Dark Matter 1-ton Era

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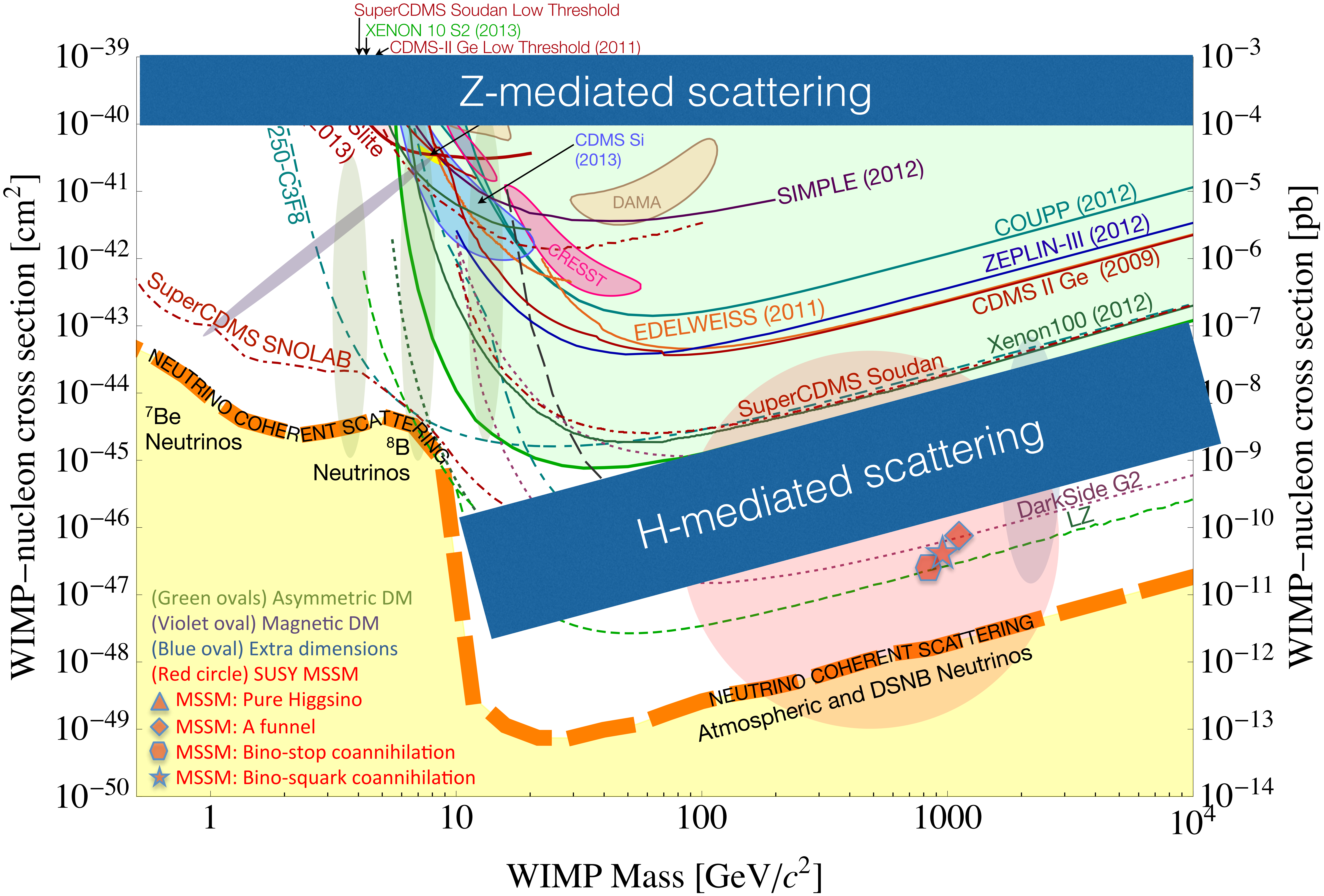
Princeton University

Rome
La Sapienza
May 26, 2014

Figueroa-Feliciano

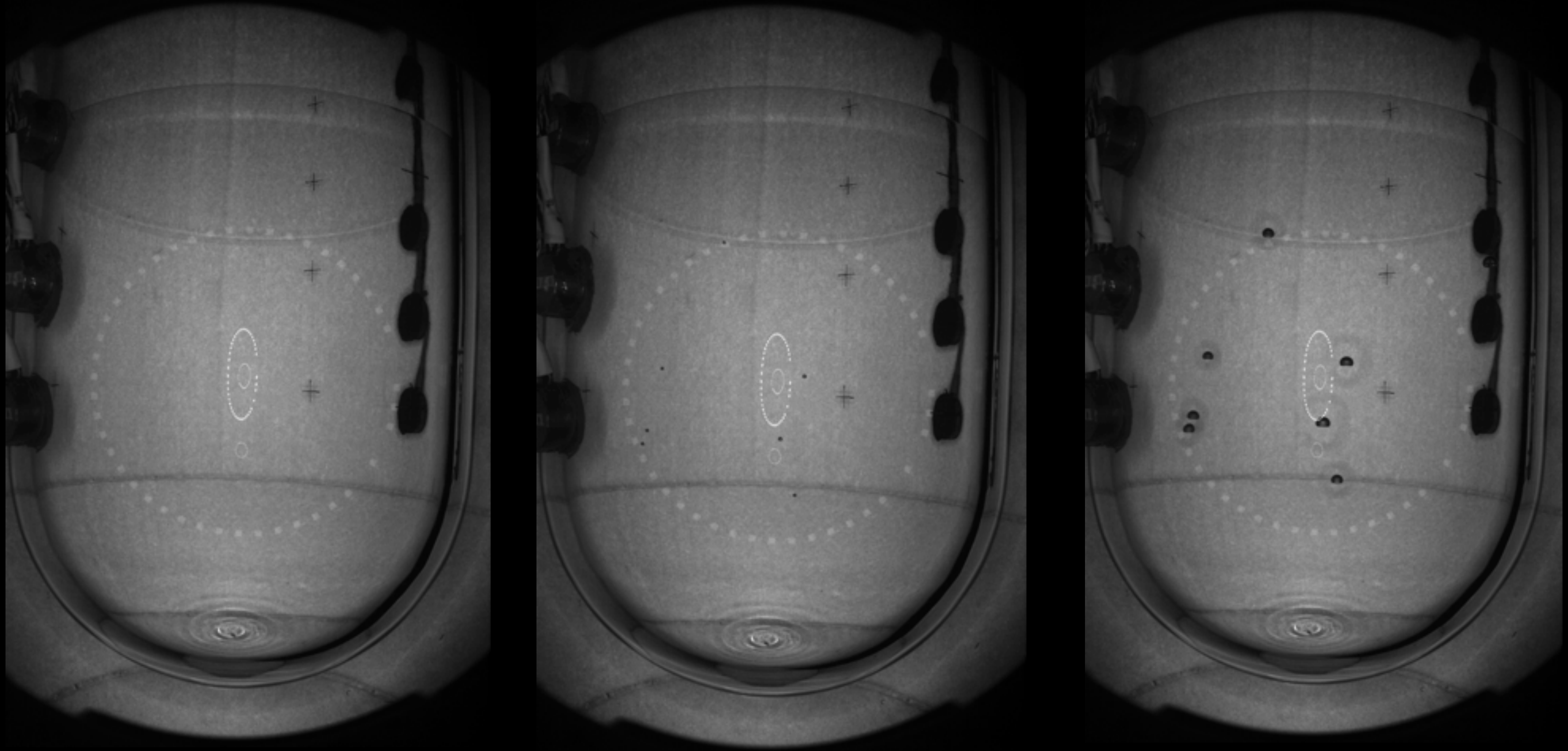


What Techniques

- ~~Si/Ge Bolometers~~
- ~~NaI Scintillating Crystals~~
- Bubble Chambers
- Noble (Xe/Ar) Scintillators
- Noble (Xe/Ar) Scintillating TPC

Remember!

- It only makes sense if you can guarantee background-free condition



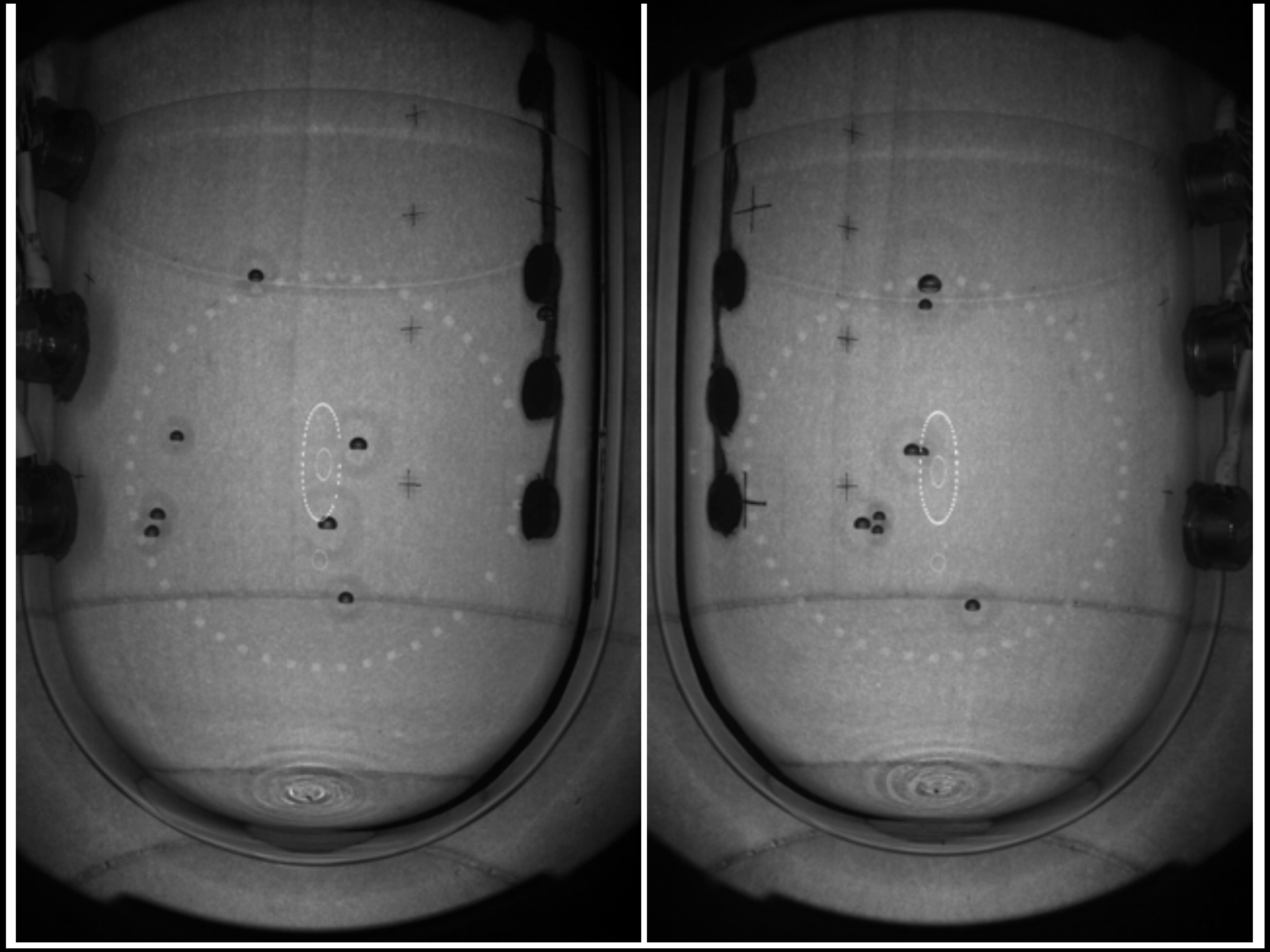
PICO Bubble Chambers and Update on COUPP60

Hugh Lippincott, Fermilab
for the PICO Collaboration
UCLA DM 2014

Why bubble chambers?

- By choosing superheat parameters appropriately (temperature and pressure), bubble chambers are blind to electronic recoils (10^{-10} or better)
- To form a bubble requires two things
  - Enough energy
  - Enough energy density - length scale must be comparable to the critical bubble size
- Electronic recoils never cross the second threshold!

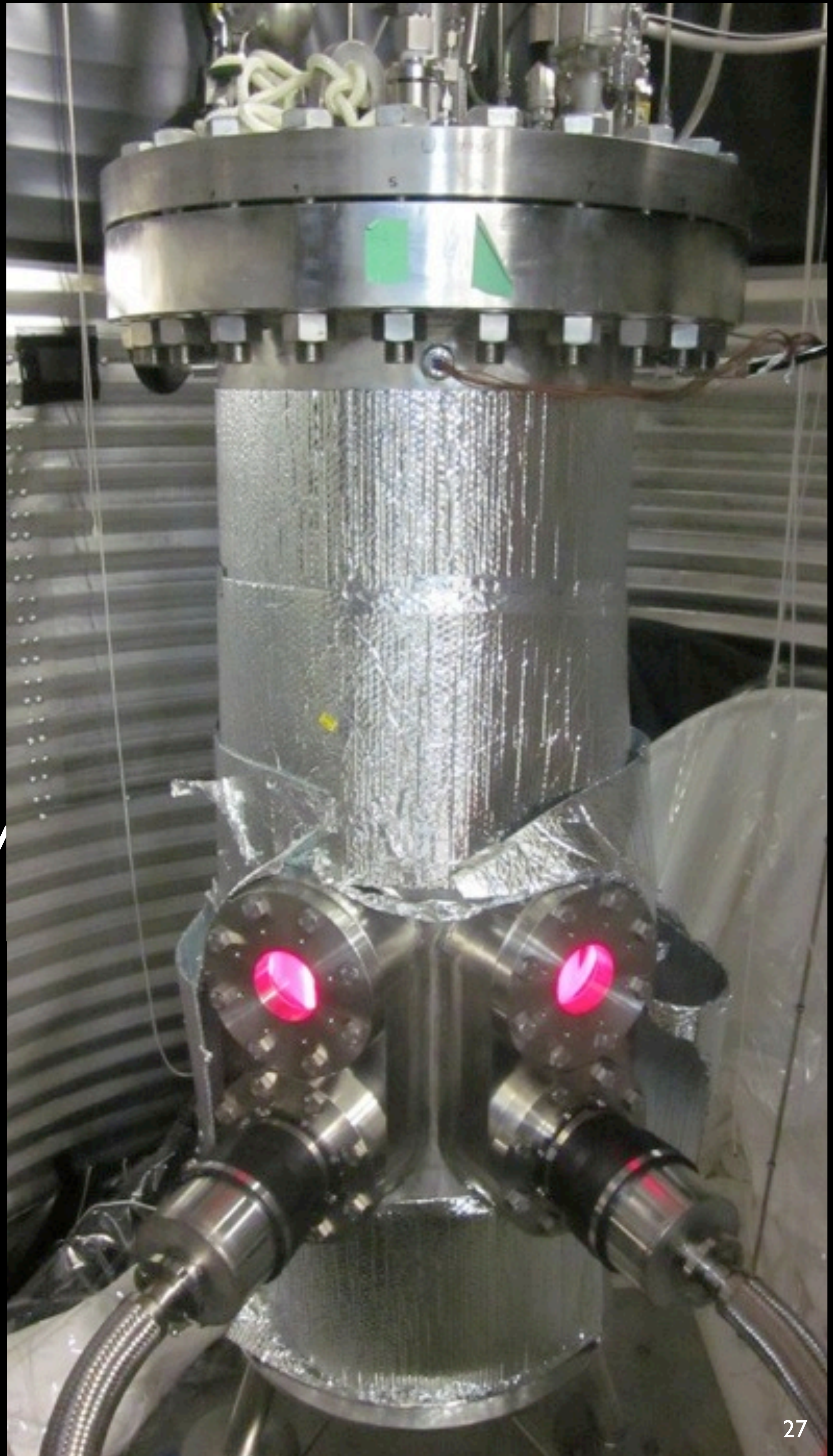
COUPP60



- Collected >3000 kg-days of dark matter search data between 9 and 25 keV threshold
  - Good live fraction > 80% (including >95% over the last month)
  - No darkening

COUPP60 - the data

- Analysis still under development
- Good news: Zero multiple bubbles, no neutrons. Limit on neutron rate is factor 7 below observed rate in COUPP4
- Bad news: Population of events that sound like nuclear recoils but are clearly not WIMPs
  - Silver lining: statistics - we can actually study them in detail

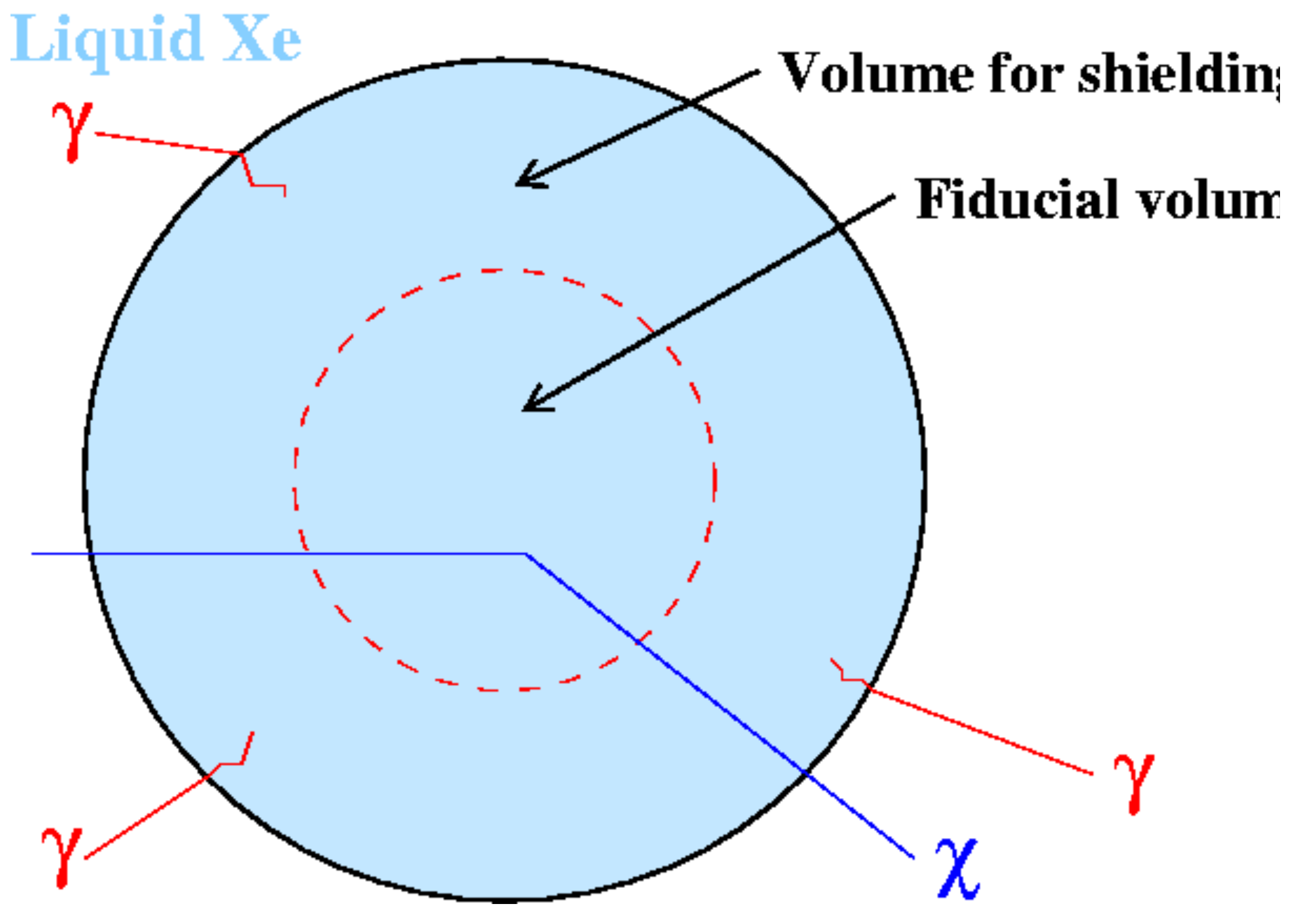


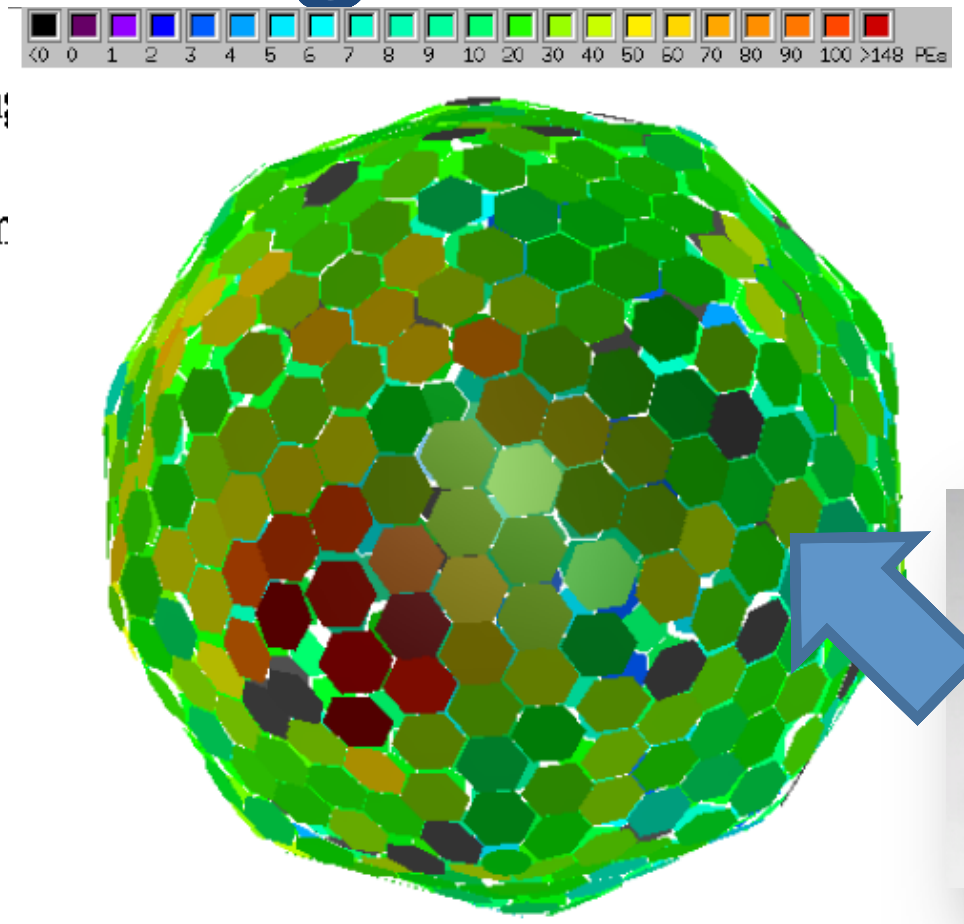
XMASS,
present and future development

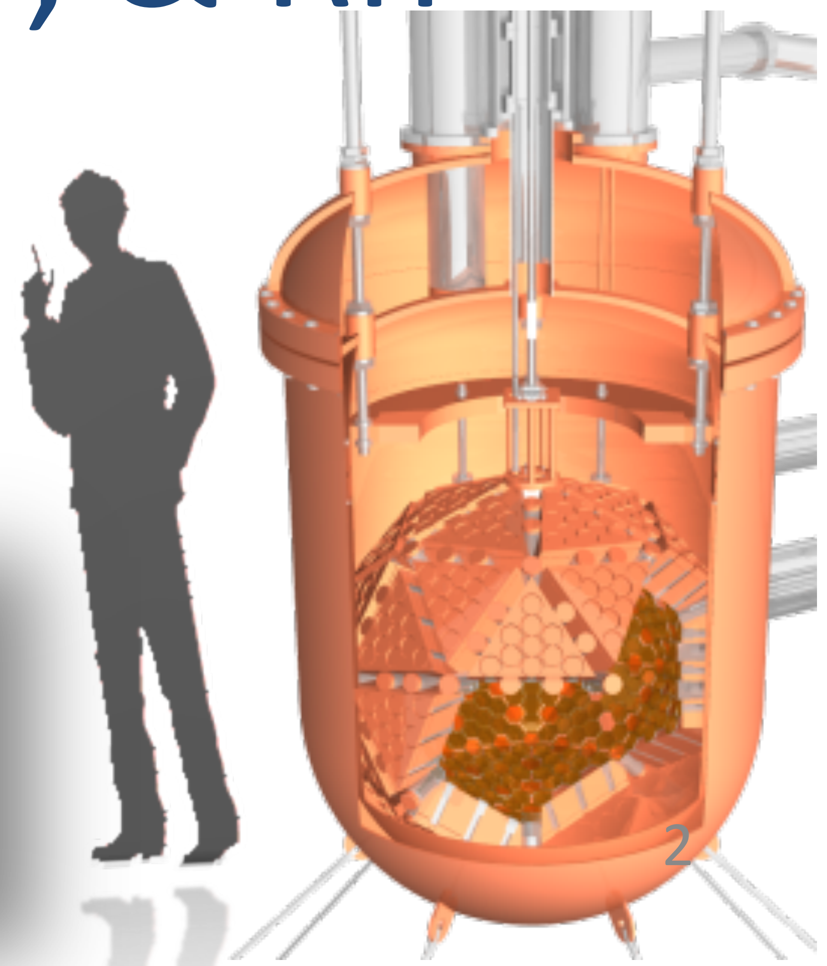
S. Moriyama
Kamioka Observatory,
Institute for Cosmic Ray Research,
The University of Tokyo
28th Feb. 2014, Dark Matter 2014, UCLA

XMASS: LXe single phase detector

- Many interesting physics targets, including EM interactions
  - Dark matter: elastic, inelastic ^{129}Xe, super-WIMPs, ALP, HP, …
  - Solar axions, 2νDEC, SN, and other unexpected signal
- Intrinsic BG of XMASS I: $O(10^{-4})$/kg/keV$_{ee}$/d @40keV dominated by ^{214}Pb, w/o part. ID (arXiv: 1401.4737)
- Larger size is advantageous. Surf. BG, Kr, & Rn

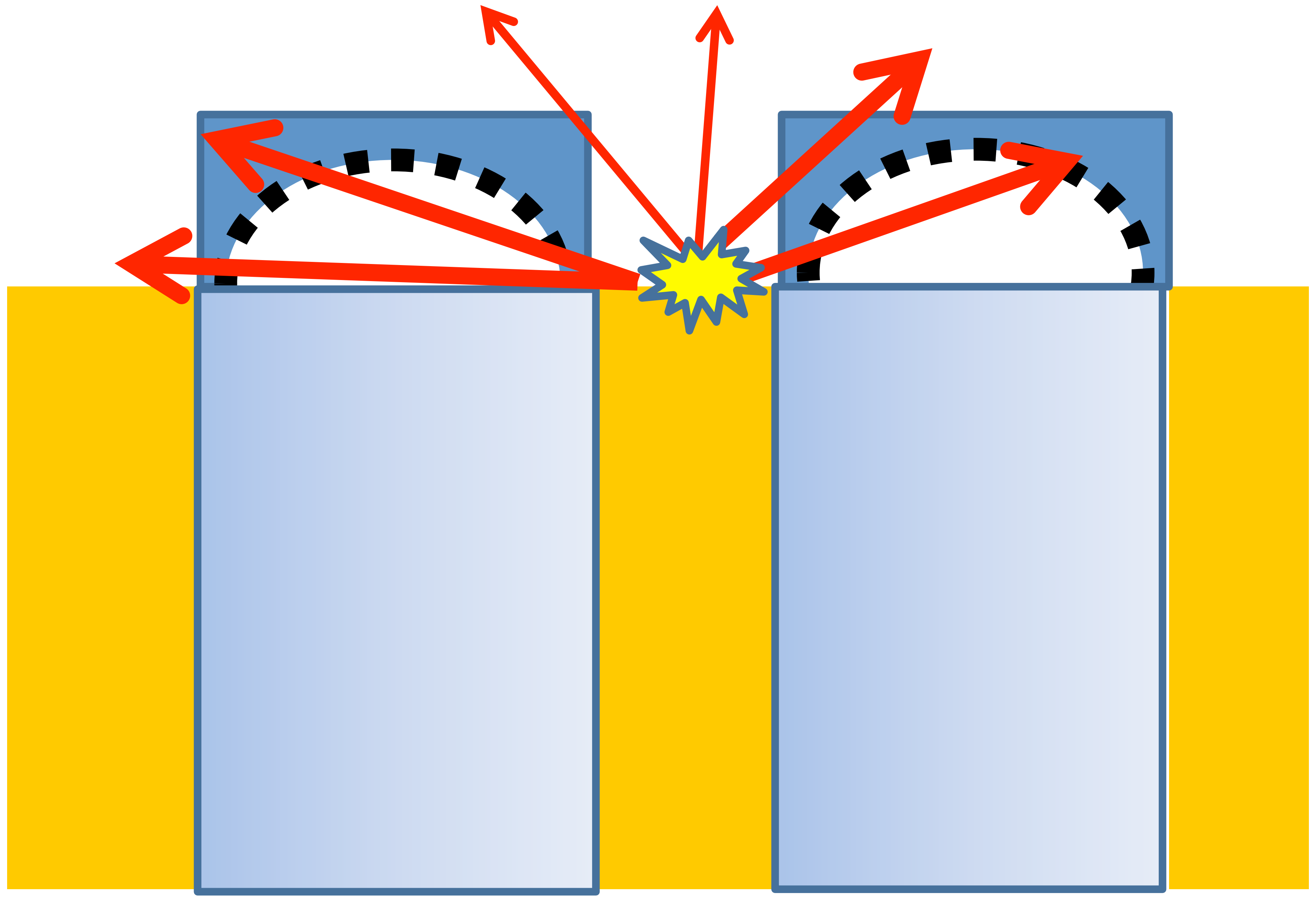
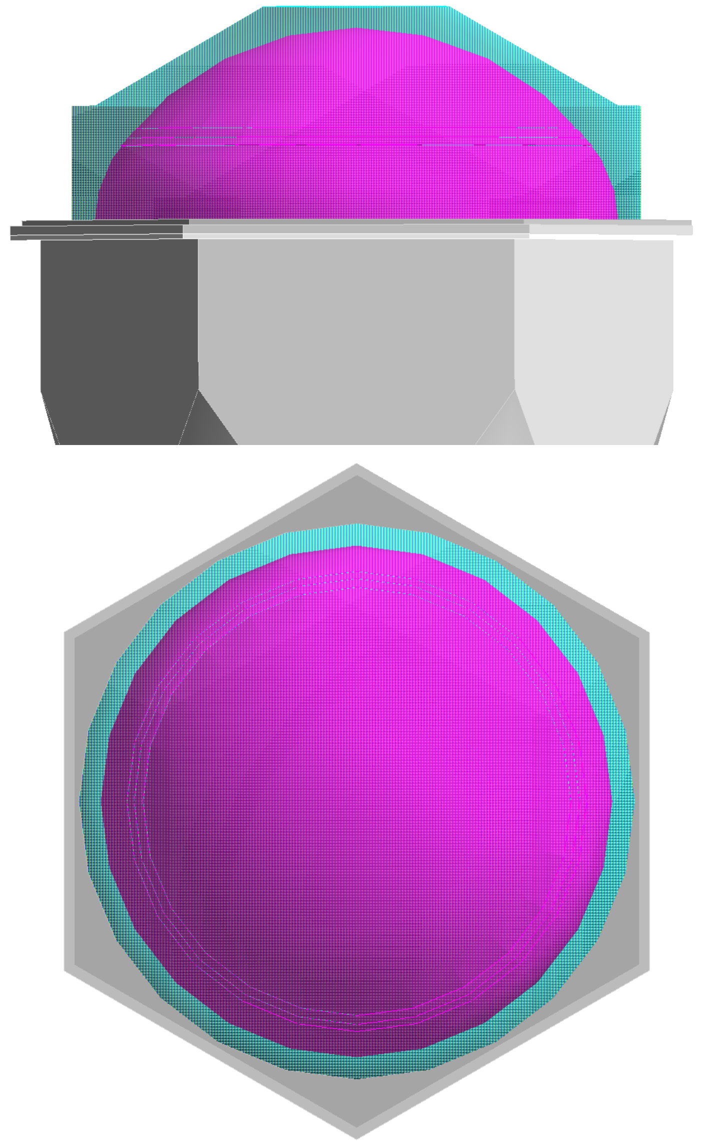






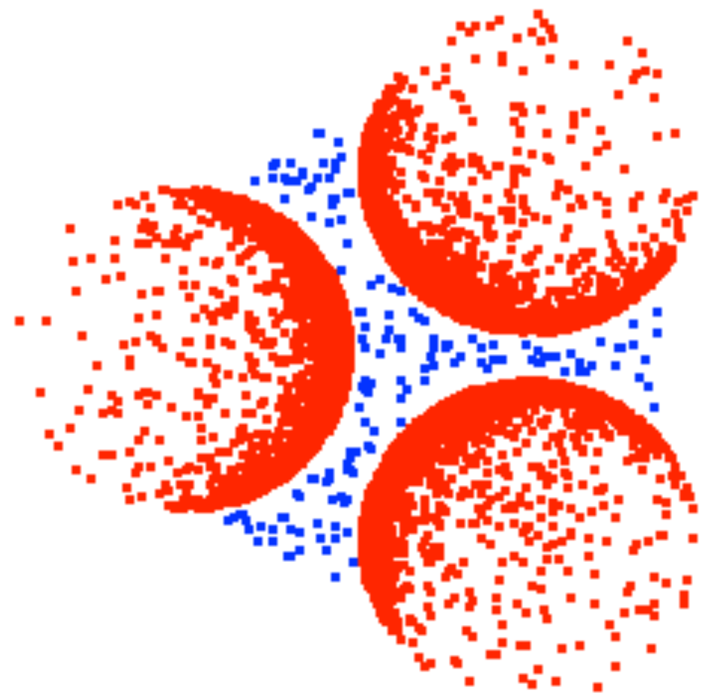
Key component to see the surface

- One of the most simple and straightforward way to see the surface events is the use of PMTs with a convex, dome shape photocathode.
- Similar shape can be seen in many examples.

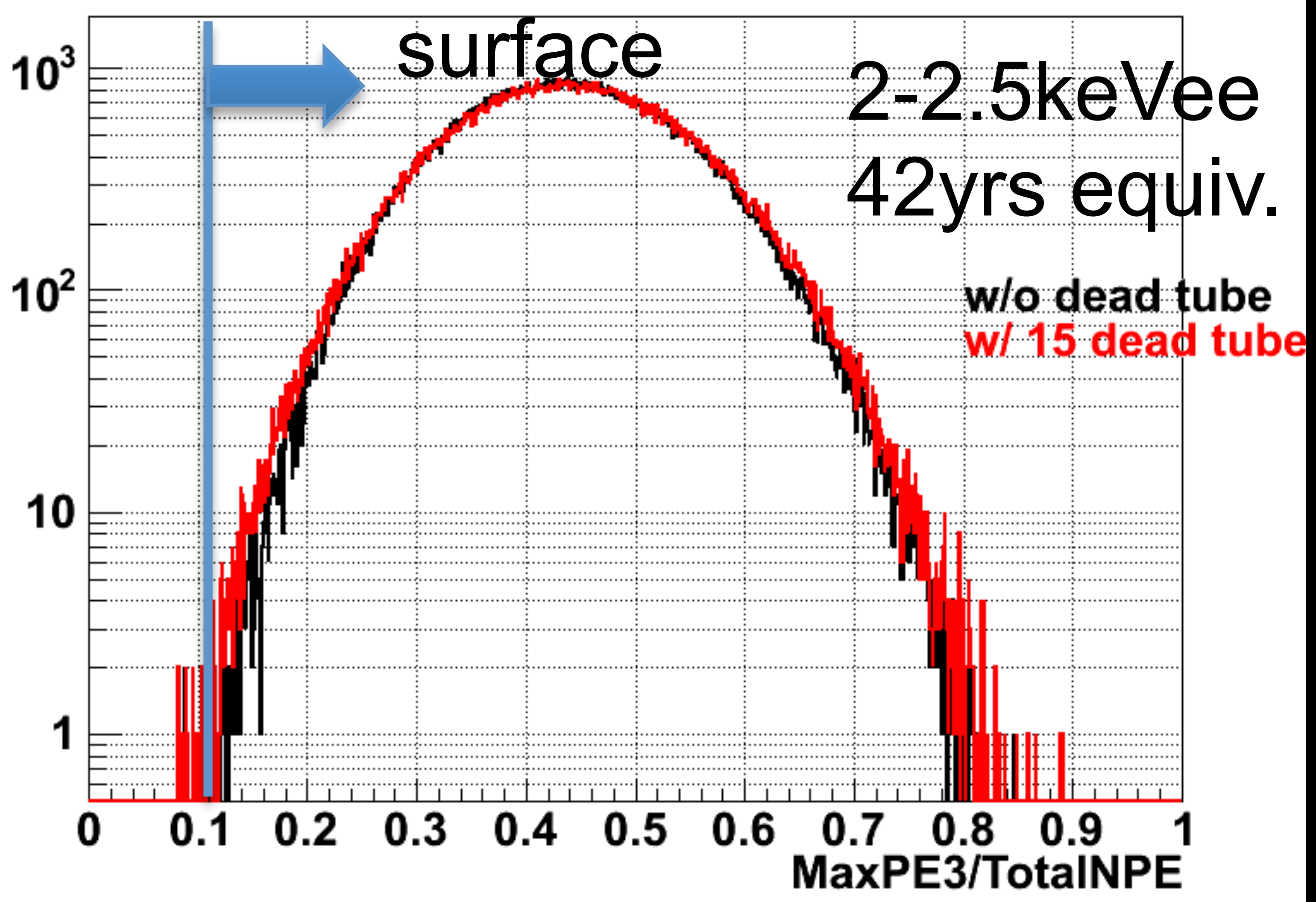




From PMT handbook (HPK)

Identification performance



- 3 PMTs accept 40-50% of total
- One example of surface ID:
  3 PMTs > 10% of total PE
- Assume surface RI 8mBq ^{210}Pb,
  10^7 events ~42y. In 2-2.5keV$_{ee}$
  0.1 events/y w/o dead tube
  0.3 events/y w/ 15 dead tubes



- DM signal efficiency ~ 20% of all volume.

Surface events can be identified and rejected effectively.

Beyond the surface: solar ppν, Kr and Rn

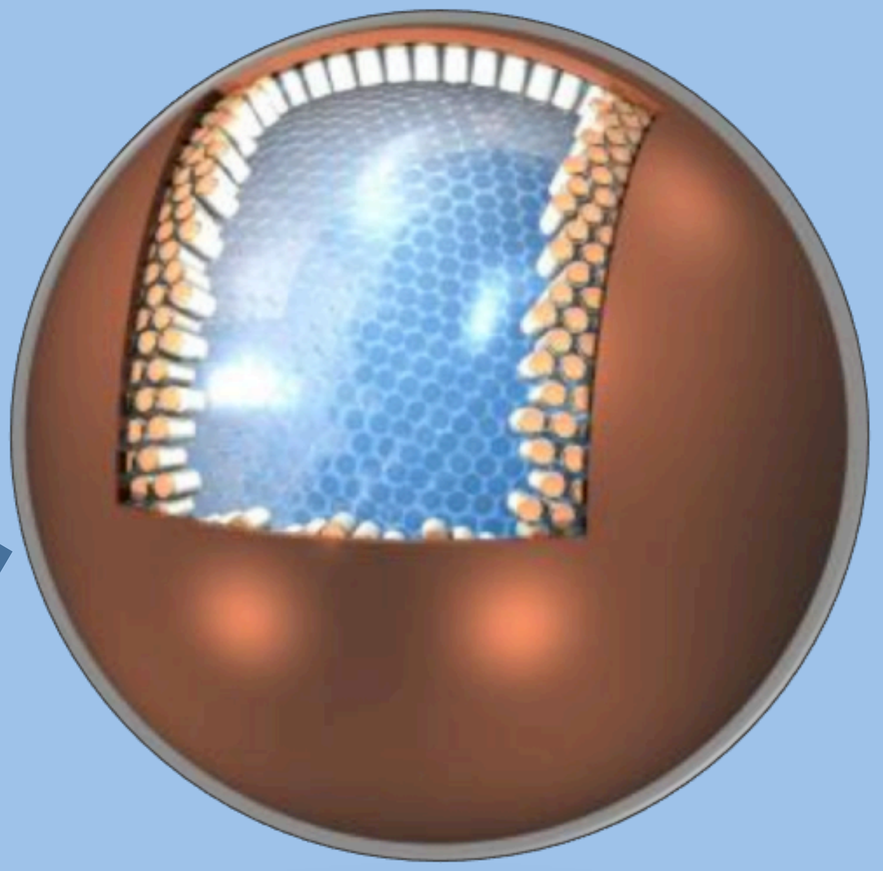
- Internal background, future goal $<10^{-5}$/kg/keV$_{ee}$/d
  - e scat. by solar pp ν ~ 10^{-5}/kg/keV$_{ee}$/d ➔ irreducible
  - ^{212}Pb, $<0.3\mu$Bq/kg ~ 10^{-5}/kg/keV$_{ee}$/d=dru ➔ 1/10
  - ^{85}Kr (Q_{β}=687keV, $\tau_{1/2}$=11yr), 1ppt ~10^{-5}dru ➔ 1/10
  - ^{214}Pb, 10mBq/kg ~ 10^{-4}dru ➔ <1/10
- γ ray and neutron contribution will be evaluated.
- Prediction of these background are accurate and will be taken into account in analyses to search for DM signal. $<\sim 10^{-46}$cm^2 would be searched for.

XMASS in future

XMASS-I

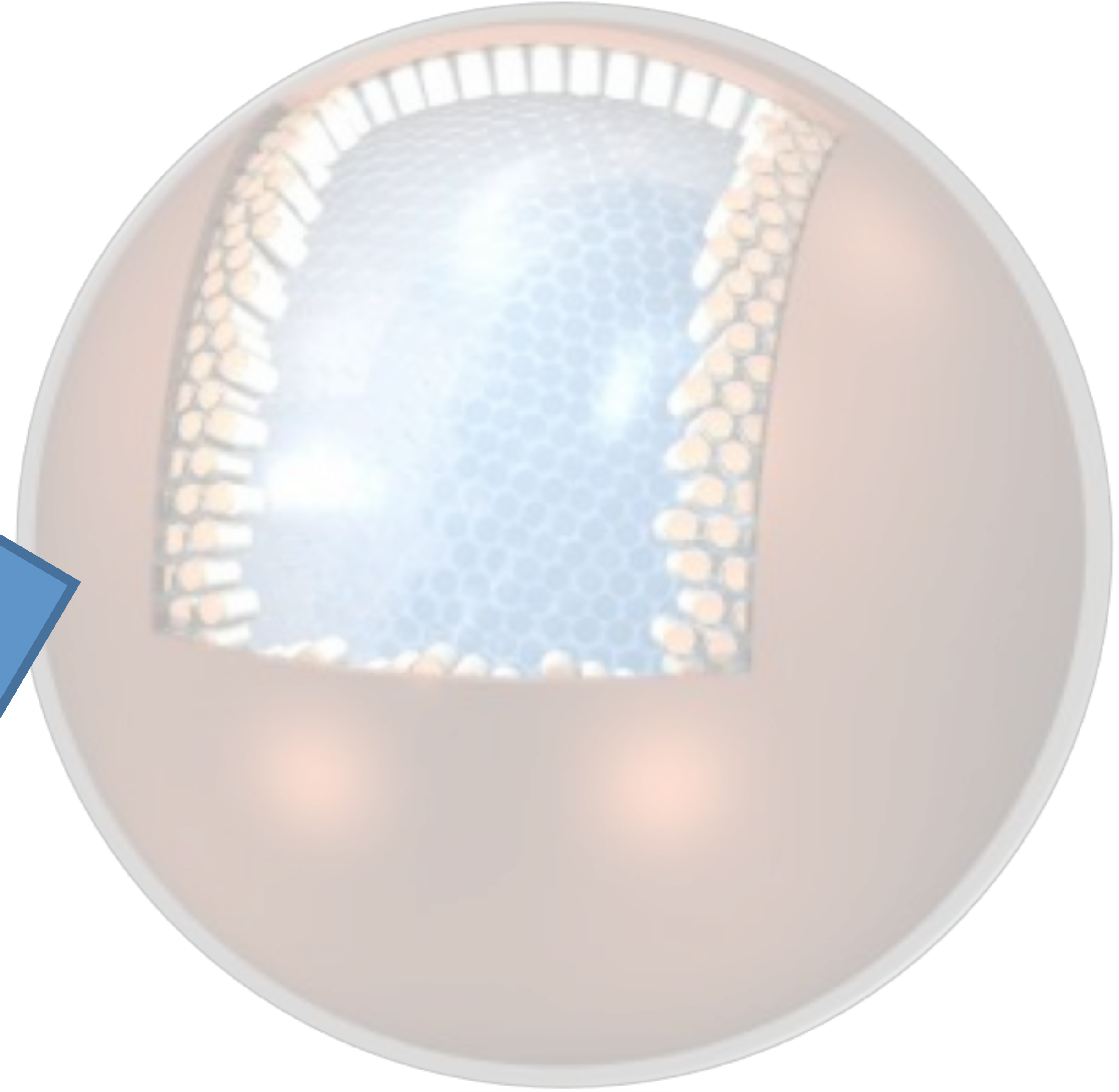
DM
100kg FV (800kg)
0.8mϕ, 642 PMTs
2007-
To discover DM

XMASS-1.5



DM
1ton FV (5ton)
1.5mϕ, ~1000 PMTs
Requesting budget
DM, pp solar ν
~10^{-46}cm^2
Annual/spectral info.

XMASS-II

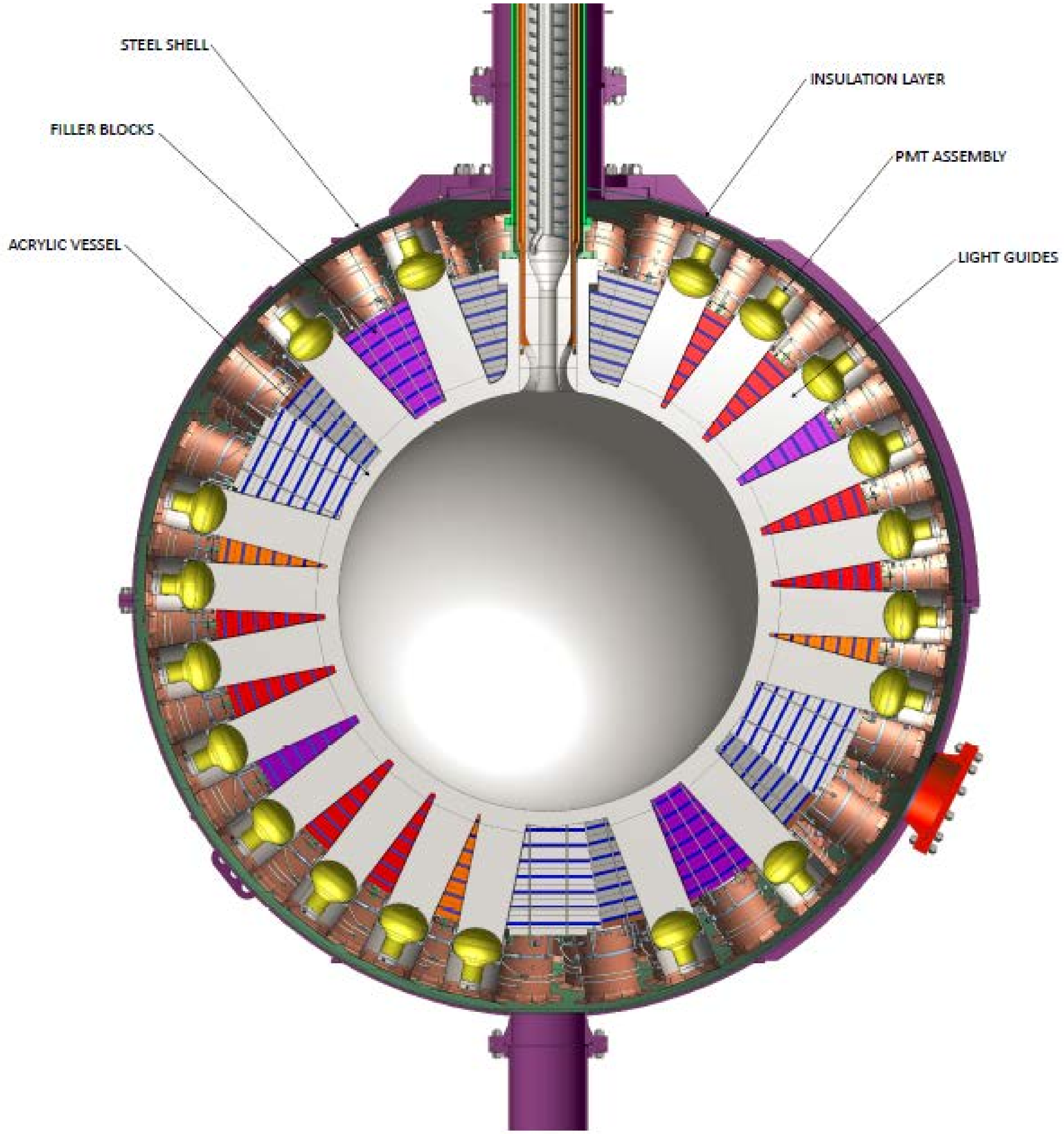


DM, solar, $\beta\beta$
10ton FV
Detailed study of DM
pp solar ν
$\beta\beta$ ~30meV(IH)

Dark-matter Experiment using Argon Pulse Shape Discrimination

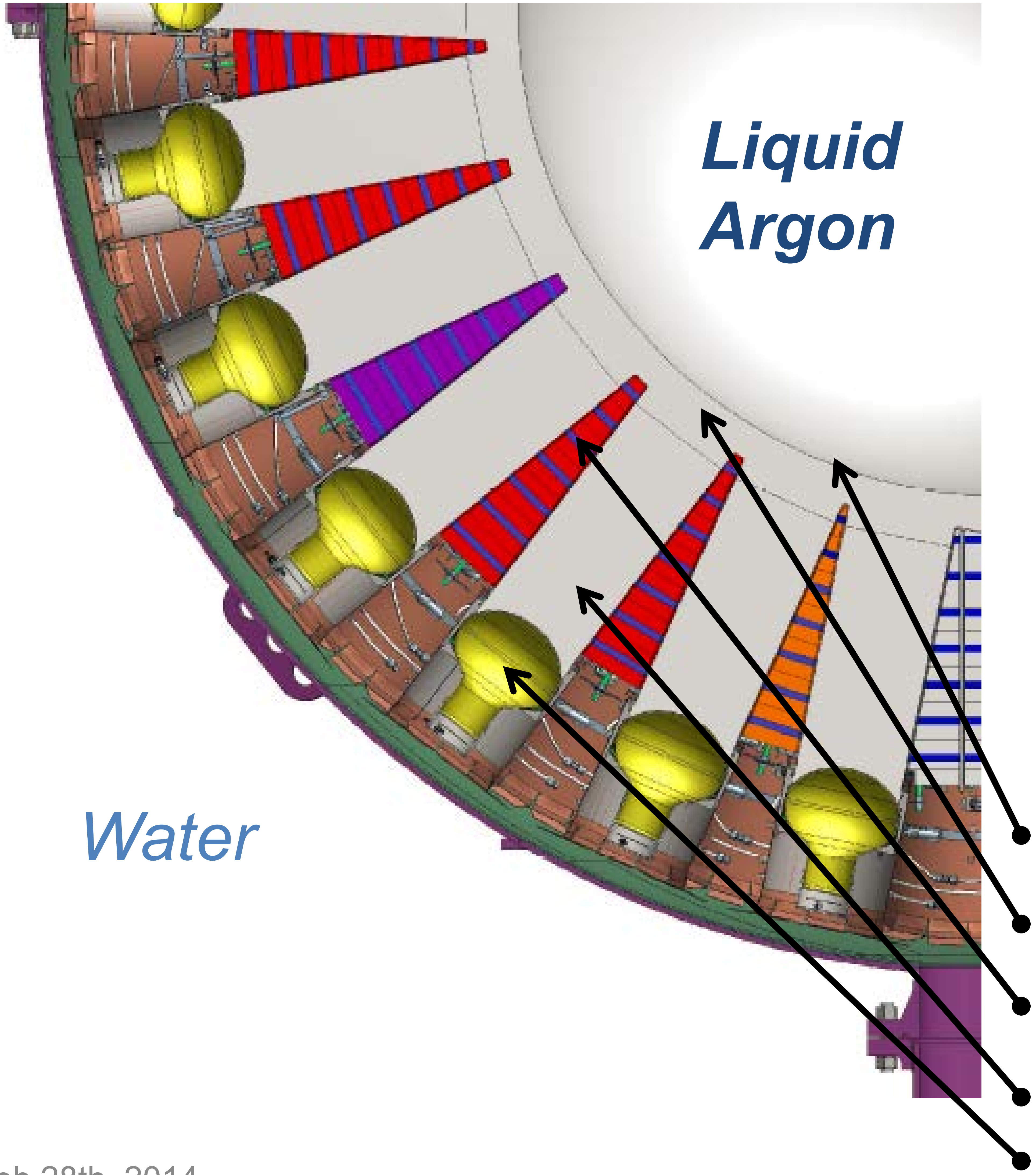
Fabrice Retière on behalf of the DEAP collaboration

DEAP-3600 concept



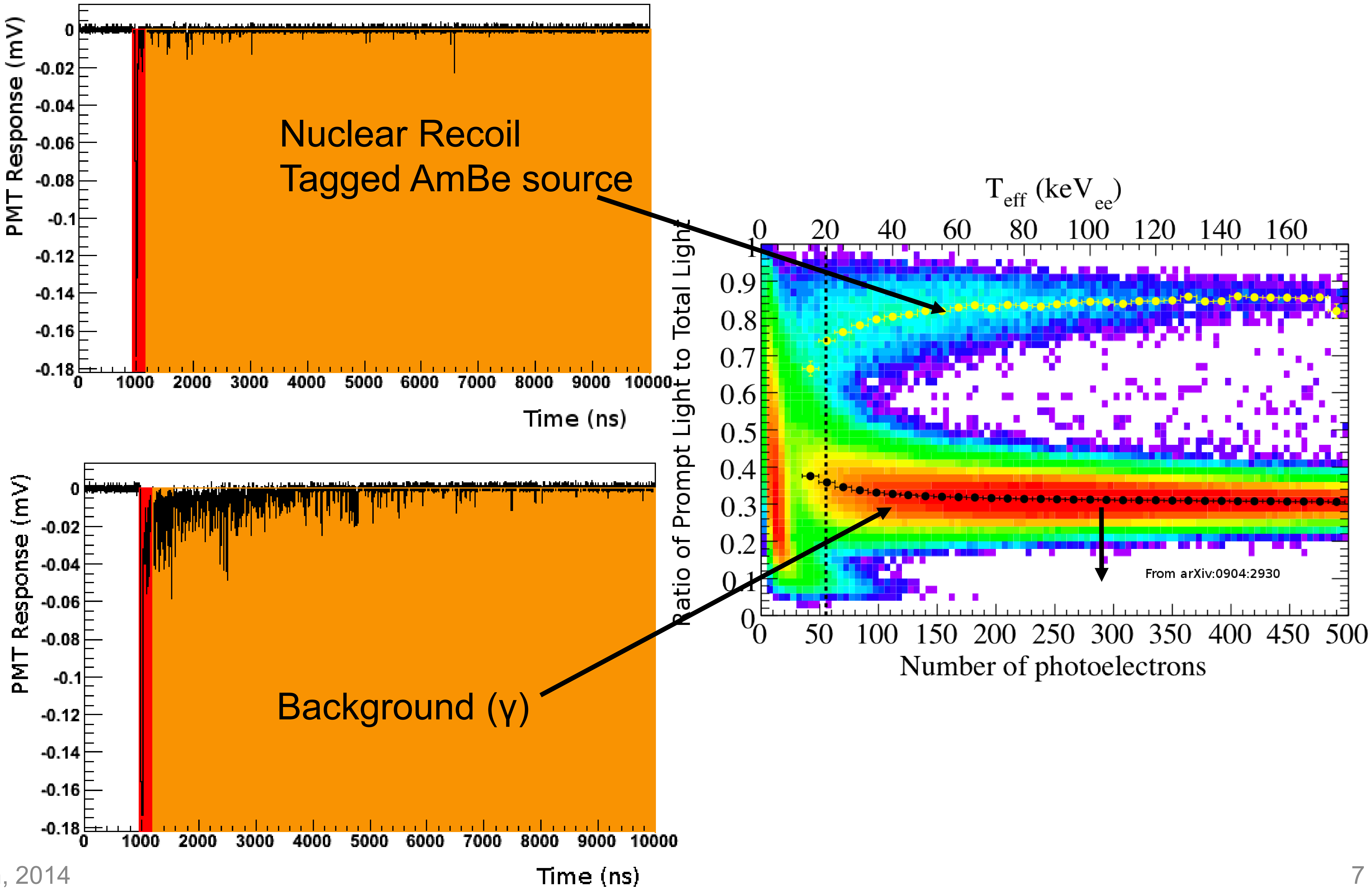
- **3.6 tonnes of liquid Argon**
  - Enclosed in 85 cm radius acrylic ball
  - 1 tonne fiducial
    - Excluding surface events
- **Scintillation only**
  - Aka single phase
  - Light viewed by 255 photo-multiplier tubes

Neutron background mitigation



- **Sited at SNOLAB**
  - 6000 meter water equivalent
- **Inside a water tank**
- **~50cm of light guide acrylic and filler blocks**
- **Ultra-low radioactivity acrylic**

Pulse shape discrimination concept



Projected backgrounds

Assuming 8PE per keV

Background	Rate/count	Mitigation
Neutron In 1t LAr	< 2 pBq/kg < 0.06 count/year	Shielding: 6000 mwe (SNOLAB), Active water shield, light guides and filler blocks Material selection
β & γ In 1t LAr	< 2 pBq/kg < 0.06 count/year	Pulse shape discrimination Material selection (for γ)
Radon In 1t LAr	< 1.4 nBq/kg < 44 count/year*	Material selection, SAES getter, cold charcoal radon trap ** High energy events, not in ROI*
Surface α In 1t LAr	< 0.2 mBq/m^2 < 0.6 count/year	Material selection (acrylic), sanding of AV (1mm removal), fiducialization.

Total of <0.6 events in ROI in 3 years for a spin-independent WIMP-nucleon cross section sensitivity of 10^{-46} cm^2 at 100GeV.

Challenge for Scintillating Detectors

Available online at www.sciencedirect.com
ScienceDirect

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 568 (2006) 700–709

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Time and space reconstruction in optical, non-imaging, scintillator-based particle detectors

C. Galbiati, K. McCarty*

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Received 22 April 2005; received in revised form 25 July 2006; accepted 29 July 2006
Available online 24 August 2006

Challenge for Noble Scintillators

t.o.f.:

$$\partial x = \frac{c\sigma}{n}\sqrt{\frac{3}{N}}$$

diffusive propagation:

$$\partial x = \frac{R}{2}\sqrt{\frac{3}{N}}$$

Scintillating Noble TPCs

$$\partial z \approx 1 \text{ mm}$$

$$\partial(x, y) \approx 1 - 3 \text{ cm}$$

How a two-phase Xe TPC is a perfect way to look for WIMPs

T. Shutt
Case Western Reserve University

Dual phase Time Projection Chamber

- Liquid Xe - large signal, strong shielding of external backgrounds
- 3D event position
- Charge (S2) / light (S1) distinguishes electron recoil backgrounds
- Single electrons and photons

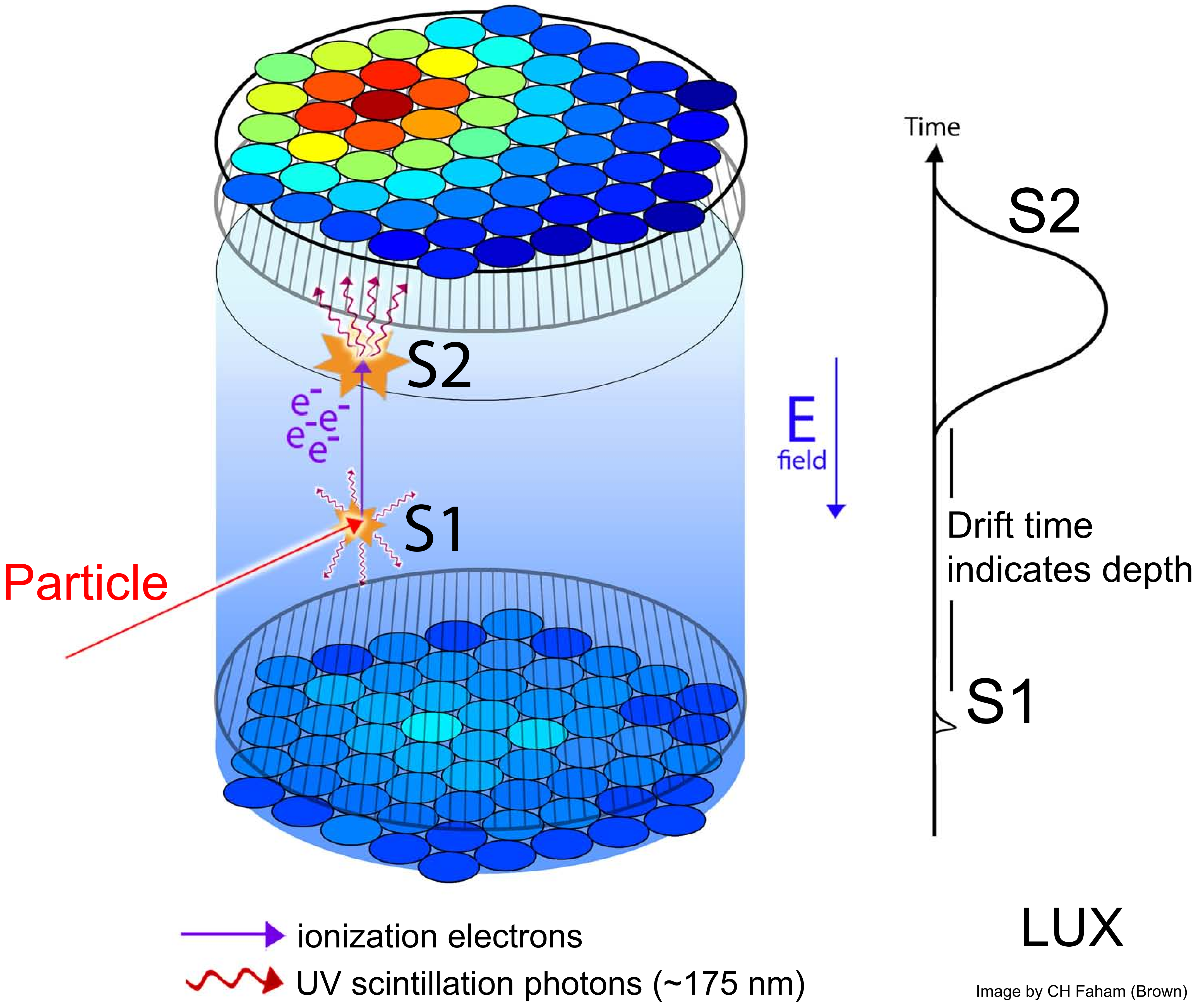


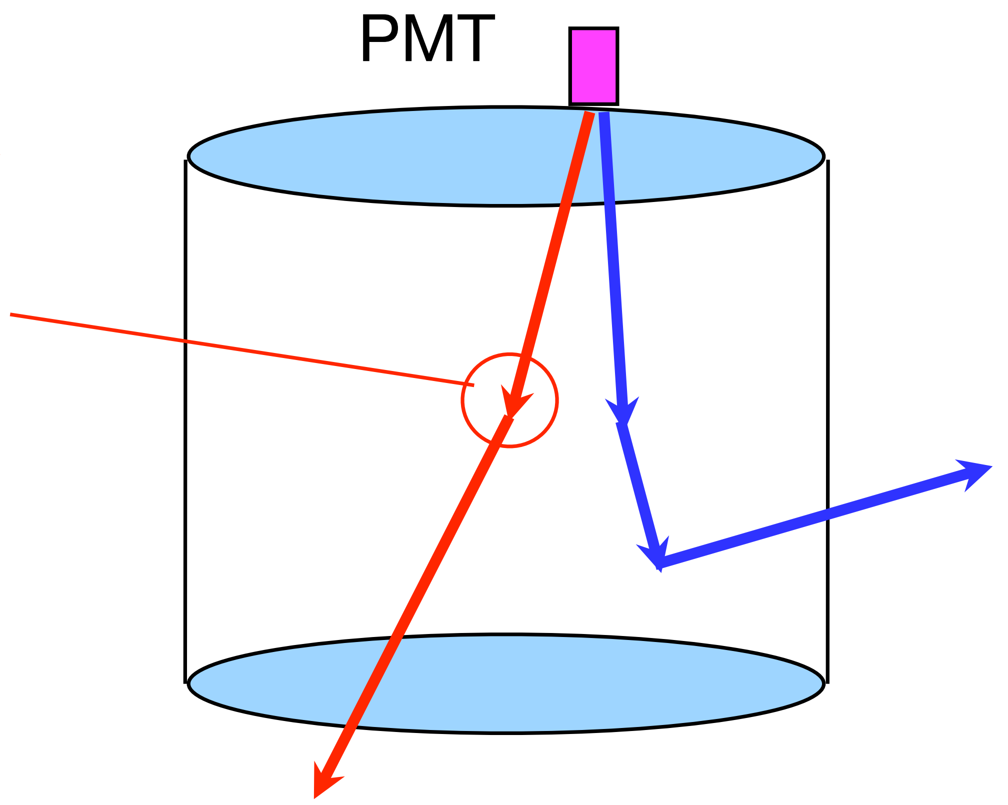
Image by CH Faham (Brown)

Self-shielding in liquid xenon

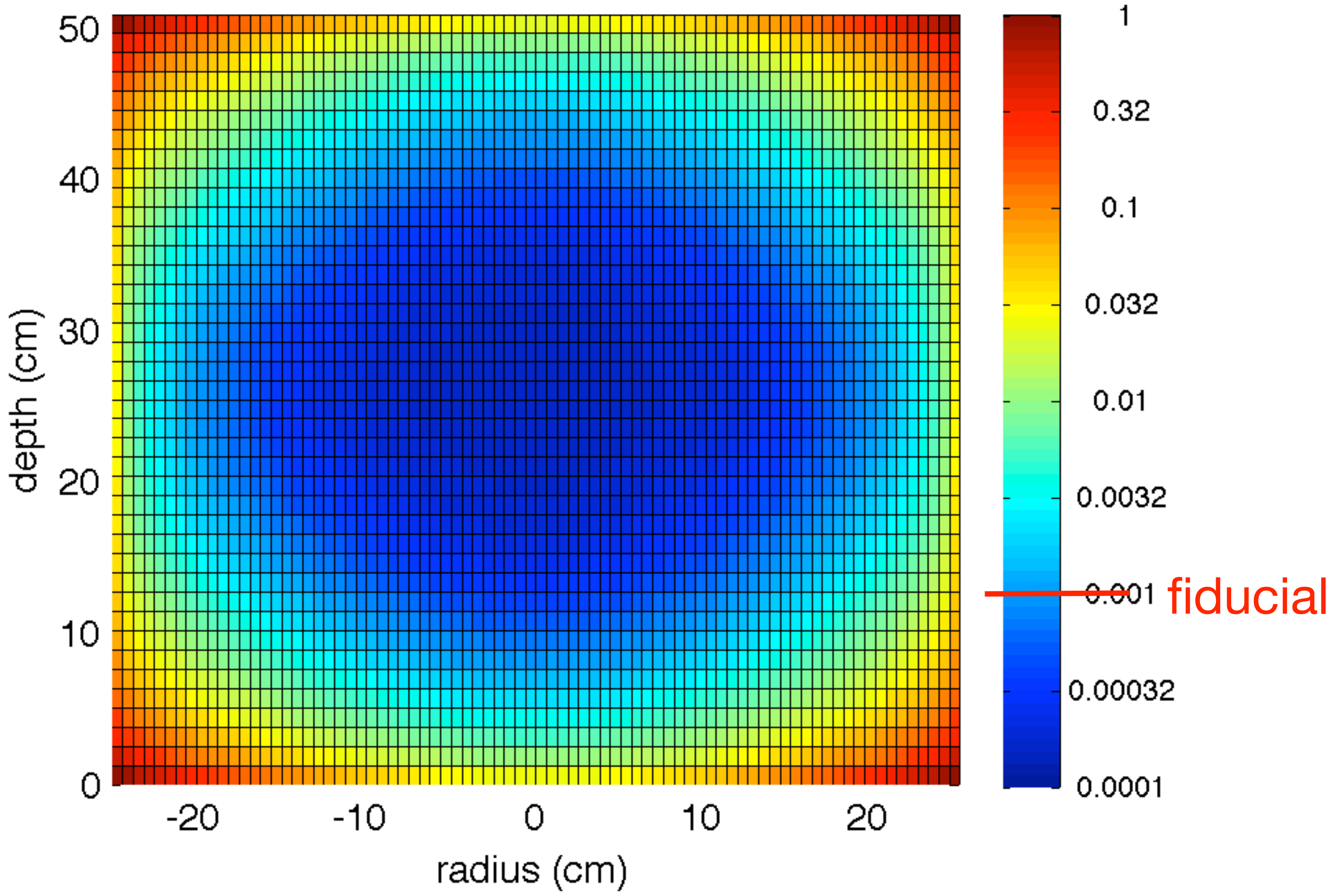
- MeV gammas and neutrons: λ ~10 cm

Single, low-energy Compton scatter

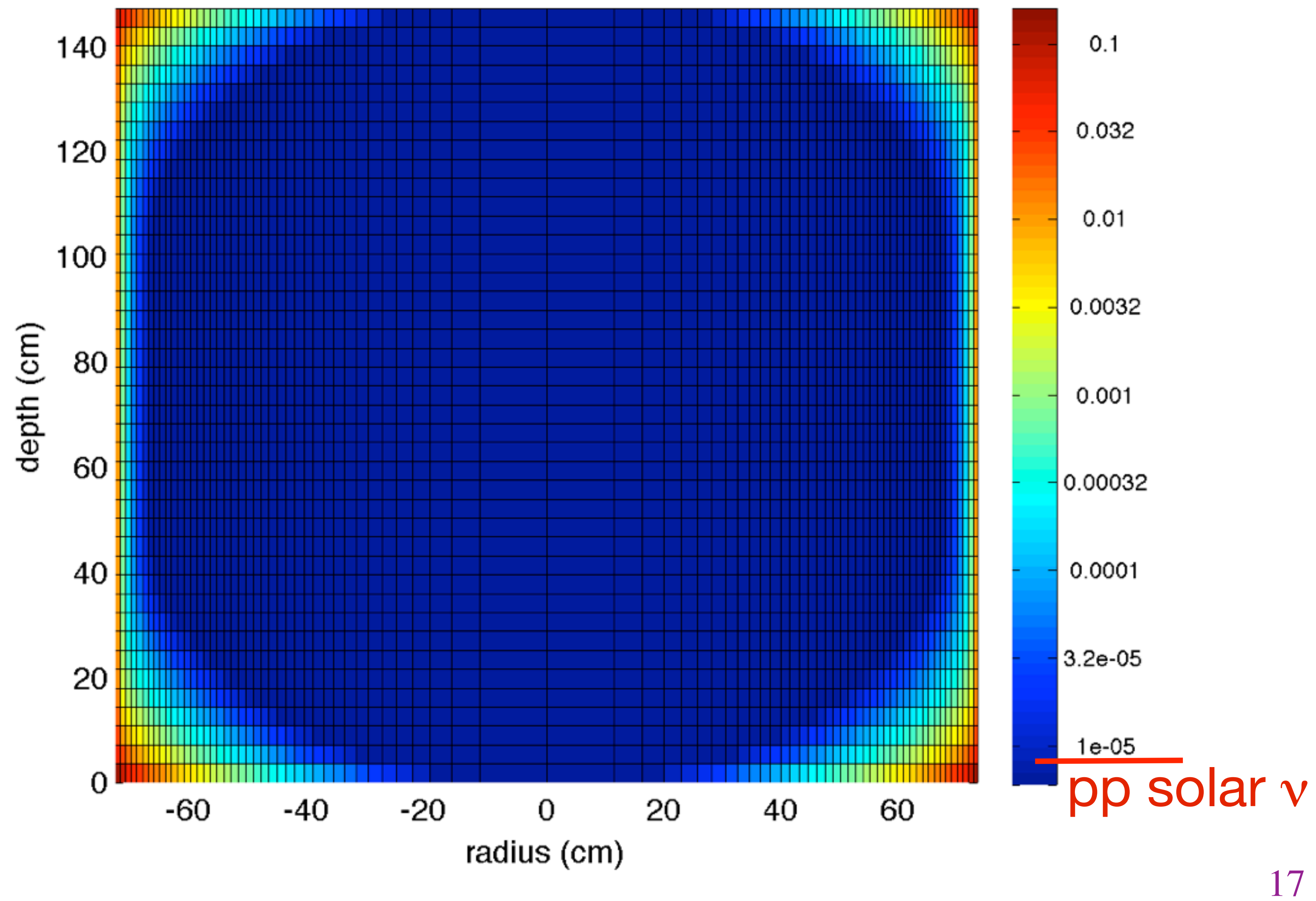
$$P(L) \cong \frac{L}{\lambda} e^{-\frac{L}{\lambda}}$$



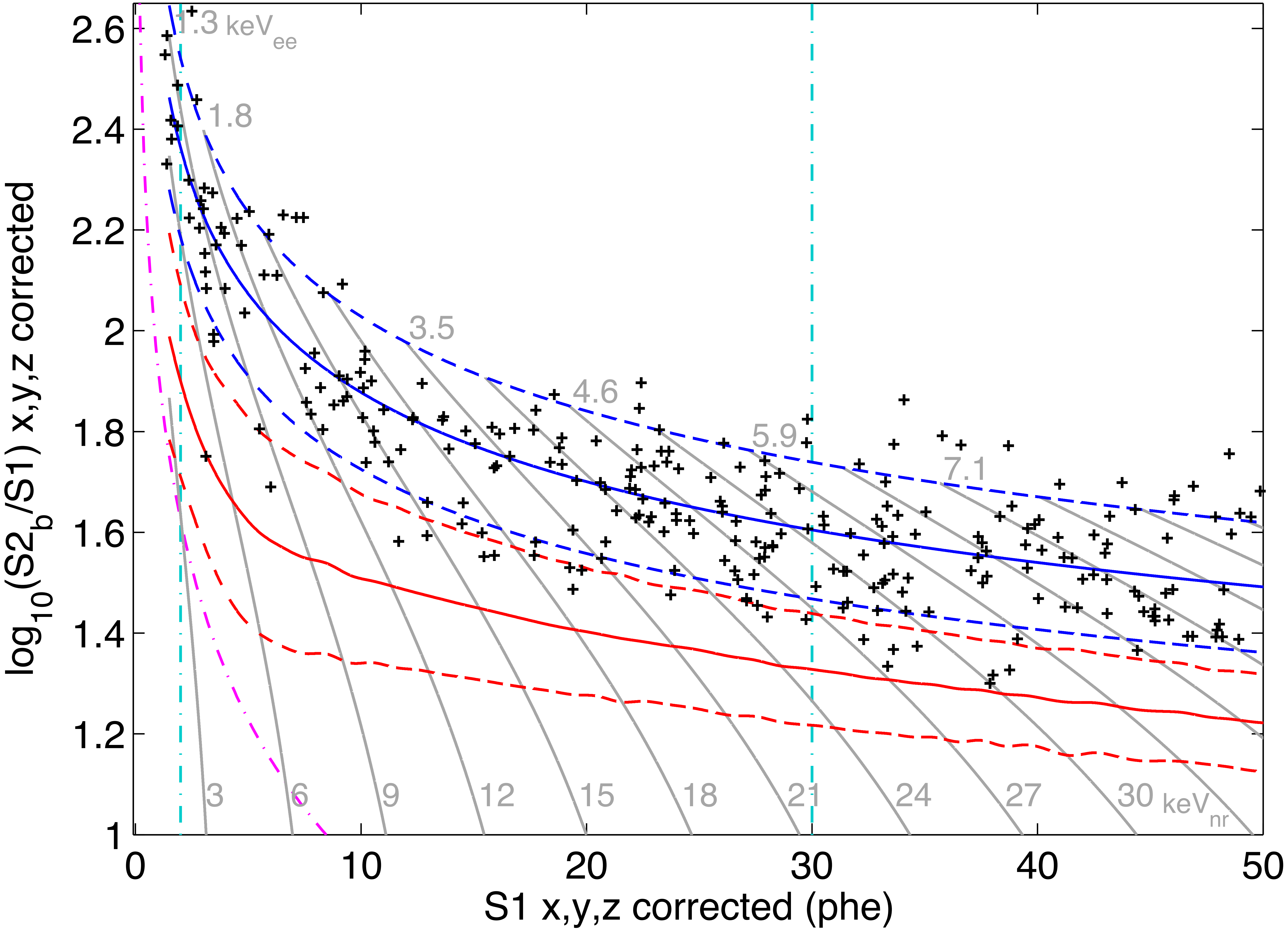
300 kg LUX



7 Ton LZ



gate grid
cathode grid
wall face
wall corner
drift time (μs)
radius^2 (cm^2)
0
50
100
150
200
250
300
350
0
100
200
300
400
500
600



1.3 keV$_{ee}$
1.8
3.5
4.6
5.9
7.1
3
6
9
12
15
18
21
24
27
30 keV$_{nr}$
$\log_{10}(S2_b/S1)$ x,y,z corrected
S1 x,y,z corrected (phe)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50

Future directions

- LZ is not quite at neutrino limit
- Background rejection might or might not be sufficient to defeat pp solar neutrino background
- Get rid of PMT radioactivity
  - Would enable simultaneous ßß-decay and DM search
- Please buy LED light bulbs

Future Directions of Xe Scintillating TPC

- XENON-1t at LNGS (2016?)
- LZ at Sanford Lab (?)
- XENON-nt at LNGS (?)

DarkSide
A scalable, zero-background technology

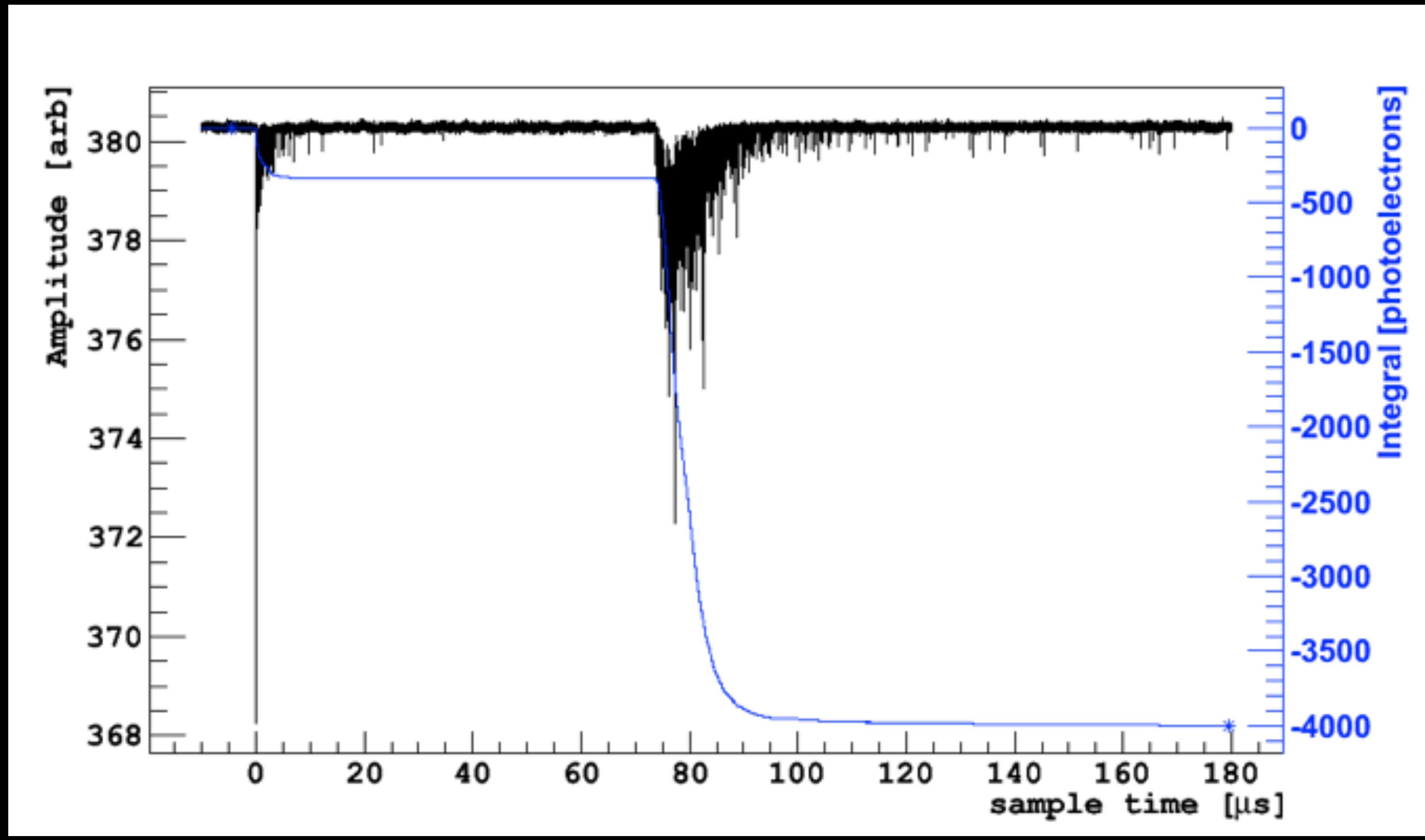
- Pulse shape of scintillation provides powerful discrimination for NR vs. EM events:
  - Rejection factor $\geq 10^8$ for >60 photoelectrons:
    - proposed by Boulay & Hime, AstropartPhys 25, 176 (2006)
    - demonstrated by WARP AstropartPhys 28, 495 (2008)

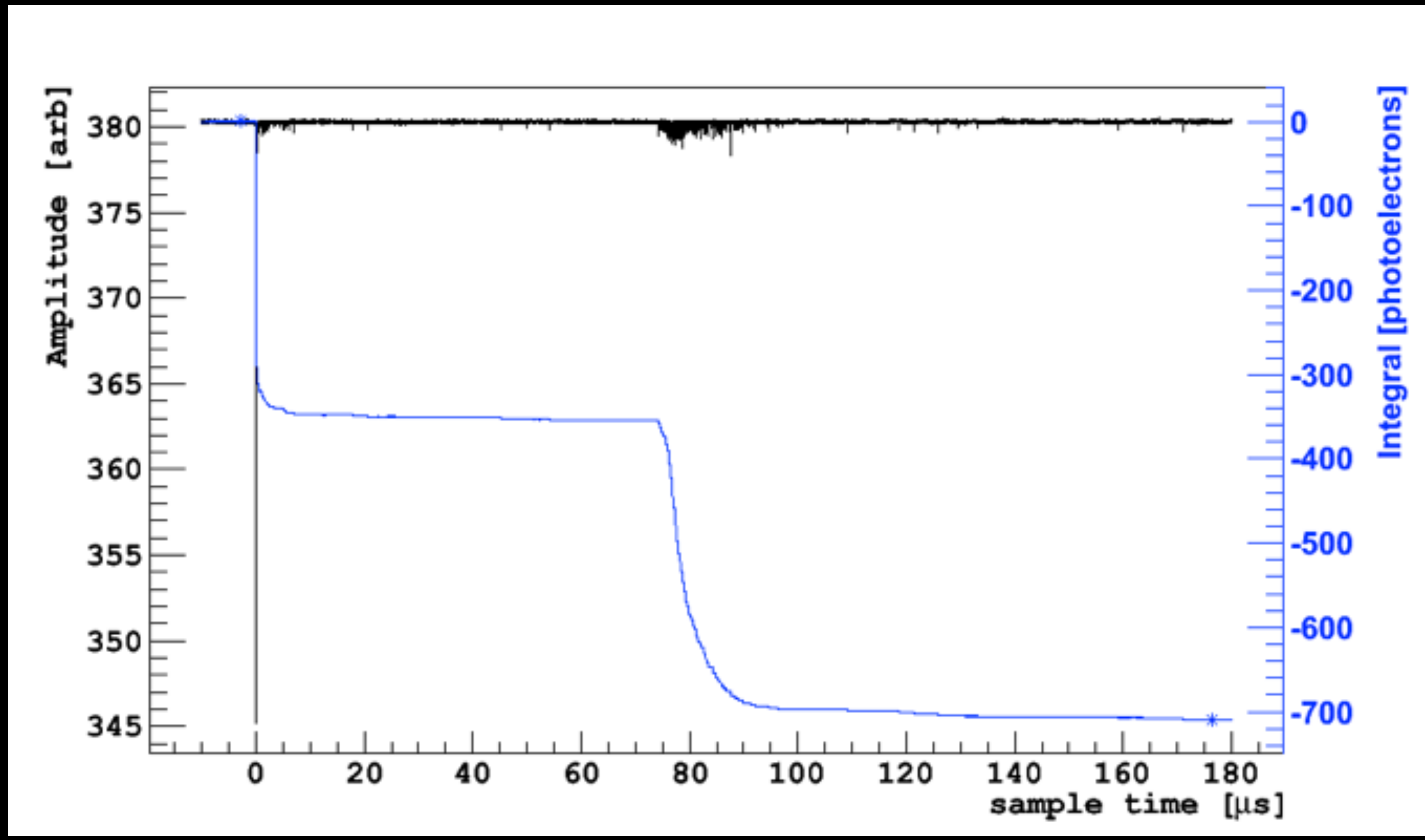
- Ionization:scintillation ratio a semi-independent discrimination mechanism:

- Great spatial resolution from ionization drift localizes events, allowing rejection of multiple interactions, "wall events", etc.

- Underground argon
  - ^{39}Ar abatement factor ≥ 150

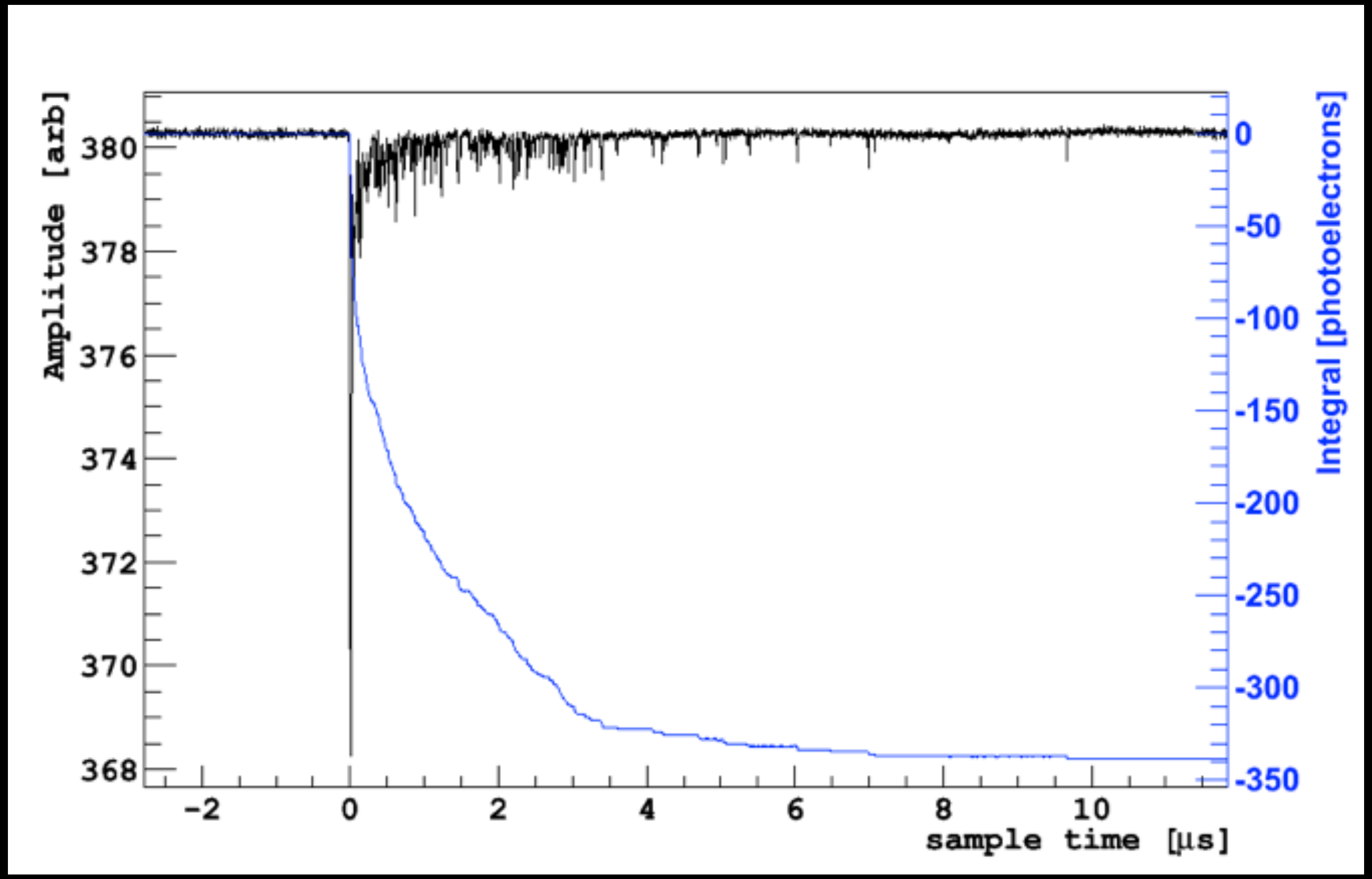
Argon Scintillating TPC

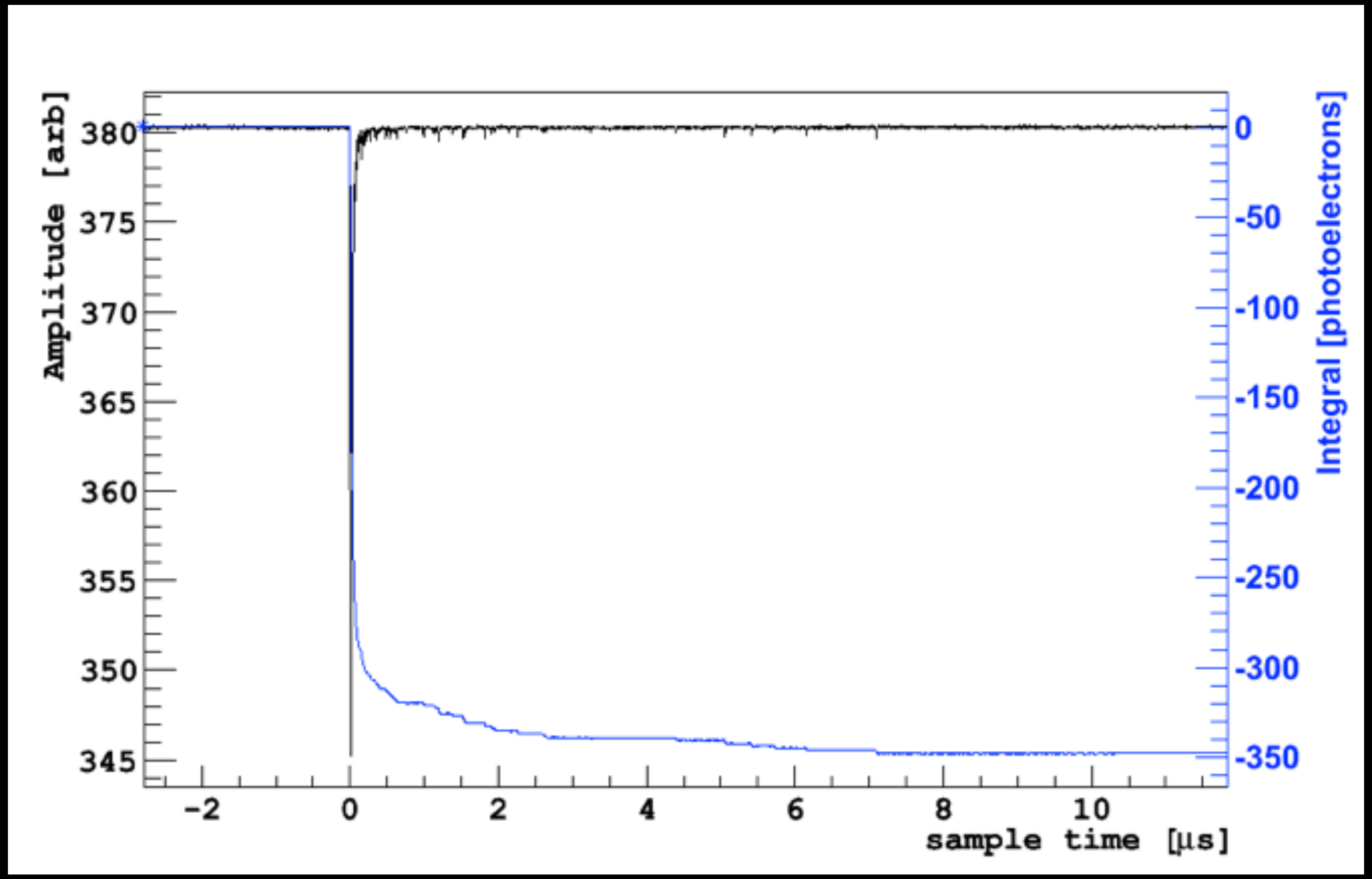




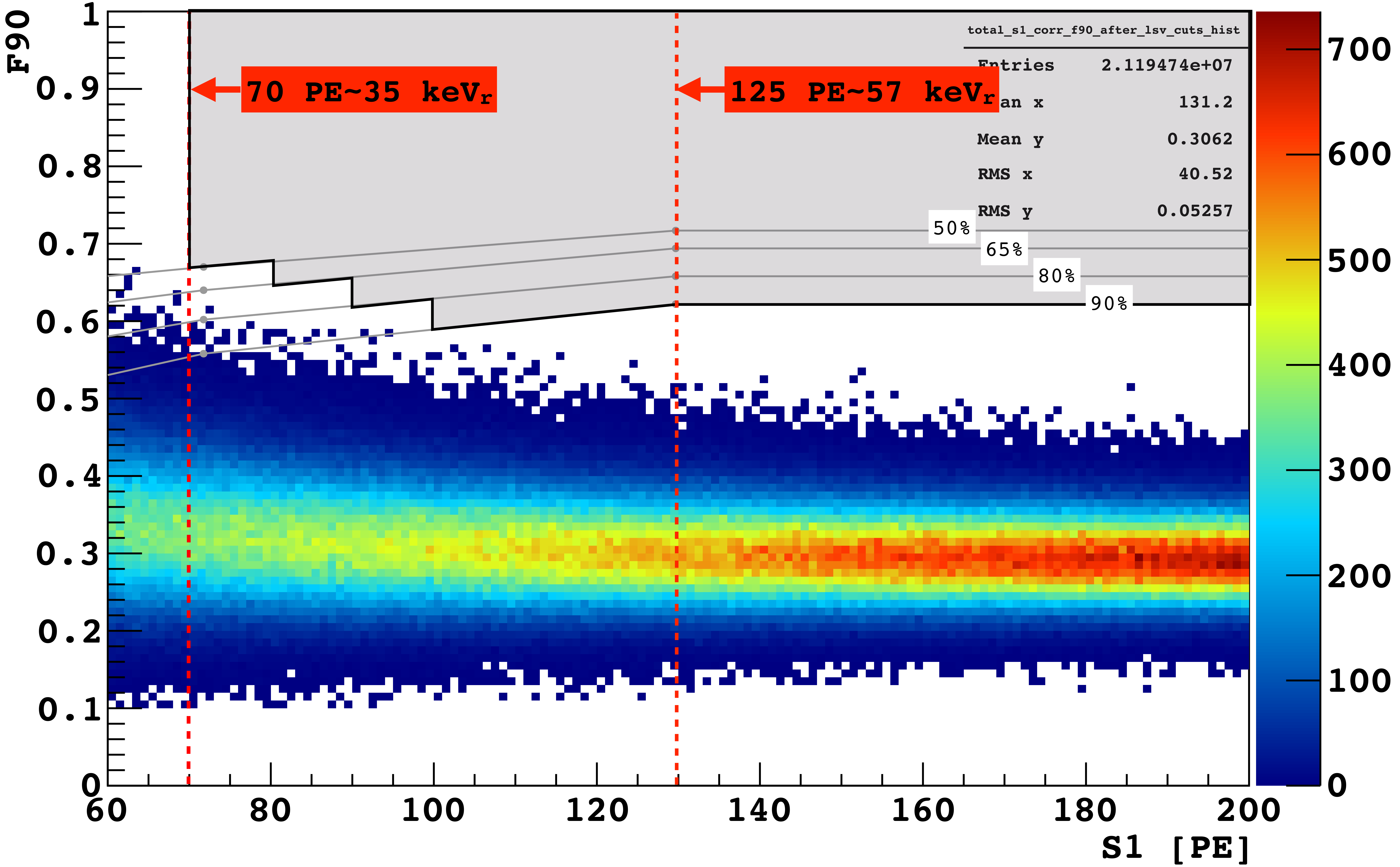
Beta/Gamma

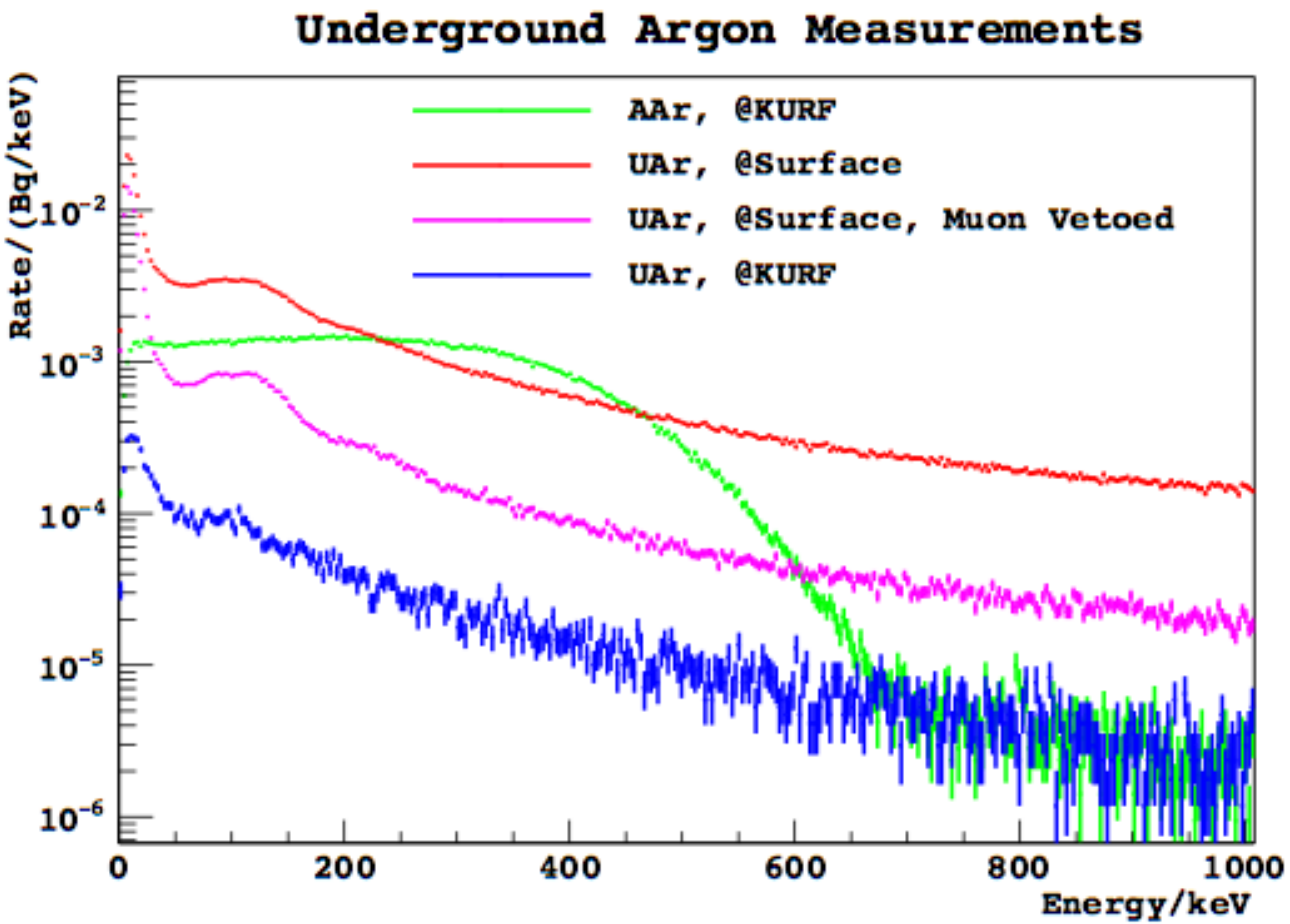
Nuclear Recoil





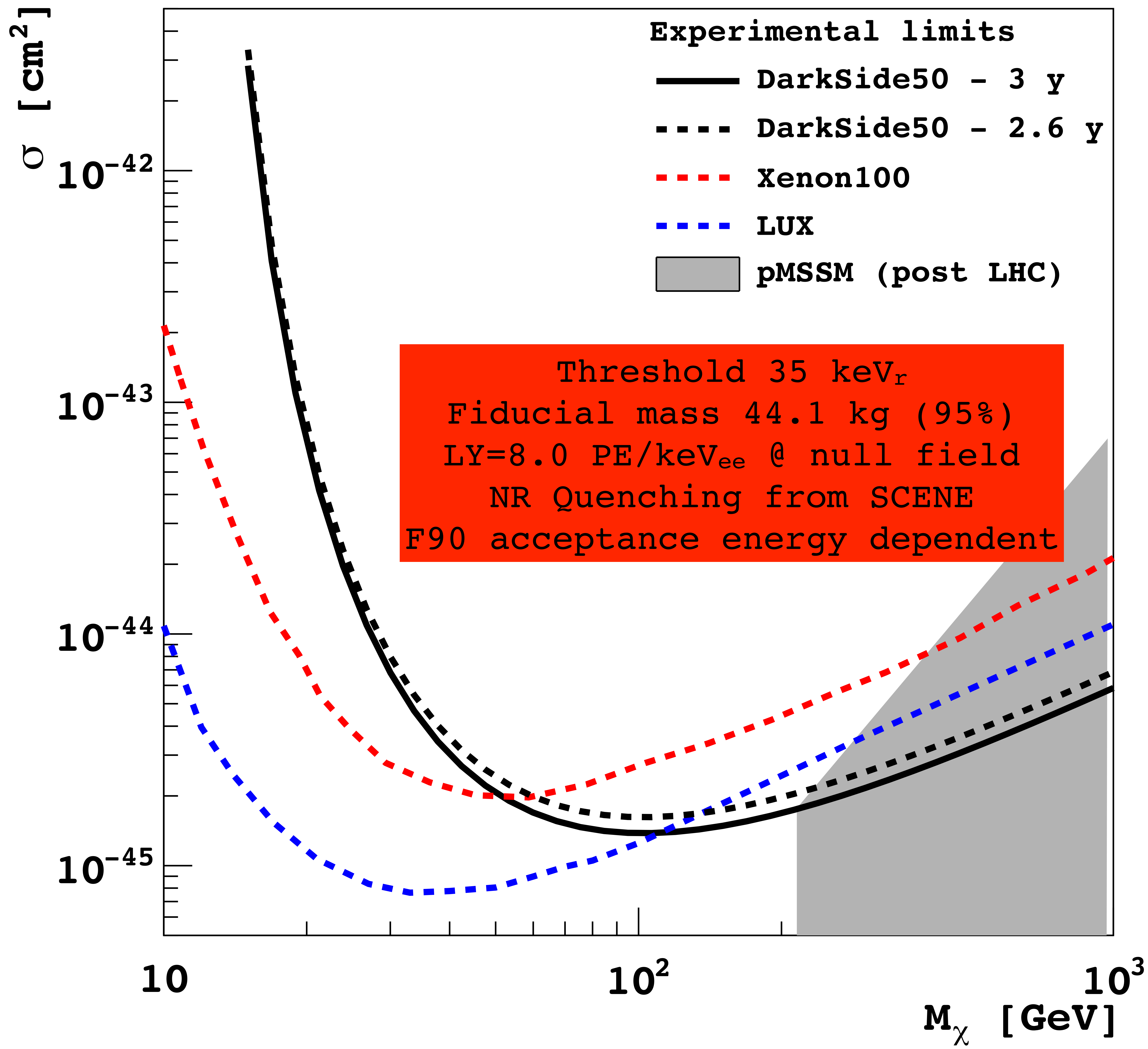
280 kg×day Exposure with Atmospheric Argon



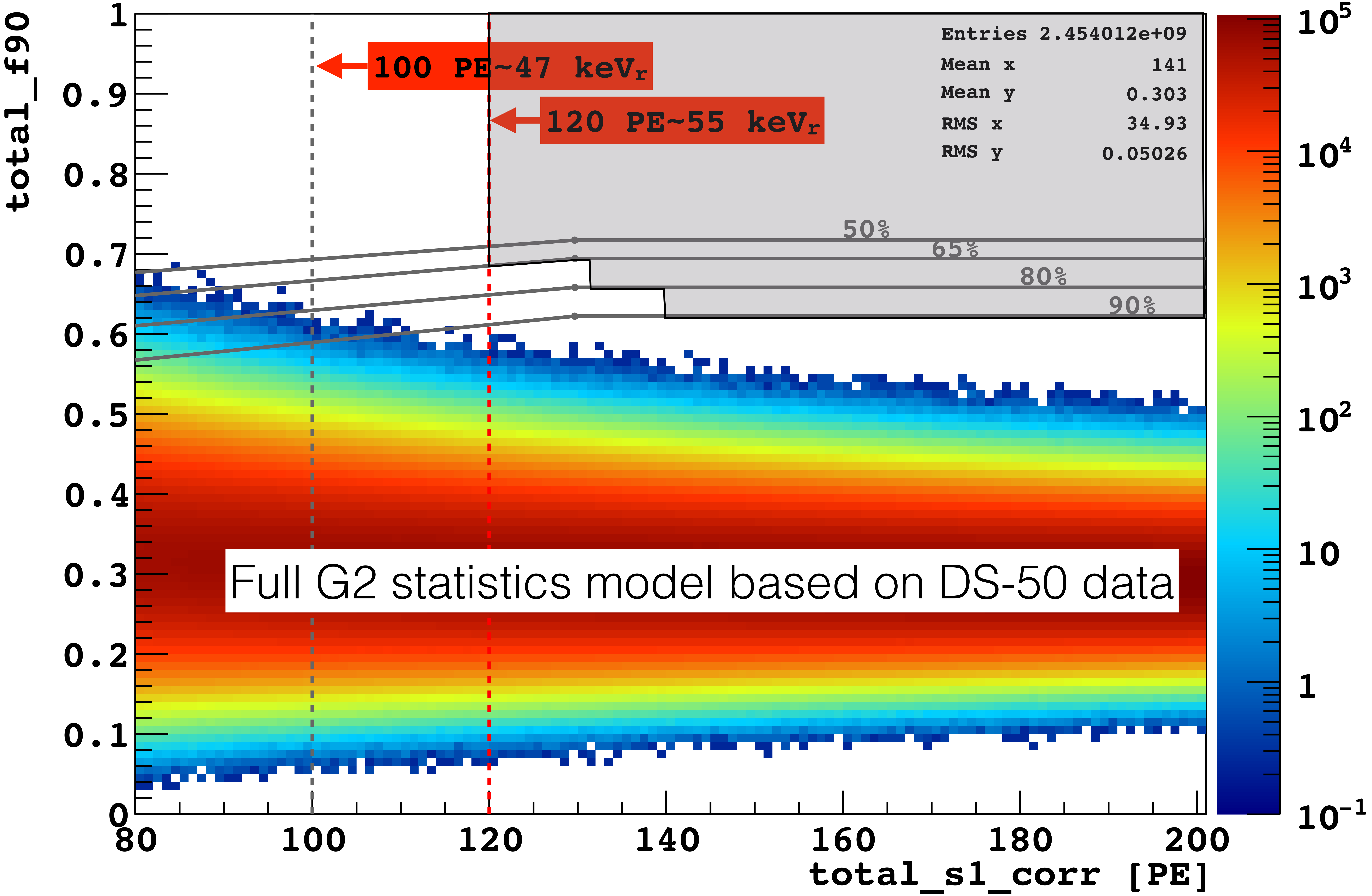


Underground Argon Measurements
AAr, @KURF
UAr, @Surface
UAr, @Surface, Muon Vetoed
UAr, @KURF
Rate/(Bq/keV)
10^-2
10^-3
10^-4
10^-5
10^-6
0
200
400
600
800
1000
Energy/keV

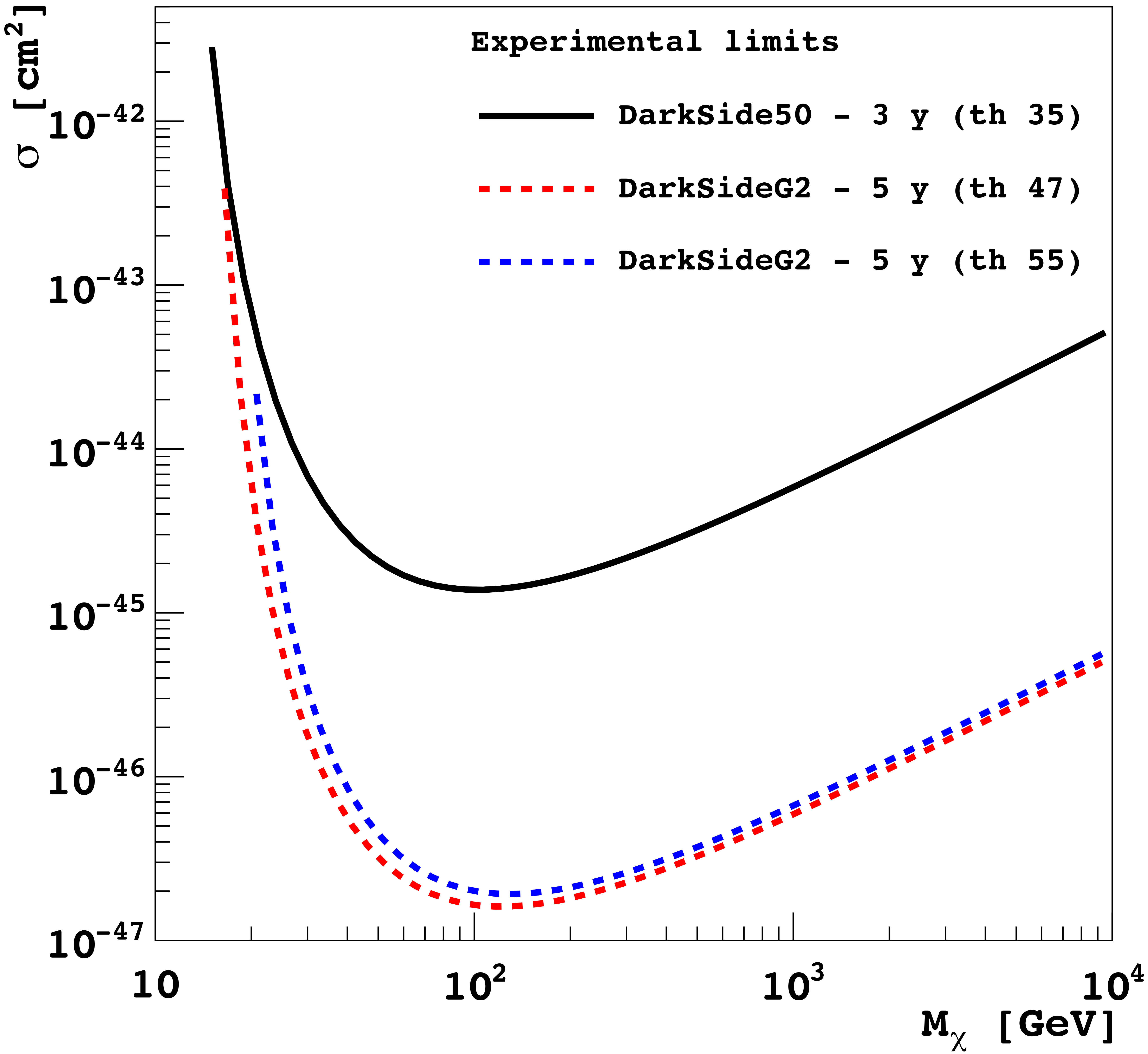
DarkSide-50 Expected Sensitivity



G2 Exposure (5 Years)

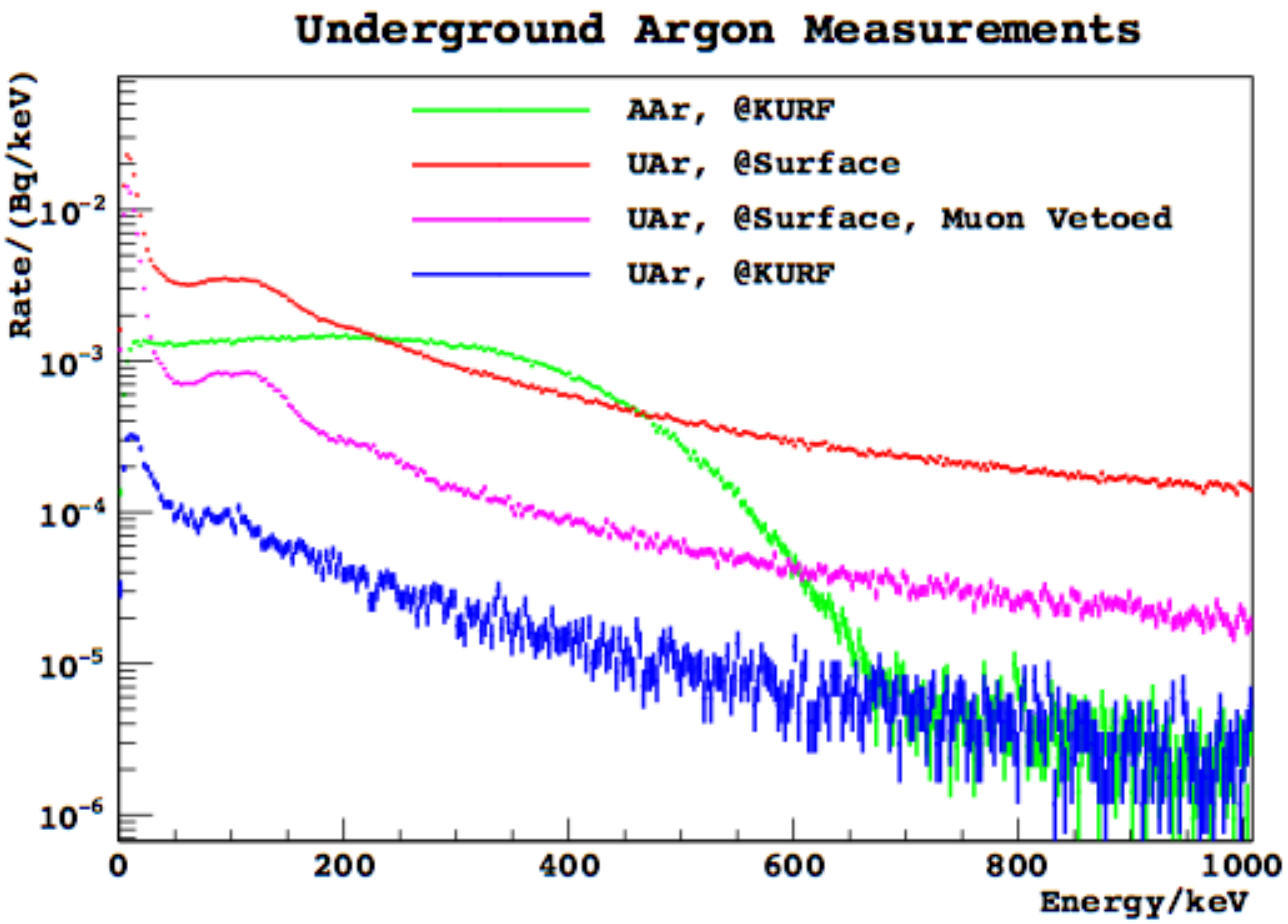


DarkSide-G2 Expected Sensitivity



Entries 187895
χ^2 / ndf 517.6 / 558
Prob 0.8888
Light Yield Mean [p.e./keV] 8.888 ± 0.009
Baseline Variance [p.e]^2 29.37 ± 54.05
Rel. LY Variance 0.002865 ± 0.000256
Ar Amplitude 1.793e+05 ± 4.532e+02
Kr Amplitude 5338 ± 113.5
Constant 1.225 ± 0.175
Counts/10 p.e.
S1 [p.e]
0
1000
2000
3000
4000
5000
6000
1
10
10^2
10^3

Over Pressure Control
V OP1
V OP2
Radon Trap
Heat Exchanger
Radon Filter
Particulate Filter
Heater
F-S
PPR-C
PT21
PT22
PT23
He Input V-C6 NC
Evac
V-V04 NC
PRV-11
PRV -21
V-22 NC
V-23 NO
V-21 NC
V-C2 NC
V-C5 NC
V-C1 NC
PRV-3
PRV-2
PT21
V25NO
V23NO
Power Failer 12psig Back Pressure Control
Open Loop Vent
MFC-20 Mass Flow Control
PT20
V24 NC
LN2
LN2 Dewar Condensor
Ar Condenser
Warm Bypass V-C3 NO
From Gas Panel
V-C4 NO
To Gas Panel
2000 Torr PI
RD .7 Bar
V-I1
PPR-C
V-I2
V-I3
Gate Valve
GV-2
VP-C Vacuum Pump
LAr
Ar
Detector Cryostat
To: Radon Trap V V04
Power Failer Bypass
NO
Q-Drive Gas Pump
PT HC1
High Cube Vacuum Pump
Getter Gas Purifier
V31
V30
PTR1
RD-3
Evac
MFC-R1 Mass Flow Control
Argon Recovery
PR-R
Rack Valve
V-10
Ar Source Gas
CRH COOLING
N2
Phase Seporator
LN2 SUPPLY
Not To Scale
C.Kendziora 9.10.13
Argon Operating pressure .5 bar



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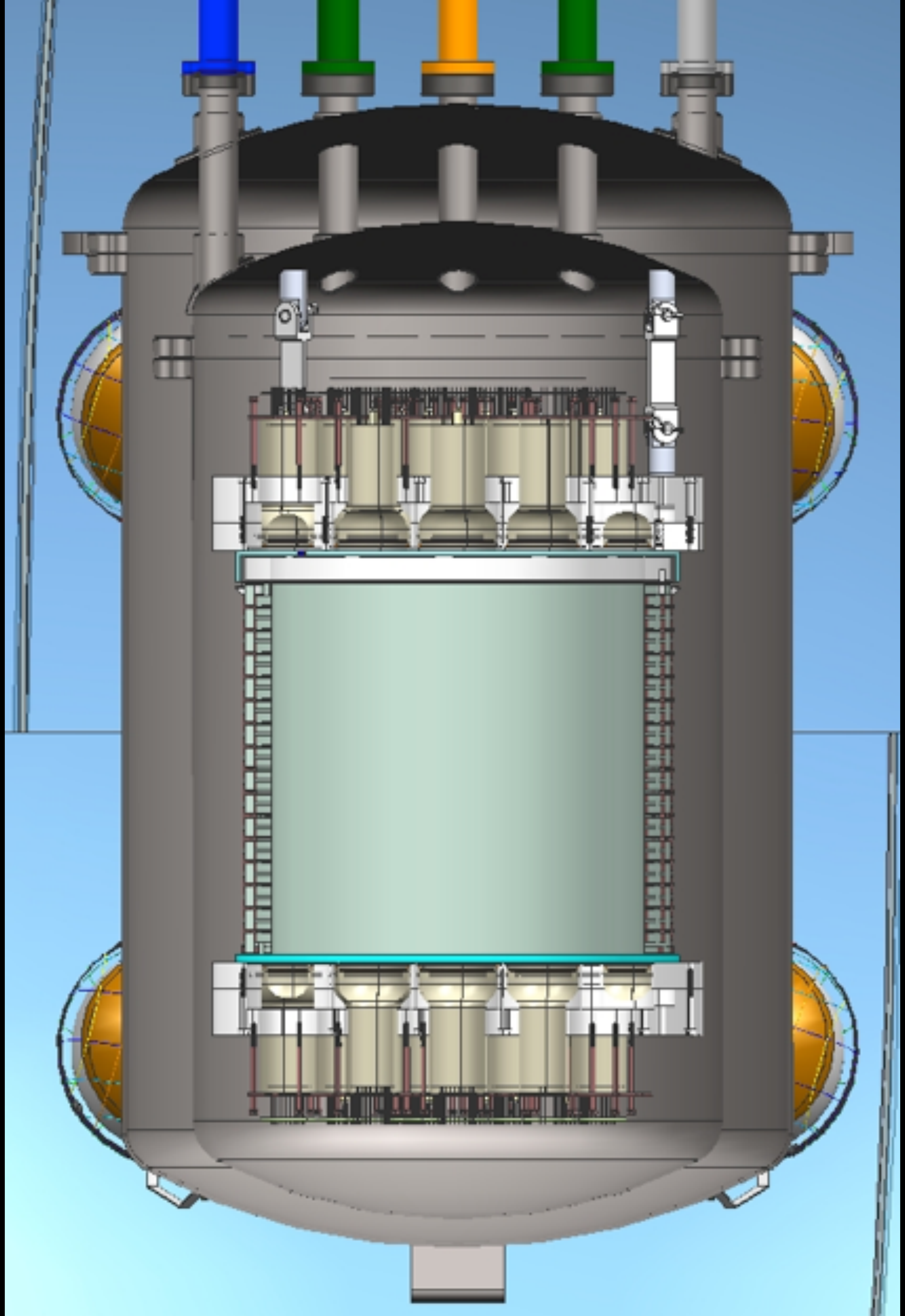
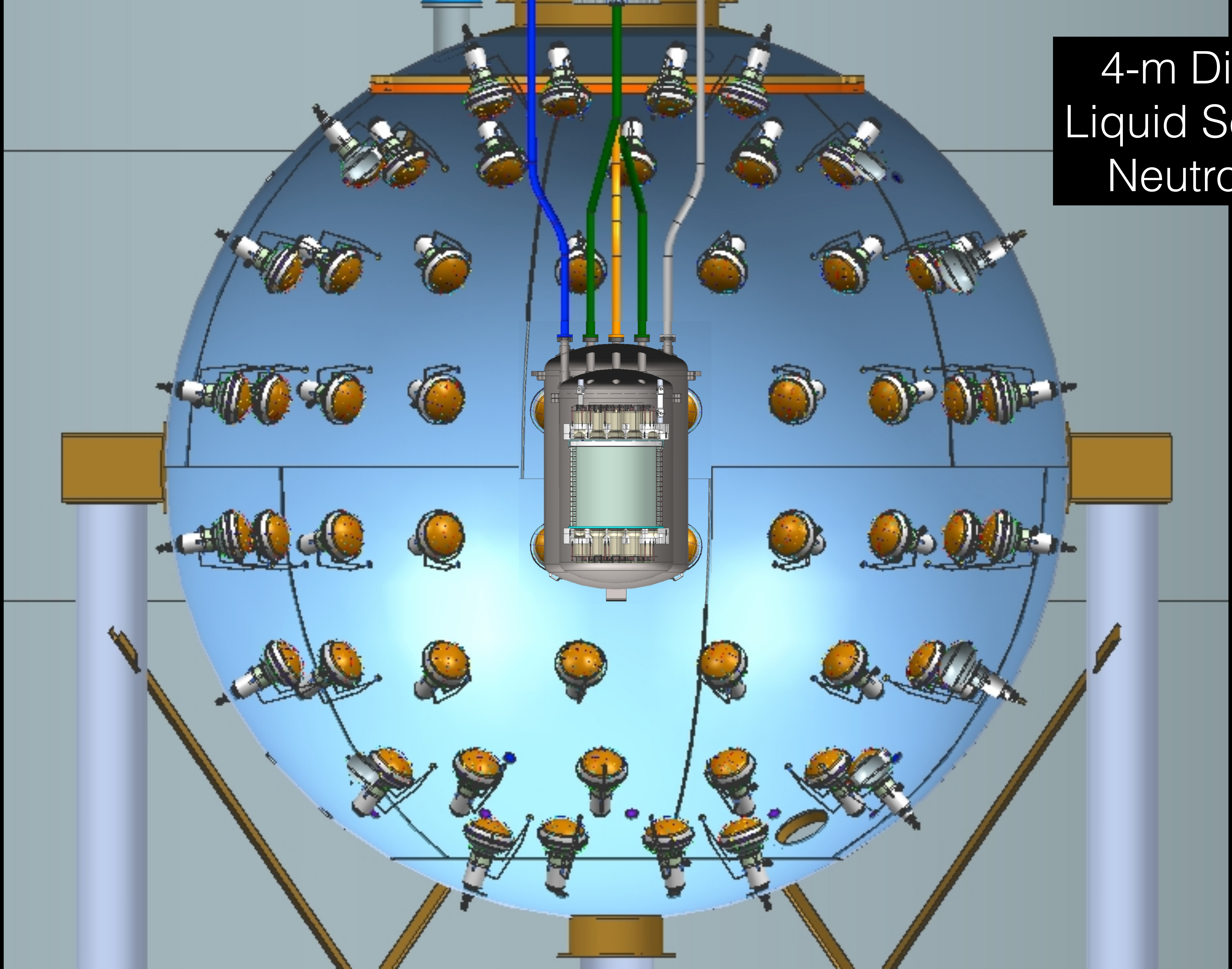
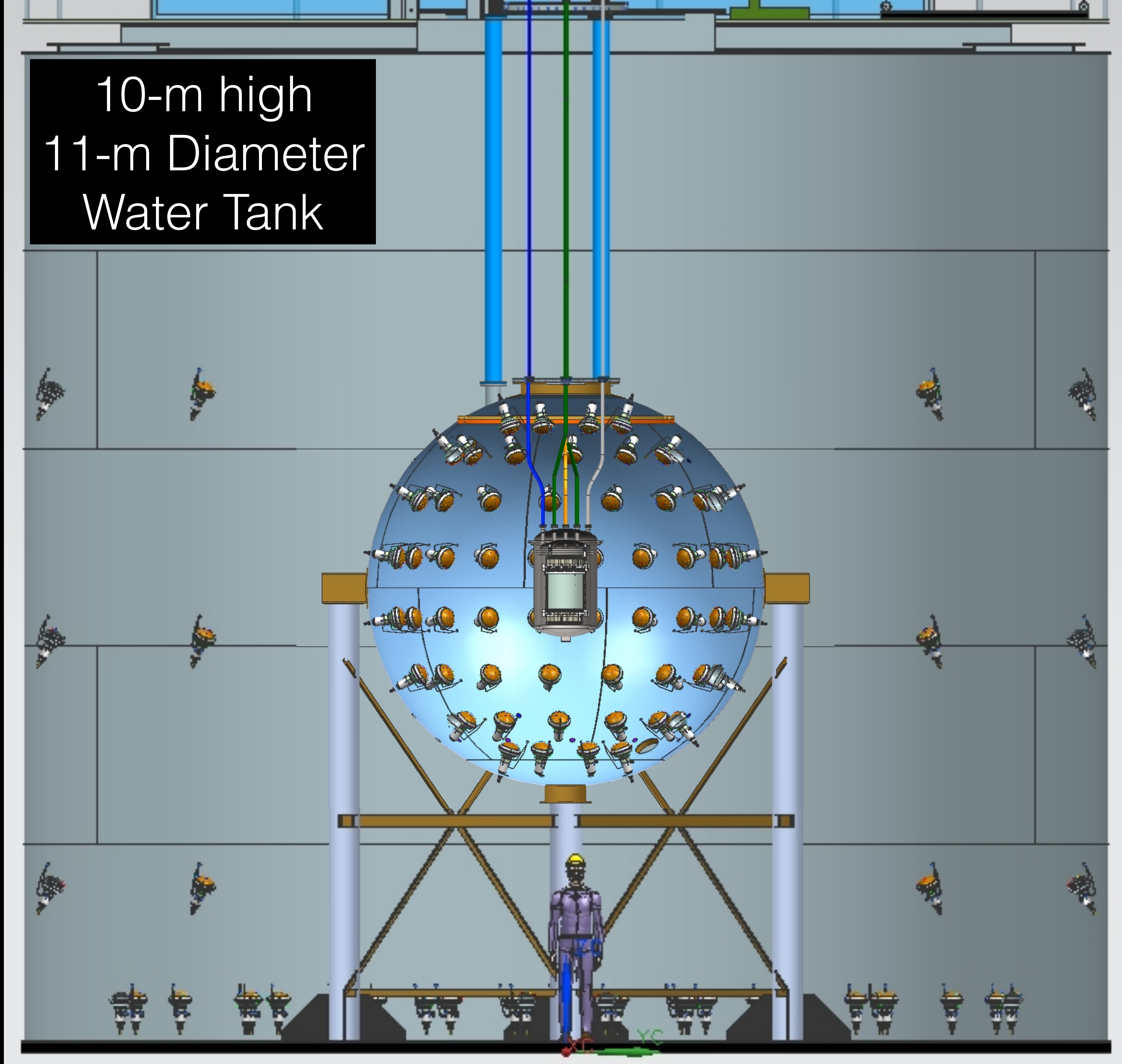
400
600
800
1000
Energy/keV



Liquid Argon TPC
& Cryostat



4-m Diameter
Liquid Scintillator
Neutron Veto

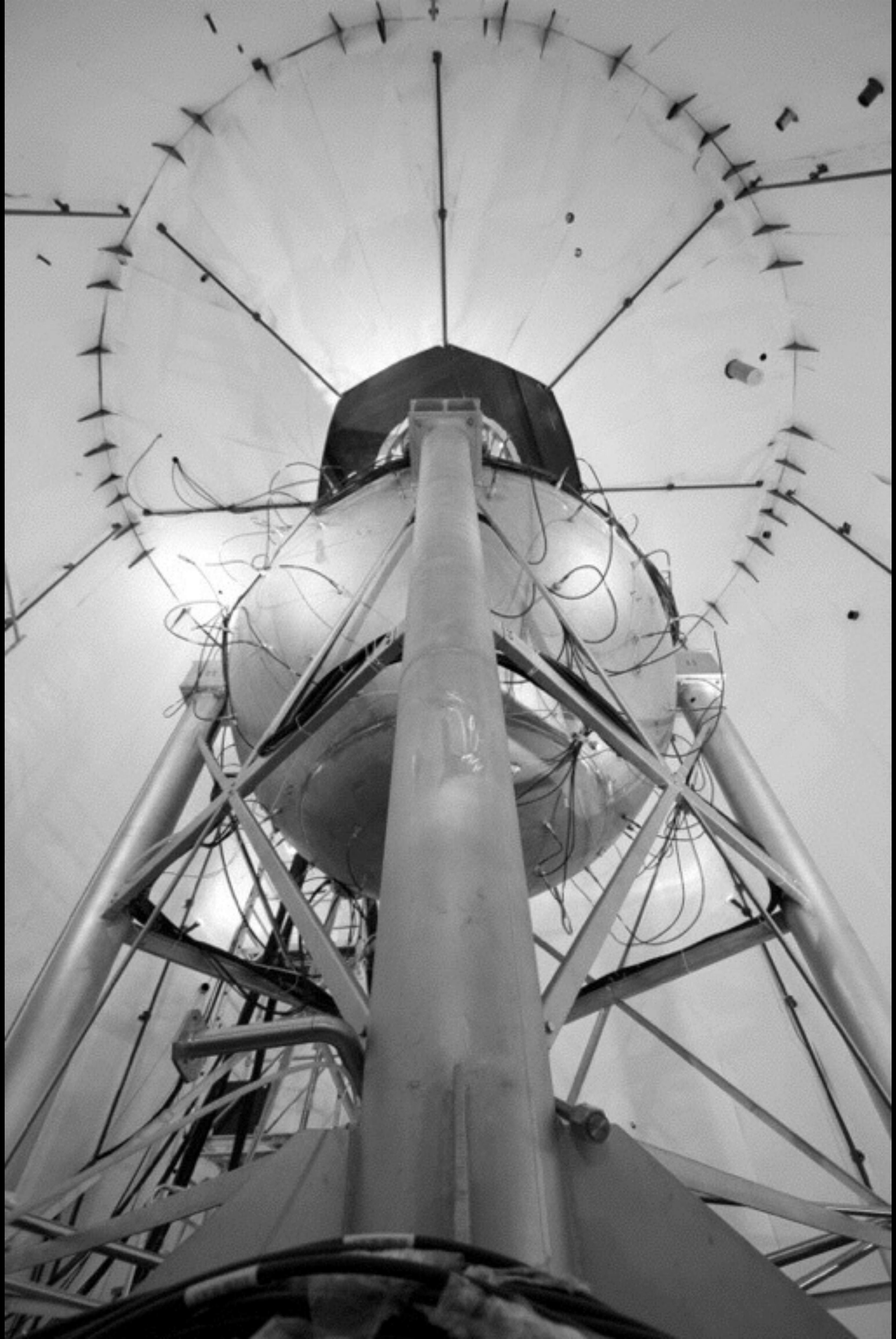

10-m high
11-m Diameter
Water Tank

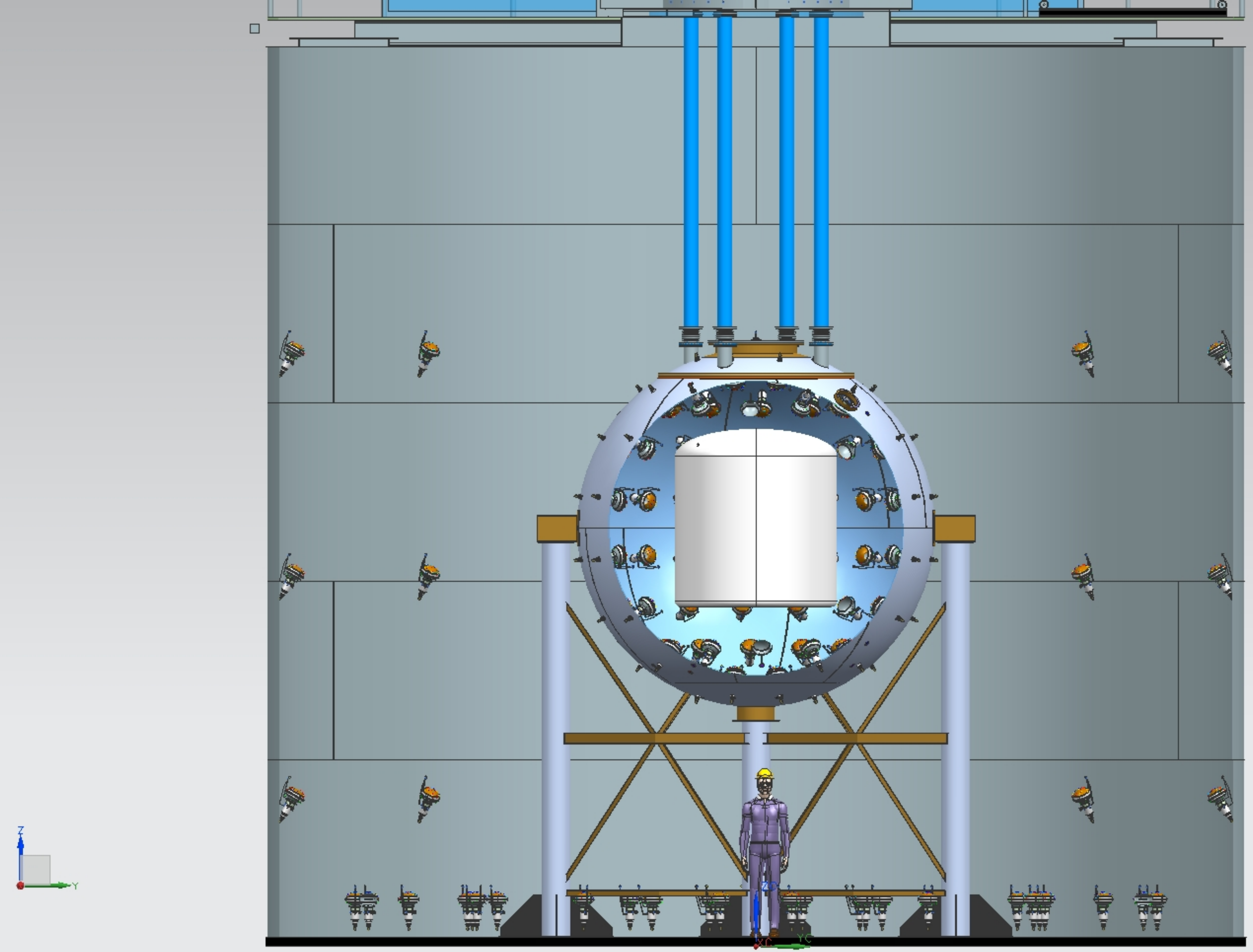

SYSTEMS CAP.


PROJETMAN

Class 100 Clean Room
Radon < 5mBq/m^3


ATEKO
Radon Reduction System
LNGS
AC1
AC2




Z
Y

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