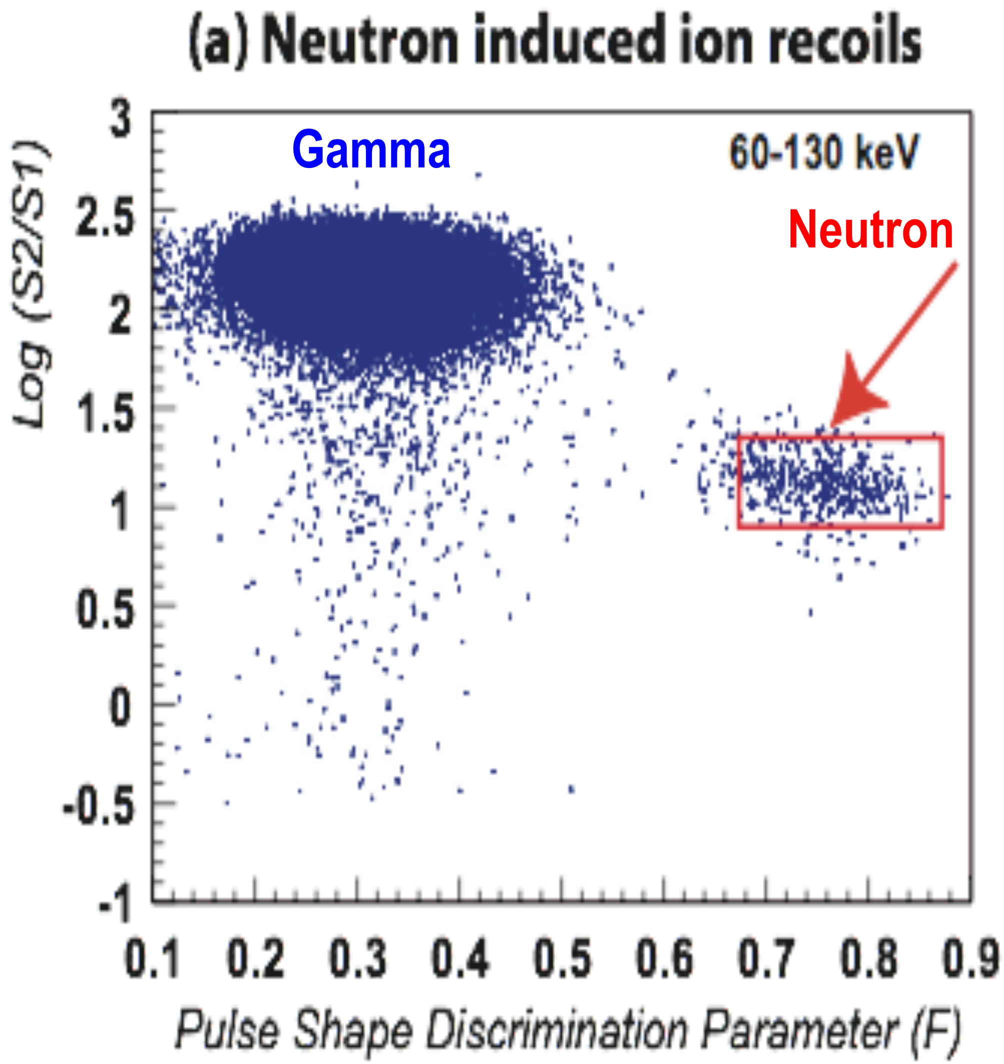


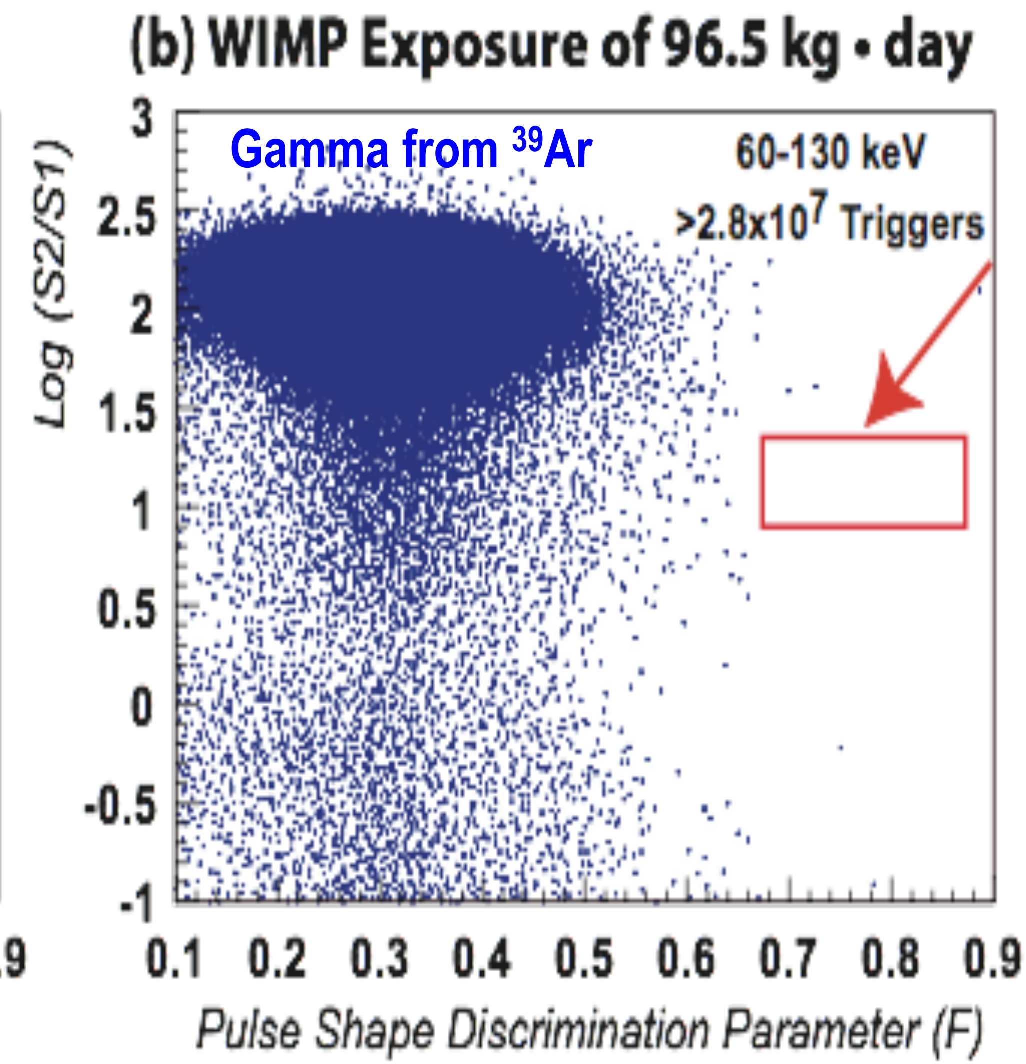
WARP 140 kg (Double Phase Argon)



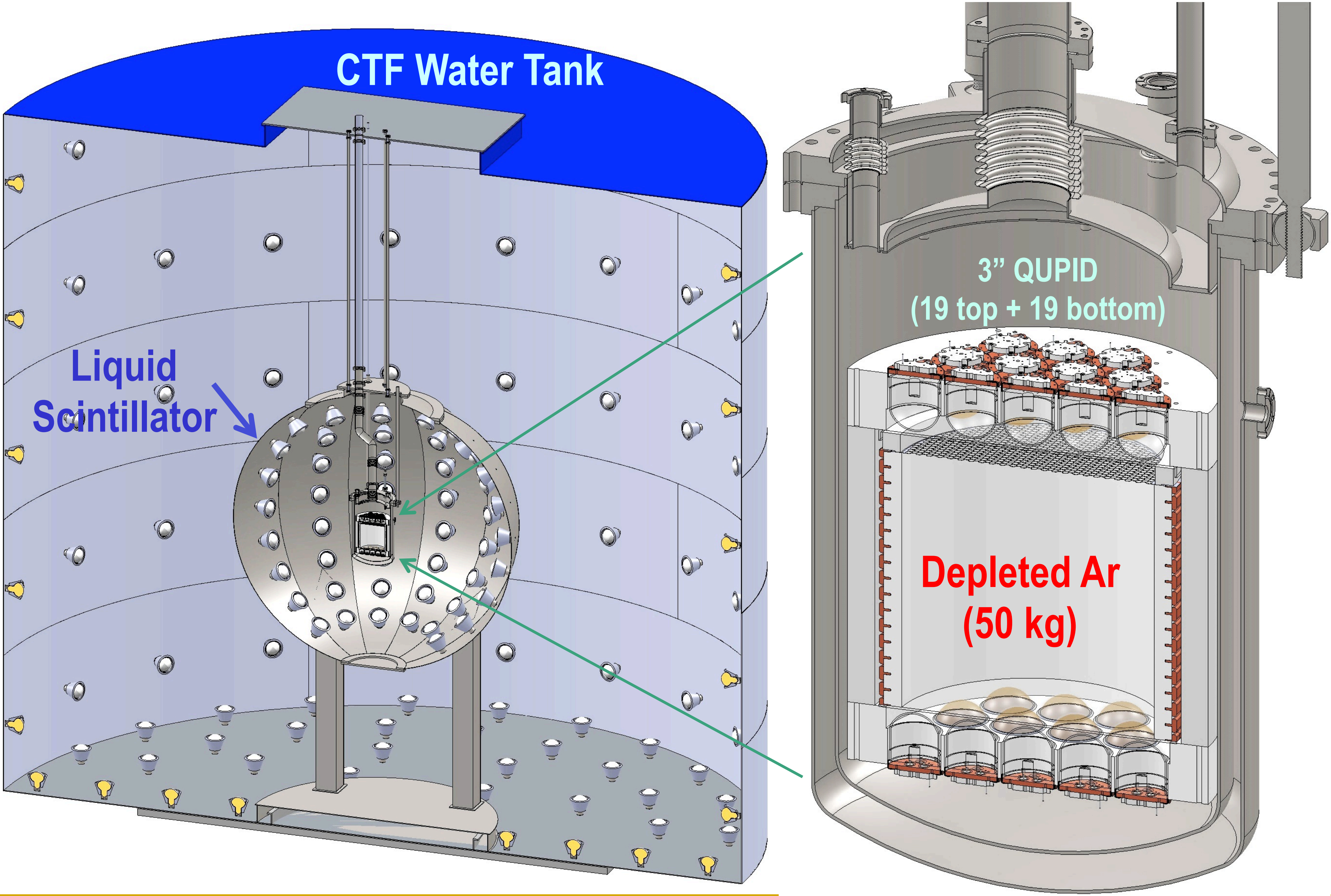


Pulse Shaping Discrimination by Ar (First WARP Results)





DarkSide 50 kg (Double phase Argon)



Comparison of G1 Experiments

Experiment Name	Location	Mass				Photon Detector				
		Target	Total	Fiducial	Phase	Type	Location	Size	Radioactivity	
			(kg)	(kg)				(inch)	(mBq / piece)	(mBq / cm^2)
XENON100	Gran Sasso	Xe	162	48	Double	R8520	Top/Bot.	1	1	0.2
XMASS	Kamioka	Xe	800	100	Single	R8778Hex	4π	2	5	0.2
LUX	DUSEL	Xe	350	100	Double	R8778	Top/Bot.	2	20	0.8
Mini-CLEAN	SNO	Ar	360	100	Single	8" PMT	4π	8	500	1.5
WARP	Gran Sasso	Ar	140	100	Double	3" PMT	Top	3	200	4.4
DarkSide 50	Gran Sasso	Ar	60	50	Double	3” QUPID	Top/Bot.	3	1	0.02

Single Phase vs. Double Phase

	Single Phase	Double Phase
HV for electron drift	Not required	Required (~1 kV/cm)
O_2 / H_2O impurity	Not critical	Critical
Energy threshold	20 PE	4 PE
Sensitivity for low mass WIMP	> 20 GeV	> 5 GeV
Position resolution	~ 10 cm	~ 2 mm
Gamma rejection by S2/S1	No	Yes (> 99.5%)
Neutron rejection by Multi-hit cut	No	Yes

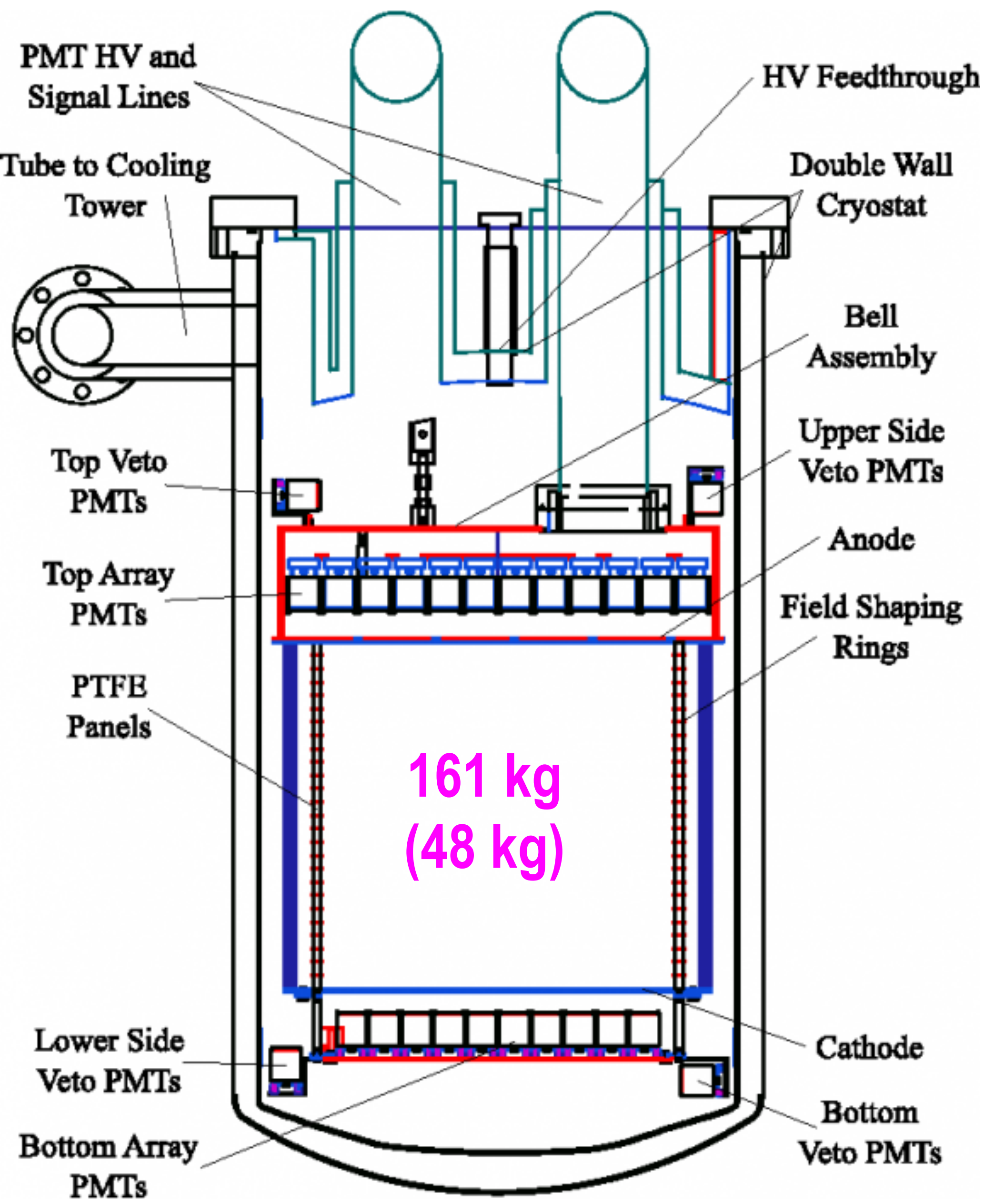
Xenon vs. Argon

- **Xenon**
  - 5 times more sensitive (per unit mass)
    - due to A^2 dependence.
  - Expensive
    - ~$1M / ton
  - Limited by pp-chain solar neutrino
    - ~0.2 event /ton/year
  - Ideal for mass range of 10 – 100 GeV
    - Spectrum is independent from mass
- **Argon**
  - Free from gamma background
    - > 10^6 rejection by pulse shaping
  - Inexpensive
  - Ideal for mass range of 20 – 200 GeV
    - Insensitive to low mass < 10 GeV

XENON100


Laboratori Nazionali del Gran Sasso, Italy
LNGS 1400 m Rock (3100 w.m.e)
XENON100
LVD
ICARUS
OPERA
WARP

XENON100 Detector



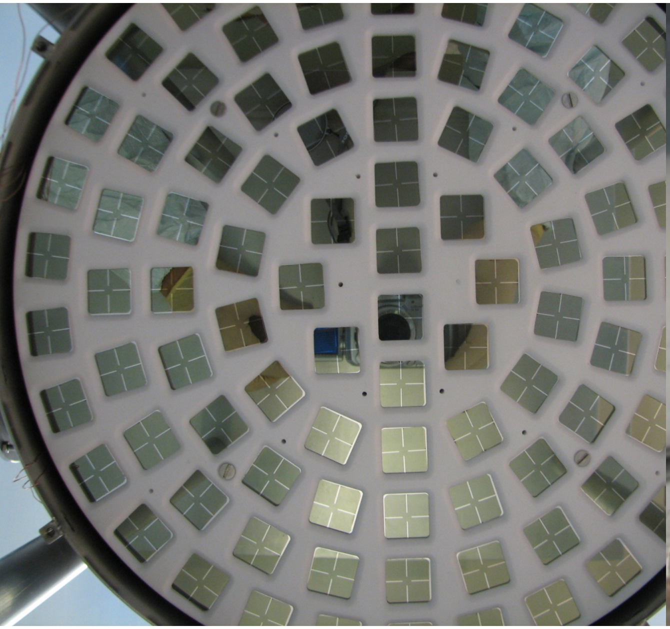
PMT Arrays

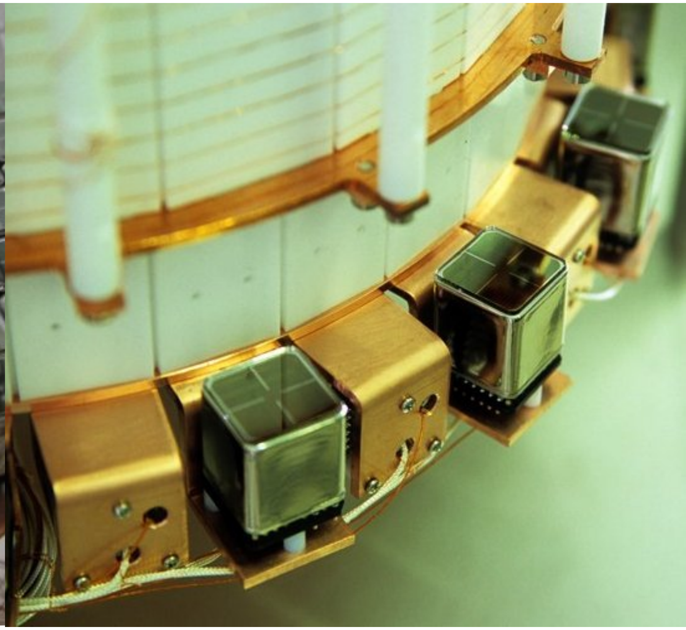
242 Hamamatsu R8520 PMTs

1"x1", optimized for response @ Xe scintillation light (178 nm)

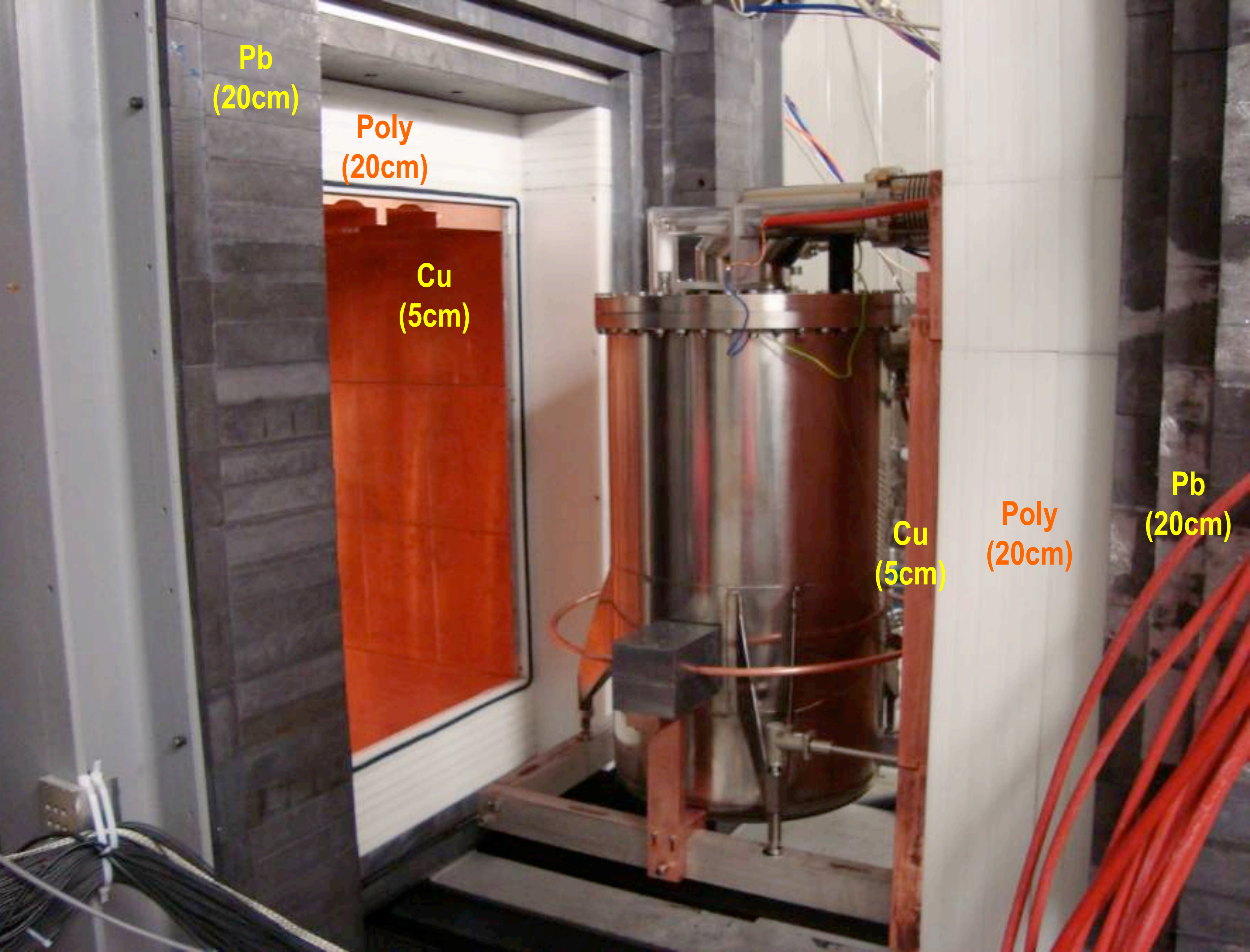
Low radioactivity (~ <1 mBq/PMT)

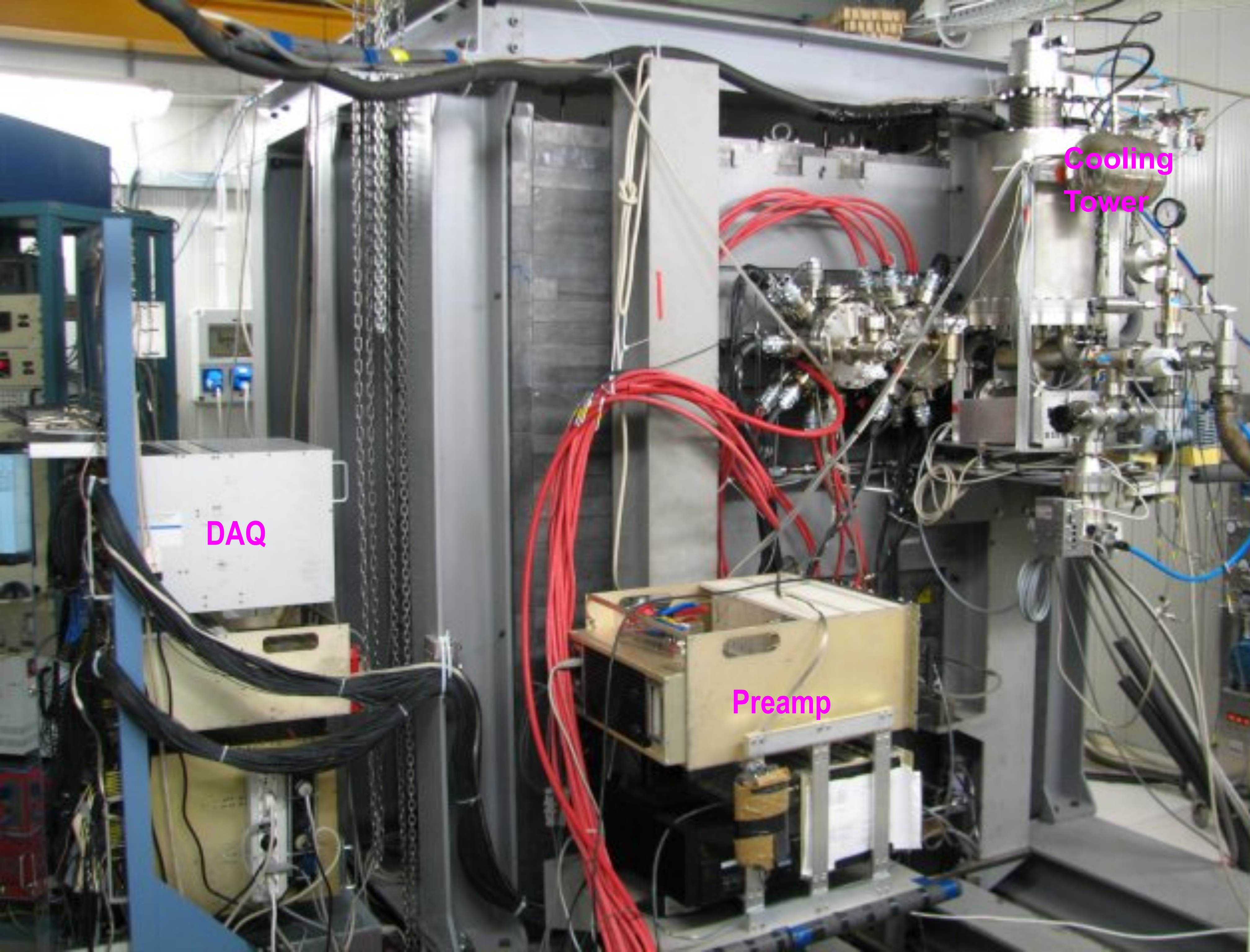
Top Array	Bottom Array	Active Veto
98 PMTs	80 PMTs	64 PMTs
~23% QE	~33% QE	~23% QE





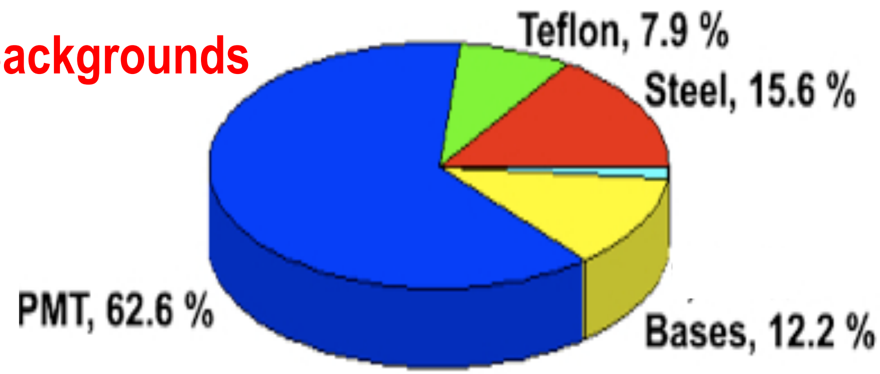
XENON100 Detector


Pb
(20cm)
Poly
(20cm)
Cu
(5cm)
Cu
(5cm)
Poly
(20cm)
Pb
(20cm)

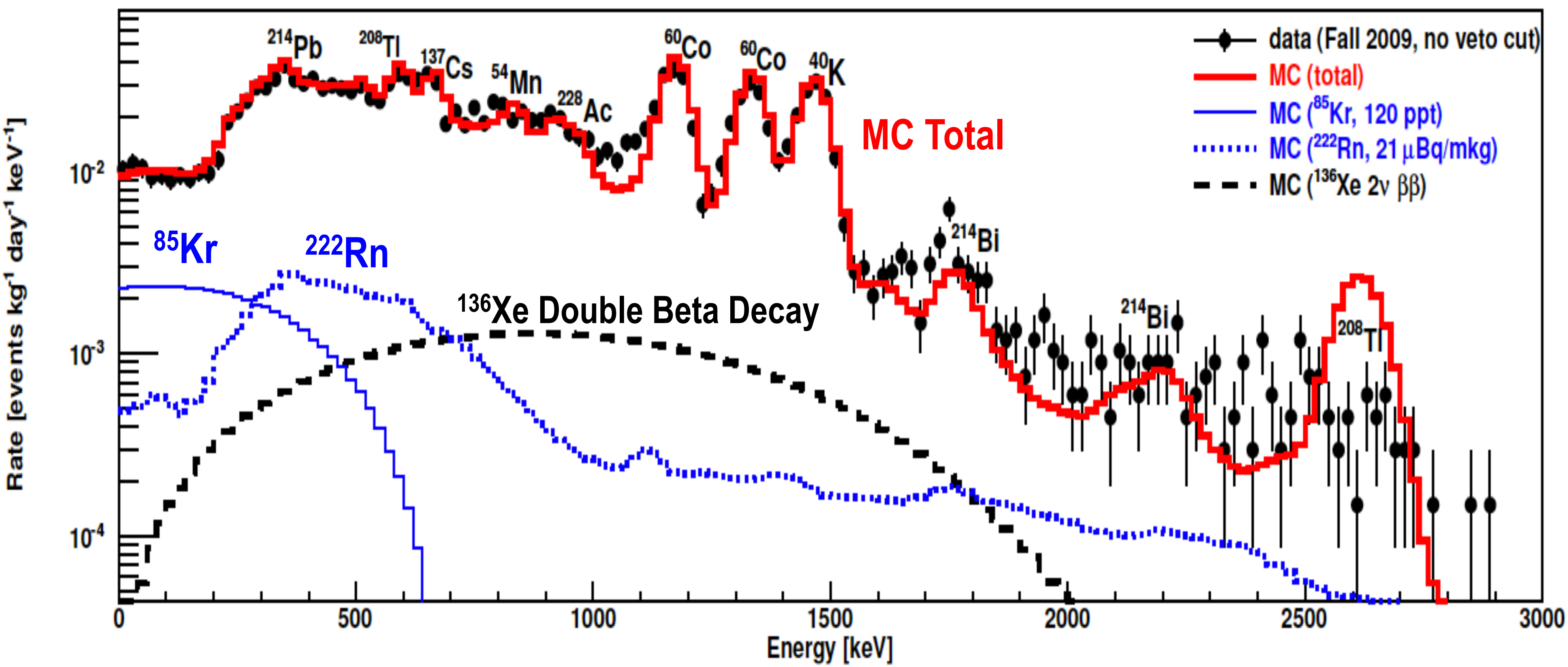

Cooling
Tower
DAQ
Preamp

Energy Spectrum of Real Data vs. MC

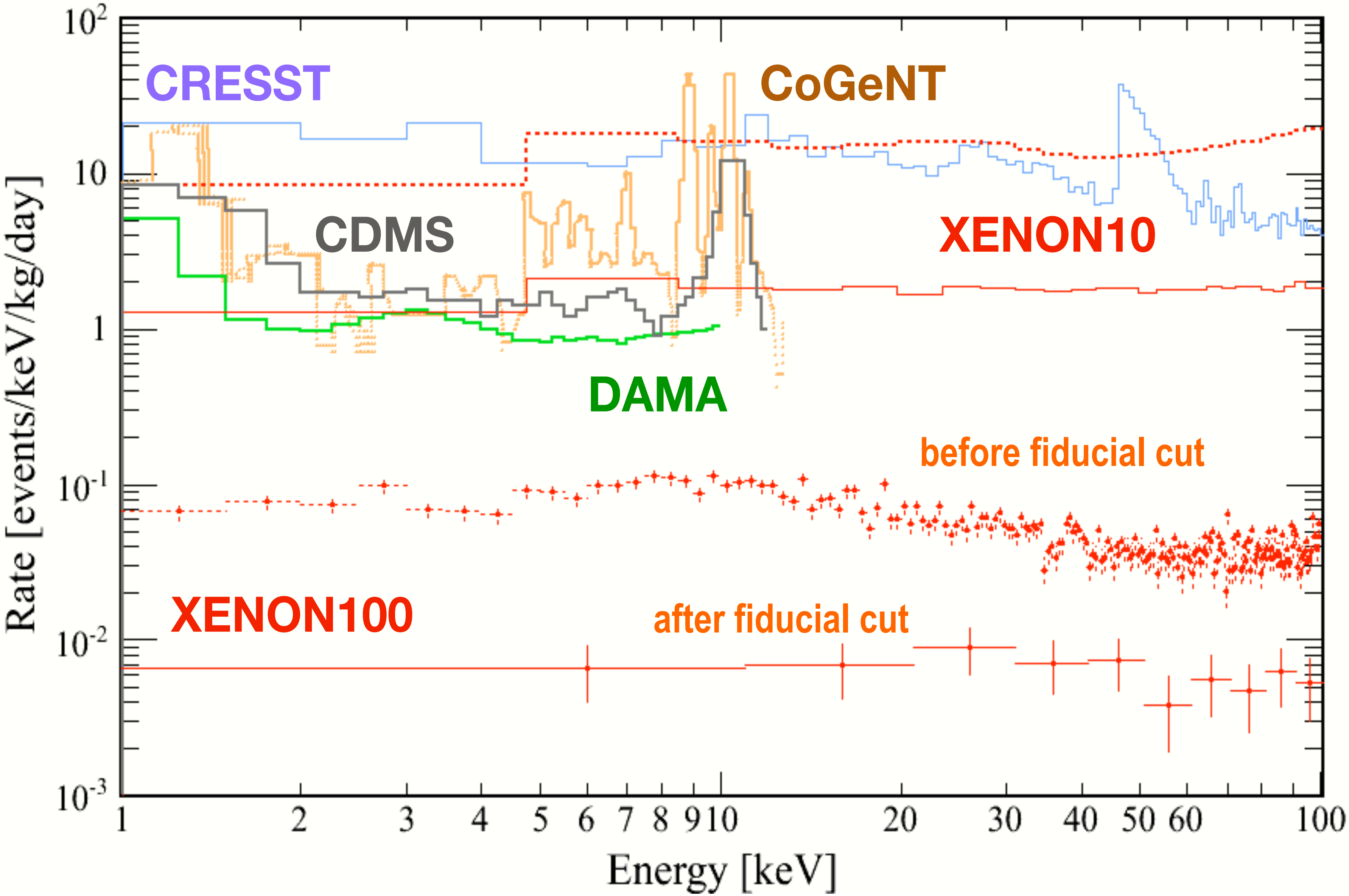
Surface Backgrounds



arXiv:1101.3866



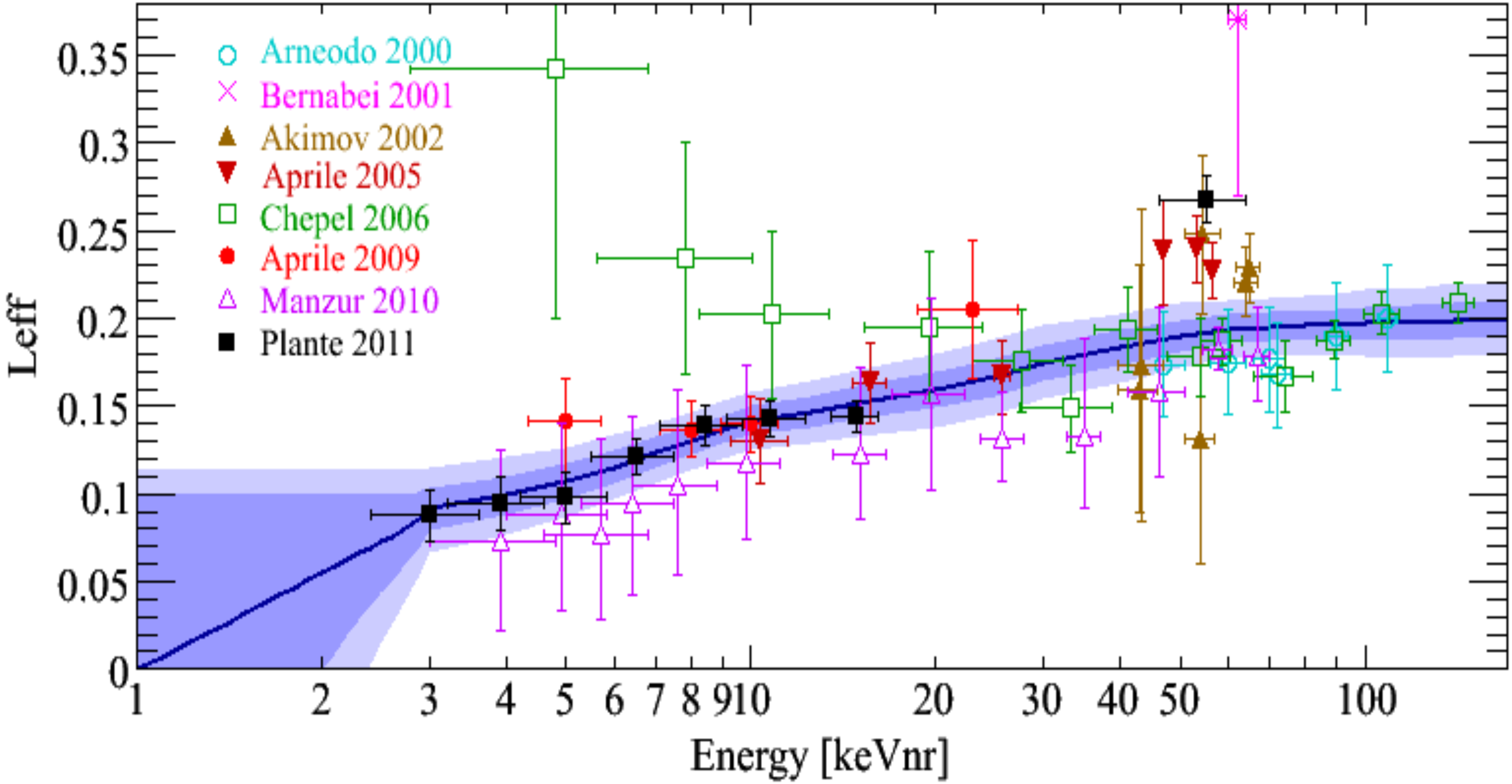
Level of Backgrounds (before S2/S1 cut)



New L_{eff} vs. Energy

Leff : Relative scintillation efficiency for nuclear recoils to 122 keV gamma rays (at zero electric field)

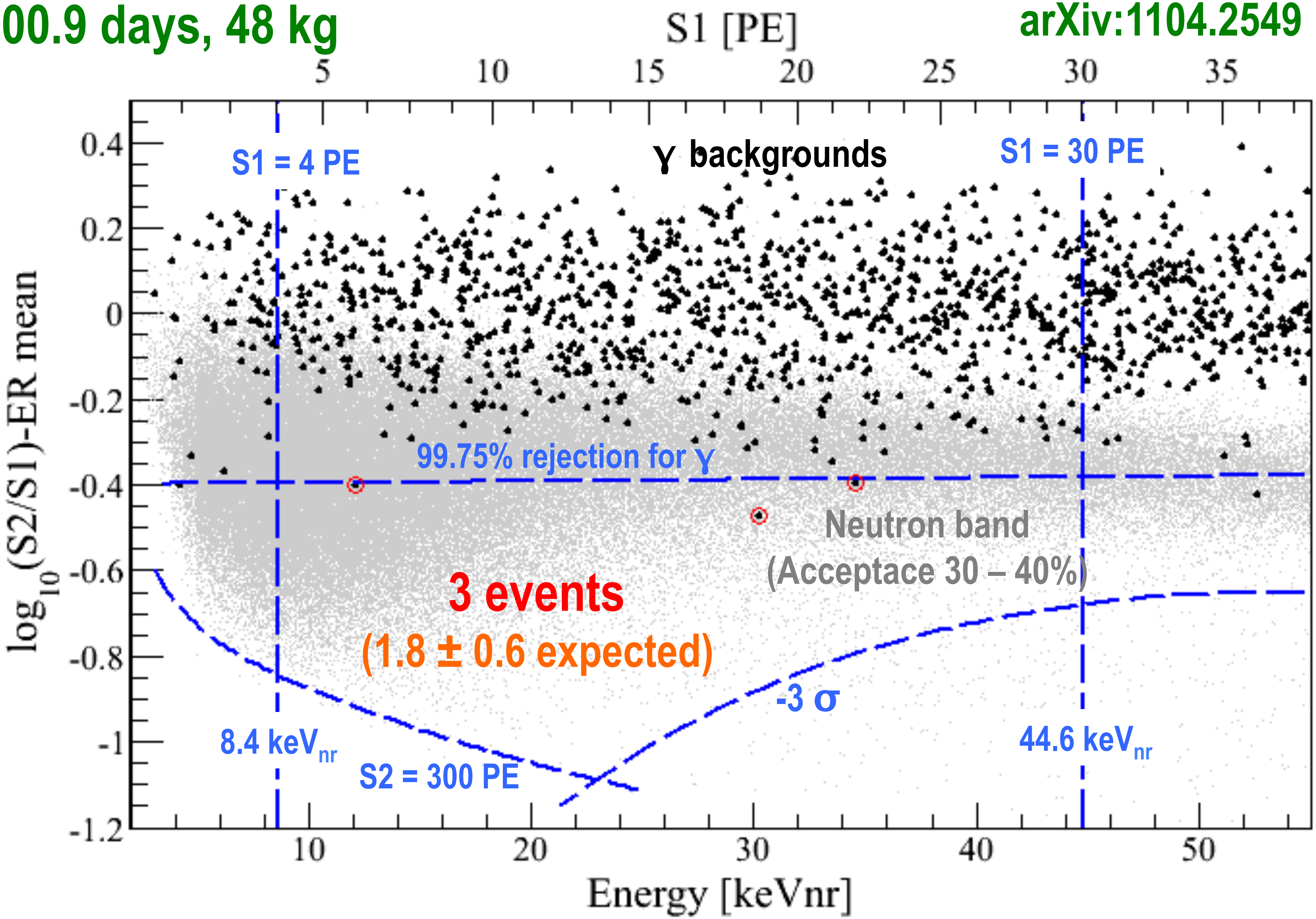
arXiv:1104.2587



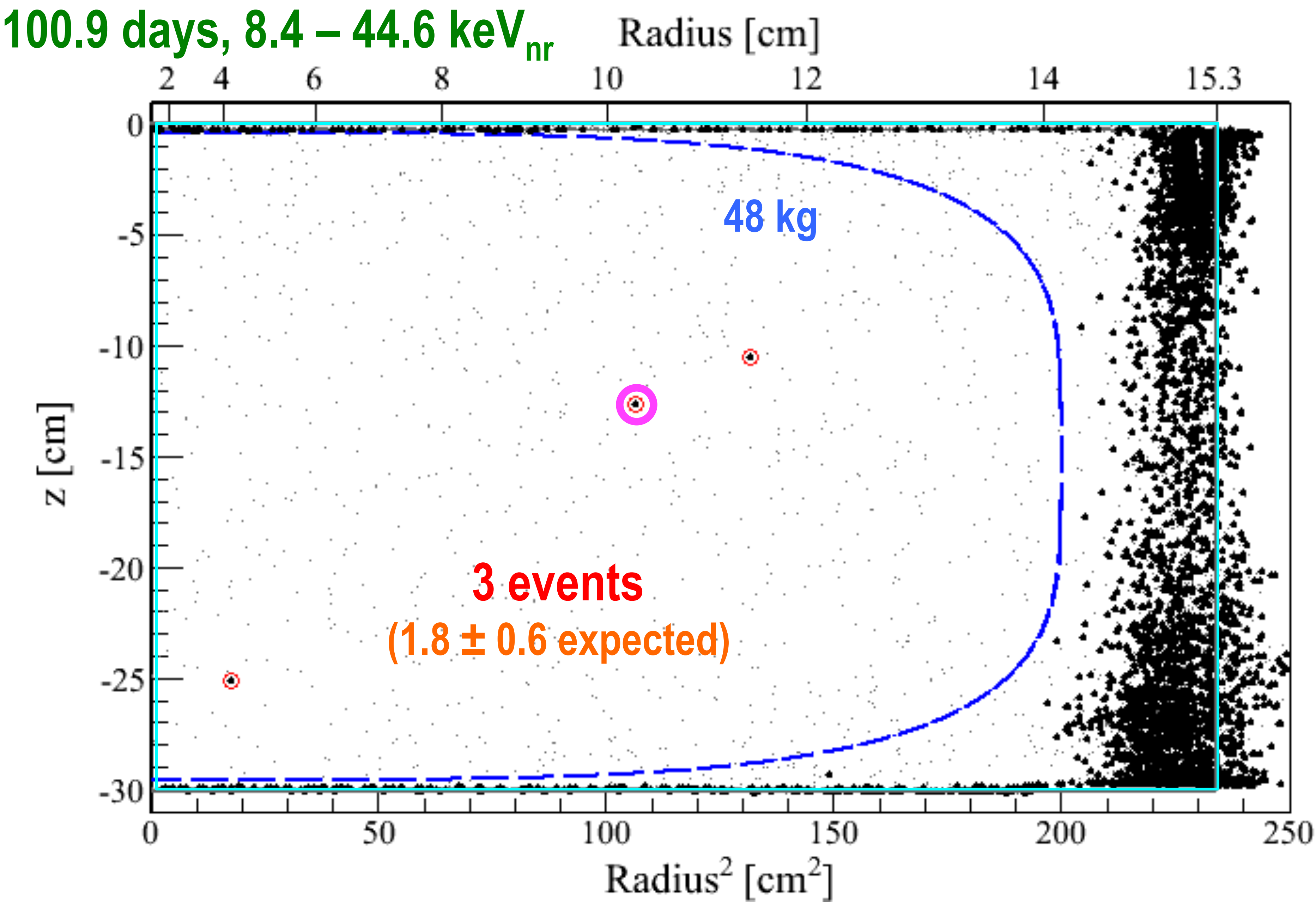
Log(S2/S1) vs. Energy

100.9 days, 48 kg

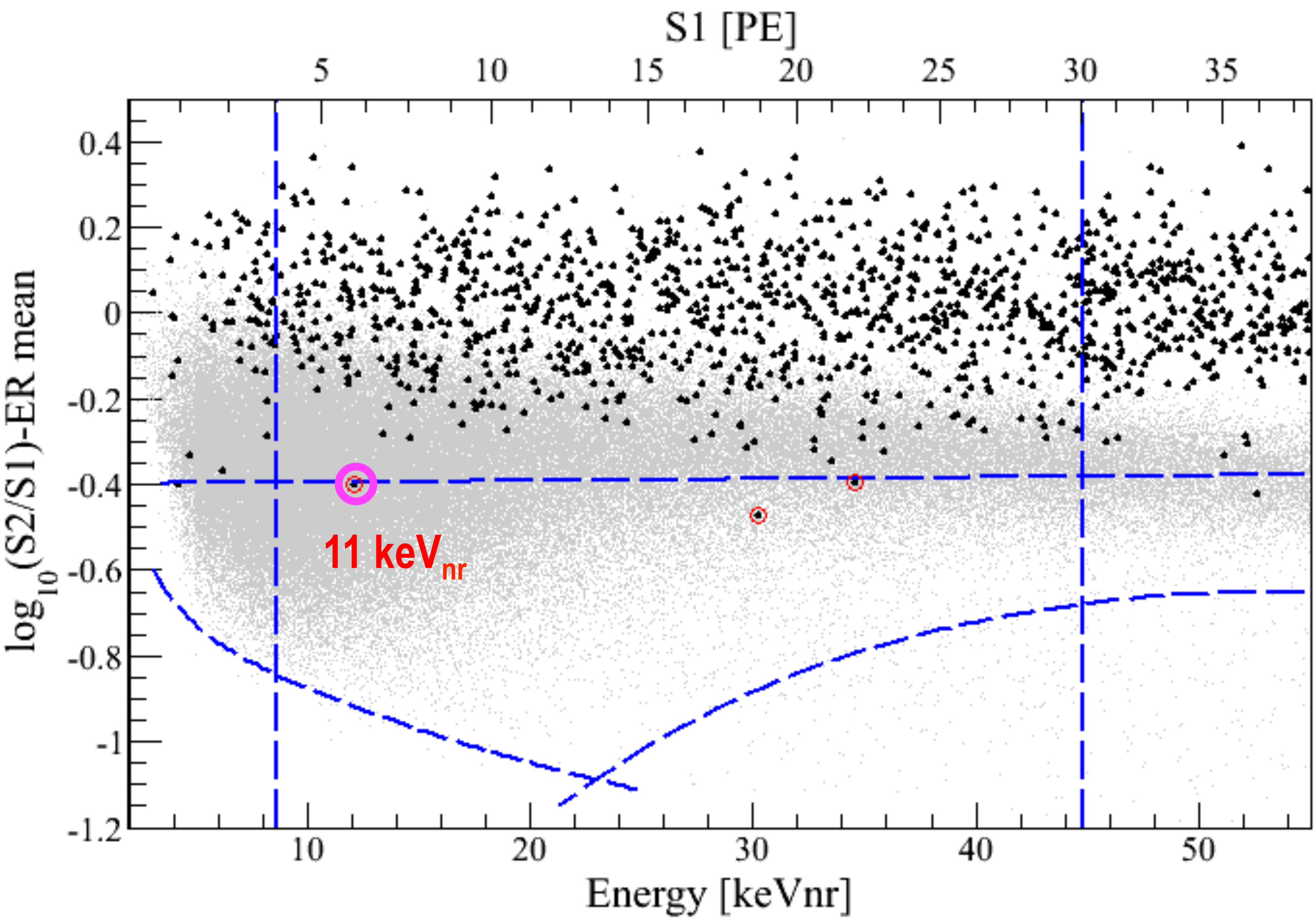
arXiv:1104.2549



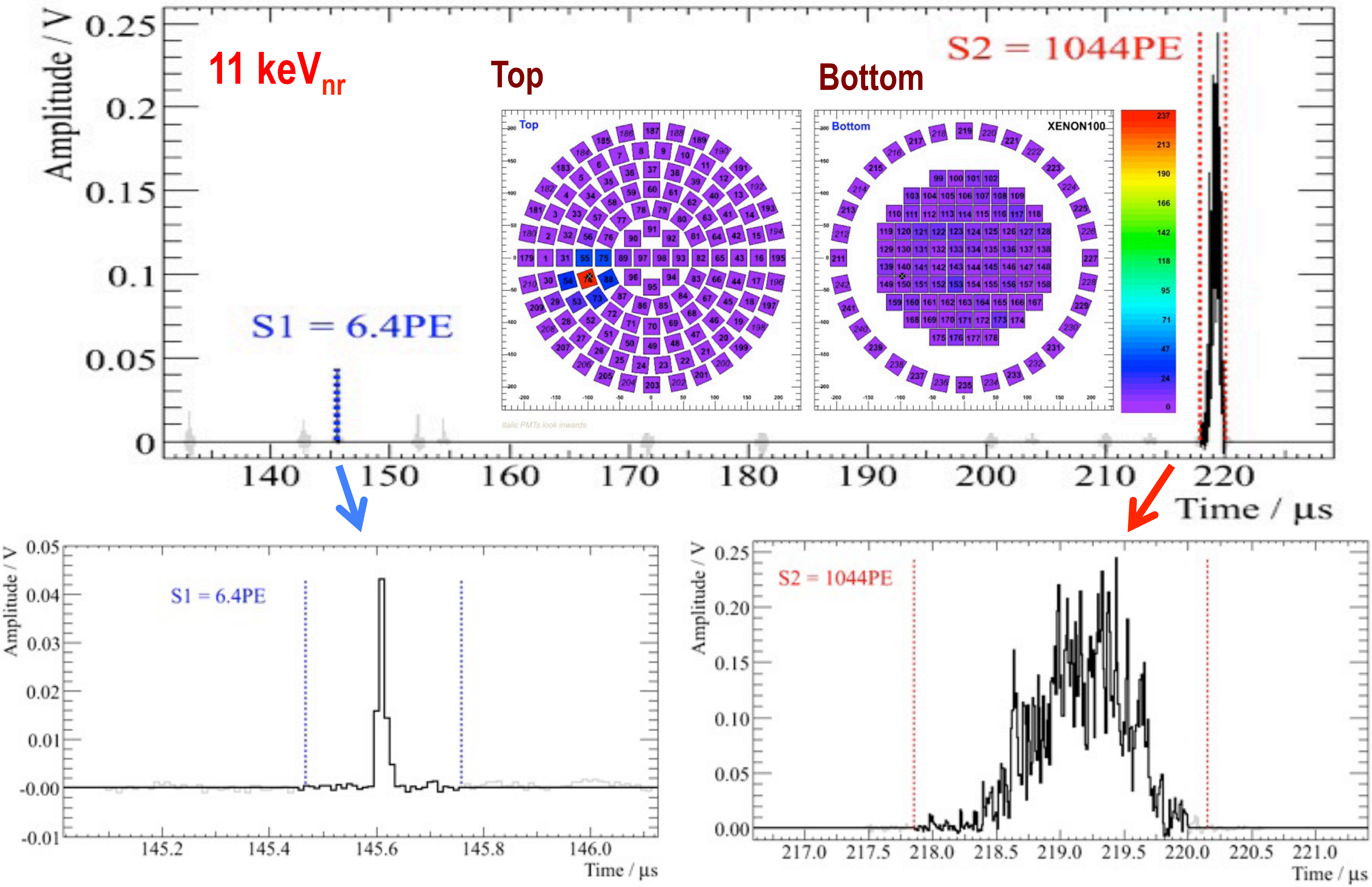
Event distribution in z vs. R^2



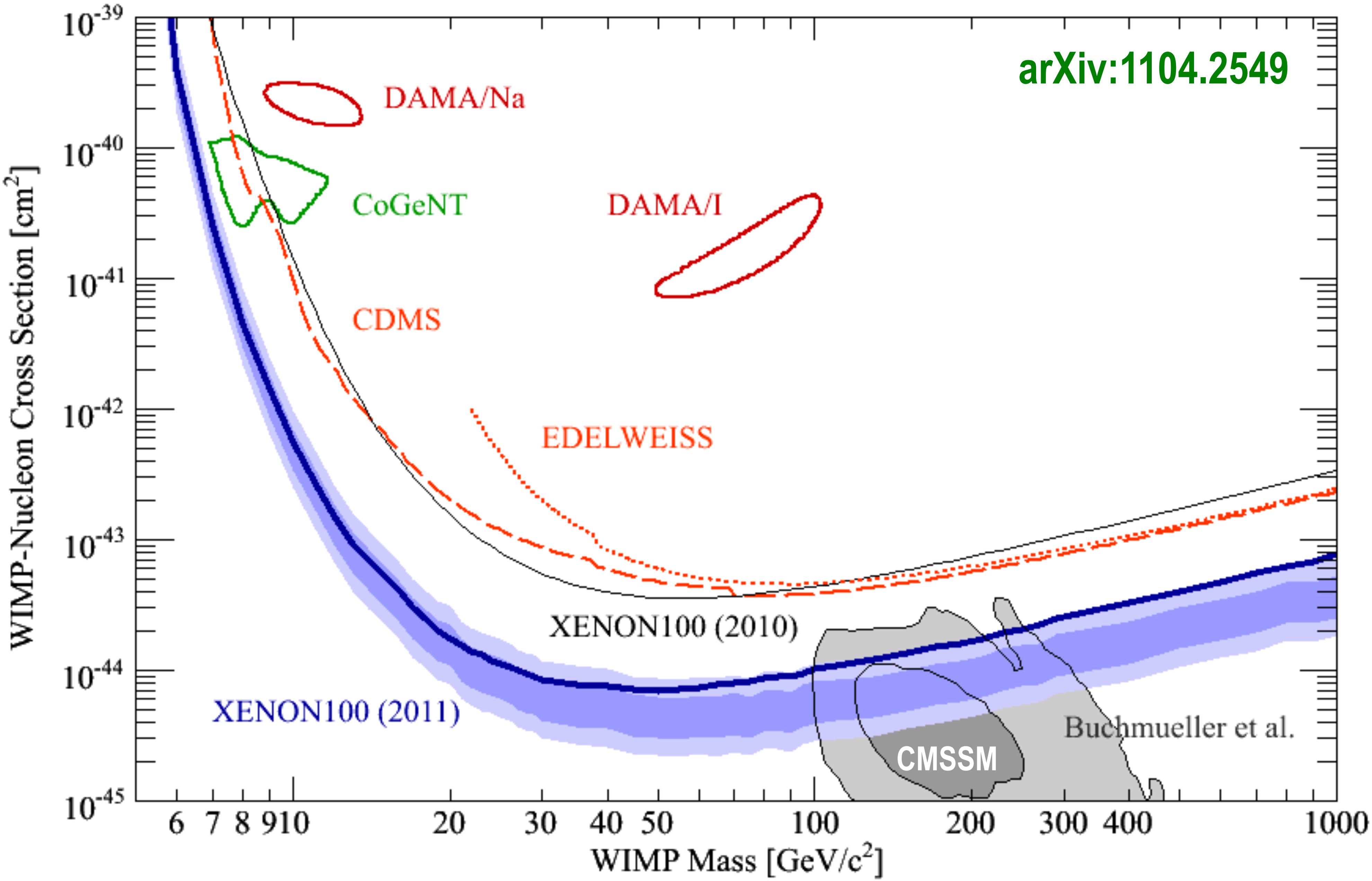
Log(S2/S1) vs. Energy



Single Scatter Nuclear Recoil Event Candidate

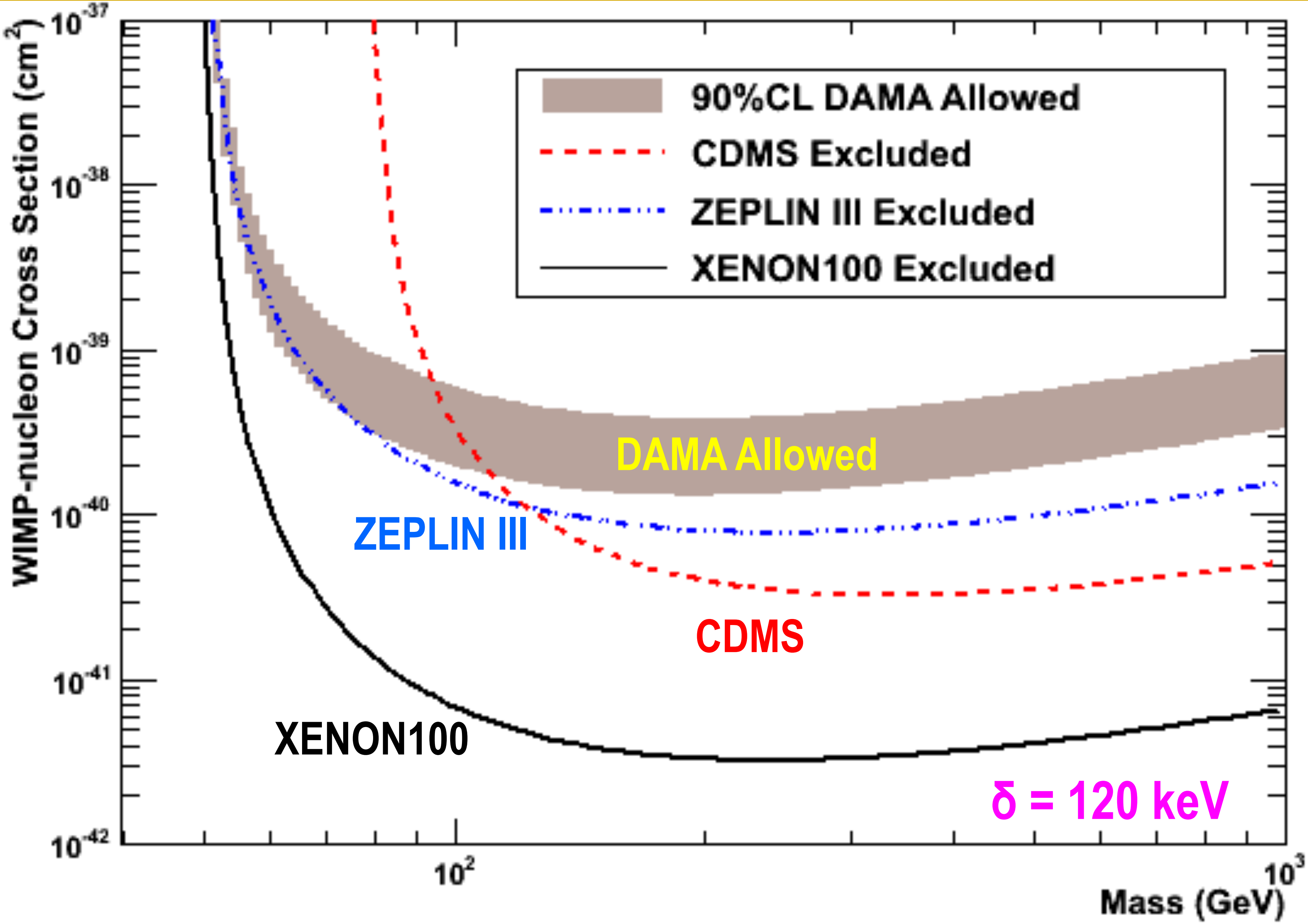


90% CL Limits of SI Cross Section (April, 2011)



Inelastic Dark Matter

arXiv:1104.3121



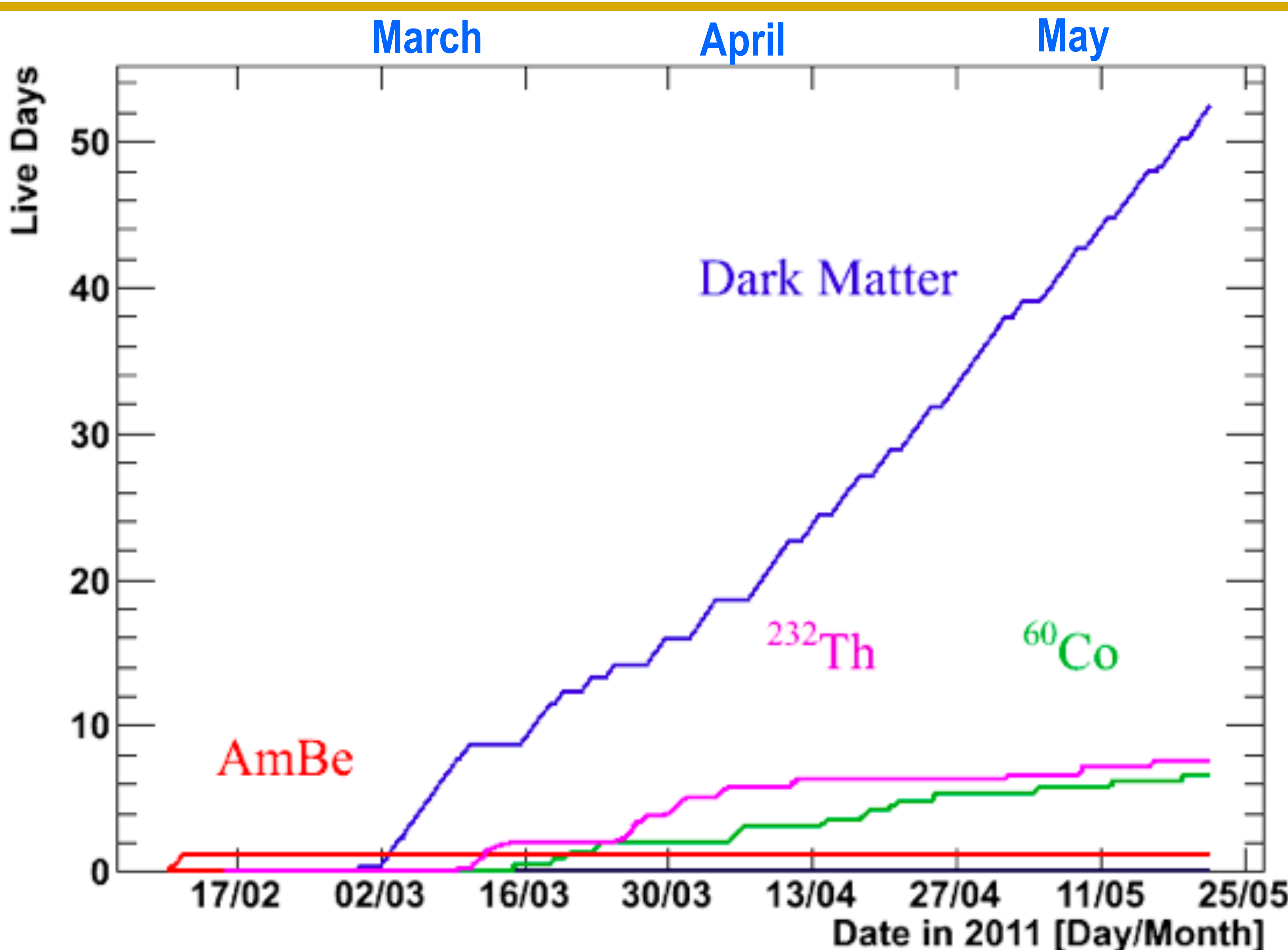
Summary of XENON100

- Purity of Xenon has achieved the design goal.

	Actual	Goal	
Light Yield:	2.2	> 2	pe/keVee
Electron Drift Time:	400	> 300	μs
Krypton 85:	80	< 100	ppt
Radon:	1.1	< 2	Bq/m^3

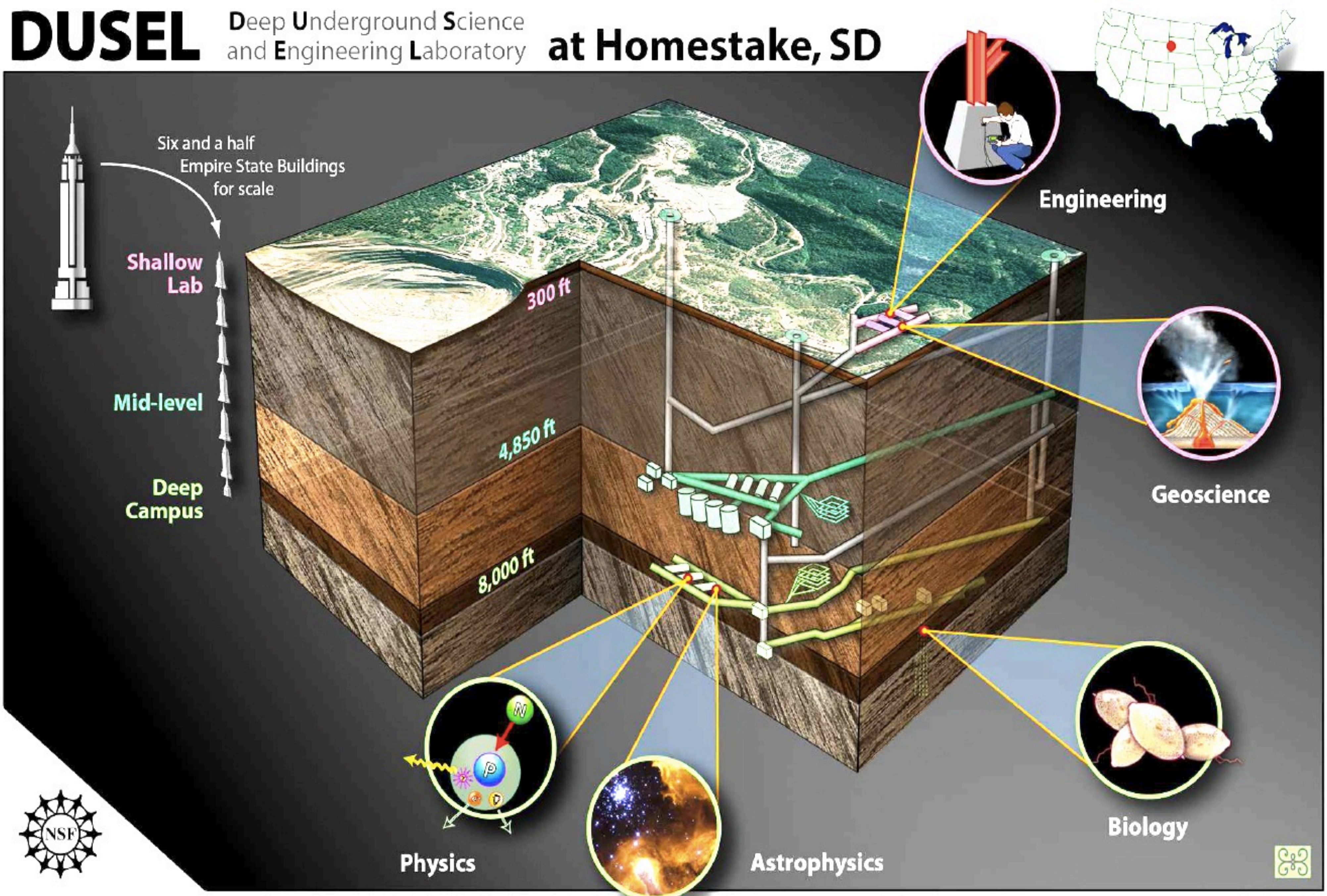
- 100 days of data published.
  - 3 event observed (1.8 +- 0.6 events expected)
    - Contaminated by ^{85}Kr at ~ 700 ppt → 1.1 events
  - < 7 x 10^{-45} cm^2 at 50 GeV arXiv:1104.2549
  - Low mass (7-10 GeV) WIMP unlikely.
  - Inelastic DM excluded. arXiv:1104.3121
- Data taking continues.
  - ^{85}Kr reduced to < 80 ppt
  - < 2 x 10^{-45} cm^2 by the end of 2011 expected.

XENON100 data taking in 2011



Future Directions

DUSEL started in 2007 (~$1B project by NSF)



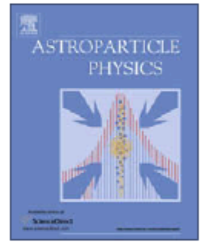
XAX by UCLA Group (2008) arXiv:0808.3968

Astroparticle Physics 31 (2009) 63–74

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart



XAX: A multi-ton, multi-target detection system for dark matter, double beta decay and pp solar neutrinos

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A R T I C L E I N F O

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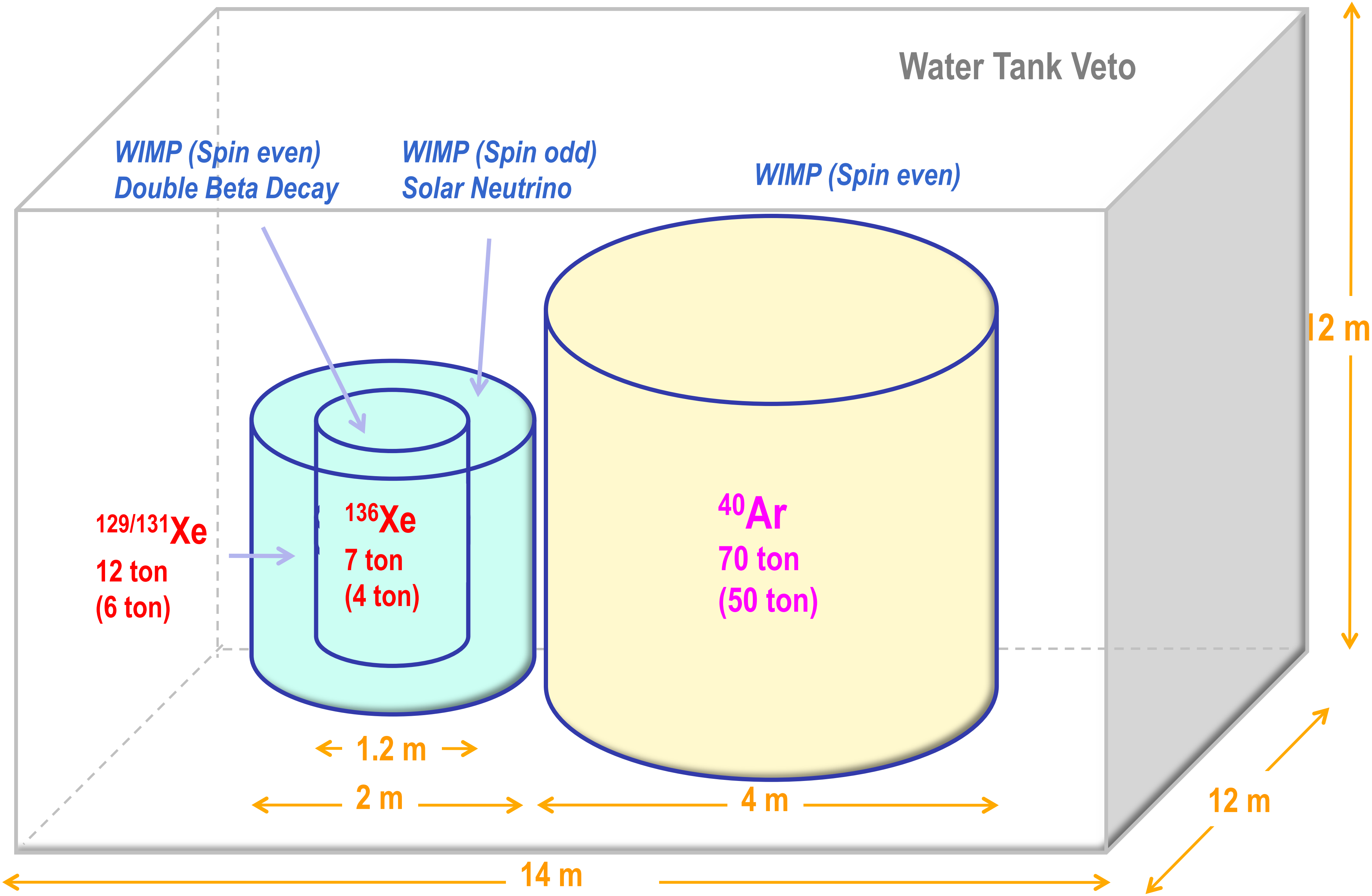
WIMPs
Double beta decay
Solar neutrino

A B S T R A C T

A multi-target detection system XAX, comprising concentric 10 ton targets of ^{136}Xe and $^{129/131}$Xe, together with a geometrically similar or larger target of liquid Ar, is described. Each is configured as a two-phase scintillation/ionization TPC detector, enhanced by a full 4π array of ultra-low radioactivity quartz photon intensifying detectors (QUPIDs) replacing the conventional photomultipliers for detection of scintillation light. It is shown that background levels in XAX can be reduced to the level required for dark matter particle (WIMP) mass measurement at a 10^{-10} pb WIMP-nucleon cross-section, with single-event sensitivity below 10^{-11} pb. The use of multiple target elements allows for confirmation of the A^2 dependence of a coherent cross-section, and the different Xe isotopes provide information on the spin-dependence of the dark matter interaction. The event rates observed by Xe and Ar would modulate annually with opposite phases from each other for WIMP mass >~100 GeV/c^2. The large target mass of ^{136}Xe and high degree of background reduction allow neutrinoless double beta decay to be observed with lifetimes of 10^{27}–10^{28} years, corresponding to the Majorana neutrino mass range 0.01–0.1 eV, the most likely range from observed neutrino mass differences. The use of a ^{136}Xe-depleted $^{129/131}$Xe target will also allow measurement of the pp solar neutrino spectrum to a precision of 1–2%.

XAX (Xenon-Argon-Xenon)



PASAG Report (2009)

Report of the HEPAP Particle Astrophysics Scientific Assessment Group (PASAG)

20 October 2009

G2 and G3 facilities defined by PASAG (2009)

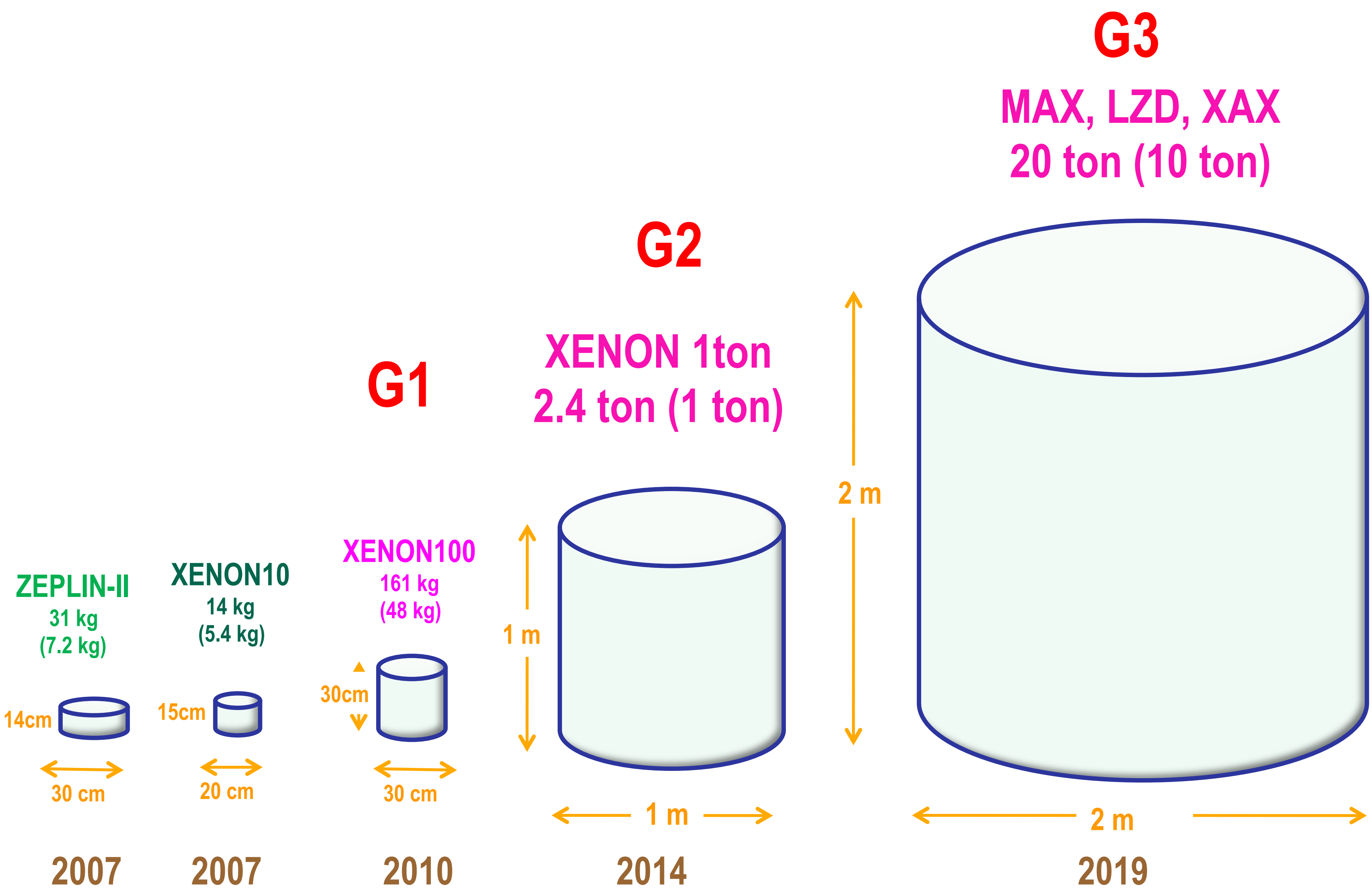
	G1	G2	G3
Sensitivity	< 10^{-44} cm^2	< 10^{-46} cm^2	< 10^{-47} cm^2
Target Mass	10 – 100 kg	~ 1 Ton	~ 10 Ton
Cost	\$1M – 5M	\$10 – 20M	~ \$100M

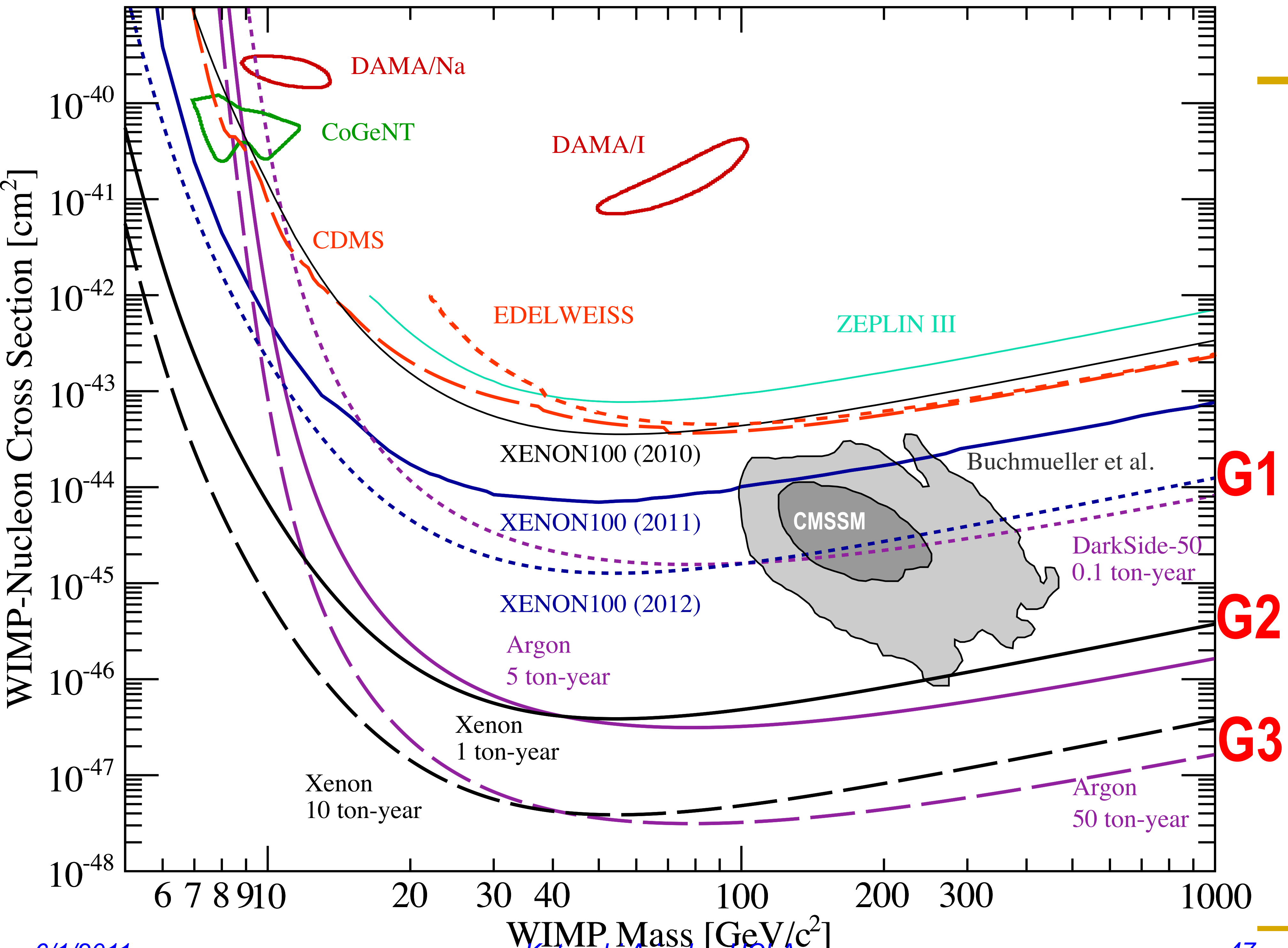
Supports on G2 and G3 Detectors

A sequence of U.S. projects, with 2-3 second-generation detectors covering the major technologies (CDMS and cryogenic liquids) and 2 third-generation detectors is optimal. More details for each of the budget scenarios are given below. Experiments should move forward as soon as they demonstrate essential technical requirements. Plausible starting years for construction of second-generation and third-generation detectors are 2013 and 2017, respectively. **An essential feature of this program is a sequence of detectors with increasing mass, operating with multiple background rejection tools, and crosschecks. A final configuration of two large G3 detectors with independent targets would assure a clear interpretation of a signal.**

The second-generation detectors should have sensitivity for detecting WIMPS with spin-independent cross-sections of 10^{-46} cm^2 or lower, while the third-generation should surpass 10^{-47} cm^2 (see Figure 3-1).

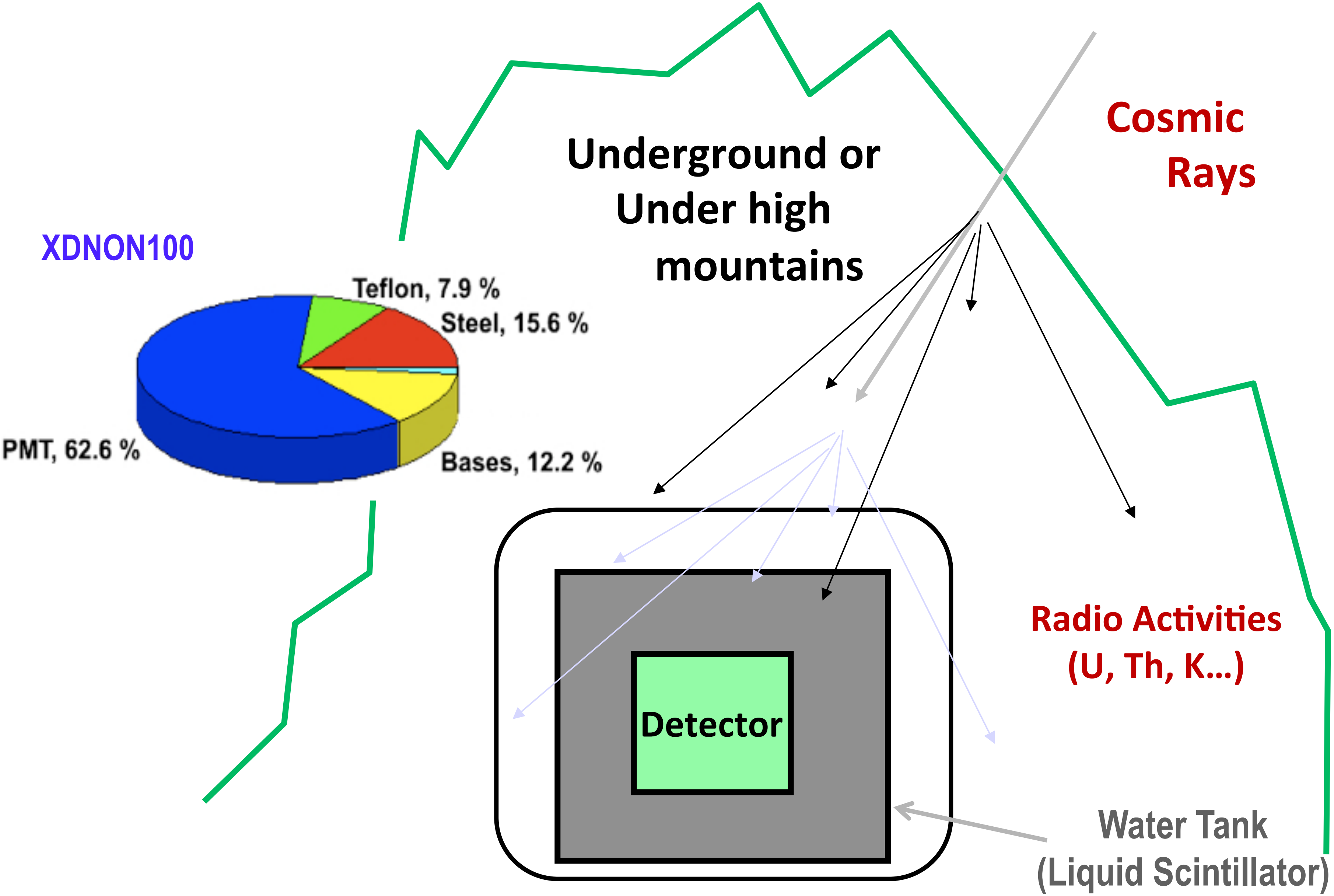
Comparison of Xenon Detector Size





DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
ZEPLIN III
XENON100 (2010)
Buchmueller et al.
XENON100 (2011)
CMSSM
DarkSide-50
0.1 ton-year
XENON100 (2012)
Argon
5 ton-year
Xenon
1 ton-year
Xenon
10 ton-year
Argon
50 ton-year
G1
G2
G3
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
6 7 8 9 10 20 30 40 100 200 300 1000

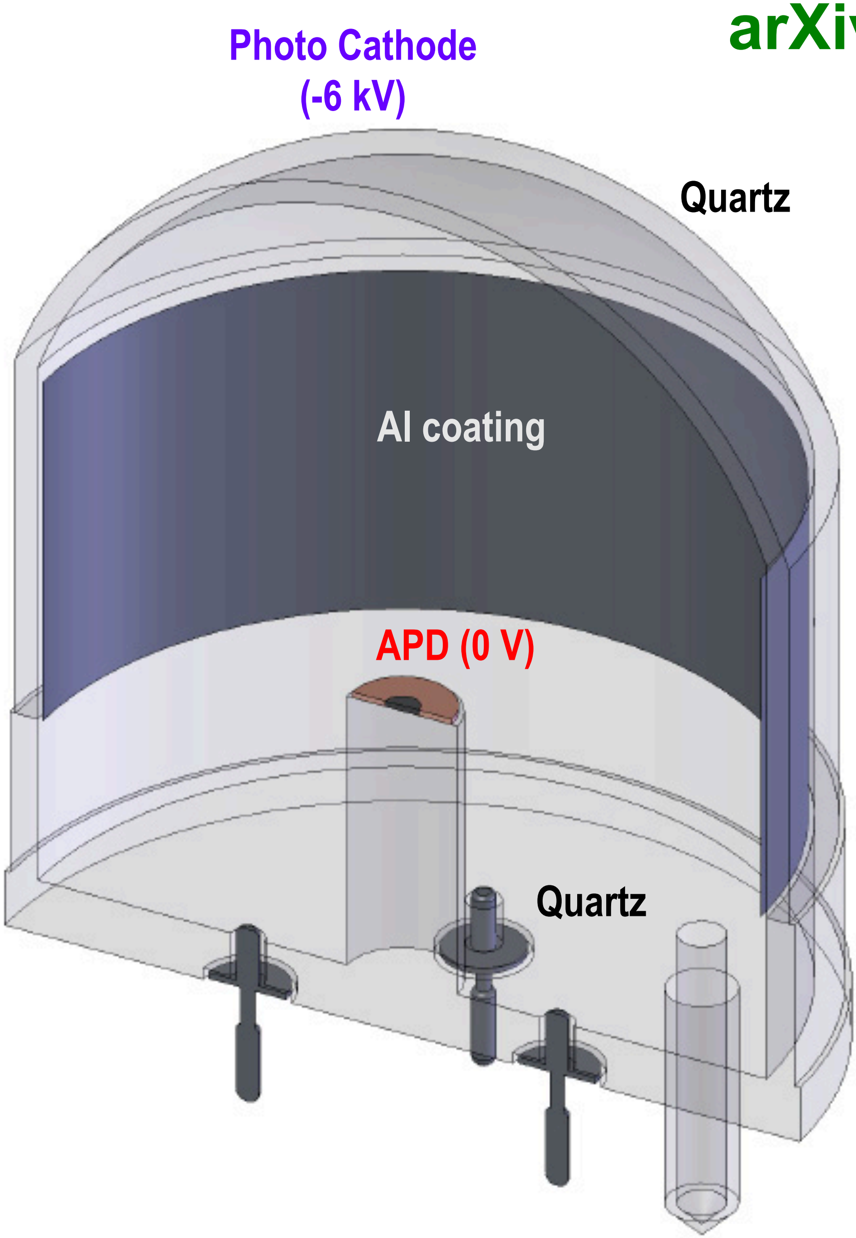
Where backgrounds come from?

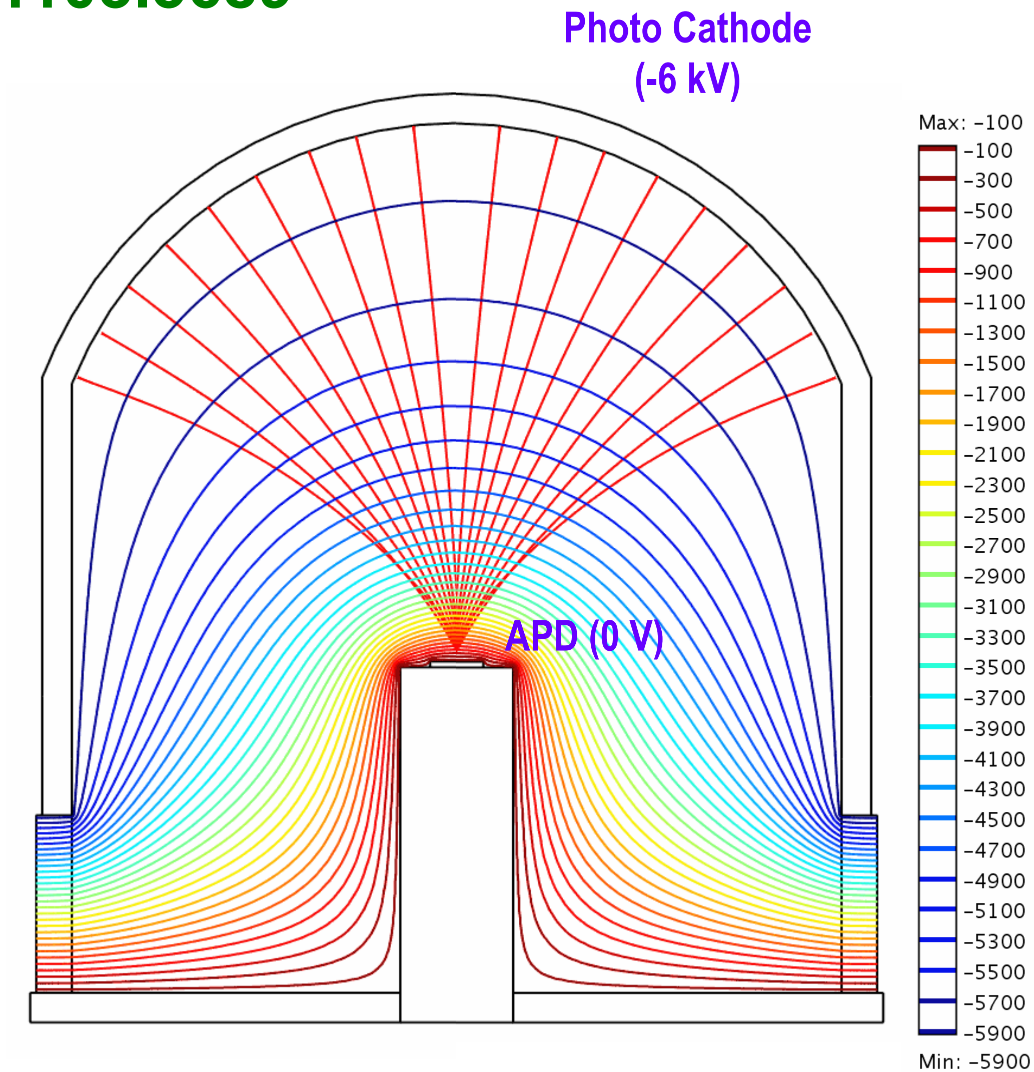


Photon detectors are the major source of backgrounds.

QUPID (QUartz Photon Intensifying Detector)

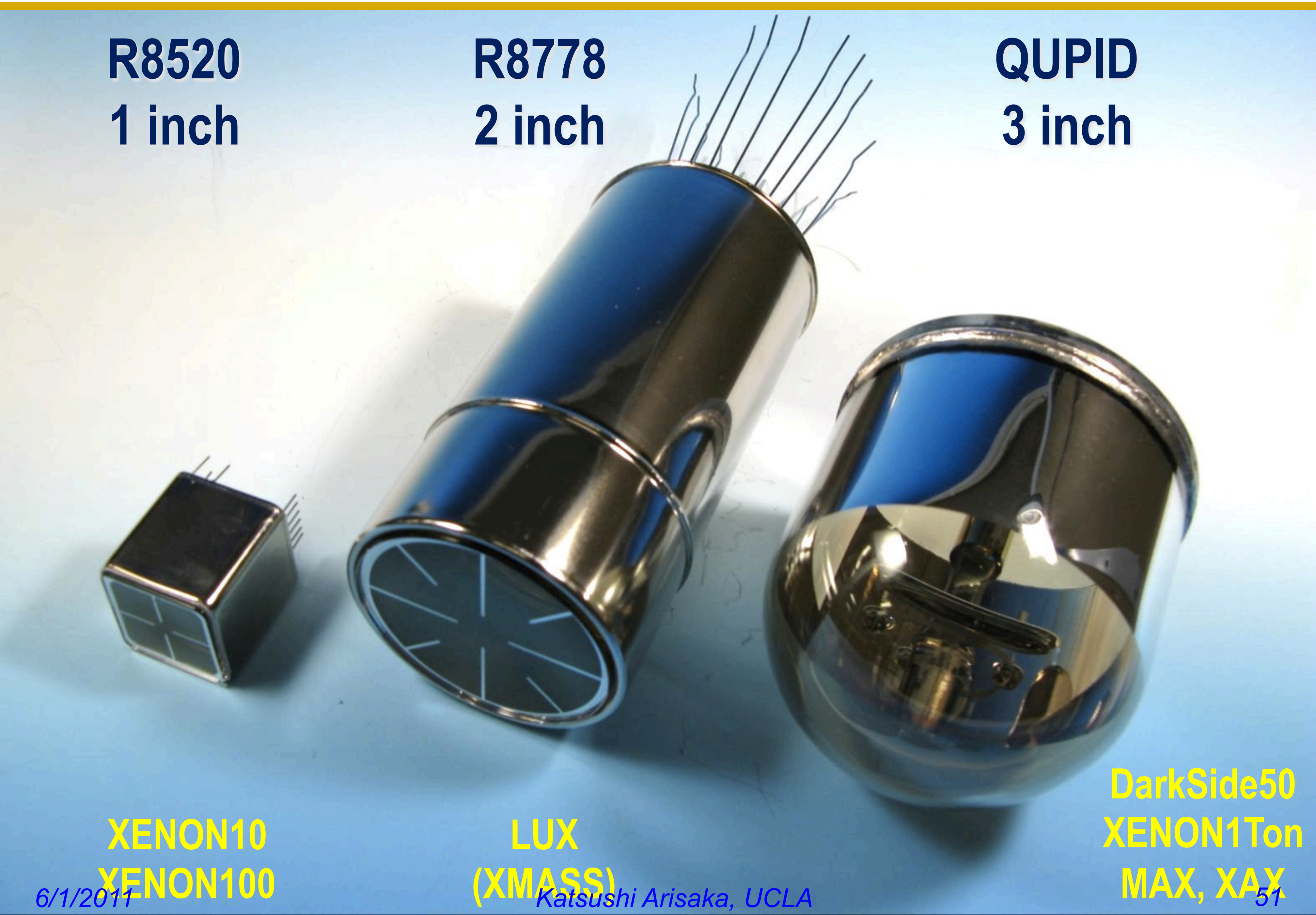
arXiv:1103.3689



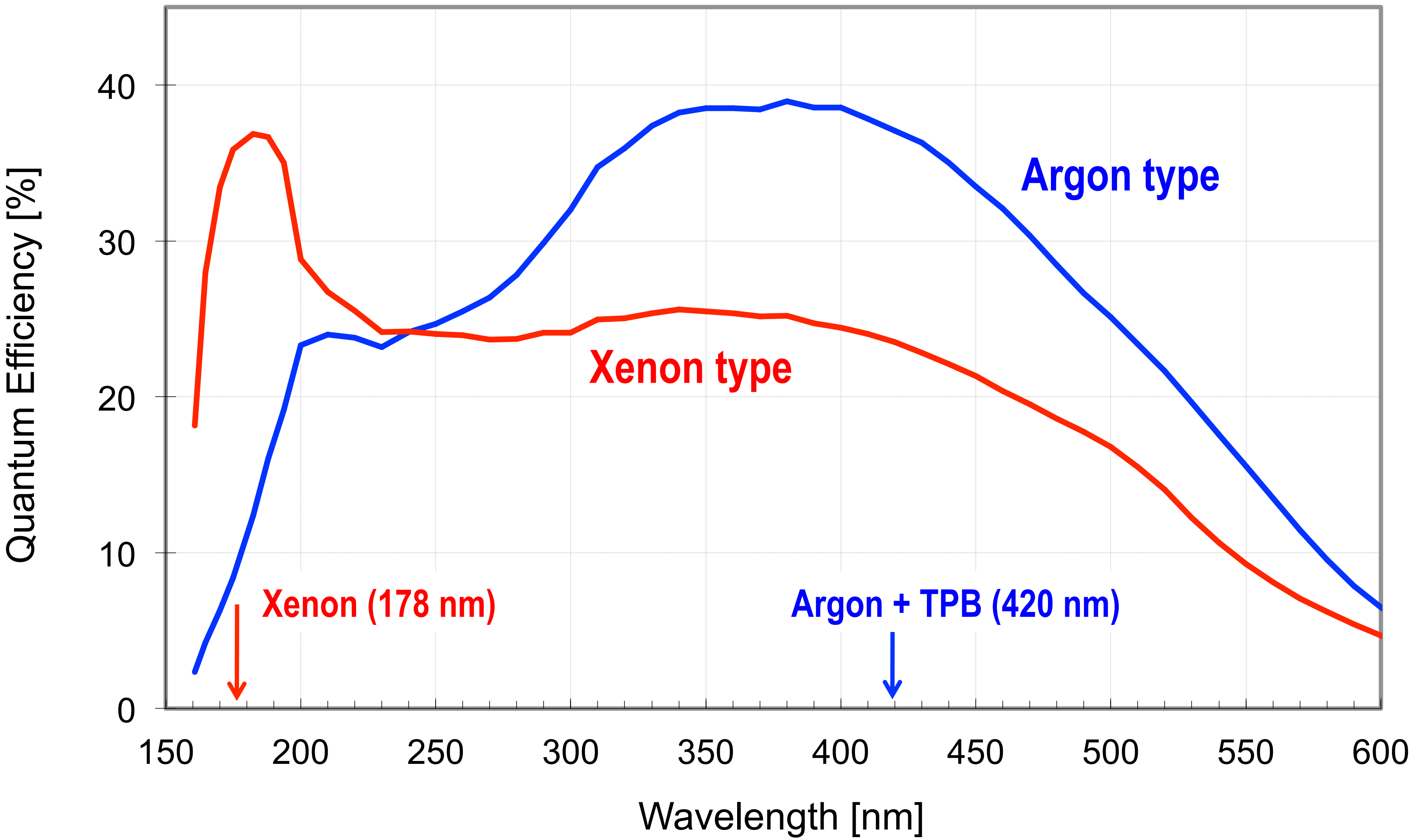


New 3” QUPID (Production Version)

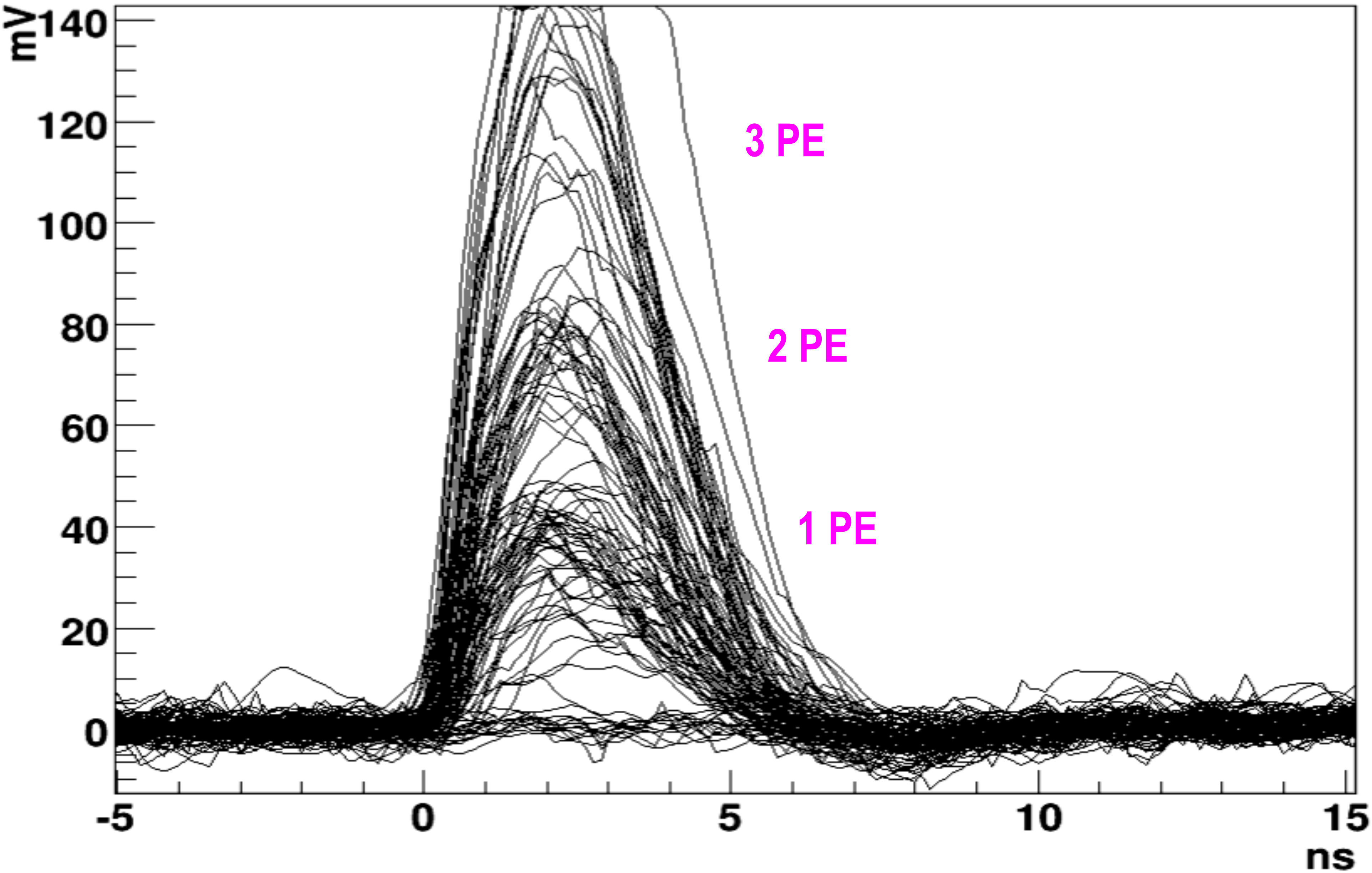
Comparison of Low-radioactive Photon Detectors from Hamamatsu



QE of two types of QUPID

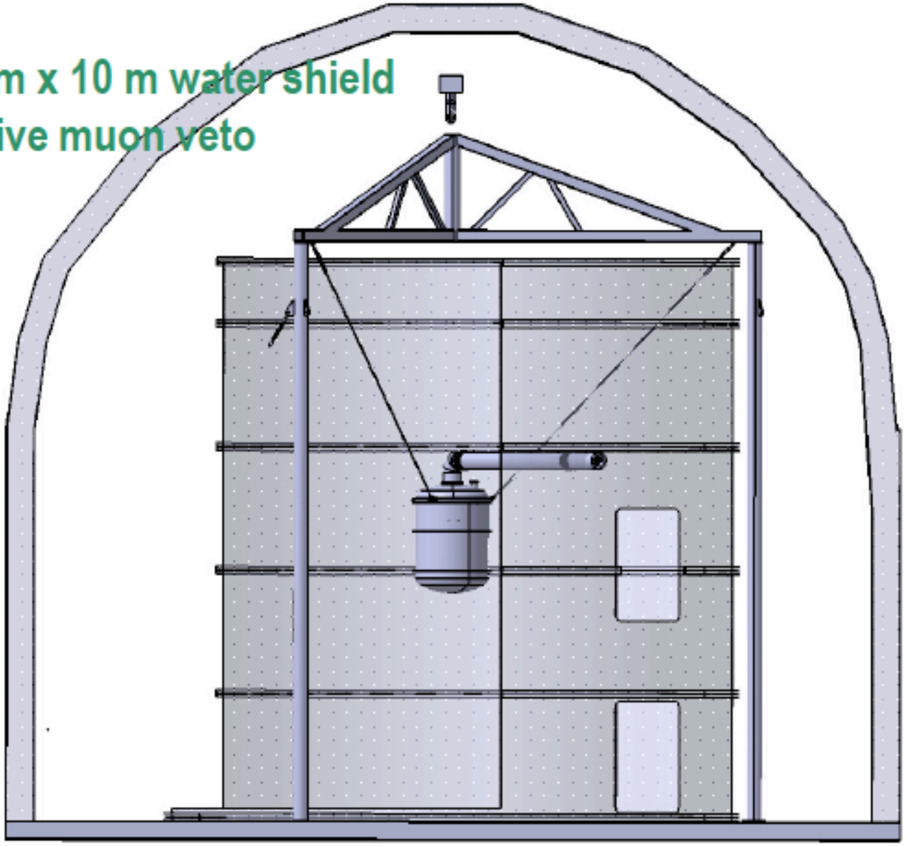


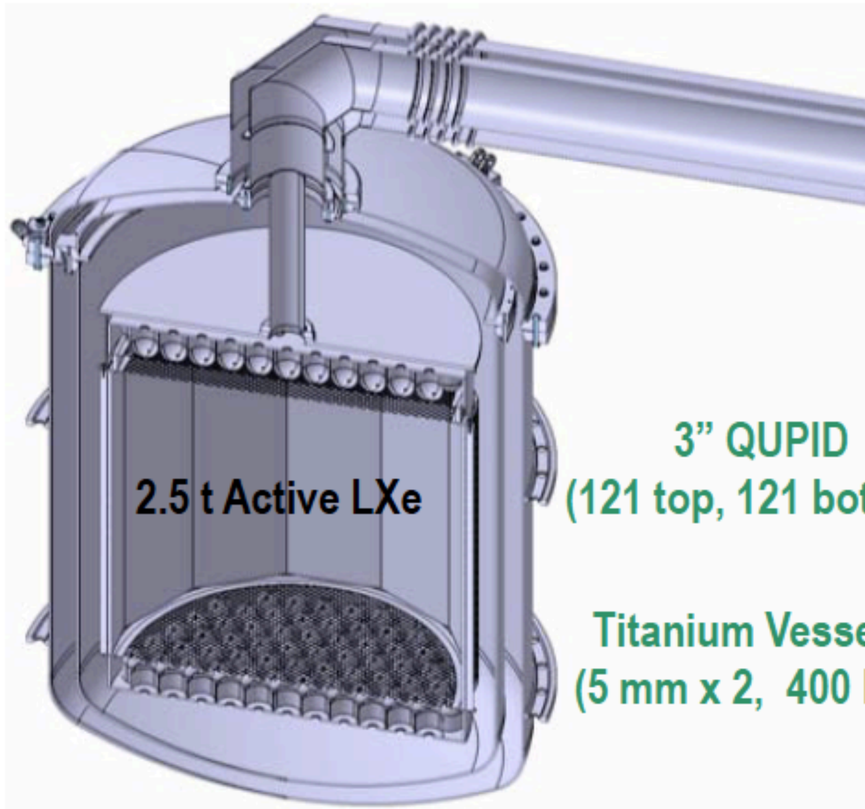
1, 2 and 3 PE Distribution with 2m cable

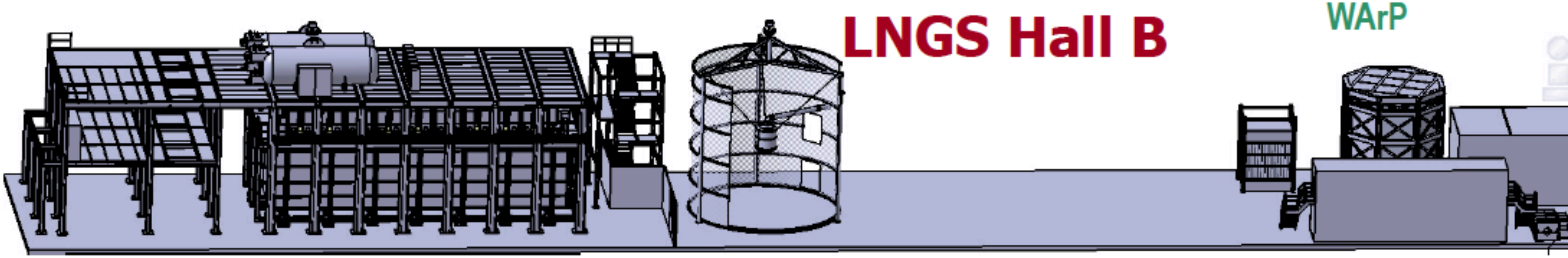


7 QUPID Array on Base Plate at UCLA

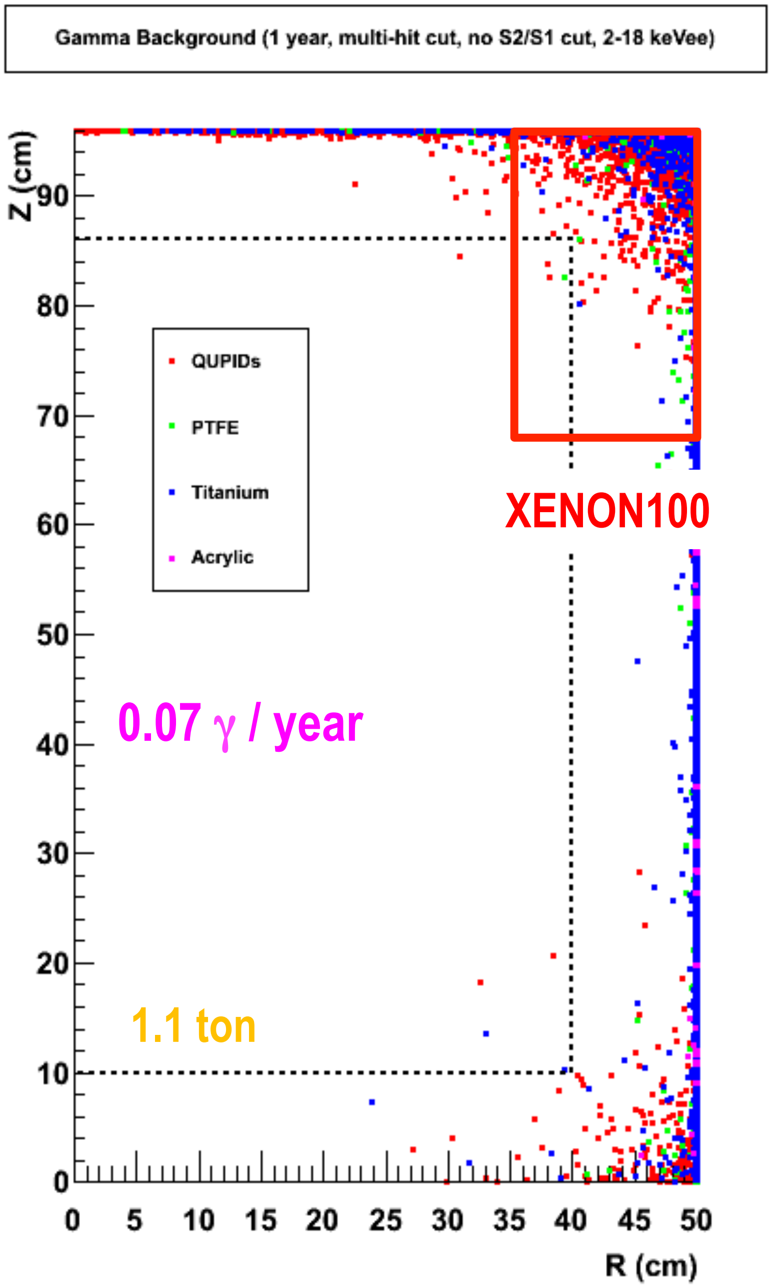
XENON1T (G2)

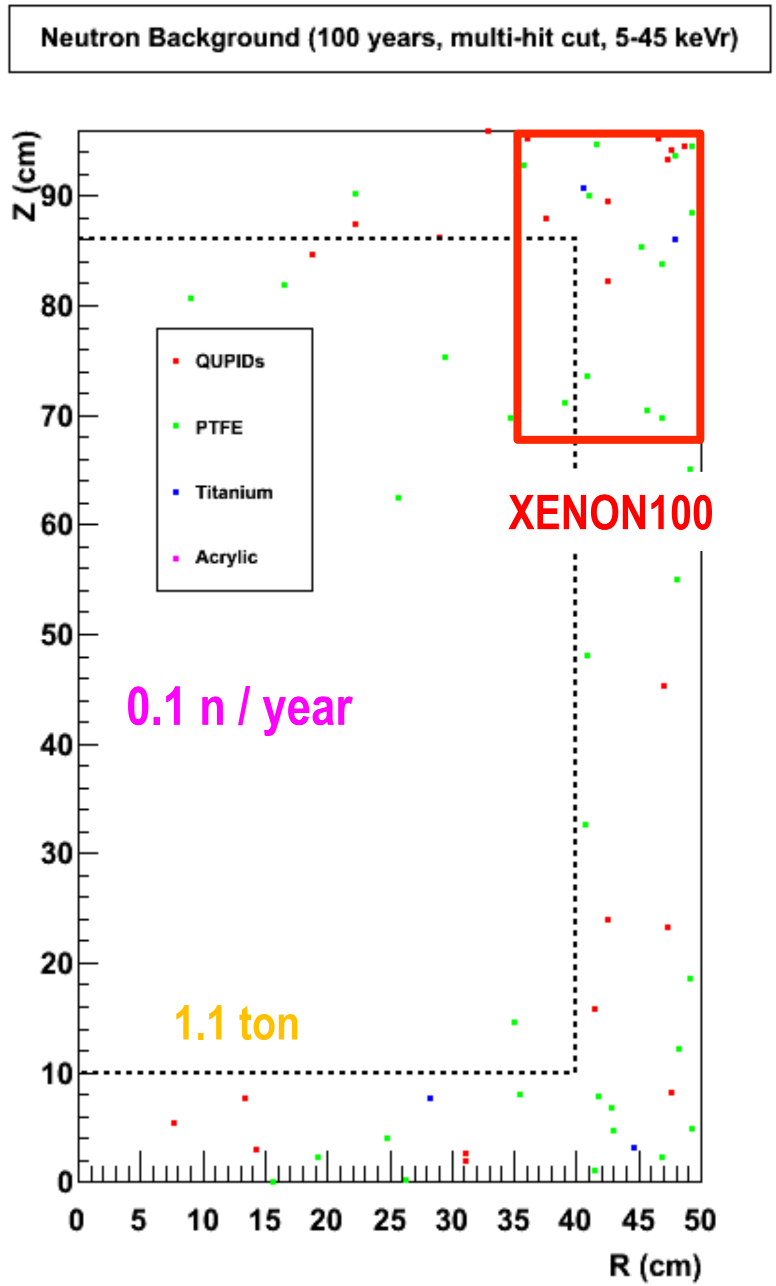

10 m x 10 m water shield
active muon veto


2.5 t Active LXe
3" QUPID
(121 top, 121 bottom)
Titanium Vessels
(5 mm x 2, 400 kg)


ICARUS
XENON1T
LNGS Hall B
WArP

Expected Backgrounds in XENON 1Ton (100 Year, Multi-hit Cut)

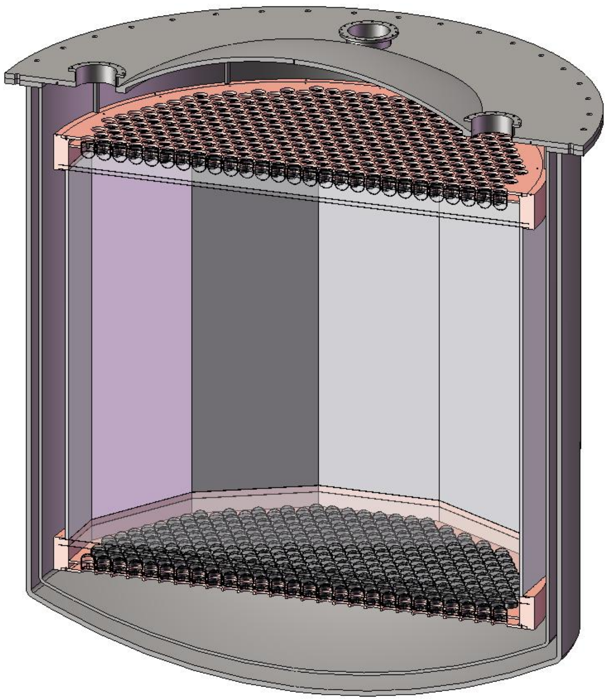




MAX Detector (G3)

Xe
20 ton
(10 ton)

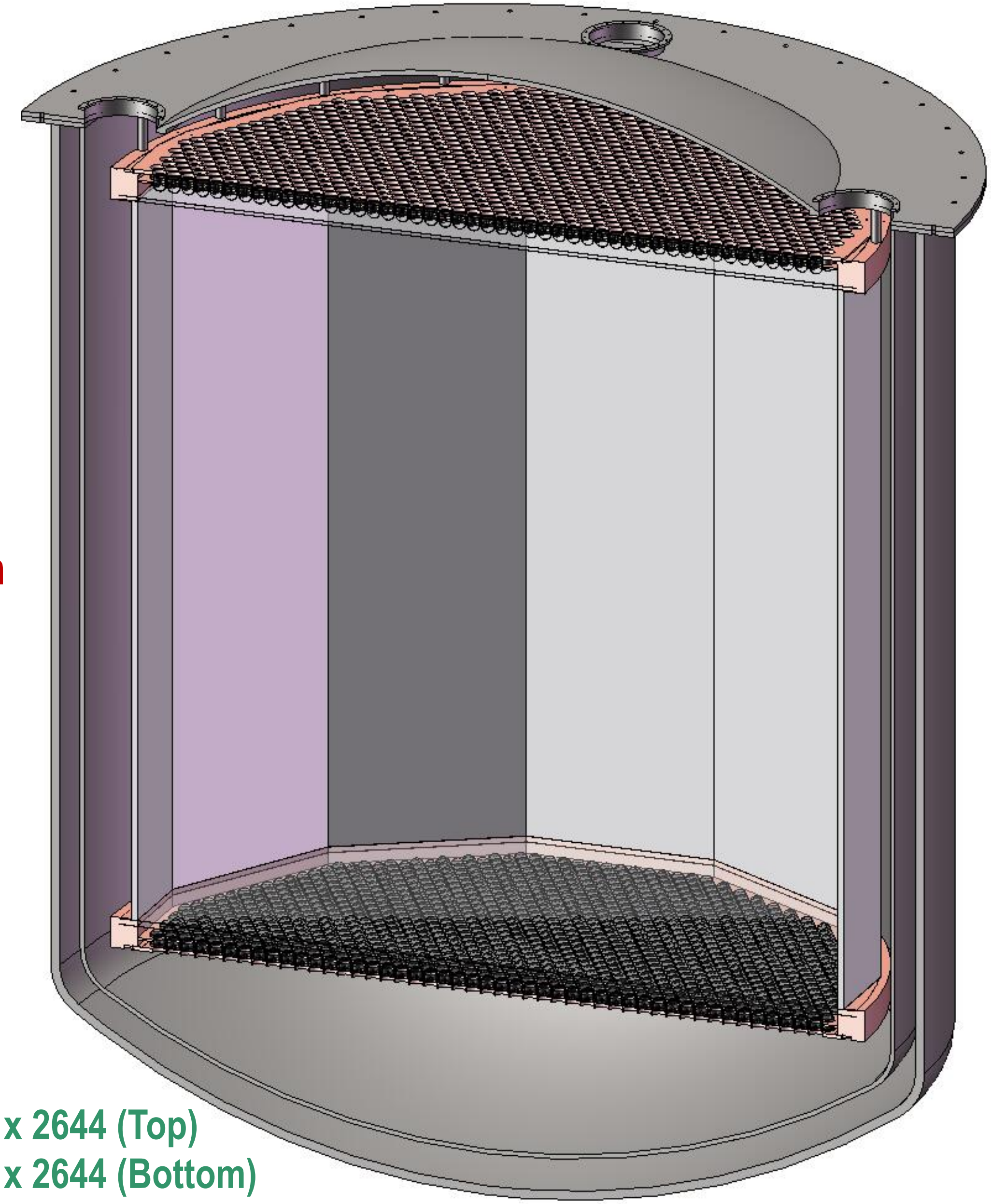
2 m



3” QUPID x 595 (Top)
3” QUPID x 595 (Bottom)

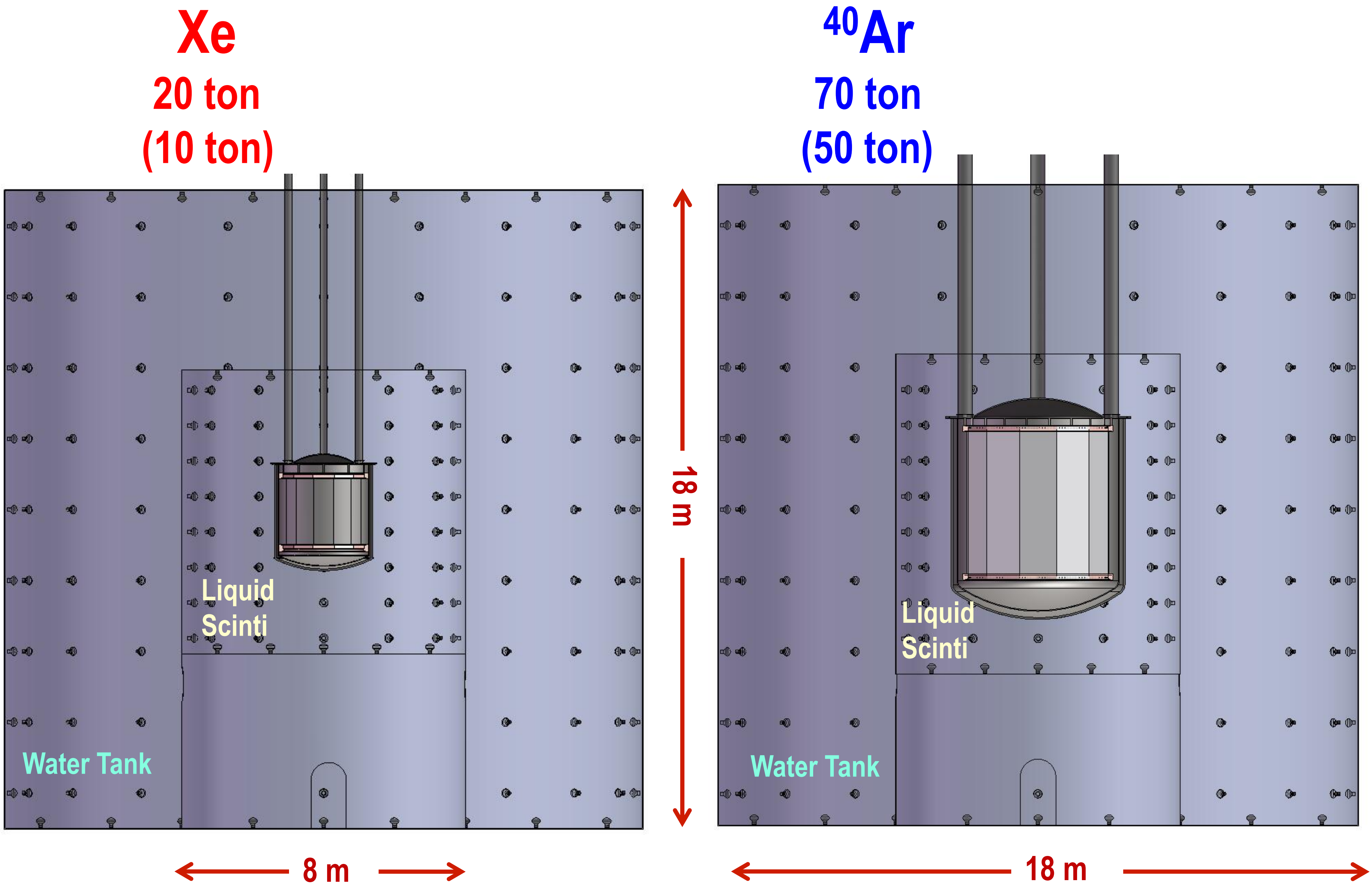
^{40}Ar
70 ton
(50 ton)

4m



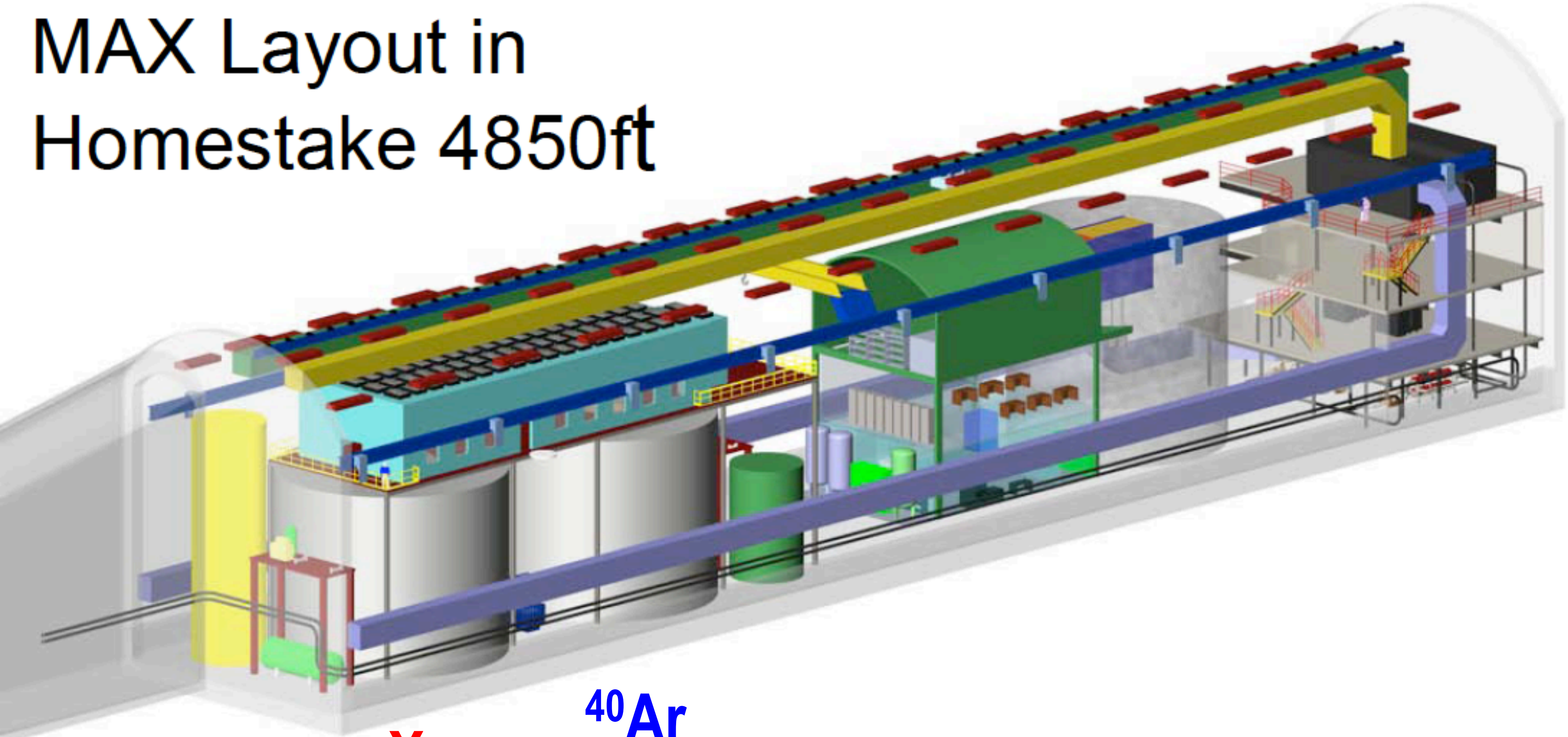
3” QUPID x 2644 (Top)
3” QUPID x 2644 (Bottom)

MAX (G3) Shielding Structure



MAX at DUSEL

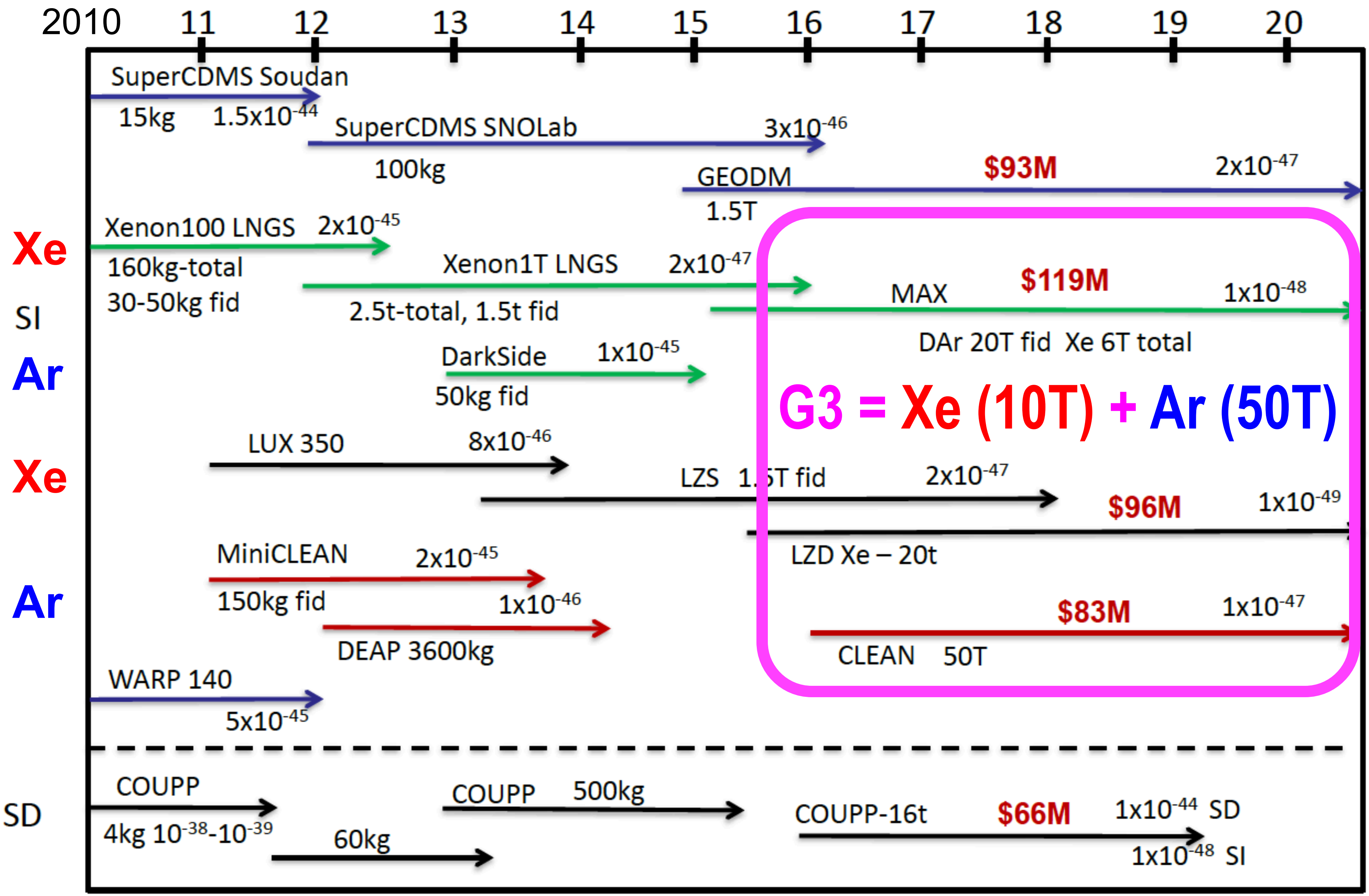
MAX Layout in
Homestake 4850ft



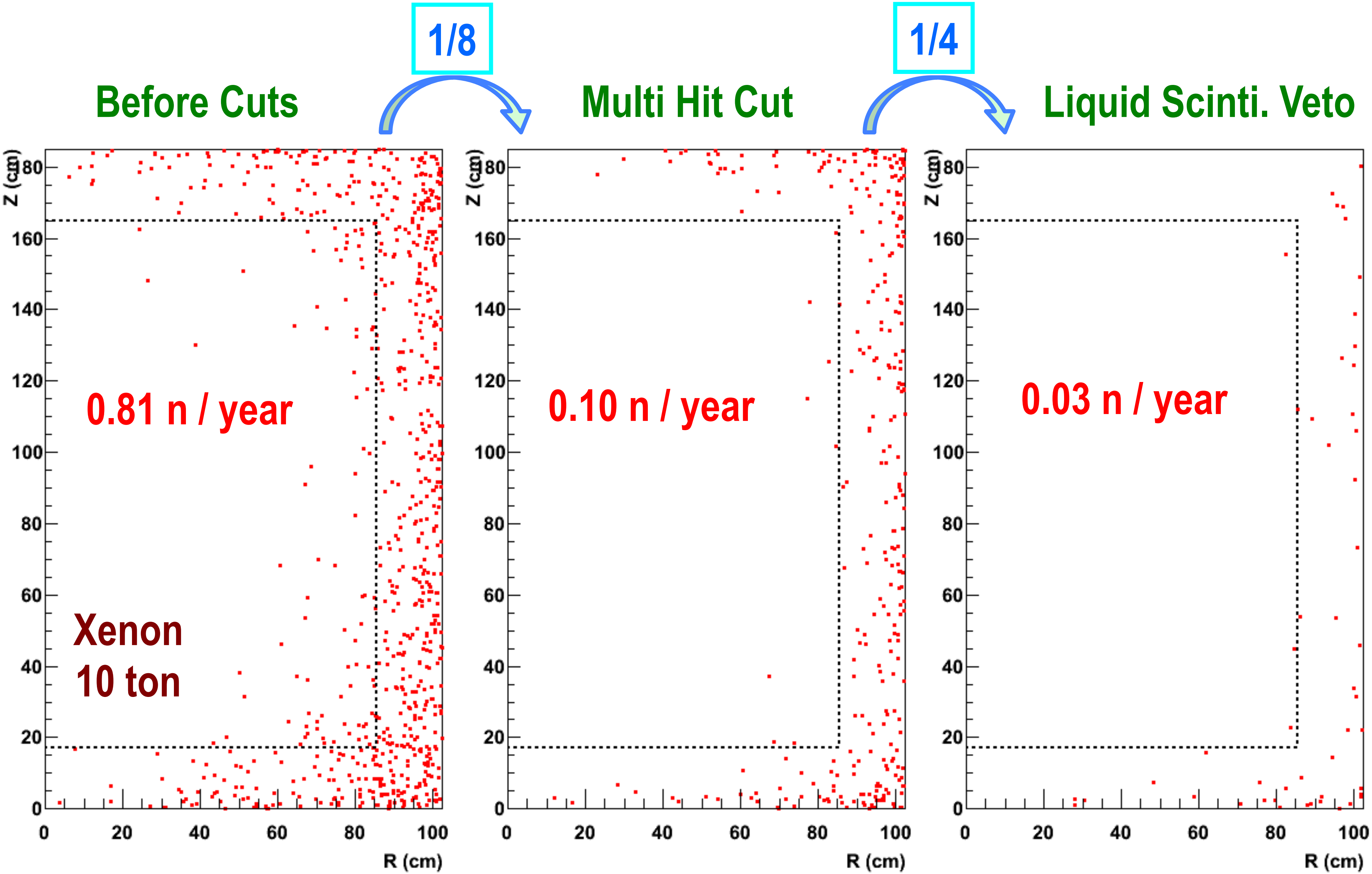
Xe
20 ton
(10 ton)

^{40}Ar
70 ton
(50 ton)

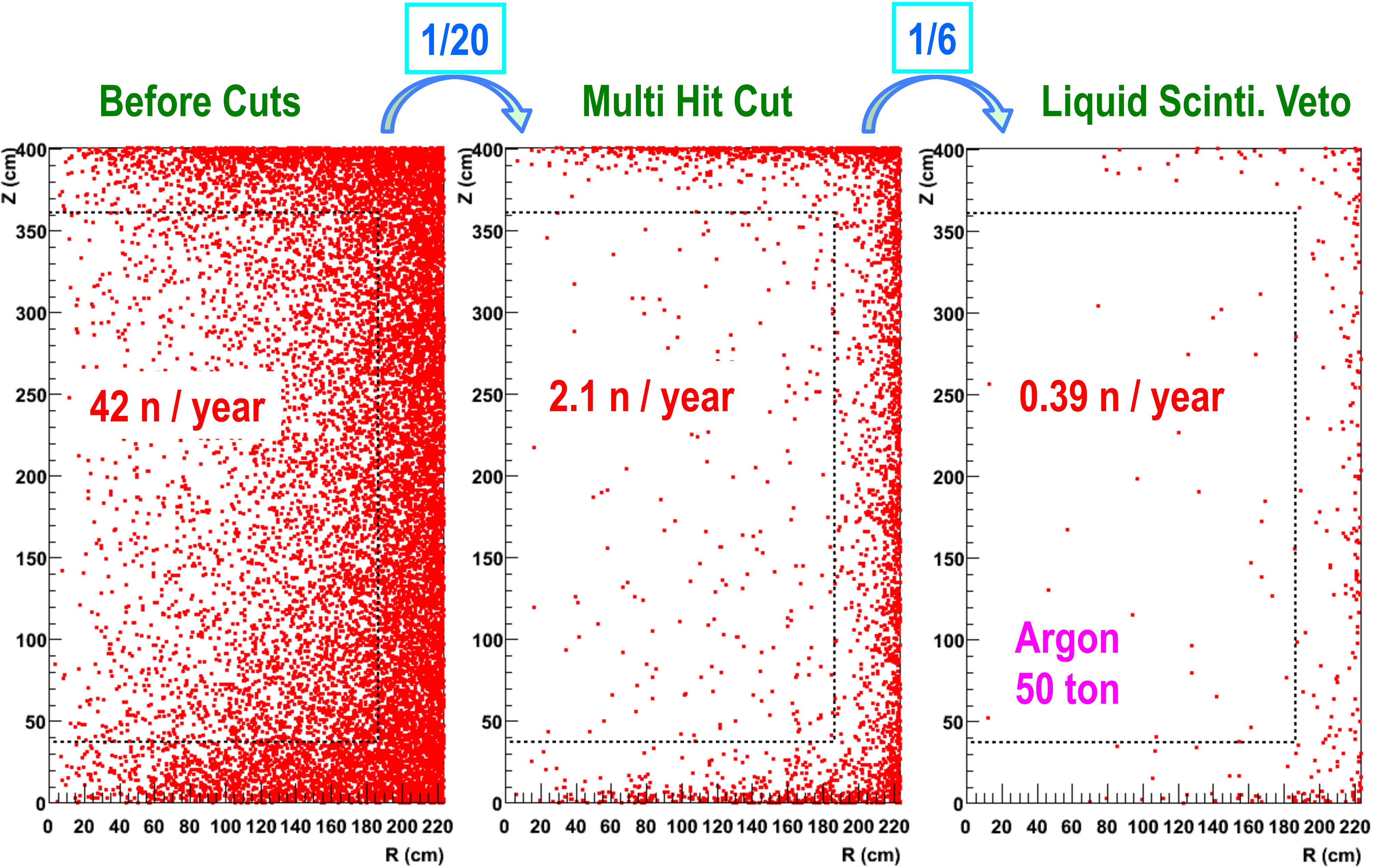
US Dark Matter Programs



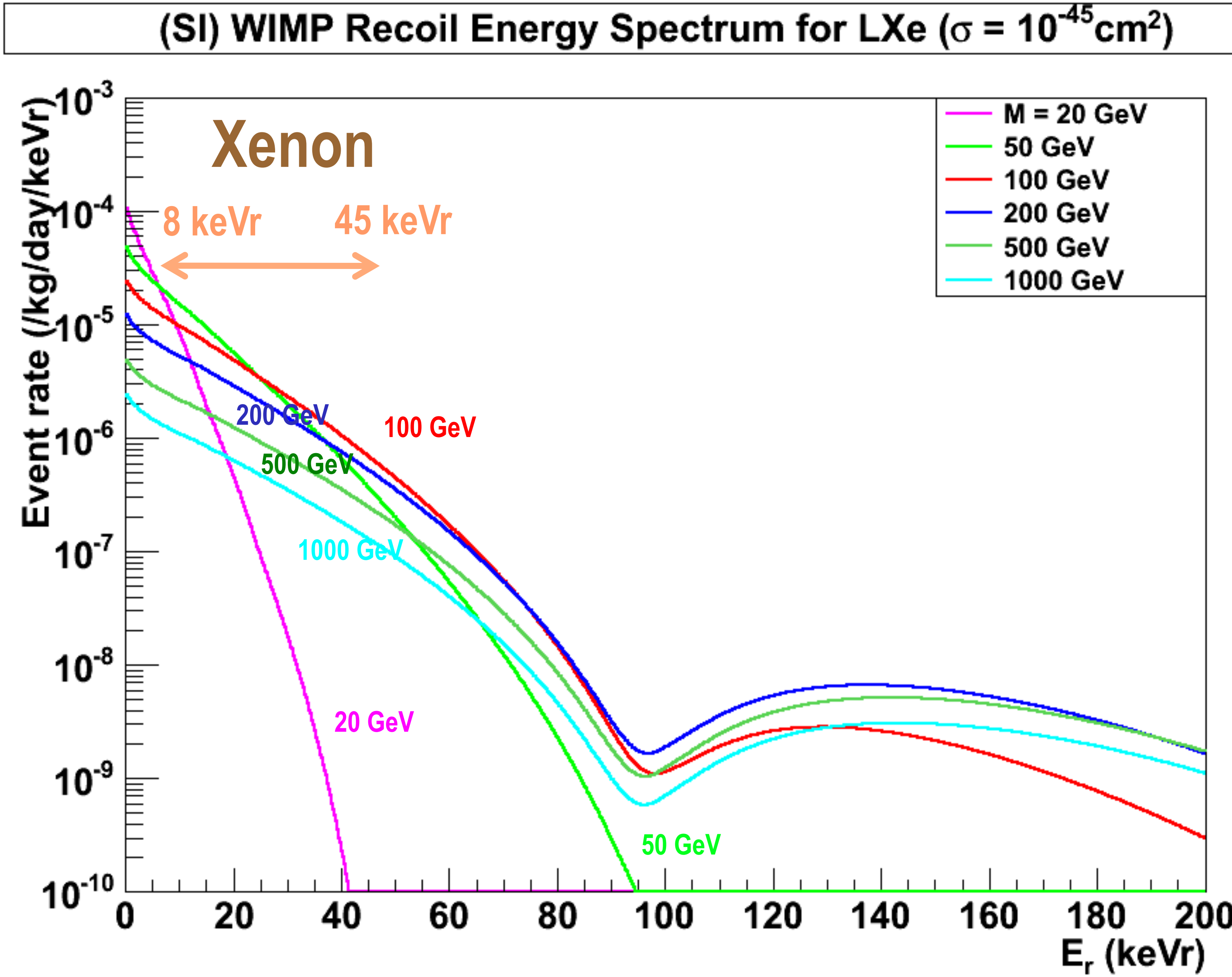
Xe 10 ton Neutron Background (100 Years)



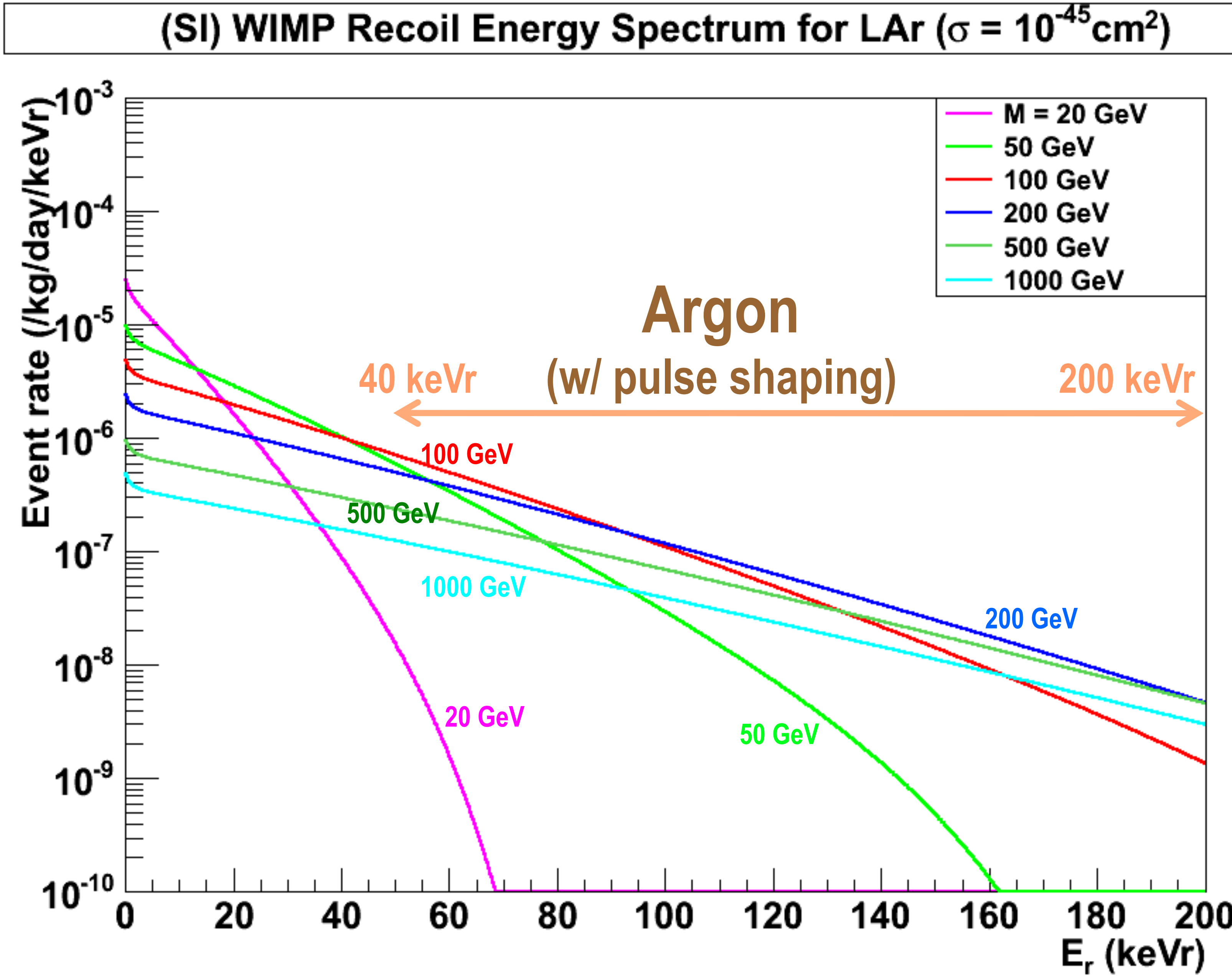
Ar 50 ton Neutron Background (100 Years)



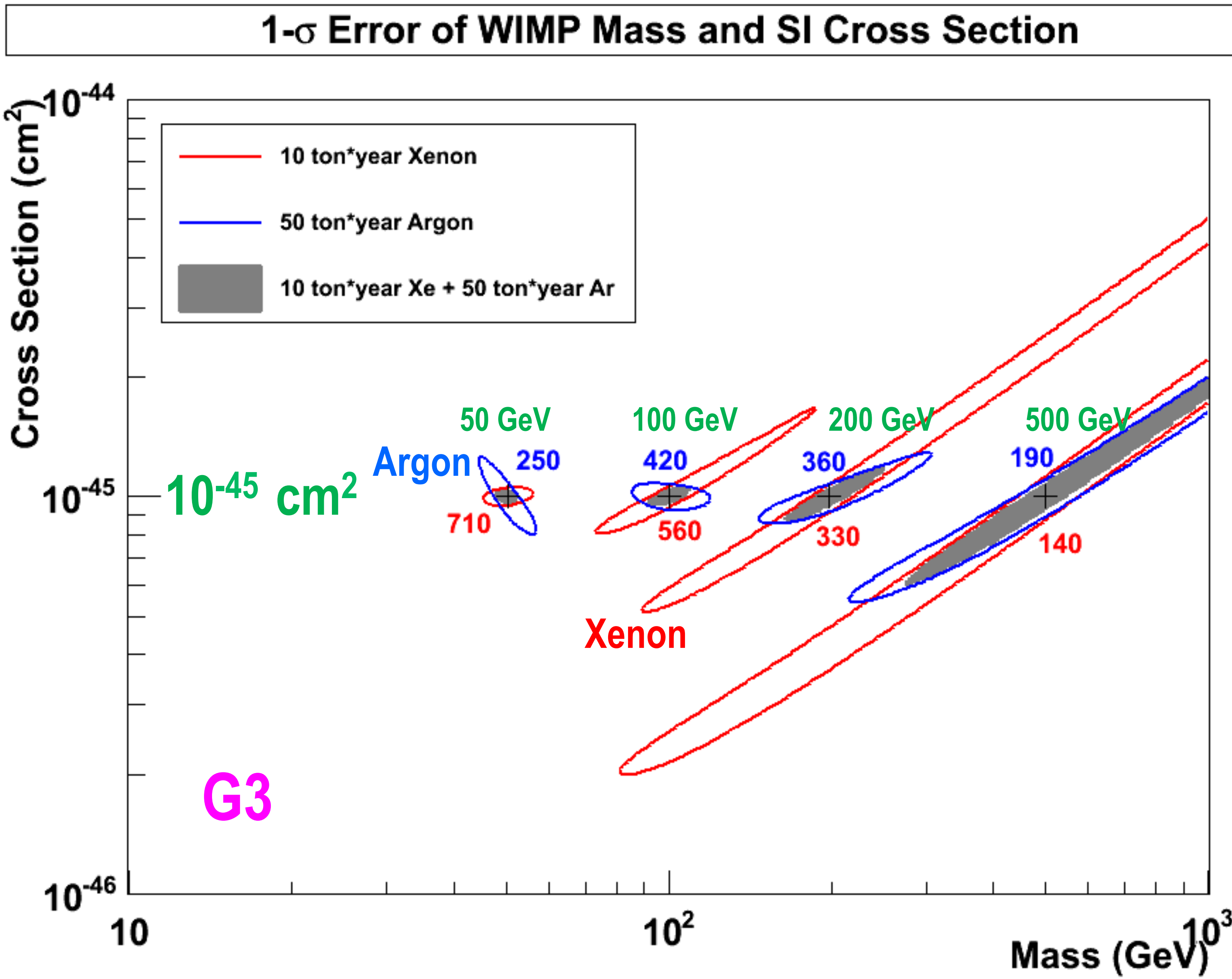
(SI) WIMP Energy Spectrum for LXe
(Cross Section = 10^{-45} cm^2)



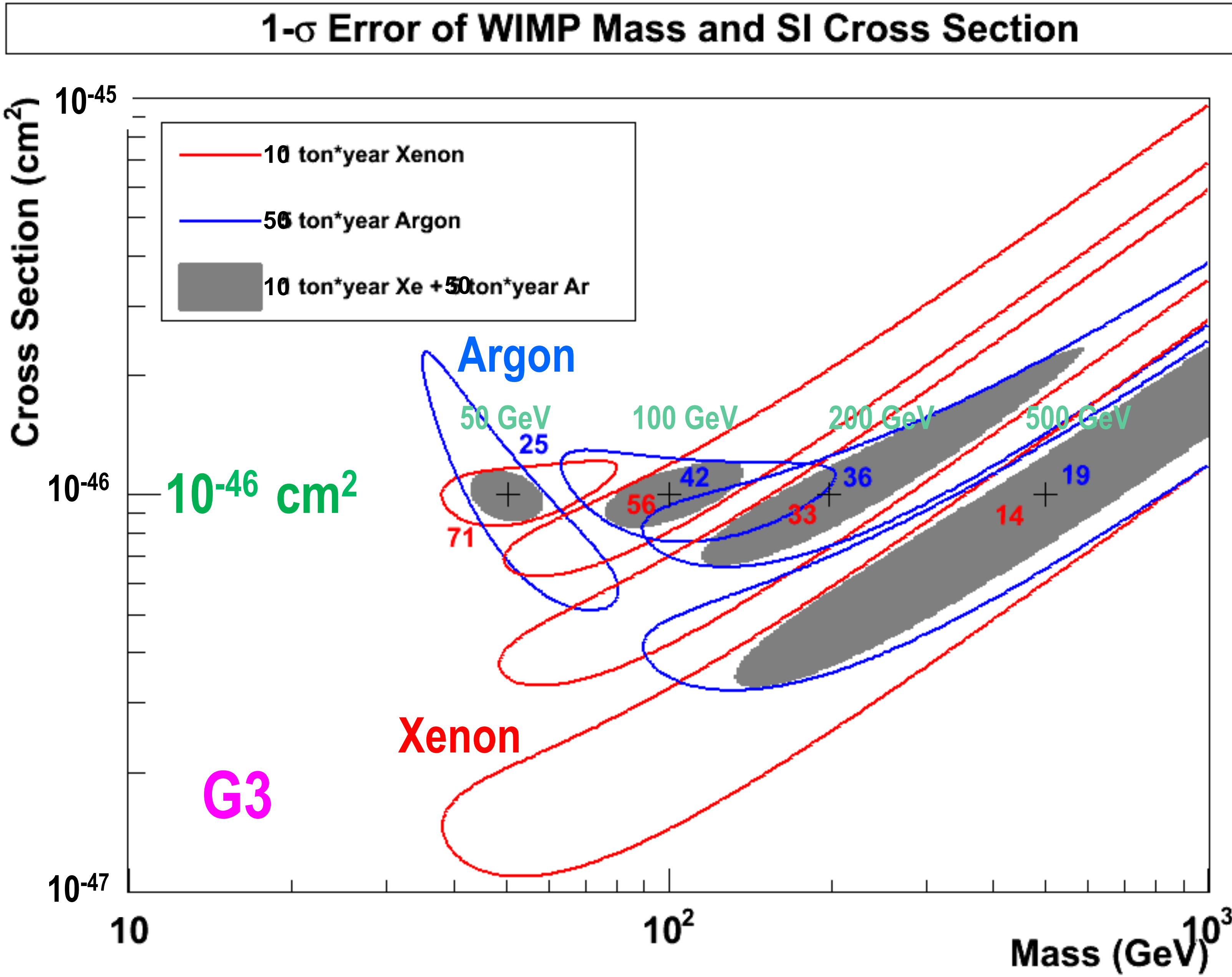
(SI) WIMP Energy Spectrum for LAr
(Cross Section = 10^{-45}cm^2)



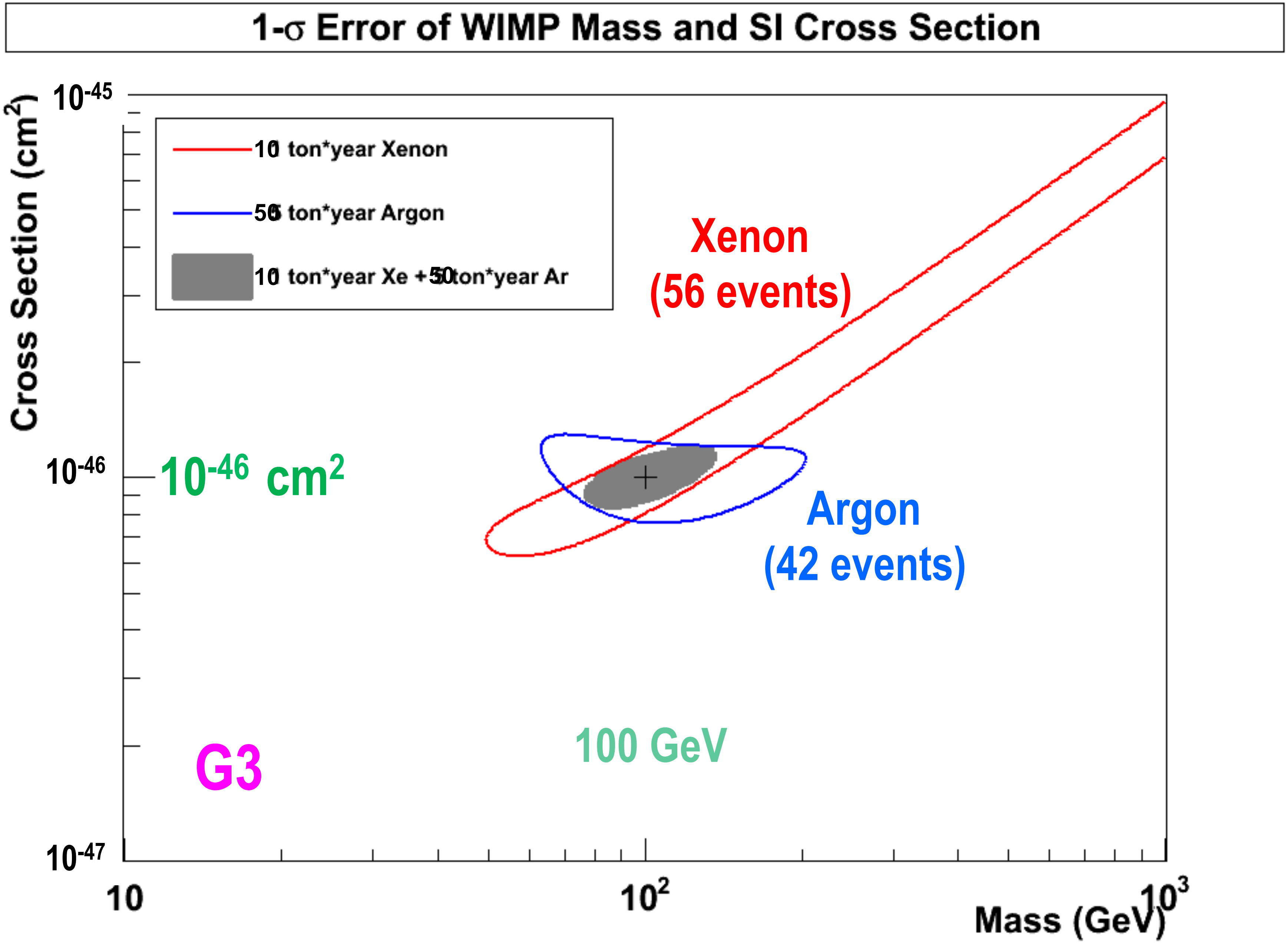
1-σ Error of WIMP Mass vs SI Cross Section (10 ton*year Xe and 50 ton*year Ar)



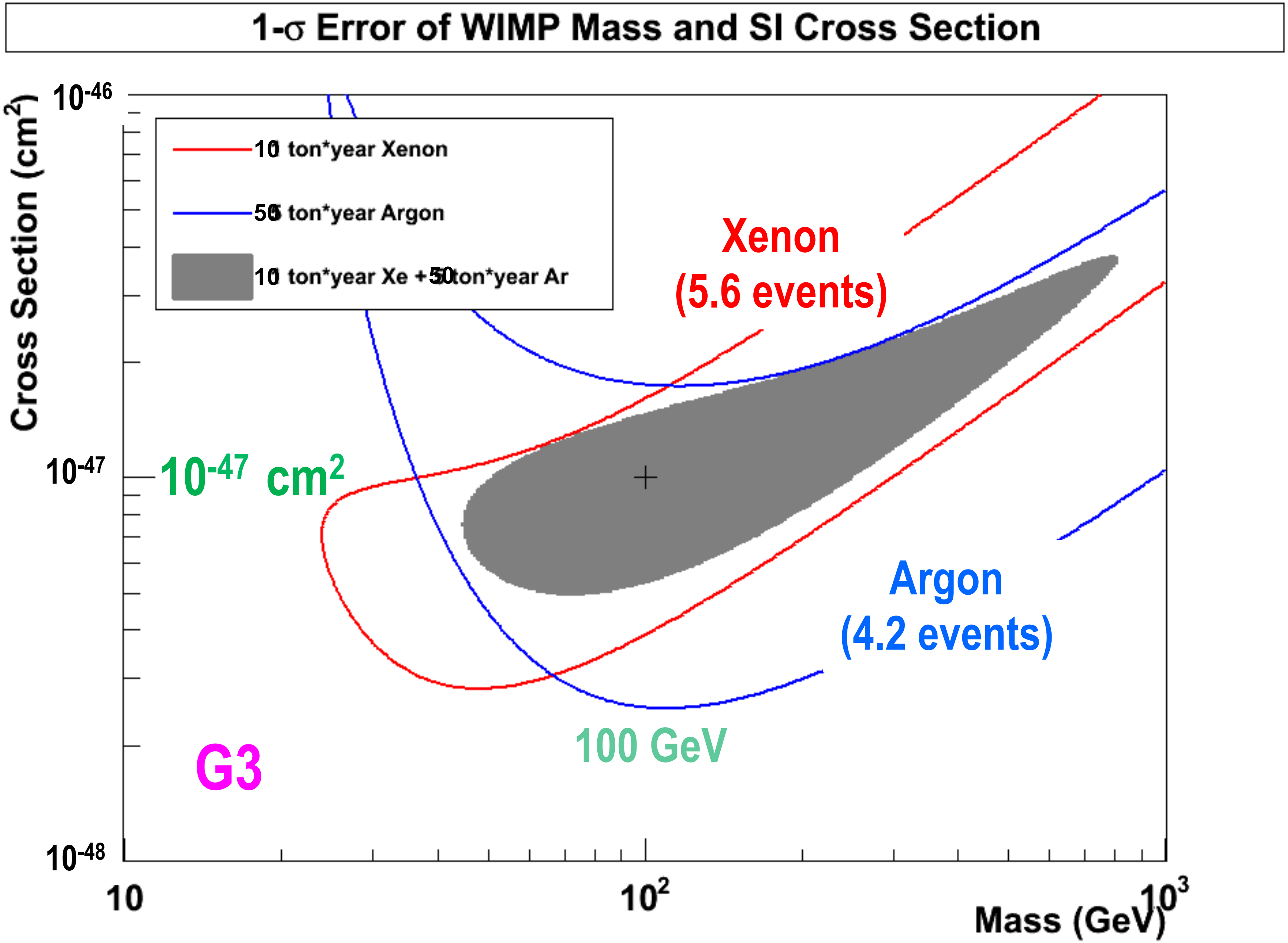
1-σ Error of WIMP Mass vs SI Cross Section
(10 ton*year Xe and 50 ton*year Ar)



1-σ Error of WIMP Mass vs SI Cross Section (10 ton*year Xe and 50 ton*year Ar)



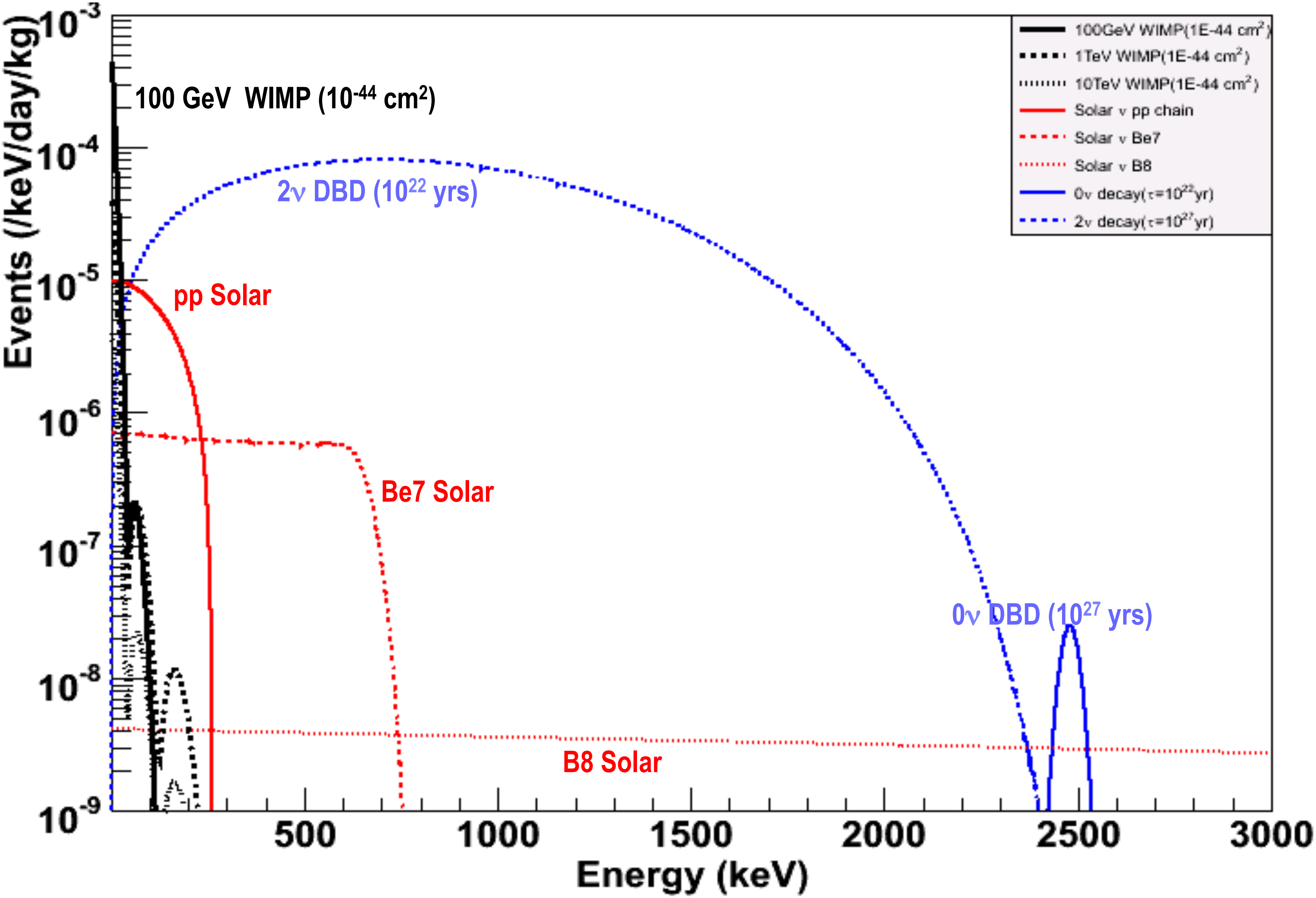
1-σ Error of WIMP Mass vs SI Cross Section
(10 ton*year Xe and 50 ton*year Ar)



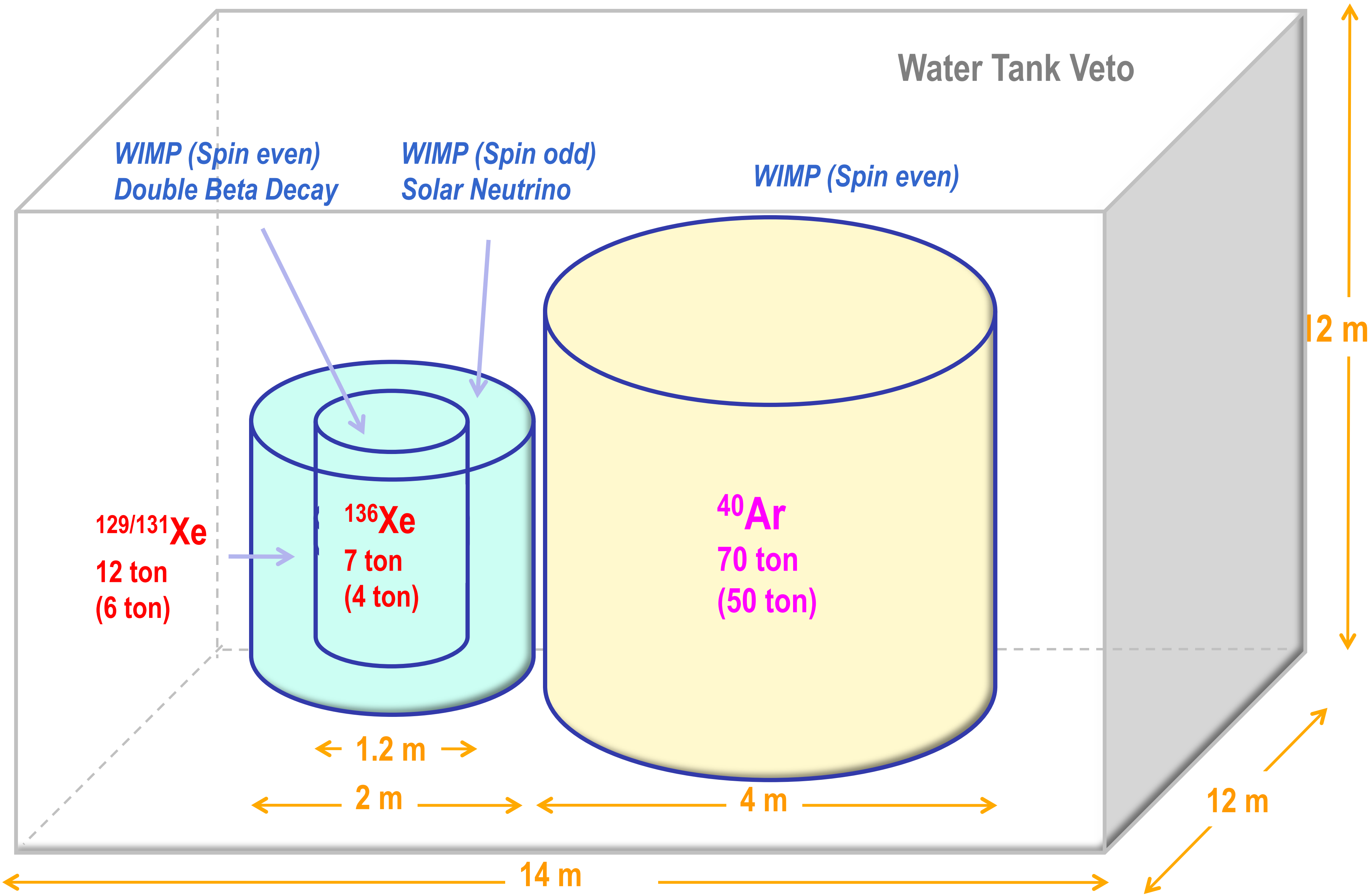
Neutrino Physics

Energy Spectrum (Natural Xe)

arXiv:0808.3968

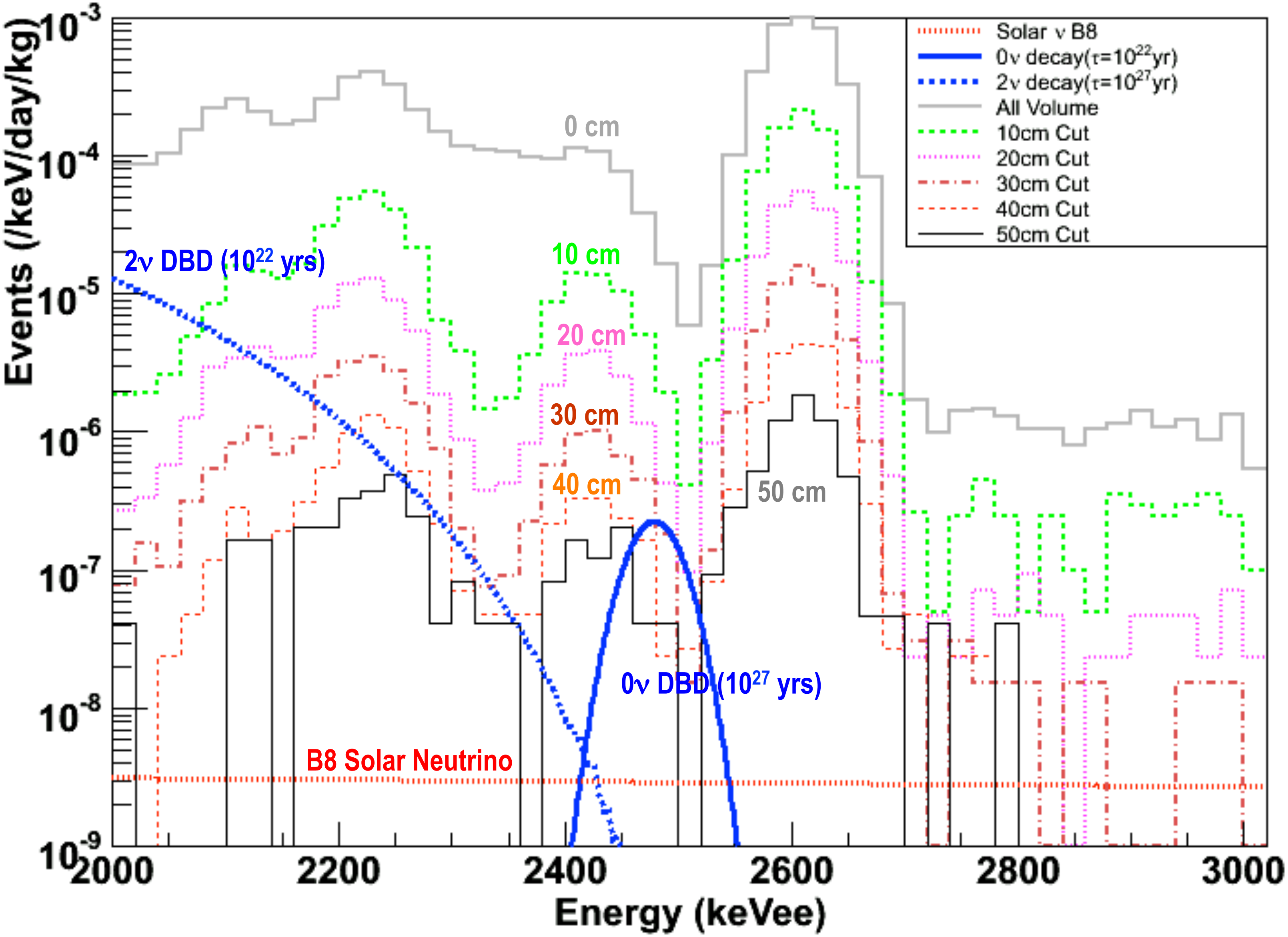


XAX (Xenon-Argon-Xenon) arXiv:0808.3968

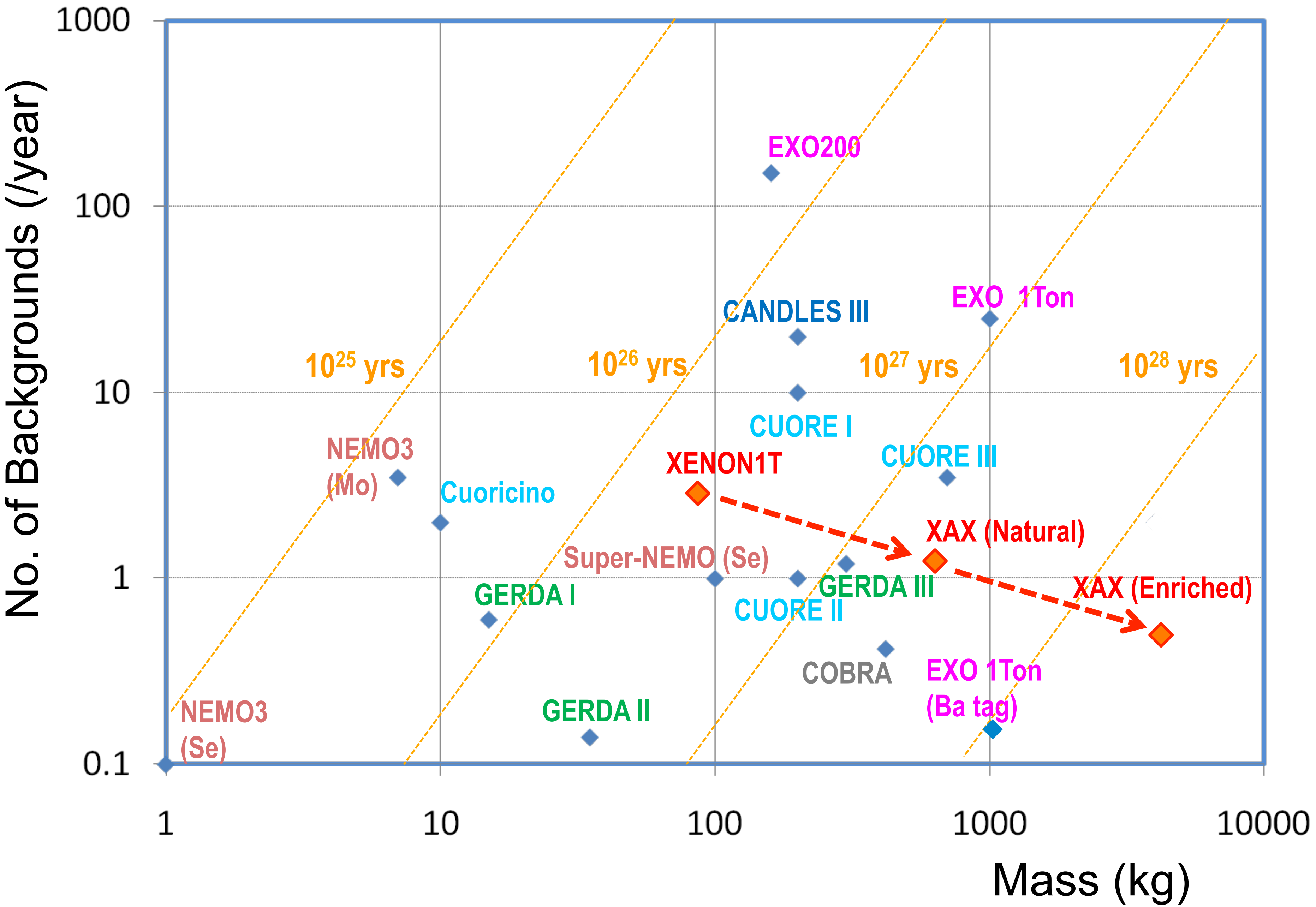


Neutrino-less Double Beta Decay

^{136}Xe Double Beta Decay and Gamma Background
(1 mBq / QUPID, 2m Xenon Detector)

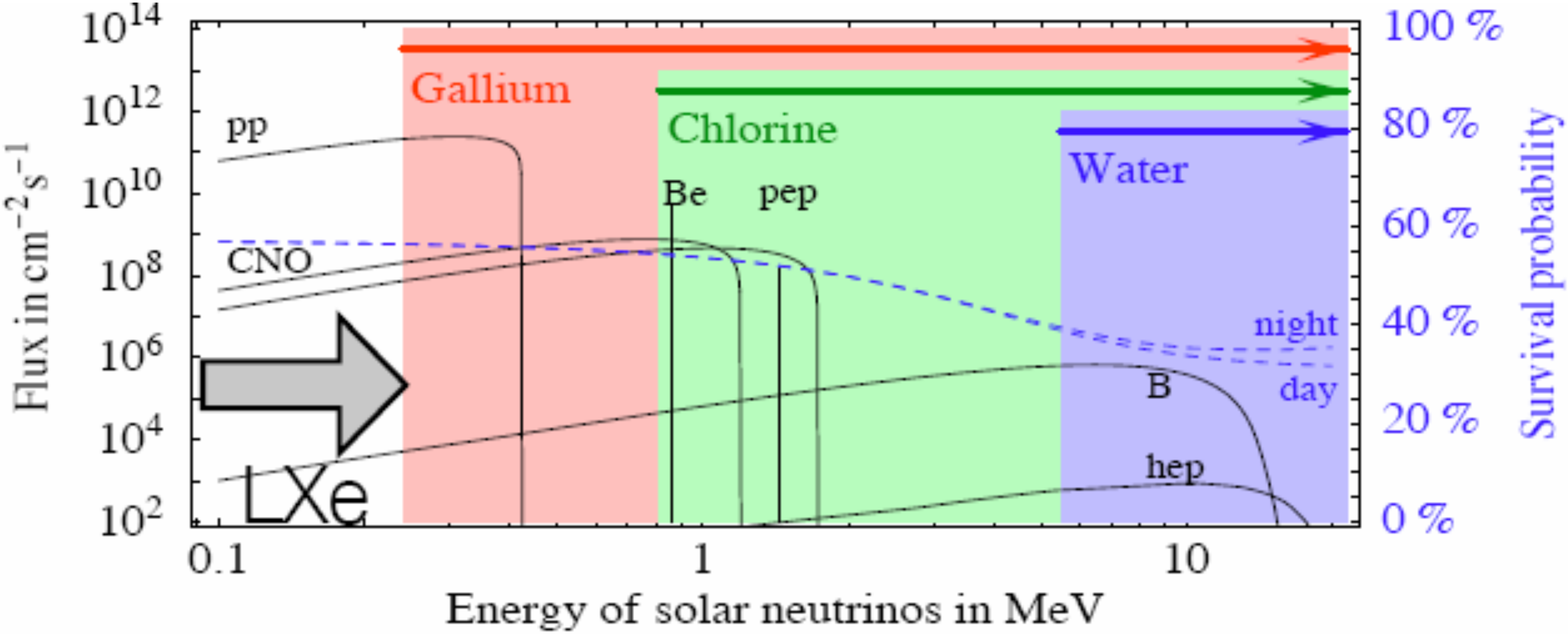


Double Beta Decay Experiments



Solar Neutrino Detection

Solar Neutrino (by XMASS group)



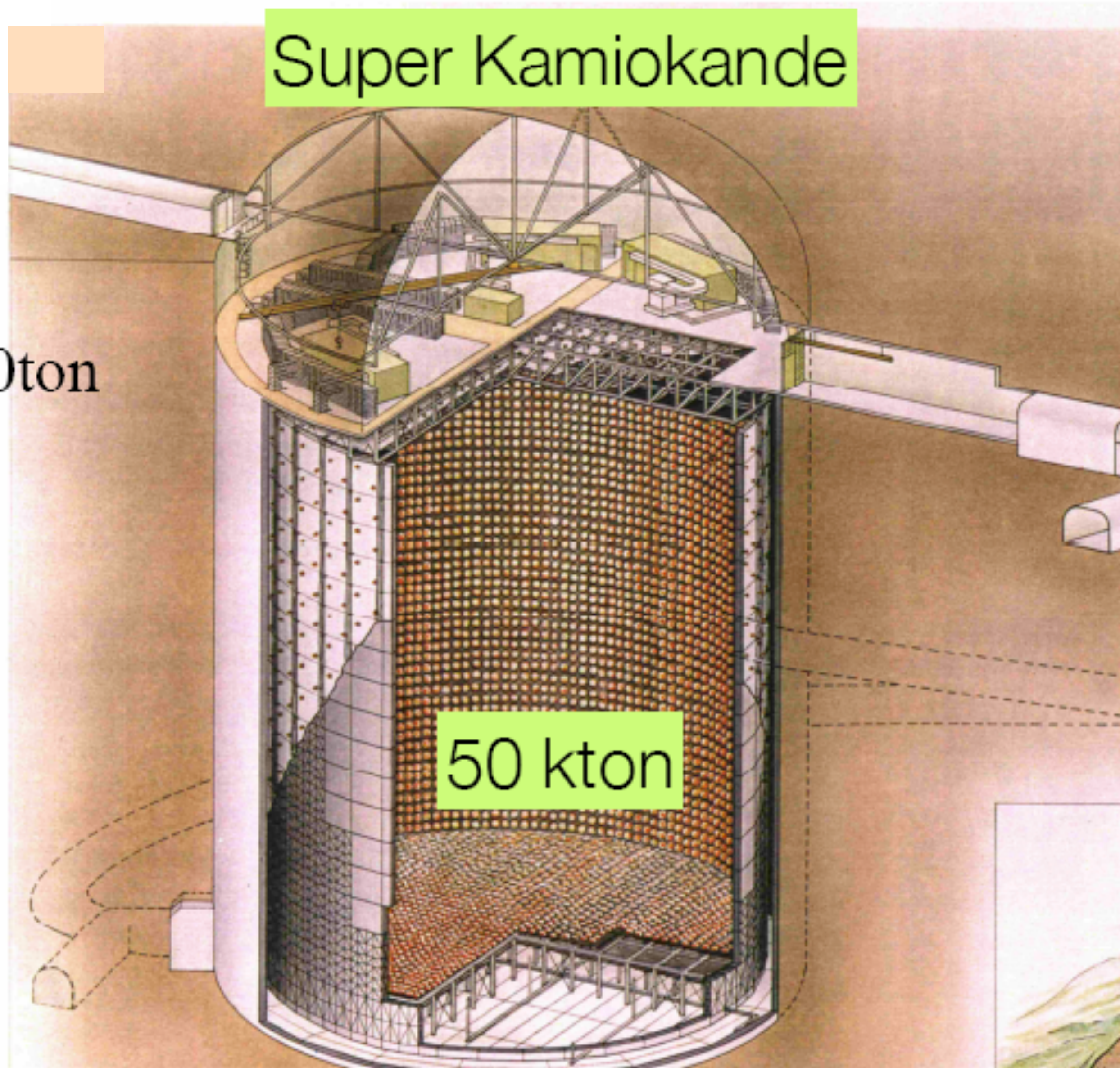
- Motivation
  - ➡99% of solar neutrinos are from pp chain
  - ➡Measurement of θ_{12} with ~1% precision
  - ➡confirmation LMA solution

M. Nakahata

Sular Neutrino Detection

10pp /5 ^{7}Be events/day/10ton

SK 13 events/day

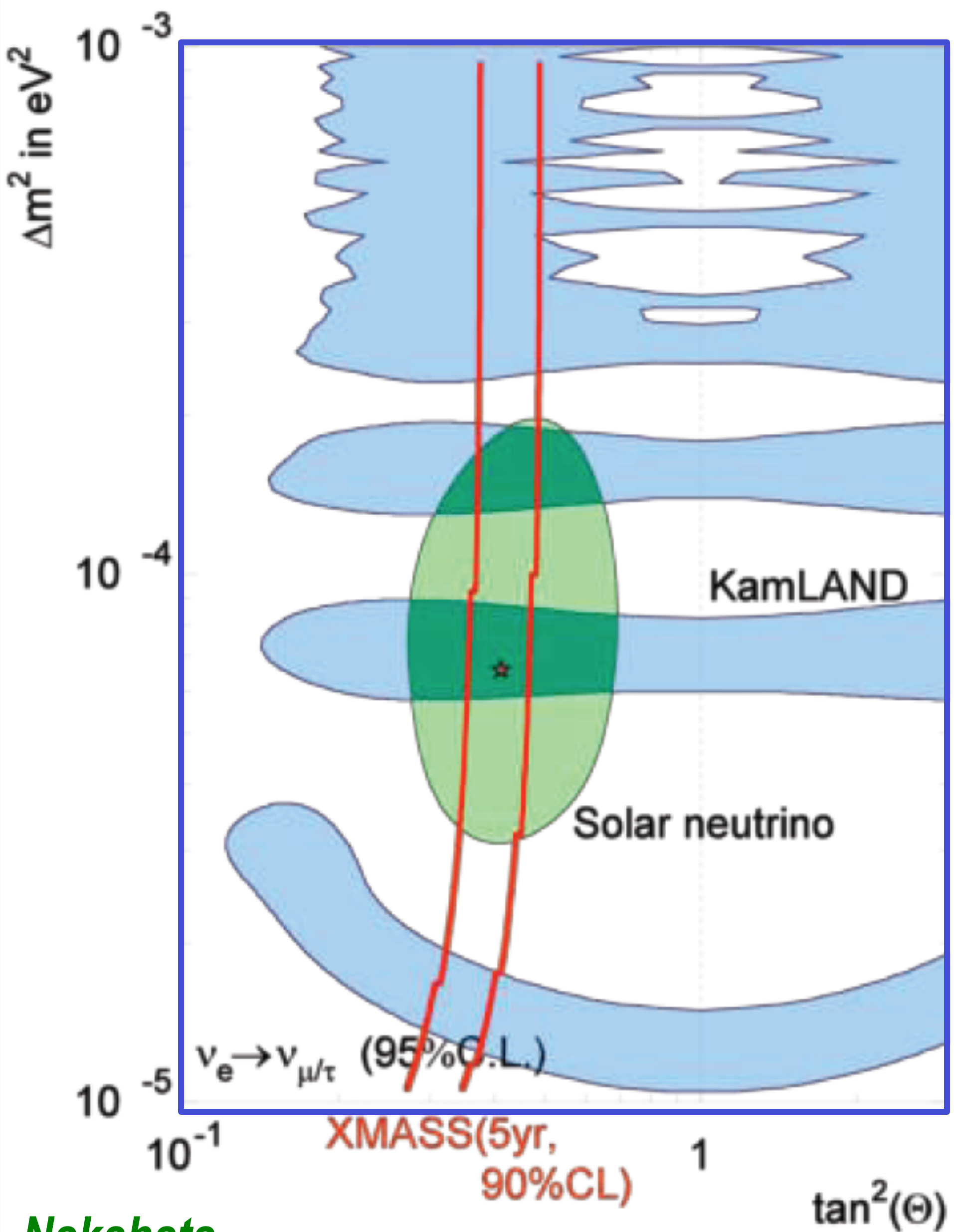


10 ton LXe

 =

M. Yamashita

Solar Neutrino Study by XMASS Group

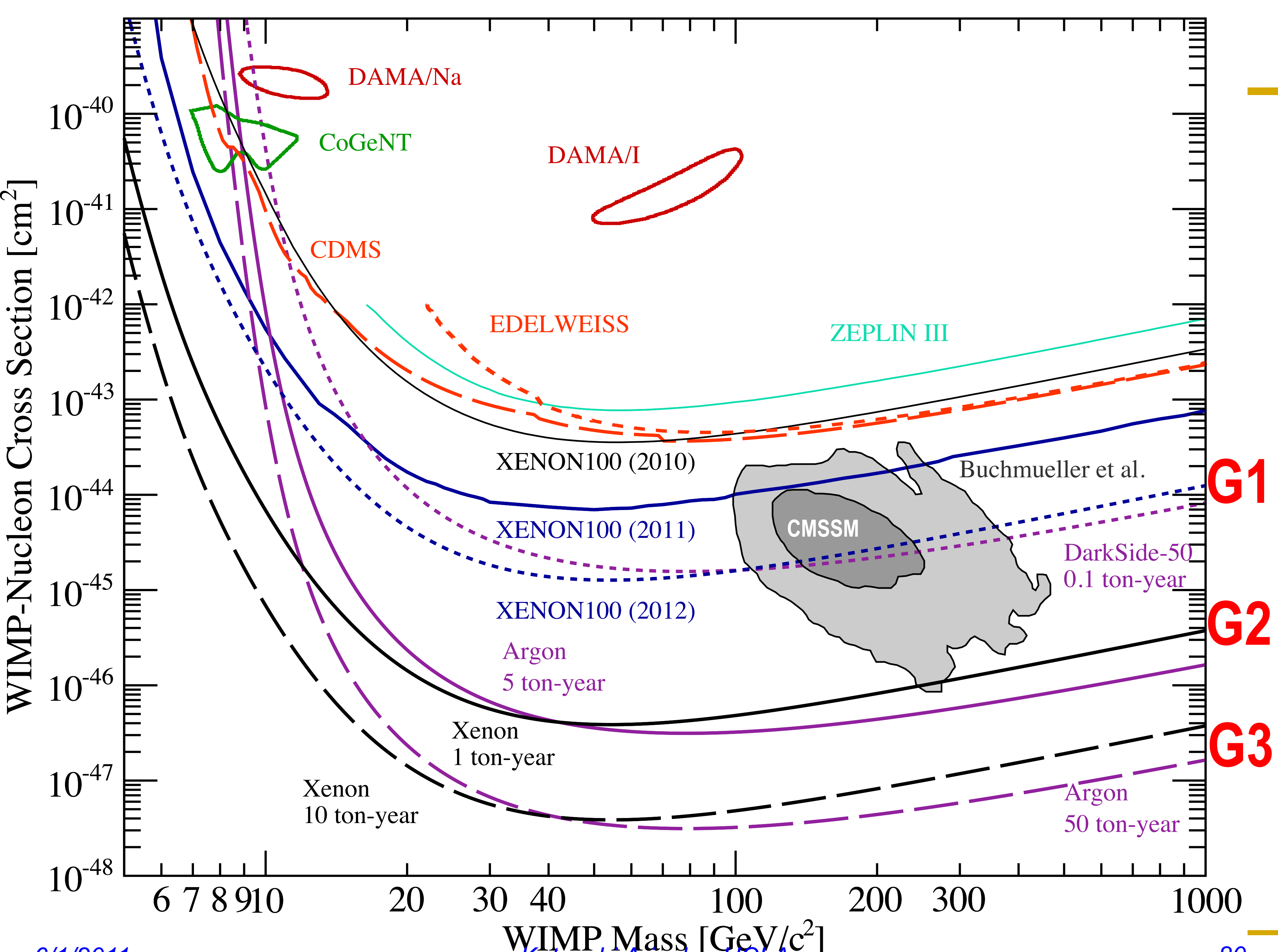


M. Nakahata

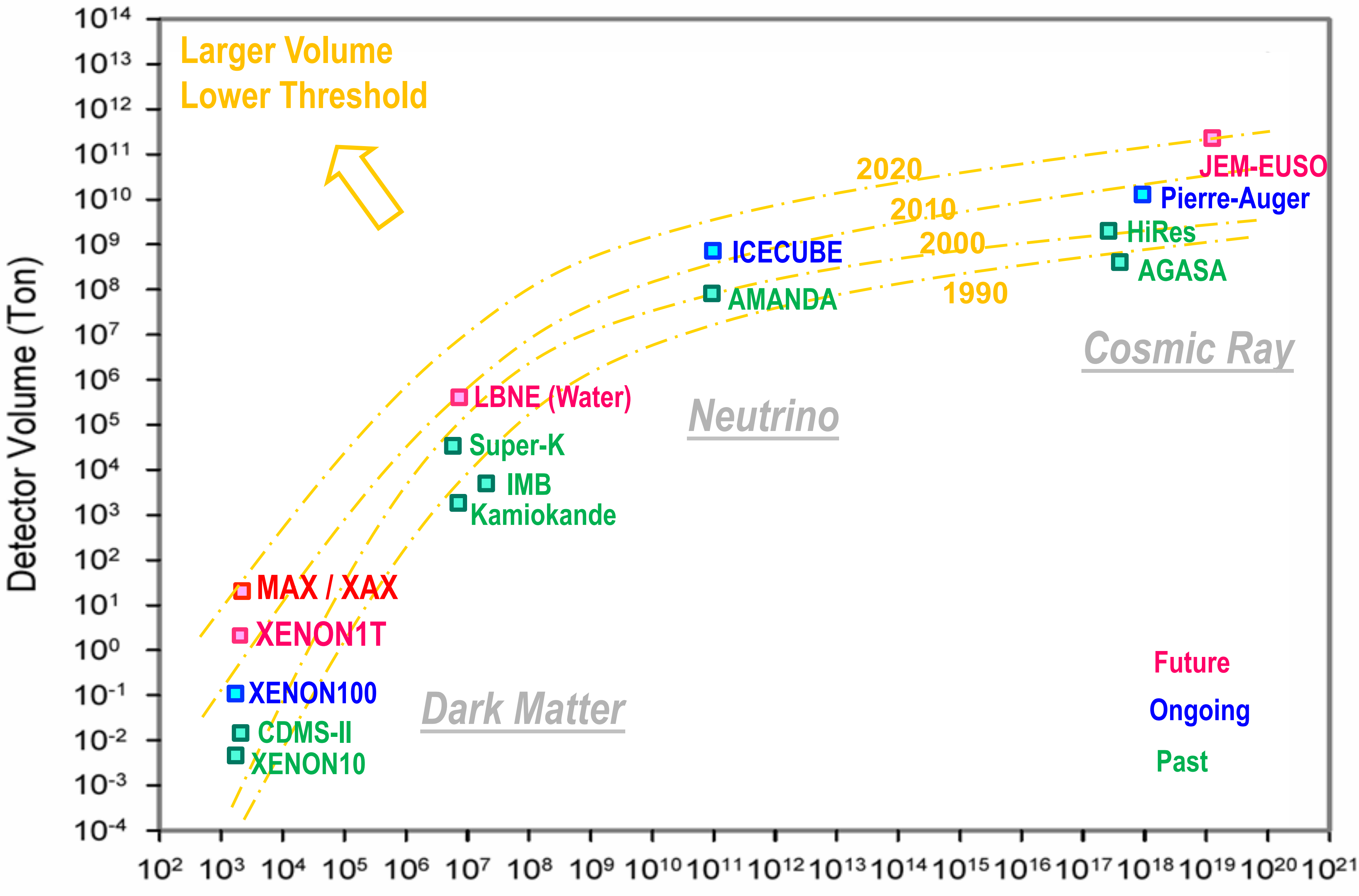
- Expected region using pp neutrinos (90 % C.L.) :
  - 10 ton Liq. Xe
  - νe scattering
  - 5 years data
  - Statistical error and SSM prediction error(1%)
- Accuracy of mixing angle: $\sin^2 2\theta = 0.77 \pm 0.03$(stat.+SSM)

KamLAND and pp solar neutrinos will determine precise oscillation parameters

Summary


DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
ZEPLIN III
XENON100 (2010)
Buchmueller et al.
XENON100 (2011)
CMSSM
DarkSide-50
0.1 ton-year
XENON100 (2012)
Argon
5 ton-year
Xenon
1 ton-year
Xenon
10 ton-year
Argon
50 ton-year
G1
G2
G3
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^-40
10^-41
10^-42
10^-43
10^-44
10^-45
10^-46
10^-47
10^-48
6 7 8 9 10
20
30
40
100
200
300
1000

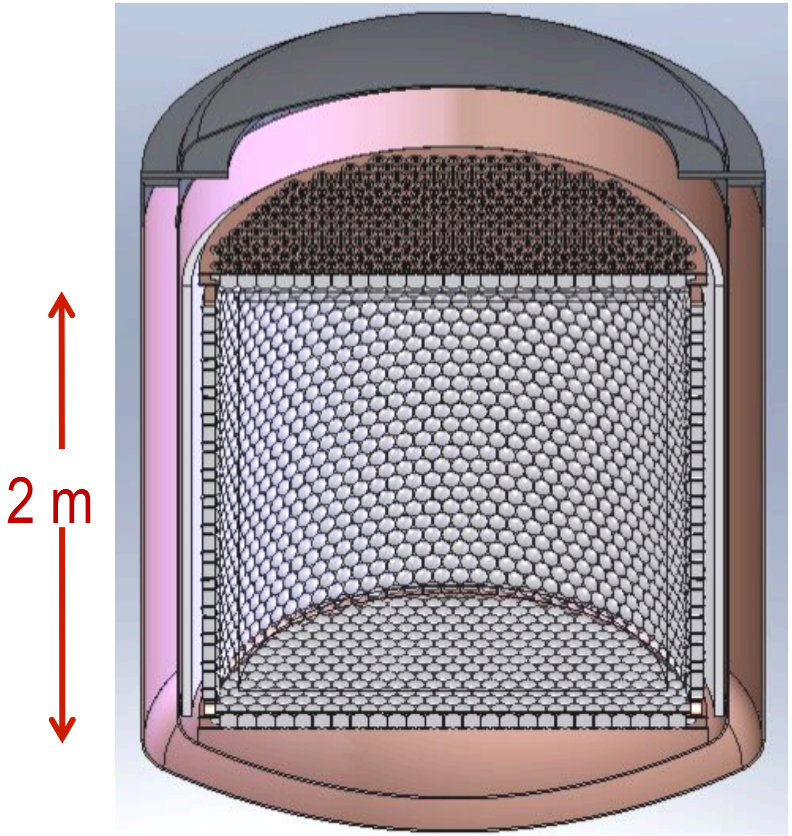
Detection of Cosmic Radiation



XAX vs. Super-K

XAX

Liquid Xenon (20 ton)

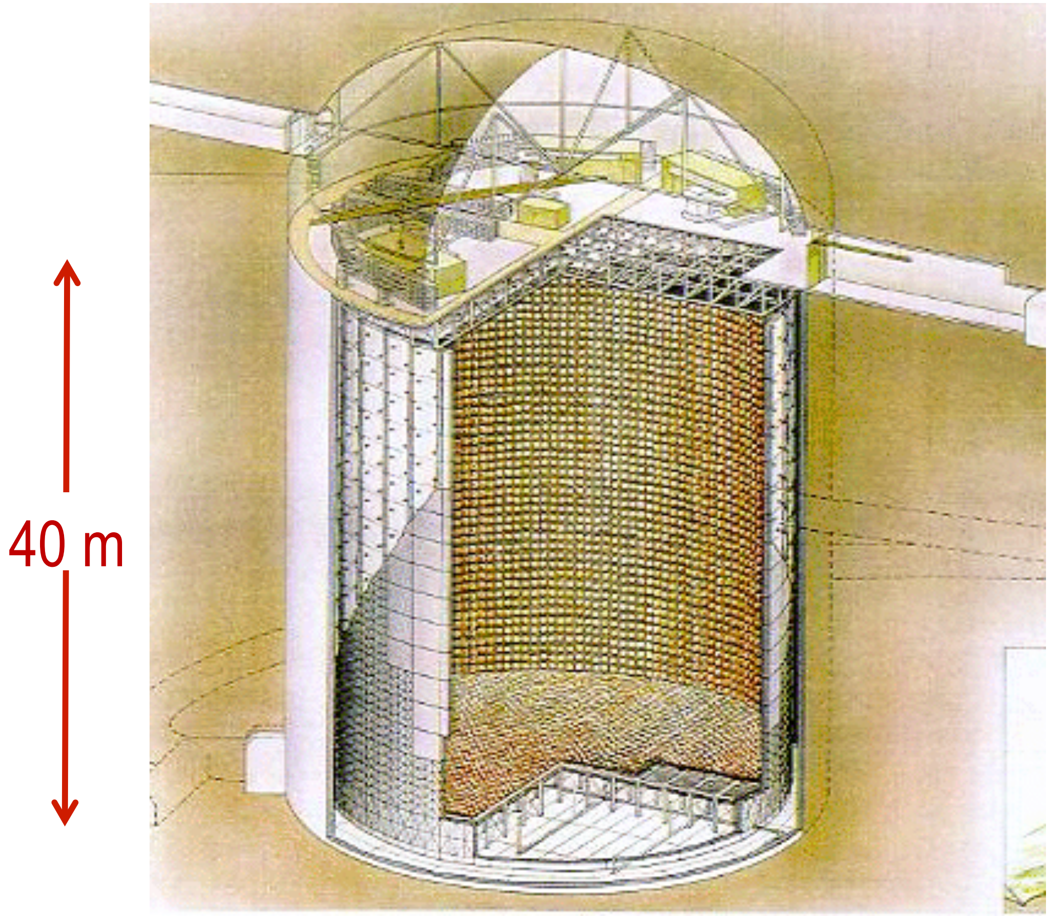


Energy Threshold = 5 keV

3” QUPID x 4,000

Super-K

Pure Water (50,000 ton)



Energy Threshold = 5 MeV

20” PMT x 11,200

Conclusions

- XENON100 new results announced.
  - 3 event observed (1.8 ± 0.6 events expected)
  - $< 7 \times 10^{-45}$ cm^2 (at 50 GeV WIMP mass)
  - $< 2 \times 10^{-45}$ cm^2 by the end of 2011 expected
- Future multi-ton Xe/Ar detectors designed and proposed.
  - G2 : XENON 1T and DarkSide 50 / 5T at Gran Sasso.
  - G3 : MAX + LZD (Xe 10T + Ar 50T) at DUSEL
- XAX is an ultimate general purpose detector with ~ 5 keV threshold.
  - Double beta decay
  - Solar (pp-chain) and supernova neutrinos