North American-led and participated Direct Dark Matter Searches

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ASPERA
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Direct Detection Requirements

- Low energy nuclear recoils (< 100 keV)
- Low rate (~1 event/ton/yr for 10^{-47} cm^2)
  - Already a discovery at low mass, high cross section?
- Background, background, background
- Golden signatures (seasonal variation, directionality)
- Depth and shielding
- Detector designed for "Discovery"

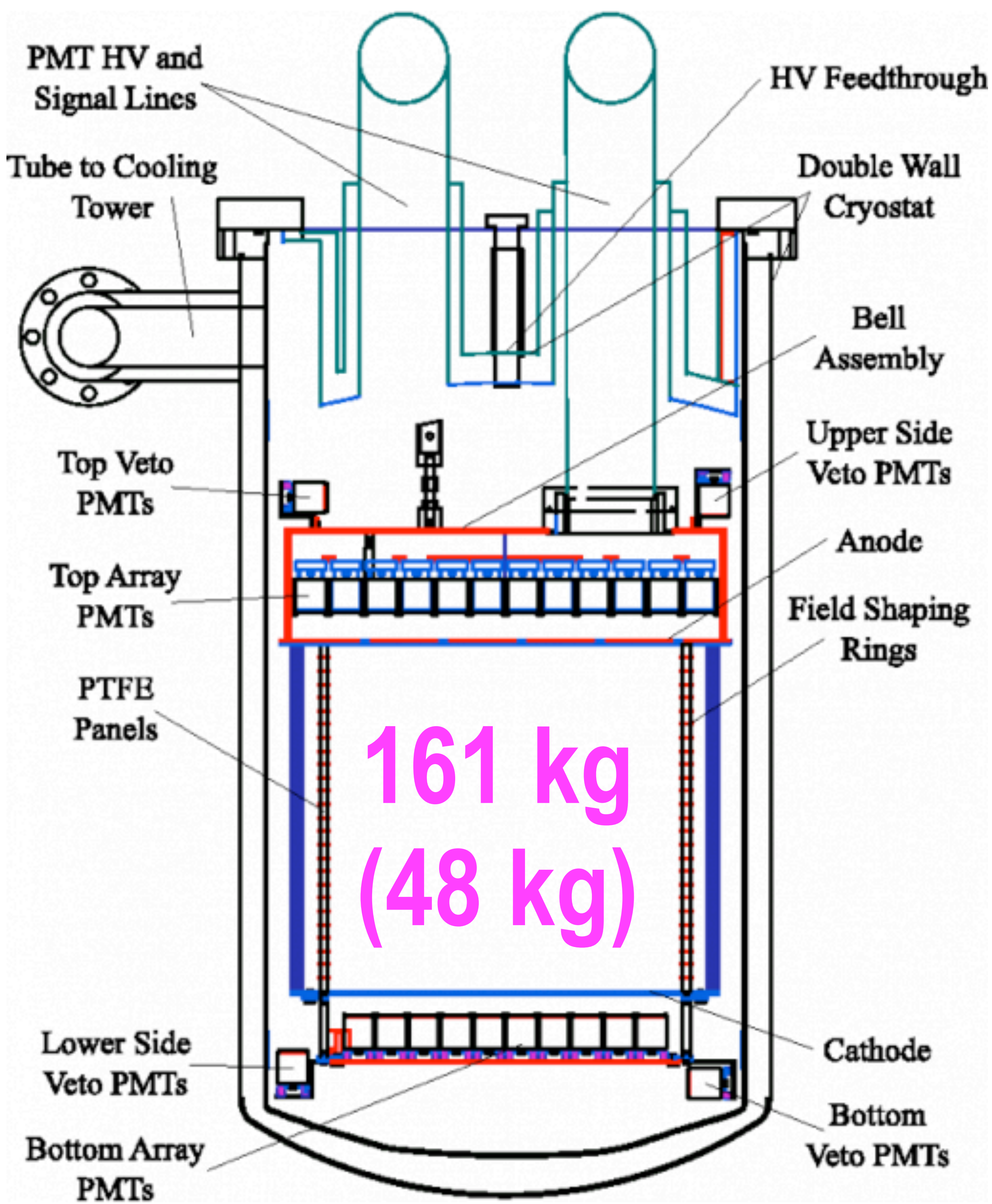
General Considerations

- Area of strong collaboration between North America, Europe, and Asia
- A great portion of the US program and of US-led experiments located in Europe (LNGS)
- International consortia (EURECA, DARWIN, MAX, LZ) under the auspices of ASPERA and NSF/S4 helping the coalescence and cross-border scientific collaboration
- Great opportunity for new science beyond sStandard Model and for opening new frontiers in particle physics

Plan of the Talk

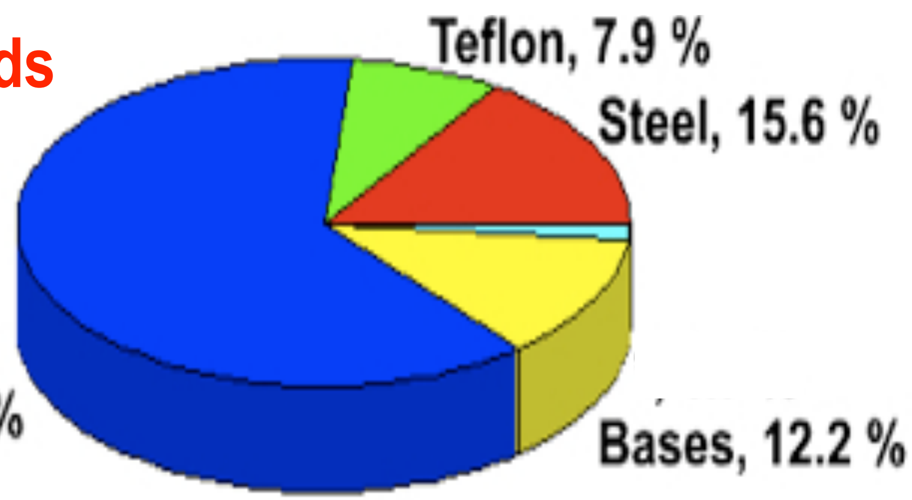
- XENON-100, XENON-1t
- LUX
- WARP
- DarkSide
- Mini-CLEAN
- DEAP
- COUPP
- CDMS
- COGENT

XENON100 (Double phase Xenon)

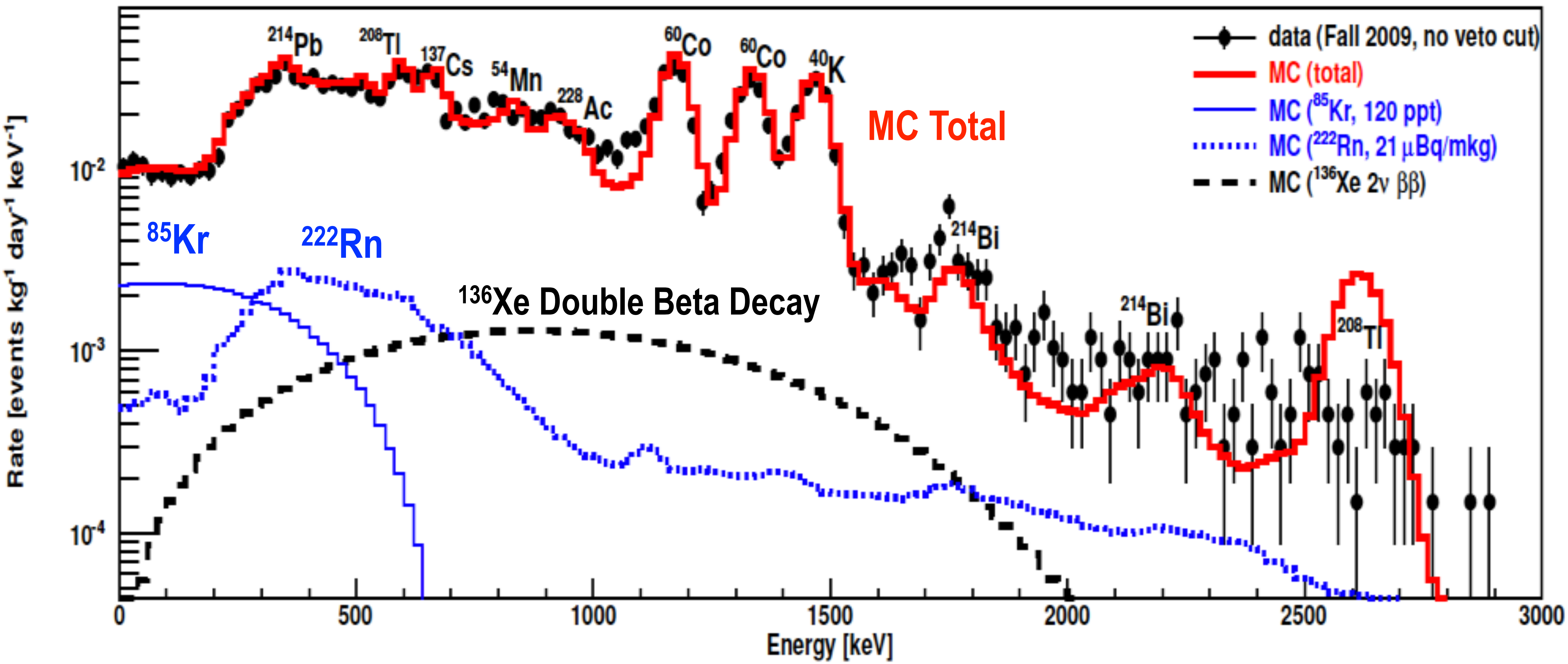


Energy Spectrum of Real Data vs. MC

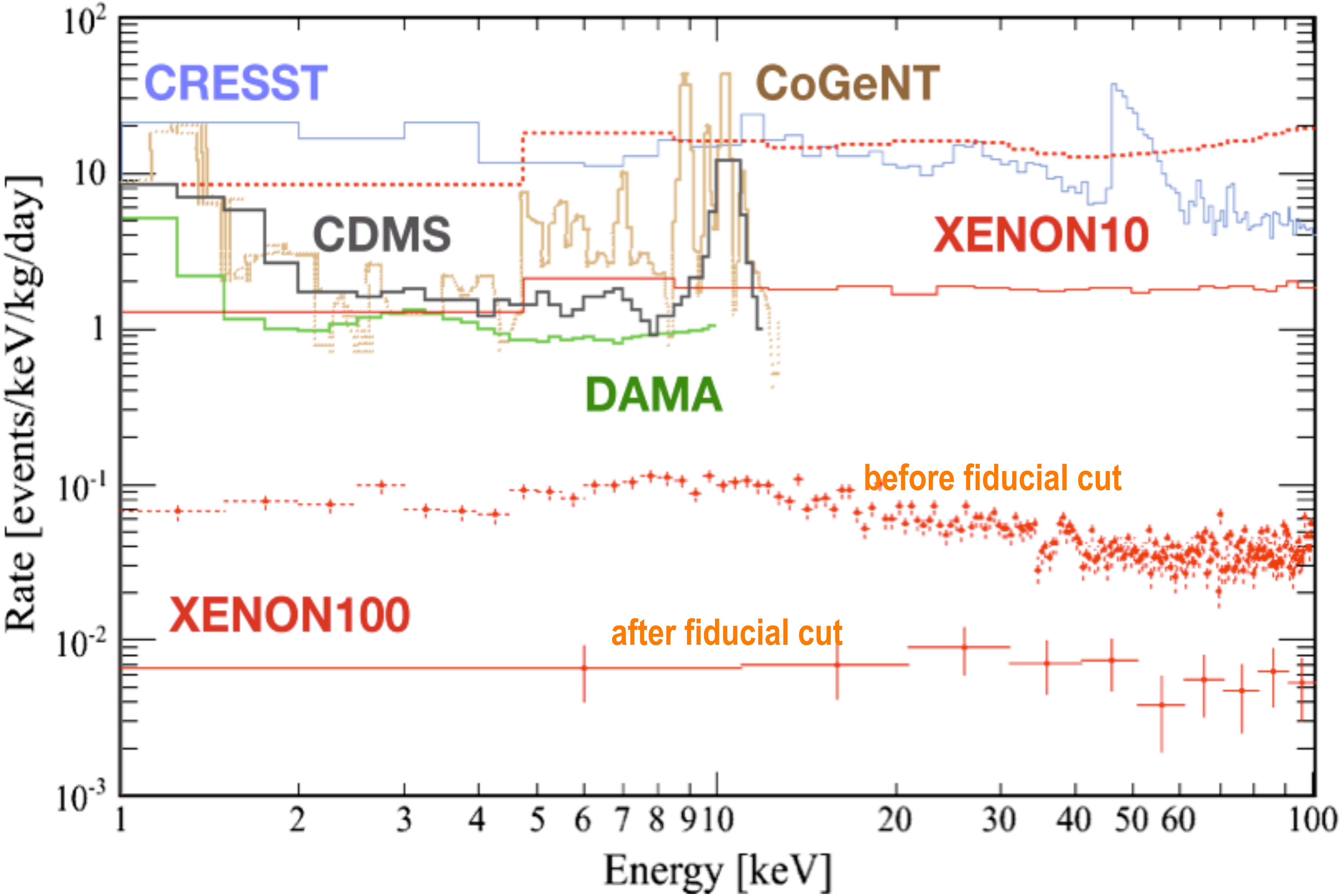
Surface Backgrounds



arXiv: 1101.3866



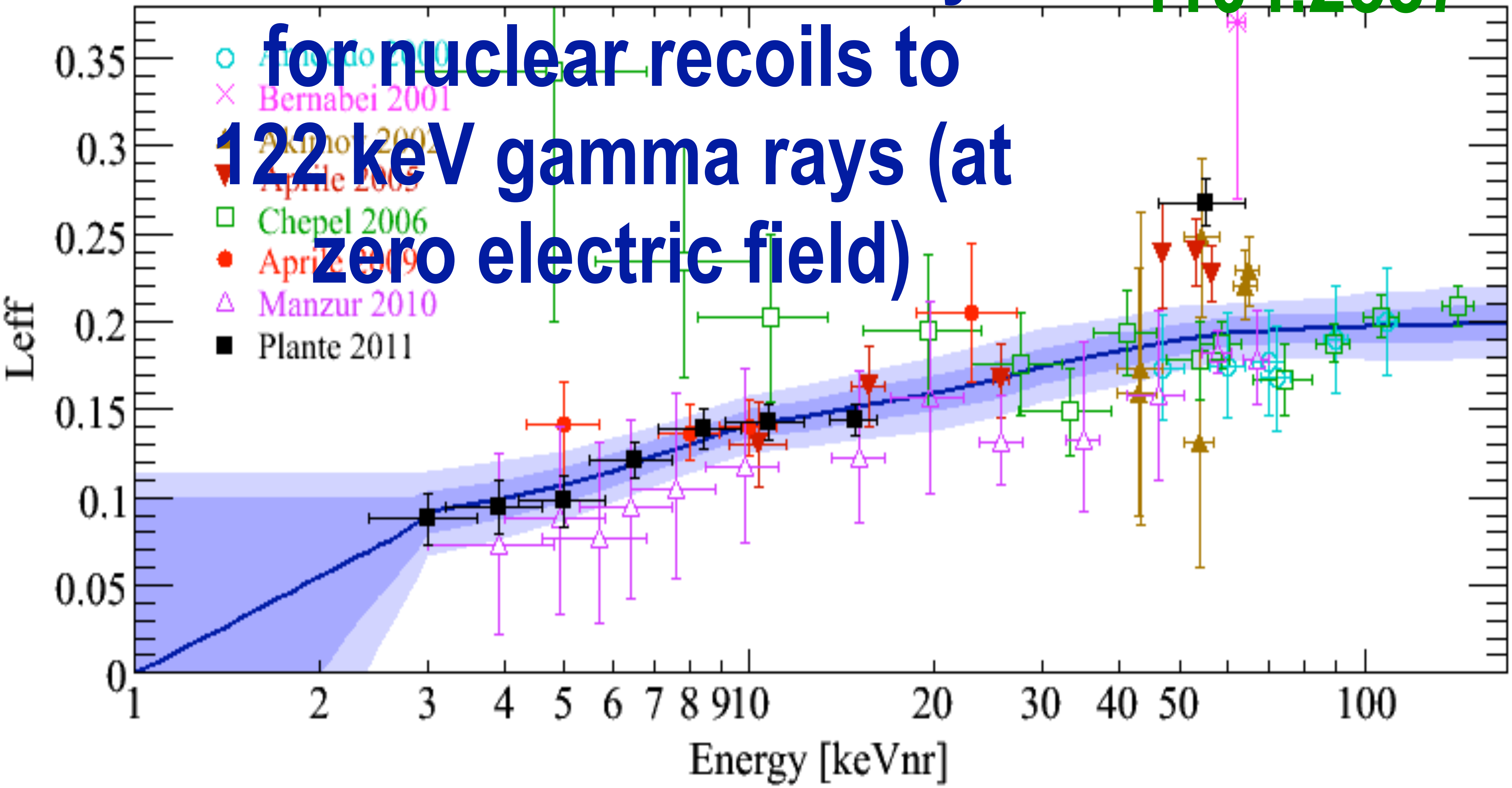
Level of Backgrounds (before S2/S1 cut)



New L_{eff} vs. Energy

Leff : Relative scintillation efficiency for nuclear recoils to 122 keV gamma rays (at zero electric field)

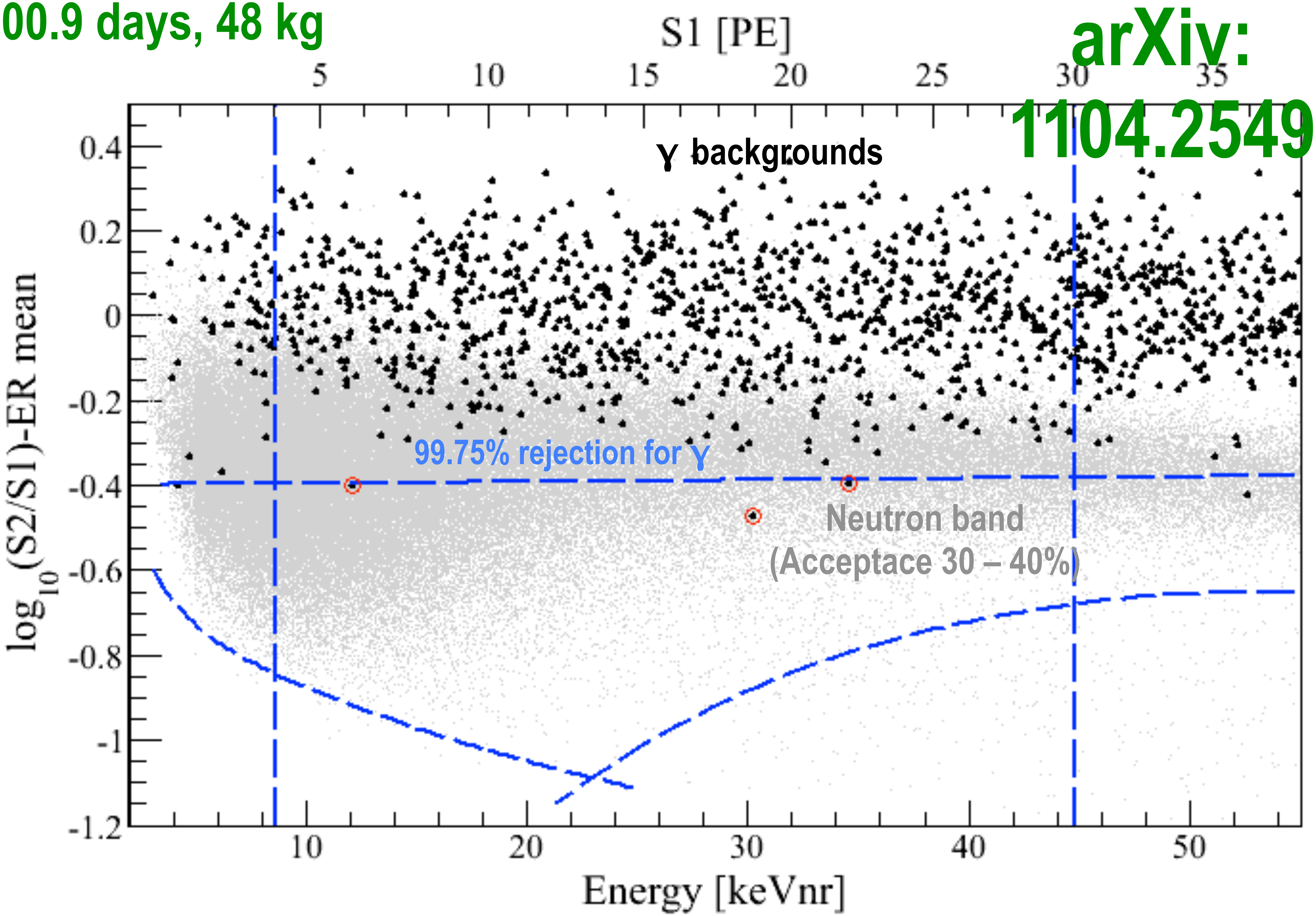
arXiv: 1104.2587



Log(S2/S1) vs. Energy

100.9 days, 48 kg

arXiv: 1104.2549



Log(S2/S1) vs. Energy

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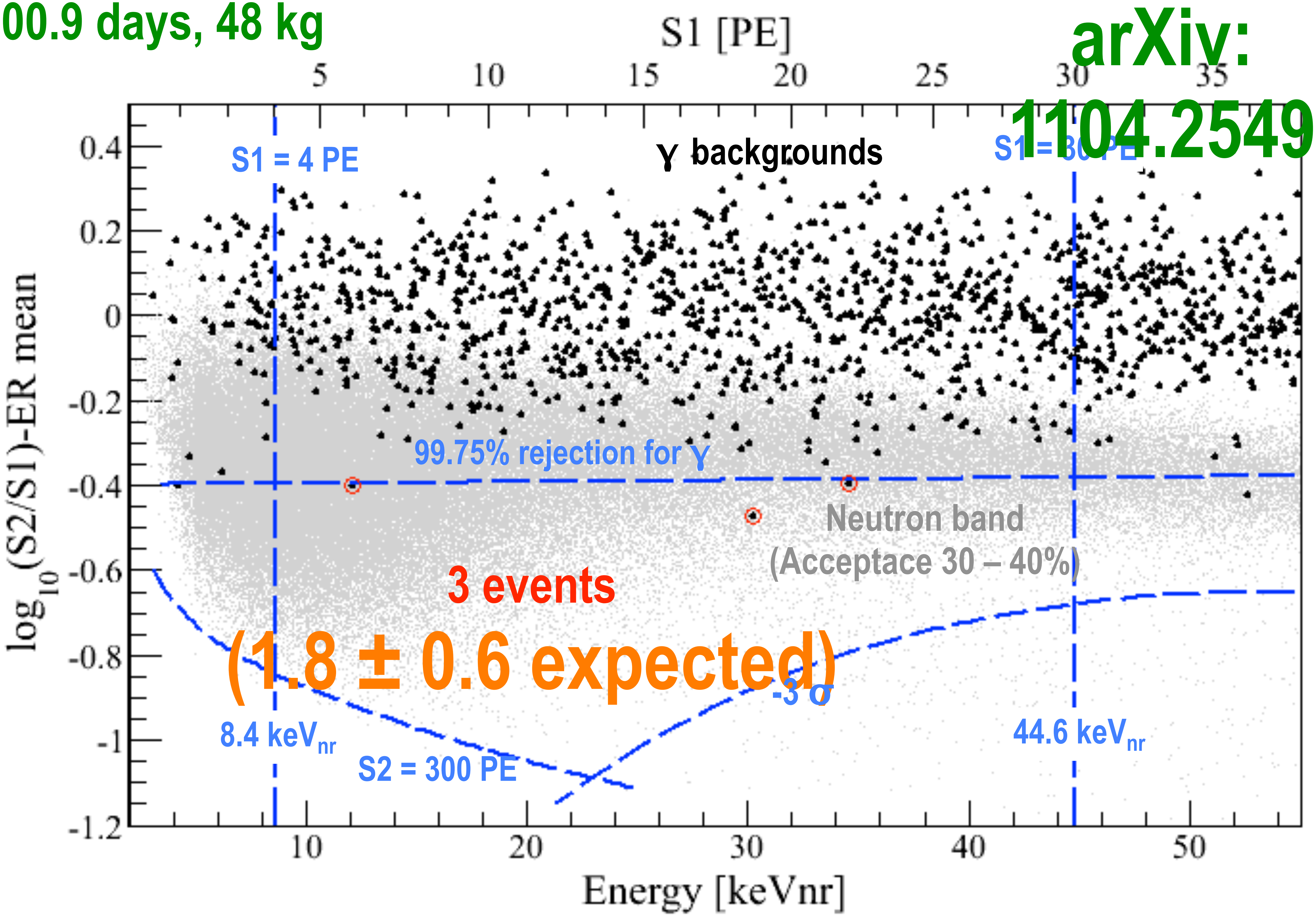
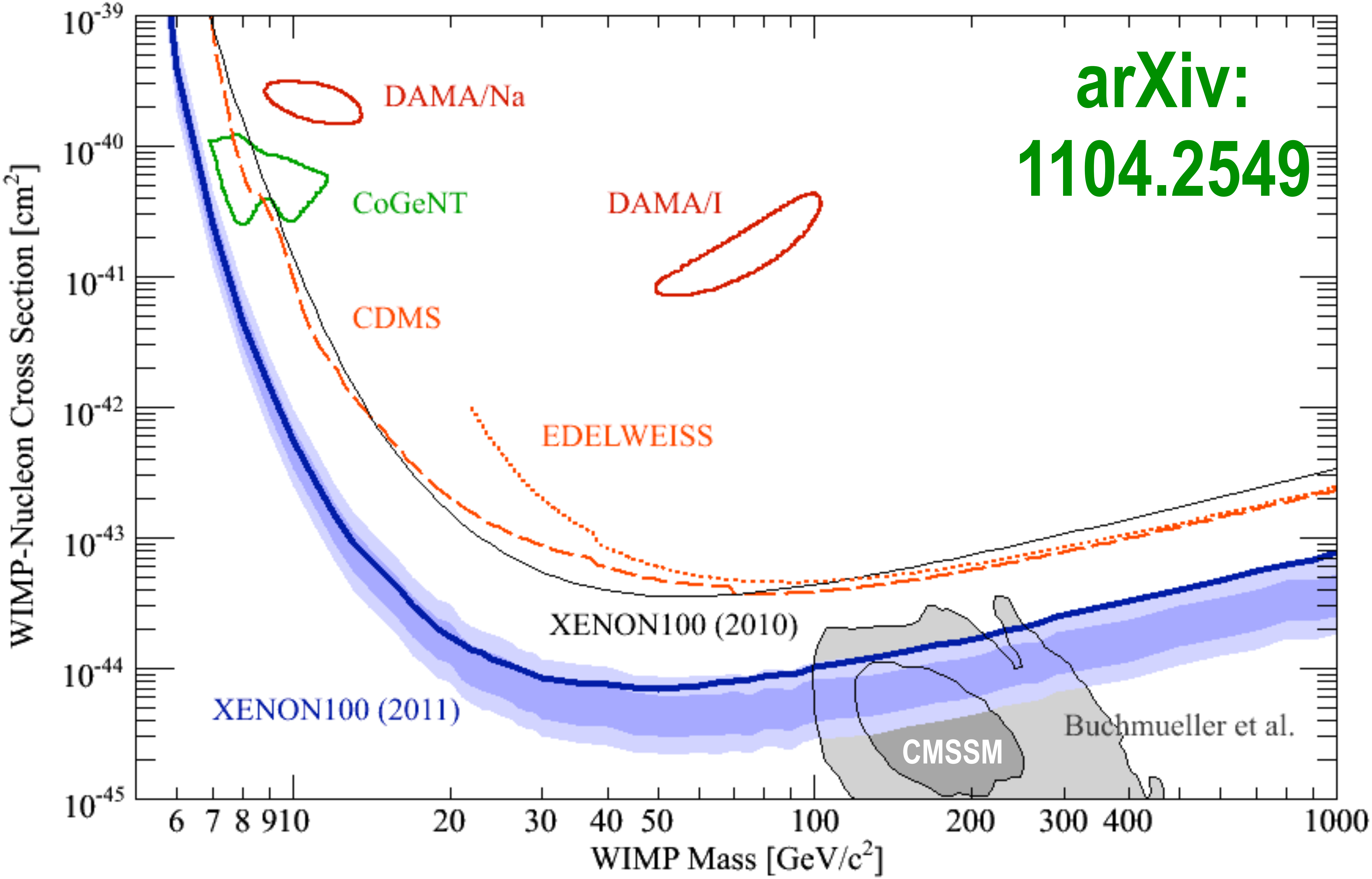
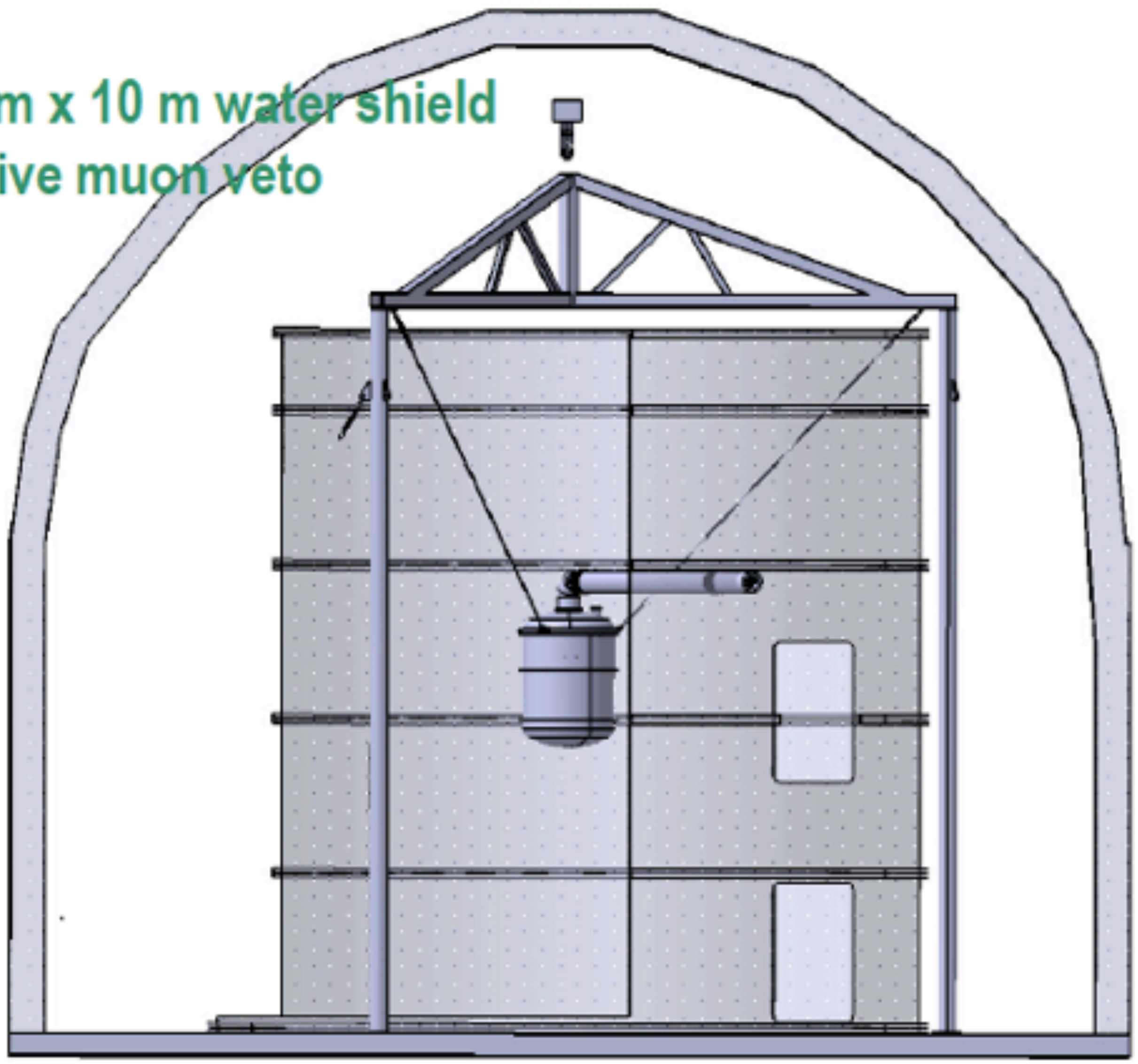
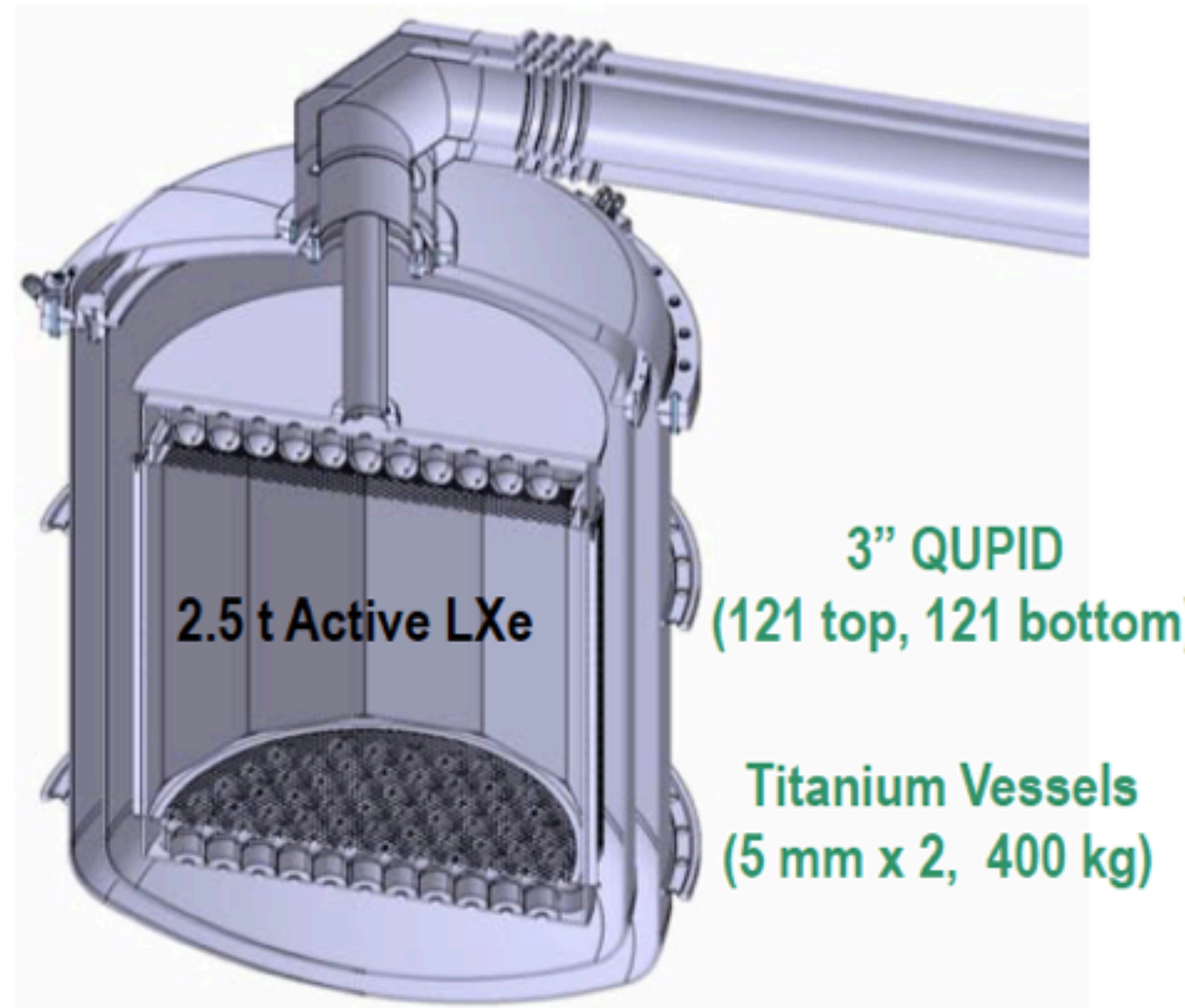


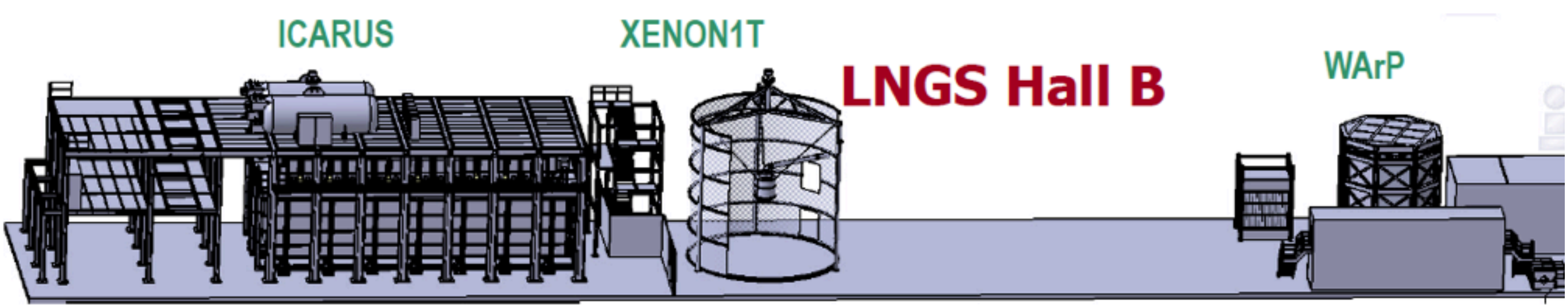
90% CL Limits of SI Cross Section (April, 2011)



XENON1T (G2)


10 m x 10 m water shield
active muon veto


2.5 t Active LXe
3" QUPID
(121 top, 121 bottom)
Titanium Vessels
(5 mm x 2, 400 kg)


ICARUS
XENON1T
LNGS Hall B
WArP

LUX - Status Summary

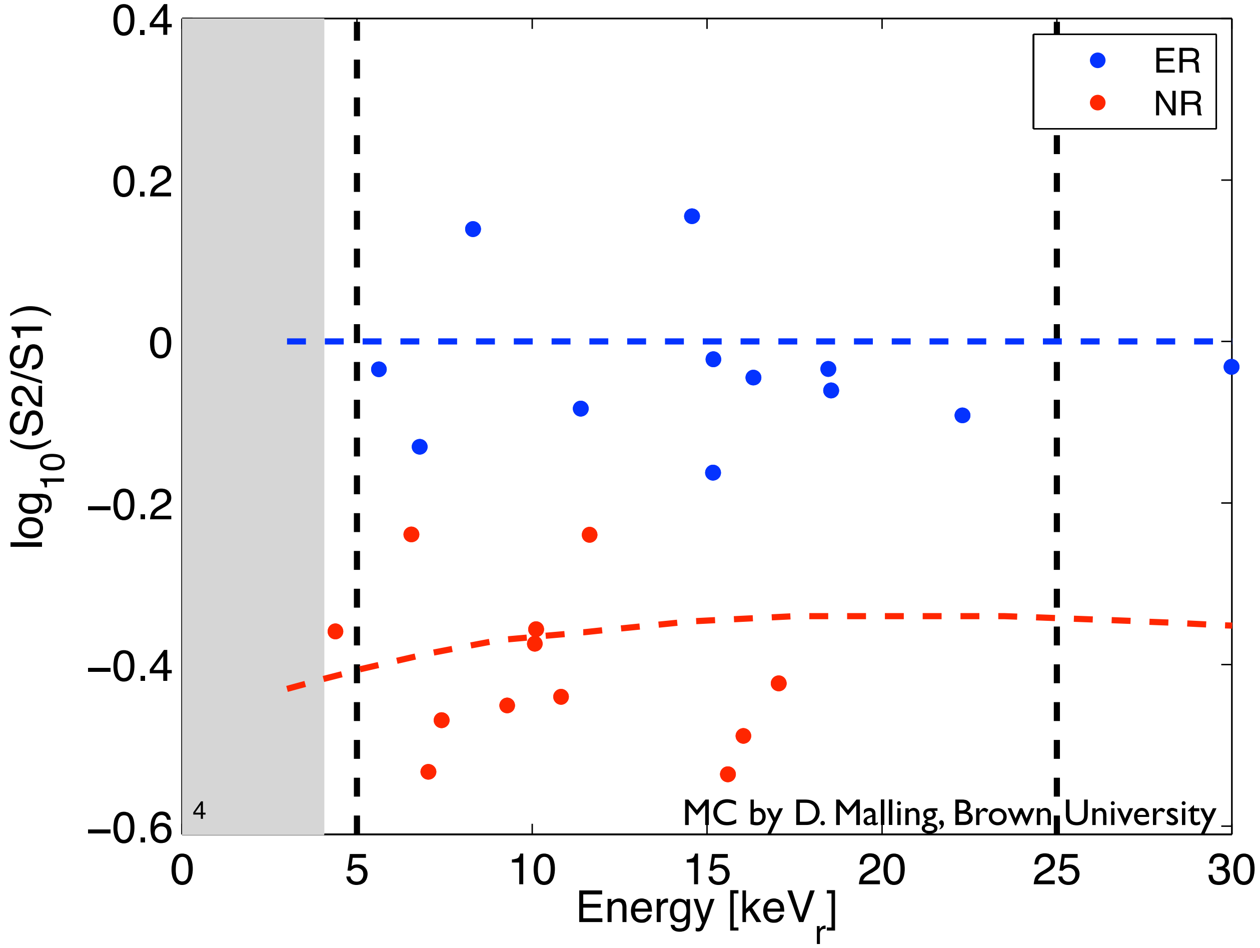
- LUX 350 kg
  - LUX detector has started series of cryogenic runs in Surface Lab -testing the full deployment configuration in water tank.
  - May 2011: $8m contract for outfitting work on new Davis Complex at 4850 level of Sanford Lab has been signed, and work is underway. (Excavation was completed in earlier in 2011.)
  - LUX will continue surface operation to verify all systems are fully functioning, and then move detector underground for physics run when outfitting is completed in Spring 2012

LUX Detector in Water Tank
Prior to May 2011 Cooldown
Sanford Surface Facility

- Self shielding of 350 kg LXe mass will deliver very low raw background rates for electron recoils (even before ER discrimination)
  - See next slide
- Important for clear discovery of WIMP nuclear recoil signal

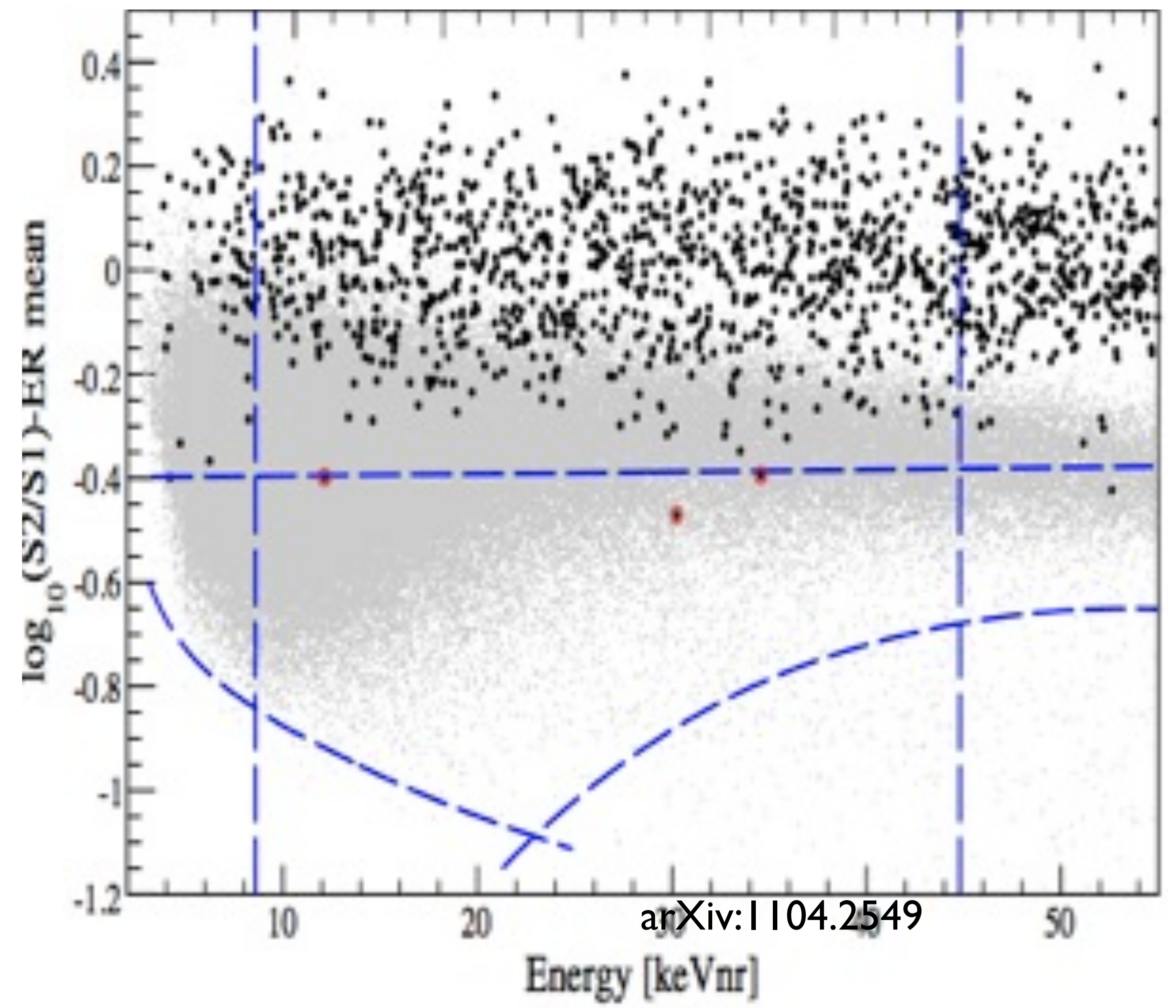
LUX: The First 40 Days

LUX (Monte Carlo)



LUX signal and background expectation for 4,000 kg-days net exposure. WIMP events assume m = 100 GeV, σ = 1×10^{-44} cm^2.

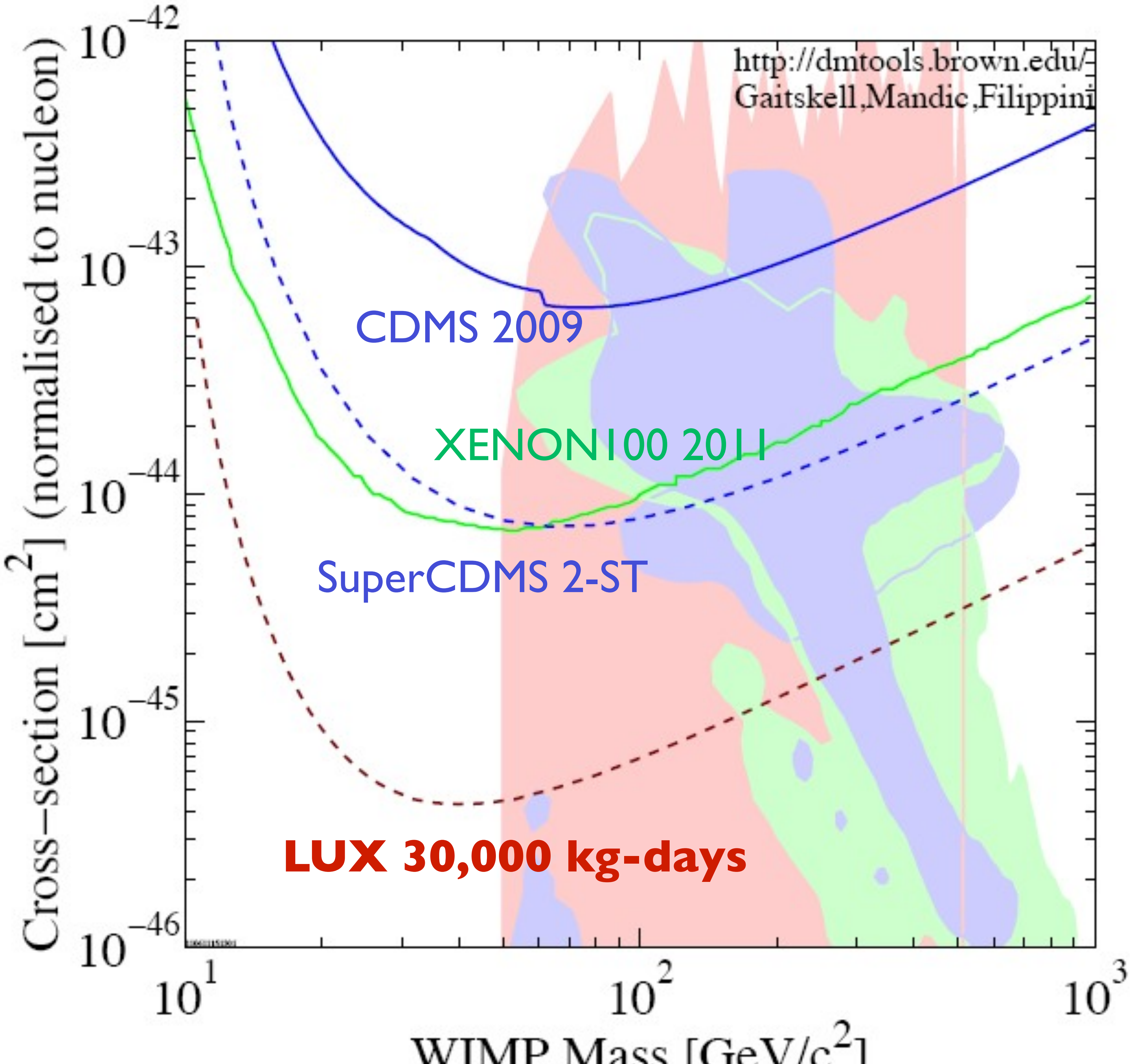
XENON100



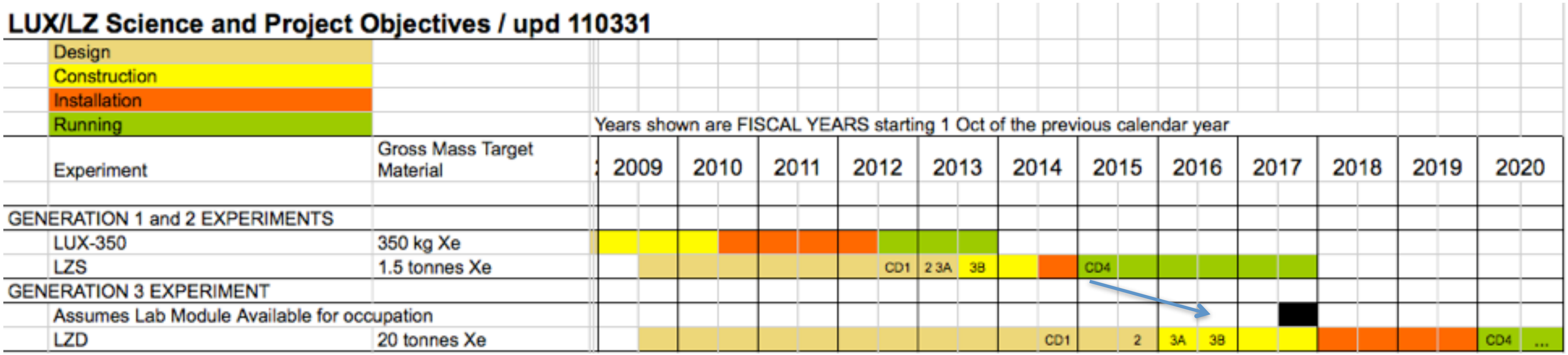
XENON100 4,000 kg-days result for comparison.
Note higher ER rate - ~800 events in 100 days x 40 kg fiducial
~60% due to 85Kr with remaining 40% due to Compton scattering of external gamma background

- **Red Points:** WIMP events after only 40 days (equivalent exposure to all of XENON100 run) assuming a WIMP model for mass 100 GeV at current best 90% CL Exclusion Limit
- **Blue Points:** Total # of single scatter electron recoil events in LUX (before any other cuts) after 40 days of running. Expect only 11 events in 100 kg fiducial x 40 days for a net 4,000 kg exposure.
- **LUX - Strong Emphasis on WIMP Discovery / Plan to run LUX for 300 days**

LUX Dark Matter Sensitivity



Evolution of LUX-LZ Program
Highlight CD stages for LZD



TPC ($M)	Homestake 4850	SNOLab
LZS (1.5t Xe)	12.48 - 17.96	16.97 - 24.39
LZD (20t Xe)	60.5 - 88.2	65.23 - 95.64*

The estimates are Pre-CD1, however, we are applying same methodology
The Low-High represents the range of technical decisions on design/construction
Contingency has been separately assessed and added to all items

See talk by Tom Shutt in Budget/ Project Breakout Section

* Further studies need to establish a baseline design which will permit LZD to fit within the Cube Hall, and adjacent service areas. Seismic design aspects of SNOLab construction not yet included.

WARP 140-kg Detector

The WARP 140-kg detector, currently under commissioning at LNGS

140 kg active target, to reach into 5×10^{-45} cm^2 and cover critical part of SUSY parameter space

Complete neutron shield!

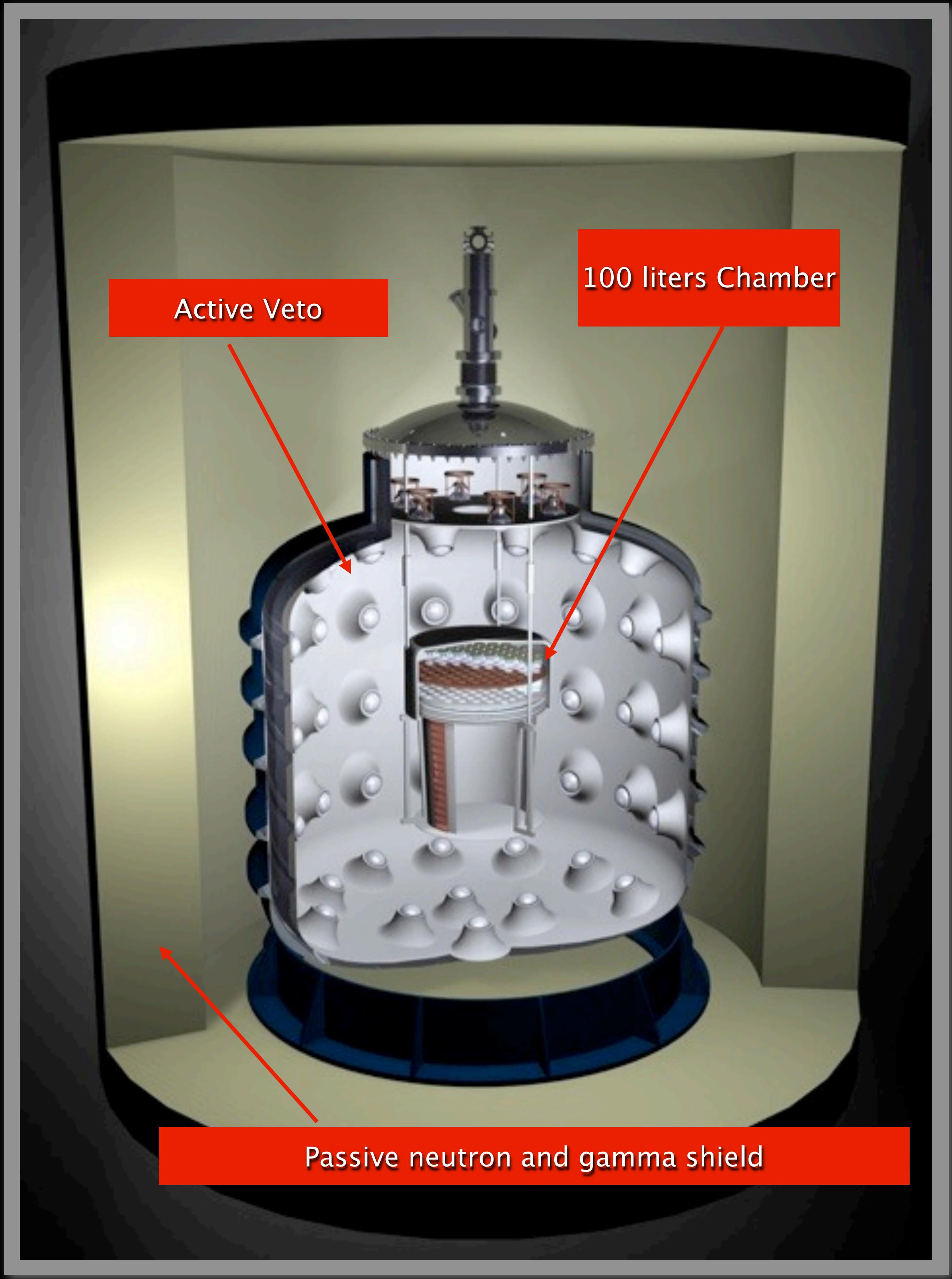
4π active neutron veto (9 tons Liquid Argon, 300 PMTs)

Active control on nuclide-recoil background, owing to unique feature (LAr active veto)

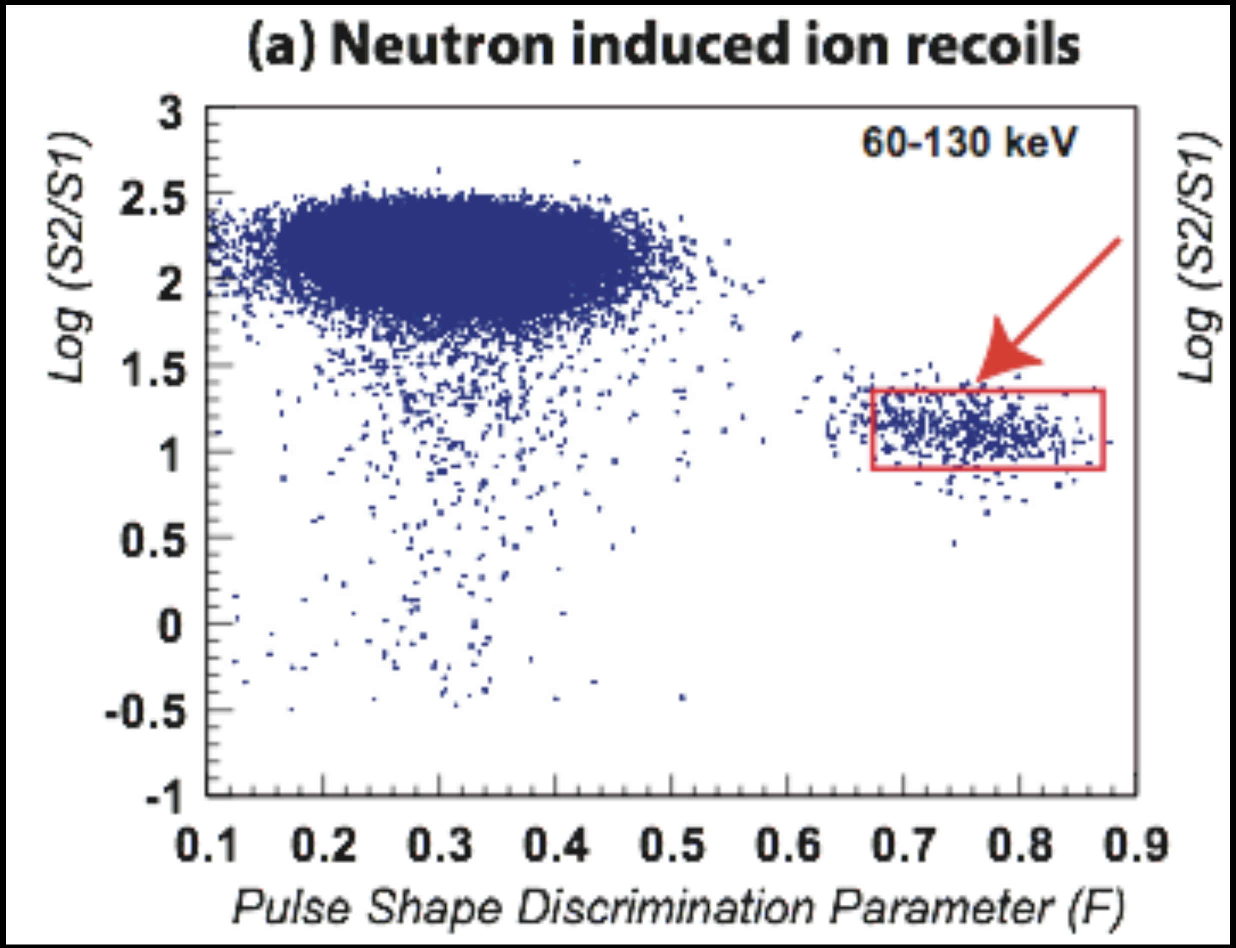
3D Event localization and definition of fiducial volume for surface background rejection

Detector designed for positive confirmation of a possible WIMP discovery

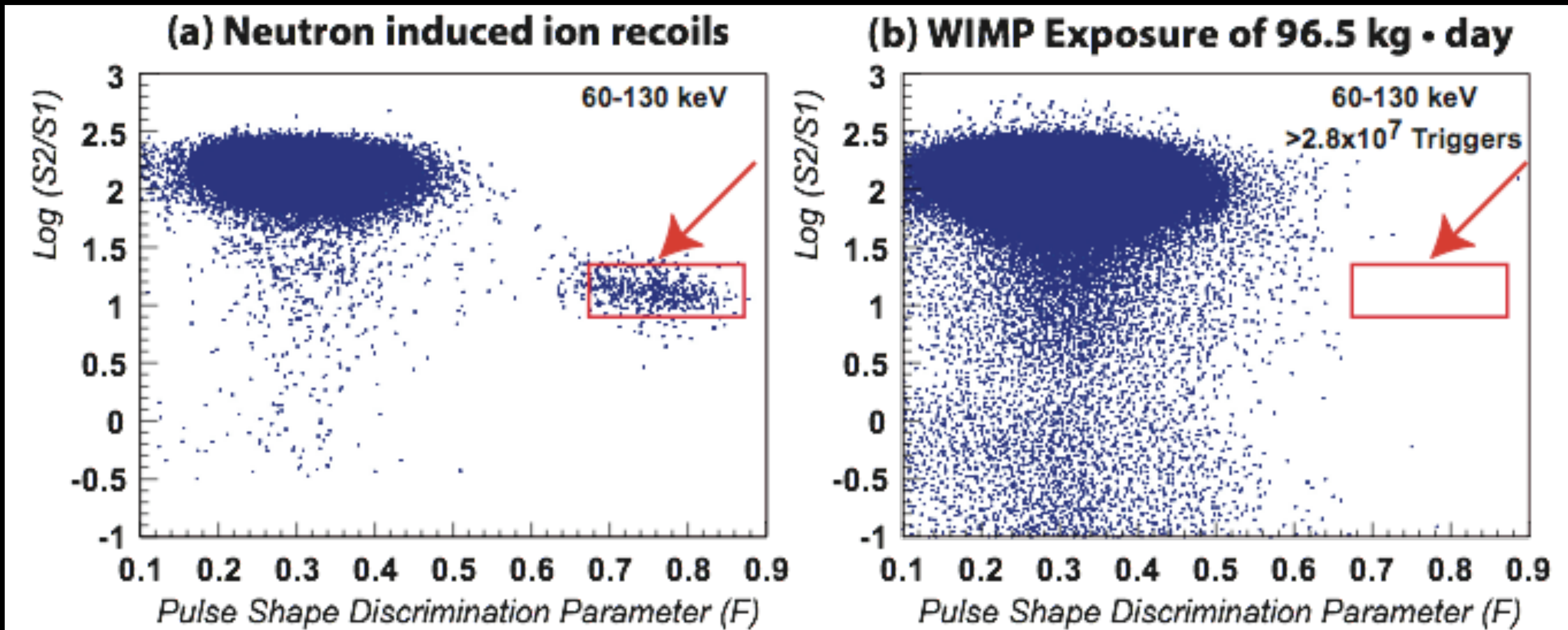
Cryostat designed to allocate a possible 1400 kg detector



First Dark Matter Results



First Dark Matter Results



Selected events in the n-induced single recoils window during the WIMP search run: None

Astropart. Phys. **28**, 495 (2008)

DarkSide
A scalable, zero-background technology

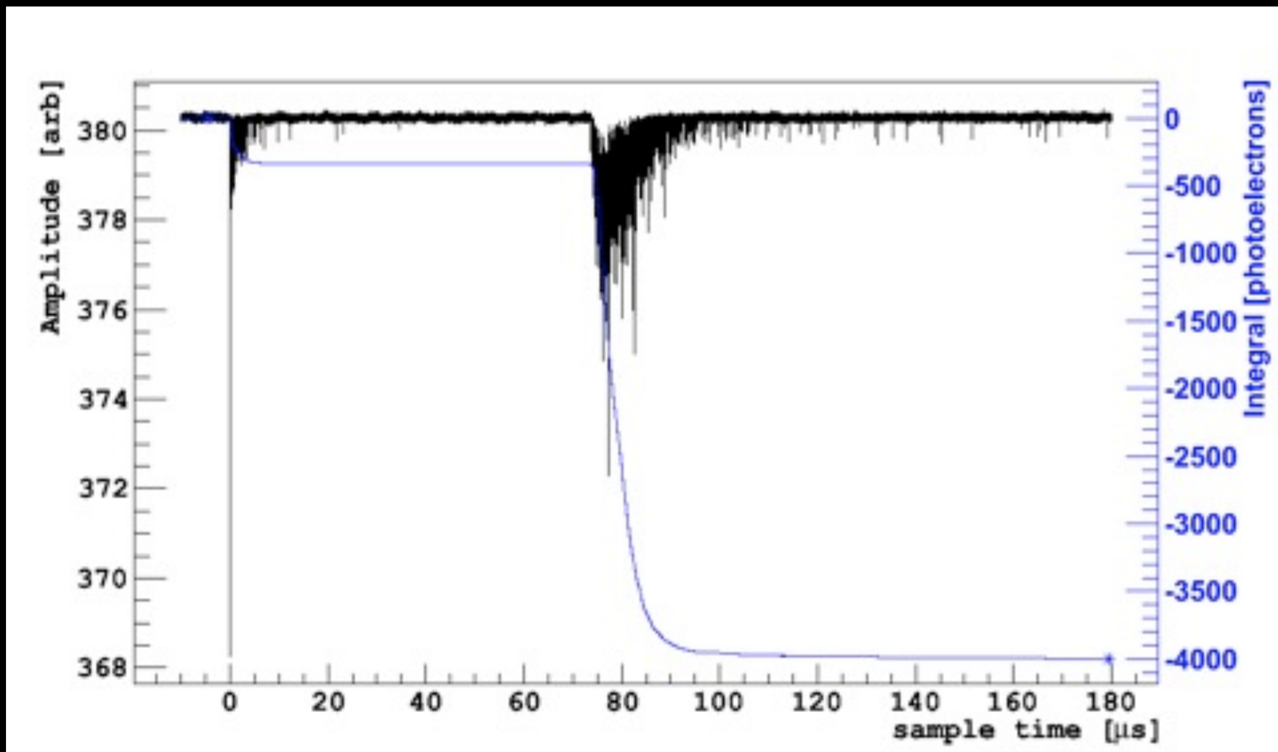
- LAr is one of the brightest scintillators known. Pulse shape of primary scintillation provides very powerful discrimination for NR vs. EM events:
  - Rejection factor $\geq 10^8$ for > 60 photoelectrons:
    - theoretical hint from Boulay & Hime, AstropartPhys **25**, 176 (2006)
    - experimental demonstration from WARP AstropartPhys **28**, 495 (2008)
    - recent confirmation from DEAP
  - Rejection factor depends solely on light yield for nuclear recoils.
  - With DarkSide-10 prototype, demonstrated that light yield for nuclear recoils in two-phase detectors can be ~1.5 ph.el/keV_{nr}, corresponding to 6 ph.el./keV_{ee}, as good as it can be achieved in single-phase detectors!

- Ionization drift is well established technology on very large scale detector. Ionization:scintillation ratio is a strong and semi-independent discrimination mechanism:
  - Rejection factor $\geq 10^2$-10^3 (Benetti et al. (ICARUS) 1993; Benetti et al. (WARP) 2006)

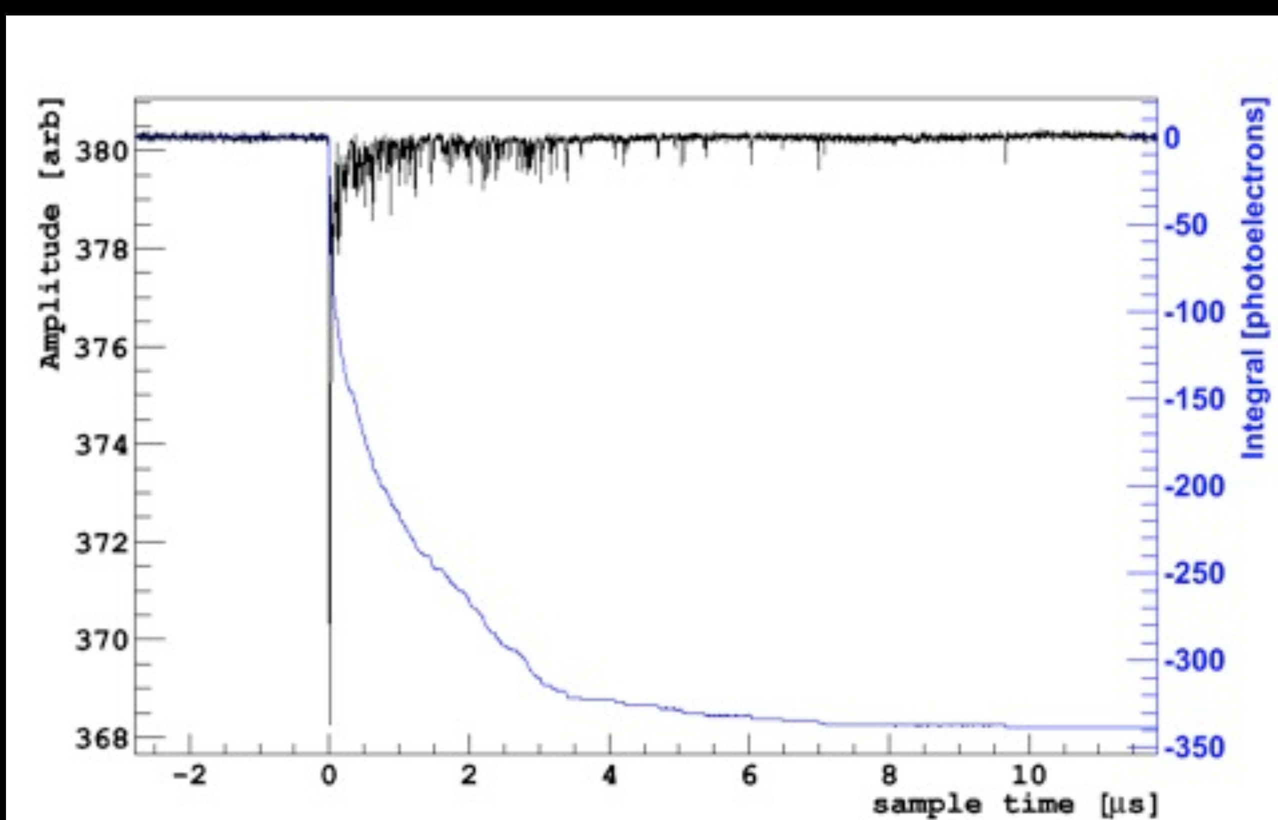
- Depleted argon
  - Production and refinement demonstrated in Princeton & Fermilab
  - Rejection factor ≥ 50!

- Spatial resolution from ionization drift localizes events, allowing rejection of multiple interactions, "wall events", etc.

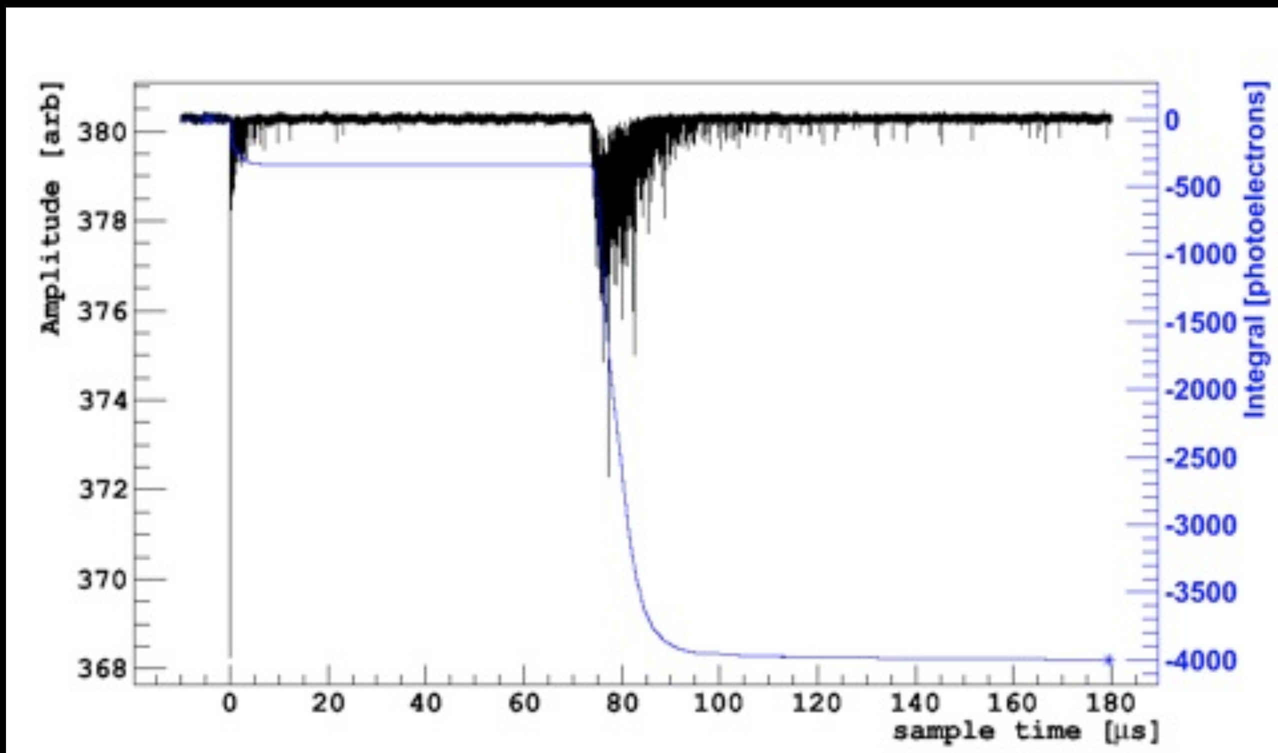
DarkSide-10

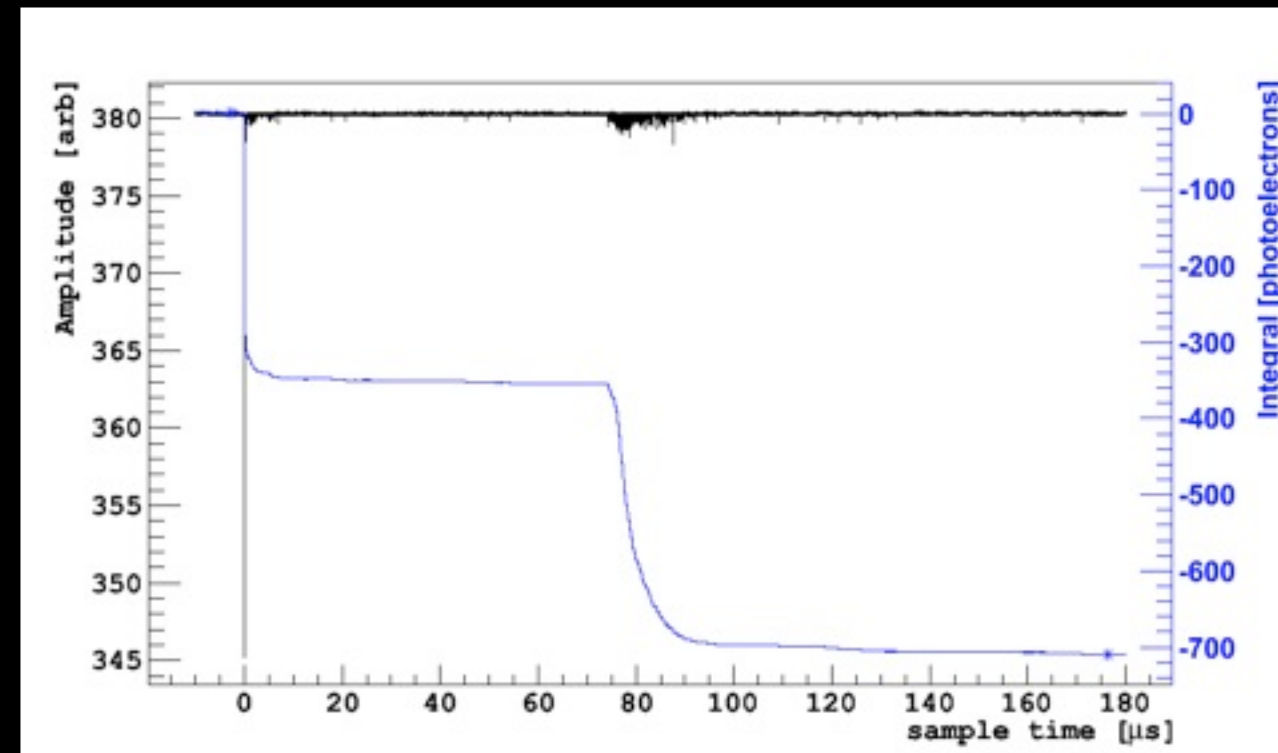


Beta/Gamma



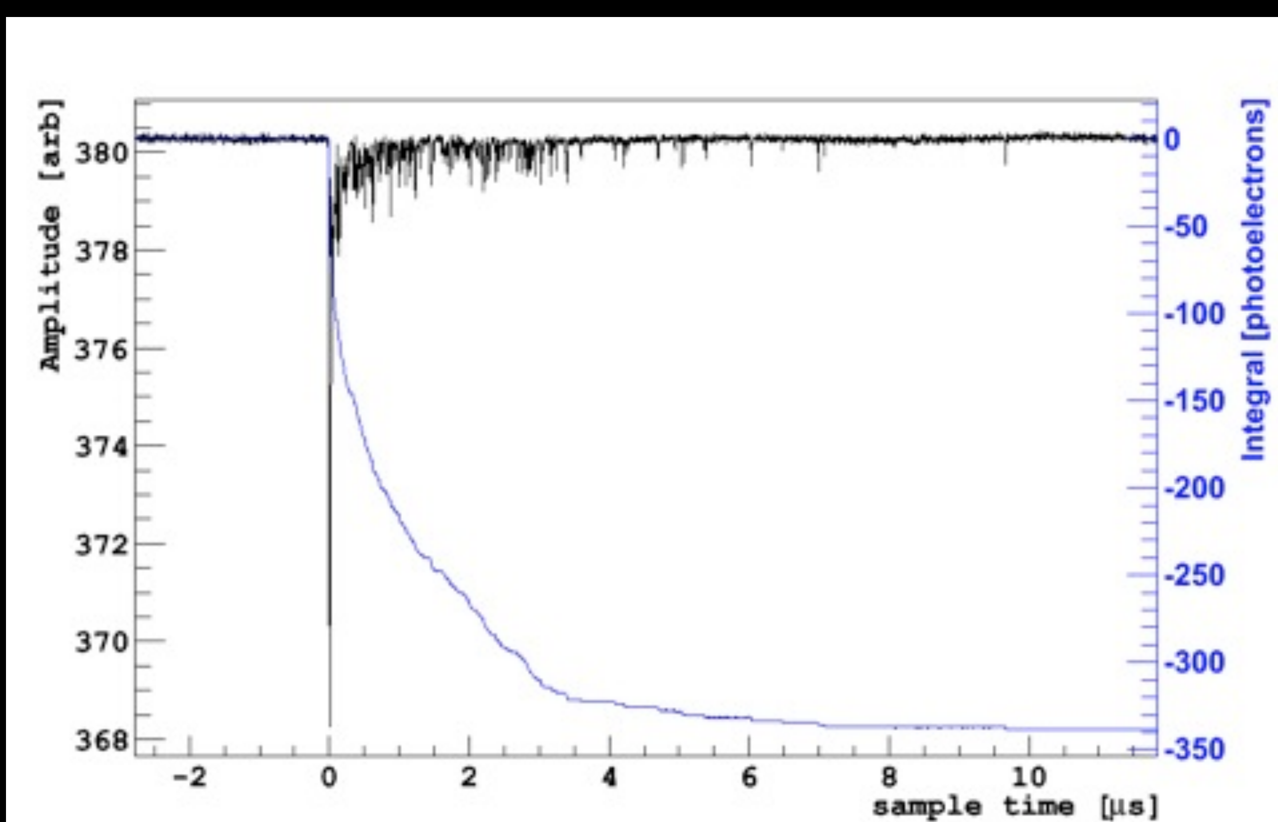
DarkSide-10

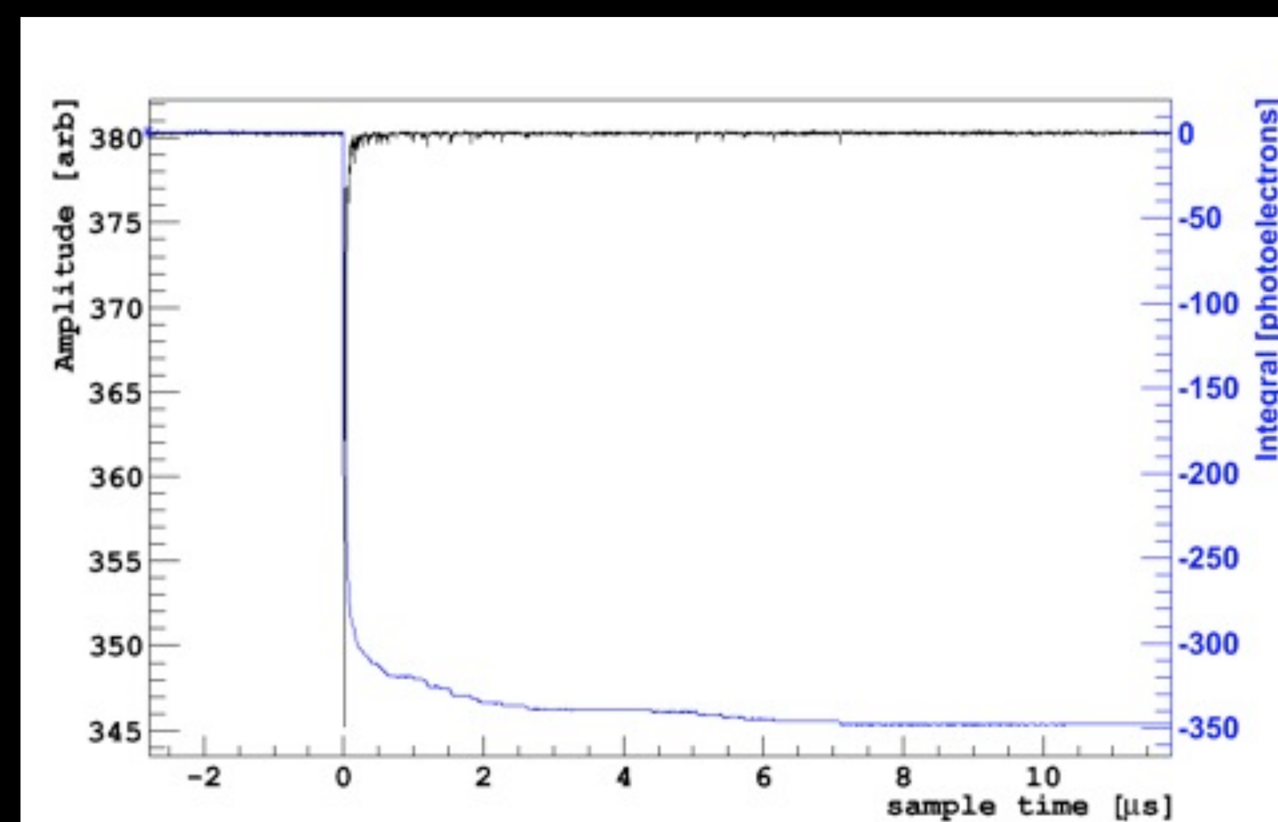




Beta/Gamma

Nuclear Recoil



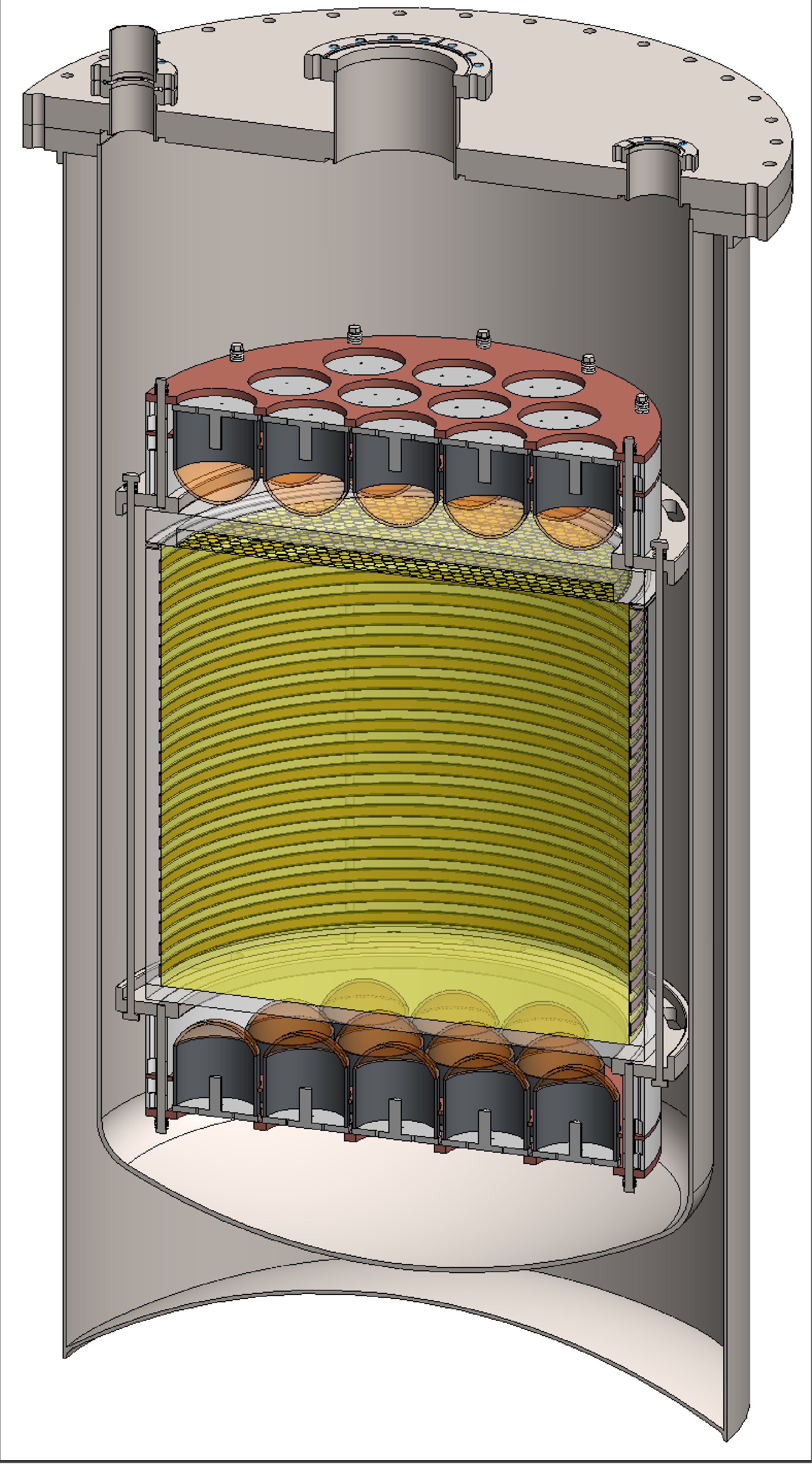


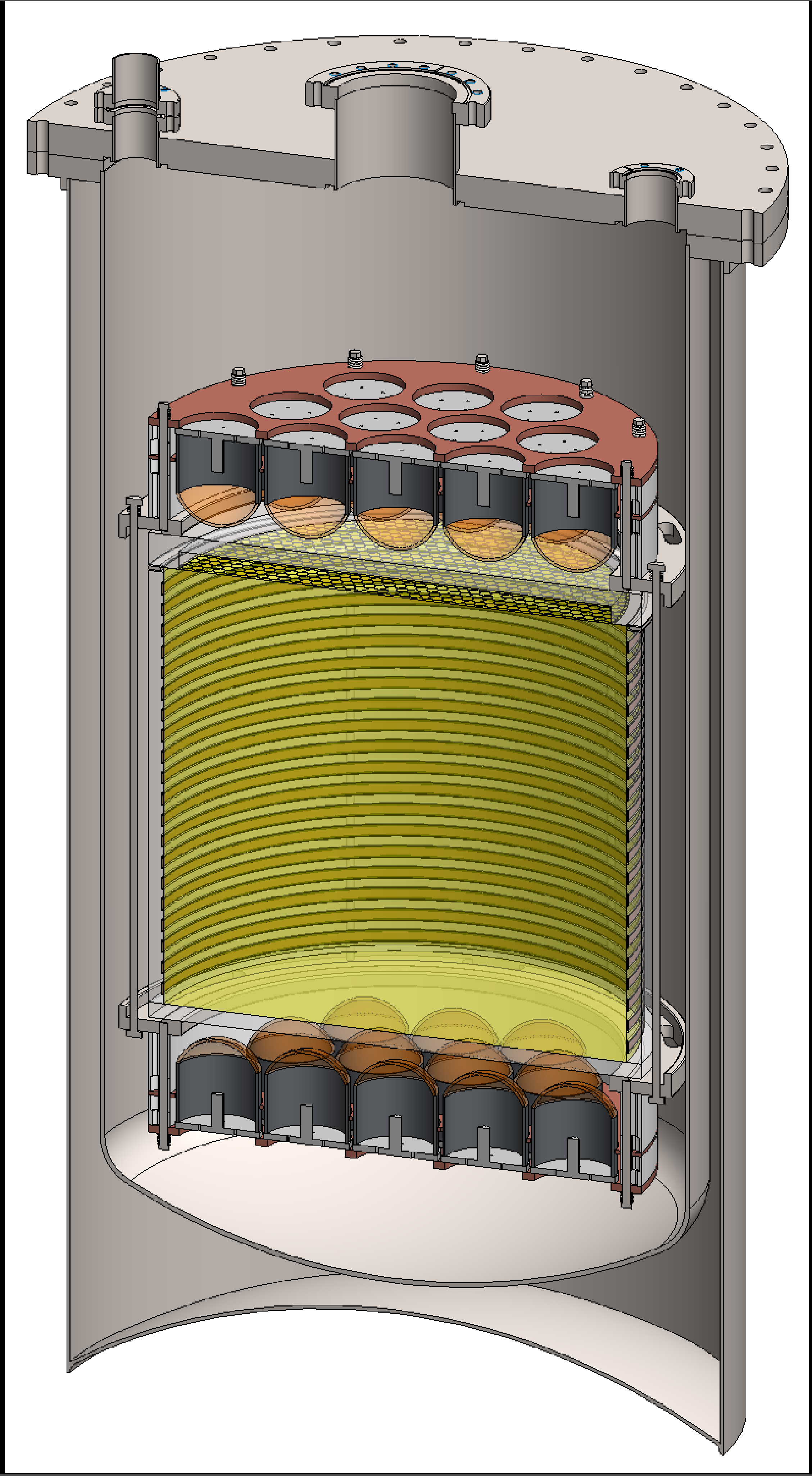
DarkSide-50

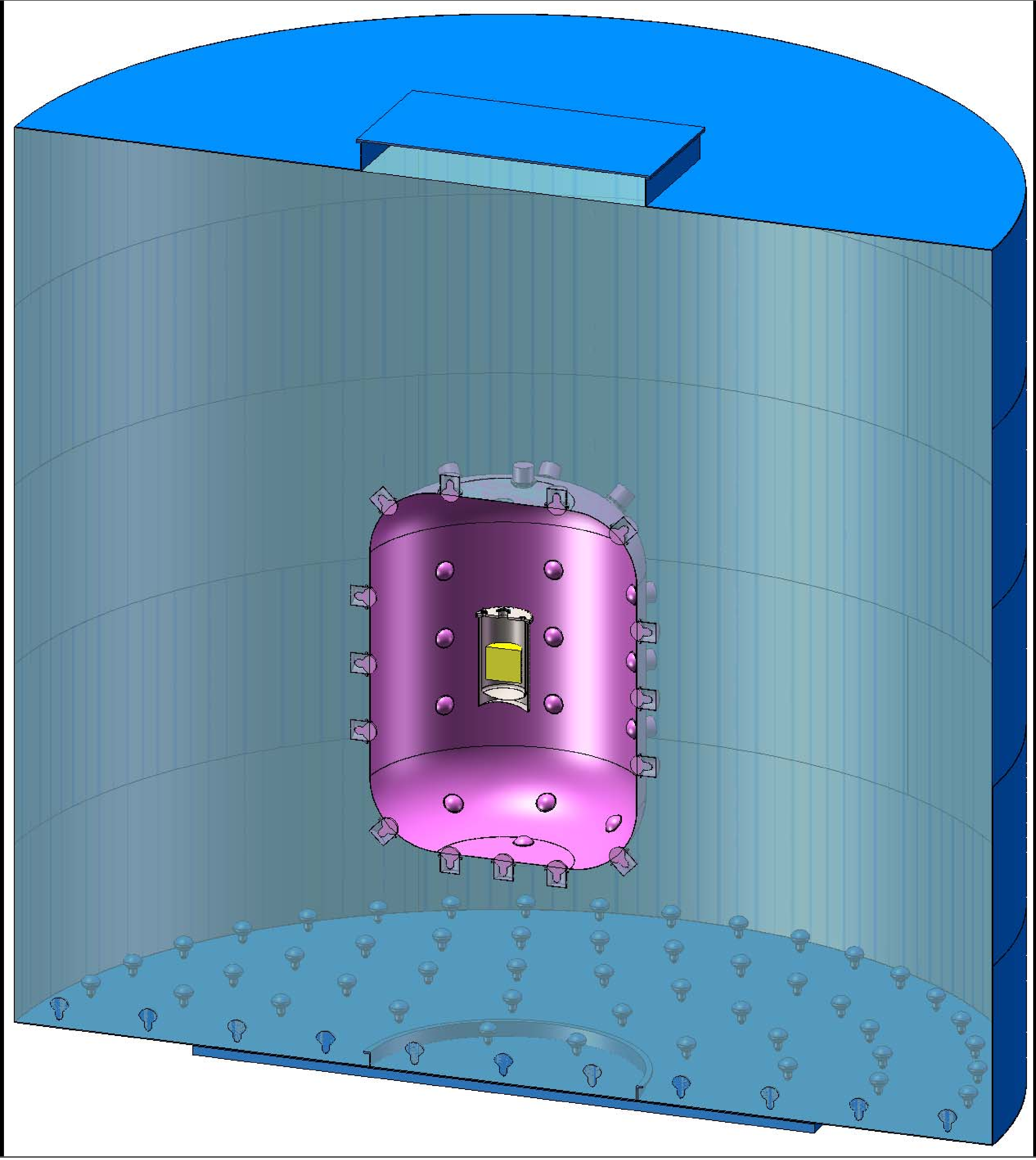
- first implementation of new technologies
  - depleted argon, QUPIDs, organic-scintillator-based neutron veto
- dual-phase TPC à la WARP
- 50 kg DAr active mass

sensitivity 10^{-45} cm^2 in 3-yrs background-free operation

demonstrate potential of the technology for multi-ton year background-free sensitivity





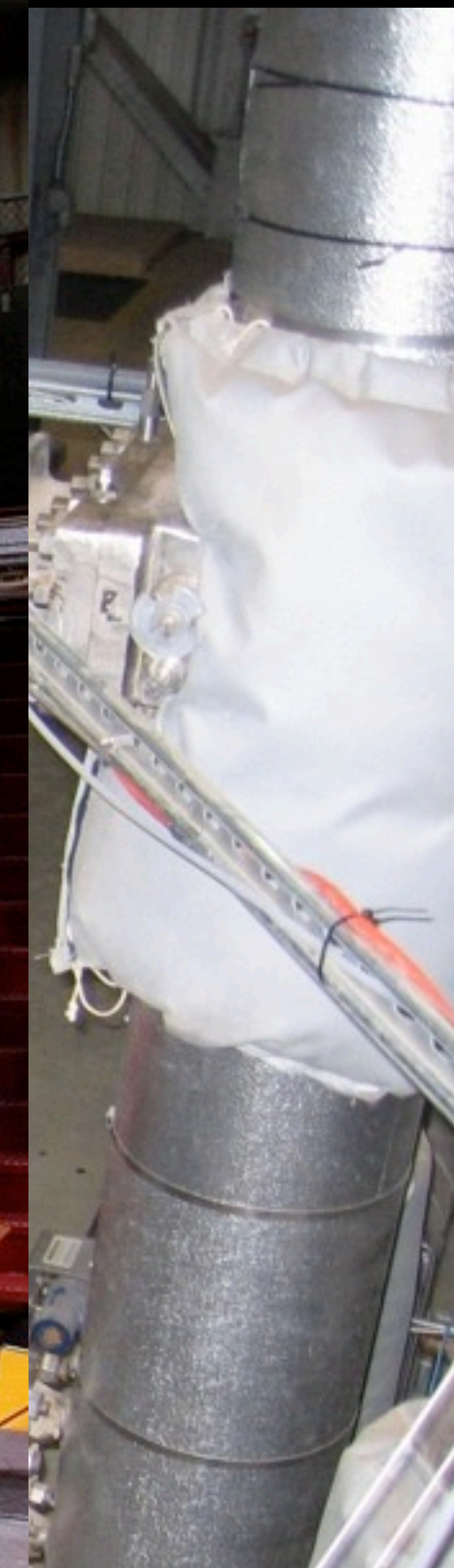


The Borexino Counting Test Facility (1995)

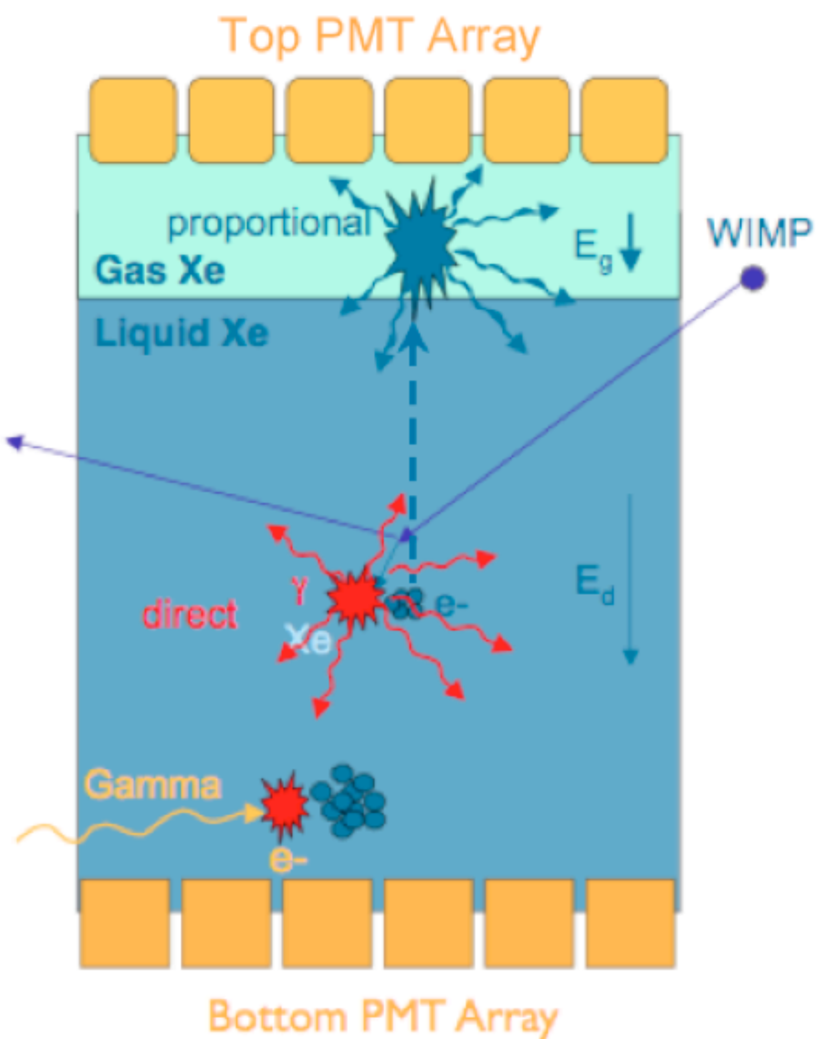
Princeton Extraction Plant

Achieved 1.0 kg/day, Collected ~40 kg

Achie 40 kg

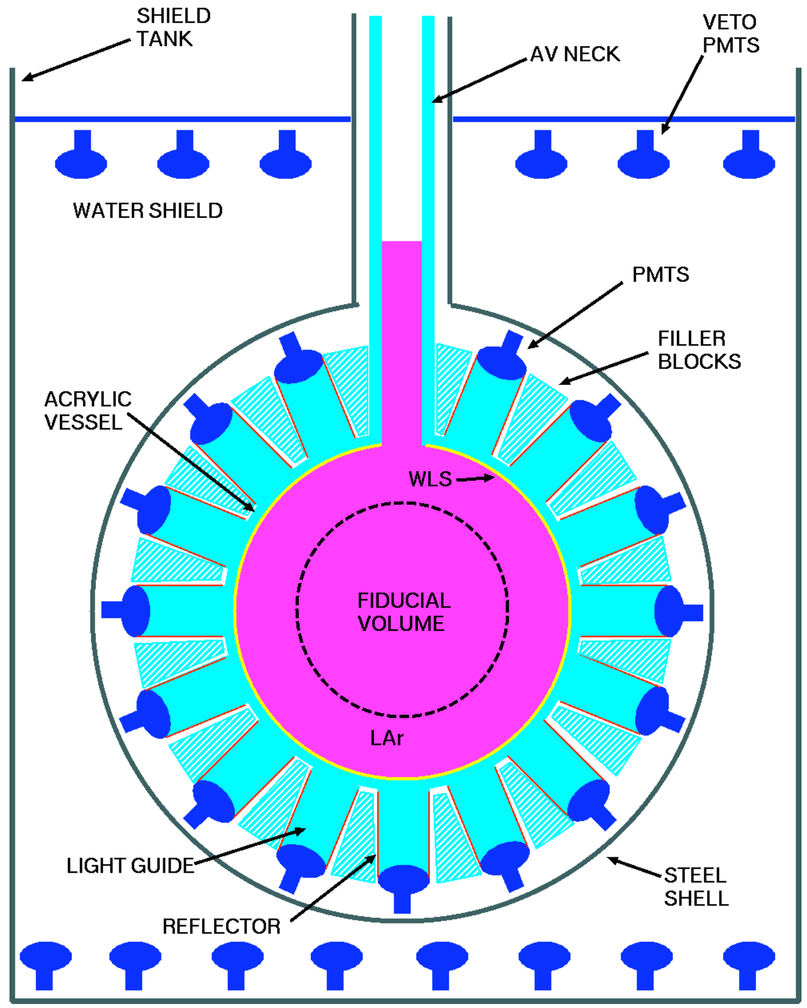


Dual-Phase



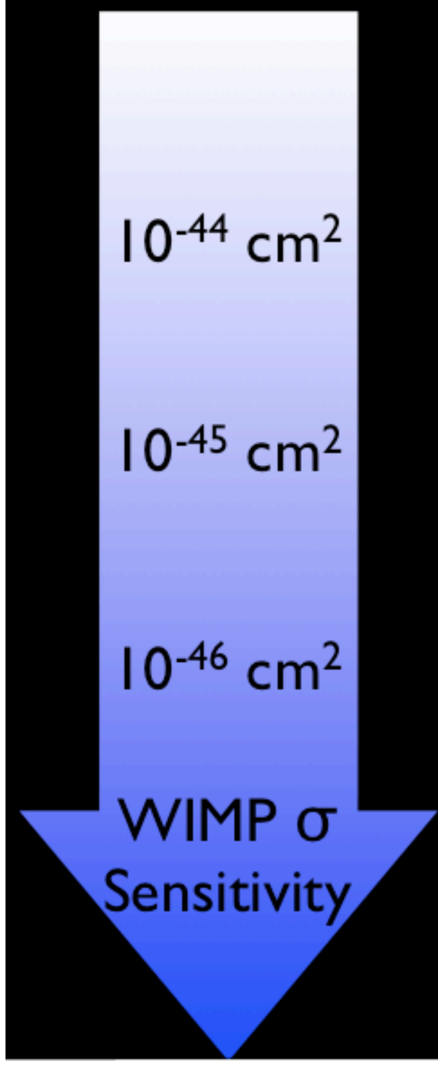
Courtesy E. Aprile

Single-Phase



D. N. McKinsey and J. M. Doyle, J. Low Temp. Phys. 118, 153 (2000).
D. N. McKinsey and K. J. Coakley, Astropart. Phys. 22, 355 (2005).
M. Boulay, J. Lidgard, and A. Hime, nucl-ex/0410025.
M. Boulay and A. Hime, Astropart. Phys. 25, 179 (2006).

The DEAP and CLEAN Family of Detectors



DEAP-0:
Initial R&D detector

DEAP-1:
7 kg LAr
2 warm PMTs
At SNOLab 2008

picoCLEAN:
Initial R&D detector

microCLEAN:
4 kg LAr or LNe
2 cold PMTs
surface tests at Yale

G1

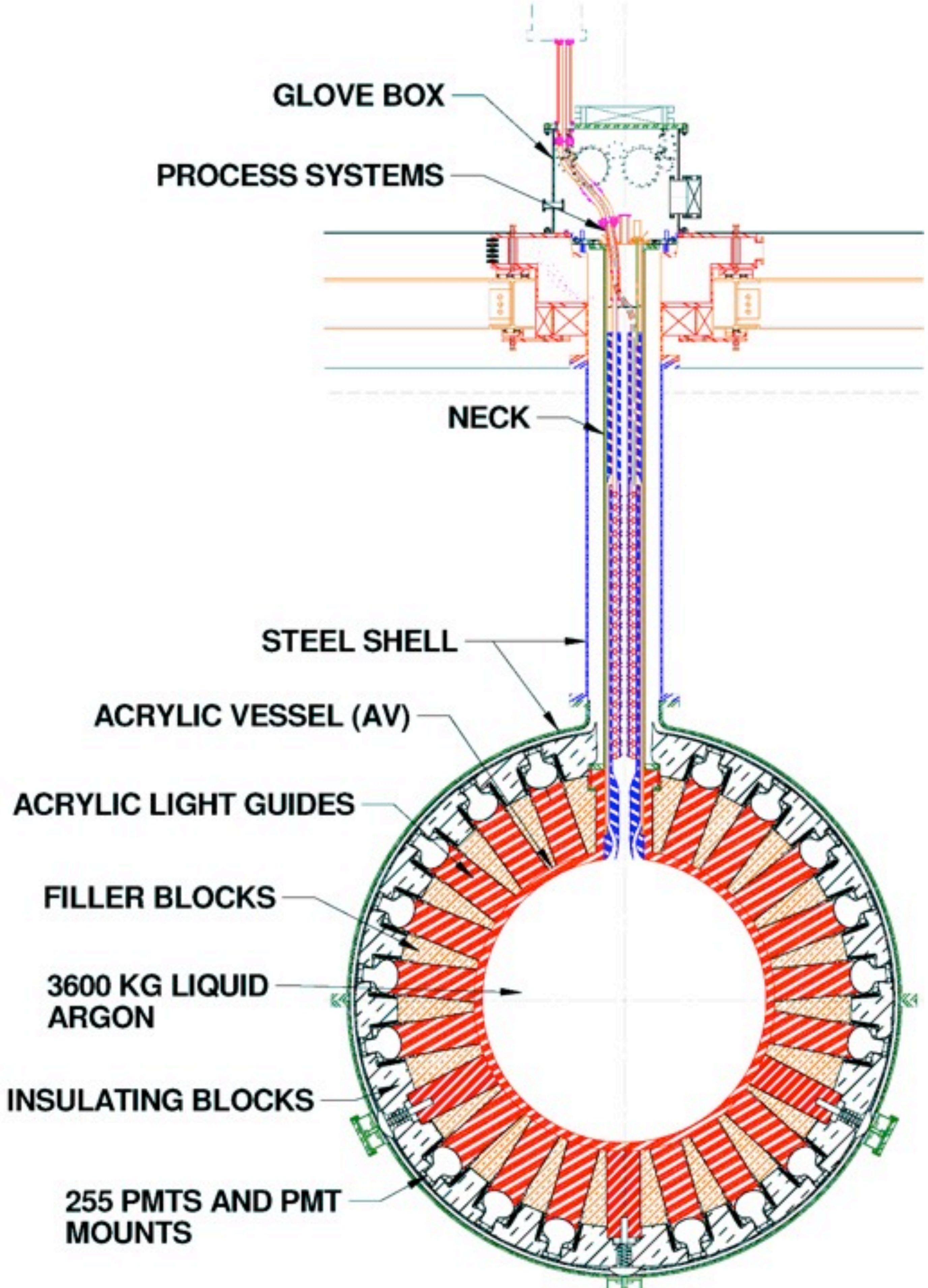
MiniCLEAN:
500 kg LAr or LNe (150 kg fiducial mass)
92 cold PMTs
At SNOLAB mid-2011

G2

DEAP-3600:
3600 kg LAr (1000 kg fiducial mass)
266 warm PMTs
At SNOLAB late 2012

G3

50-tonne LNe/LAr Detector:
pp-solar ν, supernova ν, dark matter <10^{-46} cm^2
At DUSEL ~2015?



DEAP-3600 detector

85 cm radius acrylic sphere contains 3600 kg LAr
(55 cm, 1000 kg fiducial)

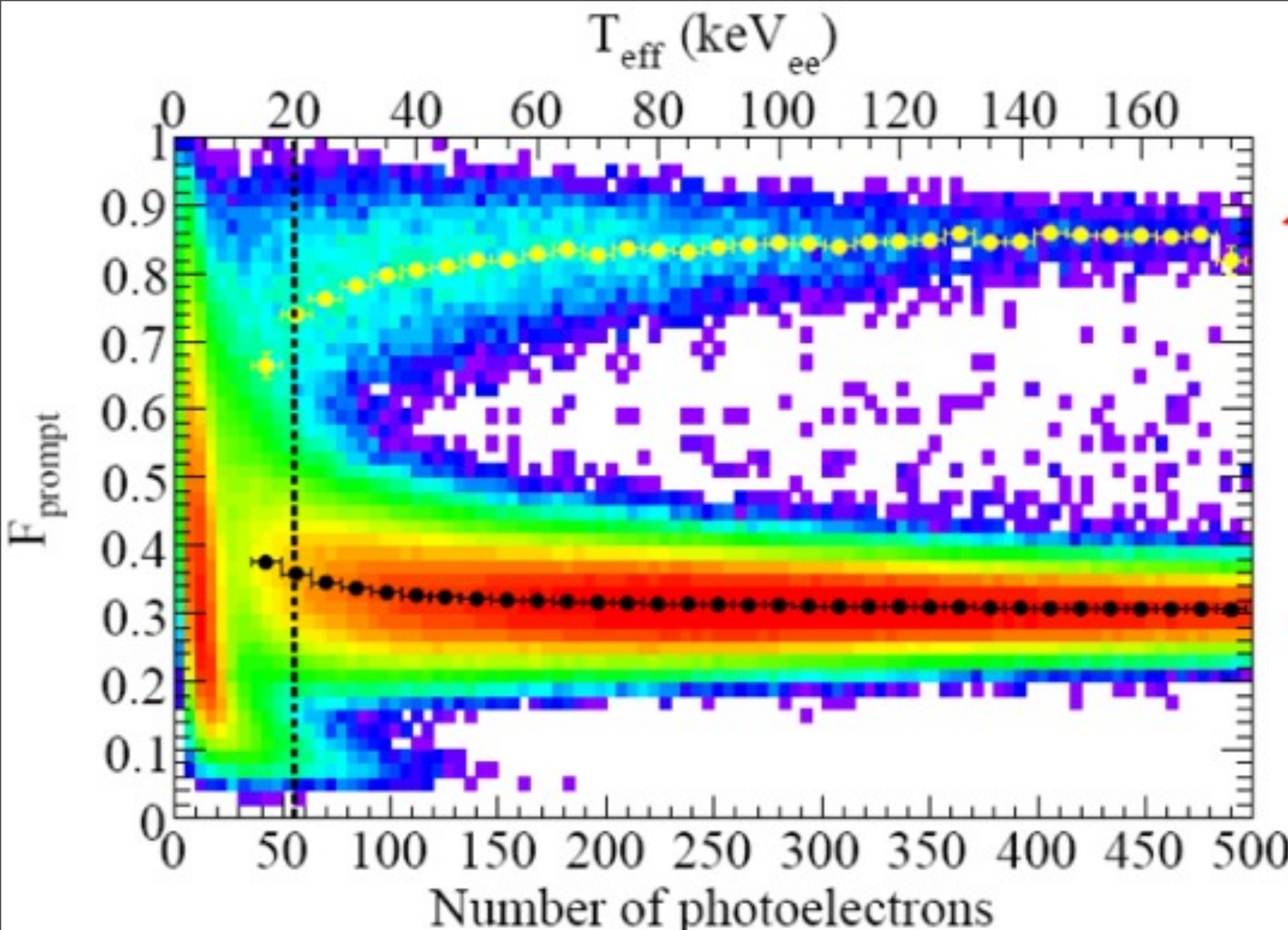
255 8” PMTs (warm)

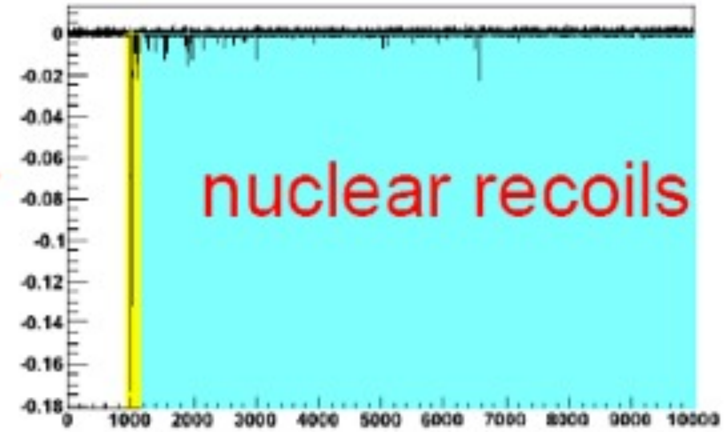
50 cm acrylic light guides and fillers for neutron shielding (from PMTs)

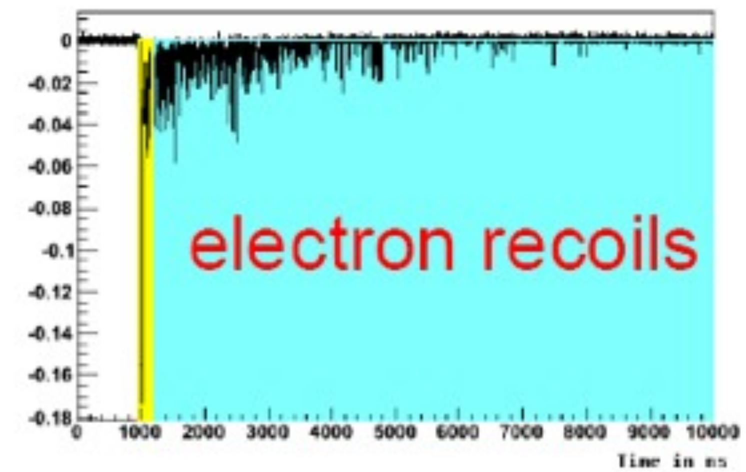
Steel shell for safety to prevent cryogen/water mixing (AV failure)

Only LAr, acrylic, and WLS (10 g) inside of neutron shield

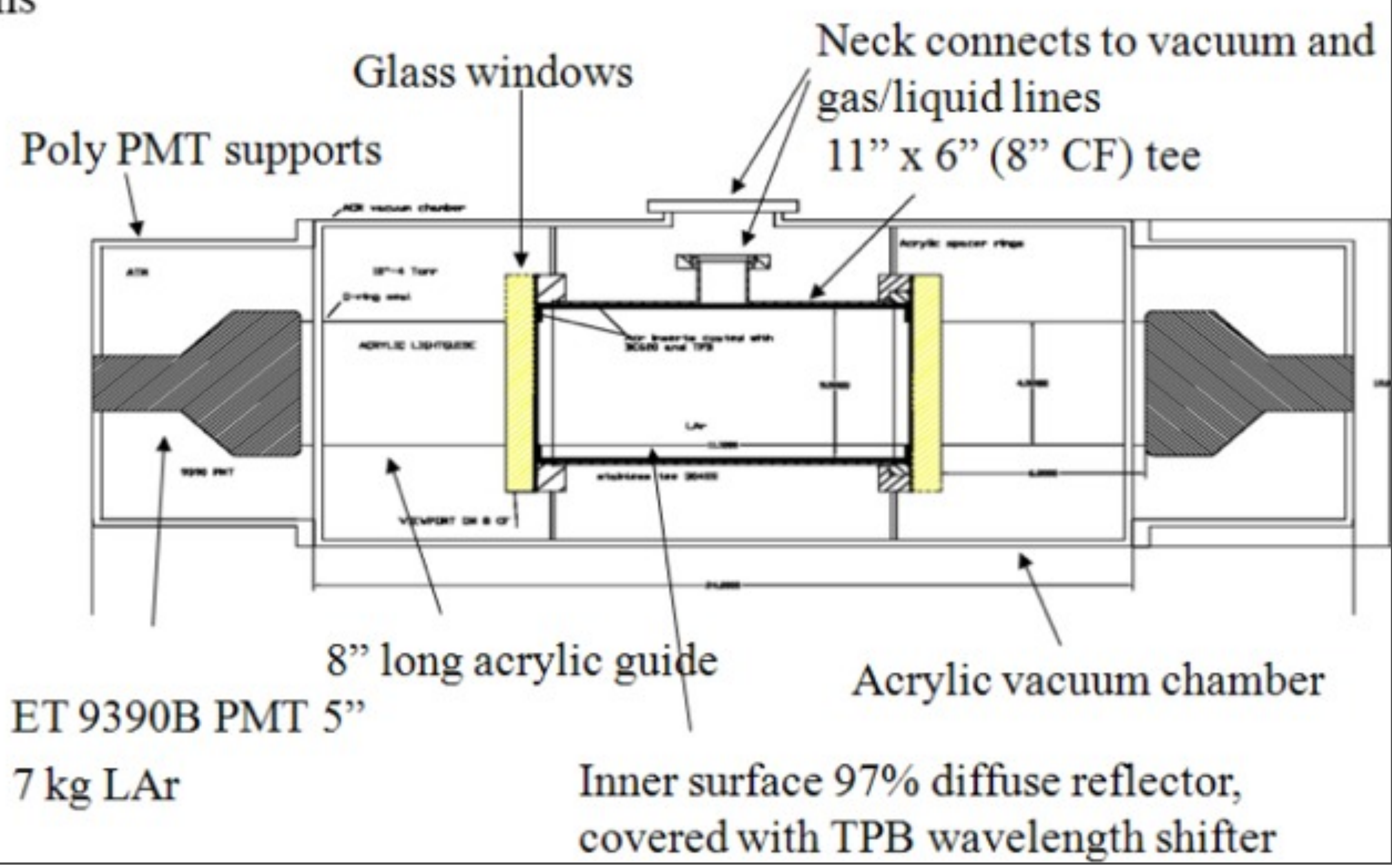
8.5 m diameter water shielding tank



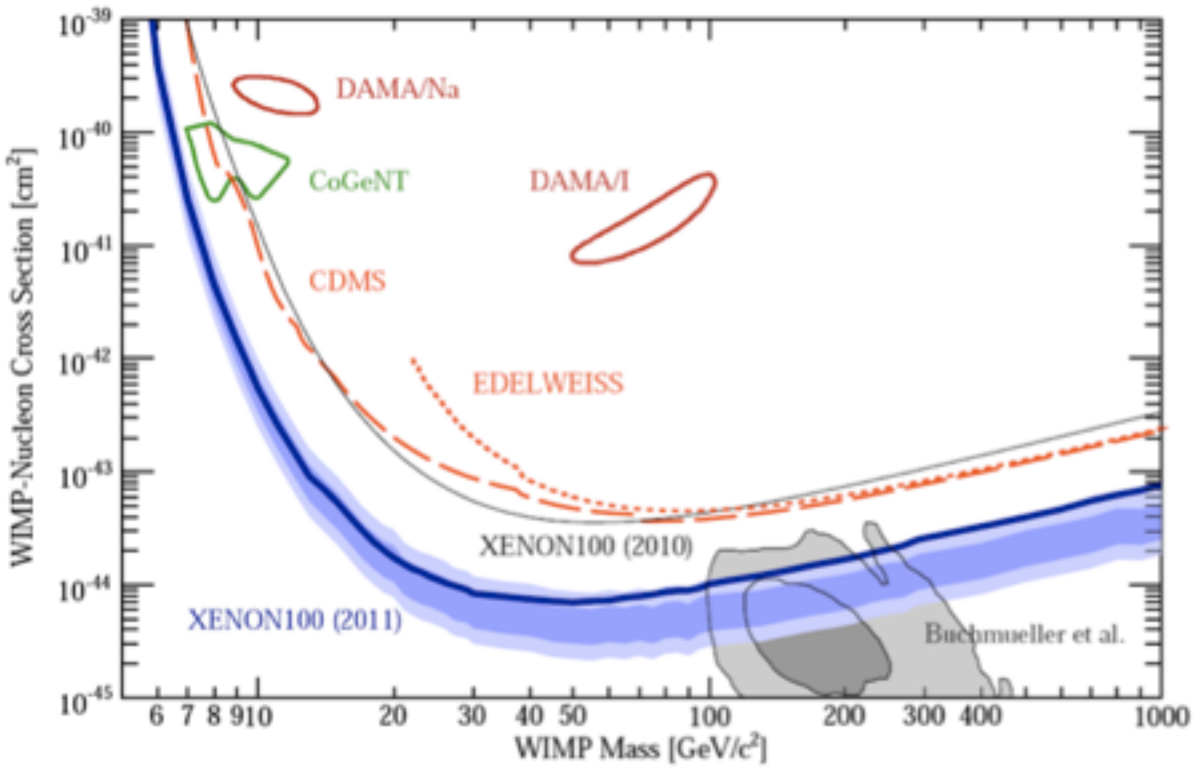




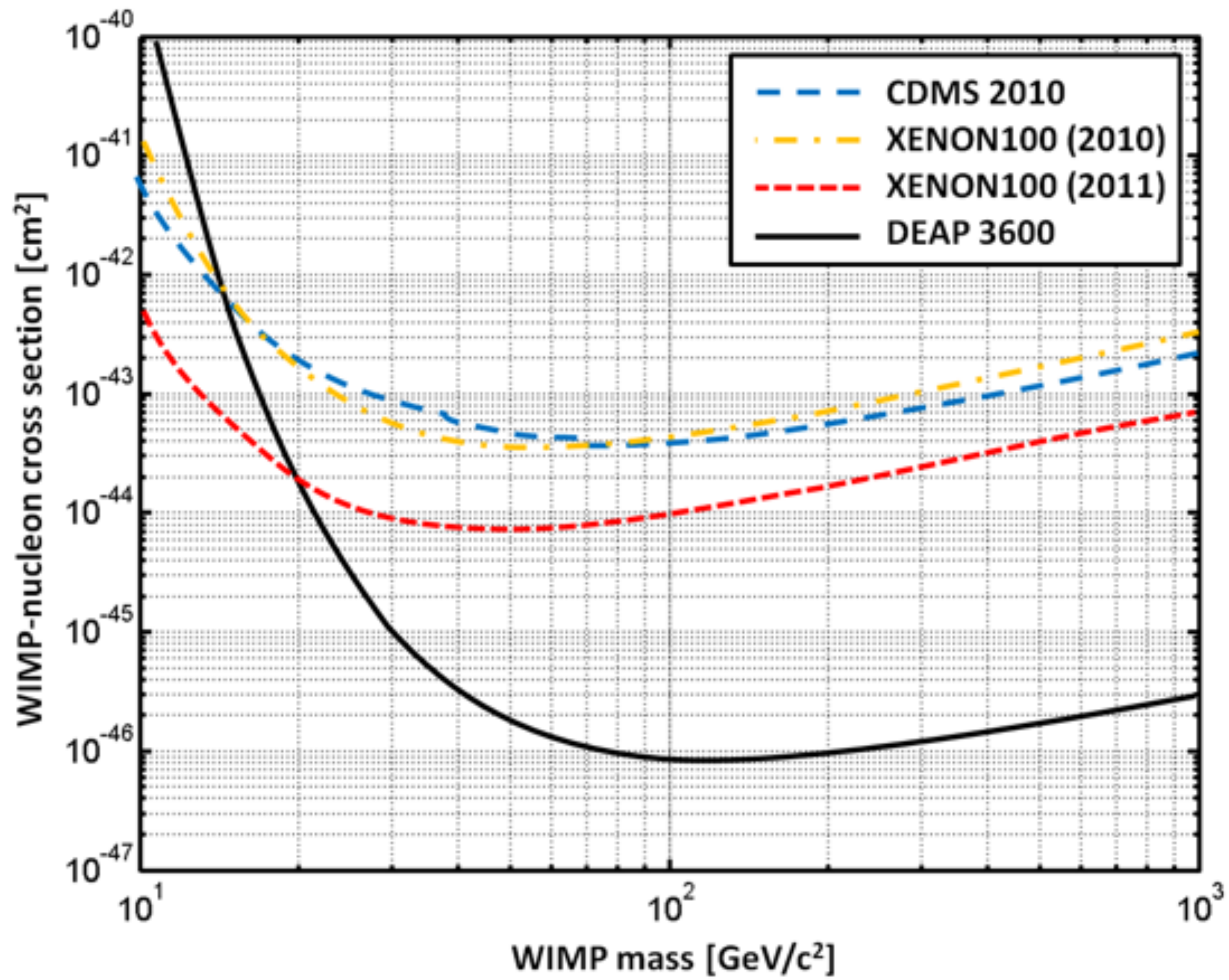
The DEAP-1 Detector



Plot courtesy of Wolfgang Rau



XENON100 arXiv:1104.2549



80 keVr threshold, without depletion of ^{39}Ar

CDMS 2010:	612 kg-days (Ge)
XENON100 2011:	1471 kg-days (Xe)
DEAP-3600:	1,000,000 kg-days (LAr) (3 years)

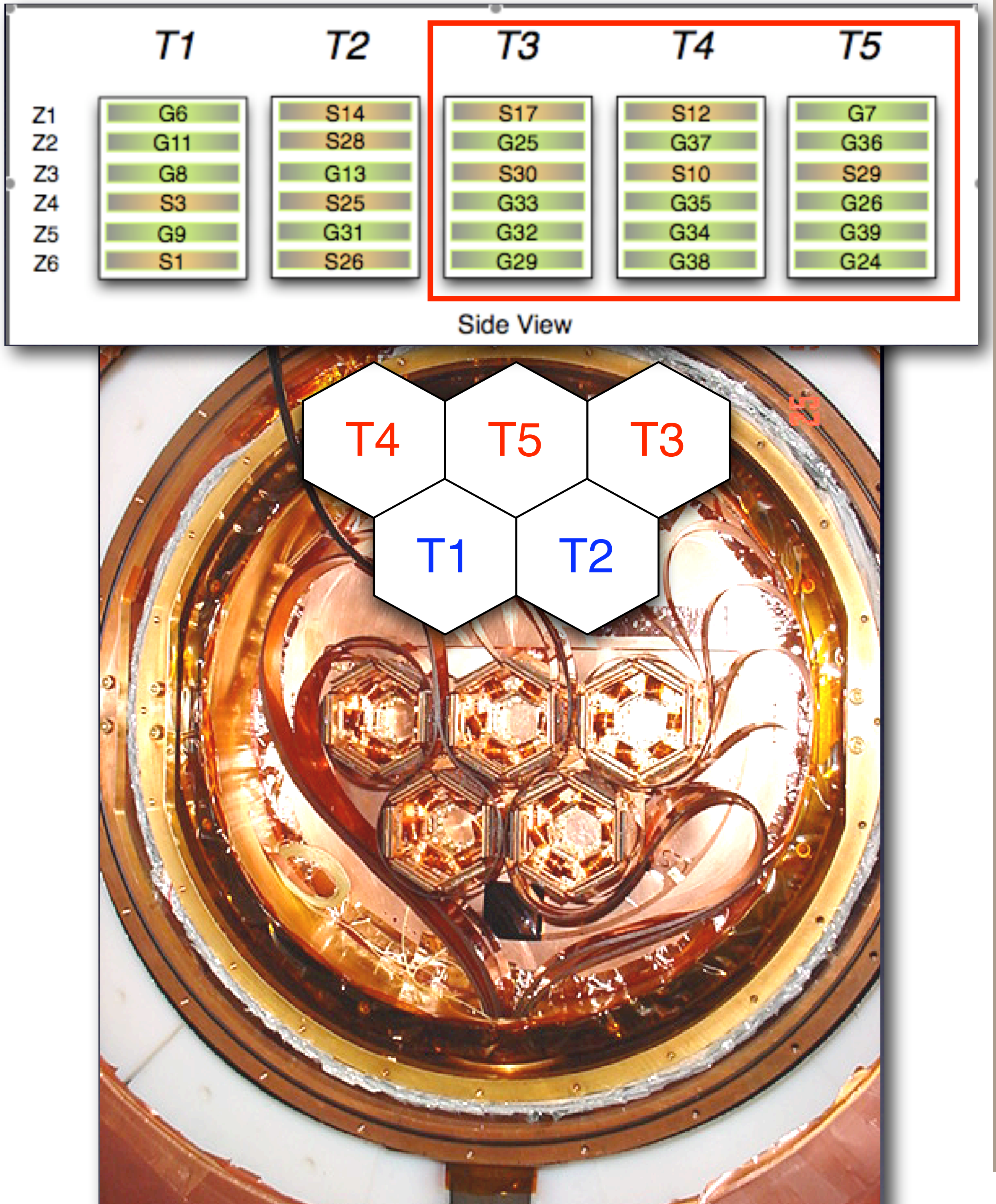
DEAP-3600 Project Status

2009	Project Funded
2010-2011	Shield Tank, Support Deck and Services Installed at SNOLAB
2011	Construction of Acrylic Vessel and Detector Subsystems
2011-2012	Installation of Detector Components at SNOLAB
Late 2012	Detector Commissioning

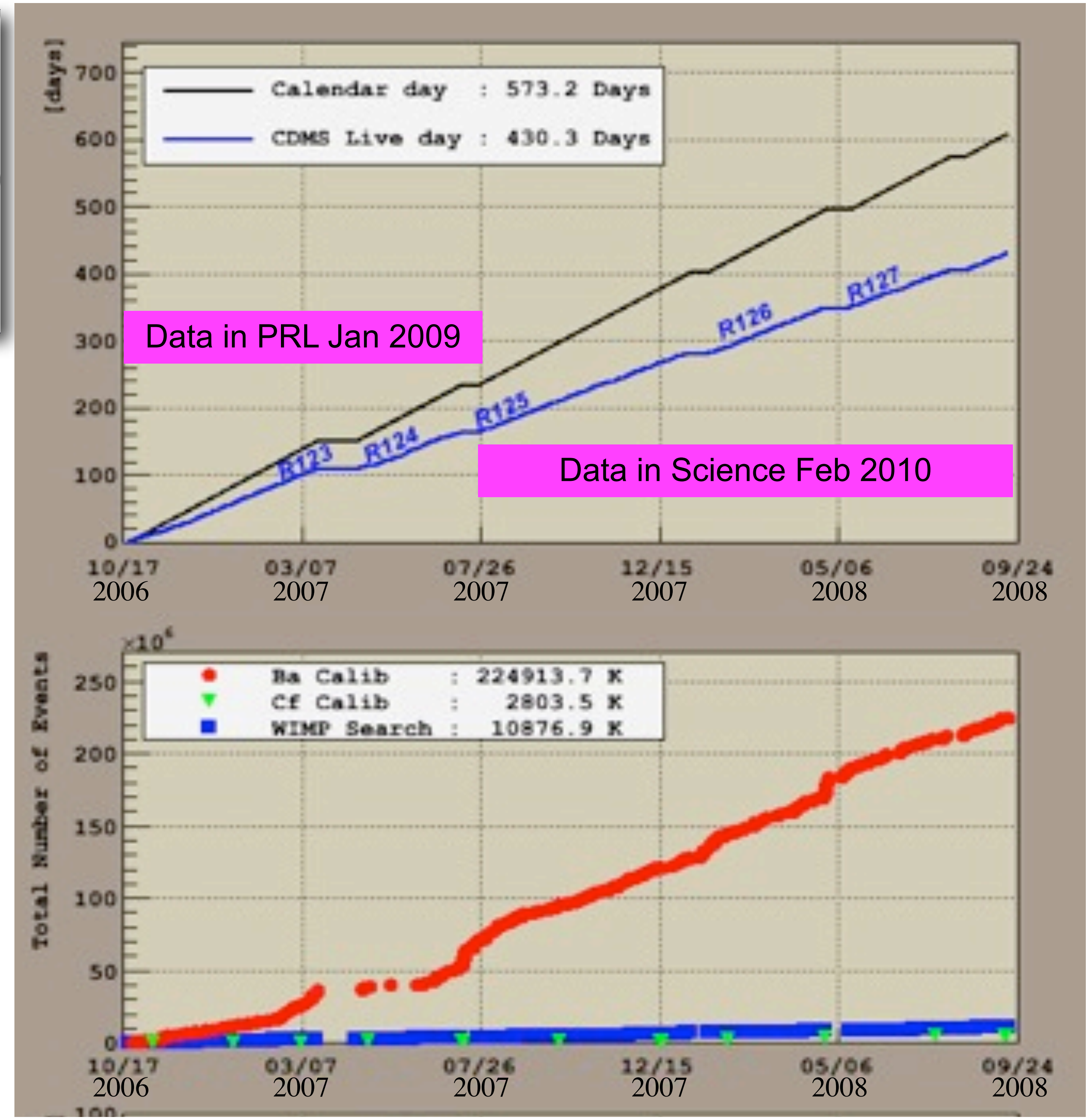
DEAP-3600 Shield Tank (8.5 m diameter) in SNOLAB Cube Hall (June 2011)

CDMS II Experiment

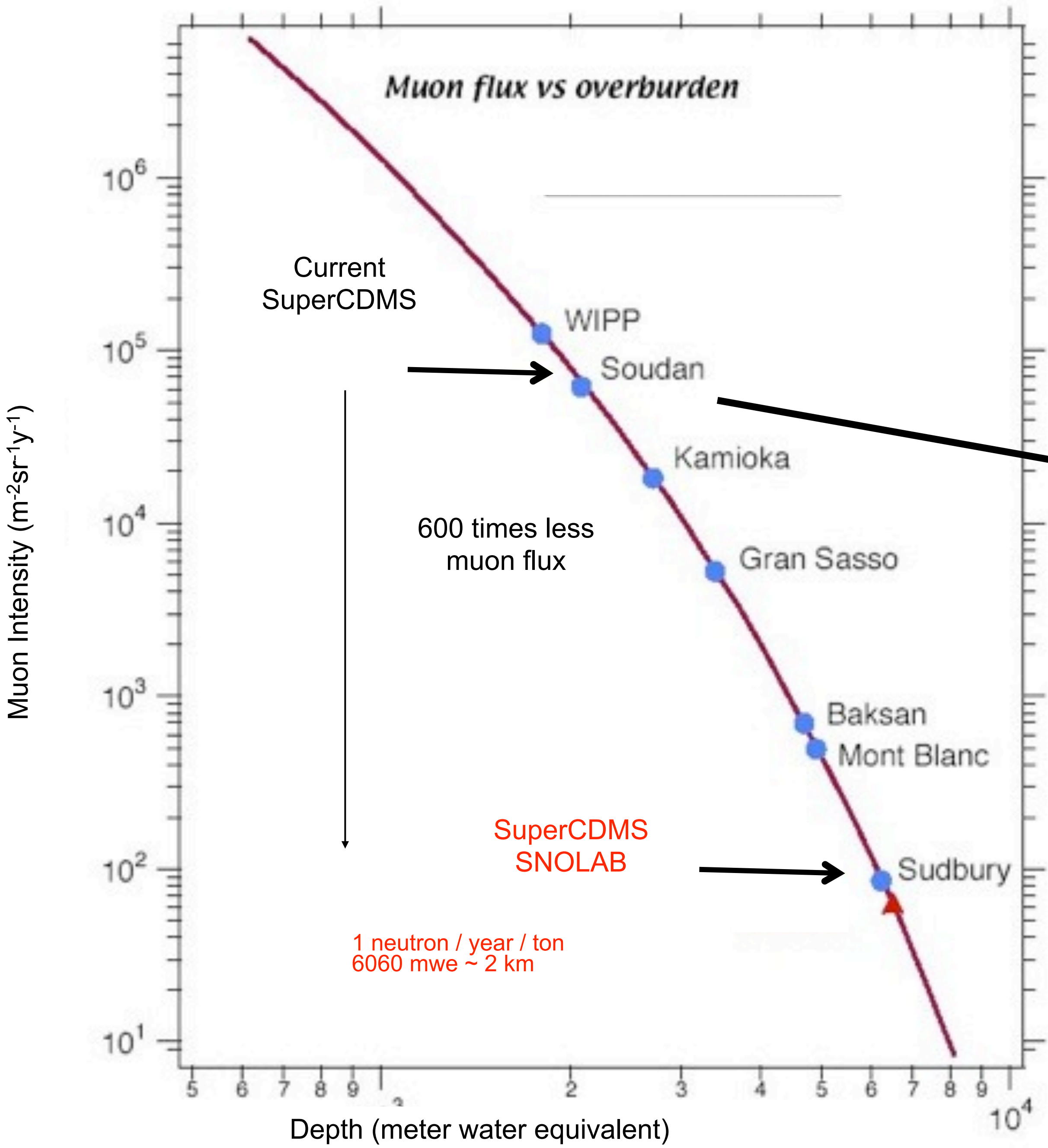
- 30 detectors - **4.75 kg of Ge**, **1.1 kg of Si**



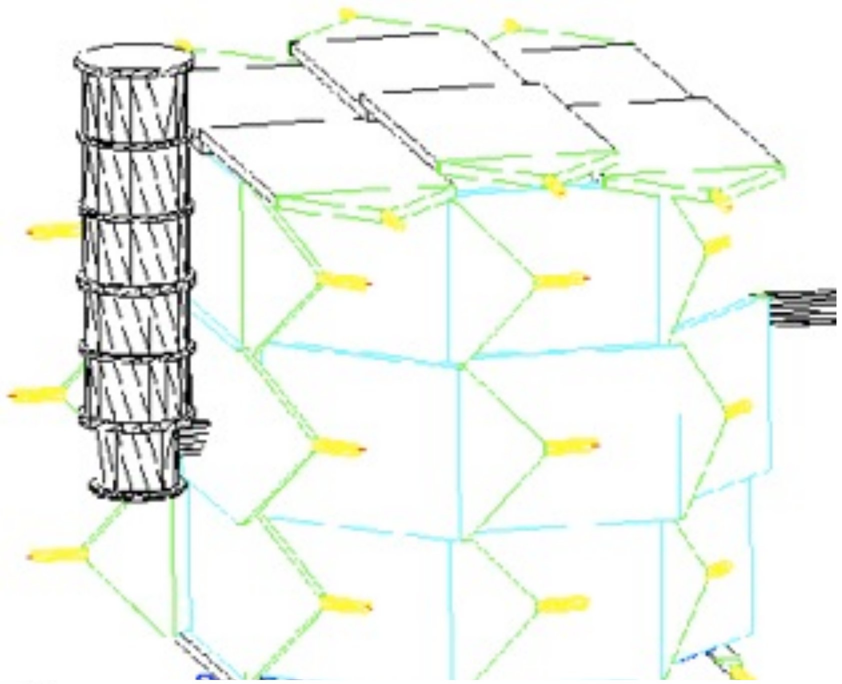
- Data Run History:

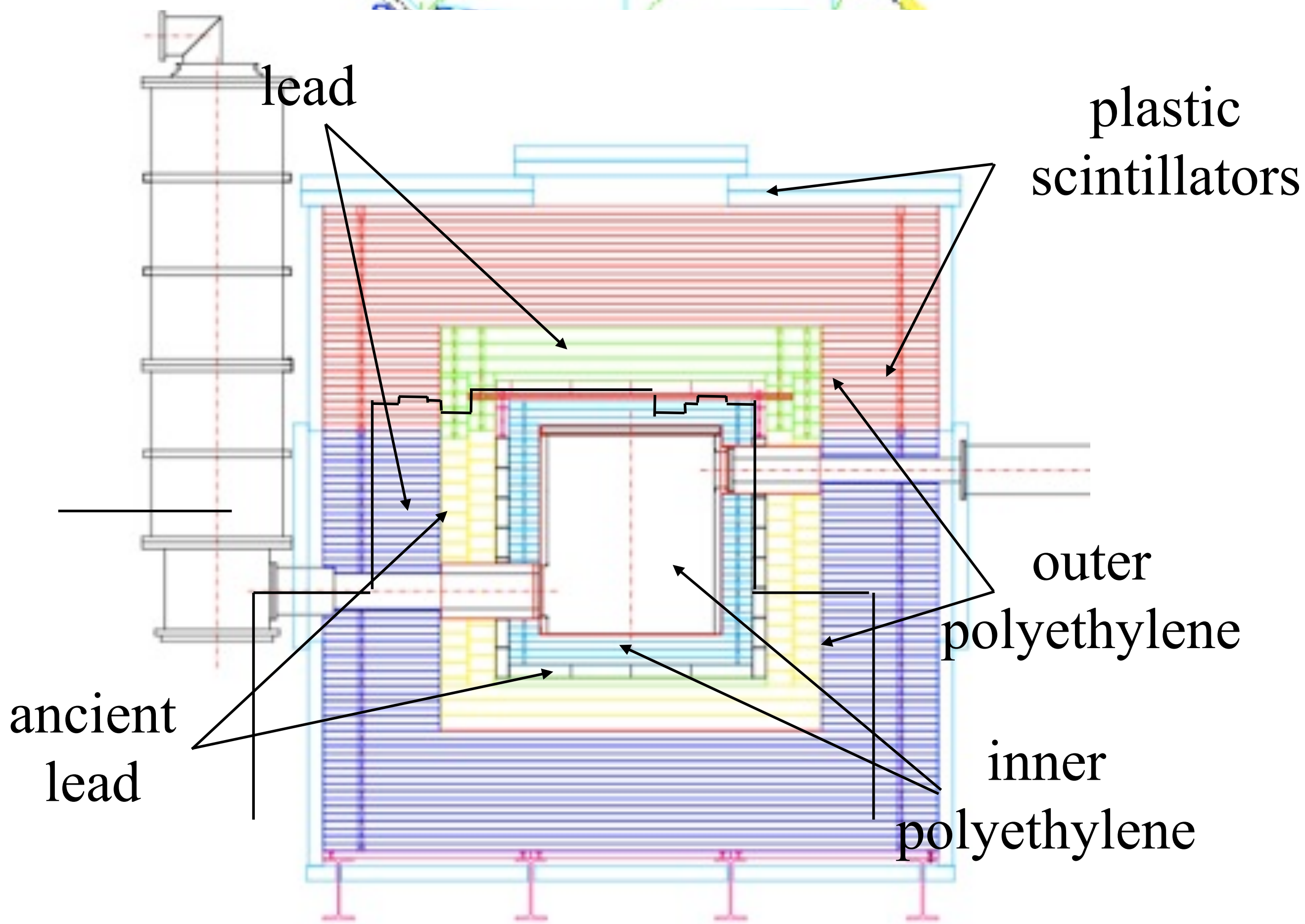


CDMS-II at Soudan (2090 mwe)



CDMS-II Soudan facility





CDMS II Results

Sciencexpress Report

11 February 2010 / Page 1 / 10.1126/science.1186112

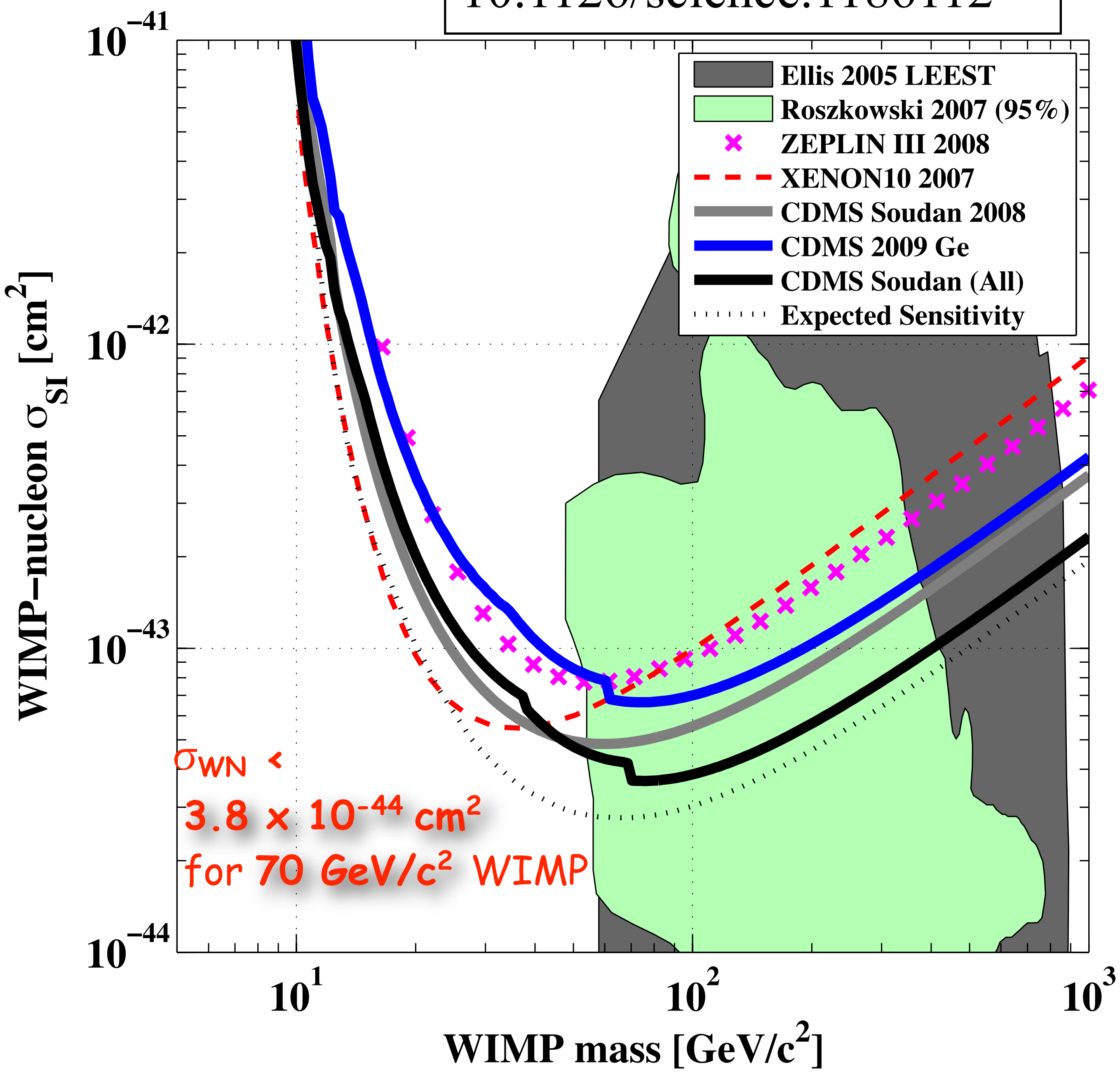
Dark Matter Search Results from the CDMS II Experiment

The CDMS II Collaboration*†

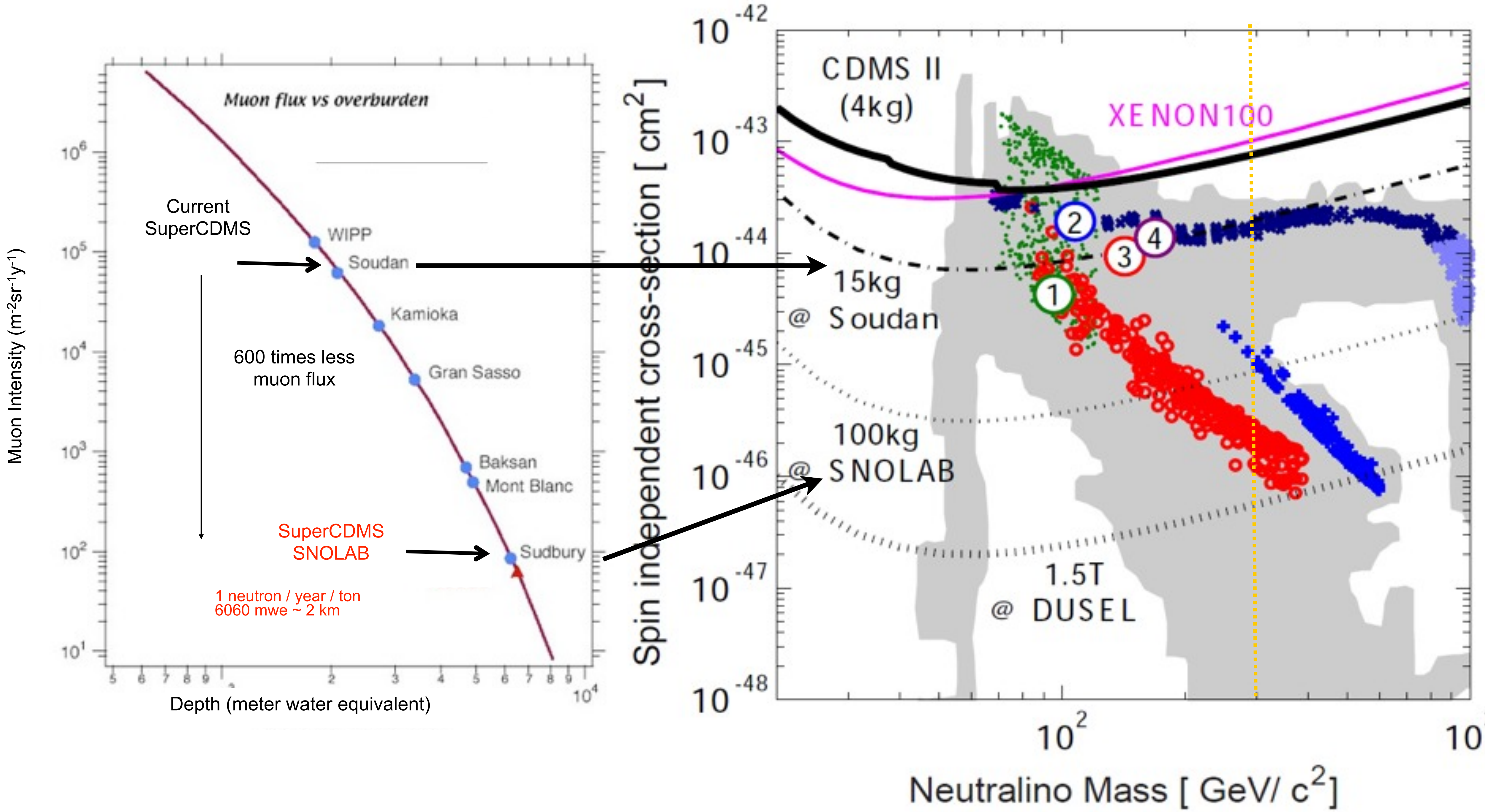
*To whom correspondence should be addressed: Jodi Cooley.

†All authors and their affiliations appear at the end of this pap

Astrophysical observations indicate that dark matter constitutes most of the mass in our universe, but its nature remains unknown. Over the past decade, the Cryogenic Dark Matter Search (CDMS II) experiment has provided world-leading sensitivity for the direct detection of Weakly Interacting Massive Particle (WIMP) dark matter. The final exposure of our low-temperature Ge particle detectors at the Soudan Underground Laboratory yielded two candidate events, with an expected background of 0.9 ± 0.2 events. This is not statistically significant evidence for a WIMP signal. The combined CDMS II data place the strongest constraints on the WIMP-nucleon spin-independent scattering cross section for a wide range of WIMP masses and exclude new parameter space in inelastic dark matter models.



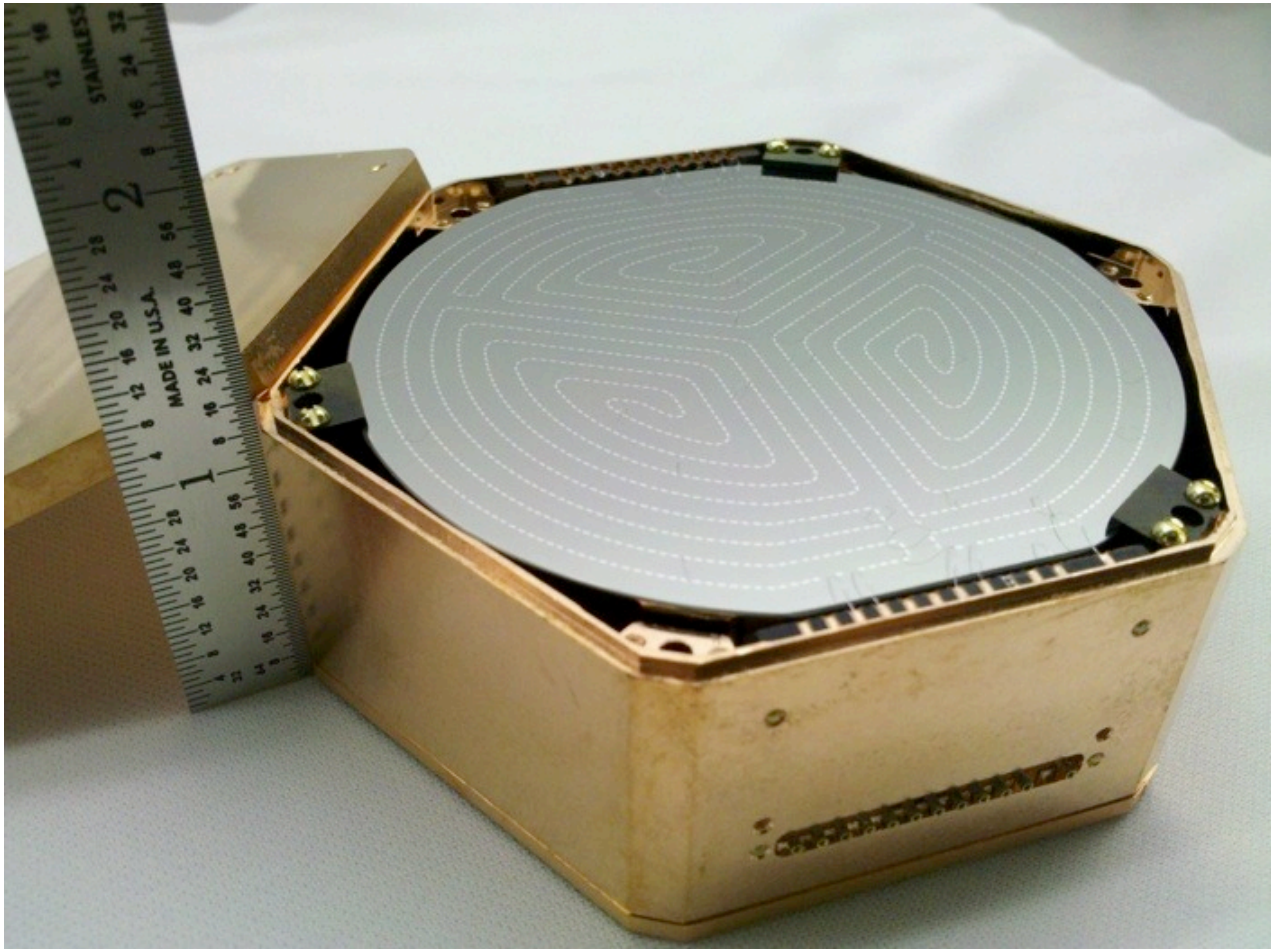
Status of Direction Detection Search



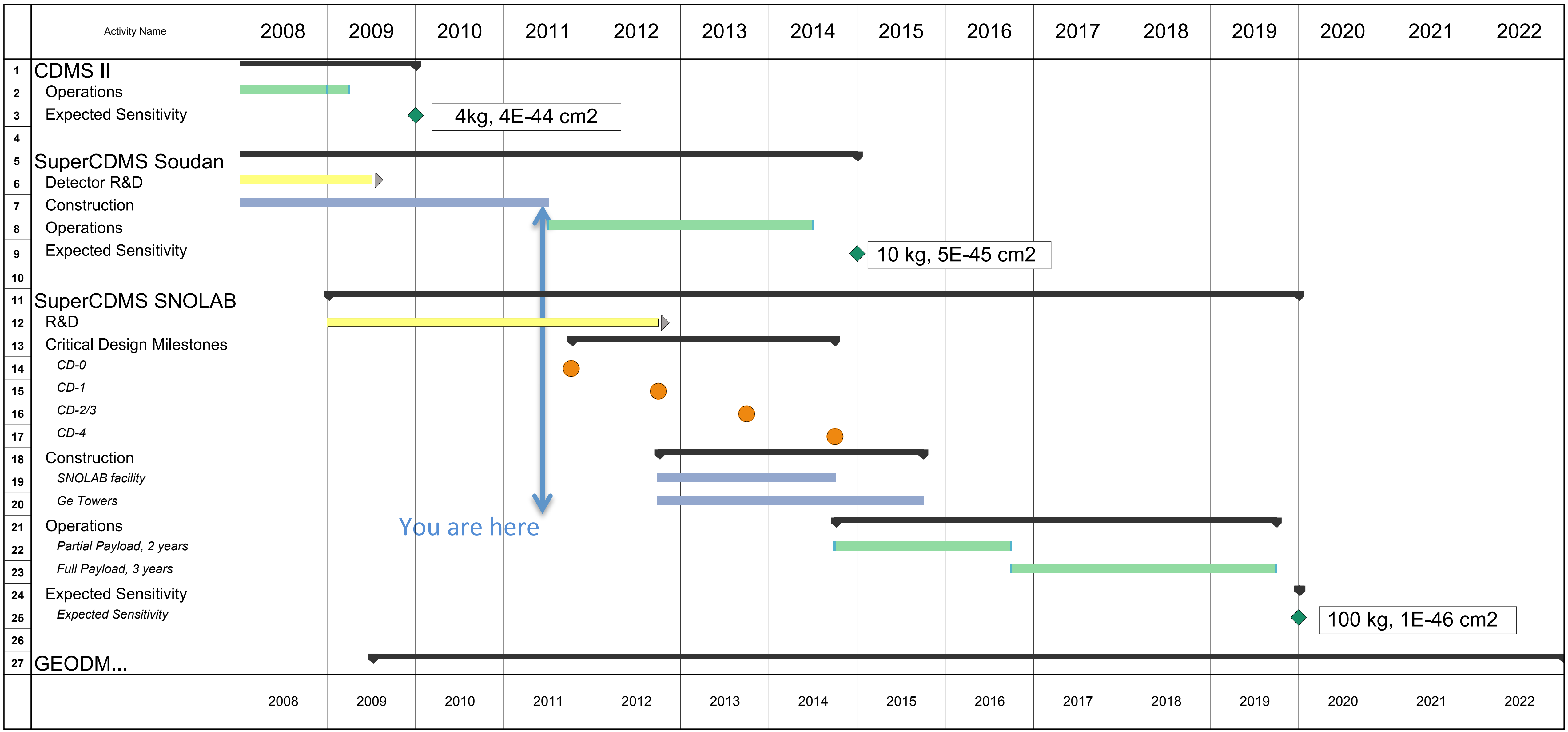
- Variety of techniques search for WIMP dark matter - interesting sensitivity
- Several have the potential to reach 10^{-44} cm^2 soon and 10^{-46} cm^2 in future

SuperCDMS Soudan iZIP Detectors

- Cool to within 0.05 degrees of absolute zero (-459.6 F)
- For each event simultaneously measure the charge produced and the heat produced.
- Allows us to tell if recoiling particle was an electron (backgrounds) or nucleus (WIMP and neutrons)
- Deep underground to avoid neutrons from cosmic ray activity

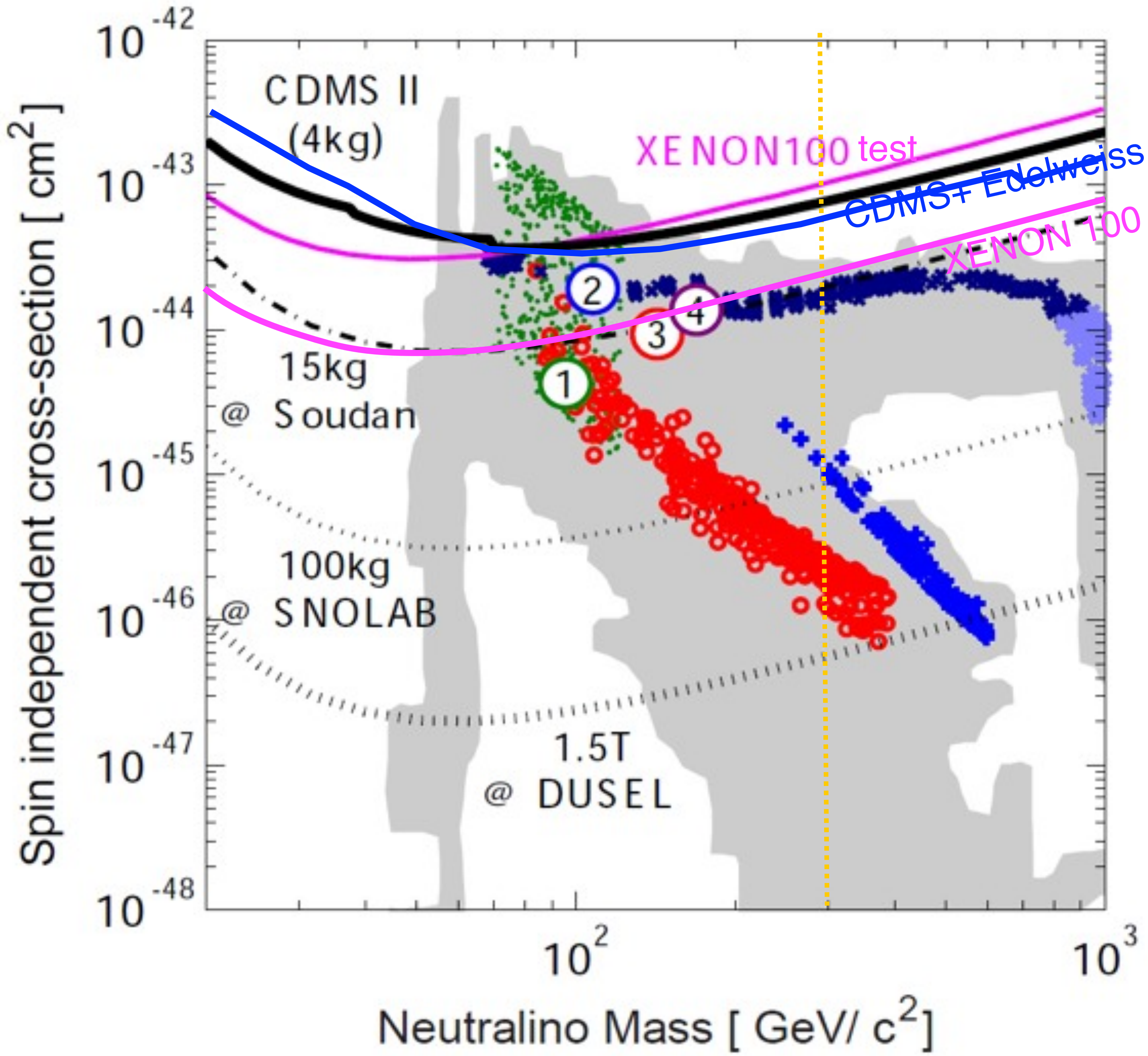


Overview of CDMS



CDMS Plans

CDMS Plans



Spin independent cross-section [cm^2]
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
CDMS II (4kg)
XENON100 test
CDMS+ Edelweiss
XENON 100
15kg @ Soudan
100kg @ SNOLAB
1.5T @ DUSEL
1
2
3
4
10^2
10^3
Neutralino Mass [GeV/ c^2]

CDMS Plans

SCDMS Soudan 10kg interdigitated ≥15kg previous CDMS

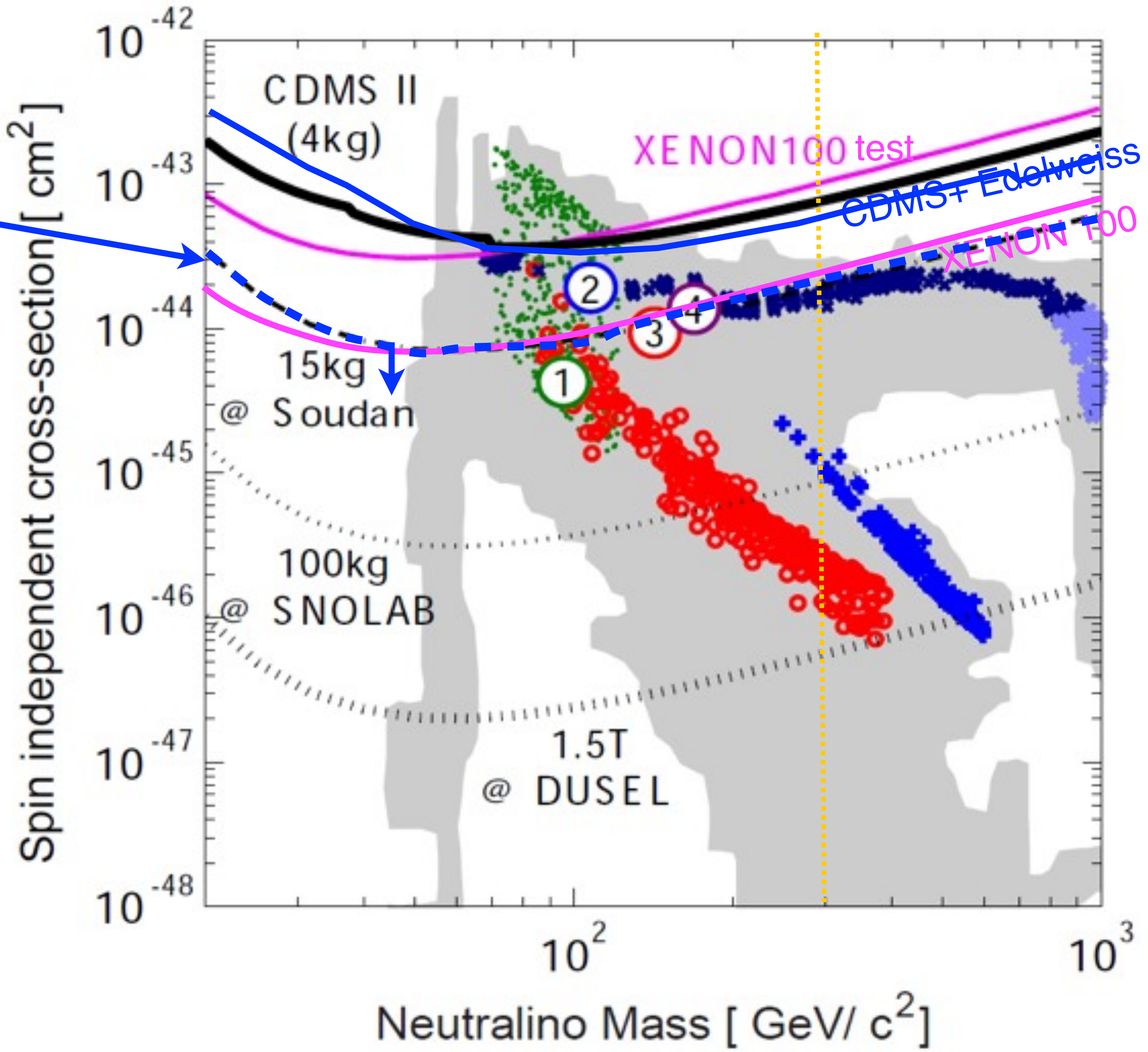
2011-2013->15?: 8-> 5? 10^{-45} cm^2

Depends on neutron background

Similar to current sensitivity of Xenon 100 (100days)

Cross check

+ demonstration of technology for SNOLAB



CDMS Plans

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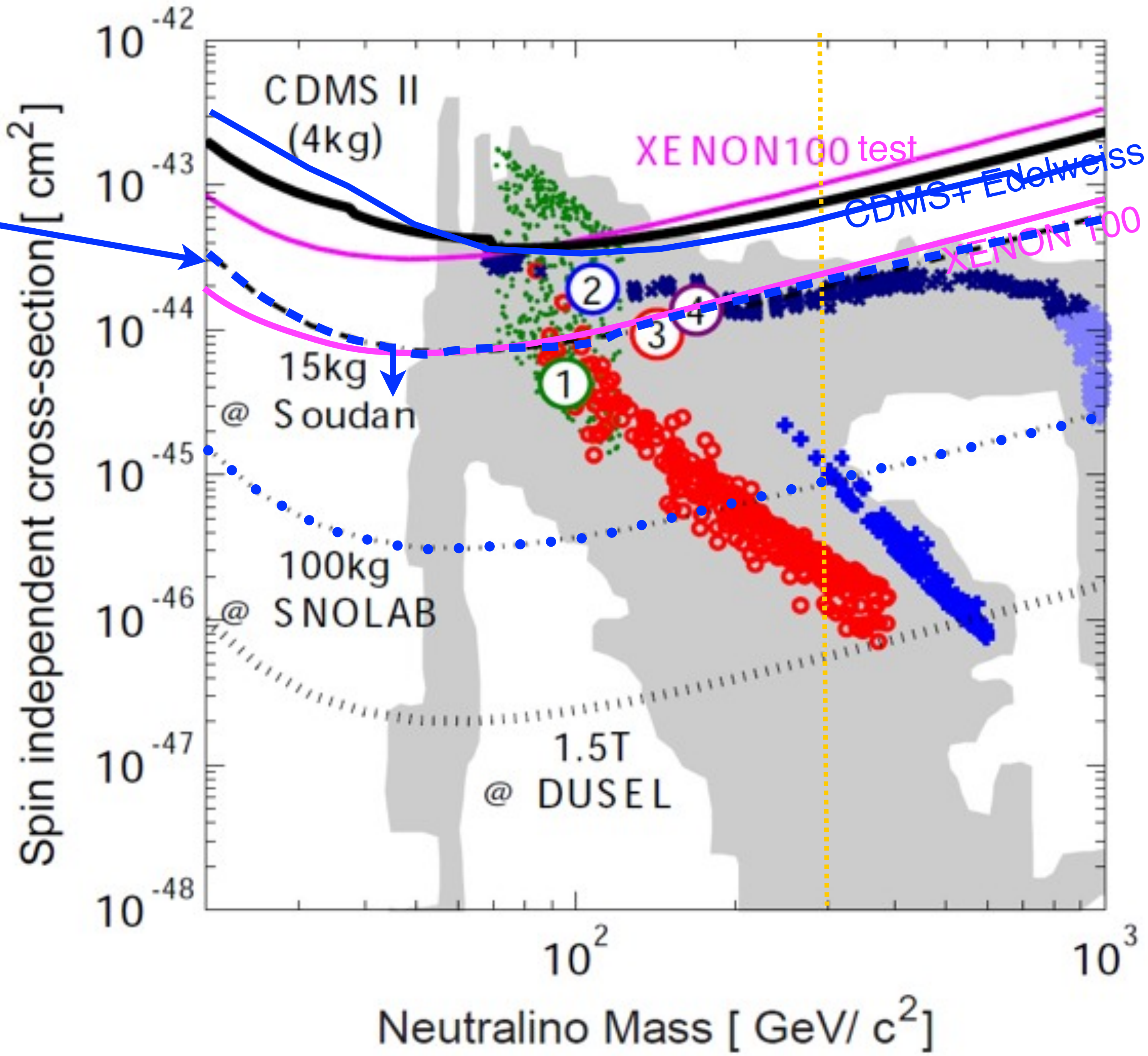
SCDMS SNOLAB 100kg

2015-2018 3 10^{-46} cm^2

Part of Generation 2 competition



CDMS Plans

SCDMS Soudan 10kg interdigitated
≥15kg previous CDMS

2011-2013->15?: 8-> 5? 10^{-45} cm^2

Depends on neutron background

Similar to current sensitivity of Xenon 100 (100days)

Cross check

+ demonstration of technology for SNOLAB

SCDMS SNOLAB 100kg

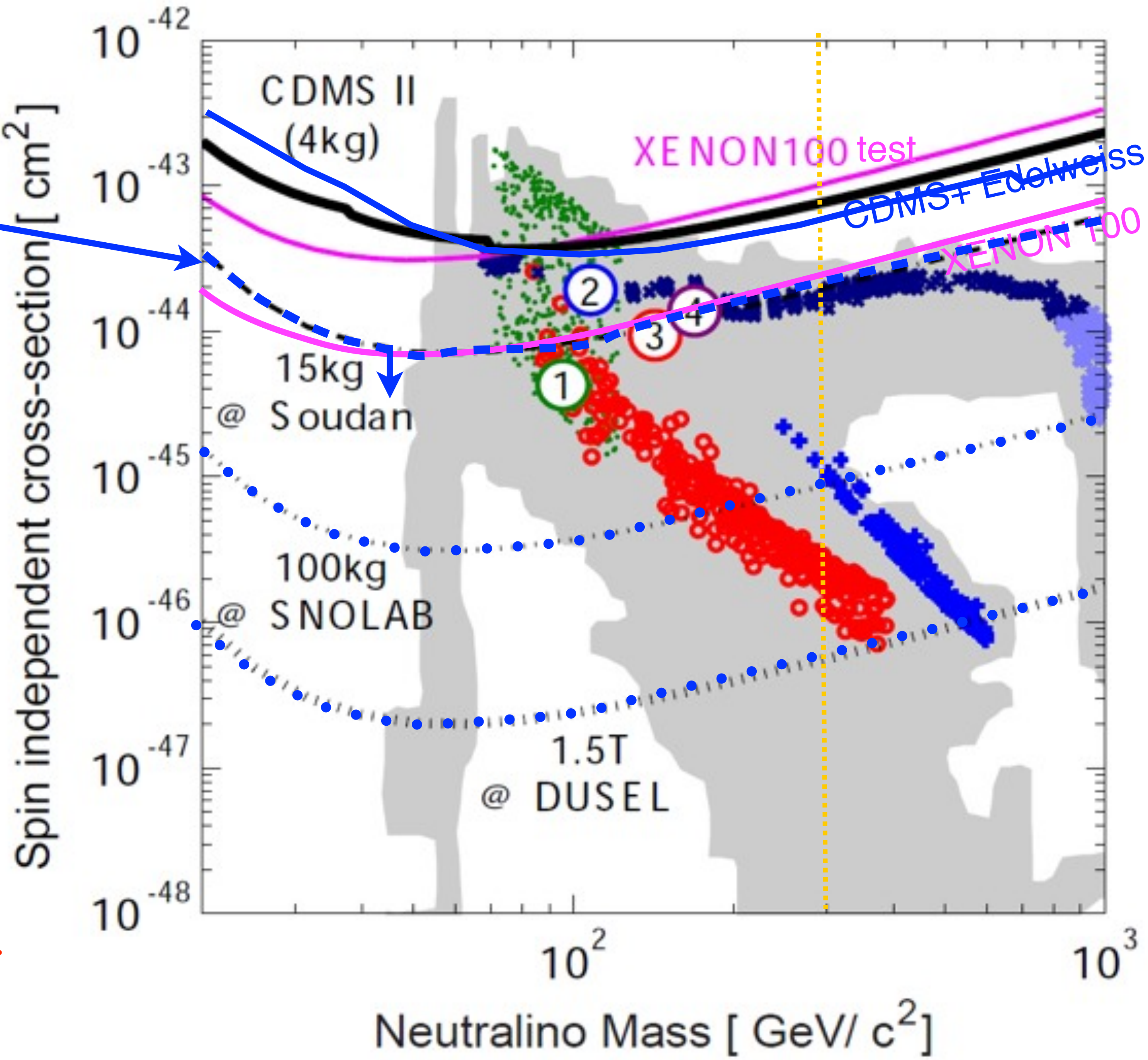
2015-2018 3 10^{-46} cm^2

Part of Generation 2 competition

GEODM DUSEL 1.5 tonne

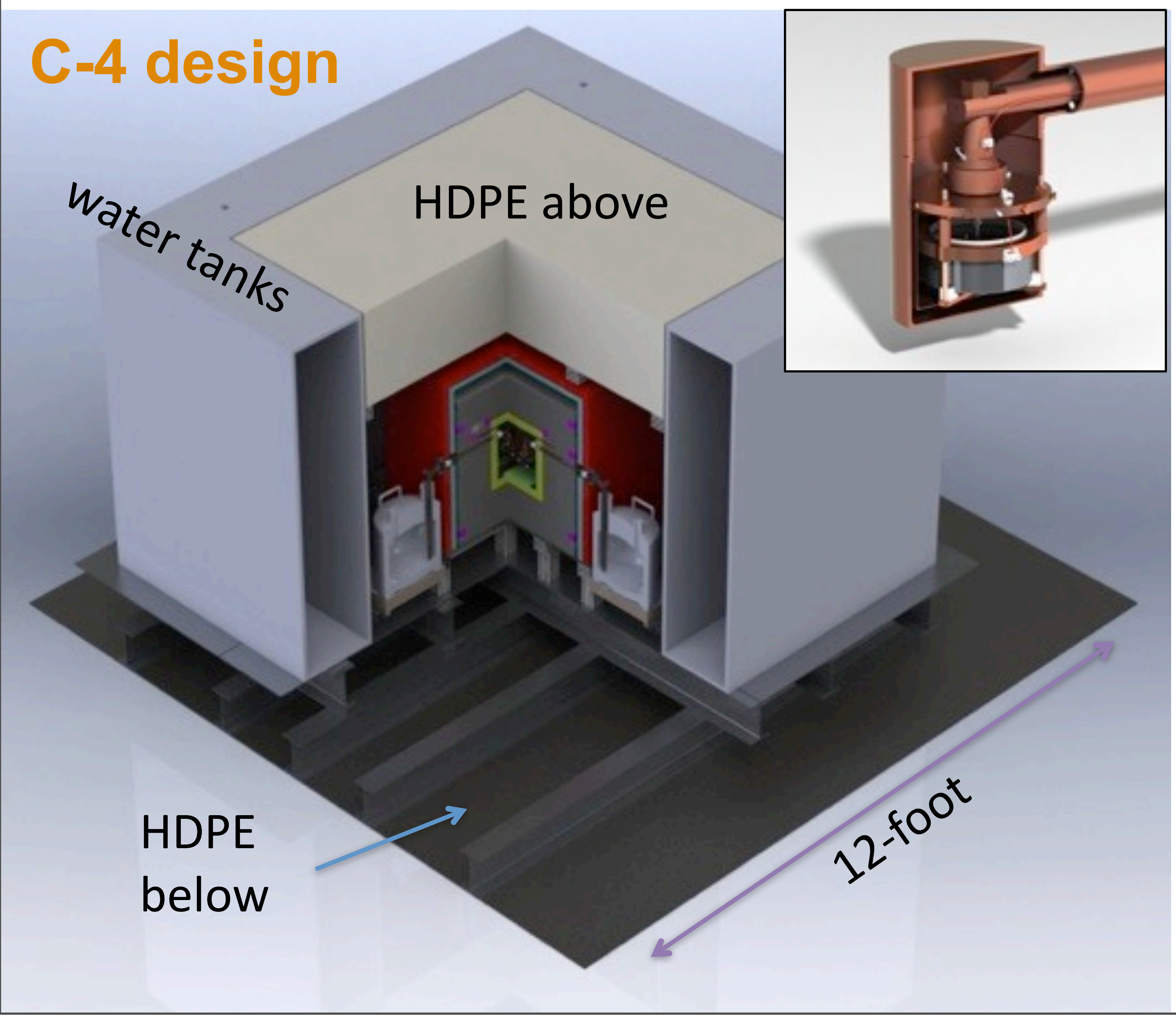
2018?-2022? 2 10^{-47} cm^2

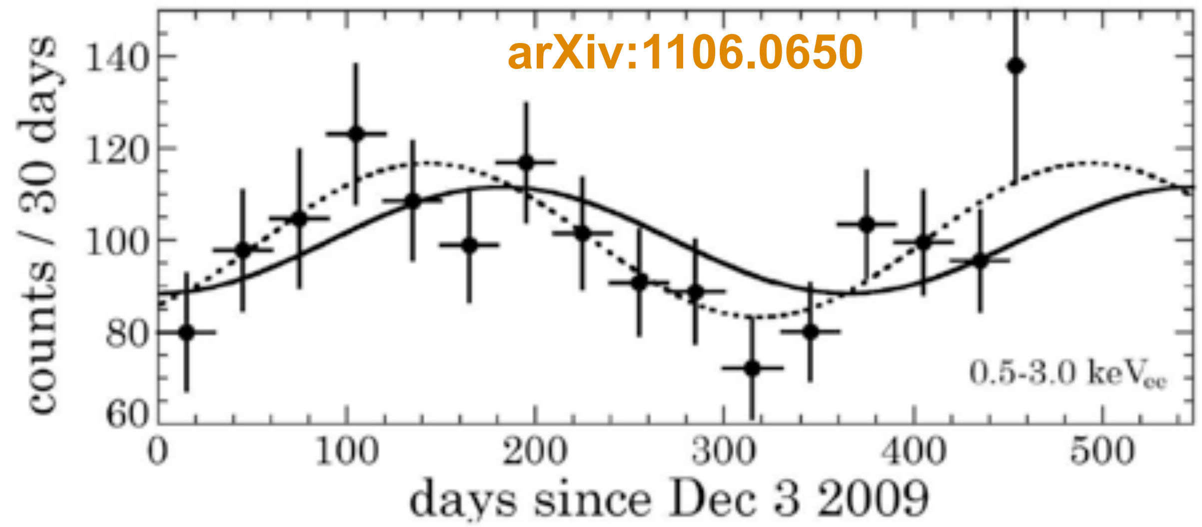
Challenge is to produce detector at low enough cost ($50M + 50% contingency)

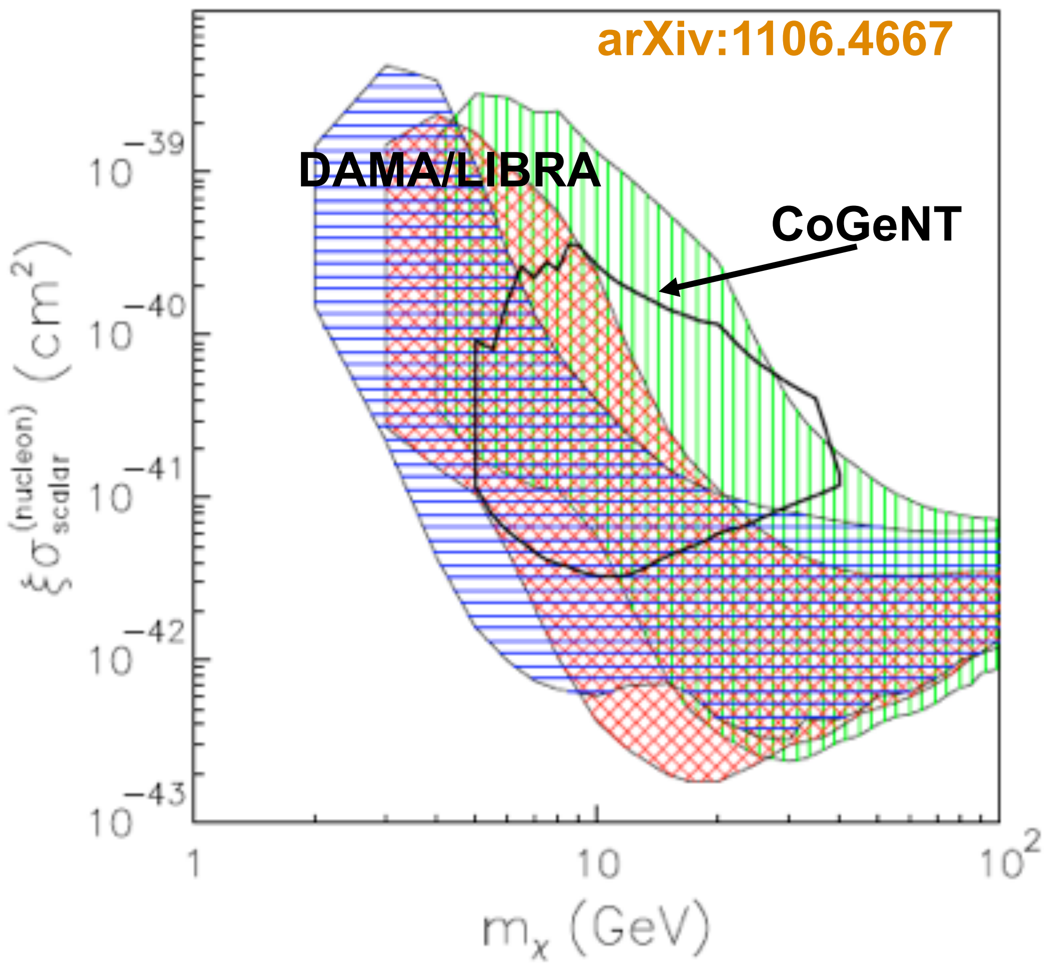


CoGeNT Present Status

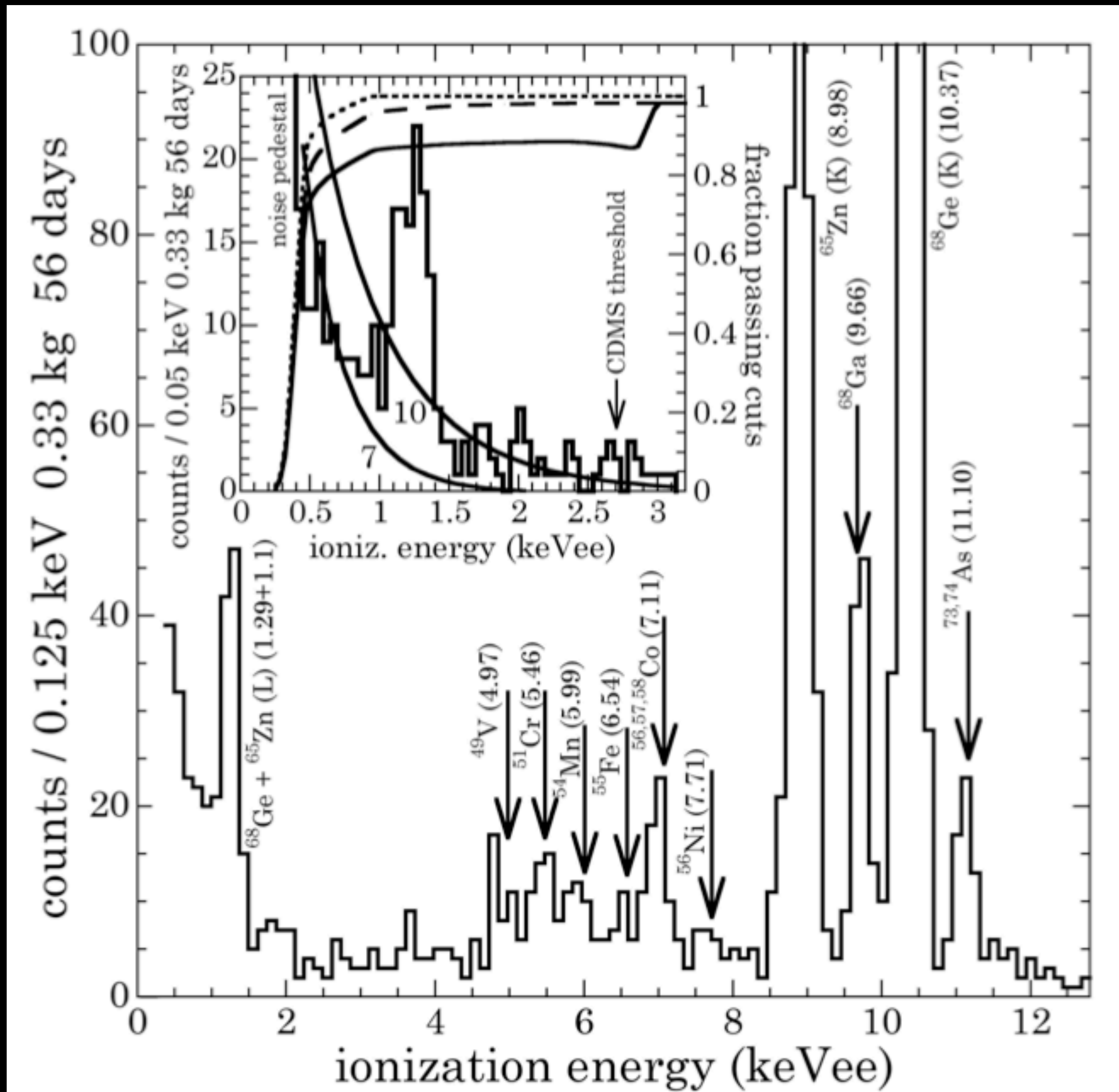
- Annual modulation of unknown origin, measured with ~0.4 kg crystal at Soudan, in possible agreement with DAMA/LIBRA.
- C-4 to start end of 2011 in Soudan (x10 present mass, significant reduction in bckg and threshold expected).





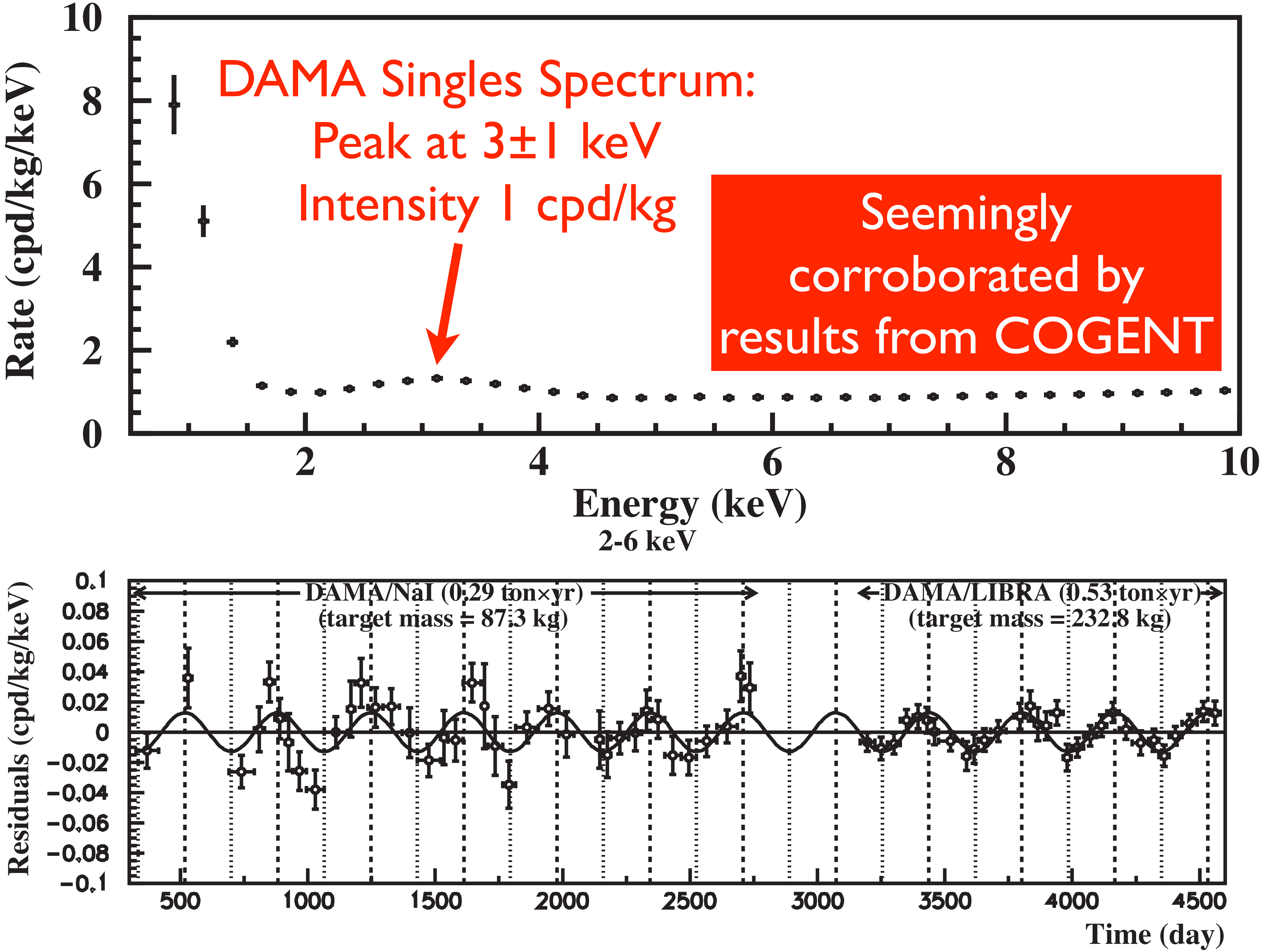


COGENT



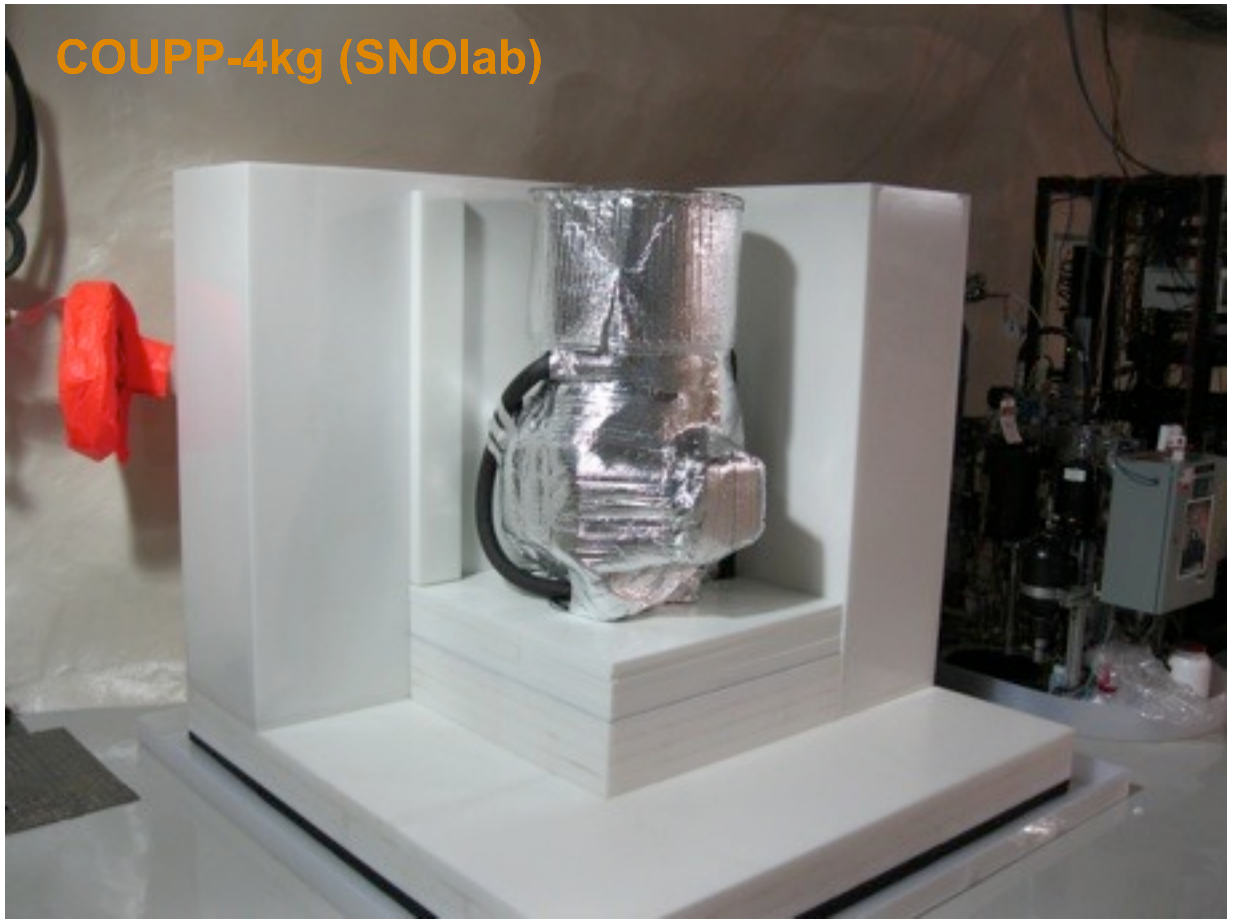
counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)
68Ge + 65Zn (L) (1.29+1.1)
49V (4.97)
51Cr (5.46)
54Mn (5.99)
55Fe (6.54)
56,57,58Co (7.11)
56Ni (7.71)
65Zn (K) (8.98)
68Ga (9.66)
68Ge (K) (10.37)
73,74As (11.10)
counts / 0.05 keV 0.33 kg 56 days
fraction passing cuts
ioniz. energy (keVee)
noise pedestal
CDMS threshold
10
7

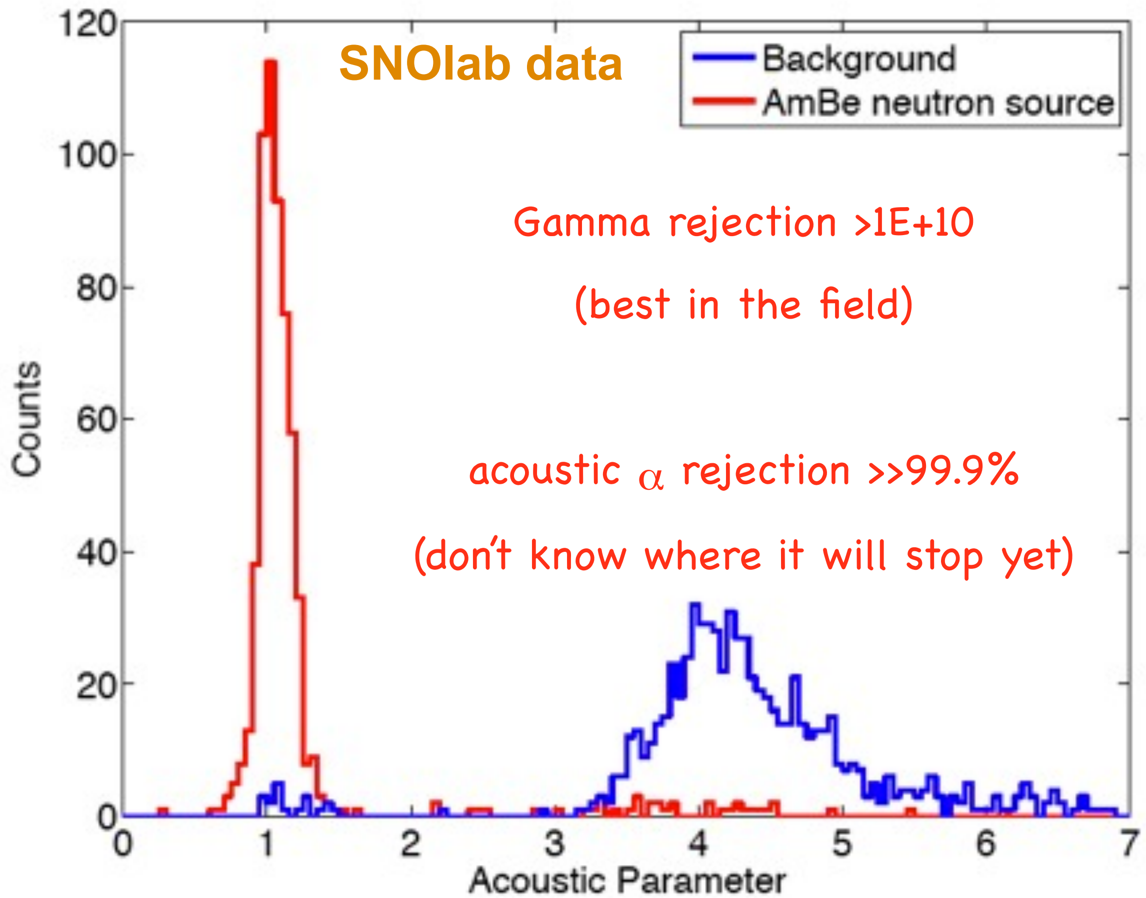

The second generation DAMA/LIBRA set-up ~250 kg ULB NaI(Tl)
(Large sodium Iodide Bulk for RAre processes)
As a result of a second generation R&D for more radiopure NaI(Tl)
by exploiting new chemical/physical radiopurification techniques
(all operations involving crystals and PMTs - including photos - in HP Nitrogen atmosphere)
installing DAMA/LIBRA detectors
assembling a DAMA/ LIBRA detector
detectors during installation; in the central and right up detectors the new shaped Cu shield surrounding light guides (acting also as optical windows) and PMTs was not yet applied
filling the inner Cu box with further shield
closing the Cu box housing the detectors
view at end of detectors' installation in the Cu box


DAMA Singles Spectrum:
Peak at 3±1 keV
Intensity 1 cpd/kg
Seemingly corroborated by results from COGENT
Rate (cpd/kg/keV)
Energy (keV)
2-6 keV
DAMA/NaI (0.29 ton×yr)
(target mass = 87.3 kg)
DAMA/LIBRA (0.53 ton×yr)
(target mass = 232.8 kg)
Residuals (cpd/kg/keV)
Time (day)

COUPP Present Status

- 4 kg chamber taking data at SNOlab.
- Weak (α,n) sources identified and in the process of elimination.
- Excellent acoustic discrimination against alphas demonstrated.
- 60 kg chamber to be installed at SNOlab during 2011.





The End