Direct Dark Matter Detection

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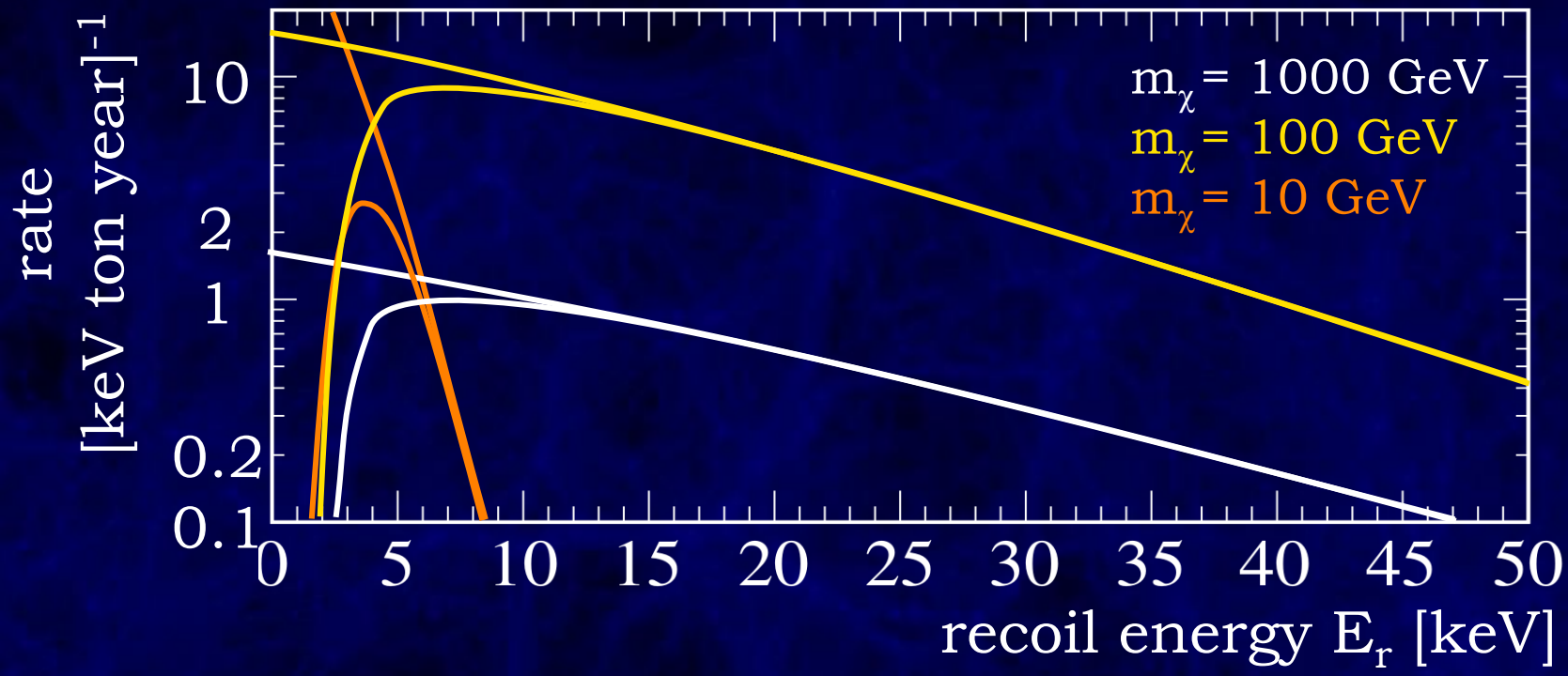
Direct Detection Spectrum

Elastic non-relativistic scattering.
Falling exponential spectrum,
e.g. Xe target, $\sigma = 10^{-45} cm^2$:



Acceptance necessarily drops to 0 at E_r=0:
Measured signal is a bump after all.

Signal/√Background

- It's about sensitivity, no point in "zero background"
- Optimize $\frac{\text{Signal}}{\sqrt{\text{Background}}}$

- Increase Signal
  - High-A targets
  - Massive detectors, long exposure
  - Optimize analysis to retain maximum acceptance

- Decrease background

Signal/√Background

Background Reduction:

- Go underground
- Shield and use active veto
- Use only low-background materials
- Employ pure targets
- Fiducialize
- Discriminate ER ↔ NR
- Disentangle artefacts

e.g. surface events, pile up, …

limiting systematic for all past experiments

→ extract redundant information from each event

easy to simulate (e.g. GEANT4)

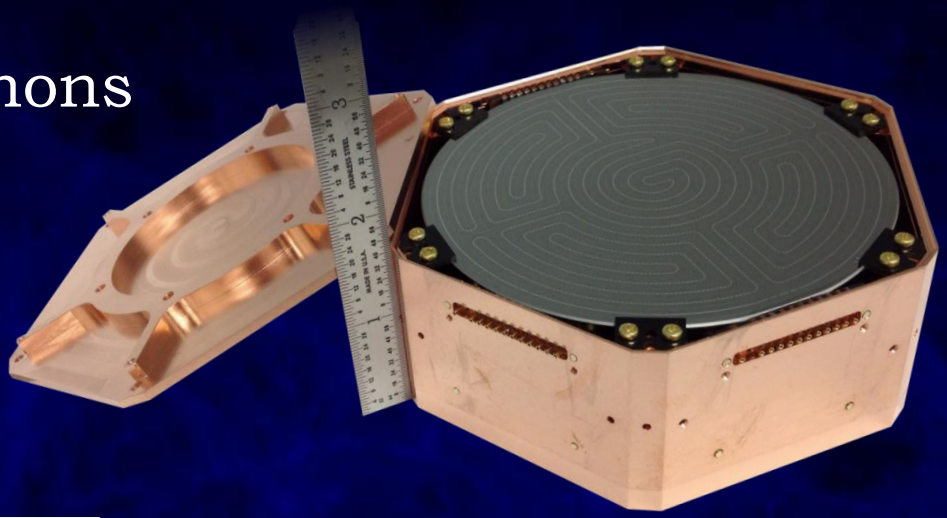
tricky: each detector is a one-of-a-kind

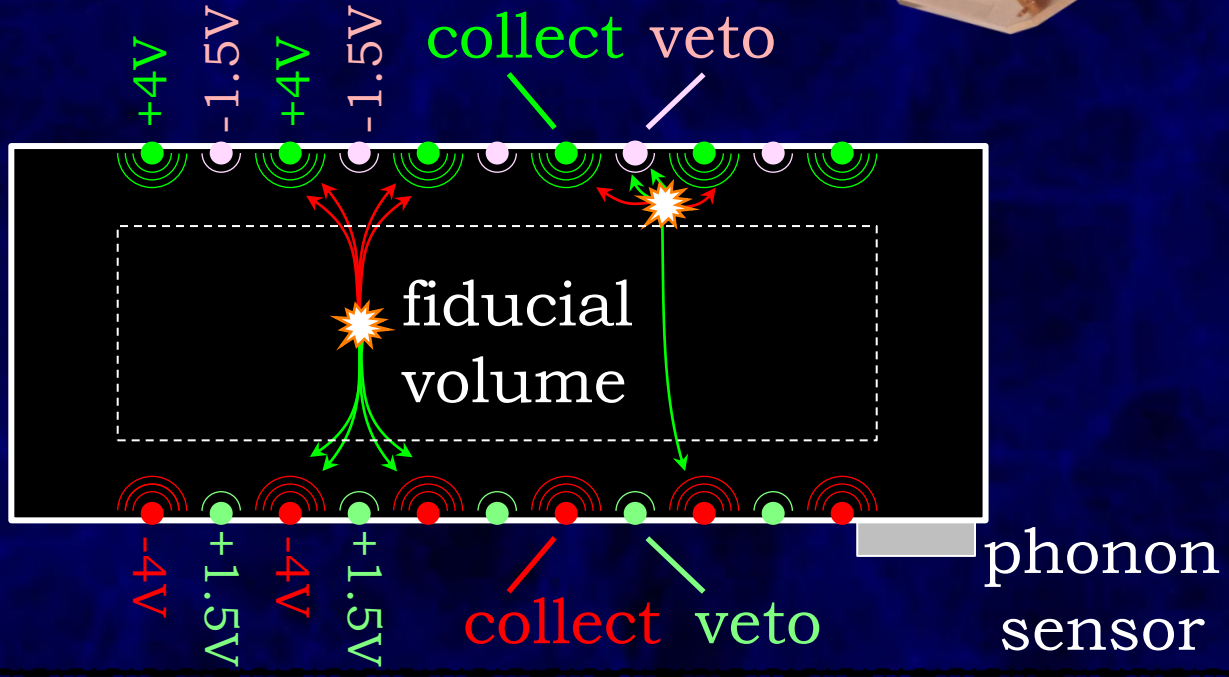
SuperCDMS

Germanium or Silicon calorimeters

Cooled to mK to collect phonons

Interleaved electrodes
for ionization

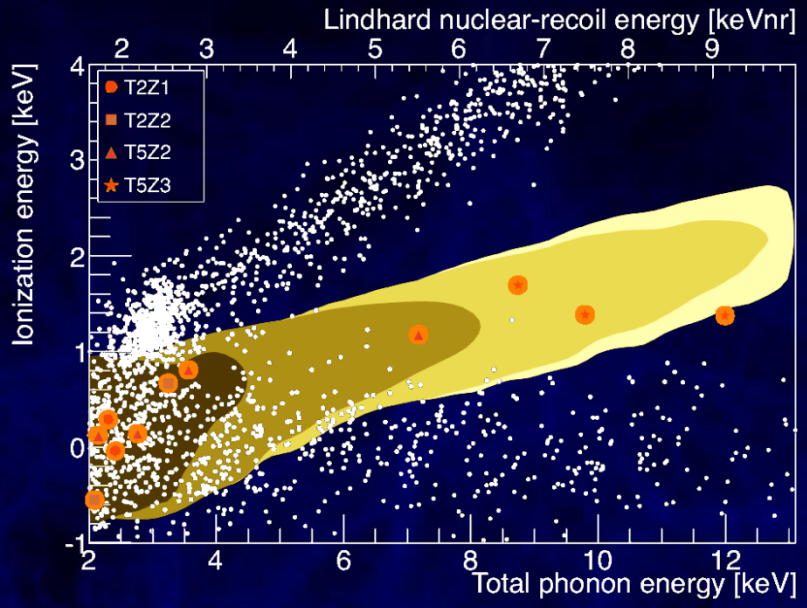


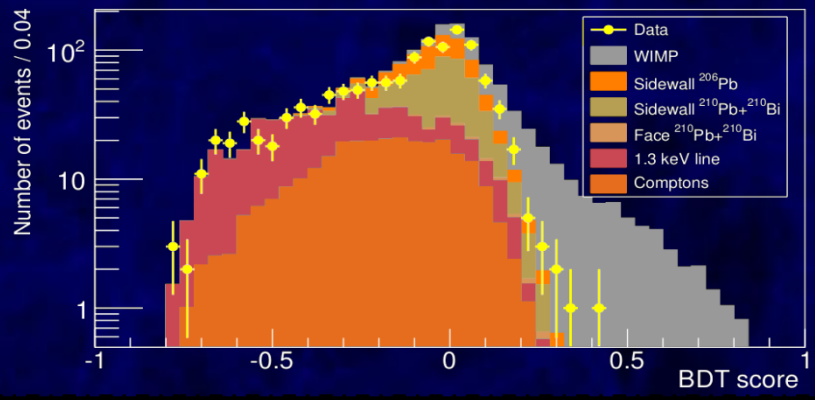


cdms.berkeley.edu

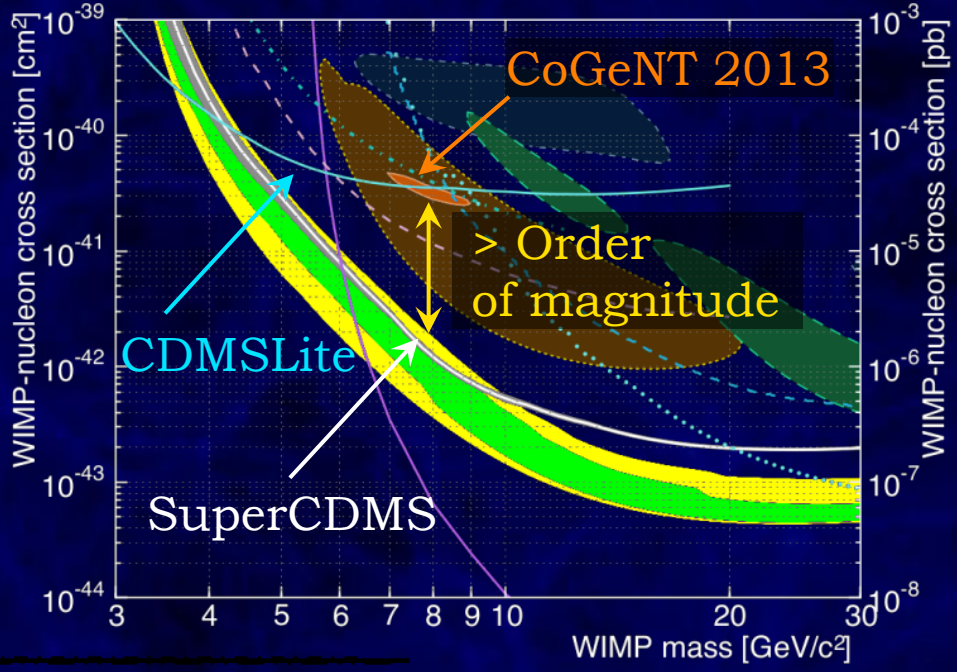
SuperCDMS Soudan → SNOLAB

577 kg days optimized for ~GeV WIMPs:





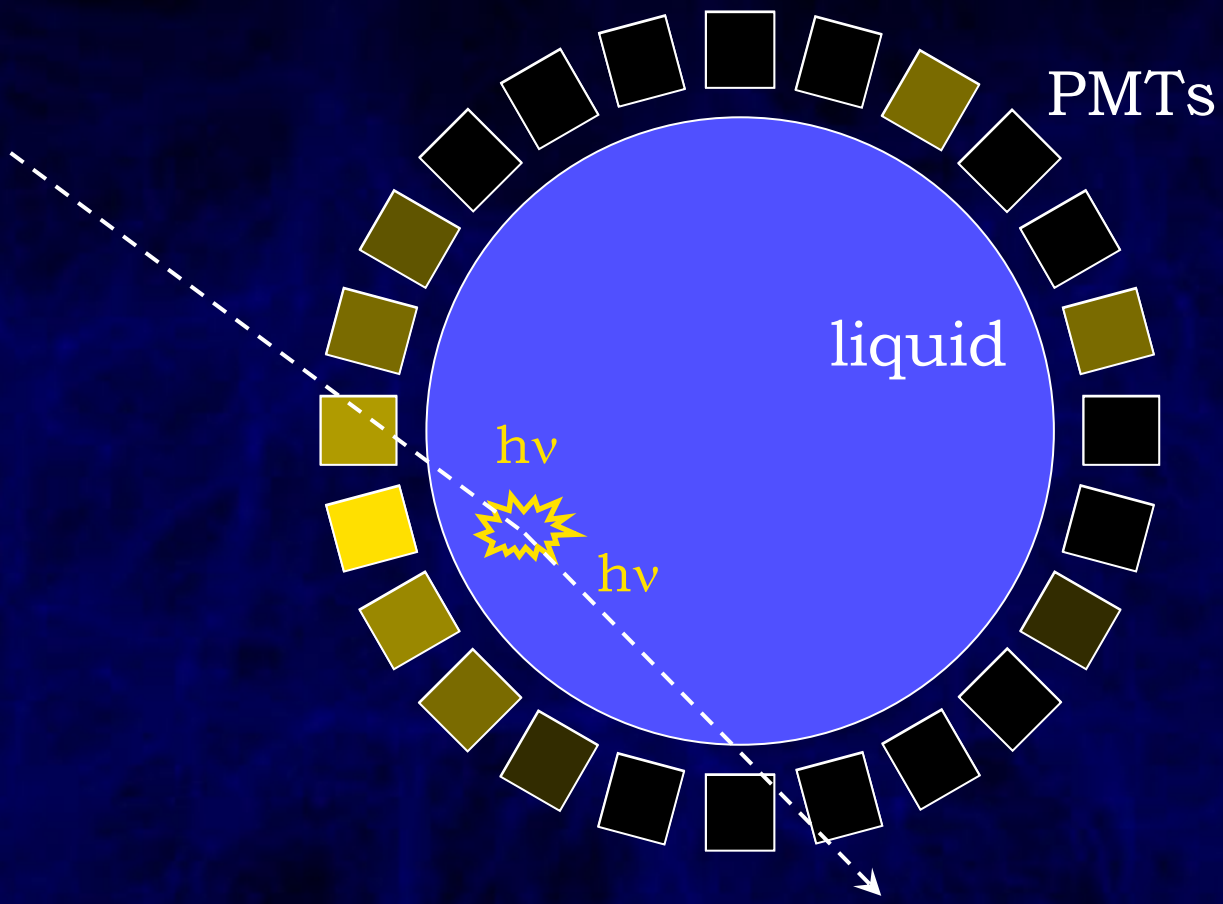
Expect $6.2^{+1.1}_{-0.8}$ events
Observe 11 (8+3)
Excludes CoGeNT
(and CDMS-Si) excess



SuperCDMS 1402.7137

Single-Phase Liquid Noble

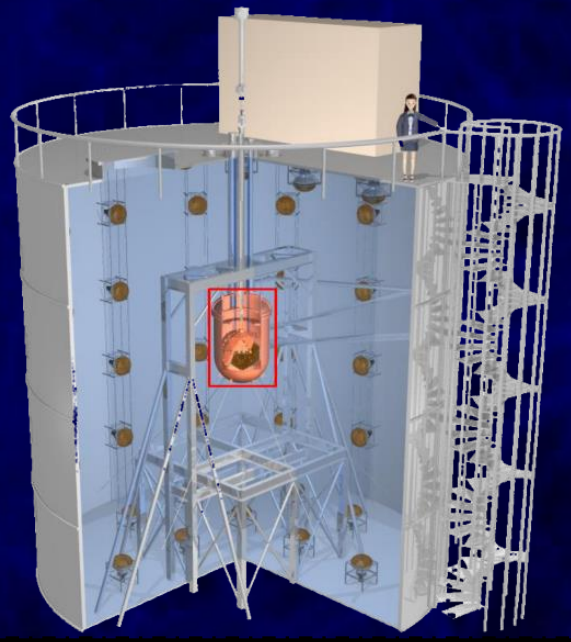
Worked great for ν experiments:



Vertex position from scintillation (S1) hit pattern

XMASS

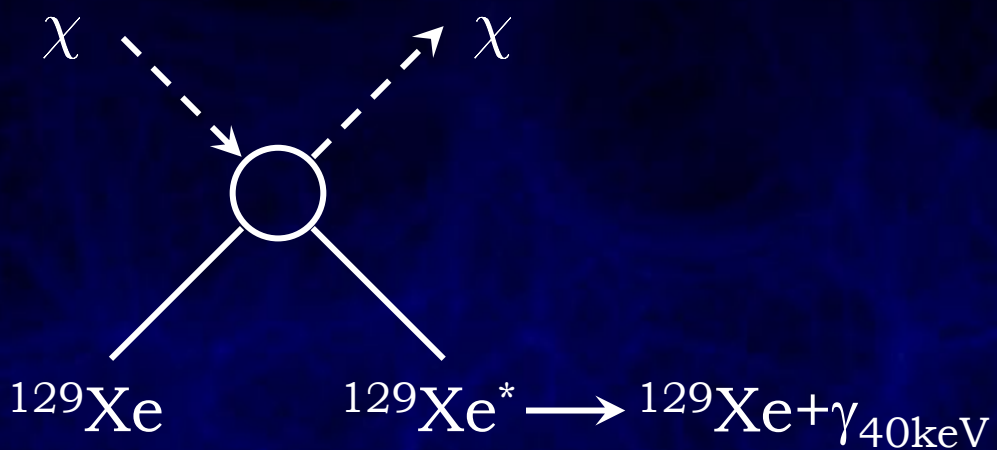
- Single-phase liquid xenon
- @ Kamioka (Japan)
- 642 2.5” hex PMTs
- 830kg total, 100kg fiducial
- Light yield 14 PE/keVee

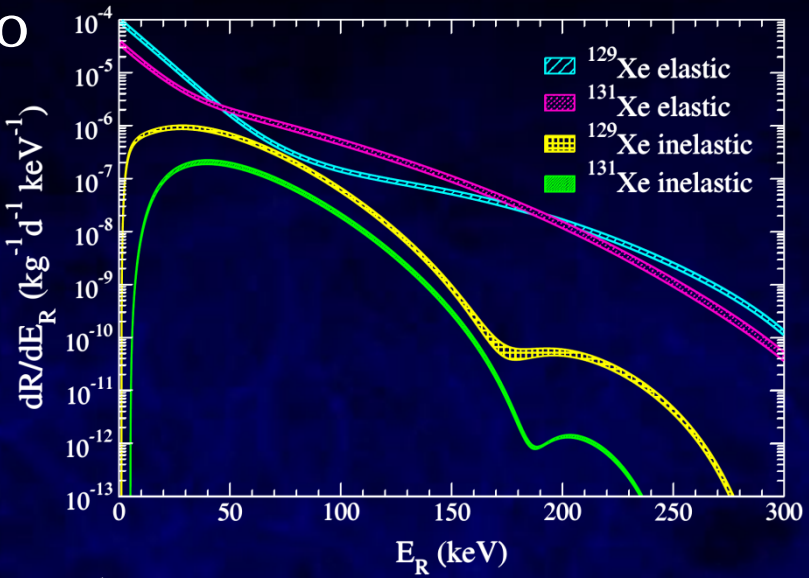


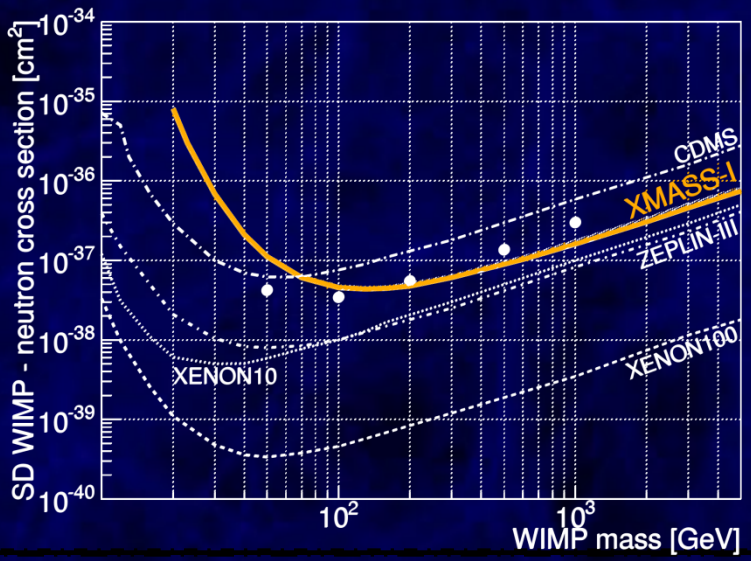
Moriyama, IDM2010

Inelastic Scattering

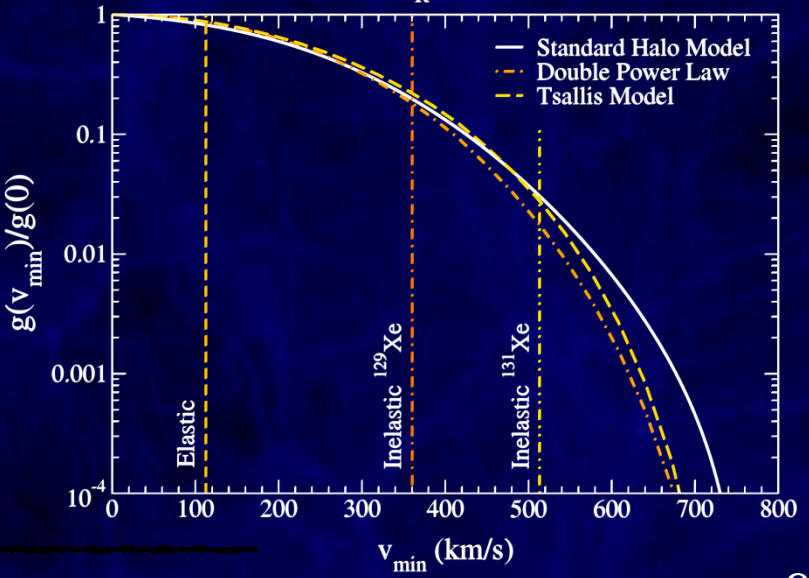
cross-check limits, measure halo







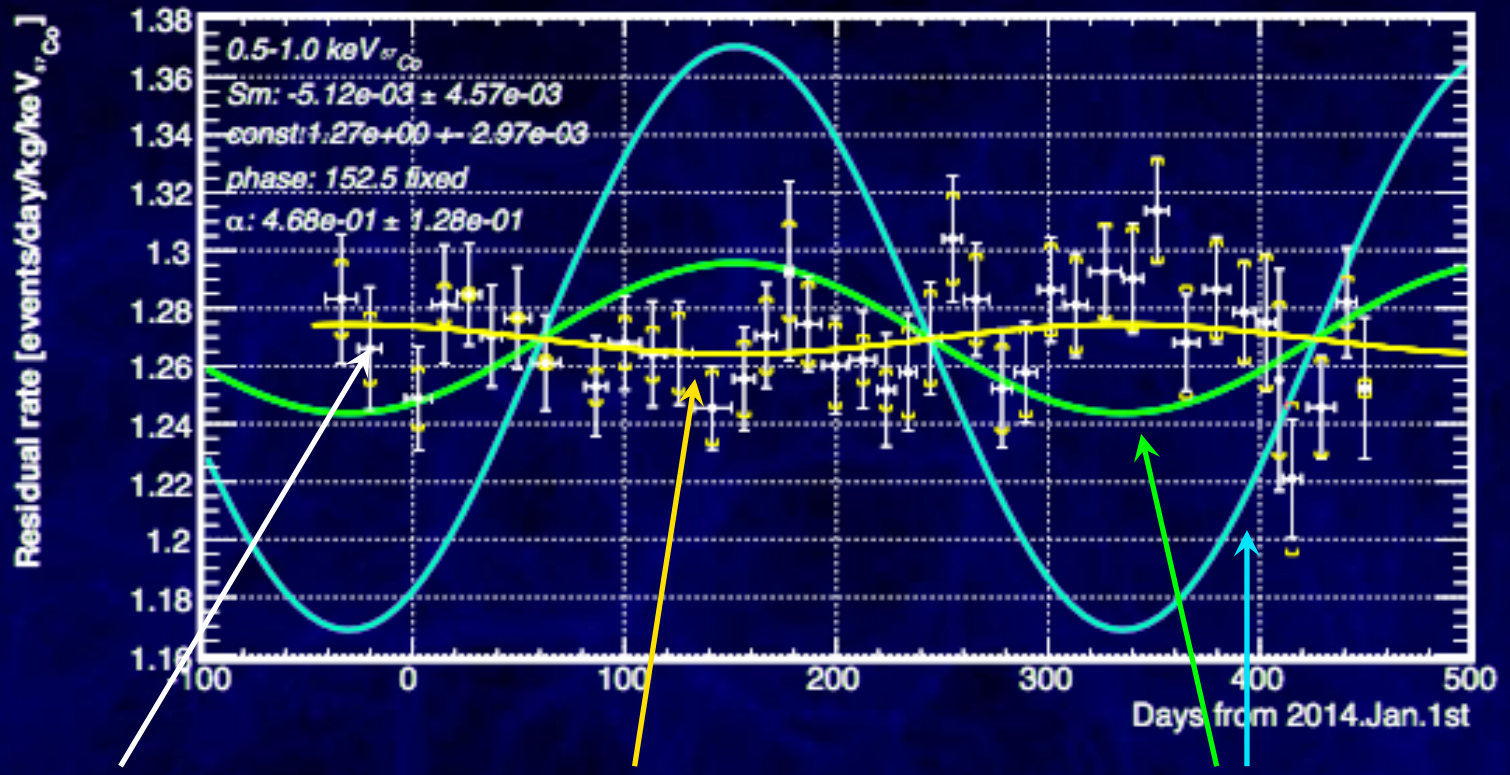
XMASS 1401.4737



Baudis+ 1309.0825

XMASS Modulation Analysis

Exposure & background similar to DAMA
but not so modulating:



XMASS
data 0.8 t yr

XMASS
best fit modulation

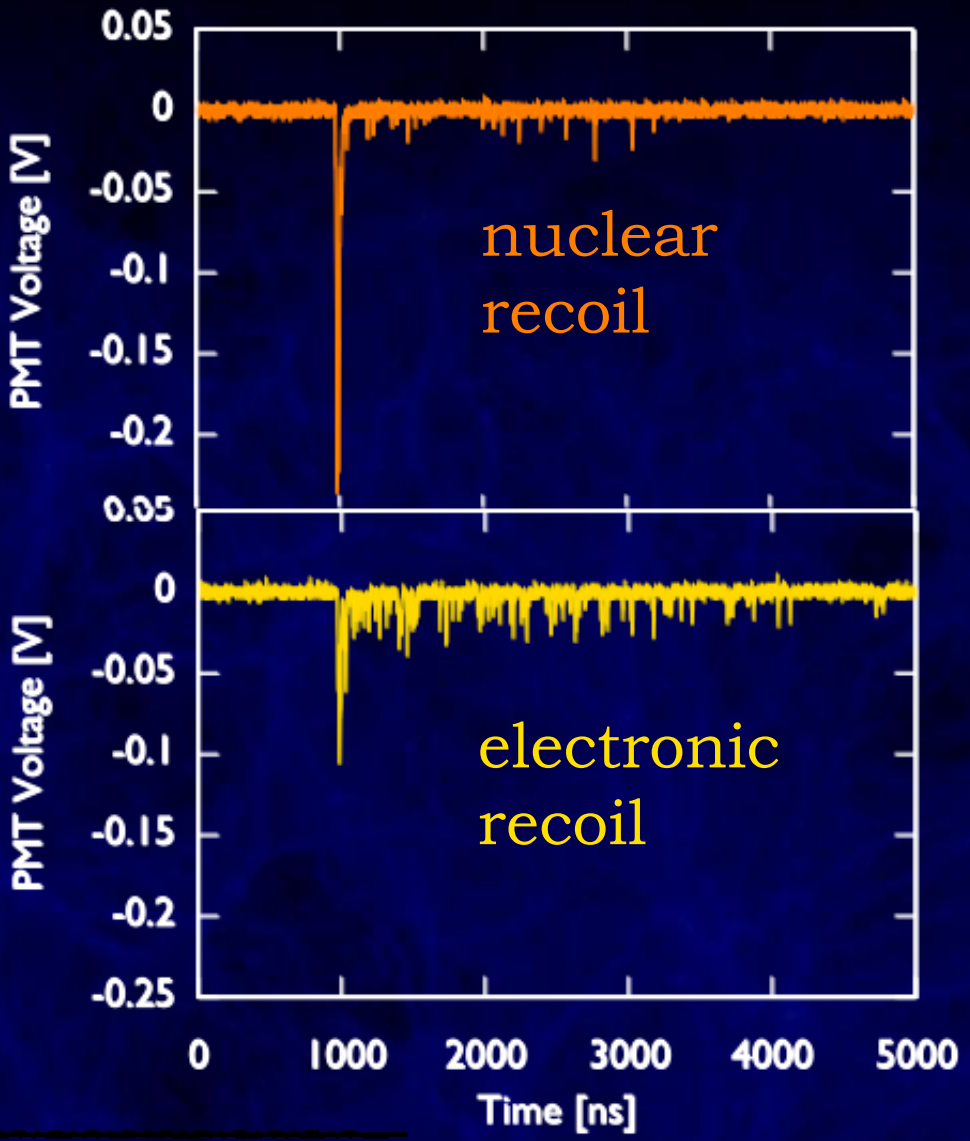
Naïve DAMA
comparison

Kazuyoshi Kobayashi TAUP 2015

Argon: Pulse Shape Discrimination

Ar_2^* dimer
singlet state decays with 6ns, triplet state with 1.5μs.
e.g. in DEAP3600:

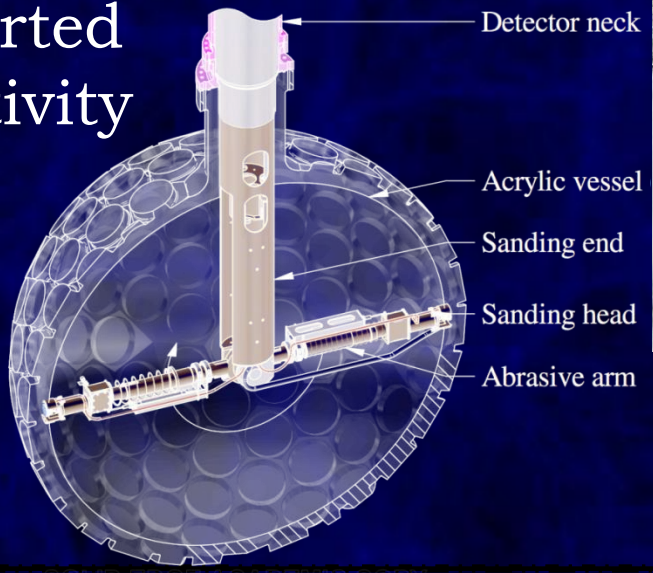
Excellent
$1:10^6$ discrimination
but only at high energy threshold ~ 40 keV_{nr}
(DarkSide-50)

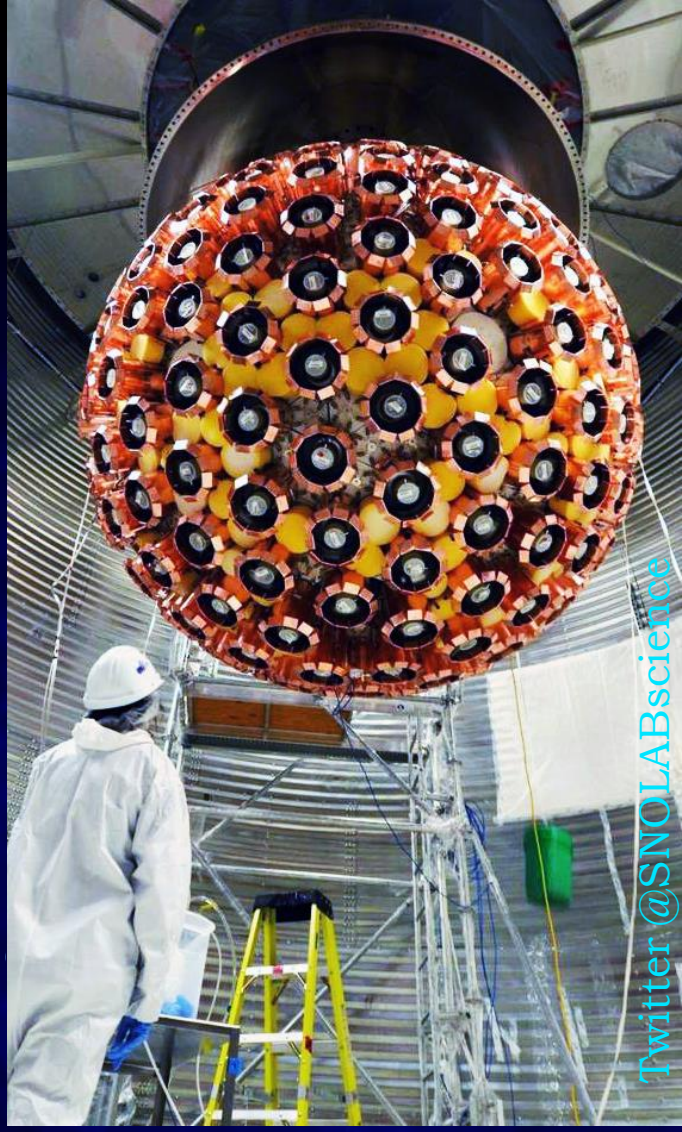


Berta Beltran TAUP2015

DEAP-3600 Status

- Single-phase liquid argon
- @ SNOLAB (Canada)
- Acrylic vessel
- 3.6t argon total, 1t fiducial
- 255 8” PMTs
- Resurfacer removed 500μm reduced Rn by factor 2000
- data taking started
- $10^{-46}cm^2$ sensitivity after 3 years





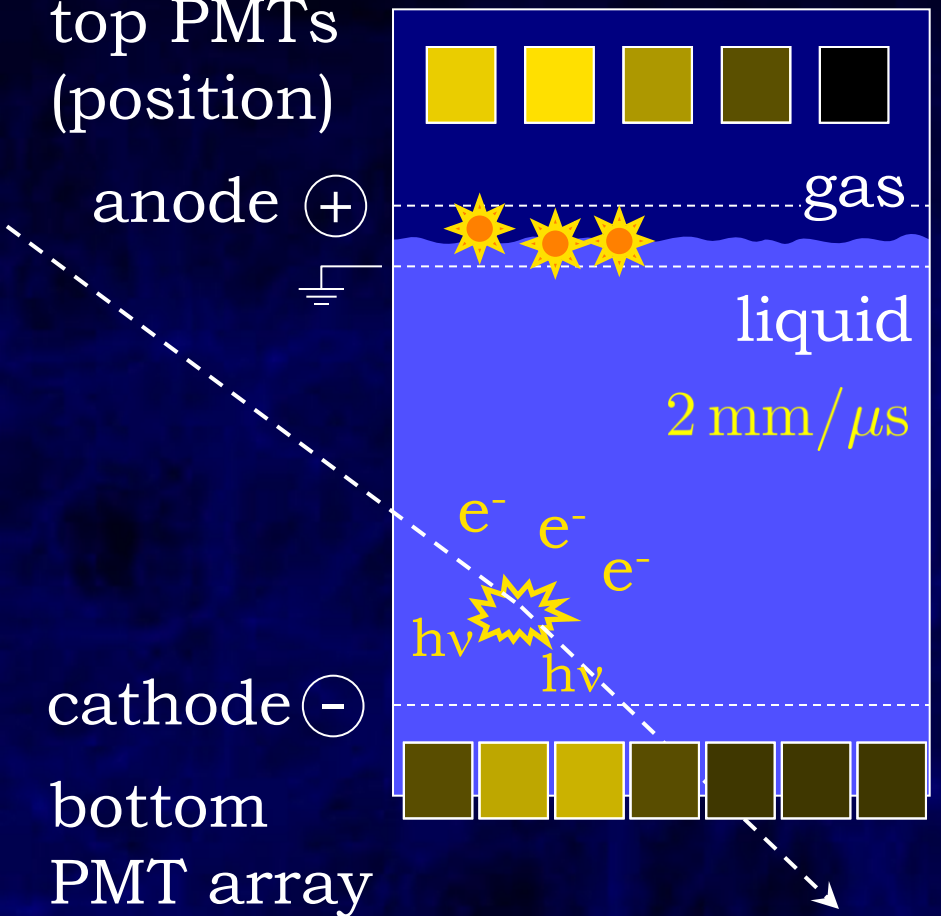
Pietro Giampa TAUP2015

Twitter @SNOLABscience

Two-Phase Liquid/Gas TPC

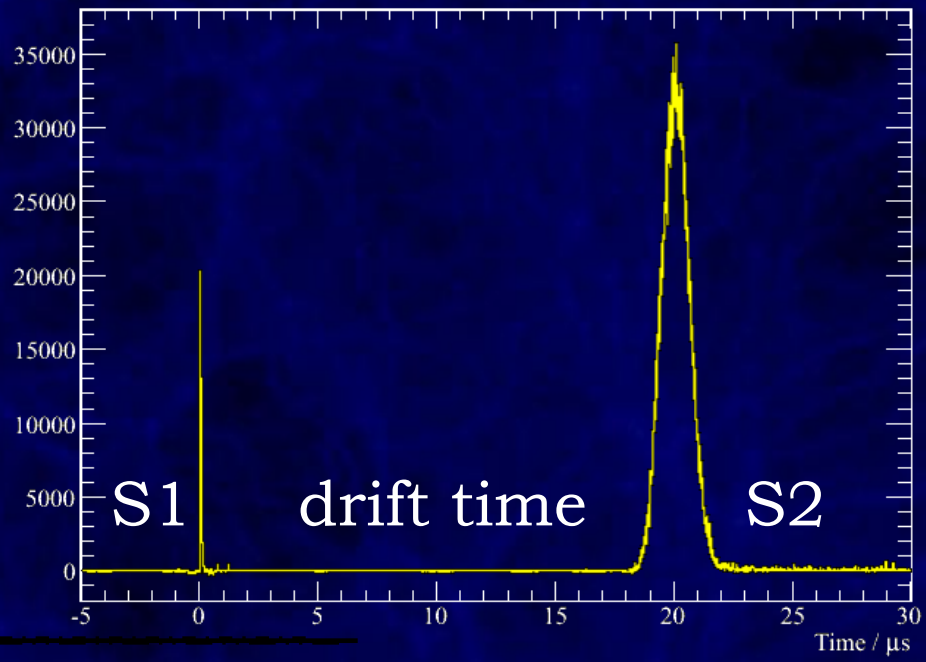
Time Projection Chamber

top PMTs (position)



bottom PMT array (S1, S2)

Vertex position from S2 hit pattern & drift time with ~mm resolution

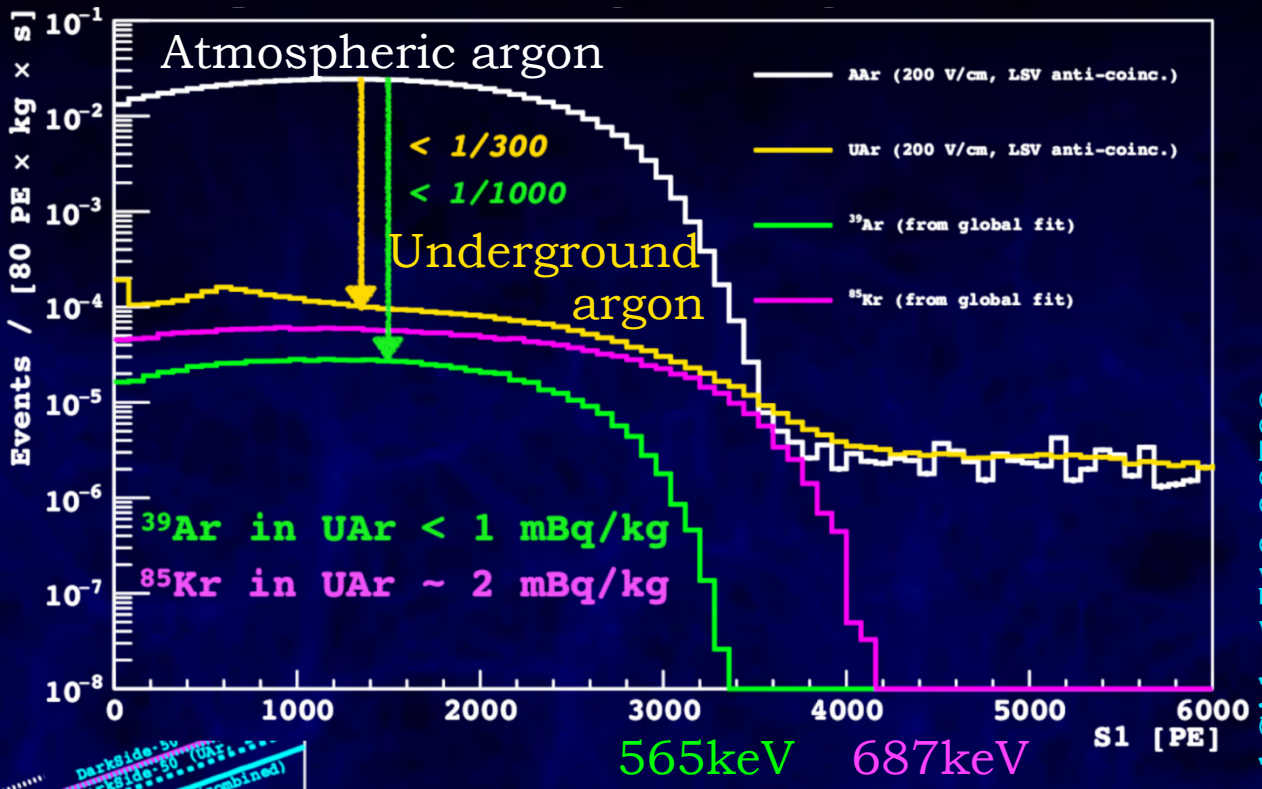


DarkSide-50

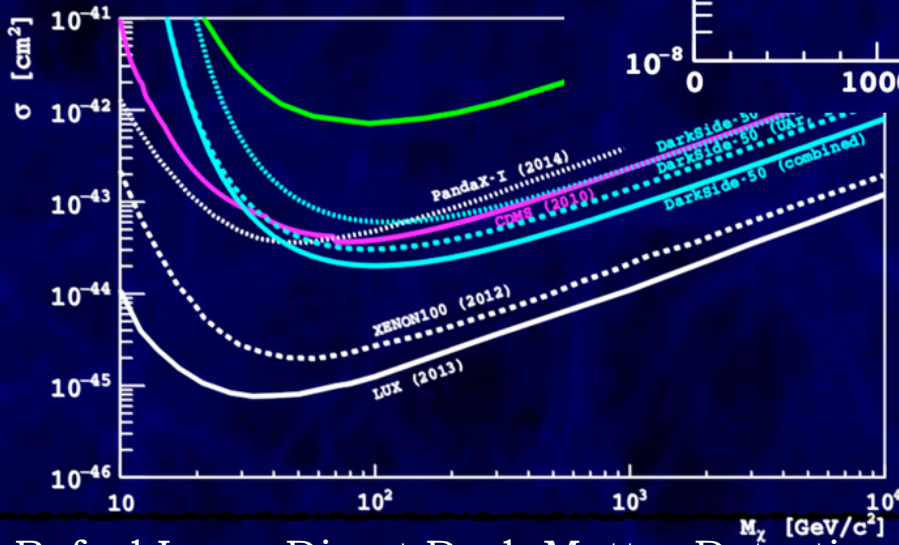
- Two-phase liquid argon
- @ Gran Sasso (Italy)
- 153kg total, 46kg fiducial
- Surrounded by borated liquid scintillator veto

DarkSide-50 Status

Use underground Argon to get rid of ^{39}Ar:

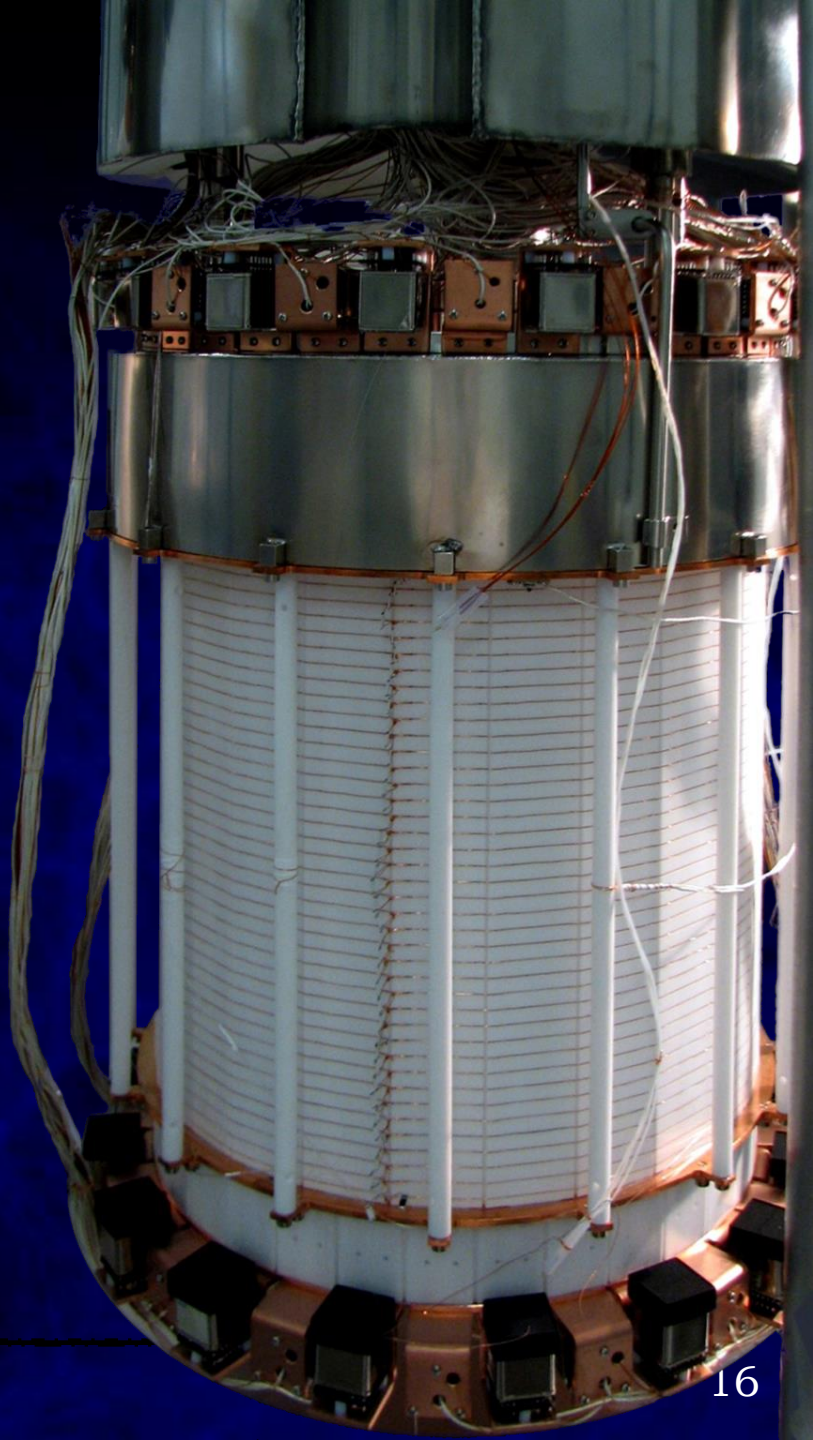


DarkSide 1510.00702



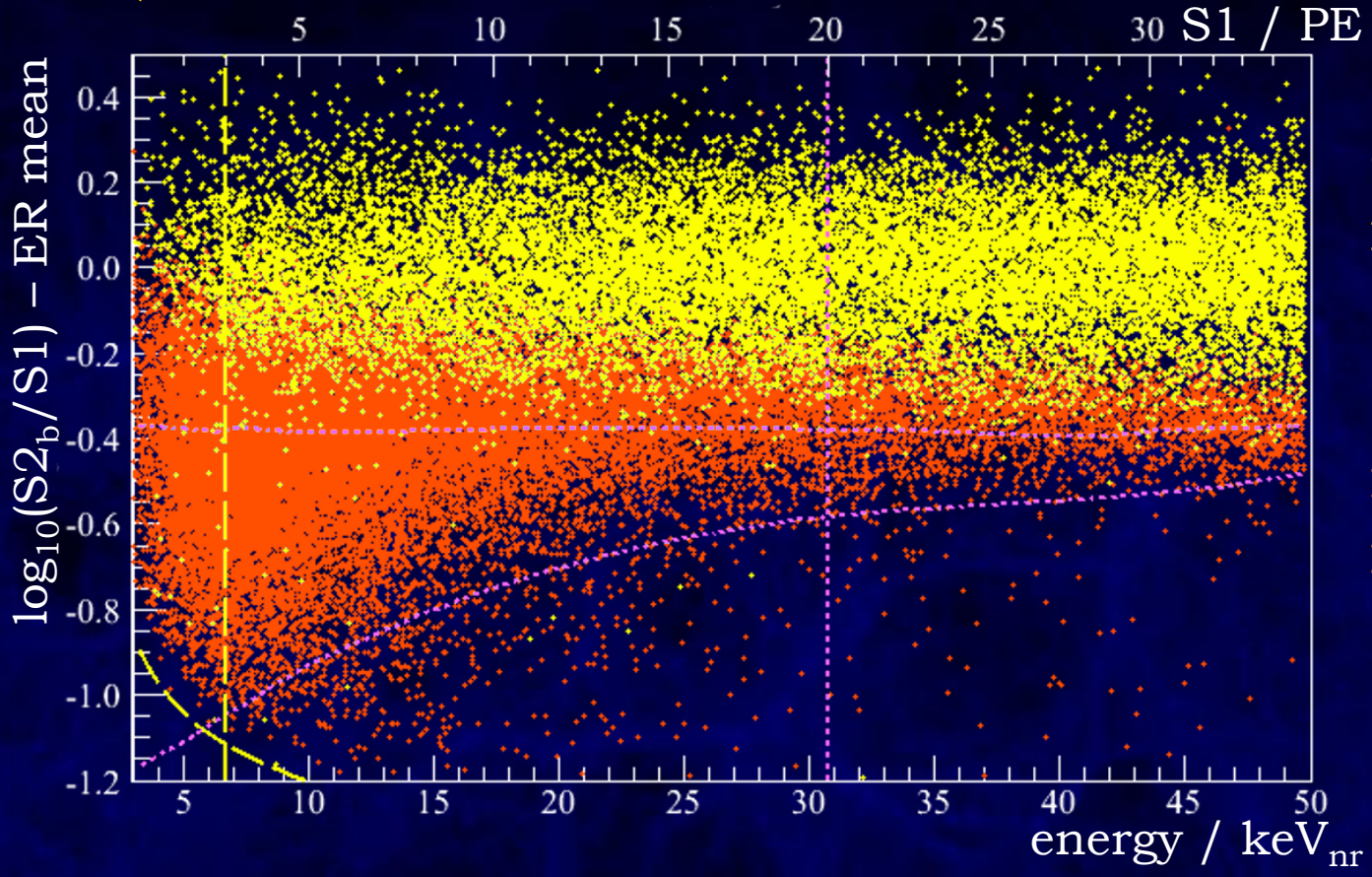
XENON100

- Two-phase liquid xenon
- @ Gran Sasso (Italy)
- 161kg total, ~34kg fiducial



Xenon: S2/S1 Discrimination

^{60}Co, ^{232}Th and ^{241}AmBe calibration



electronic recoils (background)

nuclear recoils (calibration)

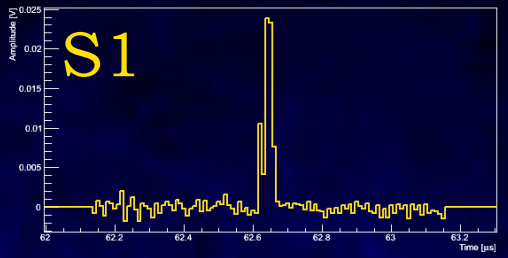
~99.5% ER rejection @ 50% NR acceptance

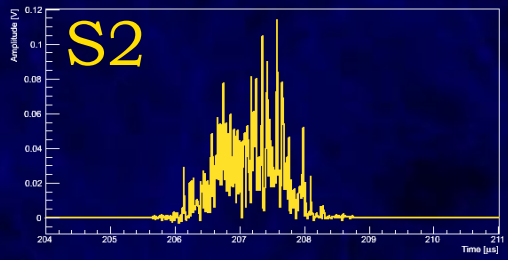
energy threshold ~3keV$_{nr}$

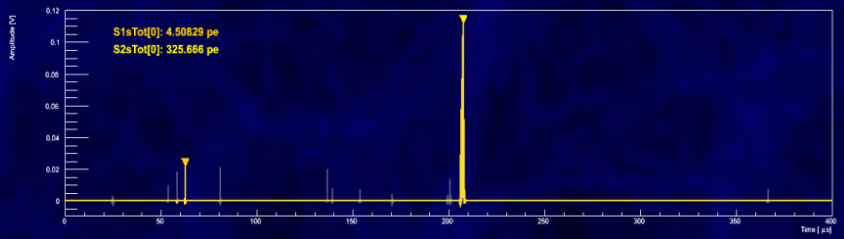
XENON100 Candidate, E~3keV$_{nr}$

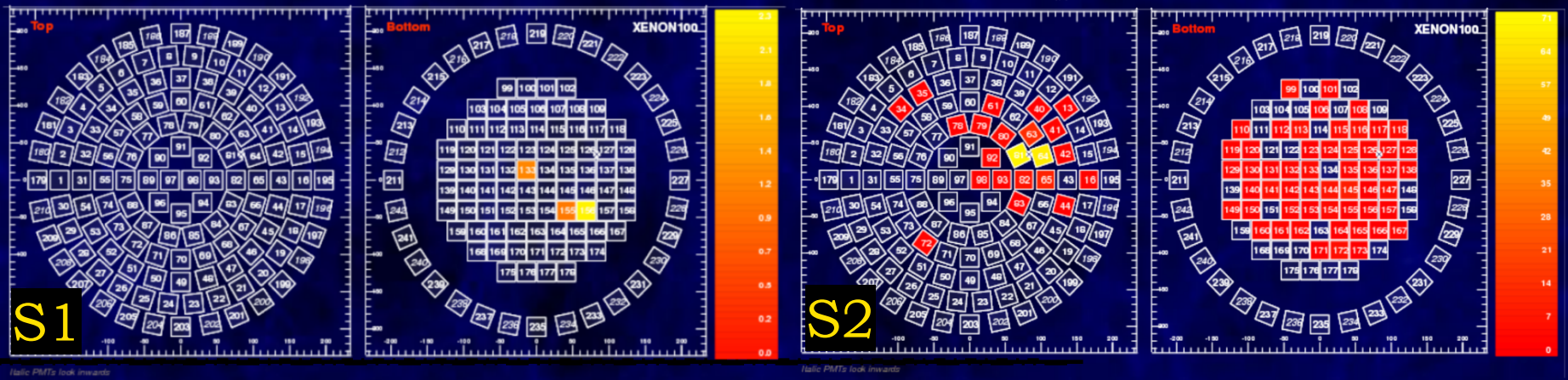
Ample, redundant information even at lowest energies:

- Scintillation S1 size. S1 PMT pattern.
- Ionization S2 size. S2 PMT pattern.
- Single/Multiple Scatter.
- Electronic/Nuclear Recoil.
- Vertex position.
- S2 width.
- Timing.





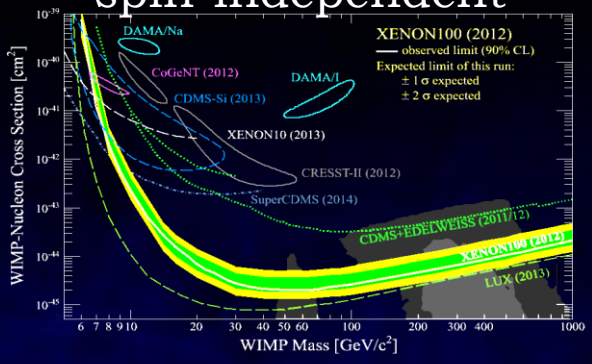




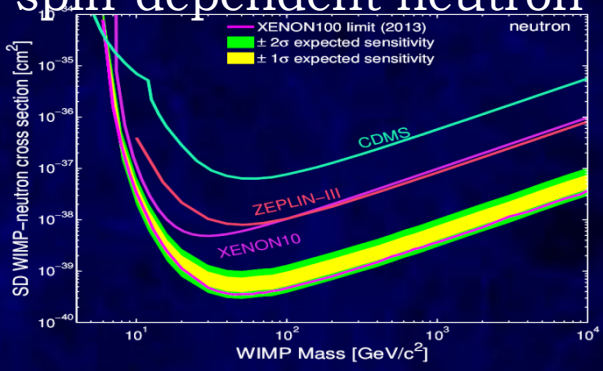
XENON100

- Two-phase liquid xenon
- @ Gran Sasso (Italy)
- 161kg total, ~34kg fiducial
- Lots of limits…

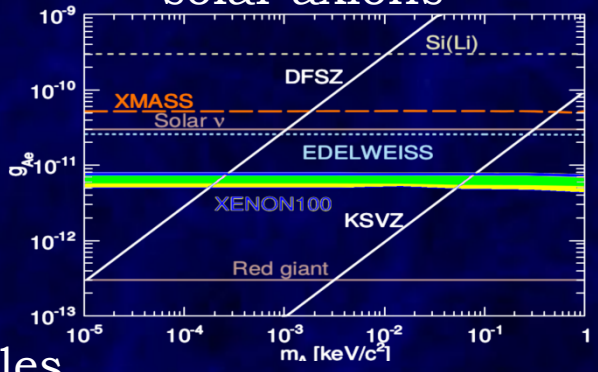
spin-independent



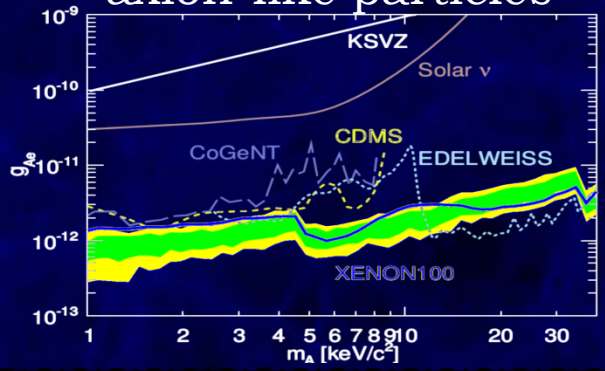
spin-dependent neutron



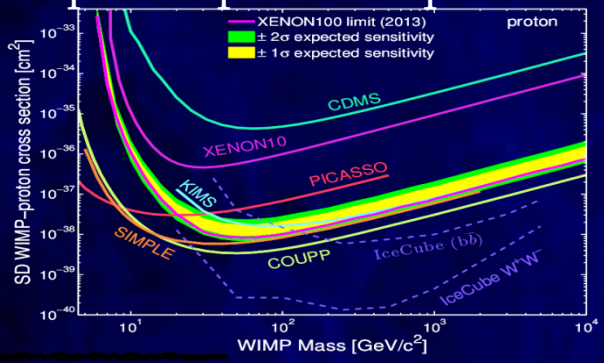
solar axions



axion-like particles

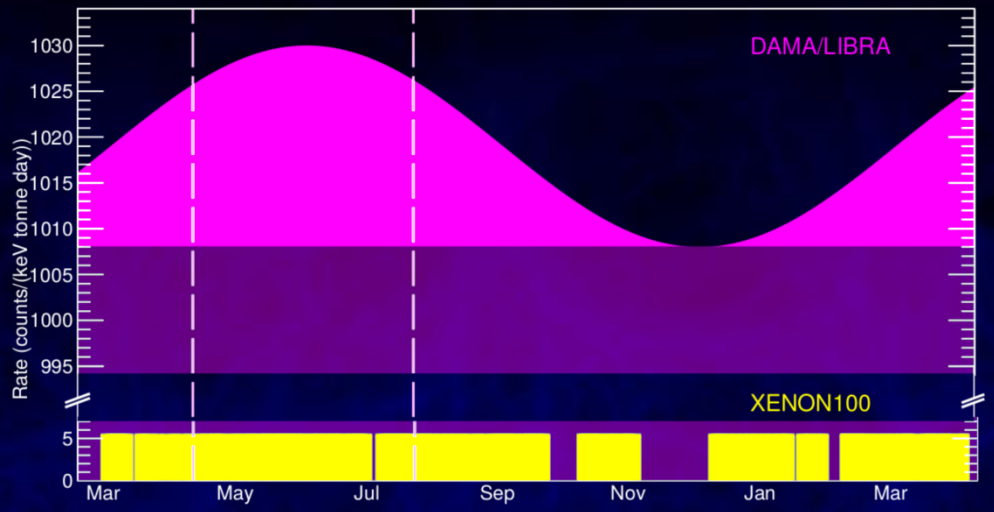


spin-dependent proton

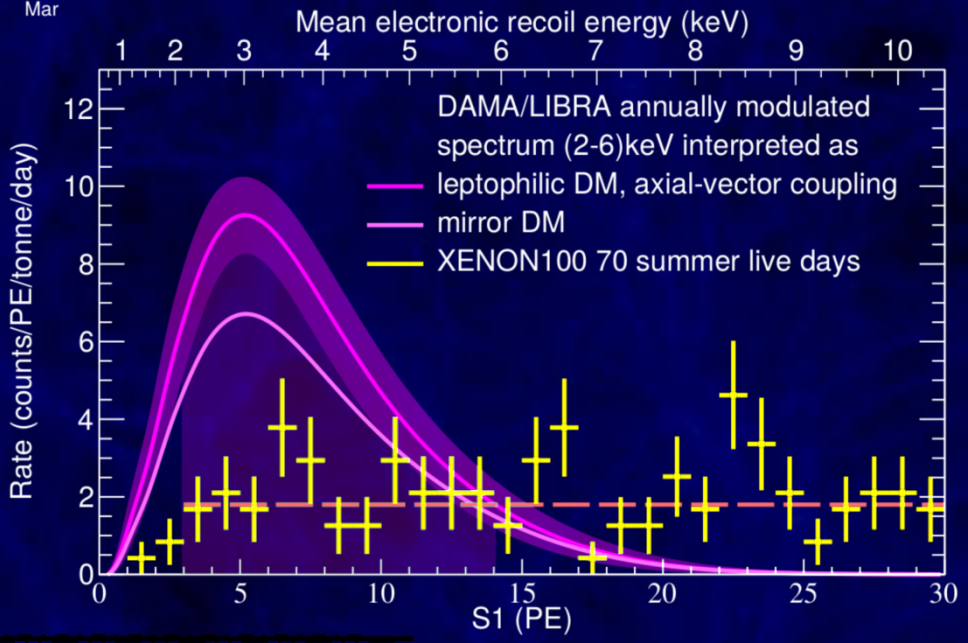


XENON100 1207.5988, 1301.6620, 1404.1455

XENON100 excludes DAMA for good



XENON100 background smaller than DAMA/LIBRA modulation *amplitude*

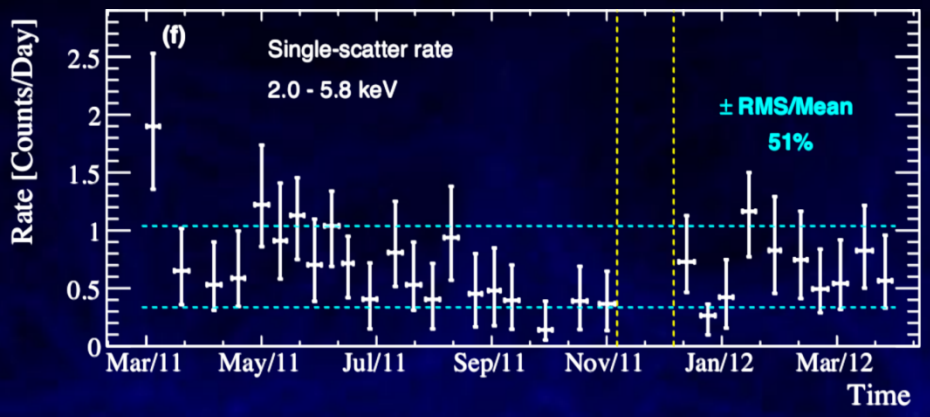


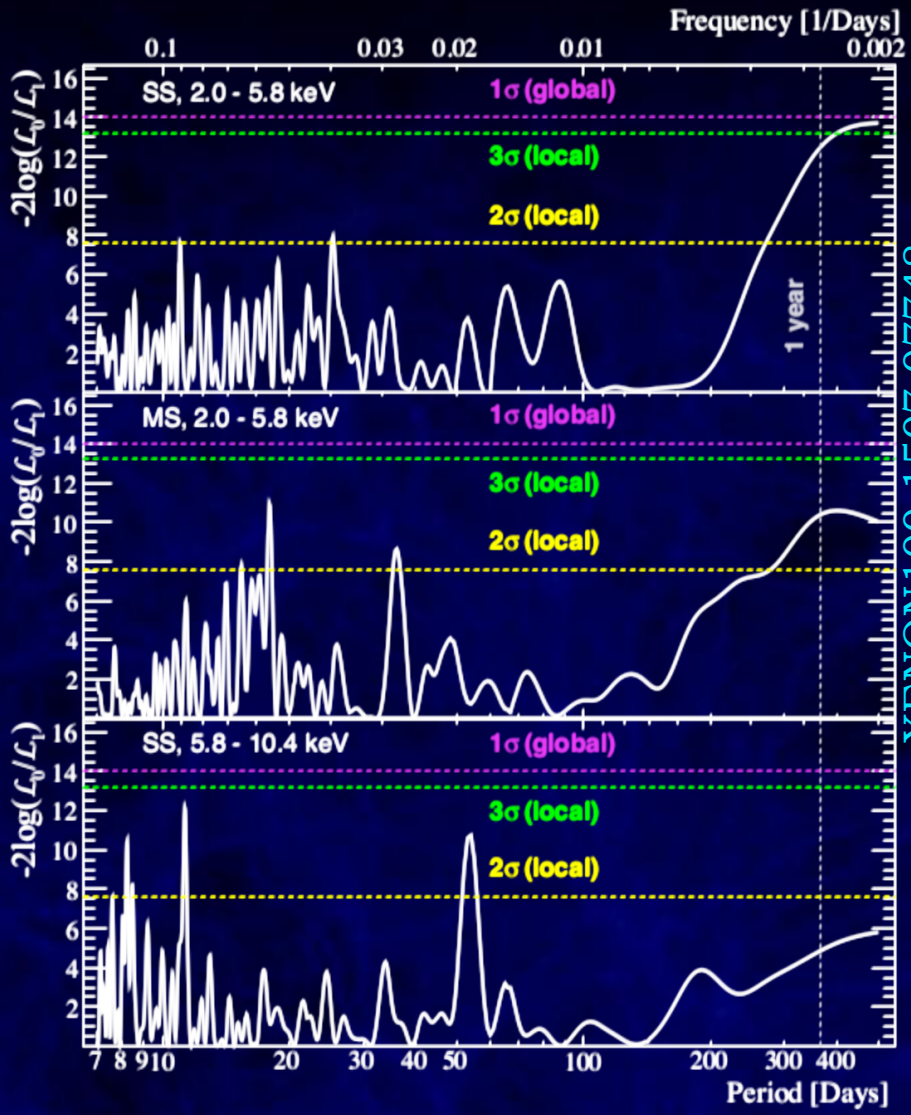
XENON100 1507.07747

Excludes

- axial-vector DM @ 4.4σ
- mirror DM @ 3.6σ
- luminous DM @ 4.6σ

XENON100 Modulation Analysis



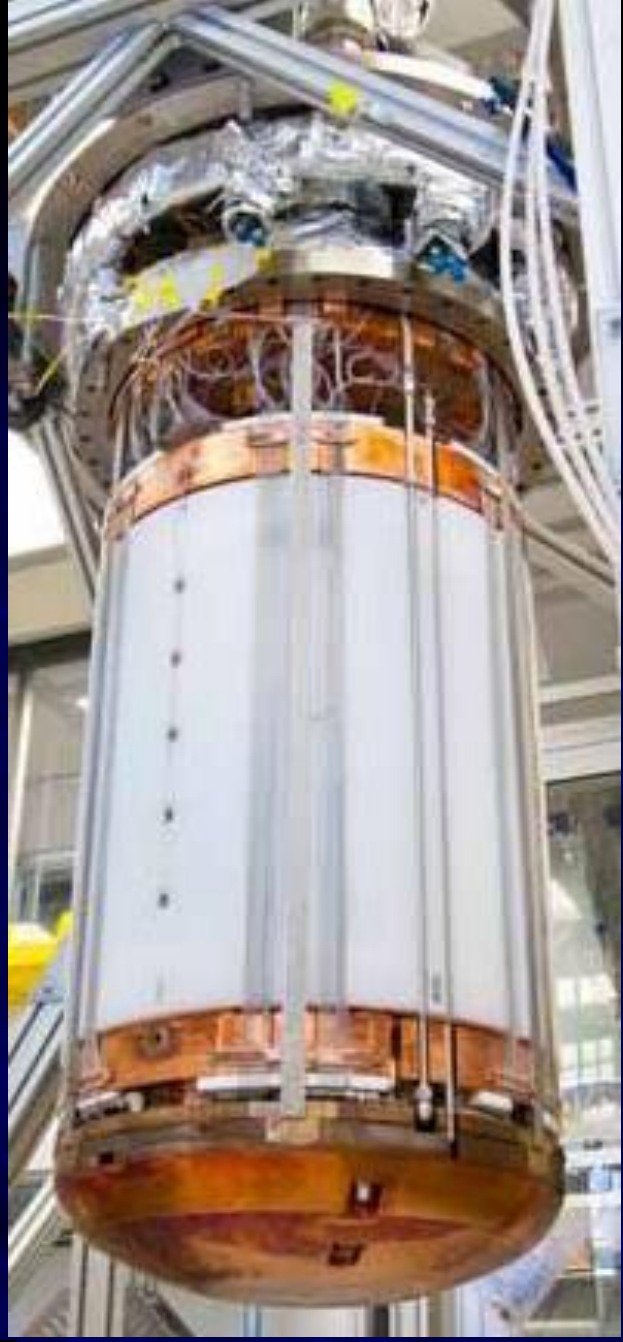


Modulation present at ~3 σ, but also in multiple scatters and at higher energy: Some systematic or statistic

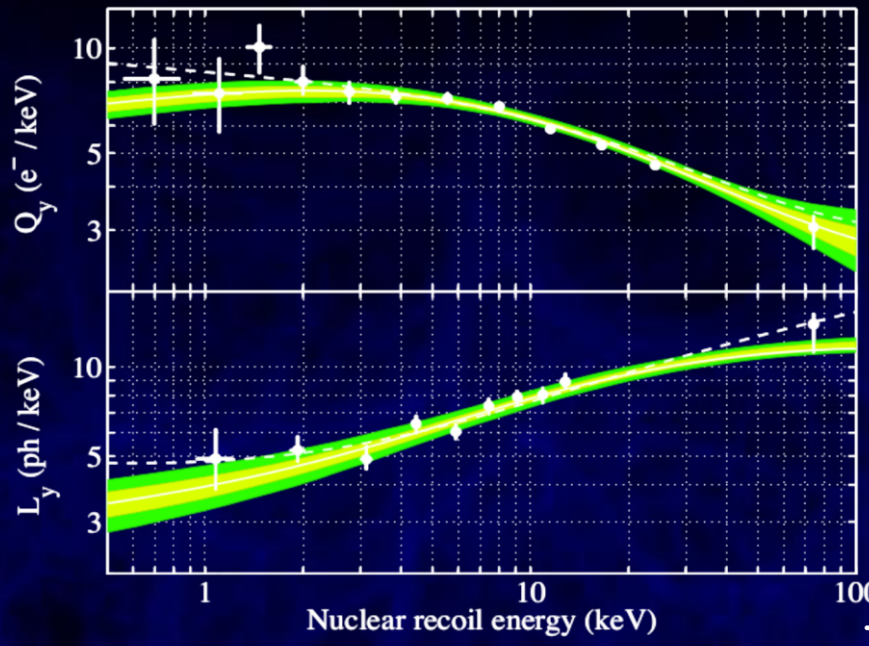
Excludes DAMA at 4.8σ

LUX

- Two-phase liquid xenon
- @ Homestake/Sanford (USA)
- 122 2” PMTs (R8778)
- 350kg total, 118/145kg fiducial

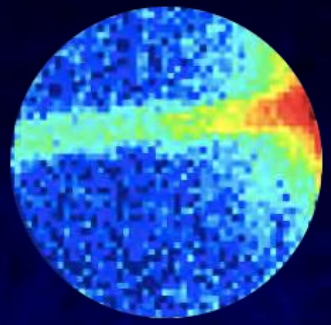


LUX in situ calibrations

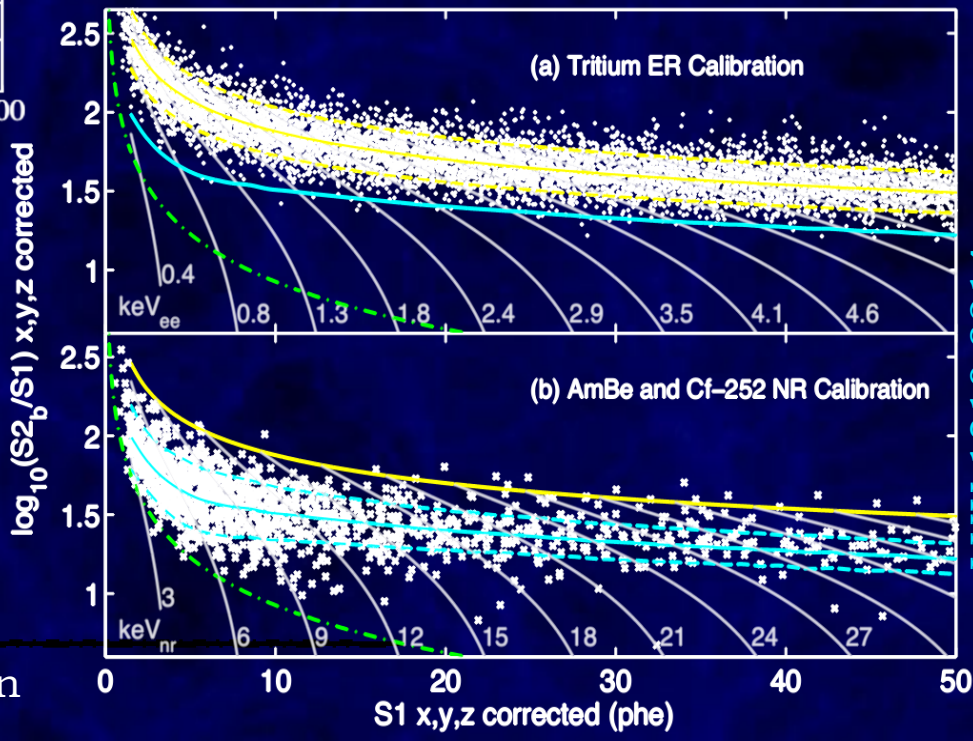


LUX 1512.03506

in situ nuclear recoil energy calibration to 1keV$_{nr}$!



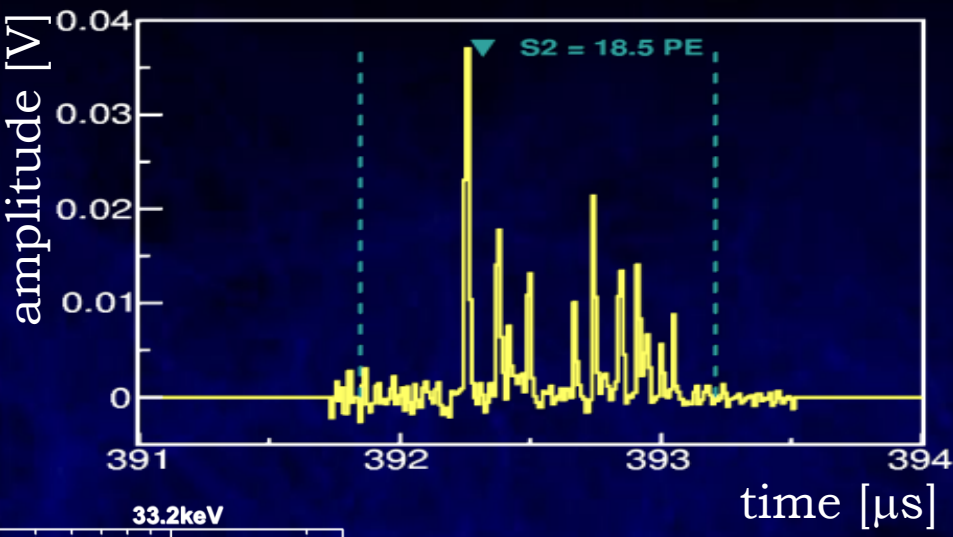
electronic recoil background calibration using tritiated methane



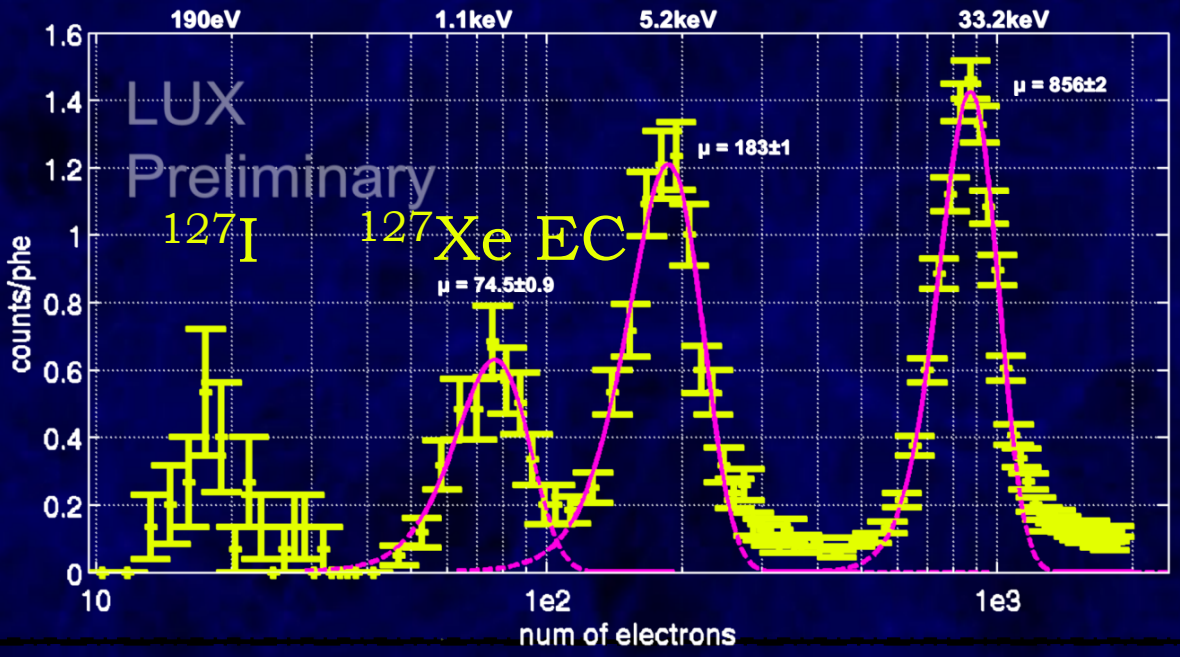
LUX 1310.8214

Extreme Low-Energy Sensitivity

Detect even individual electrons liberated in an interaction:



XENON100 1311.1088

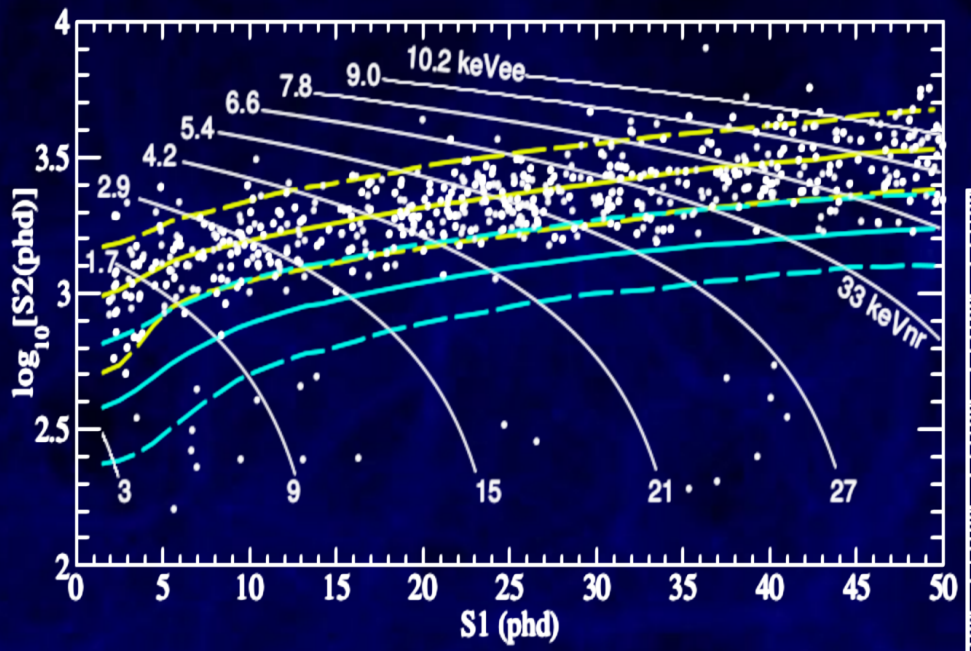


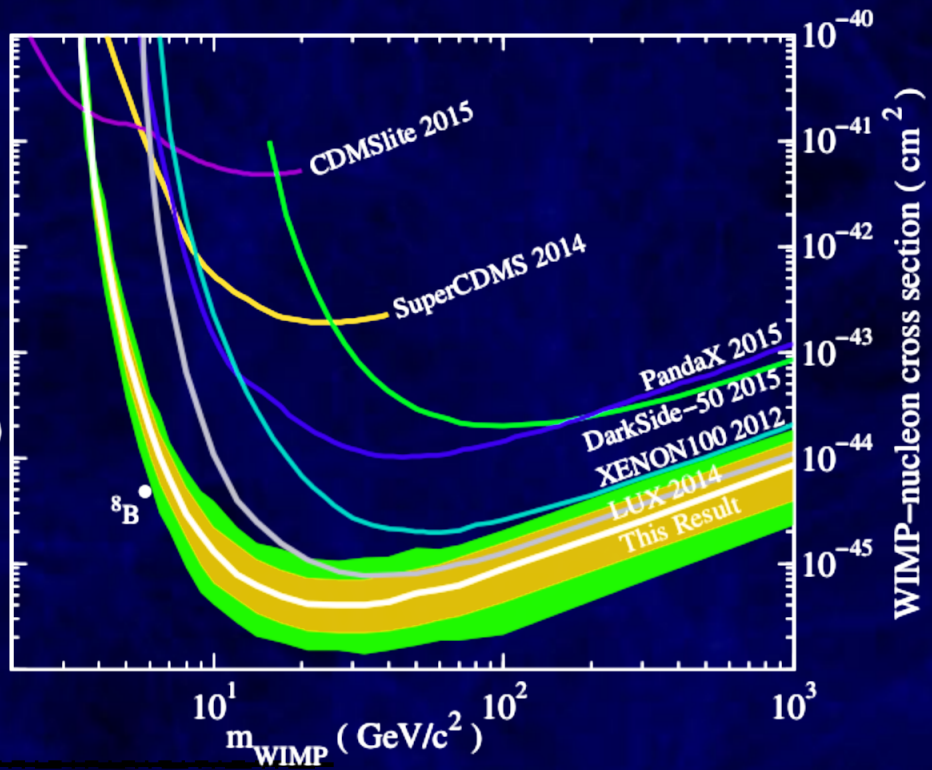
LUX D.Huang APS2015

Activated xenon calibration as low as 190eV !

LUX Status: Re-analysis published

- $3keV_{nr} \rightarrow 1.2keV_{nr}$ energy threshold; better modeling;
- 85 → 95 days; 118 → 145kg fiducial



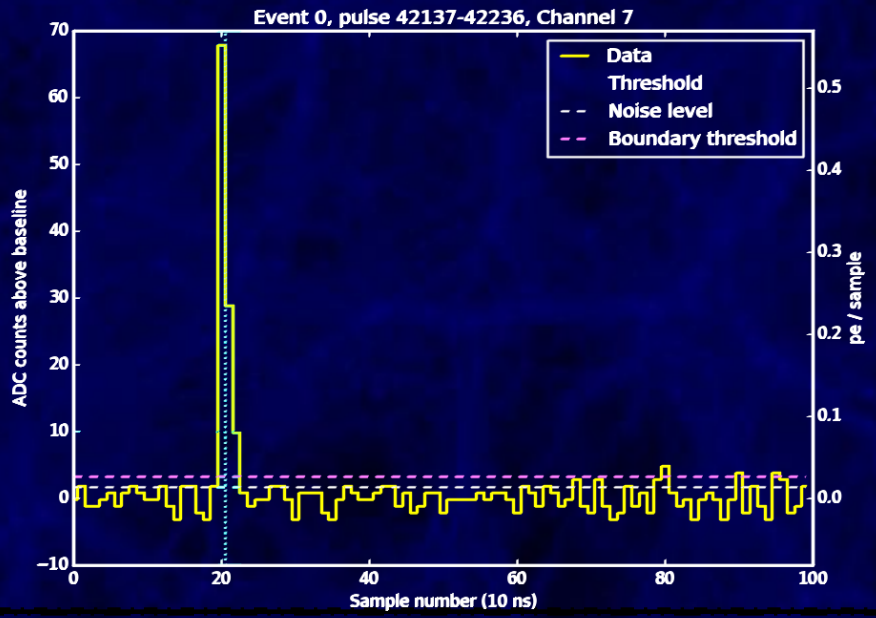


LUX 1512.03506

- 300 days run in progress

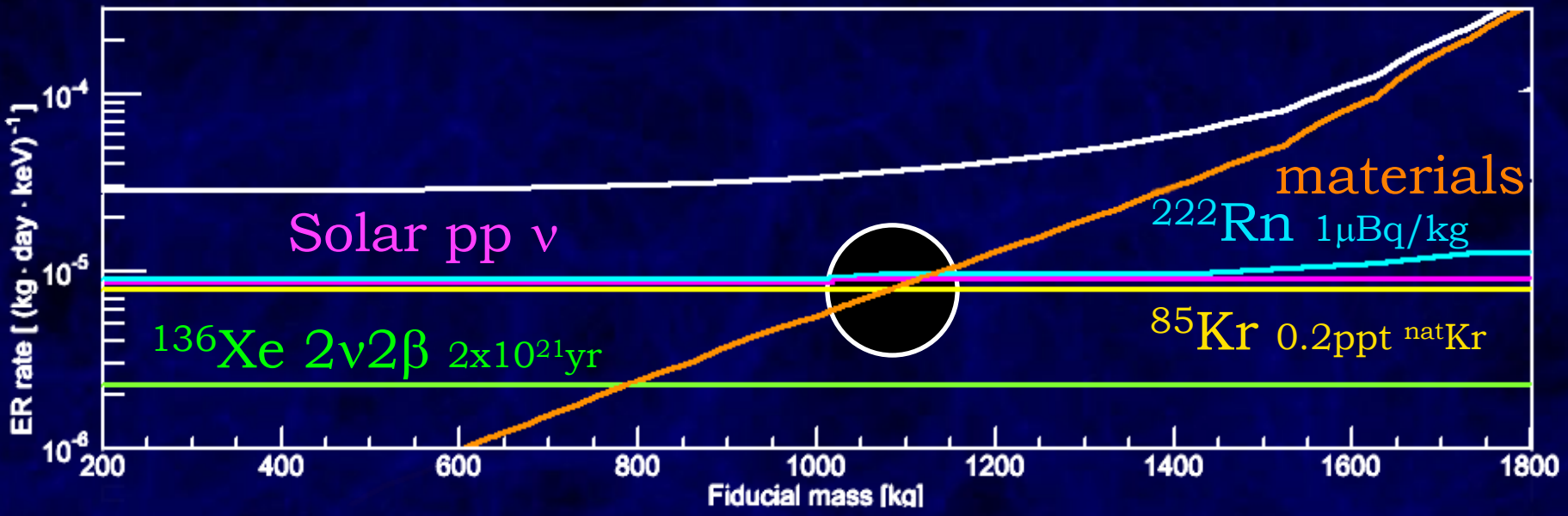
XENON1T

- Two-phase liquid xenon
- @ Gran Sasso (Italy)
- 248 3” PMTs (R11410-21)
- 3300kg total, 2000kg active
- Detector closed

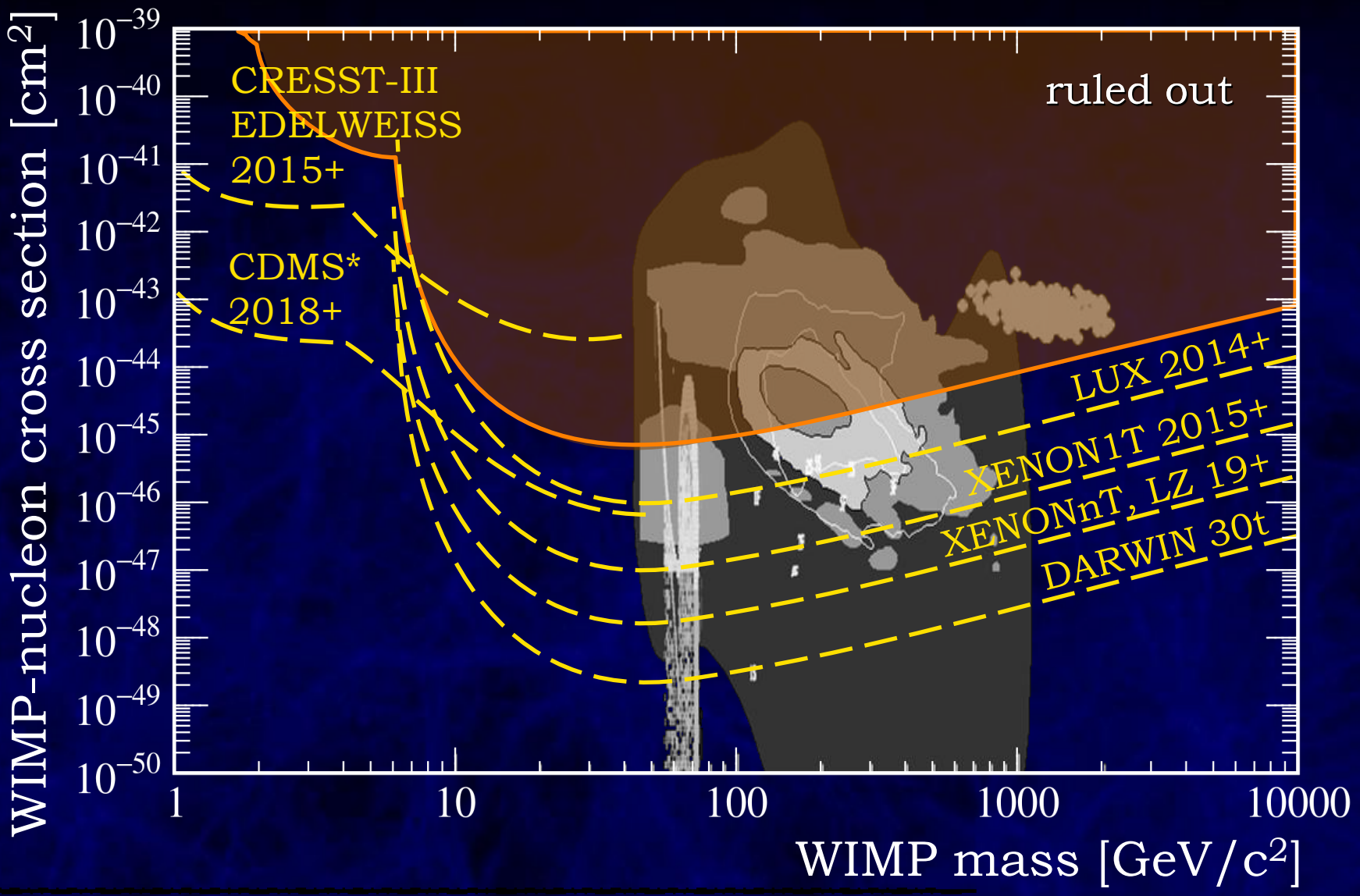


XENON1T Sensitivity

- add two orders of magnitude in cross section
- 2ν2β overall dominating background
- ¼ of ER at low energies is due to pp solar ν!



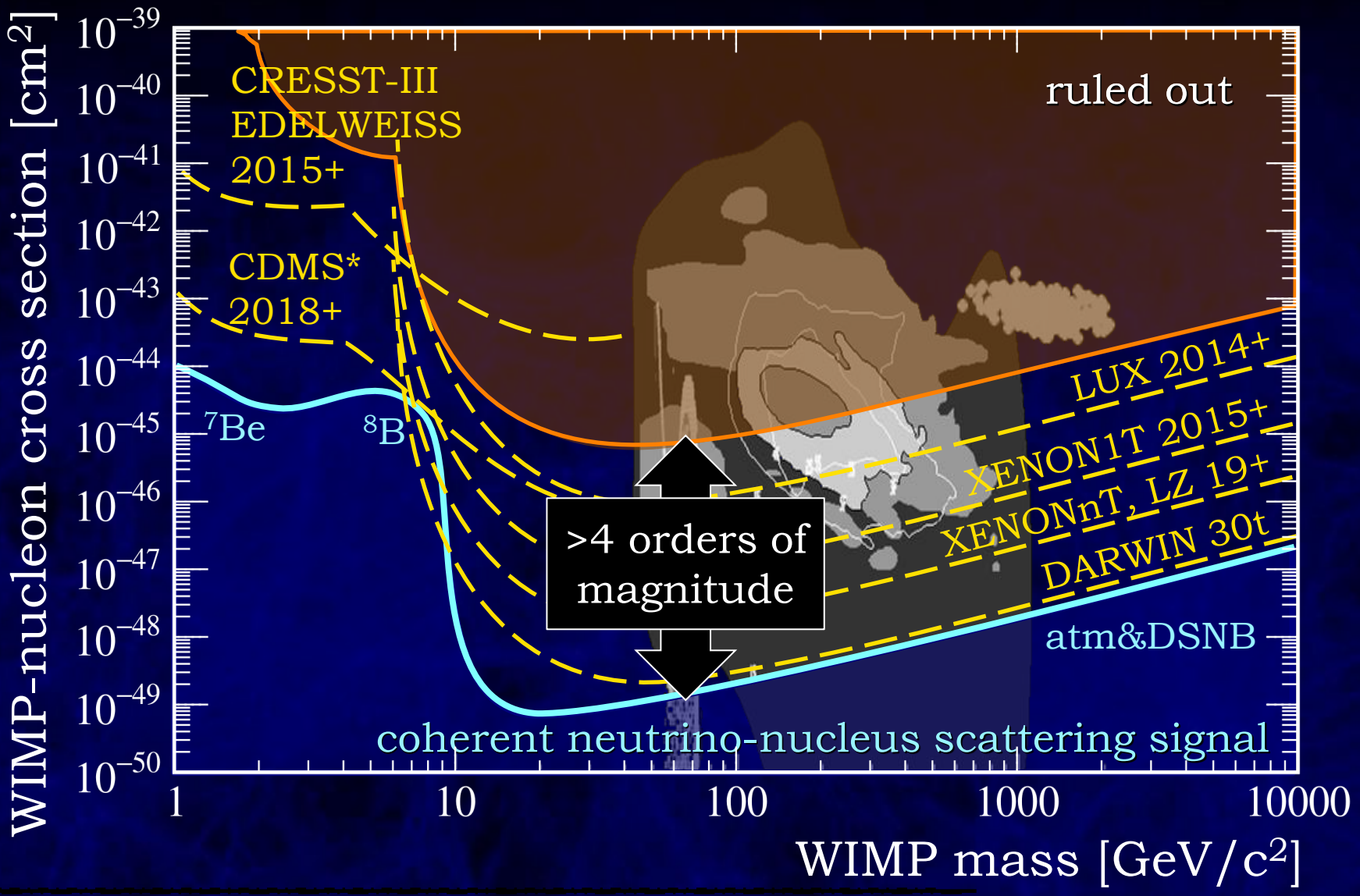
Outlook – Shown are starting dates



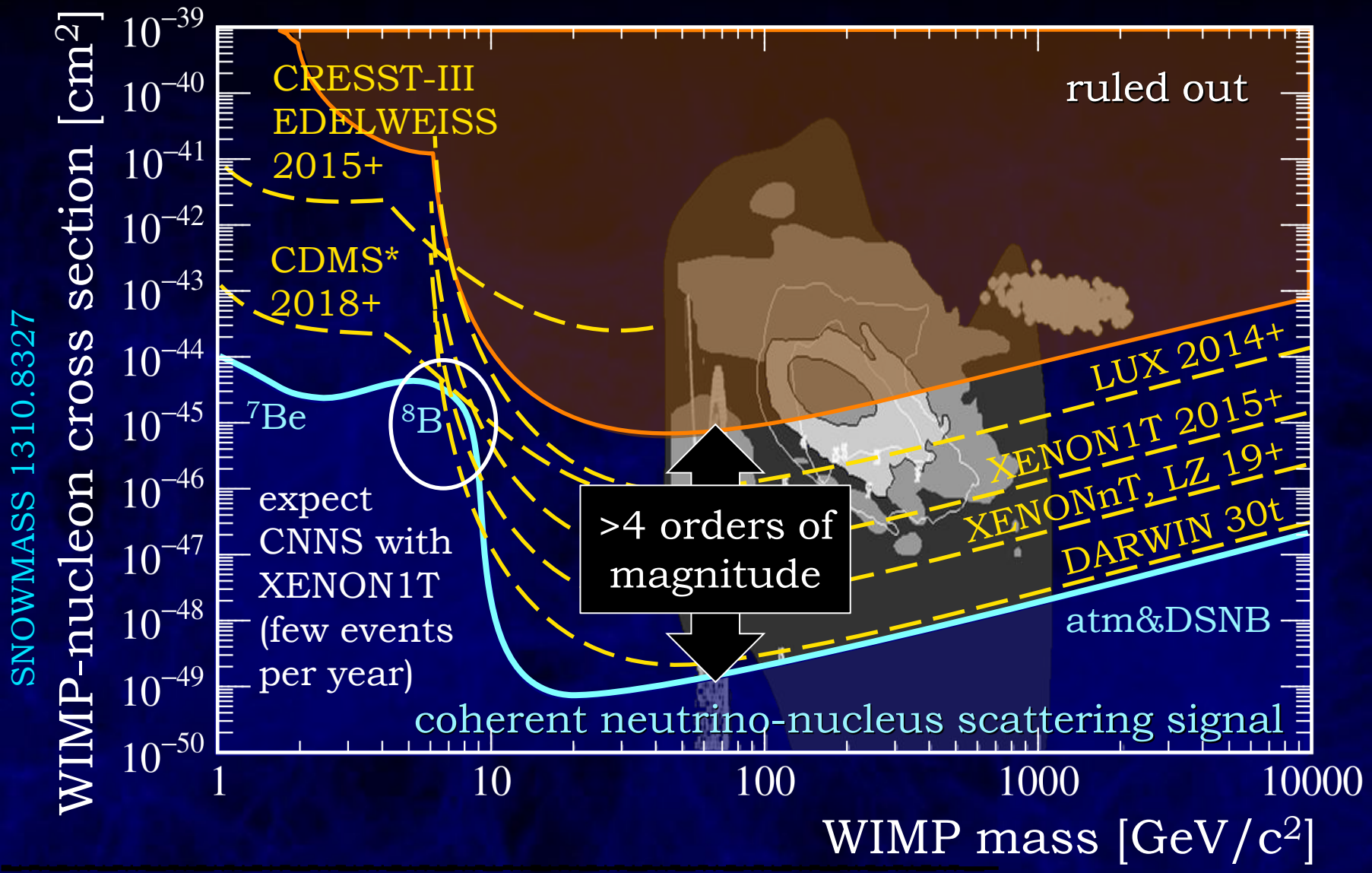
SNOWMASS 1310.8327

Baltz&Gondolo,Roszkowski+,Kadastik+,Buchmueller+,Burgess+

Atmospheric Neutrinos Far Away



8B Neutrino CNNS Within Reach



CRESST-II @Gran Sasso

Scintillating 300g $CaWO_4$ calorimeters

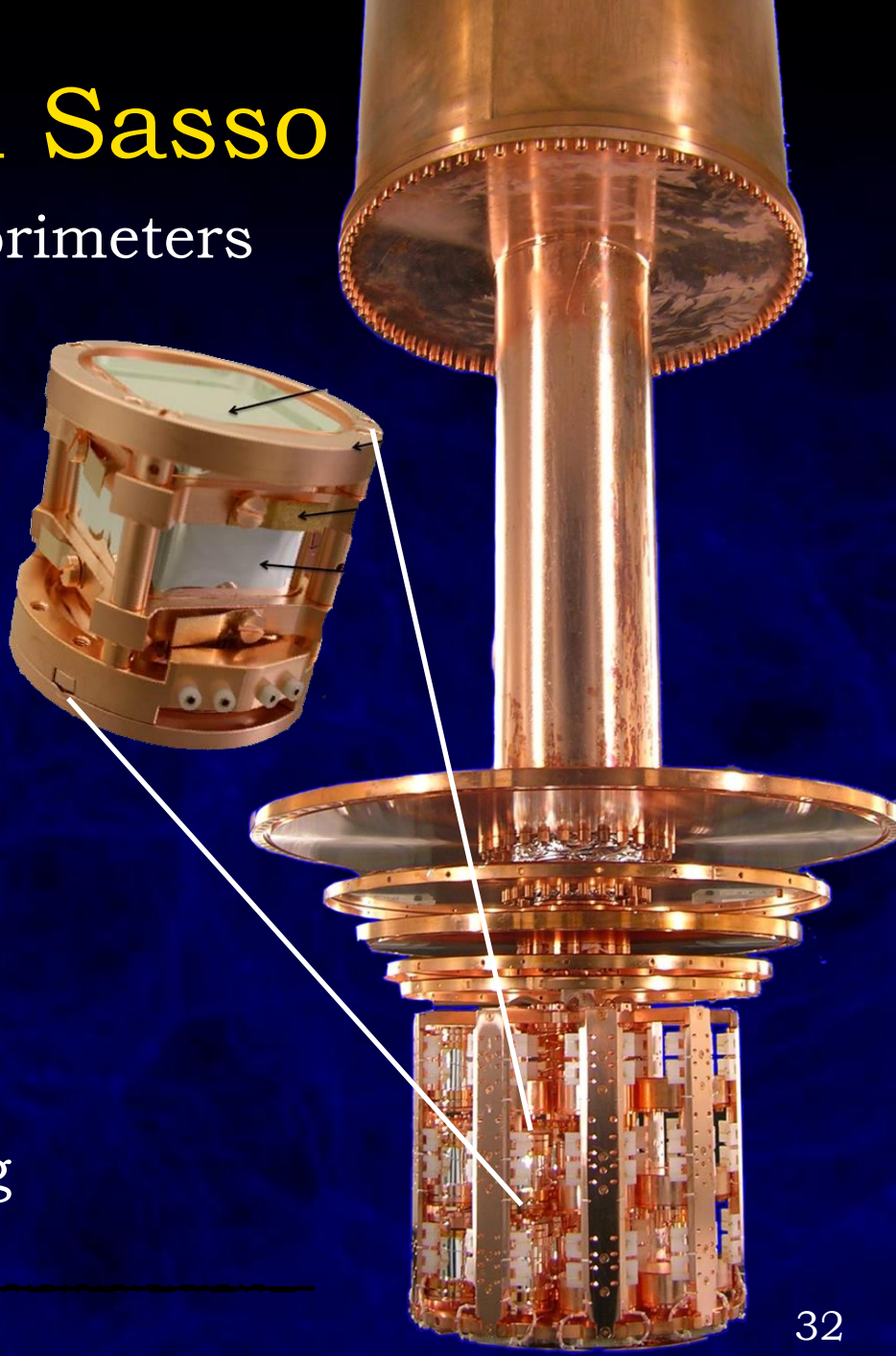
thermometer
threshold <20eV

light
absorber

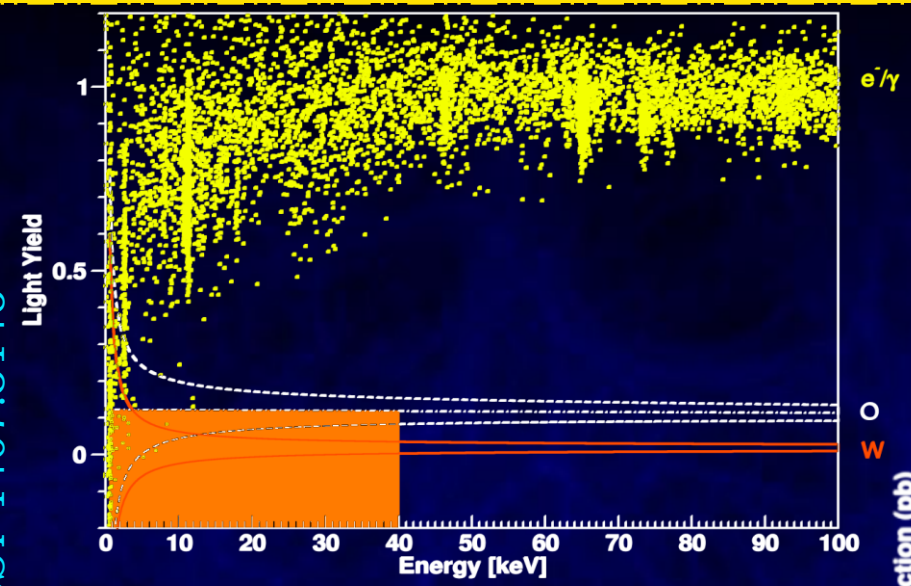
$CaWO_4$
clamps
& target

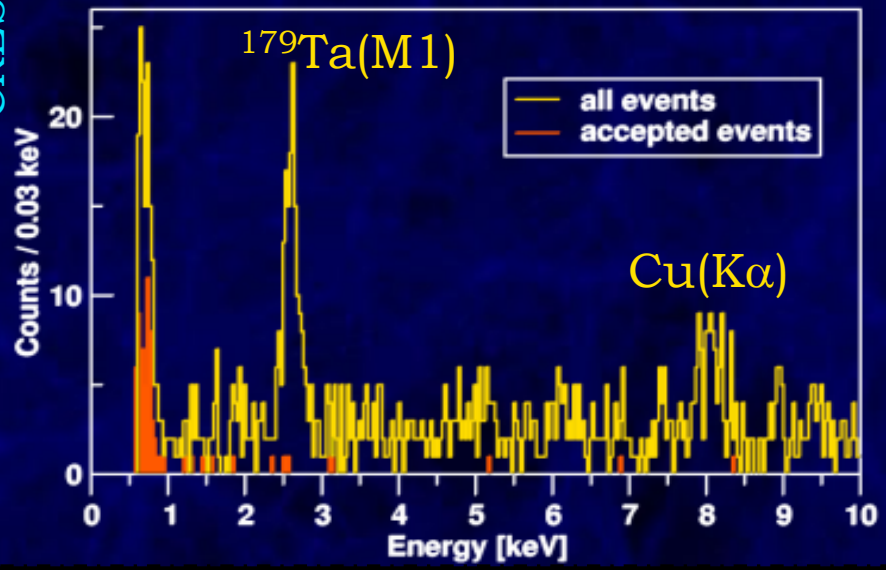
phase
transition
thermometer
~10mK

scintillating
reflector



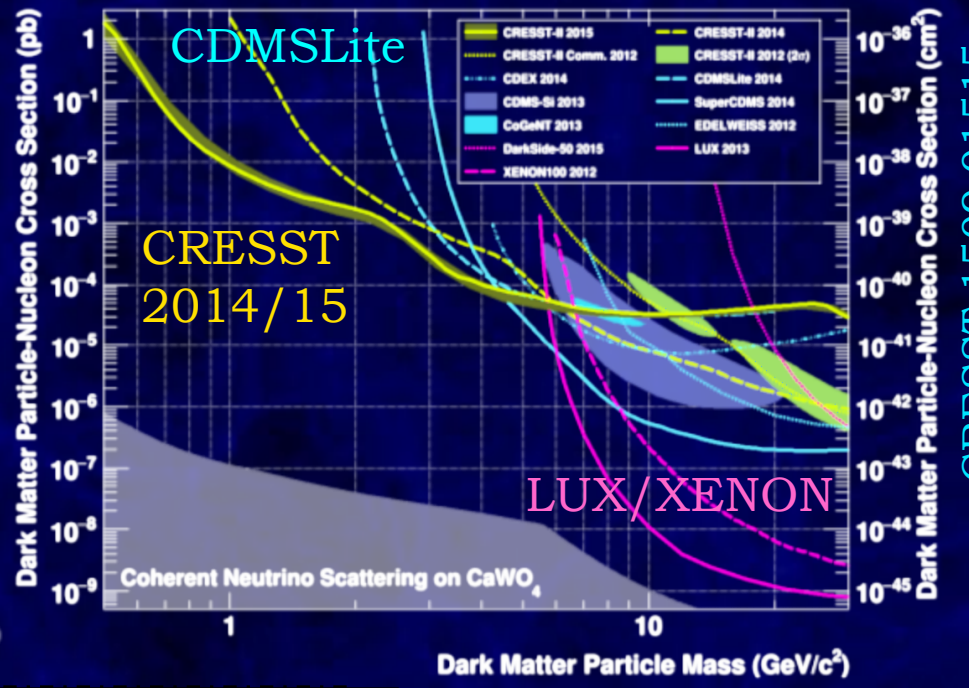
CRESST-II: Multi-Target Built-In





CRESST 1407.3146

- 52 kg days $CaWO_4$
- Ca, O for light WIMPs, W for heavy WIMPs
- Threshold 300eV !



CRESST 1509.01515

PICO @SNOLAB (=COUPP/PICASSO)

- Bubble chambers
- CF_3I or C_3F_8 targets:
  spin-dependent / light WIMPs
- Nucleate if $\int_R \mathrm{d}E/\mathrm{d}x$ sufficient

  detector blind ($<10^{-10}$)
  to electronic recoils
- Only integral energy spectrum;
  measure with different
  thresholds

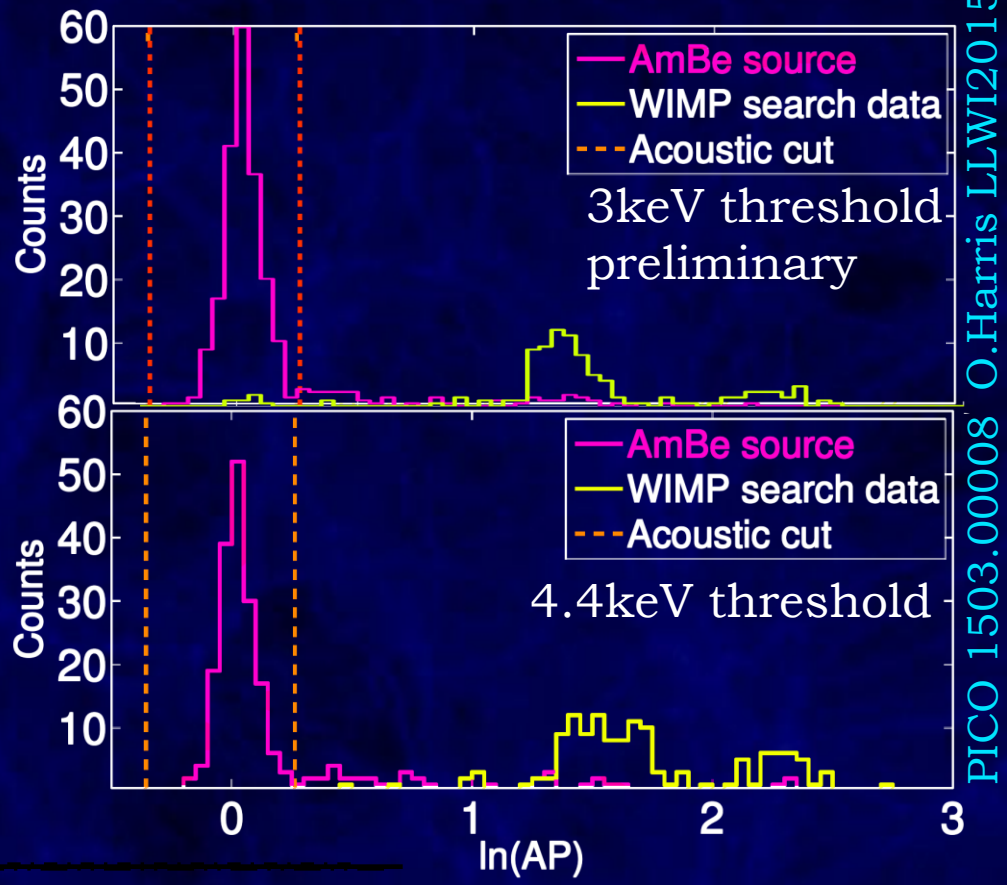
H. Lippincott TAUP2013

PICO Results 2015

Photograph:

O. Harris LLWI2015

Acoustic signal: Alphas pop louder than nuclear recoils, discriminate >98%

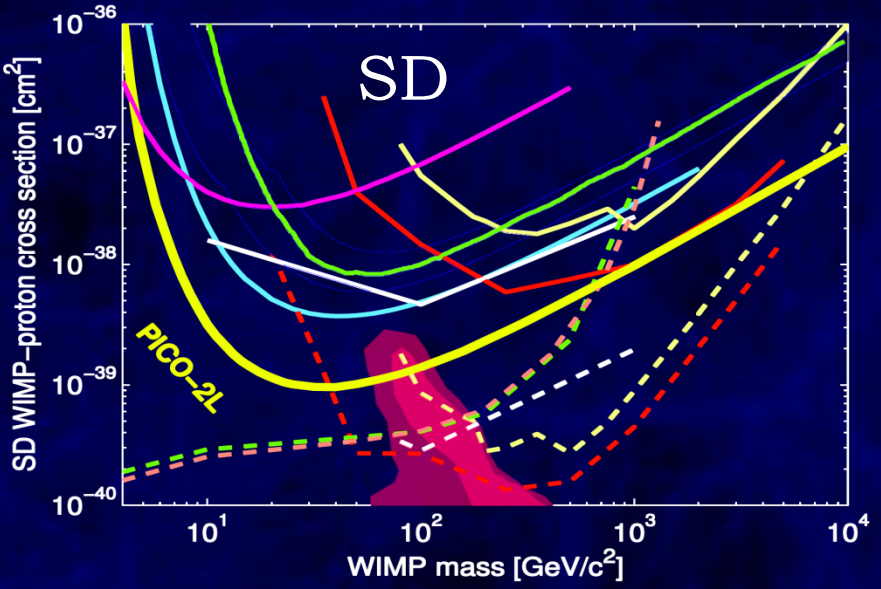


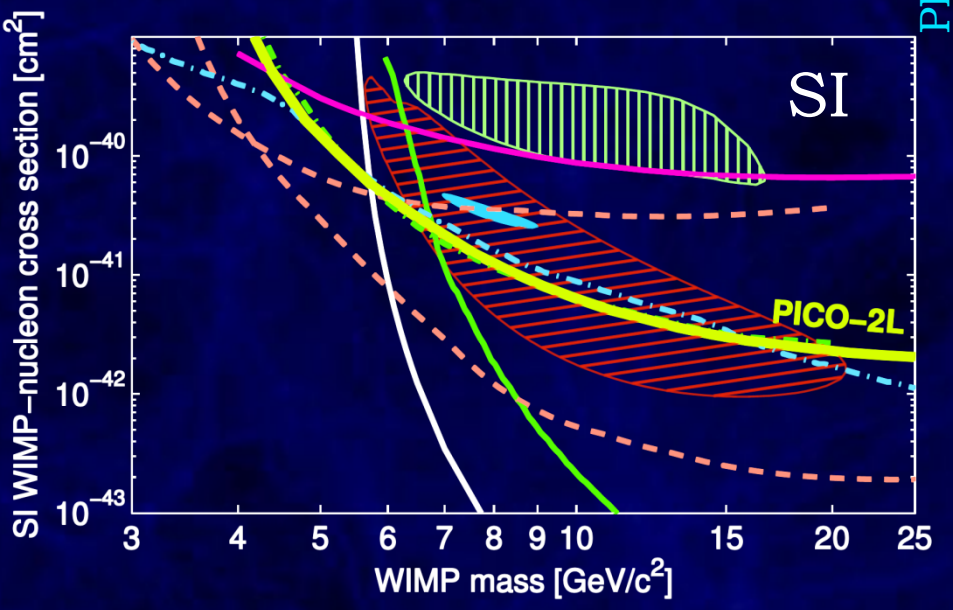
O.Harris LLWI2015 PICO 1503.00008

PICO recent limit and outlook

- Limits from 2.9kg C_3F_8 chamber
- 211 kg days total at 4 thresholds (3-8keV)
- 12 events observed (1 expected),
  correlated with expansion cycles (corrosion particles?)
- Leading spin-dependent (proton only) limits

PICO 1503.00008





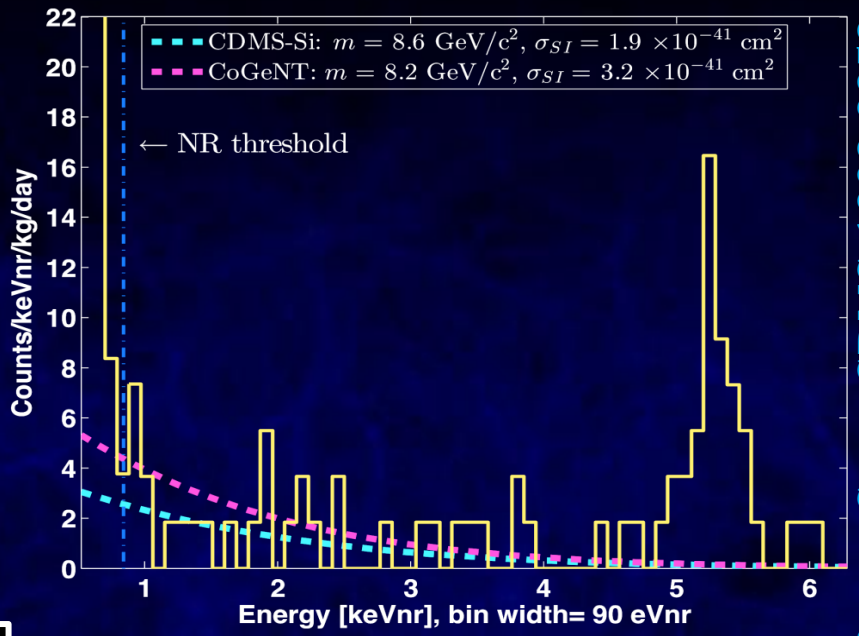
Soon: >3000 kg days from 25kg CF_3I chamber (PICO 60)

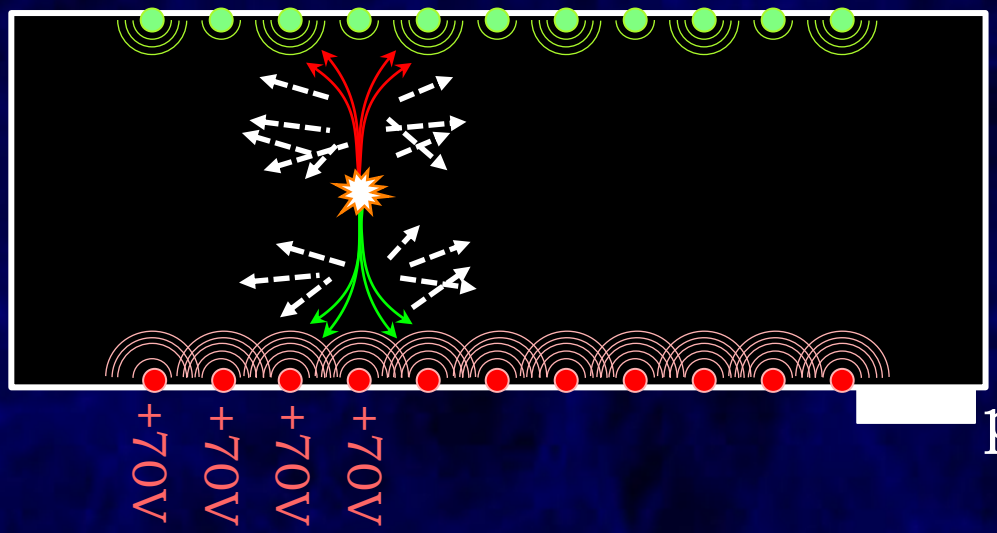
CDMSLite: Charge Amplification

Neganov-Luke amplification gives extra phonons

reduce energy threshold to <800eV$_{nr}$

Expect more data this year





phonon sensor