Measurement of ^{39}Ar in Underground Argon for Dark Matter Experiments

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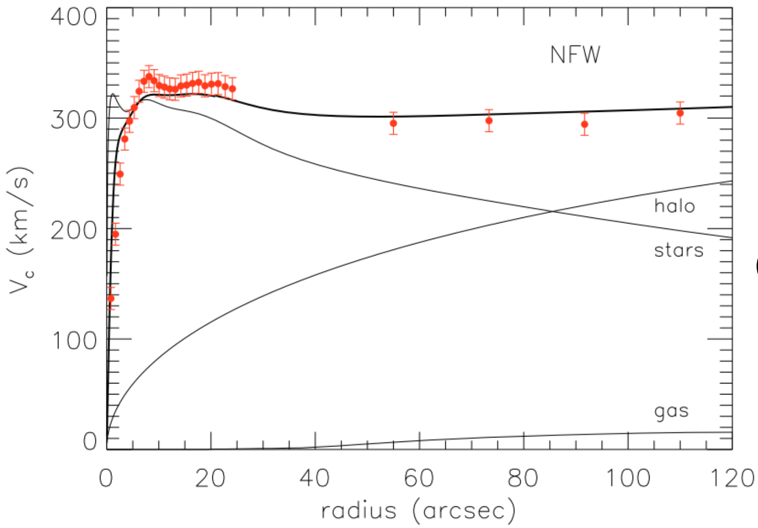
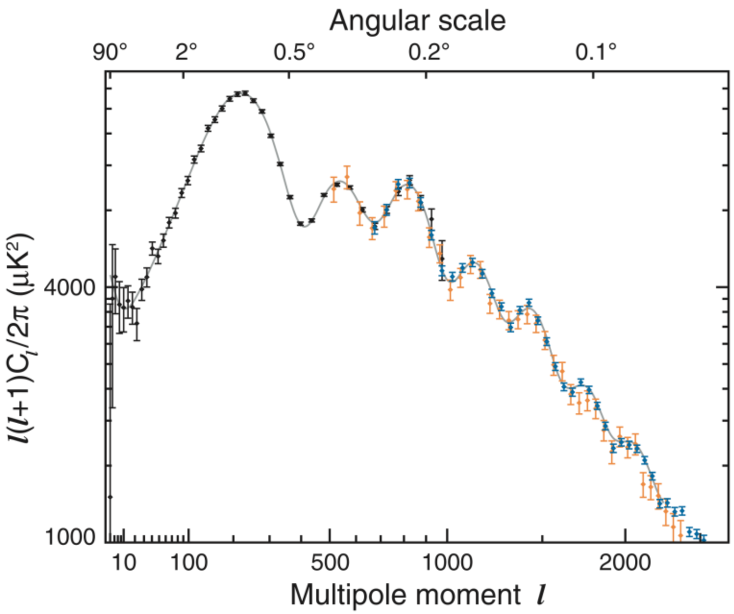
June 7th, 2013

Evidences for Dark Matter



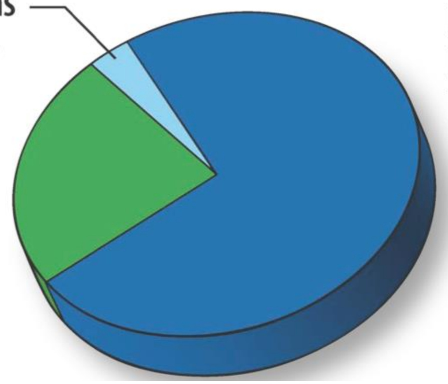
Rotation Curve

Gravitational Lensing



CMB Power Spectrum

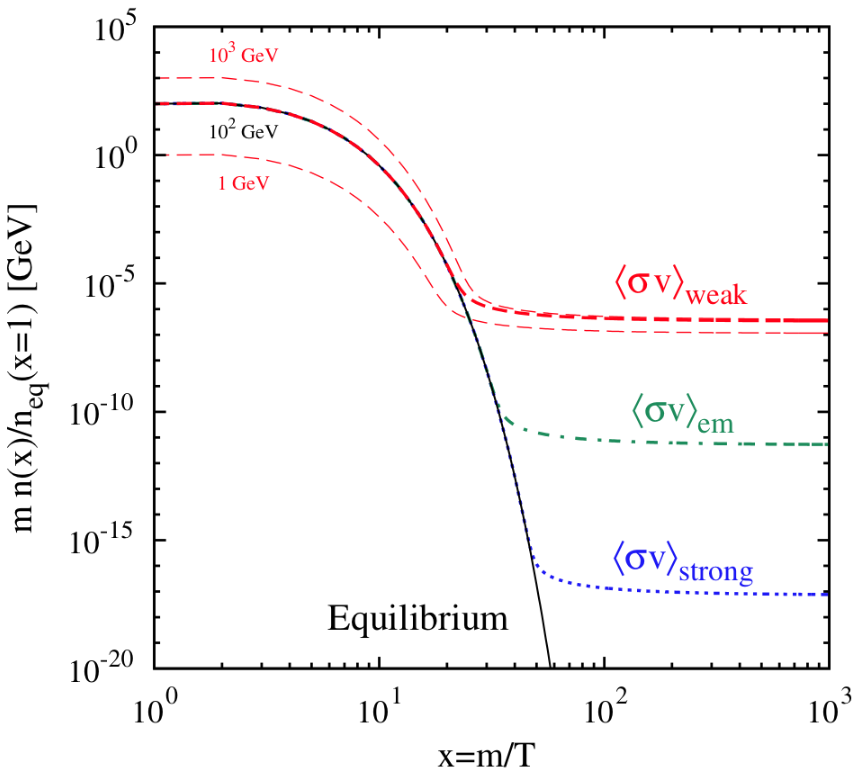
Composition of the Universe

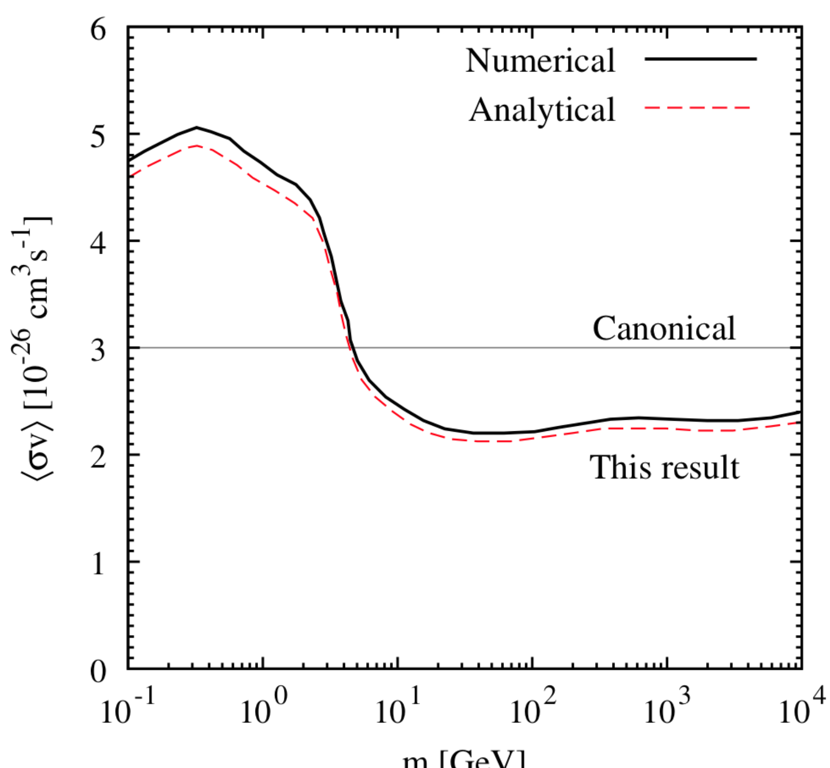


WIMP Dark Matter Miracle

Heavy particles (GeV-TeV) interacting at the weak scale, if produced at the big bang, naturally accounts for the DM density.

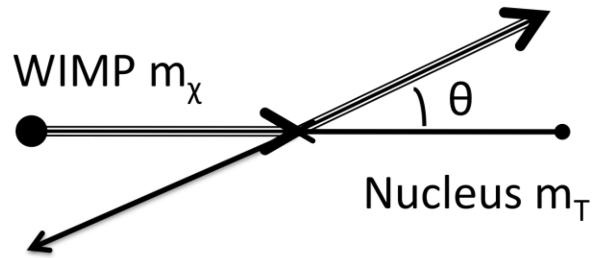
$$\frac{dn}{dt} + 3Hn = \frac{d(na^3)}{a^3 dt} = \langle \sigma v \rangle (n_{eq}^2 - n^2)$$





WIMP Dark Matter Detection

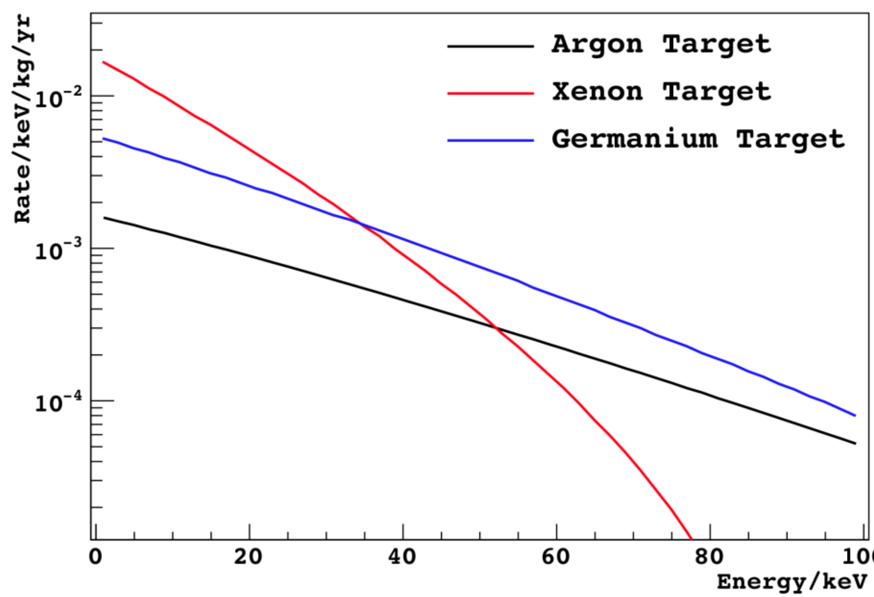
Galactic velocity-WIMPs may scatter with a nucleus and transfer ~10keV energy.



$$R_M \sim \frac{M N_A}{m_T} \frac{\rho_\chi}{m_\chi} \frac{\mu^2}{\mu_n^2} \sigma_n v_0 \left(\frac{f_p}{f_n} Z + (A - Z) \right)^2$$

WIMP induced nuclear recoil spectrum in Ar, Xe, and Ge.

100GeV WIMPs
1×10^{-45} cm^2 cross section
0.3GeV/cm^3 density
600km/s escaping velocity



Argon in Dark Matter Detection

Advantages:

High purity level can be achieved.
High Scintillation Light Yield, Pulse Shape Discrimination.
Long e^- drift distance, Scintillation/Ionization Discrimination
Scalable to large scale, ton scale possible.
Low cost: ~1% of air is argon.

Problems:

$^{39}Ar \rightarrow$ $^{39}K + e^- + v$, 565keV, 269yr
^{40}Ar (n, 2n) ^{39}Ar in the atmosphere, ~1 Bq/kg, $^{39}Ar/^{40}Ar \sim 8x10^{-16}$
The presence of ^{39}Ar limits the size of argon TPCs, and restricts the threshold and sensitivity of argon-based dark matter experiments.

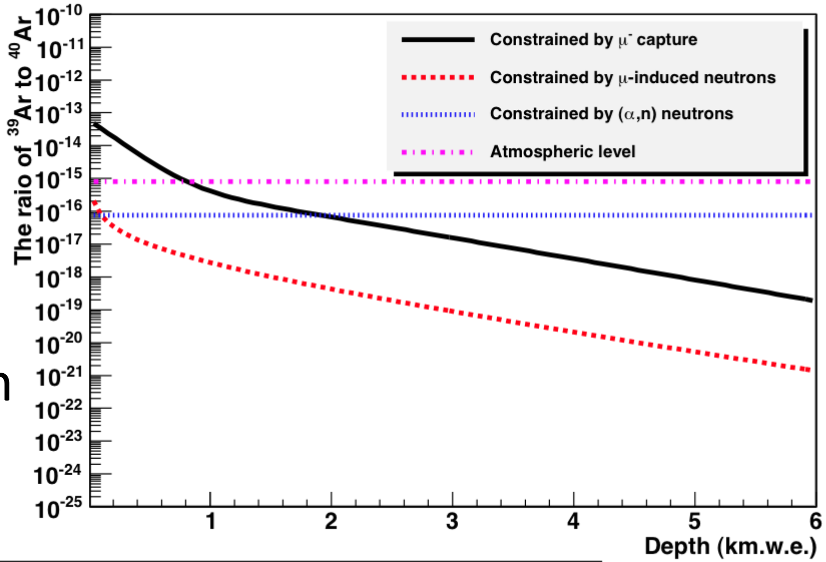
Argon from Underground Sources

$^{40}K + e^- \rightarrow {}^{40}Ar + \nu$

Underground gas is shielded from CRs.

- $^{39}K(n, p)^{39}Ar$, n from (alpha, n)
- negative muon capture on ^{39}K

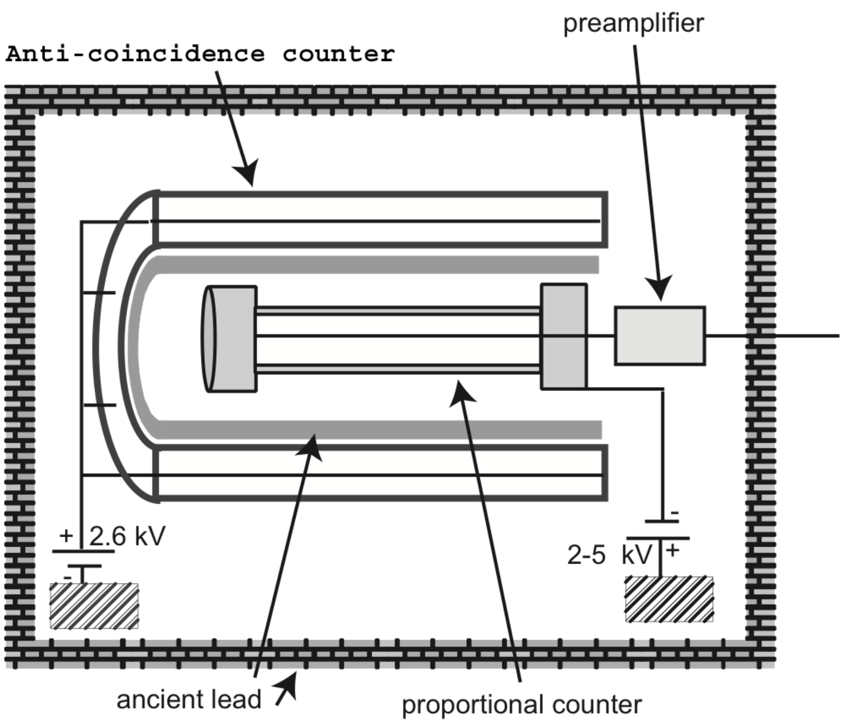
Underground argon samples have been shown to have different ^{39}Ar levels

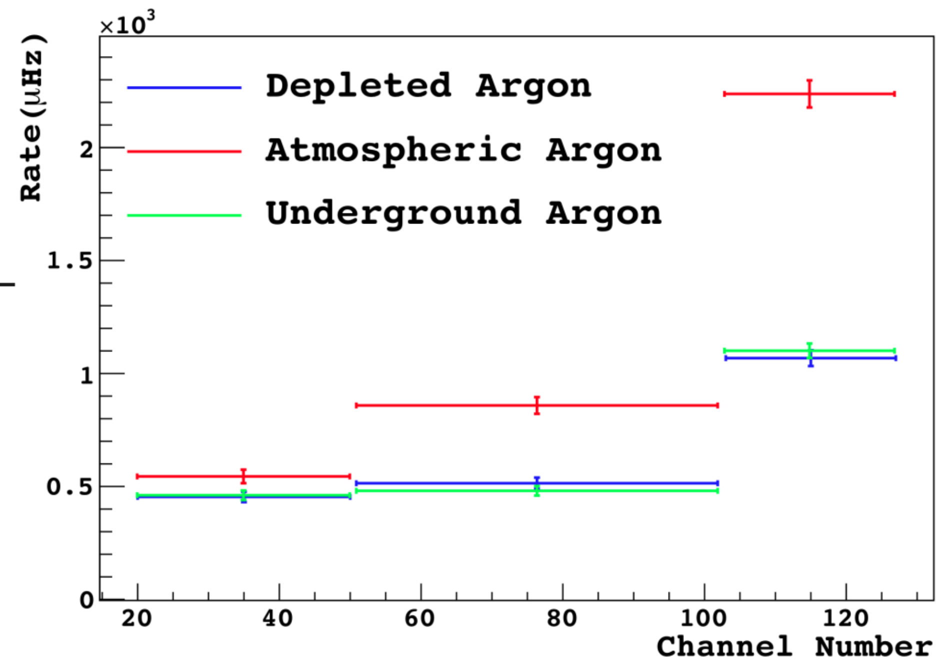


Location	Aquifer	Sample	^{39}Ar %modern
Stripa mine, Sweden	Granite	Borehole N1	1600
		Borehole V1	330
Augraben, Germany	Karstic	-	61
Krautbuckel, Germany	Karstic	-	31
Buscheletten, Germany	Karstic	1	<6.8
		2	<4.7
Lincoln, UK	Triassic sandstone	5 samples	< 5
		3 samples	55-95
Zurzach, Switzerland	Granite	1 (1976)	375
		2 (1976)	380

^{39}Ar Measurement at the Univ. of Bern

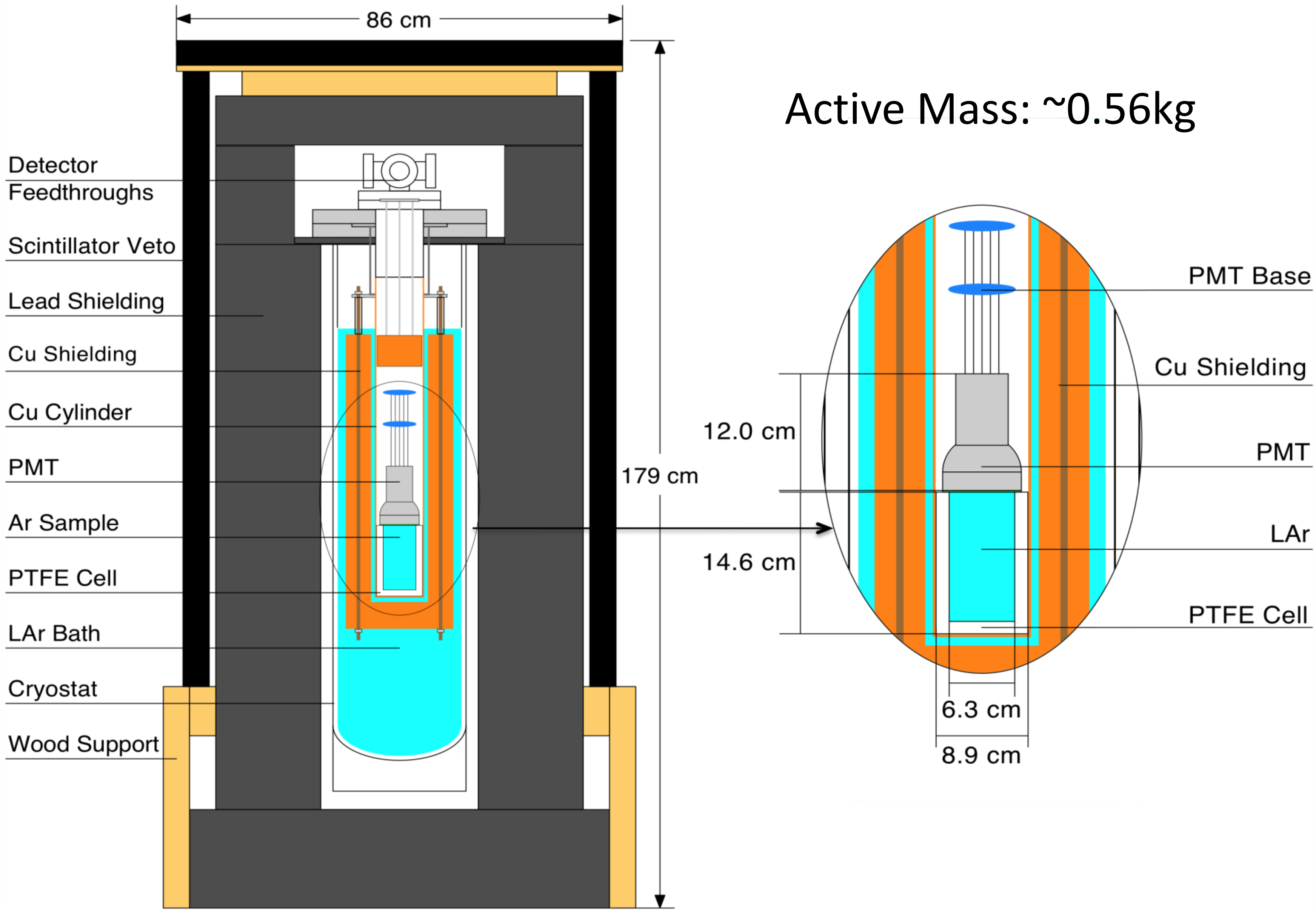
Gas from New Mexico and Colorado may rise from the Earth's mantle. Samples measured to have <5% ^{39}Ar at the university of Bern. Anti-coincident gas proportional counter, ~70m.w.e. underground, use depleted argon sample as reference.





The Low Background Liquid Argon Detector

Active Mass: ~0.56kg



Gas Handling System of the detector

Evacuate/Purge detector.

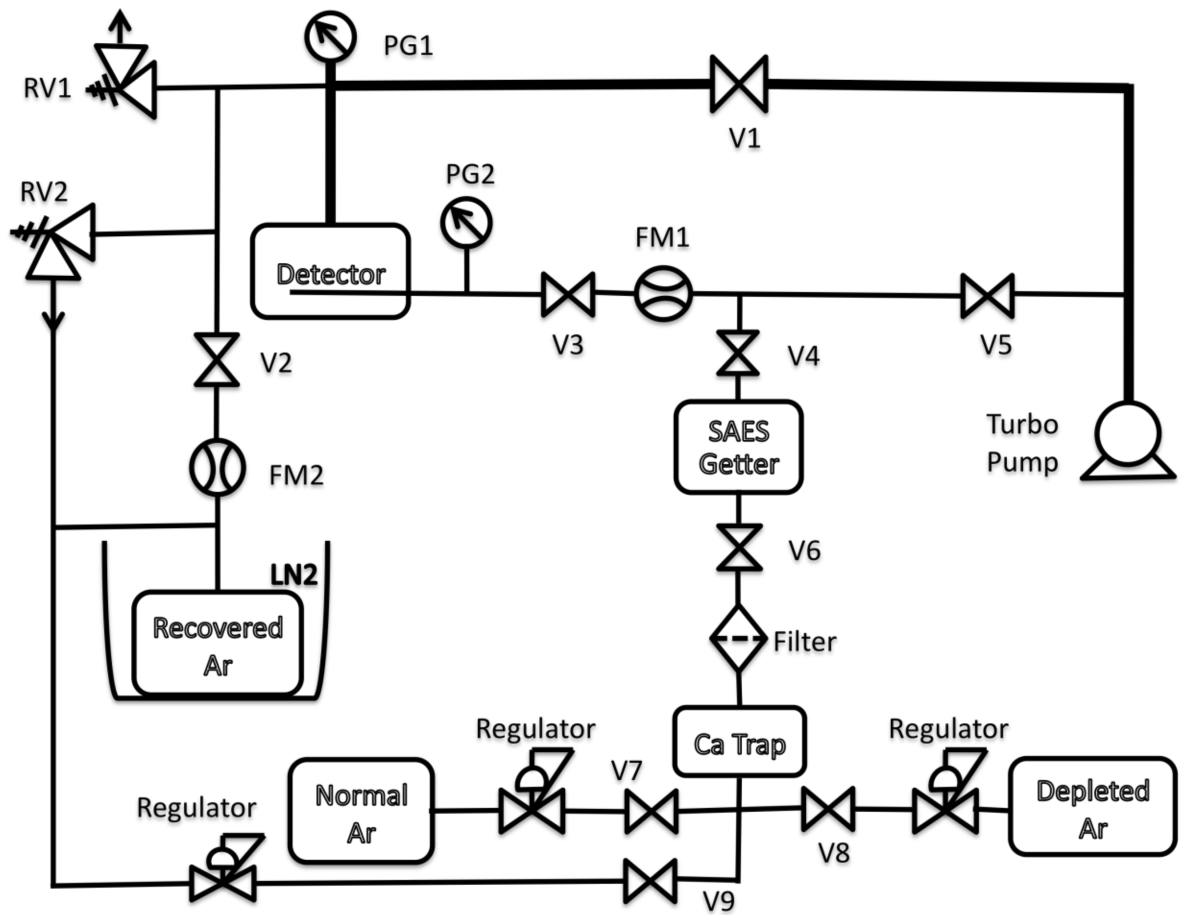
Remove impurities from detector components.

Purify argon before filling into the detector.

Keep cryogenic condition.

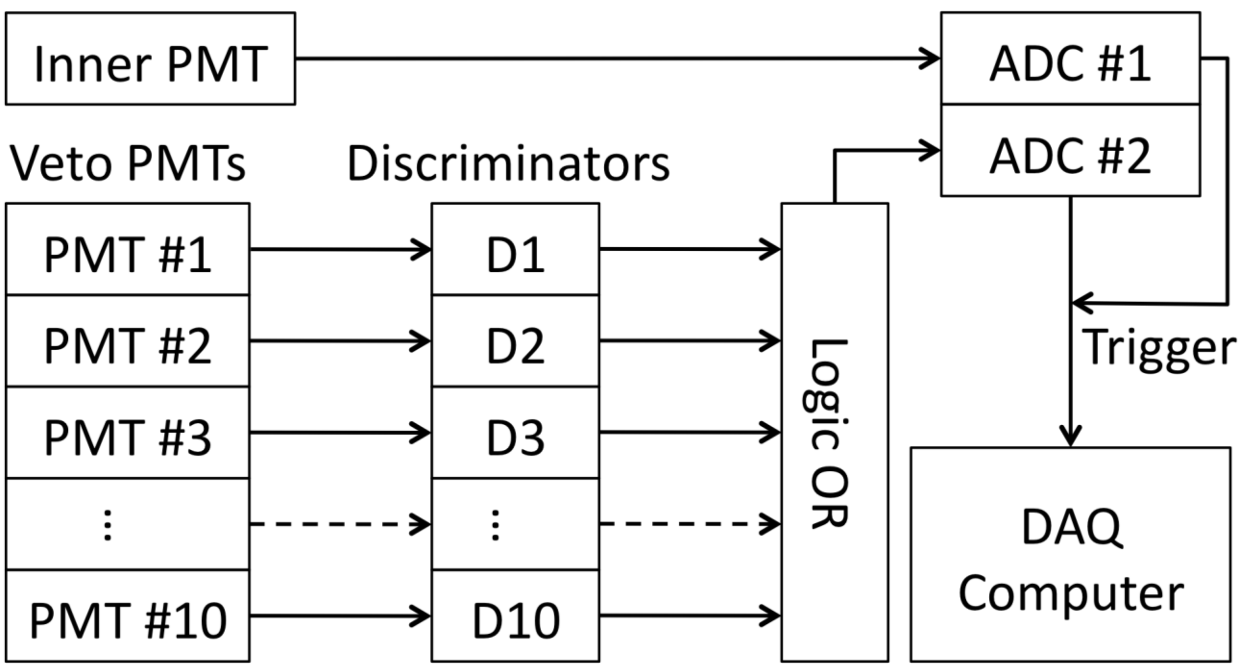
Recover argon after measurement.

Safety.



Data Acquisition System

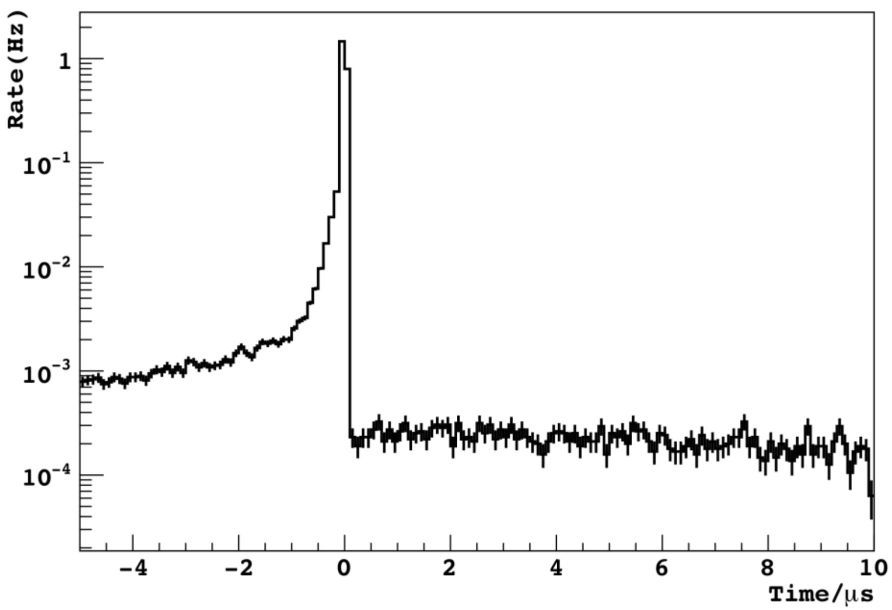
CAEN Digitizer V1720, 12 bit, 250Ms/s
Inner PMT signal digitized directly, provides trigger
Veto PMTs produce discrimination signals, anti-coincidence
Signal window, -5us to 10us

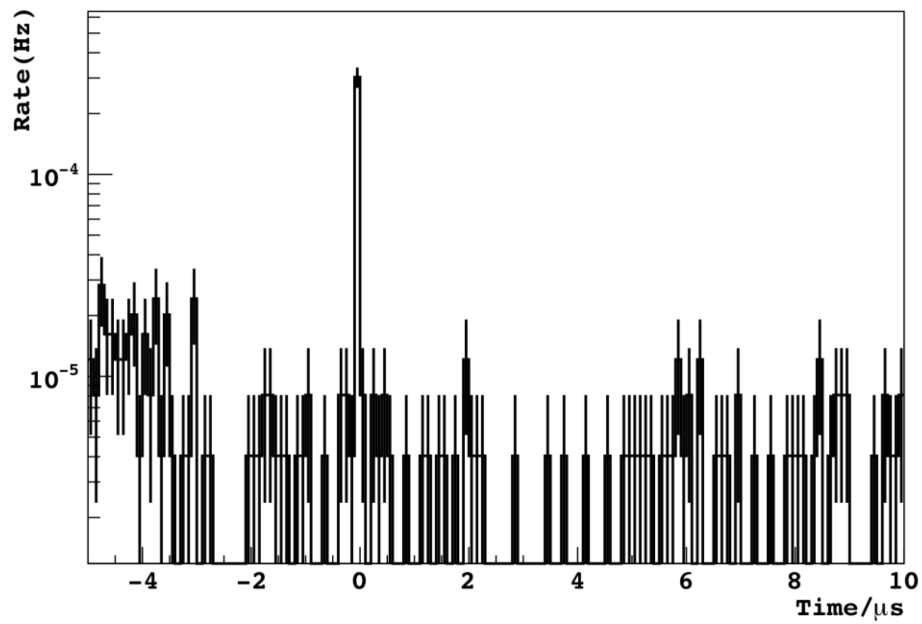


Cosmic Muon Background Rejection

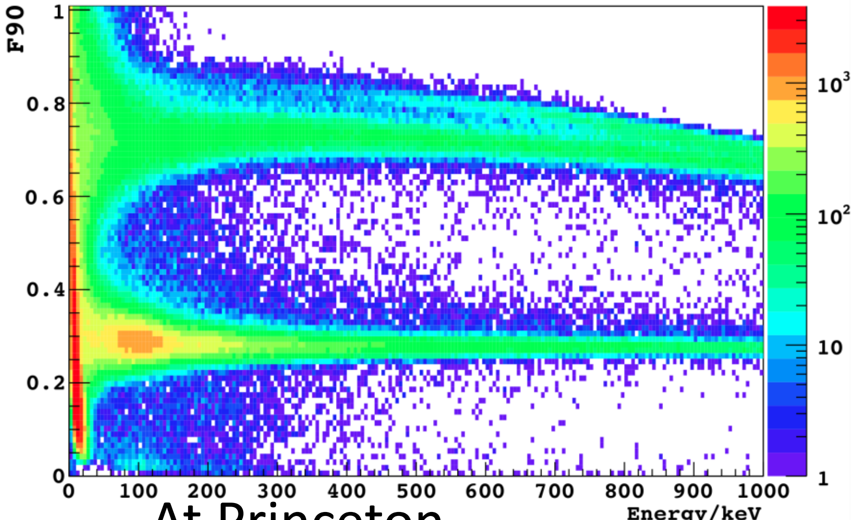
Logical OR: any veto PMT can gives a veto signal (threshold preset).

Vetoed event rate at surface: ~2.5Hz in the argon detector
underground: ~0.3mHZ at KURF

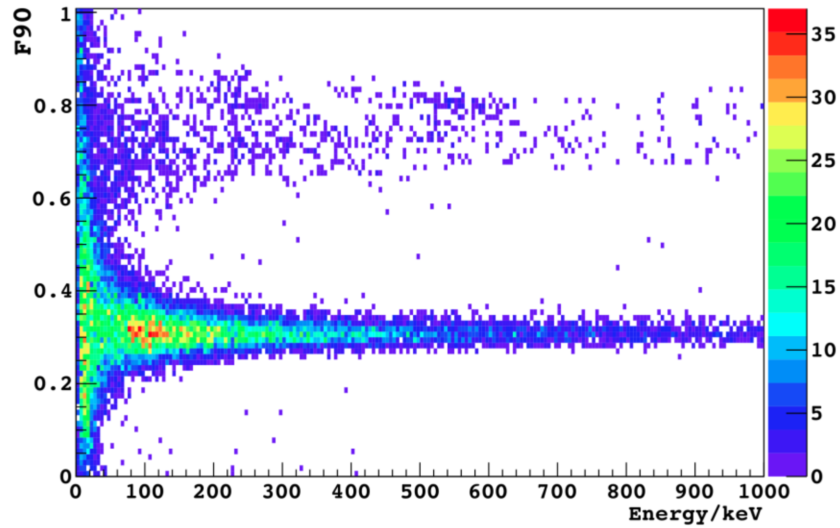




Neutron Background Rejection

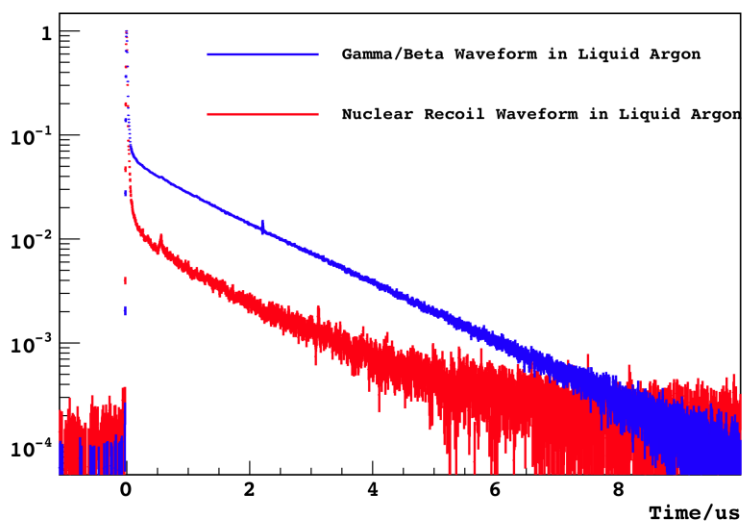


At Princeton



At KURF

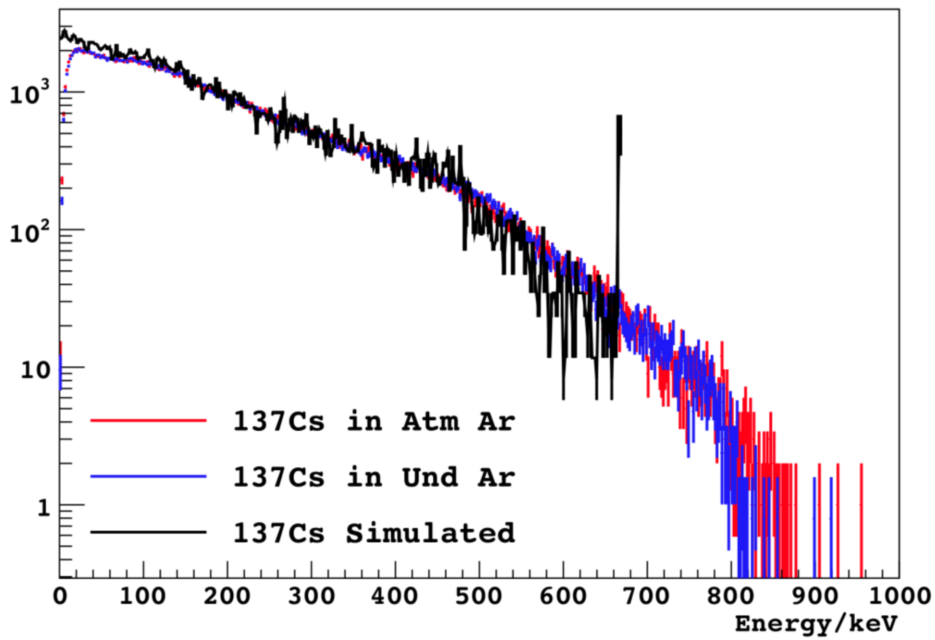
Fast Comp. ~7ns
Slow Comp. ~1.6us
Fast:Slow
~1:3 electron recoil
~3:1 nuclear recoil

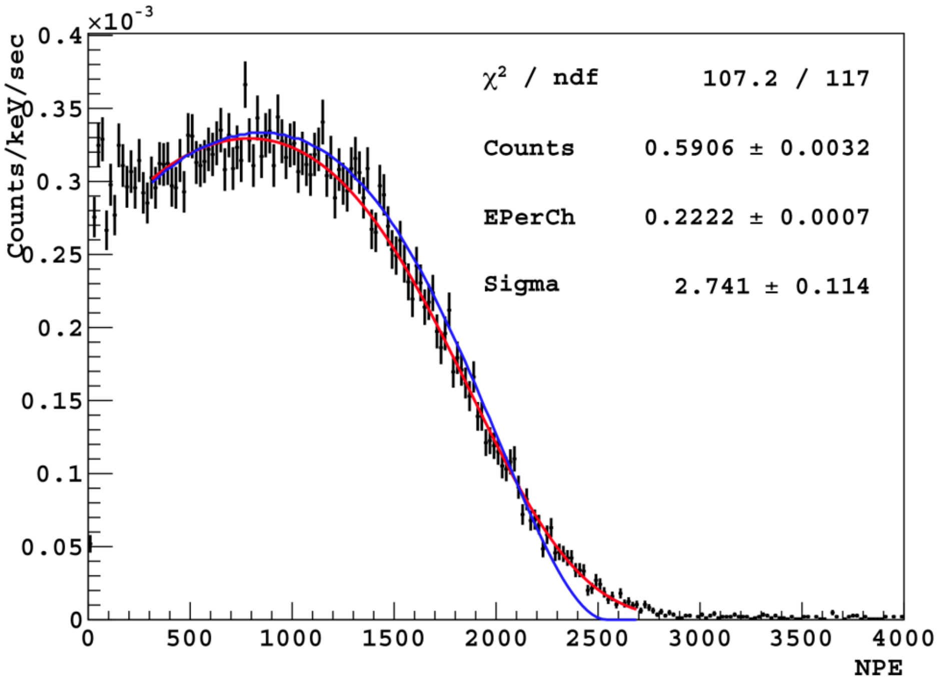


>50keV$_{ee}$
Electron recoil acceptance >99.9%
Nuclear recoil rejection power>99%

Energy Calibration of the Detector

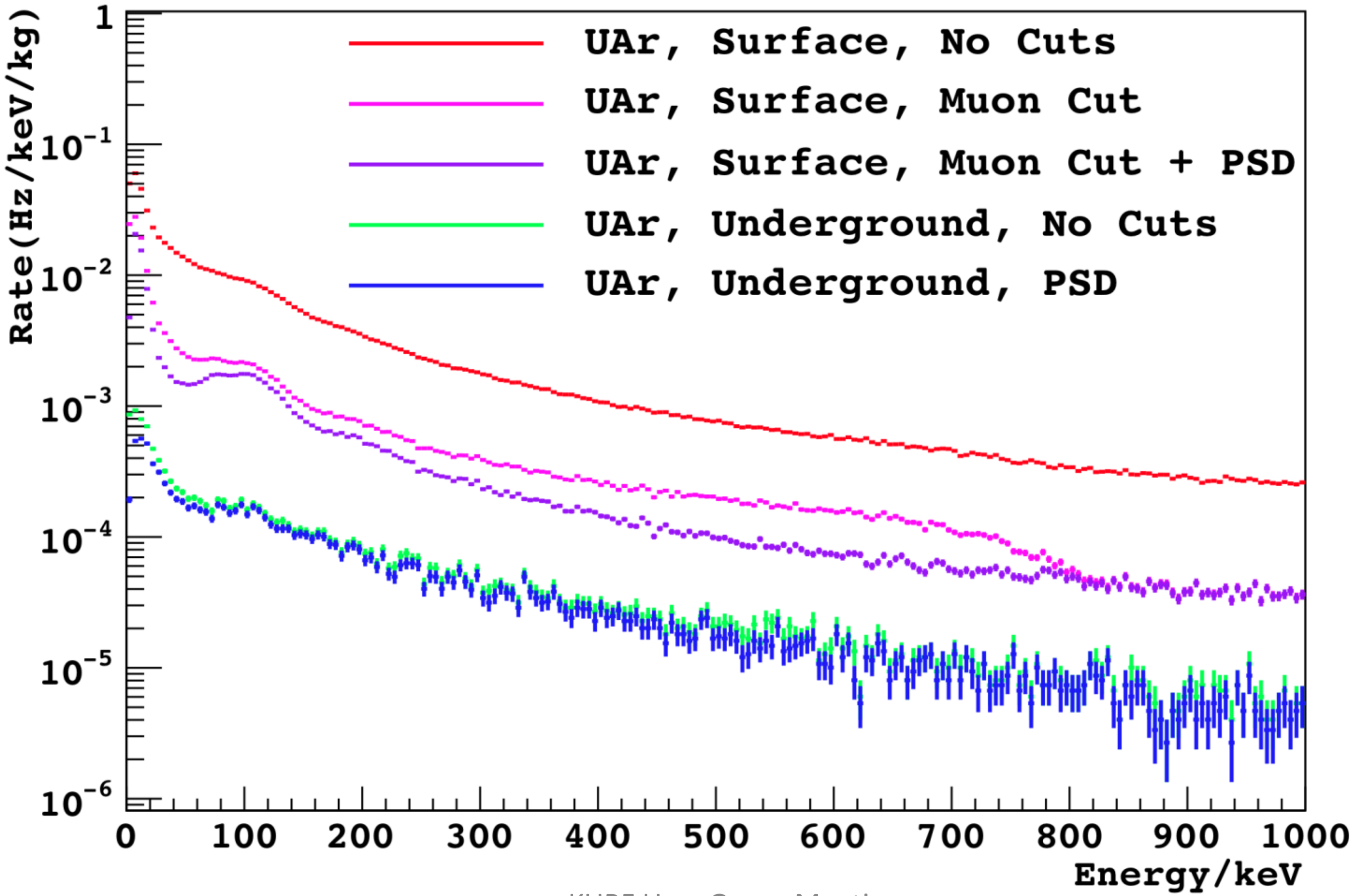
^{137}Cs monitors the degradation of light yield, 662keV gamma
spatial variation of light collection
^{39}Ar determines the energy scale, up to 565keV electron
uniformly distributed in the scintillation cell





^{39}Ar Measurement Spectrum

Event Rate: 20mBq in (40, 800)keV, <2mBq in (300,400)keV
A factor of 30-50 times lower at KURF

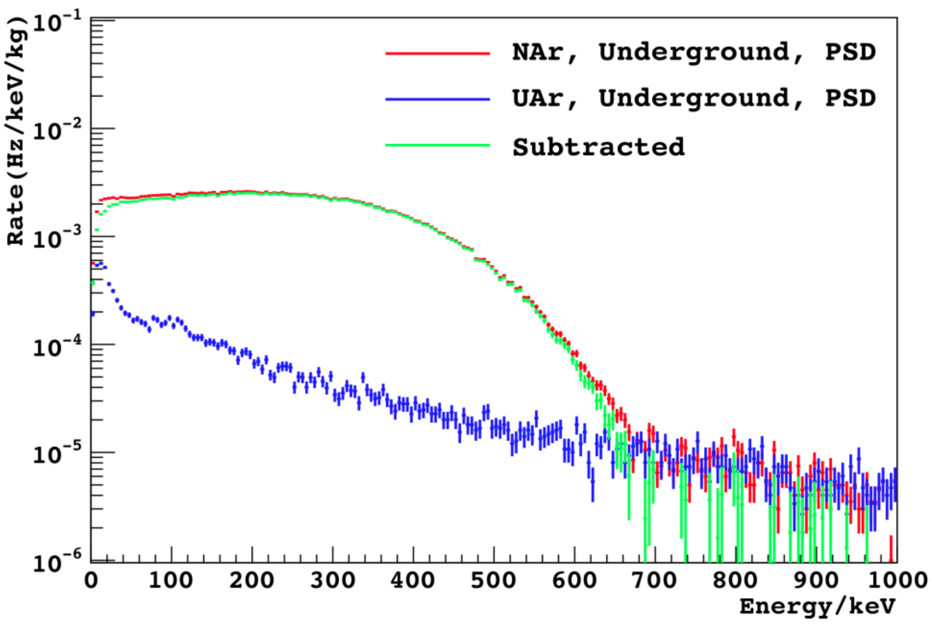


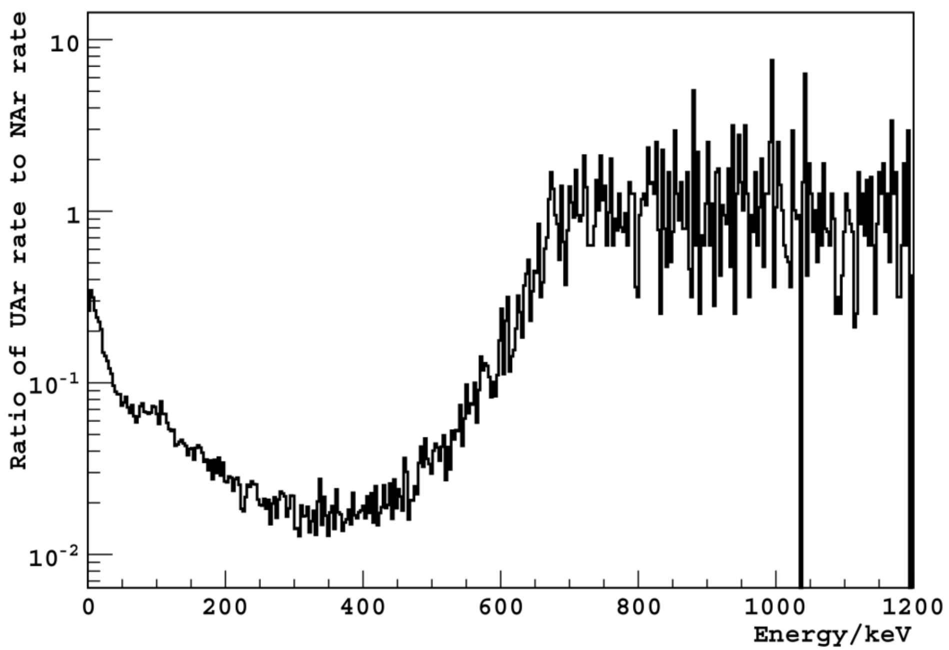
Conservative ^{39}Ar Limit

Ignore all background, assume all observed events are 39Ar electrons.

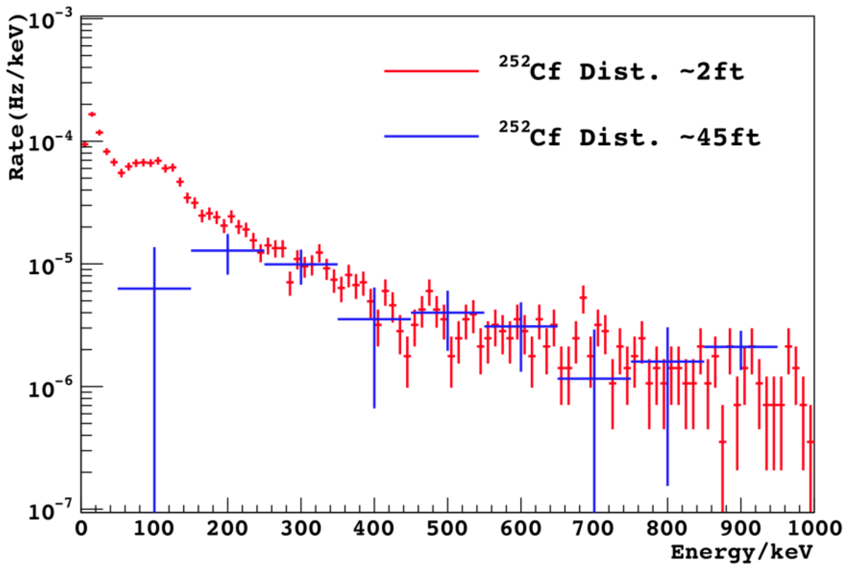
Ratio of underground argon event rate to atmospheric argon event rate

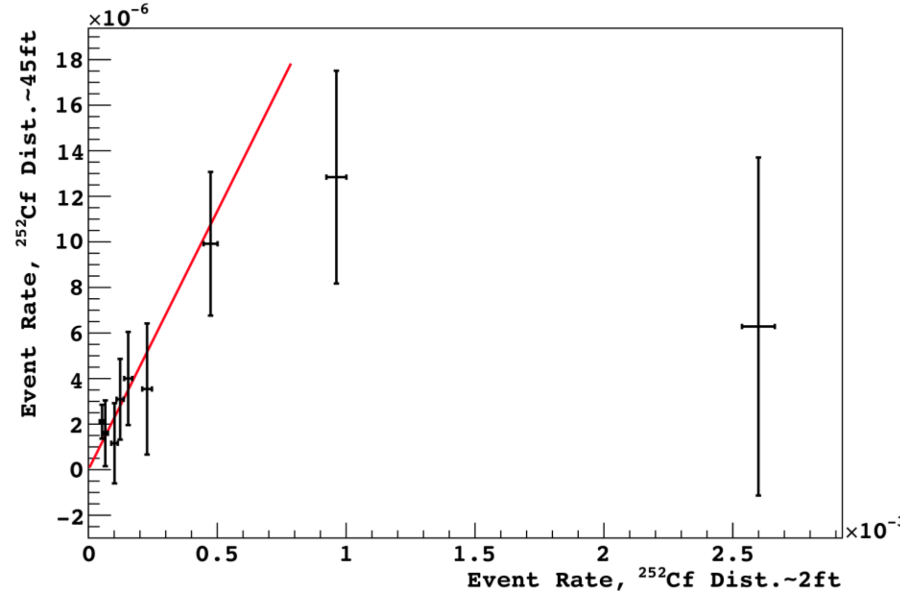
(1.71+/-0.05)% absolutely upper limit

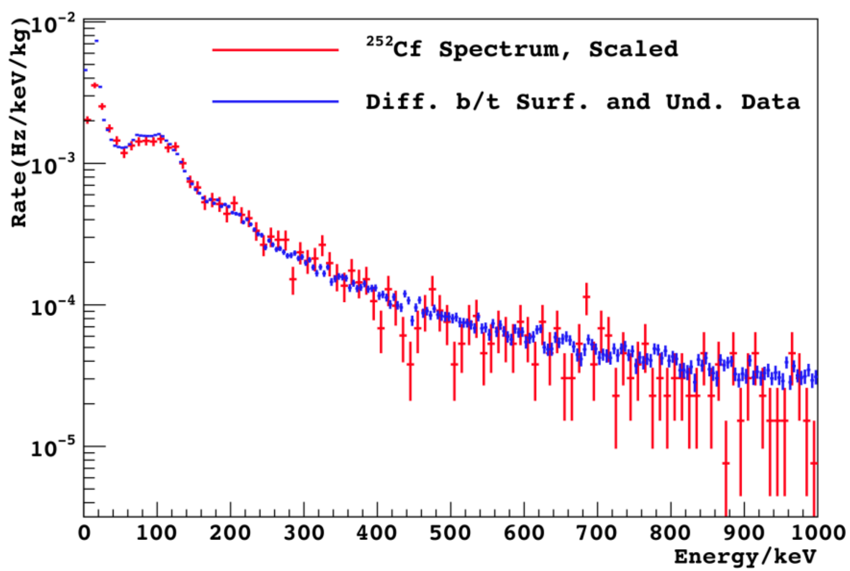




^{252}Cf Neutron Background







Neutron Interactions

Inelastic scattering between ^{19}F and fast neutrons: 110keV, 197keV

Neutron activation on detector components (Cu, etc): high energy

Gamma Ray Background

PMT and base: measured at the Gran Sasso Counting Facility.
OFHC copper: typical cosmogenic activation values, scaled to sea level.
PTFE: not measured and ignored in the analysis.

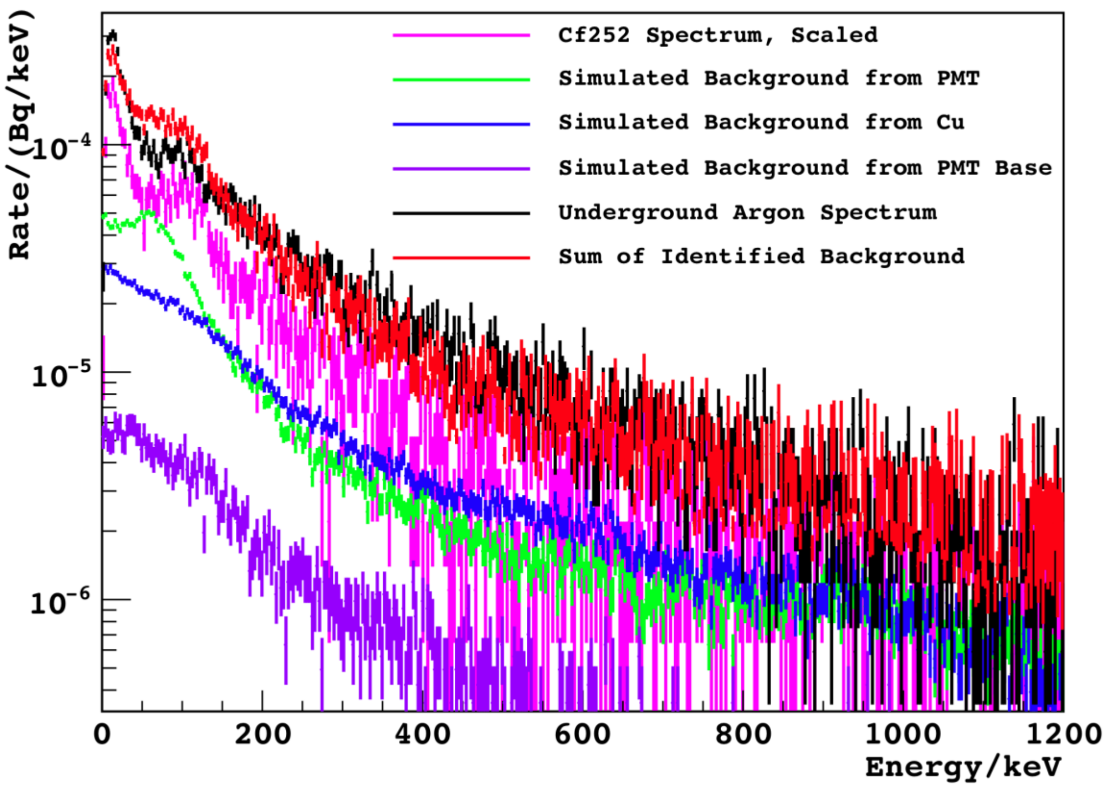
Isotope	Detected	PMT(mBq)	Base (mBq)	Cu (mBq/kg)
^{232}Th	^{228}Ra	6 ± 1	40.9 ± 2.8	-
	^{228}Th	6 ± 1	44.6 ± 4.7	< 0.02
^{238}U	^{234}Th	190 ± 40	25.1 ± 3.7	-
	^{234m}Pa	80 ± 40	< 149	-
	^{226}Ra	18.2 ± 1.2	31.6 ± 1.9	< 0.04
^{235}U	^{235}U	8 ± 2	1.4 ± 0.4	-
^{40}K	^{40}K	79 ± 10	65.1 ± 9.3	< 0.11
^{60}Co	^{60}Co	8.8 ± 0.8	< 1.2	2.1 ± 0.19
^{57}Co	^{57}Co	-	-	1.8 ± 0.4
^{58}Co	^{58}Co	-	-	1.7 ± 0.09
^{56}Co	^{56}Co	-	-	0.2 ± 0.03

Table 1: Major Radioactivity in the Detector Components

Background Analysis Summary

Source	^{252}Cf	PMT	Base	Copper
Rate/mBq, (300, 400)keV	0.82±0.16	0.29±0.08	0.07±0.02	0.41±0.05

80% of the event rate between 300keV and 400keV can be explained as detector background



^{39}Ar Limit with Background Subtracted

Summary of Background Subtraction:

	Rate/mBq, (300, 400)keV
NAr	108.78±0.39
UAr	1.87±0.06
Estimated Background	1.59±0.20
^{85}Kr Background	<1.83
NAr, Background Subtracted	107.18±1.88
UAr, Background Subtracted	0.27±0.21

Two sigma upper limit on the ^{39}Ar content in underground argon compared that in atmospheric argon:

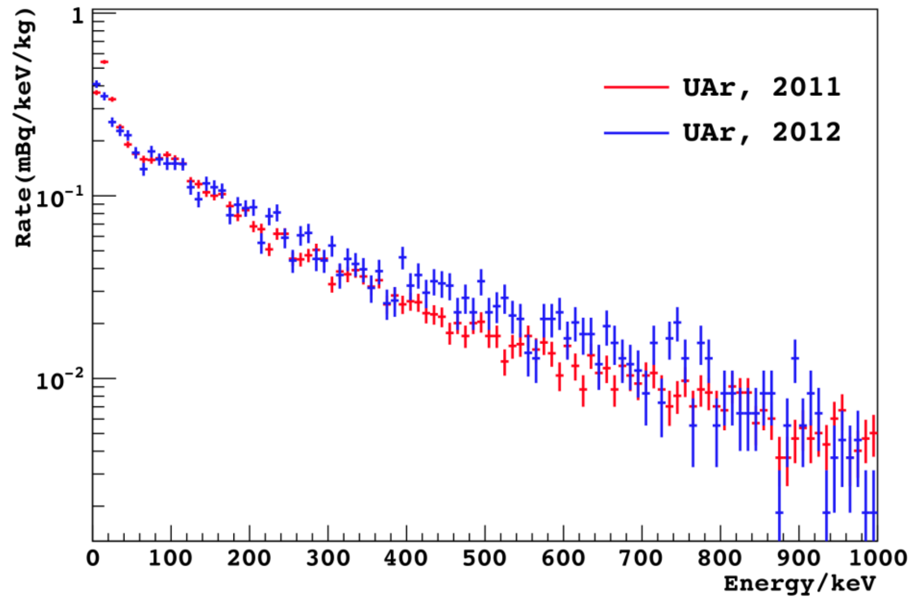
0.65%

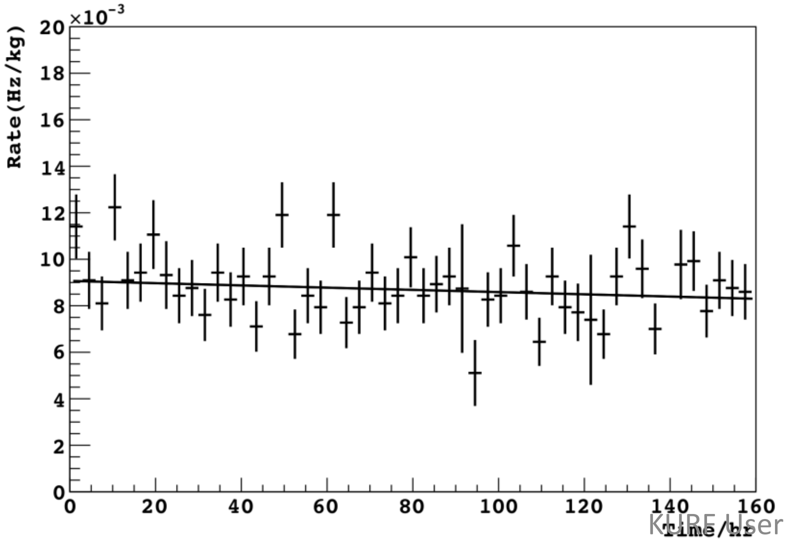
Unknown Background 2012 Measurement

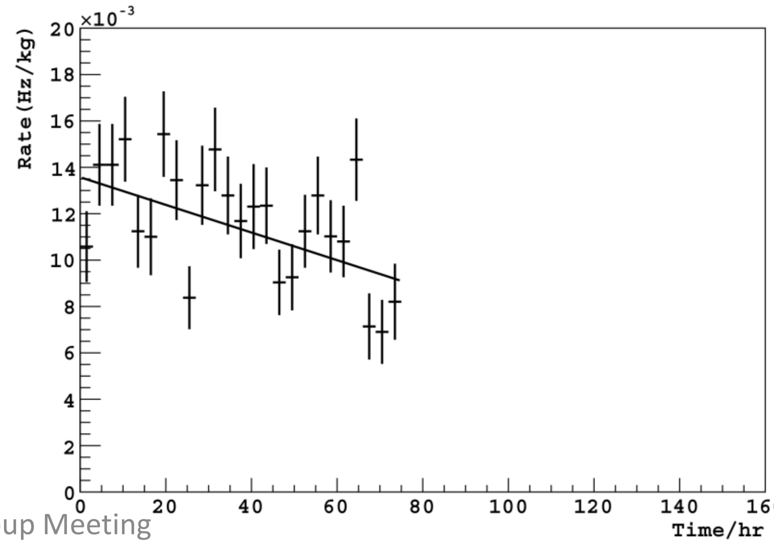
2012 Measurement

Lower radioactivity PMT
Lower radioactivity Base
No ^{252}Cf Source
Higher reflectance cell

Higher event rate!







Effect of Low ^{39}Ar on Argon TPCs

Pileup: >=1 ^{39}Ar event in the drift window

Assumptions: 2mm/us drift velocity at 1kV/cm

cylindrical detectors, equal height and diameter

$$\frac{h}{v}\frac{\pi d^2 h}{4}\rho\frac{1Bq}{1kg}R = 50\%$$

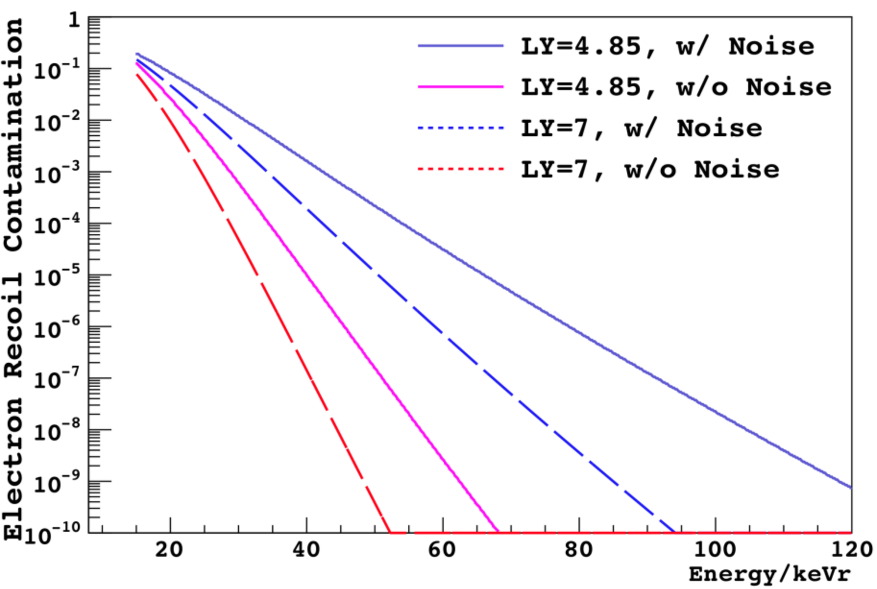
^{39}Ar Levels	M_{Ar}, 50% D.T.	TPC height	drift time
atmospheric	1 ton	1.0 m	500μs
5% atmospheric	10 ton	2.1 m	1000μs
0.65% atmospheric	45 ton	3.4 m	1700μs
0.1% atmospheric	182 ton	5.5 m	2700μs

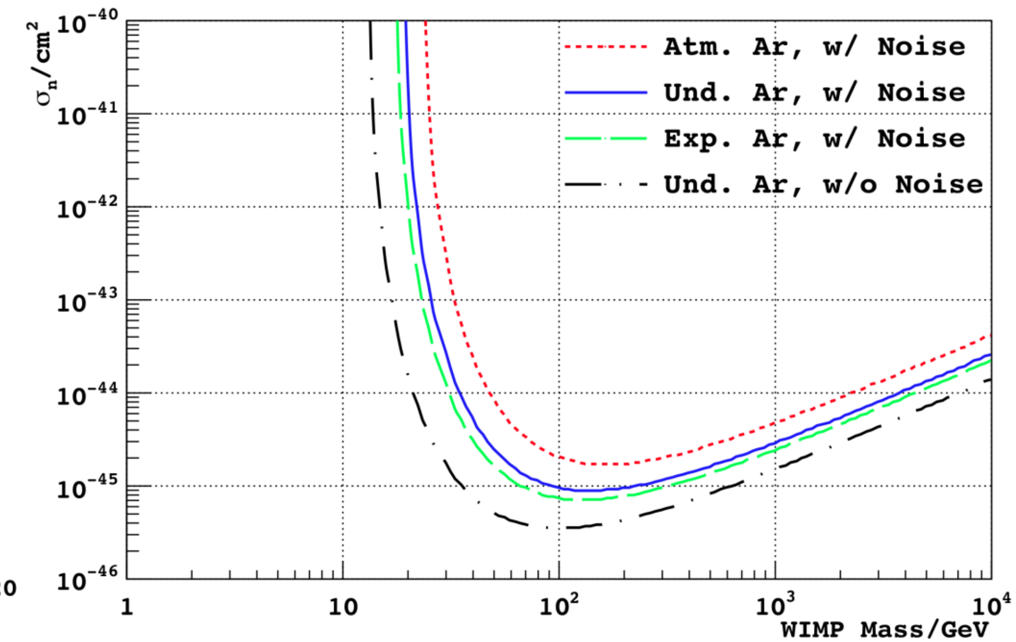
Implications to Dark Matter Sensitivity

PSD power drops at low energy

Lower 39Ar content leads to lower energy threshold

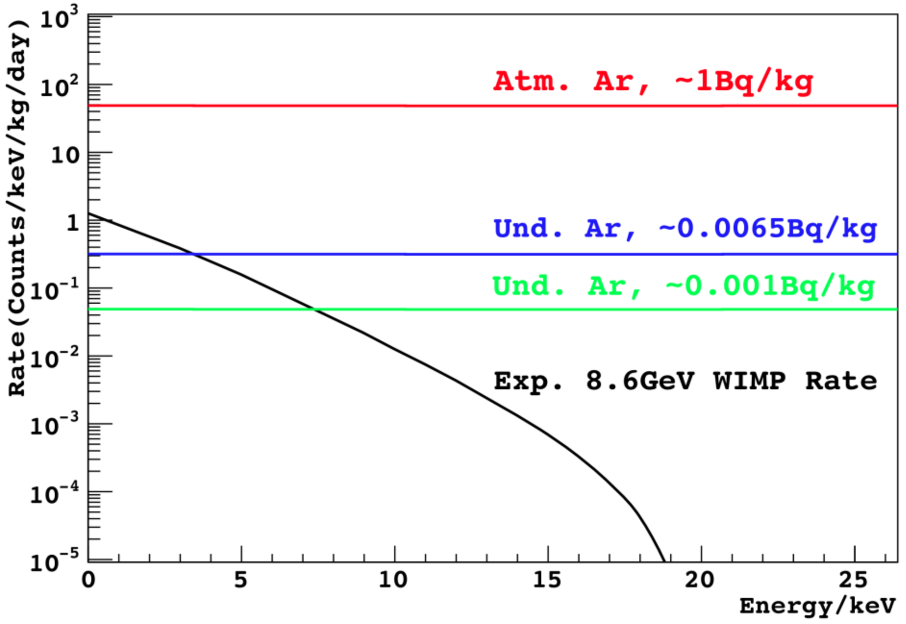
^{39}Ar Levels	E_{th} w/ noise		E_{th} w/o noise	
	E_{ee}	E_{nr}	E_{ee}	E_{nr}
atmospheric	24.3 keV	83.8 keV	13.5 keV	46.6 keV
5% atmospheric	20.9 keV	72.0 keV	12.0 keV	41.4 keV
0.65% atmospheric	18.7 keV	64.5 keV	11.0 keV	37.9 keV
0.1% atmospheric	16.7 keV	57.6 keV	10.1 keV	34.8 keV

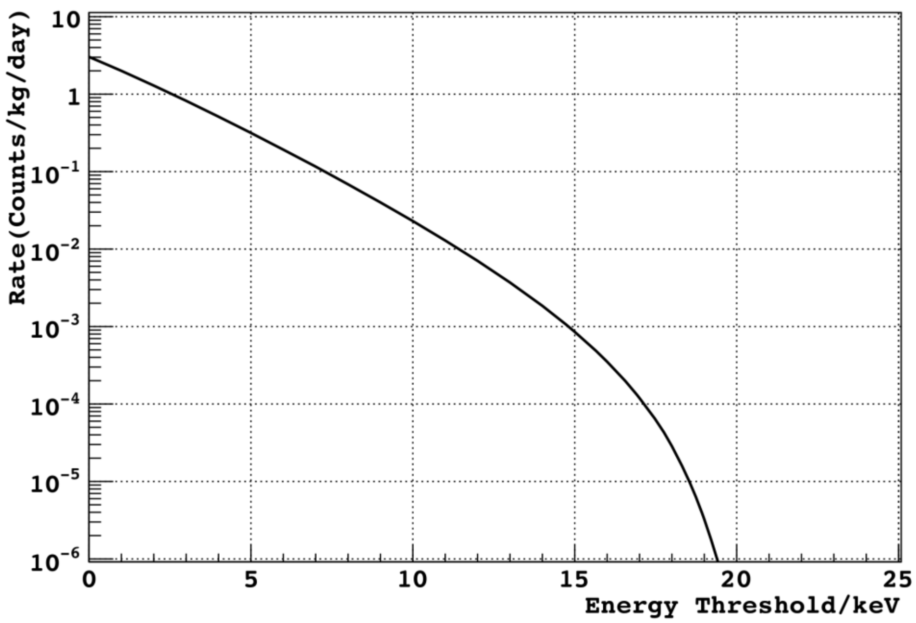




Implications to Light WIMP Search

DAMA, CoGeNT, CRESSTII, CDMSII-Si have suggested possible observation of light WIMP interactions.
CDMSII-Si and CoGeNT agree at 8.6GeV, 1.9x10-41cm2
Argon is not sensitive to light WIMPs if no background is allowed.





Thank you!