DAMA, CoGeNT, CRESST, CDMS, EDELWEISS, XENON

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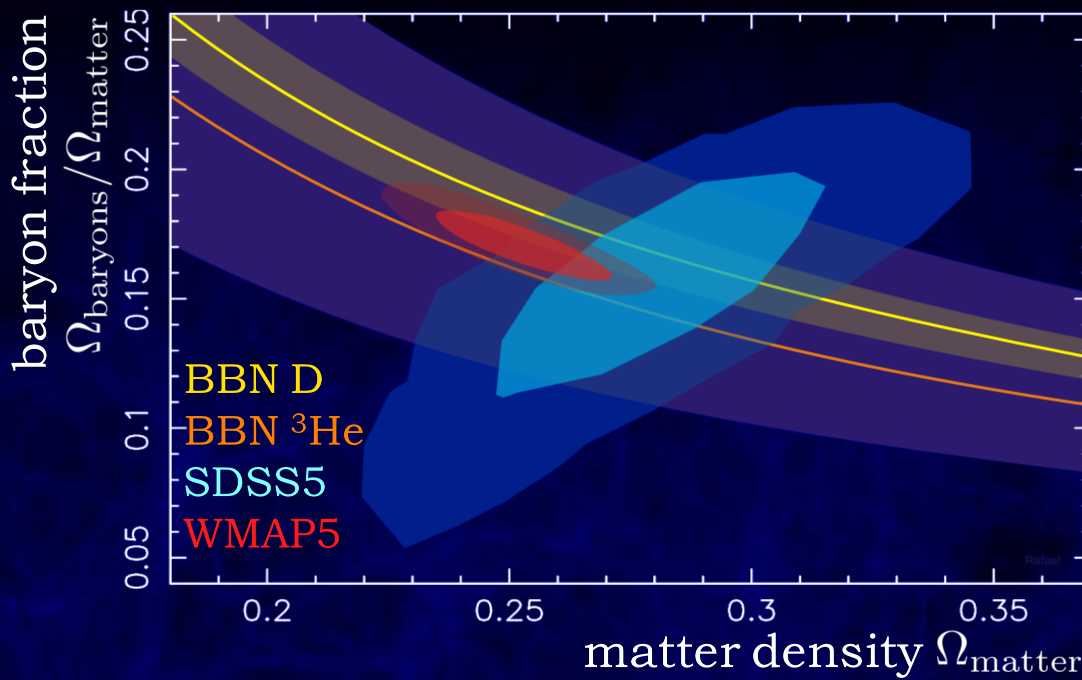
MPI Heidelberg, January 2012

picture: Thomas Tuchan

Most Matter is Dark Matter

from

- Big Bang nucleosynthesis
- cosmic microwave background
- structure formation
- galaxy clusters
- rotation curves of galaxies
- …



we know:

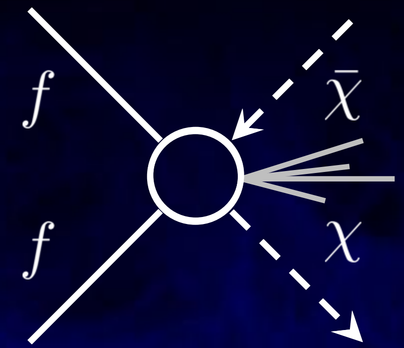
most of the matter in the Universe is not Baryons, but some new stuff

$\Omega_\Lambda \approx 0.73 \quad \Omega_{\mathrm{DarkMatter}} \approx 0.23 \quad \Omega_{\mathrm{Baryons}} \approx 0.04$

arXiv:1001.4744

How to Search a Thermal Relic

- Production



Collider Searches

- Annihilation

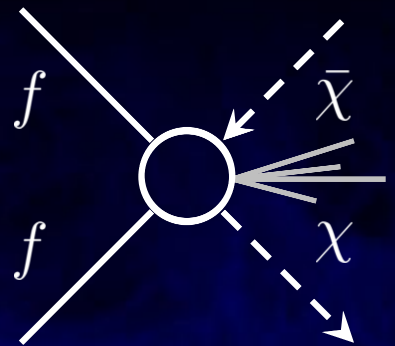
$\bar{\chi}$ f

χ f

Indirect Searches

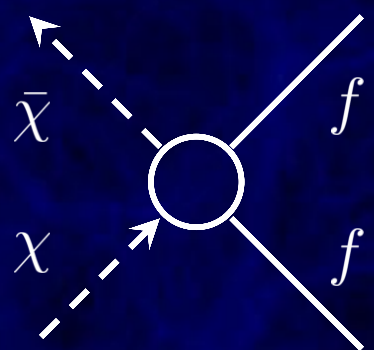
How to Search a Thermal Relic

- Production



Collider Searches

- Annihilation



Indirect Searches

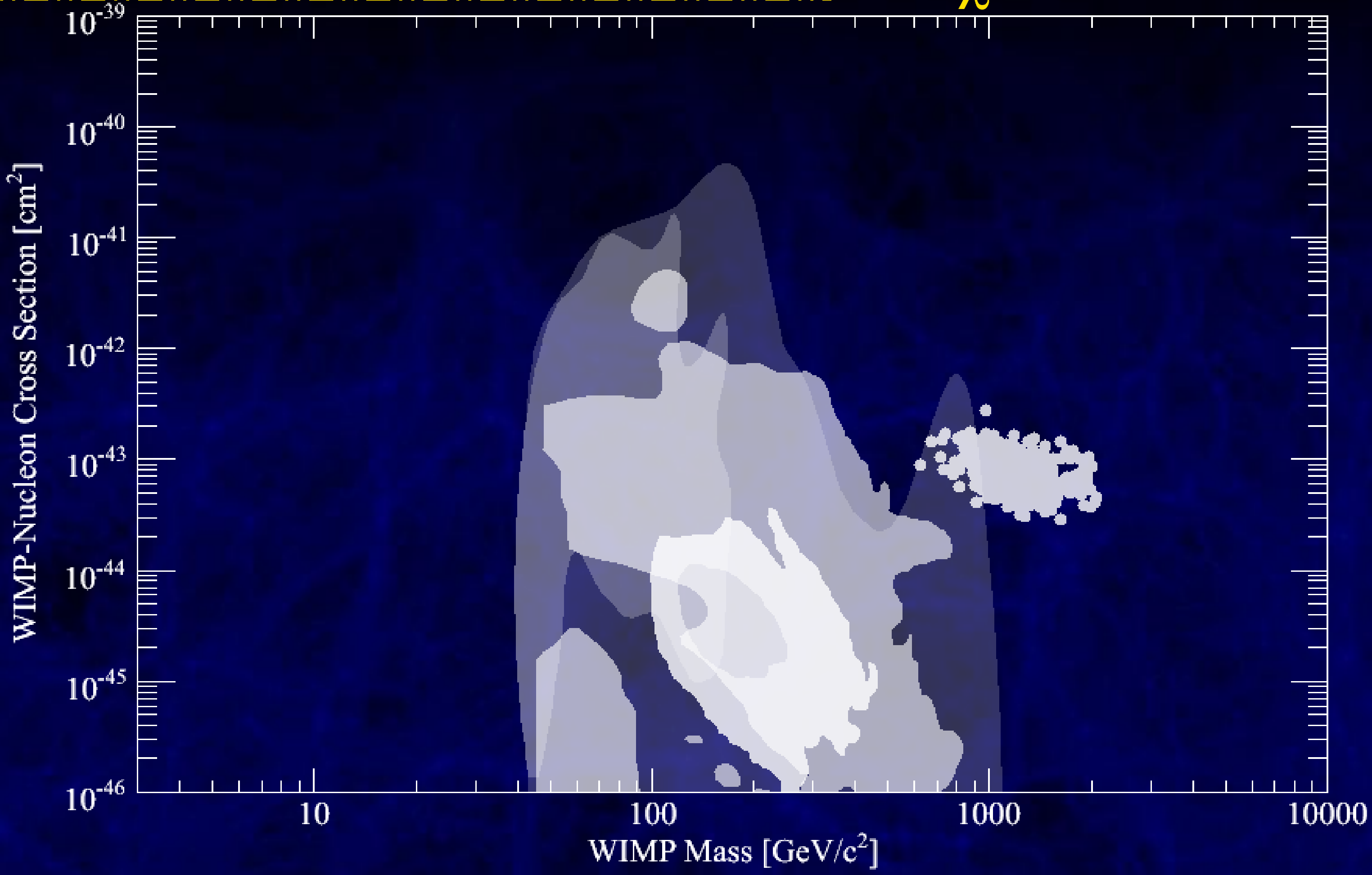
- Scattering

χ χ

f f

Direct Searches

Expectations in σ-m_χ-Space



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

Buchmueller et al. arXiv:1102.4585
Kadastik et al. PRL **104** 201301 (2010)
Roszkowski et al. JHEP**07** 075 (2007)
Baltz&Gondolo PRD **67** 063503 (2003)

How to Fish for WIMPs

- expected recoil spectrum
- discrimination techniques
- DAMA/LIBRA
- CoGeNT
- CRESST-II
- CDMS-II
- EDELWEISS
- XENON100

Direct Scattering Theory On One Slide

- Rate $\rightarrow$ large detector, long exposure

$$N = n_{\text{target}} \Phi \, \sigma_{\chi,N} \, A^2 \qquad \text{(or } \propto \sigma_{\chi,N} \, J(J+1)\text{)}$$

- 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

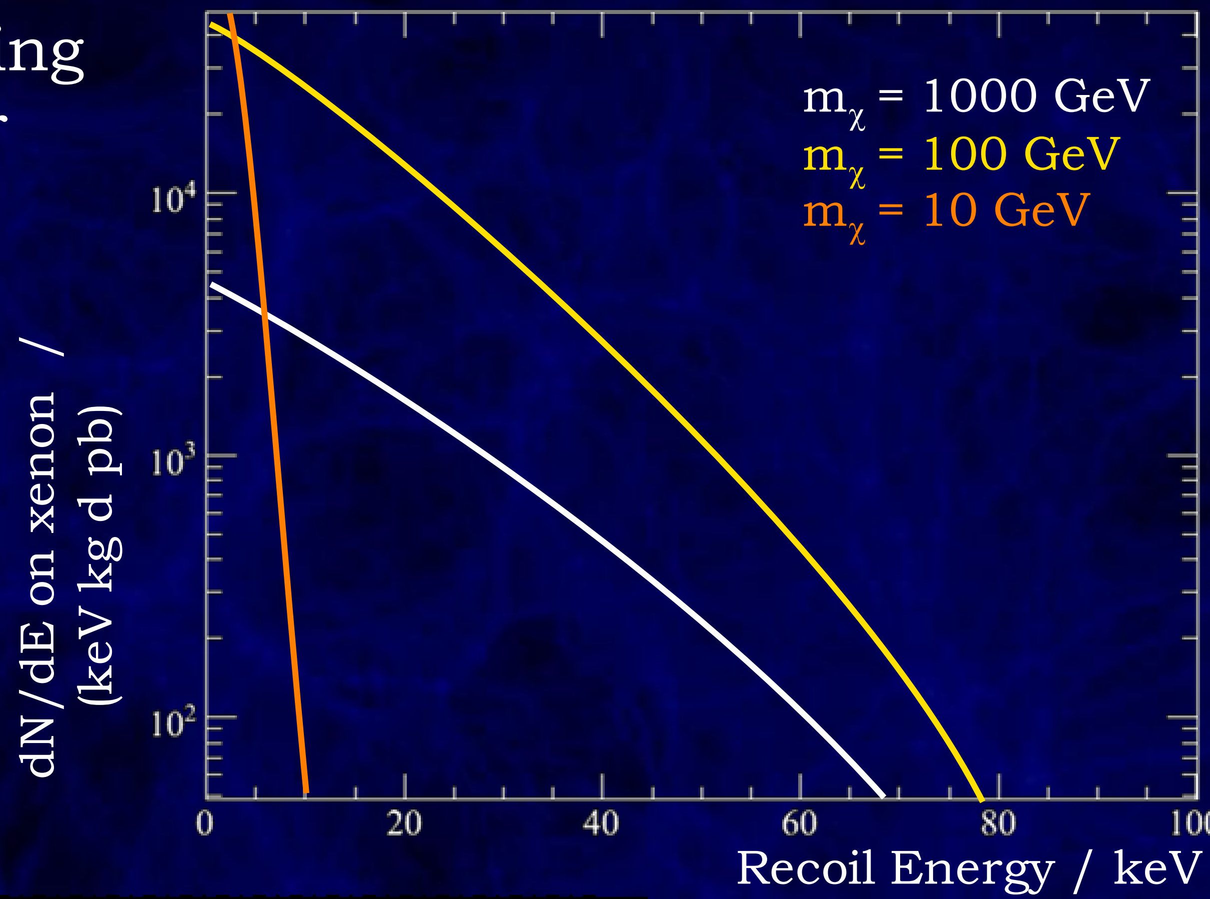
$$E_{\text{r,max}} \sim \frac{p_\chi^2}{2m_{\text{N}}} \sim \frac{\left(100\,\text{GeV}/\text{c}^2 \times 10^{-3}\text{c}\right)^2}{2 \times 100\,\text{GeV}/\text{c}^2} = 50\,\text{keV}$$

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

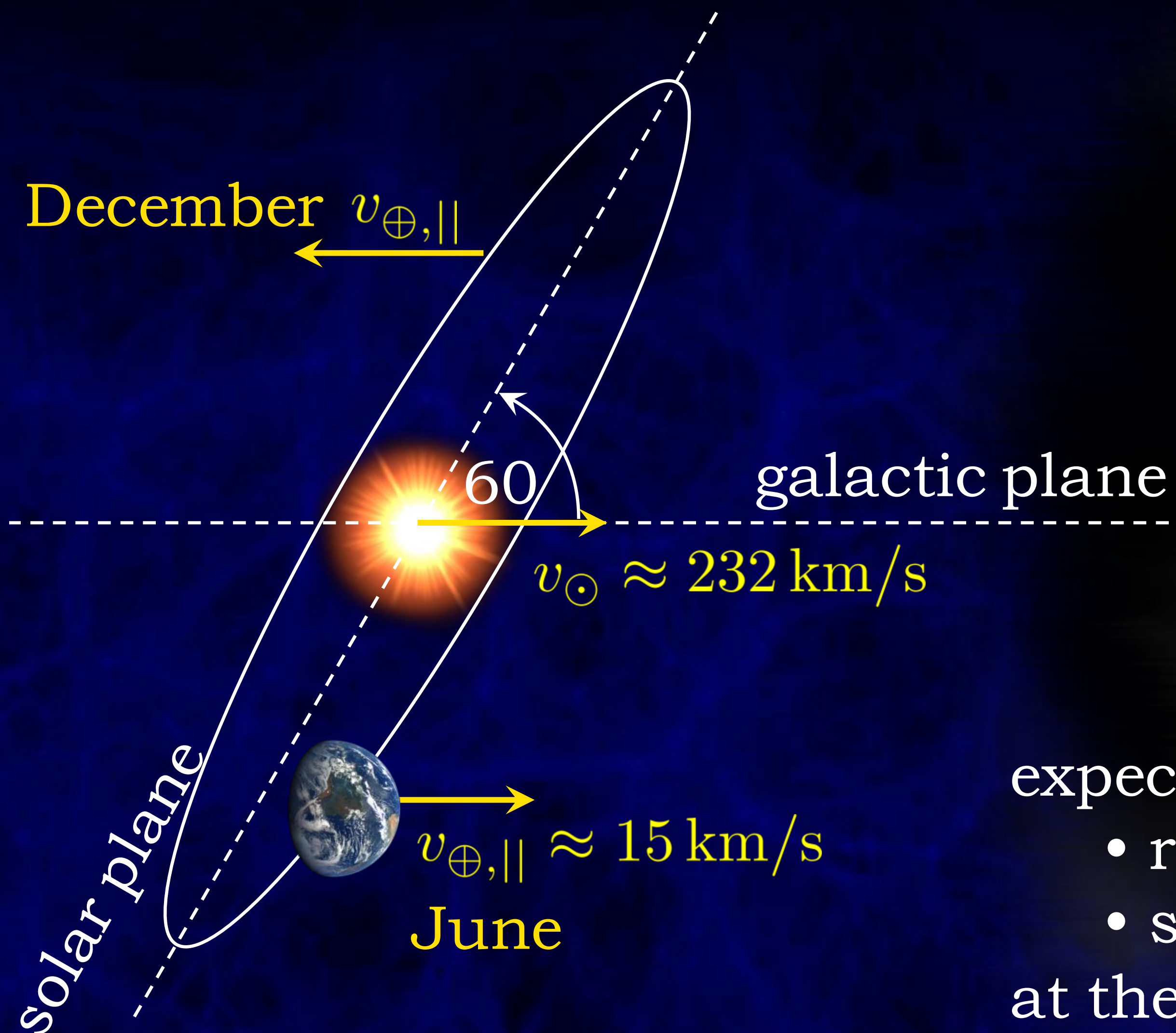
$$\frac{\text{d}N}{\text{d}E_r} \propto \Phi \propto \langle v \rangle \propto \int_{v_\chi}^{\infty} f_{\text{MB}}(v)\, v\, \text{d}v \propto \text{e}^{-v_\chi^2} \propto \text{e}^{-E_r}$$

Expected WIMP Spectrum

- isothermal halo
- local density $\varrho_\chi \approx 0.3\,\mathrm{GeV/c^2/cm^3}$
- $v_\oplus \approx 240\,\mathrm{km/s}$
- coherent scattering
- Helm form factor



Annual Modulation



expect modulation of

- rate
- spectral shape

at the percent level

How to Fish for WIMPs

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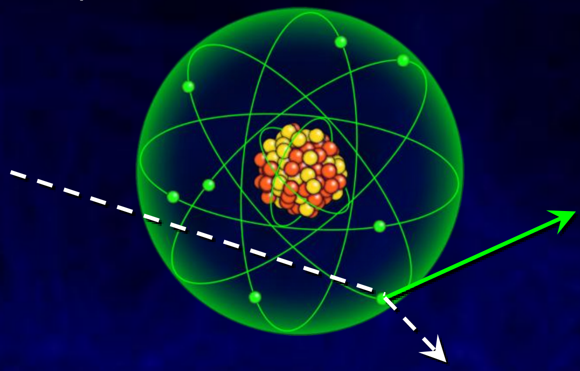
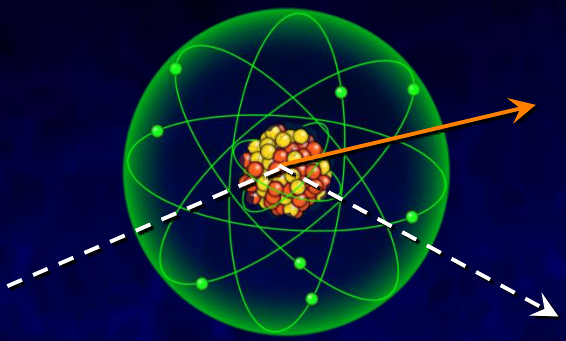
The Power of Discrimination

e^-/γ: electronic recoil



n/WIMPs: nuclear recoil



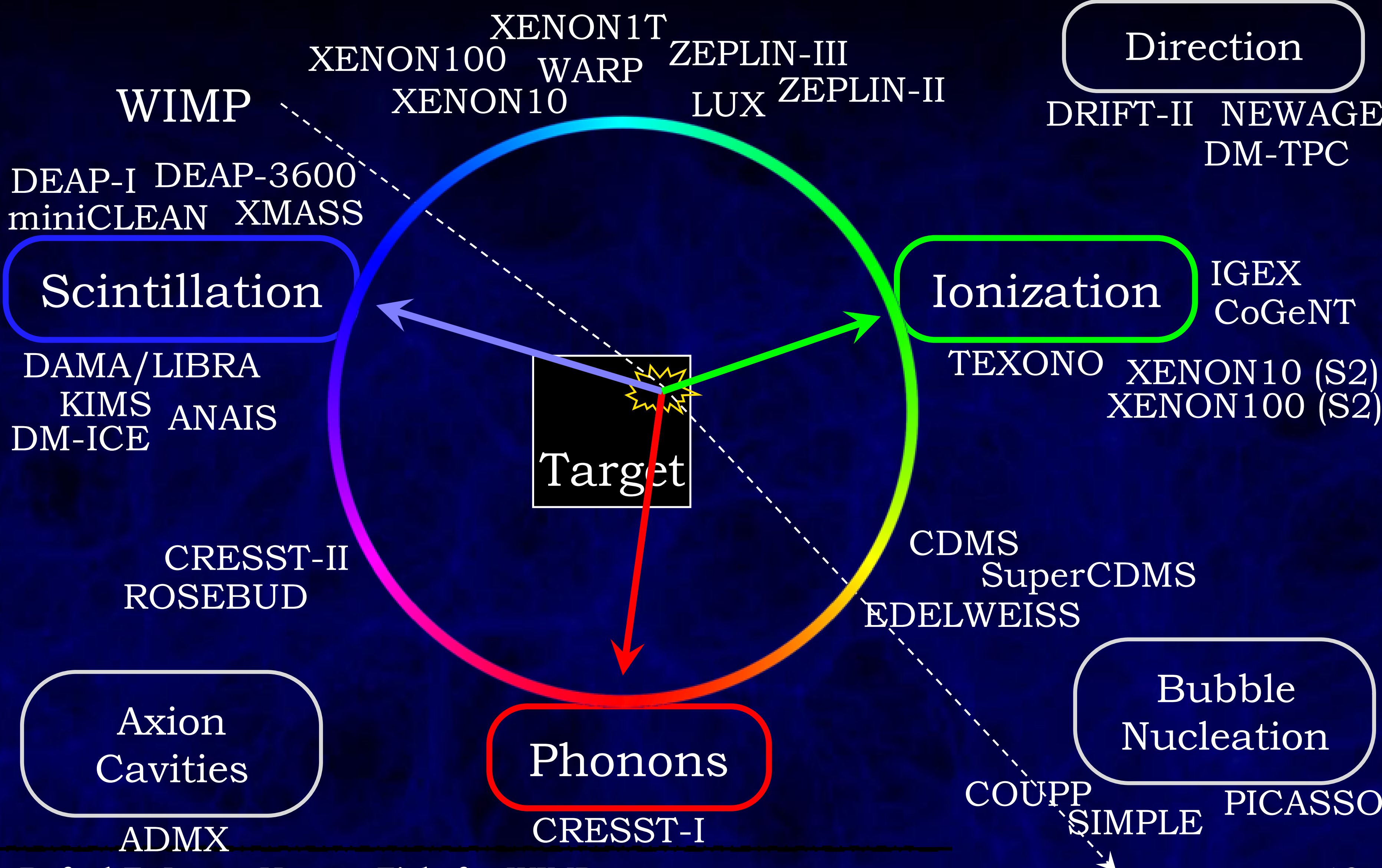
electronic recoils

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

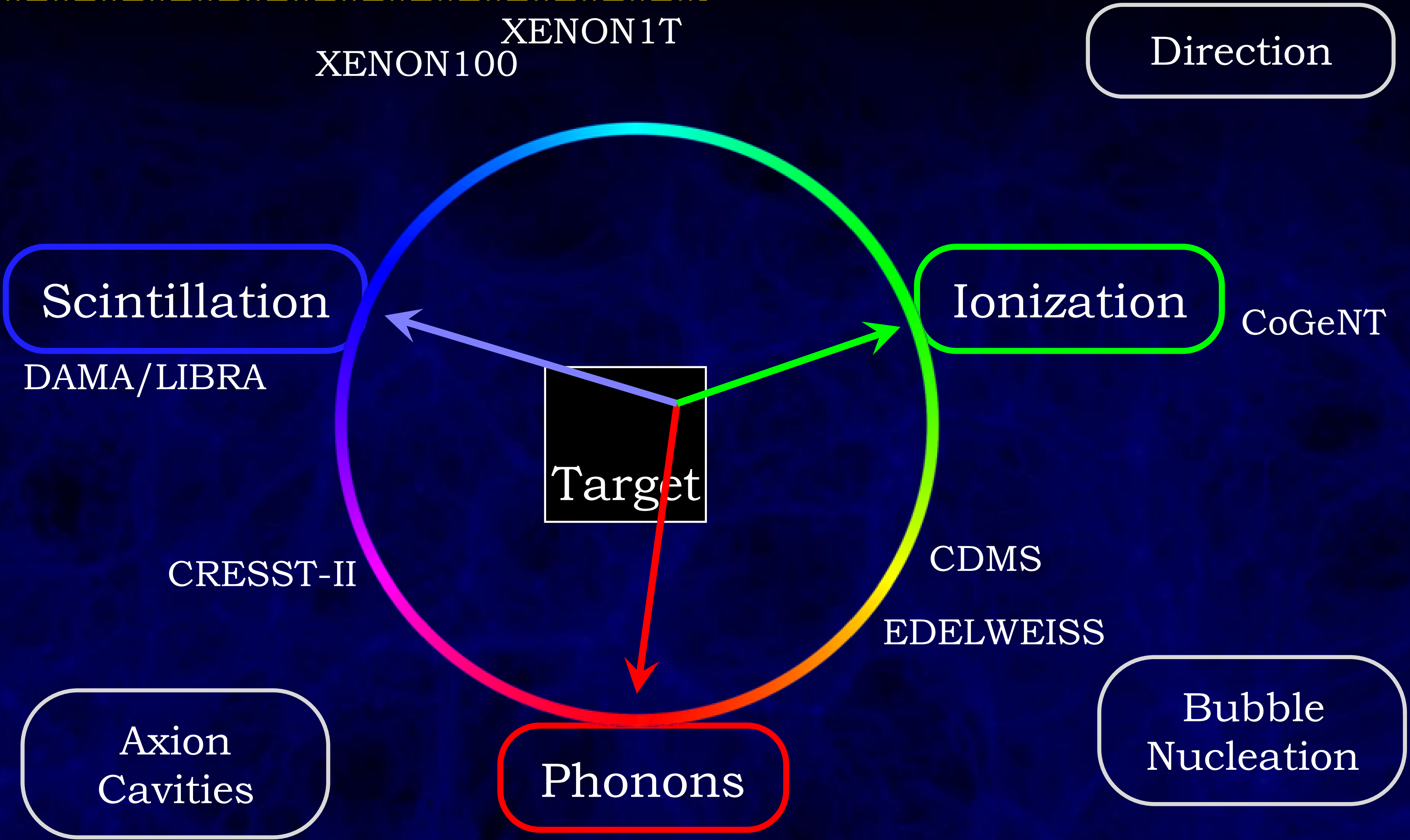
→ discriminate between the two

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

Particle Detection Channels



Particle Detection Channels



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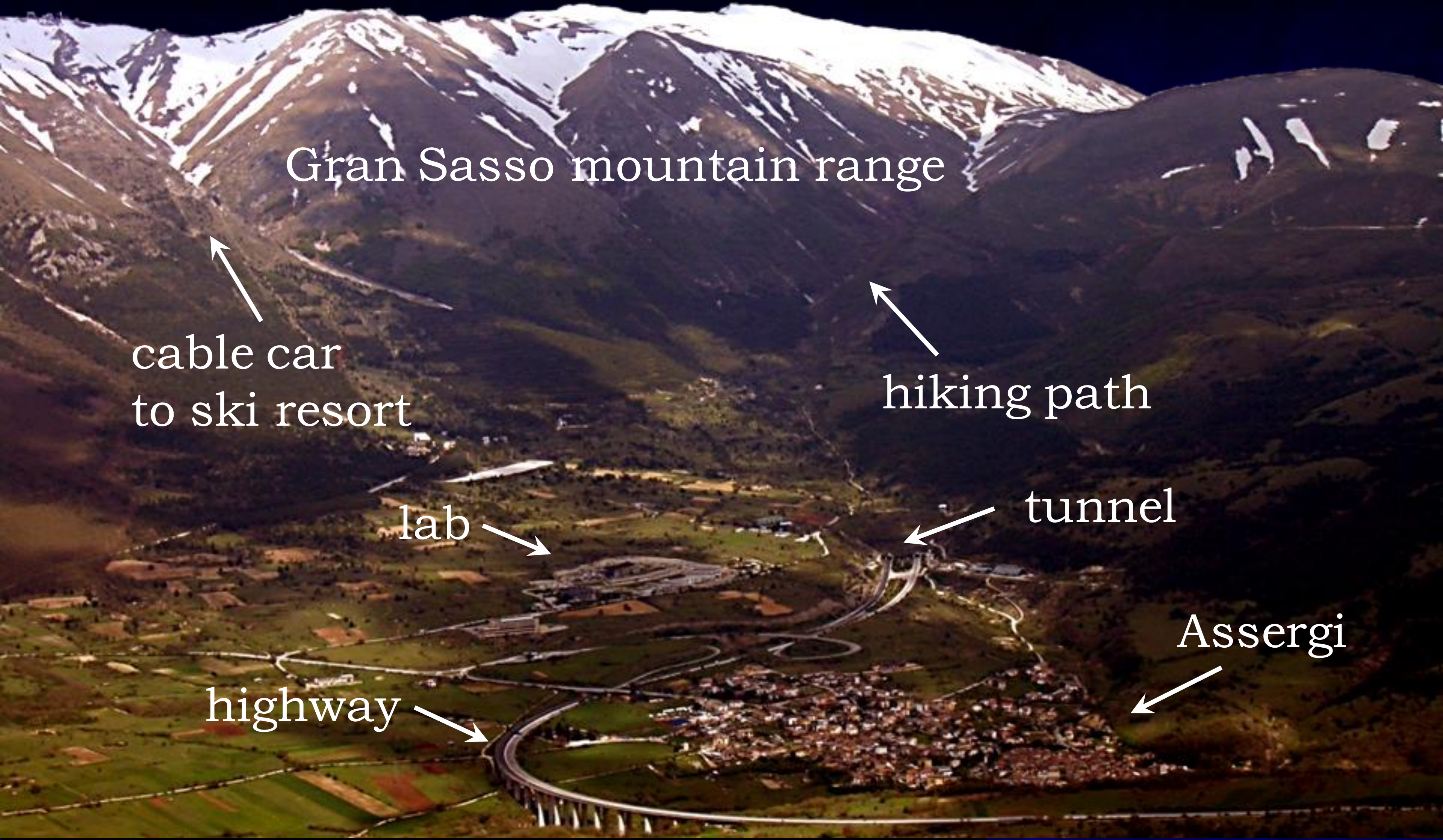
Gran Sasso Underground Lab

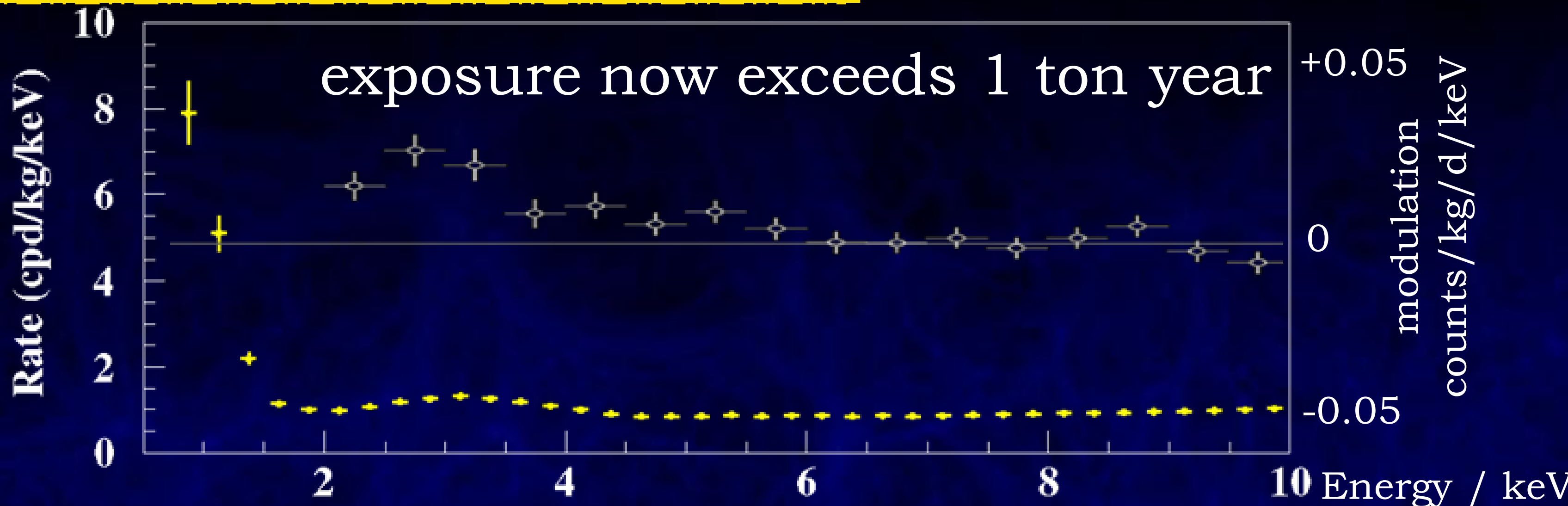


DAMA/LIBRA

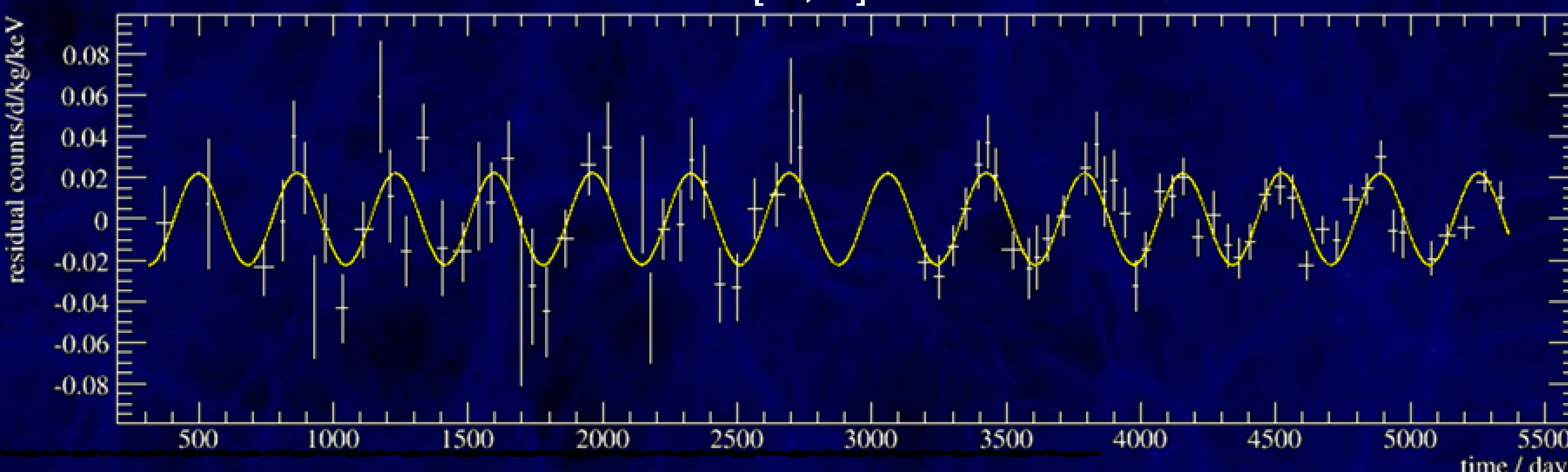
Italy/China: 230kg ultra-pure NaI(Tl) scintillators
by far largest and longest exposure but no discrimination



DAMA/LIBRA Data

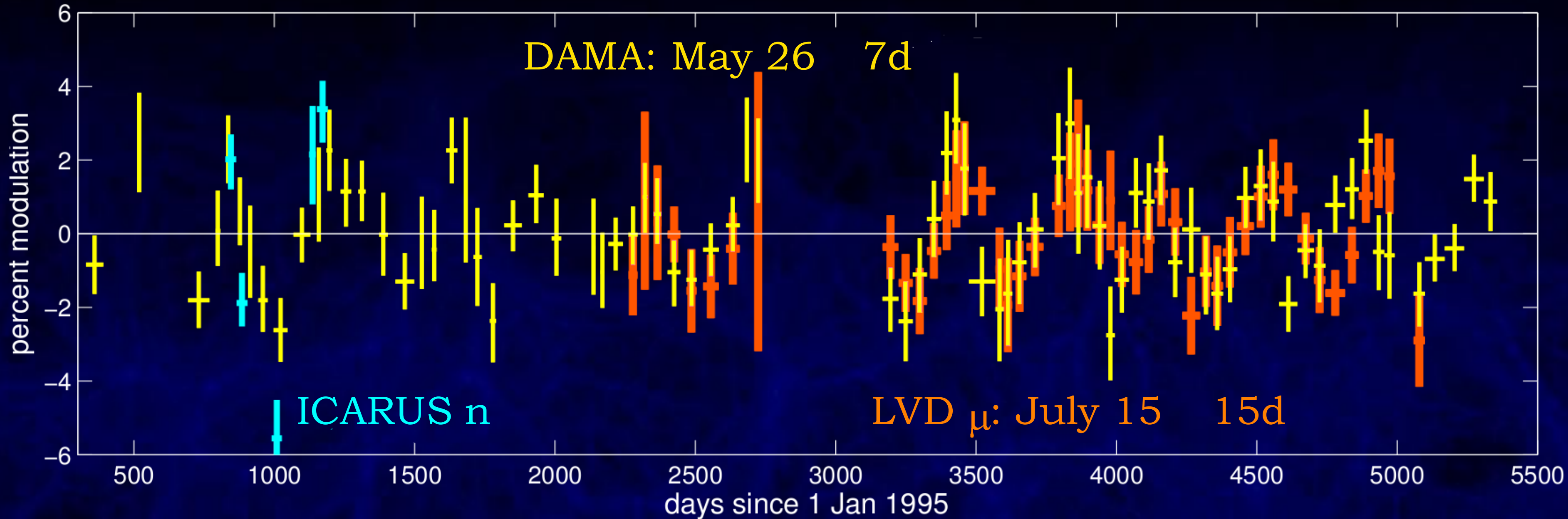


observe rate modulation in [2,4]keV:



data from arXiv:0804.2741 and arXiv:1002.1028

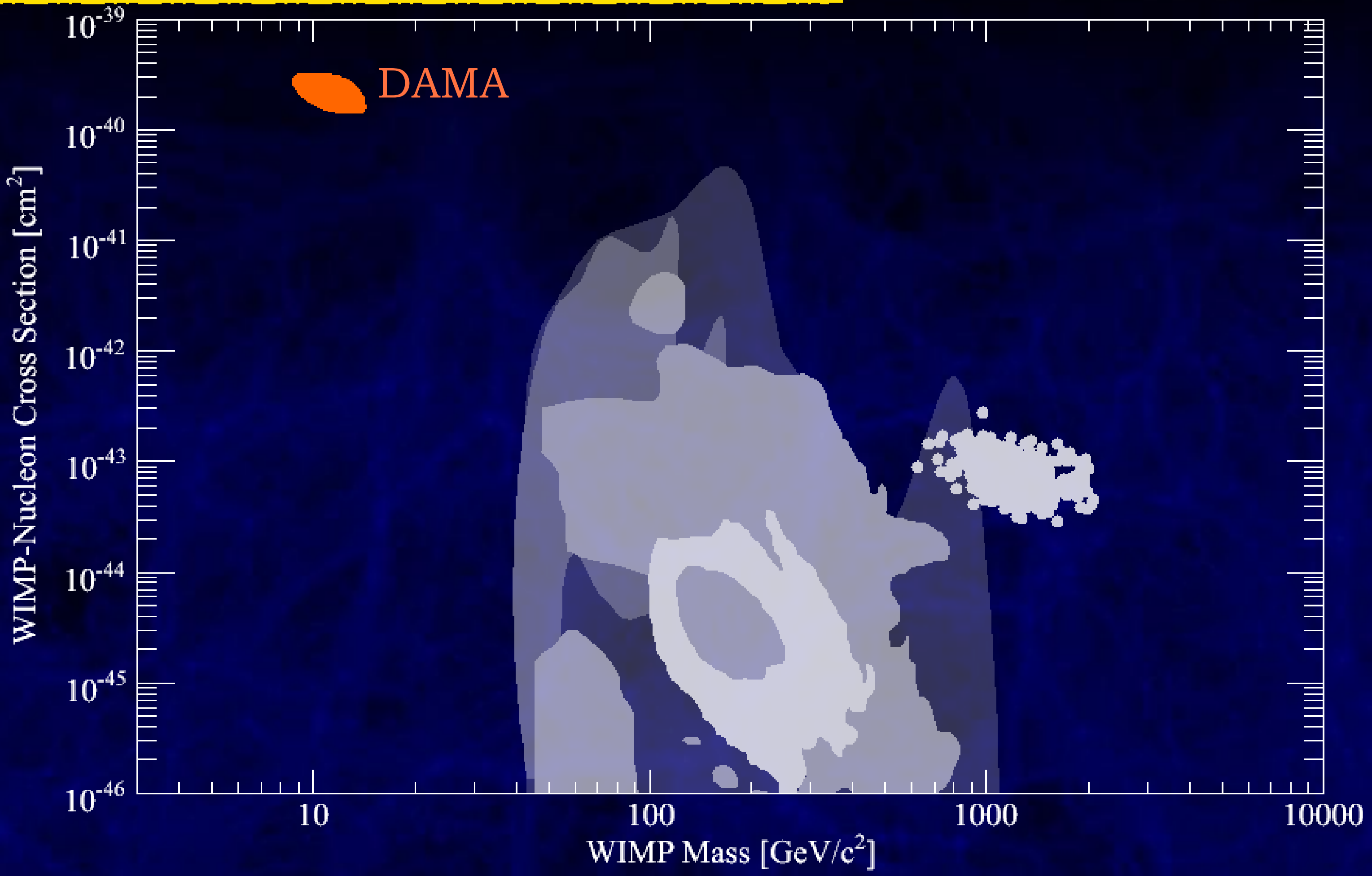
Muon Flux at Gran Sasso



DAMA and LVD μ phase are roughly consistent.

- χ^2/dof ~ 1 — arXiv:1110.0857
- delayed phosphorescence? (error bars?) — arXiv:1102.0815
- n generation in the passive shielding? — arXiv:1006.5255
- pure coincidence? — arXiv:0912.0660

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

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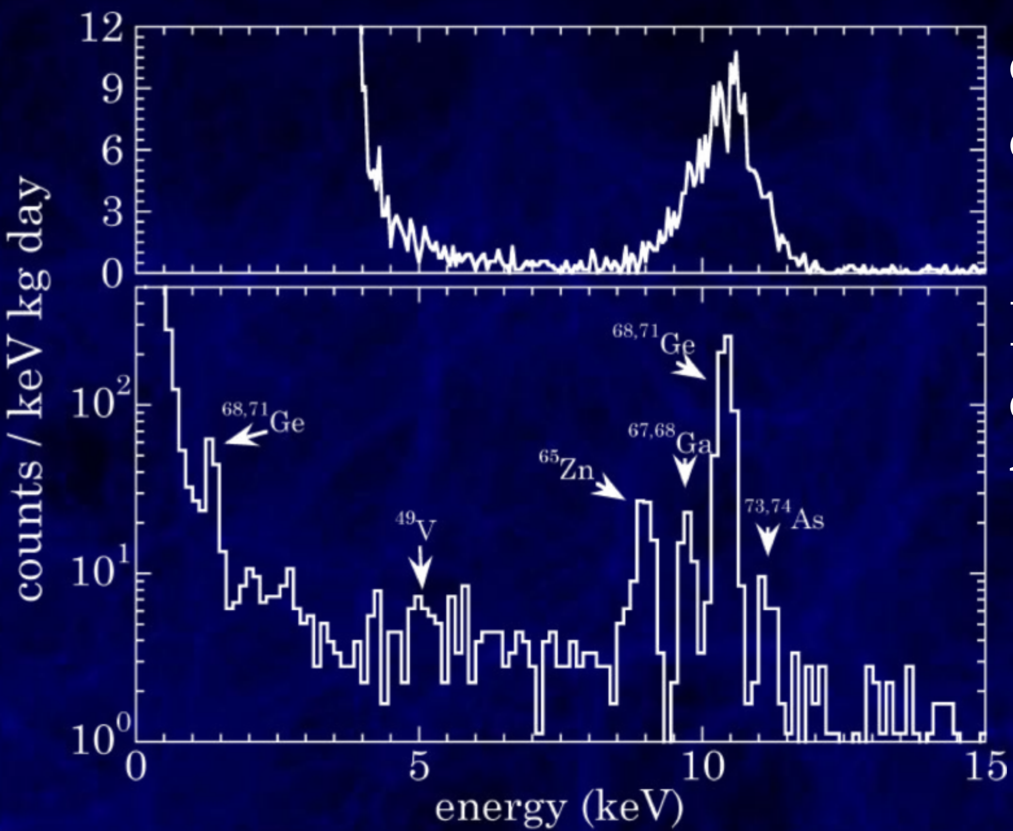
CoGeNT Performance

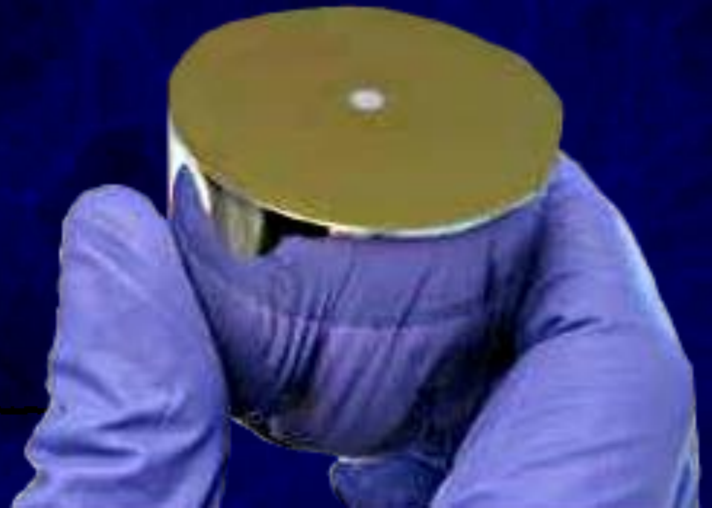
USA

440g P-type point-contact Ge detector



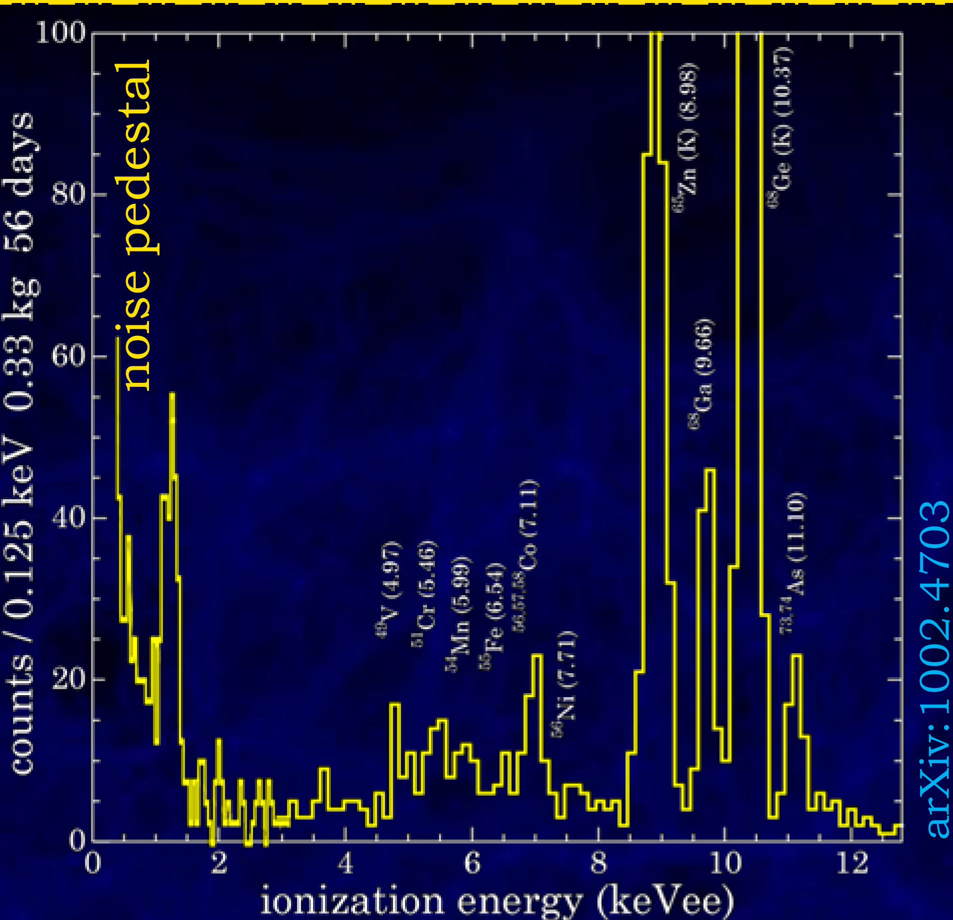
conventional coaxial HPGe

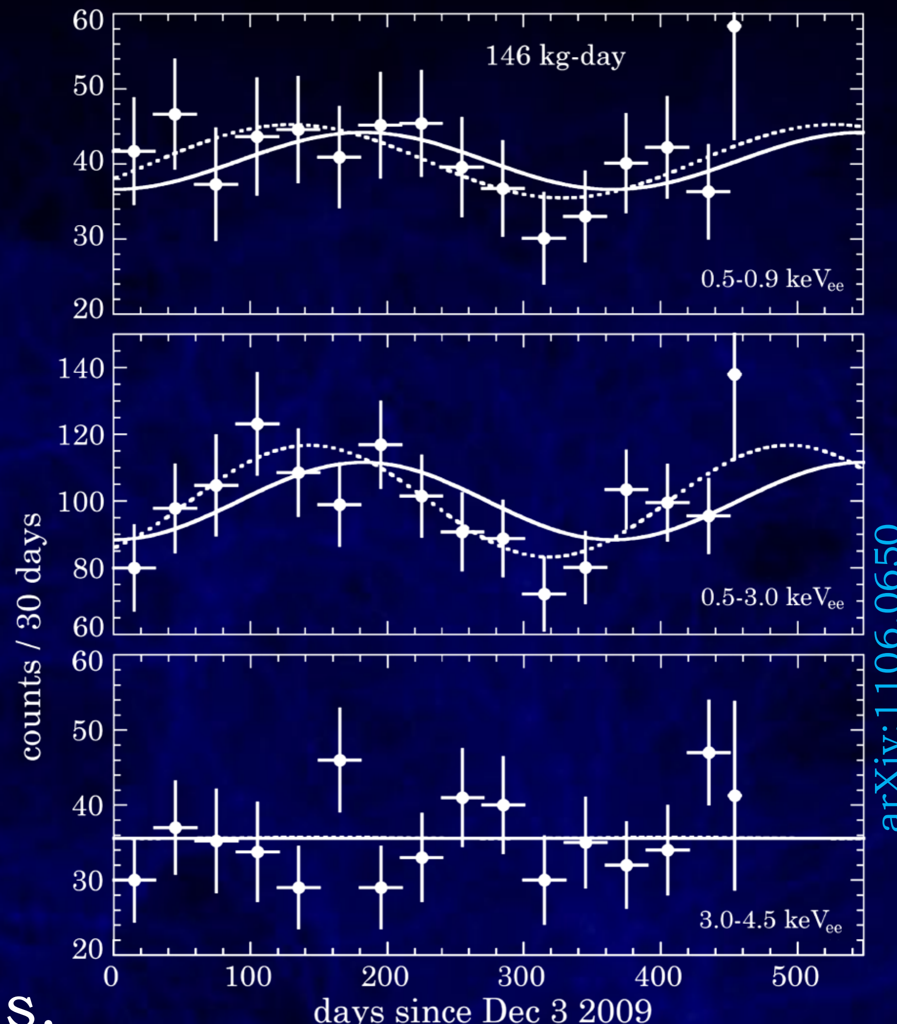
P-type point-contact HPGe threshold 400eV



Collar, UC Davis and other talks, 2010

CoGeNT Data



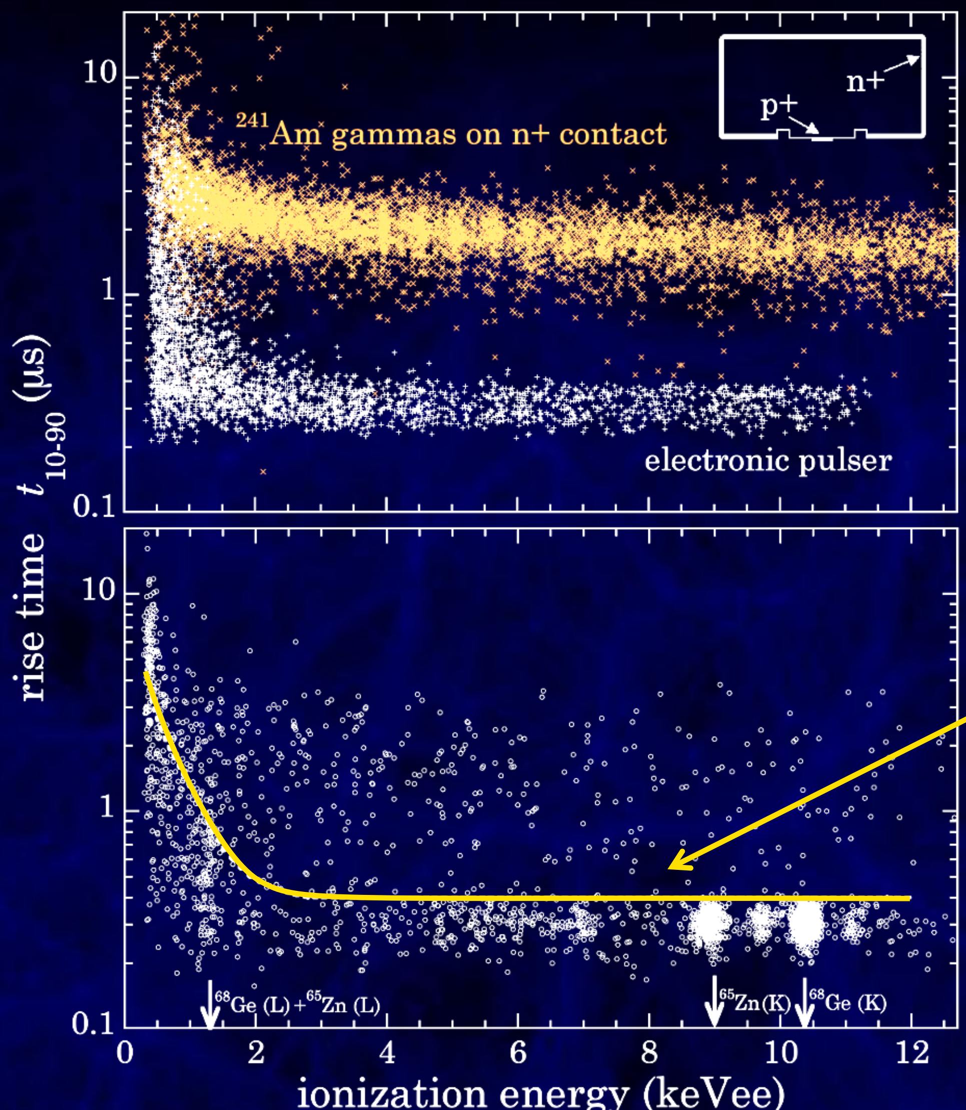


~3σ modulation after 15months.

Background rejection?

expected phase ····· fit

CoGeNT Surface Cut

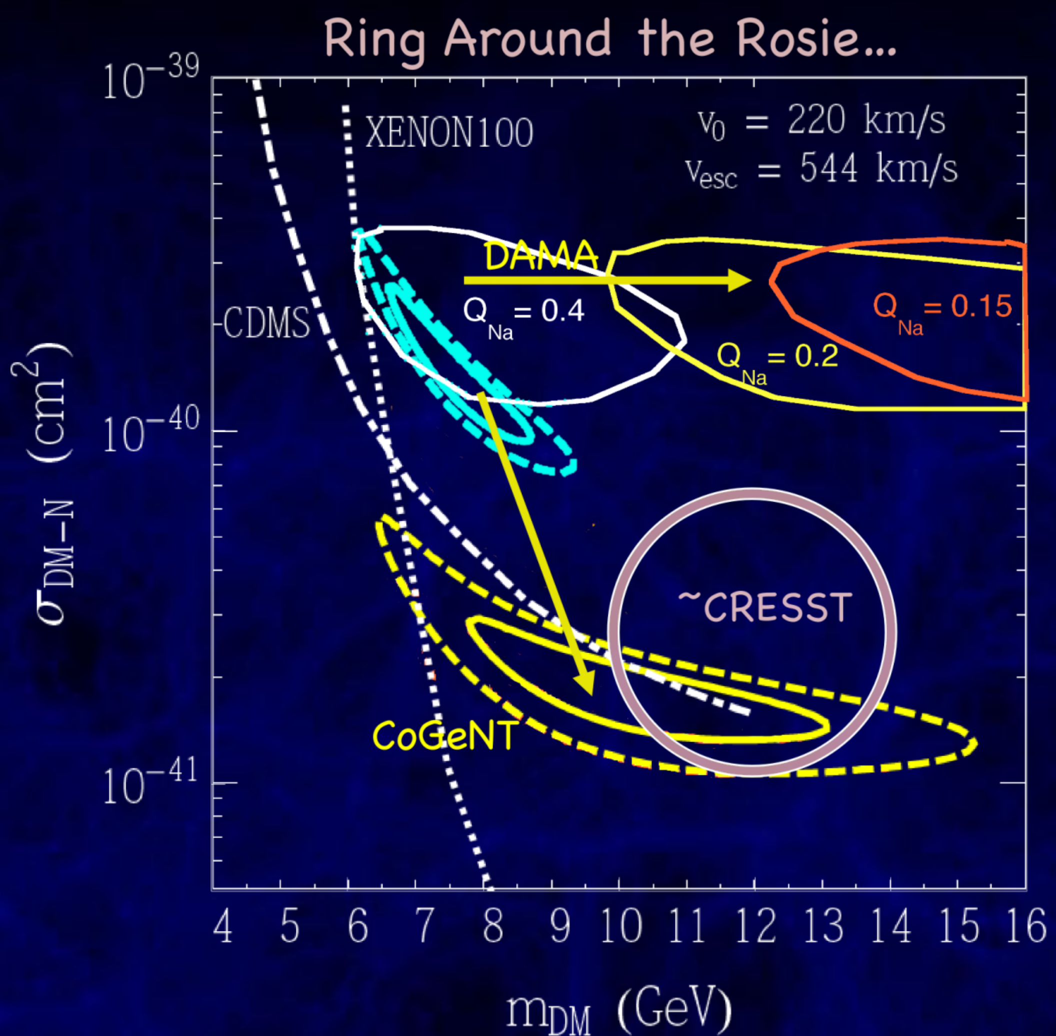


cutting at constant acceptance!

arXiv:1002.4703

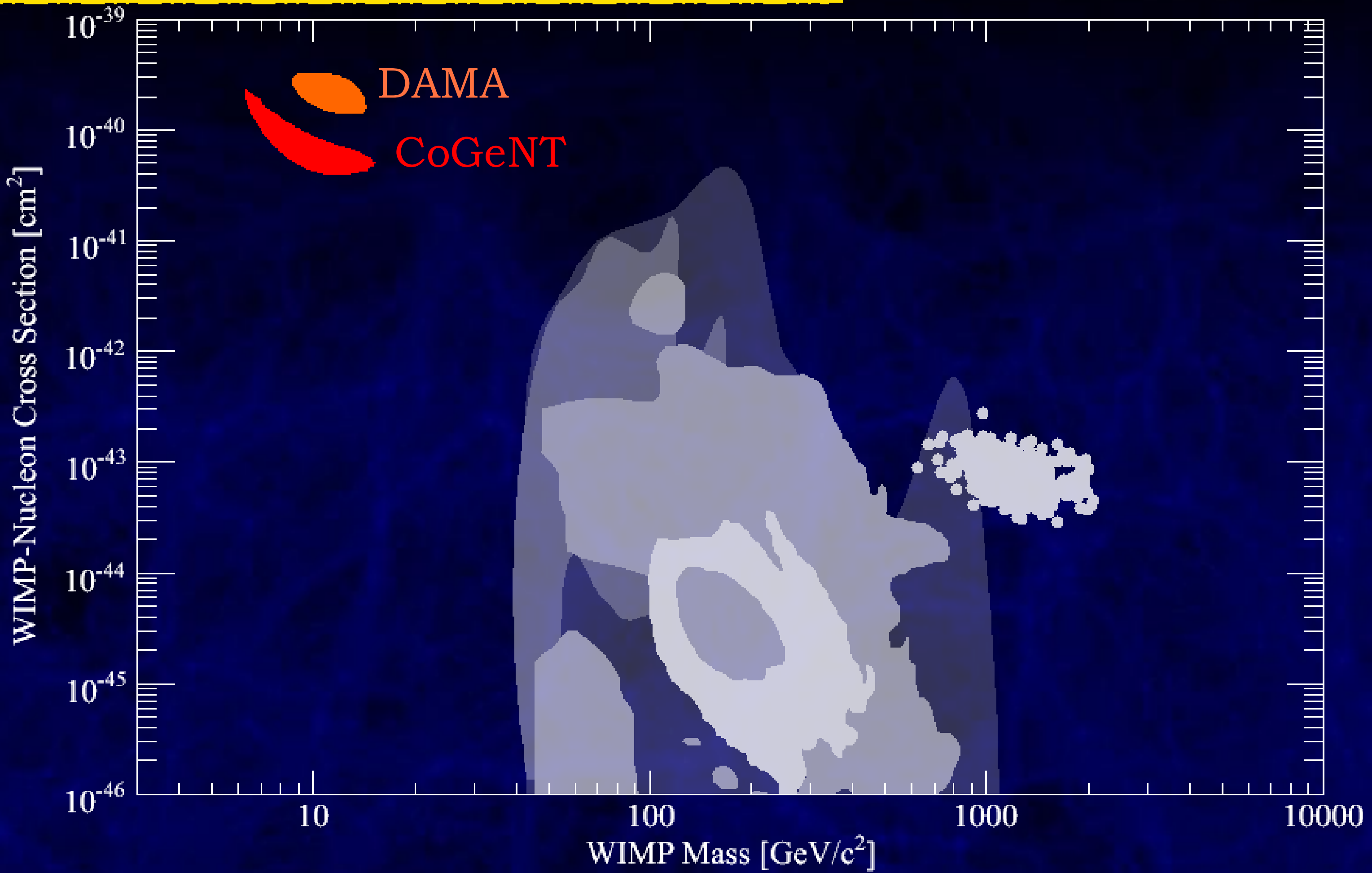
CoGeNT @ TAUP

J. Collar, TAUP 2011



lower limit shifts down by many sigma. Still different from zero?

CoGeNT Interpreted as WIMPs



Schwetz, IDM2010

another allowed region at low masses
and relatively high cross sections

How to Fish for WIMPs

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- CoGeNT: quasi-exponential background, modulation
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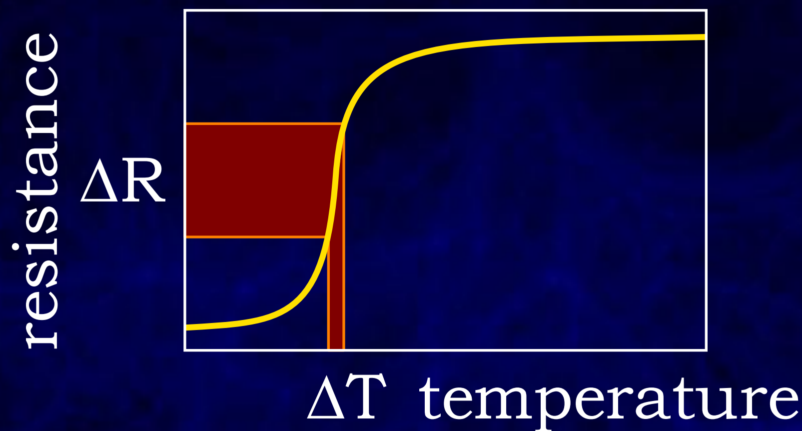
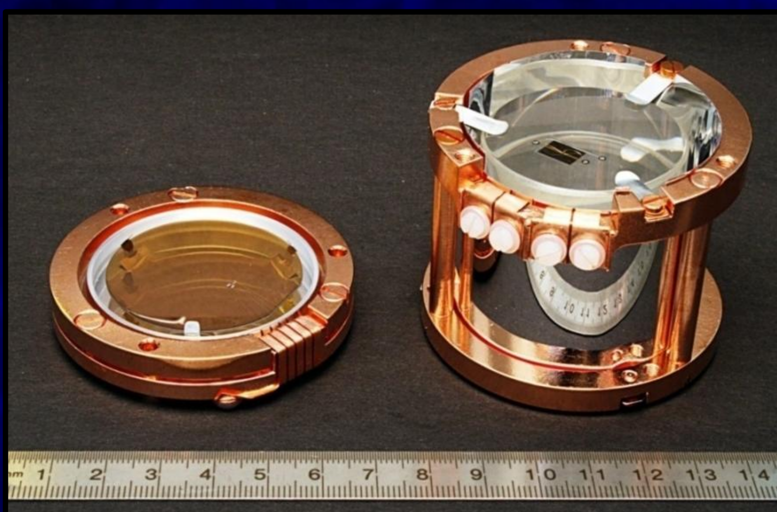
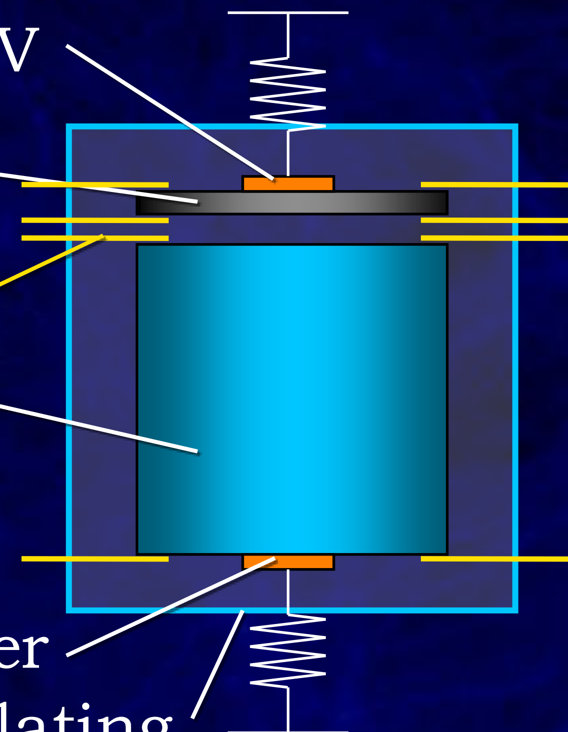
CRESST-II

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

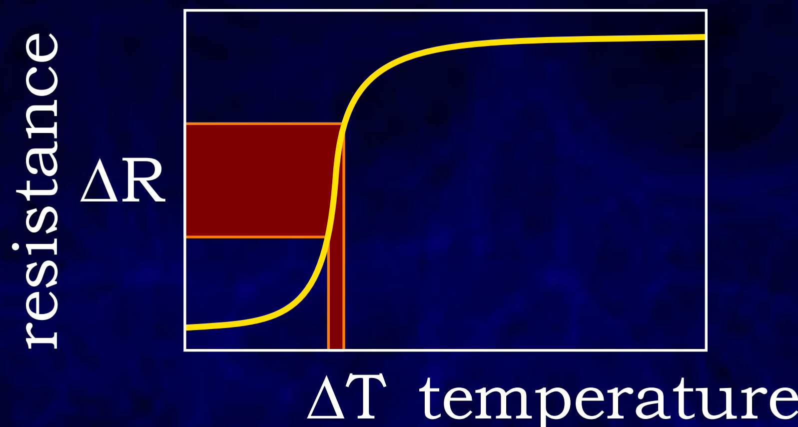


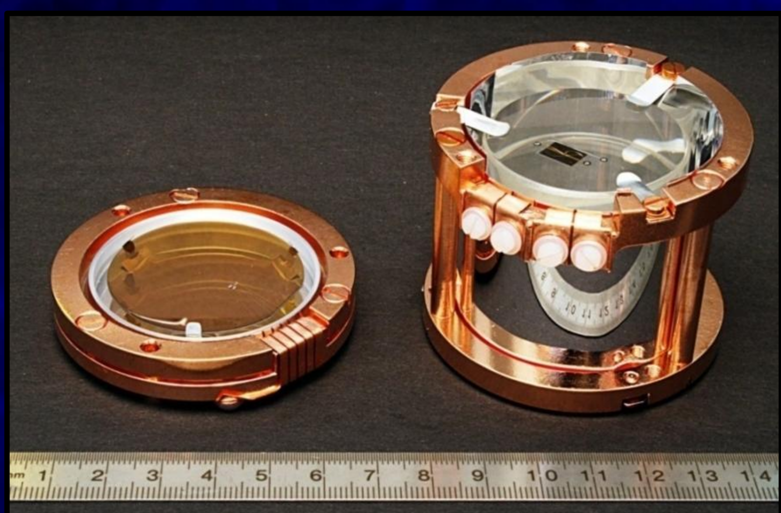


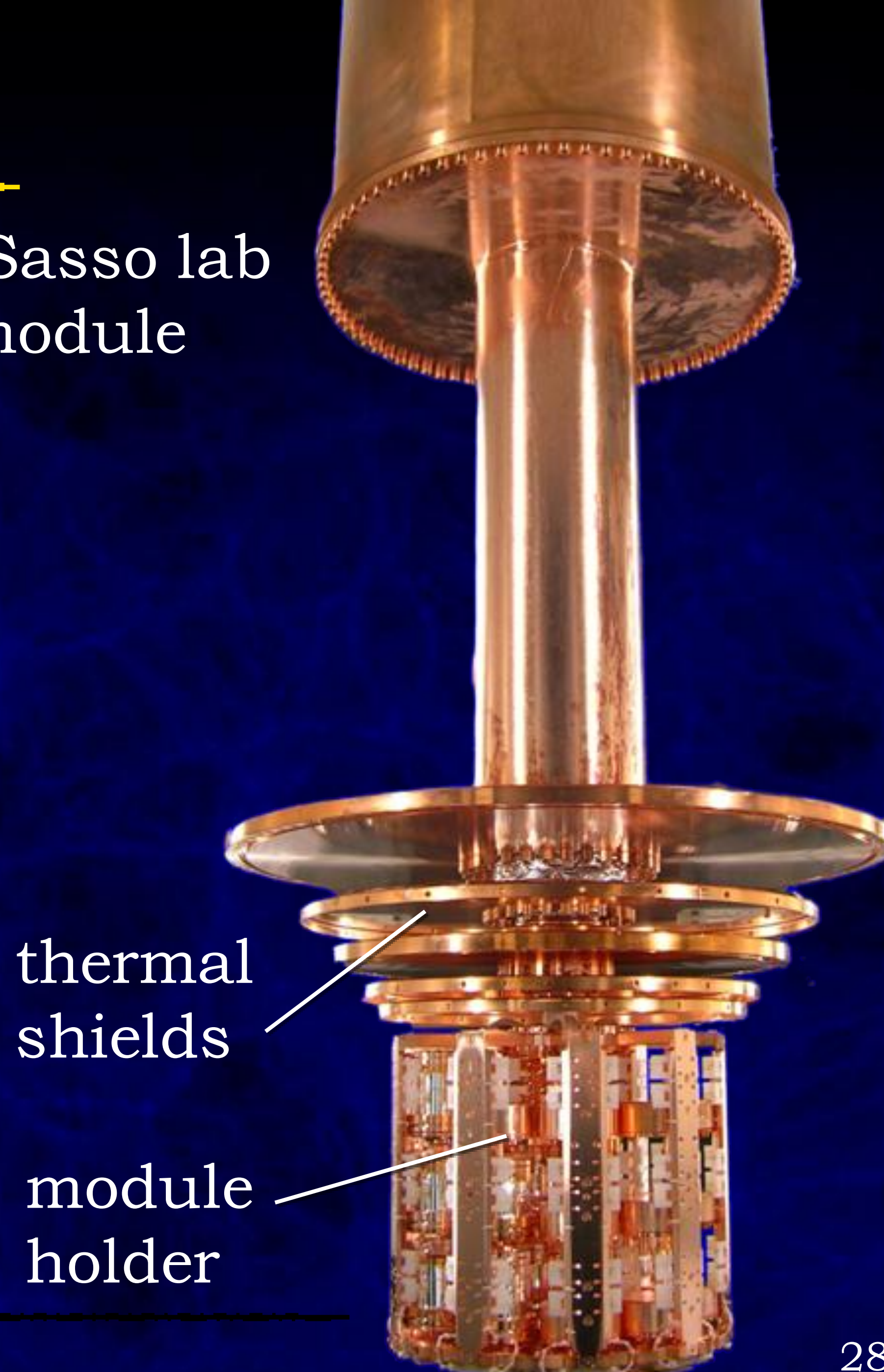


CRESST-II

Germany, Italy; at the Gran Sasso lab
8 scintillating 300g $CaWO_4$ module

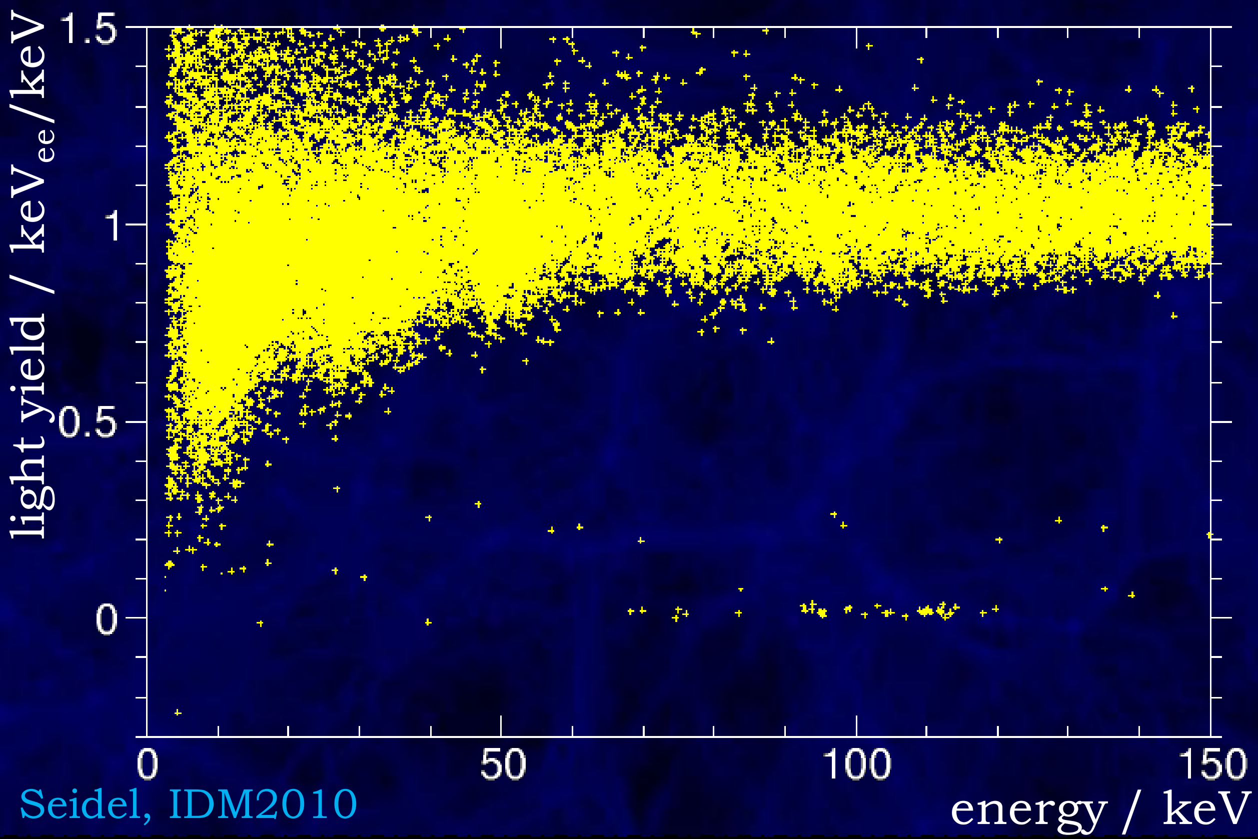






CRESST Data Example

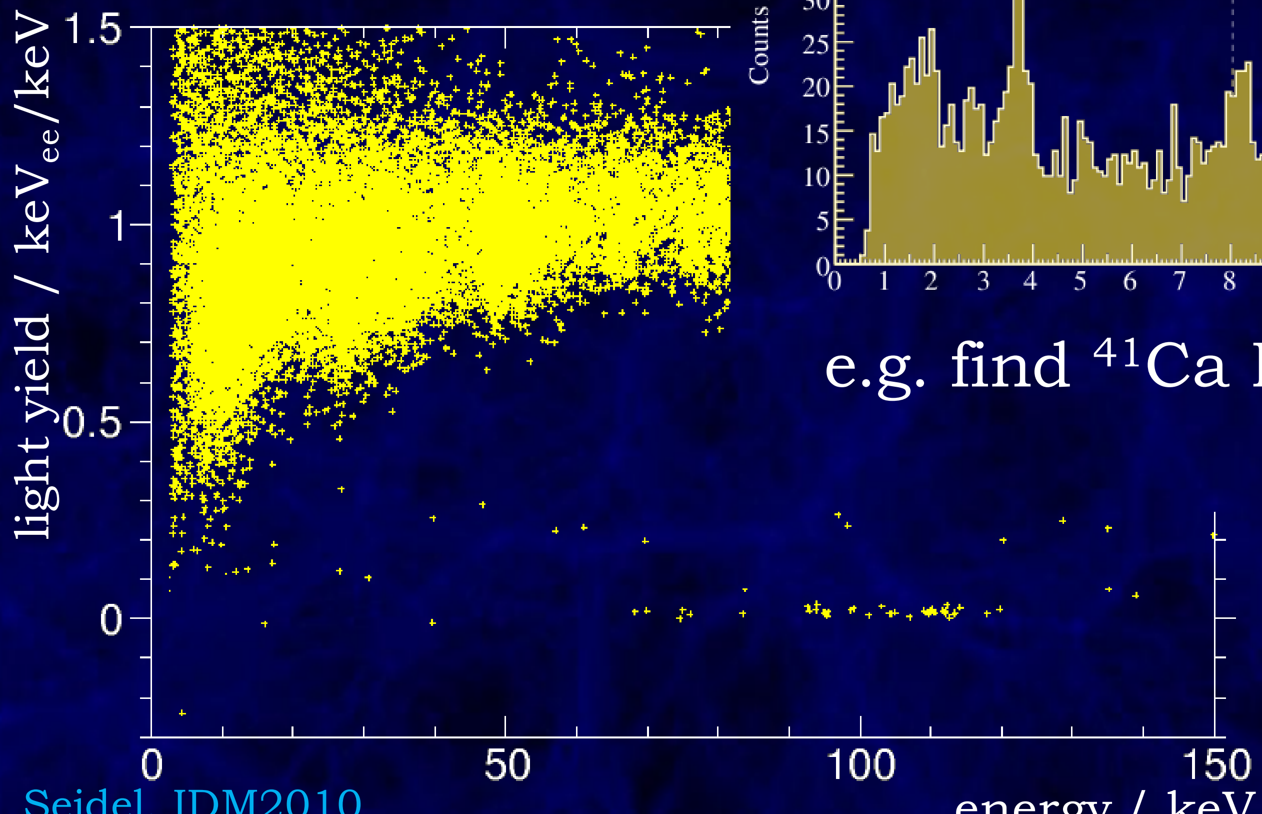
here: channels 5&6 from current data taking



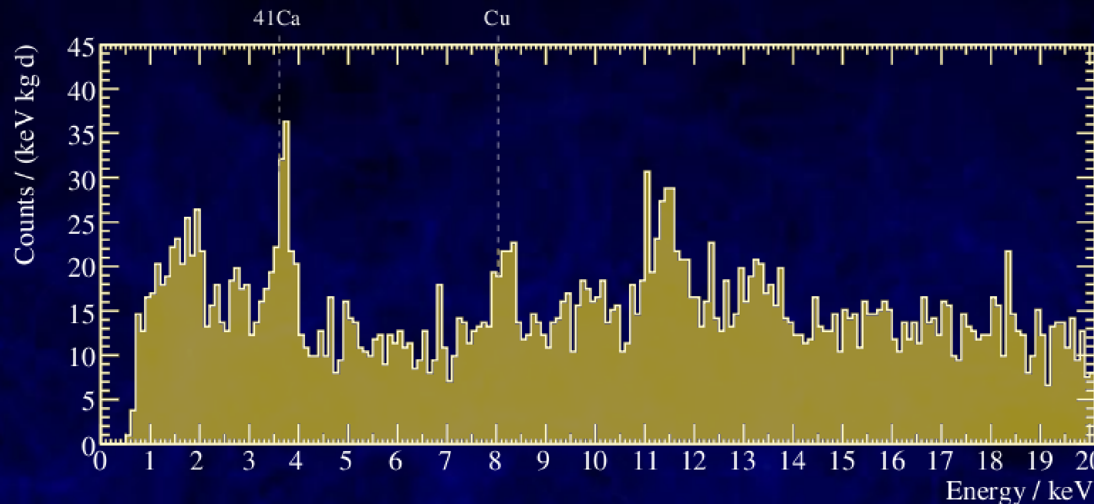
Seidel, IDM2010

CRESST Background

precise calorimetric measurement of electronic recoils



Seidel, IDM2010

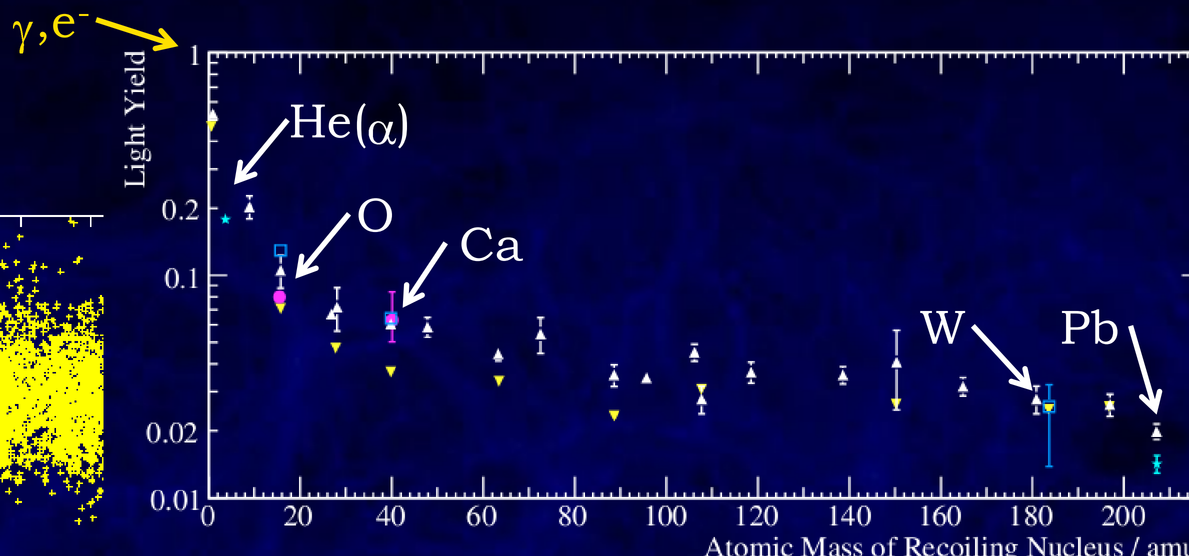


e.g. find ^{41}Ca K_α at 3.6keV

Astropart. Phys. 32 318 (2010)

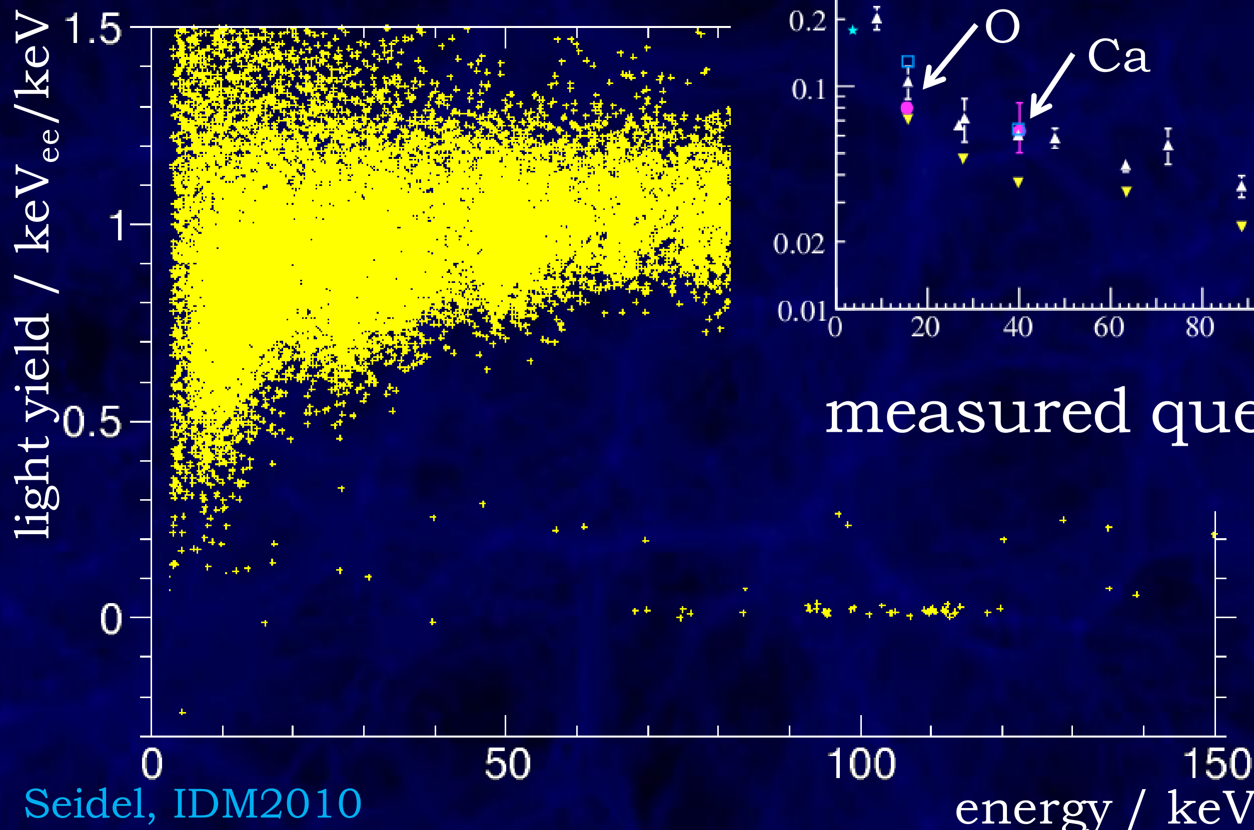
CRESST Discrimination

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



measured quenching factors

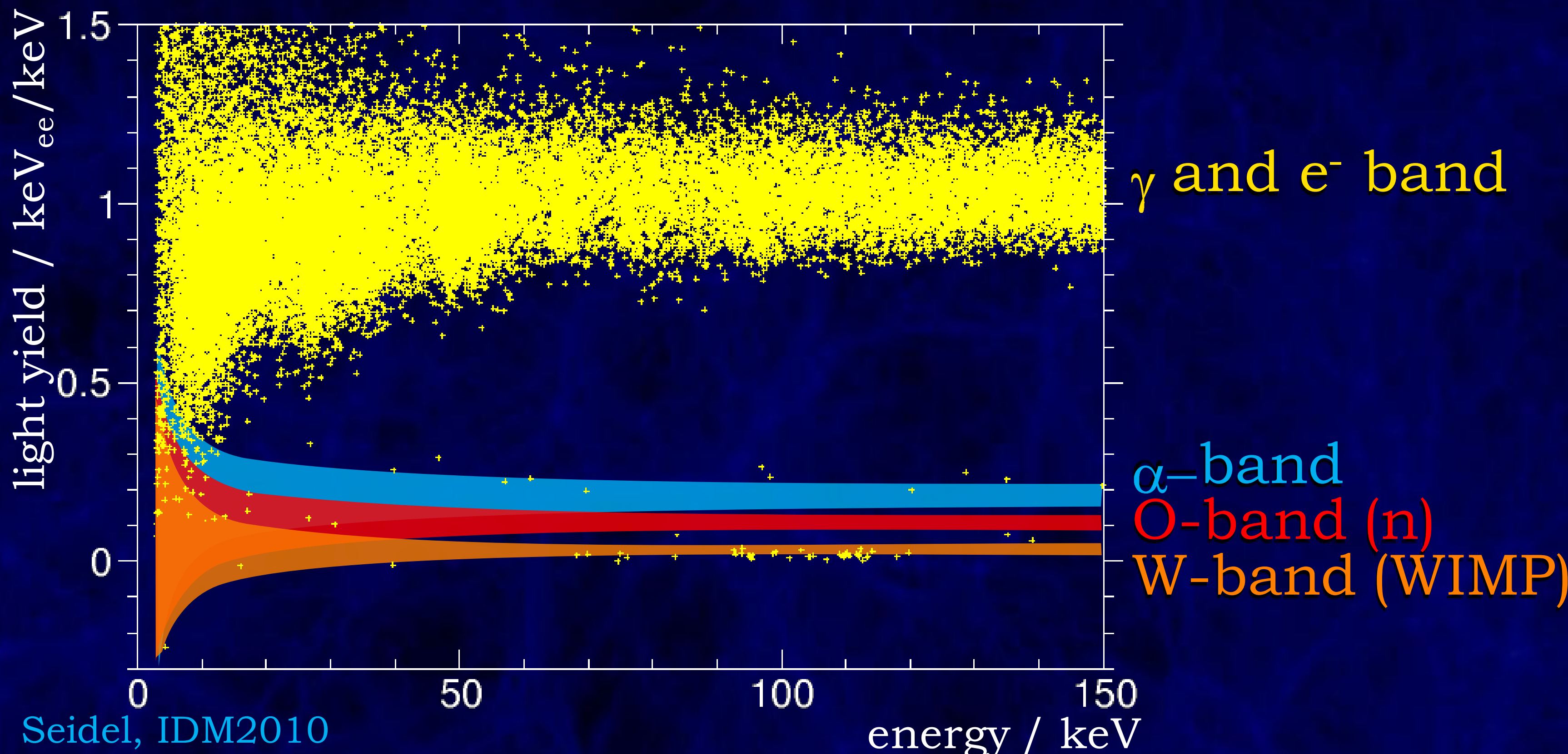
New J. Phys. 11 (2010) 105017



Seidel, IDM2010

CRESST Data Example

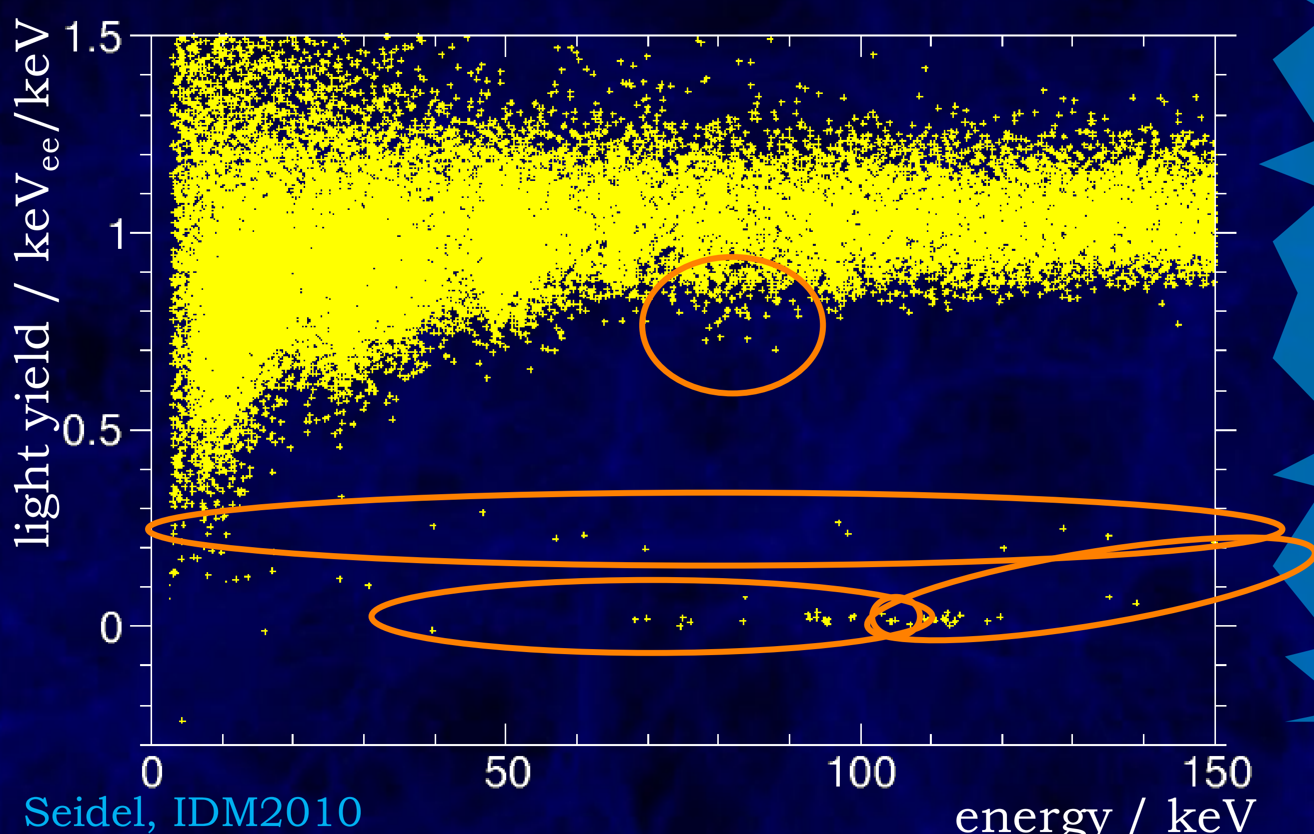
what are all these events below the electronic recoil band?
Target is $CaWO_4$!



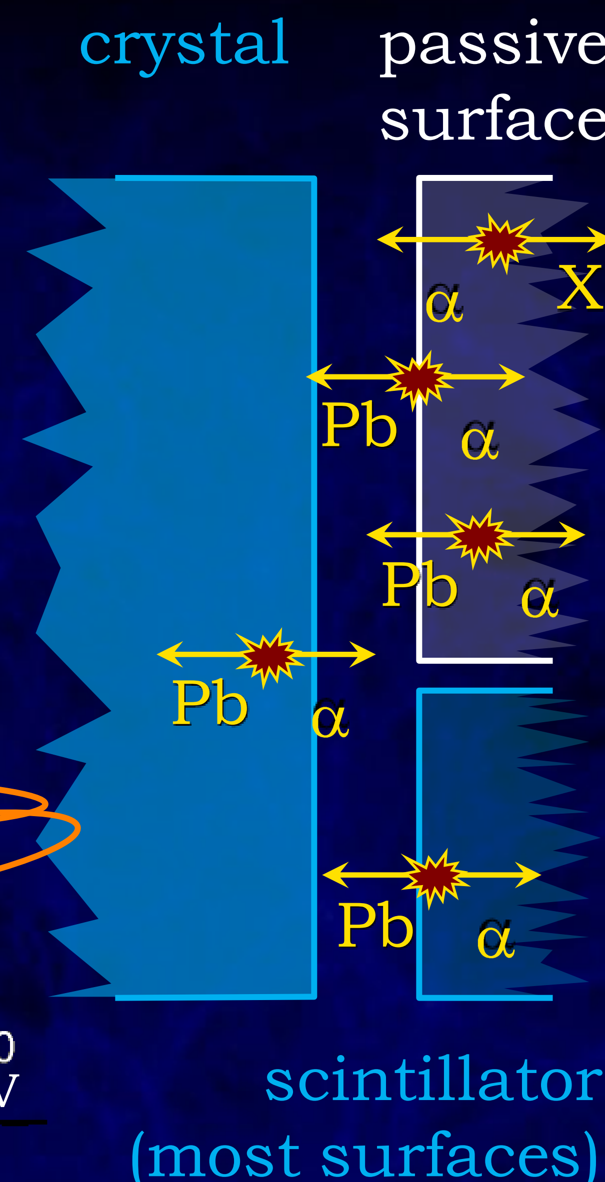
Seidel, IDM2010

CRESST Background

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



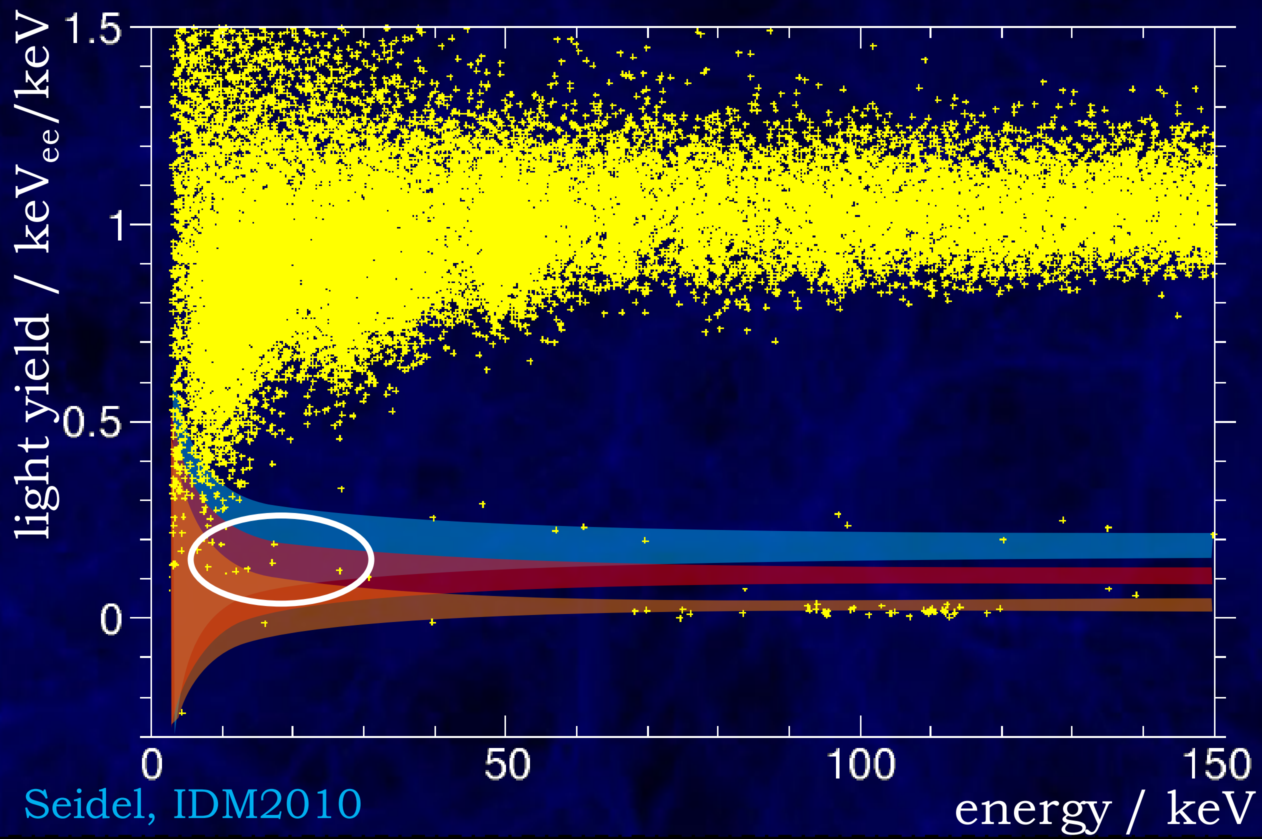
Seidel, IDM2010



CRESST Combined Results

few events in W band, but 67 events in O band

take all 8 detectors together and estimate events from known backgrounds that could leak into signal region:

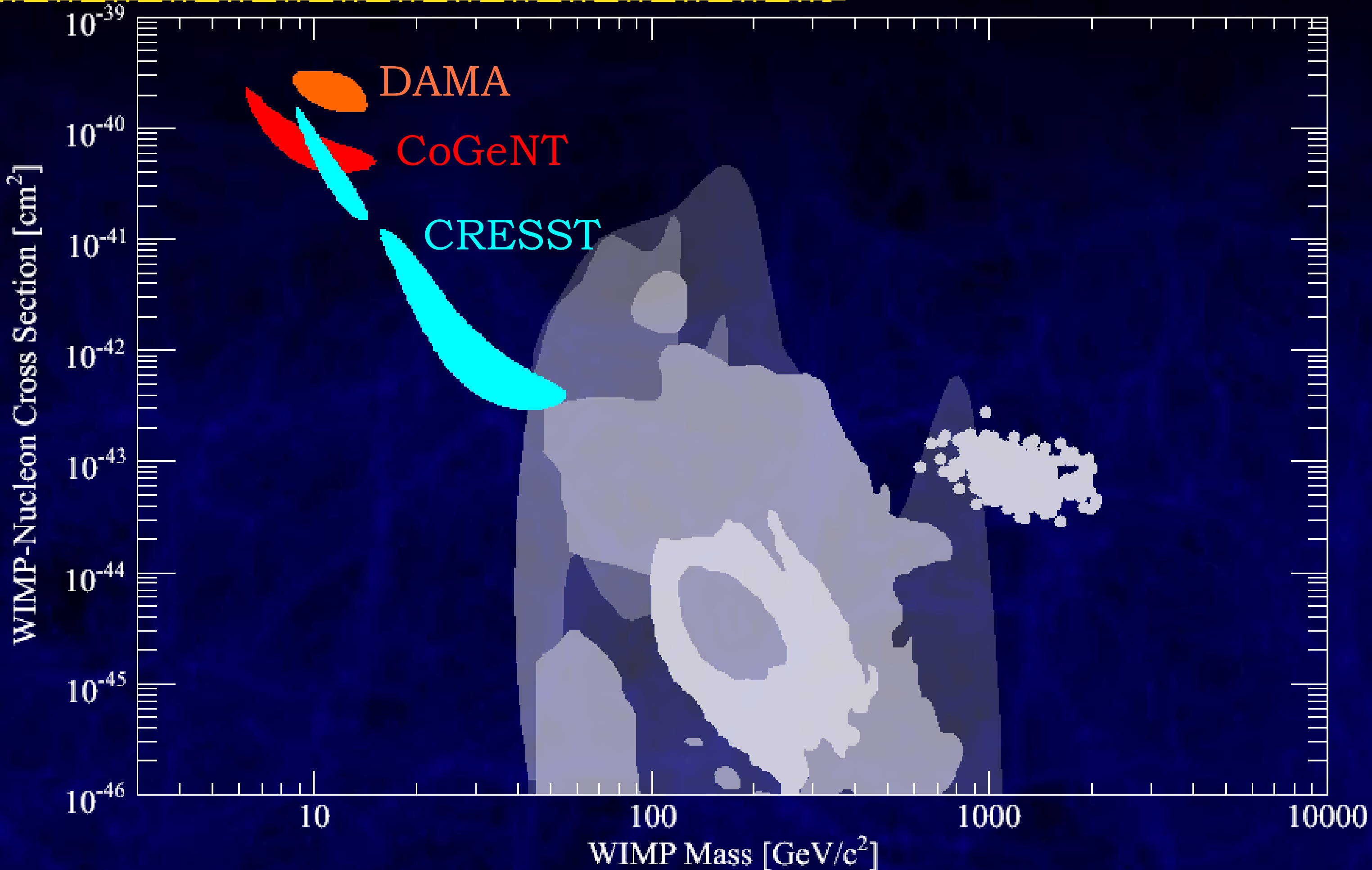


neutrons:	~ 8
alphas:	~12
leaking e^-/γ:	~ 8
^{210}Pb:	~15
sum:	~43
→ WIMPs:	~25?

Seidel, IDM2010

arXiv:1109.0702

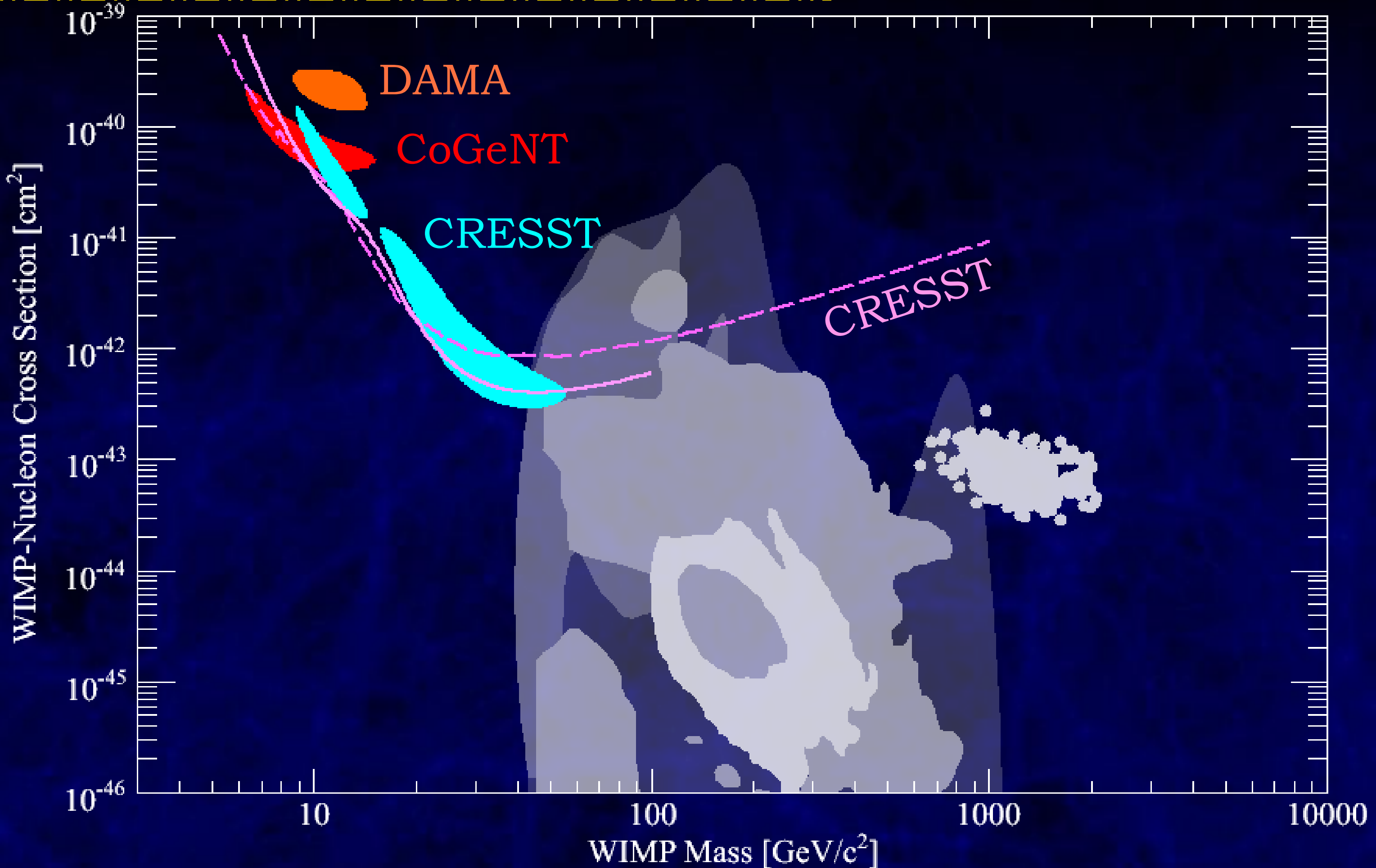
CRESST Oxygen Events as WIMPs



yet another region…

arXiv:1109.0702

CRESST Limits from Others



arXiv:1109.2589

arXiv:0911.0929

yet another region…
mostly excluded by its own, previous data set

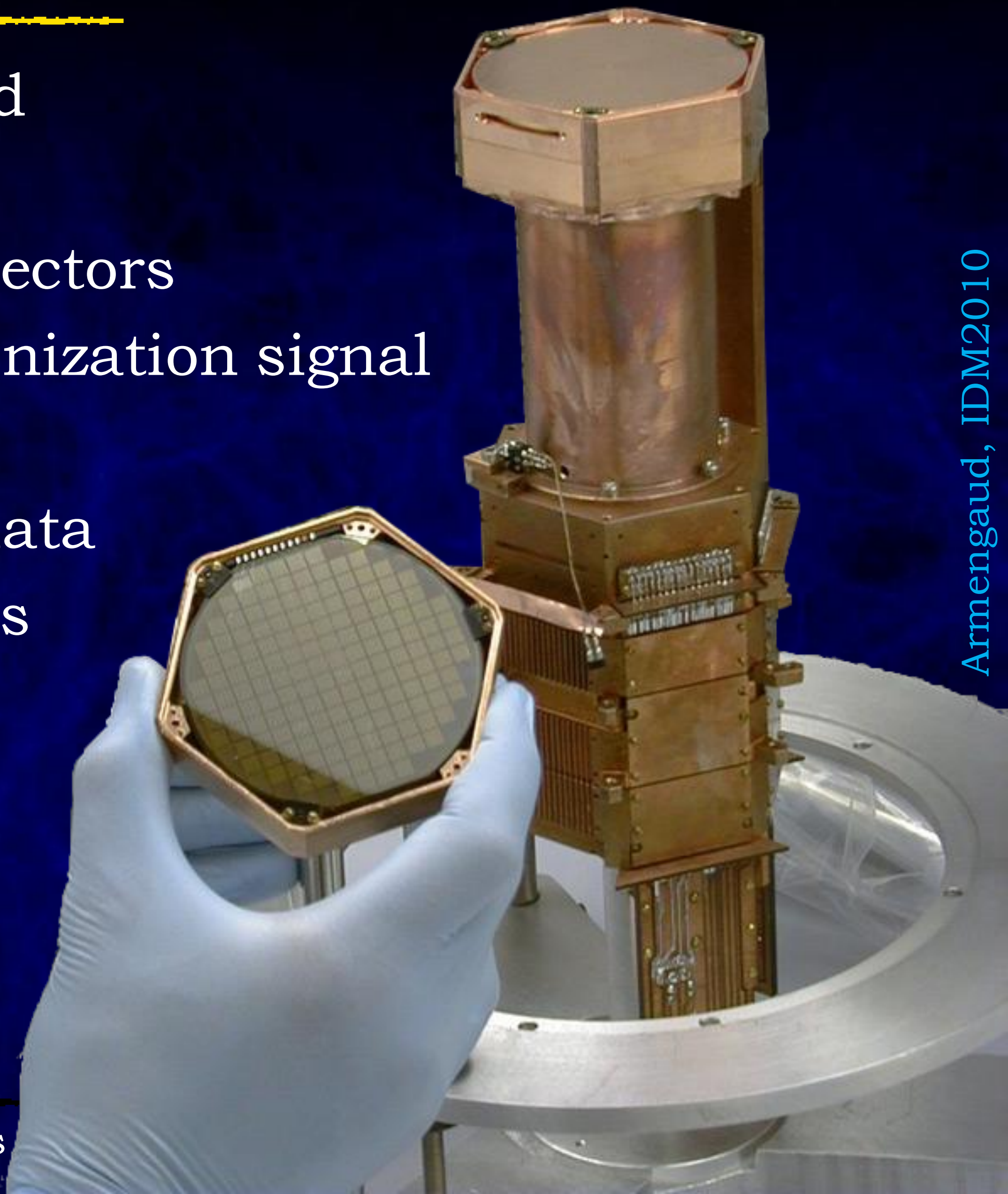
How to Fish for WIMPs

- expected recoil spectrum: falling exponential
- discrimination techniques: help increase sig/bck
- DAMA/LIBRA: claims discovery
- CoGeNT: quasi-exponential background, modulation
- CRESST-II: lots of events
- CDMS-II
- EDELWEISS
- XENON100

CDMS-II

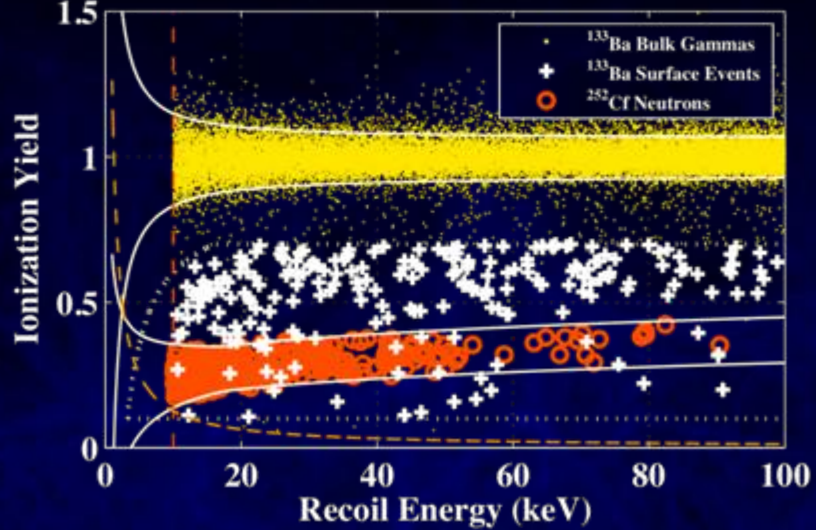
USA/Canada/Switzerland
located at Soudan
19 Ge and 11 Si "ZIP" detectors
with phonon (TES) and ionization signal
data-taking finished
final analysis of 2 years data
from 14 250g Ge detectors

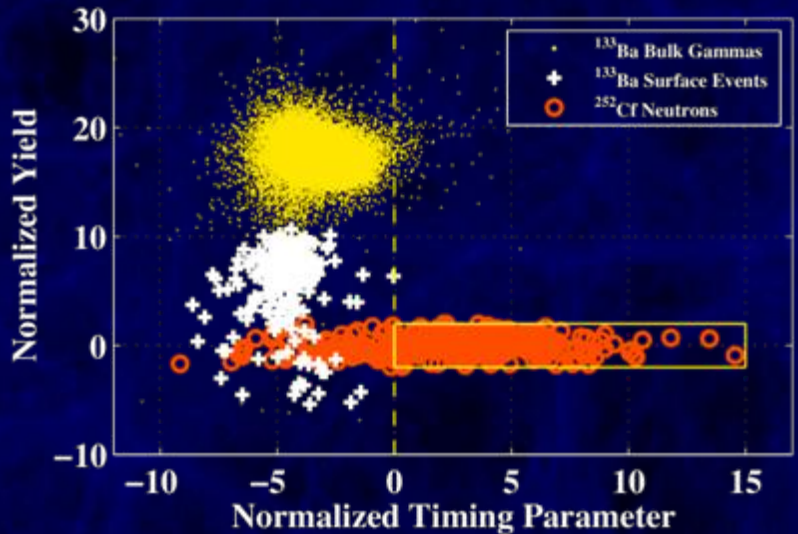
next step: SuperCDMS
with bigger and
interleaved detectors



Armengaud, IDM2010

CDMS-II Results





calibration data:

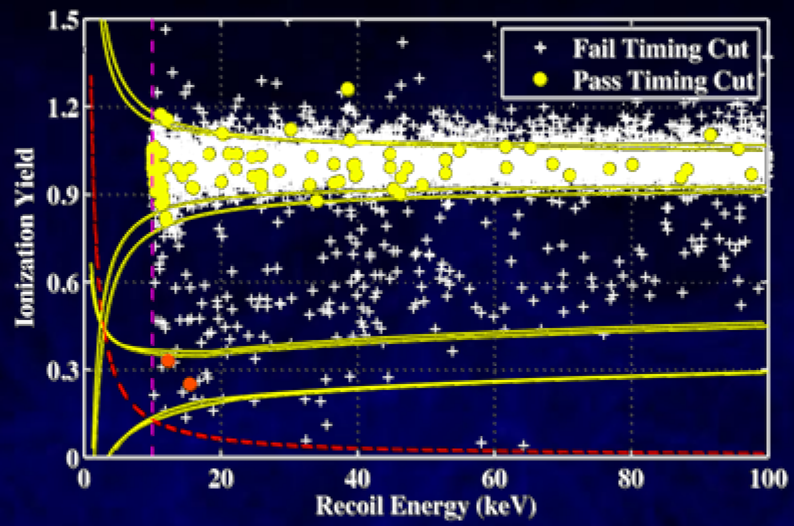
bulk electronic recoils

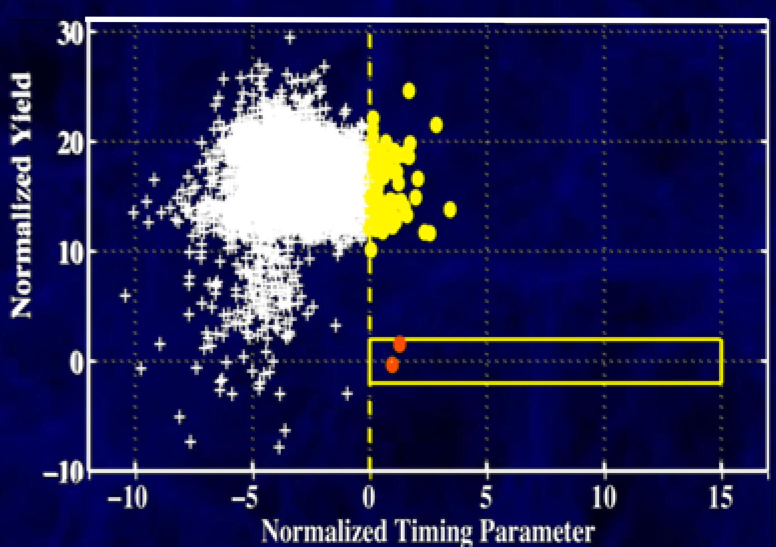
surface events

bulk nuclear recoils

arXiv:0912.3592

CDMS-II Results





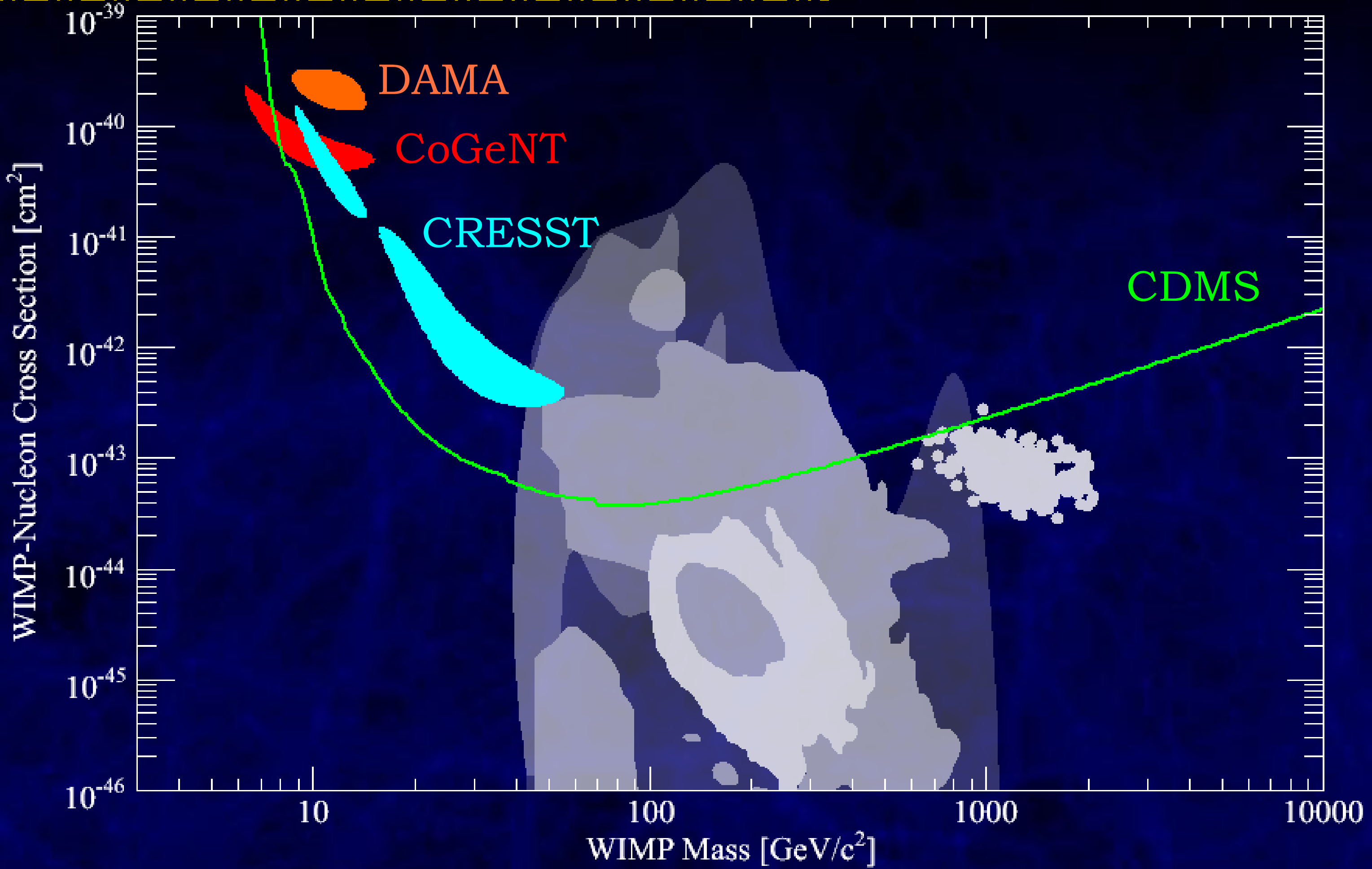
Ge dark matter search data
two detectors with signal
candidate events combined:

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

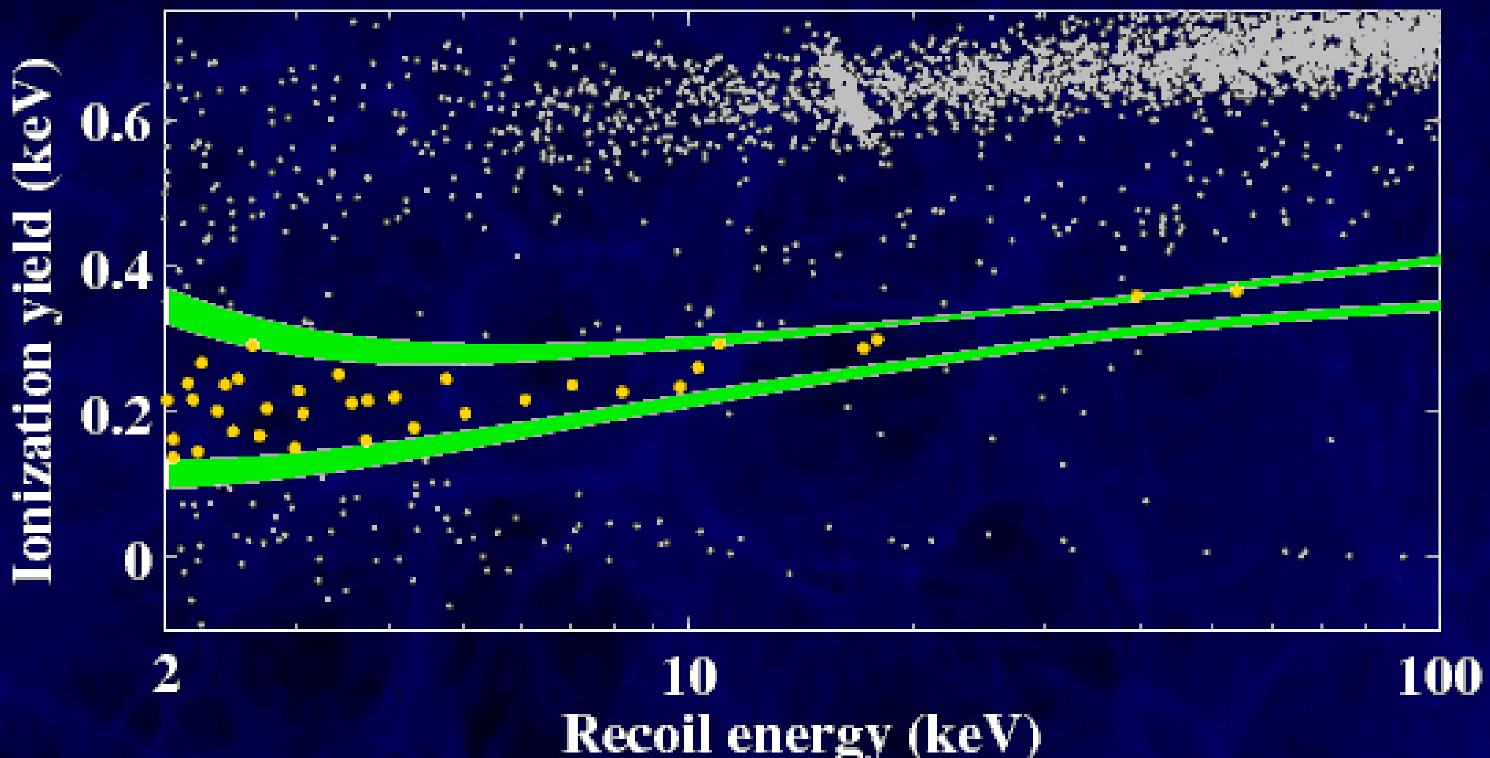


Science **327** 1619 (2010), arXiv:0912.3592

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

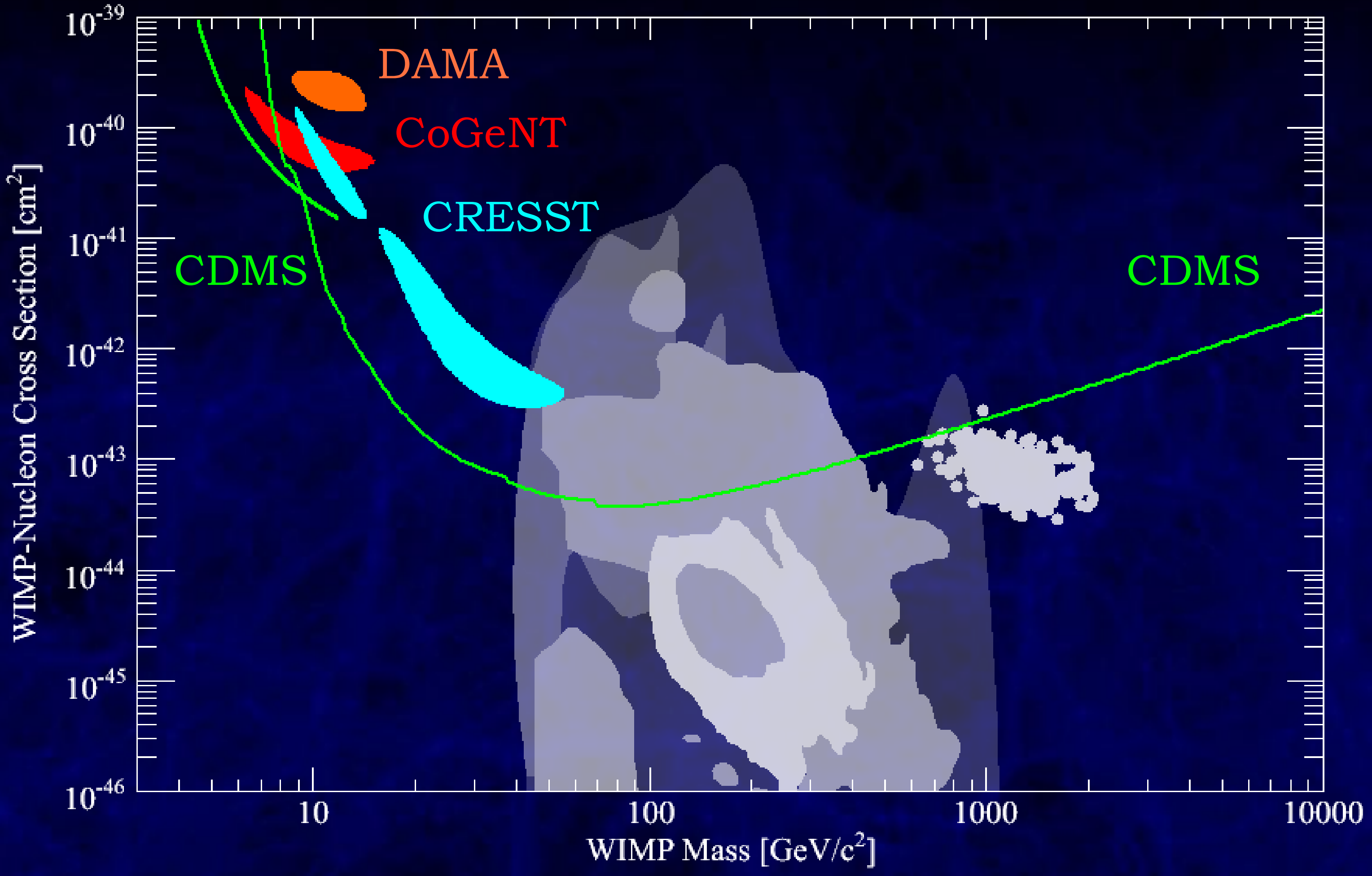
CDMS-II Low Threshold Results

dedicated analysis with threshold lowered to 2keV
to test CoGeNT (also Ge!) indication
at the expense of additional background
data from one (of 8) detectors:



arXiv:1011.2482

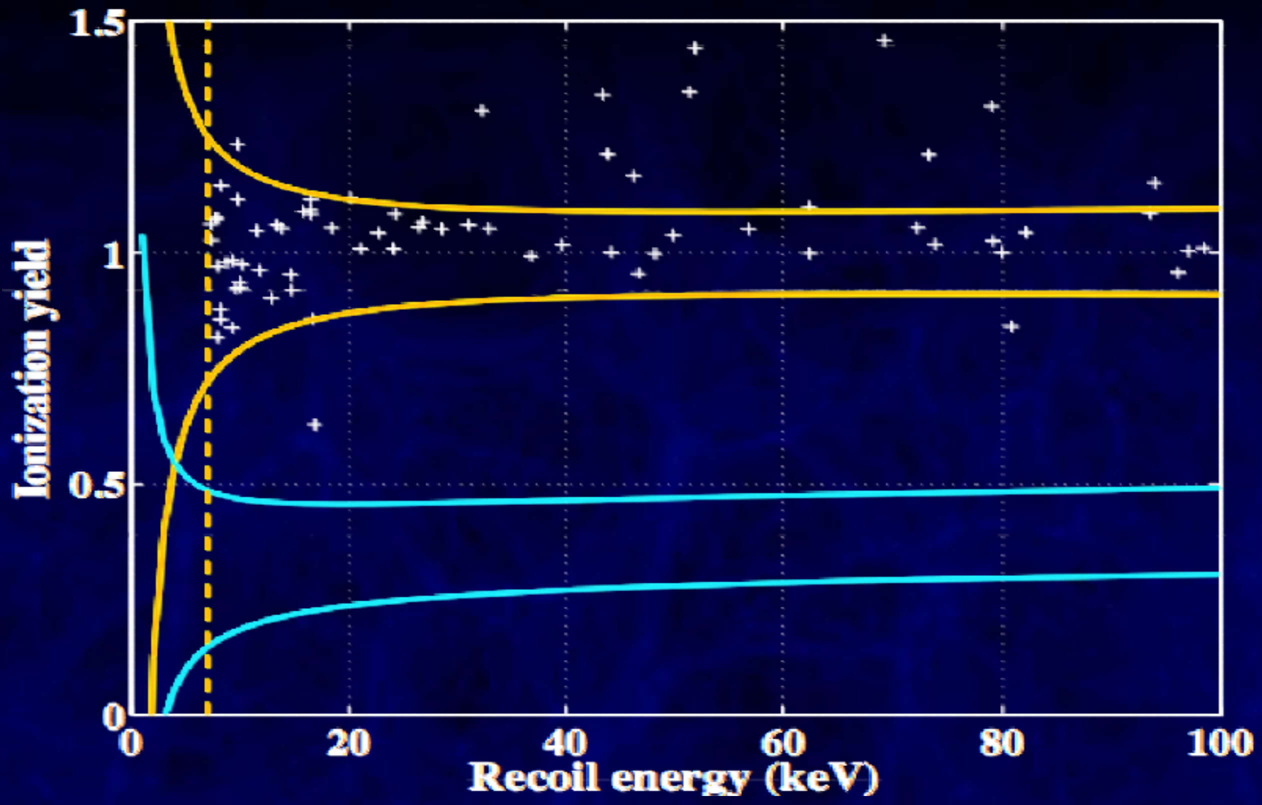
CDMS Low Threshold Limit



arXiv:1011.2482

constrains CoGeNT interpretation

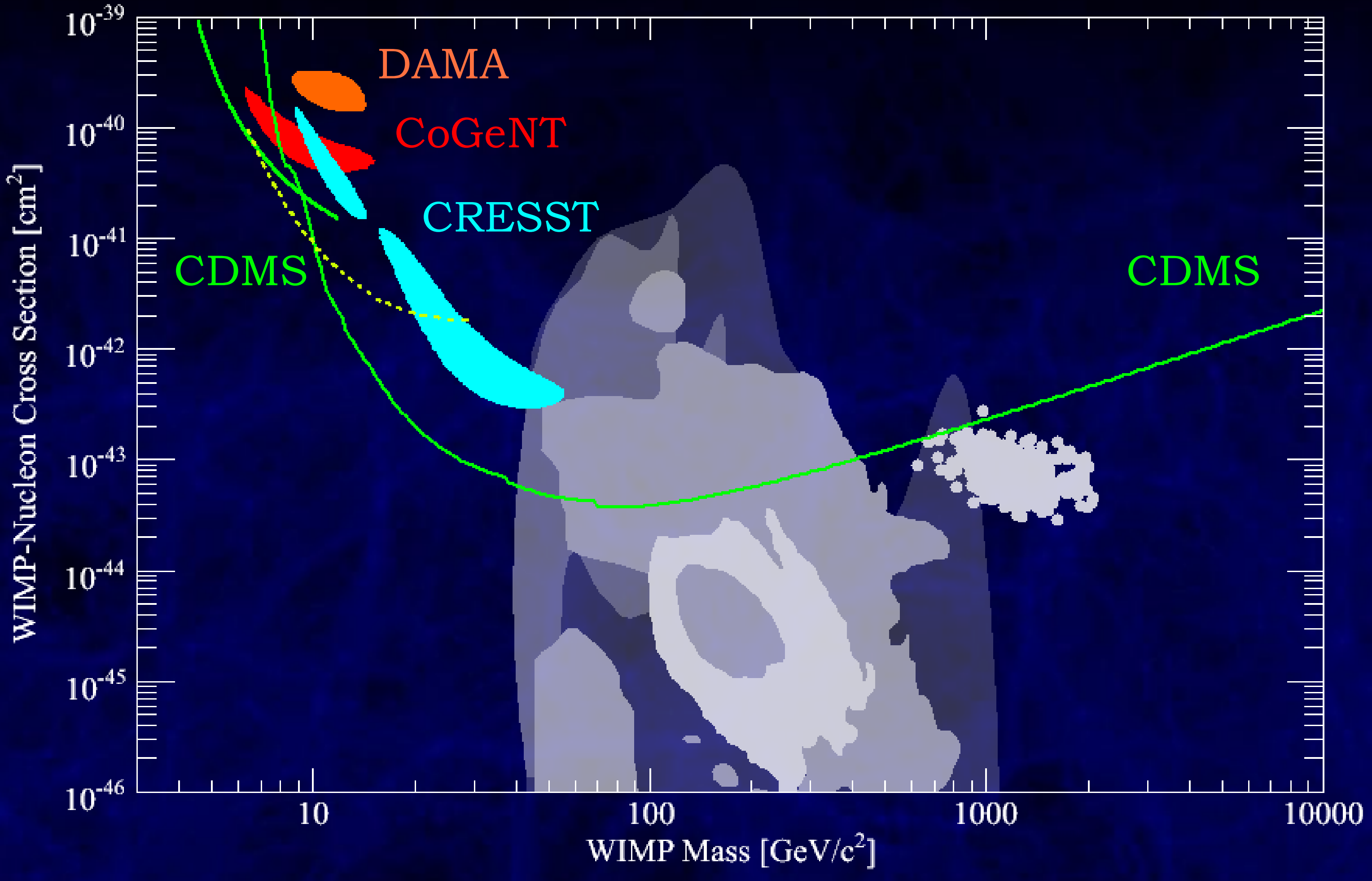
CDMS-II Silicon Results



Filippini, LaThuile 2009 and Nuovo Cimento C 32 45

there is also a talk and conference proceeding with an analysis of 6 Si detectors:
no events observed in 54kg d

CDMS Silicon Limit



Filippini, LaThuile 2009 and Nuovo Cimento C 32 45

severely constrains CoGeNT WIMP interpretation

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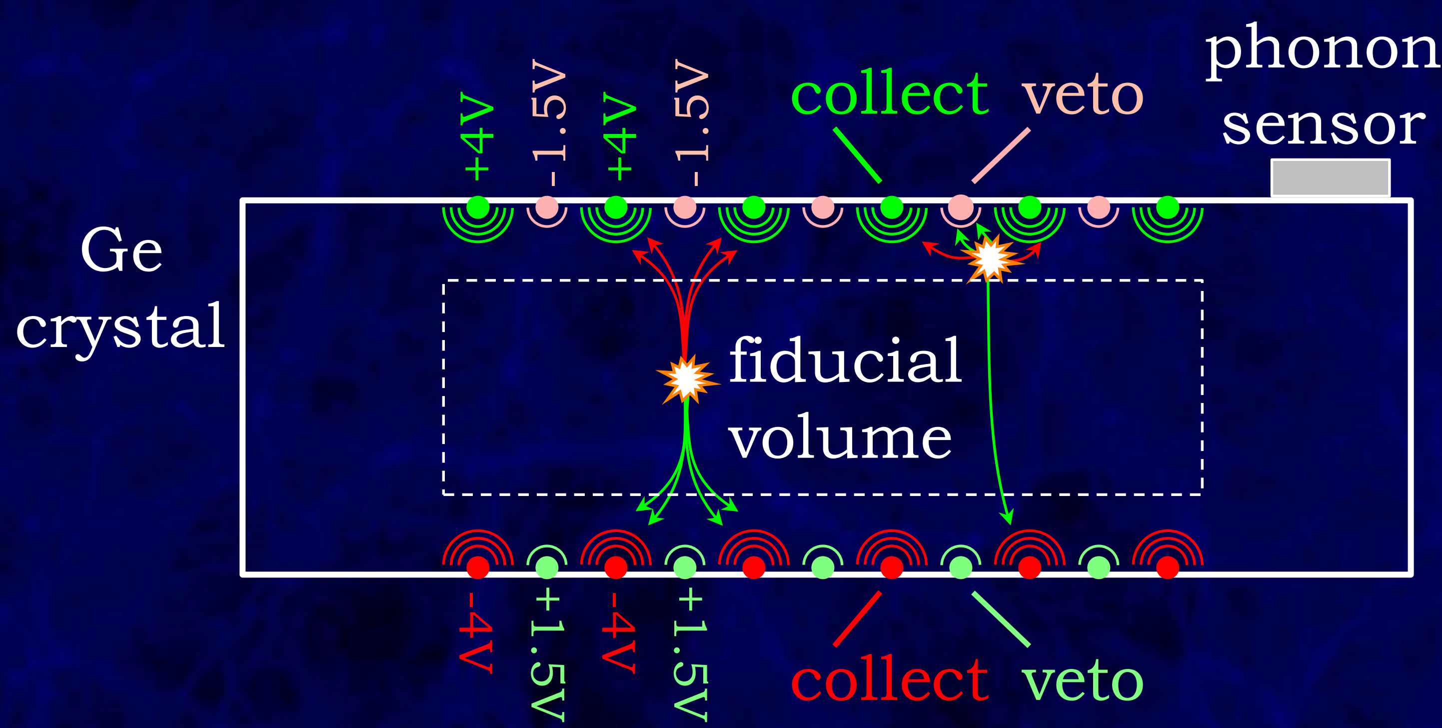
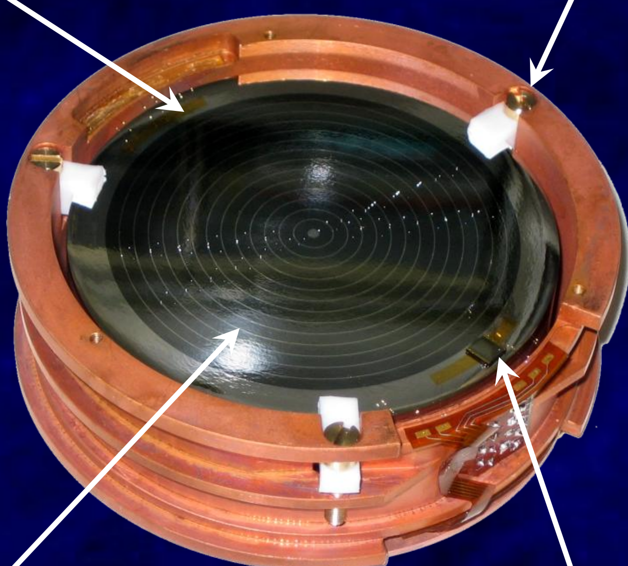
EDELWEISS-II

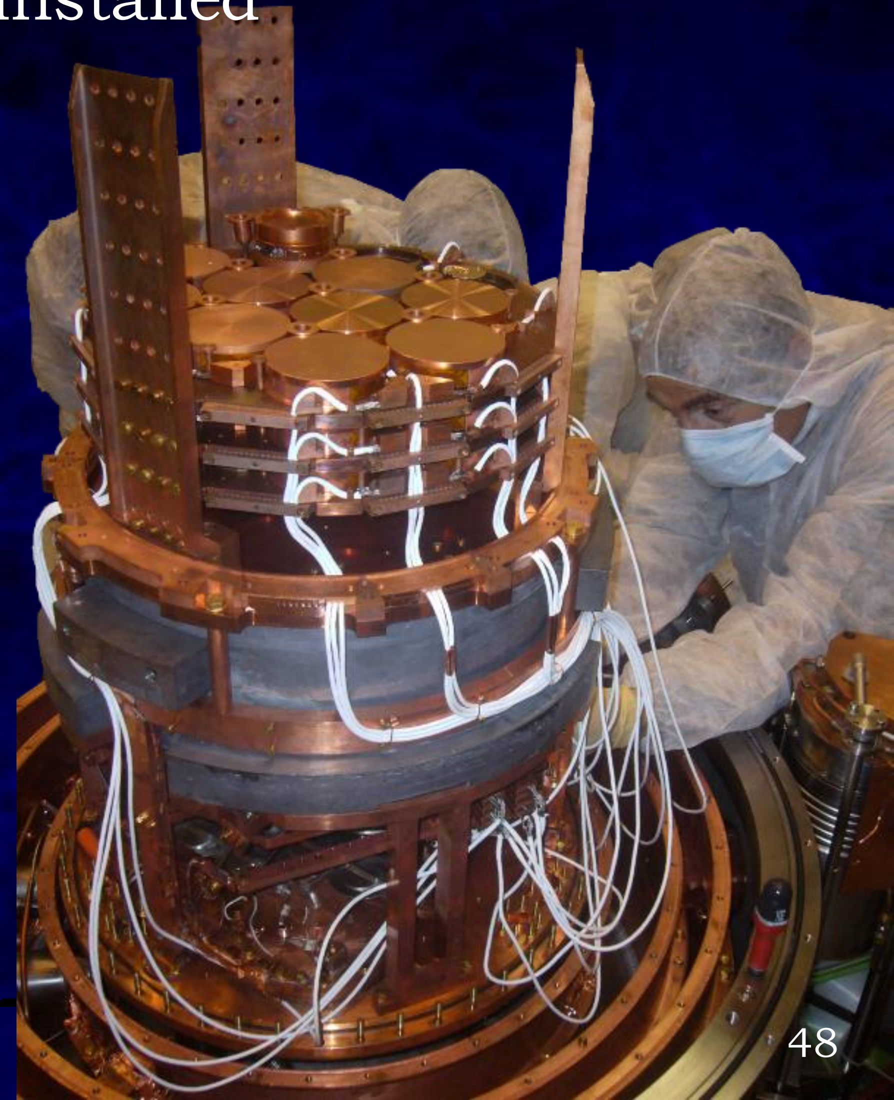
France, Germany, Russia, UK in the Frejus Lab
germanium crystals with phonon/ionization readout
NTD phonon sensors
interleaved electrodes (ionization)



EDELWEISS-II

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

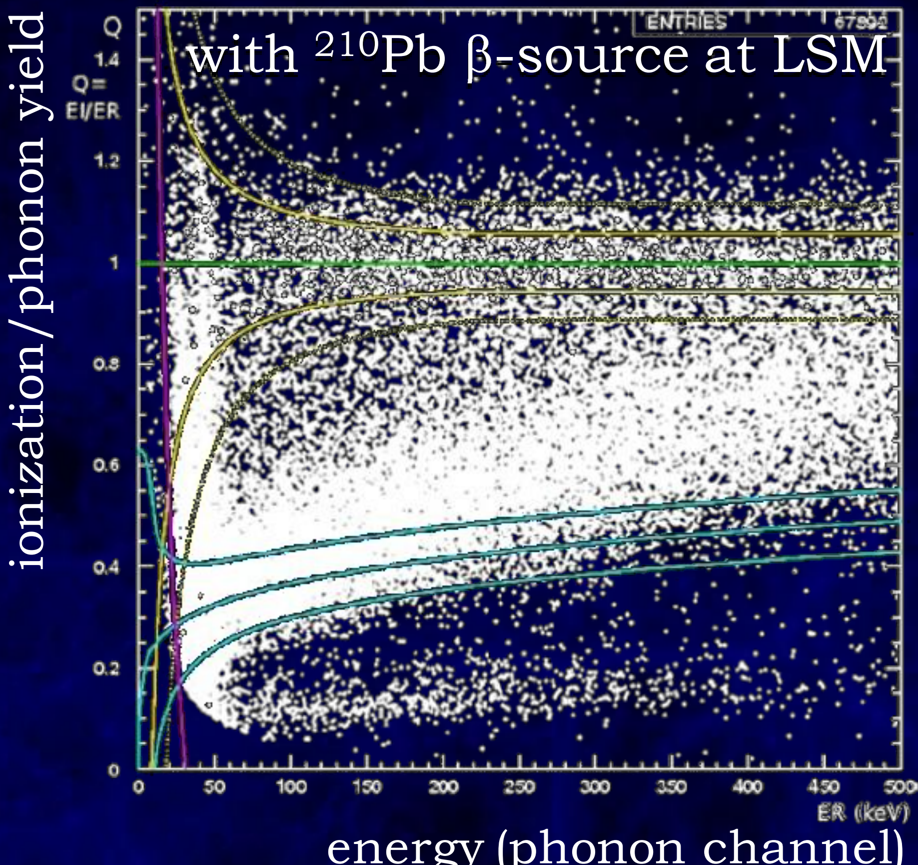




edelweiss.in2p3.fr

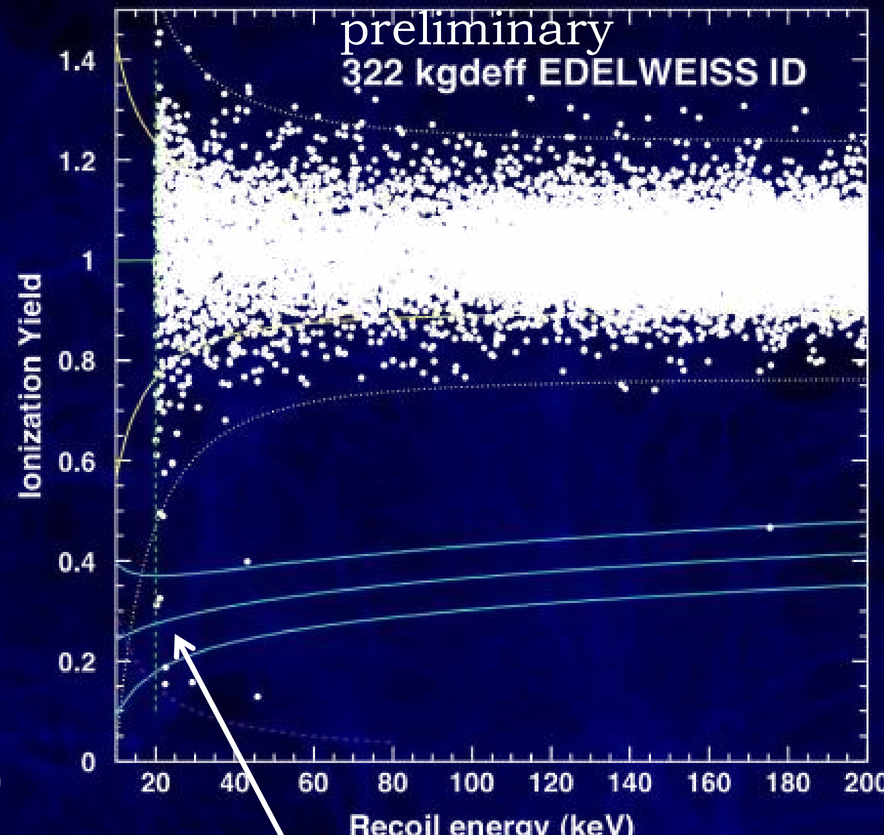
EDELWEISS-II Data

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



before after fiducialization

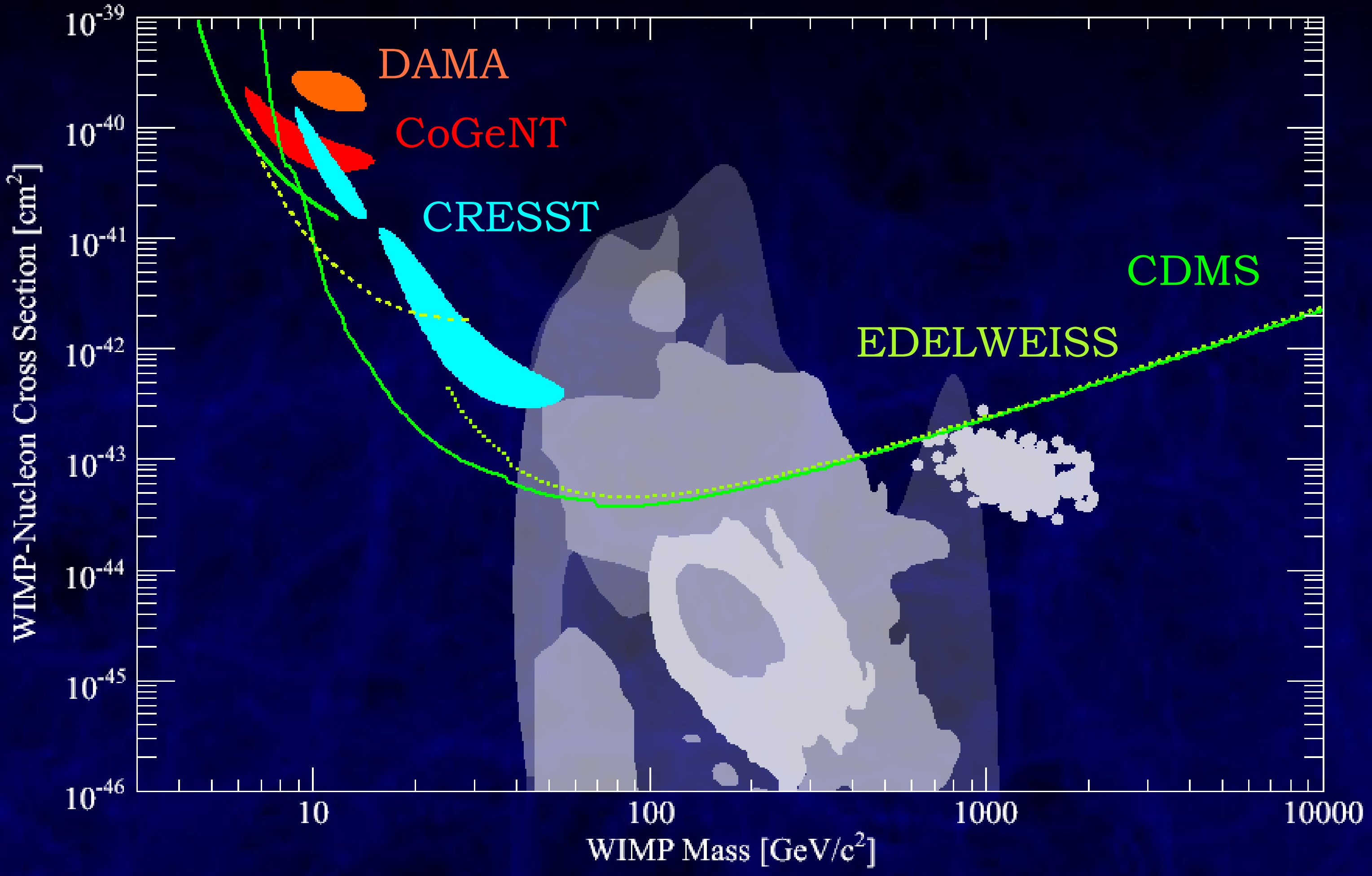
Kraus, IDM2010



3 events near threshold

Armengaud, IDM2010

CDMS Silicon Limit



Armengaud IDM2010

interleaved detectors ready for the next step in sensitivity

How to Fish for WIMPs

- expected recoil spectrum: falling exponential
- discrimination techniques: help increase sig/bck
- DAMA/LIBRA: claims discovery
- CoGeNT: quasi-exponential background, modulation
- CRESST-II: lots of events
- CDMS-II: excludes them all
- EDELWEISS: interleaved detectors work
- XENON100

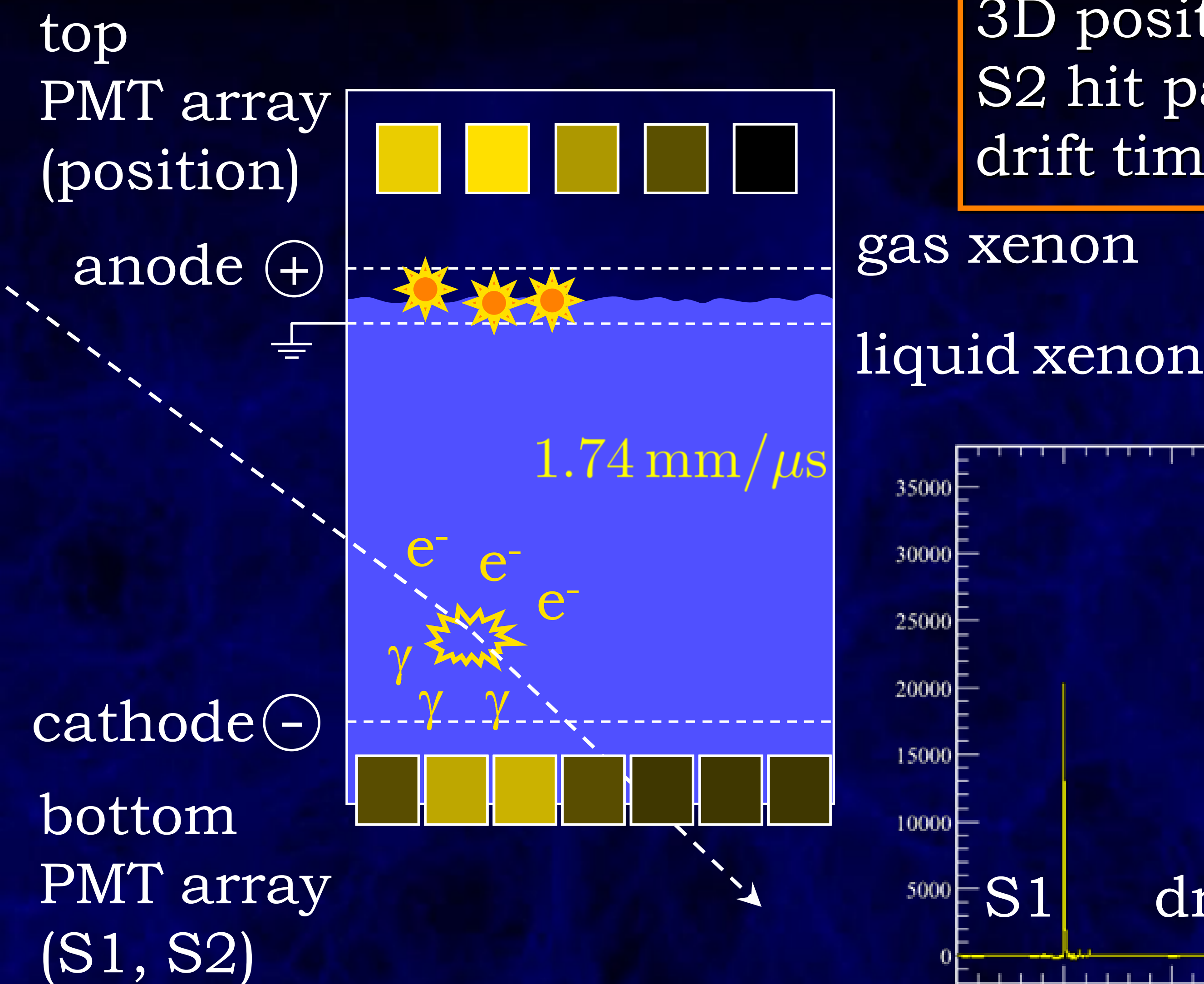
The XENON Collaboration

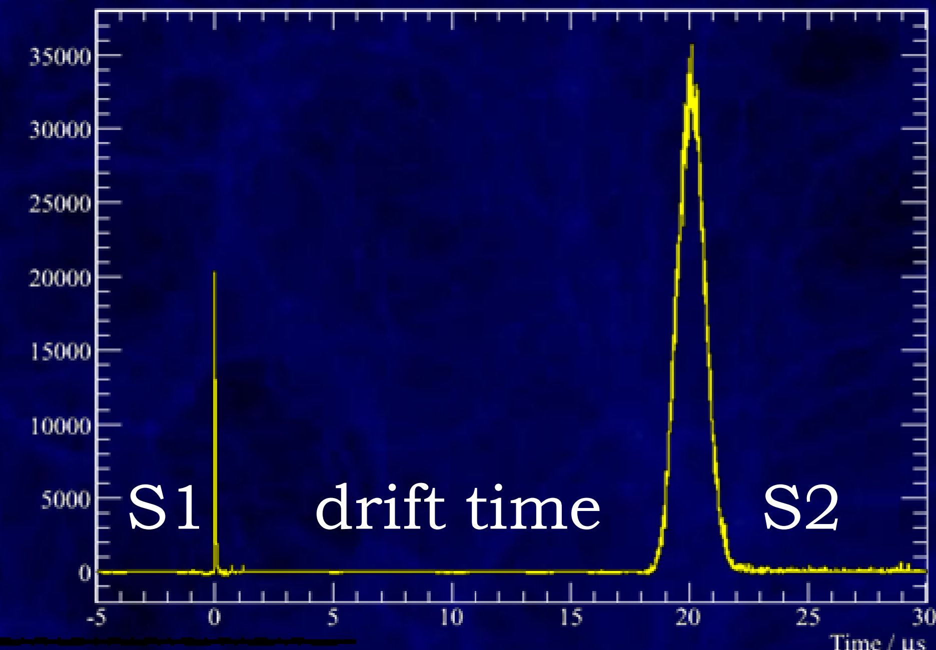
~60 scientists from 15 institutions:

- University of California Los Angeles
- Rice University Houston
- Purdue University
- Columbia University New York
- Universidade de Coimbra
- Subatech Nantes
- NIKHEF Amsterdam
- Willhelms Universität Münster
- J. Gutenberg-Universität Mainz
- Max-Planck-Institut Heidelberg
- Universität Zürich
- Laboratori Nazionali del Gran Sasso
- INFN e Università di Bologna
- Weizman Institute Rehovot
- Jiao Tong University Shanghai

Dual-Phase Xenon TPC

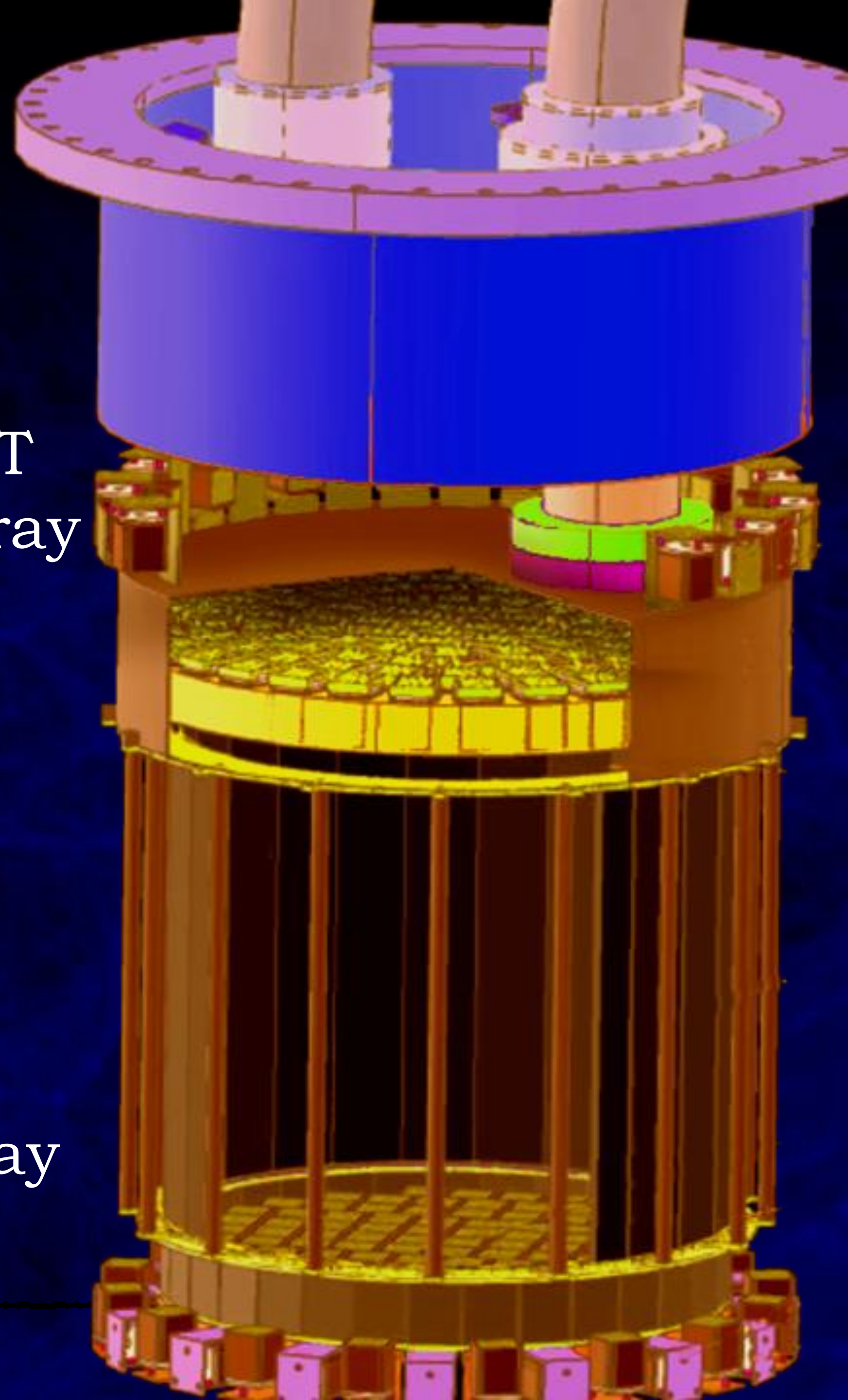
3D position information
S2 hit pattern: $\delta r < 3\,\mathrm{mm}$
drift time: $\delta z < 300\,\mu\mathrm{m}$

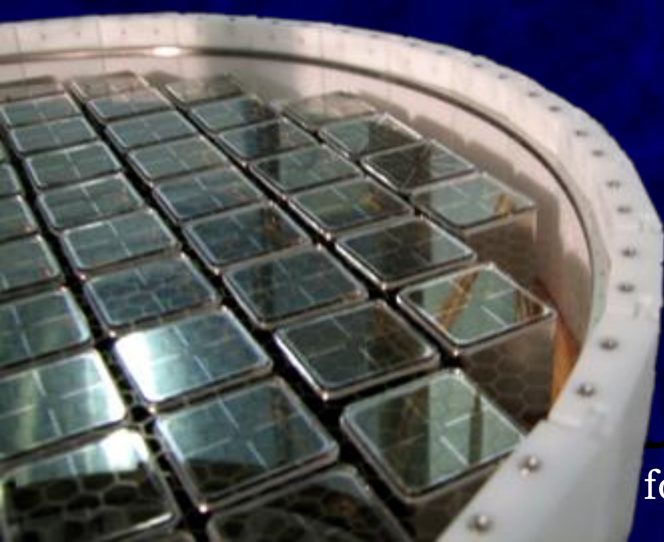




XENON100

98 PMT
top array





80 PMT
bottom array

for WIMPs

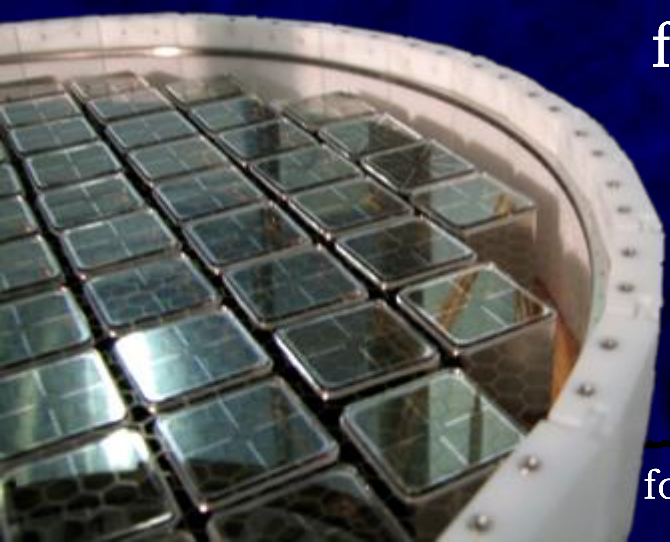
XENON100

veto PMT

bell

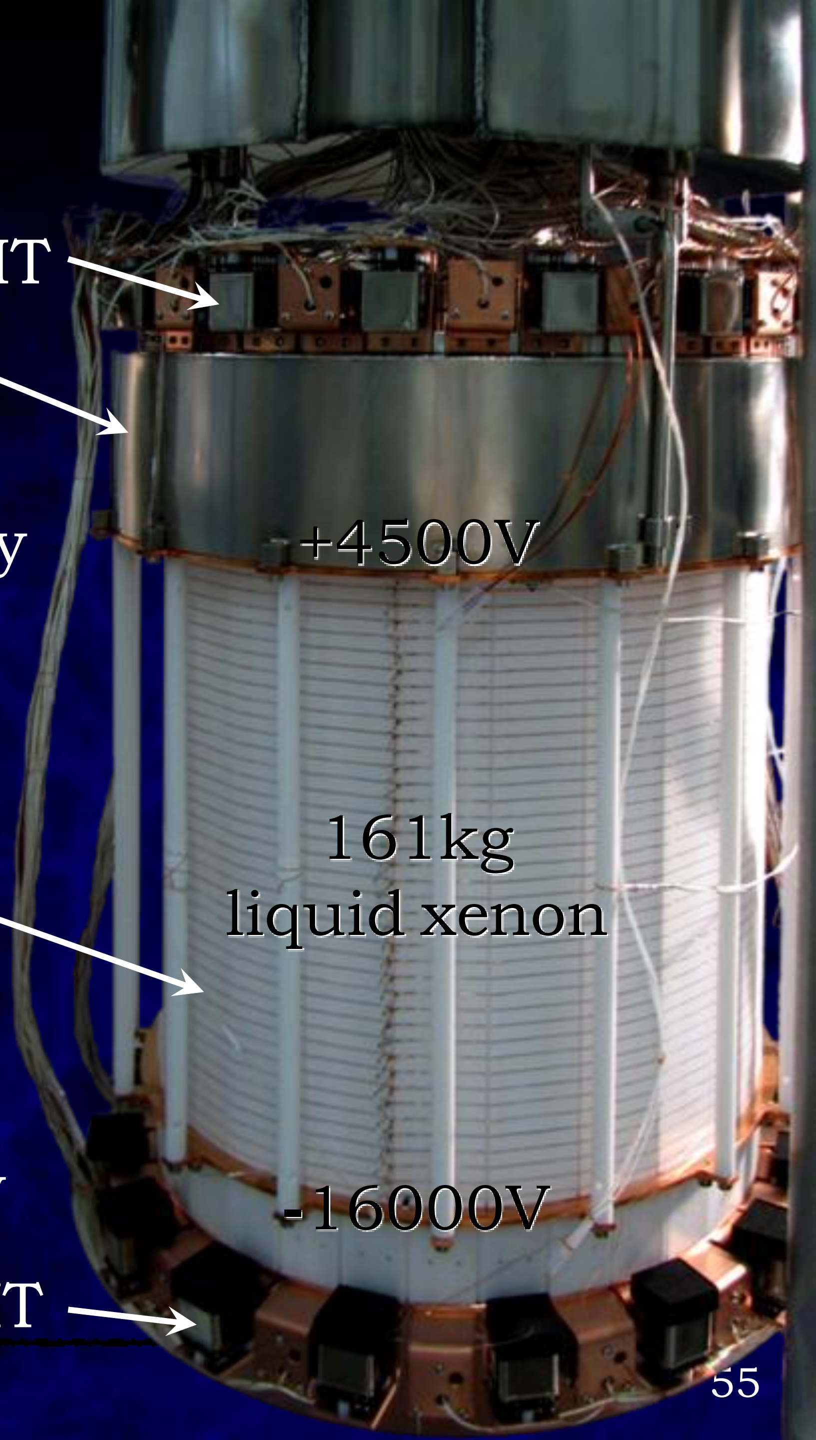
98 PMT
top array

PTFE TPC,
field shaping



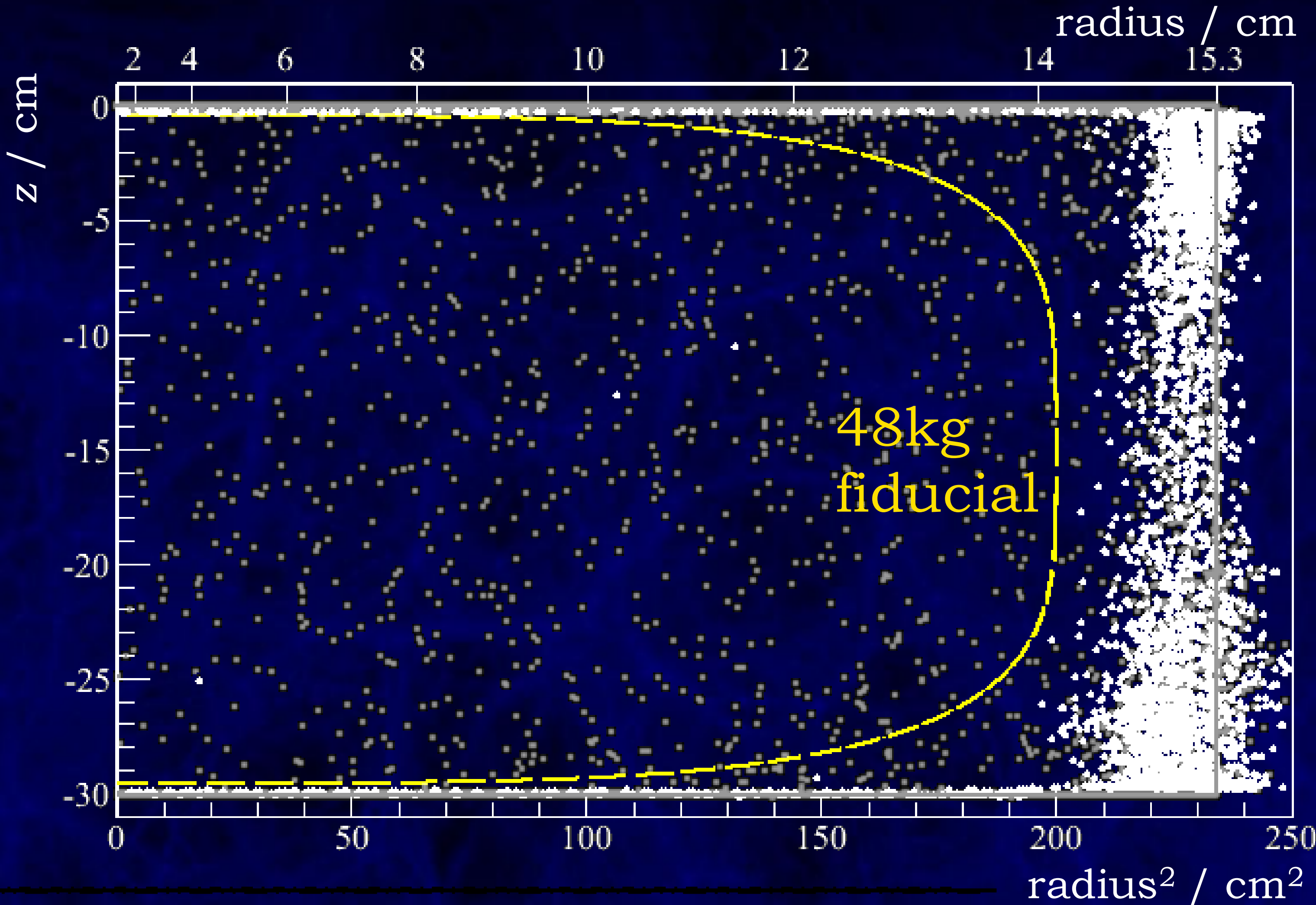
80 PMT
bottom array

veto PMT



The Power of Fiducialization

background for published run (dominated by ^{85}Kr)

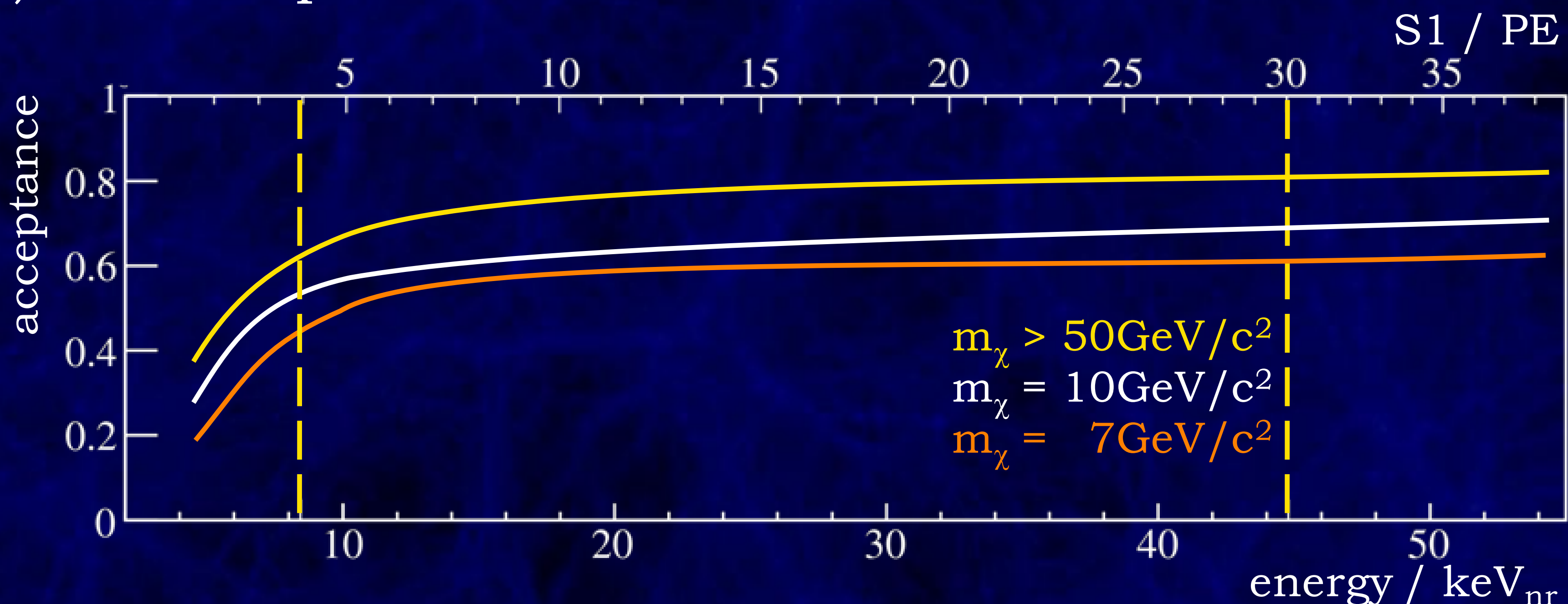


arXiv:1104.2549

Nuclear Recoil Acceptance

tuned to discover rare events: keep highest acceptance

1) S2 threshold adds keV_{nr}-dependent acceptance (via Q_y). Measure with ^{241}Am/Be data at top of TPC
2) convolve WIMP spectrum with Poisson (S1 collection)
3) measure quality cut acceptances as function of S1
4) add all up:



arXiv:1104.2549

Profile Likelihood Approach

instead of

Yellin-based limit
✗ based on events in a box

build

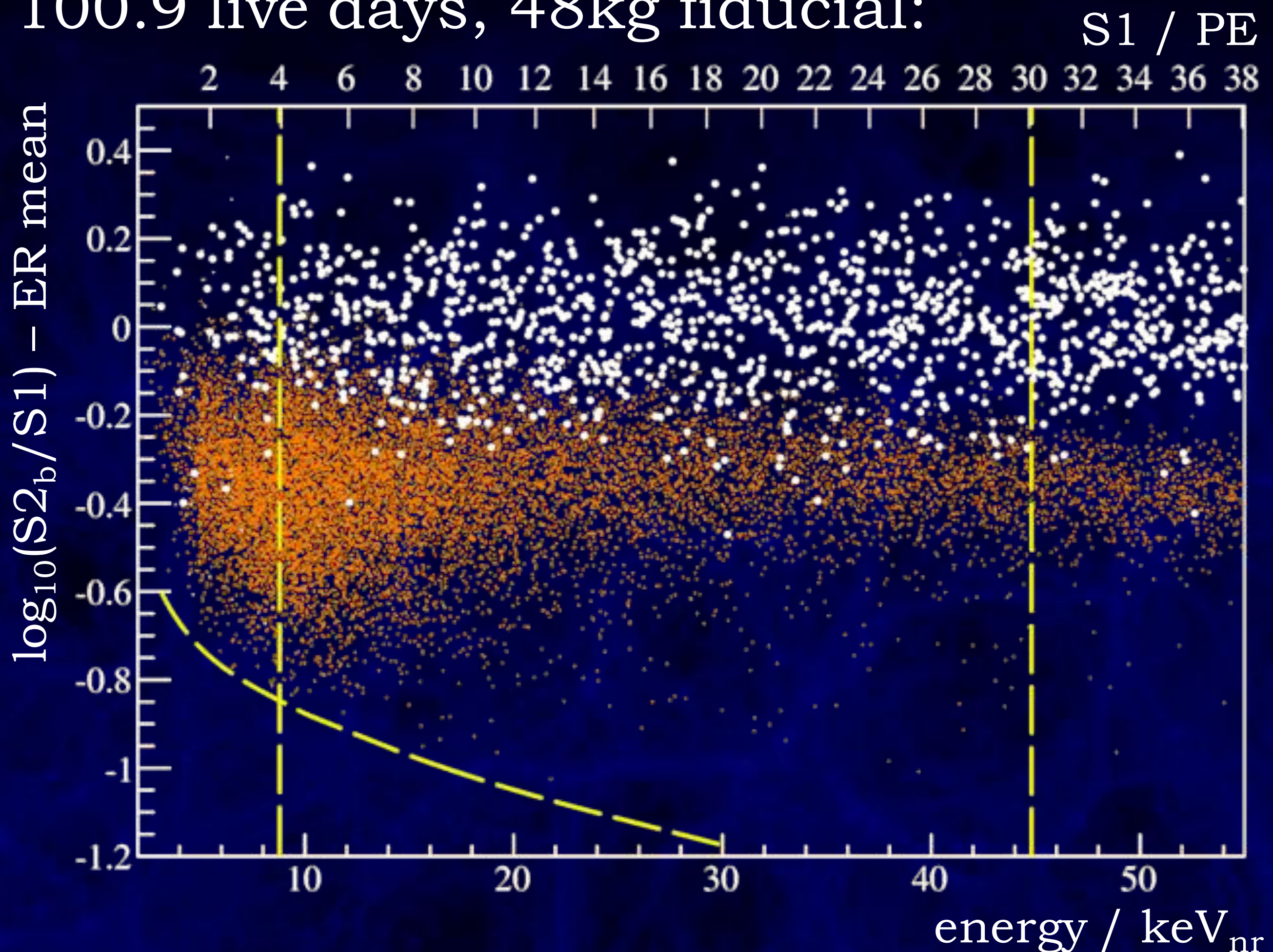
likelihood ratio
✓ using all data

- use all observed events in energy range (full energy information, no discrimination)
- incorporate calibration measurements (data + simulation) and their uncertainties
- incorporate systematic uncertainties (L_{eff}, v_{esc}, …)
- calculate only one true 90% confidence limit
- natural transition into discovery claim

arXiv:1103.0303

Discrimination using S2/S1

100.9 live days, 48kg fiducial:



electronic recoils (background)

nuclear recoils (calibration)

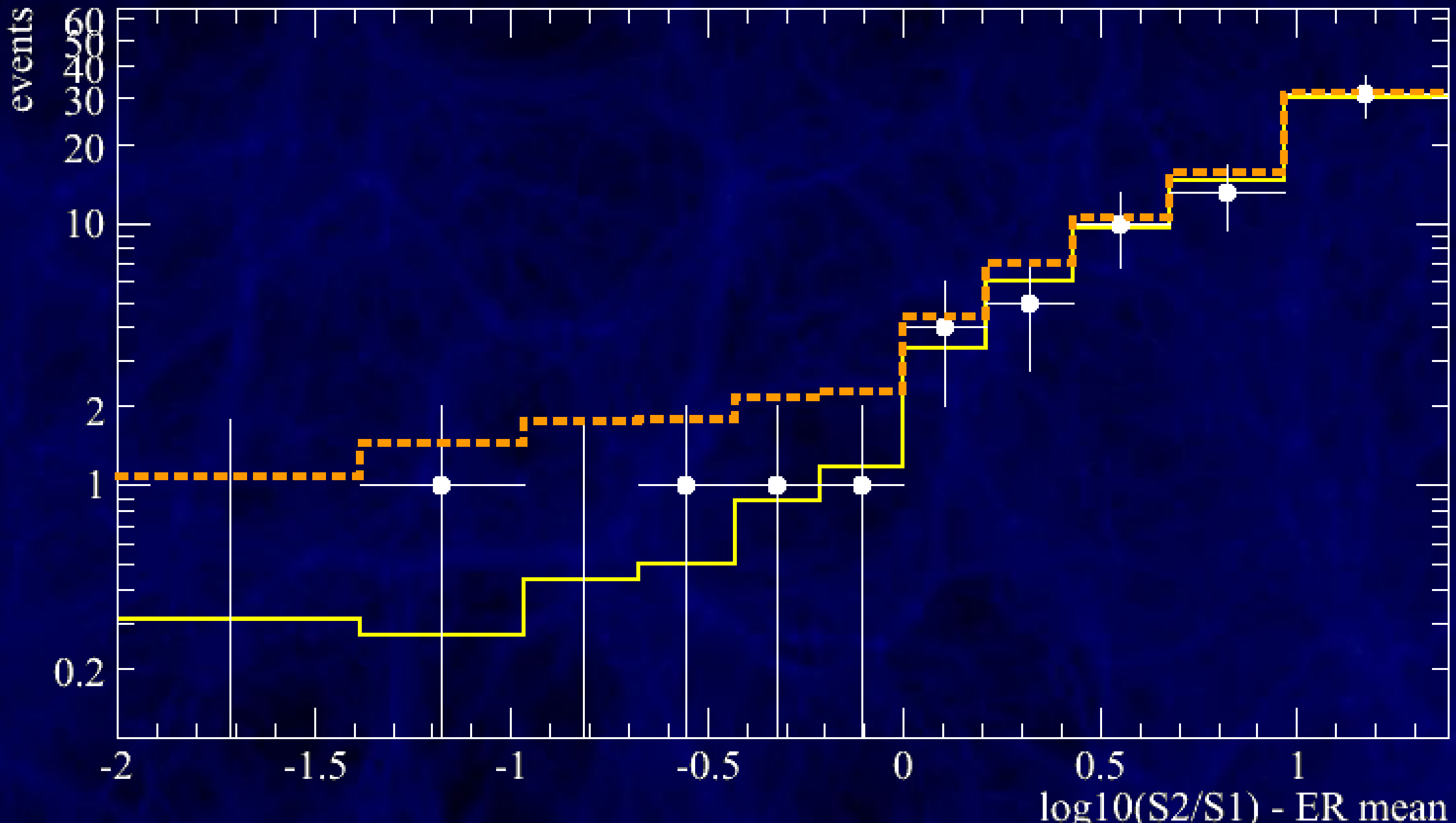
likelihood analysis: no observation of a signal (p_0=31%)

arXiv:1104.2549

Projection along Energy

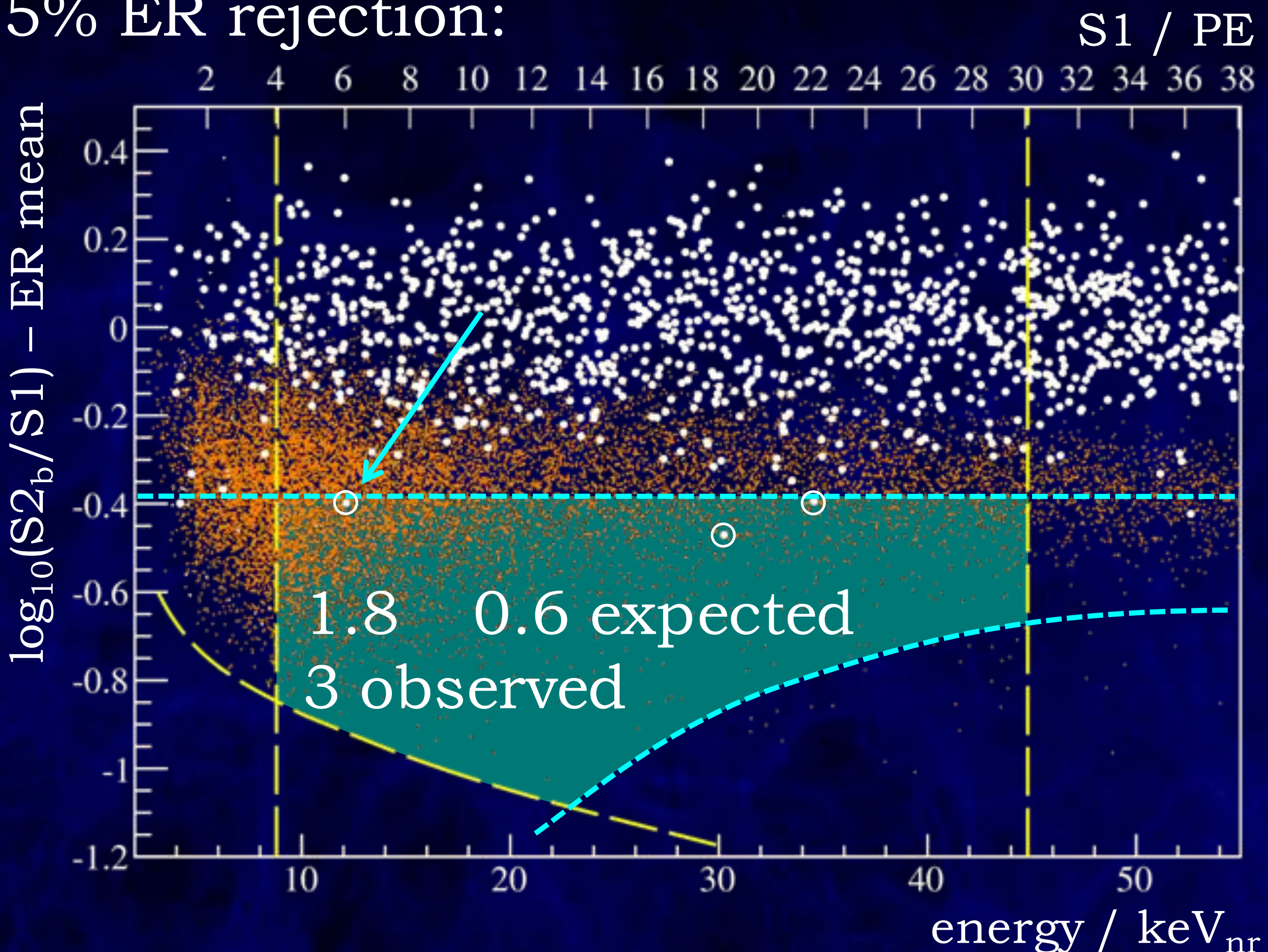
observed events

expected background + 100GeV/c^2 WIMP with σ=10^{-44}cm^2 (90%CL excluded, 13 events)



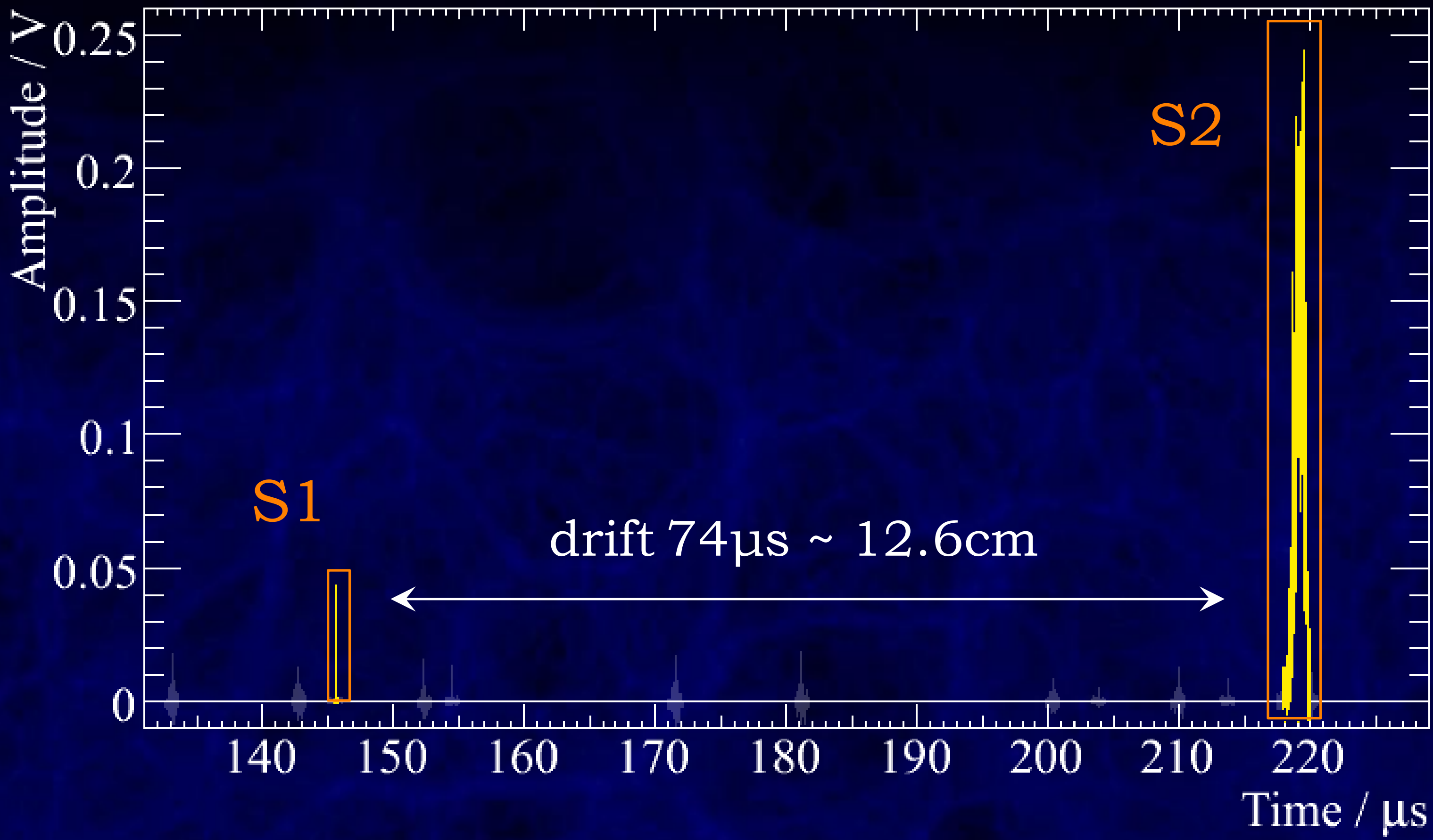
Benchmark Region

Classical analysis (Yellin) restricted to WIMP search box with 99.75% ER rejection:



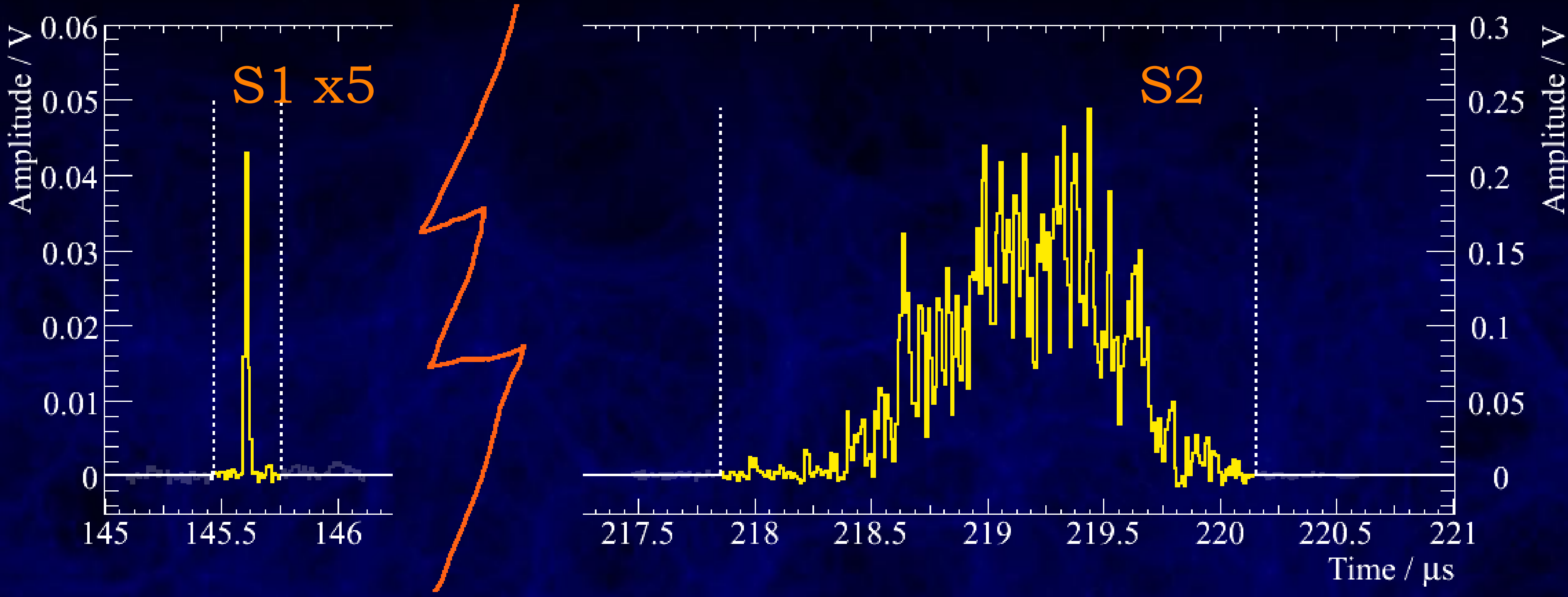
arXiv:1104.2549

Candidate Event: Waveform



xe100_100603_1620_000038-63

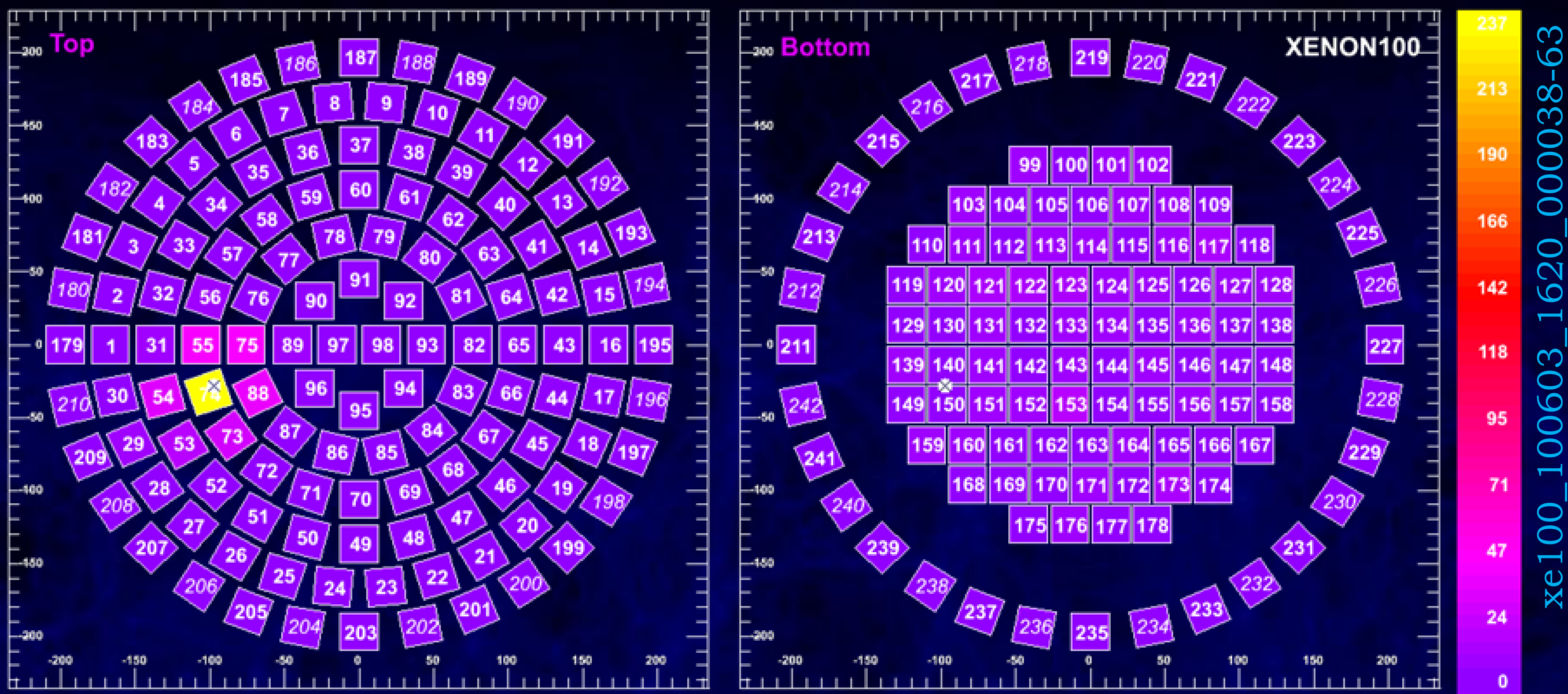
Candidate Event: S1 and S2



6.4 S1 PE detected (from ~200 S1 photons)

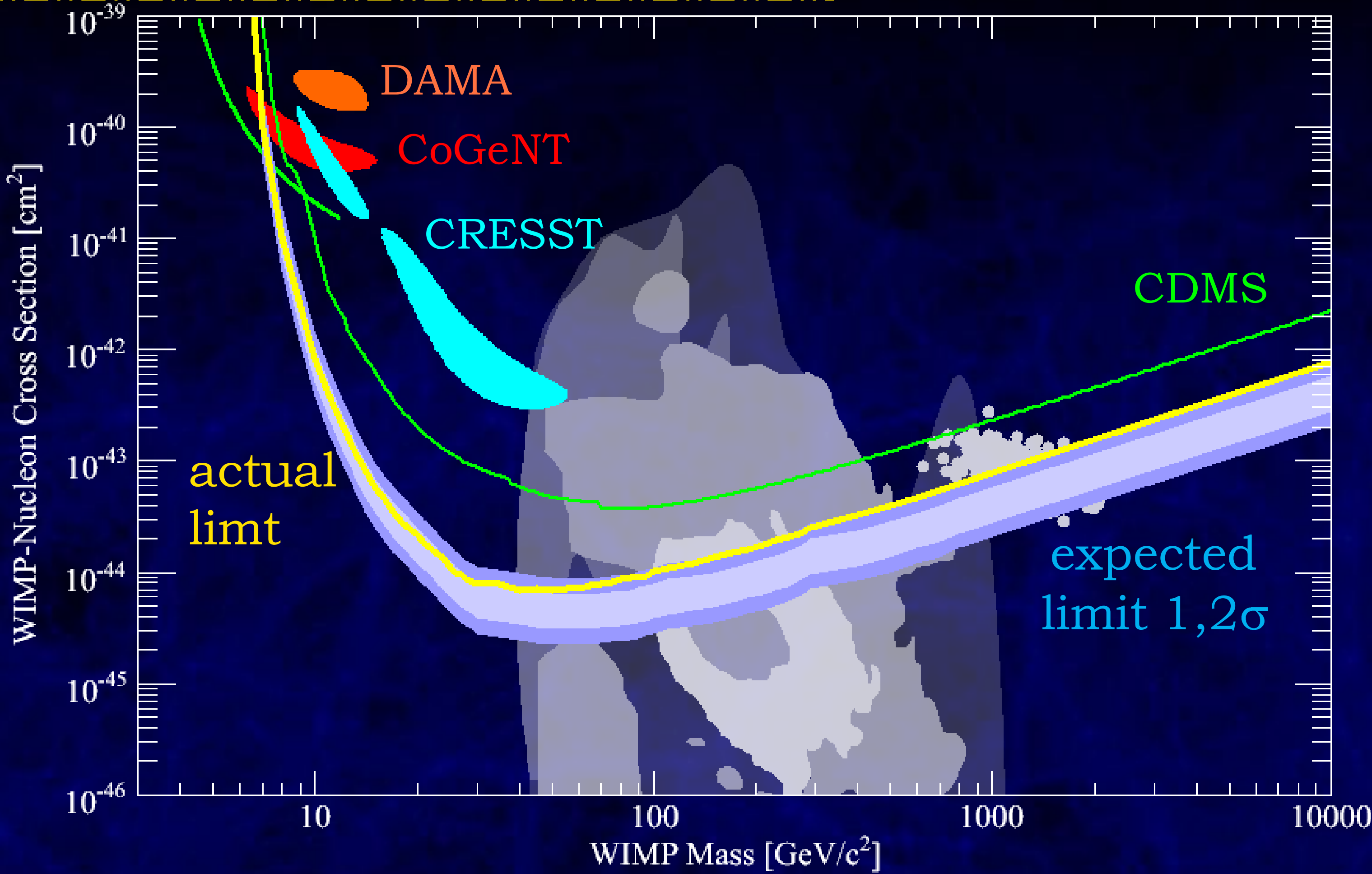
1044 S2 PE detected (from ~50 ionization electrons which generated ~5000 S2 photons)

Candidate Event: S2 PMT Pattern



excellent positioning ($\delta r < 3\,\mathrm{mm}$) even near threshold

XENON100 Limit 2011

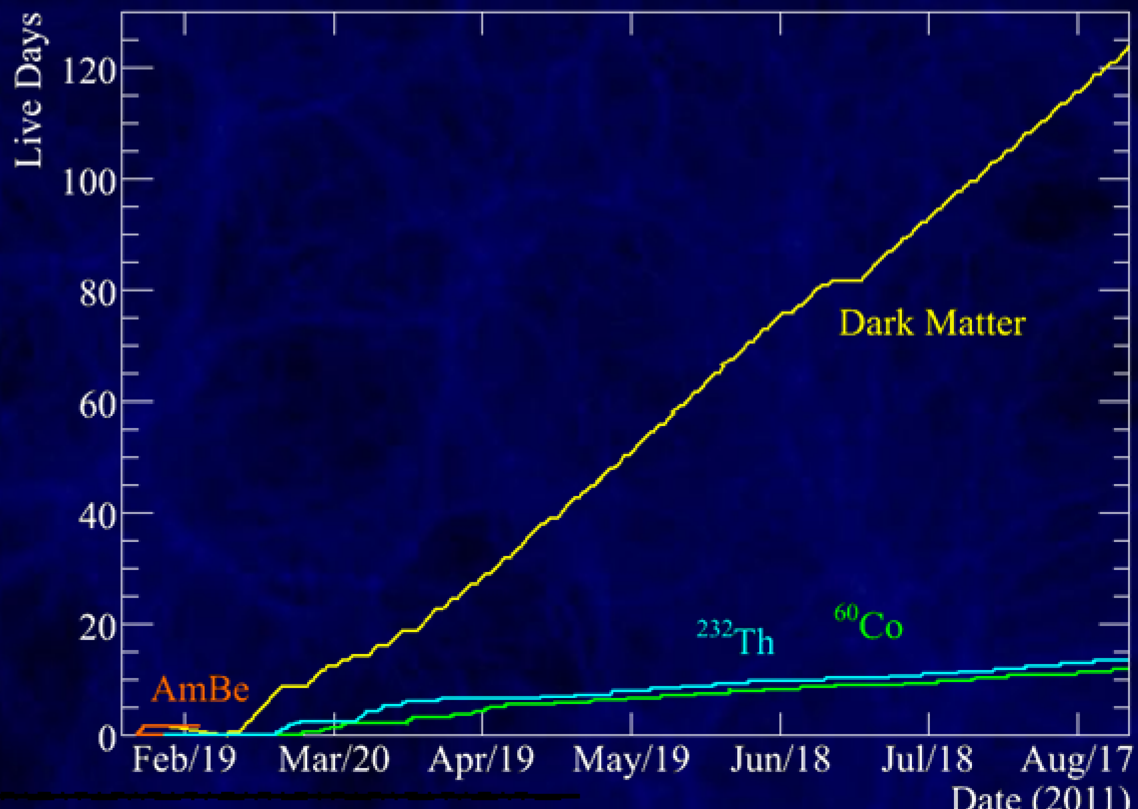


strongest limit to date; excludes SUSY parameter space
excludes iDM scattering off I as explanation for DAMA

arXiv:1104.2549, arXiv:1104.3121

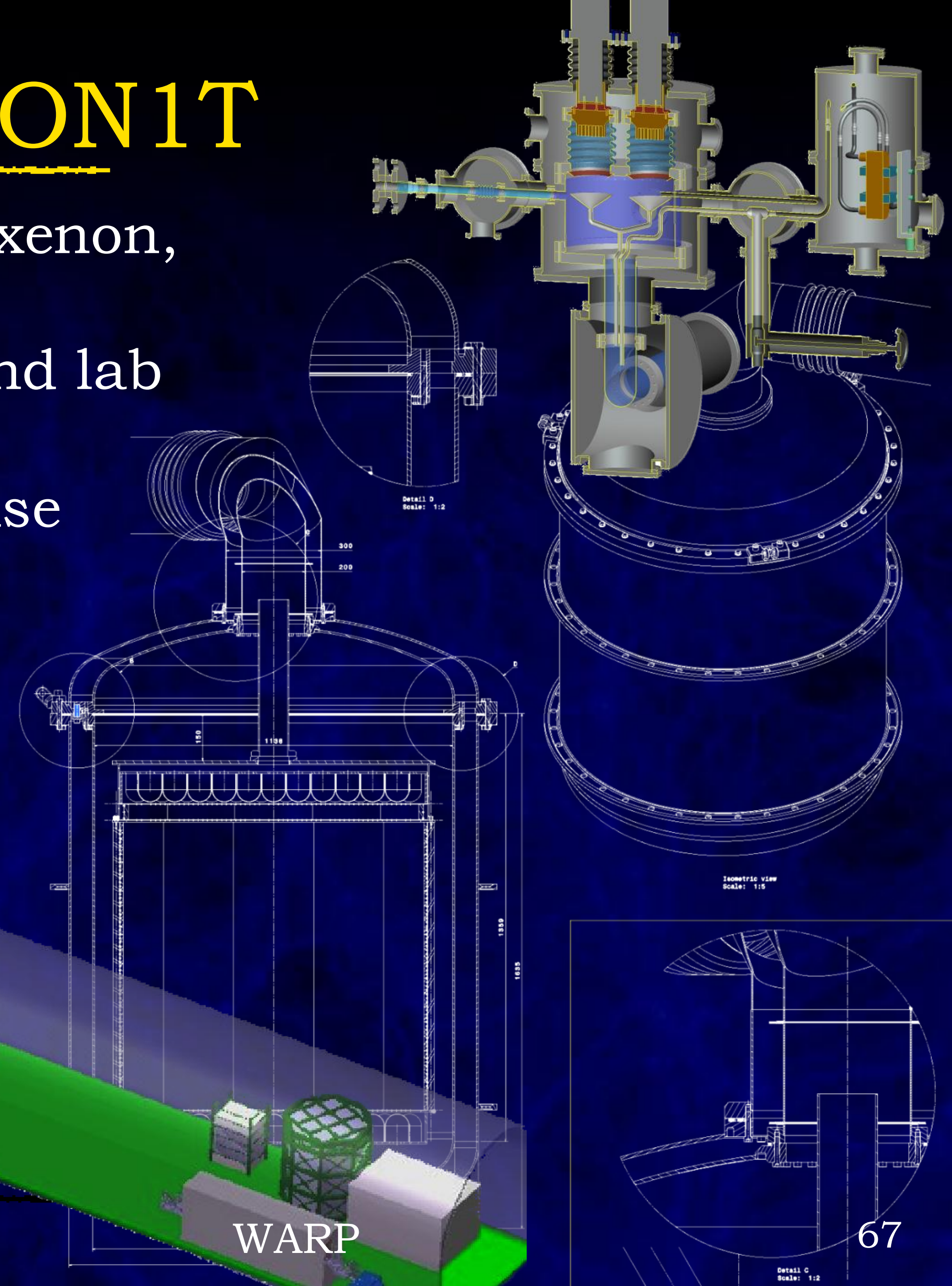
Preliminary Specs of Ongoing Run

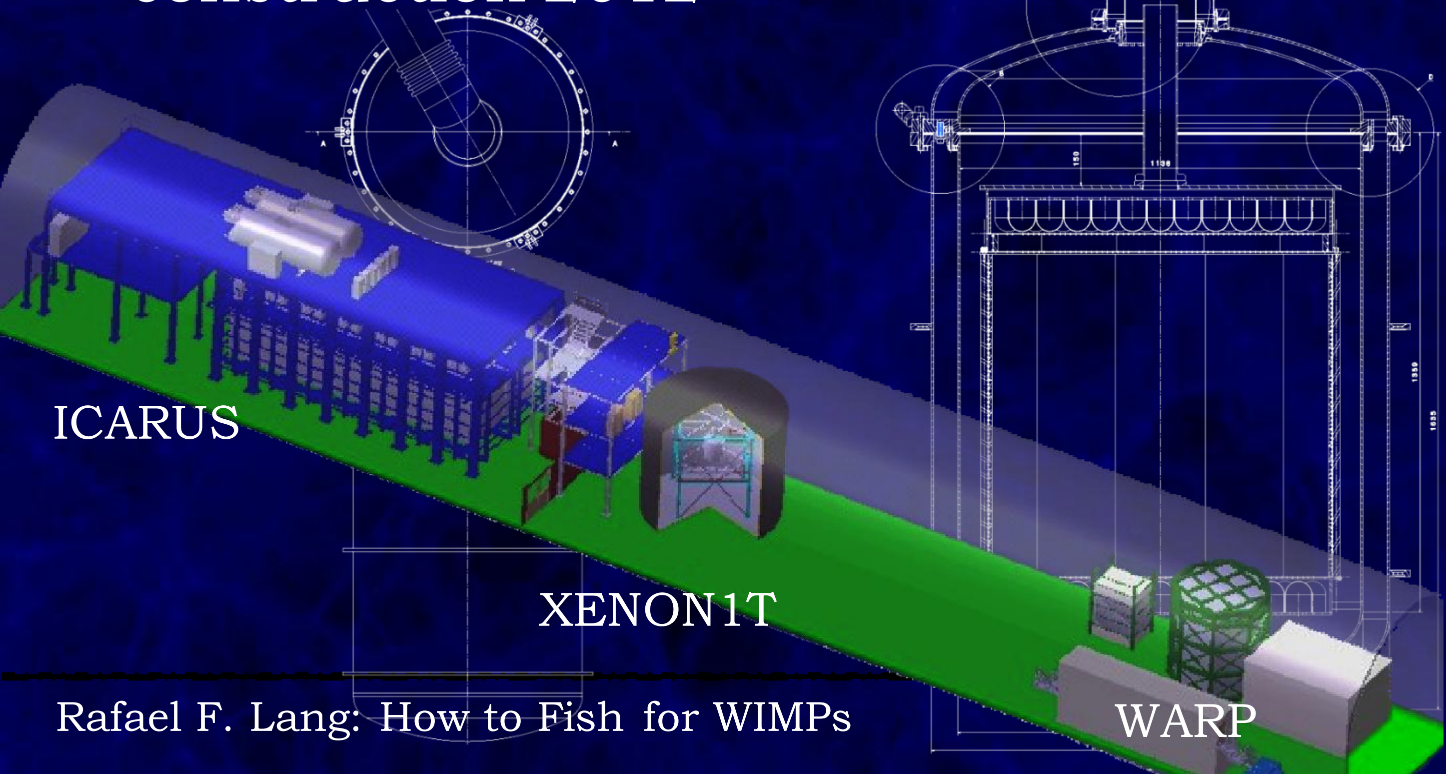
- lowered S2 trigger threshold: from 300PE to ~100PE
- increased xenon purity: increased S1 light yield; current e^- absorption length ~1m and increasing
- lowered ^{85}Kr background to initial low level
- exposure far exceeds published run
- much more calibration data (^{232}Th, ^{60}Co, ^{137}Cs, Xe*)
- run ongoing (still blinded)



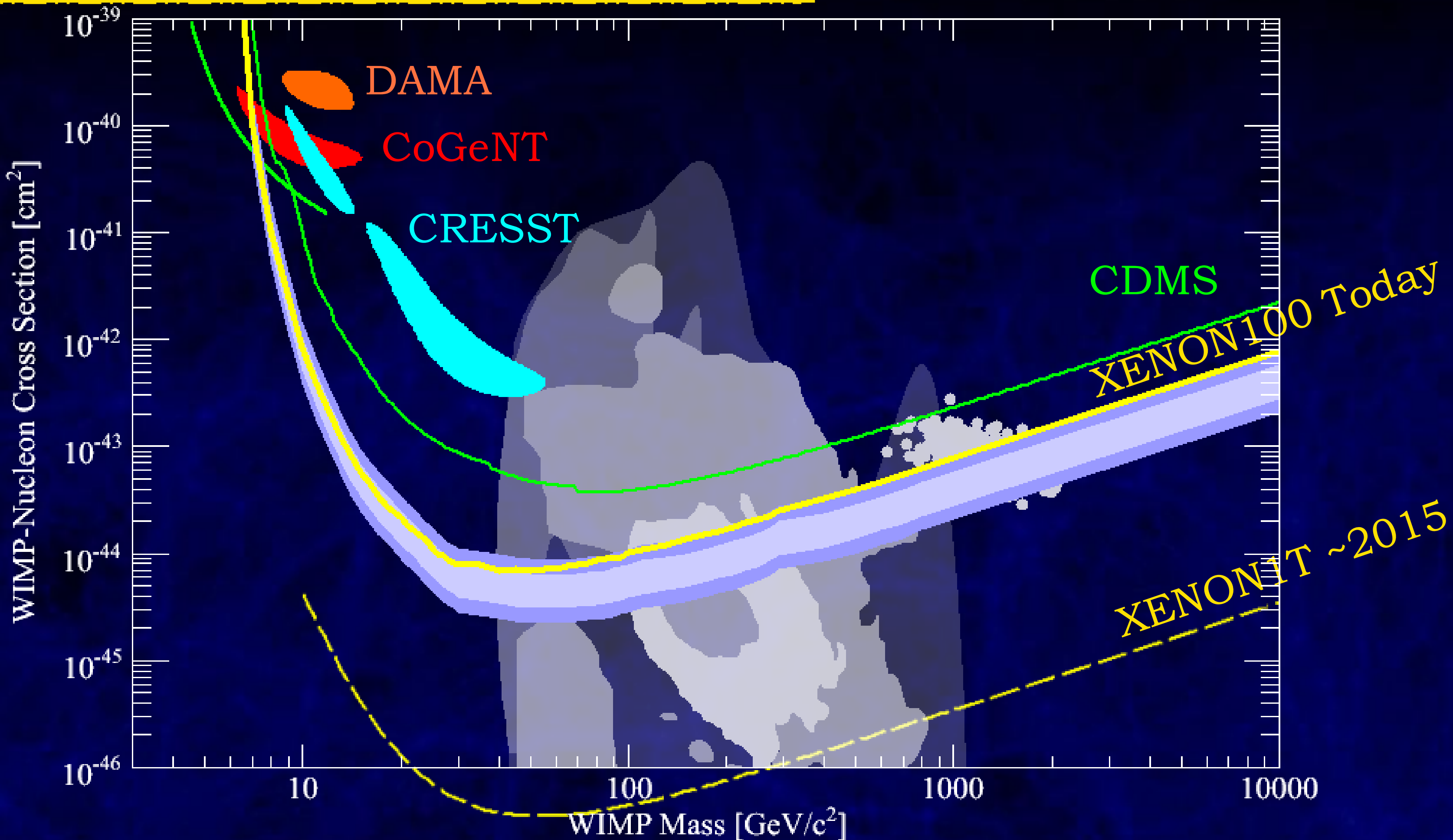
Next Step: XENON1T

- fiducial mass 1t liquid xenon, about 2.4t total
- Gran Sasso underground lab
- 975m^3 water tank
- in technical design phase
- construction 2012





Within Just a Few Years



XENON1T covers most of the expected parameter space

How to Fish for WIMPs

- expected recoil spectrum: falling exponential
- discrimination techniques: help increase sig/bck
- DAMA/LIBRA: claims discovery
- CoGeNT: quasi-exponential background, modulation
- CRESST-II: lots of events
- CDMS-II: excludes them all
- EDELWEISS: interleaved detectors work
- XENON100: most sensitive experiment around