Dark Matter Direction Detection: Experiment, Current Status and Prospects

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Warsaw Workshop on Non-Standard Dark Matter: Multi-component Scenarios and Beyond
June 3, 2016

Outline

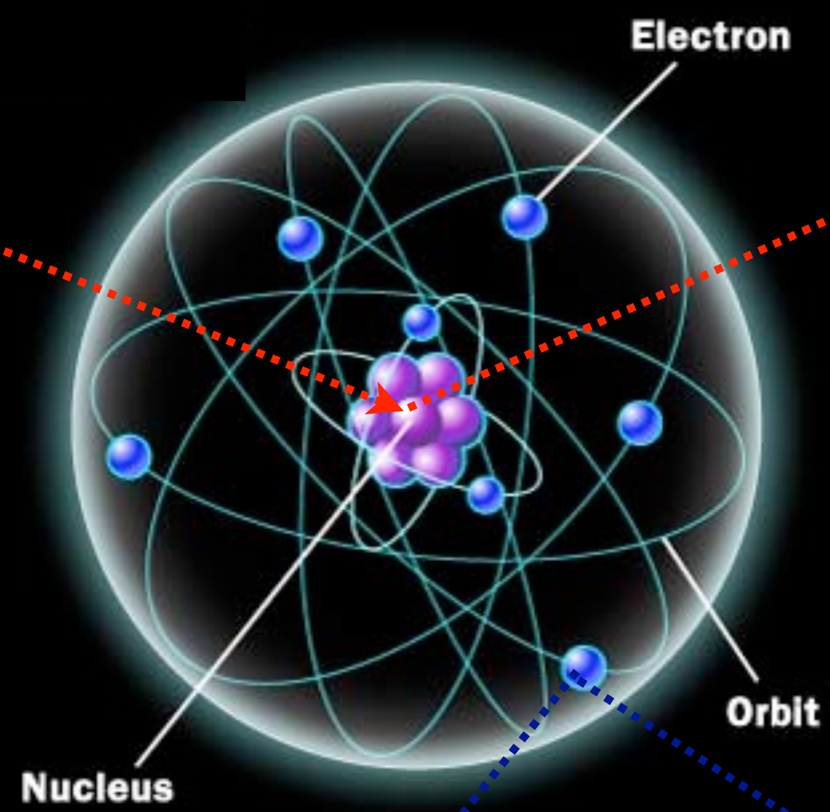
Experimental Considerations in Direct Detection Searches

Status and Prospects of Experiments

Non-WIMP Dark Matter in Direct Detection Experiments

Dark Matter Direct Detection

Signal: $\chi N \rightarrow \chi N$



Backgrounds:

$\gamma\, e^- \rightarrow \gamma\, e^-$

$n\ N \rightarrow n\ N$

$N \rightarrow N' + \alpha, e^-$

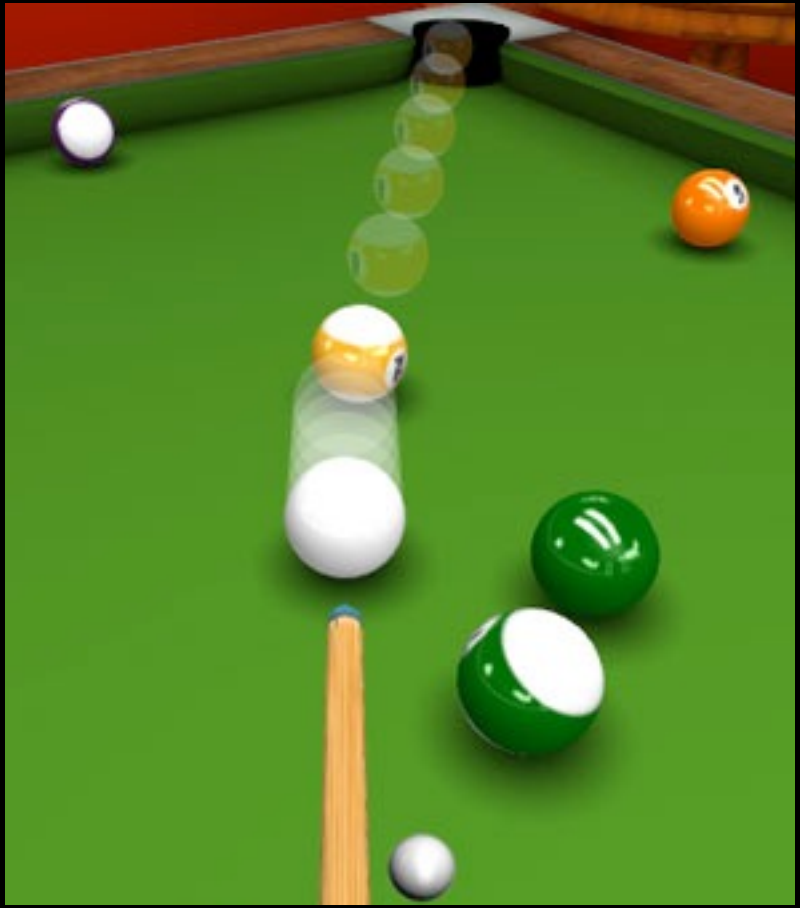
$\nu\ N \rightarrow \nu\ N$

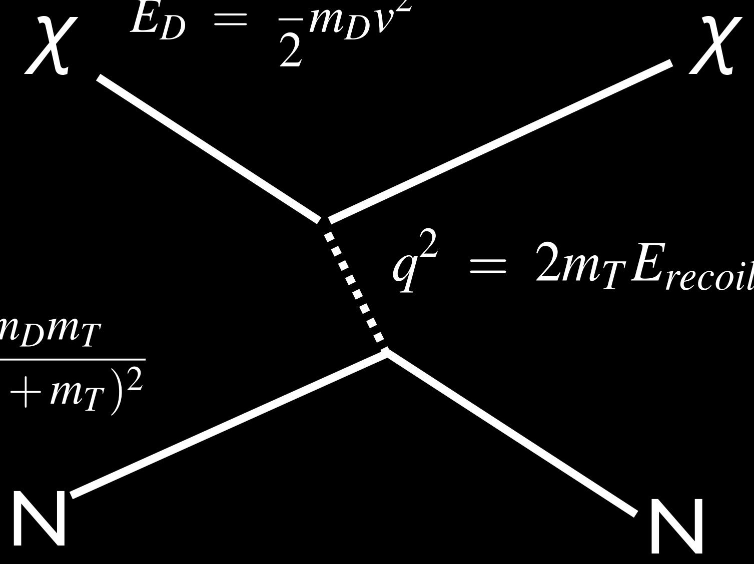
detector requirements: particle ID for recoil N, e-, alpha, n (multiple) final states

WIMP Scattering

kinematics: *v/c ~ 8E-4!*

recoil angle strongly correlated with incoming WIMP direction





$$E_D = \frac{1}{2} m_D v^2$$

$$q^2 = 2 m_T E_{recoil}$$

$$r = \frac{4 m_D m_T}{(m_D + m_T)^2}$$

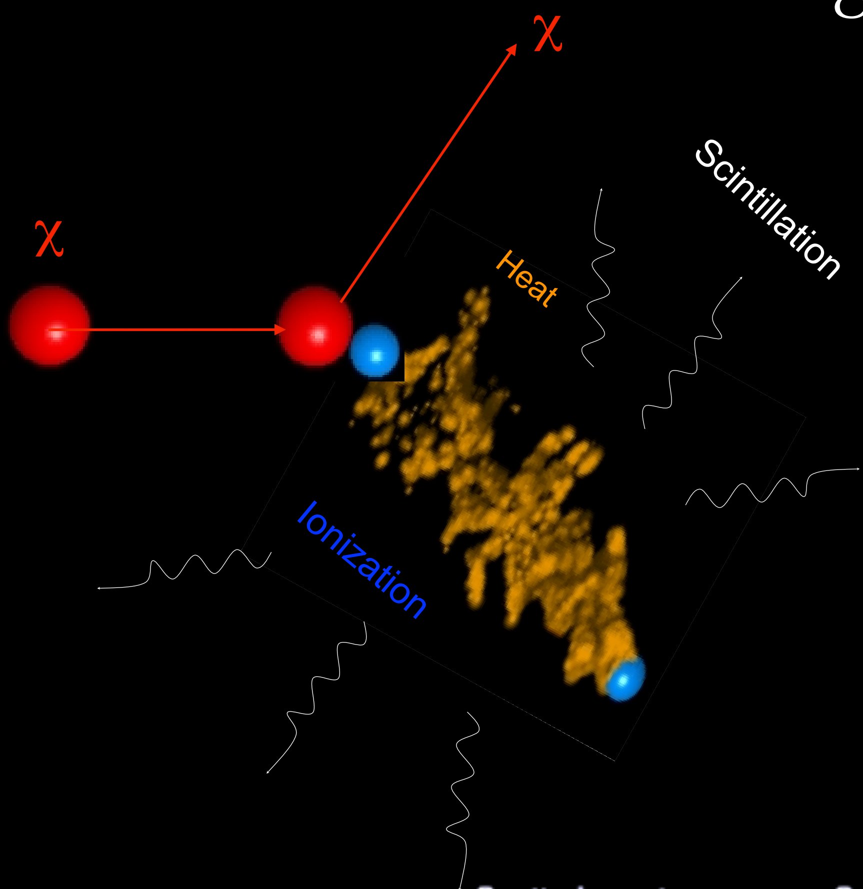
$$E_{recoil} = E_D r \frac{(1 - cos\theta)}{2}$$

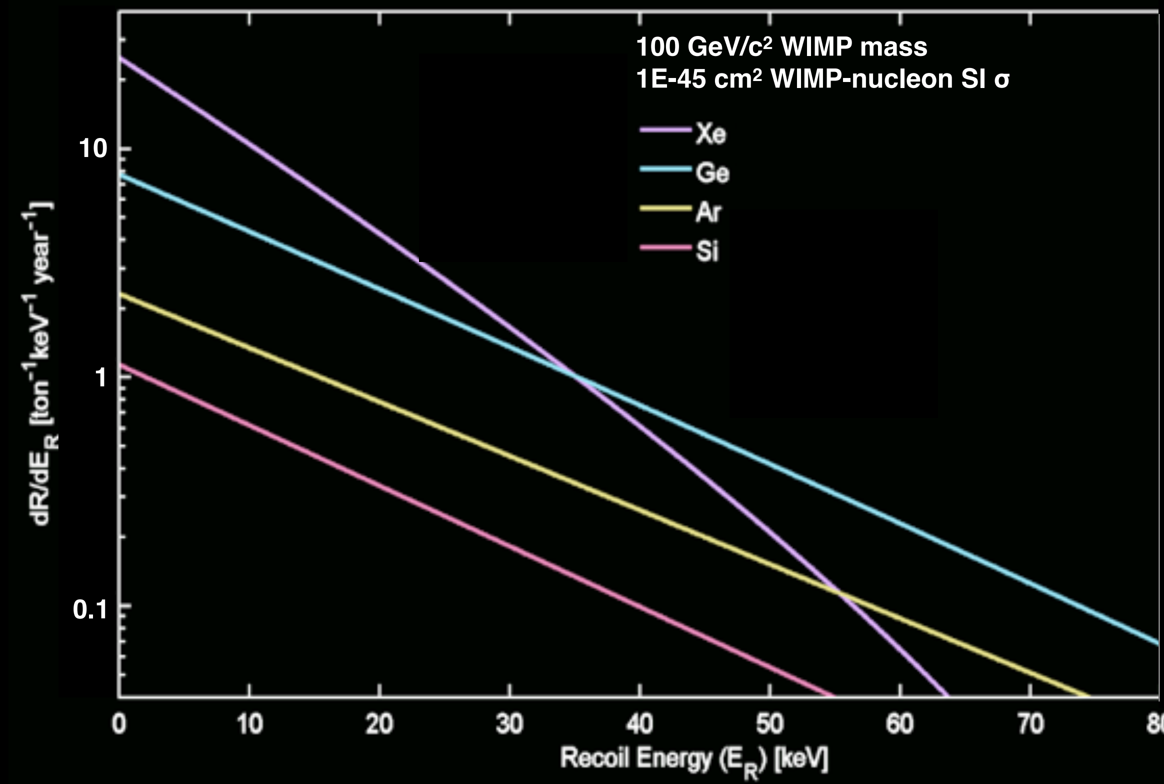
<u>Spin Independent:</u>
χ scatters coherently off of the entire nucleus A: σ~A^2
D. Z. Freedman, PRD 9, 1389 (1974)

<u>Spin Dependent:</u>
mainly unpaired nucleons contribute to scattering amplitude: σ~ *J(J+1)*

detector requirements: measure recoil energy, time, +angle

Observable: Recoil Energy





Scattering rate   Sun's velocity around the galaxy   WIMP velocity distribution

$$dR/dQ \sim (\sigma_0 \rho_0 /\sqrt{\pi}\, v_0\, m_\chi m_r^{2})\, F^{2}(Q)\, T(Q)$$

WIMP energy density, 0.3 GeV/cm³   Form factor

detector requirements: ~1-10s of keV energy threshold, very low backgrounds

Detection Signature

PICO

Cogent COUPP

Picasso

Newage

DRIFT

ArDM

Xenon100

DarcSide

CDMS

EDELWEISS

CoGeNT

LUX

Panda-X

DMTPC

ANaIS

XMASS

DEAP/CLEAN

CRESST

KIMS

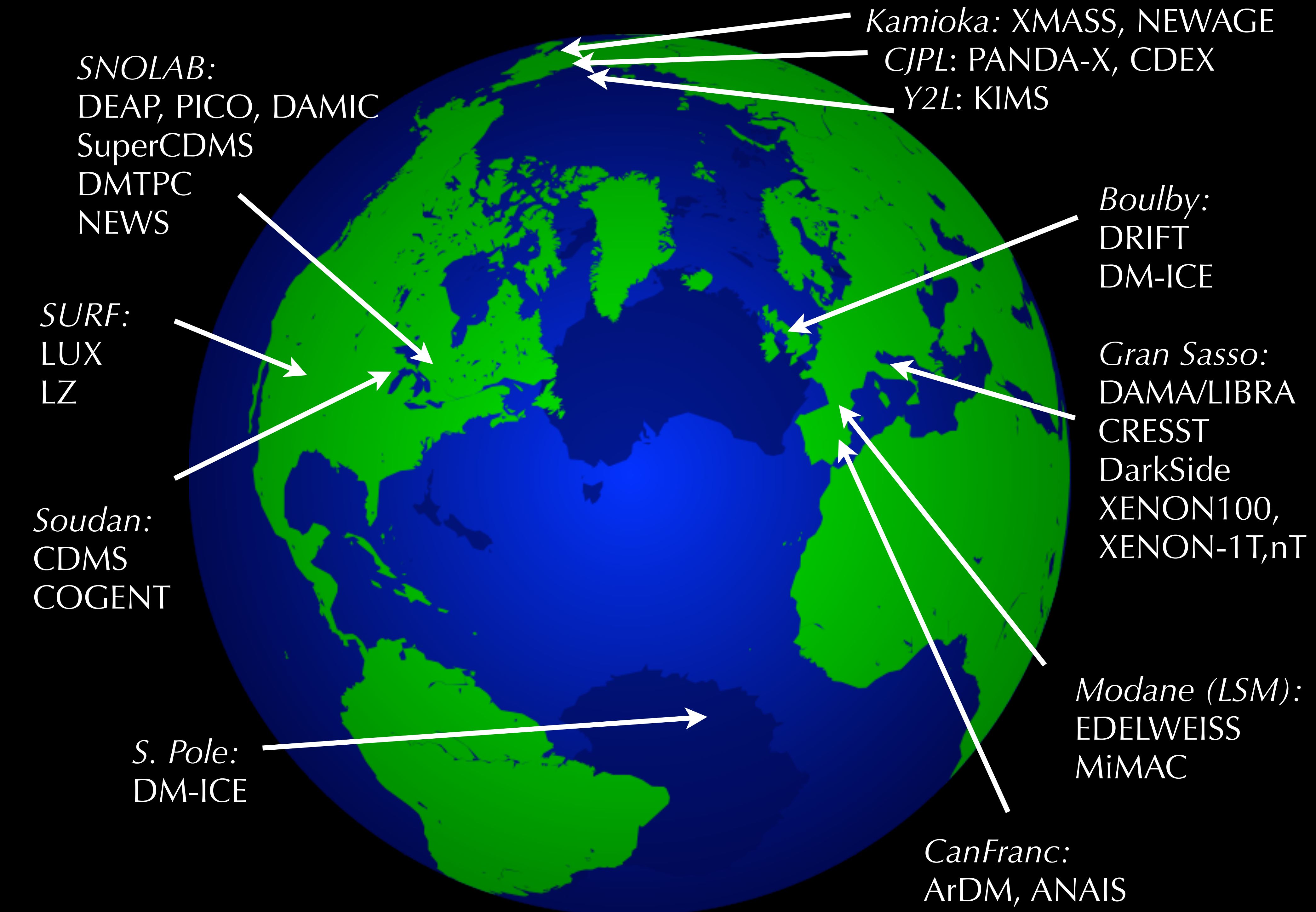
Dama/LIBRA

CRESSTII

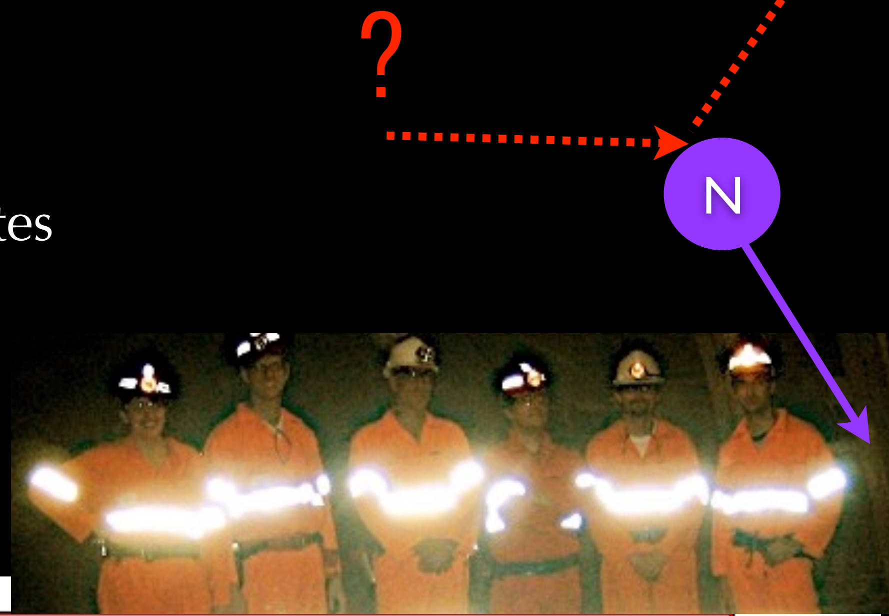
ROSEBUD

existing detectors: many targets (Xe, Ge, Ar, NaI, CsI, $CaWO_4$*,* CF_3I*,* C_3F_8*, F ...)*

Around the World

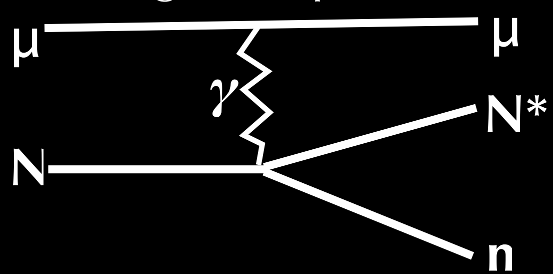


Backgrounds

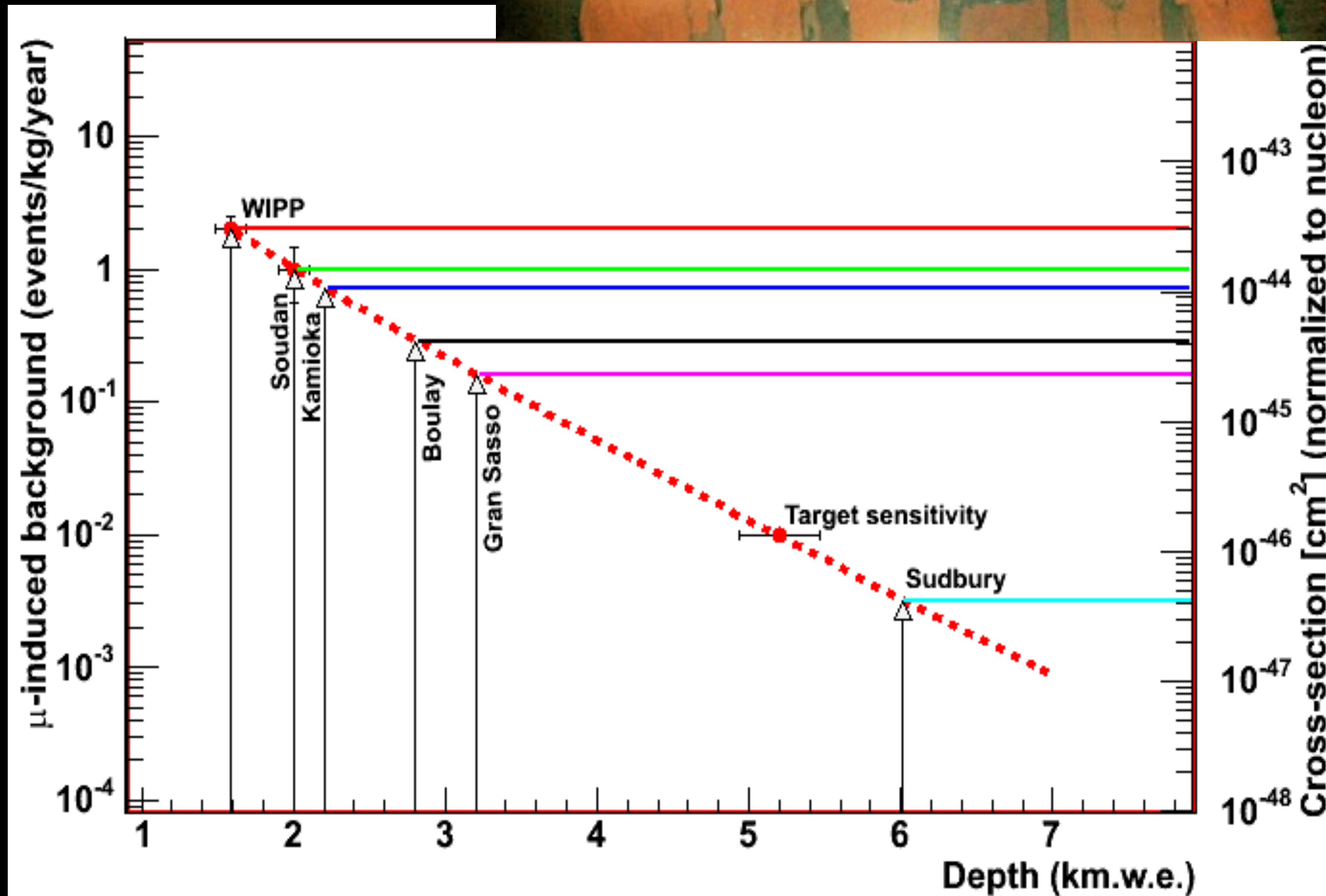


Gamma ray interactions: electron recoil final states
rate ~ N_e x (gamma flux), O(1E7) events/(kg day)
mis-identified electrons mimic nuclear recoils

Neutrons:
Nuclear recoil final state.
(alpha,n), U, Th fission,
cosmogenic spallation



Contamination:
^{238}U and ^{232}Th decays,
recoiling progeny and
mis-identified alphas, betas
mimic nuclear recoils

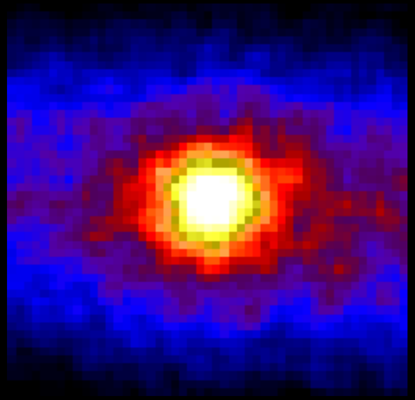


D.-M. Mei, A. Hime, PRD73:053004 (2006)

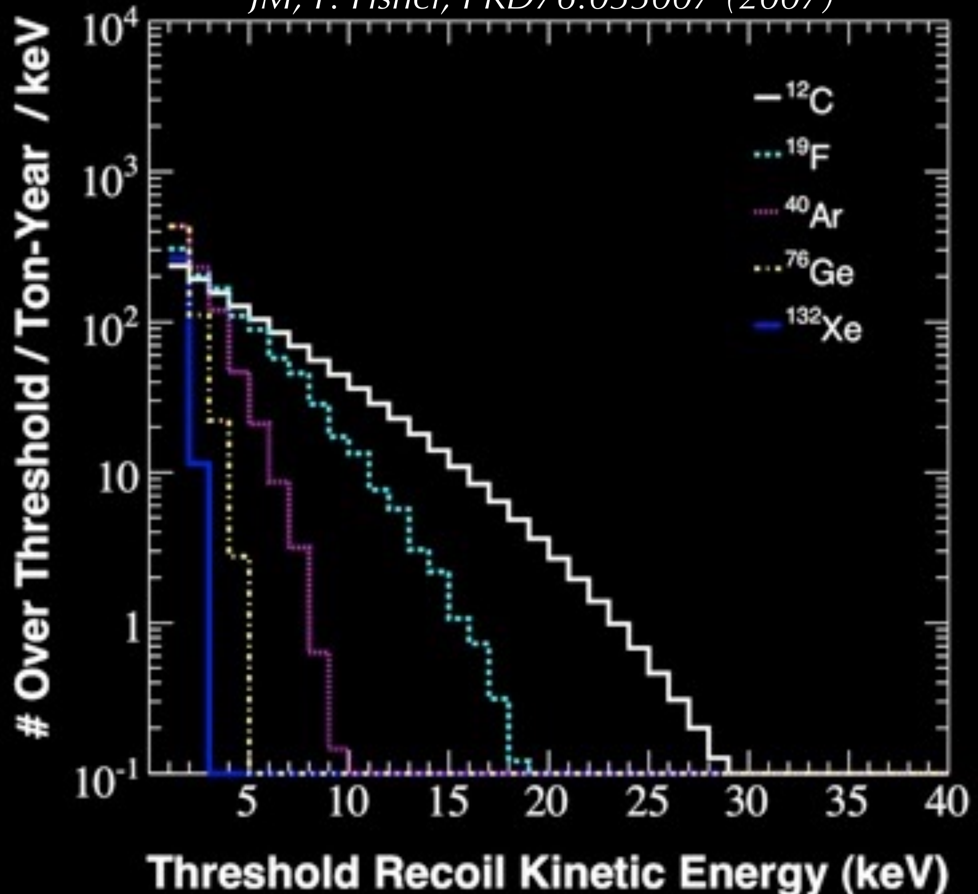
Irreducible Backgrounds

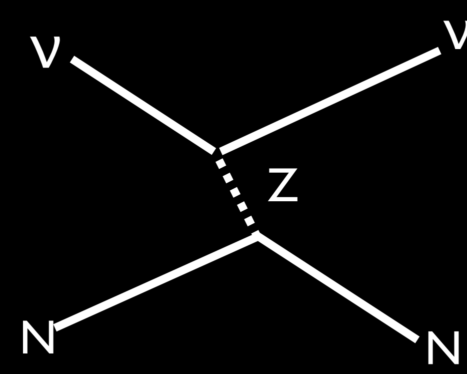
impossible to shield a detector from coherent neutrino scattering!

Φ(solar B^8) = $5.86 \times 10^6\ cm^{-2}\ s^{-1}$



JM, P. Fisher, PRD76:033007 (2007)





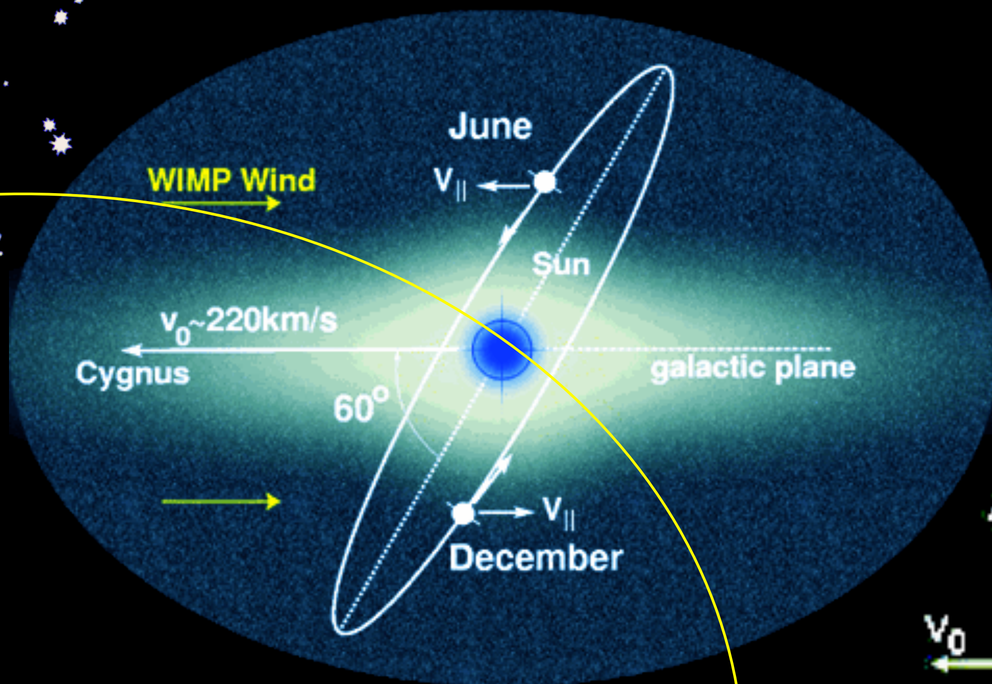
nuclear recoil final state
neutrino bound at 10^{-46}-10^{-48} cm^2
in zero-background paradigm

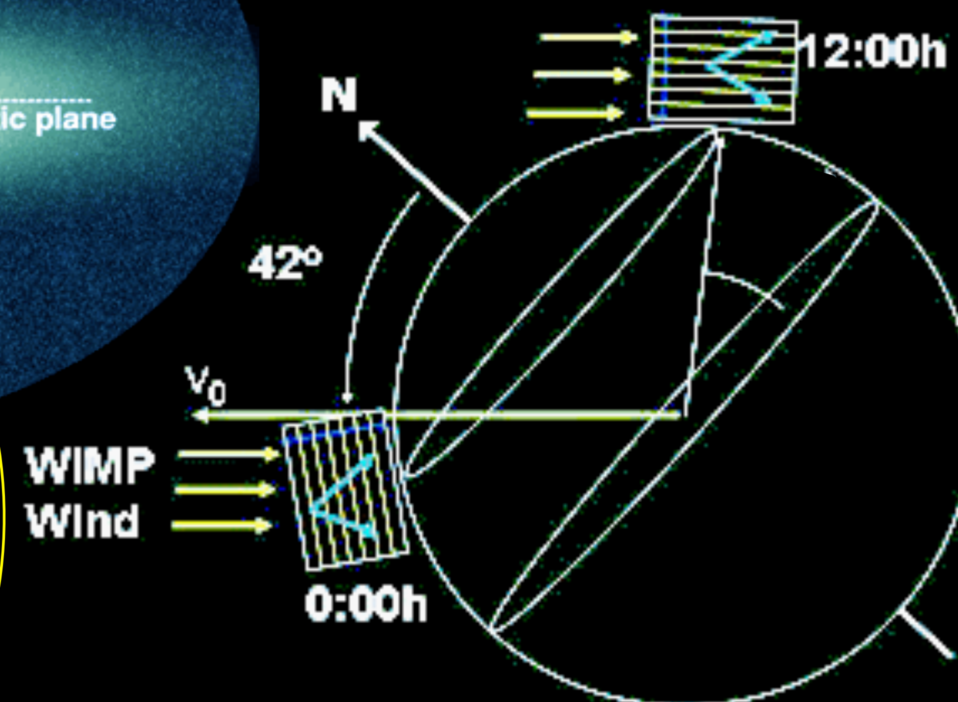
unless you measure
the direction!

Modulation Signatures

Annual event rate modulation:
June-December asymmetry ~2-10%.

Drukier, Freese, Spergel, Phys. Rev. D33:3495 (1986)





Sidereal direction modulation:
asymmetry ~ 20-100% in
forward-backward event rate.

Spergel, Phys. Rev. D36:1353 (1988)

detector requirements: achieve + measure stability vs. time to a very high level!

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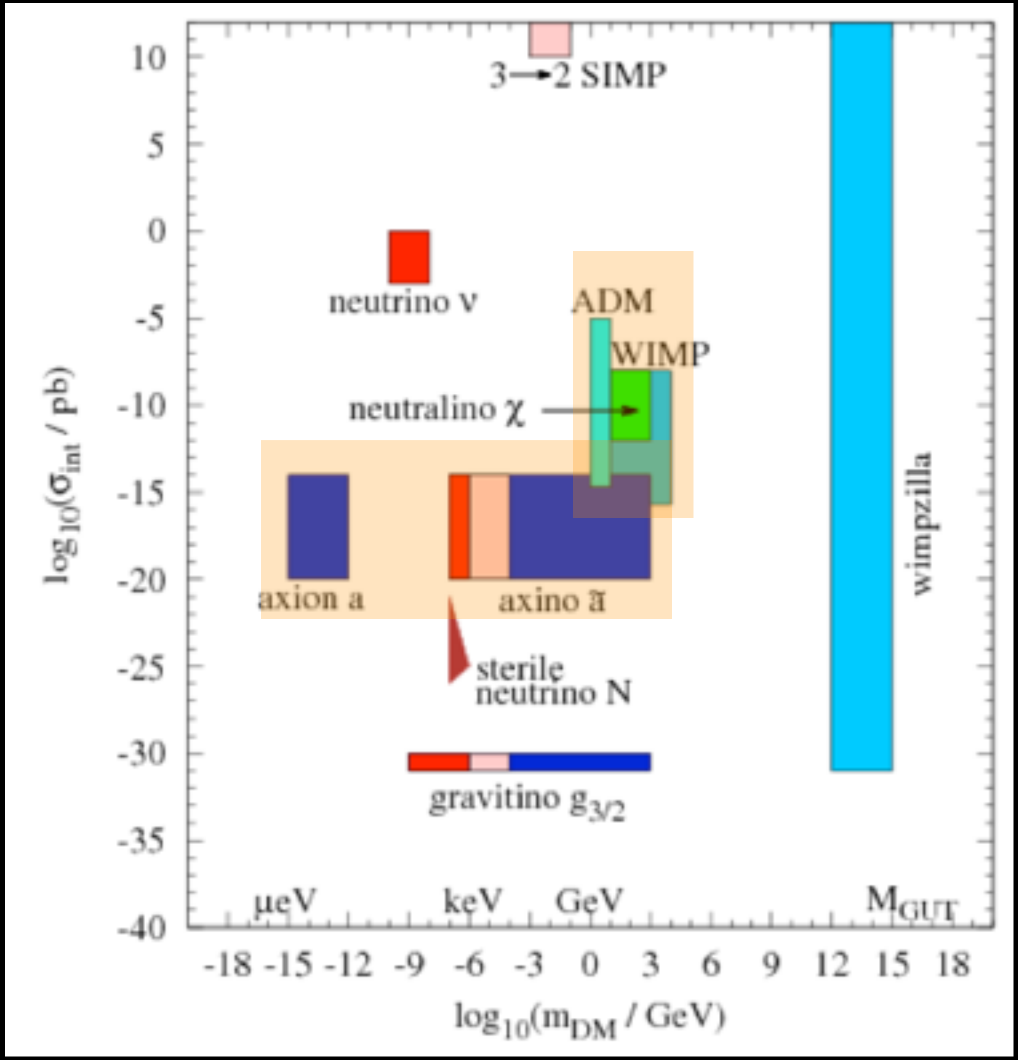
Model Space

Wide range of parameters!

Direct detection searches generally optimised for WIMP sensitivity…



Baer et al., arXiv:1407.0017

Model Space

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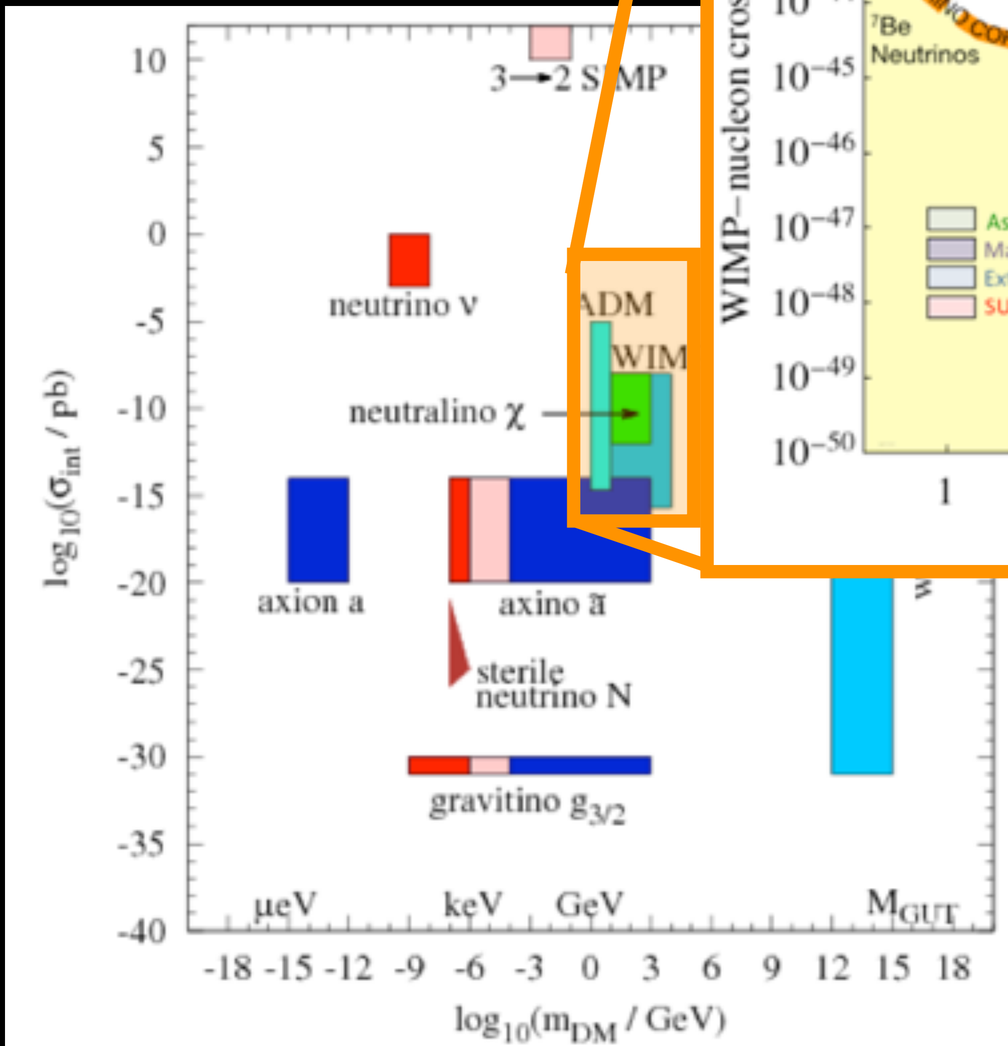
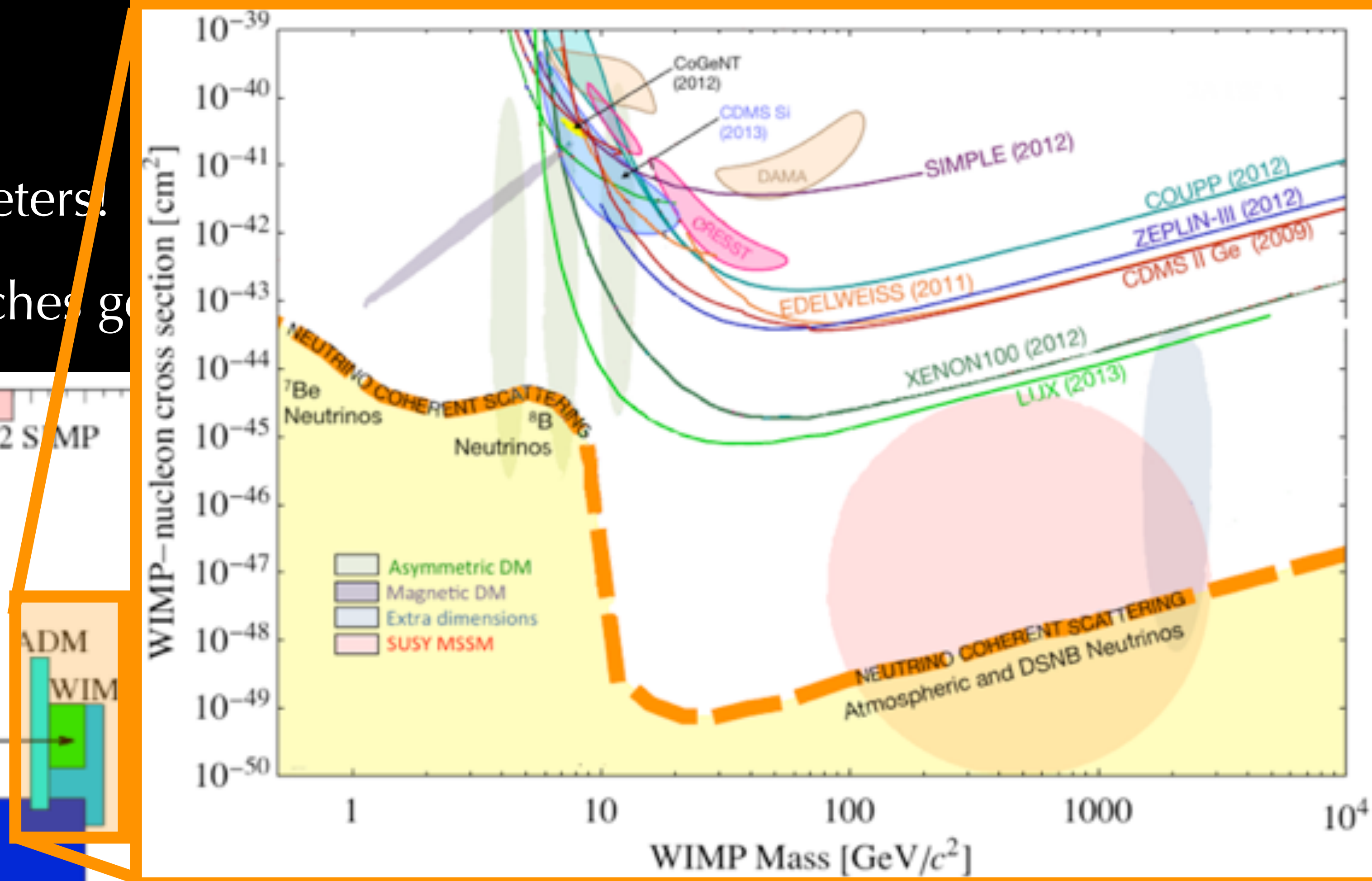
Direct detection searches g





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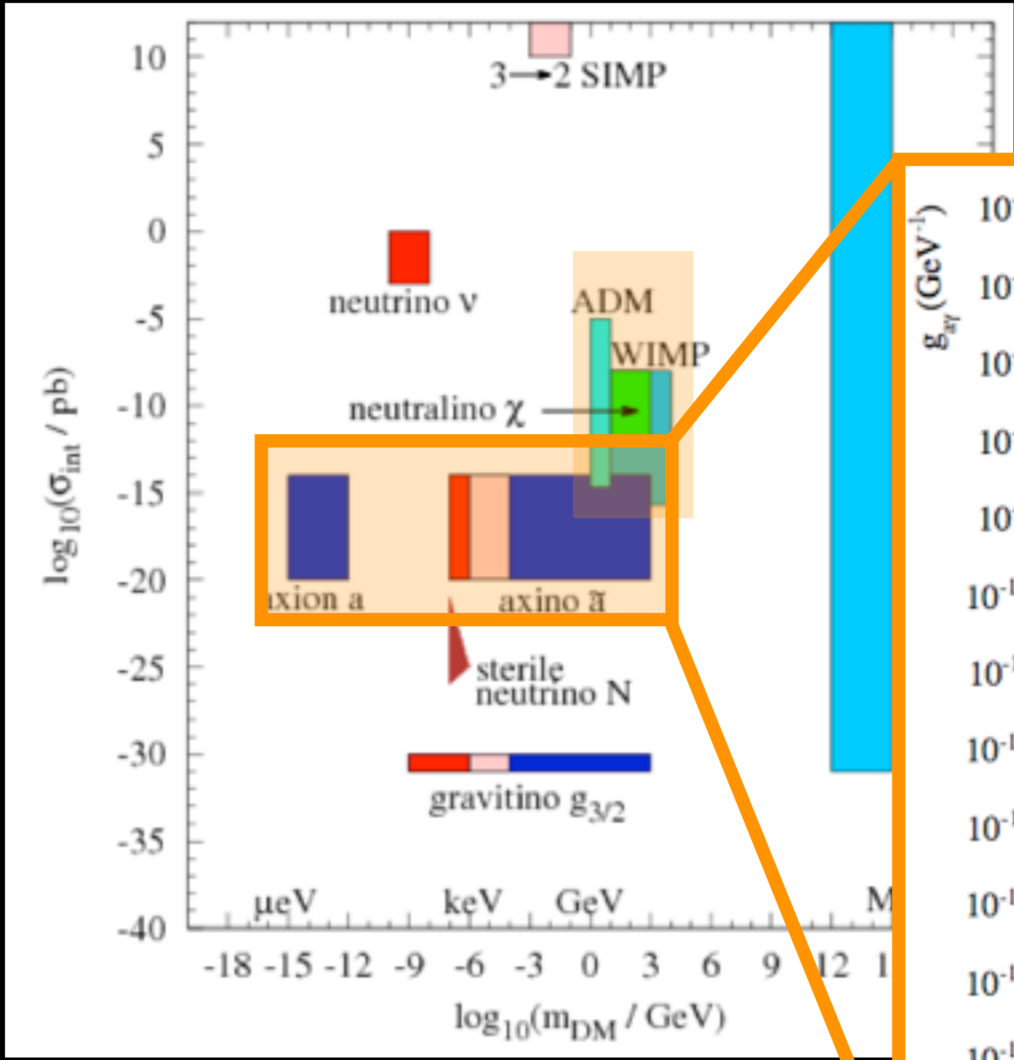
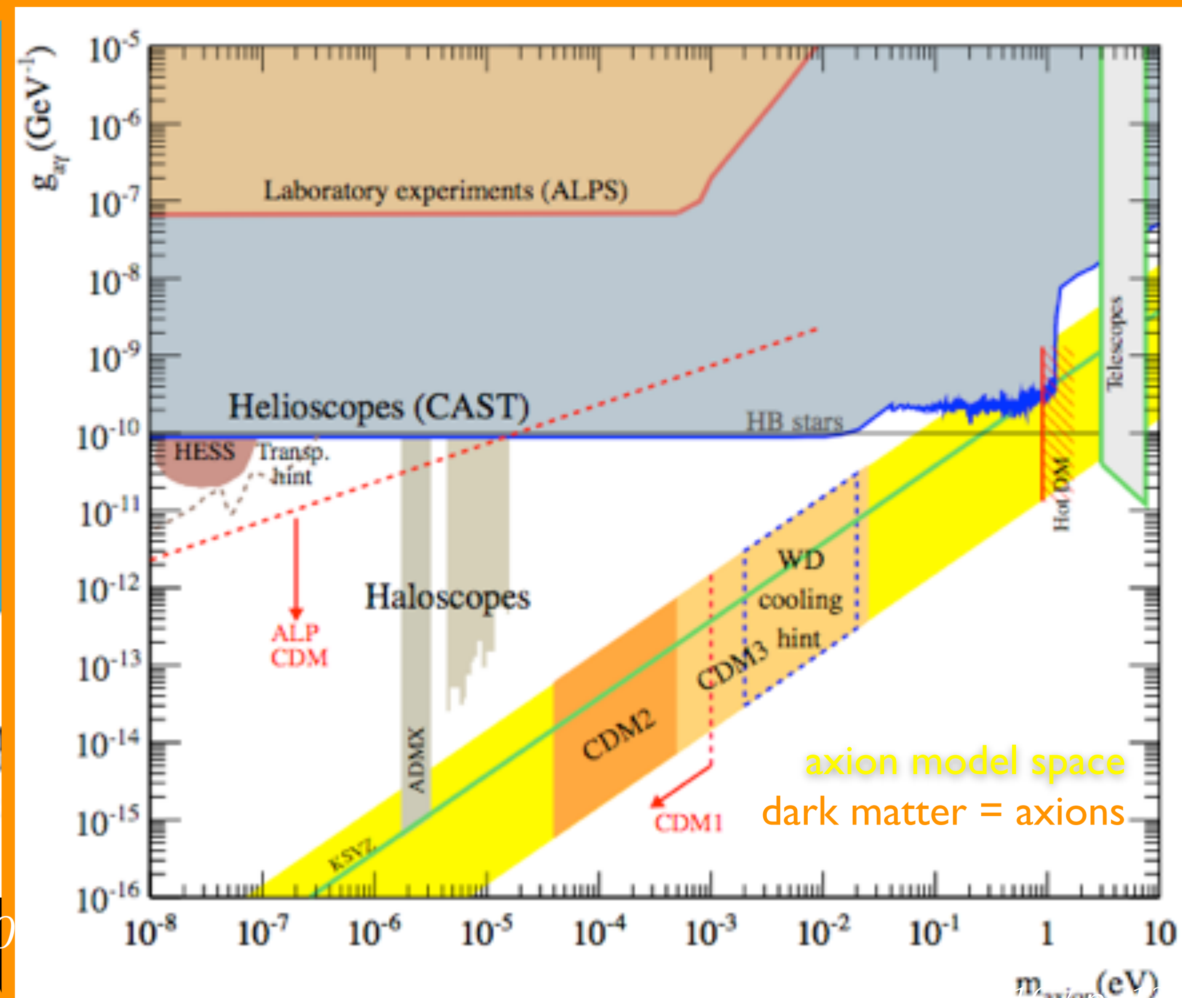
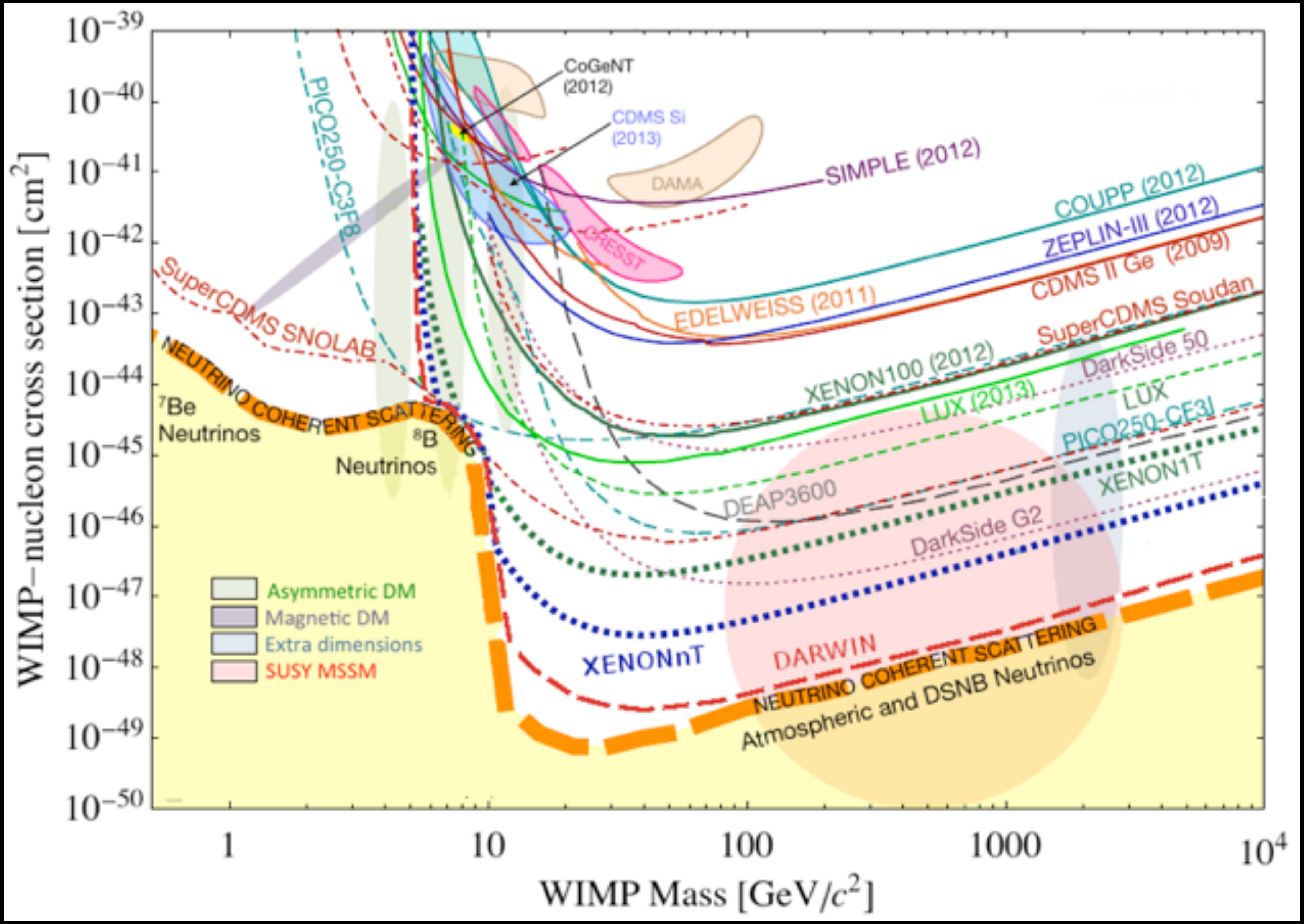


but starting to look for axions/ALPs too!



Baer et al., arXiv:1407.00

The Low-Background Frontier: Prospects



1 event/ kg/day

1 event/ 100kg/day

1 event/ 100 kg/ 100 days

so far: ~3 years / order of magnitude

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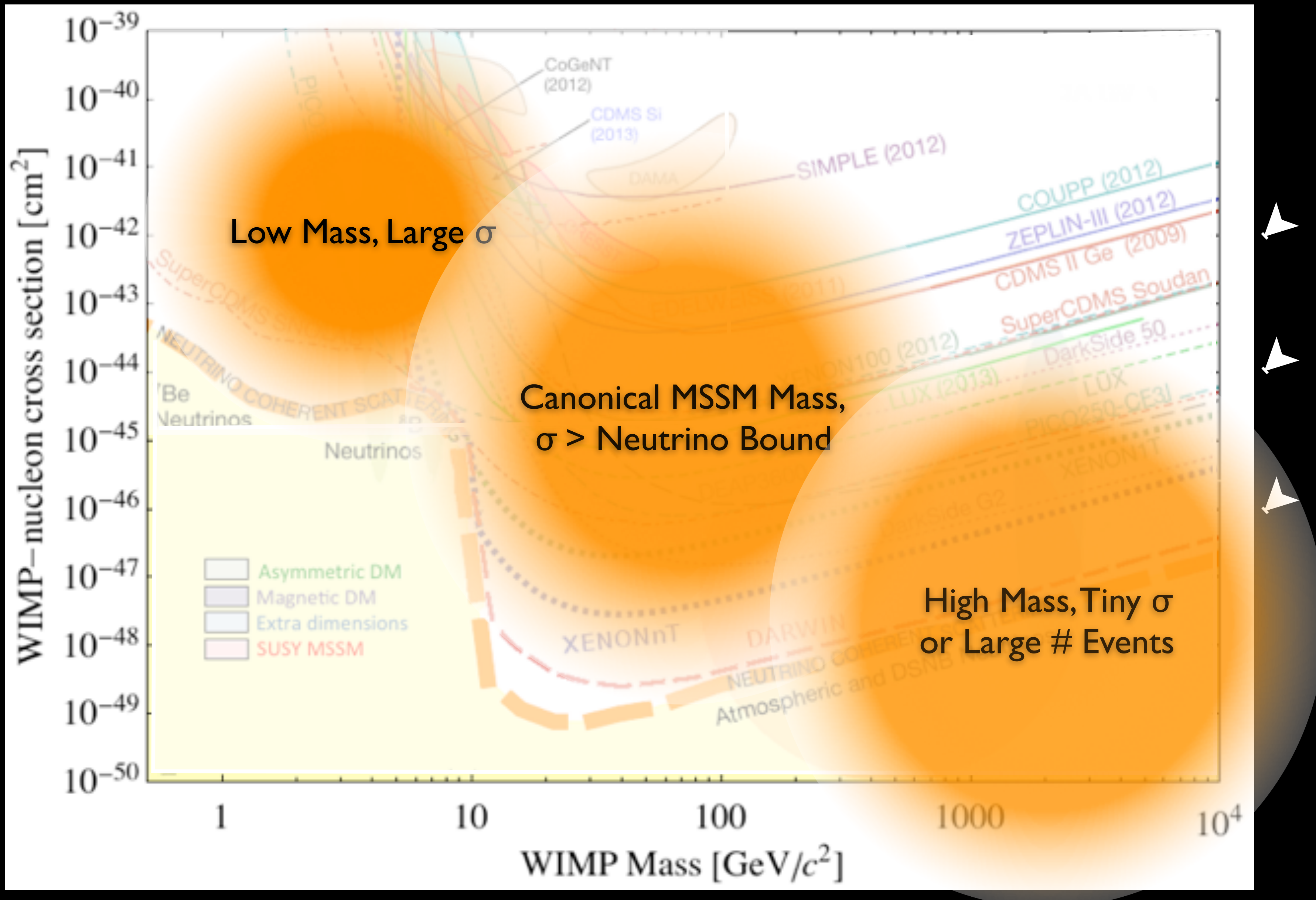

1 event/ kg/day

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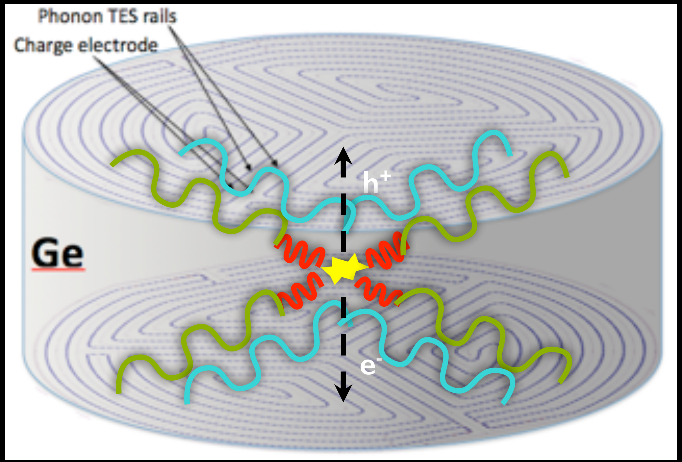
so far: ~3 years / order of magnitude

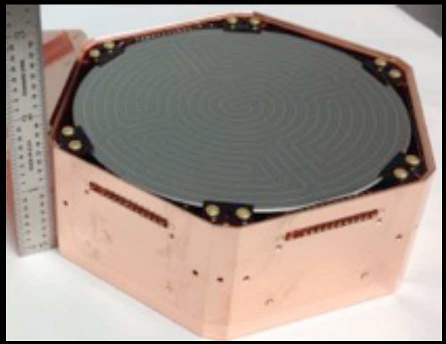
Low Mass, Large σ

Bolometers

phonon, ionisation or scintillation readout of crystals with TES at O(10 mK), using Ge (SuperCDMS, EDELWEISS, COGENT, CDEX), Si (SuperCDMS), $CaWO_4$ (CRESST)

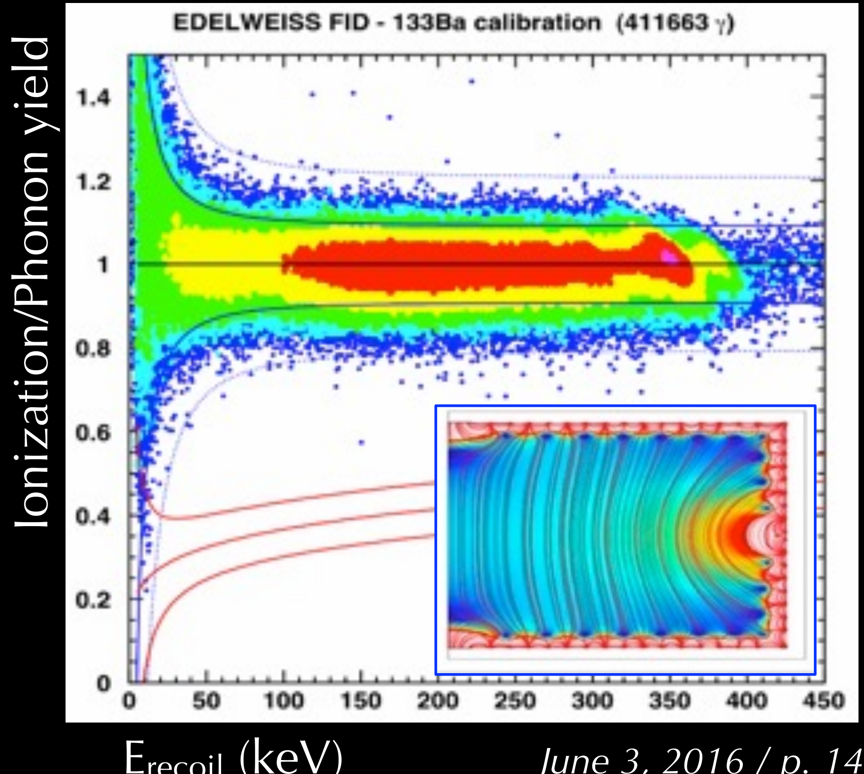
Phonon rails: 600 gm (SuperCDMS) or 800 gm (EDELWEISS) Ge, TES for E_{recoil} & R (timing)

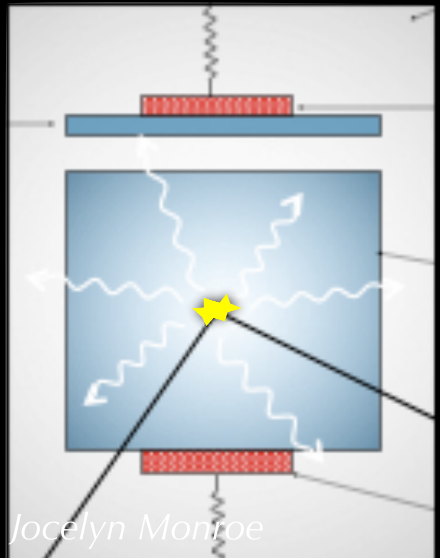




Charge electrodes: biased at +/- 2V, measure E_{recoil}, configuration optimised to reject surface events

EDELWEISS: interleaved electrodes reduce surface backgrounds by x10^5





Scintillation side:
Si absorber on 300 gm $CaWO_4$, tungsten TES readout for particle ID

Phonon side:
TES readout to measure E_{recoil}l

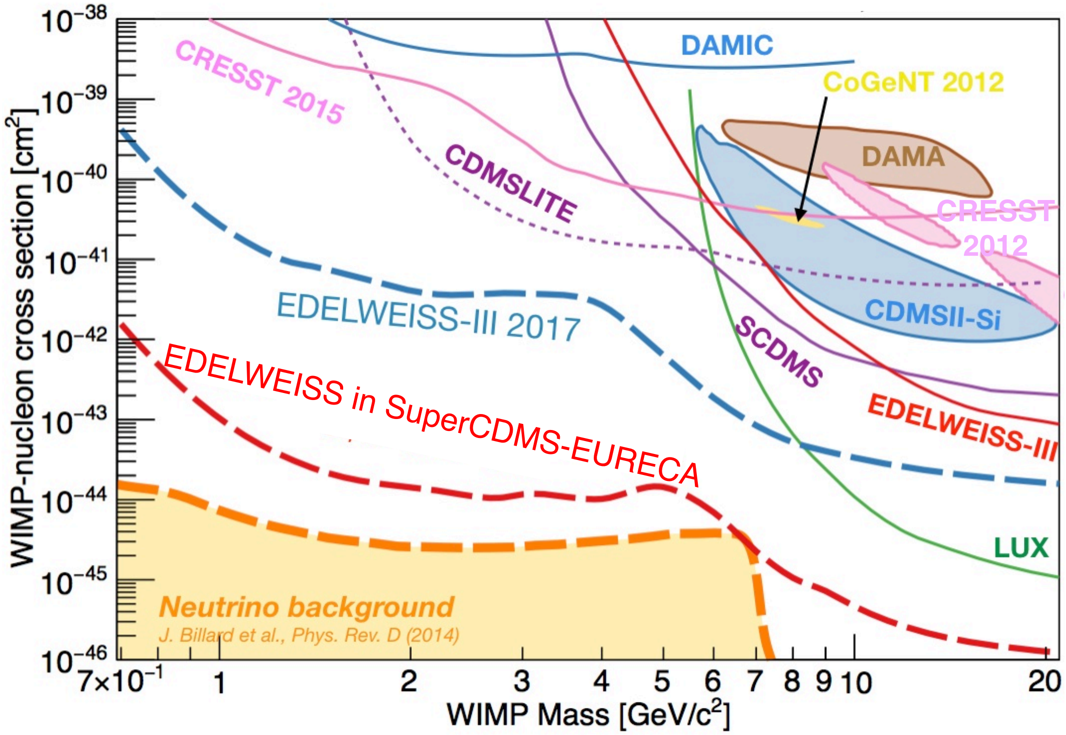
EDELWEISS (thanks to J. Gascon)

EDELWEISS

- Largest operating cryogenic Ge array (20 kg) for Direct DM search
- Latest results: arXiv:1603.05120

- 2017 goal @ LSM: optimizing sensitivity to 1-10 GeV WIMPs

- Beyond: completing the exploration of the low-WIMP mass region with a ~100 kg array of EDELWEISS detectors would require the environment projected for EURECA/SuperCDMS



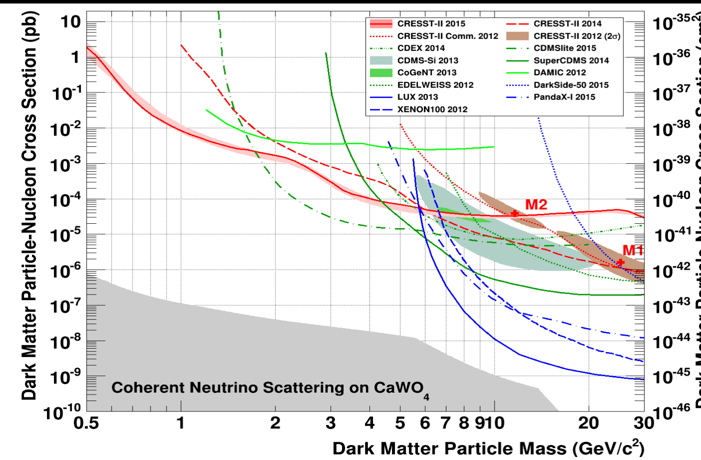
CRESST

(thanks to F. Petricca)

CRESST- II

300g scintillating $CaWO_4$ crystals
Measured nuclear recoil threshold ~300eV

- Leading sensitivity in low mass region
- Explore masses in the sub-GeV/c^2 range

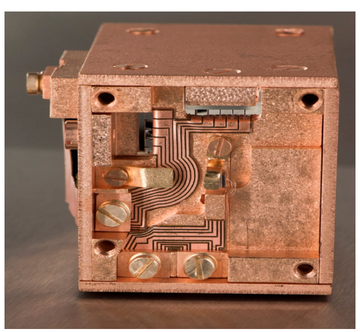


CRESST – III arXiv:1503.08065

25g $CaWO_4$ crystals
Optimized for nuclear recoil threshold <100eV

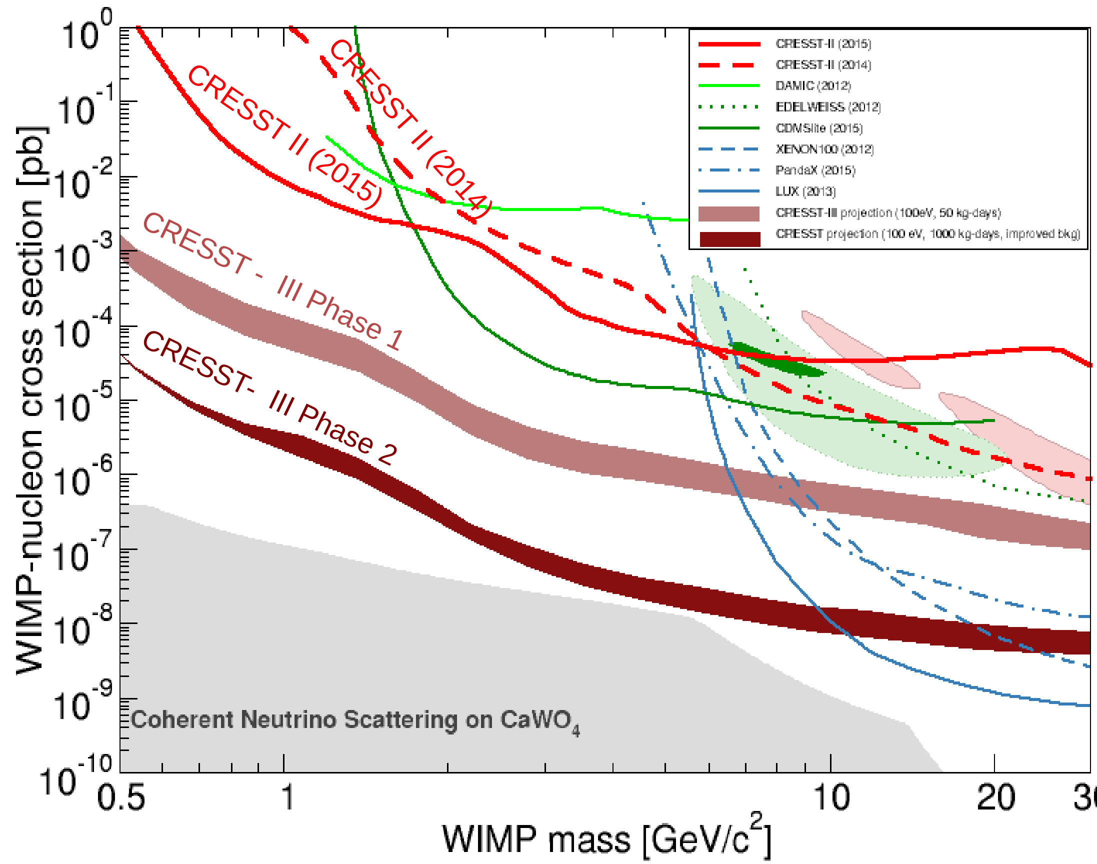
Phase 1

- Mounting of 10 modules completed
- Cool down in the next weeks
- 1 year of running ~50 kg days (2017)



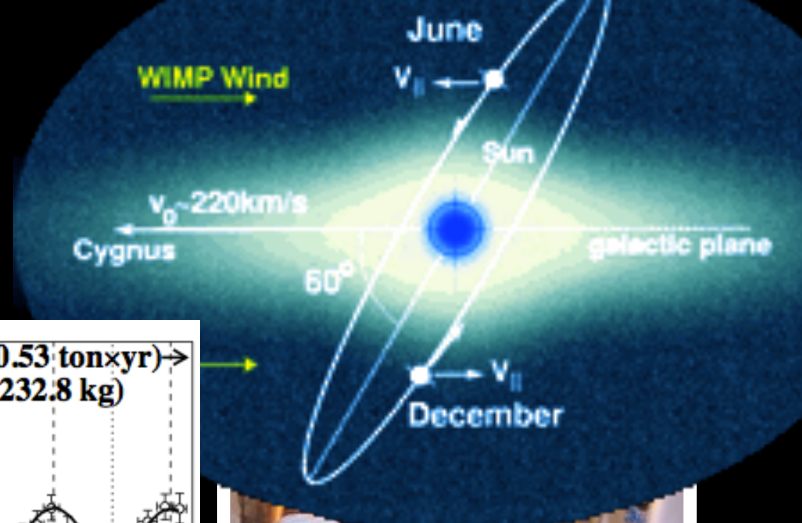
Phase 2

- 100 modules with improved background to approach the neutrino floor in the LNGS setup

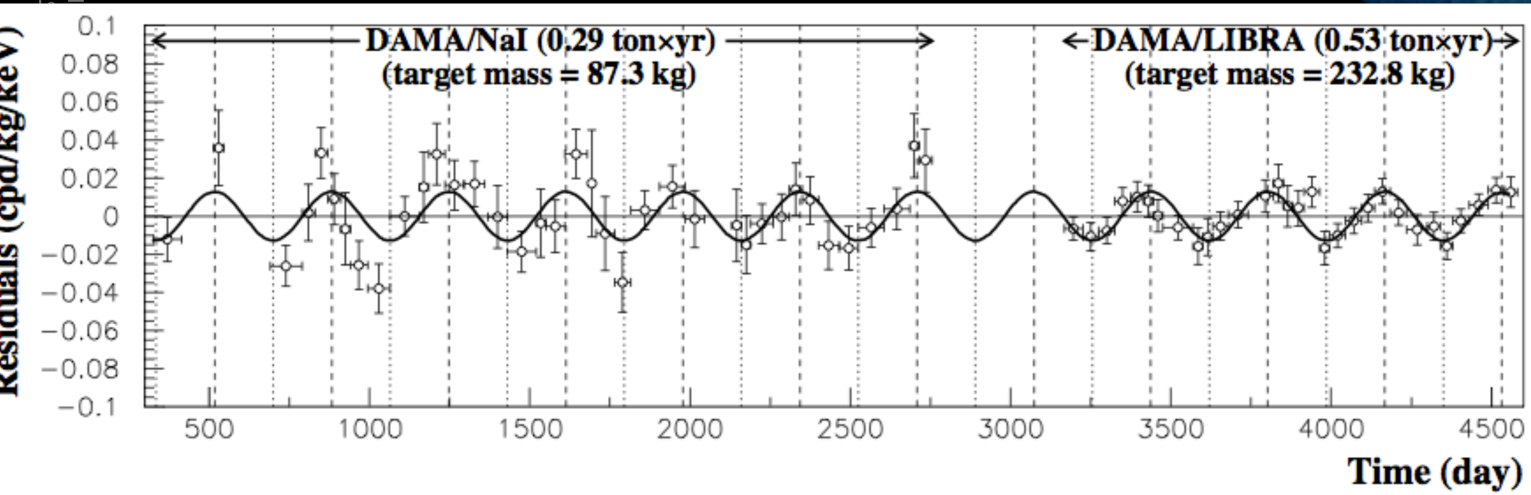


Low Mass, Large σ

Annual Modulation Tests



predicted annual modulation A~0.02-0.1, t_0 = 152.5 days



DAMA/LIBRA: measure (0.0112±0.0012) cpd/kg/keV, t_0 = (144±7) d in 1.33 T-yr.

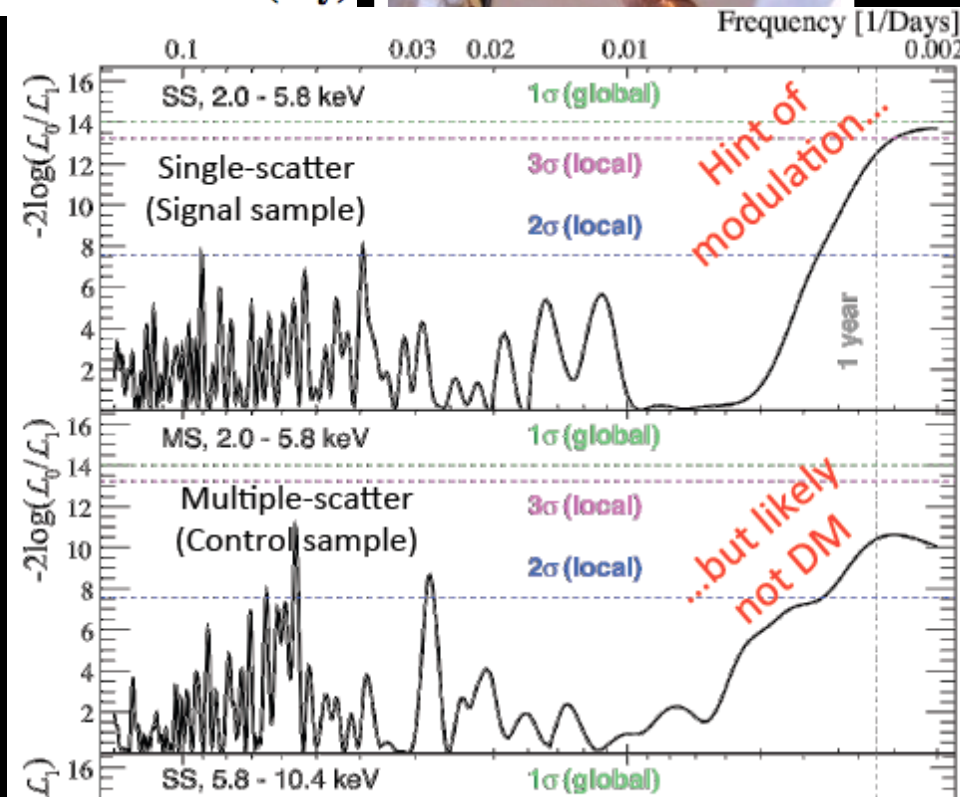
COGENT: Ge, ~2σ modulation reported. *arXiv:1401.3295*
MALBEK: Ge, no excess reported. *J. Wilkerson UCLADM'14*

CDMS: Ge, no modulation, at 98.3% CL, *arXiv:1203.1309*

KIMS: CsI (104.3 kg at YangYang), no modulation observed. *J.Phys.Conf.Ser. 384 (2012) 012020*

XENON100: Xe, 4.8σ exclusion of DAMA. *arXiv:1507.07748*

XMASS: Xe, 833 kg in Kamioka, model-independent analysis modulation result reported *arXiv:1511.04805*



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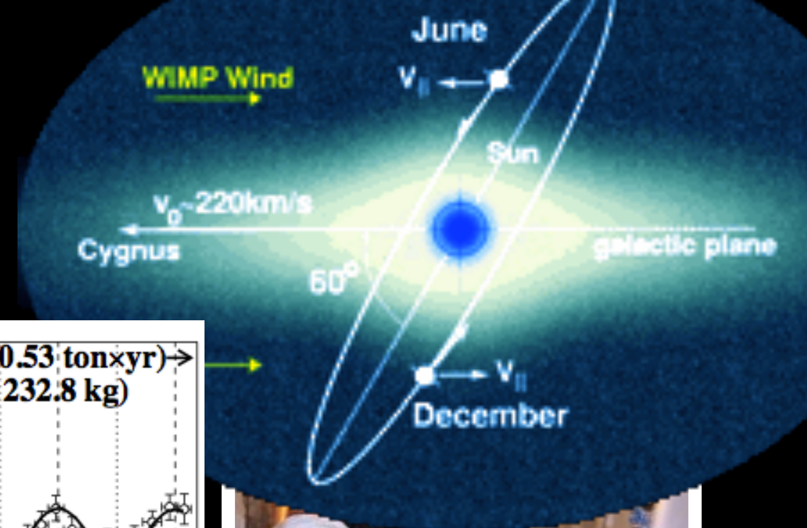

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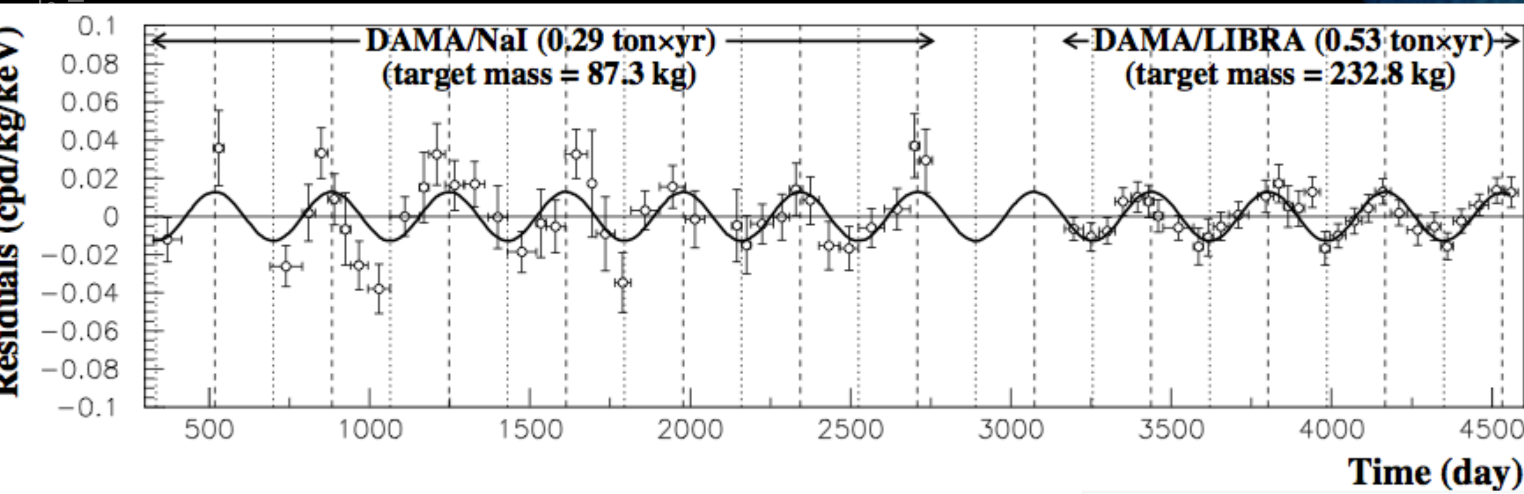

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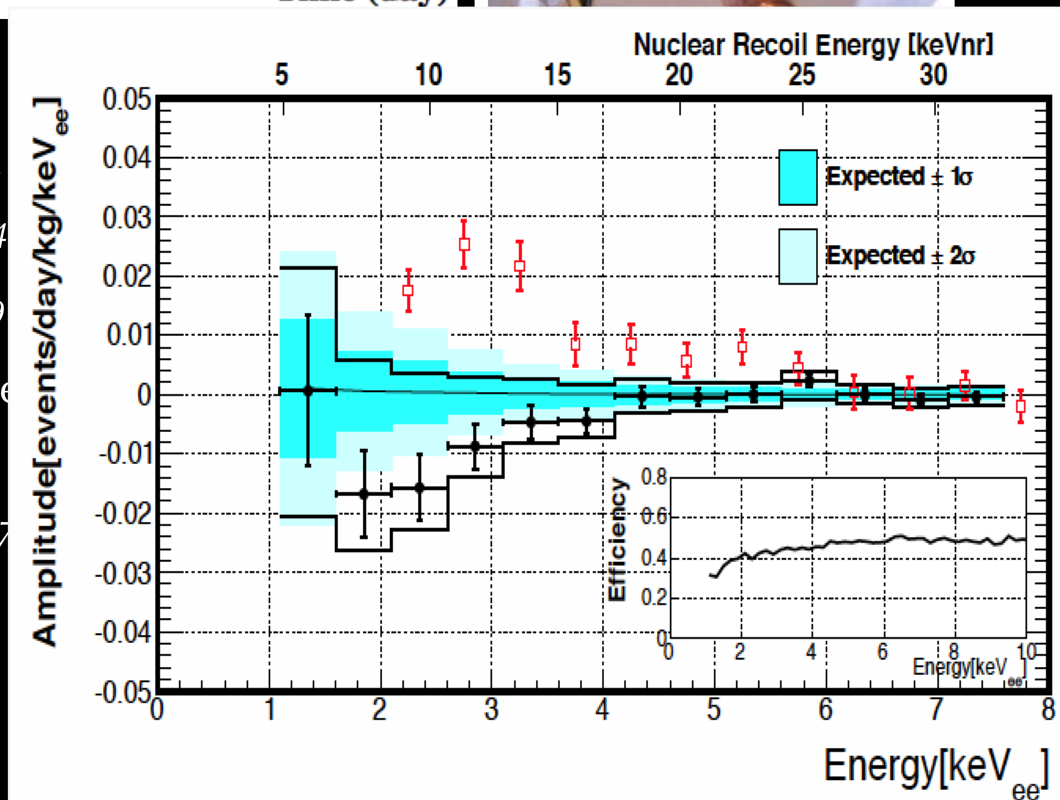


Annual Modulation Prospects

(thanks to J. Villar)

DAMA (LNGS), DM-Ice (S. Pole, Boulby), ANAIS (Canfranc), ++

INTERNATIONAL NaI(Tl)
COLLABORATIVE EFFORT

COMBINED ANALYSIS of 220 kg NaI(Tl) with present background levels

112.5 kg at Canfranc, Spain

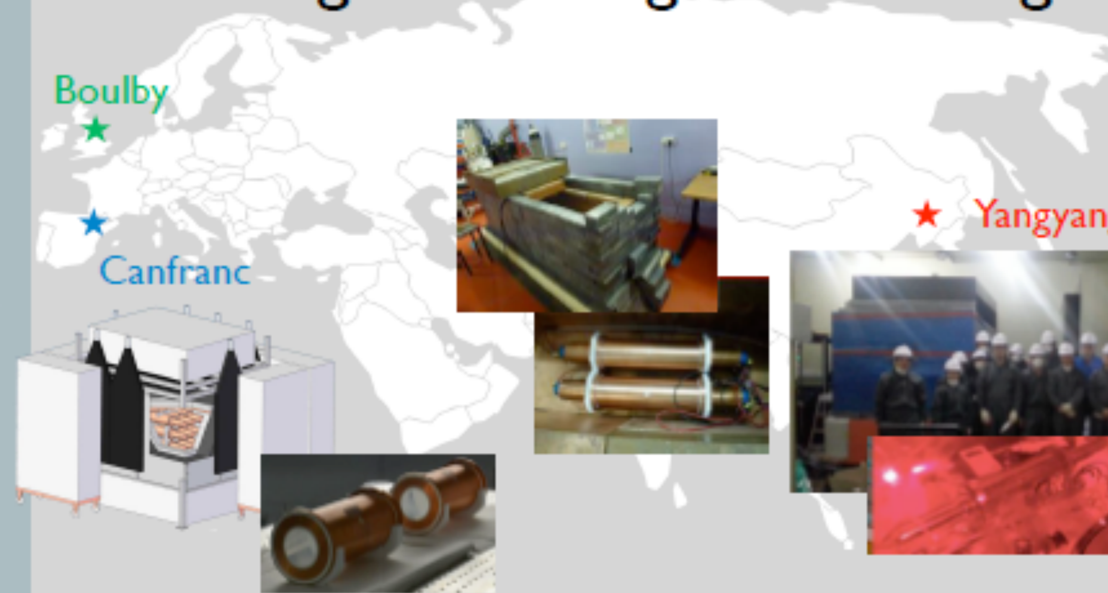
+

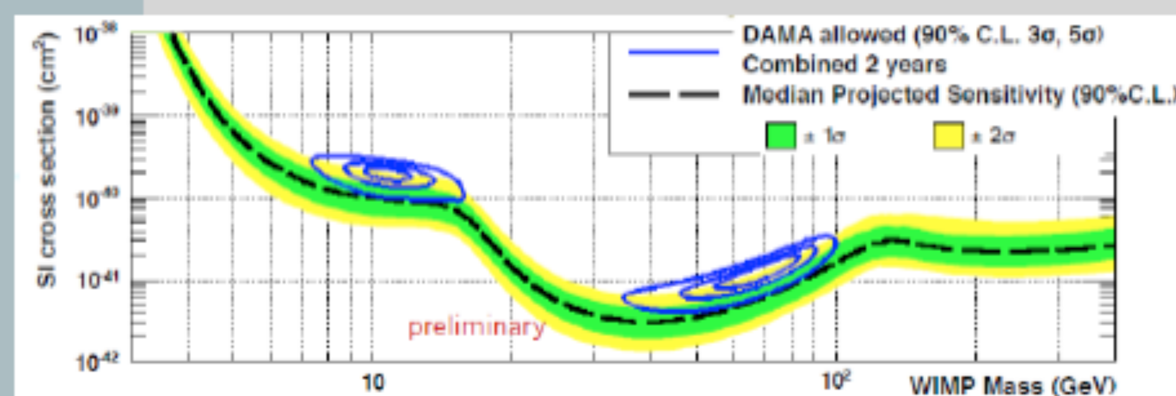
107 kg at Yangyang, South Corea

Data taking of both set-ups foreseen for the summer of 2016

Two years of data taking could explore the whole DAMA-LIBRA single out parameter space

ANAIS 112.5 kg + DM-Ice 55 kg + KIMS 52 kg





Low Mass, Large σ

Low-Mass Region Prospects

Goal: reach the neutrino bound!

EDELWEISS-III: Installing new FIDs with <0.3 keV FWHM for low mass search at LSM, with lower-background clamps.

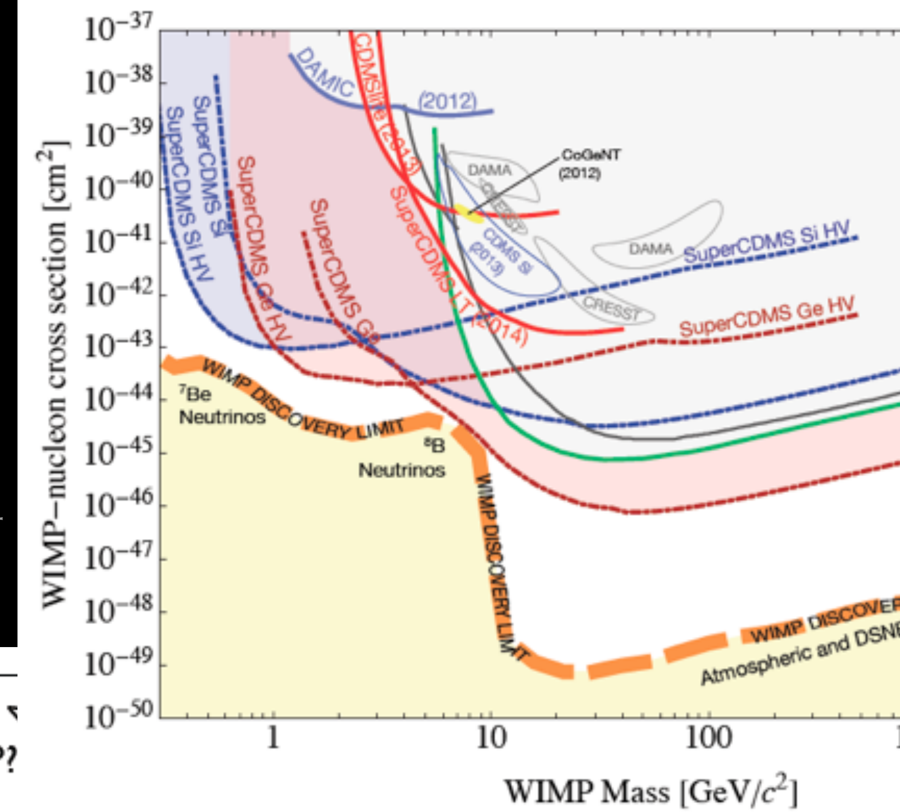
CRESST: R&D towards 0.1 keV threshold, with smaller crystals (24 lower background (3.5/keV kg day), for 1-6 GeV WIMP search.

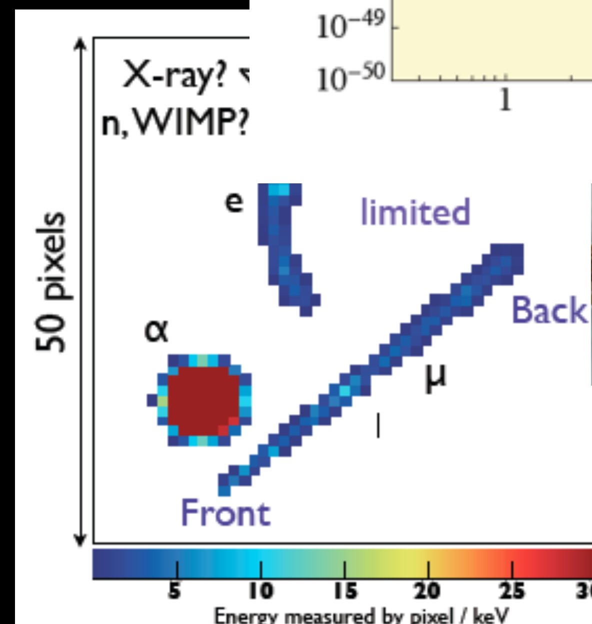
SuperCDMS: Focus on 0.3-10 GeV/c^2 WIMP masses 50 kg of 1.4 kg Ge (and Si) detectors at SNOLAB, from 2017. Can operate in HV mode, for 0.9 keV threshold. *PRL 112 (2014) 041302)*

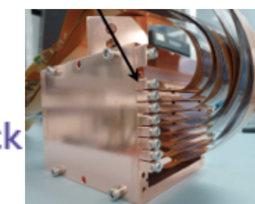
EURECA: collaboration of CRESST + EDELWEISS ++, coordinate with SuperCDMS, cryostat for 400 kg).

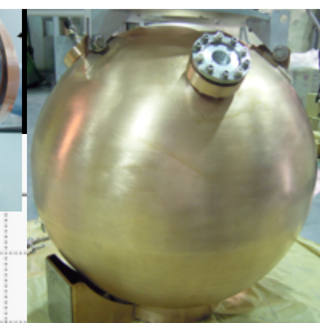
DAMIC: search for WIMP interactions in CCD Si, 100g to operate at SNOLAB. 1E-5 pb sensitivity with 1 keV threshold at 2 GeV/c^2 *arXiv:1506.02562*

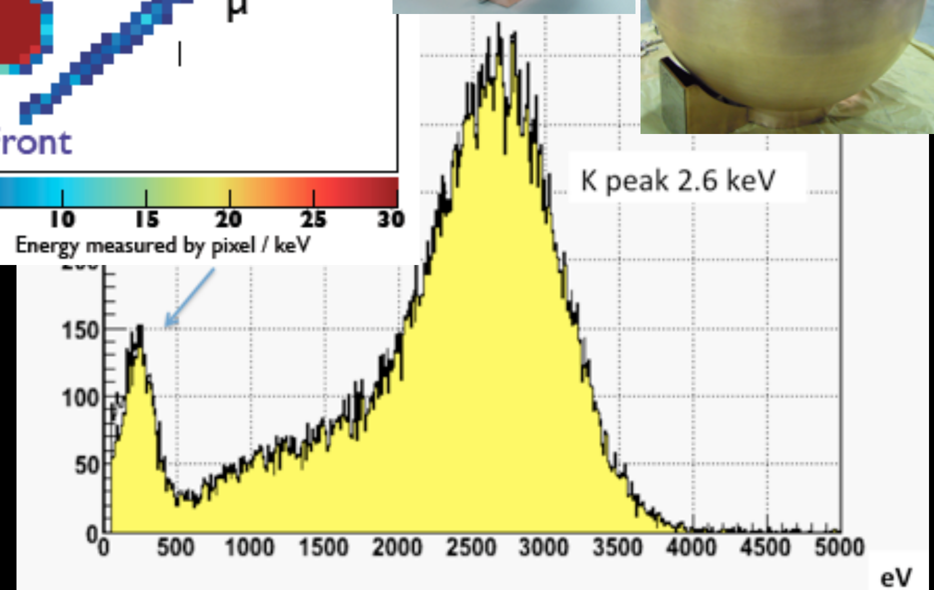
NEWS: spherical, high pressure gas detector with 0.1 keV threshold, at SNOLAB from 2017, 1E-5 pb sensitivity with Ar, Ne targets.



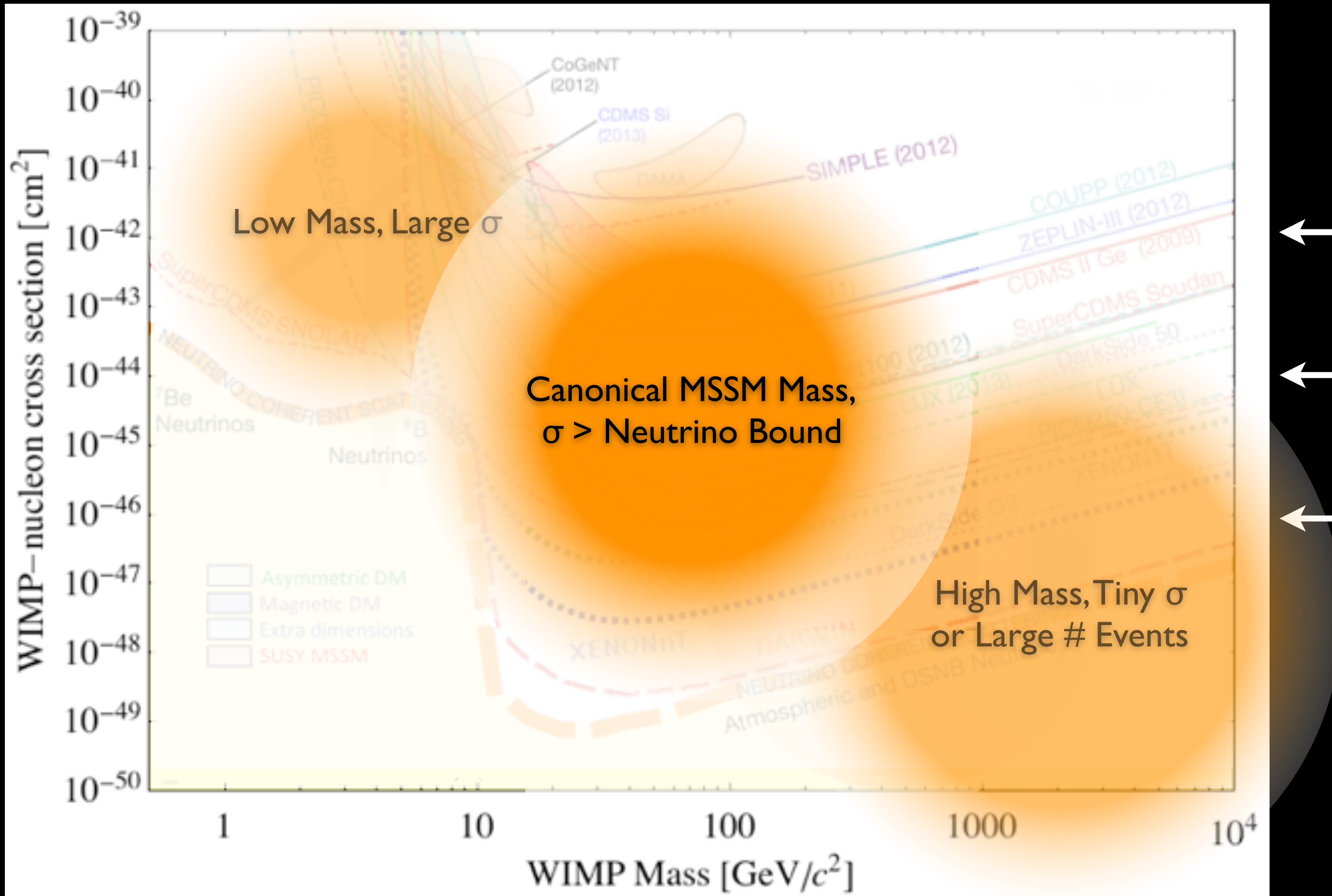








The Low-Background Frontier: Prospects



1 event/ kg/day

1 event/ 100kg/day

1 event/ 100 kg/ 100 days

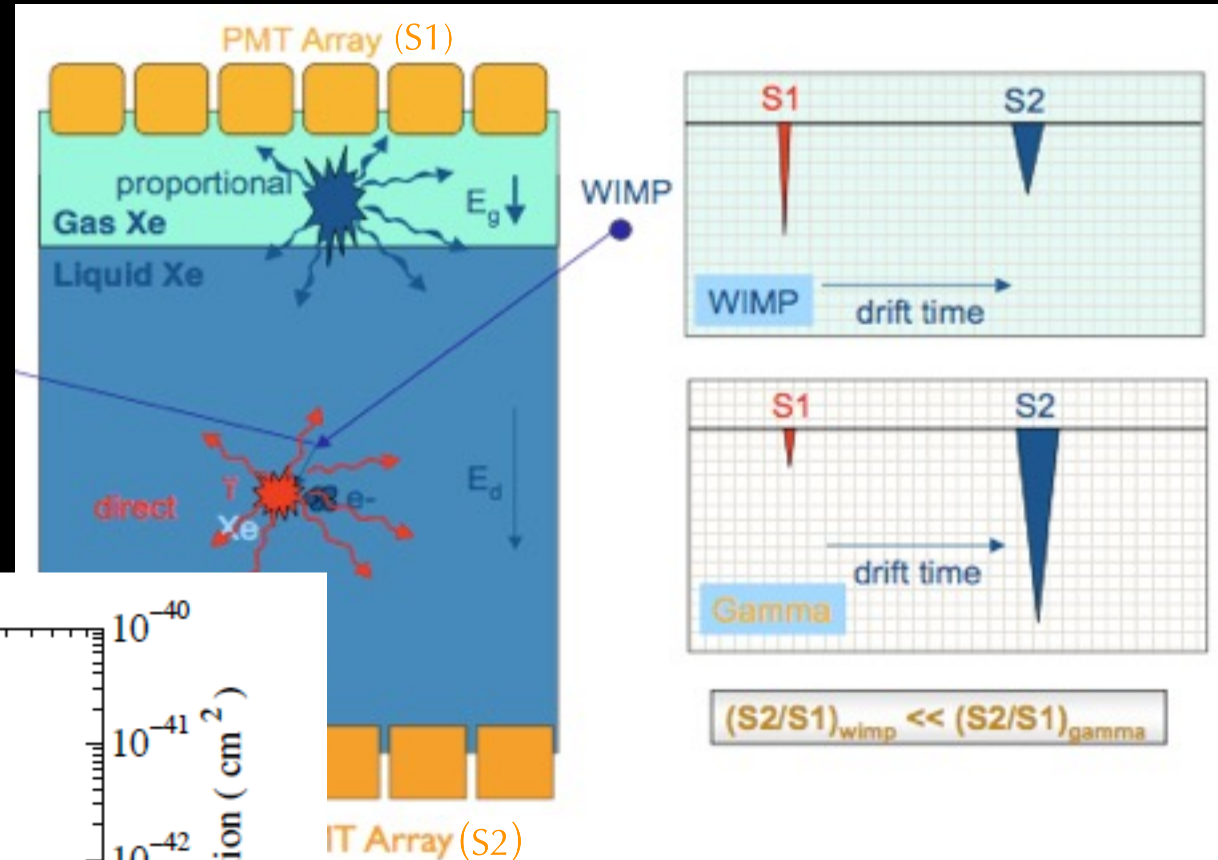
MSSM Mass, σ > ν bound

2-Phase Xe TPCs

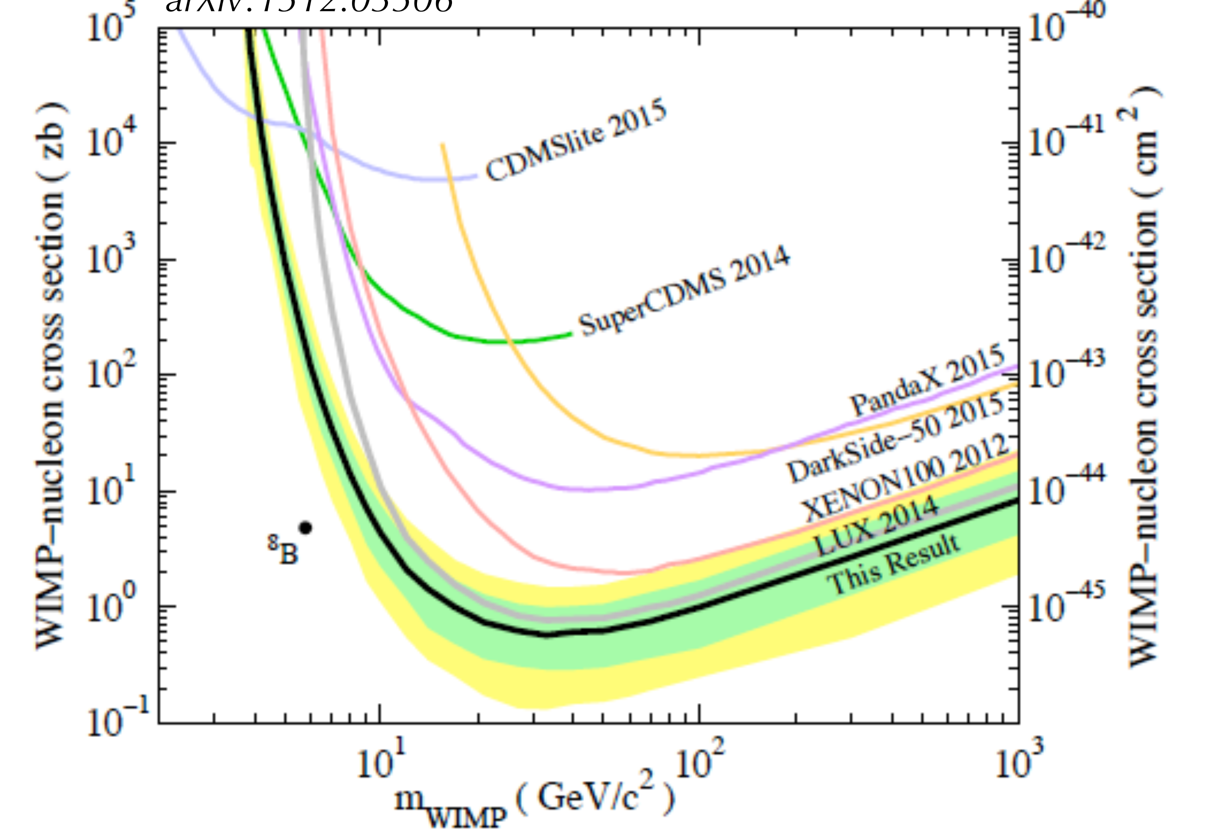
target viewed by PMTs:
"S1": amplified, drifted ionization signal
"S2": primary scintillation

Xenon 10 kg, 100 kg, 1Tonne

LUX (250 kg), PANDA-X (120kg, 500 kg)



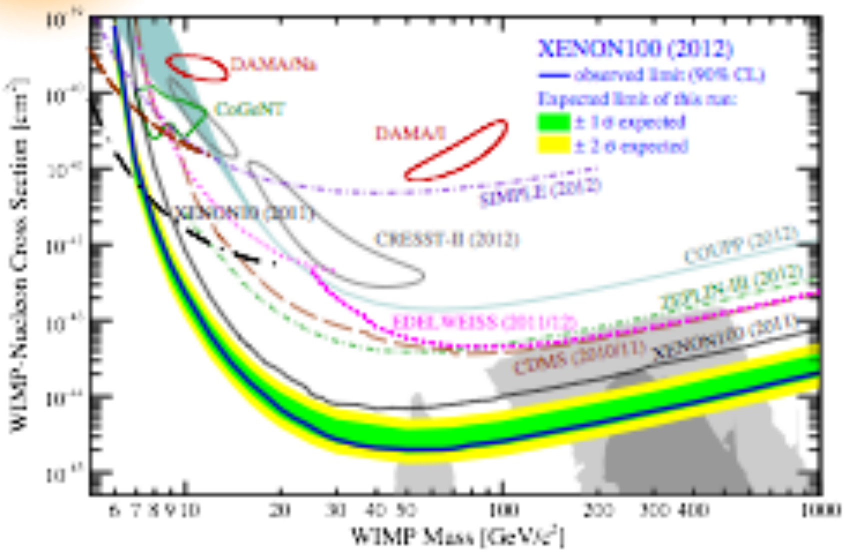
arXiv:1512.03506



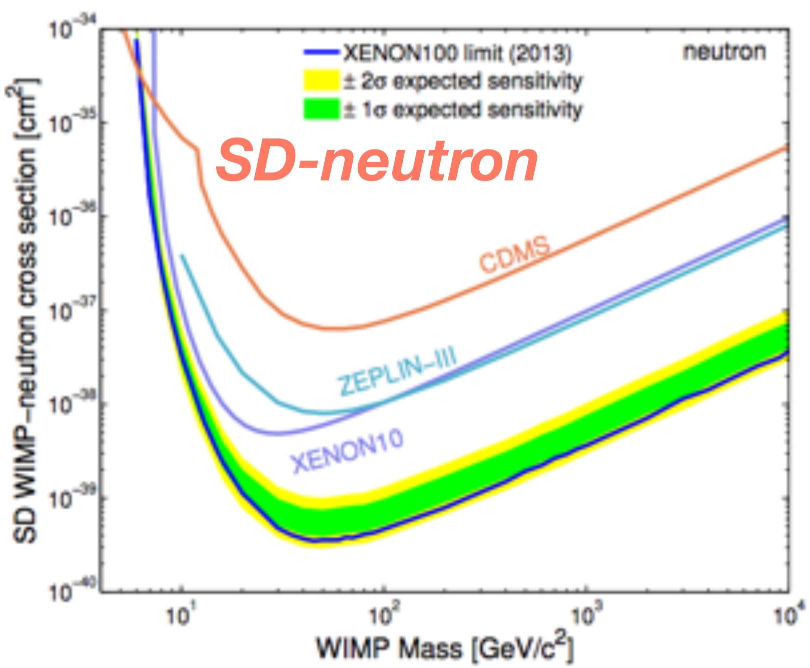
MSSM Mass,
σ > ν bound

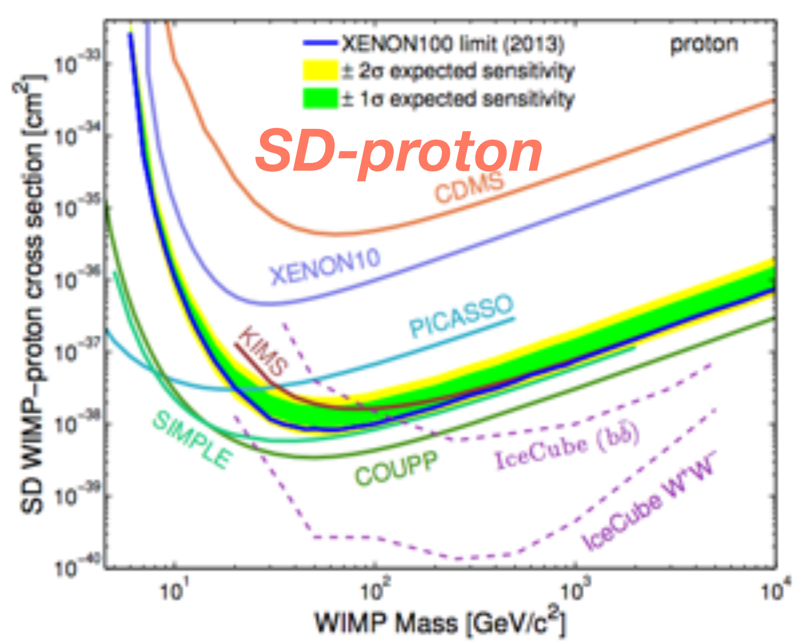
XENON-100

(thanks to L. Baudis)



- Ultra-low background and design sensitivity achieved
- Background: ~ 5 x 10^{-3} events/(kg d keV)
- No evidence for WIMP dark matter
- Upper limits on SI, SD WIMP-nucleon cross sections (PRL 109, PRL 111)
- Axion, ALPS searches (Phys. Rev. D 90, 062009 (2014)
- Annual modulation search excludes leptophilic DM explanation of DAMA/LIBRA (Science 349, 2015)





MSSM Mass, σ > ν bound

2-Phase Xe TPCs: Prospects

Goal: cover favored MSSM parameter space

XENON-100: low energy calibrations for low-mass WIMP search, search for inelastic scattering on Xe-129, test facility for x10 Rn mitigation upgrade in Xenon-1T

LUX: 300 day exposure results planned for Summer 2016, recent results lowered energy threshold to keV with precision calibration using low-E sources

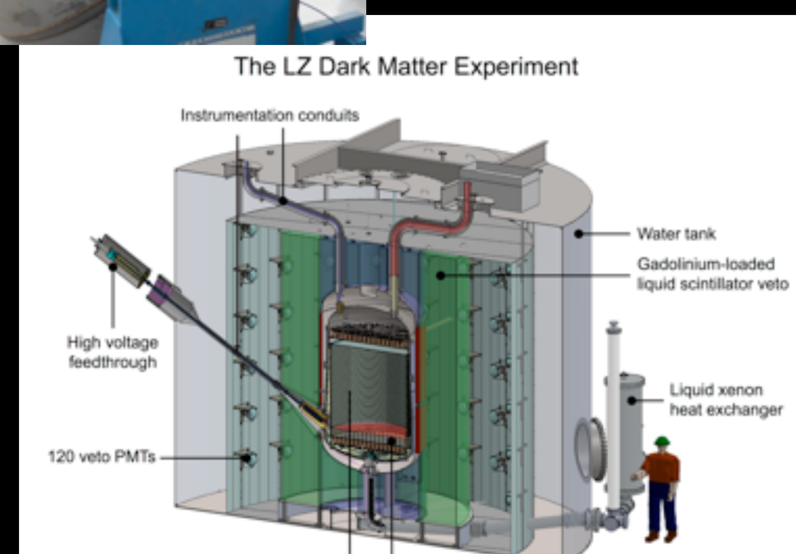
PANDA-X: low-mass WIMP results from 120 kg detector, (54 kg x 80.1 days) 500 kg detector science run now.

XENON-1T: 3300 kg LXe (1000 kg fiducial), construction at LNGS completed, TPC commissioning with Xe now. Sensitivity reach 1E-47 cm^2 after 2 Tonne-years.

XENON-nT: upgrade to Xenon-1T to 7 Tonnes LXe (total), using same LNGS infrastructure + new TPC, inner cryostat. From 2018.

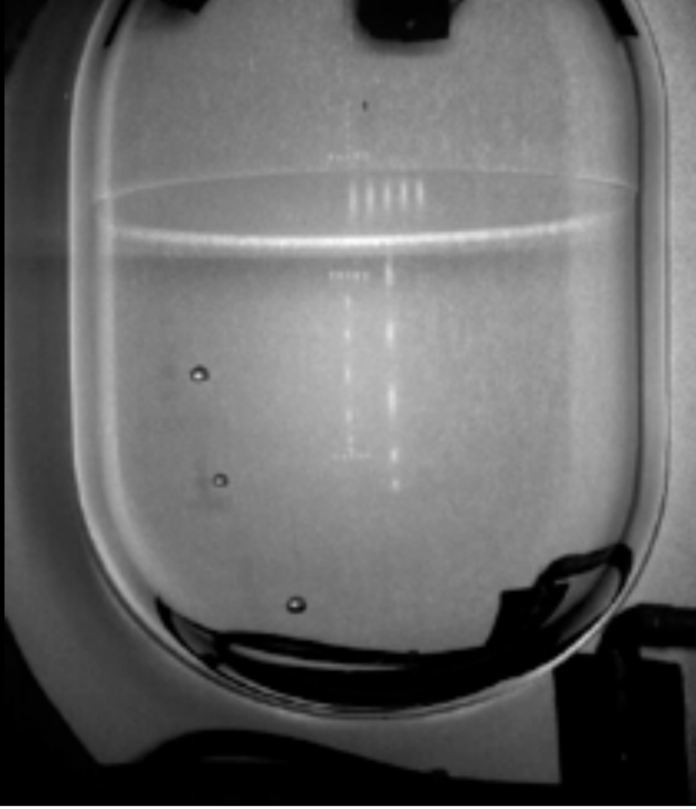
LZ: follow-on to LUX, 7 Tonnes LXe (total), using same SURF infrastructure as LUX. From 2019.

Sensitivity reach to 2E-48 cm^2.



MSSM Mass, $\sigma > \nu$ bound

Bubble Chambers



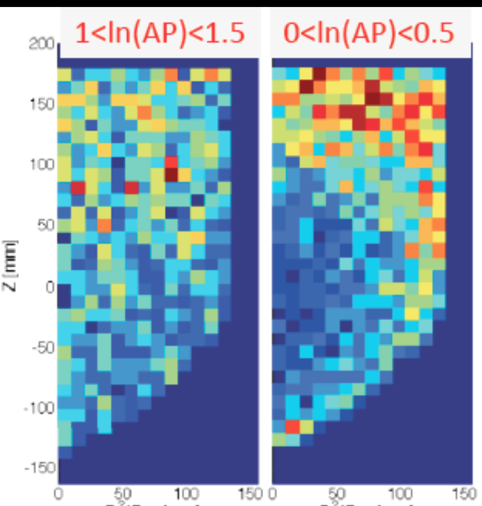
superheated CF_3I target, with camera and piezo (acoustic) readout
measure integral counts above threshold when dE/dx > nucleation

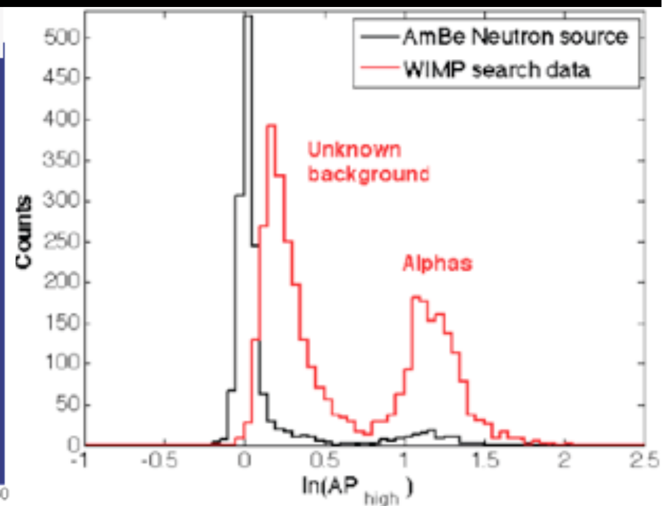
gamma rejection >1E-10, neutron discrimination from multiples,
1E-2 alpha rejection from acoustic readout

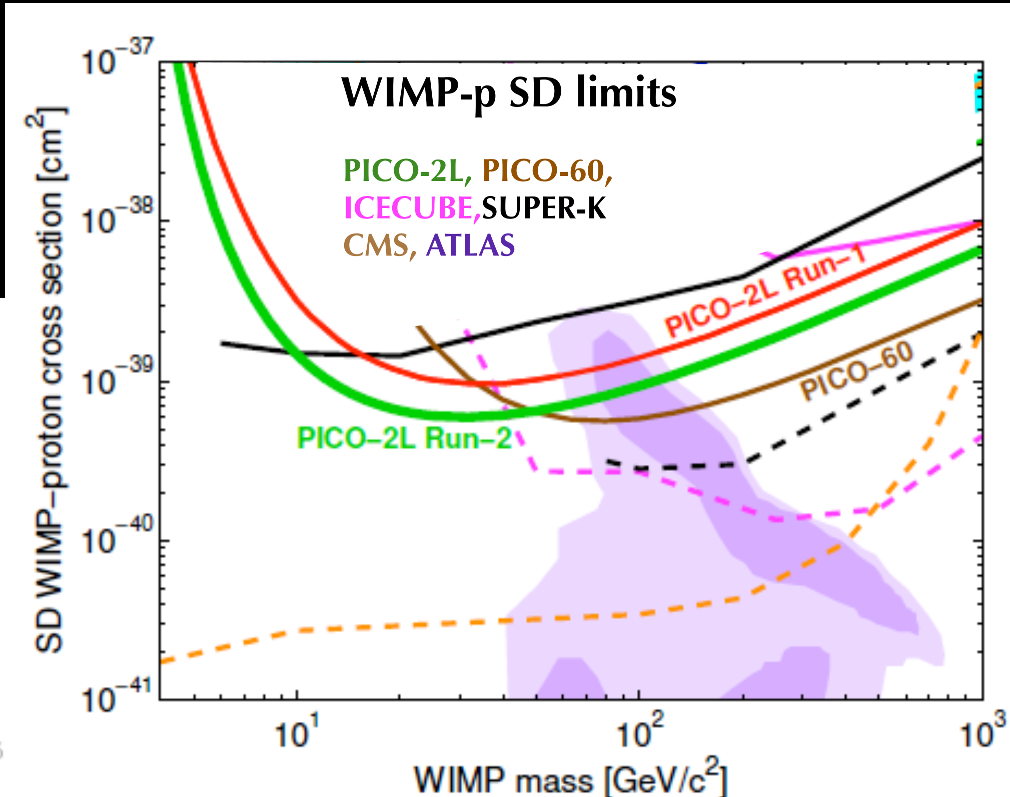
SIMPLE (Canfranc), PICASSO, COUPP, PICO (SNOLAB)

PICO-60: (PICASSO+COUPP) running since 2013 with CF_3I target
background population observed, preliminary limit (E_{th} = 7 keV)
Iodine target: expect 49 recoils above 22 keV in DAMA region, observe <4.1 @ 90% CL *(D. Jeter, CIPANP'15)*

PICO-2L: C_3F_8 target, best SD WIMP-proton limit
(129 kg-days, E_{th} = 3.3 keV) *arXiv:1601.03729*
target upgrade of PICO-60



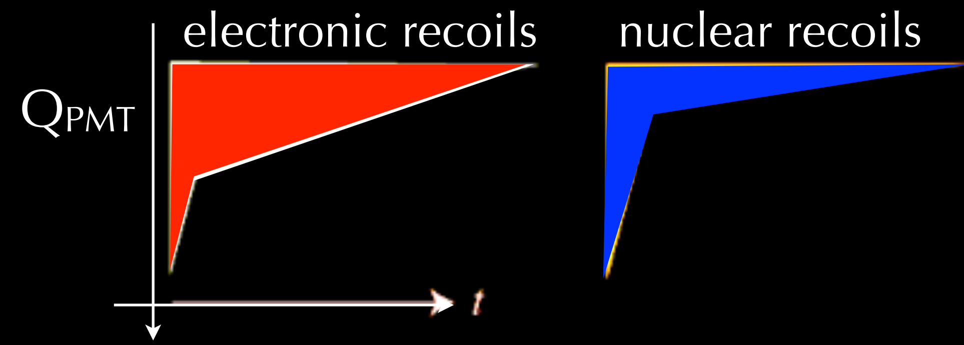


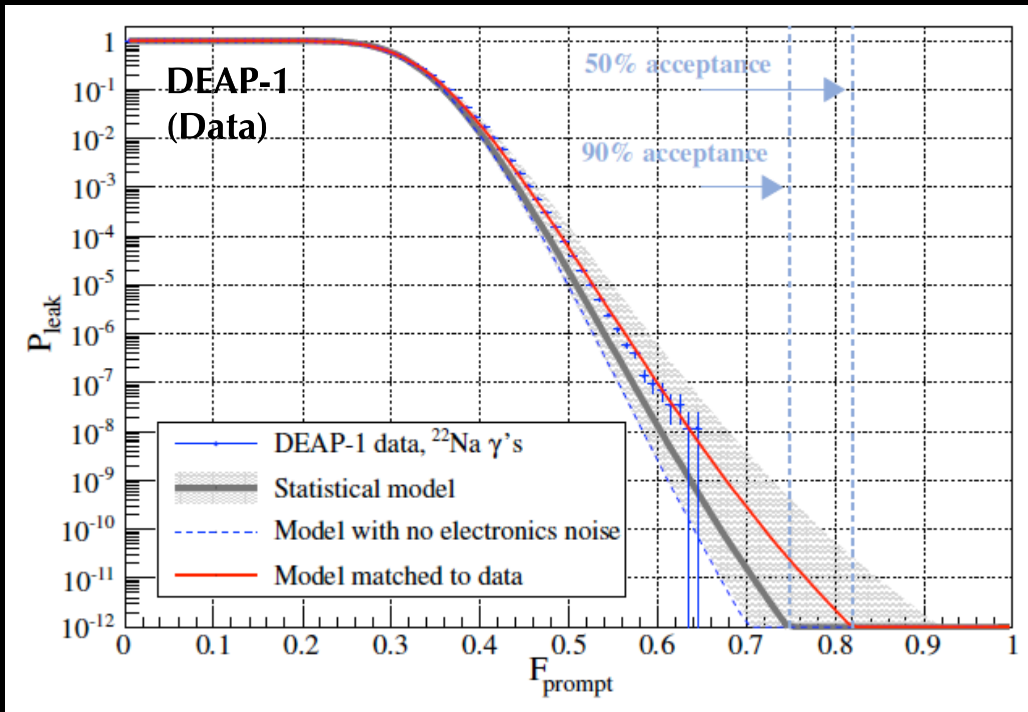


MSSM Mass,
σ > ν bound

Argon Detectors

Why? Ar costs 0.001 x Xe, so
kTonne-scale detectors feasible!

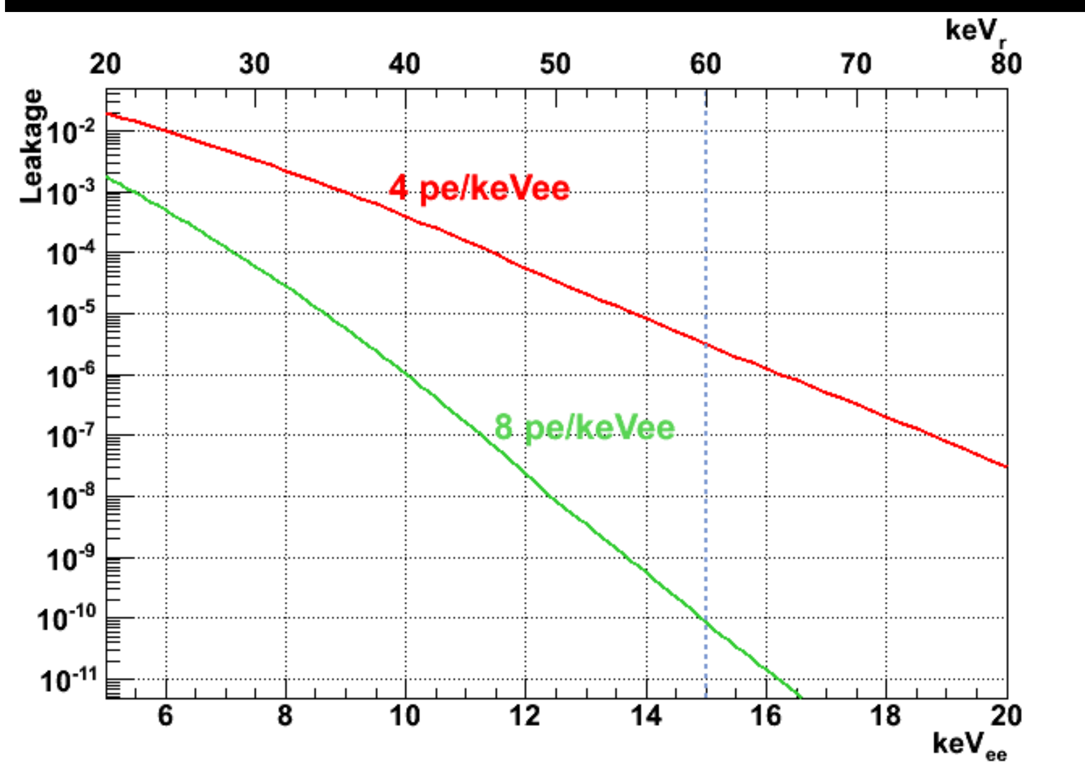




pulse shape discrimination (PSD) for particle ID: x250 difference in scintillation time constants between electronic vs. nuclear recoils in Ar.

naturat Ar has Ar-39 beta-decay background of 1 Bq/kg, with 550 keV endpoint.

Lippincott et al., Phys.Rev.C 78: 035801 (2008)
Caldwell, JM, et al.,Astropart. Phys. 65 (2014) 40



DEAP-3600: measures PSD leakage <3E-8 in DEAP-1, predict >1E-10 in DEAP-3600 *(arXiv:0904.2930)*

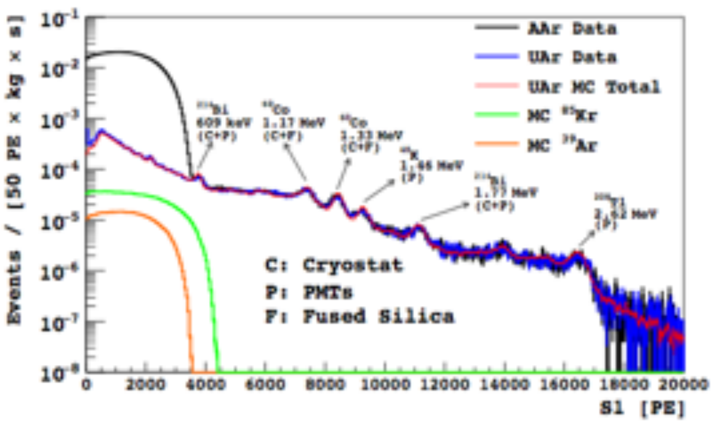
DarkSide-50: measure depletion x1600, in 50kg detector, zero background limit *(arXiv:1510.00702)*

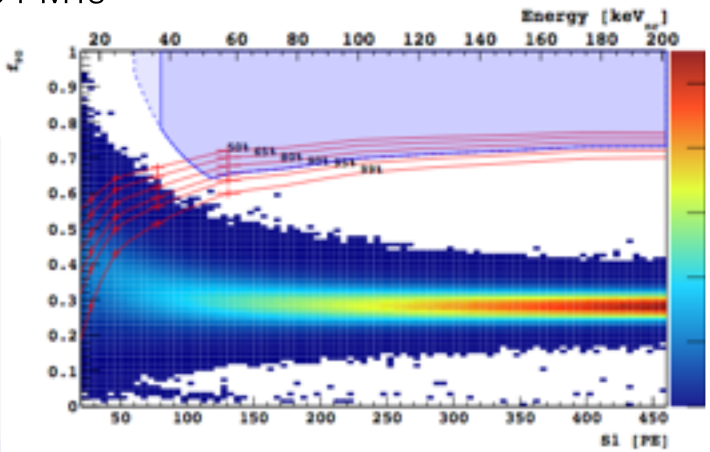
ARGO: Coordination of LAr detectors, **ArDM** will test depleted UAr samples with 100x sensitivity.

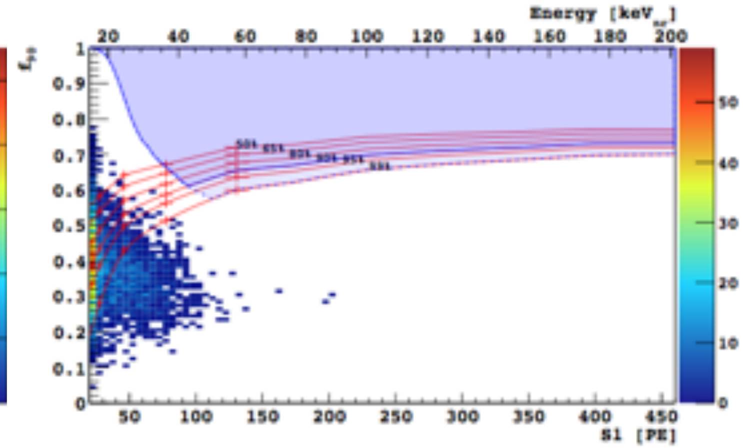
DarkSide-50

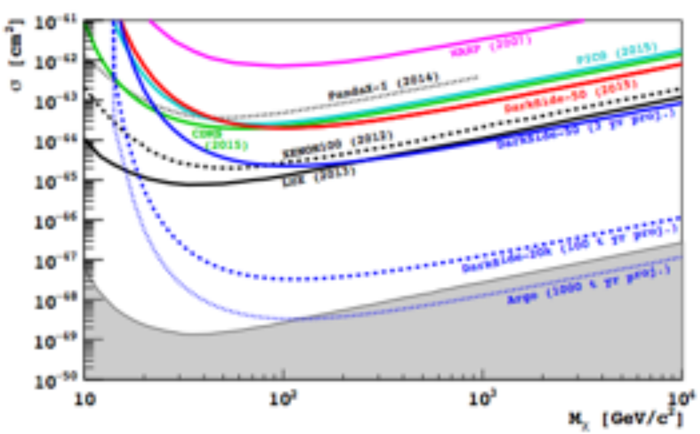
(thanks to G. Fiorillo)

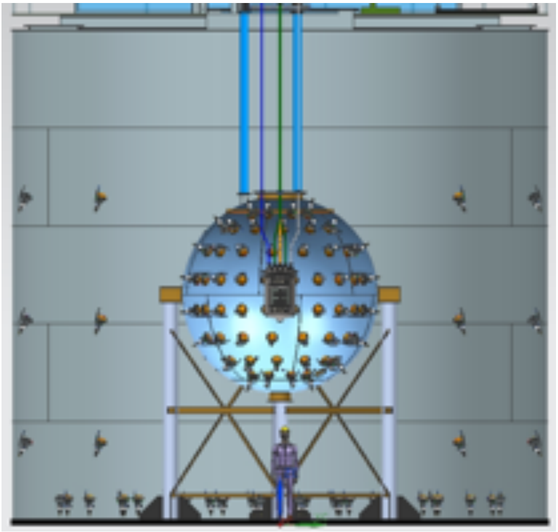
- LArTPC (50 kg active, 150kg total) 38 3” PMTs at LNGS
- Liquid scintillator veto (30 tons) 110 PMTs
- Water veto (1 ktons) 80 PMTs











Demonstrated:

- β/γ rejection capability better than $1 \div 10^7$ with atmospheric argon
- high-performance vetoing scheme and ^{39}Ar suppression in underground argon by factor over 1,000

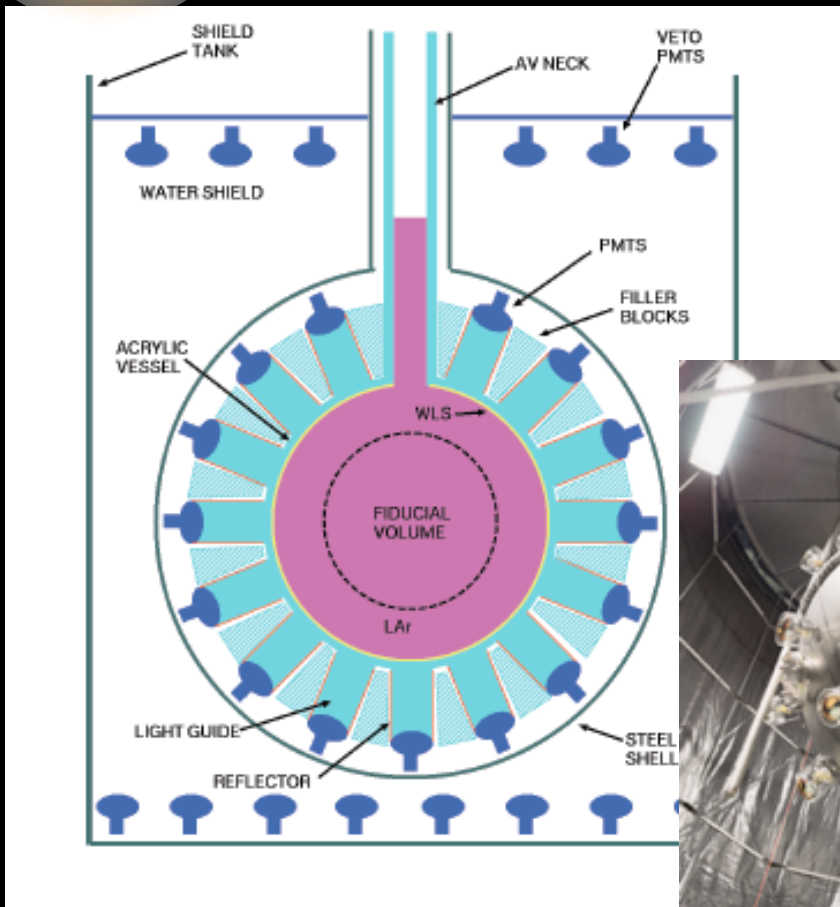
Zero background operation:

✦ 1,422 kg×d AAr (published)
✦ 2,616 kg×d UAr (published)
✦ 8,000 kg×d UAr (analysis ongoing)

MSSM Mass,
σ > ν bound

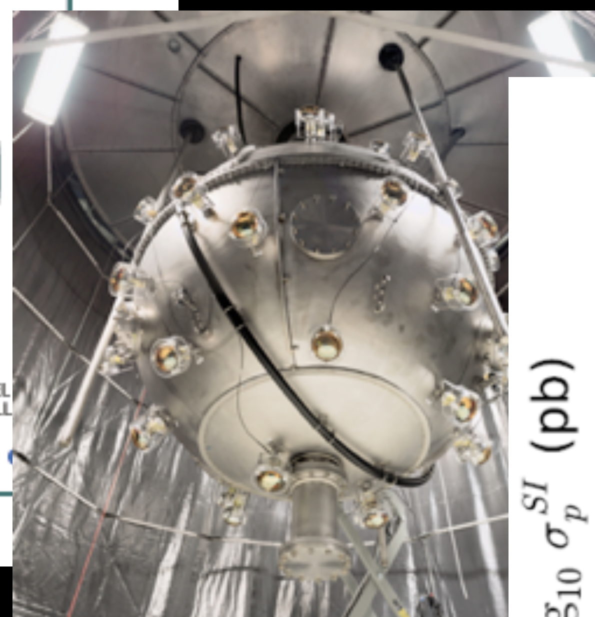
Single Phase Liquid Nobles, a la Neutrinos

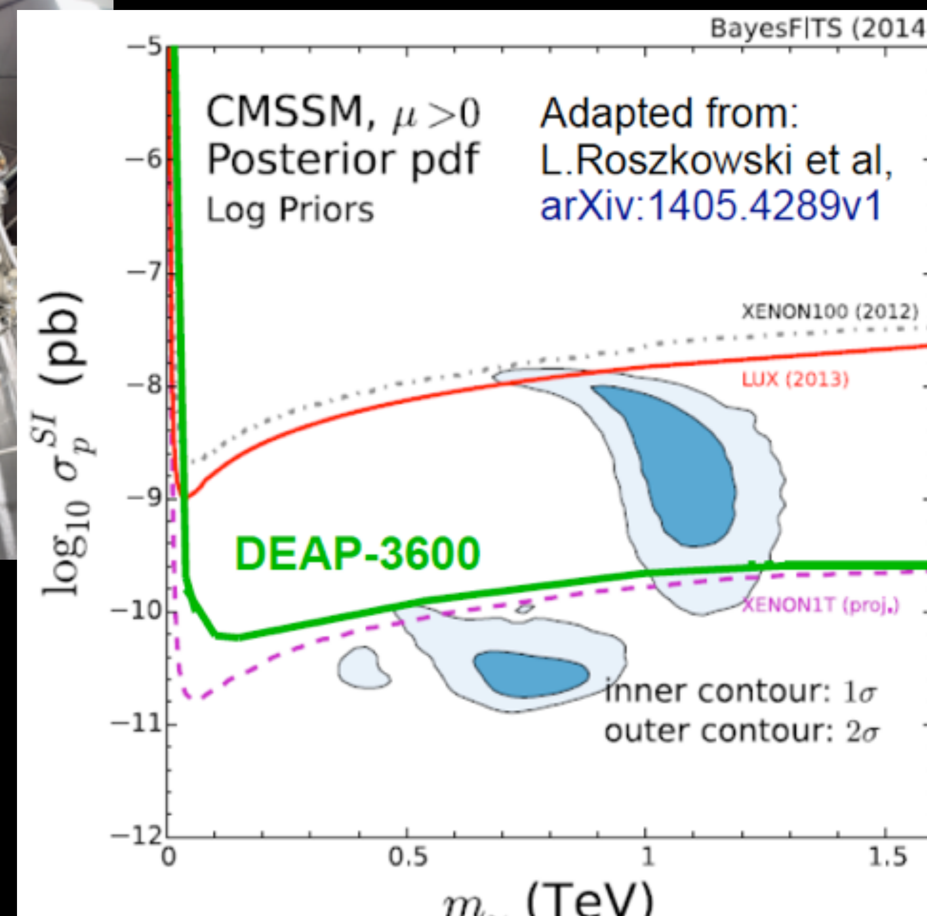
maximize light yield from 4π PMT coverage, target self-shields, only detect scintillation



XMASS: 832 kg LXe detector at Kamioka, running from 2013, upgrading PMTs to reduce backgrounds, future 5T detector.

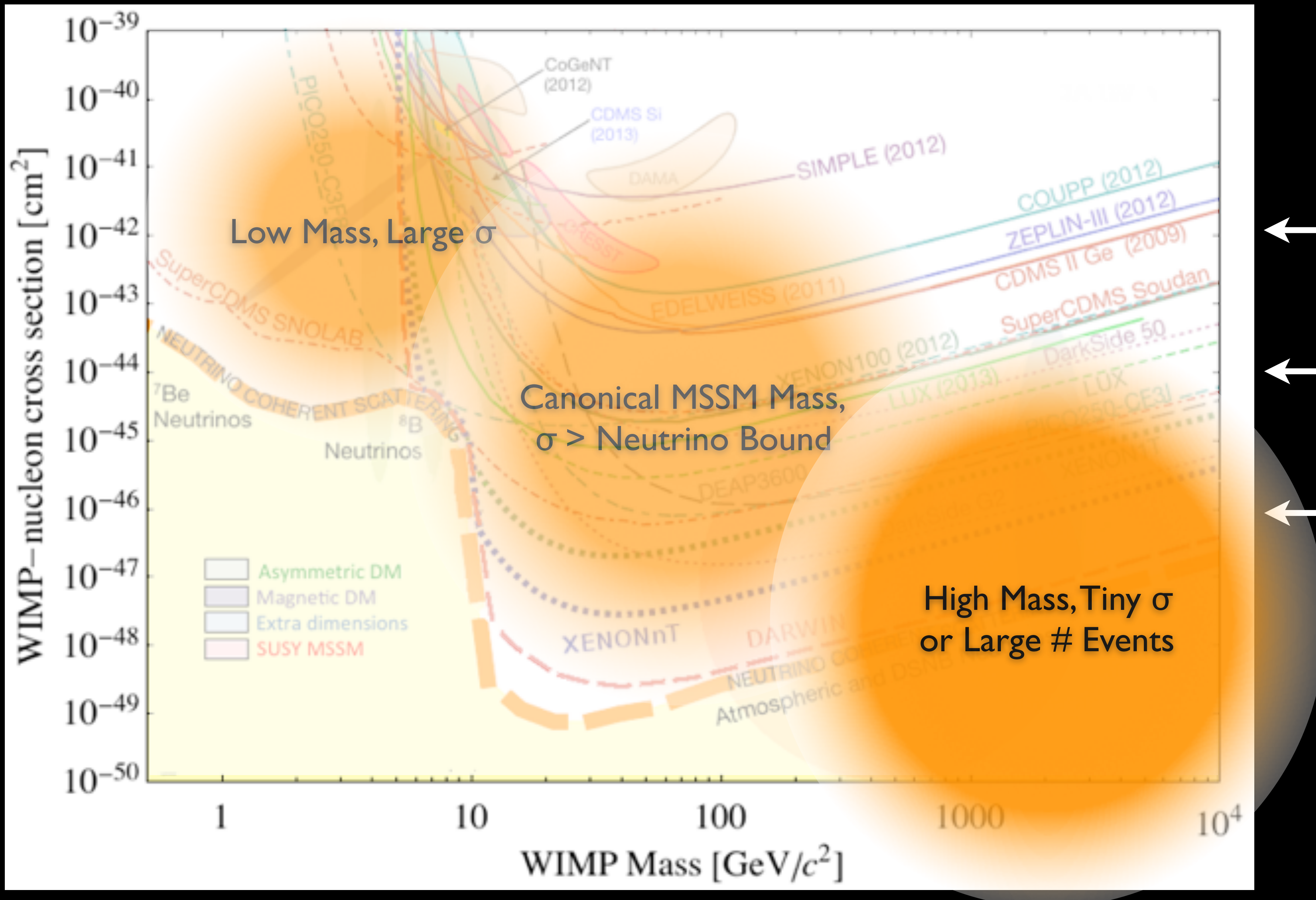
DEAP-3600: LAr at SNOLAB. 3600 kg target, with few PE threshold. detector commissioning now, physics start 2016, project <0.6 background/3000 kg-days, to reach 1E-46 cm² sensitivity





no electric fields = scale to large mass (O(100 T))
1) no pile-up from ms-scale electron drift in TPC
2) no recombination in E field
but background discrimination from scintillation only!

The Low-Background Frontier: Prospects



1 event/ kg/day

1 event/ 100kg/day

1 event/ 100 kg/ 100 days

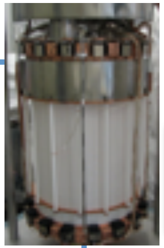
so far: ~3 years / order of magnitude

DARWIN

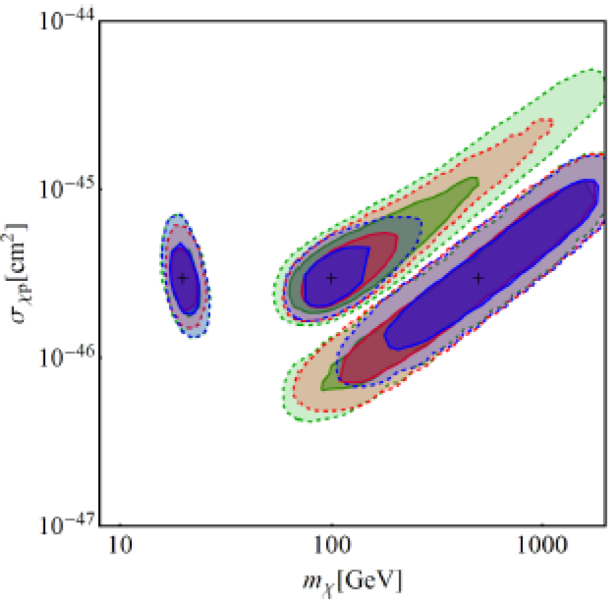
(thanks to L. Baudis)

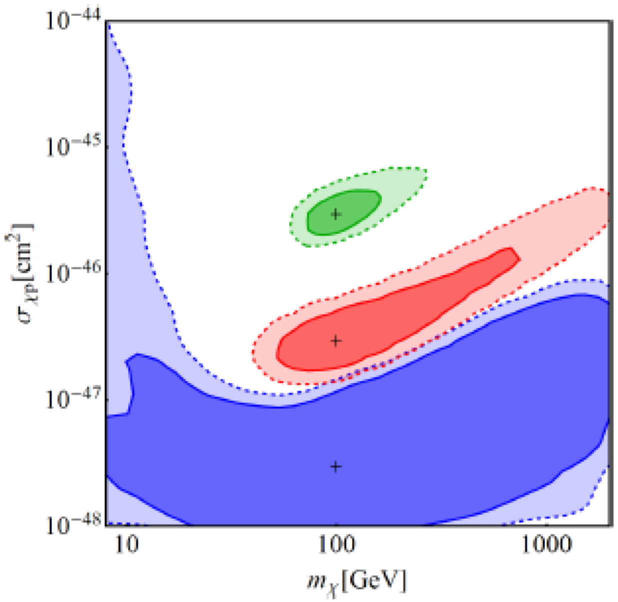
Ultimate LXe TPC at LGNS.

- ✓ 50 t (40 t) Lxe in total (in the TPC)
- ✓ ~10^3 photosensors
- ✓ 2.6 m drift length, 2.6 m diameter TPC
- ✓ Background: dominated by neutrinos
- ✓ WIMP spectroscopy, search + non-WIMP science: axion / ALP search, solar neutrinos, supernova neutrinos, sterile neutrinos, coherent neutrino – nucleus scattering, 0ν2β decay of ^{136}Xe.

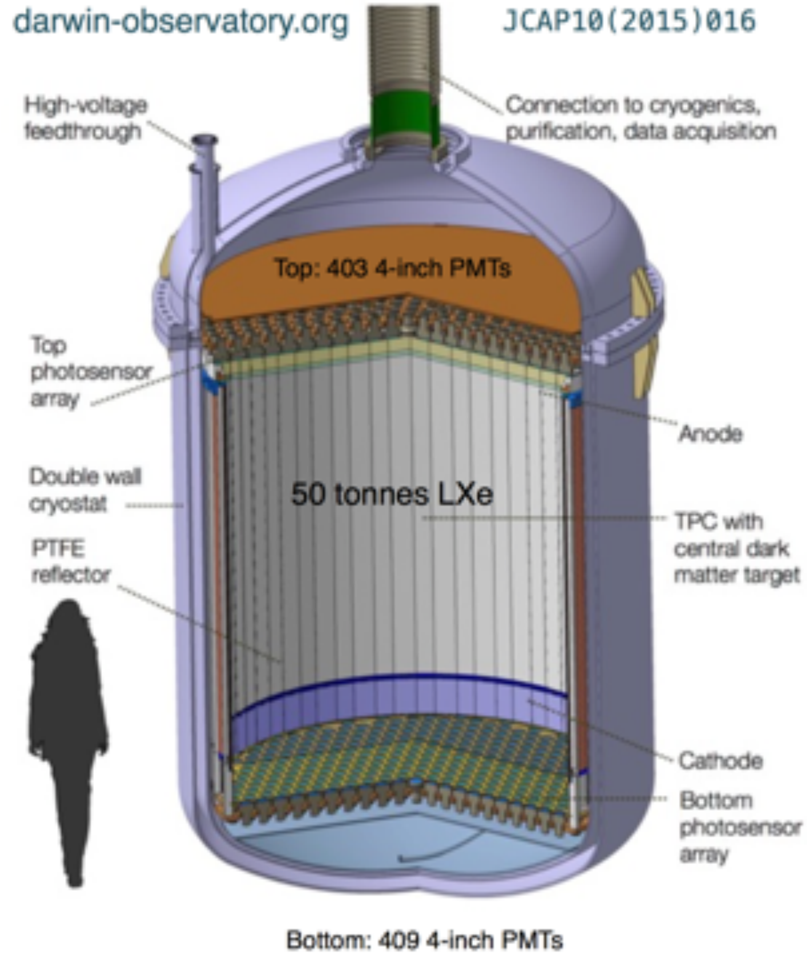


JCAP10 (2015) 016





Newstead et al., PRD D 88, 076011 (2013)

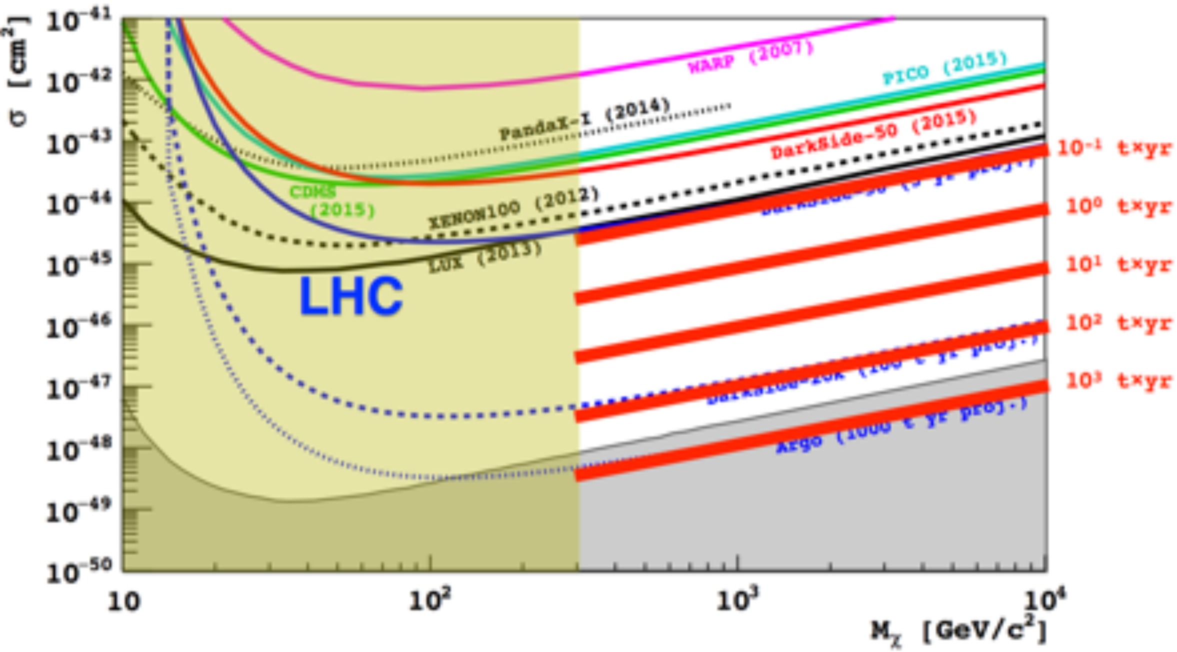


High Mass,
Large # Events
$\sigma < \nu$ bound

ARGO

(thanks to C. Galbiati)

An Integrated Program for the Ultimate DM Search with ^{39}Ar-suppressed Argon TPCs



- Ultimate search requires 1,000 T-yr **background-free exposure**
- ^{39}Ar-suppressed Ar TPC can deliver due to β/γ suppression
- Key enabling technologies R&D funded and ongoing:
  - Cryogenic SiPMs
  - Urania: 100 kg/d procurement of UAr
  - Aria: active isotopic separation of ^{39}Ar via cryogenic distillation

DarkSide-50 (now)

ArDM-1t (now)

DarkSide-20k (2020?)

100 T-yr background-free search

Argo (2025?)

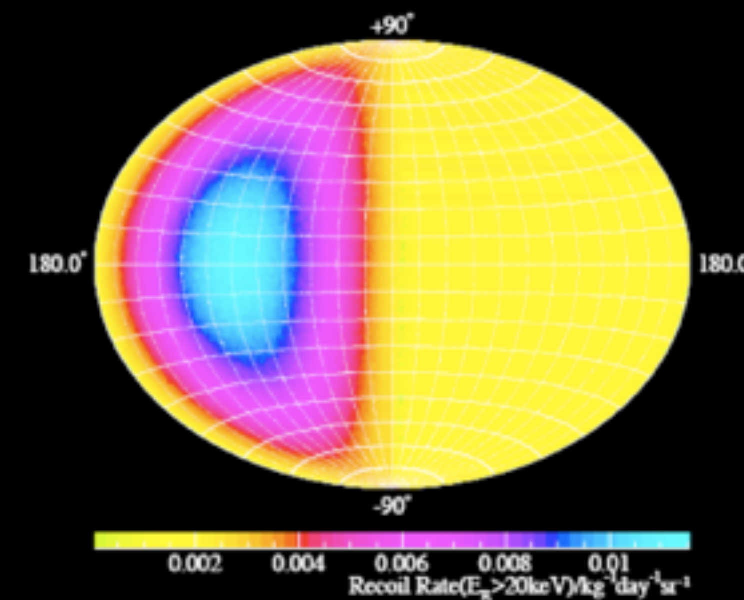
- 1,000 T-yr background-free search to *reach the "neutrino floor"*
- precision low-energy solar neutrino measurements

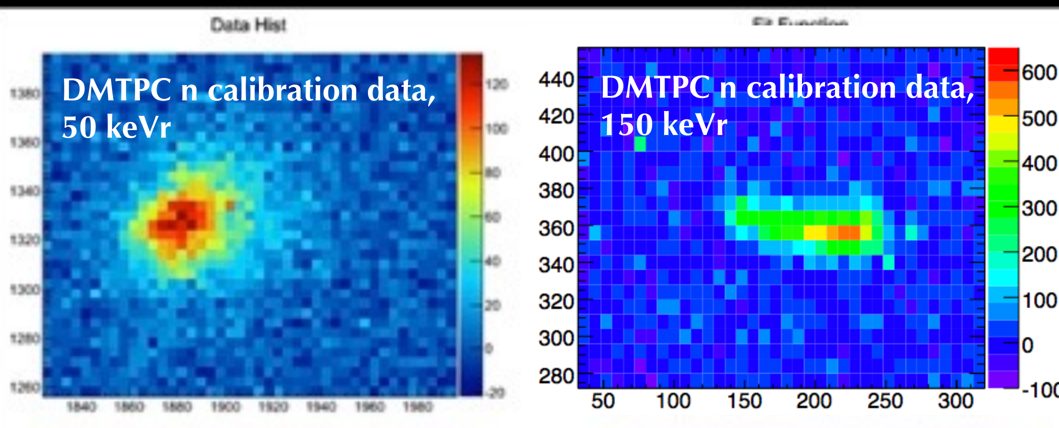
dark matter identification, σ > ν bound

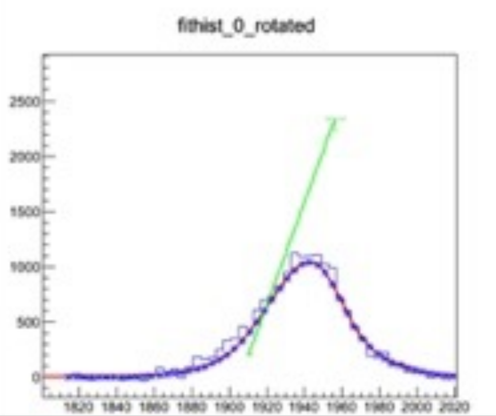
Directional Detection

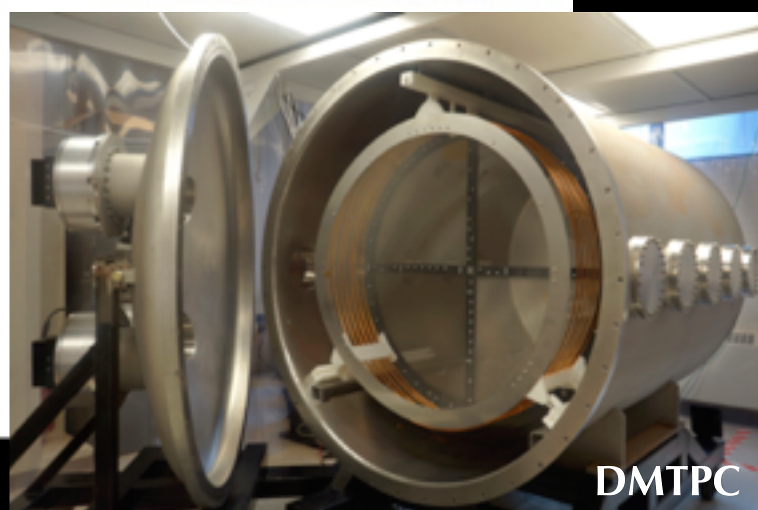
R&D towards DM recoil track direction to identify a signal with the galactic halo

Physics Reports 2016, arXiv:1602.03781









DRIFT: $1m^3$ MWPC, in Boulby since 2001

DMTPC: optical (CCD) and charge readout of CF_4; commissioning $1m^3$ module.

MIMAC: micromegas, in LSM. Low E focus.

R&D: fine-grained emulsions ++
+ projects outside Europe

CYGNUS: global coordination towards a physics-scale directional experiment.

Directionality gains up to 10x in sensitivity in the presence of backgrounds (relative to 1D).
and there is no neutrino bound for directional detectors. *Grothaus, Fairbairn, JM, PRD90 (2014) 055018*

Outline

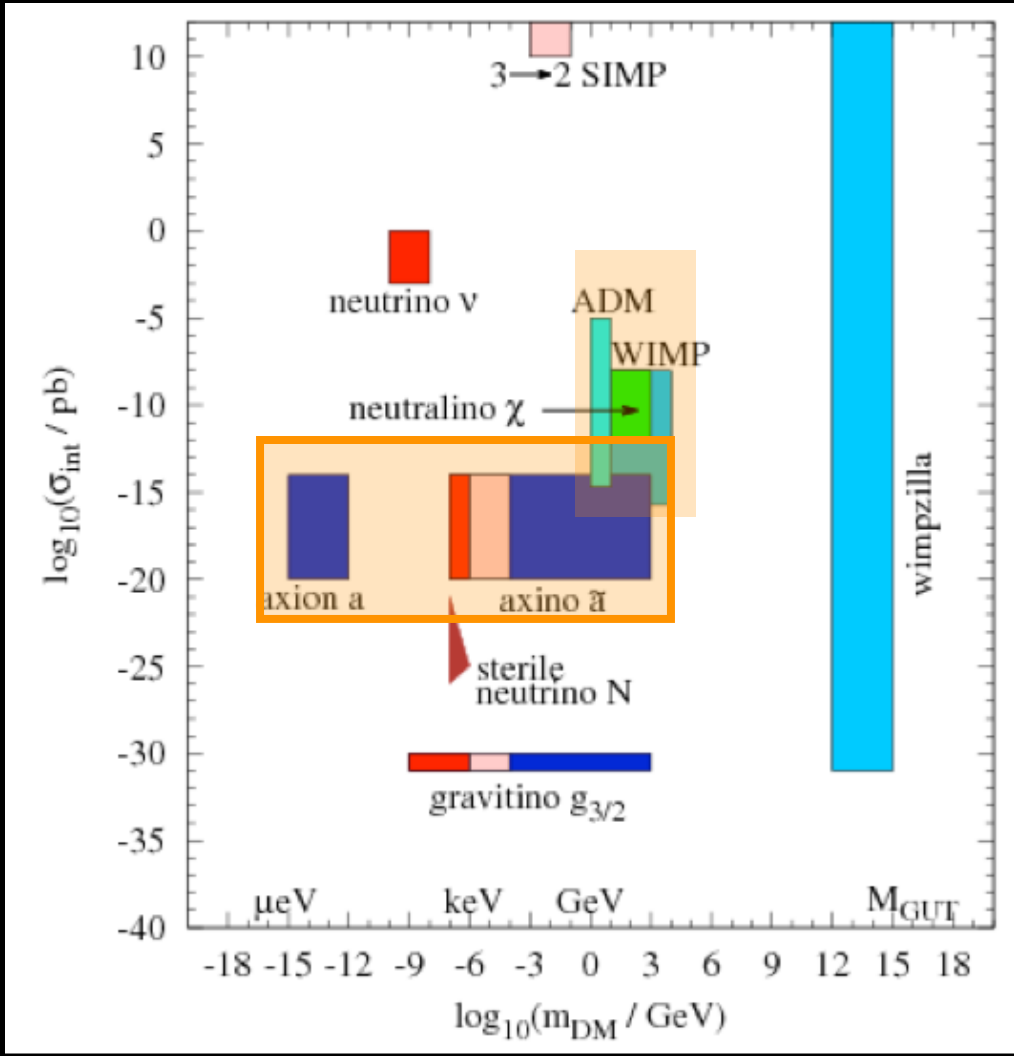
Experimental Considerations in Direct Detection Searches

Status and Prospects of Experiments

Non-WIMP Dark Matter in Direct Detection Experiments

Model Space

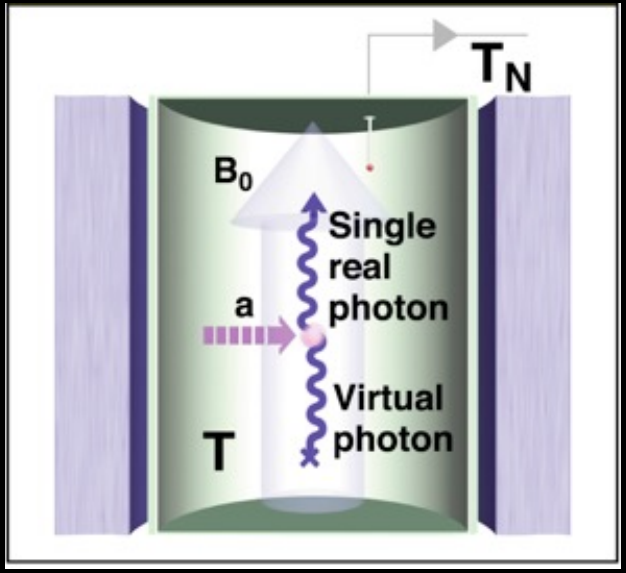
WIMPs aren't the only possibility!



Baer et al., arXiv:1407.0017

Axion and ALP detection:

Primakoff conversion searches:
ADMX, **CAST** (direction modulation)



constraints from direct detection:
EDELWEISS, **XENON100**, **XMASS**

search for axio-electric effect:

$$\sigma_{Ae} = \sigma_{pe}(E_A)\frac{{g_{Ae}}^2}{\beta_A}\frac{3{E_A}^2}{16\pi\,\alpha_{em}\,{m_e}^2}\left(1-\frac{\beta_A^{2/3}}{3}\right),$$

observable: peak in electron recoil spectrum at axion mass. Analysis: bump hunt.

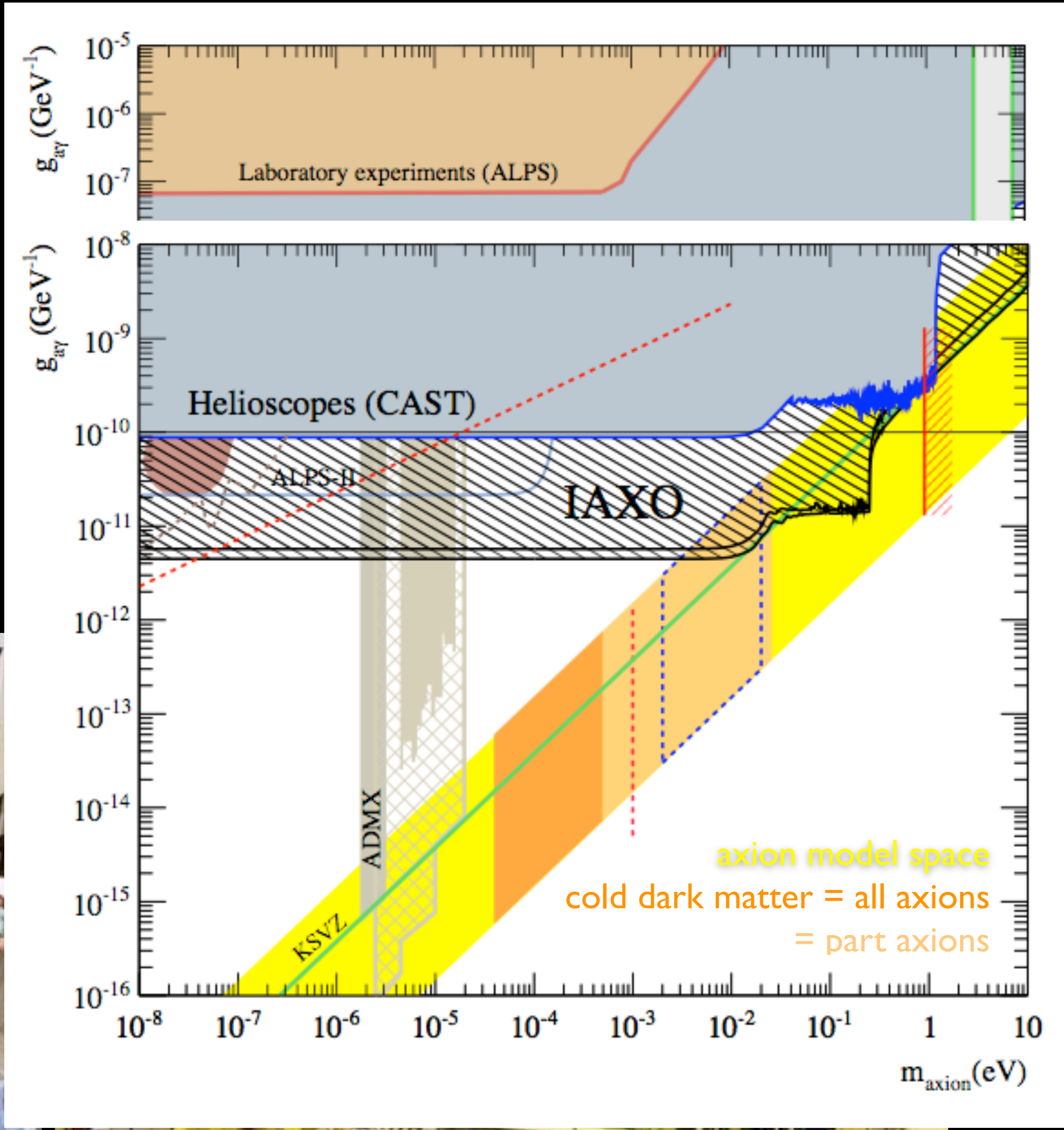
Axions: Status and Prospects

Primakoff conversion searches:

CAST: helioscope searching for solar axion conversion in an LHC magnet tracking the sun, micromegas readout

ADMX: halo axion conversion in resonant cavity with B field, scanning in frequency. Run 2 just started!

IAXO: coordination of axion experiments, proposal for axion helioscope at CERN, dedicated magnet design.
(SPSC 1-242)



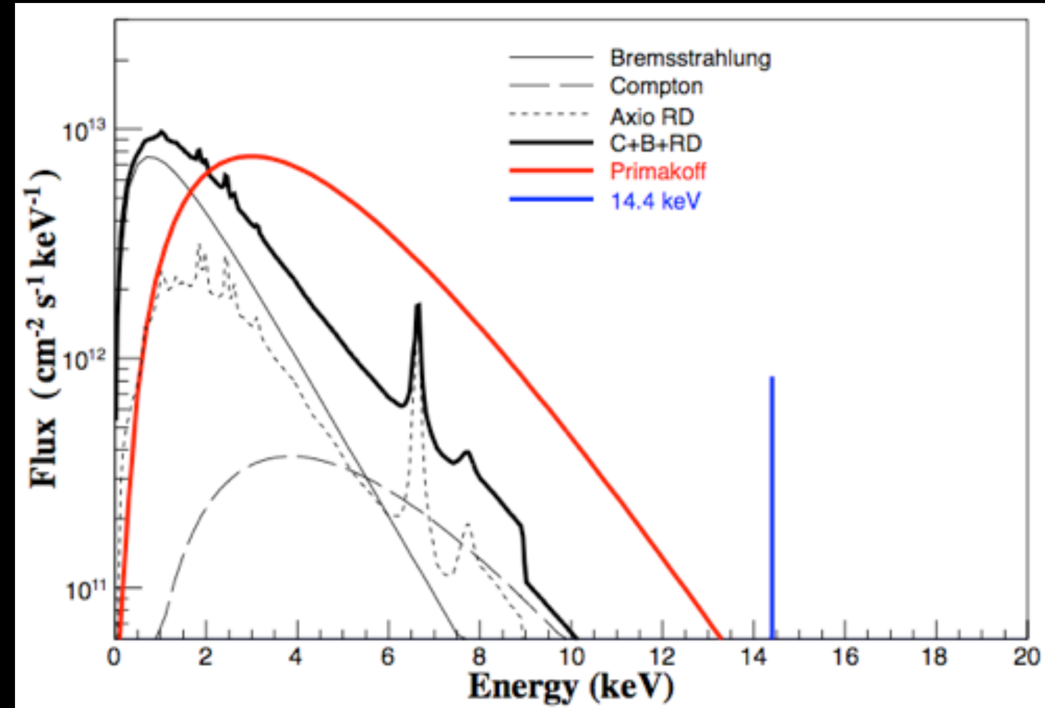
Axion/ALPs in Direct Detection: Bump Hunts

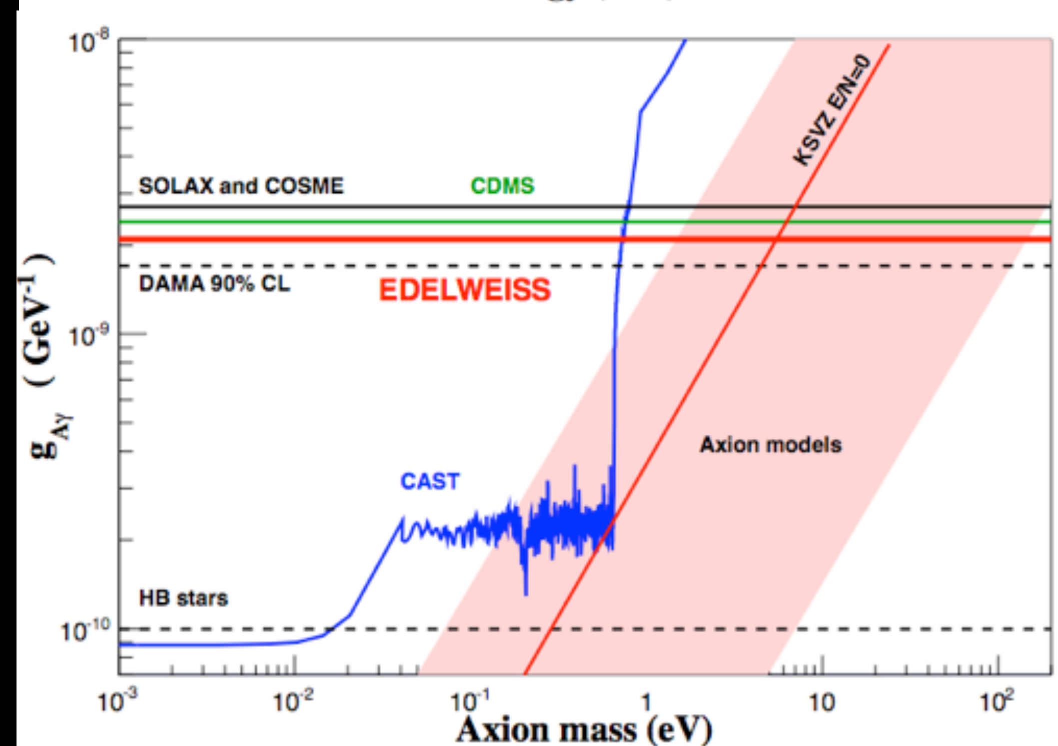
EDELWEISS: search for axion conversion to photons, 357 kg-day exposure, >2.5 keVee, uses time modulation and Primakoff spectrum to reduce backgrounds x100. *(arXiv:1307.1488)*

XMASS: search for vector or pseudo-scalar bosons with 132 live day x 41 kg fiducial mass, >40 keV. Background is O(1E-4)/(keV kg day) *(arXiv:1406.0502)*

XENON100: searches for axions and ALPS in 34 kg x 224.6 days, >2 keVee, with background of 1E-4/(keV kg day). *(arXiv:1404.1455)*

Constraints from Theorists: limits on kinetic mixing to hidden sector coupling extracted from XENON 10, 100, and XMASS spectra. *(arXiv:1412.8378)*





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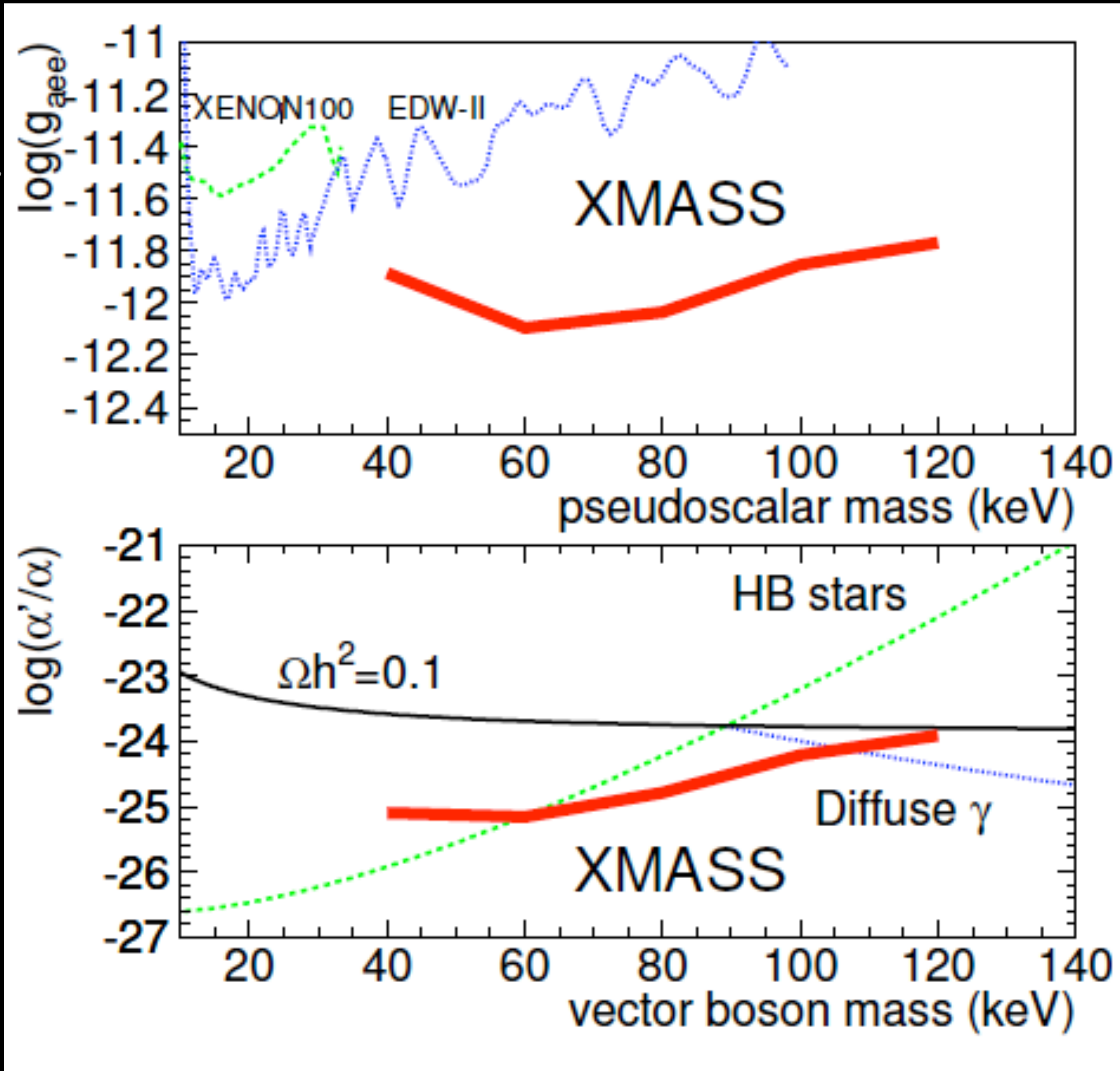

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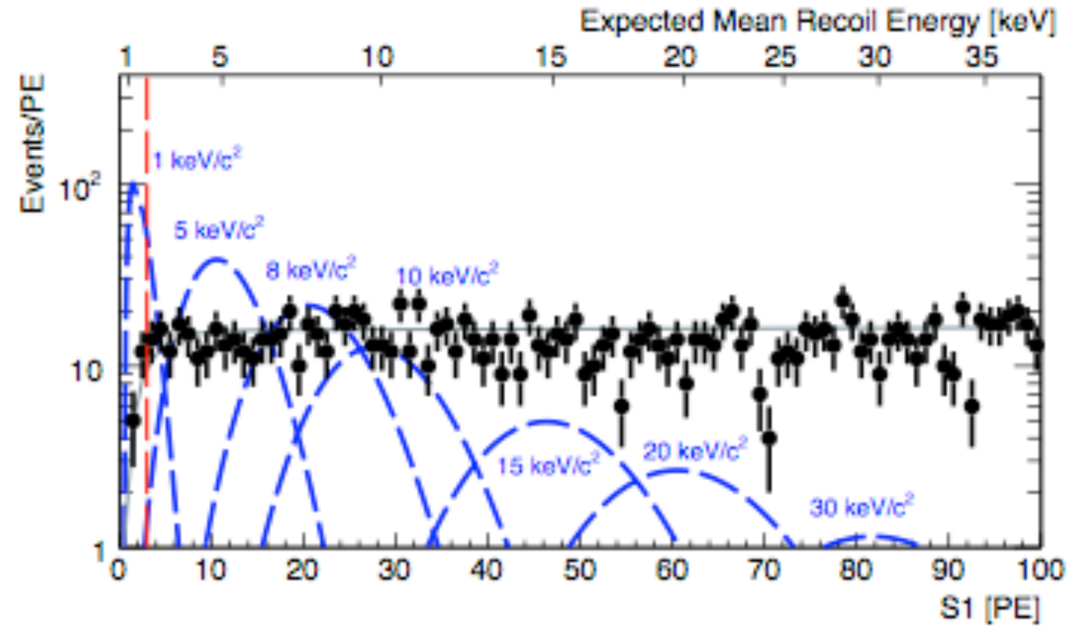

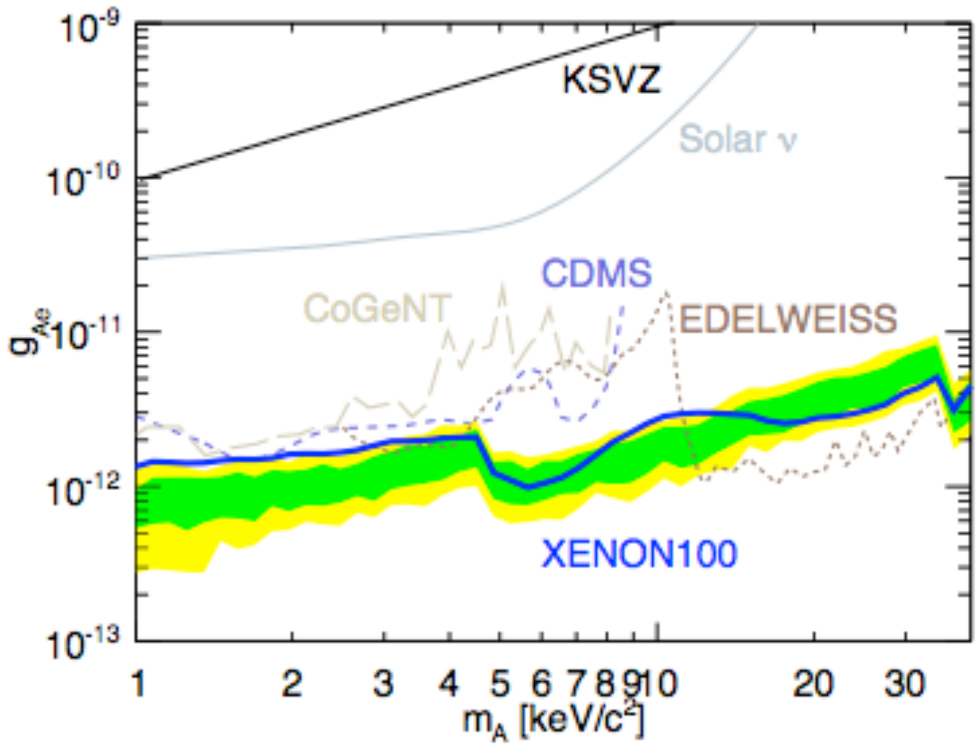

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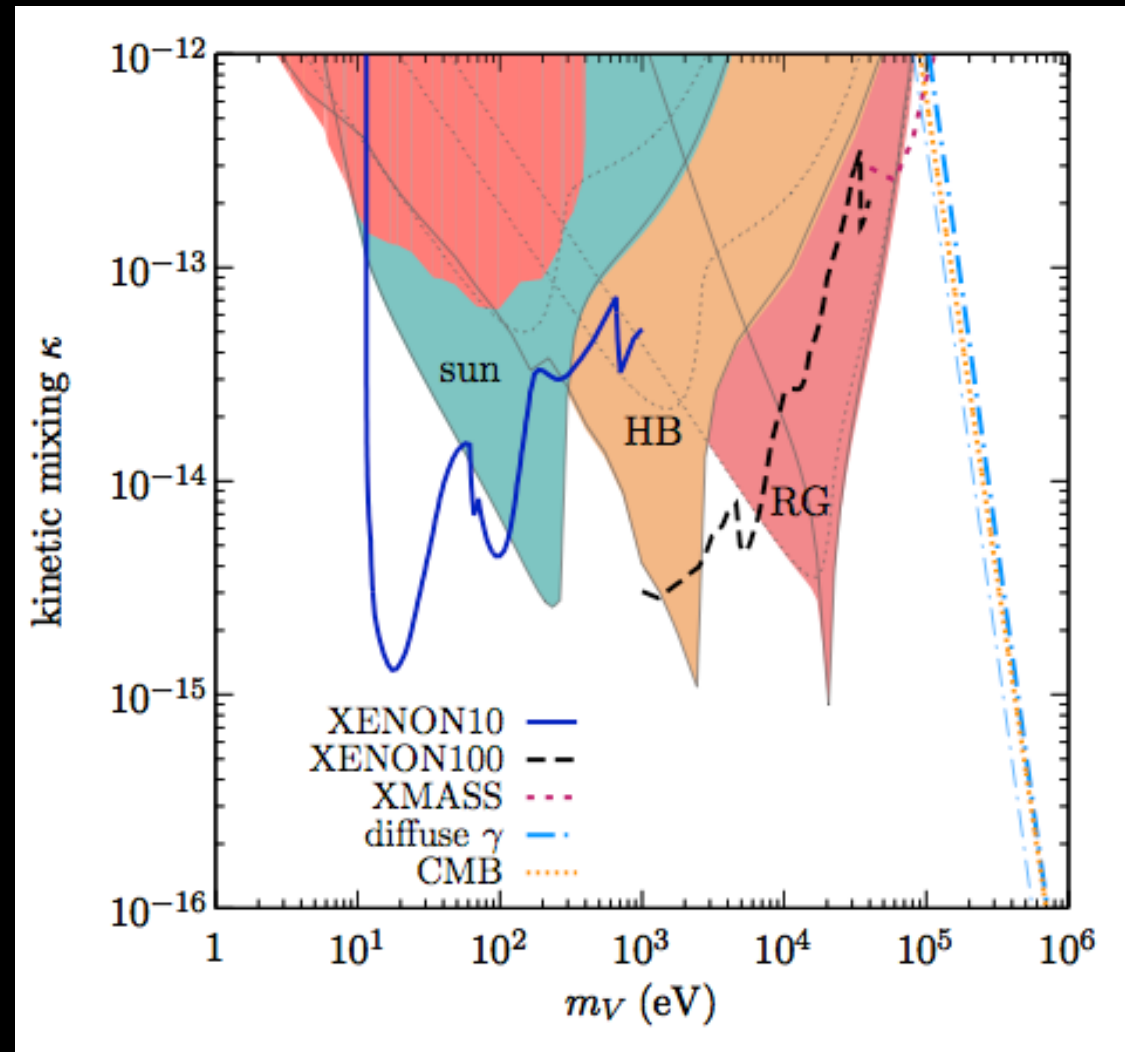
(An, Pospelov, Pradler, Ritz, Phys. Lett. B747 (2015)

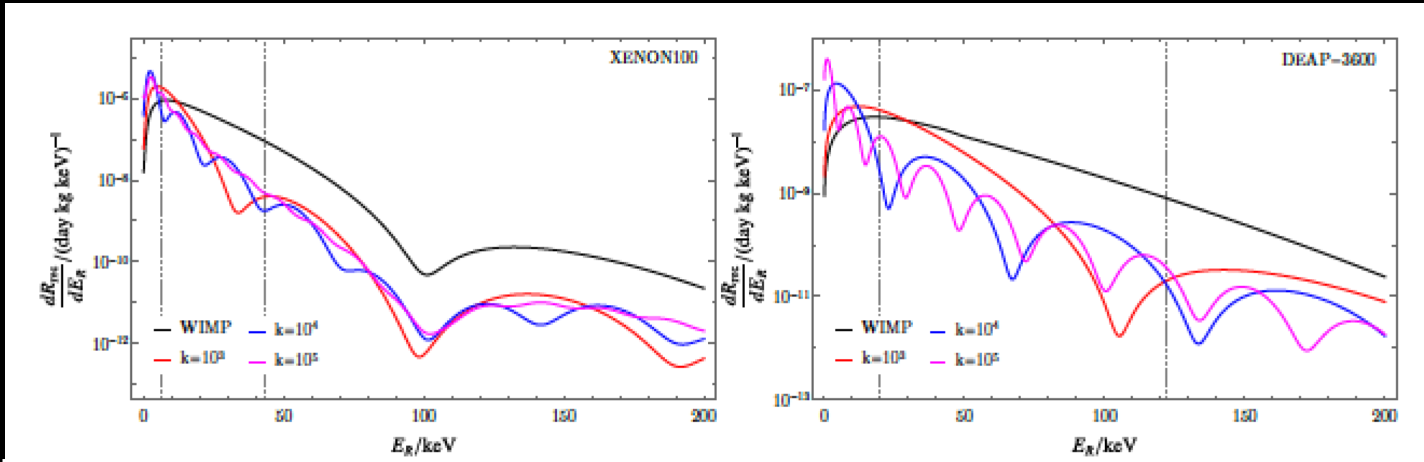


Spectral Distortion in Direct Detection

XMASS: search for inelastic dark matter scattering on Xe-129 *(arXiv:1401.4737)*

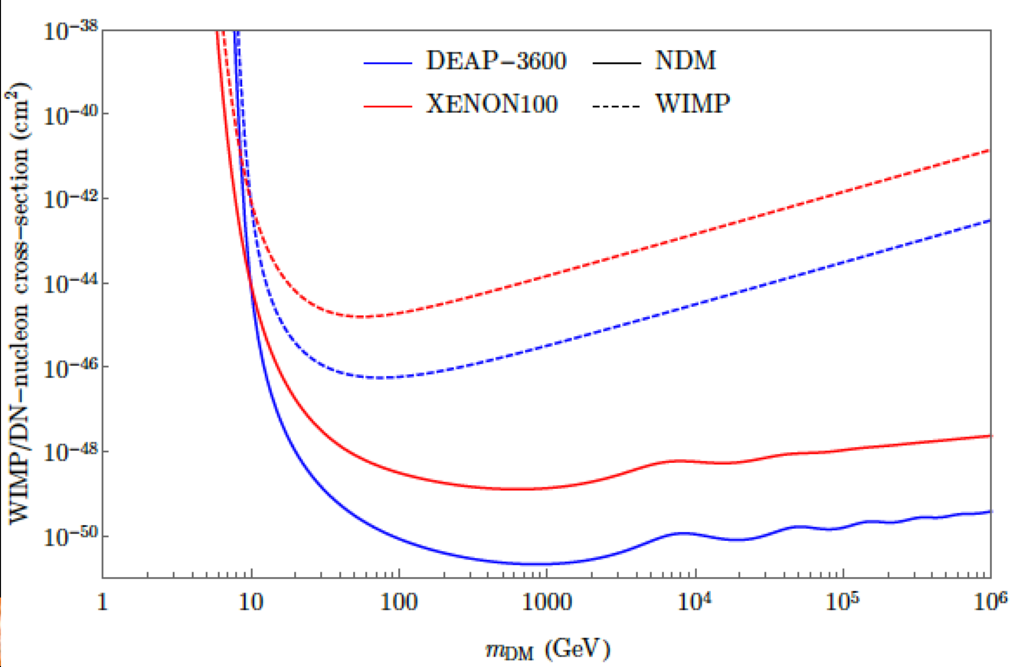
CRESST-II: momentum-dependent asymmetric dark matter search *(arXiv:1601.04447)*

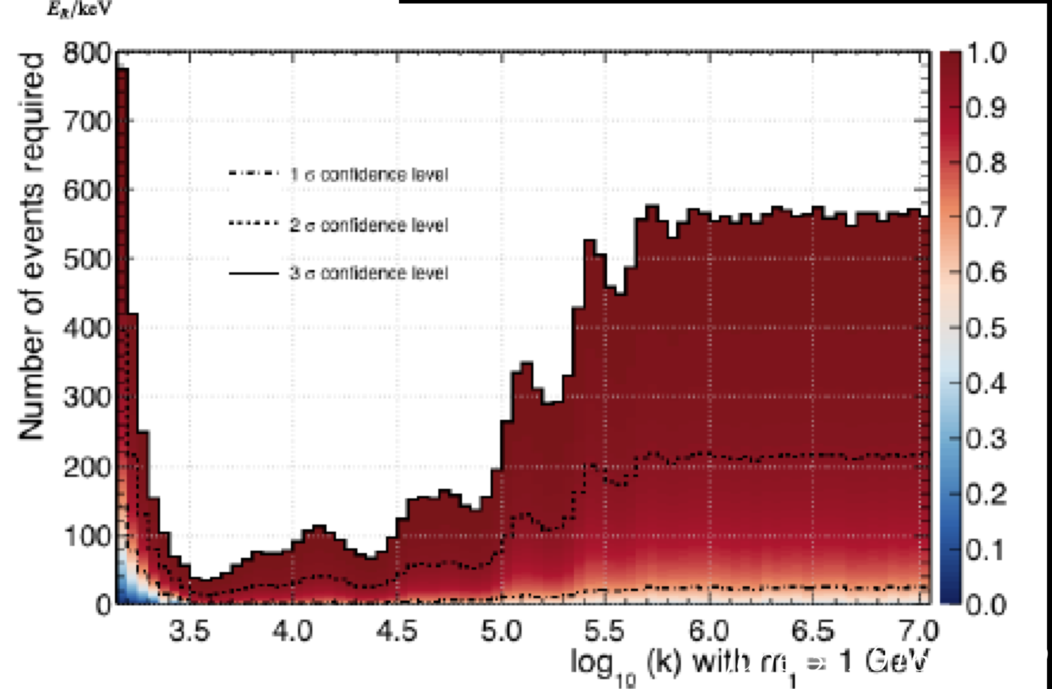
DEAP-3600: sensitivity to composite dark matter, e.g. *Hardy, Lazenby, March-Russell, West JHEP 07 (2015)*
dark nuclei, formed of *k* bound states of strongly-interacting dark nucleons, scatter with target nucleus. Scattering process now has a form factor from the nuclear dark matter and the target.



ex. case with dark nucleon mass = 1 GeV, radius = 1 fm, and per-SM nucleon scattering cross section of 1E-46 cm2.

Kirk, Butcher, JM, West, in preparation





Comments on Non-WIMP Reach

Non-WIMP sensitivity reach for direct detection experiments determined by:
(i) exposure, (ii) recoil energy threshold (and maximum), (iii) recoil particle identification, and
(ii) (iv) background rejection / systematic error in nuclear AND electron recoil channels.

Recoil energy:
Minimum recoil energy set by background rejection in most cases, can be lowered for bump-hunt above well-measured background to search for lines (e.g. ALPS). Potential for <0.1 keV.
But! A key experimental issue is the *uncertainty* on the energy response at low energies.

Particle ID:
Main task is to distinguish nuclear recoils from electrons from alphas. Ar can ID nuclear vs. electron recoils at ~1E-10, Xe at 1E-4. x2-5 further probably possible in Xe. In Ar, strong trade-off between rejection power and threshold (PSD depends exponentially on measured recoil energy).

Background rejection:
Best experiments now (Xe) achieve 1E-4 events/keV/kg/day w.r.t. intrinsic backgrounds. Big improvement possible with increase in light yield, potential from solid-state photo-sensors.

Bonus(?):
High statistics measurements of Ar-39 beta-decay spectra in very large LAr dark matter detectors may have sensitivity to other interesting possibilities through spectral shape analysis *of betas*
(e.g. 3.5 keV sterile neutrinos, Lorentz violating interactions,…)
e.g. DEAP will have >1E10 Ar-39 events with ~1% energy resolution, 1% systematic uncertainties.

Conclusions & Outlook

Direct detection searches are rapidly expanding physics reach:

to lower cross sections, probing new parameter space,
to lower masses, testing new models,
to higher masses, complementary with the LHC,
to new particle candidates (axions, ALPS, ...)

New ideas for non-standard searches in direct detection are needed! (Insert your event generator here)

Experiments running now or under construction will improve sensitivity reach by 1-2 orders of magnitude in next few years, with significant potential to test new models, new candidates, new interaction structure…

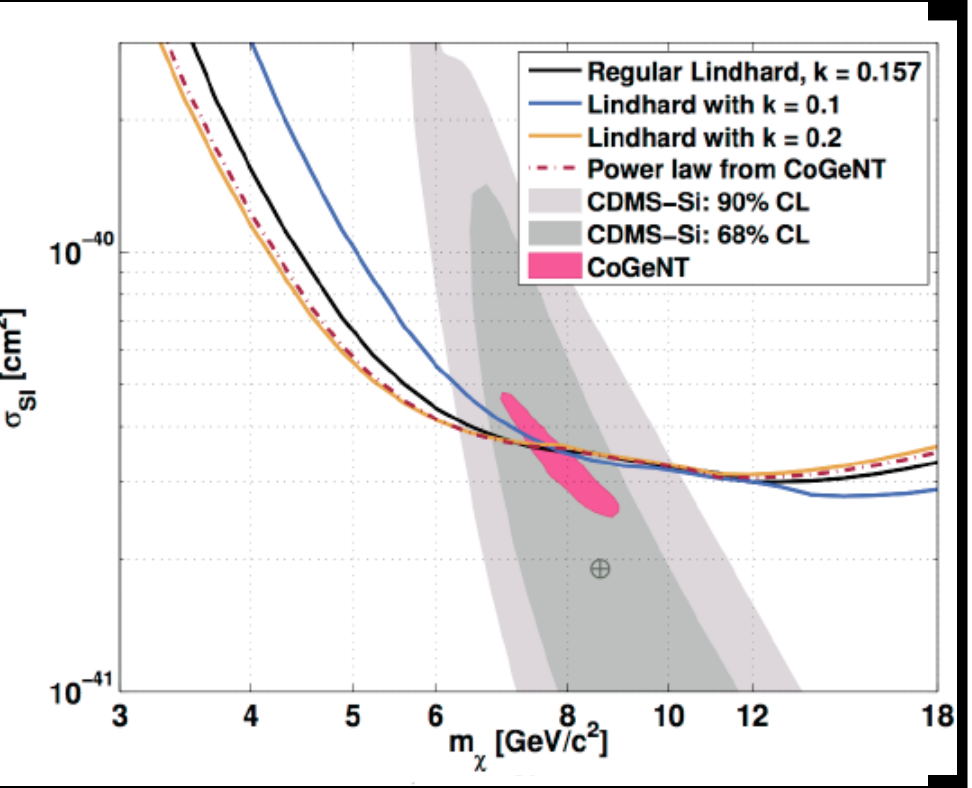
Collaboration with theorists and phenomenologists is very welcome!

Extra

Quenching

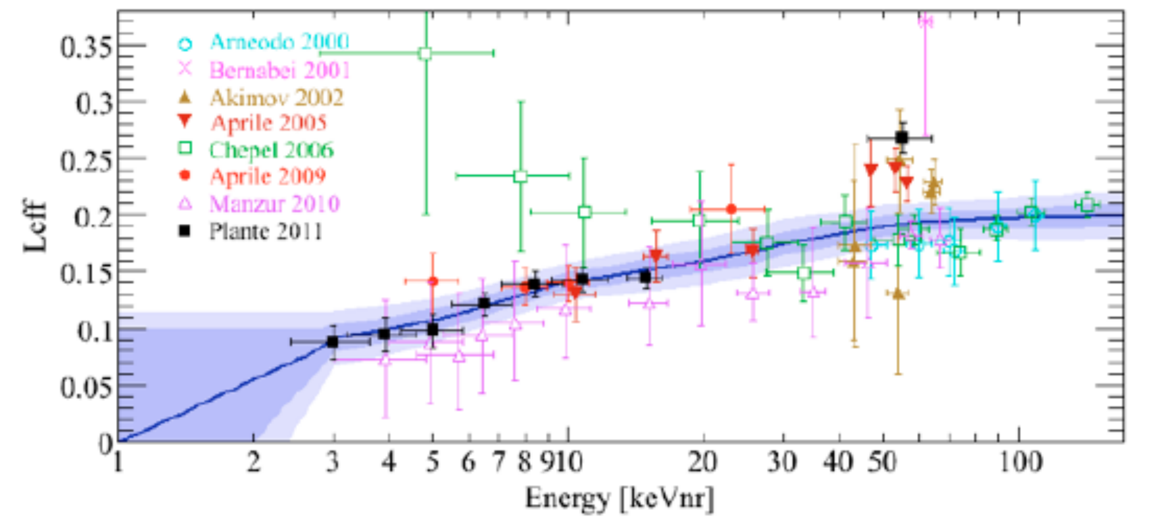
(material courtesy L. Baudis)

Current status of measurements of visible/recoil energy in
-ionization on Ge
-scintillation on Xe, Ar



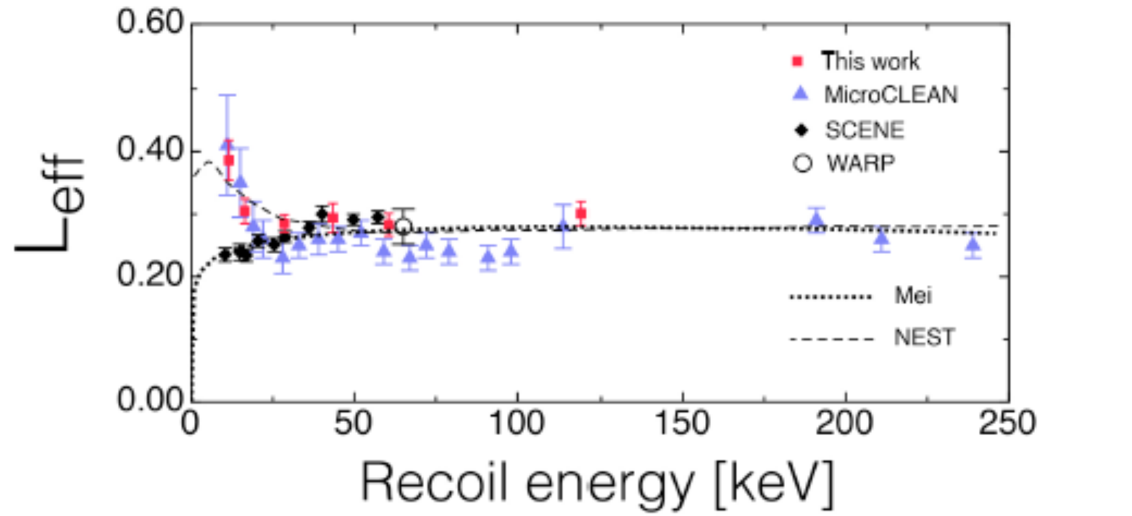
Direct method: LXe

Plante *et al.*, Phys. Rev. C **84**, 045805, 2011



Direct method: LAr

W. Creus et al., arXiv: 1504.07878



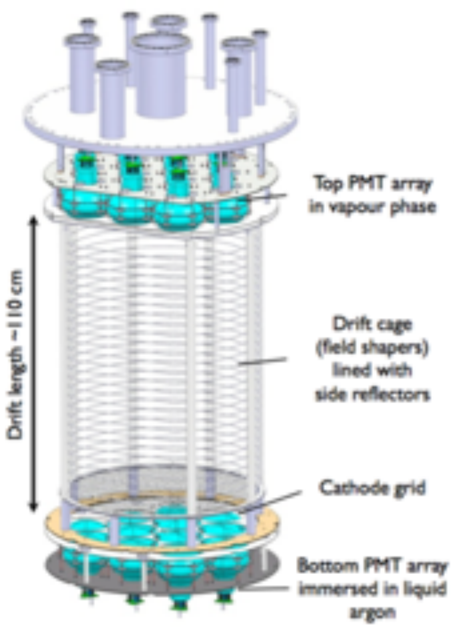
Impact of uncertainties up to x5-10 in dark matter limits, particularly at low mass!

MSSM Mass, σ > ν bound

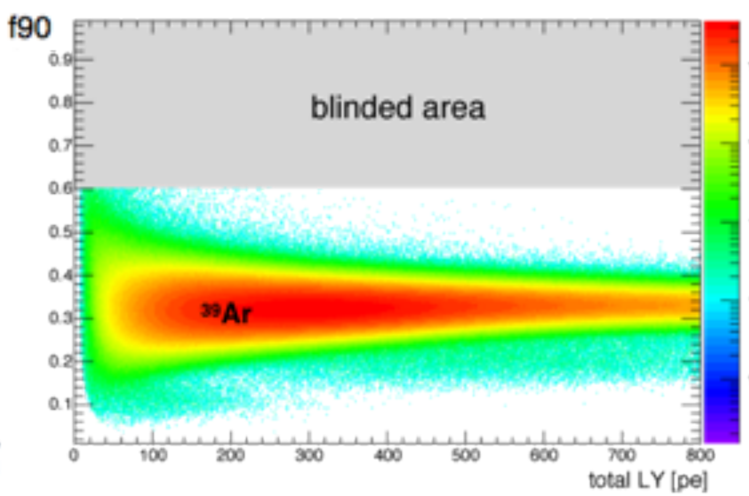
ArDM-1t

(thanks to A. Rubbia)

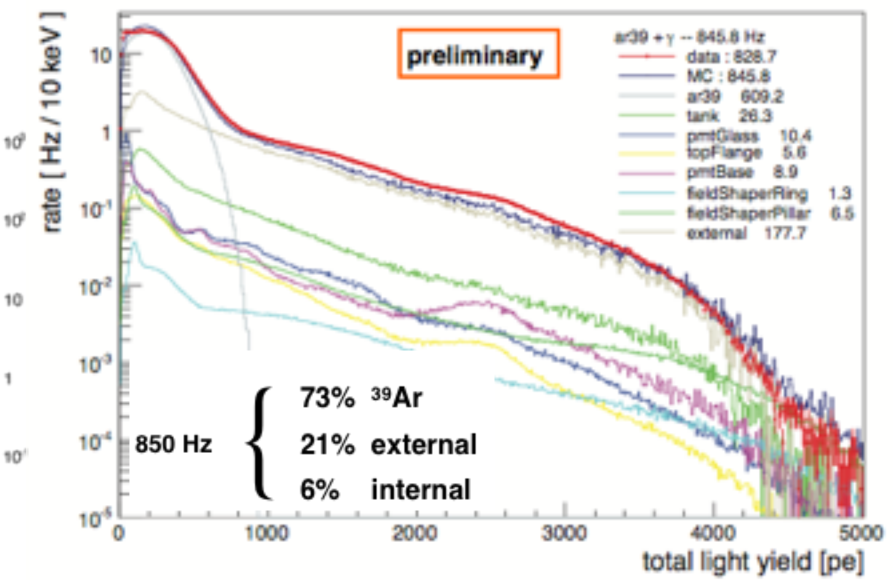
- Ton-scale LAr TPC at Canfranc underground Laboratory Spain) @ 2500 m.w.e.
- 850 kg active mass, 24 8” PMTs, low background
- 1st 6-month run in single phase in 2015: to explore features of LAr for DM@ton-scale
- Now preparing double phase Run II — scheduled for 2016
- 2017 and beyond: (a) accumulate statistics + light yield/hardware upgrades (b) depleted argon studies with sensitivity down to 10^{-5} together with DarkSide. Demonstration at the ton-scale is a necessary step towards 10-tons and beyond.



Pulse shape discrimination



Low BG studies



IAXO

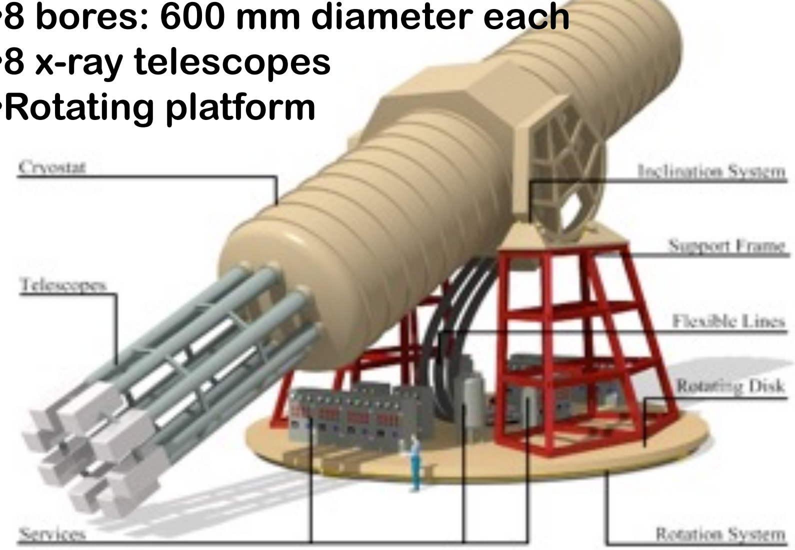
(thanks to I. Irastorza)

IAXO builds on decade of European axion helioscopes: CAST at CERN.

Timeline:

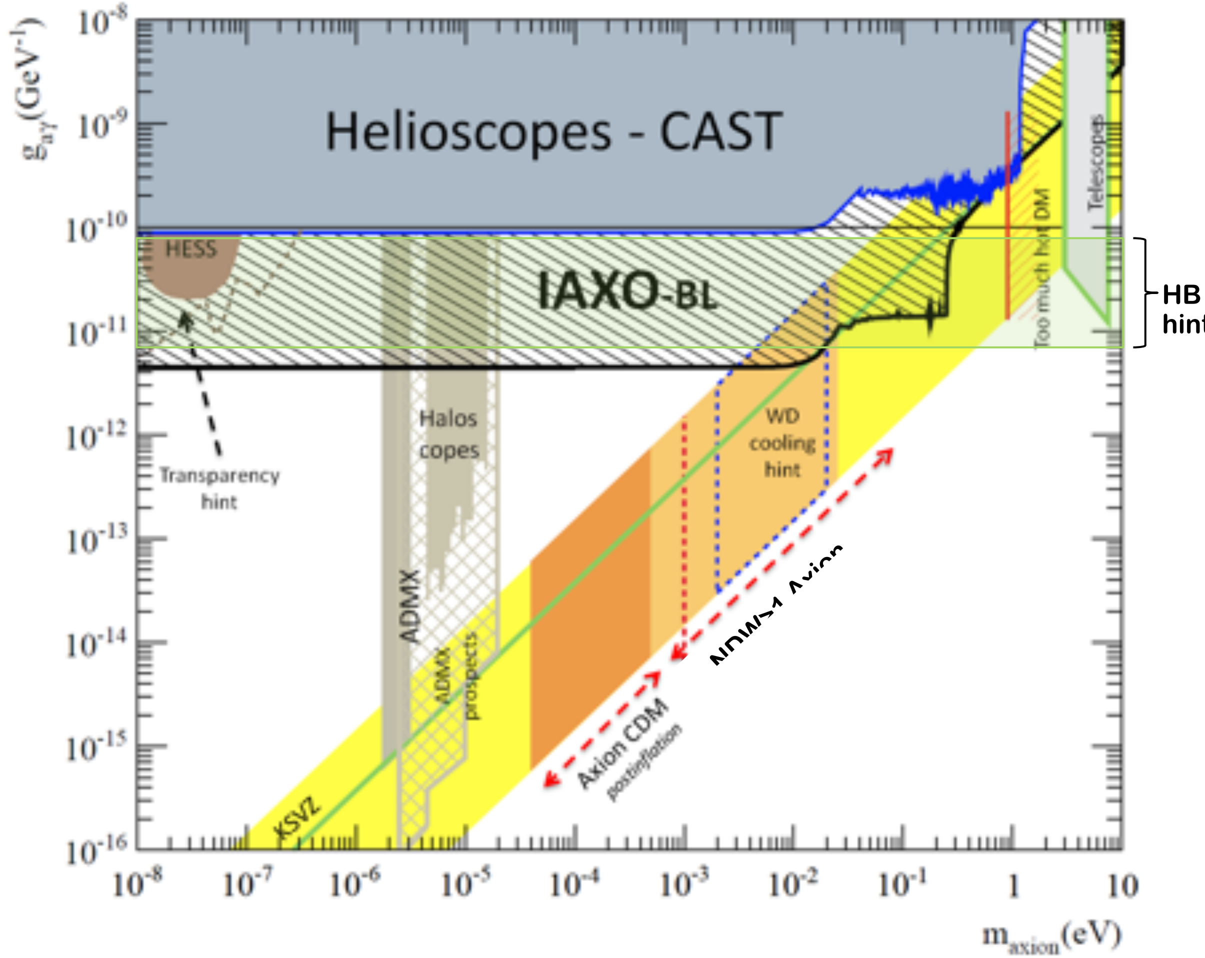
- Conceptual Design 2013
- Letter of Intent to SPSC 2014, received positive recommendation to develop TDR
- TDR design and prototyping ongoing:
  - IAXO-D0: low background x-ray detectors p
  - IAXO-X0 : x-ray optics
  - IAXO-T0: superconducting magnet coil
- Funding path for TDR (almost) clear.

•Large toroidal 8-coil magnet L = ~20 m
•8 bores: 600 mm diameter each
•8 x-ray telescopes
•Rotating platform



Enhanced axion helioscope: *JCAP 1106:013,2011*

complementary reach with cavity searches,
+ >10x gain in QCD axion reach over current results



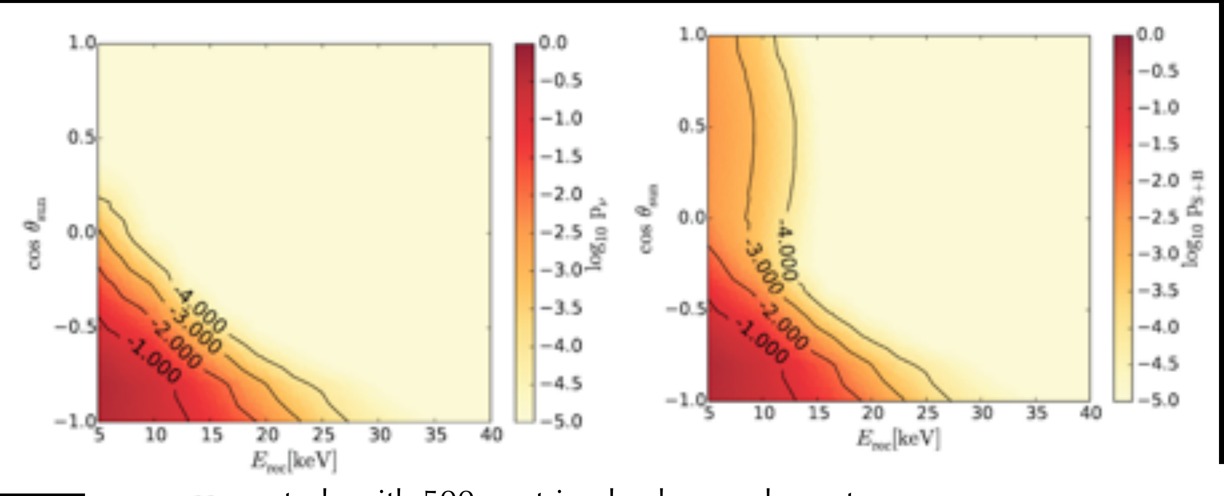
Discussion for funding path for IAXO underway

- includes scenarios with IAXO in sites alternative to CERN
- Critical moment for the project, with first dedicated funding
- support from APPEC roadmap very important for the project

Beyond the Neutrino Bound

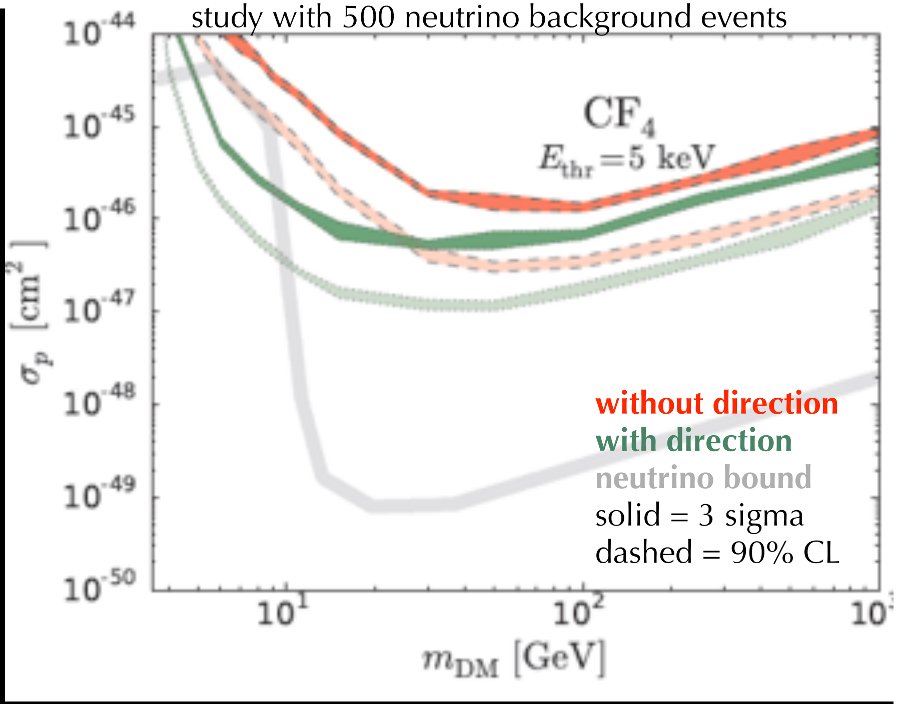
Grothaus, Fairbairn, JM
Phys.ReV.D90 (2014) 055018

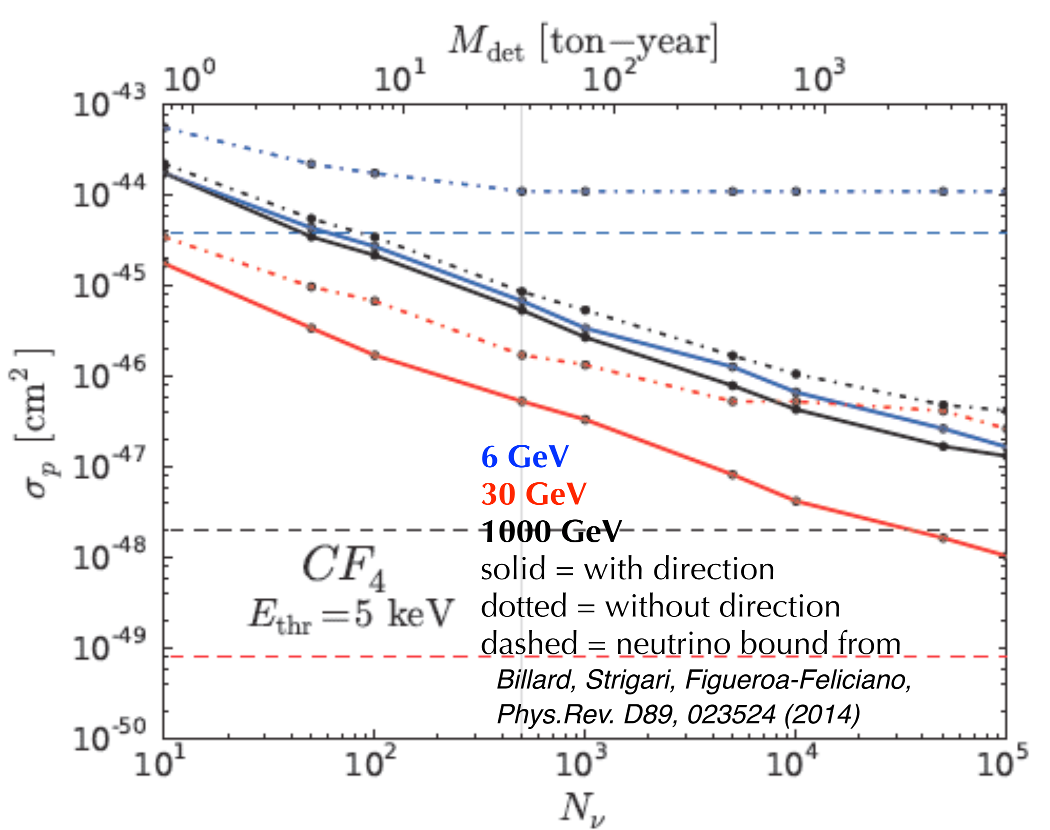
PDFs in (energy, angle, time) of event for coherent solar nu background vs. background+signal show significant differences, including 35° resolution:



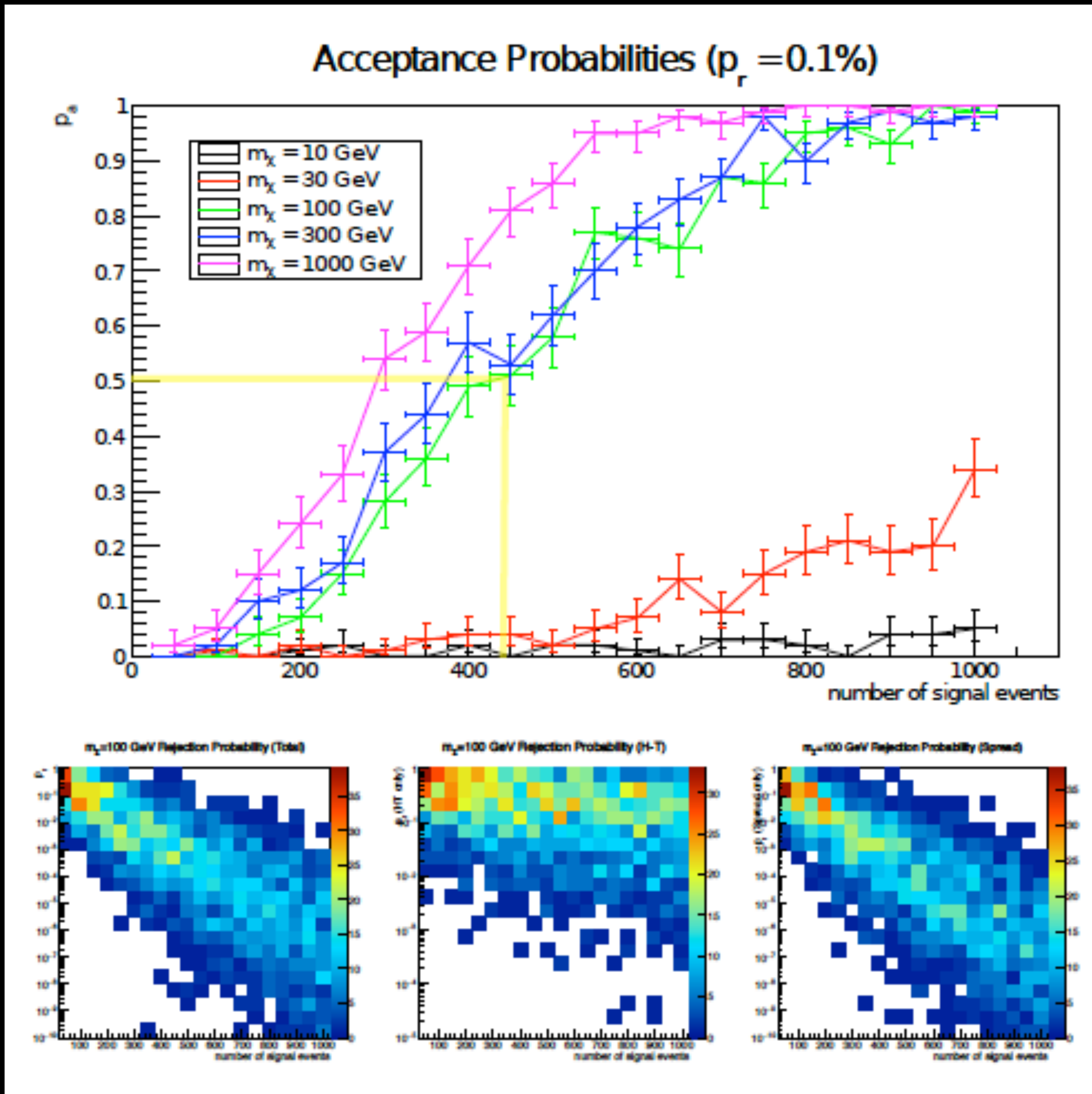
statistical test (CLs) shows

- directionality gains 10x in sensitivity with background
- no neutrino bound for directional detectors!





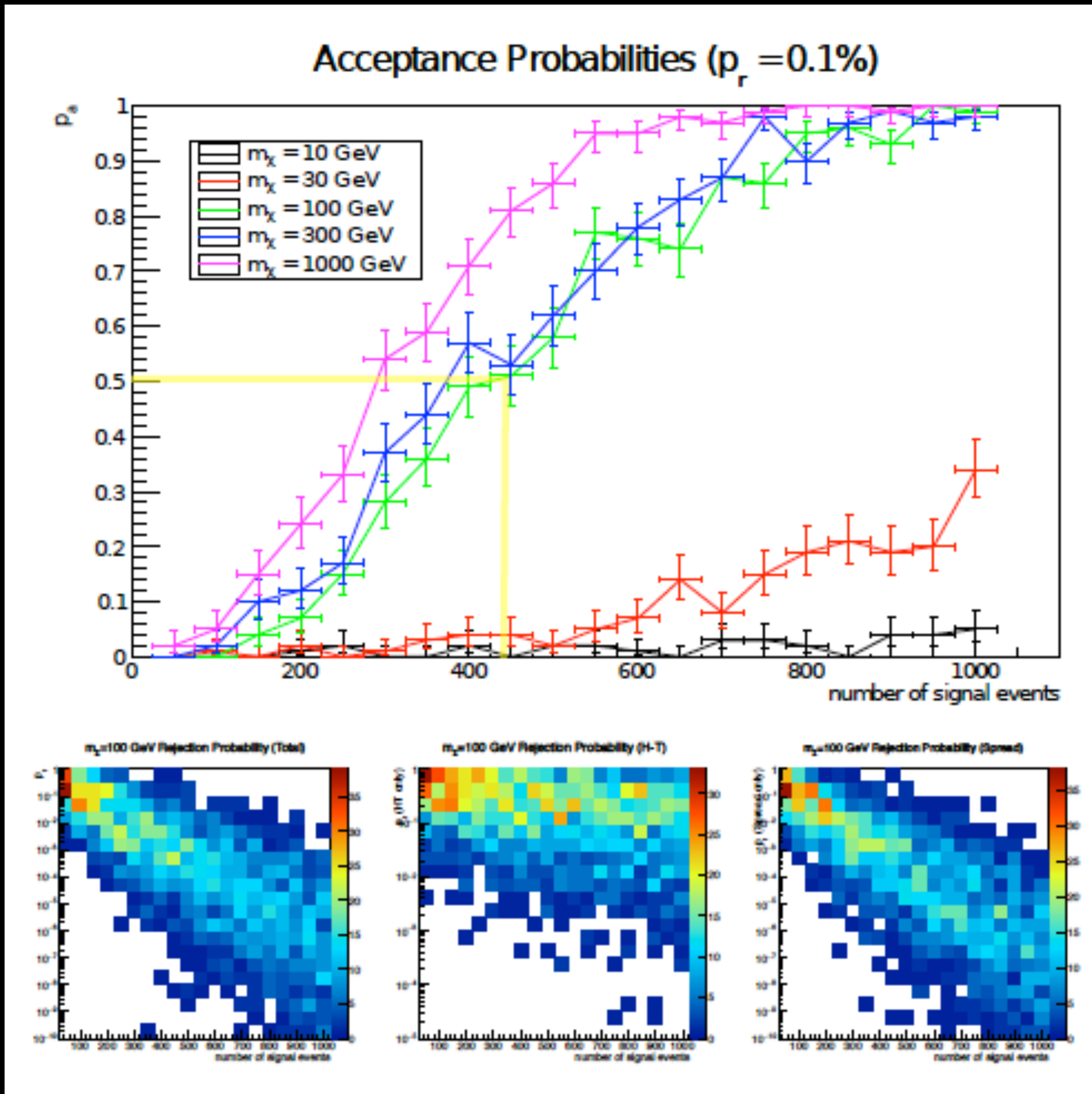
Directional Detection Signal Sensitivity



<u>Analysis assumptions</u>

- Use physics model tuned on data, assume 100k gain
- simulate *n* experiments, compute forward fraction and axial spread per bin
- calculate *p* of obtaining these values from isotropic distribution, and combine bins using Fisher's method
- Result: need 450 events to measure anisotropy at 3σ in >50% of experiments.

Directional Detection Signal Sensitivity



Analysis assumptions

e.g. DEAP veto: 200 m^3

- Result: need 450 events to measure anisotropy at 3σ in >50% of experiments.

(= 500 [300] m3-years for 100 (1000) GeV/c^2 DM at 1 fb SD xsec on F)
(=25 kg-years)