The DarkSide Program for Direct Dark Matter Search

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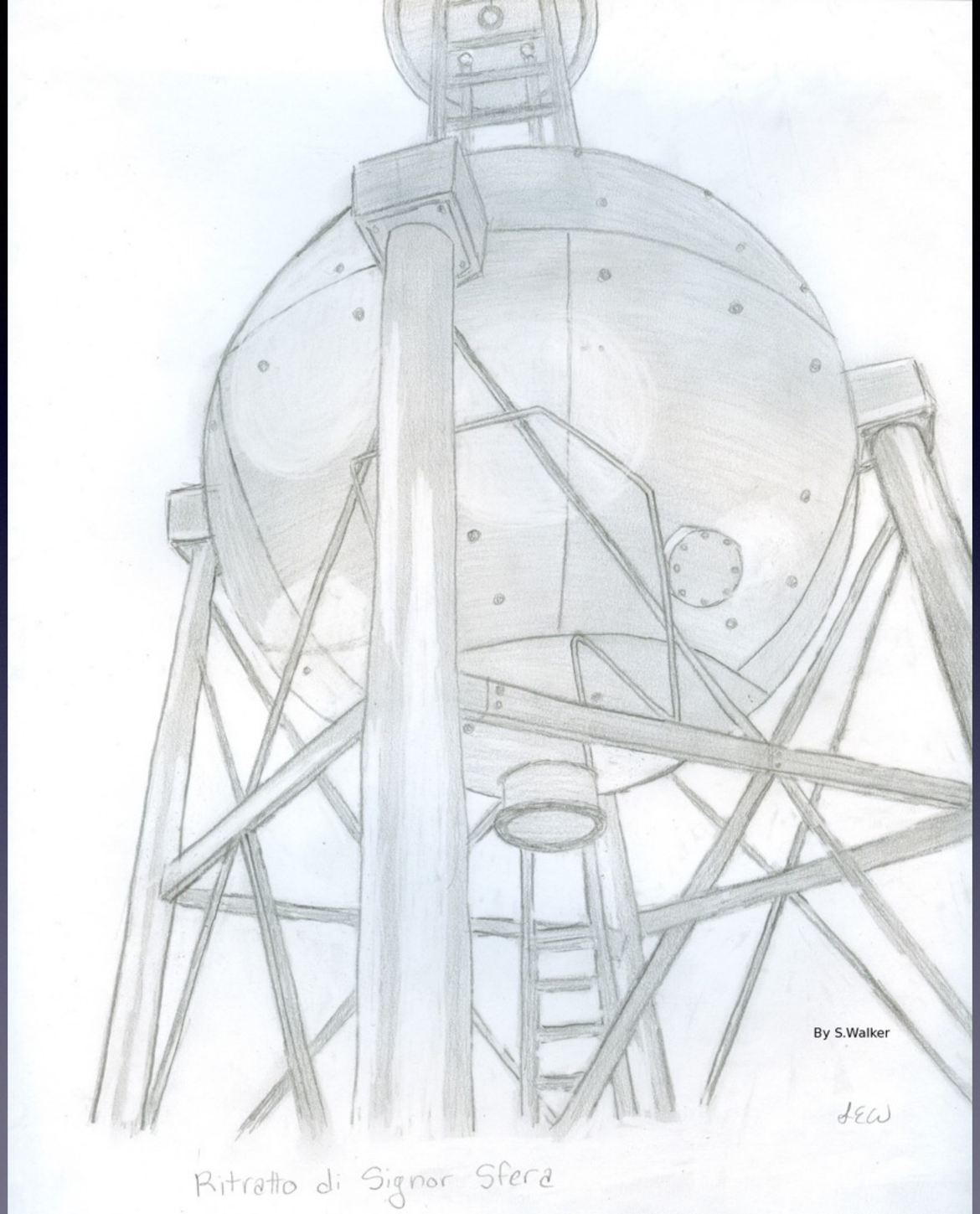


30-seconds summary

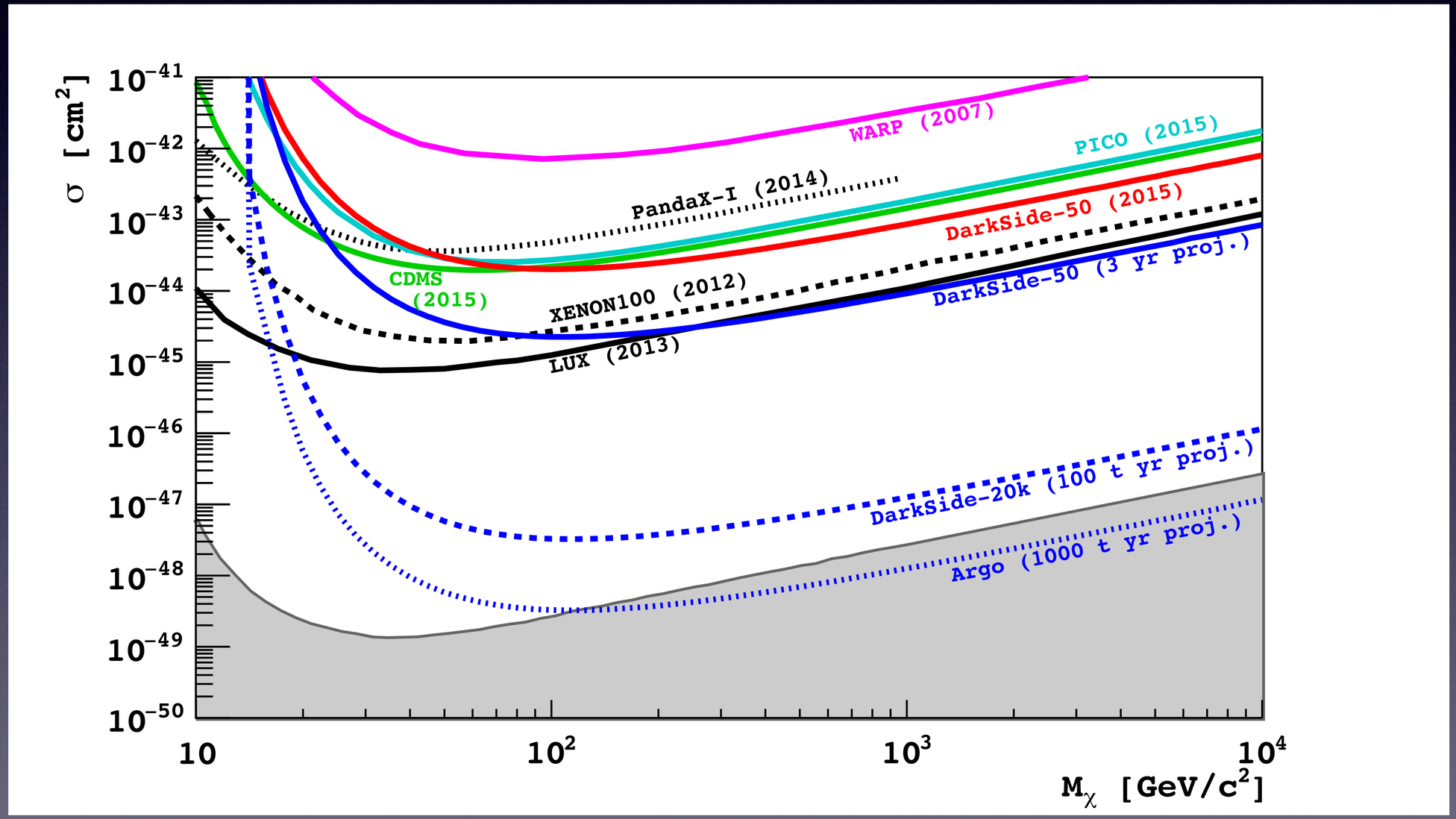
DARKSIDE

- Ambitious program for **discovery of dark matter**
- Ultra-low background, liquid argon time-projection chamber
- Operating at the Laboratori Nazionali del Gran Sasso, INFN, Italy
- Complementary to LHC and raising its energy scale:

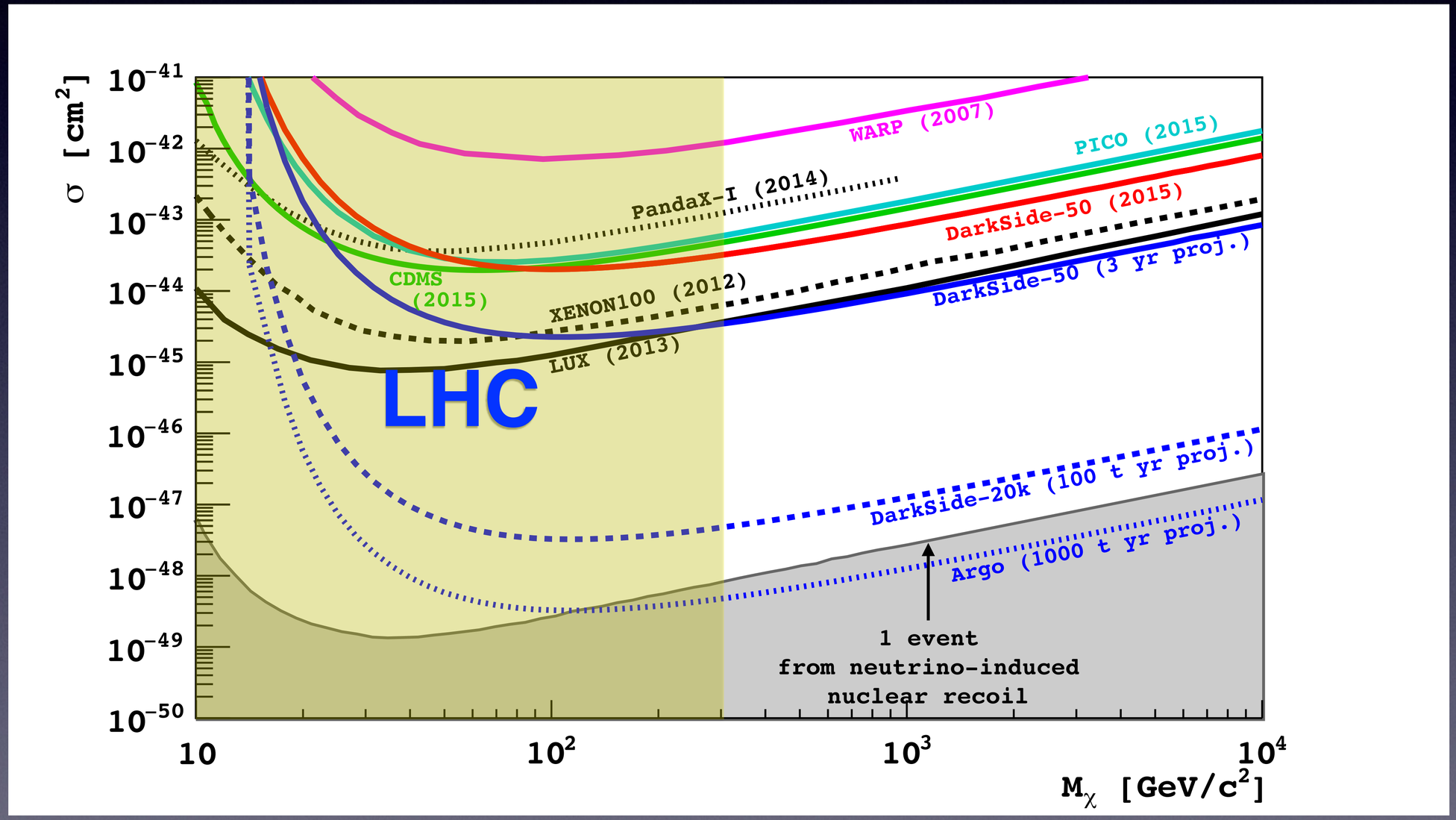
  500 GeV ⇒ 1 TeV ⇒ 10 TeV ⇒ …

- Technology development to achieve “Zero Background” and scalability
- Flagship program at LNGS participated by over forty institutions

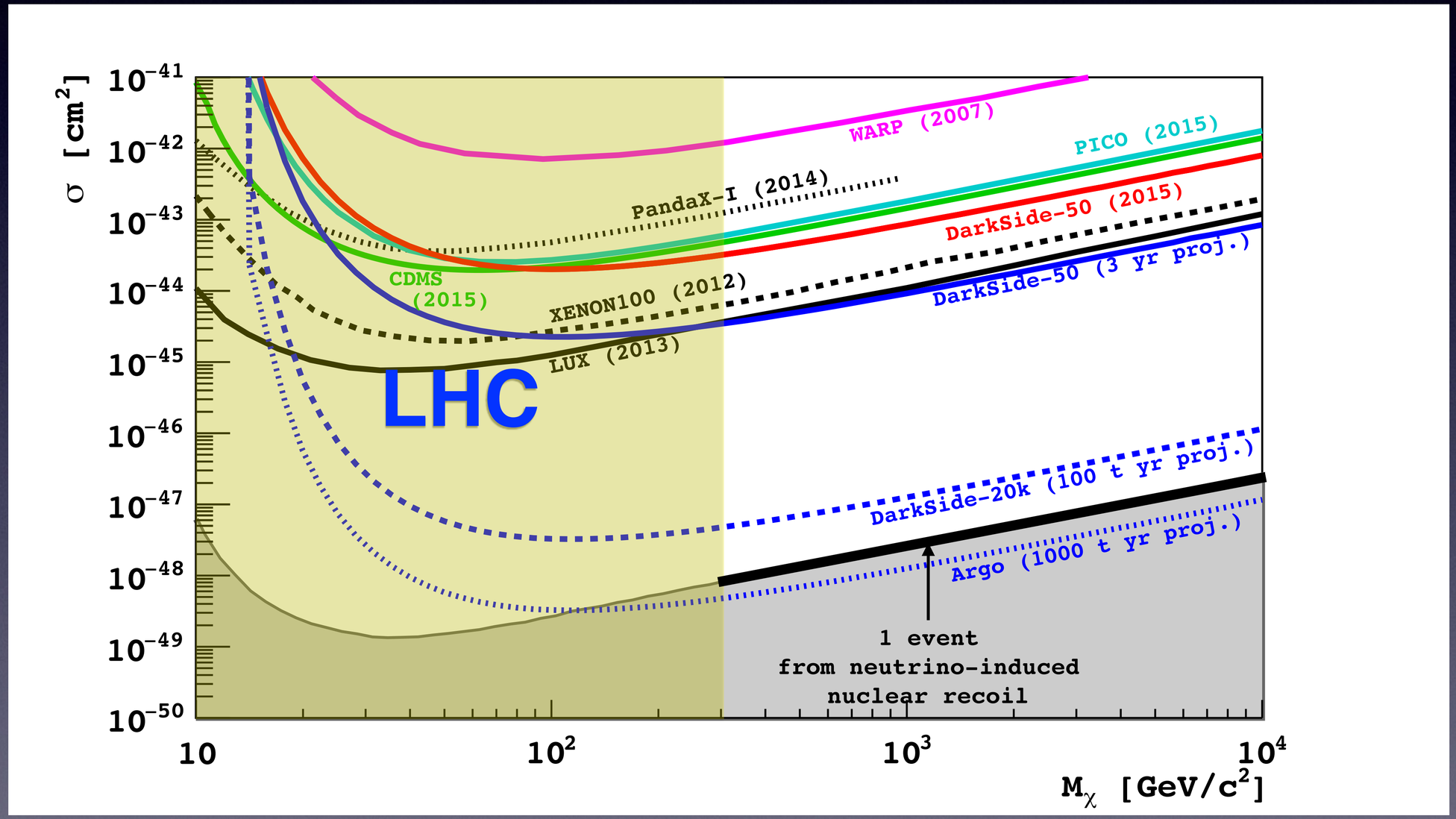
Dark Matter discovery path



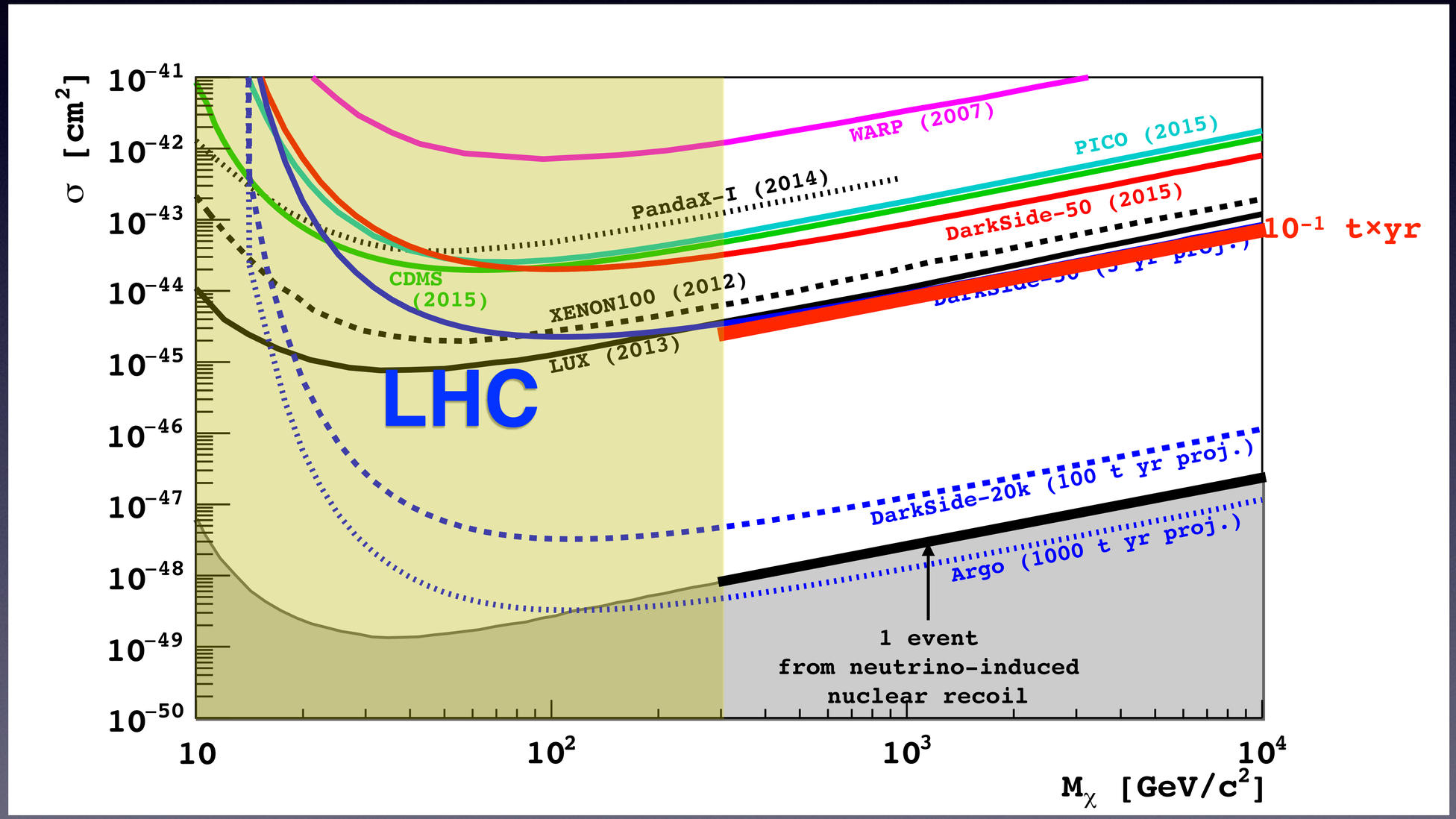
Dark Matter discovery path



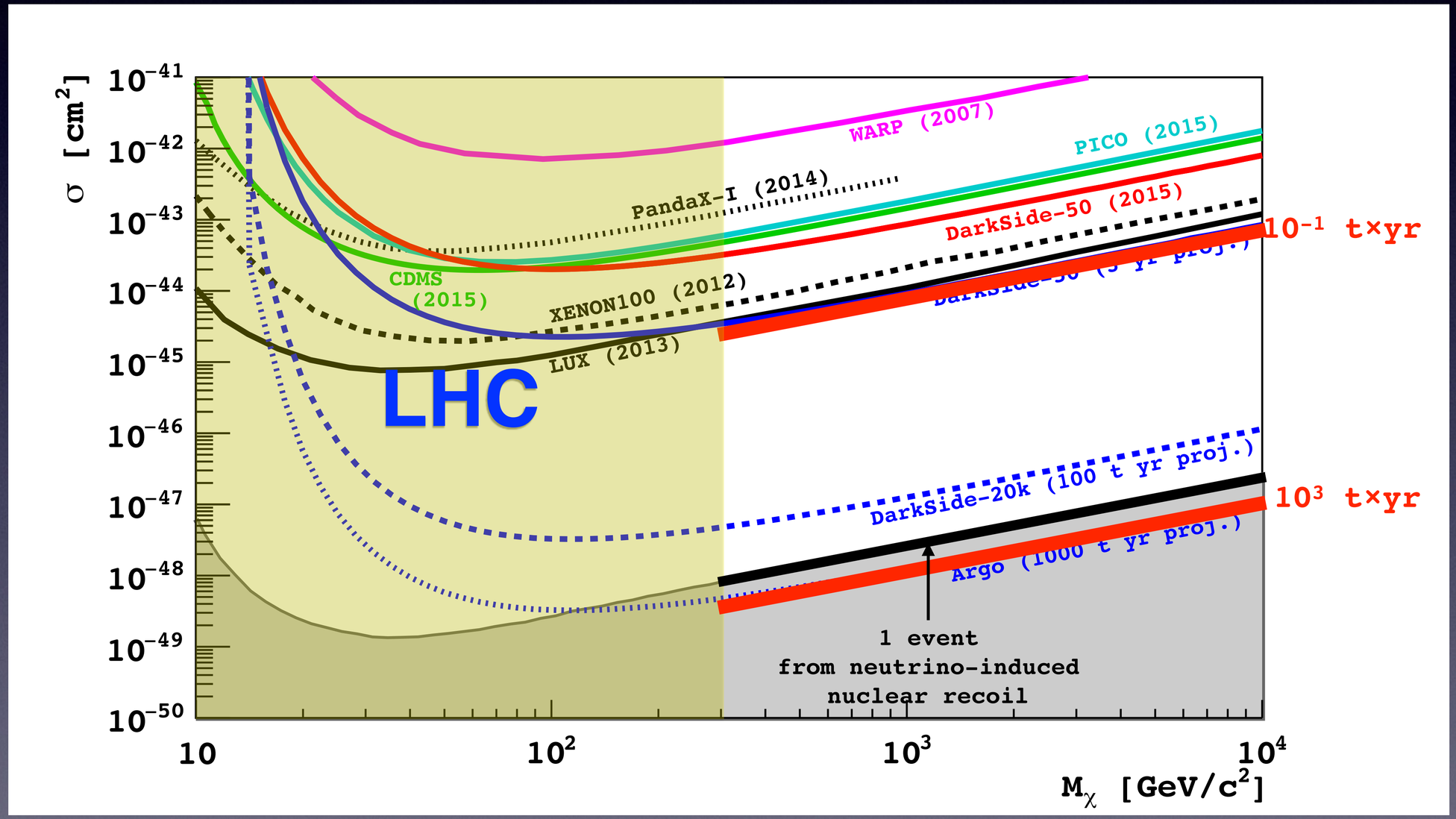
Dark Matter discovery path



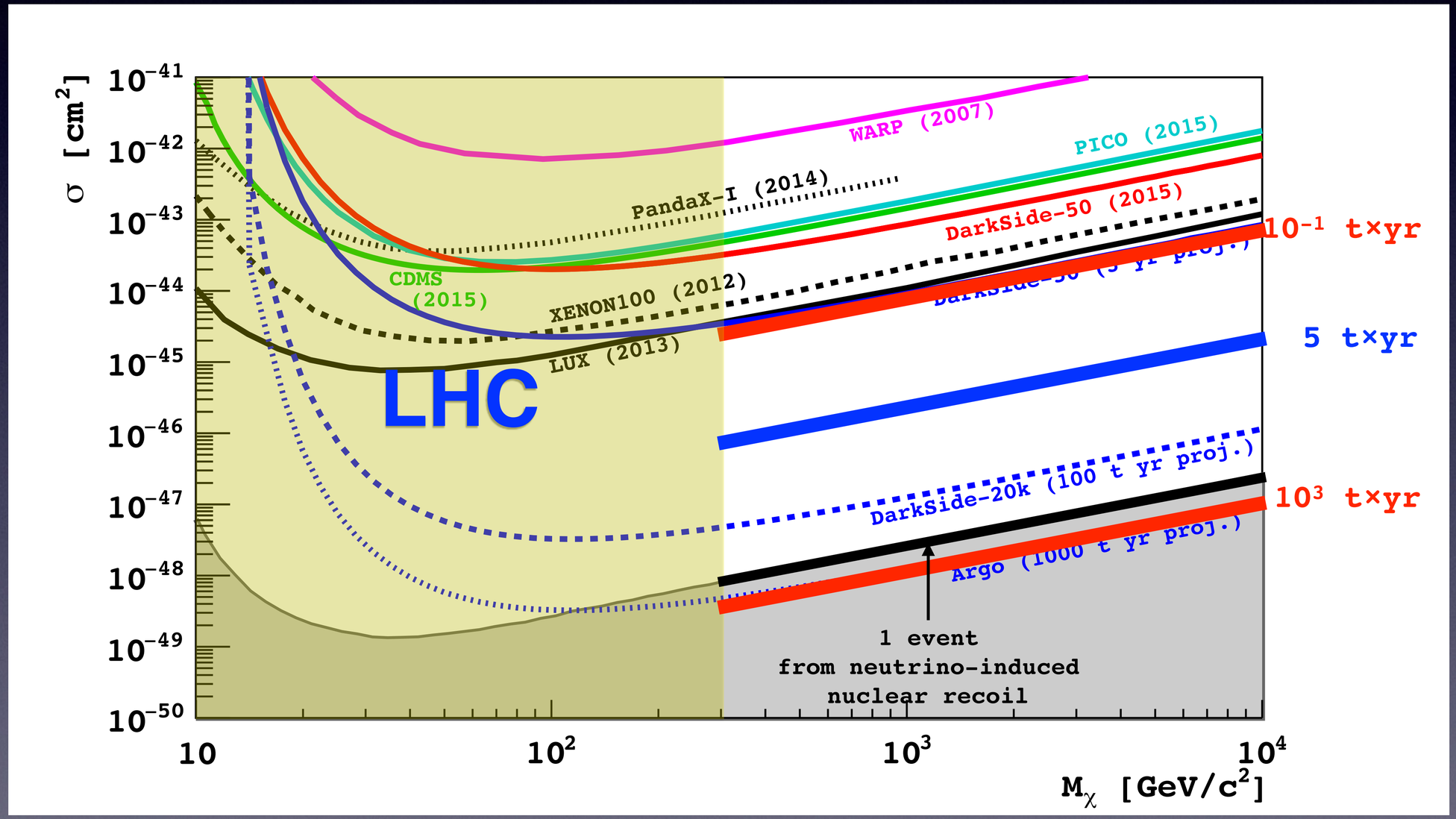
Dark Matter discovery path



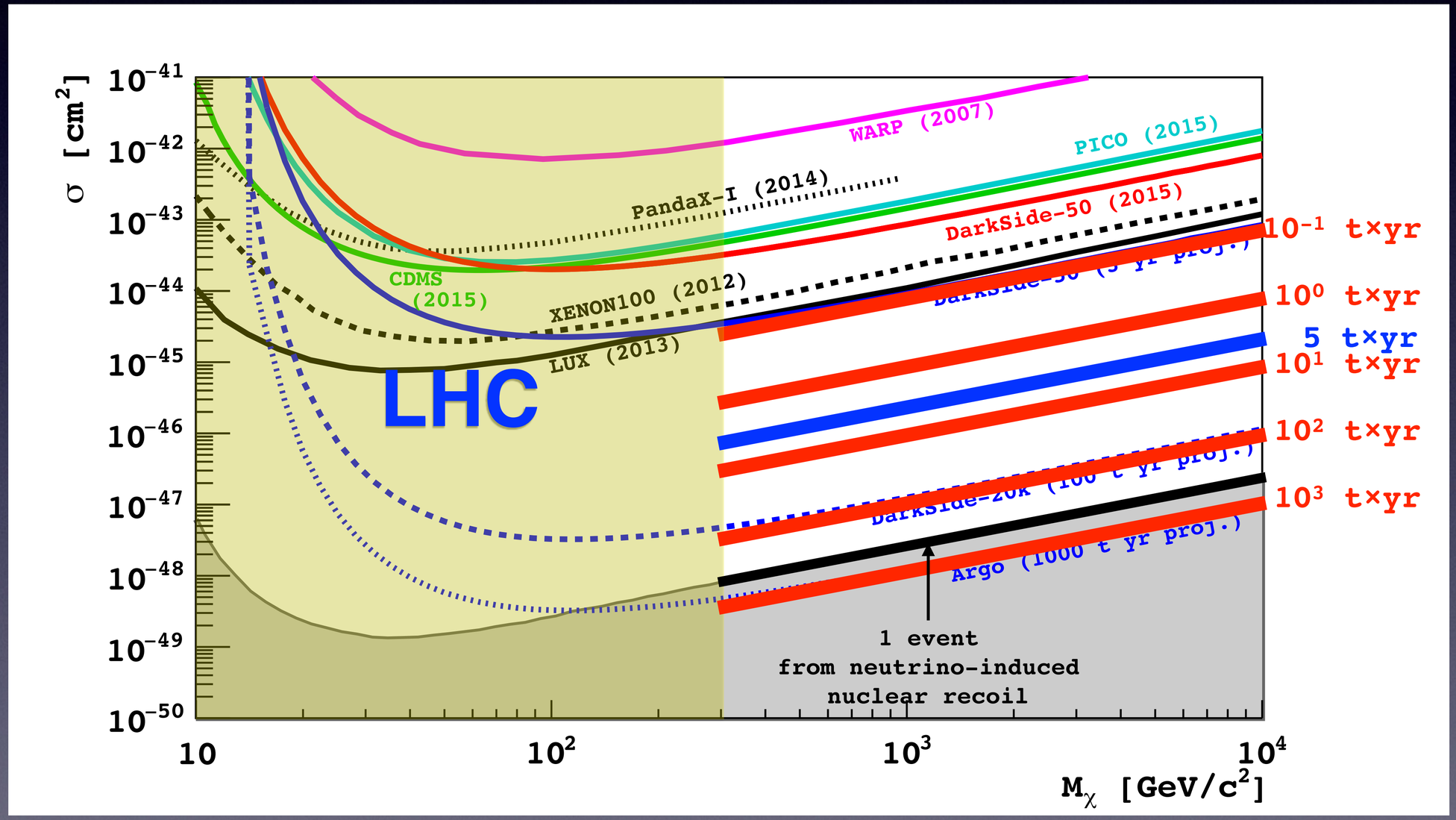
Dark Matter discovery path



Dark Matter discovery path

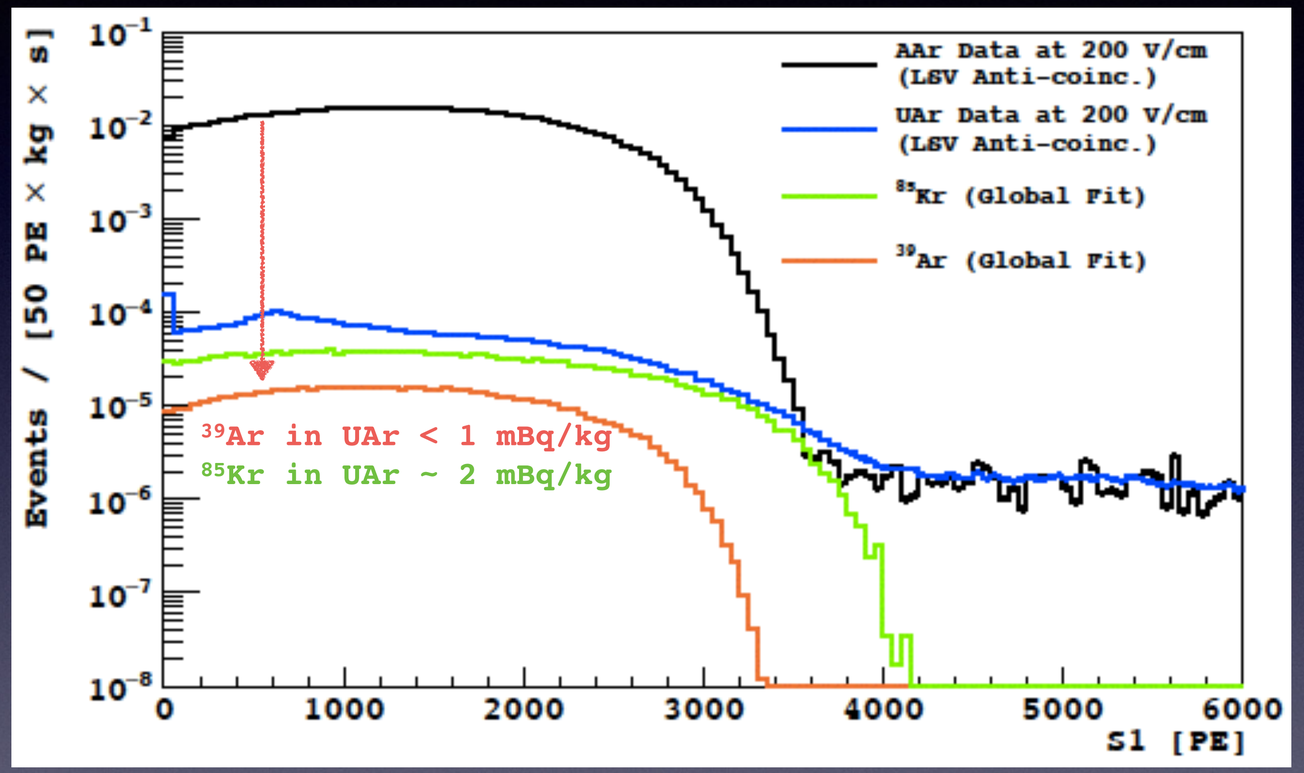


Dark Matter discovery path



Argon as target for DM detection

- Bright scintillator: Light Yield ~ 40 γ/keV and very transparent to its own scintillation light
- Relatively abundant (1% in atmosphere) and easy to purify
- Large mass detectors → scalability + self-shieding
- Possible scaling to multi-ton detectors: need to suppress ^{39}Ar
  - ➡ Underground argon (UAr): ^{39}Ar depletion factor >1400
- Very powerful rejection capability for electron recoil background



^{39}Ar beta decays with 565 keV endpoint, with half-life 269 years

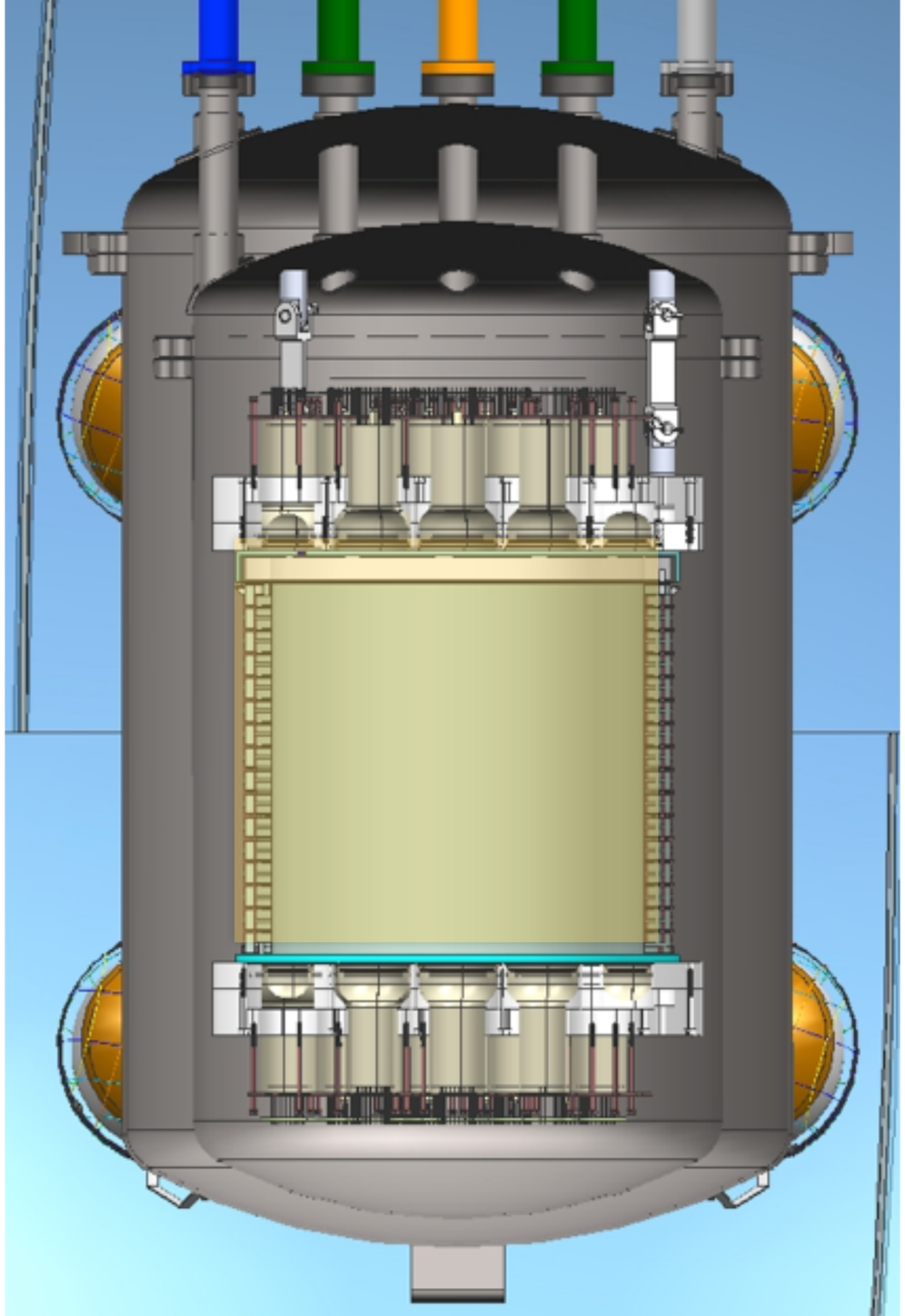
^{39}Ar production supported by cosmogenic activation via ^{40}Ar(n,2n)^{39}Ar

^{39}Ar activity in atmospheric argon ~1 Bq/kg

UAr ^{39}Ar activity (0.73 ± 0.11) mBq/kg

The running experiment: DarkSide-50

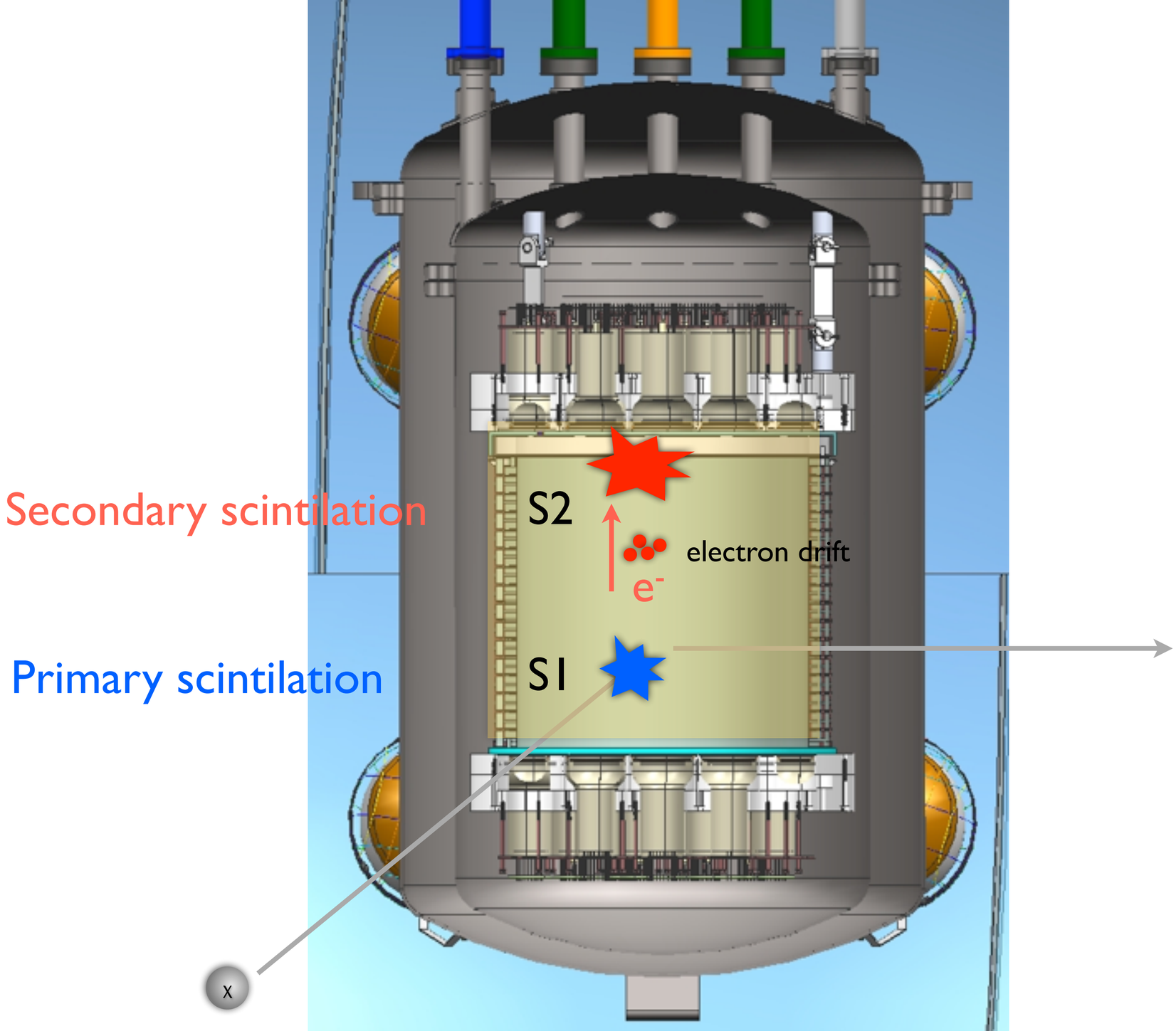
- The DarkSide-50 direct dark matter search:
  - A liquid argon TPC in stable operation having matched or surpassed all basic requirements
  - First dark matter detector operating with isotopically enhanced target
  - Dark matter search operating in background-free mode



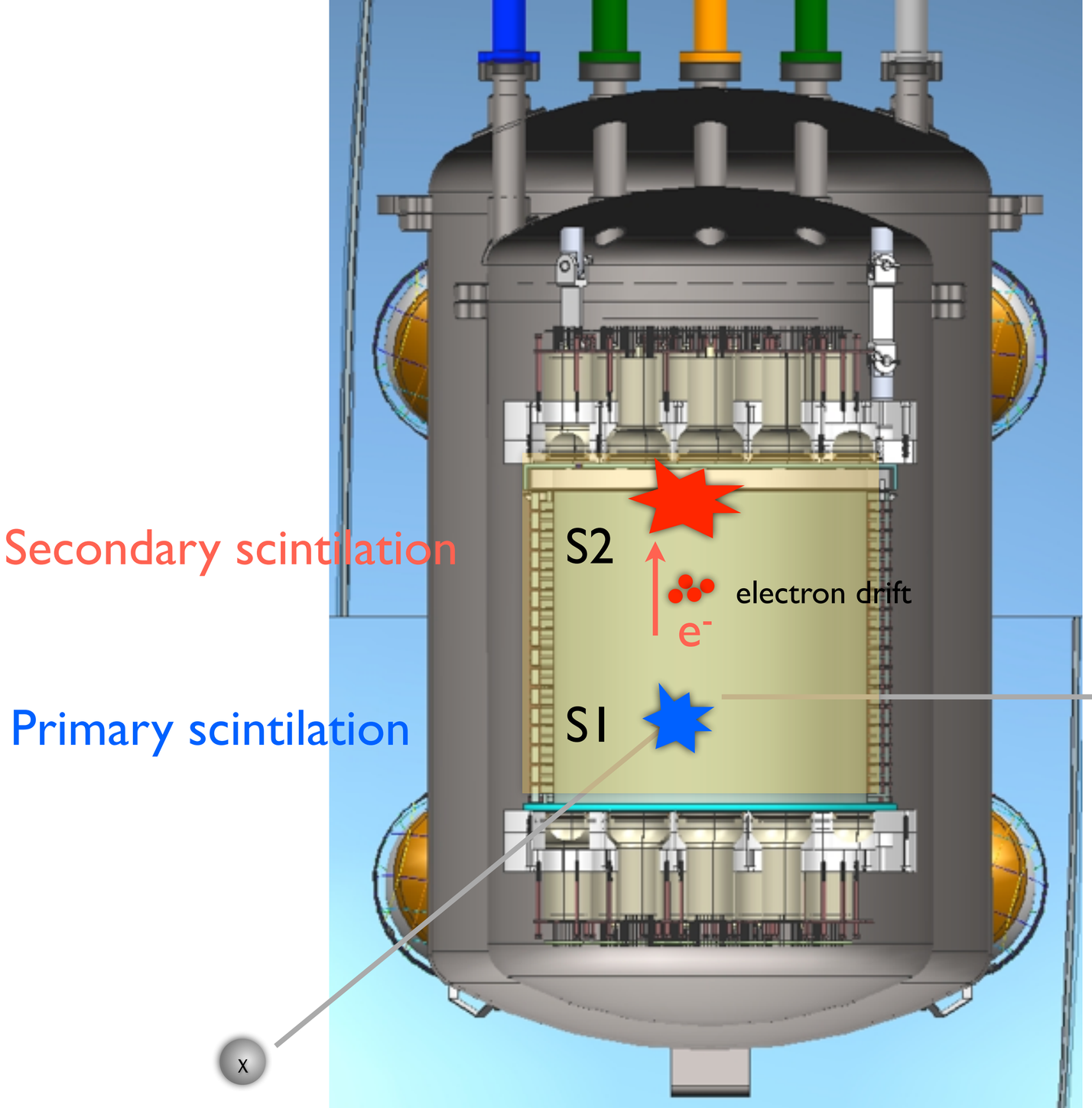
DarkSide-50
Liquid Argon TPC

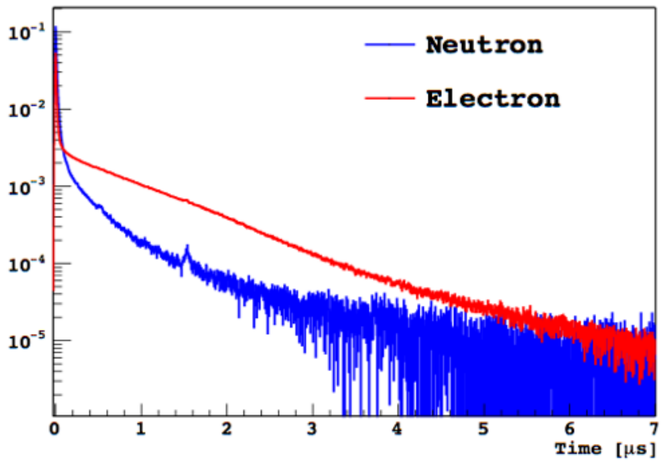
153 kg of
underground argon

50 kg fiducial target

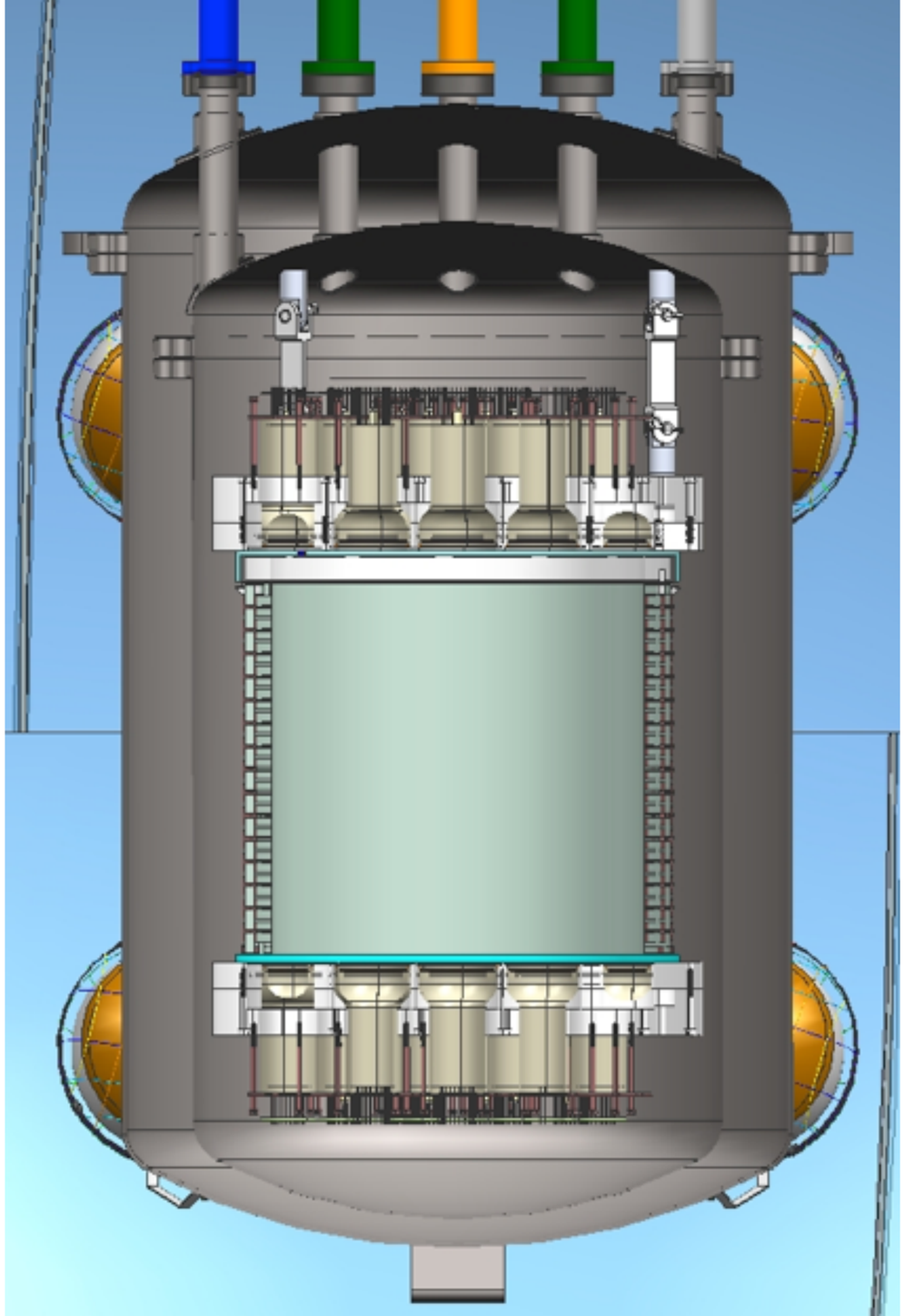

Secondary scintilation
S2
electron drift
e-
Primary scintilation
S1
x

- Pulse shape of S1 can be used to distinguish between electron and nuclear recoils
- Ratio of ionization and scintillation signal (S2/S1) provides additional discrimination power

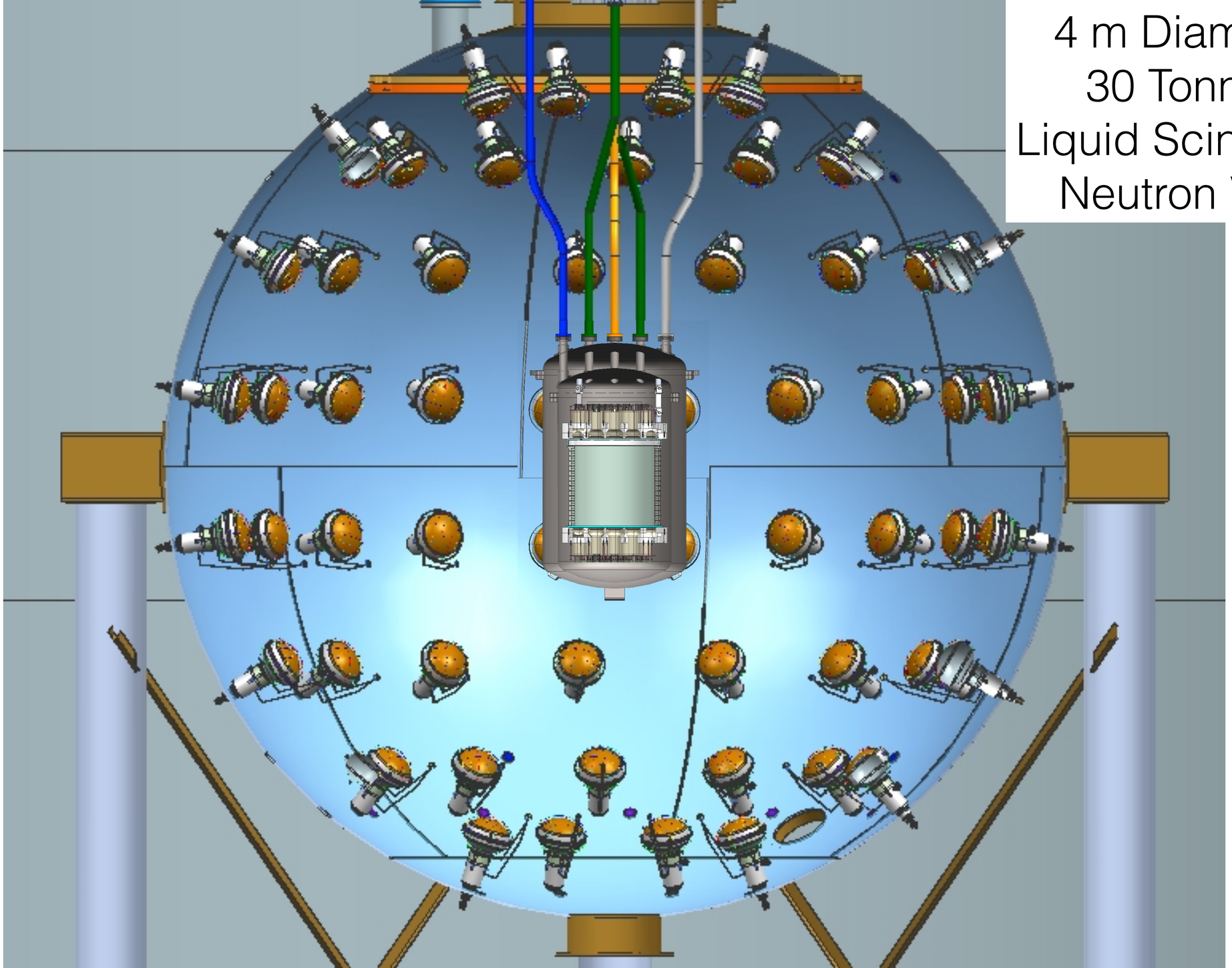




Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

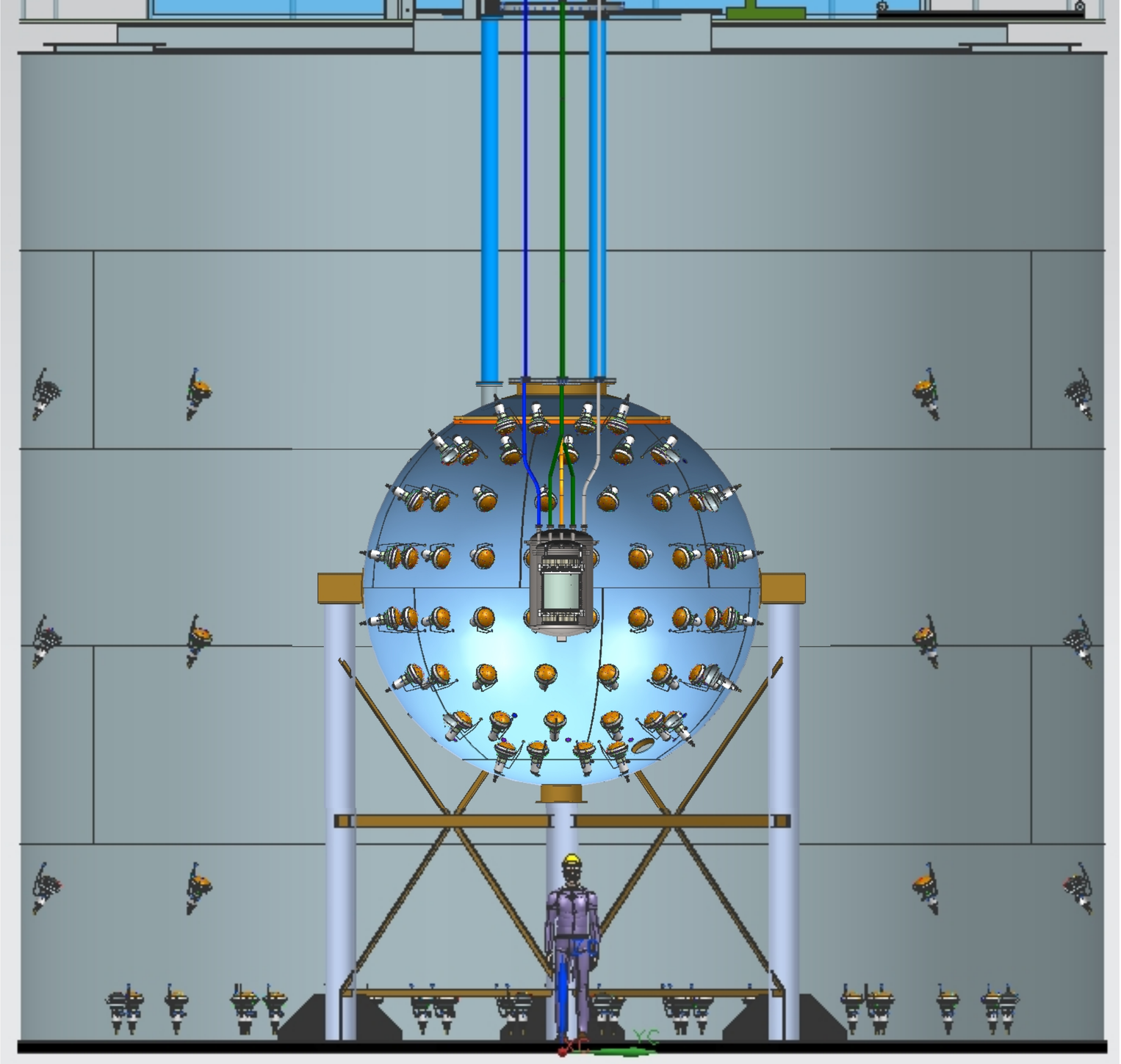


38 Cryogenic PMTs
Hamamatsu R11065



4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

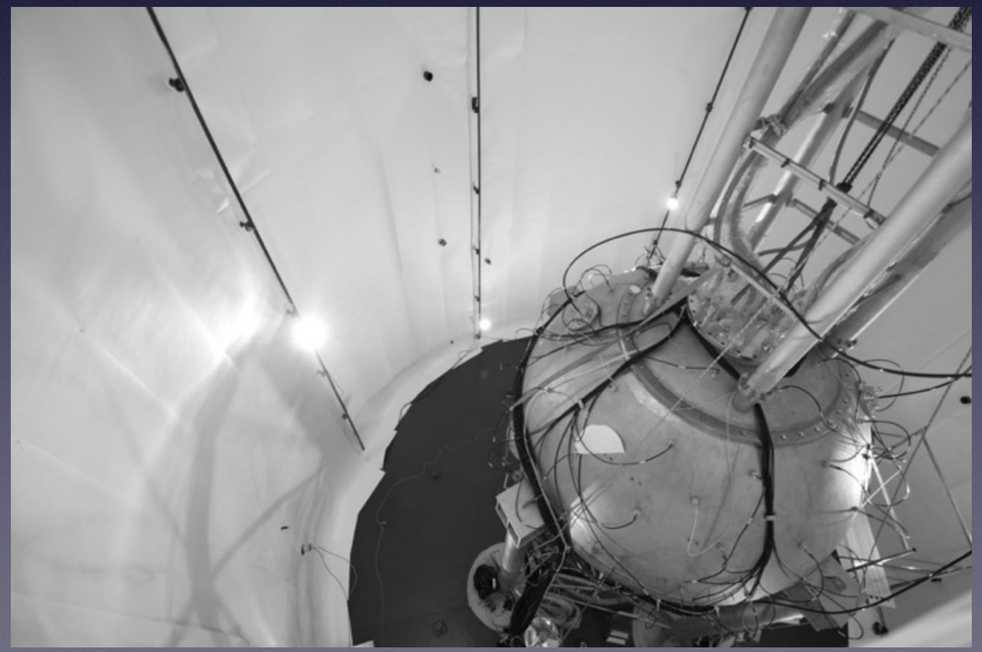
10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



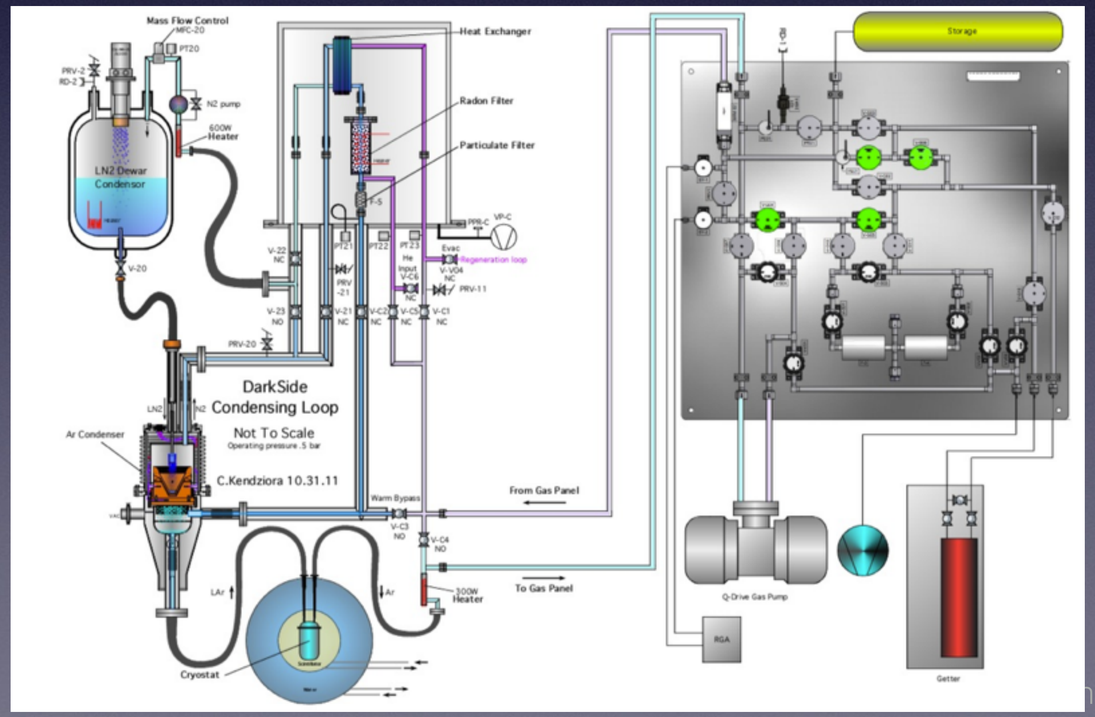
Active Veto

- 30 ton boron-loaded liquid scintillator spherical veto, 4m diameter, instrumented with 110 low background 8” PMTs
    - neutrons which escape the inner detector are detected via neutron captures on 10B or thermalization signals.
    - >99.1% efficiency to veto neutrons from neutron capture signals alone (AmBe calibration + simulation) JINST 11 P03016, 2016
    - will increase efficiency using neutron thermalization signal

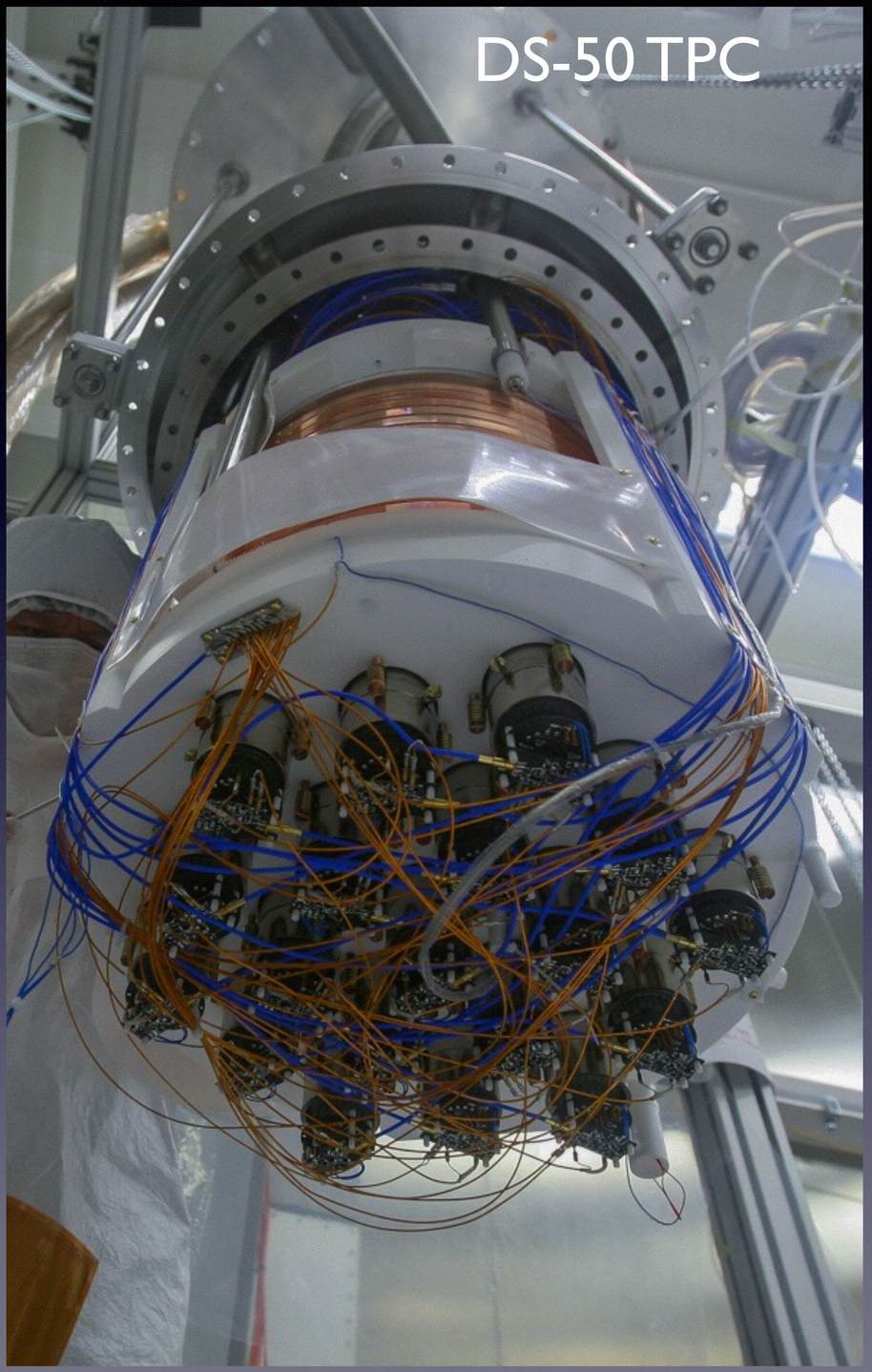
- Water Cherenkov detector, 10 m height, 11 m diameter, filled with 1000 ton ultra-pure water, observed by 80 upward facing PMTs
    - acts as a muon and cosmogenic veto (~ 99% efficiency)
    - passive shielding against external neutrons and gammas

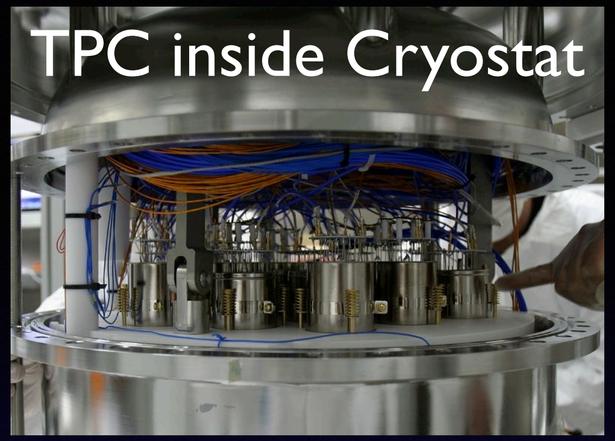


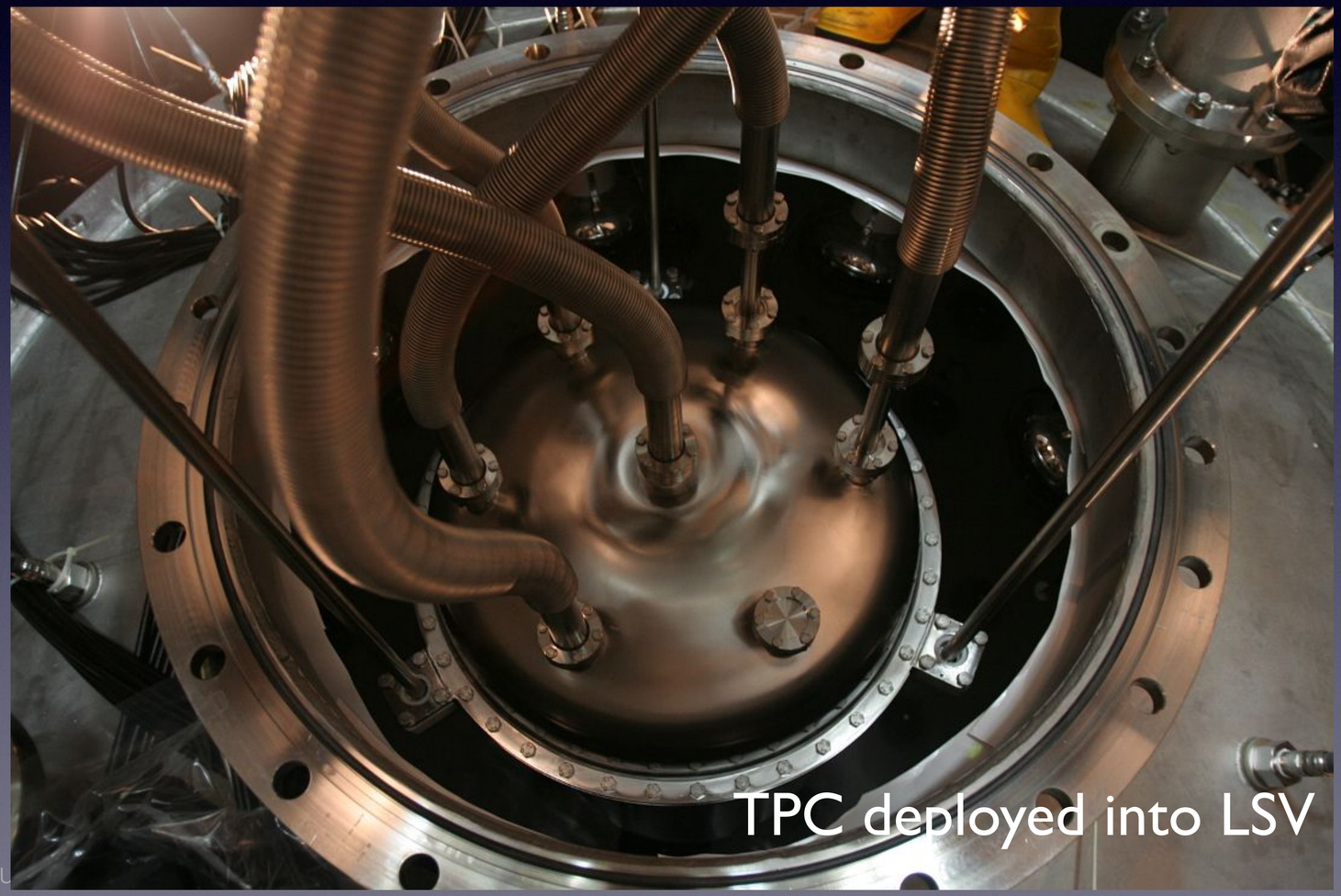
- Class 10-100 clean room above Water Tank
  - ✓ Obtained Rn <5 mBq/m^3 in >100 m^3
- Ar recirculation and purification system
  - ✓ Cooling power 300 W
  - ✓ max rec. speed ~ 75kg/day



DS-50 assembly and deployment

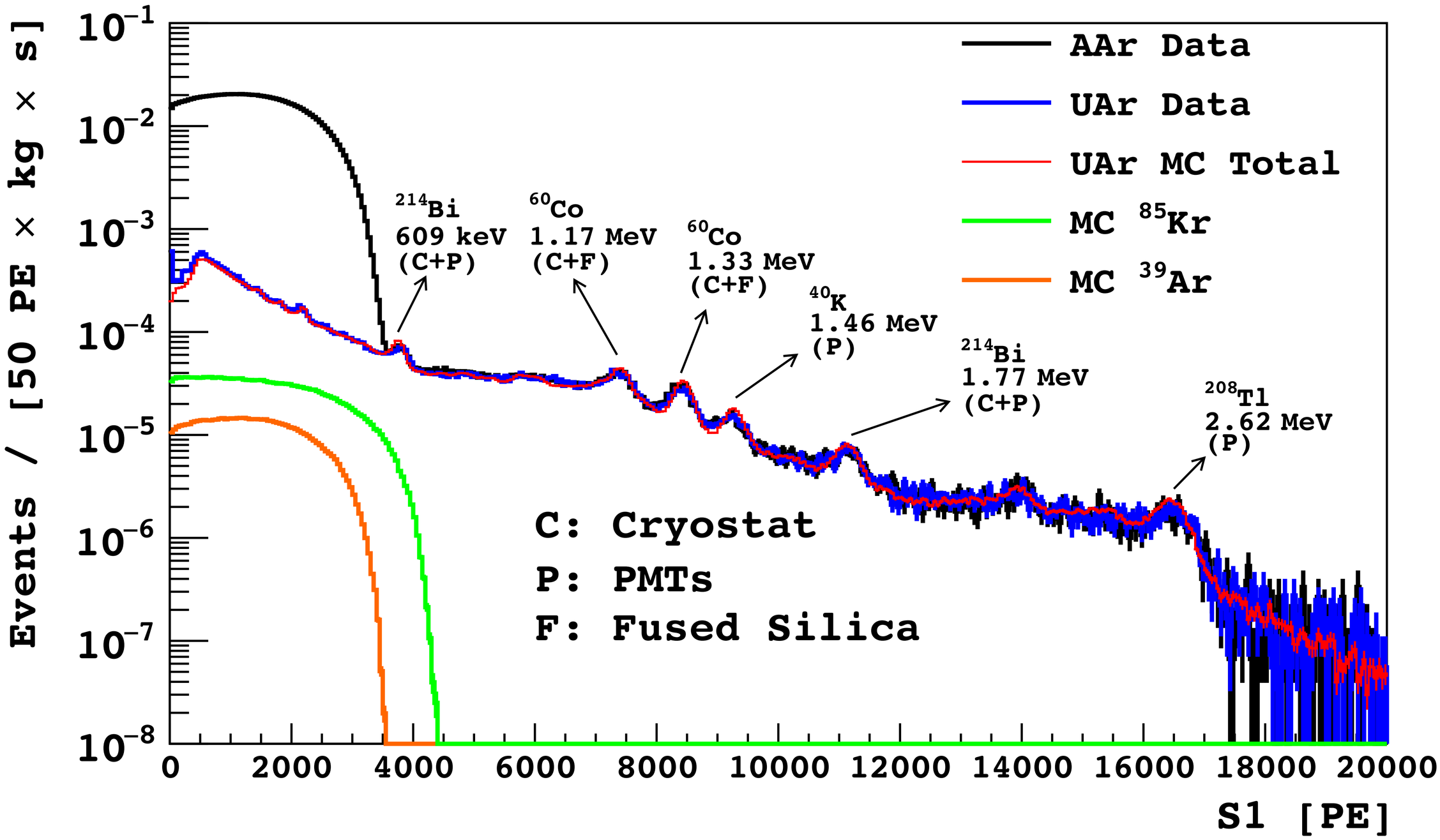




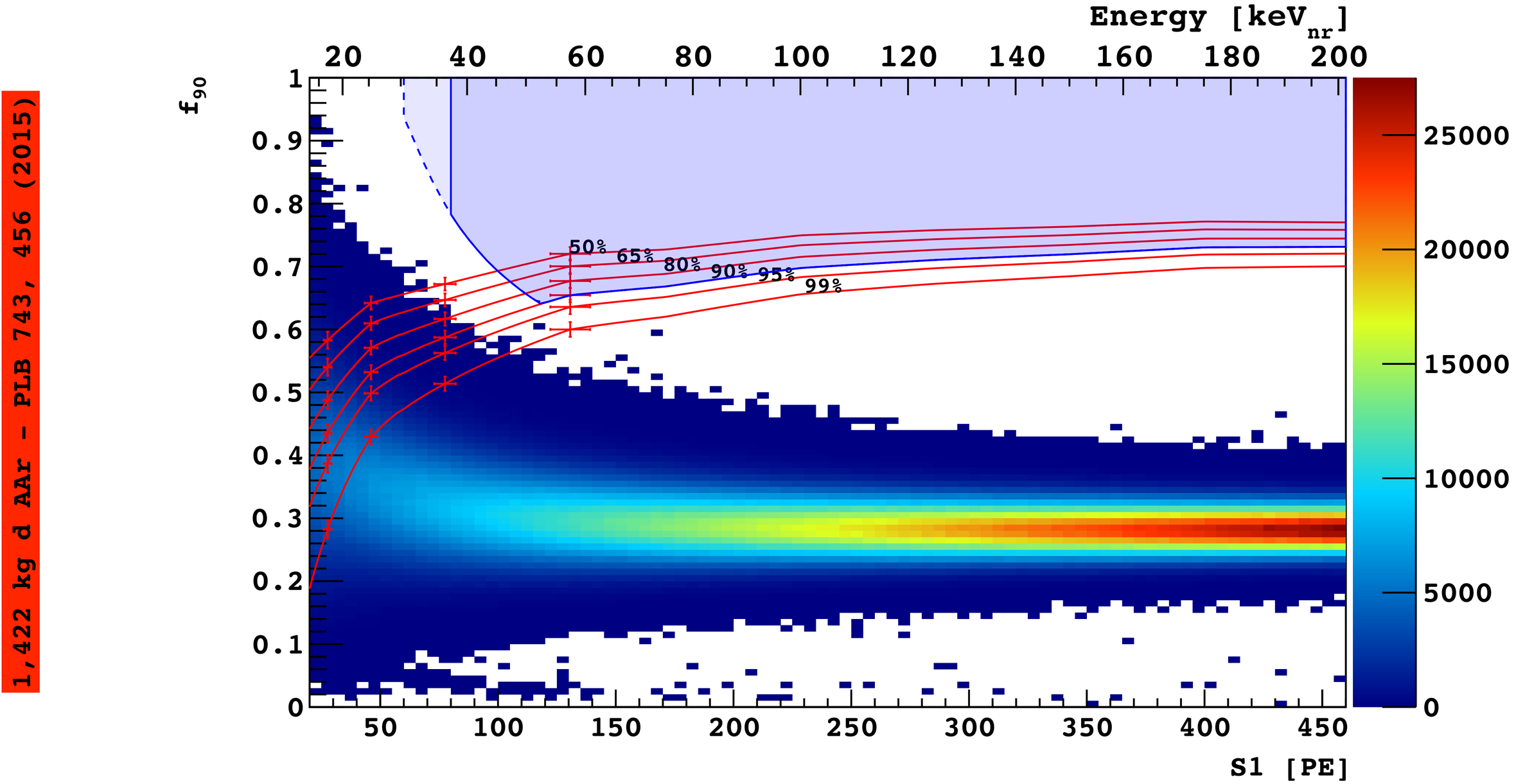


DarkSide-50 Milestones

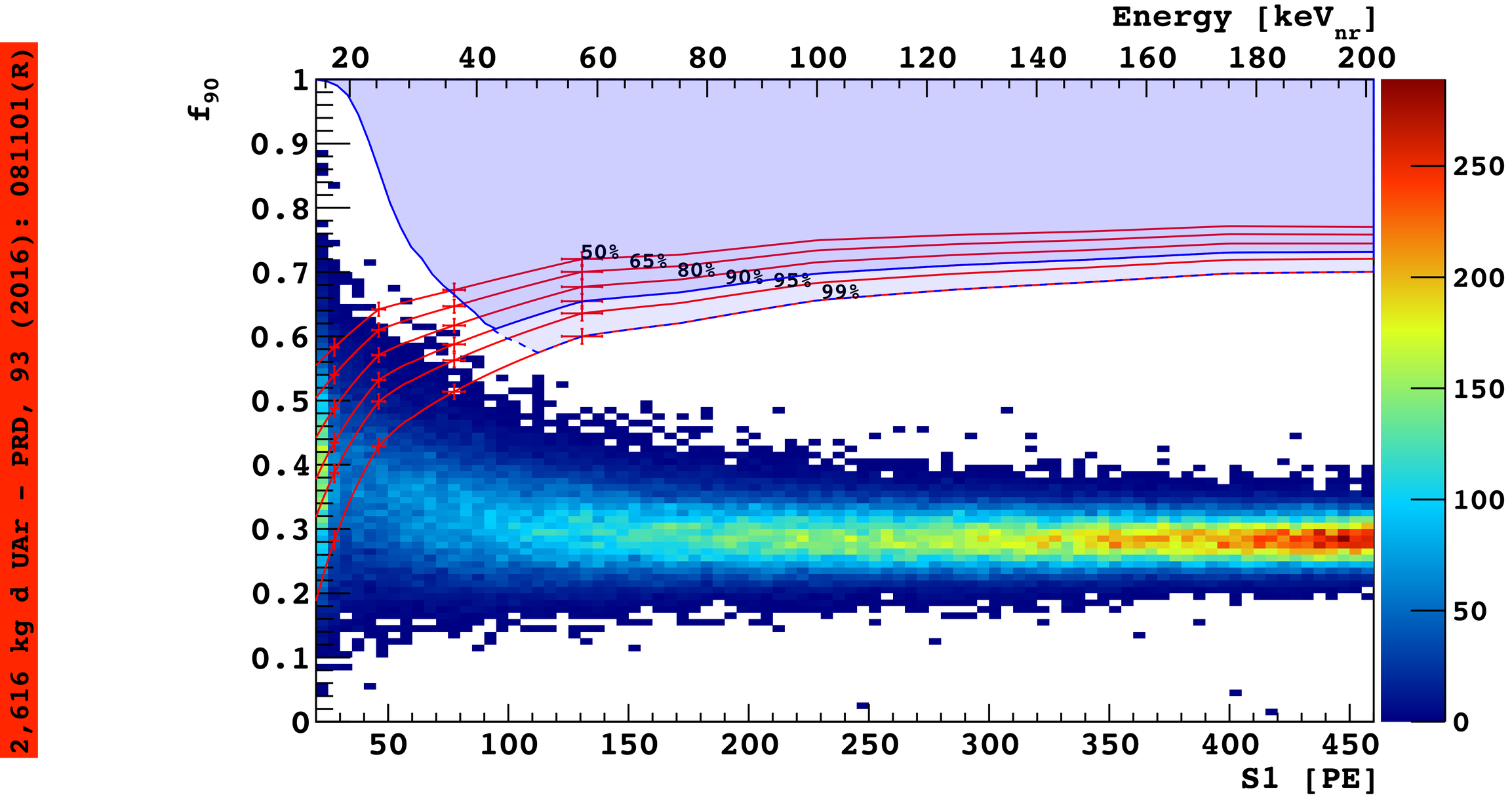
- Oct 2013: three detectors commissioned, cryostat filled with AAr
- Oct 2014: WIMP search results with 1422 kg d AAr exposure
- Fall 2014: Calibration campaign
- Winter 2014: Refurbishment of LSV, ^{14}C rate from 150 kHz to 0.3 kHz
- Apr 2015: cryostat drained and filled with 153 kg of UAr
- Oct 2015: WIMP search results with 2616 kg d UAr exposure


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
Events / [50 PE × kg × s]
S1 [PE]
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

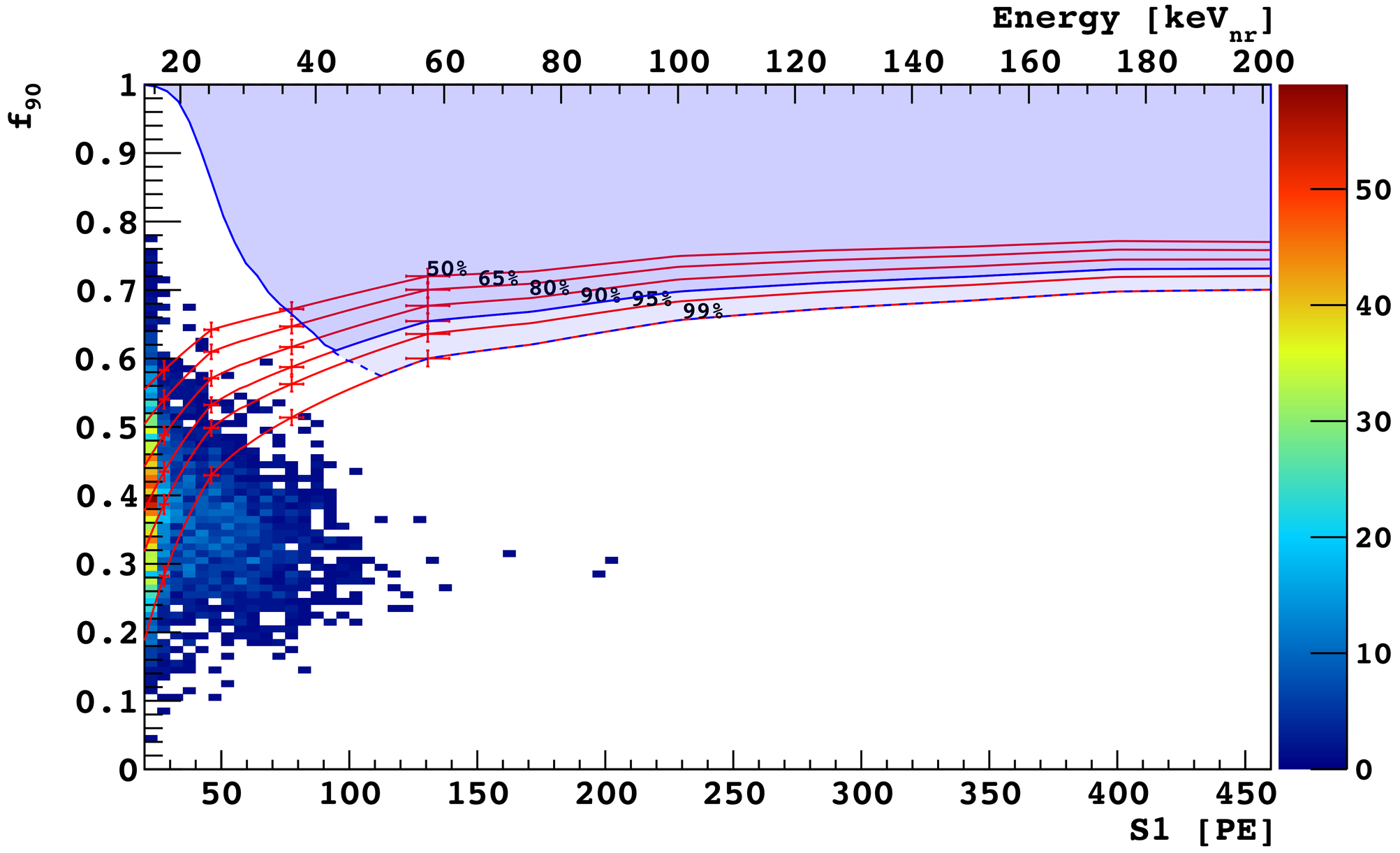
AAr events in DS50



UAr events in DS50



UAr events in DS50

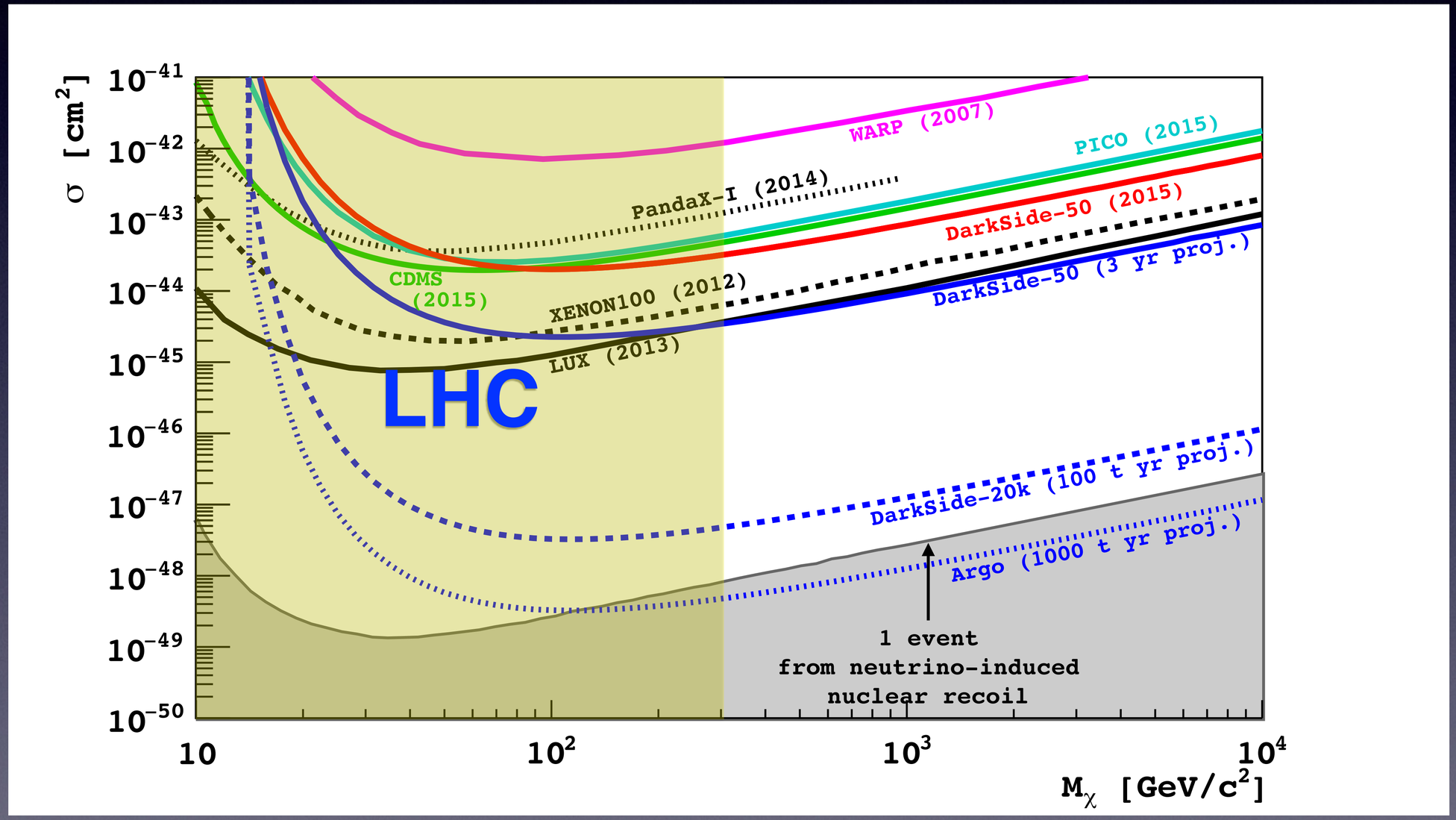


2,616 kg d UAr - PRD, 93 (2016): 081101(R)

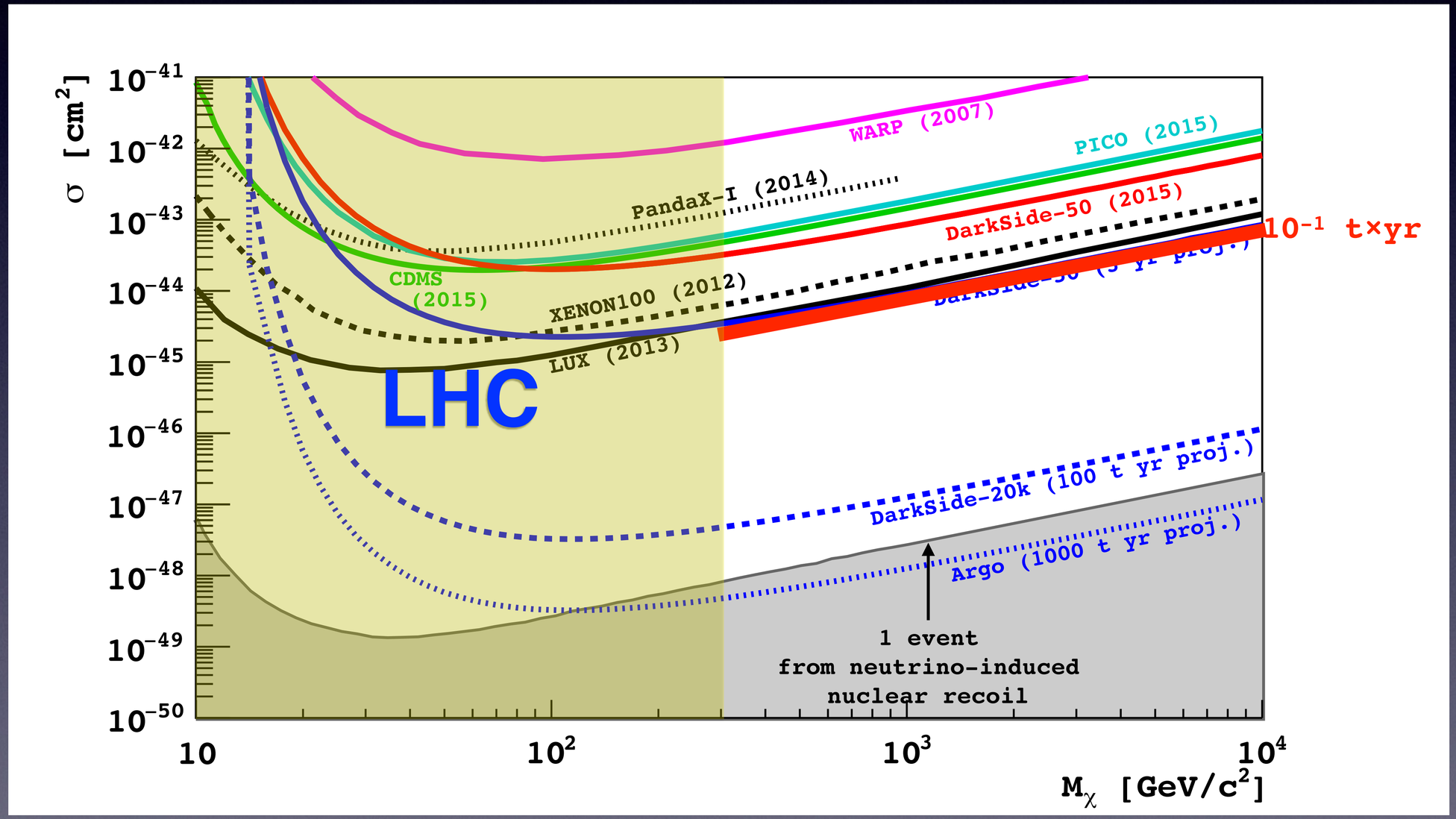
Meeting Basic Requirements Pays Off

- Light Yield: > 8 p.e./keV
- Electron meanlife: ≫5 ms
- ^{39}Ar contamination: 0.7 mBq/kg, factor 1,400 reduction res to atmosphere
- ^{222}Rn contamination: <2 μBq/kg

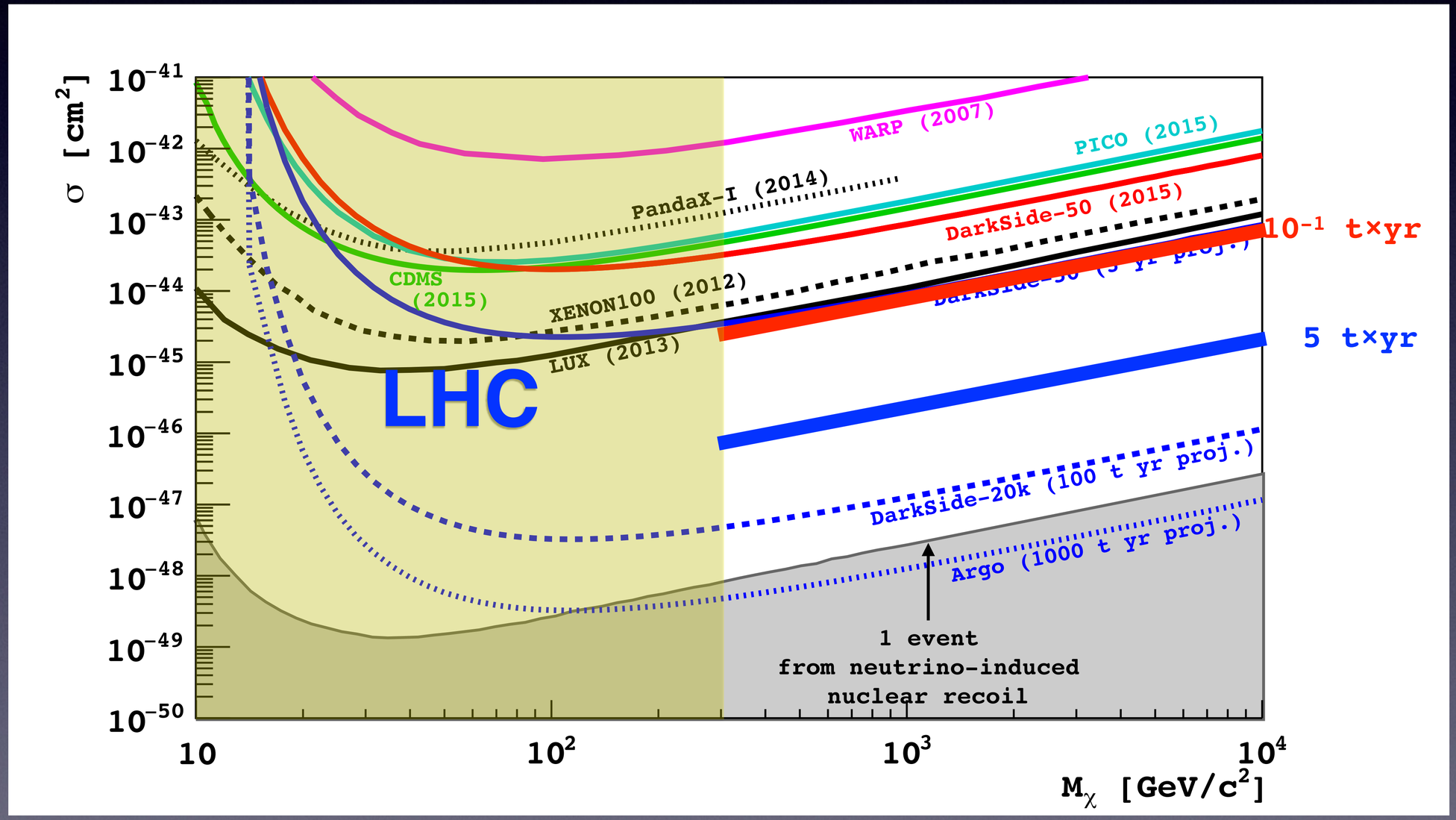
Dark Matter discovery path



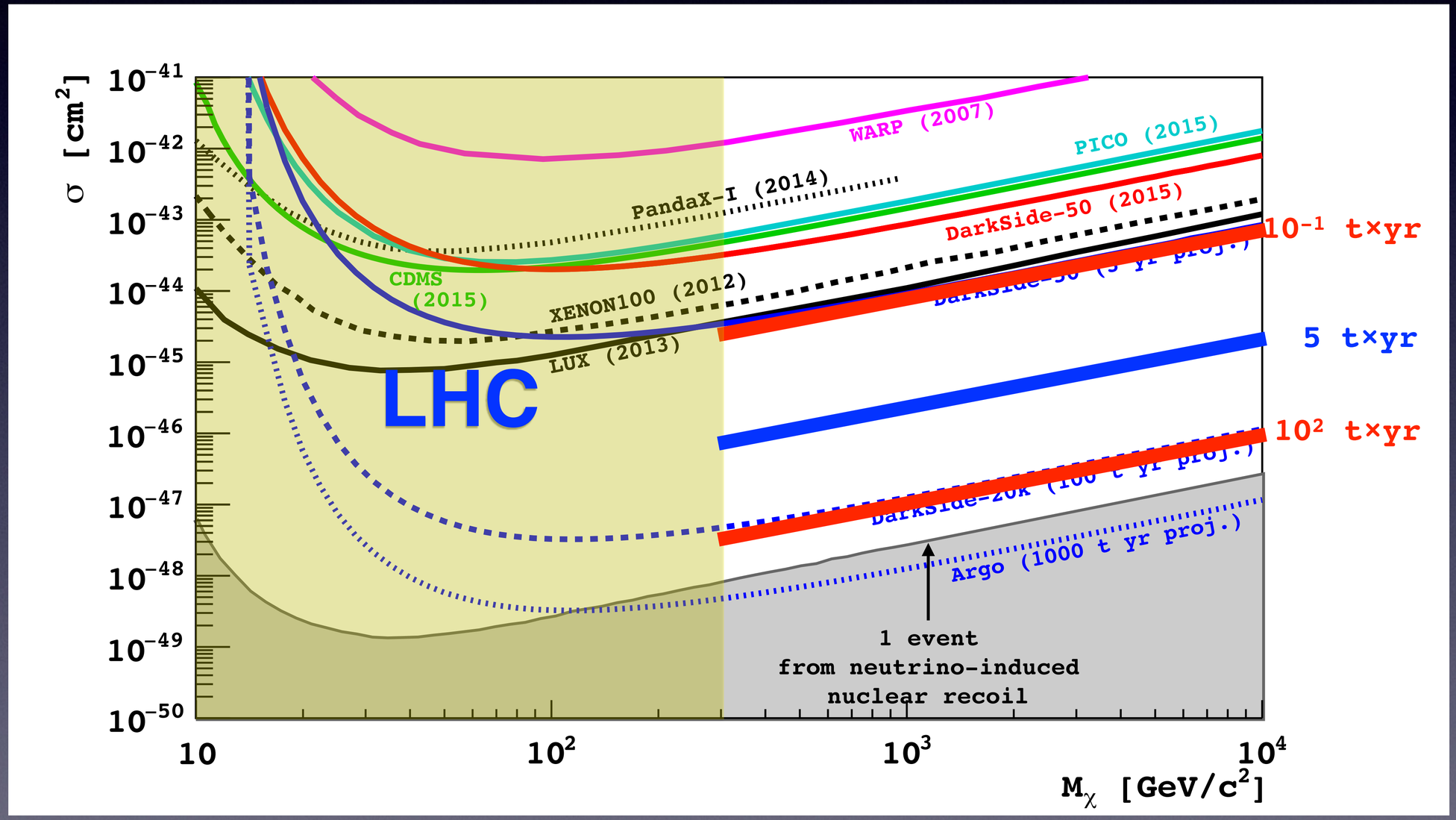
Dark Matter discovery path



Dark Matter discovery path



Dark Matter discovery path



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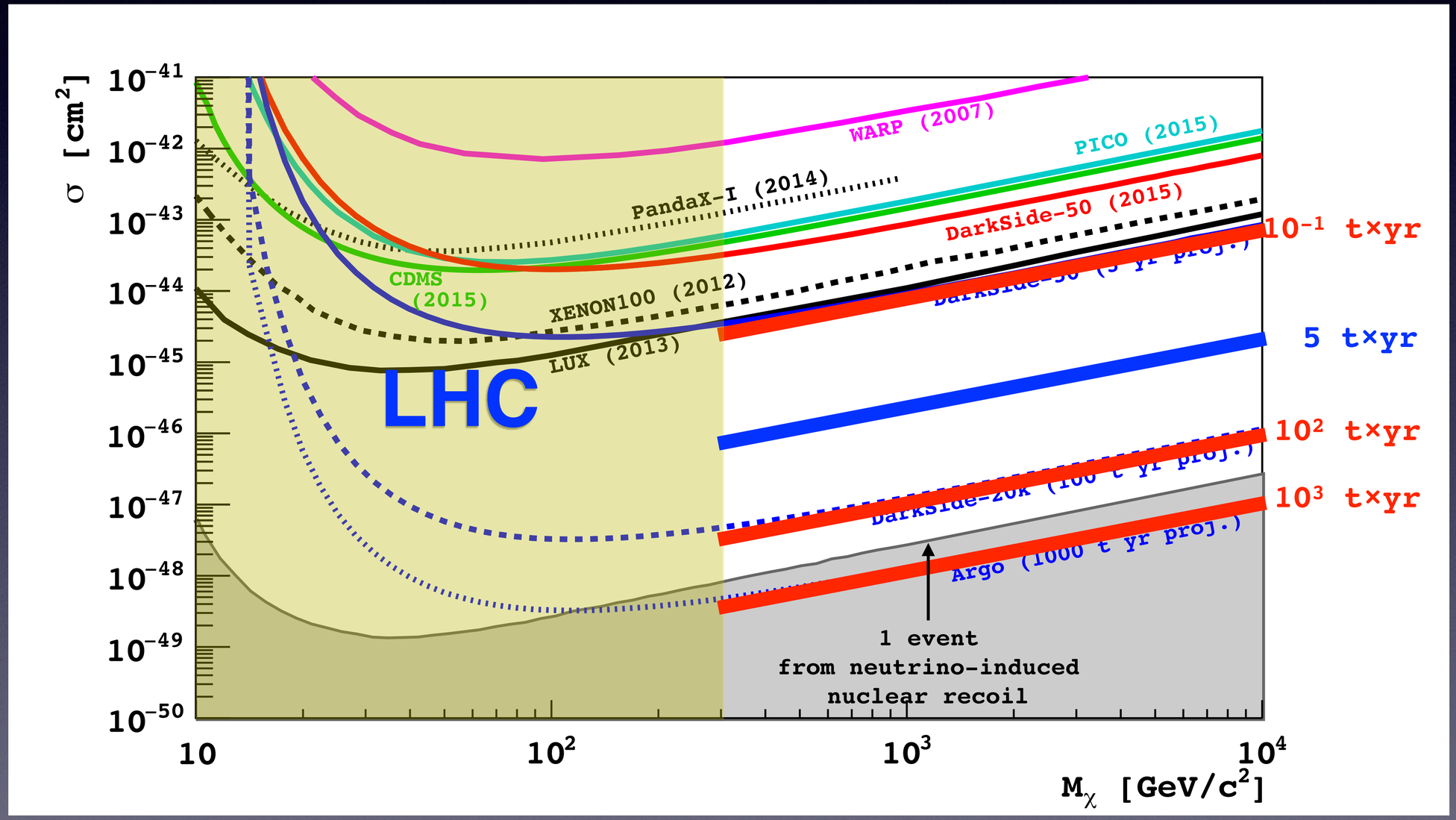
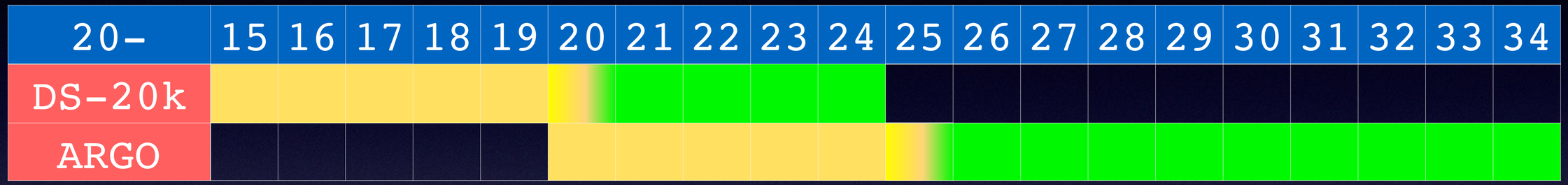


Argon: null background strategy to discovery

- The only dangerous backgrounds for large scale, high mass dark matter searches are:
  - Scatters of pp solar neutrinos on electrons
    - 200 events/tonne×yr in ROI
    - 200,000 background events @neutrino floor
    - ➡ Defeated in argon thanks to β/γ rejection better than $1 \div 1.6 \times 10^7$
  - Radioactive noble gases (^{39}Ar)
    - 1,422 kg×day (@AAr) x1400 (^{39}Ar AAr/^{39}Ar UAr)
    - ➡ 5.5 tonne×yr (UAr) already demonstrated

➡ additional active isotopic depletion and higher light yield can allow for 1,000 tonne×yr (UAr/DAr)

DarkSide future program



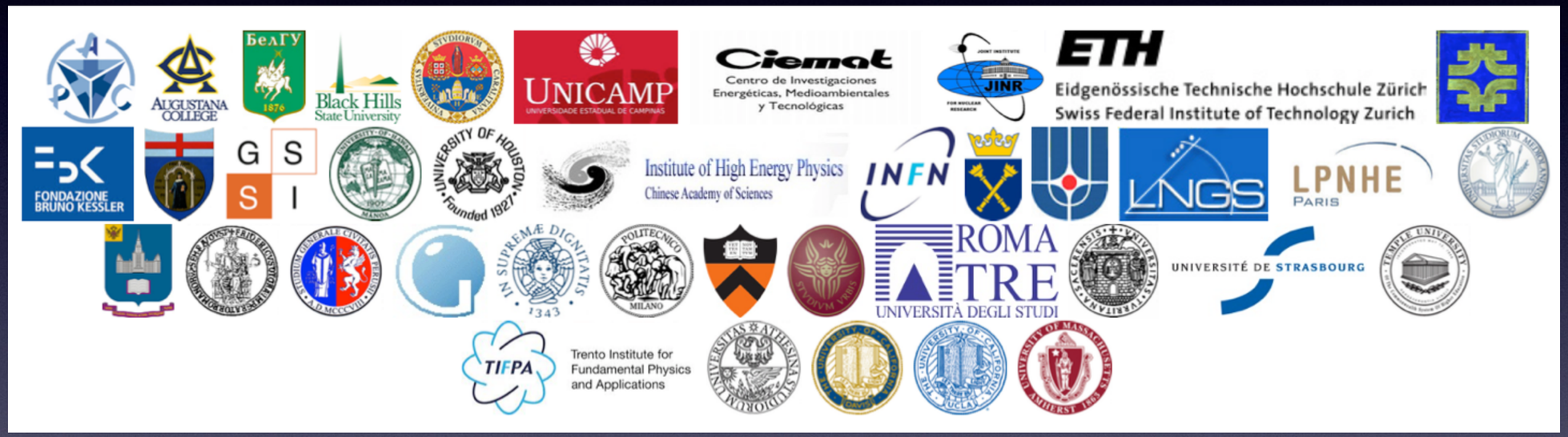
DarkSide-20k

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

ARGO

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

DarkSide-20k



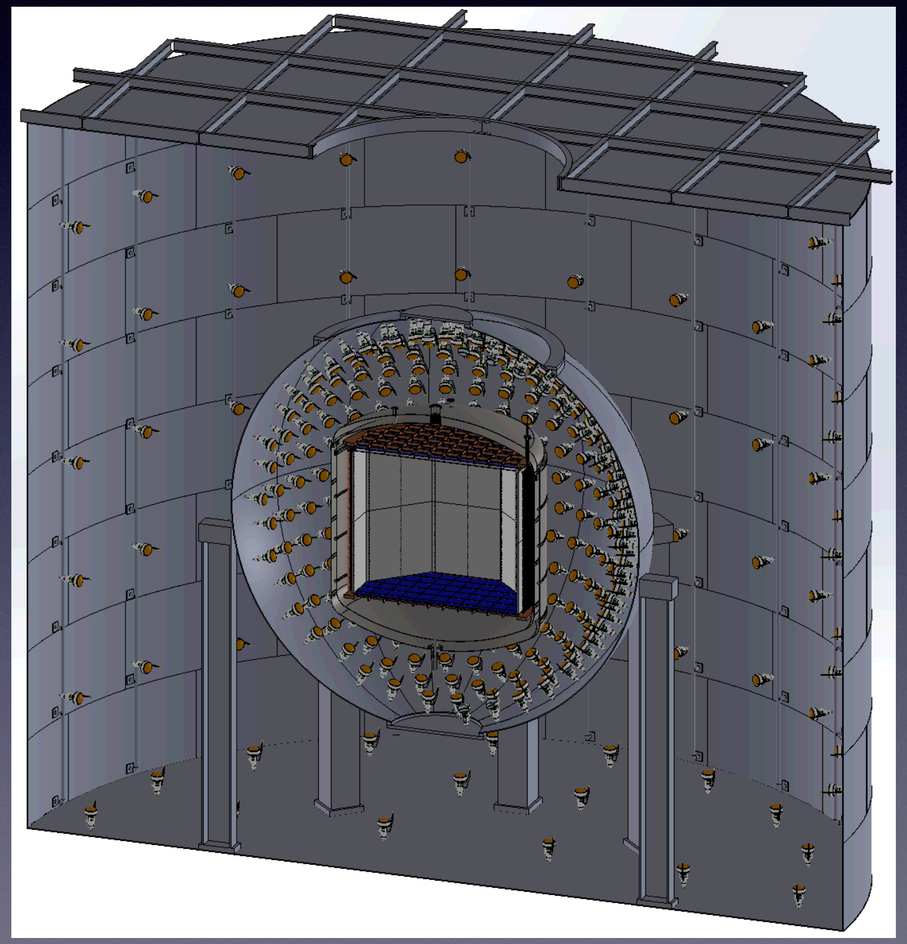
- 40 Institutions and still growing
- Proposal to INFN and NSF December 4, 2015

DarkSide-20k

Baseline design key issues:

- DAr target, 30 ton total, 20 ton fiducial
- radiopure construction, titanium cryostat
- 15m^2 SiPM sensors (low radioactivity, increased LY)
- high efficiency neutron shield/veto

Scalable design for application to larger scale detector

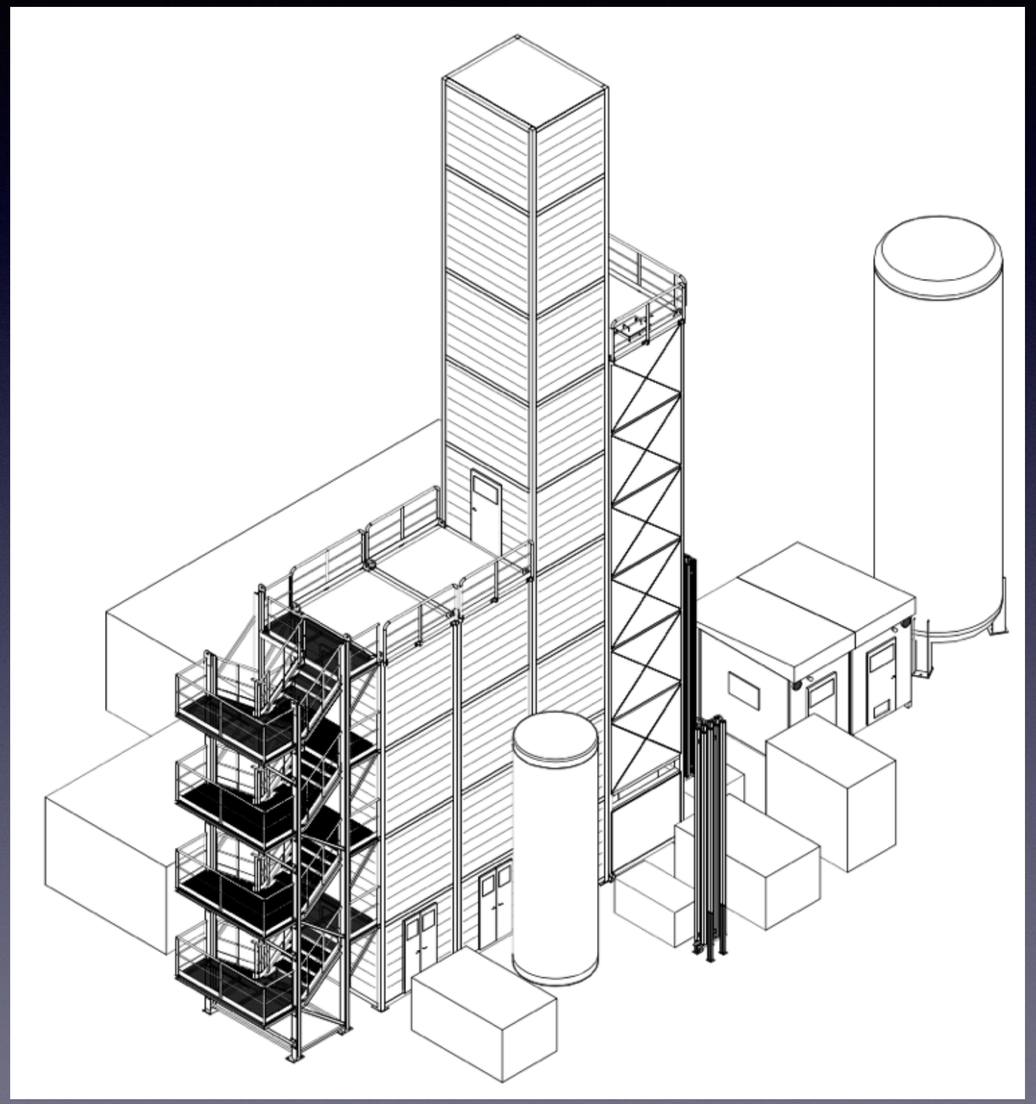


DarkSide Enabling Technologies and Broader Impact

- Extraction of large quantities of underground argon (URANIA)
- Isotopic separation via cryogenic distillation (ARIA)
- Large area, cryogenic silicon photomultipliers (SiPM)
- Vacuum, cryogenic and low-radioactivity techniques: purification, distillation, radon abatement systems, ultra-pure materials

UAr: Project URANIA

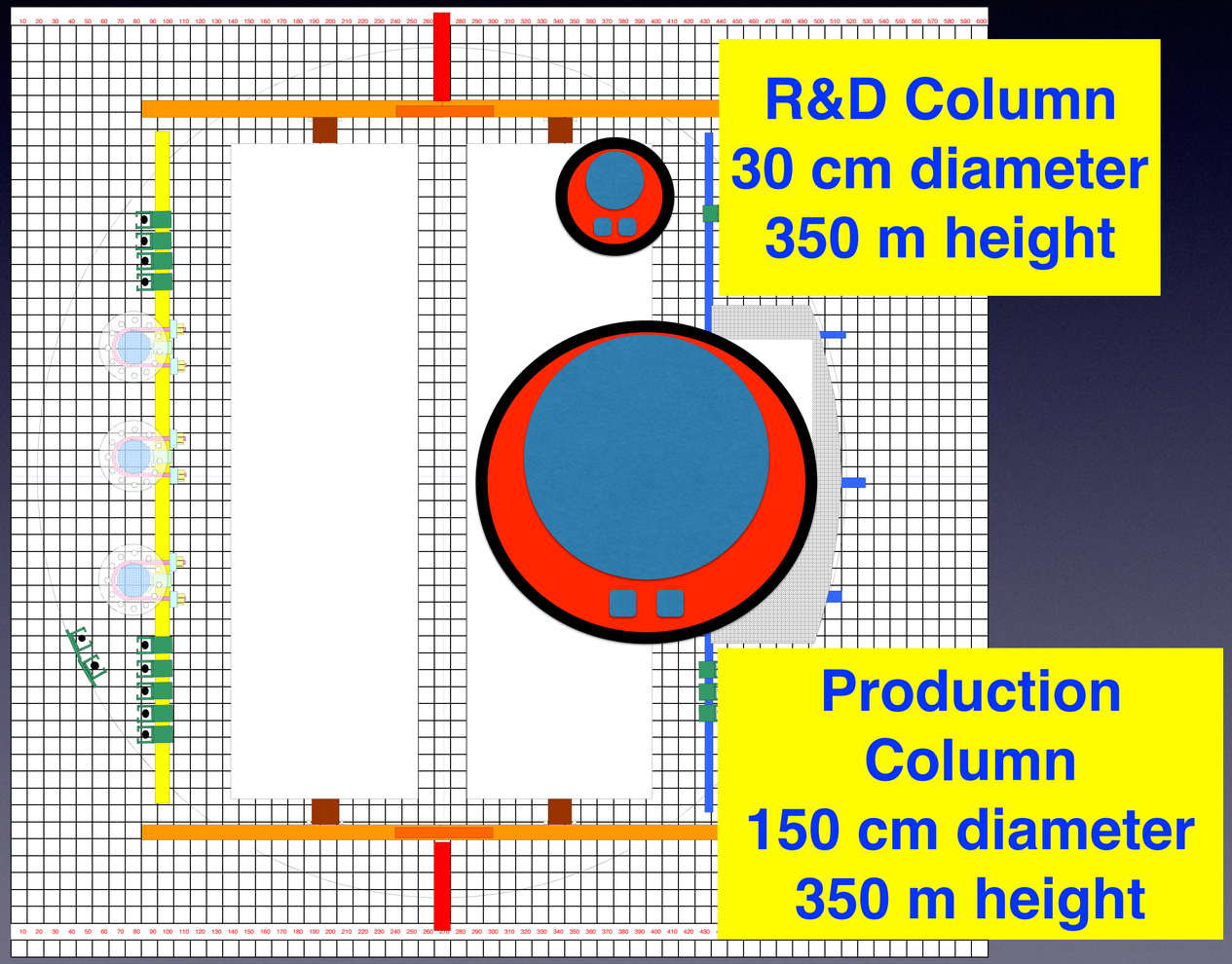
- Ar extraction plant in Colorado to reach capacity of 100 kg/day of UAr (in cooperation with Kinder Morgan)
- A set of elemental process units:
  - The first cryogenic column removes the bulk of CO_2 and CH_4
  - The Pressure Swing Adsorption columns removes the traces of CO_2 and CH_4
  - The second cryogenic column removes N_2 and He
  - The third cryogenic column refines the argon-rich stream into detector-grade argon
- Funding completed
- Argon extraction should start in 2017

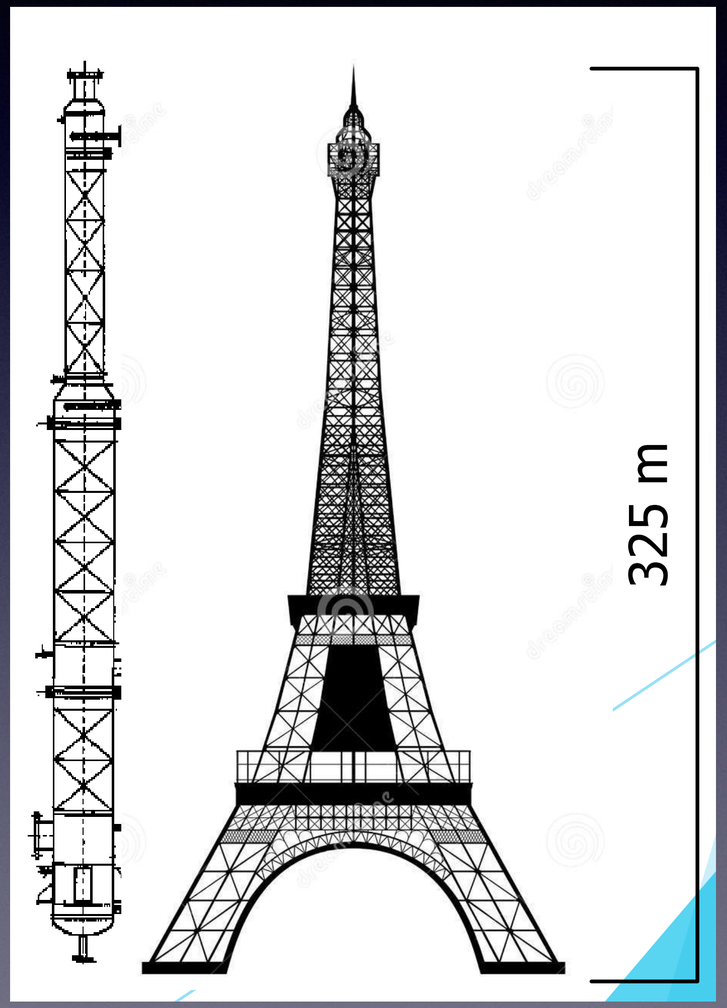


DAr: Project ARIA

- 350 m tall distillation column in the Seruci mine in Sardinia for chemical and isotopic purification of UAr
- Exploits finite vapor pressure difference between $^{39}Ar/^{40}Ar$ (^{39}Ar reduction factor of 10 per pass at the rate of 100 kg/day)
- Technique suitable also for production of ^{2}H, ^{13}C, ^{15}N, ^{18}O
- Protocollo di Intesa between INFN and Regione Sardegna in execution for the first Phase of the Project (Seruci I)

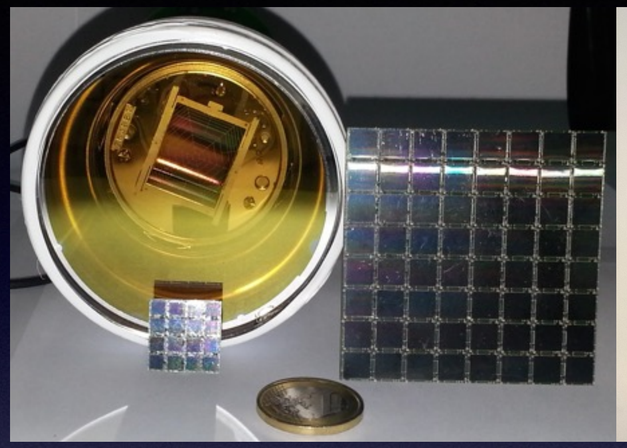
A Very Tall Column

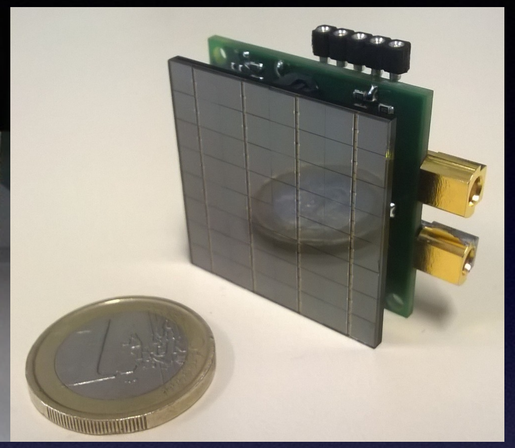




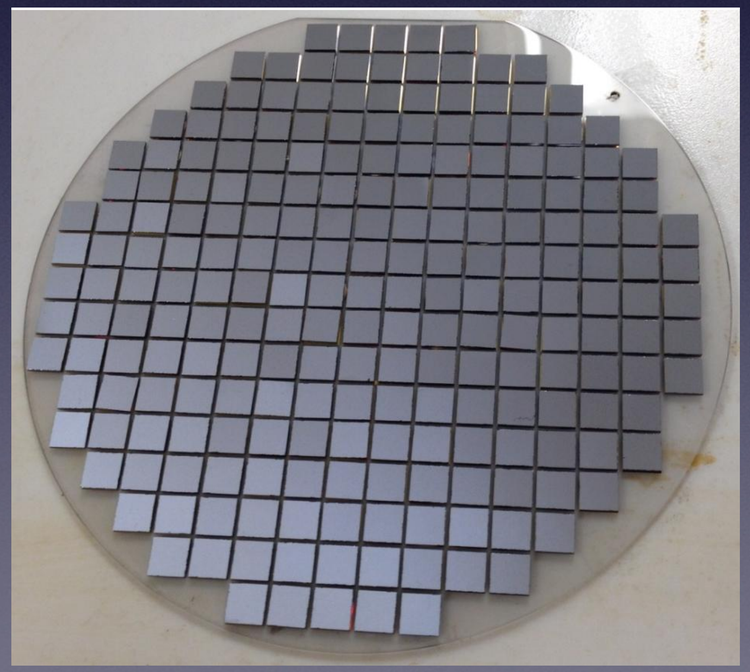
SiPM to enhance LAr technology

- Advantages w/r to cryogenic PMTs
  - Very compact, much lower radioactivity
  - Light yield increase by 50%
  - Greater stability
  - Ten-fold reduction of costs per unit area
  - SiPMs love to run at LAr temperature!





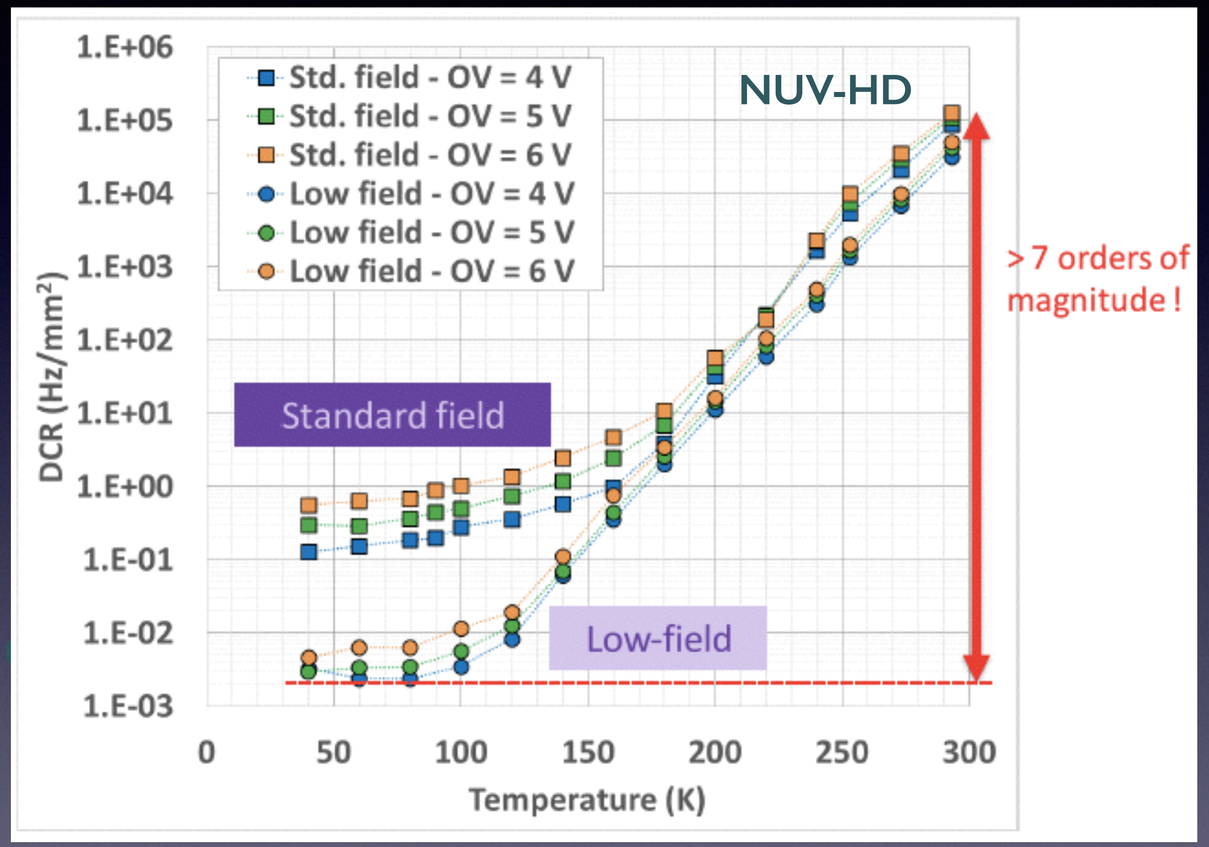
- A full chain (development-production-packaging-testing) strategy largely funded by Regione Abruzzo
  - Custom SiPM development for cryogenic temperature (FBK)
  - Industrial cooperation for large-scale production
  - Radiopure packaging of the tiles and of the cryogenic FE readout board
  - Massive test and selection of detector modules before installation in DS-20k



SIPM development at FBK

A. Gola

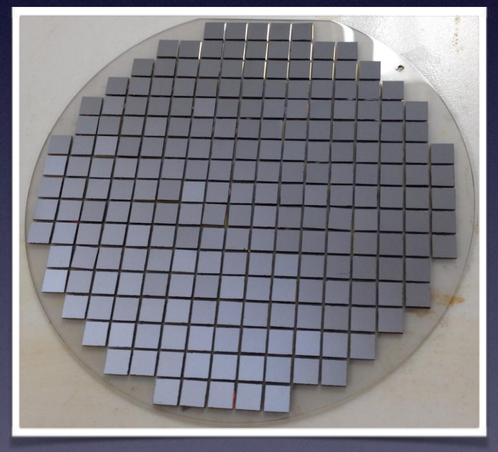
- Custom SiPMs featuring a very sharp peak in the single cell response and a slow recharge
  - **suppressed afterpulsing**
- NUV-HD technology
  - small microcells (< 30 um)
  - high FF (up to 78%)
  - **PDE in excess of 55% at 410 nm**
  - low correlated noise
- Very efficient packaging and **very high fill factor at the tile level** (≃90%)

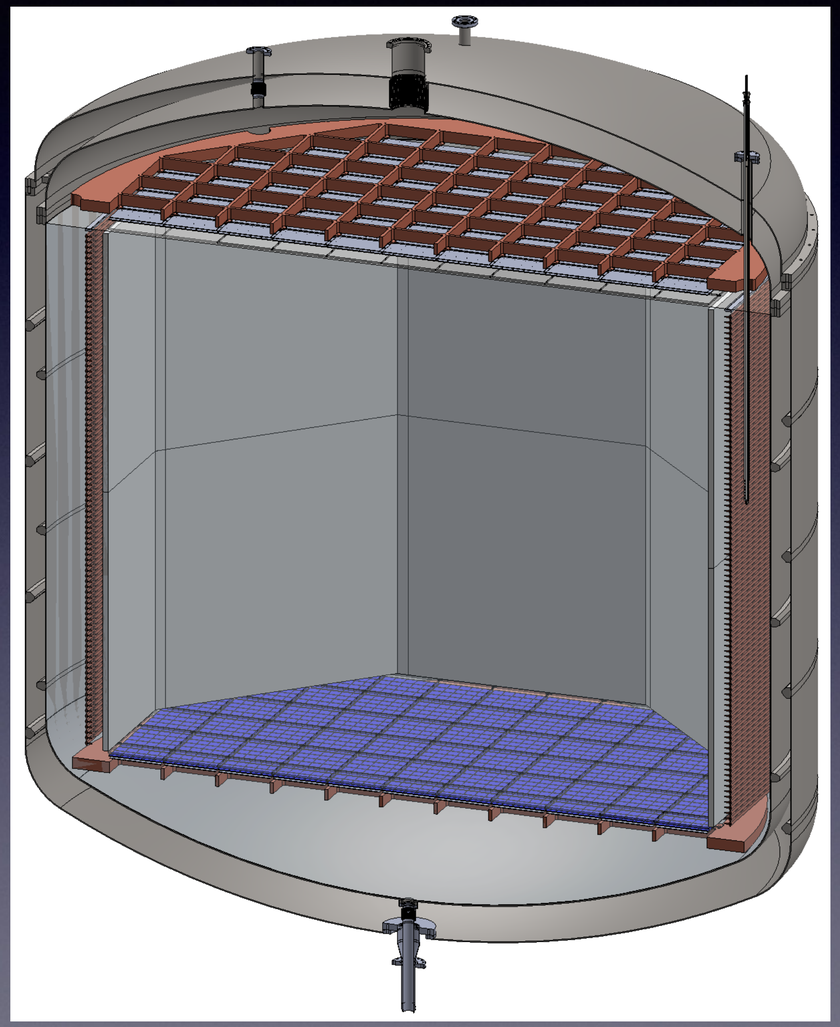


Significant part of the preliminary work to identify the device specifications and to optimise the technology already performed

DS-20k Basic Parameters

- Active volume 356 cm tall, 241 cm diameter, DAr fill 23(20) Tonne active(fiducial)
- Octagonal PTFE reflector
  - Slit-panels joined together
  - No gaps when cooled
  - Fully scalable in Φ and L
  - Split-ring field cage outside
  - reflector as in DS-50
- 50 KV total HHV
- SiPM light detectors top & bottom, immersed in LAr





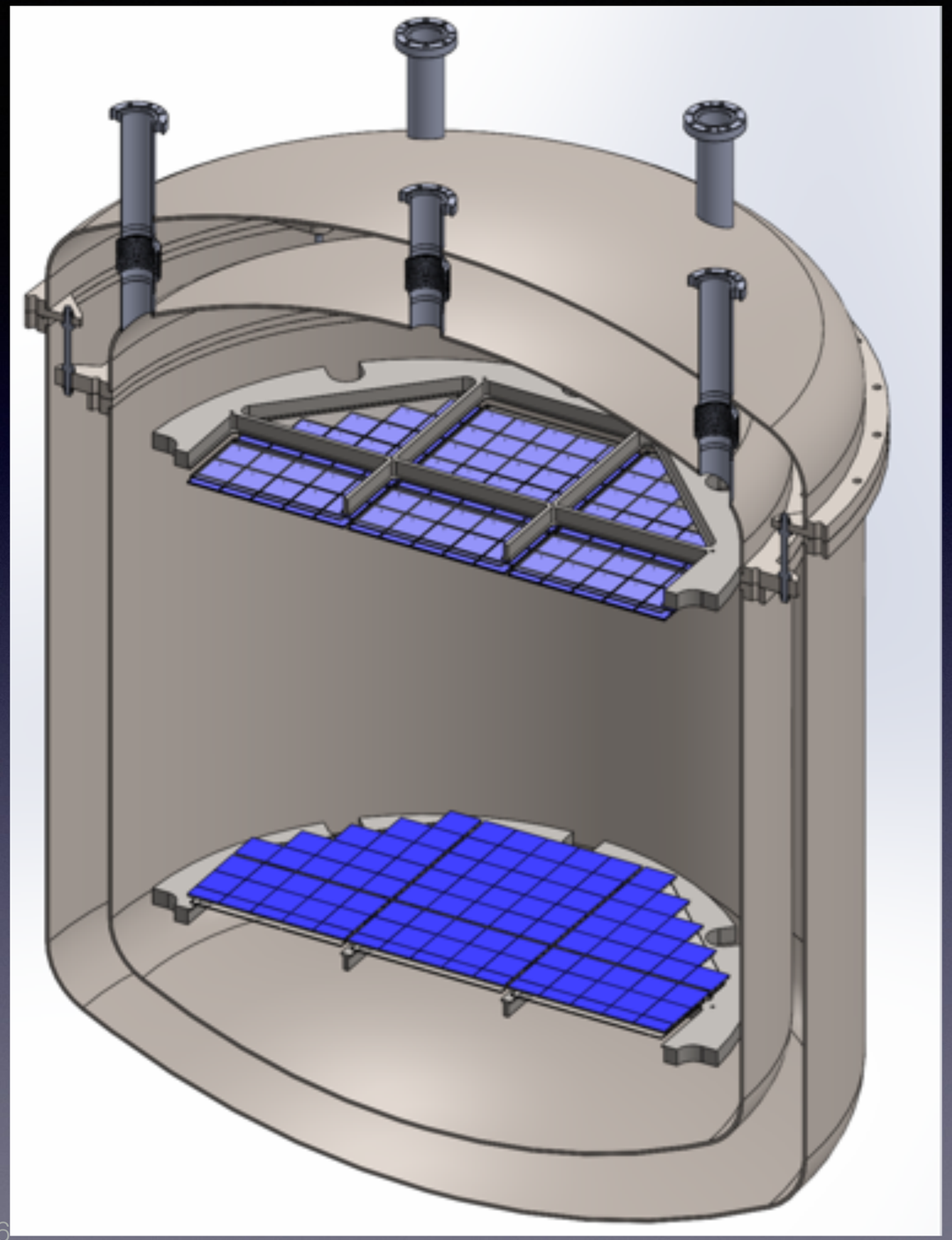
1-ton Prototype

- From DS-50 to DS-20k
  - scale-up the volume (factor >200)
  - new reflector and field cage
  - new anode, cathode and extraction system
  - new light readout
  - new front-end and DAQ electronics

➡ O(1m) linear dimensions to validate mechanics and SiPM

➡ ton scale to test full size DS-20 cryo system

TPC assembly and integration test



Conclusions

- The DarkSide program aims at exploring dark matter down to the “Neutrino Floor” at and above the mass range explored by planned accelerator experiments, well above 100 GeV
- DarkSide-20k:
  - 20-tonne low-radioactivity argon target operated within the existing DS active vetoes and infrastructure at LNGS
  - background-free exposure of 100 tonne×yr to reach a sensitivity of 1×10^{-47} cm^2 for a 1 TeV/c^2 dark matter particle mass (1×10^{-46} cm^2 for 10 TeV/c^2)
- Requires:
  - Upgrade of production of depleted argon to many tonnes (URANIA & ARIA)
  - Cryogenic photosensors based on SiPM arrays with area of 15 m^2 (R&D)
- If approved promptly, DS-20k could become the most powerful dark matter experiment searching for high mass dark matter to start data taking before 2020

Thank you