Dark Matter Searches at LNGS

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INFN
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LNGS
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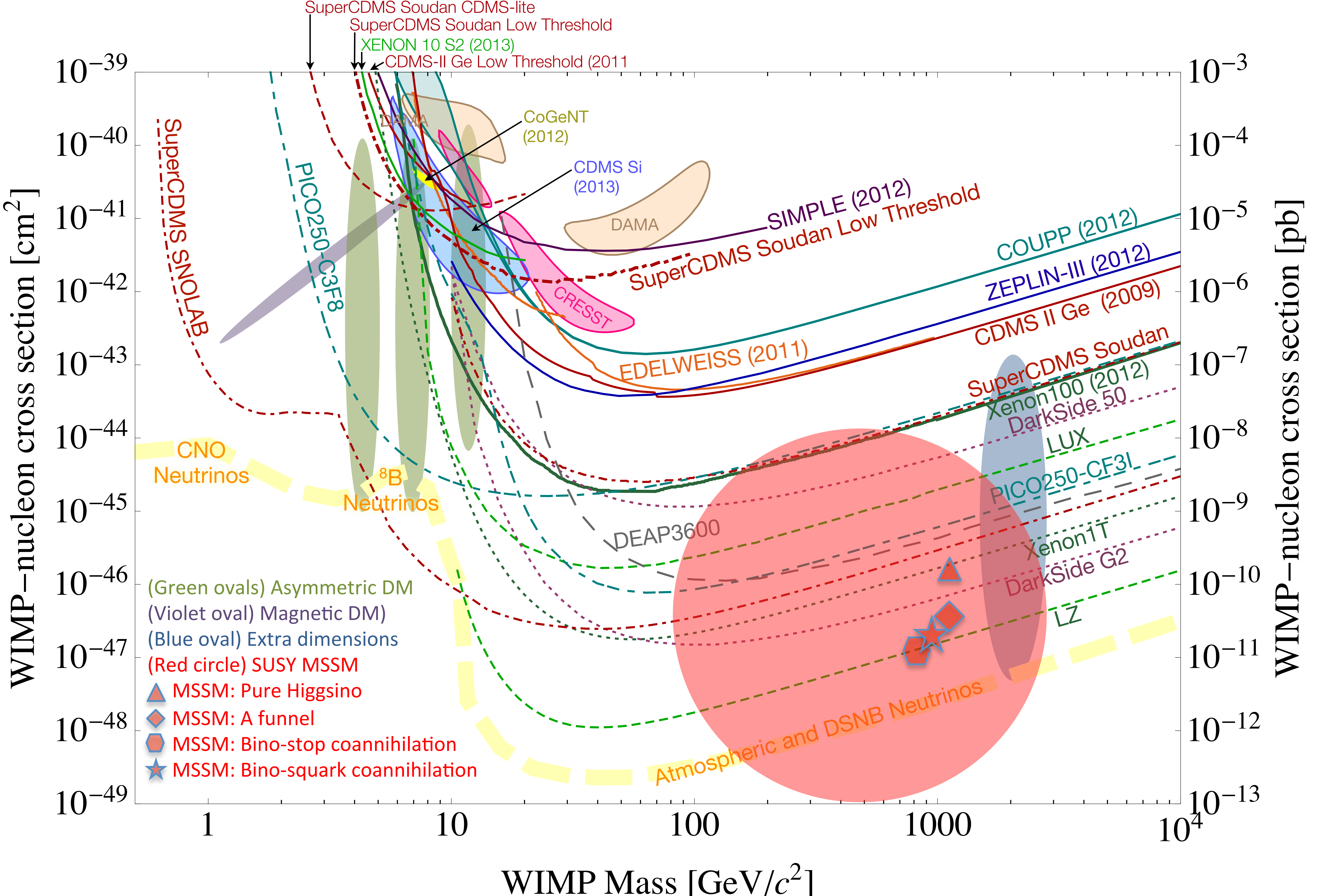
Dark Matter Program at LNGS

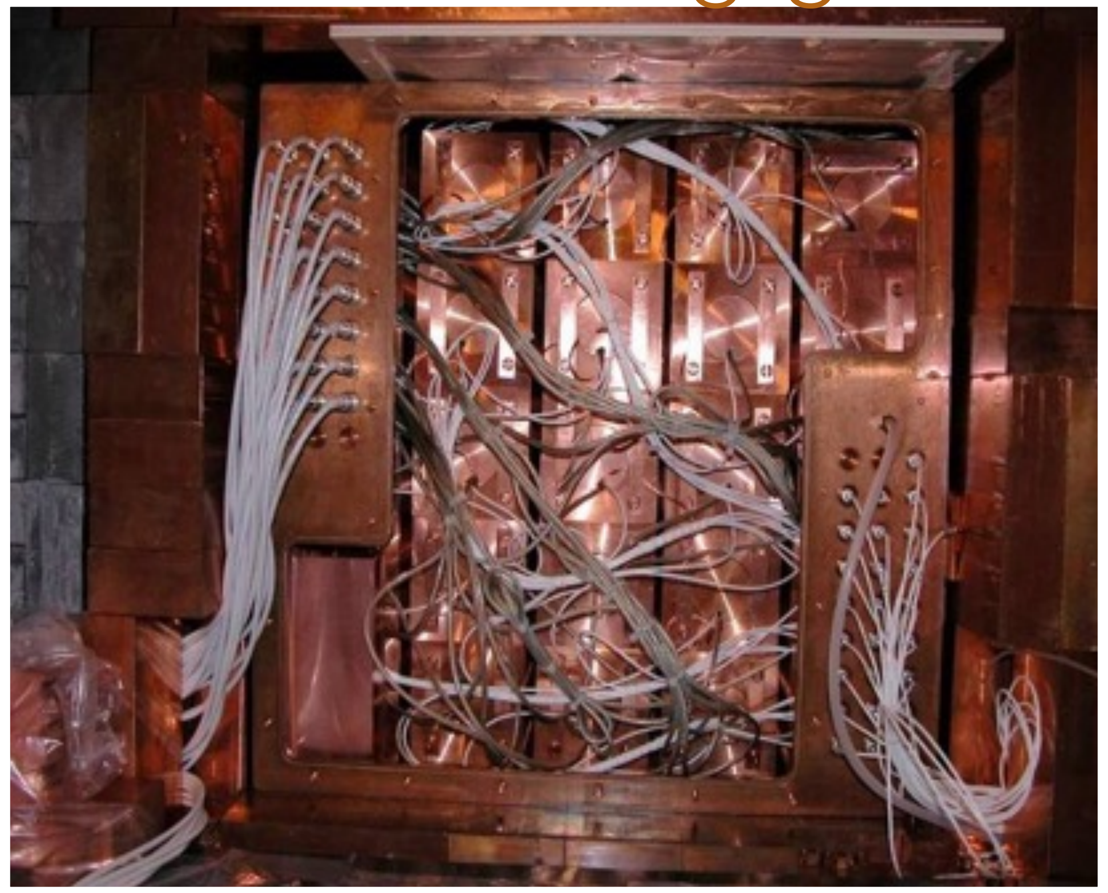
- One of two strong pillars of LNGS program
- New physics beyond the Standard Model
- Great opportunity for a fundamental discovery
- Vibrant and young community of researchers
- Development of new technologies for particle physics


SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011
CoGeNT (2012)
CDMS Si (2013)
DAMA
DAMA
SIMPLE (2012)
SuperCDMS Soudan Low Threshold
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
CRESST
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
DEAP3600
Xenon1T
DarkSide G2
LZ
SuperCDMS SNOLAB
PICO250-C3F8
CNO Neutrinos
^{8}B Neutrinos
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM)
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm^2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
1
10
100
1000
10^4

The DAMA/LIBRA set-up ~250 kg NaI(Tl) (**L**arge sodium **I**odide **B**ulk for **RA**re processes)

As a result of a 2nd generation R&D for more radiopure NaI(Tl) by exploiting new chemical/physical radiopurification techniques (all operations involving - including photos - in HP Nitrogen atmosphere)

Residual contaminations in the new DAMA/LIBRA NaI(Tl) detectors: ^{232}Th, ^{238}U and ^{40}K at level of 10^{-12} g/g



- Radiopurity, performances, procedures, etc.: NIMA592(2008)297, JINST 7 (2012) 03009
- Results on DM particles, Annual Modulation Signature: EPJC56(2008)333, EPJC67(2010)39, EPJC73(2013)2648. Related results: PRD84(2011)055014, EPJC72(2012)2064, IJMPA28(2013)1330022, EPJC74(2014)2827, EPJC74(2014)3196, EPJC75(2015)239, EPJC75(2015)400
- Results on rare processes: PEPv: EPJC62(2009)327; CNC: EPJC72(2012)1920; IPP in ^{241}Am: EPJA49(2013)64

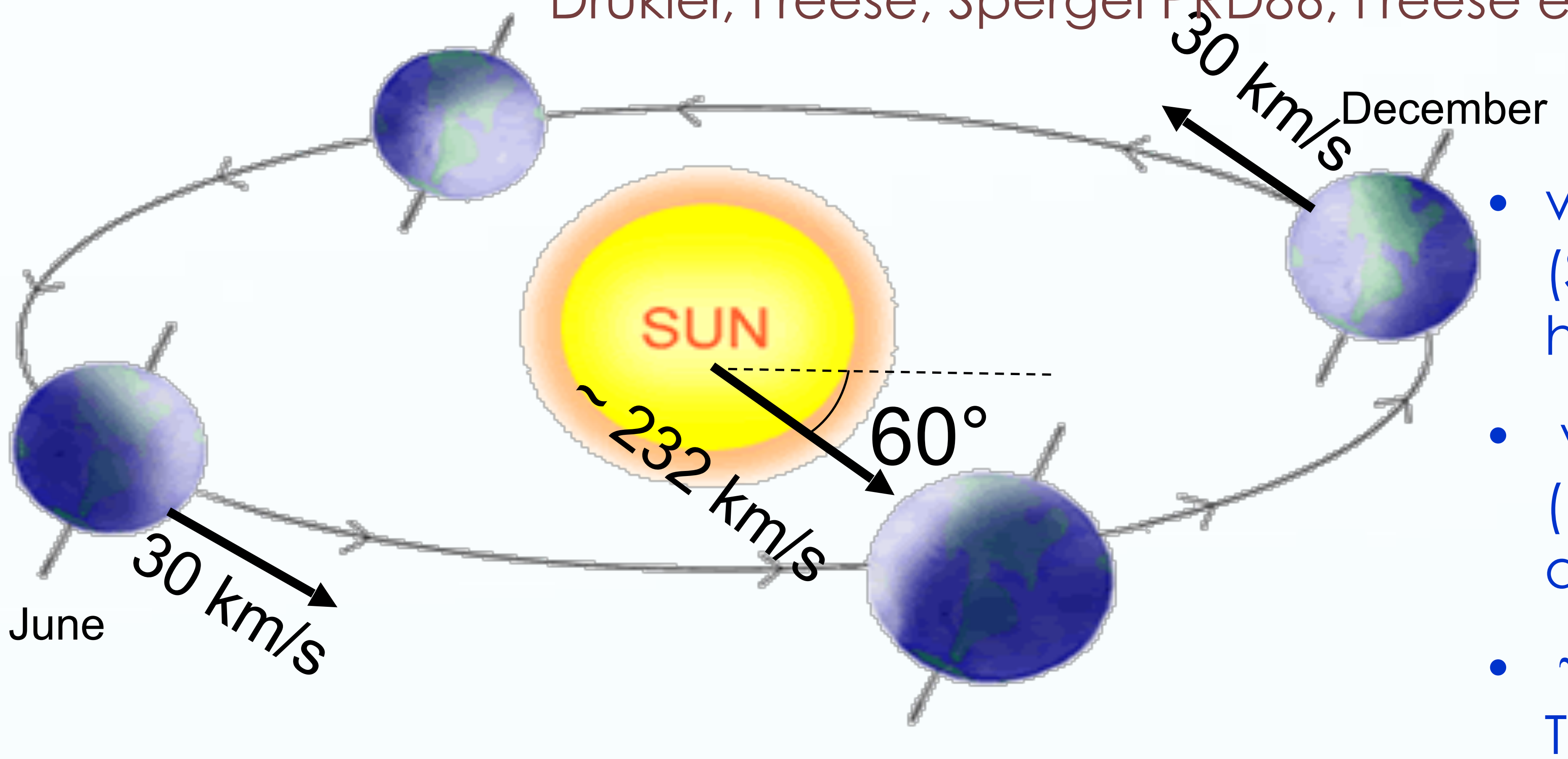
The annual modulation: a model independent signature for the investigation of DM particles component in the galactic halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions can point out its presence.

Requirements of the annual modulation

1) Modulated rate according cosine
2) In a definite low energy range
3) With a proper period (1 year)
4) With proper phase (about 2 June)
5) Just for single hit events in a multi-detector set-up
6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios

Drukier, Freese, Spergel PRD86; Freese et al. PRD88



- v_{sun} ~ 232 km/s (Sun vel in the halo)
- v_{orb} = 30 km/s (Earth vel around the Sun)
- $\gamma = \pi/3$, $\omega = 2\pi/T$, T = 1 year
- t_0 = 2nd June (when $v_\oplus$ is maximum)

$$v_\oplus(t) = v_{sun} + v_{orb}\cos\gamma\cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k}\cos[\omega(t-t_0)]$$

the DM annual modulation signature has a different origin and peculiarities (e.g. the phase) than those effects correlated with the seasons

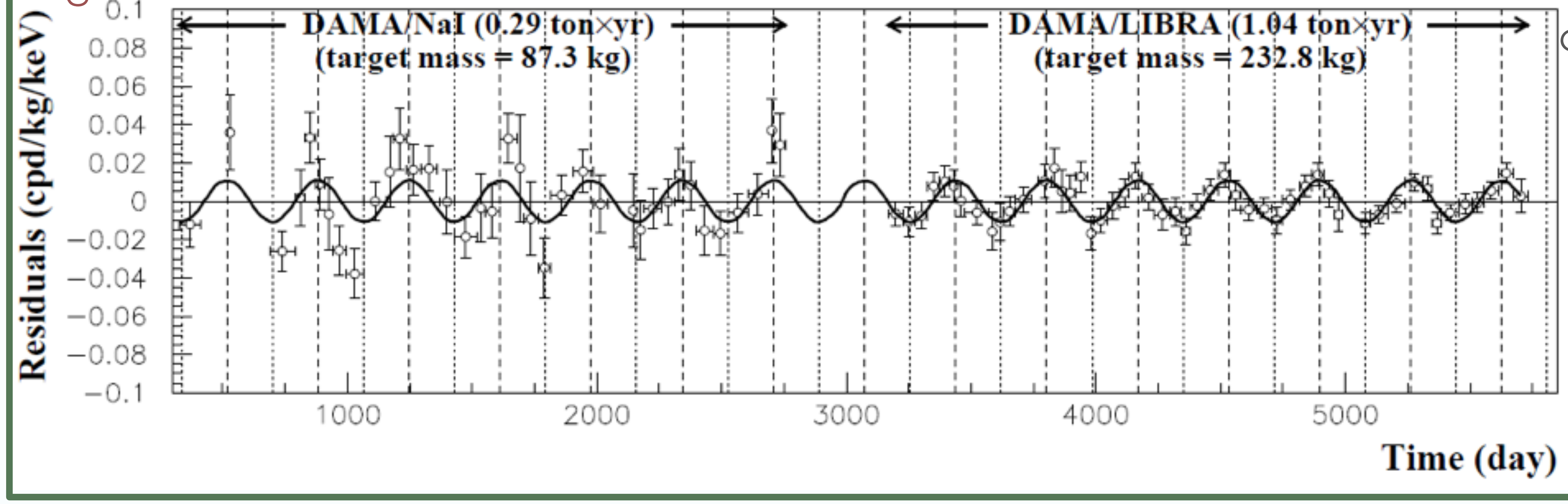
To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

Model Independent Annual Modulation Result

DAMA/NaI + **DAMA/LIBRA-phase1** Total exposure: 487526 kg×day = **1.33 ton×yr**

Single-hit residuals rate of scintillation events vs time in 2-6 keV

EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648



continuous line: t_0 = 152.5 d, T = 1.0 y

A=(0.0110±0.0012) cpd/kg/keV

χ^2/dof = 70.4/86 9.2 σ C.L.

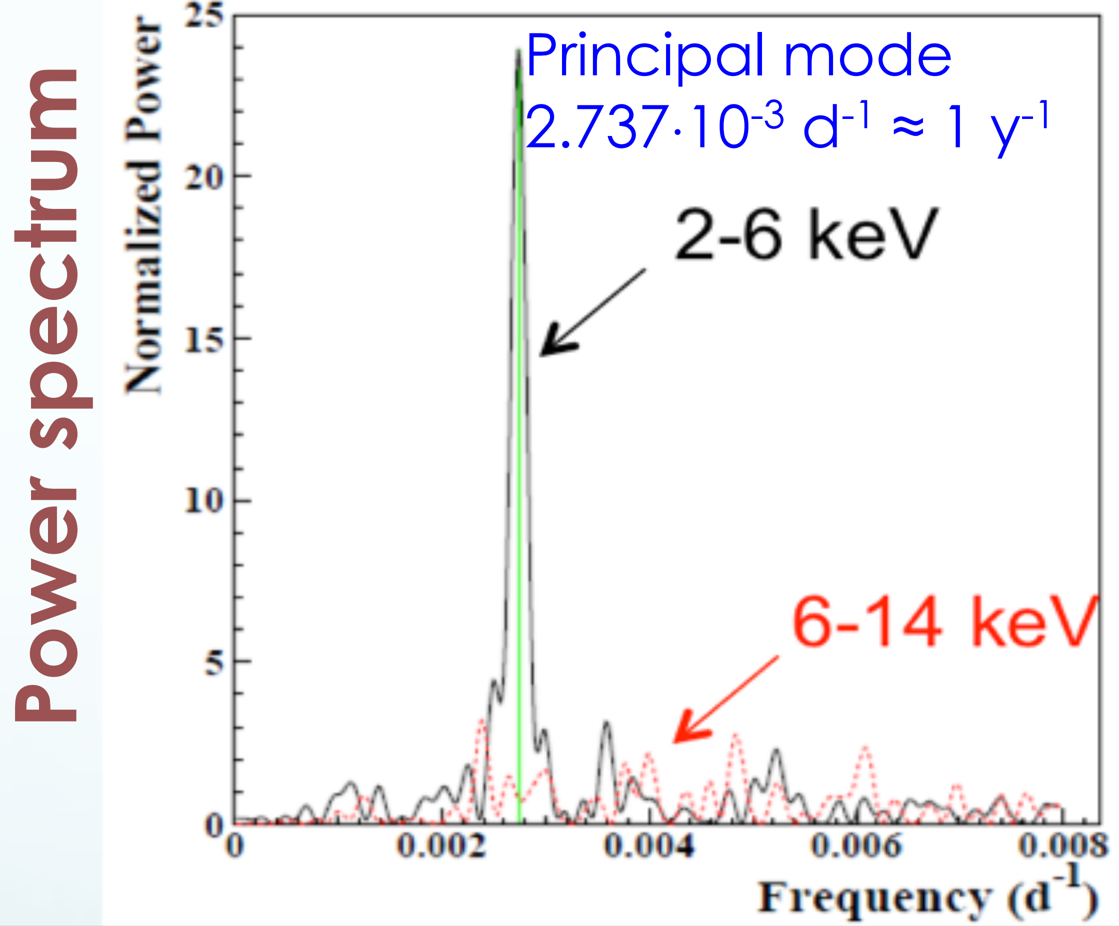
Absence of modulation? No

χ^2/dof=154/87 P(A=0) = 1.3×10^{-5}

Fit with all the parameters free:

A = (0.0112 ± 0.0012) cpd/kg/keV

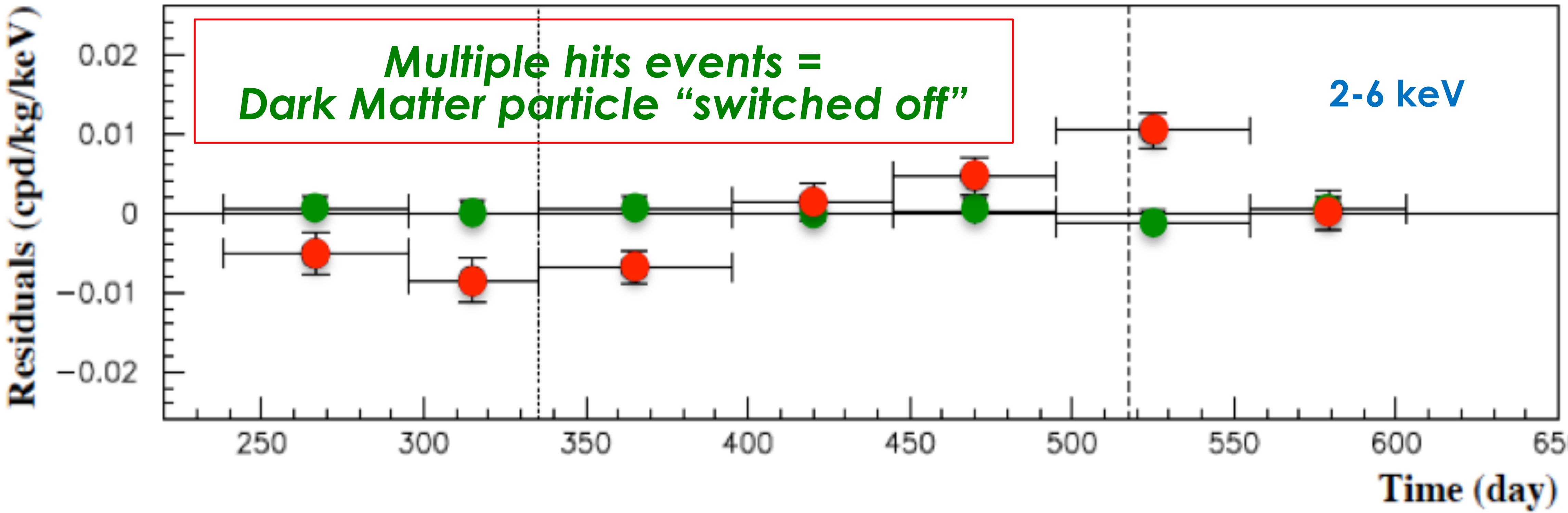
t_0 = (144±7) d - T = (0.998±0.002) y



No systematics or side reaction able to account for the measured modulation amplitude and to satisfy all the peculiarities of the signature

Comparison between **single hit residual rate (red points)** and **multiple hit residual rate (green points)**; Clear modulation in the single hit events; No modulation in the residual rate of the multiple hit events

A=-(0.0005±0.0004) cpd/kg/keV



This result offers an additional strong support for the presence of DM particles in the galactic halo further excluding any side effect either from hardware or from software procedures or from background

The data favor the presence of a modulated behaviour with all the proper features for DM particles in the galactic halo at about 9.2σ C.L.

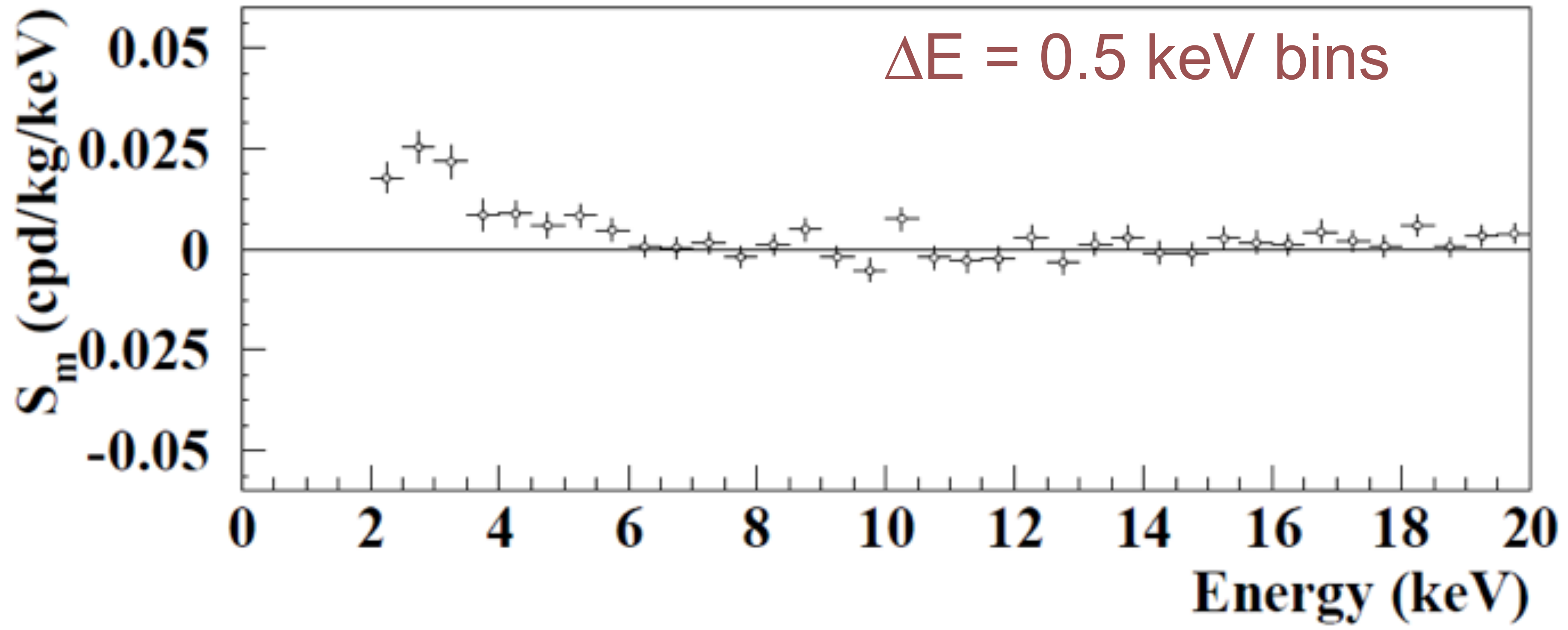
Model Independent Annual Modulation Result

DAMA/NaI + **DAMA/LIBRA-phase1** Total exposure: 487526 kg×day = **1.33 ton×yr**

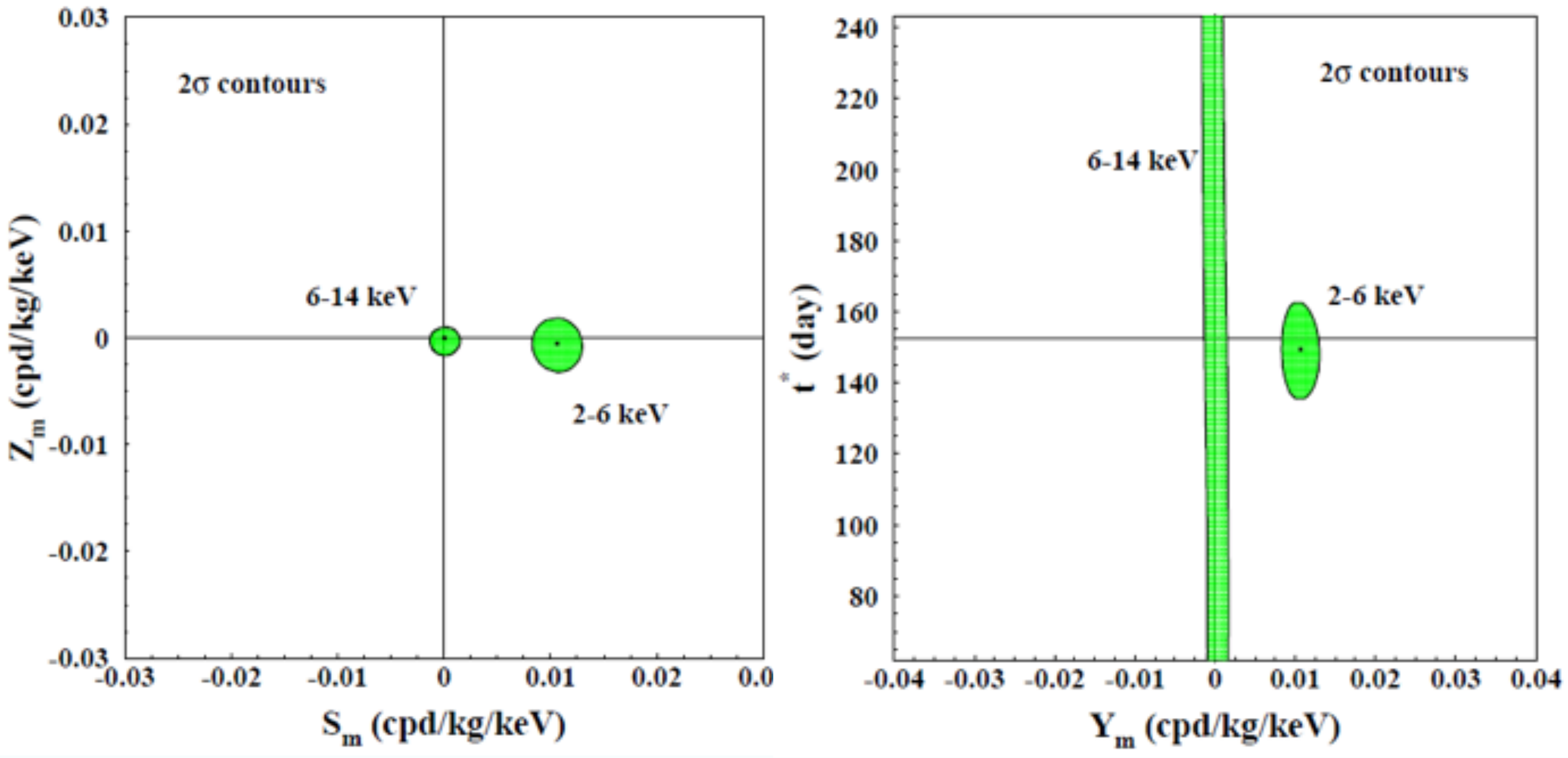
EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648

$$R(t) = S_0 + S_m \cos[\omega(t - t_0)]$$

here$T=2\pi/\omega=1$ yr and $t_0= 152.5$ day



$$R(t) = S_0 + S_m \cos[\omega(t - t_0)] + Z_m \sin[\omega(t - t_0)] = S_0 + Y_m \cos[\omega(t - t^*)]$$



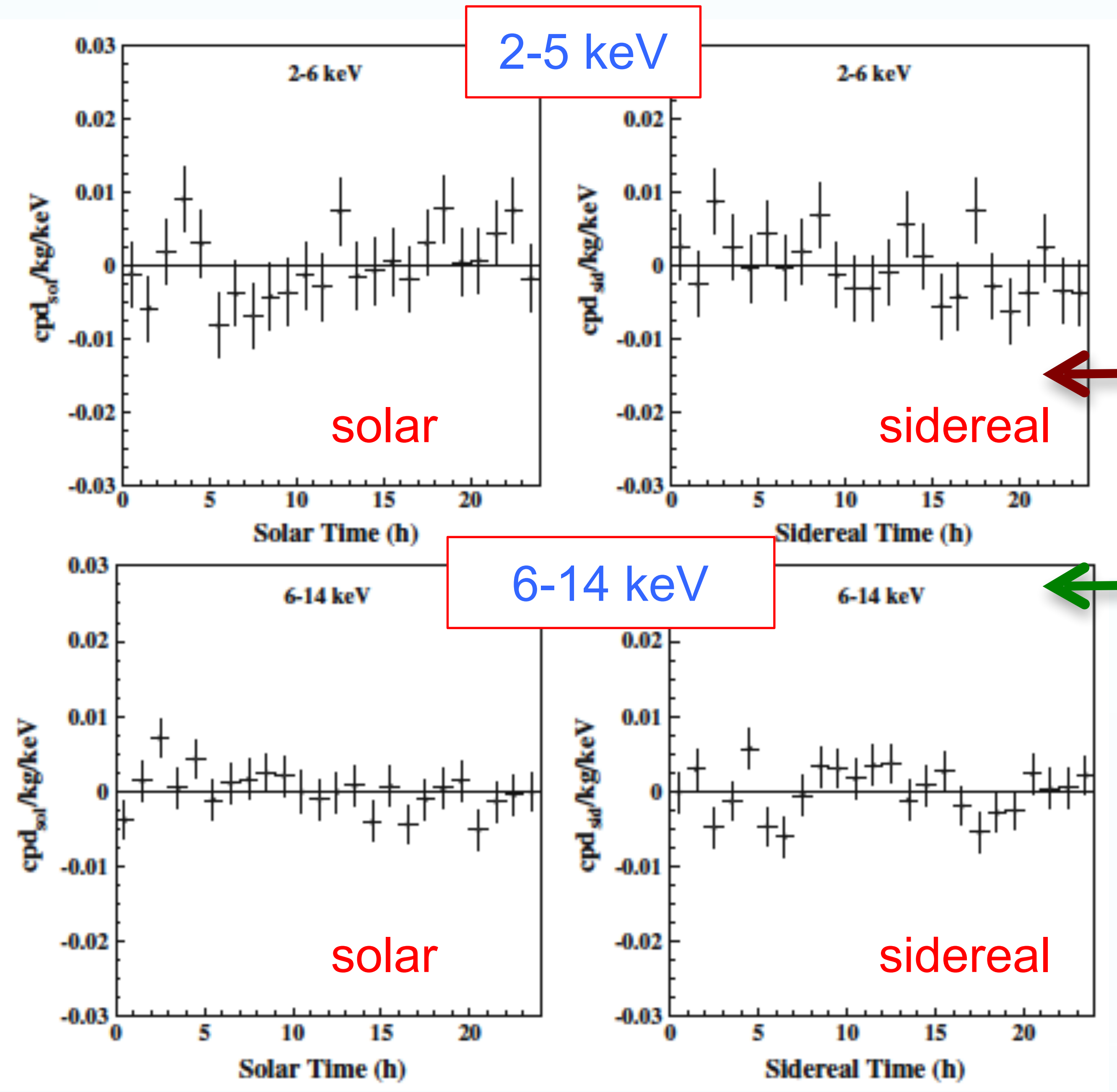
- No modulation above 6 keV
- No modulation in the whole energy spectrum
- No modulation in the 2-6 keV multiple-hit events

No systematics or side processes able to quantitatively account for the measured modulation amplitude and to simultaneously satisfy the many peculiarities of the signature are available.

✓ Compatibility with many low and high mass DM candidates, interaction types and astrophysical scenarios, and in particular with recent positive model dependent hints from direct or indirect searches

✓ No other experiment exists whose result can be – at least in principle – directly compared in a model-independent way with those by DAMA/NaI & DAMA/LIBRA-phase1

Model independent result on possible diurnal effect in DAMA/LIBRA–phase1

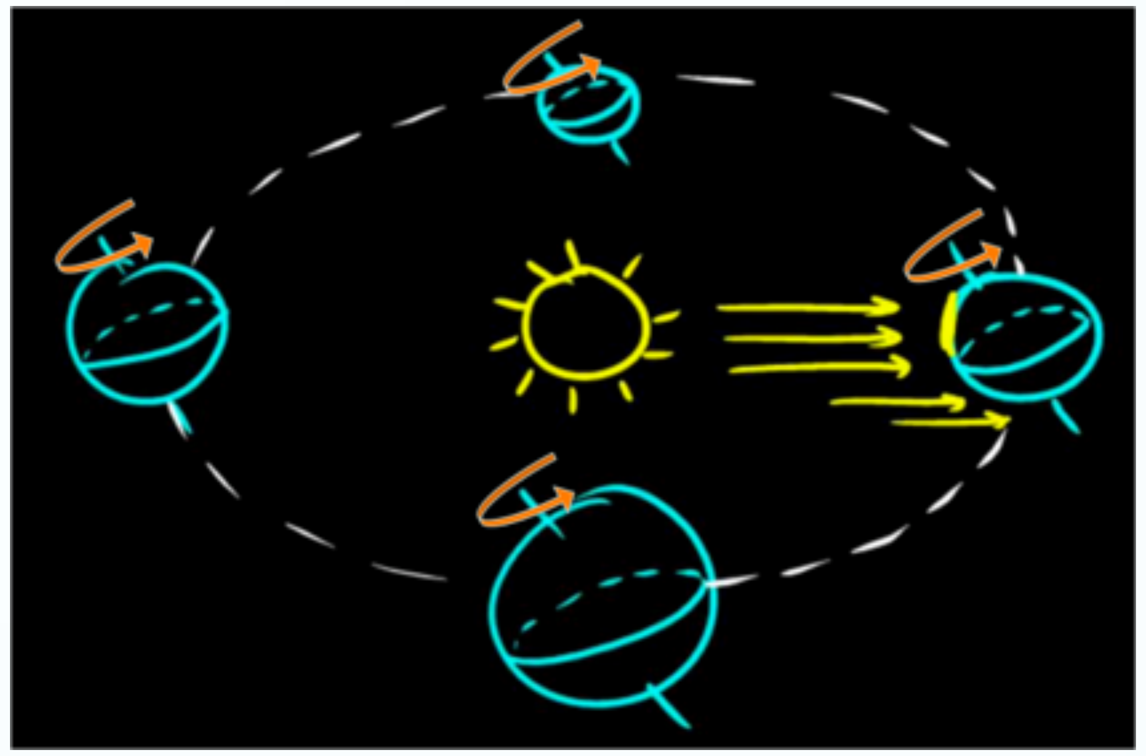


- Experimental *single-hit* residuals rate vs either sidereal and solar time and vs energy.

Energy region where the annual modulation is observed.

Energy region just above.

Eur. Phys. J. C 74 (2014) 2827



These residual rates are calculated from the measured rate of the *single-hit* events after subtracting the constant part

Energy	Solar Time	Sidereal Time
2–6 keV	χ^2/d.o.f. = 25.8/24 → P = 36%	χ^2/d.o.f. = 21.2/24 → P = 63%
6–14 keV	χ^2/d.o.f. = 25.5/24 → P = 38%	χ^2/d.o.f. = 35.9/24 → P = 6%

no diurnal variation with a significance of 95% C.L. (+ run test)

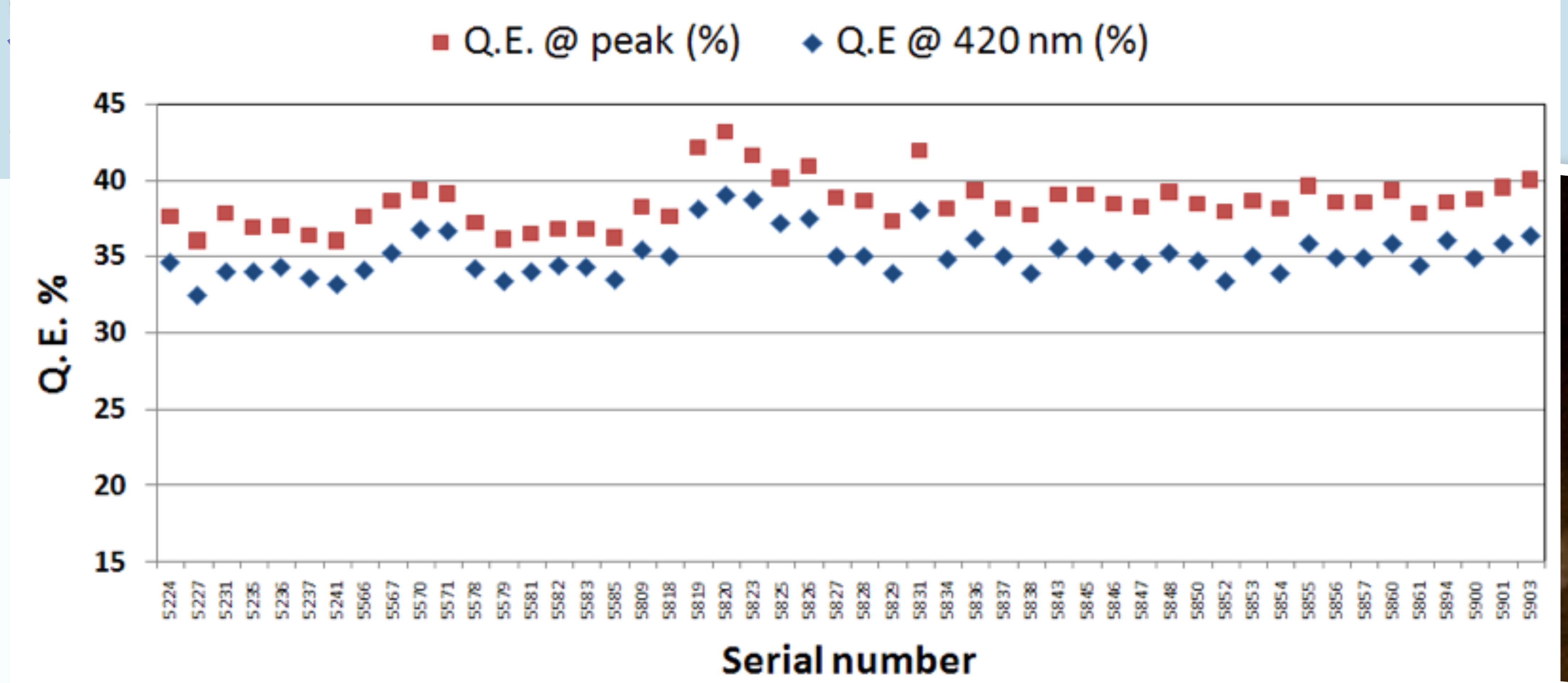
- Observed annual modulation amplitude in DAMA/LIBRA–phase1 in the (2–6) keV energy interval: (0.0097 ± 0.0013) cpd/kg/keV
- Thus, the expected value of the diurnal modulation amplitude iis $\simeq 1.5 \times 10^{-4}$ cpd/kg/keV.
- When fitting the *single-hit* residuals with a cosine function with amplitude A_d as free parameter, period fixed at 24 h and phase at 14 h: all the diurnal modulation amplitudes are compatible with zero.
- **In the 2-6 keV energy interval:** $A_d < 1.2 \times 10^{-3}$ cpd/kg/keV (90%CL)

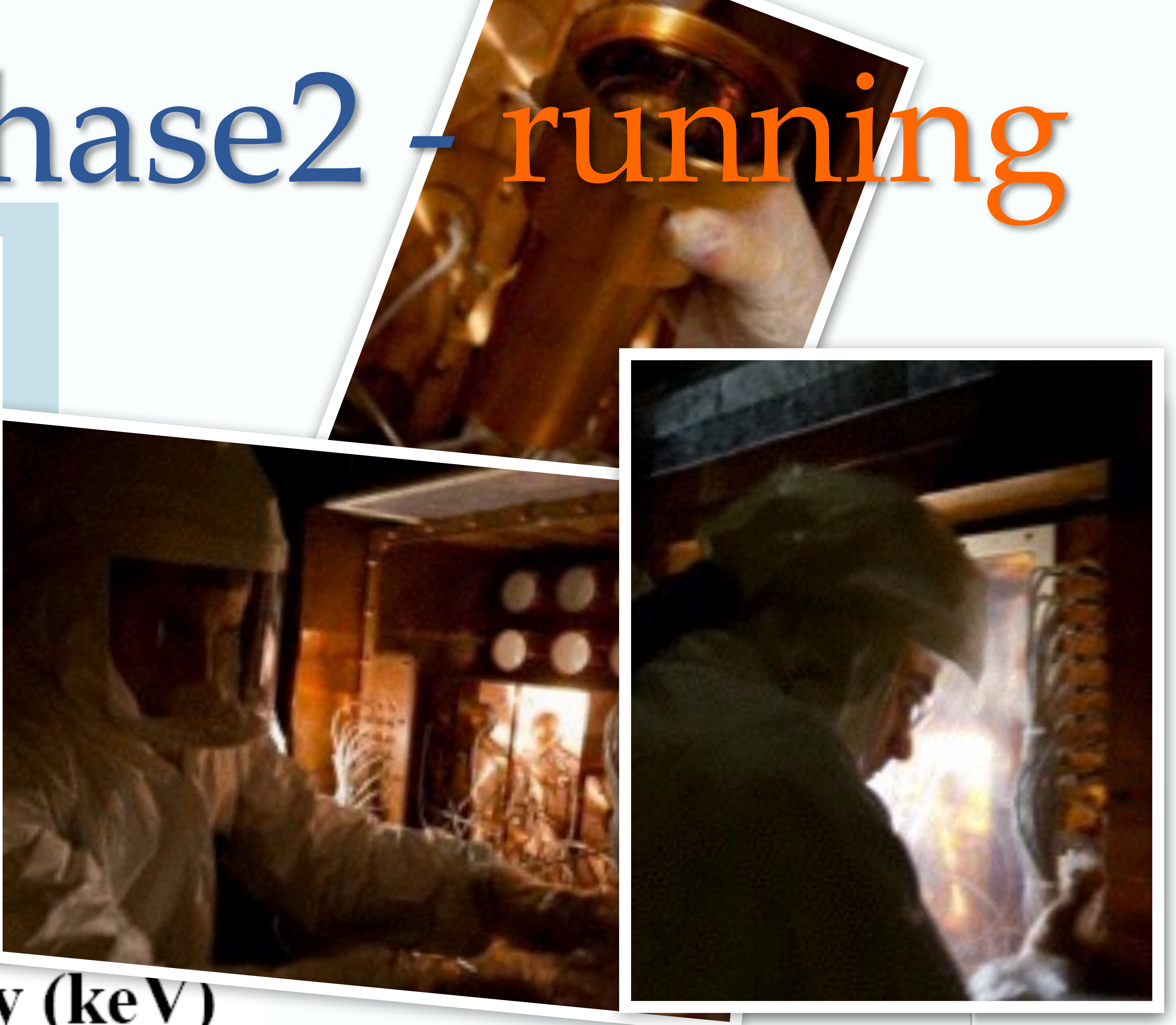
Present experimental sensitivity more modest than the expected diurnal modulation amplitude derived from the DAMA/LIBRA–phase1 observed effect.

larger exposure DAMA/LIBRA–phase2 (+lower energy threshold) offers increased sensitivity to such an effect

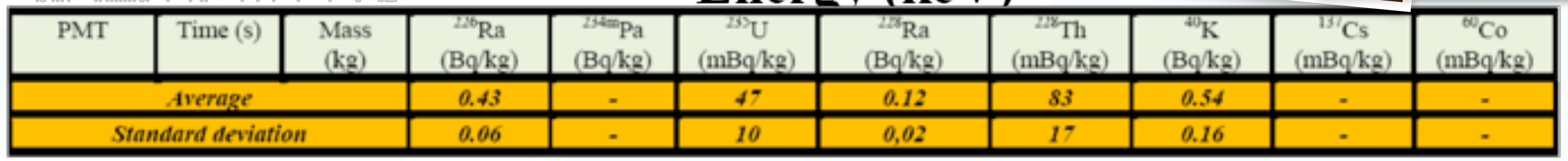
DAMA/LIBRA phase2 - running

Quantum Efficiency features





Residual Contamination

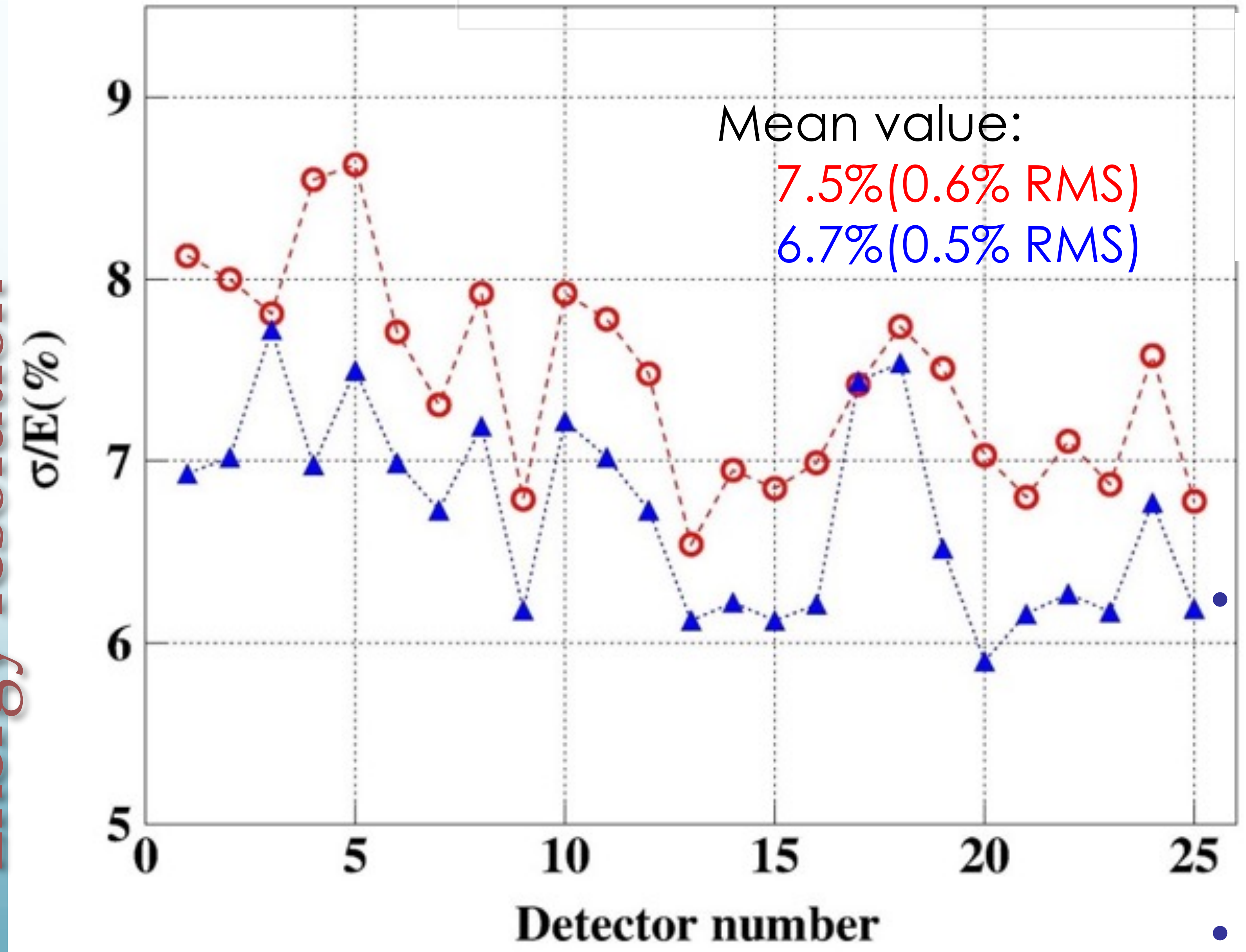


The limits are at 90% C.L.

Energy (keV)

PMT	Time (s)	Mass (kg)	^{226}Ra (Bq/kg)	^{234m}Pa (Bq/kg)	^{235}U (mBq/kg)	^{228}Ra (Bq/kg)	^{228}Th (mBq/kg)	^{40}K (Bq/kg)	^{137}Cs (mBq/kg)	^{60}Co (mBq/kg)
Average			*0.43*	*-*	*47*	*0.12*	*83*	*0.54*	*-*	*-*
Standard deviation			*0.06*	*-*	*10*	*0,02*	*17*	*0.16*	*-*	*-*

Energy resolution



σ/E @ 59.5 keV for each detector with new PMTs with higher quantum efficiency (blu points) and with previous PMT EMI-Electron Tube (red points).

The light responses

Previous PMTs:	5.5-7.5 ph.e./keV
New PMTs:	up to 10 ph.e./keV

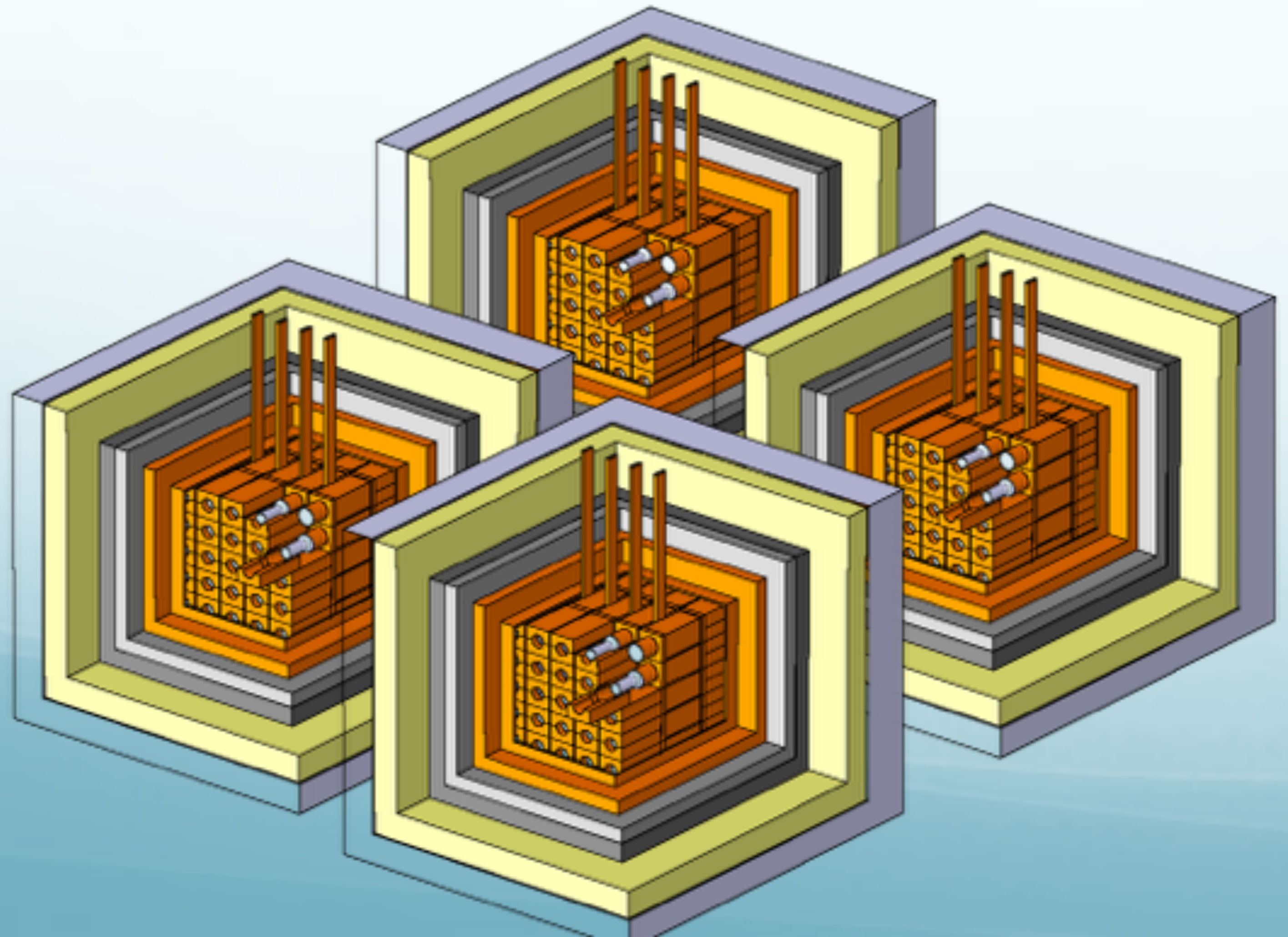
- To study the nature of the particles and features of related astrophysical, nuclear and particle physics aspects, and to investigate second order effects. This requires very high exposures
- Special data taking for *other rare processes*

Further developments for DAMA/LIBRA: The strong interest in the low energy range suggests the possibility of a new development of high Q.E. PMTs with increased radiopurity to directly couple them to the DAMA/LIBRA crystals (possible phase3), removing the special quartz light guides which act also as optical window obtaining an ultimate number of ph.e./keV.

The possible multi-purpose full sensitive mass DAMA/1ton

1) Proposed since 1996 (DAMA/NaI and DAMA/LIBRA intermediate steps+some R&D and POR fellowships)
2) Technology largely at hand and still room for further improvements in the low-background characteristics of the set-up (NaI(Tl) crystals, PMTs, shields, etc.)
3) 1 ton detector: the cheapest, the highest duty cycle, the clear signature, fast realization in few years

Design: DAMA/1 ton can be realized by adding 3 replicas of DAMA/LIBRA:



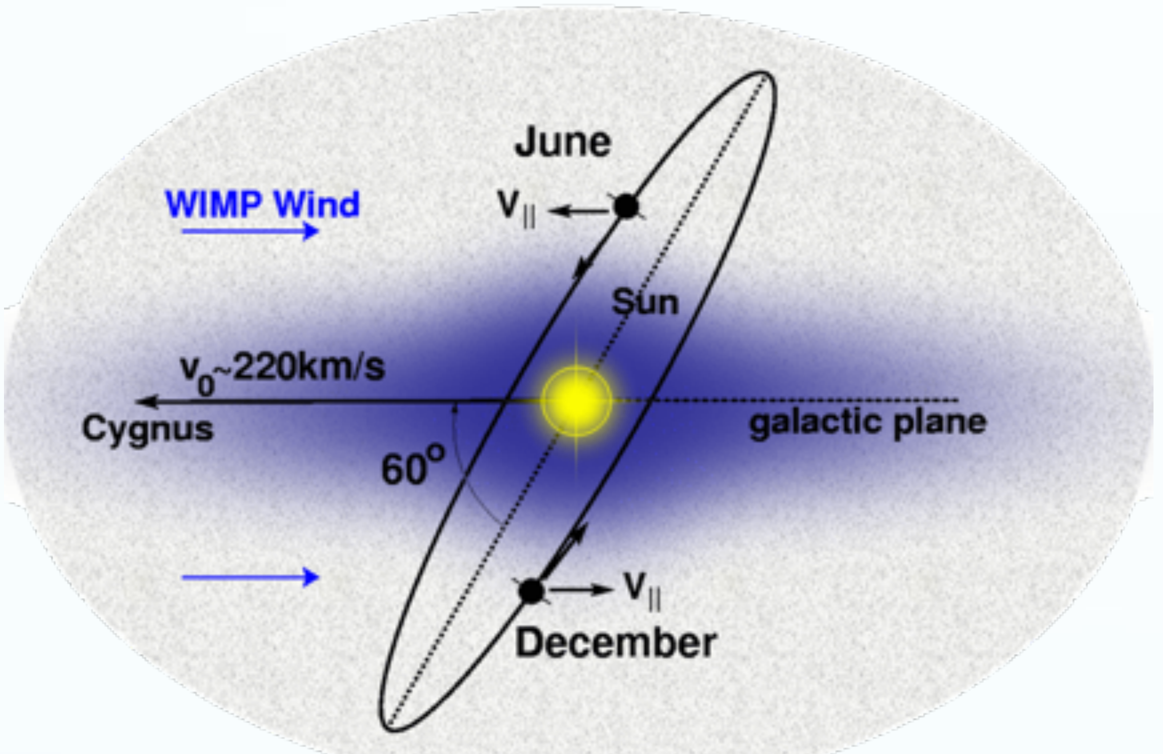
- the detectors of similar size than those already used
- the features of low-radioactivity of the set-up and of all the used materials would be assured by many years of experience in the field
- electronic chain and controls would profit by the previous experience and by the use of compact devices already developped, tested and used.
- new digitizers will offer high expandibility and high performances
- the daq can be a replica of that of DAMA/LIBRA

- Some R&Ds carried out

Directionality technique

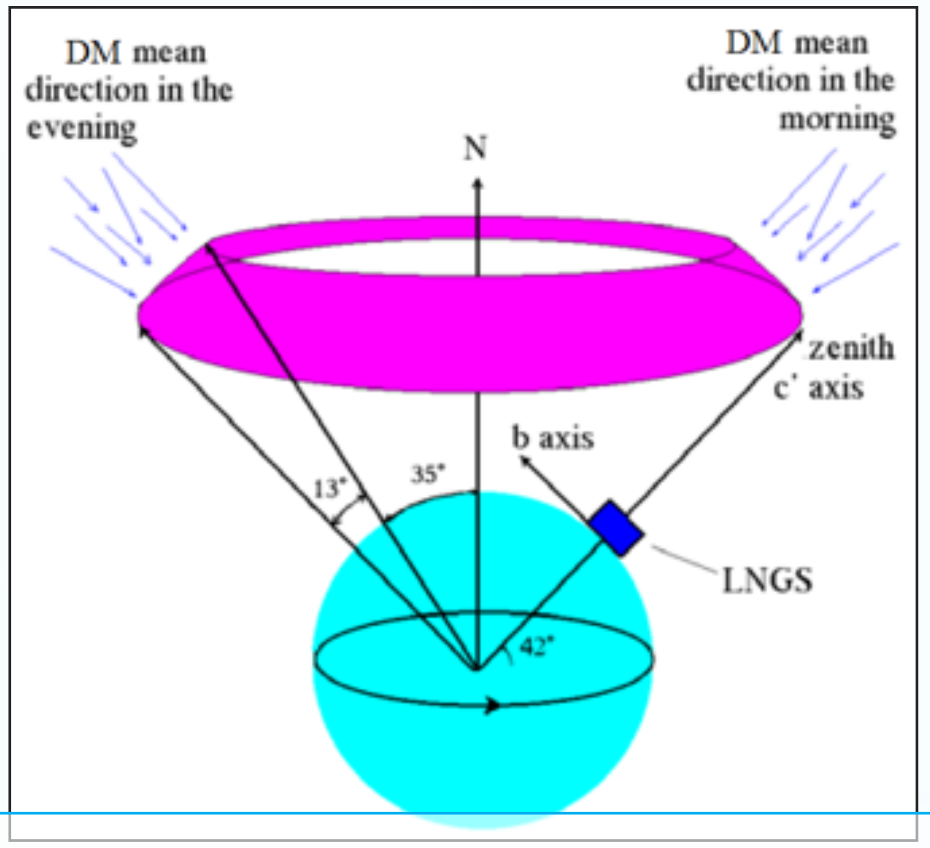
- Only for candidates inducing just nuclear recoils
- Identification of the Dark Matter particles by exploiting the non-isotropic recoil distribution correlated to the Earth velocity

The ADAMO project: Study of the directionality approach with $ZnWO_4$ anisotropic detectors



The dynamics of the rotation of the Milky Way galactic disc through the halo of DM causes the Earth to experience a wind of DM particles apparently flowing along a direction opposite to that of solar motion relative to the DM halo …but, because of the Earth's rotation around its axis, the DM particles average direction with respect to an observer fixed on the Earth changes during the sidereal day

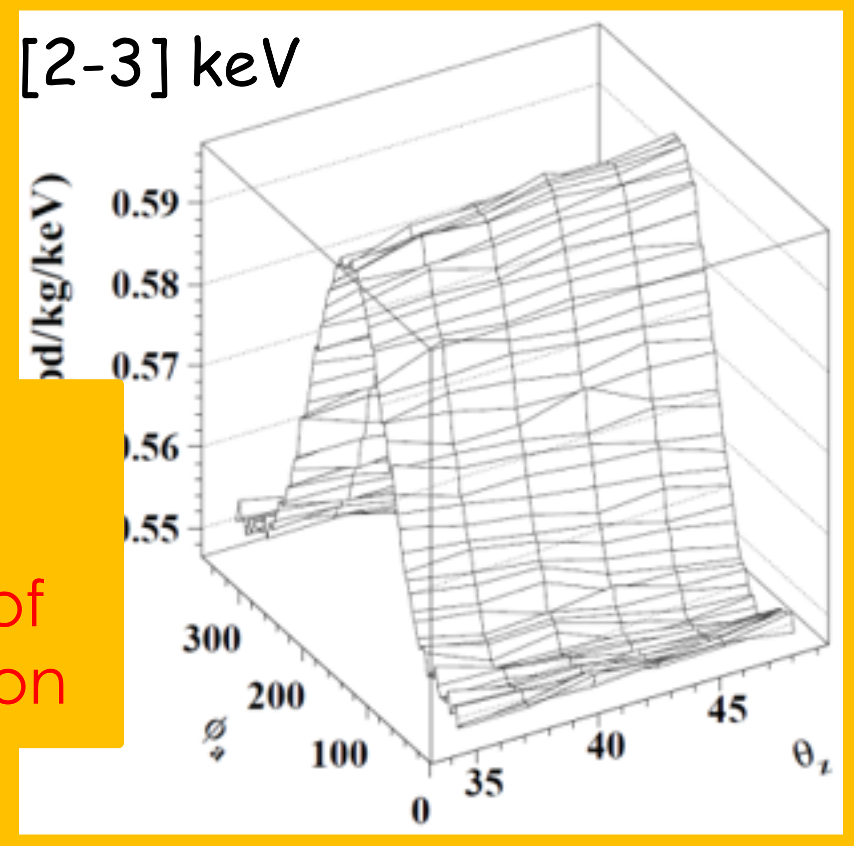
Eur. Phys. J. C 73 (2013) 2276



Nuclear recoils are expected to be correlated with the impinging direction of those DM candidates

This effect can be pointed out through the study of the variation in the response of anisotropic scintillation detectors during sidereal day

$\sigma_p = 5\times10^{-5}$ pb, m_{DM}= 50 GeV



Example (for a given model framework) of the expected counting rate as a function of the detector velocity direction

The light output and the pulse shape of $ZnWO_4$ detectors depend on the direction of the impinging particles with respect to the crystal axes

Both these anisotropic features can provide two independent ways to exploit the directionality approach

These and others competitive characteristics of $ZnWO_4$ detectors could permit to reach – in some given scenarios - sensitivity comparable with that of the DAMA/LIBRA positive result

Other detectors, on which we are working on, are CNT

The SABRE Collaboration

SABRE North

Italy

- LNGS
- University of Rome
- Milan University

United States

- Pacific Northwest National Laboratory
- Princeton University

SABRE South

- Australian National Laboratory
- Australian Nuclear Science and Technology
- Swinburne University
- University of Adelaide
- University of Melbourne

SABRE

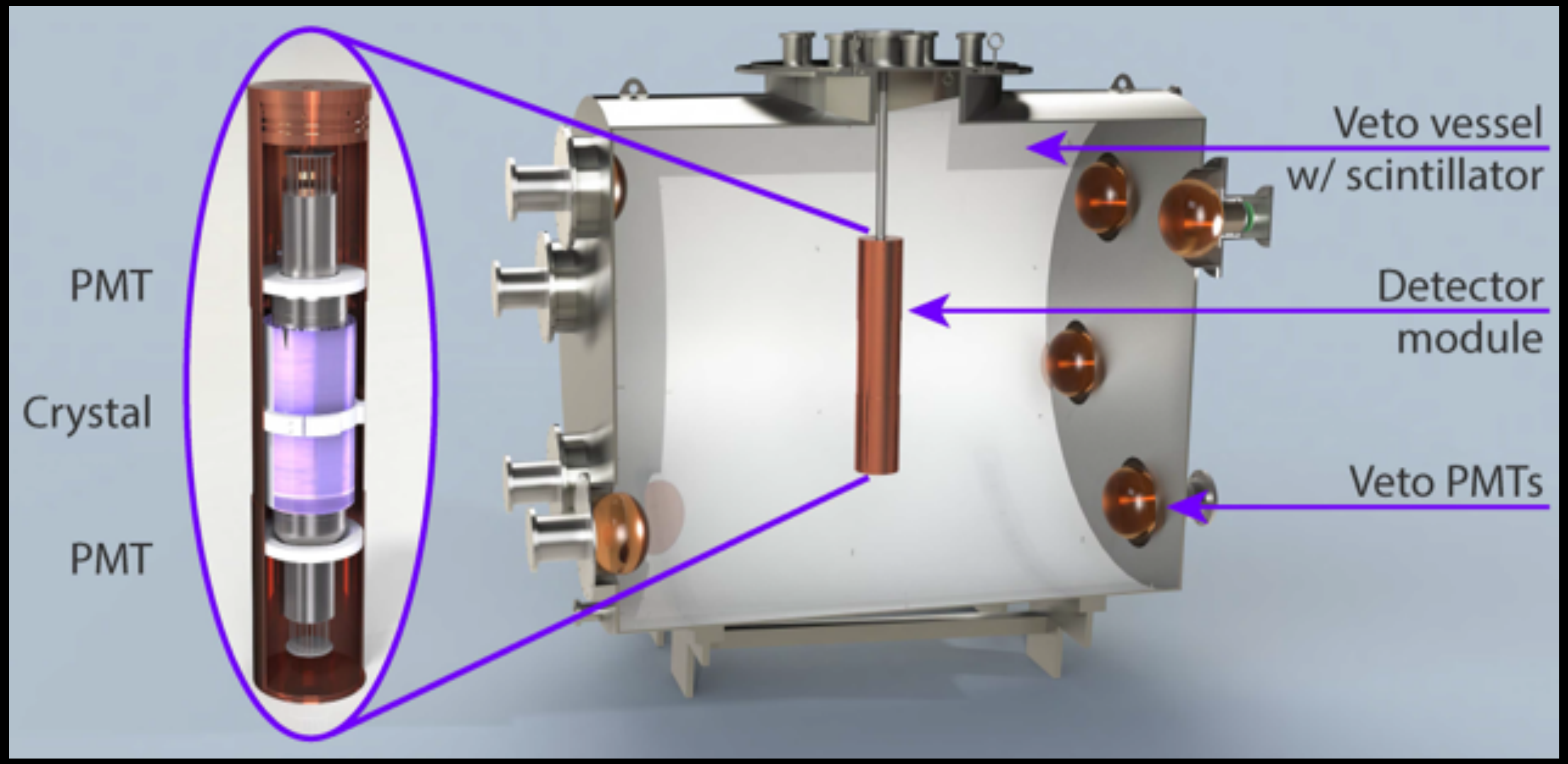
(Sodium iodide with Active Background REjection)

Testing the DAMA-LIBRA Annual Modulation for Dark Matter

Strategy

1. Reduce NaI(Tl) crystal radioactivity
   - Develop radio-pure NaI powder and special crystal growth technique.
   - Employ active scintillator veto
2. Lower threshold energy
   - High Q.E PMTs directly on crystals.
   - Reduce PMT dynode afterglow.
3. Eliminate seasonal effects.
   - Detectors in North and South Hemispheres.
   - North: LNGS, Italy
   - South: SUPL, Australia

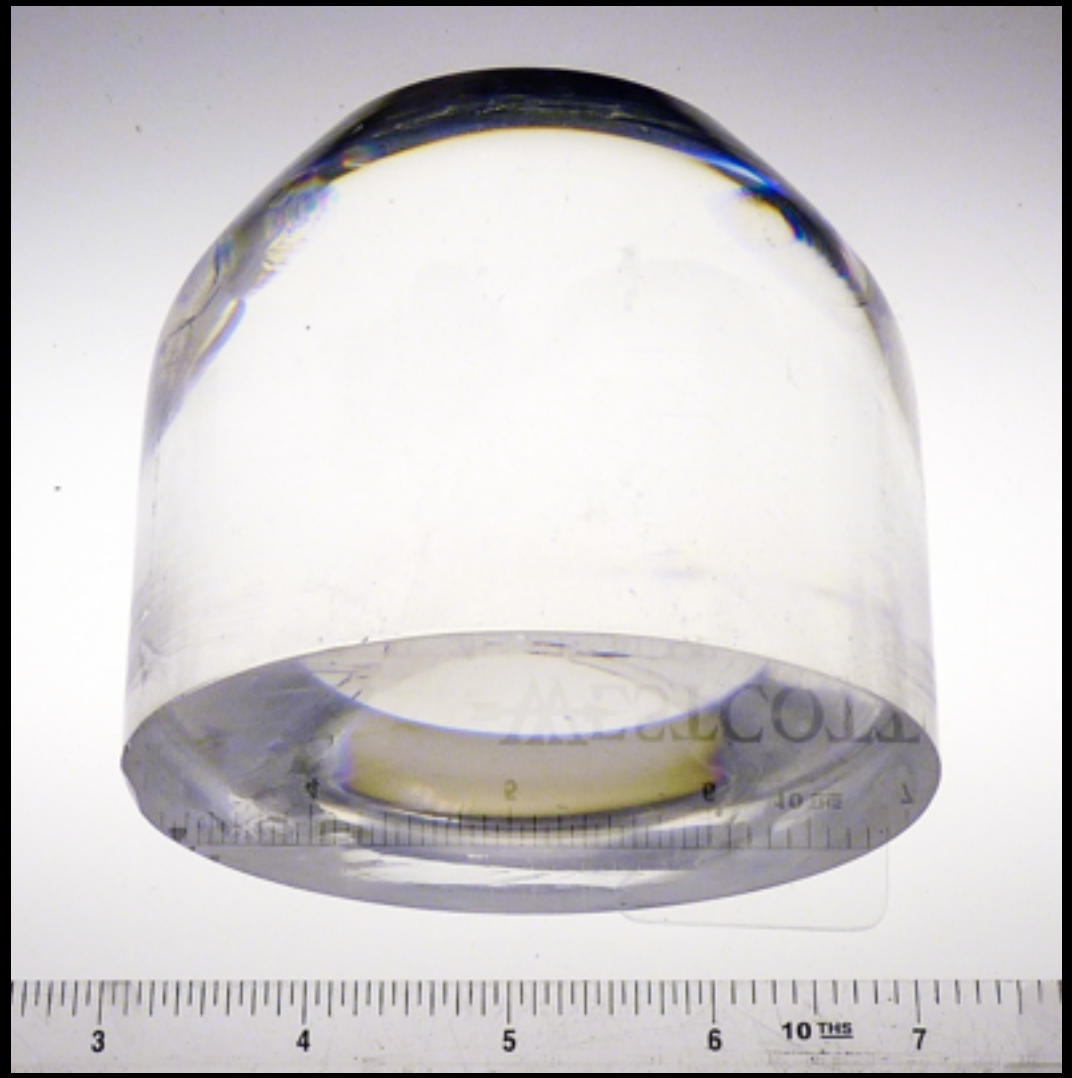
Liquid Scintillator Veto



- Veto $\beta-\gamma$ radioactivity in NaI crystal by detecting γ-ray in liquid scintillator.
  - ^{40}K 3-keV EC-γ (largest background)
  - ^{22}Na, ^{126}I, in NaI.
- PMT γ-Compton background, etc.
- Rock and cosmogenic backgrounds.

Crystal Radiopurity: K Level by ICP-MS

Seastar data (1/2016). PNNL data (4/2106)

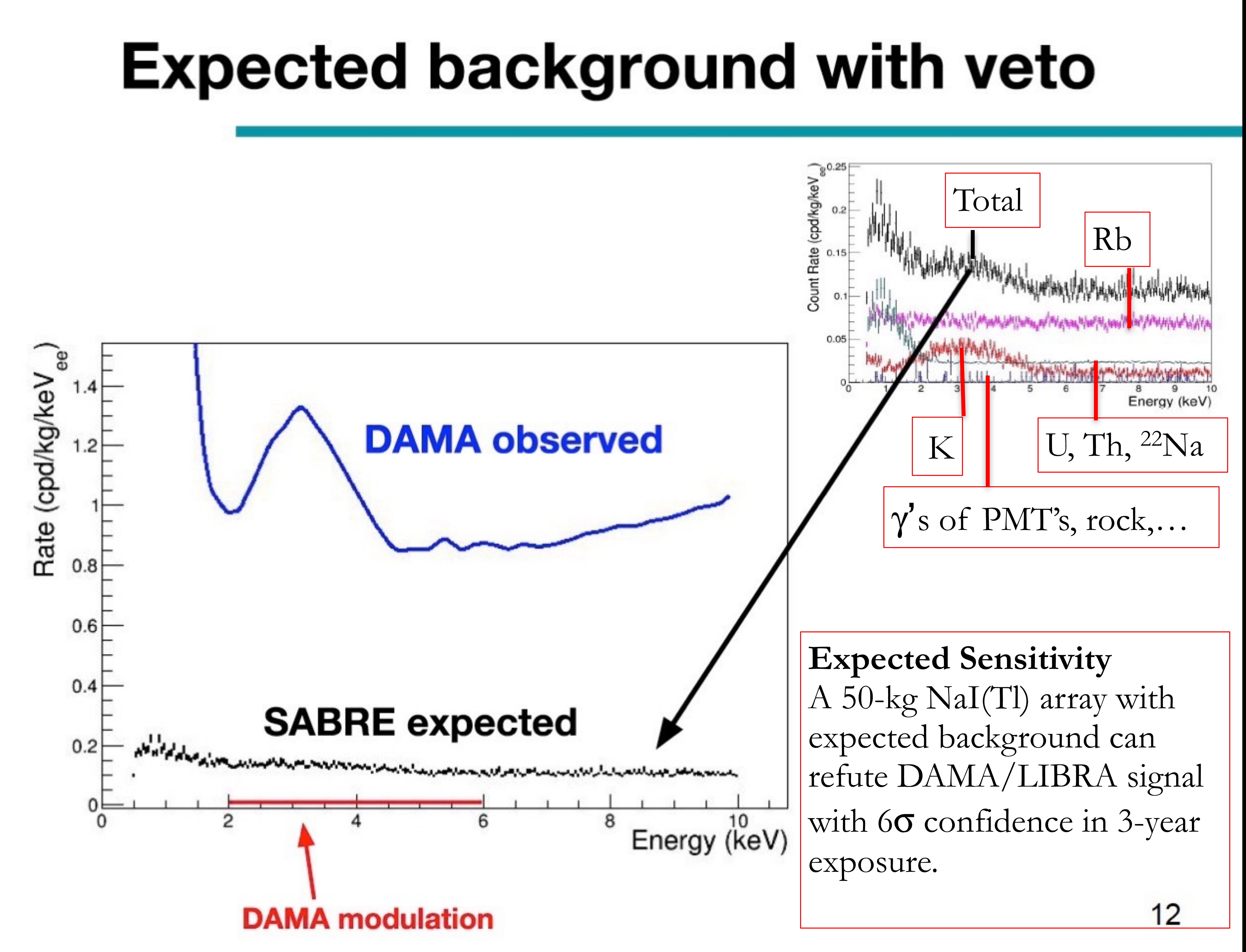


2-kg radio-pure NaI(Tl)

Sample	K(ppb) -Seastar Jan 2016	K(ppb)- PNNL Apr 2016
2A	9 ± 1	10.0 ± 0.7
2B	7 ± 1	9.1 ± 0.3
2D	11 ± 1	9.7 ± 0.4
2E	9 ±1	9.8 ± 0.4
Average	9	9.6

Good agreement for [K] between independent measurements.
[Rb] upper limit <0.1 ppb. [U], [Th] ~ 0.5 ppt
[K] here is lower than 13 ppb in DAMA/LIBRA.
Effective concentration of K is further reduced by veto.

Expected background with veto



Expected Sensitivity
A 50-kg NaI(Tl) array with expected background can refute DAMA/LIBRA signal with 6σ confidence in 3-year exposure.

COSINUS

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TU WIEN

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

COSINUS

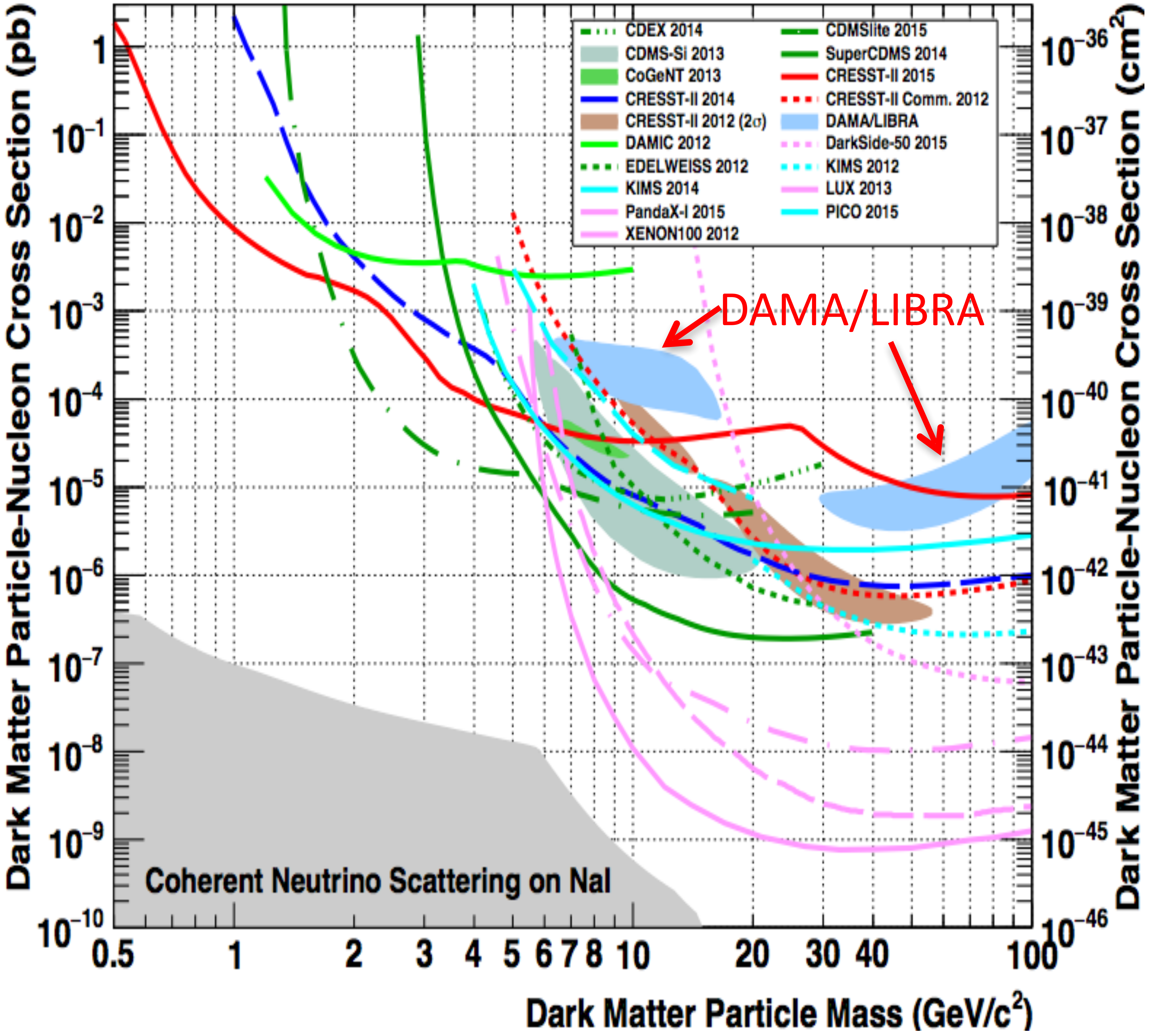
Paper under review at EPJ C
arXiv:1603.02214

- started just in **2016**
- aims to develop the first NaI detector with particle discrimination via a second, independent channel

COSINUS detectors reaching performance of existing scintillating bolometers (as e.g. CRESST)

- can answer the question whether the DAMA/LIBRA (NaI) modulation signal is nuclear recoils or interactions with the electrons → exposure of only few 10 kg-days needed
- with higher target mass: COSINUS technique also suited for modulation detection

Why another NaI detector?

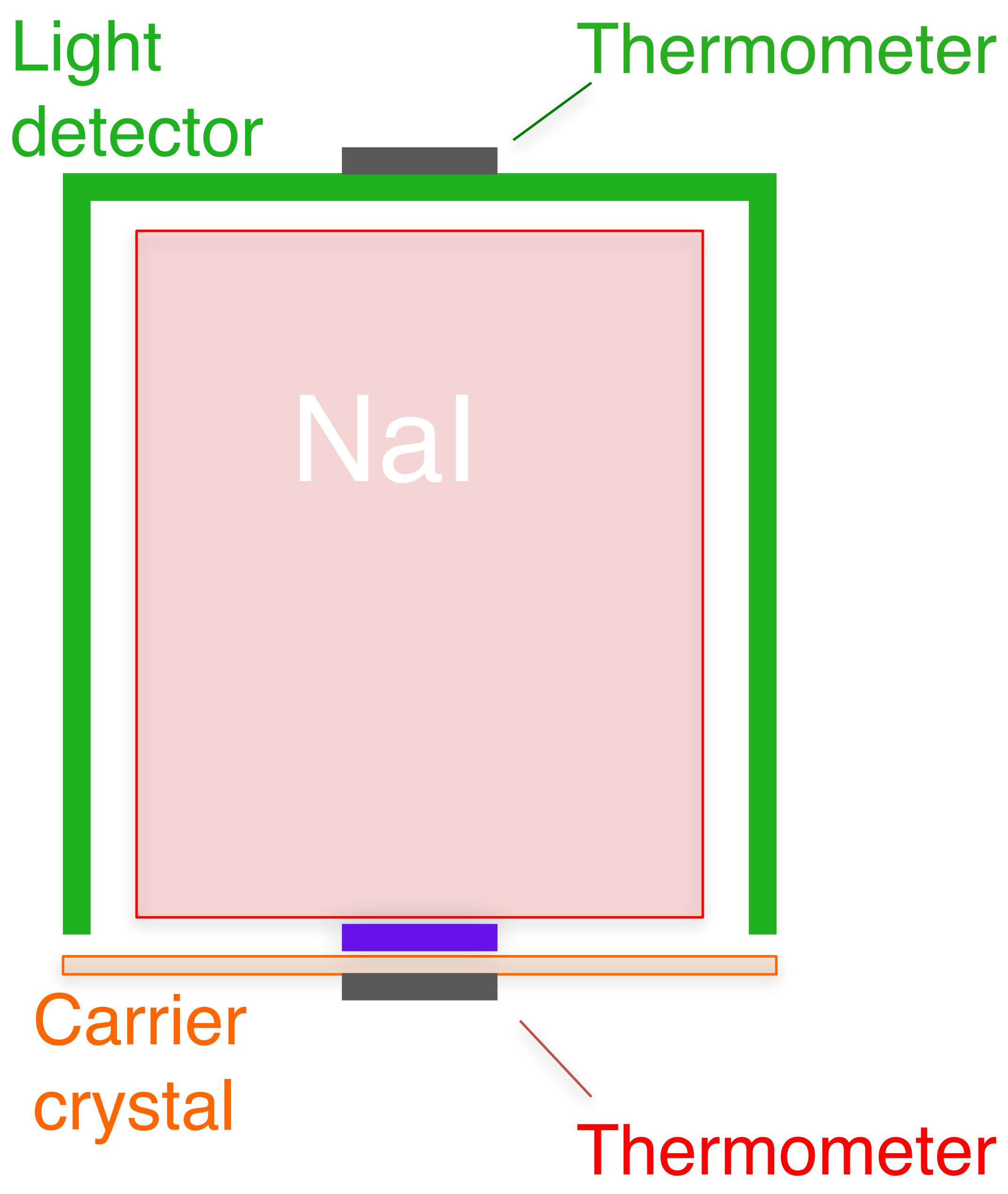


- long-standing claim from DAMA/LIBRA (NaI)
- in the standard elastic scattering scenario: excluded by null results of other experiments based on different target materials
- comparison of experiments is model dependent
- detector based on NaI can rule out material dependencies

Scintillating NaI calorimeter

Phonon channel

- (almost) independent of particle type
- precise measurement of deposited energy
- design goal: Nuclear recoil threshold of 1keV

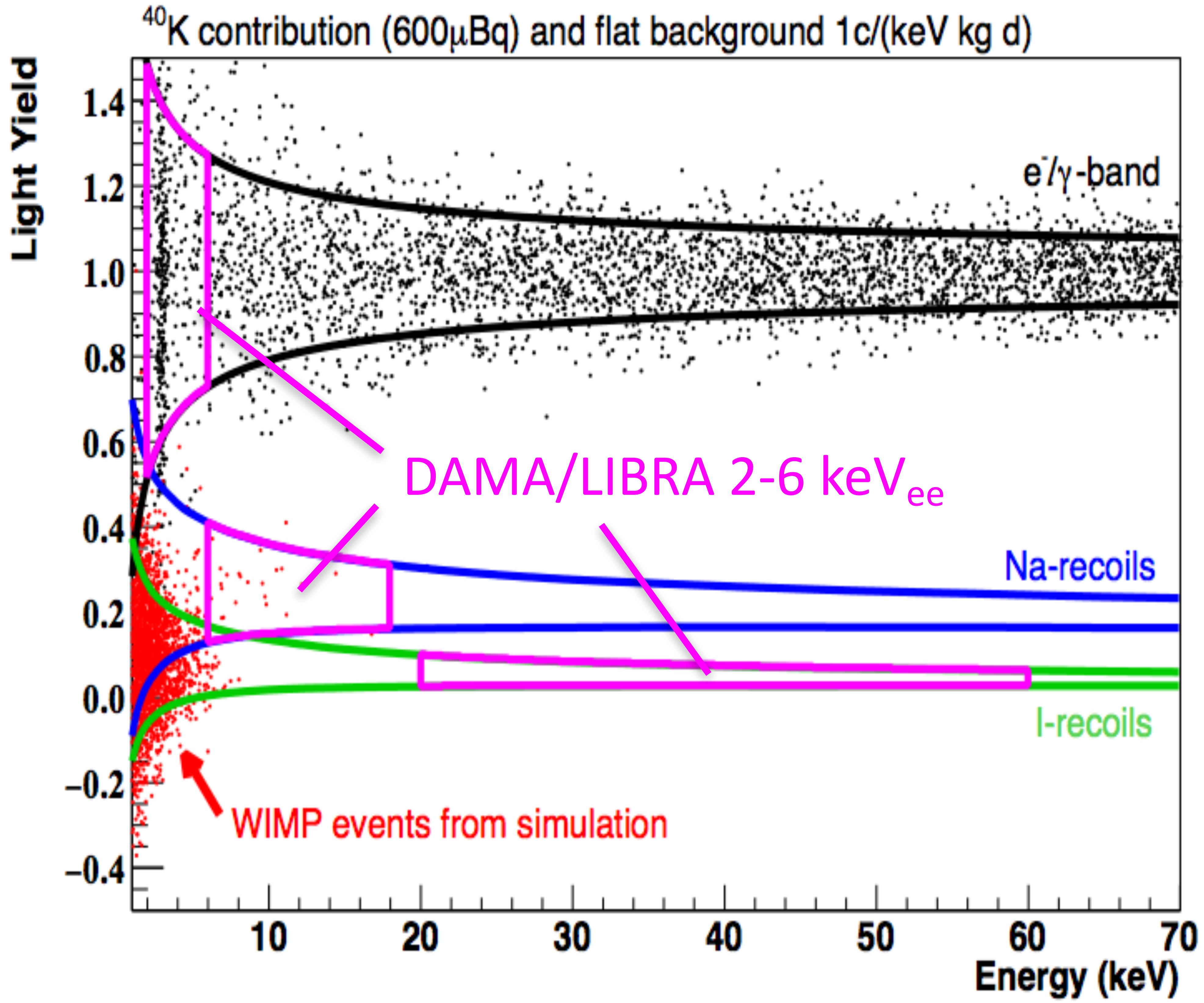


Light channel (few %)

- strongly dependent on particle type (quenching)
- particle discrimination on event-by-event basis

first NaI detector with particle identification and active background suppression via a second and independent channel

Simulated data for 100 kg days

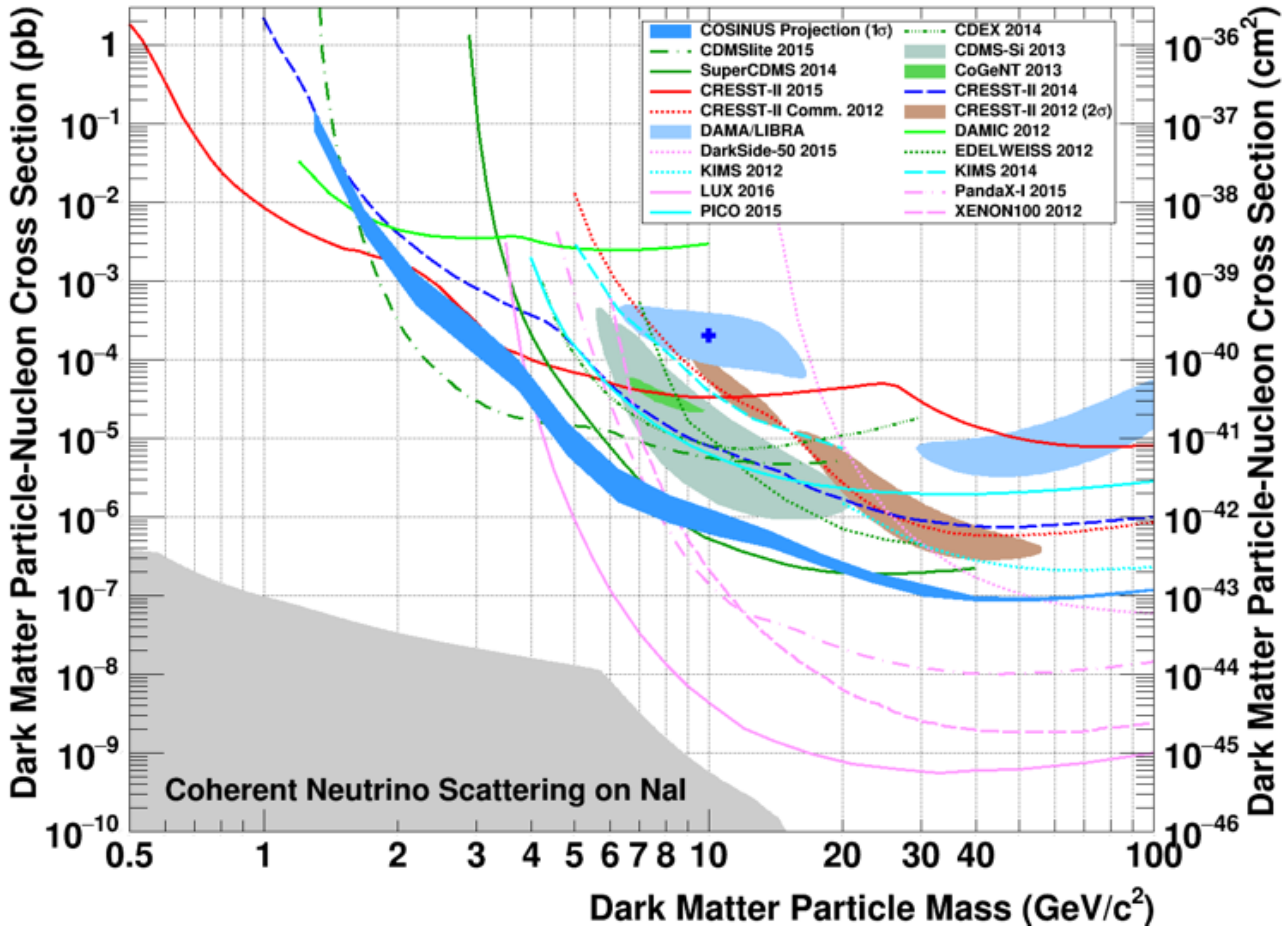


Paper under review at EPJ C
arXiv:1603.02214

- light yield: ratio of scintillation light L and deposited energy E
- solid lines: central 80% bands
- black events: background (constant + ^{40}K) as from DAMA/LIBRA
- red events: Dark matter signal from DAMA/LIBRA claim (Savage et al.)
- exposure: 100 kg-days
- threshold 1 keV for nuclear recoils
- pink colored boxes correspond to energy interval used by DAMA\LIBRA

Estimated sensitivity

Paper under review at EPJ C
arXiv:1603.02214



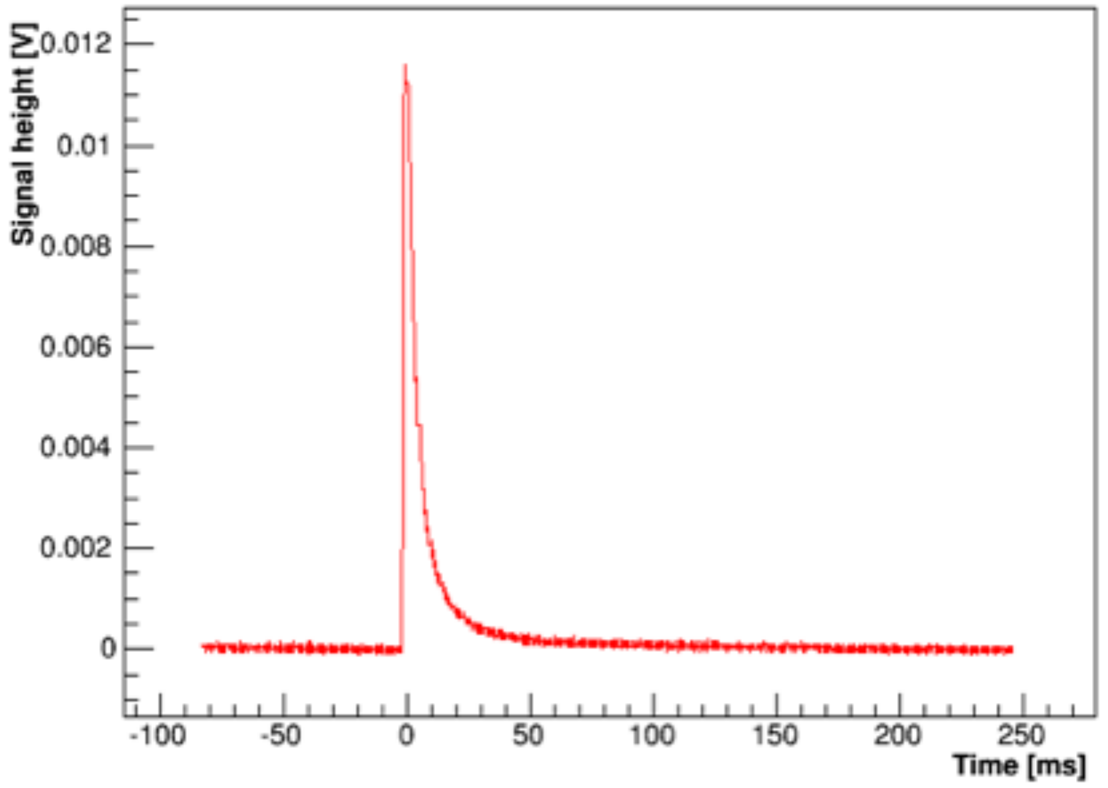
- background-only simulation
- projected limit for spin-independent elastic scattering on nuclei
- anticipated sensitivity is about two orders of magnitude below the interpretation of the DAMA/LIBRA claim under standard model assumptions

Current status

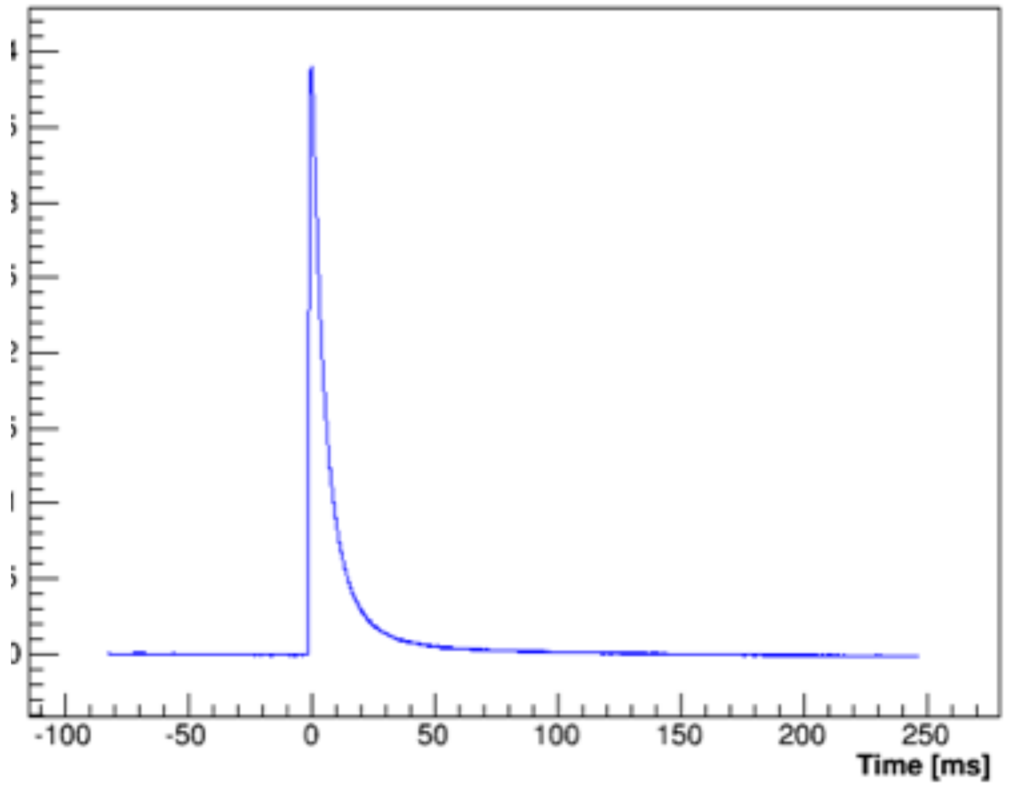
Cryostat cooled down 19.4.2016

- first COSINUS NaI prototype detector assembled and cooled down in the CRESST test facility
- crystal has a mass of 66 g
- data taking ongoing since about two months

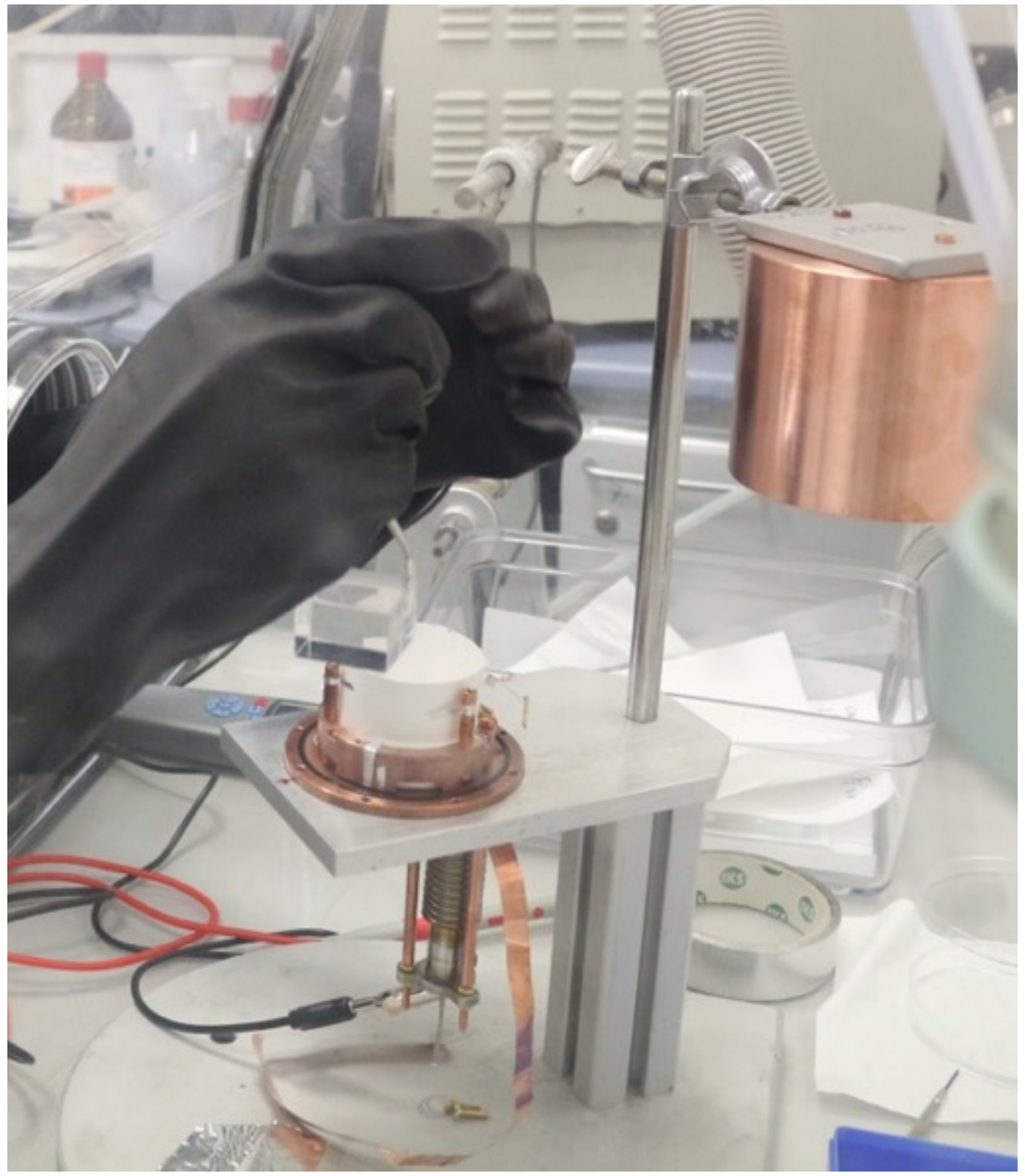
STAY TUNED!!!!



60 keV event
in NaI crystal



60 keV$_{ee}$ event
in the light detector

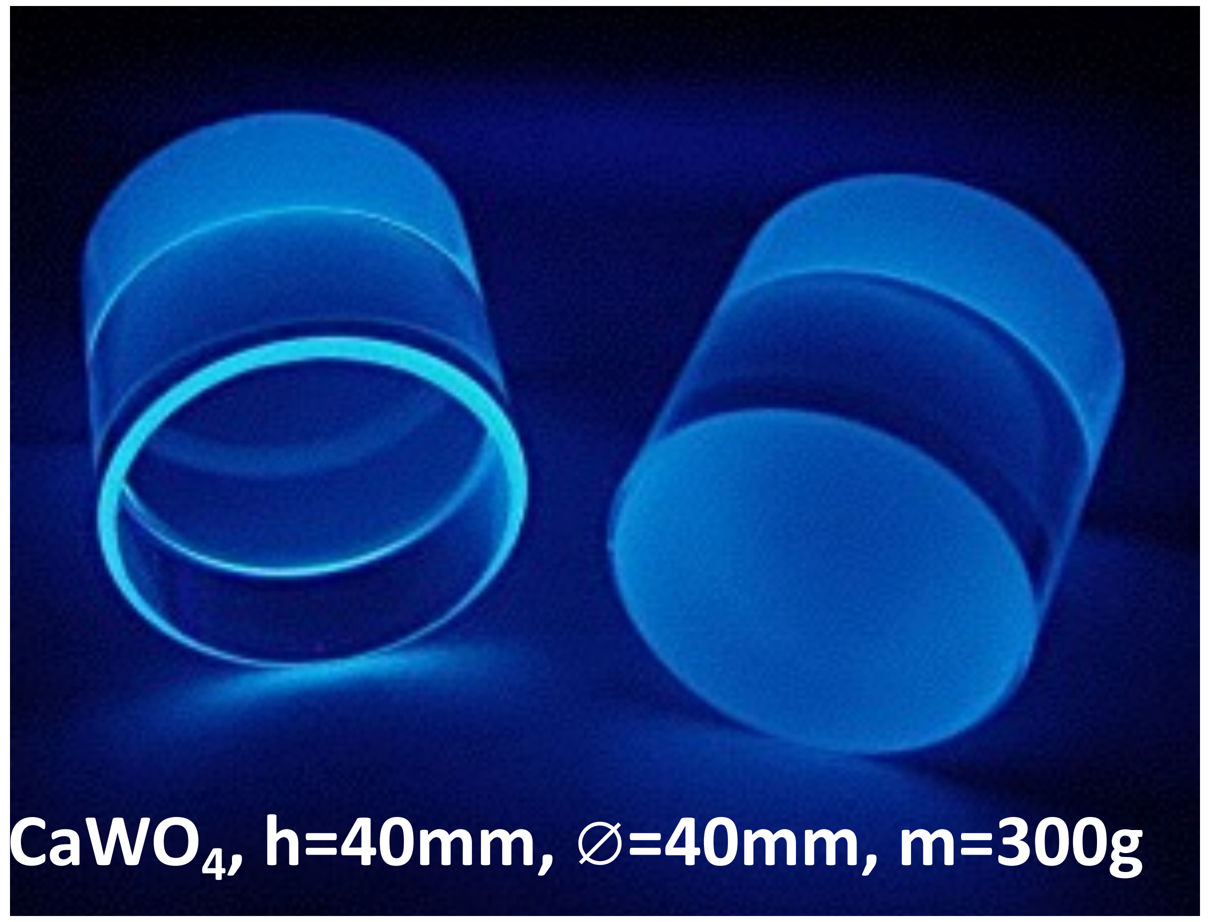


The CRESST experiment

Cryogenic Rare Event Search with Superconducting Thermometers

Direct detection of dark matter particles via their scattering off target nuclei

Scintillating $CaWO_4$ crystals as target



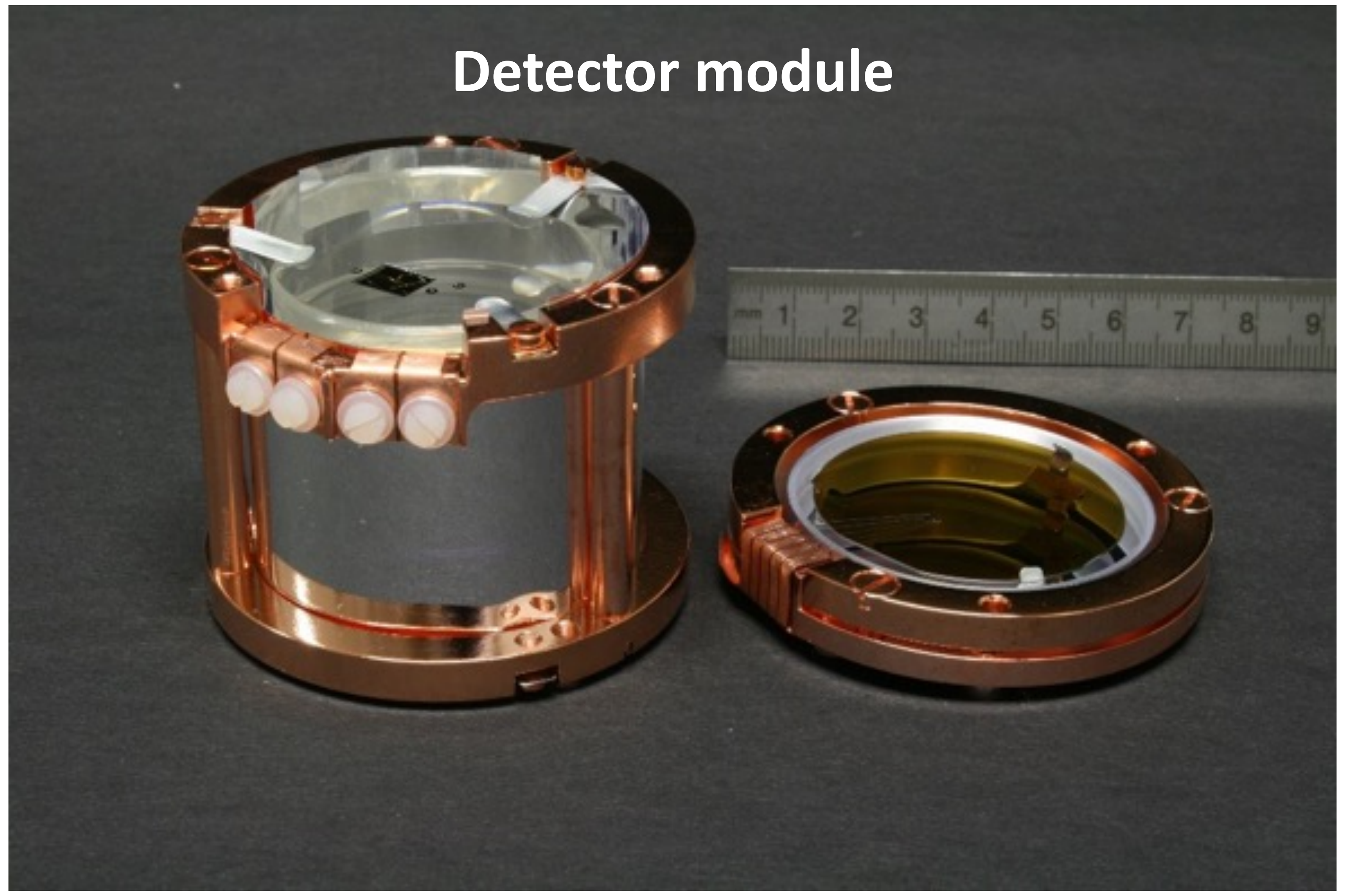
$CaWO_4$, h=40mm, ∅=40mm, m=300g

Target crystals operated as

cryogenic calorimeters (~15mK)

- **Measurement of deposited energy**

Detector module



Separate cryogenic light detector to detect the scintillation light signal

- **Particle discrimination**

CRESST II Phase 2

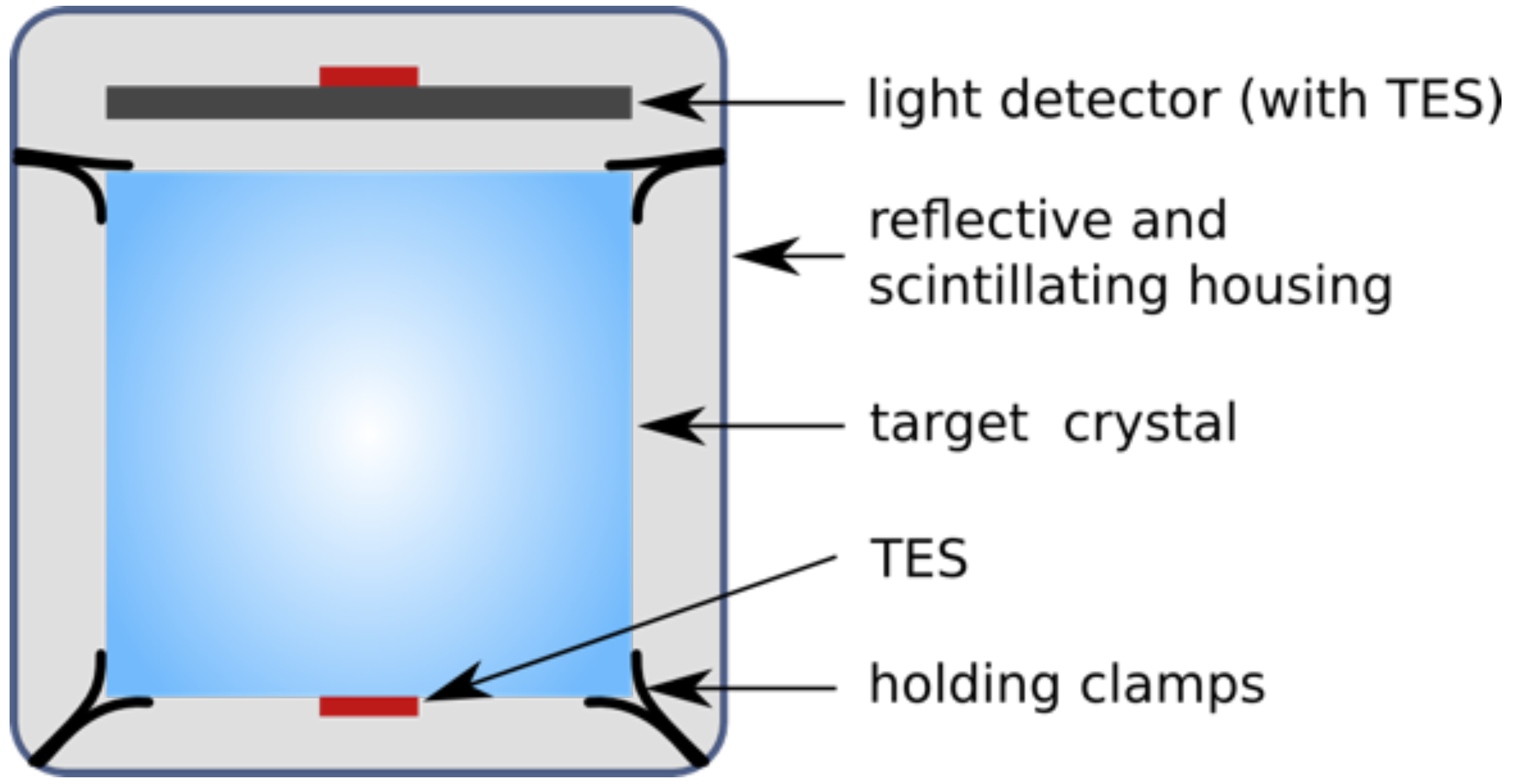
Final Phase 2 results on low-mass dark matter particles:

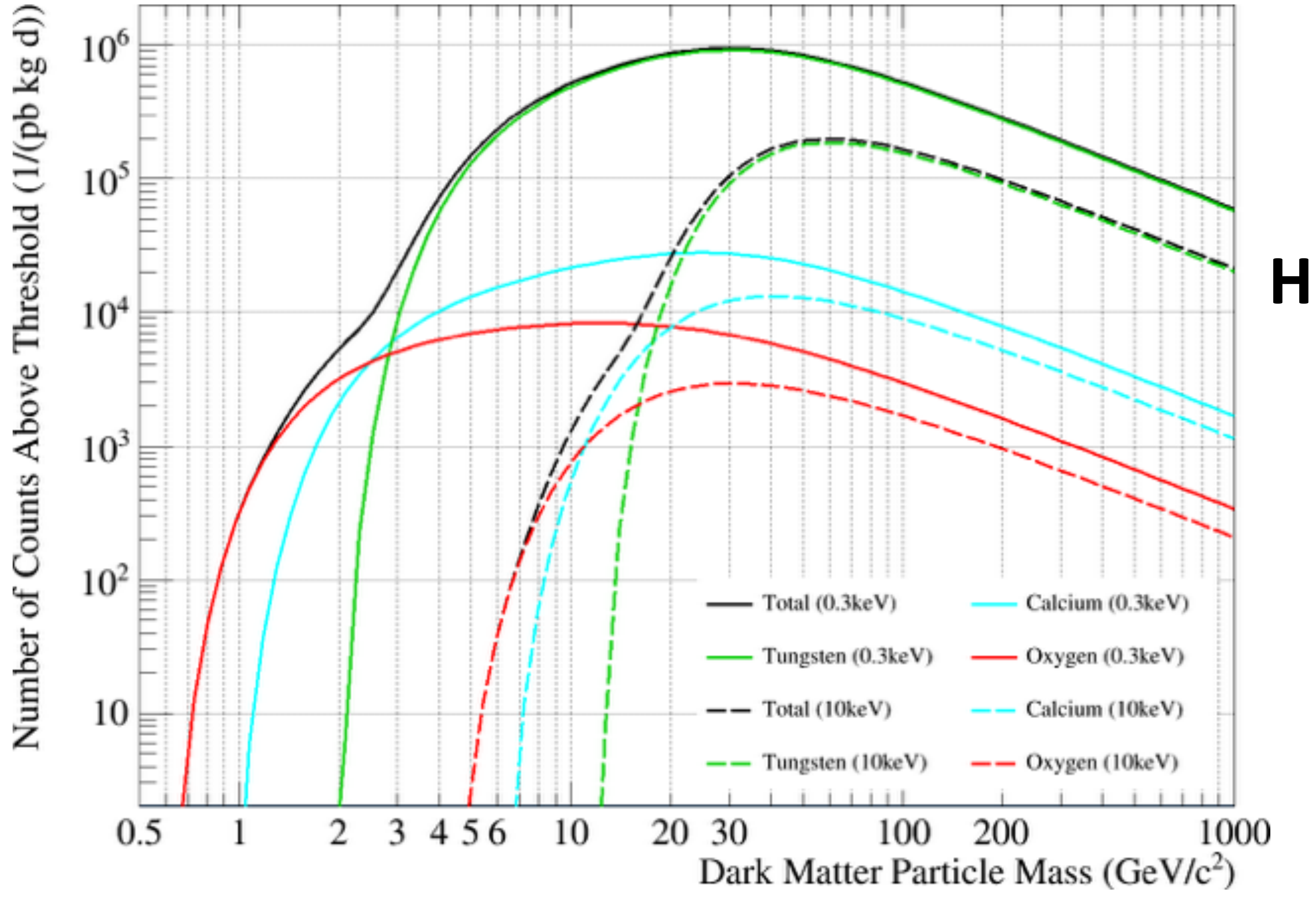
- September 2015
- Single module Lise

  Conventional (no veto for surface alpha decays)
- Crystal from external supplier

  Background level ~8.5 counts/(keV kg day)
- Lowest threshold

  (307±4)eV
- 52 kg days of exposure
- Full blind data set

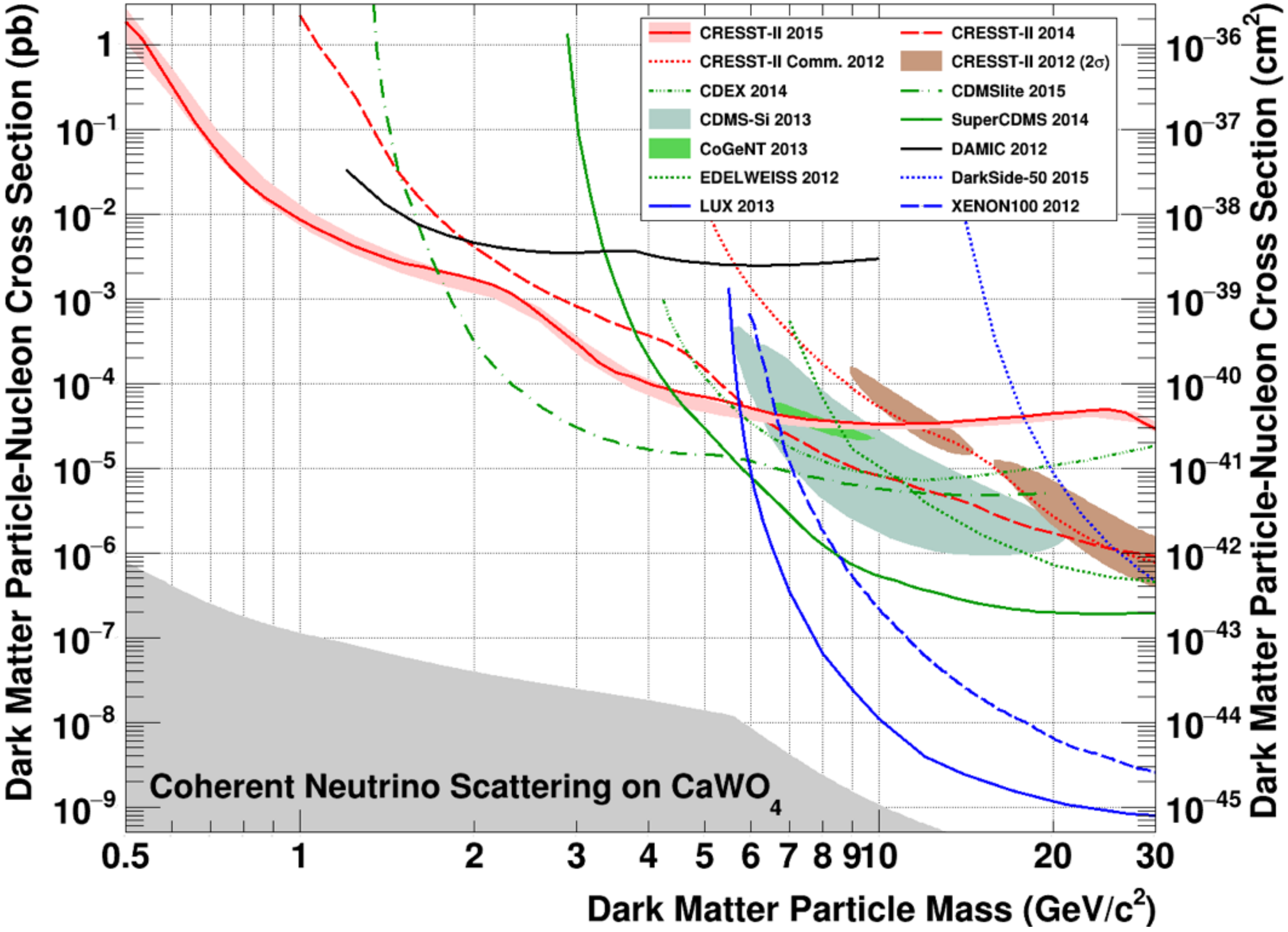




Hunting light dark matter requires a low threshold!

Exclusion limit

- World-leading below 1.7GeV/c^2
- Exploring new parameter space down to 0.5GeV/c^2

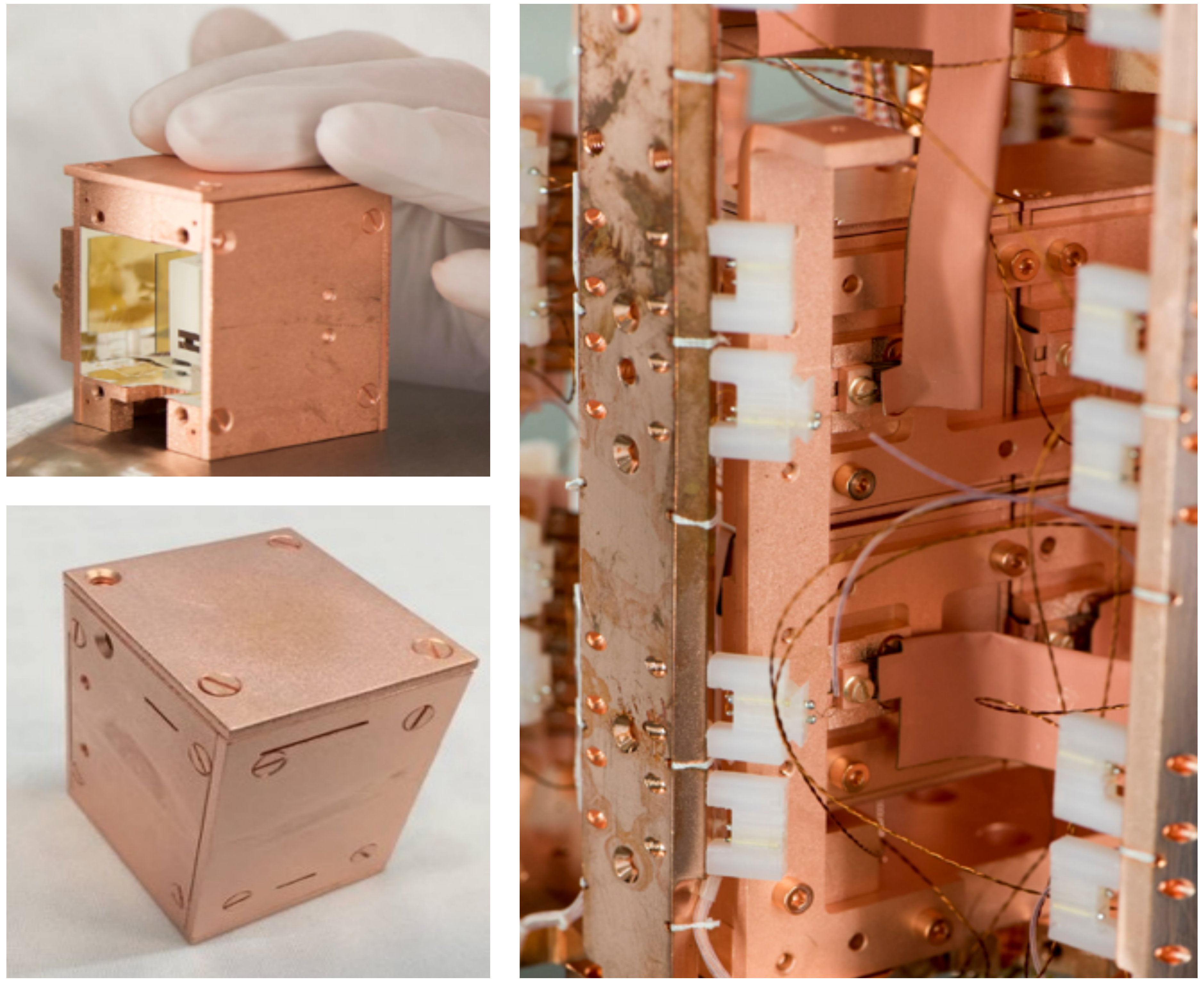


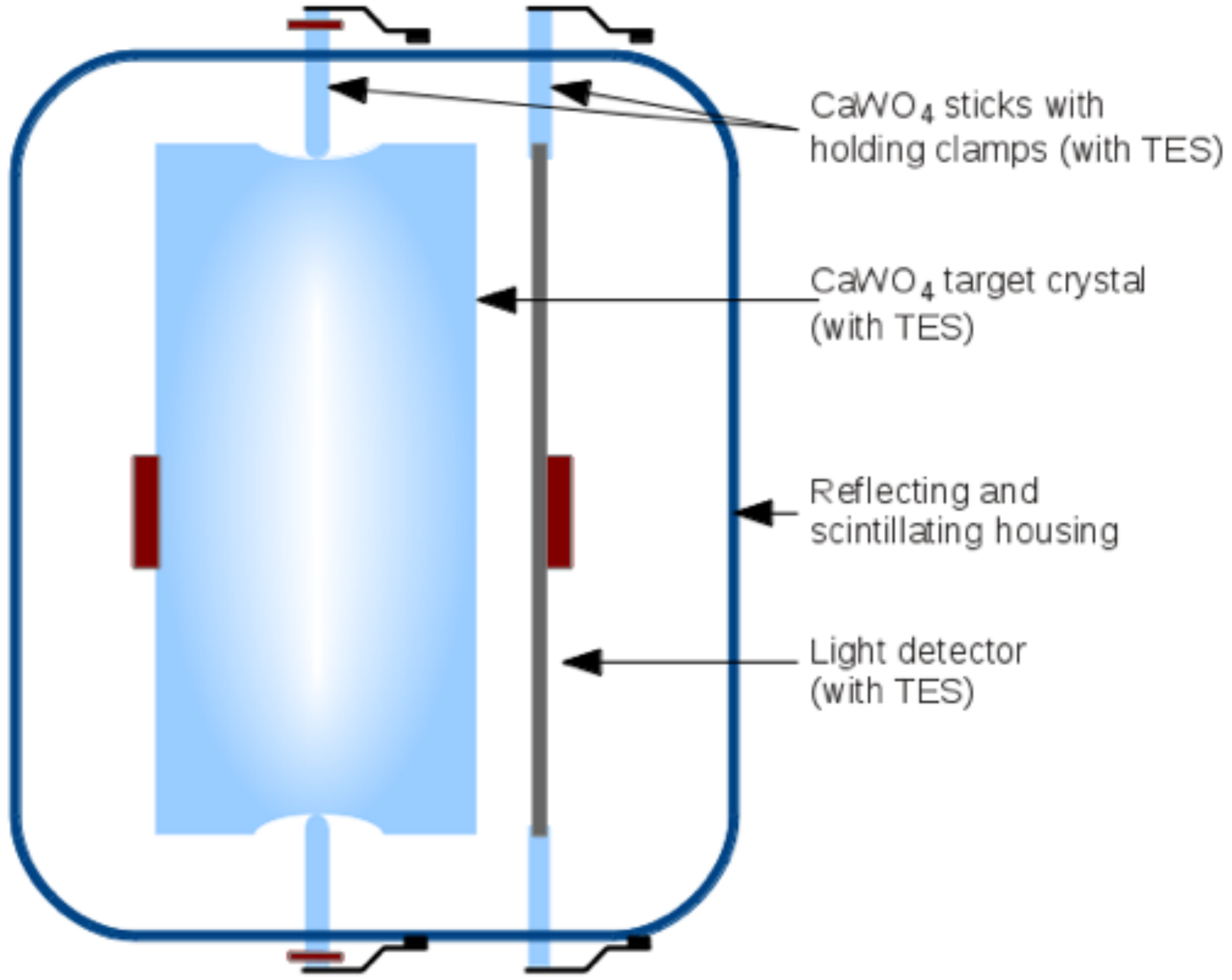
The European Physical Journal C (2016) 76:25

CRESST III

Detector layout optimized for low-mass dark matter

- Available self grown crystals - background level ~3 counts/(keV kg day)
- Cuboid crystal of $(20\times20\times10)\text{mm}^3$ (~ 25g)
- <100 eV threshold
- Light detector $(20\times20)\text{mm}^2$
- Fully scintillating housing
- Instrumented sticks



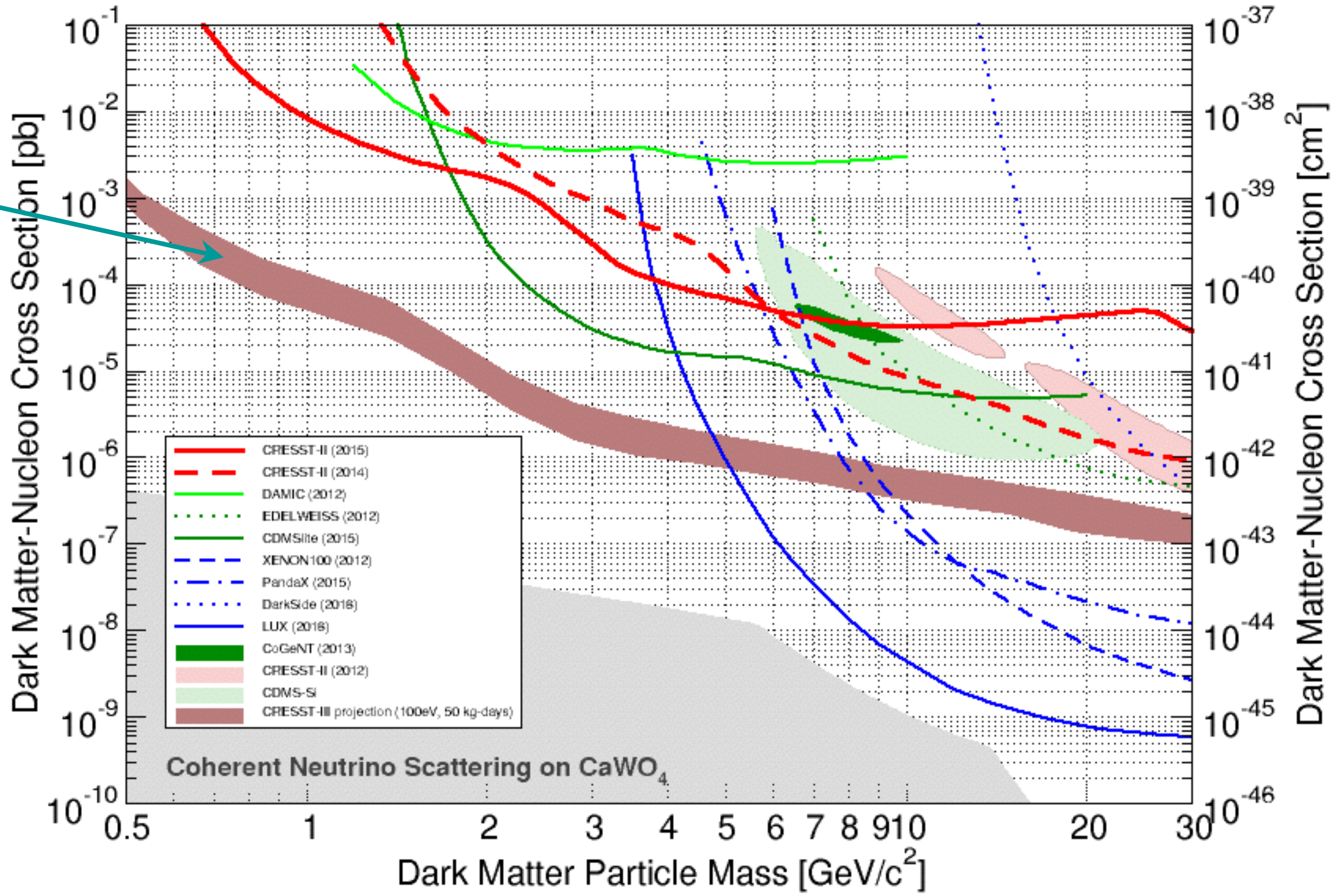


Ten modules being commissioned

CRESST III projections

Phase 1

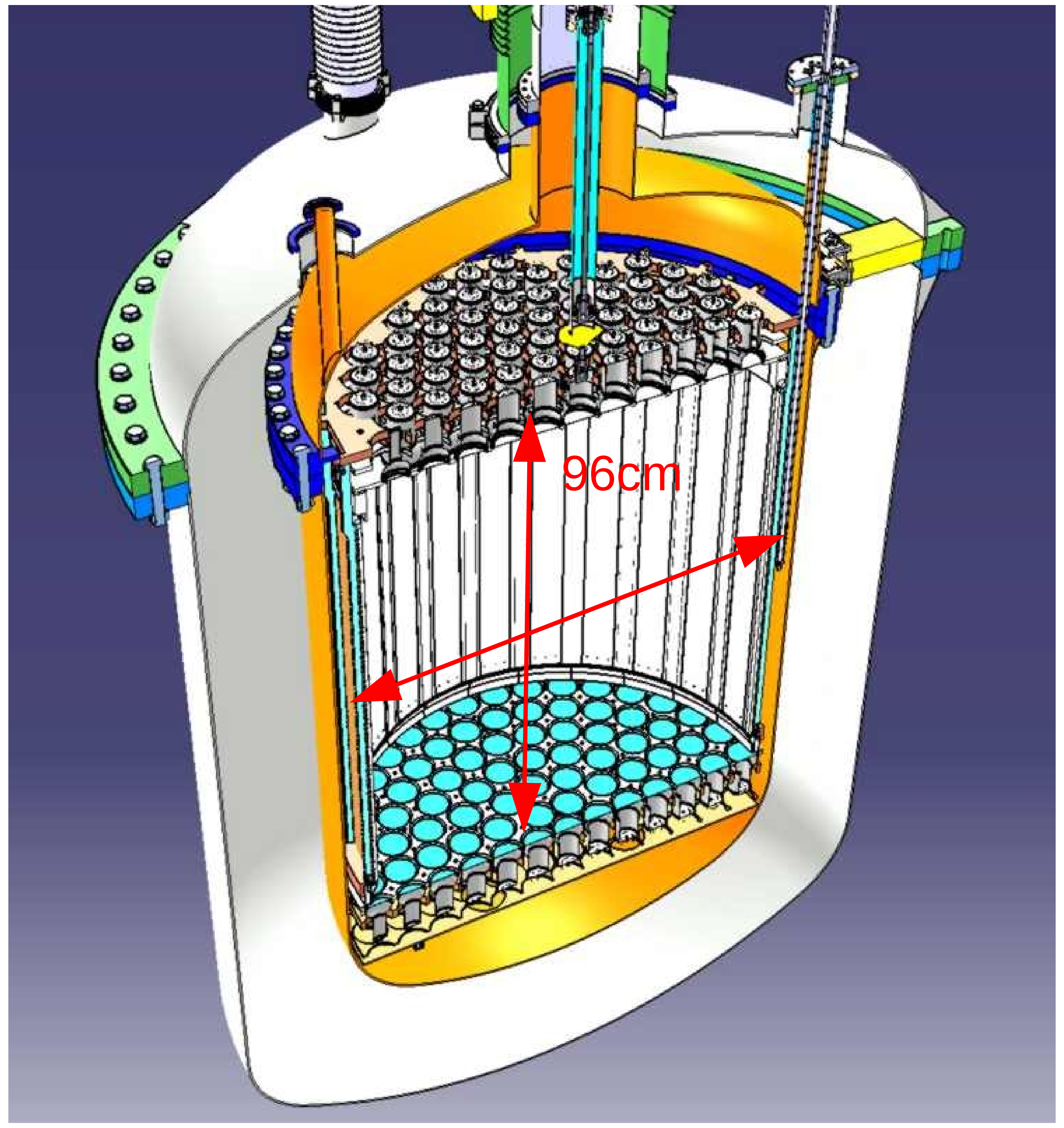
- 50 kg-days 1year of running with 10 small modules



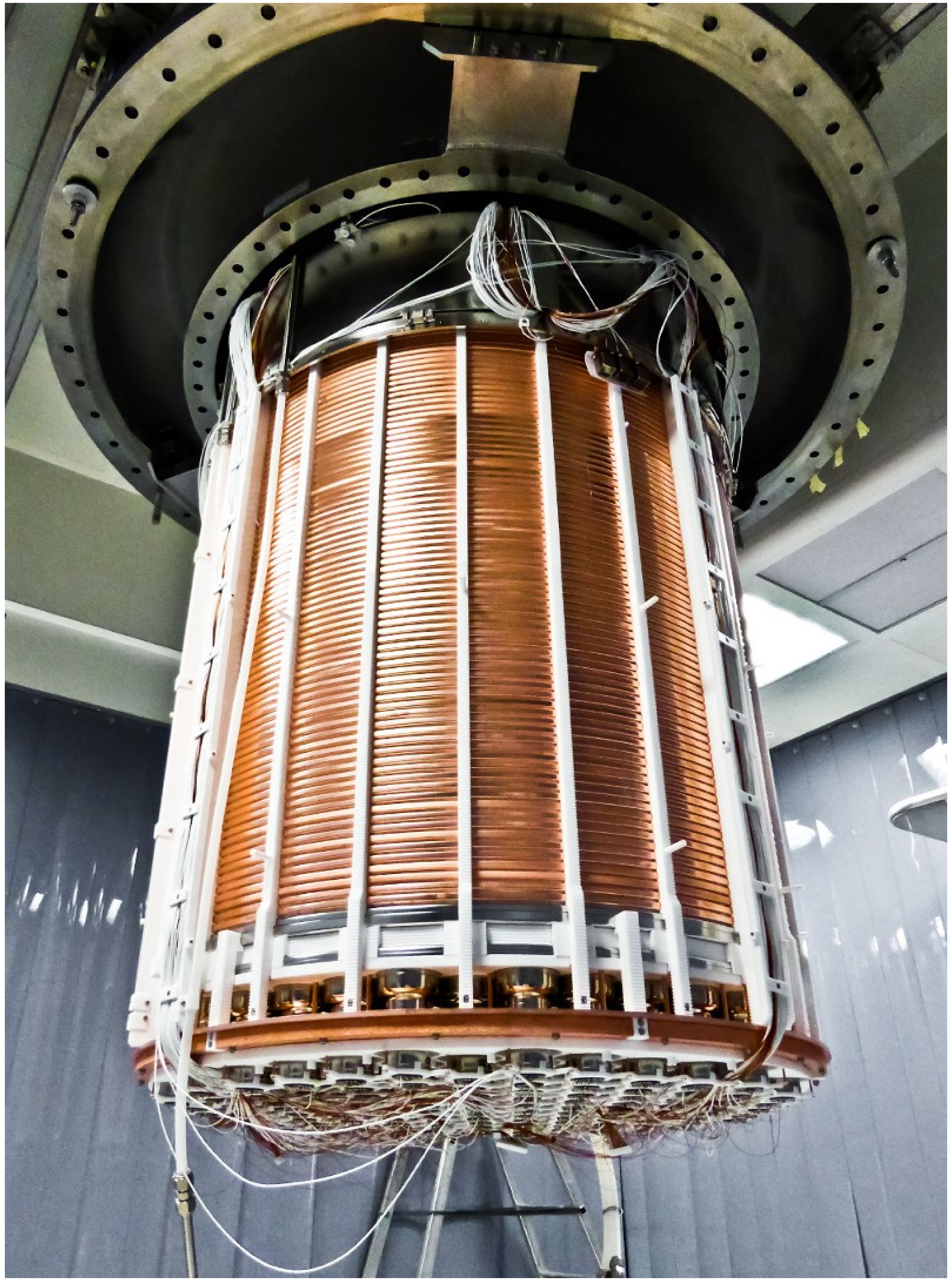
XENON1T

- **Science goal:** 100 times more sensitive than XENON100.
- **Target/Detector:** 3.2 tonnes of Xe/ dual-phase TPC readout by 248 PMTs.
- **Shielding:** Water Cherenkov muon veto.
- **Cryogenic Plants:** Xe cooling/ purification/distillation/storage systems designed to handle up to 10 tonne of Xe. Upgrade to a larger detector (XENONnT) planned for 2018
- **Status:** All systems successfully tested. Commissioning of detector ongoing. First science run this Fall.

XENON1T TPC

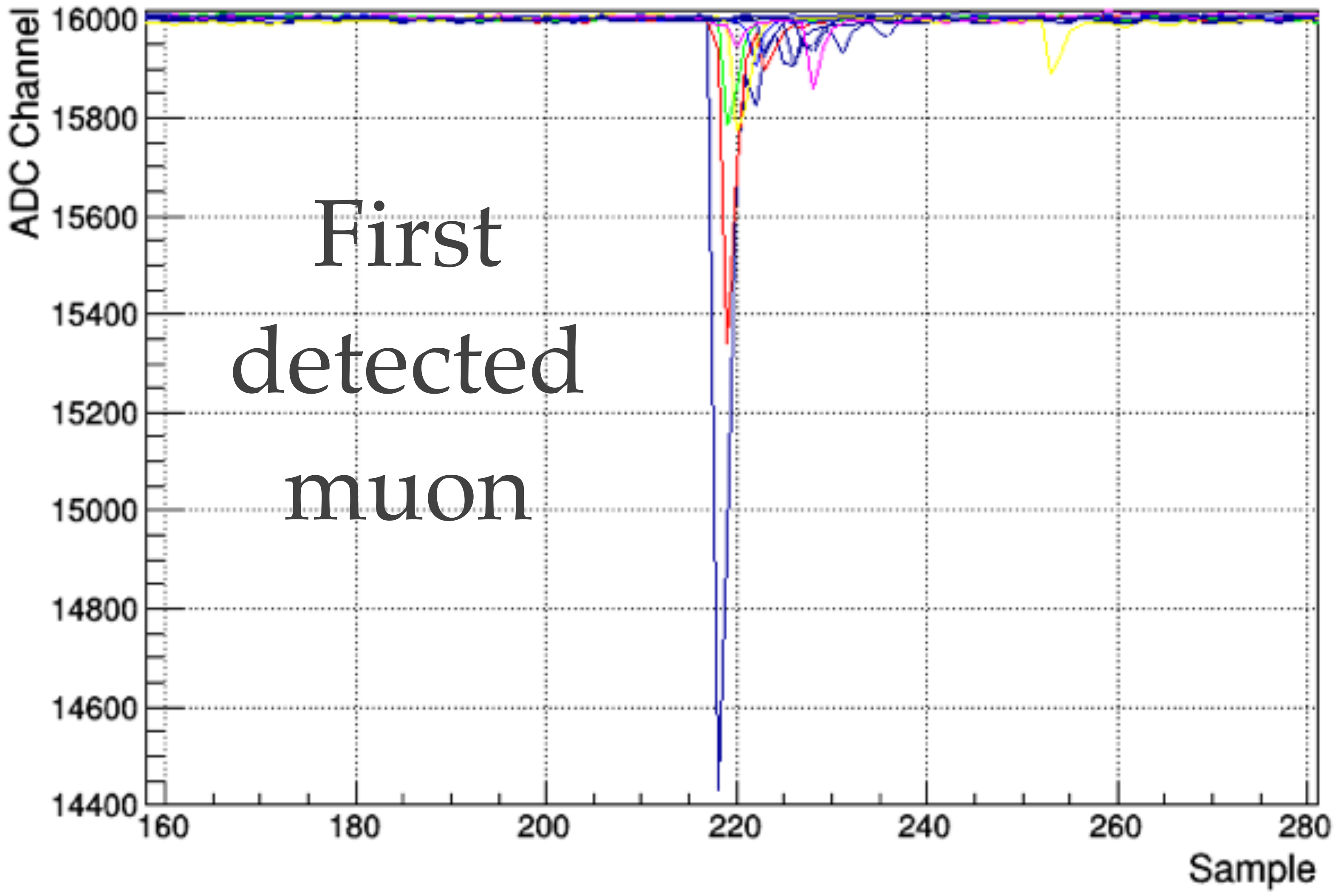


- The XENON1T Time Projection Chamber (TPC) is filled, since April 2016, with 3.2 tonnes of high-purity Xenon.
- 248 low-background 3”photomultipliers (Hamamatsu R11410-21) are reading out the 2-tonne active volume.

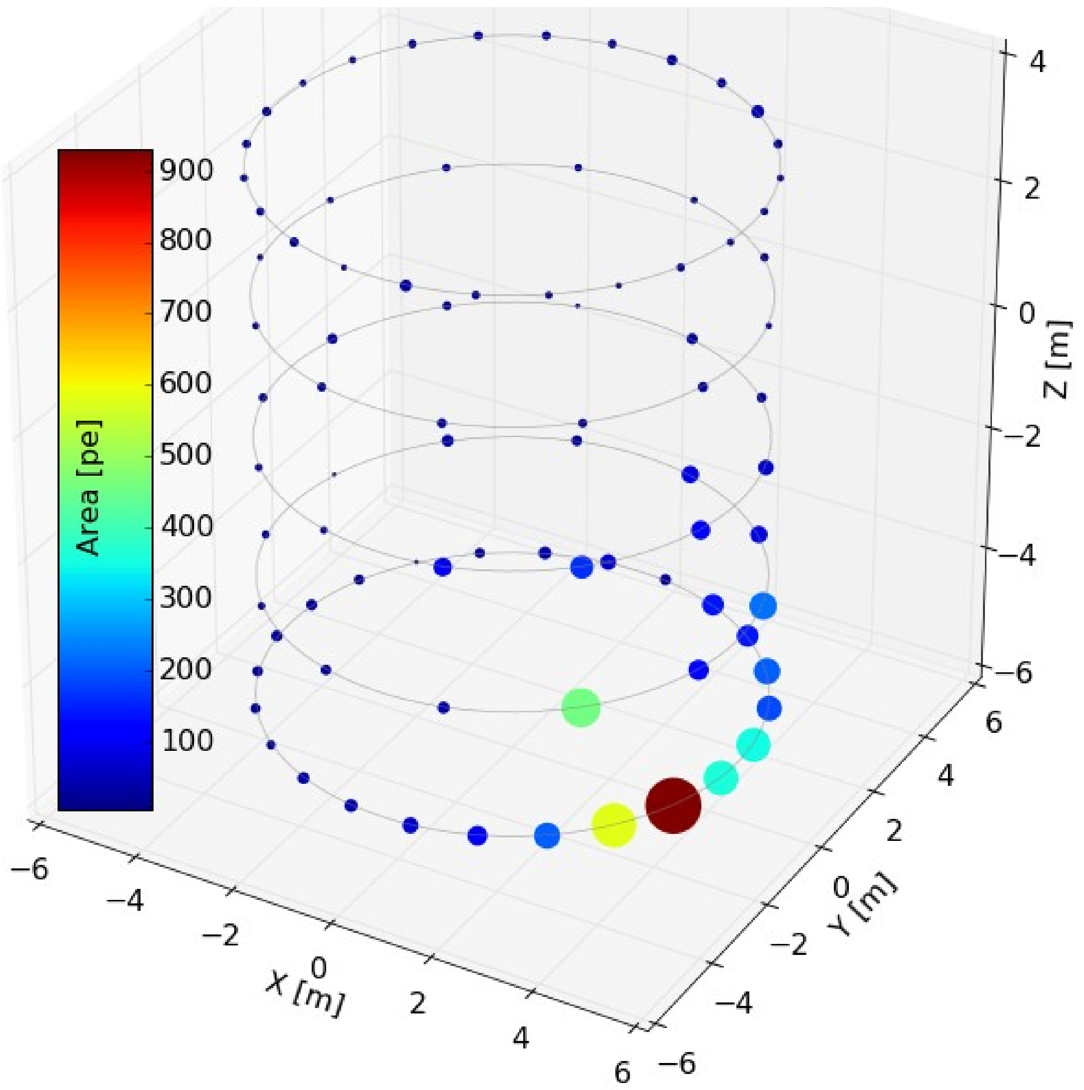


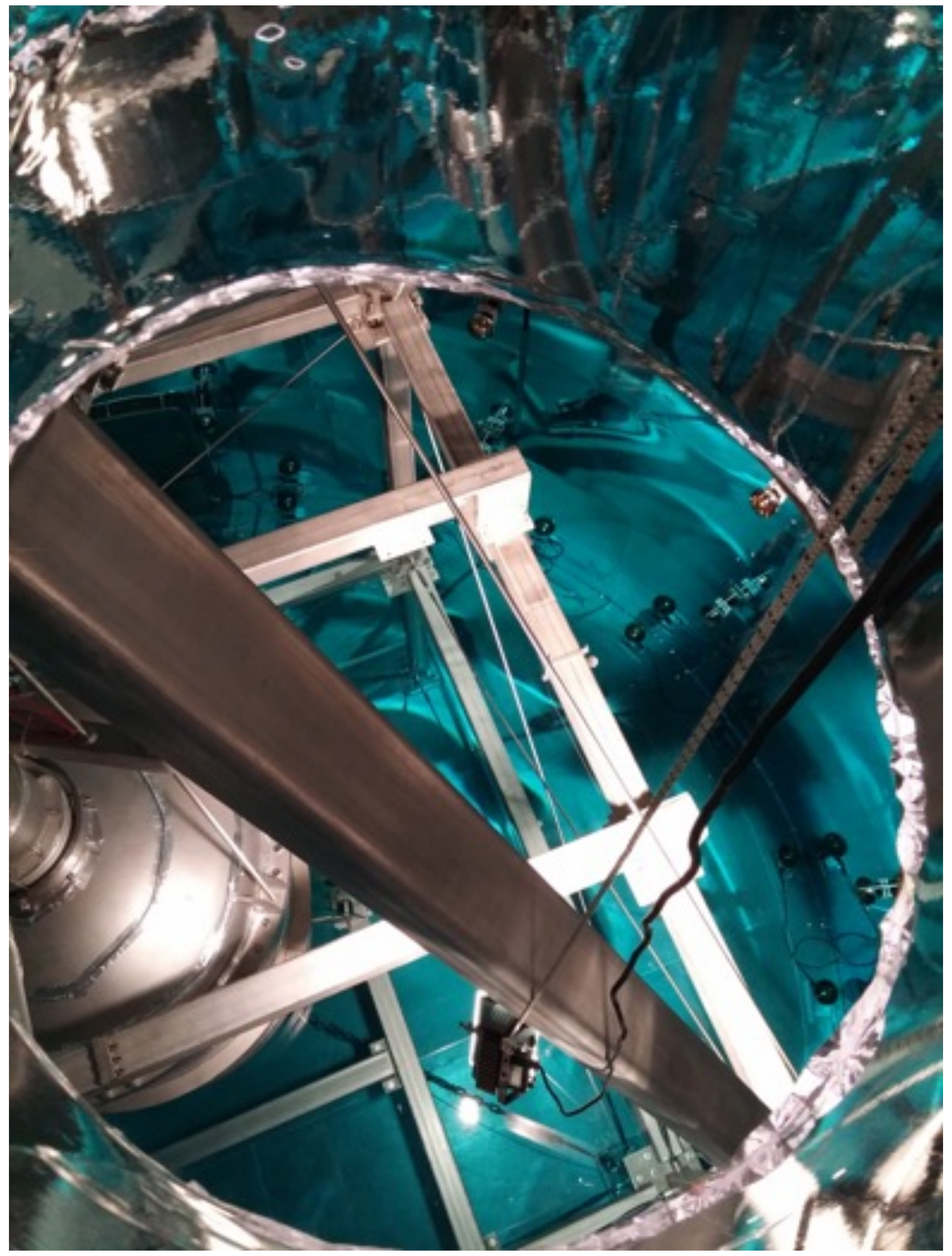
MUON VETO

- The XENON1T cryostat is immersed in a tank filled with 700 tonnes of pure water.
- The tank is instrumented with 84 high-QE, 8″ photomultipliers in order to be used as a Water Cherenkov detector and tag cosmogenic-induced background.
- The muon veto serves also as passive shield against external radioactivity.
- The muon veto has been commissioned in March 2016.



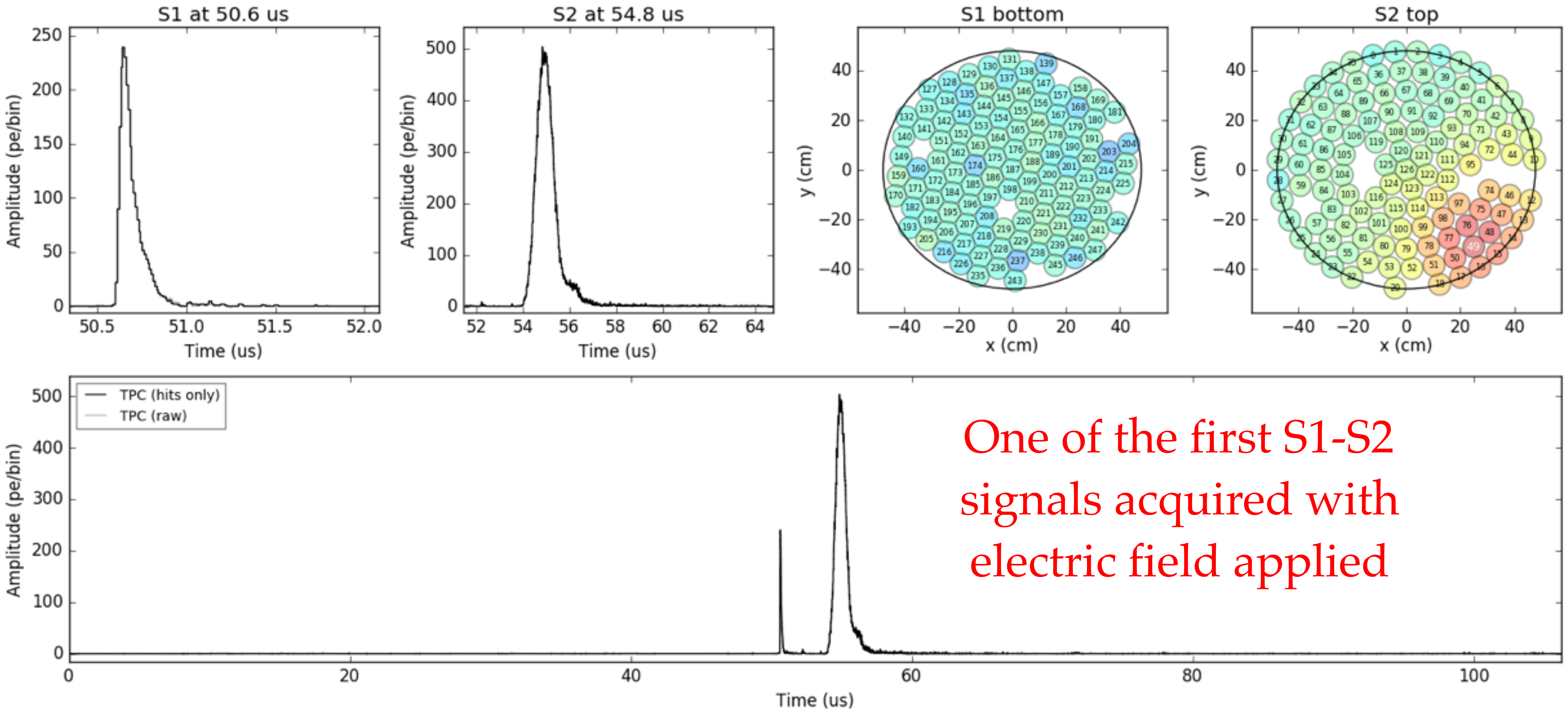
First detected muon





XENON1T TPC COMMISSIONING

- The XENON1T Time Projection Chamber and associated cryogenic system are presently under commissioning.
- Detector is responding to radiation as expected, with both charge and light being detected. The total mass of 3.2 tonnes of LXe is being continuously purified to reach the desired charge yield at the applied field.



One of the first S1-S2 signals acquired with electric field applied

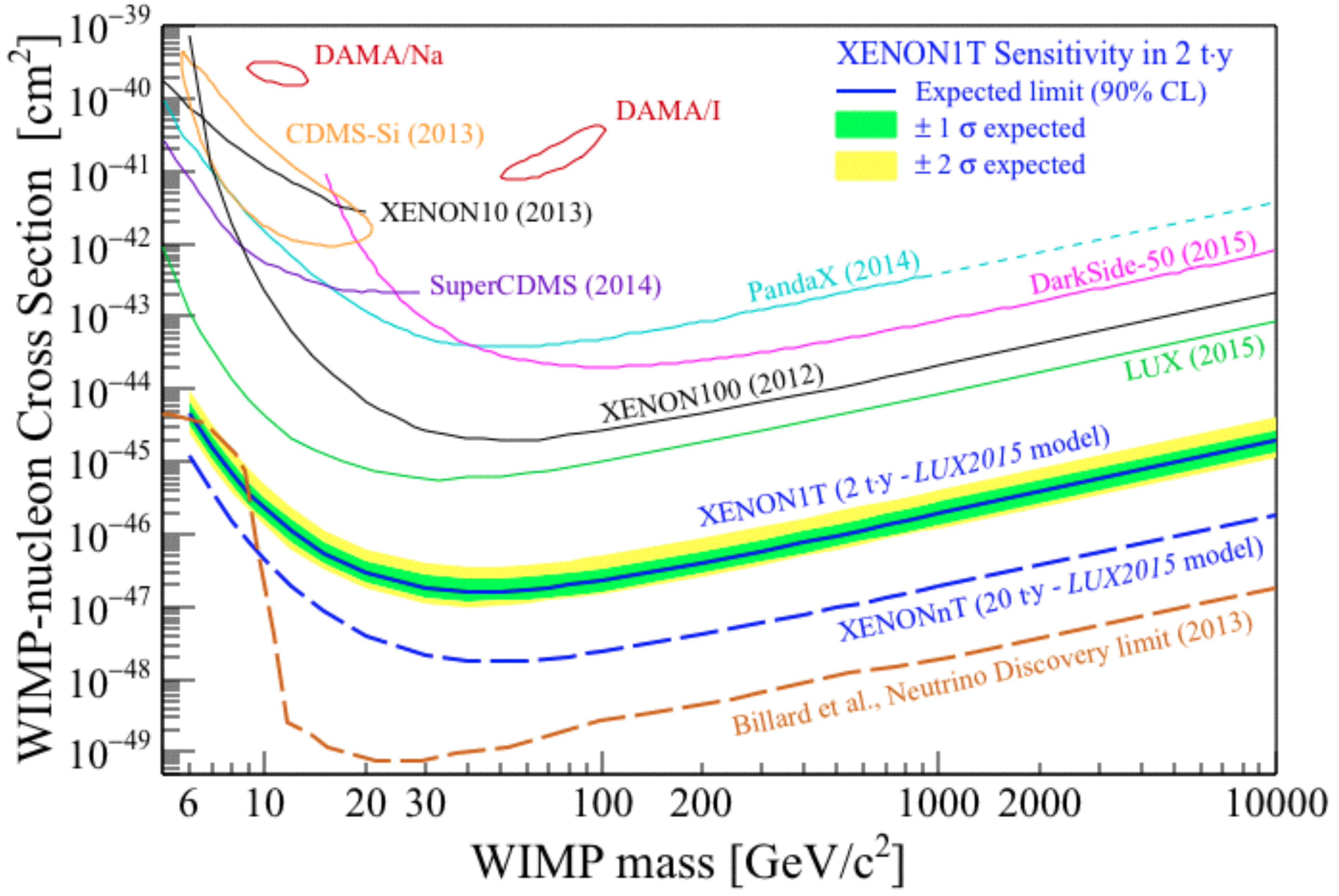
XENON1T BACKGROUND BUDGET

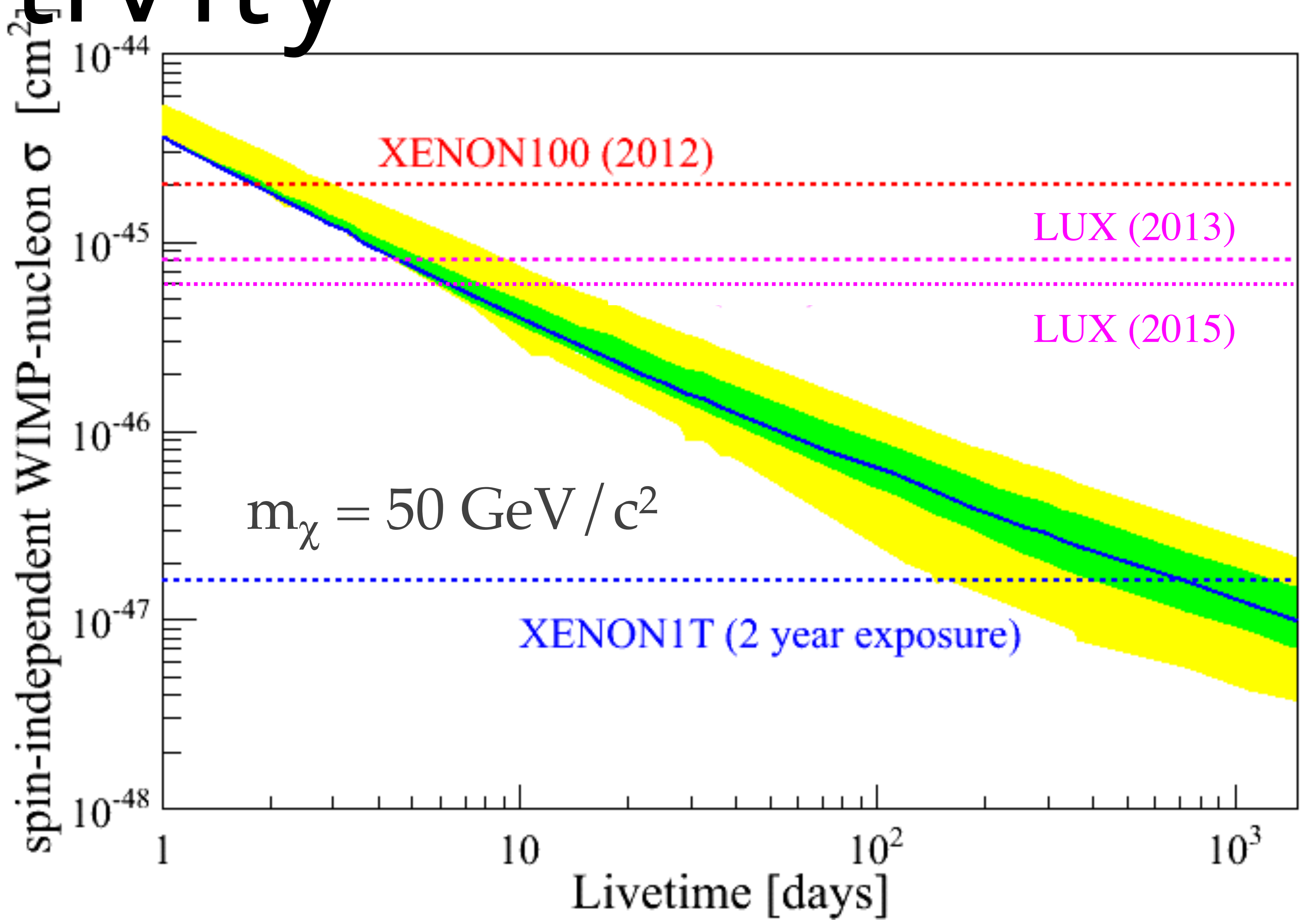
Single Scatter, 1 tonne Fiducial Volume, [2, 12] keVee, [5, 50] keVr,
99.75% S2/S1 discrimination, 40% NR acceptance

Source	Background (ev/y)
ER from materials	~0.07
^{222}Rn (10 μBq/kg)	~1.39
^{85}Kr (0.2 ppt of ^{nat}Kr)	~0.07
^{136}Xe 2ν2β	~0.02
Solar neutrinos	~0.08
Total ER	**~1.62**
Total NR	**~0.46**

* In agreement with the Radon-emanation measurements performed on the XENON1T detector after final assembly and before xenon filling.

XENON1T projected sensitivity





- Expected to reach with a 2 $t \cdot y$ exposure a sensitivity to spin-independent WIMP-nucleon interactions of $1.6\ 10^{-47}$ cm^2 for a 50 GeV/c^2 (99.75% ER rejection, 40% acceptance NR and 1 tonne fiducial volume).
- Expected to overcome presently world-leading limits just within 10 days of data taking in dark matter mode.

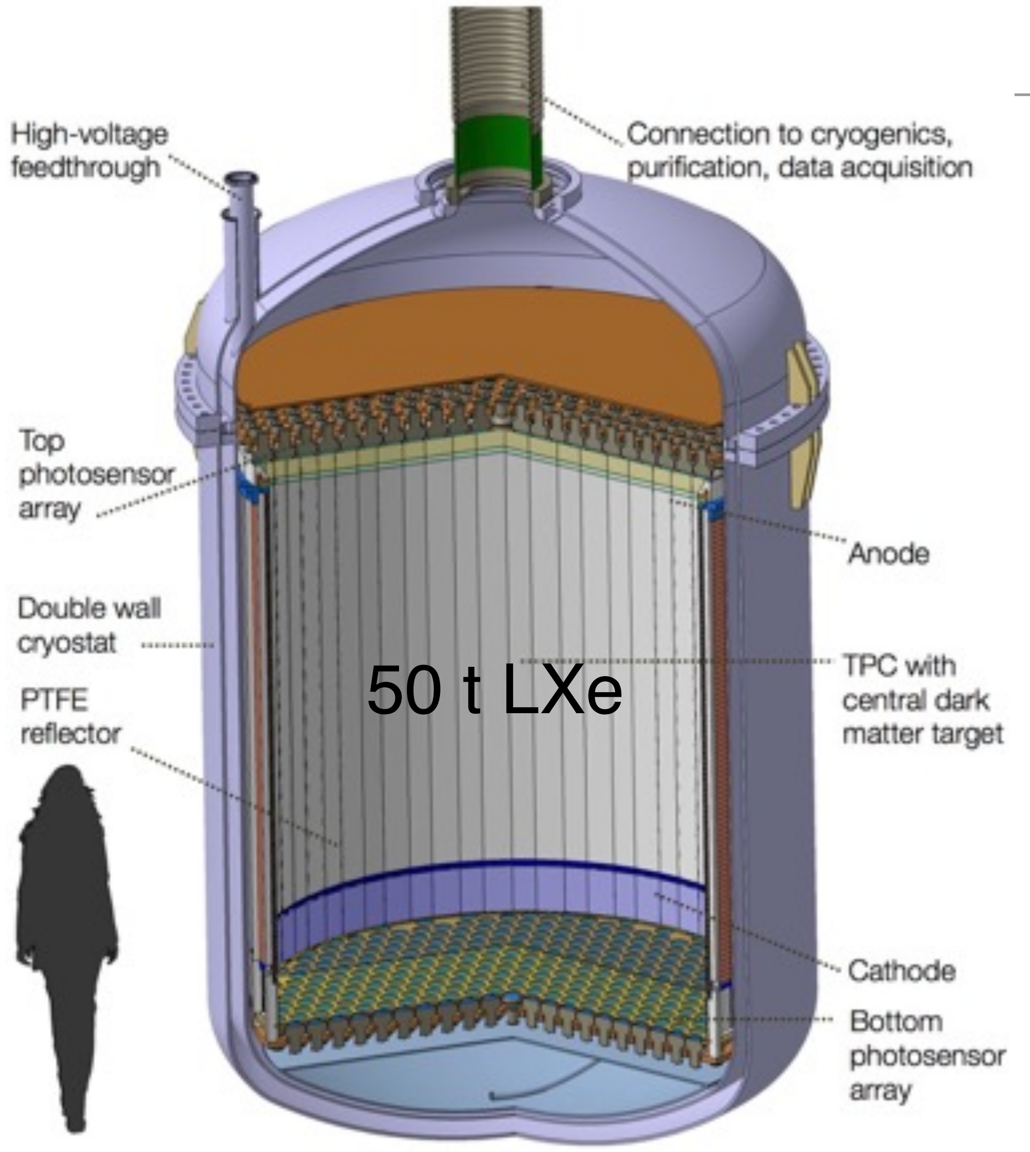
E.Aprile et al. (XENON Collaboration) Physics reach of the XENON1T dark matter experiment, JCAP no. 04 027 (2016)

DARWIN Ultimate liquid xenon TPC at LNGS

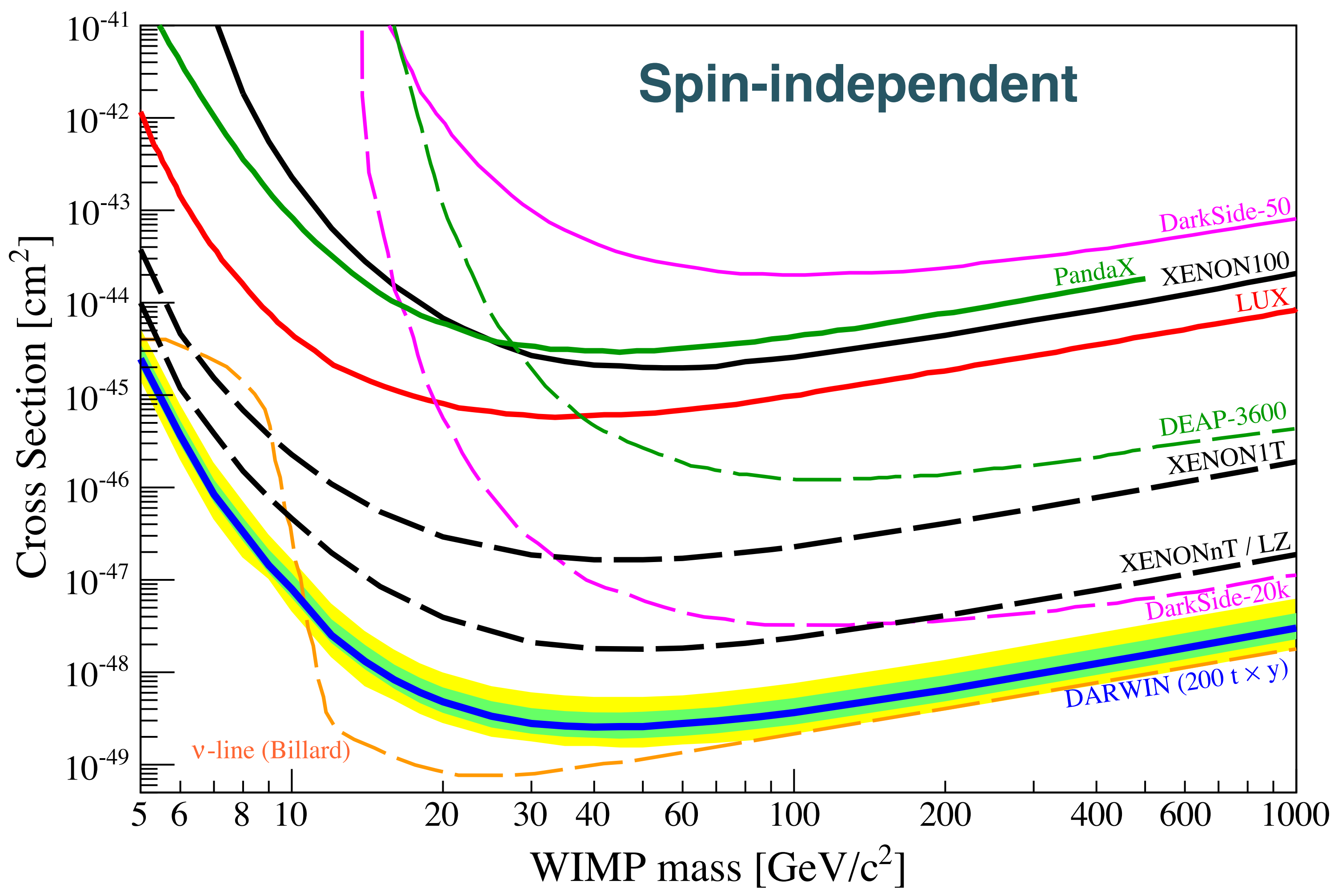
arXiv:1606.07001

XENON collaboration + new groups

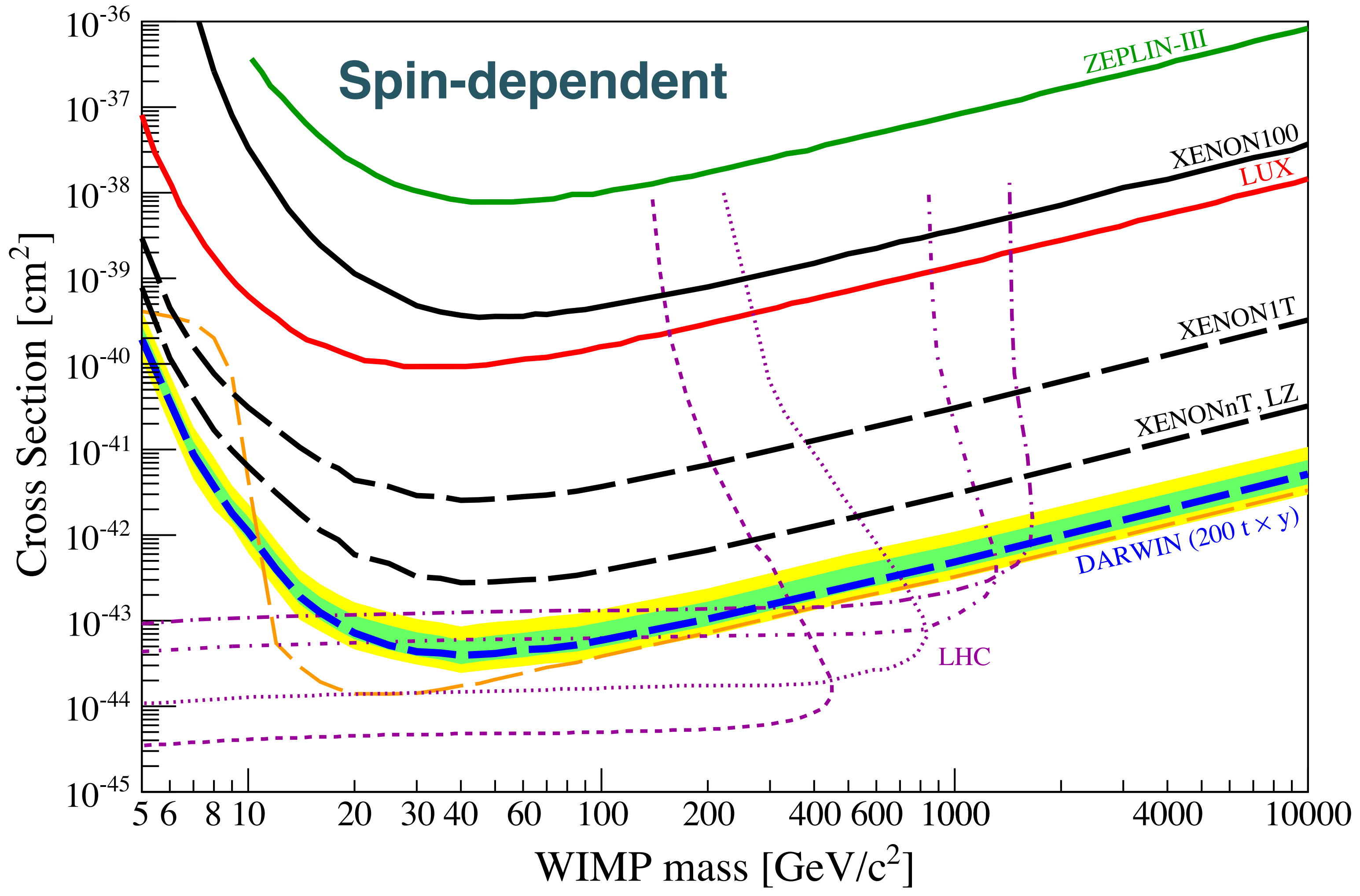
- 50 t (40 t) LXe in total (in the TPC)
- 2.6 m drift length, 2.6 m diameter TPC
- **Will reach “neutrino floor”, 200 t y exposure**
- **WIMP spectroscopy, and: axion/ALP search, solar neutrinos, 0nbb-decay of ^{136}Xe, coherent neutrino-nucleus scattering, SN neutrinos**

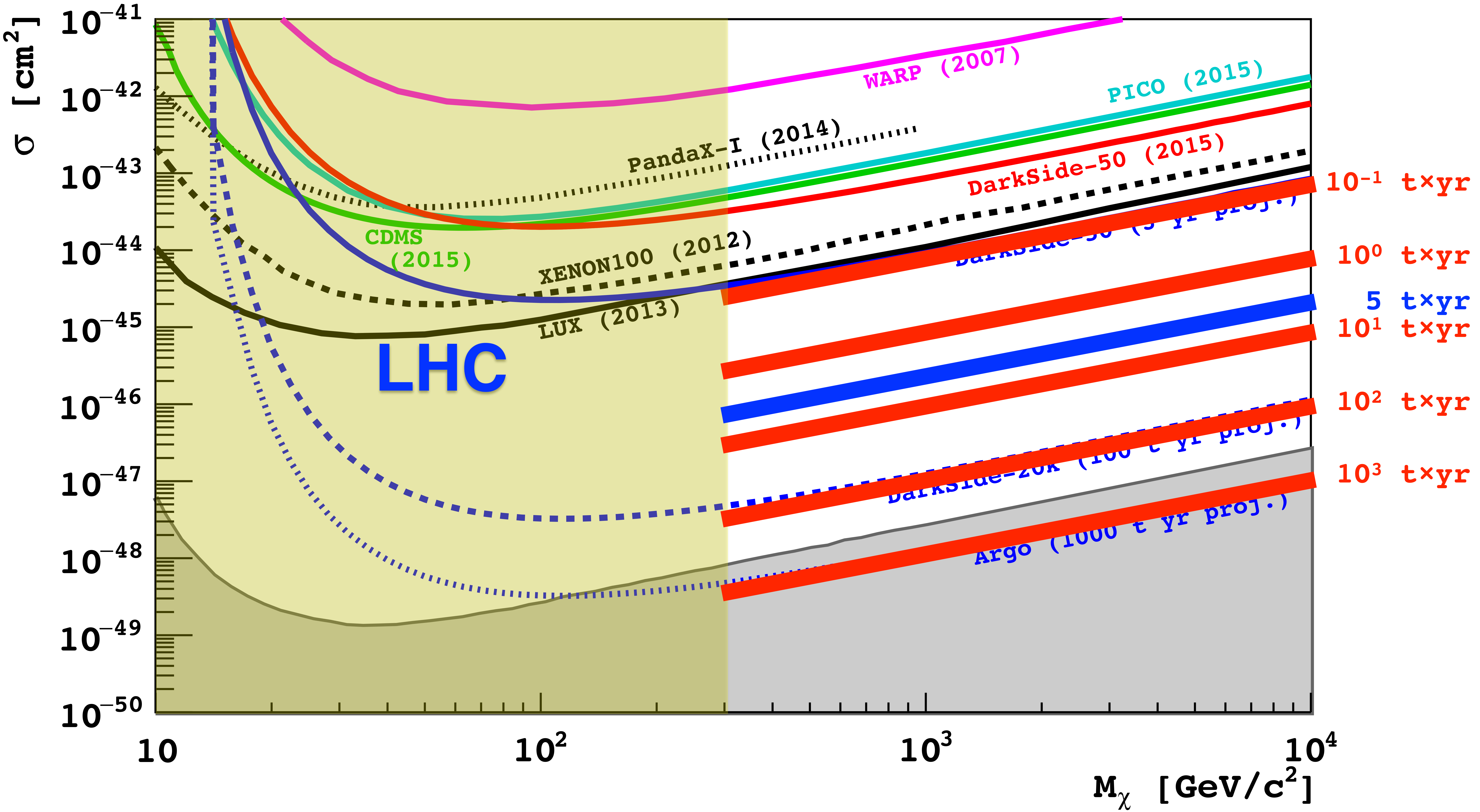


JCAP01 (2014) 044, JCAP10 (2015) 016



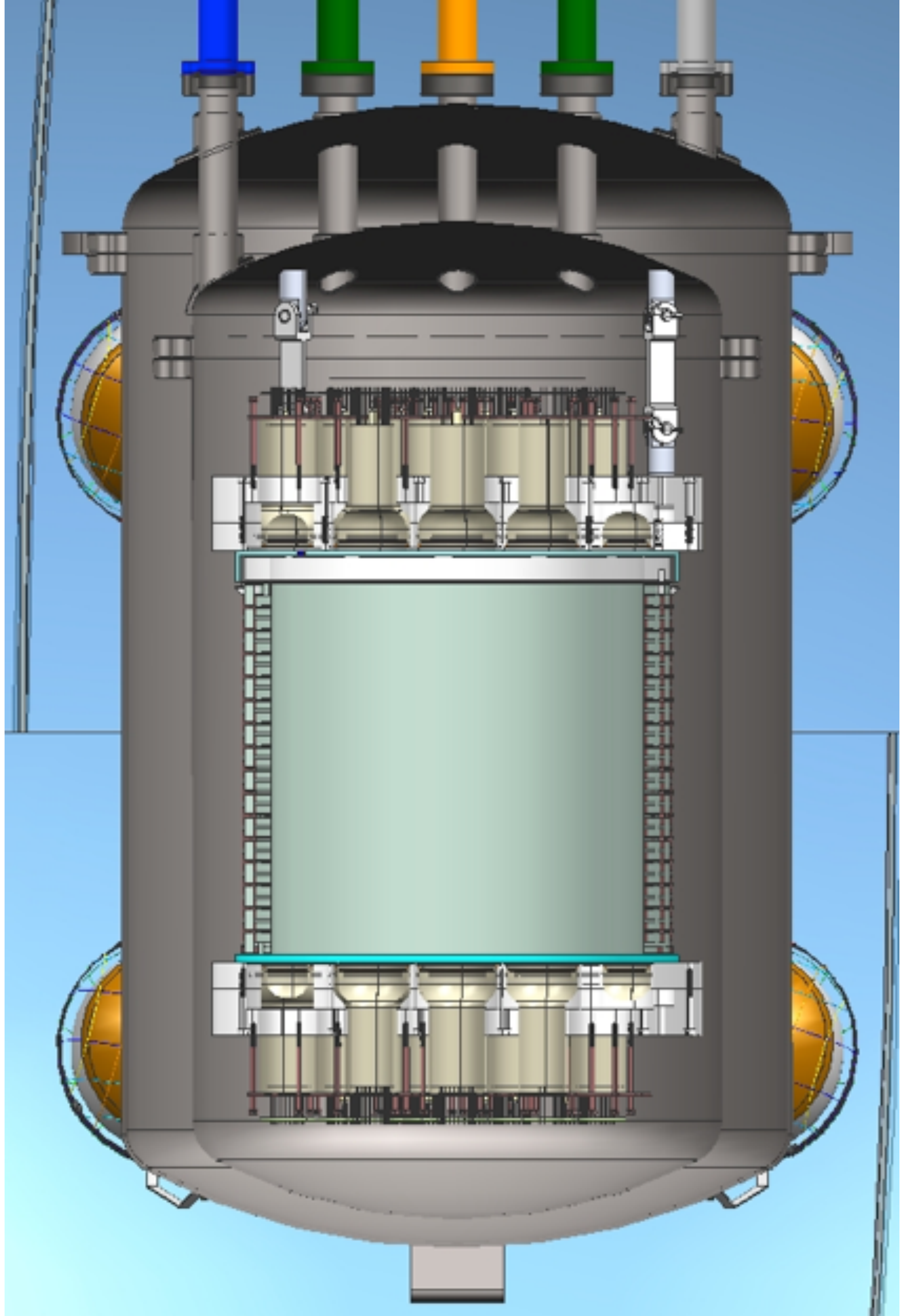
darwin-observatory.org

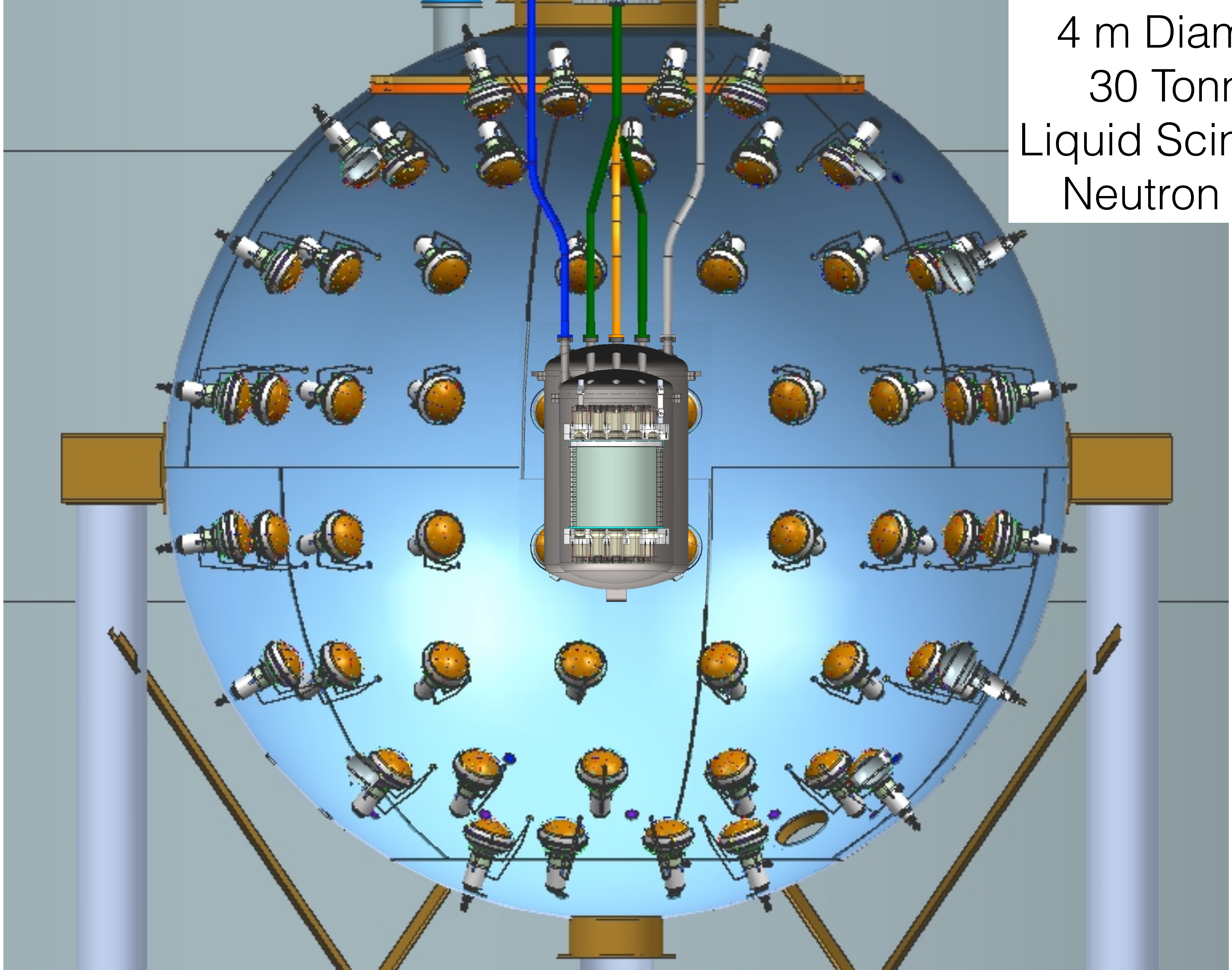




σ [cm^2]
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
10
10^2
10^3
10^4
M_χ [GeV/c^2]
WARP (2007)
PICO (2015)
PandaX-I (2014)
DarkSide-50 (2015)
CDMS (2015)
XENON100 (2012)
LUX (2013)
LHC
DarkSide-50 (3 yr proj.)
DarkSide-20k (100 t yr proj.)
Argo (1000 t yr proj.)
10^{-1} t×yr
10^0 t×yr
5 t×yr
10^1 t×yr
10^2 t×yr
10^3 t×yr

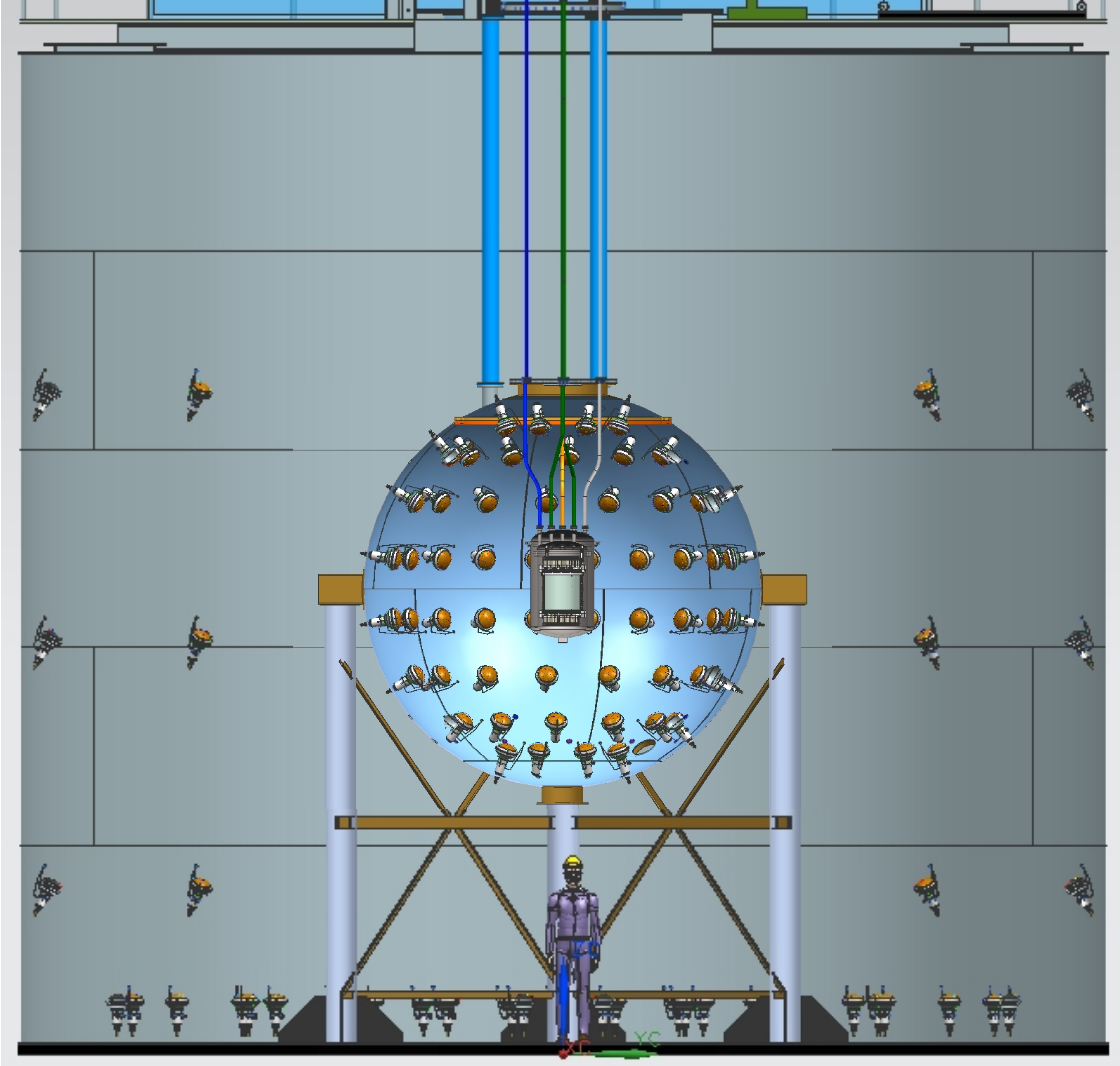
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

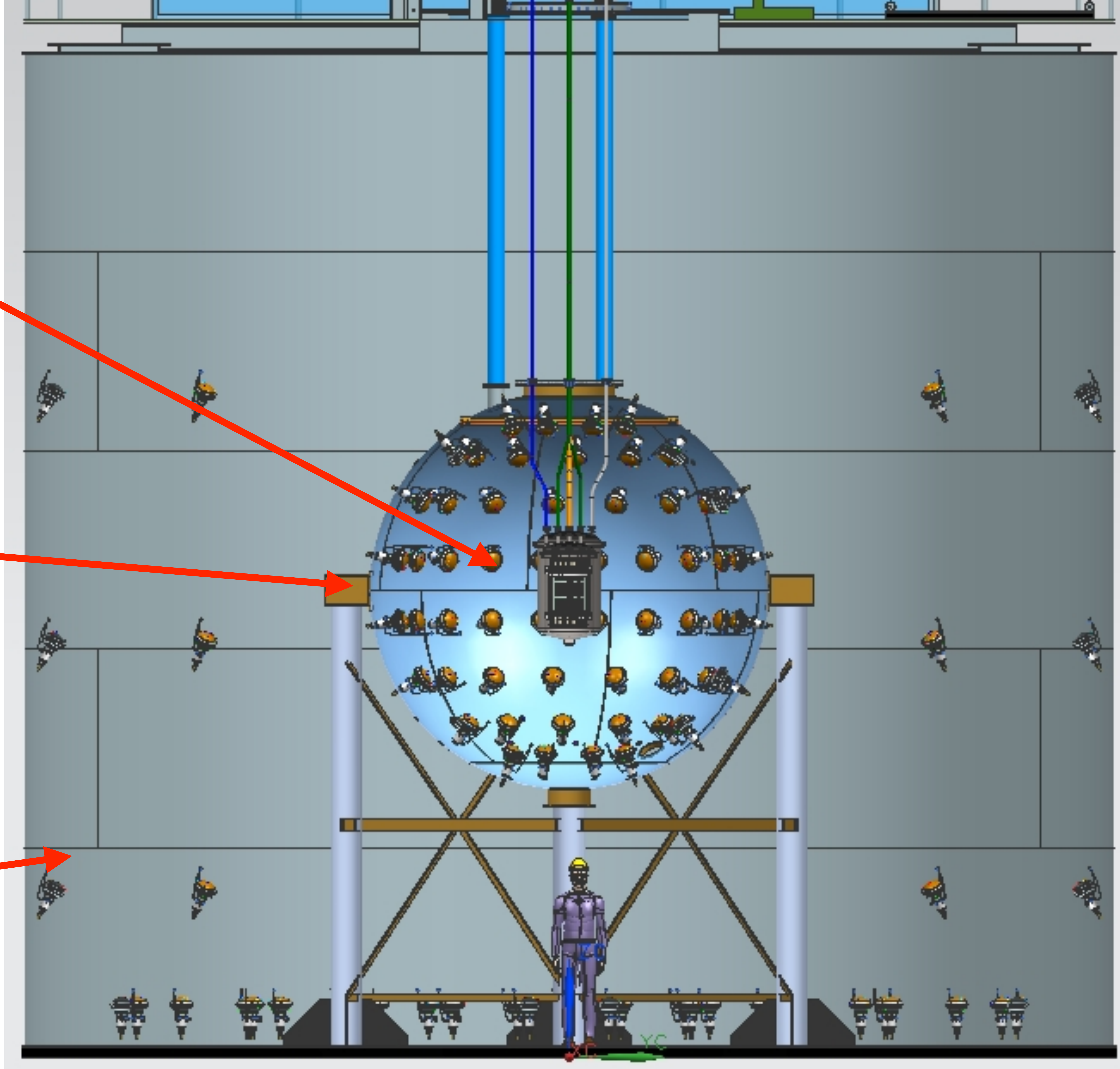




4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto

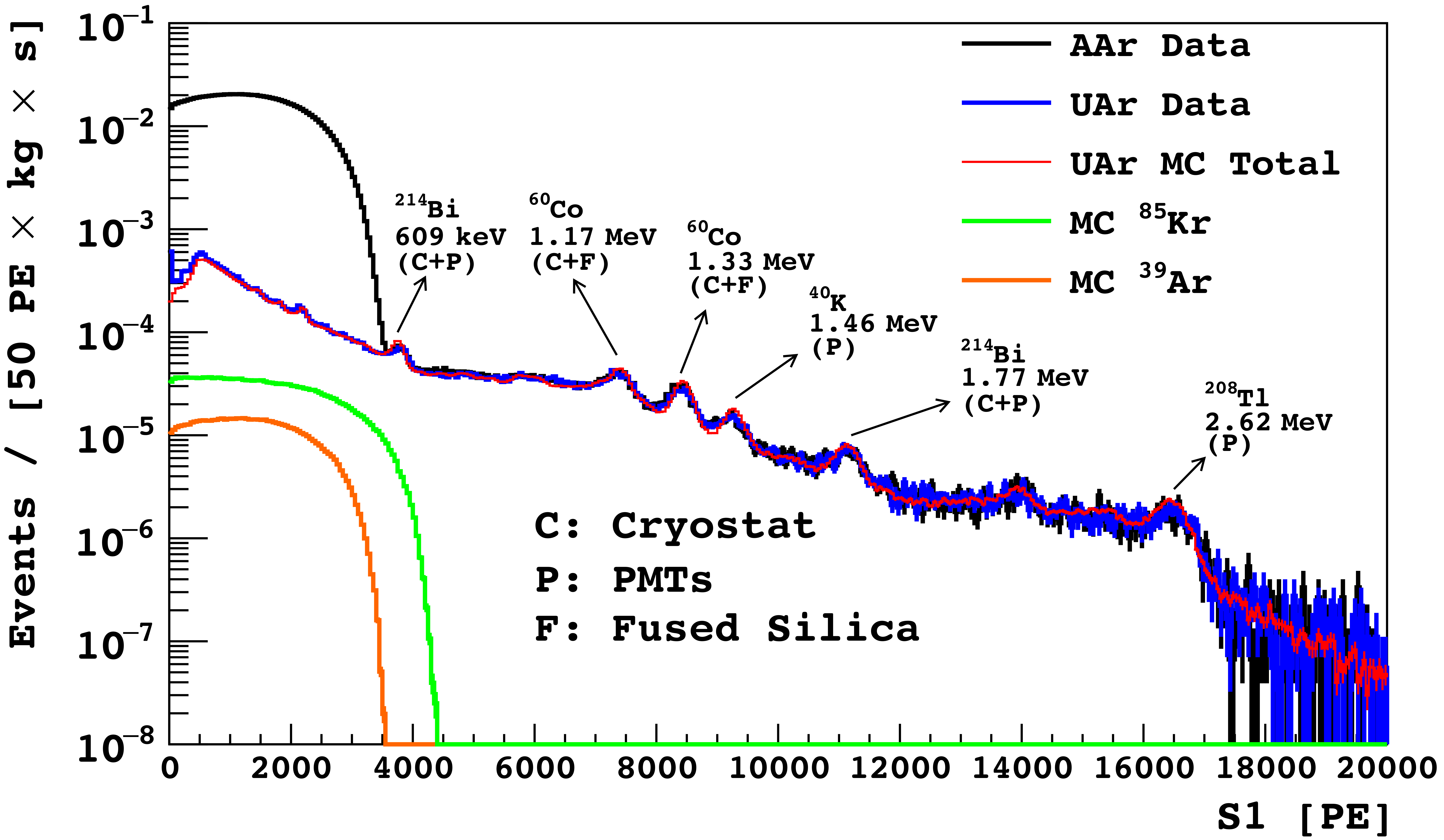


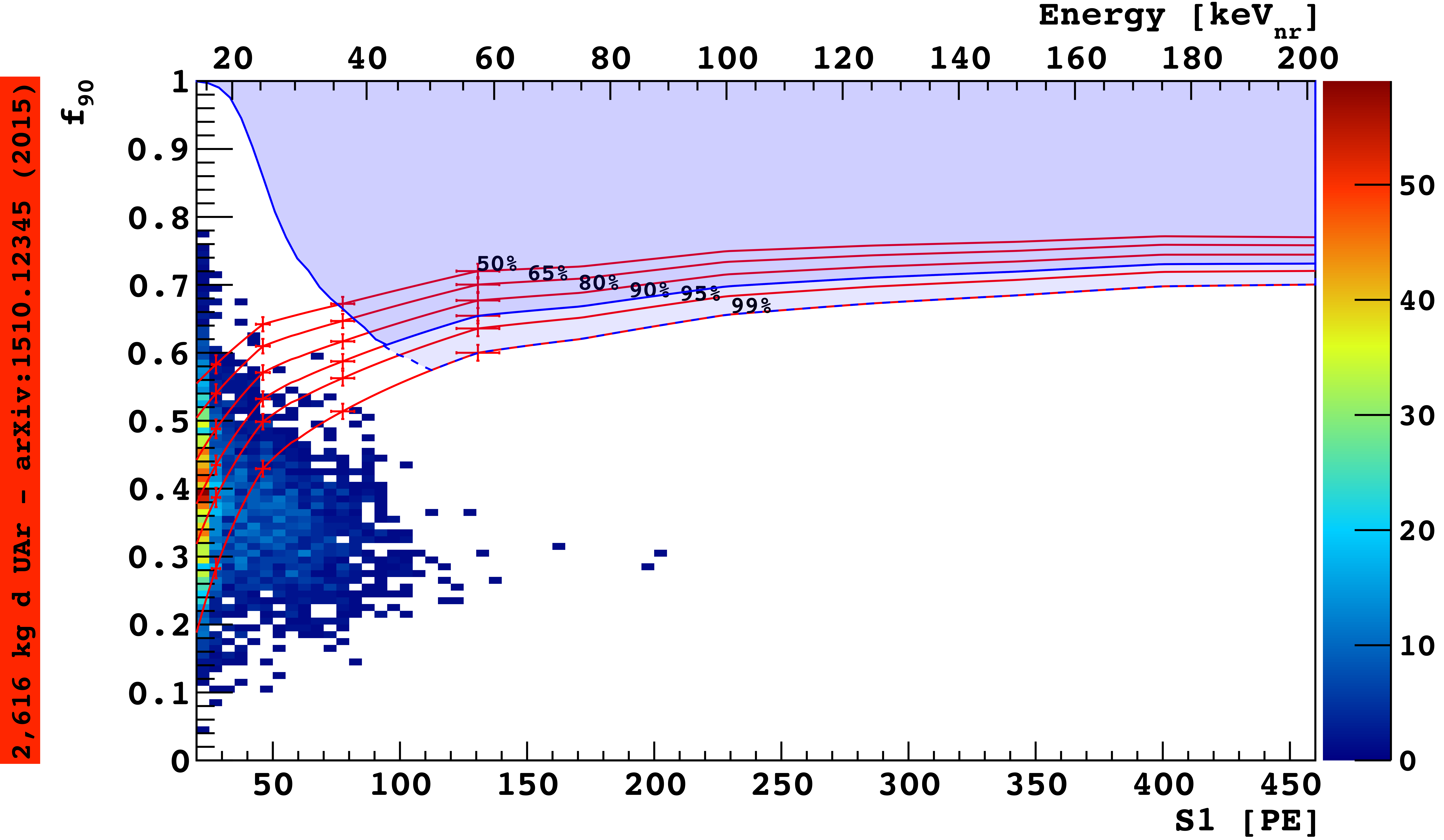


Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

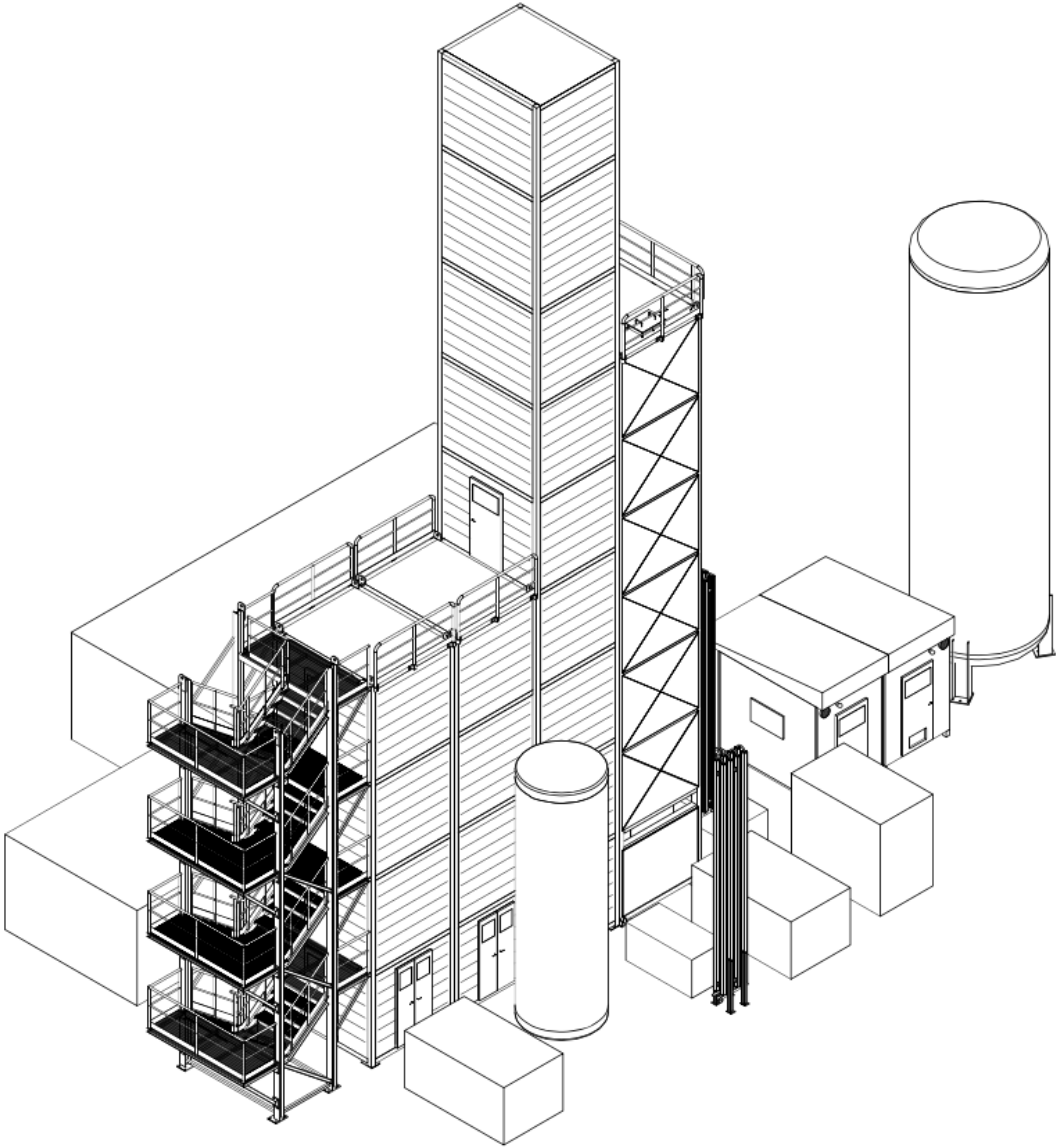
10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto

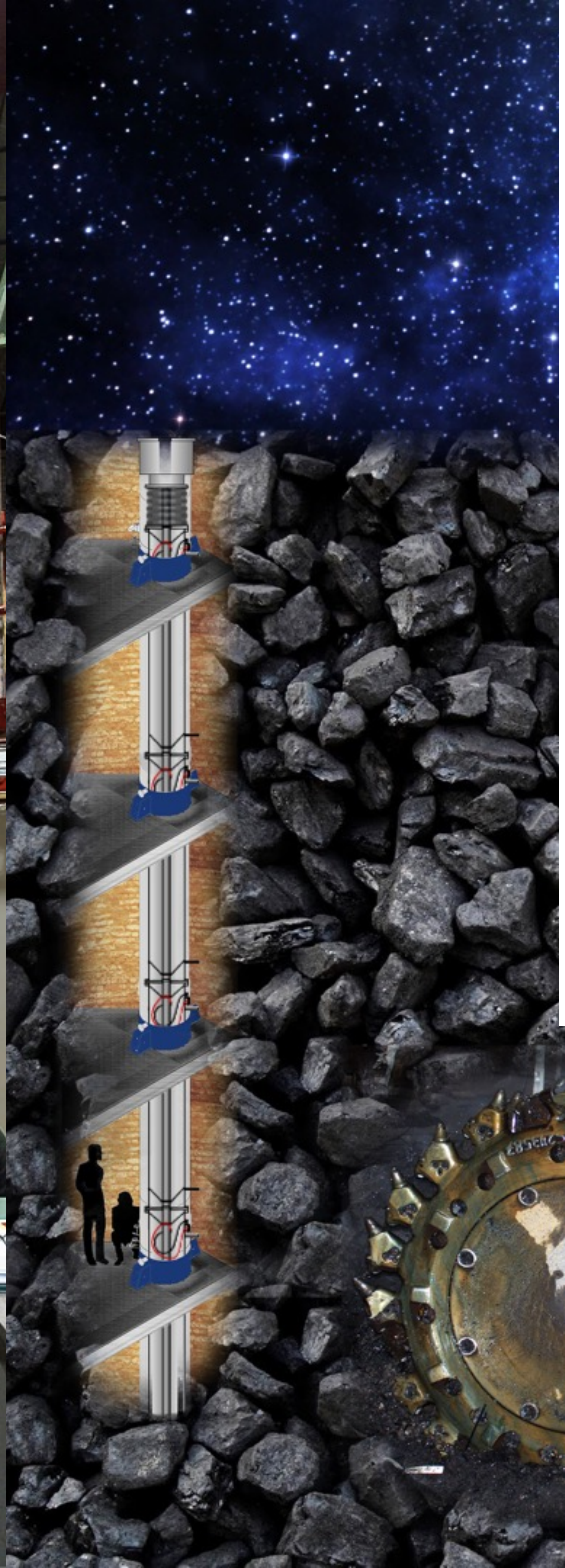

Events / [50 PE × kg × s]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
S1 [PE]
AAr Data
UAr Data
UAr MC Total
MC ^{85}Kr
MC ^{39}Ar
^{214}Bi 609 keV (C+P)
^{60}Co 1.17 MeV (C+F)
^{60}Co 1.33 MeV (C+F)
^{40}K 1.46 MeV (P)
^{214}Bi 1.77 MeV (C+P)
^{208}Tl 2.62 MeV (P)
C: Cryostat
P: PMTs
F: Fused Silica

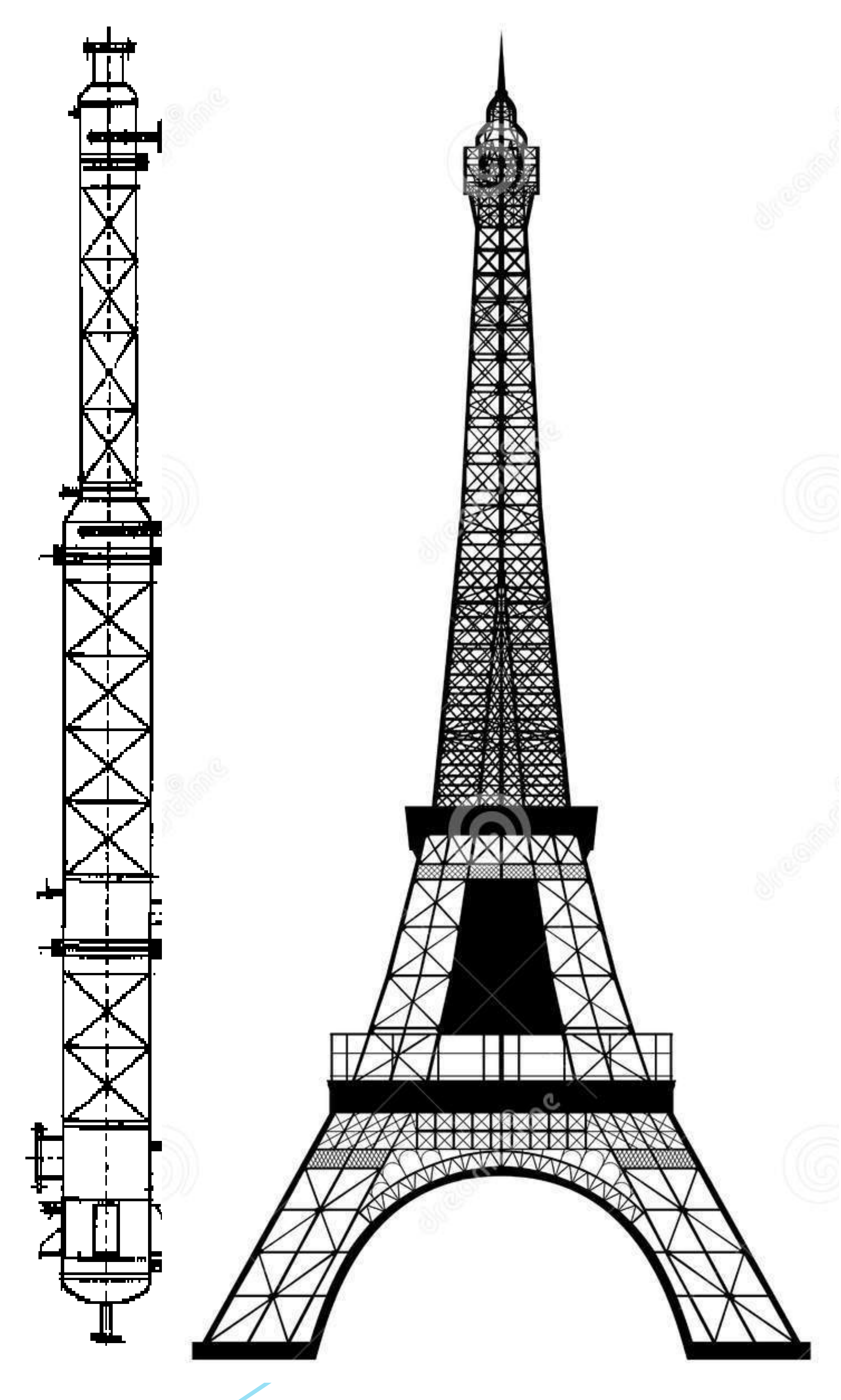

2,616 kg d UAr - arXiv:1510.12345 (2015)
Energy [keV$_{nr}$]
20
40
60
80
100
120
140
160
180
200
f_{90}
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
50
40
30
20
10
0

Italian Cowboys


HOT





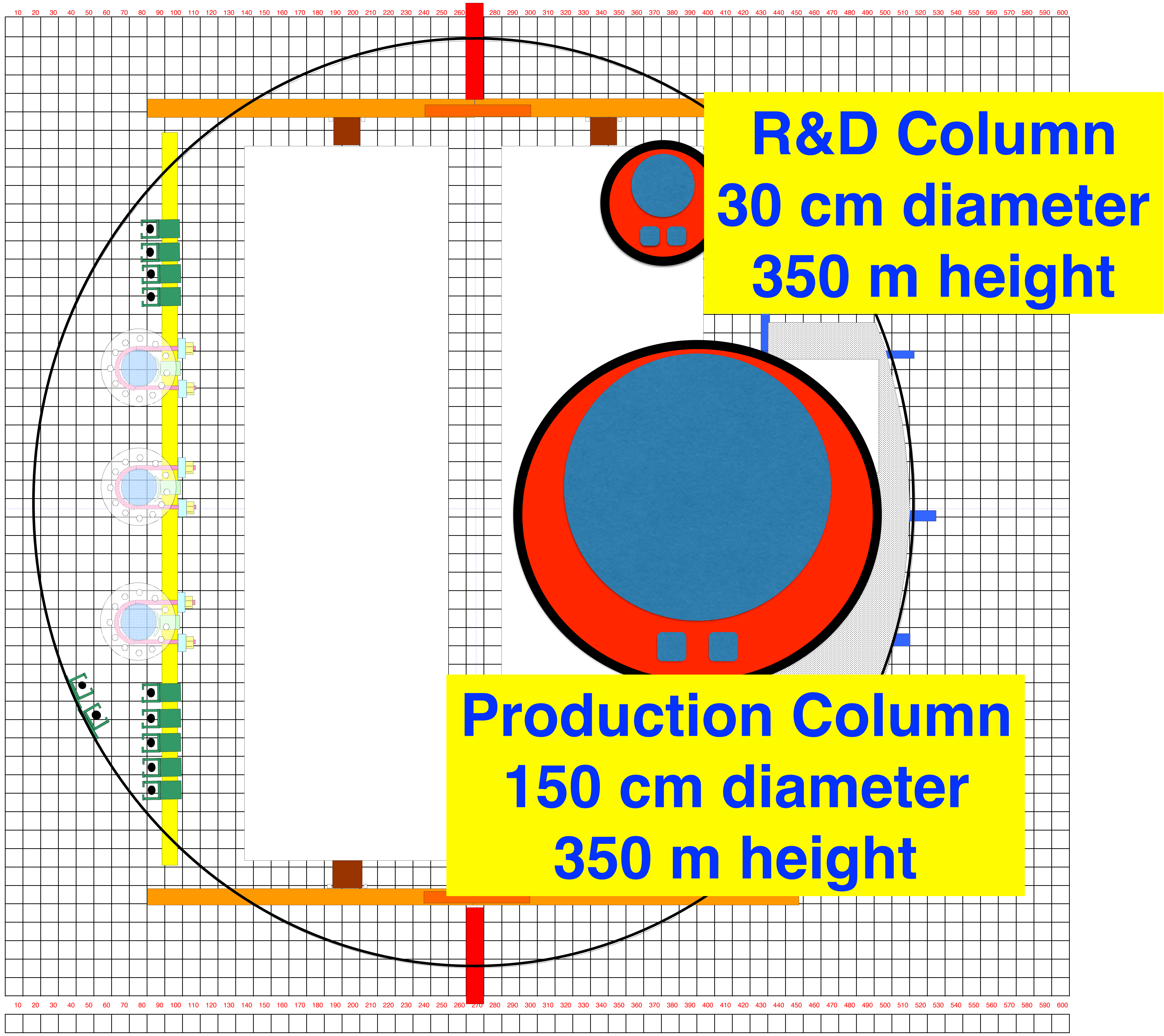


Seruci Wells

Seruci in Sardinia an excellent location

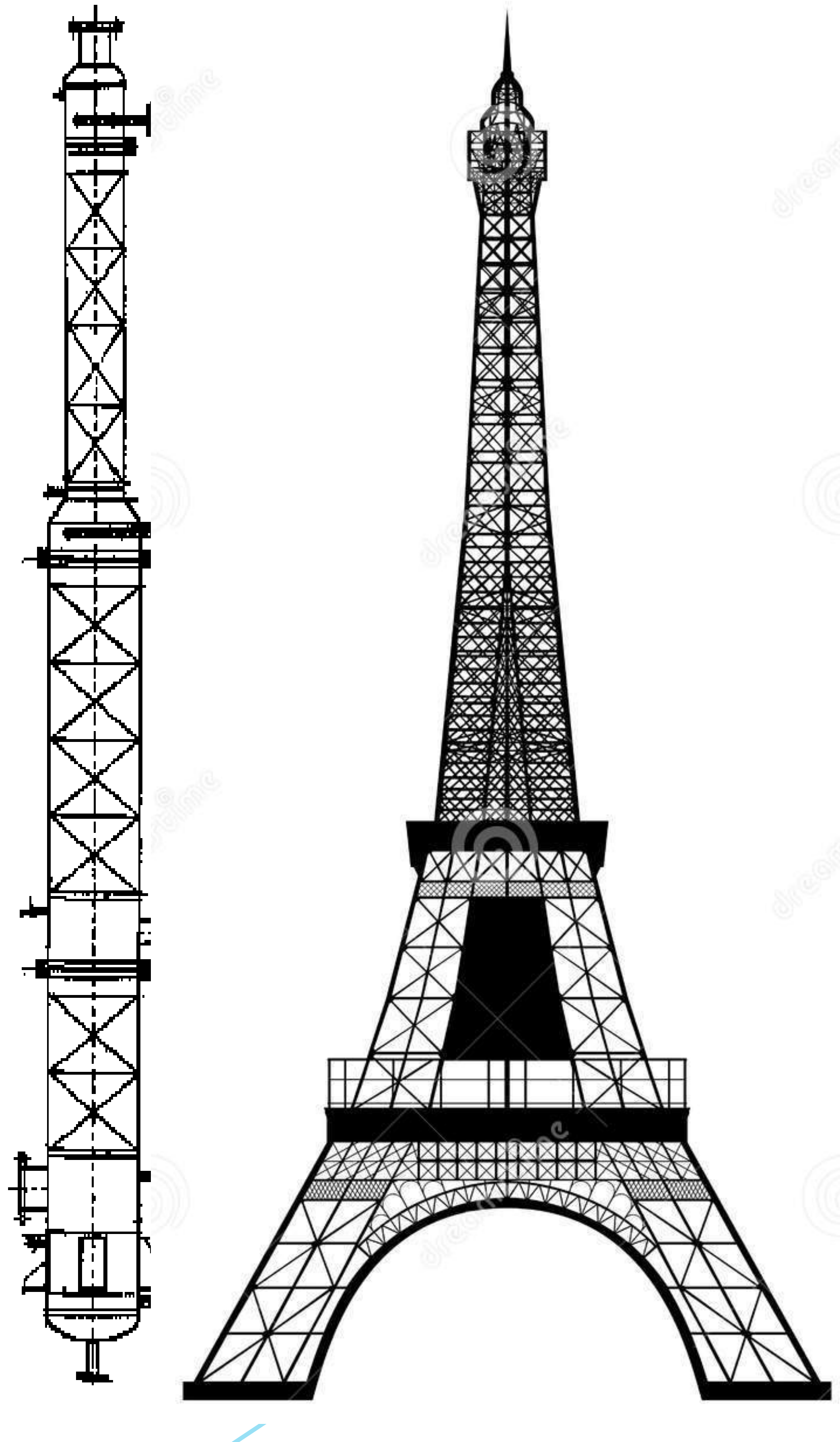

5
1
4
3
2
4

A Very Tall Column



R&D Column
30 cm diameter
350 m height

Production Column
150 cm diameter
350 m height



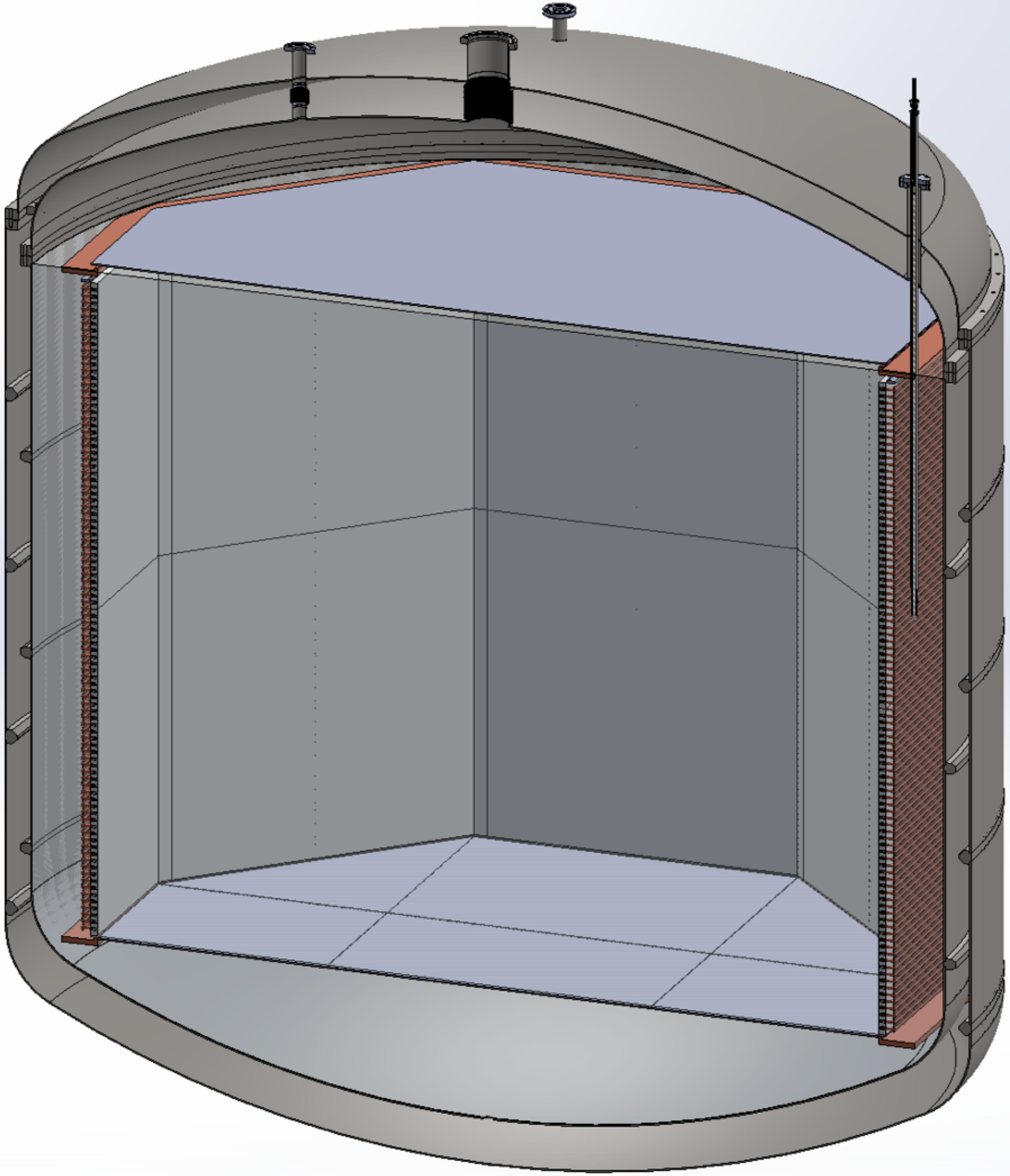
DarkSide-20k

20-tonnes fiducial dark matter detector
start of operations at LNGS within 2020
100 tonne×year background-free search for dark matter

20-	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
DS-20k	🟨	🟨	🟨	🟨	🟨	🟨🟩	🟩	🟩	🟩	🟩	🟩									
ARGO					🟨	🟨	🟨	🟨	🟨	🟨	🟨🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Argo

300-tonnes depleted argon detector
start of operations at LNGS within 2025
1,000 tonne×year background-free search for dark matter
precision measurement of solar neutrinos



The End