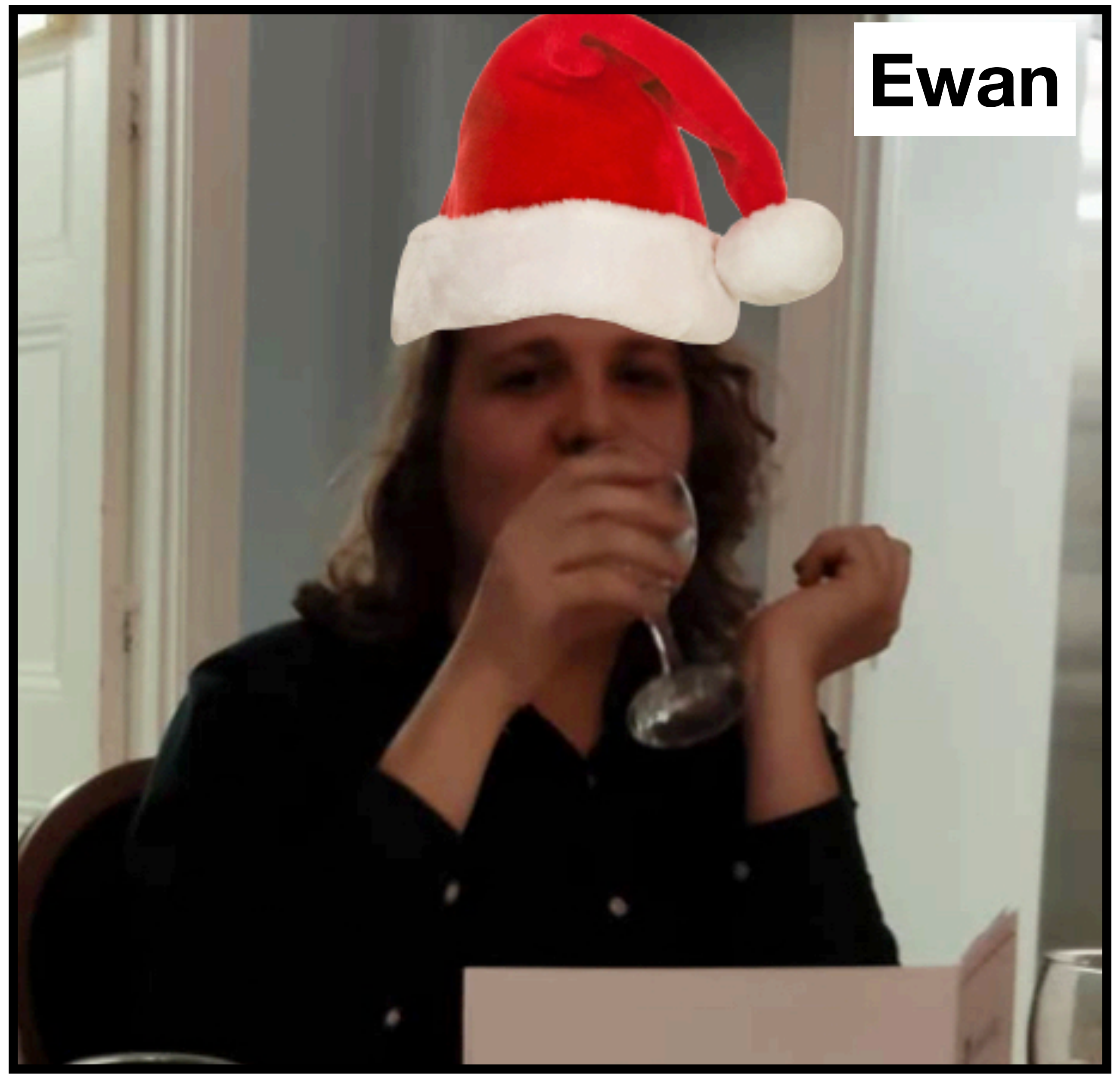
Liverpool + LZ

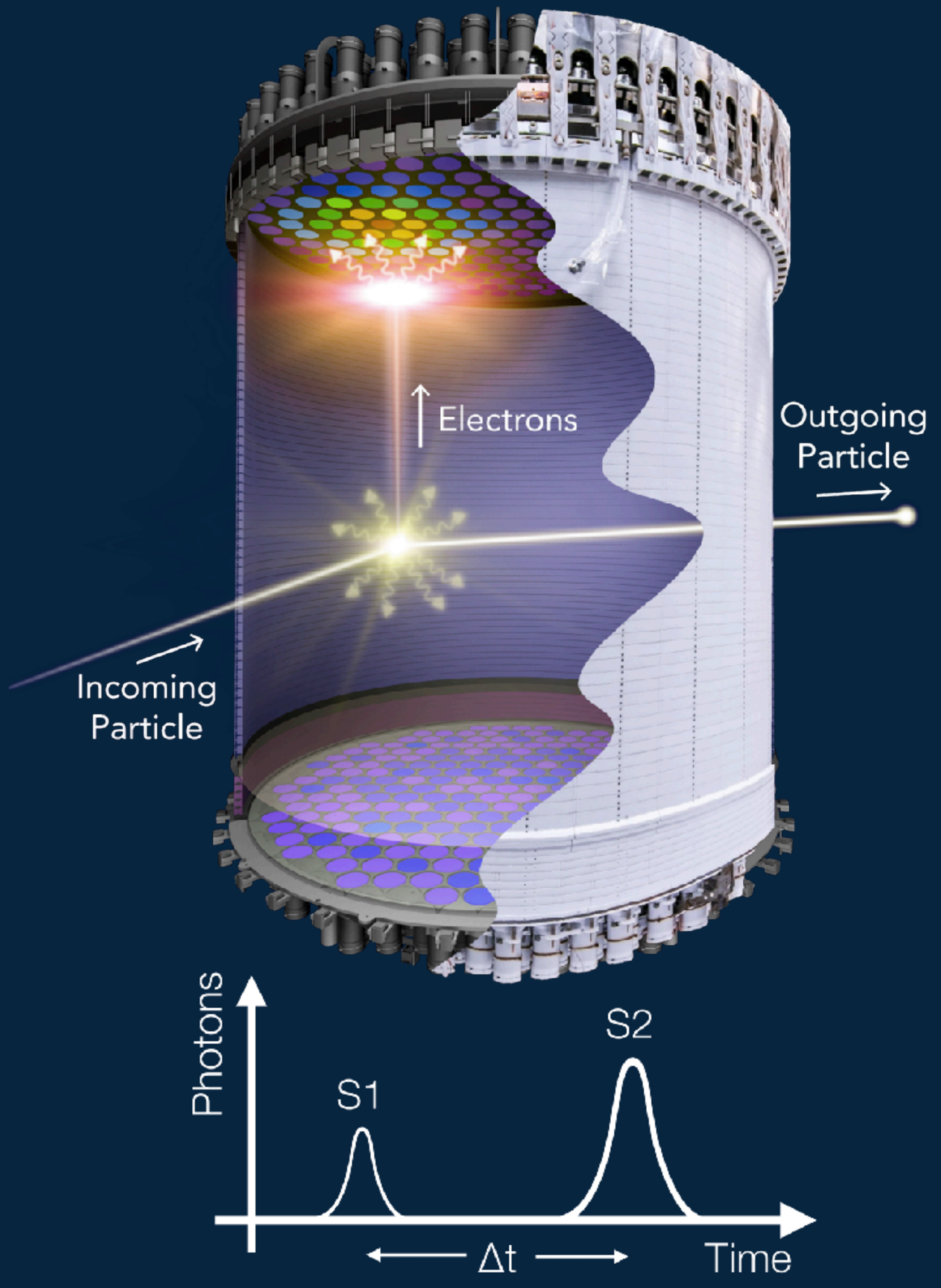
April 29th

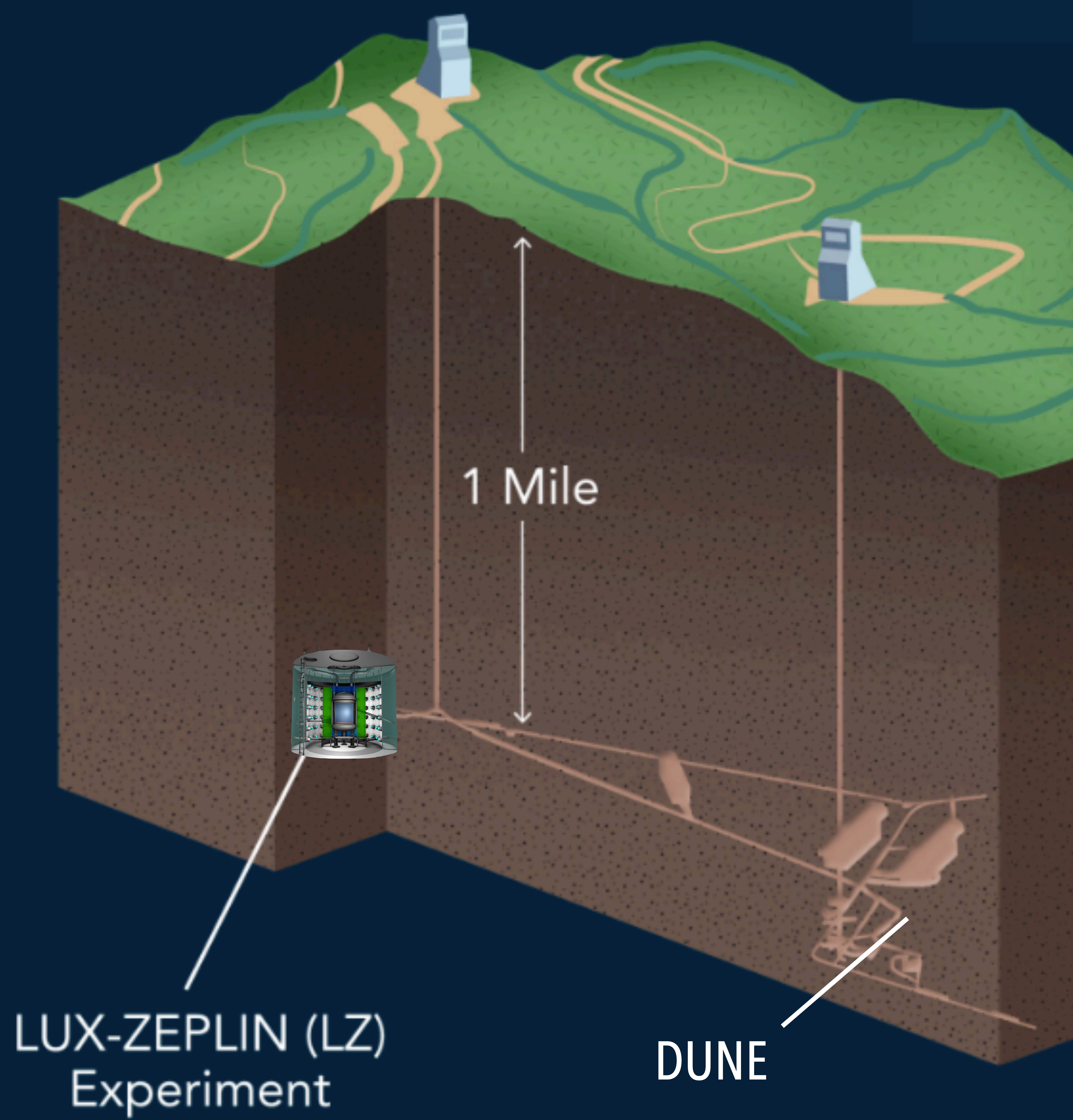
Postdoc at UCDAVIS UNIVERSITY OF CALIFORNIA

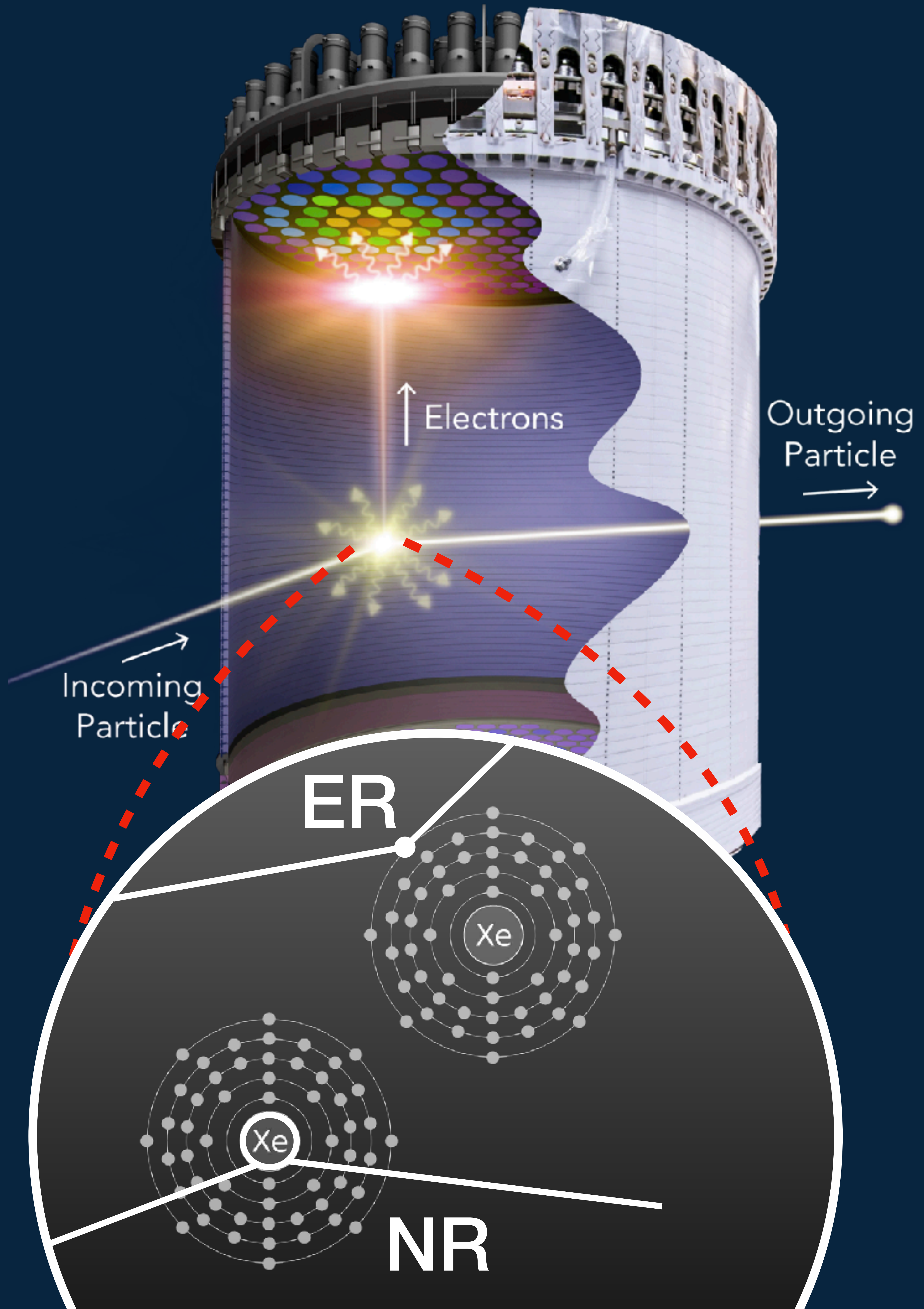


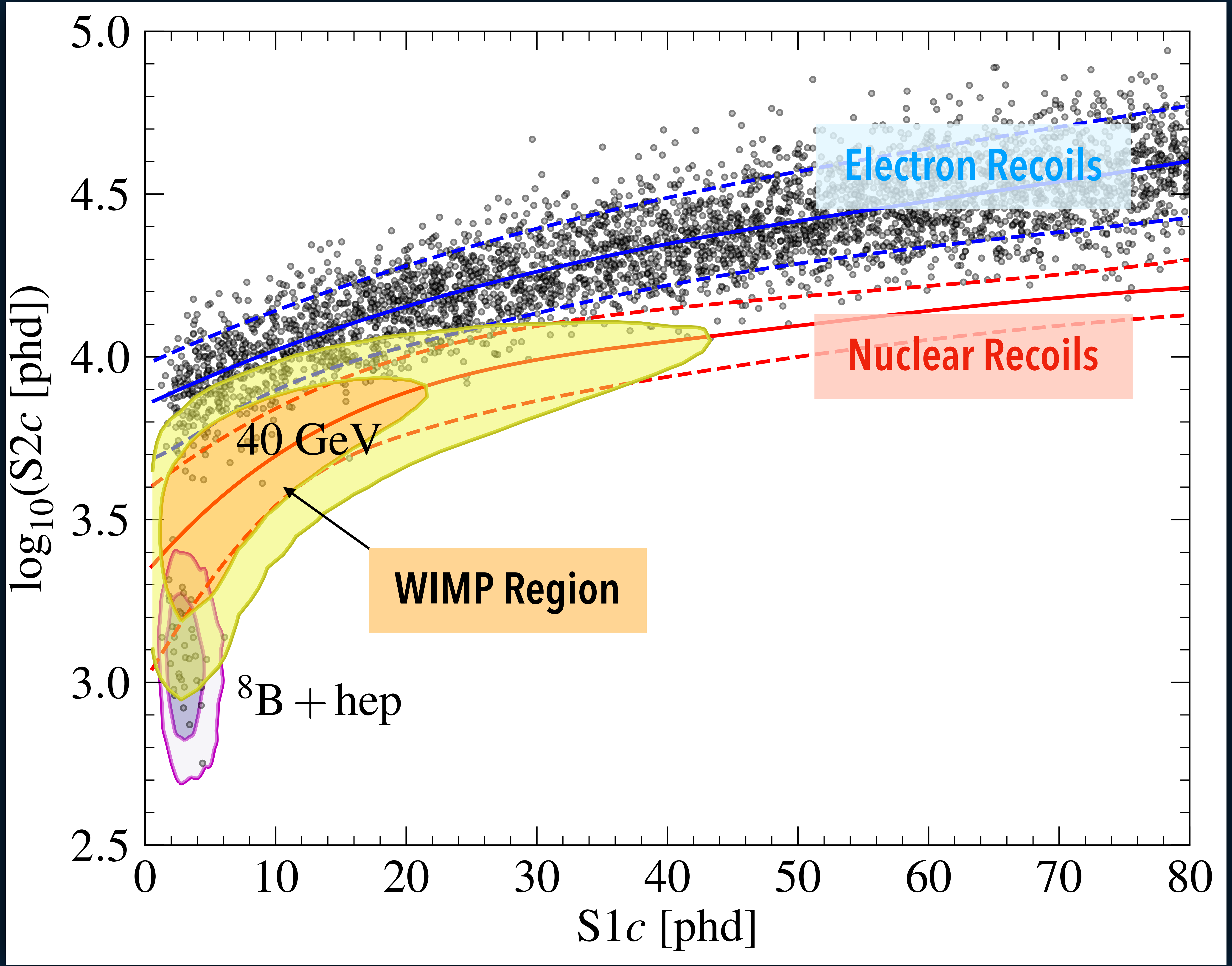
PhD at M UNIVERSITY OF MICHIGAN

Sanford Underground Research Facility
7 T
17 T
228 T
1 Mile
LUX-ZEPLIN (LZ) Experiment
DUNE


Electrons
Outgoing Particle
Incoming Particle
Photons
S1
S2
Δt
Time


Sanford Underground Research Facility
1 Mile
LUX-ZEPLIN (LZ) Experiment
DUNE

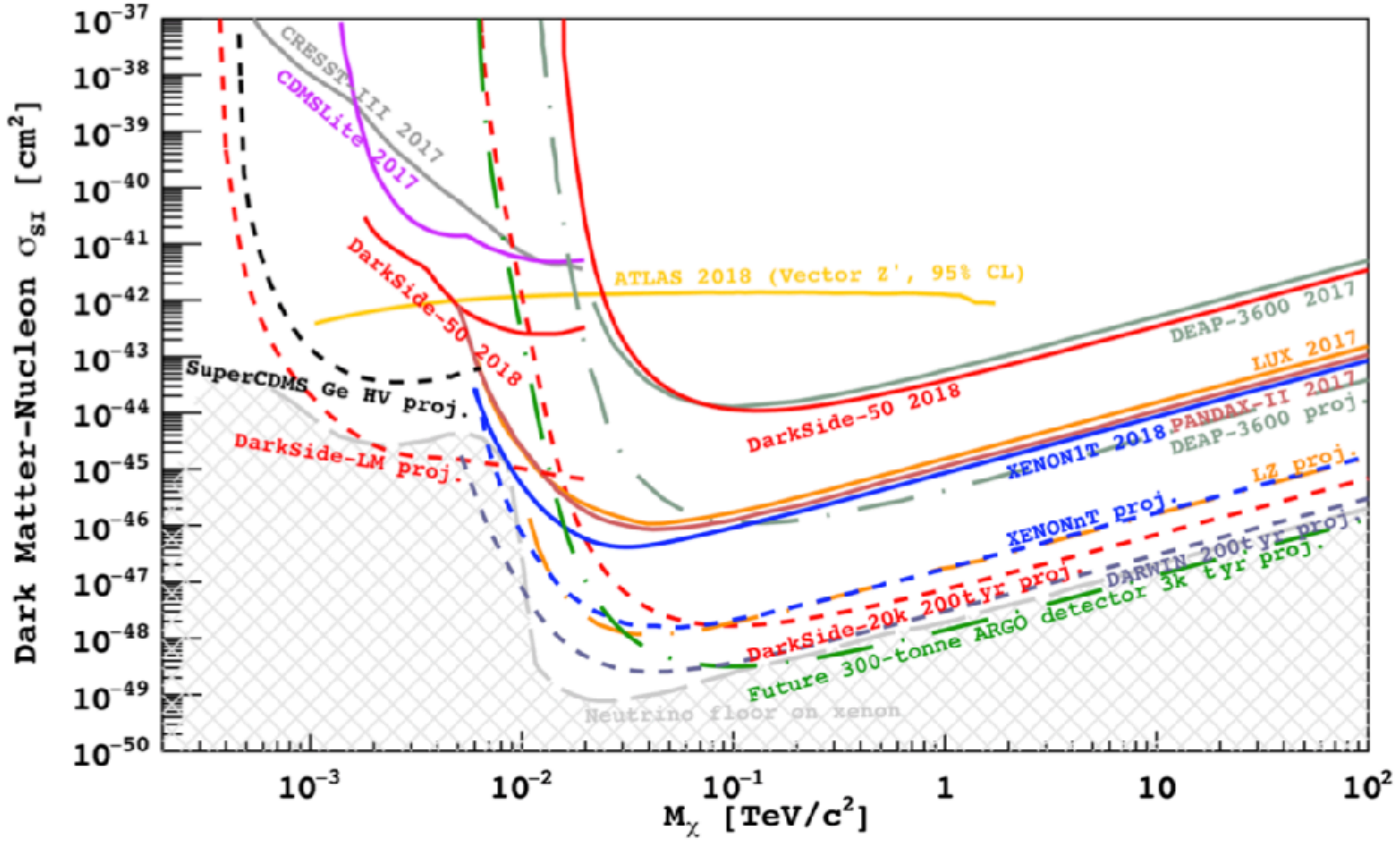


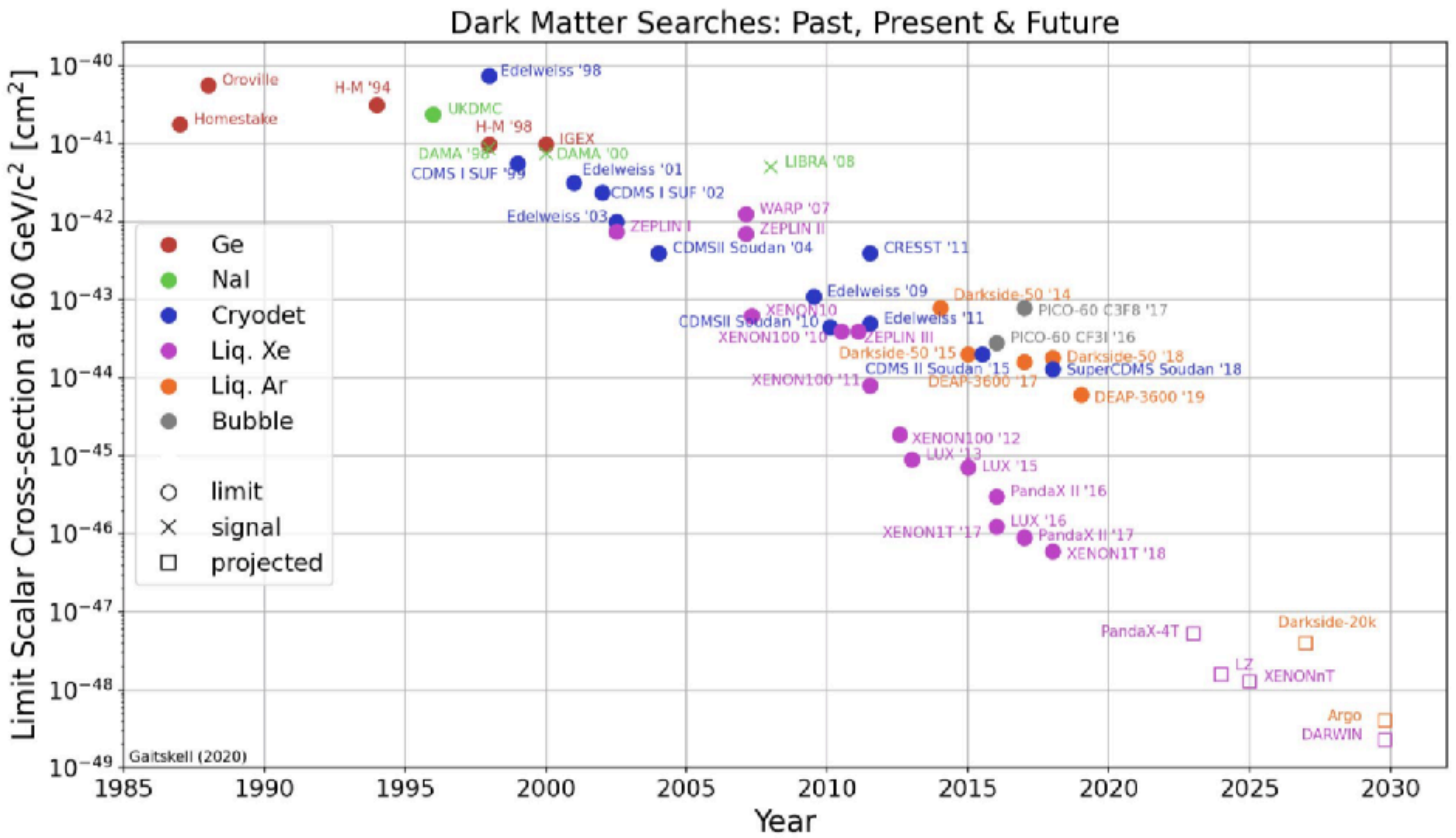


Look for anomalous nuclear recoils in a low-background detector.

Most background events are ER-like…

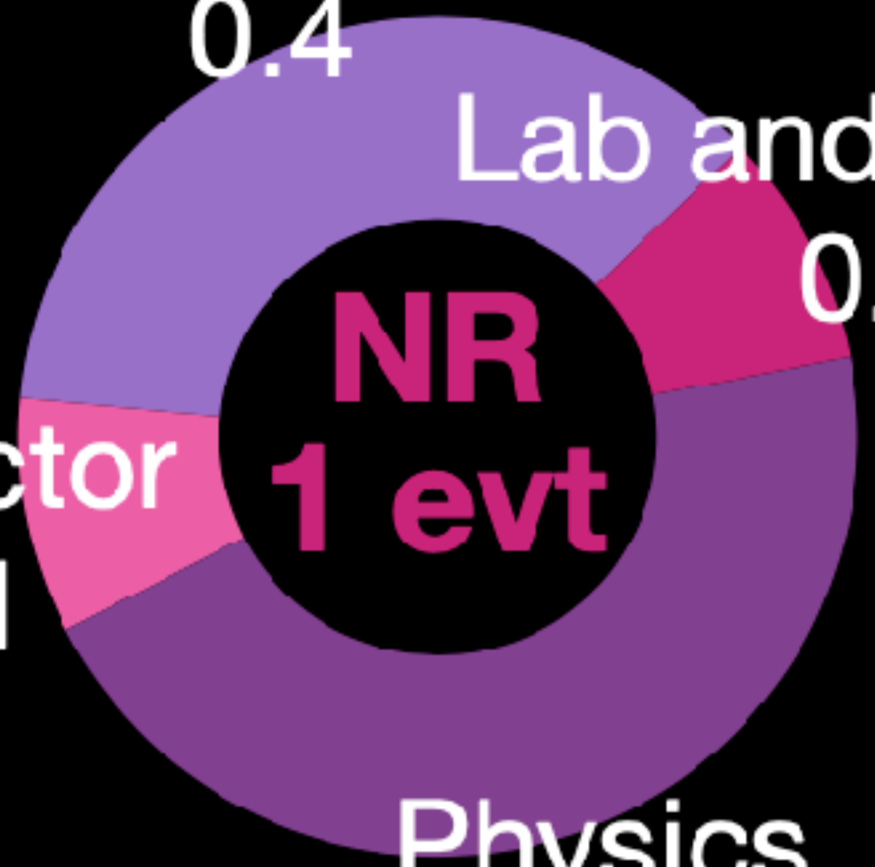
Background NR events need to be vetoed!

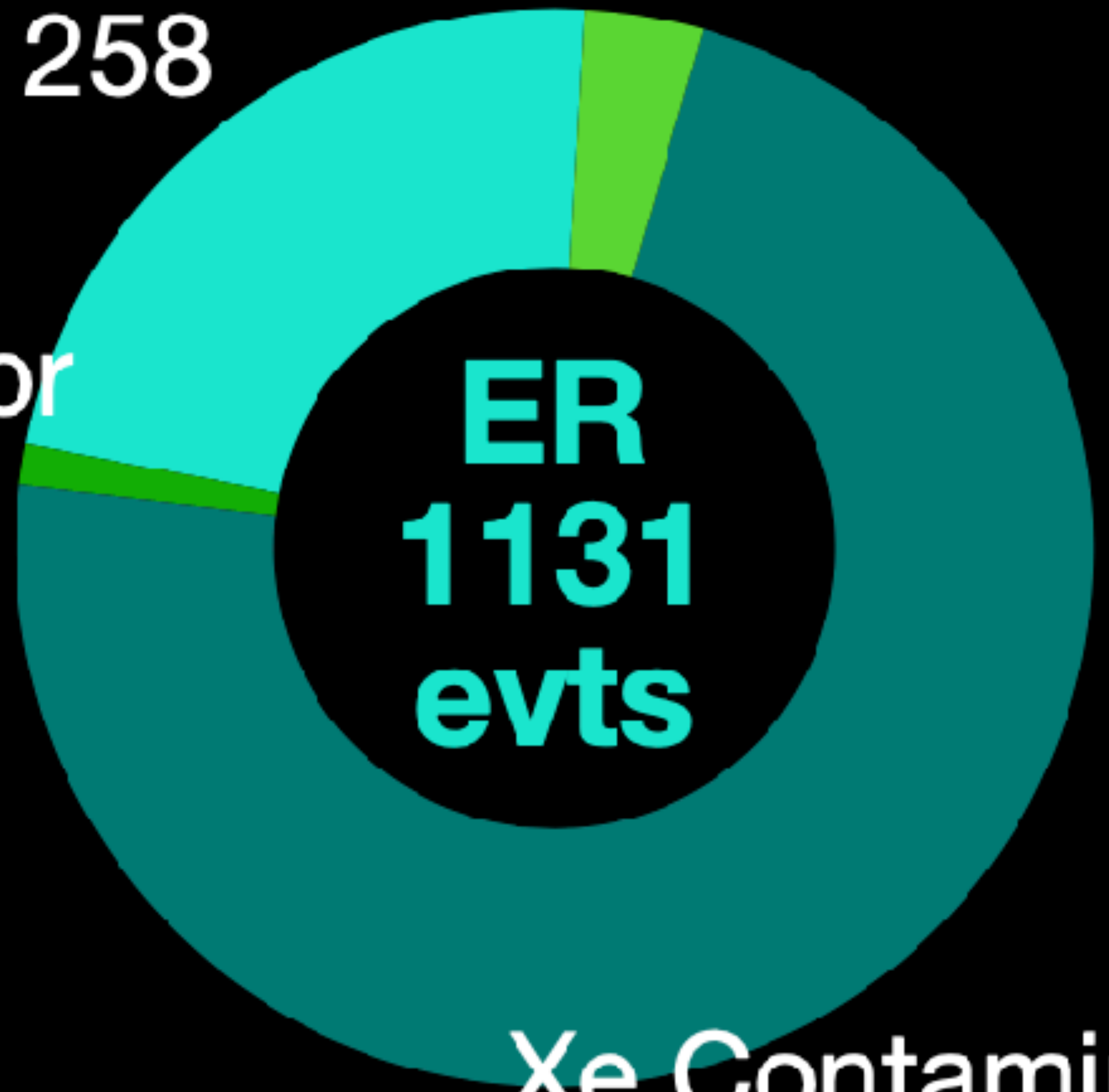

Dark Matter-Nucleon σ_{SI} [cm^2]
M_χ [TeV/c^2]
CRESST III 2017
CDMSLite 2017
DarkSide-50 2018
ATLAS 2018 (Vector Z', 95% CL)
SuperCDMS Ge HV proj.
DarkSide-LM proj.
DEAP-3600 2017
LUX 2017
PANDAX-II 2017
DEAP-3600 proj.
XENON1T 2018
LZ proj.
XENONnT proj.
DarkSide-20k 200t yr proj.
DARWIN 200t yr proj.
Future 300-tonne ARGO detector 3k tyr proj.
Neutrino floor on xenon


Dark Matter Searches: Past, Present & Future
Limit Scalar Cross-section at 60 GeV/c^2 [cm^2]
Year
Ge
NaI
Cryodet
Liq. Xe
Liq. Ar
Bubble
limit
signal
projected
Oroville
Homestake
H-M '94
UKDMC
H-M '98
IGEX
DAMA '98
DAMA '00
Edelweiss '98
CDMS I SUF '99
Edelweiss '01
CDMS I SUF '02
Edelweiss '03
ZEPLIN I
CDMSII Soudan '04
LIBRA '08
WARP '07
ZEPLIN II
CRESST '11
Edelweiss '09
XENON10
CDMSII Soudan '10
XENON100 '10
ZEPLIN III
Edelweiss '11
Darkside-50 '14
PICO-60 C3F8 '17
PICO-60 CF3I '16
Darkside-50 '15
CDMS II Soudan '15
Darkside-50 '18
SuperCDMS Soudan '18
DEAP-3600 '17
XENON100 '11
DEAP-3600 '19
XENON100 '12
LUX '13
LUX '15
PandaX II '16
LUX '16
XENON1T '17
PandaX II '17
XENON1T '18
PandaX-4T
Darkside-20k
LZ
XENONnT
Argo
DARWIN
Gaitskell (2020)

Background Expectation

WIMP ROI - 1000d - 5.6t fiducial





In signal region after cuts

0.52 NR events
5.66 ER events

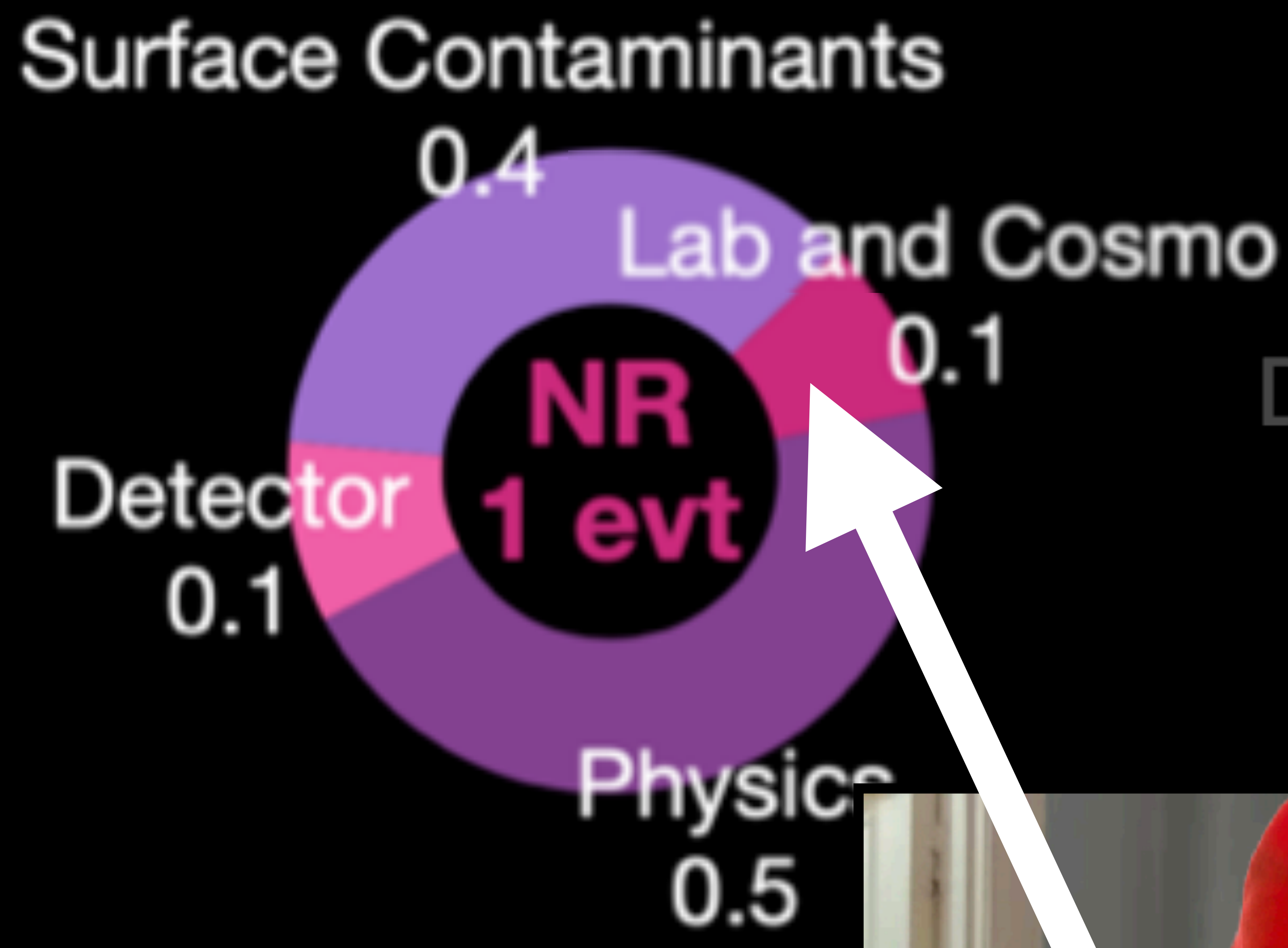
UCL

arxiv1802.06039

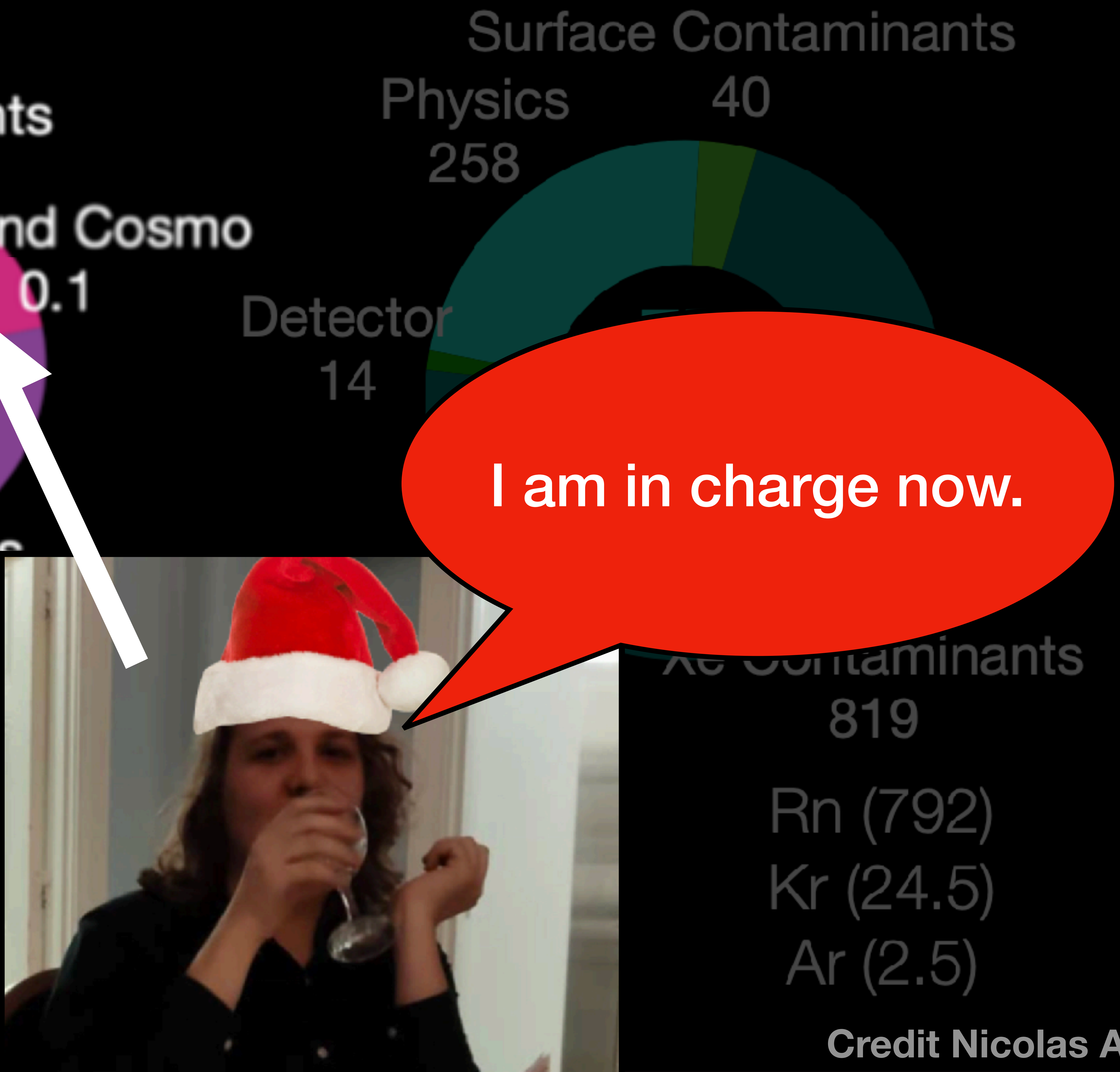
Credit Nicolas Angelides - UCL

Background Expectation

WIMP ROI - 1000d - 5.6t fiducial



In signal region after cuts



Credit Nicolas Angelides - UCL

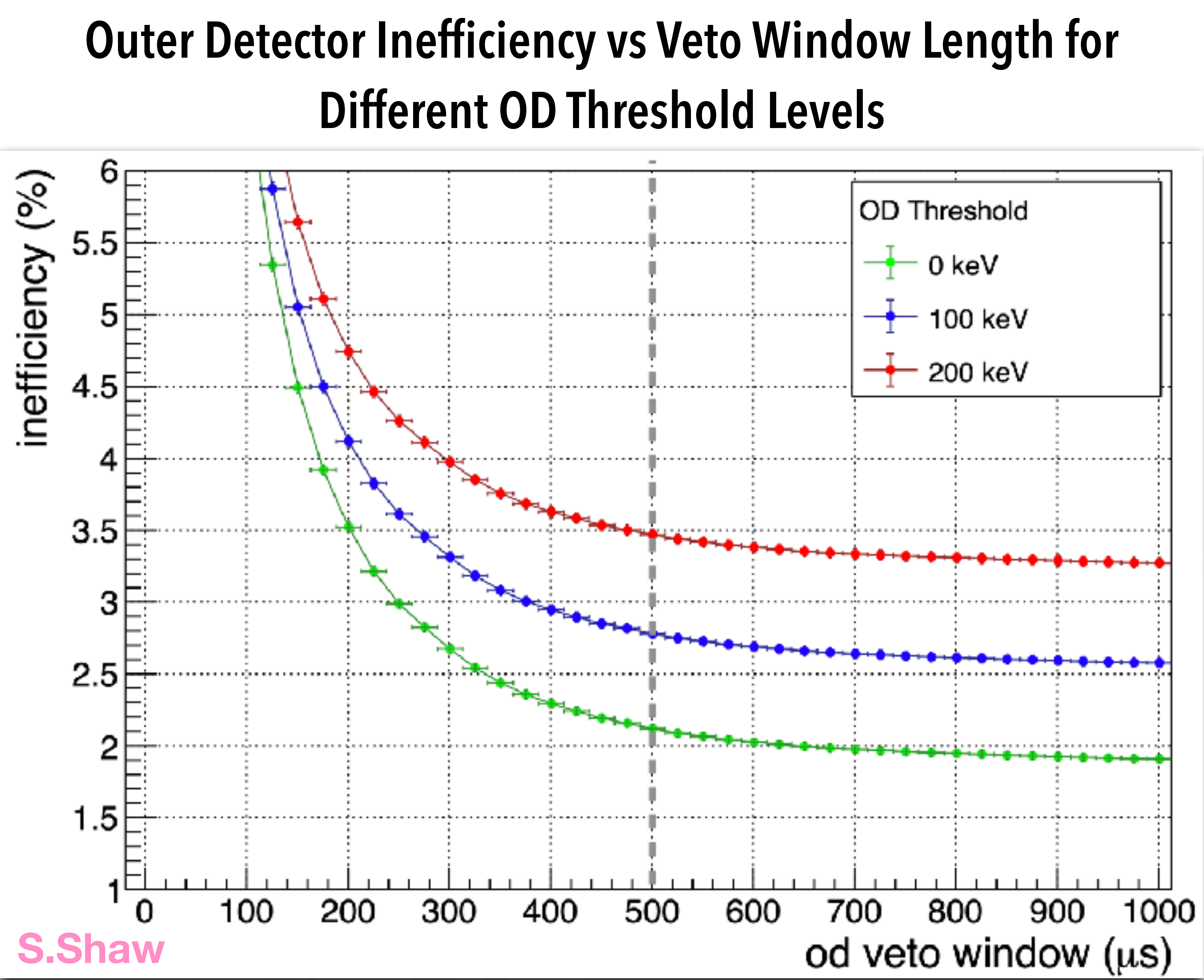

Electrons
Outgoing Particle
Incoming Particle
60cm
110cm

17 T Gadolinium loaded liquid scintillator

At 200 keV threshold, 500 μs window, the OD is only 3.5% inefficient!

∴ 96.5 % of neutrons that single scatter within the region of interest in the TPC (mimicking a WIMP) are vetoed by the OD.

Relies heavily on having a fully calibrated OD.



60cm

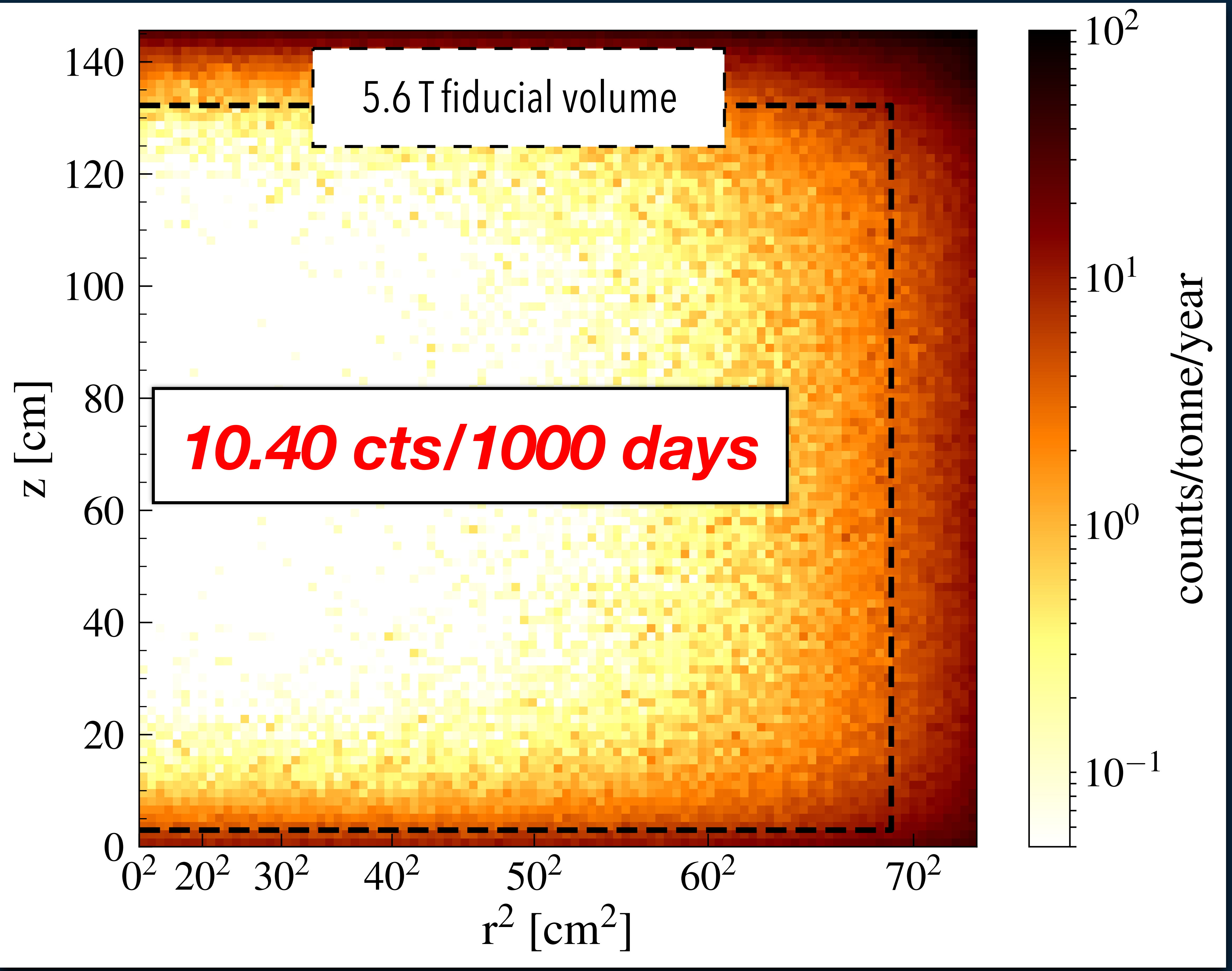
110cm

230 T Water

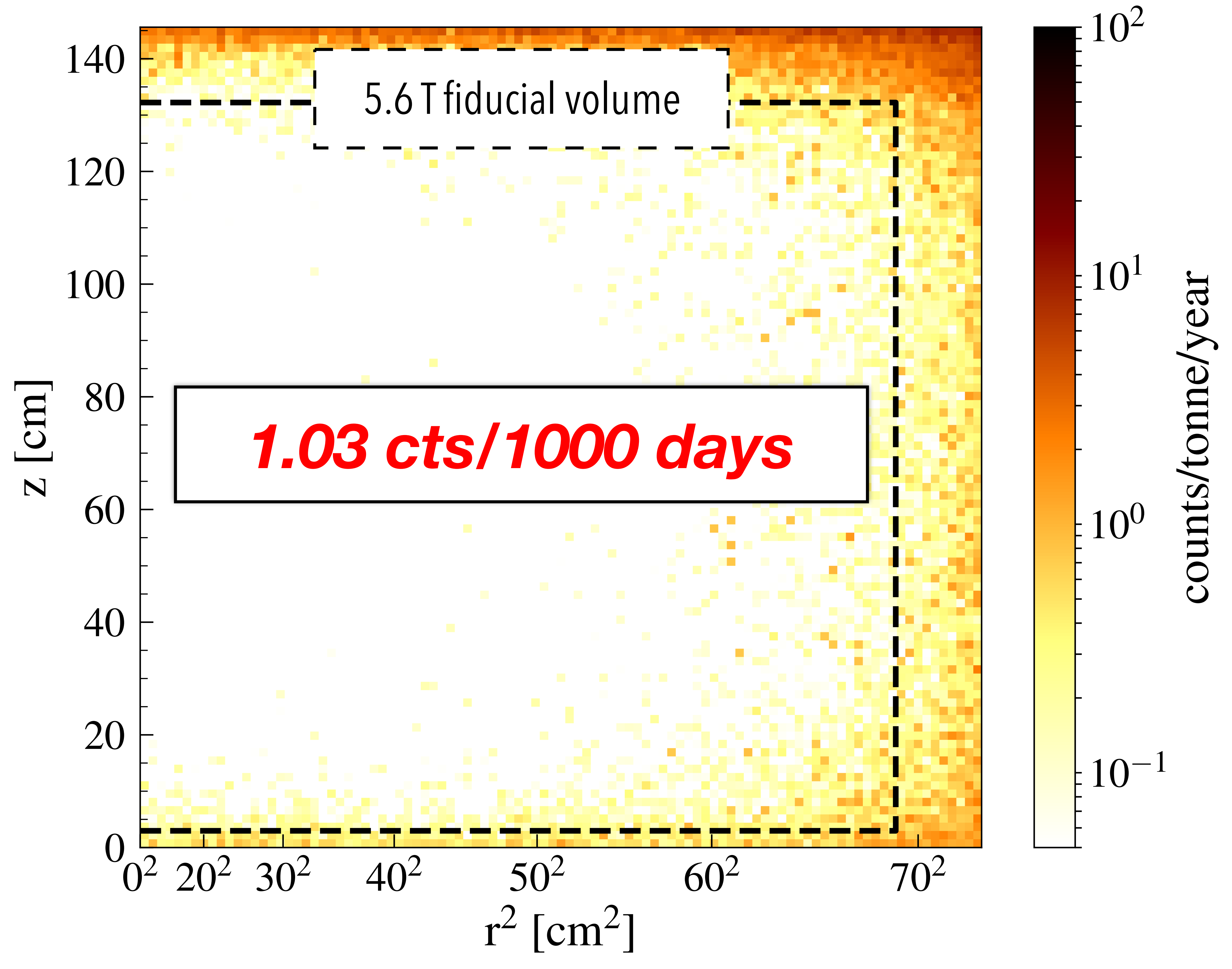
120 8” PMT

Single scatter TPC event distributions for all significant Neutron Recoil (NR) backgrounds in the region of interest relevant to a 40 GeV/c^2 WIMP.

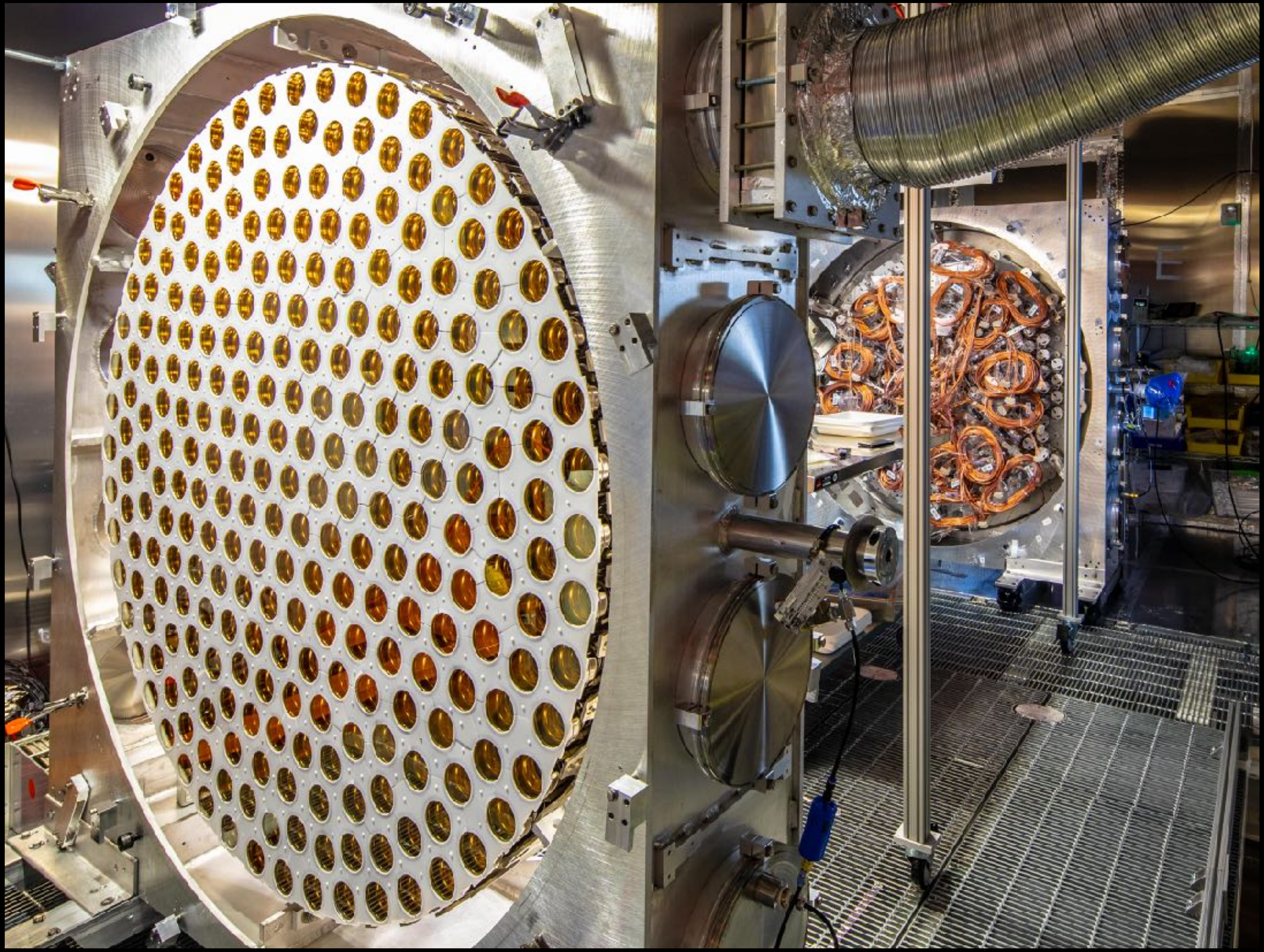
No Veto.



With Skin and OD Veto.



Bottom PMT Array



Top PMT Array


6,000 LB WLL


HOMESTAKE


DANGER
DO NOT OPEN GATE EXCEPT WHEN CAGE IS AT STATION
S
N

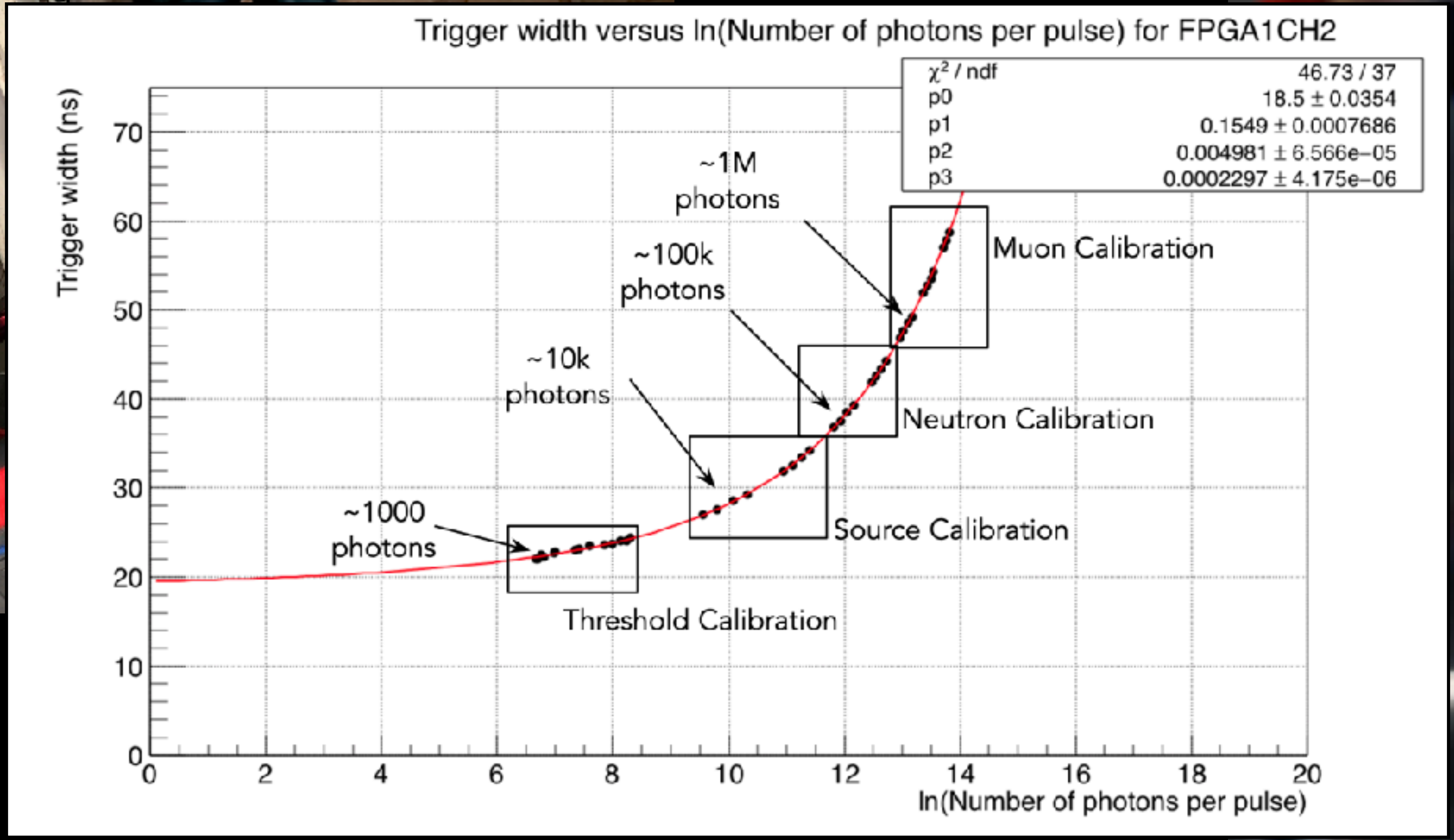
Credit Theresa Fruth

Credit Harvey


Electrons
Outgoing Particle
Incoming Particle

Electrons
Outgoing Particle
Optical Calibration Card (OCC)
OCS
UNIVERSITY OF LIVERPOOL
CH5
CH6
CH7
CH8
CH1
CH2
CH3
CH4
1
FPGA Board
Optical Coupler
Pulser Board (PB)
4 on the front
4 on the rear
Photodiode (PD) Board
(not present in the above photo)


OCS
UNIVERSITY OF
LIVERPOOL
USB ctrl
2
4
6
8
10
CH1
CH2
CH3
CH6
CH7
CH8


Trigger width versus ln(Number of photons per pulse) for FPGA1CH2
χ^2 / ndf 46.73 / 37
p0 18.5 ± 0.0354
p1 0.1549 ± 0.0007686
p2 0.004981 ± 6.566e−05
p3 0.0002297 ± 4.175e−06
Trigger width (ns)
ln(Number of photons per pulse)
~1M photons
~100k photons
~10k photons
~1000 photons
Muon Calibration
Neutron Calibration
Source Calibration
Threshold Calibration
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20


Cornell University
We gratefully acknowledge support from the Simons Foundation and member institutions.
arXiv.org > physics > arXiv:2102.06281
Search...
All fields
Search
Help | Advanced Search
Physics > Instrumentation and Detectors
[Submitted on 11 Feb 2021 (v1), last revised 16 Feb 2021 (this version, v2)]
Optical Calibration System for the LUX-ZEPLIN (LZ) Outer Detector
NIM-A Submission Pending - finishing final corrections.
primary aim of vetoing neutron single-scatter events in the liquid xenon that could mimic a weakly interacting massive particle (WIMP) dark matter signal. The outer detector consists of approximately 17 tonnes of gadolinium-loaded liquid scintillator confined to 10 acrylic tanks surrounding the cryostat and 228,000 litres of water as the outermost layer. It will be monitored by 120 inward-facing 8-inch photomultiplier tubes. An optical calibration system has been designed and built to calibrate and monitor these photomultiplier tubes allowing the veto system to reach its required efficiency and thus ensuring that LUX-ZEPLIN meets its target sensitivity.
Subjects: Instrumentation and Detectors (physics.ins-det)
Cite as: arXiv:2102.06281 [physics.ins-det]
(or arXiv:2102.06281v2 [physics.ins-det] for this version)
Submission history
From: William Turner [view email]
[v1] Thu, 11 Feb 2021 21:43:14 UTC (10,040 KB)
[v2] Tue, 16 Feb 2021 10:59:37 UTC (35,226 KB)
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physics
References & Citations
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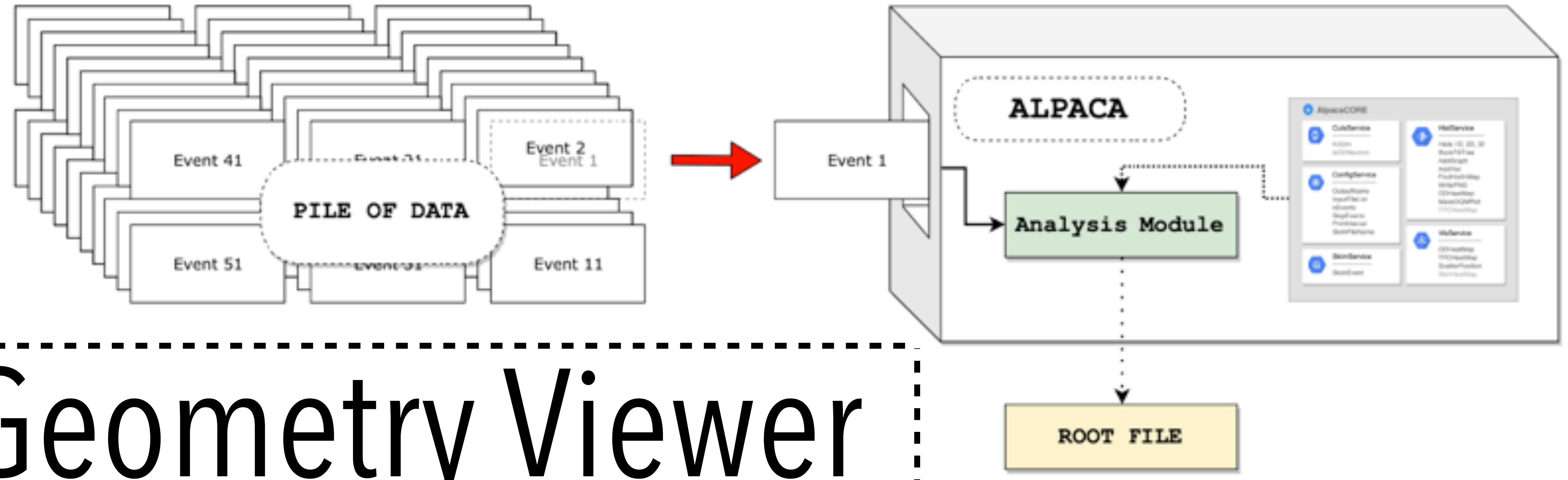
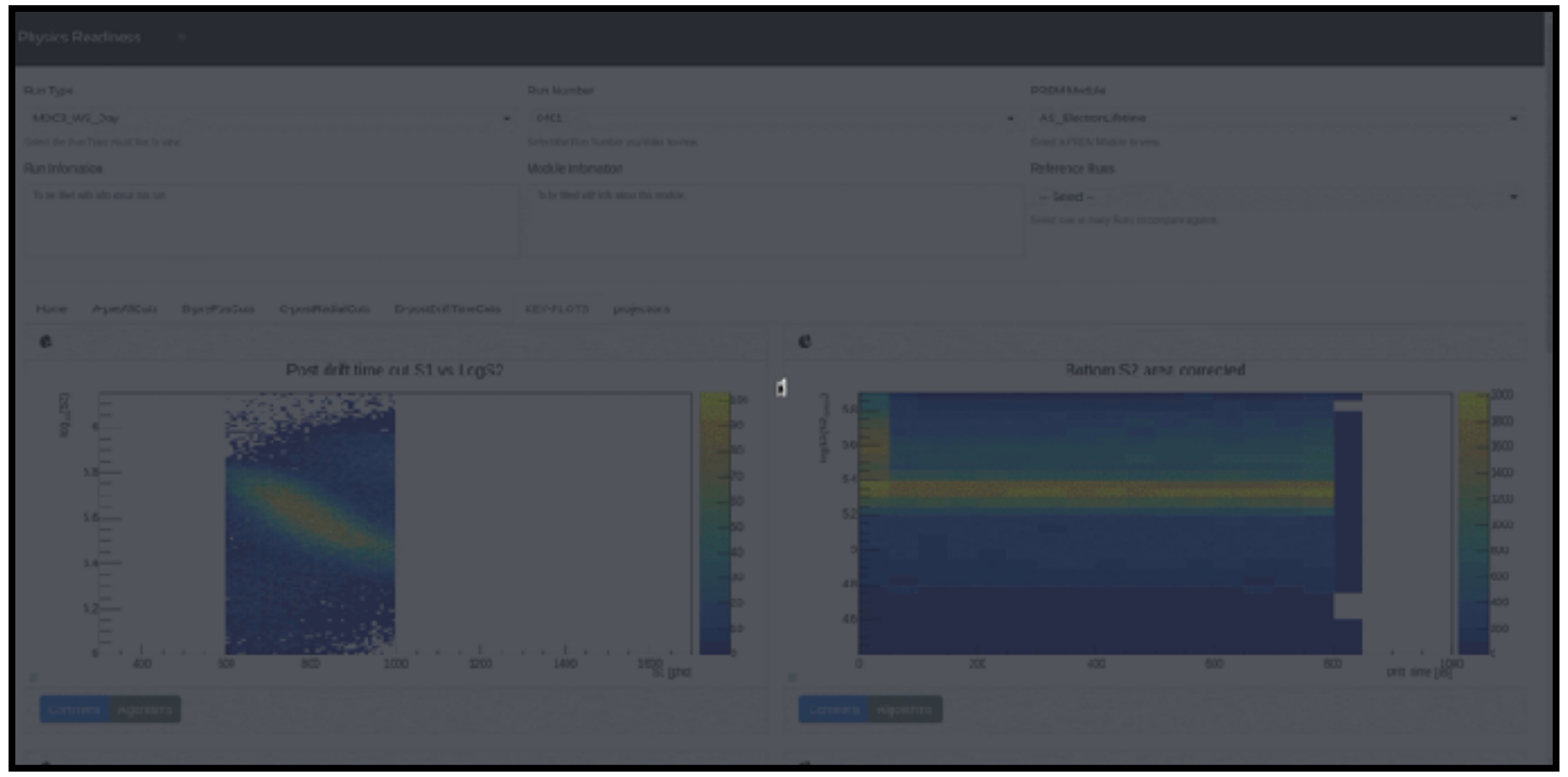
ALPACA
Analysis Framework

- The official LZ data analysis framework.
- Modular so analysis modules are ‘plug and play’.
- Many ‘Services’ to make the life of an analyser easier *Shared Cuts, Plotting, Skimming, Visualising.*
- Contains job submission engines for UKDC.

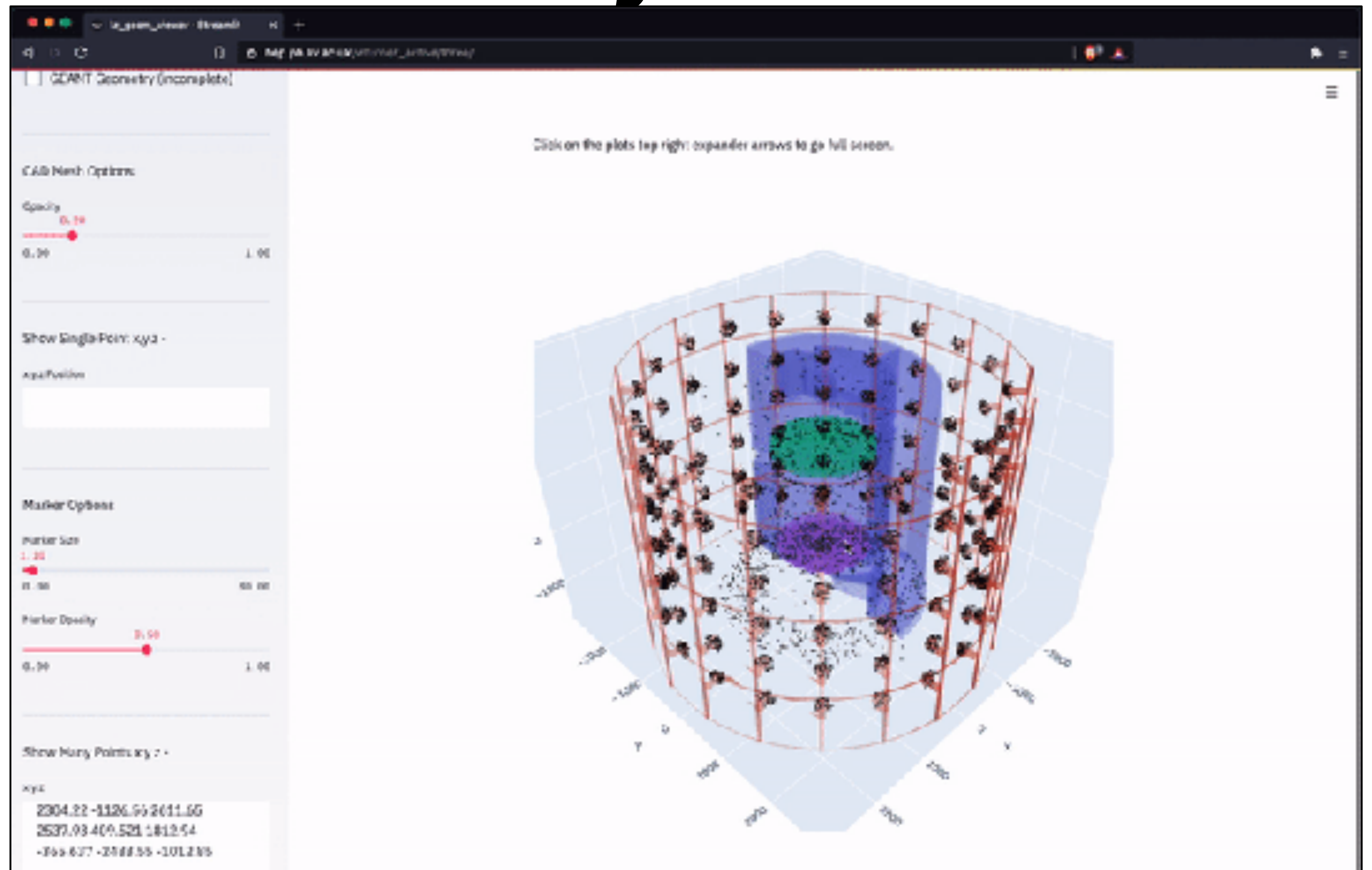


PREM
Offline DQM

- The official Offline Data Quality Monitor
- Uses ALPACA for data analysis and plot making.
- Creates JSON object containing all plots and analysis results.
- Website to view and compare these data monitoring modules over different runs.



Geometry Viewer

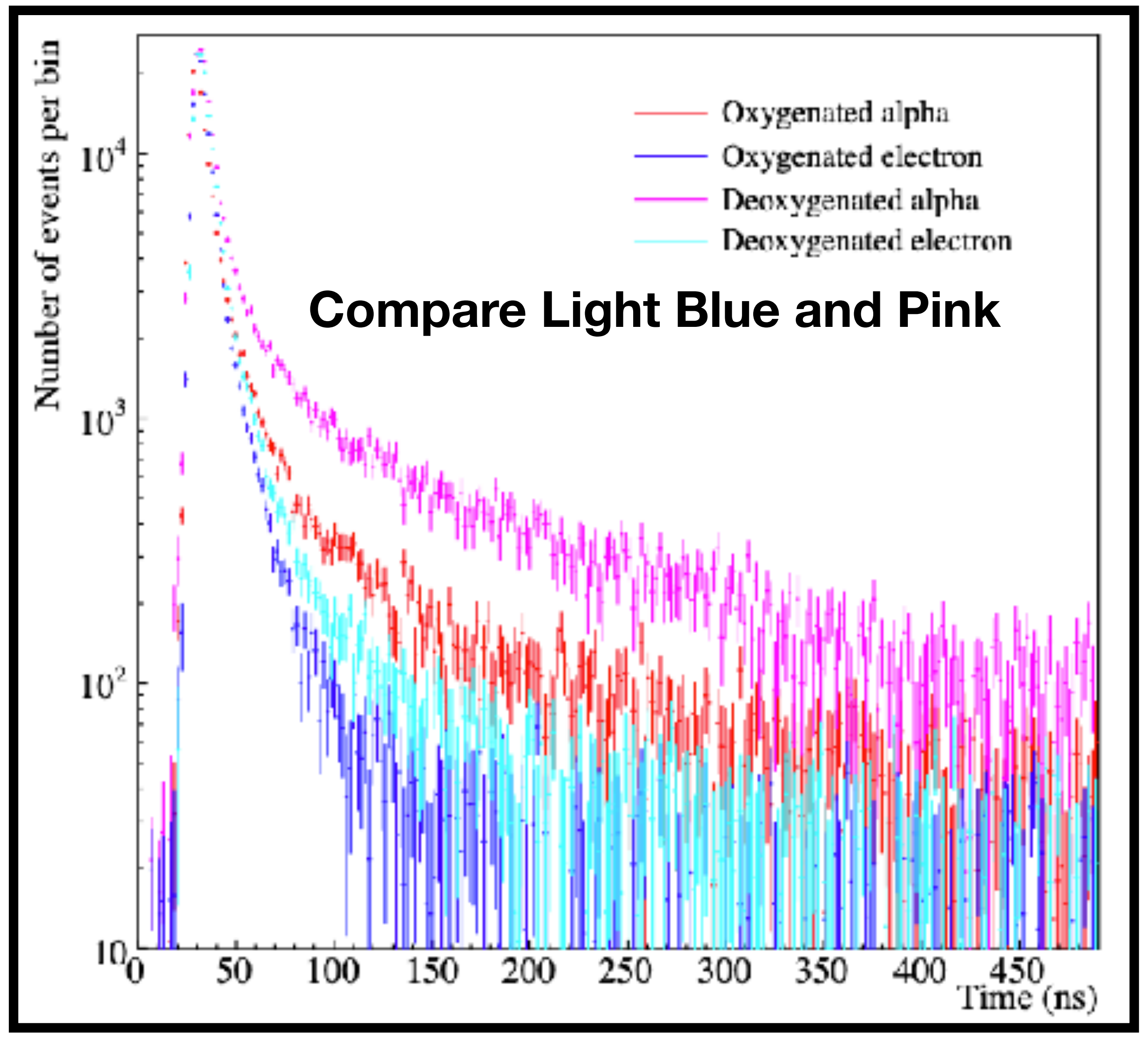


Checking the background birth positions are sensible.

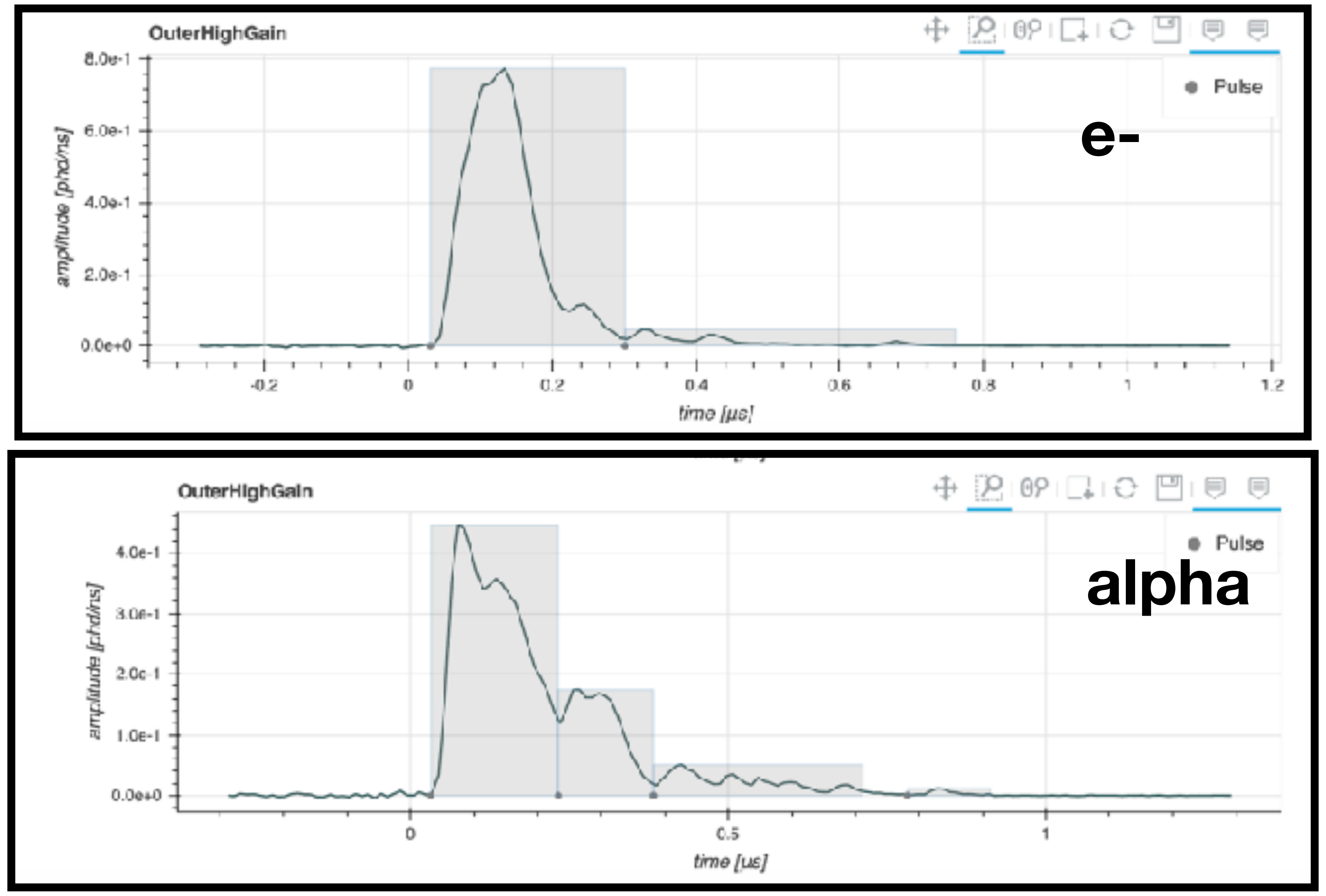
- Web-based 3D geometry viewer, easy for anyone to view.
- Each PMT is labeled and can mouse-over for position info.
- Can load sim geometry and CAD geometry.
- Can load sim/data hit positions to view ontop of geometry.
- Can load csv formatted simulated hit points and generate a 3D mesh to compare against CAD.

Use OD pulse shapes to do particle identification

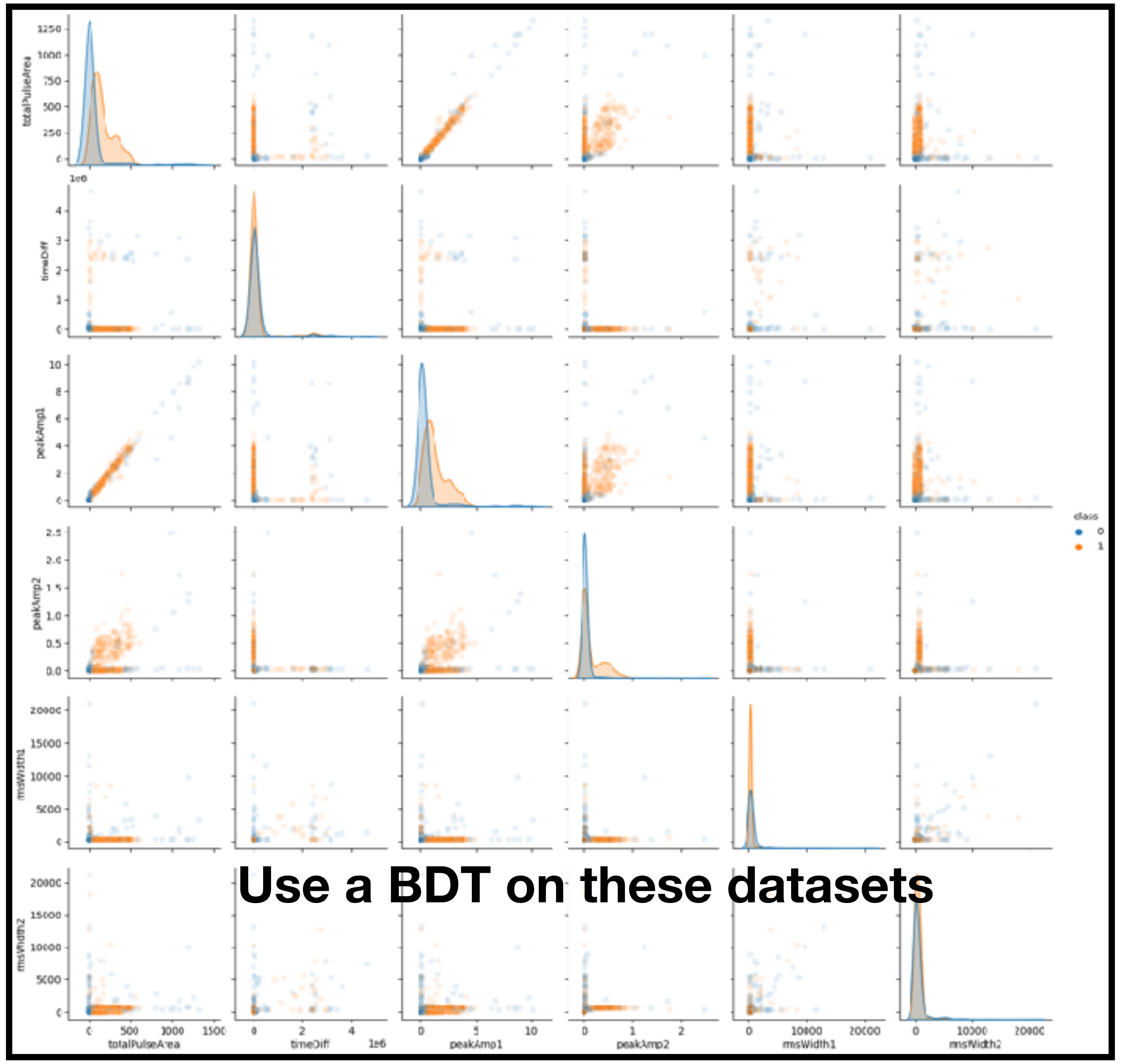
- Alice in charge of Neutron selection and made huge progress on neutron/gamma separation.
- Main background to this selection are Bi214->Po214 decays.
- Can remove this with pulse shape discrimination between e- and alpha in the Gd-Scintillator.
- Export this trained BDT in ONNX format to use in ALPACA analysis.
- Sam is leading this work.

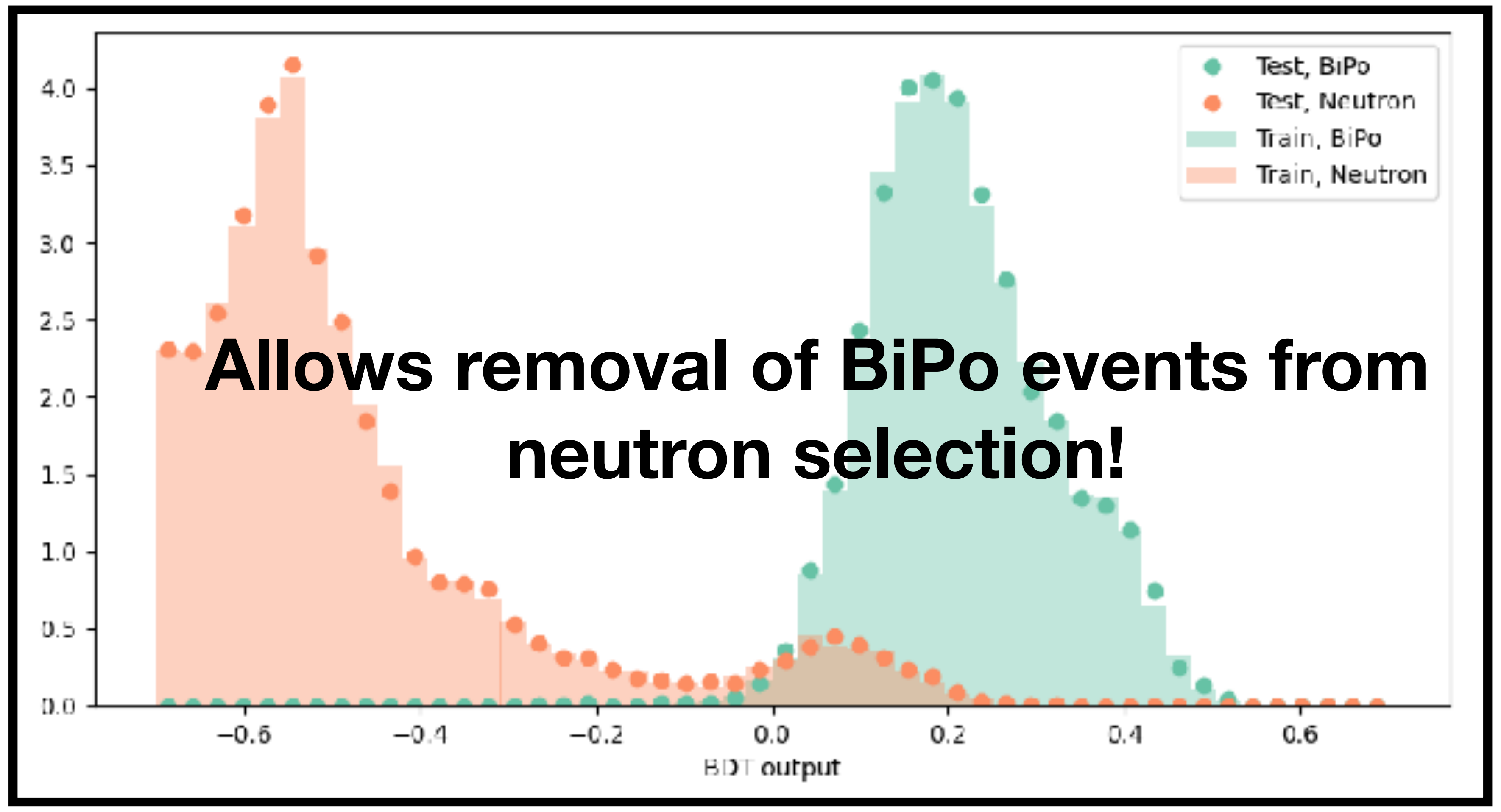


Used correct scintillator pulse shapes for different particles.



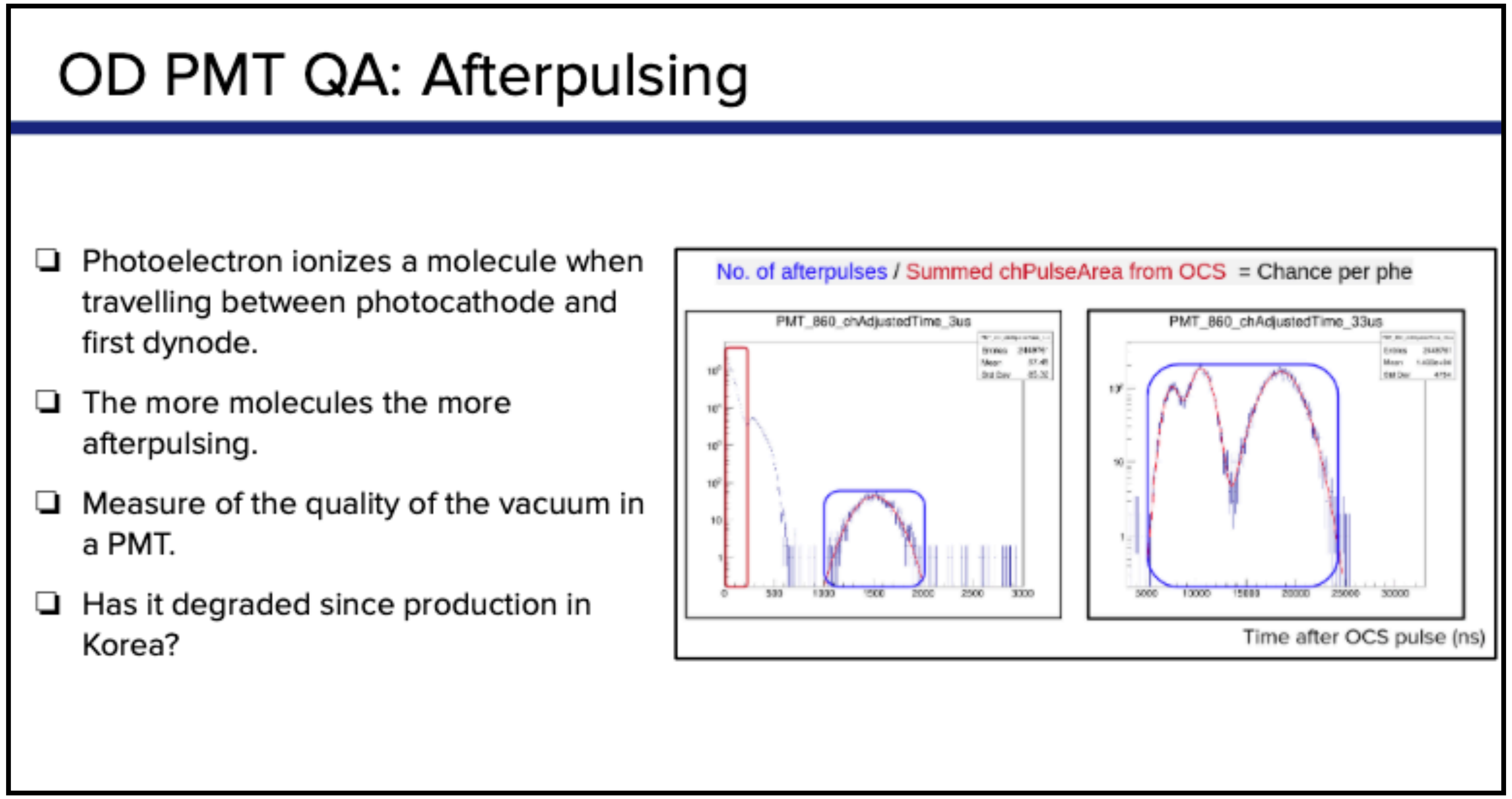
Simulated BiPo and neutron events in the Liquid Scintillator.

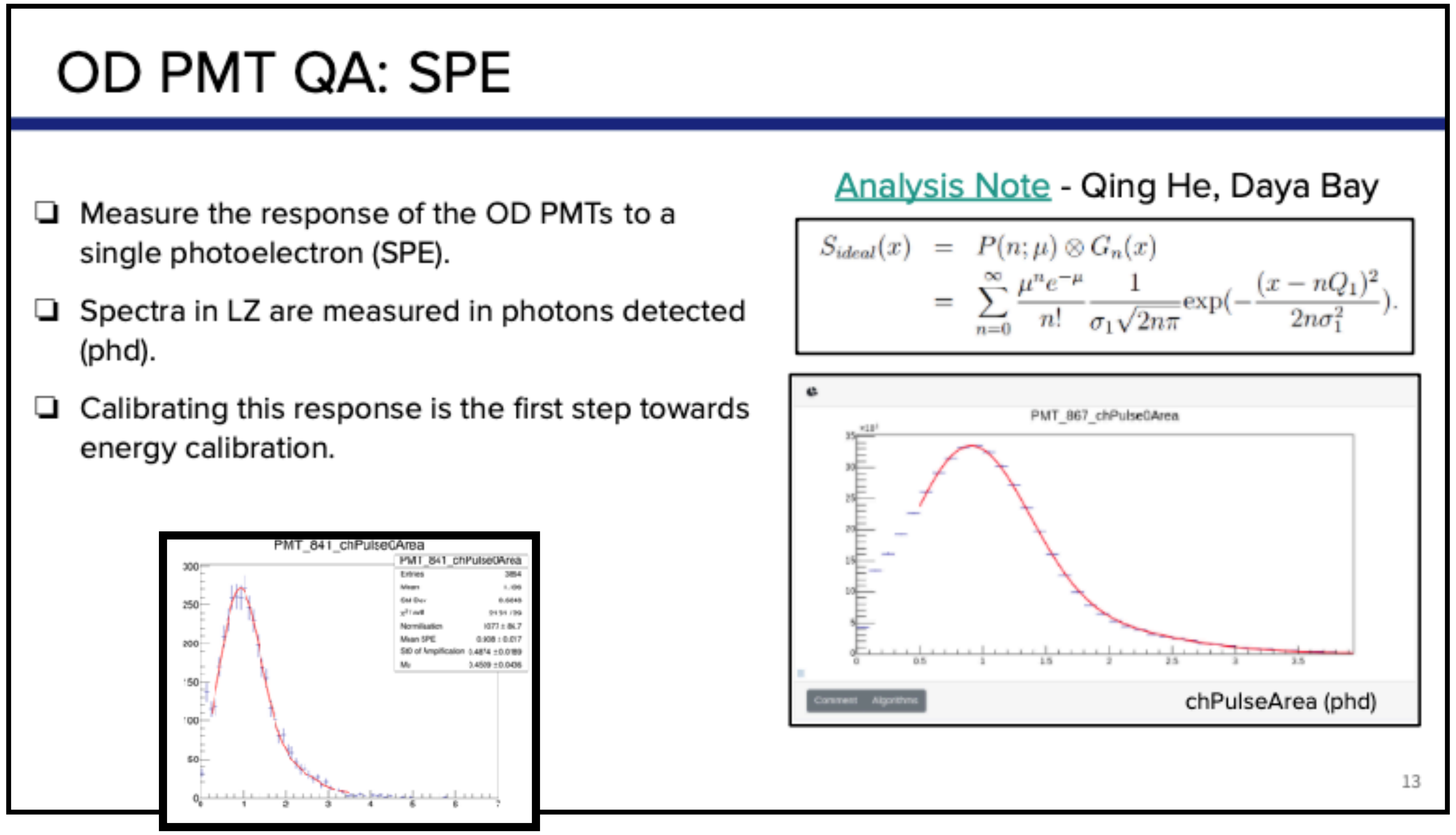




Outer Detector Commissioning

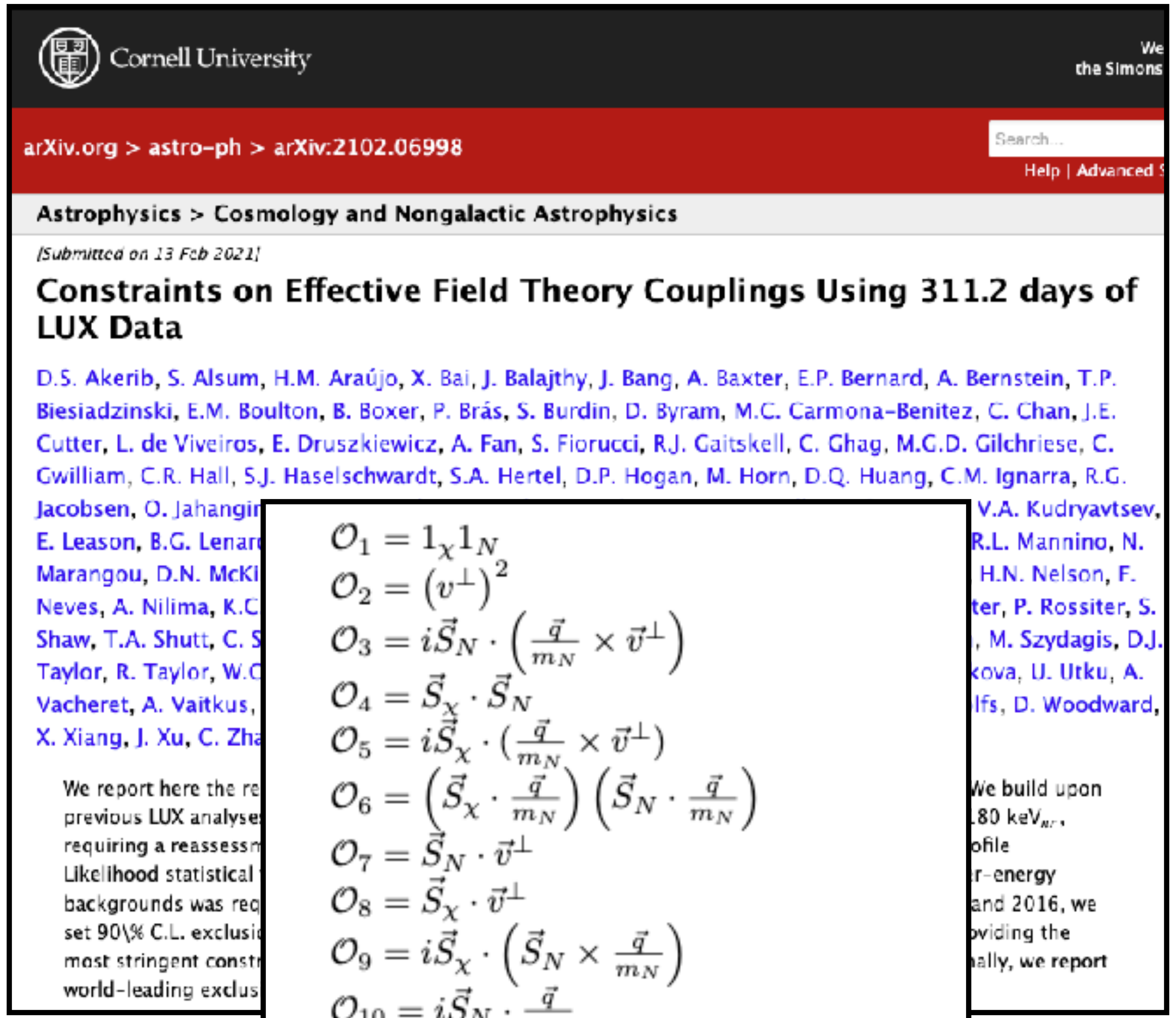
- Liverpool playing a large role in OD construction and commissioning.
- OD PMT Single Photoelectron calibration and After-pulsing calibration carried out on simulated OCS data.
- Ready for the real data.



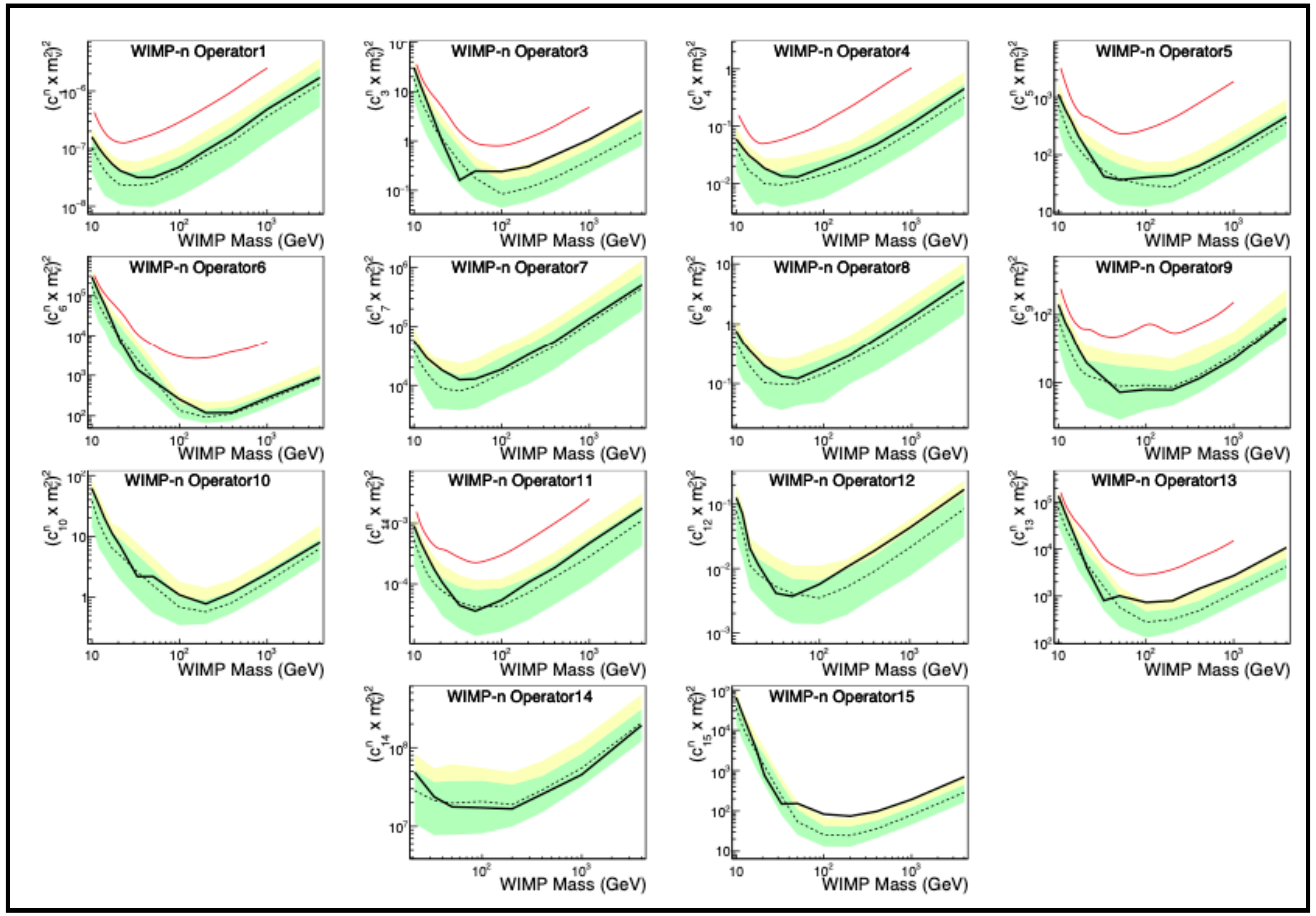


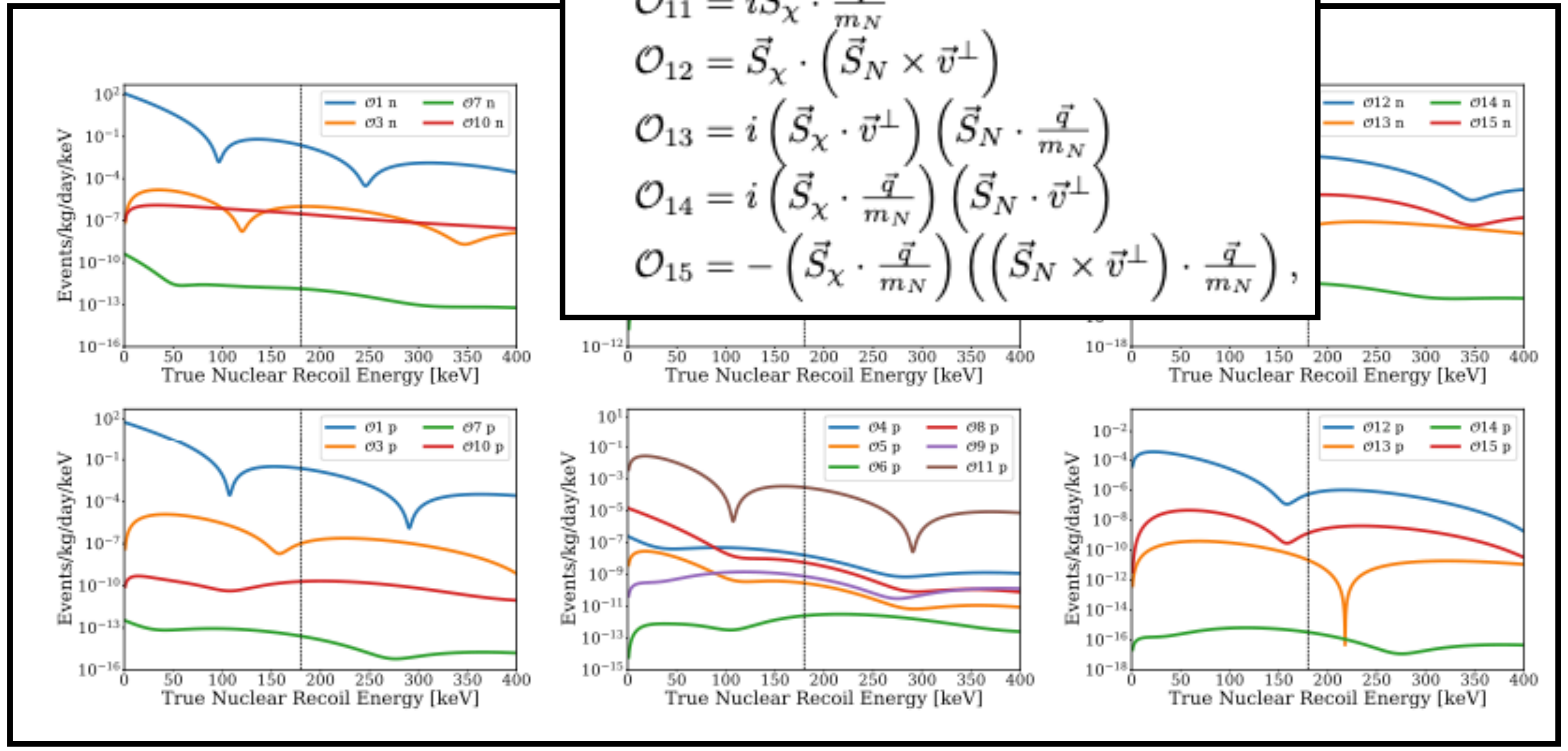
LUX Effective Field Theory

- Billy Boxer lead the EFT analysis.
- Have published a very nice result from LUX data.
- World-leading exclusion limits on inelastic EFT WIMP-nucleon recoils.


Cornell University
arXiv.org > astro-ph > arXiv:2102.06998
Astrophysics > Cosmology and Nongalactic Astrophysics
[Submitted on 13 Feb 2021]
Constraints on Effective Field Theory Couplings Using 311.2 days of LUX Data
D.S. Akerib, S. Alsum, H.M. Araújo, X. Bai, J. Balajthy, J. Bang, A. Baxter, E.P. Bernard, A. Bernstein, T.P. Biesiadzinski, E.M. Boulton, B. Boxer, P. Brás, S. Burdin, D. Byram, M.C. Carmona-Benitez, C. Chan, J.E. Cutter, L. de Viveiros, E. Druszkiewicz, A. Fan, S. Fiorucci, R.J. Gaitskell, C. Ghag, M.G.D. Gilchriese, C. Gwilliam, C.R. Hall, S.J. Haselschwardt, S.A. Hertel, D.P. Hogan, M. Horn, D.Q. Huang, C.M. Ignarra, R.G. Jacobsen, O. Jahangir ... V.A. Kudryavtsev, E. Leason, B.G. Lenar ... R.L. Mannino, N. Marangou, D.N. McKi ... H.N. Nelson, F. Neves, A. Nilima, K.C ... ter, P. Rossiter, S. Shaw, T.A. Shutt, C. S ... , M. Szydagis, D.J. Taylor, R. Taylor, W.C ... kova, U. Utku, A. Vacheret, A. Vaitkus, ... lfs, D. Woodward, X. Xiang, J. Xu, C. Zha ...
We report here the re ... We build upon previous LUX analyse ... 80 keV$_{nr}$, requiring a reassessm ... ofile Likelihood statistical ... r-energy backgrounds was req ... and 2016, we set 90\% C.L. exclusi ... oviding the most stringent constr ... ally, we report world-leading exclus ...

$$\mathcal{O}_1 = 1_\chi 1_N$$
$$\mathcal{O}_2 = (v^\perp)^2$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right)$$
$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right)$$
$$\mathcal{O}_6 = \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right)$$
$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$
$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$$
$$\mathcal{O}_9 = i\vec{S}_\chi \cdot \left(\vec{S}_N \times \frac{\vec{q}}{m_N}\right)$$
$$\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_{12} = \vec{S}_\chi \cdot \left(\vec{S}_N \times \vec{v}^\perp\right)$$
$$\mathcal{O}_{13} = i\left(\vec{S}_\chi \cdot \vec{v}^\perp\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right)$$
$$\mathcal{O}_{14} = i\left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \vec{v}^\perp\right)$$
$$\mathcal{O}_{15} = -\left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\left(\vec{S}_N \times \vec{v}^\perp\right) \cdot \frac{\vec{q}}{m_N}\right),$$





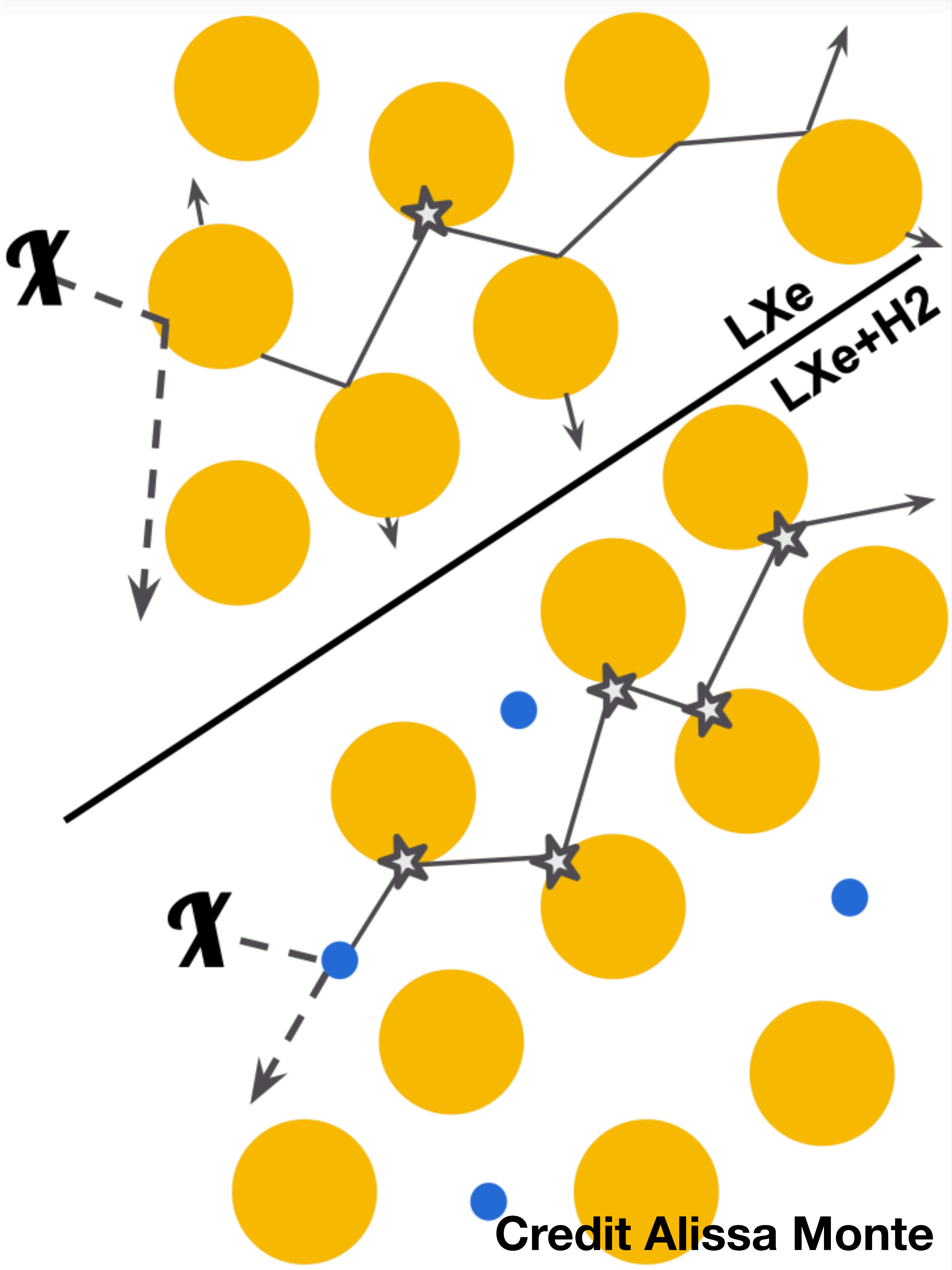
Other LXe Opportunities

HydroX

Doping LXe with a light target, like H2.

Pros.. lowers the mass reach, spin-dependent reach.

Cons.. Have to develop/build circulation/cryogenics/purification robust against presence of H2.



Other LXe Opportunities

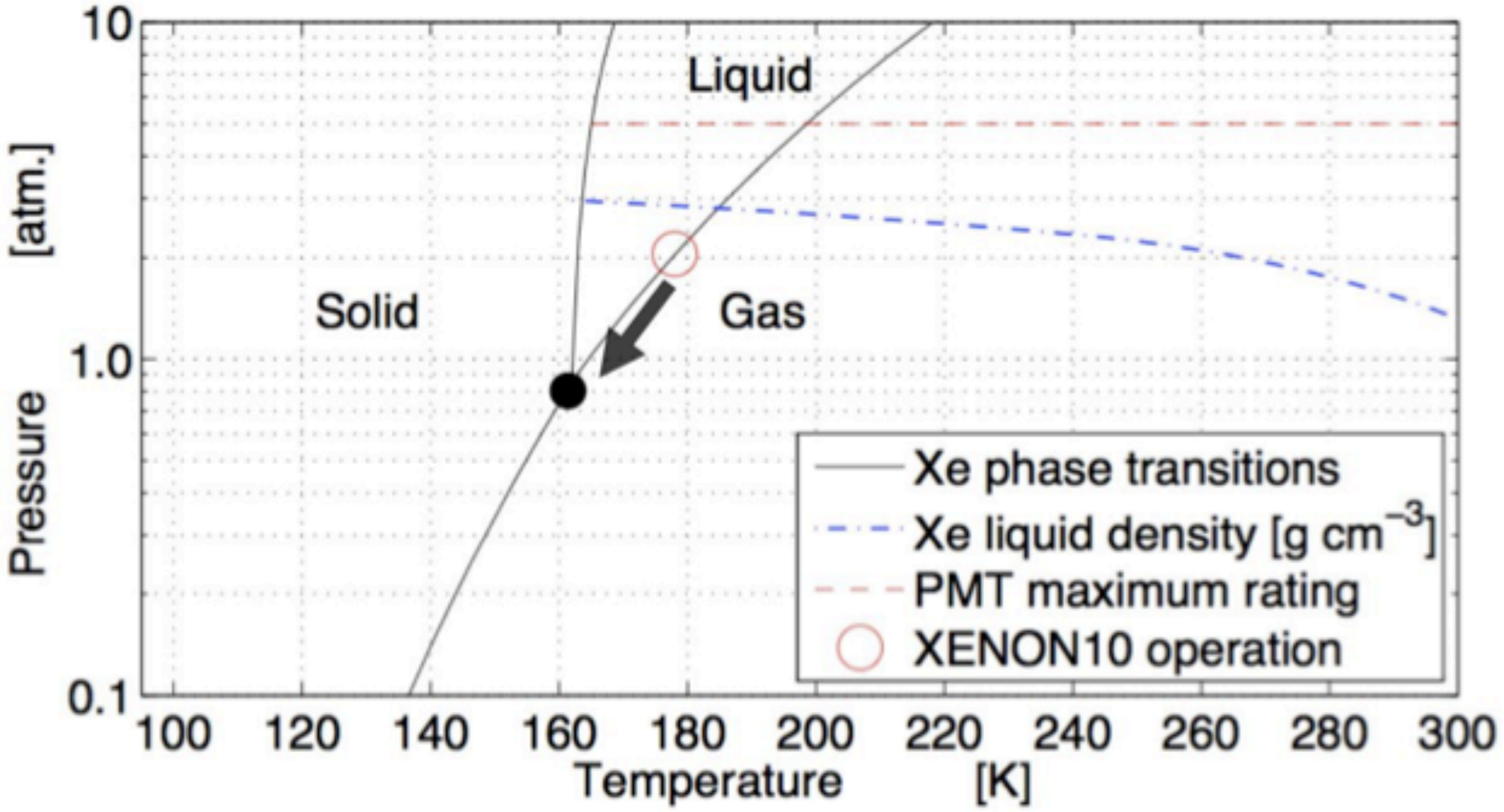
CrystaLiZe

Crystallise Xenon, this freezes the position of the main background for LXe TPCs, Rn222, so its easier to tag.

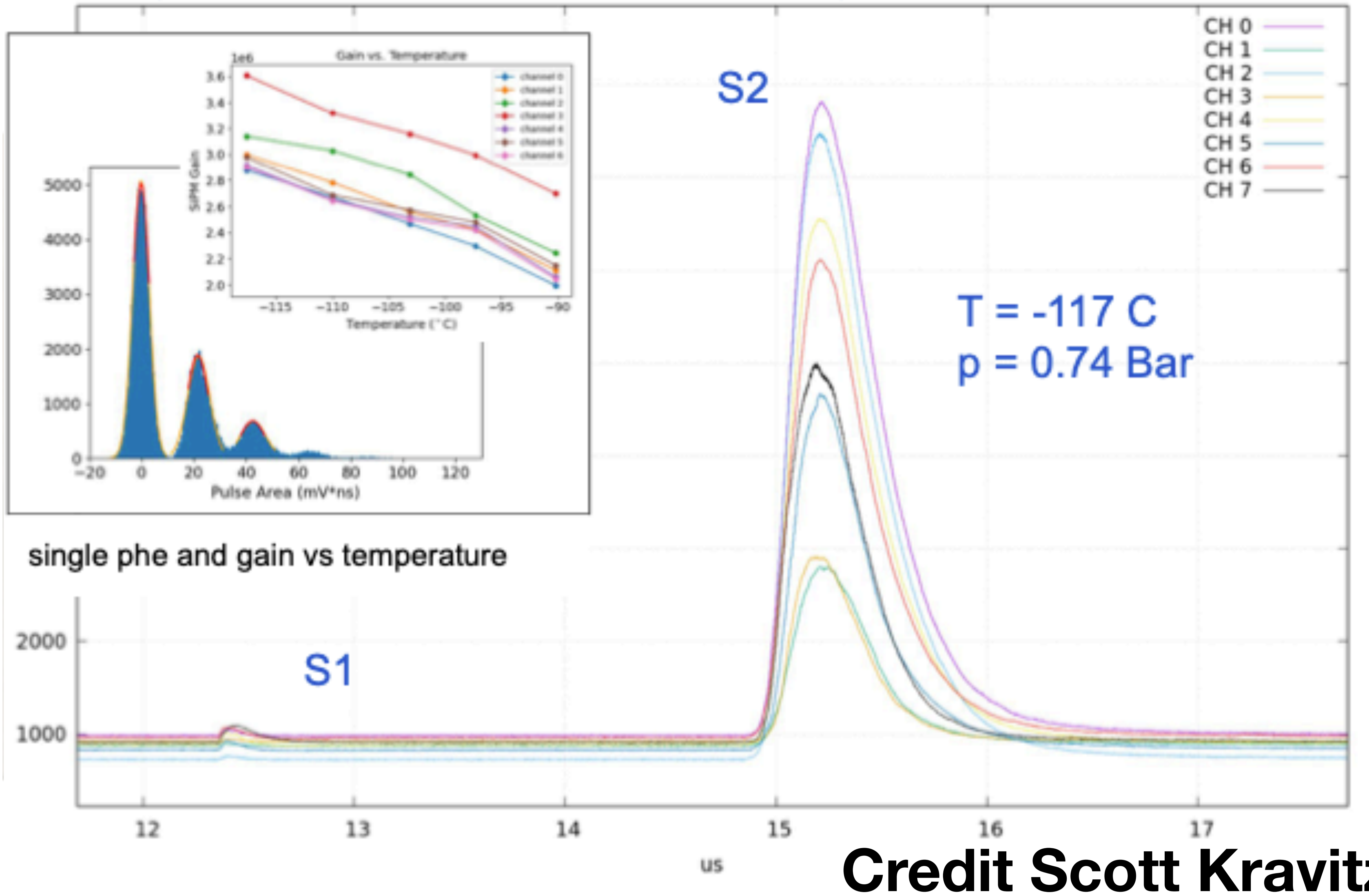
LZ, XENONnT likely to be limited by Rn222 . Radon gas gets everywhere and eventually decays to Bi214 which promptly decays to Po214.

Pros.. Convective flow of the LXe makes this difficult to tag, freezing it helps.

Cons.. R&D required for High voltage, electron drift (purity) and crystal growth (time, purity)



Typical ^{57}Co waveform recorded in crystalline/vapor TPC



Credit Scott Kravitz

The Future

- Xenon TPCs are most likely getting bigger, 50 T LXe..

- Different technologies are being investigated for light detection.

- Typically for SiPMs the number of wires is 150k-450k, this makes the interconnects crucial.

- This is something we are actively researching.

Avoid this..

	R11410-20	VUV4-MPPC	VUV-SIPM	Digital SiPM	ABALONE
Manufacturer	HAMAMATSU	HAMAMATSU	FBK	IMS	Photon Lab, Inc.
SENSITIVE AREA [mm^2]	3.216	36	100	200 (dep. on design)	9.503
TYPICAL # OF CHANNELS	1.700	~150,000	~50,000	~25,000	580
Q.E. [%] or P.D.E. [%] @178 nm	35	~24 (claimed), ~11-18 (measured)	15-18	need to be optimized and tested	35
# of wires per channel	3(1HV, 1GND, 1SGN)	3 (1LV, 1GND, 1SGN)	3 (1LV, 1GND, 1SGN)	~10 per module of ~20 chips	3 (1HV, 1GND, 1SGN)
# of wires	5,100 (1HV, 1GND, 1SGN)	450,000 (1HV, 1GND, 1SGN)	150,000 (1HV, 1GND, 1SGN)	Not yet clear, ~10,000	1,740 + 2 HV
Operating Voltage [V]	-1.500	< 50	~ 24.75 (2 V OV.V)	35 (2 V OV.V)	25 k
Gain at Op. Volt.	5 x 10^6	~ 10^6 @ 2 V OV.V.	1 * 10^6 @ 2 V OV.V	Digital OUT	10^8
DCR [Hz]/mm^2 (0.5 p.e.)	~0.02	~0.2	~1	~0.2	0,01
DCR [Hz] (0.5 p.e.)	~100 k	~1 M	~5 M	~1 M	~50 k
Power Absorption per Channel	25 mW (92 MΩ volt.divider)	Dominated by the electronics ~ 2 mW	same order MPPC	~5 mW (Active Readout)	Dominated by the electronics ~ 2 mW
Total Power Absorption	42.5 W	Dominated by the electronics ~ 200-300 W	same order MPPC	~ 130 W (no need of extra ADC)	< 2 W
Cold electronics	Possible, not required	Required to handle the number of channels + pre-amplification	Required to handle the number of channels + pre-amplification	Embedded	Possible, not required
Expected Improvements	~NO	YES (PDE, DCR, D-SiPM, VUV5, VUV-Arrays)	YES (PDE, DCR, D-SiPM, VUV-Arrays)	YES (PDE, DCR)	YES (Scintillating material, HV optimization)

Credit Alfredo D. Ferella

Thanks
From LZ at Liverpool