MAX
-
Multi-ton Argon and Xenon

Cristiano Galbiati
Princeton University

DUSEL Workshop
Lead, SD

Oct 2, 2009

MAX - Multi-ton Argon & Xenon

UMass Amherst
Arizona State University
Augustana College
Black Hills State University
Coimbra University
Columbia University
Fermilab
University of Houston
INAF
LNGS
MIT

University of Münster
University of Notre Dame
Princeton University
Rice University
Shanghai Jiao Tong University
Temple University
UCLA
University of Virginia
Waseda University
University of Zürich

Arizona State University, USA Prof. Ricardo Alarcon, Septimiu Balascuta

Augustana College, USA Prof. Drew Alton

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

Columbia University, USA Prof. Elena Aprile, Bin Choi, Dr. Karl-Ludwig Giboni, Dr. Tom Haruyama, Dr. Rafael Lang, Kyungeun Elizabeth Lim, Dr. Antonio Jesus Melgarejo, Guillaume Plante, Dr. Gordon Tajiri

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

Instituto Nazionale di Astrofisica (INAF) Gianmarco Bruno, Dr. Walter Fulgione

Laboratori Nazionali del Gran Sasso (LNGS), Italy Dr. Francesco Arneodo, Serena Fattori

Massachusetts Institute of Technology, USA Prof. Jocelyn Monroe

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

Rice University, USA Prof. Uwe Oberlack, Yuan Mei, Dr. Petr Shagin

Shanghai Jiao Tong University, PRC Prof. Xiangdong Ji, Prof. Kaixuan Ni, Yuehuan Wei, Xiang Xiao.

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

University of California at Los Angeles, USA Daniel Aharoni, Prof. Katsushi Arisaka, Ethan Brown, Prof. David Cline, Yixiong Meng, Dr. Emilija Pantic, Prof. Peter F. Smith, Artin Teymourian, Chi Wai Lam, Dr. Hanguo Wang

University of Coimbra, Portugal Dr. Joao Cardoso, Lúis Carlos Costa Coelho, Prof. Joaquim Marques Ferreira dos Santos, Prof. José António Matias Lopes, Dr. Sonja Orrigo, Antonio Ribeiro

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

University of Massachusetts at Amherst, USA Prof. Andrea Pocar

University of Muenster, Germany Dr. Marcus Beck, Dr. Volker Hannen, Karen Hugenberg, Dr. Hans-Werner Ortjoahnn, Prof. Christian Weinheimer

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

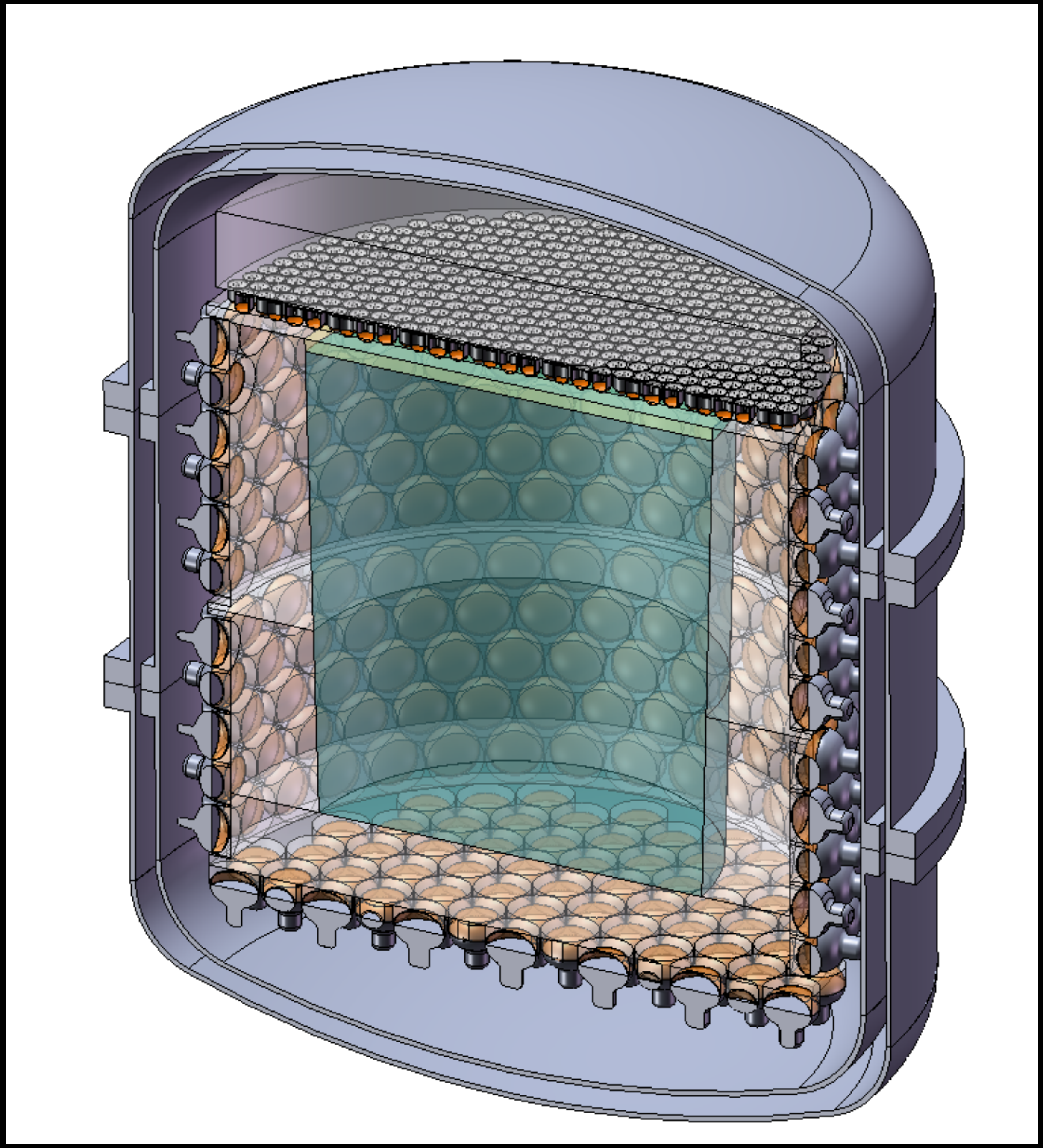
University of Virginia, USA Prof. Kevin Lehmann

University of Zürich, Switzerland Ali Askin, Prof. Laura Baudis, Dr. Alfredo Ferella, Marijke Haffke, Alexander Kish, Dr. Roberto Santorelli, Dr. Eirini Tziaferi

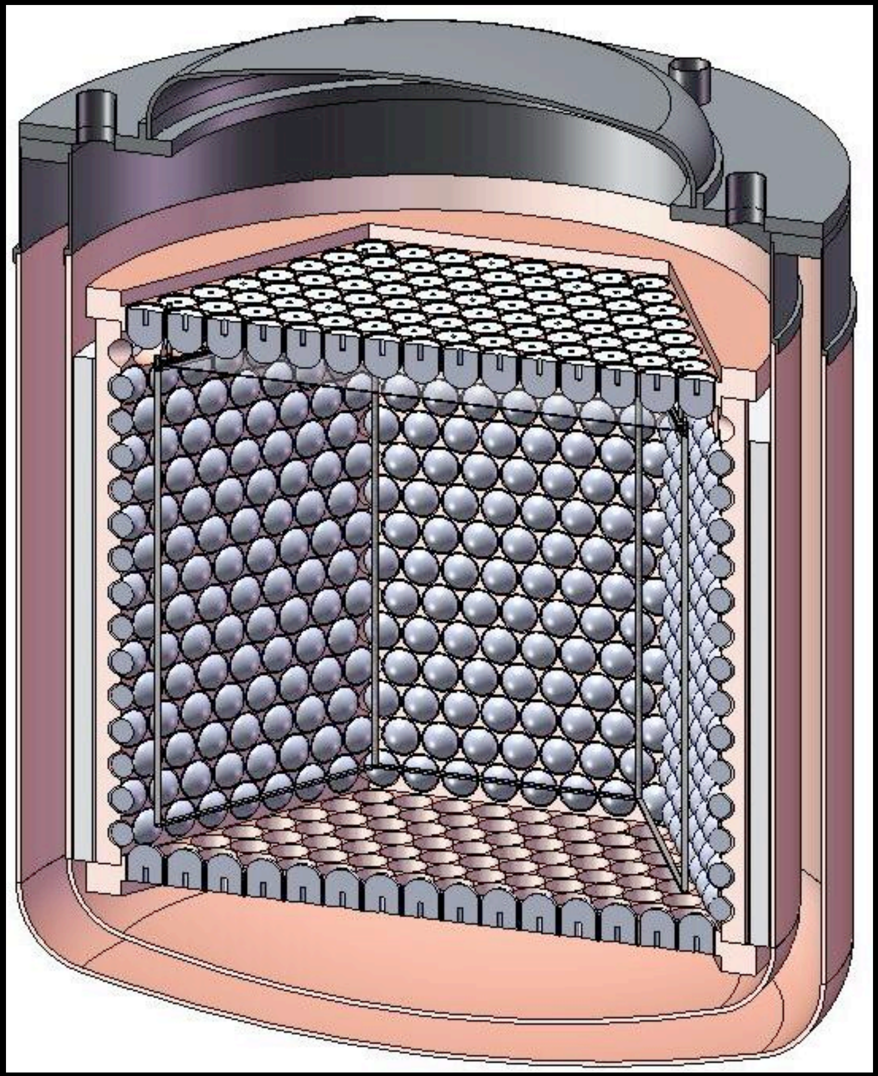
Waseda University, Japan Prof. Tadayoshi Doke, Prof. Nobuyuki Hasebe, Mitsuteru Mimura, Dr. Mitsuhiro Miyajima, Dr. Shinichi Sasaki, Dr. Satoshi Suzuki, Prof. Shoji Torii

Representing MAX

- D. Alton (Augie)
- E. Aprile (Columbia)
- D. Cline (UCLA)
- D. Durben (BHSU)
- C. Galbiati (Princeton)
- E. Hungerford (Houston)
- K. Keeter (BHSU)
- J. Martoff (Temple)
- P. Meyers (Princeton)
- U. Oberlack (Rice)
- B. Parsells (Princeton)
- A. Pocar (UMass)
- H. Wang (UCLA)
- M. Zehfus (BHSU)



5 ton DAr TPC



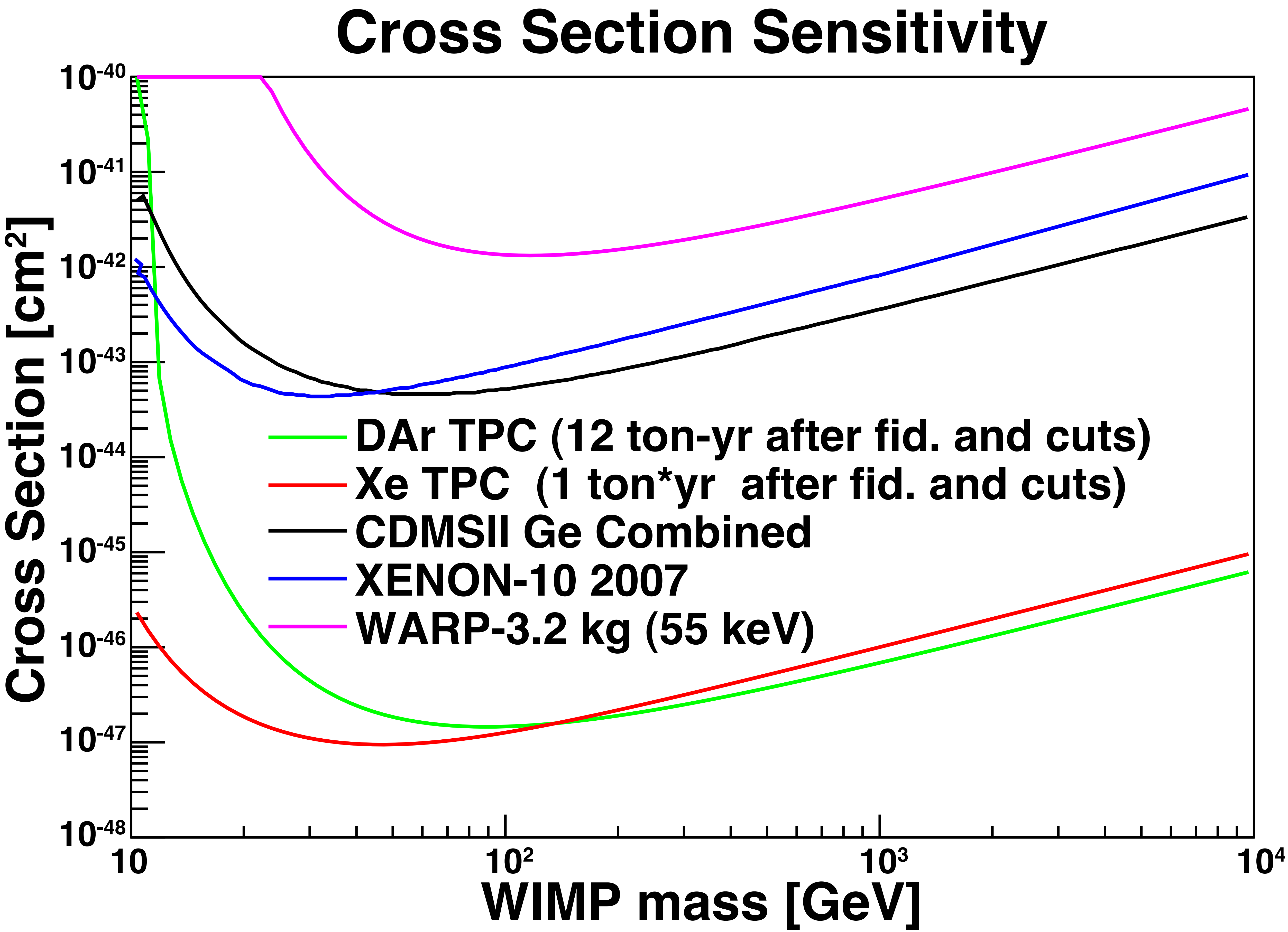
2.5 ton Xe TPC

Compelling Case for Cooperation

- Cooperative effort of XENON and DarkSide Collaborations
- Ar and Xe two enticing targets, easily scalable
- Strong commonalities to be exploited
  - Extremely low background photosensors (QUPIDs) designed for LAr and LXe temperatures
  - Common “two-phase technology” for detection of scintillation and ionization
  - Common scheme for cryocooling, mechanics, shielding, etc.
  - Common engineering and design results in significant savings with

The Physics of MAX

- Discovery potential
- Confirmation in twin targets: Xe and Ar
- Confirmation of A^2 dependence of cross section
- Measurement of the mass of the WIMP by comparison of recoil spectra in different targets
- Indication on spin-dependent or spin-independent nature of interactions



Cross Section Sensitivity
Cross Section [cm2]
WIMP mass [GeV]
10-40
10-41
10-42
10-43
10-44
10-45
10-46
10-47
10-48
10
102
103
104
DAr TPC (12 ton-yr after fid. and cuts)
Xe TPC (1 ton*yr after fid. and cuts)
CDMSII Ge Combined
XENON-10 2007
WARP-3.2 kg (55 keV)

Mass Measurement

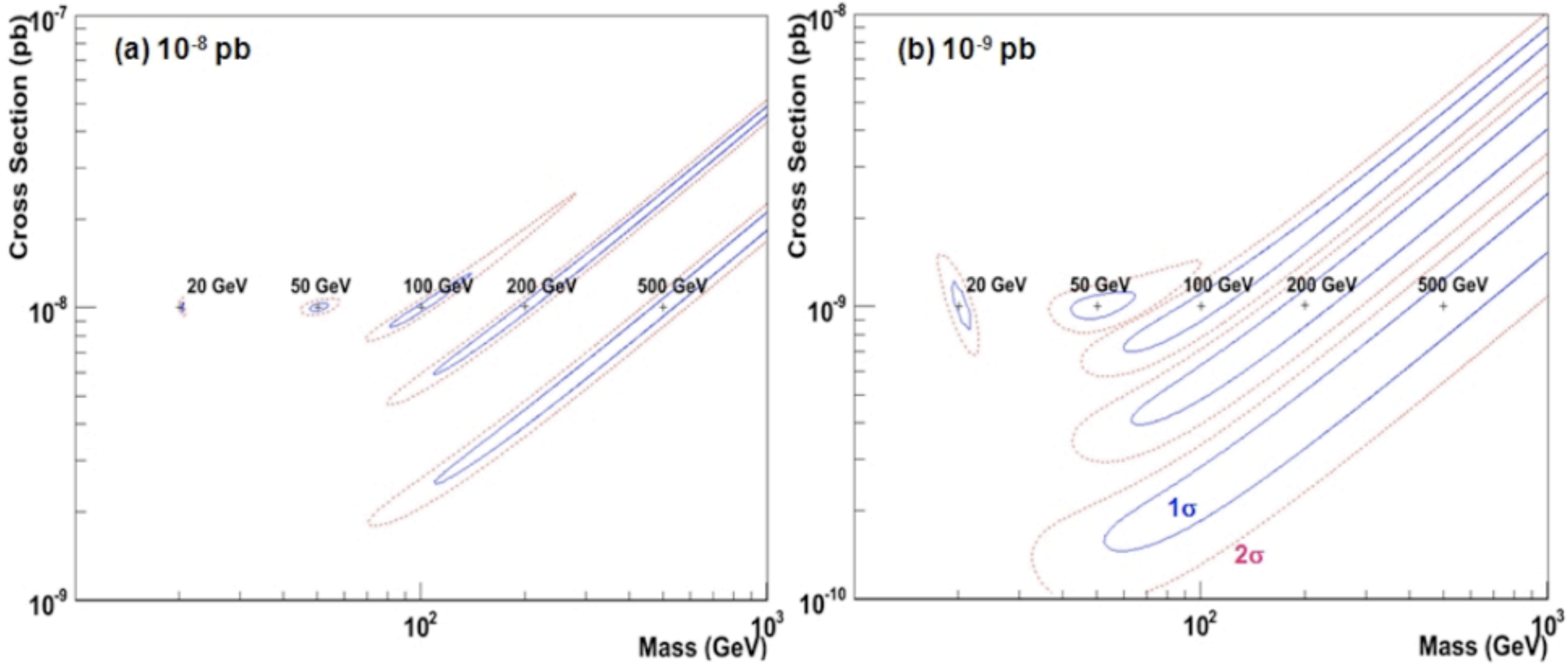


FIG. 8: 1σ and 2σ uncertainties in determining WIMP mass and cross-section by Xe target in XAX in 10 ton-years of data taking. WIMP masses 20, 50, 100, 200, 500 GeV, and cross sections of (a) 10^{-8} pb, (b) 10^{-9} pb are assumed. Above 100 GeV/c^2 WIMP mass, there is degeneracy between mass and cross section, resulting in the 45° slope in this figure.

K. Arisaka et al., Astroparticle Physics 31 (2009) 63–74

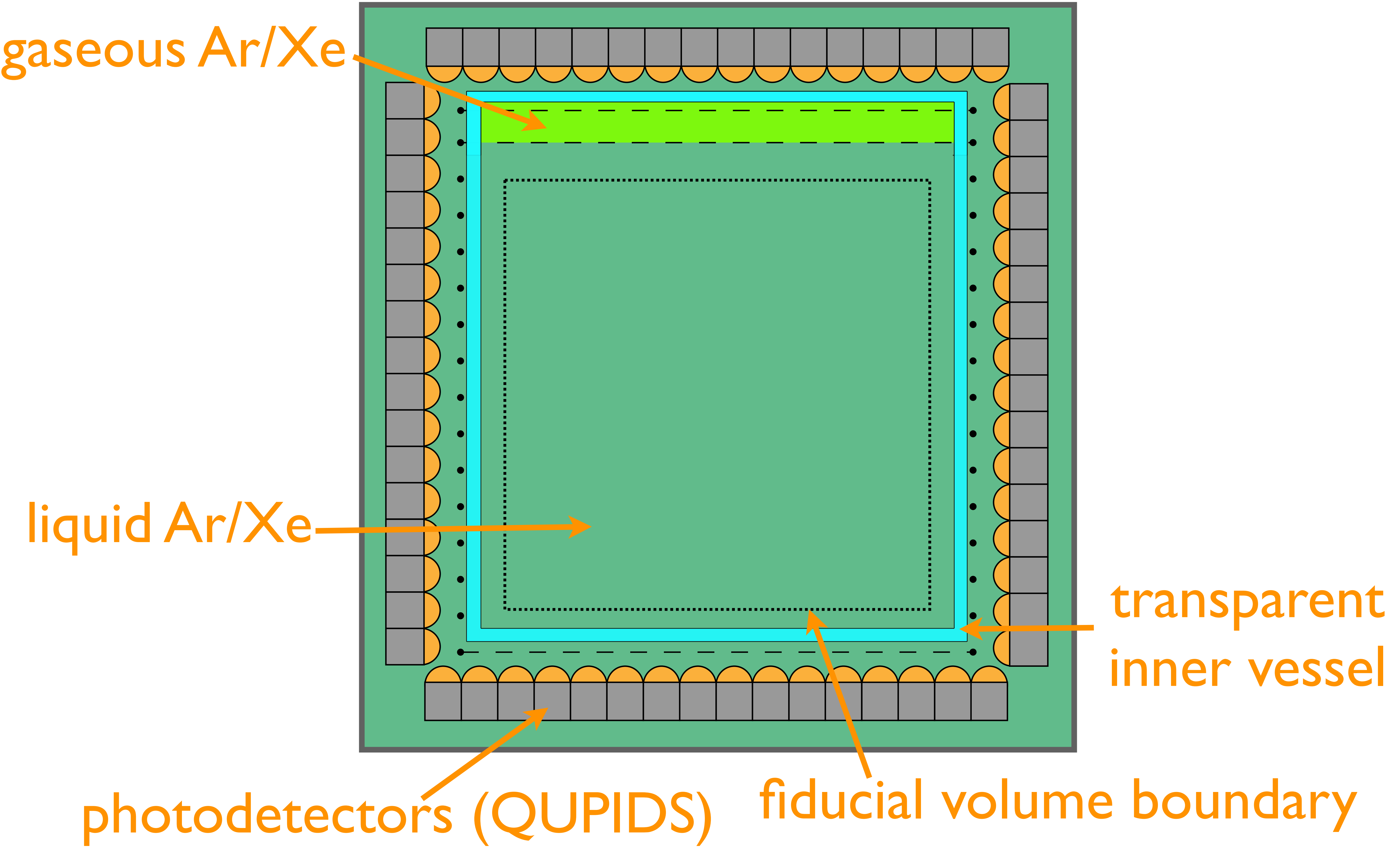
The Technology Case

- Superior 3” QUPID photosensors
  - no background detected in best Ge
  - 6” and 8” QUPIDs under study
- Bialkali-LT photocathode for >35% QE at liquid xenon and argon temperature on 3”/6”/8” photosensors
- 4π optical coverage - optimal light yield
- Strong fiducialization for xenon target
- β/γ background free by pulse shaping in Argon
- Depleted Argon from underground sources

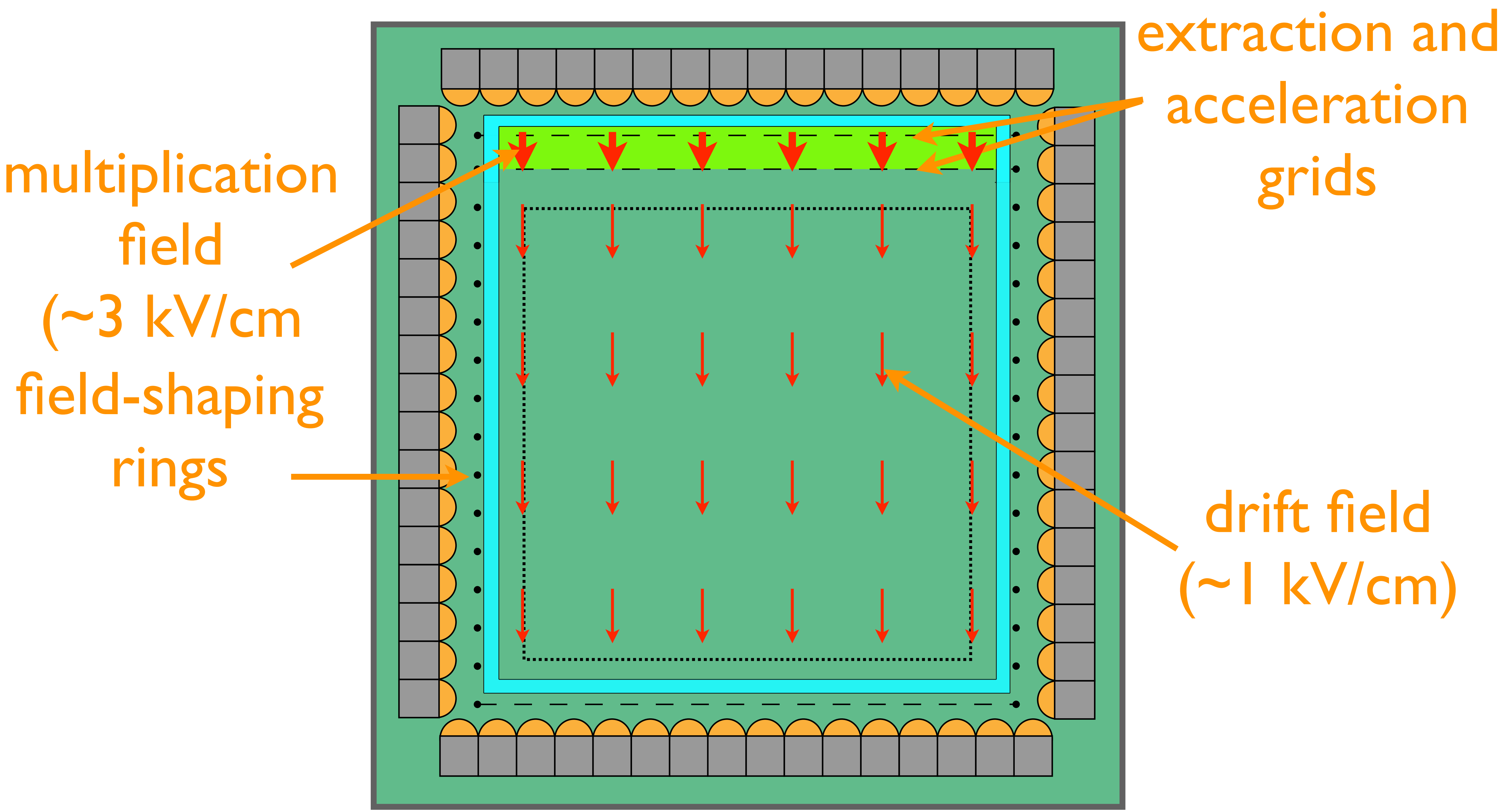
Noble Liquid Detectors

- Target = Detector
- Excellent scintillation detectors
  - 40 photons/keV (Ar, 128 nm), 46 photons/keV (Xe, 178 nm)
- Excellent ionization detectors
  - 40 electrons/keV (Ar), 64 electrons/keV (Xe)
- Photons and electrons not self-absorbed: long e drift distance
- Large multi-ton detectors possible and “cheap”
- Background discrimination possible

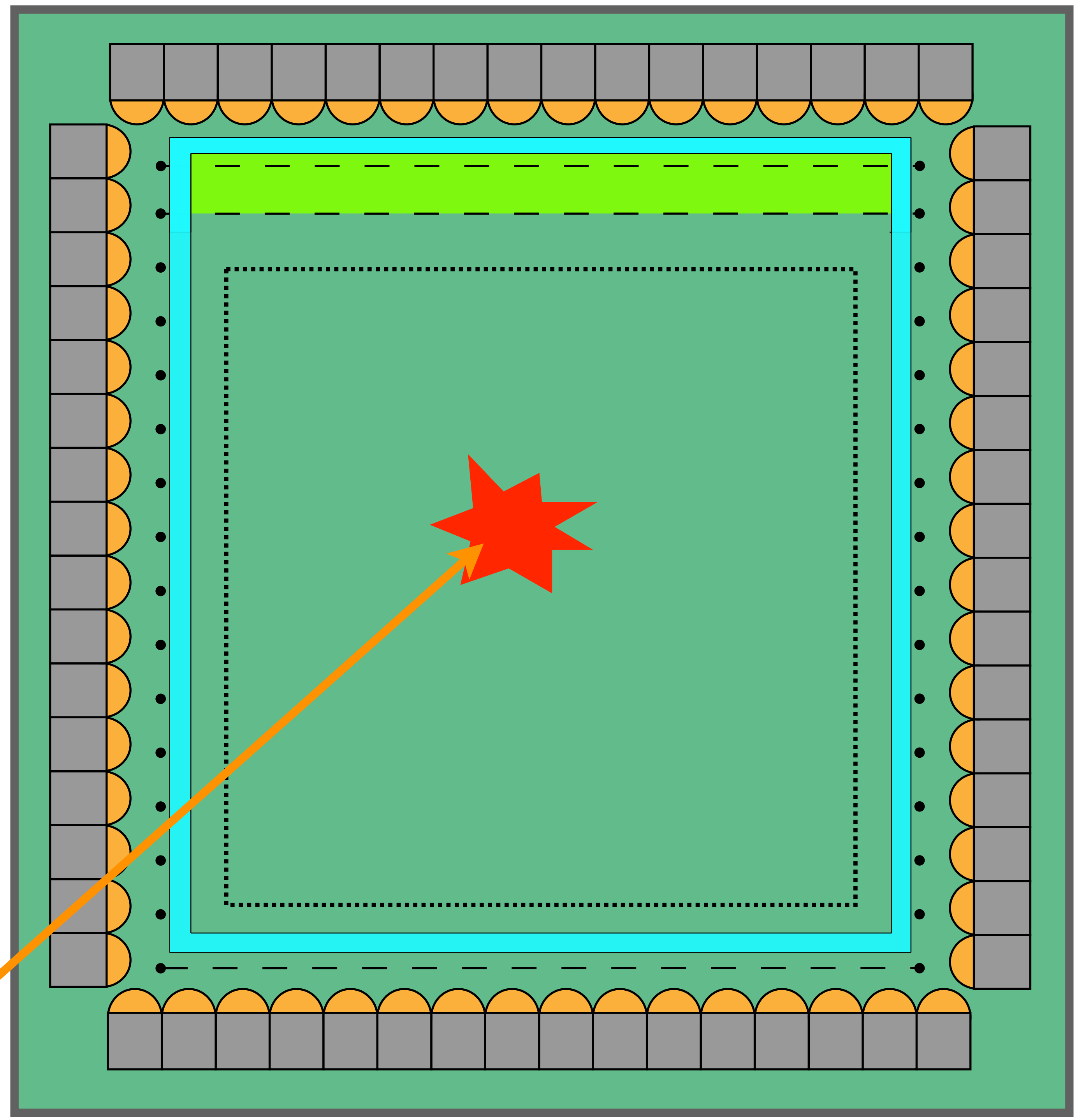
TPC in Action



TPC in Action



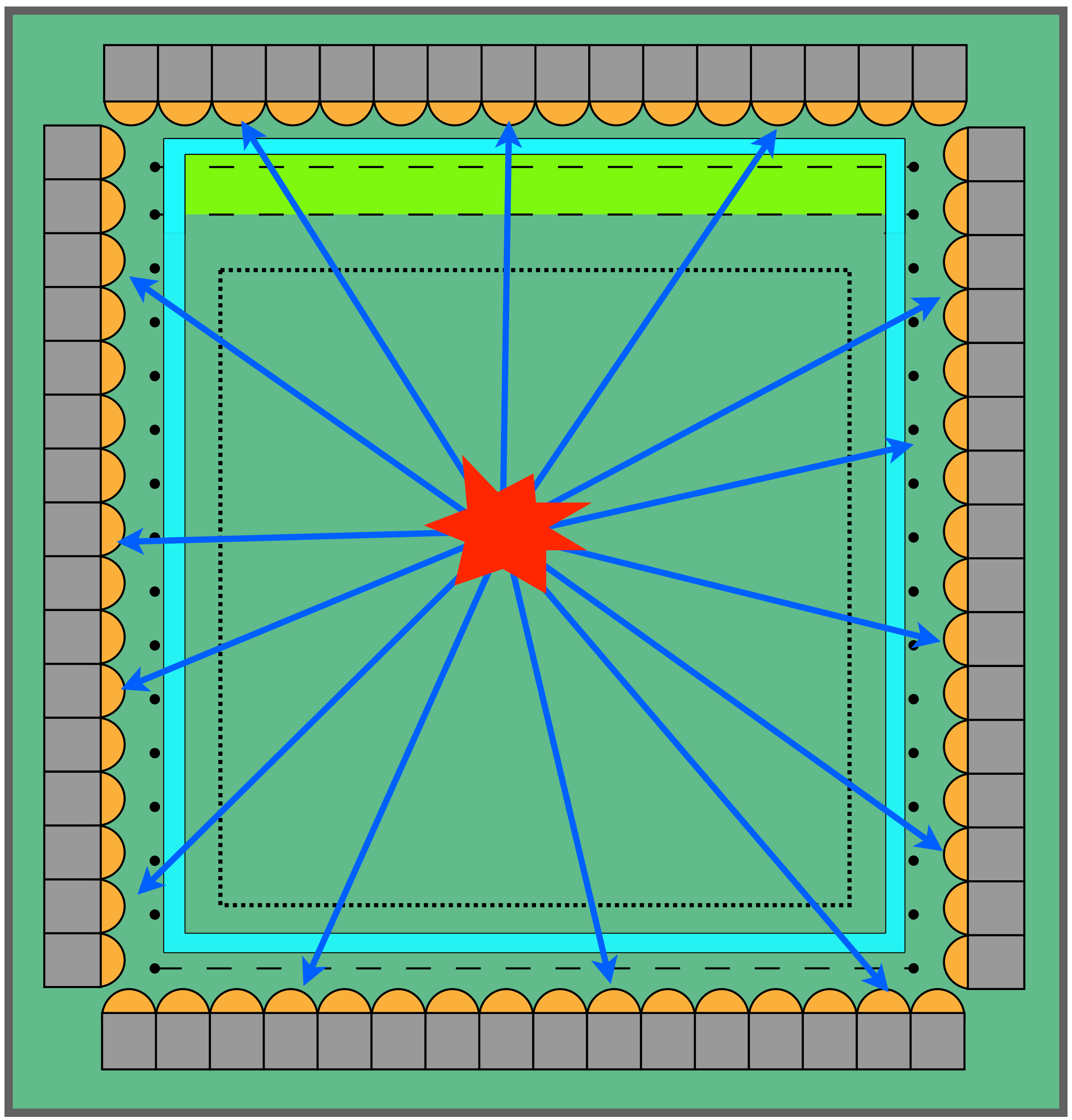
TPC in Action



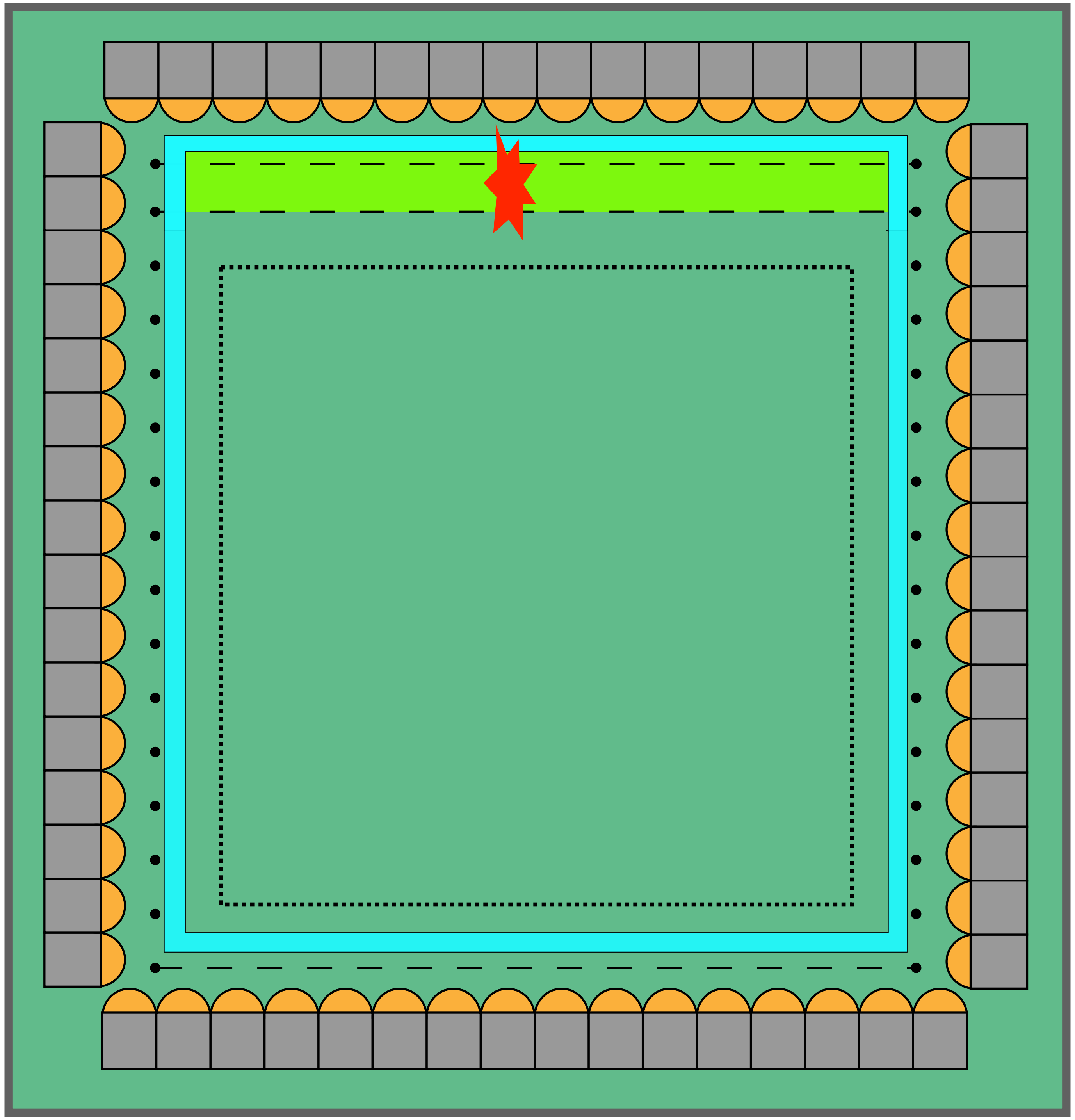
WIMP Scatter
deposits
energy in FV

TPC in Action

primary scintillation photons
emitted and detected



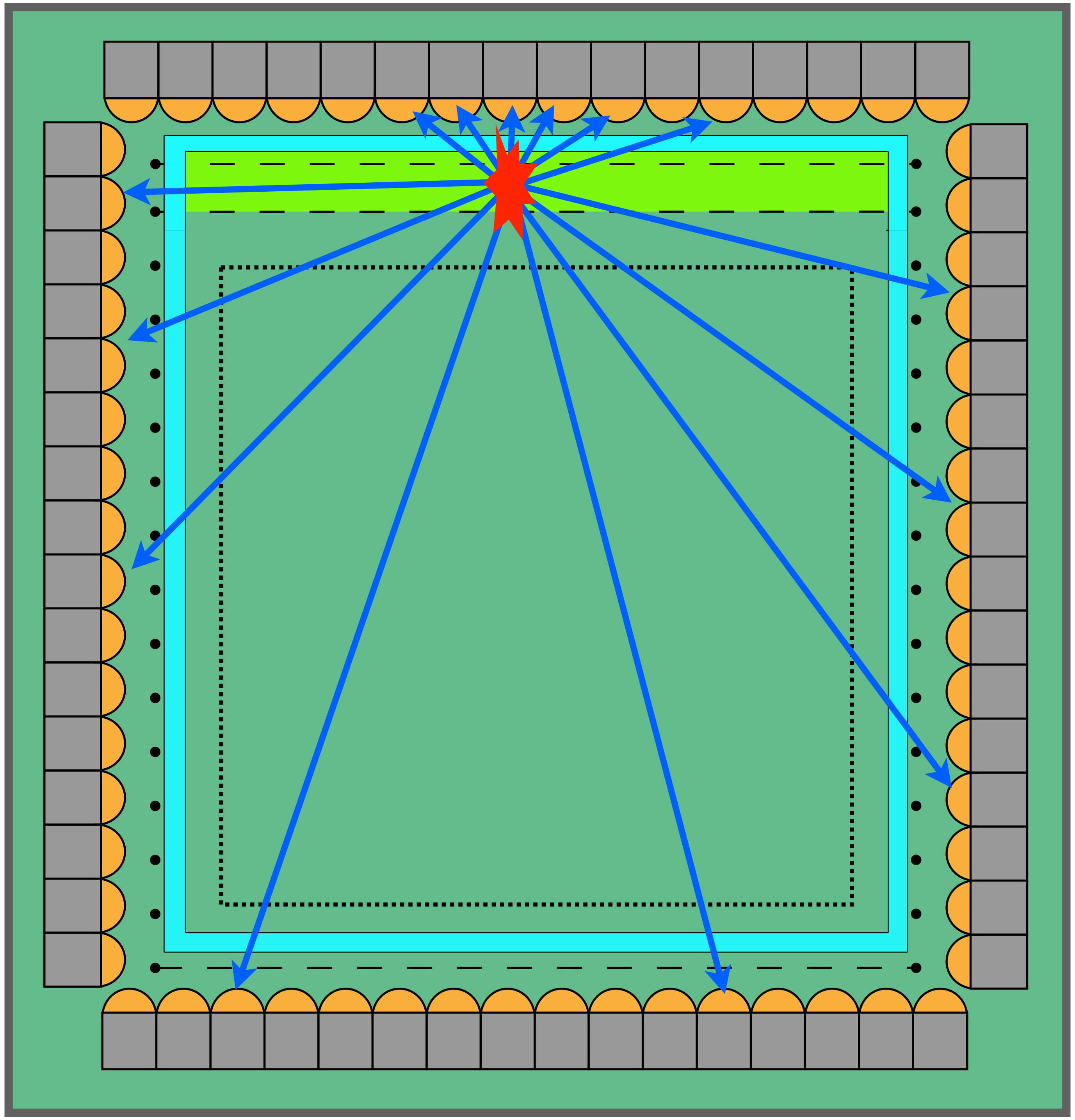
TPC in Action



ionized electrons drifted to gas region

TPC in Action

secondary photons emitted
by multiplication in gas region



Discrimination in Xenon

- Fiducialization reduces the background from construction and external materials in the fiducial region

- Difference in ratio of the prompt scintillation (S1) to the drift time-delayed ionization (S2) with 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 multiple neutron recoils and γ background

Discrimination in Argon

- Pulse shape discrimination of primary scintillation (S1) based on the very large difference in decay times between singlet (≈7 ns) and triplet (1.5 μs) components of the emitted UV light

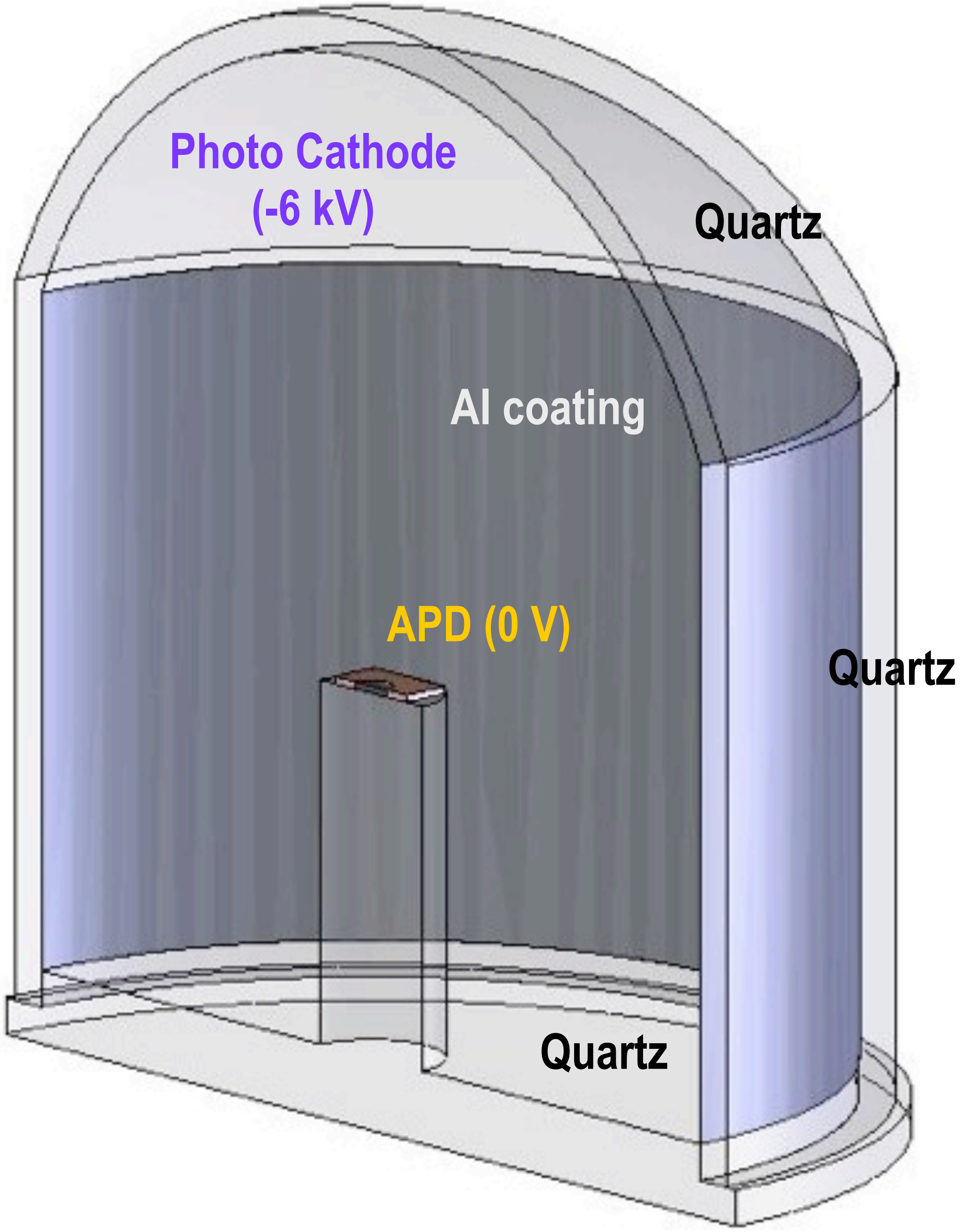
    Minimum ionizing: triplet/singlet ~ 3/1

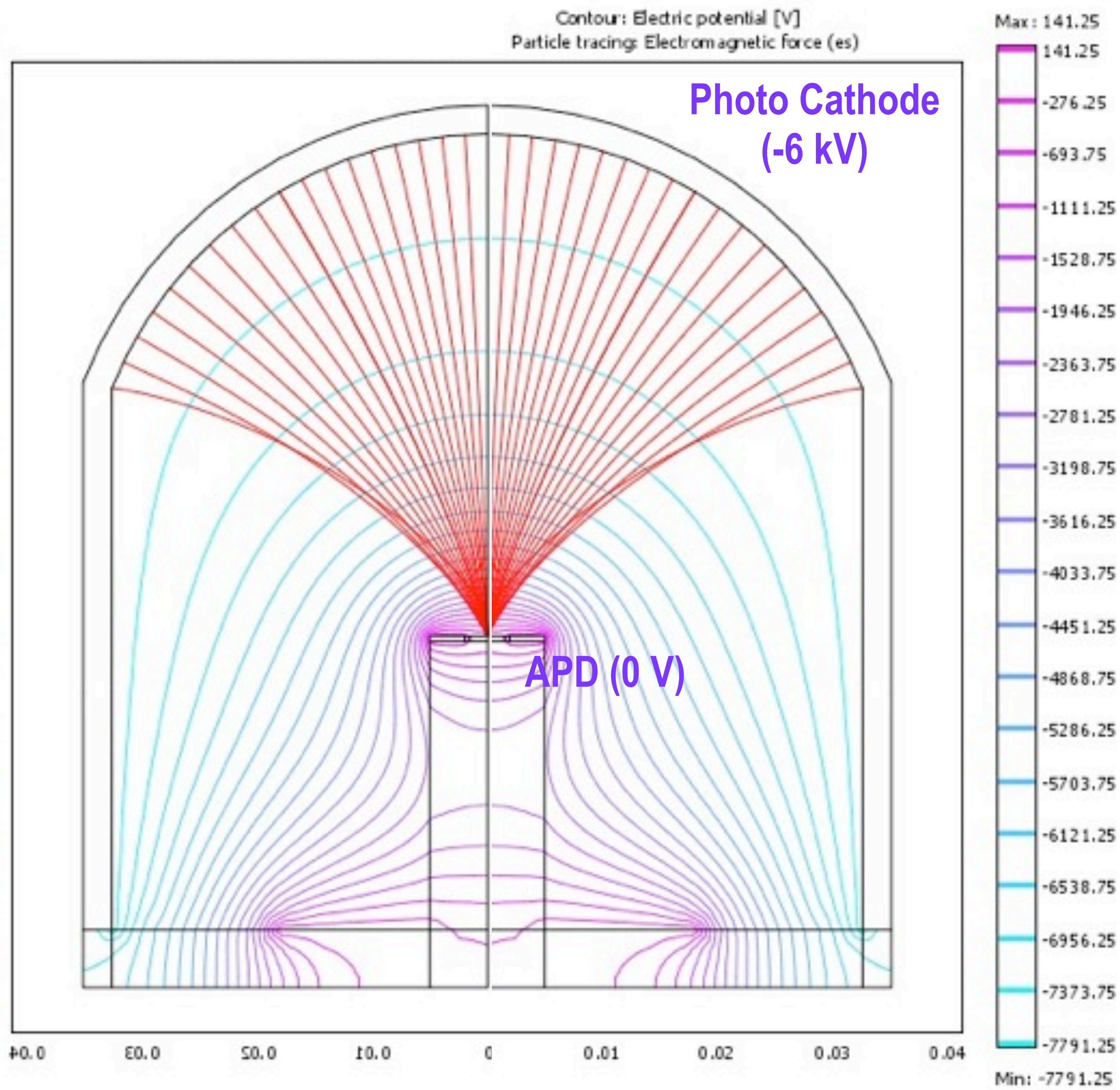
    Nuclear recoils: triplet/singlet ~ 1/3

    Theoretical Identification Power exceeds 10^8 for > 60 photoelectrons (Coakley & McKinsey; Boulay & Hime)

- Difference in ratio of the prompt scintillation (S1) to the drift time-delayed ionization (S2)
- Precise determination of events location in 3D

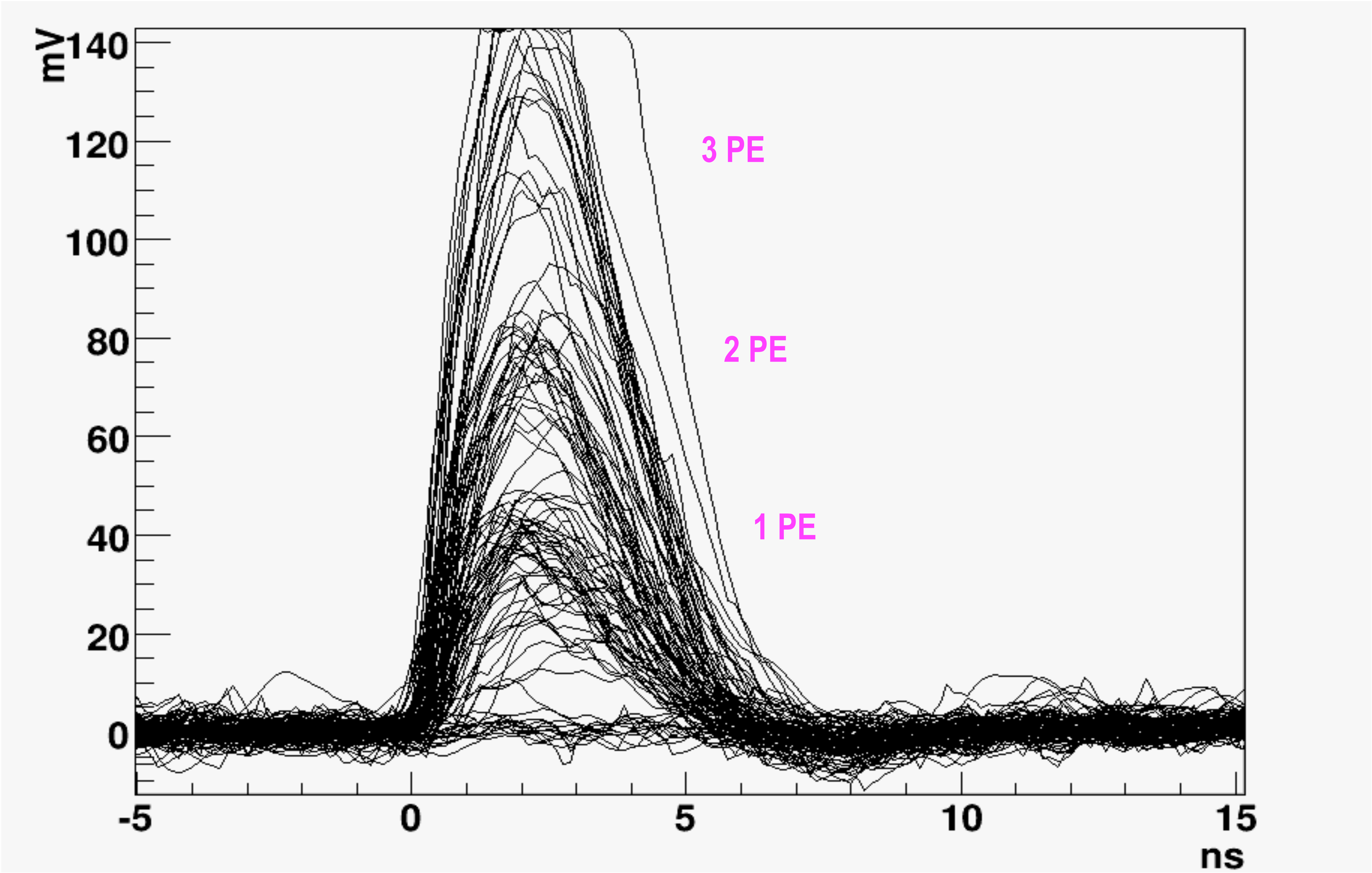
3" QUPID (Quartz Photon Intensifying Detector)



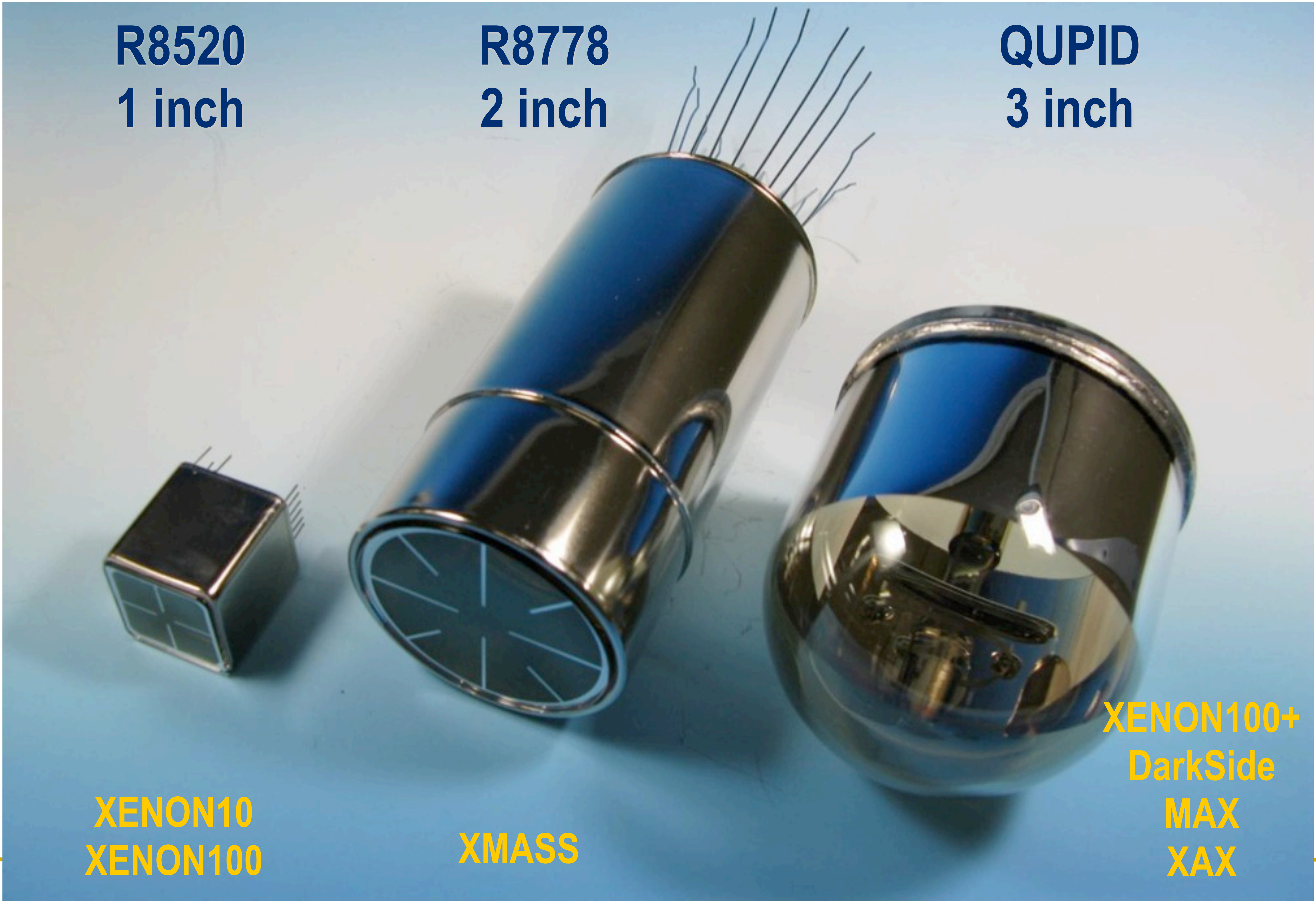


Invented by K. Arisaka & H. Wang in 2007
(US patent pending)

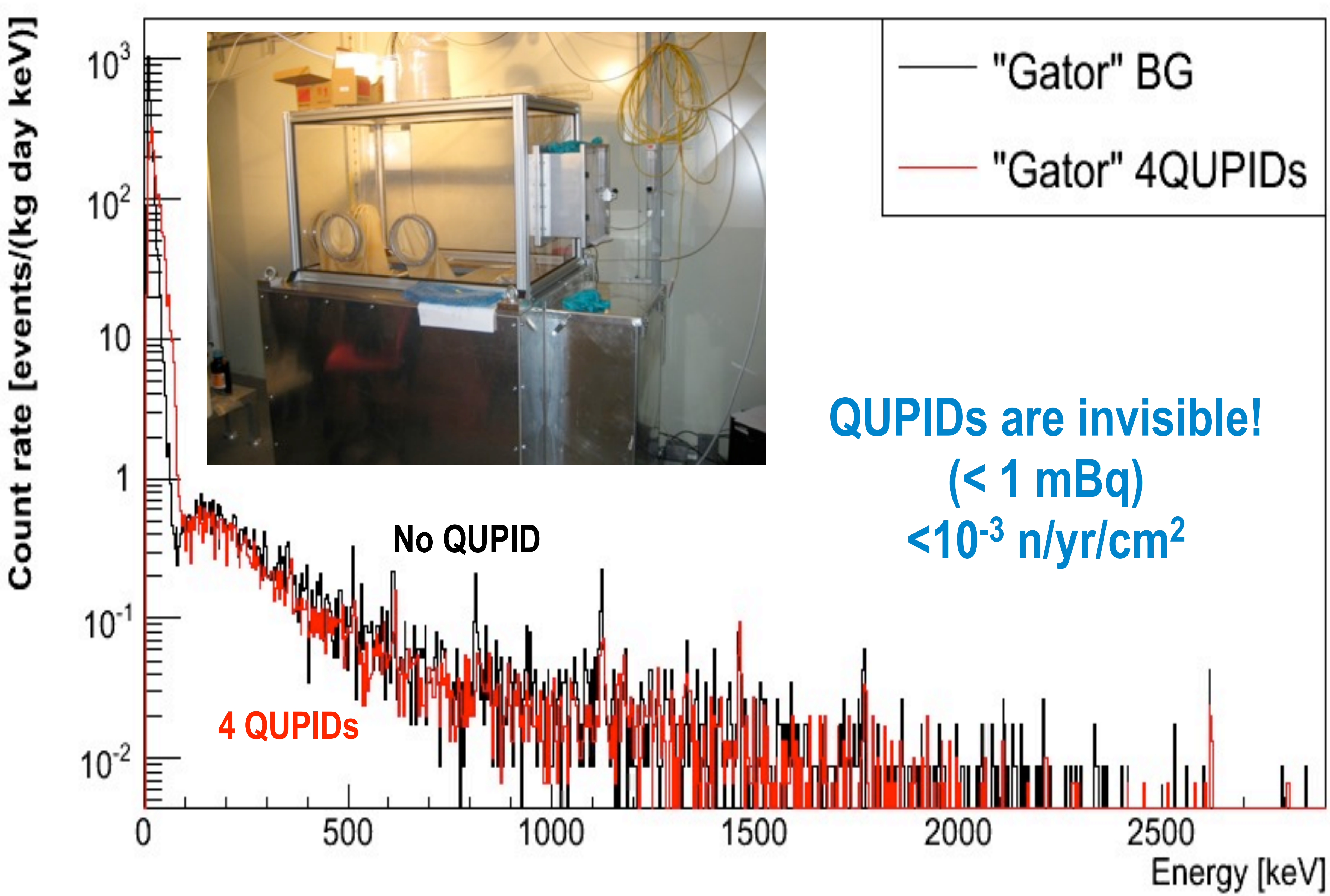
1, 2 and 3 PE Distribution with 2m cable



Comparison of Low-radioactive Photon Detectors from Hamamatsu



Spectrum of QUPIDs and Background (4 QUPIDs x 1 month data)



QUPIDs are invisible!
(< 1 mBq)
$<10^{-3}$ n/yr/cm^2

Princeton Prototype Plant for Industrial Scale Production:
Achieved 0.5 kg/day (depletion >25)
News: NSF funding (NSF PHY-0811186), goal ~10 kg/day in 2010

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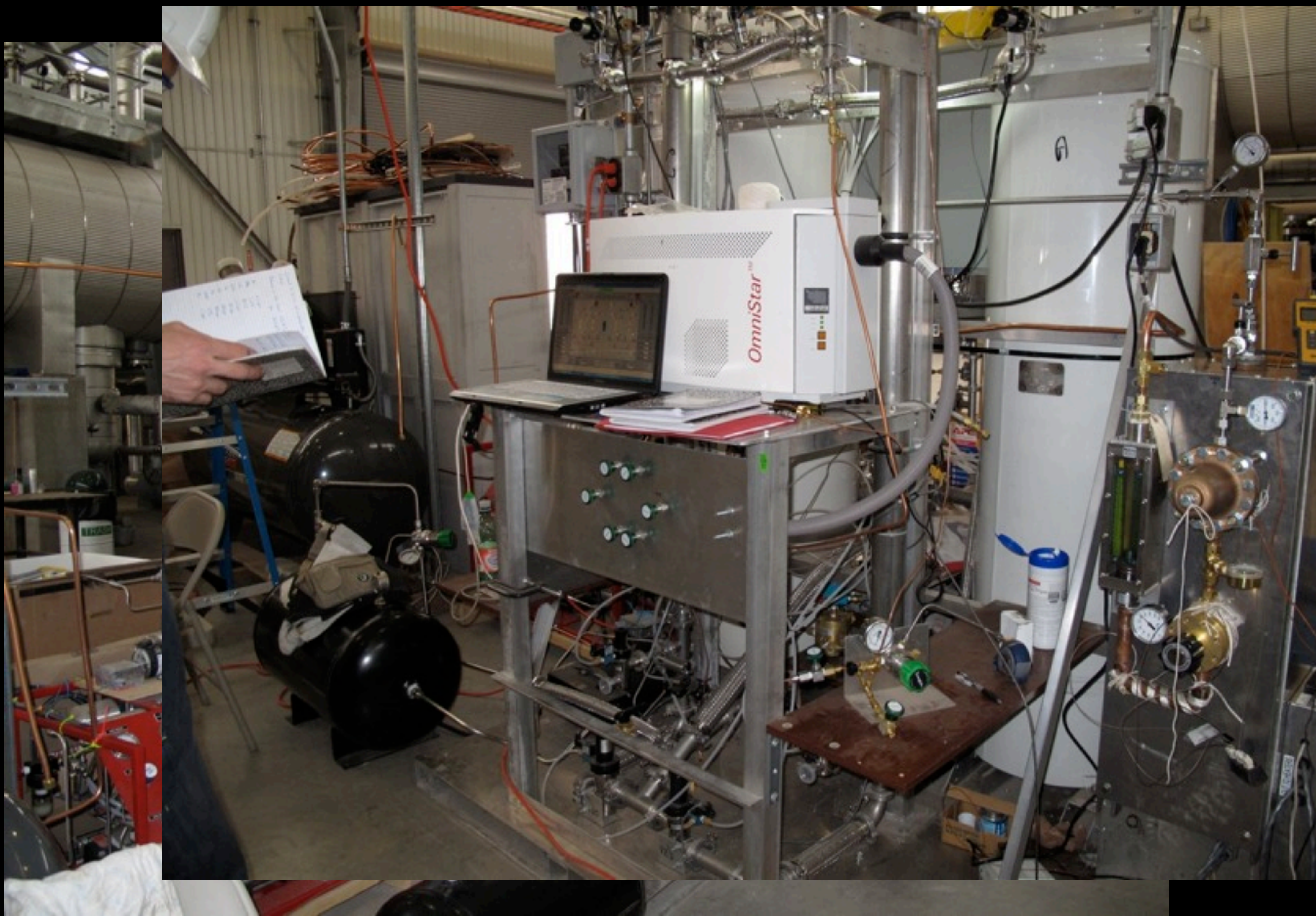

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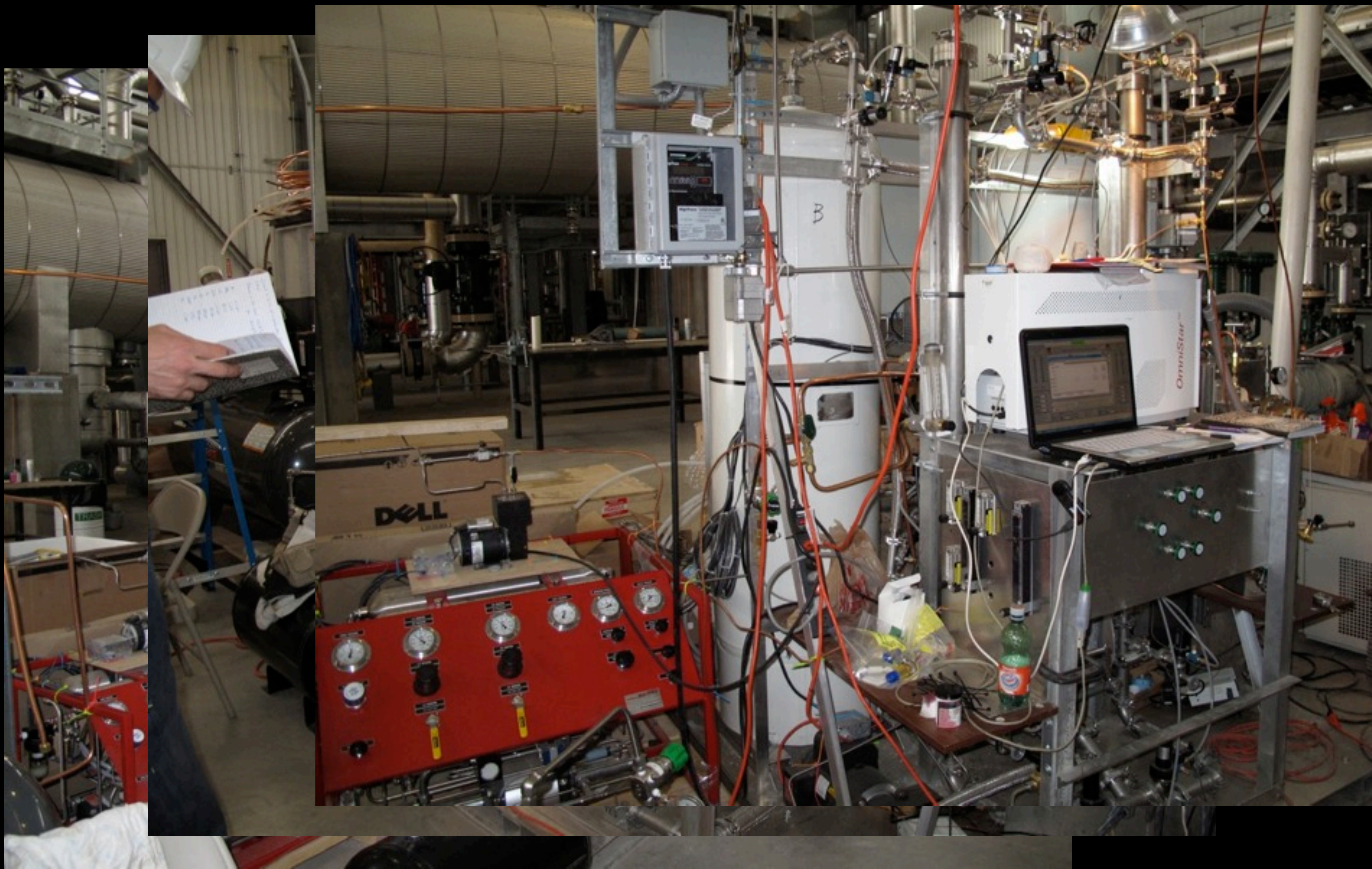
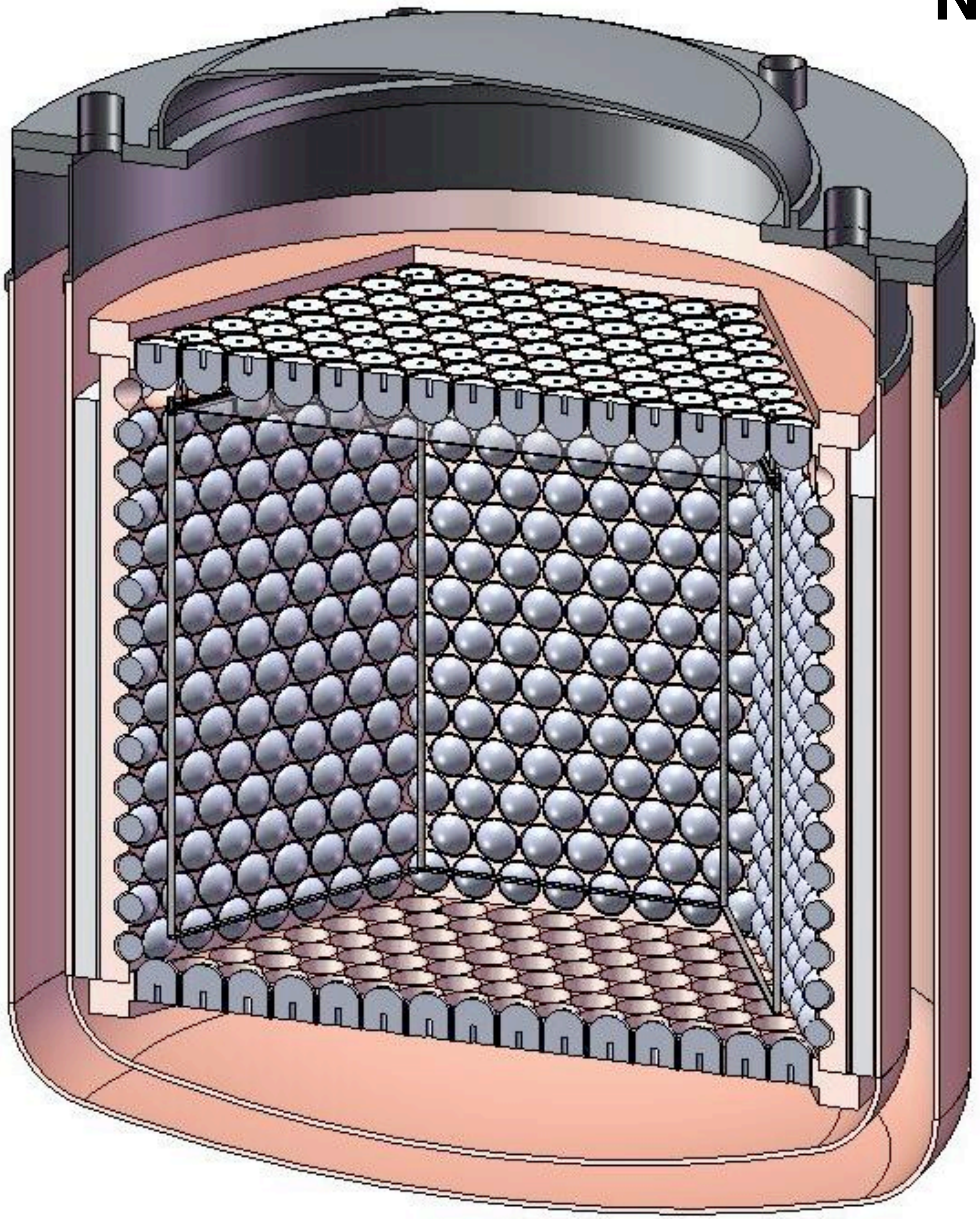
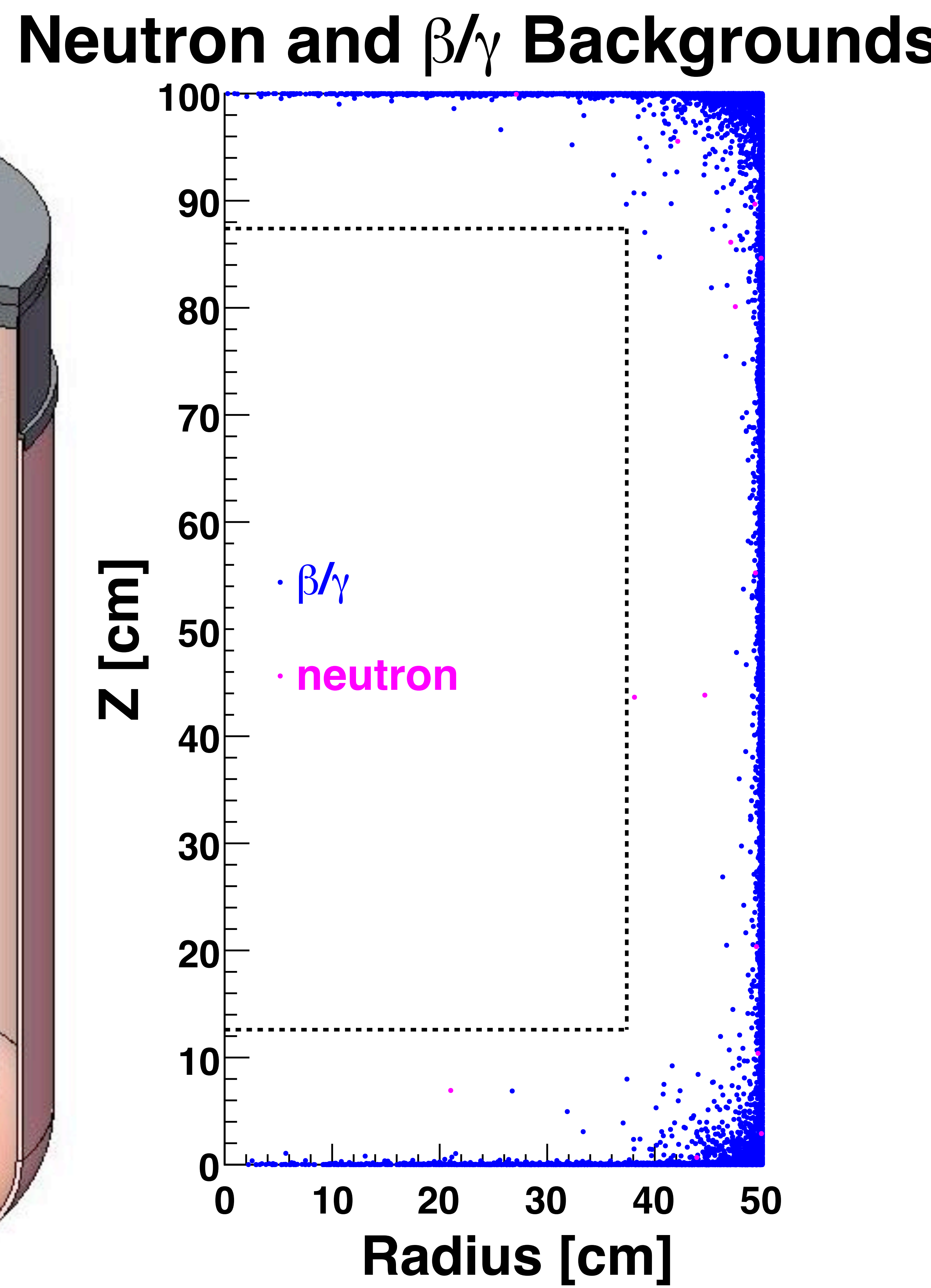






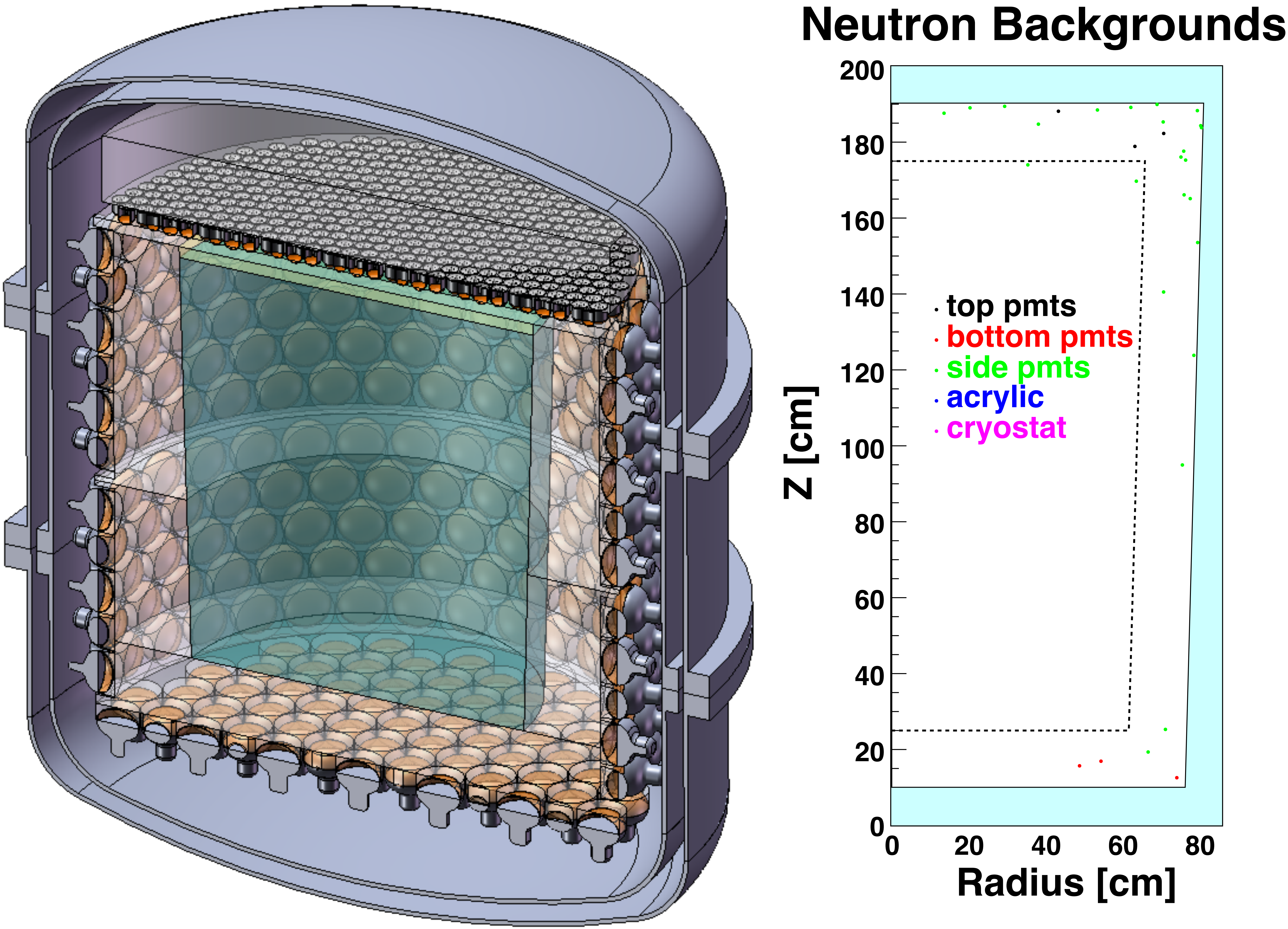
Neutron and β/γ Backgrounds
Z [cm]
Radius [cm]
β/γ
neutron
0 10 20 30 40 50
0 10 20 30 40 50 60 70 80 90 100

Component	Characteristics	Component	Characteristics
Active Liquid Volume Height	90 cm	3" QUPIDs, Top	169
Gas Height	5 cm	3" QUPIDs, Bottom	169
Drift Electric Field	1 kV/cm	3" QUPIDs, Side	630
Extraction Field	5 kV/cm	Mean Photocathode Coverage	60%
Active Volume Diameter	100 cm	Active Xenon Mass	2.4 tons
Cryostat, Height	200 cm	Passive Xenon Mass	0.6 tons
Cryostat, Diameter	180 cm	Cryostat OFHC Cu Mass	6.8 tons
Cooling Power	300 W	Mass of Detector, Full	10 tons

TABLE V: Xenon TPC: detector dimensions and other parameters

Source	Quantity	^{238}U, ^{232}Th [Bq, total]	n [$n$yr]	n after cuts [$(1\,\text{ton}\cdot\text{yr})^{-1}$]	β/γ before cuts [events/(kg·keV·d)]
Water tank steel	100 ton	1200, 400	10^5	$\ll 0.1$	$\ll 10^{-6}$
Water	2500 ton	0.25, 0.1	3×10^5	$\ll 0.1$	$\ll 10^{-6}$
Reentrant tube	25 ton	300, 48	1.3×10^4	$\ll 0.1$	$\ll 10^{-6}$
Cryostat OFHC	6.8 ton	<0.1, <0.1	<15	<0.1	$\ll 10^{-6}$
3" QUPIDs	968	<0.5, <0.4	<45	<0.2	$<5\times10^{-6}$

TABLE VI: Background sources and background budget for the Xe TPC. The sixth column reports the β/γ background before removal with $S2/S1$ discrimination.



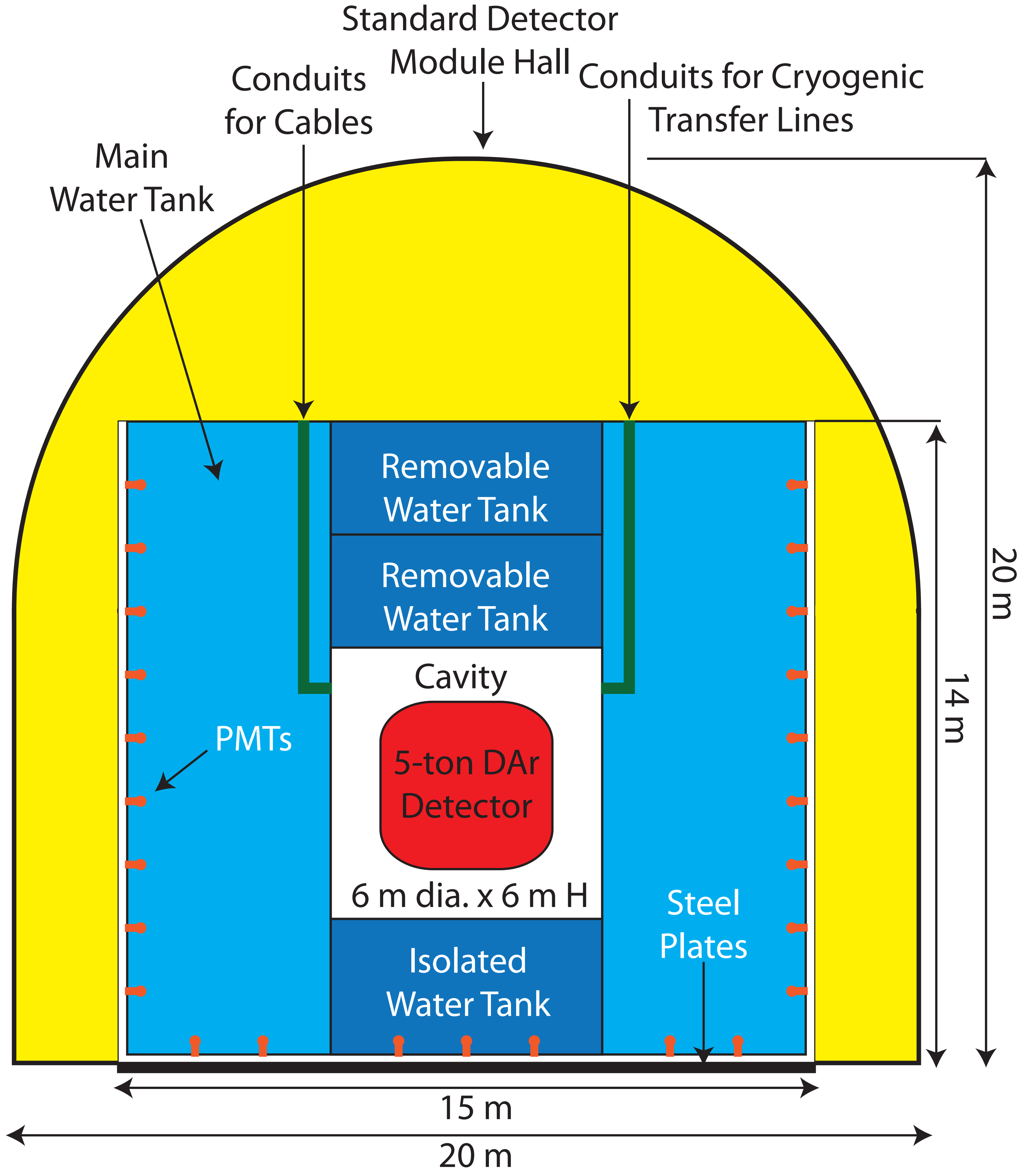
Neutron Backgrounds
Z [cm]
Radius [cm]
0
20
40
60
80
100
120
140
160
180
200
top pmts
bottom pmts
side pmts
acrylic
cryostat

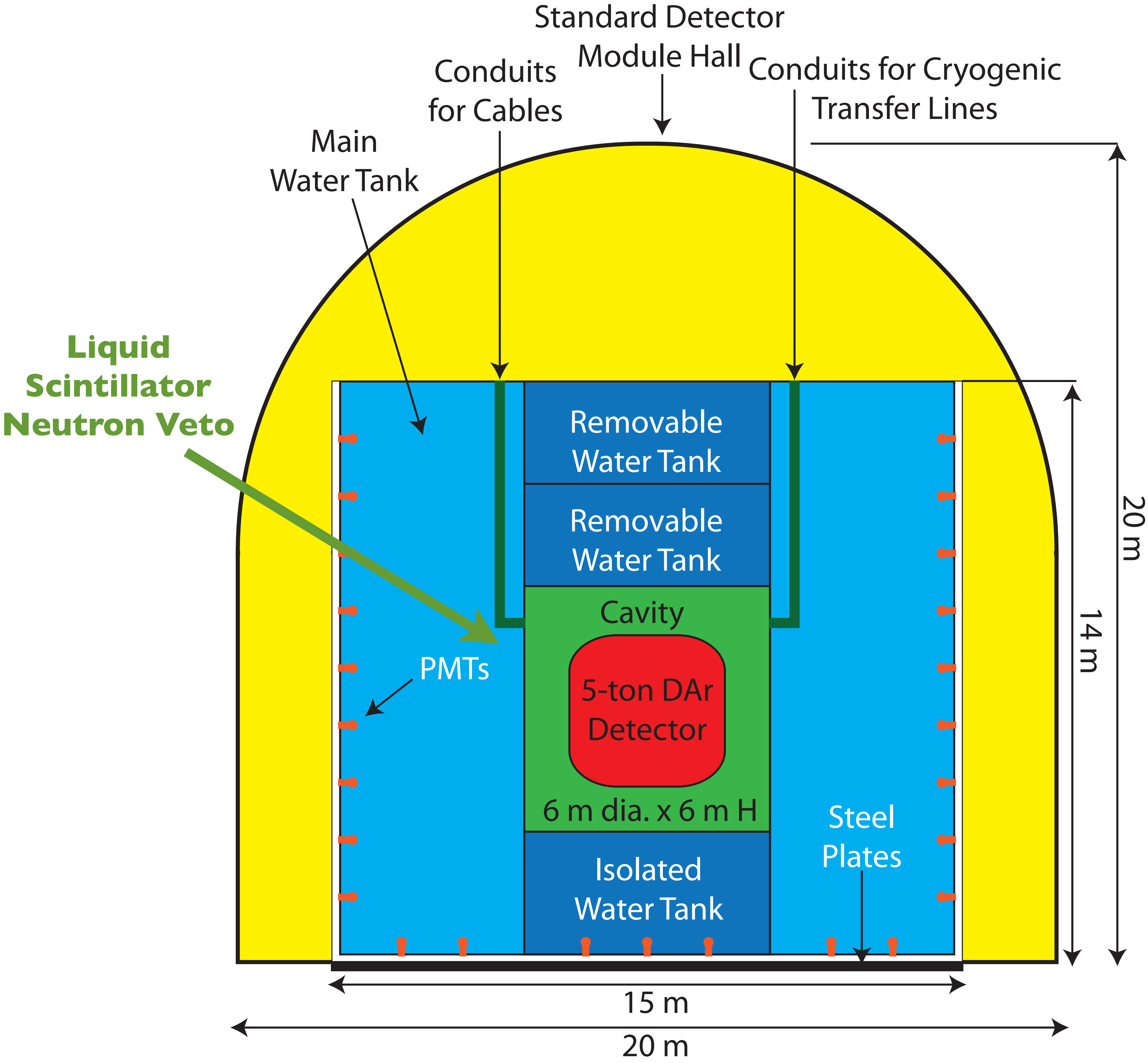
Component	Characteristics	Component	Characteristics
Active Liquid Volume Height	180 cm	3" QUPIDs, Top	745
Gas Height	5 cm	8" R5912-MOD02 PMTs, Bottom	109
Drift Electric Field	800 V/cm	8" R5912-MOD02 PMTs, Side	363
Extraction Field	3.8 kV/cm	Mean Photocathode Coverage	60%
Active Volume Diameter, Top	162 cm	Depleted Argon Mass	5 tons
Active Volume Diameter, Bottom	152 cm	Acrylic Mass	10 tons
Acrylic Minimum Thickness	40 cm	Cryostat Steel Mass	20 tons
Cryostat, Height	380 cm	Cooling Argon Mass	~10 tons
Cryostat, Diameter	366 cm	Mass of Detector, Full	55 tons
Cooling Power	440 W		

TABLE III: Depleted argon TPC: detector dimensions and other parameters

Source	Quantity	^{238}U, ^{232}Th [Bq, total]	n [n/yr]	n after cuts [(12 ton·yr)$^{-1}$]	β/γ before cuts [ev/(kg·keV·d)]
Water tank steel	100 ton	1200, 400	10^5	$\ll$0.1	$\ll 10^{-5}$
Water	2500 ton	0.25, 0.1*	2.5×10^5	$\ll$0.1	$\ll 10^{-5}$
Reentrant tube steel	25 ton	300, 48	1.3×10^4	$\ll$0.1	2×10^{-5}
Cryostat steel	20 ton	240, 40	2×10^4	$\ll$0.1	0.2
Vessel acrylic	10 ton	0.1, 0.04	2	$\ll$0.1	0.04
^{39}Ar	5 ton DAr	250**	–	–	10
8" PMTs	472	190, 85	10^5	0.3	3
3" QUPIDs	745	<0.4, <0.3	<35	$\ll$0.1	<0.07

TABLE IV: Background sources and background budget for the DAr TPC. The fifth column reports the β/γ background before any cuts (pulse shape discrimination, $S2/S1$, multiple deposition cuts). *Low energy neutrons from radioactivity in the water do not contribute significantly to the background – the 2.5×10^5 n/yr are high-energy cosmogenics. **Beta decays of ^{39}Ar.


Standard Detector
Module Hall
Conduits
for Cables
Conduits for Cryogenic
Transfer Lines
Main
Water Tank
Removable
Water Tank
Removable
Water Tank
Cavity
PMTs
5-ton DAr
Detector
6 m dia. x 6 m H
Steel
Plates
Isolated
Water Tank
20 m
14 m
15 m
20 m


Standard Detector
Module Hall
Conduits
for Cables
Conduits for Cryogenic
Transfer Lines
Main
Water Tank
Liquid
Scintillator
Neutron Veto
Removable
Water Tank
Removable
Water Tank
Cavity
5-ton DAr
Detector
6 m dia. x 6 m H
PMTs
Steel
Plates
Isolated
Water Tank
20 m
14 m
15 m
20 m

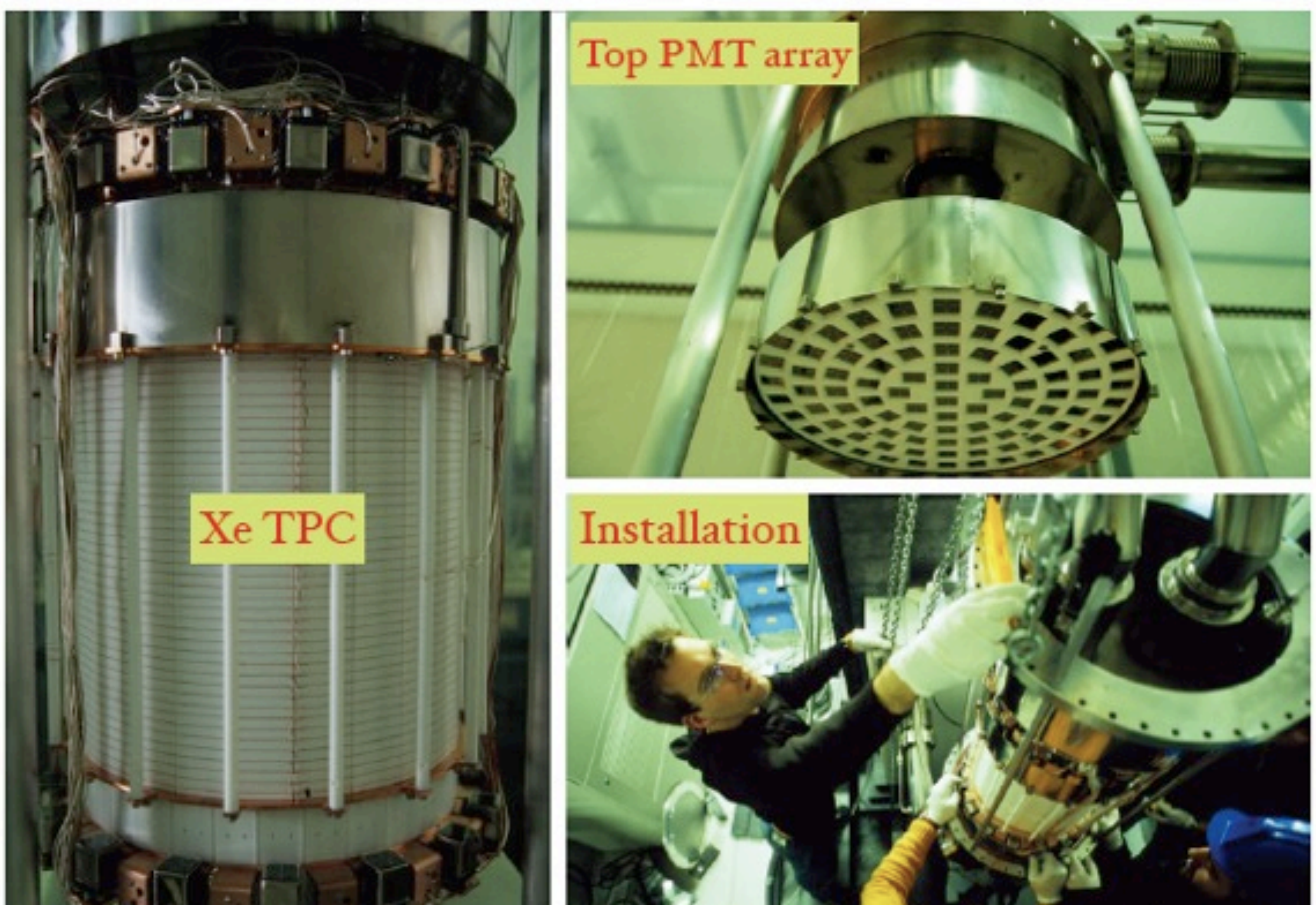
Phase 2

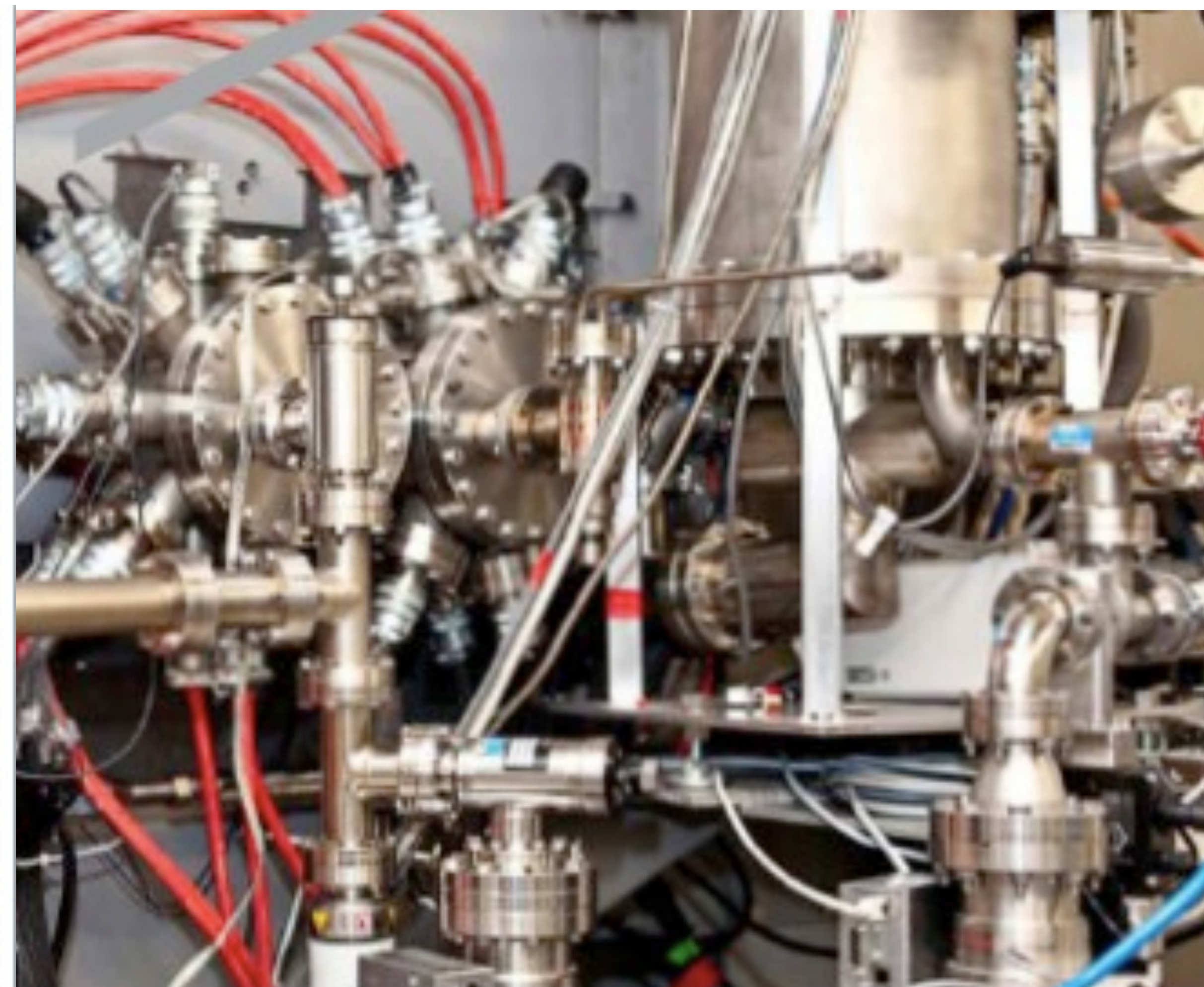
- 10 ton fiducial Xenon
- 50 ton fiducial Argon
- WIMP Dark matter reach extended to $<10^{-48}$ cm^2

The XENON100 Experiment @ LNGS

USA, Switzerland, Italy, Portugal, Germany, France, Japan, China

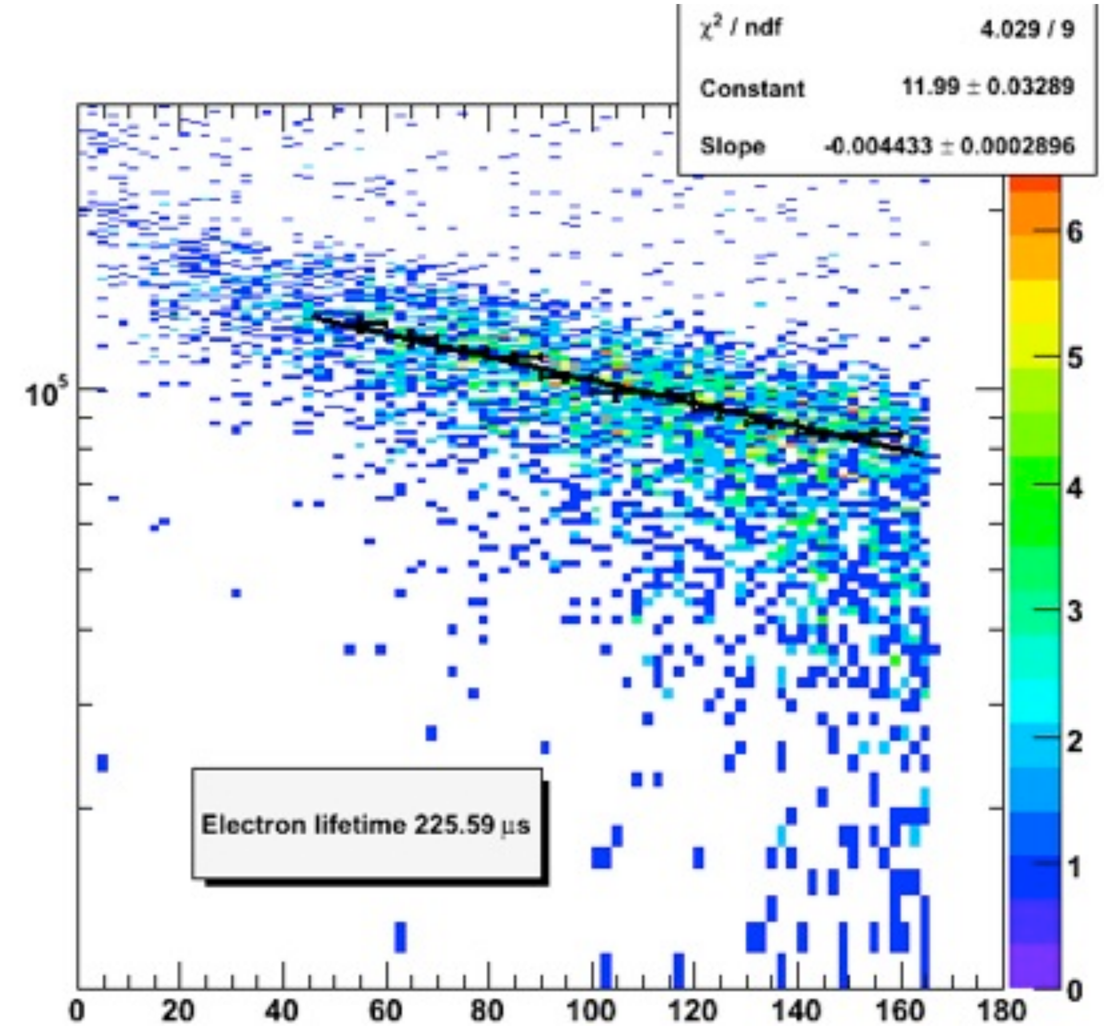
- 170 kg of ultra pure LXe: 70 kg as active target and 100 kg as 4pi LXe scintillation veto
- 200W Pulse Tube Refrigerator for Xe liquefaction: excellent operating temperature stability (<0.1C)
- 30 cm drift gap TPC with two PMT arrays to detect both charge and light signals
- 242 x 1 inch square PMTs with < 1mBq/PMT in U/Th) and high QE (25- 33 %) at 178 nm
- 3D event localization with a few millimeter resolution in X-Y and sub-millimeter in Z
- ~100 x less background than XENON10: low activity materials; LXe veto; improved passive shield

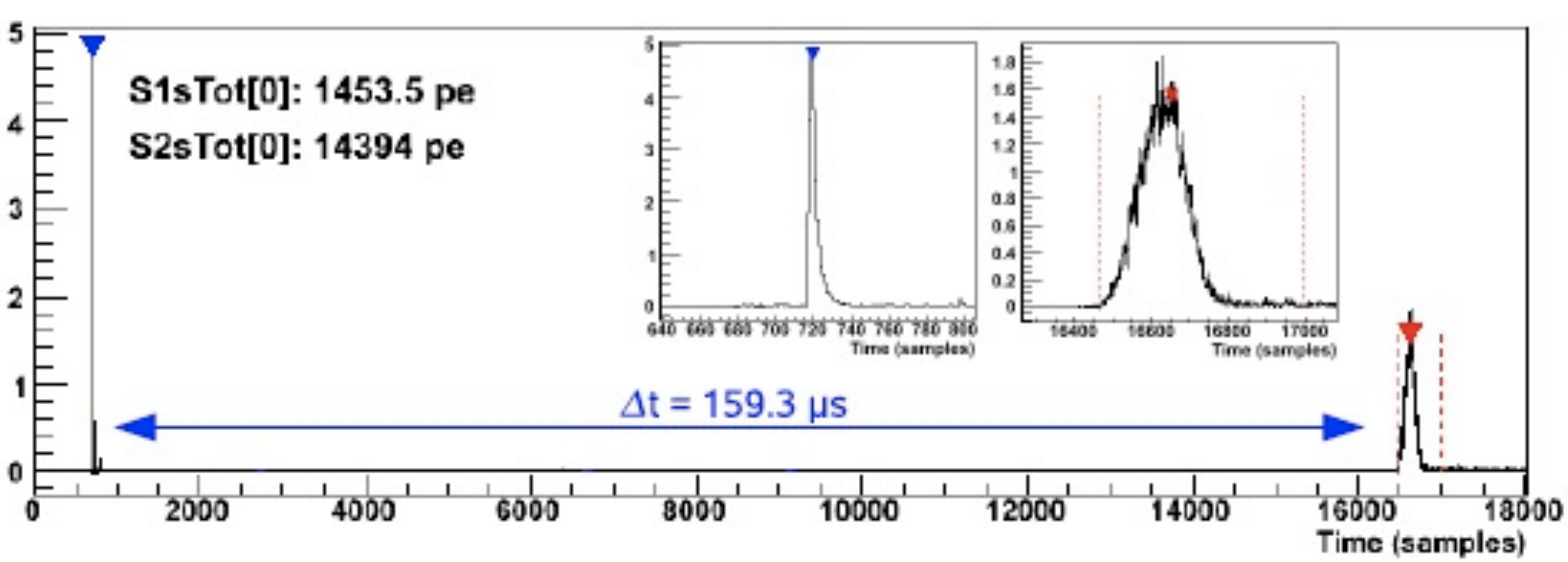




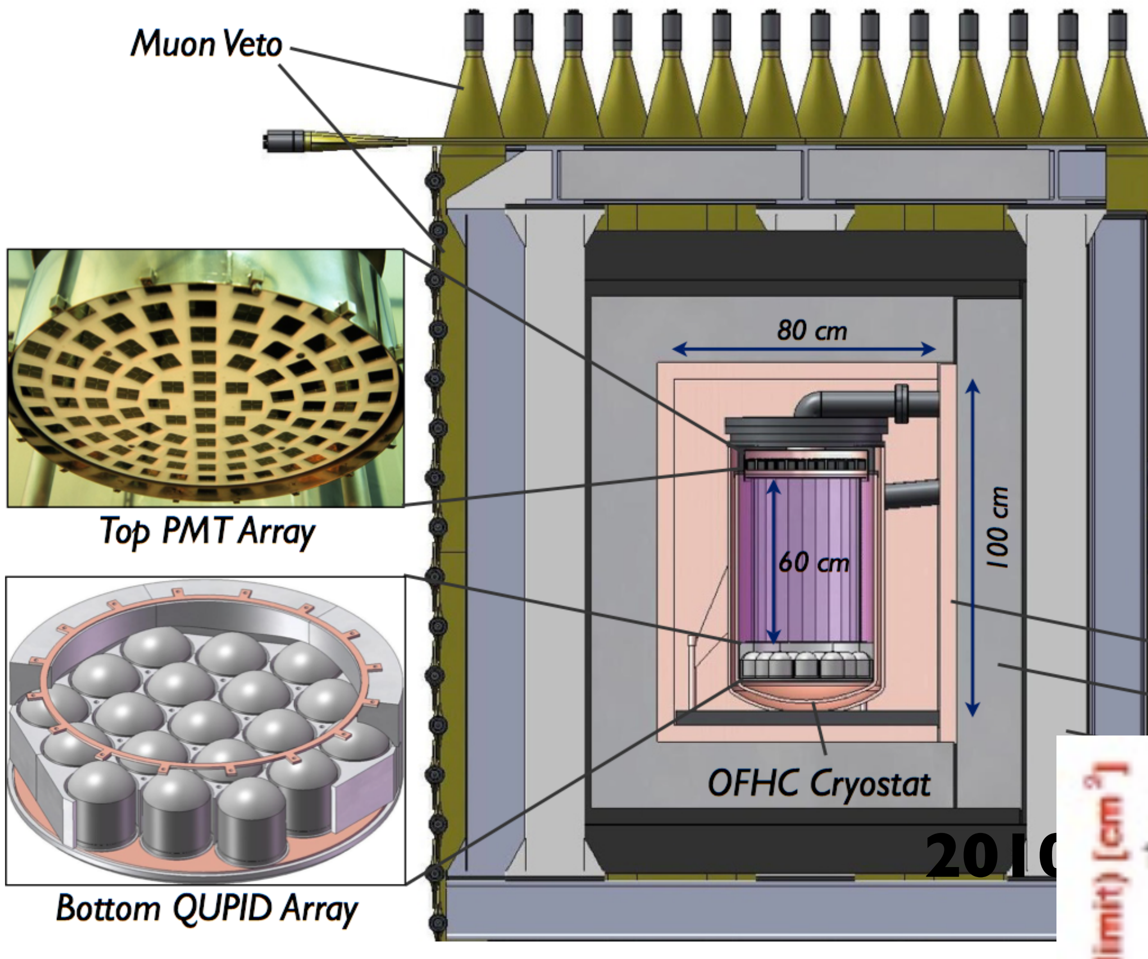
XENON100 Status and Schedule

- Detector filled with low-Kr Xe and operational underground
- Taking Gamma calibration data. Neutron calibration in Nov09
- Light Yield has reached a maximum value of ~4.5 pe/keVee
- Purity allows drift of ionization electrons across entire gap
- Initial background data show a level consistent with predicted
- Schedule: Start DM search before end of 2009.
- Take DM data for > 6 months in 2010

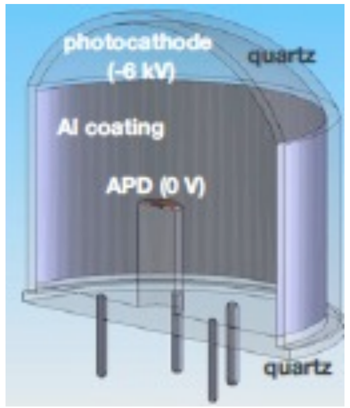


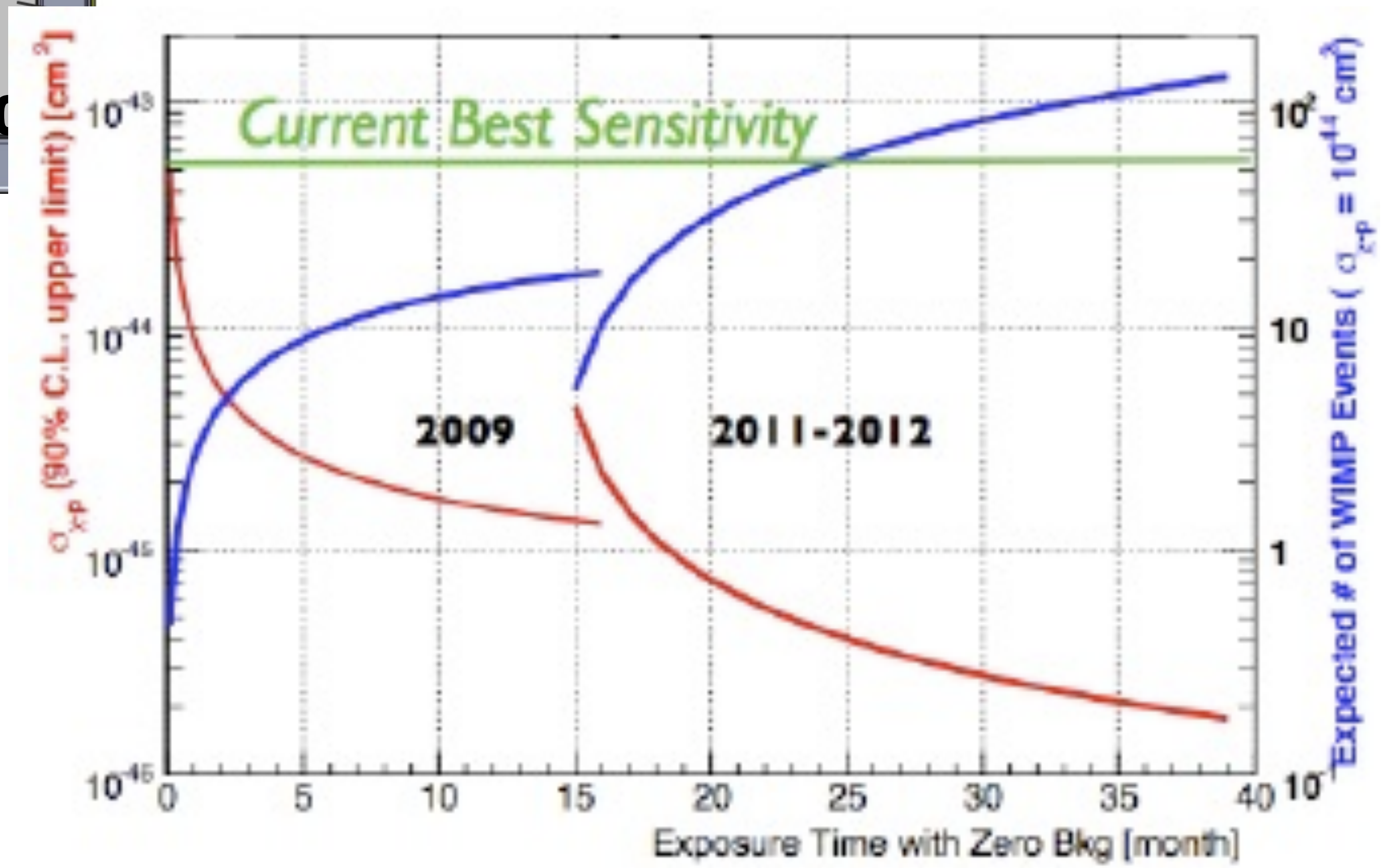


Continuation of the XENON100 Program



- reduce back from PMTs with QUPIDs
- XENON100+ funded by the NSF
- Sensitivity shown is for 100 kg fiducial
- however..much larger TPC in discussion
- test key technologies for further scale-up





WARP 140-kg Detector

The WARP 140-kg detector, currently under commissioning at LNGS

140 kg active target

4π active neutron veto (9 tons Liquid Argon, 300 PMTs)

Active control on nuclide-recoil background, owing to unique feature (LAr active veto)

Achieved 1.5 p.e./kev_{ee}

Problem with malfunctioning HV connetor

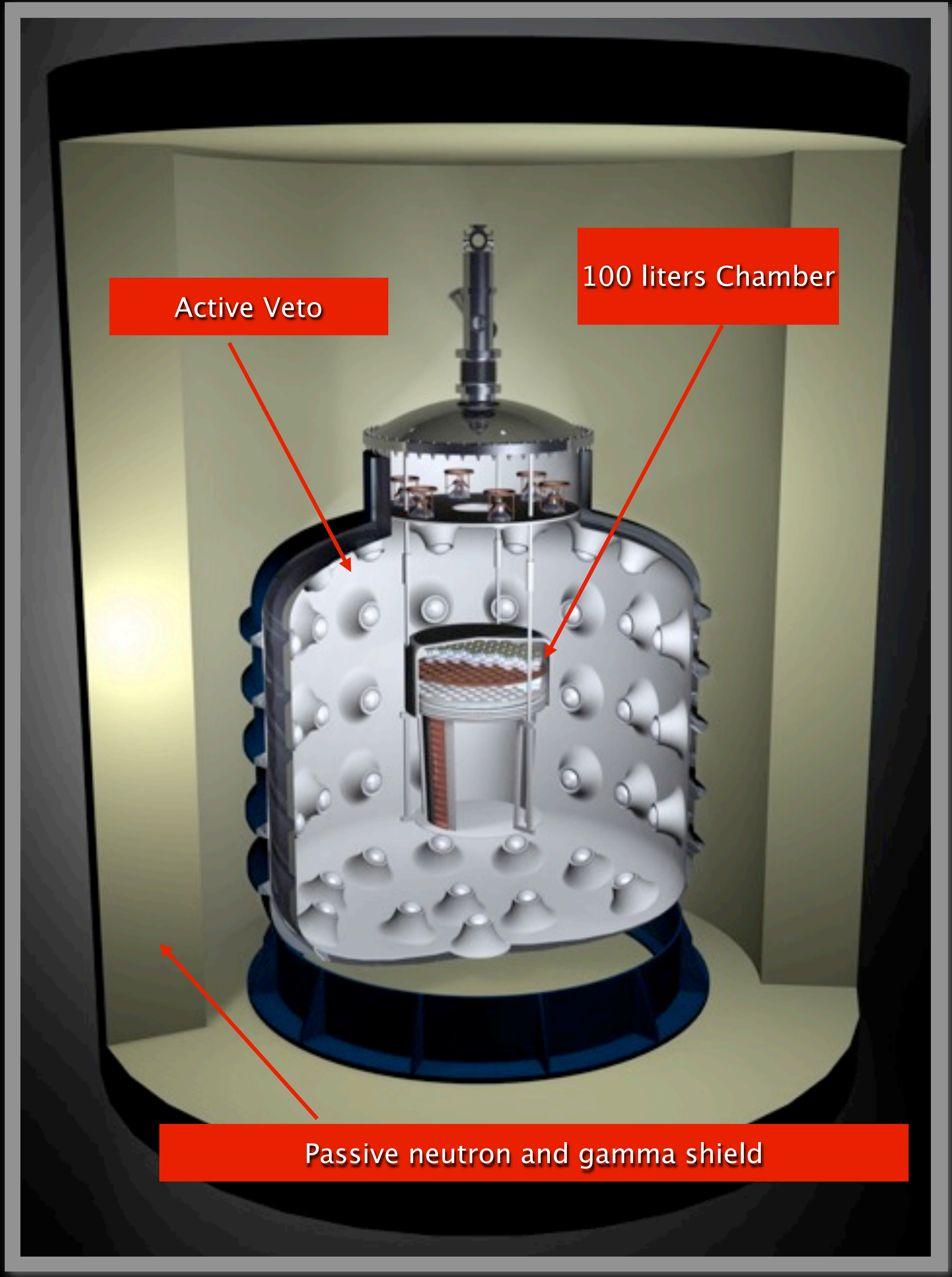
Drained Aug 2009

Restart Dec 2009

Extrapolated threshold 65 keV_r

Extrapolated sensitivity 10^{-44} cm^2

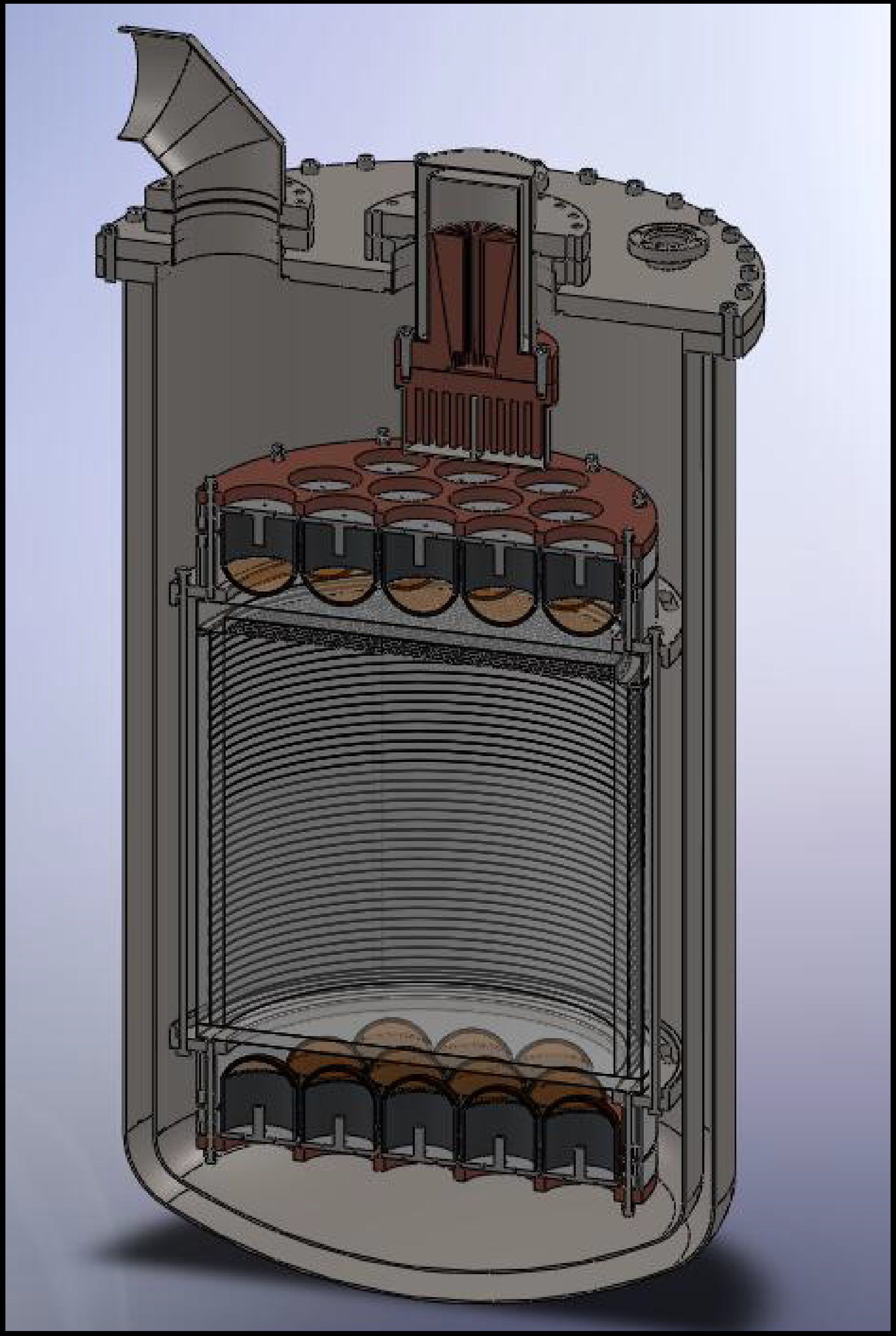
Cryostat designed to allocate a possible 1400 kg detector



DarkSide

First depleted argon detector

QUPIDs
Low background
Two discriminations
25 keV_r threshold
10^{-45} cm^2



Cooperative effort between two collaborations: XENON and DarkSide
Strong international participation

Yes, we can!

Effort open to community
Proposal to be shared on MAX websites at all participating institutions
FNAL site already up!
Grab a copy of the proposal at:
www.fnal.gov/pub/MAX

Cooperative effort between two collaborations: XENON and DarkSide
Strong international participation

Yes, we can!
... resolve our differences and work together

Effort open to community
Proposal to be shared on MAX websites at all participating institutions
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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