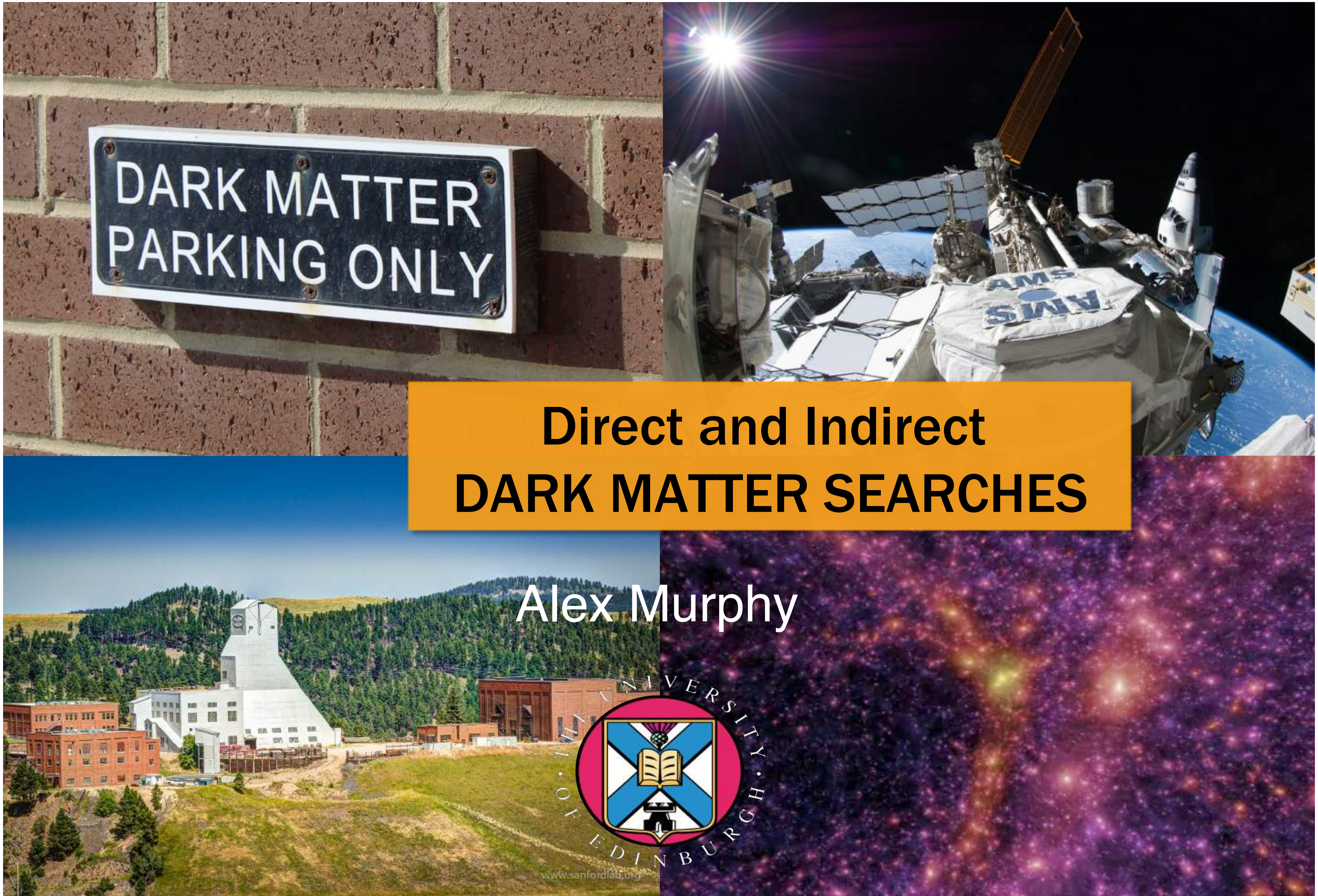


Direct and Indirect DARK MATTER SEARCHES

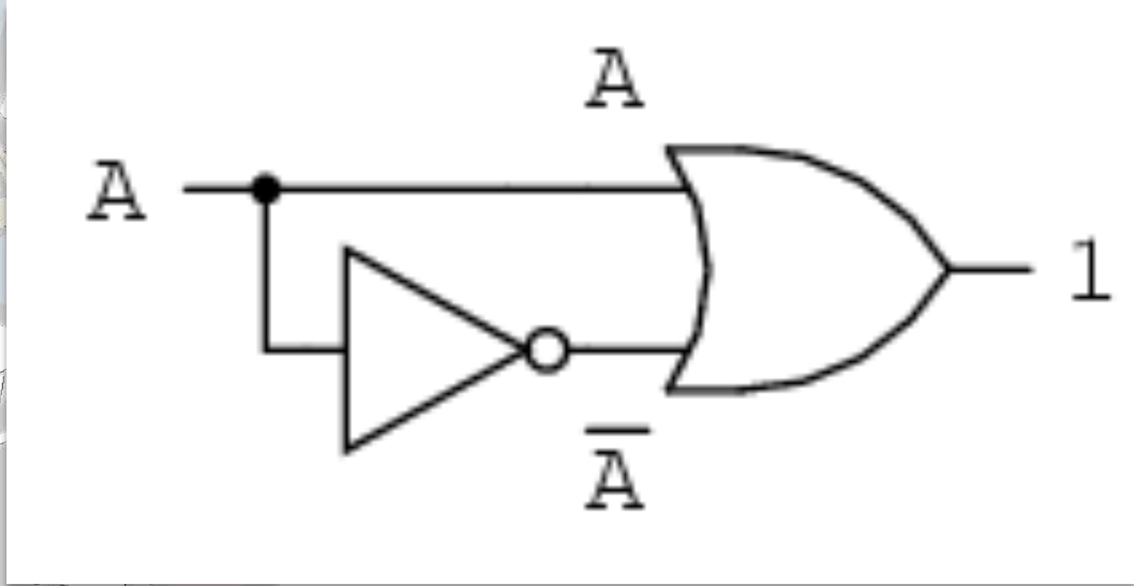
Alex Murphy

The University of Edinburgh

Science & Technology Facilities Council

UK HEP Forum
The Cosener's House

www.ippp.dur.ac.uk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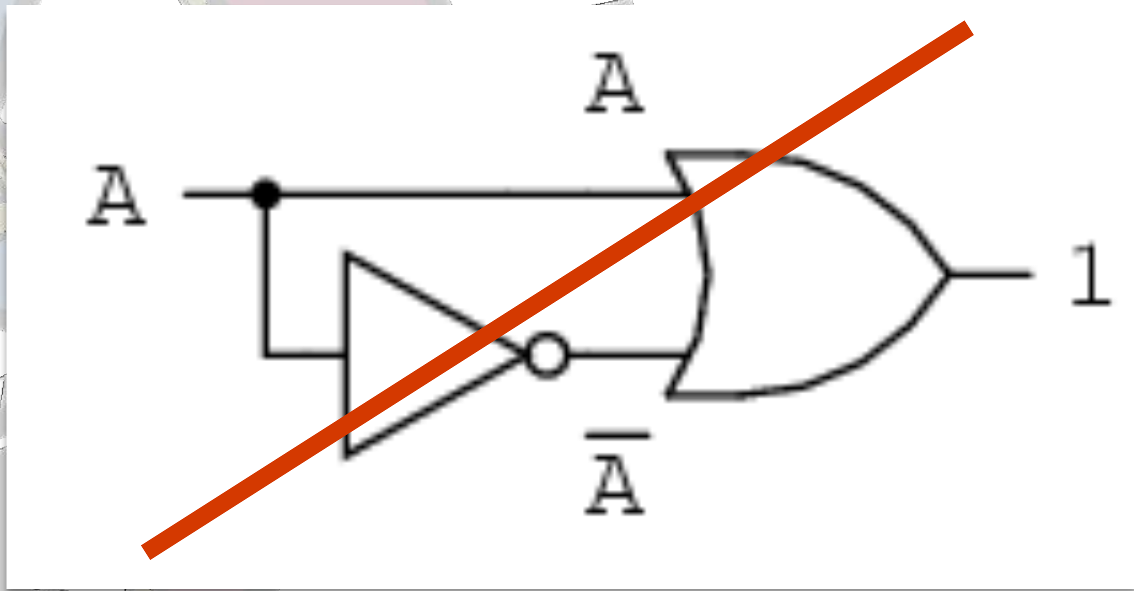
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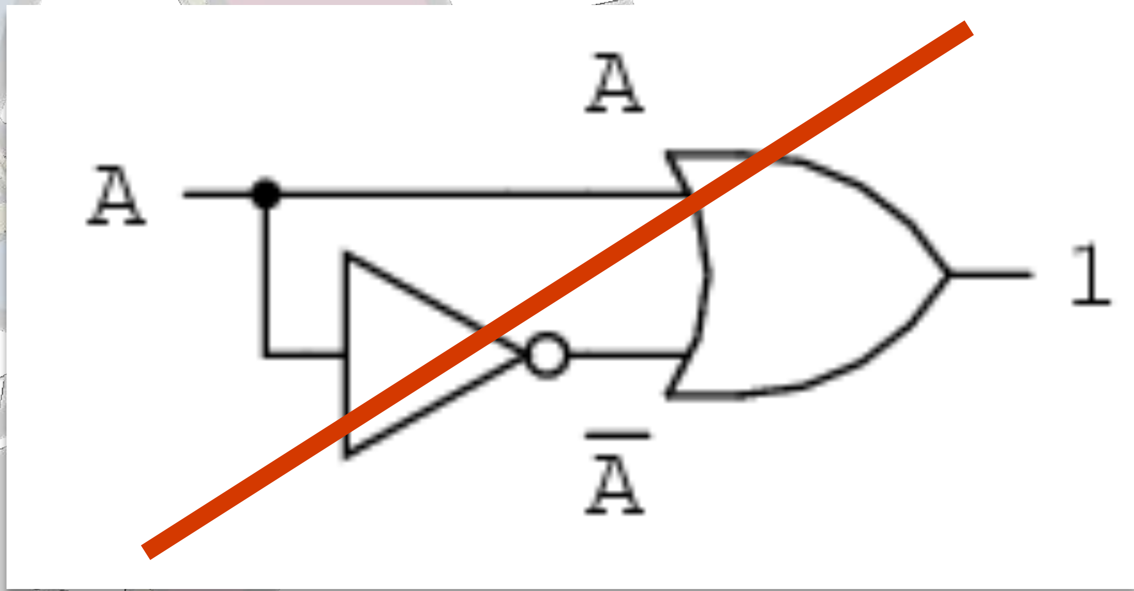
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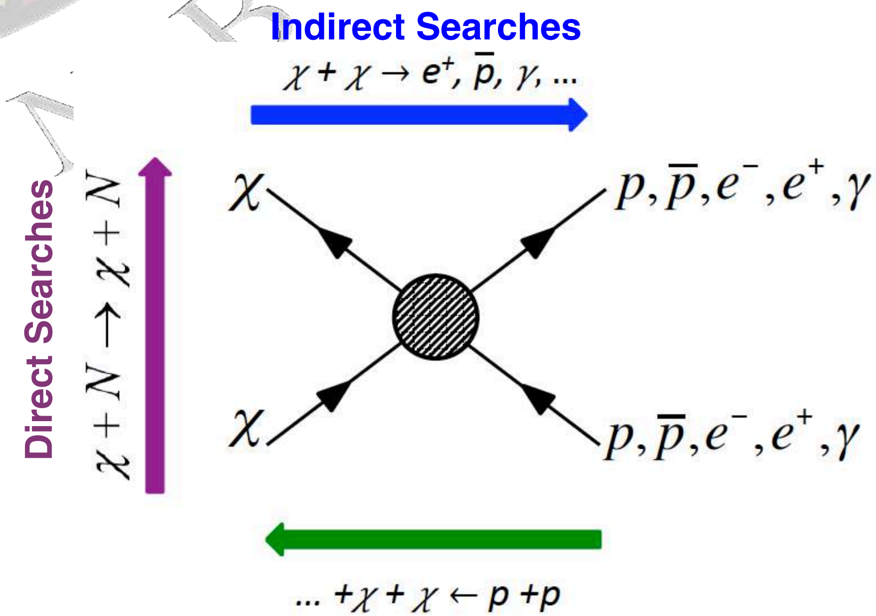
Indirect Searches
$\chi + \chi \rightarrow e^{+}, \bar{p}, \gamma, \ldots$
Direct Searches
$\chi + N \rightarrow \chi + N$
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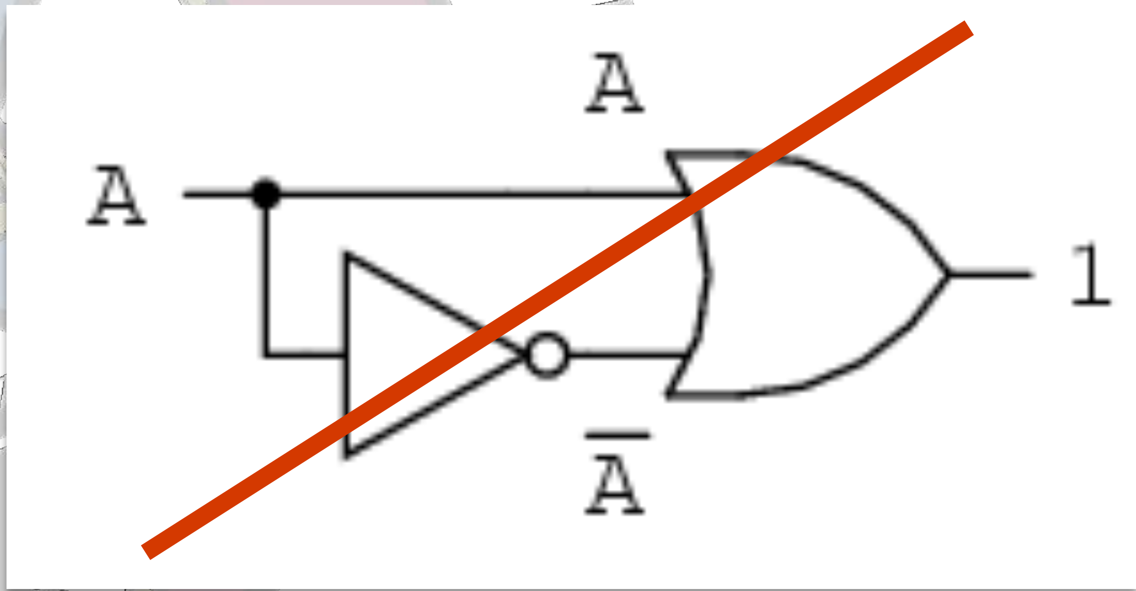
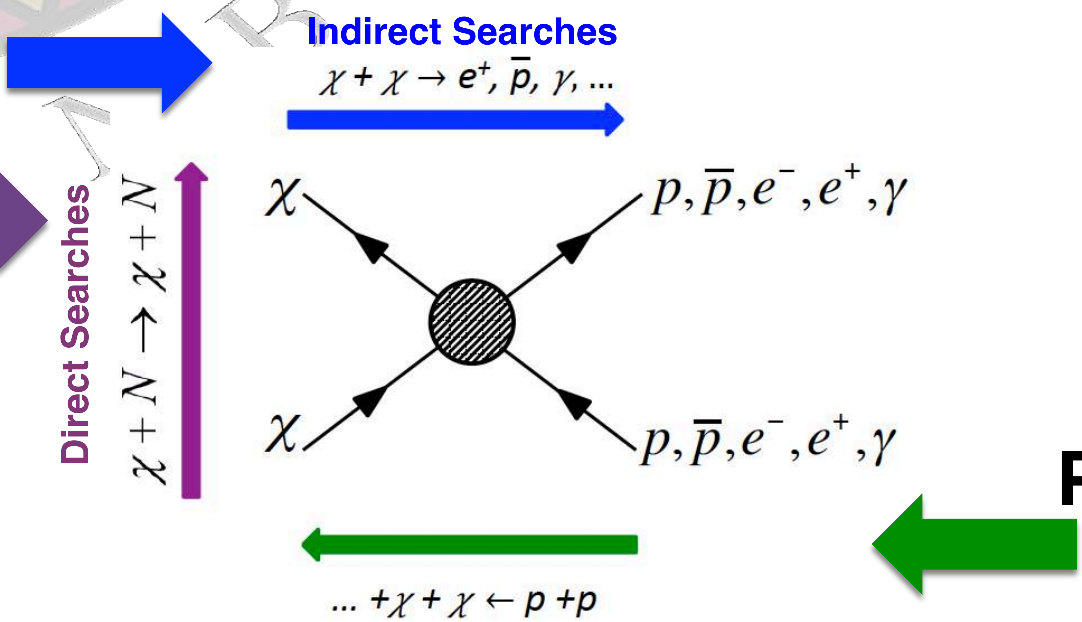
$p, \bar{p}, e^{-}, e^{+}, \gamma$
$p, \bar{p}, e^{-}, e^{+}, \gamma$
$\ldots + \chi + \chi \leftarrow p + p$



THIS TALK



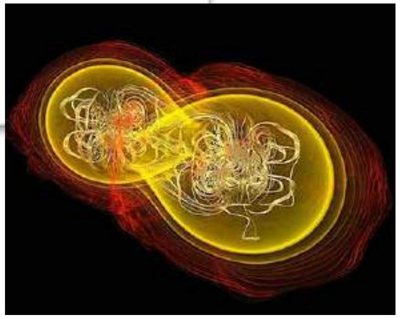
Bjoern Penning, 2pm

But first…

Gravitational Waves

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.* (LIGO Scientific Collaboration and Virgo Collaboration)
Phys. Rev. Lett. **119**, 161101 – Published 16 October 2017



See talk by Tessa Baker!

GW170817 Falsifies Dark Matter Emulators

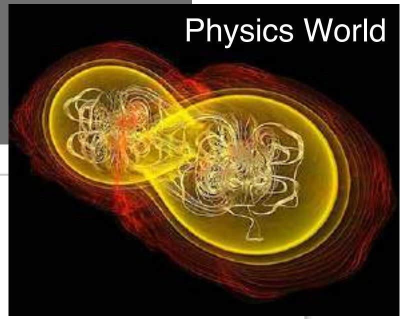
Sibel Boran, Shantanu Desai, Emre Kahya, Richard Woodard

(Submitted on 17 Oct 2017)

On August 17, 2017 the LIGO interferometers detected the gravitational wave (GW) signal (GW170817) from the coalescence of binary neutron stars. This signal was also simultaneously seen throughout the electromagnetic (EM) spectrum from radio waves to gamma-rays. We point out that this simultaneous detection of GW and EM signals rules out a class of modified gravity theories, which dispense with the need for dark matter. This simultaneous observation also provides the first ever test of Einstein's Weak Equivalence Principle (WEP) between gravitons and photons. We calculate the Shapiro time delay due to the gravitational potential of the total dark matter distribution along the line of sight (complementary to the calculation in arXiv:1710.05834) to be about 1000 days. Using this estimate for the Shapiro delay and from the time difference of 1.7 seconds between the GW signal and gamma-rays, we can constrain violations of WEP using the parameterized post-Newtonian (PPN) parameter γ, and is given by $|\gamma_{GW} - \gamma_{EM}| < 3.9 \times 10^{-8}$.

See talk by Tessa Baker!

Gravitational Waves



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Modified Gravity (MOG), the speed of gravitational radiation and the event GW170817/GRB170817A

M. A. Green†, J. W. Moffat†* and V. T. Toth†

Lig… dependent on

the…

Fo…

-
- … matter

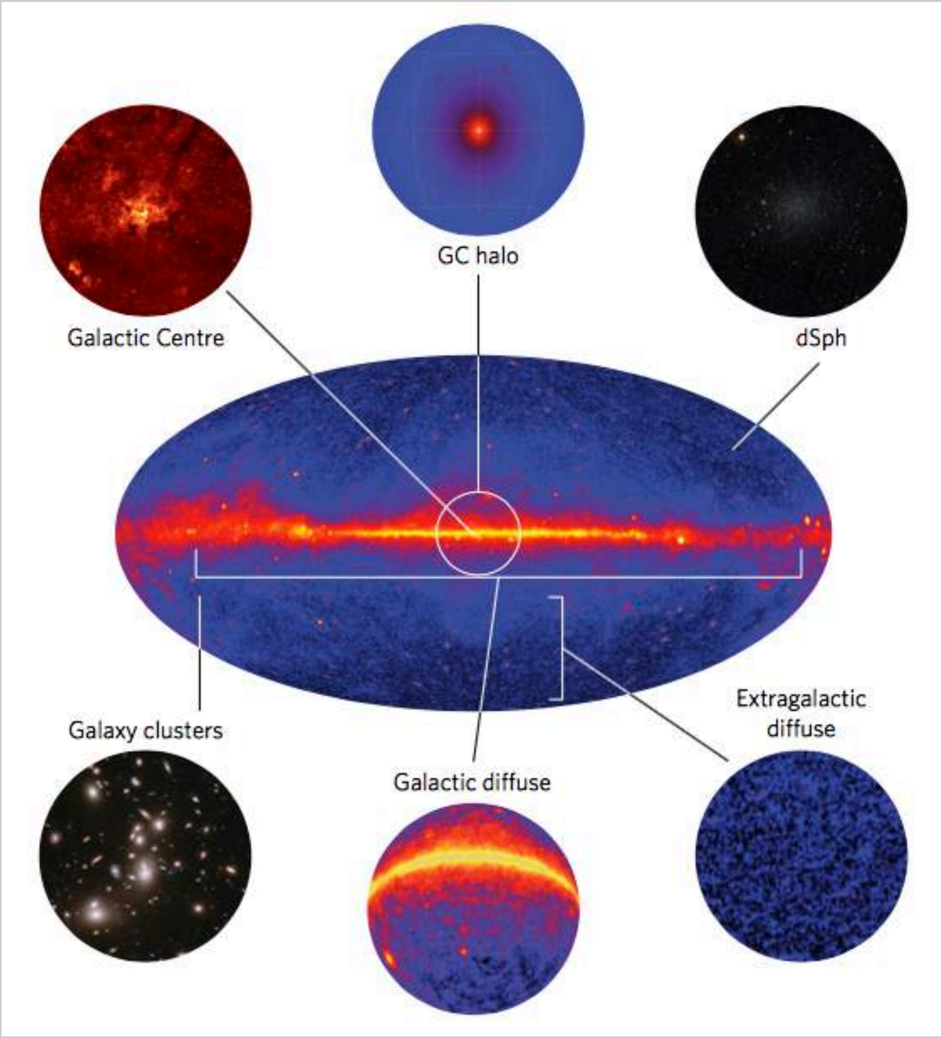
on violation of the weak equivalence principle (WEP) [1, 2]. Together with constraints on gravitational Cherenkov energy loss, this rules out, or severely constrains, many of the modified gravity theories — scalar-tensor, vector-tensor, bimetric — that have been proposed to avoid the need for dark matter and/or dark energy [3–9].

waves travel on null geodesics of the theory's one metric. Despite a recent claim to the contrary, MOG satisfies the weak equivalence principle and is consistent with observations of the neutron star merger and gamma ray burster event GW170817/GRB170817A.

In **MOG**, there's only **one** metric, so survives…

Indirect Searches

Dark matter candidates (e.g. WIMPs) are predicted to annihilate or decay to Standard Model particles, leaving distinctive signatures in γ-rays, neutrinos, positrons, antiprotons, or even antinuclei.



→ Look for imprints of dark matter on the energy spectra or spatial distribution of gamma-ray photons or charged cosmic rays.


REVIEW ARTICLES

PUBLISHED ONLINE: 2 MARCH 2017 | DOI: 10.1038/NPHYS4049

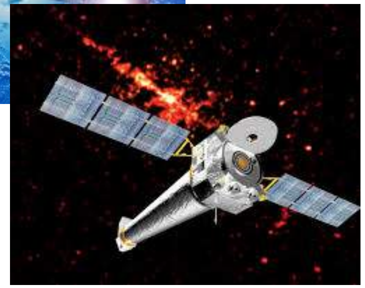
nature physics

Indirect dark matter searches in gamma and cosmic rays

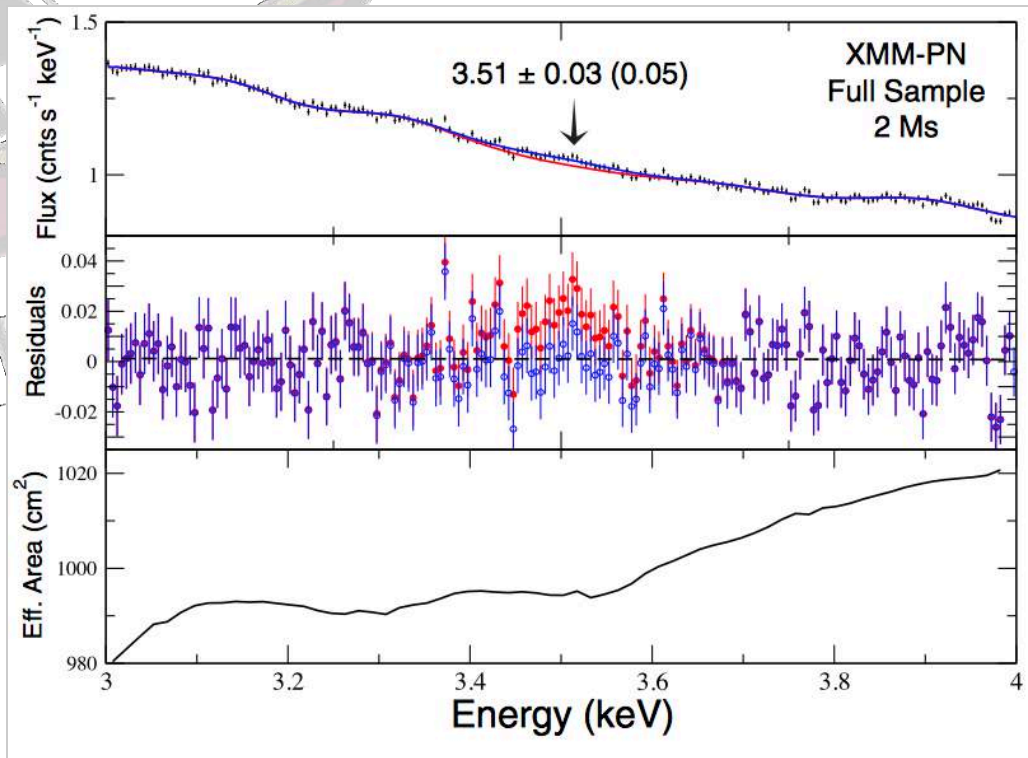
Jan Conrad[1] and Olaf Reimer[2*]

A few recent highlights…

X-ray



- Line at 3.5 keV reported by XMM-Newton and Chandra
- Stacked data from clusters of galaxies, Perseus cluster, Andromeda galaxy, Galactic center (Bulbul et al, arXiv: 1402.2301; ApJ 789:13, Boyarsky et al, arXiv:1402.4119).

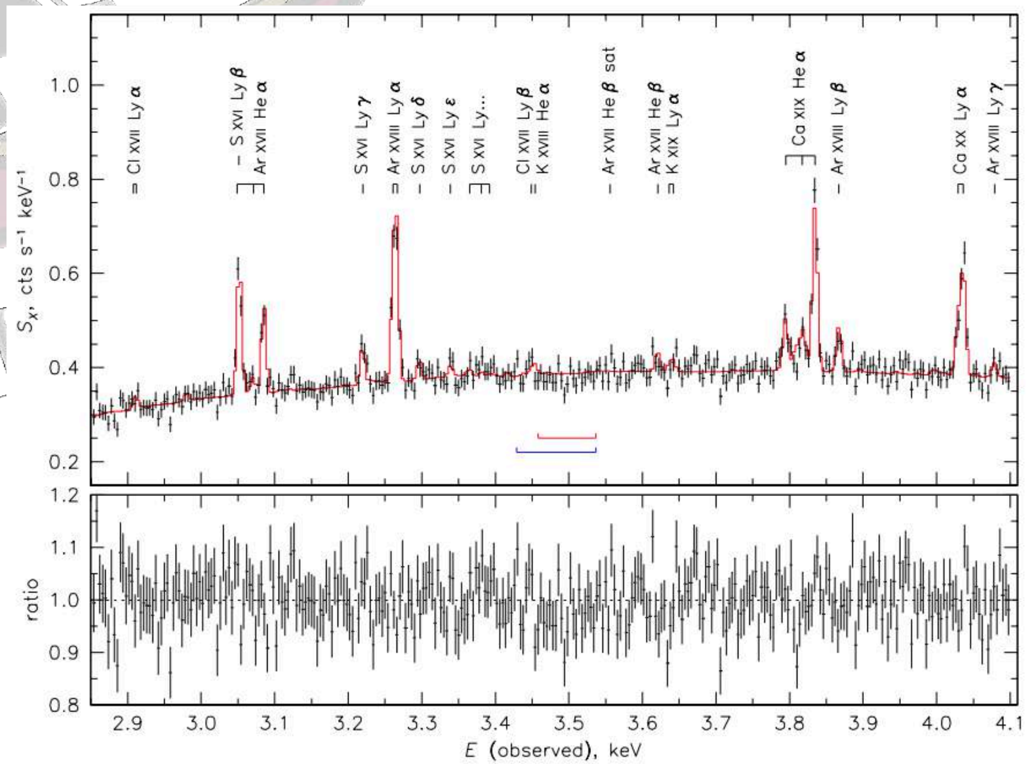


Bulbul et al, ApJ, 789,:13 (2014); arXiv: 1402.2301

X-ray

New data from Hitomi/Astro-H's very brief observation…

- Better spectral resolution



Hitomi Collaboraiton: ApJ, 837, L15 (2017); arXiv: 1607.07420

X-ray

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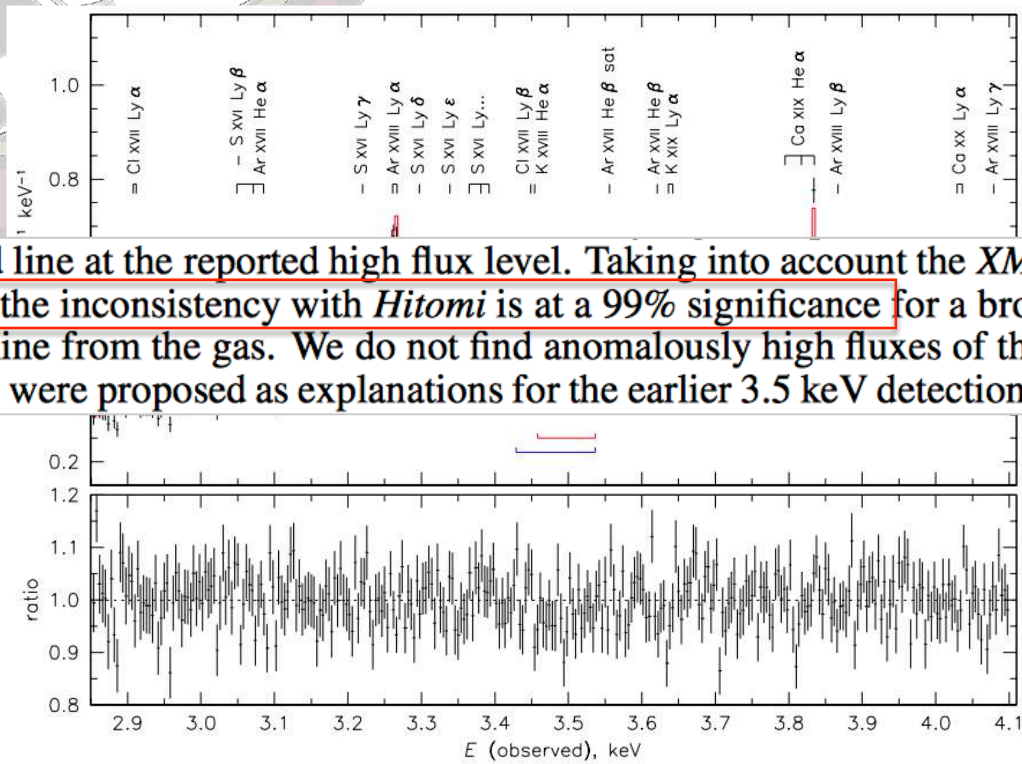
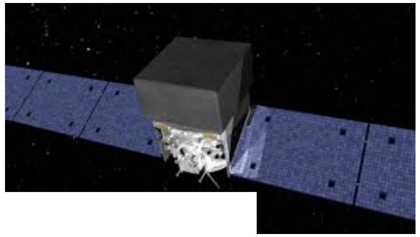
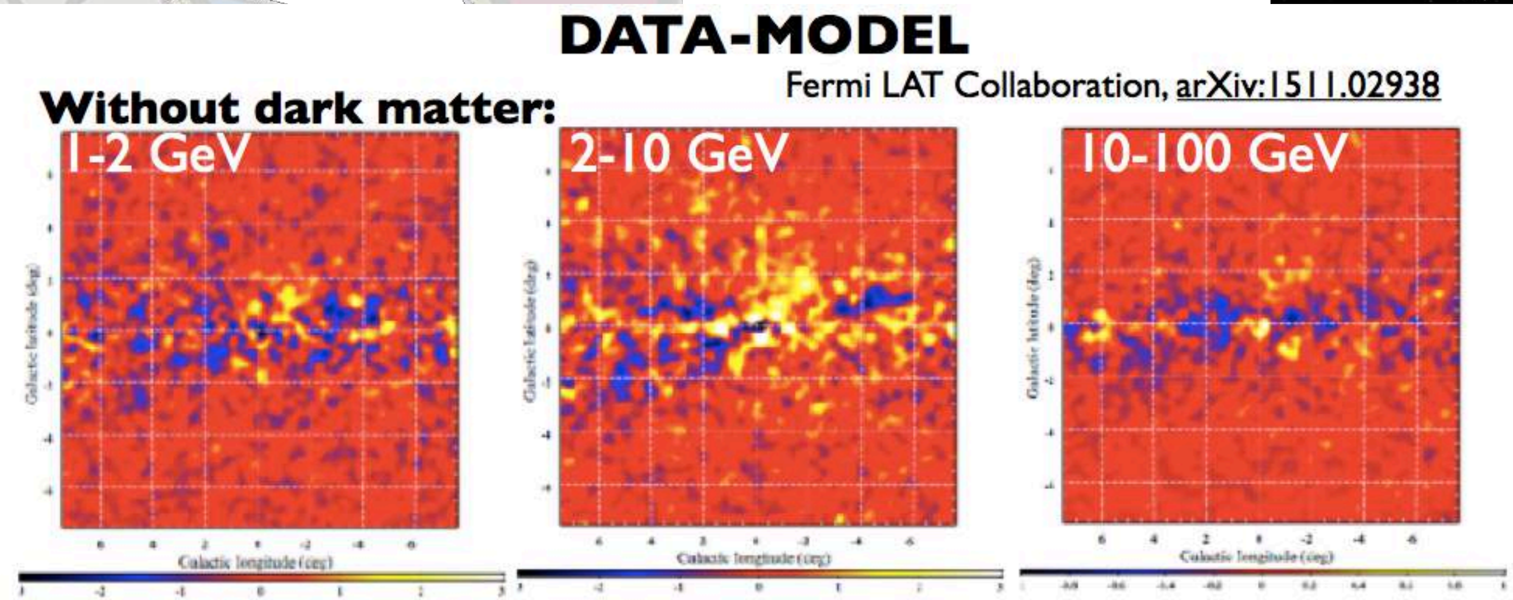


We find no unidentified line at the reported high flux level. Taking into account the *XMM* measurement uncertainties for this region, the inconsistency with *Hitomi* is at a 99% significance for a broad dark-matter line and at 99.7% for a narrow line from the gas. We do not find anomalously high fluxes of the nearby faint K line or the Ar satellite line that were proposed as explanations for the earlier 3.5 keV detections. We do find a hint of a

Hitomi Collaboraiton: ApJ, 837, L15 (2017); arXiv: 1607.07420

Galactic centre excess

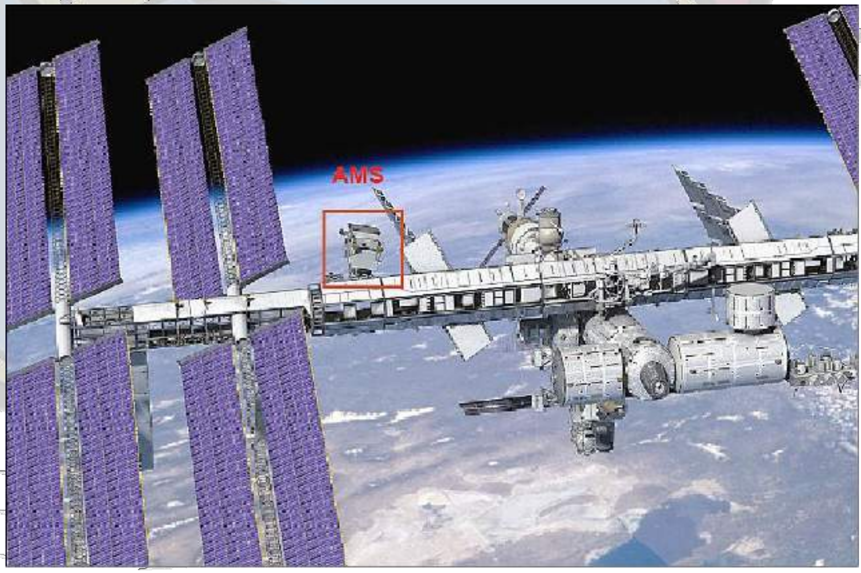


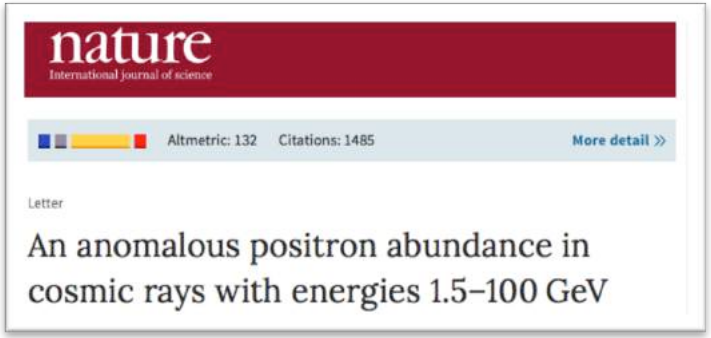


- Goodenough and Hooper (arXiv:0910.2998.)
- More recent analyses also find an excess… (e.g. arXiv:1711.04778)
- But… There are limitations in all interstellar emission models (e.g., cylindrical symmetry, the gas distribution, interplay with point sources)
- …and the GC excess is only a small fraction of the total observed emission (~5-10% in a 15^{o}x15^o region)
- 'Consistent' with 50 GeV WIMP annihilations to b-quarks
- Astrophysical sources ***not*** ruled out (e.g. $\mathcal{O}$(100) x millisecond pulsars… SKA may be crucial here)

High energy positron excess

- 2008 – PAMELA reports excess of high energy positrons. Confirmed by AMS-02; &+




nature
International journal of science

Letter

An anomalous positron abundance in cosmic rays with energies 1.5–100 GeV

High energy positron excess

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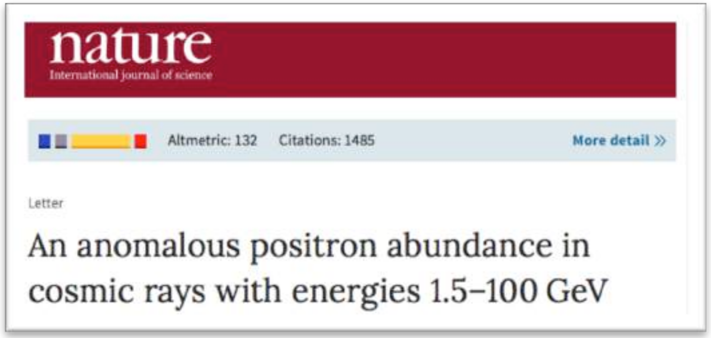
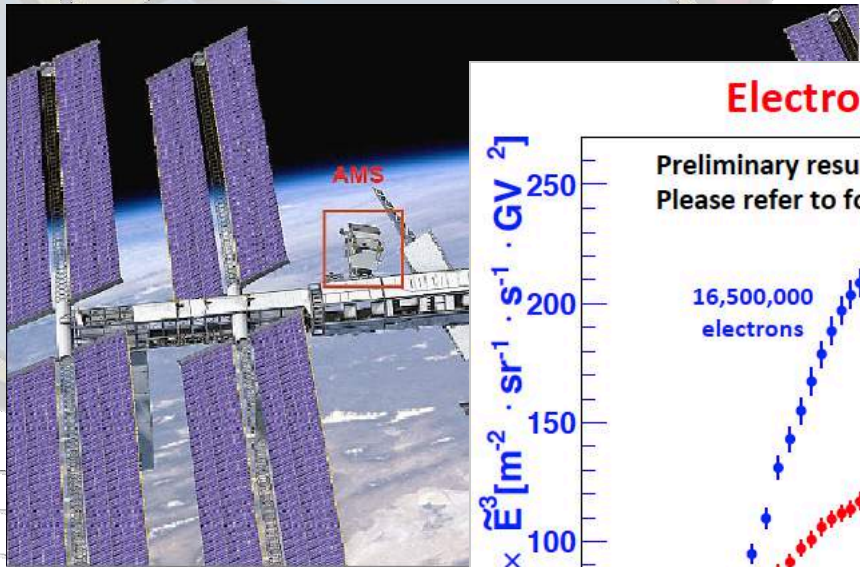
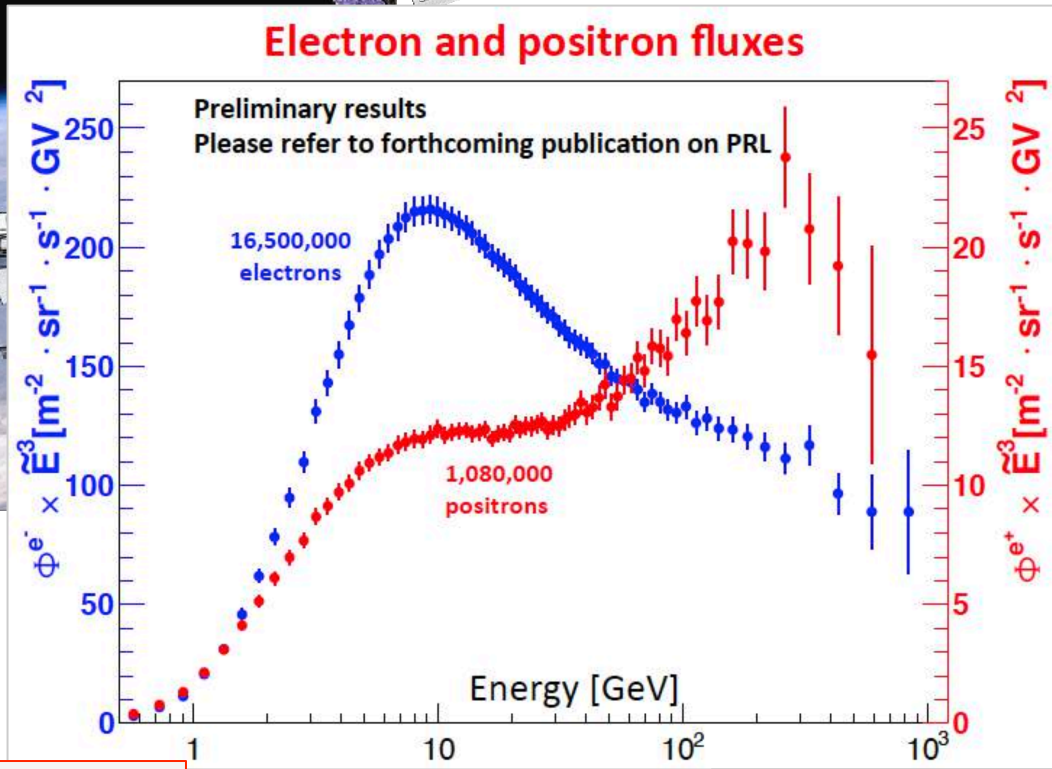

nature
International journal of science
Altmetric: 132 Citations: 1485 More detail »
Letter
An anomalous positron abundance in cosmic rays with energies 1.5–100 GeV



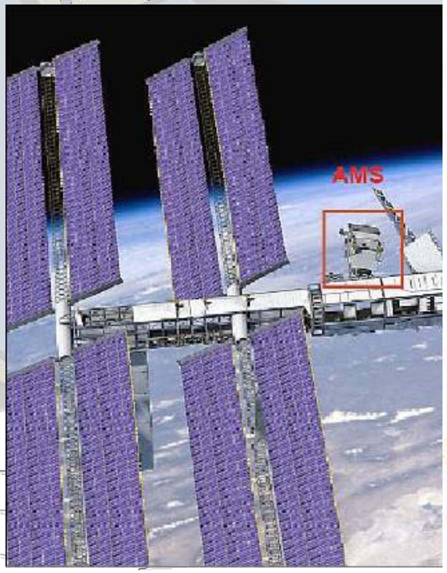


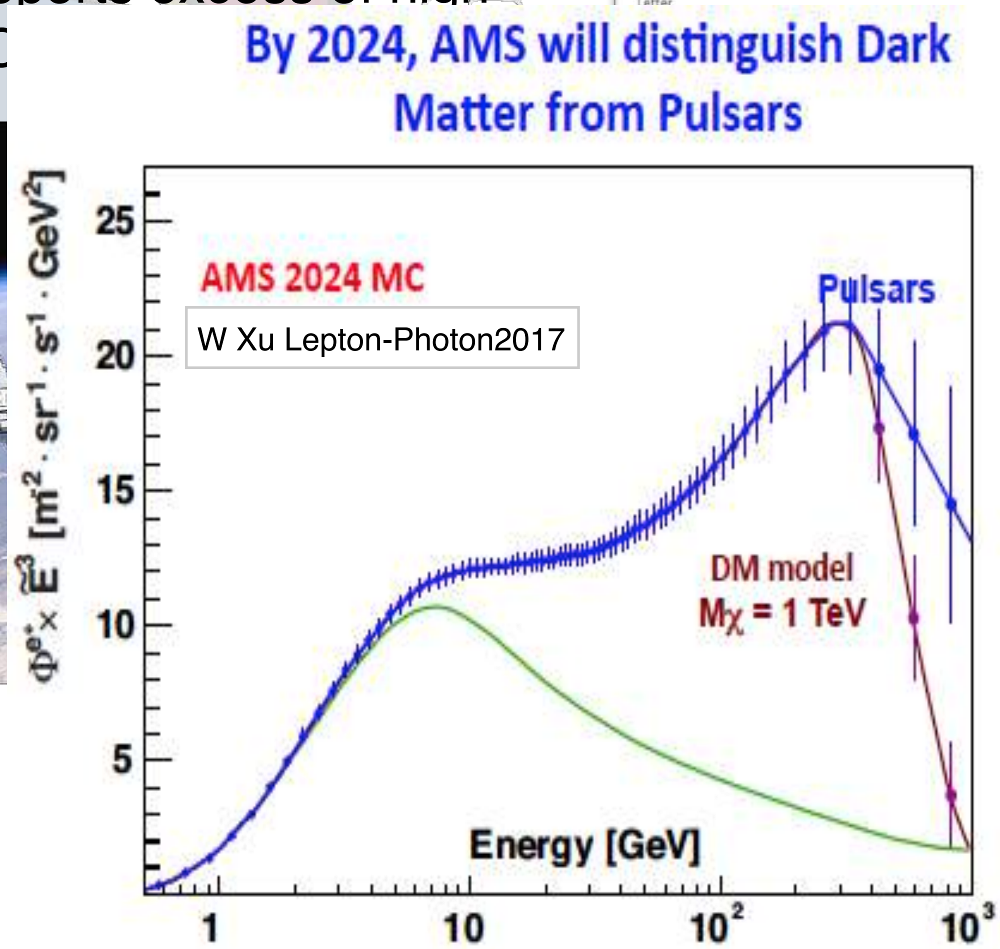
W Xu Lepton-Photon2017

But is this due to Geminga & PSR B0656+14) or DM?

High energy positron excess

- 2008 – PAMELA reports excess of high energy positrons. C





But why wait till 2024…?

But why wait till 2024…?

High Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory (And Electron Diffusion near Geminga)

Science 17 Nov 2017:
Vol. 358, Issue 6365, pp. 911-914
DOI: 10.1126/science.aan4880

Why wait till 2024…?

PHYSICAL REVIEW D

covering particles, fields, gravitation, and cosmology

17/11/17

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HAWC observations strongly favor pulsar interpretations of the cosmic-ray positron excess

Dan Hooper, Ilias Cholis, Tim Linden, and Ke Fang

Phys. Rev. D **96**, 103013 – Publishe

Hooper et al: "…*positron fluxes ARE due to pulsars…*"

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REPORT

Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

A. U. Abeysekara[1], A. Albert[2], R. Alfaro[3], C. Alvarez[4], J. D. Álvarez[5], R. Arceo[4], J. C. Arteaga-Velázquez[5], D. Avila Rojas[3], …

+ See all authors and affiliations

Science 17 No
Vol. 358, Issue
DOI: 10.1126/s

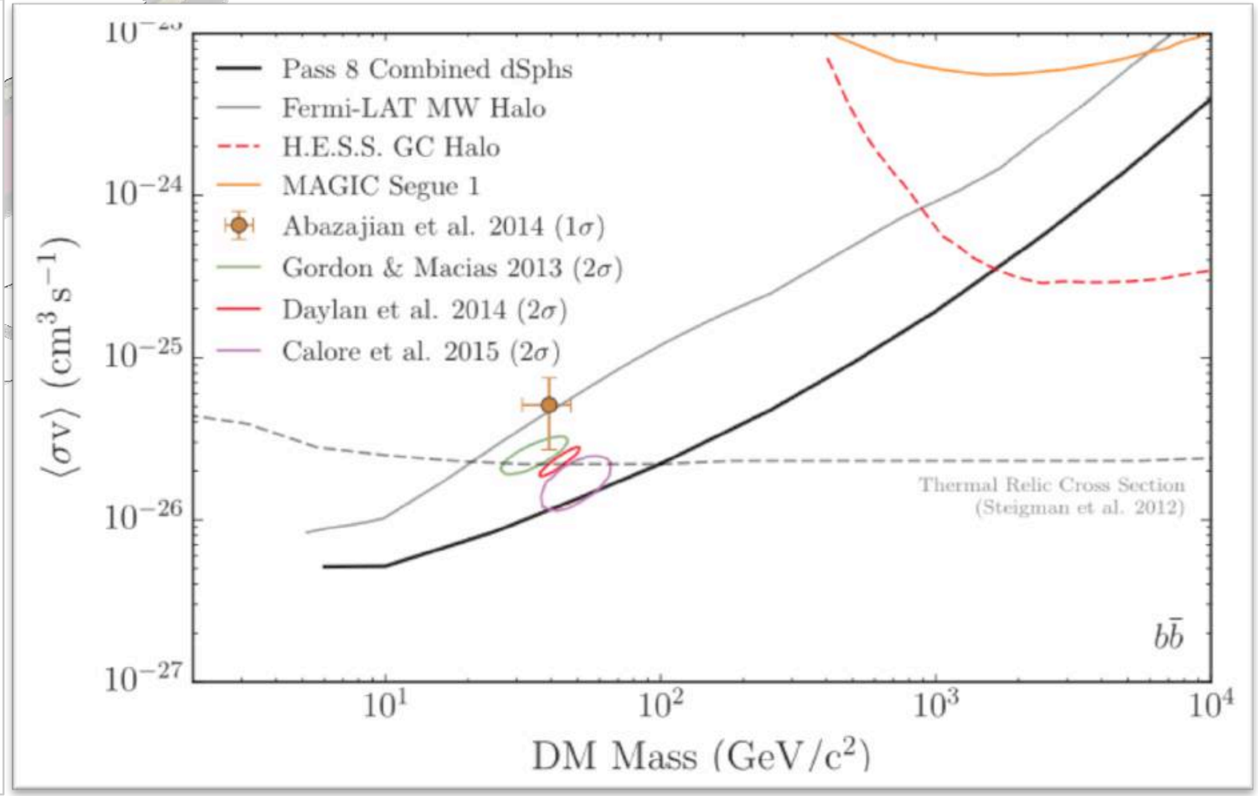
HAWC: "… It's not due to these pulsars – the surrounding dust is too thick to allow the positrons to propagate to Earth…"

Dwarf Spheroidal searches

- Very DM dominated systems – clean from many systematics and backgrounds
- Search for a signal in 25 dwarf spheroidal galaxies, 6 years of Fermi LAT data (PRL 115, 231301 (2015))

➡ No significant emission found

- Constrains DM explanation for galactic centre excess
- (Again, there are plenty of astrophysical caveats)



Indirect Searches: Summary

Several intriguing hints of potential signals have been claimed, e.g. in x-rays, gamma rays, leptons…

Conventional astrophysics backgrounds remain a limitation – but are being addressed

There is a strong complementarity of indirect searches, and a complementary to direct & accelerator searches

Direct Searches

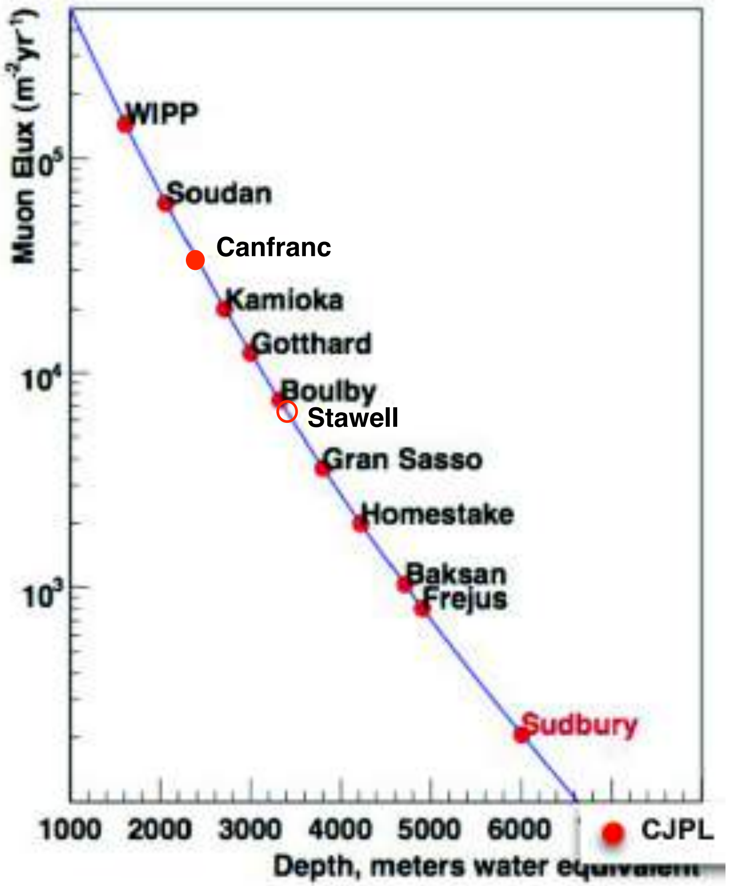
Underground labs

- A necessary evil…
- Vastly reduces muons

  The rest can be can vetoed in anti-coincidence shield, but secondary products may be an issue
- Cosmogenics

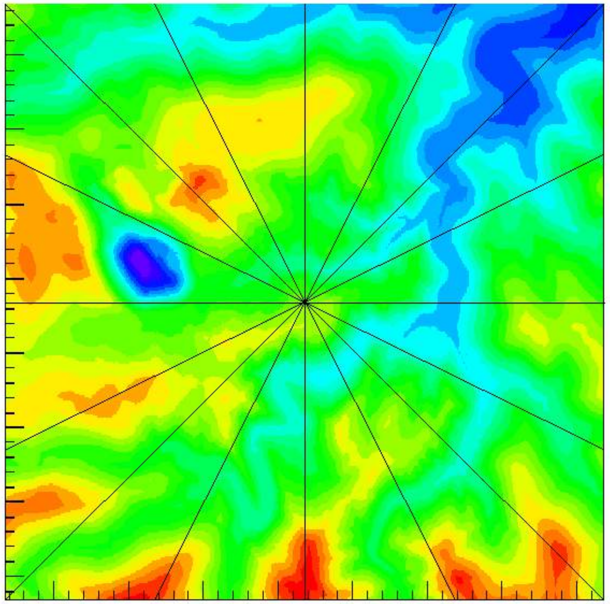
  May require underground material production or purification
- Remaining laboratory n/γ fluxes

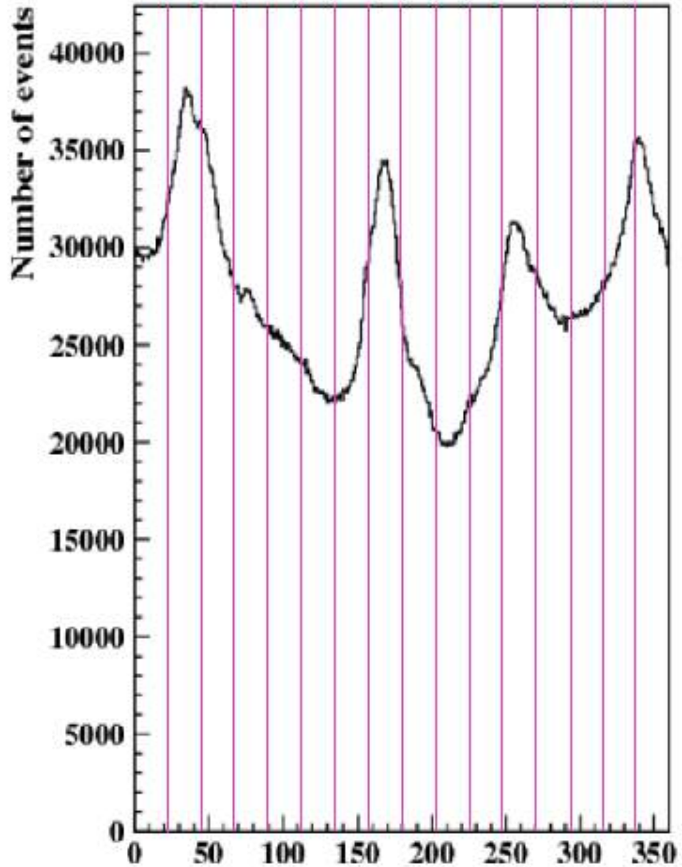
  Depend on local geology, geometry



arXiv:1509.02910

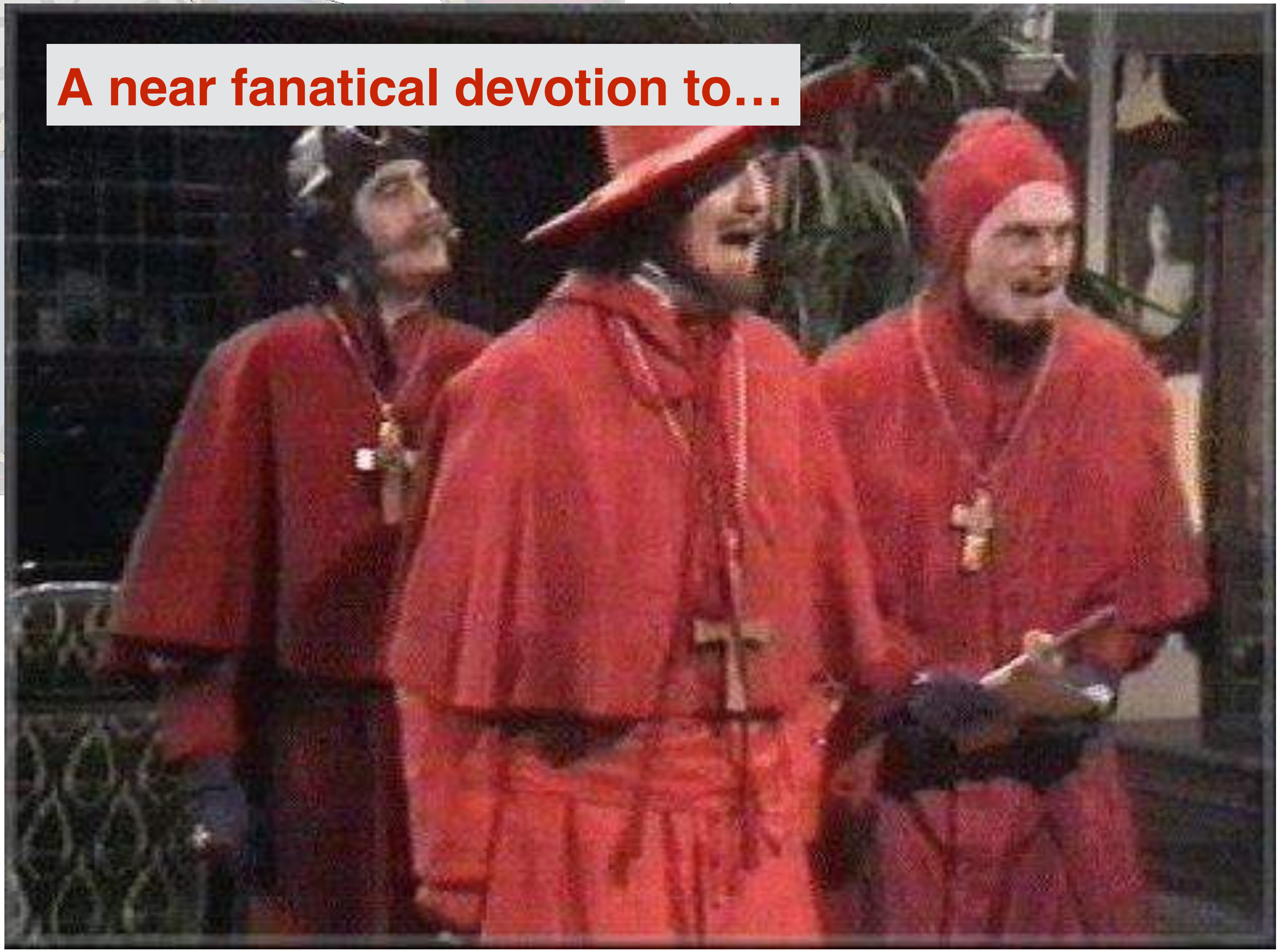
Modelling muon fluxes and impacts





More than just depth, direct dark matter searches require….

A near fanatical devotion to…



More than just depth, direct dark matter searches require….

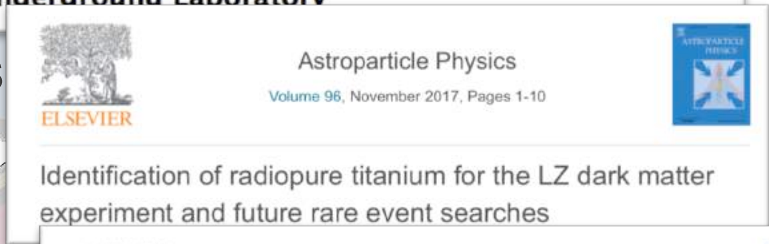
Cleanliness… cleanliness… cleanliness…

- Laboratory background measurements
- Materials assays
  - HPGe screening (e.g. BUGS suite @ Boulby)
  - ICPMS
  - neutron activation
  - radon emanation, plateout
- Materials cleaning
- Modifying manufacture…
  - Deep involvement in manufacture (e.g. LZ titanium)
  - Underground manufacture (e.g. electroformed Cu for Majorana demonstrator)
- Radon purging
- Target purification, Kr removal…


arXiv.org > physics > arXiv:1708.06086

Physics > Instrumentation and Detectors

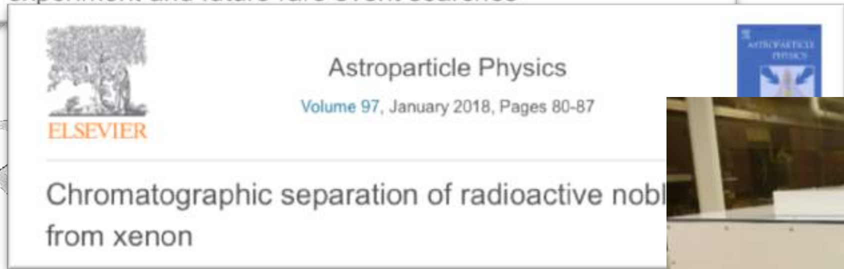
Low Background Gamma Spectroscopy at the Boulby Underground Laboratory


ELSEVIER

Astroparticle Physics

Volume 96, November 2017, Pages 1-10

Identification of radiopure titanium for the LZ dark matter experiment and future rare event searches

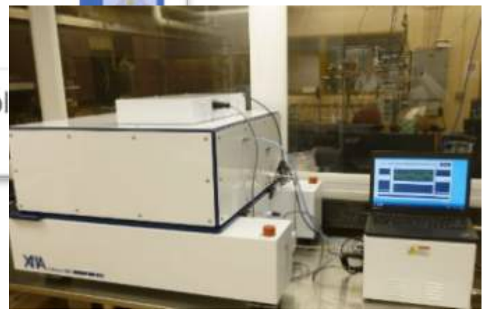

ELSEVIER

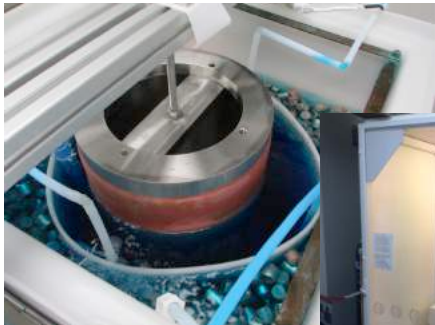
Astroparticle Physics

Volume 97, January 2018, Pages 80-87

Chromatographic separation of radioactive nobl

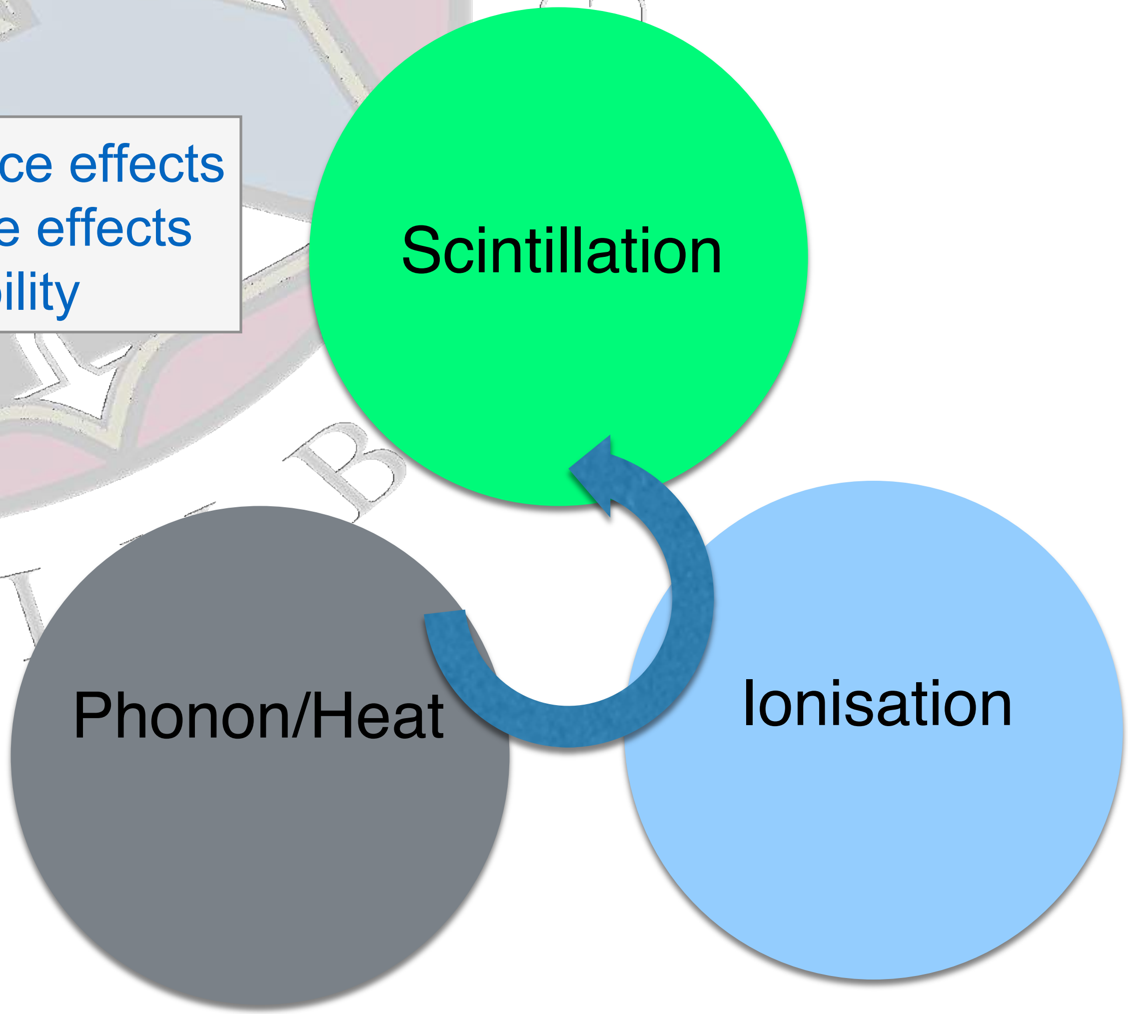
from xenon





Following Araujo

Improved surface effects
Improve volume effects
Improve scalability



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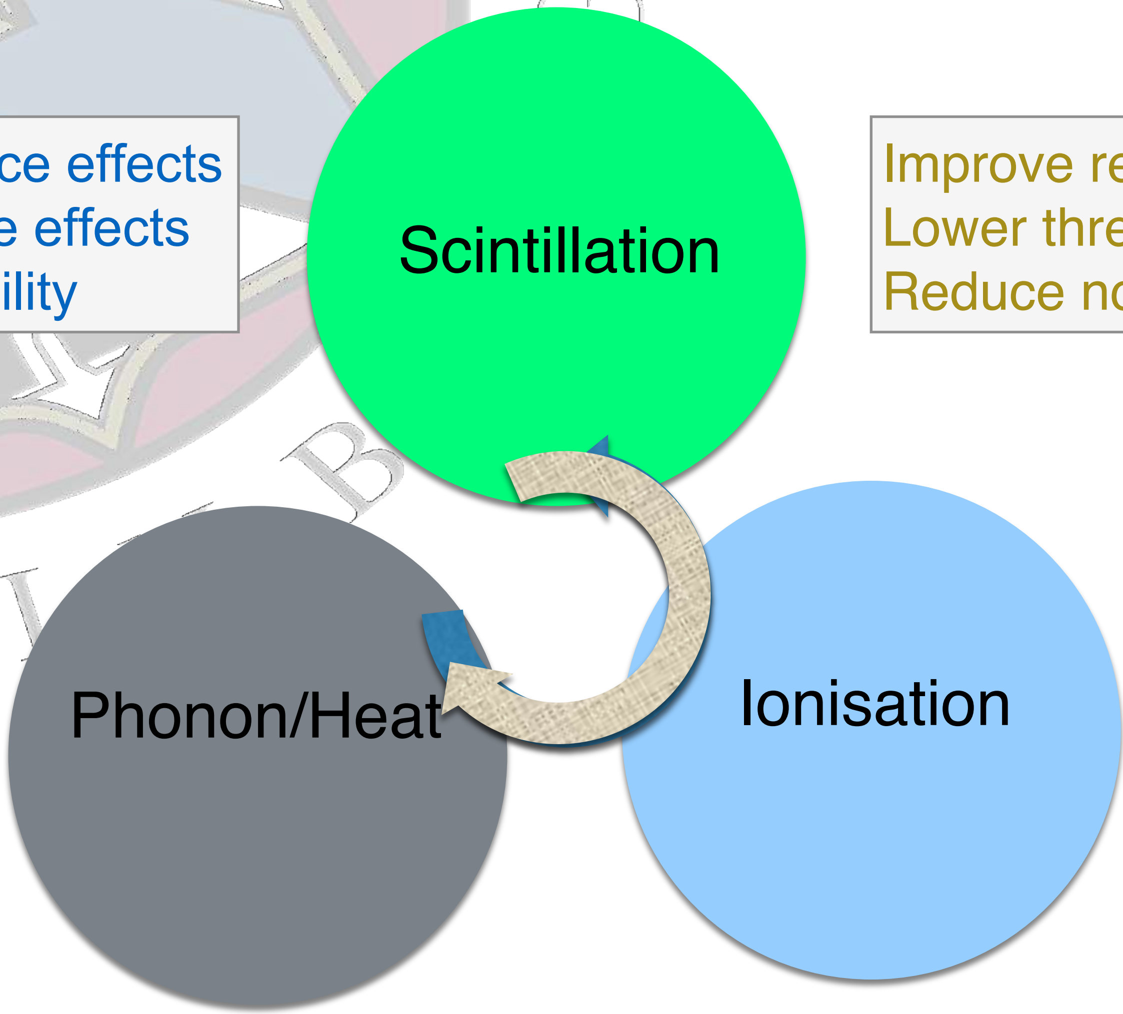
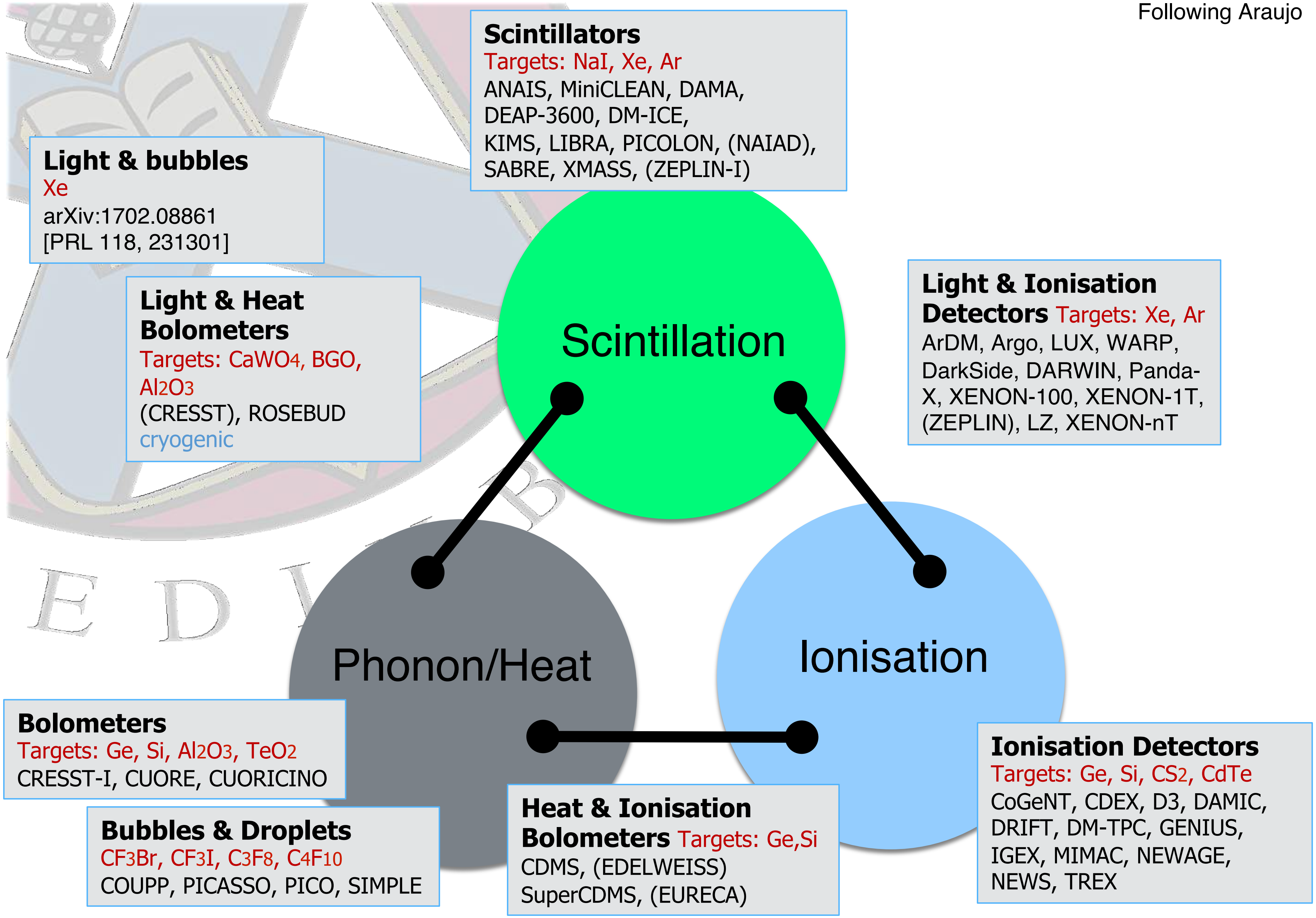
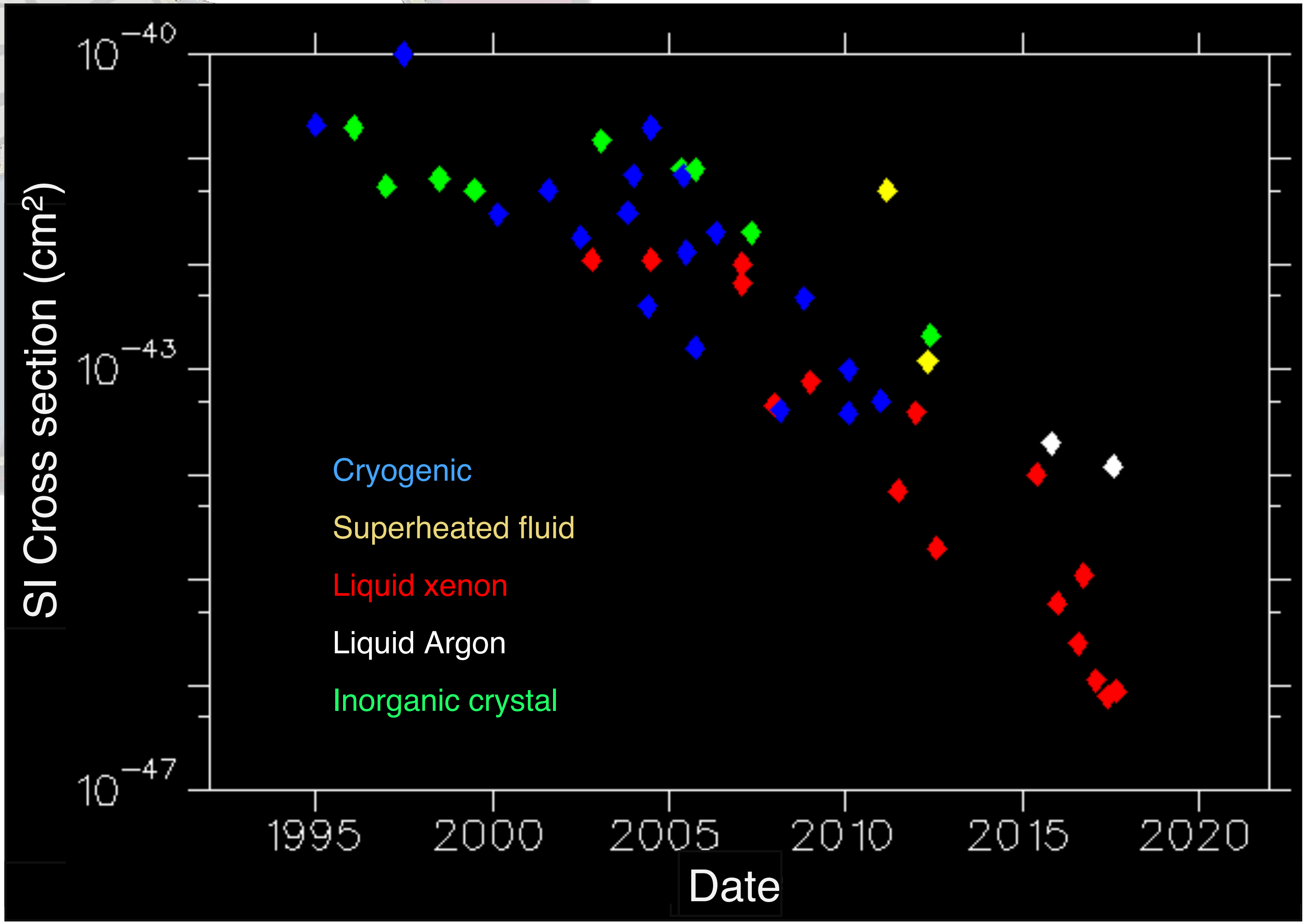


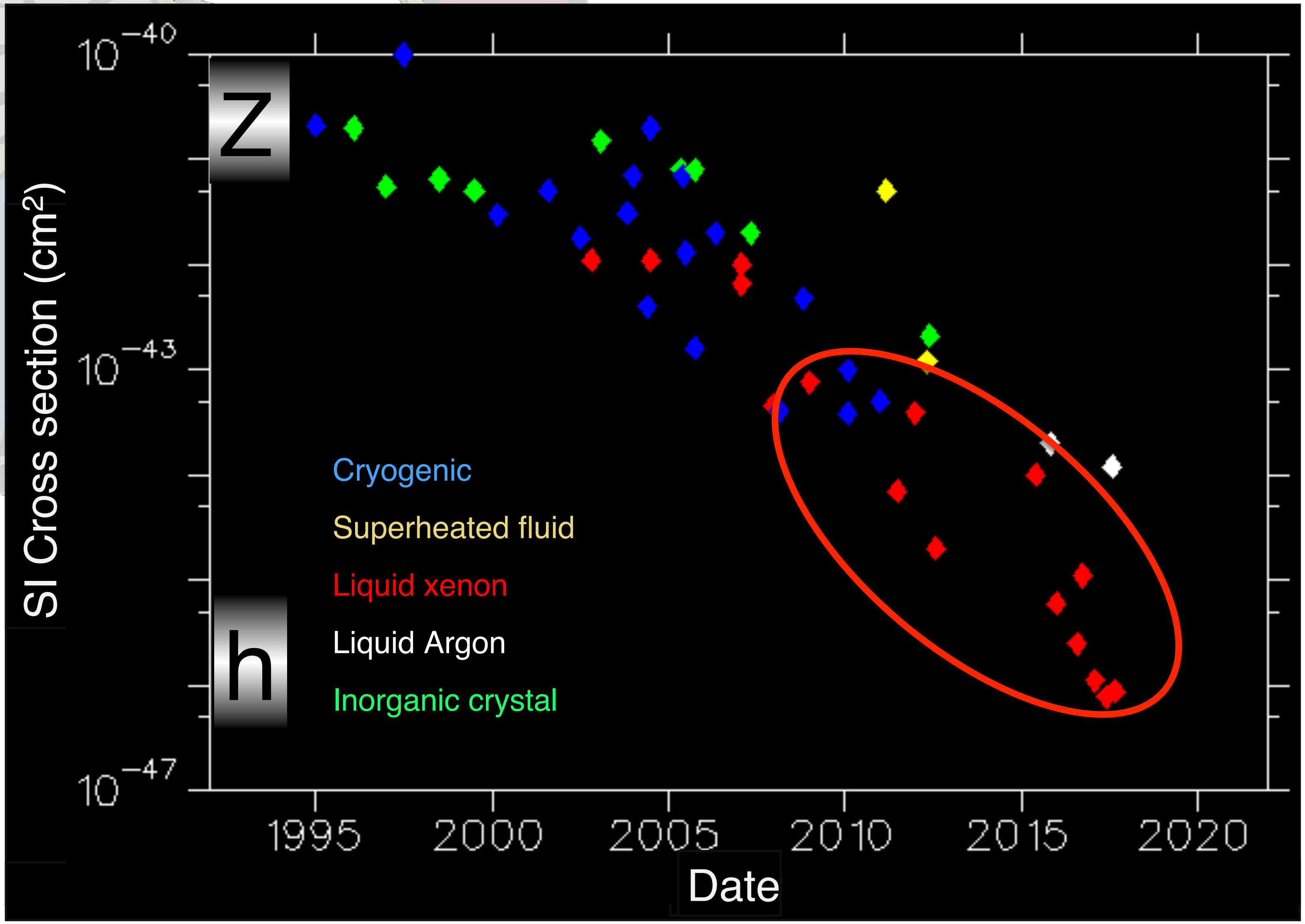
Improve resolution
Lower threshold
Reduce noise

Following Araujo



Rapid progress – faster than exponential!



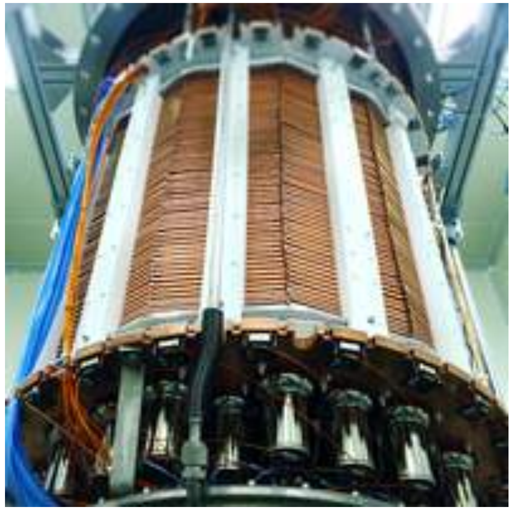


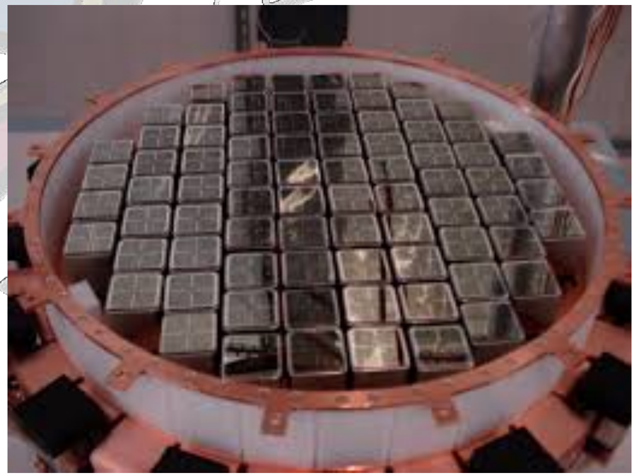
SI Cross section (cm²)
10⁻⁴⁰
10⁻⁴³
10⁻⁴⁷
Z
h
Cryogenic
Superheated fluid
Liquid xenon
Liquid Argon
Inorganic crystal
1995
2000
2005
2010
2015
2020
Date

The first two-phase liquid xenon TPC!

The first two-phase liquid xenon TPC!

ZEPLIN-II






gettyimages
PANDAX

World status - SI

Results from a Search for Dark Matter in the Complete LUX Exposure

D. S. Akerib *et al.* (LUX Collaboration)
Phys. Rev. Lett. **118**, 021303 – Published 11 January 2017

Physics See Viewpoint: Dark Matter Still at Large

LUX
370 kg
~100 kg fiducial

Dark Matter Results from 54-Ton-Day Exposure of PandaX-II Experiment

Xiangyi Cui *et al.* (PandaX-II Collaboration)
Phys. Rev. Lett. **119**, 181302 – Published 30 October 2017

Physics See Viewpoint: The Relentless Hunt for Dark Matter

PandaX-II
580 kg
~300 kg fiducial

First Dark Matter Search Results from the XENON1T Experiment

E. Aprile *et al.* (XENON Collaboration)
Phys. Rev. Lett. **119**, 181301 – Published 30 October 2017

Physics See Viewpoint: The Relentless Hunt for Dark Matter

XENON-1T
2000 kg
~1042 kg fiducial

World status - SI

Results from a Search for Dark Matter in the Complete LUX Exposure

D. S. Akerib *et al.* (LUX Collab
Phys. Rev. Lett. **118**, 021303 –

Physics See Viewpoint: Dark

Dark Matter R
Experiment

Xiangyi Cui *et al.* (Pand
Phys. Rev. Lett. **119**, 181

Physics See Viewpoint

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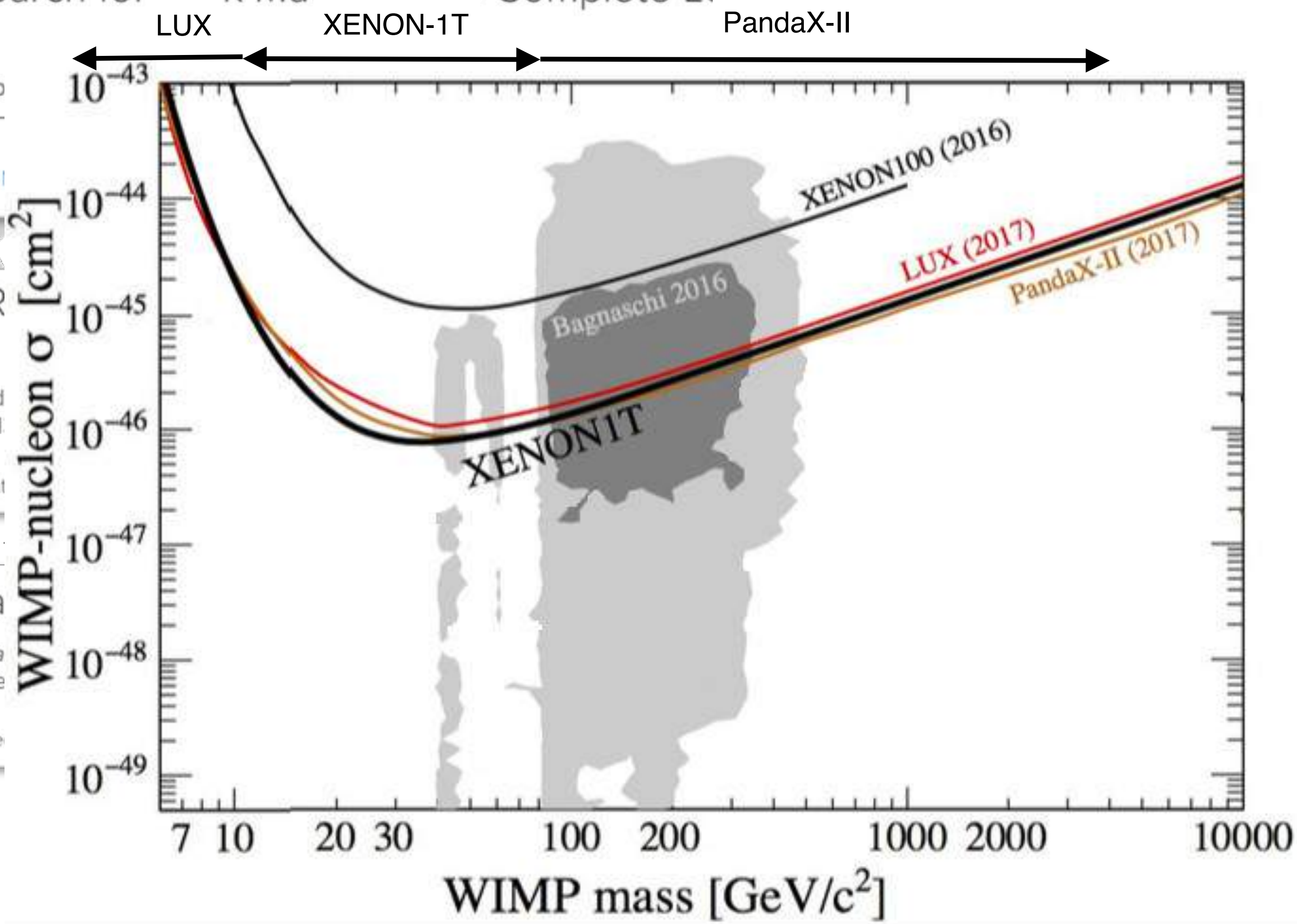
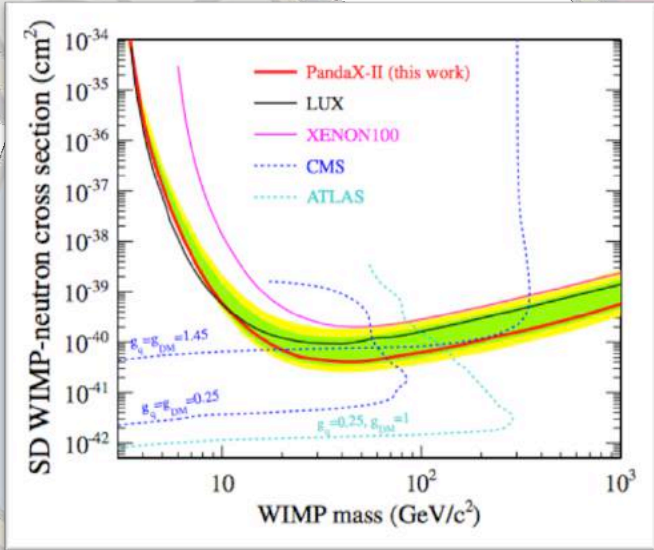
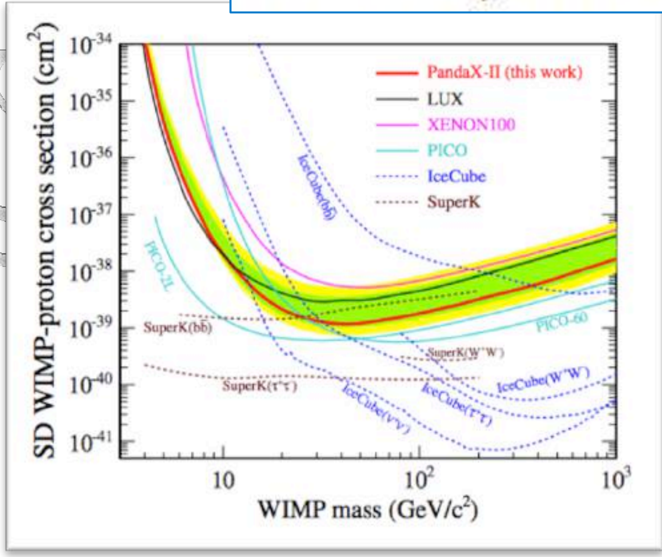
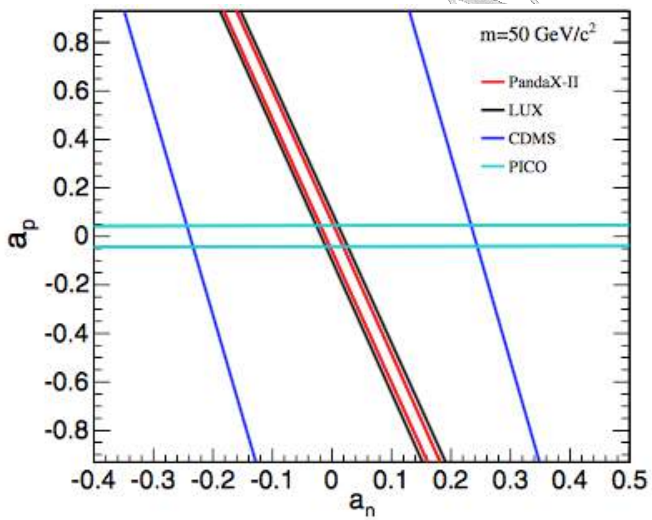


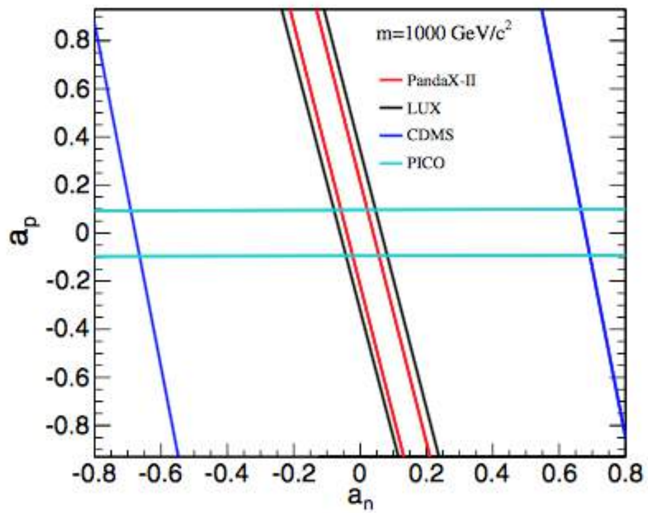
World status - SD

PRL **118,** 071301 (2017)







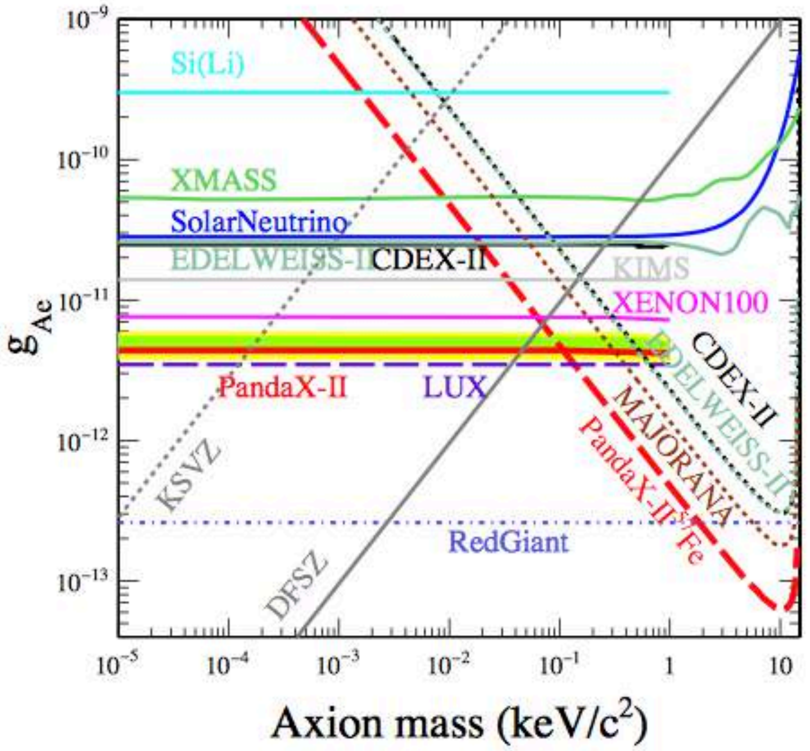


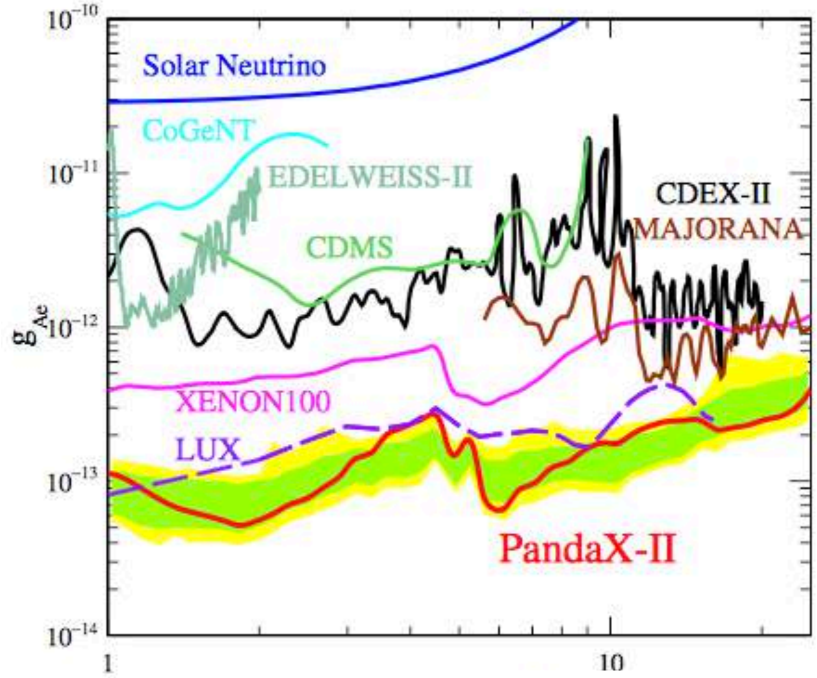
World status – Axions/ALPs

Electron-recoil signatures

QCD axions emitted from the Sun

Galactic DM ALPs

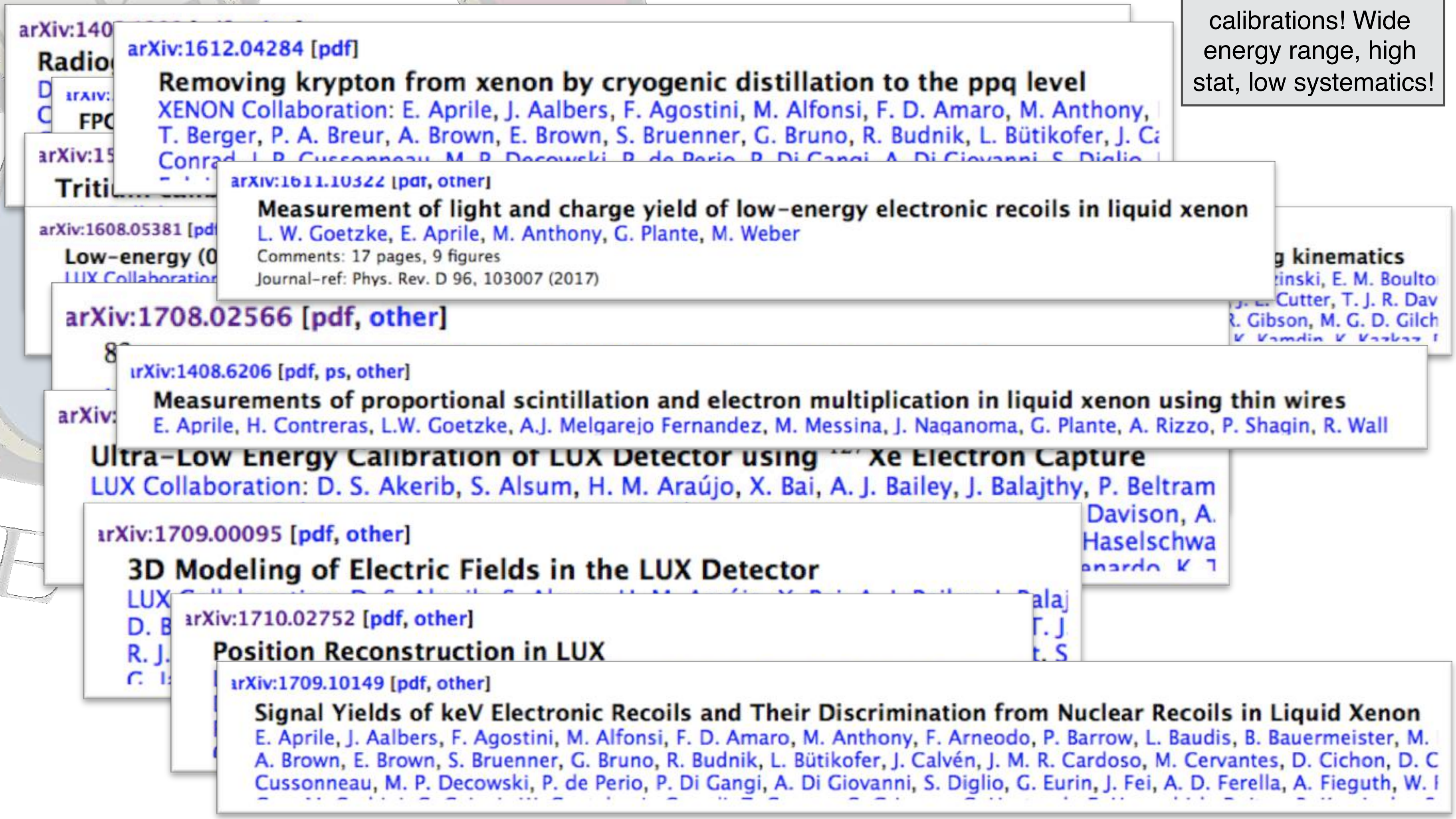




ALP mass (keV/c^2)

More to come soon…!

Not to mention…



arXiv:1612.04284 [pdf]
Removing krypton from xenon by cryogenic distillation to the ppq level
XENON Collaboration: E. Aprile, J. Aalbers, F. Agostini, M. Alfonsi, F. D. Amaro, M. Anthony,
T. Berger, P. A. Breur, A. Brown, E. Brown, S. Bruenner, G. Bruno, R. Budnik, L. Bütikofer, J. Ca

arXiv:1611.10322 [pdf, other]
Measurement of light and charge yield of low-energy electronic recoils in liquid xenon
L. W. Goetzke, E. Aprile, M. Anthony, G. Plante, M. Weber
Comments: 17 pages, 9 figures
Journal-ref: Phys. Rev. D 96, 103007 (2017)

arXiv:1608.05381 [pdf
Low-energy (0

arXiv:1708.02566 [pdf, other]

arXiv:1408.6206 [pdf, ps, other]
Measurements of proportional scintillation and electron multiplication in liquid xenon using thin wires
E. Aprile, H. Contreras, L.W. Goetzke, A.J. Melgarejo Fernandez, M. Messina, J. Naganoma, G. Plante, A. Rizzo, P. Shagin, R. Wall

Ultra-Low Energy Calibration of LUX Detector using Xe Electron Capture
LUX Collaboration: D. S. Akerib, S. Alsum, H. M. Araújo, X. Bai, A. J. Bailey, J. Balajthy, P. Beltram

arXiv:1709.00095 [pdf, other]
3D Modeling of Electric Fields in the LUX Detector

arXiv:1710.02752 [pdf, other]
Position Reconstruction in LUX

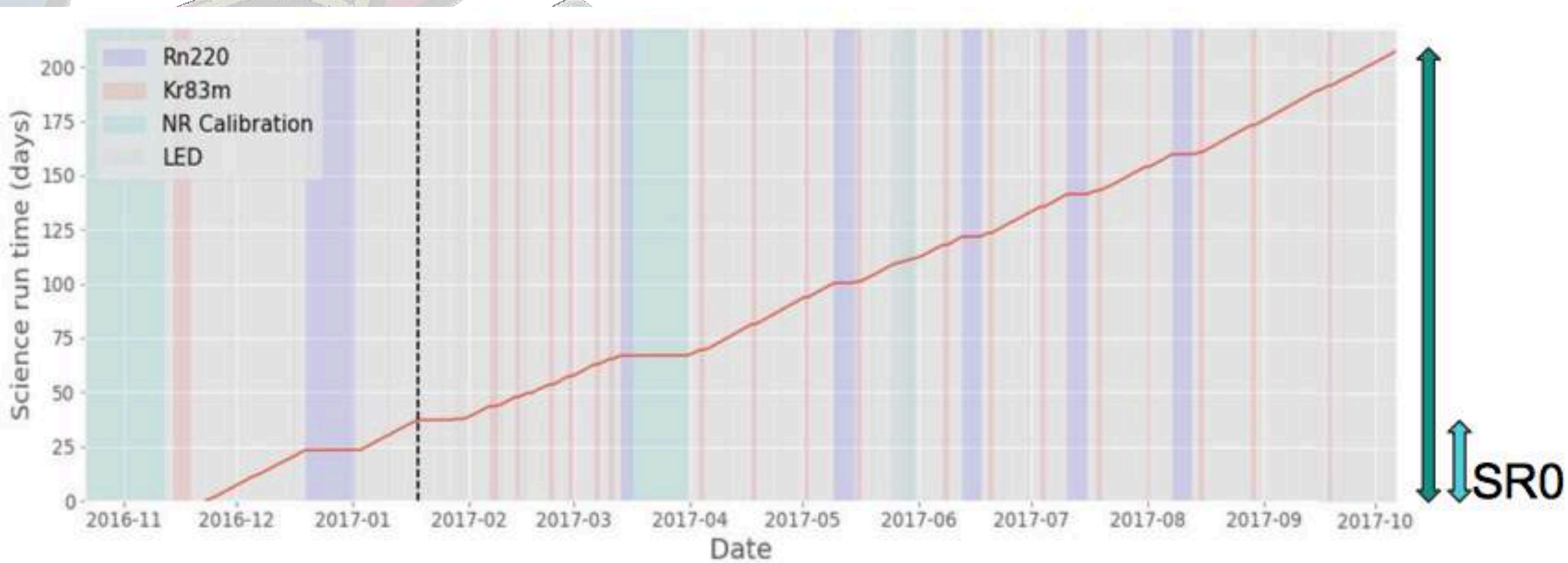
arXiv:1709.10149 [pdf, other]
Signal Yields of keV Electronic Recoils and Their Discrimination from Nuclear Recoils in Liquid Xenon
E. Aprile, J. Aalbers, F. Agostini, M. Alfonsi, F. D. Amaro, M. Anthony, F. Arneodo, P. Barrow, L. Baudis, B. Bauermeister, M.
A. Brown, E. Brown, S. Bruenner, G. Bruno, R. Budnik, L. Bütikofer, J. Calvén, J. M. R. Cardoso, M. Cervantes, D. Cichon, D. C
Cussonneau, M. P. Decowski, P. de Perio, P. Di Gangi, A. Di Giovanni, S. Diglio, G. Eurin, J. Fei, A. D. Ferella, A. Fieguth, W. I

Emphasise the huge contribution from LUX ER & NR calibrations! Wide energy range, high stat, low systematics!

Ever improving understanding of xenon physics and instrument performance

Near future

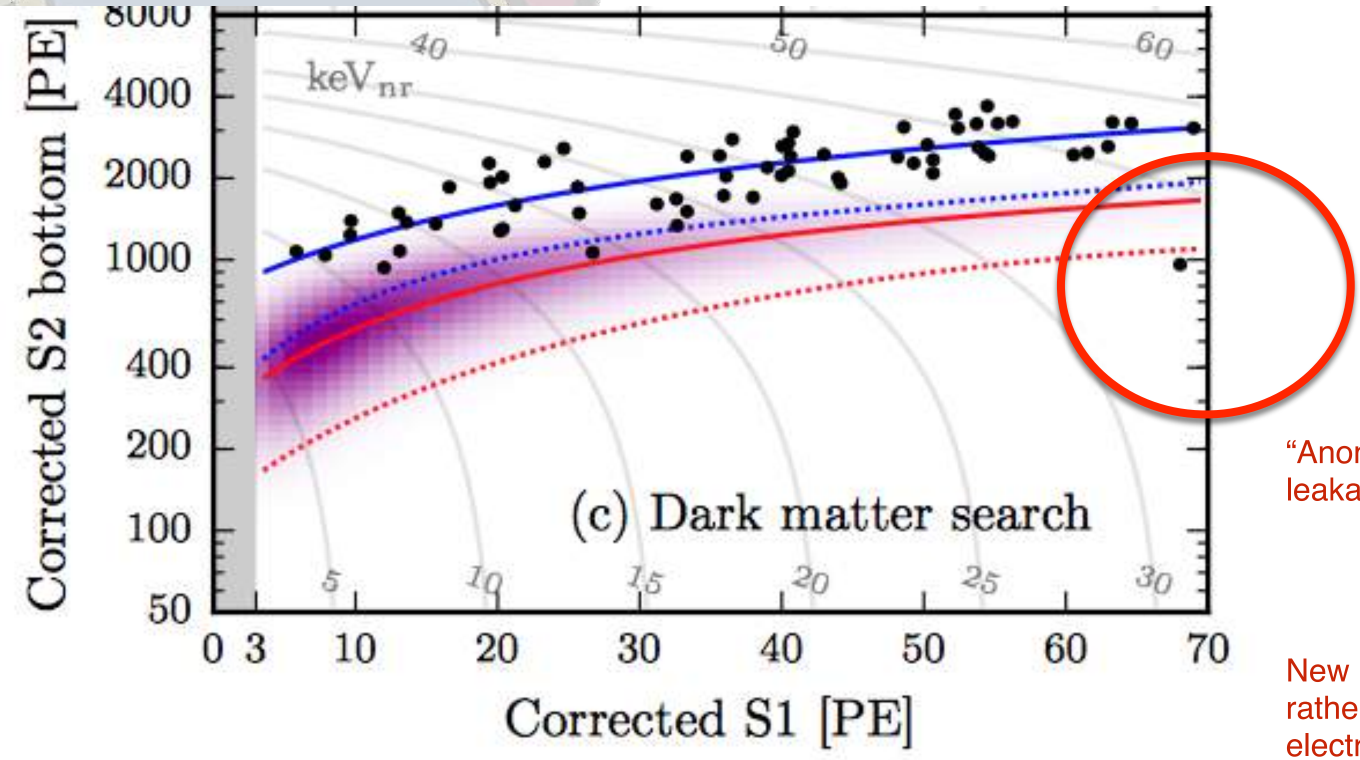
- LUX Completed operations in 2016
- XENON-1T and PandaX-II are still running…
- Anticipating major updates for ? DM2018@UCLA



XENON mid October….

Near future…

XENON-1T ‘First results…’

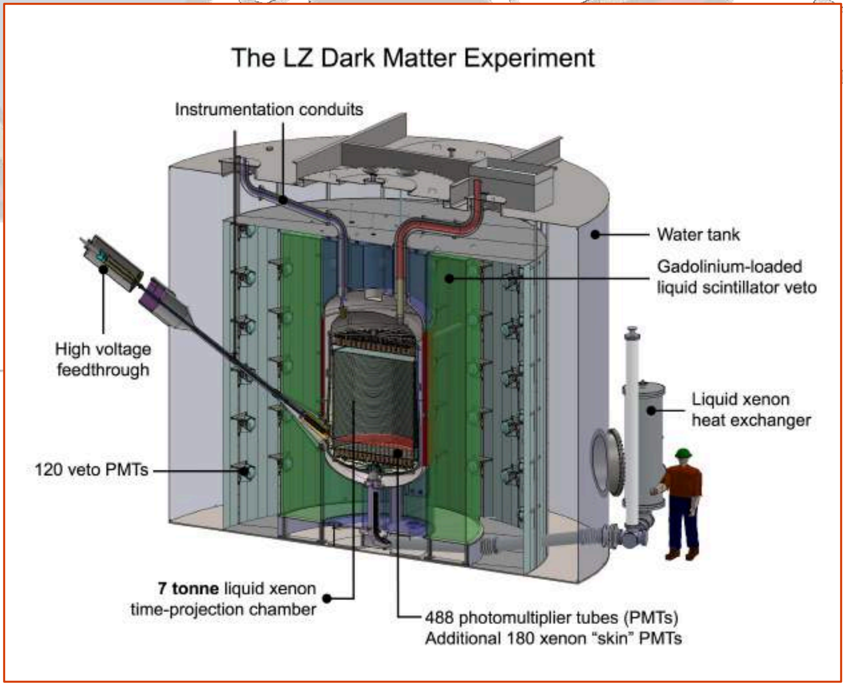


“Anomalous leakage events”

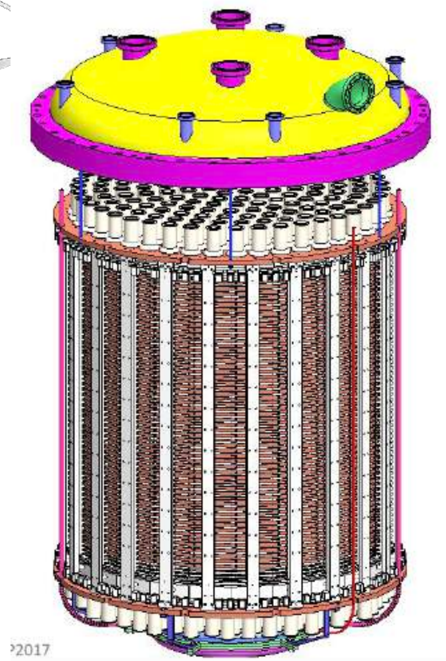
New run is at rather low electric field…

What's next for LXe TPCs?

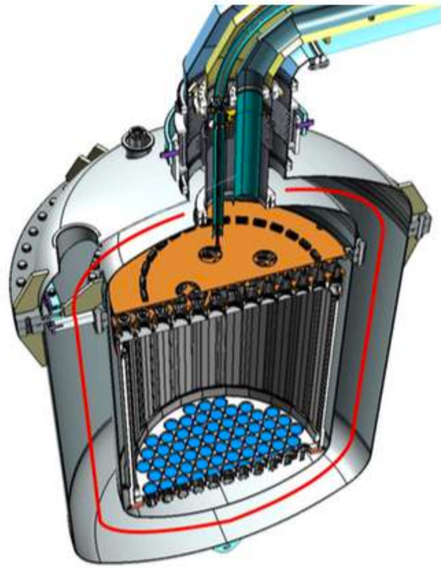
- LUX removed… LUX-ZEPLIN under construction
- XENON-1T planning to upgrade to XENON-nT
- PandaX-II planning to upgrade to PandaX-4T



10 T Xe, 7T active, 5.6T fiducial



4T sensitive



n ~ 7

UK focus…

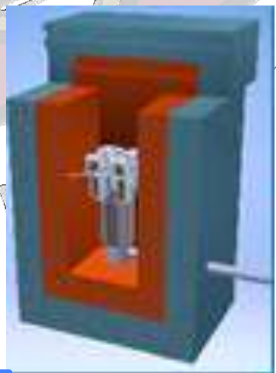
lz.ac.uk


Titanium Cryostat

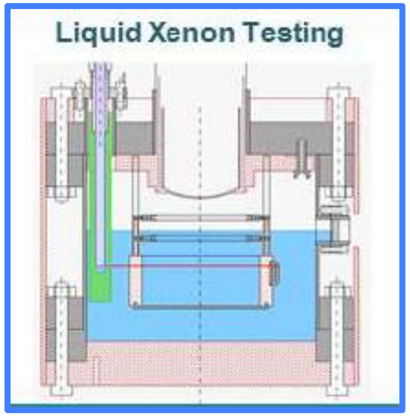

UK Data Centre & Simulations


1/3 TPC PMTs, Xenon Bases


Calibration Delivery



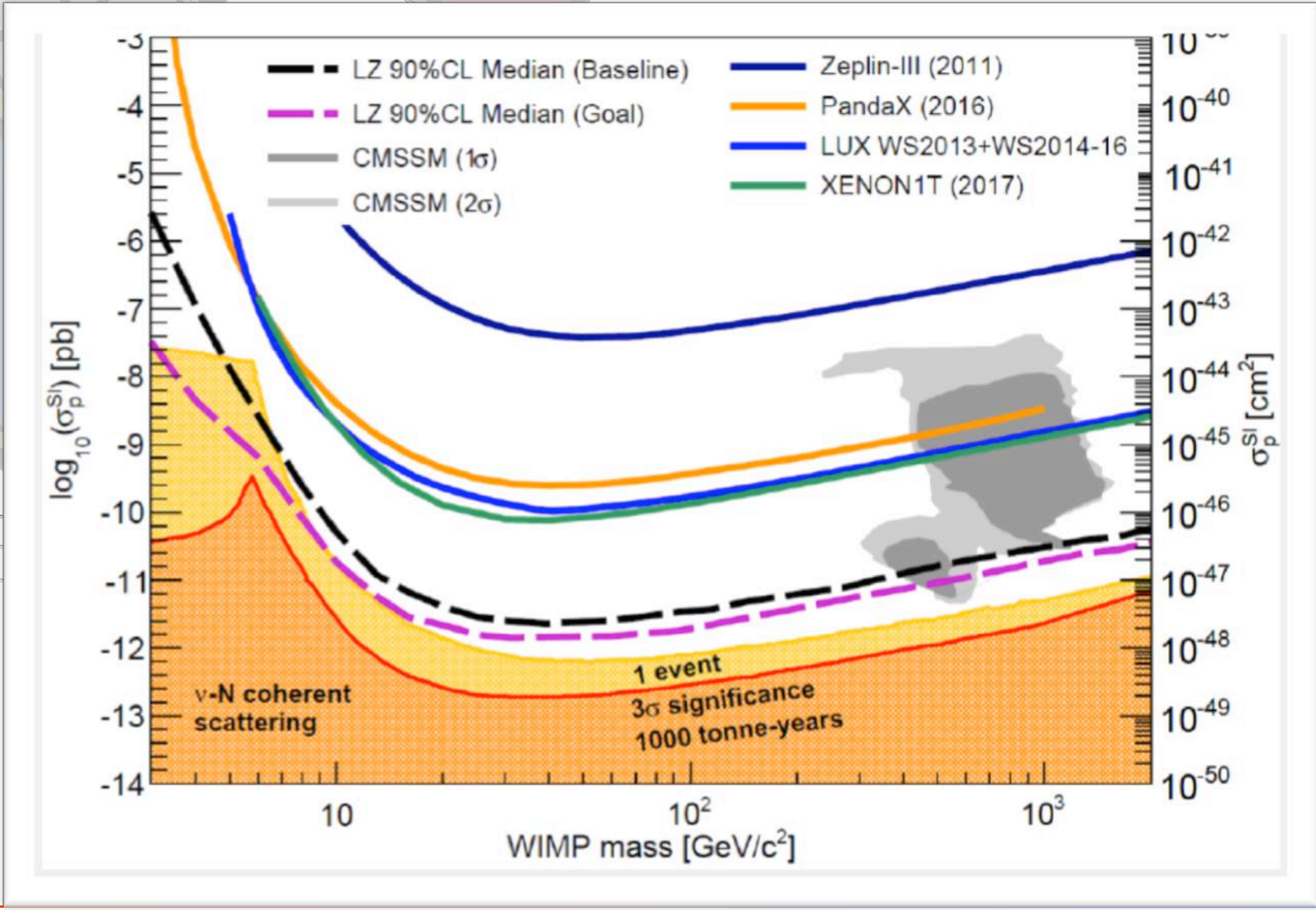

Materials Screening


Liquid Xenon Testing


TPC Monitoring Sensors

OD Optical Calibration System

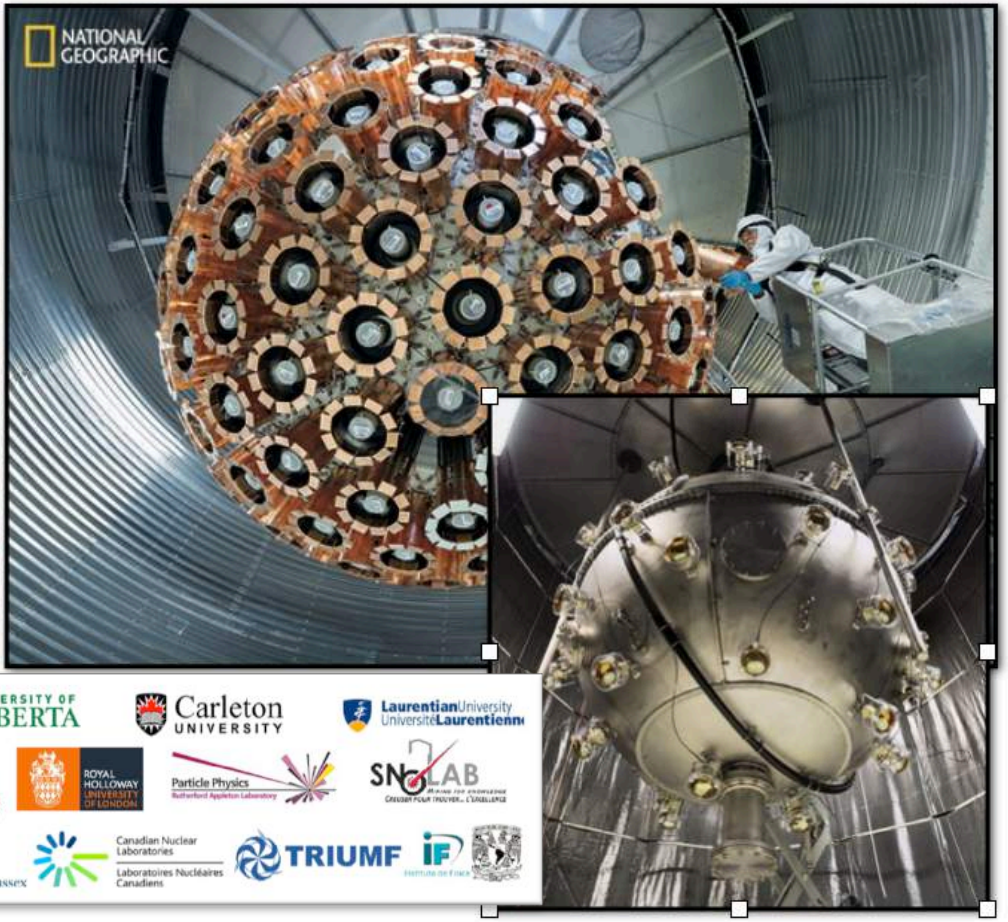

Skin PMT Validation



LZ 90%CL Median (Baseline)
LZ 90%CL Median (Goal)
CMSSM (1σ)
CMSSM (2σ)
Zeplin-III (2011)
PandaX (2016)
LUX WS2013+WS2014-16
XENON1T (2017)
ν-N coherent scattering
1 event
3σ significance
1000 tonne-years
log10(σpSI) [pb]
σpSI [cm2]
WIMP mass [GeV/c2]
10
10^2
10^3
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
10^-40
10^-41
10^-42
10^-43
10^-44
10^-45
10^-46
10^-47
10^-48
10^-49
10^-50

DEAP-3600 Detector (single-phase)

Argon, single phase, large! SNOLAB



3600 kg argon
in sealed ultraclean
Acrylic Vessel (1.7 m ID)

Vessel is "resurfaced"
in-situ to remove
deposited Rn daughters
after construction

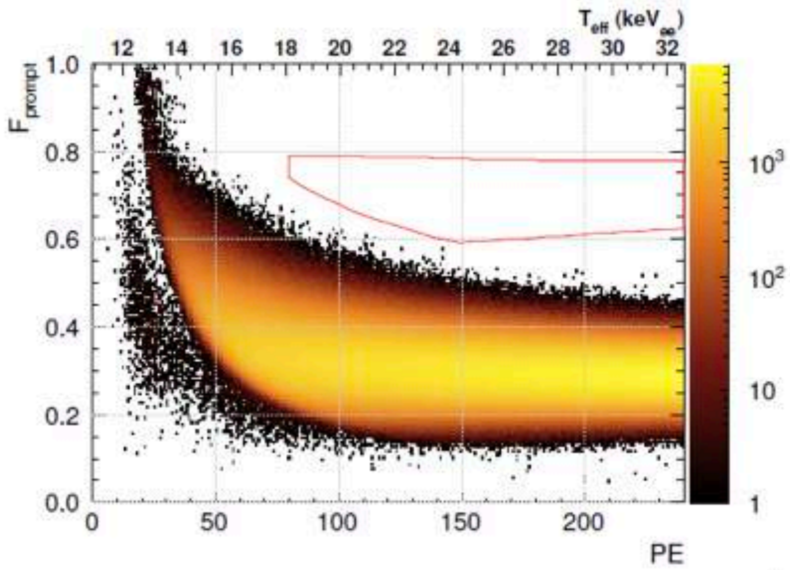
255 Hamamatsu
R5912 HQE PMTs 8-inch
(Light Sensors)

50 cm light guides +
PE shielding provide neutron
moderation

Steel Shell immersed in 8 m
water shield at SNOLAB

Courtesy J. Monroe

First results:

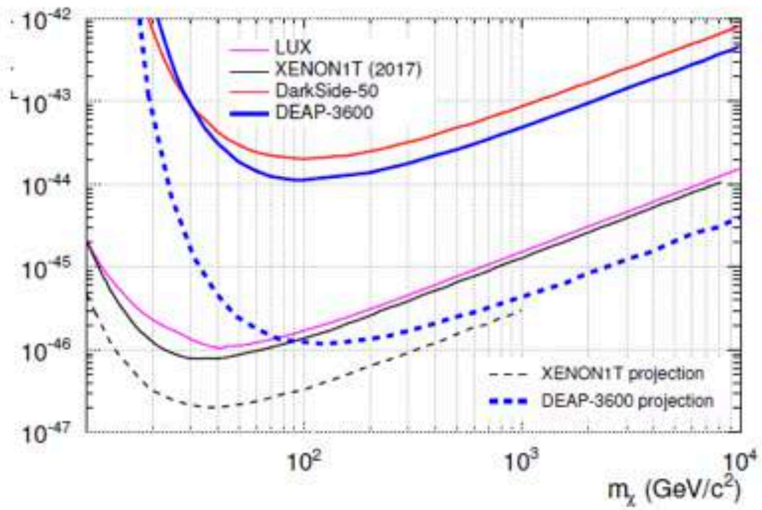


	Cut	Livetime	Acceptance %		# evt.
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			128153
	Deadtime corrected	4.68 d			780
quality	Max charge fraction per PMT		99.58±0.01		647
	Event time		99.85±0.01		645
	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	0
	Total	4.68 d	96.94±0.03	$66.91^{+0.20}_{-0.15}$	0

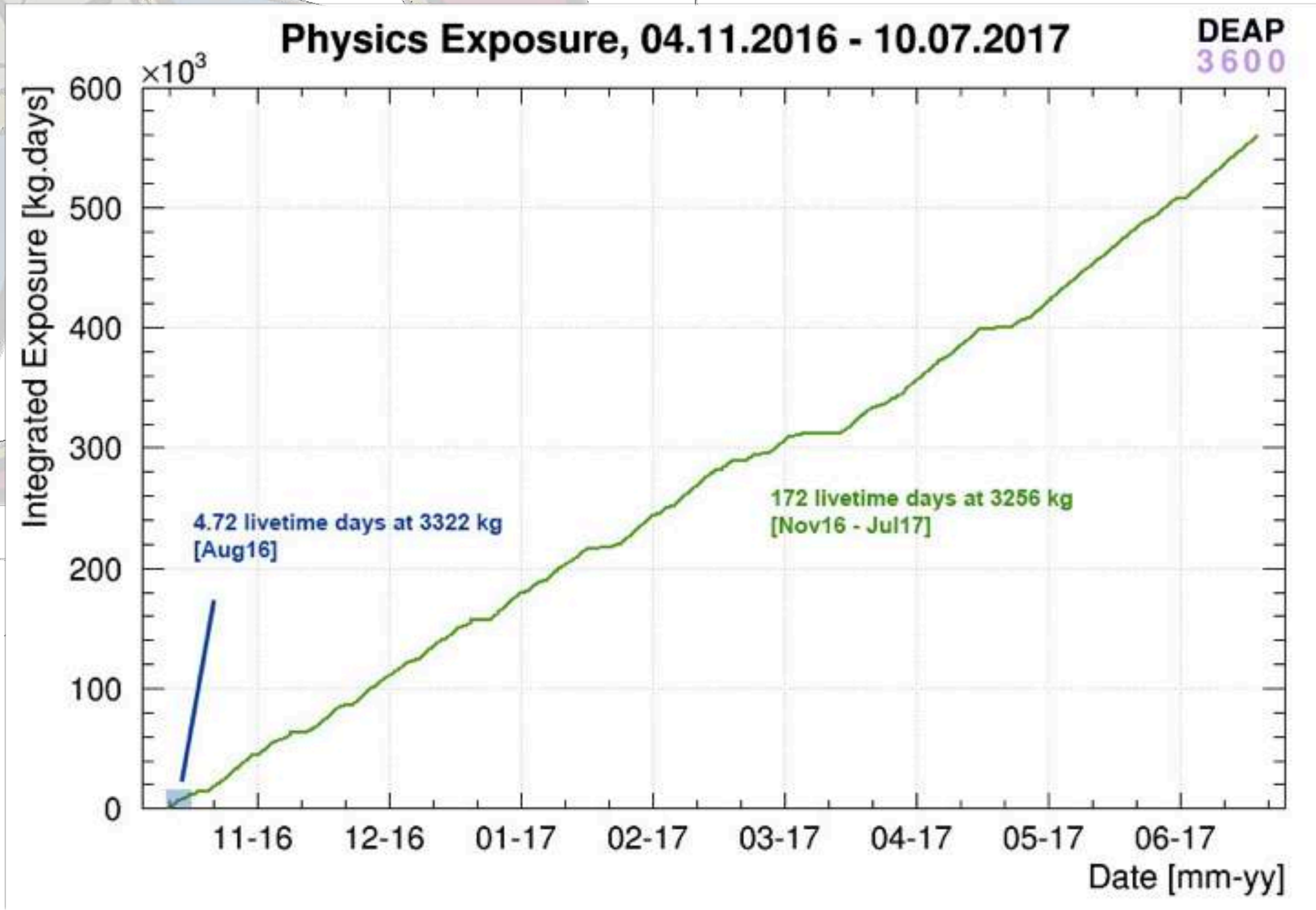
4.7 live days = 12,000 kg-day exposure

Energy threshold: 80 PE (projection was 120 PE)
Fiducial mass: 2 tonne (projection was 1 tonne)

No events observed in ROI.
Leading result in LAr, first at tonne-scale.



Courtesy J. Monroe

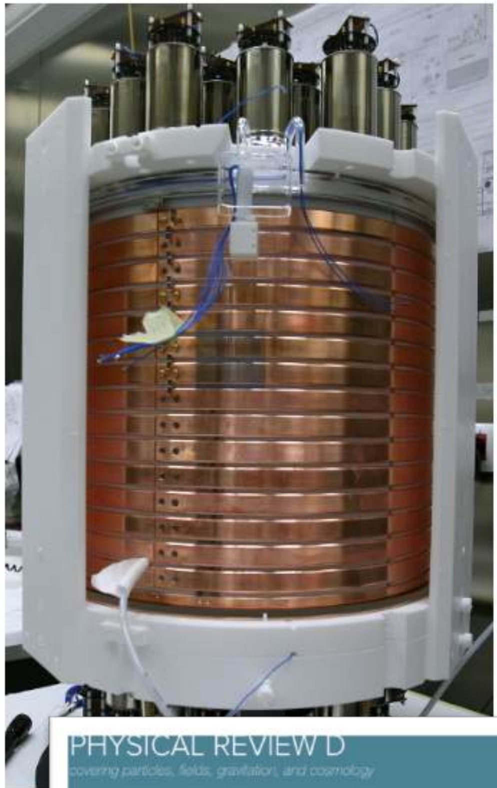


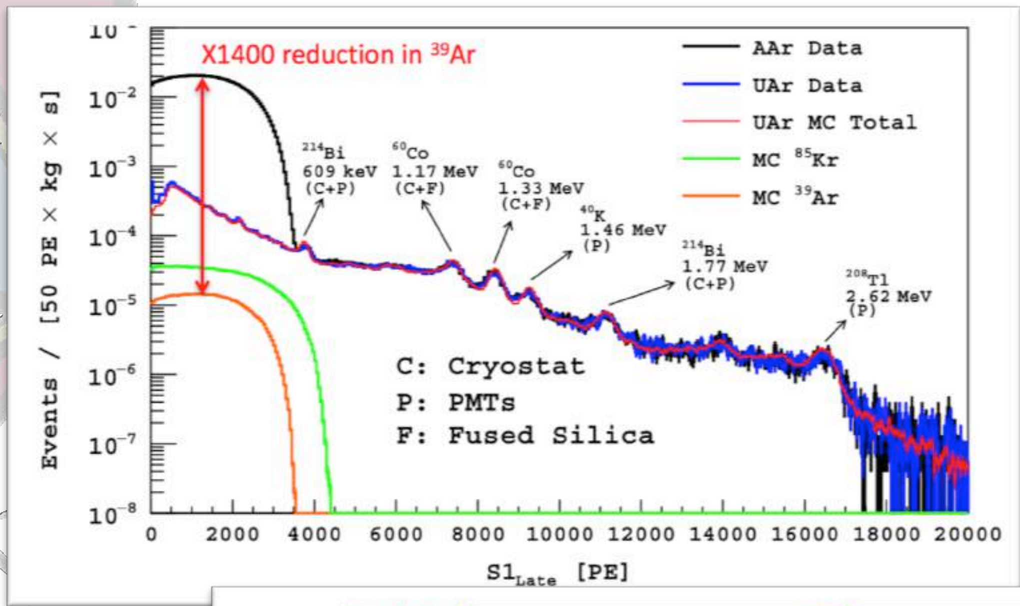
Courtesy J. Monroe

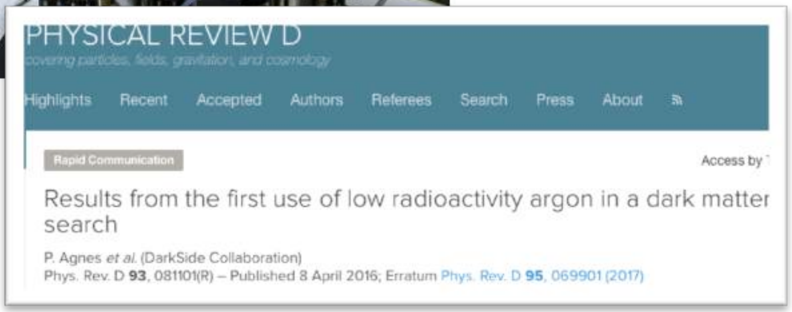
Slide from MG Boulay – TAUP 2017, Sudbury

DarkSide-50

Two-phase argon





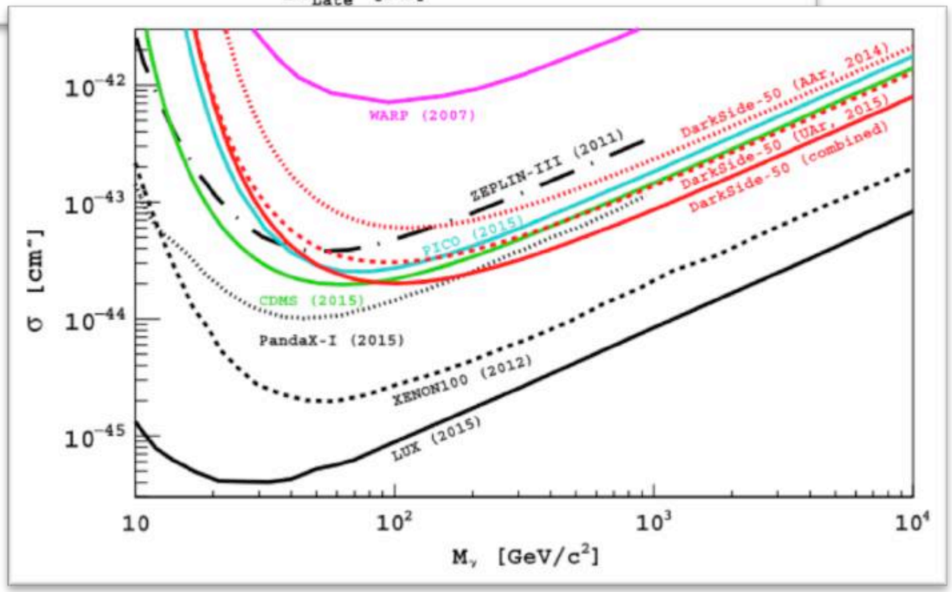

PHYSICAL REVIEW D
covering particles, fields, gravitation, and cosmology
Highlights Recent Accepted Authors Referees Search Press About

Rapid Communication

Access by

Results from the first use of low radioactivity argon in a dark matter search

P. Agnes *et al.* (DarkSide Collaboration)
Phys. Rev. D **93**, 081101(R) – Published 8 April 2016; Erratum Phys. Rev. D **95**, 069901 (2017)

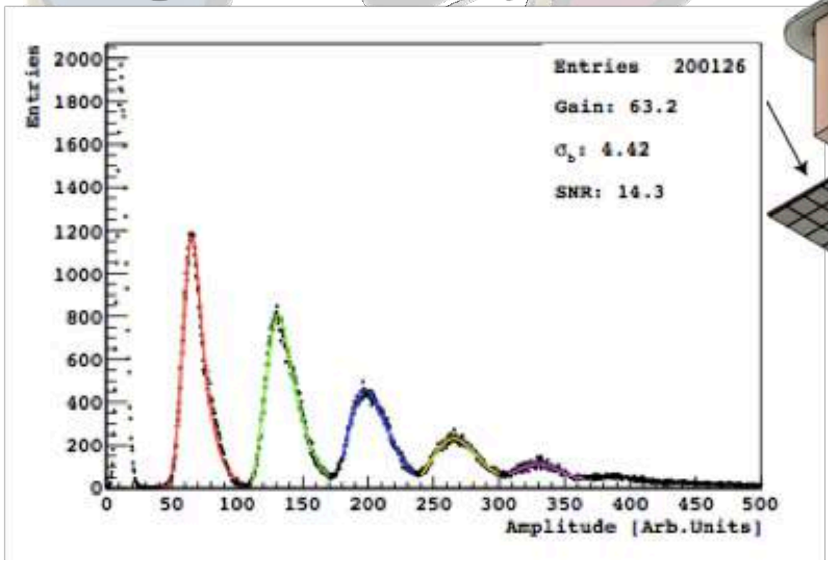


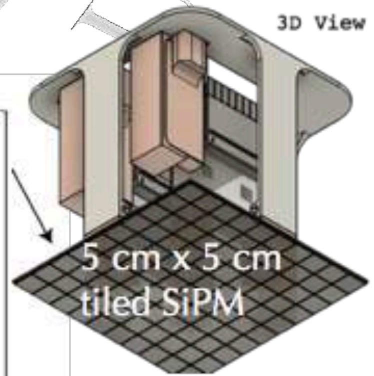
Next: Global Argon Dark Matter Collaboration

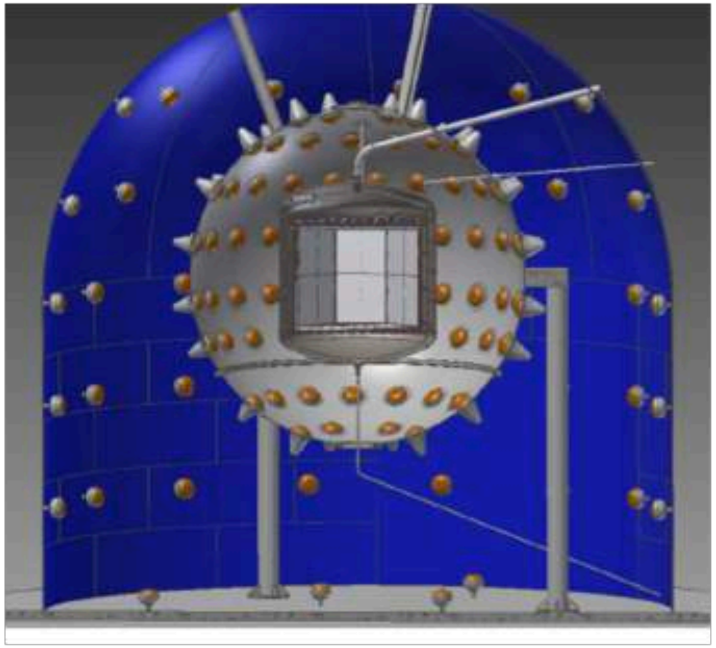
DarkSide + DEAP + miniCLEAN + ArDM > 350 researchers, collaborating on INFN & NSF-funded 20 t LAr experiment at LNGS: DarkSide-20k.

Complementary with LHC: background-free exploration of high masses with direct search
First large-scale use of large area cryogenic SiPMs

UK efforts on calibration, DAQ, large area SiPMs response







Courtesy J. Monroe

DarkSide-20k

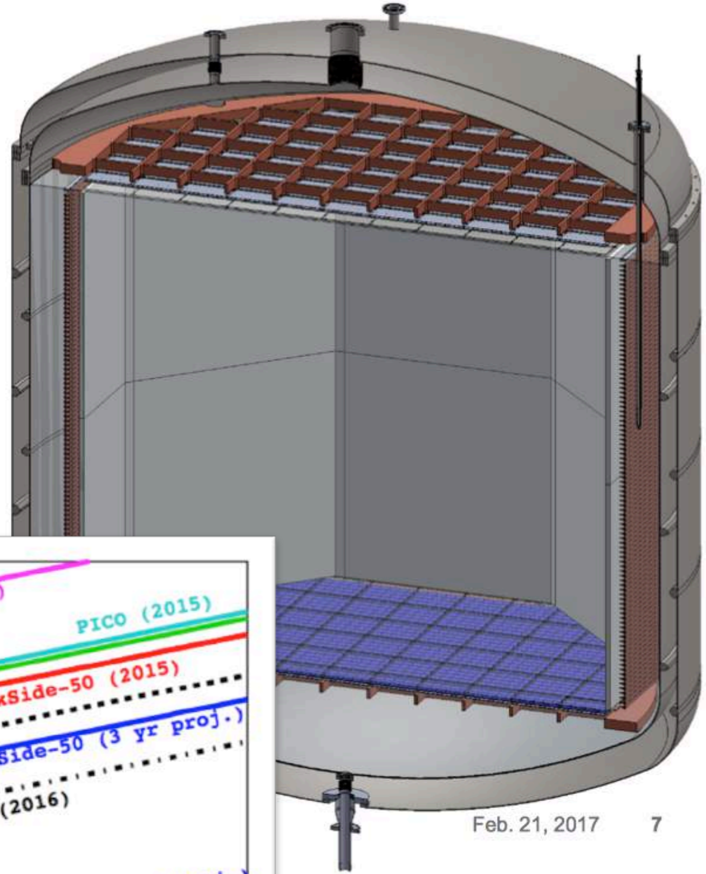
arXiv.org > physics > arXiv:1707.08145

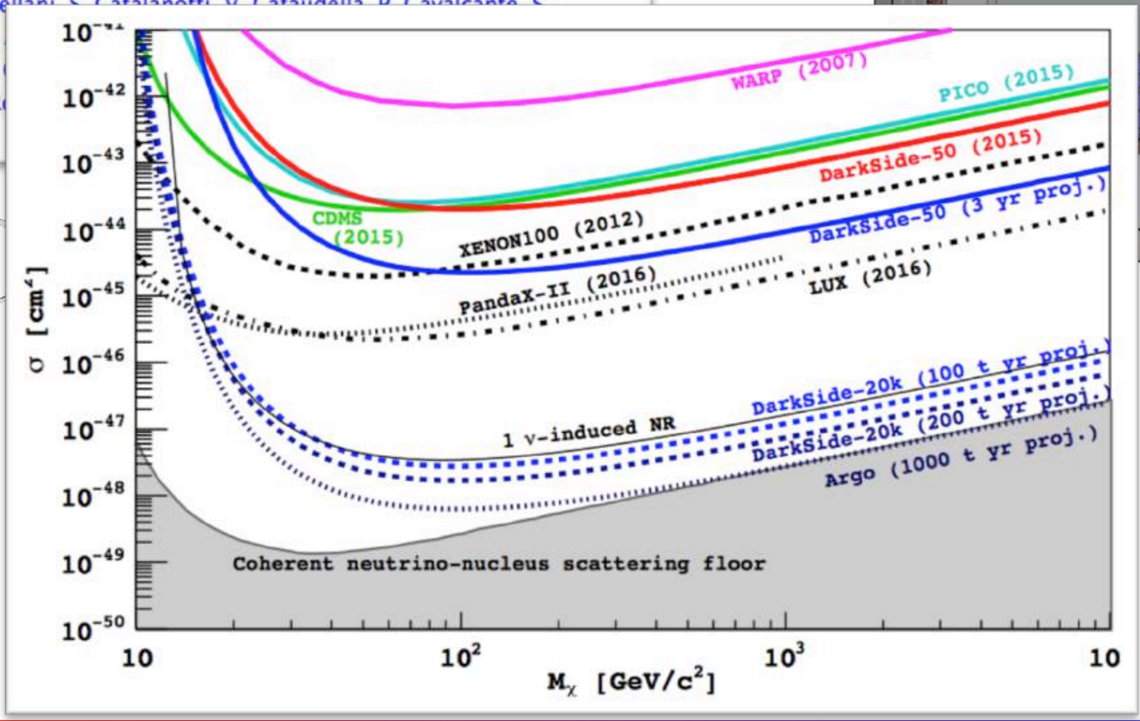
Search or Artic...
(Help | Advanced se...

Physics > Instrumentation and Detectors

DarkSide-20k: A 20 Tonne Two-Phase LAr TPC for Direct Dark Matter Detection at LNGS

C. E. Aalseth, F. Acerbi, P. Agnes, I. F. M. Albuquerque, T. Alexander, A. Alici, A. K. Alton, P. Antonioli, S. Arcelli, R. Ardito, I. J. Arnquist, D. M. Asner, M. Ave, H. O. Back, A. I. Barrado Olmedo, G. Batignani, E. Bertoldo, S. Bettarini, M. G. Bisogni, V. Bocci, A. Bondar, G. Bonfini, W. Bonivento, M. Bossa, B. Bottino, M. Boulay, R. Bunker, S. Bussino, A. Buzulutskov, M. Cadeddu, M. Cadoni, A. Caminata, N. Canci, A. Candela, C. Cantini, M. Caravati, M. Cariello, M. Carlini, M. Carpinelli, A. Caste... Cavuoti, R. Cereseto, ... Cocco, M. Colocci, S. ... D. D'Urso, M. D. Da R... authors not shown)

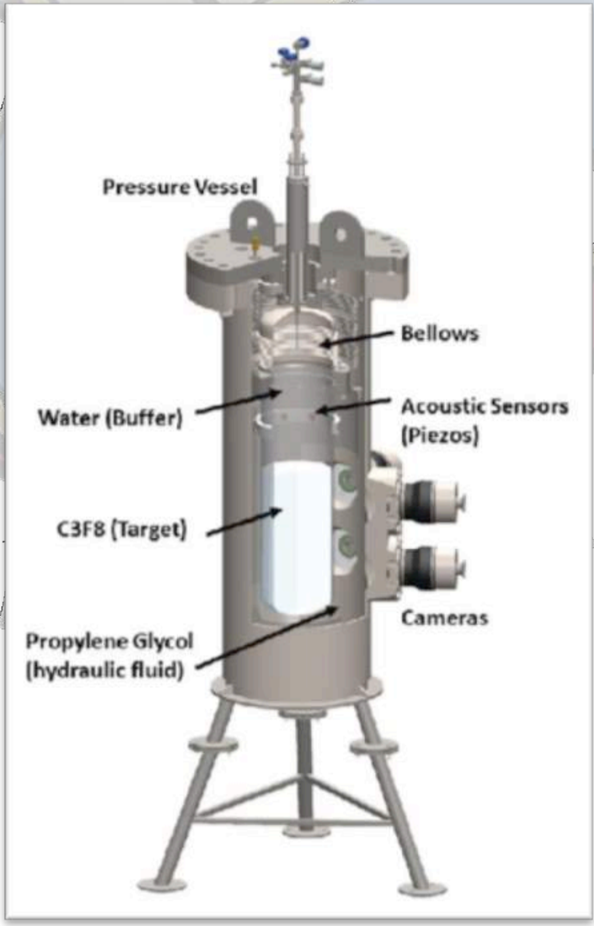


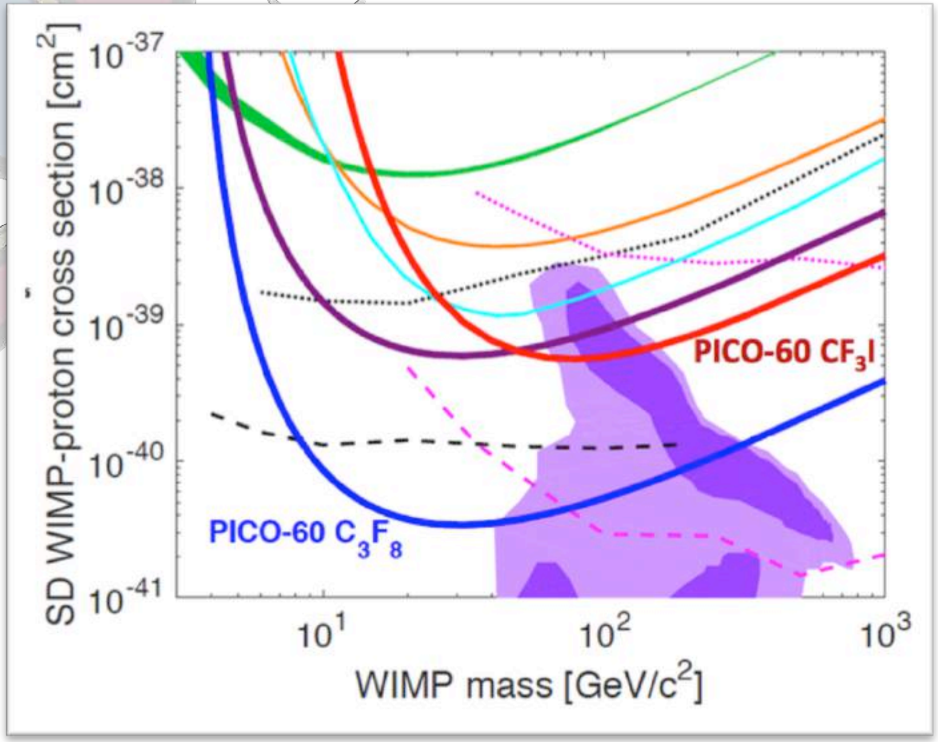


Feb. 21, 2017 7

PICO-60

Bubble chamber, SNOLAB

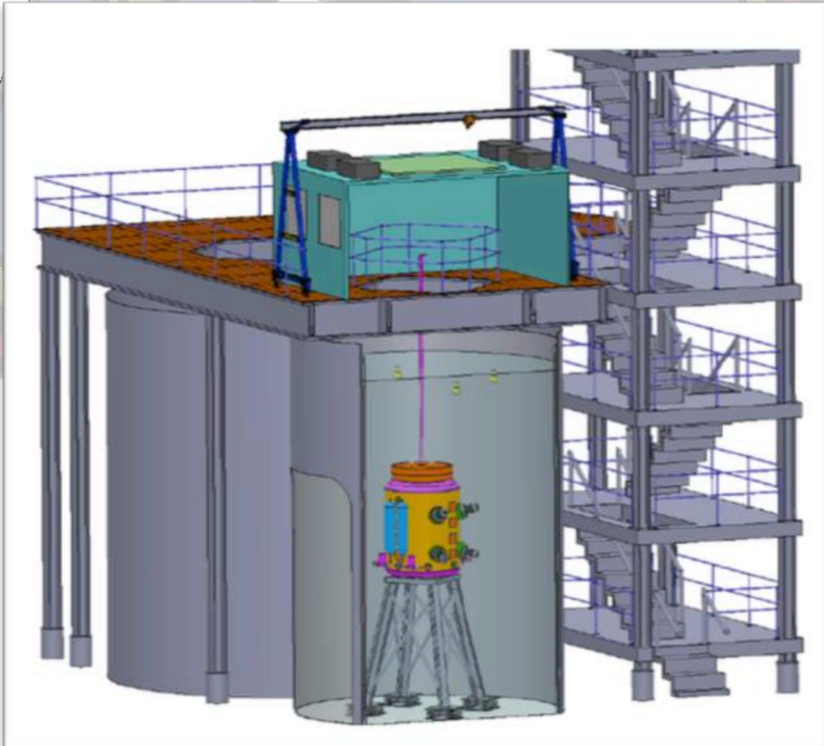


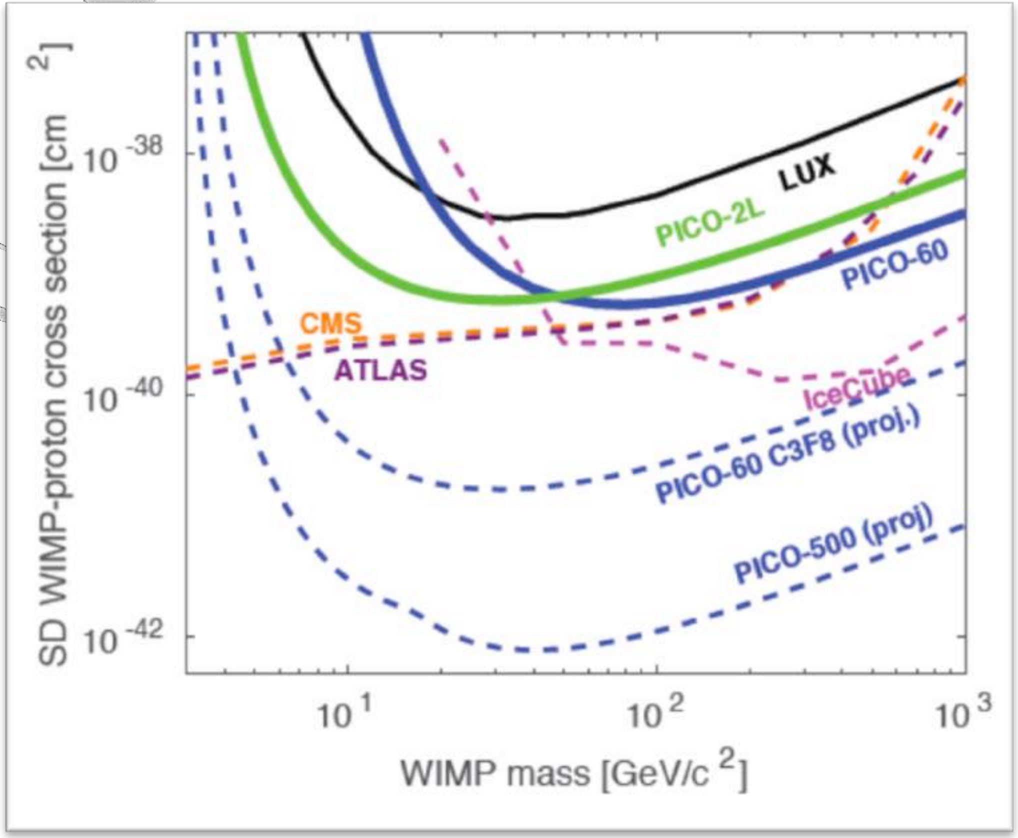


Un-paired proton → strong SDp sensitivity

PICO-500

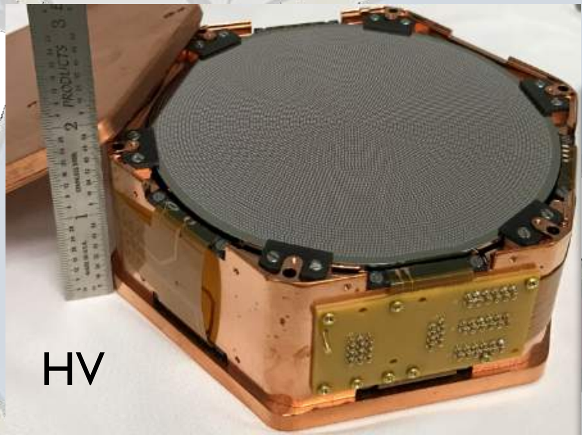
Bubble chamber, SNOLAB

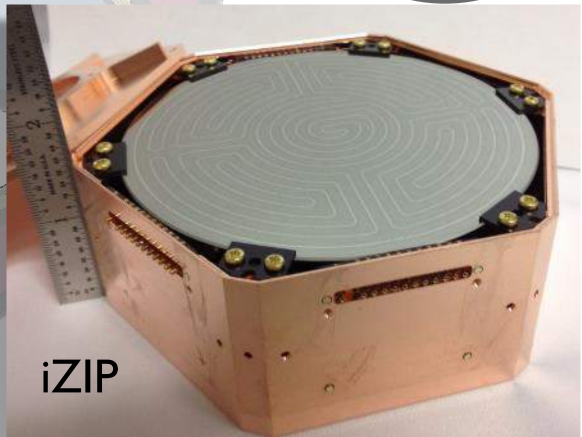




SuperCDMS

Planned for SNOLAB



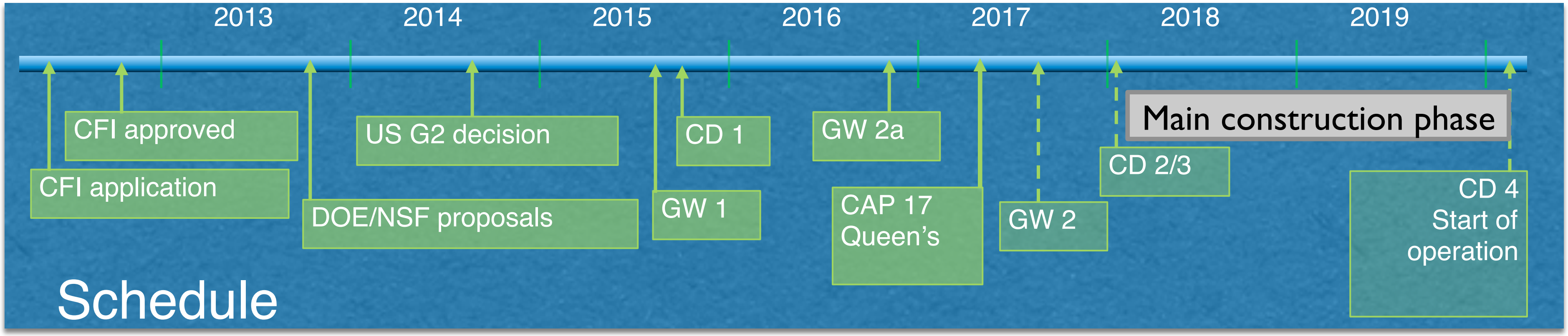


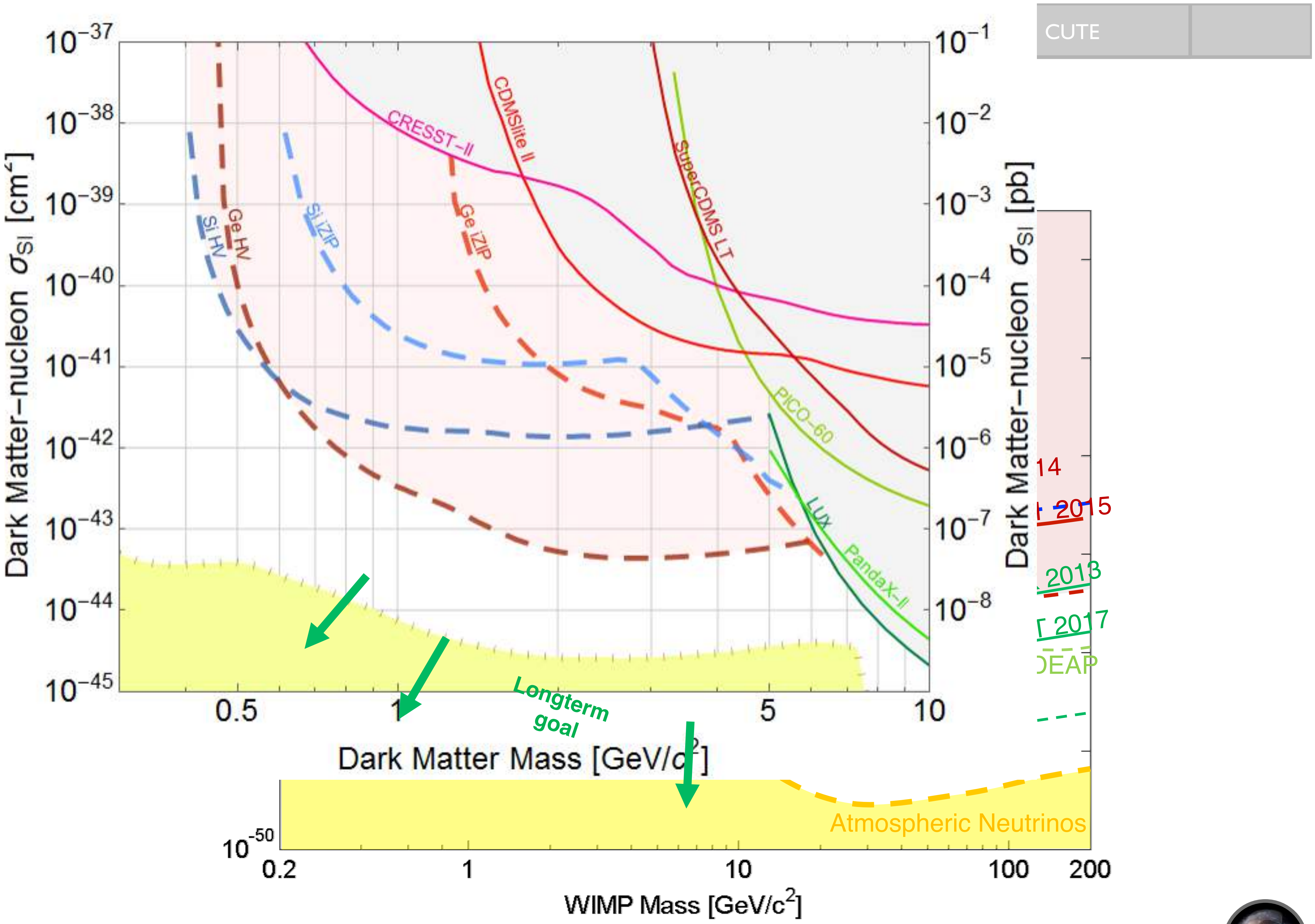
- Charge & phonon signals
- 100 mm Ø, 33 mm thick:
- Operated at 30 mK

6 detectors
→ 1 tower

Initial Payload:

T1: 6 Ge iZIP
T2: 4 Ge, 2 Si iZIP
T3: 4 Ge, 2 Si HV
T4: 4 Ge, 2 Si HV

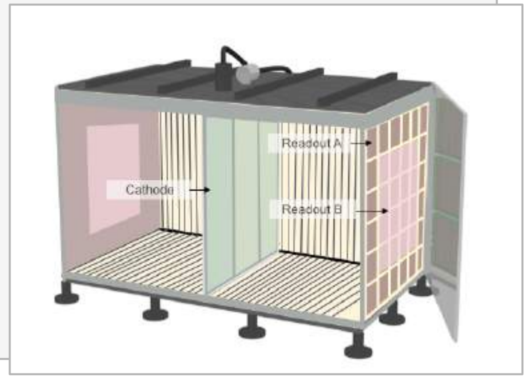



CUTE
CRESST-II
CDMSlite II
SuperCDMS LT
Si HV
Ge HV
Si iZIP
Ge iZIP
PICO-60
LUX
PandaX-II
Longterm goal
Dark Matter–nucleon σSI [cm²]
Dark Matter–nucleon σSI [pb]
Dark Matter Mass [GeV/c²]
WIMP Mass [GeV/c²]
Atmospheric Neutrinos
2015
2013
2017
DEAP

Directional Searches

Exploit anisotropic recoil direction to uniquely confirm the DM signal

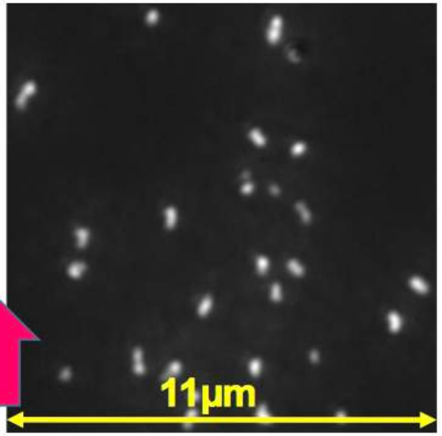
- DRIFT: Discovery of minority carrier capability (allows fiducialisation)
- SF_6: Negative Ion TPC ✓ minority carriers ✓ high F content ✓ +low A ✓
- Working towards an array of 10 SF_6 ~m^3 modules with ~keV threshold.
- New funded activities now in Italy, Australia, Japan.
- CYGNUS-KM vessel (Kobe/Japan) is built & used to down-select readouts (use DUNE electronics?)
- The US now has some DOE money.
- Cooperation with MIMAC, France



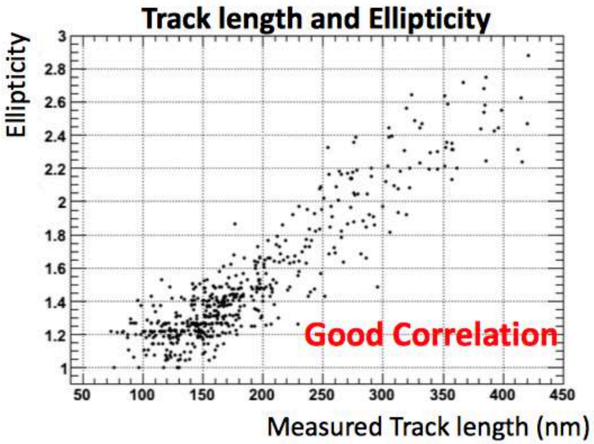
Courtesy N. Spooner

NEWS dm — Nuclear Emulsions for WIMP Search - directional measurement

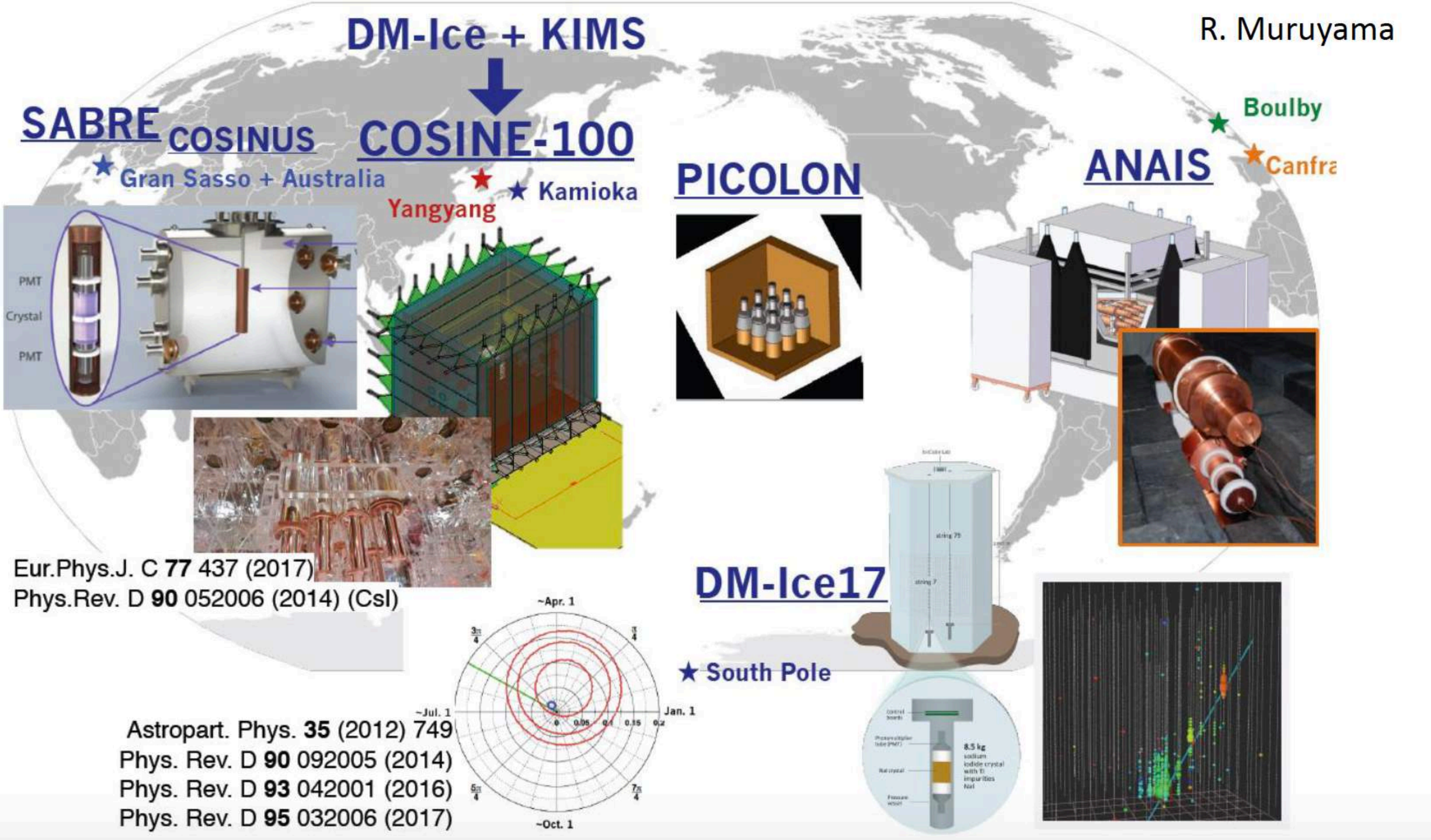
arXiv:1604.04199



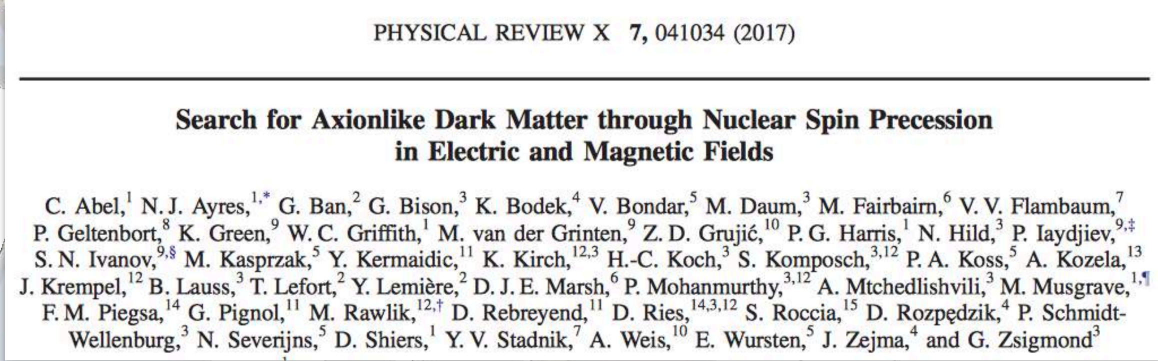
C100keV



NaI(Tl) tests of DAMA



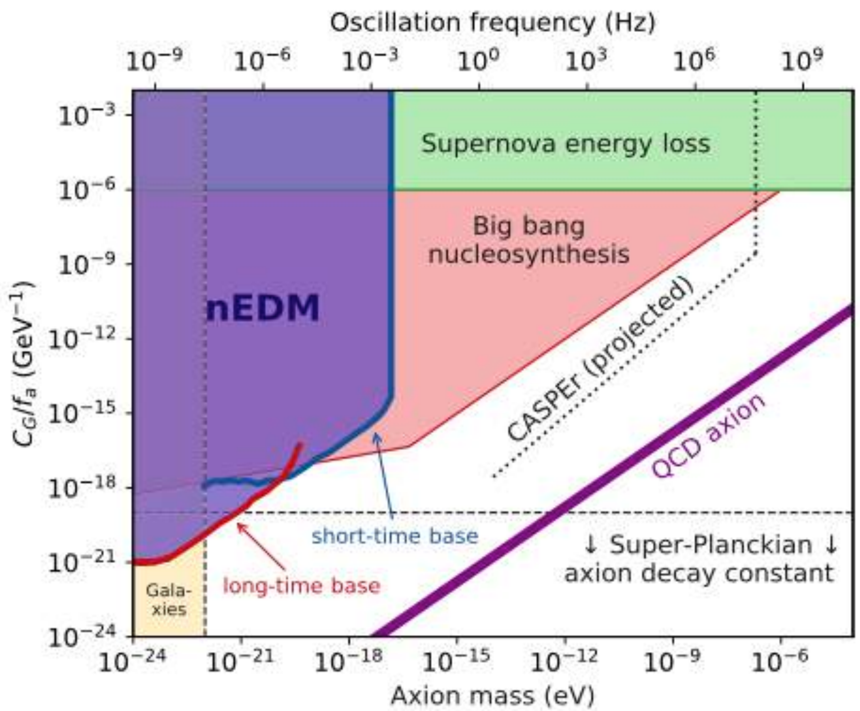
A ‘different’ direct search

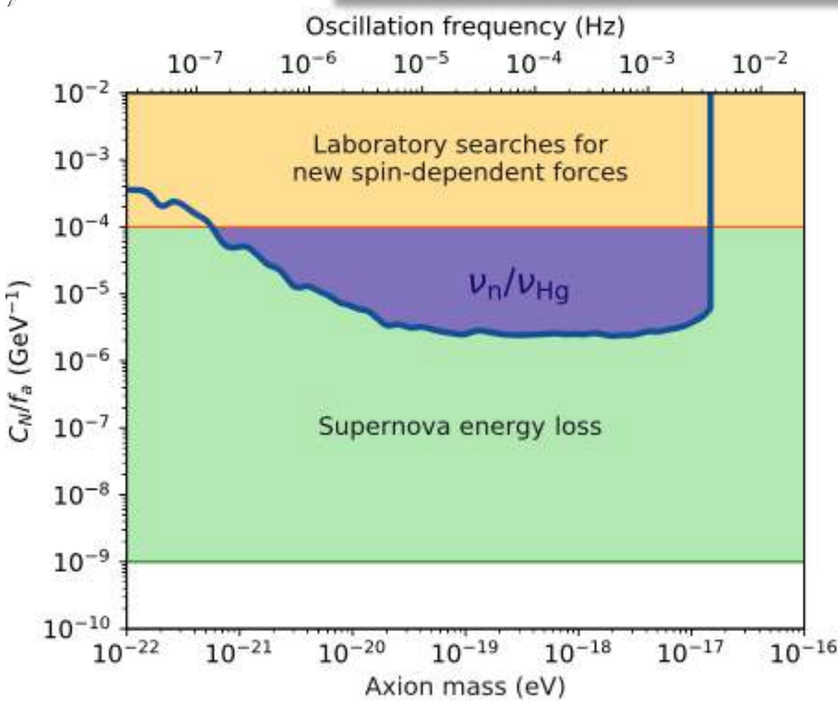


PHYSICAL REVIEW X **7,** 041034 (2017)

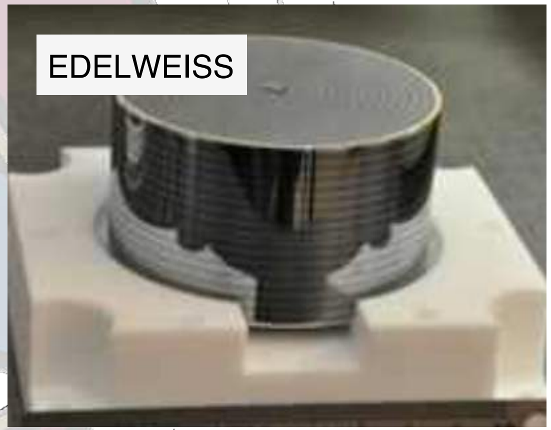
Search for Axionlike Dark Matter through Nuclear Spin Precession in Electric and Magnetic Fields

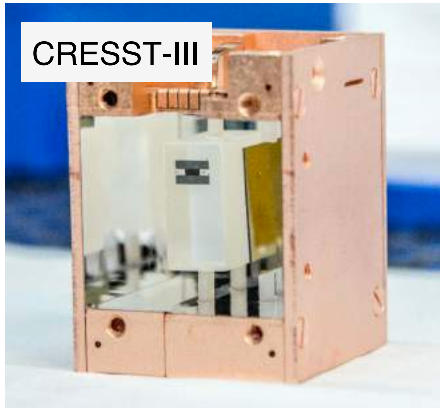
C. Abel,[1] N. J. Ayres,[1,*] G. Ban,[2] G. Bison,[3] K. Bodek,[4] V. Bondar,[5] M. Daum,[3] M. Fairbairn,[6] V. V. Flambaum,[7] P. Geltenbort,[8] K. Green,[9] W. C. Griffith,[1] M. van der Grinten,[9] Z. D. Grujić,[10] P. G. Harris,[1] N. Hild,[3] P. Iaydjiev,[9,‡] S. N. Ivanov,[9,§] M. Kasprzak,[5] Y. Kermaidic,[11] K. Kirch,[12,3] H.-C. Koch,[3] S. Komposch,[3,12] P. A. Koss,[5] A. Kozela,[13] J. Krempel,[12] B. Lauss,[3] T. Lefort,[2] Y. Lemière,[2] D. J. E. Marsh,[6] P. Mohanmurthy,[3,12] A. Mtchedlishvili,[3] M. Musgrave,[1,¶] F. M. Piegsa,[14] G. Pignol,[11] M. Rawlik,[12,†] D. Rebreyend,[11] D. Ries,[14,3,12] S. Roccia,[15] D. Rozpędzik,[4] P. Schmidt-Wellenburg,[3] N. Severijns,[5] D. Shiers,[1] Y. V. Stadnik,[7] A. Weis,[10] E. Wursten,[5] J. Zejma,[4] and G. Zsigmond[3]

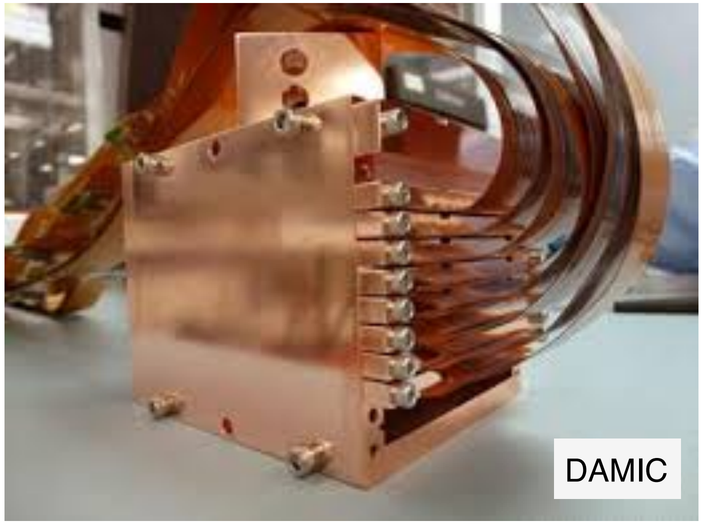


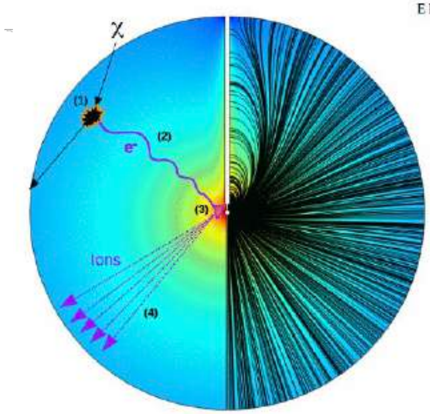


Not mentioned…









NEWS

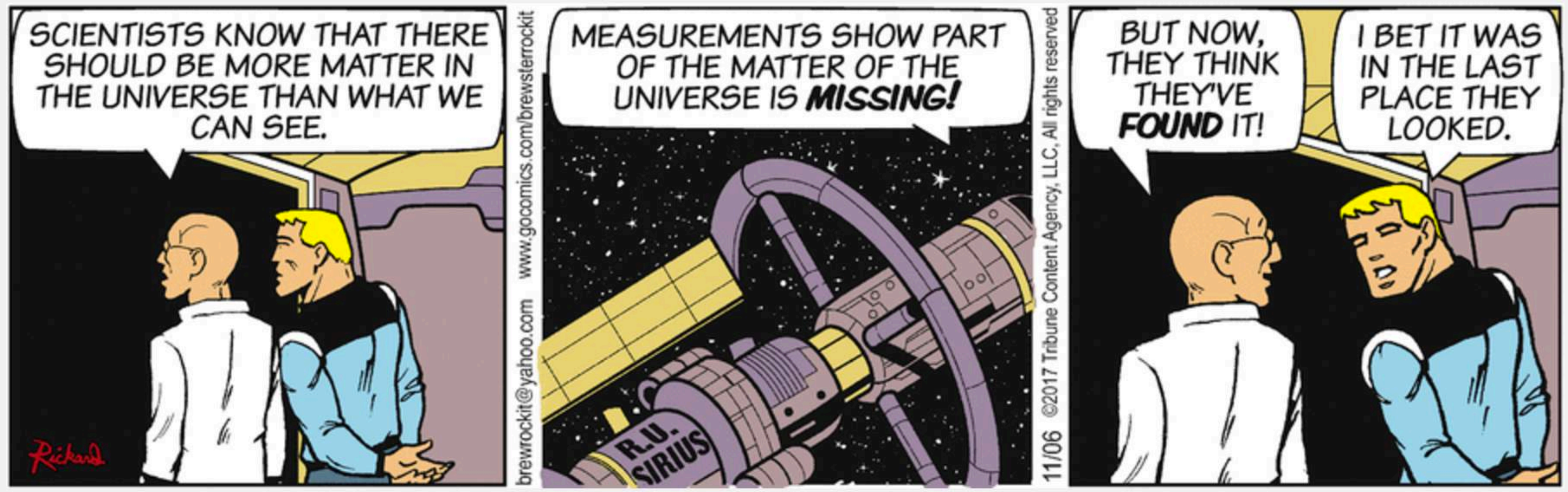
+ probably many more…

Huge progress over the past 2 decades. ~5 orders of magnitude in sensitivity, detector physics, low background physics

Expect major updates from DEAP3600, PandaX, XENON-1T… in ?February?

UK well placed with **LUX-ZEPLIN** & others for next decade at least.

One day, not too far in the future…

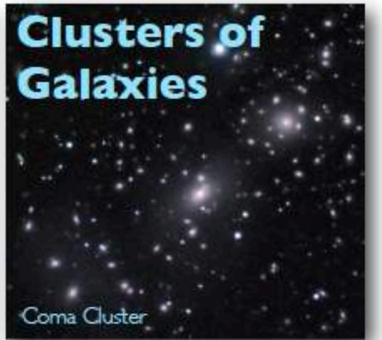


EXTRA

"4850 Feet Below: The Hunt for Dark Matter"
https://www.youtube.com/watch?v=YxMGWQMoR10

"Dark Matter Hunt with LUX-ZEPLIN (LZ)"
https://www.youtube.com/watch?v=bKCsiK4ZZBY

Targets - Dark Matter Annihilations



Extra-galactic	Milky Way Halo	Galactic Center	Dwarf Spheroidal	Clusters of Galaxies
Small halo model dependence, boost factors	Large DM content, nearby source, O(10) larger flux than extra-galactic	Very dense DM accumulation, nearby source	No astrophysical backgrounds	Large DM content, high boost factors from sub structure
Diffuse flux, spectral feature	Anisotropy	Extended Source	Point source	Extended source
Signal weak compared to Galactic signal	Relatively independent from DM halo profile	Very strong dependence on DM density profile	Cored profiles favored, less flux	Understanding of boost factors

For discovery observations at multiple sources with different observatories (Multiwavelength !) that yield a consistent picture

Indirect Searches

Decaying DM:

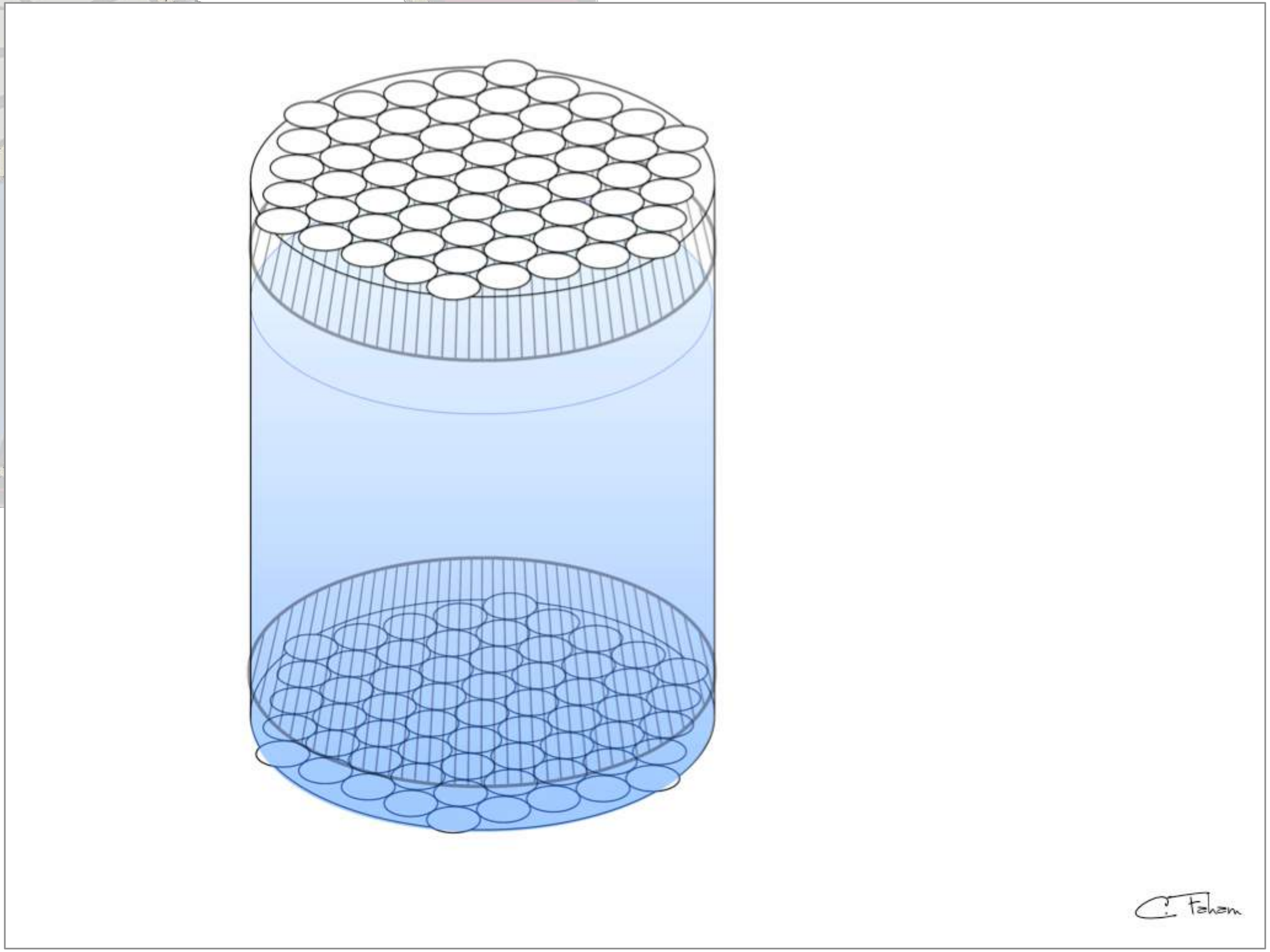
Example, $\mathcal{O}$(TeV) DM candidate decays through a dimension-6 operator suppressed by the GUT scale.

$$\tau \sim M_{GUT}^{4} / m_{DM}^{5} \sim 10^{26}\ \text{s.}$$

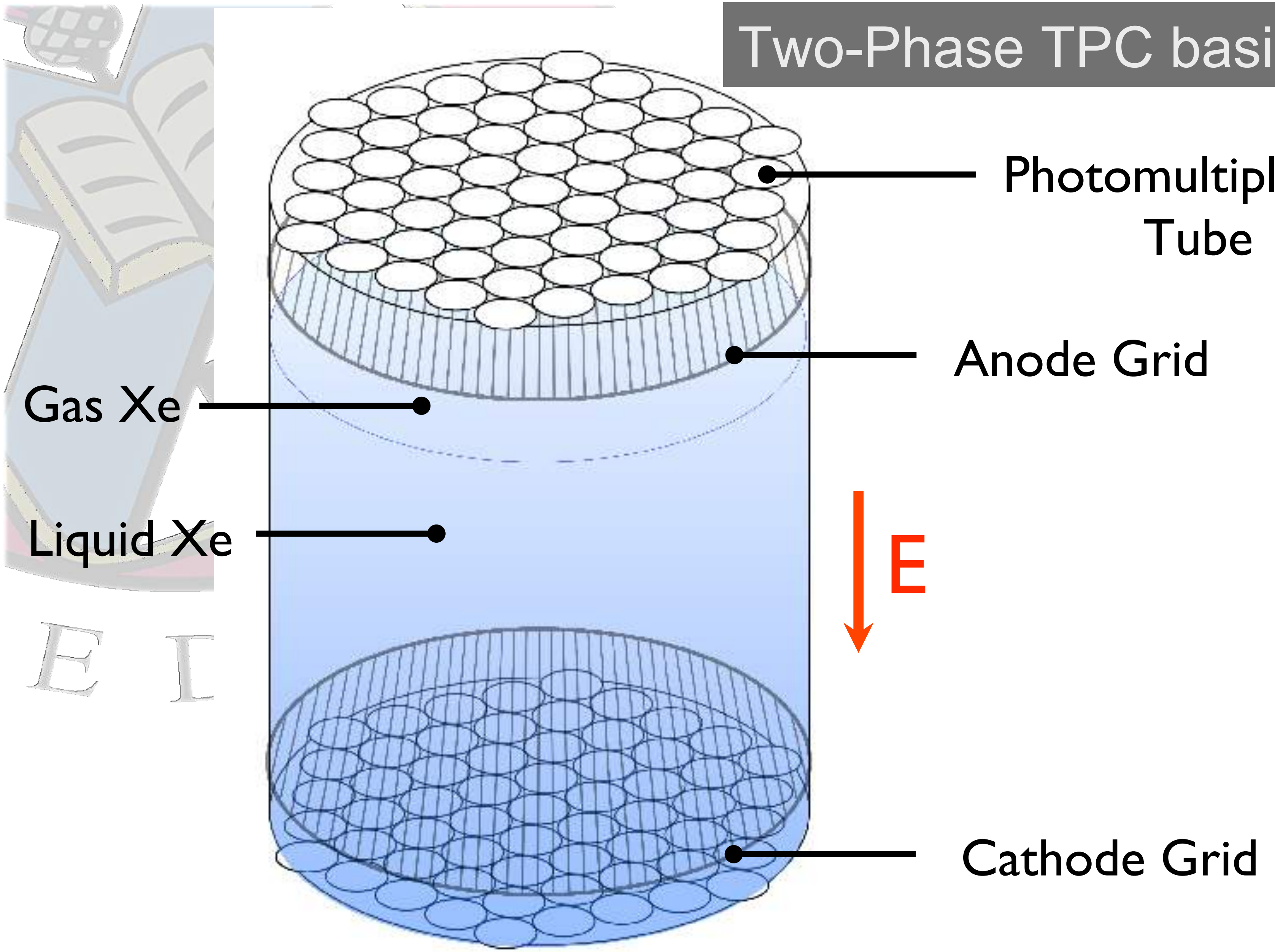
Take $\rho_{DM} = 0.4\ \text{GeV/cm}^3$ →

$$dN/dt = 10^{-4}\ \text{s}^{-1}\ \text{m}^{-2}$$

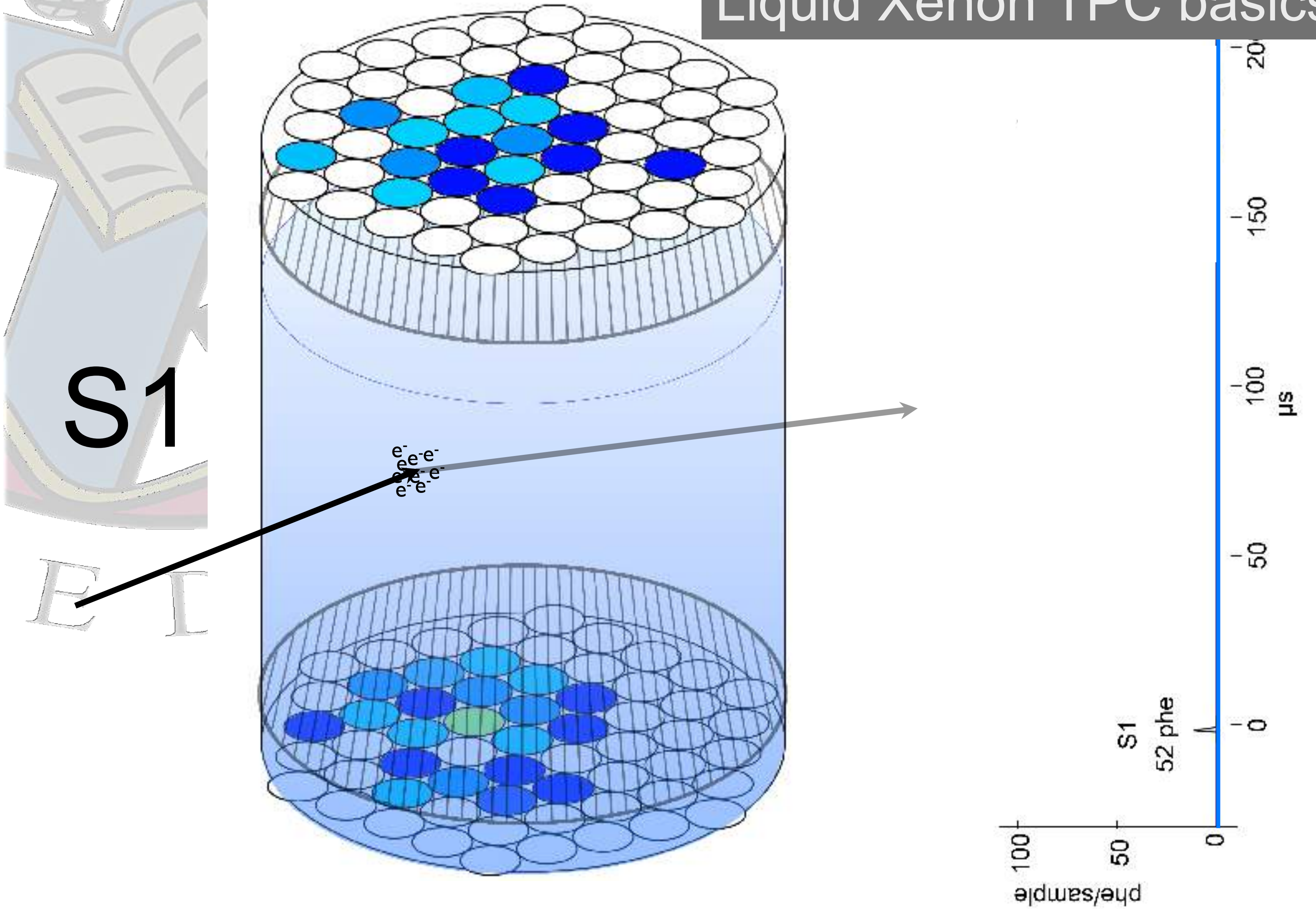
Liquid xenon TPC basics…



Two-Phase TPC basics



Liquid Xenon TPC basics



Liquid Xenon TPC basics

top hit pattern:
x-y localization

S2