DarkSide

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E-1000

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Princeton/FNAL

DM2010
Marina del Rey, CA

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DarkSide

UMass Amherst
Arizona State University
Augustana College
Black Hills State University
Fermilab
University of Houston
University of Notre Dame
Princeton University
Temple University
UCLA

Augustana College, USA Prof. Drew Alton

Black Hills State University, USA Prof. Dan Durben, Prof. Kara Keeter, Prof. Michael Zehfus

Fermi National Accelerator Laboratory, USA Dr. Steve Brice, Dr. Aaron Chou, Dr. Jeter Hall, Dr. Hans Jostlein, Dr. Stephen Pordes, Dr. Andrew Sonnenschein

Princeton University, USA Jason Brodsky, Prof. Frank Calaprice, Huajie Cao, Alvaro Chavarria, Ernst de Haas, Prof. Cristiano Galbiati, Eng. Augusto Goretti, Eng. Andrea Ianni, Tristen Hohman, Ben Loer, Pablo Mosteiro, Prof. Peter Meyers, Eng. David Montanari, Allan Nelson, Eng. Robert Parsells, Richard Saldanha, Eng. William Sands, Dr. Alex Wright, Jingke Xu

Temple University, USA Prof. Jeff Martoff, Prof. Susan Jansen-Varnum, Christy Martin, John Tatarowicz

University of California at Los Angeles, USA Prof. Katsushi Arisaka, Prof. David Cline, Chi Wai Lam, Kevin Lung, Prof. Peter F. Smith, Artin Teymourian, Dr. Hanguo Wang

University of Houston, USA Prof. Ed Hungerford and Prof. Lawrence Pinsky

University of Massachusetts at Amherst, USA Prof. Laura Cadonati and Prof. Andrea Pocar

University of Notre Dame, USA Prof. Philippe Collon, Daniel Robertson, Christopher Schmitt

University of Virginia, USA Prof. Kevin Lehmann

Program Goal

- Bring together techniques that offer the best characterization and rejection of background in noble liquid detectors

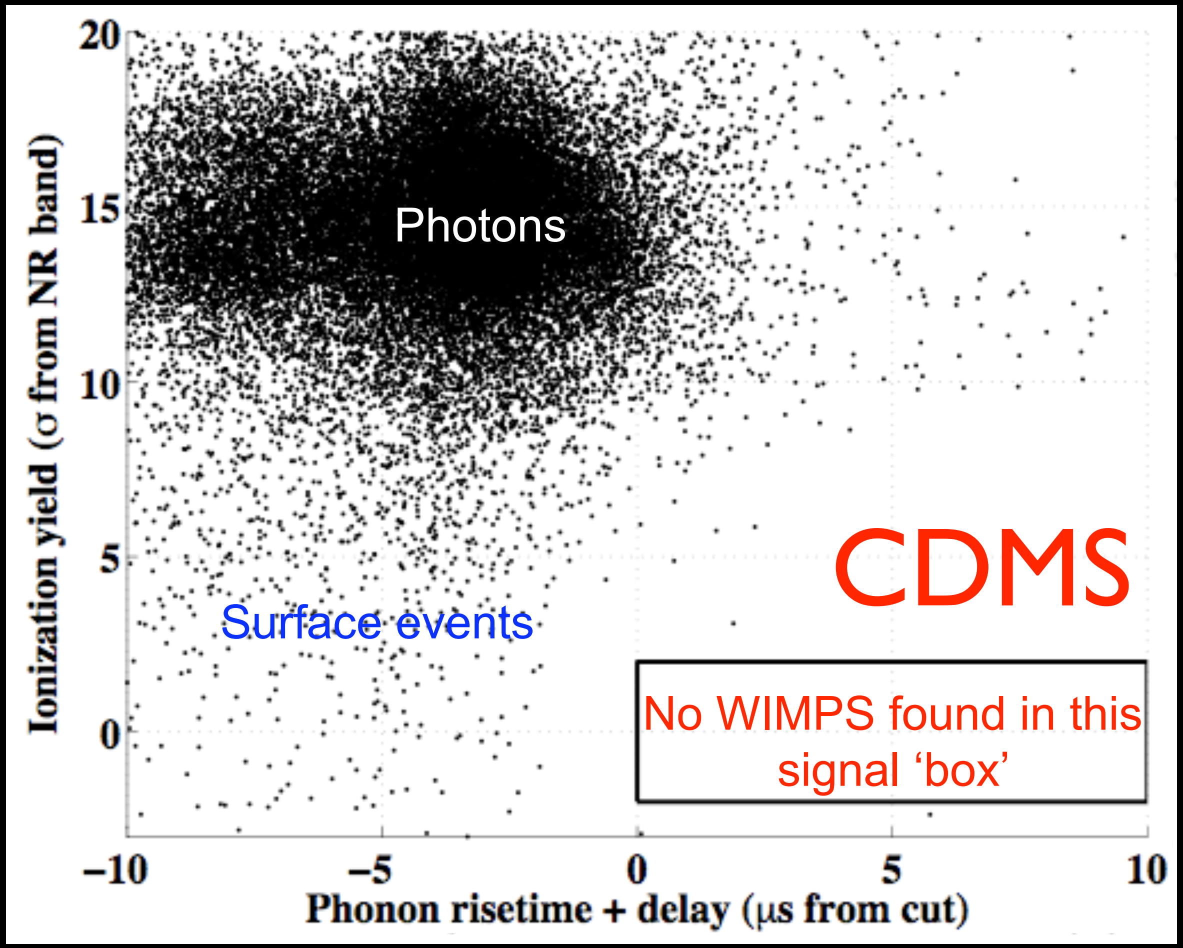
- The goal is: zero background (à la CDMS) with very large exposure - many tons·years

- Choice of LAr dual-phase TPC (WARP) offers many handles on background
  - P. Benetti et al., Nucl. Instr. Meth. A **327**, 203 (1993); M.G. Boulay and A. Hime, Astropart. Phys. **25**, 179 (2006); P. Benetti et al. (WARP Collaboration), Astopar. Phys. **28**, 495 (2008).

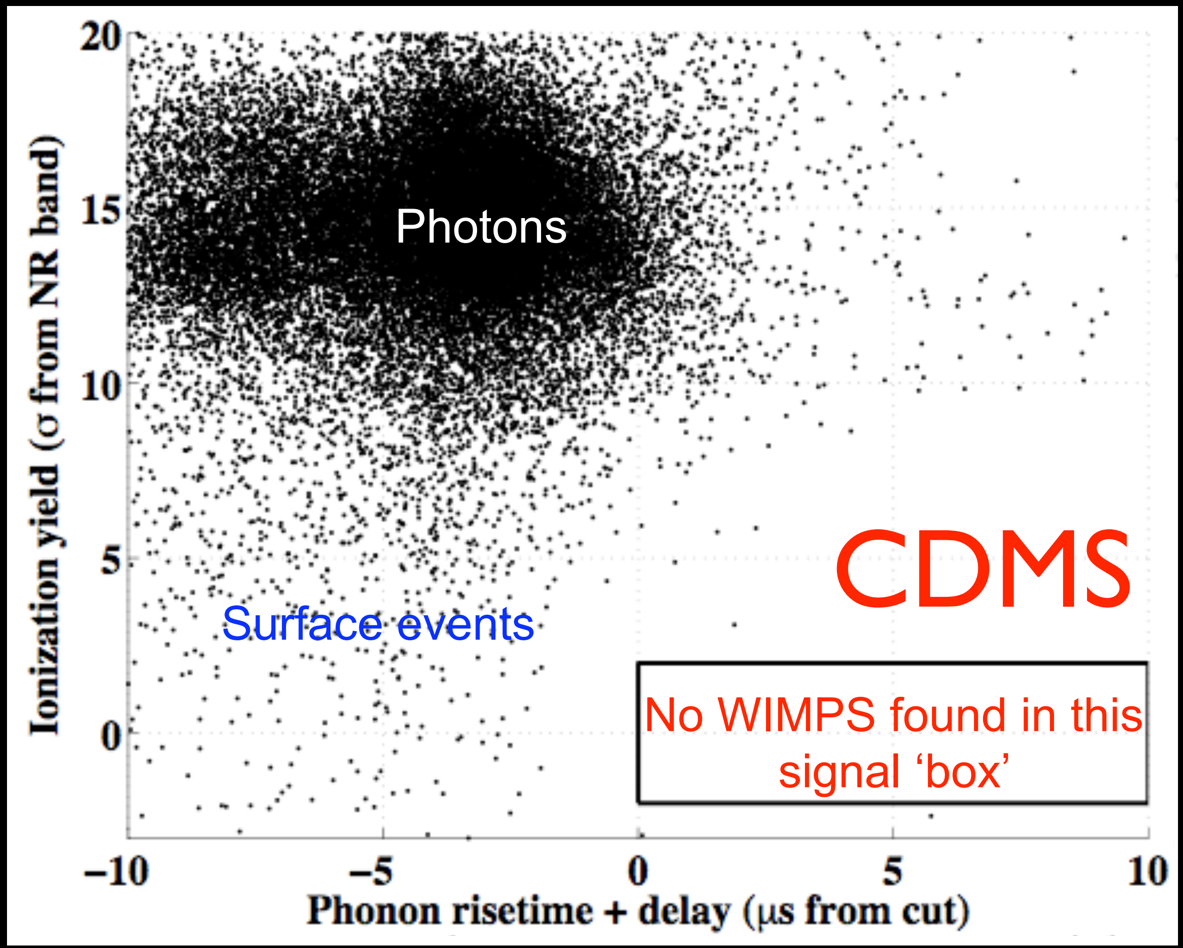
- DarkSide program introduces 3 innovative technologies crucial for achievement of zero background in very large detectors

Game Changing Technologies

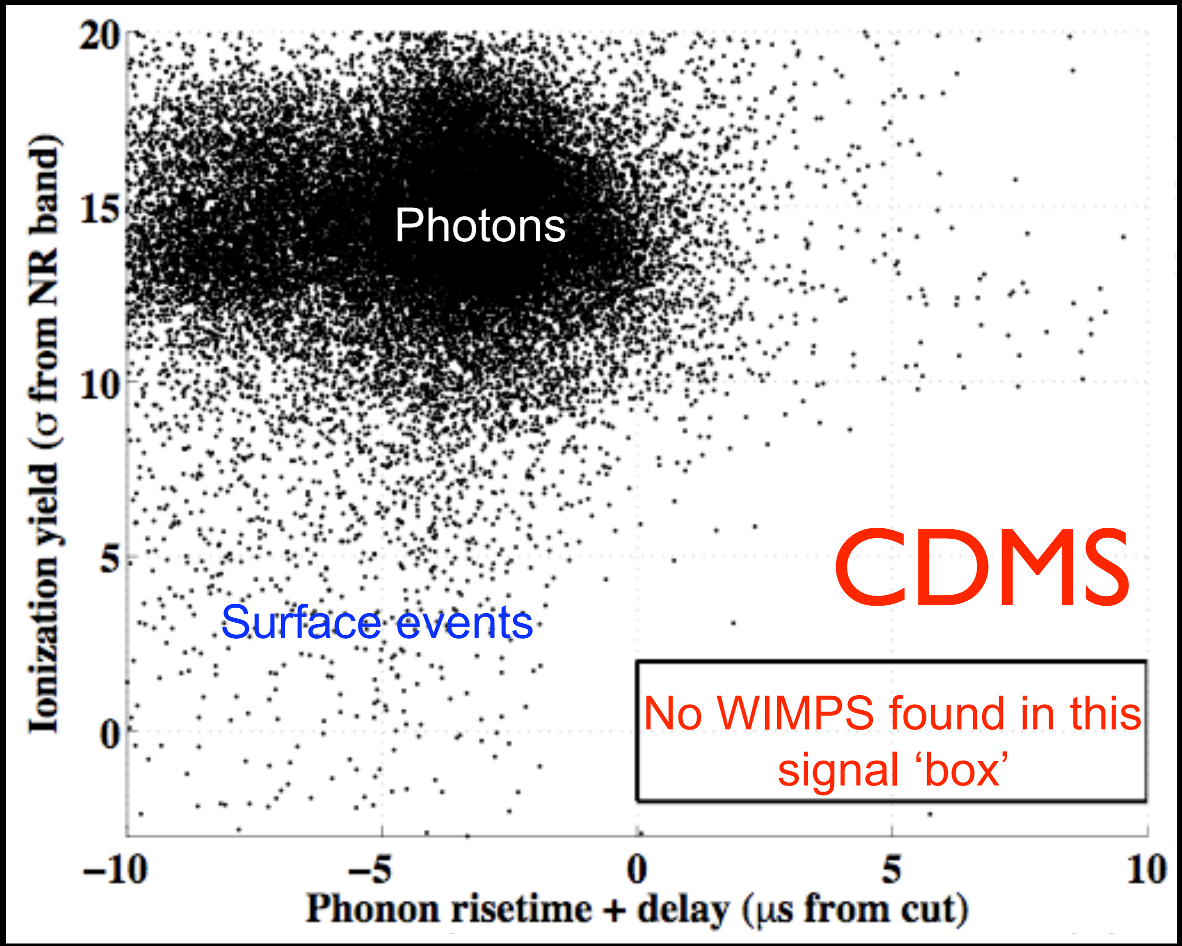
1. Depleted Argon from underground sources
2. 3” QUPID photosensors
   - no background detected in best Ge
   - new Bialkali-LT photocathode form Hamamatsu for high QE at liquid argon temperature
3. High efficiency borated liquid scintillator neutron veto (>99%)


Photons
Surface events
CDMS
No WIMPS found in this signal 'box'
Ionization yield (σ from NR band)
Phonon risetime + delay (μs from cut)
20
15
10
5
0
−10
−5
0
5
10

Two is Better than One!



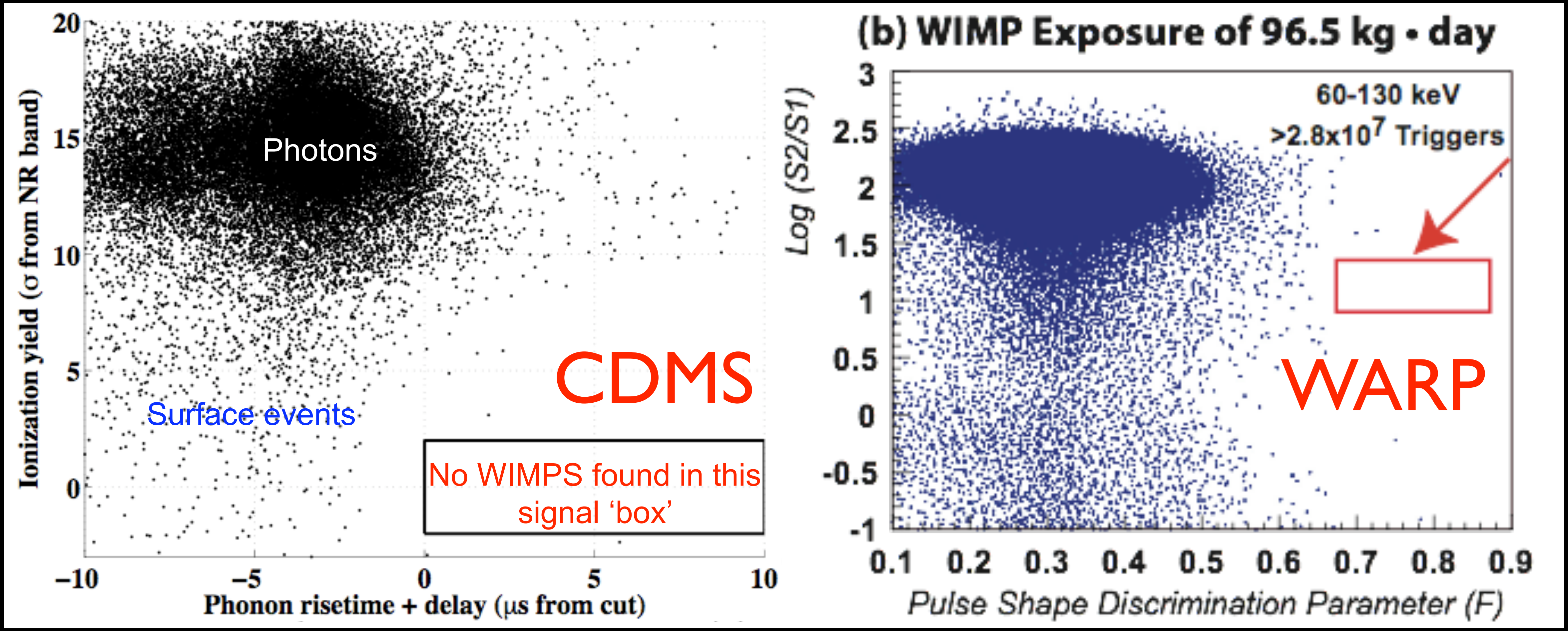
Two is Better than One!



Required Identification of few events in ~Tons per Yr at few tens of keV with zero background!

Presence of dual, semi-independent discrimination crucial

Two is Better than One!

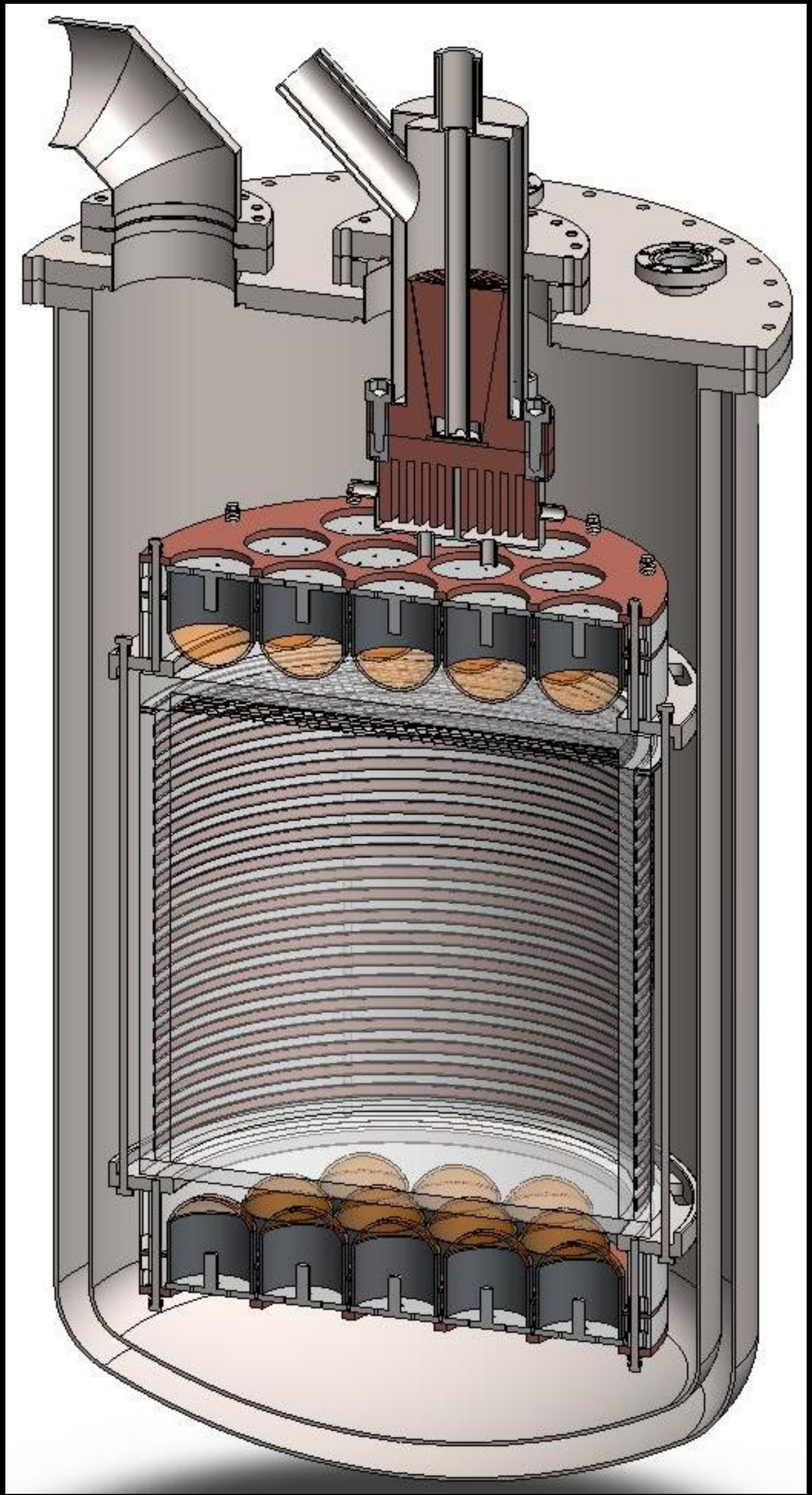


Required Identification of few events in ~Tons per Yr at few tens of keV with zero background!

Presence of dual, semi-independent discrimination crucial

DarkSide-50

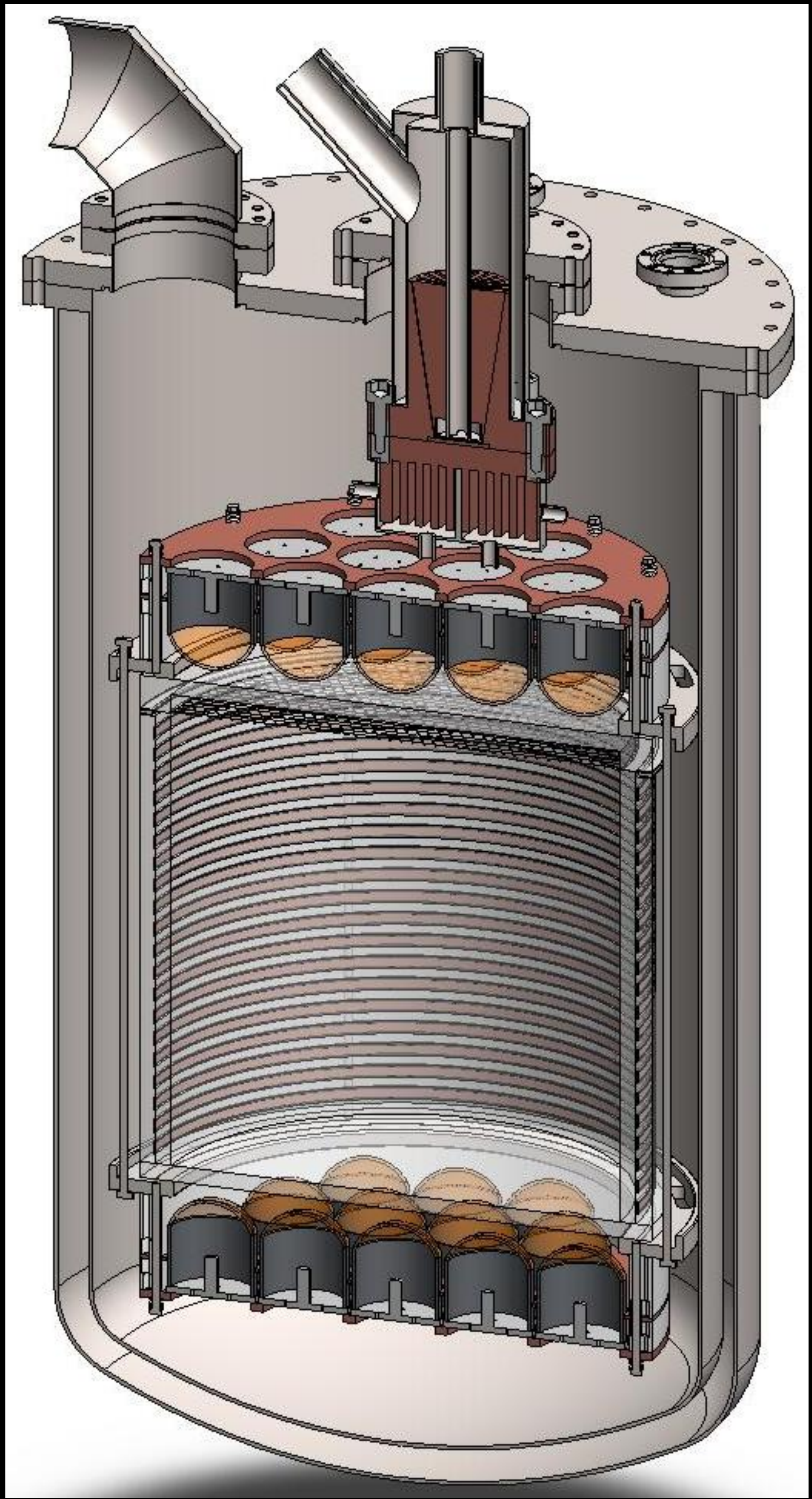
dual-phase TPC
50 kg active mass
5 ph.el/keV_{ee}
23 keV_r threshold
background-free for 3 yrs
sensitivity 10^{-45} cm^2

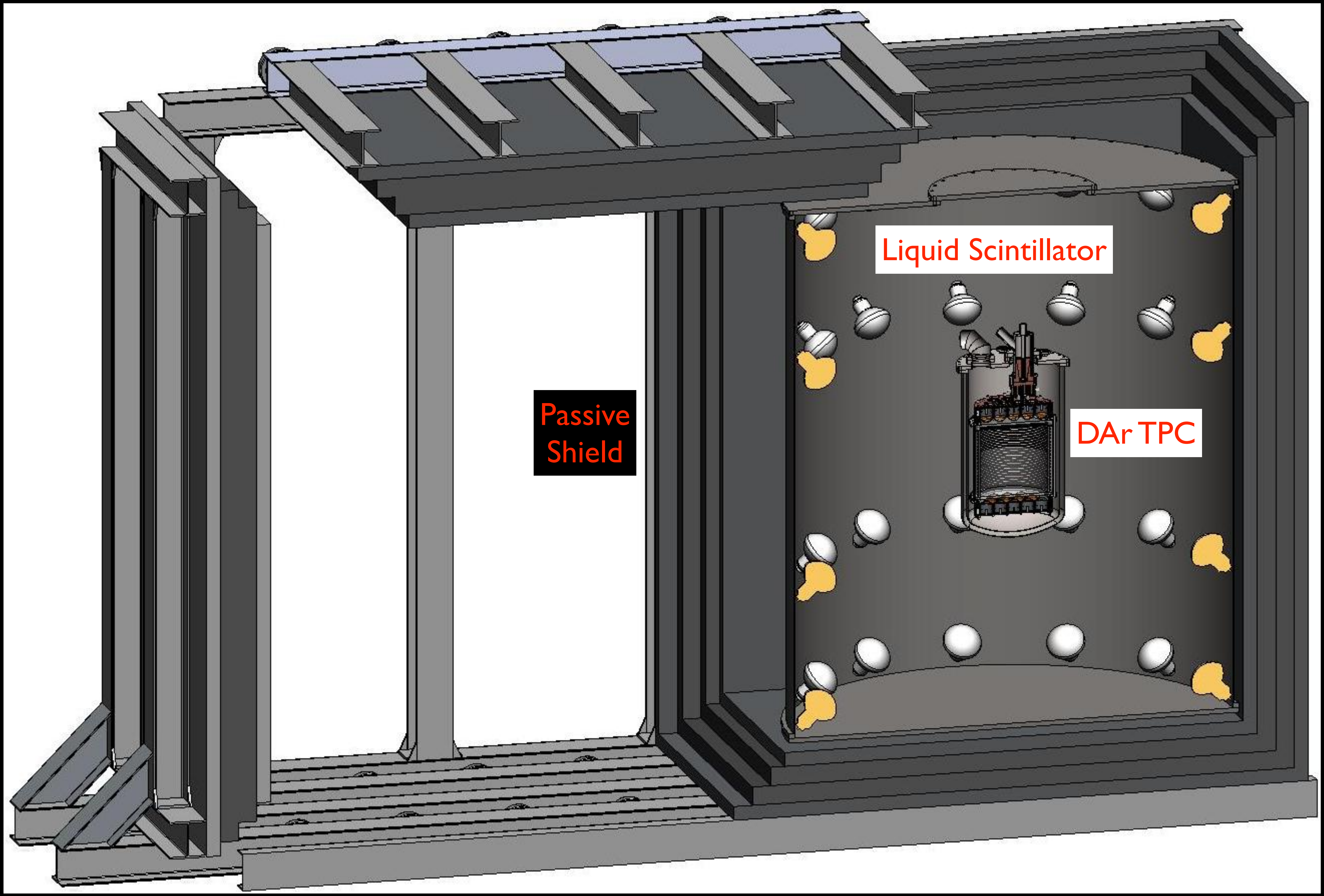


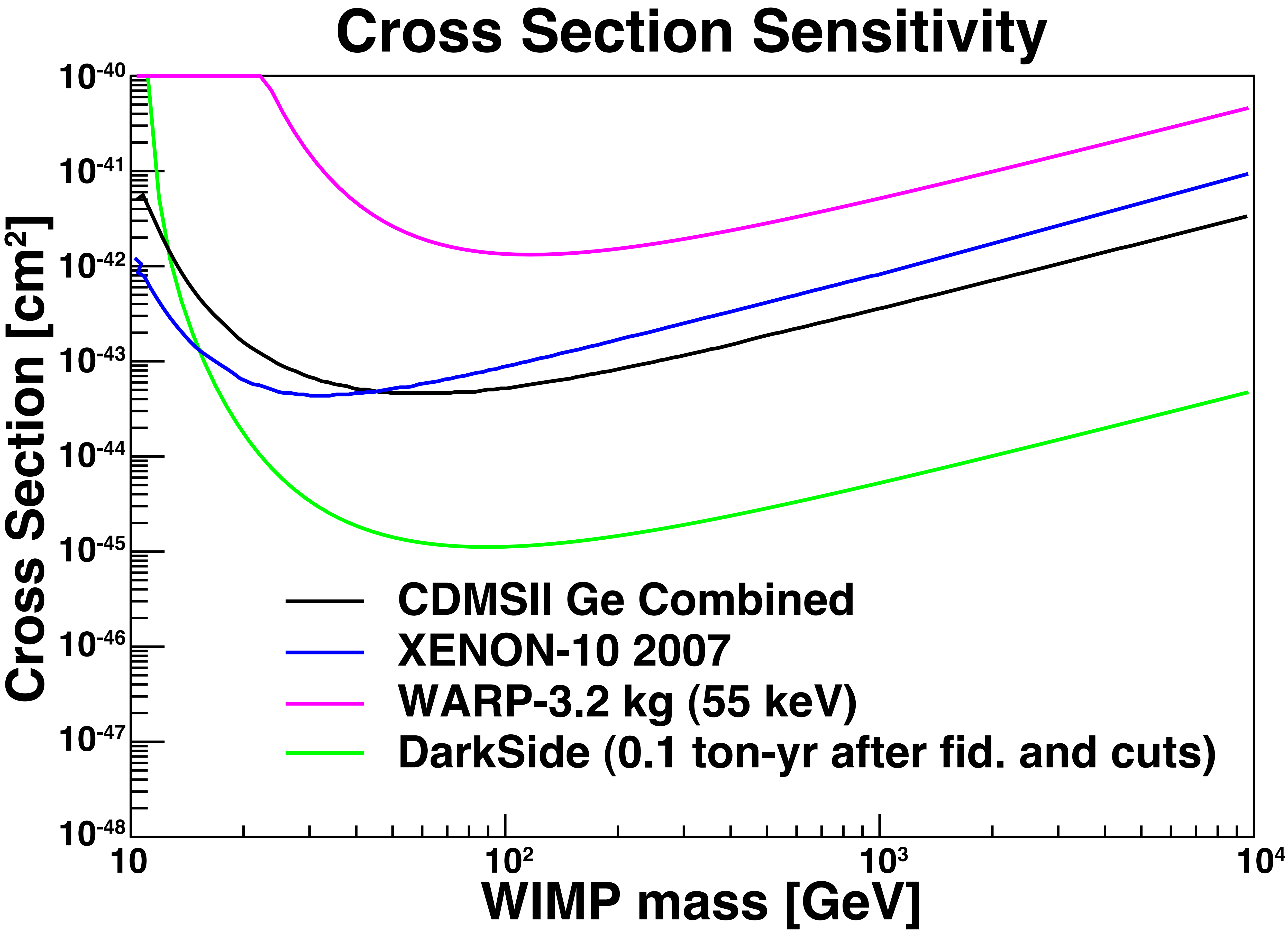
DarkSide-50

First test for three technological advances crucial to achieve zero background:

1) depleted argon
2) QUPIDs at LAr temp
3) active liquid scintillator neutron veto




Liquid Scintillator
Passive Shield
DAr TPC



Cross Section Sensitivity
Cross Section [cm²]
WIMP mass [GeV]
CDMSII Ge Combined
XENON-10 2007
WARP-3.2 kg (55 keV)
DarkSide (0.1 ton-yr after fid. and cuts)

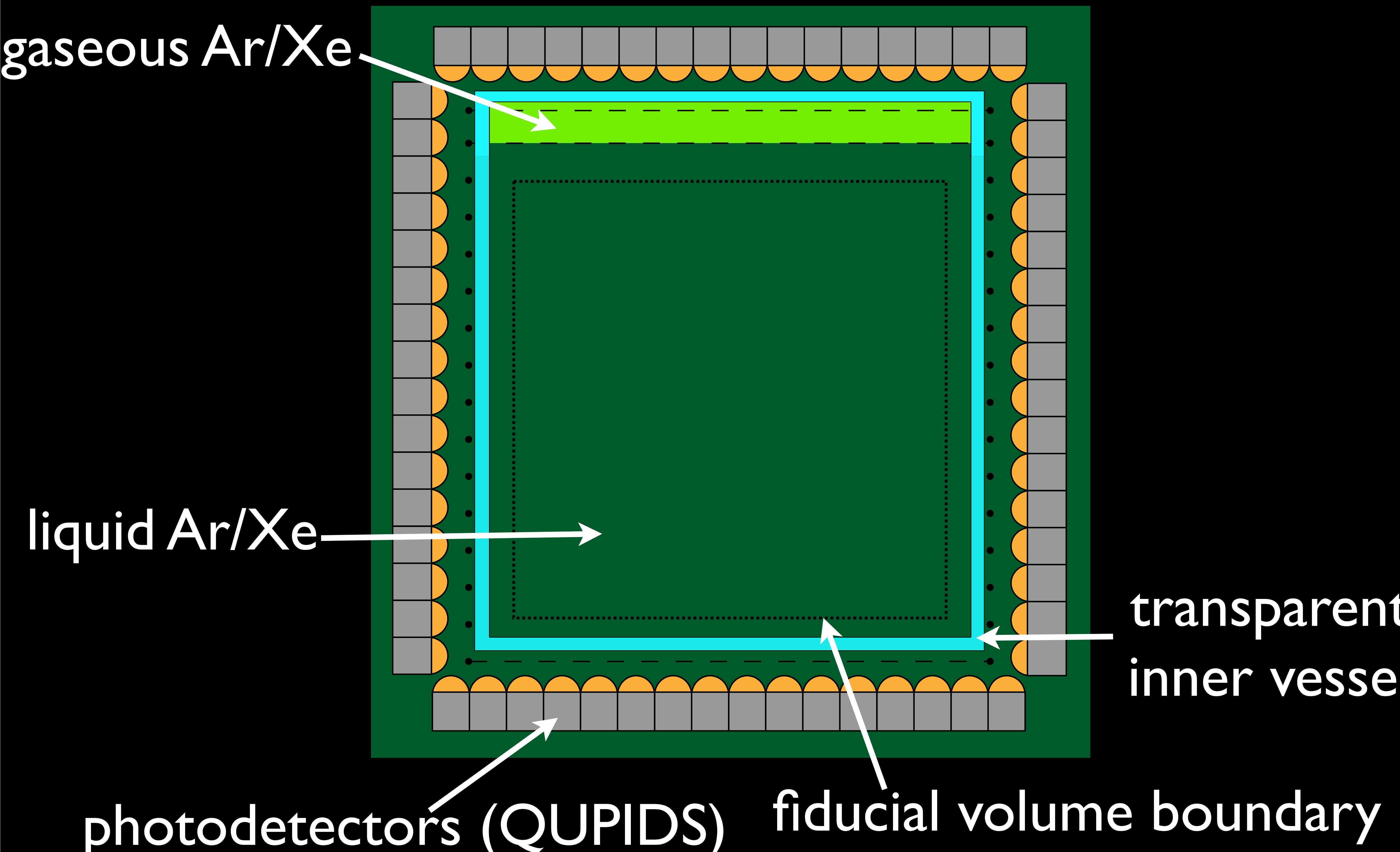
Discrimination in Argon

- Pulse shape discrimination of primary scintillation (S1) based on the large difference in decay times between singlet (≈ 7 ns) and triplet (1.6 μs) components of the UV scintillation light
  Minimum ionizing: triplet/singlet ~ 3/1
  Nuclear recoils: triplet/singlet ~ 1/3
  Theoretical Identification Power exceeds 10^8 for > 60 photoelectrons (Boulay & Hime 2004)

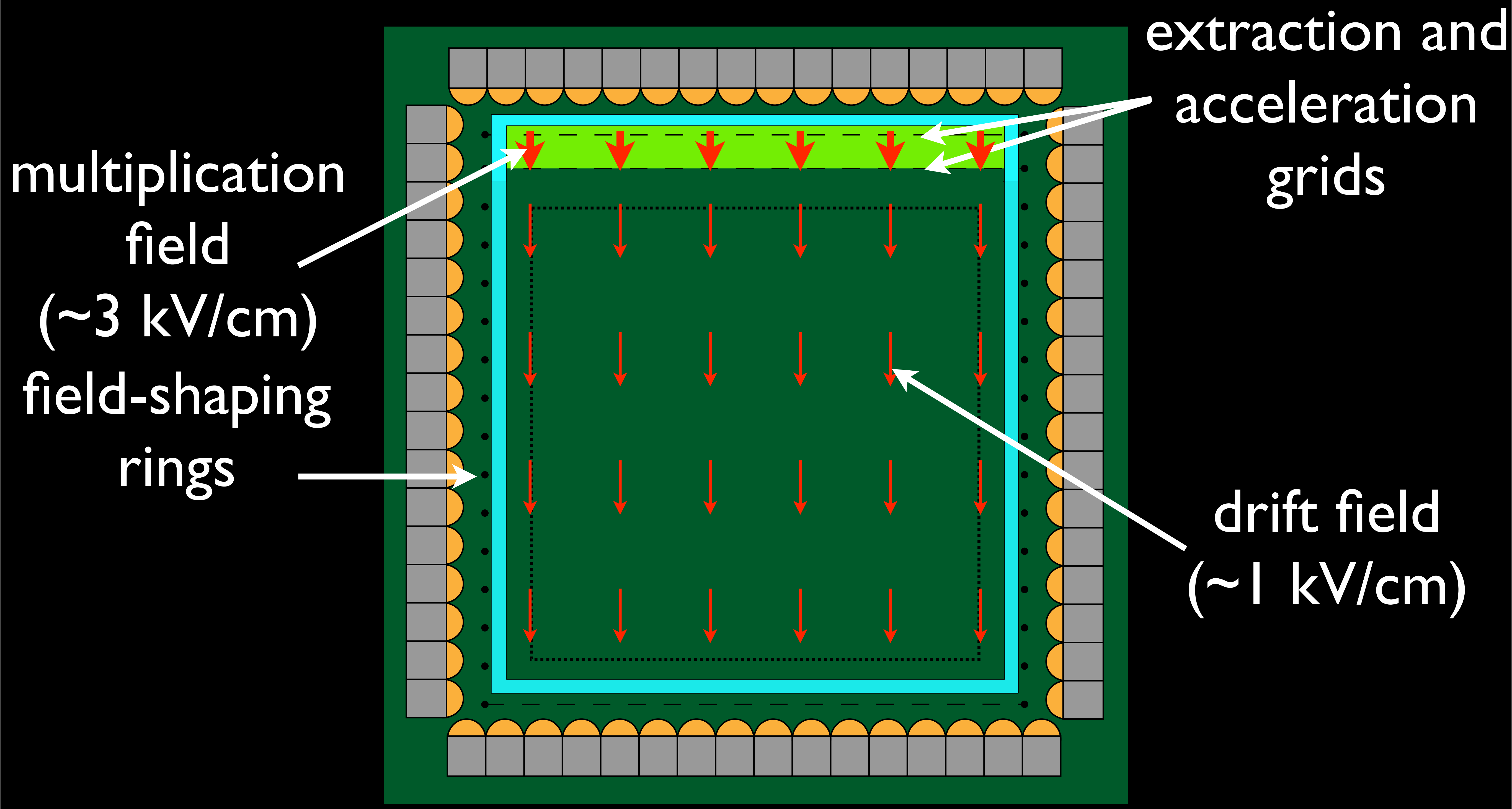
- Difference in ratio of the prompt scintillation (S1) to the drift time-delayed ionization (S2) strongly dependent upon recombination of ionizing tracks, which in turn depends on ionization density
  - Rejection ~ 10^2-10^3

- Precise determination of events location in 3D
  - 1-5 mm x-y, 1 mm z
  - Additional rejection for neutron and γ background

TPC in Action

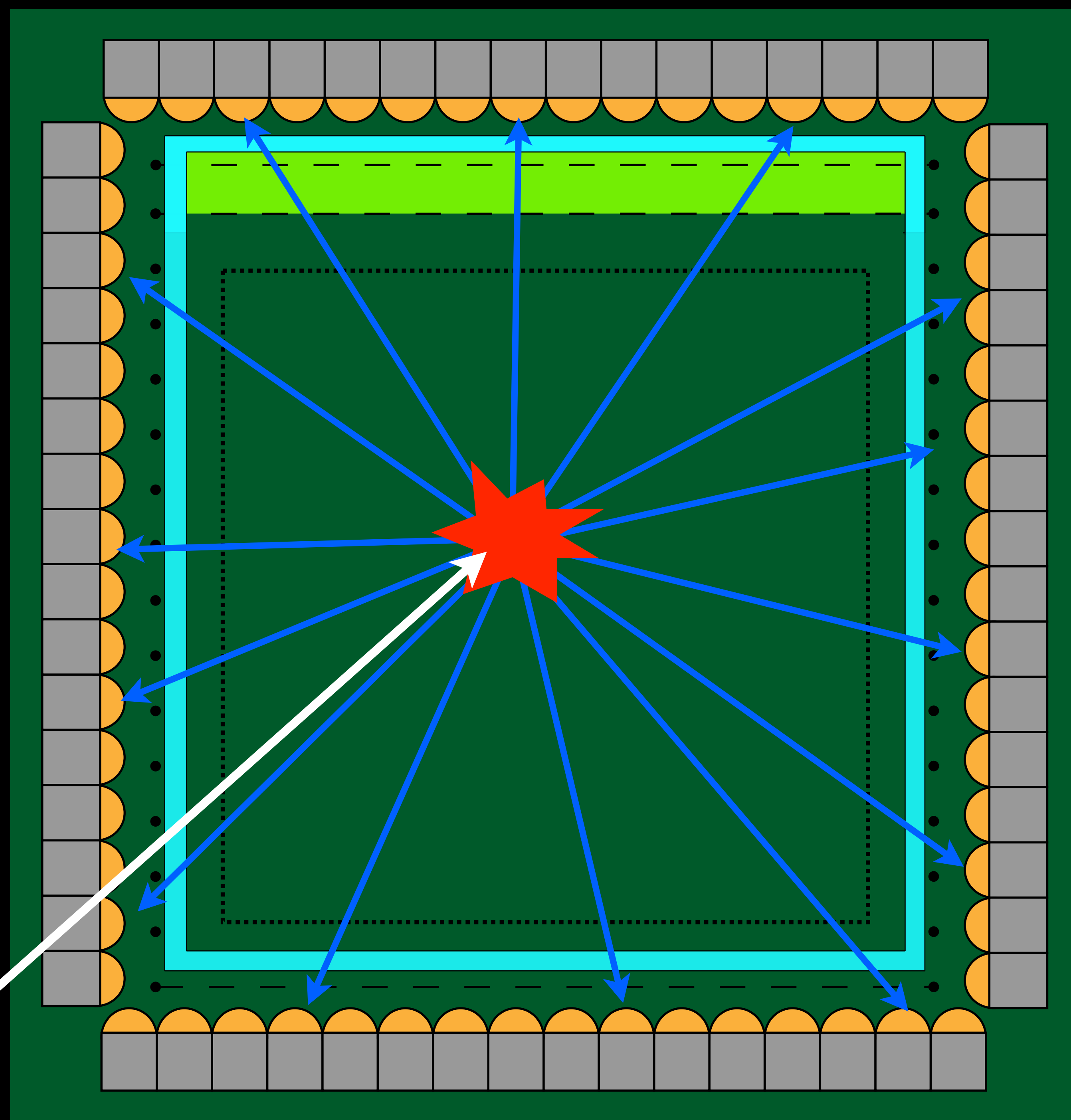


TPC in Action



TPC in Action

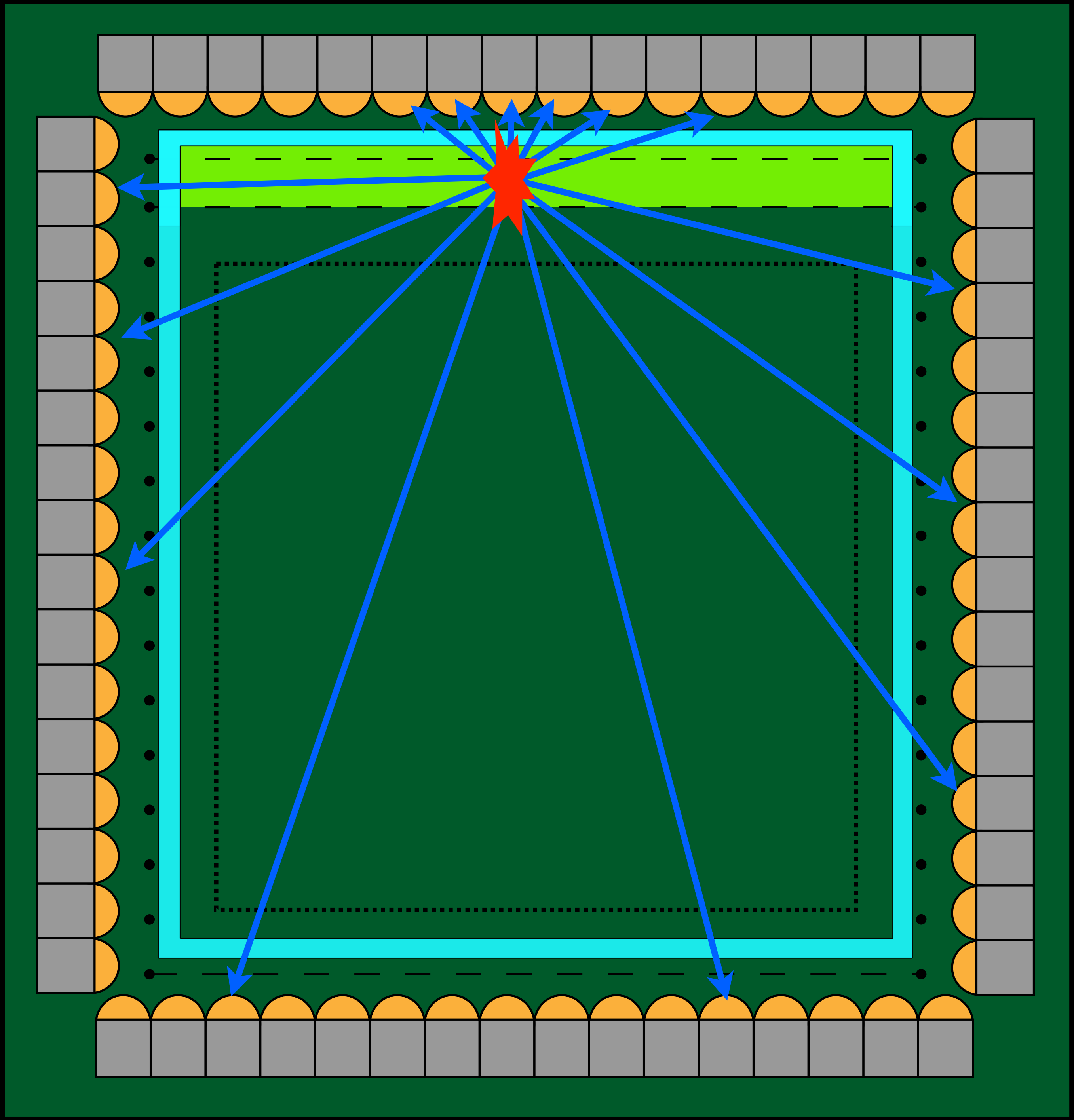
primary scintillation photons
emitted and detected



WIMP Scatter
deposits
energy in FV

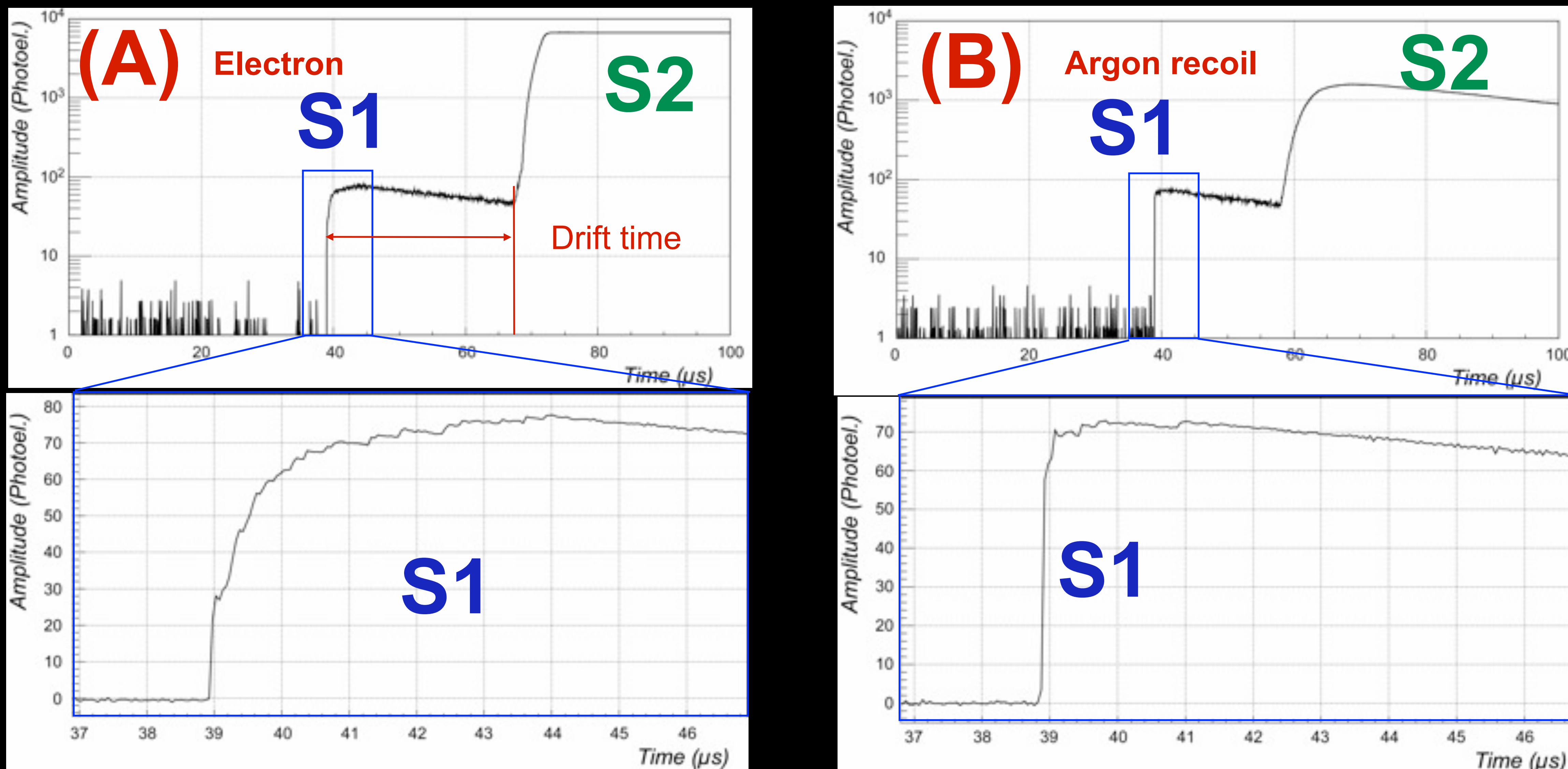
TPC in Action

secondary photons emitted
by multiplication in gas region



ionized
electrons
drifted to
gas region

First Two Discrimination Methods



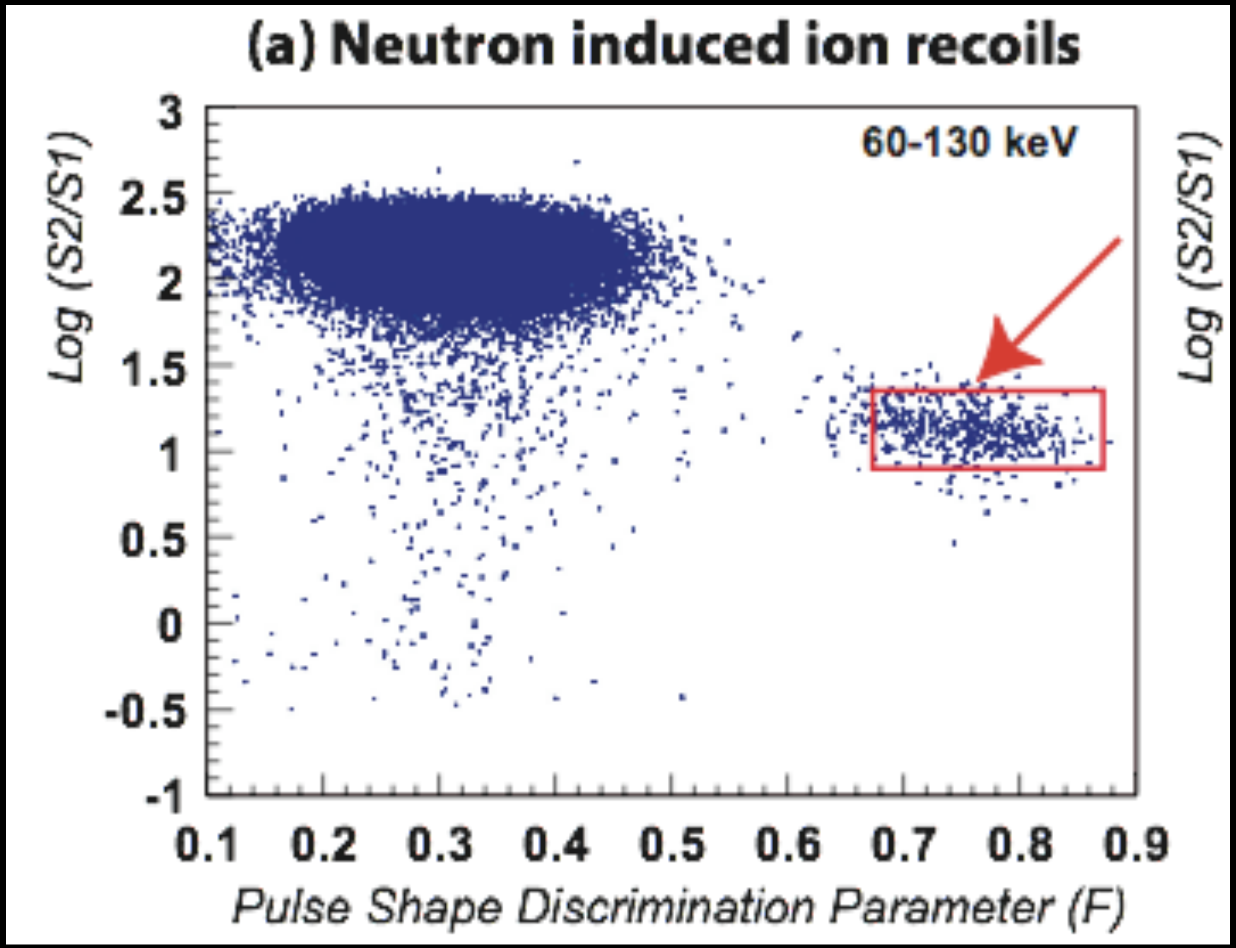
Events are characterized by:

- the ratio S2/S1 between the primary (S1) and secondary (S2)
- the rising time of the S1 signal

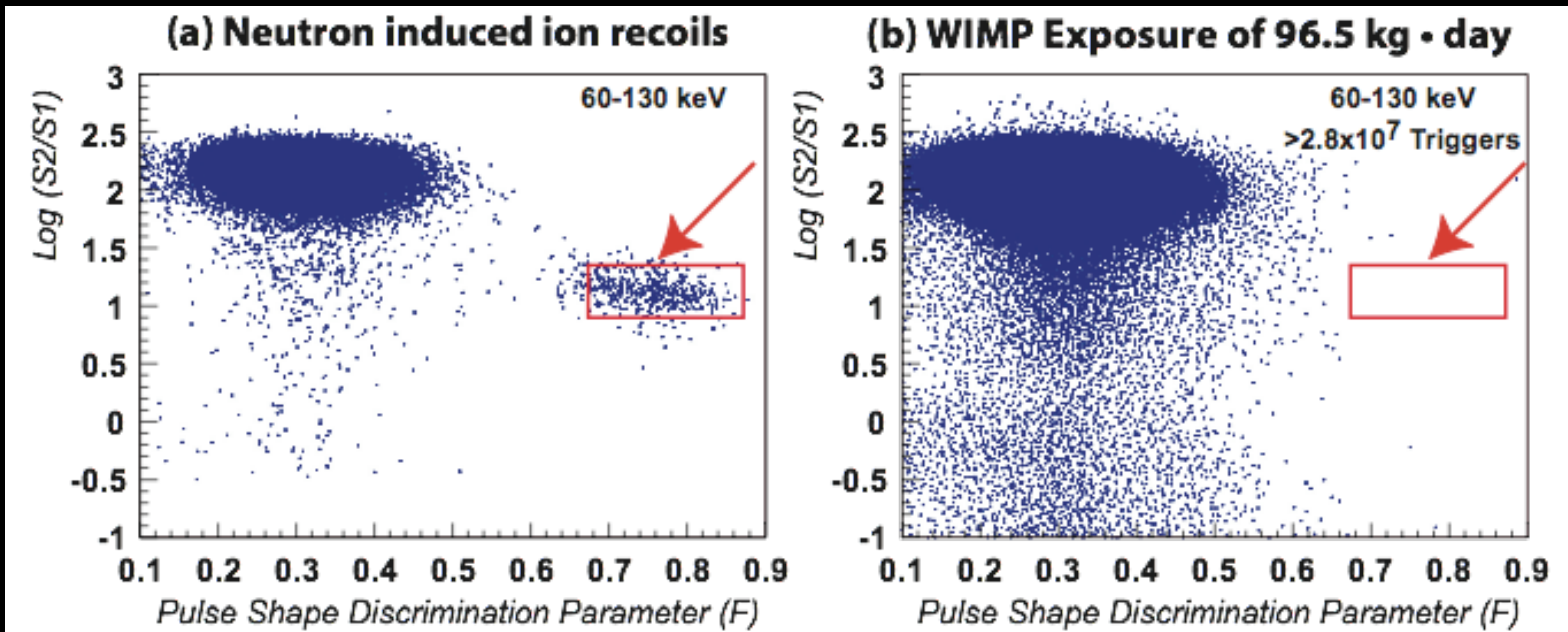
Minimum ionizing particles: high S2/S1 ratio (~100) and by slow S1 signal

Ar recoils: low (≤10) S2/S1 ratio and fast S1 signal

First Dark Matter Results



First Dark Matter Results



Events in the recoils window during the WIMP search run: zero

P. Benetti et al. (WARP Collaboration), Astropart. Phys. **28**, 495 (2008)

Why is depleted argon from underground crucial?

- Radioactive ^{39}Ar produced by cosmic rays in atmosphere
  - beta decays, Q = 565 keV, $t_{1/2}$ = 269 years
- In atmospheric argon:
  - ^{39}Ar/Ar ratio 8×10^{-16}
  - specific activity 1 Bq/kq
- Limits size (and sensitivity) of argon detectors to 500-1000 kg due to ^{39}Ar events pile-up

Why is depleted argon from underground crucial?

- ^{39}Ar-depleted argon available via centrifugation or thermal diffusion, but expensive at the ton scale!

- Motivated by suggestion from Bernard and success in Borexino
  - Low background from ^{14}C crucial for observation of low energy neutrinos with organic liquid scintillators.
  - Hydrocarbons in deep underground reservoirs results in low cosmogenic ^{14}C

- ^{39}Ar production by cosmic rays strongly suppressed underground

Princeton Prototype Plant for Industrial Scale Production

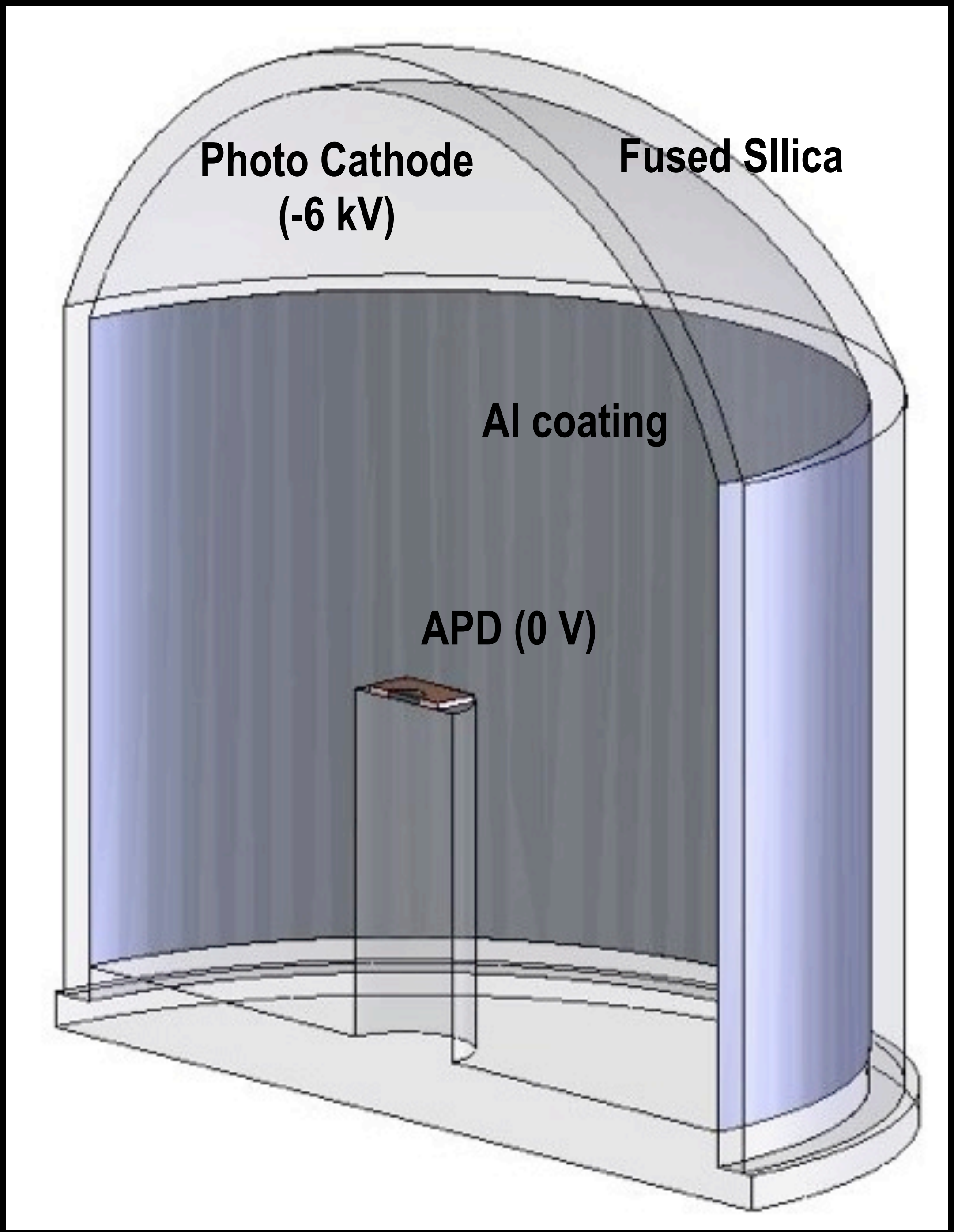
News: NSF funding (NSF PHY-0811186)

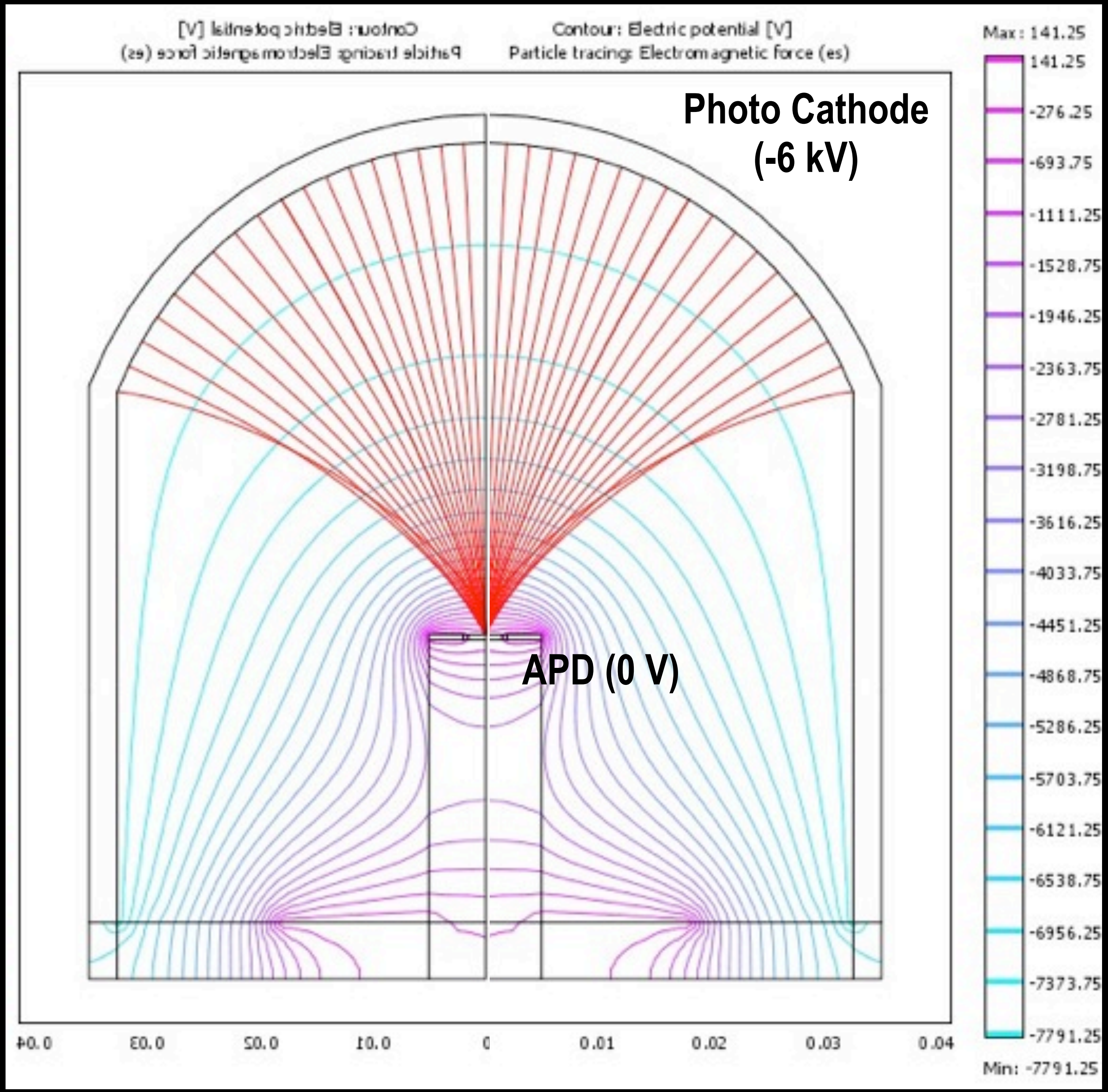
Achieved 1.5 kg/day (depletion >25)

Princeton Prototype Cryogenic Distillation Column @ FNAL PAB

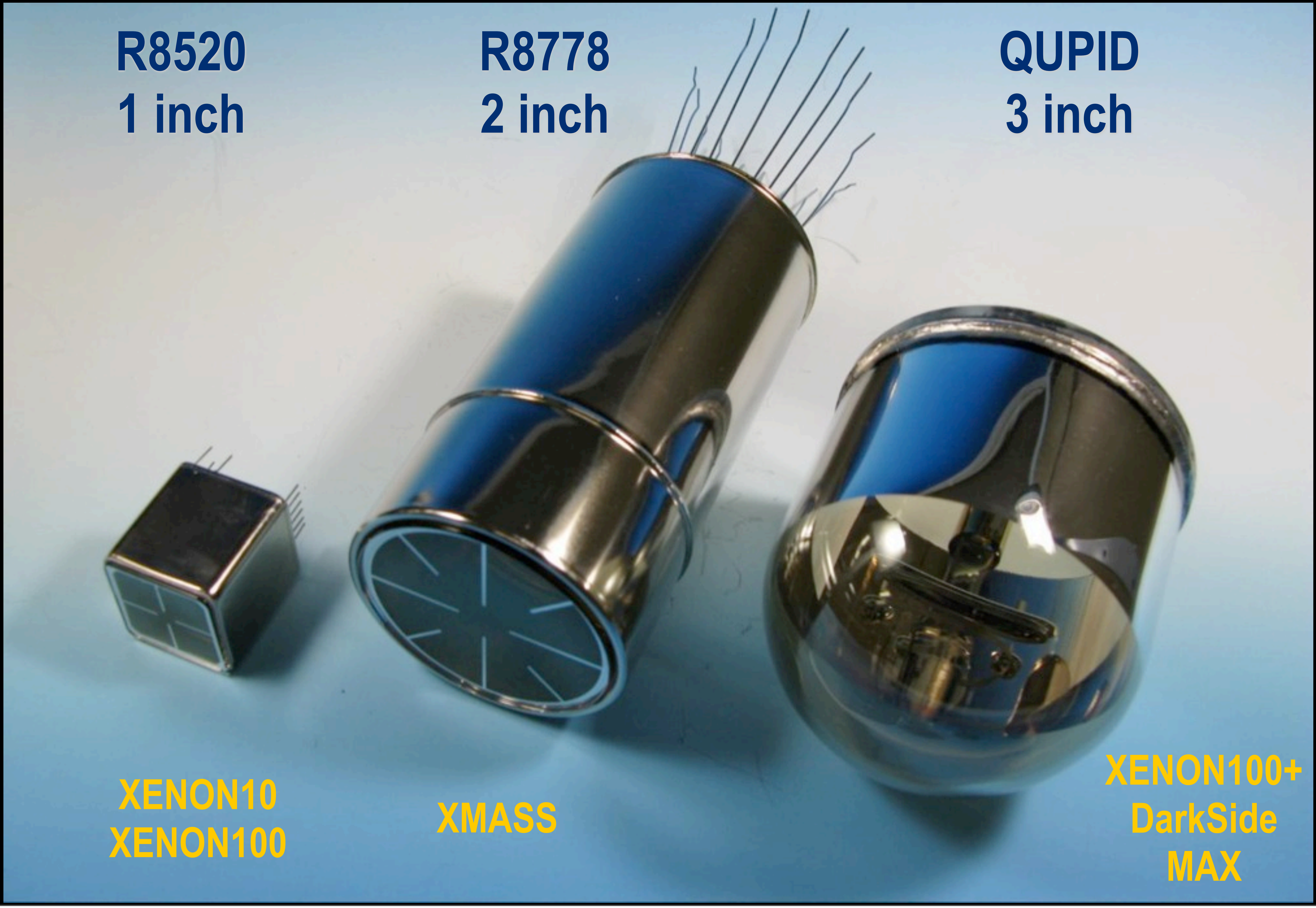
Princeton Prototype Cryogenic Distillation Column @ FNAL PAB

3” Quartz Photon Intensifying Detector (QUPID)

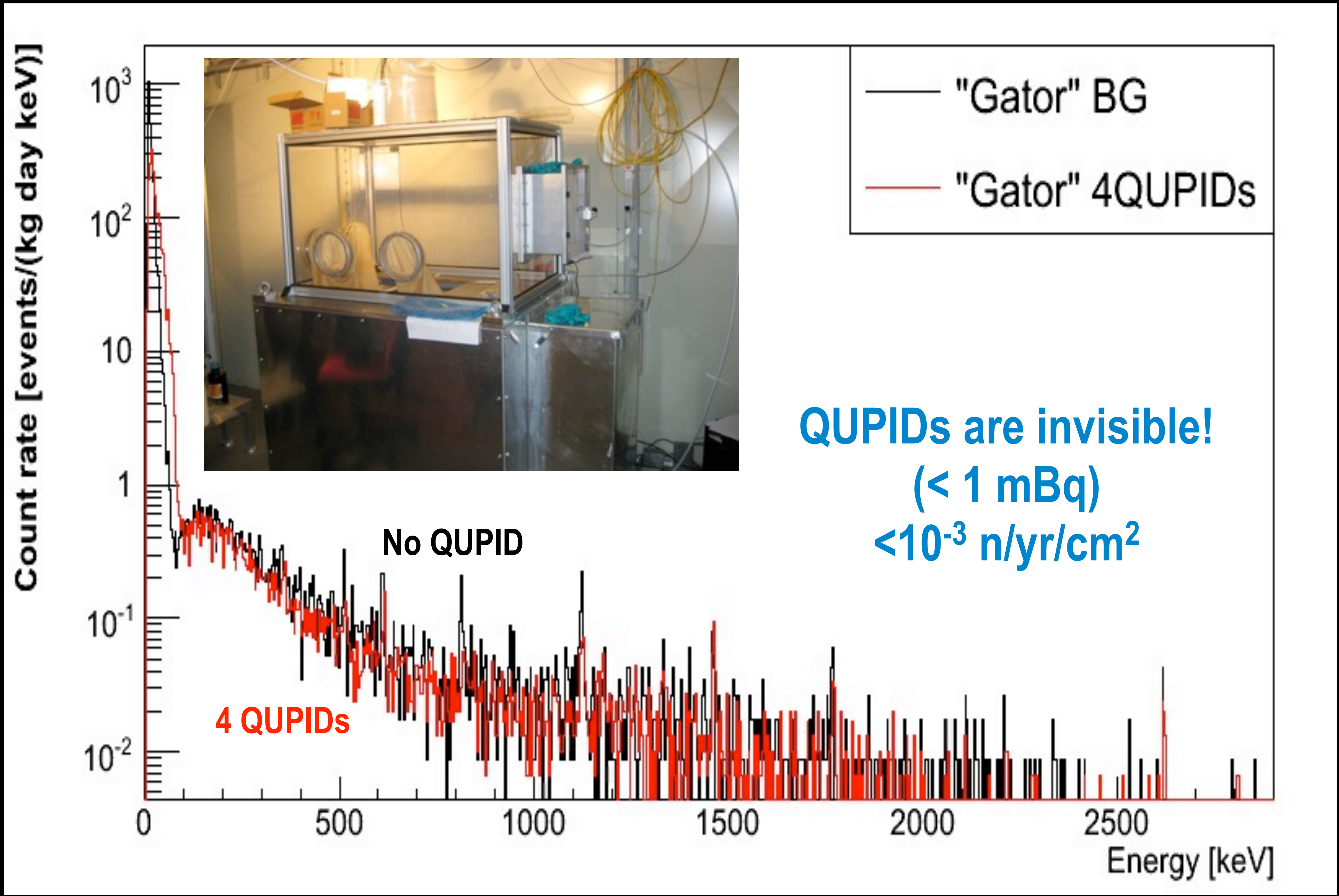




Low Radioactivity Photosensors for Dark Matter Searches



QUPID Radioactivity



Neutron Veto

- Typical efficiency of xenon-based vetos ~60%
- Efficiency of 9-ton WARP liquid argon veto ~98%
- Efforts relying on neutron capture on Gd in water limited to 95% due to long range of γ-rays from capture

Neutron Veto

- Our approach (F. Calaprice): abandon (n,γ) capture agents, rely on (n,α) on ^{10}B
- Alpha particle extremely low range
- Alpha particle can be observed using borated liquid scintillator ... remember BOREX?
- 99.8% efficiency for radiogenic neutrons

Light Yield

- Light Yield extremely important for PSD
- Our goal (>5 pe/keV)
- Already achieved and exceeded on ~1 kg prototype: 7 p.e./keV (Hamamatsu R11065)

Built upon Support from:

NSF PHY-0919363
"MAX - Multi-ton Argon and Xenon TPCs"

NSF PHY-0811186
"DUSEL R&D: Depleted Argon from Underground Sources"

NSF PHY-0704220
"Study of Argon for WIMP Dark Matter Detectors and Earth Sciences"

NSF PHY-0603376
"WARP: WIMP Dark Matter search with Liquid Argon"

Program Goal

- Bring together three innovative techniques
  1. Depleted Argon from underground sources
  2. 3” QUPID photosensors
  3. High efficiency borated liquid scintillator neutron veto (>99%)
- Goal of zero background with very large exposures to dark matter
  - Many tons fiducial target
  - Many years of background-free exposure

The End

Like the jelly beans in this jar, the Universe is mostly dark: 96 percent consists of dark energy (about 70%) and dark matter (about 26%). Only about four percent (the same proportion as the lightly colored jelly beans) of the Universe - including the stars, planets and us - is made of familiar atomic matter.

The End