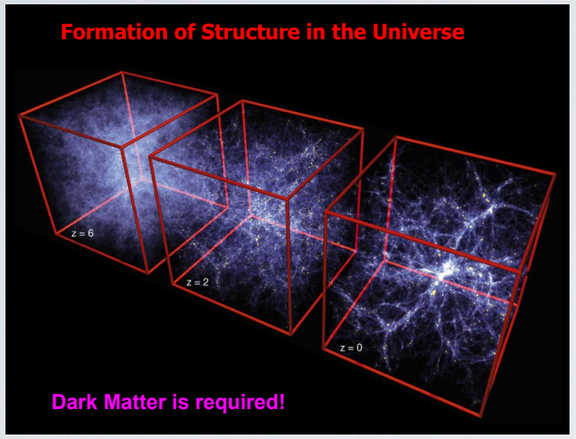
THE STATUS OF DIRECT DARK MATTER SEARCHES

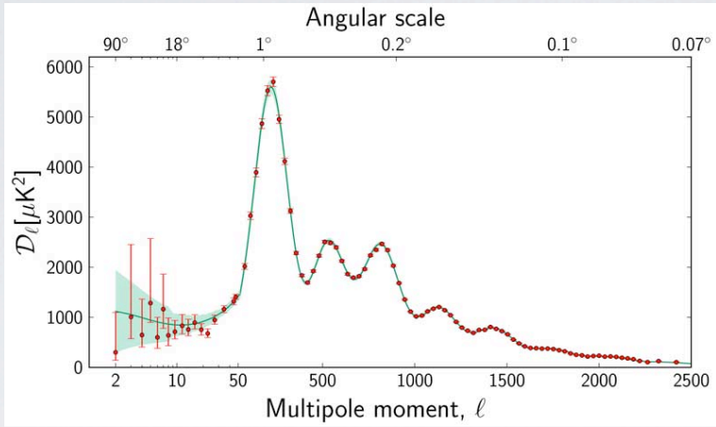
Chamkaur Ghag
University College London

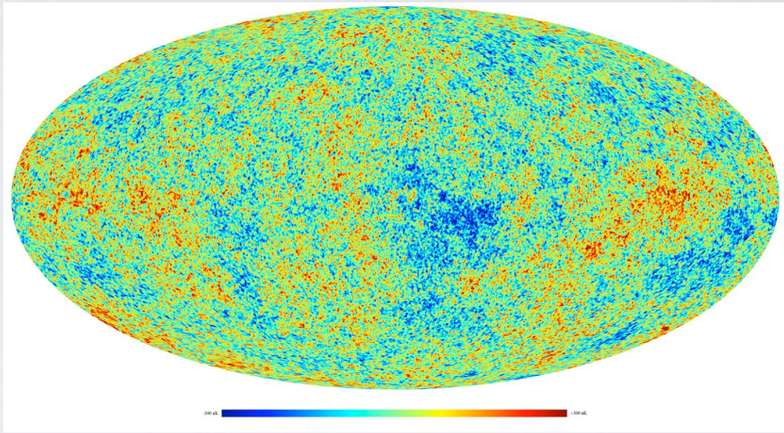
Outline

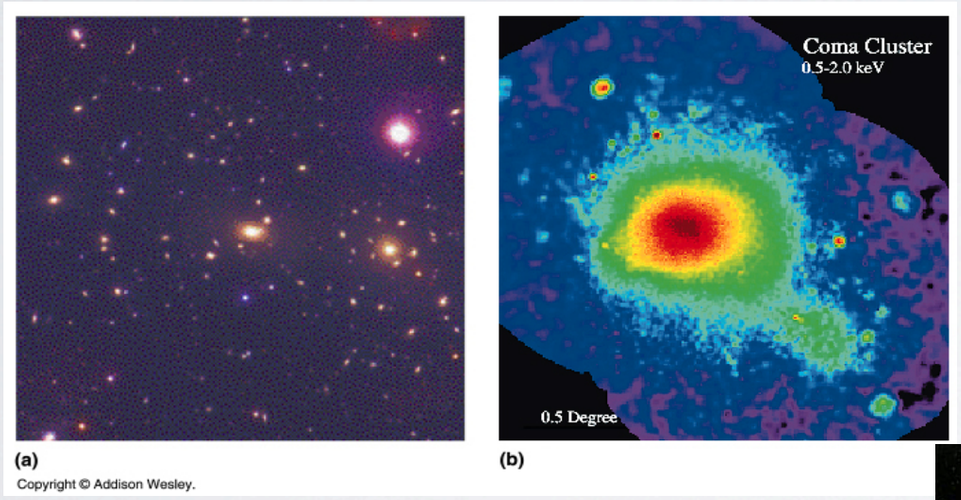
- Evidence and direct detection
- Current state of play
- The next crop
- Tonne scale experiments

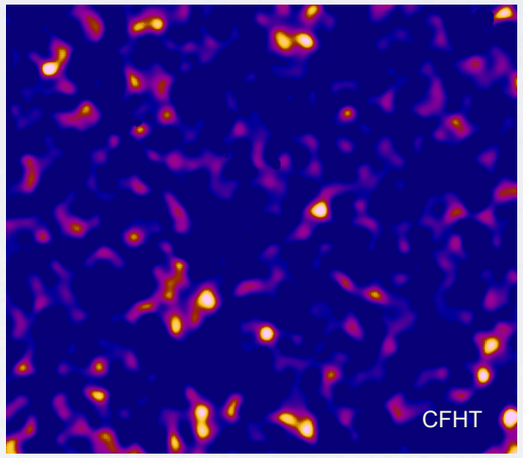
Evidence for Dark Matter

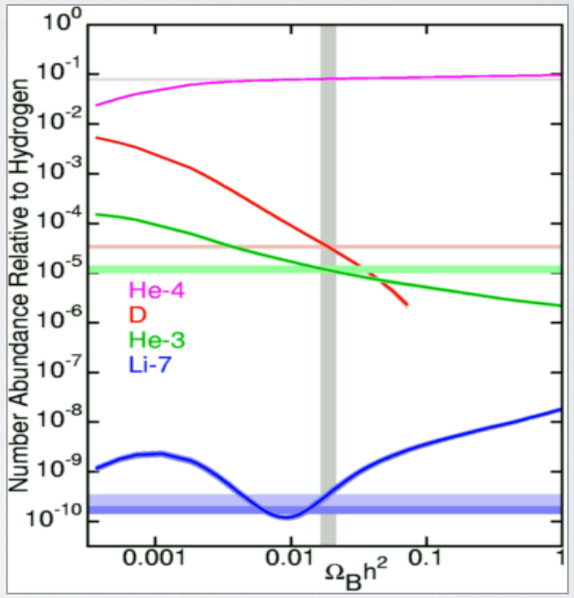


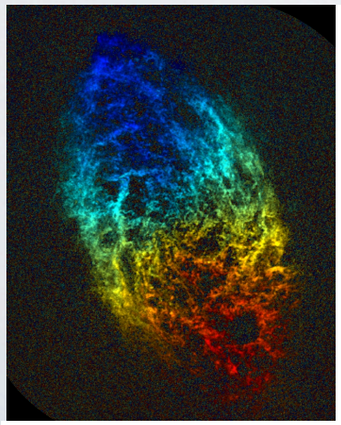


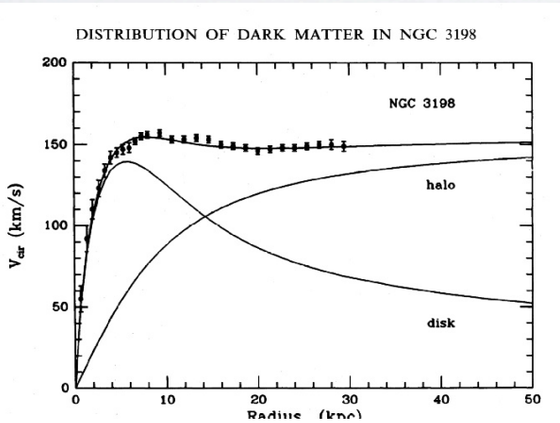


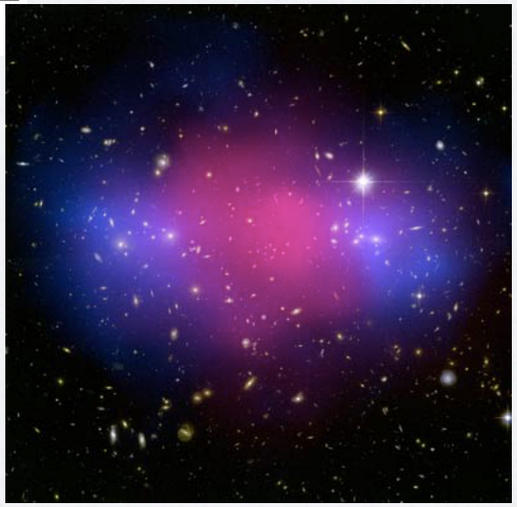


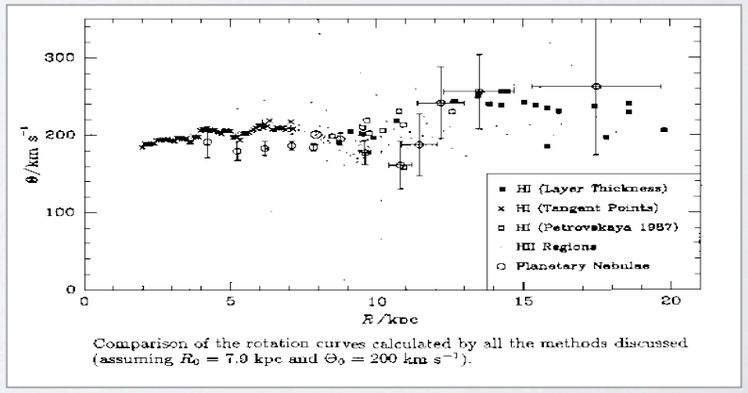




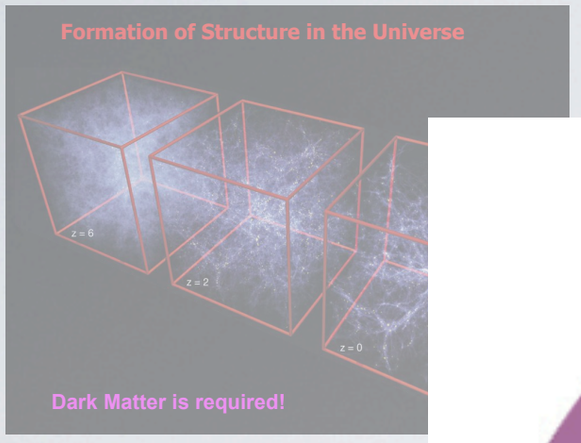


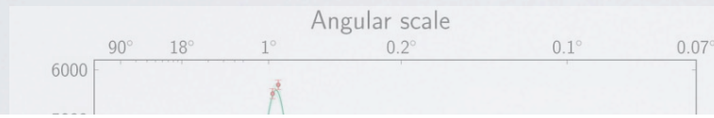


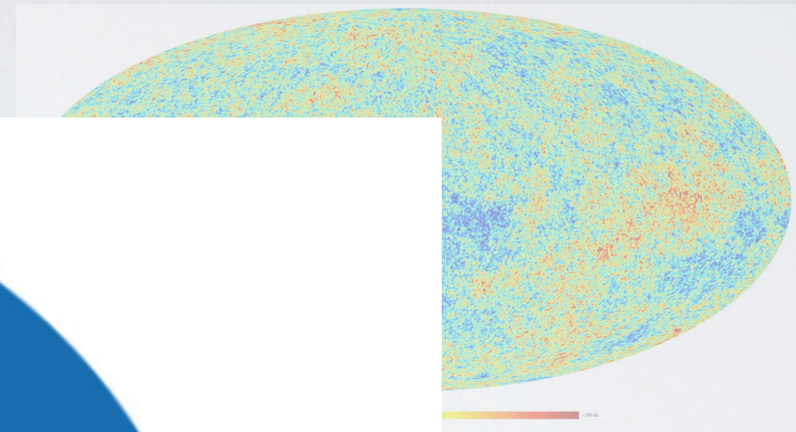


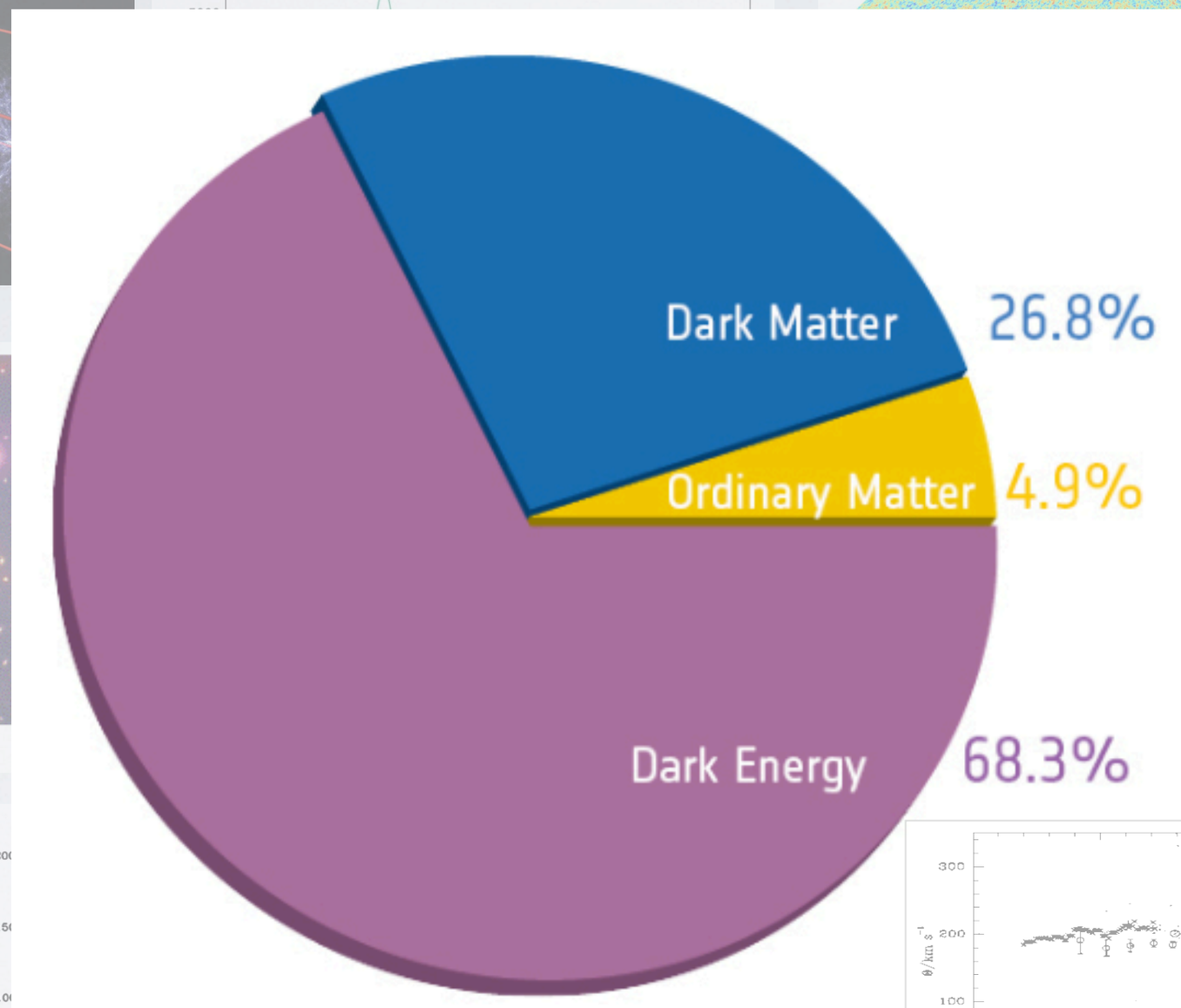


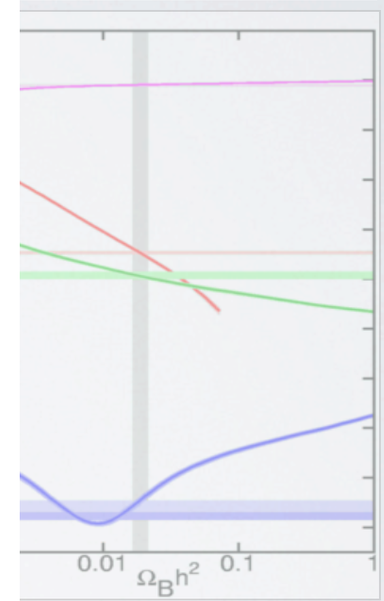
Evidence for Dark Matter











(a)
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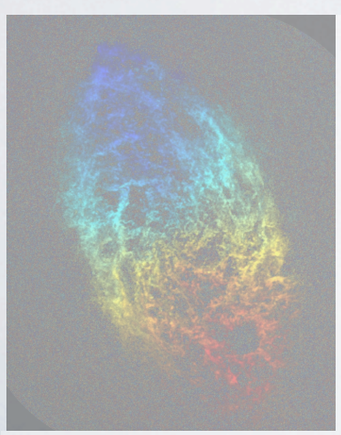

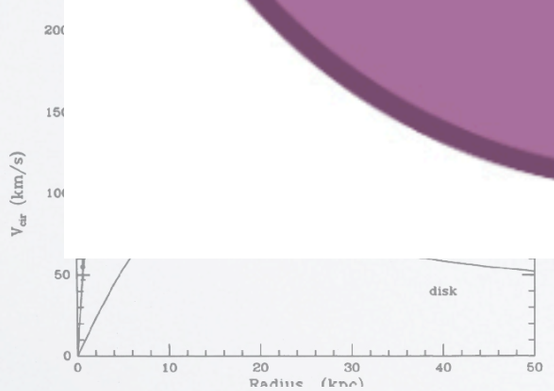

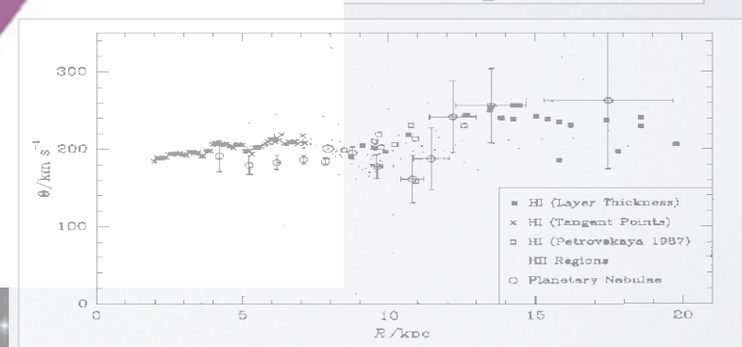

Comparison of the rotation curves calculated by all the methods discussed (assuming $R_0 = 7.9$ kpc and $\Theta_0 = 200$ km s^{-1}).

Dark Matter Properties

- No electromagnetic interaction
- No strong interaction
- Stable
- Neutrinos are too hot
- Likely weak interaction (WIMPs)
- One possibility is LSP of SUSY

$$\chi = \alpha\tilde{B} + \beta\tilde{W} + \gamma\tilde{H}_1 + \delta\tilde{H}_2$$

- If SUSY is wrong that won't stop galaxies rotating too fast!
- Zoo of WIMP candidates - direct searches must be broadband

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The existence of Dark Matter points to BSM physics

Dark Matter Searches

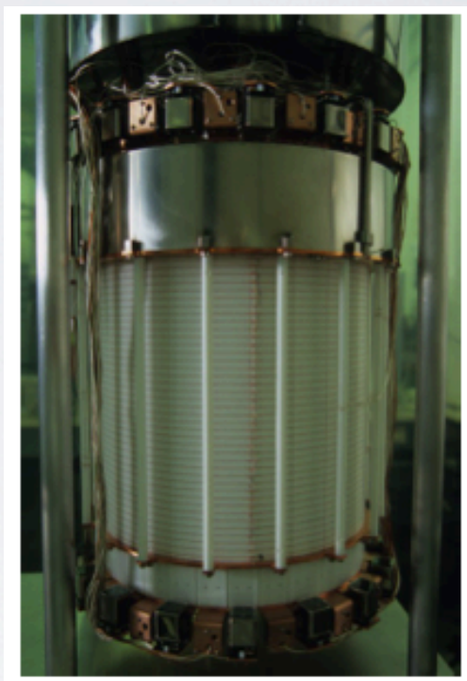
Collider

Production

Indirectly

Annihilation

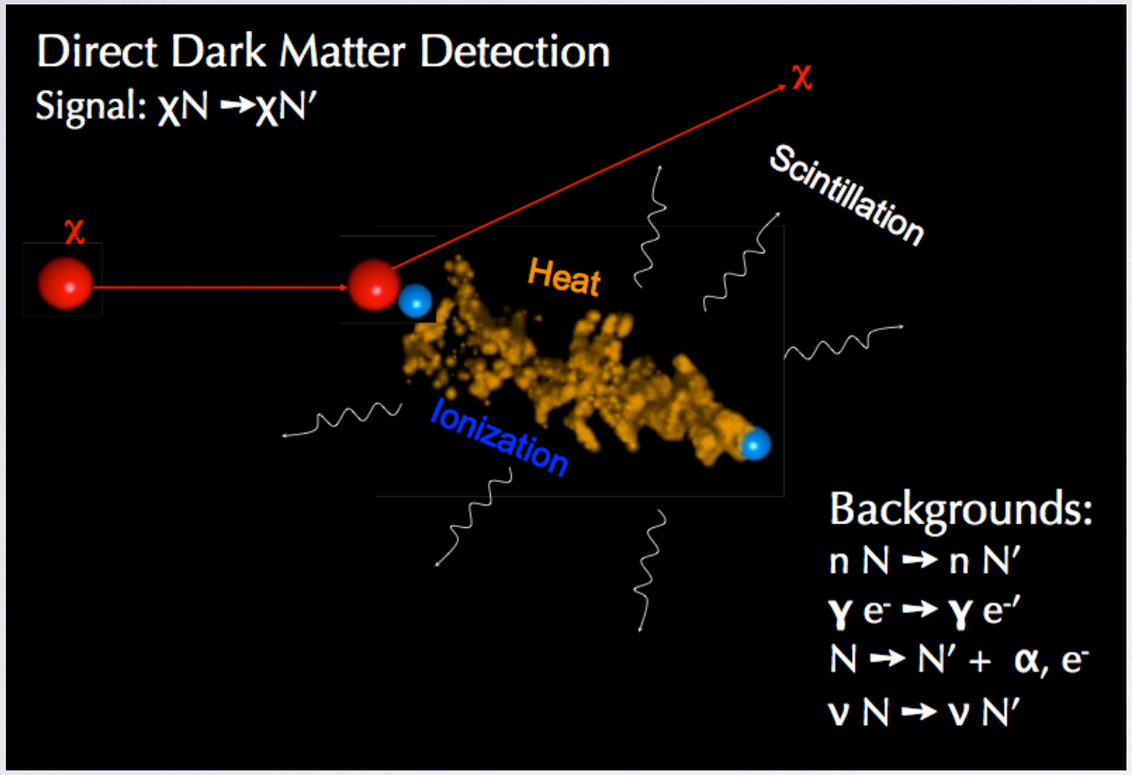
Directly

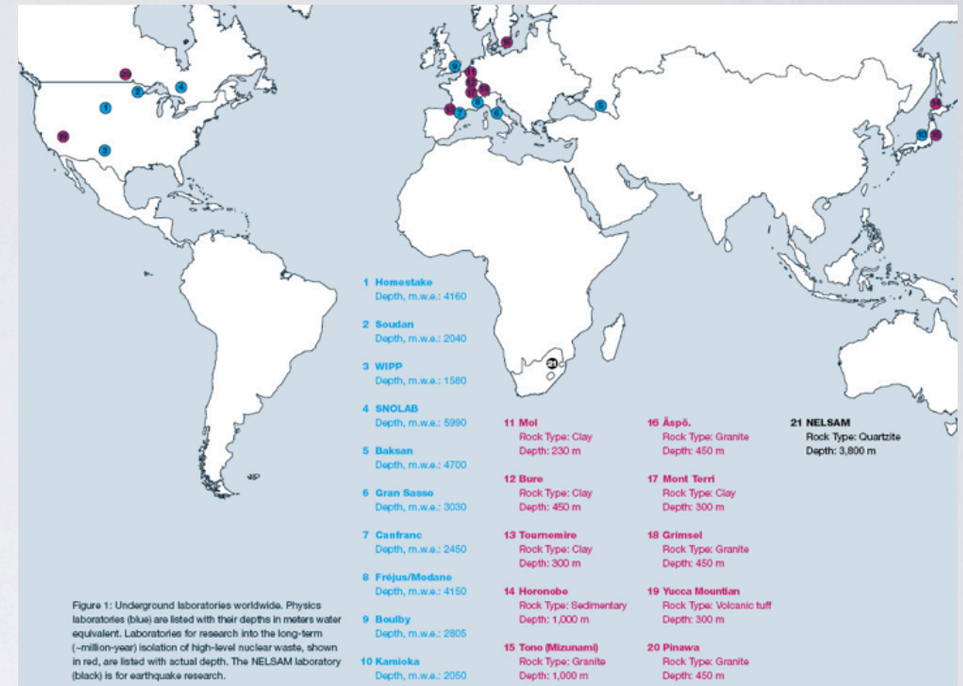


Scattering

see M. Gustaffson's talk on indirect detection with Fermi - 5:30pm tomorrow

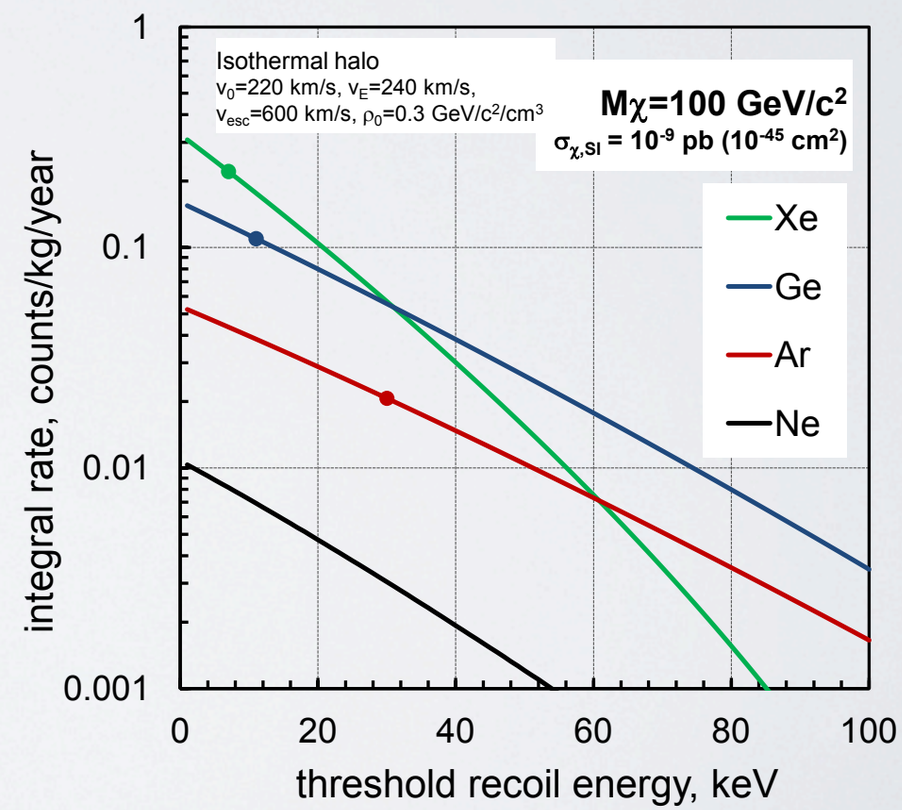
Direct Detection





http://www.deepscience.org/contents/facilities_popup01.shtml

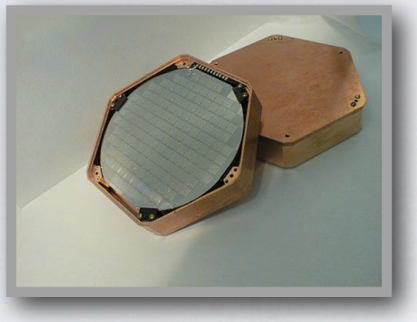
- Weak elastic scatters
- ~tens of keV nuclear recoils
- Underground operation
- Background rejection

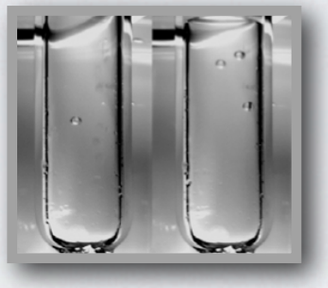


V. Chepel & H. Araujo 'Liquid noble gas detectors for low energy particle physics' arXiv:1207.2292

Detector Technologies

CDMS
EDELWEISS





CUOPP
PICASSO
SIMPLE

Phonons

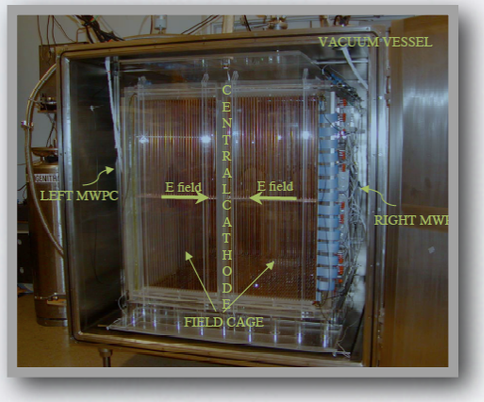
CRESST
ROSEBUD

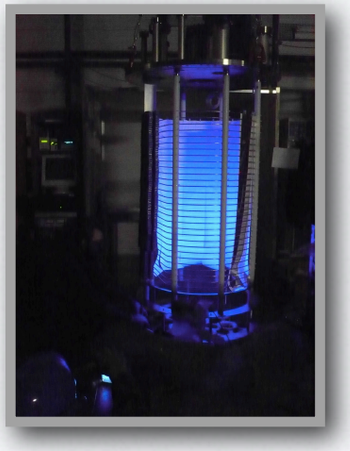
dE/dx

Charge

Light

DRIFT
DMTPC
GENIUS
NEWAGE

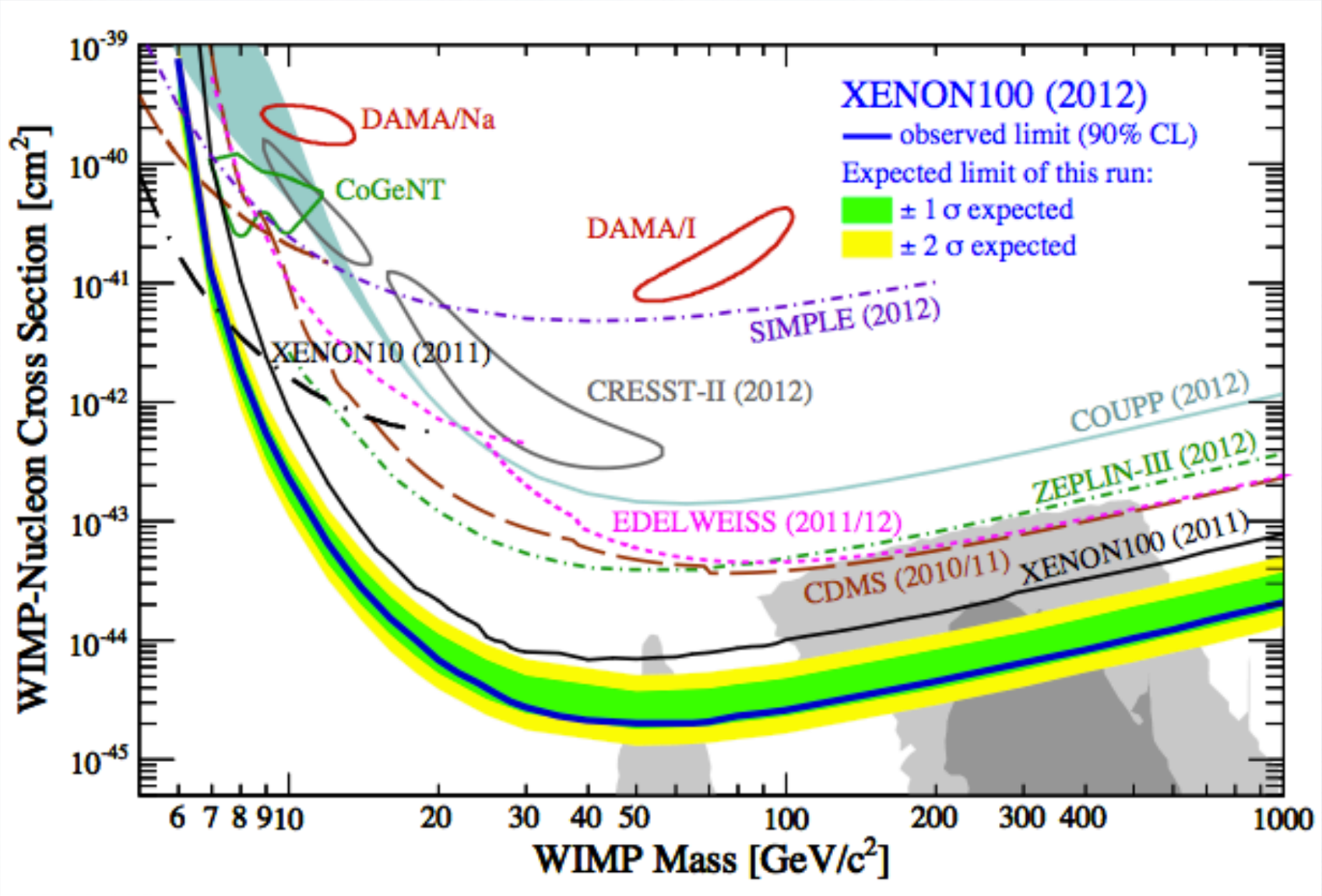




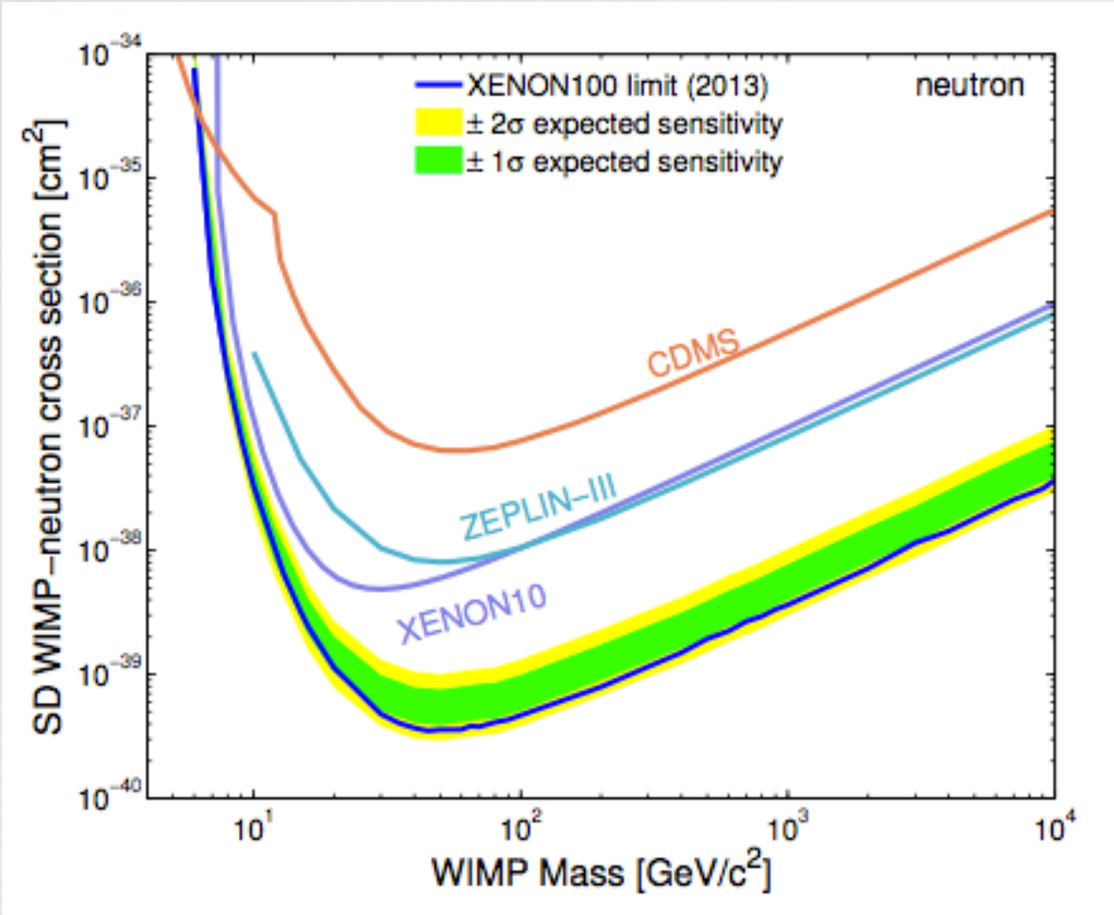
LUX
XENON
WARP
ArDM
ZEPLIN
DARKSIDE

DAMA
LIBRA
XMASS
CLEAN
ANAIS
KIMS
DEAP/CLEAN

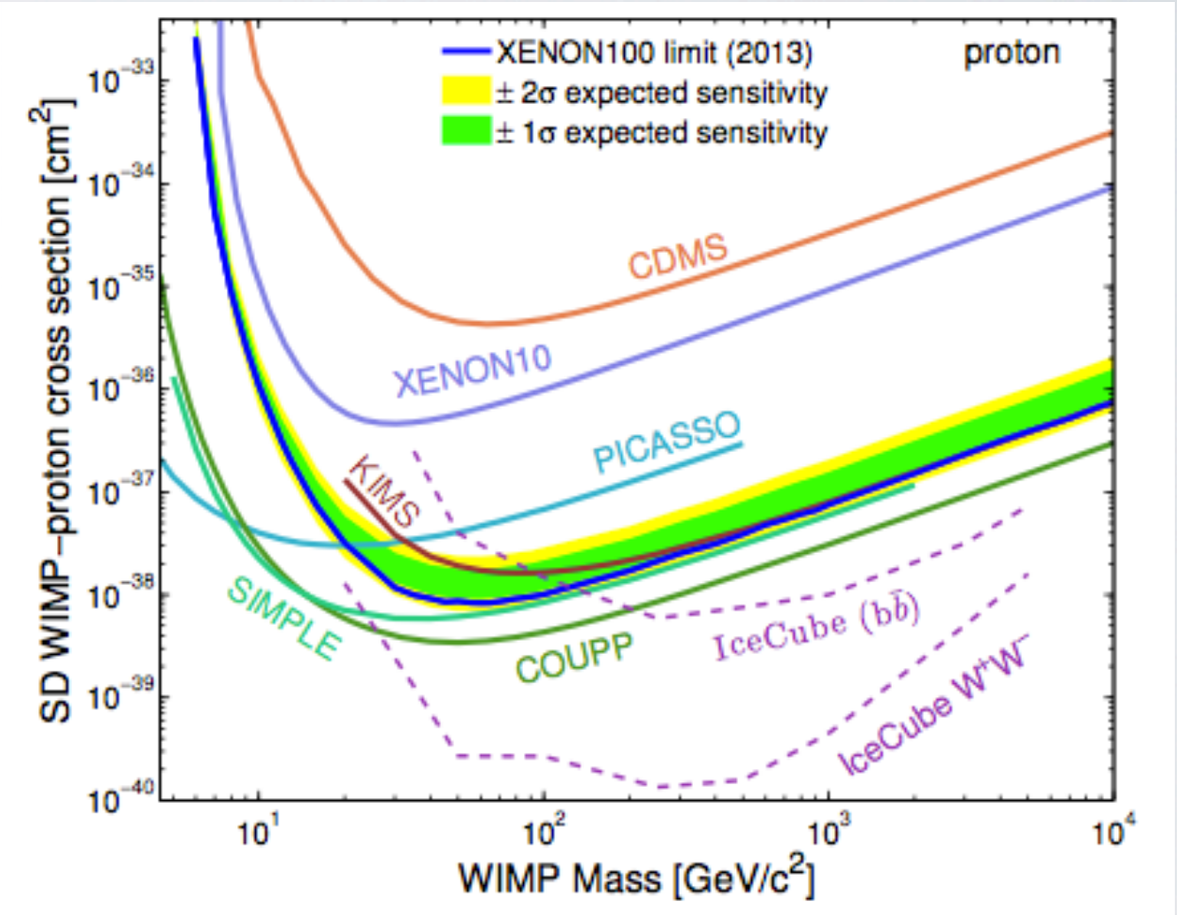
Current state of play



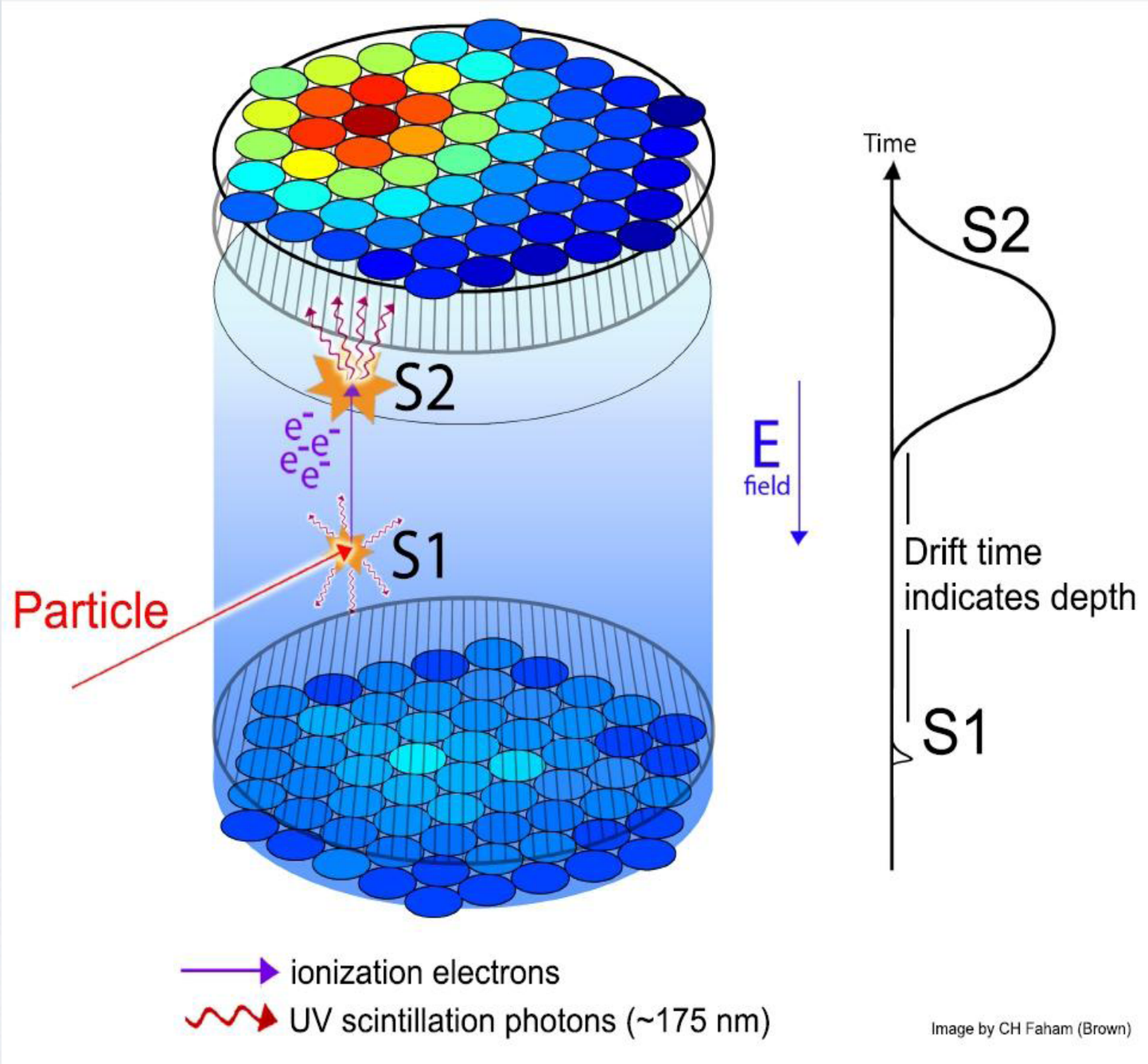
Current state of play (SD)



WIMP-Neutron

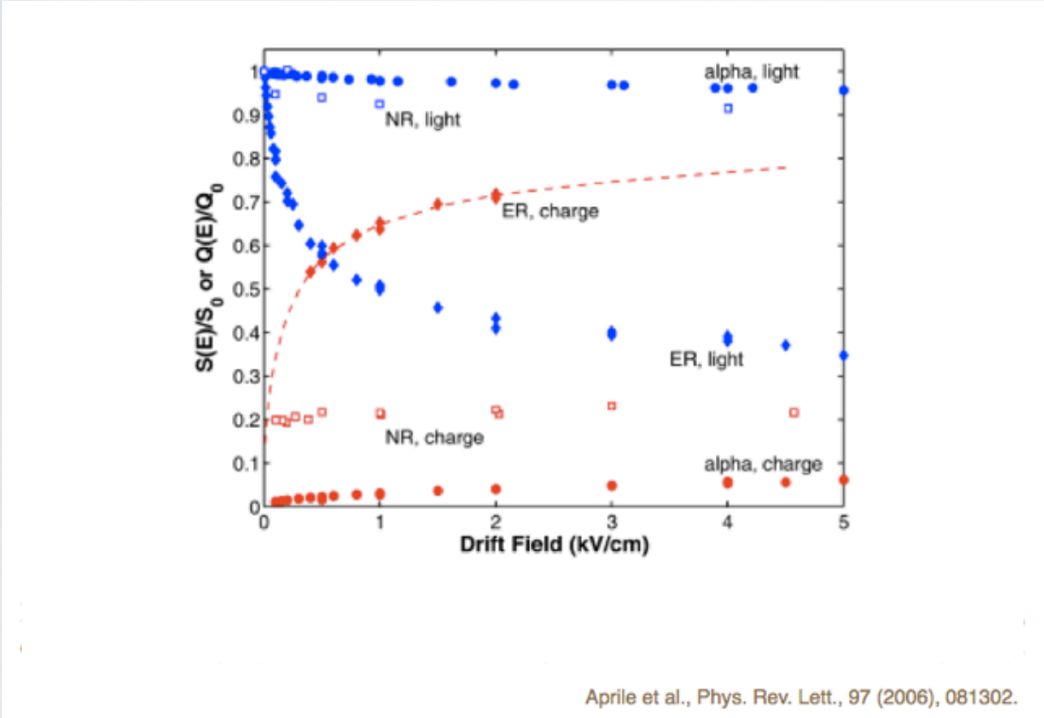


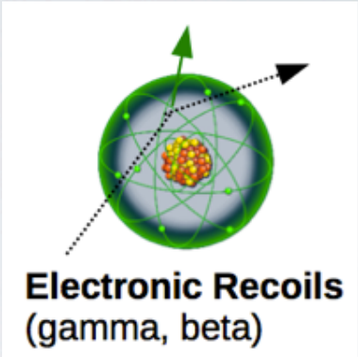
WIMP-Proton

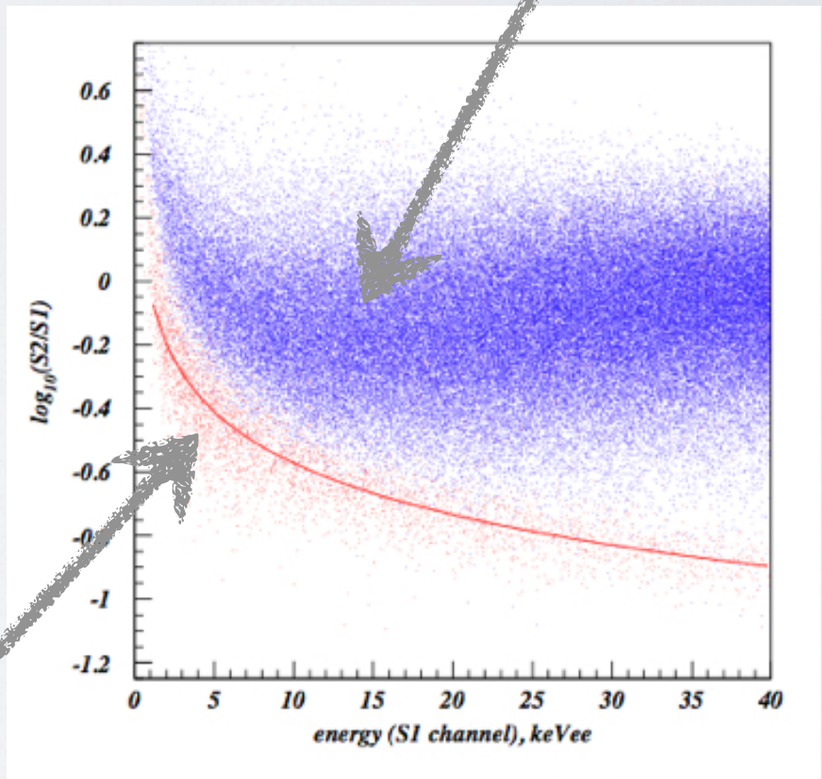

S2
S1
Particle
E
field
Time
S2
Drift time
indicates depth
S1
ionization electrons
UV scintillation photons (~175 nm)
Image by CH Faham (Brown)

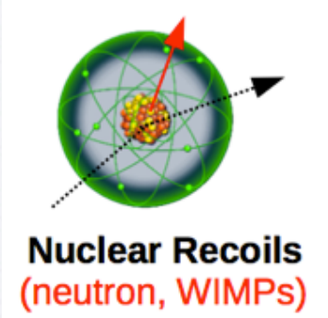
Particle Discrimination

Light (S1) and charge (S2) depend on recoil dE/dx

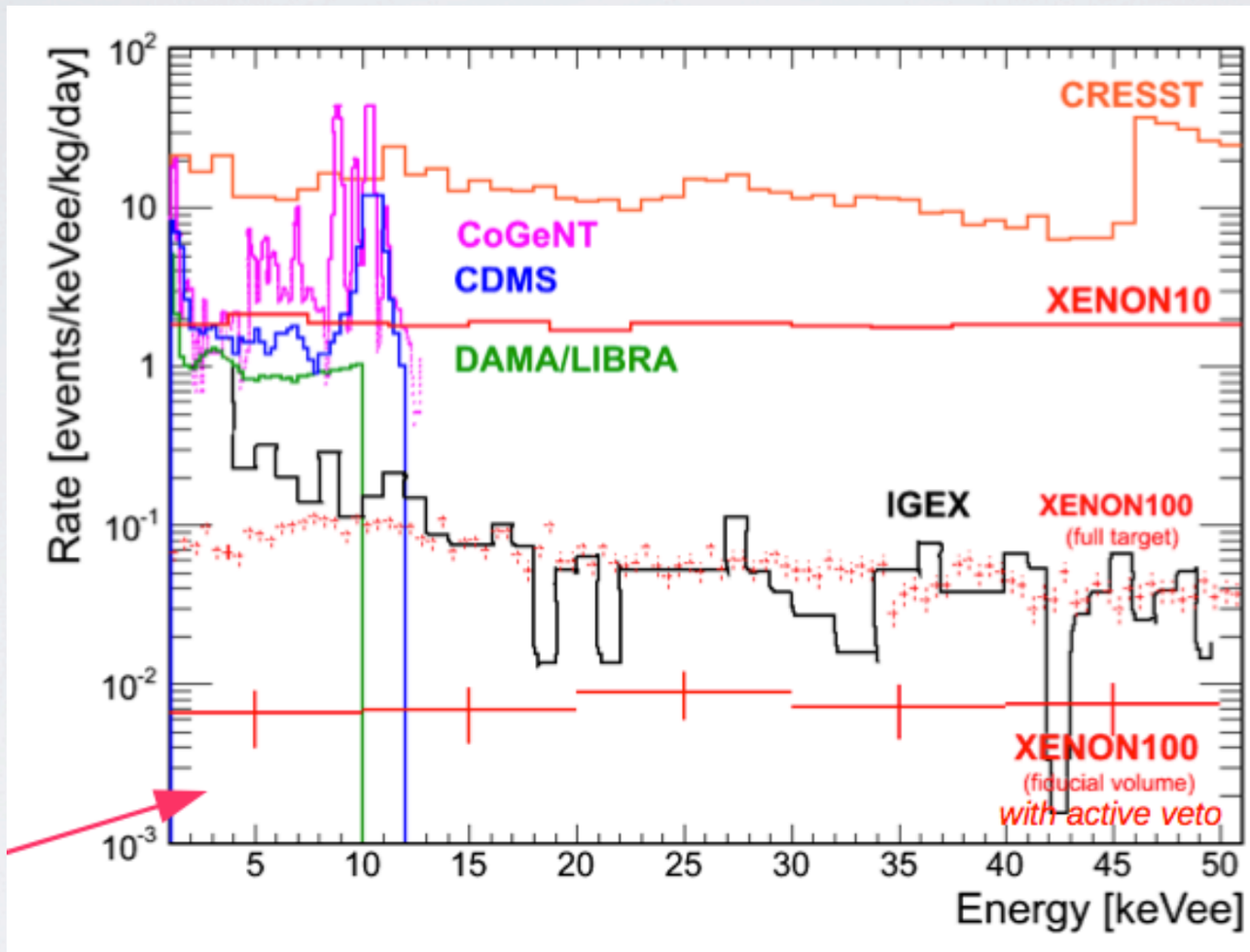








Fiducialisation

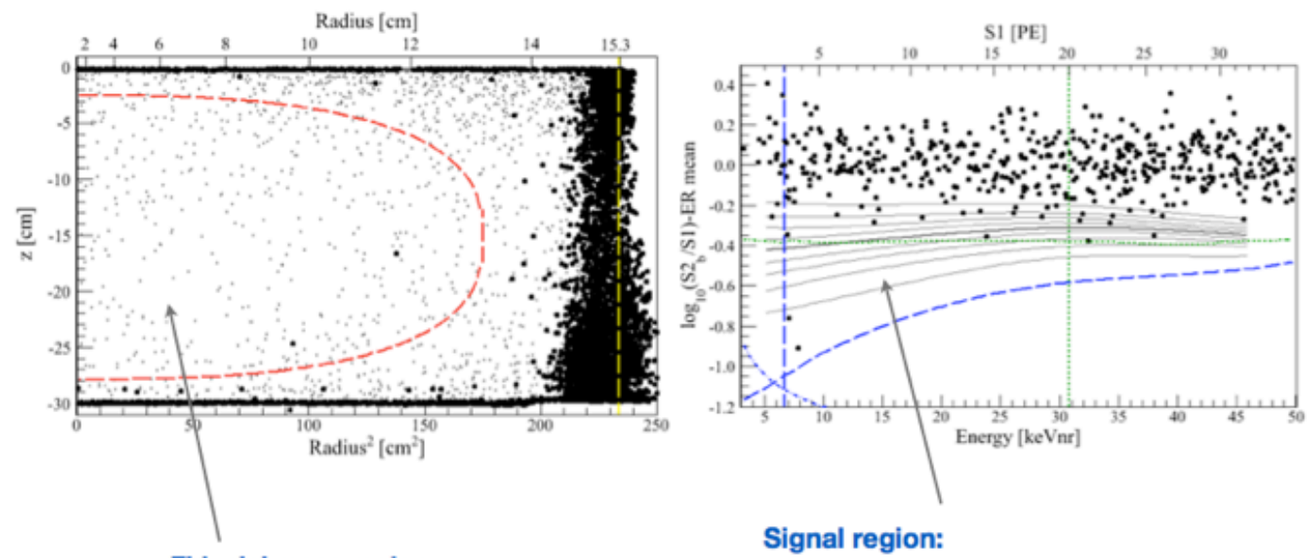


XENON100

XENON100

- LNGS
- 100x less bkgd than XENON10
- 62 kg target (34 kg fiducial)
- 99 kg LXe active veto
- 1” square PMTs
- 225 day WIMP run 2011-2012
- S.I. limit: 2×10^{-47} cm^2

Exposure: 225 days x 34 kg fiducial mass



Fiducial mass region:
34 kg of liquid xenon
406 events in total

Signal region:
2 events are observed
0.79 ± 0.16 gamma leakage events expected
0.17 +0.12-0.7 neutron events expected

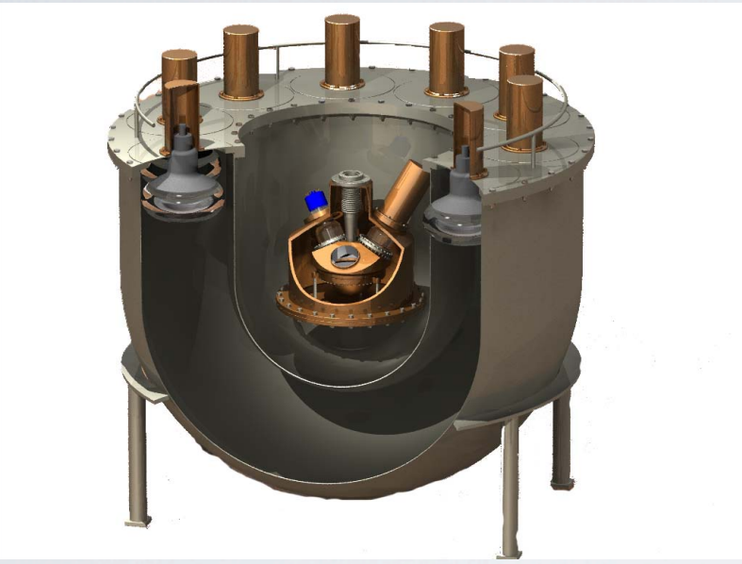
(1.0 ± 0.2) events expected
2 events observed

→ 26.4% probability that background fluctuated to 2 events
→ PL analysis cannot reject the background only hypothesis

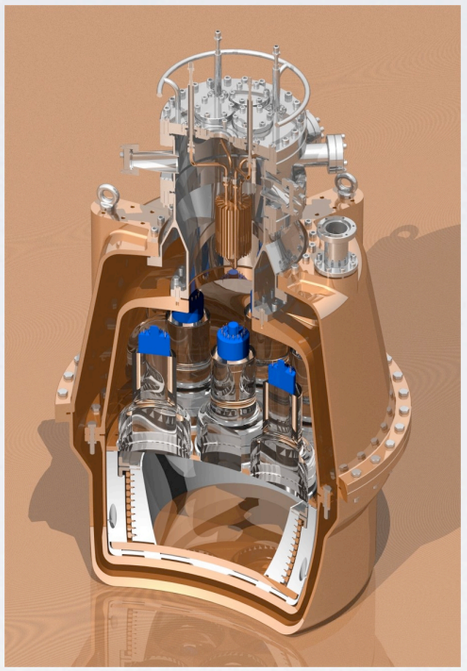
No significant excess due to a signal seen in XENON100 data.

Next up!

ZEPLIN Programme

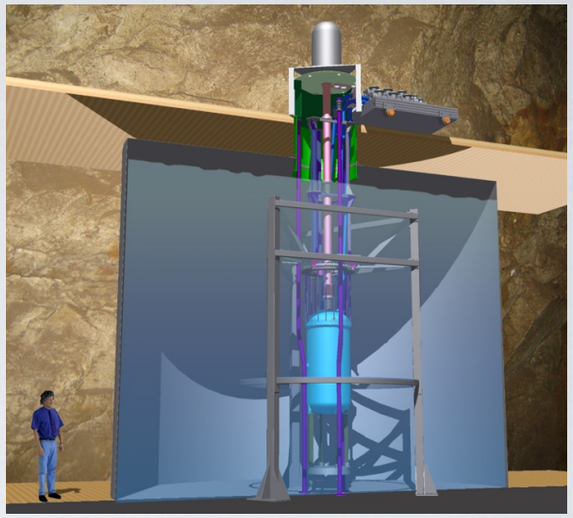


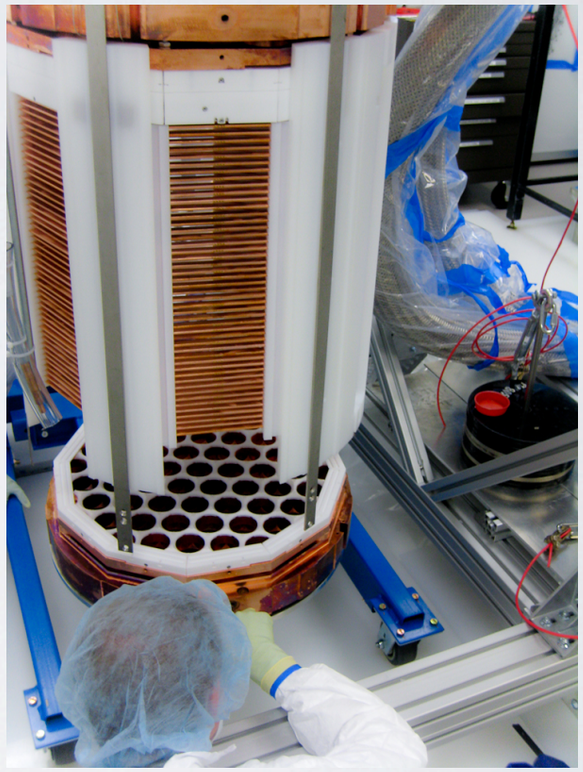
ZEPLIN I
Single phase, 3 PMTs, 5/3.1 kg
Run 2001-04
Limit: $1.1*10^{-6}$ pb

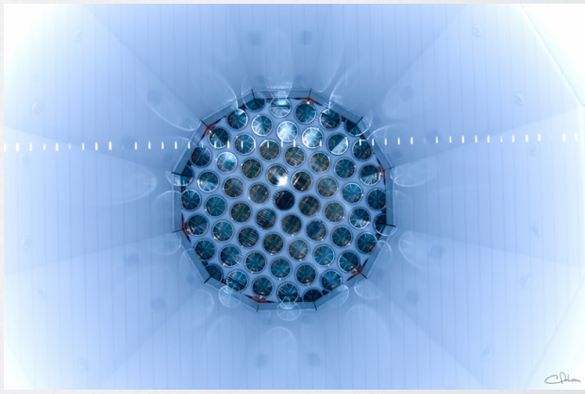


ZEPLIN II
Double phase, 7 PMTs,
moderate E field, 31/7.2 kg
Run 2005-06
Limit: $6.6*10^{-7}$ pb

ZEPLIN III
Double phase, 31 PMTs,
high E field, 10/6.4 kg
Run 2009-11
Limit: $3.9*10^{-8}$ pb







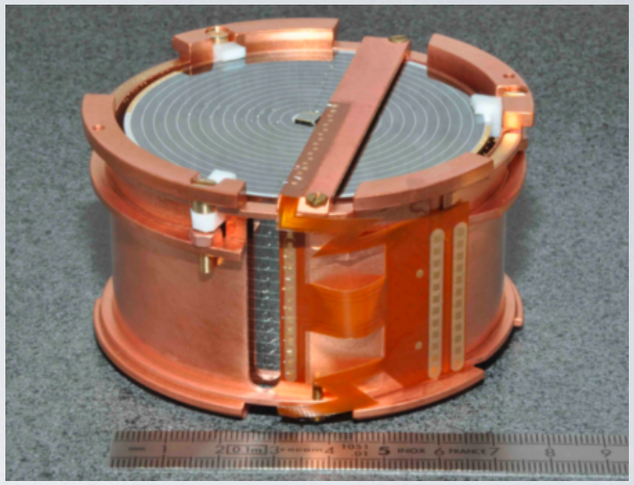
- 350 kg LXe TPC
- Homestake Mine (Davis cavern 4850ft)
- 122 low bkgd PMTs and Ti cryostat
- Sensitivity reach x10 over XENON100
- Active water Cerenkov shield
- Fully assembled and tested in surface facility before underground deployment

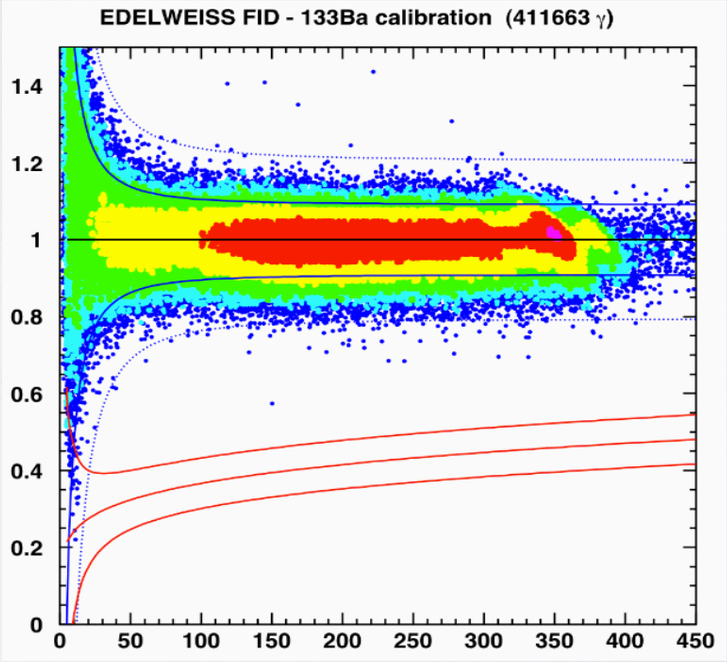
Could surpass XENON100 sensitivity in 2013

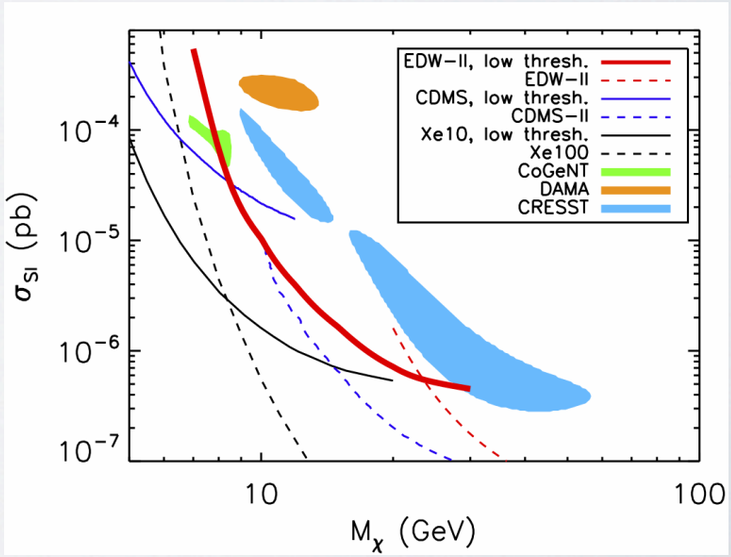
see H. Araujo's talk - Wed 9:30am, Track 4

EDELWEISS-III

- Laboratoire Souterrain de Modane
- 40 cryogenic germanium detectors
- Phonon-ionisation for discrimination
- 5 keV recoil threshold
- 24 kg fiducial mass
- Upgrading to 32 kg Ge in summer 2013
- 2 year WIMP run to begin by end 2013
- Sensitivity of few x10^{-9} pb (depending on backgrounds)







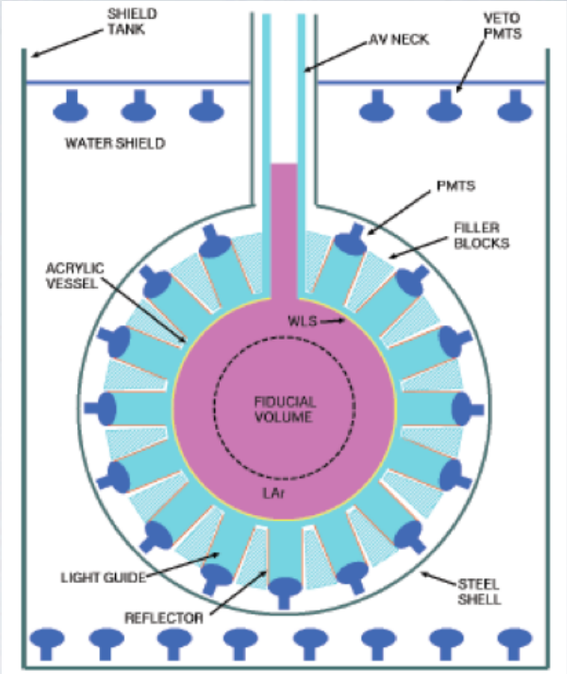
DEAP-3600 & miniCLEAN

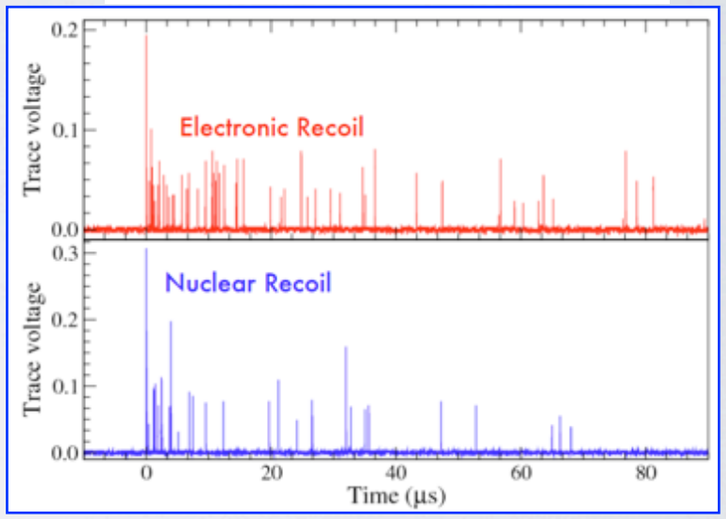
- SNOlab, Canada
- Single phase open volume, 4π PMT coverage
- No E-field (maximize phe/keVee)
- Pulse shape discrimination, ~40 keV thresh.
- Active water shield
- MiniCLEAN (150 kg fiducial)

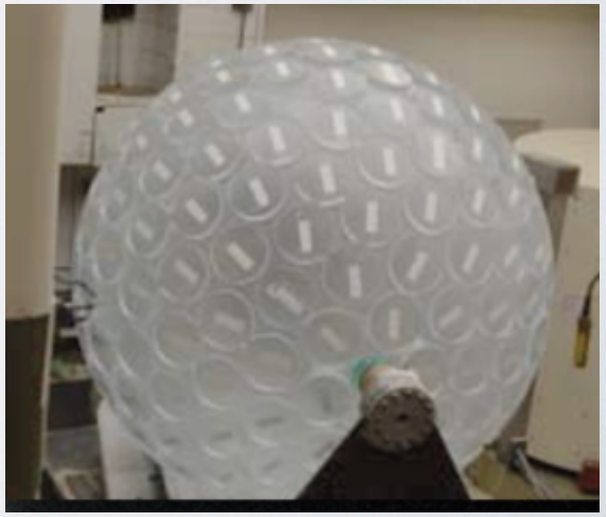
  construction: 2011-2013, run: 2013-2014
  sensitivity: 1E-45 cm^2
- DEAP-3600 (1 tonne fiducial)

  construction: 2011-2013, run: 2014-2017
  sensitivity: 1E-46 cm^2

see J. Walding's talk - Wed 9:20am Track 3

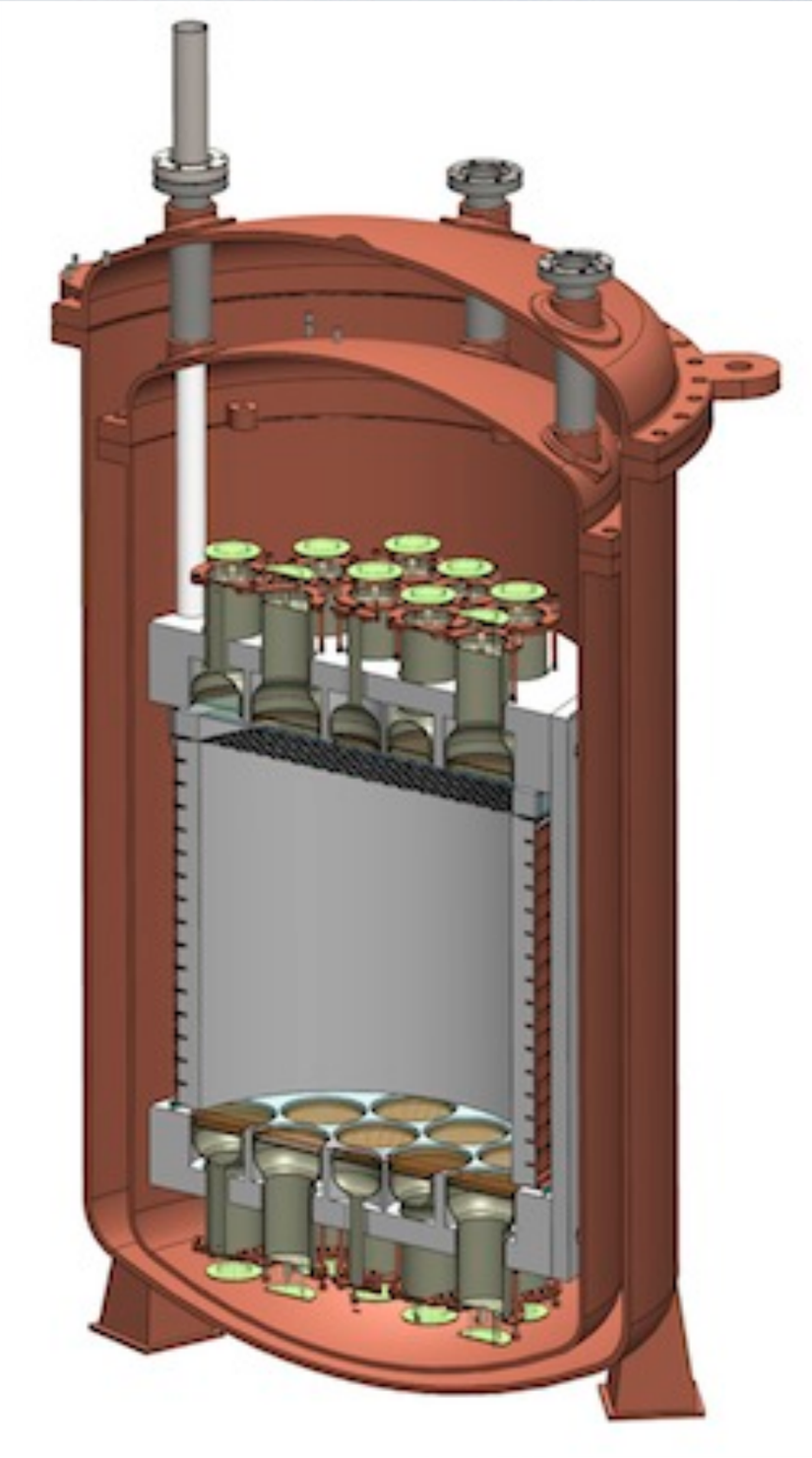






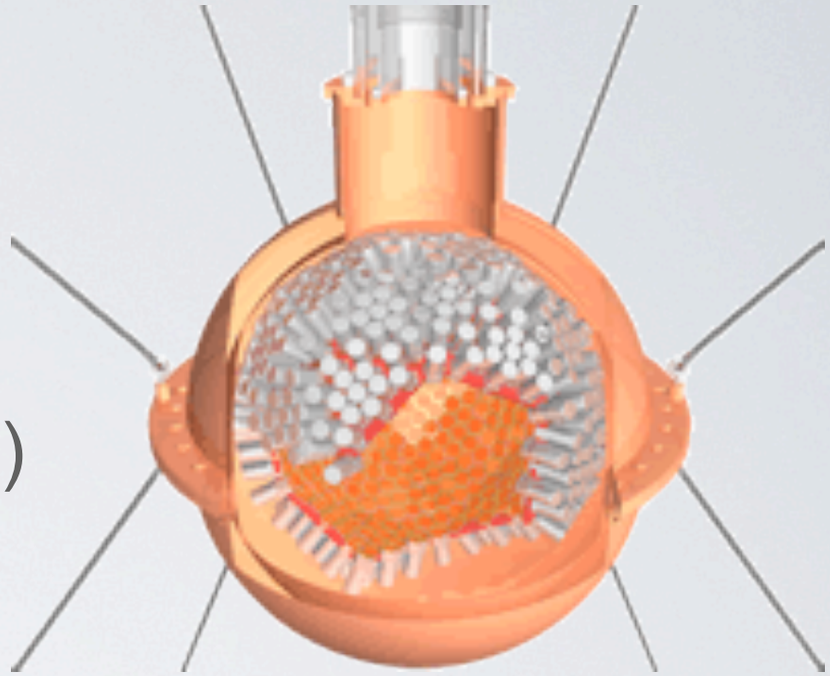
DarkSide-50

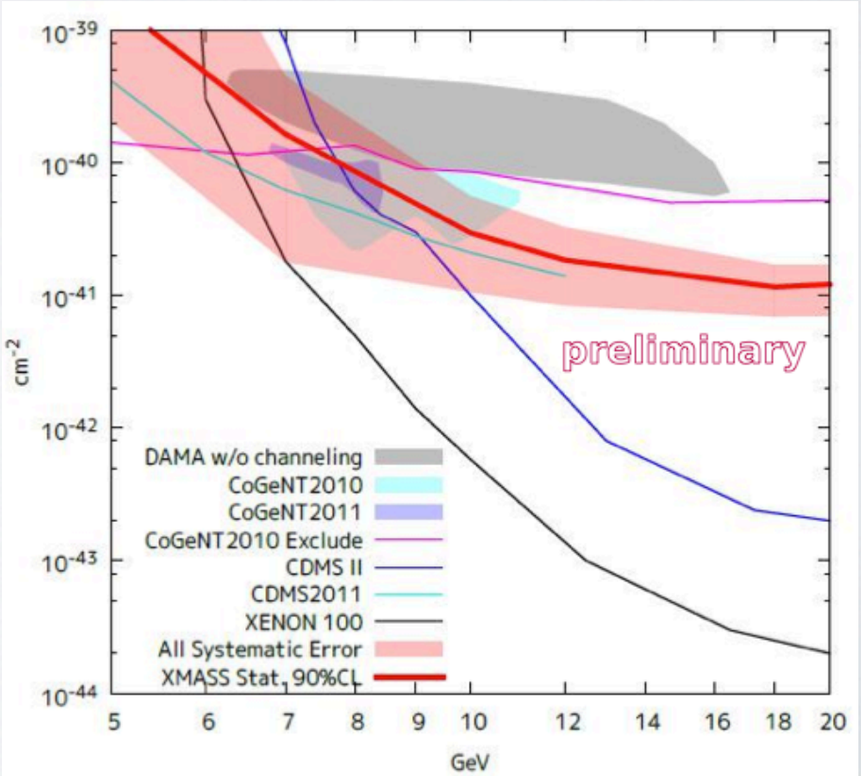
- Based at LNGS, under construction
- Liquid Ar 2-phase TPC
- Low background science device (unlike DS-10)
- Neutron veto inside Borexino CTF
- Used underground (depleted) Ar target
- Adopts v. successful Xe technology
- PSD + S2/S1 discrimination
- 3D position reconstruction for surface background rejection (ala LXeTPCs)
- DarkSide-10 decommissioned last month



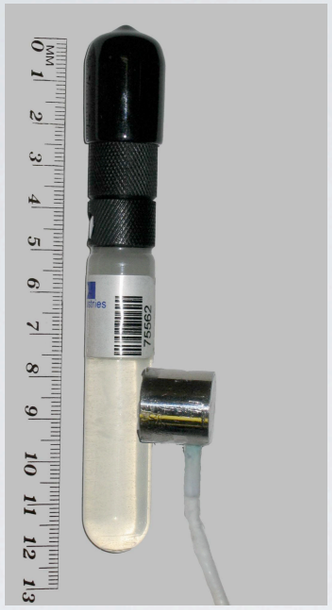
XMASS

- Based at Kamioka, Japan
- Single phase detector (no E-field so no S2's)
- 100 kg Xe fiducial (800 kg active)
- 4π PMT coverage
- Unexpected background observed
- Performance severely compromised
- Undergoing refurbishment of PMTs
- Data taking to begin 2014





Acoustic Bubble Chambers



1st generation* : 10ml

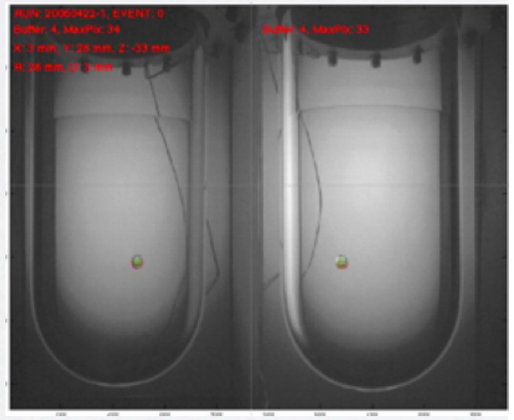
2nd generation : 1L

3rd generation : 4.5L

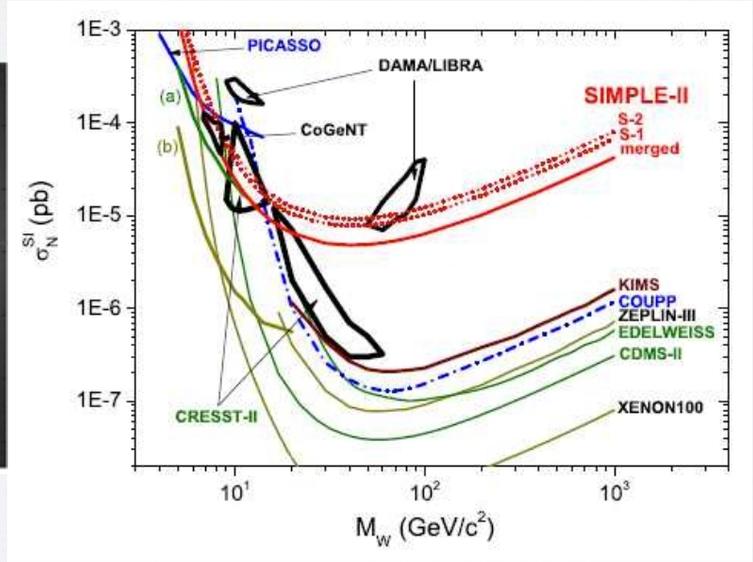
Picasso

SNOLAB, Ca

SIMPLE (Freon target)



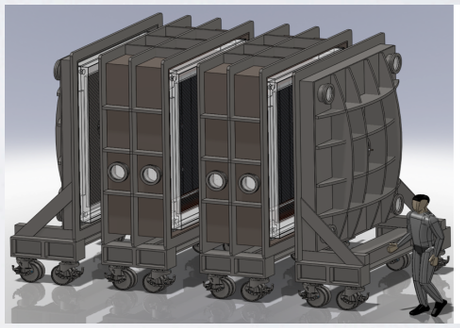
COUPP (CF_3I)

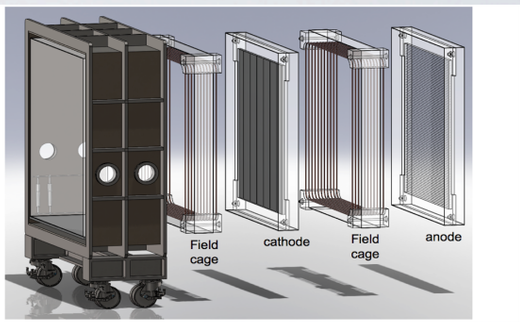


Directional Gas TPCs

DRIFT-II/III

- CS_2:CF_4 low pressure target (33 g fid.)
- MWPC readout for 3D track reconstruction
- 1 m^3 modules in Boulby Mine, UK
- DRIFT-IIe incorporates major modifications to improve backgrounds and track reconstruction
- DRIFT-III plans for 24 m^3

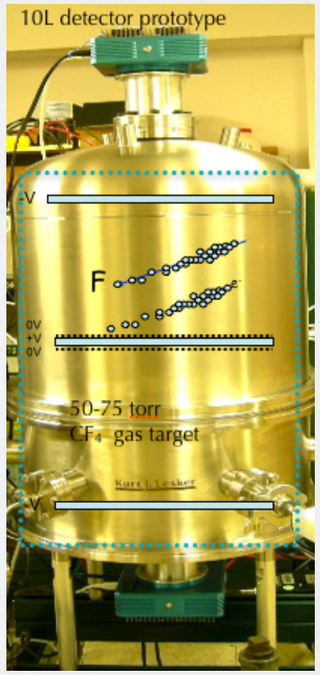


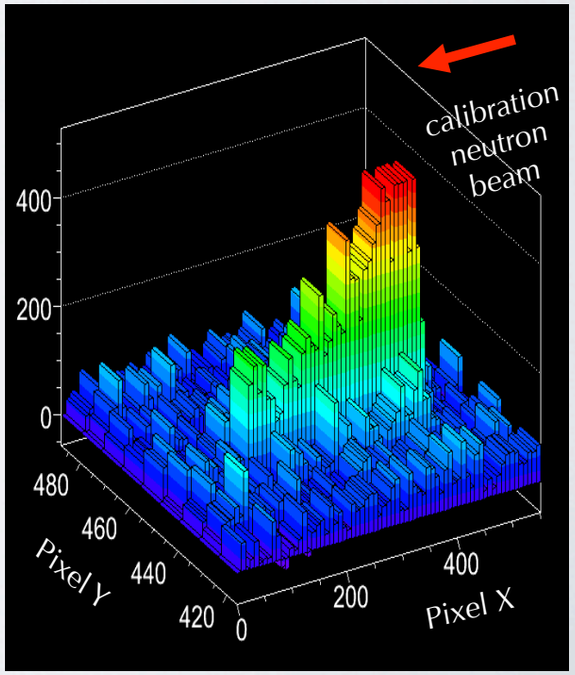


see S. Sadler's talk - tomorrow 3pm, Track 3

DMTPC

- CF_4 target (10l prototype)
- 1 m^3 modules under development presently
- Charge ***and*** optical readout for background rejection





Next generation (tonne scale) Experiments

EURECA

European Underground Rare Event Calorimeter Array

The future European 1-tonne cryogenic dark matter search

Aim:	$<10^{-10}$pb
Detectors:	Cryogenic Ge (from EDELWEISS) and scintillator calorimeters (from CRESST)
Shielding:	Radiopure Cu, polyethelene, 3m water tank with PMTs
Infrastructure:	Cryostat to cool 1-tonne target
Collaboration:	EDELWEISS, CRESST, new members

see X. Zhang's talk - tomorrow 3pm, Track 4

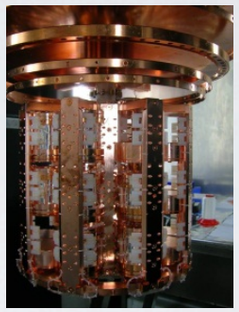
Global convergence of CryoDetectors

phonon – ionization

Germanium

SuperCDMS
Soudan, 10kg
$5x10^{-9}$pb

LSM
Germanium
10 – 32 kg
$2x10^{-9}$pb



CRESST
Gran Sasso
$CaWO_4$
phonon – scintillation

SuperCDMS
SNOLAB
200kg, $8x10^{-11}$pb

MoU since 2009
Increasing collaboration towards common experiment

150 – 1000 kg
$3x10^{-10}$pb to
$2x10^{-11}$pb

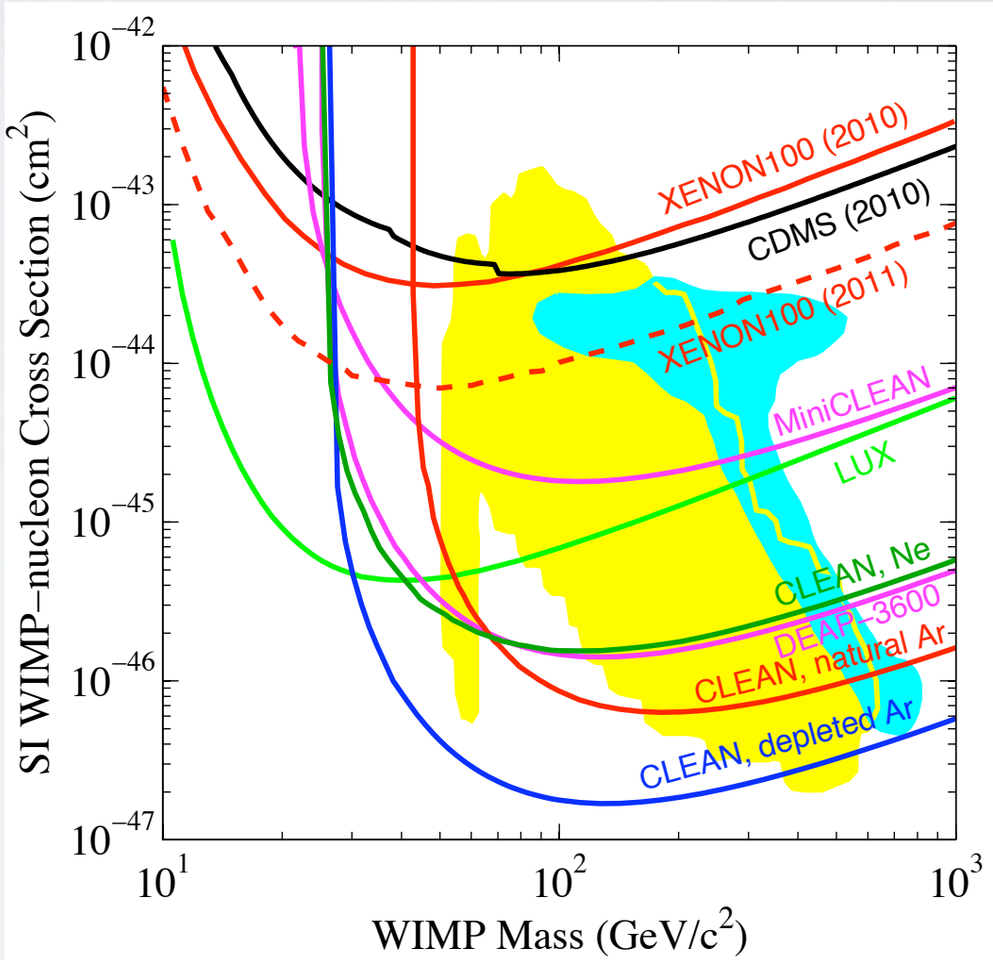
DEAP/CLEAN

DEAP-1 (7 kg) → μCLEAN (4 kg) → MiniCLEAN (300 kg) → DEAP-3600 (3600 kg) → CLEAN(100T) → ...

2006 — 2007 — 2012 — 2014 — 2016

DEAP/CLEAN
O(10) tonne fiducial

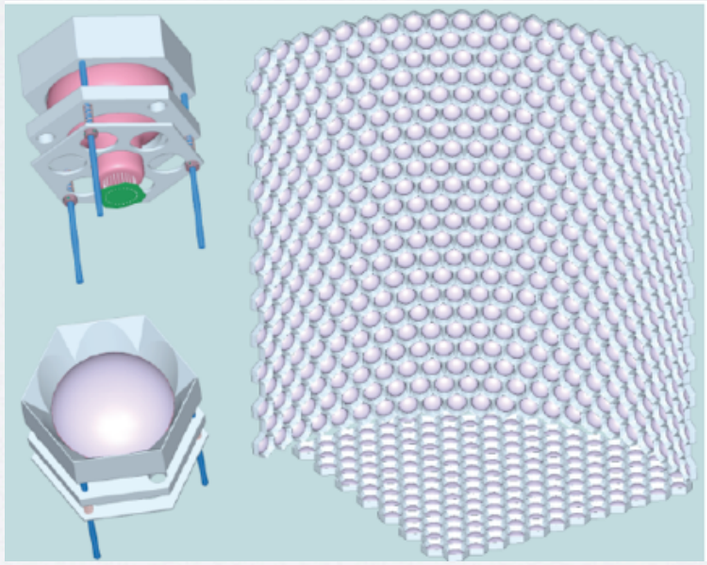
future goal, 1E-47 cm^2 sensitivity

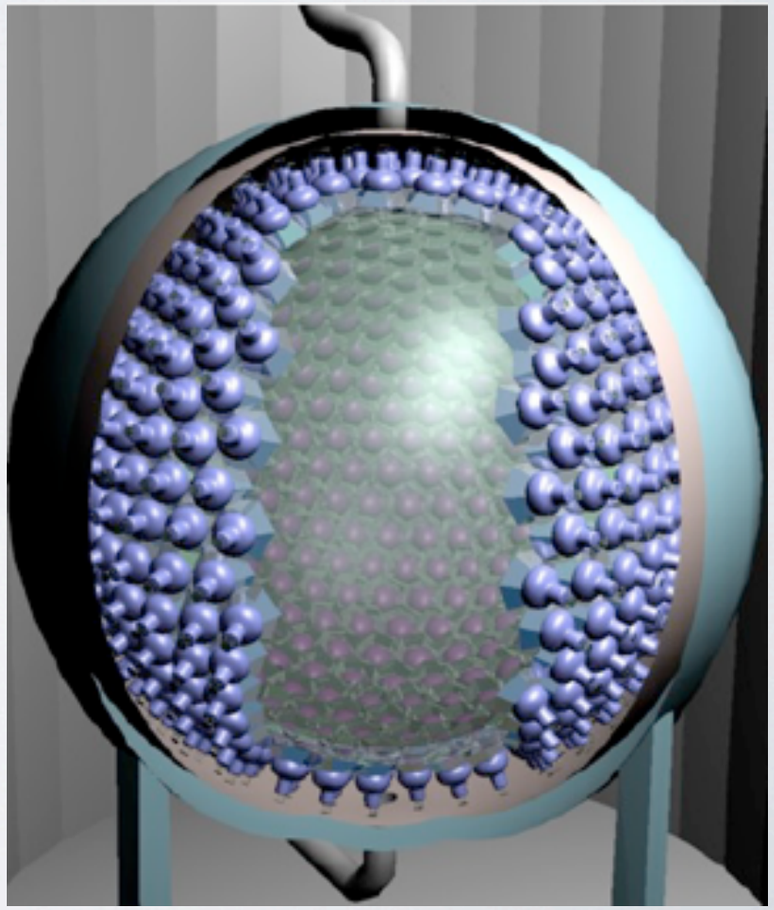


emphasis on scalability to 100T-scale, for dark matter and solar neutrino physics

DEAP/CLEAN

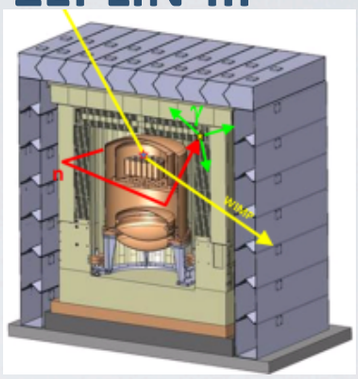
- Concept design: 140 tonne fiducial mass single phase detector with PMT readout, in SNOLAB Cryopit Hall
- technical design based on MiniCLEAN, DEAP3600 technology, R&D + MicroBooNE
- active Gd-doped veto
- same scale as MicroBooNE@FNAL, exploring similar cylindrical cryostat
- coordinated proposals to NSERC (CA), STFC (UK), DOE (US) planned for 2014
- UK group activities: detector design, background model, calibration R&D, technology synergy with LAr ν efforts





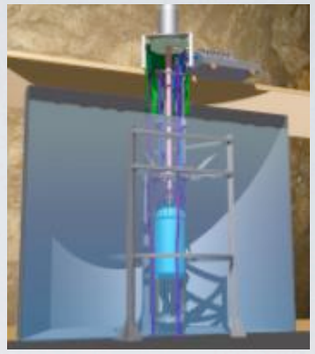
LUX-ZEPLIN (LZ)

ZEPLIN-III



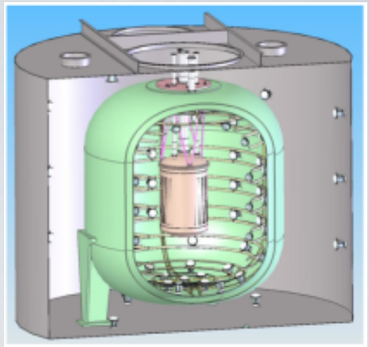
6 kg LXe (fid)

LUX350



100 kg

LZ

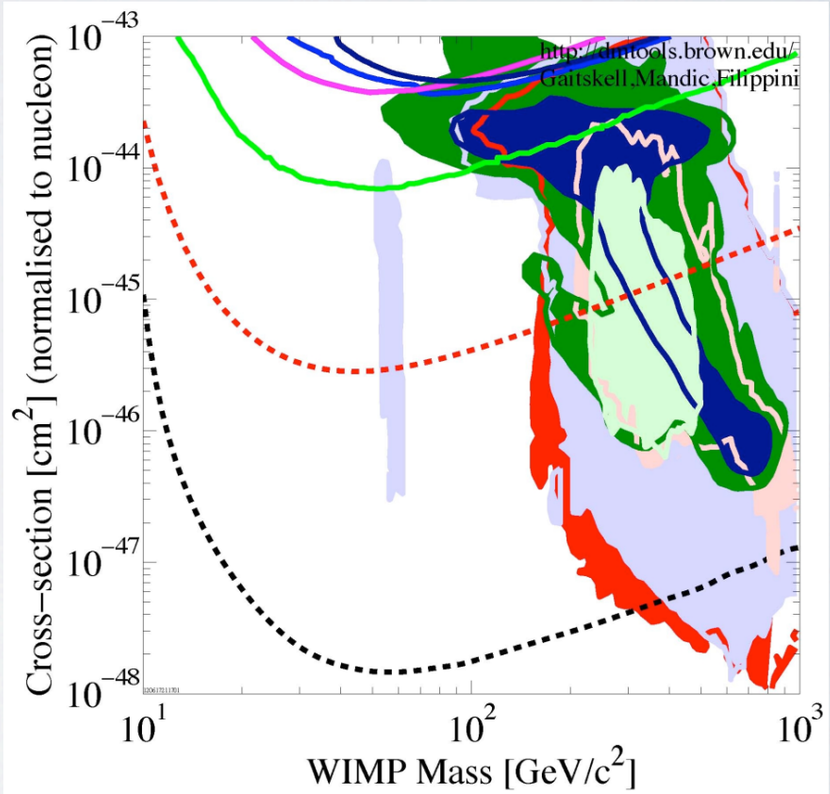


5,000 kg

Next-generation LXe experiment

building on LUX and ZEPLIN programmes

- **Route to detection & study: a <u>progressive</u> programme**
  - UK-led **ZEPLIN** programme pioneered liquid xenon for WIMP searches
  - **LUX** (now with UK) about to turn on – expect leading sensitivity in 2013
  - **LZ** could discover at 10^{-11} pb or exclude at 10^{-12} pb with 3 year run
- **Experimental approach: a <u>low risk</u> and <u>aggressive</u> programme**
  - Background free strategy (self-shielding, modest discrimination assumed)
  - Two-phase Xe technology: high readiness level (ZEPLIN, XENON, LUX)
  - Teams with huge track record in DM searches
  - Much infrastructure inherited from LUX350
- **LXe provides exciting physics for light & heavy WIMPs (GeV-TeV)**
  - Since we do not yet know what BSM physics looks like!



Down-selects

- Science Board Sub-Group convened in 2012 to review UK involvement in DDMS...

"...the UK undoubtedly possesses unique expertise and has the potential to secure significant leadership within the relatively large international collaborations currently forming..."

- ...and propose a coordinated strategy for supporting next generation DDMS experiments that could potentially position the UK for leadership

"...it should be made clear to the community that further consolidation of activities would be viewed as a strength of any proposal."

DEAP/CLEAN | DRIFT | EDELWEISS | EURECA | LUX | LZ

DMUK

spokesperson: H. Kraus, Oxford

DMUK ‘down-select’

- DMUK founded to focus UK effort and as a body in which we build on mutual strength
- DMUK groups currently active in selecting the UK ‘flagship’ DM experiment
- Selected experiment(s) should seek to absorb UK expertise across DMUK
- Next meeting: 15th April 2013
- Next generation experiment selection coupled to international partners and funding

U.S. 'down-select'

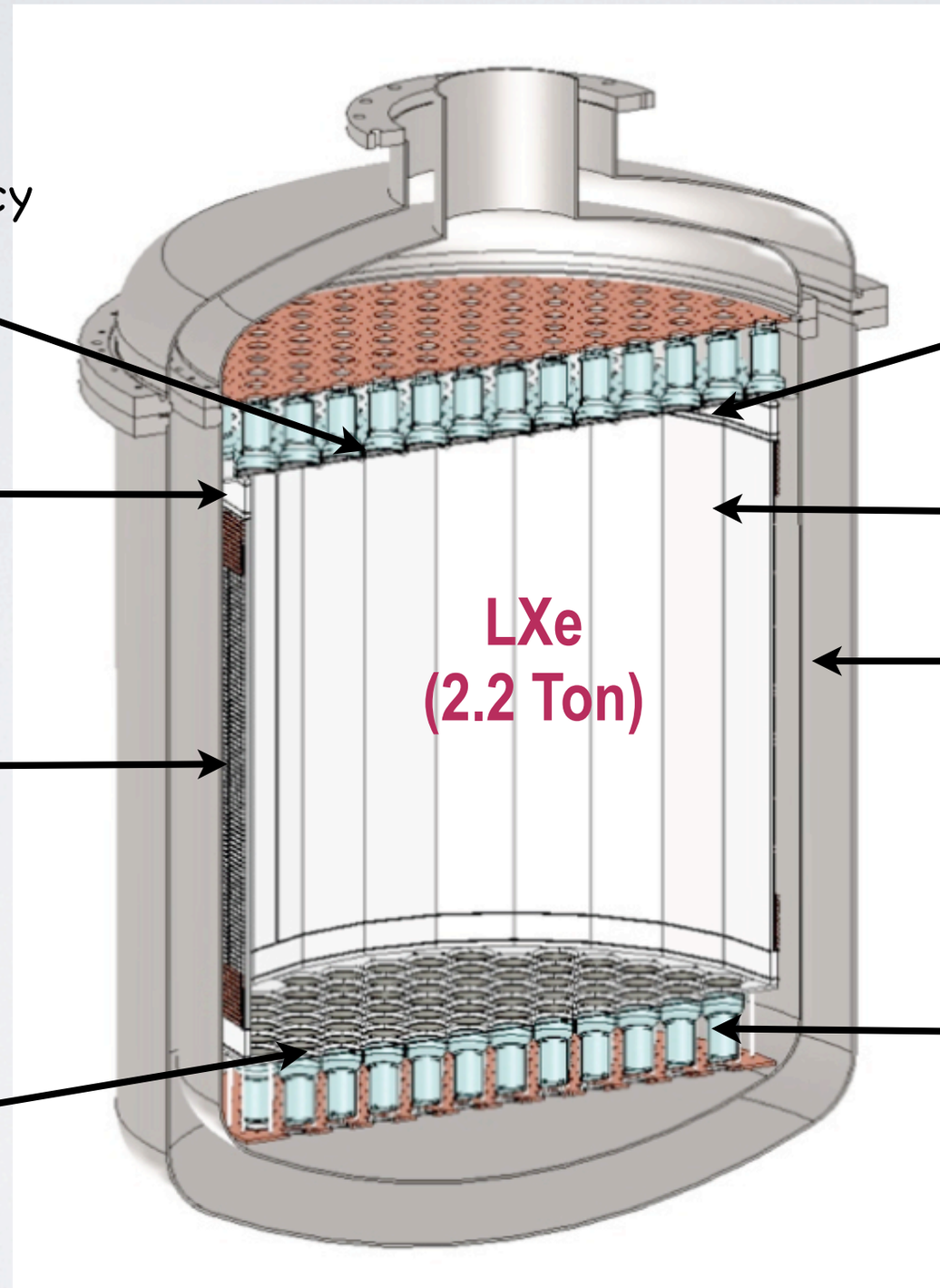
- DOE conducting down-select in two phases: R&D and then Project
- From 13 proposals to DOE, 5 selected for R&D funds and continuation in the down-selection process:
  - LZ
  - SuperCDMS
  - DarkSide-G2
  - COUPP
  - ADMX (axion search)
- 2-3 of these Next Generation ("G2") experiments to be funded
- Pursuit of a wide-range of technologies is not expected
- Merging of the communities is expected after down-select

Summary

- The nature of Dark Matter remains one of the most fundamental questions today
- Direct detection experiments have accelerated rapidly in sensitivity, with high technology readiness levels or advanced detector development for the Next Generation tonne scale devices
- Tonne scale experiments have sensitivities ideally matched to probe the bulk of the favoured parameter space on timescales compatible with accelerator and indirect
- DMUK making excellent progress in consolidating UK direct detection activity

Back-up Slides

XENON1T



High transparency electrodes

No top array screening mesh

Active LXe veto

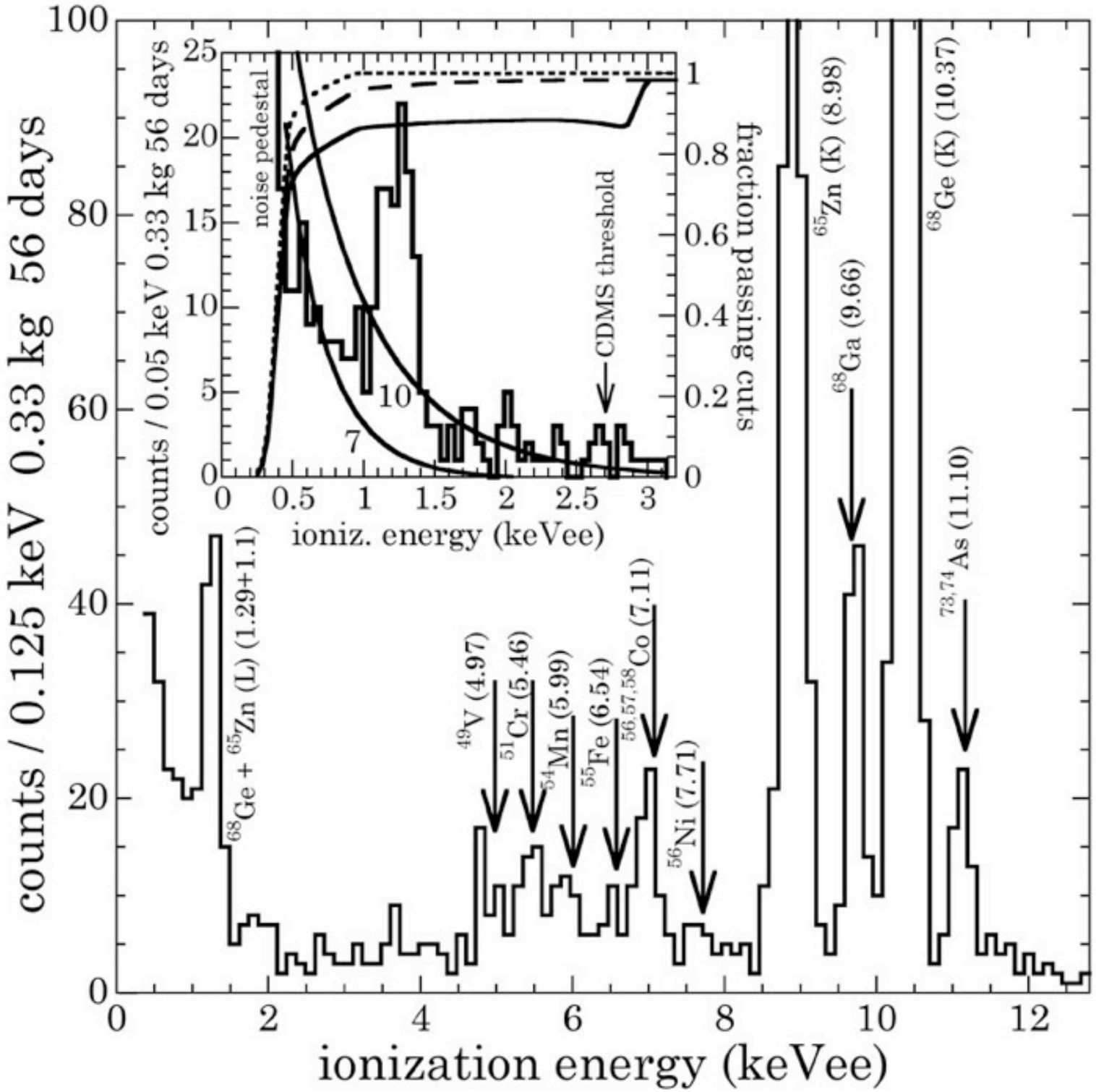
Three interlocking PTFE panels

Titanium cryostat and vacuum jacket

1 kV/cm drift field with external field shaping rings

2 arrays of 121 high QE 3" photodetectors

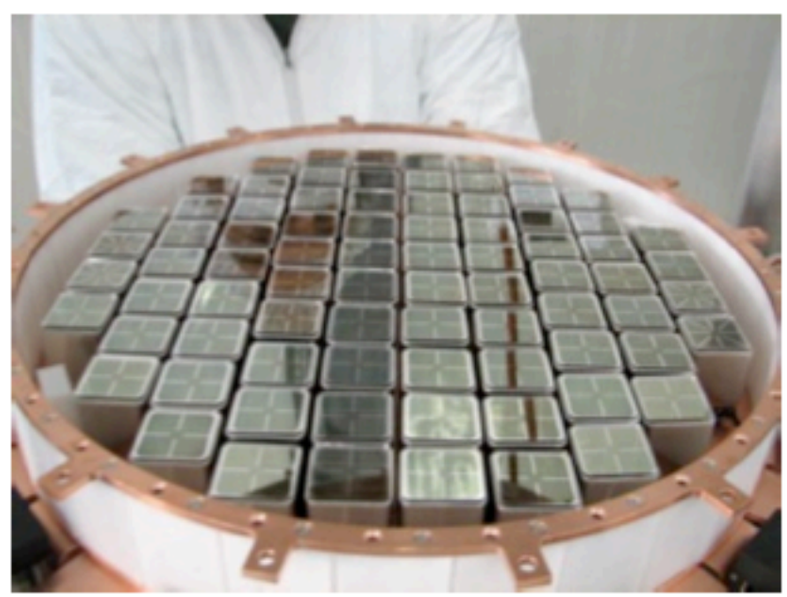
No charge insensitive regions below photocathode


counts / 0.125 keV 0.33 kg 56 days
ionization energy (keVee)
counts / 0.05 keV 0.33 kg 56 days
ioniz. energy (keVee)
fraction passing cuts
noise pedestal
CDMS threshold
7
10
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)
68Ga (9.66)
65Zn (K) (8.98)
68Ge (K) (10.37)
73,74As (11.10)

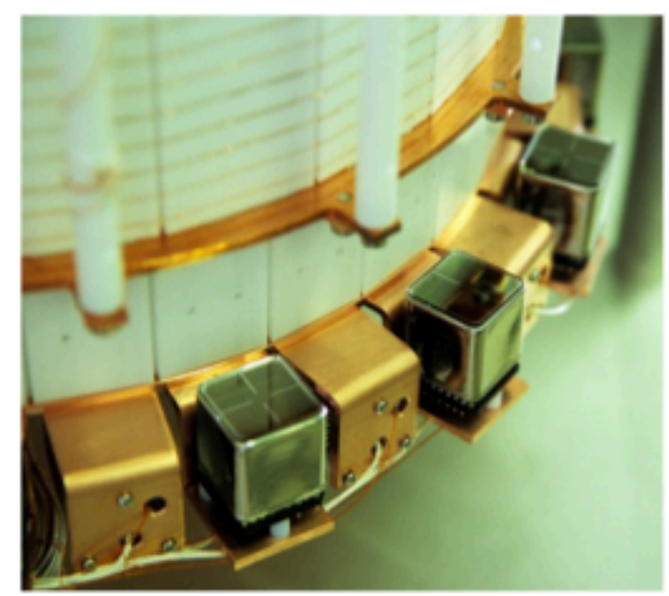
The XENON100 photosensors

- 1-inch square R8520 Hamamatsu PMTs, optimized to work at LXe T and P, and of low-radioactivity (< 1 mBq/PMT in $^{238}U/^{232}Th$)
- Top array: 98 PMTs (23% quantum efficiency) in concentric circles to improve radial event position reconstruction, teflon holder
- Bottom array: 80 PMTs, closely packed, and of higher quantum efficiency (32-34% at 178 nm), for efficient S1 light collection
- LXe veto: 64 PMTs, 23% quantum efficiency

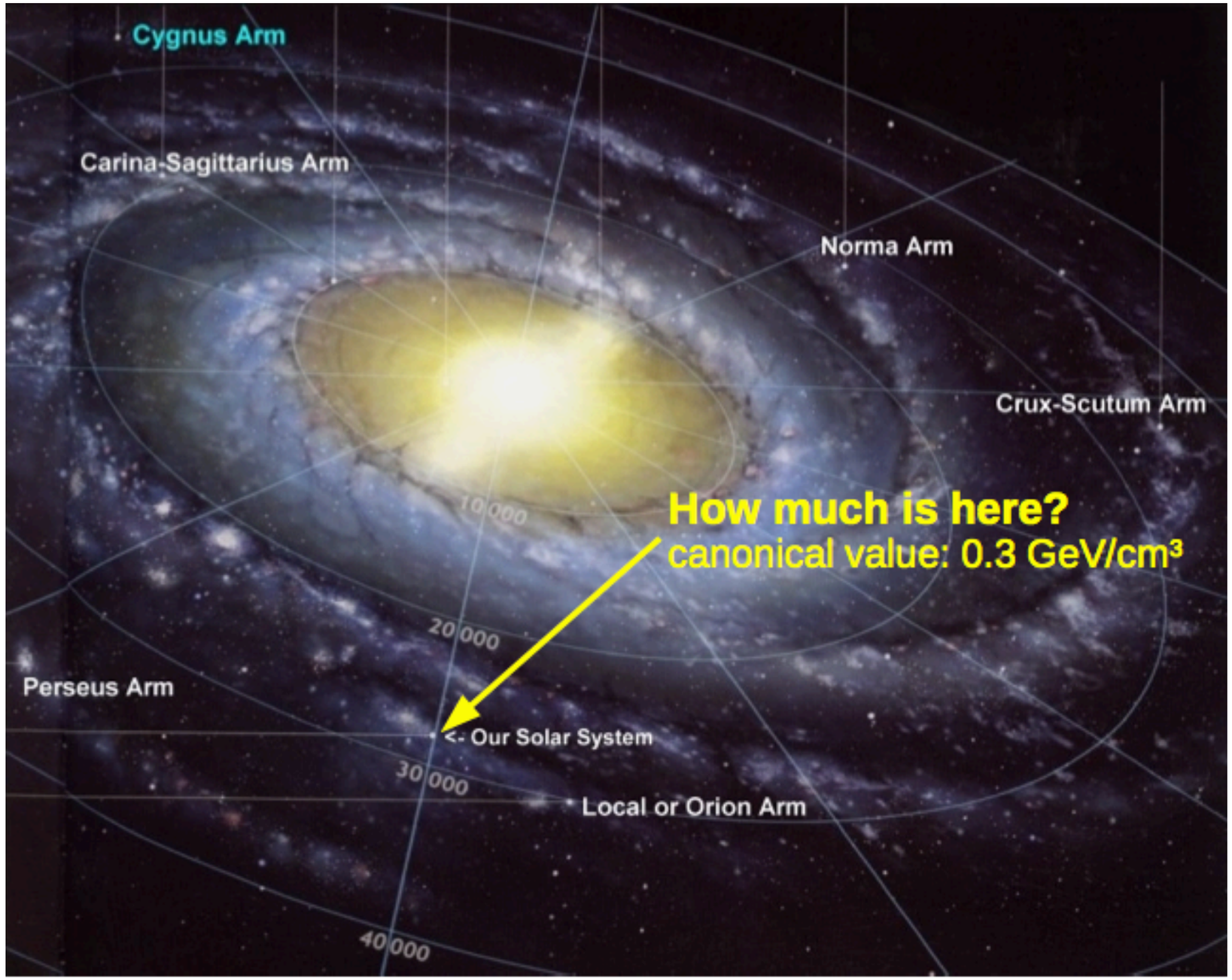
top array



bottom array



veto PMTs


Cygnus Arm
Carina-Sagittarius Arm
Norma Arm
Crux-Scutum Arm
How much is here?
canonical value: 0.3 GeV/cm³
10 000
20 000
Perseus Arm
<- Our Solar System
30 000
Local or Orion Arm
40 000

arXiv.org > astro-ph > arXiv:1204.3924

Astrophysics > Galaxy Astrophysics

Kinematical and chemical vertical structure of the Galactic thick disk II. A lack of dark matter in the solar neighborhood

C. Moni Bidin, G. Carraro, R. A. Mendez, R. Smith

We estimated the dynamical surface mass density Sigma at the solar position between Z=1.5 and 4 kpc from the Galactic plane, as inferred from the kinematics of thick disk stars.

We extrapolate a dark matter (DM) density in the solar neighborhood of 0+-1 mM_sun pc^-3,

In particular, our results may indicate that any direct DM detection experiment is doomed to fail if the local density of the target particles is negligible.

arXiv.org > astro-ph > arXiv:1205.4033

Astrophysics > Galaxy Astrophysics

On the local dark matter density

Jo Bovy, Scott Tremaine (IAS)

An analysis of the kinematics of 412 stars at 1-4 kpc from the Galactic mid-plane by Moni Bidin et al. (2012) has claimed to derive a local density of dark matter that is an order of magnitude below standard expectations. We show that this result is incorrect and that it arises from the invalid assumption that the mean azimuthal velocity of the stellar tracers is independent of Galactocentric radius at all heights; the correct assumption---that is, the one supported by data---is that the circular speed is independent of radius in the mid-plane.

we find that the data imply a local dark-matter density of 0.3 +/- 0.1 Gev/cm^3

Perseus Arm

arXiv.org > astro-ph > arXiv:1206.0015

Astrophysics > Galaxy Astrophysics

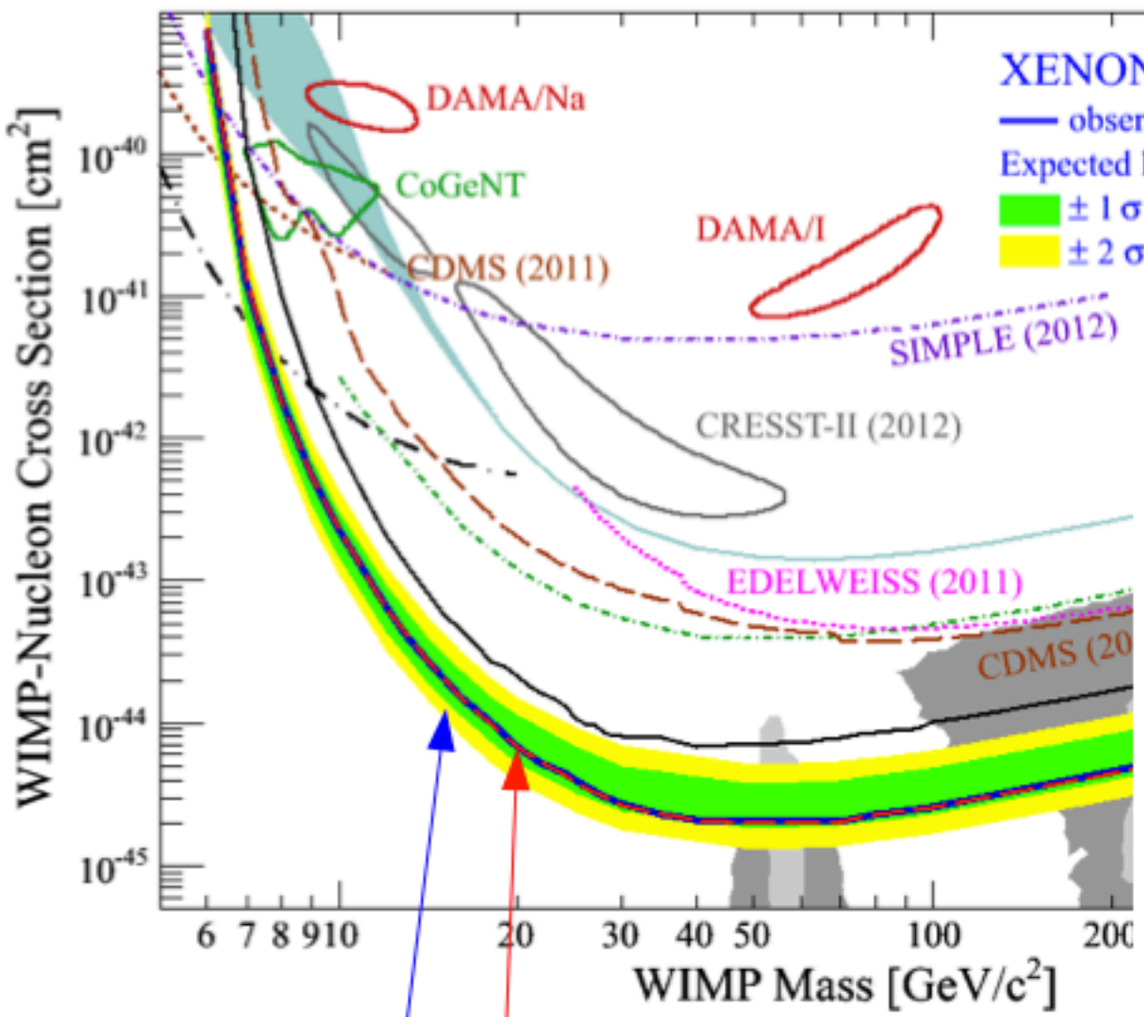
A new determination of the local dark matter density from the kinematics of K dwarfs

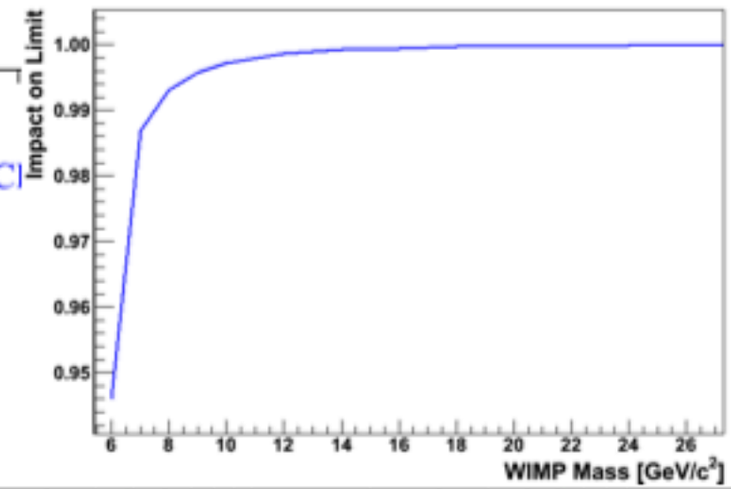
Silvia Garbari, Chao Liu, Justin I. Read, George Lake

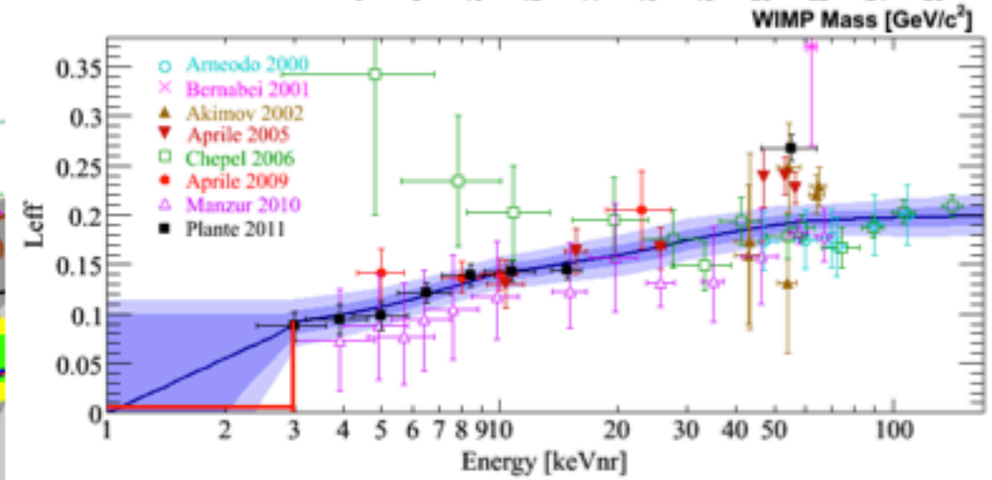
We apply a new method to determine the local disc matter and dark halo matter density to kinematic and position data for \sim2000 K dwarf stars taken from the literature.

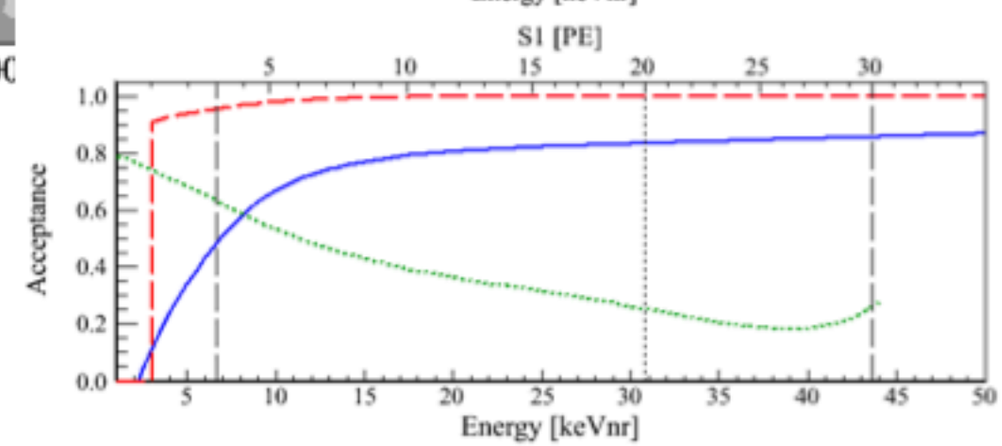
We perform a series of tests to demonstrate that our results are insensitive to plausible systematic errors in our distance calibration, and we show that our method recovers the correct answer from a dynamically evolved N-body simulation of the Milky Way. We find a local dark matter density of (0.95+0.53-0.49 GeV cm^-3) at 90% confidence assuming no correction for the non-flatness of the local rotation curve, and (0.85+0.57-0.50 GeV cm^-3) if the correction is included.

No Impact of L_{eff} below 3 keVr





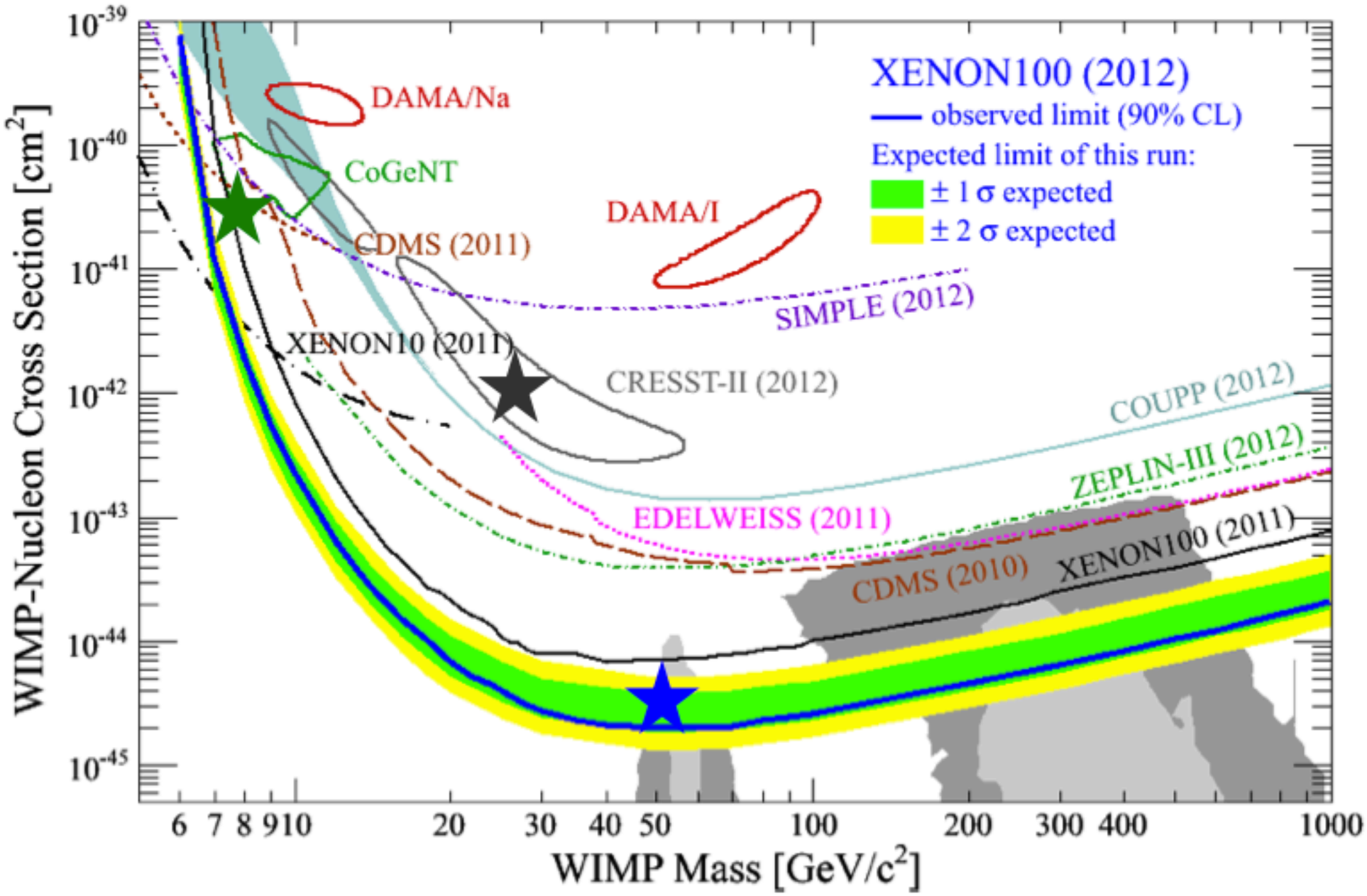




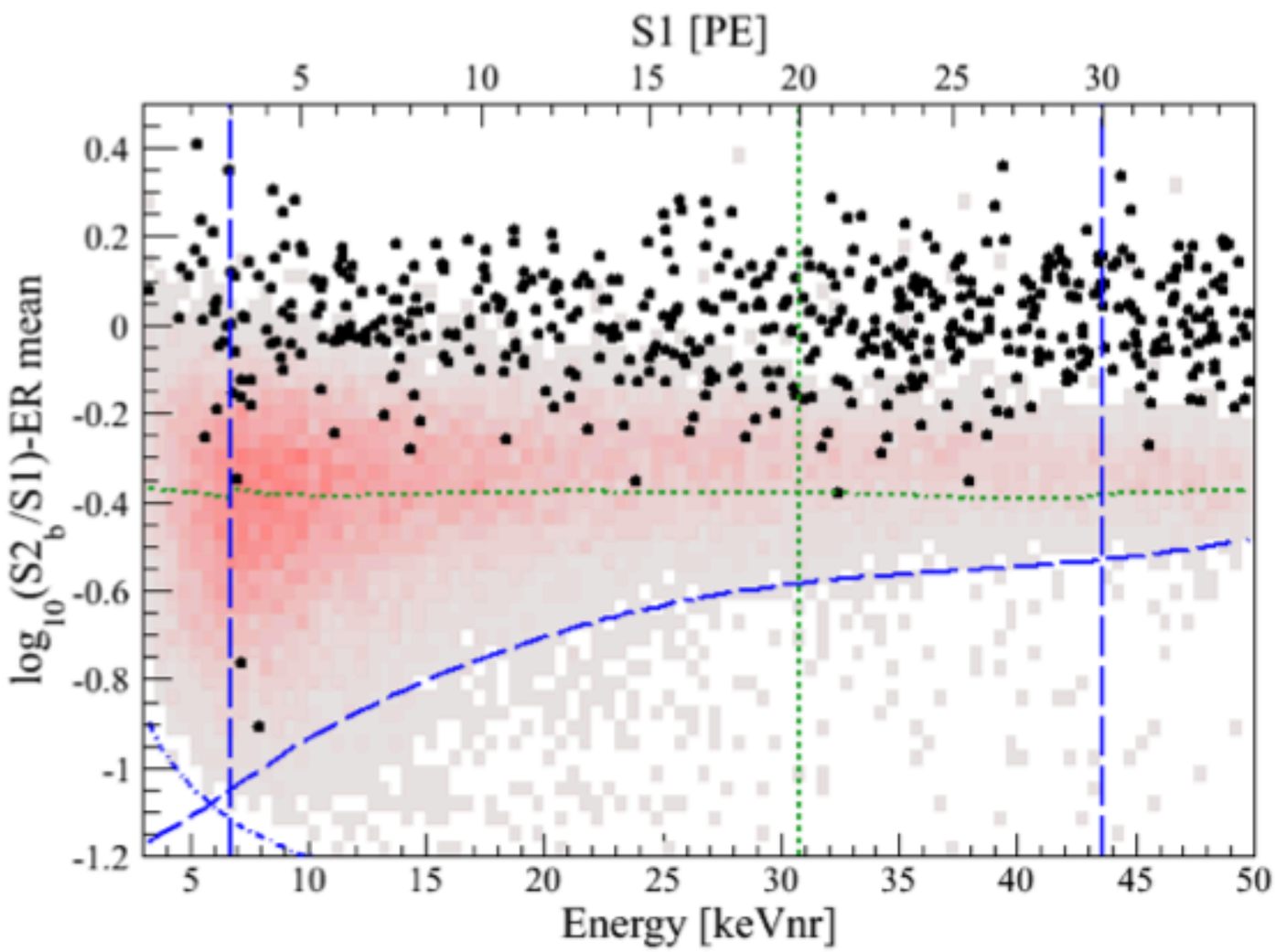
„standard“ Leff

L_{eff}=0 below 3 keVnr

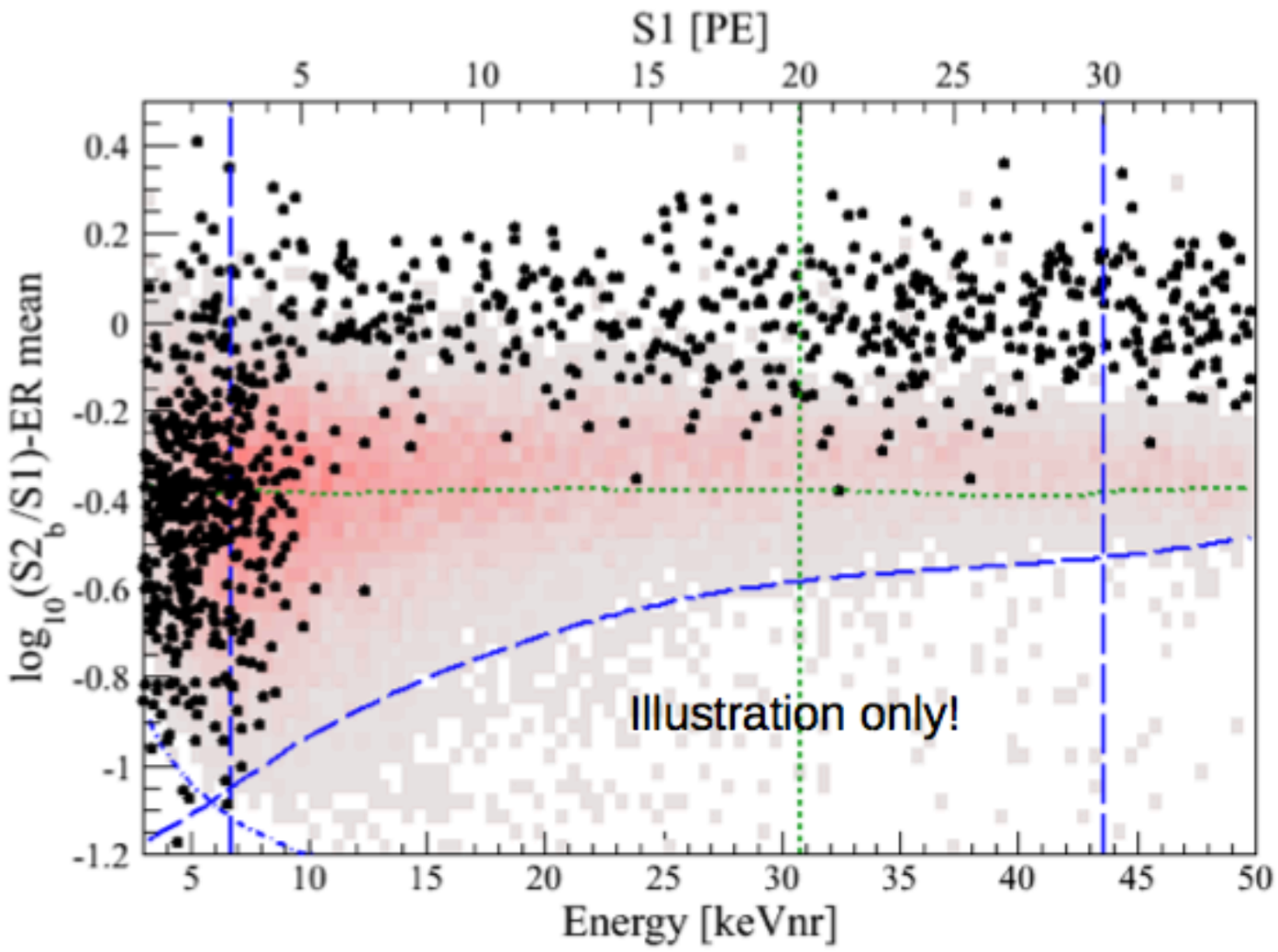
The new XENON100 Limit



What XENON100 sees...

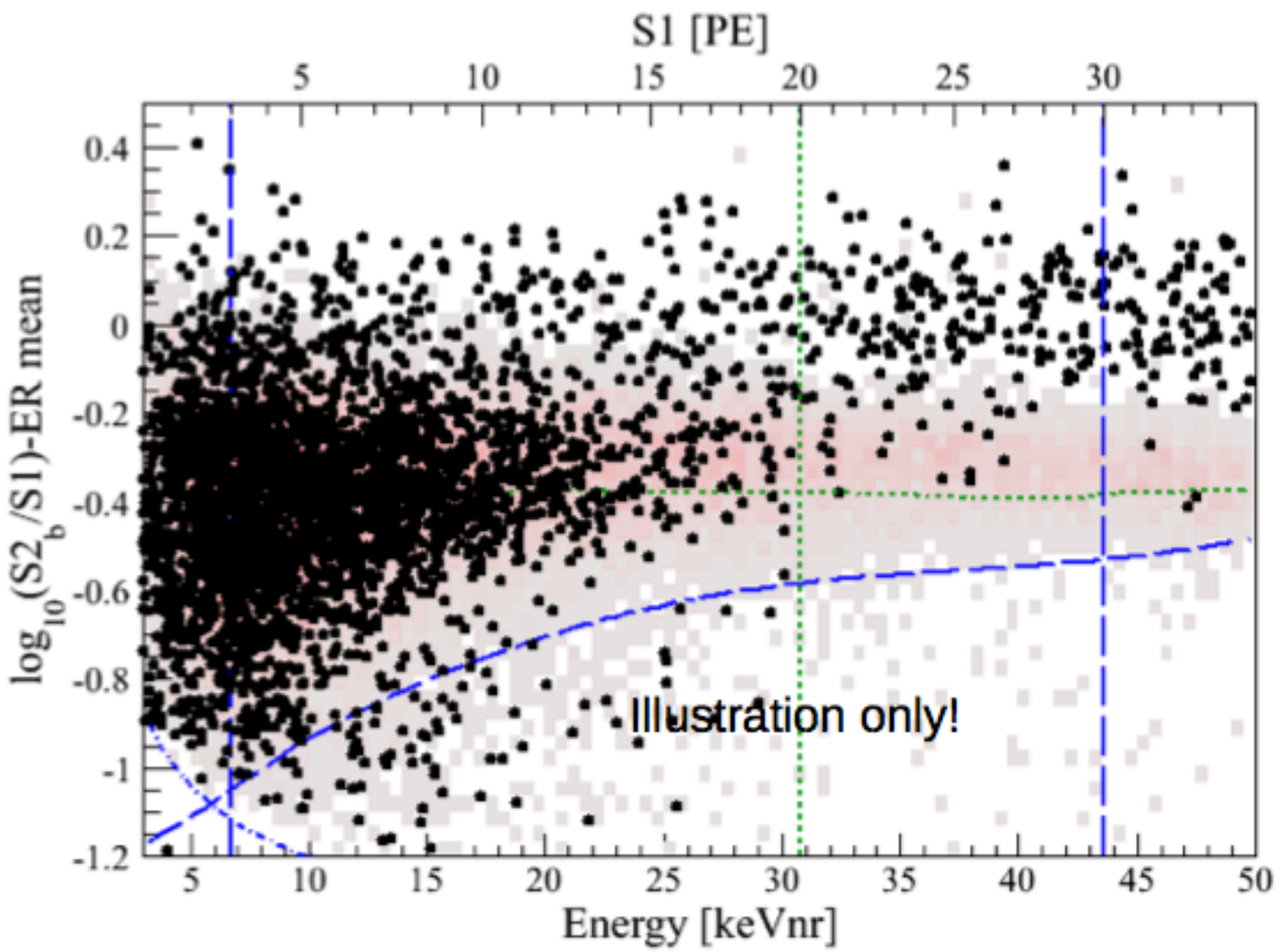


A light mass WIMP...



m_χ= 8 GeV/c² σ=1.0x10^{-40}cm²

A CRESST-like signal...



m_χ= 25 GeV/c² σ=1.6 x10^{-40} cm²