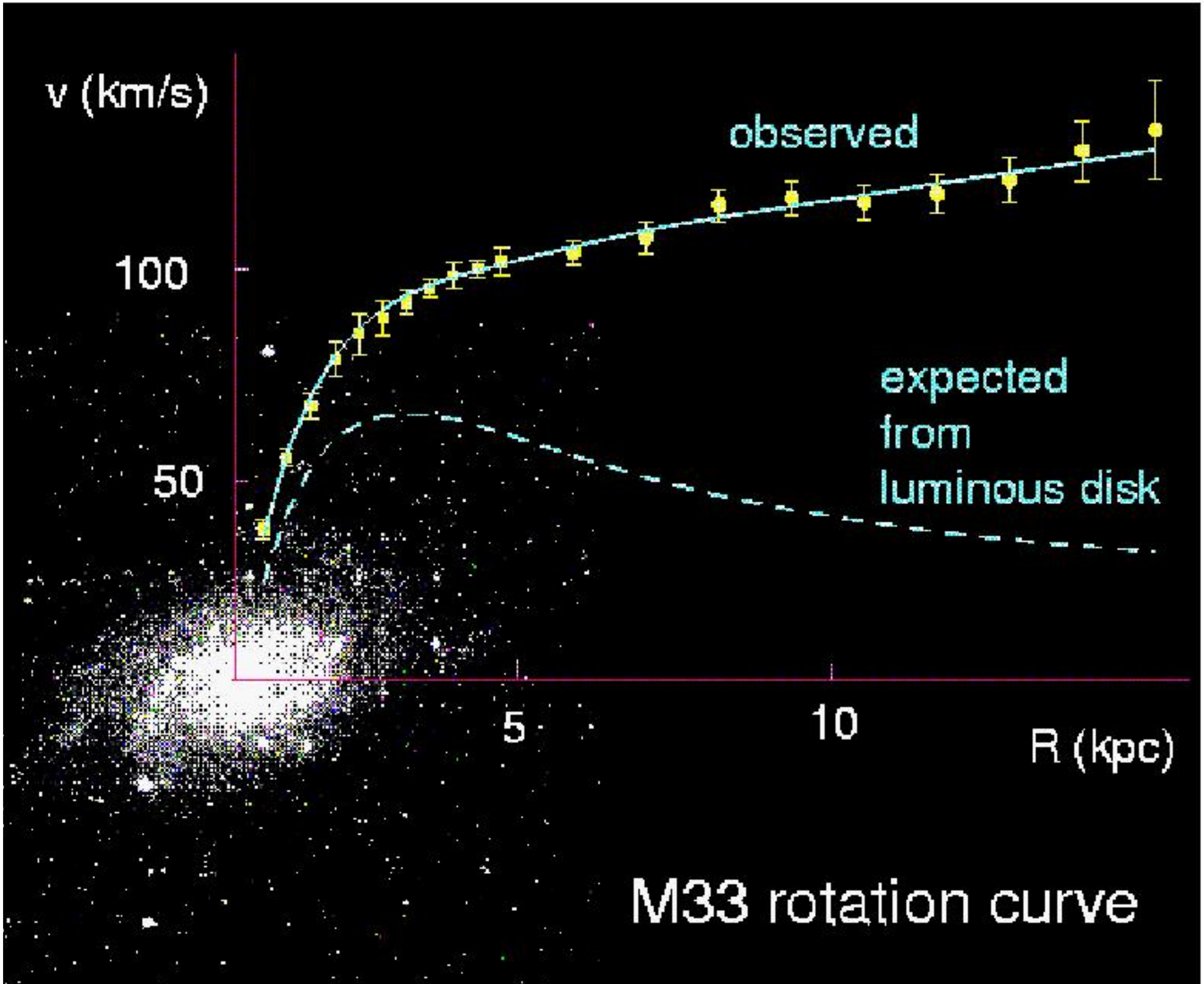
FIRST RESULTS FROM THE DARKSIDE-50 DARK MATTER EXPERIMENT AT GRAN SASSO

Maria Elena Monzani

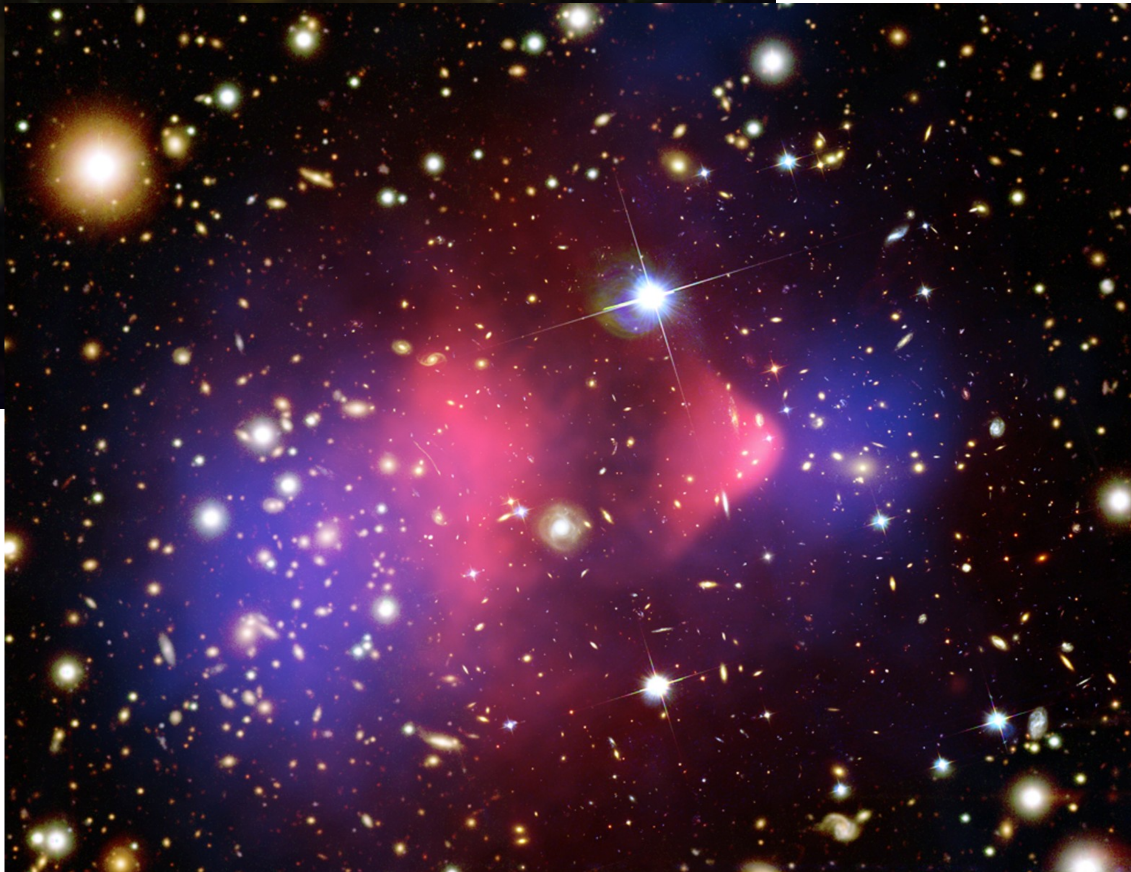
Research Progress Meeting

LBNL, March 5th, 2015

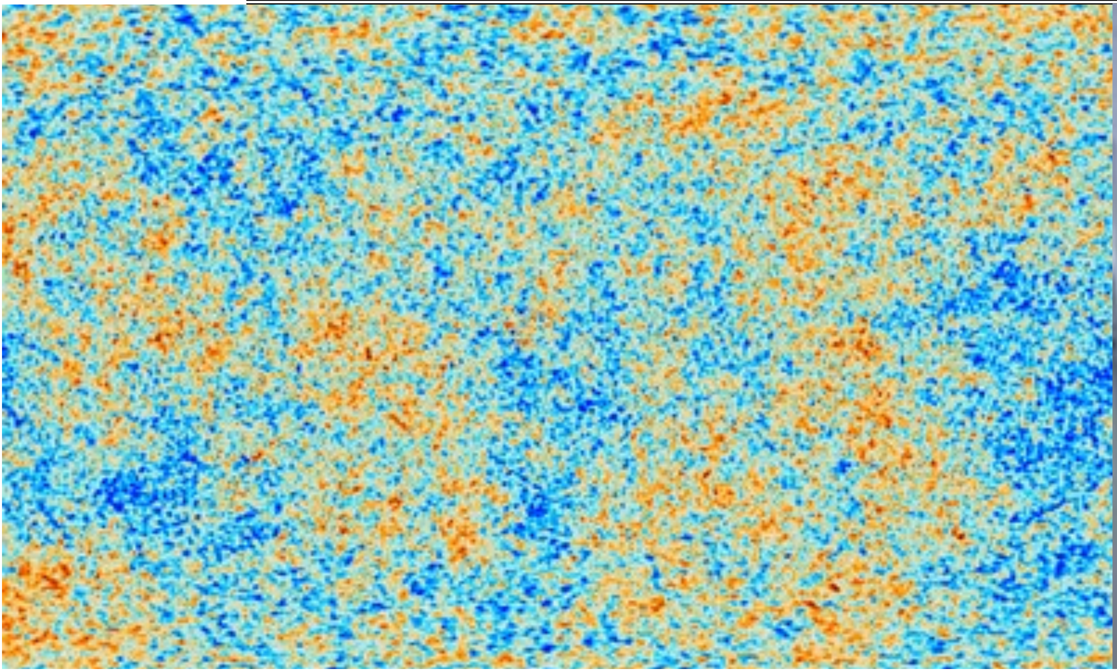
Something fishy with Spiral Galaxies



Something Fishy with Galaxy Clusters



SOMETHING FISHY WITH THE UNIVERSE



CMB anisotropies:

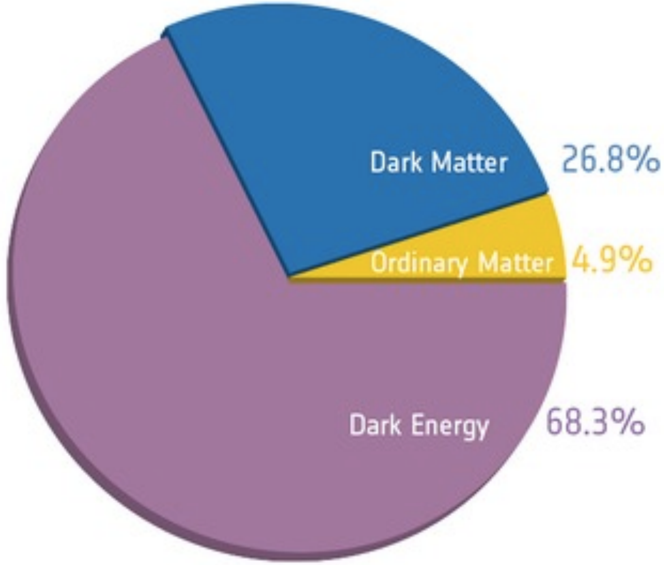
Angular Scale: $\Omega_{tot} \approx 1 \Rightarrow \Omega_\Lambda + \Omega_M \approx 1$

Odd-vs-even peaks: $\Omega_B / \Omega_{tot} \approx 4.9\%$

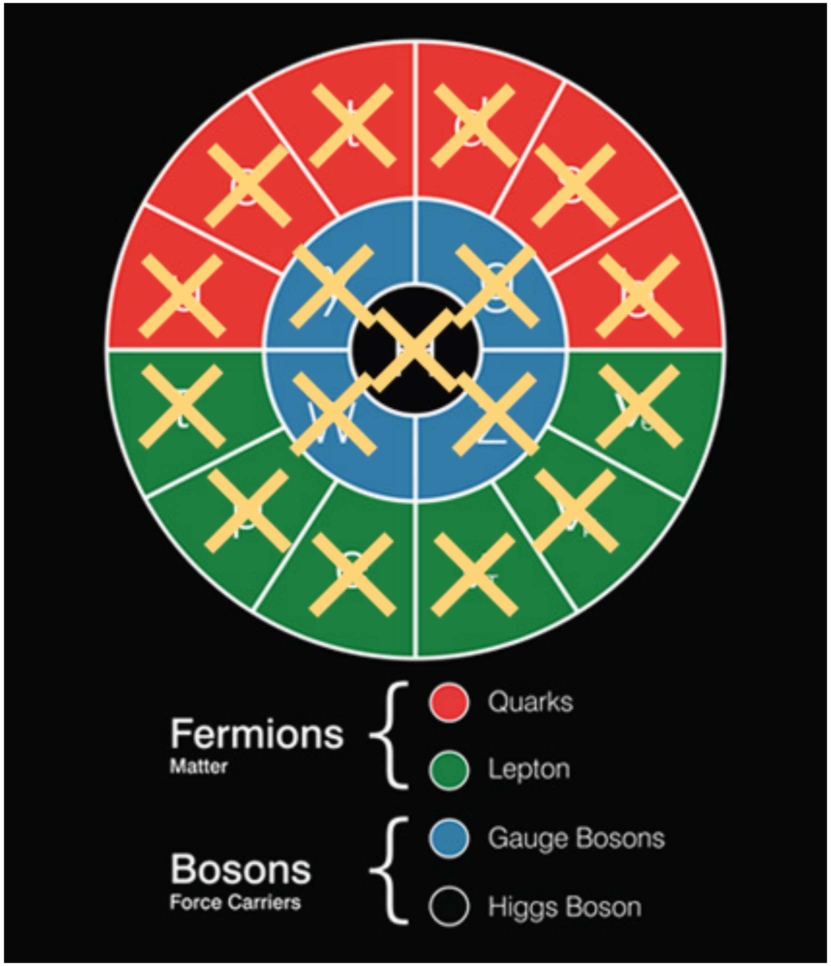
Type Ia SN:

$\Omega_\Lambda \approx 1.33\, \Omega_M + 0.33 \Rightarrow \Omega_M / \Omega_{tot} \approx 32\%$

$\Rightarrow \Omega_{DM} / \Omega_{tot} \approx 27\%$



Known Dark Matter Properties

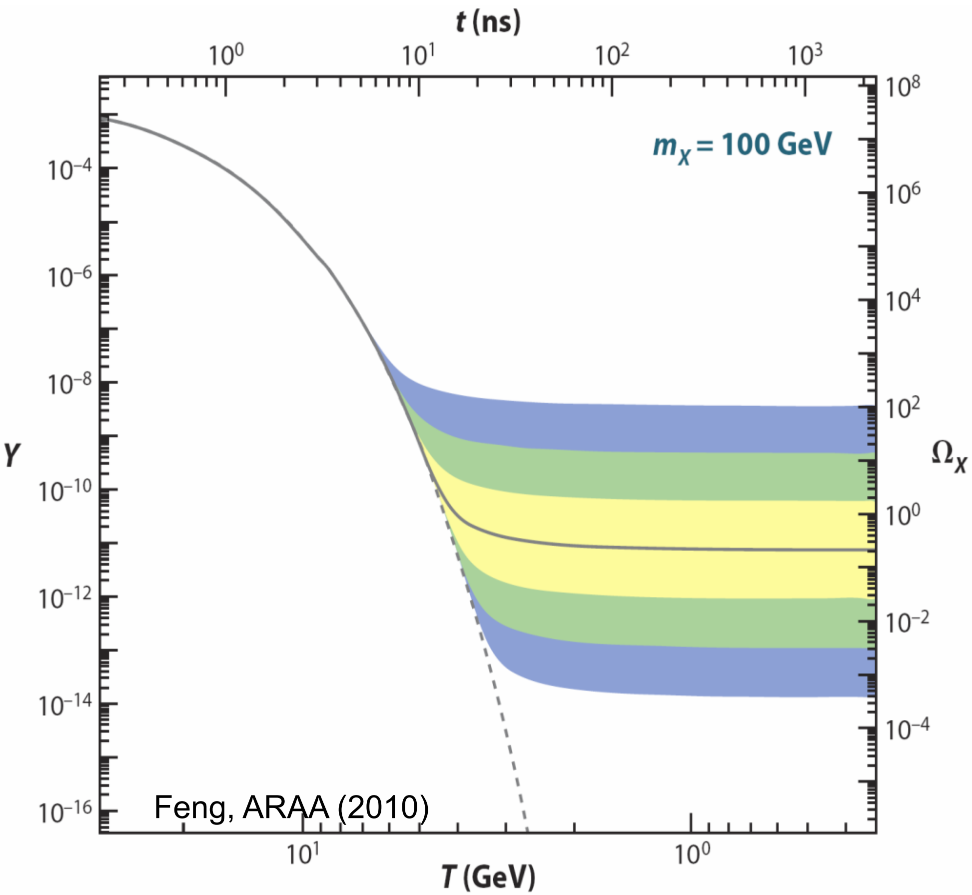


- Gravitationally interacting
- Not short-lived
- Not hot
- Not baryonic

Unambiguous evidence for new particles

Adapted from J. Feng

THE WIMP MIRACLE



If Dark Matter particles are relics from the Big-Bang, the amount of Dark Matter left over from the universe cool-down is determined by its annihilation strength:

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

$\Omega_\chi \sim 0.1 \to \langle \sigma v \rangle \sim 1\text{pb}$

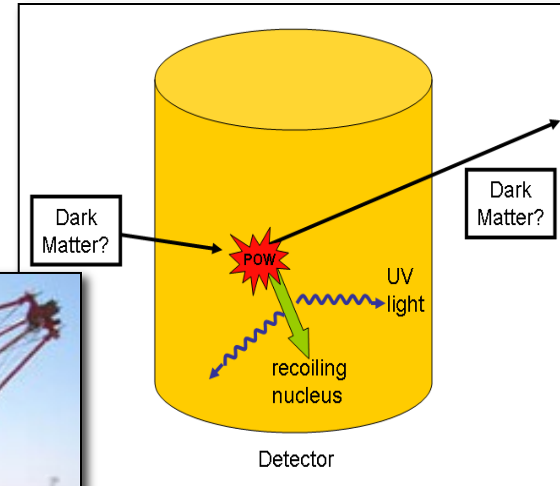
$m_\chi \sim 100$ GeV – 1 TeV

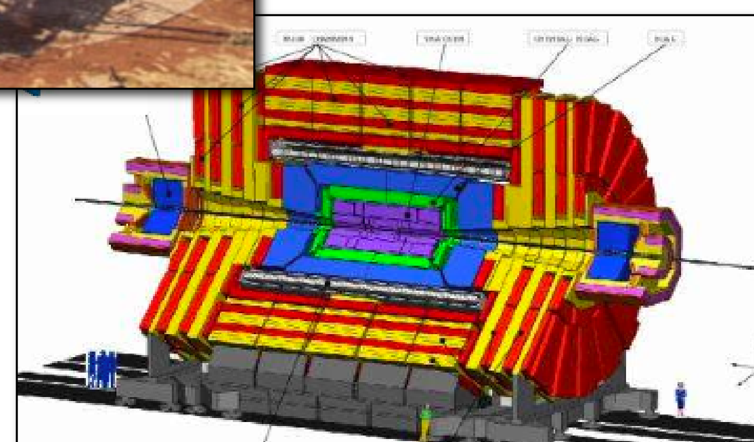
Remarkable coincidence: particle physics independently predicts particles with the right density to be dark matter

J. Feng

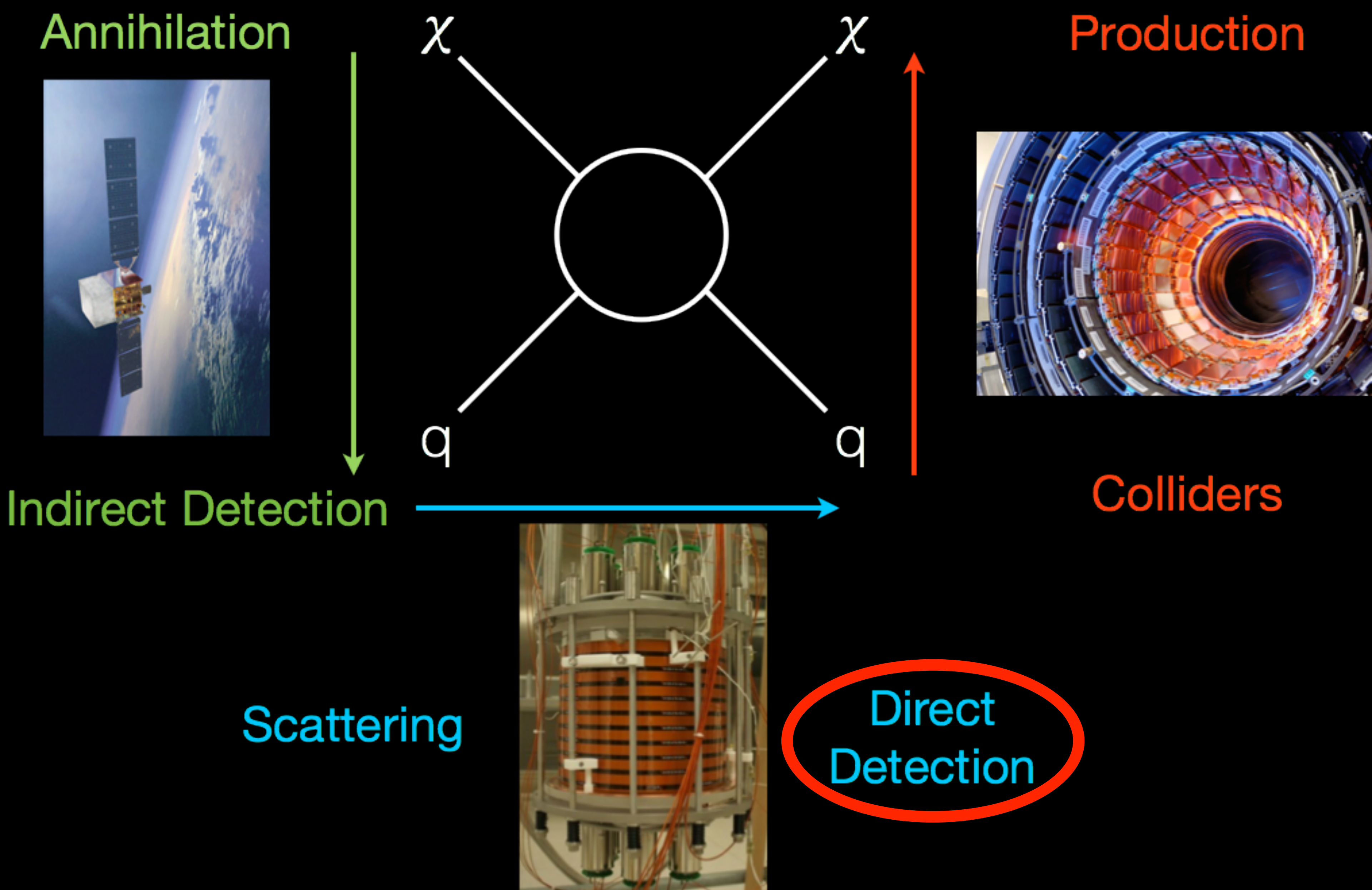
STRATEGIES FOR DARK MATTER HUNTING

- Direct Detection
- Indirect Detection
- Collider Searches

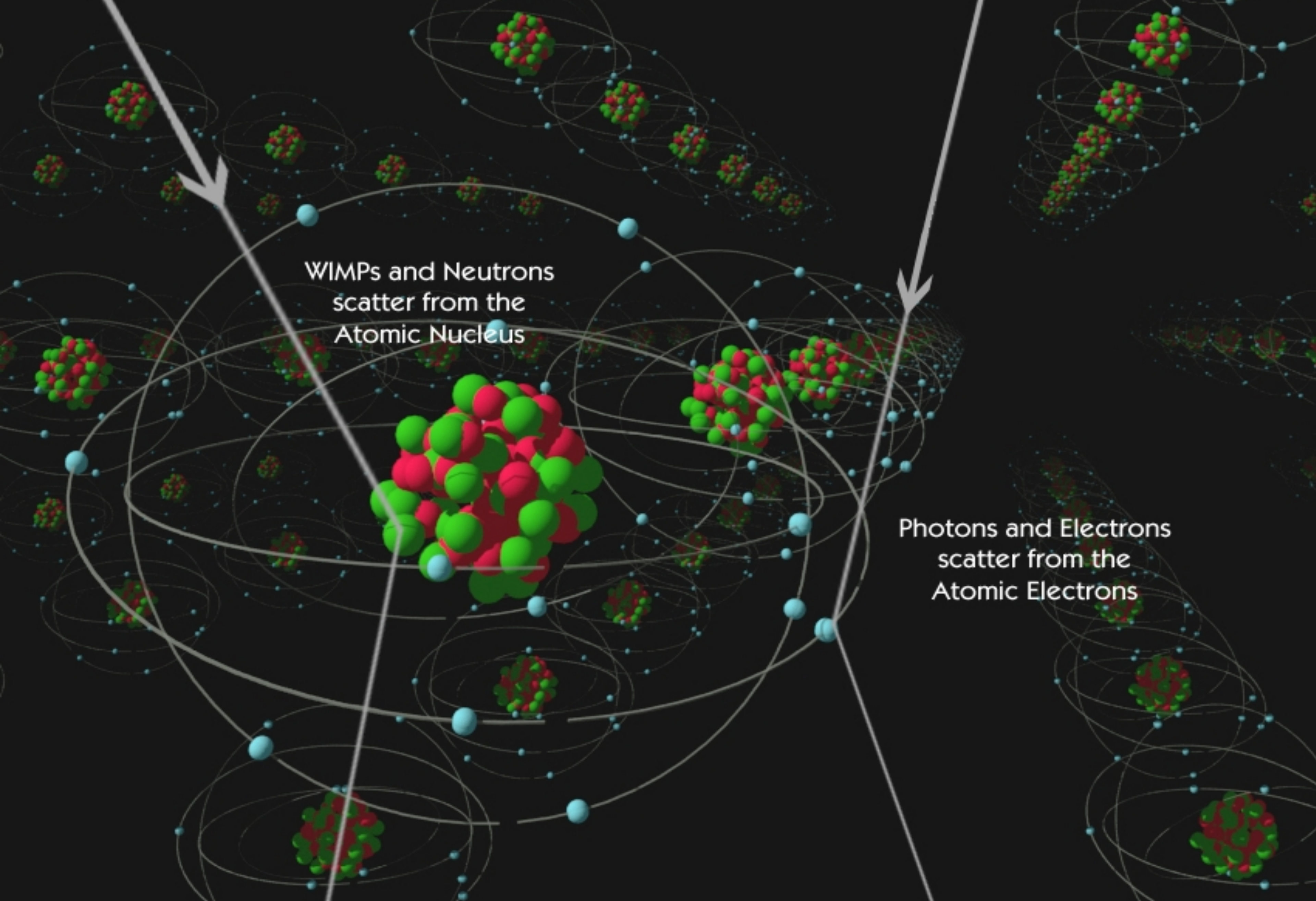




3 Ways to Detect WIMPs

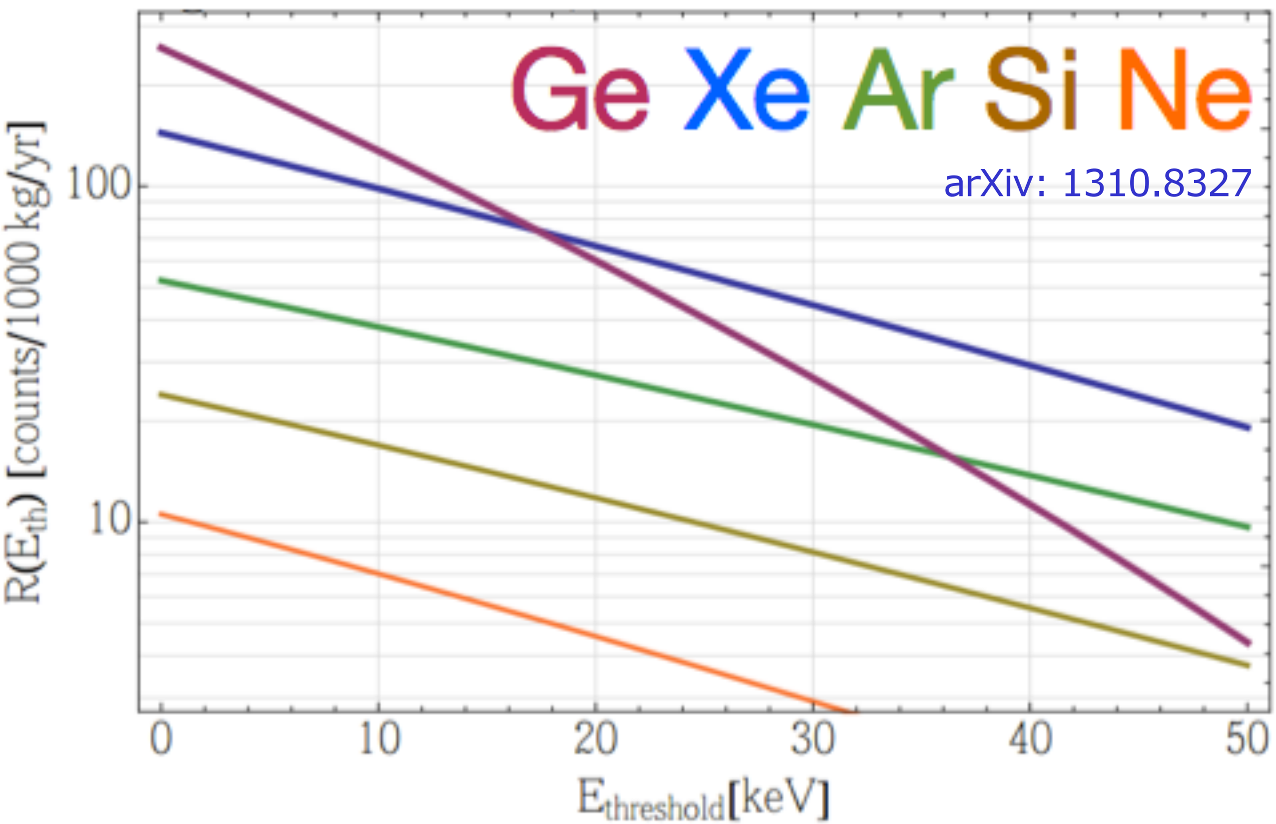


THE PRINCIPLE OF DIRECT DETECTION



Noble Liquid Detectors for WIMPs

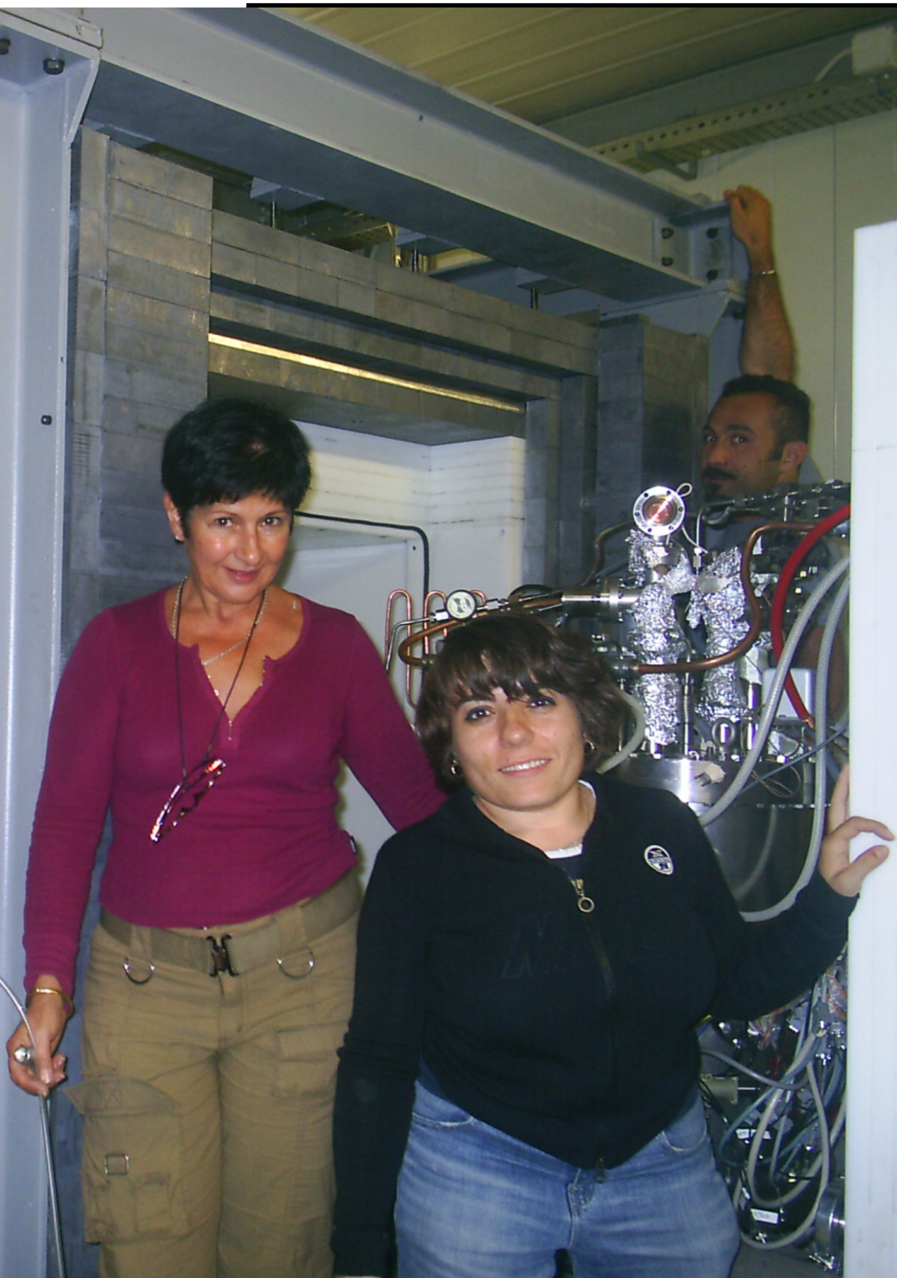
- ✓ Liquids provide a variety of targets (Xe, Ar, Ne)
- ✓ Easily scalable to ton-scale detectors + self-shielding
- ✓ Easy to purify for both electro-negative and radioactivity
- ✓ Large signals (high photon yield and high charge yield)
- ✓ Several background rejection techniques (S2/S1, PSD)



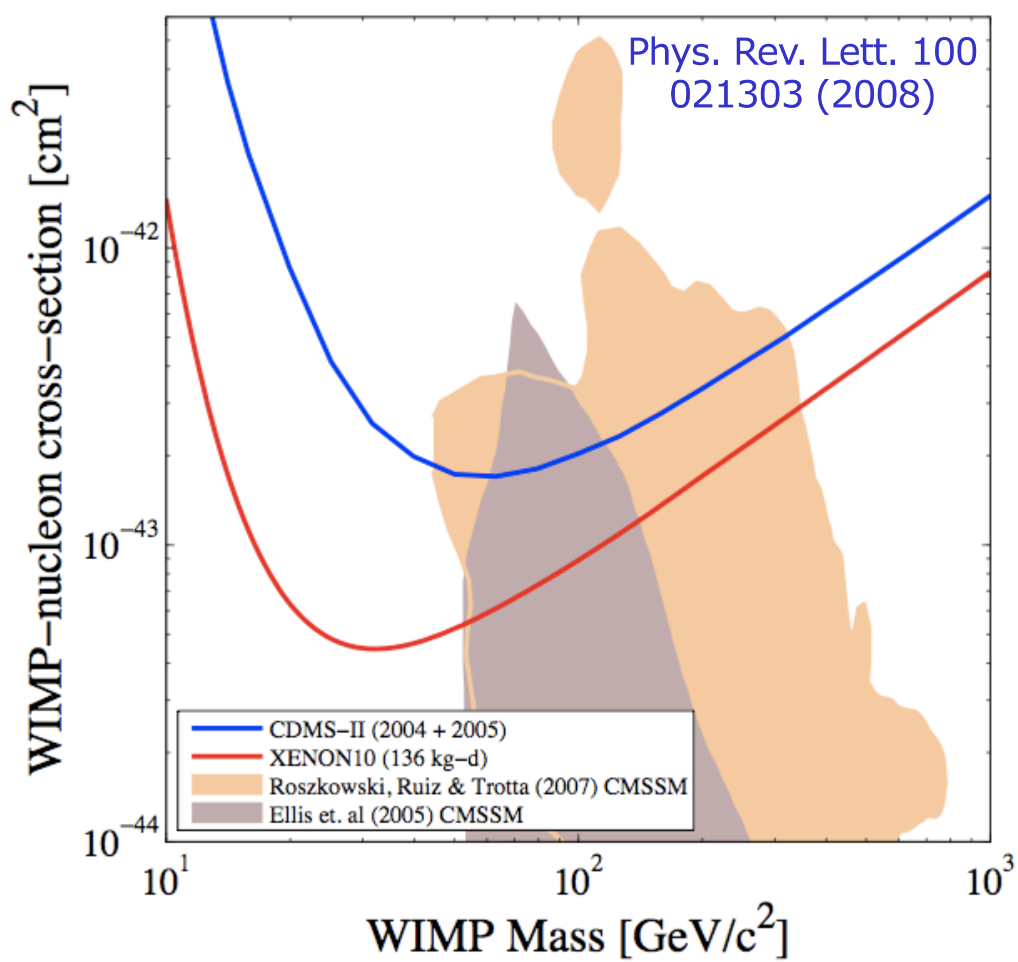
Example: WIMP interaction rates in five different DM targets

- m_χ: 100 GeV
- $\sigma_{\chi\text{-}n}$: 10^{-45} cm^2
- 1 ton·year

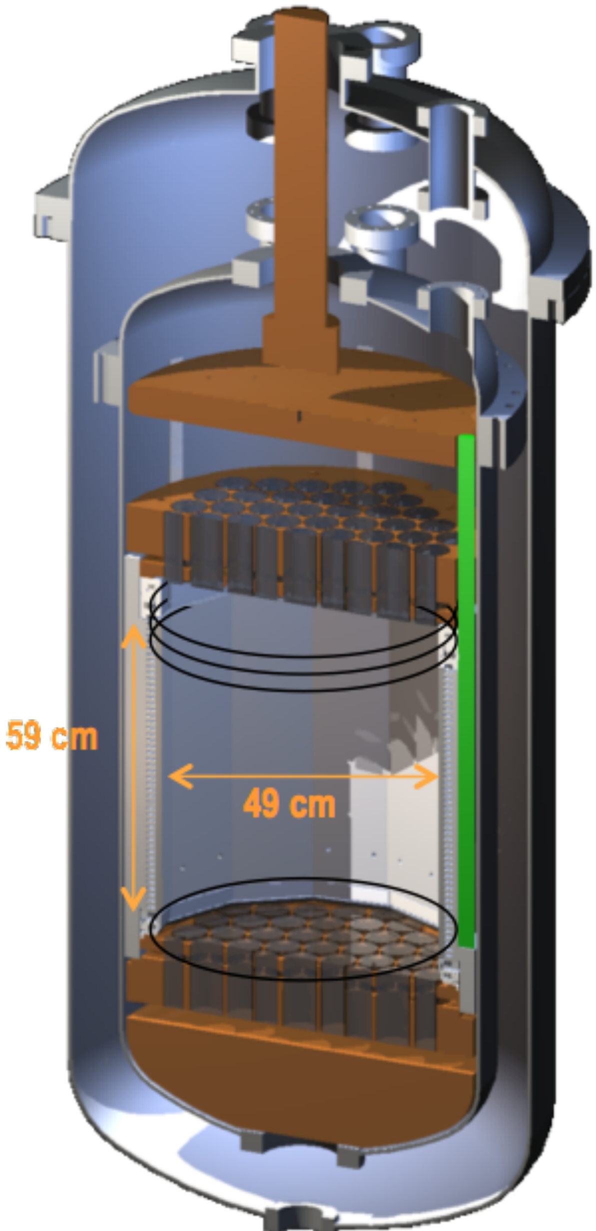
The XENON-10 Experiment at Gran Sasso



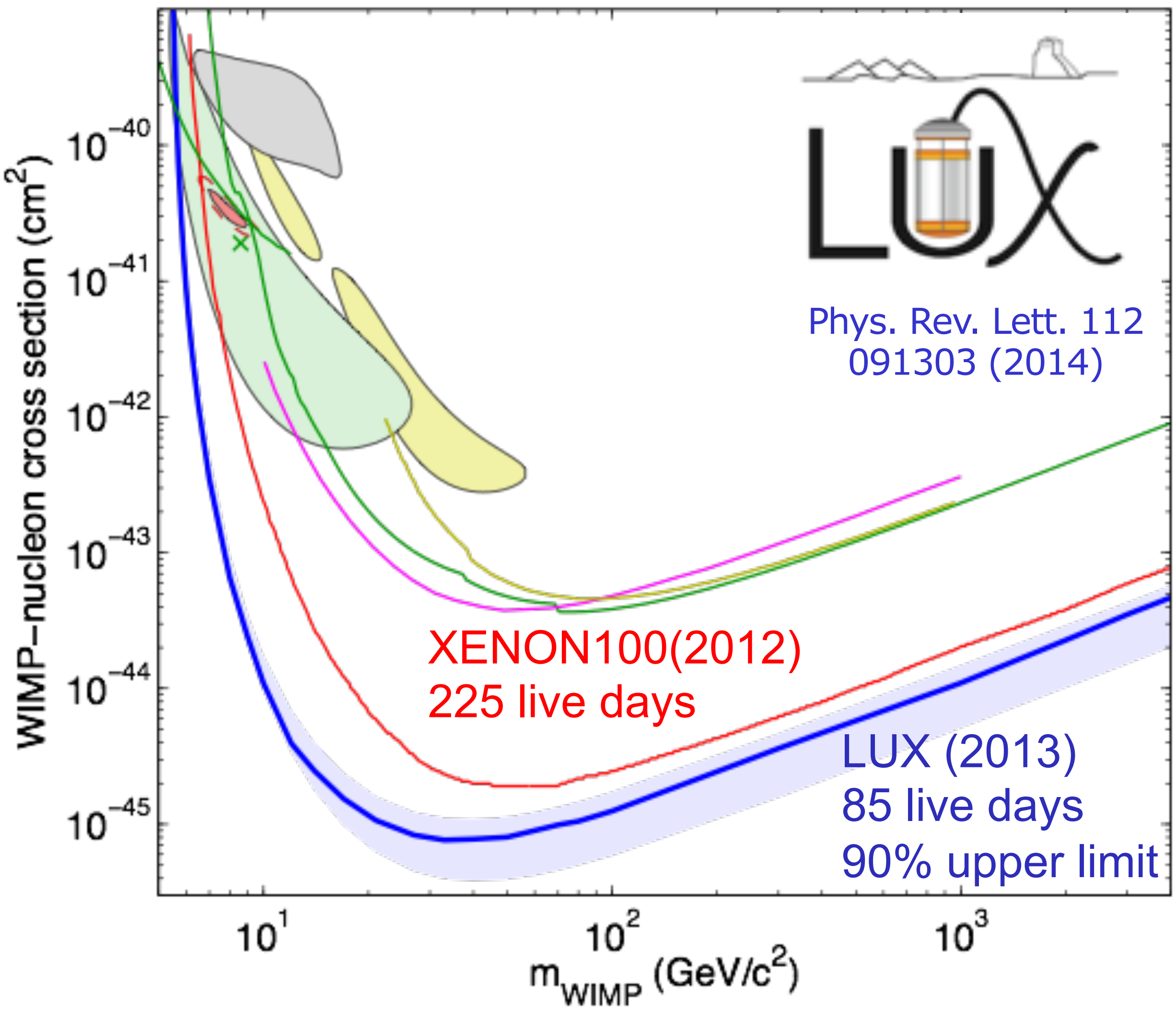
- Operated in 2006-2007
- 15 kg Liquid Xenon target
- $\sigma < 4.5 \cdot 10^{-44}$ cm^2 @30 GeV



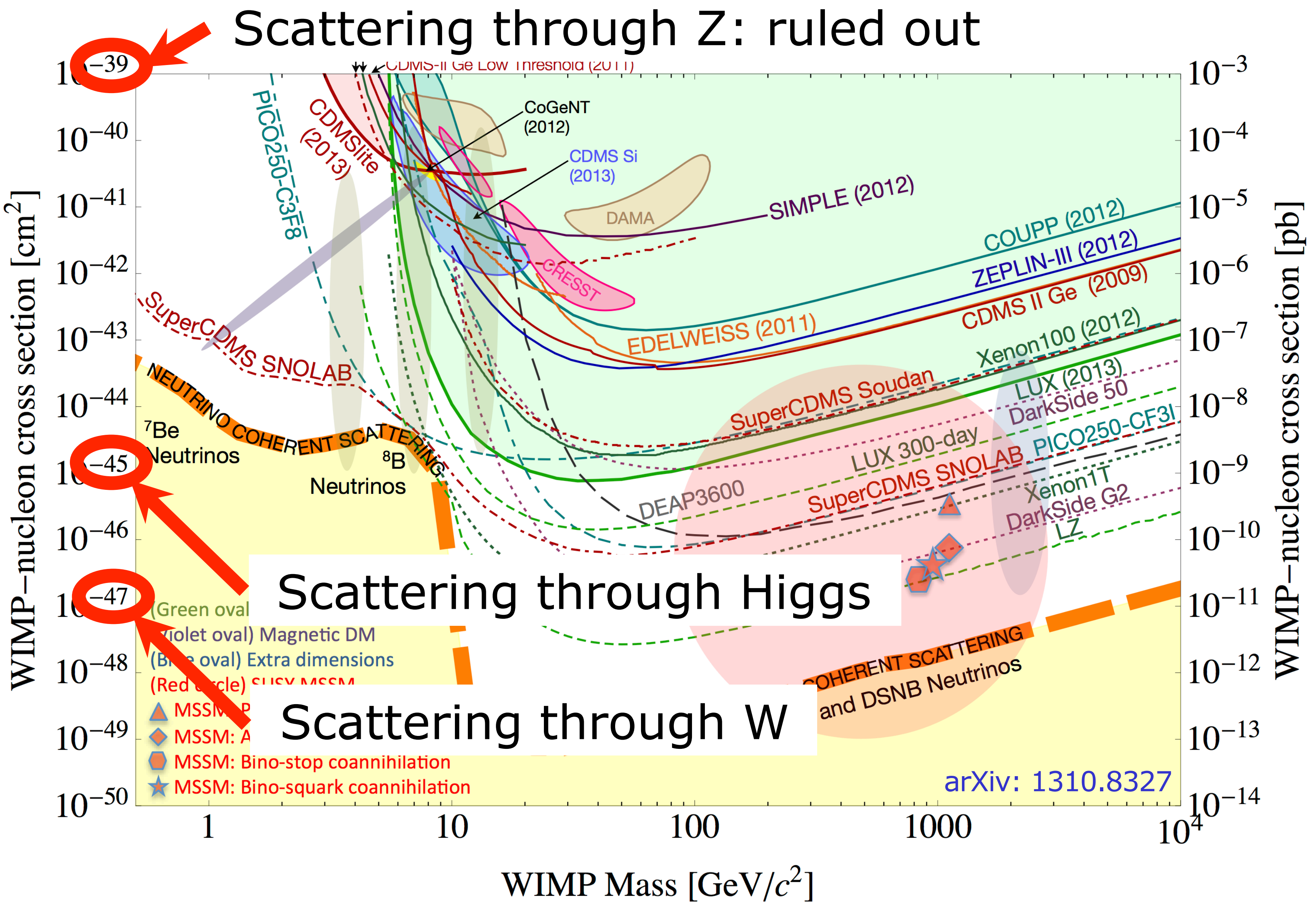
The Large Underground Xenon Experiment



- world's most sensitive experiment
- $\sigma < 7.6 \cdot 10^{-46}$ cm^2 @33 GeV (2013)



State of the Art in Direct Detection

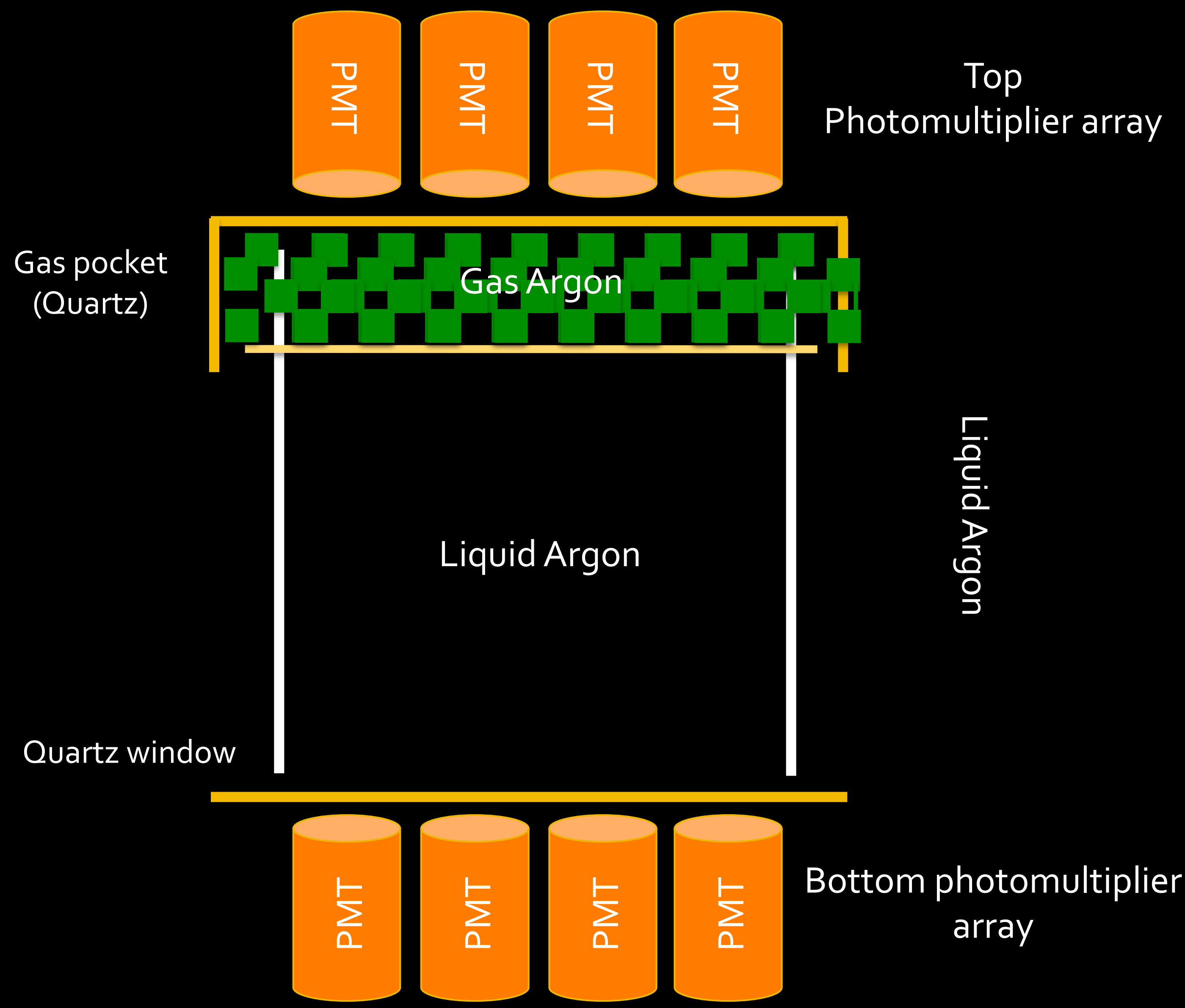


THE DARKSIDE PROGRAM AT LNGS

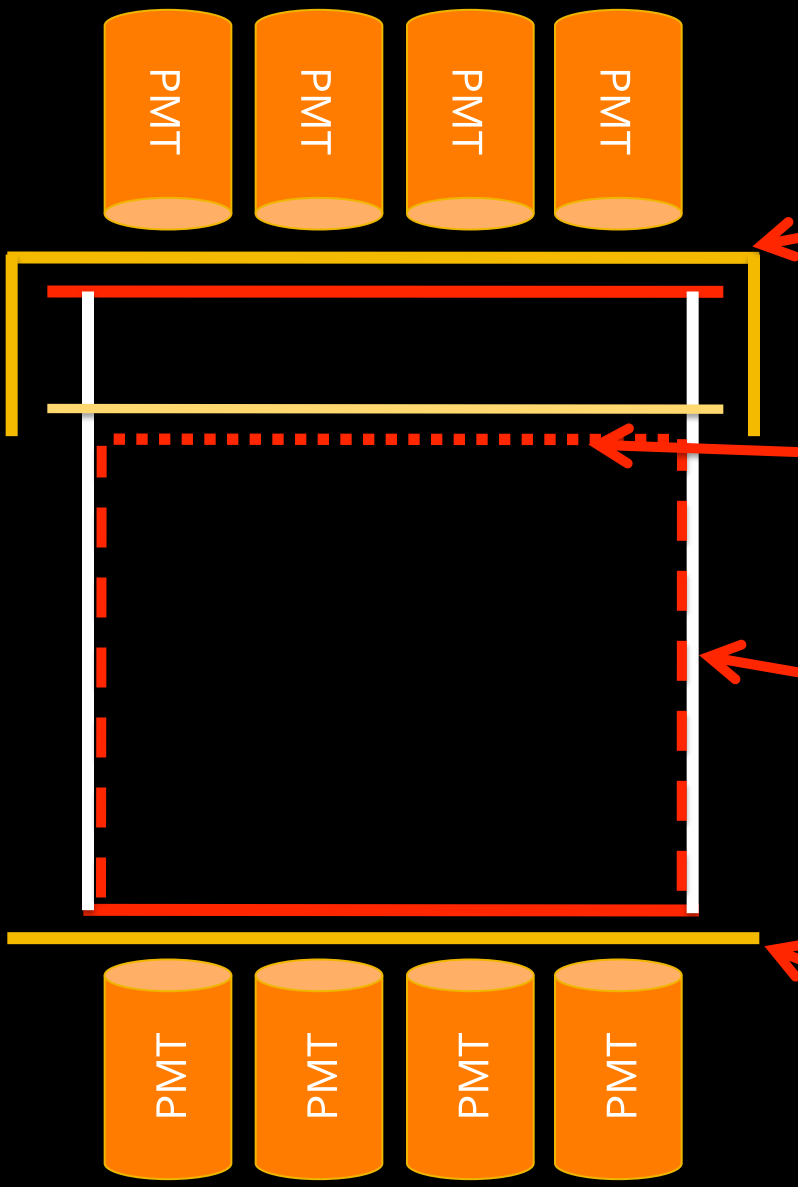
- Dual-phase argon TPC
- Underground argon, depleted in ^{39}Ar
- Three-fold discrimination (S1 pulse shape, S2/S1, 3D reconstruction)
- TPC immersed in active neutron and muon vetoes

- DS-50: took data with atmospheric Argon in 2014 (presented here)
- sensitivity goal 10^{-45} cm^2

Dual-Phase Noble Liquid TPC



Dual-Phase Noble Liquid TPC



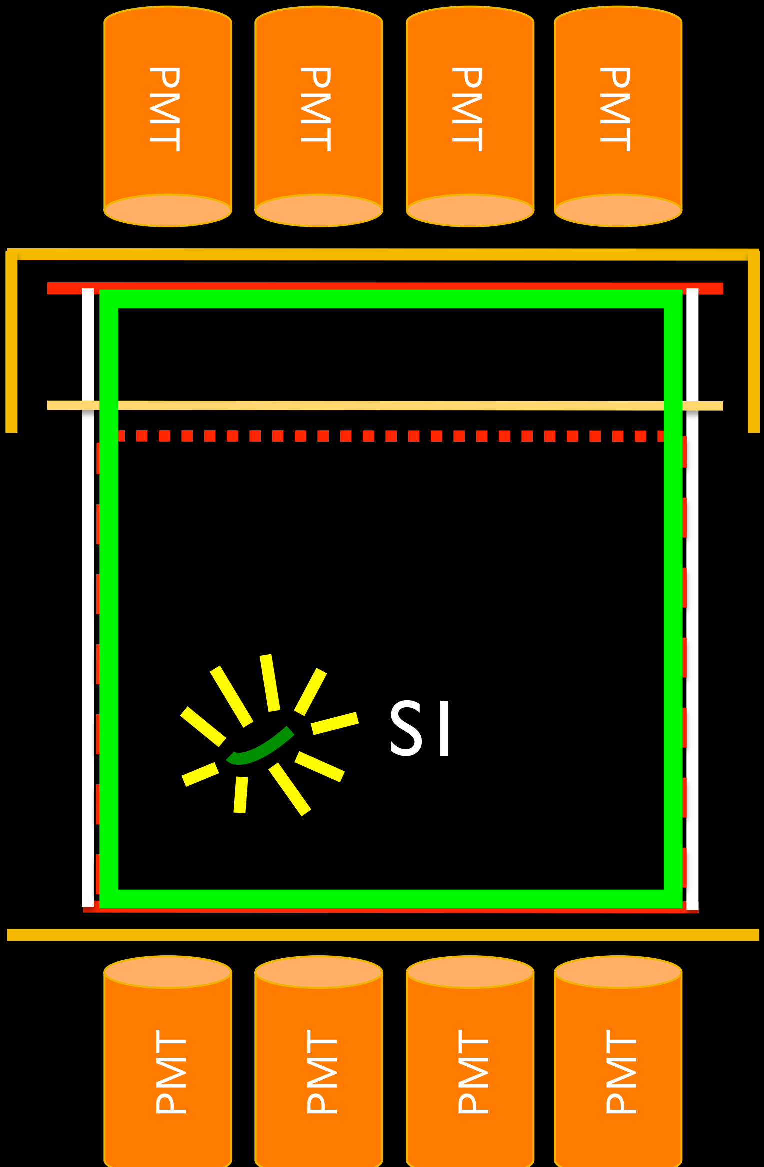
Anode:
gas pocket contained in fused silica dome, coated with conductive, UV transparent thin film (ITO)

Grid:
extraction of drift electrons

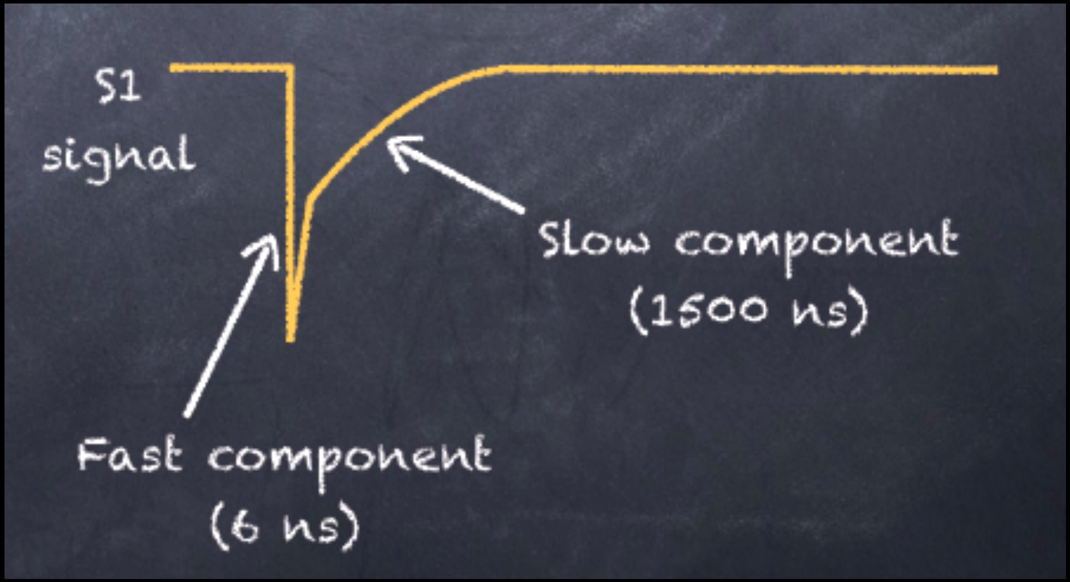
Field-shaping rings:
uniform electric field (200 V/cm)

Cathode:
fused silica plate coated with conductive, UV transparent thin film (ITO)

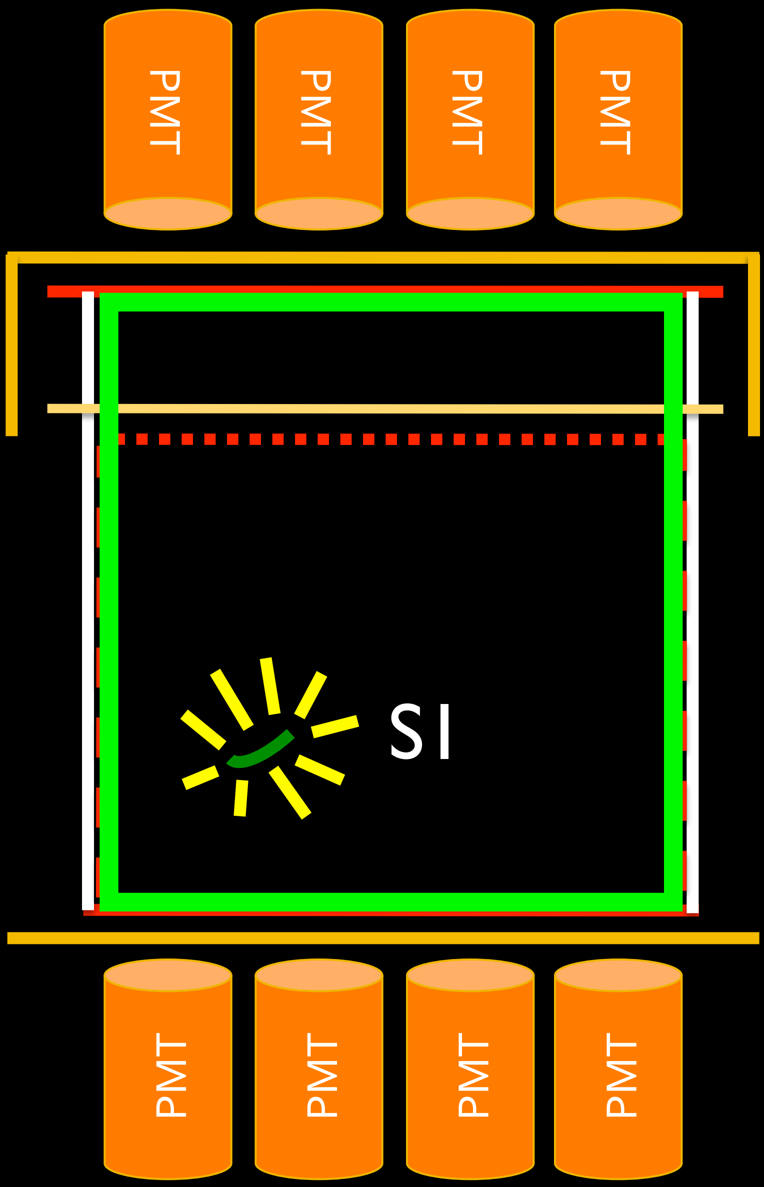
S1 Signal Shape in Argon

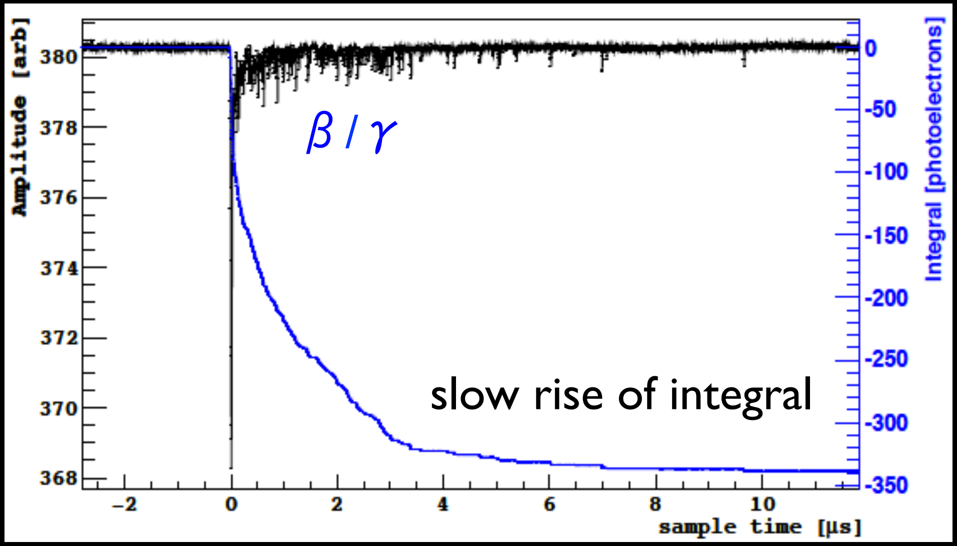


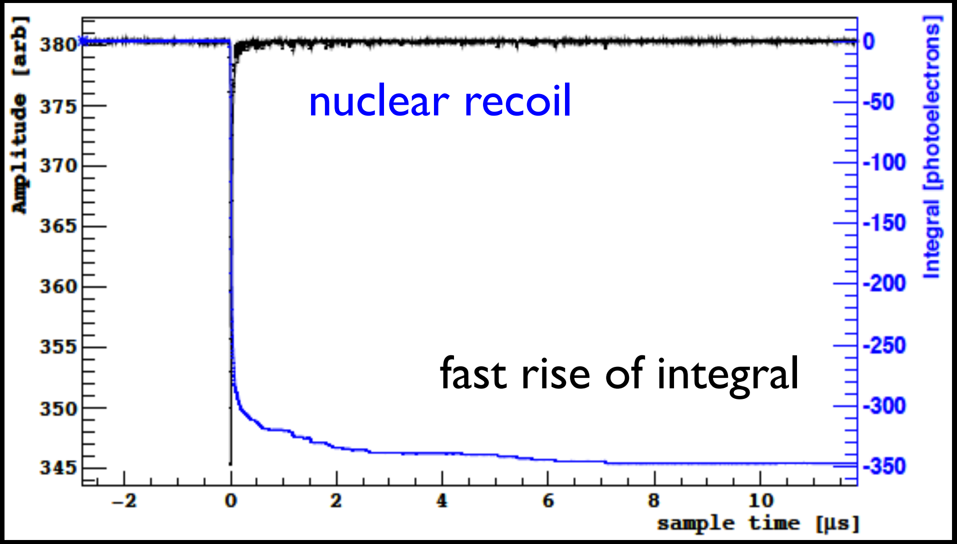
Nuclear and electron recoils produce ionization and excitation along their tracks. Excited Ar_2^* are formed and their de-excitation leads to the emission of scintillation light with two separate components, fast and slow (associated to Ar_2^* singlet and triplet state). The distribution of light on the two components is very strongly dependent on dE/dx.



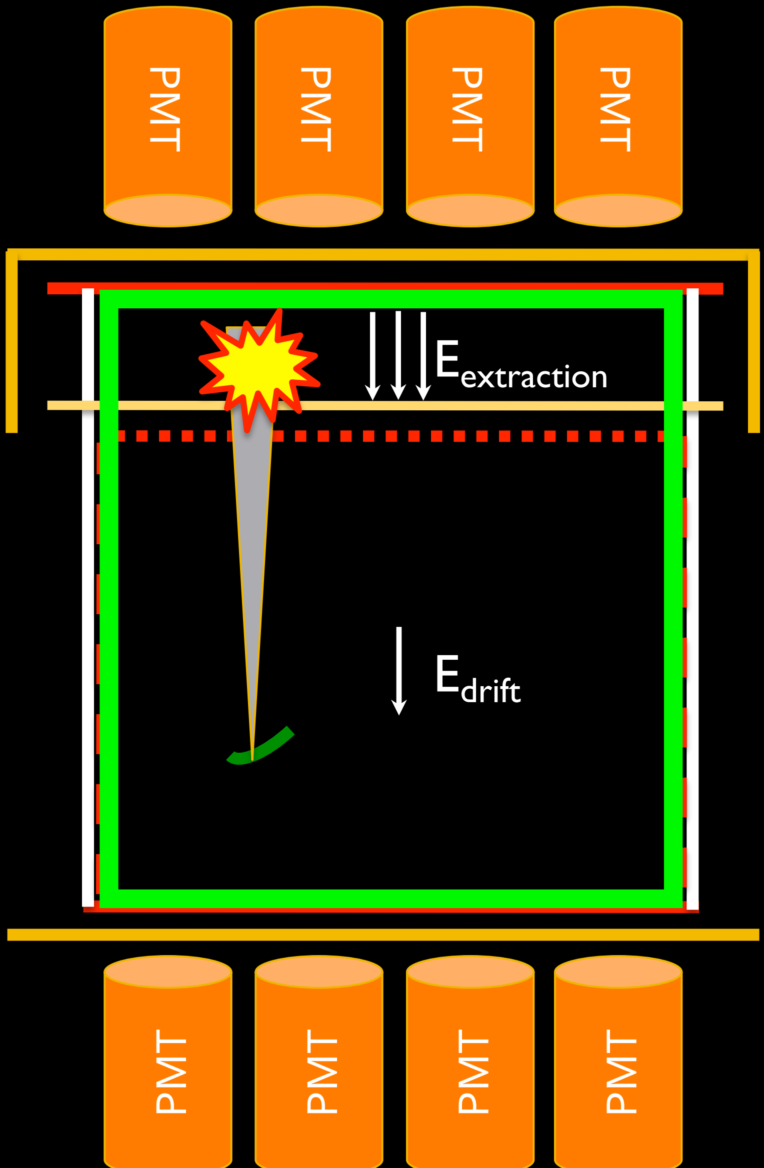
S1 Pulse Shape Discrimination



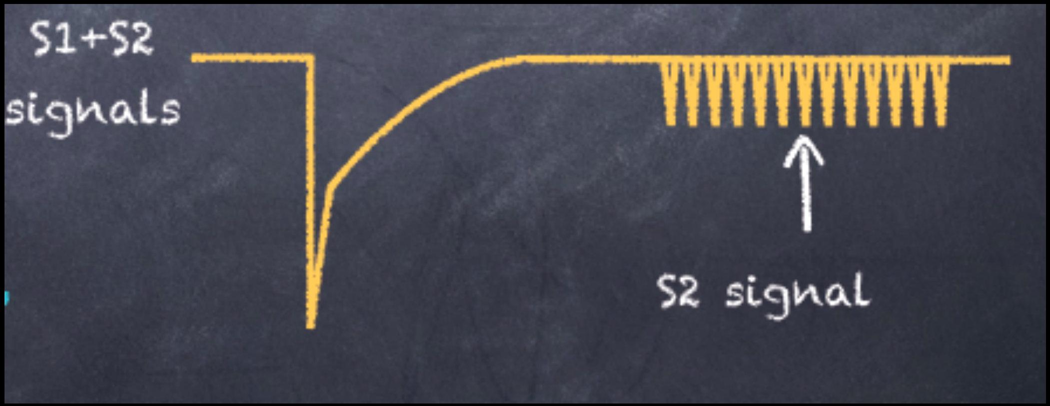




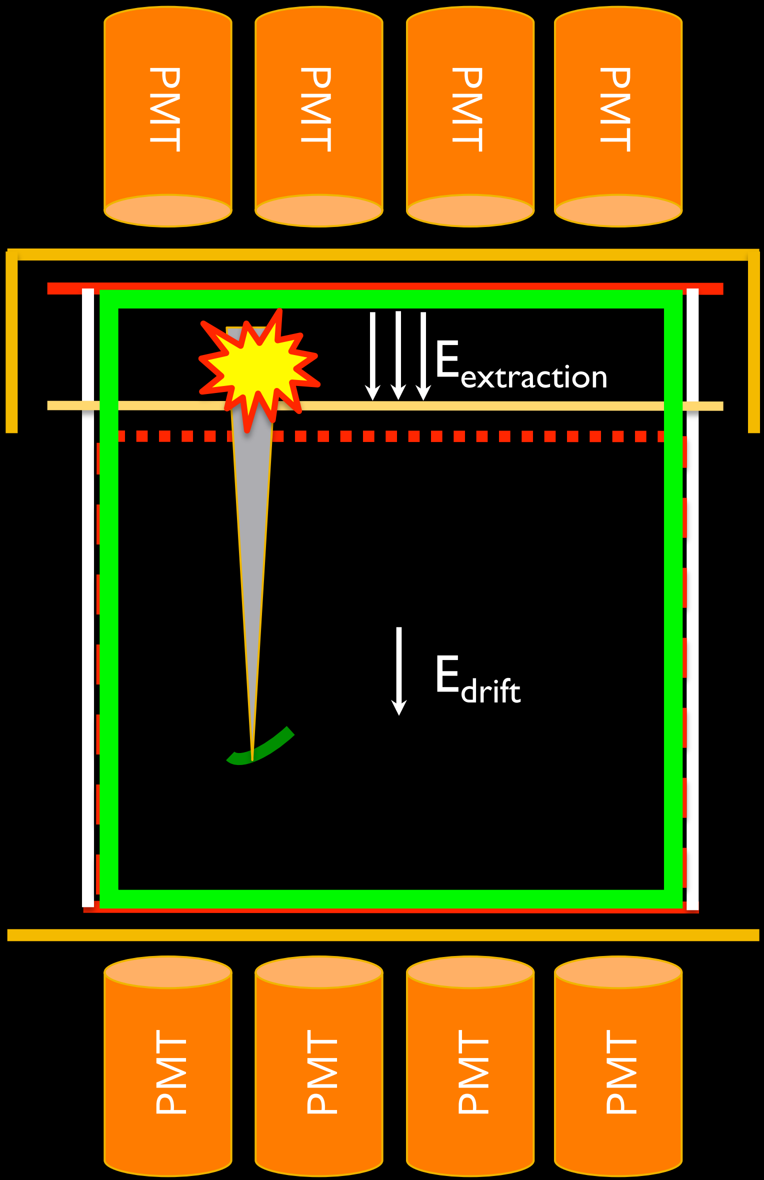
S2 SIGNAL GENERATION

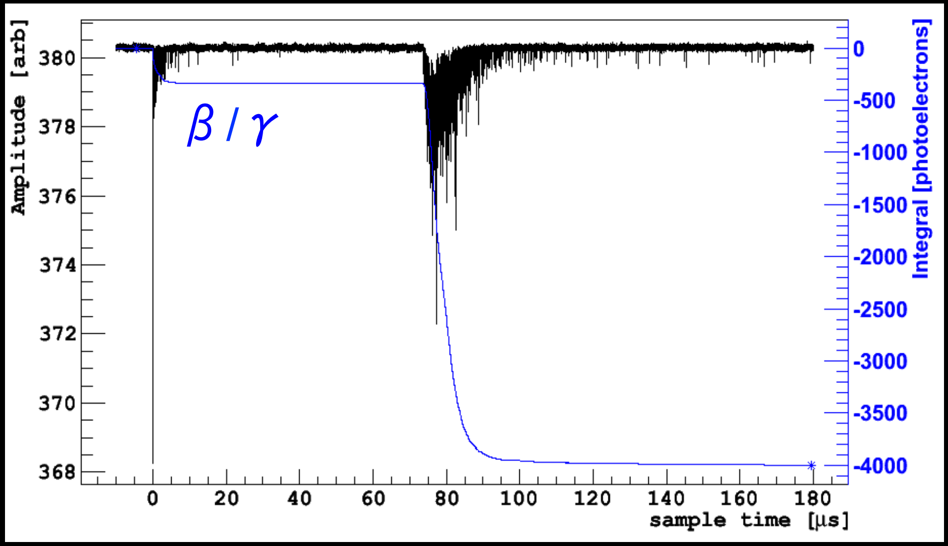


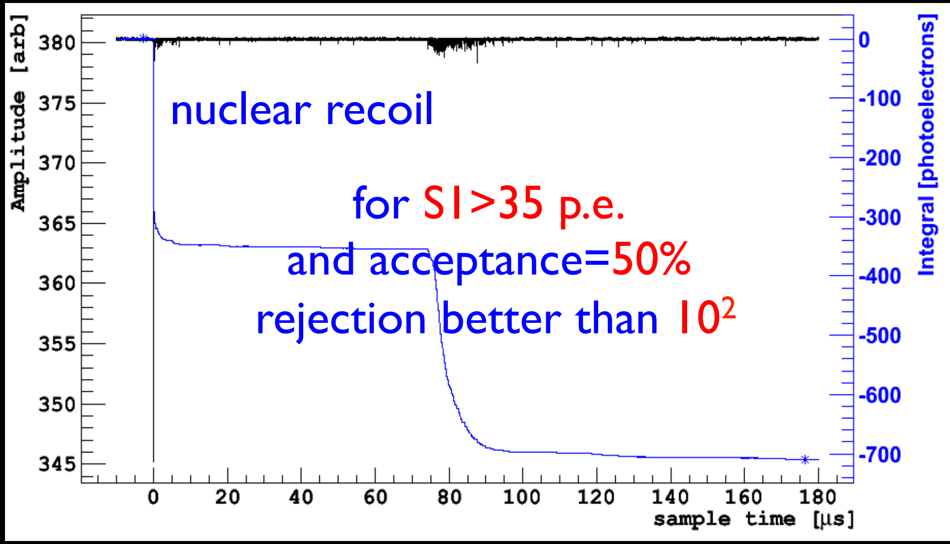
The ionization electrons surviving the recombination are drifted towards the liquid-gas interface (E_{drift}=200 V/cm). A field of 2.8 kV/cm is applied to fully extract electrons to the gas phase. Electroluminescence in gas produces a secondary scintillation signal (S2) proportional to the ionization signal. The ratio S2/S1 depends very strongly on the probability of surviving the initial recombination, and therefore on dE/dx.



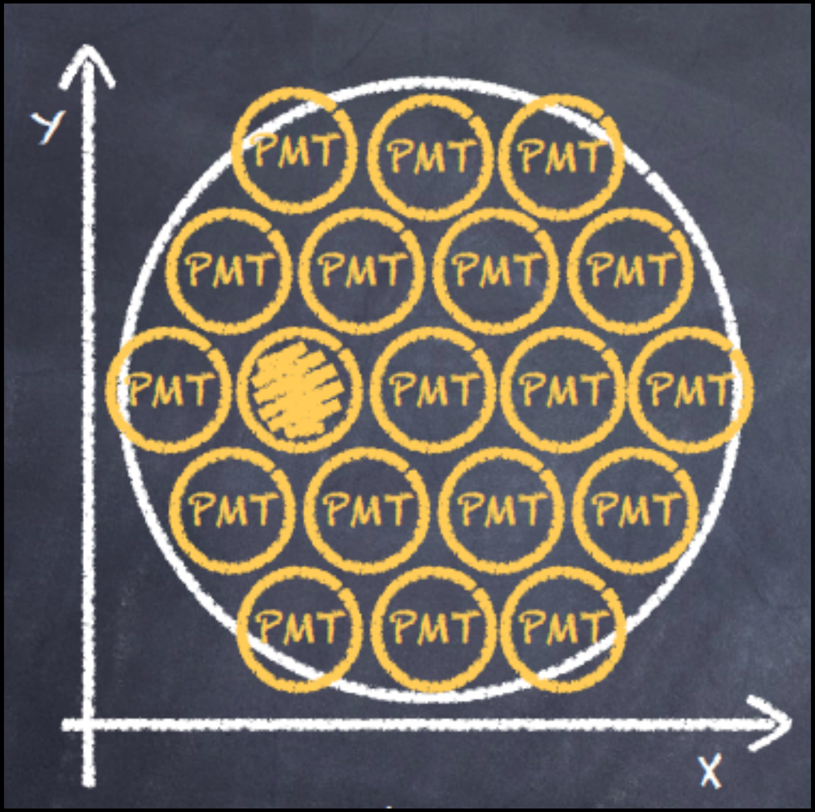
S2/S1 Discrimination



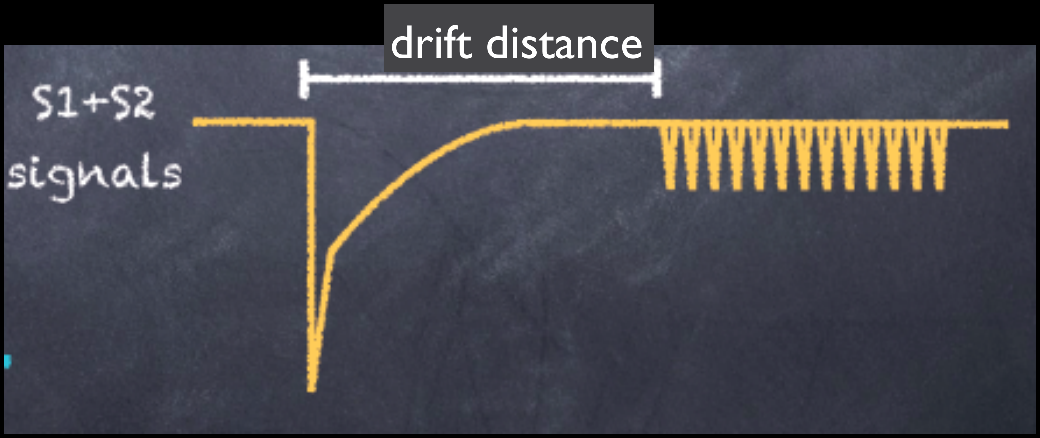




3D EVENT LOCALIZATION



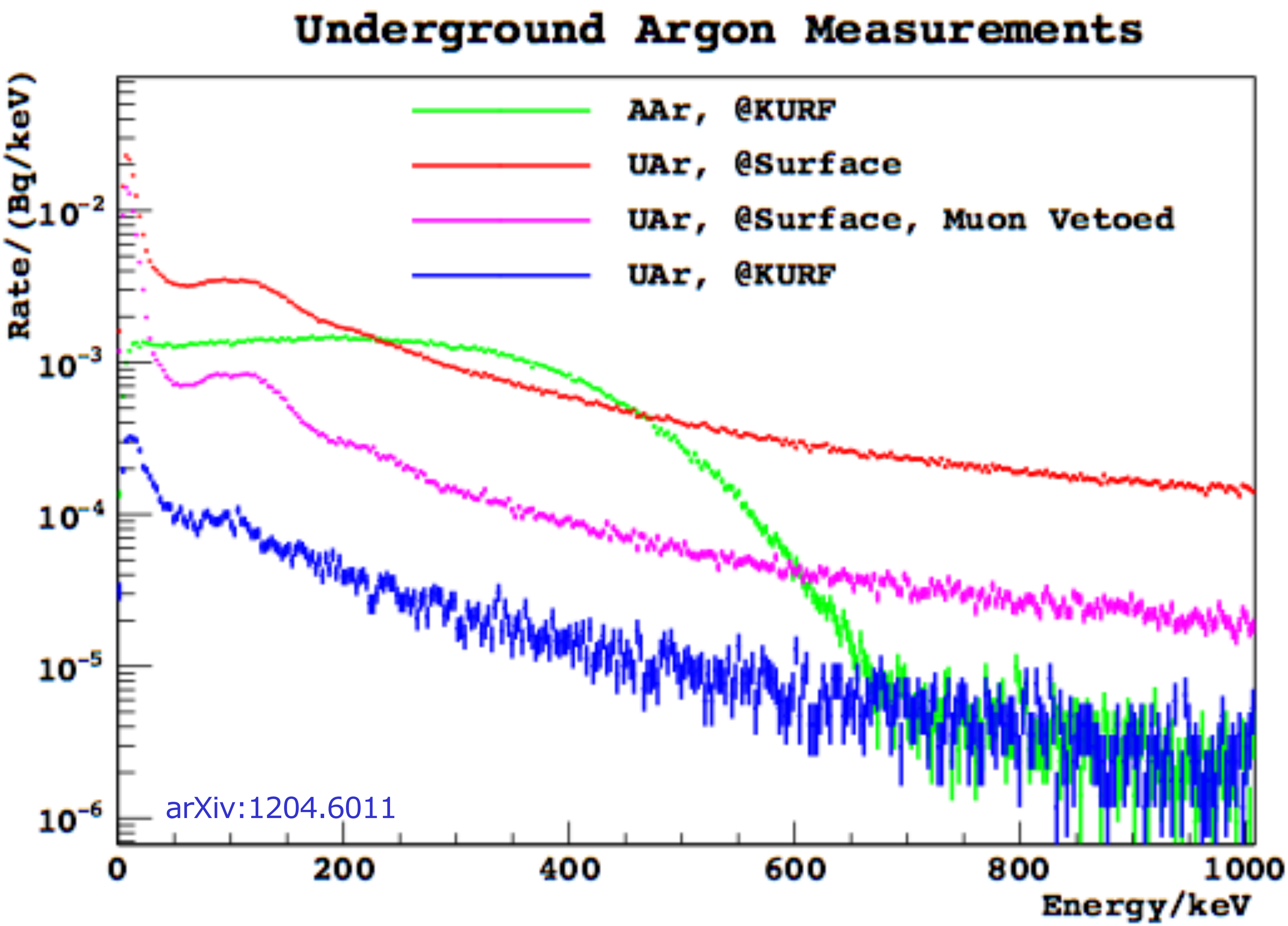
The time difference between S1 and S2 corresponds to the e^- drift time and it is used to estimate the z coordinate of the interaction. Drift speed in Argon at 200 V/cm is about 1 mm/μs.



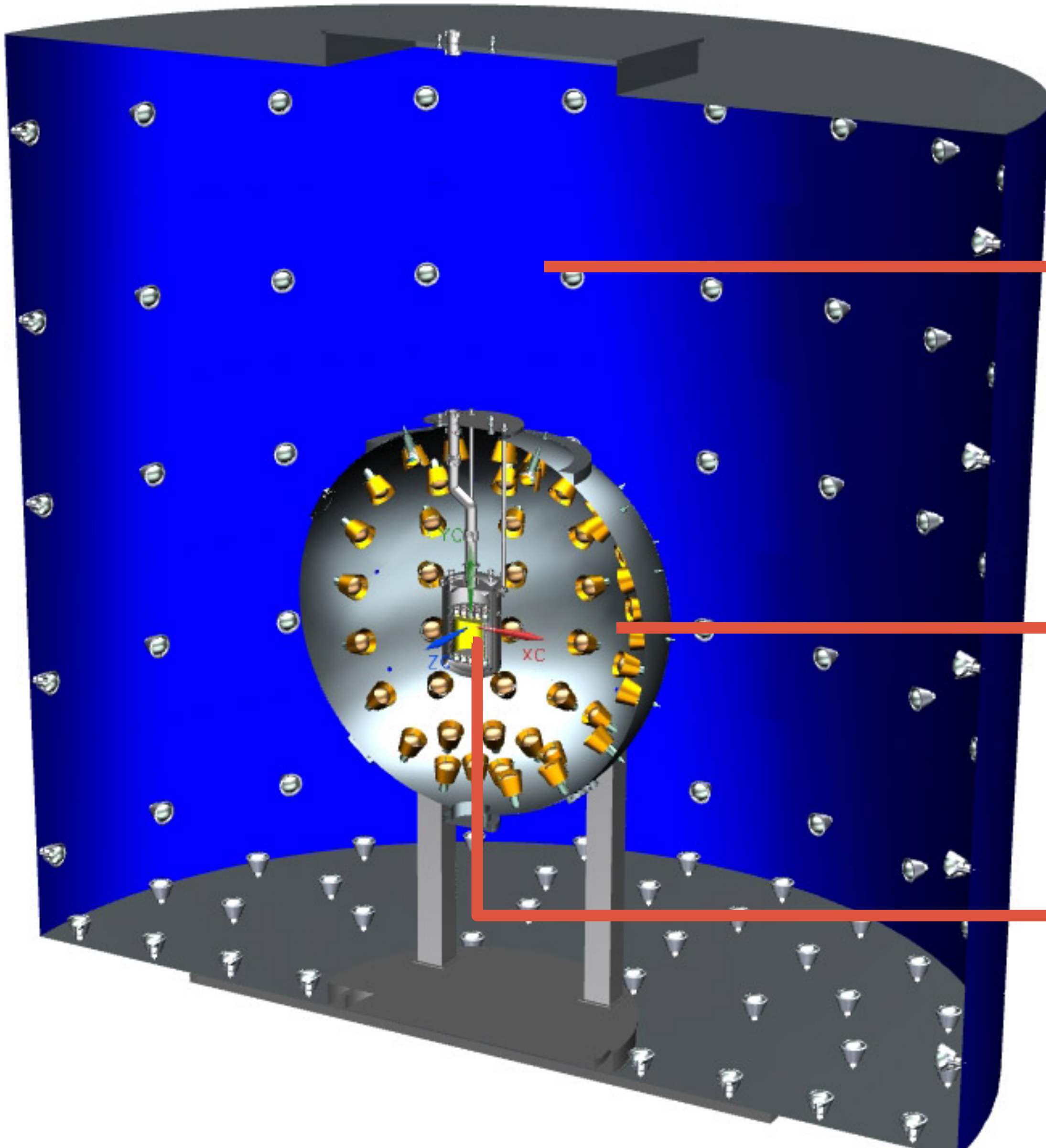
Since S2 production occurs very close to the top PMTs, the signal distribution will be strongly not uniform and can be used to locate the ionization event in the x-y plane

3D localization allows the implementation of fiducial volume cuts (thereby removing external background)

UNDERGROUND ARGON: DEPLETION FACTOR > 100



DarkSide-50 within its Veto Detectors



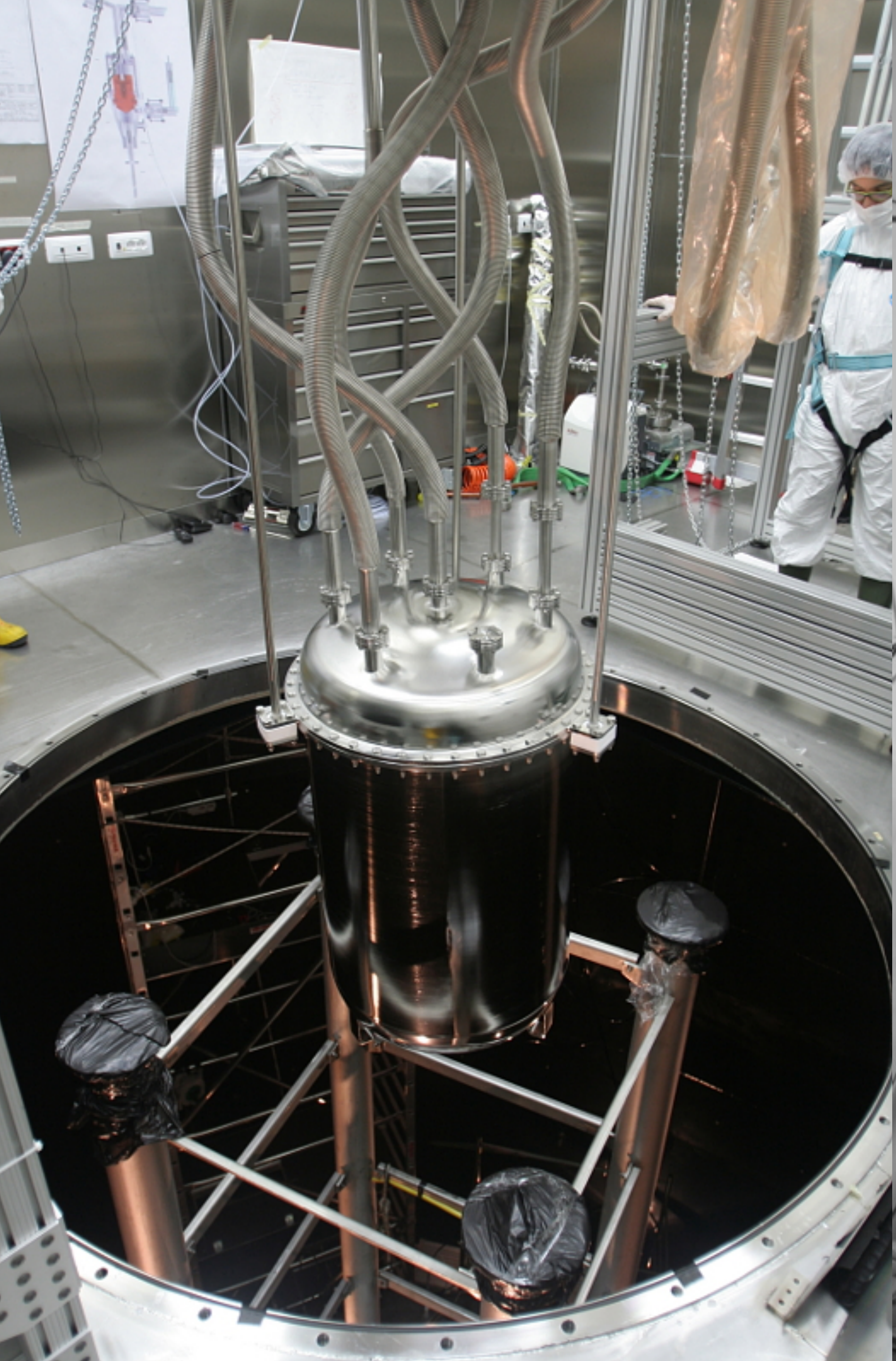
Water Čerenkov detector:
- active muon veto +
- passive neutron veto
- 11 m wide, 10 m tall
- 80 PMTs in Water Tank

Liquid Scintillator detector:
- active neutron veto
- boron-loaded scintillator
- 4 m diameter (20ns)
- 110 PMTs in Scintillator

Liquid Argon TPC
- 50 kg active mass
- 2x19 PMT arrays
- 37 kg fiducial volume

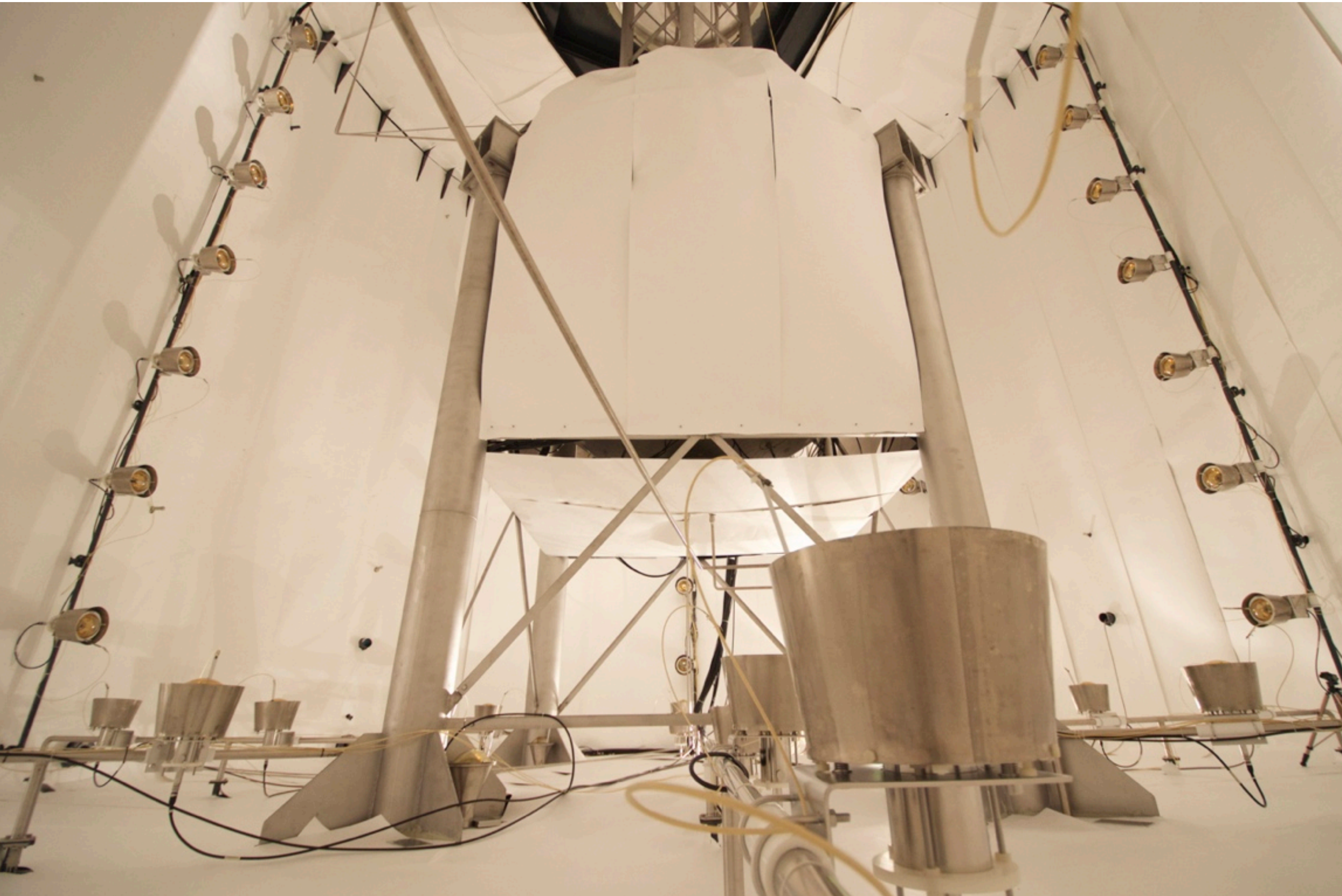
TPC CONSTRUCTION – SUMMER 2013

Neutron Veto Detector during Installation



Neutron Veto with TPC Cryostat

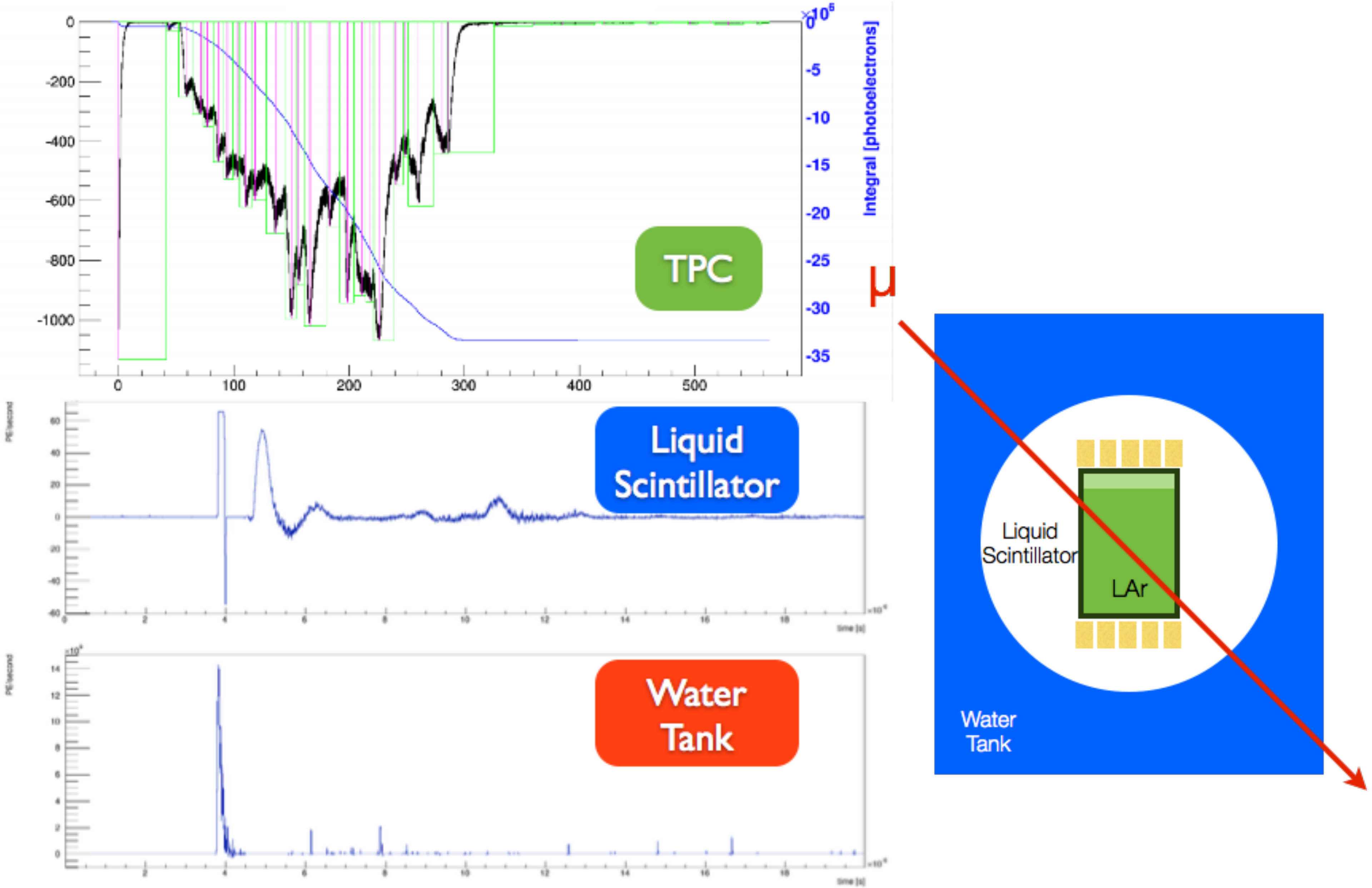
Muon Veto, right before Water filling



DarkSide-50 Timeline

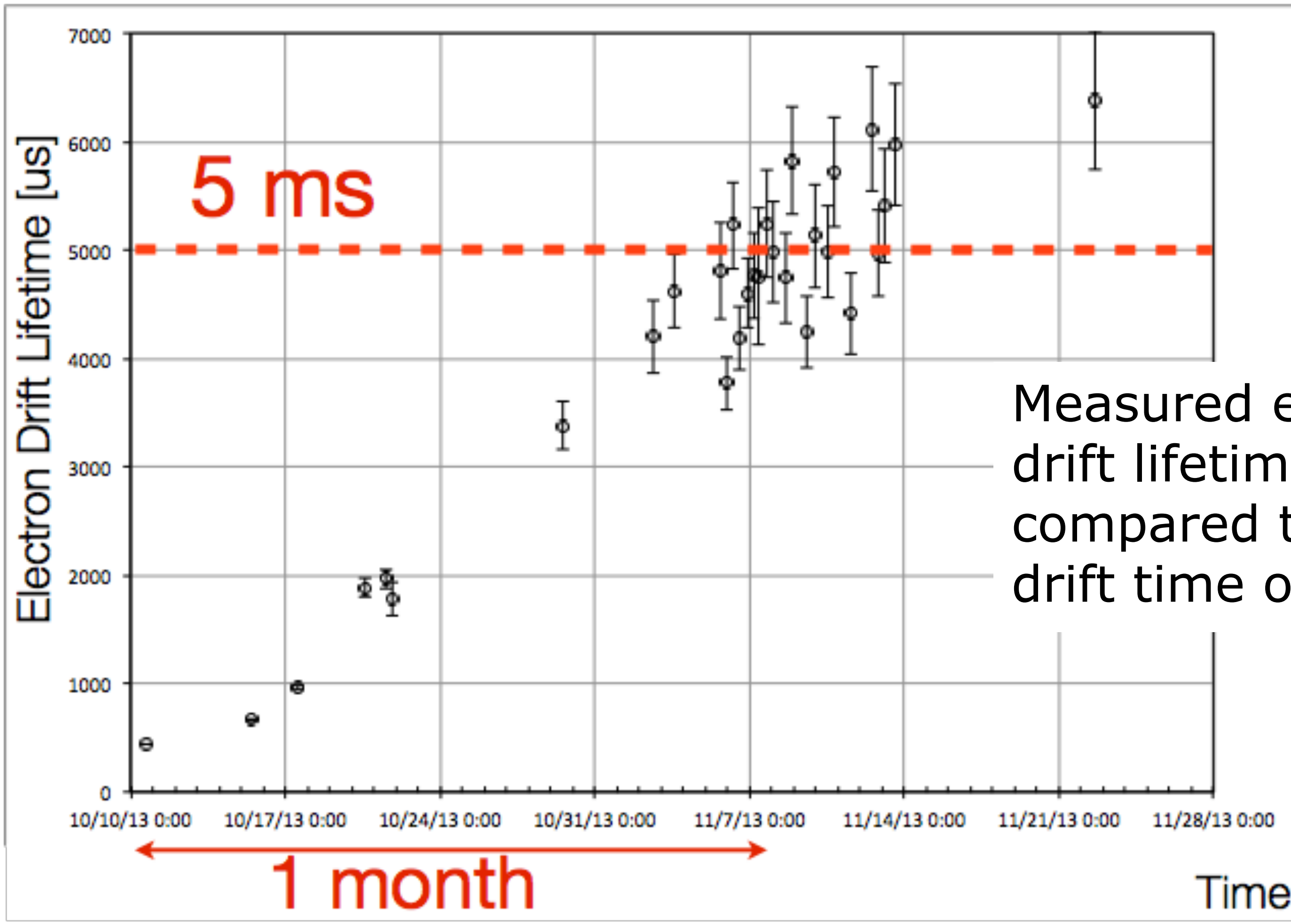
- **Nov. 2013**: All 3 detectors filled
  - Coordinated data taking started Nov. 6
  - TPC filled with atmospheric argon (AAr)
  - LSV filled with high-radioactivity TMB
- **Nov. - Jan. 2014**: mainly DAQ/trigger improvements
  - accumulated 6 live-days (exposure 280 kg·day)
  - equivalent to ~3 years with underground argon
  - PSD performance presented at UCLA-DM 2014
- **Nov. - June 2014**: dataset discussed here
  - High ^{14}C TMB: degraded veto performance
  - 47.1 live days exposure (1422 kg·day fiducial)
  - ^{39}Ar statistics corresponds to 19.4 years of UAr
- **Jun. 2014 – Feb. 2015**: veto scintillator operations
- **Oct. 2014 – Feb. 2015**: source calibration campaign

ALL SYSTEMS CHECK OUT!



TPC Commissioning: Purity

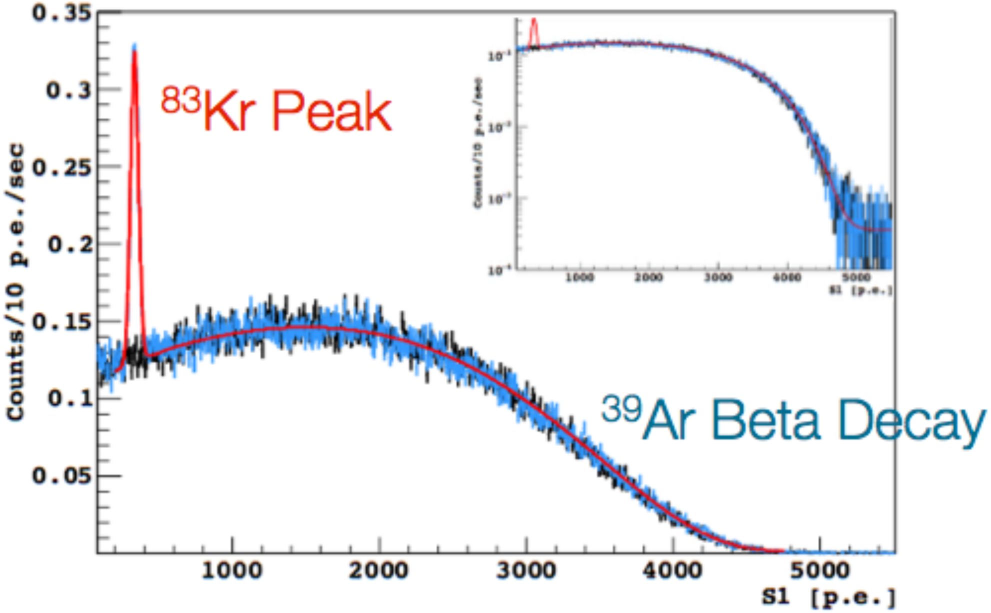
- Closed loop argon recirculation (~30 slpm)
- Gaseous phase purification using commercial getter
- Cryogenic charcoal trap to remove Rn contamination

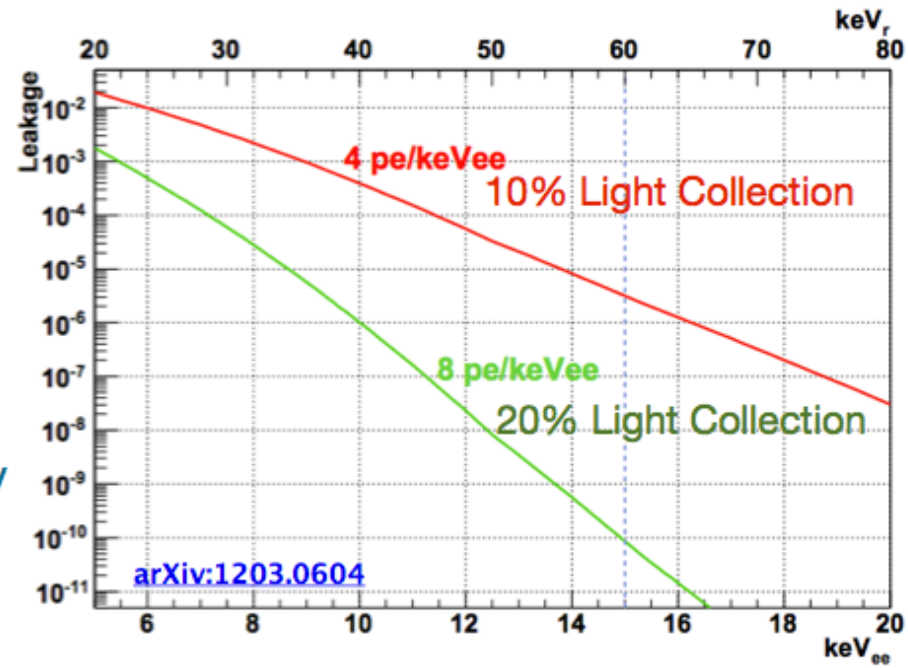


Measured electron drift lifetime > 5 ms compared to max. drift time of ~ 375 μs

TPC Commissioning: Light Yield

- TPC filled with atmospheric argon (1 Bq/kg)
- ^{83m}Kr gas deployed into detector (41.5 keV_{ee})

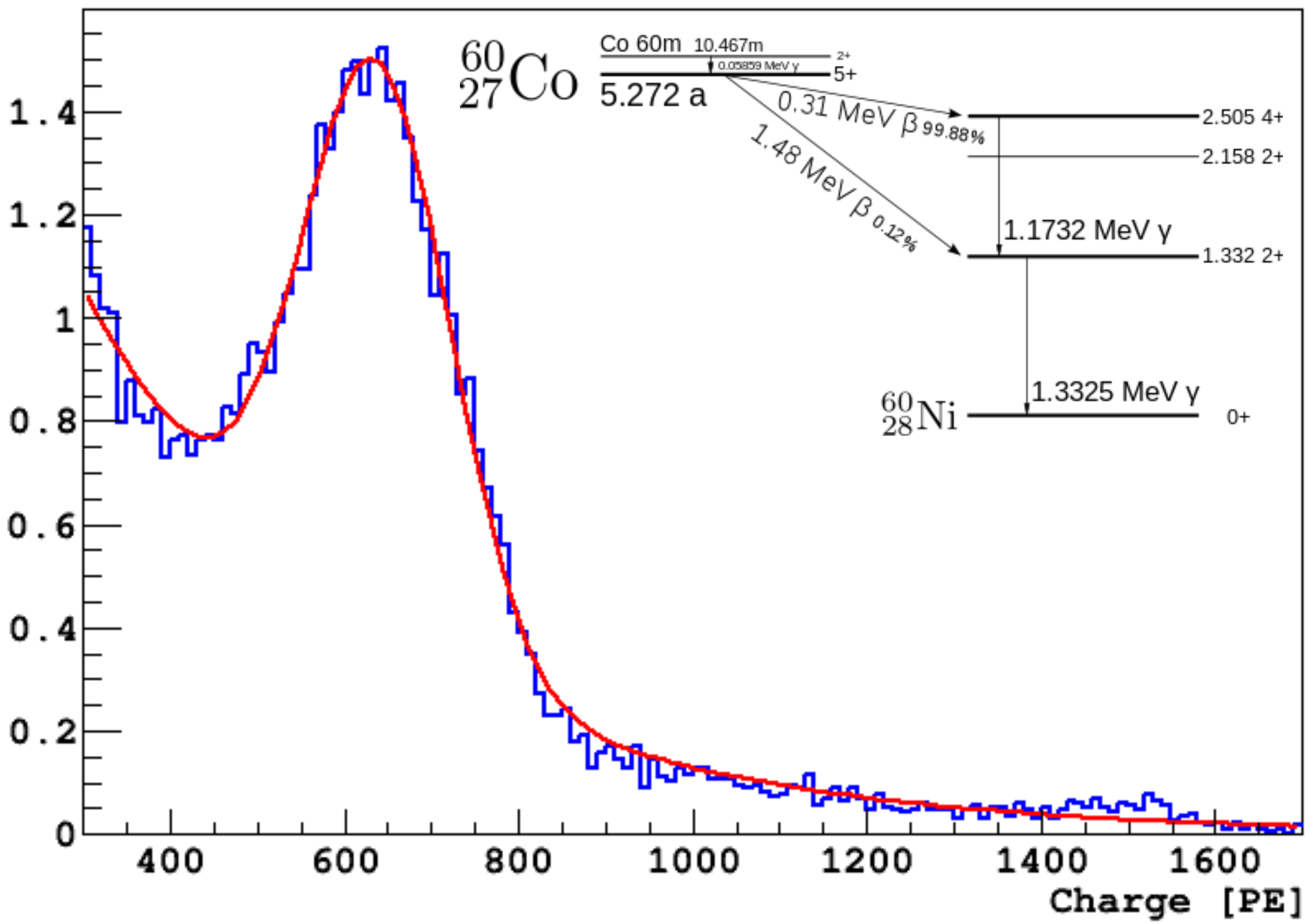




- Light yield at zero field: (7.9 ± 0.4) PE/keV
- Light yield at 200 V/cm: (7.0 ± 0.3) PE/keV
- Exceeding design requirements of 6.0 PE/keV

NEUTRON VETO COMMISSIONING: LIGHT YIELD

- Neutron veto setup to trigger on events in the LAr TPC
- High energy coincident ^{60}Co events from cryostat steel
- LY was measured by combining ^{60}Co and ^{14}C spectra
- LY = (0.54 ± 0.04) PE/keV (exceeding design specs.)



- High ^{14}C rate in (biogenic) TMB
- **~98% LSV efficiency in this dataset**

- TMB replaced with low-^{14}C (fossil) batch
- ^{14}C content measured at LLNL via AMS prior to filling

Analysis Cuts: DAQ & Quality

	Cut	Residual Livetime
Run	Usable runs	(53.8 ± 0.2) d
	Automated selection	(51.1 ± 0.2) d
	Single run	(48.8 ± 0.2) d
Quality	Baseline found	(48.8 ± 0.2) d
	Time since previous trigger	(48.7 ± 0.2) d
	Large gap	(48.1 ± 0.2) d
	Veto data present	(47.1 ± 0.2) d
	Total	(47.1 ± 0.2) d

9.3% of livetime removed by run-level quality cuts

3.5% of livetime removed by event-level quality cuts

Uncertainty dominated by the accuracy of the trigger board

arXiv: 1410.0653

Analysis Cuts: Physics Cuts

	Cut	Acceptance	Fiducial Mass
Physics	Number of pulses	$0.95^{+0.00}_{-0.01}$	
	First pulse time	$1.00^{+0.00}_{-0.01}$	
	No S1 saturation	1.00	
	S2 pulse shape	1.00	
	Minimum S2	$0.99^{+0.01}_{-0.04}$	
	Max S1 fraction per PMT	0.99	
	Prompt LSV	0.95	
	Delayed LSV and WCD	0.94	
	Drift time fiducialization		(36.9 ± 0.6) kg
	Total	$0.82^{+0.01}_{-0.04}$	(36.9 ± 0.6) kg

82% global acceptance, dominated by veto cuts

20% of exposure sacrificed to drift time fiducialization

Mass uncertainty dominated by Teflon contraction at 87K

arXiv: 1410.0653

Analysis Cuts: Putting it all Together

	Cut	Residual Livetime	Acceptance	Fiducial Mass
Run	Usable runs	(53.8 ± 0.2) d		
	Automated selection	(51.1 ± 0.2) d		
	Single run	(48.8 ± 0.2) d		
Quality	Baseline found	(48.8 ± 0.2) d		
	Time since previous trigger	(48.7 ± 0.2) d		
	Large gap	(48.1 ± 0.2) d		
	Veto data present	(47.1 ± 0.2) d		
Physics	Number of pulses		$0.95^{+0.00}_{-0.01}$	
	First pulse time		$1.00^{+0.00}_{-0.01}$	
	No S1 saturation		1.00	
	S2 pulse shape		1.00	
	Minimum S2		$0.99^{+0.01}_{-0.04}$	
	Max S1 fraction per PMT		0.99	
	Prompt LSV		0.95	
	Delayed LSV and WCD		0.94	
	Drift time fiducialization			(36.9 ± 0.6) kg
	Total	(47.1 ± 0.2) d	$0.82^{+0.01}_{-0.04}$	(36.9 ± 0.6) kg

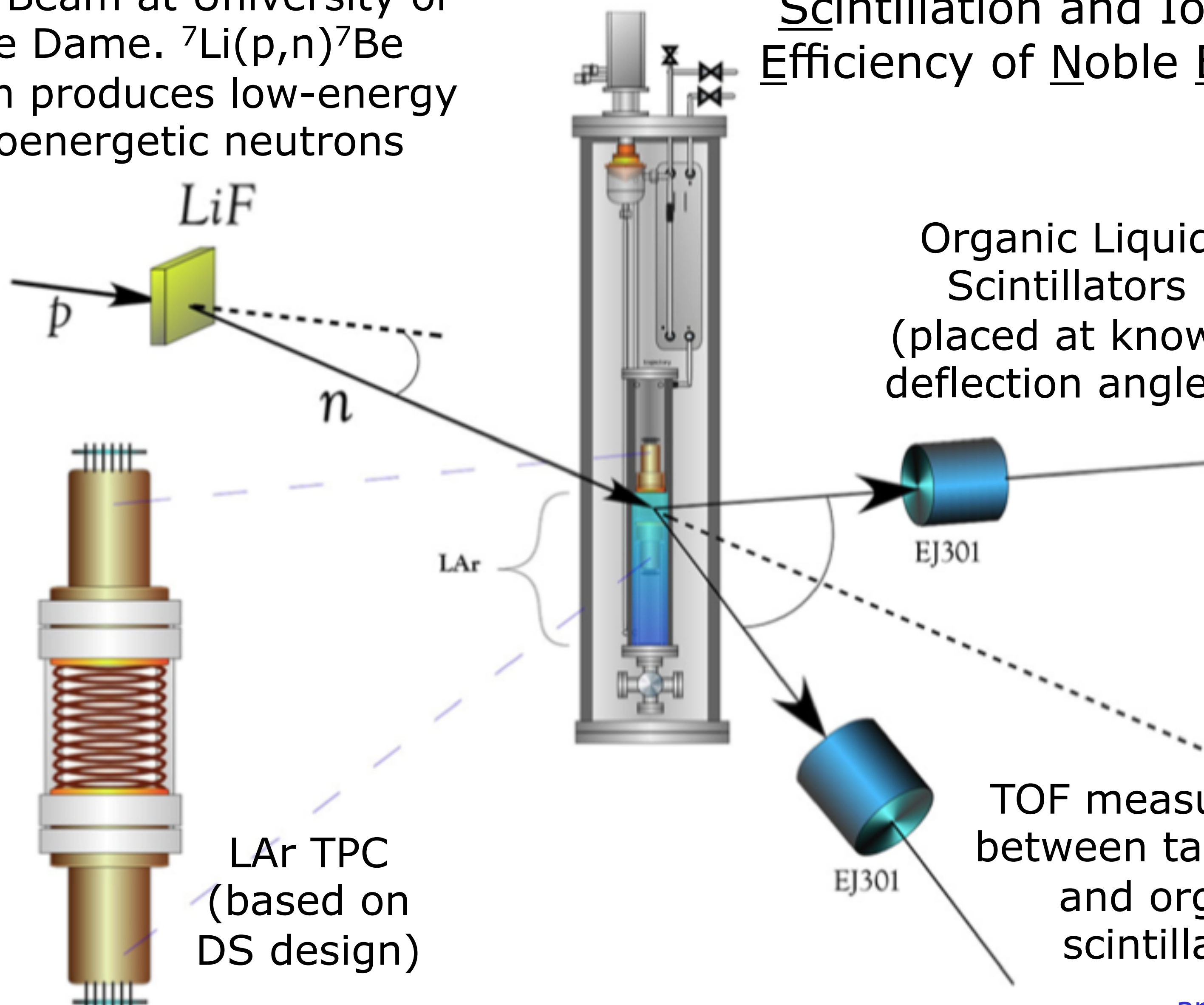
Total Exposure for this run: (1422 ± 67) kg·d

arXiv: 1410.0653

Neutron Calibrations with SCENE

Proton Beam at University of Notre Dame. $^{7}Li(p,n)^{7}Be$ reaction produces low-energy monoenergetic neutrons

Scintillation and Ionization Efficiency of Noble Elements



Organic Liquid Scintillators (placed at known deflection angles)

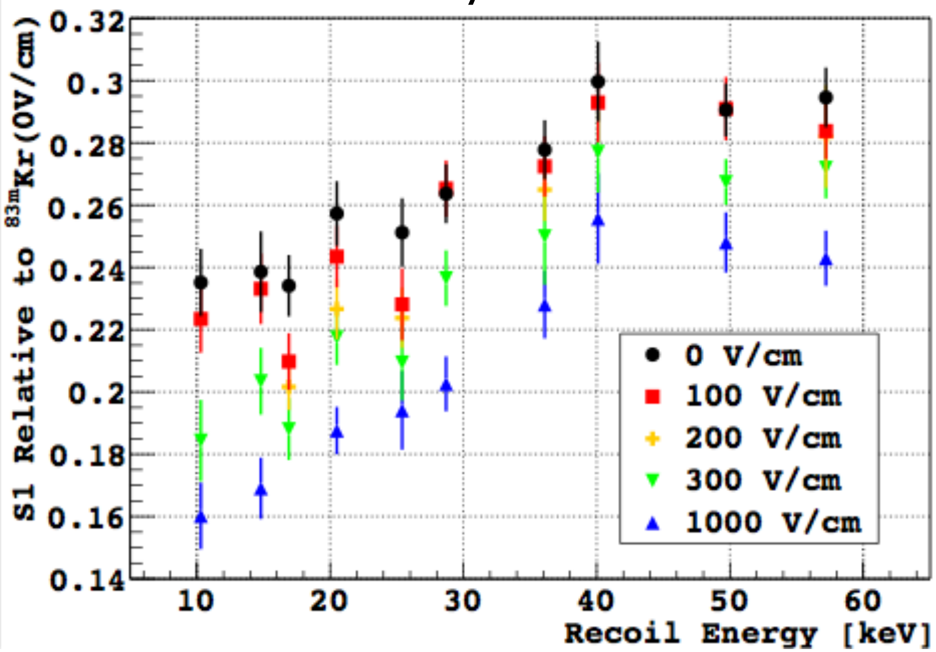
LAr TPC (based on DS design)

TOF measurement between target, LAr and organic scintillators

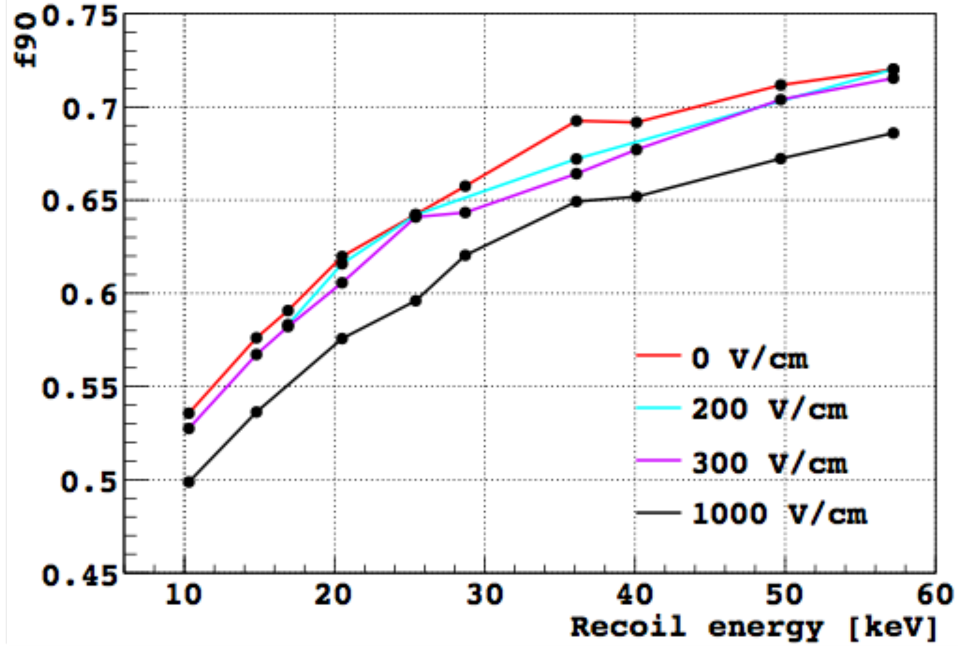
arXiv:1406.4825

Neutron Calibrations with SCENE

Scintillation yield vs. drift field



Pulse Shape vs. drift field



Source	Energy [keV]	$\mathcal{L}_{\mathrm{eff},\,^{83m}\mathrm{Kr}}$	$\mathrm{S1}_{\mathrm{DS-50}}$ [PE]
^{83m}Kr	41.5		298 ± 9
^{7}Li(p,n)	16.9	0.202 ± 0.008	27.0 ± 1.8
^{7}Li(p,n)	20.5	0.227 ± 0.010	36.8 ± 2.7
^{7}Li(p,n)	25.4	0.224 ± 0.010	45.0 ± 3.3
^{7}Li(p,n)	36.1	0.265 ± 0.010	75.7 ± 5.0
^{7}Li(p,n)	57.2	0.282 ± 0.013	127.6 ± 9.1

Scintillation yield extrapolated to DS-50 using ^{83m}Kr

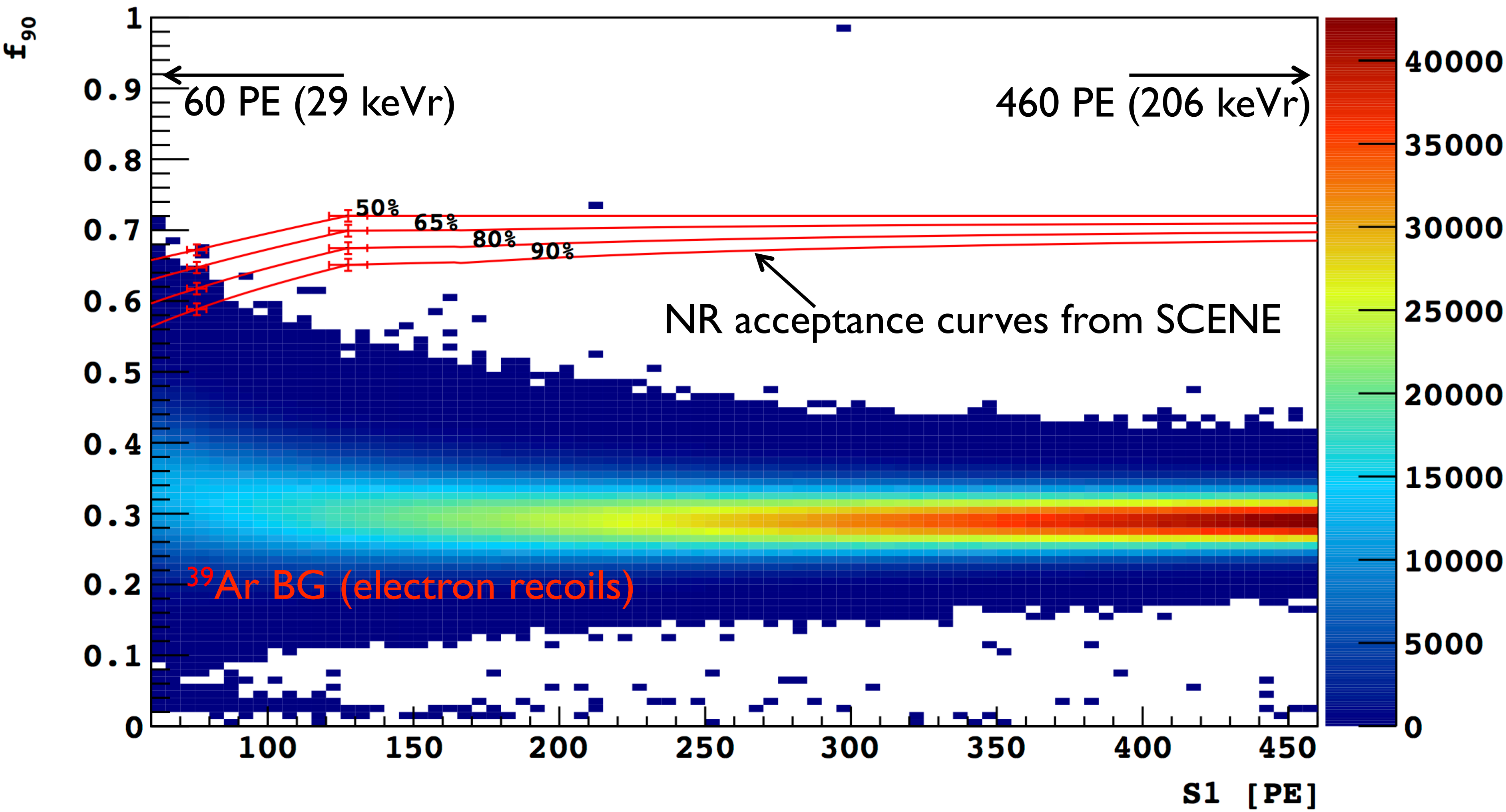
Nuclear Recoil Acceptance Curves also extrapolated from SCENE data

Neutron source calibration in DS-50 just completed

arXiv:1406.4825

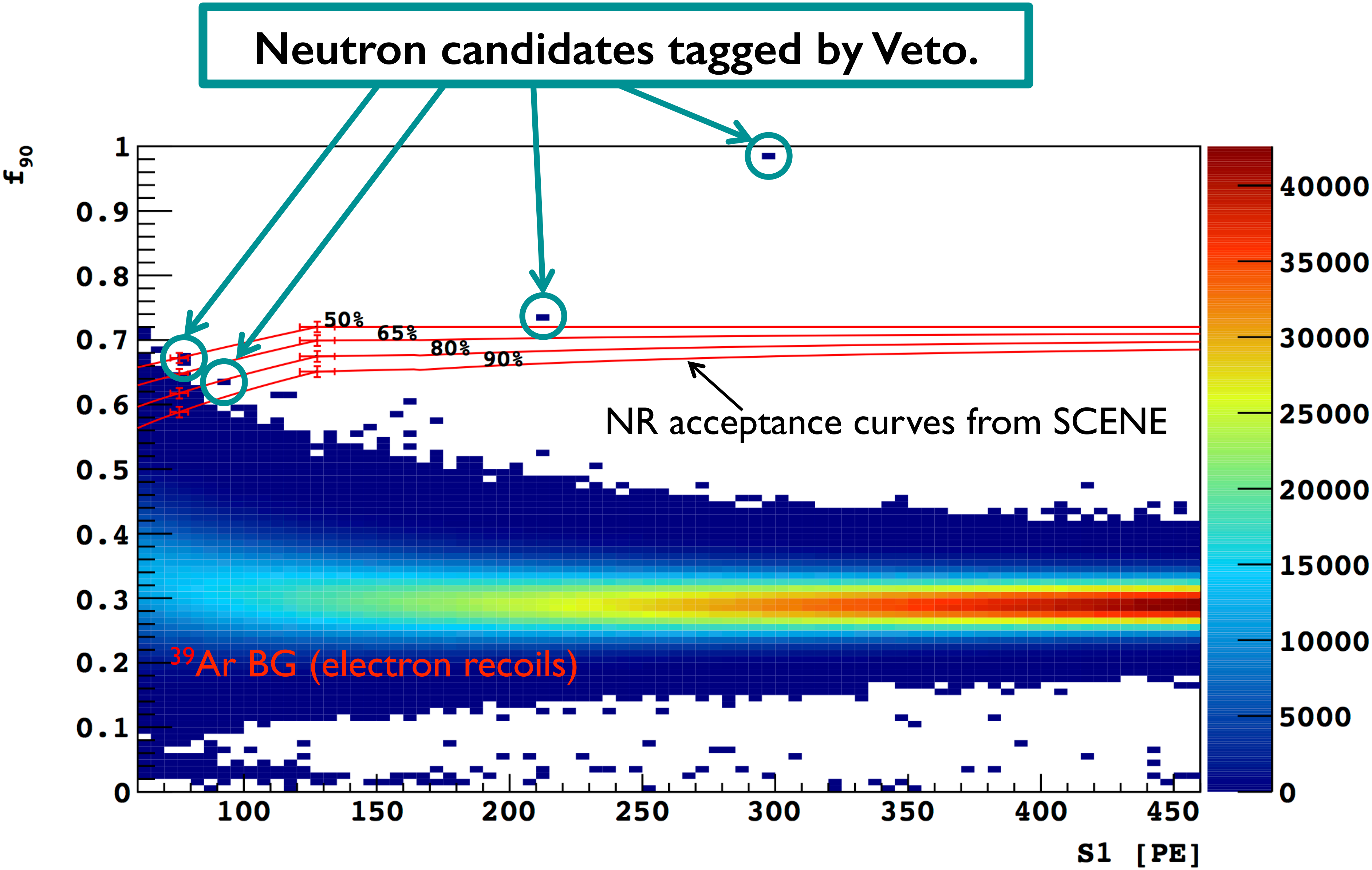
WIMP Search Box (1422 ± 67) kg·d

WIMP search plot. All analysis cuts except for veto.



arXiv: 1410.0653

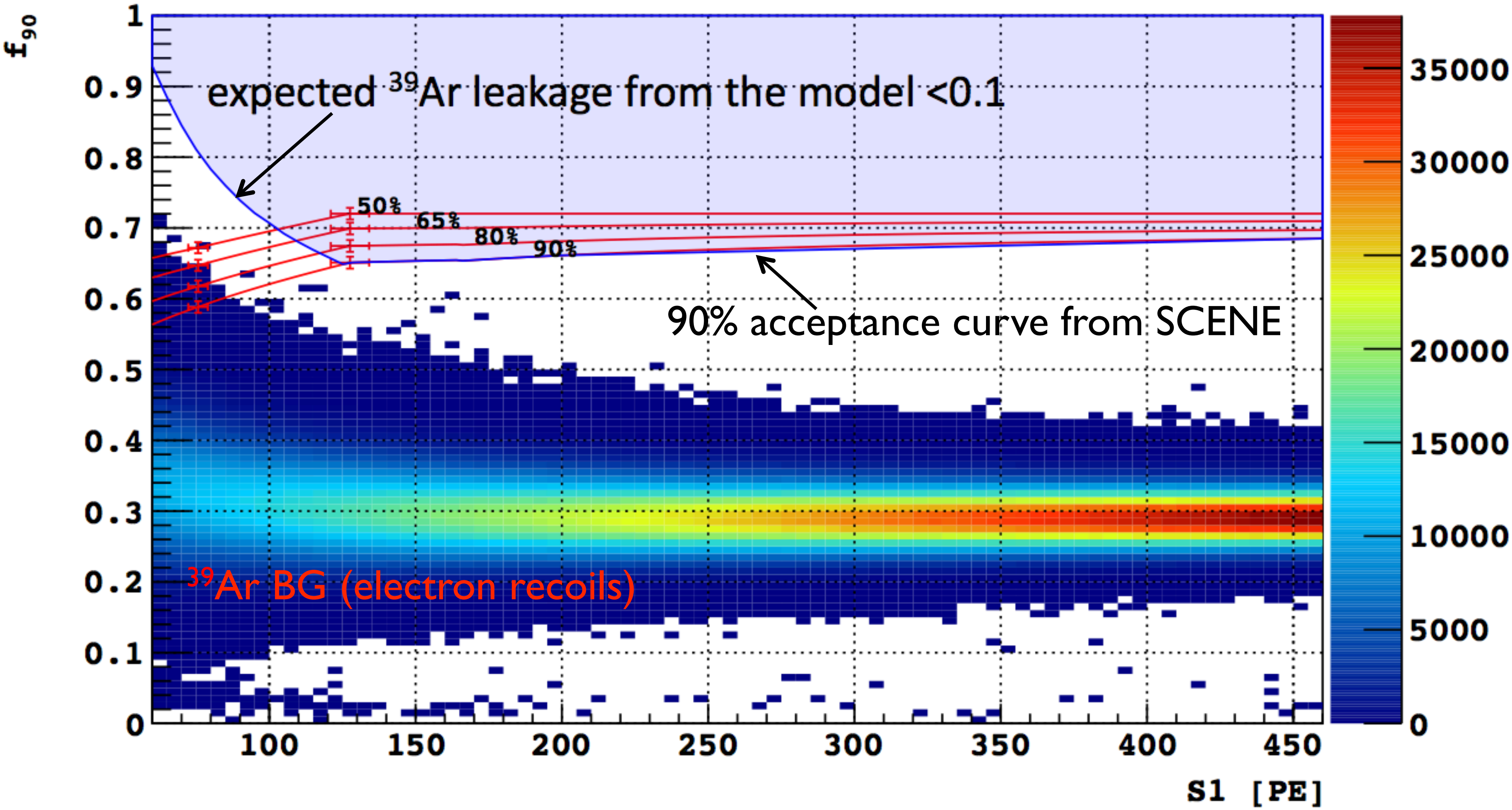
WIMP Search Box (1422 ± 67) kg·d



arXiv: 1410.0653

WIMP SEARCH BOX (1422 ± 67) kg·d

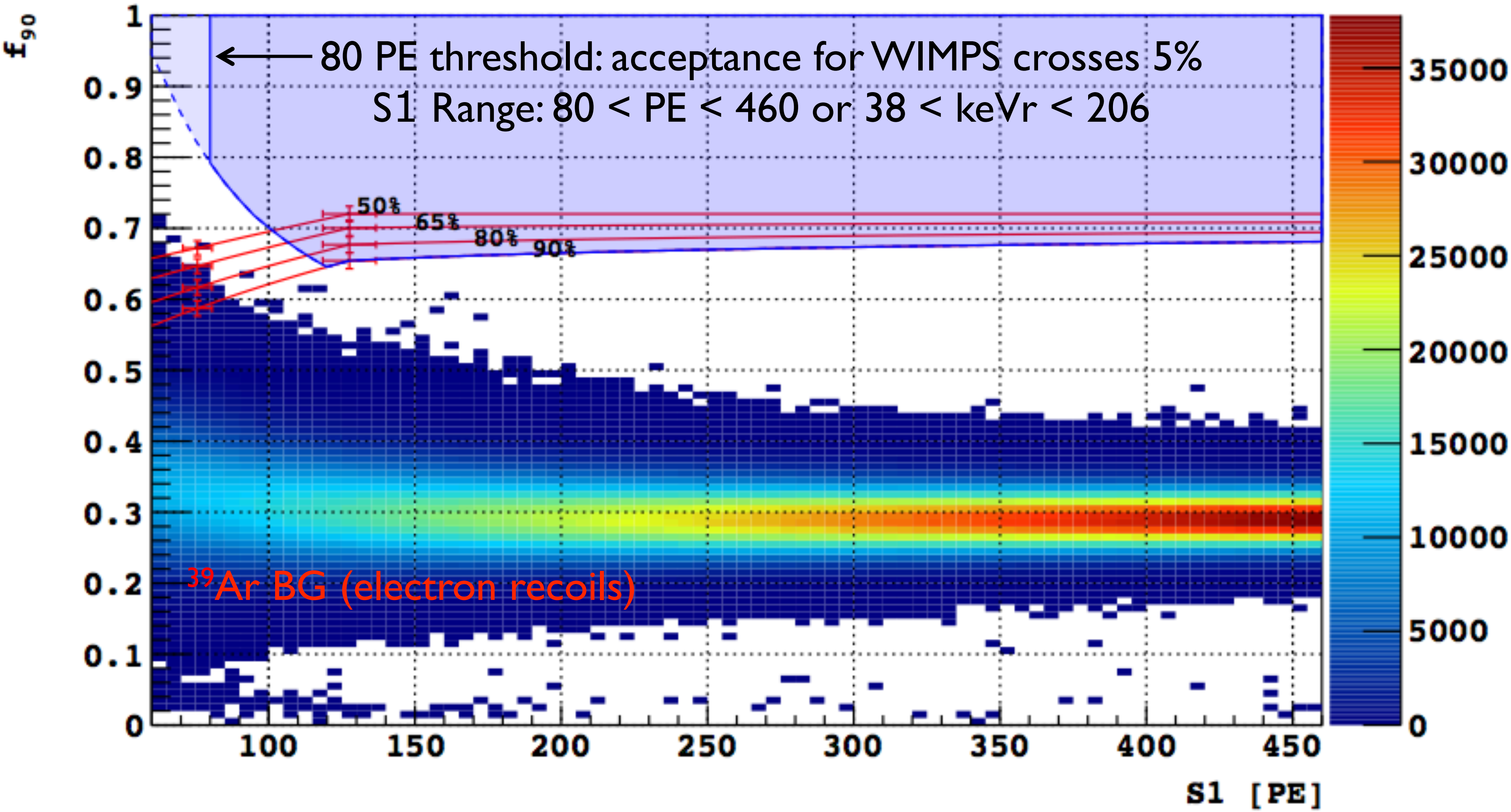
WIMP search box. All analysis cuts applied in this plot.



arXiv: 1410.0653

WIMP Search Box (1422 ± 67) kg·d

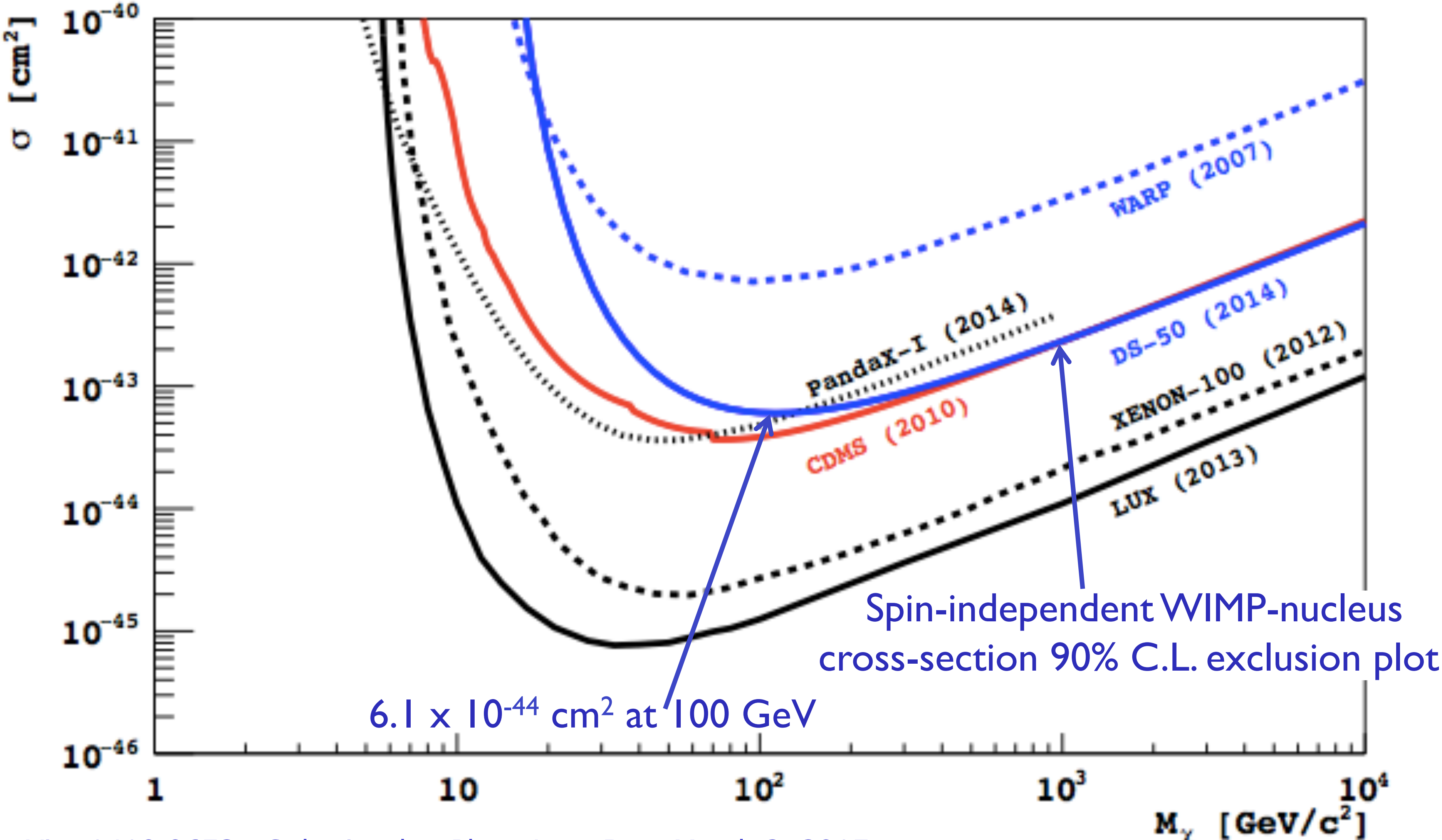
No candidates in search region after all analysis cuts.



arXiv: 1410.0653

EXCLUSION PLOT FROM DS-50

Most sensitive DM search ever performed with an argon target



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Summary and Outlook

- Background-free exposure of (1422 ± 67) kg·d
  - ^{39}Ar background in a ~20-years UAr run would be rejected
  - Future ton-scale LAr TPCs can be free of ^{39}Ar background
  - Most sensitive DM search ever performed with an argon target
  - Only background-free detector to reach 10^{-44} cm^2 sensitivity
- We finally have better calibrations!
  - Deploy calibration sources, perform calibration campaign
  - Calibrate veto and TPC using gamma and neutron sources
  - Calibrations completed in February, results coming soon
- Vastly improved detector sensitivity in 2015
  - LSV scintillator replaced with low-^{14}C (fossil) TMB
  - Fill TPC with underground argon in the next weeks
  - Begin dark matter search with underground argon
  - Expected sensitivity for a 3-years run is 10^{-45} cm^2