# Search for the DarkSide

Richard Saldanha

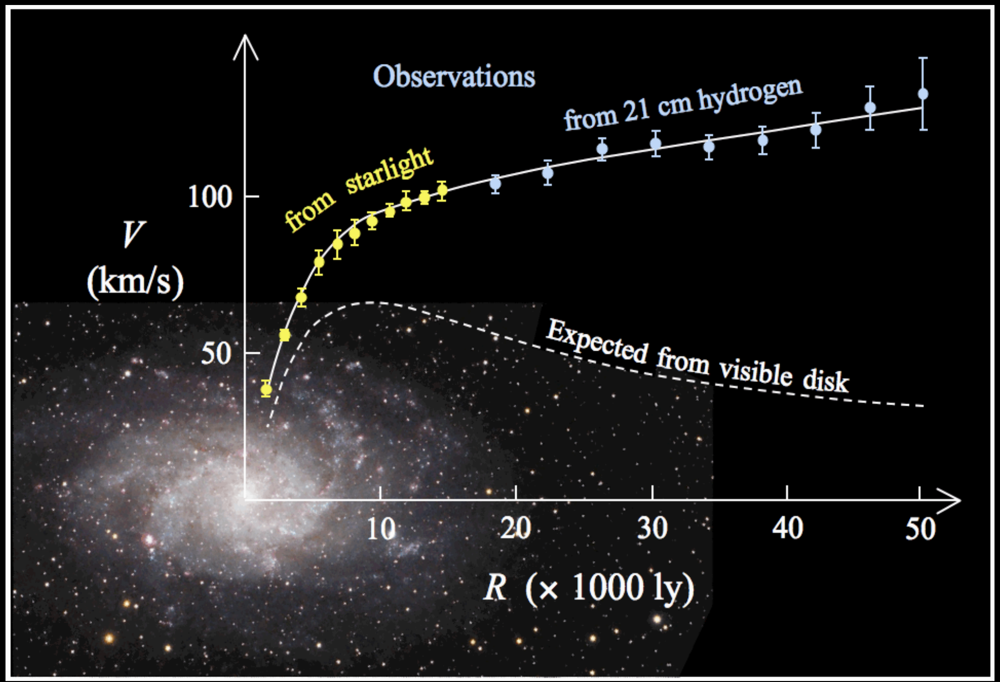
10th December 2013

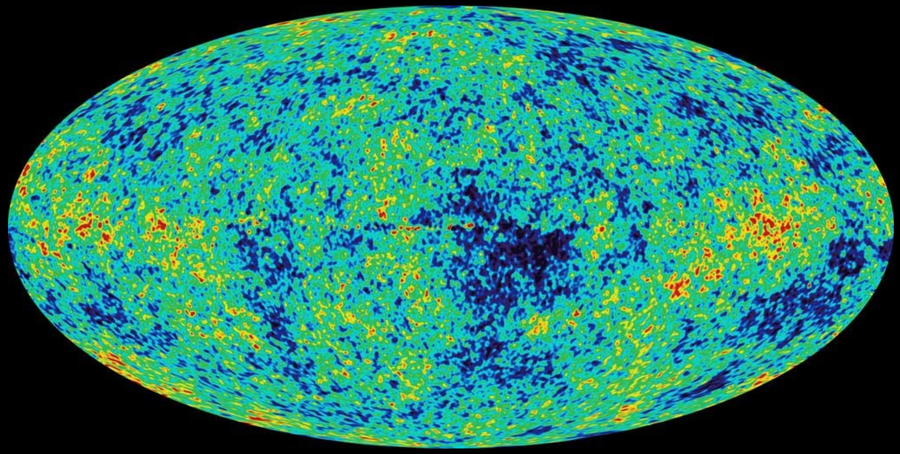
Laboratory for Nuclear Science
Lunchtime Seminar

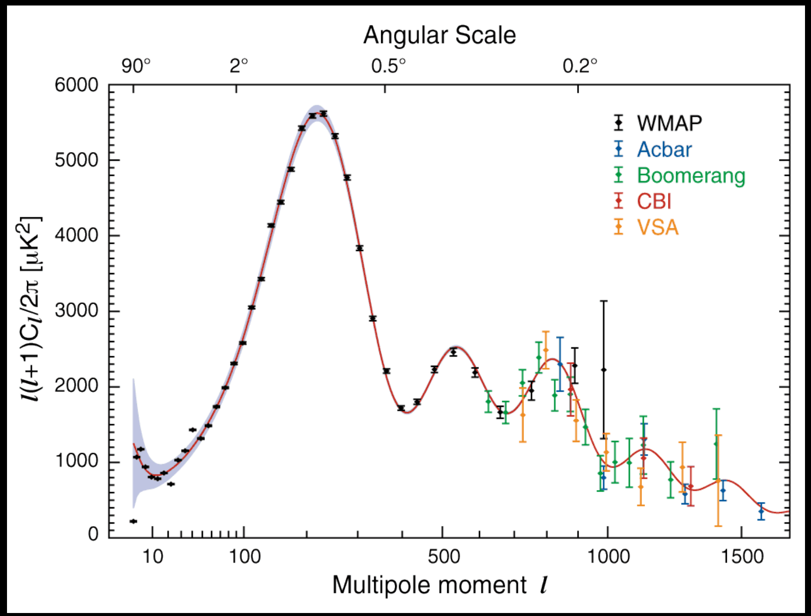
# Outline

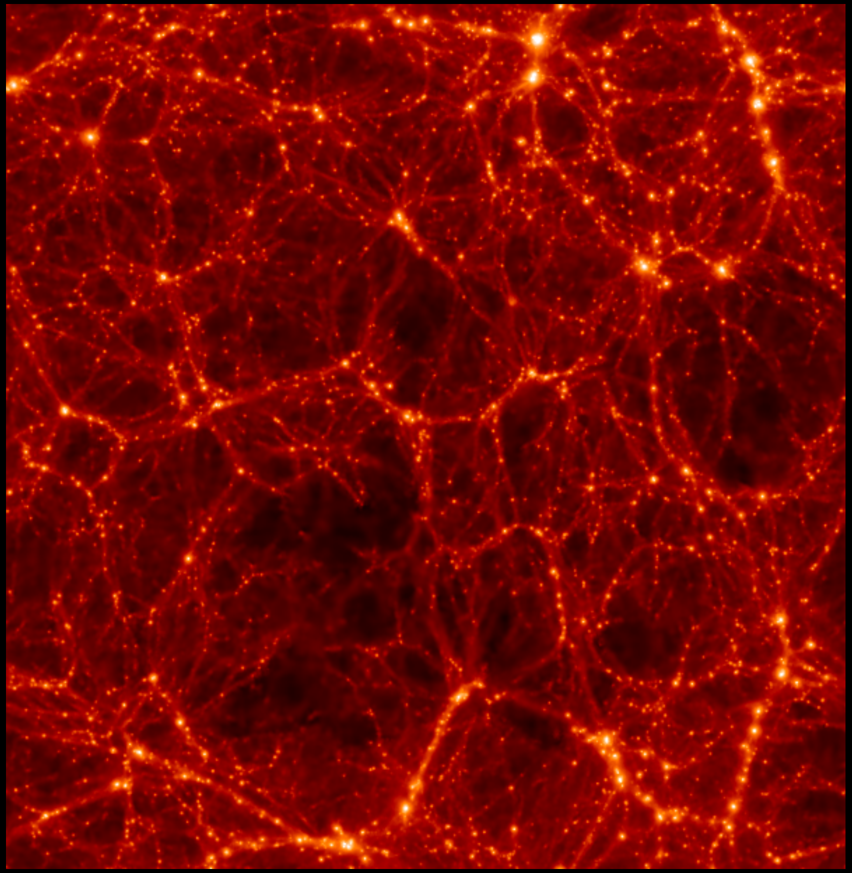
- Introduction to Direct Detection of Dark Matter
- DarkSide
- DarkSide-10 Prototype
- DarkSide-50

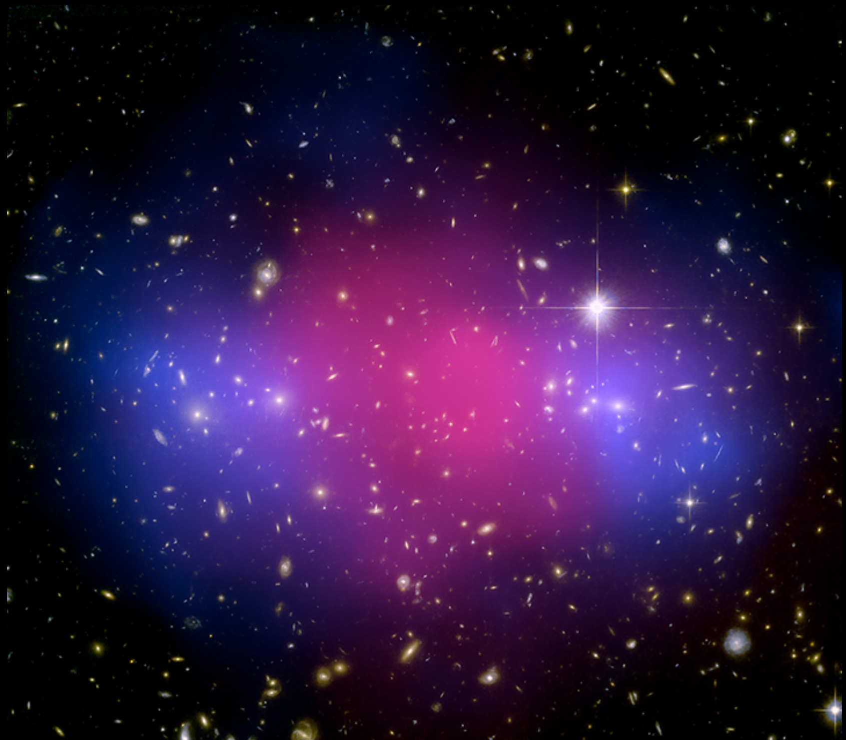
# Evidence for Dark Matter



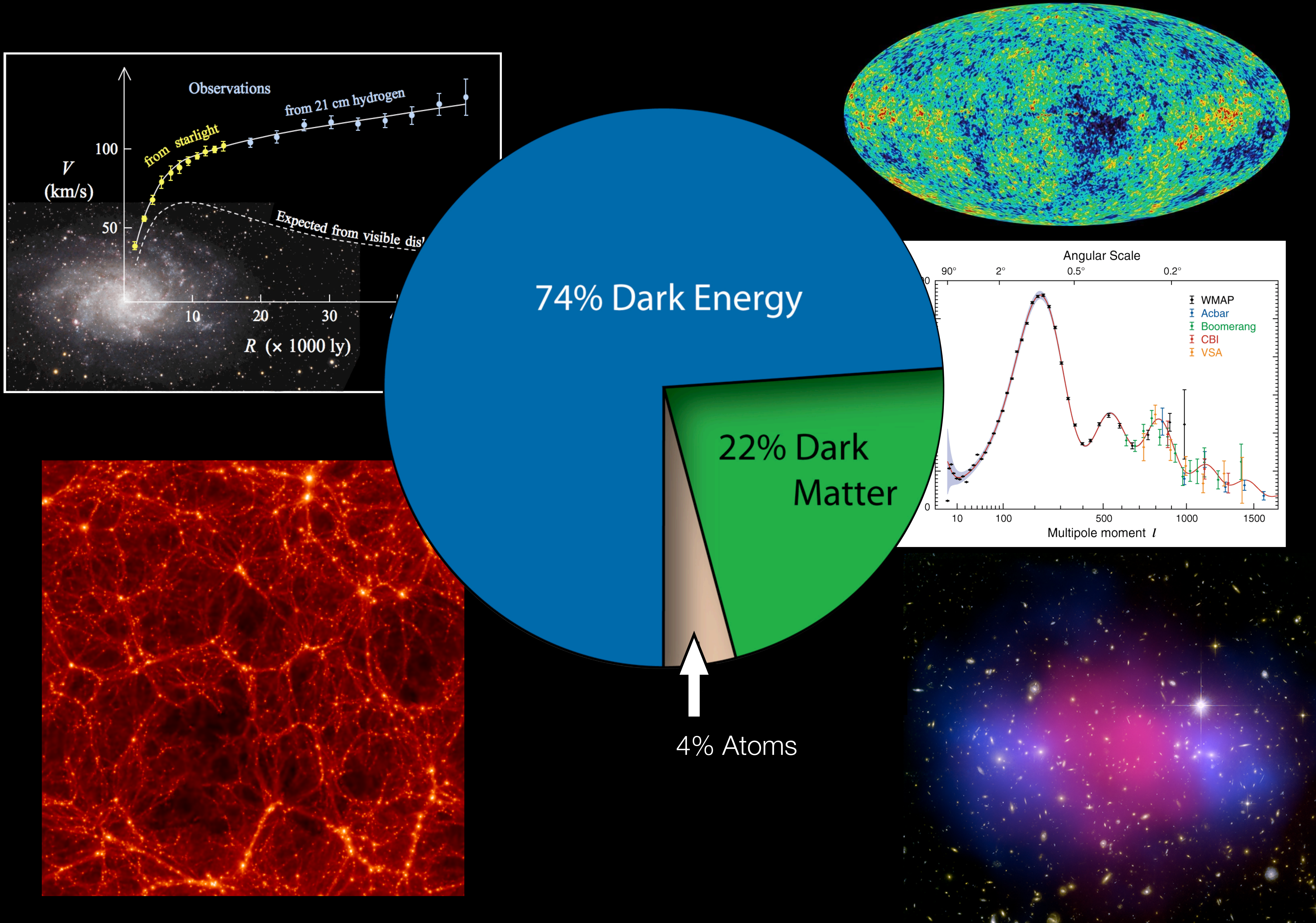







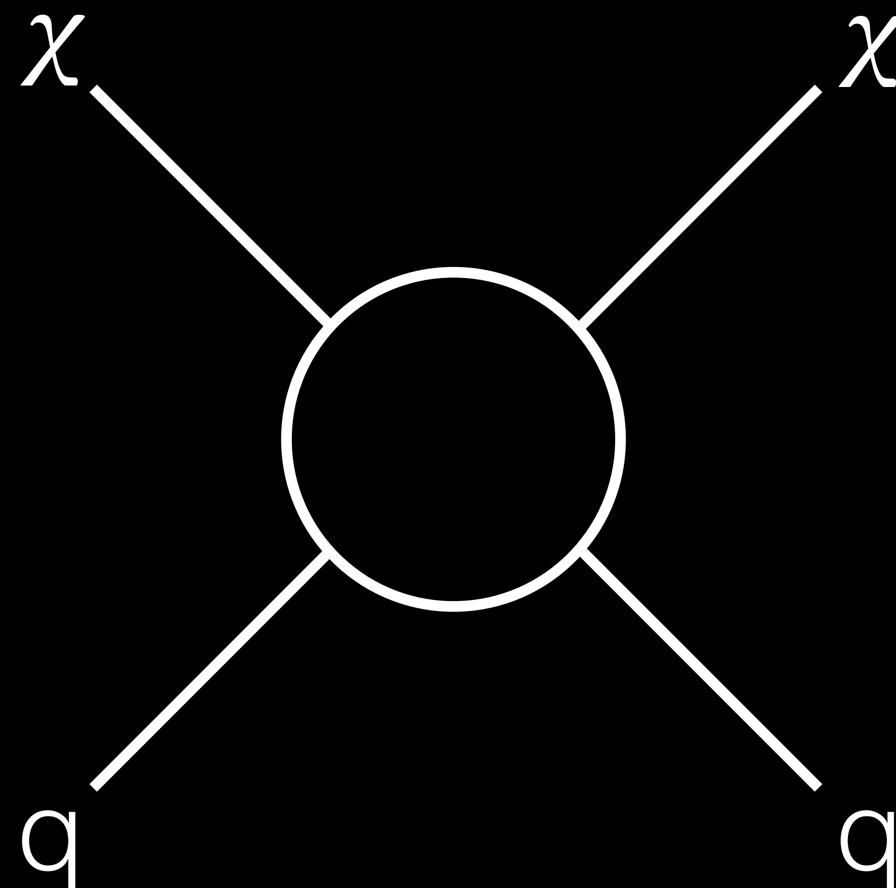
# Evidence for Dark Matter

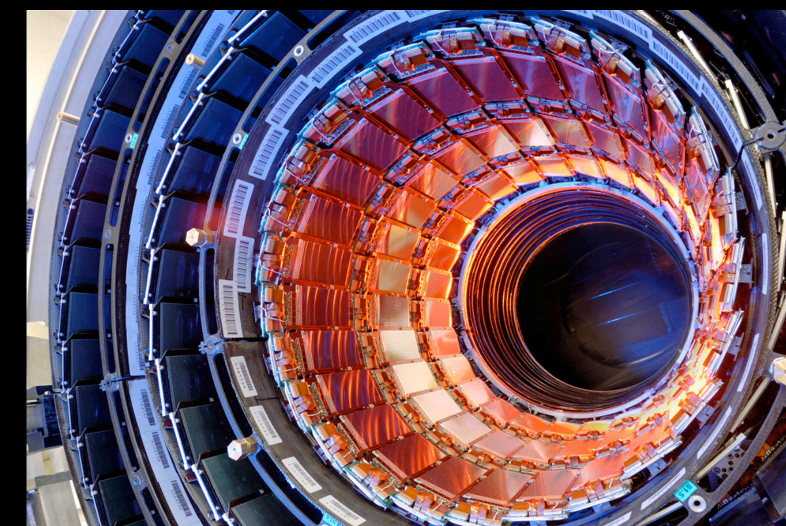


# Detecting WIMPs

Annihilation

Production

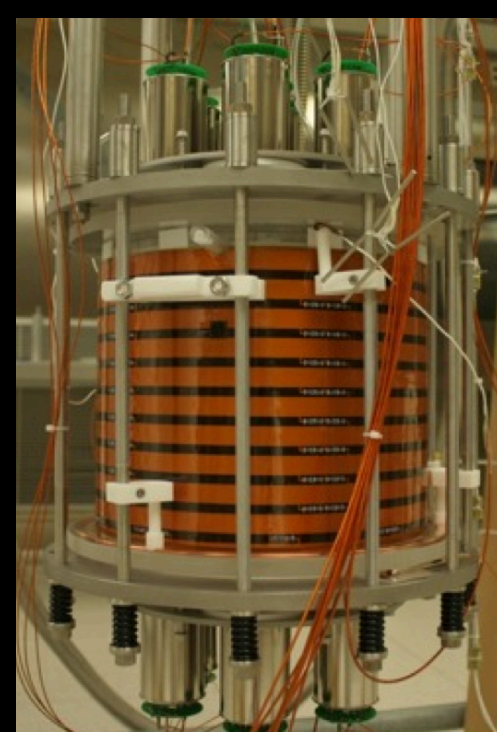


Indirect Detection

Colliders

Scattering



Direct Detection

# Direct Detection Rates

R (events/kg/yr) = $\langle \Phi_\chi \cdot \sigma_{\chi-N} \rangle \cdot n$

| | |
|---|---|
| $\Phi_\chi$ | Flux of WIMPS |
| $\sigma_{\chi-N}$ | WIMP-Nucleus Scattering Cross Section |
| $n$ | Target Nuclei / kg |

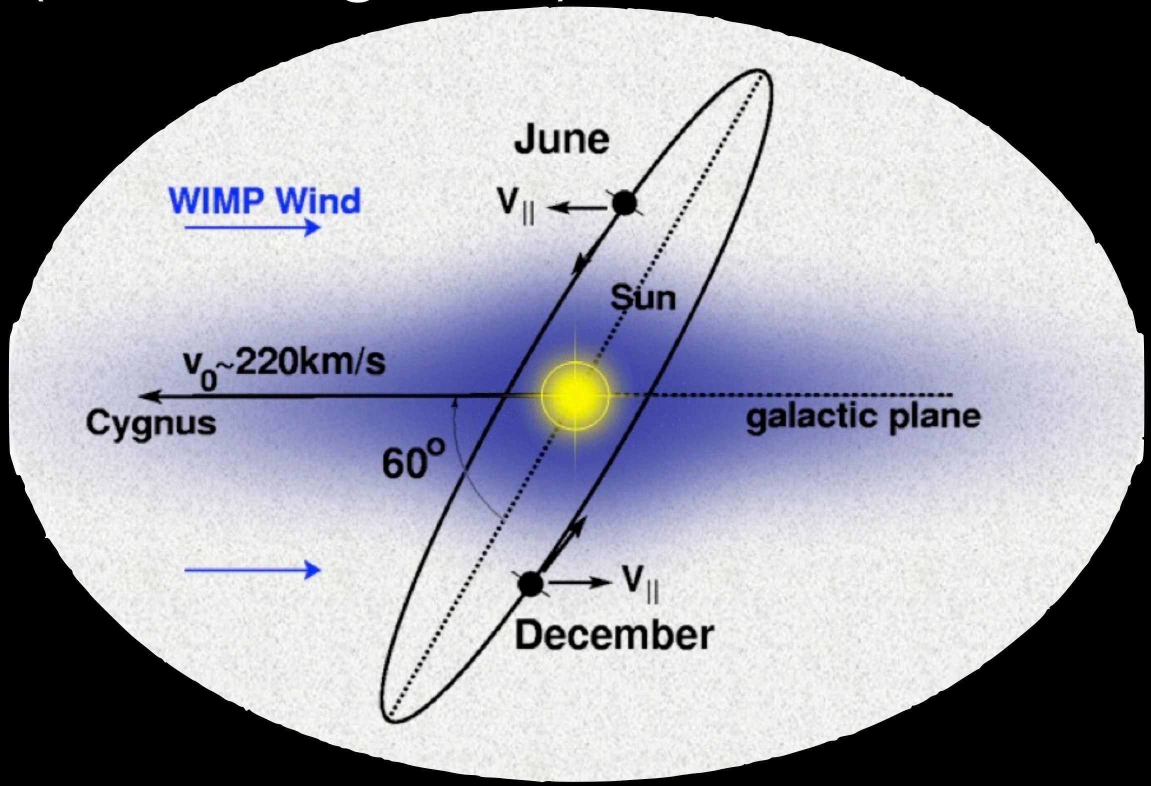
R (events/kg/yr) = $\langle \Phi \cdot \sigma \rangle \cdot n$

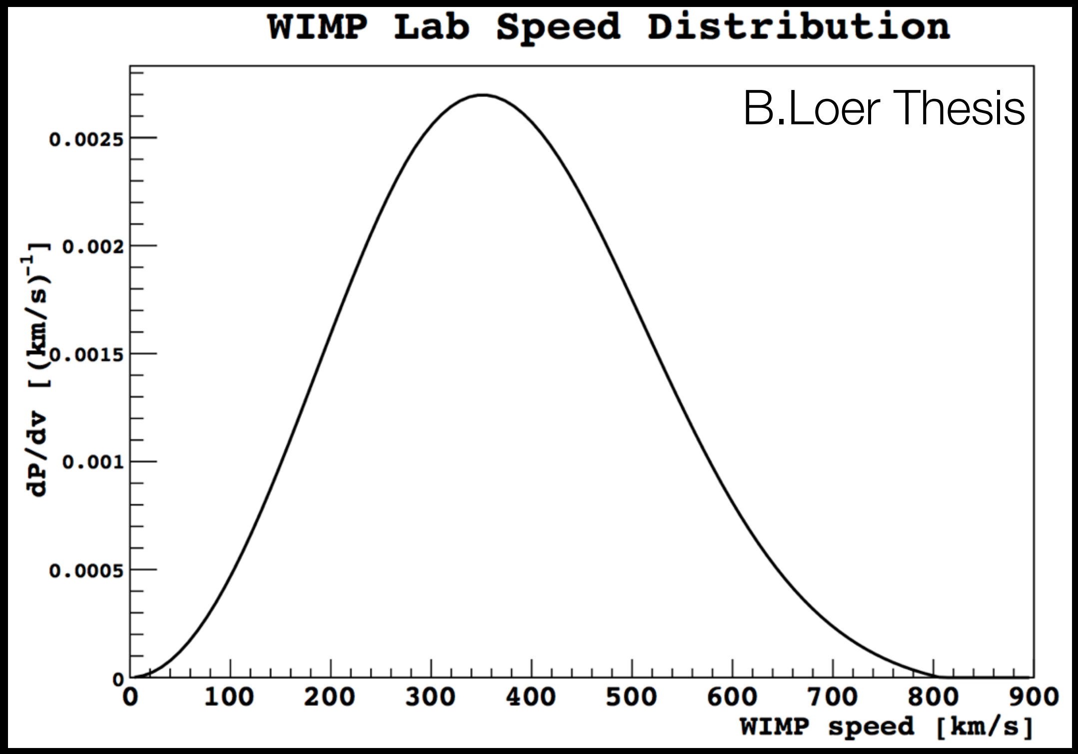
## Surrounded by a Dark Matter Halo

$$\Phi(v) = \frac{\rho_\chi}{m_\chi} v_\chi f(v_\chi, t)$$

Local density
~ 0.3 GeV/cm$^3$
(5x10$^{-25}$ g/cm$^3$)

Maxwellian Velocity Distribution
Local speed ~ 220 km/s
Escape Velocity ~ 500 - 600 km/s



$$\text{R (events/kg/yr)} = \langle \Phi \cdot \boxed{\sigma} \rangle \cdot n$$

# WIMP - Nucleus SI Scattering Cross-Section

$$\sigma(v_\chi) \propto \frac{M_N}{\mu_n^2 v_\chi^2} \cdot \sigma_n \cdot A^2 \cdot F^2(q)$$

WIMP-Nucleon Cross-Section

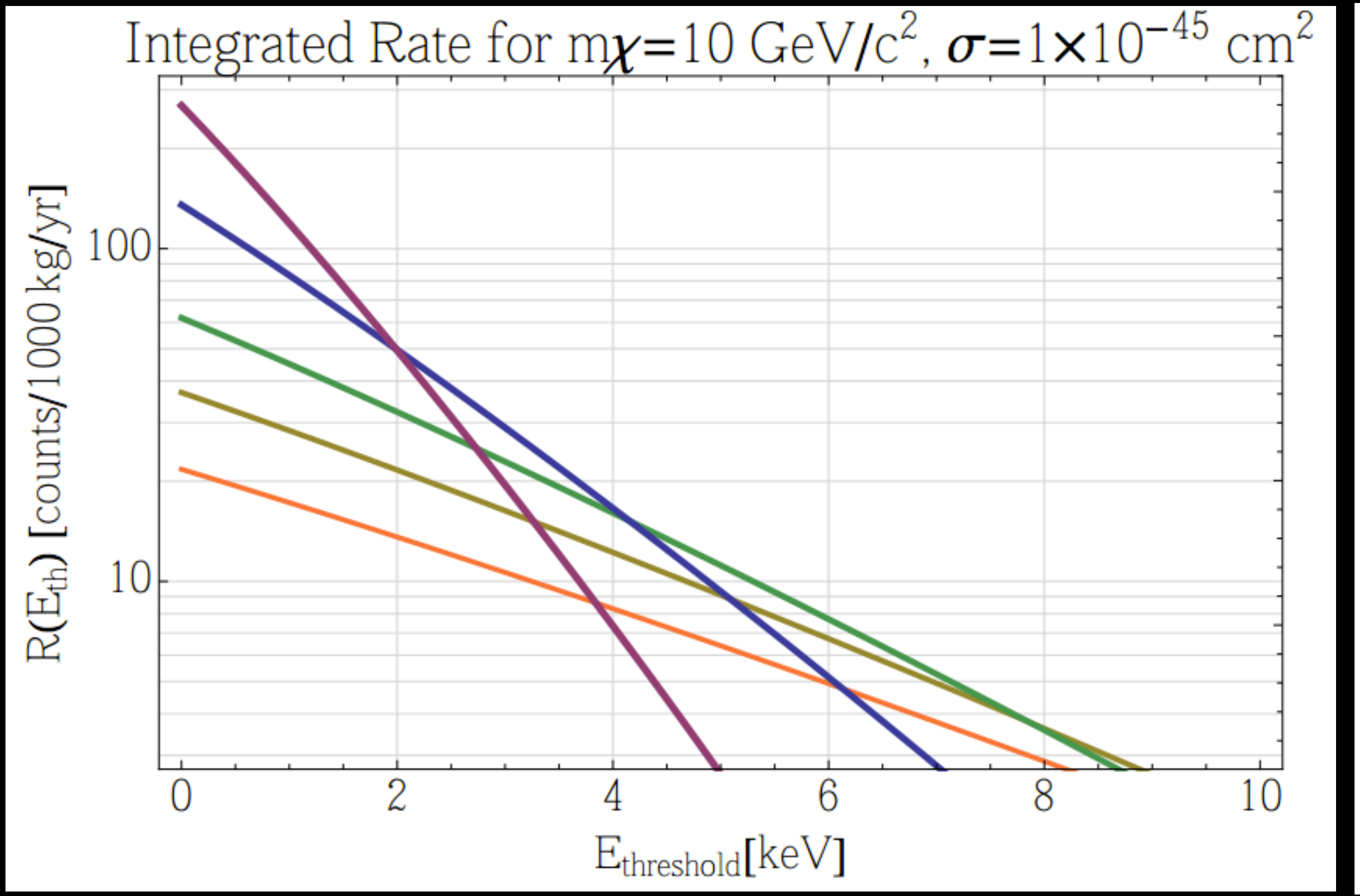
Coherent Scattering over entire nucleus for zero-momentum transfer (assumes same interaction for neutrons and protons)

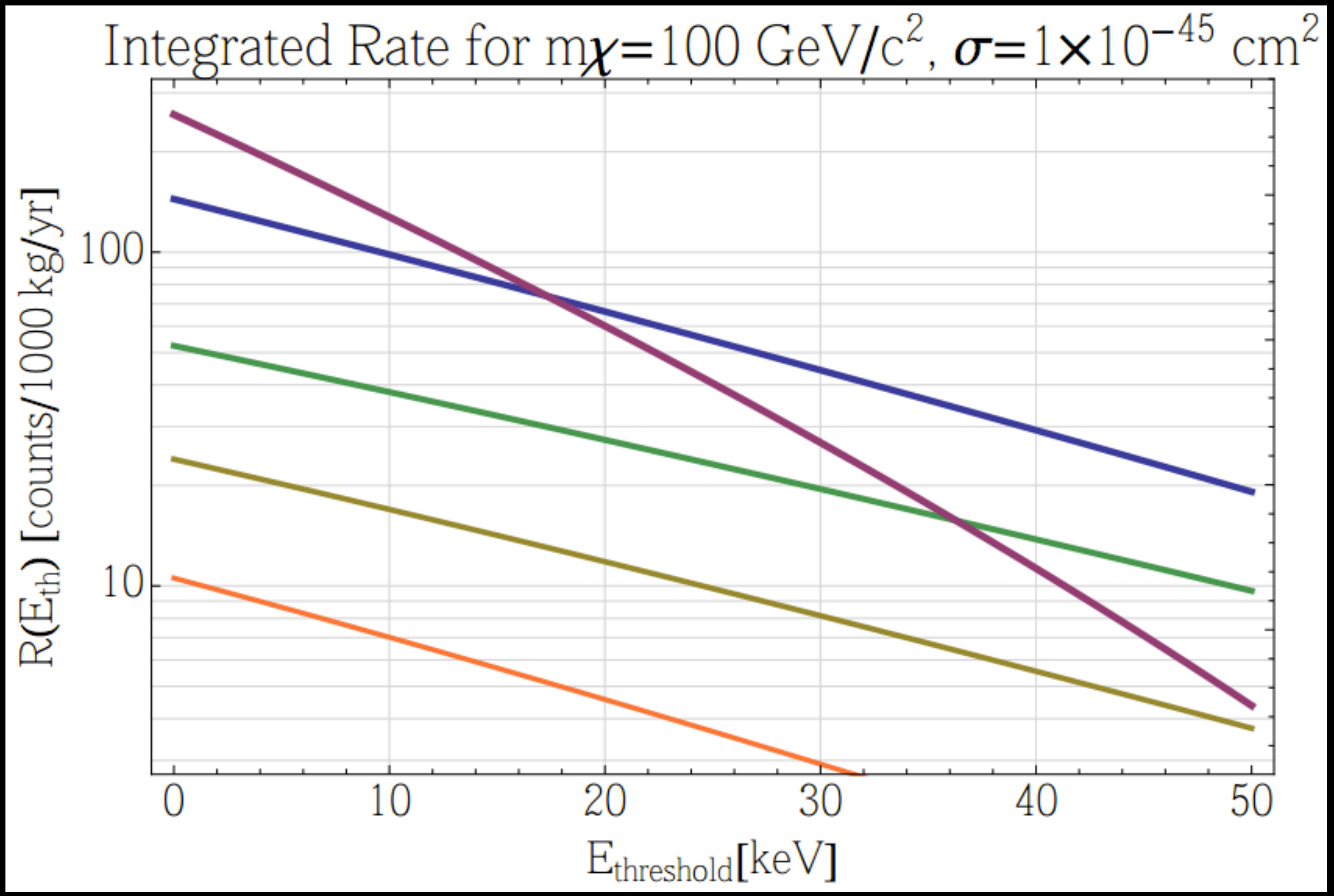
Nuclear Form Factor Correction for decoherence at non-zero momentum transfer

# Interaction Rates

Ge Xe Ar Si Ne

10 GeV, $10^{-45}$ cm$^2$ 100 GeV, $10^{-45}$ cm$^2$




arXiv:1310.8327v2 [hep-ex]

Total Interaction Rate ~ $10^{-4}$ ev/kg/day

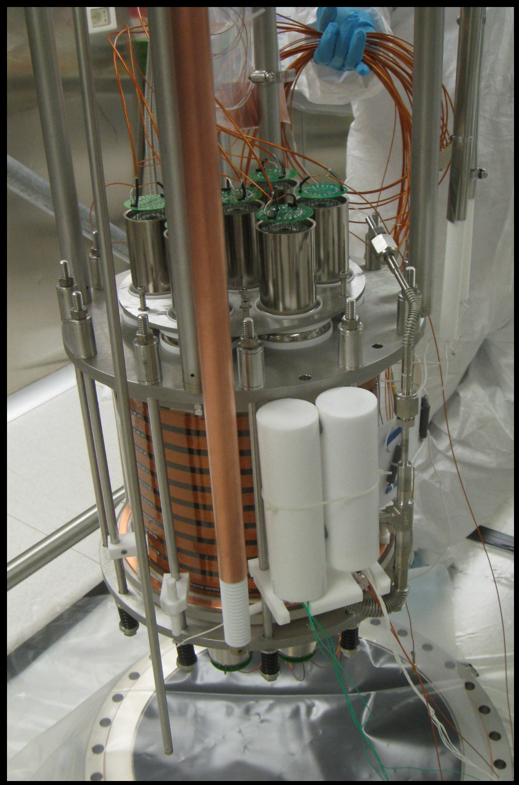
Rock Natural Radioactivity ~ $10^{7}$ ev/kg/day

# DarkSide Program

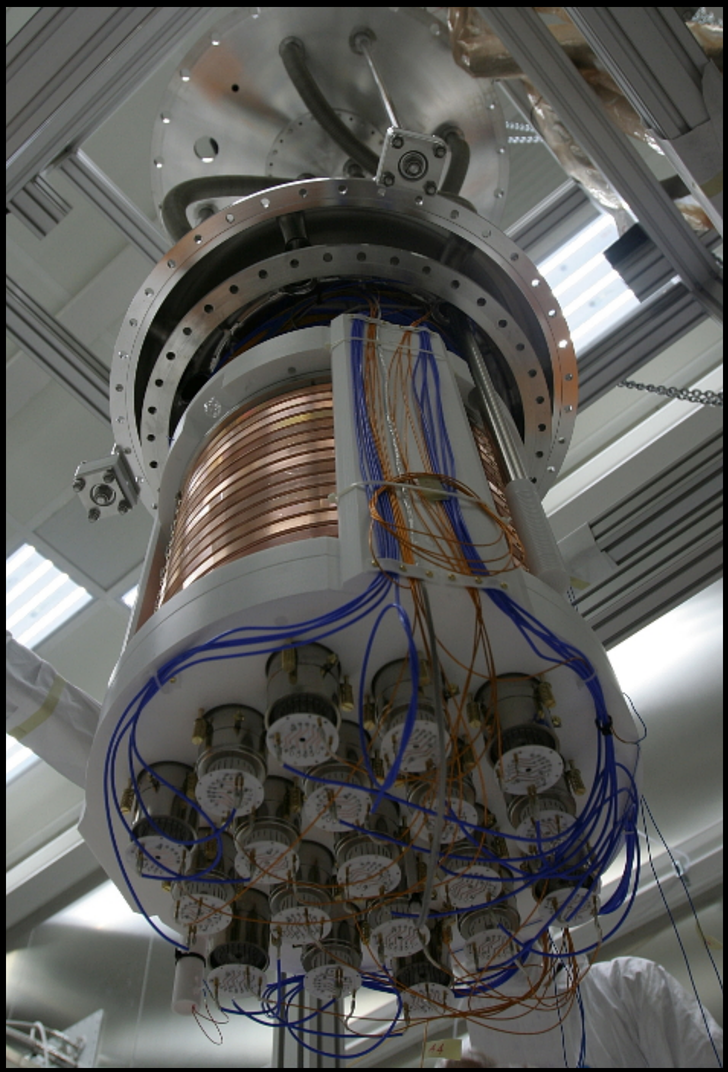
- Direct detection search for WIMP dark matter
- Based on a two-phase argon time projection chamber (TPC)
- Design philosophy based on having very low background levels that can be further reduced through active suppression, for background-free operation

# DarkSide Program

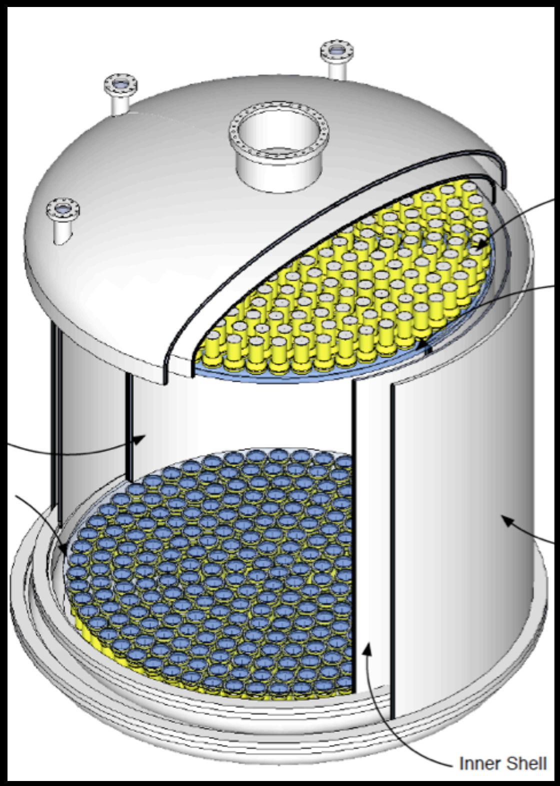
Multi-stage program at Gran Sasso National Laboratory



DarkSide 10
Prototype detector



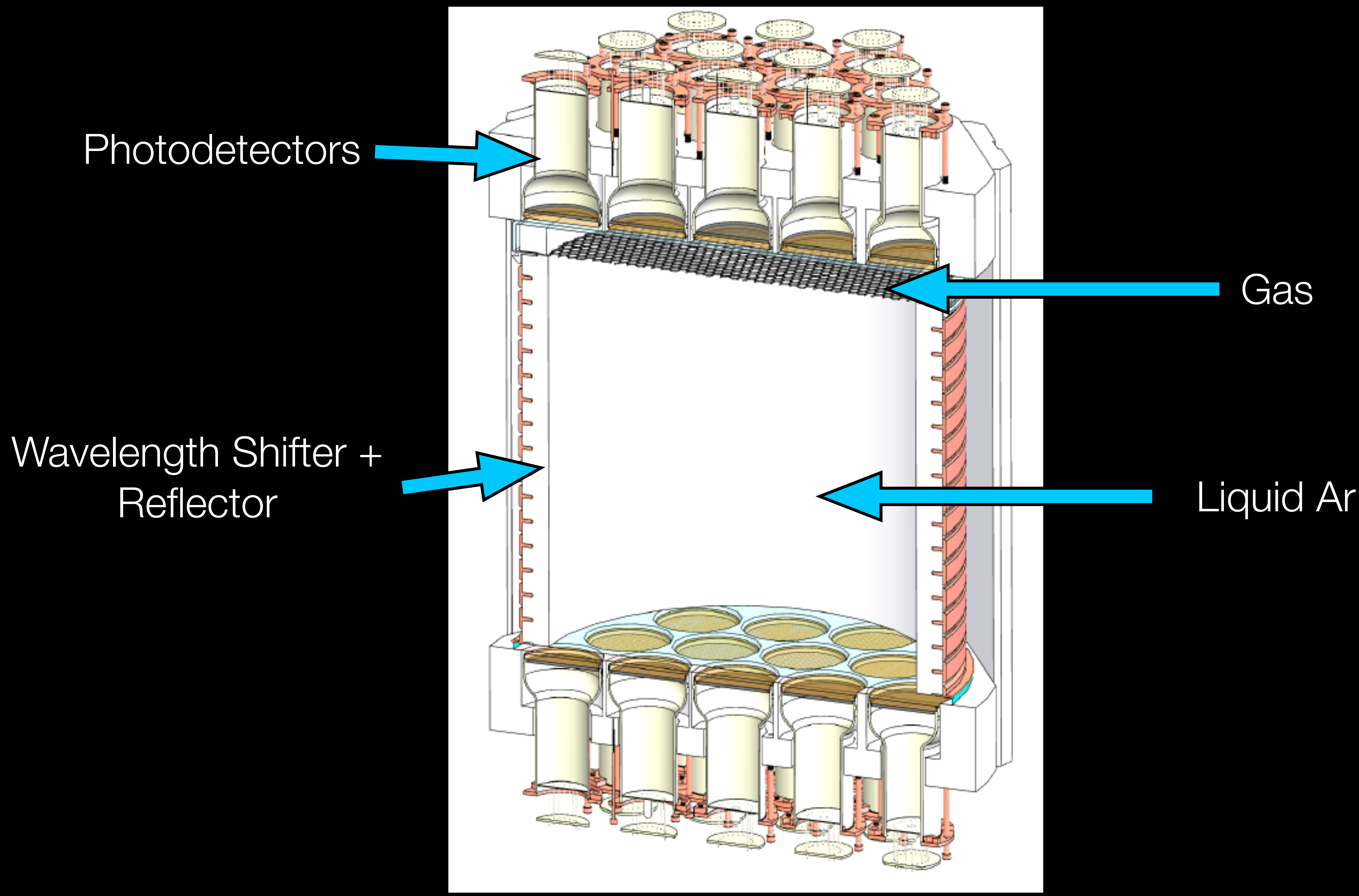
DarkSide 50
First physics detector
Recently commissioned



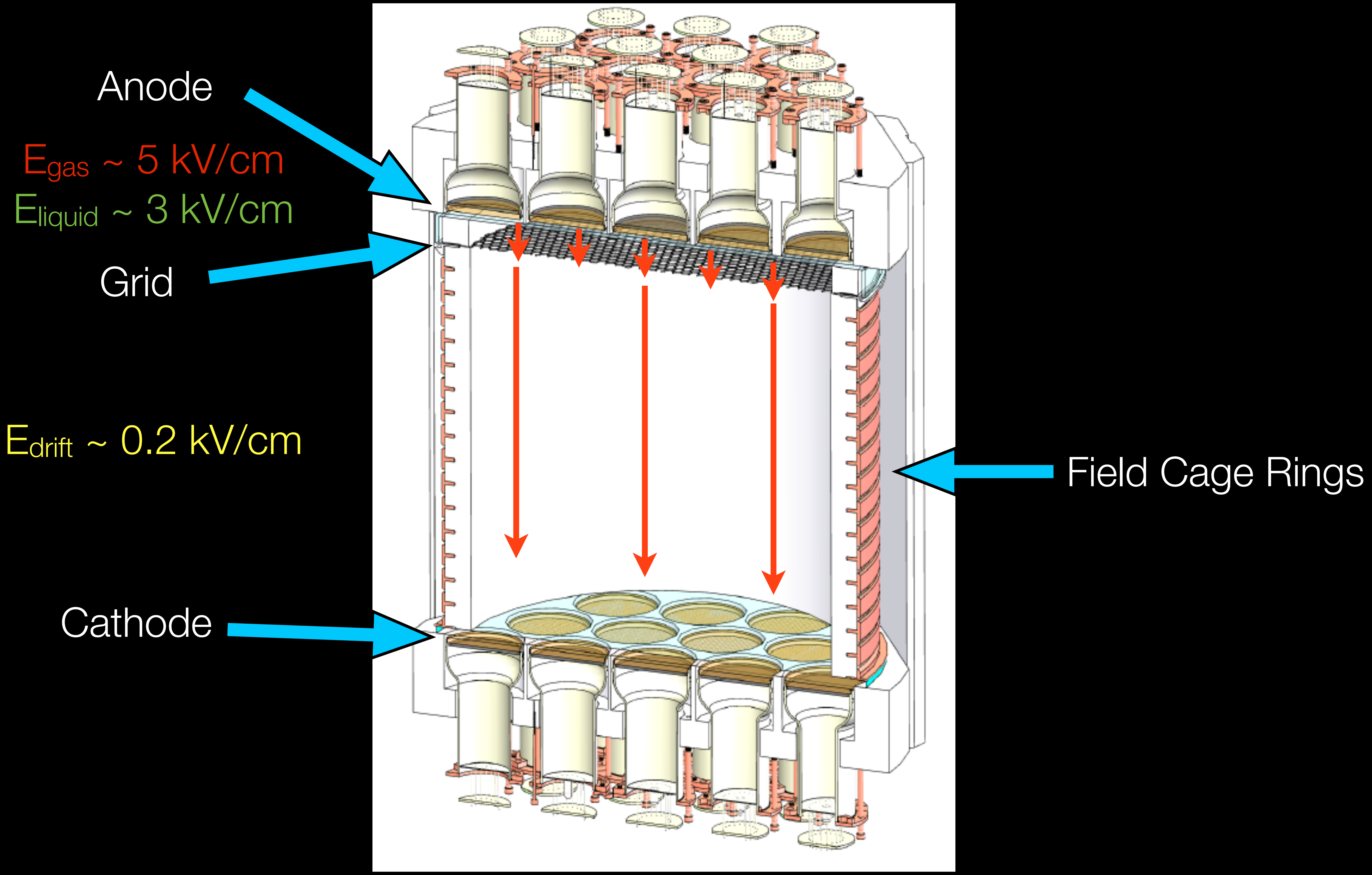

DarkSide G2
Future multi-ton detector

+ multiple smaller test setups and prototypes

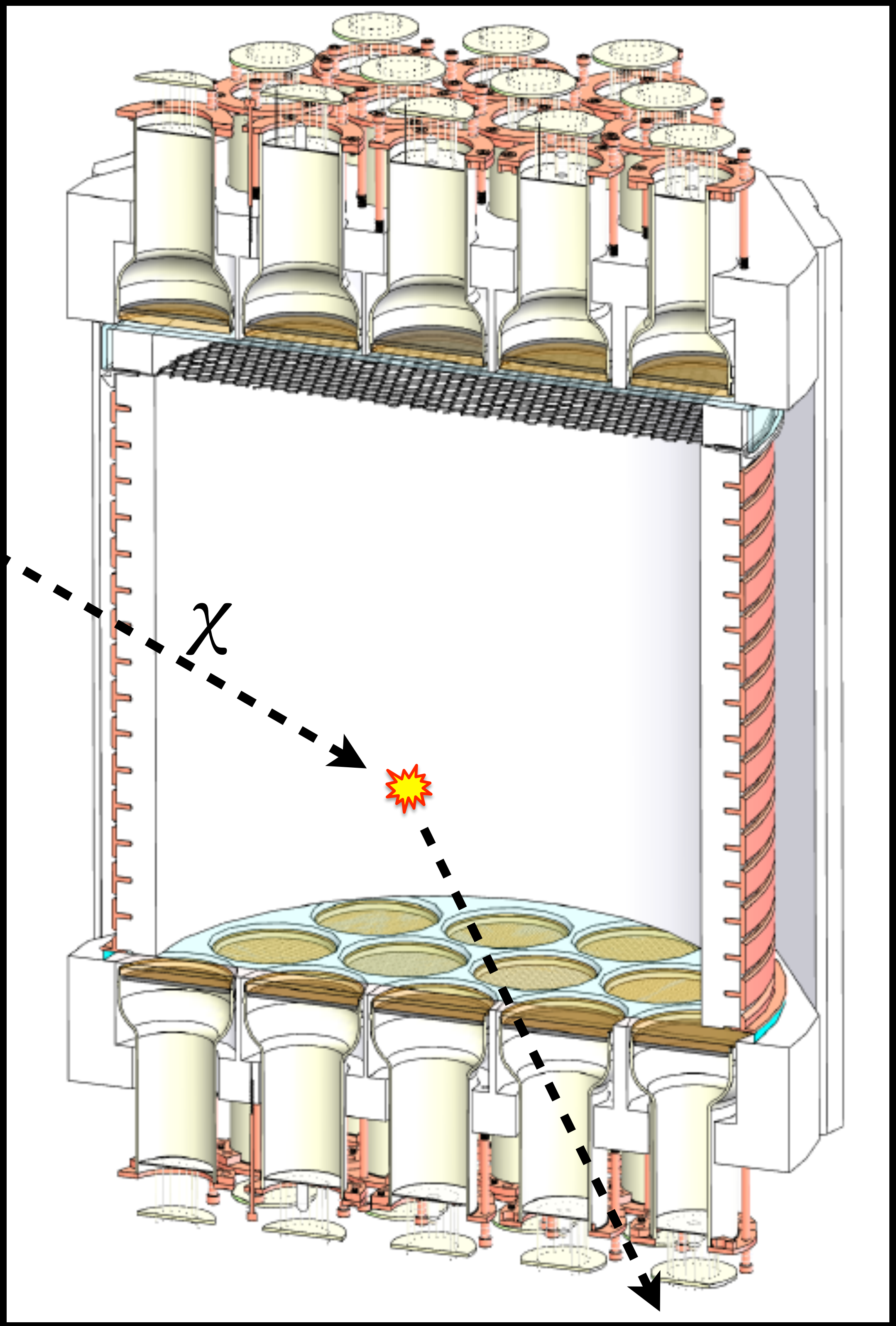
# Two Phase Argon TPC



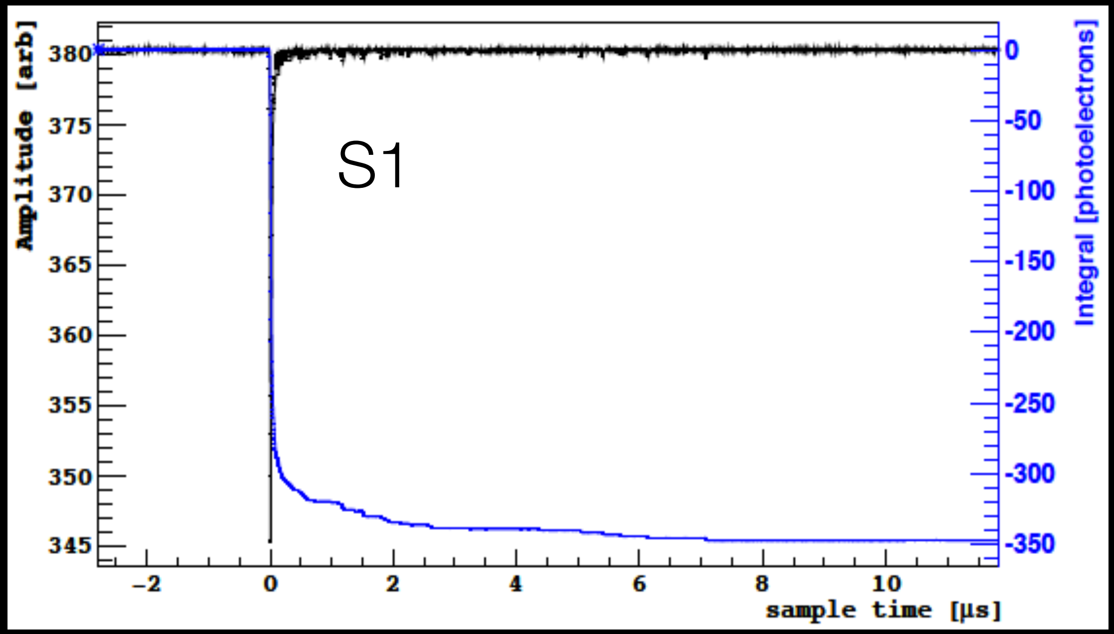
# Two Phase Argon TPC



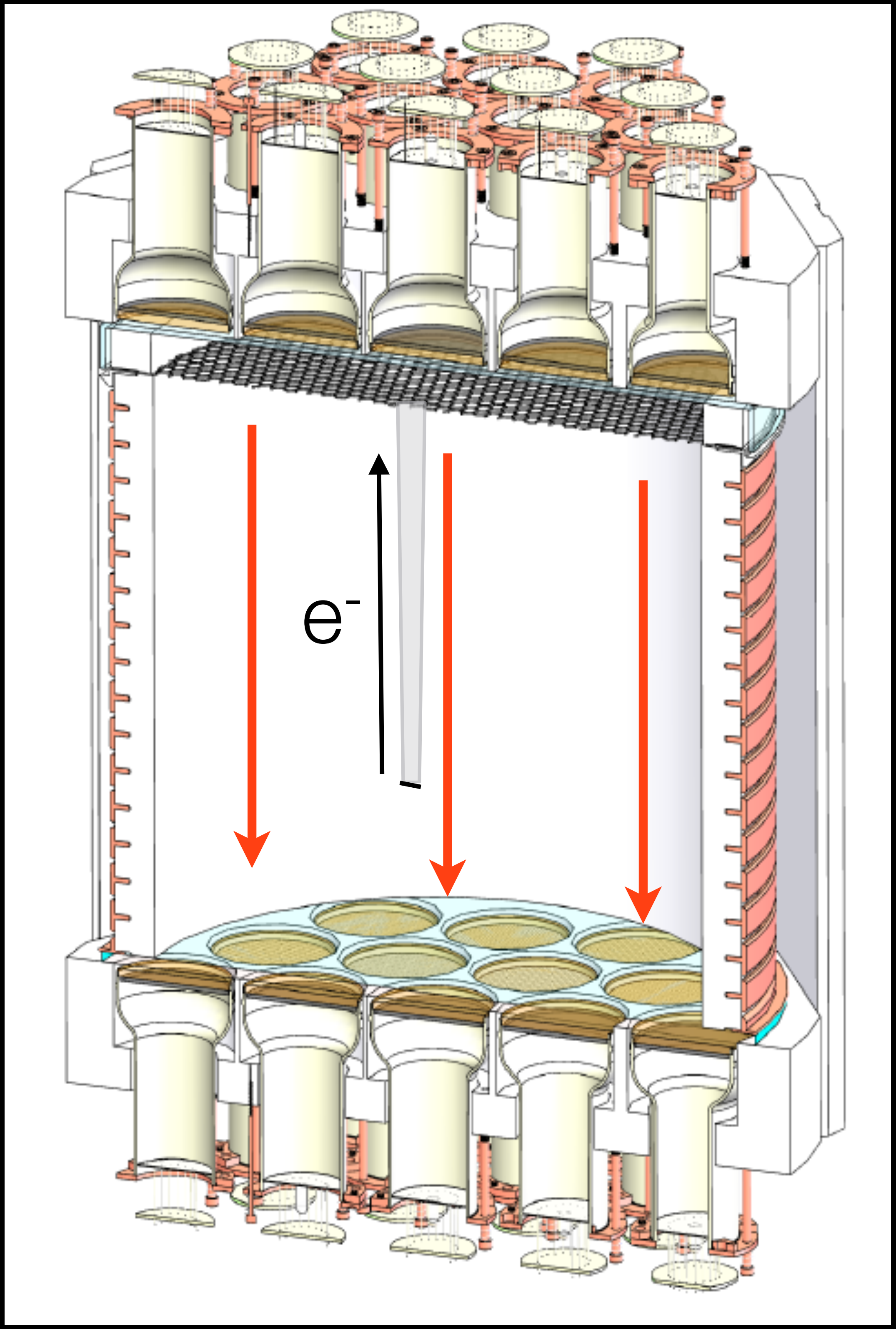
# Detecting WIMPs




Nuclear Recoil excites and ionizes the liquid argon, producing scintillation light (S1)that is detected by the photomultipliers

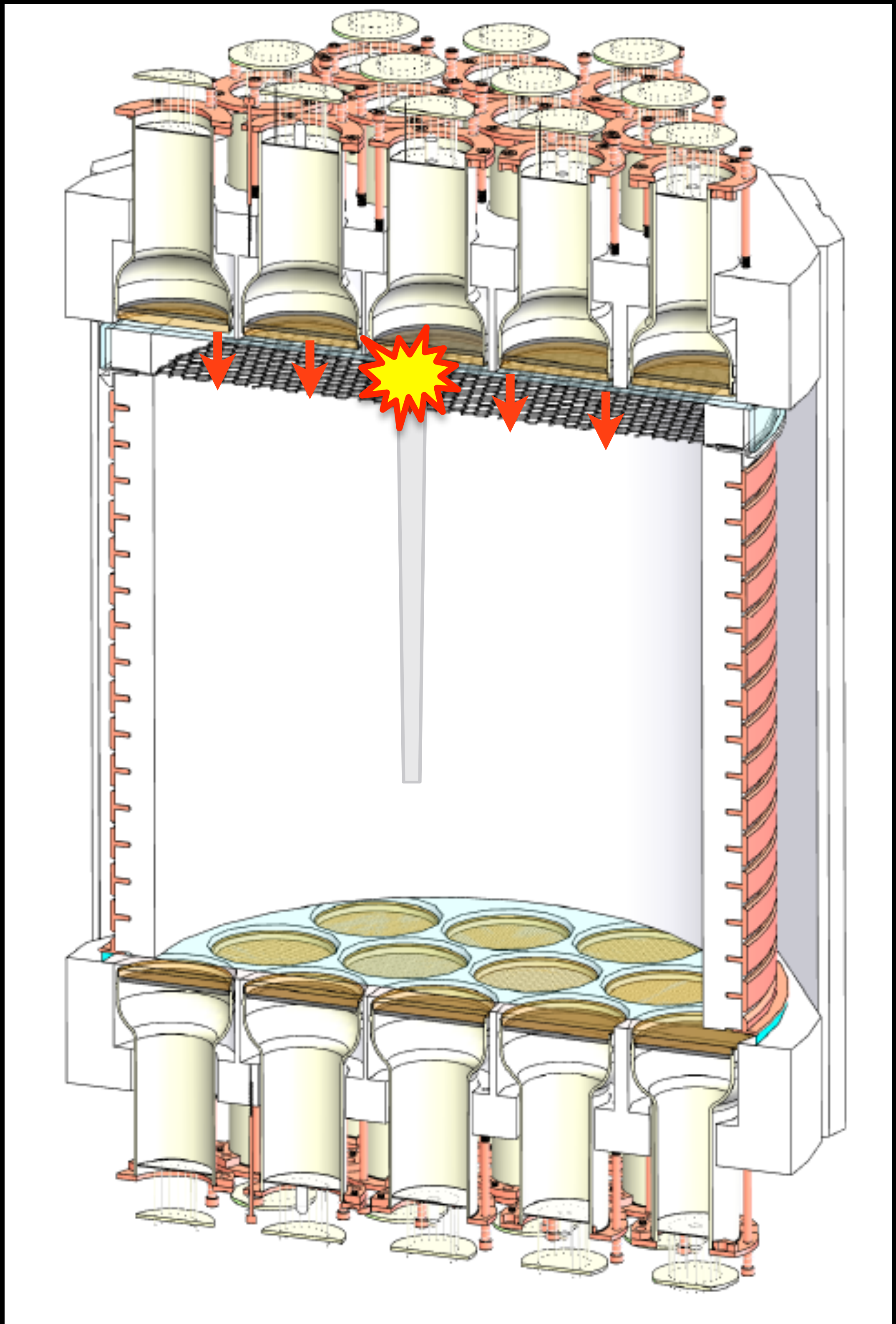


# Detecting WIMPs

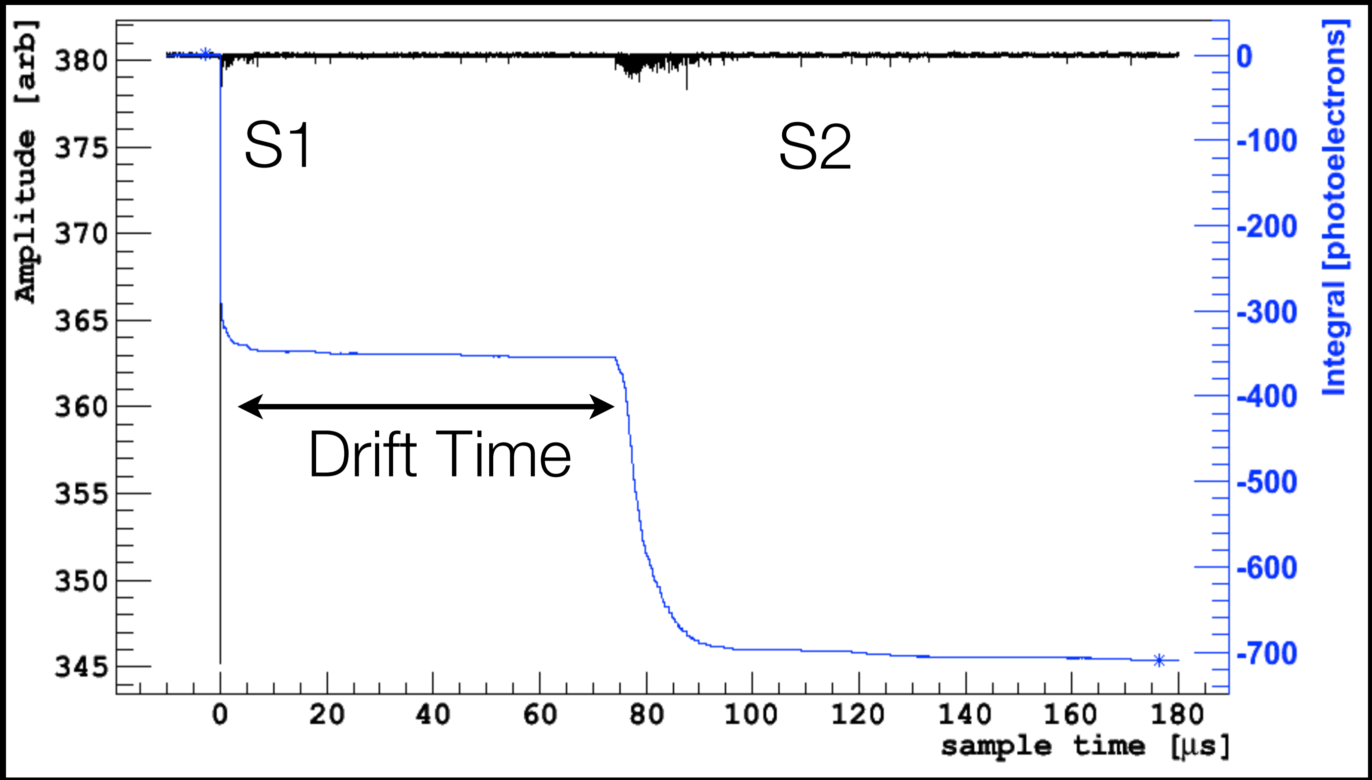



The ionized electrons that survive recombination are drifted towards the liquid-gas interface by the electric field

# Detecting WIMPs



The electrons are extracted into the gas region, where they induce electroluminescence (S2)




The time between the S1 and S2 signals gives the vertical position

# DarkSide 10

7x 3” PMTs

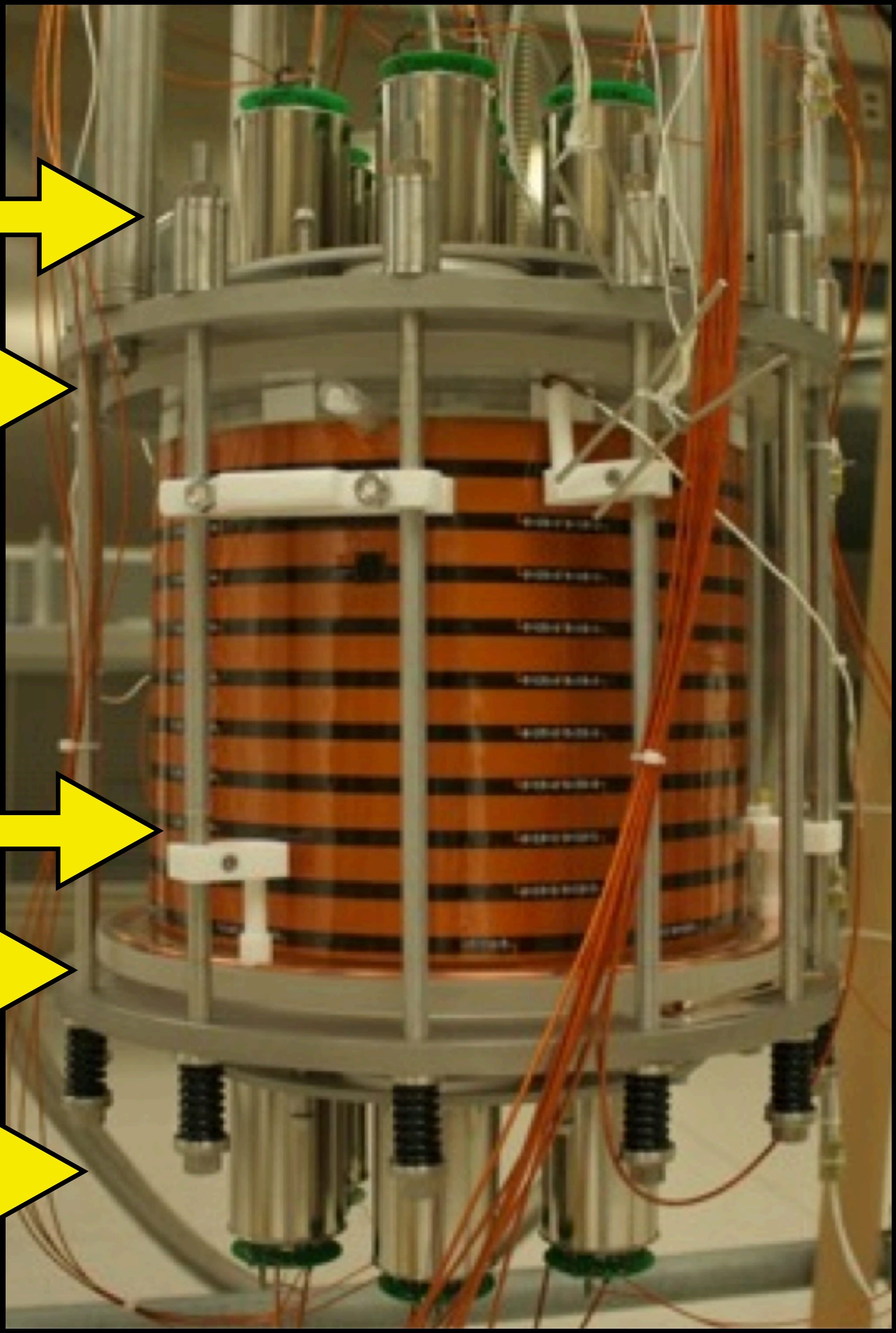
TPB + ITO coated quartz window

Acrylic cylinder
with TPB-coated reflector

Flexible PCB field cage

TPB + ITO coated quartz window

7x 3” PMTs



# DarkSide 10

First designed, built and operated at Princeton University

Moved underground at Gran Sasso to operate in a low-background environment

Dedicated campaigns to test light collection, high voltage and other technical solutions for future detectors

# DS-10 Performance

- Compare performance of different reflectors for light collection
  Detector run with both 3M foils (~ 9 p.e./keV$_{ee}$) and highly crystalline PTFE (~ 7 p.e/keV$_{ee}$)†

- Study feasibility of ITO coatings

- Test HHV system (feedthroughs, grid etc.)
  Detector running without problems at nominal field configuration (1 kV/cm drift, 3.8 kV/cm extraction, -35 kV)

- Perform calibration of detector
  Calibrations performed with external γ and neutron sources.

†Astroparticle Physics, Volume 49, 2013, Pages 44-51

# DarkSide-50

(50 kg active mass)

- First physics-capable detector
- All components were chosen/designed to have the lowest possible radioactivity (including the active target !)
- Auxiliary detectors to identify and veto residual backgrounds

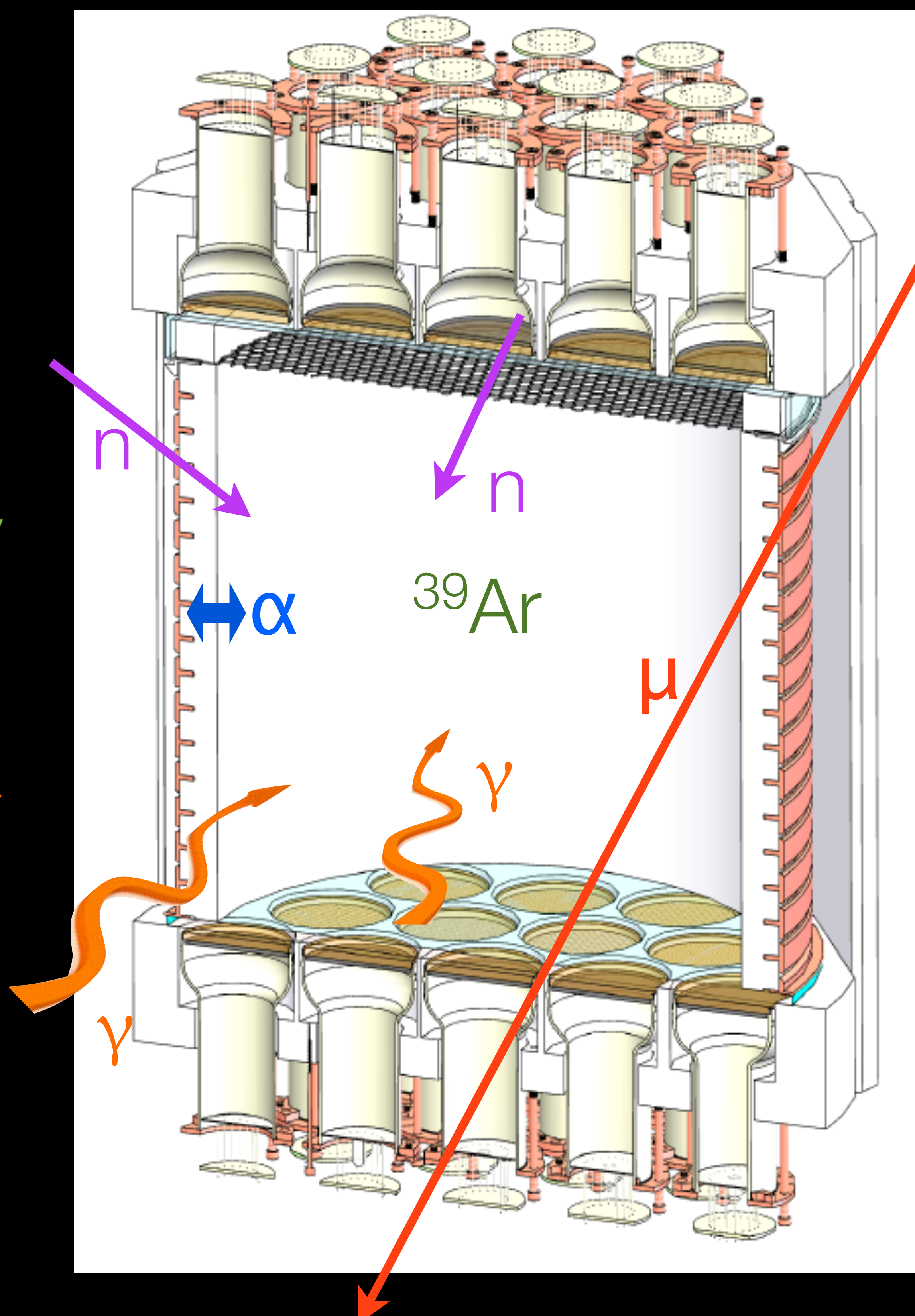
# Backgrounds

[30-200 ]keVr

## ELECTRON RECOILS

$^{39}$Ar
~1x10$^{4}$ ev/kg/day

γ
~1x10$^{2}$ ev/kg/day




## NUCLEAR RECOILS

μ
~30 ev/m$^{2}$/day

Radiogenic n
~6x10$^{-4}$ ev/kg/day

α

~10 ev/m$^{2}$/day

100 GeV, 10$^{-45}$cm$^{2}$ WIMP Rate ~ 10$^{-4}$ ev/kg/day

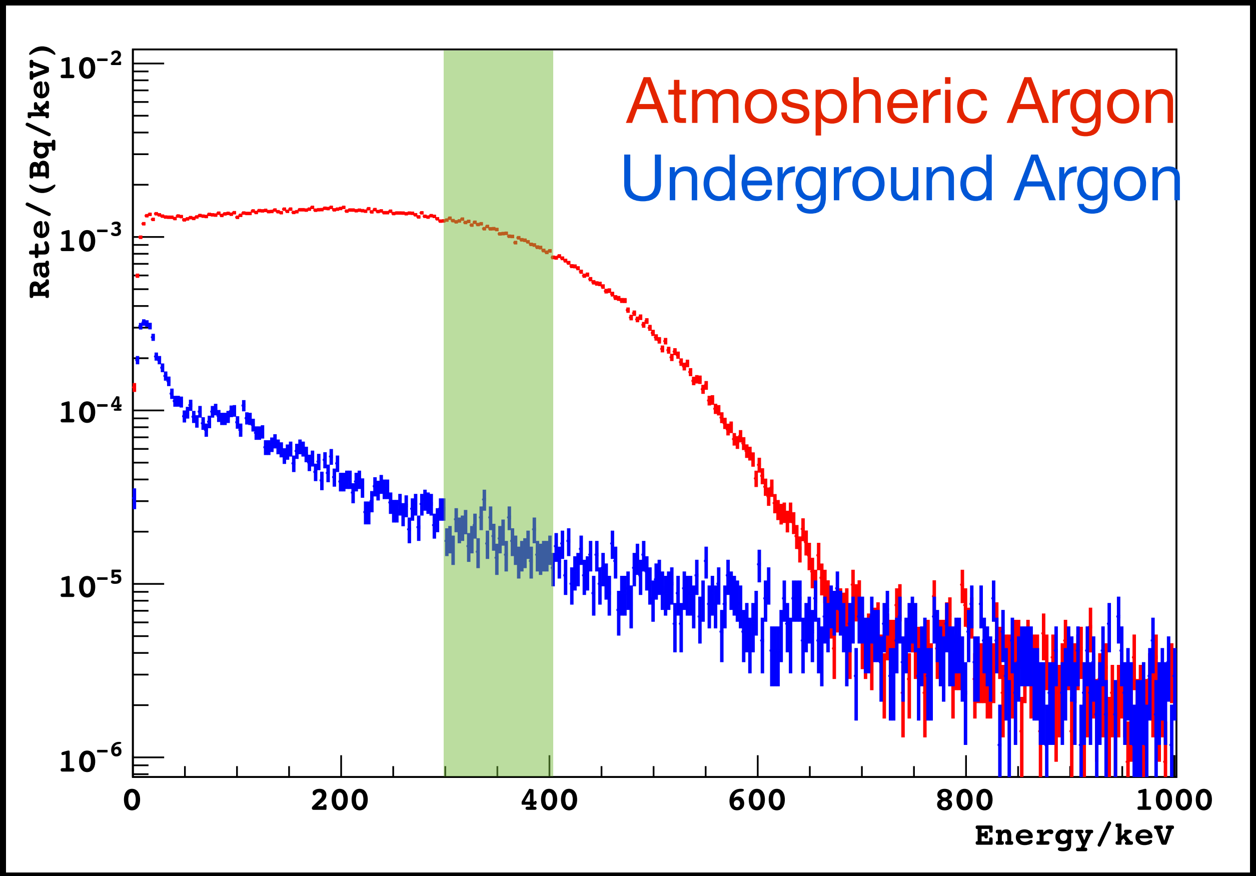
# $^{39}$Ar

- Intrinsic $^{39}$Ar radioactivity in atmospheric argon is the primary background for argon-based detectors
- $^{39}$Ar activity sets the dark matter detection threshold at low energies (where pulse shape discrimination is ineffective)
- $^{39}$Ar is a cosmogenic isotope, and the activity in argon from underground sources can be significantly reduced compared to atmospheric argon

# Underground Argon Measurement

Low background LAr detector was operated underground at KURF with both atmospheric and underground argon

arXiv:1204.60111 [physics.ins-det]



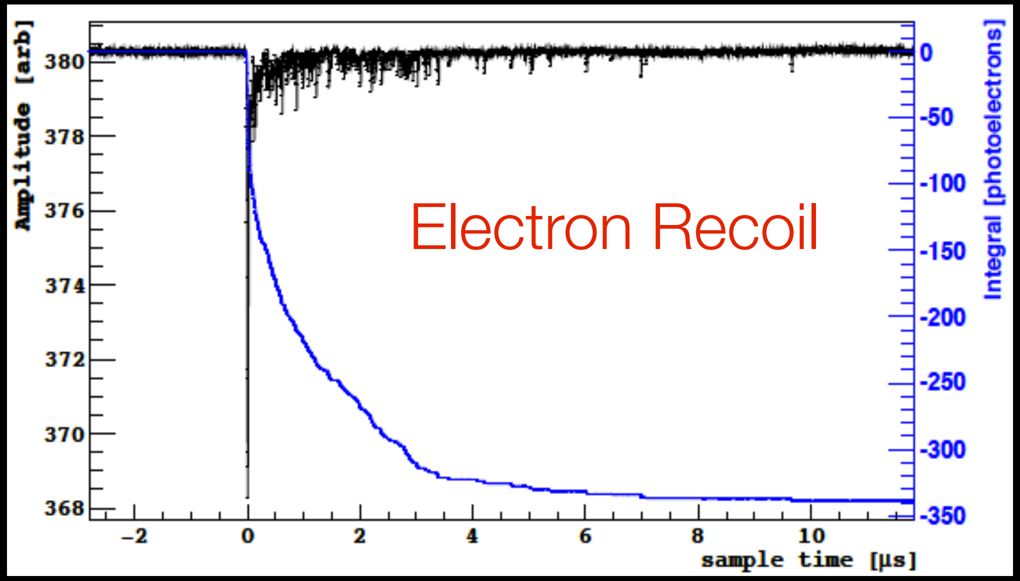

| | Total Rate [mBq/100 keV] | Estimated Background Rate [mBq/100 keV] | Background Subtracted Rate [mBq/100 keV] |
|---|---|---|---|
| Underground Argon | 1.87 +/- 0.06 | 1.5 +/- 0.2 | 0.32 +/- 0.23 |
| Atmospheric Argon | 108.8 +/- 0.4 | | 107.2 +/- 1.9* |
| $^{39}$Ar Depletion Factor | 1.71 +/- 0.05 % | | < 0.65 % (95 CL) |

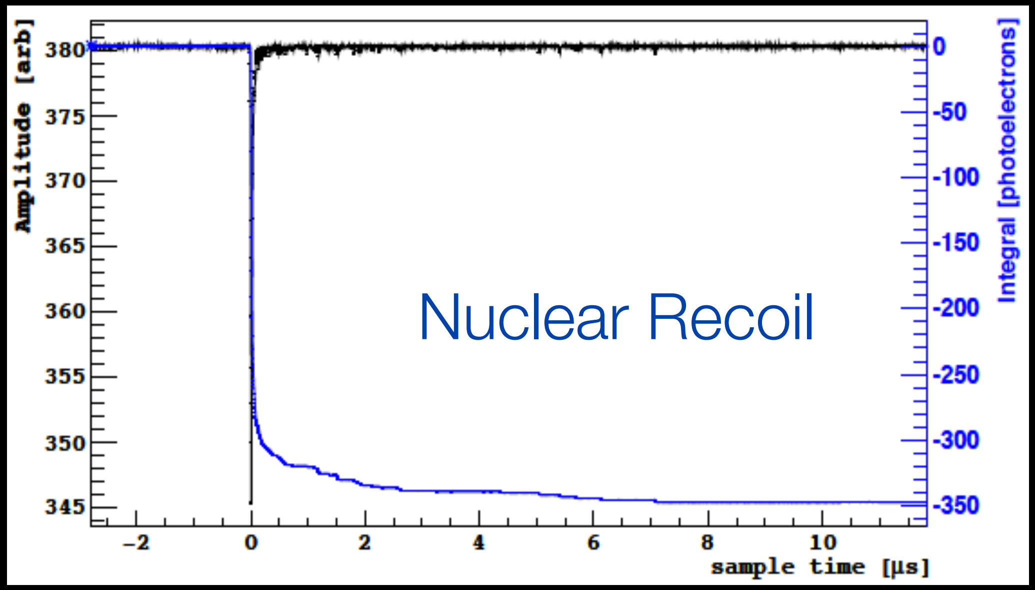
* Includes $^{85}$Kr upper limit

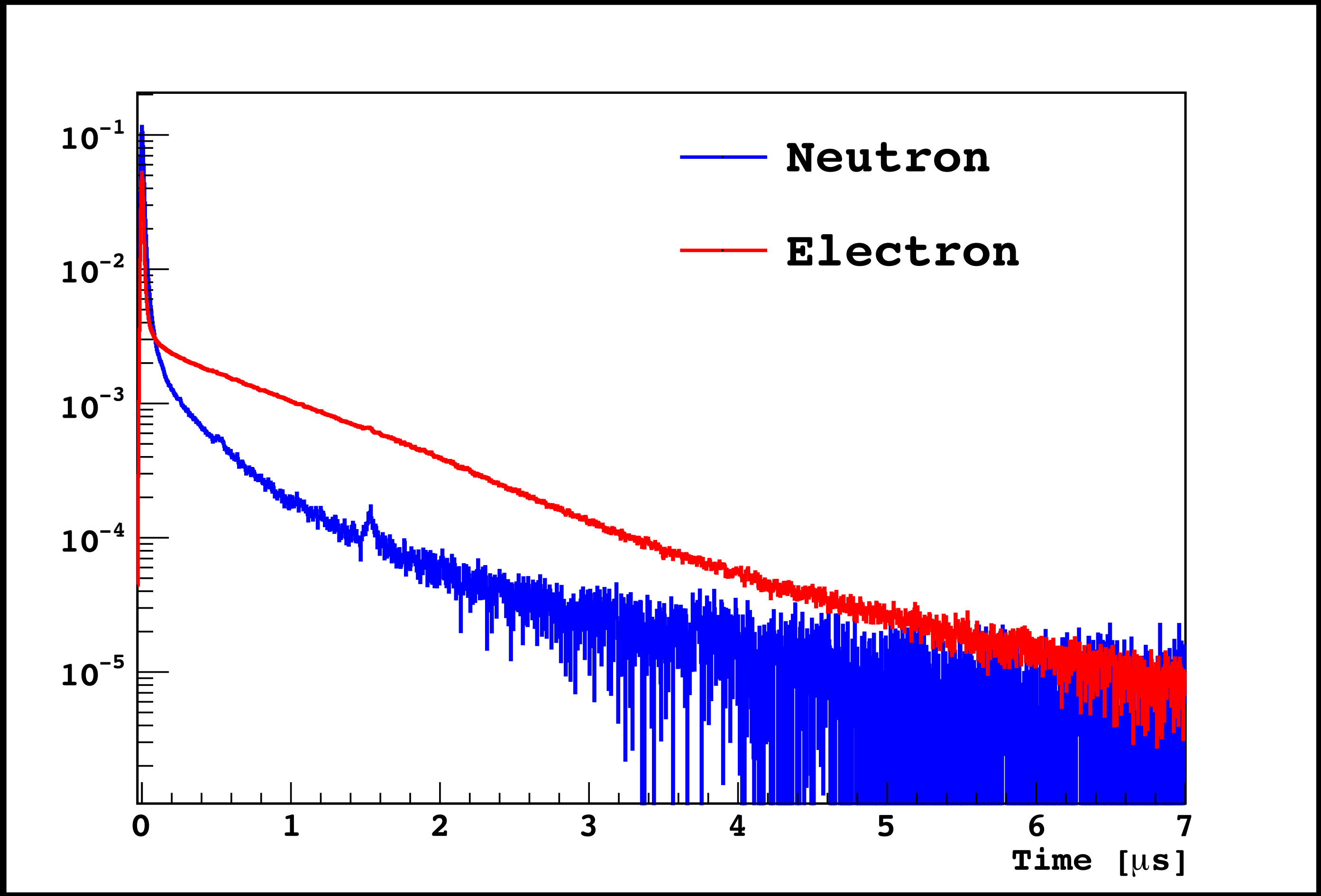
# Pulse Shape Discrimination

Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states

$\tau_{singlet} \sim 7$ ns
$\tau_{triplet} \sim 1600$ ns



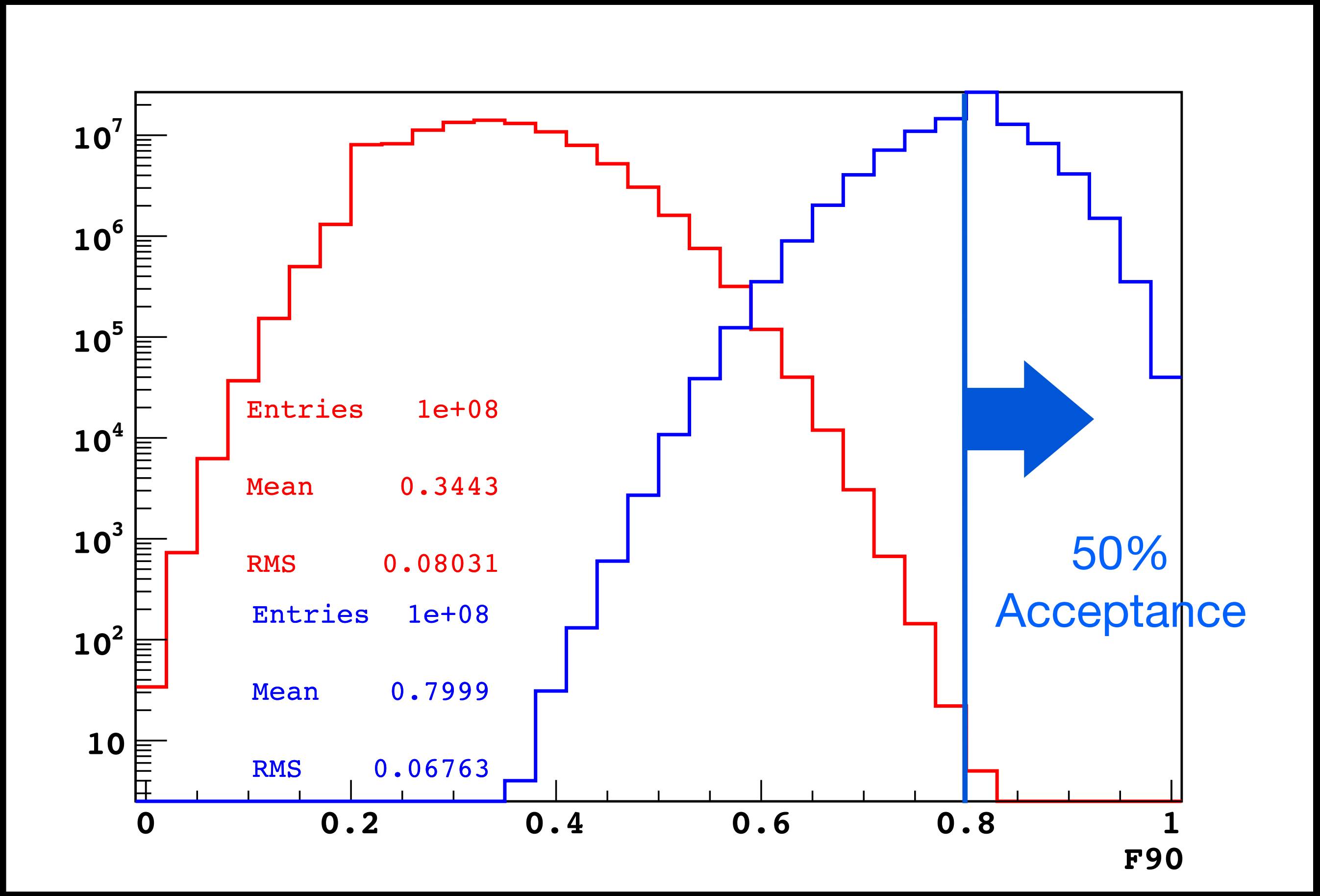
# Pulse Shape Discrimination

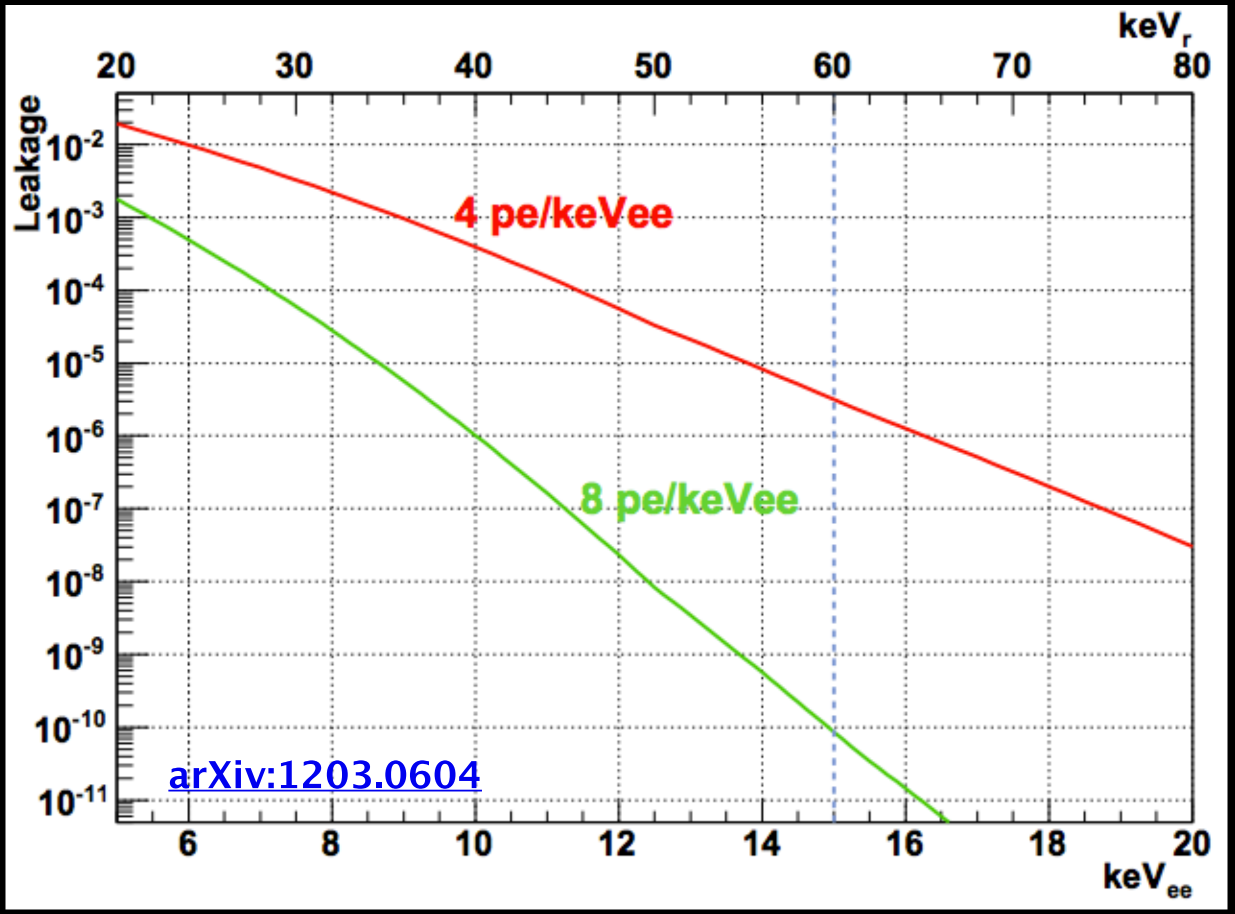
F90: Ratio of detected light in the first 90 ns, compared to the total signal

$\tau_{singlet} \sim 7$ ns

$\tau_{triplet} \sim 1600$ ns

F90 ~ Fraction of singlet states

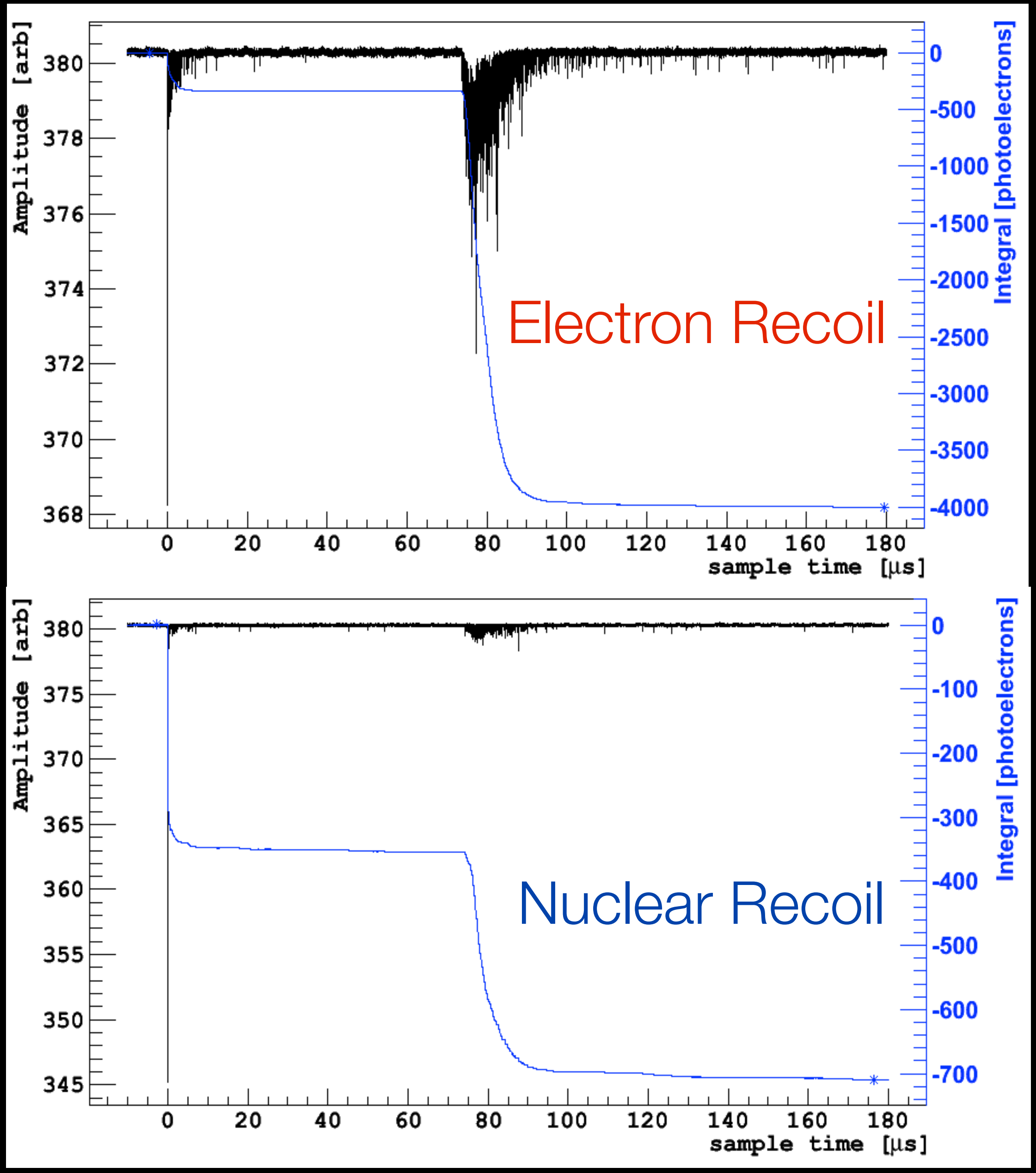


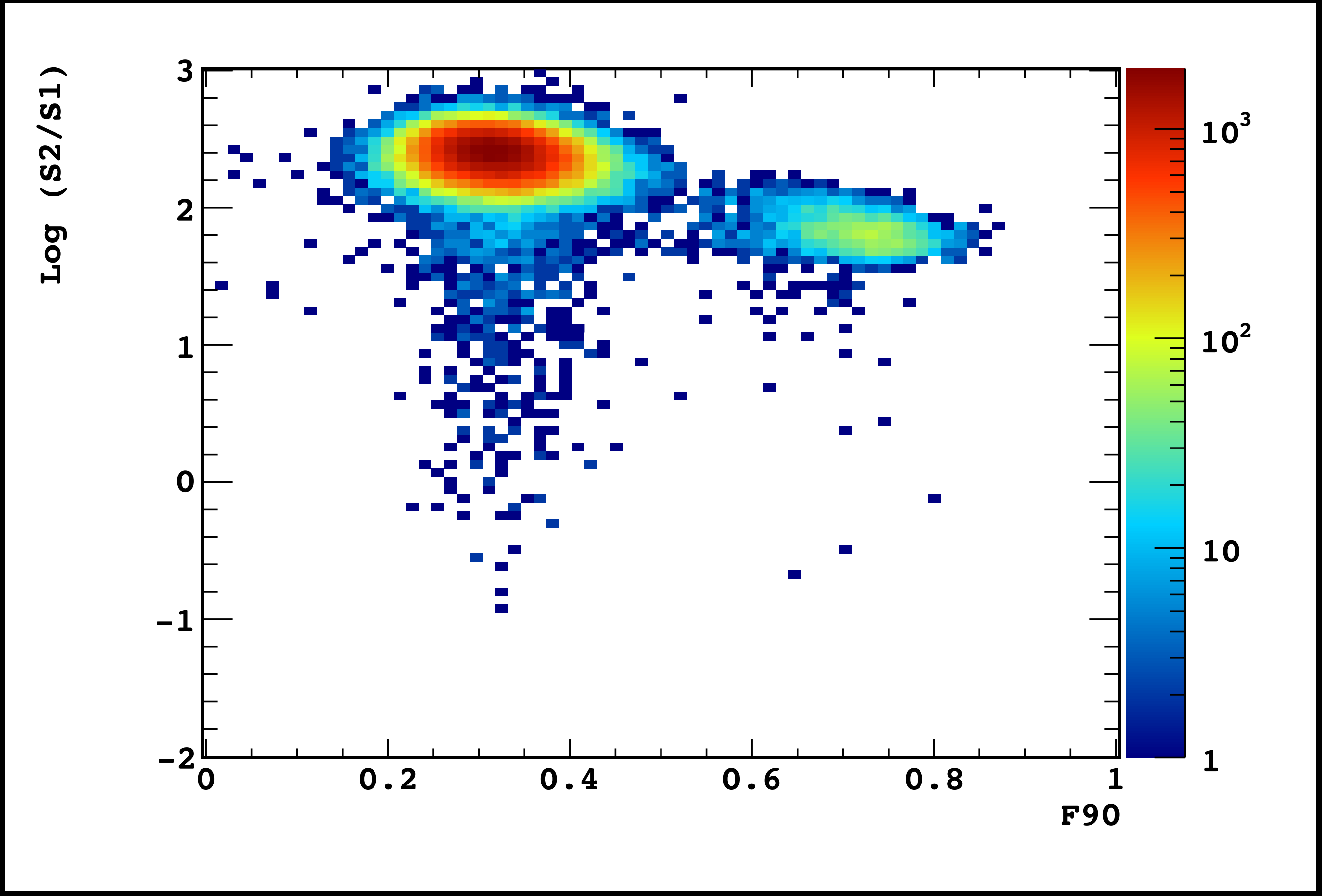




Discrimination power strongly dependent on light collection

# S2/S1

Electron and nuclear recoils produce different ionization densities that lead to different fractions of electrons that survive recombination



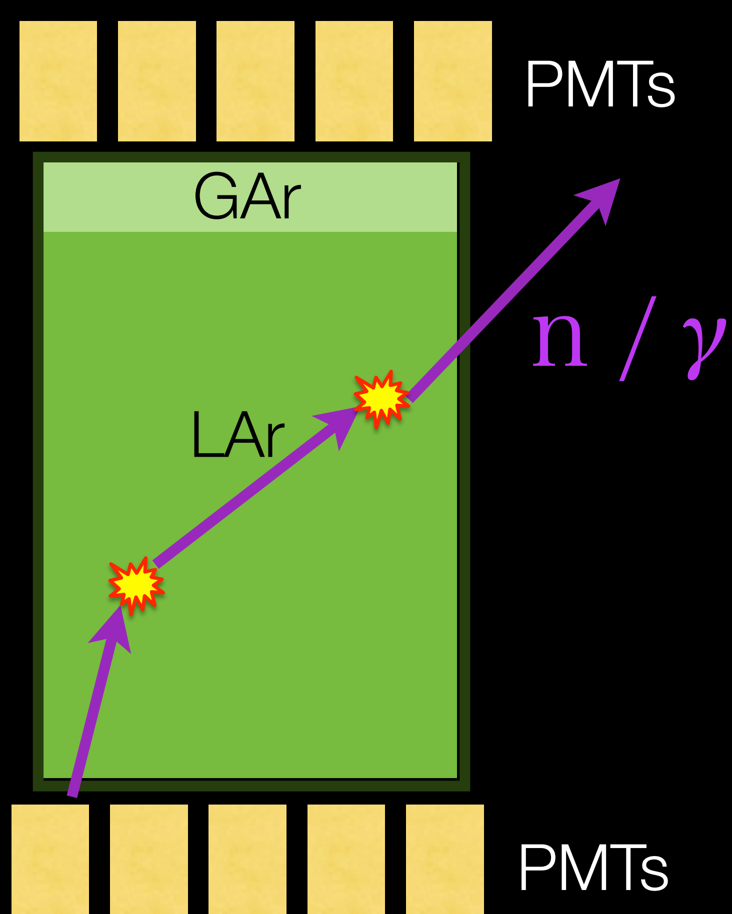



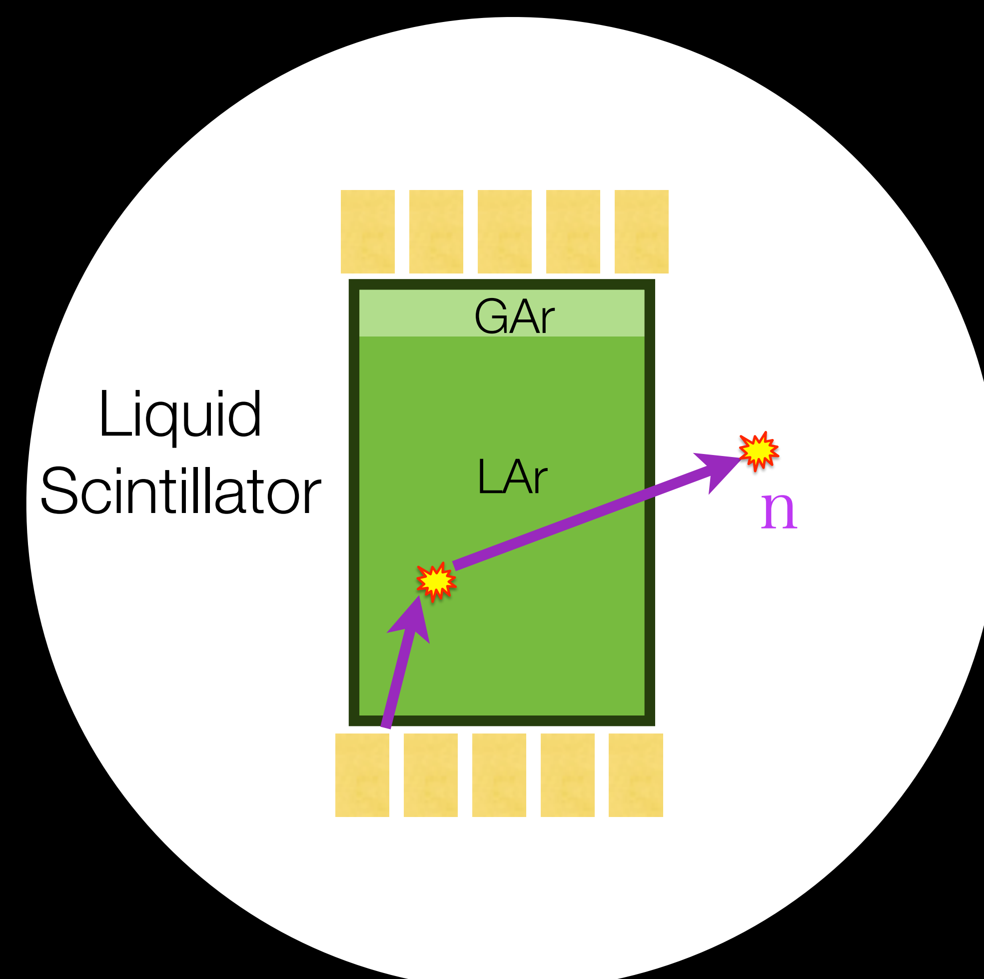

Am-Be Source

Ratio of ionization and scintillation signal (S2/S1) can be used to distinguish between the two populations

# Multiple Interactions

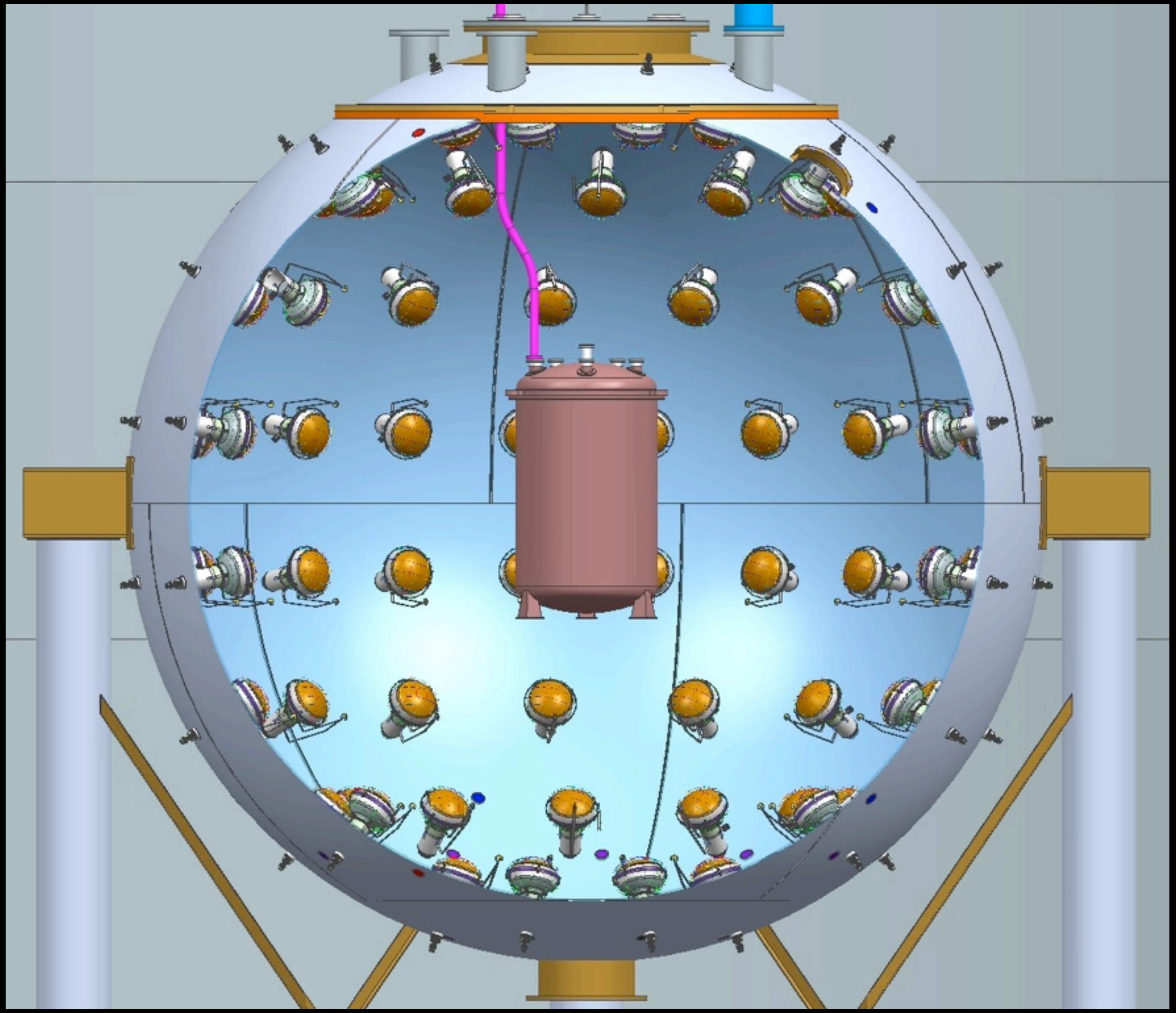
| Expected WIMP signal | Background Rejection Technique | Backgrounds Removed |
|---|---|---|
| Single Interaction | Multiple S2 Cut in TPC<br>Liquid Scintillator Veto | Neutrons, Gamma rays |



# Liquid Scintillator Veto

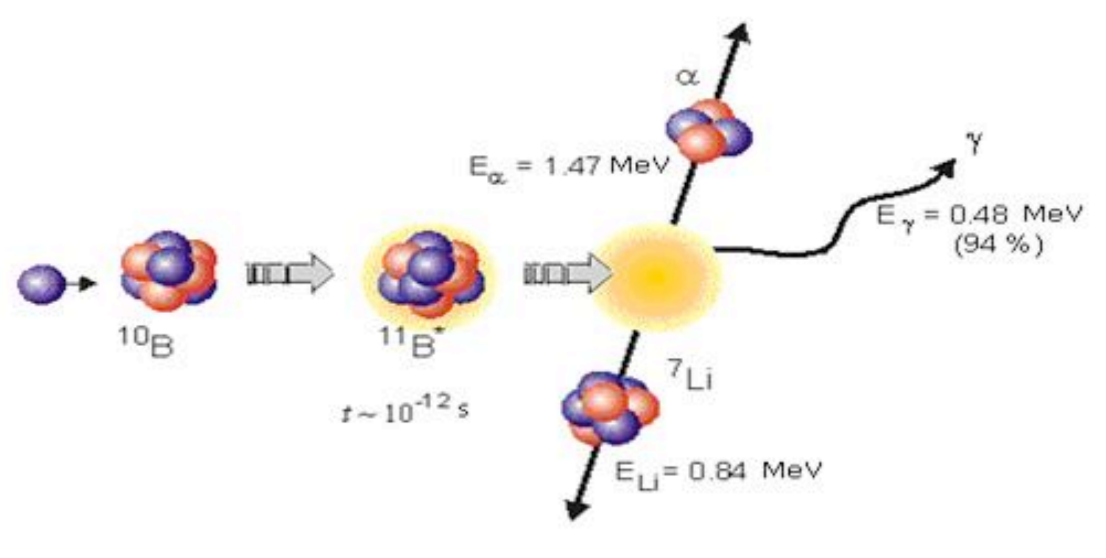
Liquid scintillator allows coincident veto of neutrons in the TPC and provides *in situ* measurement of the neutron background rate



- 4 m diameter sphere containing 1:1 PC + TMB scintillator
- Instrumented with 110  8” PMTs

# Borated Liquid Scintillator

- High neutron capture cross section on boron allows for compact veto size
- Capture results in 1.47 MeV α particle - detected with high efficiency
- Short capture time (2.3 µs) reduces dead time loss



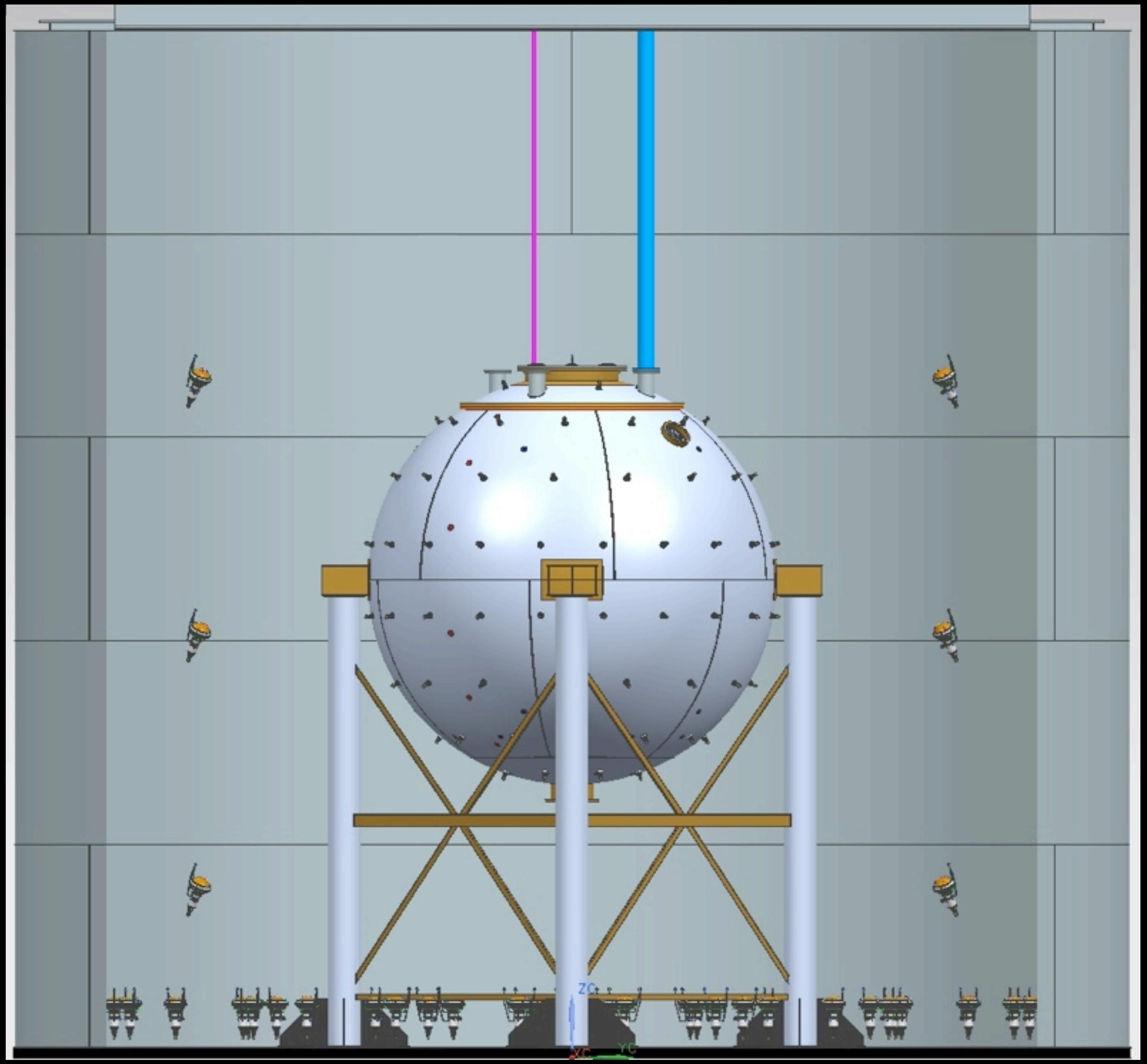

| | Veto Efficiency (MC) |
|---|---|
| Radiogenic Neutrons | > 99%* |
| Cosmogenic Neutrons | > 95% |

Nuclear Instruments and Methods A 644, 18 (2011)

*Based on 60 µs veto window

# External Water tank

- 80 PMTs within Borexino CTF
(11m dia. x 10 m high)
- Acts as a muon and cosmogenic veto
(~ 99% efficiency)
- Provides passive gamma and neutron shielding



Surface contamination

# Radon-Free Clean Rooms

Radon daughters plate out on surfaces of the detector causing dangerous alpha-induced nuclear recoils

Final preparation, cleaning, evaporation and assembly of all inner detector parts was carried out in radon-free clean rooms

Typical radon in air ~ 30 Bq/m$^3$
Cleanroom radon levels < 5 mBq/m$^3$

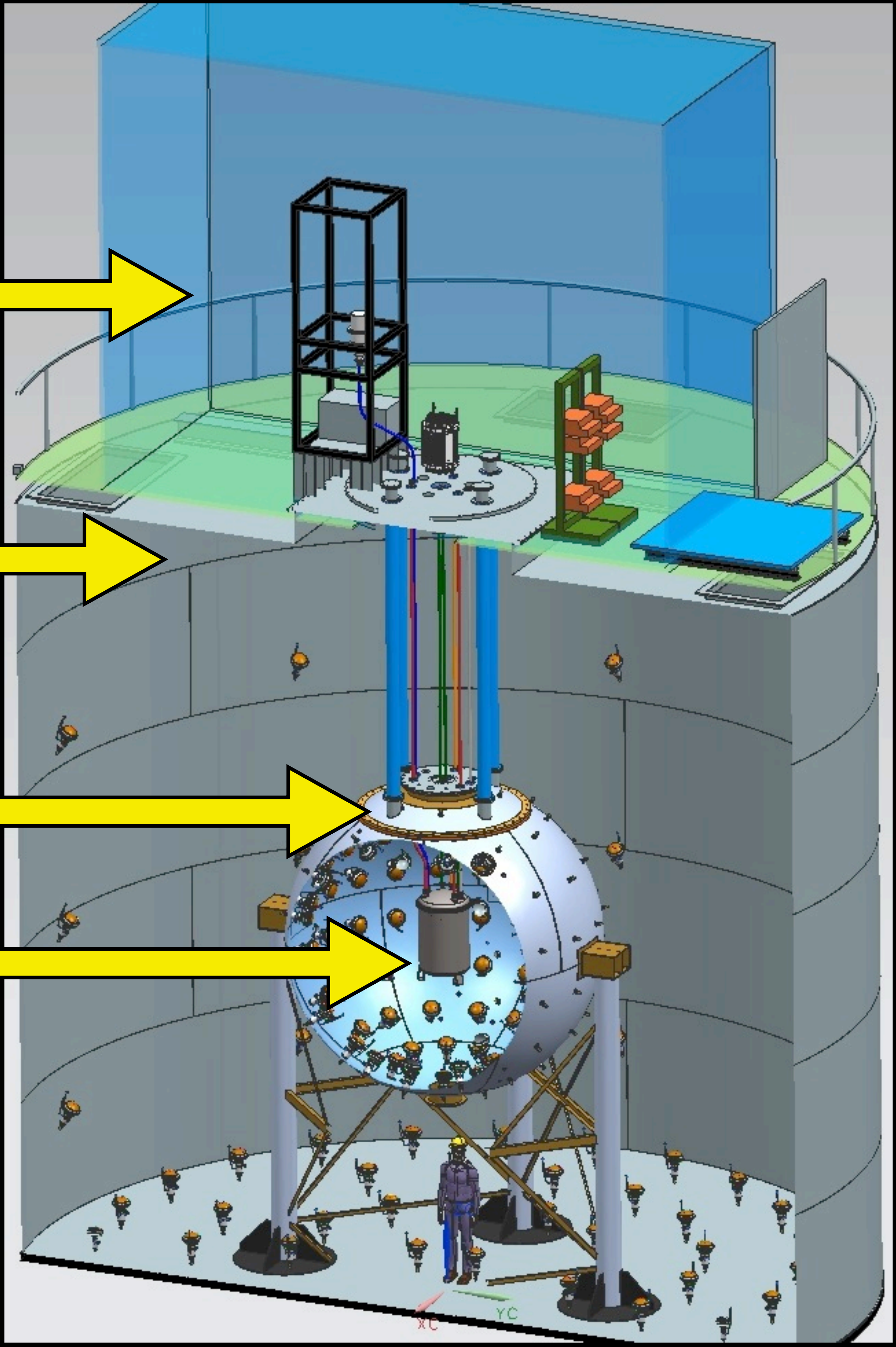
# DarkSide 50

Radon-free clean room

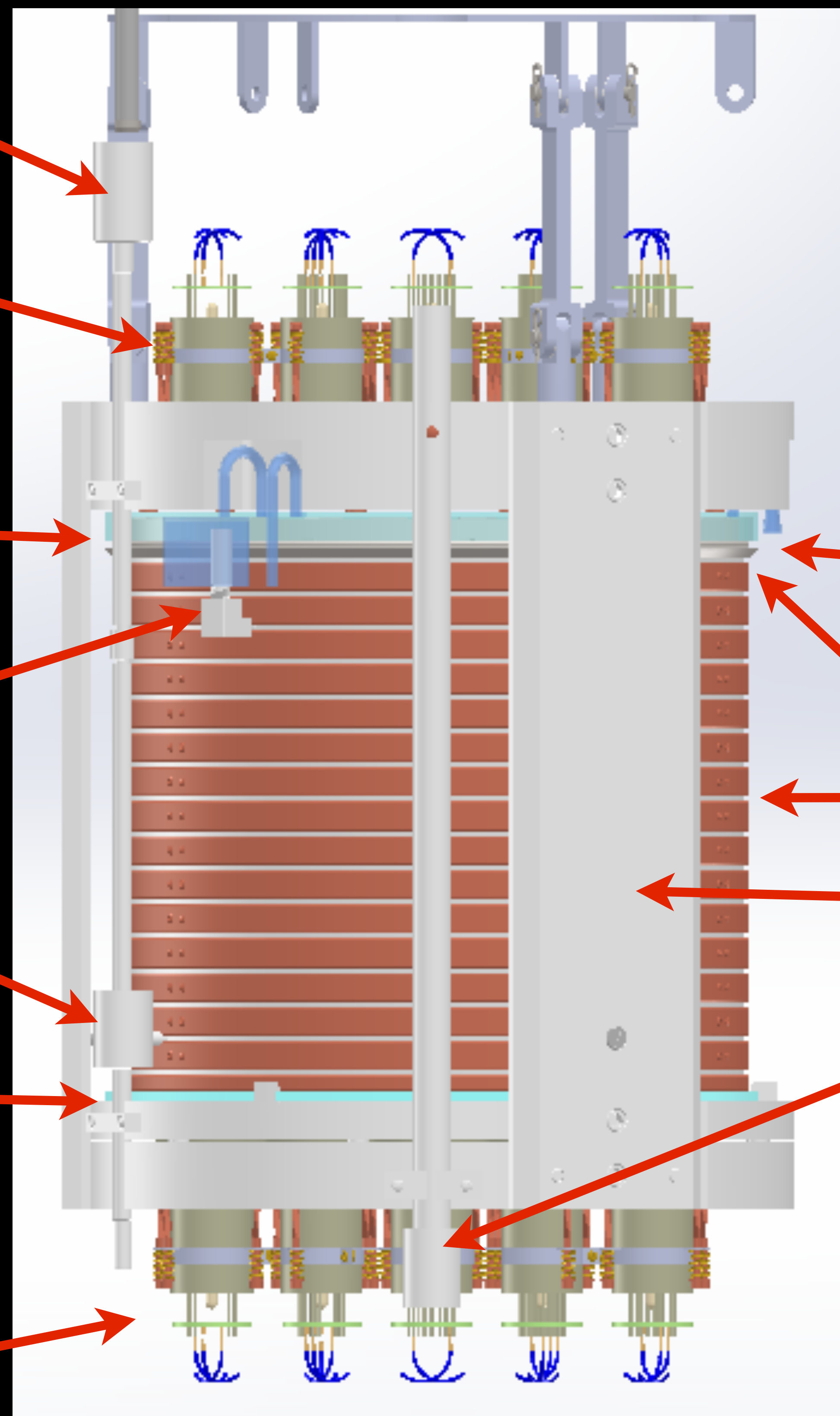
Instrumented water tank

Liquid scintillator

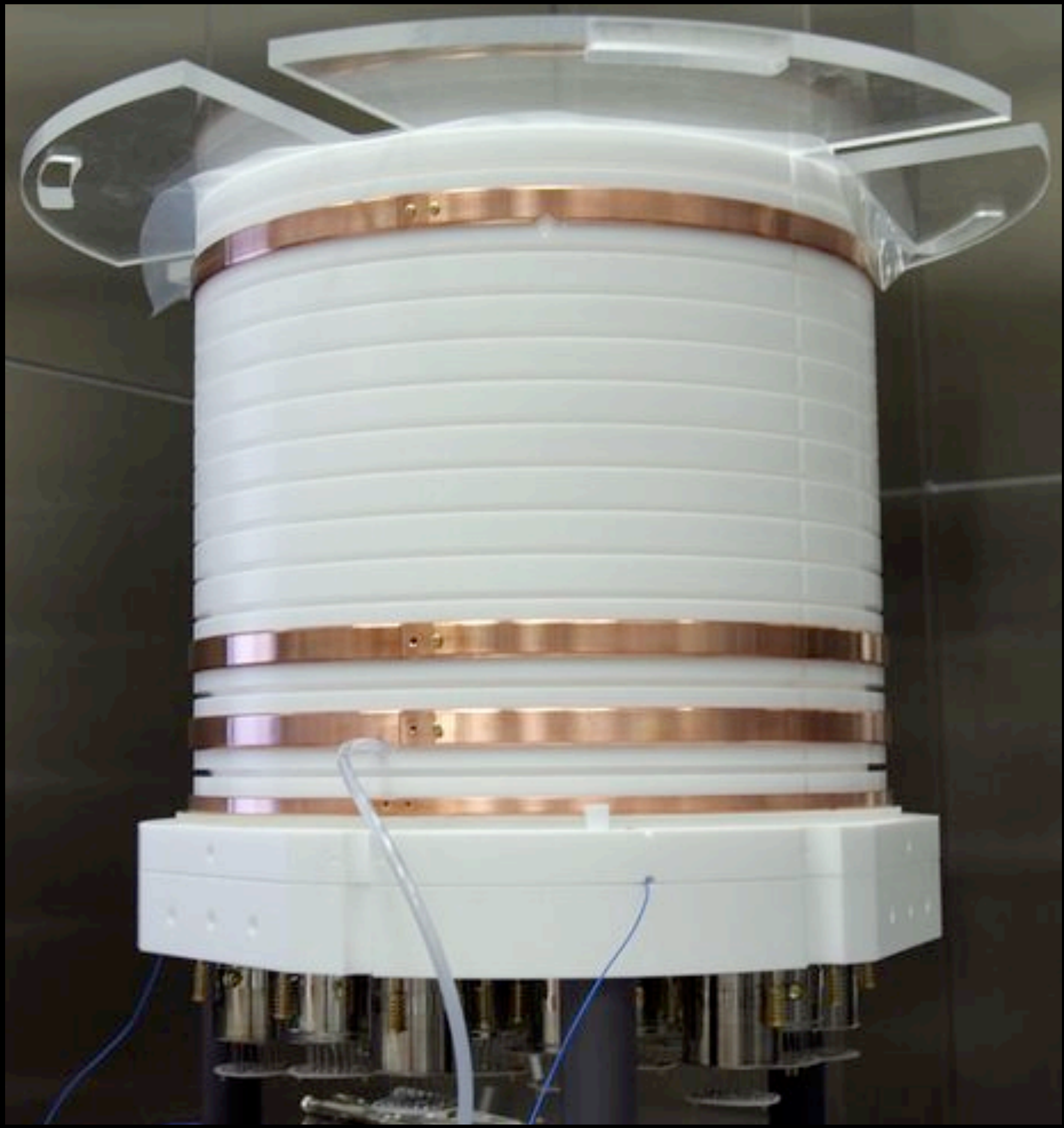
Inner detector TPC



# DarkSide 50 TPC



# DS50 TPC assembly



# DS50 TPC assembly

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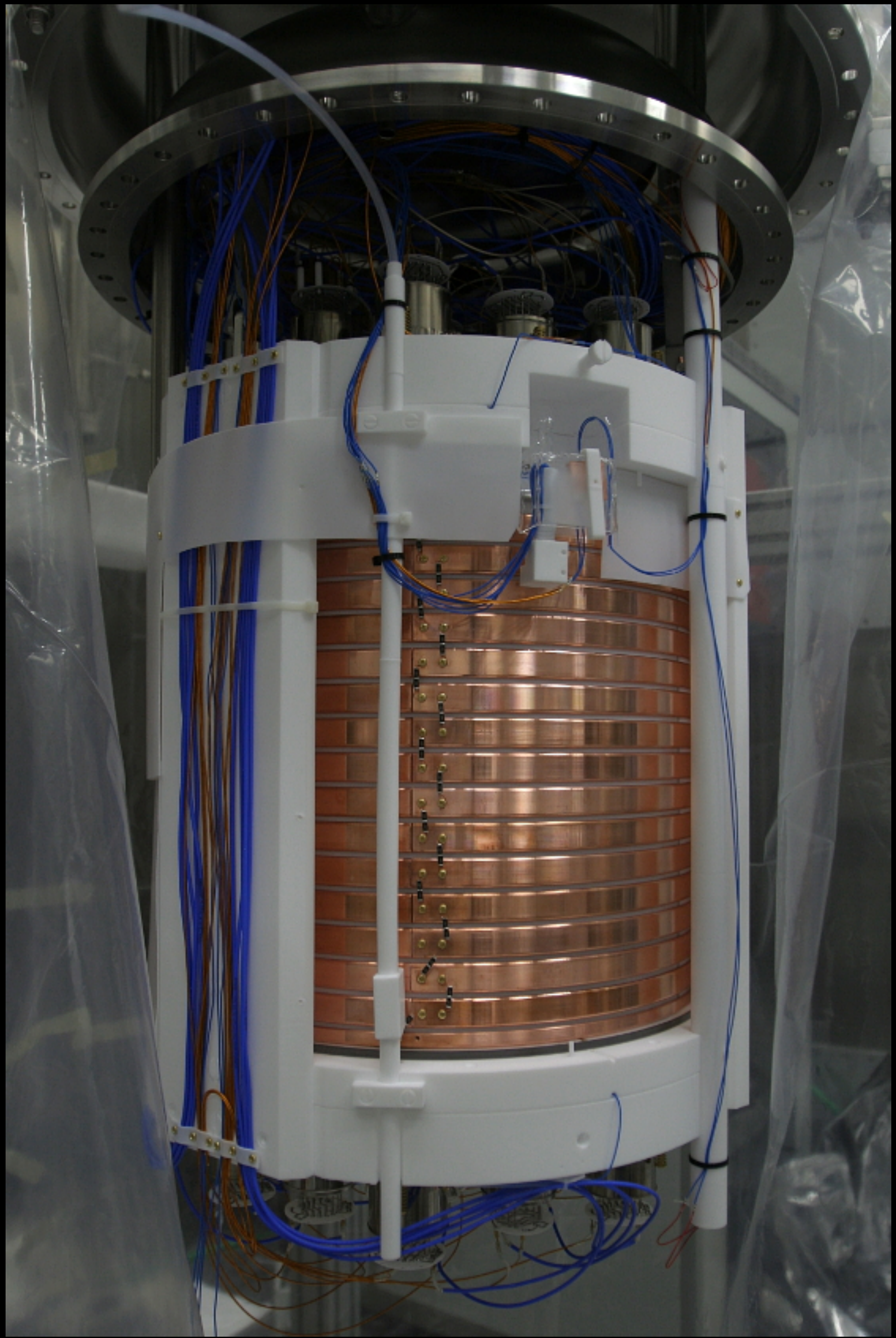
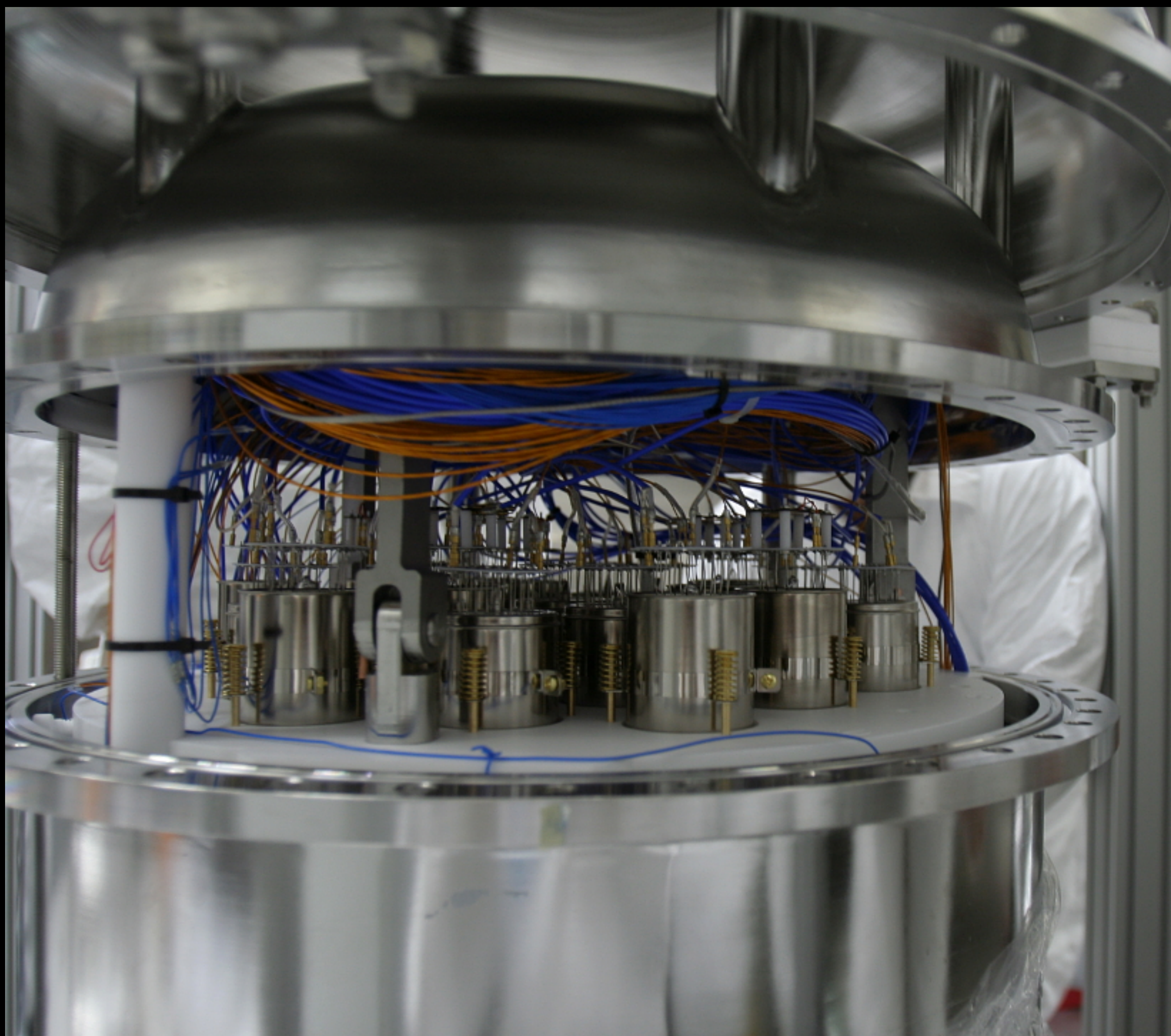
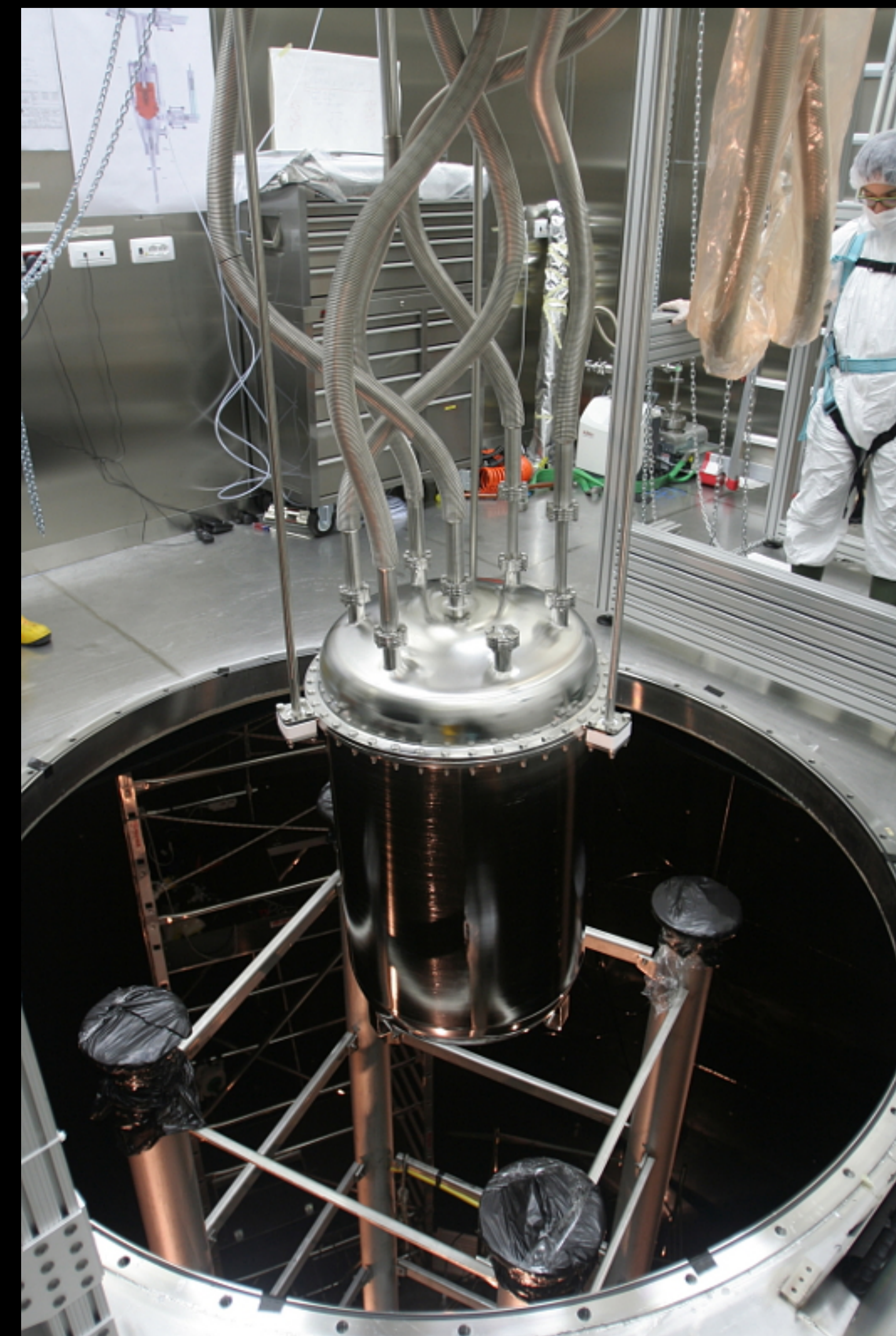


# DS50 TPC deployment



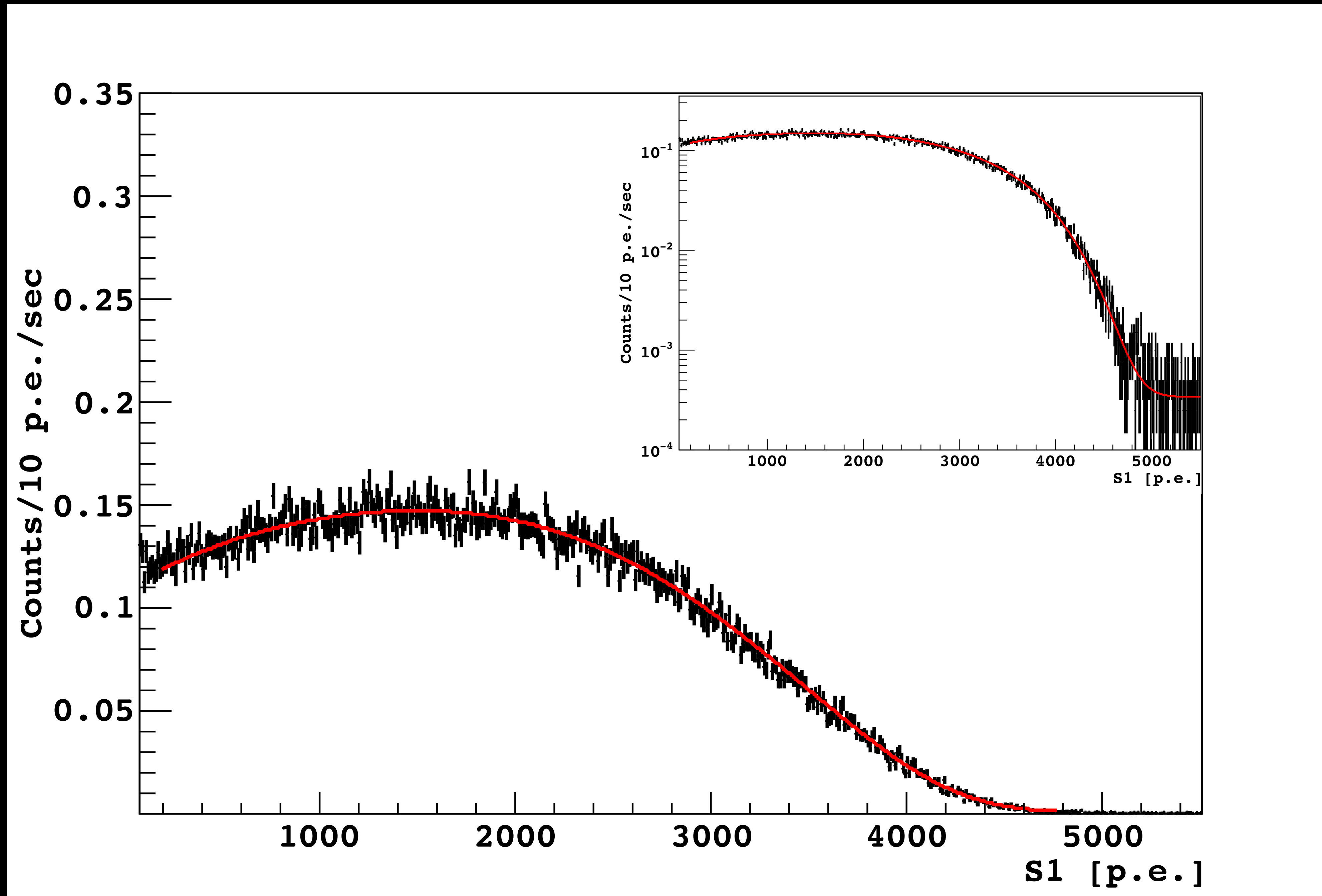


# DS50 Timeline

- Sept 13: TPC deployed in Neutron Veto sphere
- Sept 16 - 20: TPC cooled and filled with atmospheric argon
- Sept 30 - Oct 13: Neutron Veto filled with scintillator
- Oct 2 - Nov 11: Muon Veto filled with water

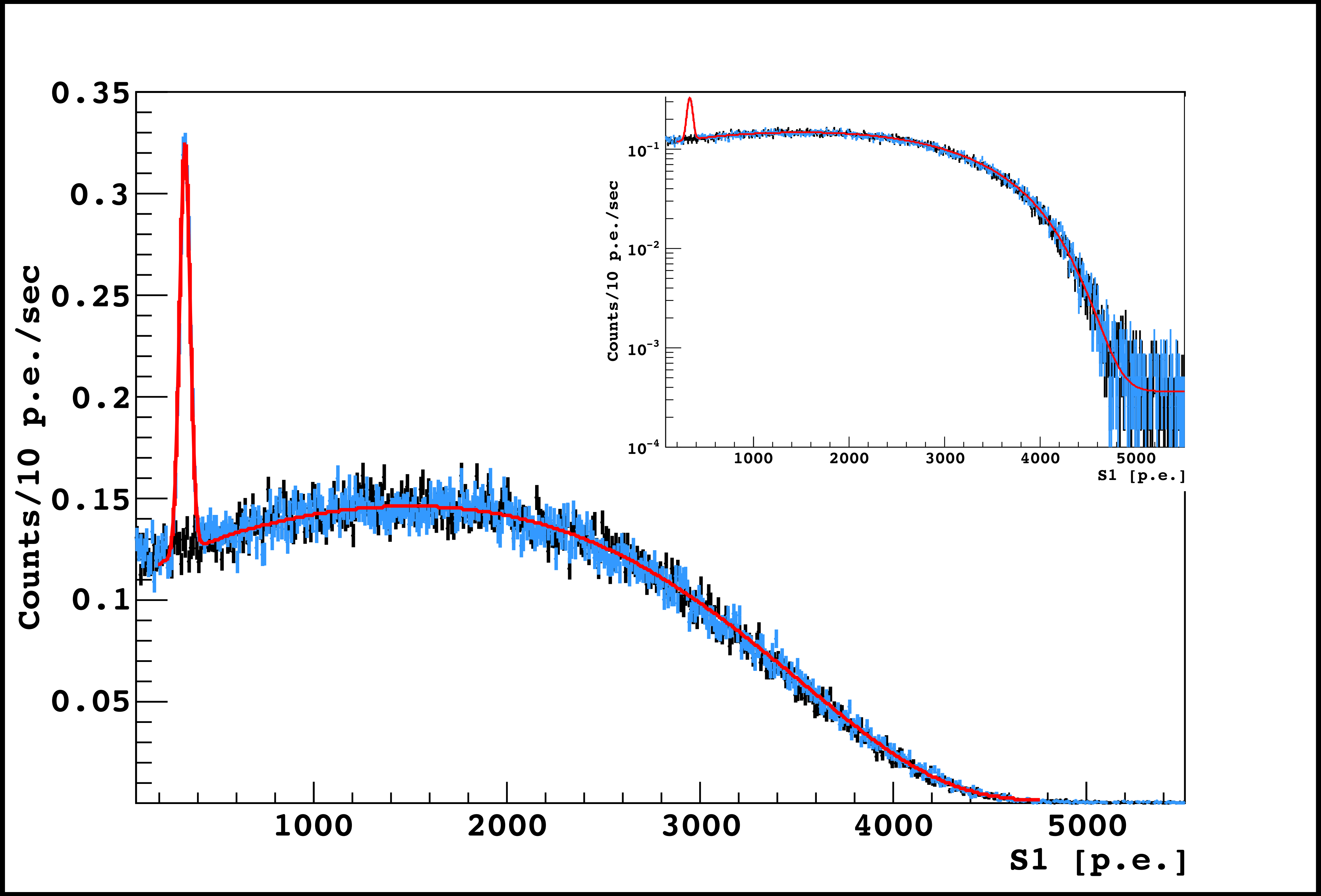
All 3 detectors are filled and currently operating

# S1 Spectrum




Event rate dominated by internal $^{39}$Ar contamination
(low internal radioactivity, neutron veto passive shielding)

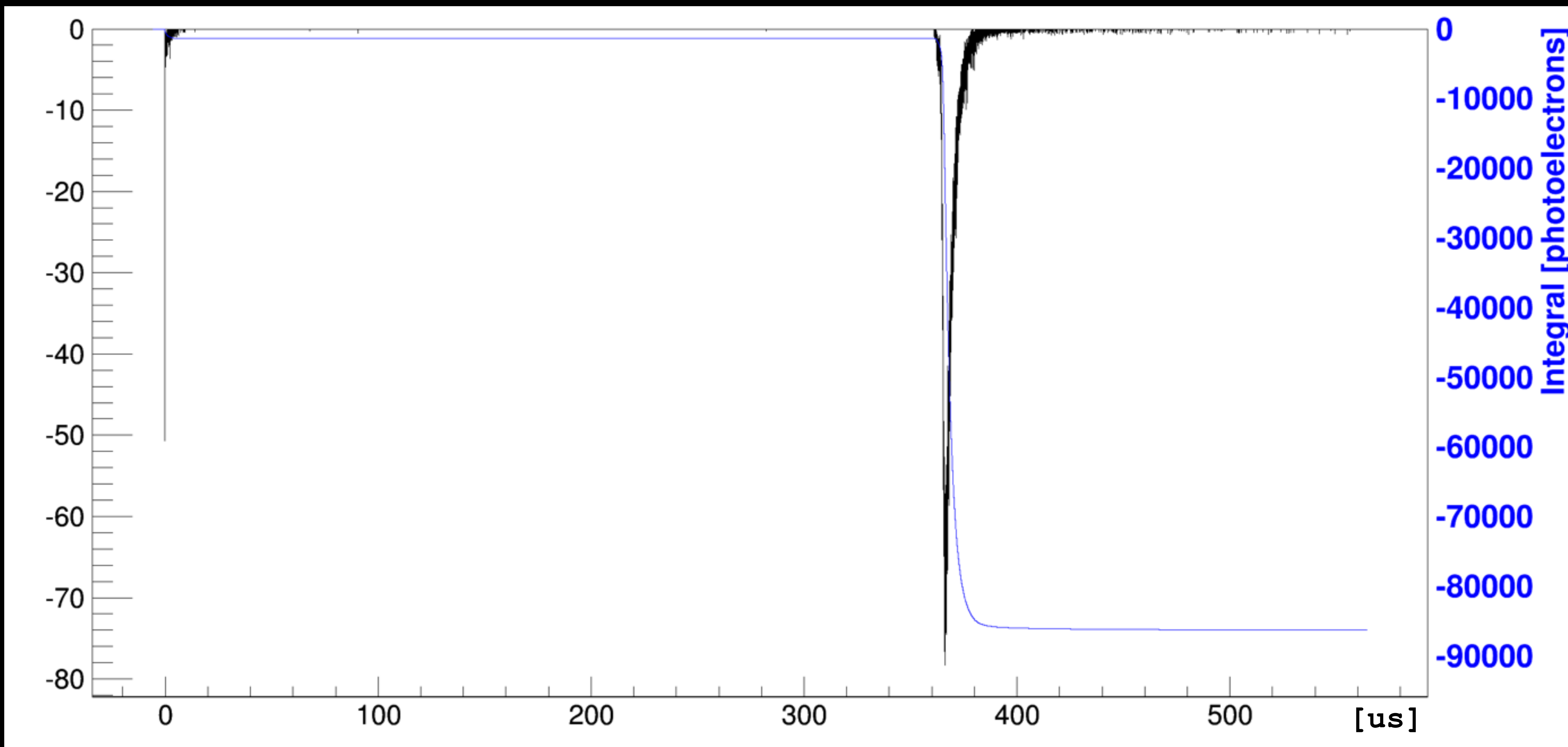
# S1 Spectrum



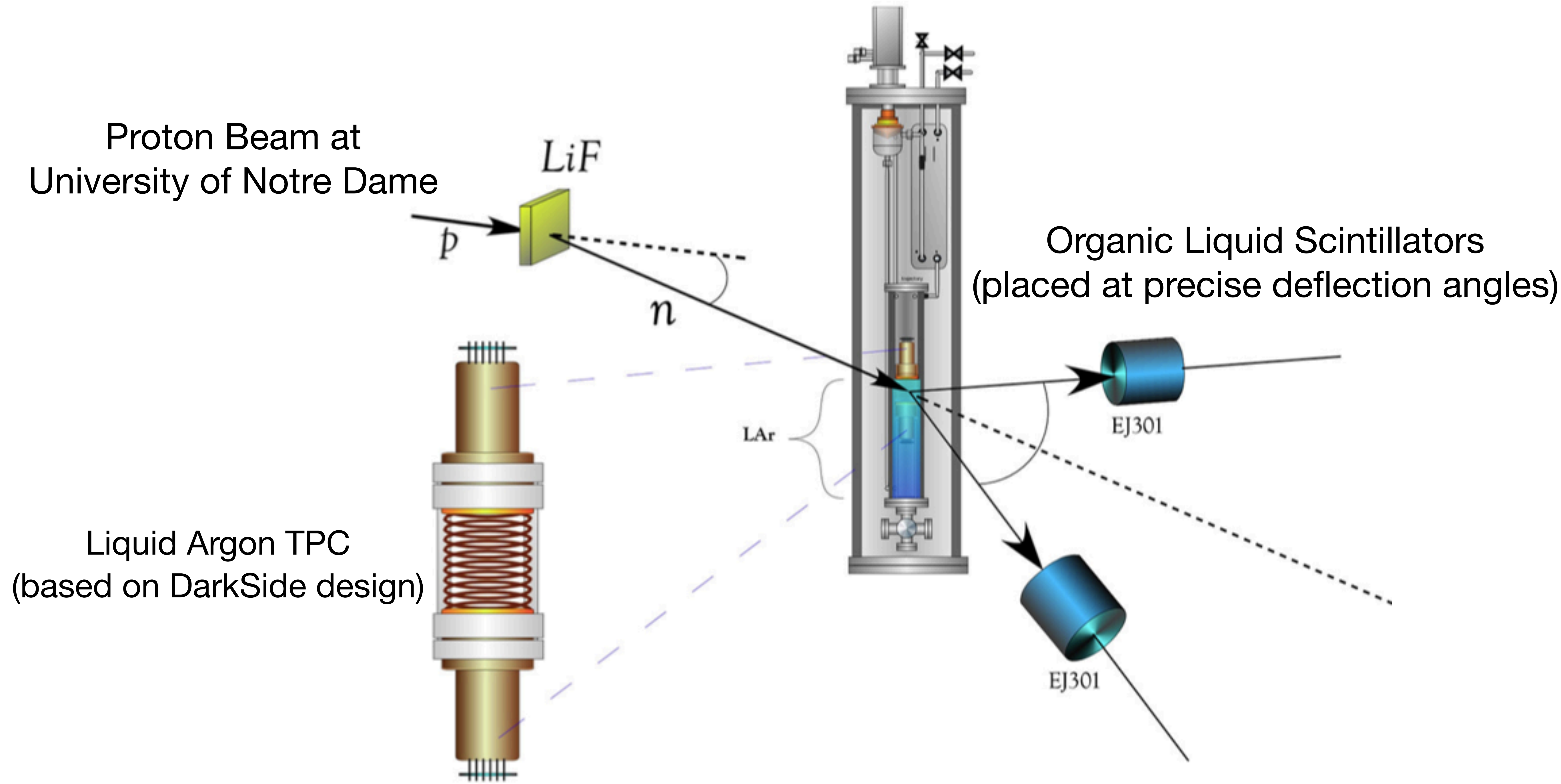

$^{83m}$Kr gas deployed into detector (41.5 keV$_{ee}$)

Fits to $^{39}$Ar and $^{83m}$Kr spectrum indicate a light yield of 8.0 +/- 0.5 p.e./keV

# S1 + S2 waveform

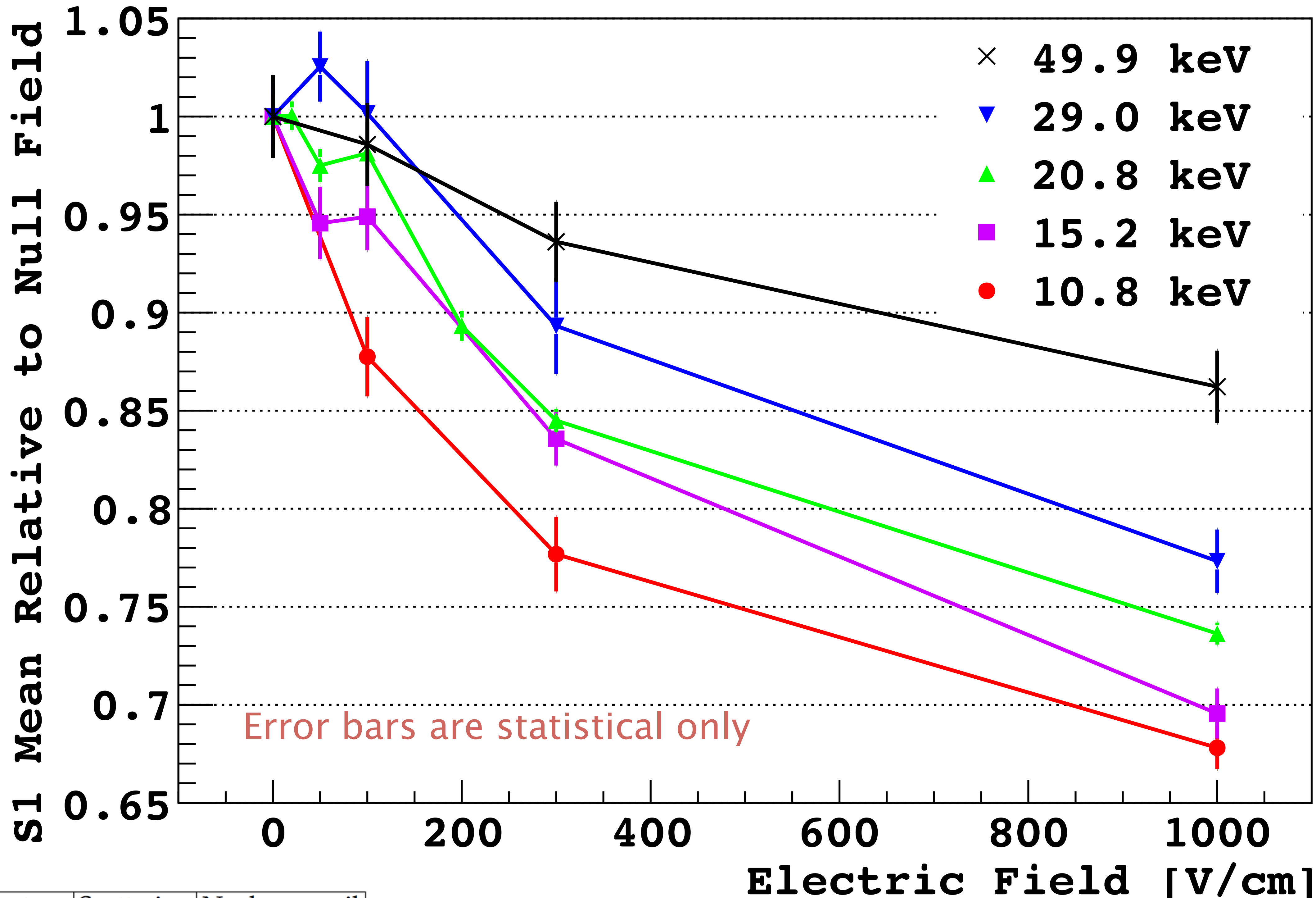


# SCENE
# (Scintillation Efficiency of Nuclear Recoils in Noble Elements)




$^{7}Li(p, n)^{7}Be$ reaction produces low energy monoenergetic neutrons
TOF measurement between target, LAr and organic scintillators allows clean identification of elastic neutron interactions of known energy

# Scintillation yield as a function of applied field

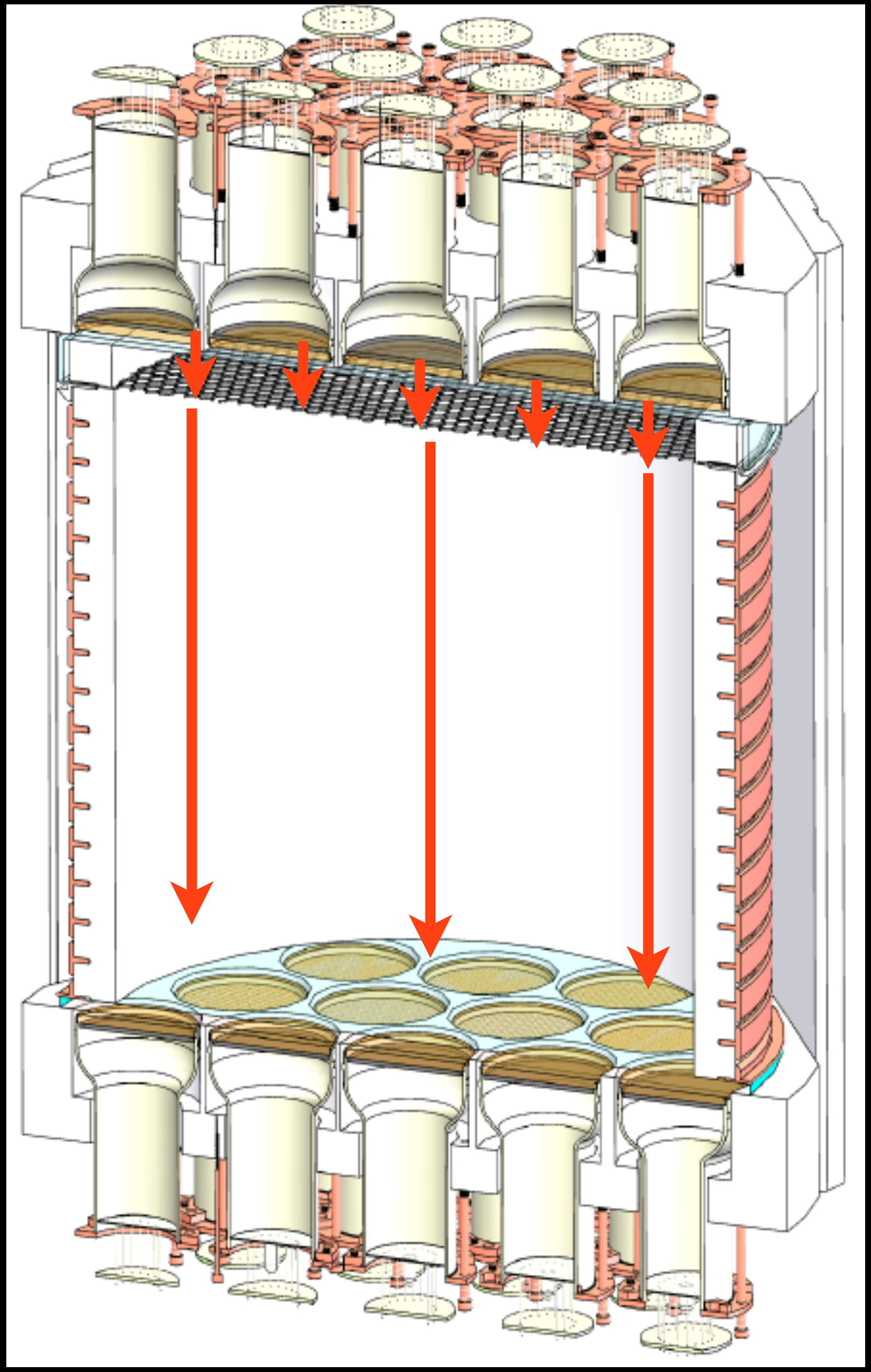



| Proton energy (MeV) | Neutron energy (MeV) | Scattering angle (°) | Nuclear recoil energy (keVr) |
|---|---|---|---|
| 2.376 | 0.604 | 49.9 | 10.8 |
| 2.930 | 1.168 | 42.2 | 15.2 |
| 2.930 | 1.168 | 49.9 | 20.8 |
| 2.930 | 1.168 | 59.9 | 29.0 |
| 2.930 | 1.168 | 82.2 | 49.9 |


**arXiv:1306.5675v2 [physics.ins-det]**
**Accepted for publication in Phys. Rev. D**

# Drift Field

DS50 has been operating at a drift field of 200 V/cm
and an extraction field of 2.8 kV/cm



Anode: 0 V

$E_{gas}$ : 4200 V/cm

$E_{ext}$ : 2800 V/cm

Grid: -5600 kV

$E_{drift}$ : 200 V/cm

Cathode: -12700 V

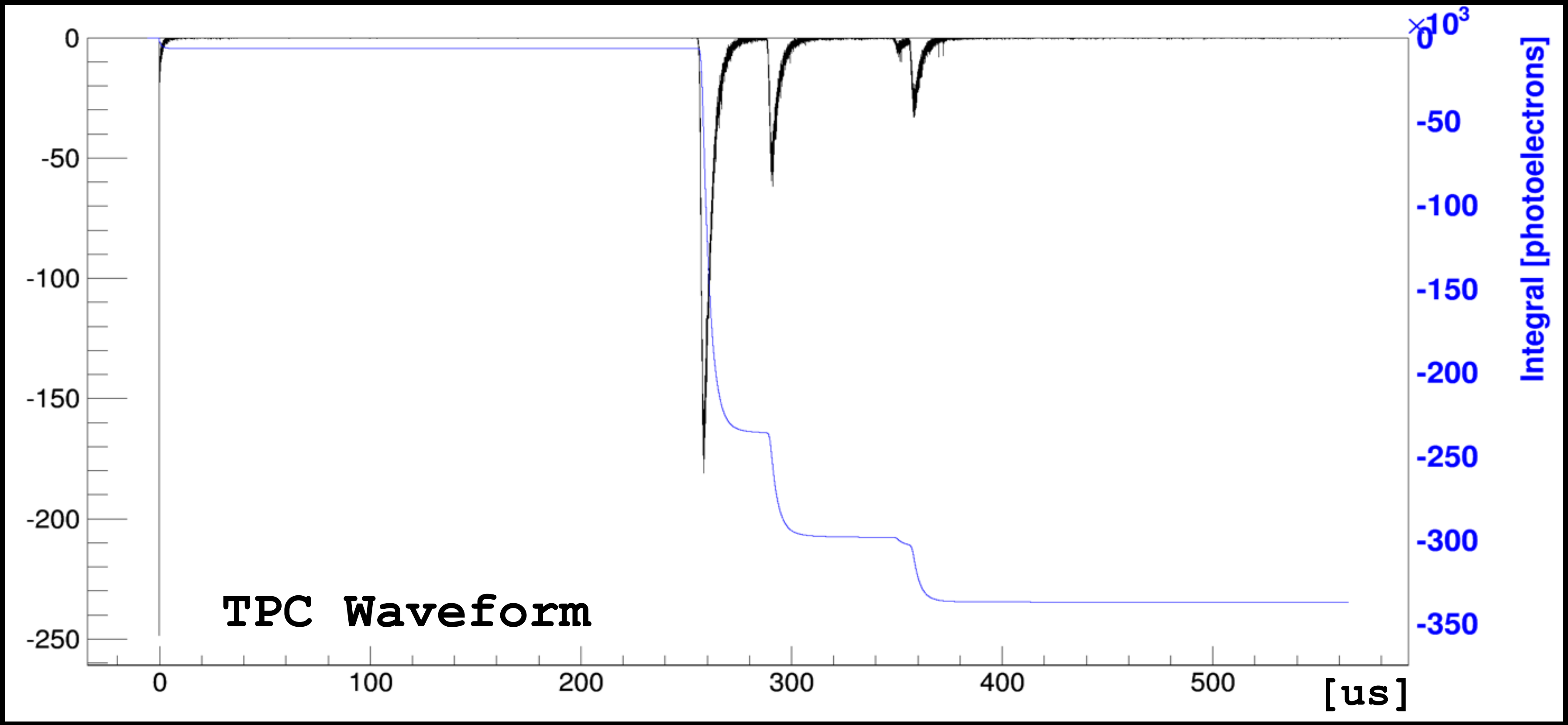
Stable operation for several months at -12700 V

Max Drift Time ~ 370 us

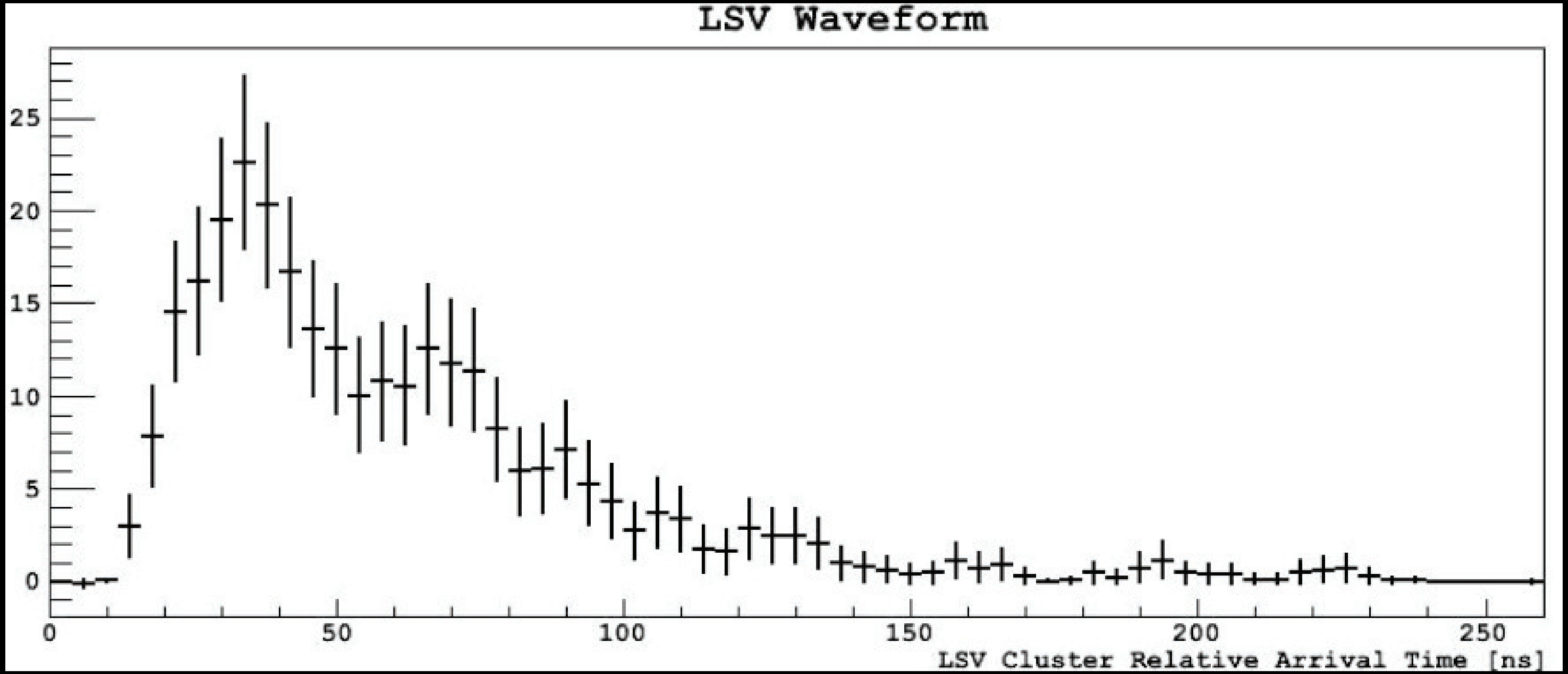
Electron Drift Lifetime > 3ms

# Neutron Veto Commissioning

## Coincident event in TPC and Neutron Veto




Electron recoil event with multiple S2 signals in TPC



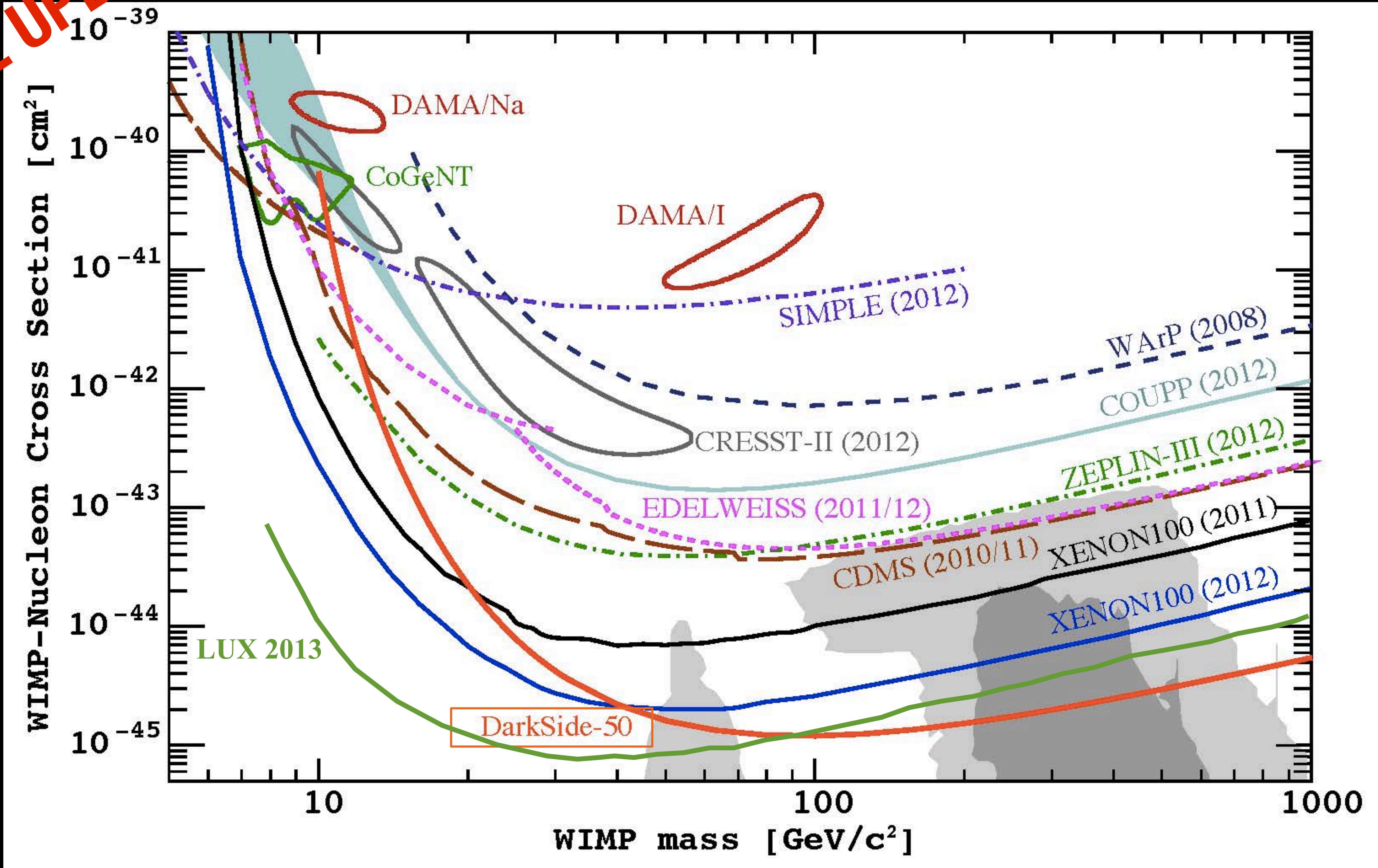

Coincident signal in liquid scintillator veto

# Future Plans

- Collect Background Statistics
  1 week of running with atmospheric argon ~ 3 yrs with underground argon
- Deploy calibration sources
  Calibrate both neutron veto and TPC using gamma and neutron sources
- Refill with underground argon
  Fill TPC with underground argon around April 2014
- Begin dark matter search

# DS50 Sensitivity

TO BE UPDATED




Sensitivity projection made at time of DarkSide 10
Will soon be updated with accurate DS50 parameters
(LY, SCENE measurements, better background estimates)

# THE END