

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

Rafael F. Lang

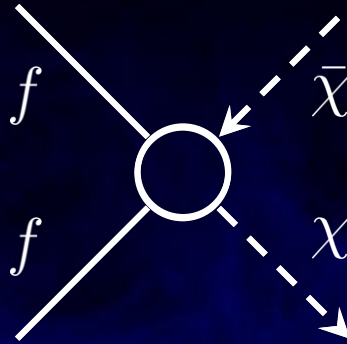
Columbia University New York

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Pheno2011, Madison

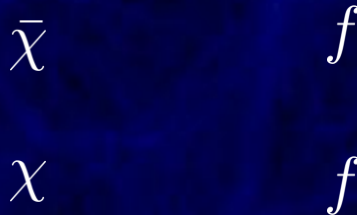
How to Search a Thermal Relic

- Production



Collider Searches

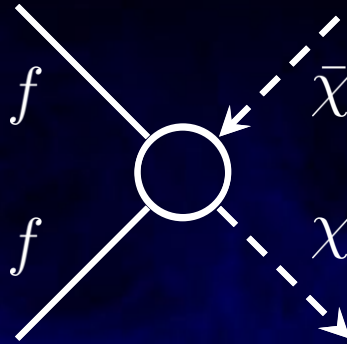
- Annihilation



Indirect Searches

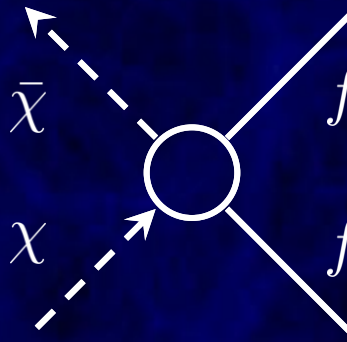
How to Search a Thermal Relic

- Production



Collider Searches

- Annihilation



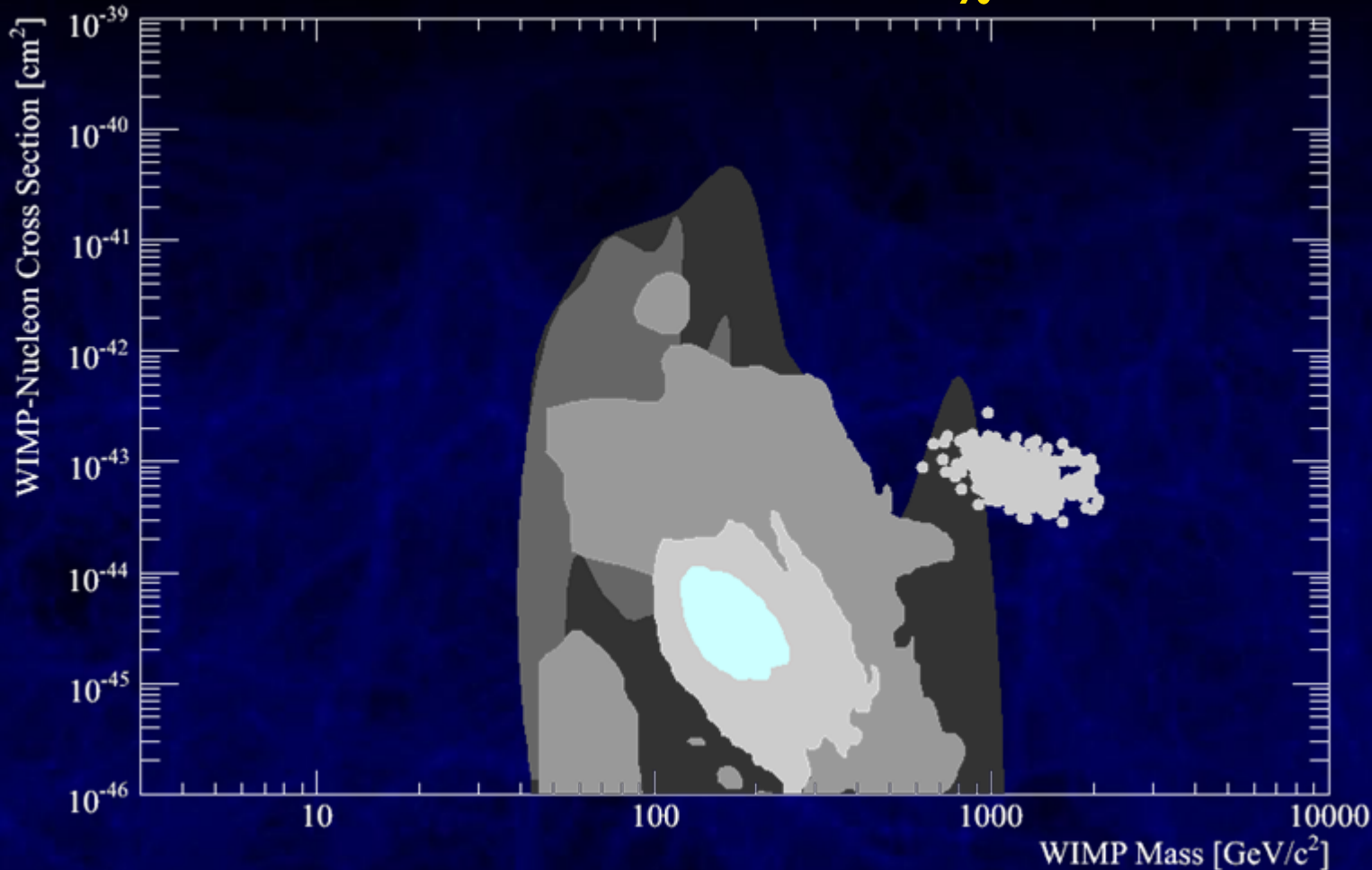
Indirect Searches

- Scattering



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

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

- 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

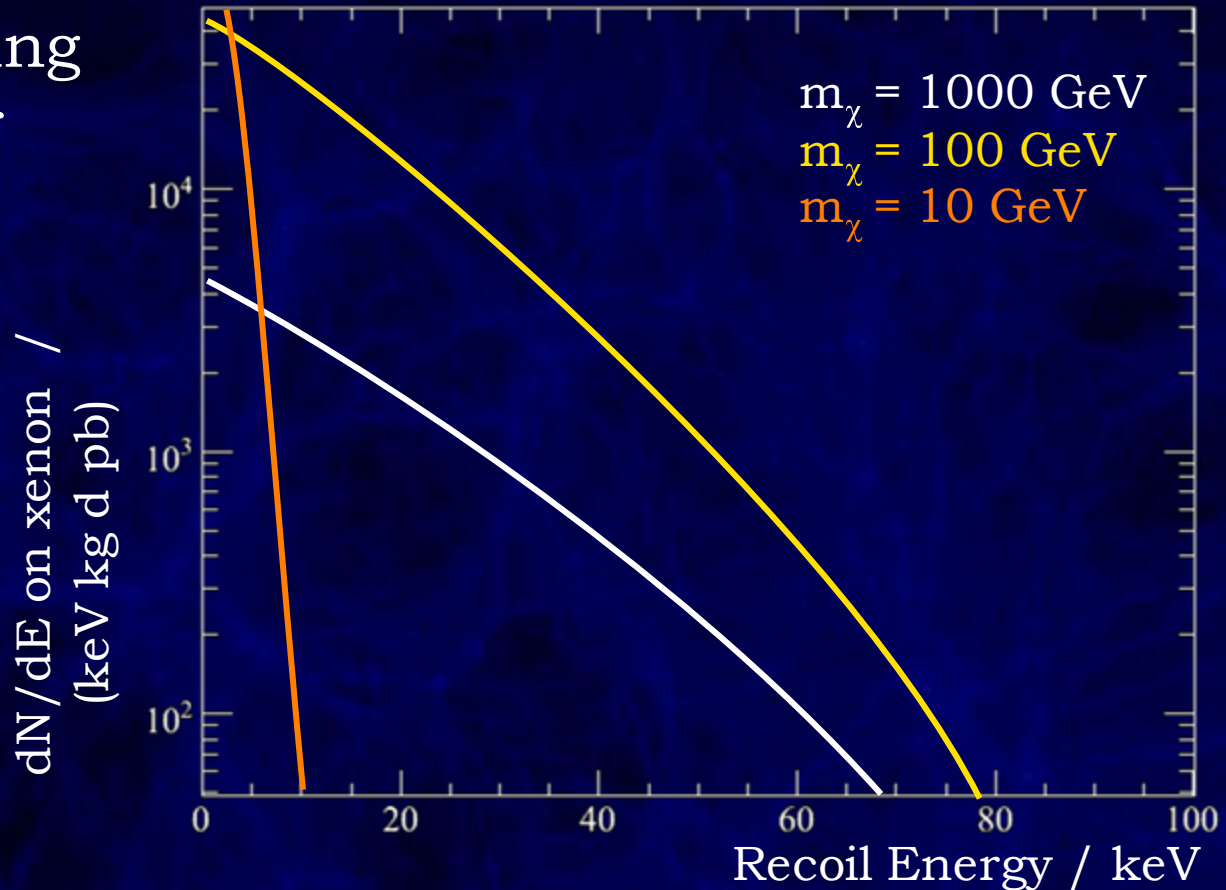
$$E_{r, \text{max}} \sim \frac{p_{\chi}^2}{2m_N} \sim \frac{(100 \text{ GeV}/c^2 \times 10^{-3} c)^2}{2 \times 100 \text{ GeV}/c^2} = 50 \text{ keV}$$

- Spectrum \rightarrow shielding, discrimination, multi target

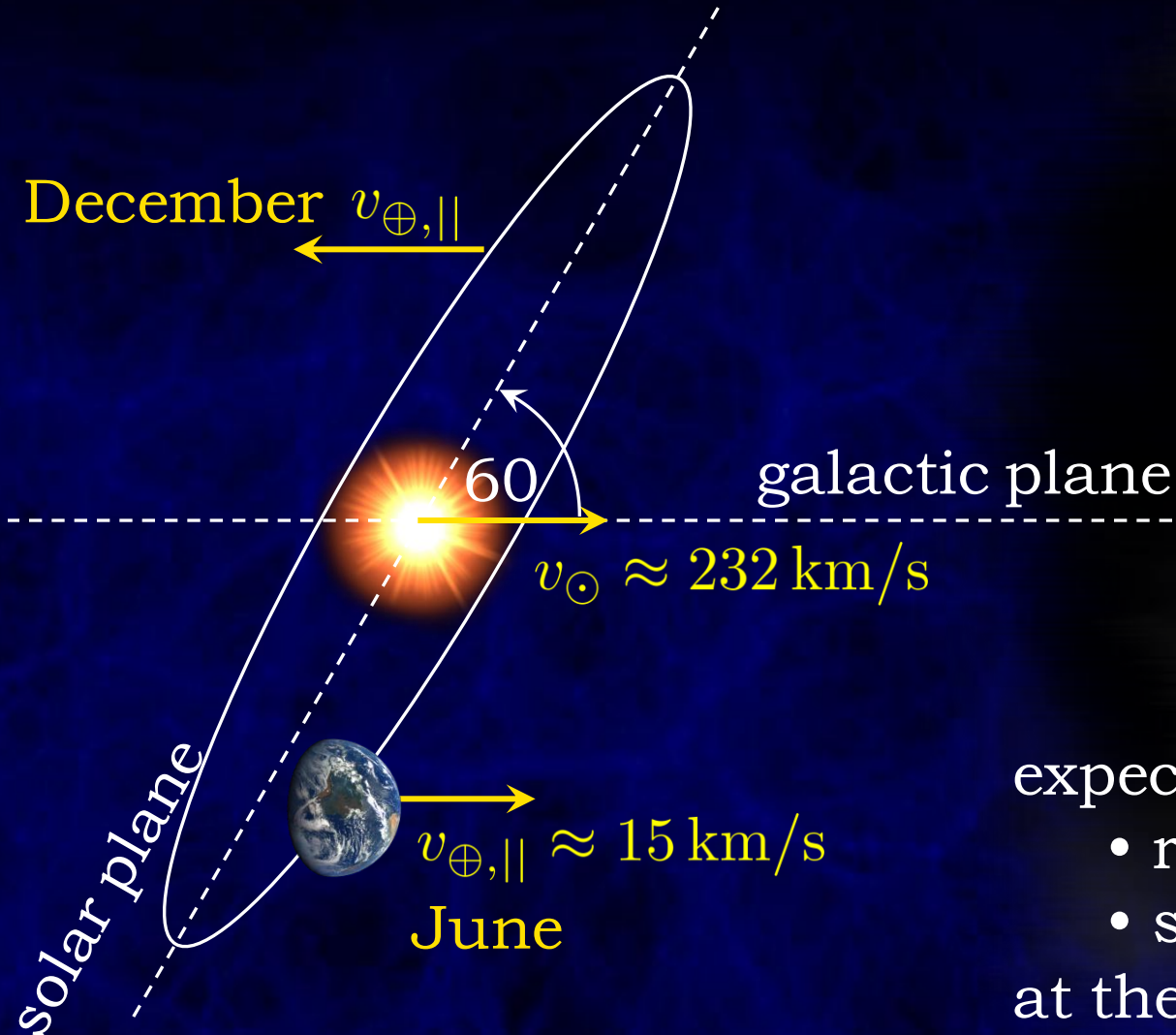
$$\frac{dN}{dE_r} \propto \Phi \propto \langle v \rangle \propto \int_{v_x}^{\infty} f_{\text{MB}}(v) v dv \propto e^{-v_x^2} \propto e^{-E_r}$$

Expected WIMP Spectrum

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



Annual Modulation



expect modulation of

- rate
- spectral shape

at the percent level

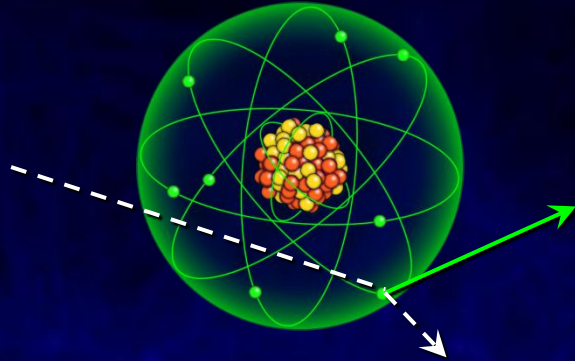
How to Fish for WIMPs

- expected recoil spectrum: falling exponential
- **discrimination techniques**
- DAMA/LIBRA
- CoGeNT
- CRESST-II
- CDMS-II
- EDELWEISS
- XENON100

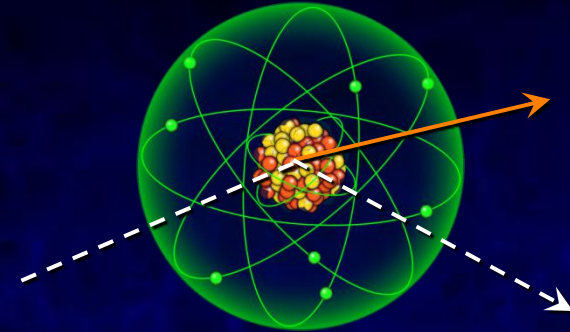


The Power of Discrimination

e^-/γ : electronic recoil



n /WIMPs: nuclear recoil

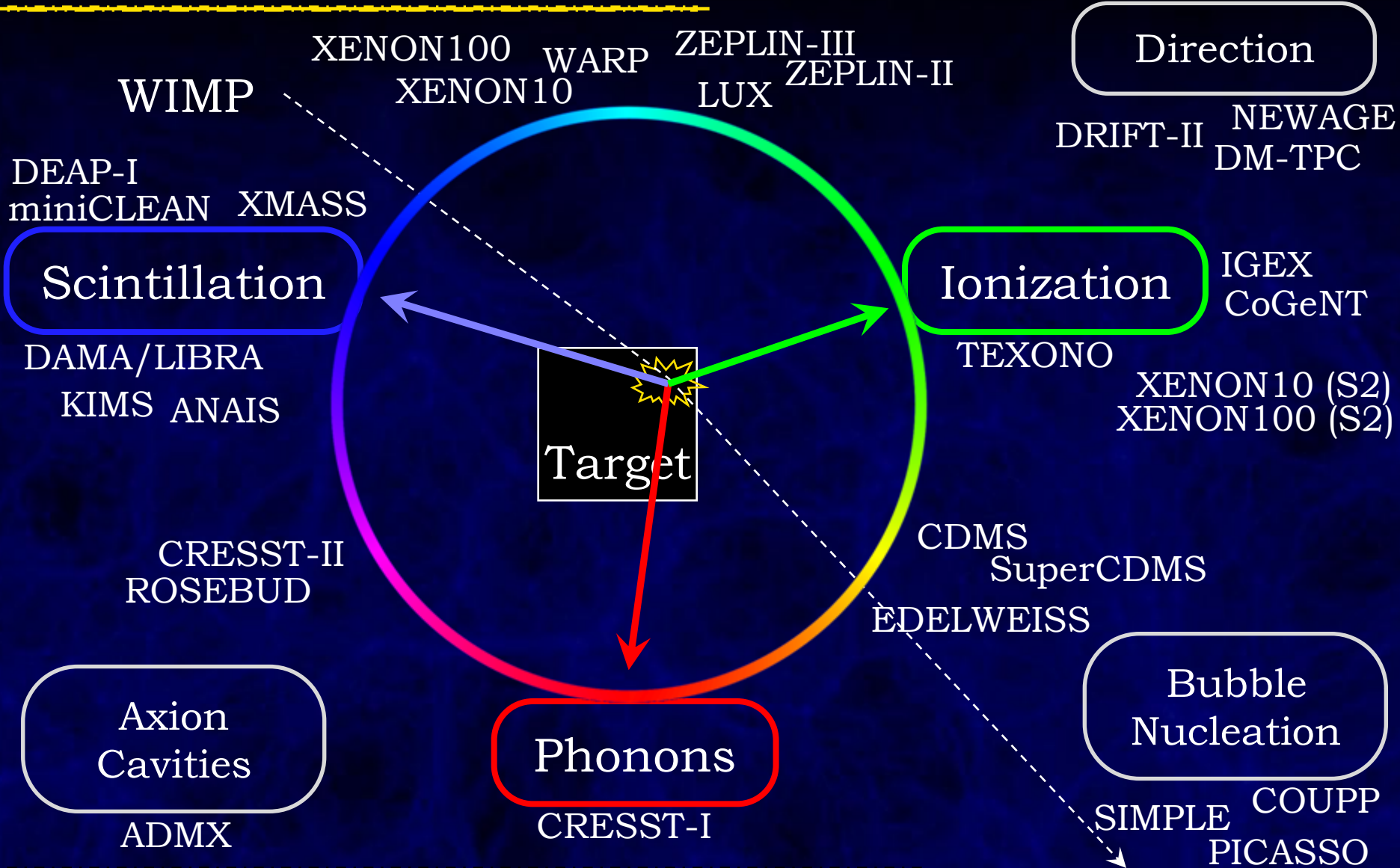


electronic recoils

- 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



How to Fish for WIMPs

- expected recoil spectrum: falling exponential
- discrimination techniques: help increase sig/bck
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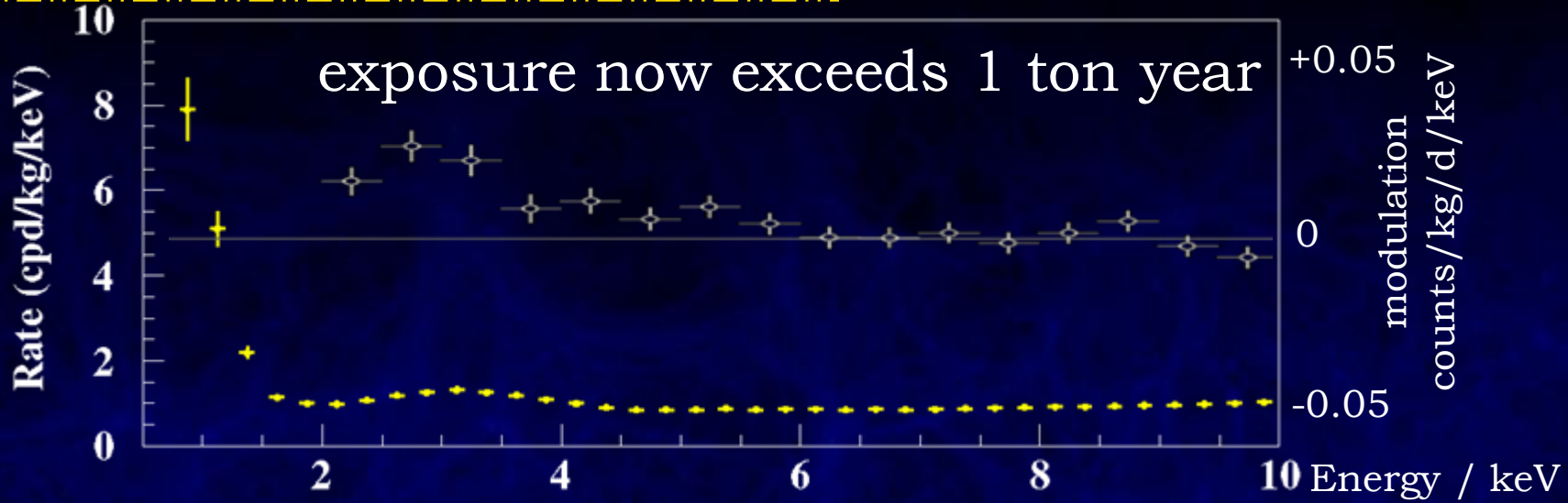
DAMA/LIBRA

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

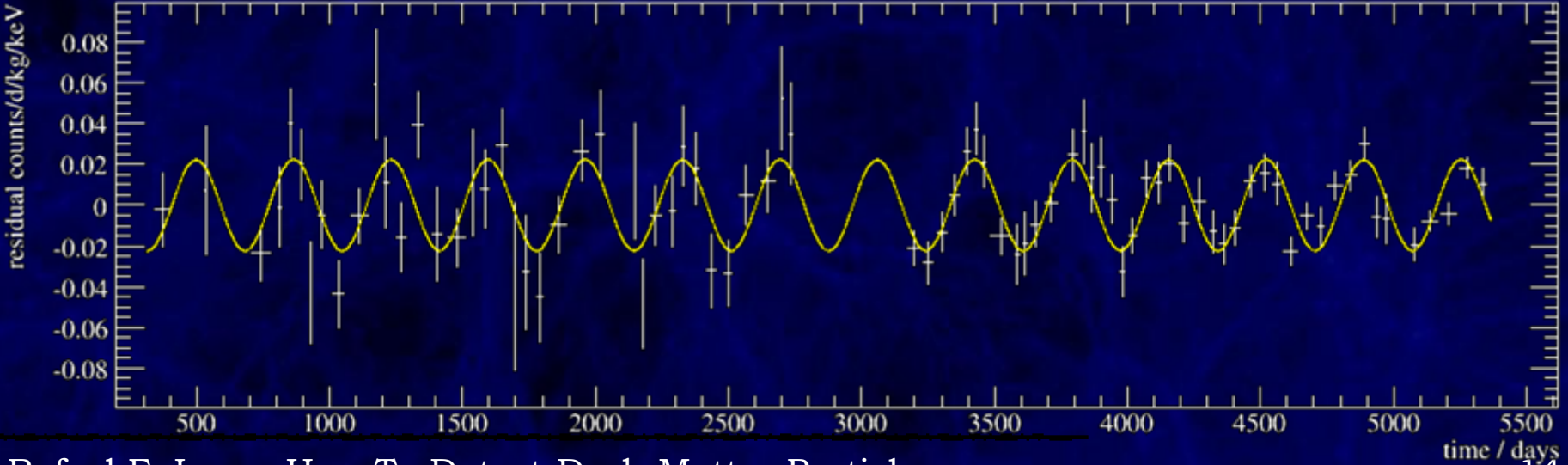


DAMA/LIBRA Data

arXiv:0804.2741

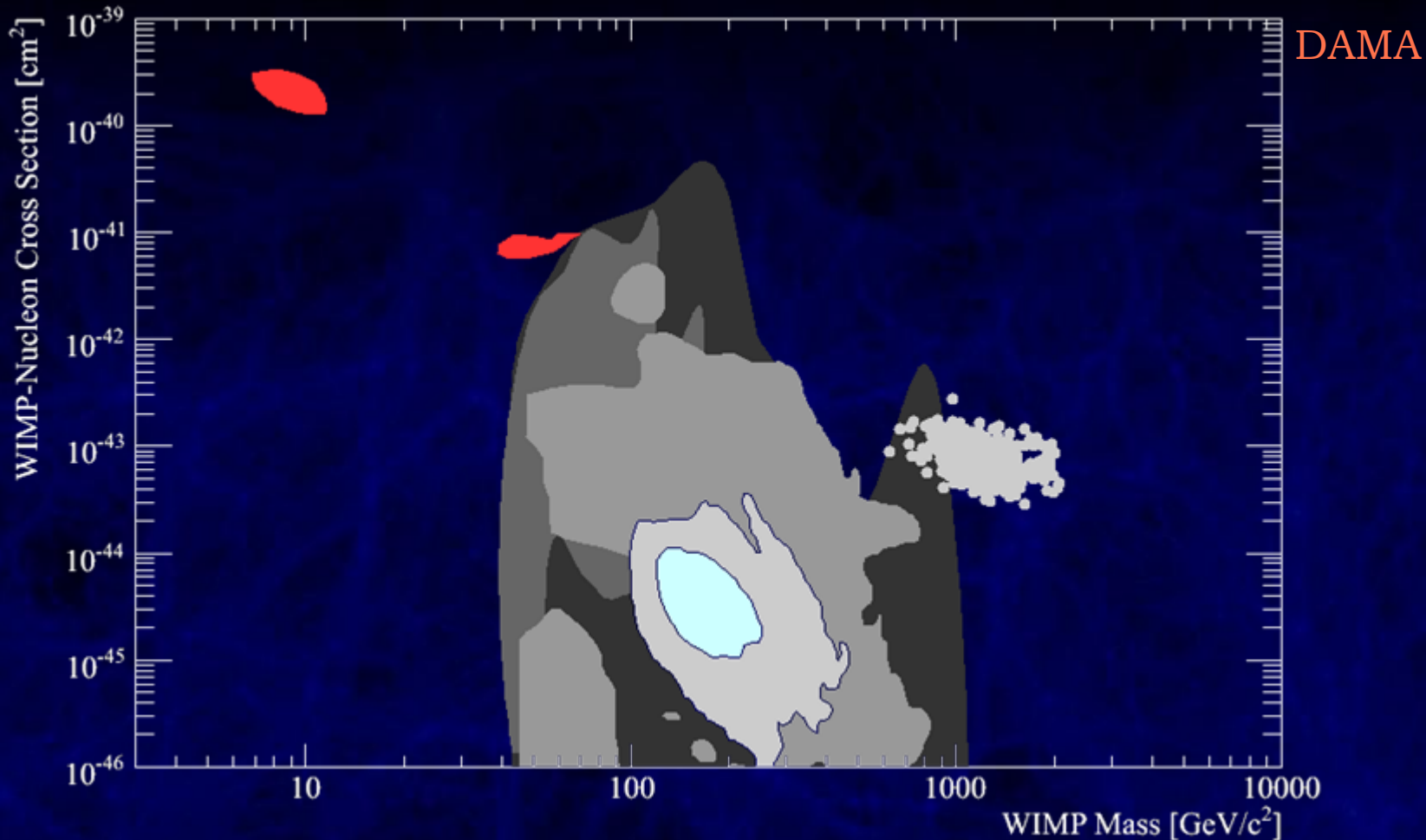


observe rate modulation in [2,4]keV:



data from arXiv:0804.2741 and arXiv:1002.1028

DAMA Interpreted as WIMPs



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

How to Fish for WIMPs

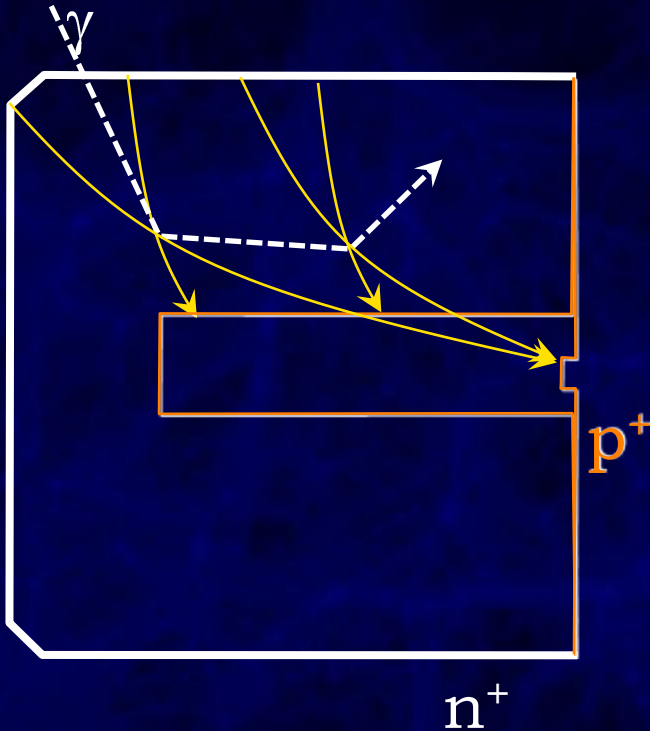
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CoGeNT

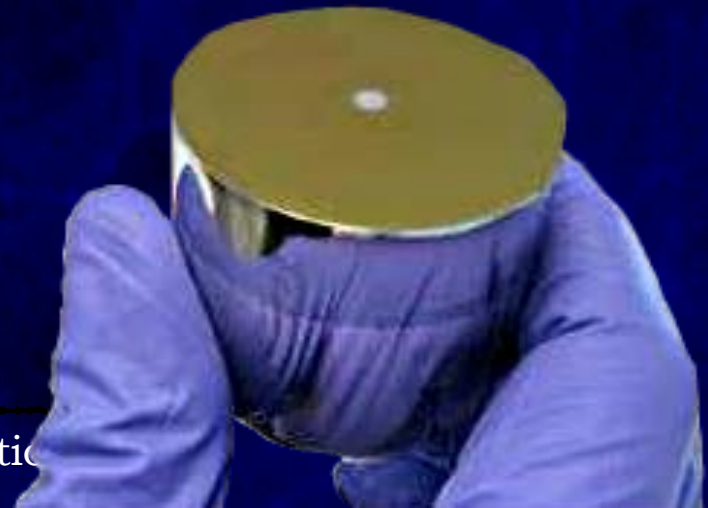
USA

440g P-type point-contact Ge detector

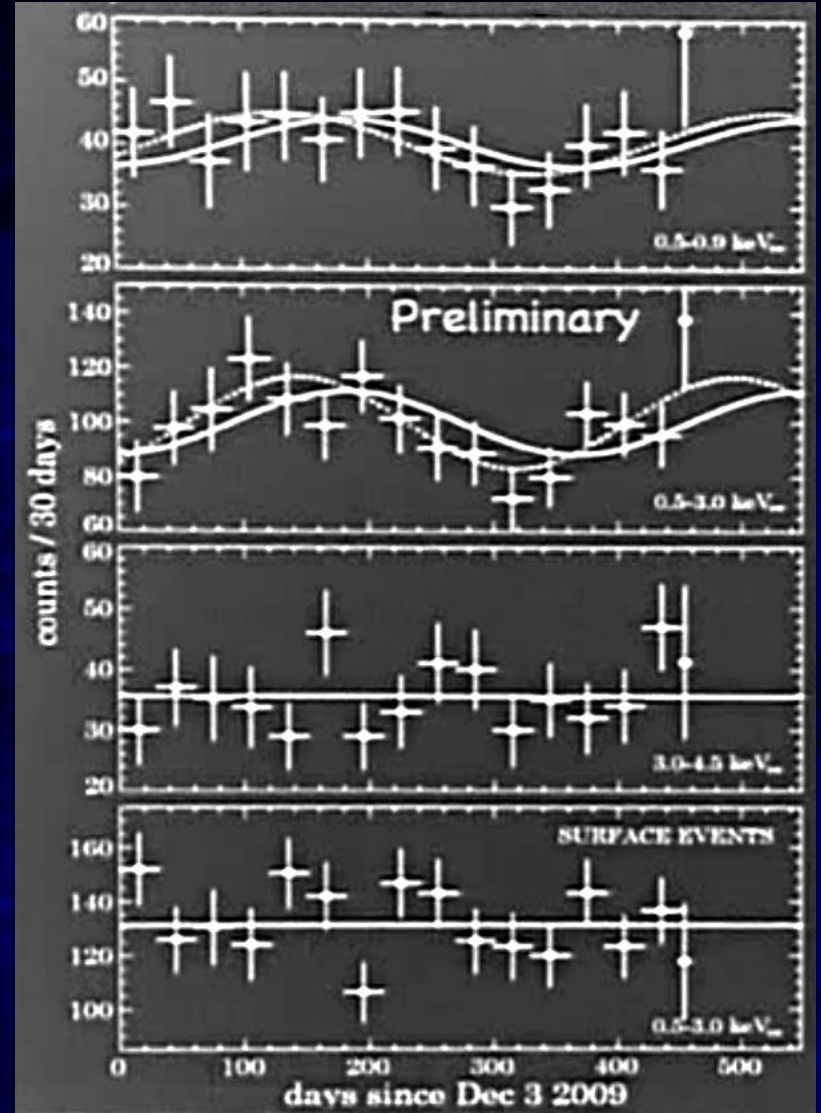
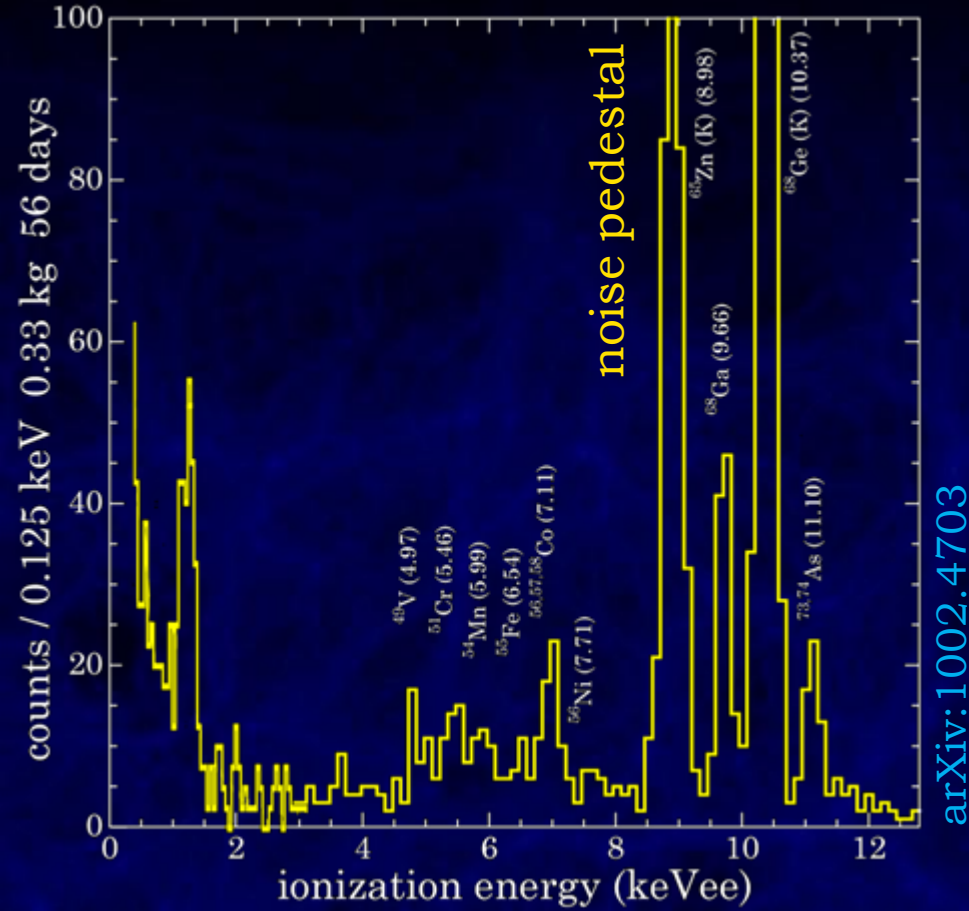


Standard point-contact Ge detector

- smaller p^+ electrode = smaller capacitance & smaller noise
- no radial degeneracy for multiple interactions

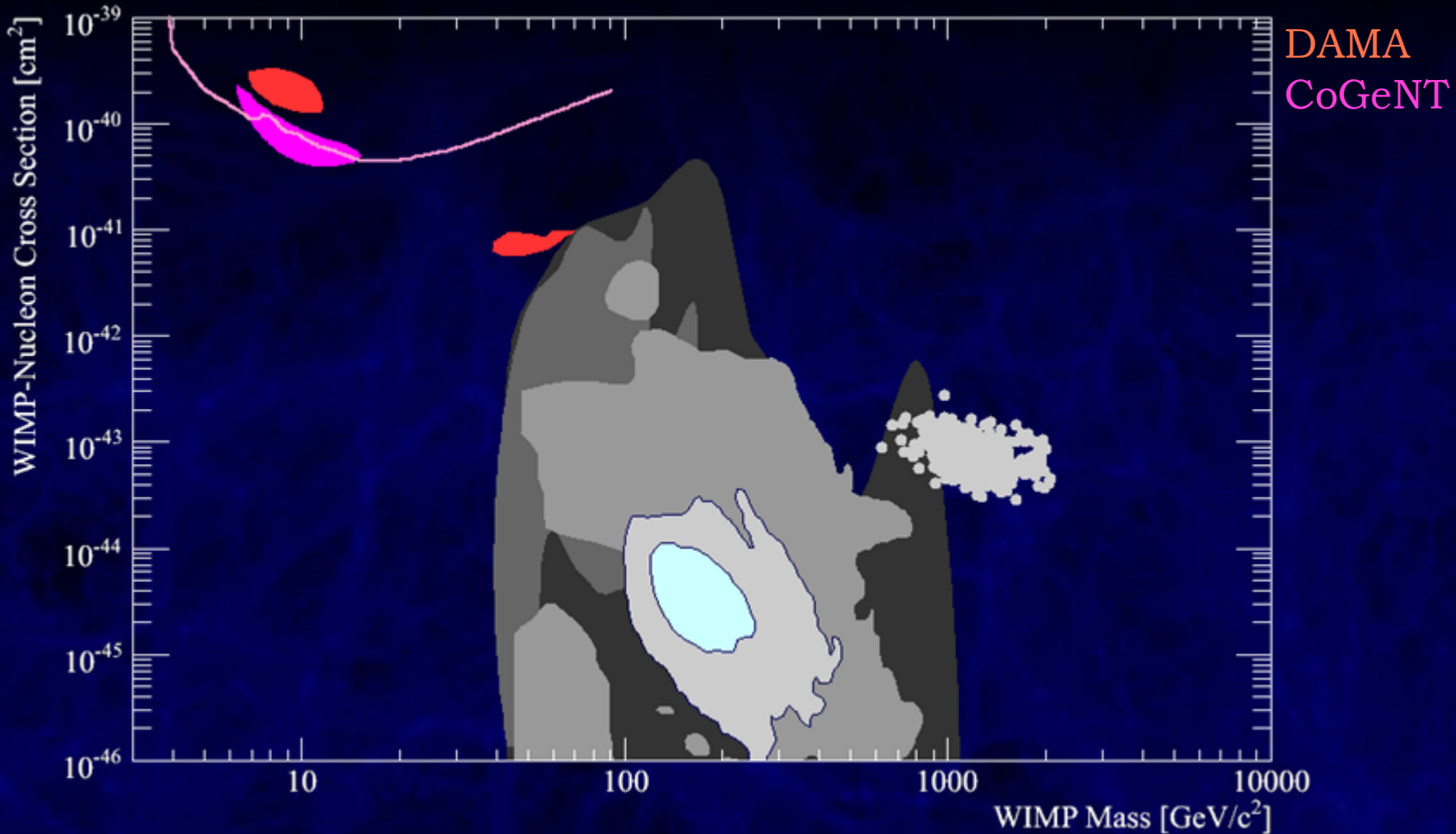


CoGeNT Data



...awaiting preprint

CoGeNT Interpreted as WIMPs



another allowed region at low masses
and relatively high cross sections

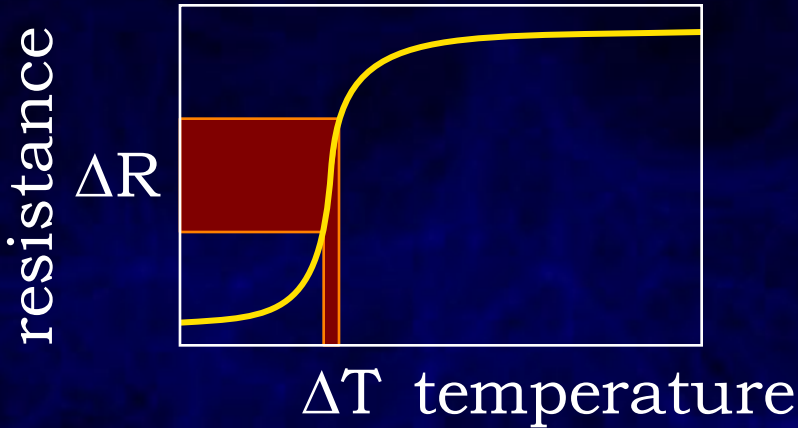
How to Fish for WIMPs

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CRESST-II

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



thermometer
threshold $< 20\text{eV}$

light
absorber

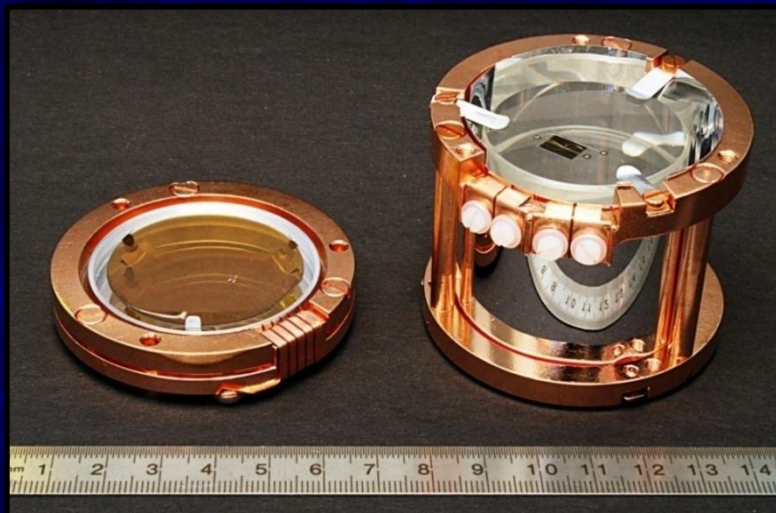
clamps

crystal

phase
transition

thermometer

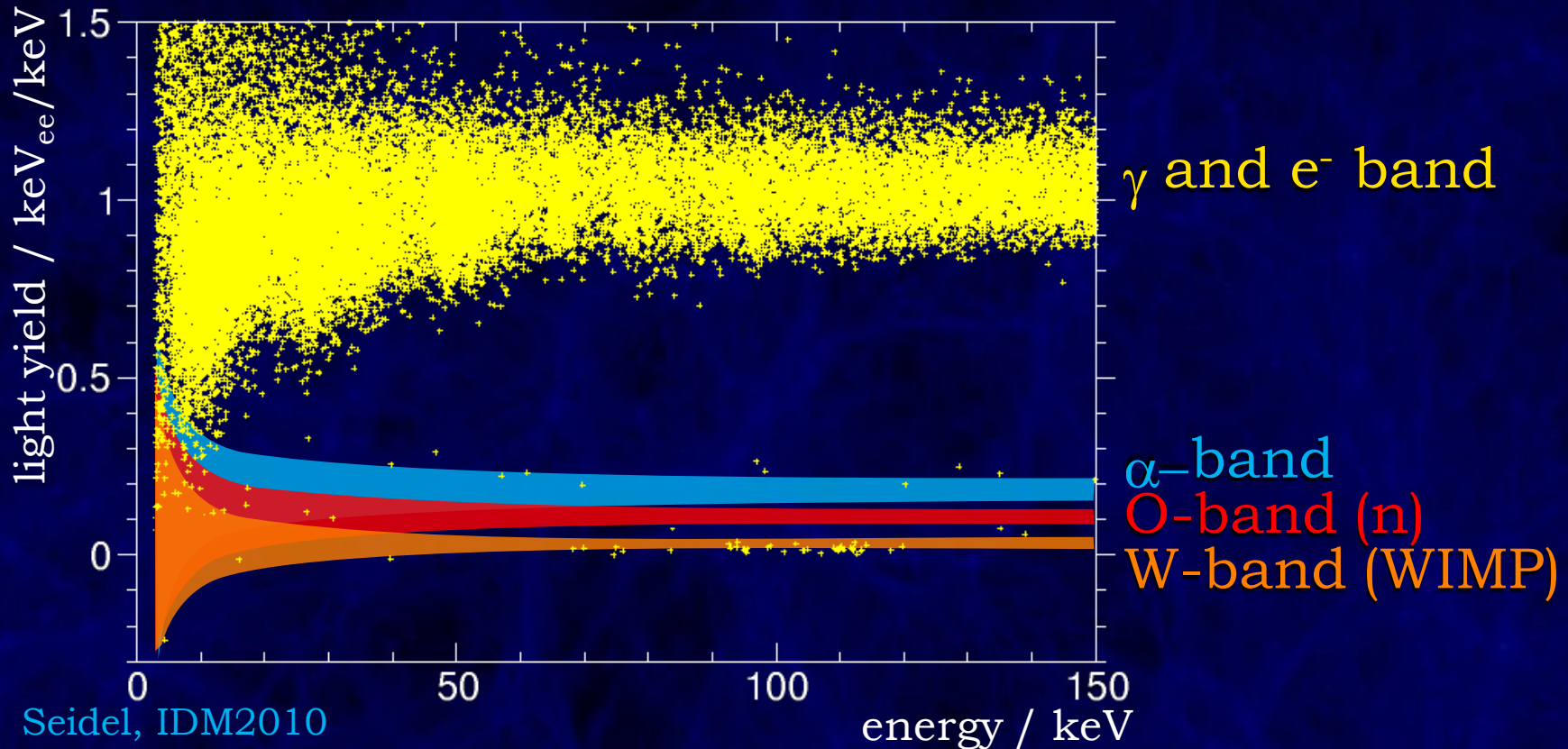
scintillating
reflector



CRESST Preliminary Run32 Data

so far no paper, only plots from talks

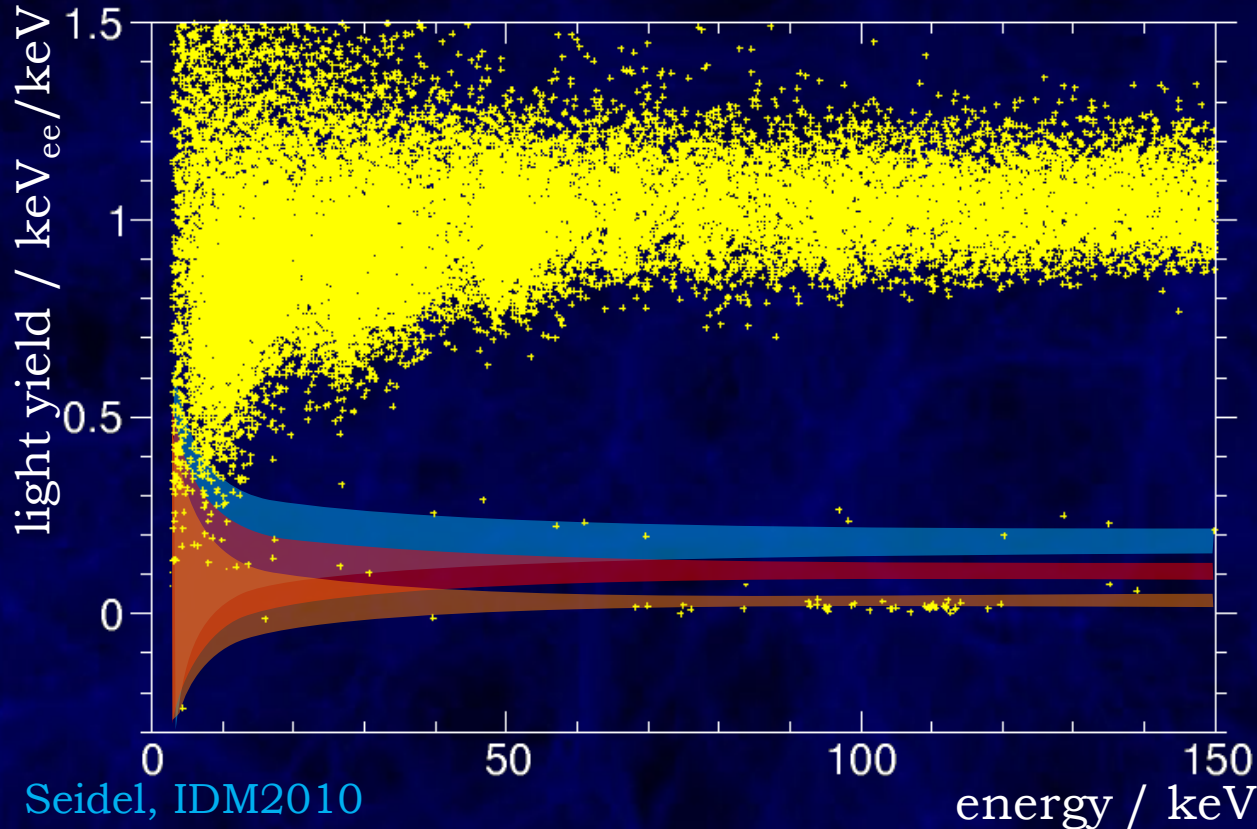
what are all these events below the electronic recoil band?



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:

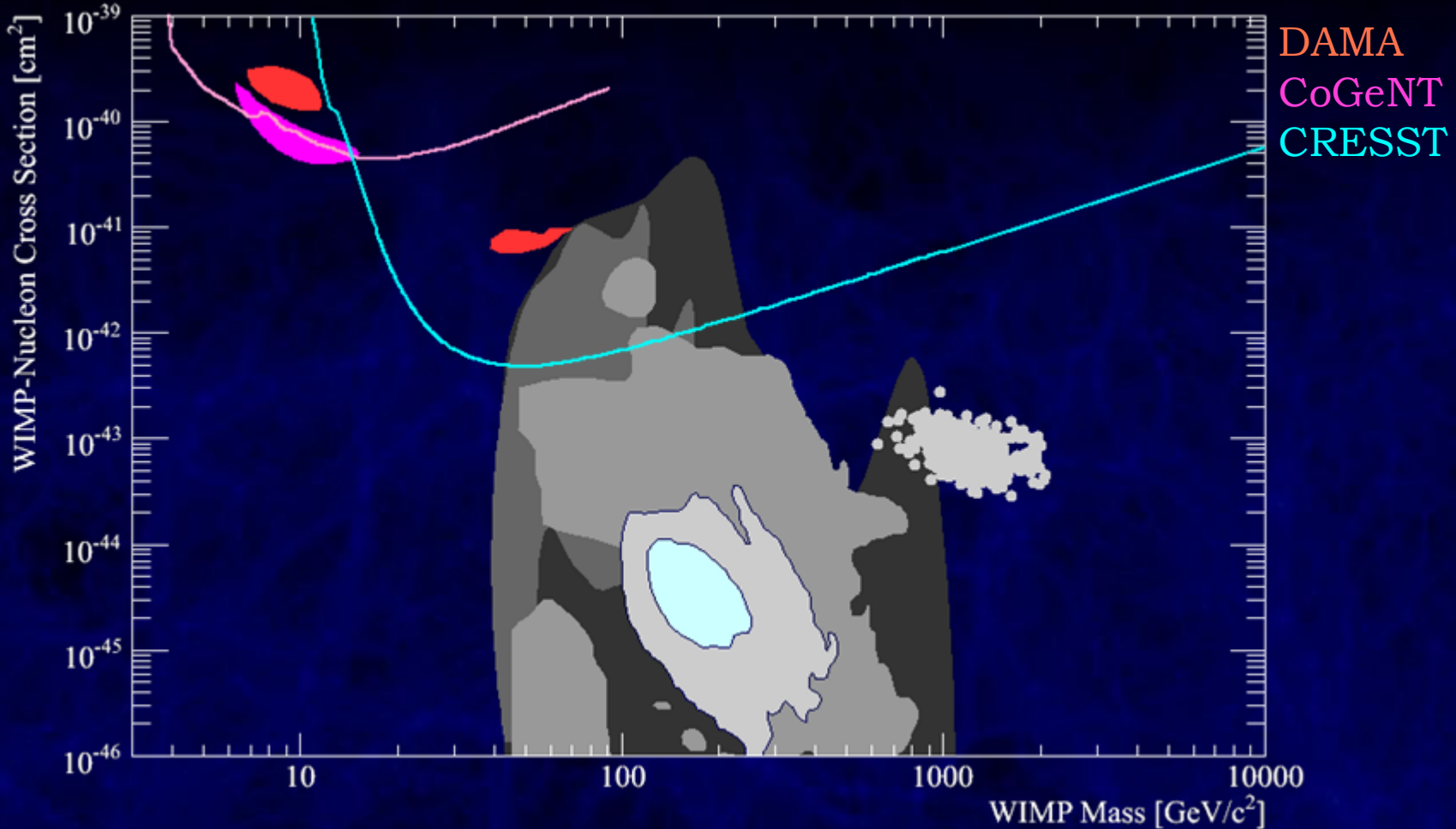


n-source:	~0
(b/c multiplicity)	
μ -induced n:	~1
degraded α :	~7
leaking γ :	~1
sum:	<hr/> ~9
observed:	32

“leaving space
for a light WIMP”

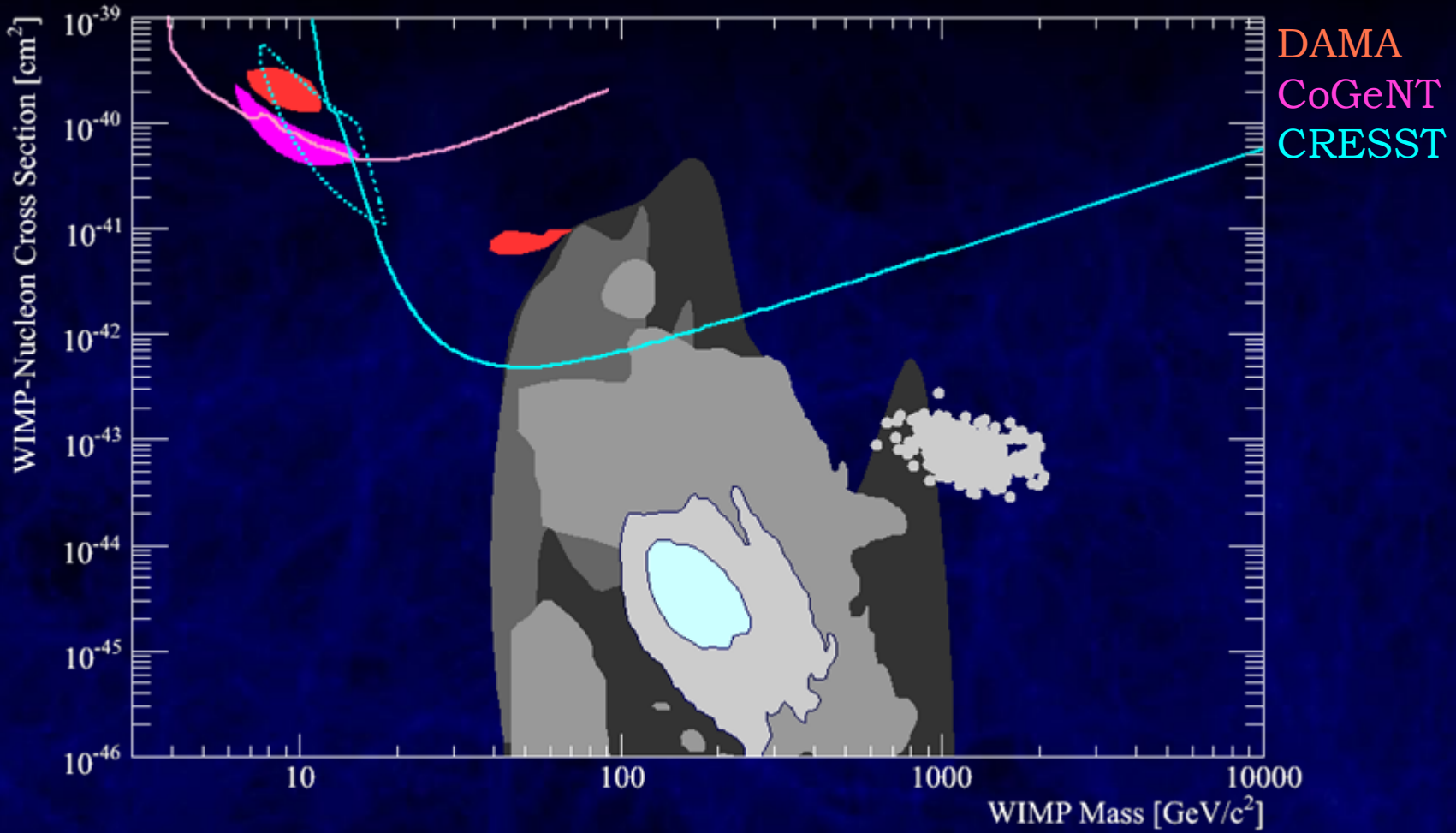
Seidel, IDM2010

CRESST-W: Limit (2008)



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

CRESST-O: Events as WIMPs?



region speculative since analysis preliminary
and not yet fully released

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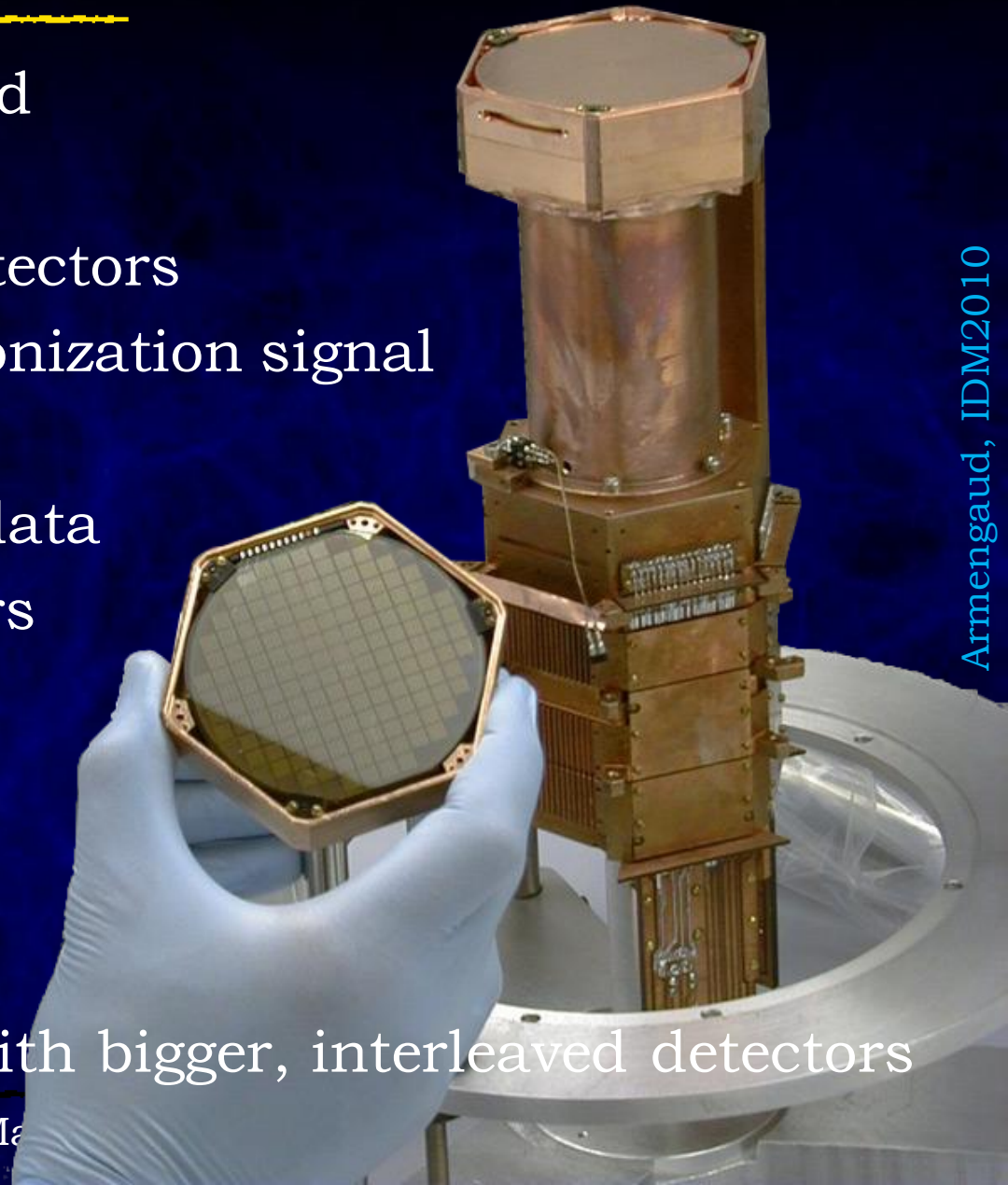
CDMS-II

USA/Canada/Switzerland
located at Soudan

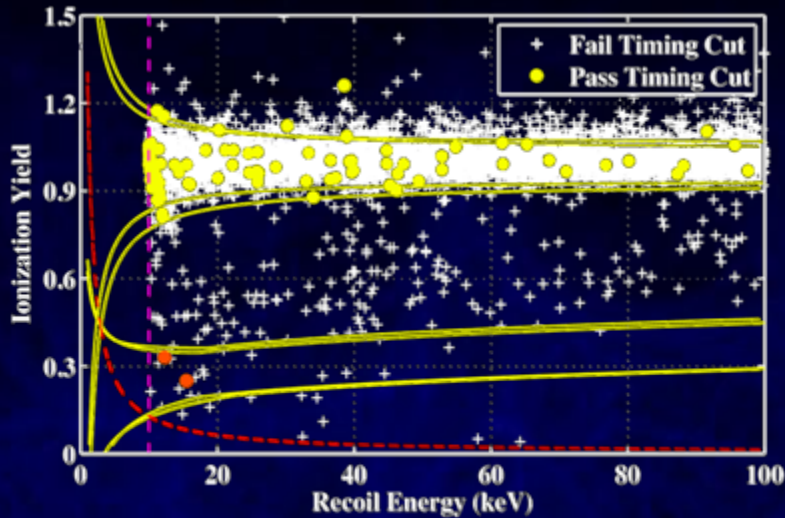
19 Ge and 11 Si “ZIP” detectors
with phonon (TES) and ionization signal
data-taking finished
final analysis of 2 years data
from 14 250g Ge detectors

next step: SuperCDMS with bigger, interleaved detectors

Rafael F. Lang: How To Detect Dark Matter

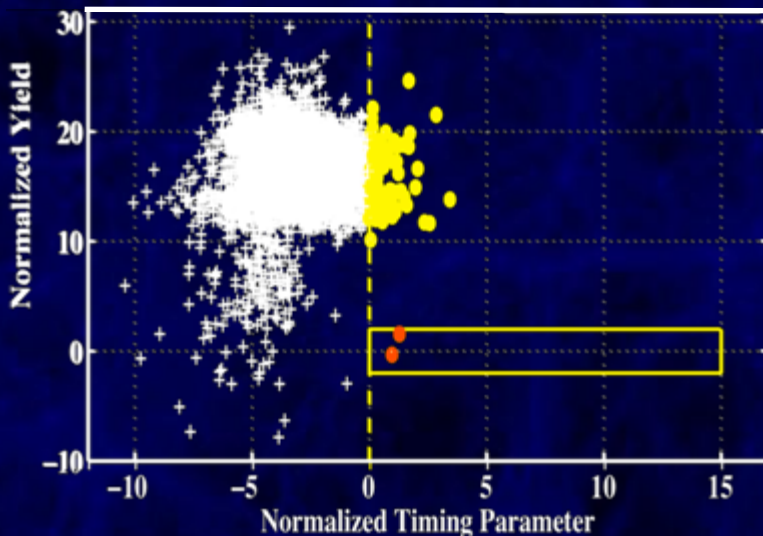


CDMS-II Results



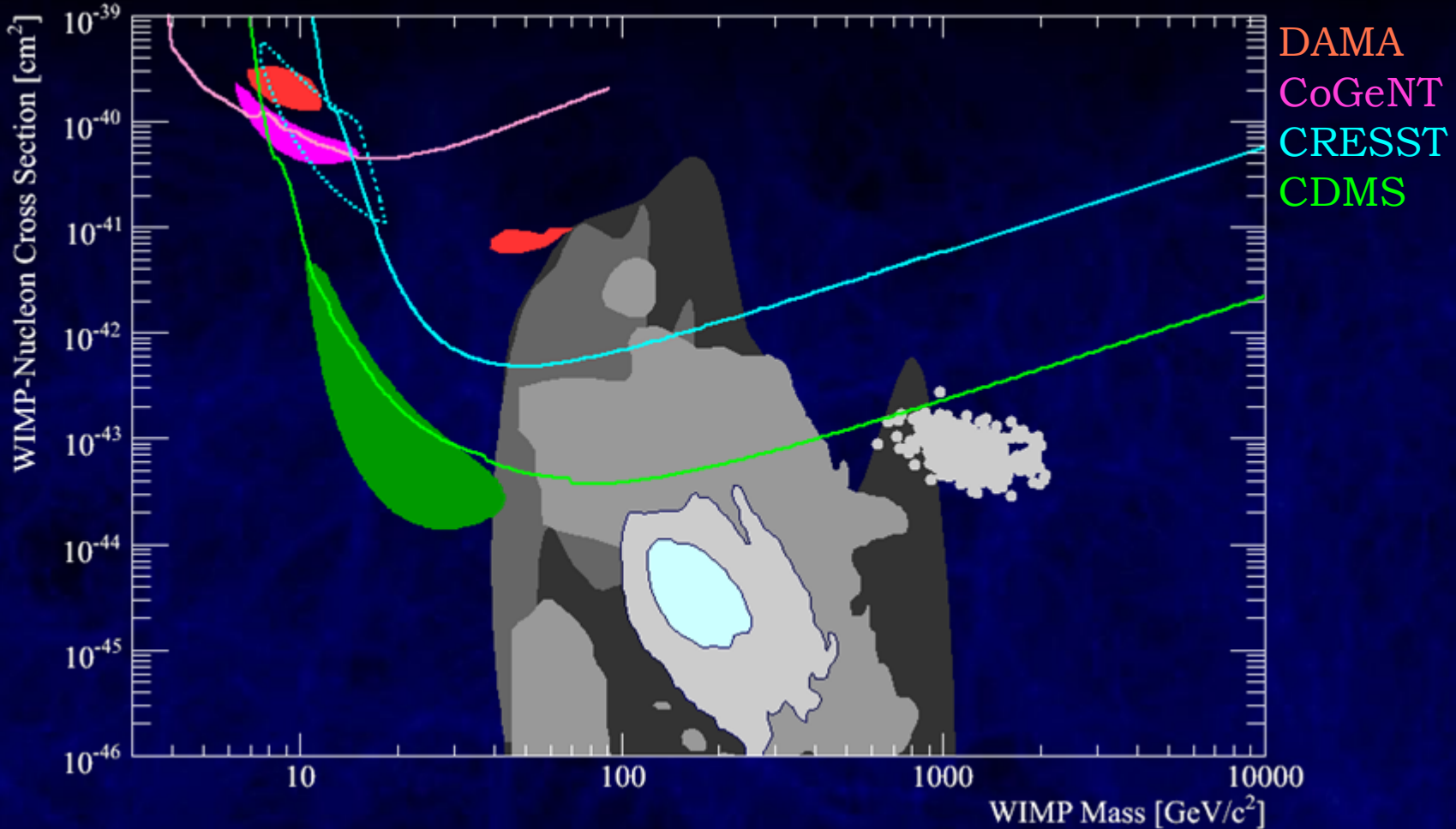
Ge dark matter search data
two detectors with signal
candidate events combined:

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

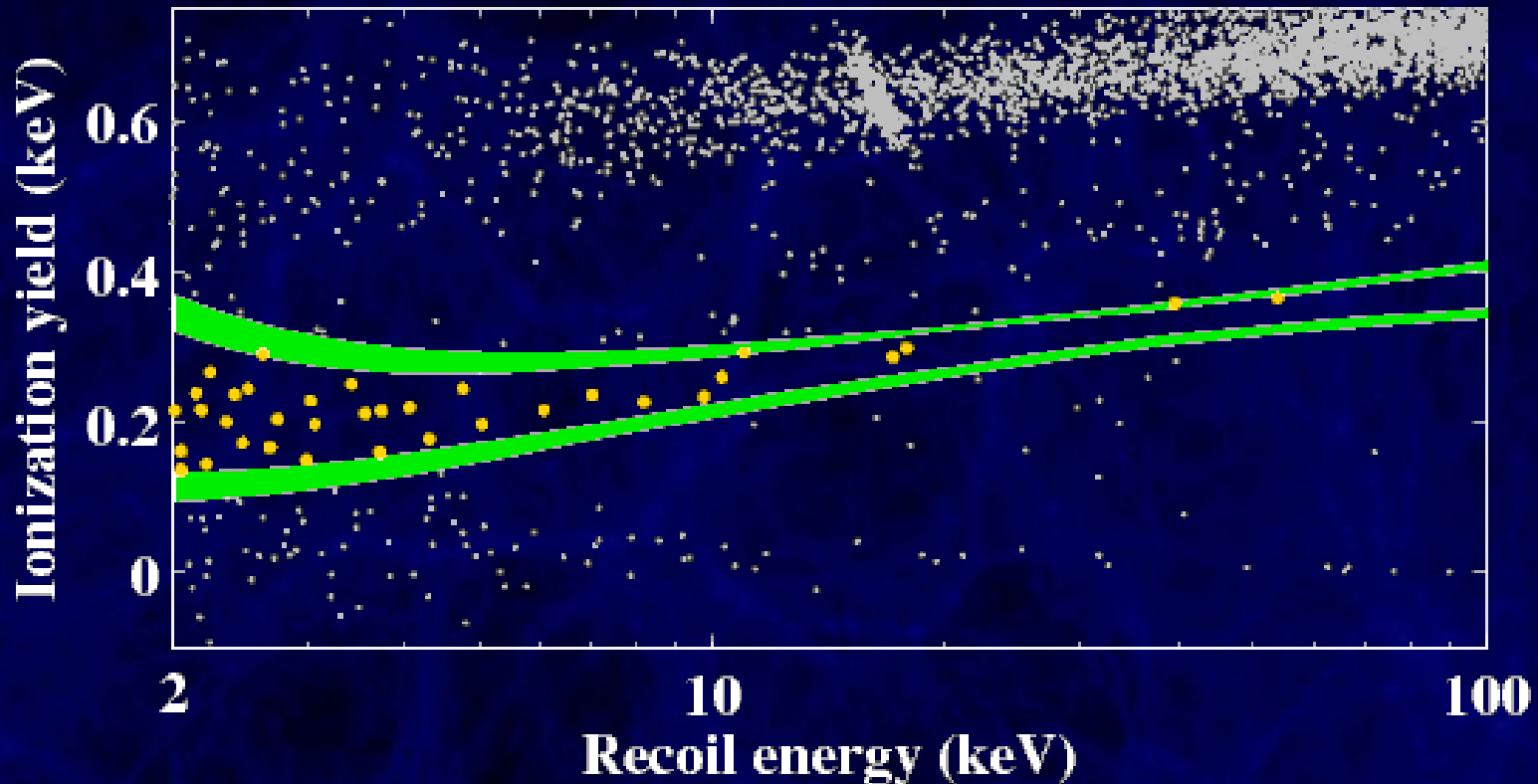
CDMS Limit & WIMP Interpretation



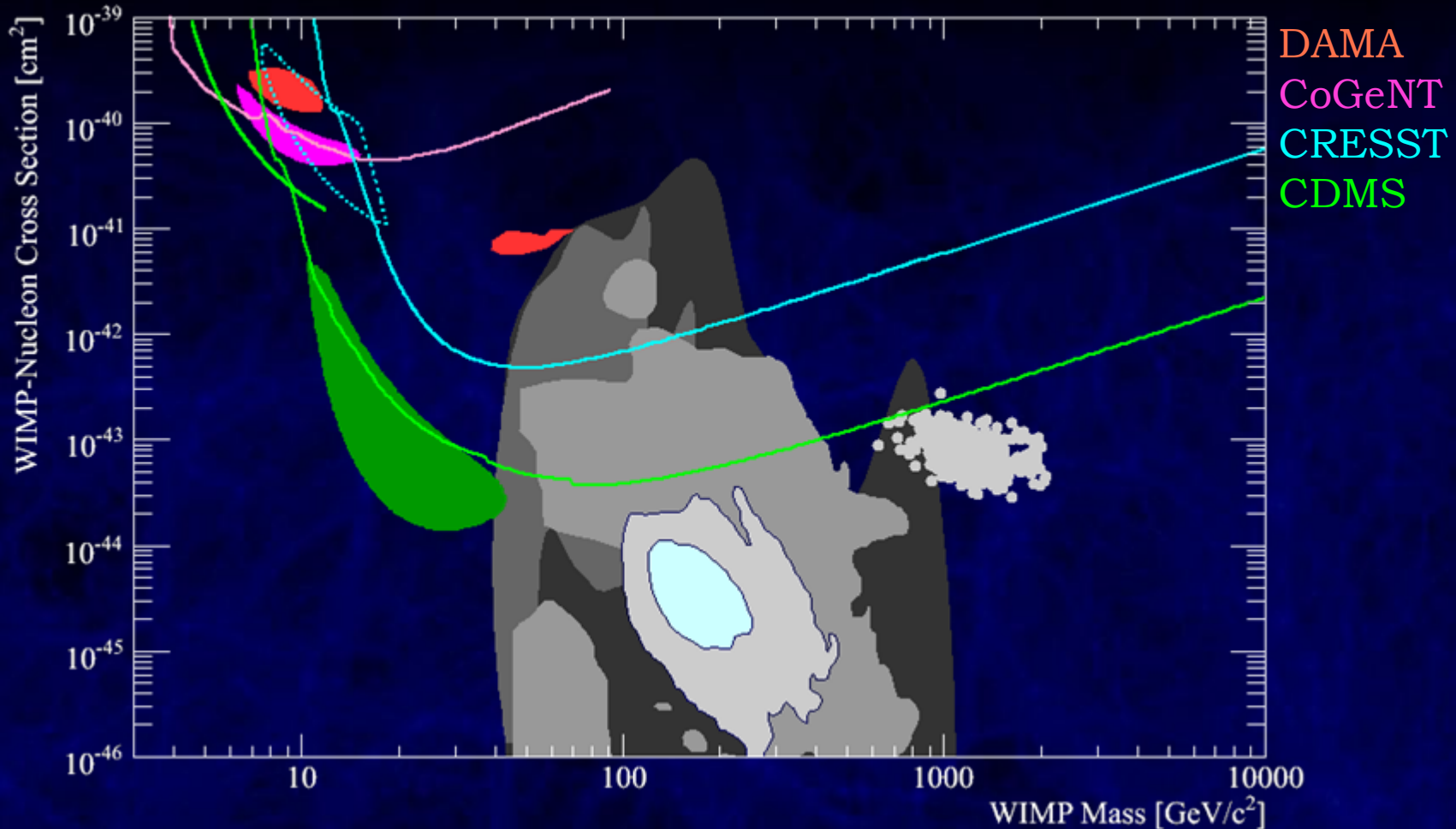
CDMS collaboration does not claim any Dark Matter signal (2 events observed over 0.9 - 0.2 expected)

CDMS-II Low Threshold Results

recent analysis with threshold lowered to 2keV
at the expense of additional background
data from one (of 8) Ge detector:

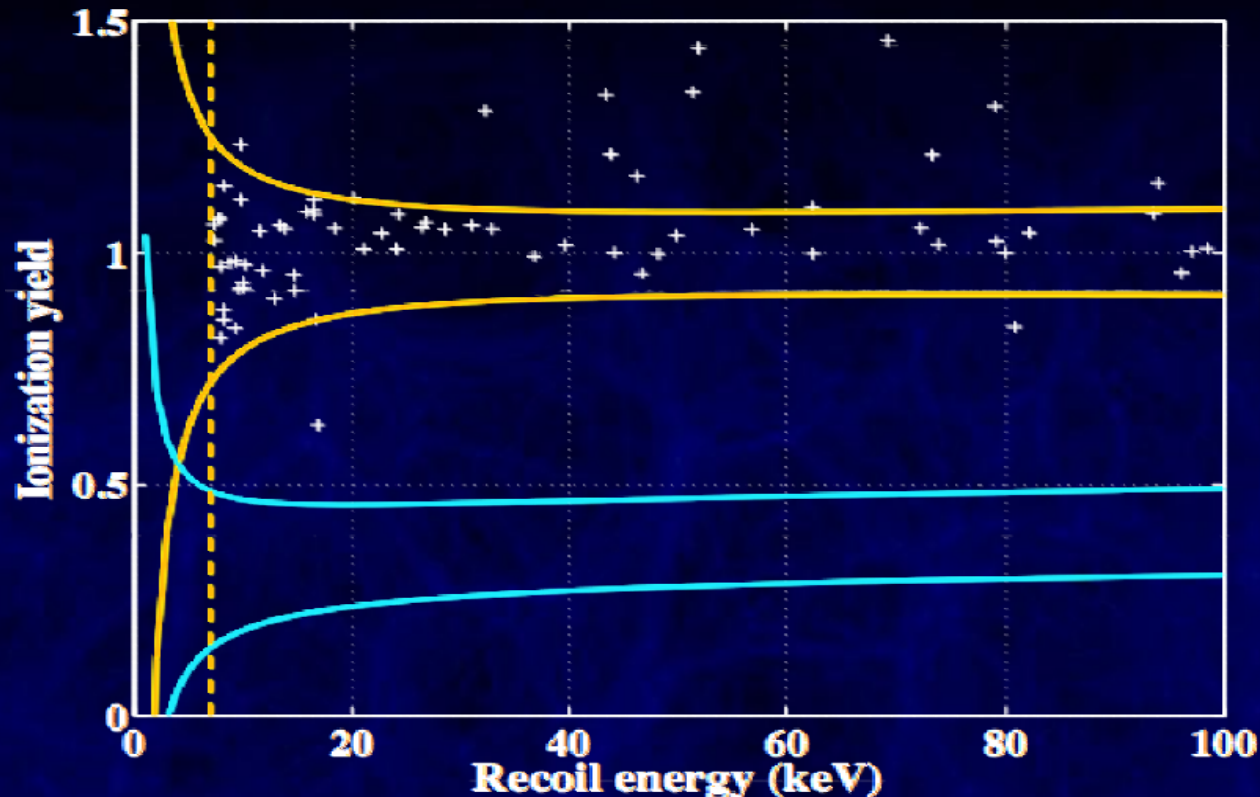


CDMS Low Threshold Limit



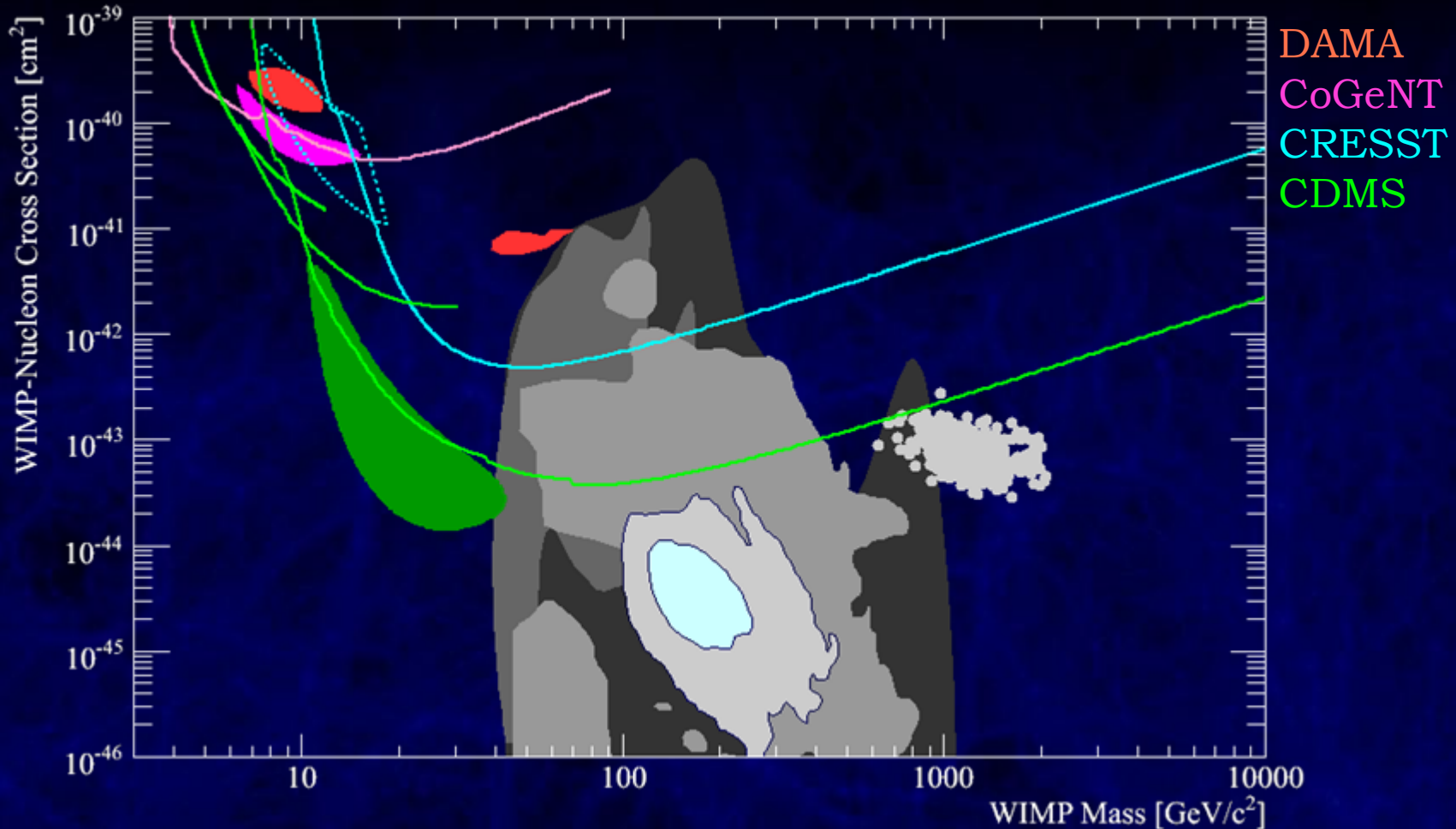
severely constrains CoGeNT WIMP interpretation

CDMS-II Silicon Results



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

CDMS Silicon Limit



severely constrains CoGeNT WIMP interpretation

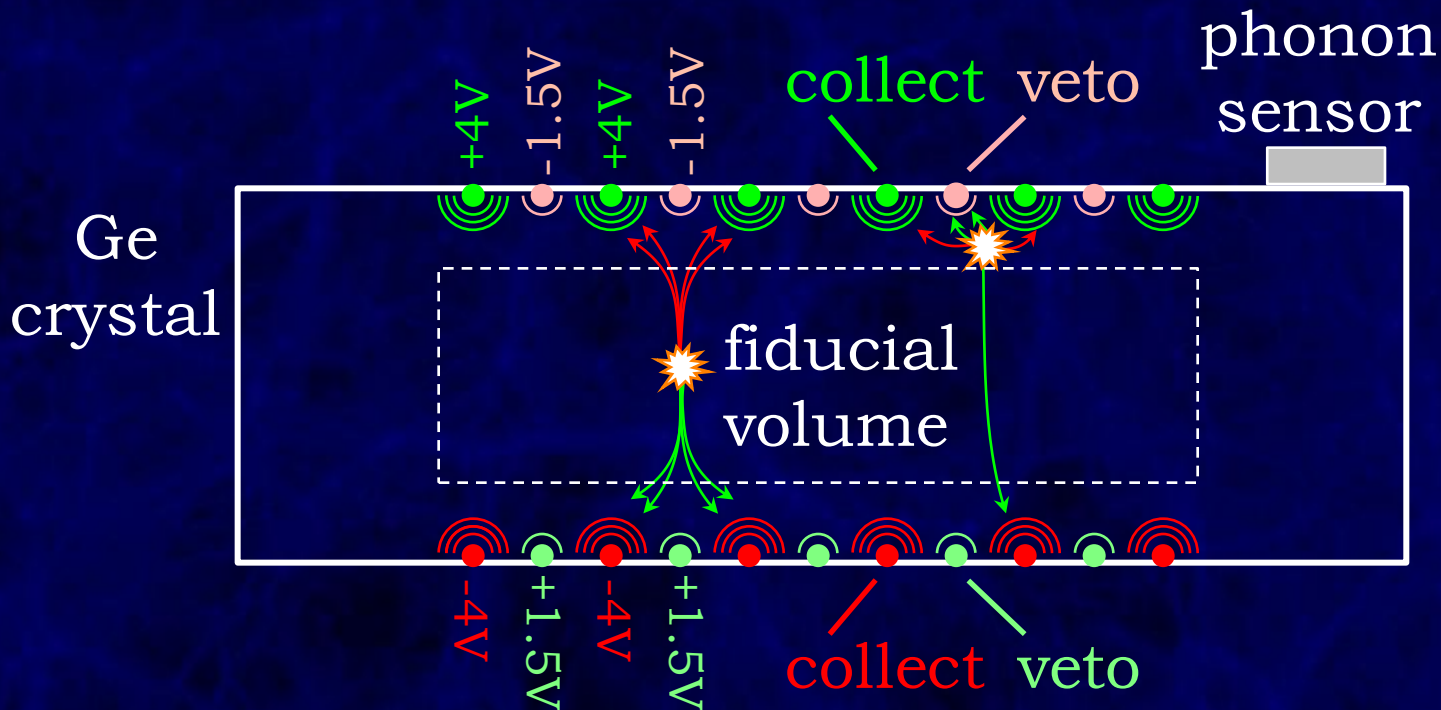
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- **EDELWEISS**
- XENON100

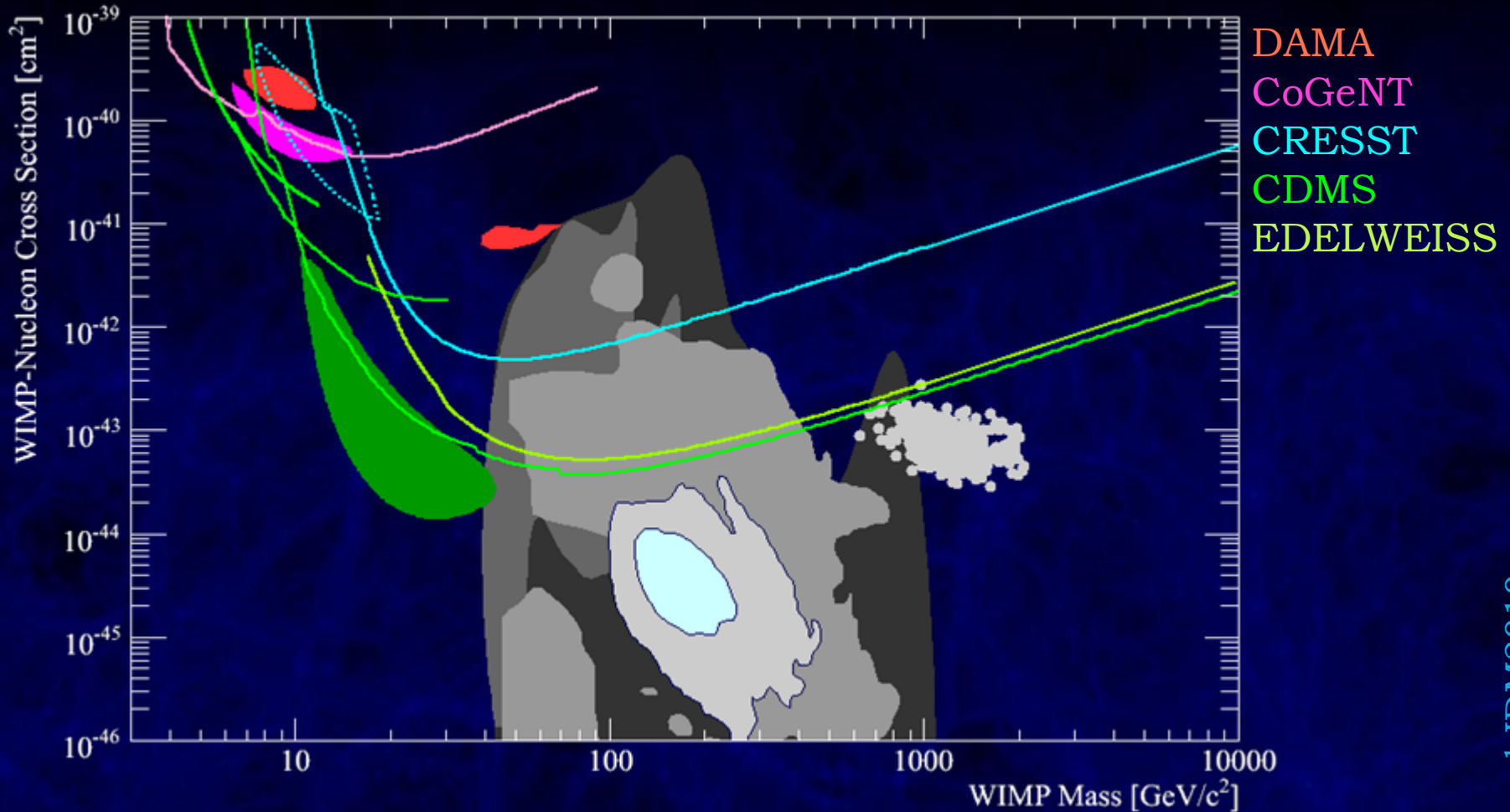


EDELWEISS-II

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



EDELWEISS 2010



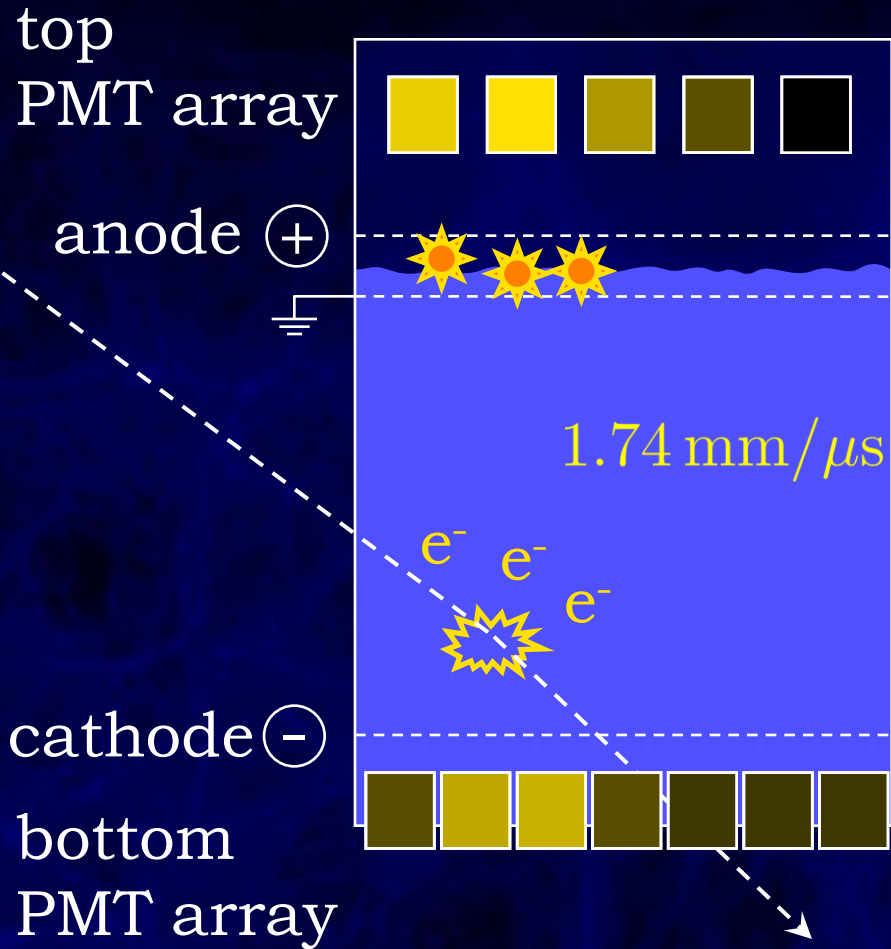
back to the forefront of searches

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- EDELWEISS: interleaved detectors work
- **XENON100**



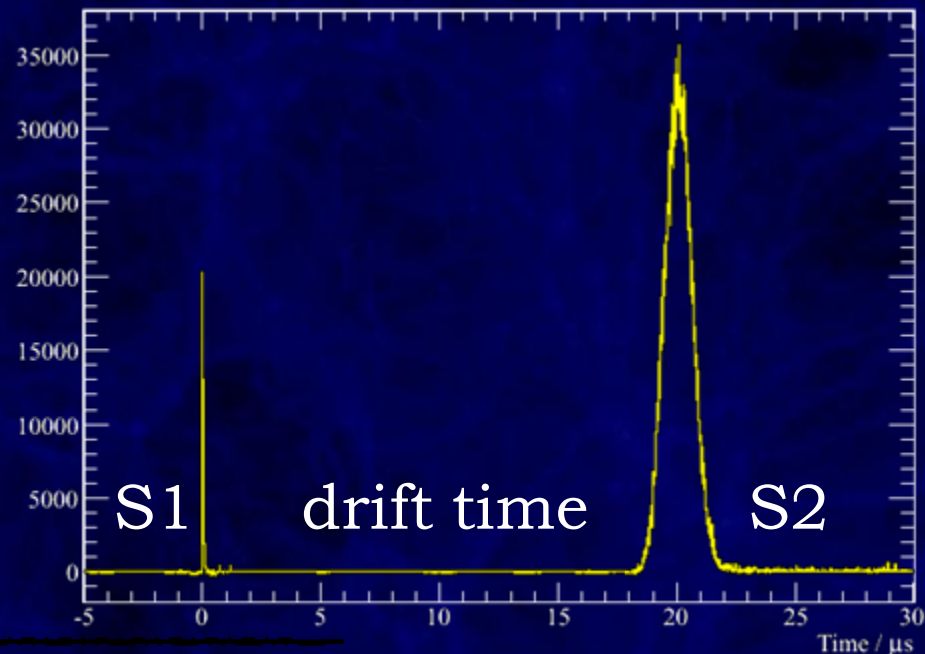
Dual-Phase Xenon TPC



3D position information
S2 hit pattern: $\Delta r < 3 \text{ mm}$
drift time: $\Delta z < 300 \mu\text{s}$

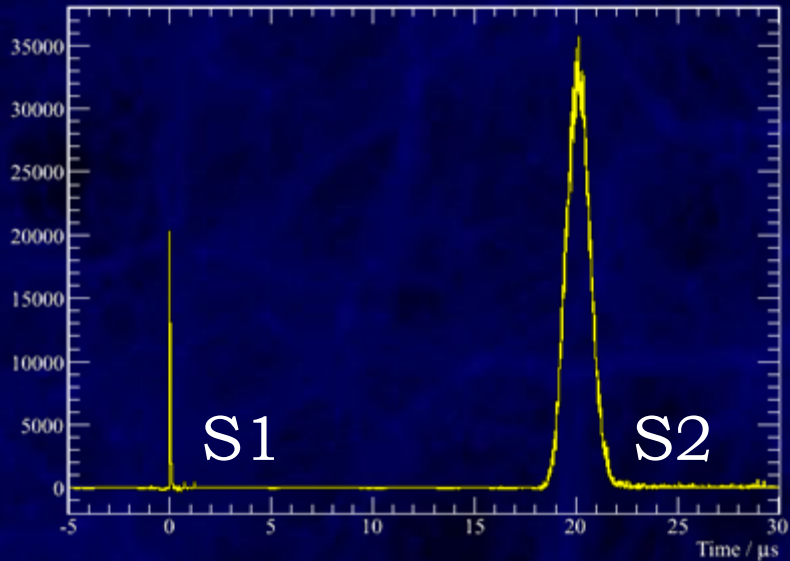
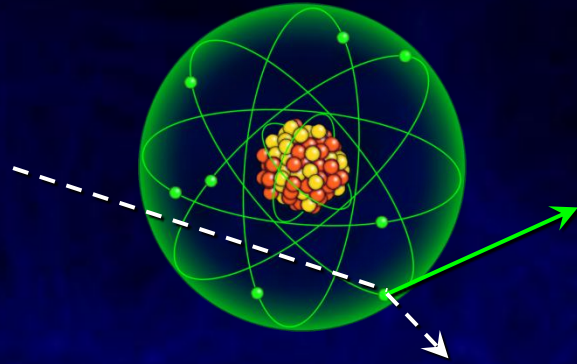
gas xenon

liquid xenon

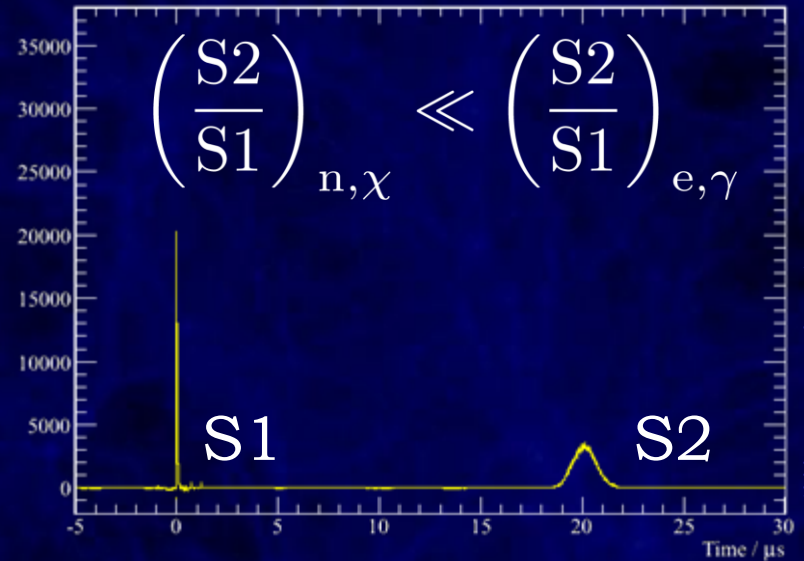
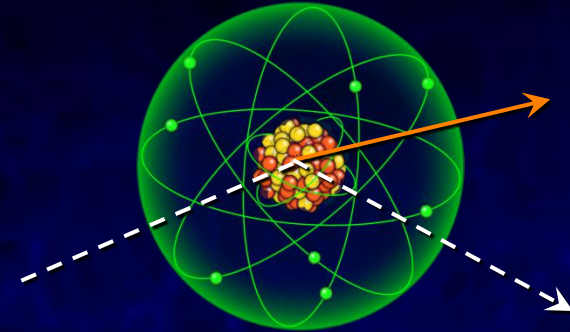


Recoil Discrimination > 99%

e^-/γ : electronic recoil



n/WIMPs: nuclear recoil



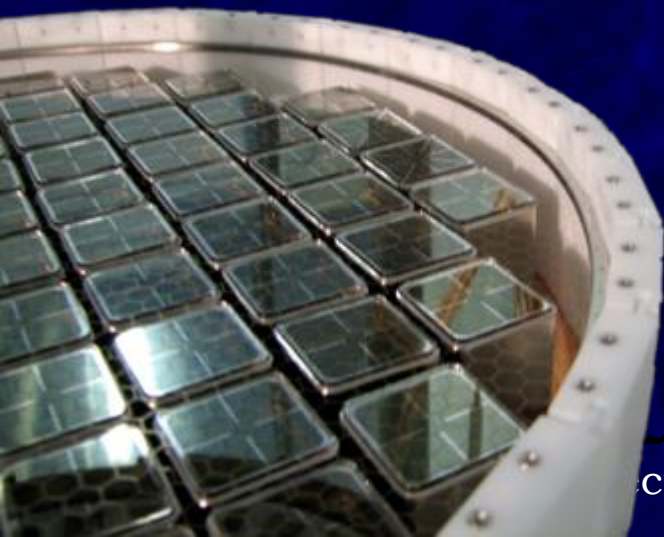
(illustration)

→ lots of information for each event

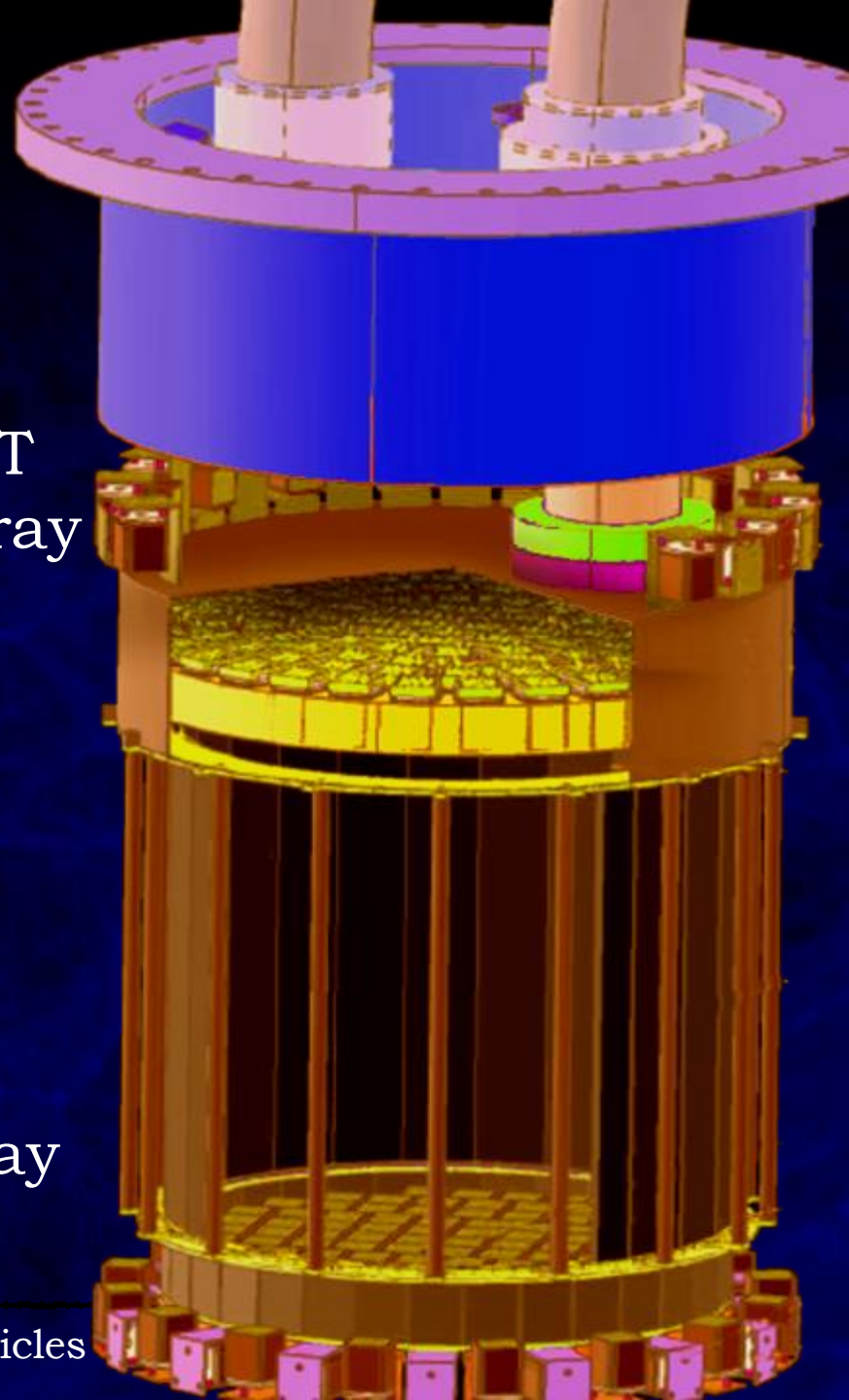
XENON100



98 PMT
top array



80 PMT
bottom array



Direct Dark Matter Particles

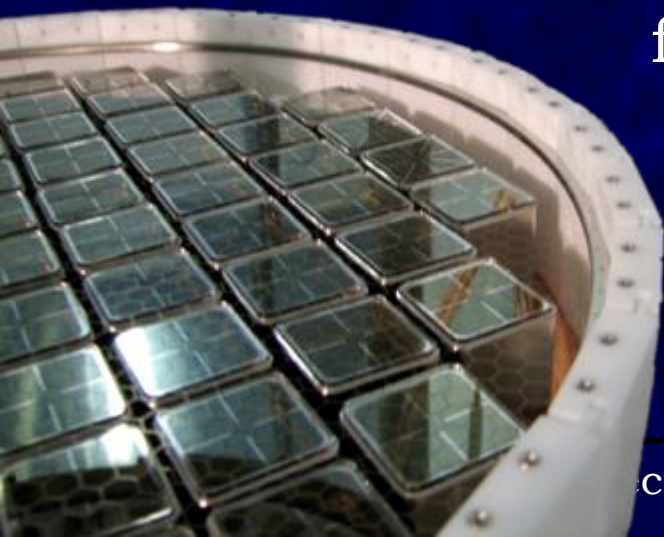
XENON100



veto PMT

bell

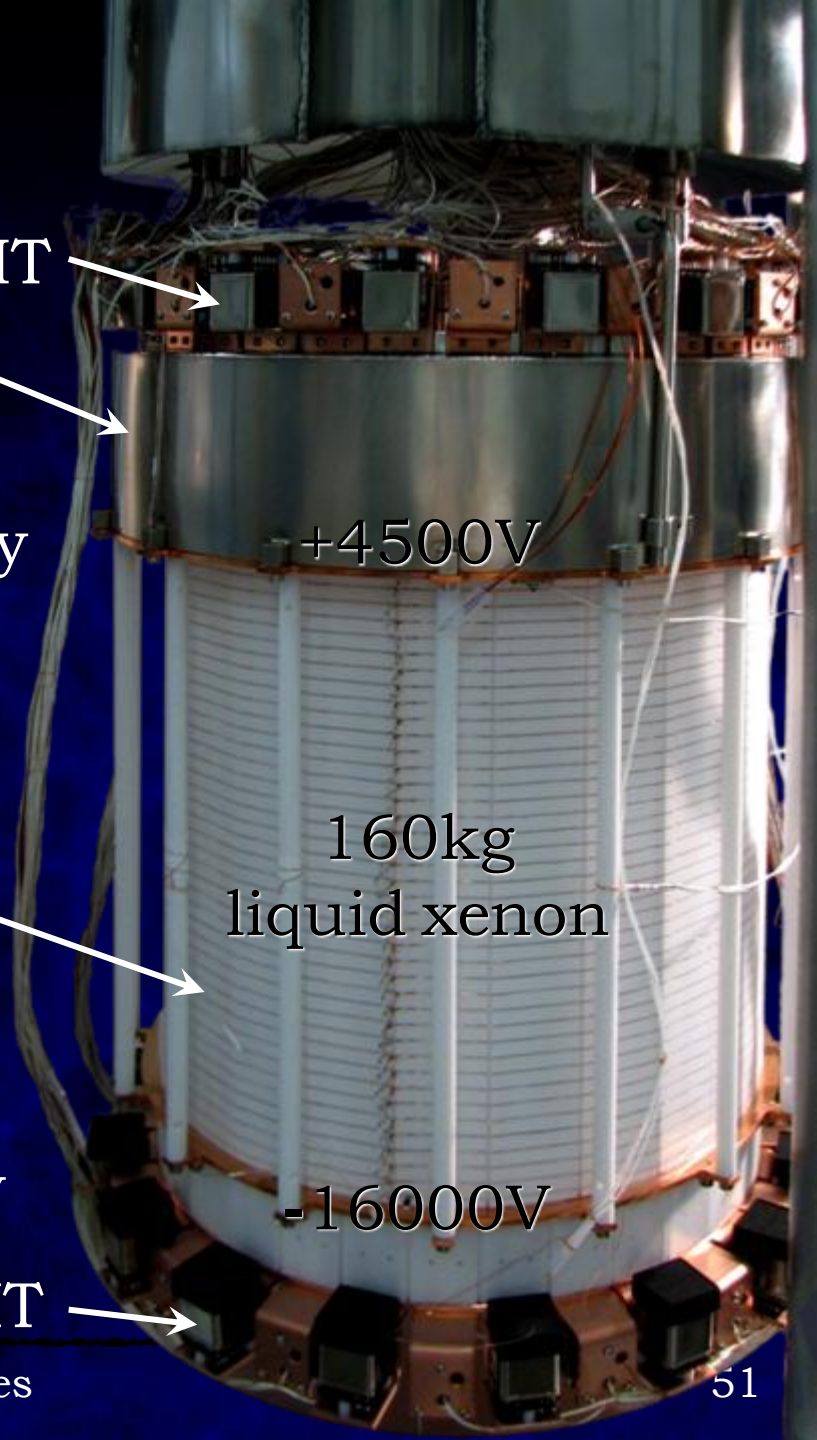
98 PMT
top array



PTFE TPC,
field shaping

80 PMT
bottom array

veto PMT



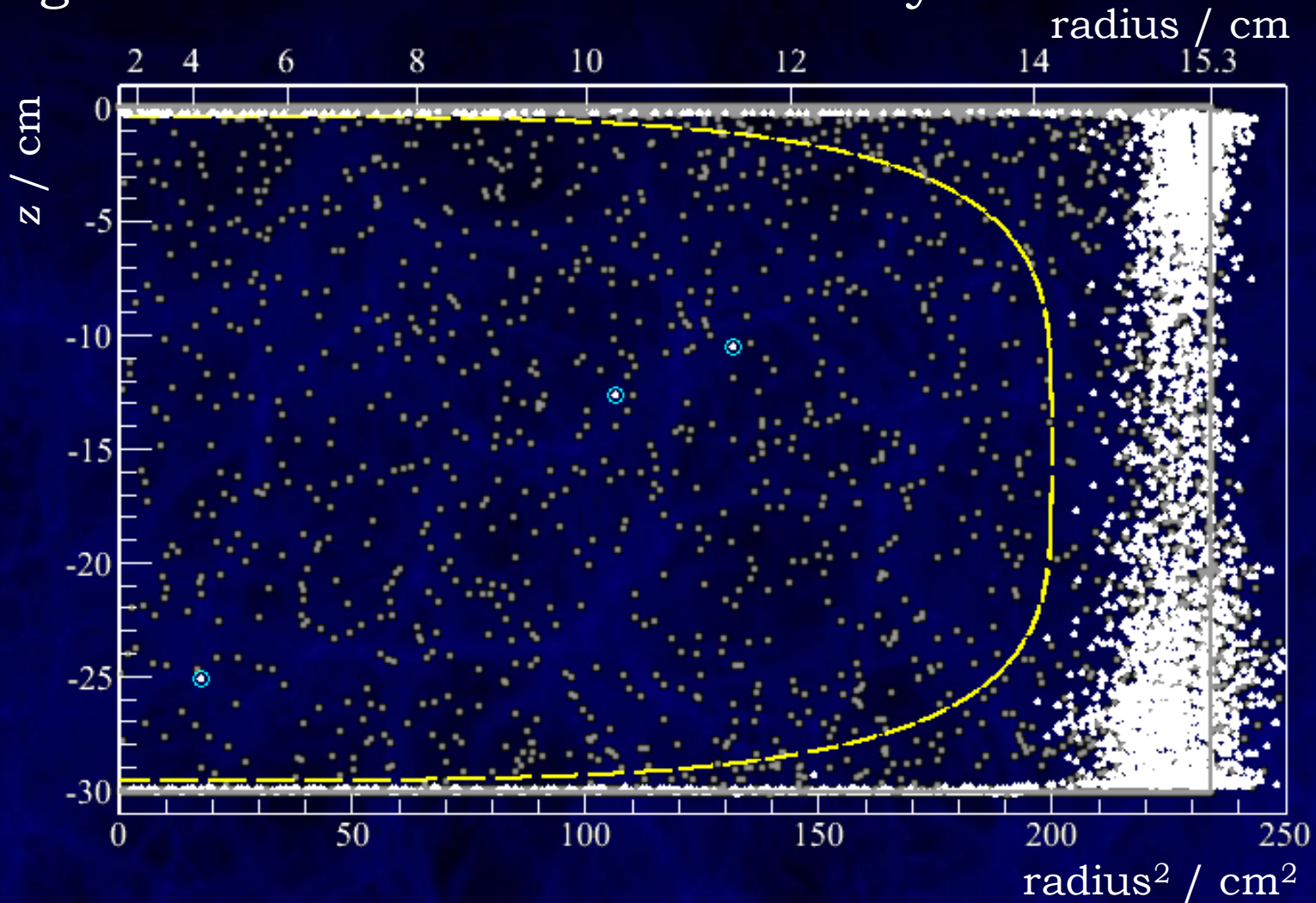
+4500V

160kg
liquid xenon

-16000V

Event Distribution in TPC

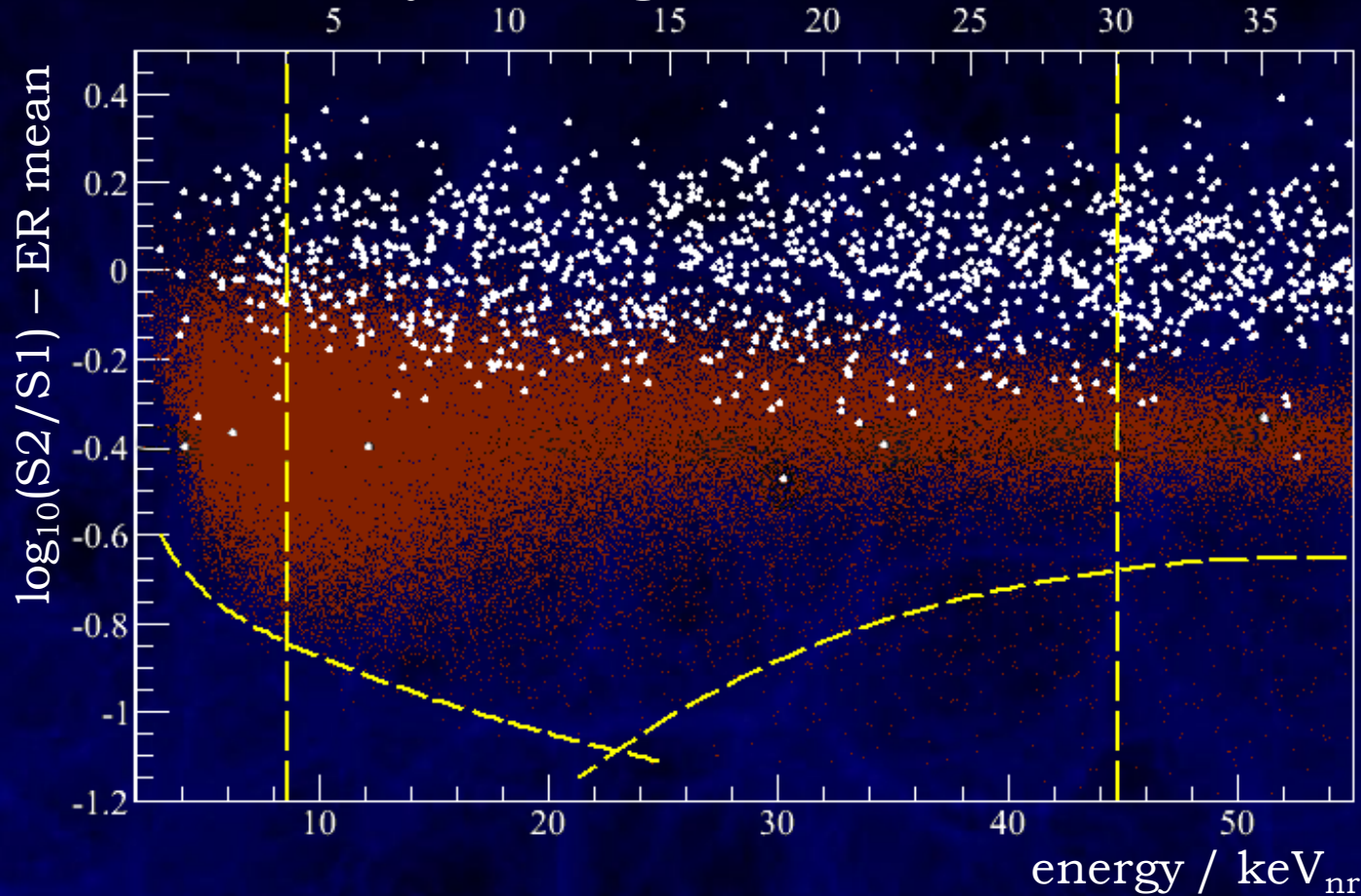
background for this run dominated by ^{85}Kr



Discrimination

100.9 live days, 48kg fiducial:

S1 / PE



electronic
recoils
(background)

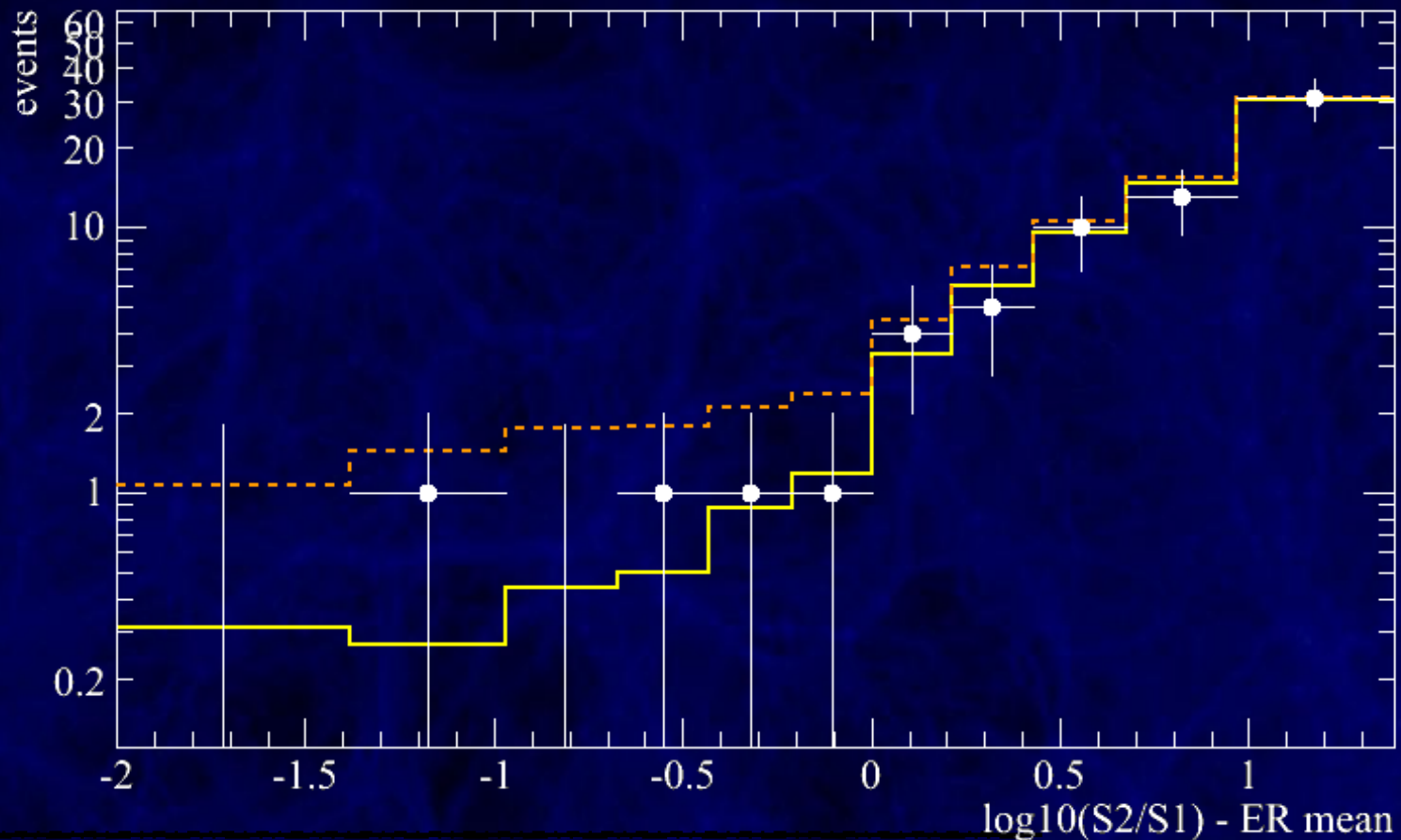
nuclear
recoils
(calibration)

likelihood analysis: no observation of a signal

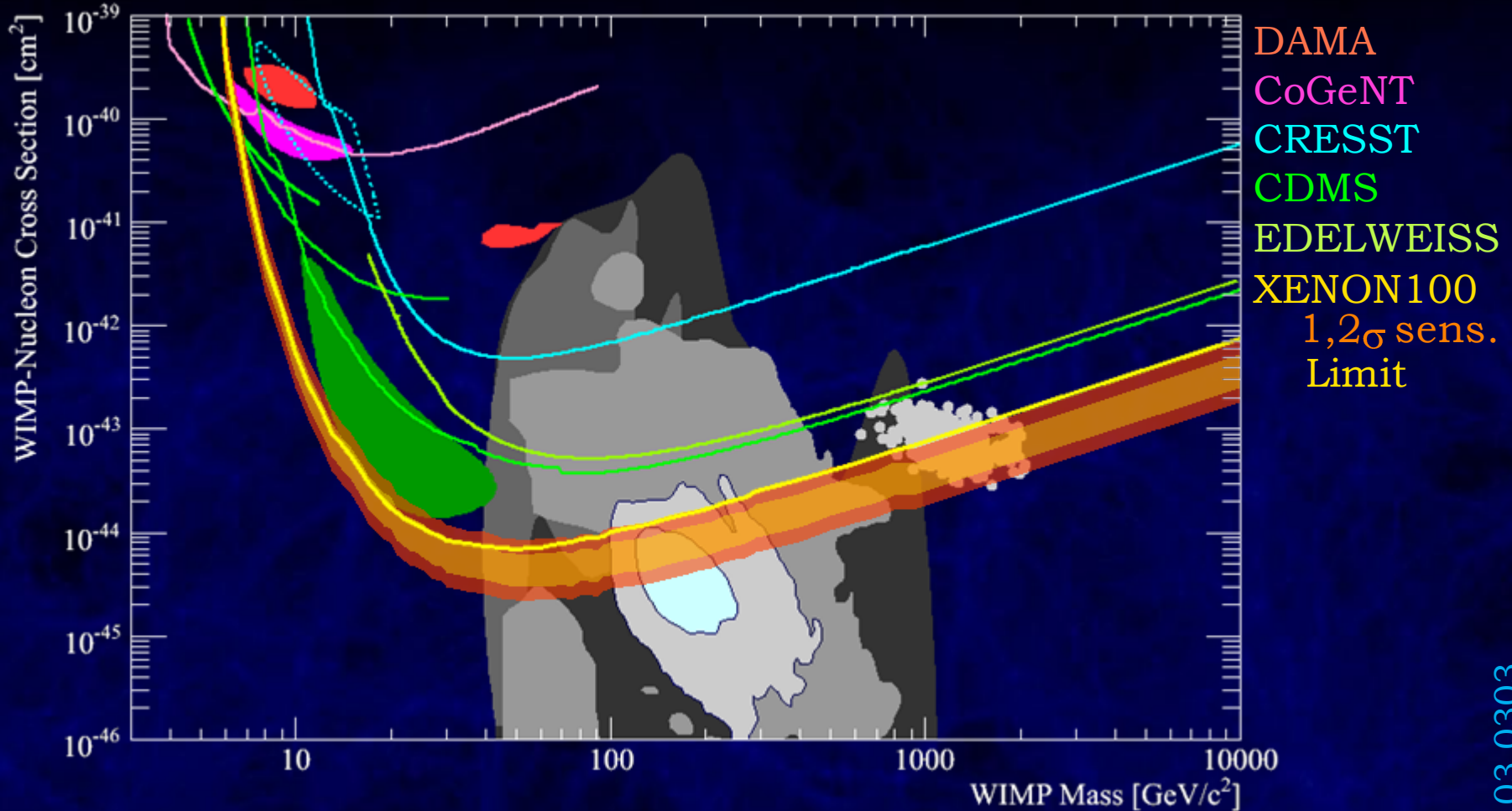
Projection along Energy

expected background + 100GeV/c² WIMP with $\sigma=10^{-44}\text{cm}^2$
(90%CL excluded, 13 events)

observed events



XENON100 Limit 2011



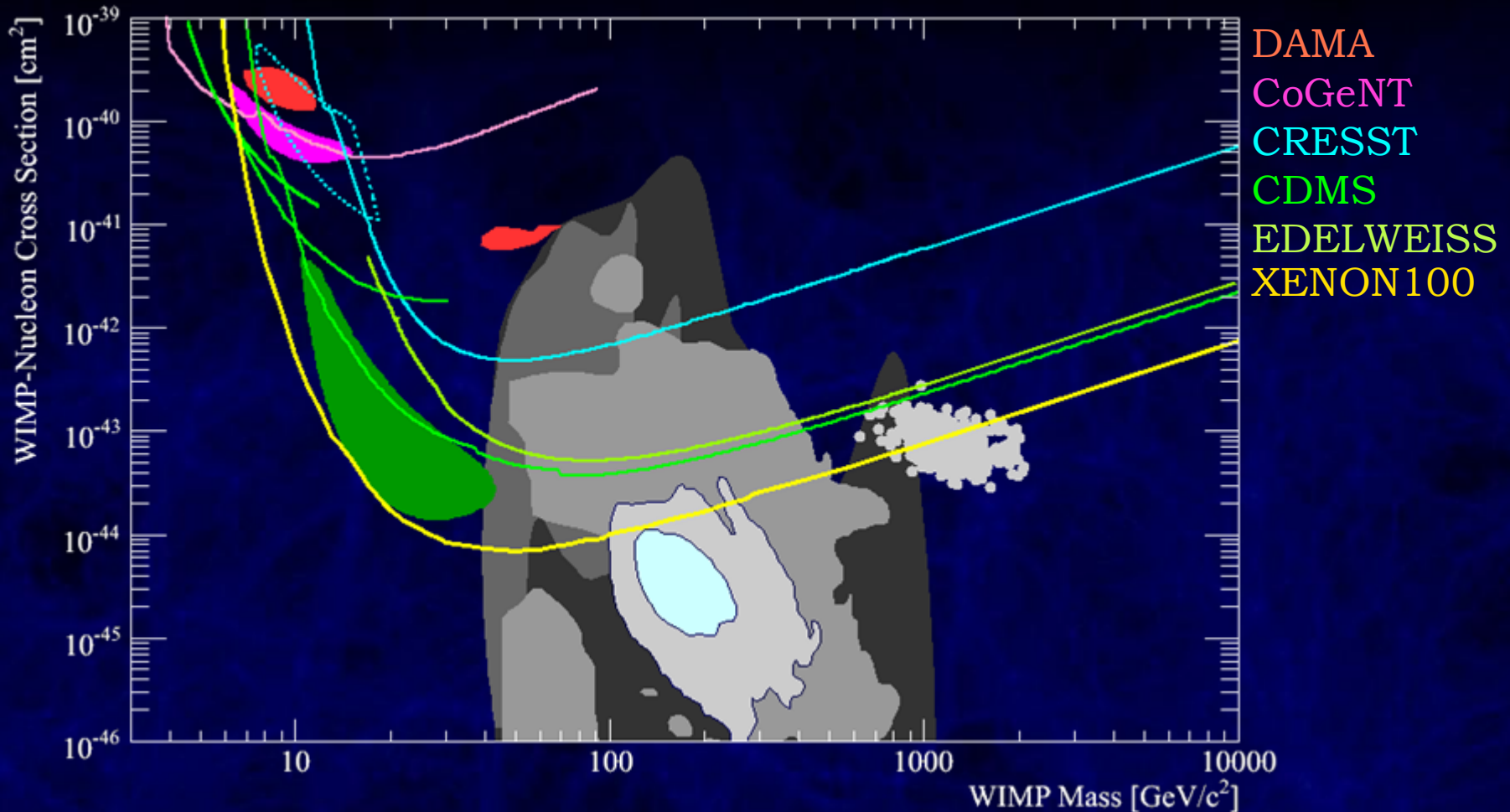
excludes significant SUSY parameter space
excludes iDM scattering off I as explanation for DAMA

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- CRESST-II: room for a light WIMP
- CDMS-II: excludes them all
- EDELWEISS: interleaved detectors work
- XENON100: most sensitive experiment around



Direct Search Summary



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