在惰性元素中探索中微子和暗物质

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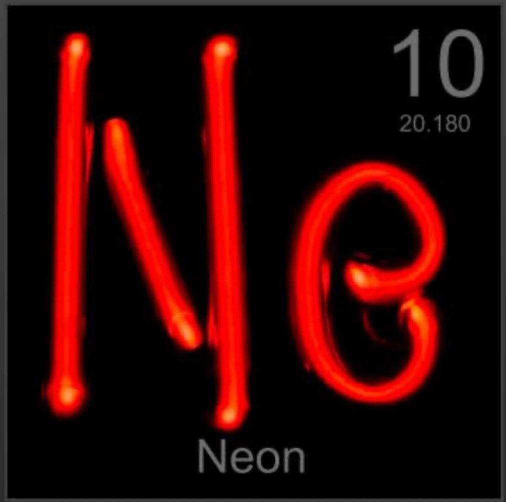
中微子暑期学校，广东江门， 07/09/2024


2
4.003
Helium

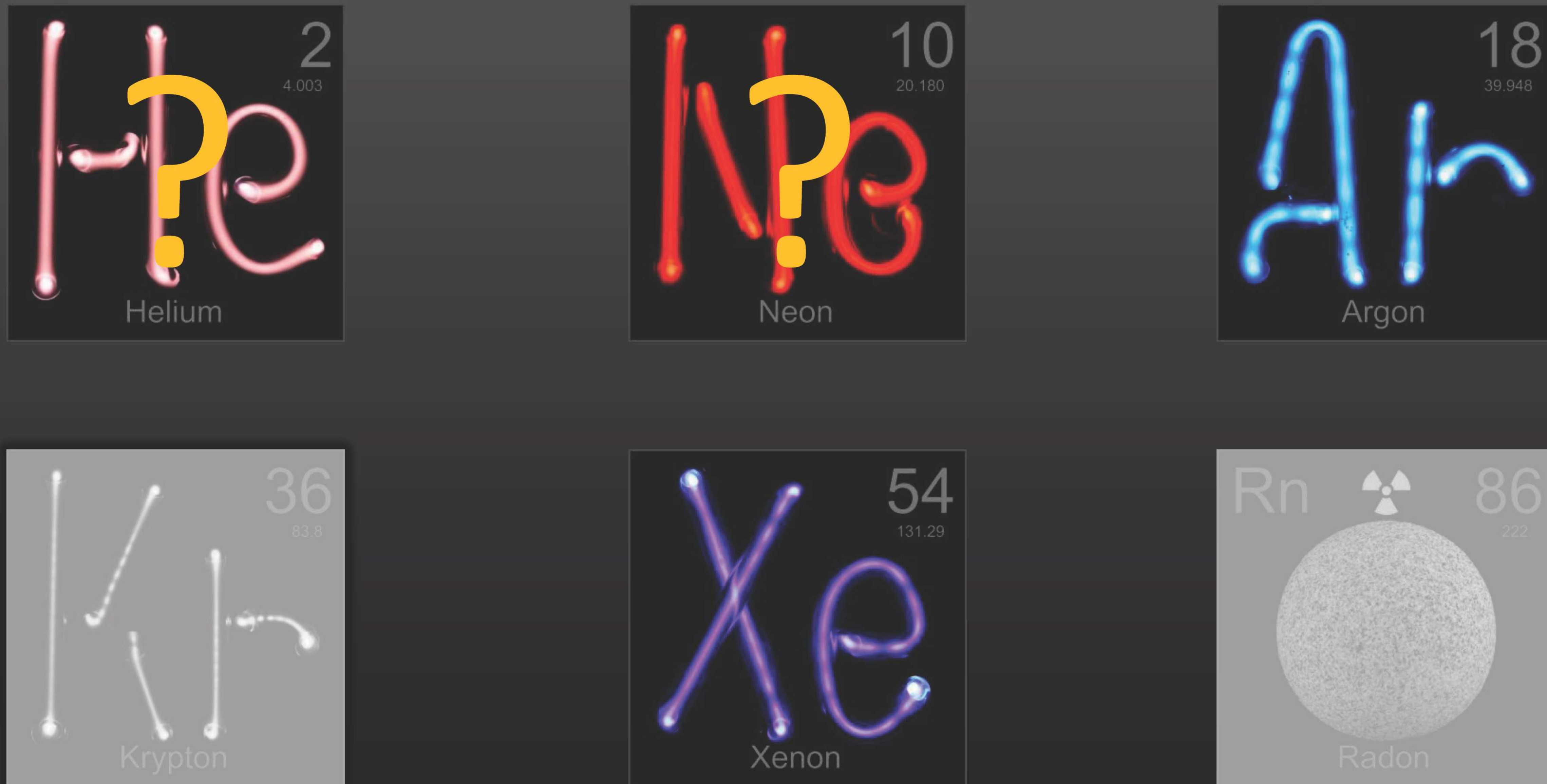

10
20.180
Neon


18
39.948
Argon


36
83.8
Krypton


54
131.29
Xenon


Rn
86
222.
Radon


2
4.003
Helium
10
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Neon
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39.948
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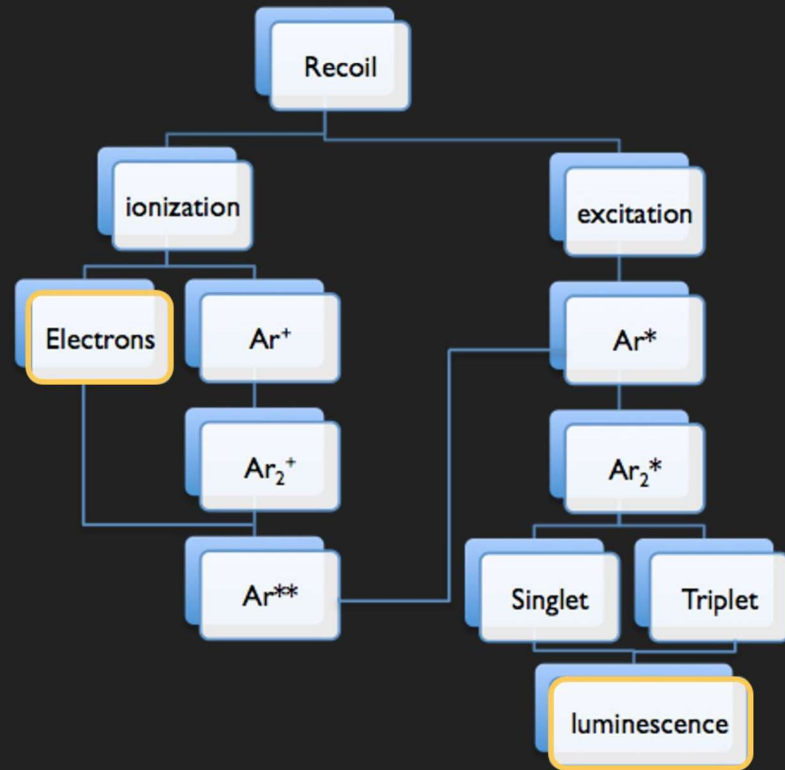
83.8
Krypton
54
131.29
Xenon
Rn
86
222
Radon

- high density and large stopping power
  - Massive and self-shielding detectors
- both scintillation/ionization with high yields
  - Calorimetry, excellent energy resolution
  - Particle identification
  - Precise timing
- do not attach electrons, can be purified in-situ
  - Tracking, 3D reconstruction, low-background
- inert, non flammable, very good dielectrics
- can be obtained commercially



Large homogenous detectors for rare events

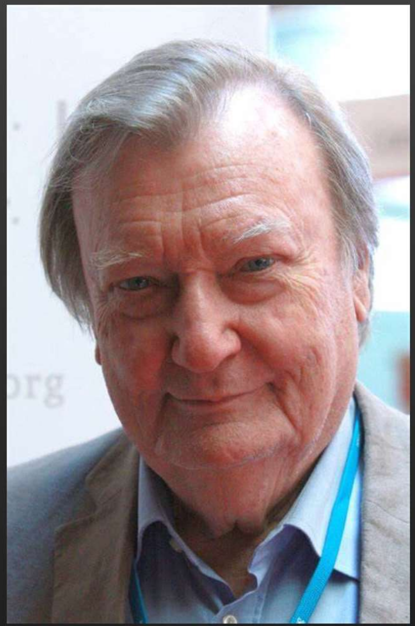
Properties	Argon	Xenon
Boiling Point T_b at 1 atm [K]	87.3	165.0
Liquid density at T_b [g/cm^3]	1.40	2.94
Dielectric constant of liquid	1.51	1.95
Scintillation wavelength	128 nm	178 nm
Time constant	6 ns, 1.5 μs	3 ns, 27ns
Scintillation yield [γ/MeV]	40000	46000
Ionization yield [e/MeV]	42000	64000
Volume fraction in Earth's atmosphere [ppm]	9340	0.09

What can we do with noble liquid?

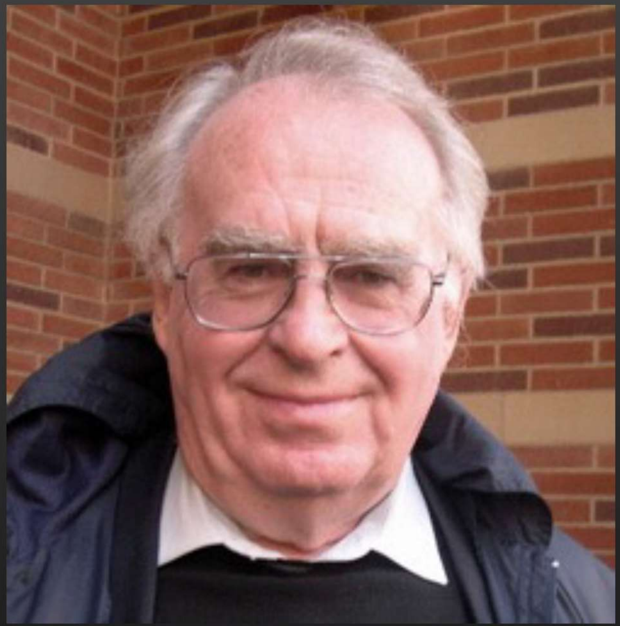
- Neutrino physics:
  - ICARUS (Ar), MicroBoone (Ar), SBND (Ar), DUNE (Ar)…
- Dark matter searches:
  - DarkSide (Ar), XENON (Xe), PandaX (Xe), LZ (Xe)…
- Rare decays (0vbb):
  - nEXO (Xe)…

Neutrinos with Argon

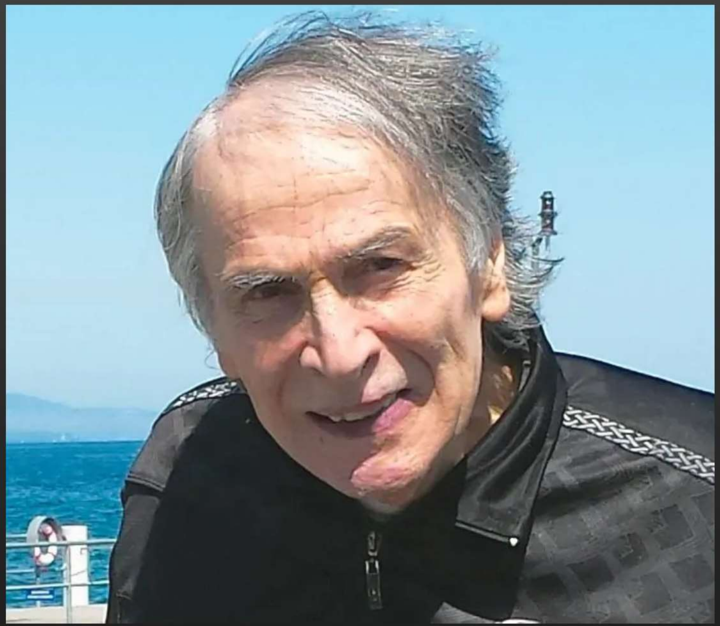
Argon for neutrino physics



Carlo Rubbia
(1934~)



David B. Cline
(1933~2015)



Pio Picchi
(1942~2019)

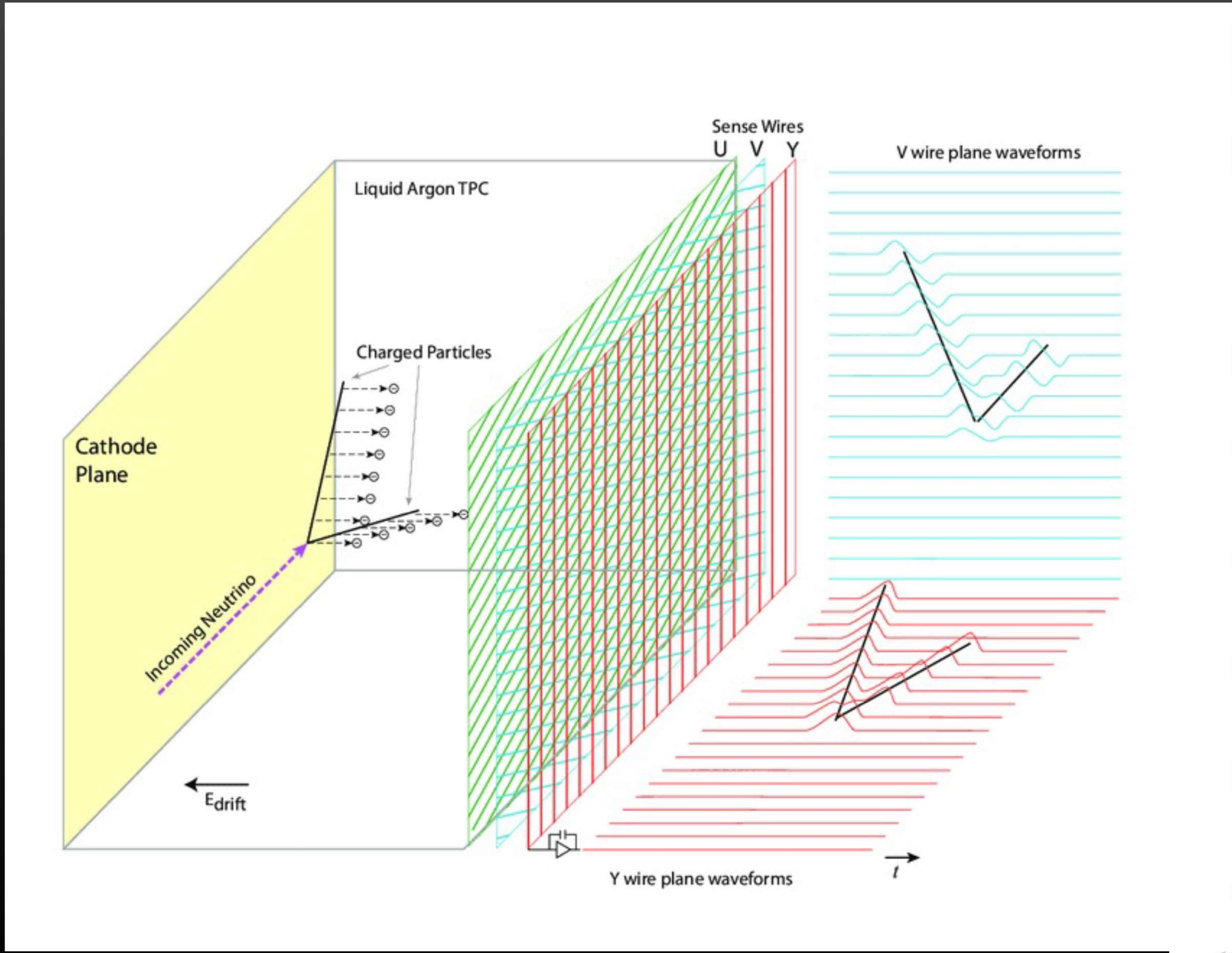
Liquid Argon Time Projection Chamber (LArTPC) technology was proposed.
ICARUS (Imaging Cosmic And Rare Underground Signals) was proposed in 1977.

LArTPC: how does it work?

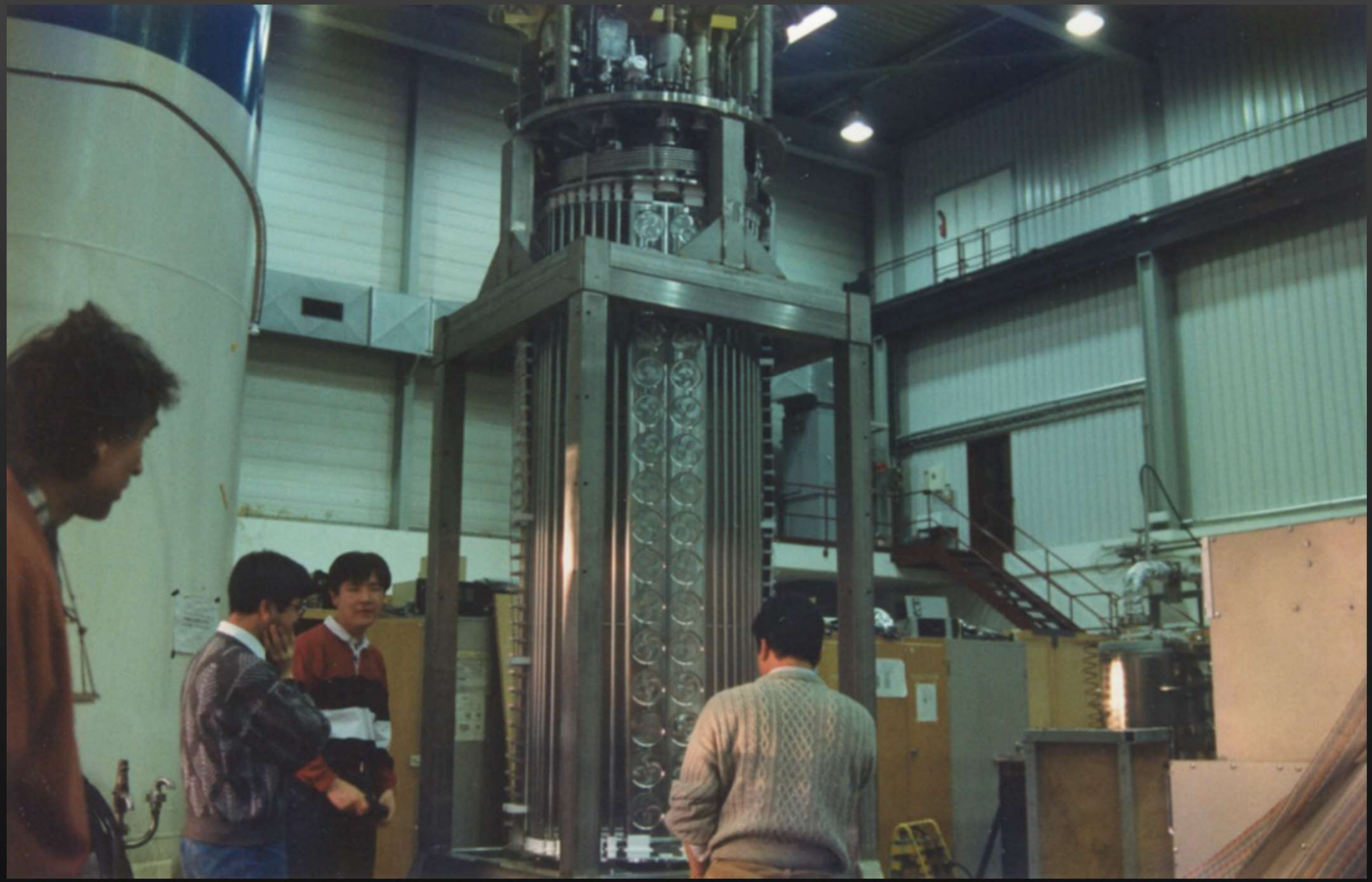
- Cathode – High Voltage
- Anode – multi parallel wires
- 3D imaging for tracks
- Good calorimetry

- R&D over 3 decades

->from a few ton to kton



ICARUS-3T



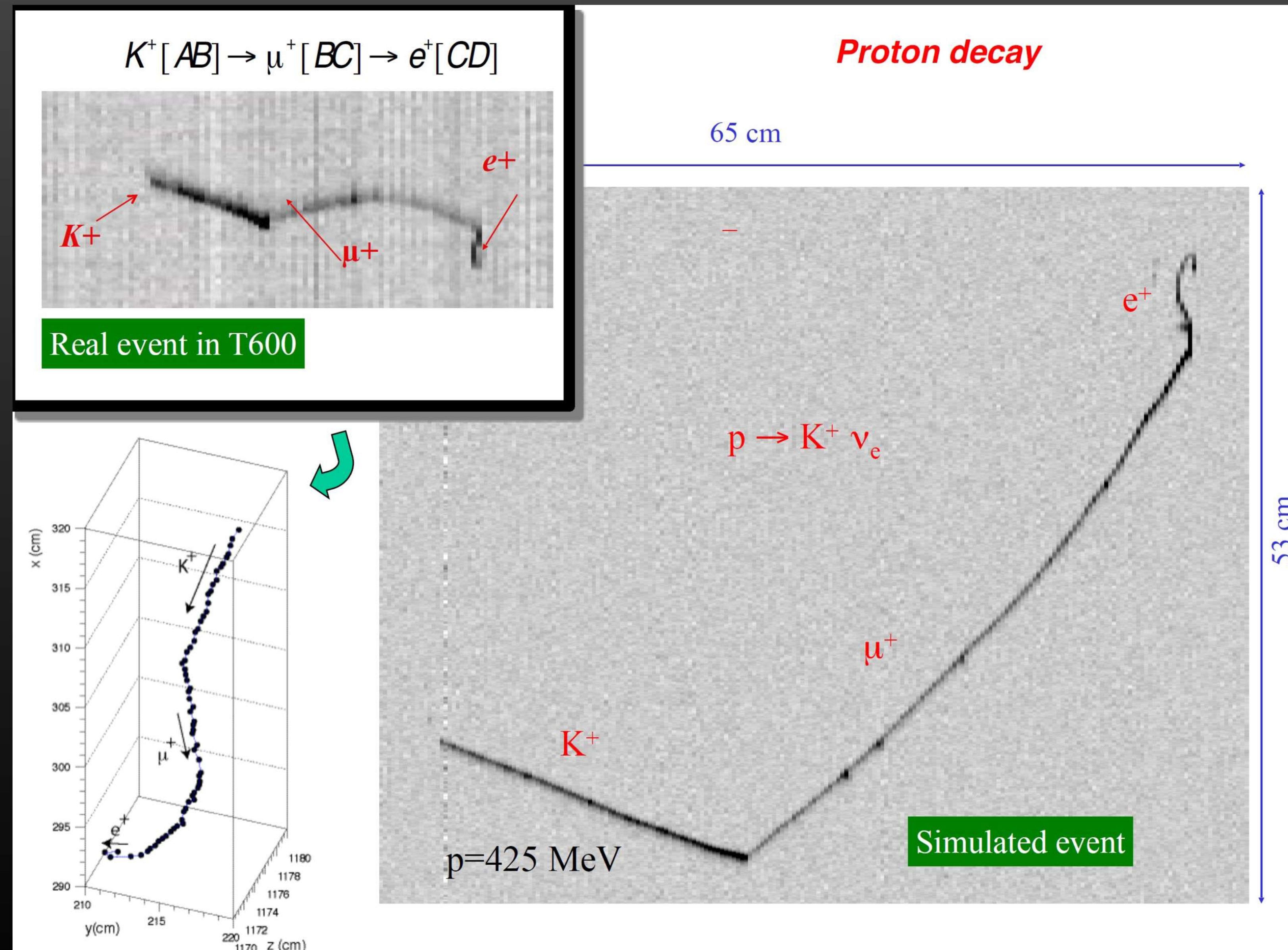
1980s~1990s at CERN

2018 at CERN

ICARUS-T600

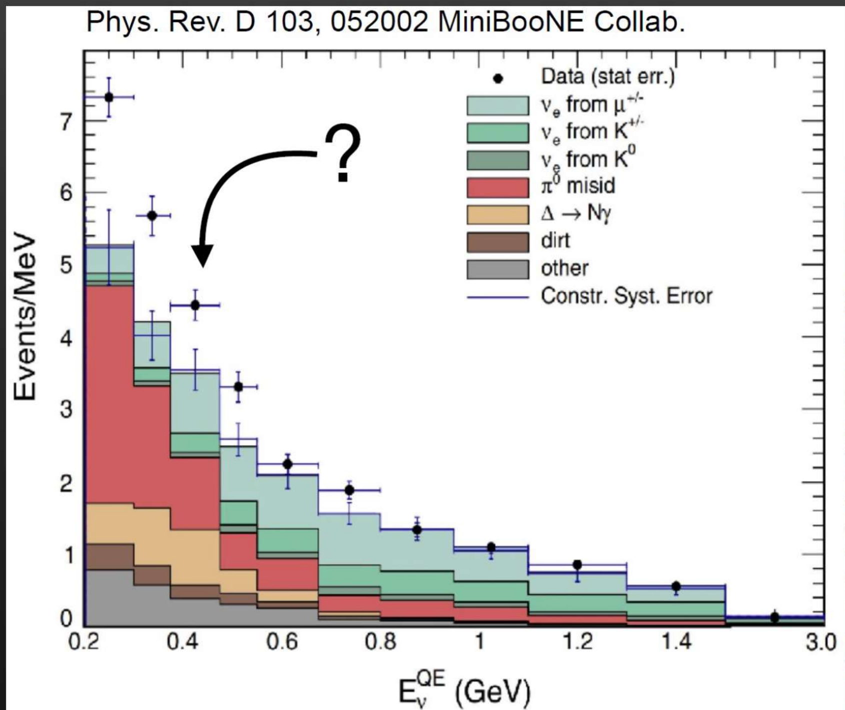
@LNGS in Italy

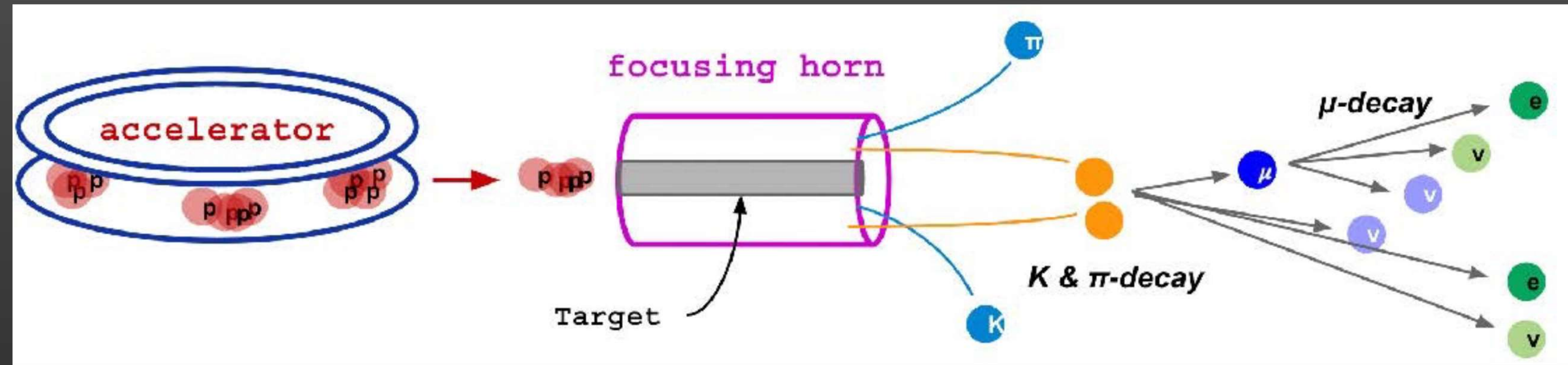
Taking data with CNGS from 2010~2013

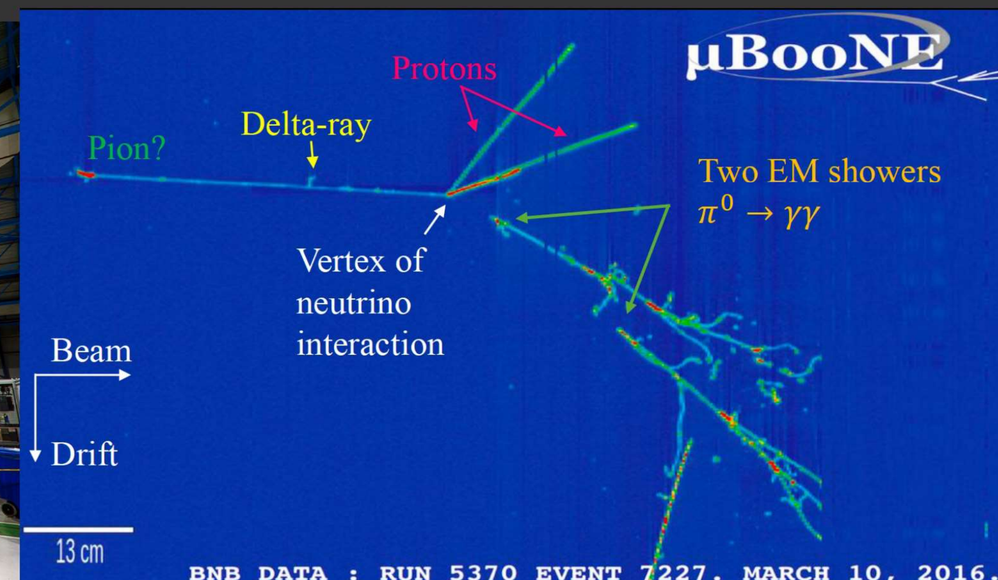


MicroBooNE

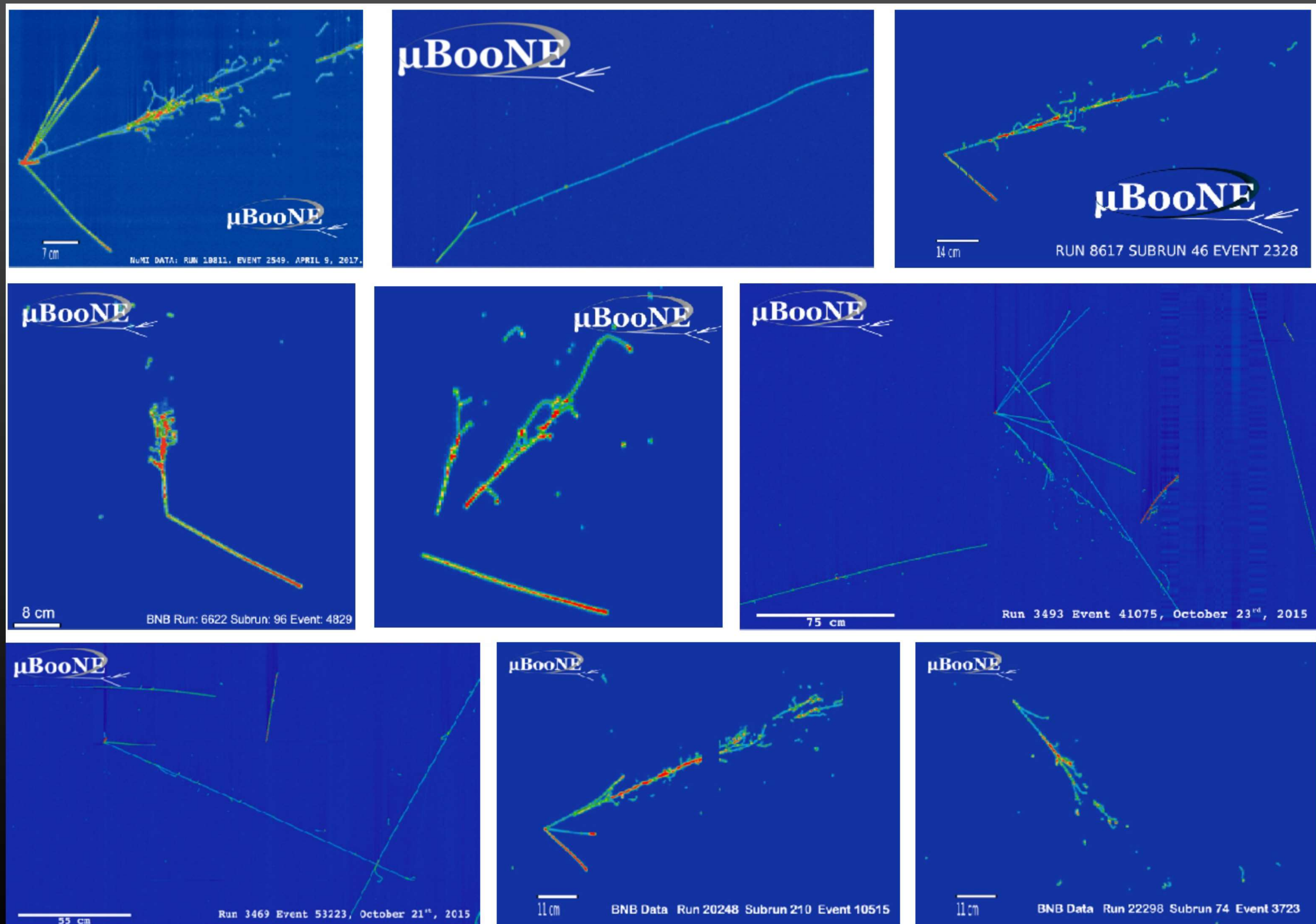
@FNAL 2015~2021

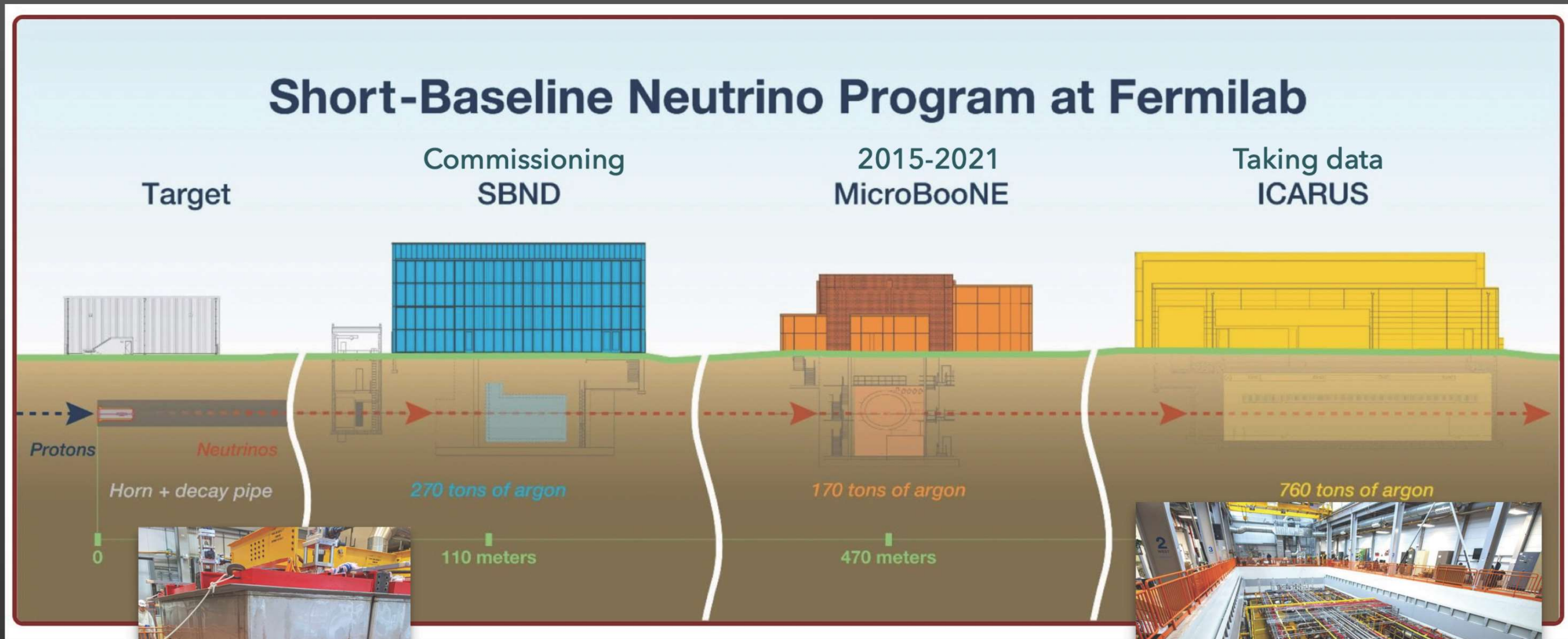




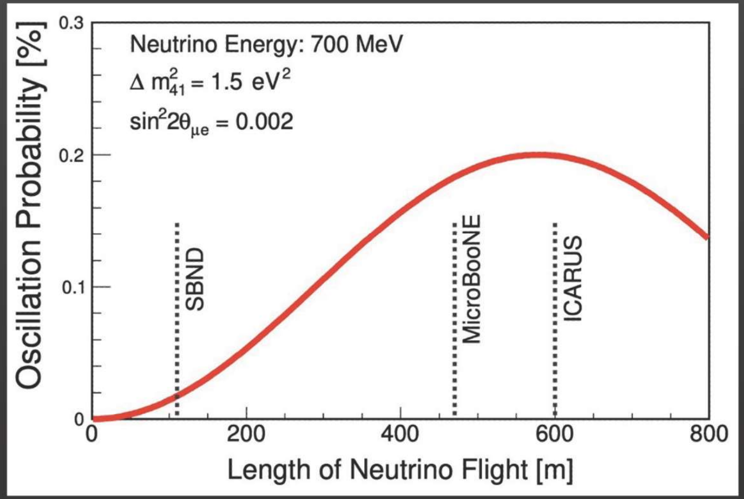


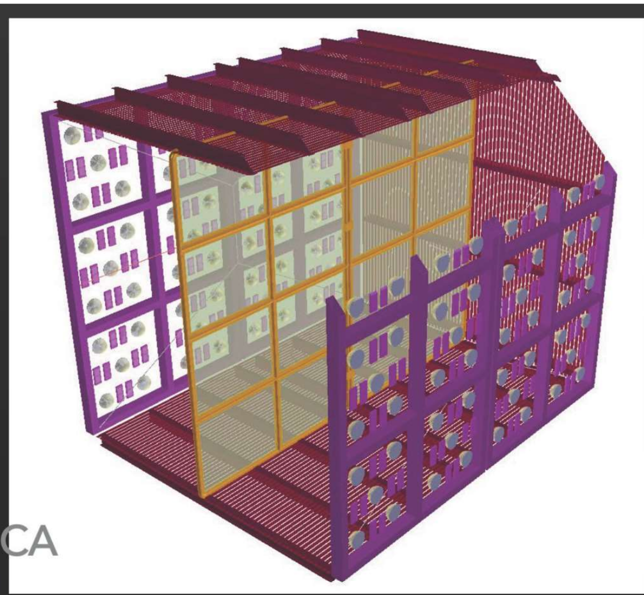
To understand the source of the MiniBooNE excess;
Cherenkov detector is not capable to distinguish an electron from a photon converting near the vertex.


µBooNE
7 cm
NuMI DATA: RUN 10811. EVENT 2549. APRIL 9, 2017.
14 cm
RUN 8617 SUBRUN 46 EVENT 2328
8 cm
BNB Run: 6622 Subrun: 96 Event: 4829
75 cm
Run 3493 Event 41075, October 23rd, 2015
55 cm
Run 3469 Event 53223, October 21st, 2015
11 cm
BNB Data Run 20248 Subrun 210 Event 10515
BNB Data Run 22298 Subrun 74 Event 3723



- Booster Neutrino Beam $\nu_\mu(93.6\%), \nu_\mu(5.9\%), \nu_e + \bar{\nu}_e(0.5\%)$
- Sterile neutrino searches, BSM searches, cross-section measurements





SBND

270 ton - 5 x 4 x 4 m

2 TPC 2 m drift

Wire readout

PDS: 120 PMTs, 192 X-ARAPUCA

ICARUS

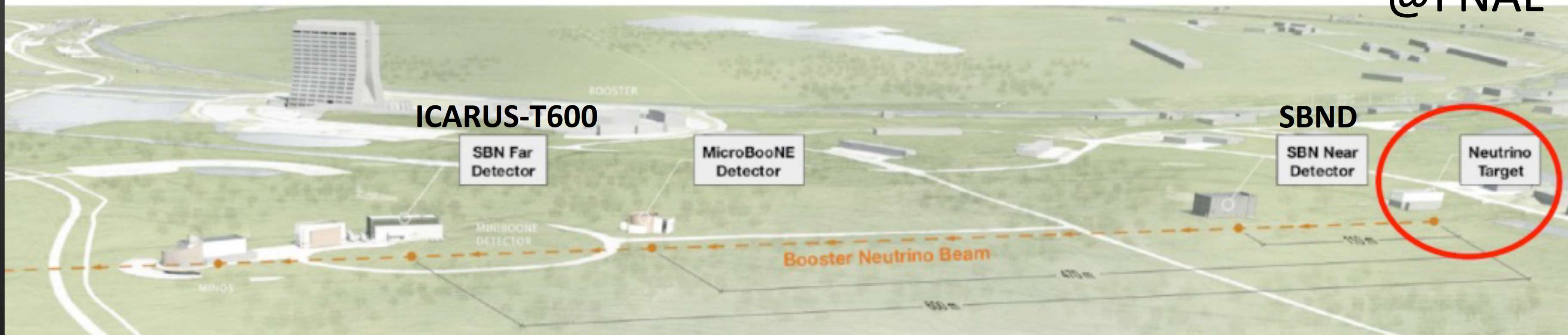
760 ton - 2 x (19.6 x 3.6 x 3.9 m)

4 TPC 1.5 m drift

Wire readout

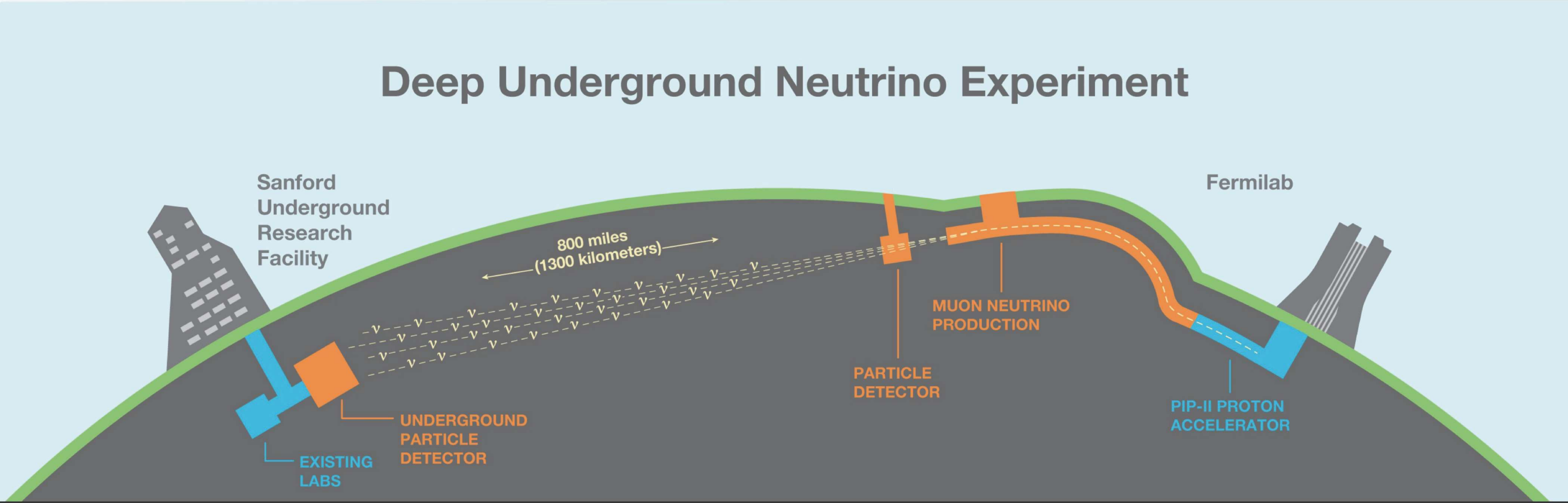
PDS: 360 PMTs

The SBN program: Booster beam



- **Search for neutrino oscillations at O(Δm2) ~ 0.1-10 eV^2**
- **Measure ν-Ar interactions**
- **Search for physics beyond the Standard Model**

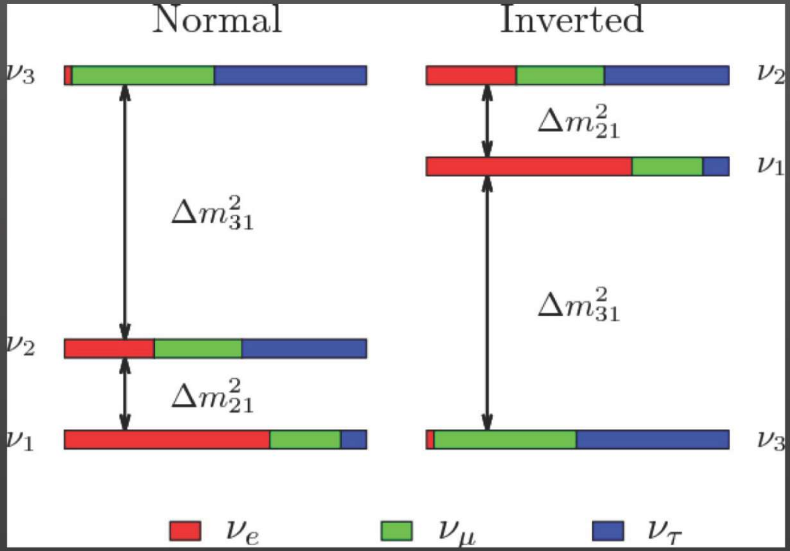
-> DUNE



- New broad-band (mostly in 0.5-5 GeV) neutrino beam at **Fermilab** (1.2 MW, upgradeable to 2.4 MW), 1300 km baseline
- Phase I: 2×17 kton LArTPC Far Detector (FD) modules at **Sanford Underground Research Facility**, South Dakota, 1.5 km underground; 2 additional modules in Phase II
- Multiple technologies for the Near Detector (ND) at **Fermilab**, LAr target to control systematic uncertainties

PRECISION 3ν OSCILLATIONS: KNOWNS & UNKNOWNS

- The 3 known flavor states ν_e, ν_μ, ν_τ are linear combinations of 3 states ν_1, ν_2, ν_3 with definite masses m_i through a unitary matrix $U_{\alpha i}$, also called the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix
- We know the two mass squared differences and three mixing angles from neutrino oscillations
- We don't know the sign of Δm^2_{31} (hierarchy) and the size of the Dirac phase δ_{CP}
- We also don't know the absolute neutrino mass or if neutrino is its own anti-particle
- Finally we don't know if our 3-flavor picture of oscillations is complete



PMNS Matrix

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$P_{\nu_\mu\to\nu_e,(\bar\nu_\mu\to\bar\nu_e)} \approx 4\sin^2\theta_{13}\sin^2\theta_{23}\frac{\sin^2\Delta}{(1-A)^2} + \alpha^2\sin^2 2\theta_{12}\cos^2\theta_{23}\frac{\sin^2 A\Delta}{A^2} + 8\,\alpha\, J_{CP}^{max}\cos(\Delta \pm \delta_{CP})\frac{\sin\Delta A}{A}\frac{\sin\Delta(1-A)}{1-A}$$

$$J_{CP}^{max} = \cos\theta_{12}\sin\theta_{12}\cos\theta_{23}\sin\theta_{23}\cos^2\theta_{13}\sin\theta_{13}$$

$$\Delta \equiv \frac{\Delta m^2_{31}L}{4E_\nu} \qquad A \equiv \frac{2E_\nu V}{\Delta m^2_{31}} \qquad \alpha \equiv \Delta m^2_{21}/\Delta m^2_{31} \qquad V_C = \sqrt{2}G_F n_e\,.$$

3ν knowns: Δm^2_{21}, $|\Delta m^2_{31}|$, $\theta_{23}, \theta_{13}, \theta_{12}$

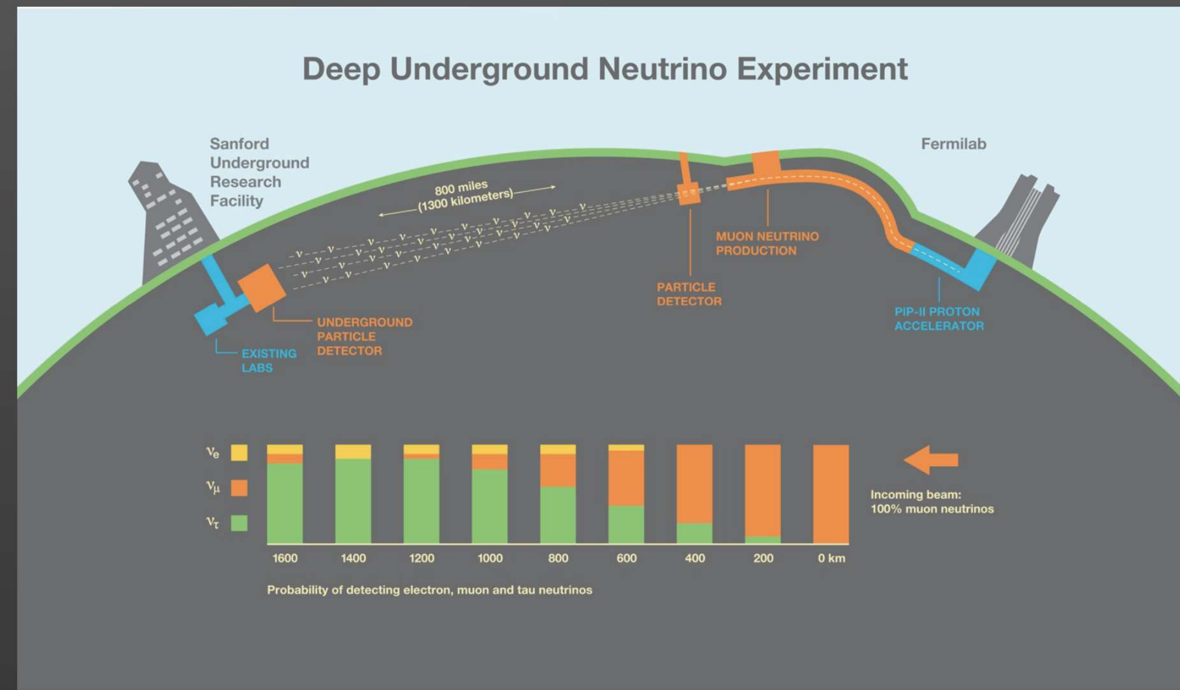
3ν unknowns: δ, sign(Δm^2_{31}), sign($\theta_{23} - \pi/4$), min(m_i), Dirac/Majorana nature

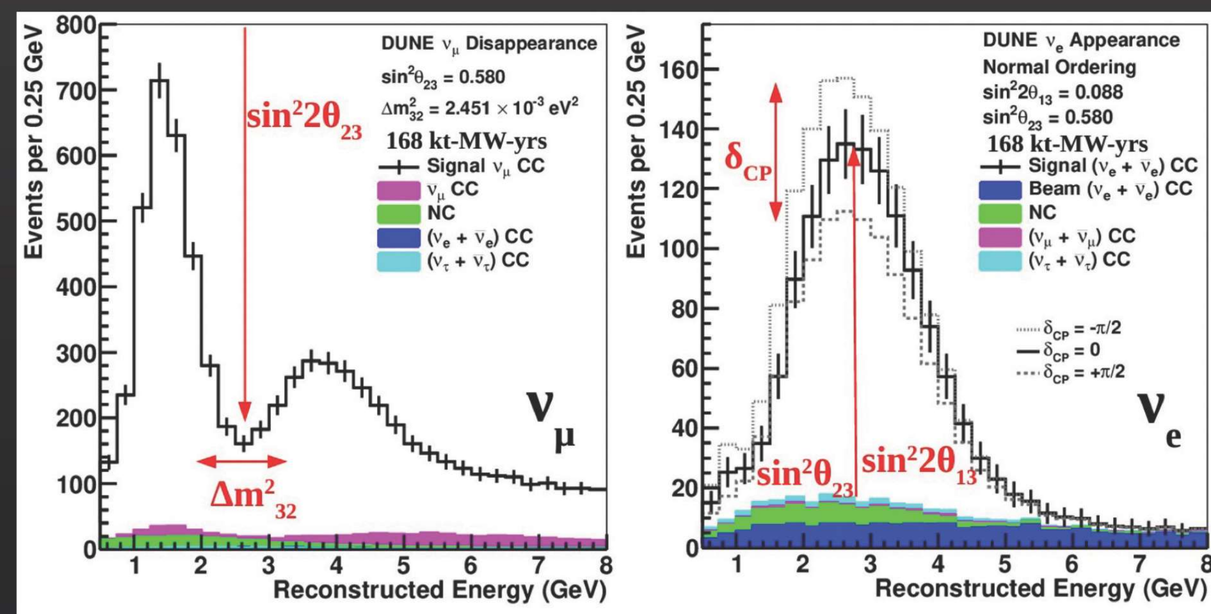
CP is conserved for $\delta = 0$ or π

CP violation is max for $\delta = \pi/2$ or $3\pi/2$

NEUTRINO OSCILLATIONS IN DUNE

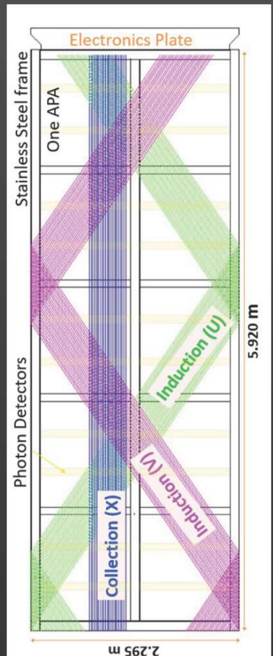
- Near Detector : measurements of ν_μ un-oscillated beam
- Far Detector: measurements of oscillated ν_μ & ν_e spectra
- THEN repeat for antineutrinos – and compare oscillations of neutrinos and antineutrinos
  - ν_μ disappearance: $|\Delta m^2_{32}|$, θ_{23}
  - ν_e appearance: octant of θ_{23}, δ_{CP} , mass ordering

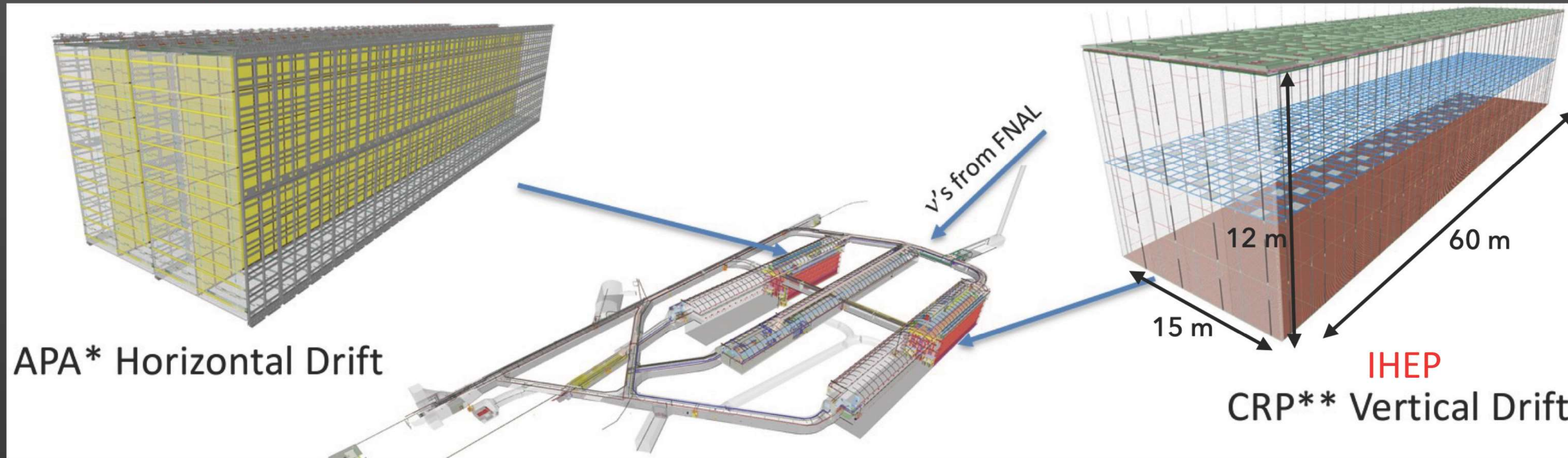




DUNE FAR DETECTORS (PHASE I)

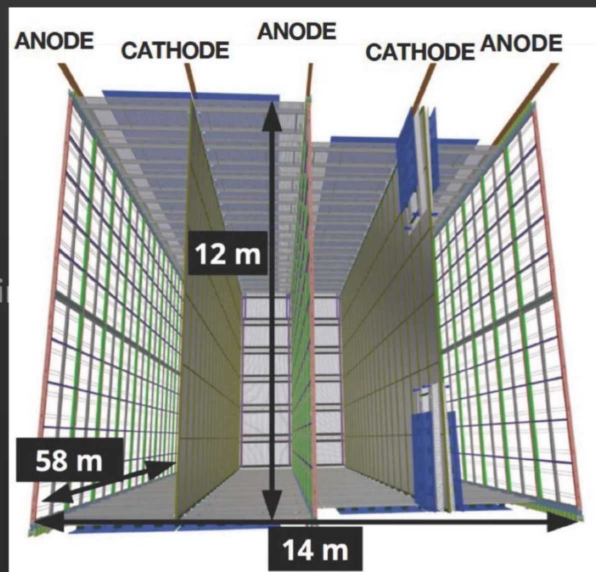
2 ×17 kton single phase LArTPCs





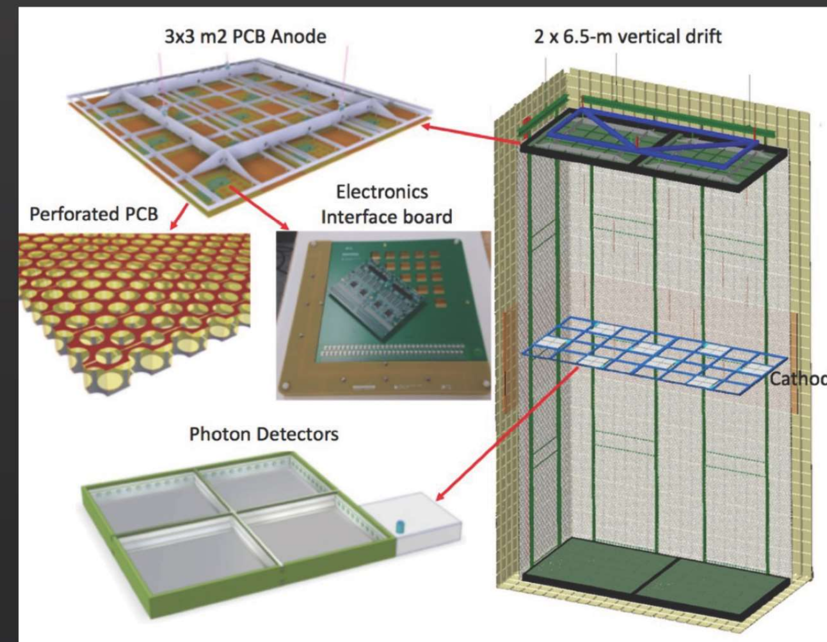
FD1-HD

- 4 TPC 3.6 m horizontal drift
- HV = -180 kV IHEP
- High-resistivity CPA for fast discharge prevention
- Anode: 150 APAs, each with 4 wi planes (Grid, 2x Induction, Collection)
- Photon Detectors: X-ARAPUCA modules embedded in APA



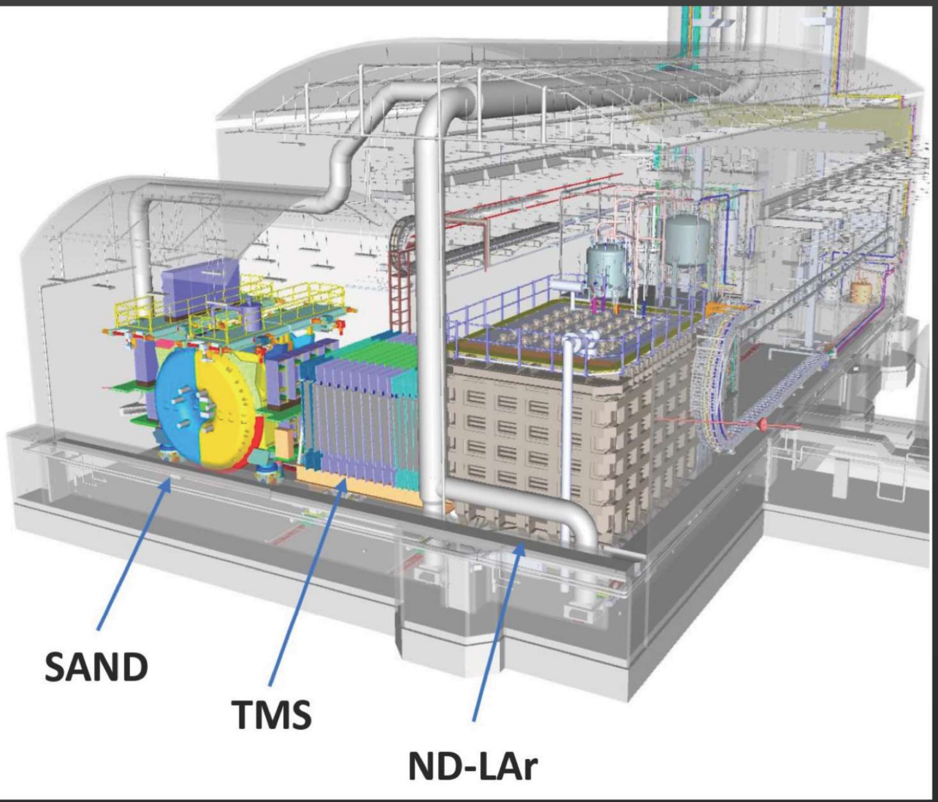
FD2-VD

- 2 TPC 6.5 m vertical drift
- HV = -300 kV IHEP
- Anode: 2 CRPs (top & bottom)
- Charge Readout via perforated PCB anode, fully immersed in LAr
- Doping w/ O(10 ppm) xenon for greater light collection uniformity
- Photon Detectors: X-ARAPUCA megacell modules integrated on cathode and on cryostat walls



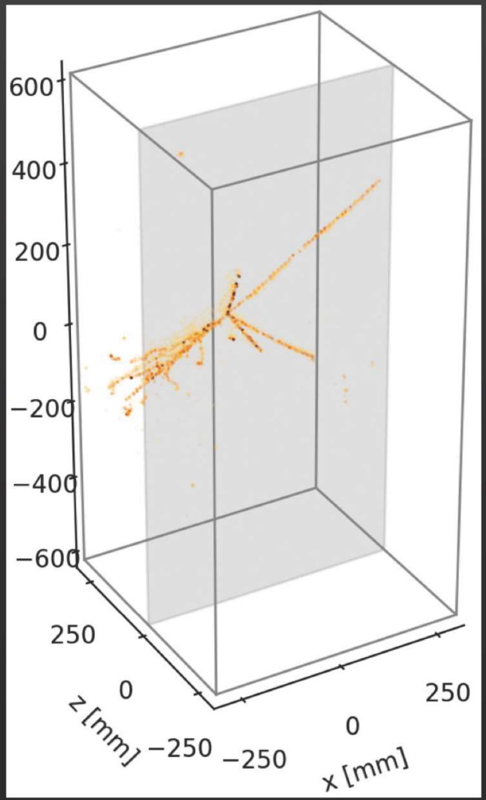
DUNE NEAR DETECTOR COMPLEX (PHASE I)

- Measures the neutrino beam rate and spectrum to predict un-oscillated event rates in the far detector
- Constrains systematic uncertainties (flux, cross sections, detector response) for oscillation measurements
- Additional physics program



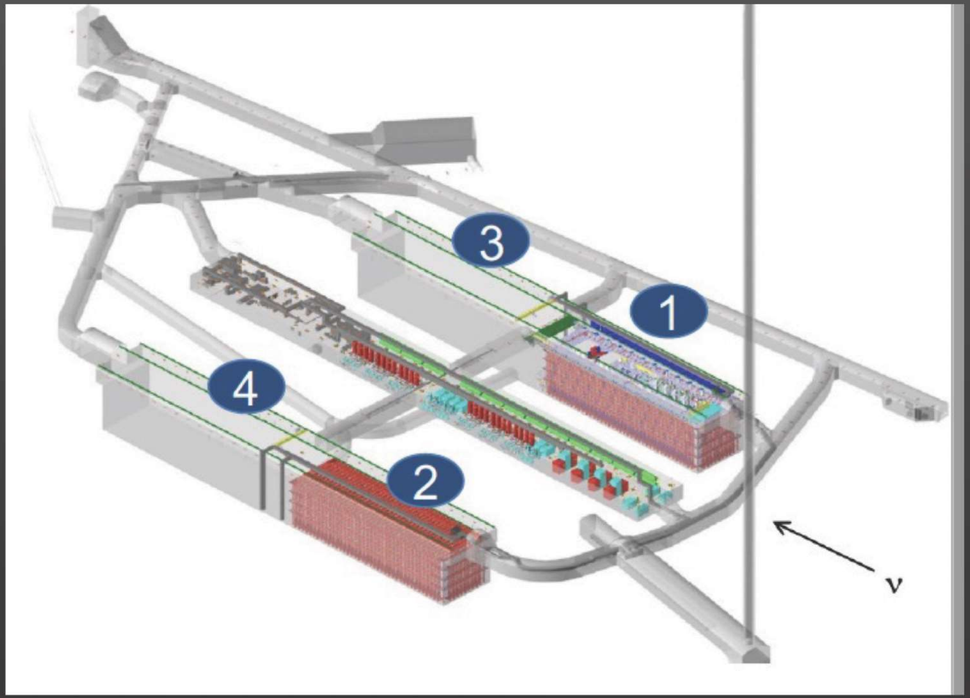
- ND-LAr: 67 ton 7×5 array of modular 1×1×3 m LArTPCs with 50 cm drift, pixel readout and high coverage light readout
- TMS: magnetized steel range stack for measuring muon momentum/sign from ν_μ CC interactions in ND-LAr
  - DUNE-PRISM: ND-LAr + TMS move up to 28.5m off-axis
- SAND: on-axis magnetized neutrino detector with 1 ton LAr target (GRAIN), tracking (STT), and calorimeter (ECAL)

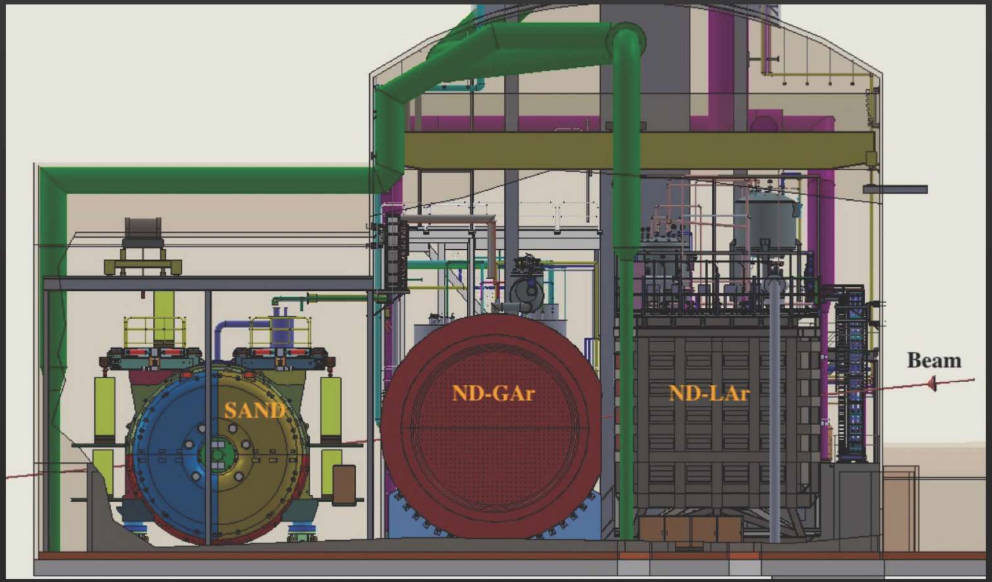
Raw 3D images of cosmic rays in ton-scale prototype



DUNE PHASE II

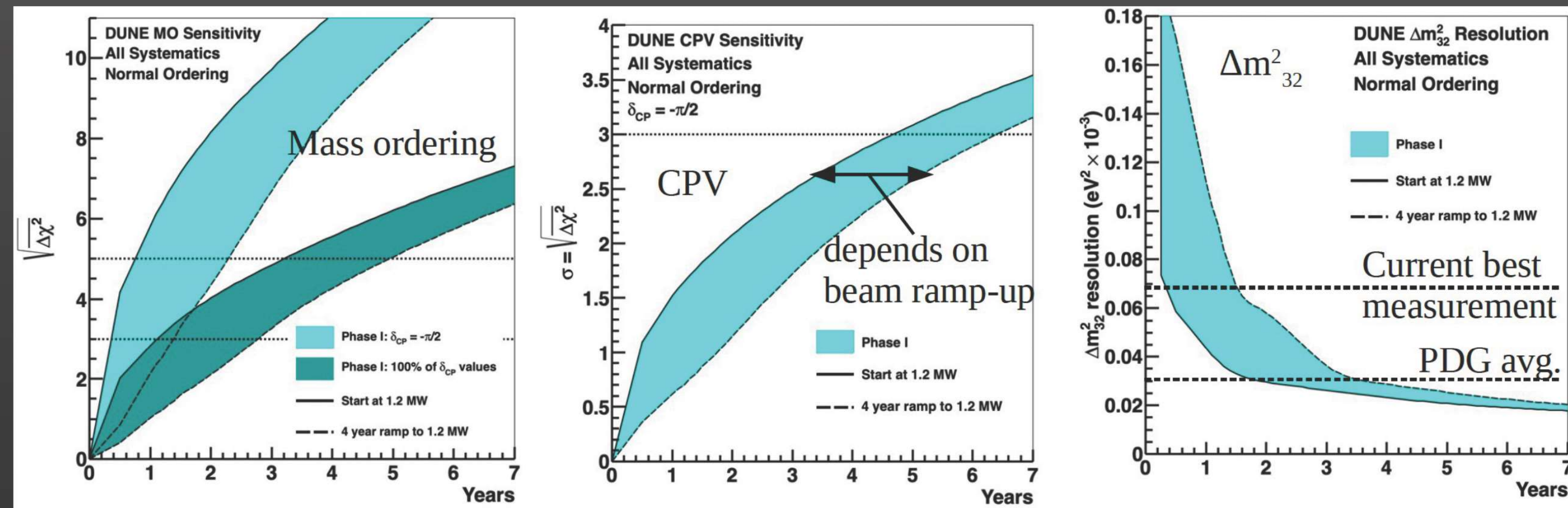
- **Far Detector with 4 modules**
  - FD-3 SP LArTPC enhanced VD 4π concept TBD (by 2027),
  - FD-4 : «module of opportunity»: decision by 2028
- **Beam power upgrade to 2.4 MW**
- **Near Detector: TMS replaced by ND-GAr**
  - ND-LAr
  - ND-GAr important for higher precison ν-Ar measurements and when the statistics reach ~200 kt-MW-yrs
  - SAND

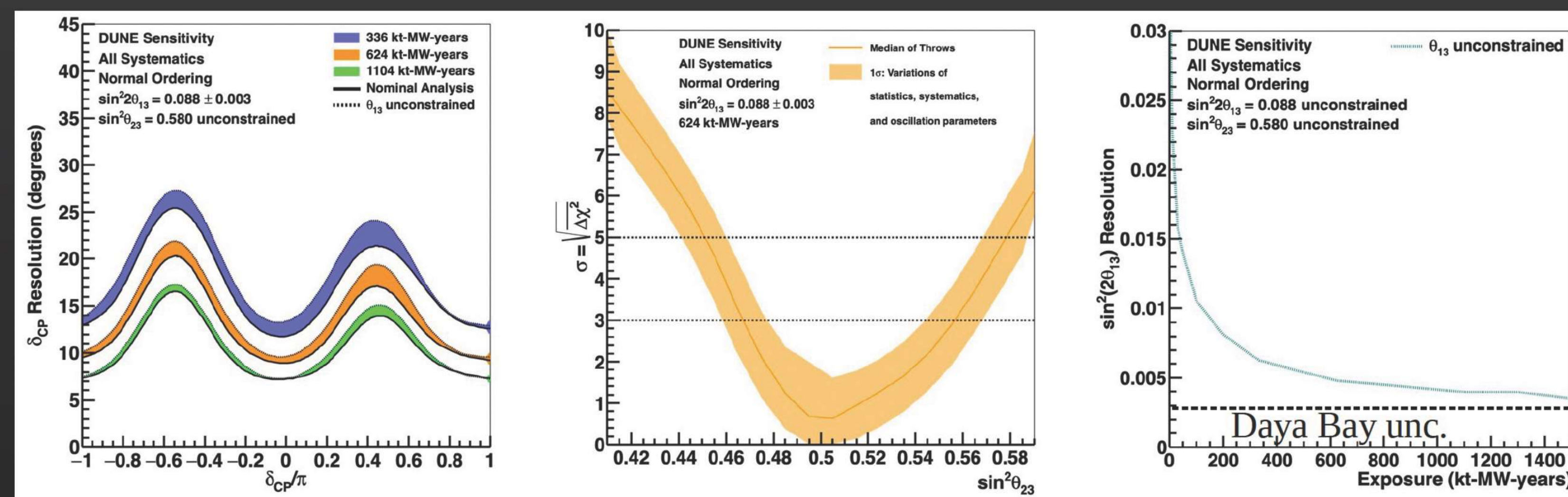




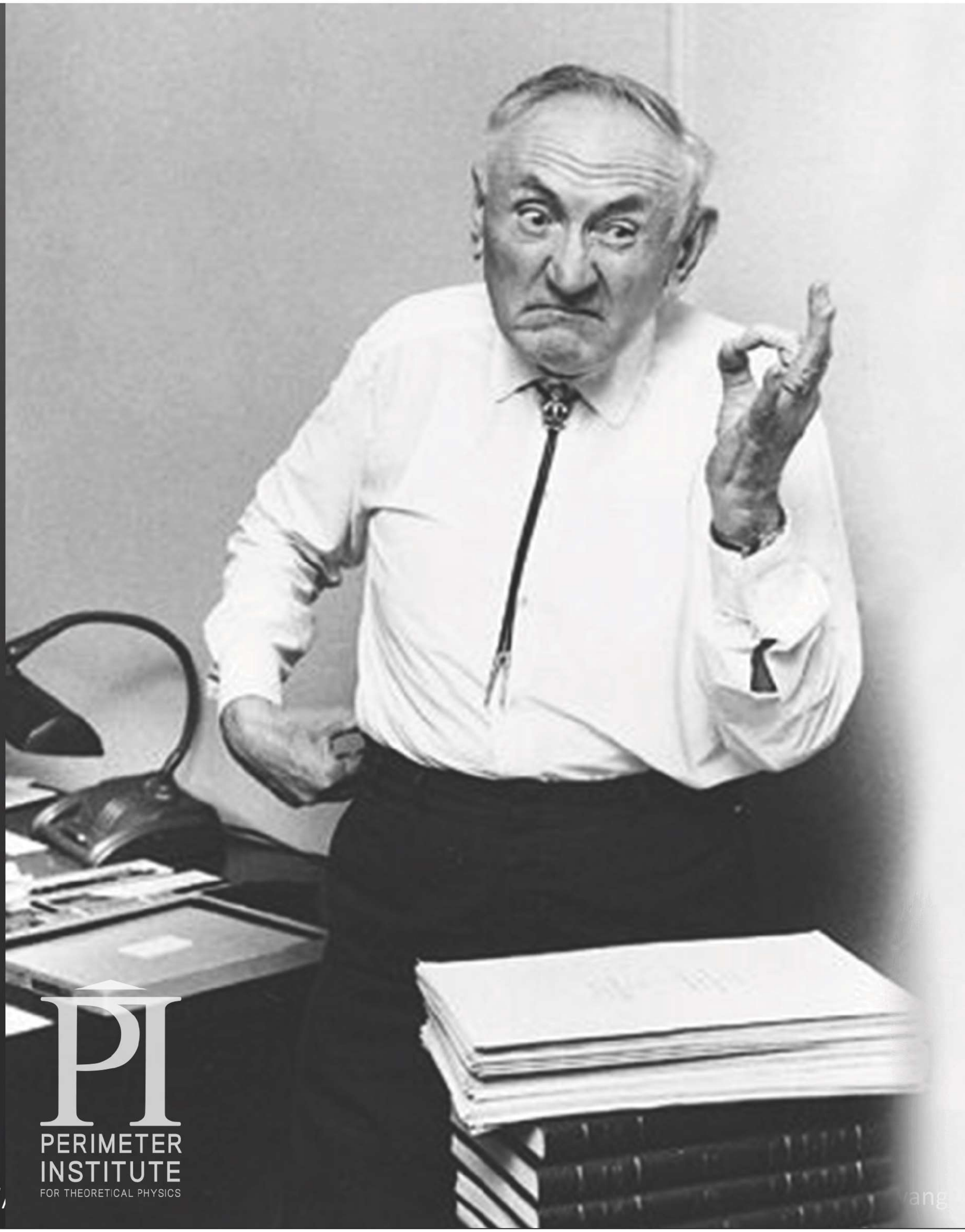
DUNE SENSITIVITIES: PHASE I & PHASE II

- DUNE Phase I:
  - establish the **neutrino mass ordering** at the 5σ level for 100% of δ_{CP} values
  - **CP violation** (CPV) with 3σ significance after about 7 years if $\delta_{CP} = -\pi/2$ and after about 10 years for 50% of δ_{CP} values.
  - Δm^2_{32} can be measured with the resolution better than any other measurements after 2 years
- DUNE Phase II:
  - Measure δ_{CP} to 6-16° → **>5σ CPV** over >50% of δ_{CP} values
  - Measure θ_{23} and Δm^2_{32} → **resolve θ_{23} octant** if non-maximal
  - Measure θ_{13} with precision comparable to reactors → indirect **test of PMNS non-unitarity**





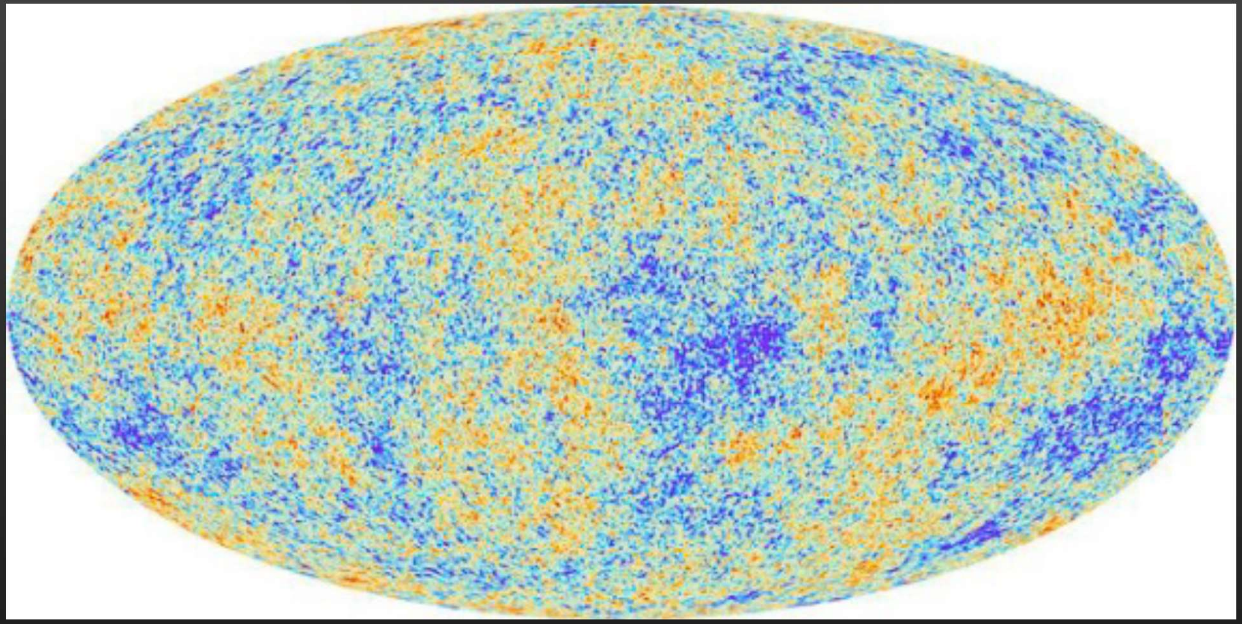
Dark Matter with Argon

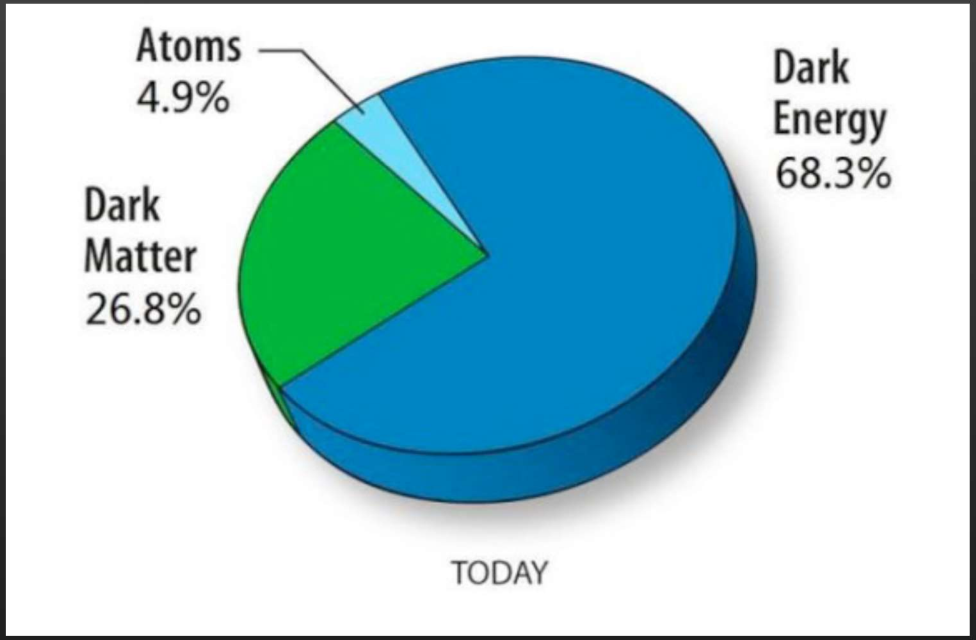


In 1933, Swiss astronomer Fritz Zwicky applied a mathematical theorem to infer the existence of what he called Dunkle Materie, coining the term dark matter. Zwicky was a noted curmudgeon and self-described “lone wolf” who claimed to “have a good idea every two years.”

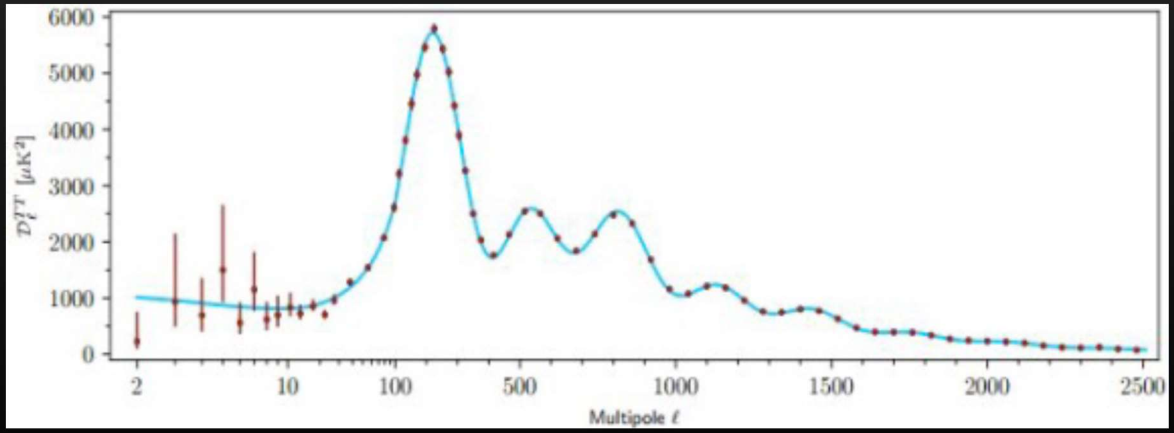
PERIMETER INSTITUTE
FOR THEORETICAL PHYSICS

Evidence for DM

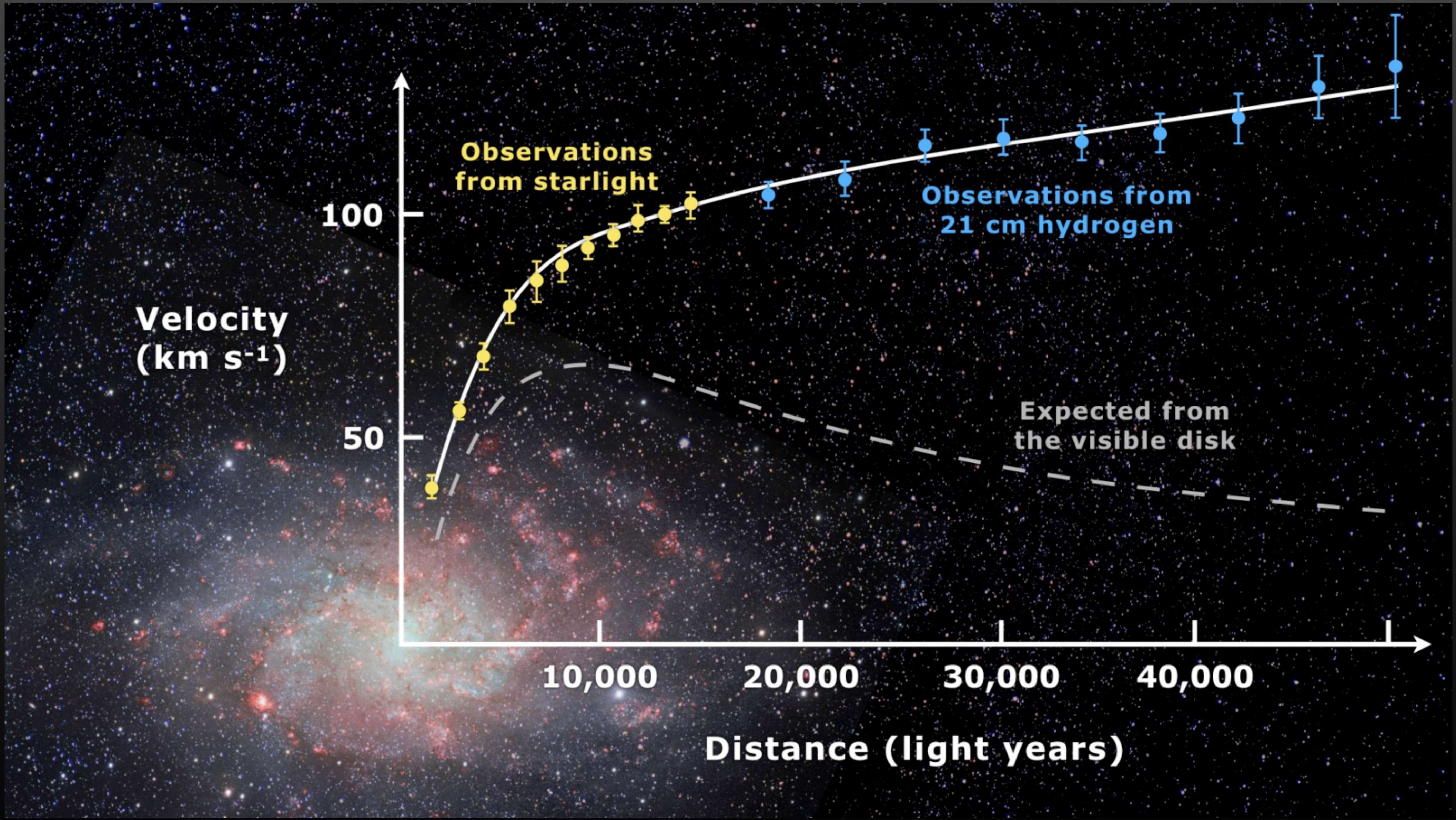




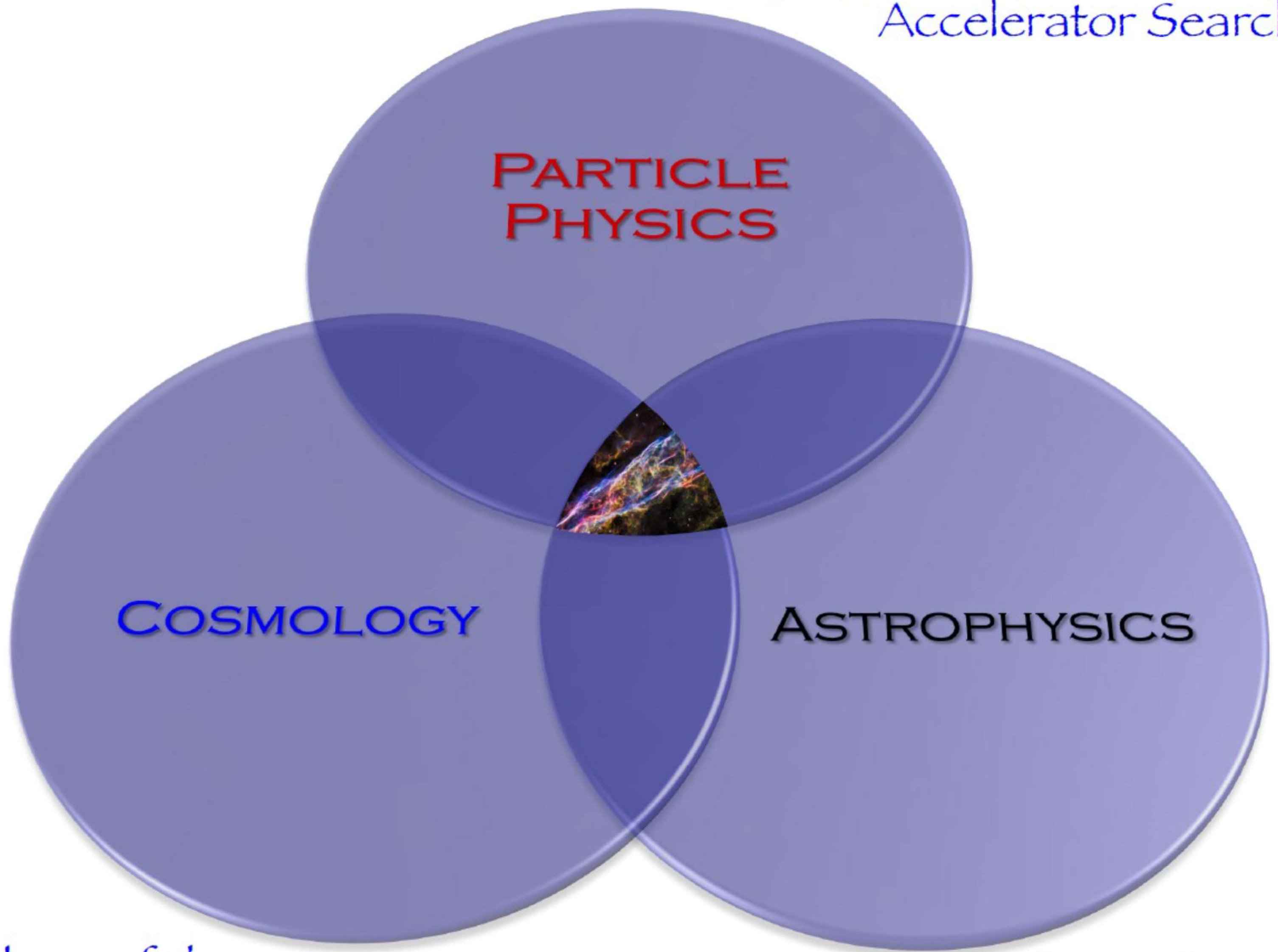
Cosmic microwave background (CMB) observations, resulting in precise estimates (WMAP, Planck) supporting LCDM model.



Evidence for DM



Particle Candidate: Models of New Physics
(Superymmetry, Extra-dimensions, ...)
Accelerator Searches



Cosmology of the
Dark Matter Particle

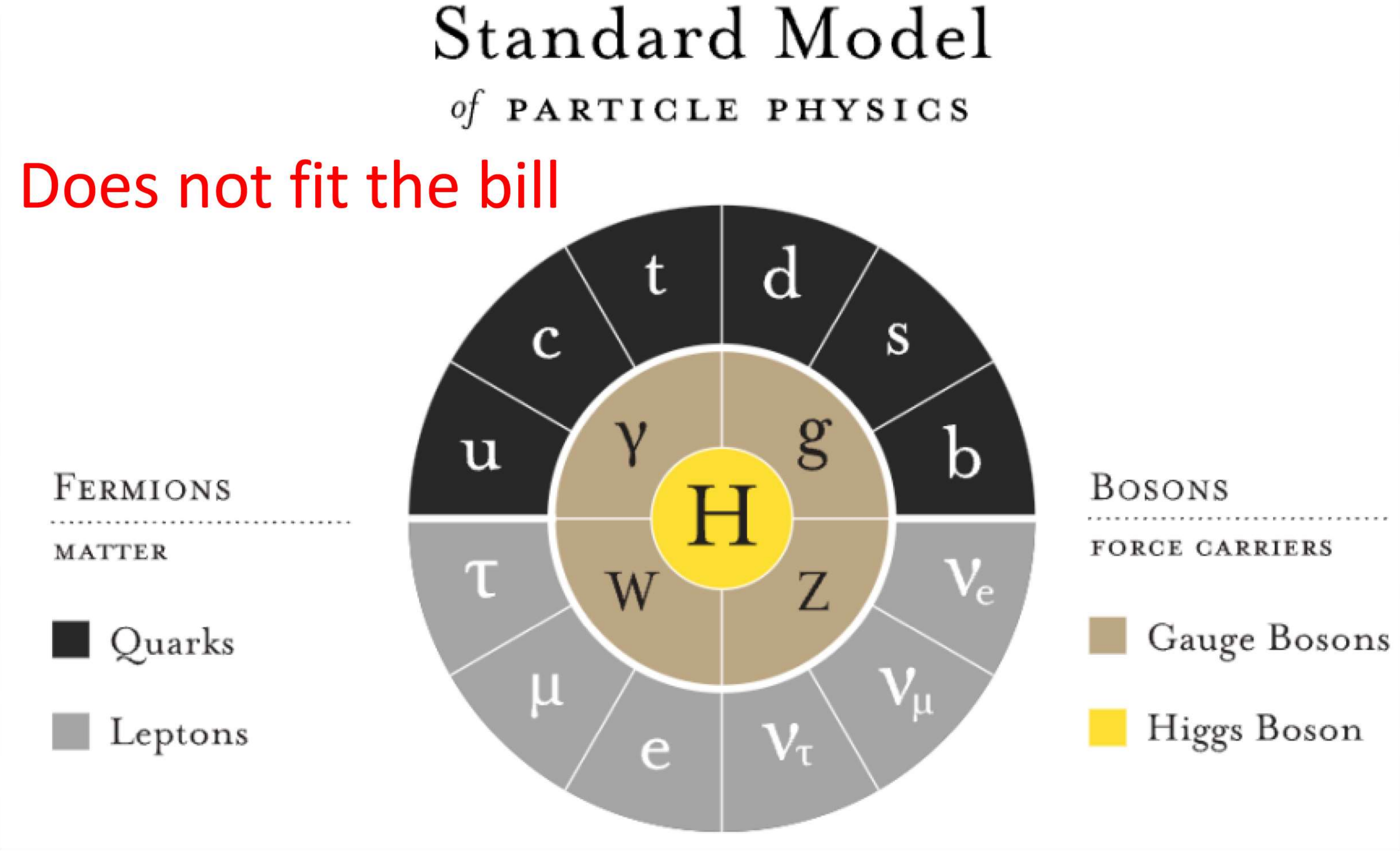
Astrophysical Signals of the
Dark Matter Particle

Properties of DM

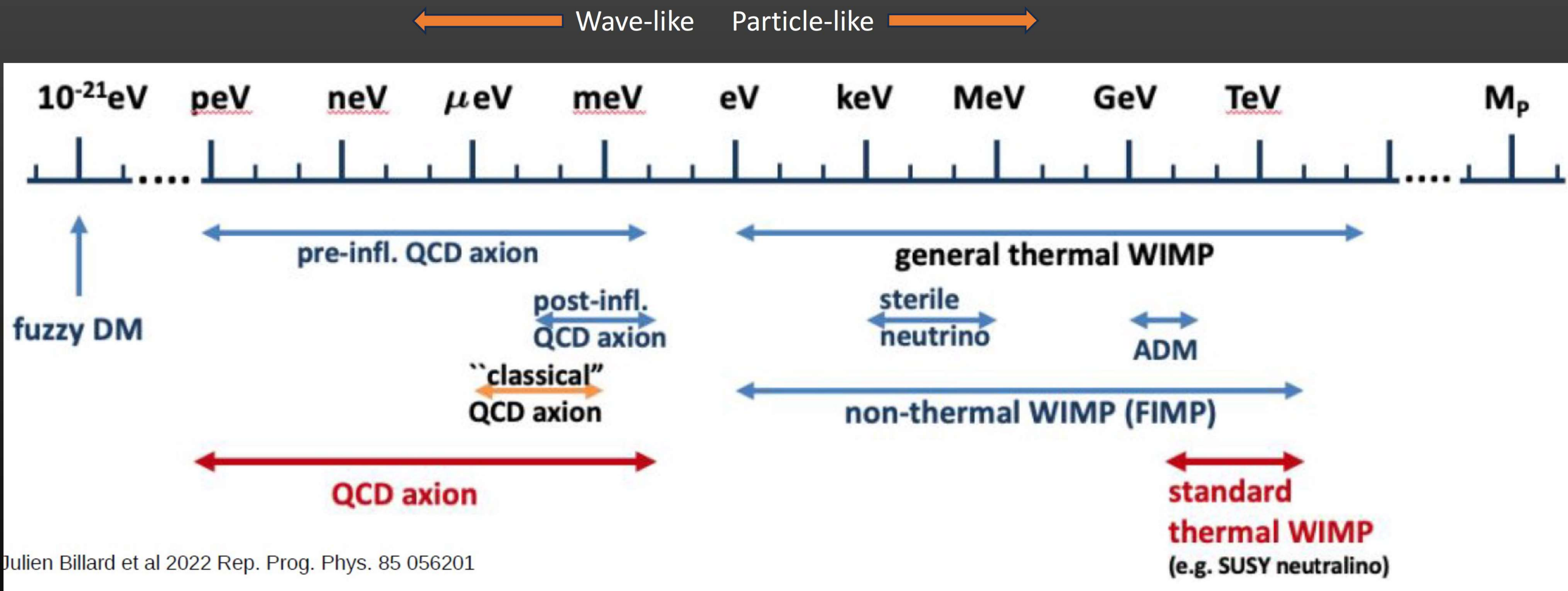
- We know it is cold
- We know it is neutral
- We know it is non-baryonic
- We know it is stable

- New physis beyond SM

Does not fit the bill



DM candidates



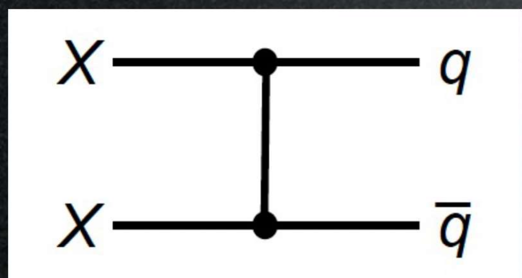
Weakly Interacting Massive Particle

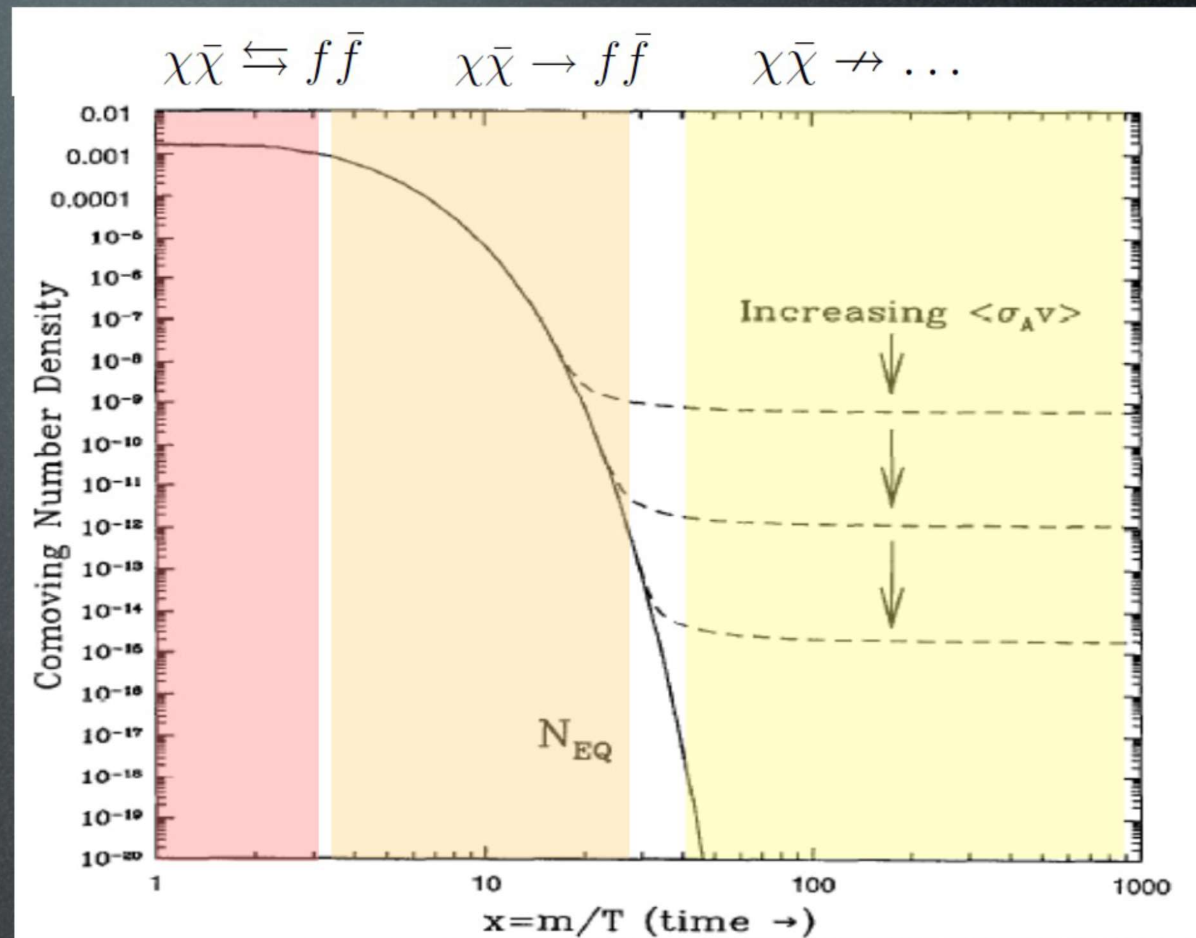
Boltzmann equation
in the Early Universe:

$$\Omega_X \approx \frac{6\ 10^{-27}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma_{\mathrm{ann}} v \rangle}$$

Relic $\Omega_{\mathrm{DM}} \simeq 0.23$ for

$\langle \sigma_{\mathrm{ann}} v \rangle = 3 \cdot 10^{-26}\mathrm{cm}^3/\mathrm{sec}$





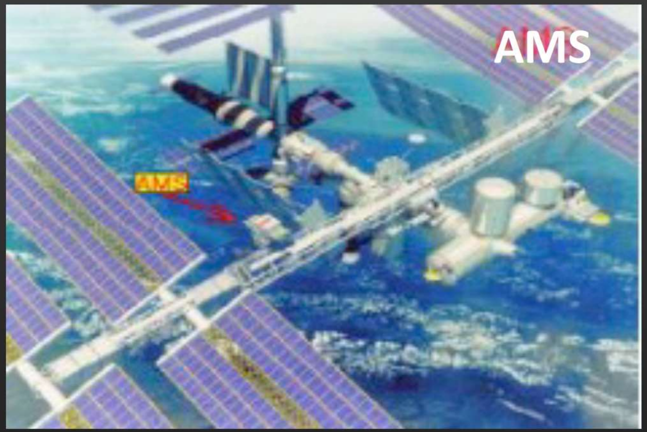
Kolb,Turner, The Early Universe, 1995

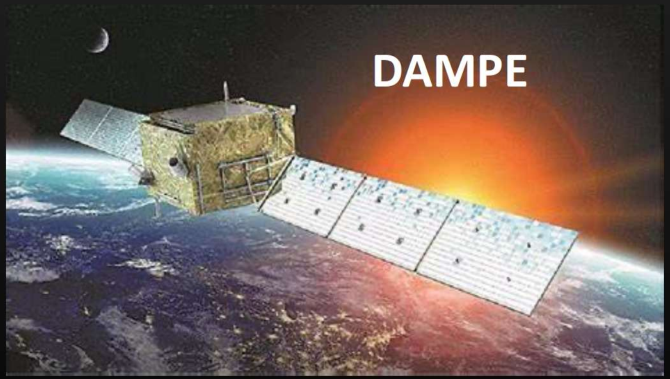
Weak cross section:

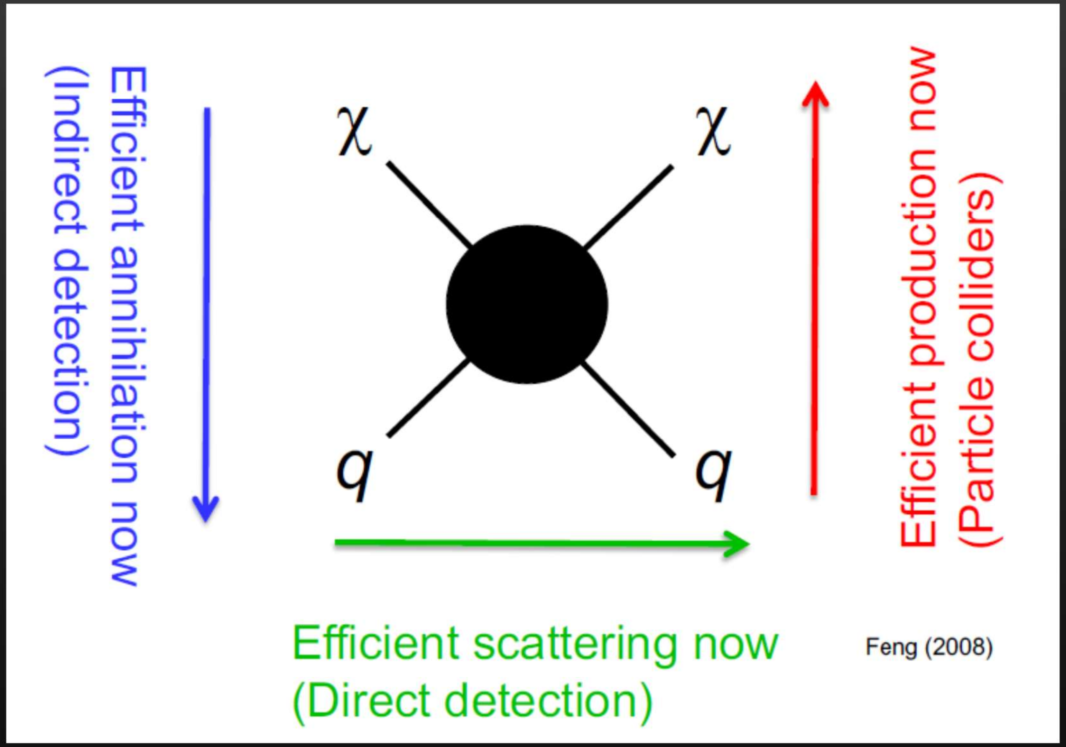
$$\langle \sigma_{\mathrm{ann}} v \rangle \approx \frac{\alpha_w^2}{M^2} \approx \frac{\alpha_w^2}{1\,\mathrm{TeV}^2} \Rightarrow \Omega_X \sim \mathcal{O}(\text{few } 0.1)$$

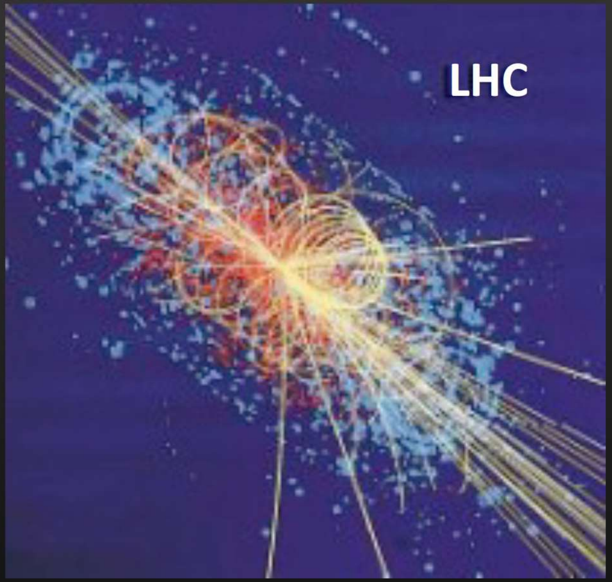
(WIMP)

How to detect DM ?









Historical perspective

Direct dark matter detection started nearly 40 years ago from these 2 papers:

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1984

Principles and applications of a neutral-current detector for neutrino physics and astronomy

A. Drukier and L. Stodolsky
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany
(Received 21 November 1983)

We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detect
realization in terms of the superconducting-
through extension and extrapolation of curre
determination of the neutrino energy spectr
since it detects all neutrino types. Various ap
sources, reactors, supernovas, and solar and
most difficult backgrounds is attempted.

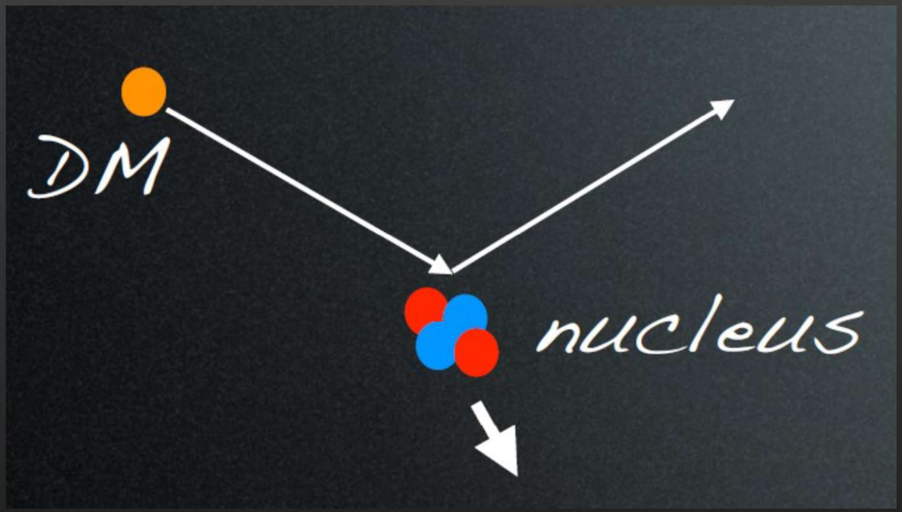
PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

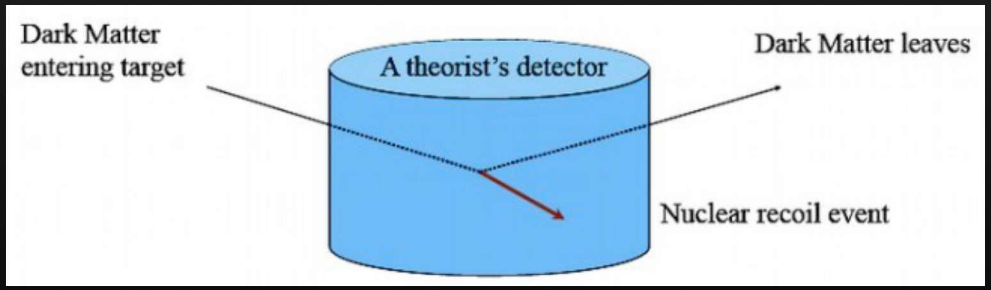
Detectability of certain dark-matter candidates

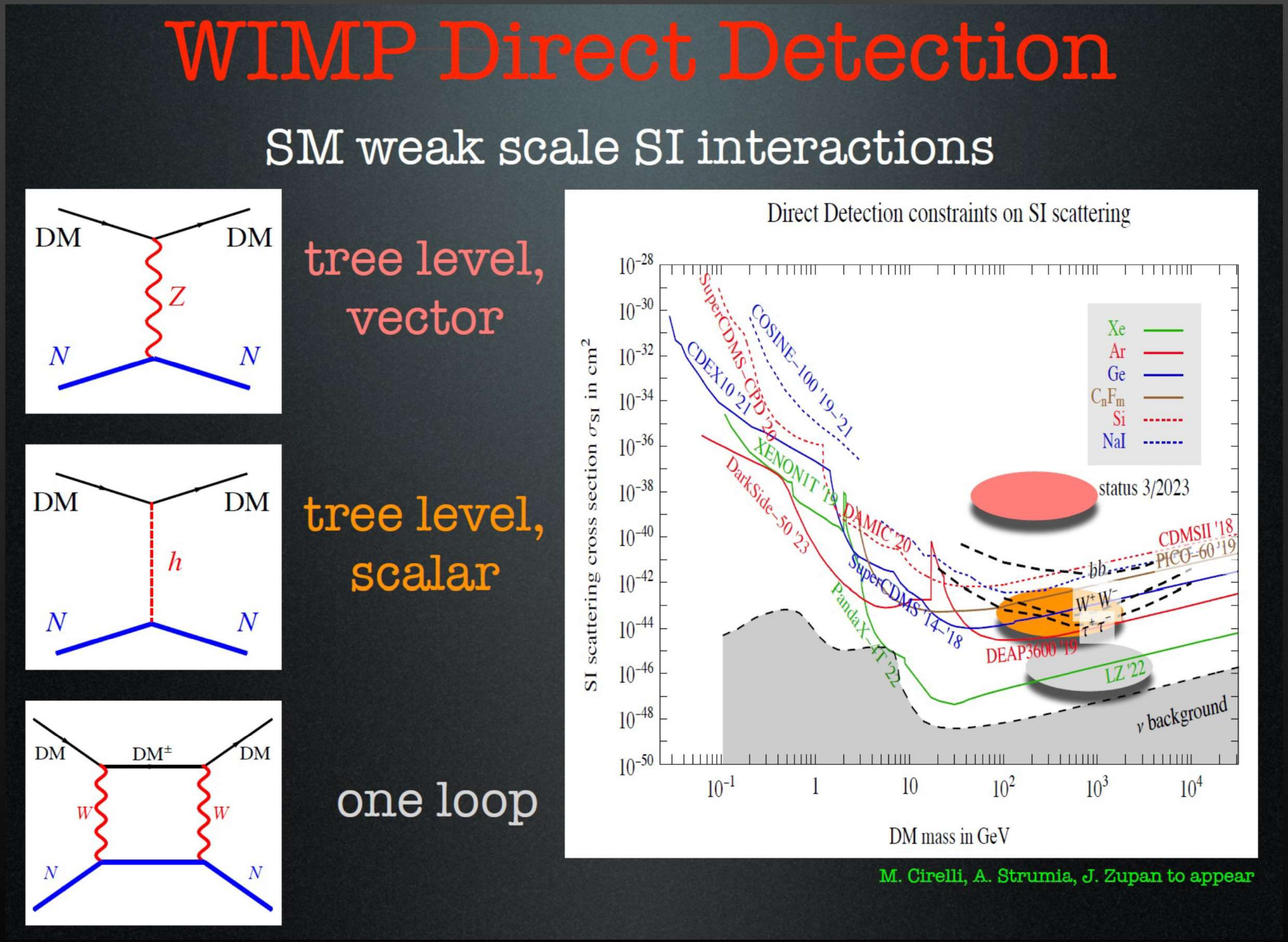
Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

Direct detection

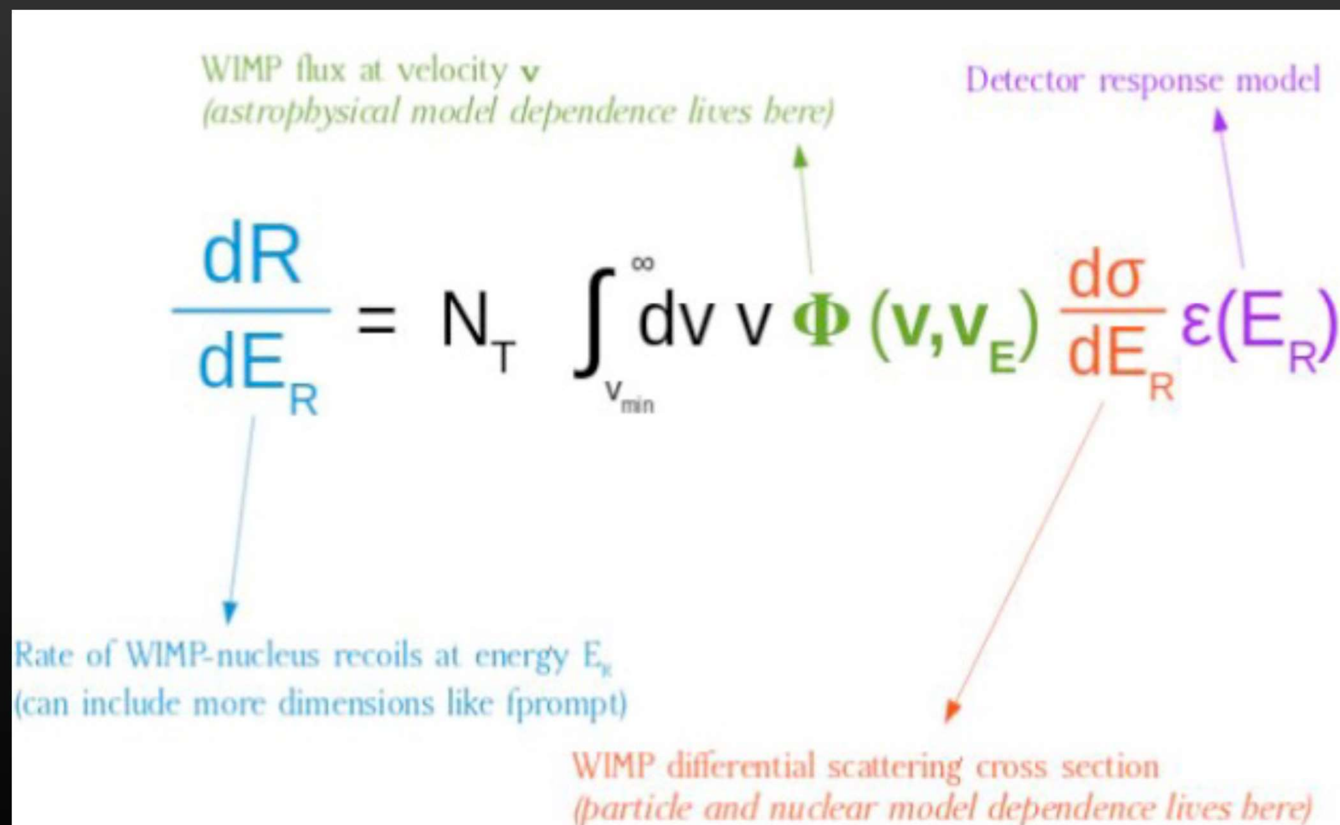




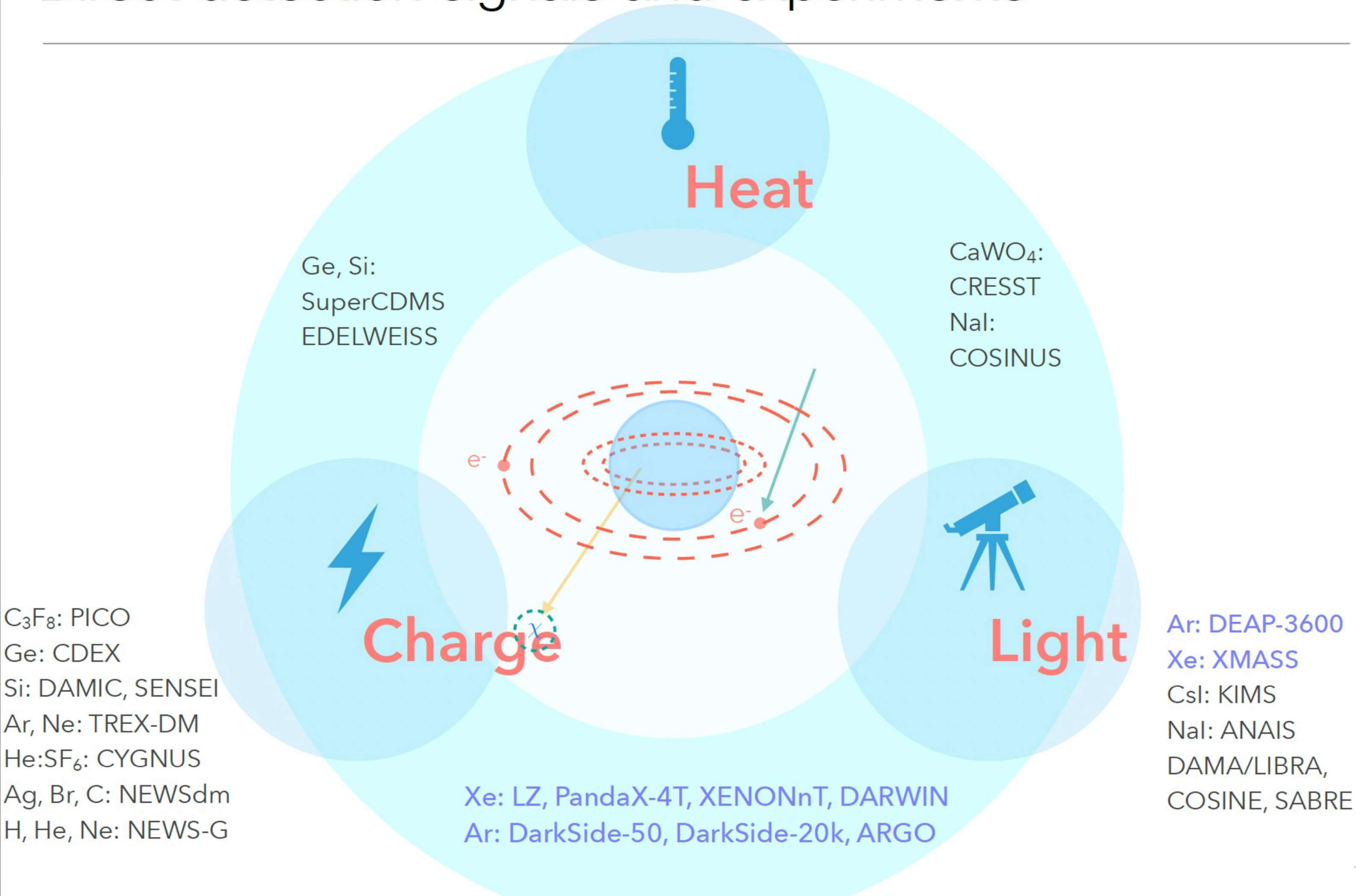


DM direct detection signature

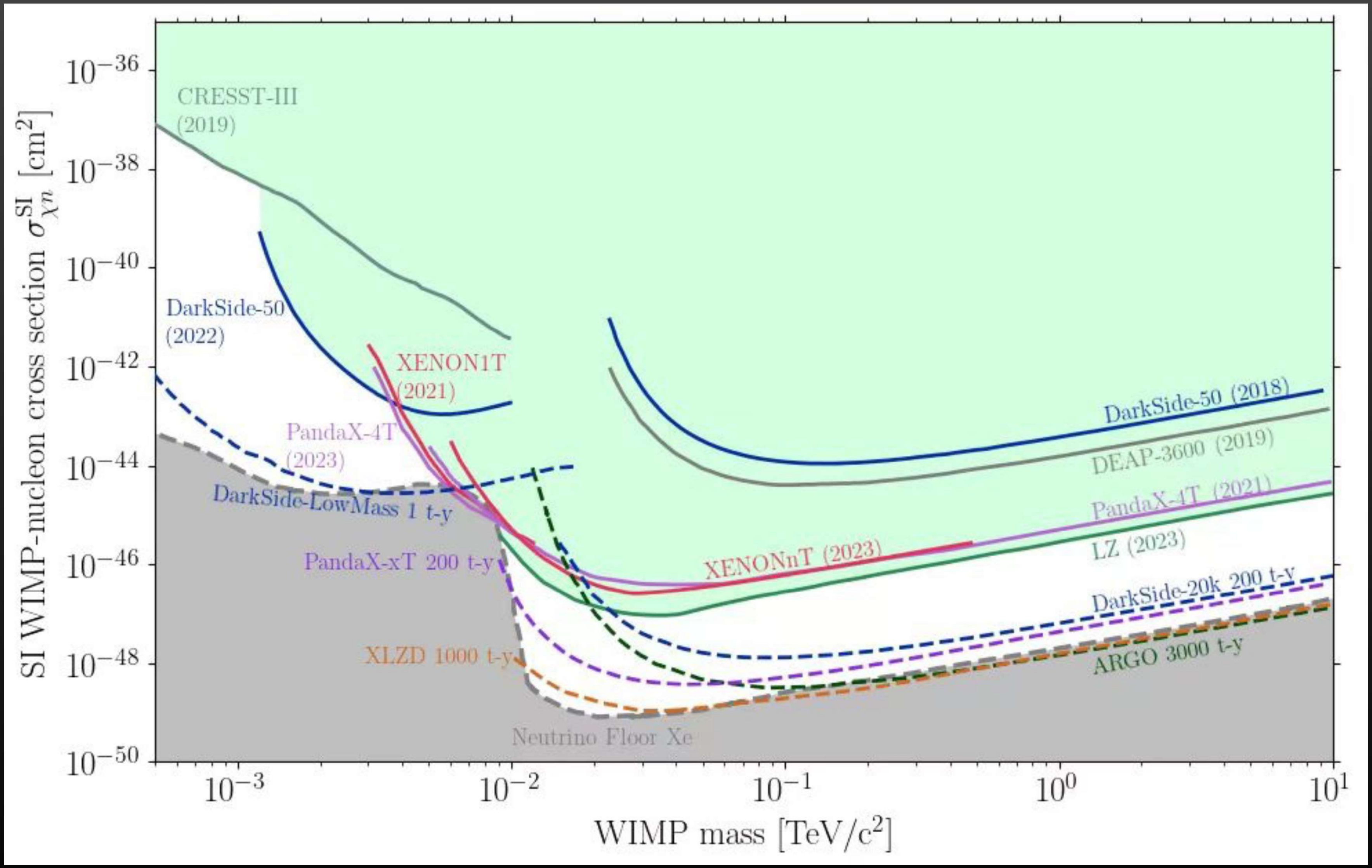
- Only through rare interactions with ordinary matter
- After the interaction, recoiling nucleus deposits energy in the detector, which is detectable (heat, light, electric charge, ...



Direct detection signals and experiments

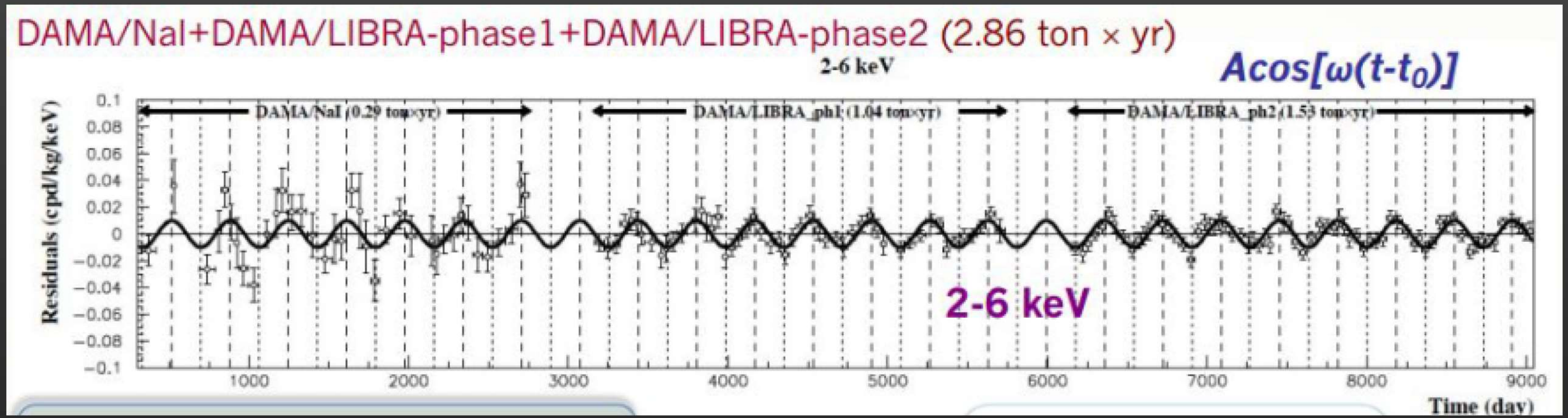


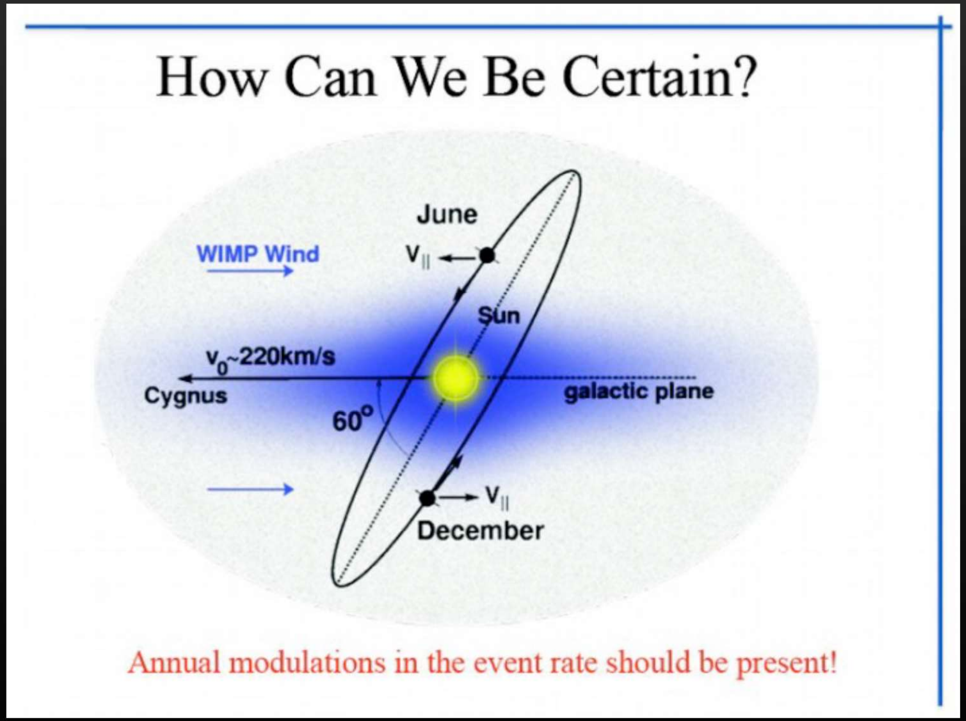
Status of WIMP searches

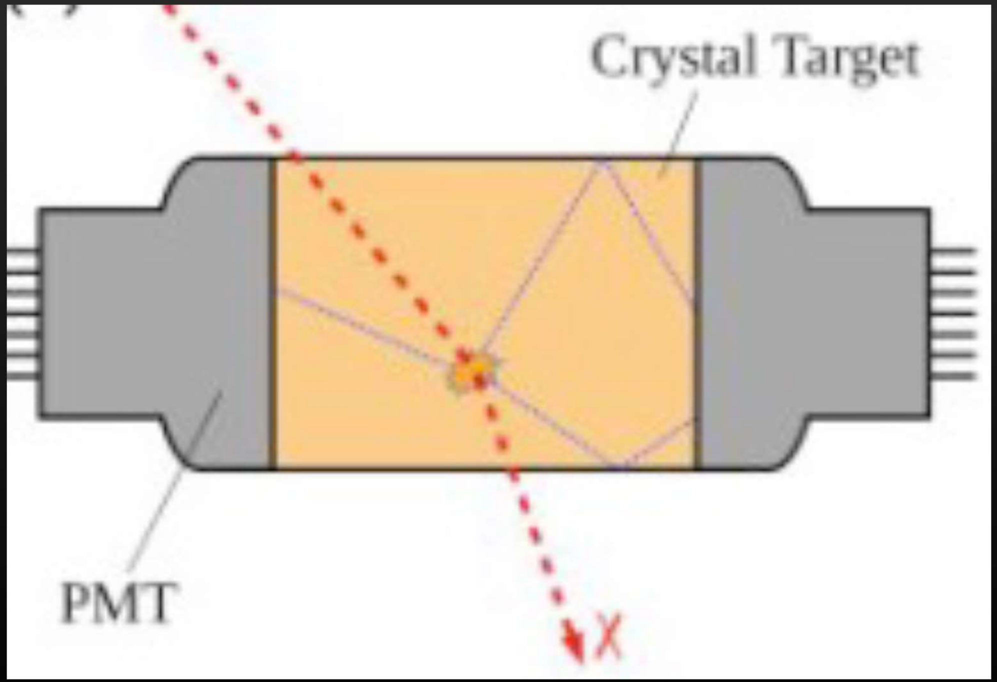


Noble liquid technology plays a major role.
WIMP mass > 1 GeV/c^2

DAMA did see something…

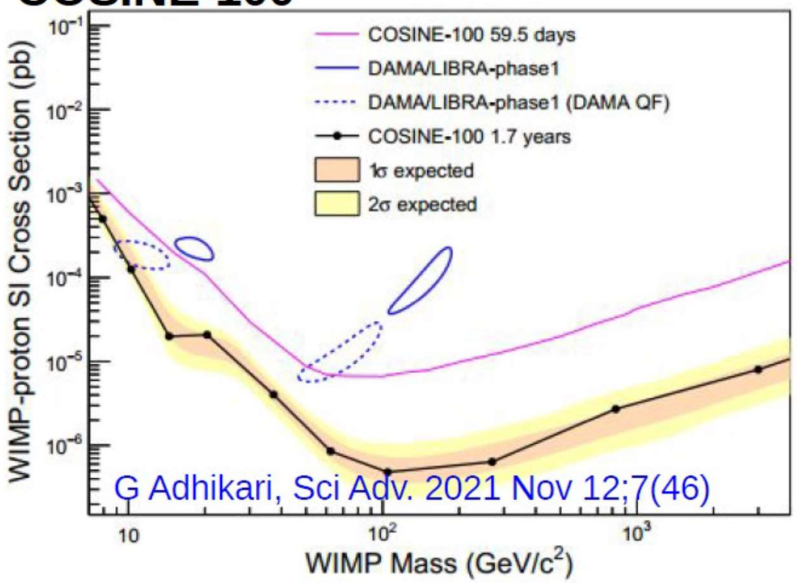






Other DAMA tests

COSINE-100

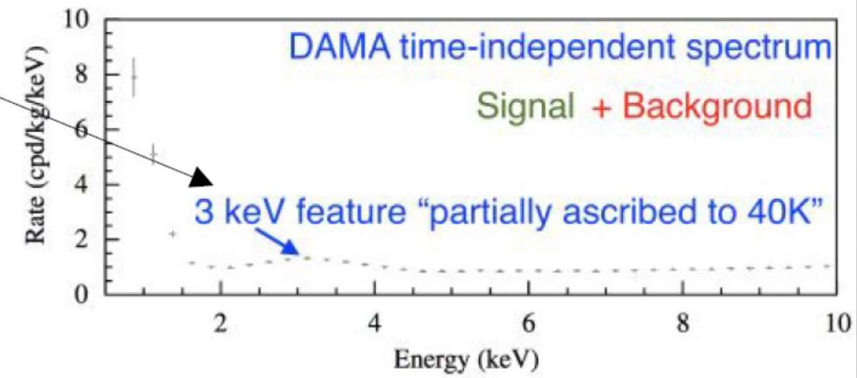


- Modulation search with 2.8 yr of data consistent with both DAMA and no modulation [PRD 106, 052005]
- New result soon (2x exposure and lower threshold)

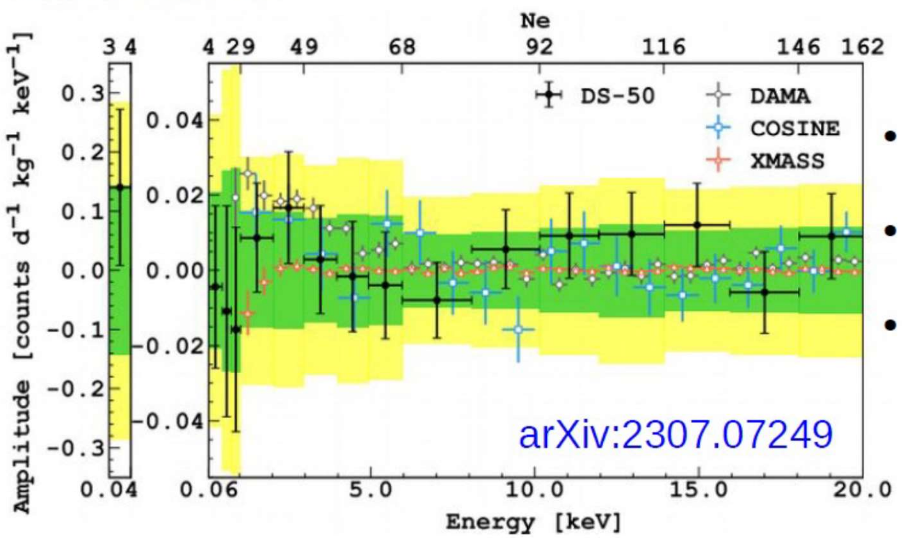
SABRE

- Same NaI technology as DAMA, independently purified crystals
- 2 detectors planned:
  - North: LNGS
  - South: Australia

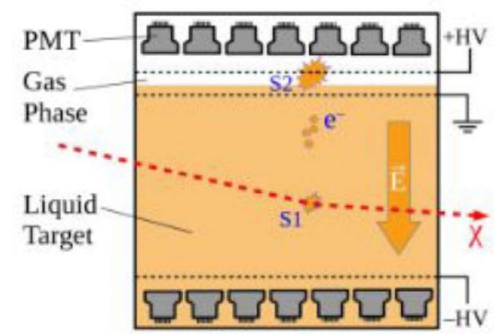
KDK: First measurement of direct-to-ground-state EC of ^{40}K, potential constraint on DM interpretation of DAMA
→ see M. Stukel's talk (Wednesday) [PRL 131, 052503 (2023)]



DarkSide-50



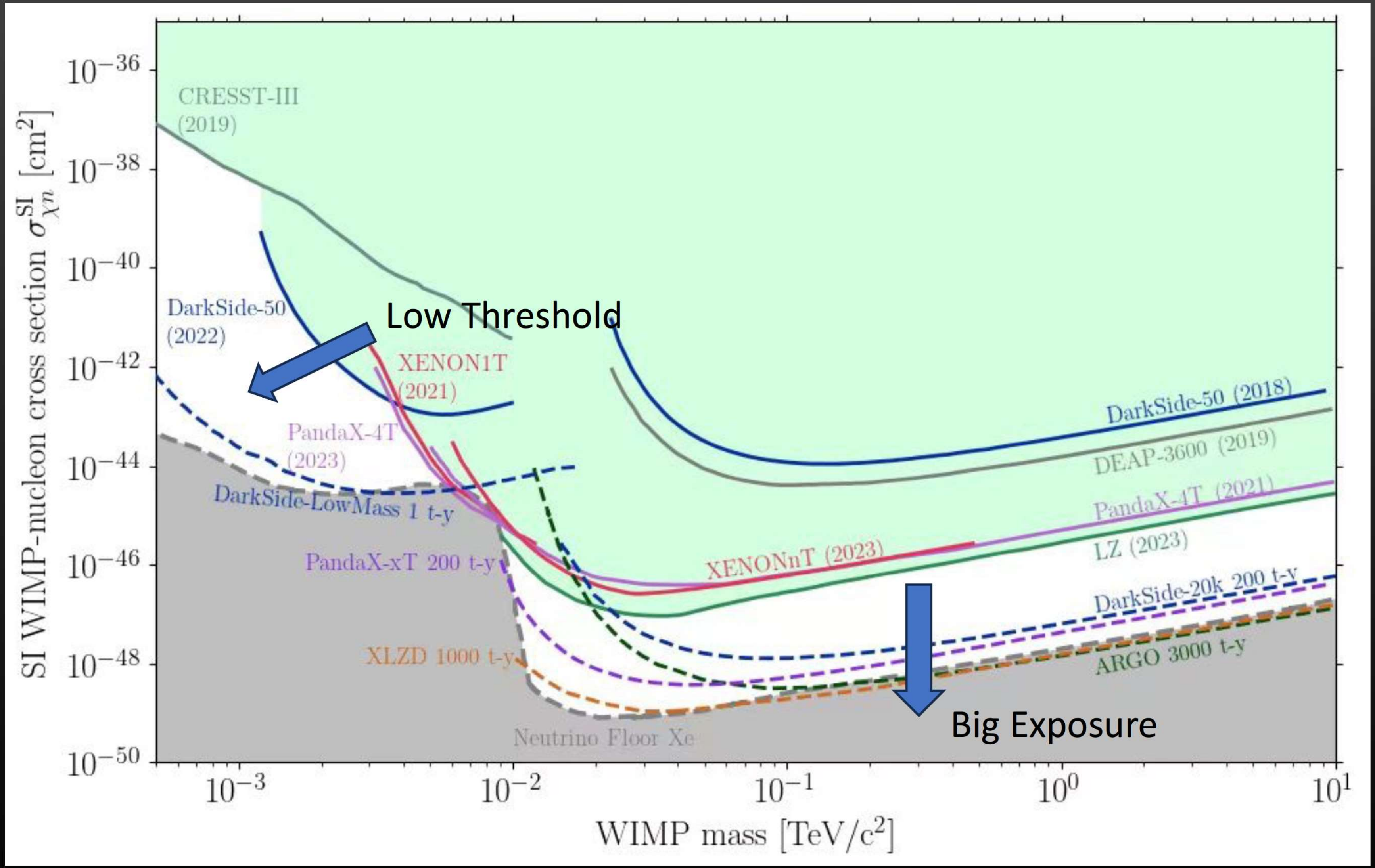
- First annual modulation search using argon
- The lowest energy threshold 0.04 keV
- Neither confirm nor reject DAMA
  → see T. Hugues' talk (Tuesday)

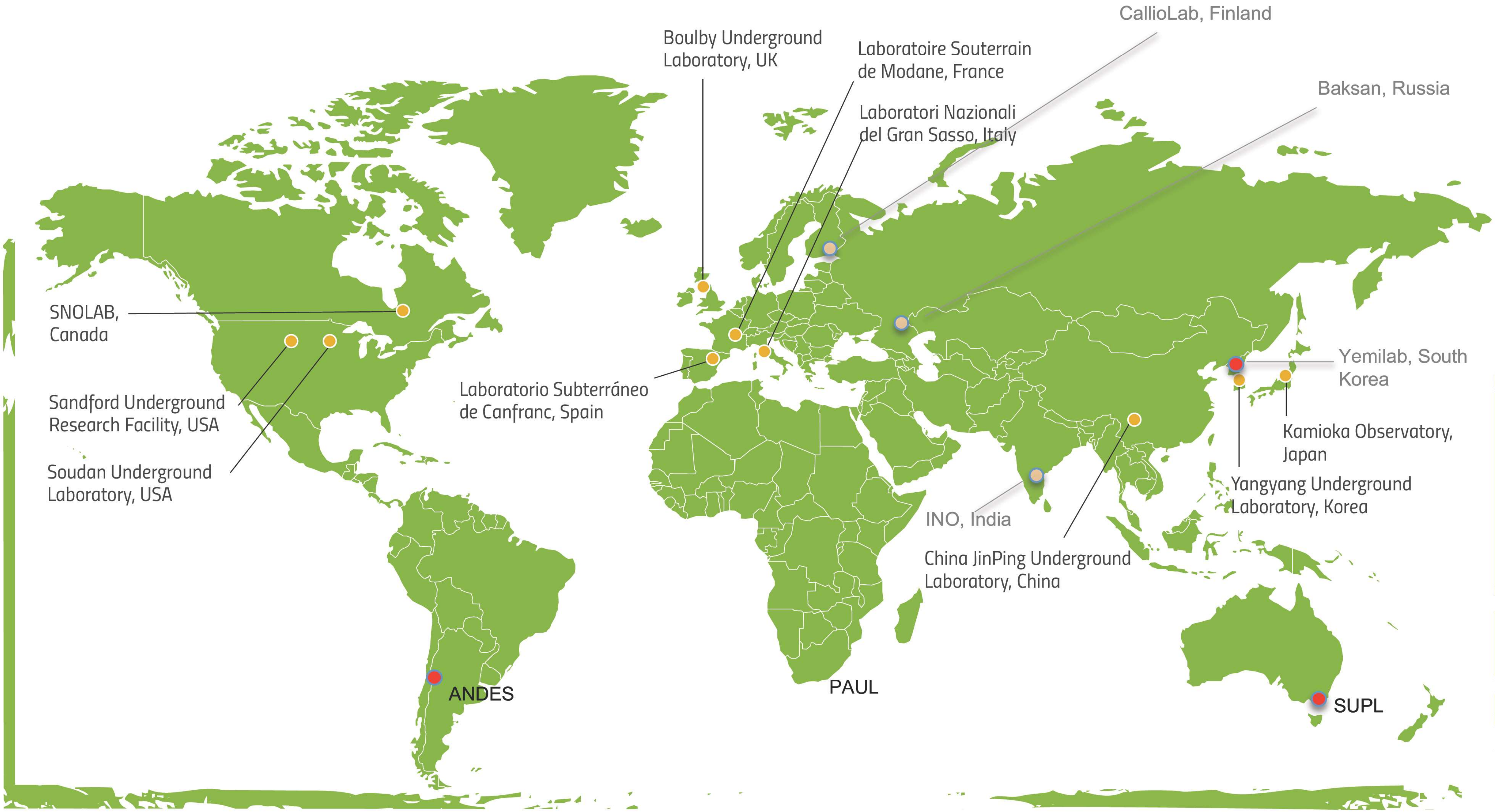


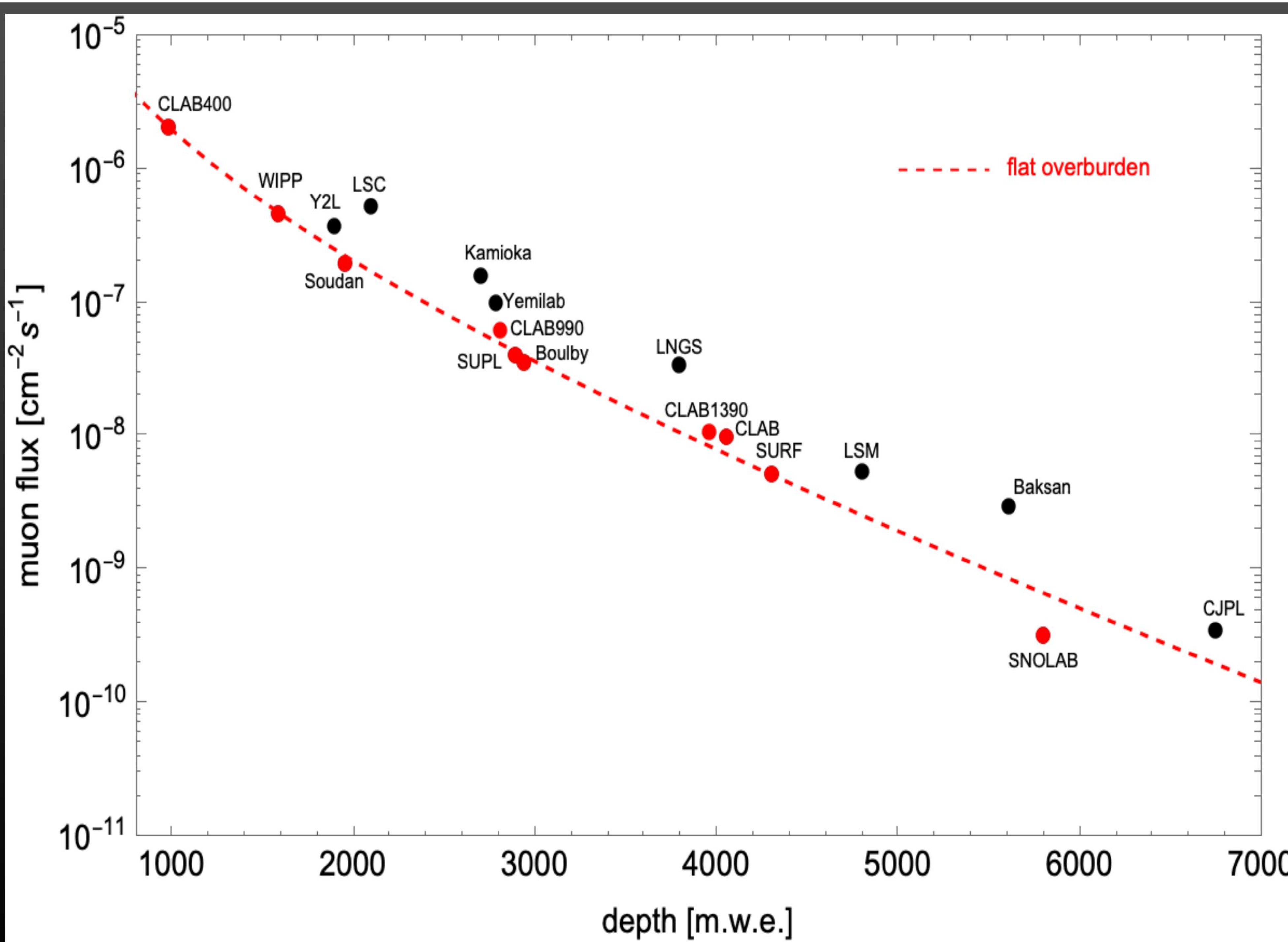
Direct searches with noble liquid

- Xenon community
- Argon community

- Underground lab



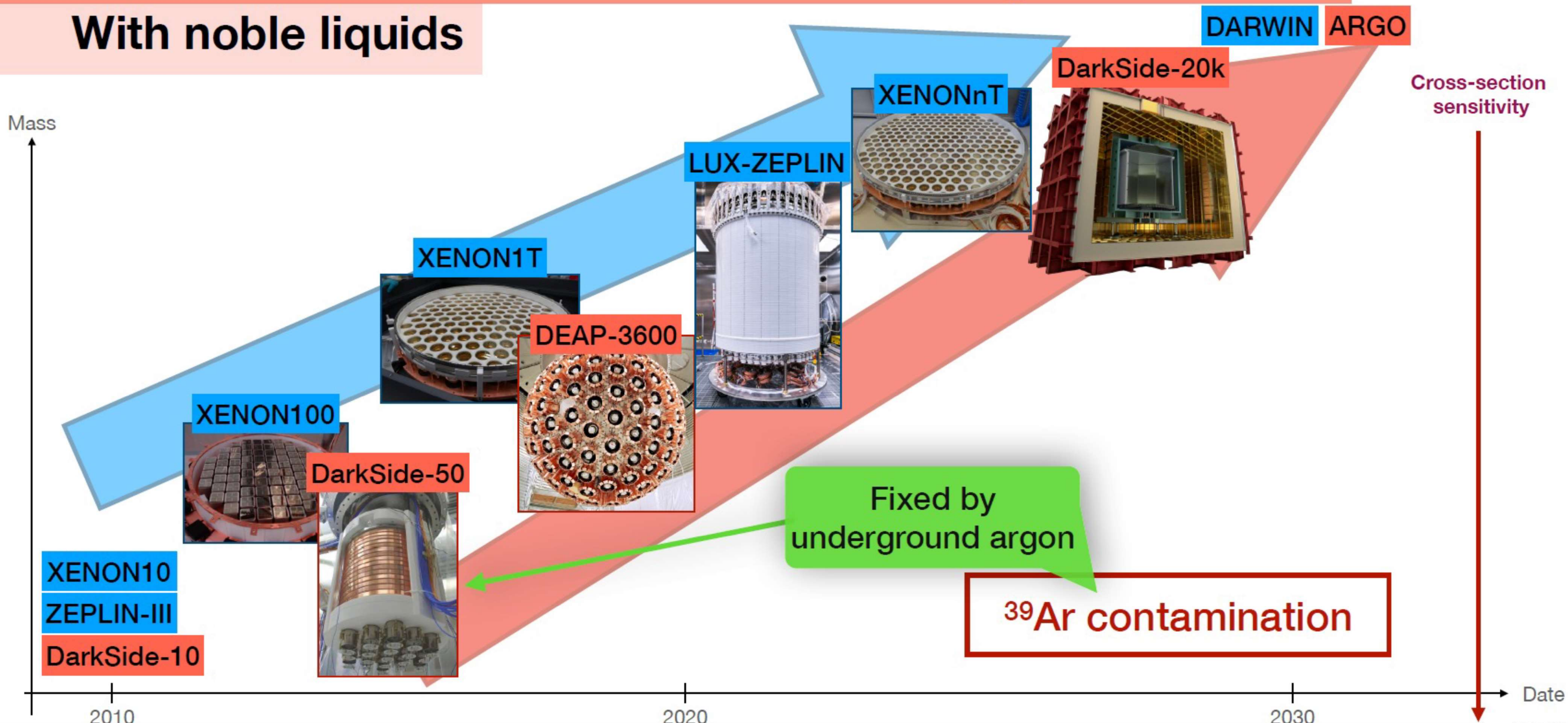

CallioLab, Finland
Boulby Underground Laboratory, UK
Laboratoire Souterrain de Modane, France
Baksan, Russia
Laboratori Nazionali del Gran Sasso, Italy
SNOLAB, Canada
Yemilab, South Korea
Laboratorio Subterráneo de Canfranc, Spain
Sandford Underground Research Facility, USA
Kamioka Observatory, Japan
Soudan Underground Laboratory, USA
Yangyang Underground Laboratory, Korea
INO, India
China JinPing Underground Laboratory, China
ANDES
PAUL
SUPL



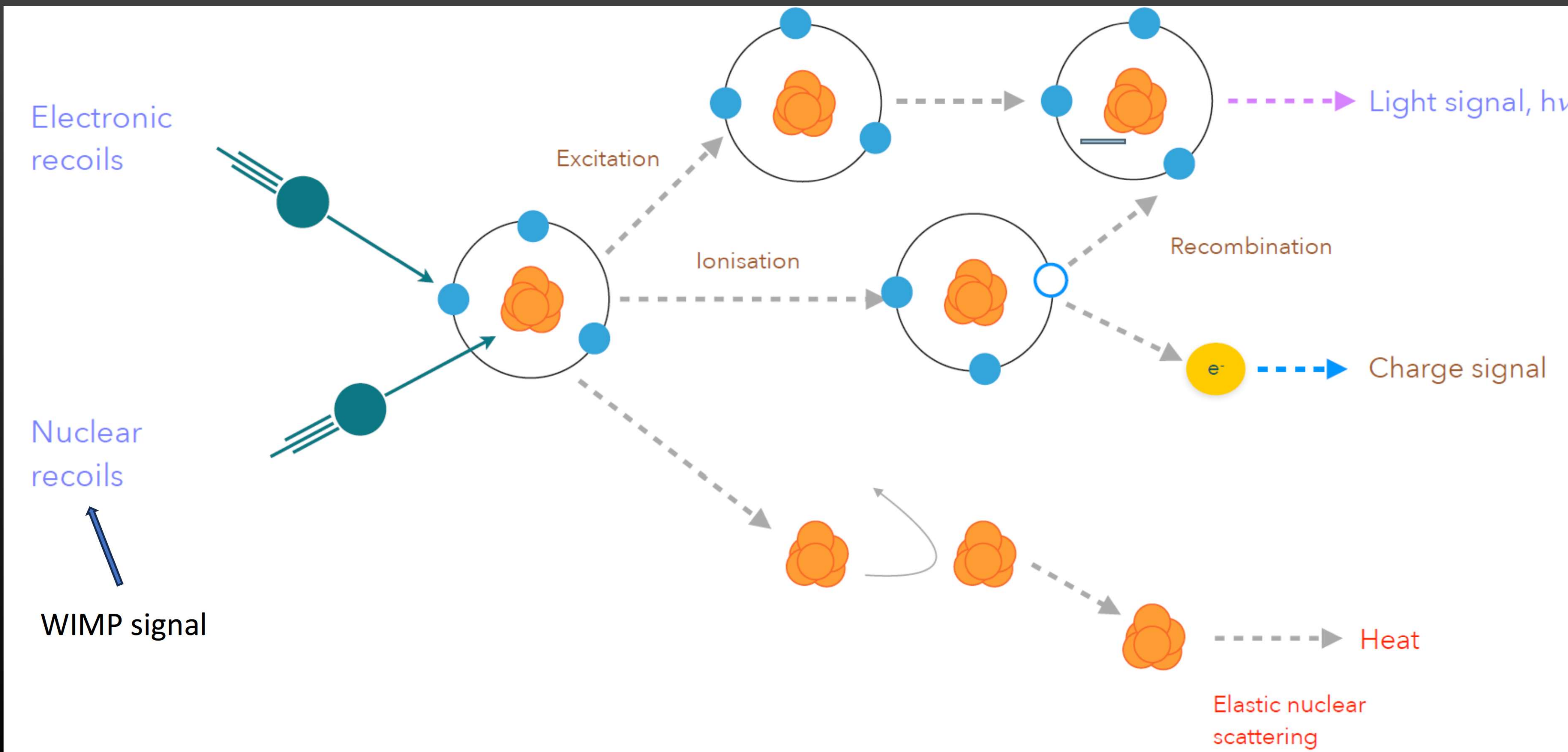
muon flux [cm^{-2}s^{-1}]
depth [m.w.e.]
flat overburden
CLAB400
WIPP
Y2L
LSC
Soudan
Kamioka
Yemilab
CLAB990
SUPL
Boulby
LNGS
CLAB1390
CLAB
SURF
LSM
Baksan
SNOLAB
CJPL
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
1000
2000
3000
4000
5000
6000
7000

Direct dark matter search experiments

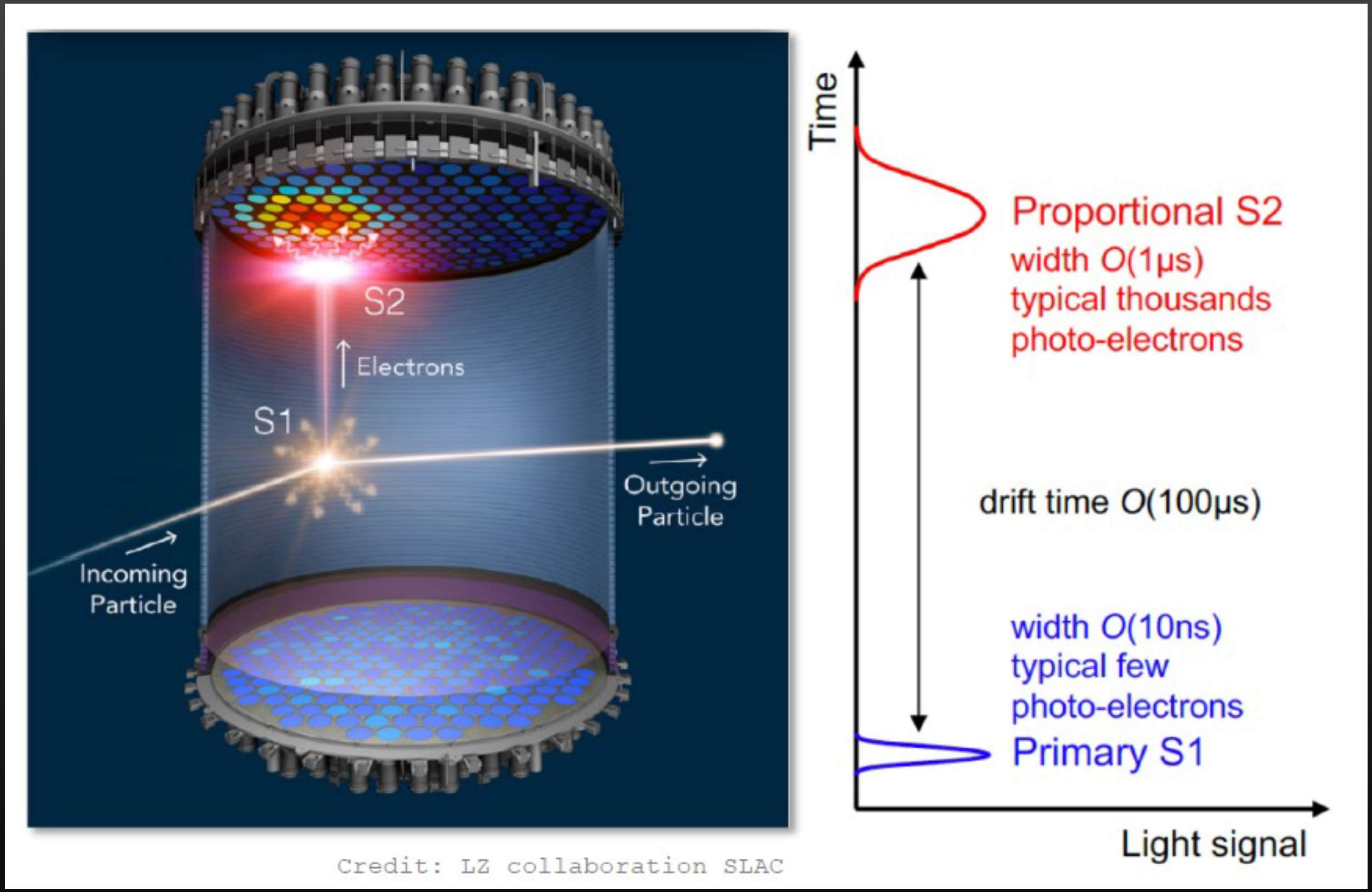
With noble liquids



Interaction in Ar/Xe



Dual-phase TPC



Dual-phase time projection chambers

→ primary scintillation signal S1

→ ionisation electrons via secondary scintillation S2 in the gas

→ particle identification via ratio S2/S1

→ position reconstruction

→ multi-scatter rejection

+ in Ar: pulse shape discrimination

Light production less efficient than ionization

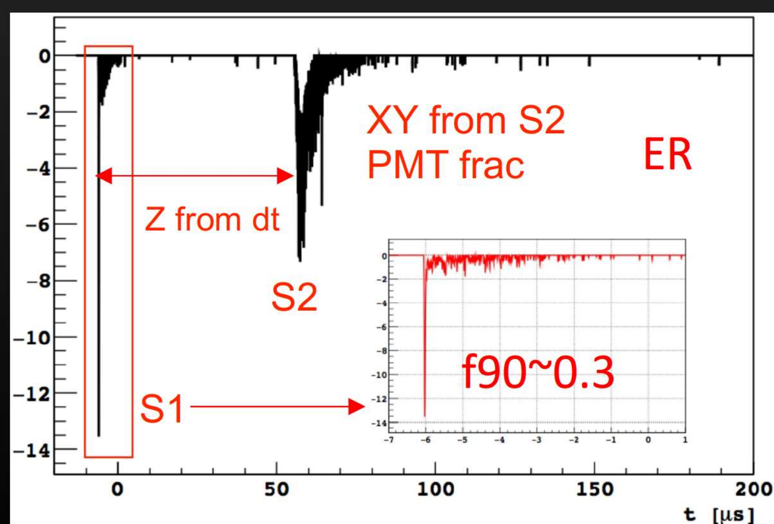
S2 only-mode

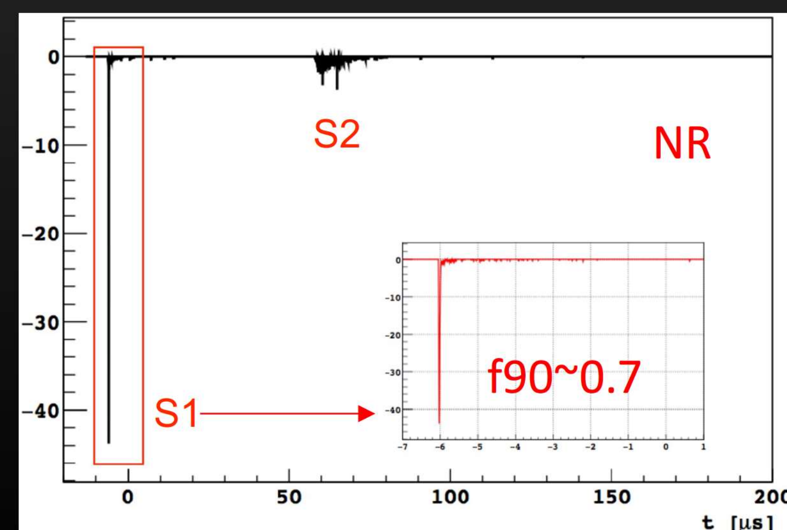
→ sensitive to single extracted electrons

→ lower energy thresholds

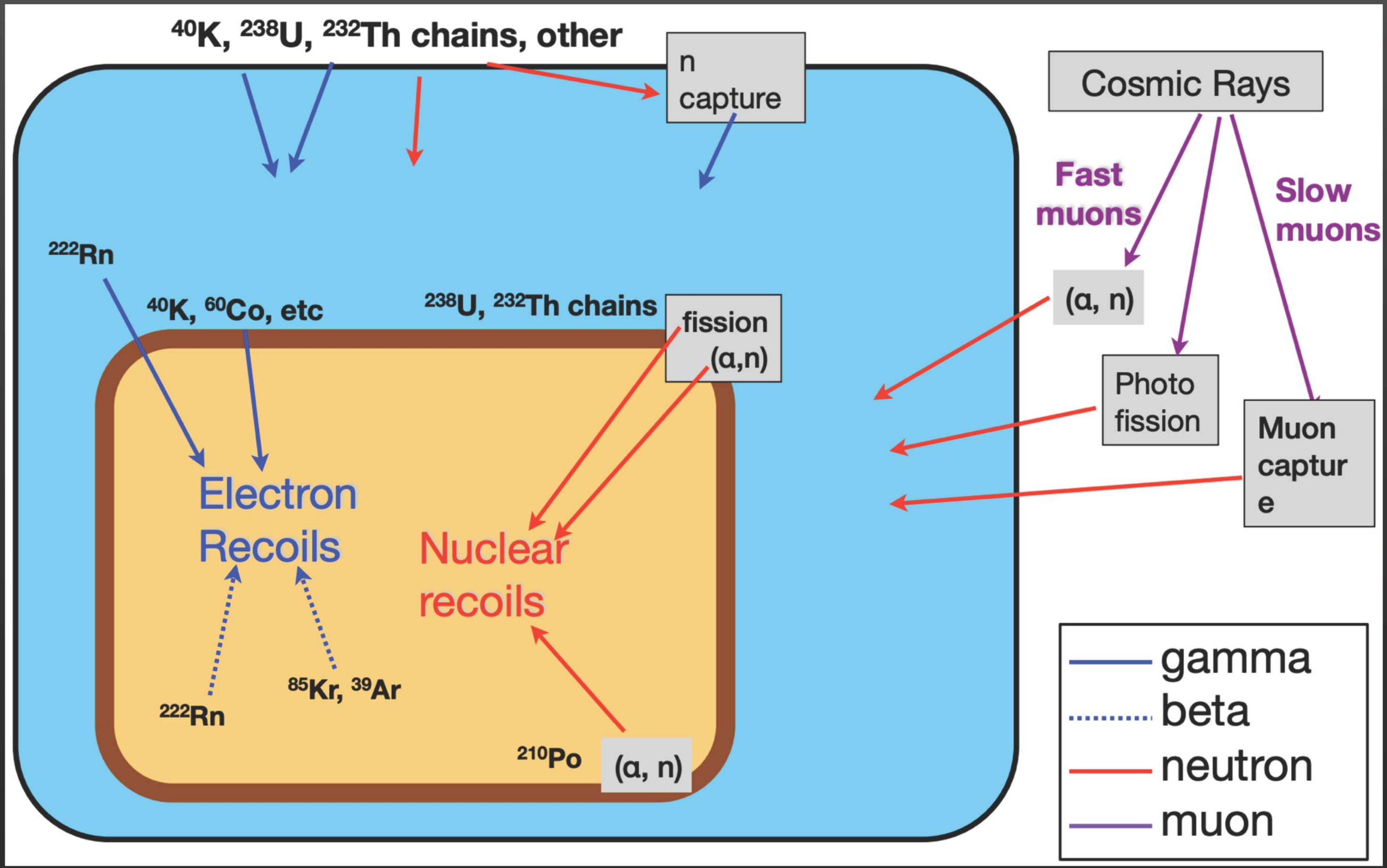
Why argon is of interest to me ?

- Pro:
  - Low temperature (87K), Rn removal is easier Where in Xe, Rn is the major BG
  - Scintillation light has powerful ER discrimination Not applicable in Xe
  - More NR energy deposit compared to the case of Xe
- Con:
  - Intrinsic ER BG from ^{39}Ar. Solution: use argon from underground source.
  - Wavelength is too short, 128 nm. Solution: use wavelength shifter.



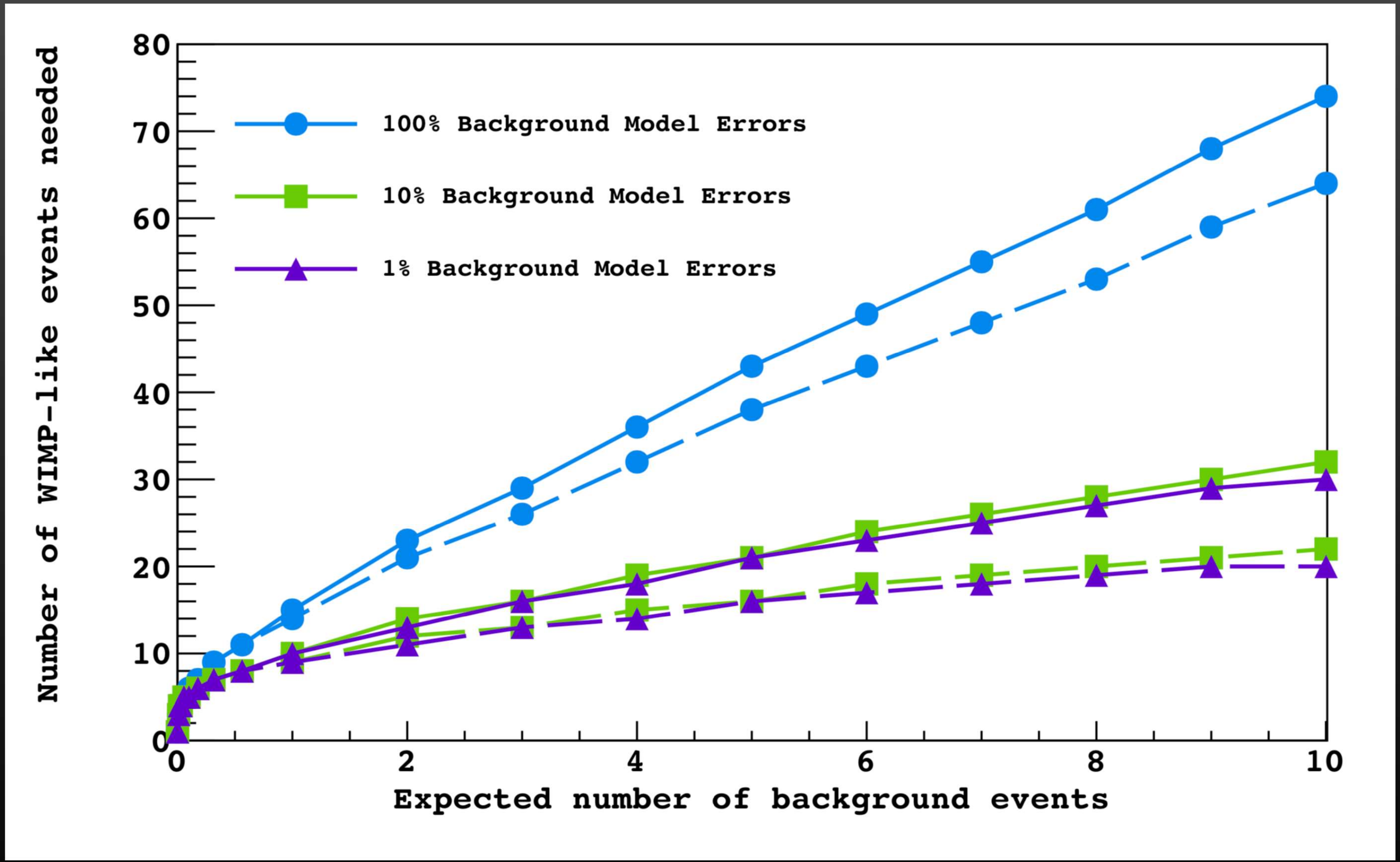


Background



Ambient background ~10^{11} times DM rate

Signal ?

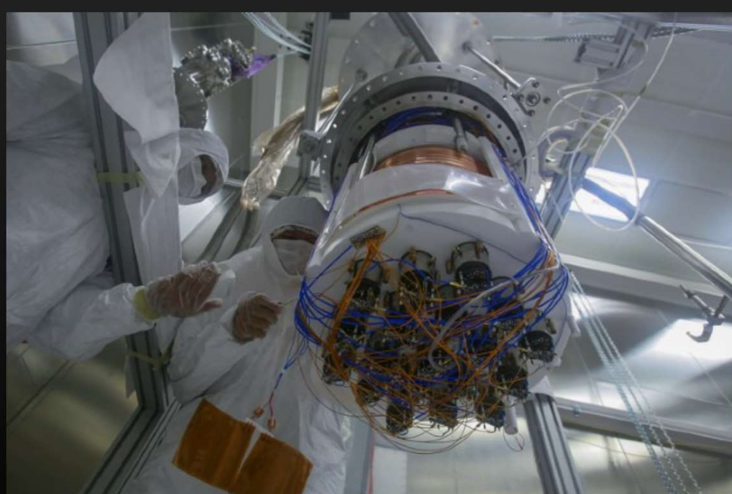


As few as 5 events would claim discovery, if the number of background events is < 0.1

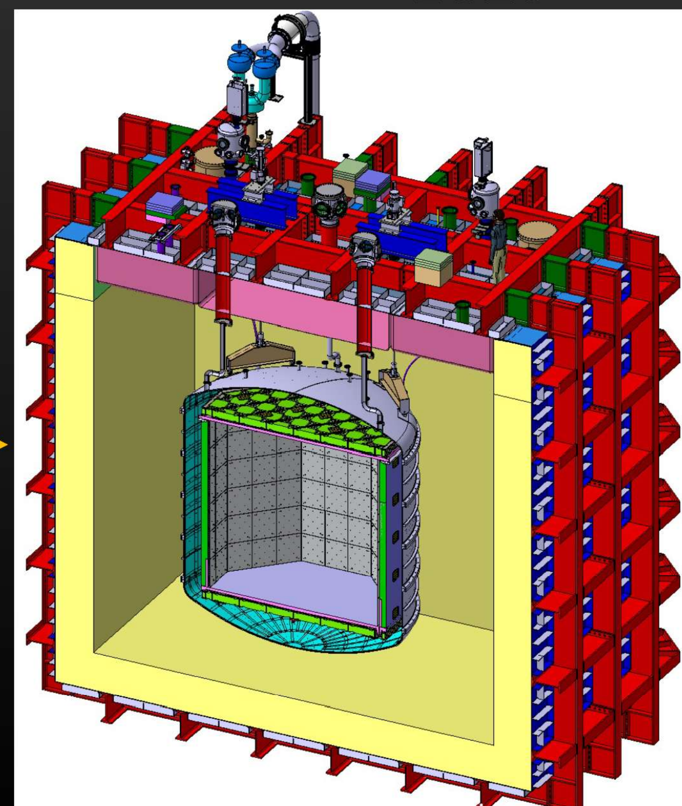
The Roadmap of DarkSide

- Dual phase argon time projection chamber (TPC);
- Argon from underground source;
- Goal: background-free WIMP search

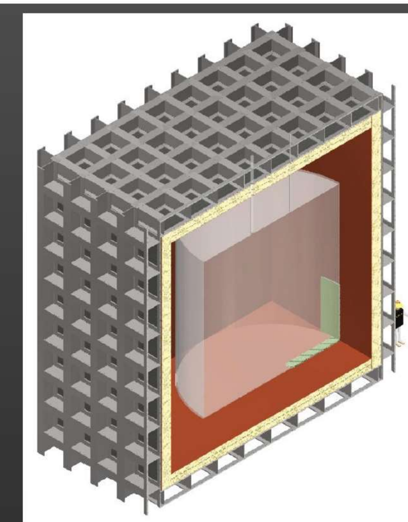
DarkSide-50 @LNGS
46.4 kg (active)
2013~2021

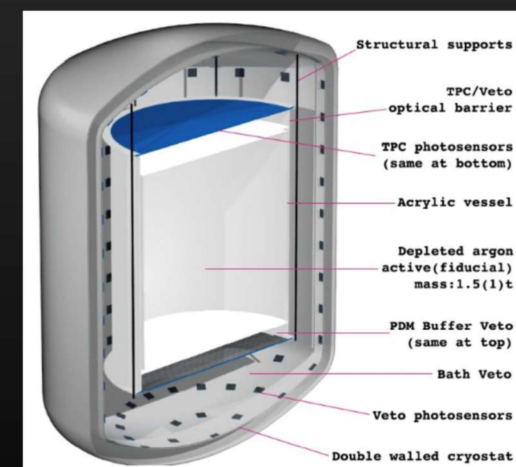


DarkSide-20k @LNGS
49.7 tonnes (active)
2026~



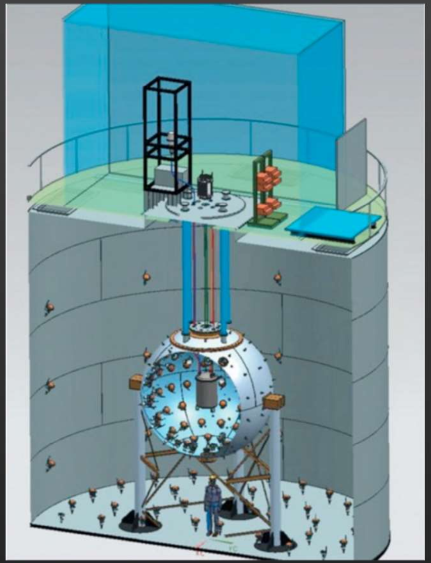
ARGO @SNOLAB
3000 tonne-year exposure
2030s

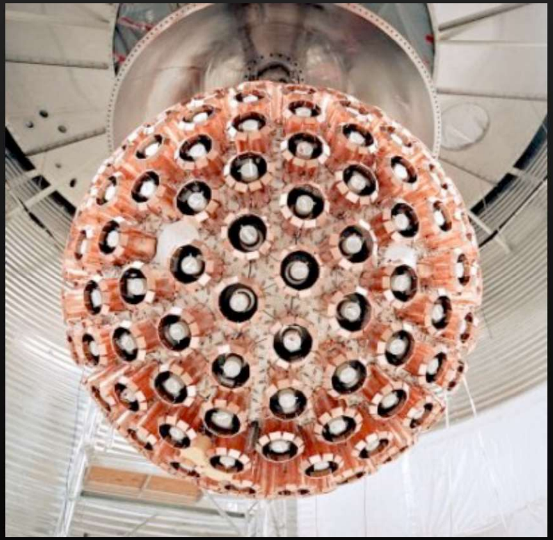




DarkSide-LowMass @CJPL
1 tonne-year exposure
2028~

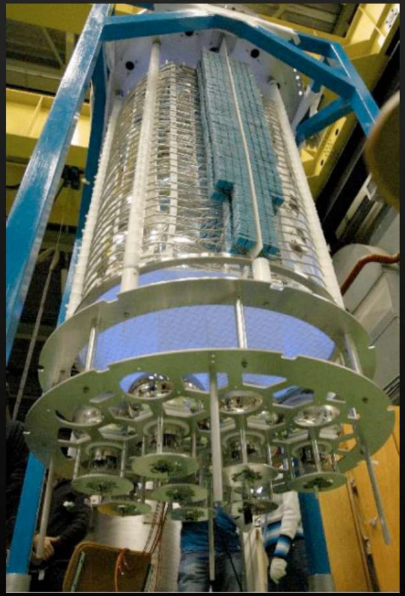
Global Argon Dark Matter Collaboration

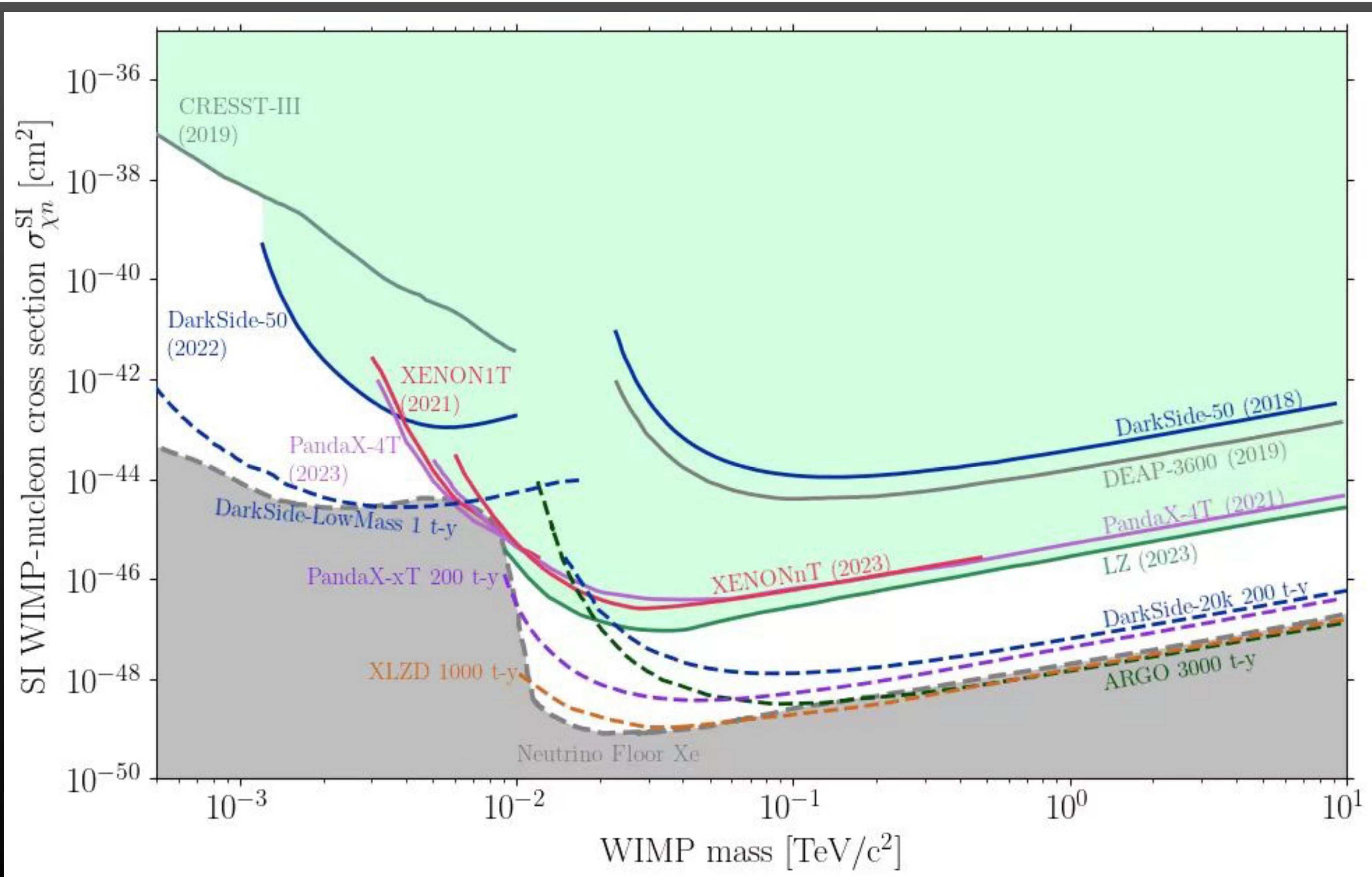




- **Combined expertise from 4 LAr experiments**
- **Over 400 collaborators from 100 different institutes**

GOAL:
To explore dark matter to the neutrino floor and beyond with extremely low instrumental background



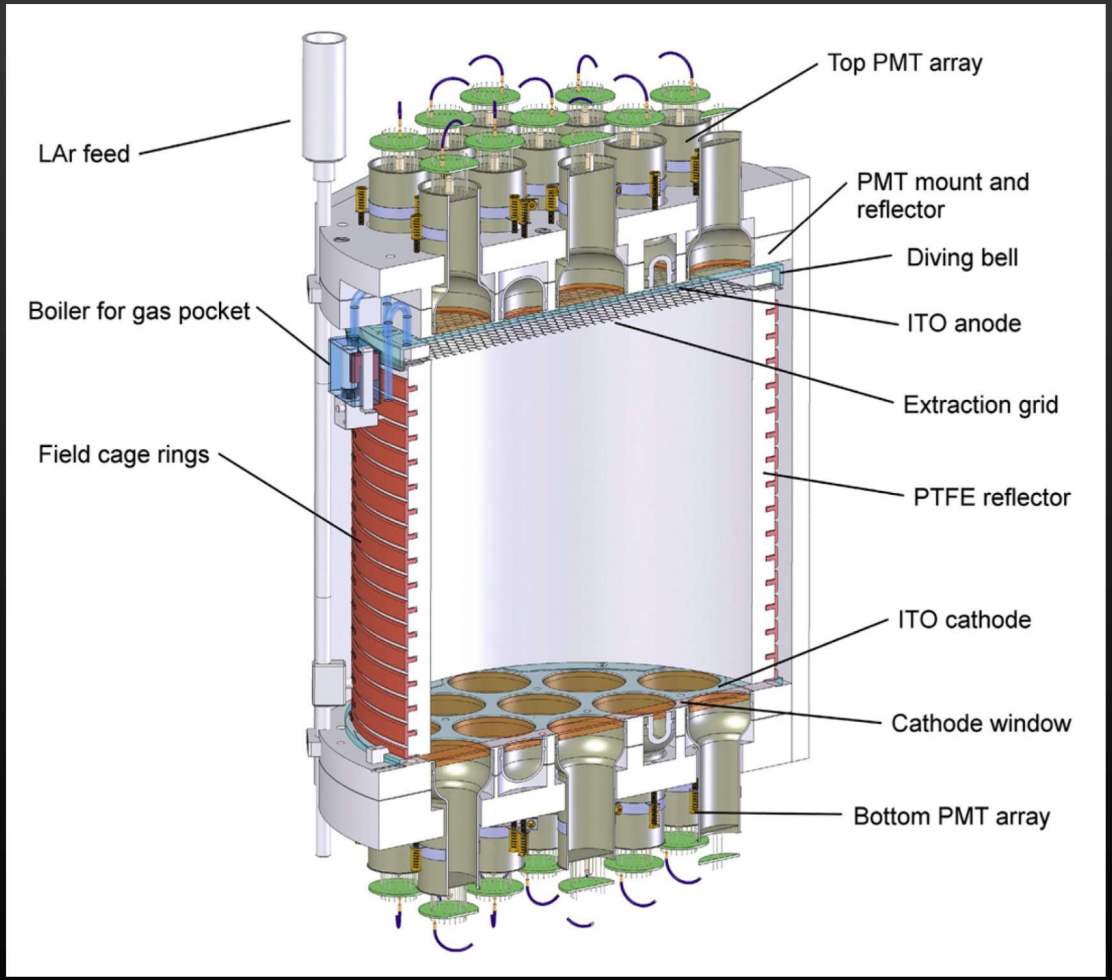


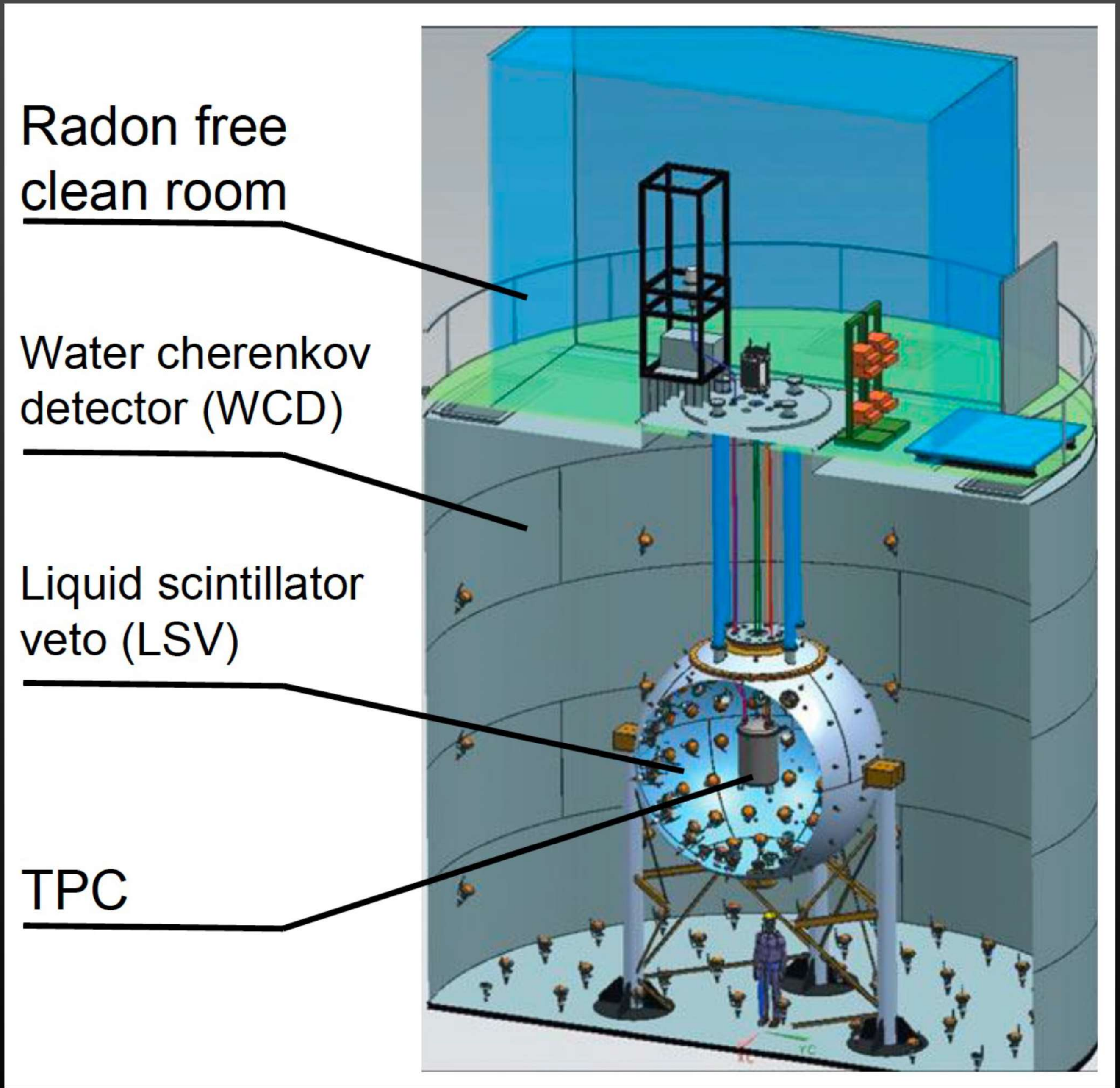
CRESST-III (2019)
DarkSide-50 (2022)
XENON1T (2021)
PandaX-4T (2023)
DarkSide-LowMass 1 t-y
PandaX-xT 200 t-y
XLZD 1000 t-y
Neutrino Floor Xe
XENONnT (2023)
DarkSide-50 (2018)
DEAP-3600 (2019)
PandaX-4T (2021)
LZ (2023)
DarkSide-20k 200 t-y
ARGO 3000 t-y
SI WIMP-nucleon cross section $\sigma^{SI}_{\chi n}$ [cm^2]
WIMP mass [TeV/c^2]
10^{-36}
10^{-38}
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

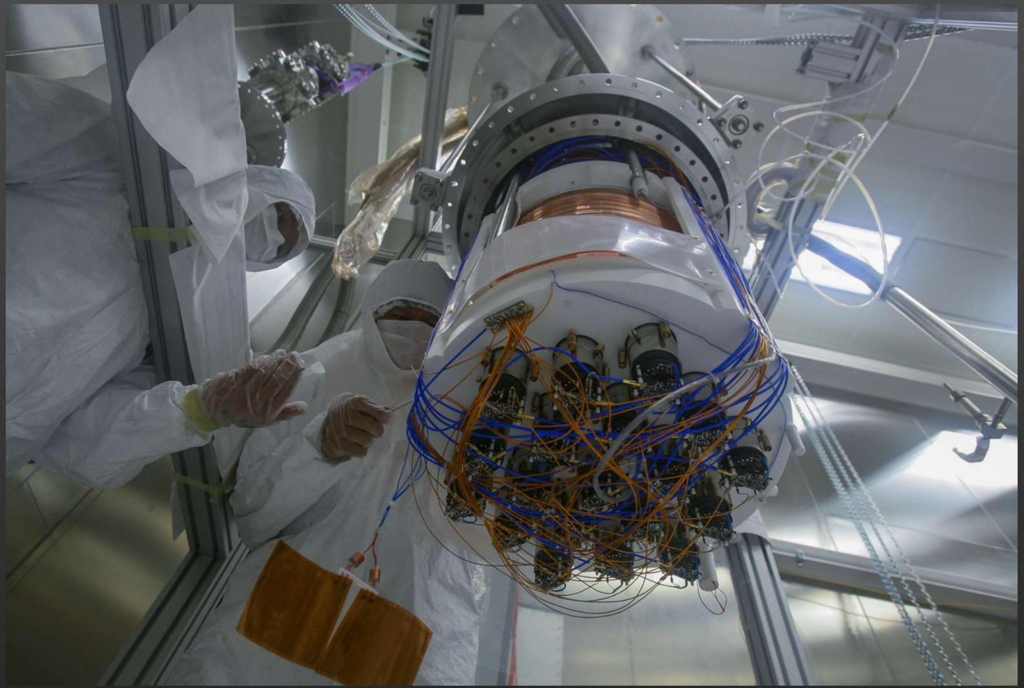
DarkSide-50 @LNGS

DarkSide-50

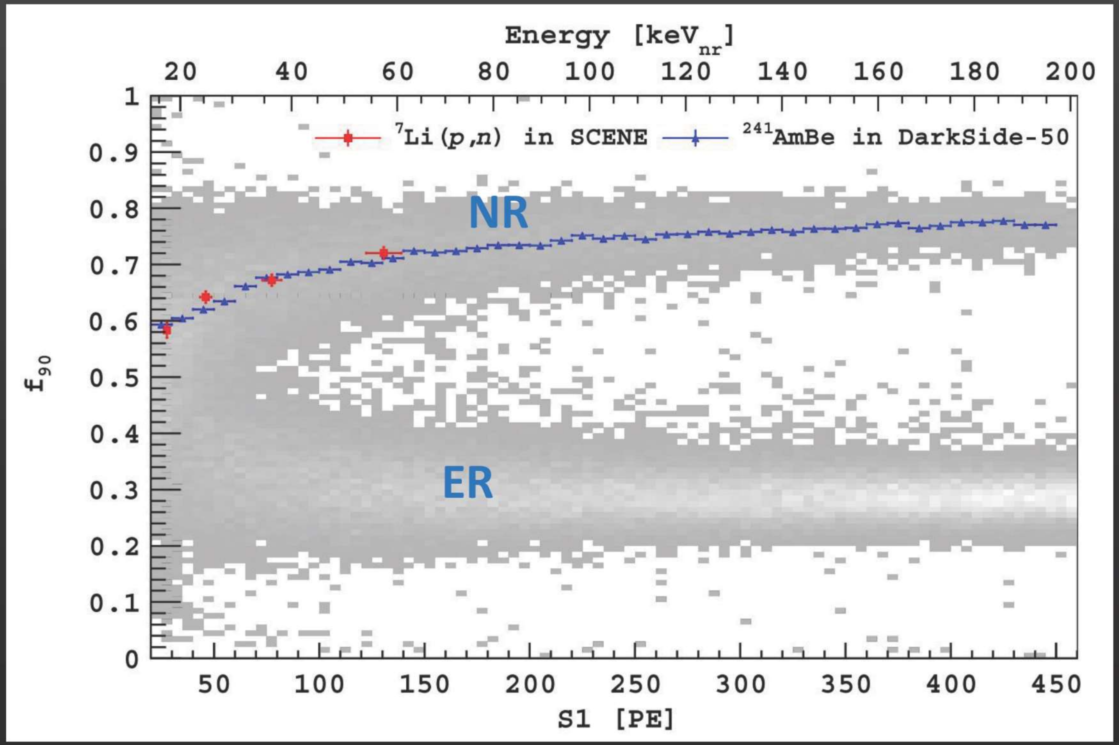
- 156kg total, 46kg fiducial



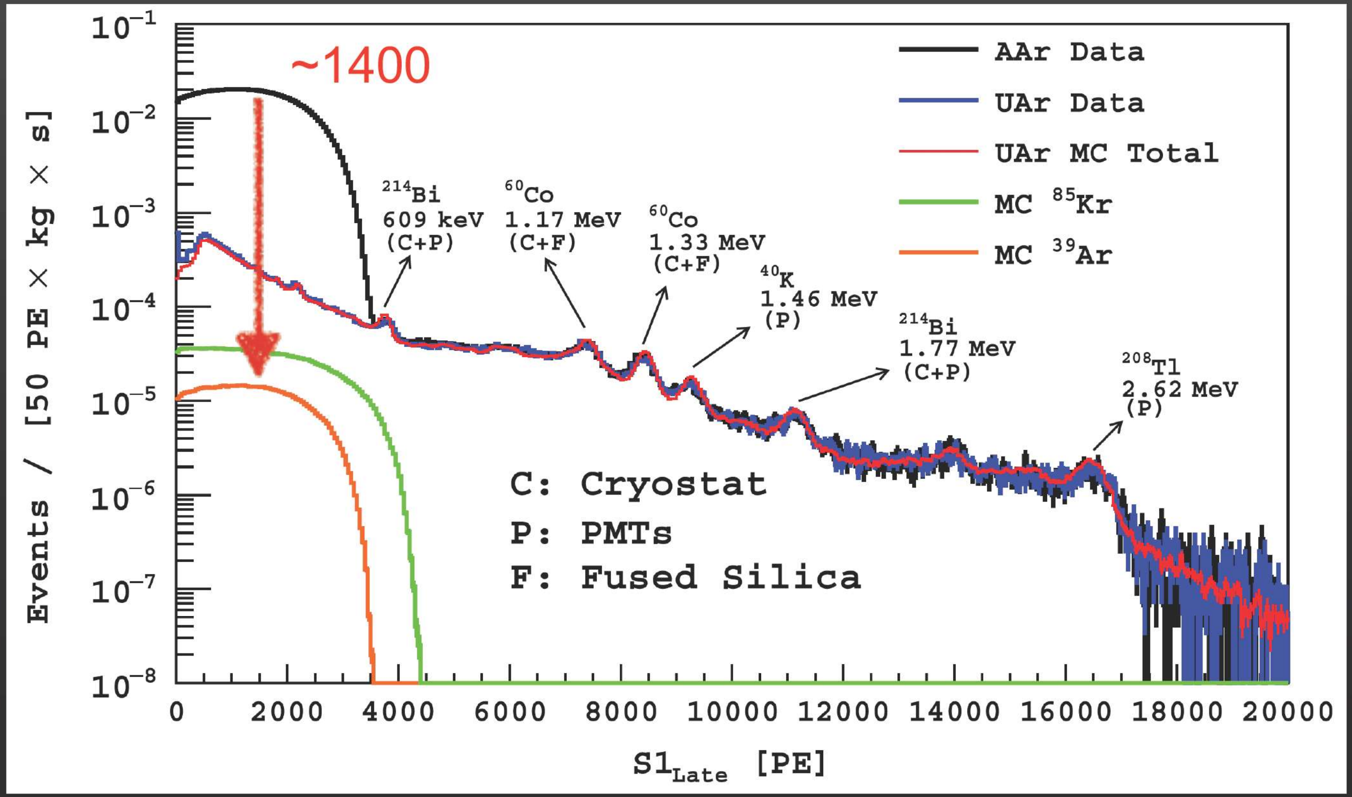




DarkSide-50 backgrounds

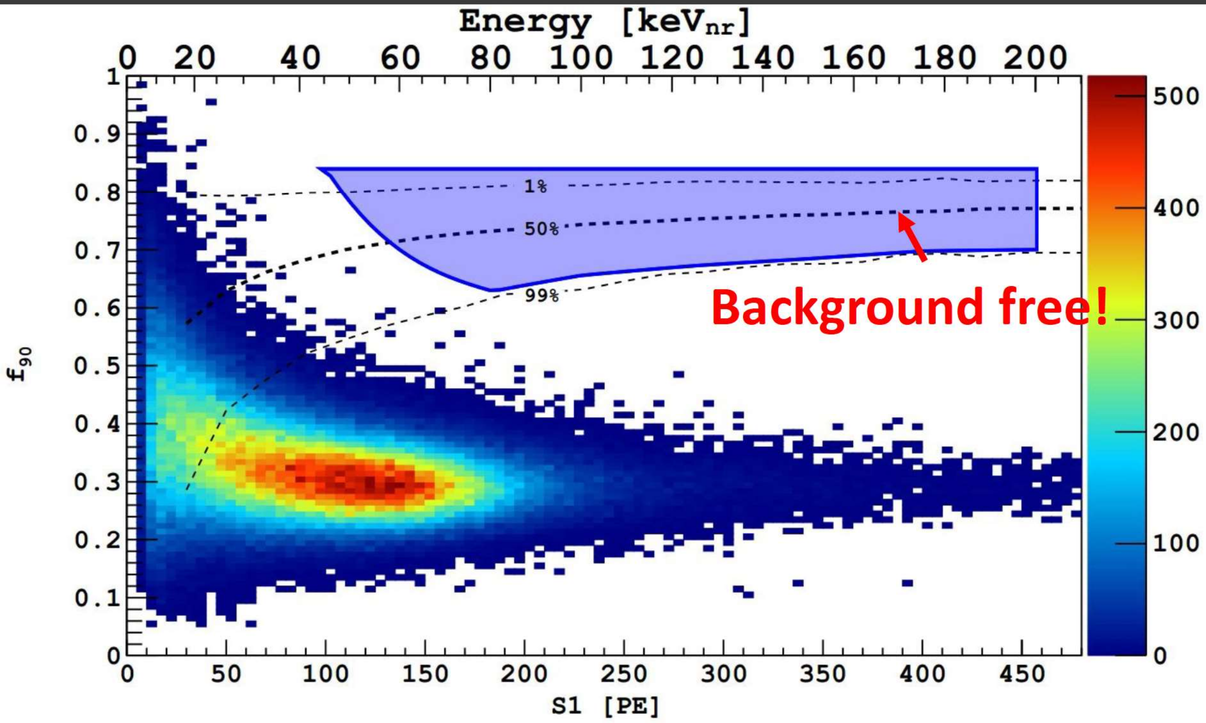


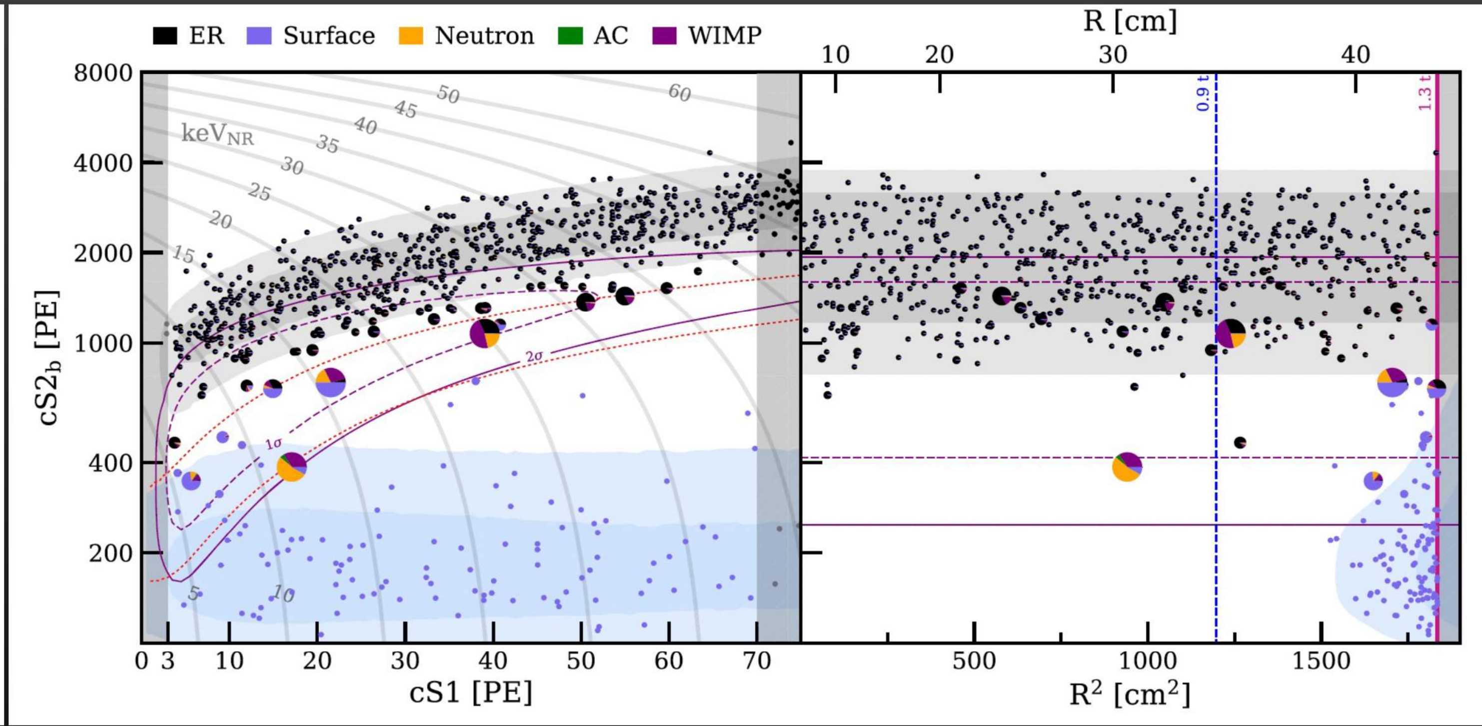
S1 ER rejection power > 10^8



Demonstration of UAr, ^{39}Ar has been reduced by 1400

DarkSide-50 results





DarkSide-50
Background-free high mass WIMP search results

XENON1T high mass WIMP search results

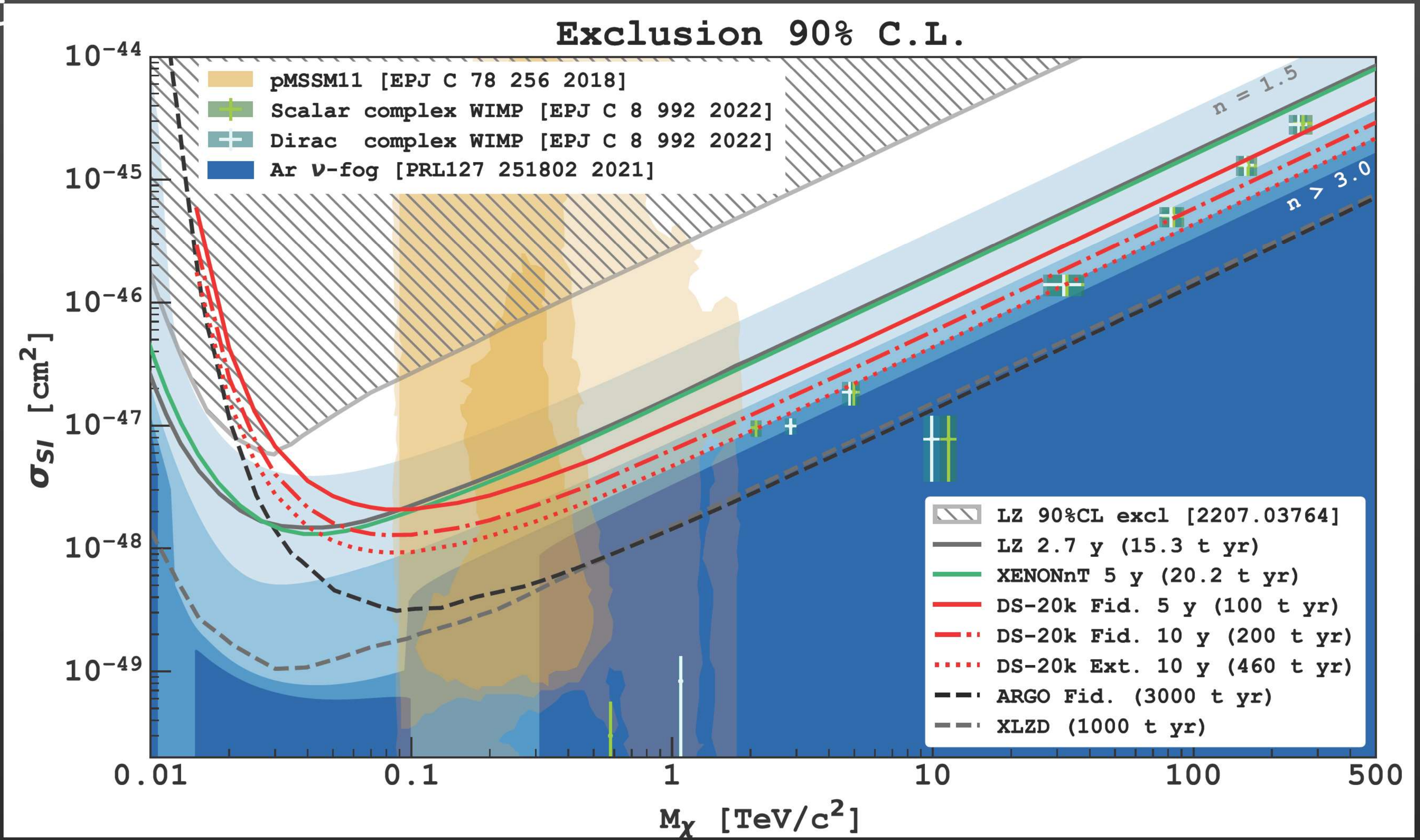
DarkSide-20k @LNGS

DarkSide-20k Projections

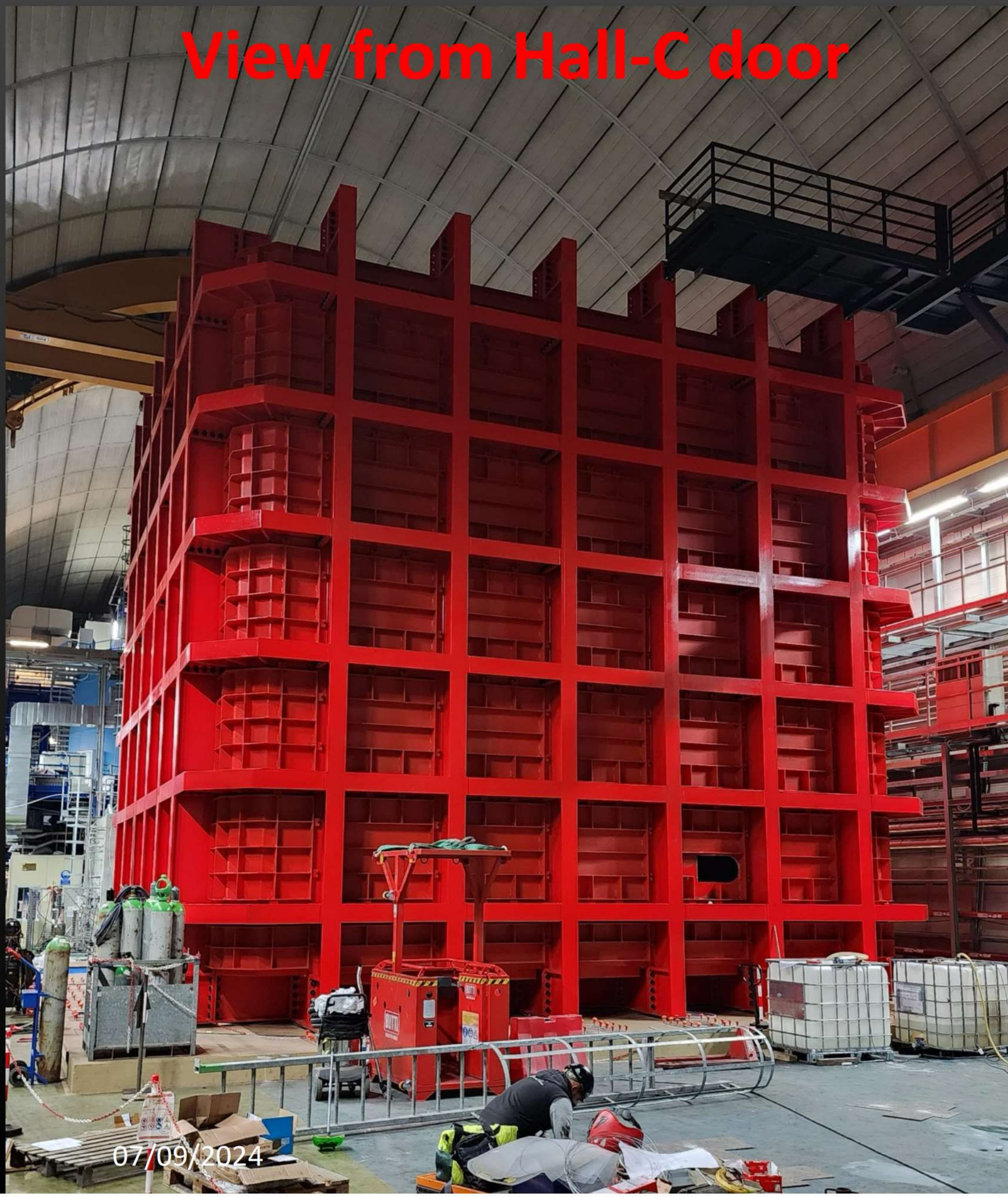
- Sensitivity to Spin-Independent WIMPs;
- With nominal exposure 200 t-y (20 t x 10 years):
  - 90% C.L. exclusion: 6.3×10^{-48} cm^2 @1 TeV/c^2 ;
  - 5 σ discovery: 2.1×10^{-47} cm^2 @1 TeV/c^2 ;
  - Sensitivity of core-collapse supernova neutrinos.

JCAP03(2021)043

- Instrumental background: < 0.1 neutrons in RoI (30~200 keVnr) with 200 t-y exposure.



DarkSide-20k Overview



Membrane "ProtoDUNE-like" cryostat

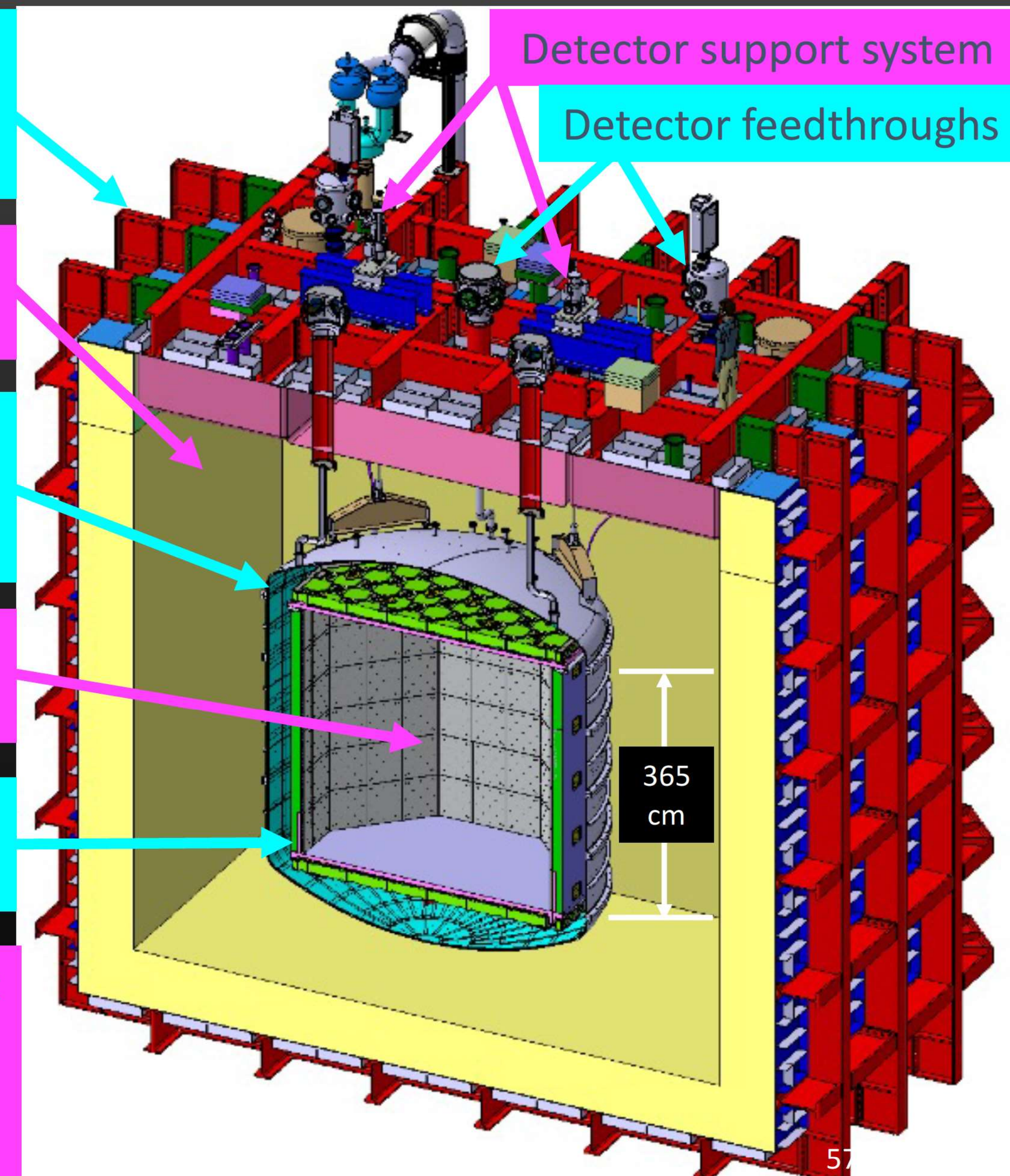
Atmospheric argon (AAr) volume (≈700 t)

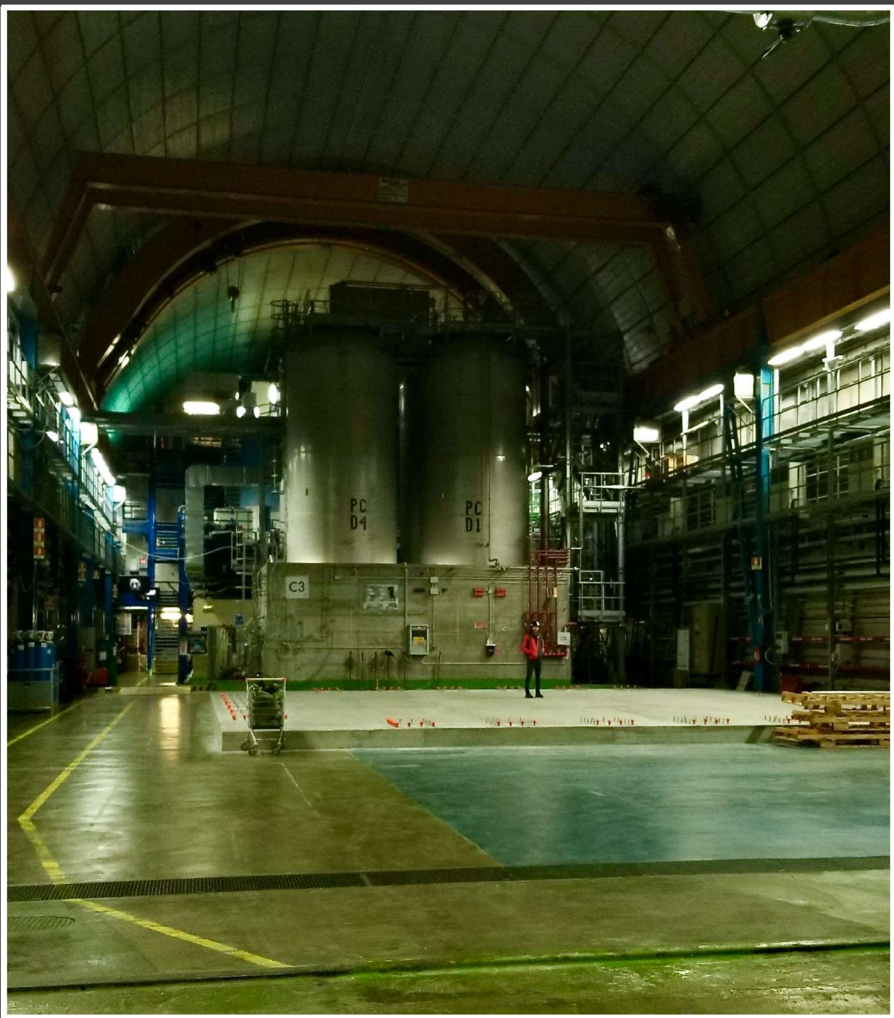
Vacuum vessel containing UAr and TPC/veto

Underground argon (UAr) volume (≈100 t)

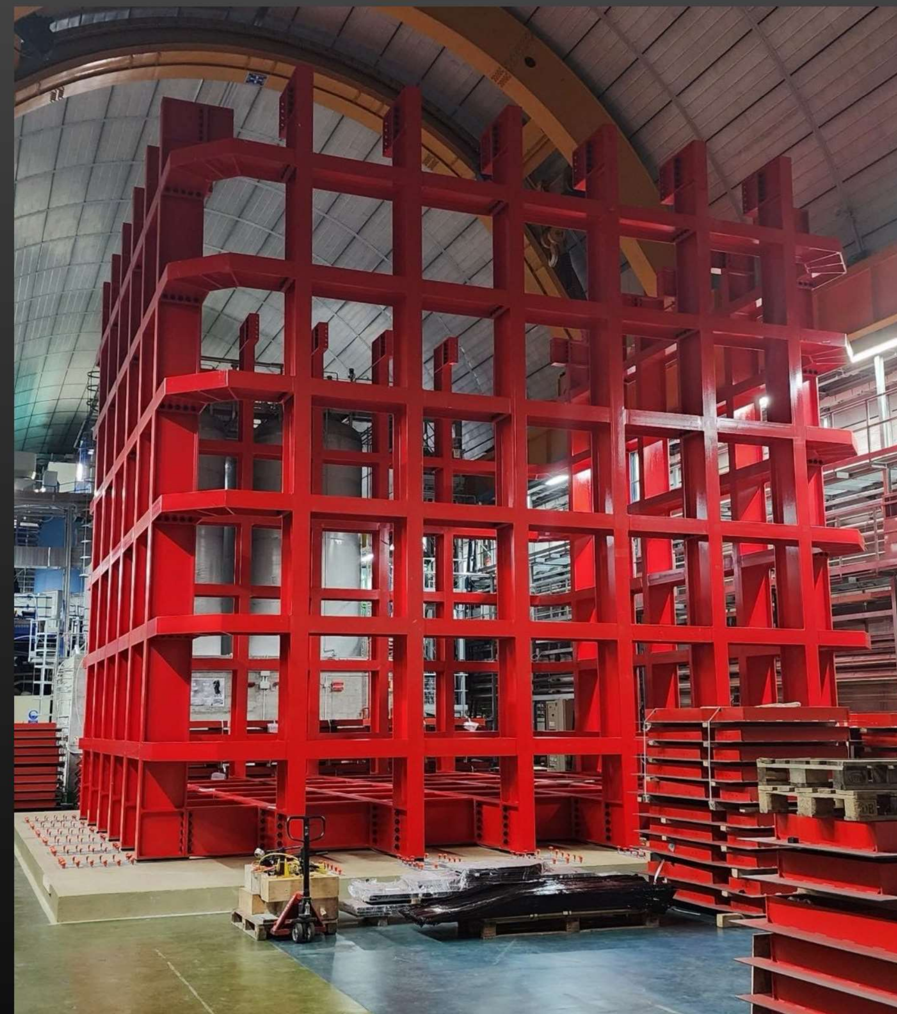
"Inner detectors", TPC and neutron veto

Outer veto will consist of SiPM arrays near the cryostat walls looking inward





Feb 2023

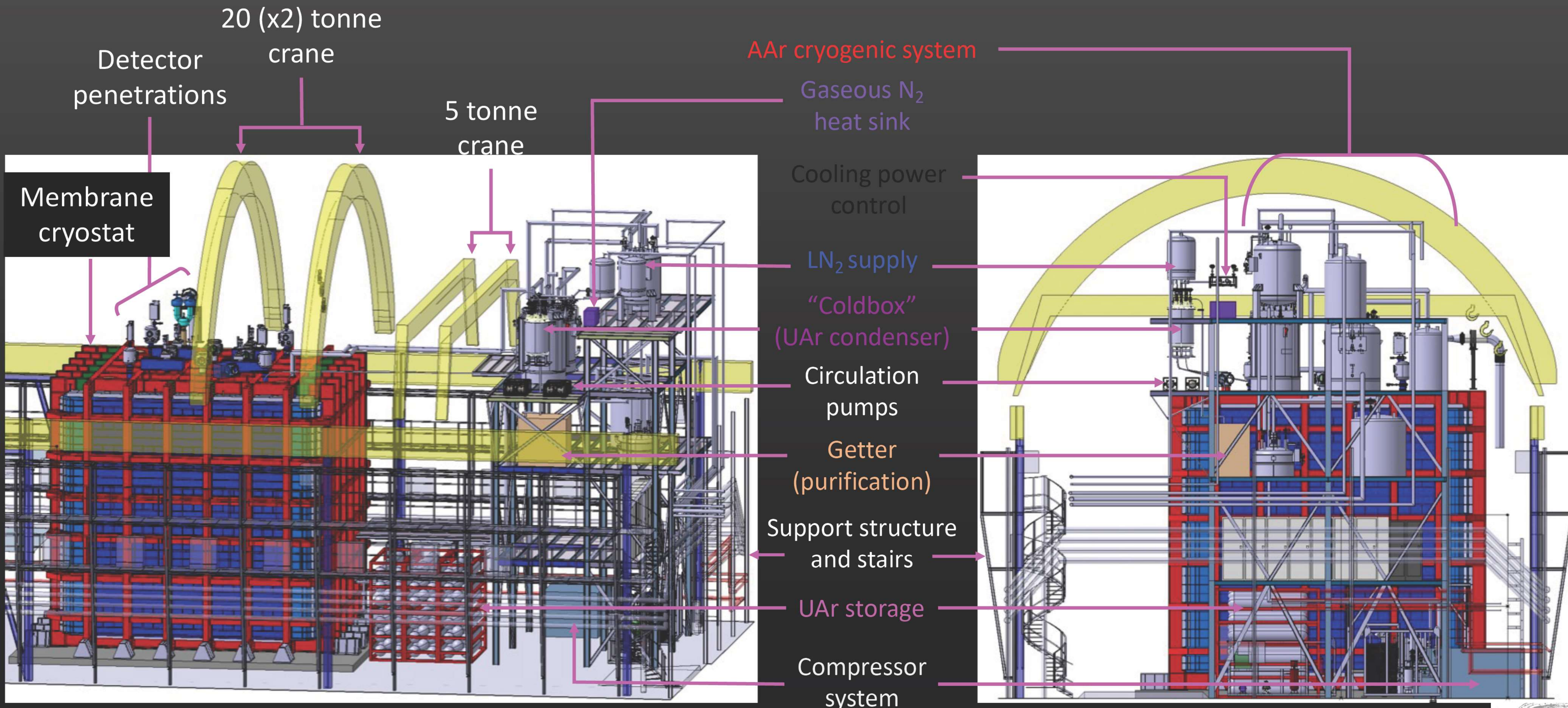


June 2023

October 2023

DarkSide-20k Overview

@Hall C LNGS in Italy



Challenge of DarkSide-20k

- World largest dual-phase TPC for scintillation purpose, a huge amount of R&D.

  IHEP

- 100 tonnes of UAr is required, DarkSide-50 only required 160 kg.

  IHEP

- Efficient neutron veto for "background-free" goal.

  IHEP

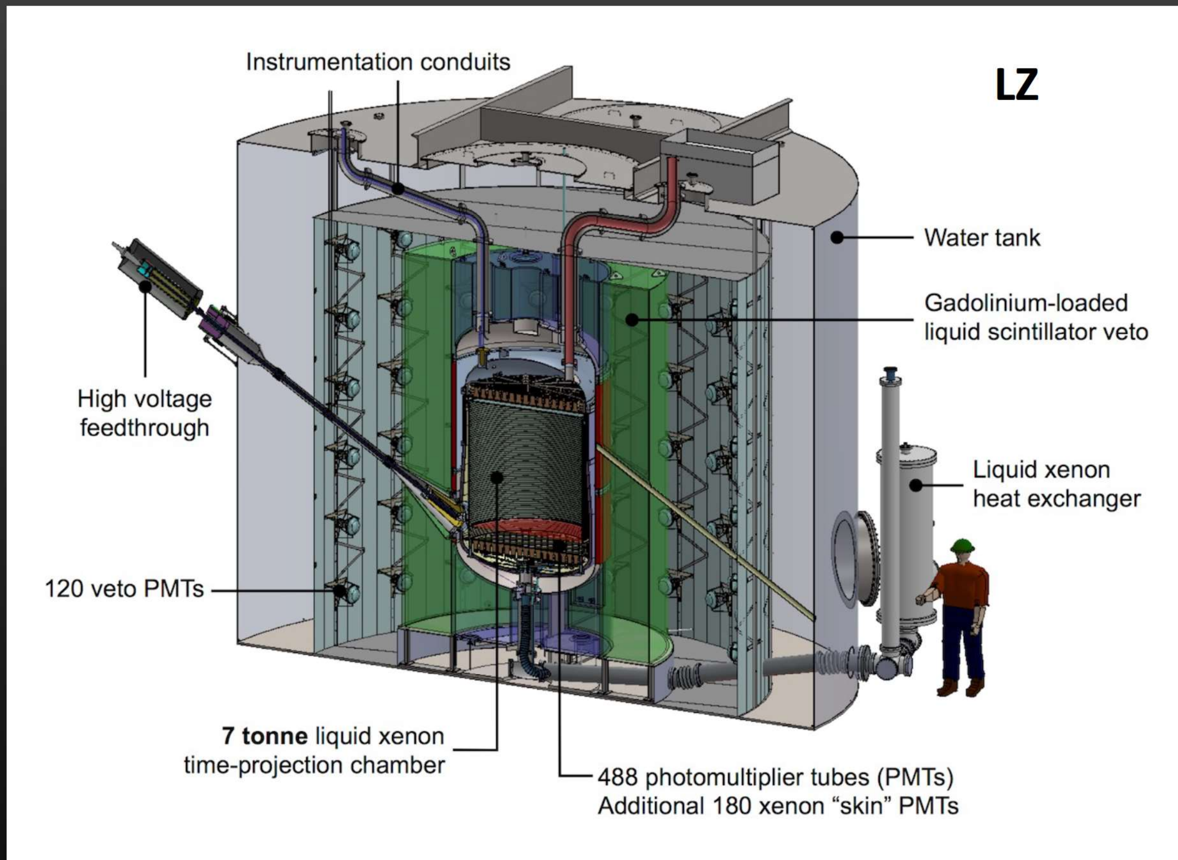
- Large area photon detection technique.

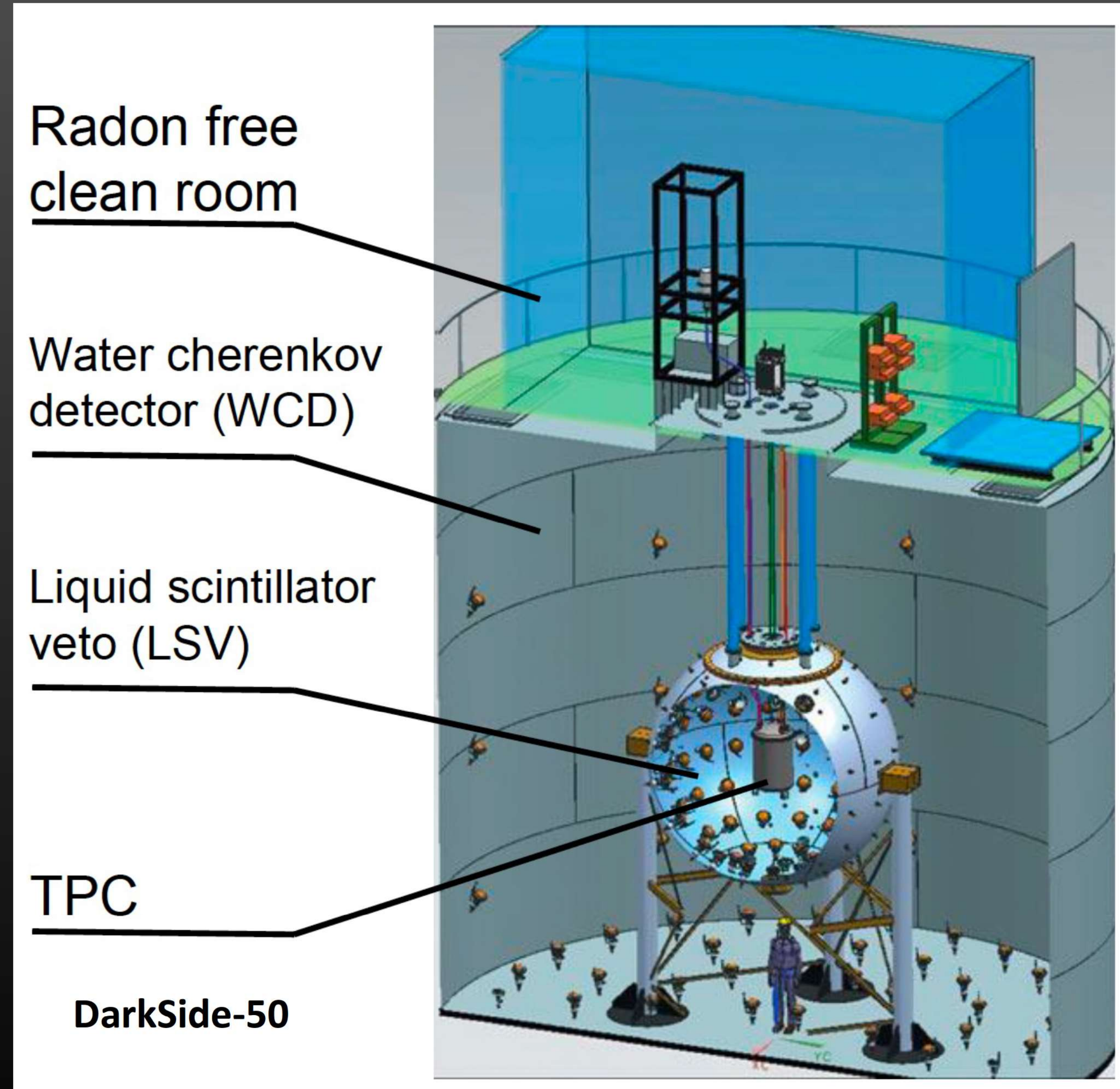
  IHEP

How do we suppress the background for such a large detector ??

Neutron veto, ^{39}Ar, U & Th

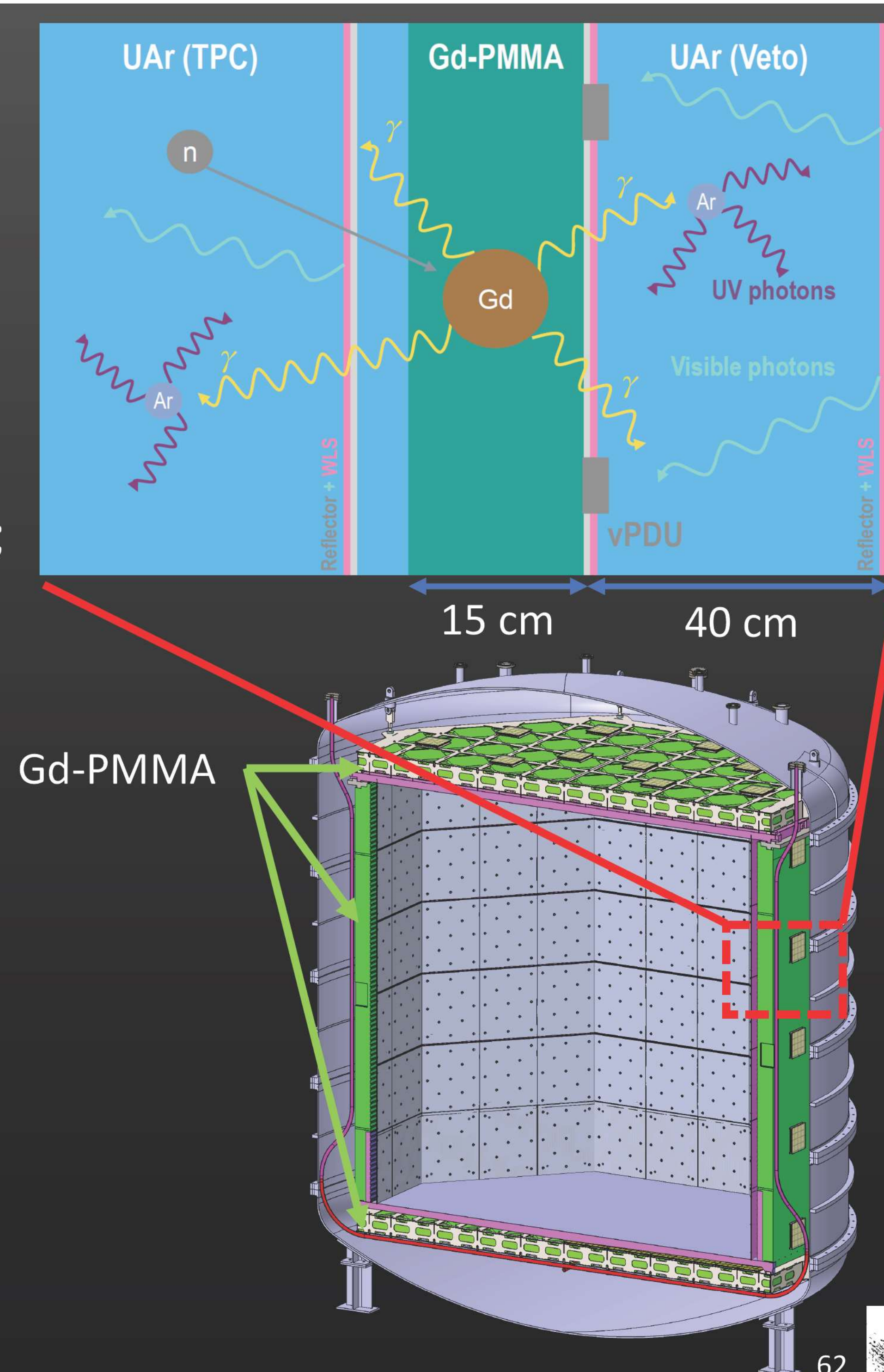
Neutron veto

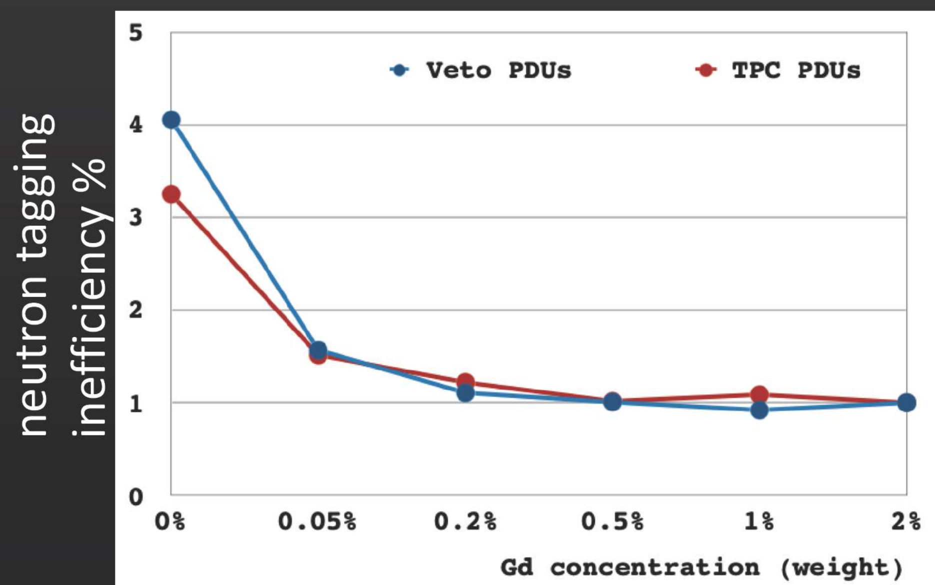




Novel neutron veto

- Acrylic (Hydrogen) + Gadolinium + Argon
  - ➢Gd-PMMA (1 wt%), 15 cm thick;
  - →4π coverage: TPC walls, top & bottom endcaps;
  - ➢40 cm thick UAr buffer + UAr in TPC;
- Produced γ rays interact in UAr in both buffer and TPC;
- ESR as reflector and PEN as wavelength shifter;
- Scintillation lights detected by SiPMs in both buffer and TPC.

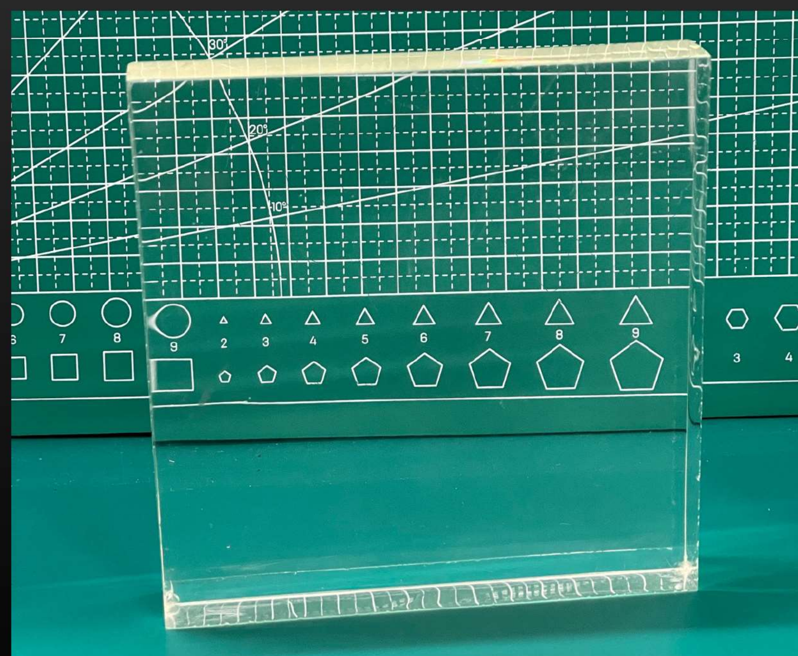




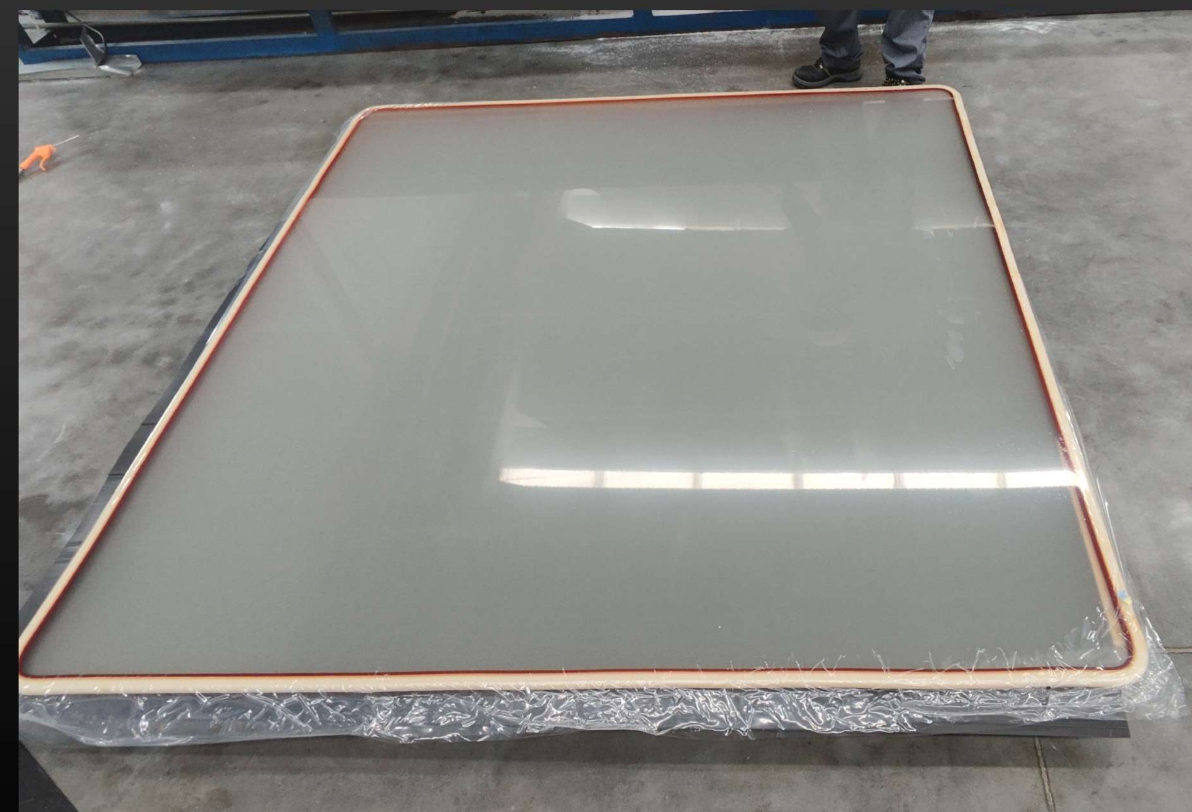
Gd-PMMA R&D and Production in China

Gd-PMMA based on Gd(MAA)3 is developed at IHEP.

Gd-PMMA samples during the R&D phase.
Gd concentration is 1 wt%.



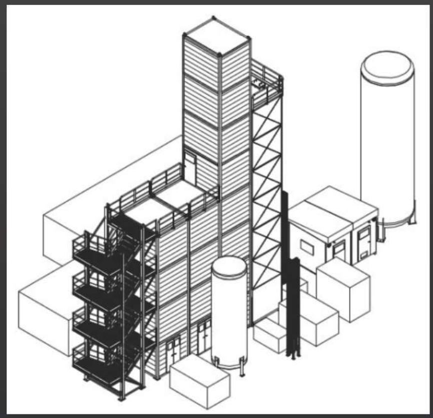
First full-size Gd-PMMA panel produced at Donchamp in China.



UAr Production

URANIA (Extraction)

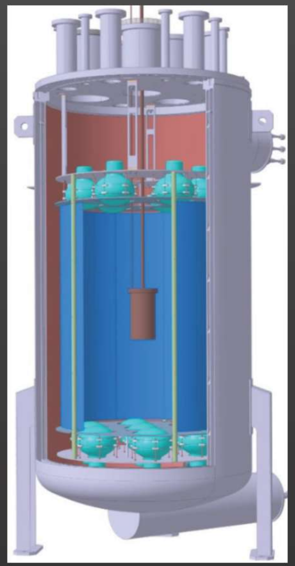
An industrial scale extraction plant in Cortez, CO, USA;
Extraction rate: 250~330 kg/day; UAr purity: 99.99%;
Capable to extract 120 tonnes UAr for DS-20k in 2 years;
Plant assembly in progress.

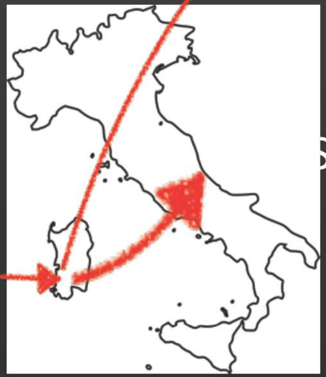


DArT in ArDM (Radiopurity assay)

At Canfranc Lab, Spain (LCS);
A single-phase detector to measure the ^{39}Ar depletion factor;
Sensitive to measure UAr depletion factors in excess of 1000;
DArT will soon be installed inside ArDM.

First result in
2020 JINST 15 P02024



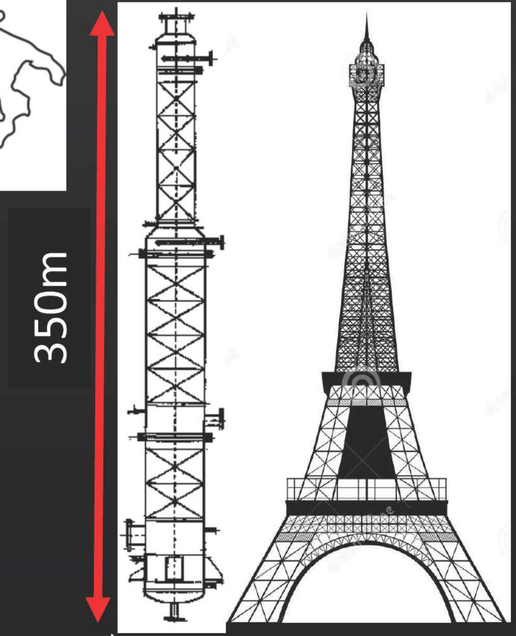


ARIA (Purification)

350 m tall cryogenic distillation column in Sardinia, Italy;
Chemical purification rate O (1 tonne/day);
UAr purity after ARIA: 99.999%;
Seruci-0 tested, Seruci-1 under construction;

Eur. Phys. J. C (2021) 81:359, Eur. Phys. J. C (2023) 83:453

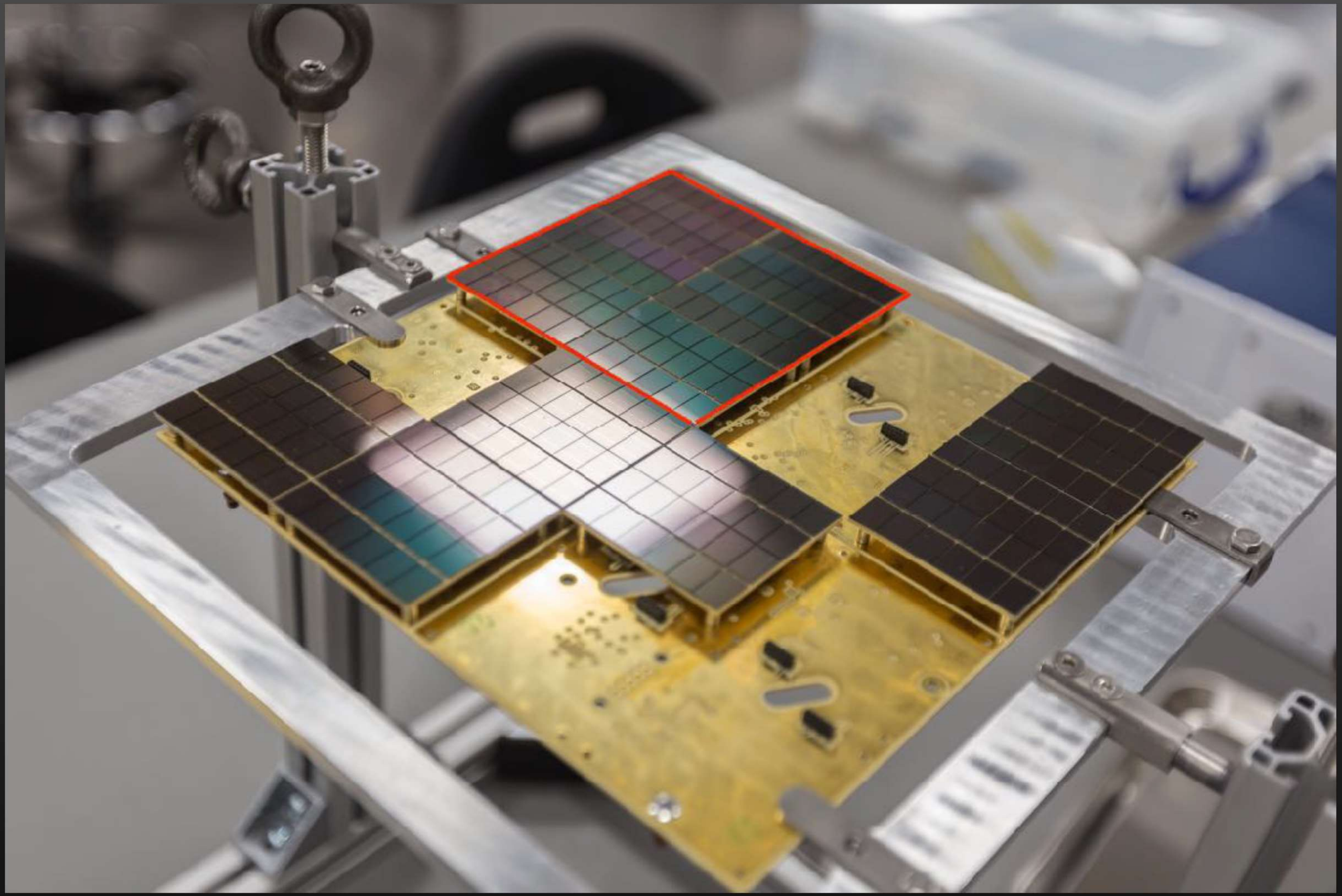
Capable to separate ^{39}Ar from ^{40}Ar at O (10 kg/day).



Distillation column assembly at CERN

PMT -> SiPM

Hamamatsu 3in PMT
R11065 for LAr



SiPM array
Developed by FBK, produced by LFoundry

4 PDMs are summed and read as a single channel.
Largest SiPM array!

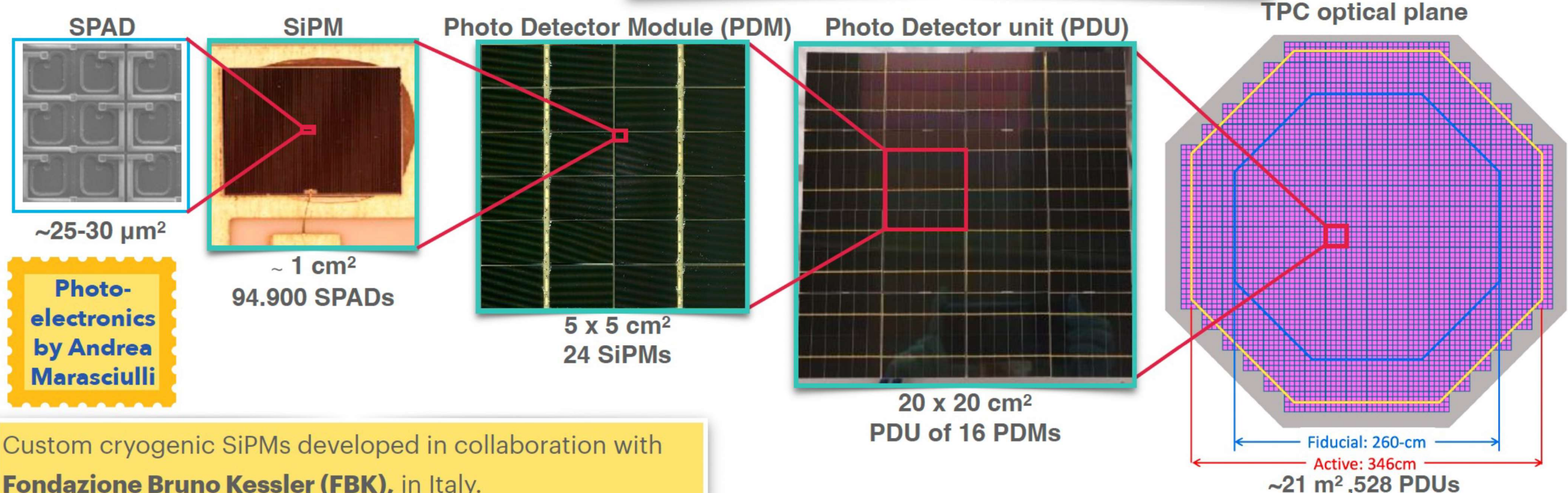


Photo-electronics by Andrea Marasciulli

Custom cryogenic SiPMs developed in collaboration with **Fondazione Bruno Kessler (FBK),** in Italy.

- **Photon detection efficiency (PDE) ~45%**
- **Low dark-count rate < 0.01 Hz/mm² at 77K (7 VoV)**
- **Timing resolution ~ 10 ns**

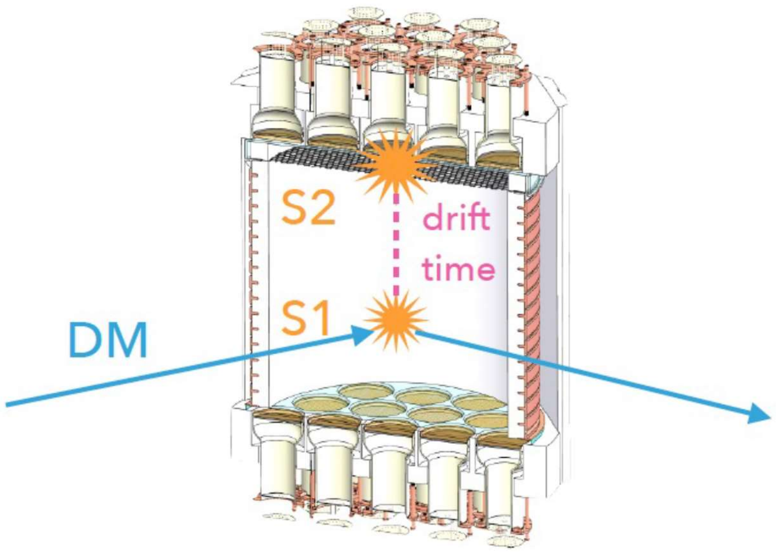
Mass production of the raw wafers at **LFoundry (Italy)**

- SiPM testing and assembling facility at **NOA (Nuova officina Assergi).**

DarkSide-20k will start taking data at the beginning of 2027 !

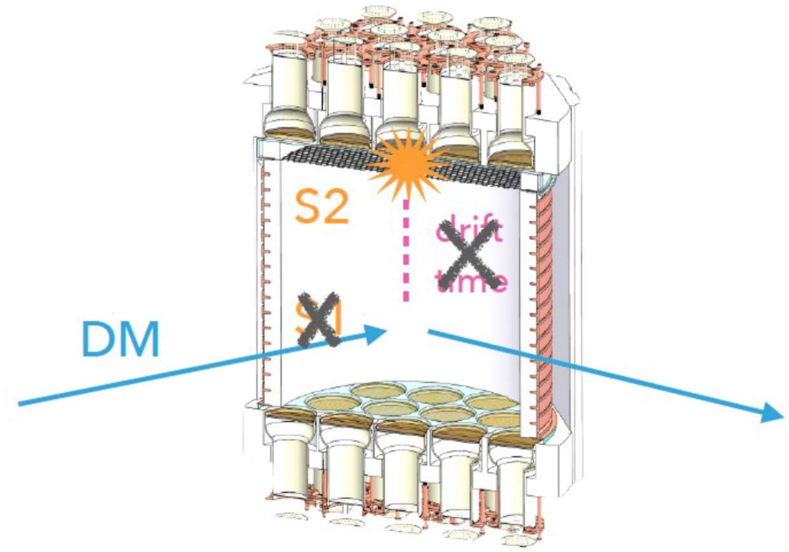
DarkSide-LowMass @CJPL

High Mass Search
High Energy Events



- Scintillation (S1) & Ionization (S2)
- Pulse Shape Discrimination (PSD)
- Drift time provides vertical event position

Low Mass Search
Low Energy Events

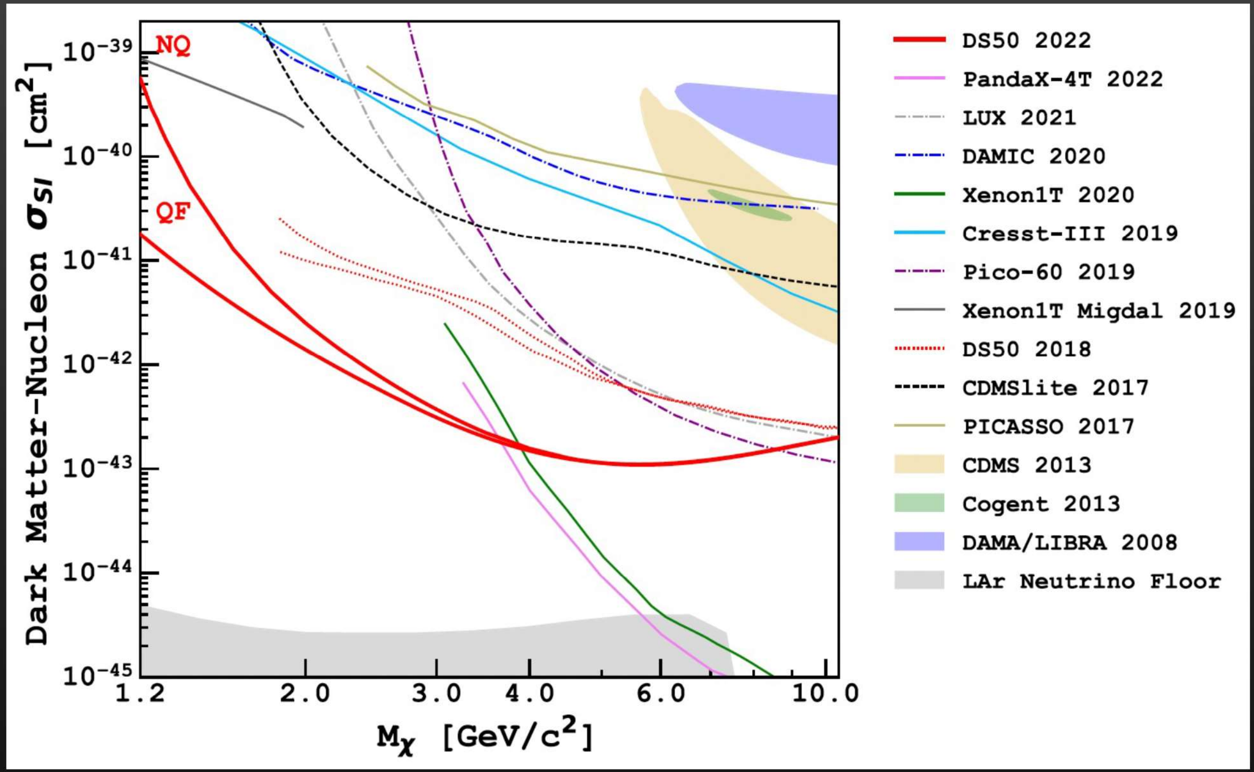


- Electrofluorescence in gas gap lets us detect single e- with high efficiency.
  →**Lower energy threshold**
- **No** PSD
- **No** vertical position

DarkSide-50 results for low mass

- Scintillation signal (S1): threshold at ~2 keVee / 6 keVnr;
- Ionization signal (S2): threshold < 0.1 keVee / 0.4 keVnr.

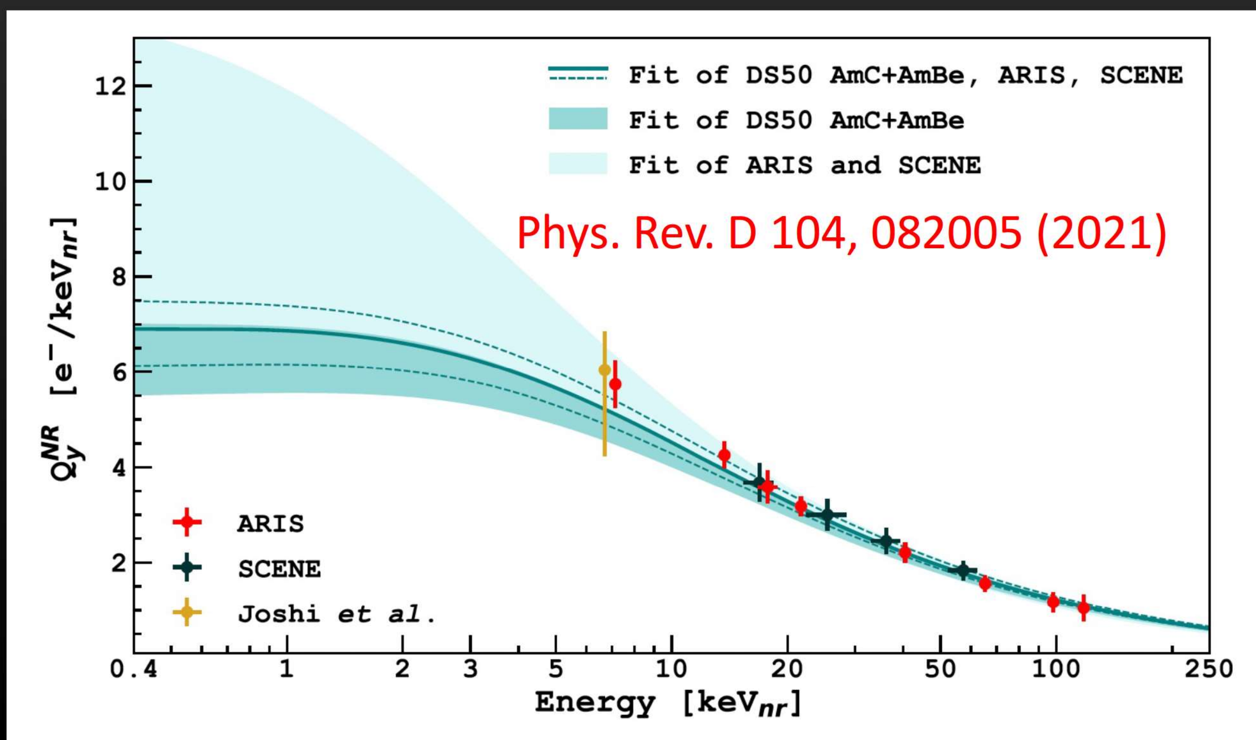
- With ionization only (S2):
  Amplification in gas > 23 p.e./e-;
  Sensitive to a single extracted electron.



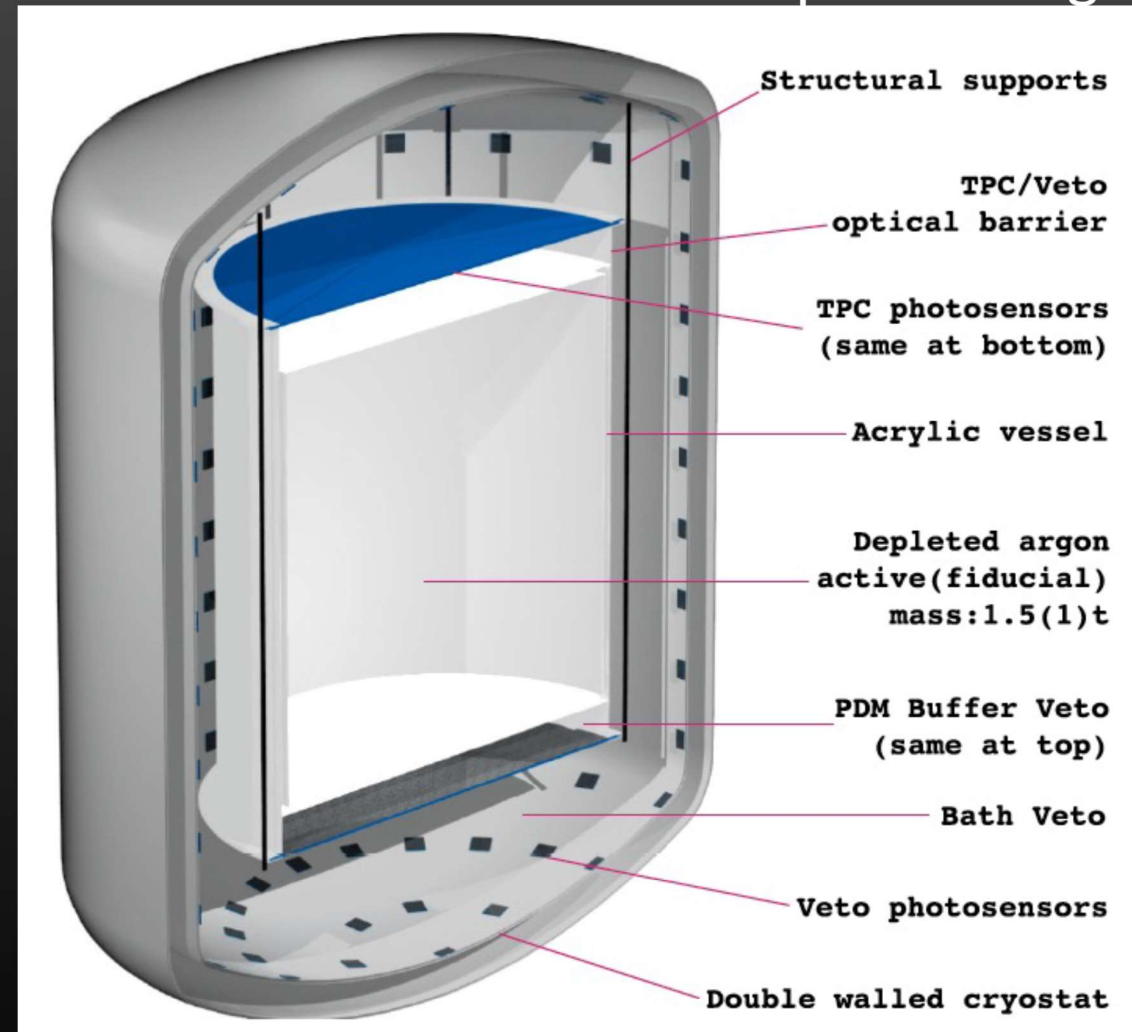
World-leading low mass WIMP search results

DarkSide-LowMass

- Dedicate to WIMP mass < 10 GeV/c^2.
- A tonne-scale dual phase Ar TPC,
  - ~1 tonne active mass.
- A better NR calibration is needed.
- Detector R&D at IHEP.



DarkSide-LowMass Conceptual Design

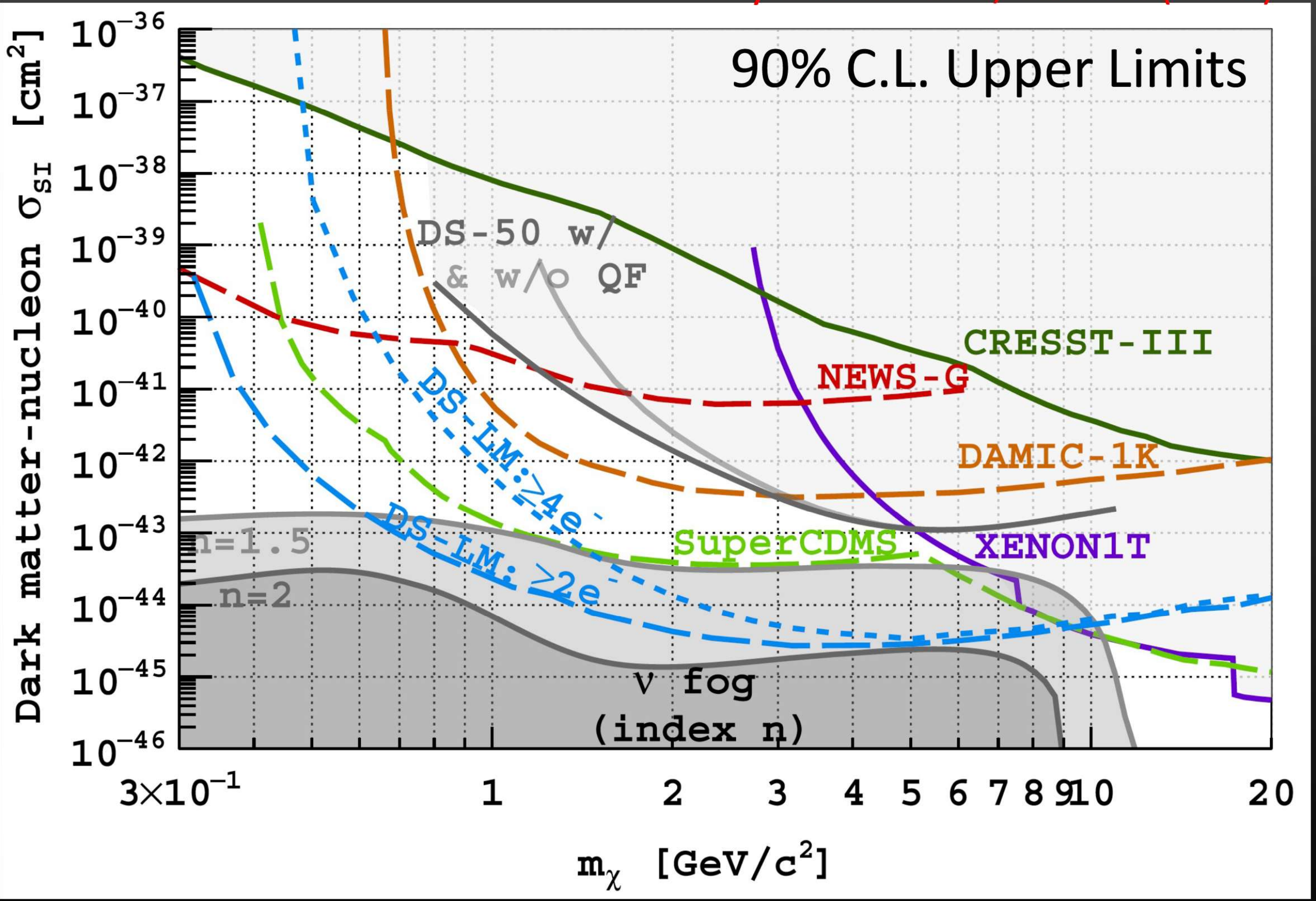


Phys. Rev. D 107, 112006 (2023)

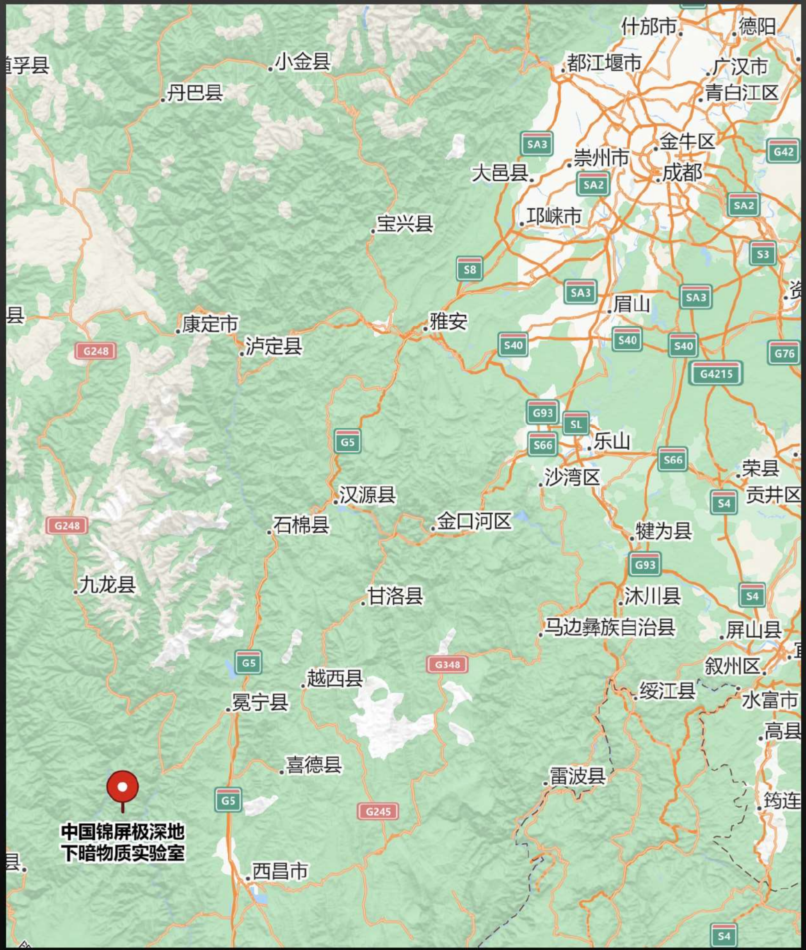
Sensitivity Prediction

- Assumptions:
  - ^{85}Kr expect to fully remove;
  - ^{39}Ar ~73 µBq/kg;
  - γ rate based on the assay of DS-20k photosensors;
  - 1 ty exposure.
- Neutrino fog is reachable!
- Candidate lab: CJPL-II.
- Construction starts in 2027.

Phys. Rev. D 107, 112006 (2023)



中国锦屏地下实验室



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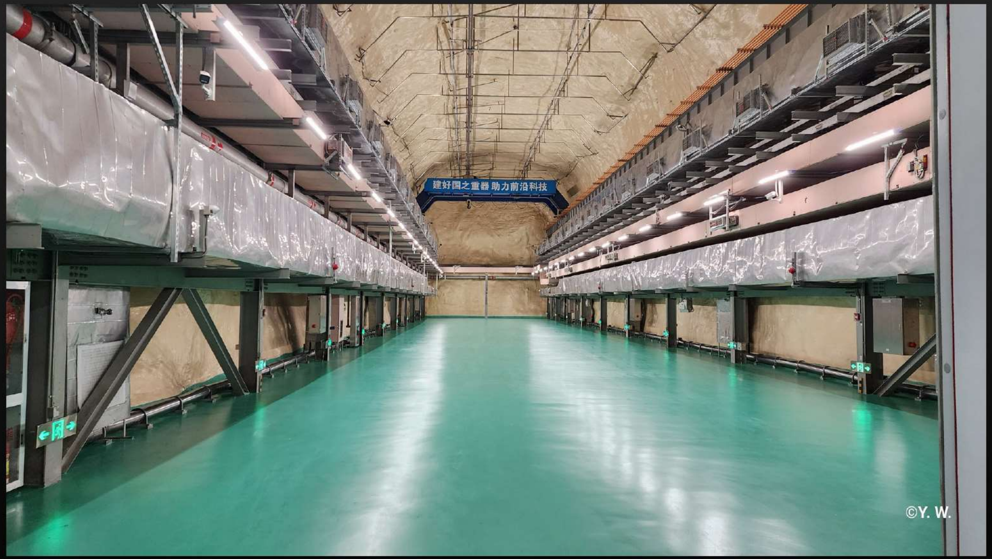

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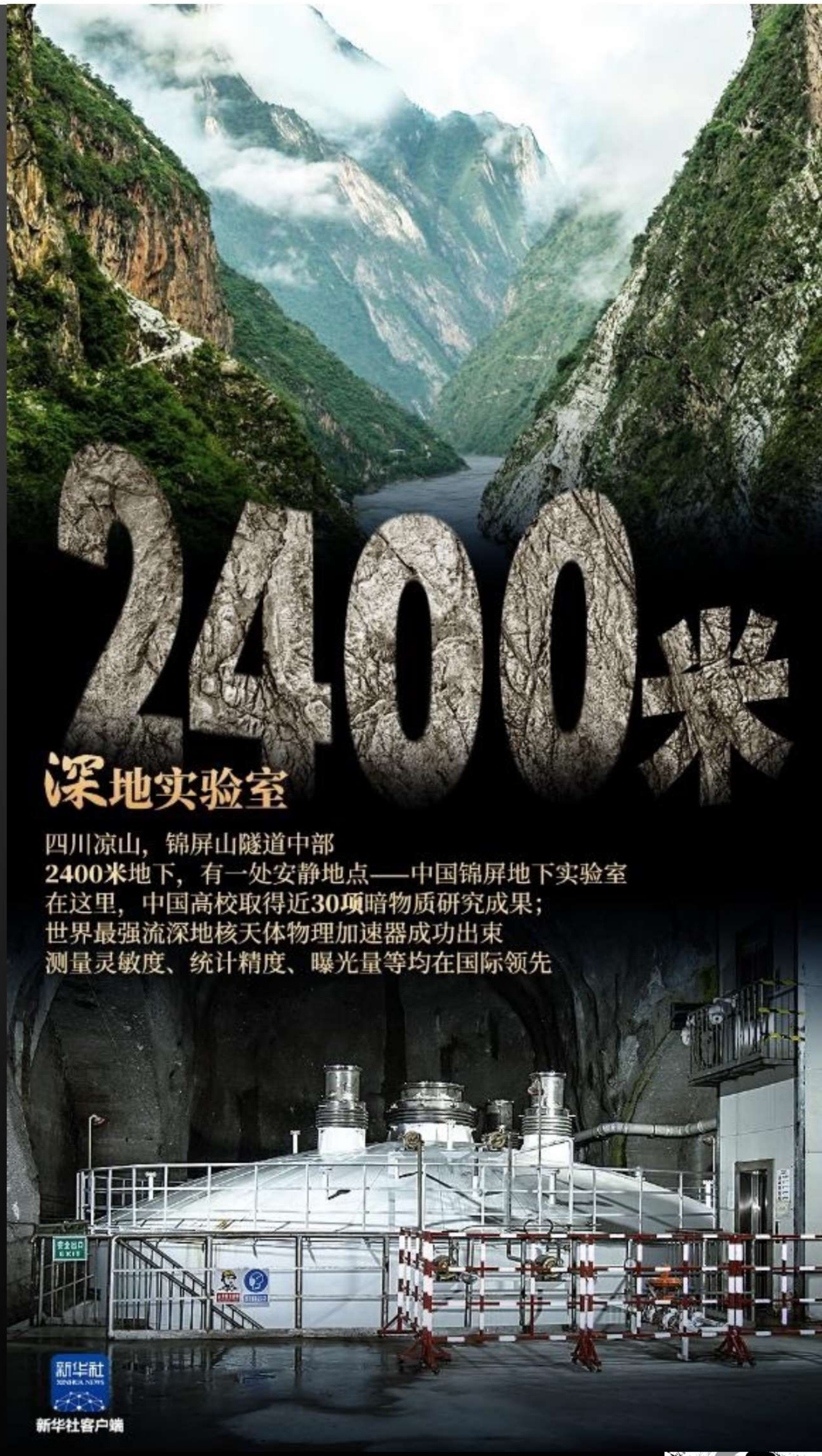

2400米
深地实验室
四川凉山，锦屏山隧道中部
2400米地下，有一处安静地点——中国锦屏地下实验室
在这里，中国高校取得近30项暗物质研究成果；
世界最强流深地核天体物理加速器成功出束
测量灵敏度、统计精度、曝光量等均在国际领先
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Welcome to join the argon community !

王毅
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