There are 0.3GeV/cm^3 of Galactic Dark Matter in this room. We fly through this matter at 220km/s. How can we detect this particle wind?

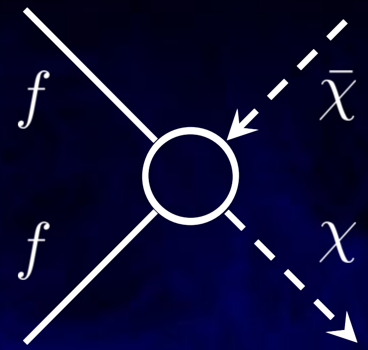
Rafael F. Lang
Columbia University New York
rafael.lang@astro.columbia.edu

Physics in Collision, Karlsruhe, September 2010

picture: Thomas Tuchan

How to Search a Thermal Relic

- Production



Collider Searches

- Annihilation

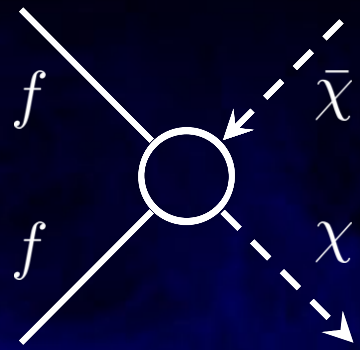
$\bar{\chi}$ f

χ f

Indirect Searches

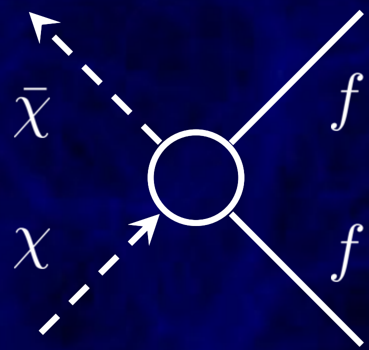
How to Search a Thermal Relic

- Production



Collider Searches

- Annihilation

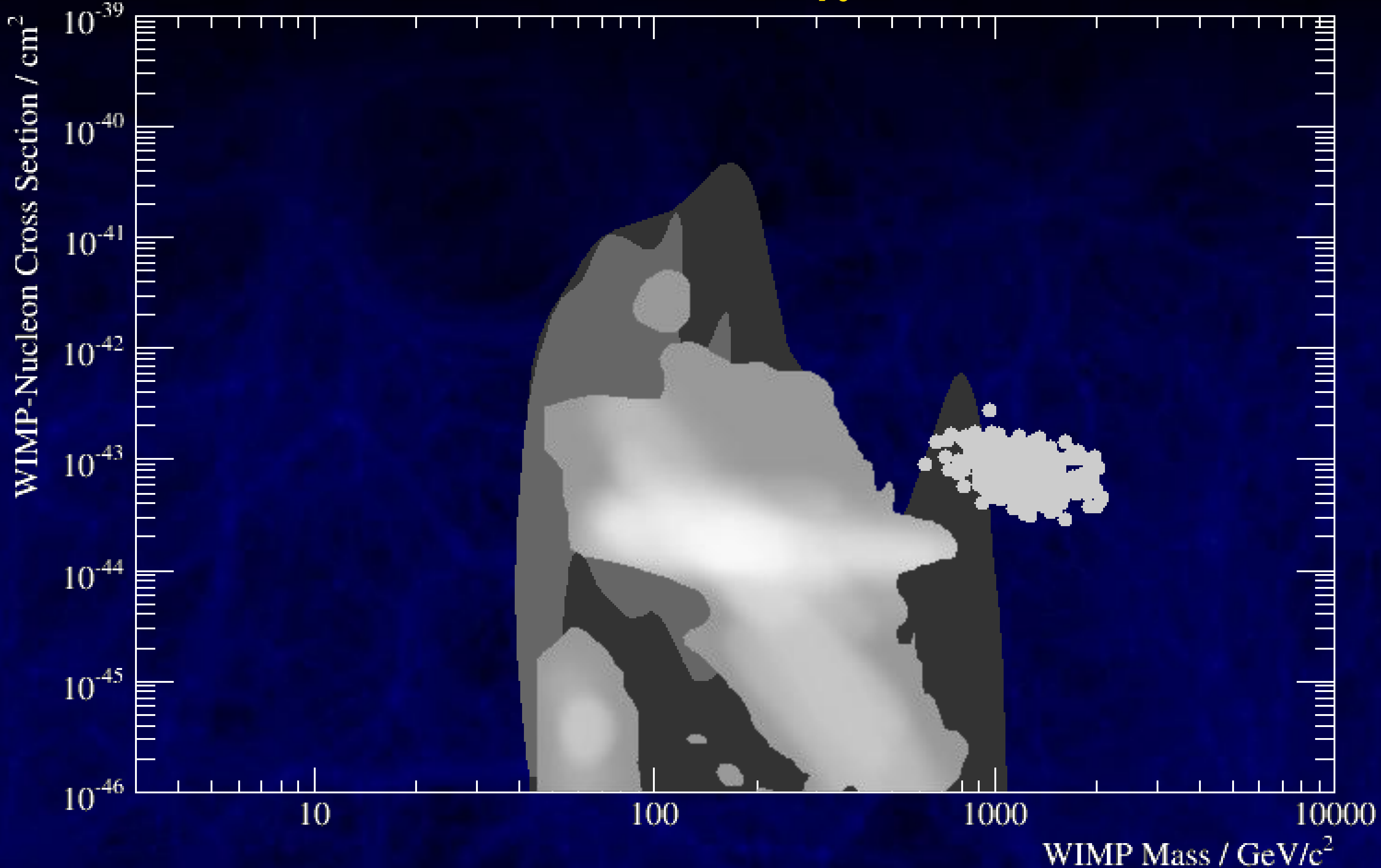


Indirect Searches

- Scattering

Direct Searches

Expectations in σ-m_χ-Space



Kadastik et al. PRL **104** 201301 (2010)
Roszkowski et al. JHEP**07** 075 (2007)
Baltz&Gondolo PRD **67** 063503 (2003)

this is where we would expect the usual new physics (MSSM etc.) to show up

Direct Scattering Theory On One Slide

- Rate $\rightarrow$ large detector, long exposure

$$N = n_{\text{target}} \Phi \, \sigma_{\chi,N} \, A^2$$

- Coherent Scattering $\rightarrow$ heavy target material

$$\frac{\lambda_{\text{deBroglie}}}{2\pi} = \frac{\hbar}{p} = \frac{\hbar c}{mc^2 \, v/c} \sim \frac{197\,\text{MeV fm}}{100\,\text{GeV}\,10^{-3}} \approx \text{fm} \approx r_{\text{nucleus}}$$

- Maximum Recoil Energy $\rightarrow$ low energy detector

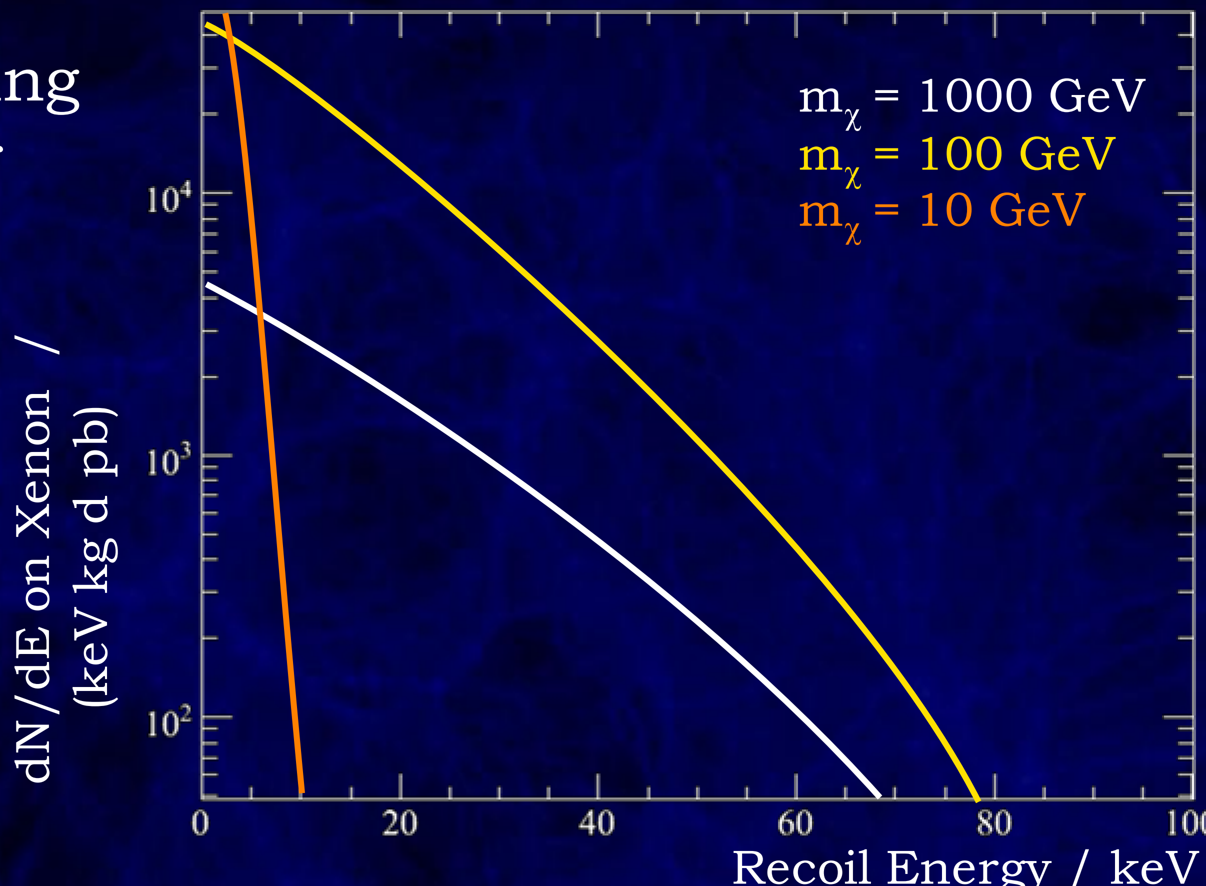
$$E_{\text{r,max}} \sim \frac{p_\chi^2}{2m_{\text{N}}} \sim \frac{\left(100\,\text{GeV/c}^2 \times 10^{-3}\text{c}\right)^2}{2 \times 100\,\text{GeV/c}^2} = 50\,\text{keV}$$

- Spectrum $\rightarrow$ shielding, discrimination, multi target

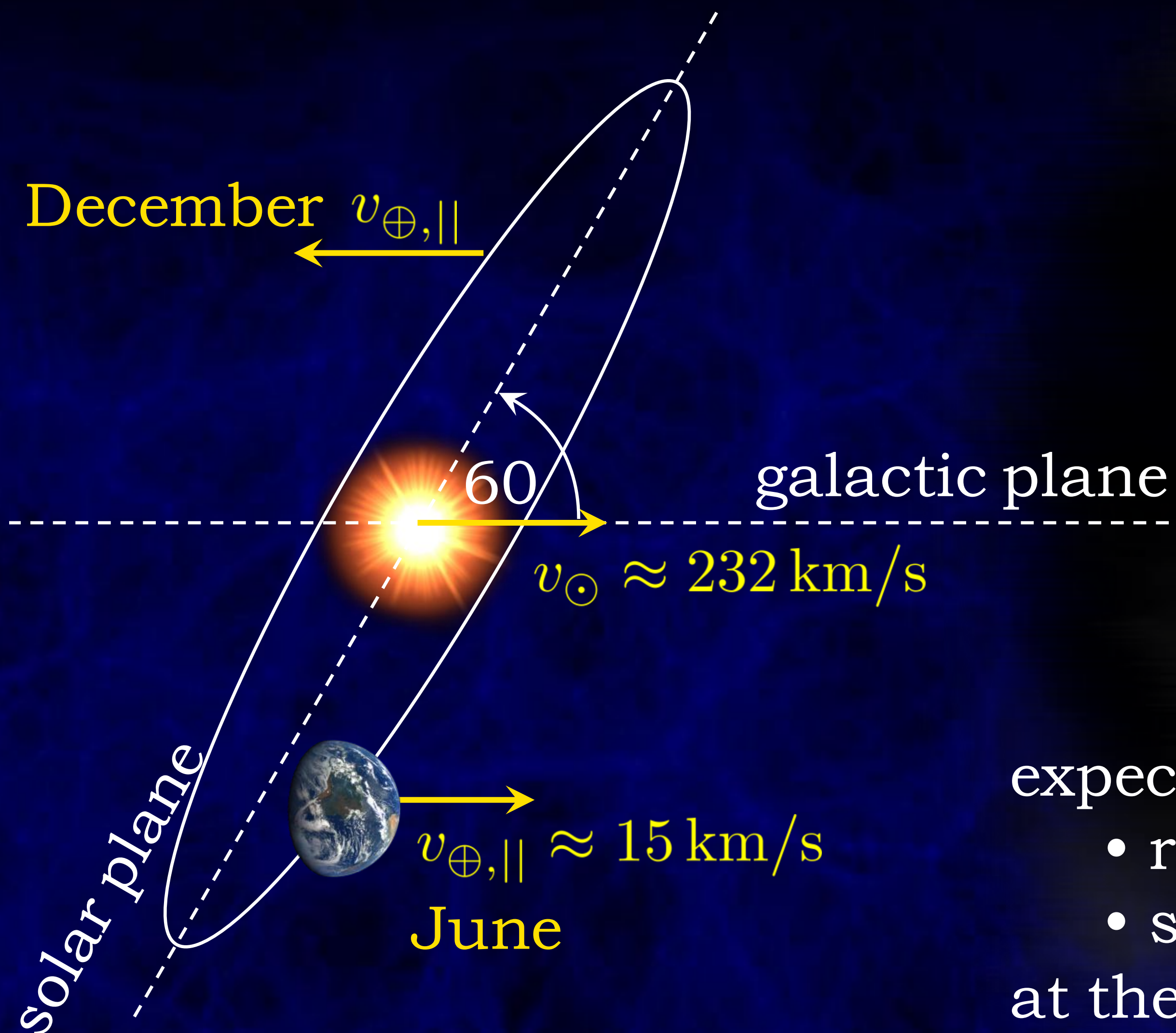
$$\frac{\mathrm{d}N}{\mathrm{d}E_r} \propto \Phi \propto \langle v \rangle \propto \int_v^\infty f_{\text{MB}}(v)\, v \,\mathrm{d}v \propto \mathrm{e}^{-v} \propto \mathrm{e}^{-E}$$

Expected WIMP Spectrum

- isothermal halo
- local density $\varrho_\chi \approx 0.3\,\mathrm{GeV}/c^2$
- $v_\oplus \approx 240\,\mathrm{km/s}$
- coherent scattering
- Helm form factor



Annual Modulation

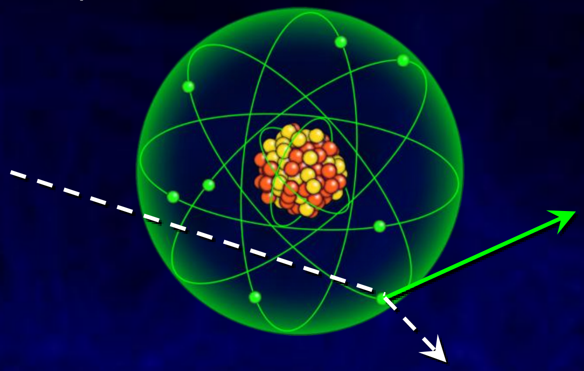


expect modulation of
- rate
- spectral shape

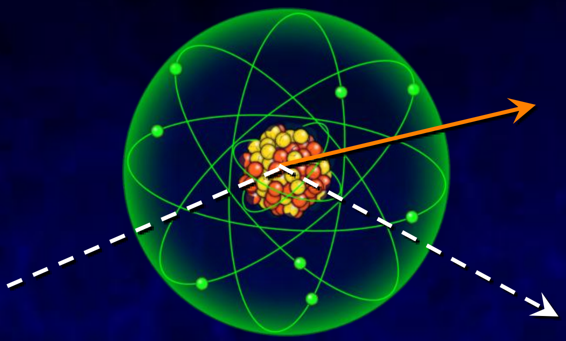
at the percent level

The Power of Discrimination

e^-/γ: electronic recoil



n/WIMPs: nuclear recoil



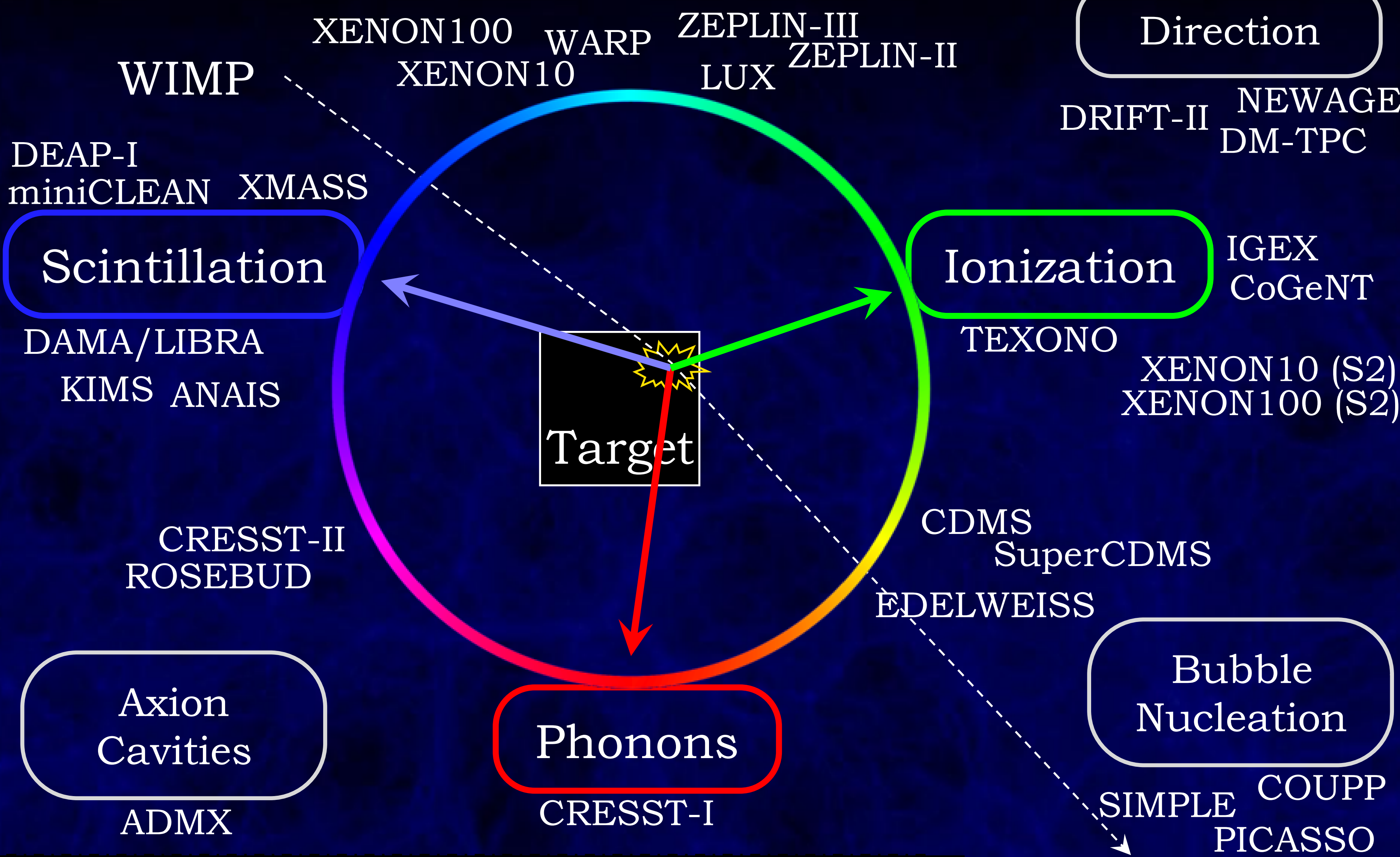
electronic recoils

- are most common background
- scintillate and ionize more (for given energy)

→ discriminate between the two

e.g. measure both energy and some additional parameter (ionization yield, scintillation yield, ratio ionization/ scintillation, pulse decay times, acoustic signal)

Particle Detection Channels

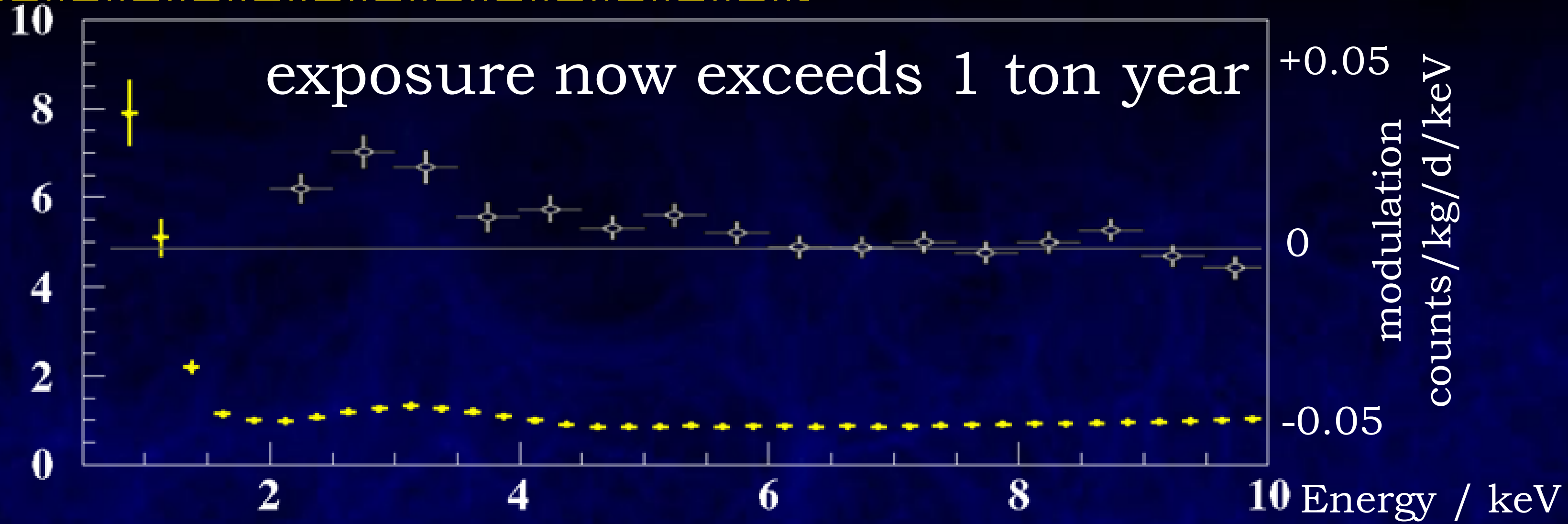


DAMA/LIBRA

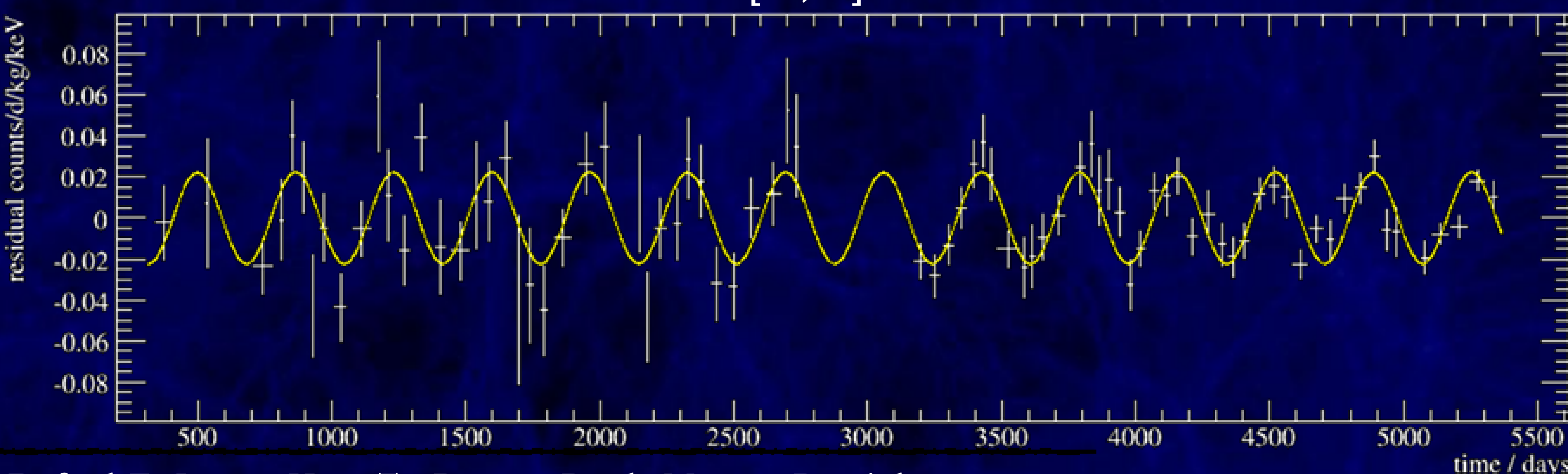
Italy/China: 230kg ultra-pure NaI(Tl) scintillators
by far largest and longest exposure but no discrimination



DAMA/LIBRA Data



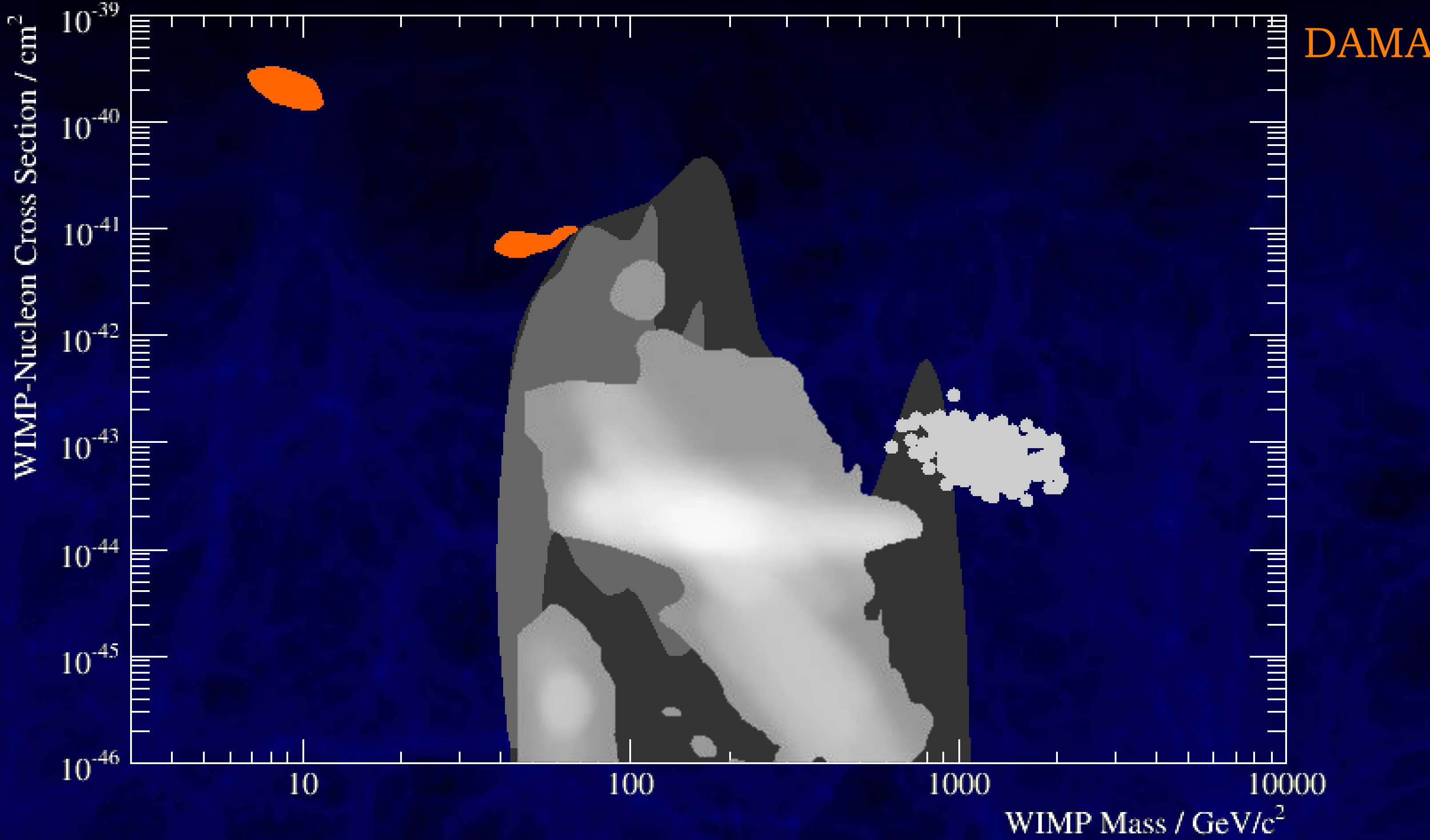
observe rate modulation in [2,4]keV:



arXiv:0804.2741

data from arXiv:0804.2741 and arXiv:1002.1028

DAMA Interpreted as WIMPs



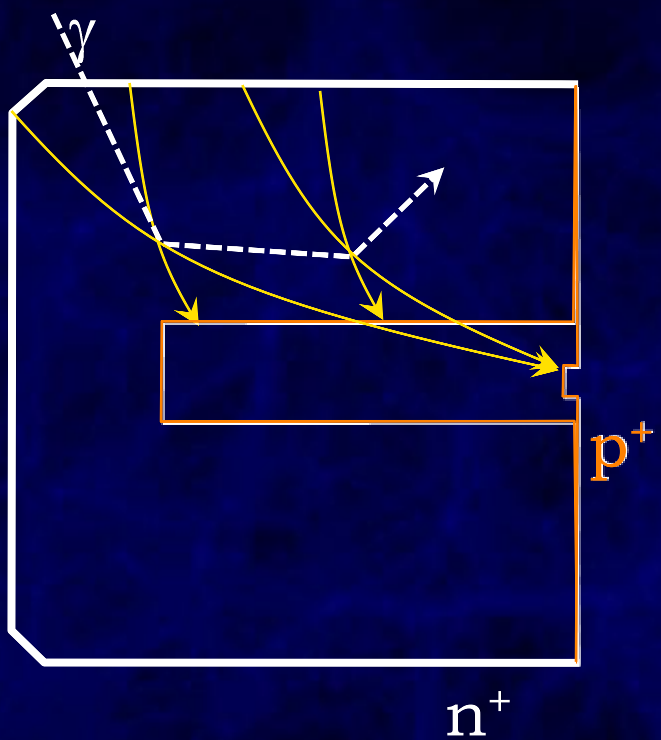
Kopp,Schwetz,Zupan arXiv:0912.4264

a bit low in mass and a bit high cross section, but a priori OK

CoGeNT

USA

440g P-type point-contact Ge detector

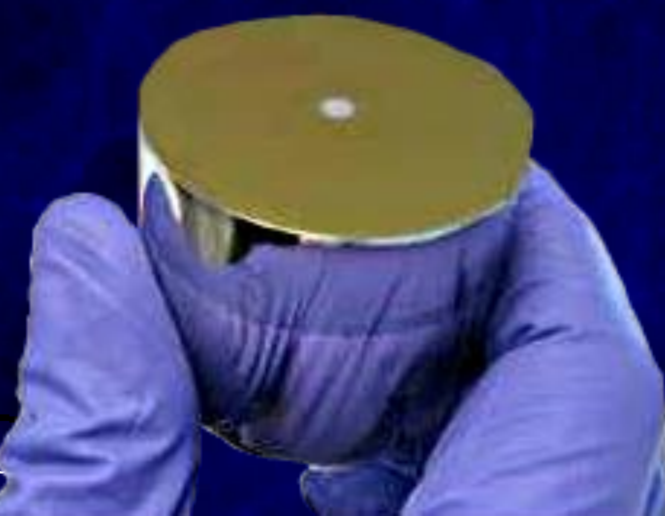


standard coaxial HPGe

P-type point contact

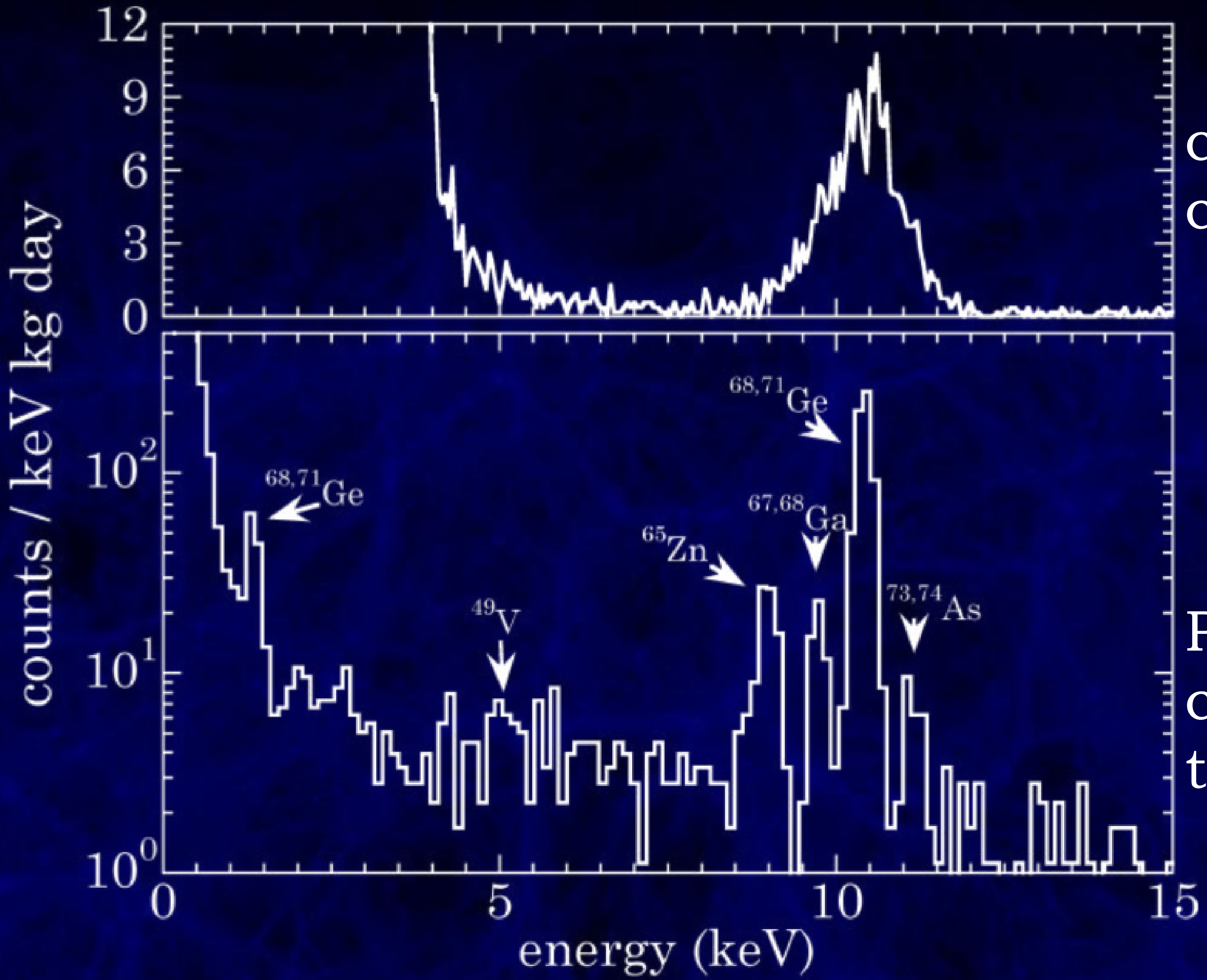
- smaller p^+ electrode
  = smaller capacitance
  & smaller noise

- no radial degeneracy for multiple interactions



Collar, UC Davis and other talks, 2010

CoGeNT Performance

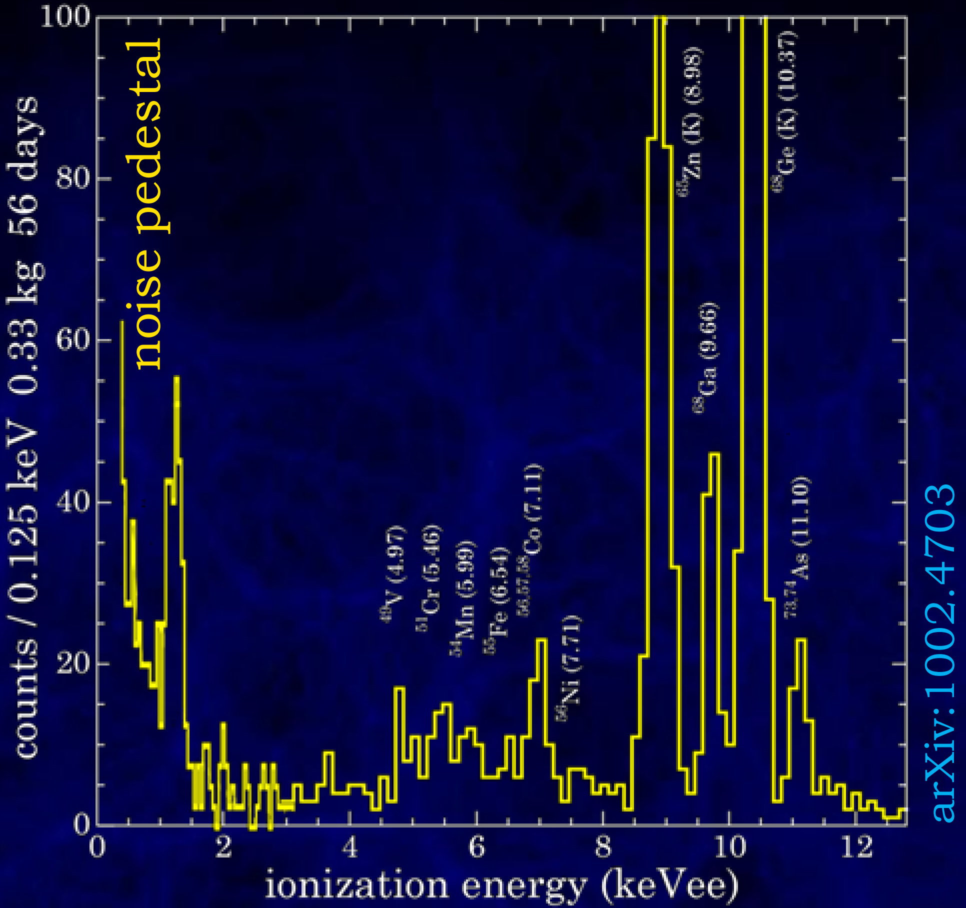


conventional coaxial HPGe

P-type point-contact HPGe threshold 400eV

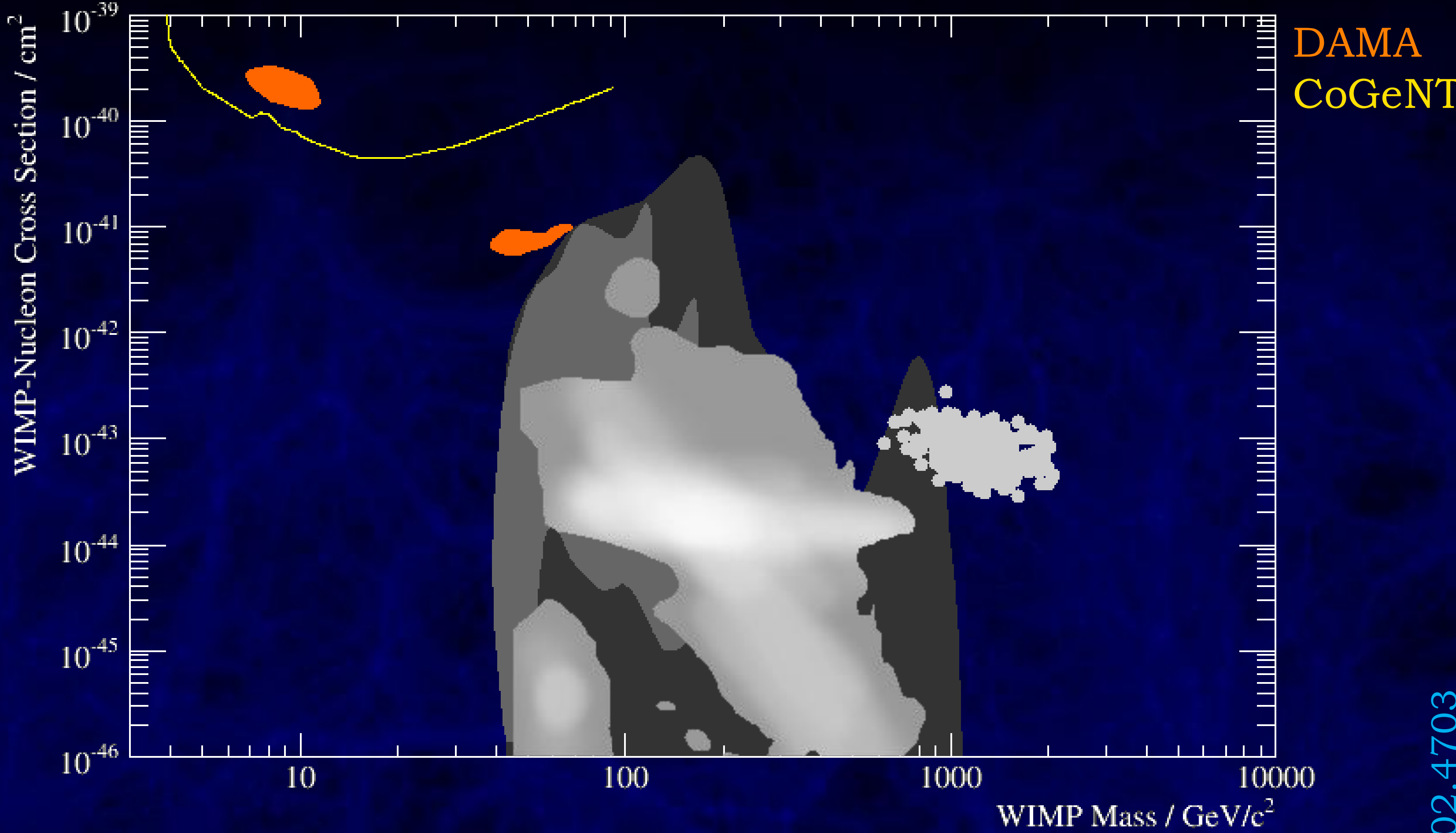
Collar, UC Davis and other talks, 2010

CoGeNT Results with 18kg d



"Take-home message: [...] Not a big deal on its own, it simply means that our irreducible bulk-like bckg is ~exponential [...] We presently cannot find an obvious known source" (J. Collar)

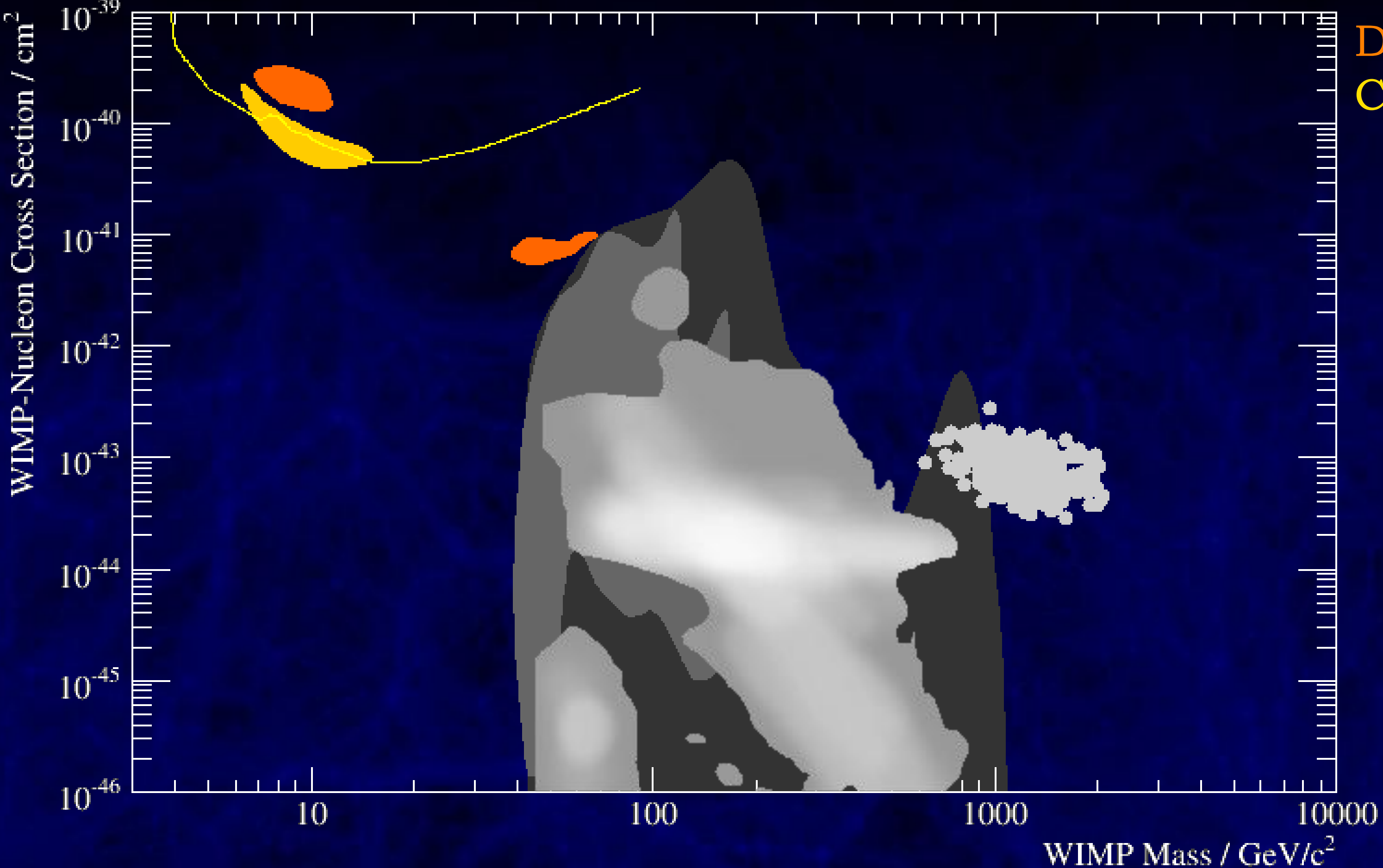
CoGeNT ≠ Light DAMA



CoGeNT excludes low mass DAMA interpretation at 90% C.L.

arXiv:1002.4703

CoGeNT Interpreted as WIMPs

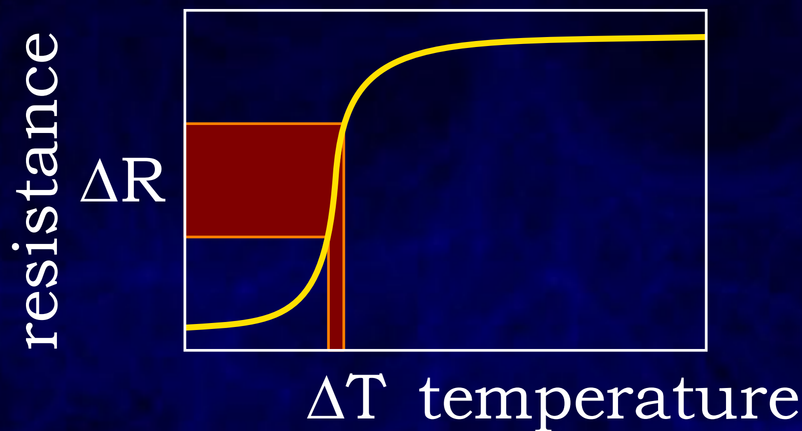


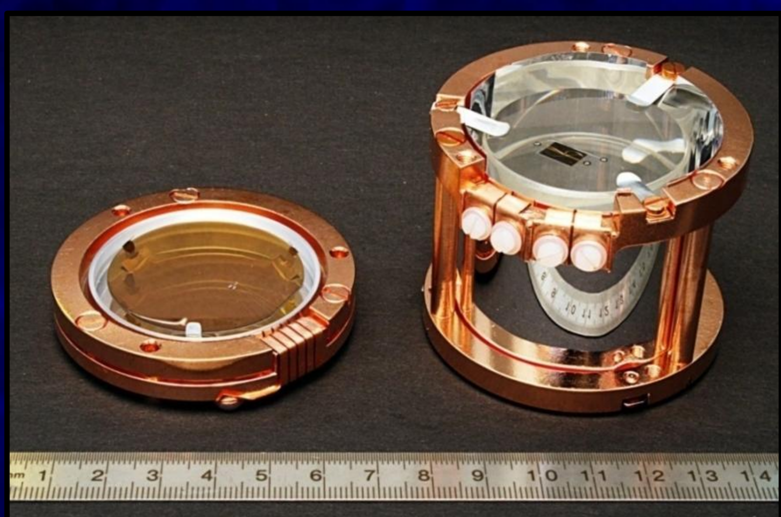
Schwetz, IDM2010

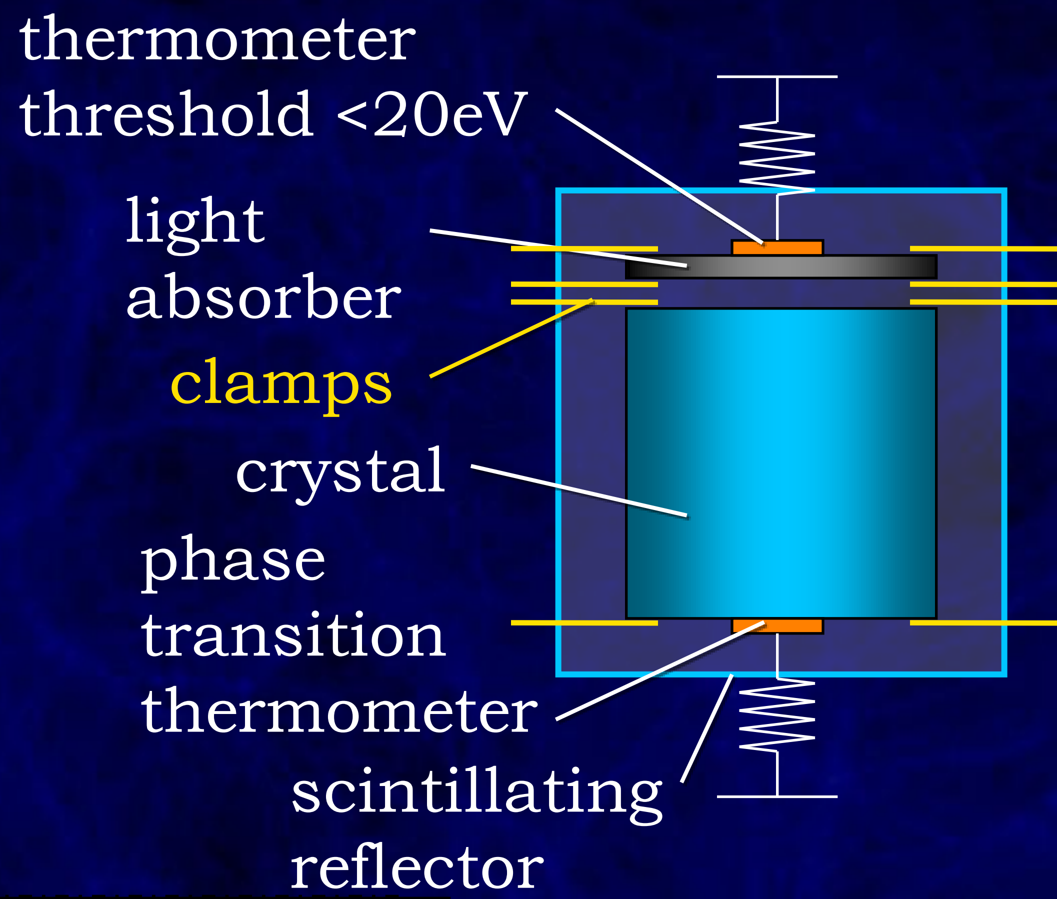
another allowed region at low masses
and relatively high cross sections

CRESST-II

Germany, UK, Italy collaboration at the Gran Sasso lab
scintillating 300g $CaWO_4$ calorimeters (phonon/light)



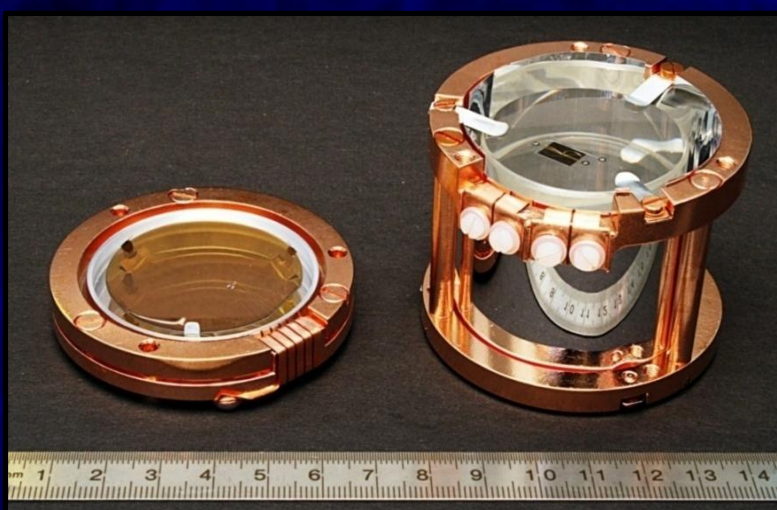




CRESST-II

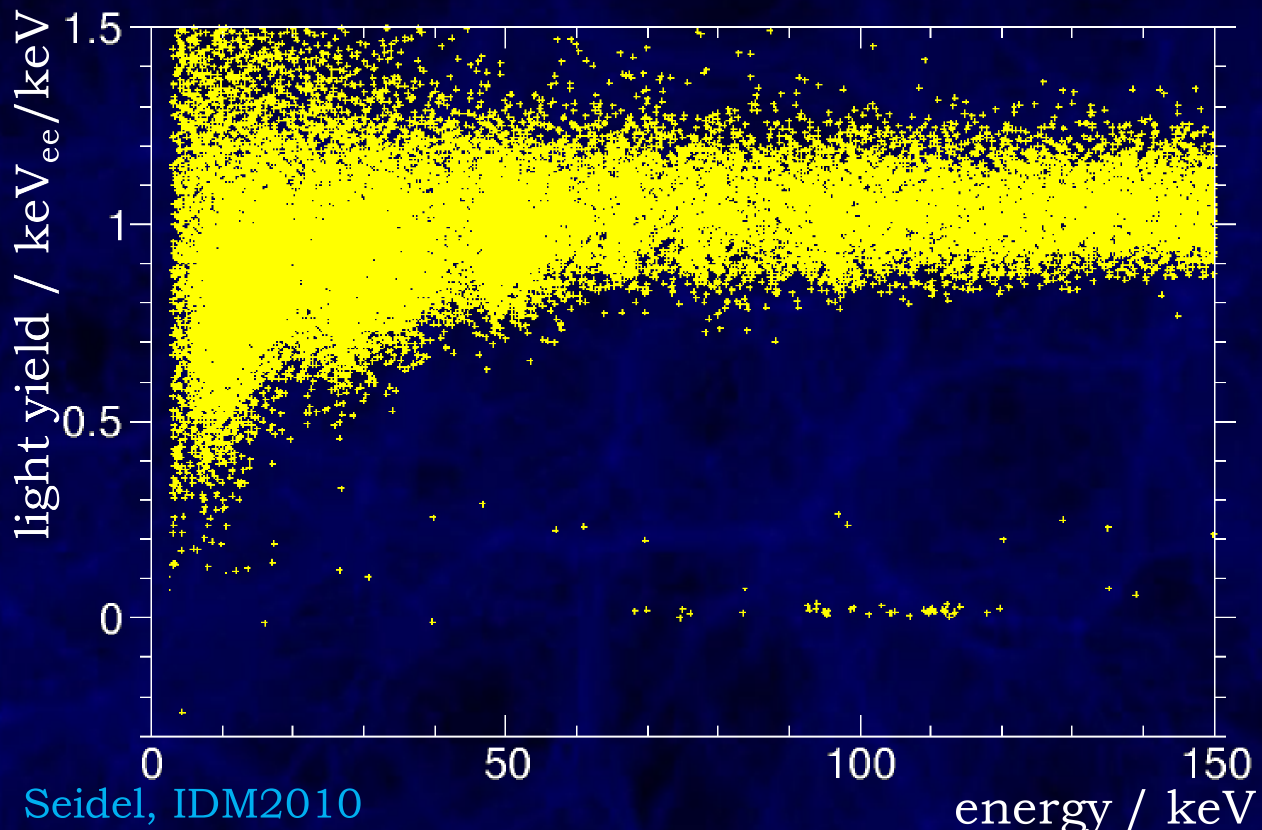
currenty 9 $CaWO_4$ and 1 $ZnWO_4$ modules installed

only preliminary results available (WONDER2010, IDM2010 talks)



CRESST Preliminary Run32 Data

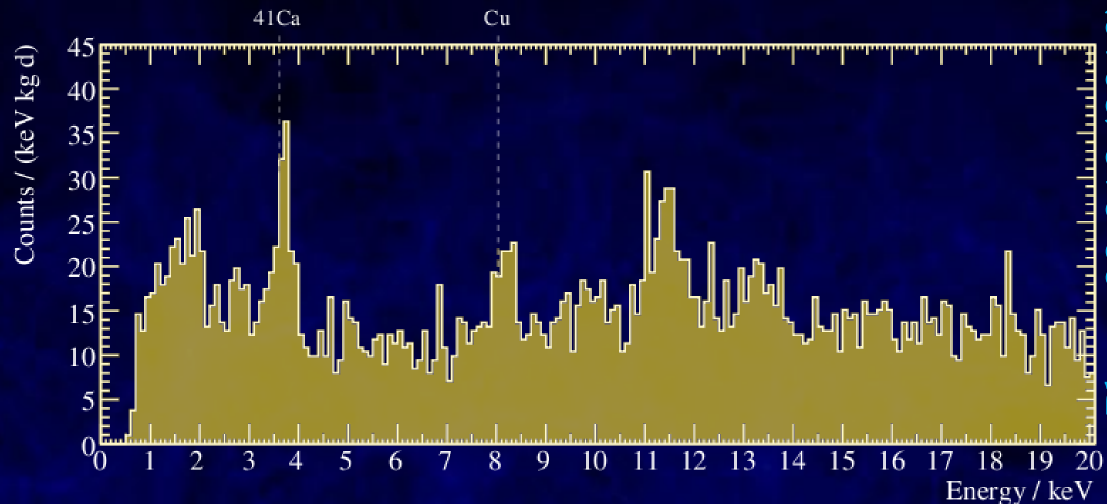
example: channels 5&6 from current data taking



Seidel, IDM2010

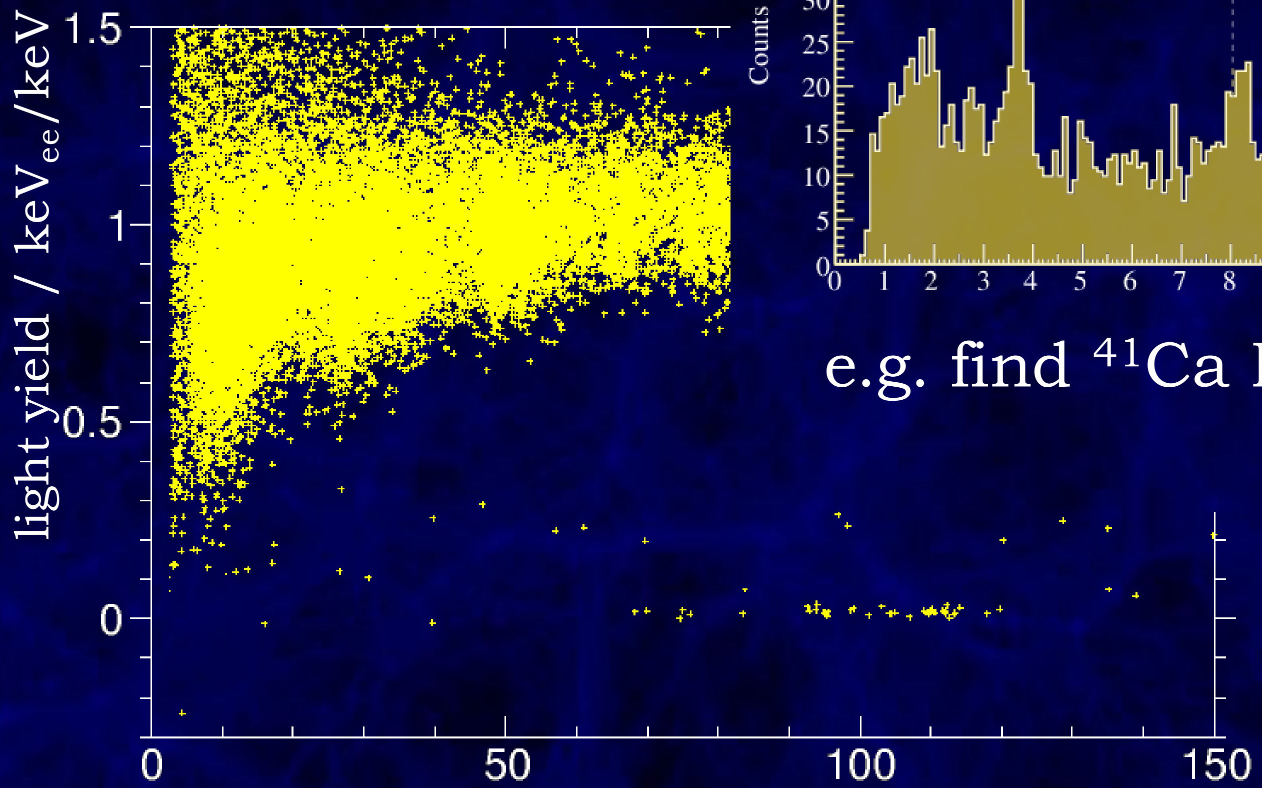
CRESST Background

precise calorimetric measurement of electron recoil energies



e.g. find ^{41}Ca K_α at 3.6keV

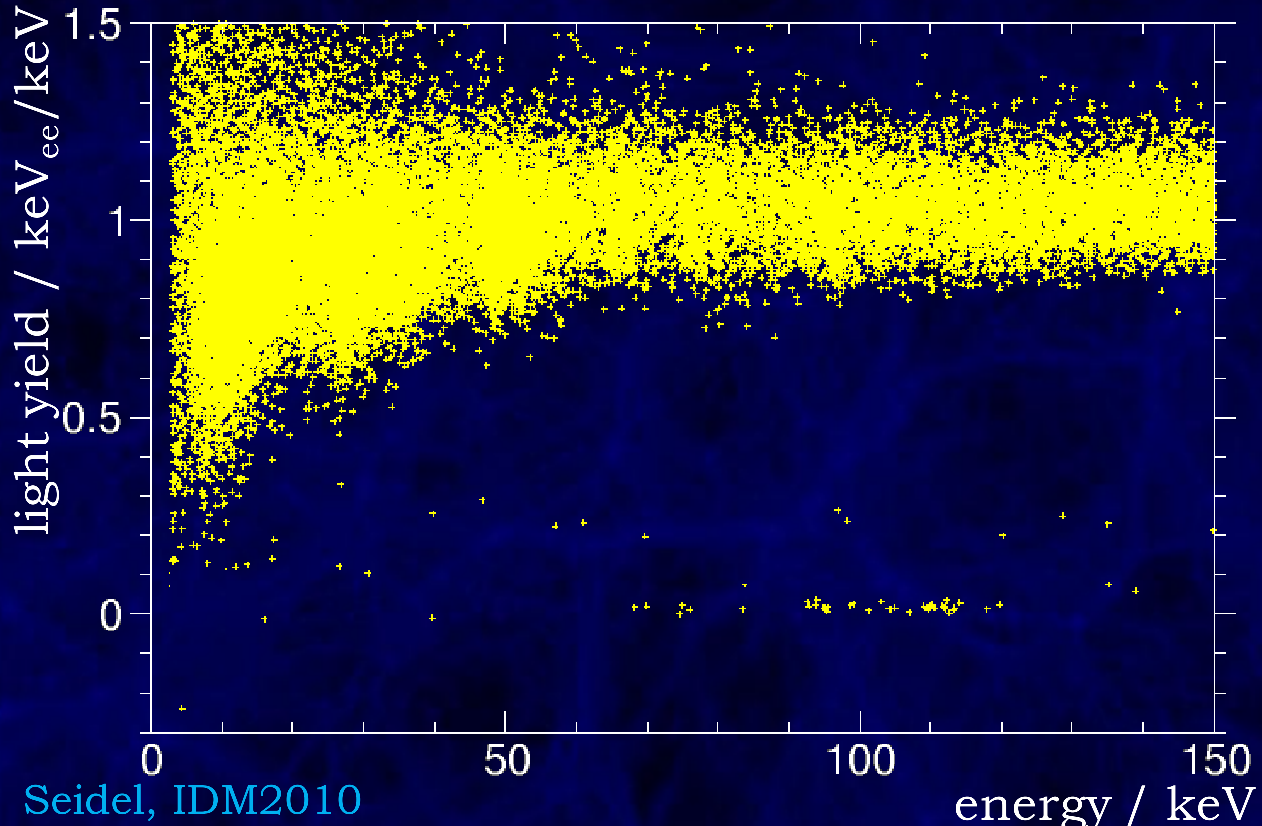
Astropart. Phys. 32 318 (2010)



Seidel, IDM2010

CRESST Background

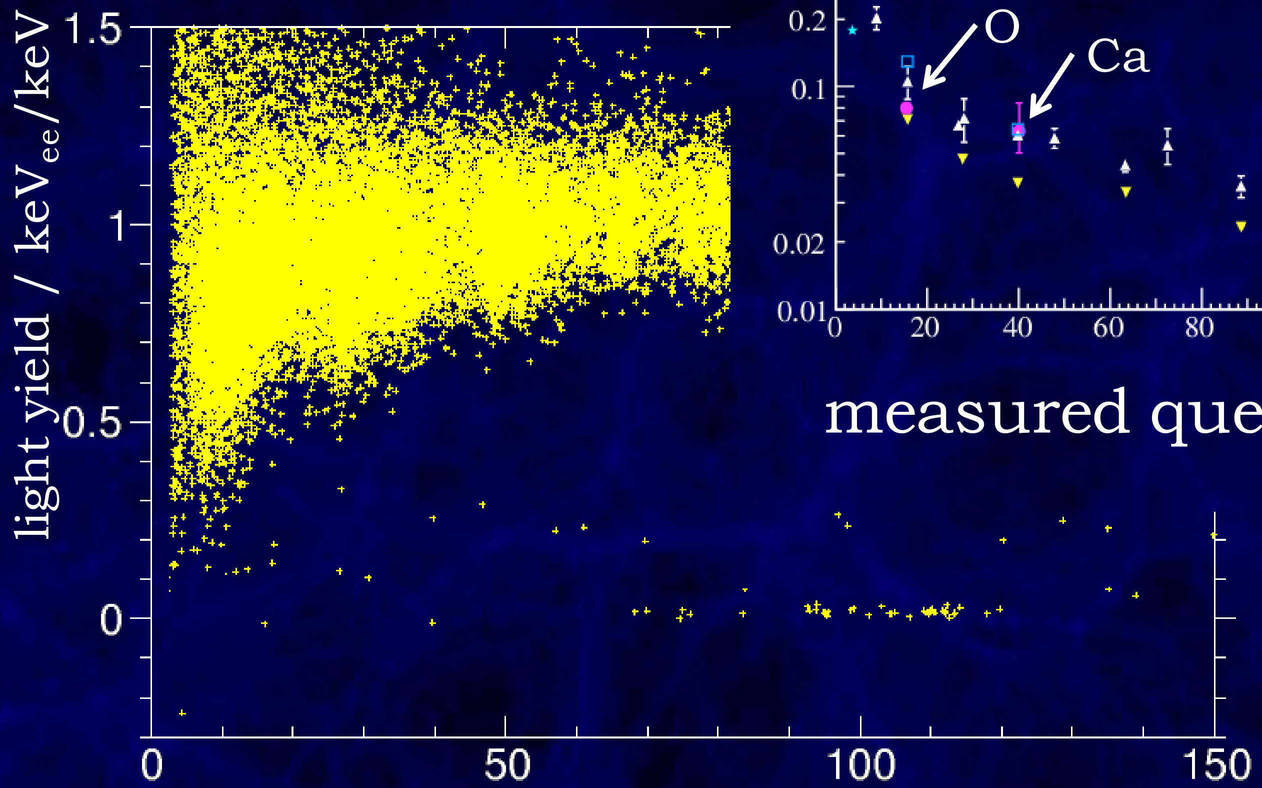
what are all these events below the electronic recoil band?



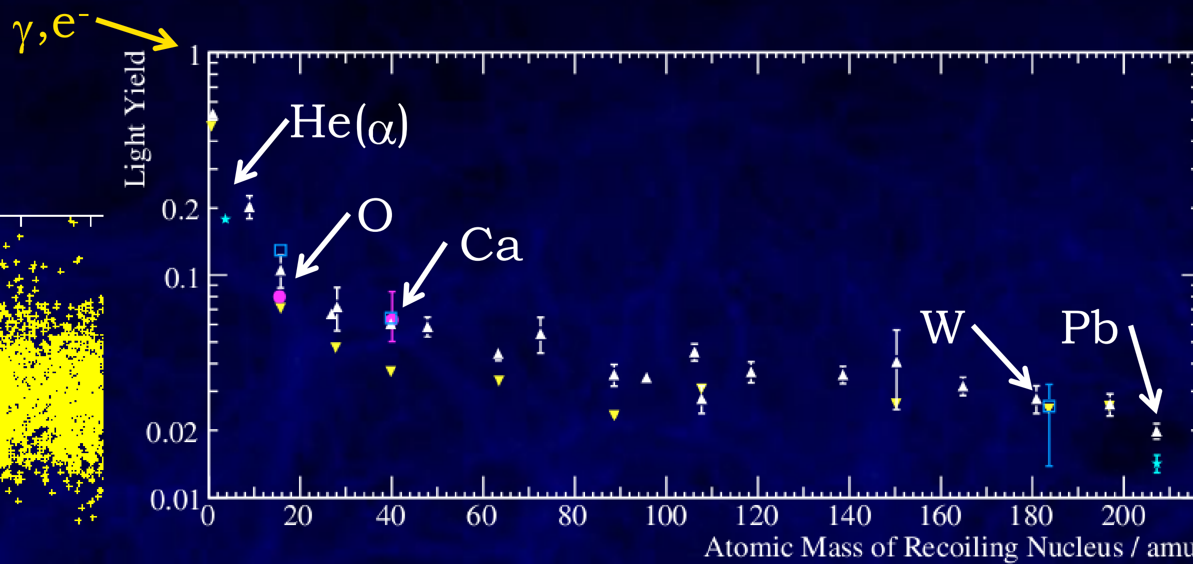
Seidel, IDM2010

CRESST Discrimination

where are α-events and O/W/Pb recoils?



Seidel, IDM2010

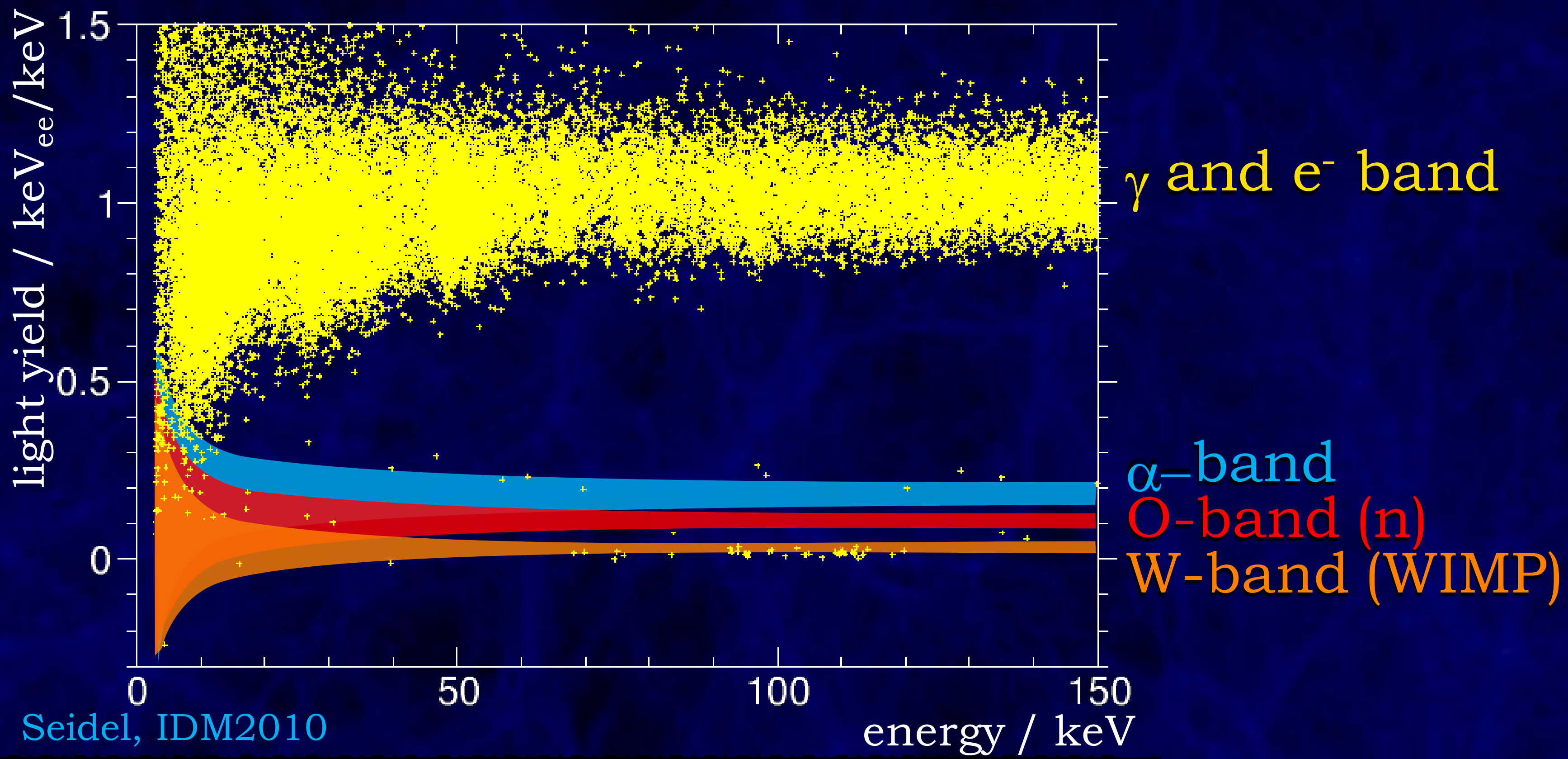


measured quenching factors

New J. Phys. 11 (2010) 105017

CRESST Background

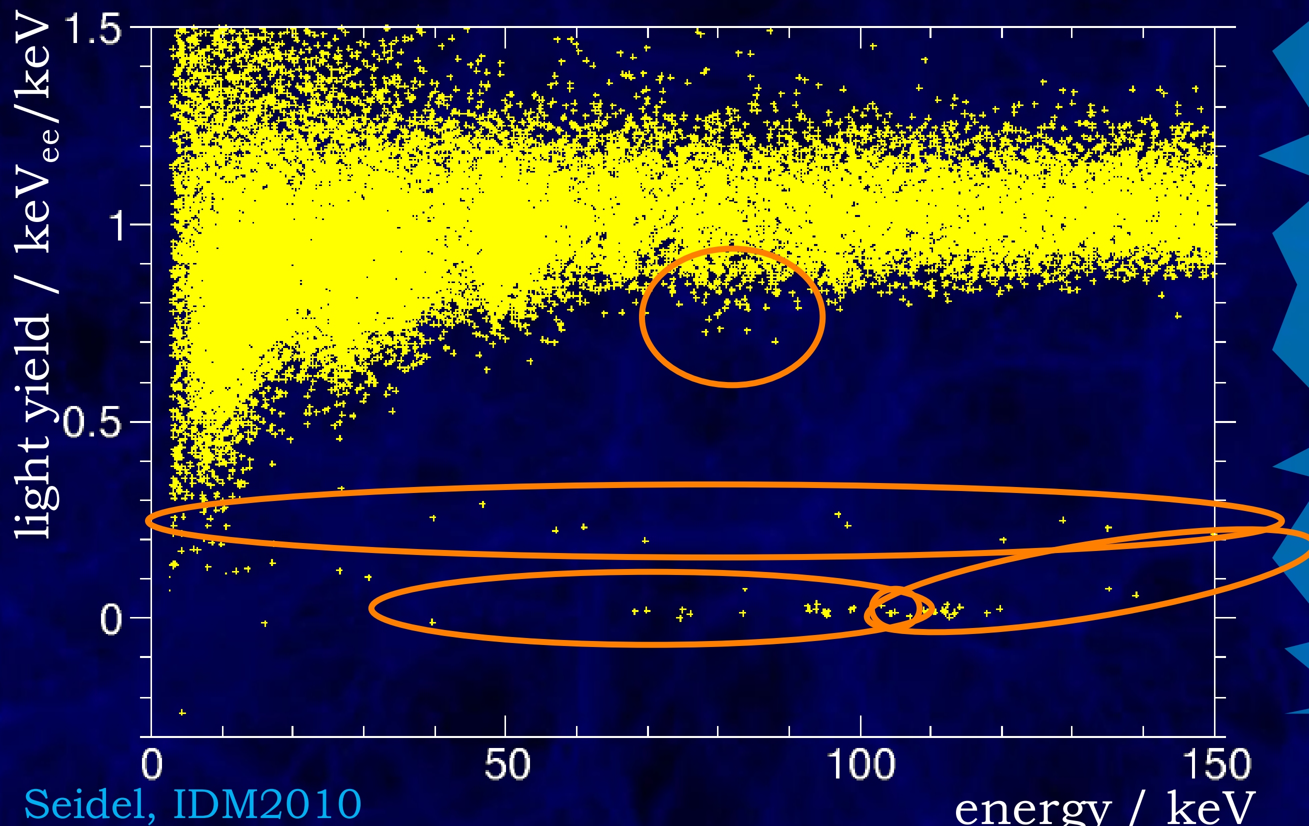
what are all these events below the electronic recoil band?



Seidel, IDM2010

CRESST Background

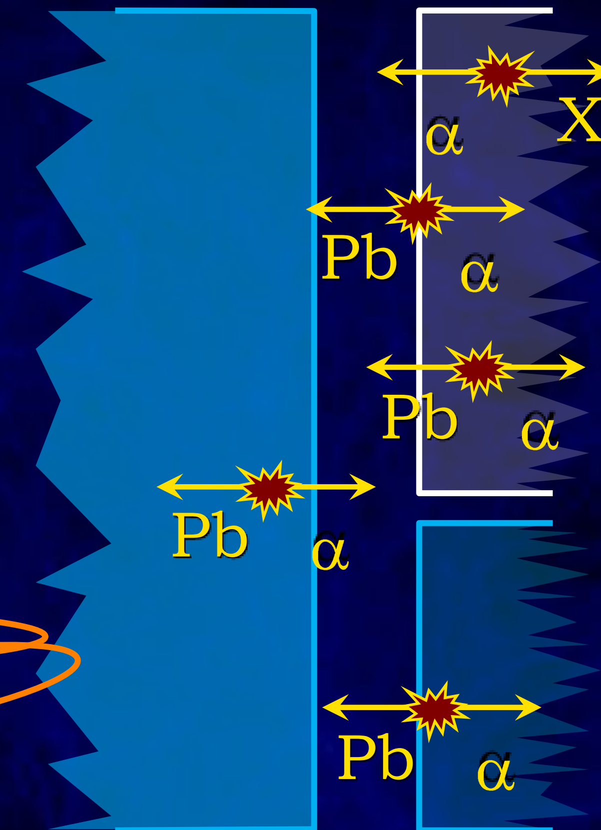
$^{210}Po \rightarrow {}^{206}Pb$ (104keV) + α (5.4MeV)



Seidel, IDM2010

crystal

passive surface

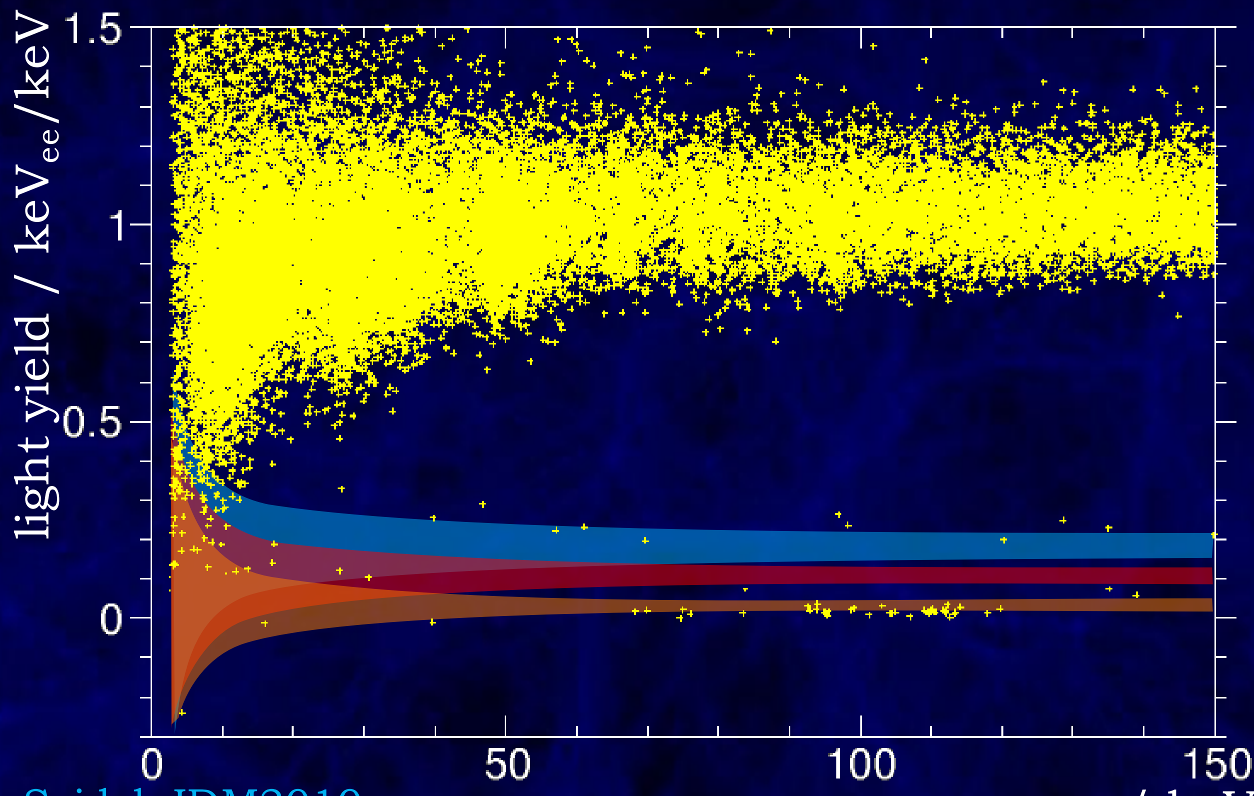


scintillator (most surfaces)

CRESST Combined Results

few events in W band, but 32 events in O band

take all 9 detectors together and estimate events from known backgrounds that could leak into O-band:

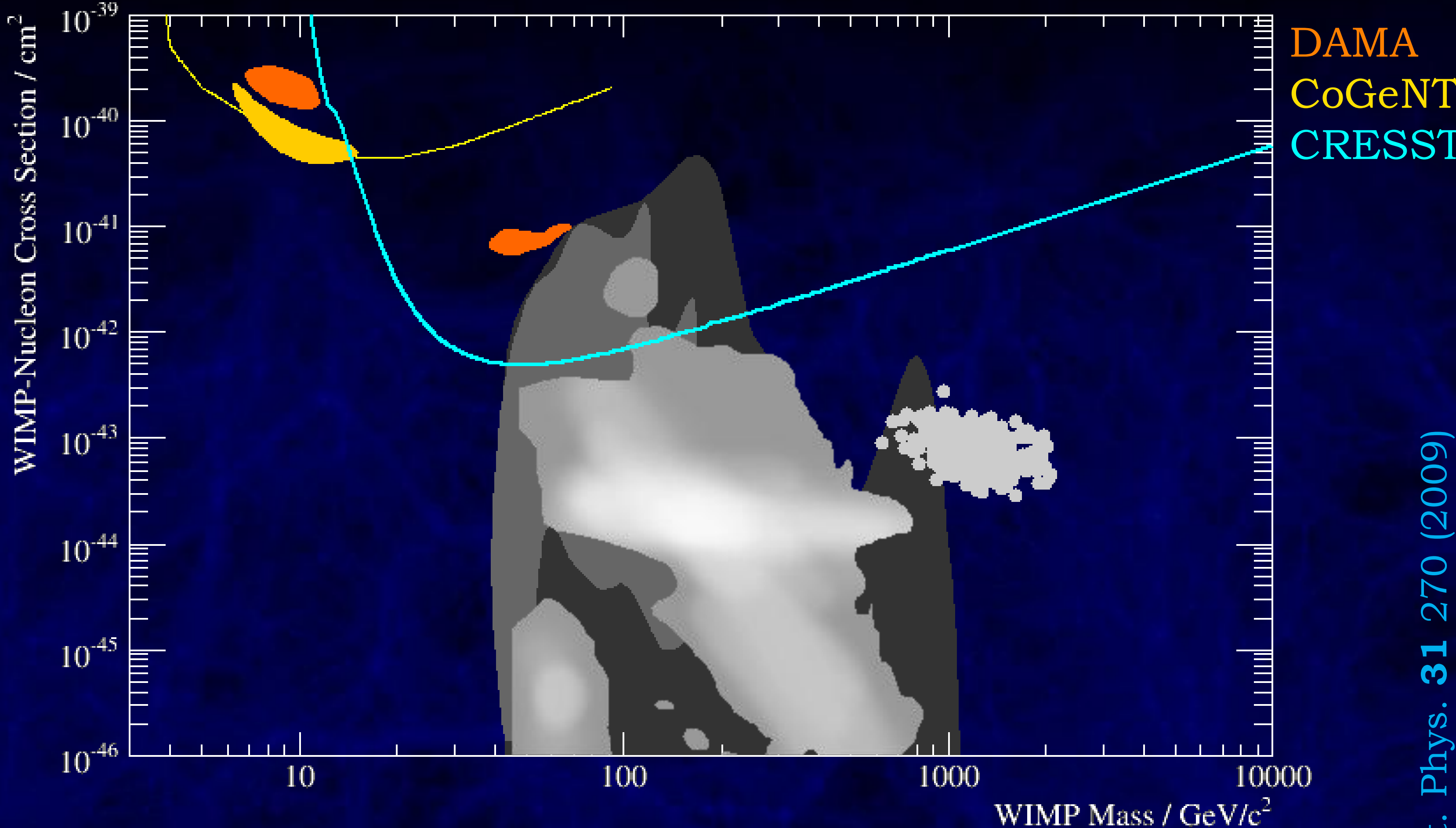


Seidel, IDM2010

n-source: (b/c multiplicity)	~0
μ–induced n:	~1
degraded α:	~7
leaking γ:	~1
sum:	~9
observed:	32

"leaving space for a light WIMP"

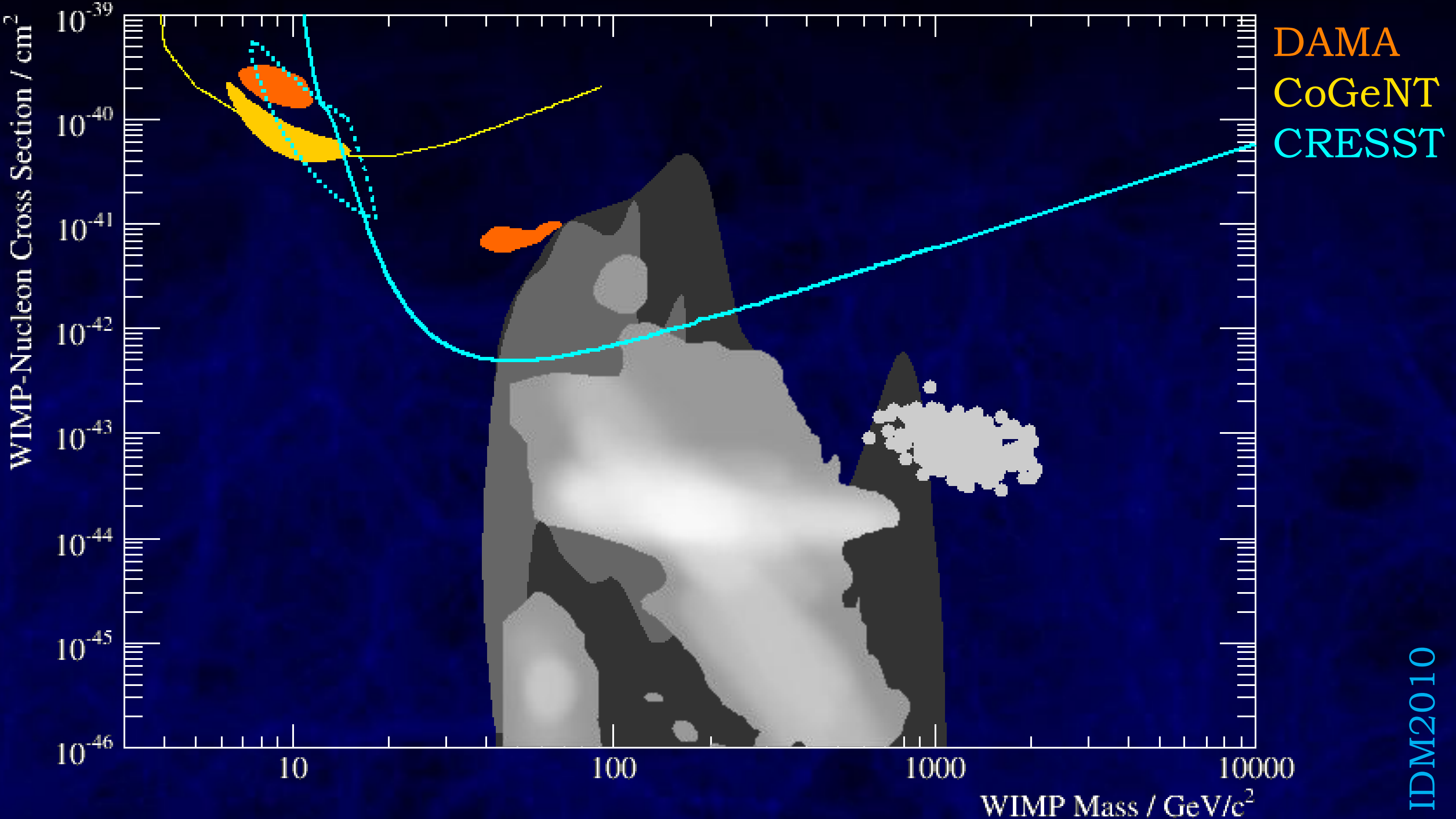
CRESST-W: Limit (2008)



Astropart. Phys. **31** 270 (2009)

W most heavy target material
more interesting for e.g. inelastic Dark Matter models

CRESST-O: Events as WIMPs?

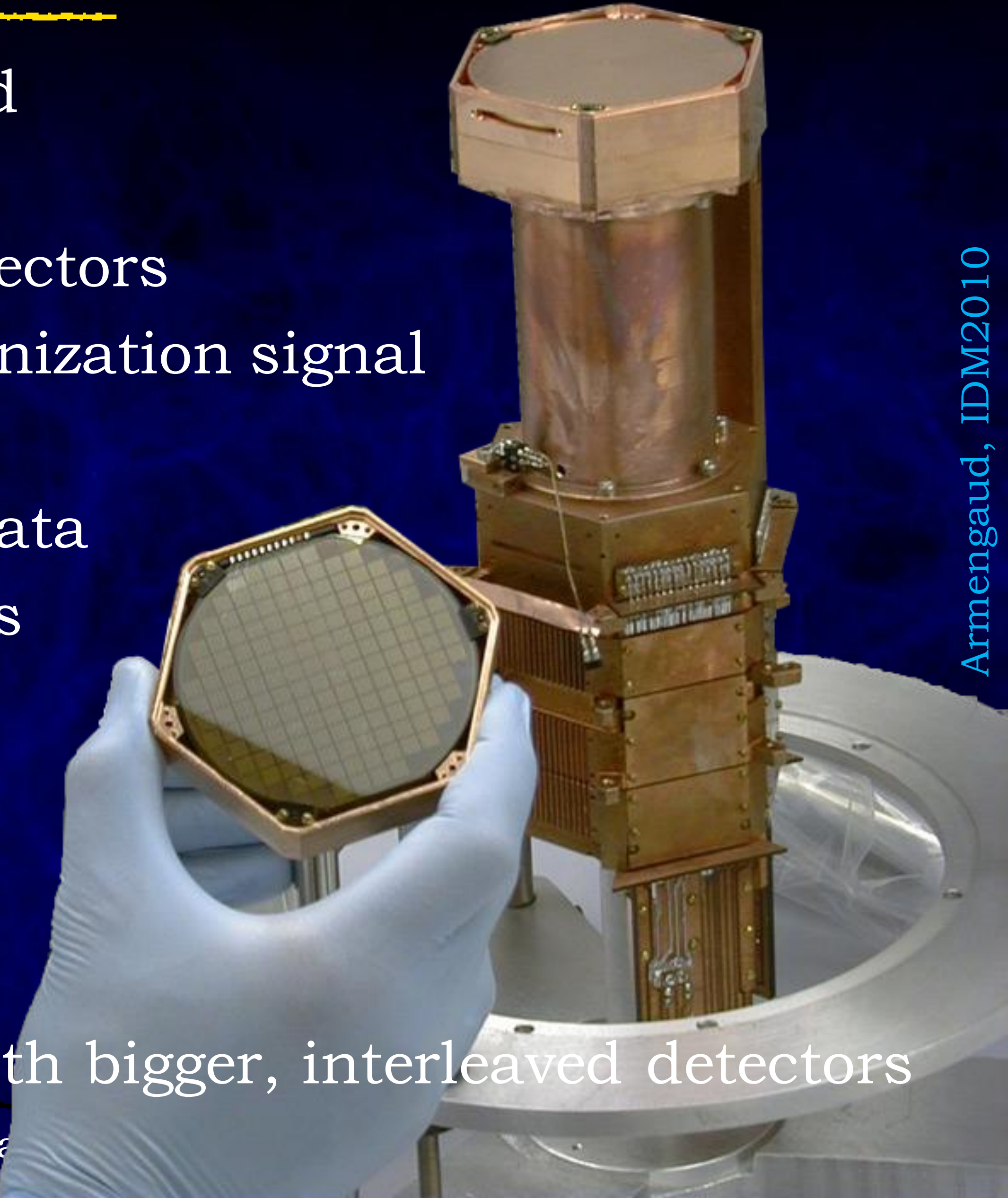


Schwetz, IDM2010

region speculative since analysis preliminary and not yet fully released

CDMS-II

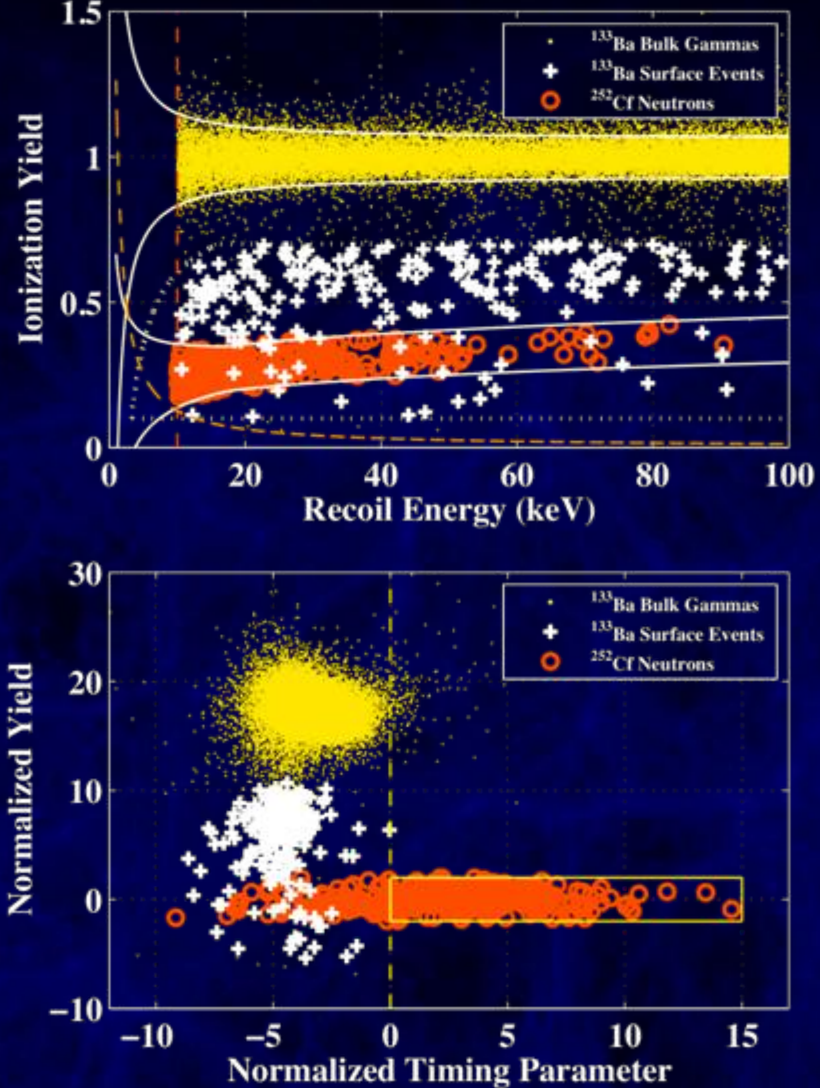
USA/Canada/Switzerland
located at Soudan
19 Ge and 11 Si "ZIP" detectors
with phonon (TES) and ionization signal
data-taking finished
final analysis of 2 years data
from 14 250g Ge detectors



Armengaud, IDM2010

next step: SuperCDMS with bigger, interleaved detectors

CDMS-II Results



calibration data:

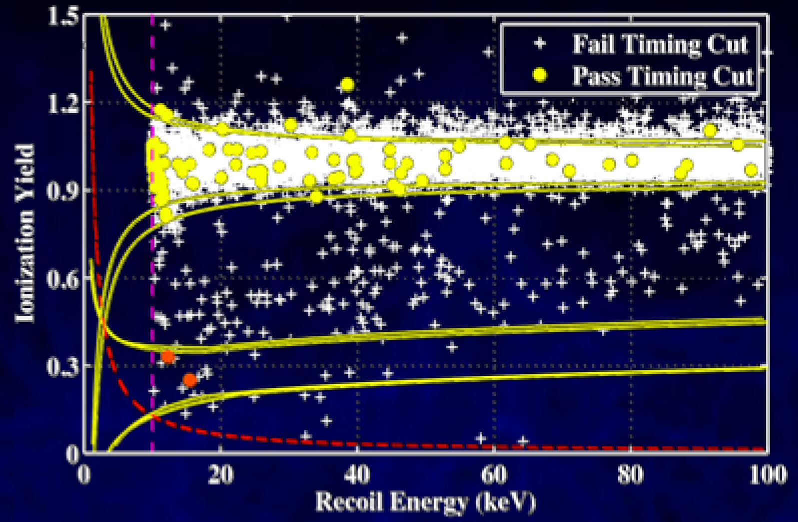
bulk electronic recoils

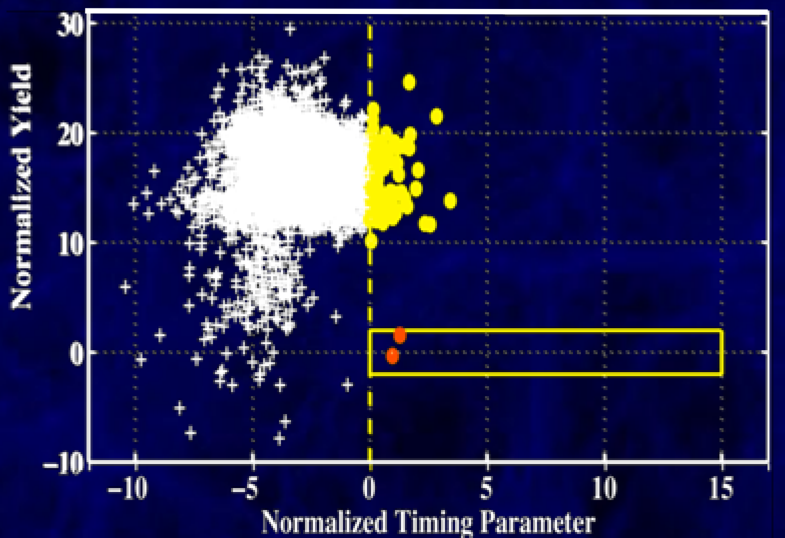
surface events

bulk nuclear recoils

arXiv:0912.3592

CDMS-II Results





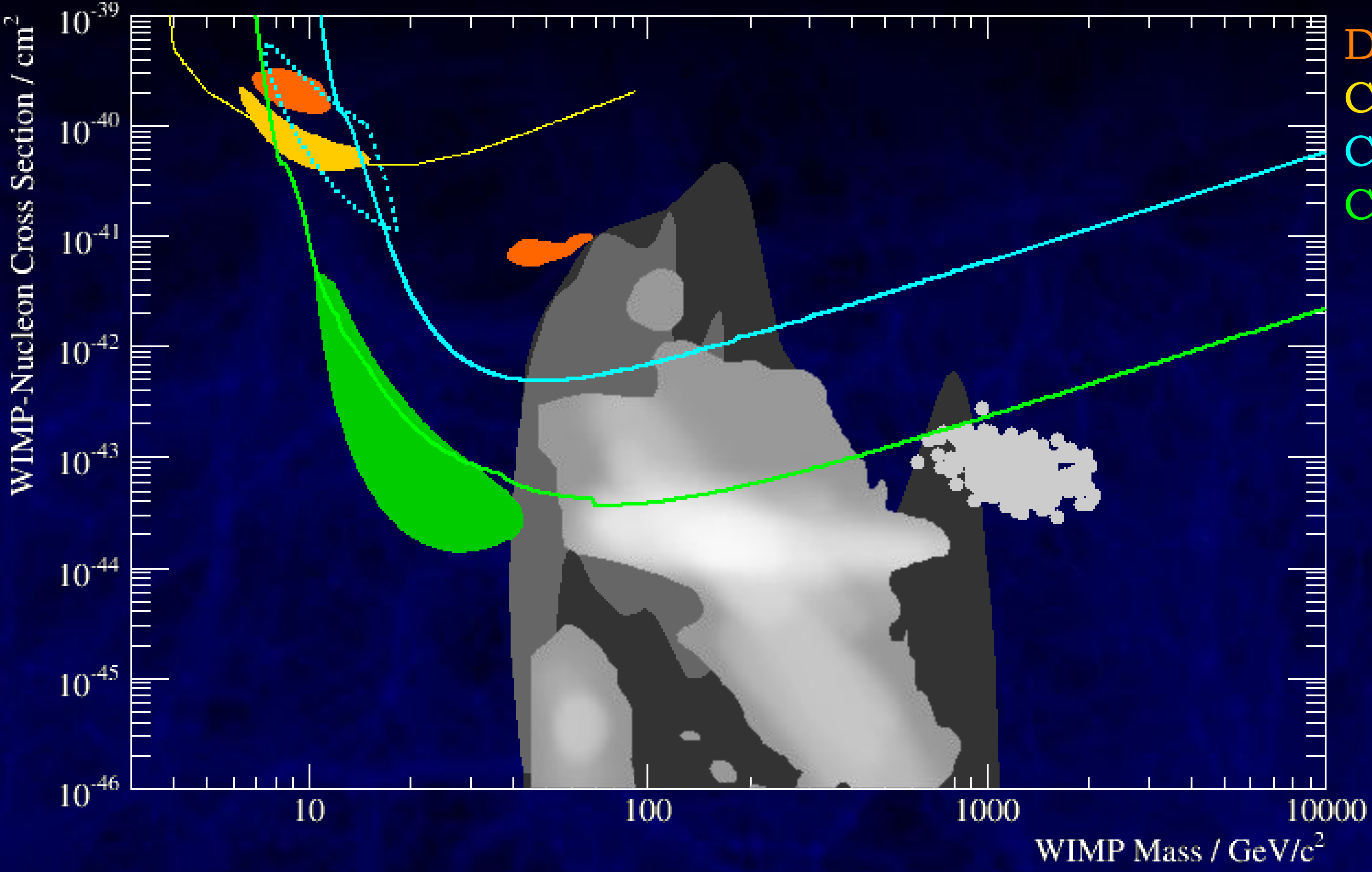
Ge dark matter search data two detectors with signal candidate events combined:

bulk electronic recoils
surface events
bulk nuclear recoils

two events observed, consistent with (revised) background expectation of 0.9   0.2 events. In addition, neither event golden

arXiv:0912.3592 and Saab, IDM2010

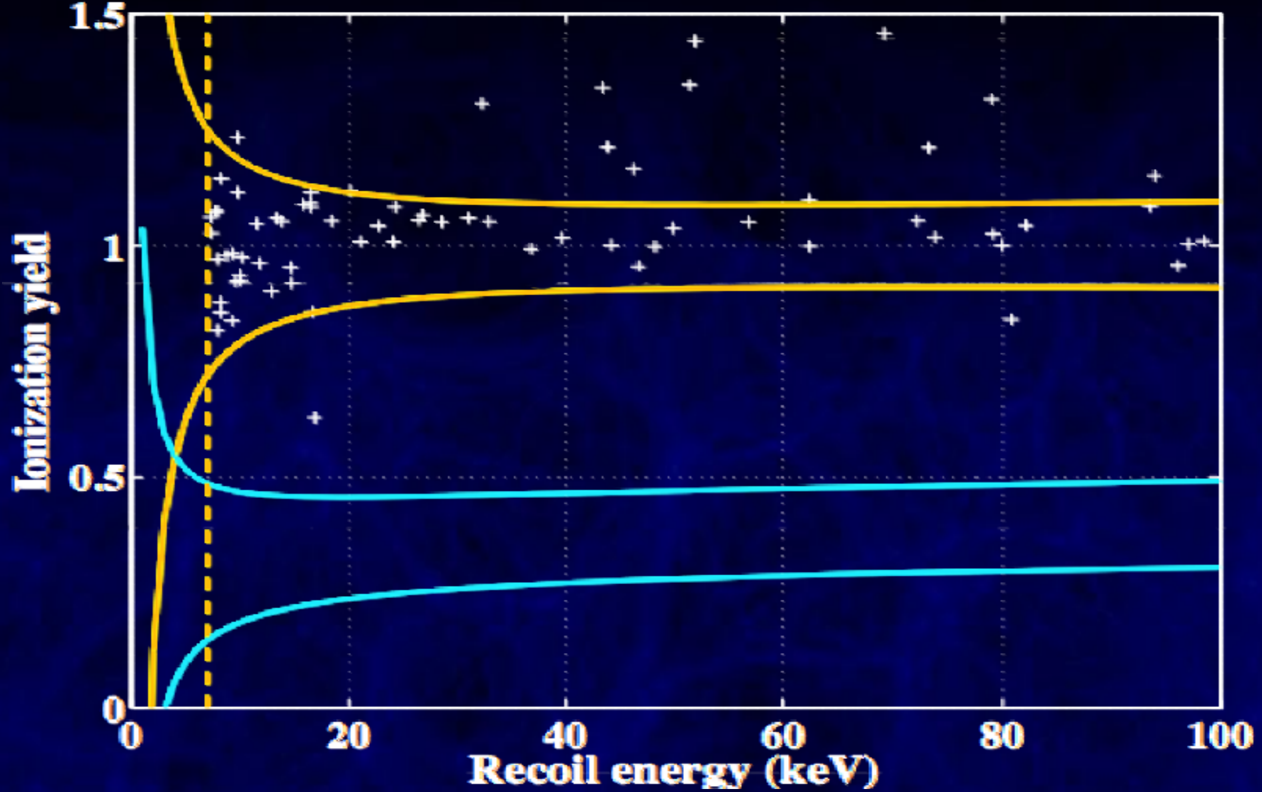
CDMS Limit & WIMP Interpretation



Kopp,Schwetz,Zupan arXiv:0912.4264
Science **327** 1619 (2010), arXiv:0912.3592

CDMS collaboration does not claim any Dark Matter signal (2 events observed over 0.9 0.2 expected)

CDMS-II Si Results

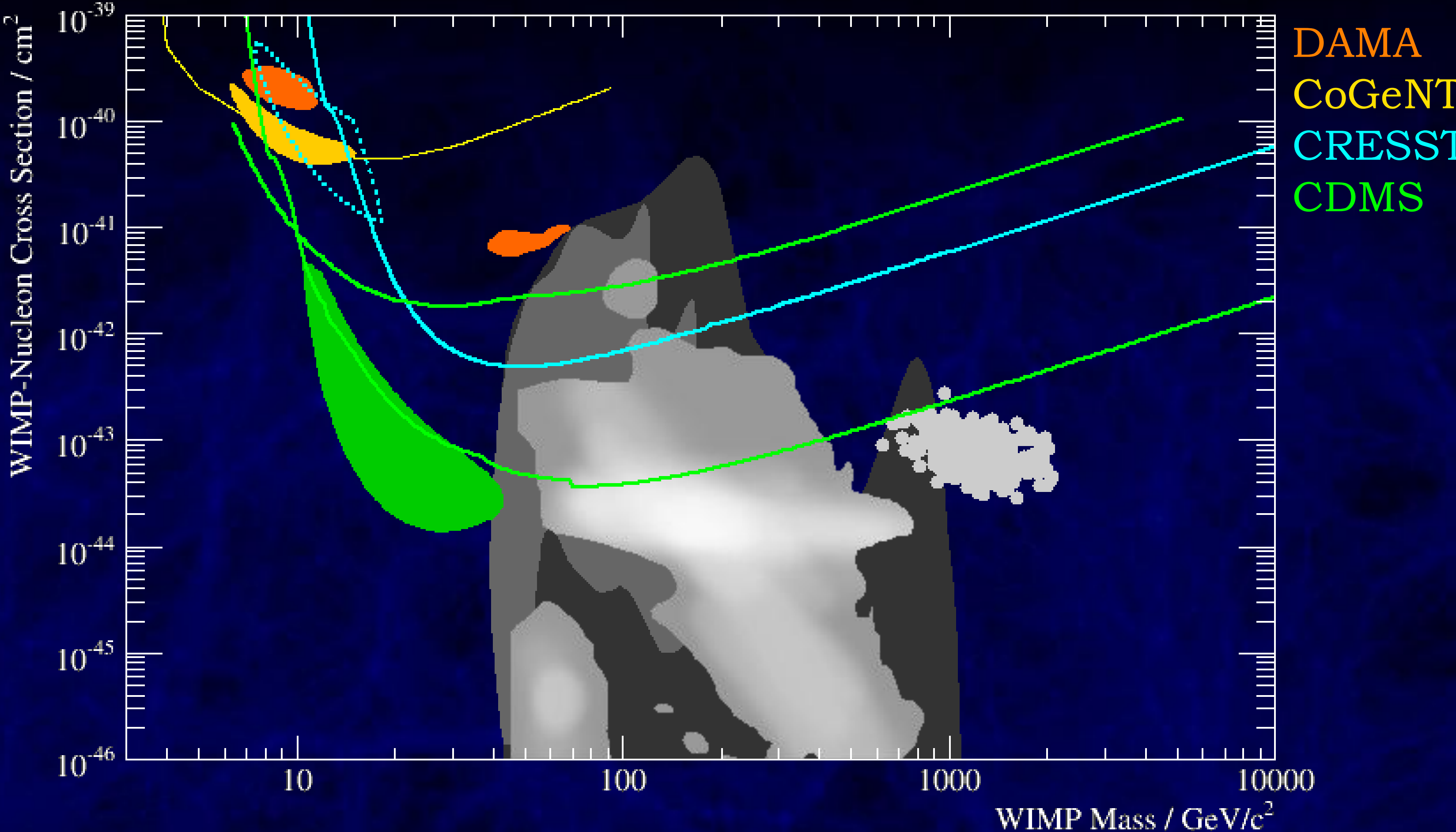


Filippini, LaThuile 2009 and Nuovo Cimento C 32 45

there's also a talk and conference proceeding with an analysis of 6 Si detectors (important for light WIMPs)

no events observed in 54kg d

CDMS Si Limit

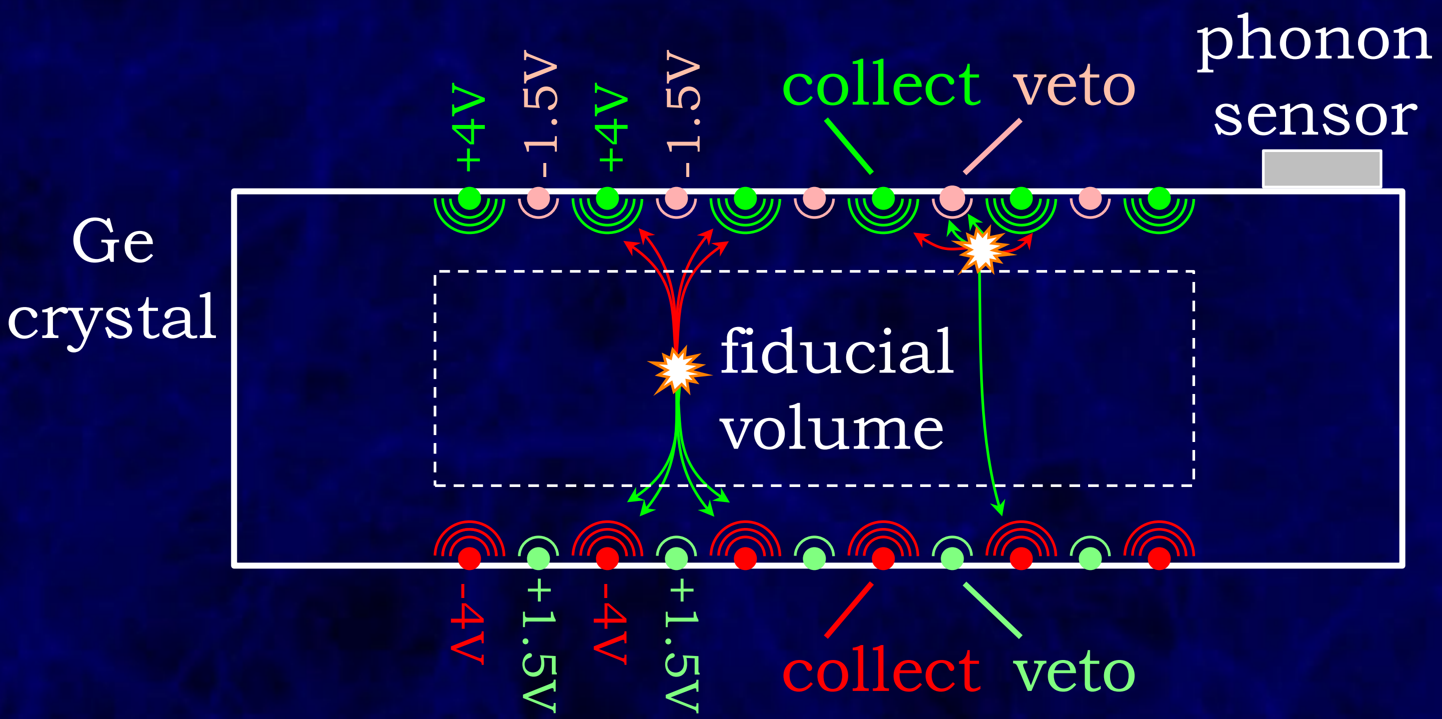


Filippini, LaThuile 2009 and Nuovo Cimento C 32 45

severely constrains CoGeNT WIMP interpretation

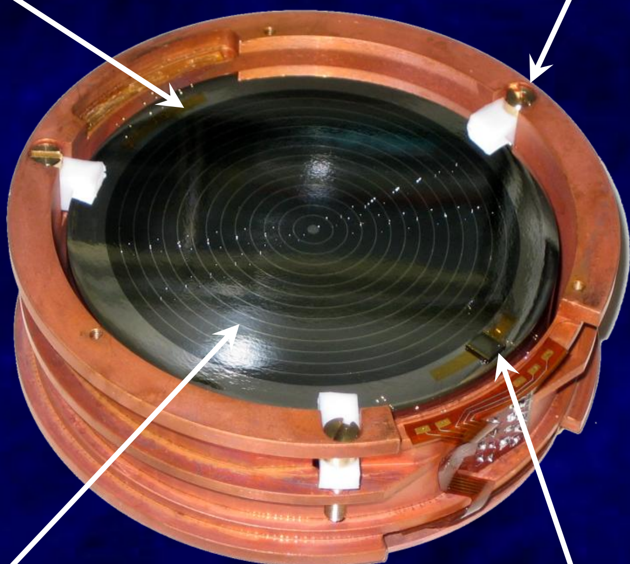
EDELWEISS-II

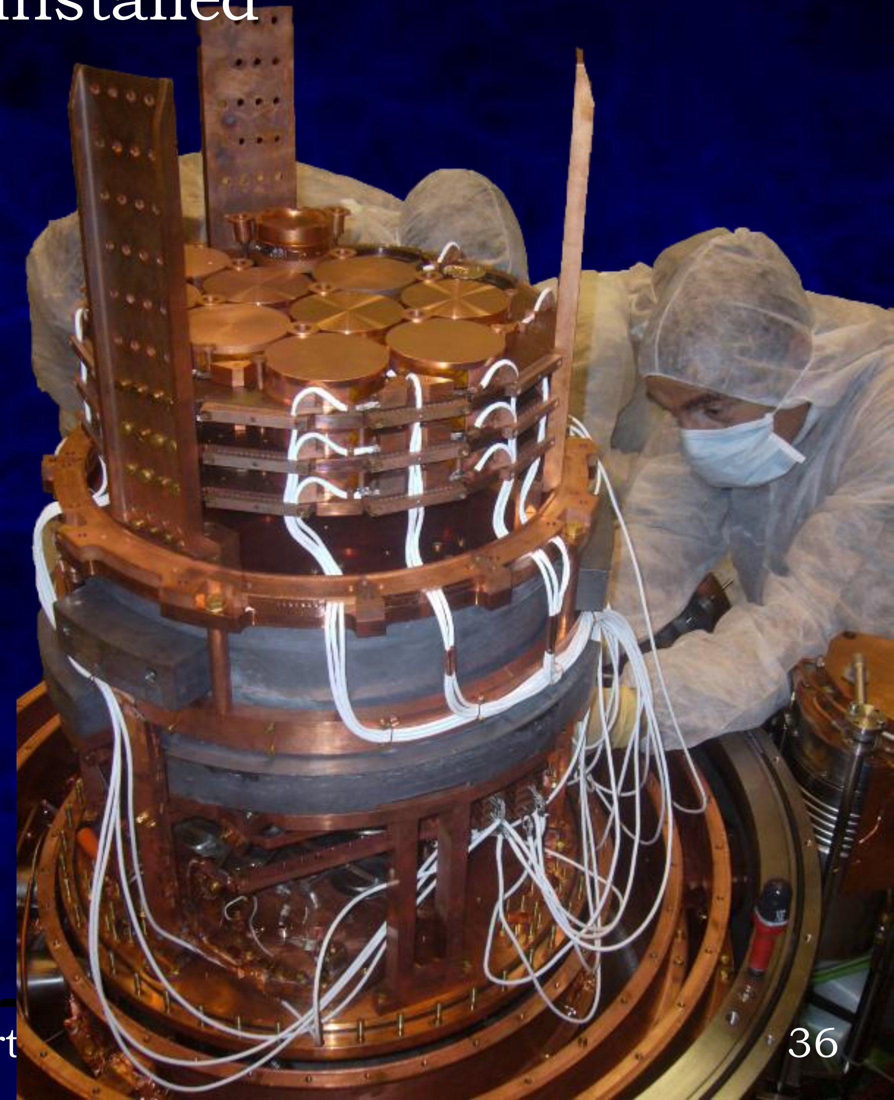
France, Germany, Russia, UK in the Frejus Lab
germanium crystals with phonon/ionization readout
NTD phonon sensors
interleaved electrodes (ionization)



EDELWEISS-II

data from 1 year with ten 400g Ge crystals
meanwhile four 800g modules installed



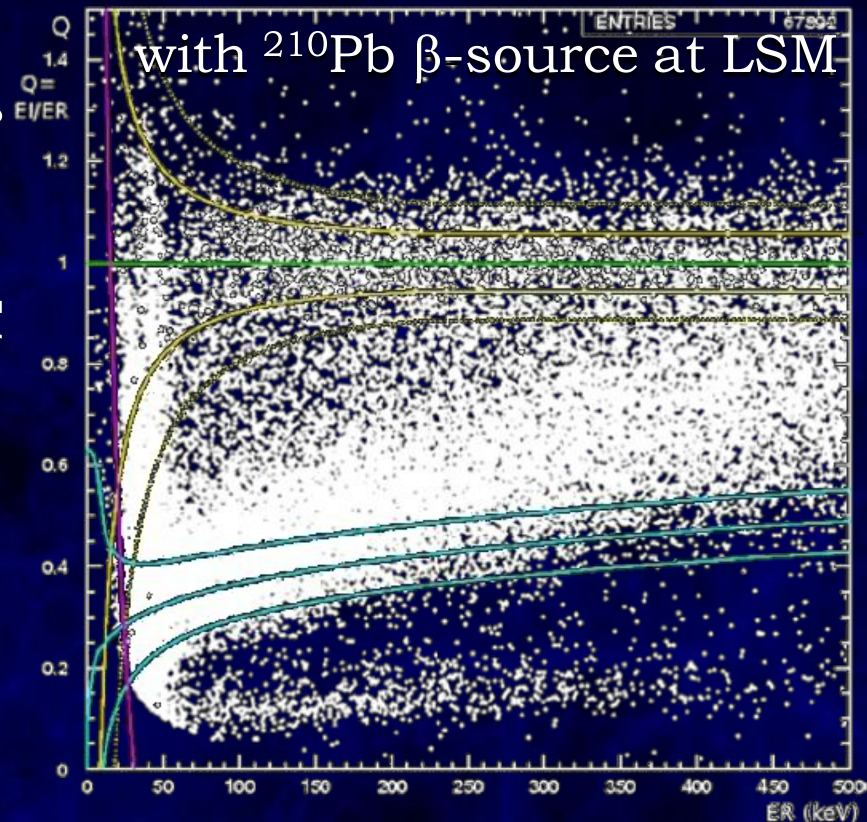


edelweiss.in2p3.fr

EDELWEISS-II Data

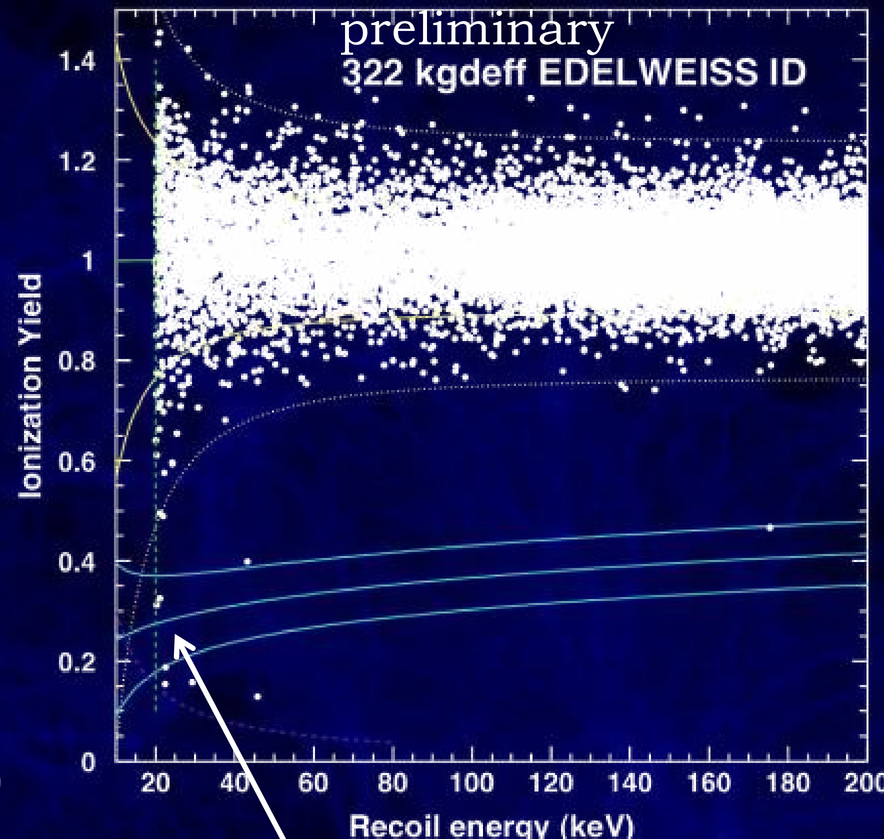
data from 1 year with ten 400g Ge crystals
meanwhile four 800g modules installed

ionization/phonon yield



energy (phonon channel)

before/after fiducialization

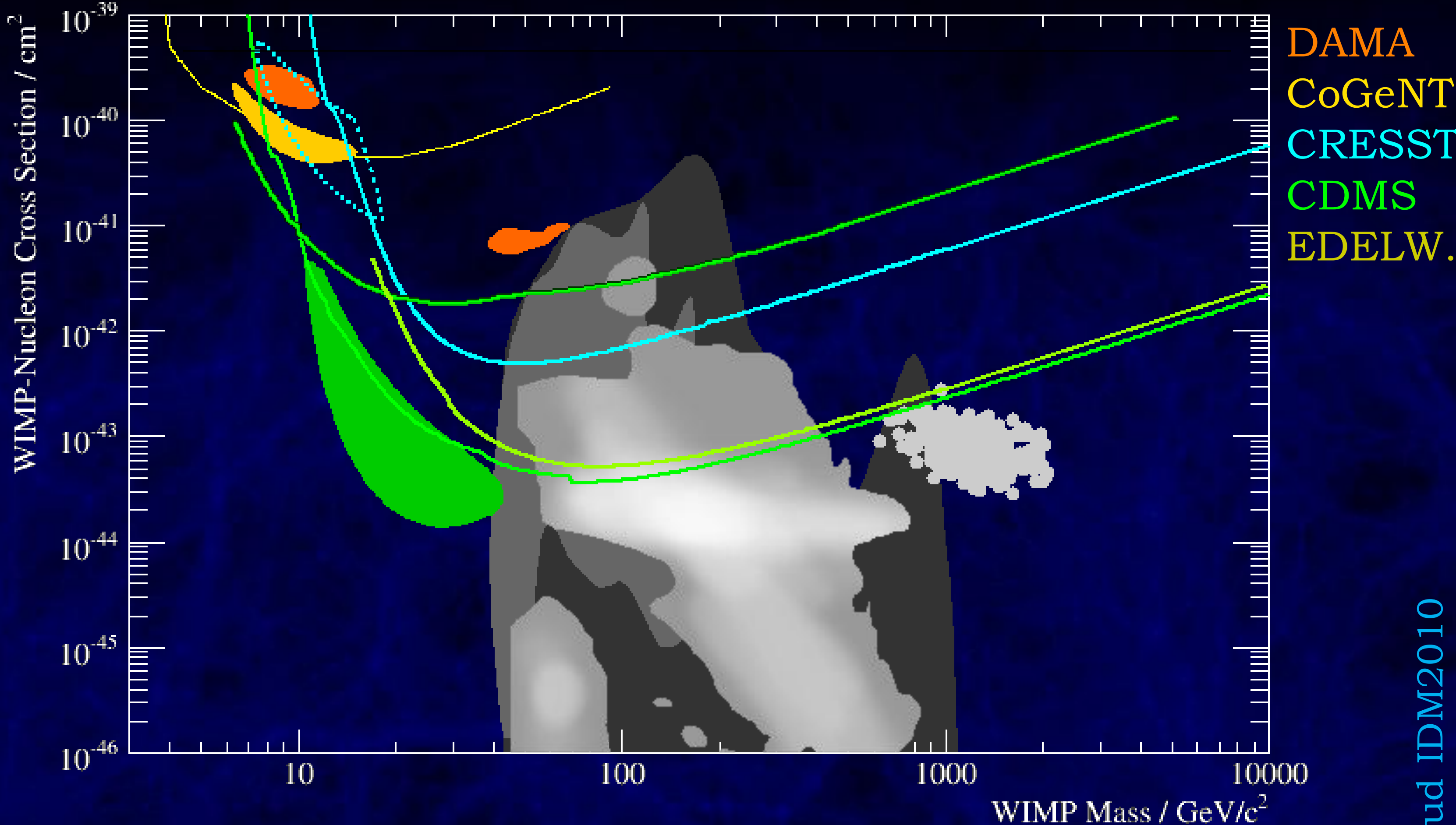


3 events near threshold

Kraus, IDM2010

Armengaud, IDM2010

EDELWEISS (Preliminary) 2010

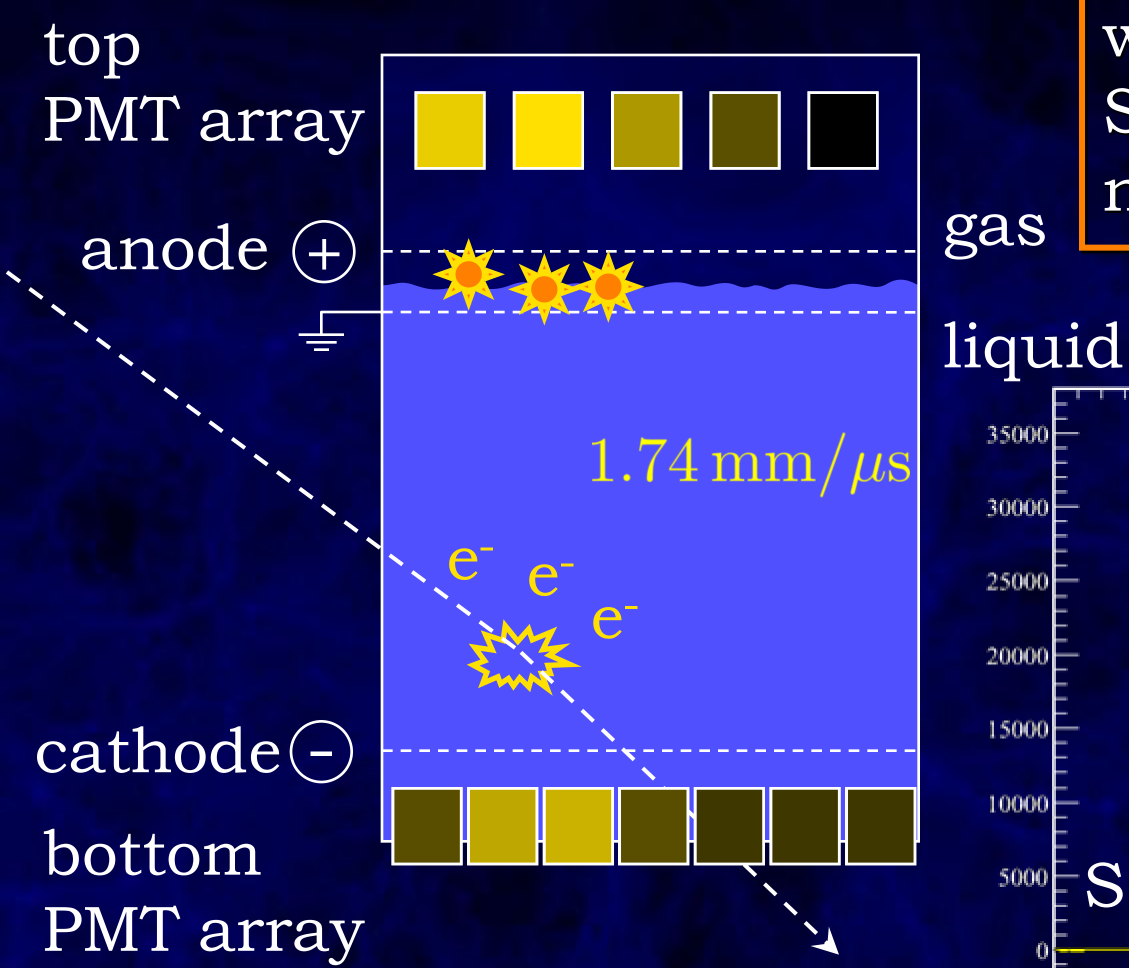


Armengaud IDM2010

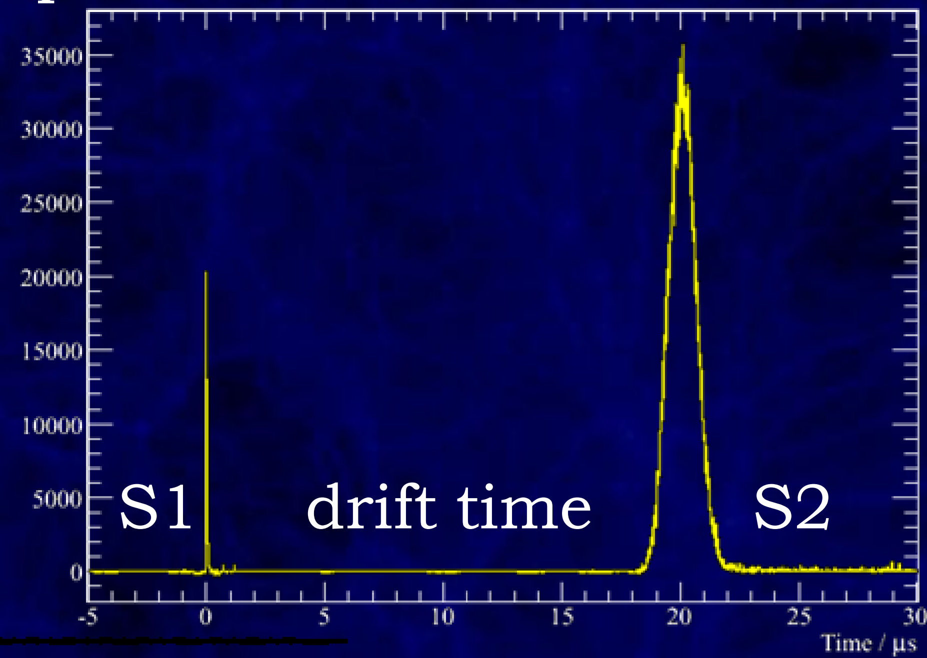
back to the forefront of searches

XENON100: Dual-Phase Xe TPC

USA/Europe/Israel/China

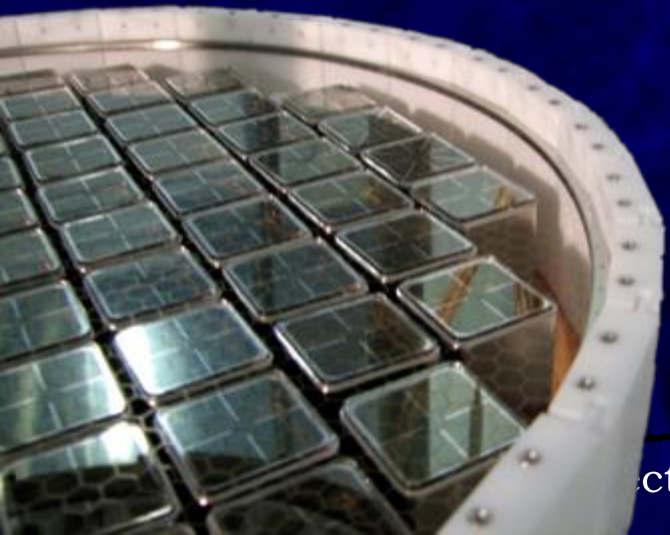


3D position information with mm resolution S2/S1-based discrimination better than 99%

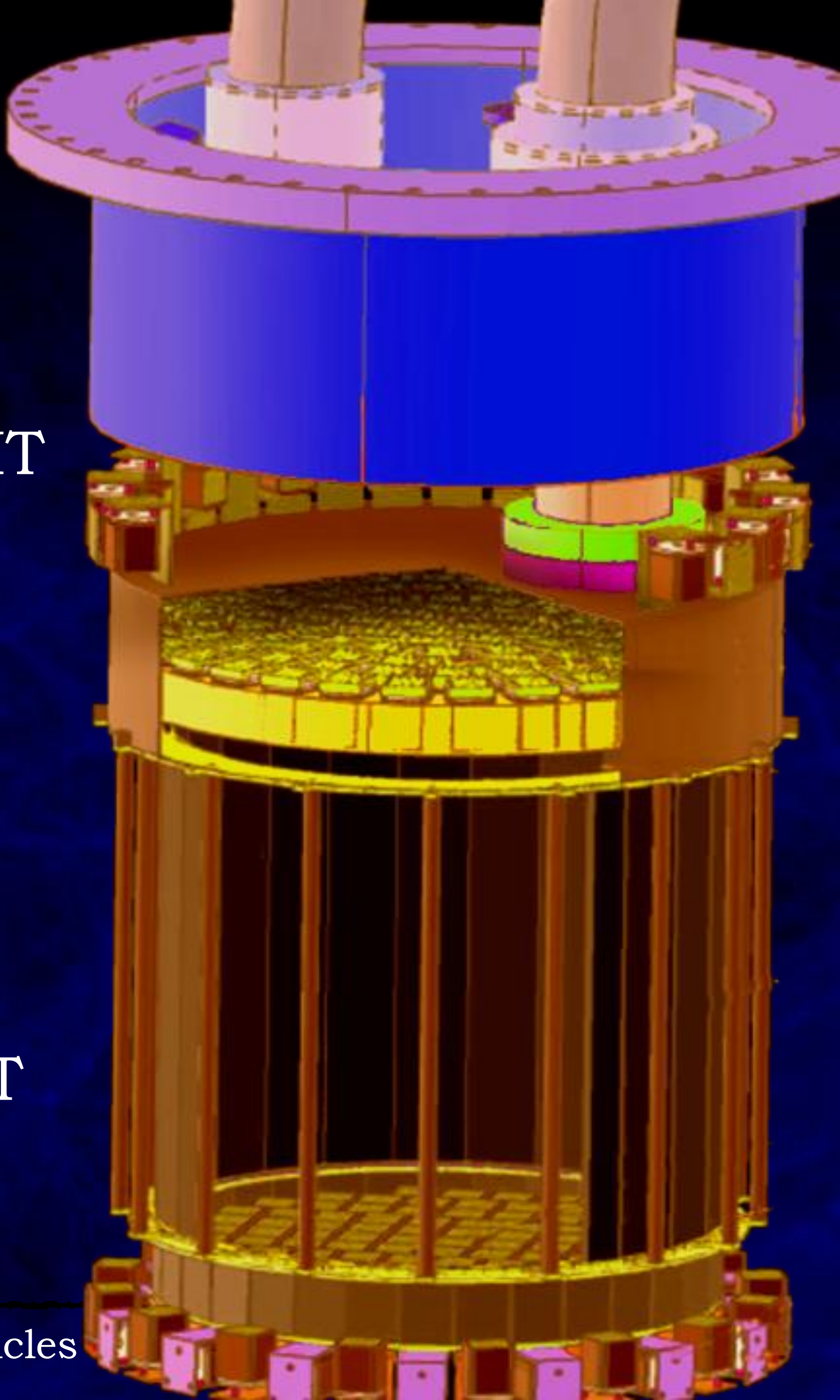


XENON100

top PMT
array



bottom PMT
array



XENON100

veto PMT

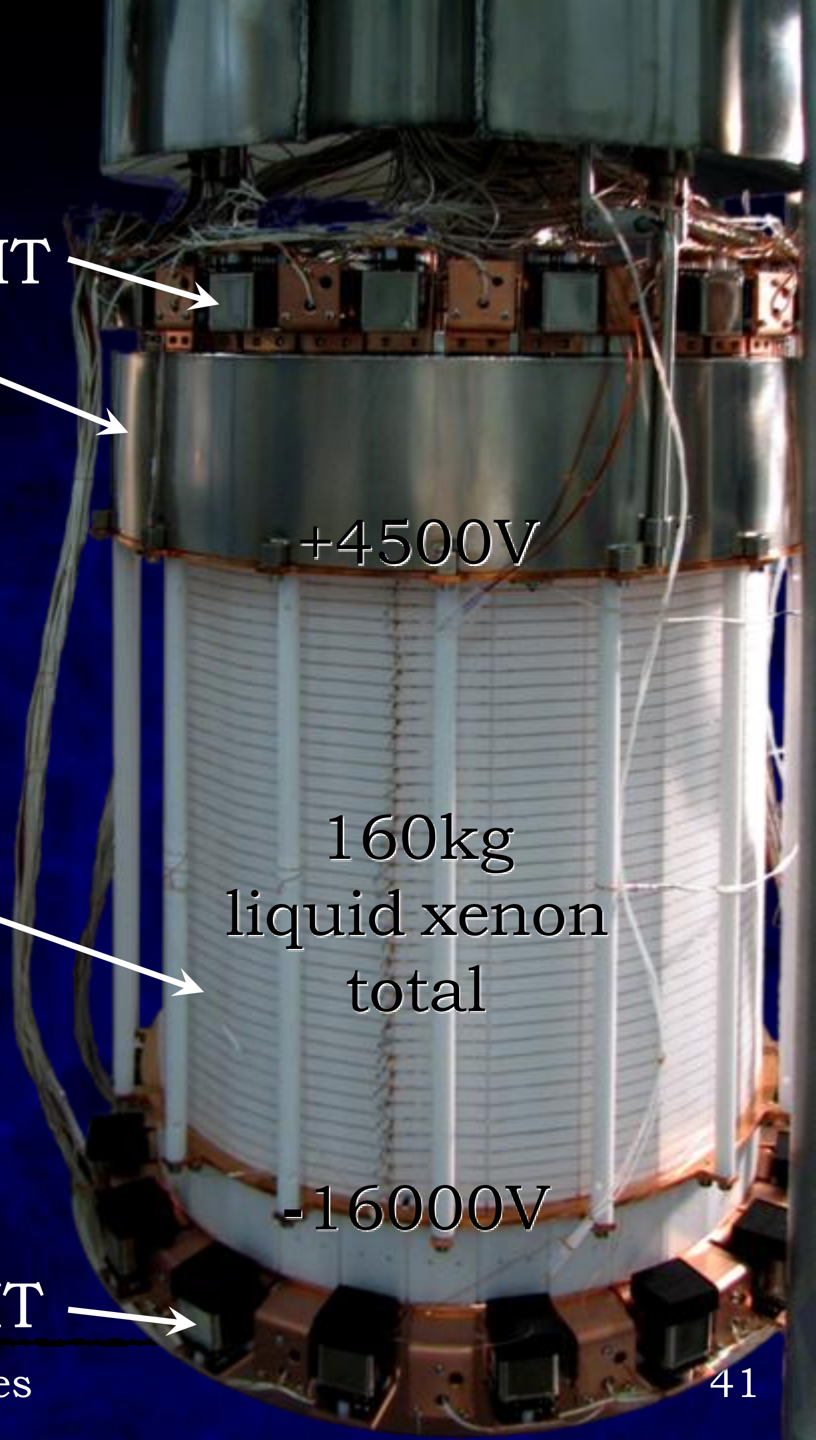
bell

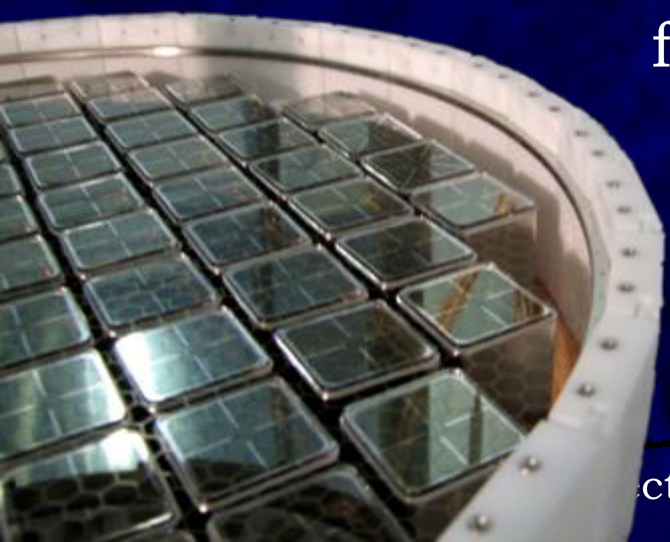
top PMT
array

PTFE TPC,
field shaping

bottom PMT
array

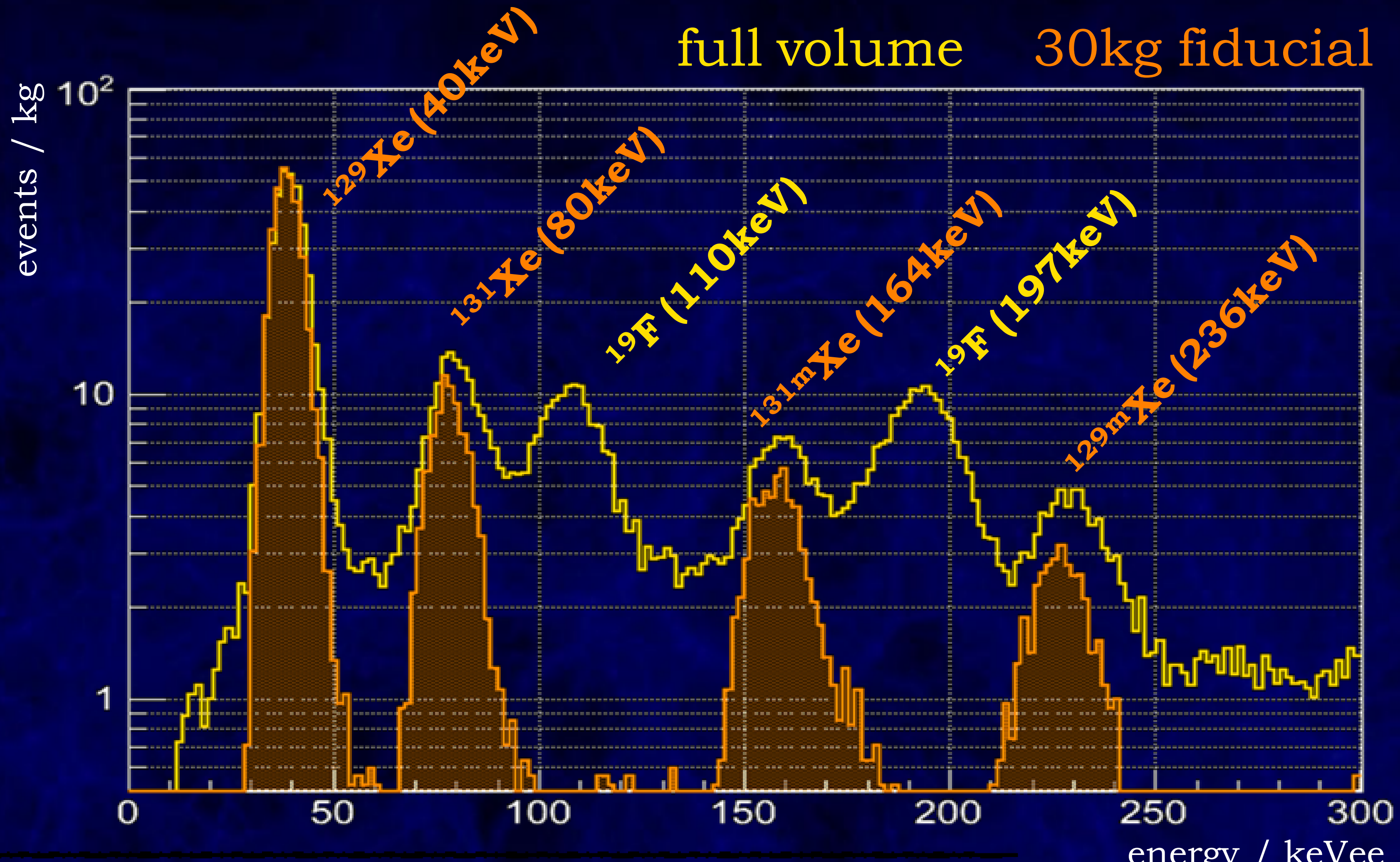
veto PMT



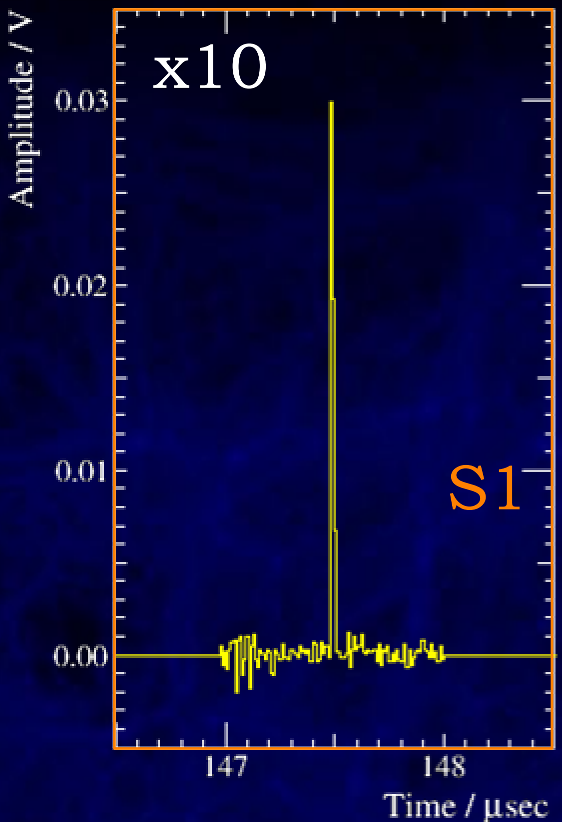


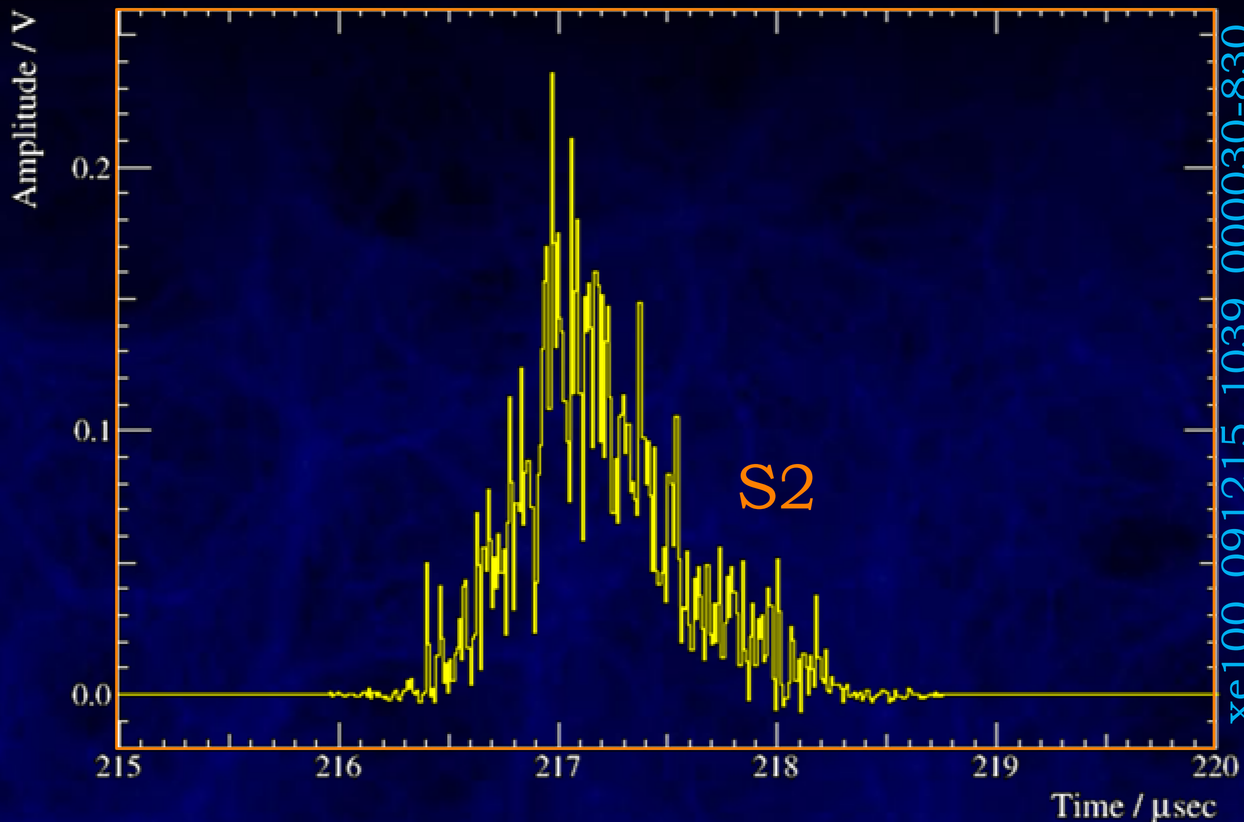
Inelastic Scatters & Fiducialization

Electronic recoils during ^{241}AmBe calibration:



Example: 9keV$_{nr}$ Nuclear Recoil



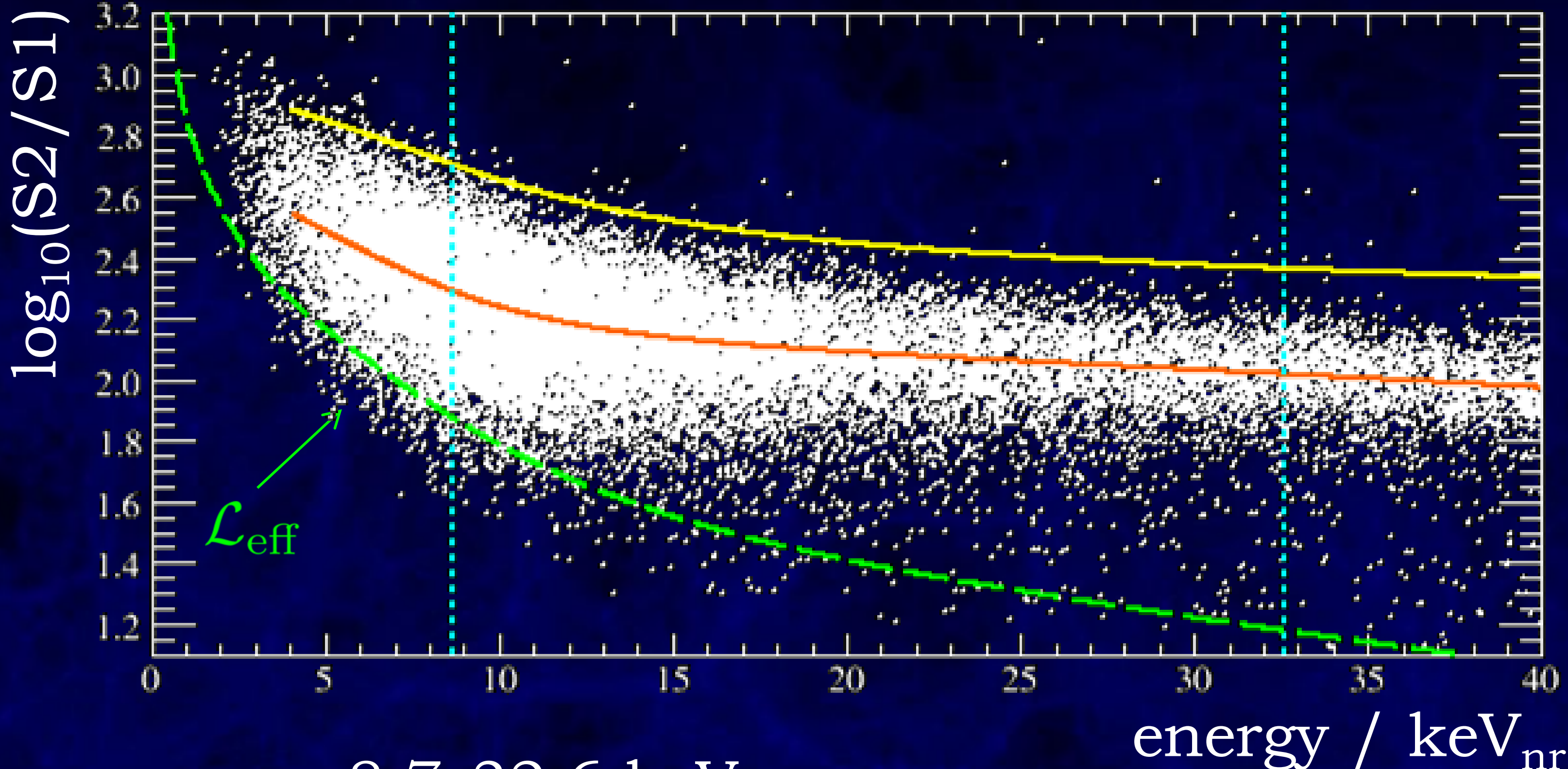


3.6 PE detected (from ~100 S1 photons)

645 PE detected (from 32 ionization electrons which generated ~3000 S2 photons)

Nuclear Recoil Band

Neutrons from ^{241}AmBe

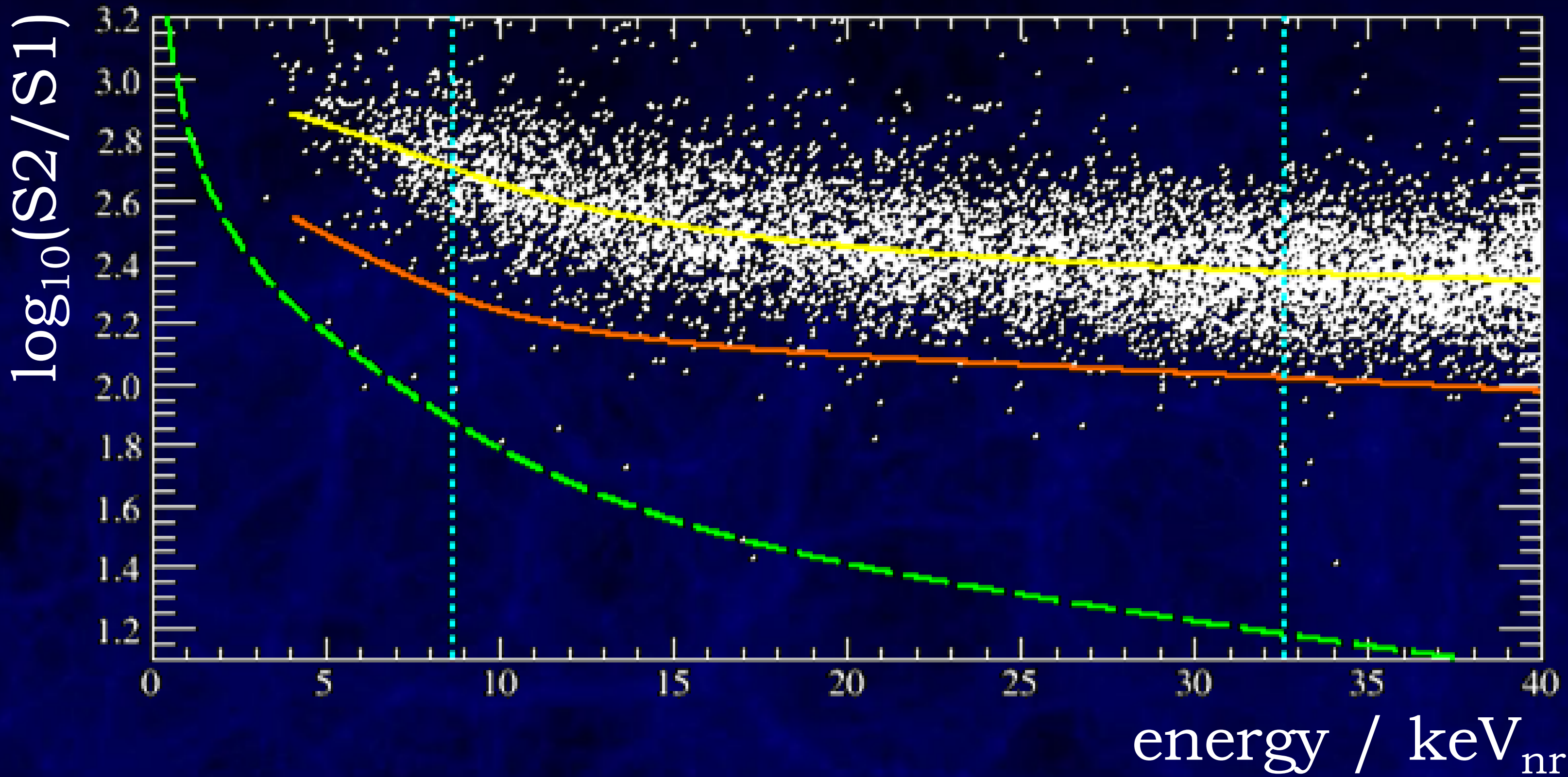


energy range 8.7-32.6 keV_{nr}
(4-20 PE, S1 coincidence with >90% efficiency above 4PE) and below nuclear recoil median

arXiv:1005.0380

Electron Recoil Band

Compton scatters from ^{60}Co

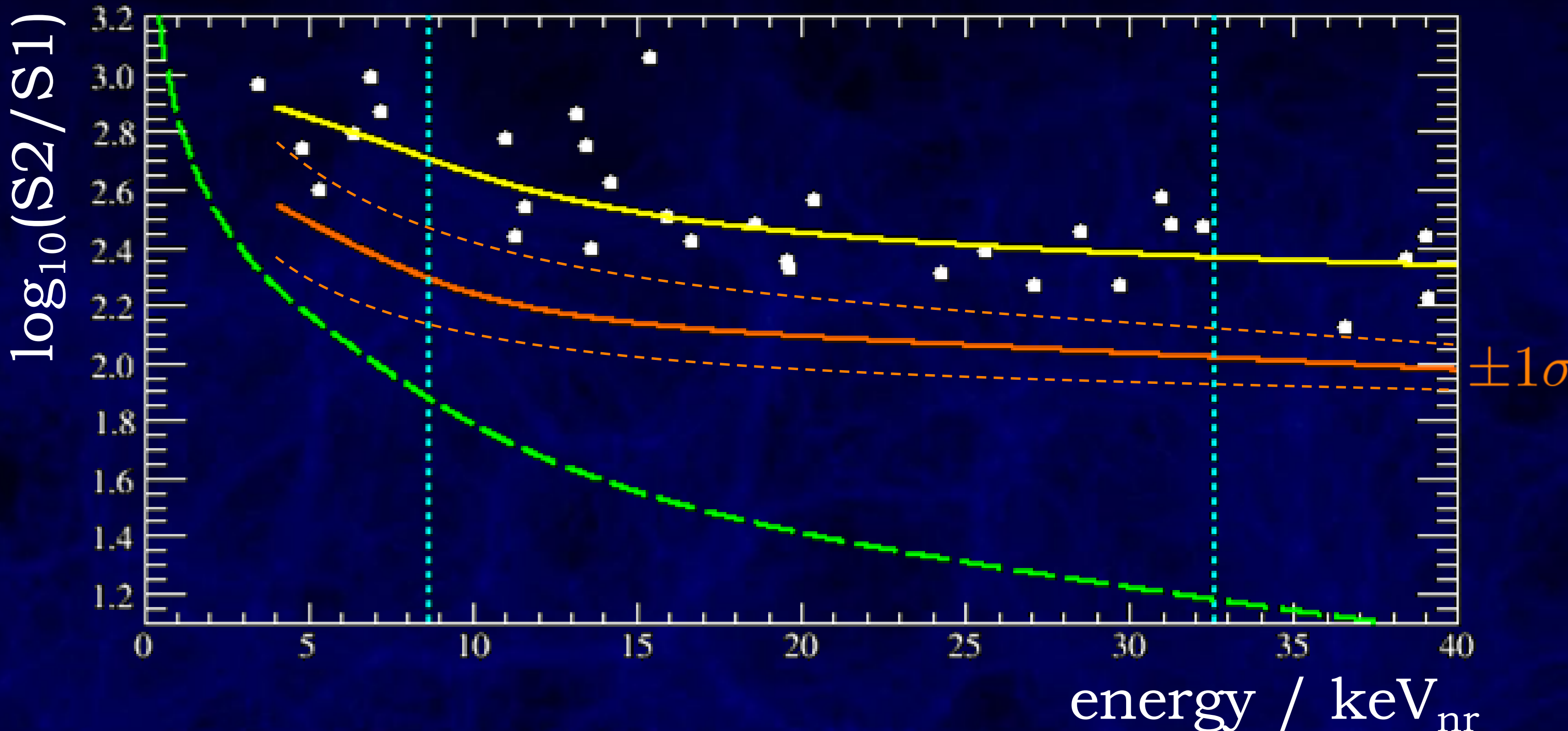


arXiv:1005.0380

50% nuclear recoil acceptance gives
>99% discrimination at low energies

Discrimination

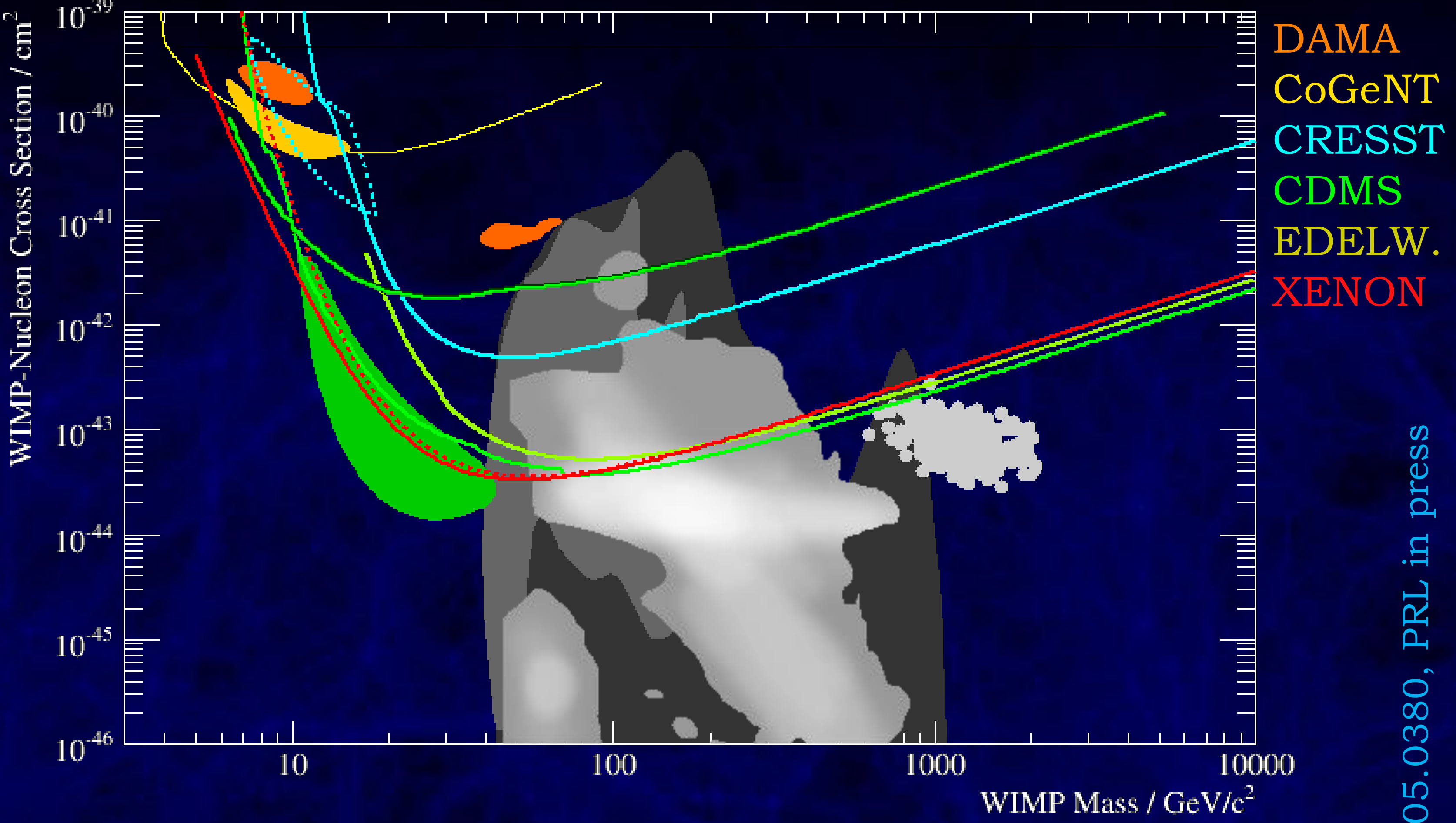
11.17 days, 40kg fiducial, 30%-40% efficiency



no events below the nuclear recoil median
(even no events below 4PE or at 84% acceptance)

arXiv:1005.0380

XENON100 Limit after 11 Days



arXiv:1005.0380, PRL in press

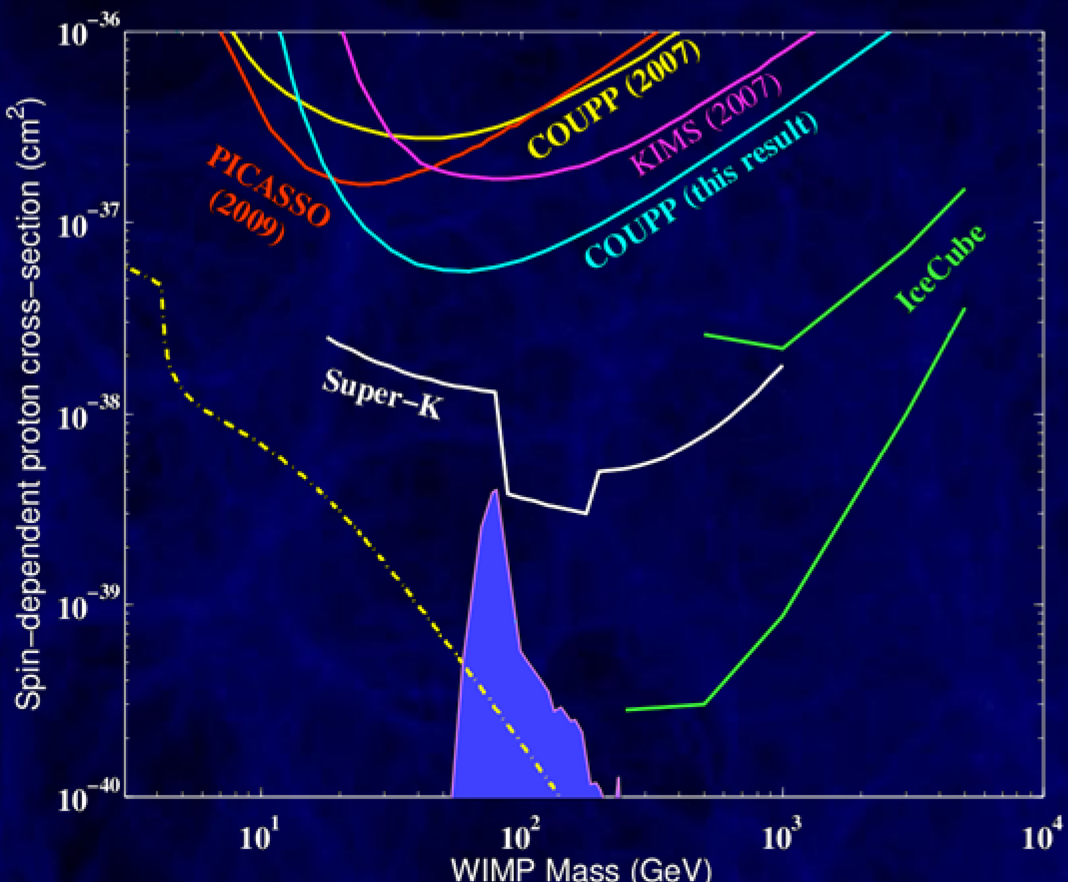
cleanest limit of all: no events expected, none observed
still some uncertainty at low masses (energy calibartion)

Alternative: Spin-Dependence

- spin-dependent scattering → light target with spin

$$N = n_{\text{target}} \Phi \, \sigma_{\chi,N} \, J(J+1)$$

latest result:
(two weeks ago)



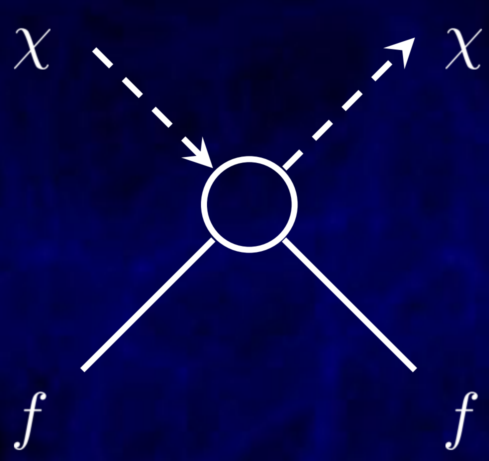
arXiv:1008.3518

Alternative: Inelastic Dark Matter

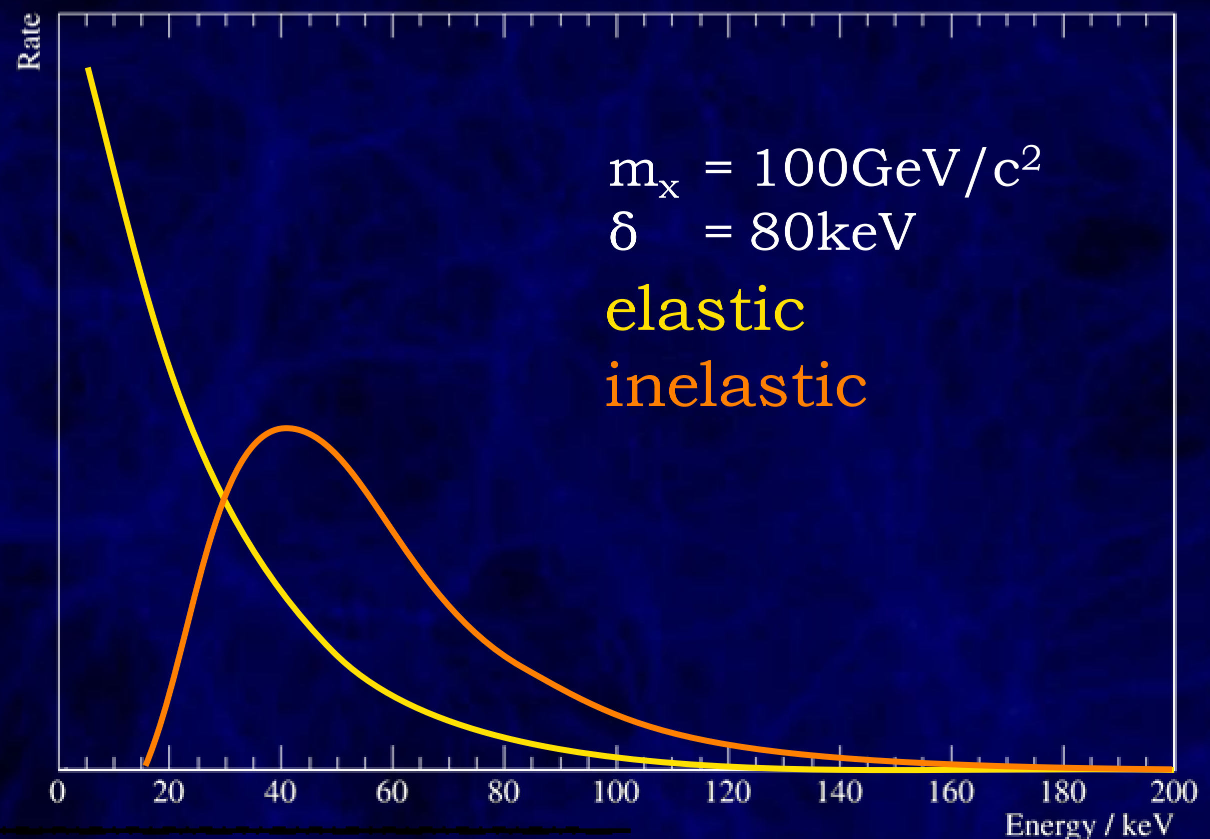
Tucker-Smith&Weiner PRD **64** 043502 (2001)

- allow only vector interactions → heavy target

  originally proposed to reconcile DAMA with others



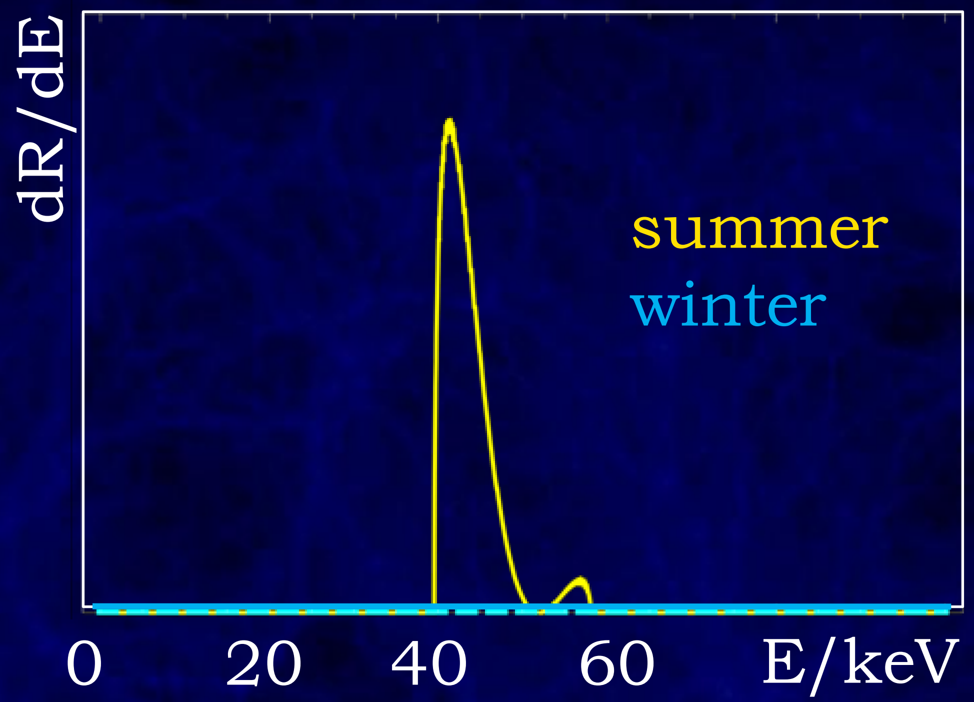
χ^* excited state with energy δ



Inelastic Dark Matter

- allow only vector interactions → heavy target
  originally proposed to reconcile DAMA with others

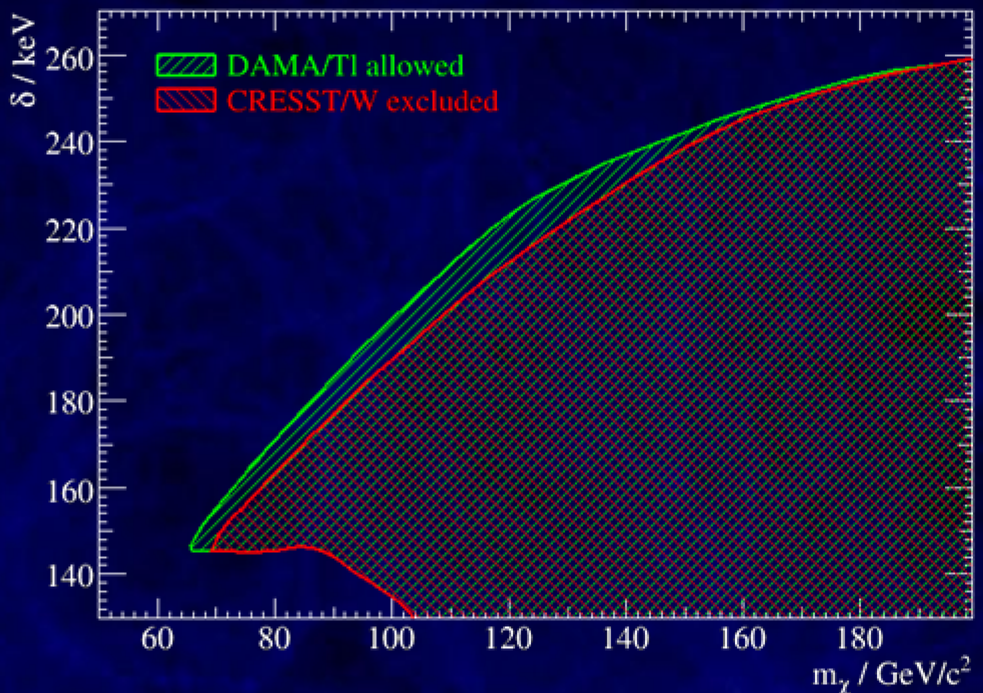
- can produce extremely peaked signals
  Lang & Weiner, JCAP **06** 032 (2010)



Inelastic Dark Matter

- allow only vector interactions $\rightarrow$ heavy target
  originally proposed to reconcile DAMA with others

- can produce extremely peaked signals
  Lang & Weiner, JCAP **06** 032 (2010)



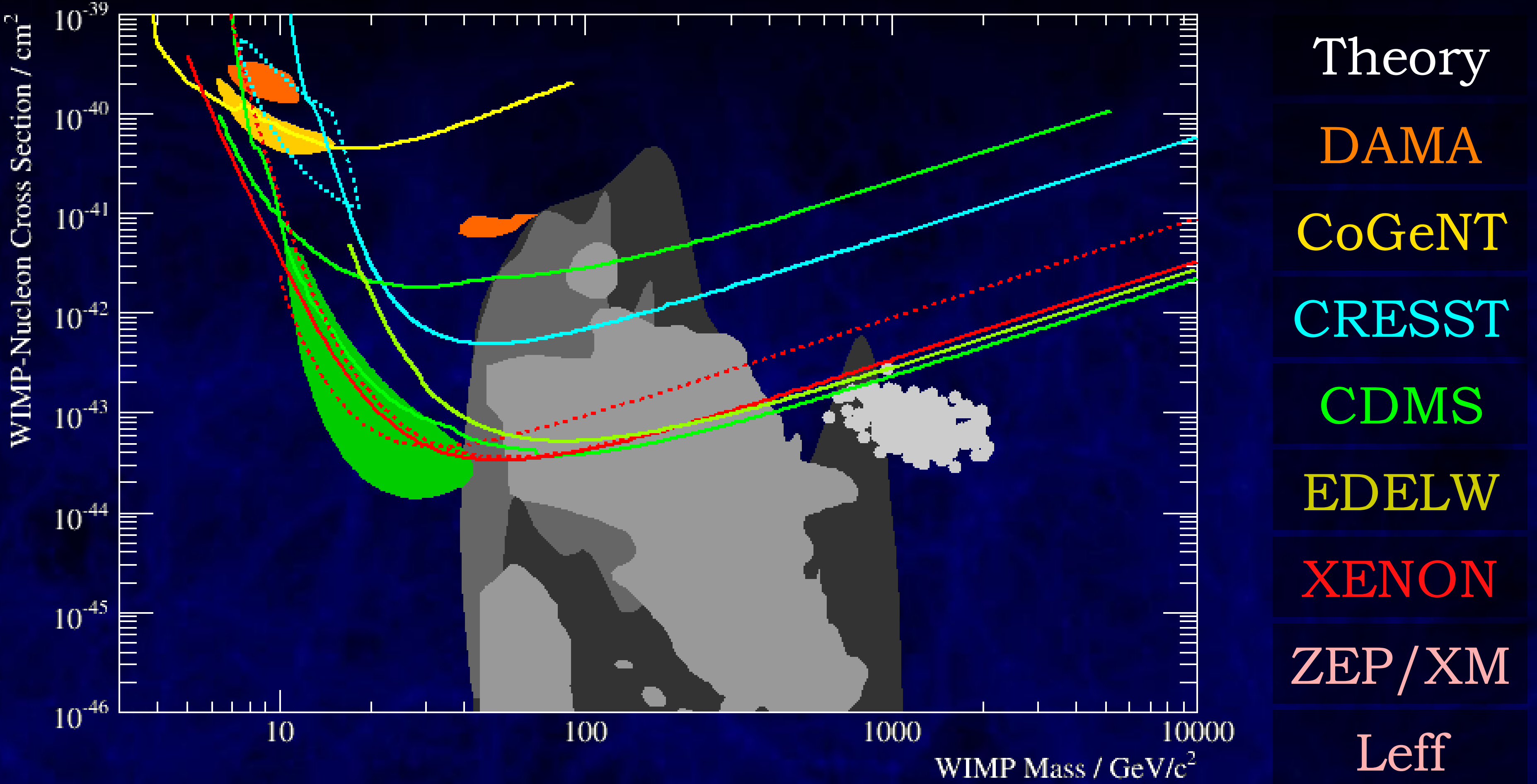
- can make the scintillator dopant the dominant target
  Chang, Lang & Weiner, arXiv:1007.2688

- or produce delayed coincidences from magnetic inelastic dark matter
  Chang, Weiner & Yavin, arXiv:1007.4200

News Forecast for 2010

- CoGeNT: release of higher statistics spectrum. Measured K-shell lines will allow to subtract L-shell lines, which will shift the spectrum to lower energies (which, if interpreted as WIMPs, will point to lower masses around 7GeV). What about M-shell lines?
- CRESST: write-up of run32 data (2009/2010) will clarify many open questions and allow for checks of consistency. Hopefully, they'll show individual detectors and time-distribution of events.
- XENON100: release of x10 more data, covering for the first time the next decade in sensitivity. Probably only one or two events expected from background.
- WARP, XMASS, LUX, DEAP/miniCLEAN: come online

Summary

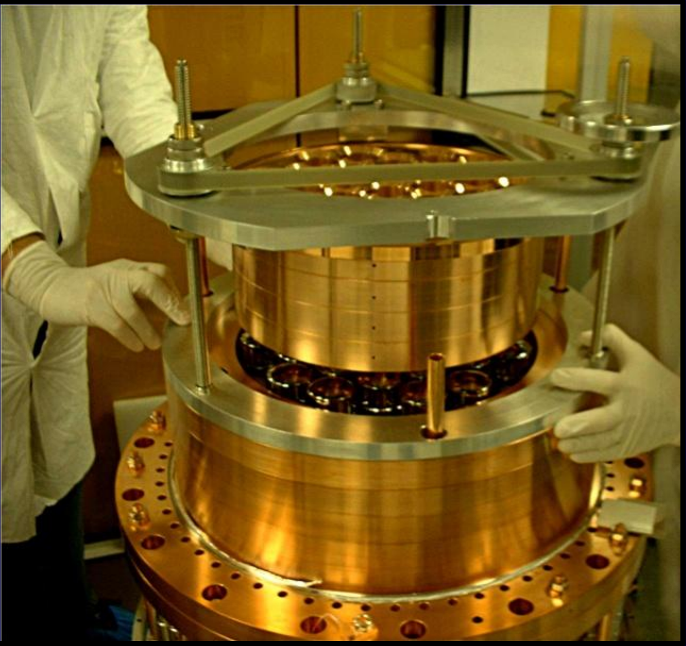


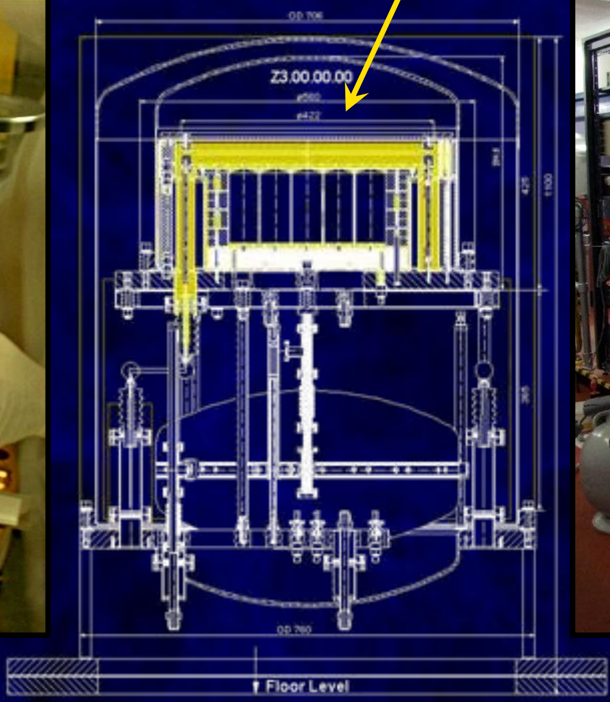
A very active and versatile field of research
many hints to follow up, many promising experiments

ZEPLIN-III

UK/Portugal/Russia collaboration, at Boulby mine
liquid xenon dual-phase TPC
8kg fiducial volume
(12kg total, 31 2” PMTs)

liquid xenon target





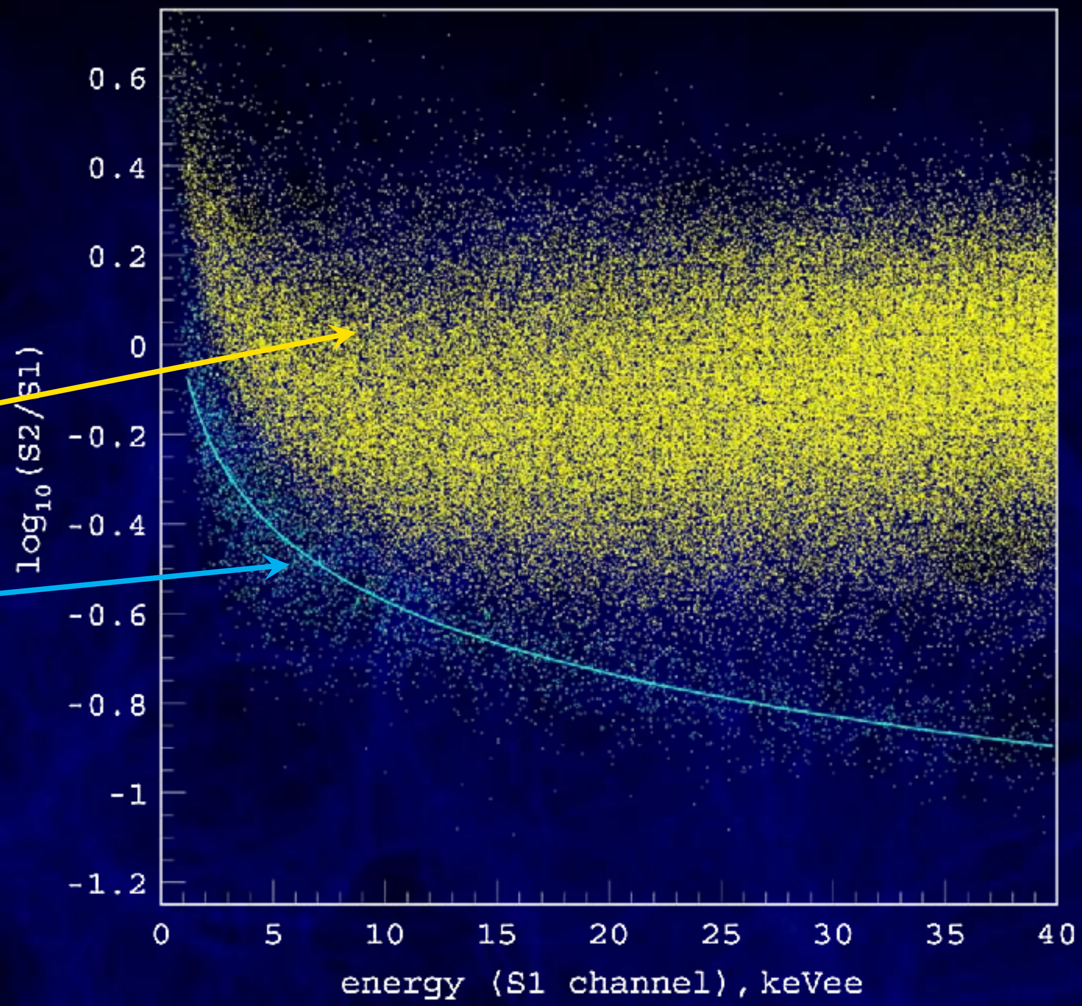
Sumner, IDM 2010

ZEPLIN-III

calibration:

electronic recoils (^{137}Cs)

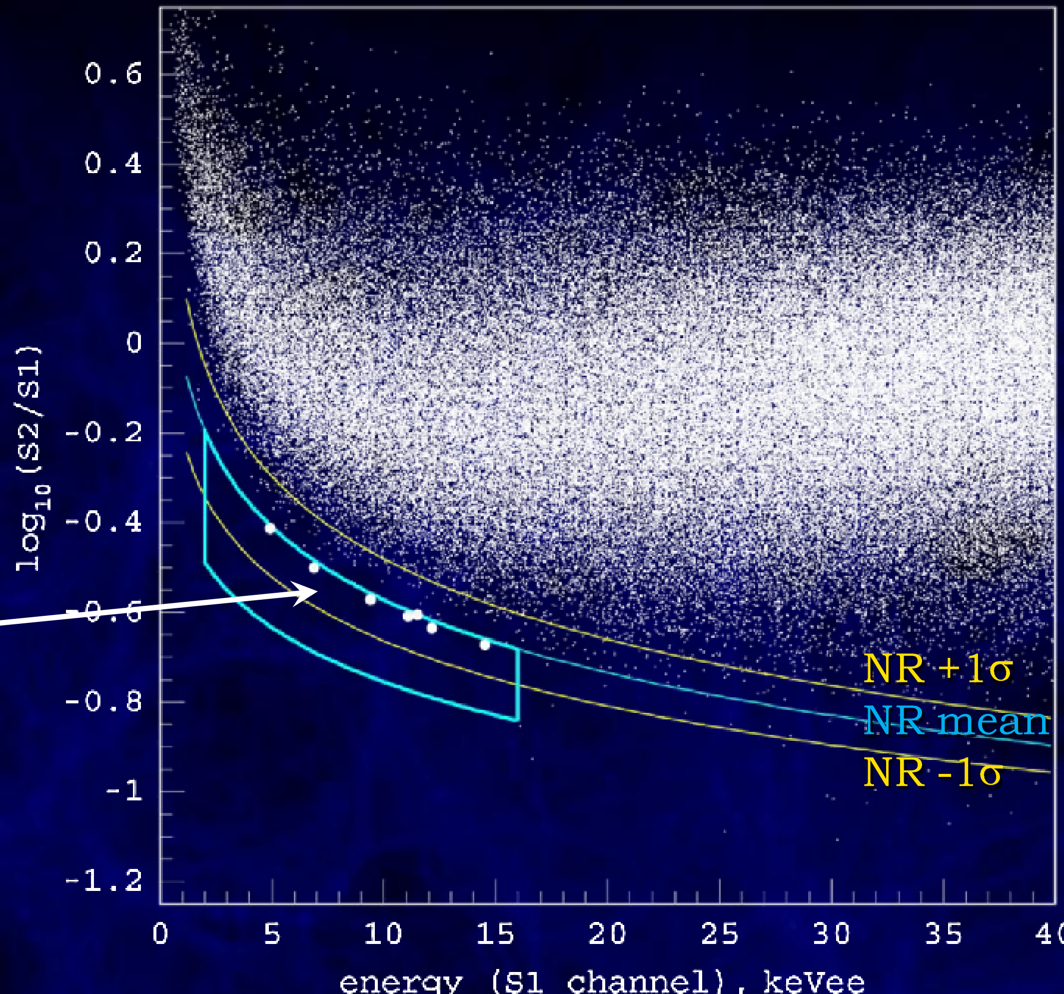
nuclear recoils ($^{241}AmBe$)



PRD 80, 052010 (2009)
arXiv:0812.1150

ZEPLIN-III

first science run 2008
3 months data taking
resulting data:



7 events in signal box

PRD 80, 052010 (2009)
arXiv:0812.1150

second science run in progress

XMASS

Japan collaboration, at Kamioka
860kg (100kg fiducial) single-phase liquid xenon detector

vessel installed in water shield
liquid xenon filling expected October 2010

Moriyama, IDM2010

Nuclear Recoil Equivalent Energy

Nuclear Recoil Energy: $E_{\mathrm{nr}} = \frac{S1}{L_y} \cdot \frac{S_{\mathrm{ee}}}{S_{\mathrm{nr}}} \cdot \frac{1}{\mathcal{L}_{\mathrm{eff}}}$

$L_y(122\mathrm{keV}_{ee}) = (2.2 \pm 0.1)\ \frac{\mathrm{PE}}{\mathrm{keV}_{ee}}$

$S_{ee} = 0.58$
$S_{nr} = 0.95$

$\mathcal{L}_{\mathrm{eff}}$ best fit

Manzur et al. 2010
Aprile et al. 2009
Chepel et al. 2006
Aprile et al. 2005
Akimov et al. 2002
Bernabei et al. 2001
Arneodo et al. 2000