Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

DARKSIDE

DARKSIDE-50

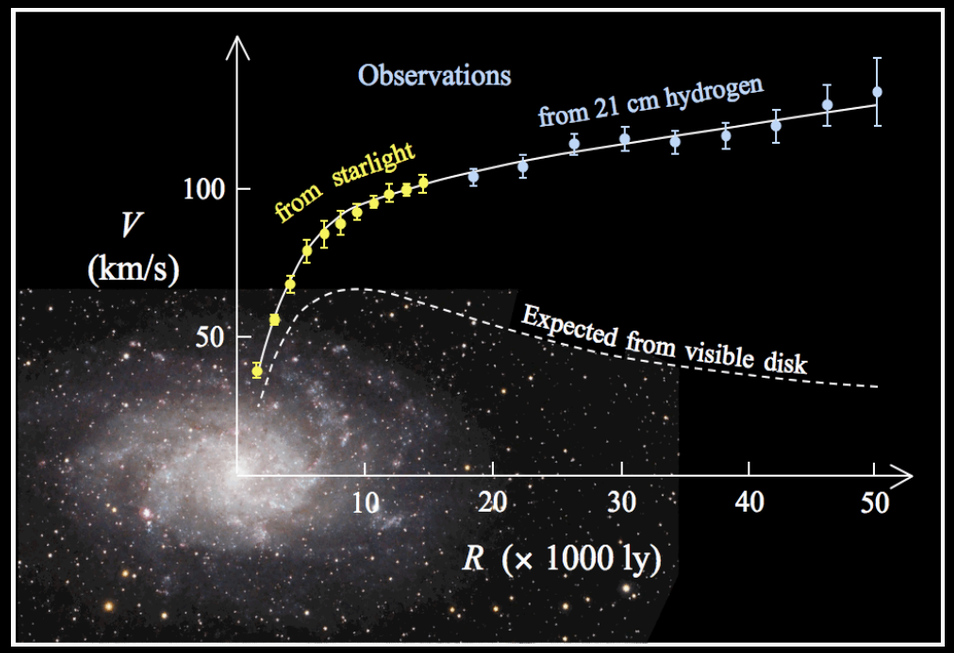
RICHARD SALDANHA
FERMILAB

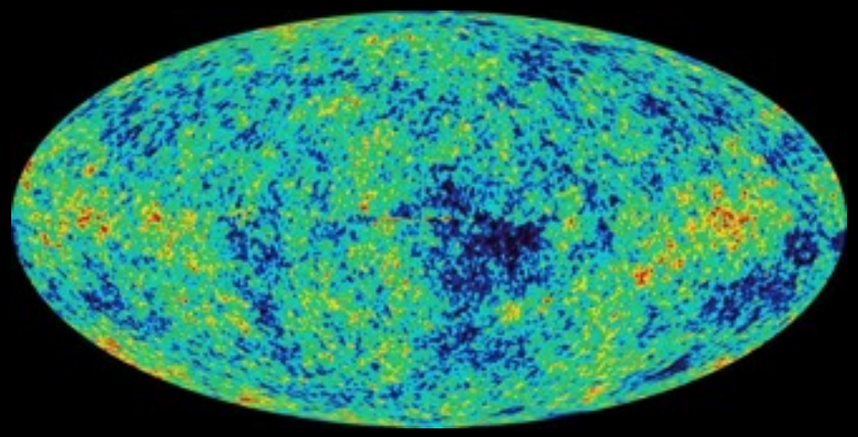
6TH APRIL 2015

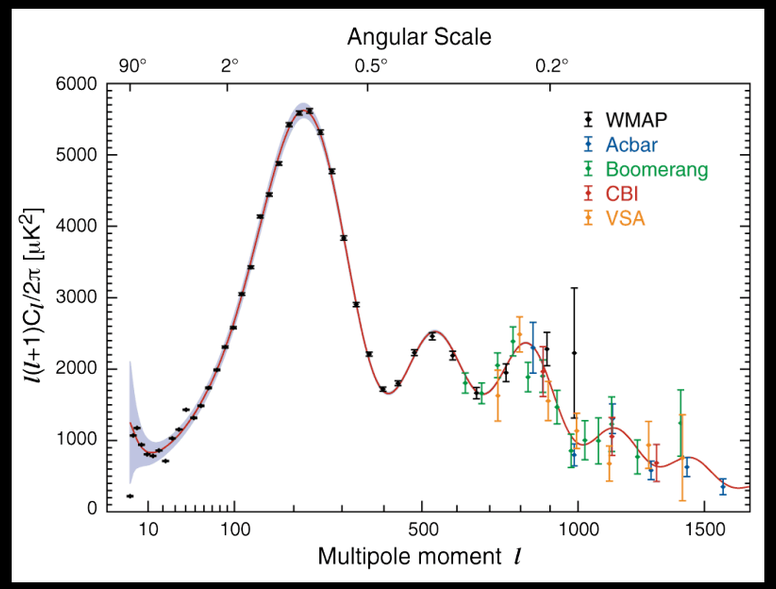
Outline

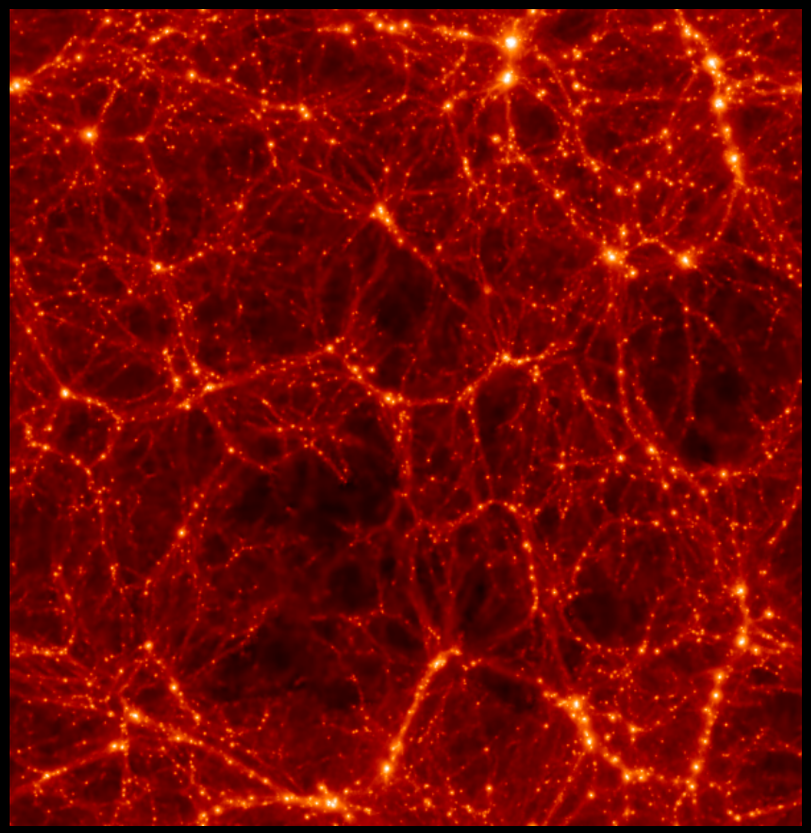
- Introduction to Direct Detection of Dark Matter
- DarkSide-50: Concept and Design
- DarkSide-50: Early Running and First Results
- DarkSide-50: Current Status

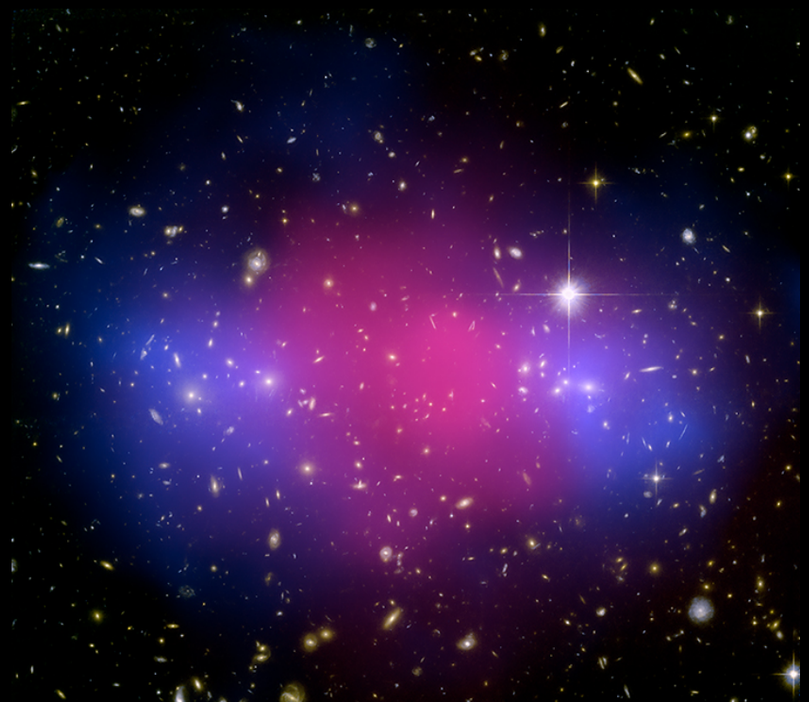
Evidence for Dark Matter



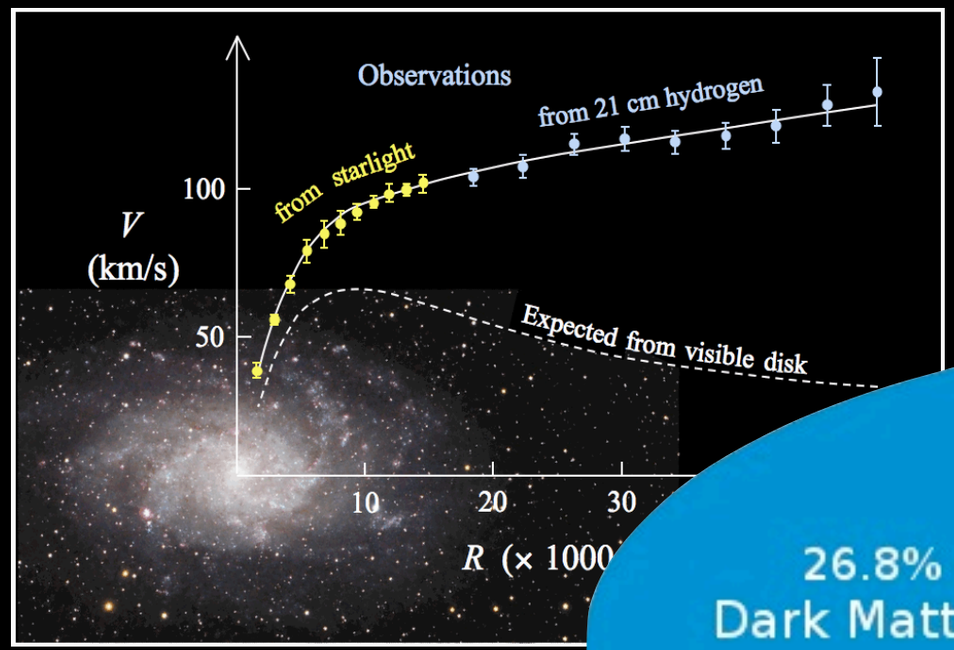


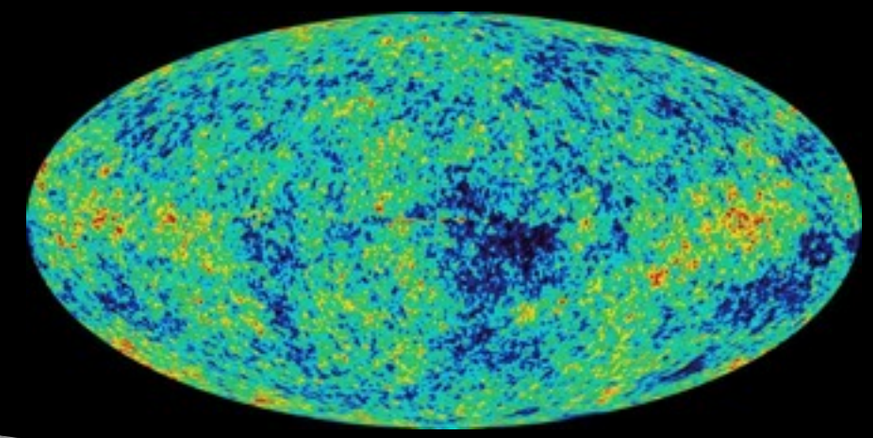


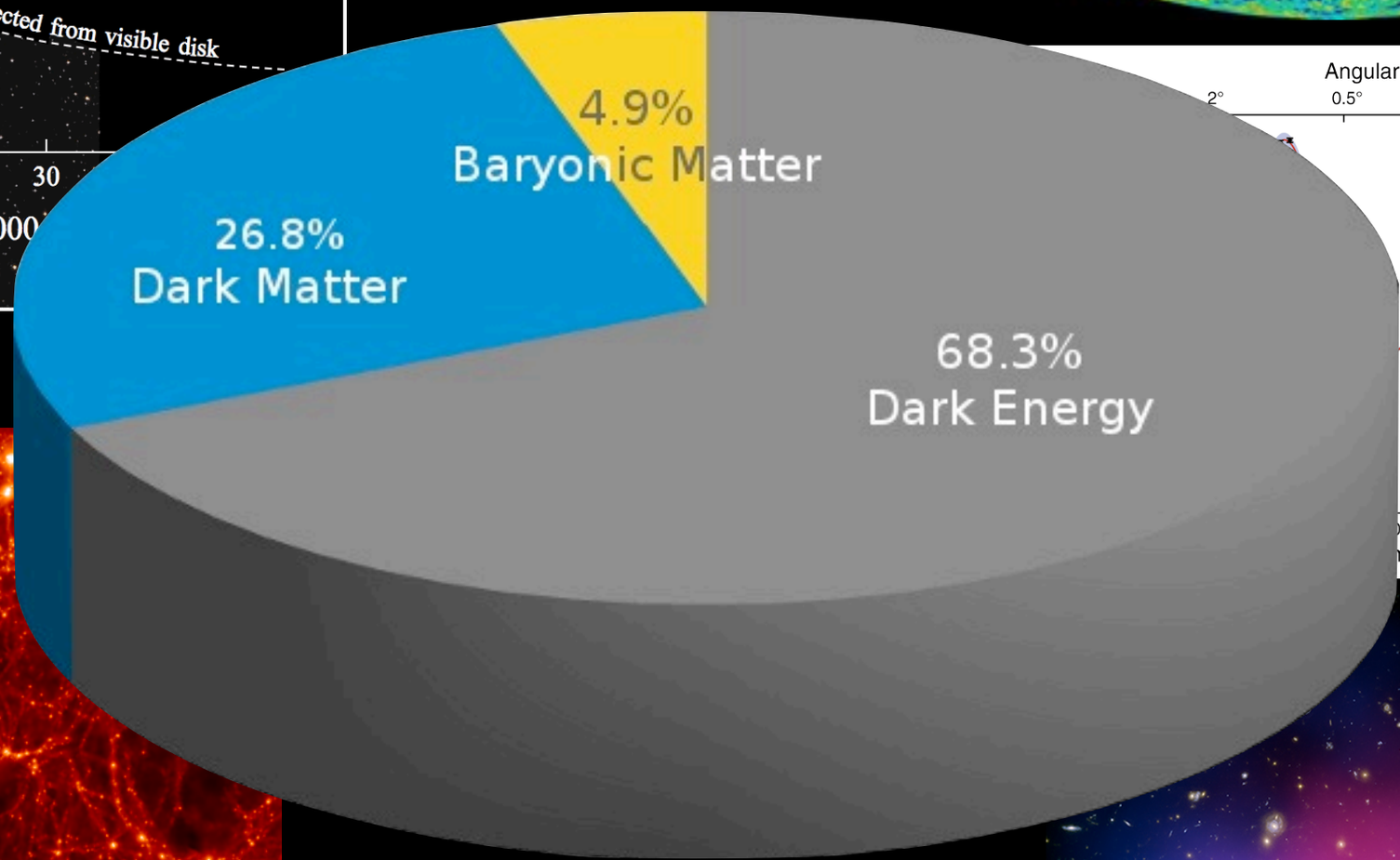


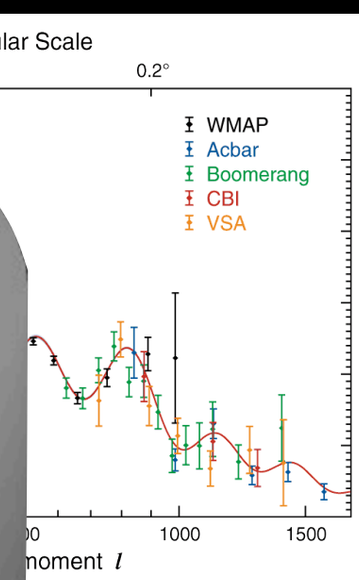


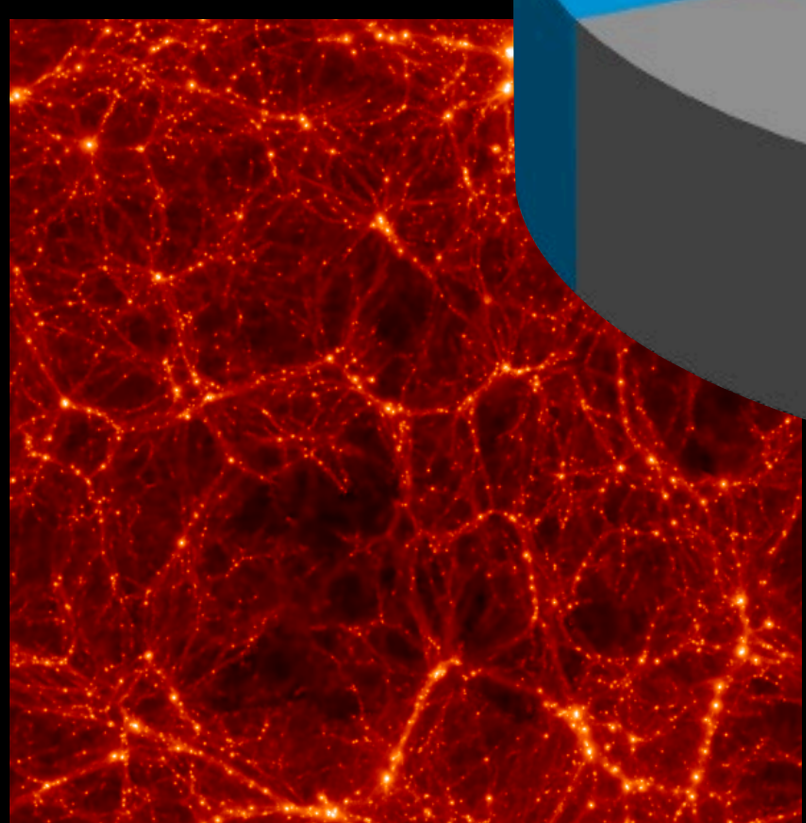
Evidence for Dark Matter

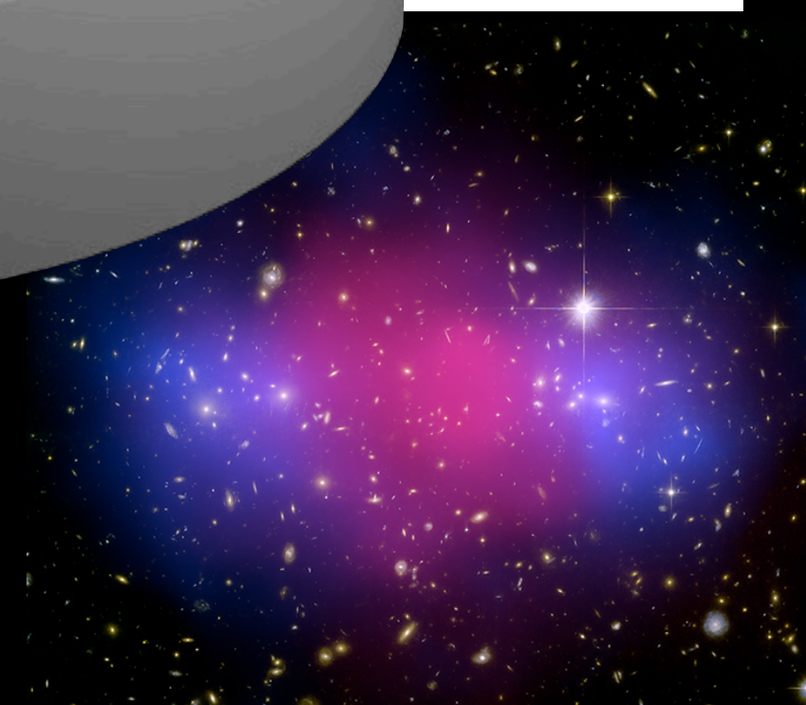








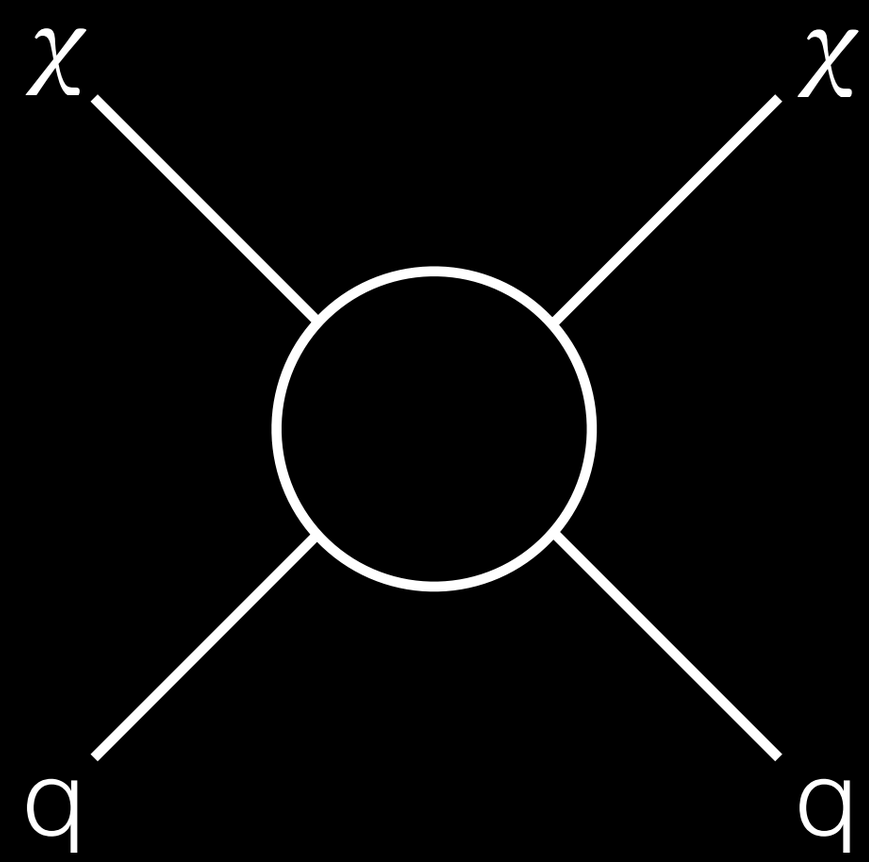




Detecting WIMPs

Annihilation

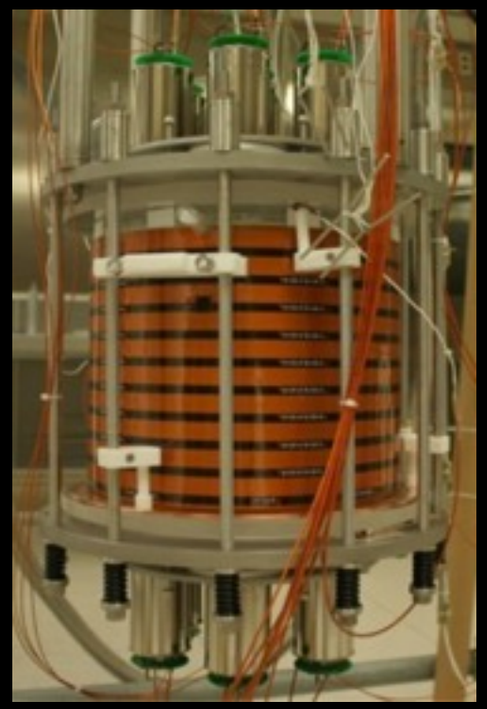
Indirect Detection



Production

Colliders

Scattering



Direct Detection

Direct Detection Rates

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

Φ_χ Flux of WIMPS

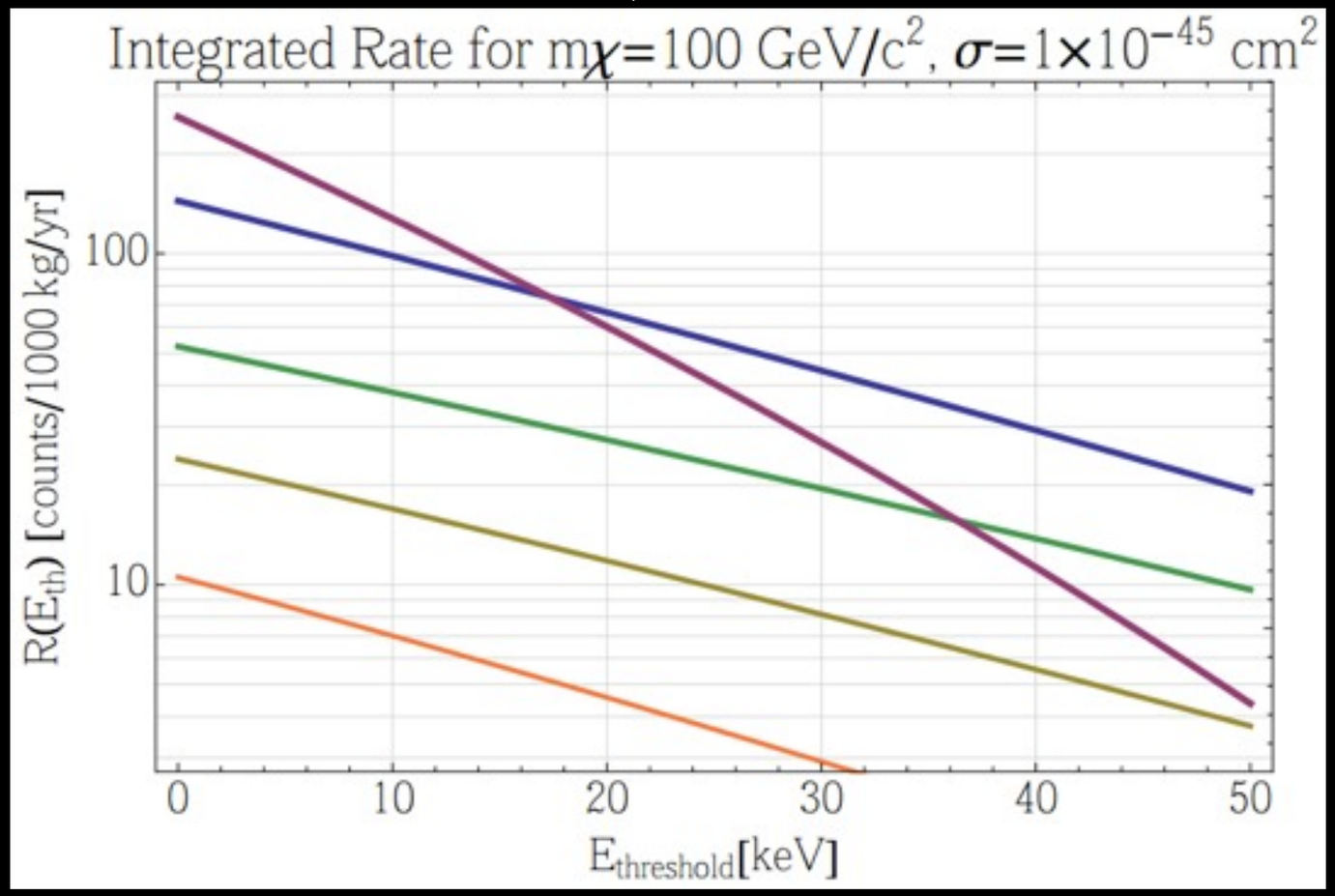
$\sigma_{\chi-N}$ WIMP-Nucleus Scattering Cross Section

n Target Nuclei / kg

Interaction Rates

Xe Ge Ar Si Ne

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



arXiv:1310.8327v2 [hep-ex]

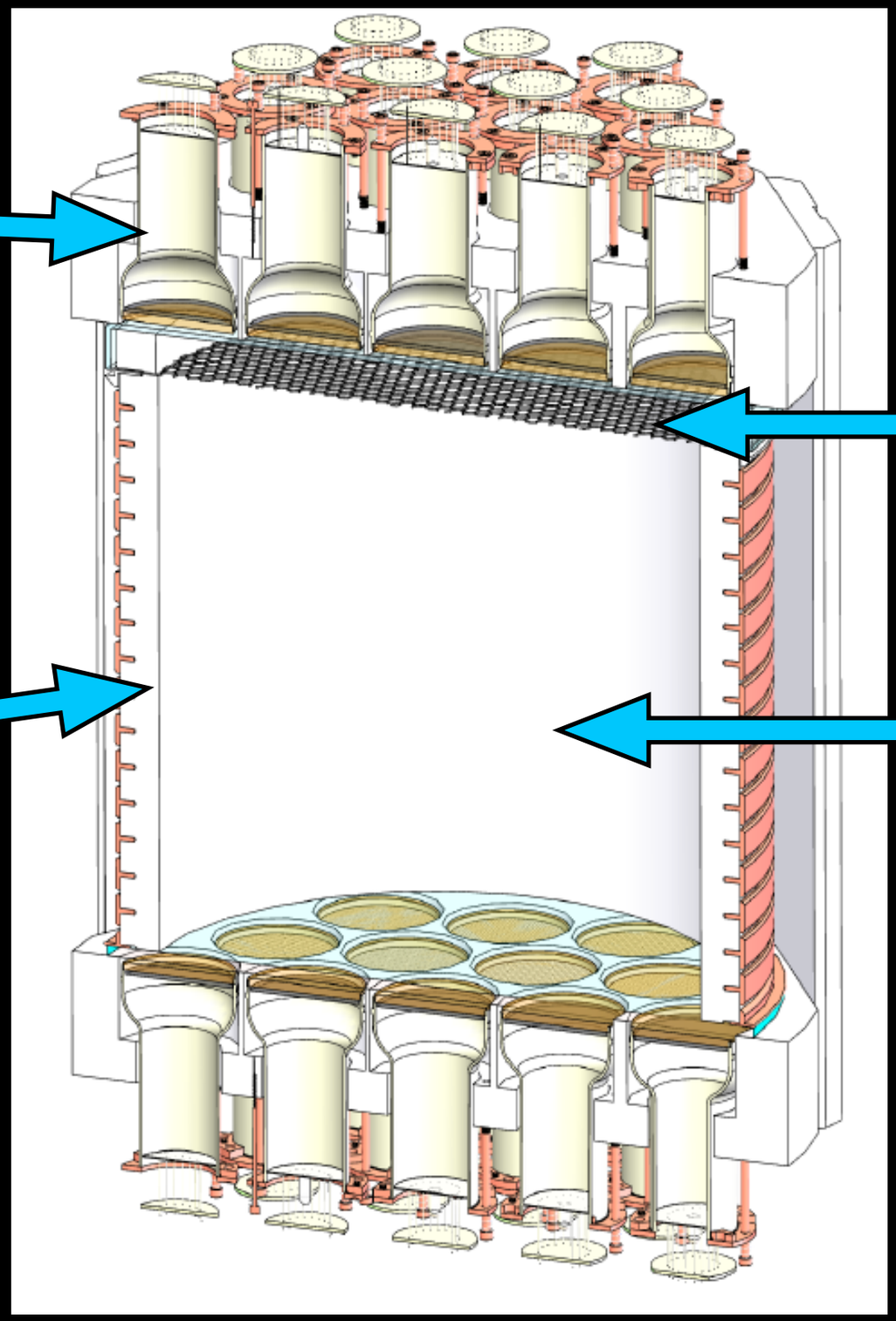
Total Interaction Rate ~ 10^{-4} ev/kg/day

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

Two Phase Argon TPC



Two Phase Argon TPC

Anode

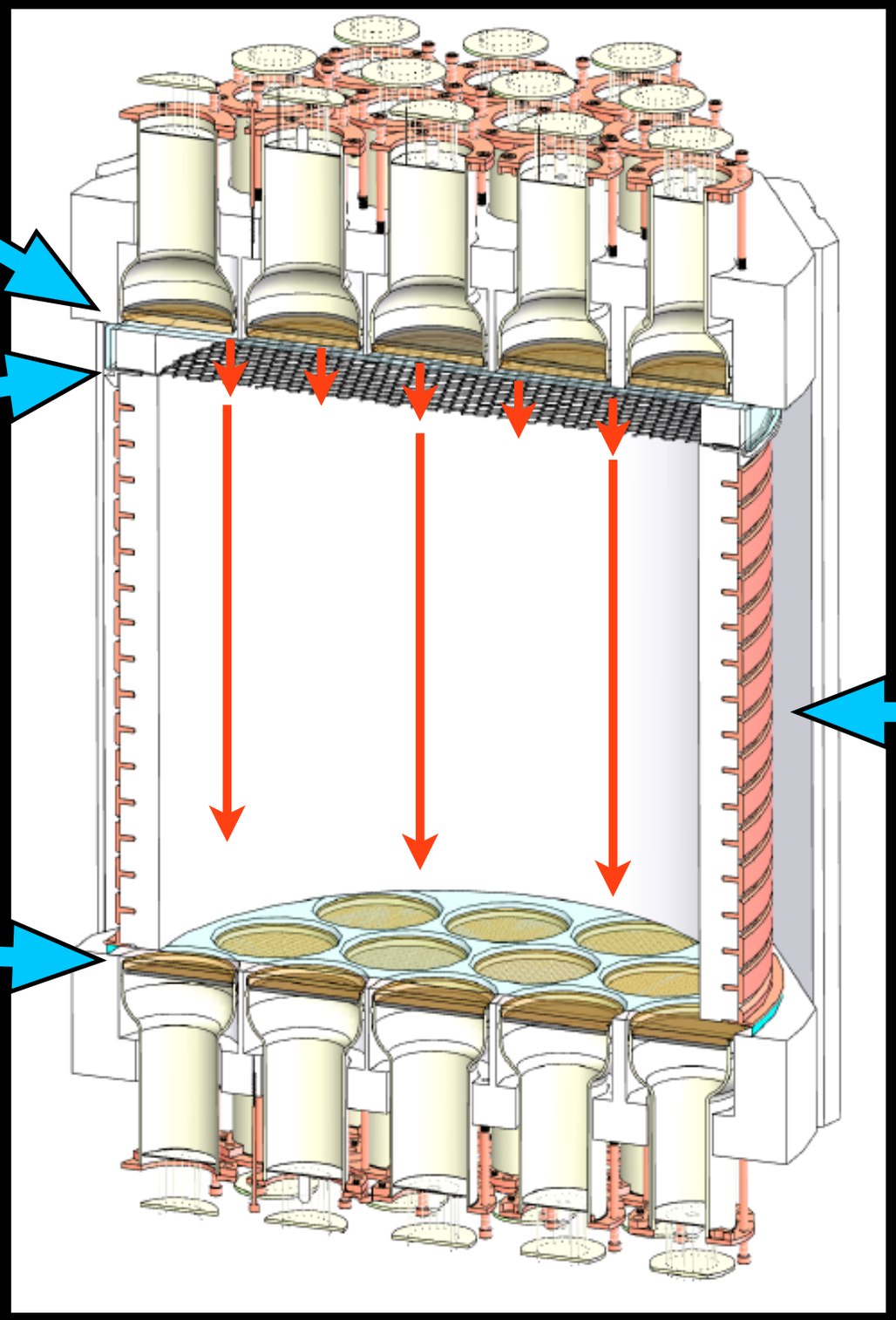
E_{gas} ~ 5 kV/cm

E_{liquid} ~ 3 kV/cm

Grid

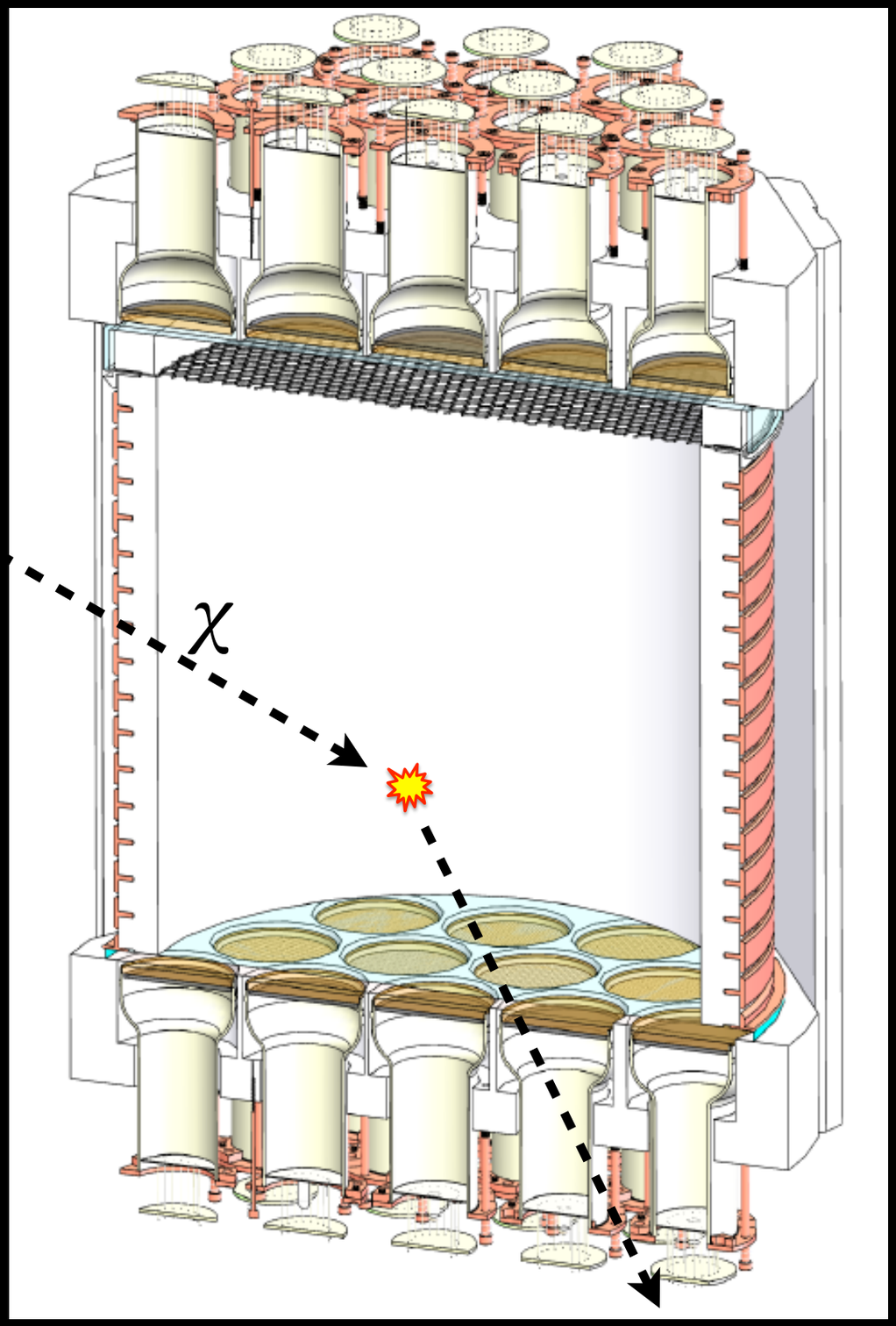
E_{drift} ~ 0.2 kV/cm

Cathode

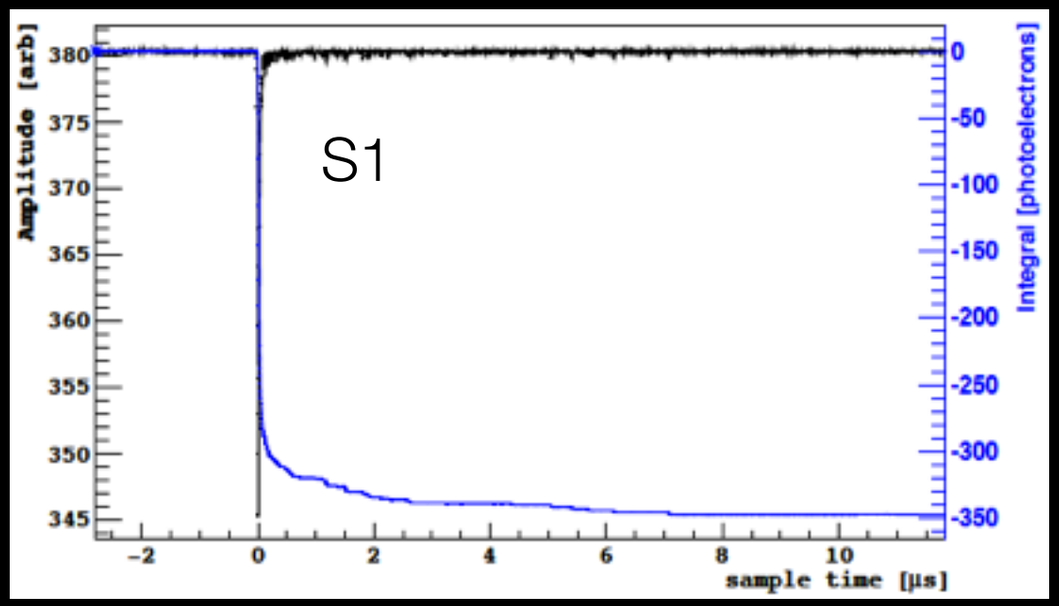


Field Cage Rings

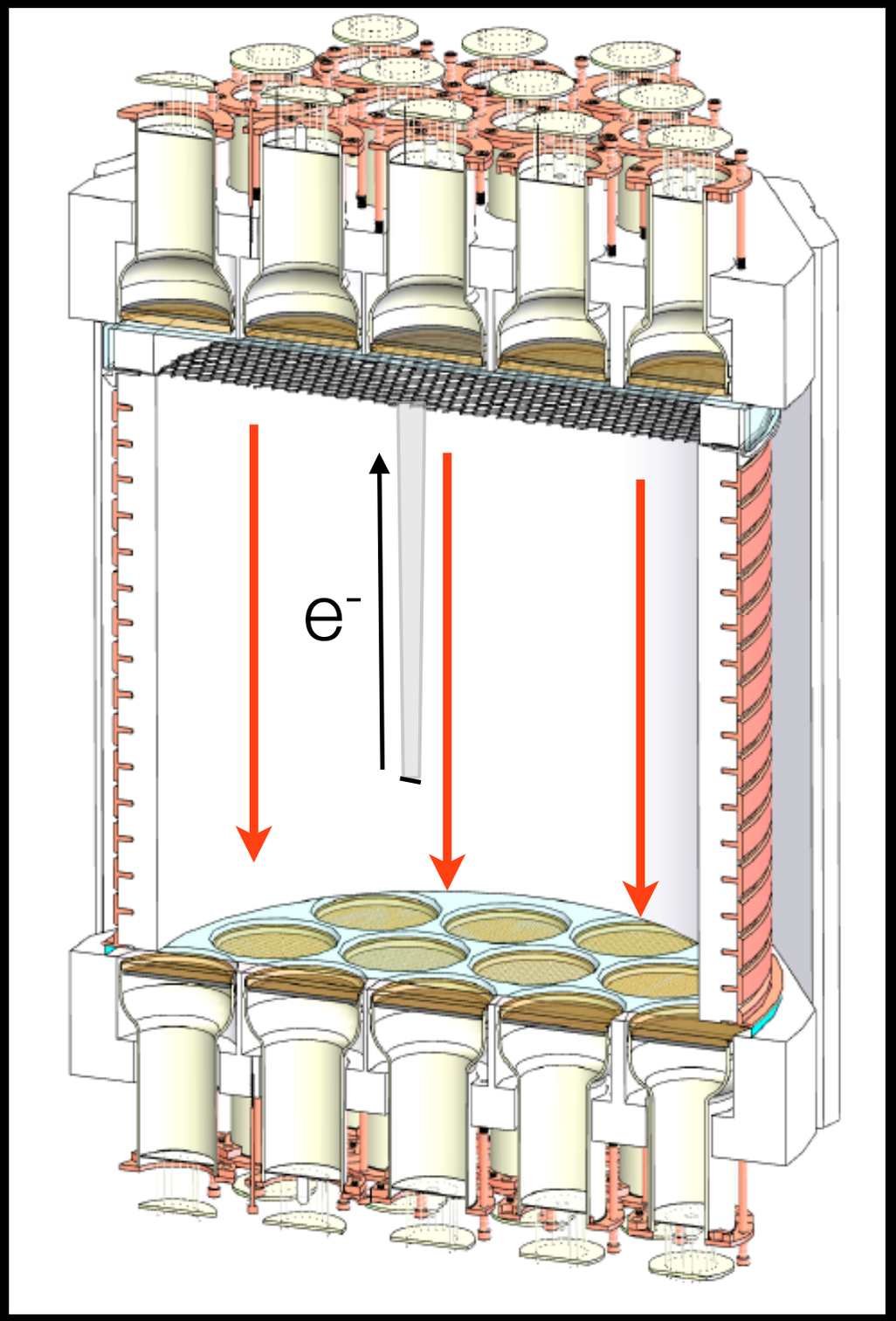
Detecting WIMPs



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

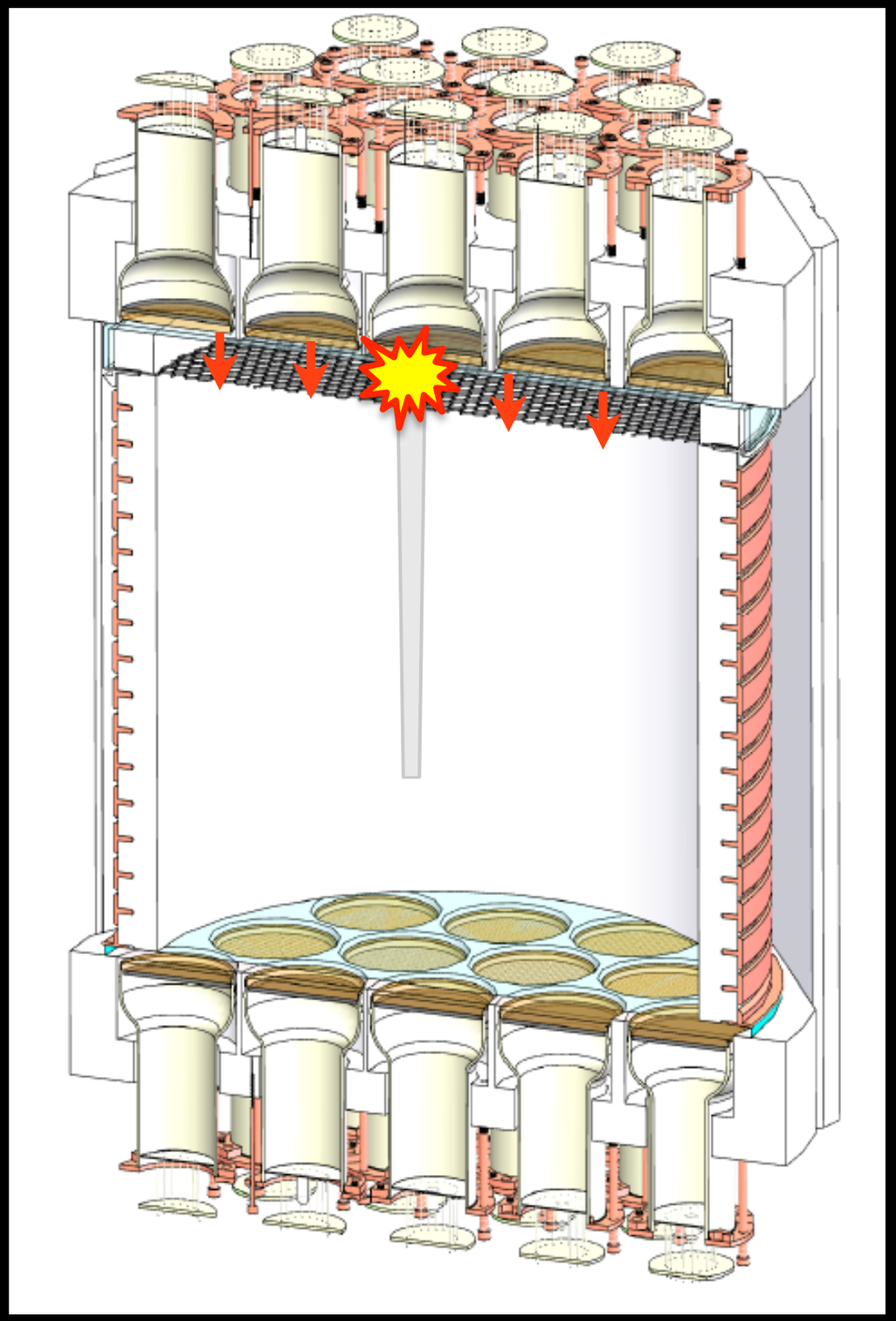


Detecting WIMPs

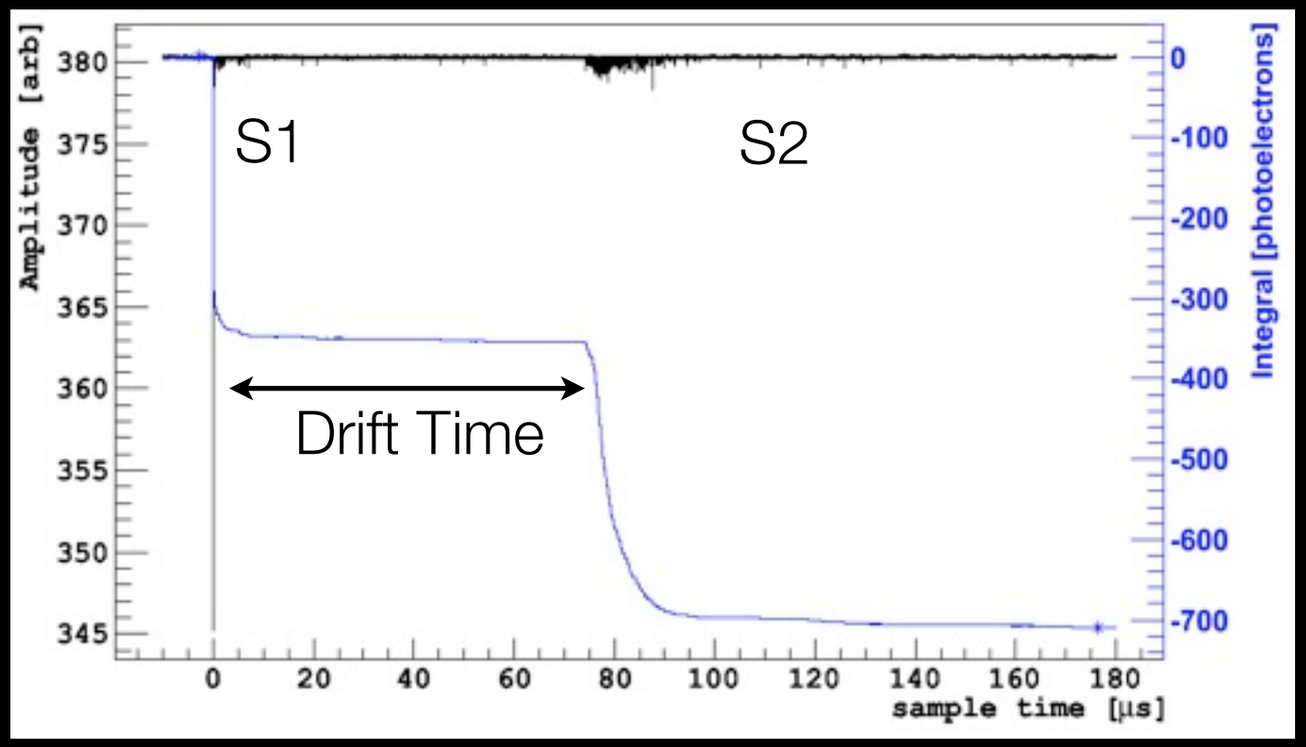


The ionized electrons that survive recombination are drifted towards the liquid-gas interface by the electric field

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

Backgrounds

[30-200]keVr

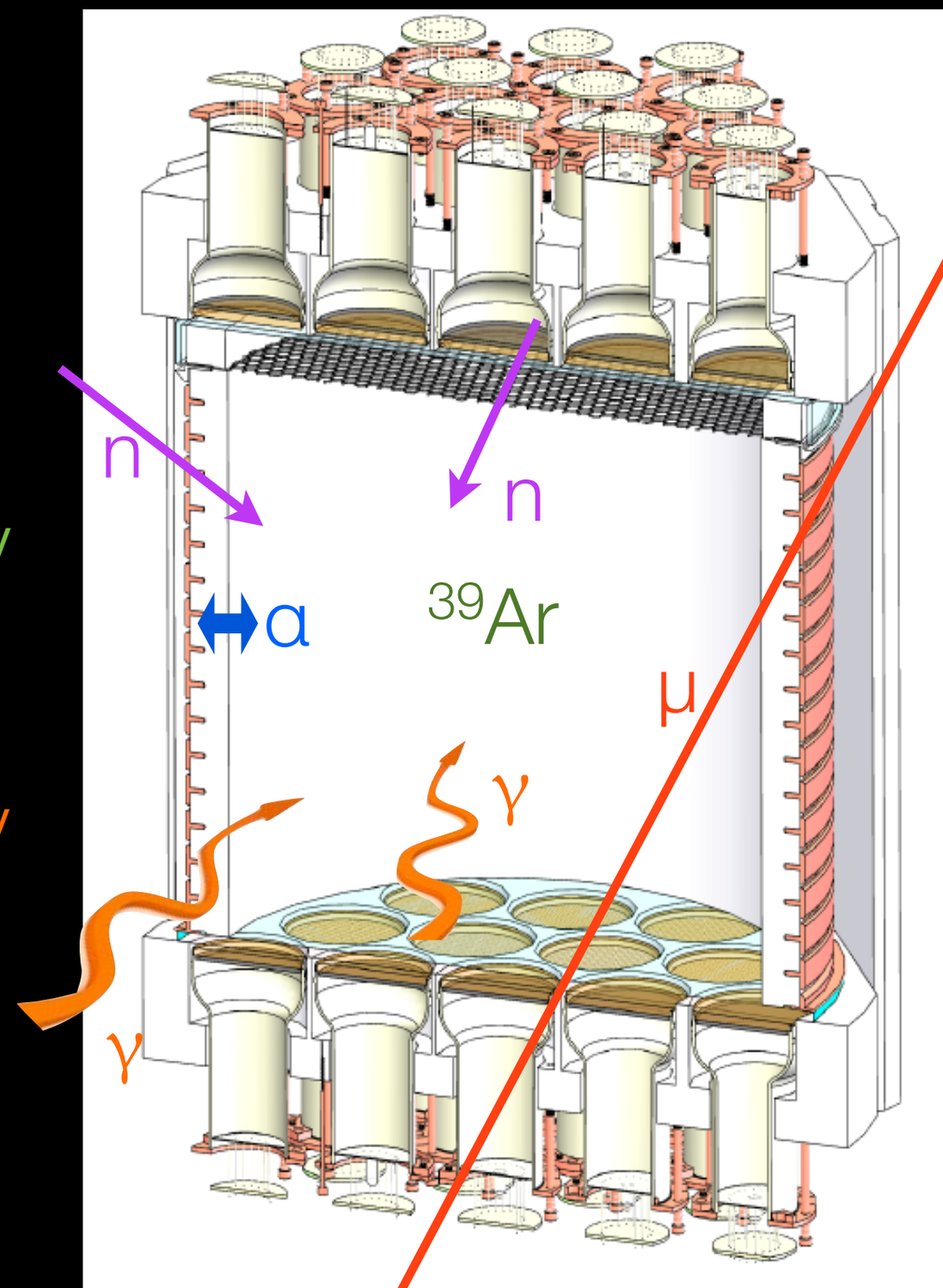
ELECTRON RECOILS

^{39}Ar

~1×10^{4} ev/kg/day

γ

~1×10^{2} ev/kg/day



NUCLEAR RECOILS

μ

~30 ev/m^2/day

Radiogenic n

~6×10^{-4} ev/kg/day

α

~10 ev/m^2/day

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

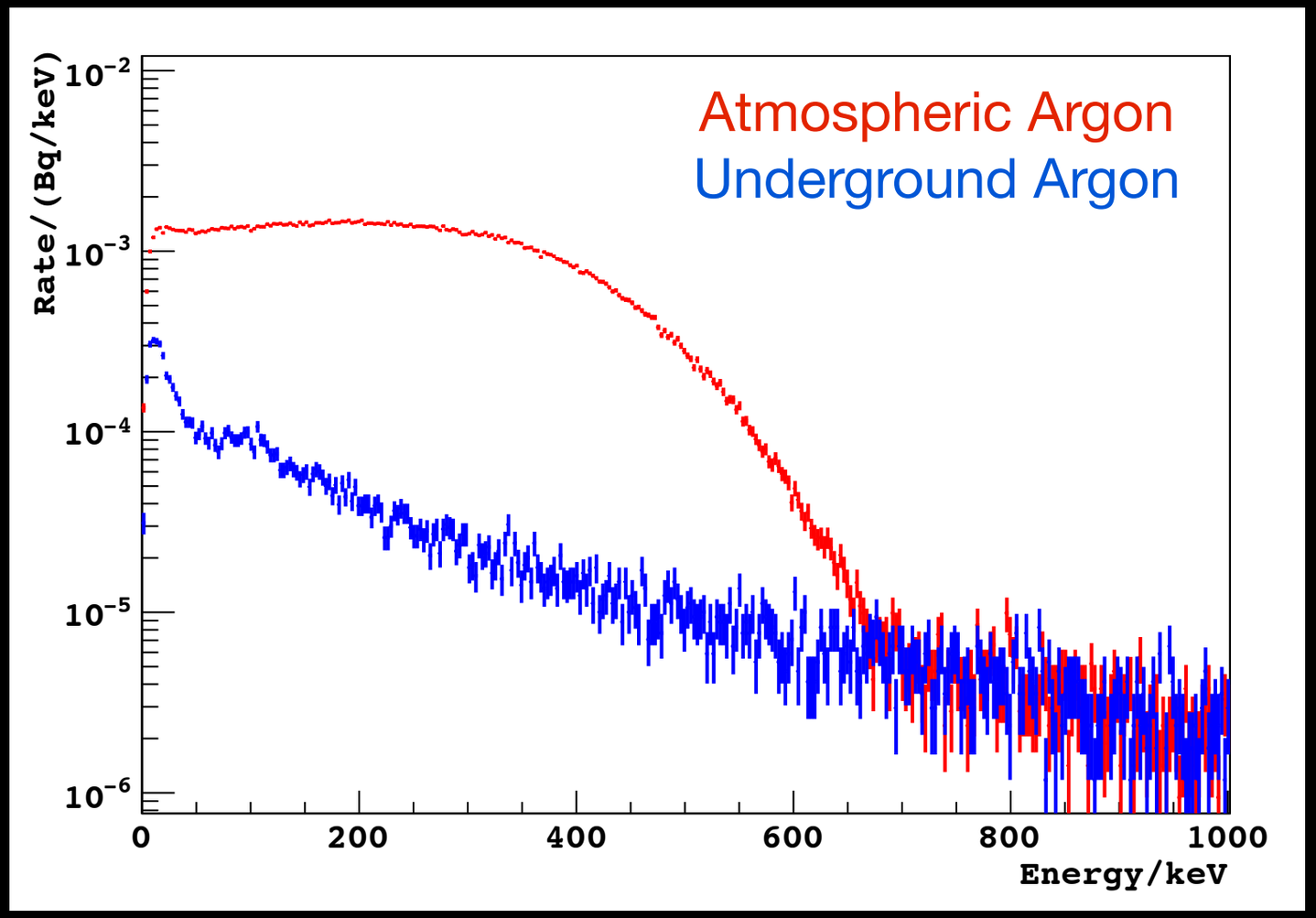
Underground Argon

- **^{40}Ar** is mostly produced **underground** (through decay of ^{40}K)
- **^{39}Ar** is **cosmogenic**, produced by ^{40}Ar(n,2n) interactions in the atmosphere
- Argon that has remained underground can therefore have extremely low levels of ^{39}Ar
- However, ^{39}Ar can also be produced underground through ^{39}K(n, p) interactions, where the neutron originates from (α, n) reactions.

^{39}Ar/^{40}Ar depends on the local concentration of ^{238}U and ^{232}Th

^{39}Ar

Source of underground argon measured to have
> 150 times lower rate of ^{39}Ar (90 CL),
compared to atmospheric argon



Astroparticle Physics
66 (2015): 53-60

No ^{39}Ar detectable - only upper limit

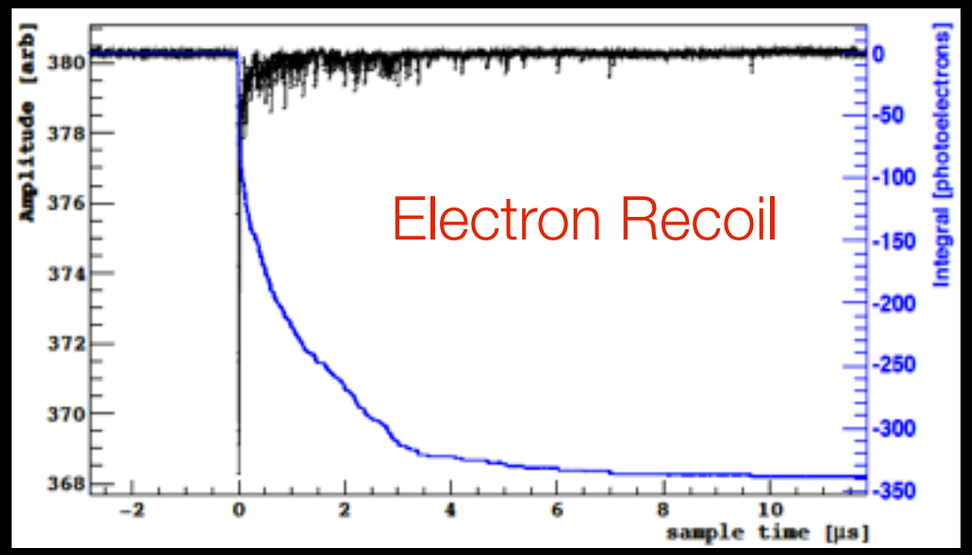
Pulse Shape Discrimination

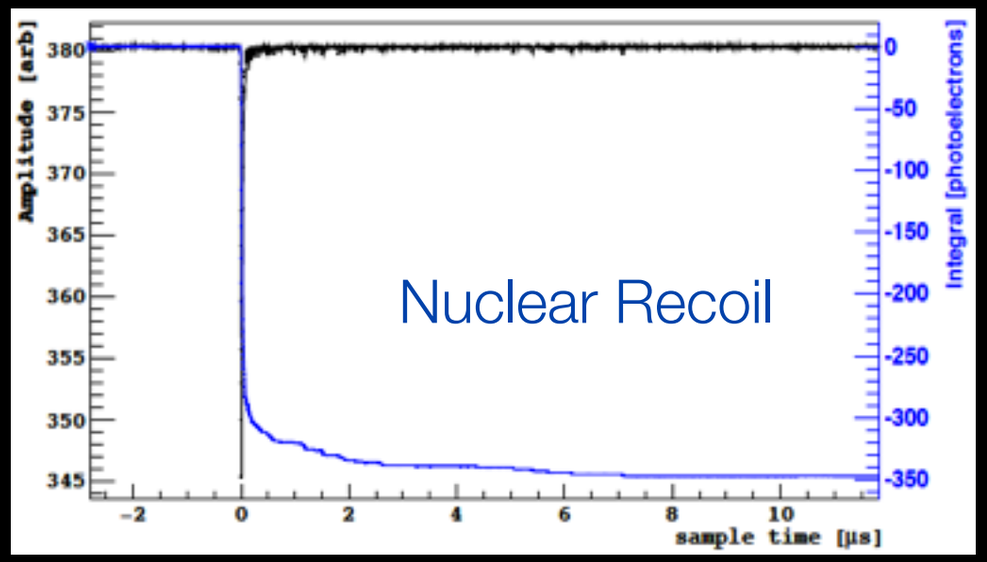
Electron Recoil Discrimination

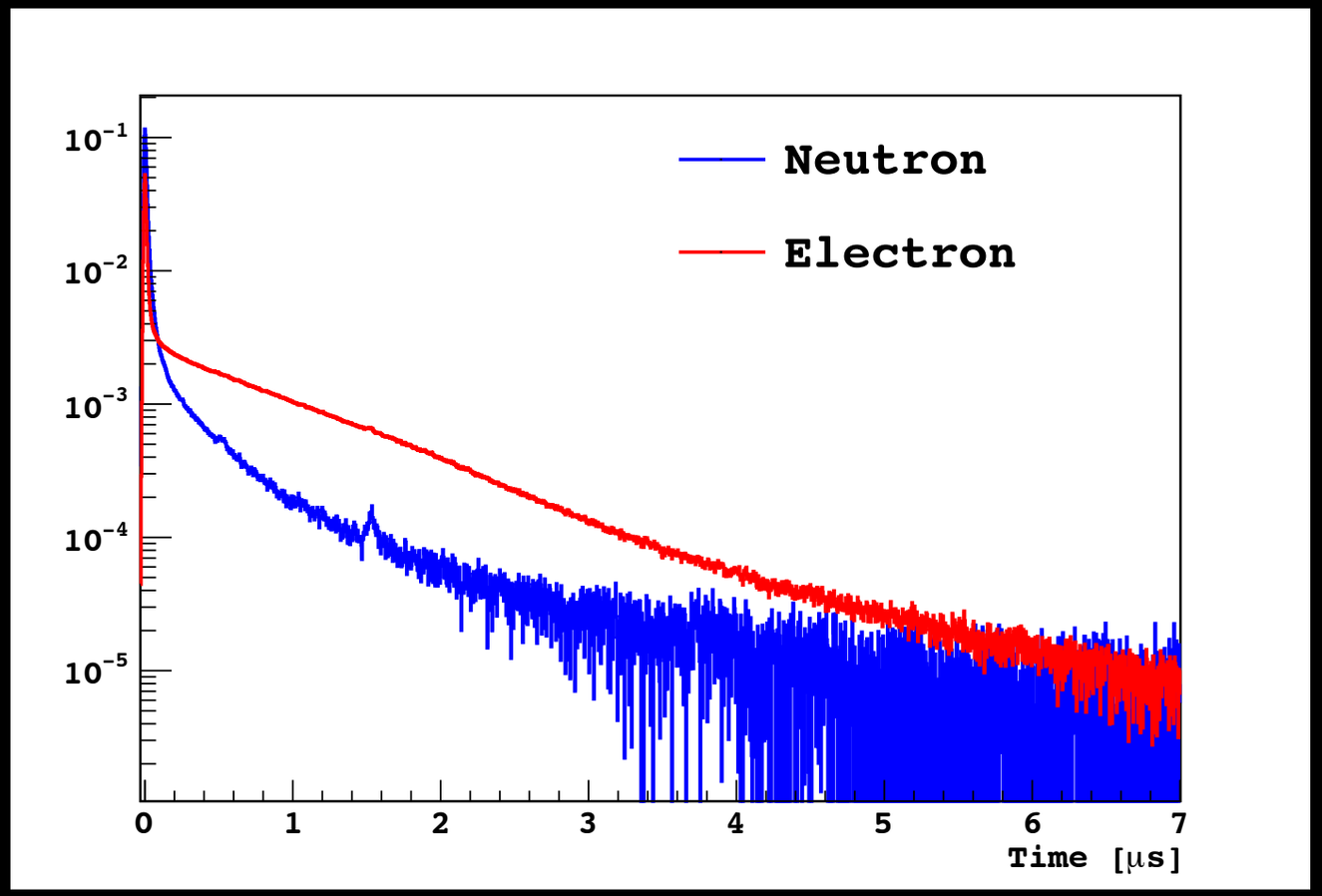
Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states

$\tau_{\text{singlet}} \sim 7$ ns

$\tau_{\text{triplet}} \sim 1600$ ns







Pulse Shape Discrimination

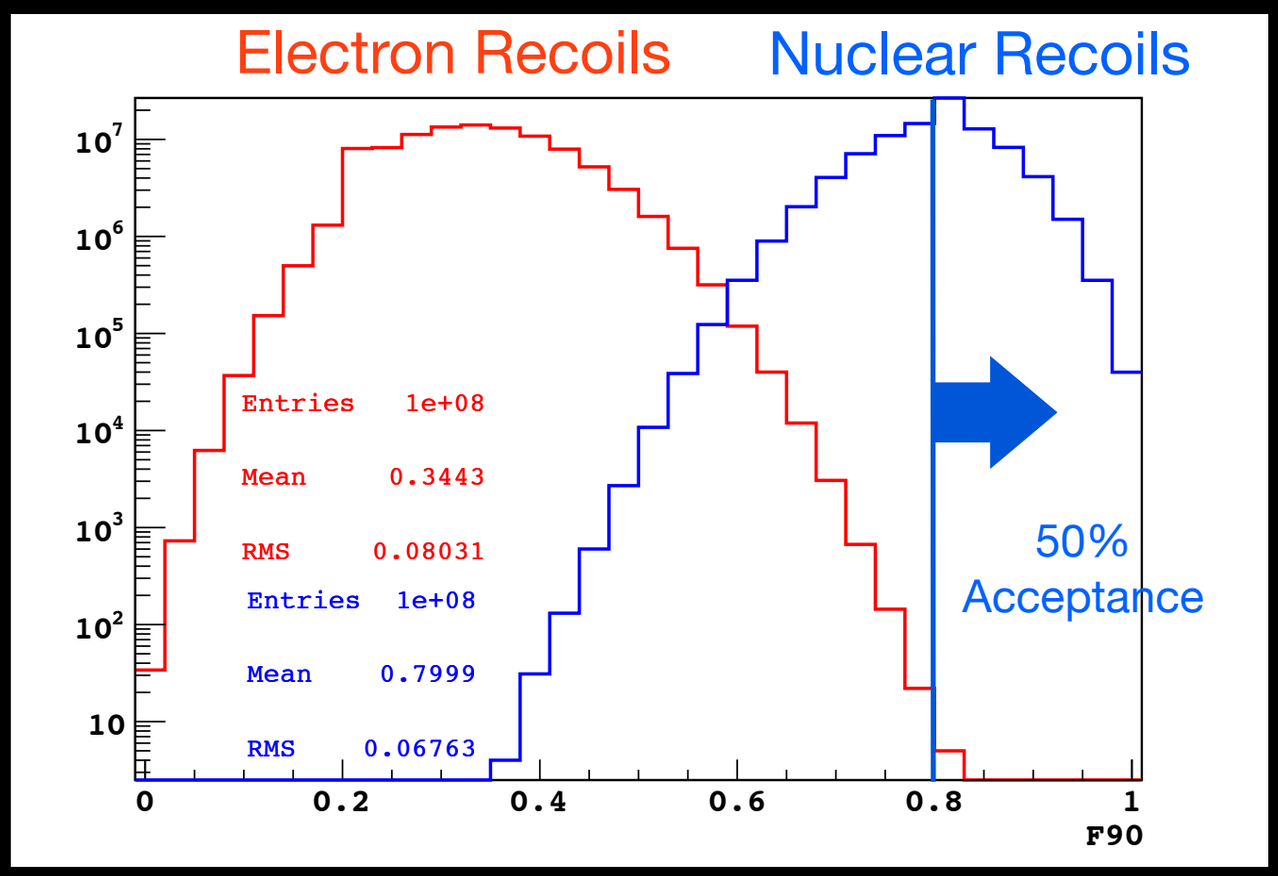
Electron Recoil Discrimination

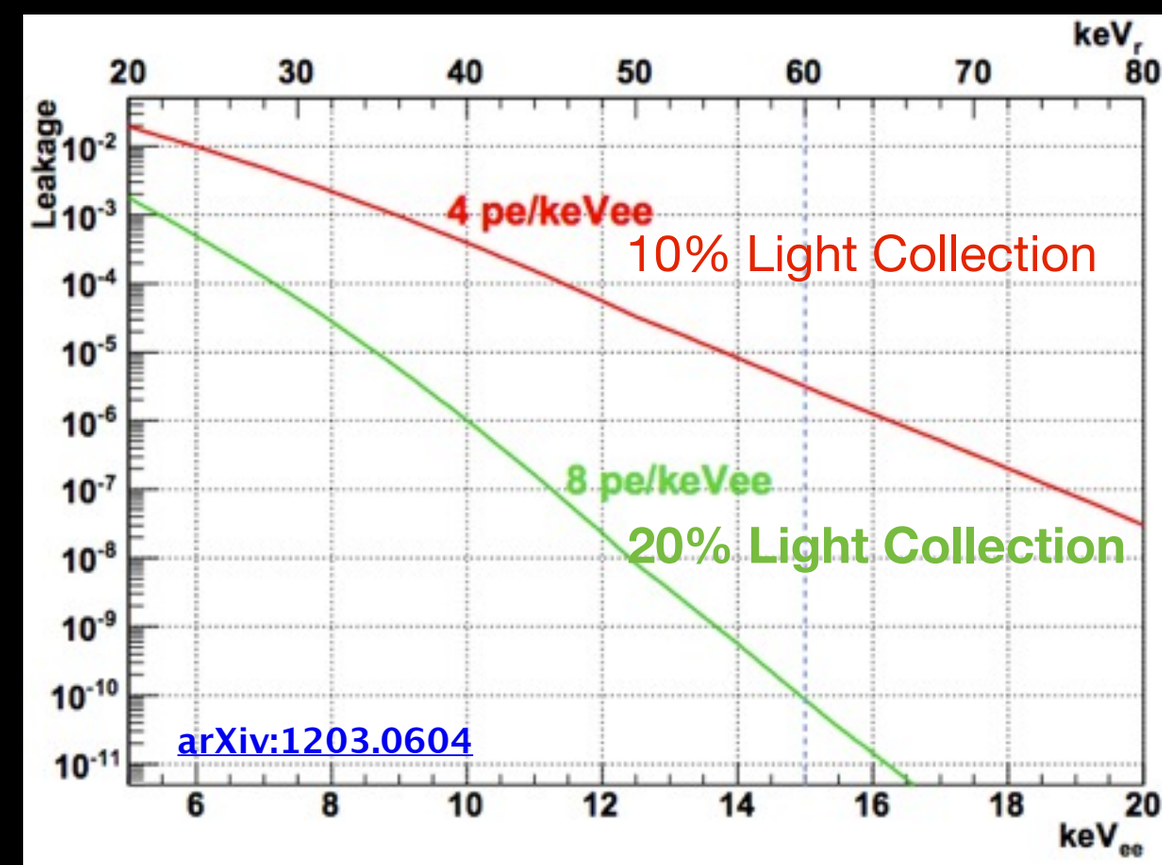
F90: Ratio of detected light in the first 90 ns, compared to the total signal

$\tau_{\text{singlet}} \sim 7$ ns

$\tau_{\text{triplet}} \sim 1600$ ns

F90 ~ Fraction of singlet states



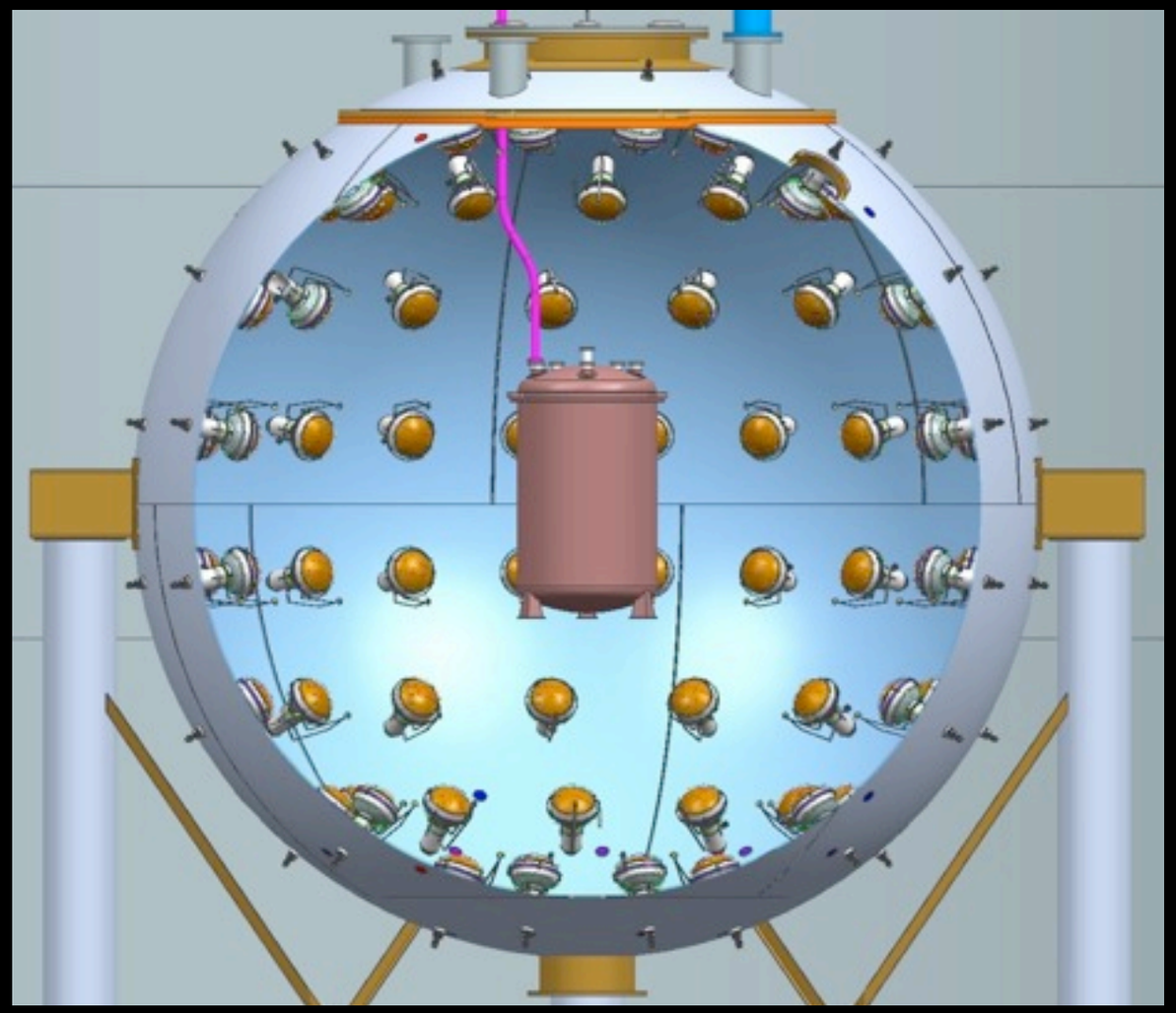


Discrimination power strongly dependent on light collection

Neutron Rejection

Liquid Scintillator Veto

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

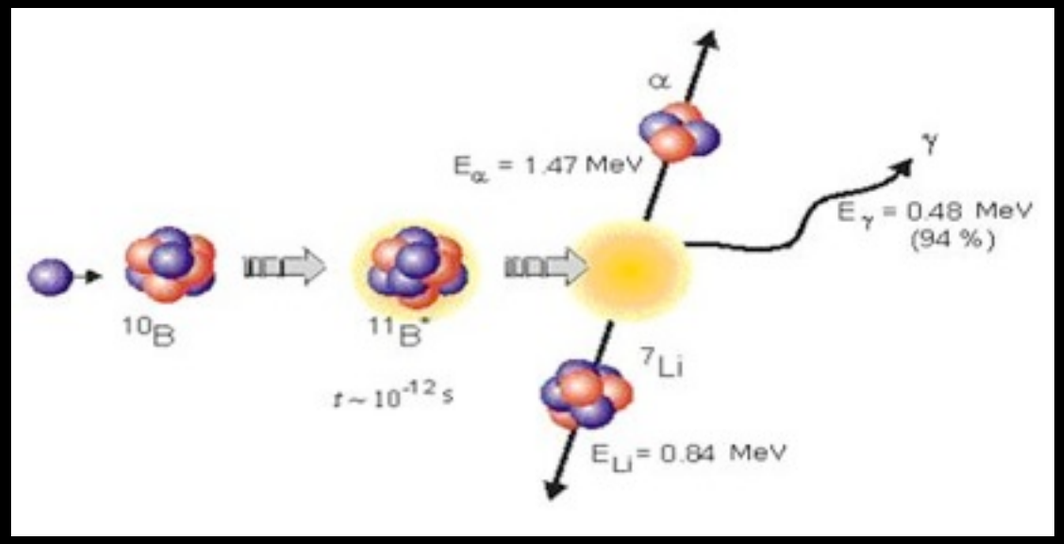


- 4 m diameter sphere containing PC + TMB scintillator
- Instrumented with 110 8” PMTs

Neutron Rejection

Borated Liquid Scintillator

- High neutron capture cross section on boron allows for compact veto size
- Capture results in 1.47 MeV α particle
  - quenched to ~ 50 keV_{ee}
  - can be detected with high efficiency
- Short capture time reduces dead time loss



	Veto Efficiency (MC)
Radiogenic Neutrons	> 99.5%*
Cosmogenic Neutrons	> 95%

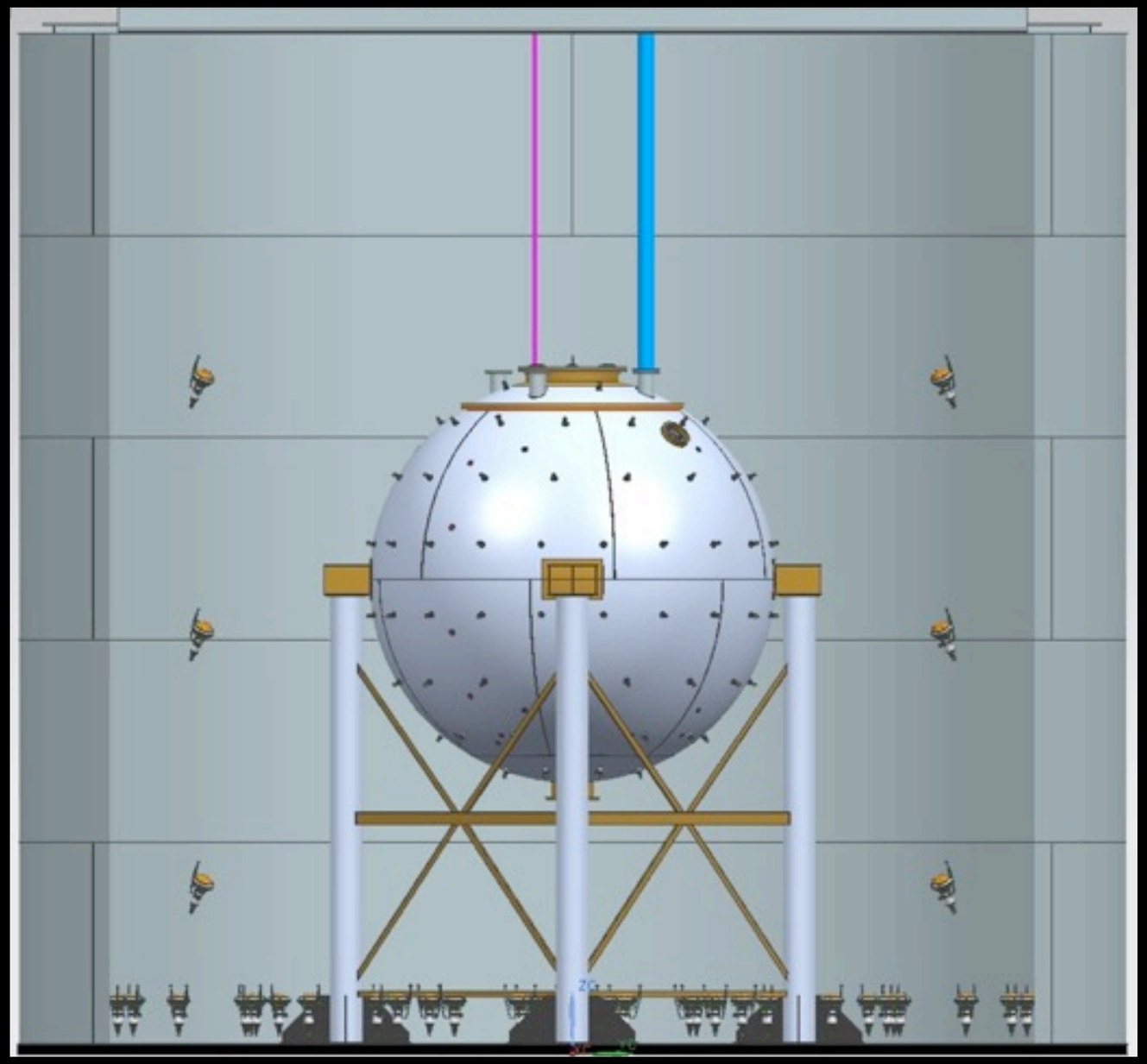
Nuclear Instruments and Methods A 644, 18 (2011)

*Based on 50% TMB and 60 μs veto window

Cosmogenics Rejection

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

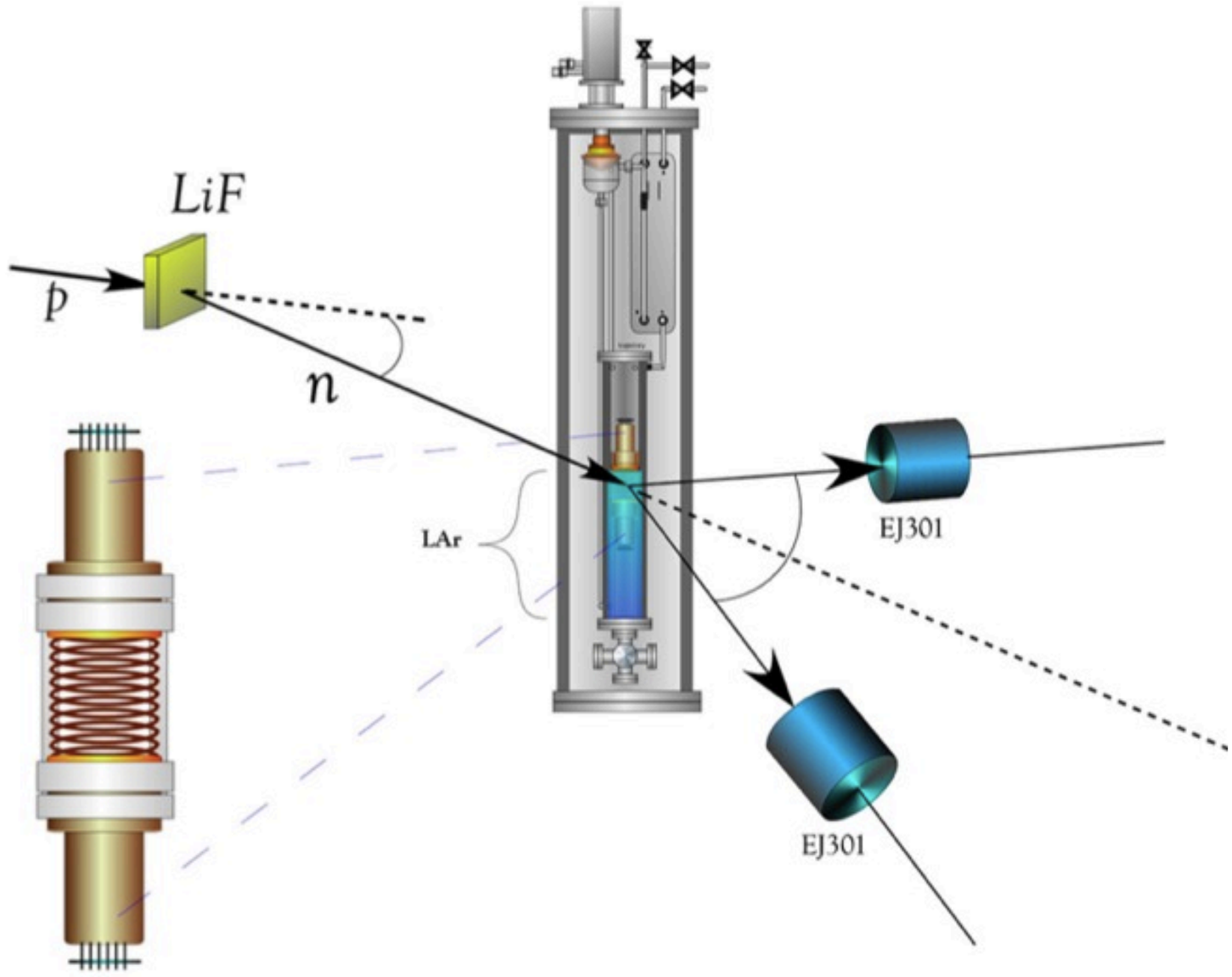
Final preparation, cleaning, evaporation and assembly of all inner detector parts was carried out in radon-free clean rooms

Typical radon in air ~ 30 Bq/m^3

Cleanroom radon levels < 5 mBq/m^3

SCENE

(**Sc**intillation and Ionization **E**fficiency of **N**oble **E**lements)

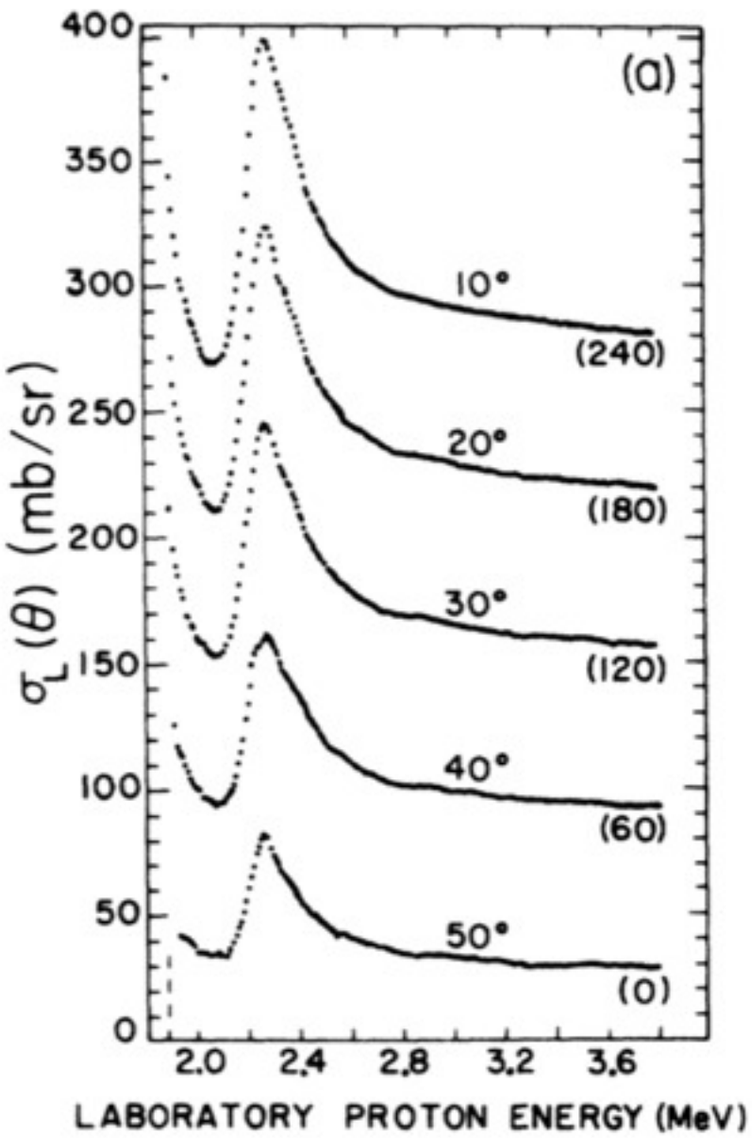


Neutron Generation

$^{7}Li(p, n)^{7}Be$ Reaction

Produces **monoenergetic** low energy neutrons

Reaction Threshold at 1.88 MeV
Cross-section peaks at a proton energy of 2.3 MeV



Vertical offset in ( ) to be subtracted

2.3 MeV protons generate ~0.5 MeV neutrons
Neutron energy has strong angular dependence

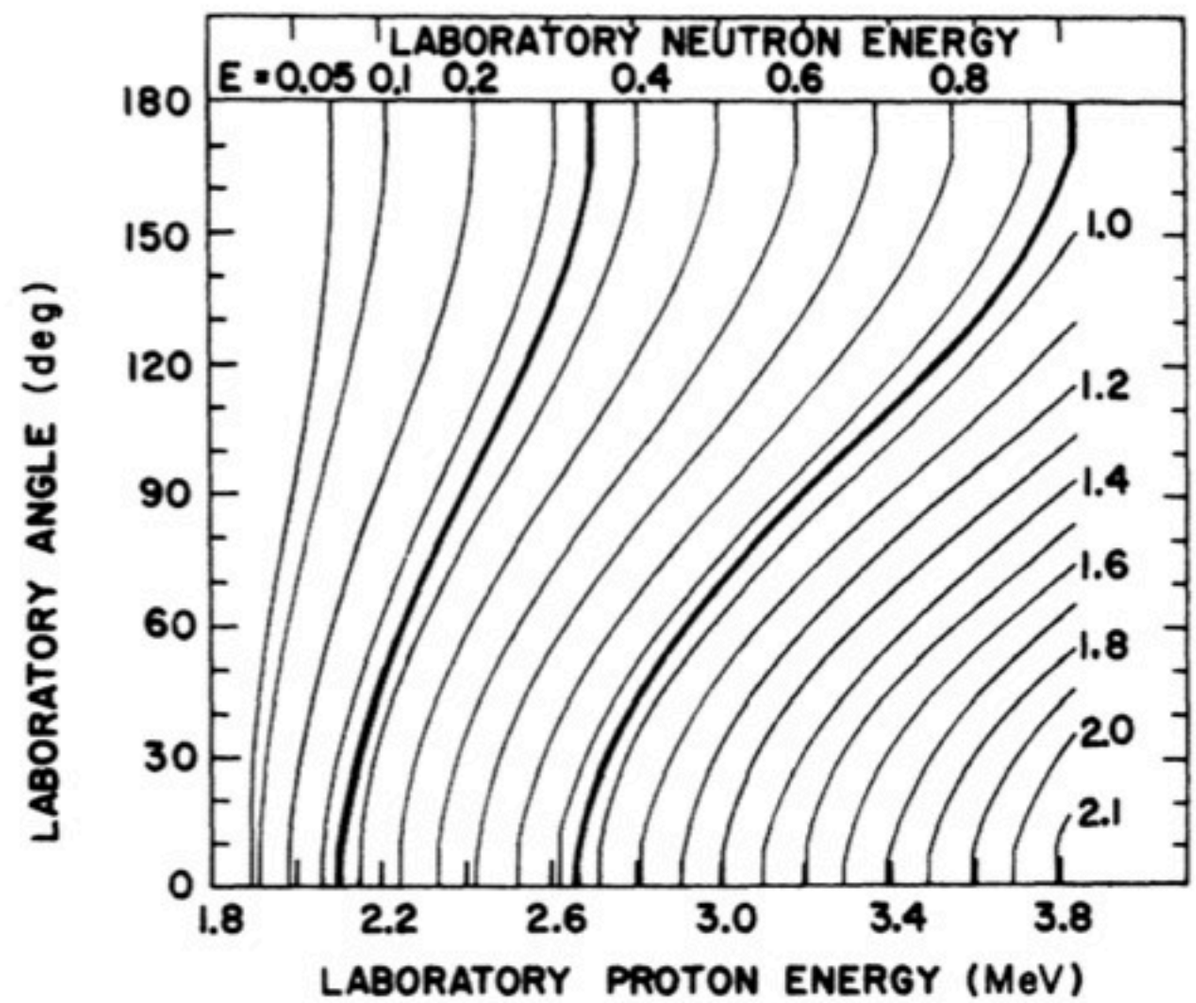


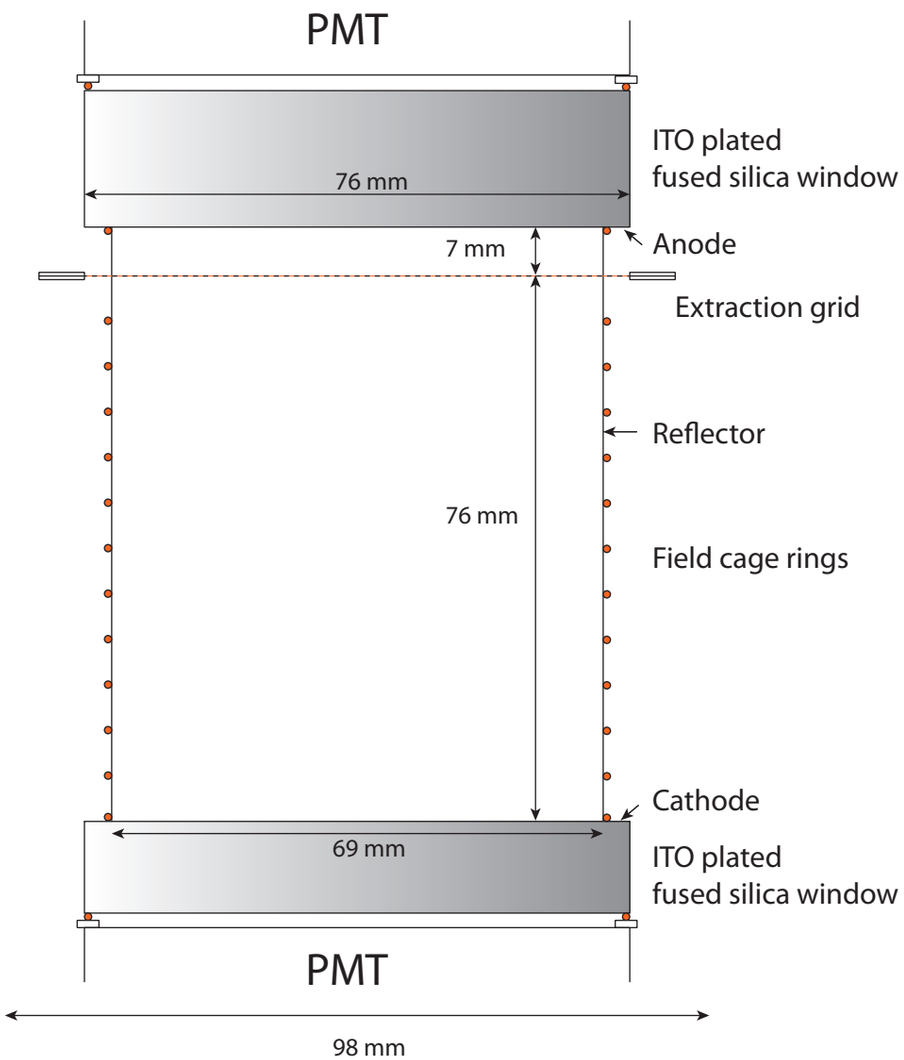
FIG. 4. Traces of constant laboratory neutron energy versus laboratory proton energy and reaction angle for $^{7}Li(p,n_0)^{7}Be$. The wide lines delimit the neutron energies for which complete angular distributions were obtained.

Ref: C.A.Burke et al., Phys. Rev. C 10, 1299 (1974)

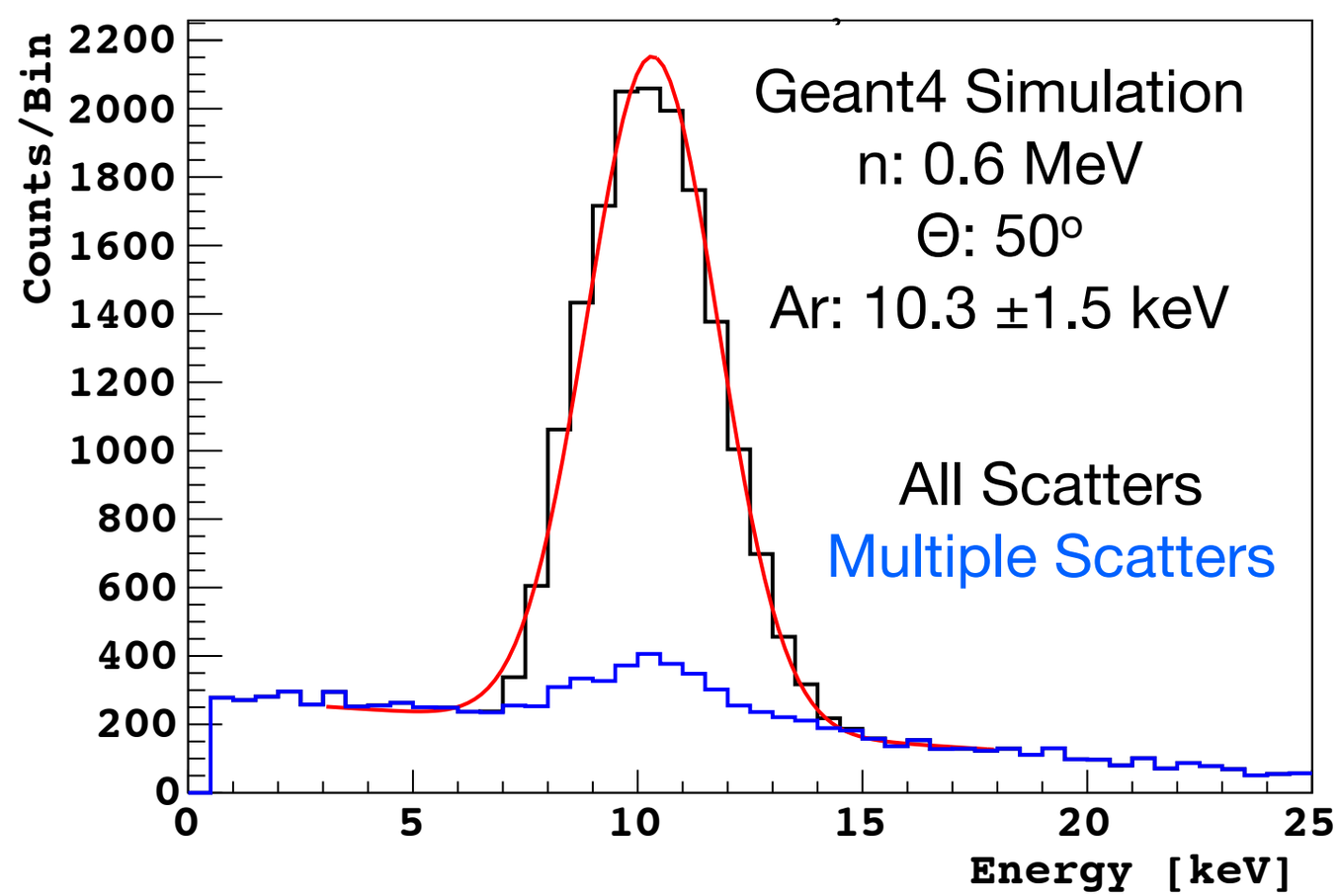
SCENE Detector

Fully functional two-phase argon TPC
capable of measuring scintillation, ionization and pulse shape

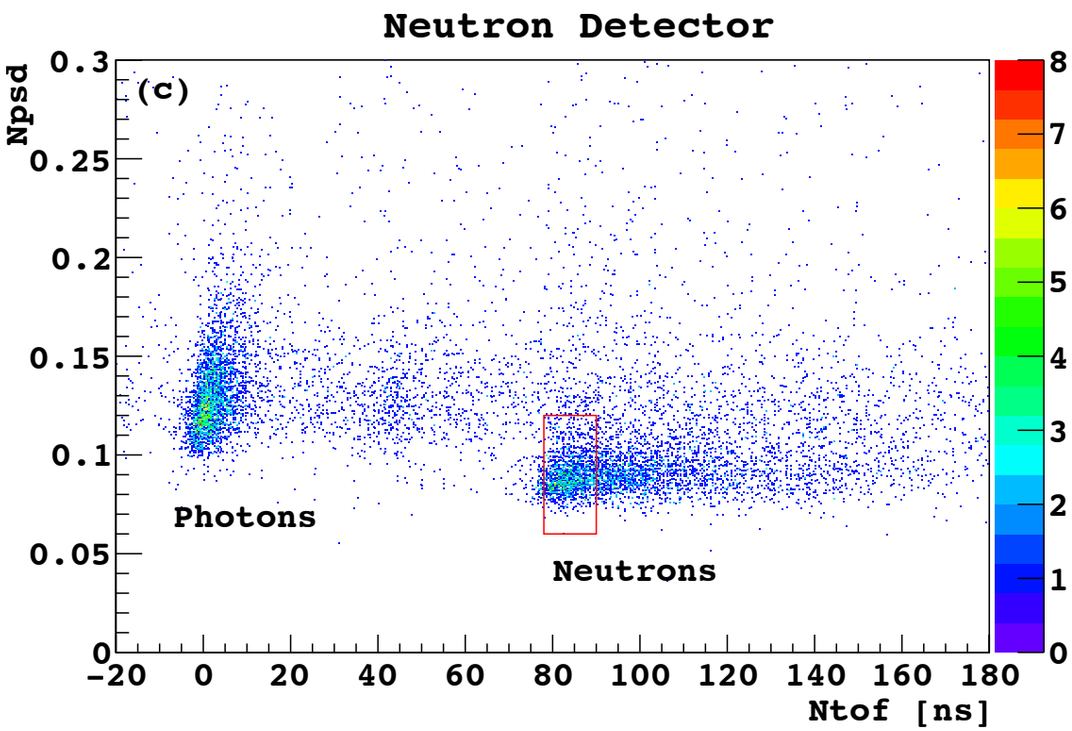
Similar design to DarkSide-50

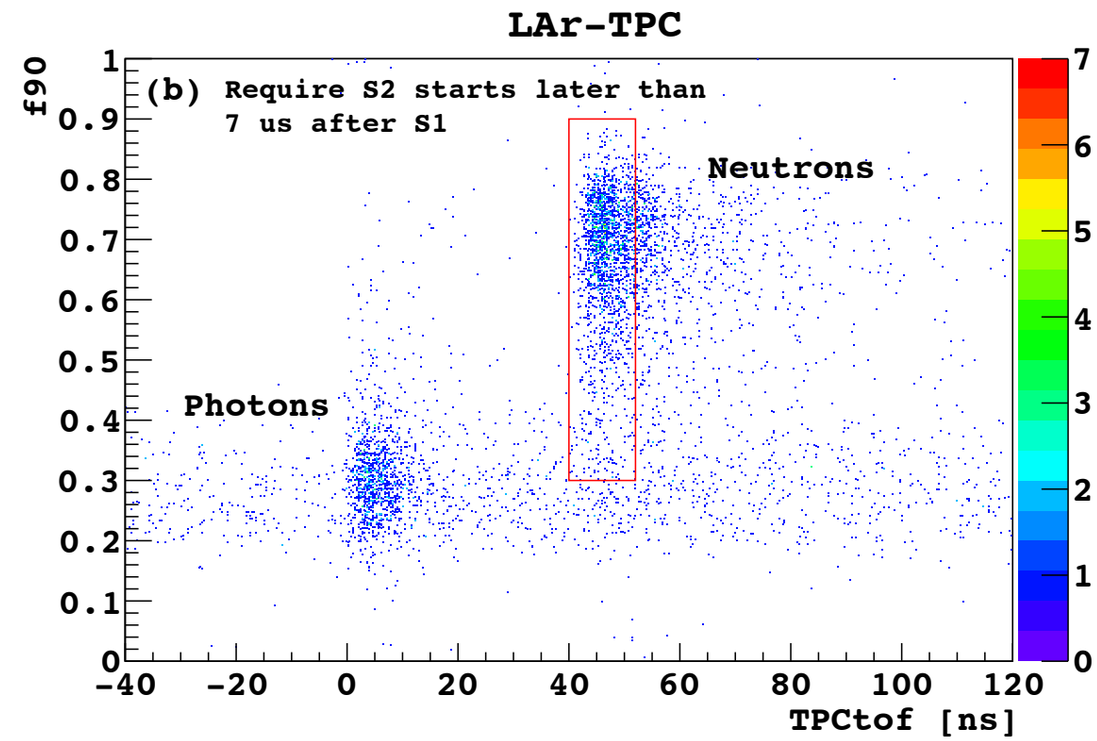


Designed to minimize multiple neutron interactions



NR Selection



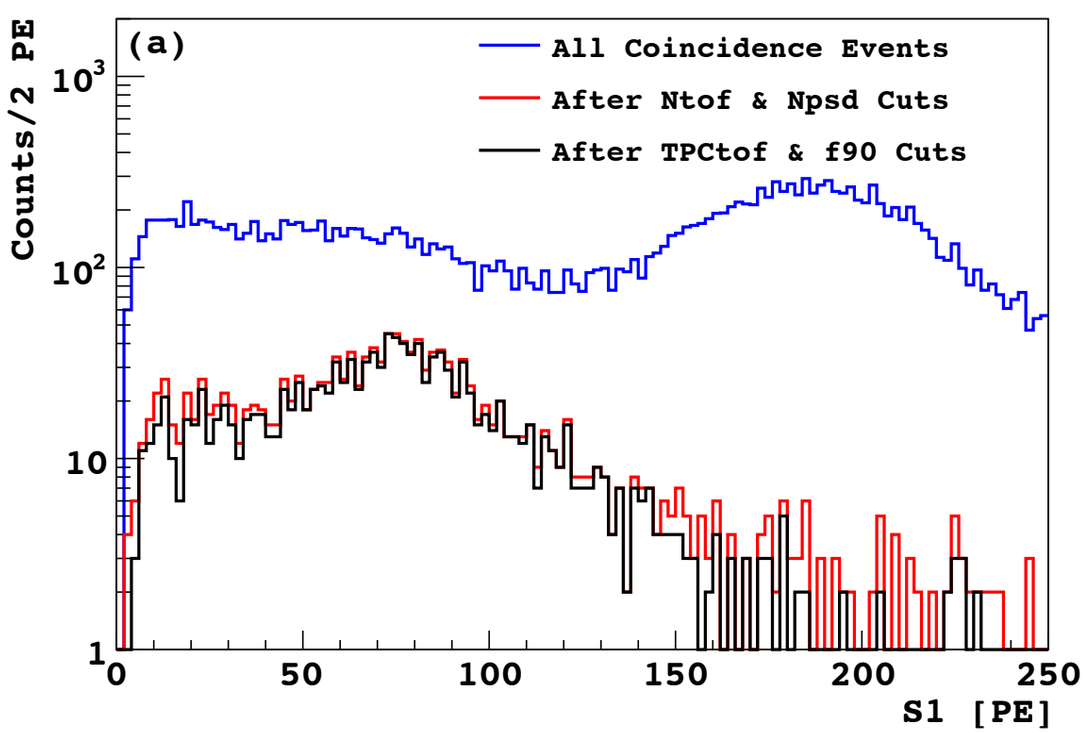


Ntof: Time difference between the proton-beam-on-target and the neutron detector signal

TPCtof: Time difference between the proton-beam-on- target and the TPC signal

Npsd: PSD in the neutron detector

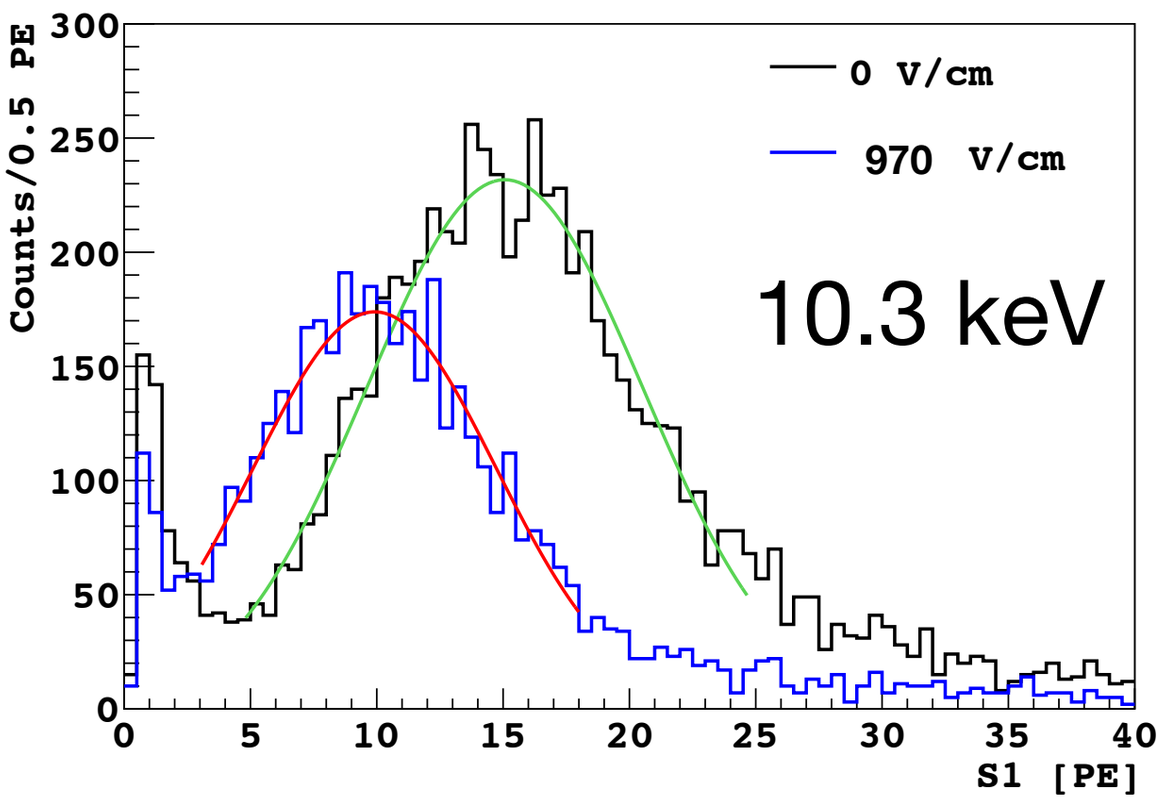
F90: PSD parameter in LAr

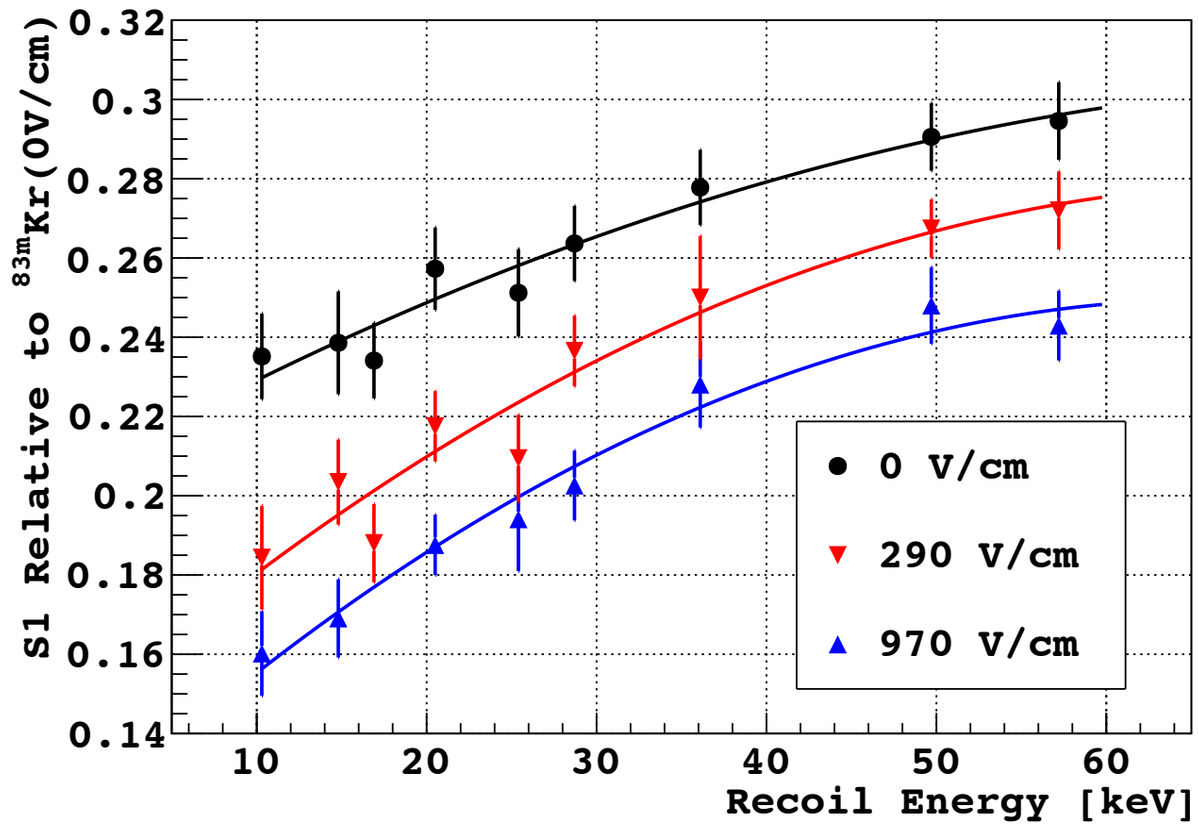


The bunched and pulsed proton beam, combined with accurate timing in neutron detector and TPC allows for a very clean selection of single-scatter nuclear recoils of known energy.

NR Scintillation Yield

First direct evidence of
field-dependent quenching in liquid argon

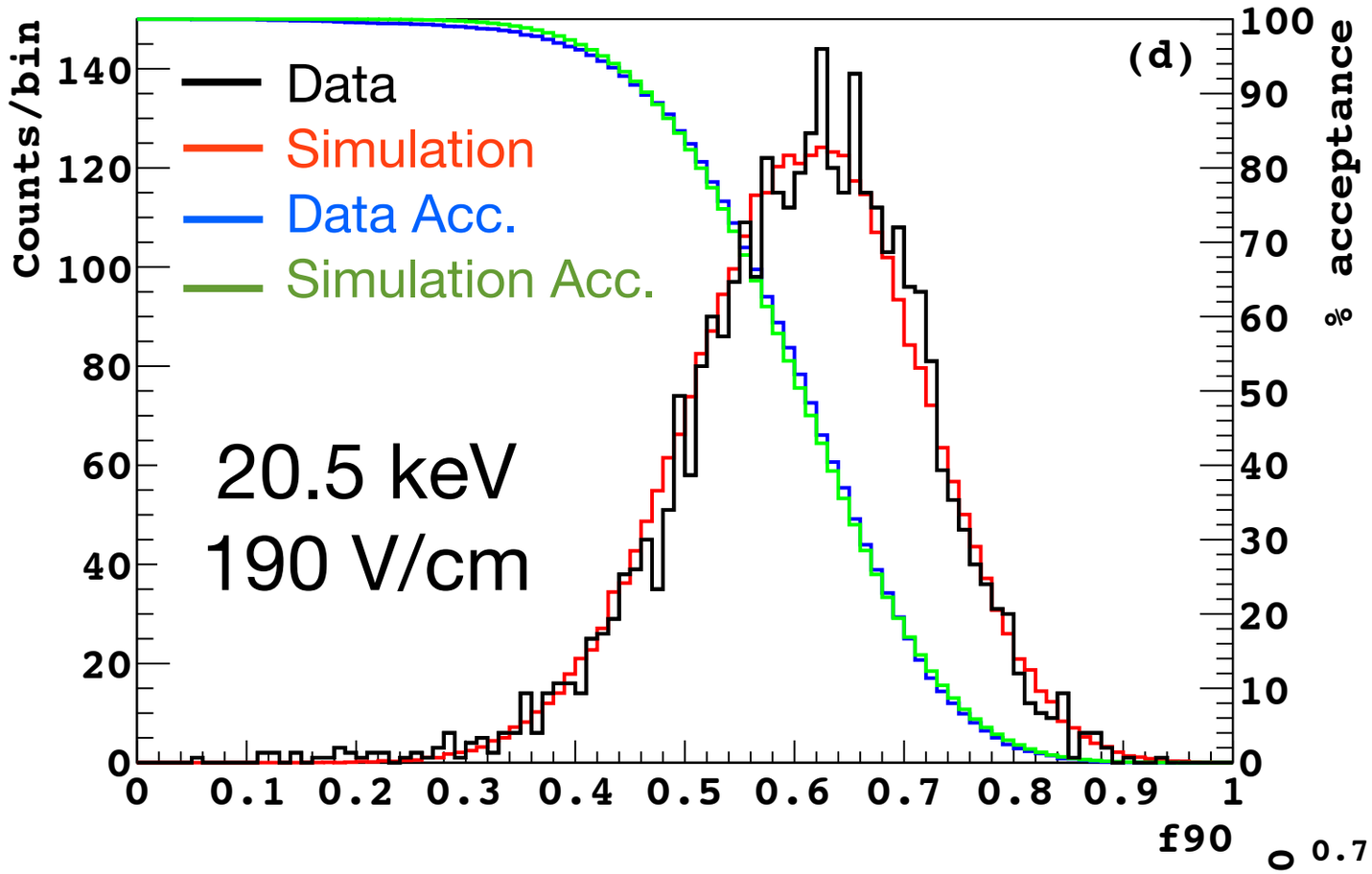




Measurement indicates that it is beneficial to run LAr TPC at low fields, where scintillation yield is higher

Reduces technical difficulties of applying high voltage
DarkSide-50 now runs at 200 V/cm, 12.7 kV

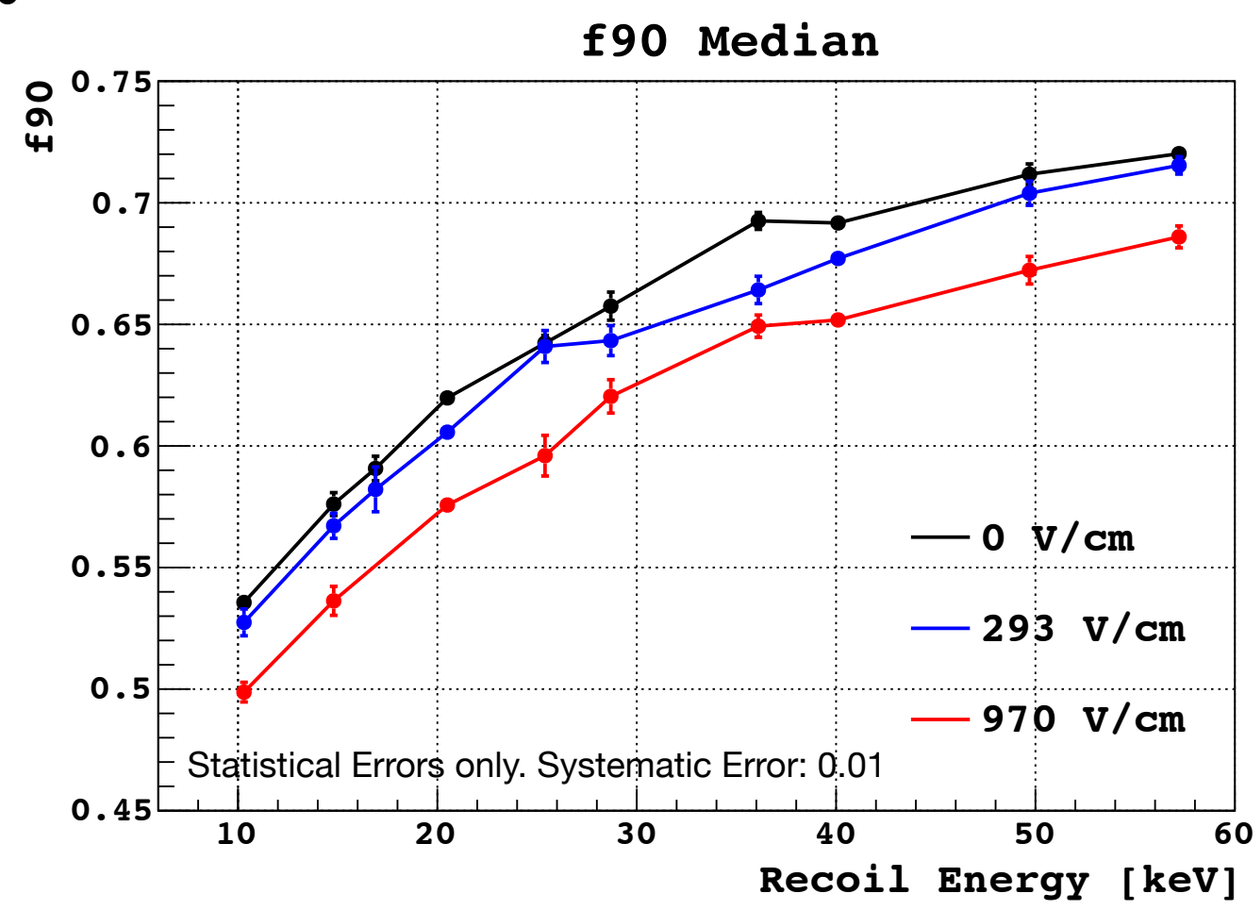
NR Pulse Shape



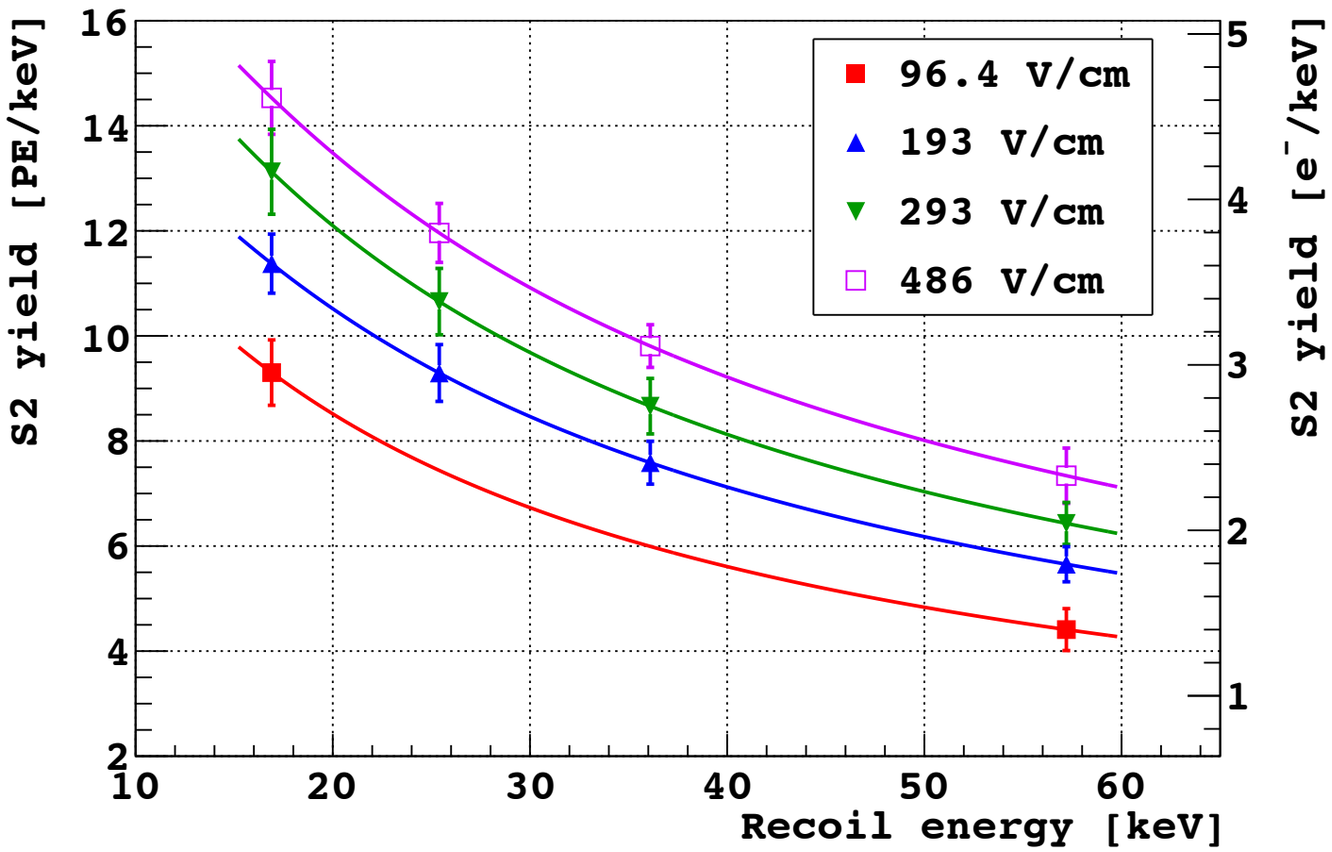
Clear identification of nuclear recoils through TOF produces a clean sample that can be used to evaluate the scintillation pulse shape parameters

Good agreement between statistical model and data indicates that **NR F90 distribution can be modeled accurately using only the F90 median** as input

Other contributions to the width, such as lightyield, PMT response, noise etc. are detector-dependent



NR Ionizaton Yield

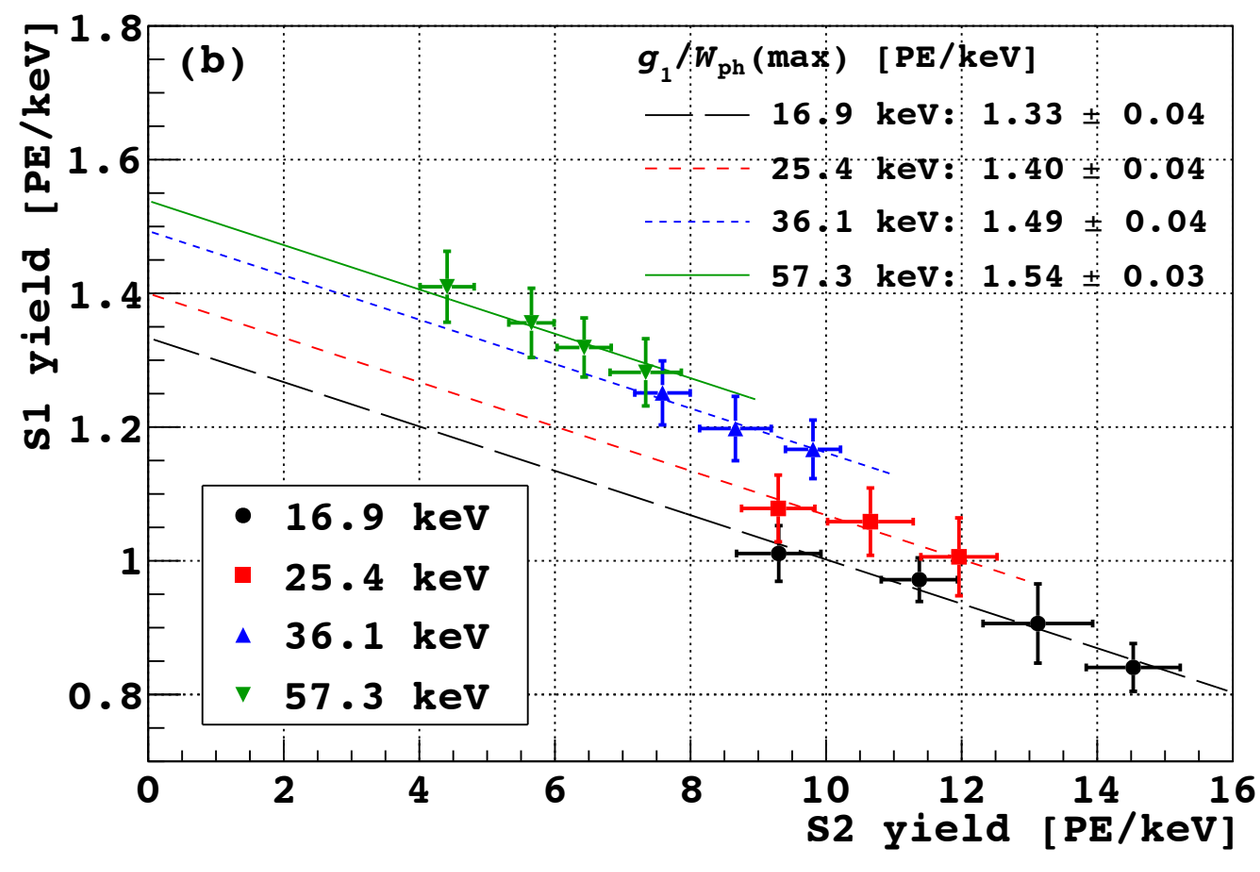


Ionization yield from NR increases at low energies

Can be expressed in detector-independent units of extracted electrons/keV

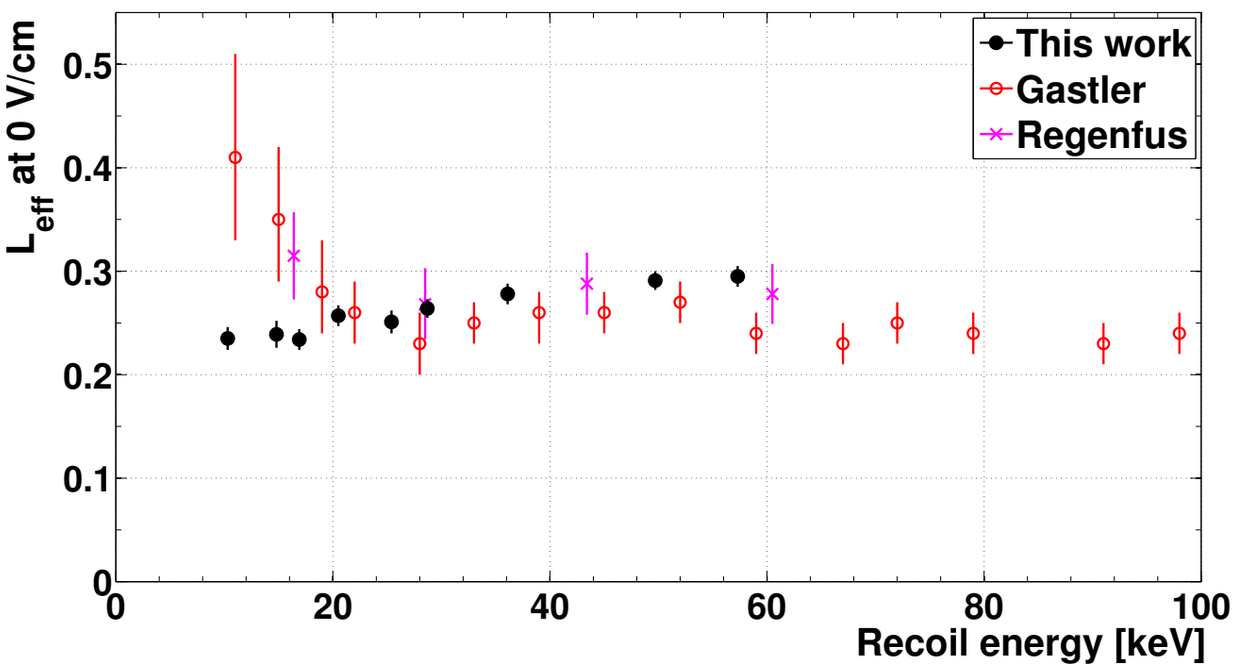
S1 and S2 yields for NR are **globally linearly anti-correlated** (as for ER)

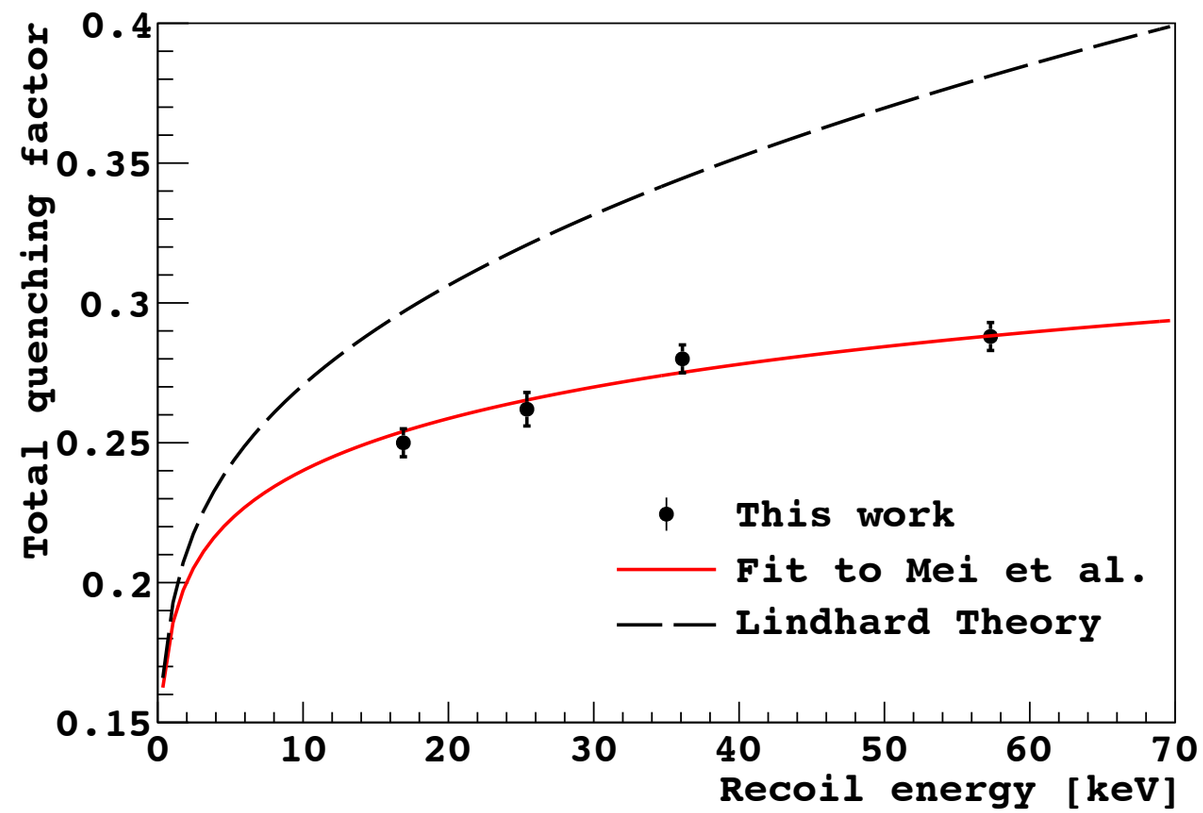
Varying y-intercepts indicates that the **fraction of NR energy that goes into ionization and scintillation varies with energy** (unlike ER)



SCENE Publications

Lots more interesting results ...





Phys. Rev. D 88, 092006
arXiv:1406.4825 - submitted to PRD

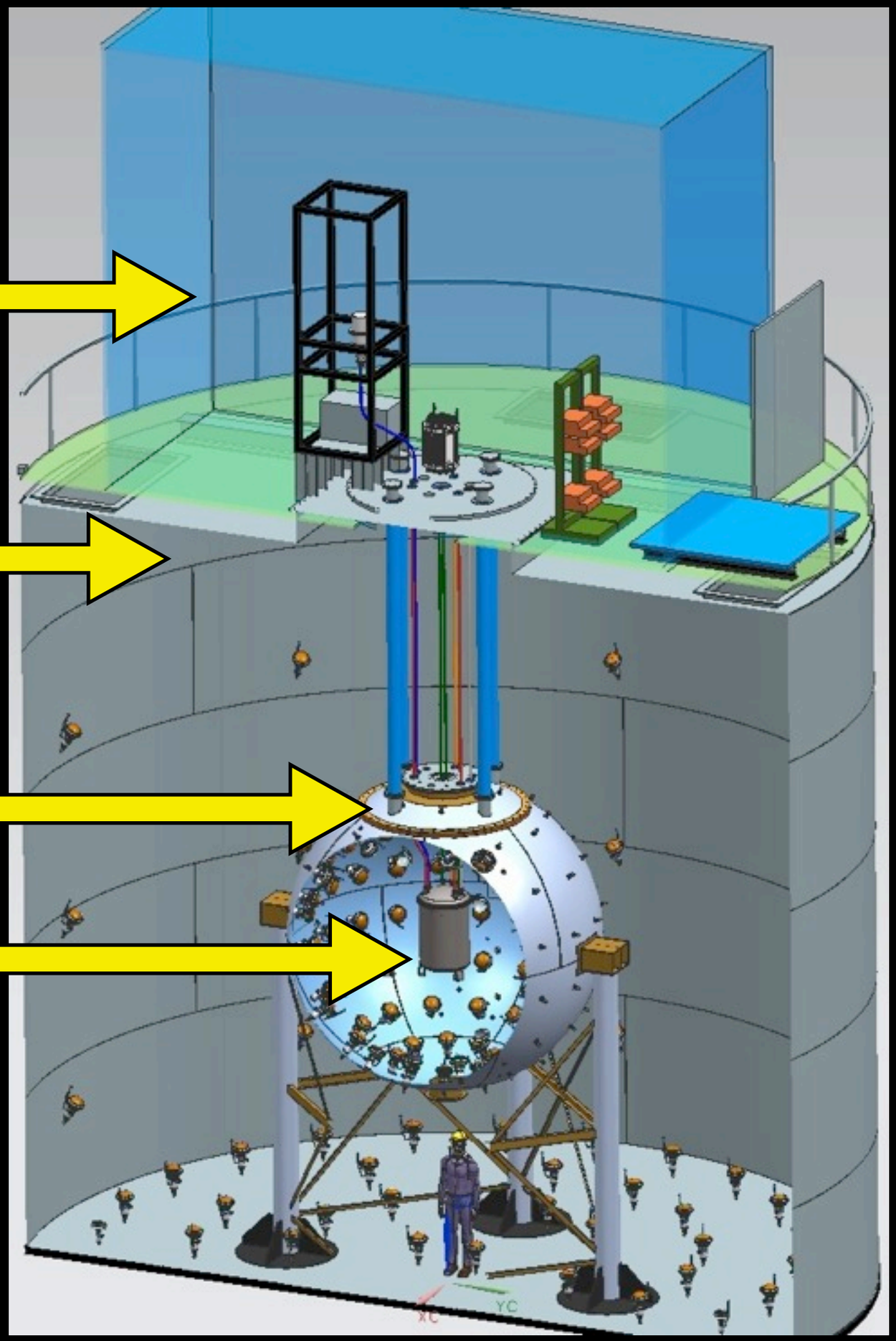
DarkSide 50

Radon-free clean room

Instrumented water tank

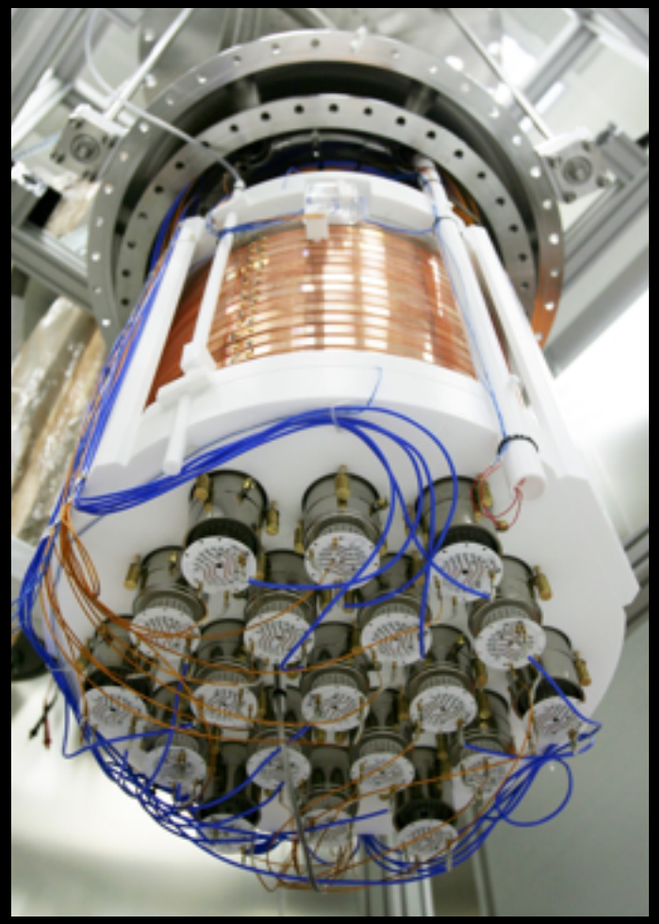
Liquid scintillator

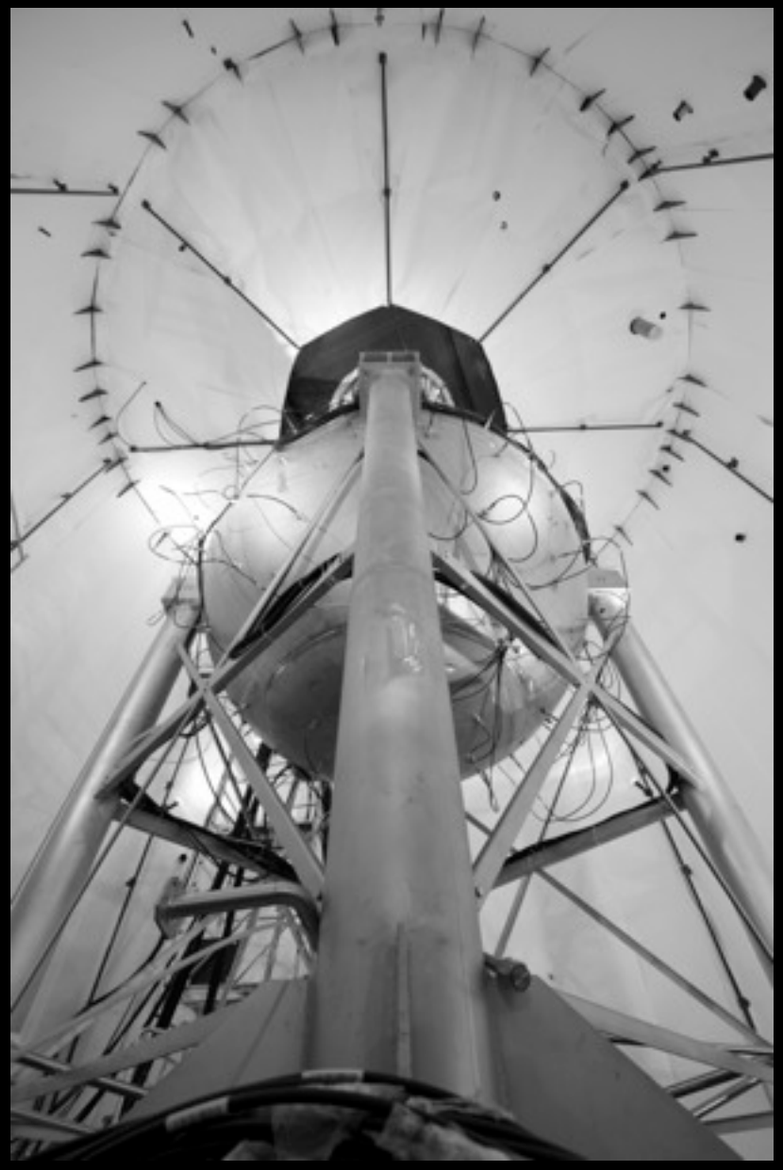
Inner detector TPC



DS-50 Assembly

Sept - Oct 2013

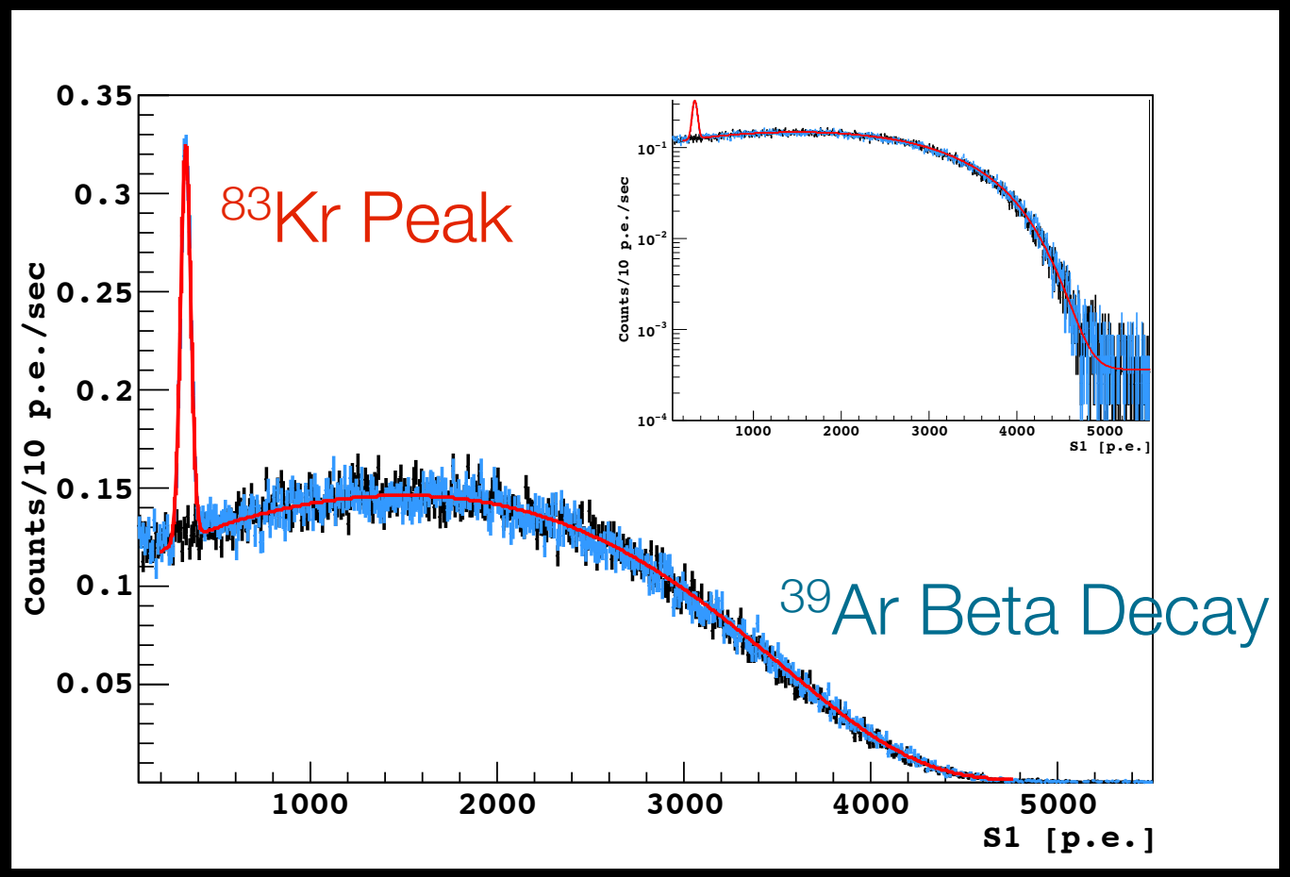


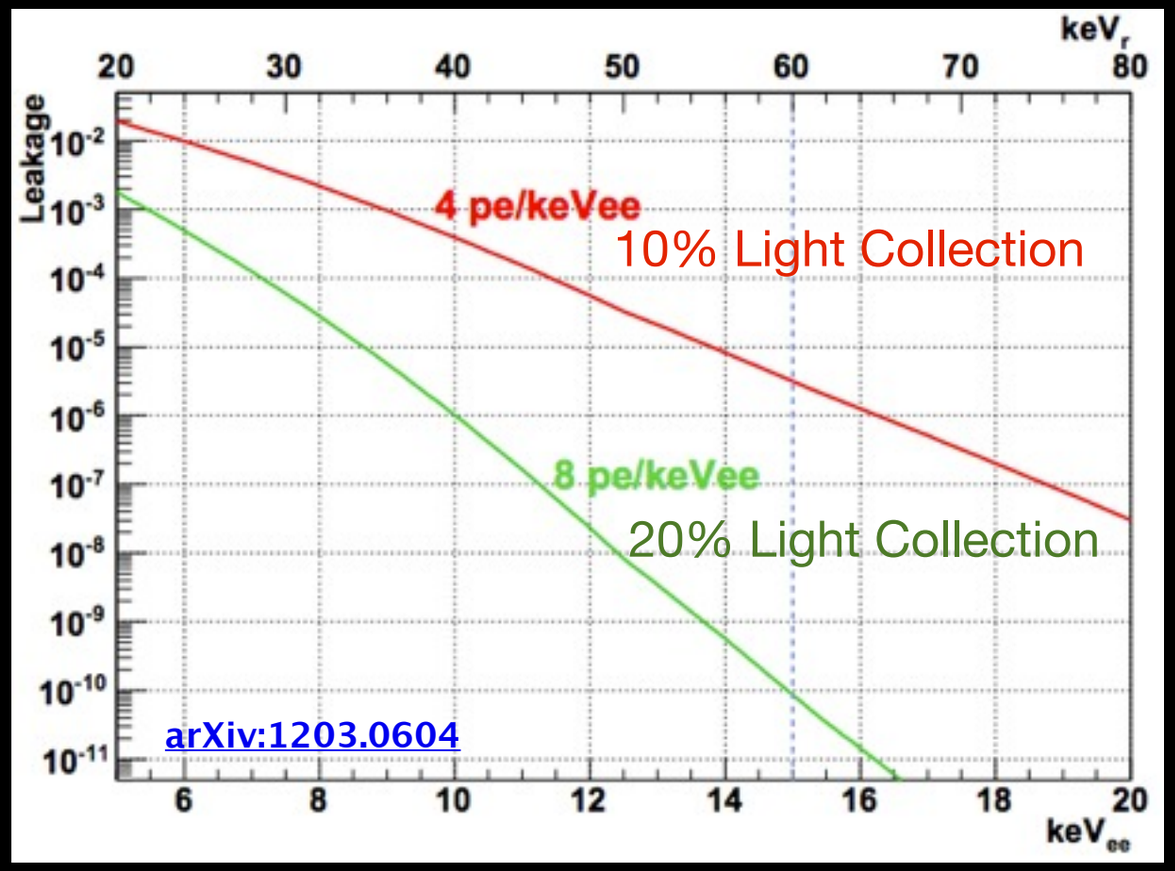


TPC Commissioning

TPC initially filled with **atmospheric** argon (1 Bq/kg)

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





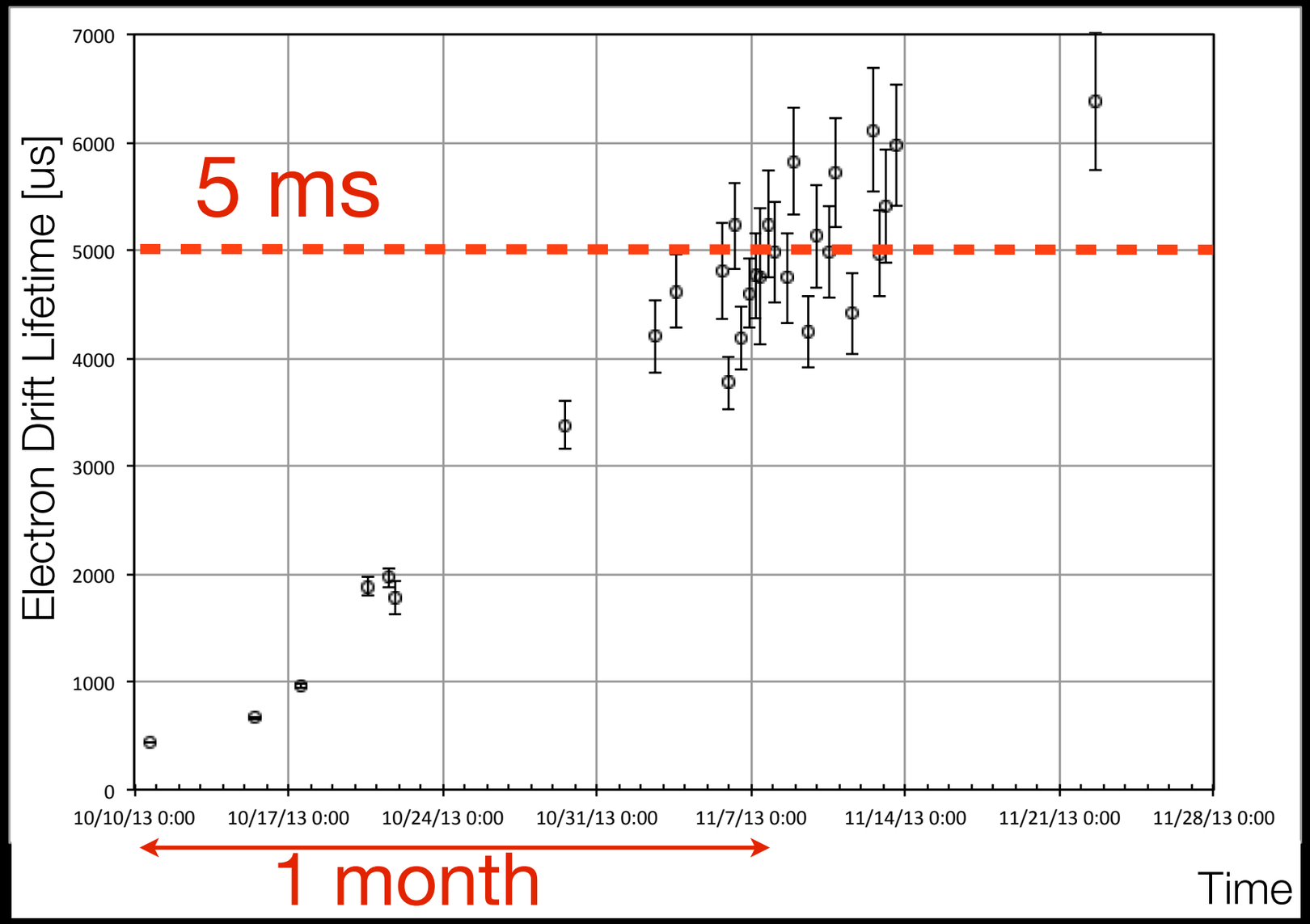
Light Yield

7.9 ± 0.4 PE/keV$_{ee}$

Measured light yield **exceeds** previous projections of 6 PE/keV$_{ee}$

TPC Commissioning

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



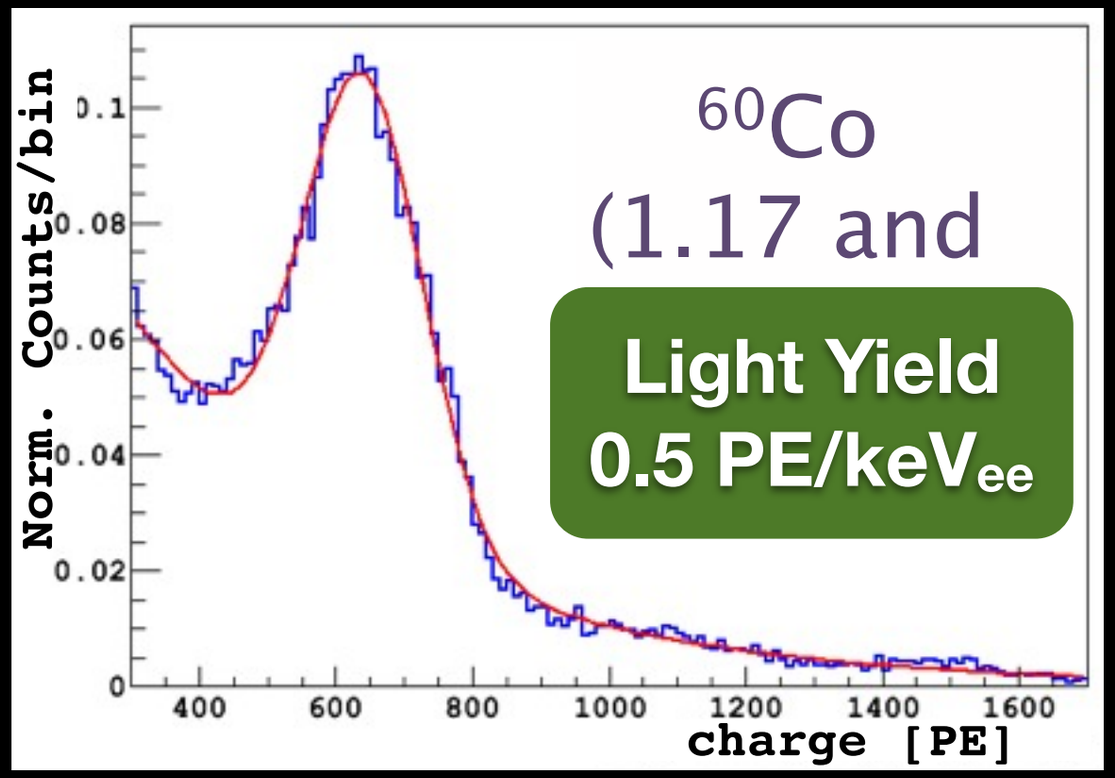
Electron drift lifetime **> 5 ms**,
Compare to max. drift time of **~ 375 us**

Neutron Veto Commissioning

Neutron veto setup to trigger on events in the liquid Ar TPC

Use high energy coincident ^{60}Co events from cryostat stainless steel to evaluate lightyield in scintillator

Lightyield ~ 0.5 PE/keV$_{ee}$ sufficient to detect ~ 50 keV$_{ee}$ α from neutron capture



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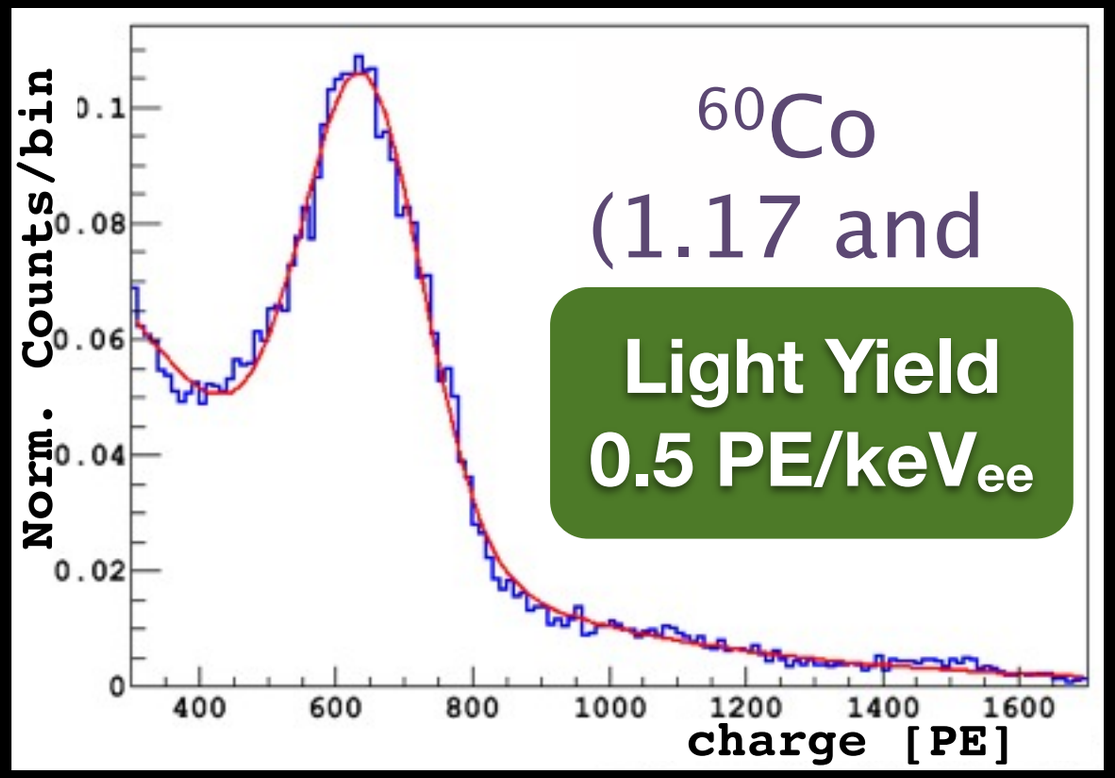
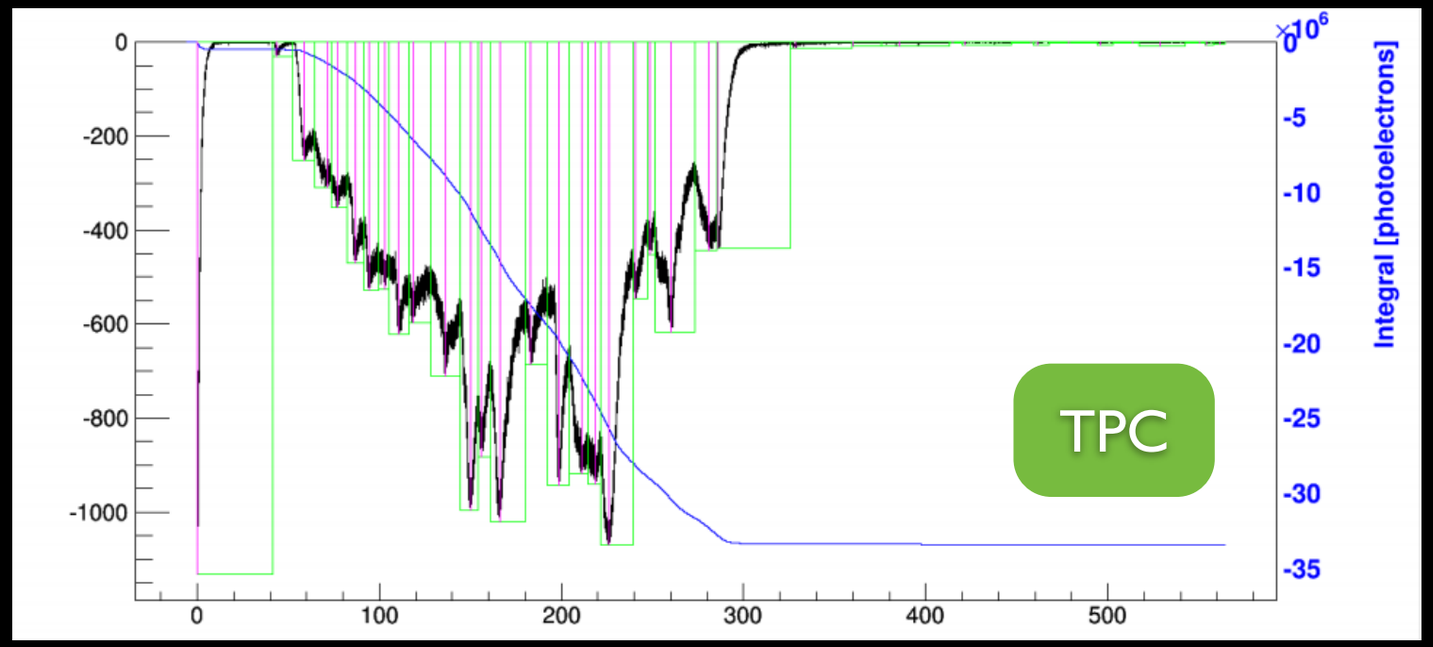


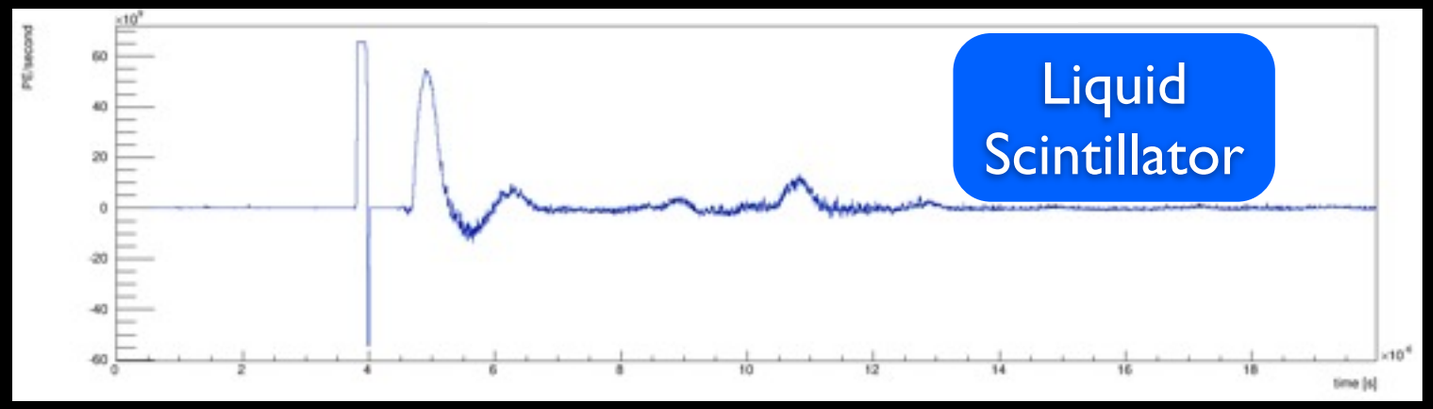
Found high rate (~ 150 kHz) at low energies due to intrinsic ^{14}C in (biogenic) TMB

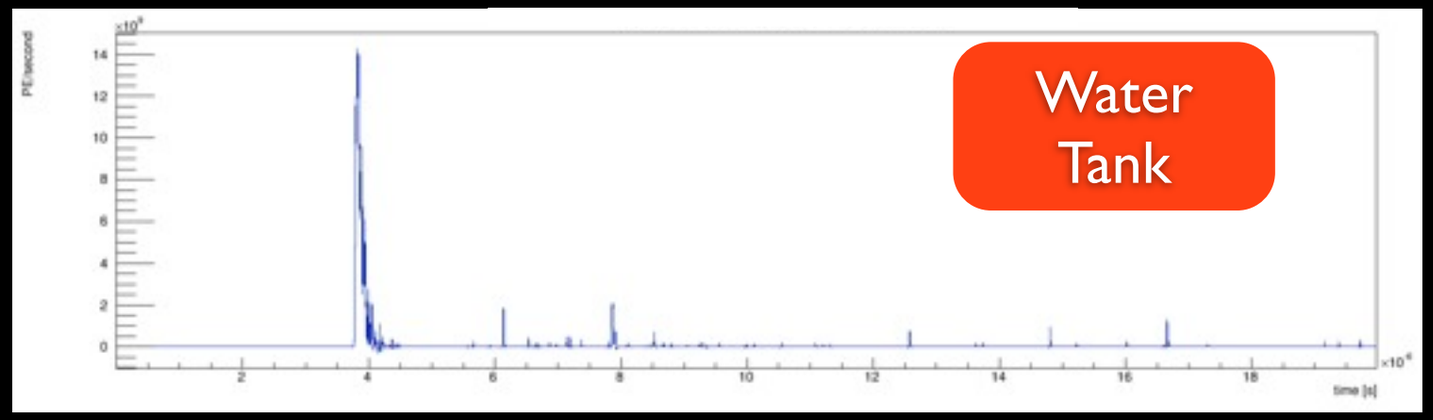
Presence of ^{14}C creates dead time issues
Limits neutron veto capability to ~98%

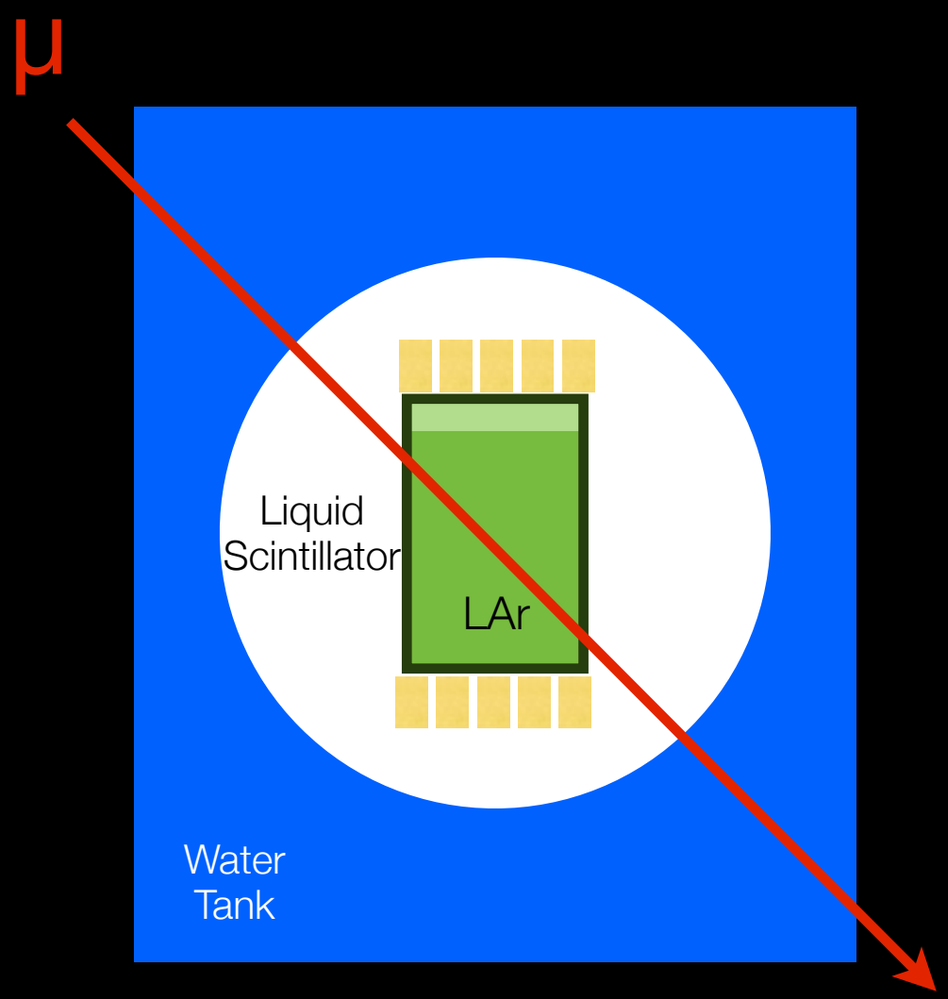
DS-50

All 3 detectors are filled and operating









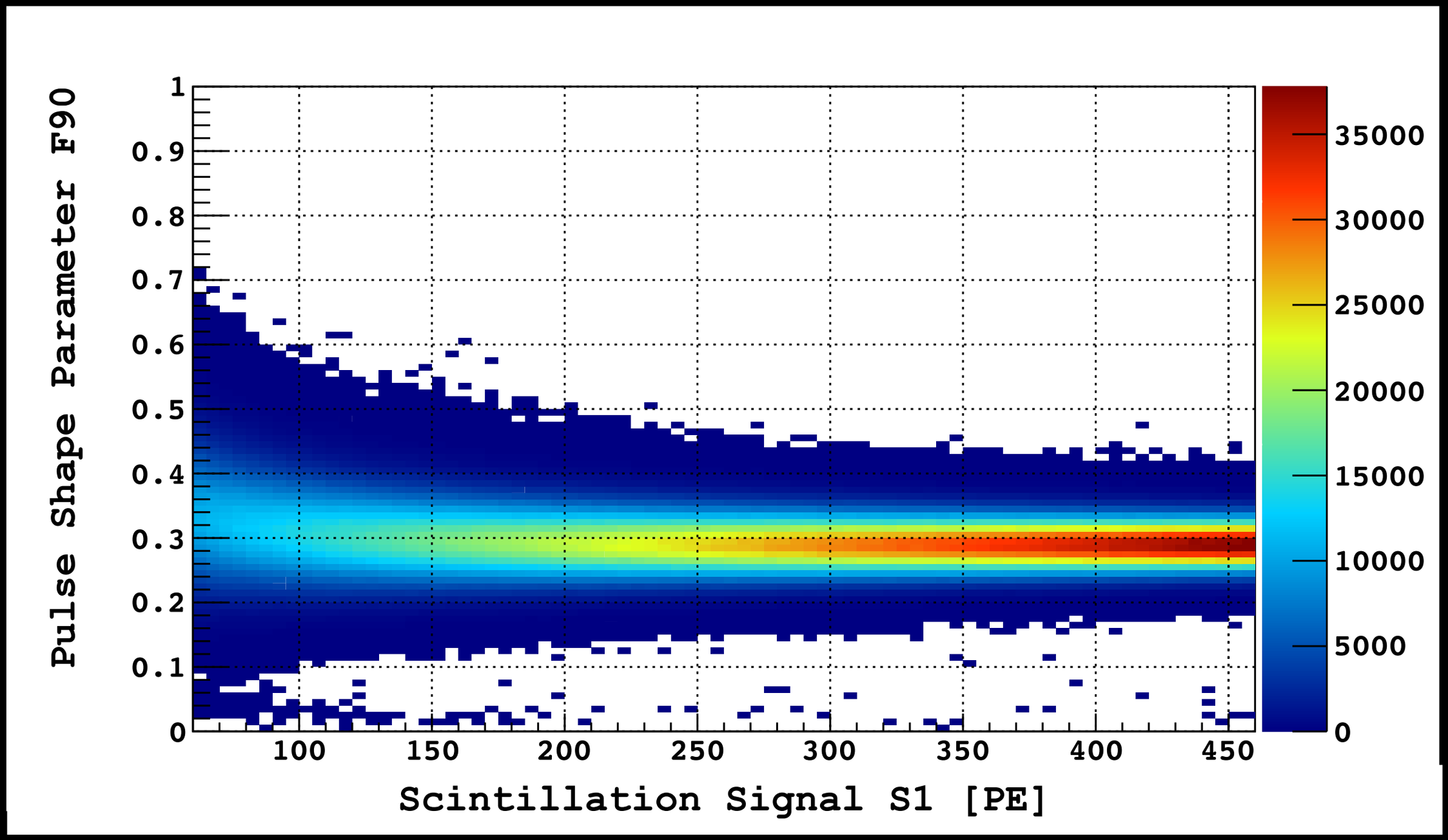
First Results

- November 2013 - May 2014
- 54 days livetime (47.1 ± 0.2 after cuts)
- Atmospheric Argon target
- Drift Field: 200 V/cm
- Non-blind analysis

Event Selection

CUT	PURPOSE	ACCEPT.
Single Good S1 and S2	Remove multiple scatters and mis-reconstructed events	96%
S1 distribution over PMTs	Remove dangerous signal-like Cerenkov events in PMT windows and fused silica	99%
Drift Time Fiducialization	Remove cathode, grid and poorly understood signal-like events at top and bottom	80%
Veto Cuts	Remove events with coincident signals in neutron veto or water tank **(Neutron Rejection Efficiency ~ 98%)**	89%

1.42 ton x days Exposure



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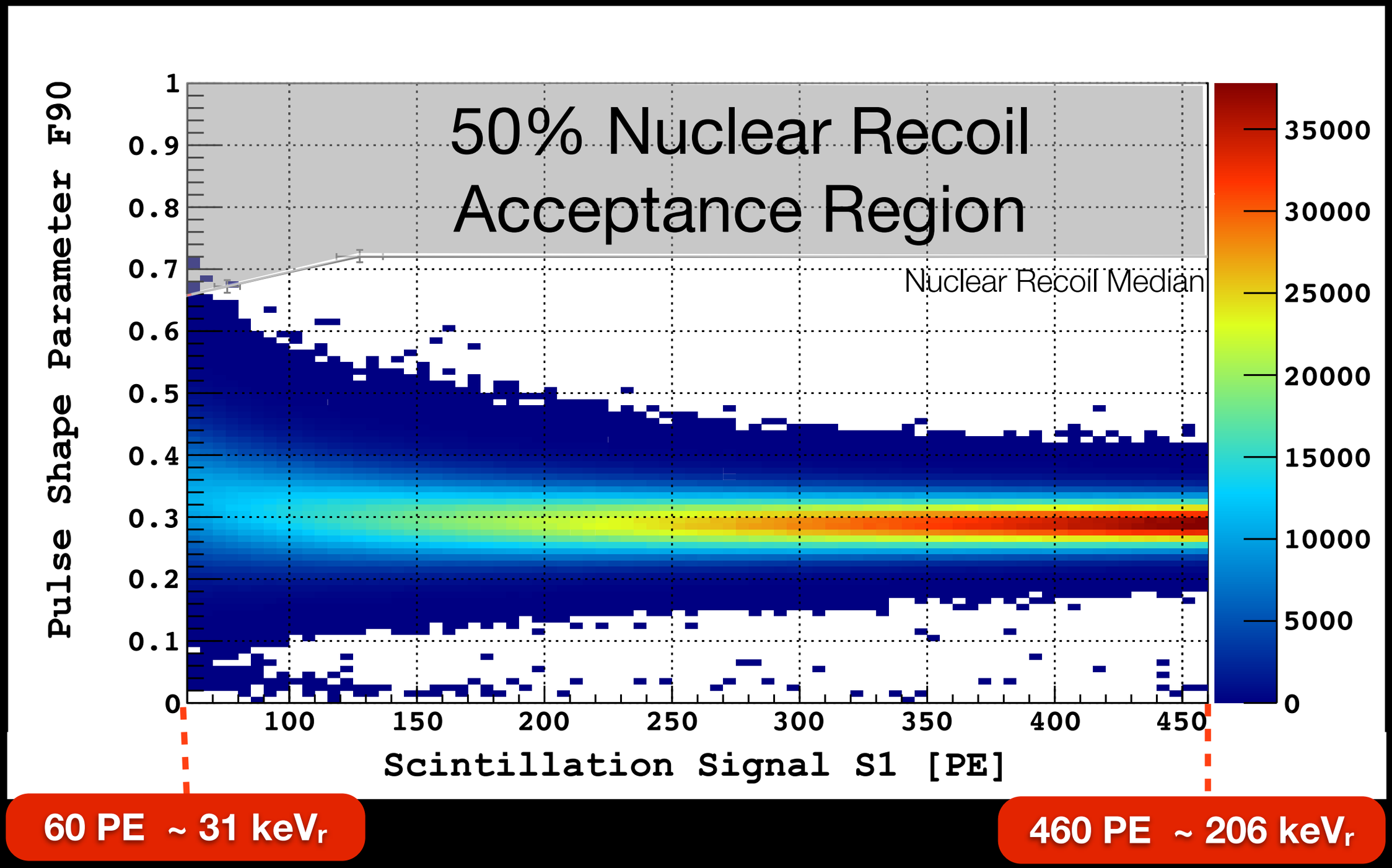
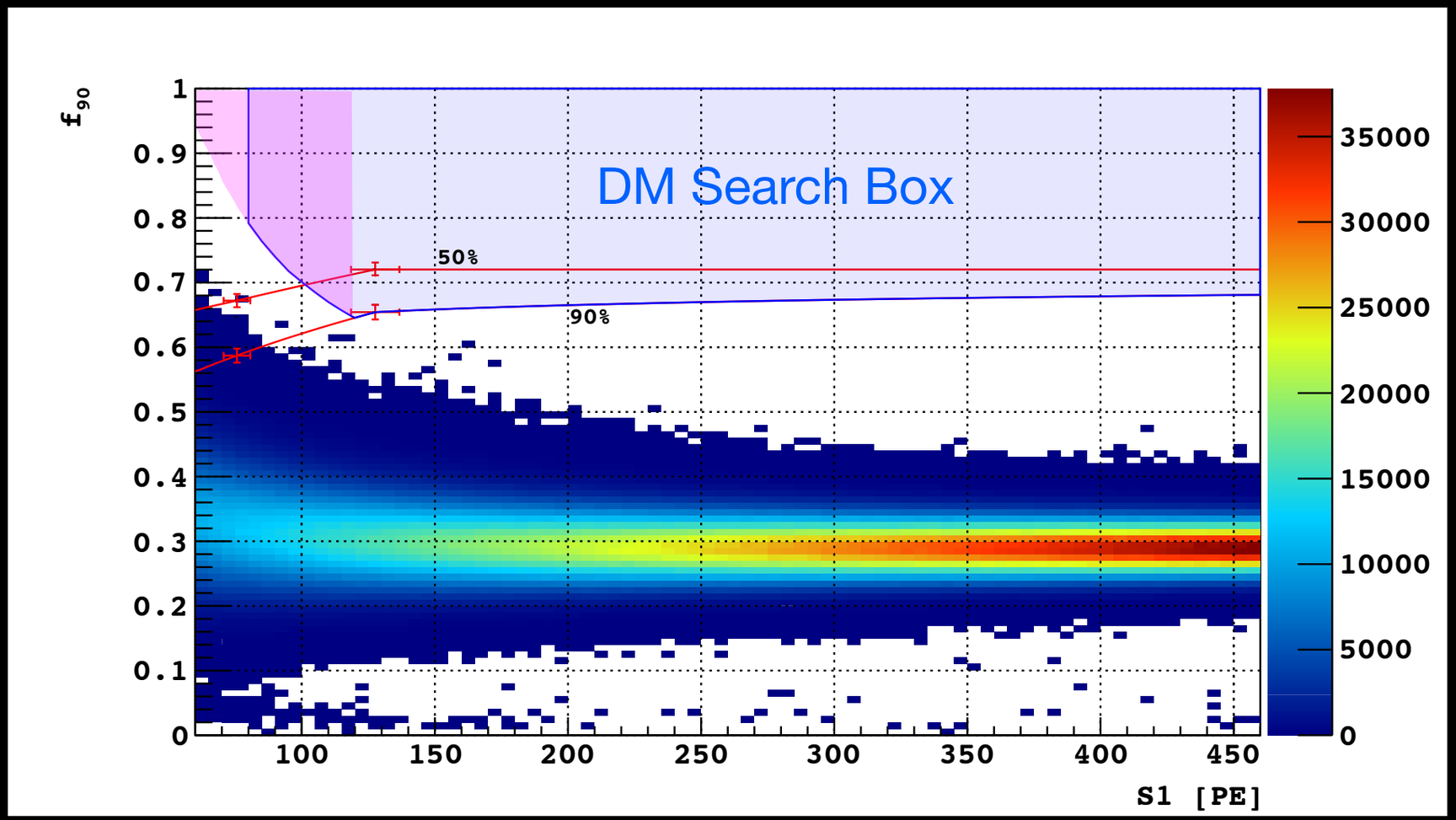


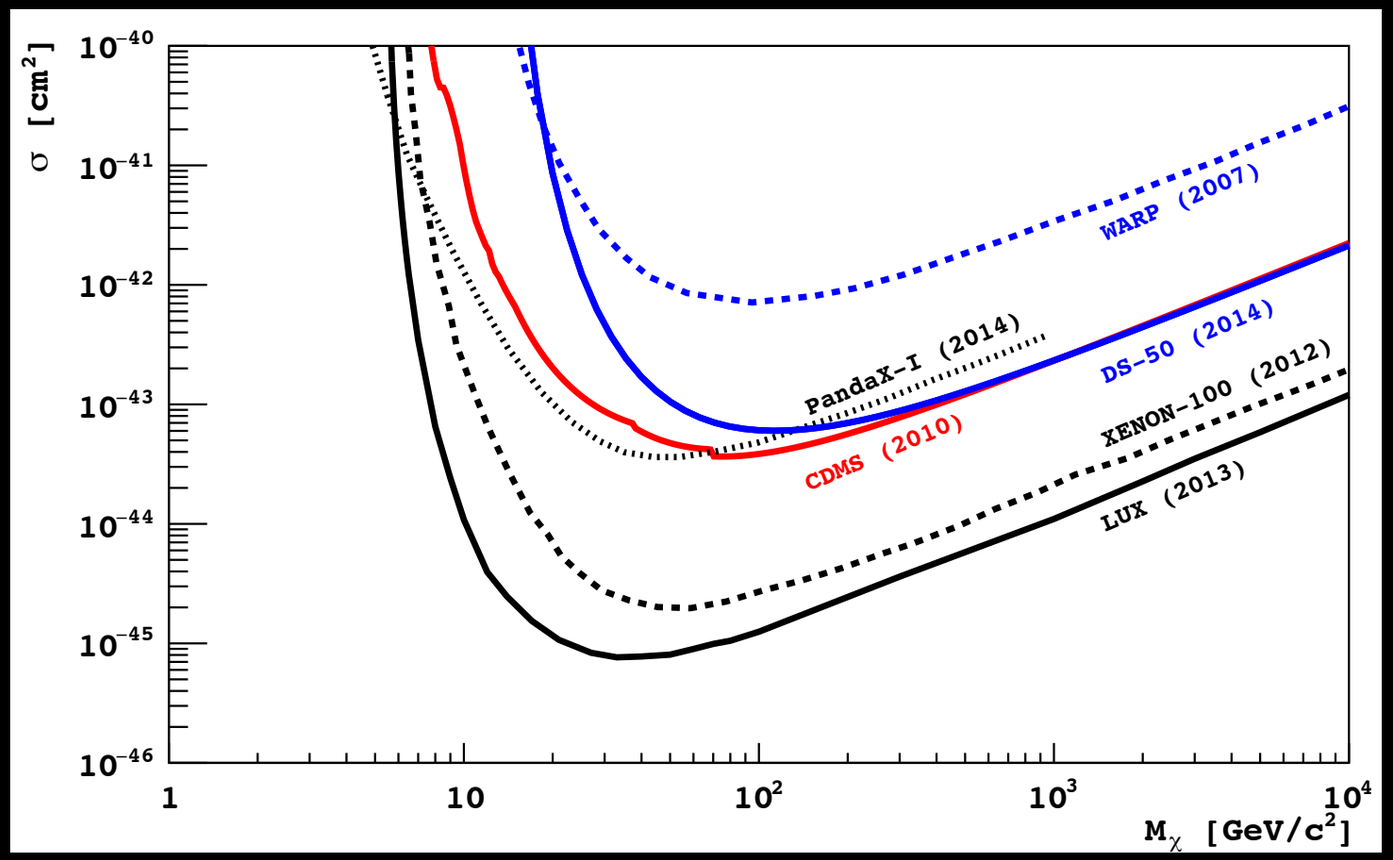
Nuclear Recoil median and Energy scale extrapolated from SCENE



< 0.01 ER / 5 PE bin

S1 > 80 PE
< 0.01 ER / 5 PE bin
90% NR Acceptance

50% Acceptance, < 0.1 ER Leakage at 102 PE, 47 keVr



Most sensitive search with argon target

TMB Replacement

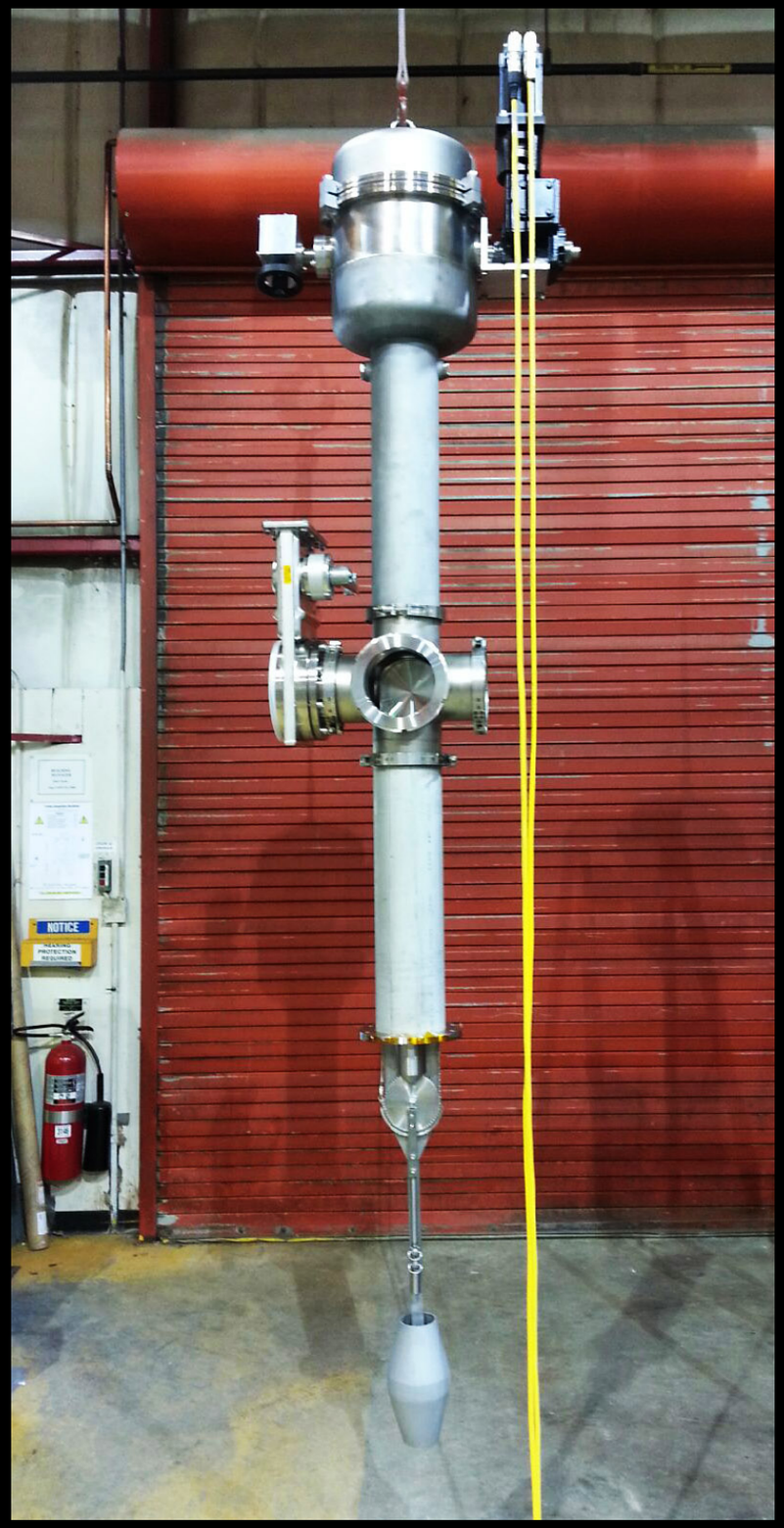
^{14}C produced by cosmic rays in atmosphere

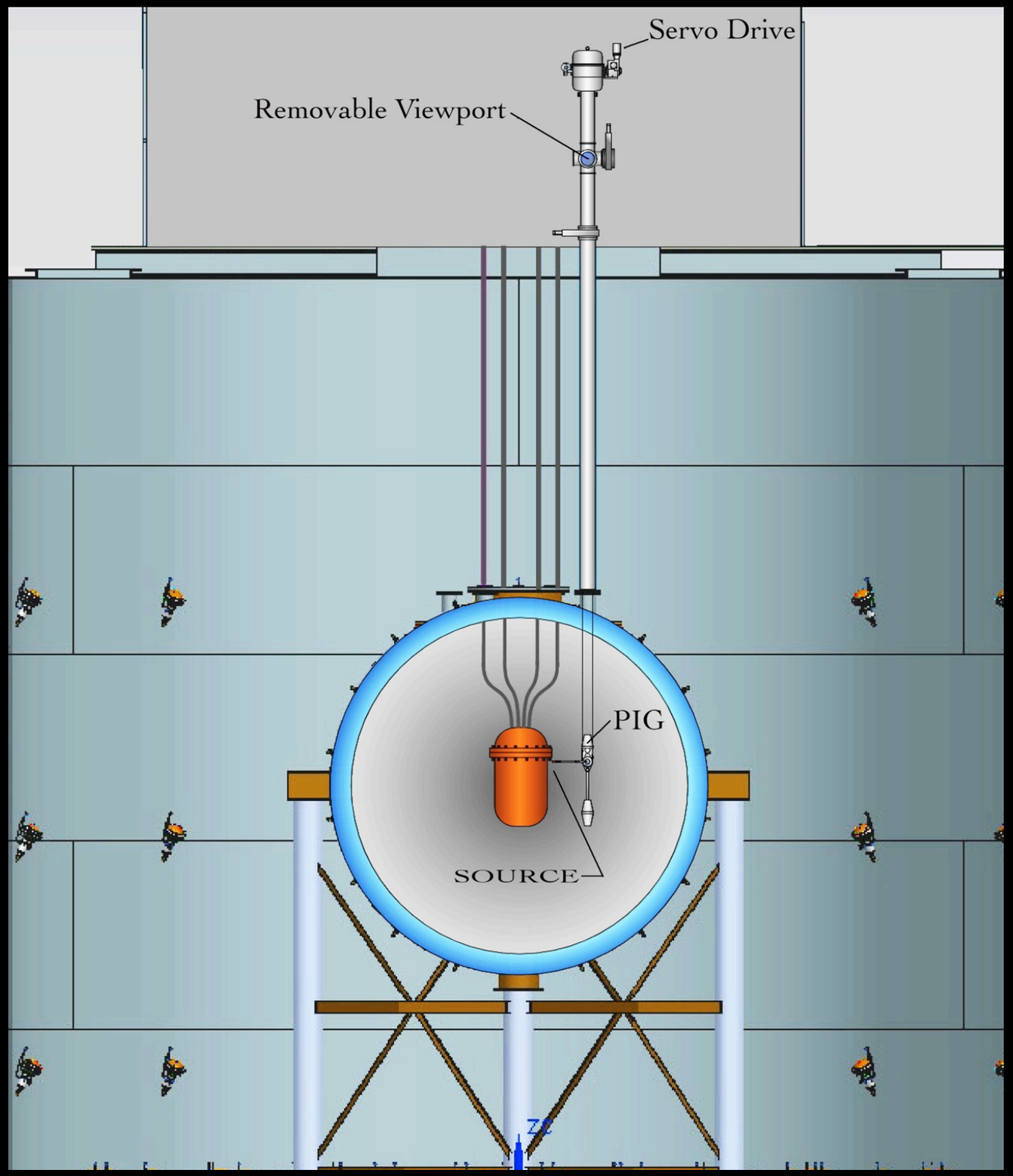
In atmosphere/biological material: $^{14}C/^{12}C \sim 10^{-12}$

Deep underground (petroleum reserves): $^{14}C/^{12}C \sim 10^{-18}$

Initial Fill	TMB Removal	TMB Replacement
15 tons of PC 15 tons of TMB	30 tons of PC ~ 30 kg of TMB	28.6 tons of PC 1.4 tons of TMB
150 kHz ^{14}C 60us Veto Window for 99.5% Rejection	300 Hz ^{14}C (500x Reduction)	300 Hz ^{14}C 140us Veto Window

Calibration Source System





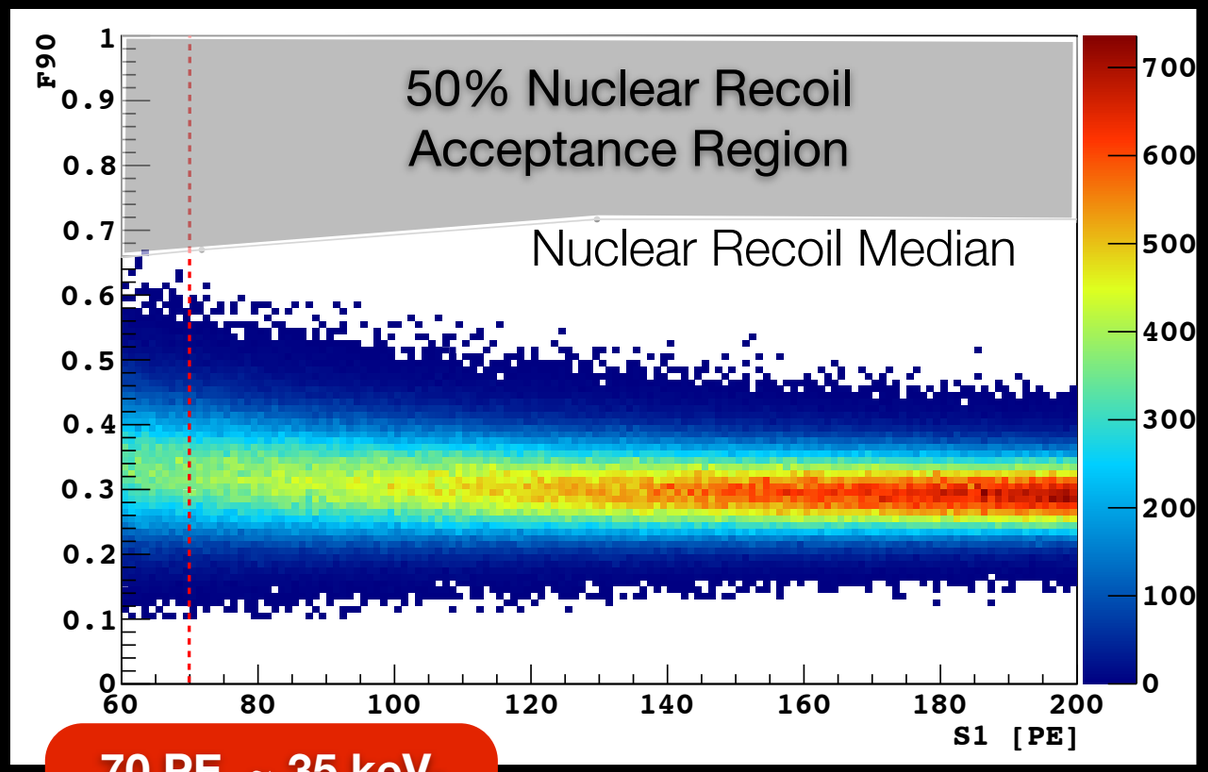
Underground Argon

Level of ^{39}Ar in UAr is critical

IF level of ^{39}Ar in UAr is at sample upper limit of 6 mBq/kg,
AND ^{39}Ar is the dominant ER background at that level

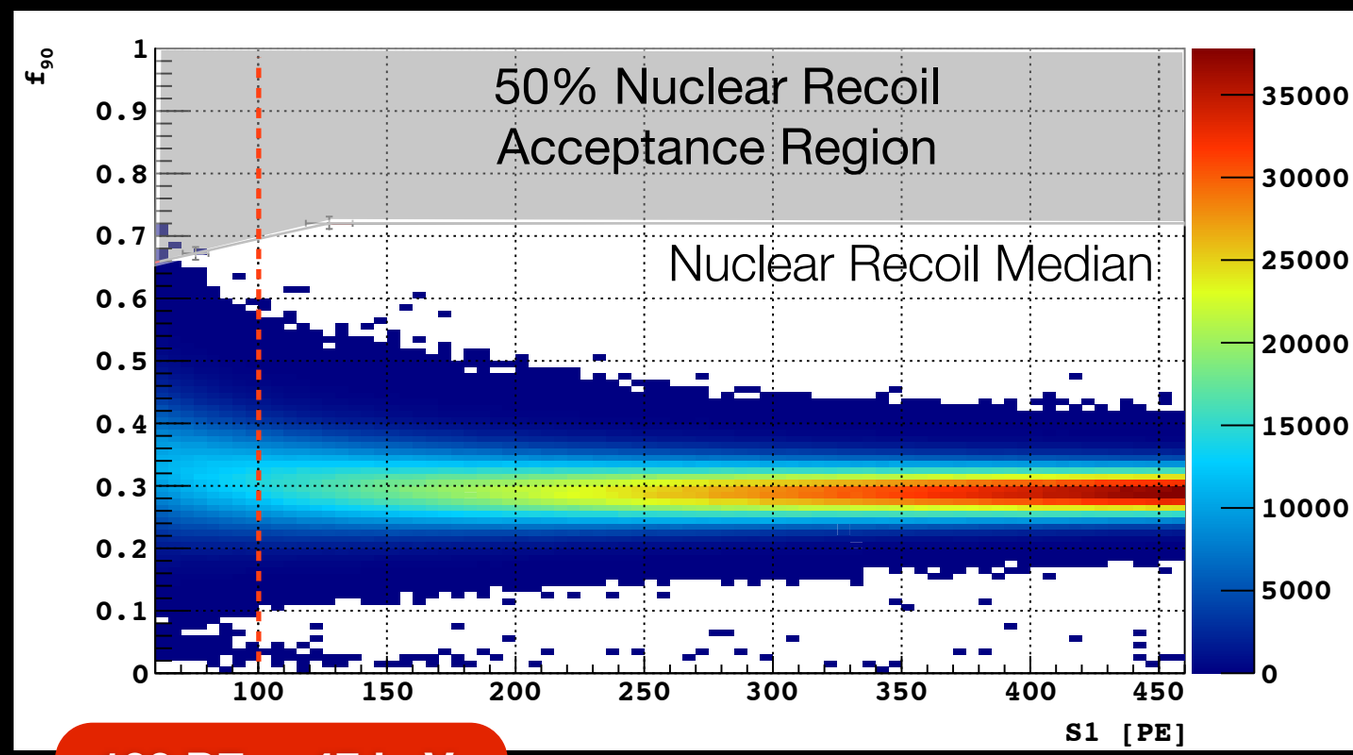
1 day of AAr ER background = 150 days of UAr ER background

DS-50 AAr: 6.3 days
DS-50 UAr: 2.6 yrs



70 PE ~ 35 keV$_r$

DS-50 AAr: 47 days
1 Ton UAr: 0.6 yrs



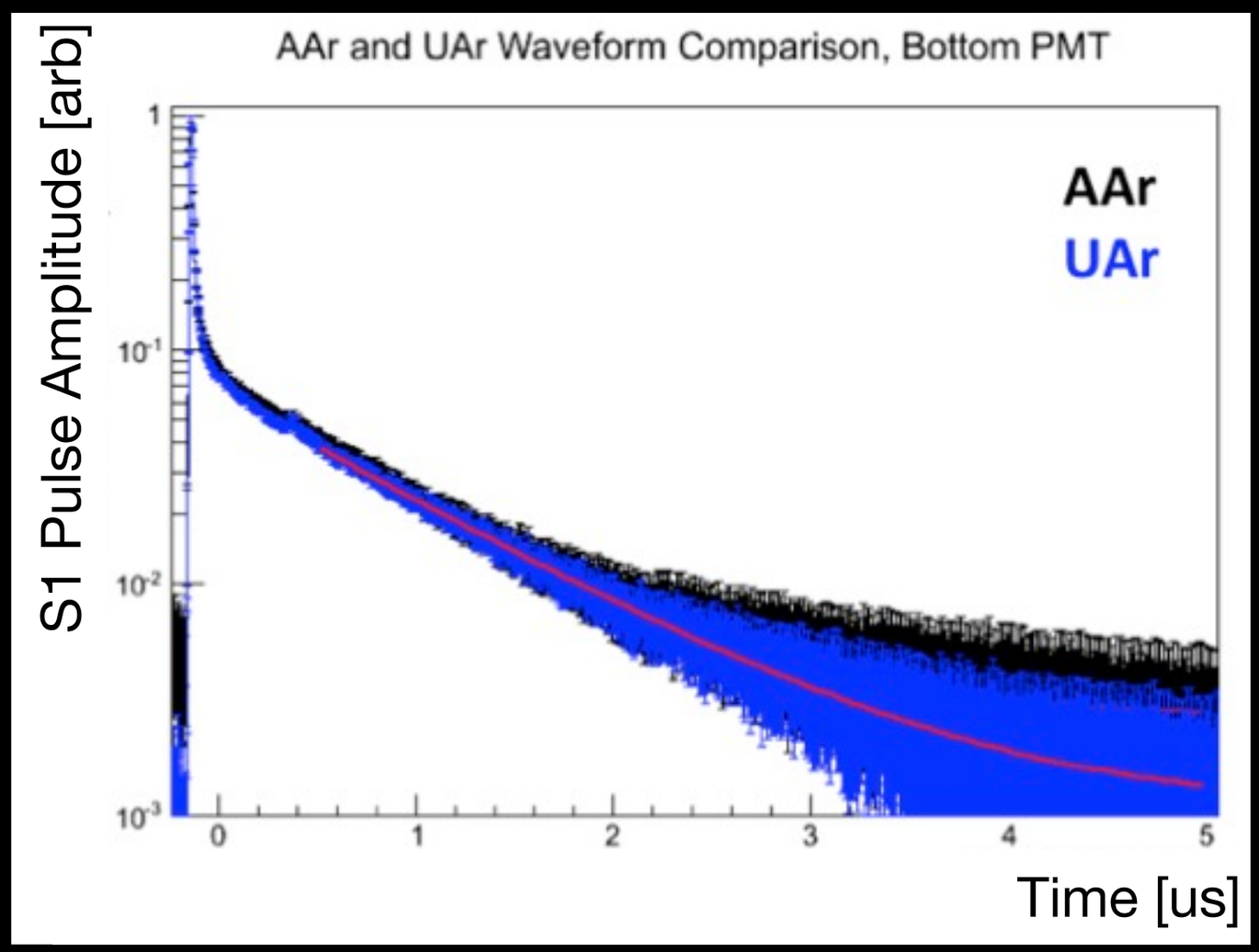
100 PE ~ 47 keV$_r$

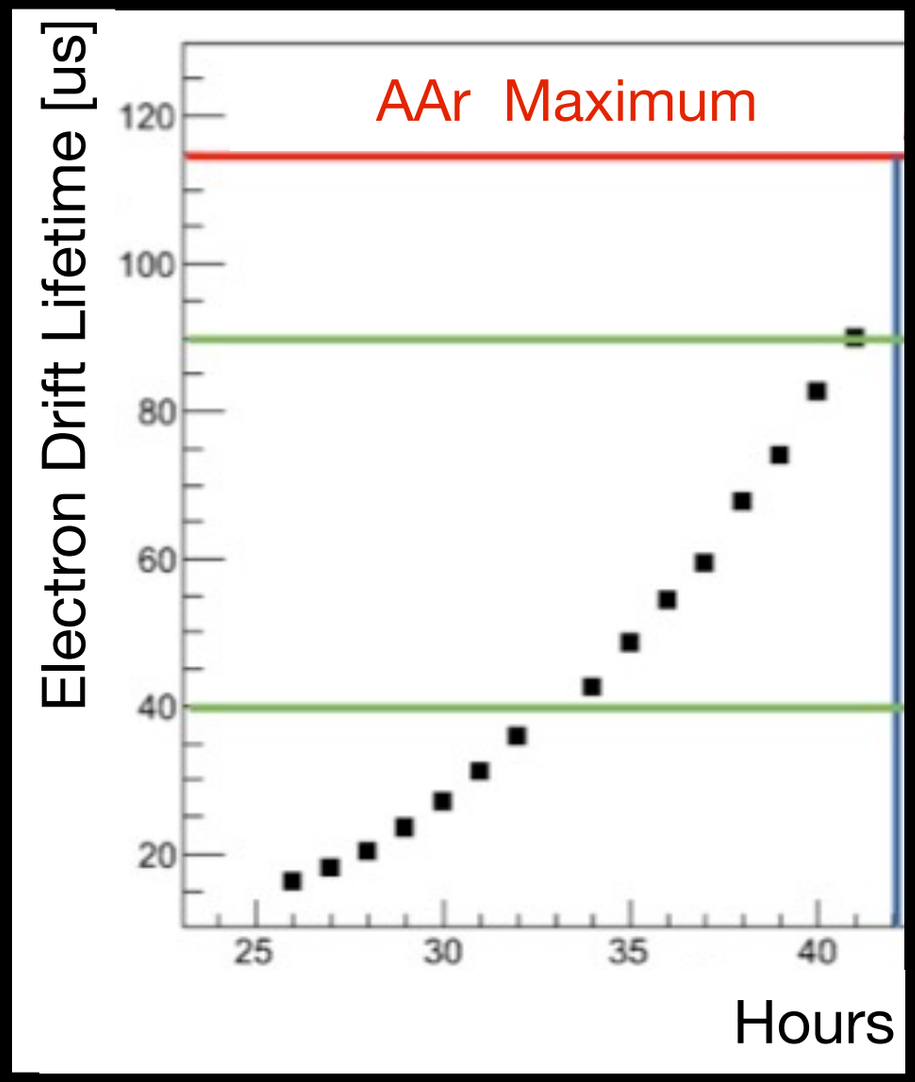
PROVEN ^{39}Ar-FREE EXPOSURES

Underground Argon Status

Entire target mass of underground argon purified at Fermilab

Tested small sample (~3.5 kg) to ensure detector grade





Underground Argon Status

Dec 17th: 142 kg of underground argon "shipped" from Fermilab to Gran Sasso
Remaining 15kg flown in early March

Mar 17th-22nd: Draining AAr from DS-50

Mar 25th - Apr 1st: Filling DS-50 with UAr

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The level of ^{39}Ar in UAr is ...

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The level of ^{39}Ar in UAr is ...

We need a few more weeks to be certain

Conclusions

- We have recently published the most sensitive WIMP search with an argon target
- The liquid scintillator veto has been purified to reduce the high rate of ^{14}C
- We have introduced calibration sources into the veto to study the response of both the veto and the TPC
- **DarkSide-50 is now filled with underground argon**
- The rate of ^{39}Ar is ... TBA

THE END